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Formal Report

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The Physics of W and Z Bosons

June 24-25, 2010

Organizers:

S. Dawson, K. Okada, A. Patwa, J. Qiu and B. Surrow

RIKEN BNL Research Center

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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Memorandum of Understanding between RIKEN and BNL, initiated in 1997, has been renewed in 2002 and again in 2007. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

The RBRC has both a theory and experimental component. The RBRC Theory Group and the RBRC Experimental Group consists of a total of 25-30 researchers. Positions include the following: full time RBRC Fellow, half-time RHIC Physics Fellow, and full-time, post-doctoral Research Associate. The RHIC Physics Fellows hold joint appointments with RBRC and other institutions and have tenure track positions at their respective universities or BNL. To date, RBRC has ~50 graduates of which 14 theorists and 6 experimenters have attained tenure positions at major institutions worldwide.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RBRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. In most cases all the talks are made available on the RBRC website. In addition, highlights to each speaker's presentation are collected to form proceedings which can therefore be made available within a short time after the workshop. To date there are ninety seven proceeding volumes available.

A 10 teraflops RBRC QCDOC computer funded by RIKEN, Japan, was unveiled at a dedication ceremony at BNL on May 26, 2005. This supercomputer was designed and built by individuals from Columbia University, IBM, BNL, RBRC, and the University of Edinburgh, with the U.S. D.O.E. Office of Science providing infrastructure support at BNL. Physics results were reported at the RBRC QCDOC Symposium following the dedication. QCDSP, a 0.6 teraflops parallel processor, dedicated to lattice QCD, was begun at the Center on February 19, 1998, was completed on August 28, 1998, and was decommissioned in 2006. It was awarded the Gordon Bell Prize for price performance in 1998.

N. P. Samios, Director
March 2010

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

CONTENTS

Introduction

A two-day workshop on "The Physics of W and Z Bosons" was held at the RIKEN BNL Research Center at Brookhaven National Laboratory on June 24-25, 2010.

With the recent release of the first measurement of W bosons in proton-proton collisions at RHIC and the first observation of W events at the LHC, the workshop was a timely opportunity to bring together experts from both the high energy particle and nuclear physics communities to share their ideas and expertise on the physics of W and Z bosons, with the aim of fully exploring the potential of the W/Z physics programs at RHIC and the LHC.

The focus was on the production and measurement of W/Z bosons in both polarized and unpolarized proton-proton collisions, and the role of W/Z production in probing the parton flavor and helicity structure of the colliding proton and in the search for new physics. There were lively discussions about the potential and future prospects of W/Z programs at RHIC, Tevatron, and the LHC.

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First Measurement of W+/W- Boson Production at STAR in Polarized pp Collisions at RHIC

Jan Balewski (For the STAR Collaboration)
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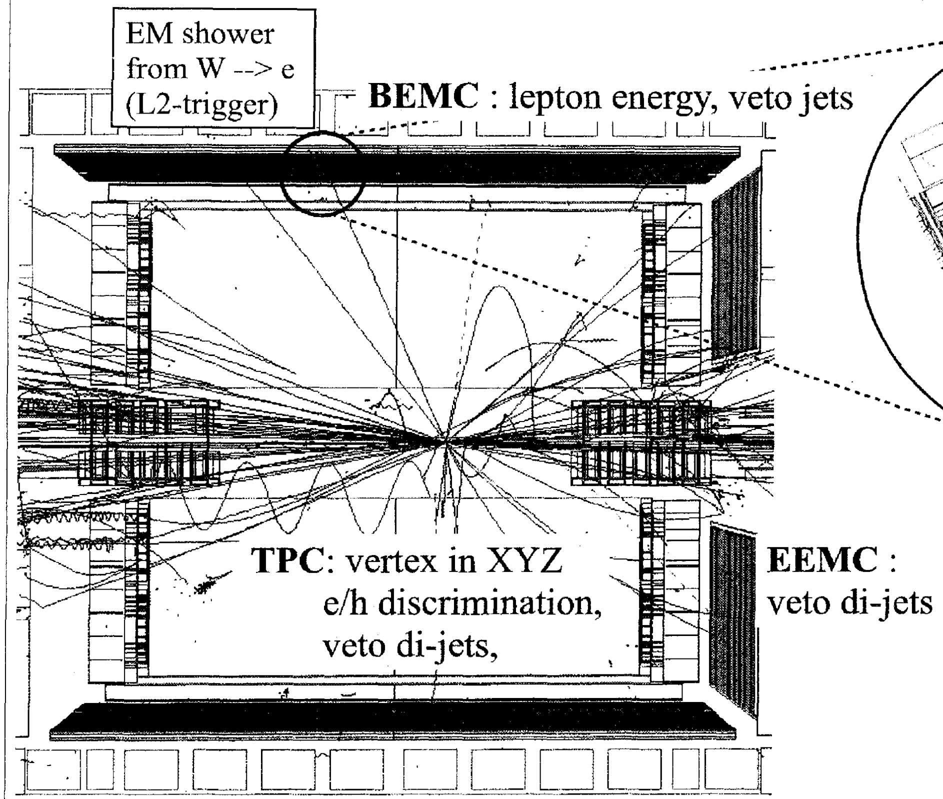
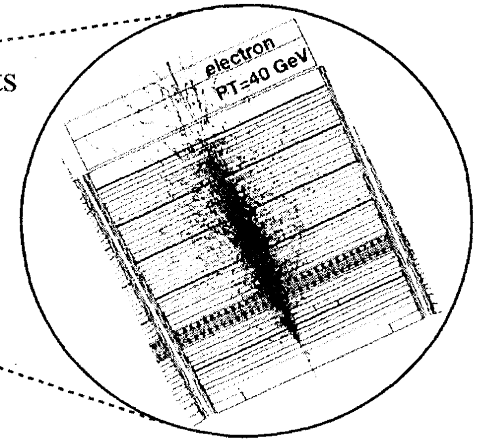
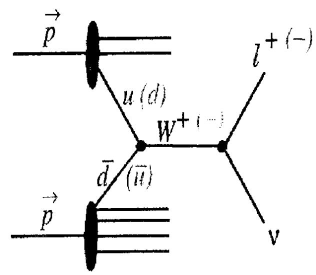
The STAR experiment has acquired its first set of W-boson events from collisions of longitudinally polarized protons at $\sqrt{s} = 500$ GeV. The STAR Electromagnetic Calorimeter triggered on electrons/positrons from the weak decay of the W and provided the energy of the lepton, while the STAR Time Projection Chamber allowed reconstruction of the lepton track and its charge sign. The QCD physics background was suppressed by isolation cuts around a candidate lepton track as well as vetoing on transverse energy opposite in azimuth. In the standard model leading-order $W^{\pm}$ production is through $u+\bar{d} \to W^{+}$ and $d+\bar{u} \to W^{-}$. These interactions are ideal tools to study the spin-flavor structure of the proton, because the spin-dependent W production cross section $\Delta\sigma = \sigma(\overrightarrow{p}p) - \sigma(\overleftarrow{p}p)$ depends strongly on the polarization of the quark and anti-quark in the proton, with $\overrightarrow{p}(\overleftarrow{p})$ representing a proton with its spin aligned with (against) its momentum. We will present the status of the STAR measurement of $A_L = \Delta\sigma/(\sigma(\overrightarrow{p}p) + \sigma(\overleftarrow{p}p))$ for mid-rapidity charge separated W^{+} and W^{-}.

Simulated W→e+ν event at STAR

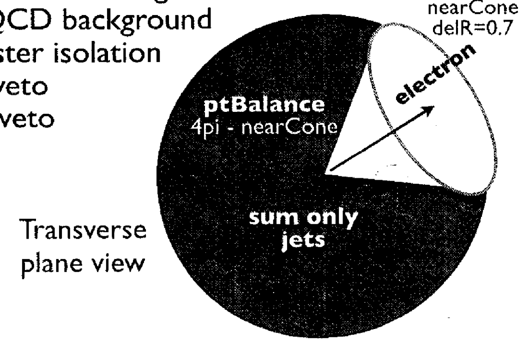




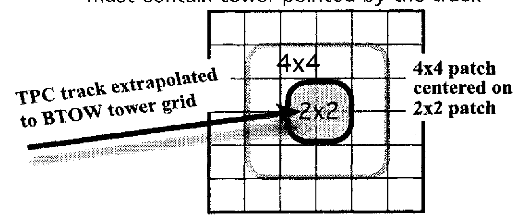


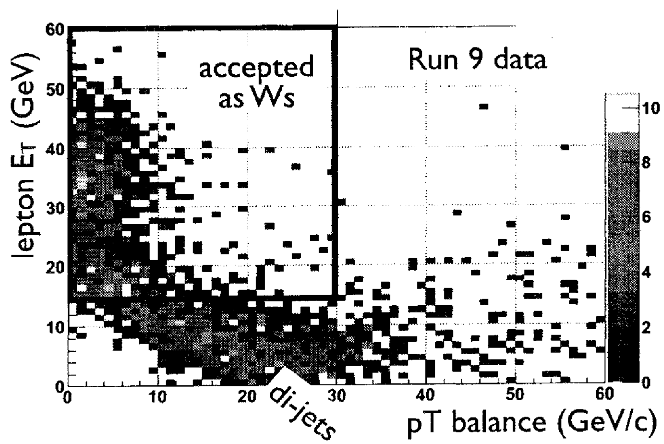
p+p→W→e+ν events selection

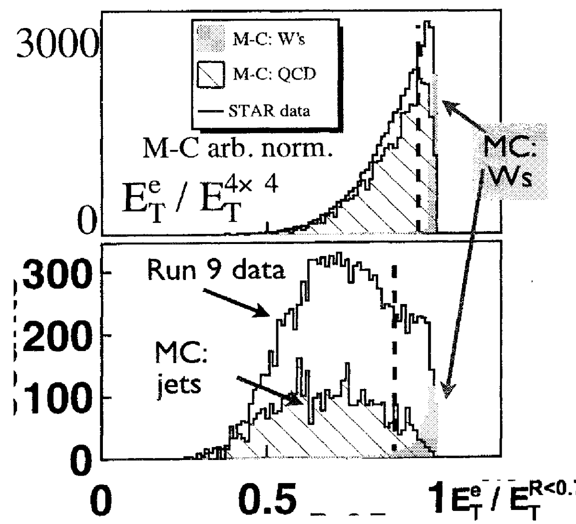
1. Find lepton in TPC (direction) and in EMC (energy)
   - TPC & EMC matching
2. Suppress QCD background
   - EMC cluster isolation
   - near jet veto
   - away ET veto



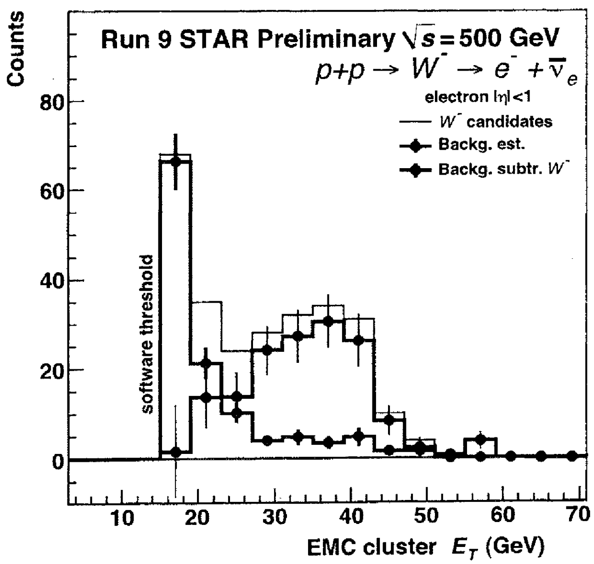
2x2 EM cluster with highest ET sum, must contain tower pointed by the track

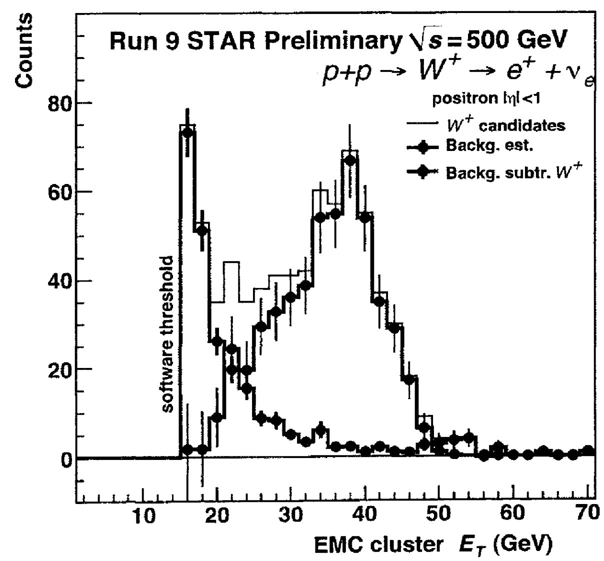




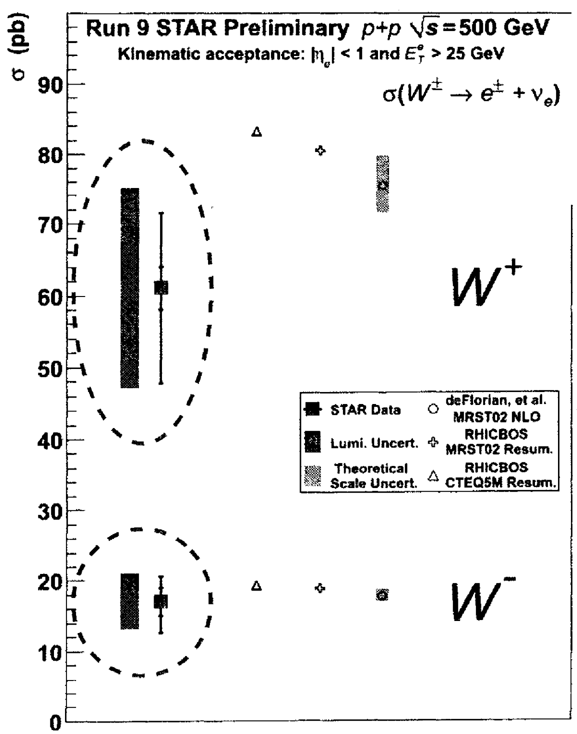


Reconstructed Jacobian Peak for W+, W-





W Cross Section – Results



	$W^- \rightarrow e^- + \bar{\nu}_e$	$W^+ \rightarrow e^+ + \nu_e$
N_W^{obs}	156	513
N_{back}	$25\ ^{+21}_{-7}$	$46\ ^{+36}_{-11}$
ϵ_{total}	$0.56\ ^{+0.11}_{-0.09}$	$0.56\ ^{+0.12}_{-0.09}$
$\int Ldt\ (\mathrm{pb}^{-1})$	13.7 ± 3.2	13.7 ± 3.2

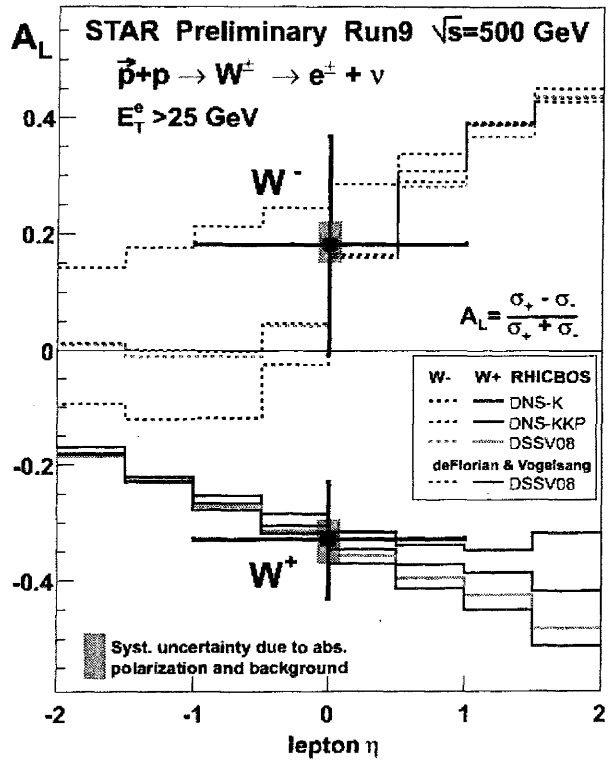
Run 9 STAR Preliminary (p+p 500 GeV)

$$\sigma_{W^+} = 61 \pm 3\,(\mathrm{stat.})\ ^{+10}_{-13}\,(\mathrm{syst.}) \pm 14\,(\mathrm{lumi.})\ \mathrm{pb}$$

$$\sigma_{W^-} = 17 \pm 2\,(\mathrm{stat.})\ ^{+3}_{-4}\,(\mathrm{syst.}) \pm 4\,(\mathrm{lumi.})\ \mathrm{pb}$$

There is reasonable agreement between the measured and expected cross sections.

A_L for Ws measured in Run 9



$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

STAR Preliminary Run 9

$$A_L(W^+) = -0.33 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.})$$

$$A_L(W^-) = 0.18 \pm 0.19(\text{stat.}) \ {}^{+0.04}_{-0.03}(\text{syst.})$$

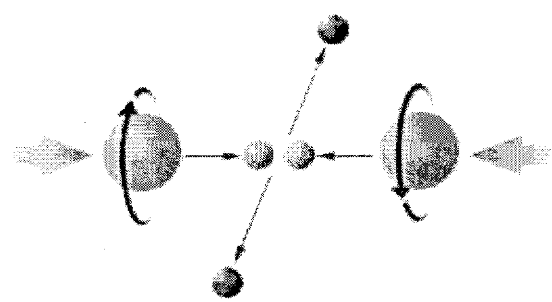
Summary

(for mid rapidity leptons)

- $A_L(W^+)$ negative, as predicted, **~3 sigma <0**
- $A_L(W^-)$ central value positive, as expected
- systematic errors of A_L under control
- TPC charge separation works up to ET~50 GeV

First Observations at PHENIX of W Production from Polarized pp Collisions at RHIC

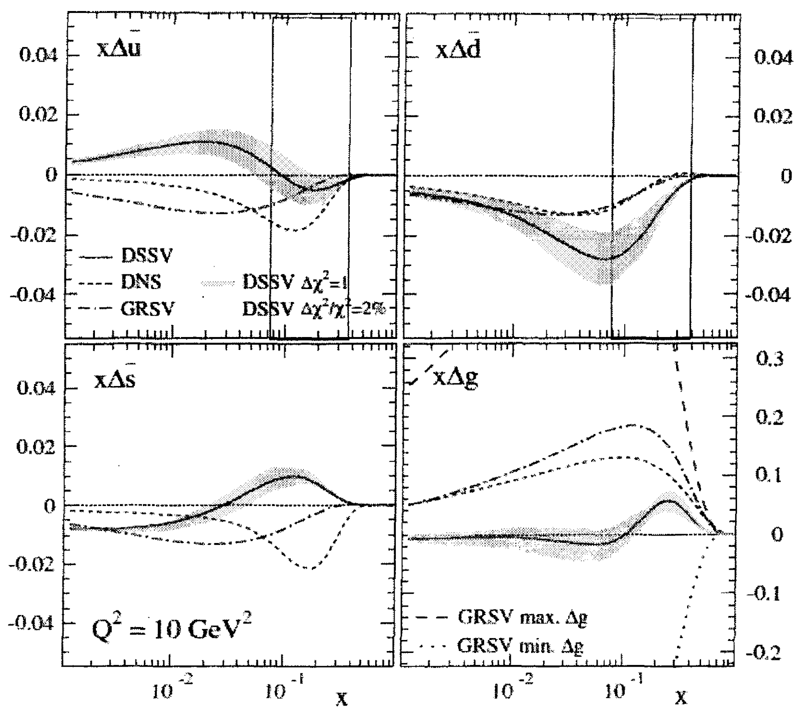
Dave Kawall, RIKEN-BNL Research Center and University of Massachusetts Amherst
on behalf of the PHENIX Collaboration



The evidence for $pp \to W + X \to e + X'$ in polarized pp collisions at $\sqrt{s} = 500$ GeV in the PHENIX detector at RHIC is presented. The physics importance, analysis strategy, and preliminary results on the single longitudinal, parity-violating spin asymmetry $A_L^{W^+}$ are also presented.

Motivation for Spin Physics with Ws at RHIC

- Key measurement of spin program : flavor separated, polarized PDFs $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- Semi-inclusive polarized DIS experiments (SMC, HERMES, COMPASS) have made such measurements
- STAR and PHENIX can do it exploiting maximal-parity violation in W production in polarized pp collisions
  - Measurements made at high scale ($M_W^2 > 6000$ GeV^2)
  - No uncertainty from fragmentation (couplings of W well known), no higher twist effects

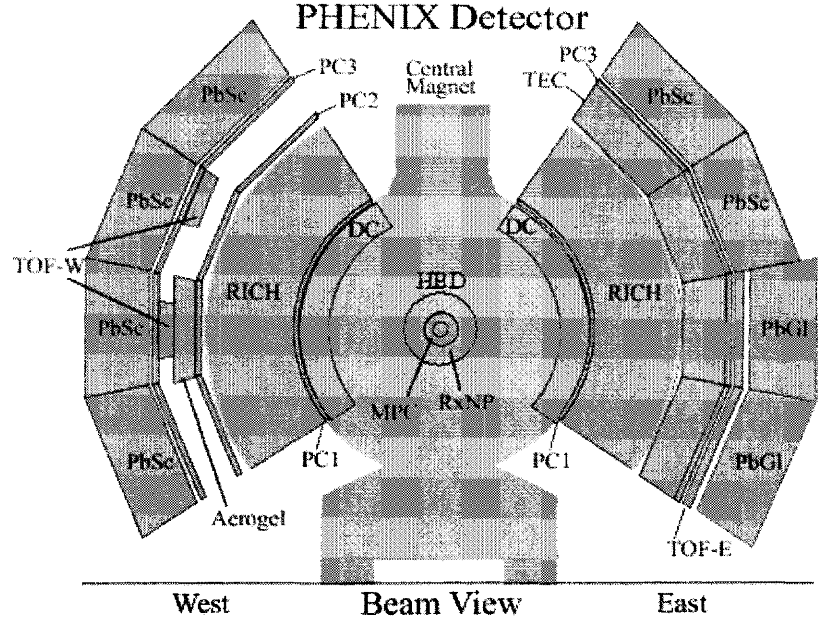


- Unpol. PDFs known to about 10%
- Theoretical uncertainties small (NLO+resummation)
- Robust extraction of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- Can also measure ratio $\bar{u}(x)/\bar{d}(x)$

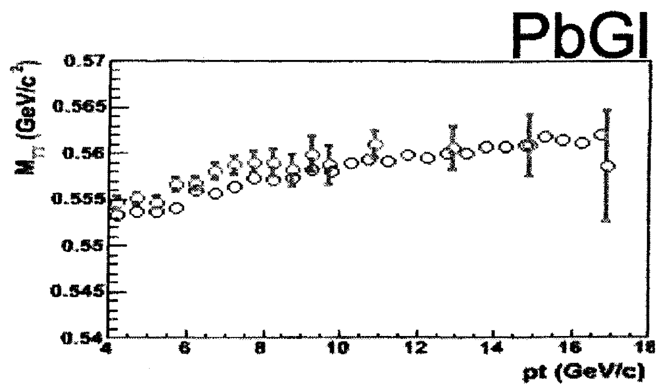
$\Leftarrow$ D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang, Phys. Rev. Lett. **101**, 072001 (2008)
(At $Q^2 = 10$ GeV^2)

6

PHENIX Central Arm Spectrometers



- Electromagnetic calorimeter (EMCal finely segmented : $\Delta\phi \times \Delta\eta \approx 0.01 \times 0.01$
- Calibrated with $M_{\gamma\gamma}$ of π^0 at high p_T

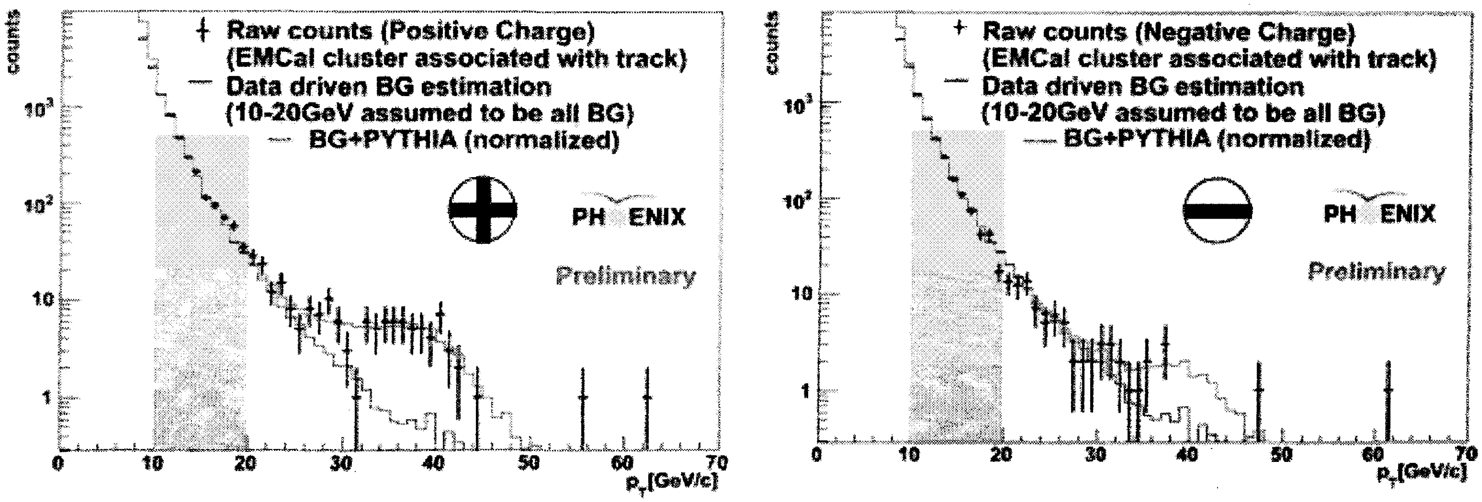


$\Rightarrow$ Focus on $\vec{p}p \Rightarrow W^{\pm} + X \Rightarrow e^{\pm} + X'$

- Detect high E $e^{\pm}$ in central arms of PHENIX
- Acceptance of each arm : rapidity $|\eta| < 0.35$ $(70 < \theta < 110)$, $\Delta\phi = \pi/2$
- Vertex cut : $|z| < 30$ cm

- Tracking : Charged tracks measured i Drift Chamber (DC) and Pad Cham ber(PC1)
- $\int \vec{B} \cdot d\vec{l} = 0.78$ Tesla-meters

Comparison of Data with Background Estimation



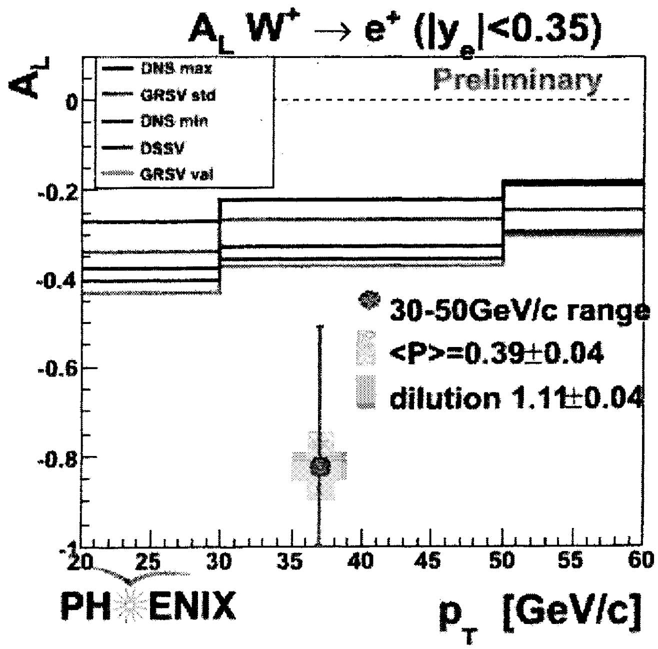
To determine background under signal region (30-50 GeV) :

- Take measured $\pi^0 + \gamma$ spectrum $\times$ conversion prob $+$ accidental matching track $\otimes$ acceptance
- Add charged hadrons (NLO) $\otimes$ detector response (GEANT) $+ e^{\pm}$ from FONLL c/b decays
- Normalize $h^{\pm}$ component so total background matches data in range 10-20 GeV
- Black histogram : background estimate; largest component from $\pi^0 + \gamma$, $h^{\pm}$ slightly less

Parity-Violating Single Spin Asymmetry $A_L(\vec{p}p \to W^+ \to e^+)$

- Preliminary result, using $P_B = 0.38 \pm 0.04$ and $P_Y = 0.40 \pm 0.04$ $(\delta P/P = 9.2\%)$
- Raw asymmetry in background region (12-20 GeV/c) consistent with 0 : $\epsilon_{\rm raw}^{\rm Bkgd} = 0.035 \pm 0.047$
- Raw asymmetry in signal region (30-50 GeV/c) inconsistent with 0 : $\epsilon_{\rm raw}^{\rm Signal} = -0.29 \pm 0.11$
- $A_L = \frac{1}{P} \times \epsilon_{\rm raw} \times D$, correct for dilution of A_L by Z and QCD background $(D = 1.11 \pm 0.04)$

$$A_L(\vec{p}p \to W^+ \to e^+) \;=\; -0.83 \;\pm\; 0.31$$



Summary and Outlook

- Developed analysis techniques to isolate $W \rightarrow e$ signal above backgrounds
- Clear evidence for $W^{\pm} \rightarrow e^{\pm}$ at $|\eta| < 0.35$ in PHENIX central arms
- Preliminary determination of single-spin parity-violating asymmetry :
  $A_L^W(\vec{p}p \rightarrow W^+ \rightarrow e^+) \;=\; -0.83 \;\pm\; 0.31$
- Analysis underway for cross-section estimates, final $A_L^{W^{\pm}}$ determinations

- Upgrades will help refine analysis, add acceptance and new physics channels :
  - Si Barrel vertex detectors in PHENIX central arms
  - Muon arms : RPCs + muon trigger upgrade : $W \rightarrow \mu$ signal $1.2 < |\eta_{\mu}| < 2.2$

- C-AD getting closer to design luminosity at $\sqrt{500}$ GeV, $\approx 40\%$ polarization
- Will need 300+ pb^{-1} integrated luminosity, 60% polarization to meet goals of program

ResBos and RhicBos

Q_T resummation for (un)polarized EW boson production

13

Pavel Nadolsky

Southern Methodist University

June 24, 2010

Objectives of the talk

An overview of physics in

- **ResBos: Res**ummation for electroweak **Bos**ons and their decays in **unpolarized** pp or $p\bar{p}$ collisions
- **RhicBos** = **ResBos** adapted to compute longitudinal single-spin and double-spin asymmetries in **leptonic** decays of γ^*, W, Z in pp collisions
- Single-spin asymmetries in **hadronic** decays of W bosons – a useful measurement **complementary to the leptonic mode**

Interruptions and questions are welcome!

15

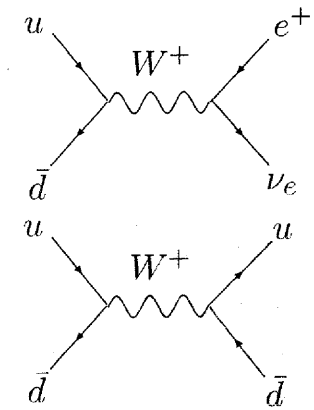
Today's focus is on...

- unpolarized parton distributions: $$f_{a/p}(x,Q) \equiv f_{a/p}^{+/+}(x,Q) + f_{a/p}^{-/+}(x,Q)$$
- longitudinally polarized parton distributions: $$\Delta f_{a/p}(x,Q) \equiv f_{a/p}^{+/+}(x,Q) - f_{a/p}^{-/+}(x,Q)$$
- unpolarized cross sections: $$\sigma = \frac{1}{2}\left[\sigma(p^{\rightarrow}p) + \sigma(p^{\leftarrow}p)\right]$$
- single-spin cross sections ($\neq 0$ if $V - A$ interaction): $$\Delta_L\sigma = \frac{1}{2}\left[\sigma(p^{\rightarrow}p) - \sigma(p^{\leftarrow}p)\right]$$
- single-spin asymmetry as a function of W boson rapidity y: $$A_L(y) \equiv \frac{d\Delta_L\sigma/dy}{d\sigma/dy}$$

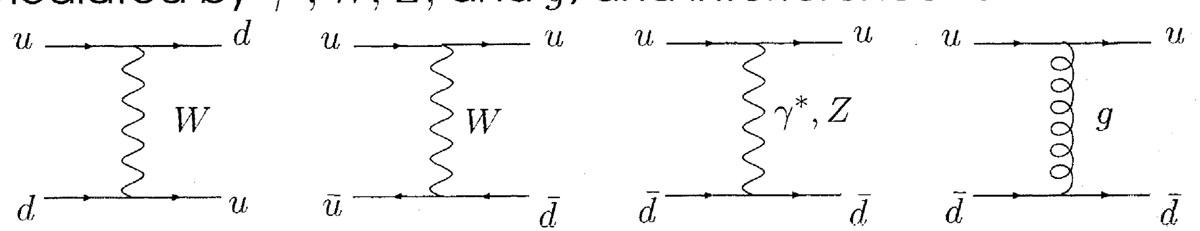
Two classes of subprocesses with W bosons

1: Resonant (s-channel) W boson production

- dominant parity-violating process at $Q \approx M_W$
- Leptonic decays: Br($W \to e\nu_e$) $\approx$ 10.8% - RhicBos
- Hadronic decays: Br($W \to$ hadrons) $\approx$ 67%



2: Non-resonant scattering into a dijet final state, mediated by γ^*, W, Z, and g, and interference terms



, etc.

Related publications

On-shell W boson production

1. C. Bourrely, J. Soffer, PLB 314, 132 (1993); Nucl.Phys. B423, 329 (1994)
2. A. Weber, Nucl. Phys. B 403, 545 (1993)
3. P. Nadolsky, hep-ph/9503419
4. T. Gehrmann, Nucl. Phys. B534, 21(1998)
5. M. Gluck, A. Hartl, and E. Reya, Eur. Phys. J. C19, 77 (2001)

Leptonic decay mode

1. B. Kamal, Phys. Rev. D57, 6663 (1998)
2. P. Nadolsky and C.-P. Yuan, Nucl. Phys. B666, 3 and 31 (2003)

Dijet mode

1. H. Haber and G. Kane, Nucl. Phys. B146,109 (1978)
2. F. Paige, T. L. Trueman, T. Tudron, Phys. Rev. D 19, 935 (1979)
3. C. Bourrely, J. P. Guillet, and J. Soffer, Nucl. Phys. B361, 72 (1991)
4. S. Arnold, A. Metz, V. Vogelsang, arXiv:0807.3688; S. Arnold, K. Goeke, A. Metz, P. Schweitzer, W. Vogelsang, Eur.Phys.J.ST 162 (2008)

Data-driven search for resonant $W \to$ jet + jet contributions

$A_L(y)$ is most accessible in the signal region:

$$Q = M_W \pm 10 - 15 \text{ GeV}, \; p_{Tj} \gtrsim 25 \text{ GeV}, \; |y_{1j} - y_{2j}| \lesssim 1$$

The measurement can be based on the following strategy:

1. Discard events with gluon-like jets (wide, large multiplicity) to the best of one's ability
2. Precisely measure the smooth background outside of the signal region
3. Use this measurement to predict and subtract the background inside the signal region
4. Look for a large $A_L(y)$ at $y > +1$ (driven by a large $\Delta u(x)/u(x)$ at $x \to 1$)
5. Measure moderate $A_L(y)$ at $y < -1$ to constrain $\Delta \bar{d}(x)/\bar{d}(x)$ at $x < 0.1$

Precision determination of MW from observables at hadron colliders

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Abstract

The measurement of MW will probably reach the 15 MeV level at the Tevatron. The measurement of this pseudo-observable heavily involves theoretical ingredients . In order to attempt an estimate of the final theoretical systematic uncertainty, one needs a classification of the impact of different classes of radiative corrections in terms of shifts of the final value of MW.

Once known higher order effects have been estimated and possibly included in the data analysis, it will be possible, by comparing the predictions of different codes, to study the remaining sources of theoretical uncertainty and to obtain a final theoretical systematic error on MW.

Fixed order calculations provide the first basic estimates of the relevant cross sections, but a realistic simulation shows which effects survive after e.g. the convolution with multiple gluon/photon emission and with the smearing of lepton momenta or the lepton-photon recombination.

In this talk I will describe a simple procedure to perform a template fit of theoretical distributions, treated as pseudo-data, deriving a classification of the impact of MW of different classes of radiative corrections. This procedure will be applied to study: i) change of EW input scheme, use of factorized expressions, EW higher orders; ii) QCD corrections by different codes; iii) combination of QCD+EW corrections; iv) PDF uncertainties.

The template fitting procedure

A distribution computed with a given set of radiative corrections and with a given value MW_0 is treated as a set of pseudo-data. The templates are prepared in Born approximation, using 100 values of MW_i Each template is compared to the pseudo-data and a distance is measured.

$$\chi_i^2 = \sum_{j=1}^{N_{bins}} \frac{\left(O_j^{data} - O_j^{templ=i}\right)^2}{\left(\sigma_j^{data}\right)^2} \qquad i = 1, \dots, N_{templ} \tag{1}$$

The template that minimizes the distance is considered as the preferred one and the value of MW, used to generate it, is the measured MW.

The difference $MW-MW_0$ represents the shift induced on the measurement of the W mass by including that specific set of radiative corrections

The distributions used in the evaluation of χ_i^2 in general do not have the same normalization. It is also possible to compare distributions that have been normalized to their respective cross-sections, to appreciate the role of the shape differences.

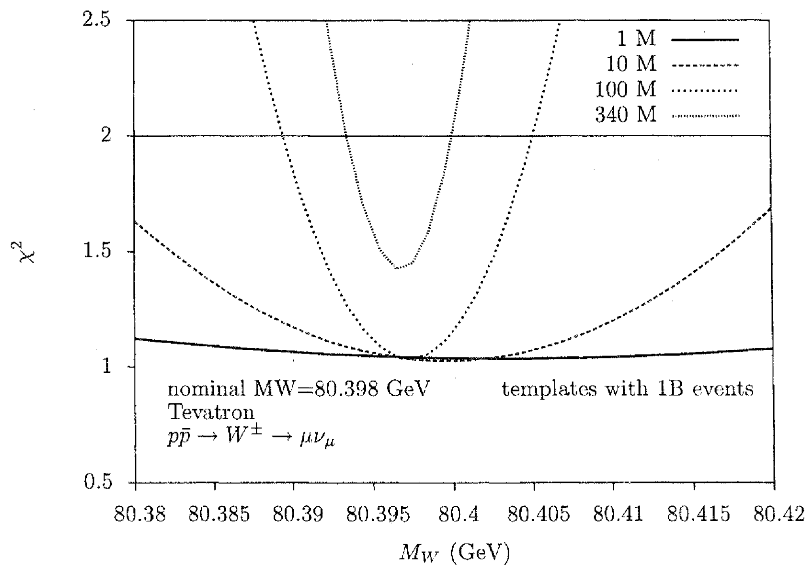


Figure 1: Pseudodata in Born approximation, fitted with Born templates. The nominal MW value used to generated the pseudodata is found from the fitting procedure, with increasing accuracy depending on the number of events in the pseudodata sample. The $\Delta\chi^2 = 1$ rule, valid in this exercise, determines the uncertainty in the fitting procedure associated to the extraction of a preferred value of MW.

Effect of higher order corrections in the $\alpha(0)$ input scheme

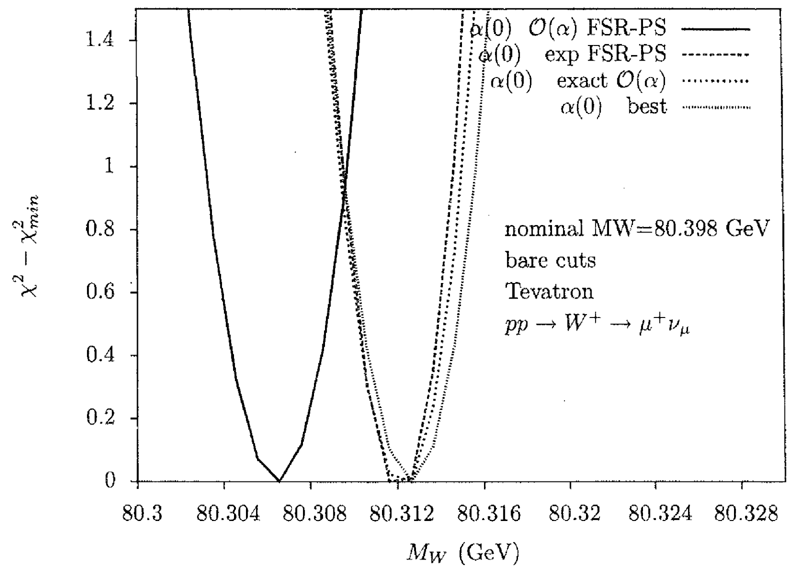


Figure 2: Impact of different higher order corrections, all evaluated in the $\alpha(0)$ input scheme, on the extraction of a preferred MW value.

The templates used to evaluate the effects in fig.2 have been prepared using HORACE, Born approximation, $\alpha(0)$ input scheme, 10 billions of events, $80.248 \leq MW \leq 80.348$ GeV.

Effect of different EW input scheme choices

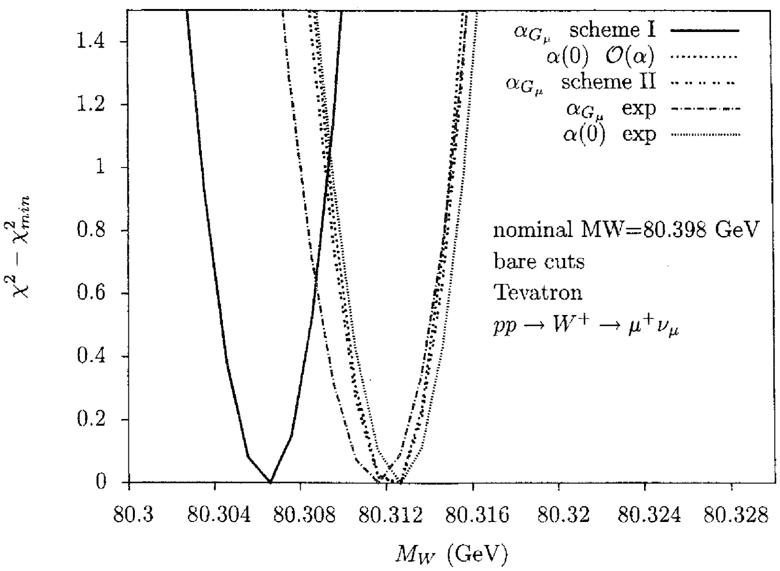


Figure 3: Impact of different EW input scheme choices on the extraction of a preferred MW value, in different perturbative approximations.

The templates used to evaluate the effects in fig.3 have been prepared using HORACE, Born approximation, $\alpha(0)$ input scheme, 10 billions of events, $80.248 \leq MW \leq 80.348$ GeV.

Effect of different methods to include multiple gluon radiation

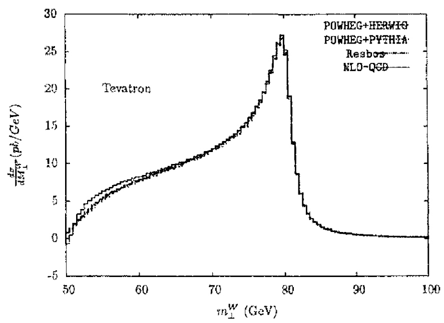


Figure 4: Transverse mass distribution obtained with different code that share NLO-QCD accuracy but include multiple gluon radiation with different approaches: analytical resummation (Resbos) or QCD Parton Shower with different ordering algorithms (HERWIG vs PYTHIA)

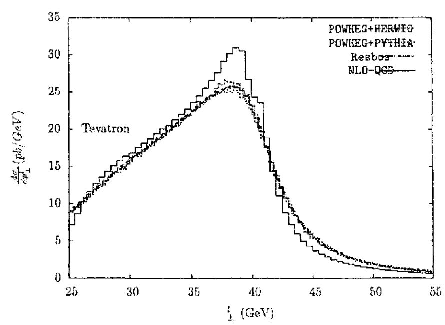


Figure 5: Same as in fig.4, for the transverse lepton distribution.

The templates used to evaluate the effects in fig.4,5 have been prepared using Resbos, best approximation, $\alpha(0)$ input scheme, 1 billion of events, $80.348 \leq MW \leq 80.448$ GeV.

The effect of the corrections is very stable in the case of the transverse mass distribution ($\Delta MW = +18$ MeV) for both POWHEG+HERWOG and POWHEG+PYTHIA. In the case of the lepton transverse momentum distribution, the fitting procedure is much more sensitive to the QCD details of the different approximations, both for their impact on the normalization and on the shape of the distribution.

Effect of the combination of EW and QCD corrections

The QCD and EW corrections to different distributions can be combined, up to terms of $\mathcal{O}(\alpha\alpha_s)$ and of terms of $\mathcal{O}(\alpha_s^2)$, according to the following recipes.

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\oplus EW} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{QCD} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{Born}\right\} \tag{2}$$

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\otimes EW} = \left(1 + \frac{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{MC@NLO} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{HERWIG\ PS}}{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{LO/NLO}}\right) \times \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW}\right\}_{HERWIG\ PS} \tag{3}$$

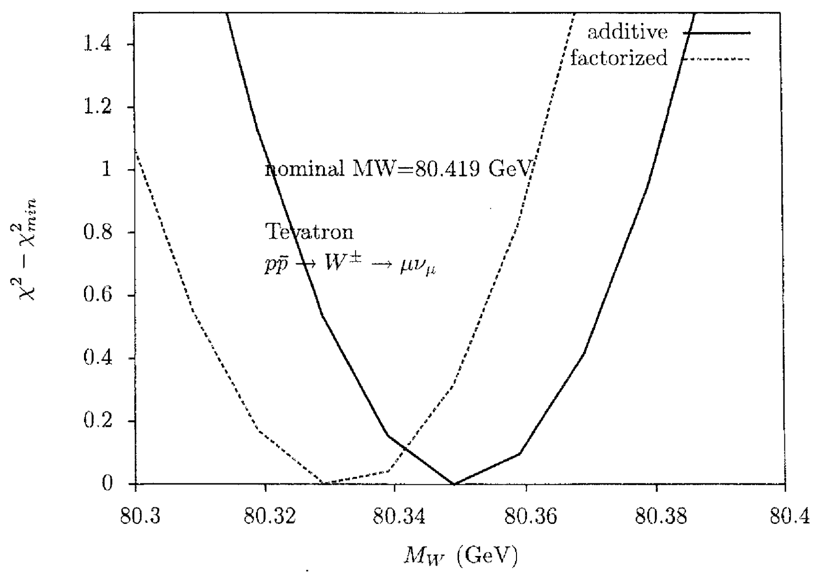


Figure 6: Preferred MW value obtained in the two approximations of eq.2 and of eq.3

The templates used to evaluate the effects in fig.6 have been prepared using Resbos, best approximation, $\alpha(0)$ input scheme, 1 billion of events, $80.219 \leq MW \leq 80.419$ GeV.

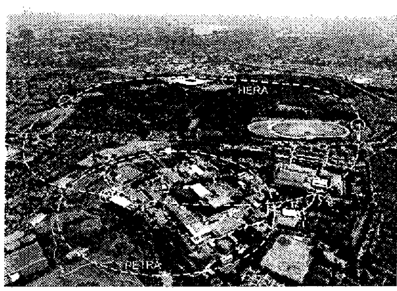
technische universität dortmund

W and Z Physics from HERA

David South (Technische Universität Dortmund)

on behalf of the H1 and ZEUS Collaborations

The Physics of W and Z Bosons, June 24 - 25 2010, BROOKHAVEN NATIONAL LABORATORY



Outline:

Introduction to HERA, H1 and ZEUS

High Q^2 Measurements of Neutral and Charge Current

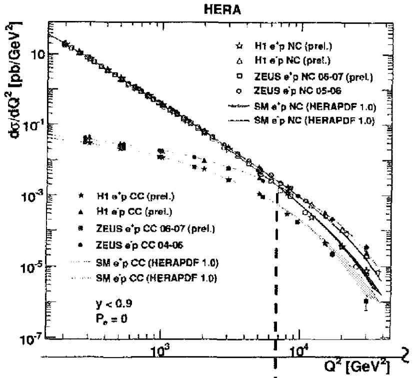
Combined H1 and ZEUS measurements and QCD/EW fits

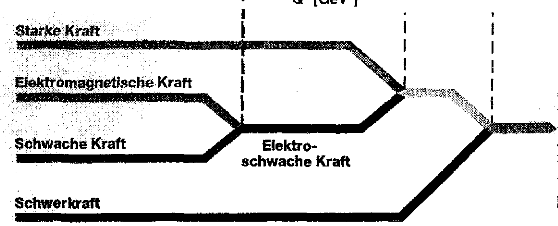
Rare processes at HERA involving W and Z Bosons

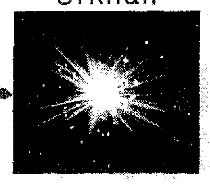
Summary

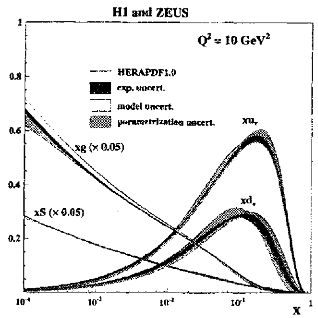
Electroweak Physics at HERA

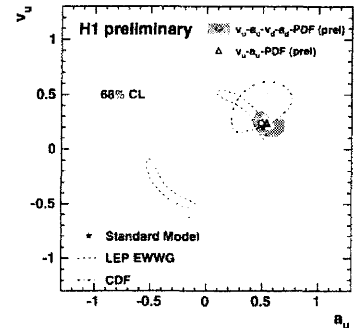
Inclusive measurements
electroweak effects at $Q^2 \sim M_{W,Z}$



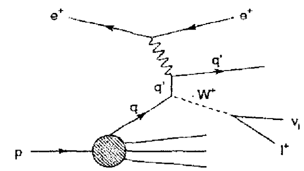


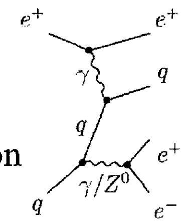






QCD and electroweak fits to the HERA data



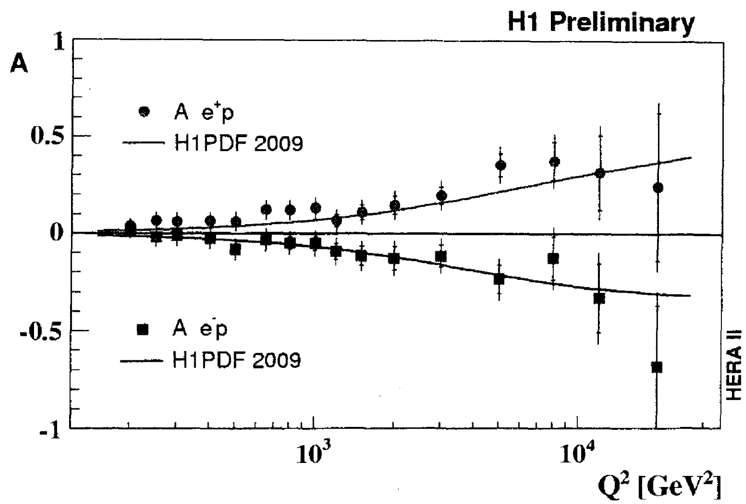


Exclusive production of W and Z bosons

Measurements with W and Z bosons at HERA are within reach!

HERA II Polarisation Asymmetry in NC

γ ⟶ *influence of* Z^0



$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}_{NC}(P_R) - \sigma^{\pm}_{NC}(P_L)}{\sigma^{\pm}_{NC}(P_R) + \sigma^{\pm}_{NC}(P_L)}$$

$$P_e = \frac{N_R - N_L}{N_R + N_L} \qquad P_R > 0 \qquad P_L < 0$$

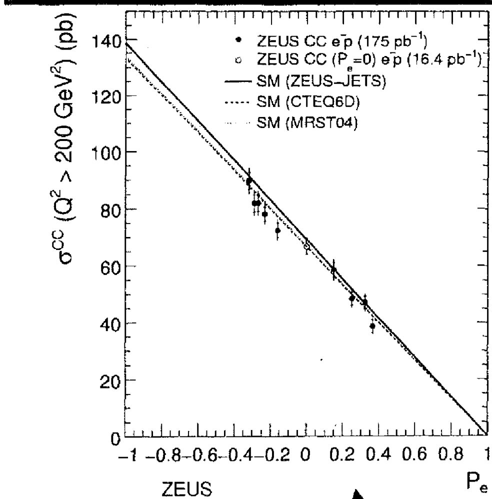
Form polarisation asymmetry from HERA II Neutral Current measurements

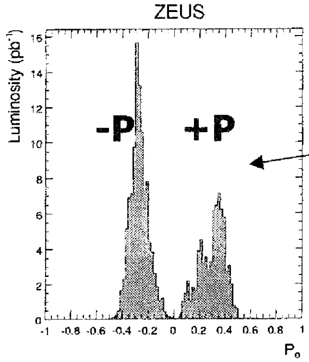
- clear observation of parity violation of NC electroweak exchange

Nicely illustrates the properties of the different polarisation and lepton charge data

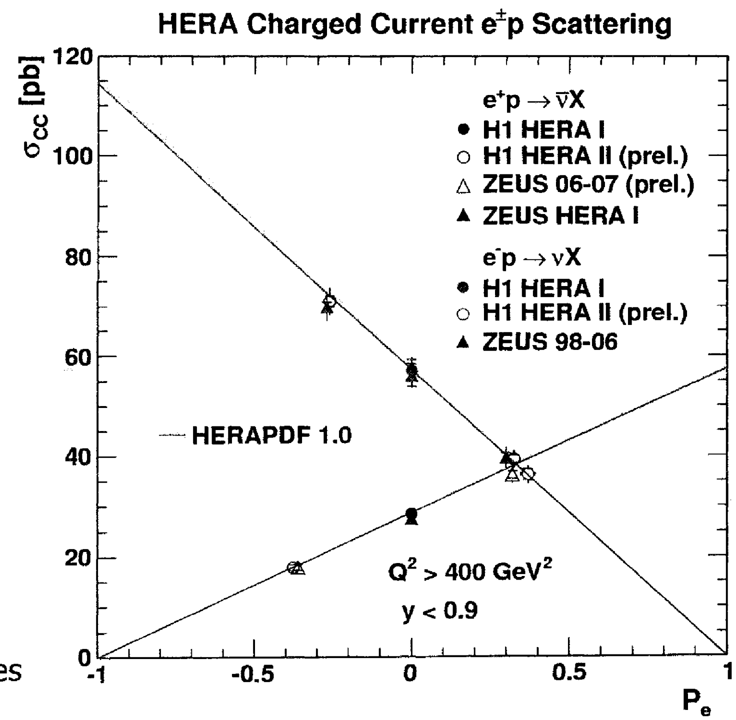
Well described by the SM prediction

Charged Current Cross Section vs. Polarisation





Measurements made by ZEUS using various polarisation values

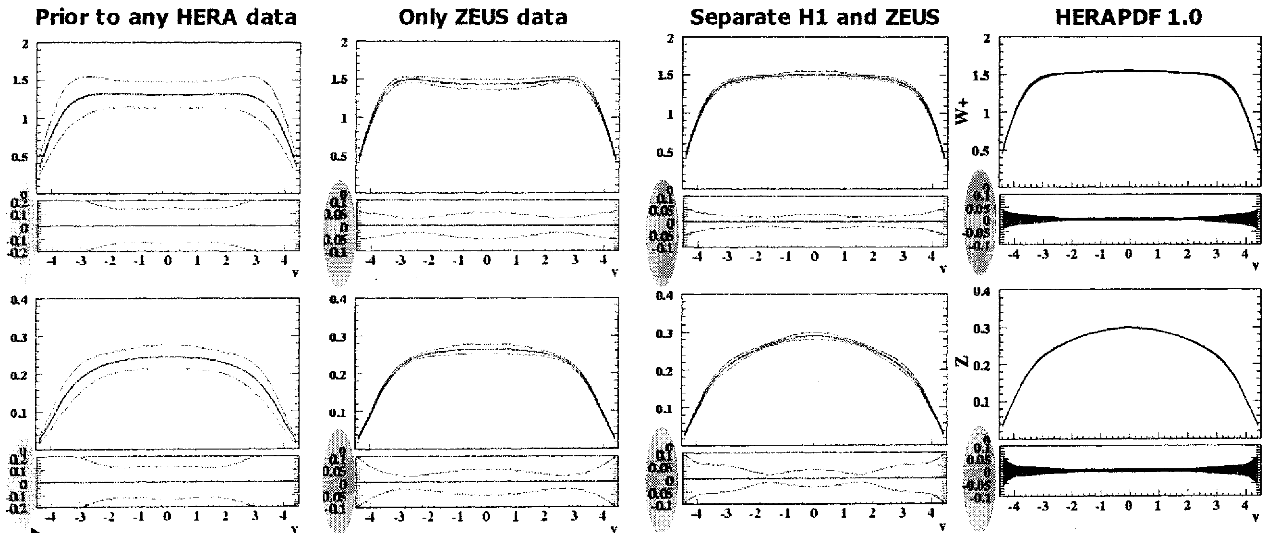


Data exhibit linear dependence of average polarisation and HERA I and II measurements agree with the SM prediction

Impact of HERA Data at the LHC

W^+, Z rapidities (at 14 TeV!)

after Voica Radescu, and Amanda Cooper-Sarkar



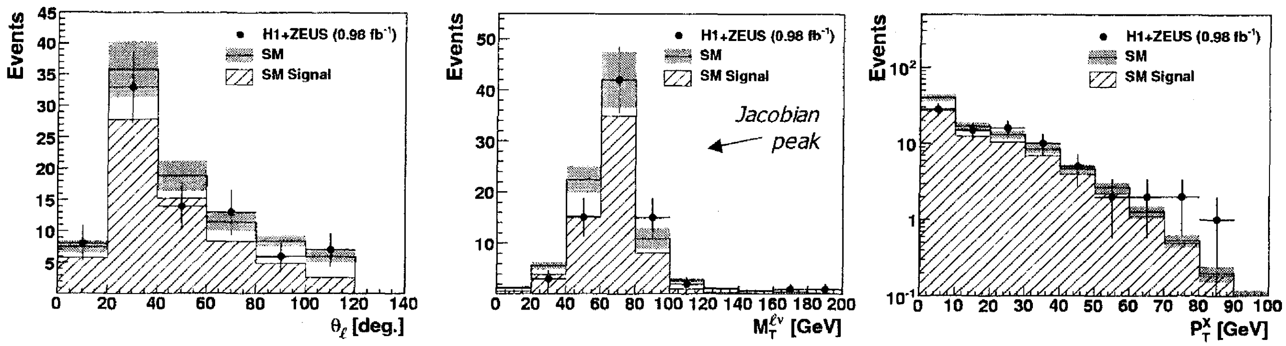
Note scale!

Experimental uncertainty at central rapidities using combined HERA data~1%!
http://www.desy.de/h1zeus/combined_results/benchmark/herapdf1.0.html

Impressive precision on the low x sea and gluon of the HERAPDF 1.0 is relevant for W,Z production at the LHC

Inclusion of HERA data shows the tremendous improvement on the predictions for W and Z production at the central rapidity

H1+ZEUS Isolated Leptons: Results



H1+ZEUS 1994–2007 $e^{\pm}p$ 0.98 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	61	69.2 ± 8.2	48.3 ± 7.4	20.9 ± 3.2
	$P_T^X > 25$ GeV	16	13.0 ± 1.7	10.0 ± 1.6	3.1 ± 0.7
Muon	Total	20	18.6 ± 2.7	16.4 ± 2.6	2.2 ± 0.5
	$P_T^X > 25$ GeV	13	11.0 ± 1.6	9.8 ± 1.6	1.2 ± 0.3
Combined	Total	81	87.8 ± 11.0	64.7 ± 9.9	23.1 ± 3.3
	$P_T^X > 25$ GeV	29	24.0 ± 3.2	19.7 ± 3.1	4.3 ± 0.8

Good overall agreement with the Standard Model

SM expectation dominated W production
→ *Cross section*

Measured: 1.06 ±0.16 (stat.) ± 0.07 (sys.) pb SM: 1.26 ± 0.19 pb from EPVEC NLO

Measurement of W boson mass at DØ

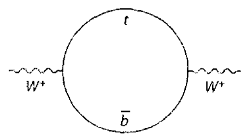
Junjie Zhu
University of Michigan

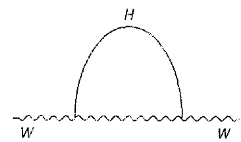
The Physics of W and Z Bosons
June 24, 2010

W boson mass

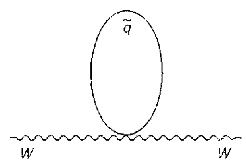
$$M_W^2 = \frac{\pi\alpha}{\sqrt{2}G_F}\frac{1}{\sin^2\theta_W}\frac{1}{(1-\Delta r)}$$

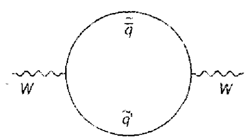
Δ r ~ 3%





$\Delta r \propto M_t^2$ $\Delta r \propto \log M_H$



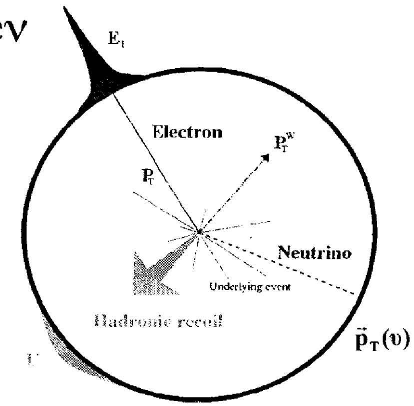


M_W can be increased by up to 250 MeV in MSSM

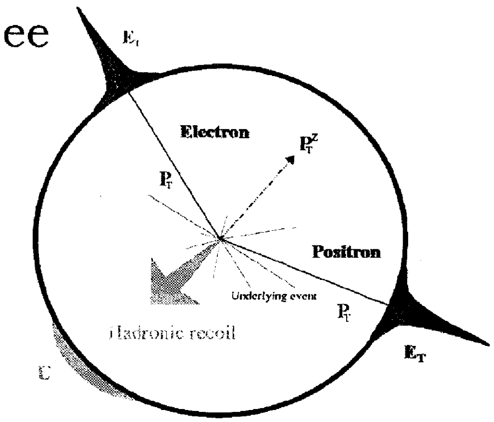
A precise measurement of M_W can be used to make indirect constraints on M_H and possible new physics

Measurement strategy

$W \rightarrow e\nu$

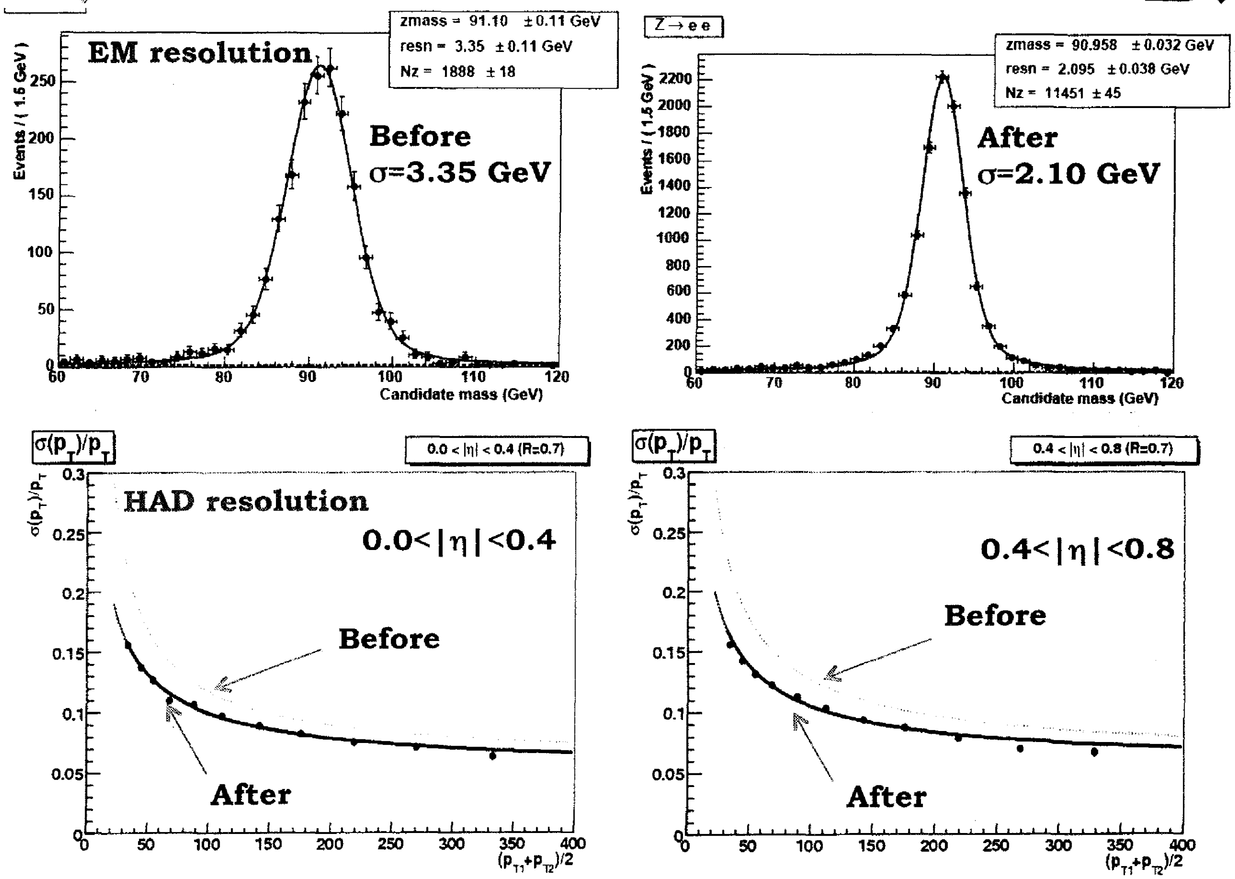


$Z \rightarrow ee$



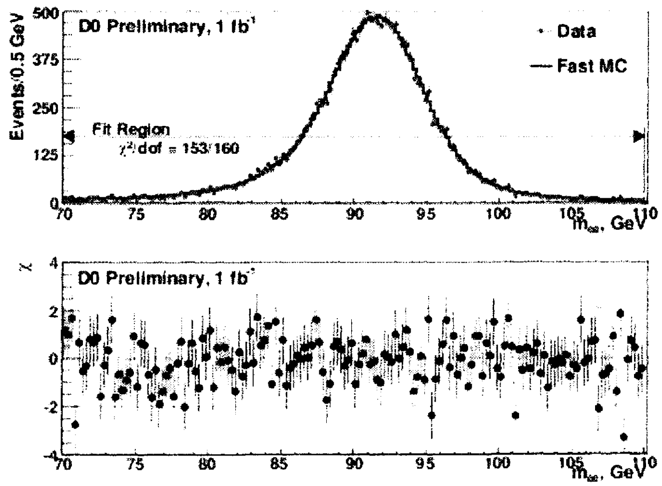
- Three observables: $p_T(e)$, $p_T(\nu)$ (inferred from missing transverse energy), transverse mass $M_T^2=(E_{Te}+E_{T\nu})^2-|\overrightarrow{p}_{Te}+\overrightarrow{p}_{T\nu}|^2$
- Develop a parameterized MC simulation with parameters determined from the collider data (mainly $Z \rightarrow ee$ events)
- Generate MC templates with different input M_W, compare with data distributions and extract M_W
- $Z \rightarrow ee$ events are used to set the absolute electron energy scale, so we are effectively measuring M_W/M_Z

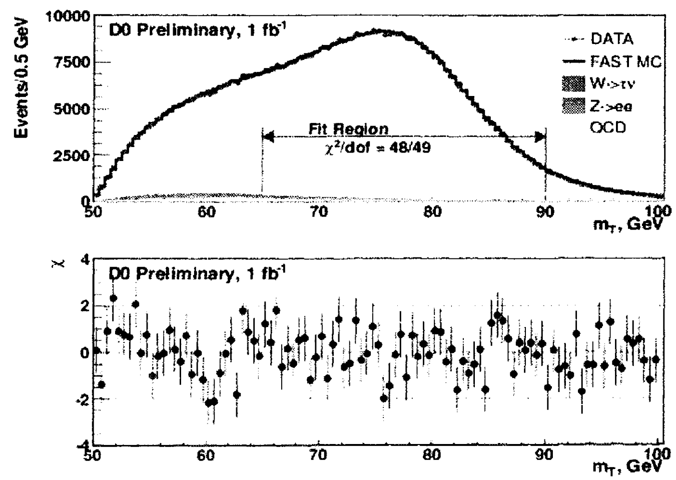
Calibration results



Mass fits

Z invariant mass (M_{ee}), 18k | **W transverse mass (M_T), 500k**





M_Z = 91.185 ± 0.033 (stat) GeV | **M_W = 80.401 ± 0.023 (stat) GeV**

(WA M_Z=91.188 ± 0.002 GeV)

PRL 103, 141801 (2009)

Uncertainties

Source	$\sigma(m_W)$ MeV m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron energy offset	4	6	7
Electron energy loss model	4	4	4
Recoil model	6	12	20
Electron efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	9	11	14
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	17
Total Systematic	37	40	44
Statistical	23	27	23
Total	44	48	50

Measurement of the W Boson Mass at CDF

Ashutosh Kotwal
Duke University

We present a techniques used for precise measurements of the W boson mass at the CDF experiment at Fermilab. We present the results and the prospects for future improvements at Fermilab and the LHC.

Riken Brookhaven Research Center Workshop
June 24-25, 2010

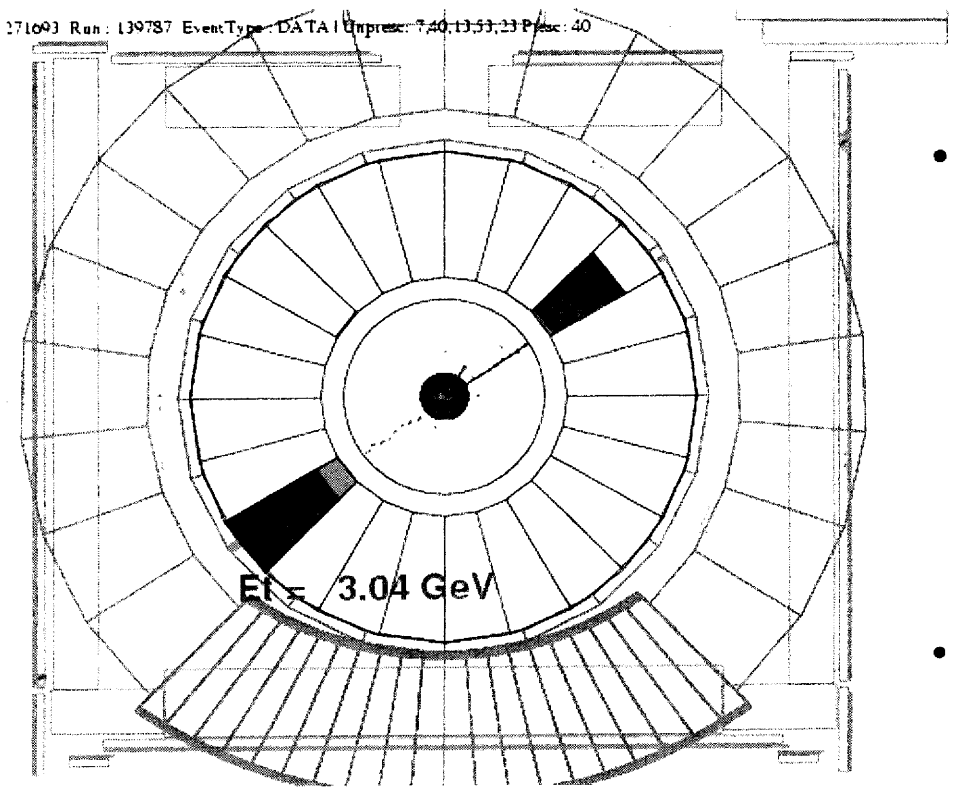
Outline of CDF Analysis

Energy scale measurements drive the W mass measurement

- Tracker Calibration
  - alignment of the central drift chamber (COT with ~2400 cells) using cosmic rays
  - COT momentum scale and tracker non-linearity constrained using $J/\psi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$ mass fits
    - Confirmed using $Z \rightarrow \mu\mu$ mass fit
- EM Calorimeter Calibration
  - COT momentum scale transferred to EM calorimeter using a fit to the peak of the E/p spectrum, around $E/p \sim 1$
  - Calorimeter energy scale confirmed using $Z \rightarrow ee$ mass fit
- Tracker and EM Calorimeter resolutions
- Hadronic recoil modelling
  - Characterized using p_T-balance in $Z \rightarrow ll$ events

Internal Alignment of COT

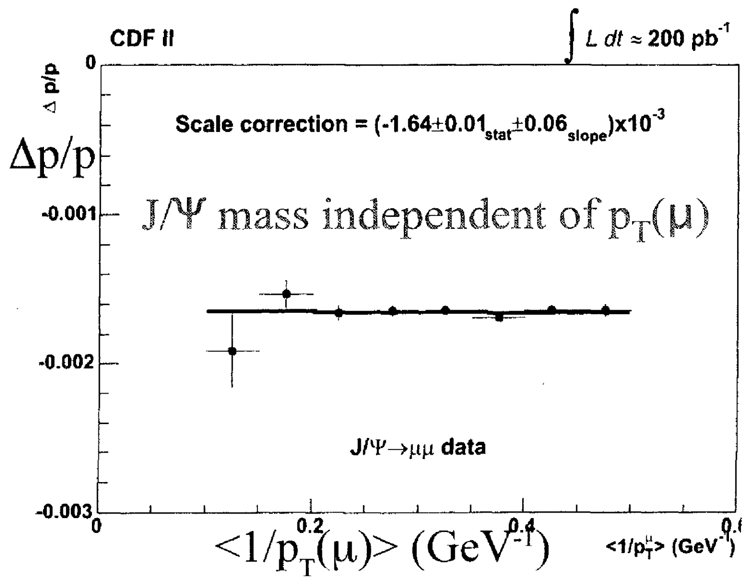
- Use a clean sample of ~200*k* cosmic rays for cell-by-cell internal alignment

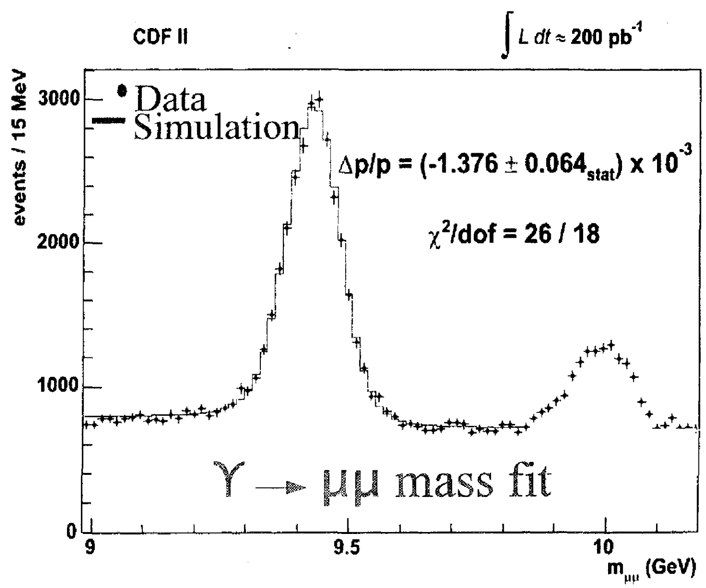


- Fit COT hits on both sides simultaneously to a single helix (A.Kotwal, H. Gerberich and C. Hays, NIMA 506, 110 (2003))
  - Time of incidence is a floated parameter
- Same technique being used on ATLAS and CMS

Tracking Momentum Calibration

- Set using $J/\Psi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$ resonances
  - Consistent within total uncertainties
- Use J/Ψ to study and calibrate non-linear response of tracker
- Systematics-dominated, improved detector modelling required

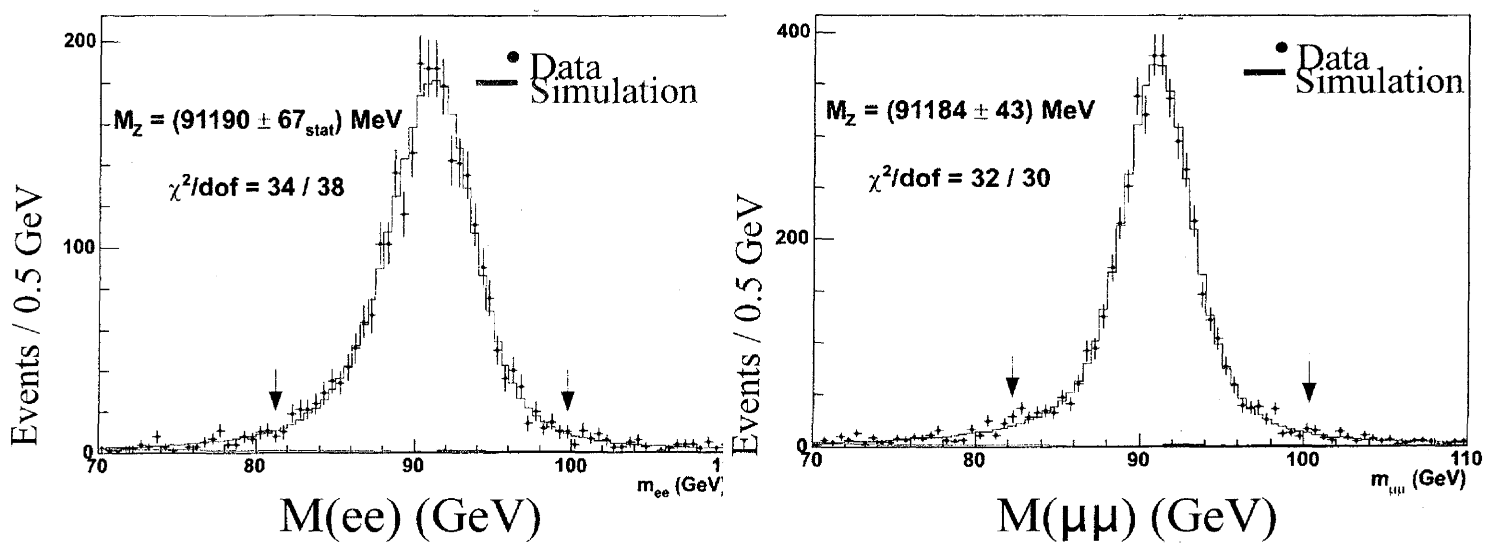




$Z \rightarrow ll$ Mass Cross-checks

- Z boson mass fits consistent with tracking and E/p-based calibrations

CDF II $L \sim 200$/pb



Summary

- The *W* boson mass is a very interesting parameter to measure with increasing precision
- CDF Run 2 W mass result with 200 pb^{-1} data:
  - $M_W = 80413 \pm 48$ MeV
- D0 Run 2 W mass result with 1 fb^{-1} data:
  - $M_W = 80401 \pm 43$ MeV
- Most systematics limited by statistics of control samples
  - CDF and D0 are both working on $\delta M_W < 25$ MeV measurements from ~ 2 fb^{-1} (CDF) and ~ 4 fb^{-1} (D0)
- Learning as we go: Tevatron → LHC may produce $\delta M_W \sim 5\text{-}10$ MeV

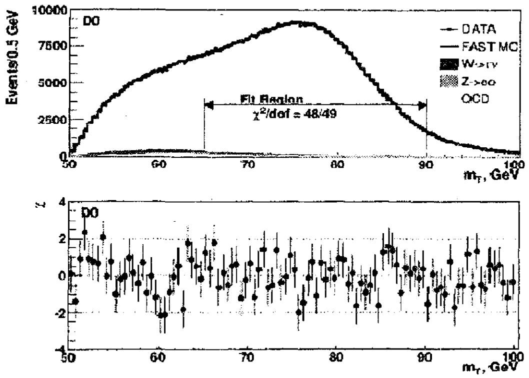
Monte Carlo modelling issues for W measurements

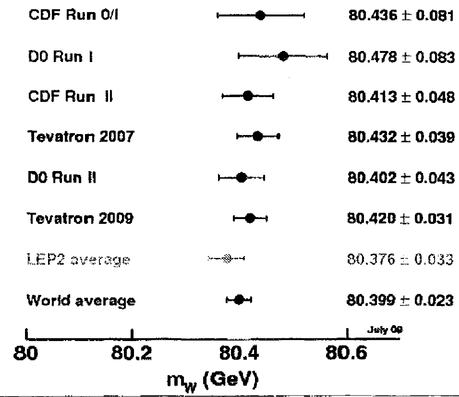
Jan Stark
Laboratoire de Physique Subatomique et de Cosmologie
Grenoble, France

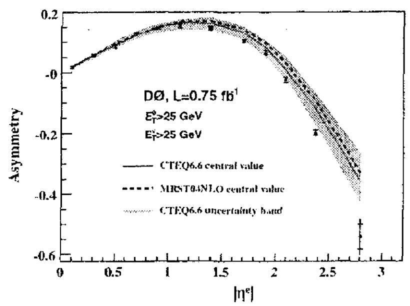
The physics of W and Z bosons
RIKEN BNL Research Centre Workshop, June 24-25, 2010

Context

Most of the comments in this talk are based on experience from the DØ 1 fb^{-1} measurement of the W boson mass. A complete overview of this analysis was described in Junjie Zhu's talk earlier today. Here we provide more details on the use of simulations in this measurement.



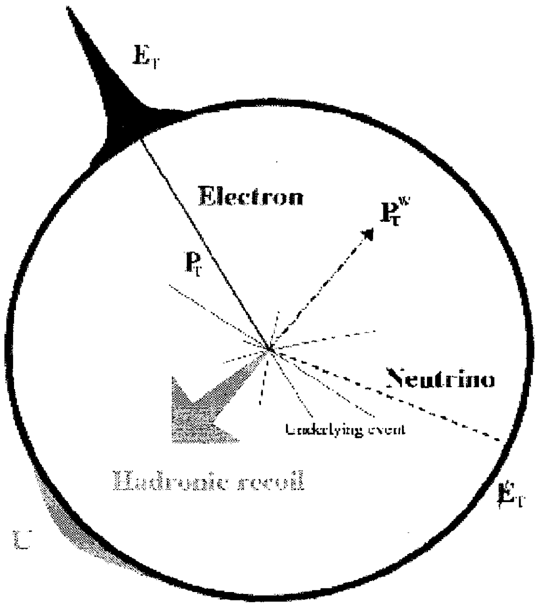




PRL **101**, 211801 (2008)

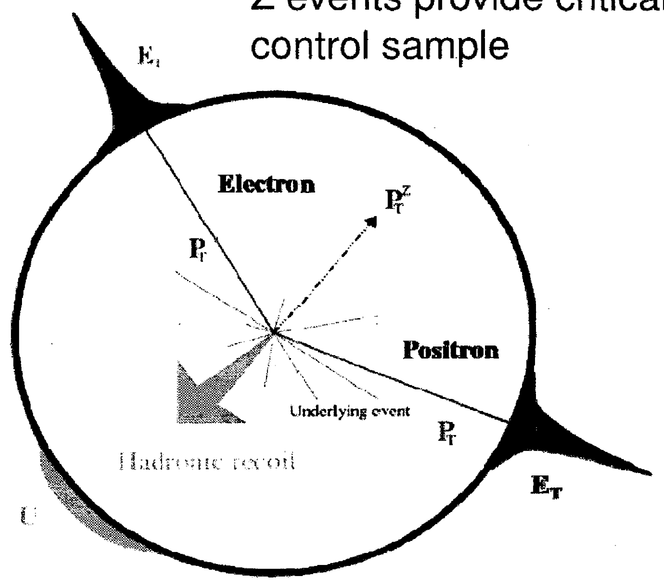
But many of the techniques and strategies discussed here also apply to many other W and Z measurements ...

Reminder: signature in the detector, requirements on precision



Isolated, high p_T leptons,
missing transverse momentum in W's

Z events provide critical control sample

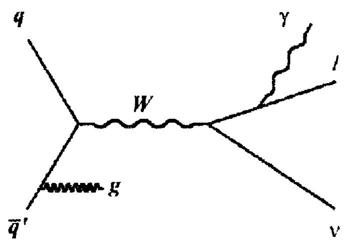


In a nutshell, measure two objects in the detector:
- Lepton (in principle e or μ; e in our analysis), need energy measurement with 0.2 per-mil precision (!!)
- Hadronic recoil, need ~ 1% precision

Measurement strategy

W mass is extracted from transverse mass, transverse momentum and transverse missing momentum:

Need Monte Carlo simulation to predict shapes of these observables for given mass hypothesis



NLO event generator : DØ uses **ResBos** [Balazs, Yuan; Phys ReV D56, 5558] + **Photos** {Barbiero, Was; Comp Phys Com 79, 291] for W/Z production and decay

+

Parameterised detector model ← Validated in "MC closure test"

↓

W mass templates

+

backgrounds

Detector calibration
- calorimeter energy scale
- recoil

data → binned likelihood fit ← backgrounds

↓

W mass

"First principles" vs. "parameterised" simulations

We all like "first principles" simulations, *i.e.* simulations where everything is based on a formal theory that predicts everything.

Examples:
- A gauge theory used to simulate some $e^+ e^- \to X$ collision.
- A simulation based on the known laws of the interactions between high-energy particles and matter, as well as a model of the DØ detector geometry is used to predict the electron energy response in DØ.

But what to do when the "first principles" cannot be made precise/complete enough ?

Examples:
- Tricky mathematical issues in QCD description of $p^+ p^{+/-} \to X$.
- Response to hadrons not simulated quite right in detector simulation.
- ...

Here "parameterised" simulations can be very powerful, because they have simple "knobs" that we can turn to adjust things.

Examples:
- Non-perturbative form factors to be determined from collider data.
- Simple parameterisation of hadron energy response, to be fit to control sample from collider data.

In practice, the trick is to combine the two approaches. In the DØ m(W) measurement we have a parameterised simulation with many parameterisations derived from first-principles simulations.

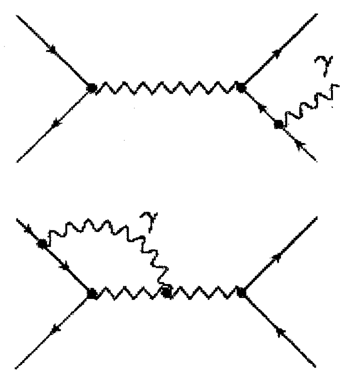
Model of W production and decay

Tool	Process	QCD	EW
RESBOS	W,Z	NLO	-
WGRAD	W	LO	complete $\mathcal{O}(\alpha)$, Matrix Element, ≤ 1 photon
ZGRAD	Z	LO	complete $\mathcal{O}(\alpha)$, Matrix Element, ≤ 1 photon
PHOTOS			QED FSR, ≤ 2 photons

Our main generator is "**ResBos+Photos**". The NLO QCD in **ResBos** allows us to get a reasonable description of the p_T of the vector bosons. The two leading EWK effects are the first FSR photon and the second FSR photon. **Photos** gives us a reasonable model for both.

We use **W/ZGRAD** to get a feeling for the effect of the full EWK corrections.
The final "QED" uncertainty we quote is 7/7/9 MeV (m_T,p_T,MET).
This is the sum of different effects; the two main ones are:

- Effect of full EWK corrections, from comparison of W/ZGRAD in "FSR only" and in "full EWK" modes (5/5/5 MeV).
- Very simple estimate of "quality of FSR model", from comparison of W/ZGRAD in FSR-only mode vs **Photos** (5/5/5 MeV).

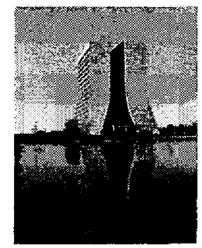


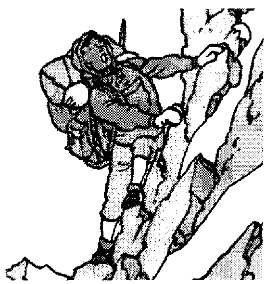
Theoretical issues in Monte Carlo modelling for W/Z production

[Physics of W and Z bosons – workshop @ RIKEN BNL research center]

Jan Winter [a]

– Fermilab –





I give an overview of how vector boson production is processed in Monte Carlo event generators. In a high-energy hadron collider environment this is always affected by QCD radiation. Parton showers can capture the leading effects of soft and collinear emissions, but fail to sufficiently describe hard jets associated with the vector boson. One therefore has to improve parton-shower approaches to gain a good understanding of V+n jets – a major background to all new physics searches. I briefly review tree-level matrix-element plus parton-shower merging and NLO calculations as means to predict V+n jet production. I compare both types of calculations and discuss their results.

[a] Sherpa authors: J. Archibald, T. Gleisberg, S. Höche, H. Hoeth, F. Krauss, M. Schönherr, F. Siegert, S. Schumann, J. Winter and K. Zapp

http://www.sherpa-mc.de/

Monte Carlo modelling of a (high-p_T) event

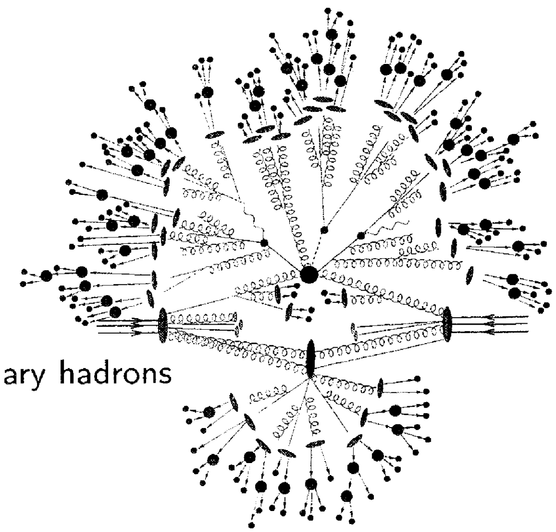
➲ ***Factorization approach: divide jet simulation into different phases***

➜ ***Perturbative Phases:*** *[parton jets]*

- ***Hard process/interaction (hard jet production)***
  exact matrix elements $|\mathcal{M}|^2$
- ***QCD bremsstrahlung (soft/coll multiple emissions)***
  initial- and final-state parton showering
- ***Multiple/Secondary interactions***
  modelling the underlying event

➜ ***Non-perturbative Phases:*** *[jet confinement – particle jets]*

- ***Hadronization***
  phenomenological models to convert partons into primary hadrons
- ***Hadron decays***
  phase-space or effective models to decay unstable into stable hadrons as observed in detectors

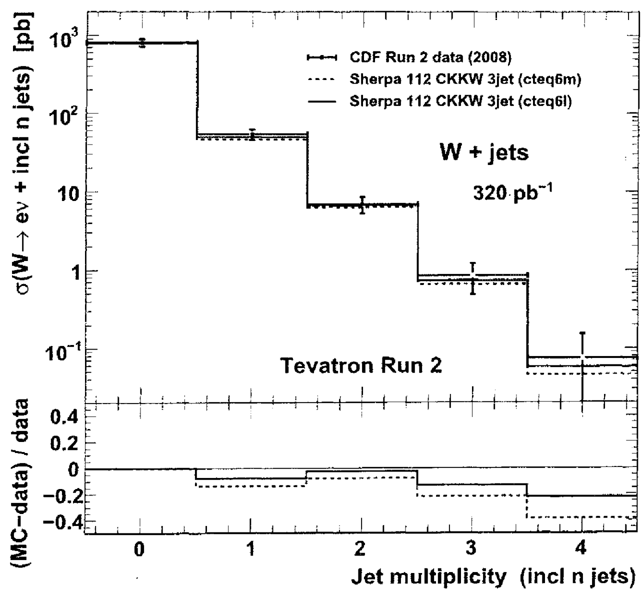


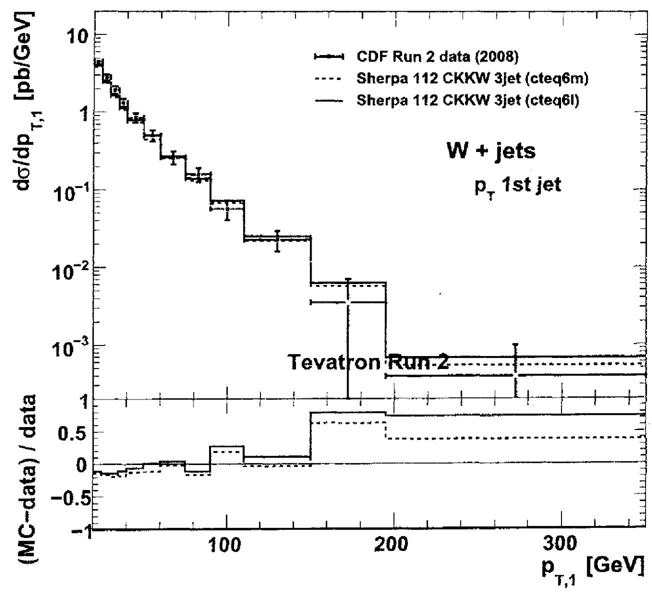
➲ predictions at hadron level – comparable to experimental data if corrected for detector effects

Comparison with CDF data: W+jets production

[T. Aaltonen et al., PRD **77** (2008) 011108]

- Monte Carlos need to be validated and tuned against most recent Tevatron data.
- Sherpa vs1.1.3 predictions normalized to total inclusive cross section. Two choices of PDFs.
- Tree-level ME+PS can reproduce W+>=n jet xsecs to 20% after applying overall K factor.

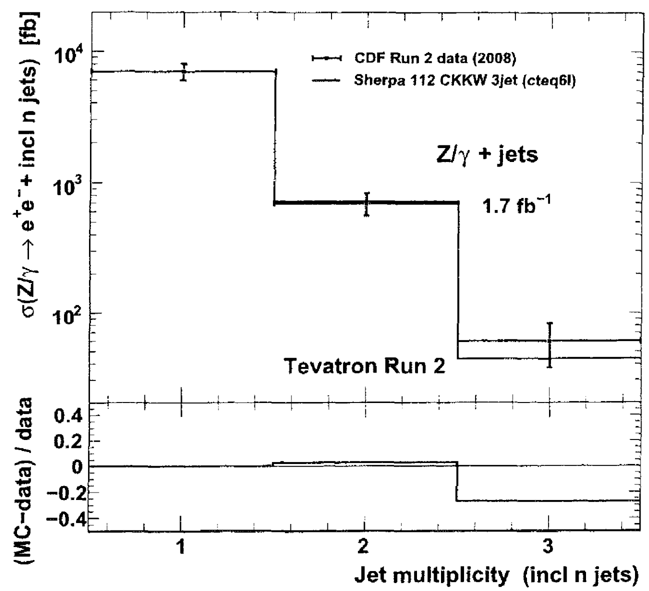


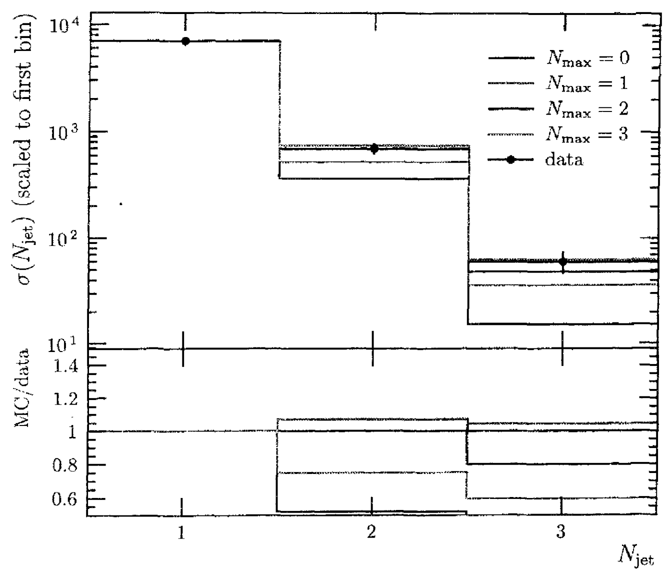


Comparison with CDF data: Z+jets production

ME&TS :: COMIX + CSS [T. Aaltonen et al., PRL **100** (2008) 102001]

- Sherpa vs1.1 [CKKW] (left) compared with Sherpa vs1.2 [ME&TS] (right).
- Examples of jet observables: new approach better describes the data.
- Sherpa predictions multiplied by constant K factor, normalized to first-jet bin xsec.

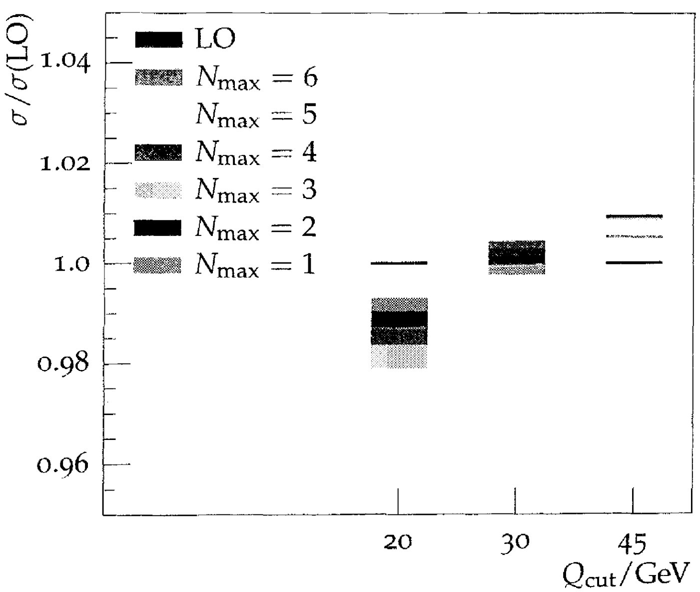


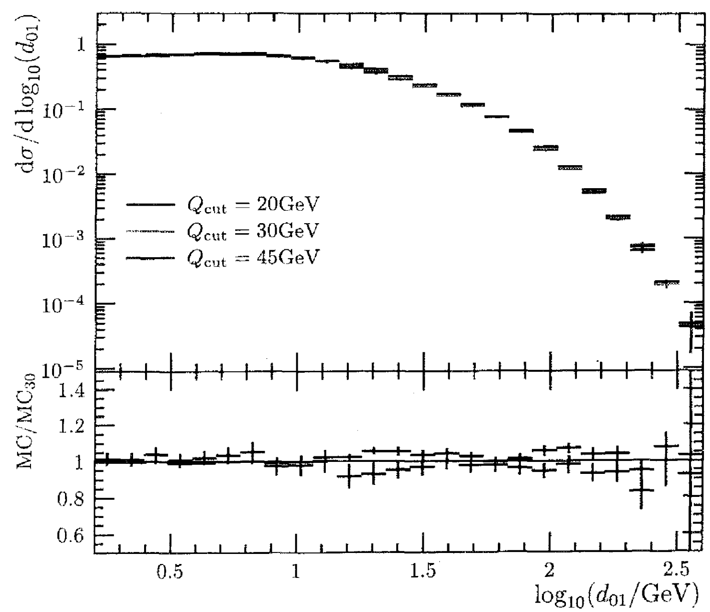


Z+jets production @ Tevatron Run2 energies

ME&TS :: COMIX + CSS [HÖCHE, KRAUSS, SCHUMANN, SIEGERT, JHEP 05 (2009) 053]

- Merging systematics of total cross section (LO) has improved: $\Delta\sigma_{\rm tot}/\sigma_{\rm tot} < \pm 3\%$
- Differential k_T jet rates in $Q_{\rm cut} = Q_{\rm jet}$ variation @ hadron level. Note $N_{\max} = 5$.
- $Q_{\rm cut}$ variation now within $\pm 10\%$. Note $\mu_F^2 = M_{ee}^2$ and 66 GeV $< M_{ee} <$ 116 GeV.

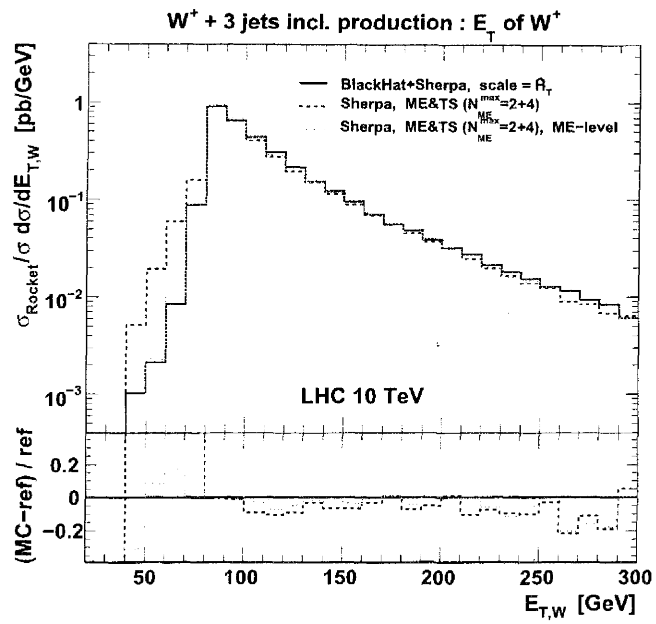


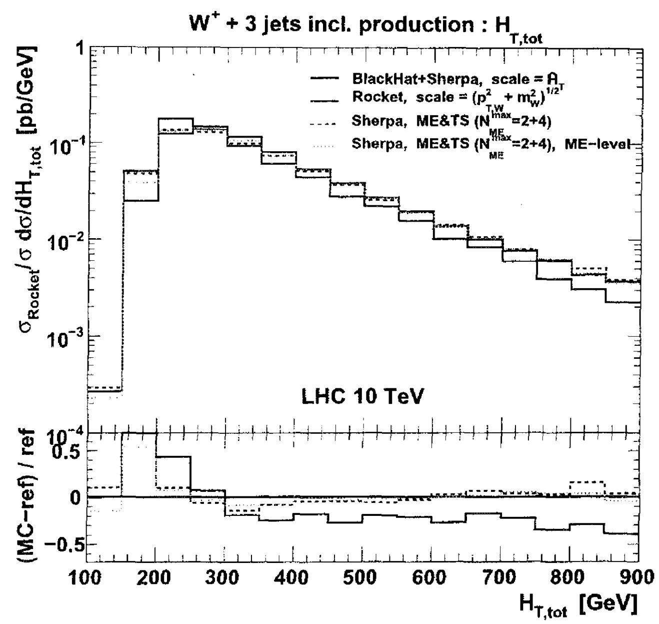


Recent comparison of LHC predictions for W+3jets

[HÖCHE, HUSTON, MAITRE, WINTER, ZANDERIGHI; LH09 PROCEED.: ARXIV:1003.1241]

- between BLACKHAT [BERGER ET AL.], ROCKET [ELLIS, MELNIKOV, ZANDERIGHI] and SHERPA [GLEISBERG ET AL.]
- rather different scale choices at NLO yield > 20% deviations ... impact on BSM searches !
- SHERPA's ME&TS merging in good agreement with NLO once rescaled to NLO xsec





CTEQ

W Boson Physics and Global Analysis of PDFs

C.-P. Yuan
Michigan State University

June 24, 2010 @ BNL

Workshop on
The Physics of W and Z Bosons

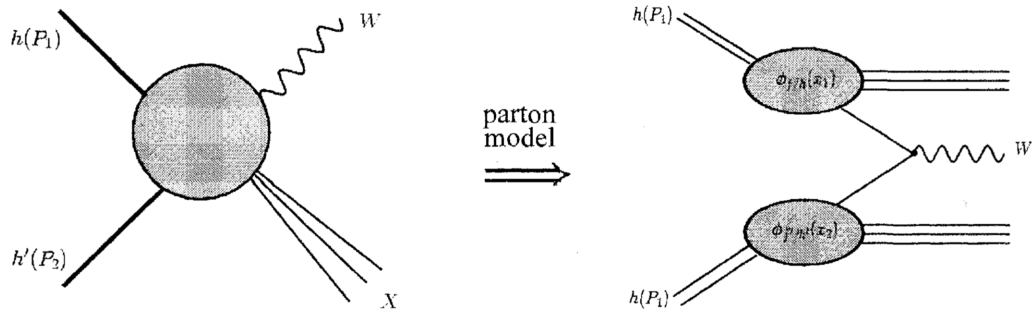
Precision Electroweak Physics at Hadron Colliders

Physics of Drell-Yan, *W* and *Z* Bosons

W-boson physics

1. W-boson production and decay at hadron collider
2. How to measure W-boson mass and width?
3. High order radiative corrections:
   - ☞ QCD (NLO, NNLO, Resummation)
   - ☞ EW (QED-like, NLO)
4. ResBos and ResBos-A

W-boson production at hadron colliders

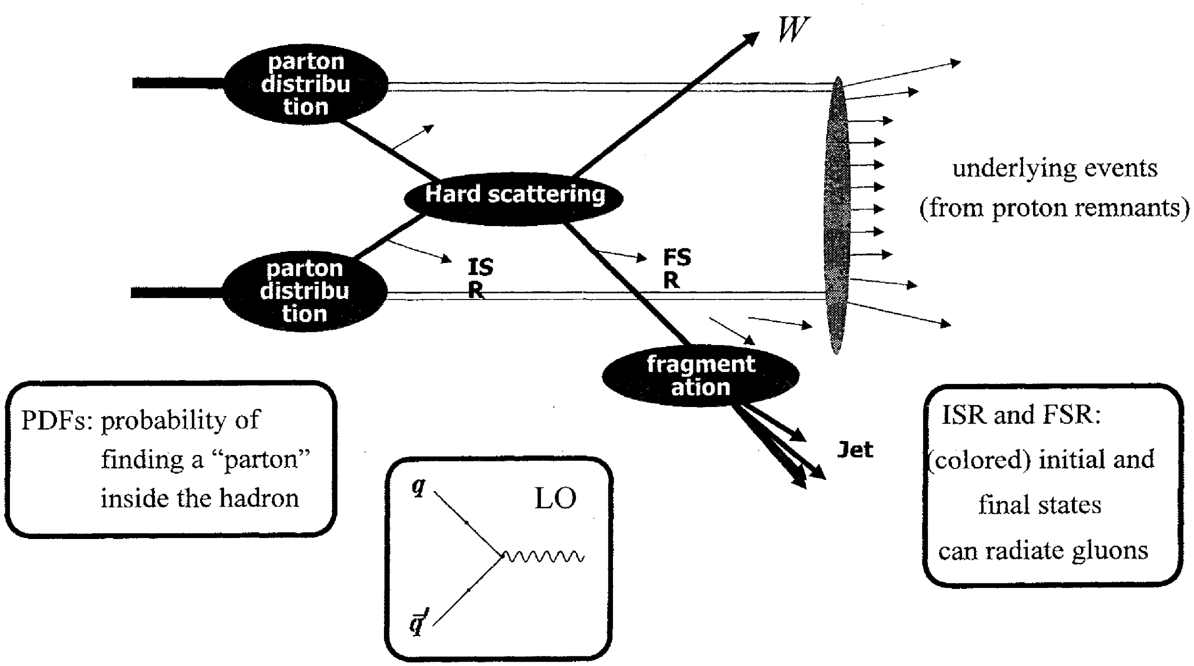


$$\sigma_{hh' \to W+X} = \sum_{f,f'} \int_0^1 dx_1 dx_2 \left\{ \phi_{f/h}(x_1)\, \hat{\sigma}_{ff'}\, \phi_{\bar{f}'/h'}(x_2) + (x_1 \leftrightarrow x_2) \right\}$$

PDFs are known from deep inelastic scattering

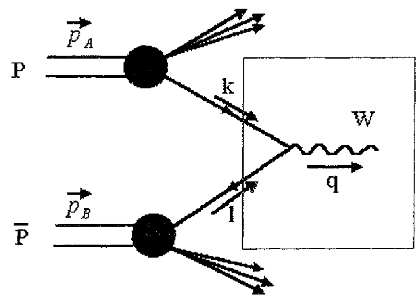
partonic “Born” cross section of $f\bar{f}' \to W^+$

W-boson production at hadron colliders



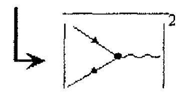
Fixed order pQCD prediction

$\alpha_S^{(0)}$



$$\sigma = \frac{1}{2S}\int \frac{d\xi_A}{\xi_A}\frac{d\xi_B}{\xi_B} f_{i/A}(\xi_A,\mu)\, f_{i/B}(\xi_B,\mu)\cdot d\hat{\sigma}$$

$$d\hat{\sigma} = \overline{|M|}^2 (2\pi)^4 \delta^{(4)}(q-k-l)\frac{d^3q}{(2\pi)^3 2q_0}$$



$$s = (p_A + p_B)^2$$
$$k = \xi_A p_A$$
$$l = \xi_B p_B$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2\mathrm{d}y\mathrm{d}Q^2} = \frac{1}{S}\int \frac{\mathrm{d}\xi_A}{\xi_A}\frac{\mathrm{d}\xi_B}{\xi_B} f_{i/A}(\xi_A,\mu)\, f_{i/B}(\xi_B,\mu)$$
$$\cdot\left(\frac{\pi^2}{Q^2}\right)\cdot\overline{|M|}^2\cdot\delta\left(1-\frac{x_A}{\xi_A}\right)\cdot\delta\left(1-\frac{x_B}{\xi_B}\right)$$
$$\cdot\delta\left(q_T^2\right)\cdot\delta\left(Q^2 - M_W^2\right)$$

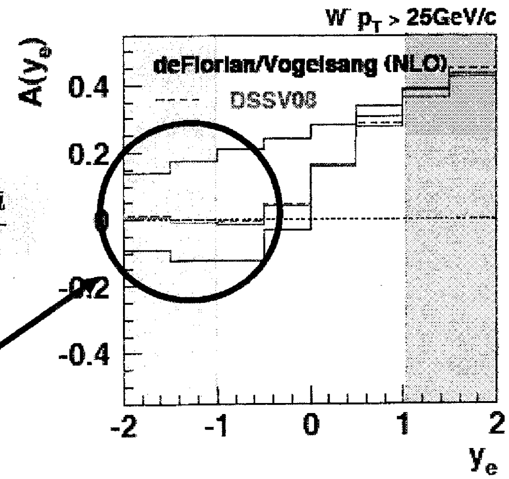
$$Q \equiv \sqrt{Q^2} = \sqrt{q^2},\ \mu = Q = M_W,\ x_A = \frac{Q}{\sqrt{S}}e^{y},\ x_B = \frac{Q}{\sqrt{S}}e^{-y}$$

Prospects and Future of the STAR W Program

Joe Seele (MIT) for the STAR Collaboration

The STAR experiment is planning a number of upgrades and measurements that will constrain the polarized anti-quark distributions in a polarized proton. The Forward GEM Tracker will add charged particle tracking in the forward rapidity allowing for charge sign identification and background rejection in the forward rapidity region.

"Predictions" for A_L's



$$A_L^{W^-} = \frac{\Delta \bar{u}}{\bar{u}}$$

$x_1 \ll x_2$

$$A_L^{W^-} = -\frac{\Delta d}{d}$$

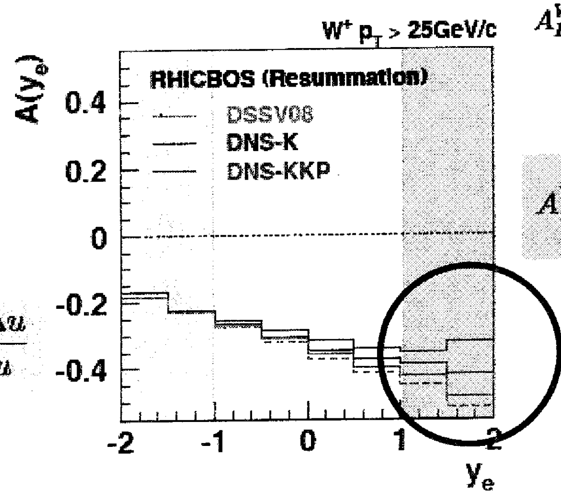
$x_1 \gg x_2$

$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta \bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$x_1 = x_2$

$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta \bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

Roughly the uncertainty in delta-ubar



$$A_L^{W^+} = \frac{\Delta \bar{d}}{\bar{d}}$$

$x_1 \gg x_2$

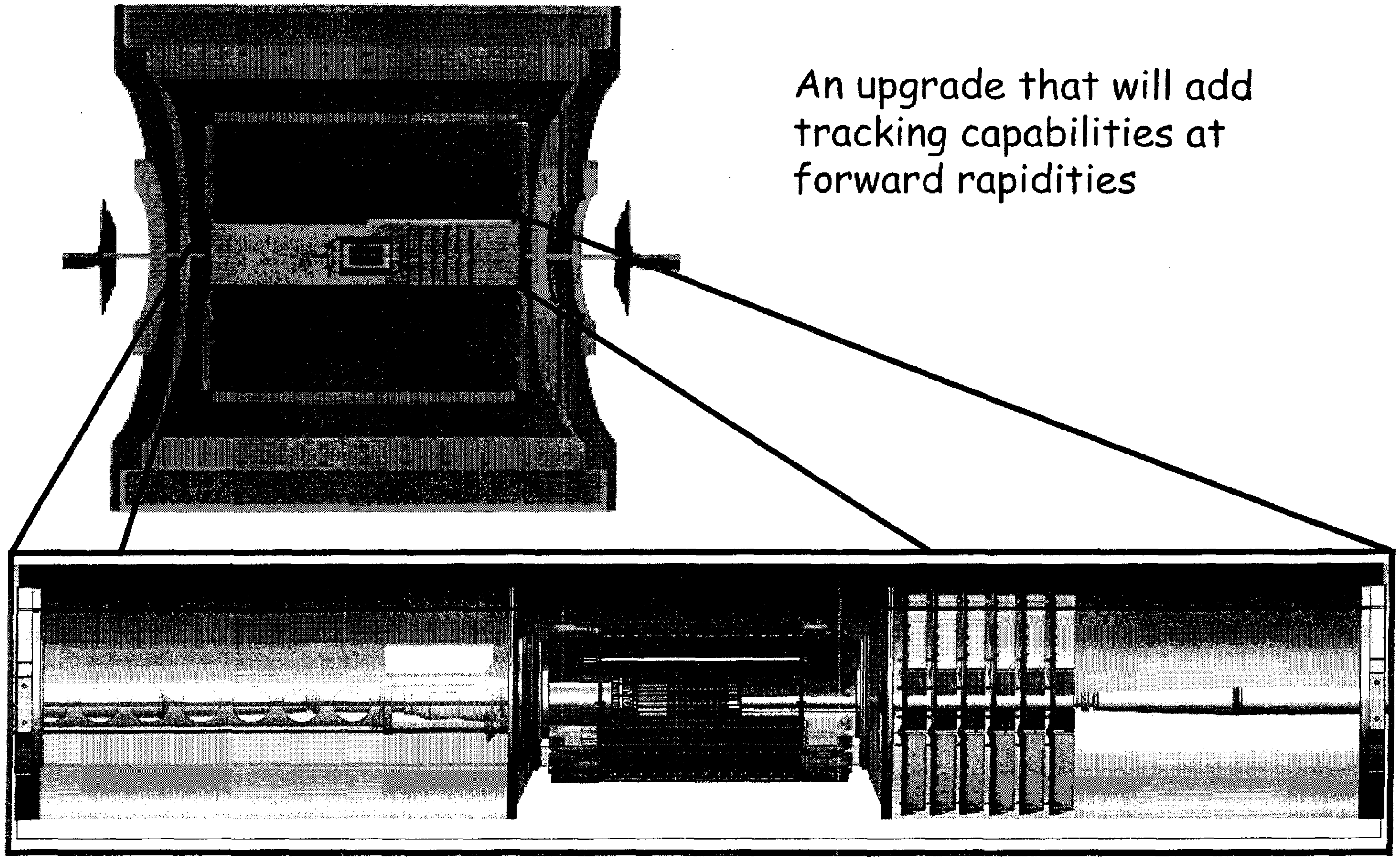
$$A_L^{W^+} = -\frac{\Delta u}{u}$$

$x_1 \ll x_2$

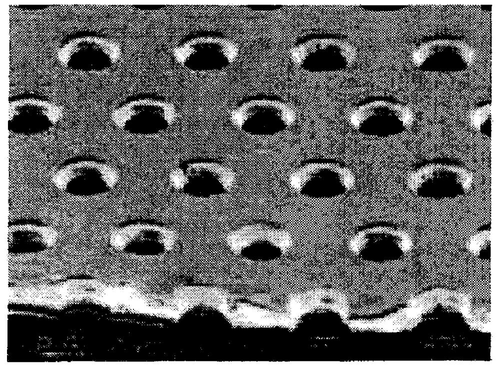
Roughly the uncertainty in delta-dbar

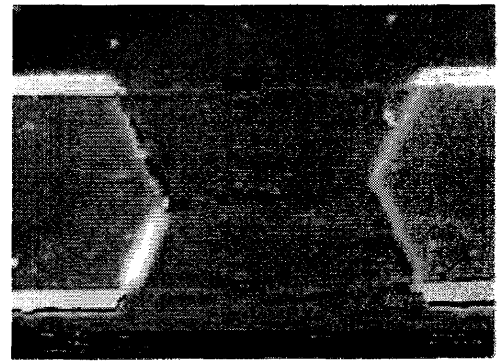
Forward GEM Tracker (FGT)

An upgrade that will add tracking capabilities at forward rapidities

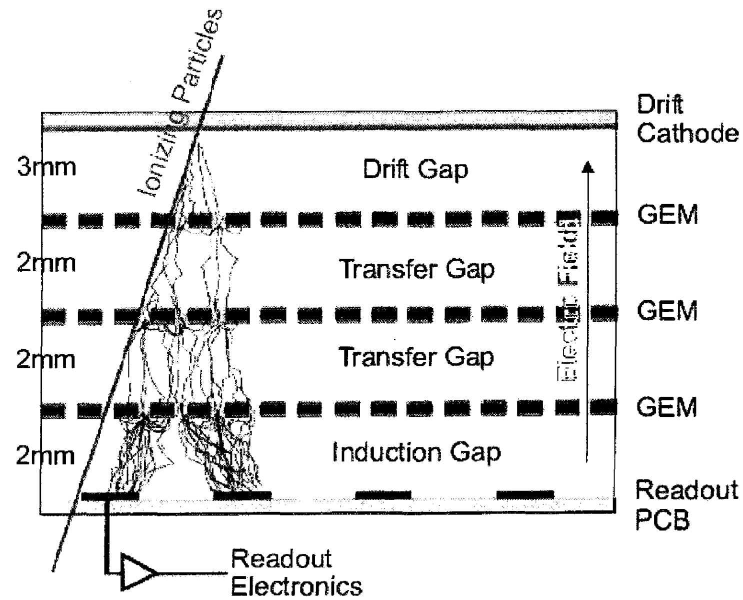


GEM Foil Technology



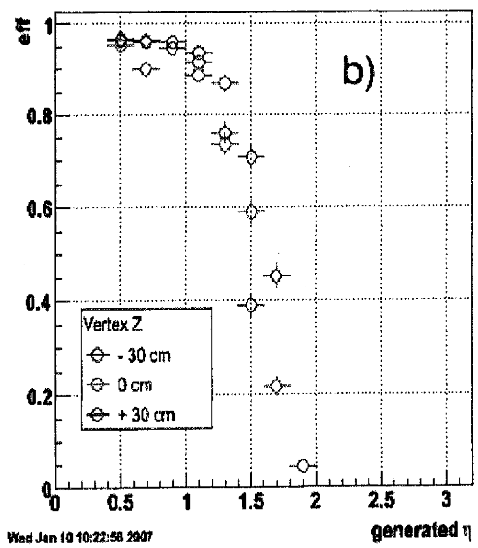


- High gain (~10^6)
- Fast (<20 ns FWHM)
- Low mass
- Good spatial resolution
- Inexpensive
- Foils produced by CERN and Tech-etch

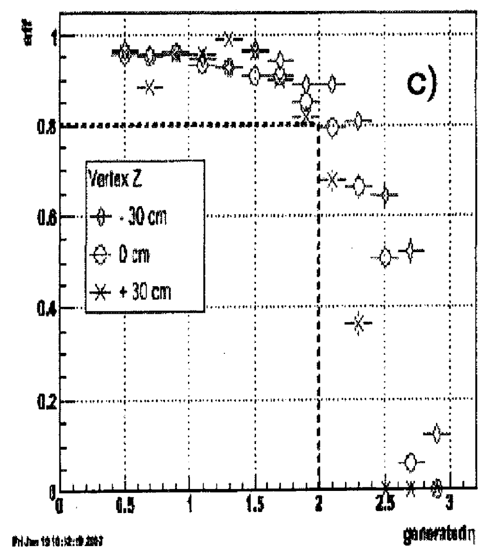


Performance of FGT

Charge sign reconstruction efficiency



without FGT



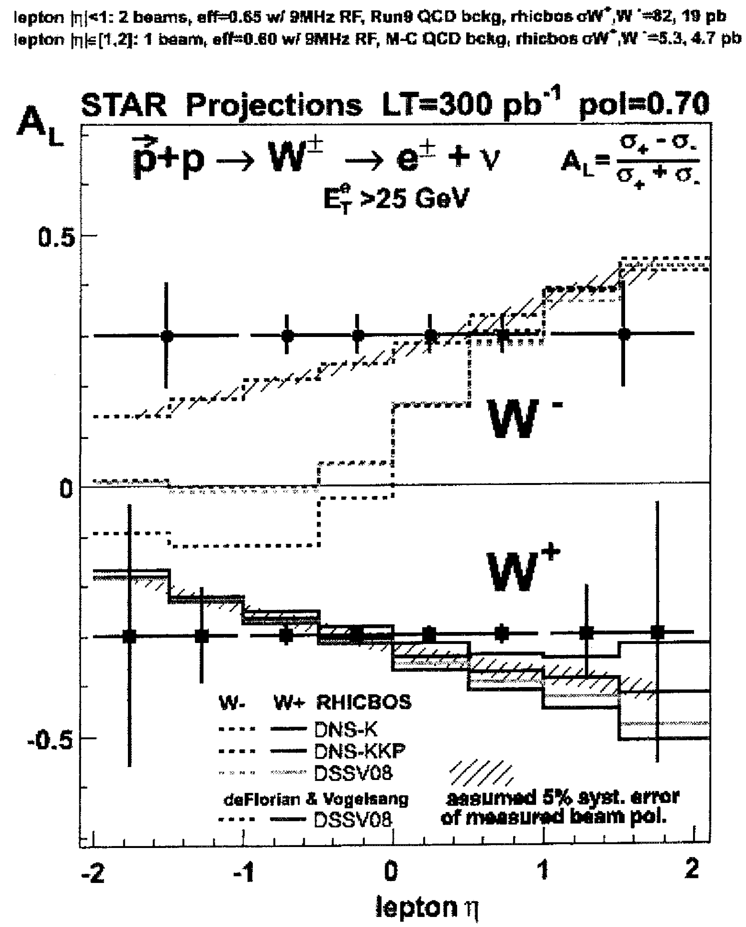
with FGT

The addition of the FGT will allow for charge sign identification at forward rapidities

Expected Data

RHIC is planning to run 500 GeV polarized p+p collisions in a multi-year effort to constrain the polarization of the anti-quarks in the proton

Calculations assume the demonstrated S/B (6 and 11) for the mid-rapidity projections and S/B~1 for the forward and backward rapidity projections

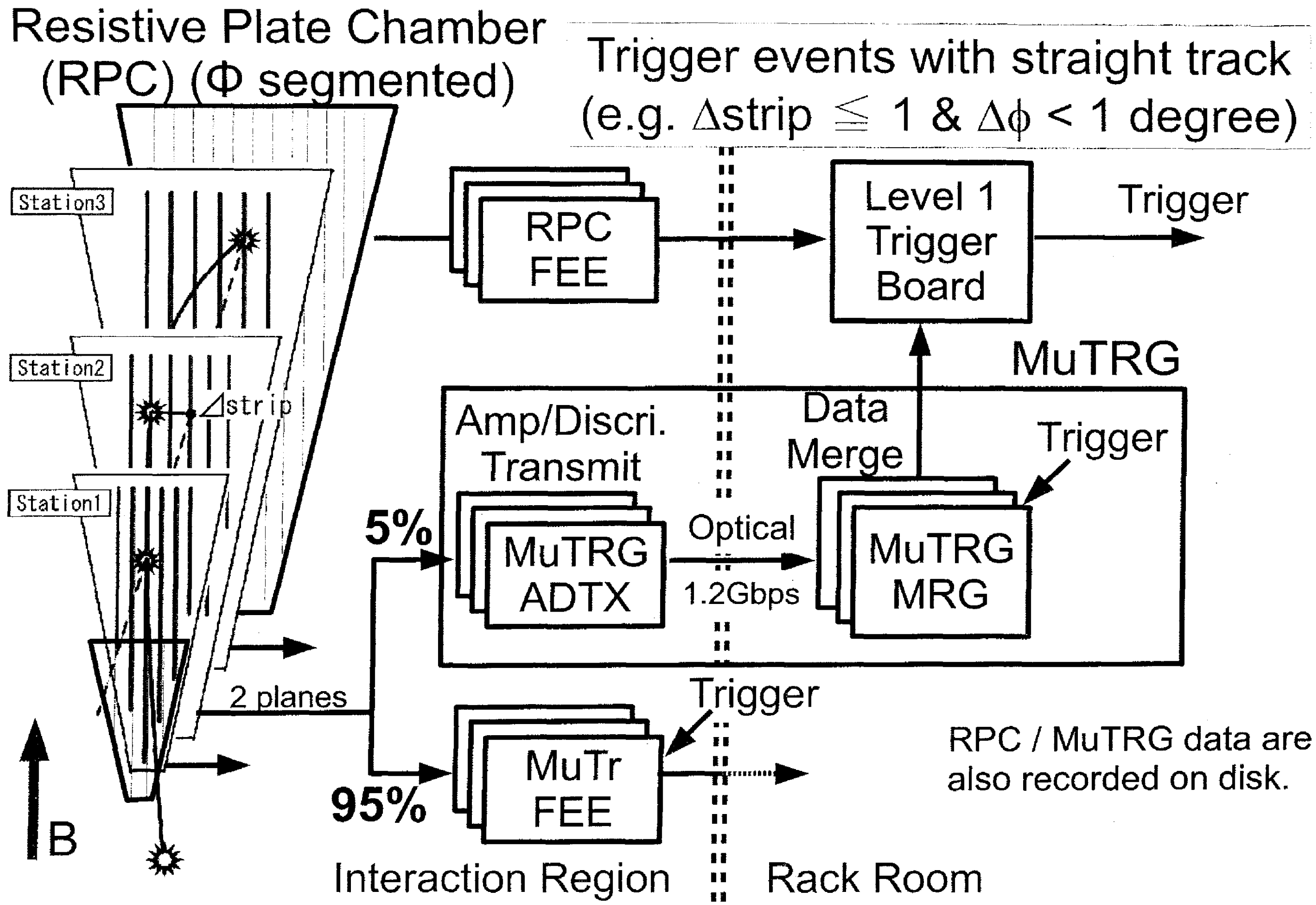


Prospects of the Forward W Measurement in Polarized pp Collisions at the RHIC-PHENIX Experiment

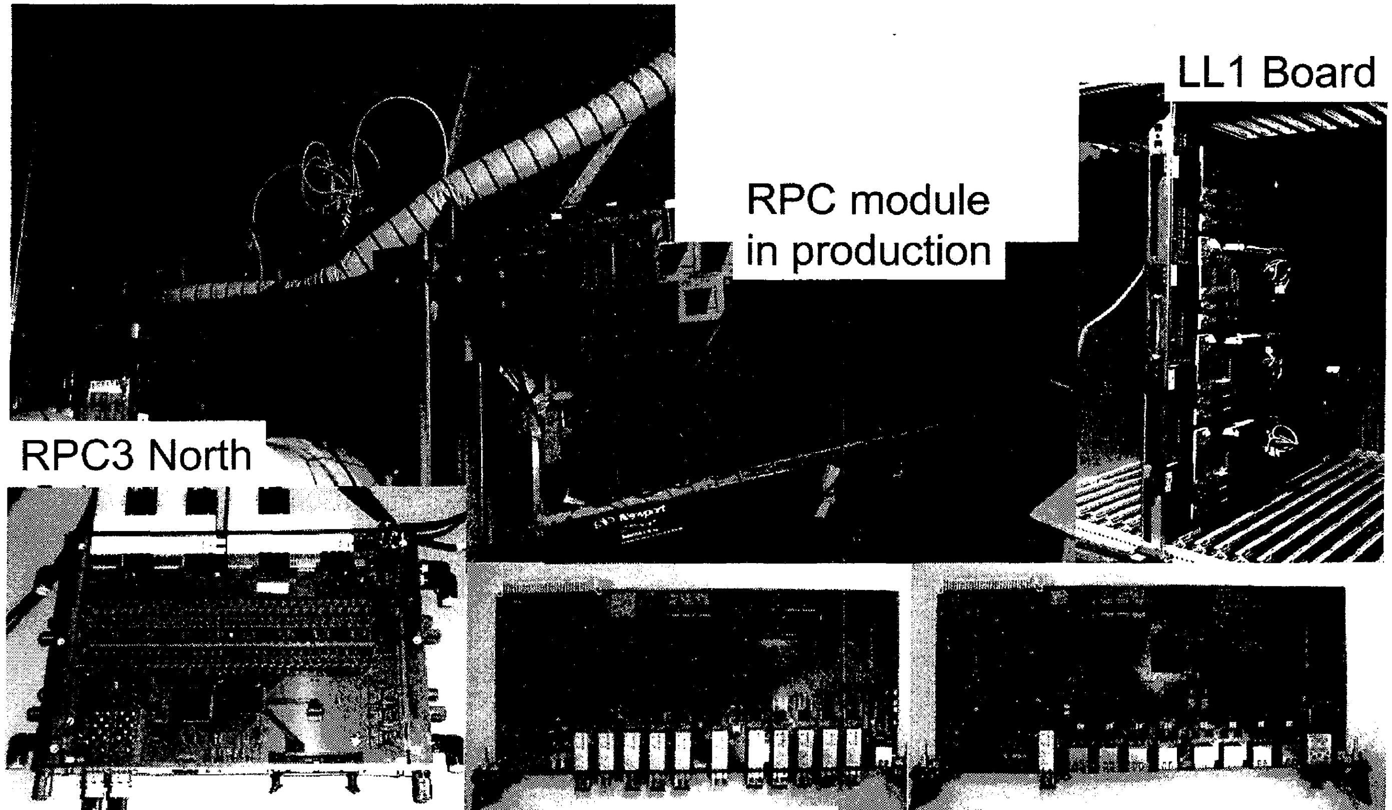
RIKEN Nishina Center for Accelerator-Based Science,
Wako, Saitama 351-0198, Japan
Fukao, Yoshinori

RHIC-PHENIX experiment aim to measure AL in W → m process and impose significant constraint on polarized anti-quark PDF with 500 GeV polarized pp collisions. One of the major upgrade work is the development of new W trigger system, which consists of MuTRG and RPC. We completed MuTRG and RPC3 North installation and will finish RPC3 South installation during 2010 shutdown period. The commissioning of the W trigger system was performed with beam and cosmic ray, and final performance evaluation of full-chain trigger system is ongoing. In addition to the trigger development, new hadron absorber, which provide powerful background rejection, is in manufacture and will be installed in 2010. Offline analysis and simulation for W signal extraction are also in progress towards coming physics run in 2011 and future.

W Trigger System

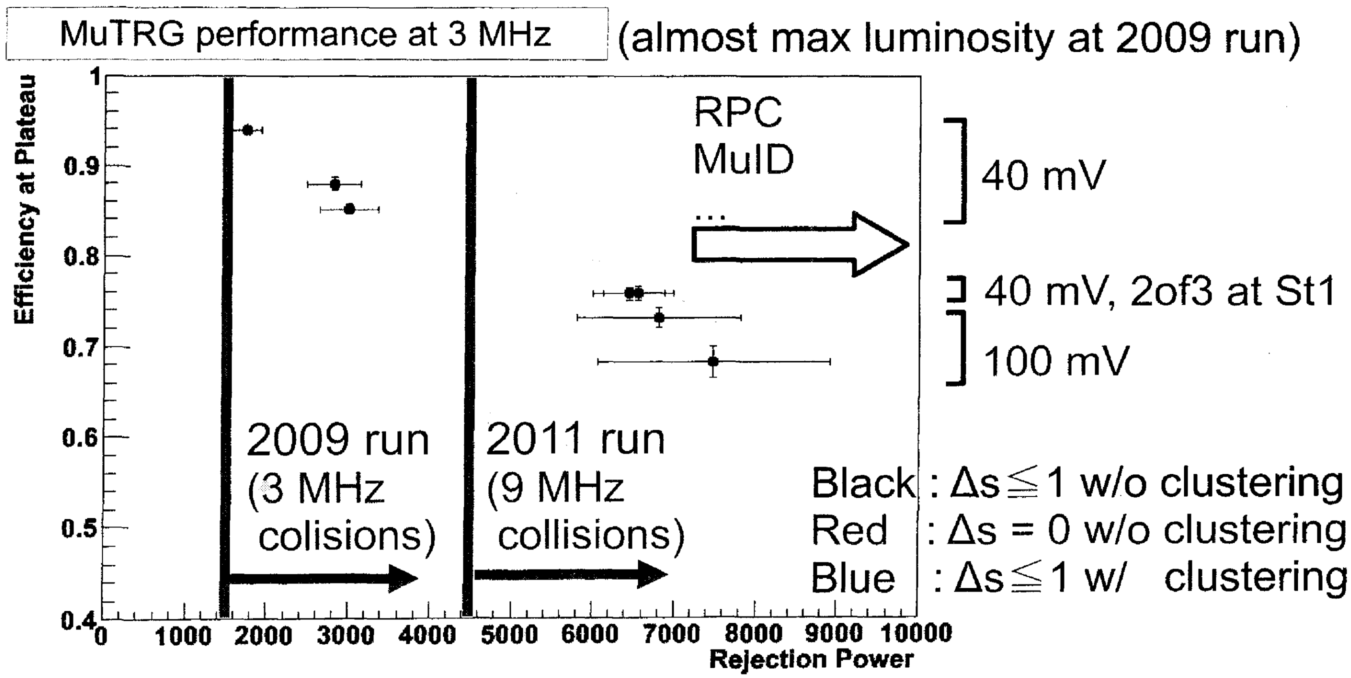


Components of W trigger



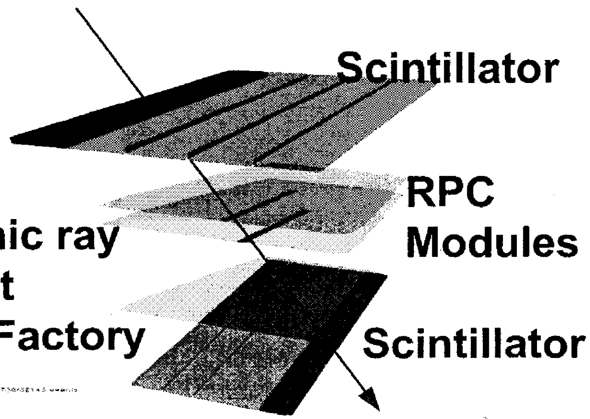
MuTRG-ADTX MuTRG-MRG MuTRG-DCMIF

Rejection Power with MuTRG only
(MuID & BBC & MuTRG)

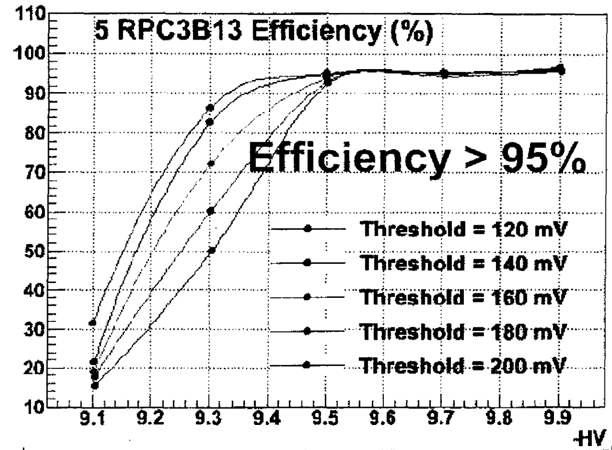


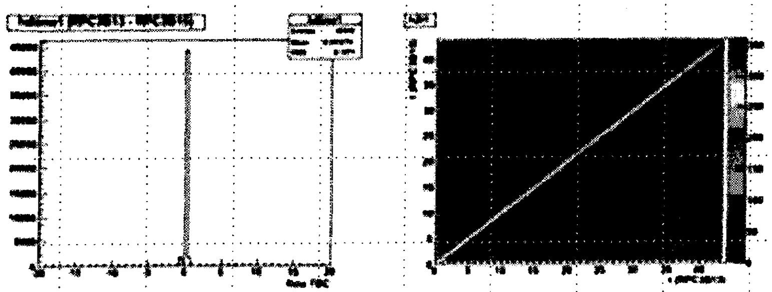
- Larger rejection power can be obtained by applying tight cut.
- More improvement is expected by RPC and other items.

RPC Module Performance

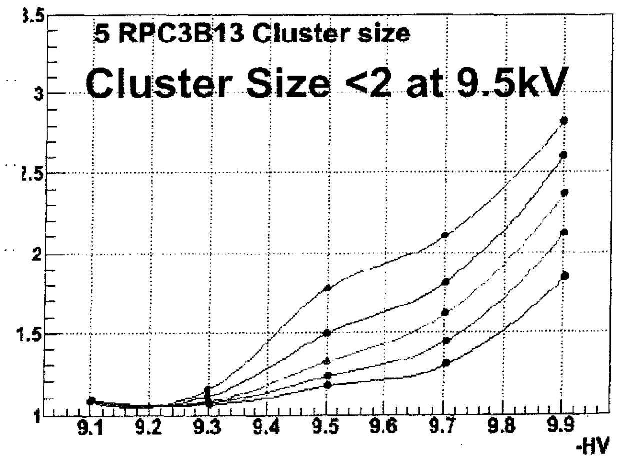


Cosmic ray test at RPC Factory



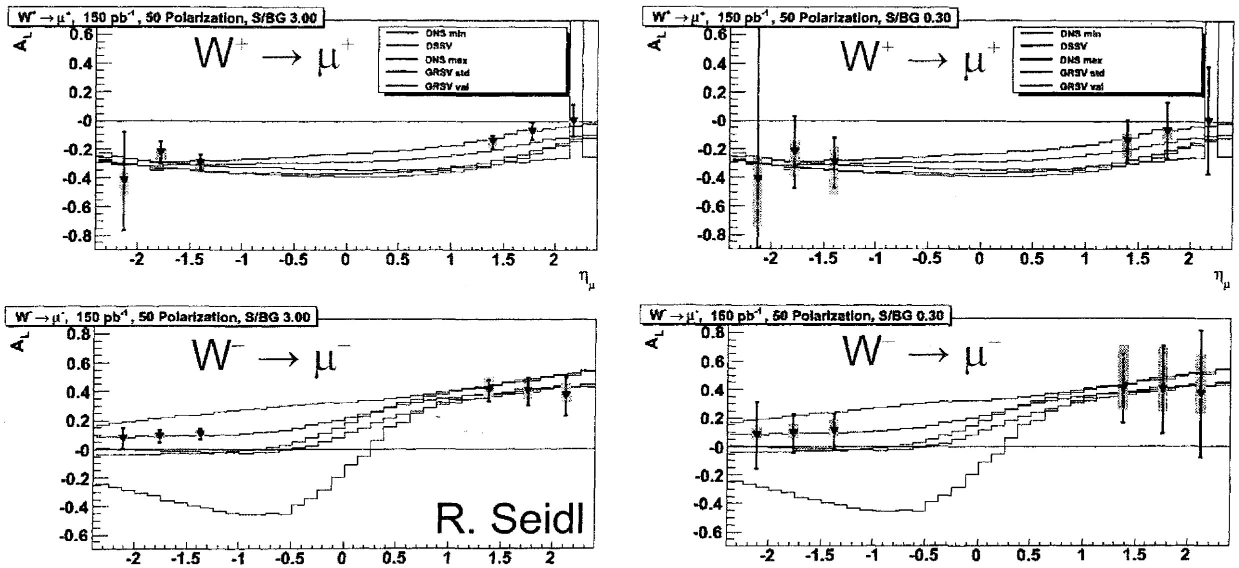


Timing difference between two RPC modules
Timing resolution ~ 2 ns



Offline Analysis / Simulation

Run 2011+2012 Projection (150 pb^{-1}, 50% pol.)



η_μ (muon pseudorapidity) η_μ (muon pseudorapidity)

S/B = 3.0 (optimistic) S/B = 0.3 (conservative)

> Offline background evaluation using Run 2009 data and simulation study to optimize event selection is ongoing.
> New Forward VTX detector will be installed and improve S/B.

A_N of W Production in Polarized pp Collisions

Zhong-Bo Kang
RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973, USA

Much of the predictive power of perturbative Quantum Chromodynamics (QCD) is contained in factorization theorems. They normally include two assertions: a physical quantity can be factorized into perturbatively calculable short-distance hard parts convoluted with nonperturbative long-distance distribution functions; the *universality* of the nonperturbative functions. Predictions follow when processes with different hard scatterings but the same distribution functions are compared.

The phenomenon of single transverse-spin asymmetry (SSA), $A_N \equiv (\sigma(\vec{S}_\perp) - \sigma(-\vec{S}_\perp))/(\sigma(\vec{S}_\perp) + \sigma(-\vec{S}_\perp))$, defined as the ratio of the difference and the sum of the cross sections when the spin vector $\vec{S}_\perp$ is flipped, was first observed in the hadronic Λ^0 production at Fermilab in 1976. Large SSAs, as large as 30%, have been consistently observed in various experiments involving one polarized hadron at different collision energies.

One of the approach to describe the observed SSAs in QCD is so-called Transverse Momentum Dependent (TMD) factorization approach, which factorizes $\sigma(\vec{S}_\perp)$ in terms of the TMD parton distributions and attributes the SSAs to the nonvanishing Sivers function, the spin dependent part of TMD parton distribution. One of the most non-trivial feature is that the Sivers function could be process dependent (non-universal). It was predicted by Collins around 2002 on the basis of time-reversal and parity arguments that the quark Sivers function in semi-inclusive deep inelastic scattering (SIDIS) and in Drell-Yan process (DY) have the same functional form but an *opposite sign*, a time-reversal modified universality.

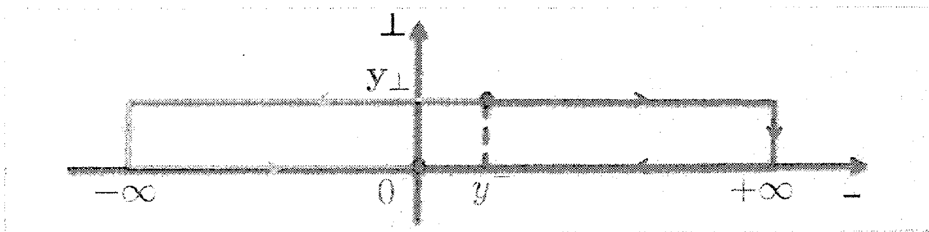
The experimental check of this time-reversal modified universality of the Sivers function would provide a critical test of the TMD factorization approach and our current understanding of the SSAs. Recently, the quark Sivers function has been extracted from data of SIDIS experiments by Anselmino *et.al.* Future measurements of the SSAs in DY production have been planned. In this talk, we present the SSAs of inclusive single lepton production from the decay of W bosons, and show that the lepton SSAs is significant and measurable for a good range of lepton rapidity at RHIC. We find that the lepton SSAs are sharply peaked at transverse momentum $p_T \sim M_W/2$ with W mass M_W. This is because the most W bosons at RHIC have $q_T \ll M_W$. On the other hand, leptons from heavy quarkonium decay and other potential backgrounds are unlikely to be peaked at the $p_T \sim M_W/2$. Since the W production and DY share the same Sivers function, we argue that the SSA of inclusive high p_T leptons at RHIC is an excellent observable for testing the time-reversal modified universality.

Non-universality of the Sivers function

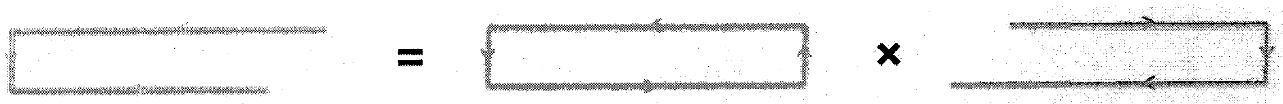
- Different gauge link for gauge-invariant TMD distribution in SIDIS and DY

$$f_{q/h^\uparrow}(x,\mathbf{k}_\perp,\vec{S}) = \int \frac{dy^- d^2y_\perp}{(2\pi)^3} e^{ixp^+y^- - i\,\mathbf{k}_\perp\cdot\mathbf{y}_\perp} \langle p,\vec{S}|\overline{\psi}(0^-,\mathbf{0}_\perp)\boxed{\text{Gauge link}}\frac{\gamma^+}{2}\psi(y^-,\mathbf{y}_\perp)|p,\vec{S}\rangle$$

  - SIDIS: $\Phi_n^\dagger(\{+\infty,0\},\mathbf{0}_\perp)\Phi_{\mathbf{n}_\perp}^\dagger(+\infty,\{\mathbf{y}_\perp,\mathbf{0}_\perp\})\Phi_n(\{+\infty,y^-\},\mathbf{y}_\perp)$
  - DY: $\Phi_n^\dagger(\{-\infty,0\},\mathbf{0}_\perp)\Phi_{\mathbf{n}_\perp}^\dagger(-\infty,\{\mathbf{y}_\perp,\mathbf{0}_\perp\})\Phi_n(\{-\infty,y^-\},\mathbf{y}_\perp)$



Wilson Loop ~ $\exp\left[-ig\int_\Sigma d\sigma^{\mu\nu}F_{\mu\nu}\right]$ Area is NOT zero



  - For a fixed spin state:

$$f_{q/h^\uparrow}^{\text{SIDIS}}(x,\mathbf{k}_\perp,\vec{S}) \neq f_{q/h^\uparrow}^{\text{DY}}(x,\mathbf{k}_\perp,\vec{S})$$

Time-reversal modified universality of the Sivers function

- Relation between Sivers functions in SIDIS and DY
  - From P and T invariance:

$$f_{q/h^{\uparrow}}^{\mathrm{SIDIS}}(x, \mathbf{k}_{\perp}, \vec{S}) = f_{q/h^{\uparrow}}^{\mathrm{DY}}(x, \mathbf{k}_{\perp}, -\vec{S})$$

    - **Spin-averaged parton distribution function is universal**

  - From definition:

$$f_{q/h^{\uparrow}}(x, \mathbf{k}_{\perp}, \vec{S}) \equiv f_{q/h}(x, k_{\perp}) + \frac{1}{2}\Delta^{N} f_{q/h^{\uparrow}}(x, k_{\perp})\, \vec{S}\cdot\hat{p}\times\hat{\mathbf{k}}_{\perp}$$

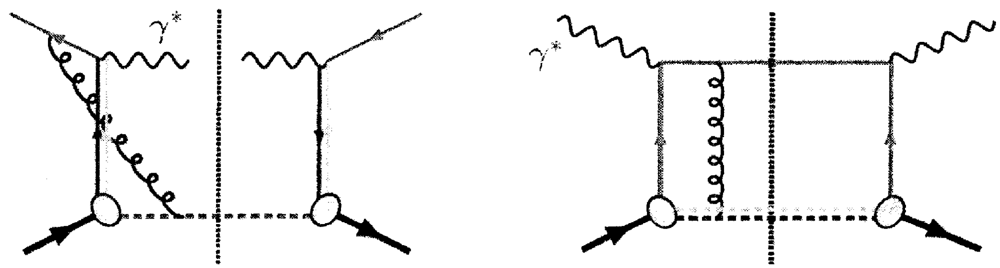
  - One can derive:

$$\Delta^{N} f_{q/h^{\uparrow}}^{\mathrm{SIDIS}}(x, k_{\perp}) = -\Delta^{N} f_{q/h^{\uparrow}}^{\mathrm{DY}}(x, k_{\perp})$$

Most critical test for TMD approach to SSA

Intuitive understanding of the sign change

- Difference between initial and final state interactions



$p^\uparrow + p \to \left[\gamma^* \to \ell^+ \ell^-\right] + X$ — **DY: repulsive**

$\ell + p^\uparrow \to \ell + \pi + X$ — **SIDIS: attractive**

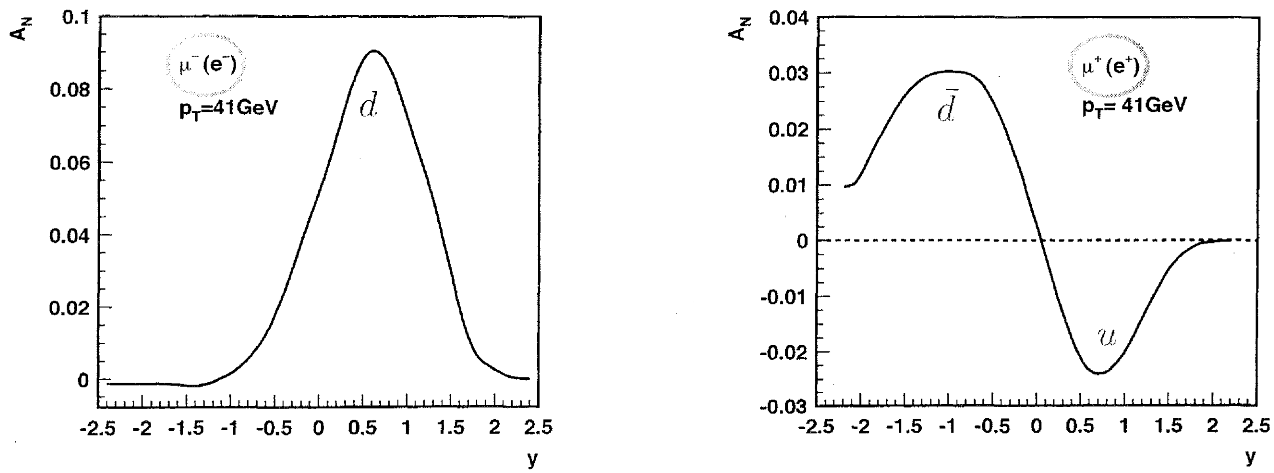
$$\Delta^N f_{q/h^\uparrow}^{\mathrm{SIDIS}}(x, k_\perp) = -\Delta^N f_{q/h^\uparrow}^{\mathrm{DY}}(x, k_\perp)$$

- Sign change:
  - Test of TMD factorization
  - Test of current understanding of SSA

SSA of lepton from W decay: rapidity dependence

- SSA of inclusive lepton is still sufficient for measurement:

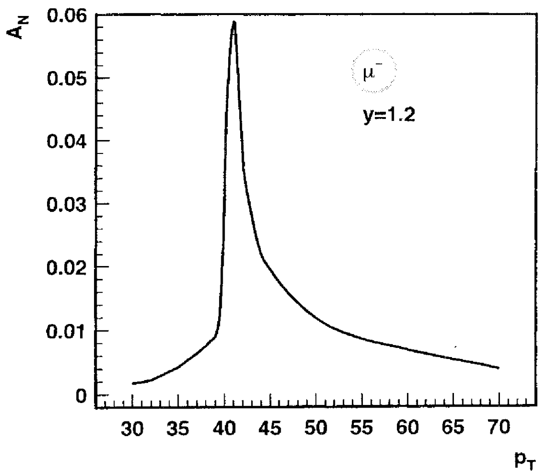
Kang, Qiu, PRL 103, 172001 (2009)

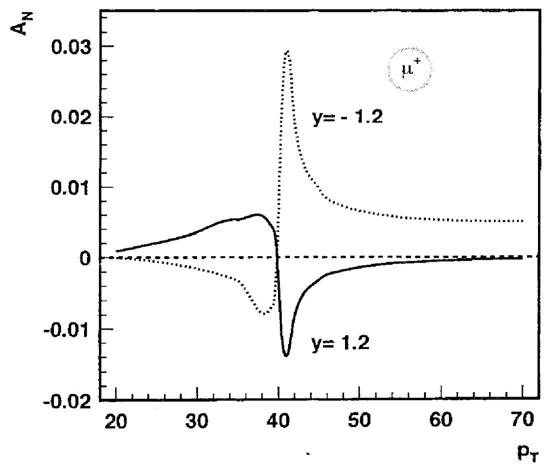


- Good flavor separation:
  - $\mu^-(e^-)$ at central-forward rapidity is sensitive to d Sivers function
  - $\mu+(e^+)$ at forward is sensitive to u Sivers function, at backward is sensitive to d-bar Sivers function

SSA of lepton from W decay: p_T dependence

- p_T behavior of SSA of leptons:





  - inherit the key features of W asymmtry
  - sharply peeked around $p_T \sim M_W/2$, should help control the potential background

Precision Measurement of the W Mass and New Physics

1. Why?
2. W Mass: Status and Measurement Techniques
3. Status of Theory Calculations for W/Z Production
4. Conclusions

Ulrich Baur
State University of New York at Buffalo

1 – Why?

- The LHC is a discovery machine. Why should we measure the W mass, and more generally, do precision physics at such a facility?
- After all a precise measurement of M_W in a hadron collider environment is no walk in the park (see talks by Ashutosh Kotwal, Junjie Zhu)
- more bluntly:
  "I rather commit suicide than measure M_W at the LHC"(Guido Altarelli at an early LHCC meeting)

- Which measurements are of interest?

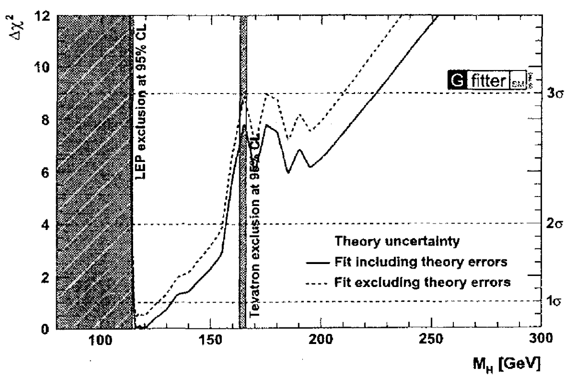
  ▻ m_t, M_W and $\sin^2\theta_W$

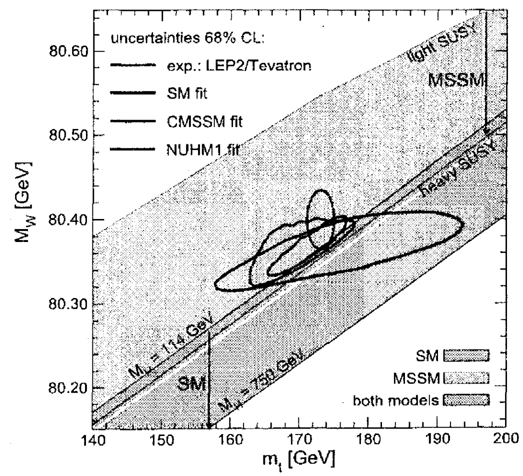
  → make it possible to constrain the mass of the SM Higgs boson: winter 2010: $M_H < 155$ GeV (95% CL)
  one-loop corrections to M_W and $\sin^2\theta_W$ depend logarithmically on M_H

  → thus providing a consistency check on the SM (once a Higgs boson candidate has been observed)

  → may give hints of new physics, or provide constraints on new physics models
  new particles contribute to the one-loop corrections

Data in better agreement with SUSY models than SM
but this is not surprising as SUSY models have more free parameters



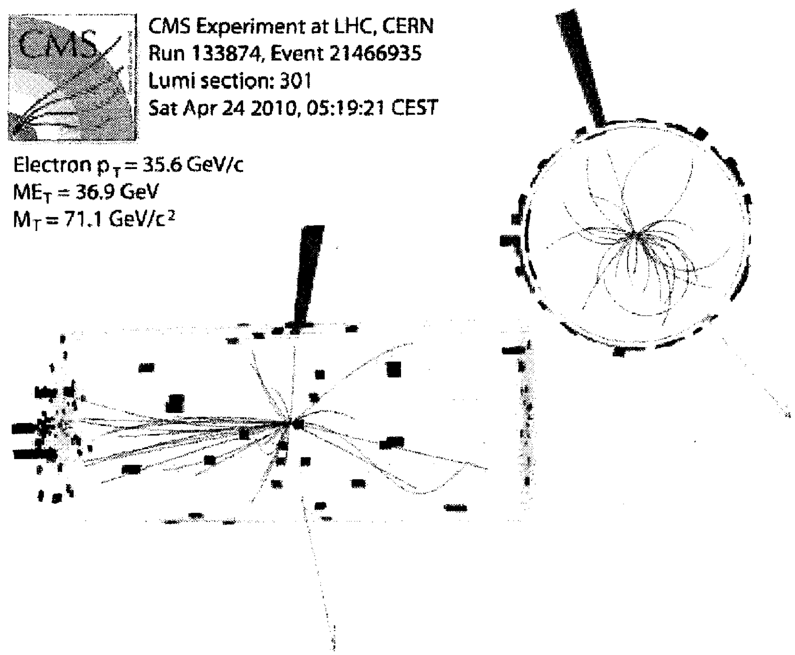


CMSSM: Constrained MSSM

NUHM1: a common SUSY-breaking contribution to the Higgs masses is allowed to be non-universal

W and *Z* Production has been observed at the LHC

$W \to e\nu$ candidate



4 – Conclusions

- M_W, together with m_{top}, make it possible to constrain the Higgs boson mass
- need $\delta M_W = \mathcal{O}(10\text{ MeV})$ to match anticipated precision for m_{top}
- sensitive to new physics via loop corrections
- measuring M_W at the LHC is non-trivial and may require special runs (deuterium, helium) and/or special detector configurations (reverse magentic field)
- EW radiative corrections affect the M_T line shape and thus the W mass extracted from data
- need better understanding how to combine calculations of QCD and EW corrections into one unified generator

W MEASUREMENTS AND PROSPECTS WITH ATLAS

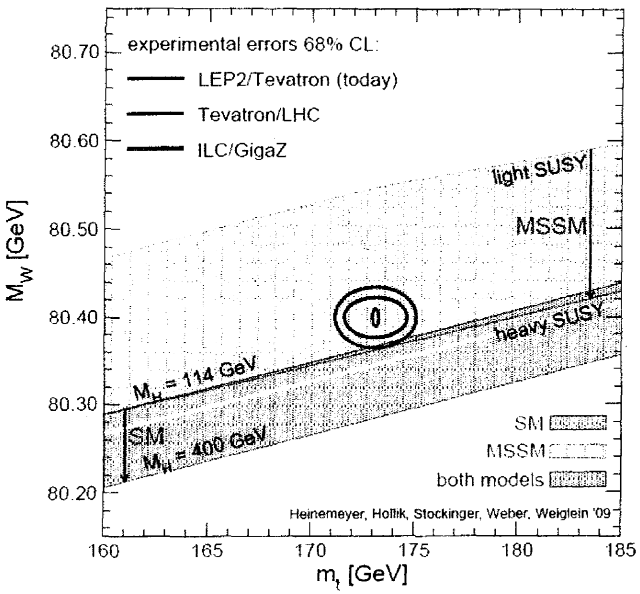
KEVIN BLACK
HARVARD UNIVERSITY

Friday, June 25, 2010

OUTLINE

- Motivations
- Cross-Sections at 7 TeV and expected event yield
- Asymmetry Measurements
- W mass prospects
- First W results from ATLAS

Precision Electroweak



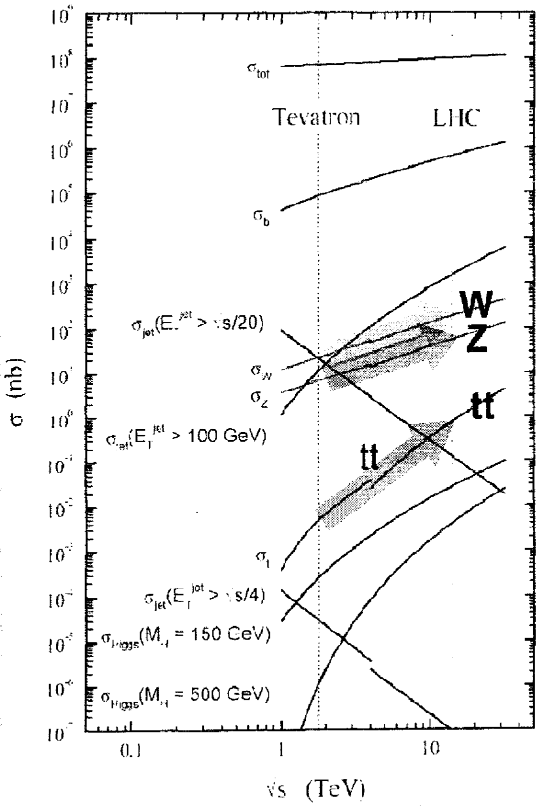
$$m_W = \left(\frac{\pi \alpha_{EM}}{\sqrt{2} G_F}\right)^{\frac{1}{2}} \frac{1}{sin\theta_W \sqrt{1 - \Delta r}}$$

$$f(m_{top}^2, log m_h)$$

$$\Delta m_W \approx 0.7 \times 10^{-2} \Delta m_{top}$$

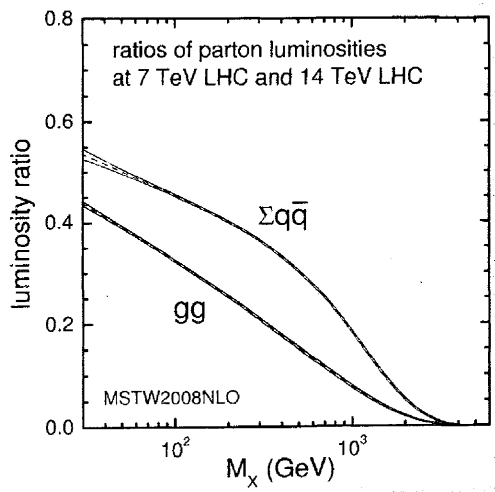
$$\Delta m_W \approx 10\text{MeV}$$

EXPECTED CROSS-SECTIONS



At 7 TeV

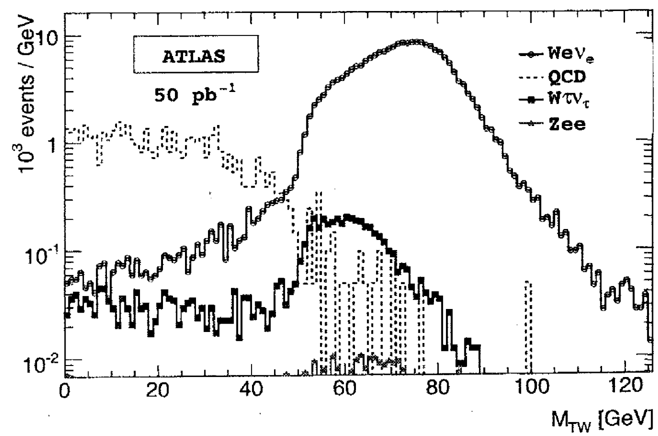
$\sigma^{NNLO}(W \rightarrow l\nu) = 10.45$ nb
roughly x2 at 14 TeV



Cross-section Measurements

14 TeV

- P_T > 25 GeV lepton
- Missing Et > 25 GeV
- Expected uncertainty (stat+sys , no lumi):
  - ~5% after 50 pb^{-1}
  - ~2.5% after 1 fb^{-1}



$$M_T = \sqrt{p_T^l E_T^{miss}(1 - cos\Delta\phi(p_T^l, E_T^{miss}))}$$

~factor of 2 less W's at 7 TeV

SUMMARY

- LHC will offer unprecedented number of W's for a variety of studies:
  - Detector Commissioning
  - Precision Electroweak Physics
  - Backgrounds for 'new' physics
- Just getting started but excellent early results

The Physics of W and Z Bosons
RIKEN BNL Research Center Workshop
June 24/25, 2010

Current Status and Prospects for W and Z Cross Section Measurements at CMS

Carsten Magass[1]
(for the CMS Collaboration)

III. Physikalisches Institut A
RWTH Aachen
D-52056 Aachen (Germany)

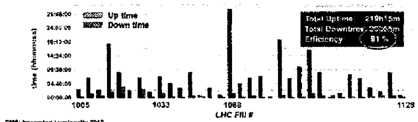
Abstract:

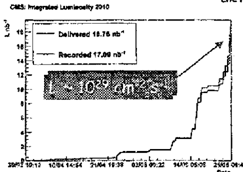
Current status and prospects for W and Z cross section measurements at CMS are presented. Events have been selected in electron and muon channels, and candidate W and Z decays have been examined. The measurements of the cross sections are in progress, and details of lepton identification, missing energy measurement, and event selection are described. Furthermore, prospects for future measurements are presented, like the measurement of the Z boson rapidity distribution and the muon charge asymmetry in W decays. Finally, selected studies of W/Z boson production in association with jets are discussed.

CMS Physics Results Webpage:
`https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResults`

[1]magass@physik.rwth-aachen.de

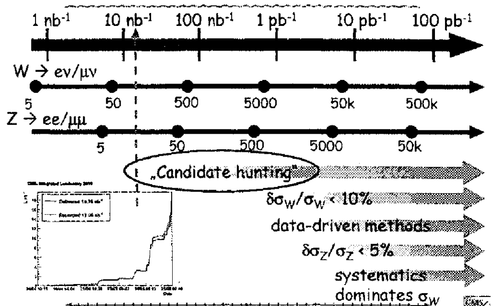
CMS Performance



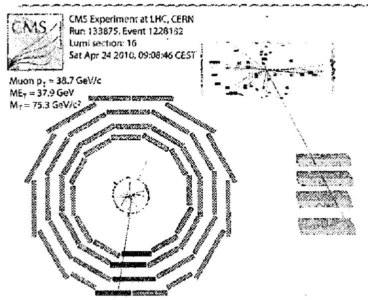


Detector	In readout (%)
Pixel	98.2
Strips	98.1
ECAL Crystals	99.2 (EB=99.3%, EE=98.9%)
ECAL Preshower	99.8
HCAL	99.2 (HB=99.9%, HE=100.0% HF=99.9%, HO=96.9%)
DT	99.8
RPC	96.6
CSC	98.5

Roadmap

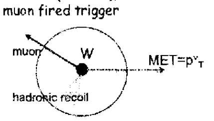


W → μ ν : Candidate Event

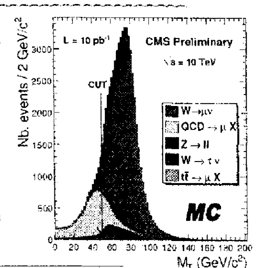


W → μ ν : Selection

Selection :
1 Muon with $p_T > 25$ GeV in $|\eta| < 2$,
isolated (tracker),
muon fired trigger

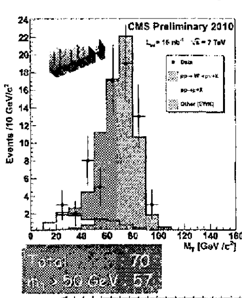


Neutrino escapes
→ observe missing energy in transverse plane (MET)



Reconstruct :
Transverse mass $m_T = \sqrt{2 \not{E}_T \, p_T^\mu (1 - \cos \Delta\varphi)}$

W → μ ν : Data - Monte Carlo Comparison



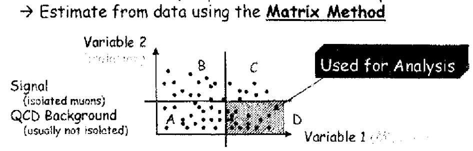
EWK Cross sections :
MCFM NLO using
MSTW08 NLO PDF

W Signal shape :
POWHEG NLO
EWK shapes :
mixed (POWHEG, PYTHIA)
QCD shape :
PYTHIA LO (k = 1)

Data-Driven (later)

W → μ ν : Matrix Method

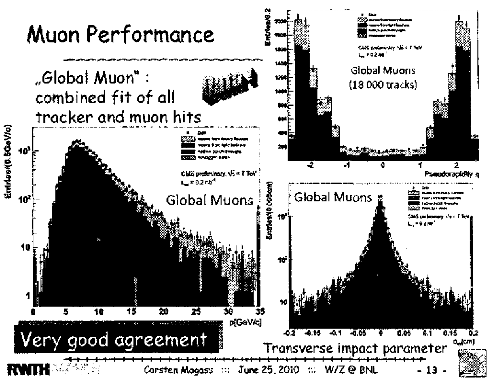
Contributions from QCD processes difficult to predict
→ Estimate from data using the **Matrix Method**



Assume :
Two variables are uncorrelated

$$N_{QCD} \equiv N_D = N_A \cdot \frac{N_C}{N_B}$$

Important :
Correct for correlations & signal contamination in A, B, C


Muon Performance
„Global Muon" : combined fit of all tracker and muon hits
Global Muons
Global Muons (18 000 tracks)
Global Muons
Very good agreement
Transverse impact parameter
RWTH
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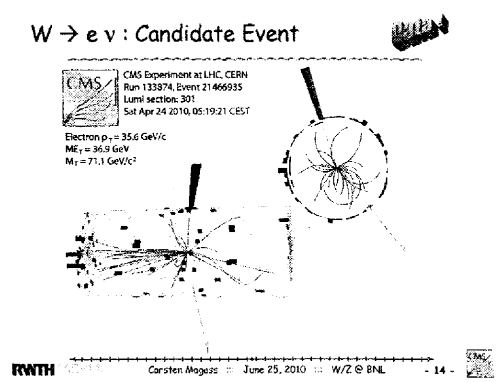
- 13 -


W → e ν : Candidate Event
CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST
Electron p_T = 35.6 GeV/c
ME_T = 36.9 GeV
M_T = 71.1 GeV/c²
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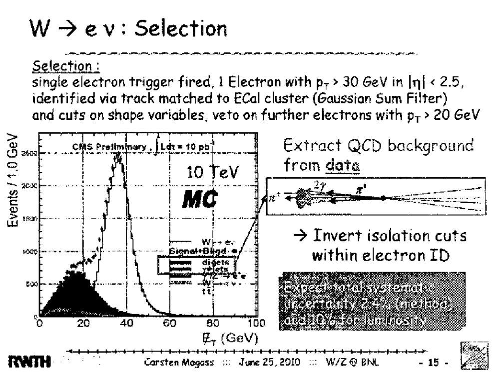
- 14 -


W → e ν : Selection
Selection :
single electron trigger fired, 1 Electron with p_T > 30 GeV in |η| < 2.5,
identified via track matched to ECal cluster (Gaussian Sum Filter)
and cuts on shape variables, veto on further electrons with p_T > 20 GeV
Extract QCD background from data
→ Invert isolation cuts within electron ID
Expect total systematic uncertainty 2-4% (method) and 10% for luminosity
10 TeV
MC
Events / 1.0 GeV
E_T (GeV)
RWTH
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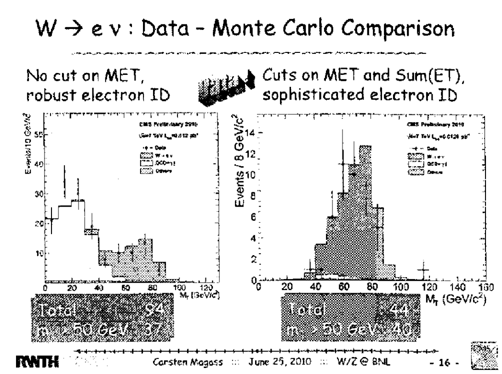
- 15 -


W → e ν : Data - Monte Carlo Comparison
No cut on MET, robust electron ID
Cuts on MET and Sum(ET), sophisticated electron ID
Events / 8 GeV/c²
M_T (GeV/c²)
RWTH
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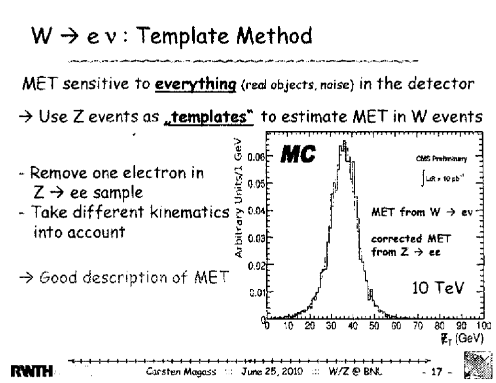
- 16 -


W → e ν : Template Method
MET sensitive to everything (real objects, noise) in the detector
→ Use Z events as „templates" to estimate MET in W events
- Remove one electron in Z → ee sample
- Take different kinematics into account
→ Good description of MET
MC
MET from W → eν
corrected MET from Z → ee
10 TeV
Arbitrary Units/1 GeV
E_T (GeV)
RWTH
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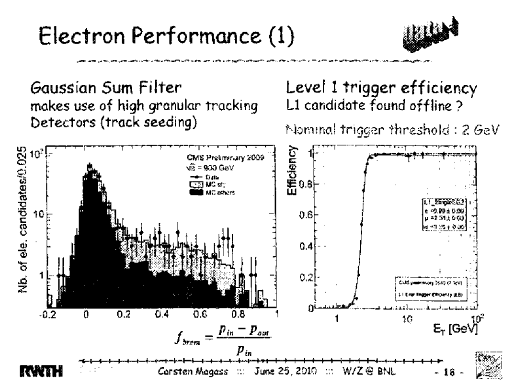
- 17 -


Electron Performance (1)
Gaussian Sum Filter
makes use of high granular tracking Detectors (track seeding)
Level 1 trigger efficiency
L1 candidate found offline ?
Nominal trigger threshold : 2 GeV
Nb. of ele. candidates/0.025
Efficiency
E_T [GeV]
$f_{brem} = \frac{p_{in} - p_{out}}{p_{in}}$
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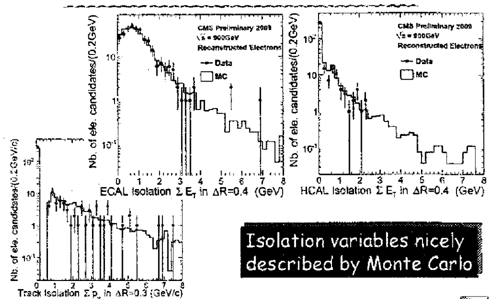
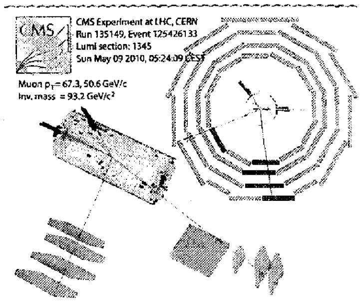
- 18 -

Electron Performance (2)



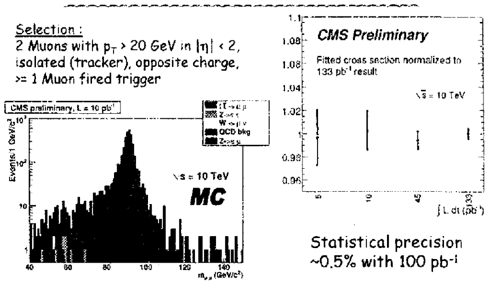
Isolation variables nicely described by Monte Carlo

Z → μ μ : Candidate Event



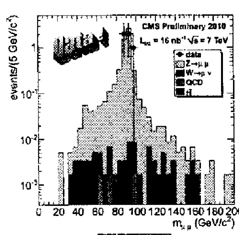
Z → μ μ : Selection

Selection :
2 Muons with p_T > 20 GeV in $|\eta|$ < 2,
isolated (tracker), opposite charge,
>= 1 Muon fired trigger



Statistical precision ~0.5% with 100 pb⁻¹

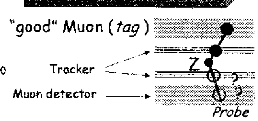
Z → μ μ : Data - Monte Carlo Comparison



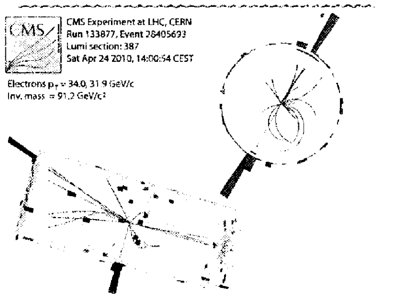
Total : 5

Measure efficiencies from data using **Tag-and-Probe Method**

Z decays provide such samples used for muon (and electron) efficiency measurements

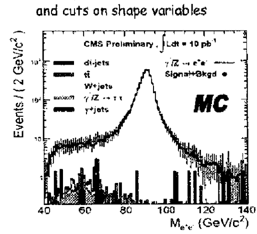


Z → e e : Candidate Event



Z → e e : Selection

Selection :
single electron trigger fired, 2 Electrons with p_T > 20 GeV $|\eta|$ < 2.5,
identified via track matched to ECal cluster (Gaussian Sum Filter)
and cuts on shape variables



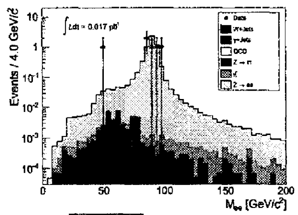
Efficiencies :
ε_{trig} = ~100%
ε_{ID} = 90 %
$\varepsilon_{tot} = \varepsilon_{ID}^2 * (1 - (1 - \varepsilon_{trig})^2)$
= 82 %

Acceptance : 40 %

Efficiencies again via Tag-and-Probe Method

Expect total systematic uncertainty 4% (method) and 10% for luminosity

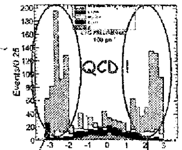
Z → e e : Data - Monte Carlo Comparison



Total : 6

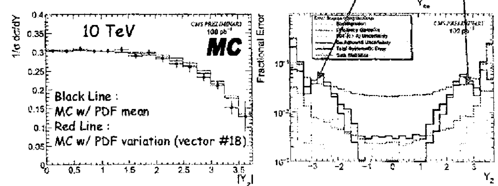
. . . this is just the beginning . . .

Z → e e : Rapidity



Cross section as a function of Z Boson rapidity $Y = \frac{1}{2}\ln\frac{E+p_L}{E-p_L}$

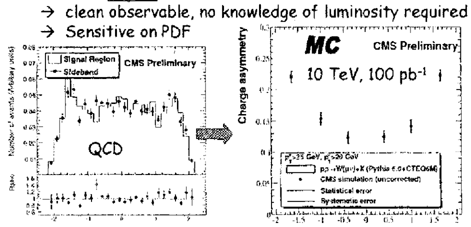
→ Constrain PDF uncertainties



Muon Charge Asymmetry

$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\bar{\nu}_\mu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu_\mu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\bar{\nu}_\mu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu_\mu)}$

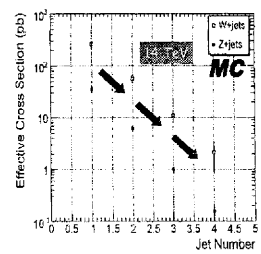
Provides **robust** measurement
→ clean observable, no knowledge of luminosity required
→ Sensitive on PDF



Matrix method for QCD Background estimation

Dominant systematic uncertainties due to efficiency measurements

W and Z with Jets



Important channels :
- test QCD
- background for searches
- Jet Energy Scale (Z + Jets)

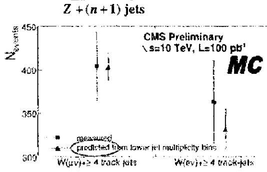
W/Z + Jets analyses need estimates of :
- Jet Energy Scale
- QCD background
- top background (!)

$$\frac{\sigma(W/Z + (N+1)\ Jets)}{\sigma(W/Z + N\ Jets)} = \alpha_s$$

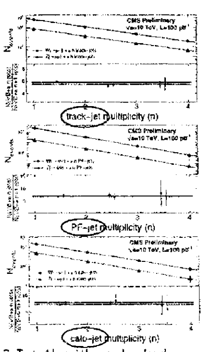
W/Z + Jets : Ratio

Interesting : Double Ratio

$$\frac{C_W}{C_Z} = \frac{\frac{W+n\ \text{jets}}{W+(n+1)\ \text{jets}}}{\frac{Z+n\ \text{jets}}{Z+(n+1)\ \text{jets}}}$$ → uncertainties cancel



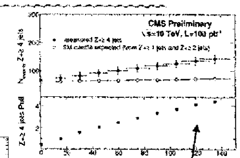
Understand/estimate ttbar background !

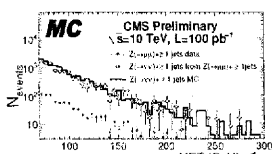


3 Jet Algorithms checked

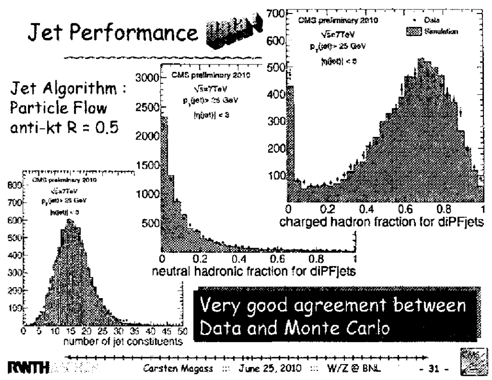
Z + Jets : Tool for New Physics

- ✓ Z + jets → ee and μμ + jets
- ✓ loose selection
- ✓ different jet reconstruction algorithms
- ✓ cross section and ratio





Applications :
- look for deviations at high jet multiplicites
- calibrate (W → μν) + jets using (Z → μμ) + jets
- predict MET in (Z → νν) + jets using (Z → μμ) + jets


Jet Performance
Jet Algorithm :
Particle Flow
anti-kt R = 0.5
charged hadron fraction for diPFjets
neutral hadronic fraction for diPFjets
number of jet constituents
Very good agreement between Data and Monte Carlo
RWTH
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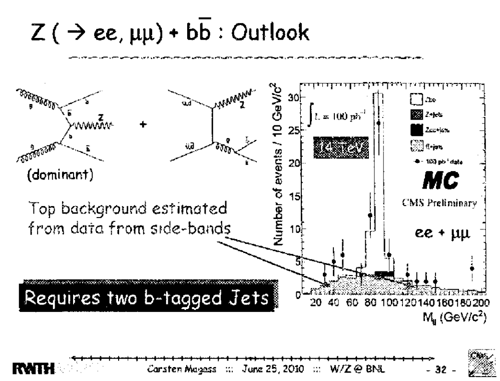
- 31 -


Z (→ ee, μμ) + b$\bar{b}$: Outlook
(dominant)
Top background estimated from data from side-bands
Requires two b-tagged Jets
14 TeV
MC
CMS Preliminary
ee + μμ
Number of events / 10 GeV/c²
M$_{ll}$ (GeV/c²)
RWTH
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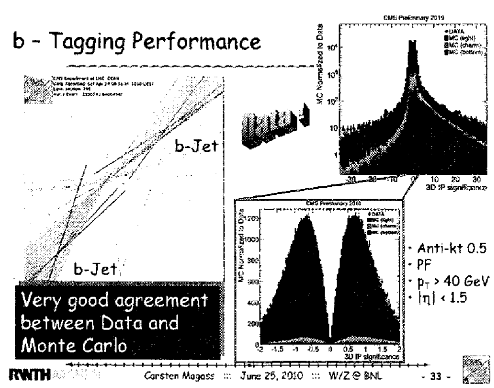
- 32 -


b - Tagging Performance
b-Jet
b-Jet
Very good agreement between Data and Monte Carlo
3D IP significance
Anti-kt 0.5
PF
p_T > 40 GeV
|η| < 1.5
RWTH
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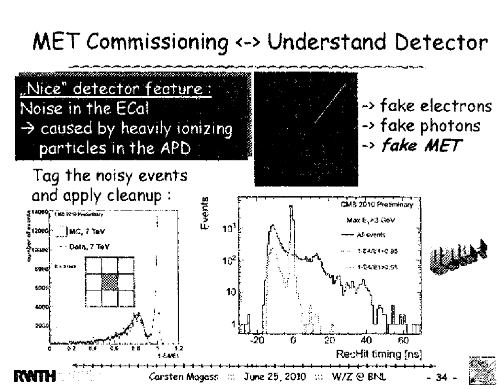
- 33 -


MET Commissioning <-> Understand Detector
„Nice" detector feature :
Noise in the ECal
→ caused by heavily ionizing particles in the APD
-> fake electrons
-> fake photons
-> fake MET
Tag the noisy events and apply cleanup :
Events
RecHit timing [ns]
RWTH
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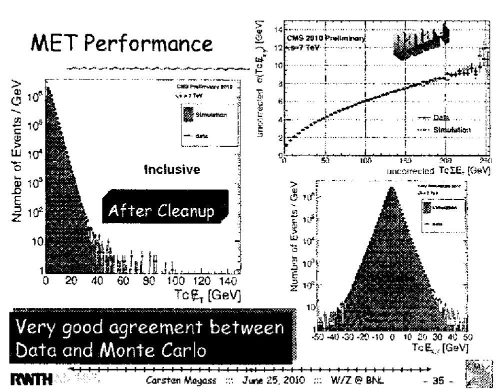
- 34 -


MET Performance
Number of Events / GeV
Inclusive
After Cleanup
Tc$\not{E}_T$ [GeV]
uncorrected TcΣE$_T$ [GeV]
Very good agreement between Data and Monte Carlo
RWTH
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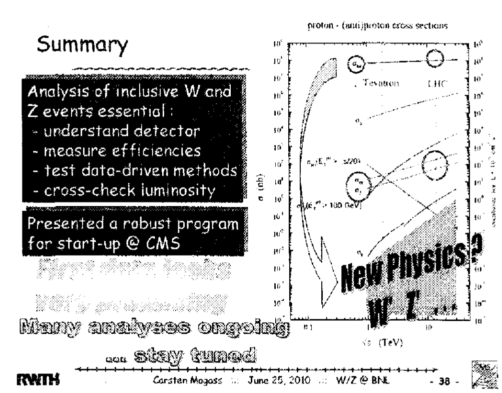
- 35 -


Summary
Analysis of inclusive W and Z events essential :
- understand detector
- measure efficiencies
- test data-driven methods
- cross-check luminosity
Presented a robust program for start-up @ CMS
Many analyses ongoing
... stay tuned
New Physics?
W' Z' ...
proton - (anti)proton cross sections
Tevatron
LHC
√s (TeV)
RWTH
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- 38 -

The Status of NNLO Tools for W/Z Production at Hadron Colliders

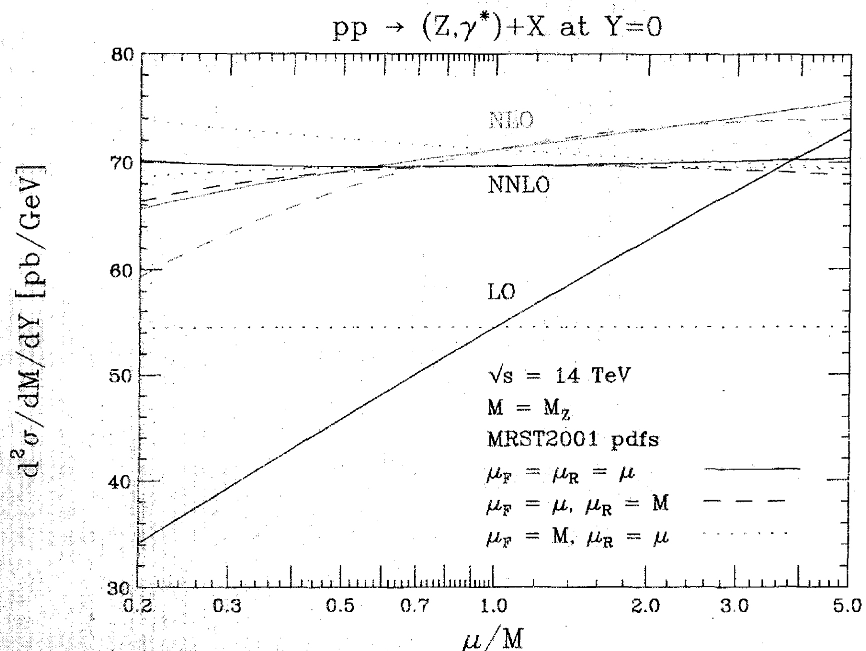
Frank Petriello

University of Wisconsin, Madison

The Physics of W and Z Bosons
June 25, 2010

Standard Candles

$$\sigma(\mu_R, \mu_F) = \sigma^{(0)}(\mu_F) + \frac{\alpha_s(\mu_R)}{\pi}\sigma^{(1)}(\mu_R, \mu_F) + \left(\frac{\alpha_s(\mu_R)}{\pi}\right)^2 \sigma^{(2)}(\mu_R, \mu_F)$$

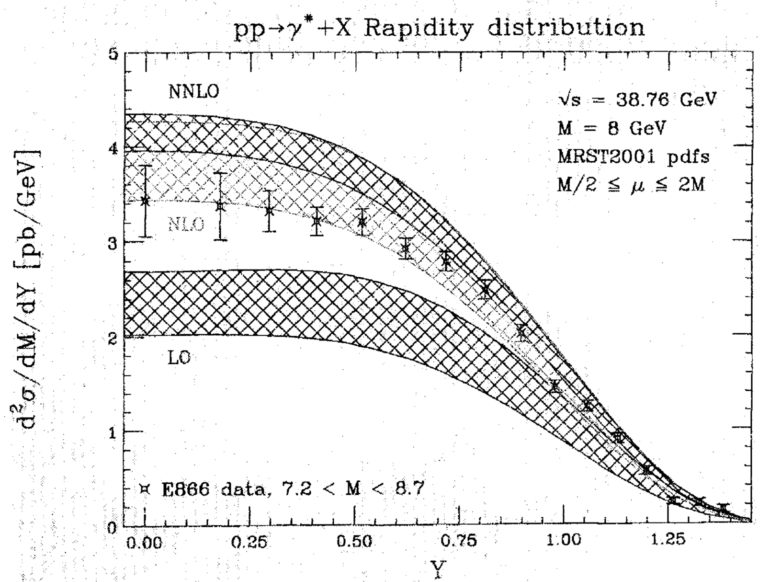


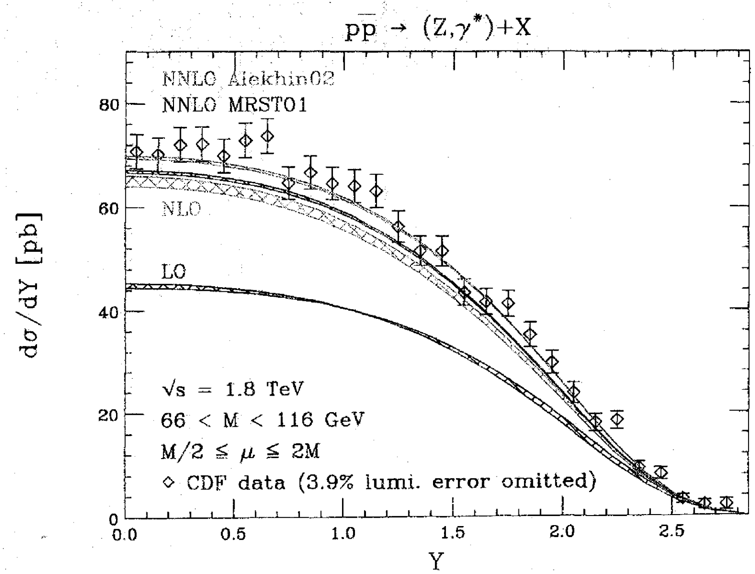
Anastasiou, Dixon, Melnikov, FP (ADMP) hep-ph/0312266

- W,Z production known through NNLO in pQCD
- Residual theoretical uncertainties from scale variations <1% on inclusive quantities
- "Gold-plated" observables suited to high-precision measurements

γ^*/Z rapidity distributions

ADMP hep-ph/0306192





- Significant impact on fixed-target data, quark distributions
  MSTW 0706.0459, 0901.0002
- Generally good agreement with CDF/D0 data

from ***VRAP***: NNLO γ^*+Z,W rapidity distributions

Spin correlations

$$\sigma = \frac{N}{\epsilon \times \mathcal{L} \times A} \longrightarrow$$

Measure leptons, not W/Z, with cuts imposed ⇒spin correlations between production, decay

- **Cut 1** : $p_T^e > 20$ GeV , $|\eta^e| < 2.5$, $\not{E}_T > 20$ GeV ;
- **Cut 2** : $p_T^e > 40$ GeV , $|\eta^e| < 2.5$, $\not{E}_T > 20$ GeV .

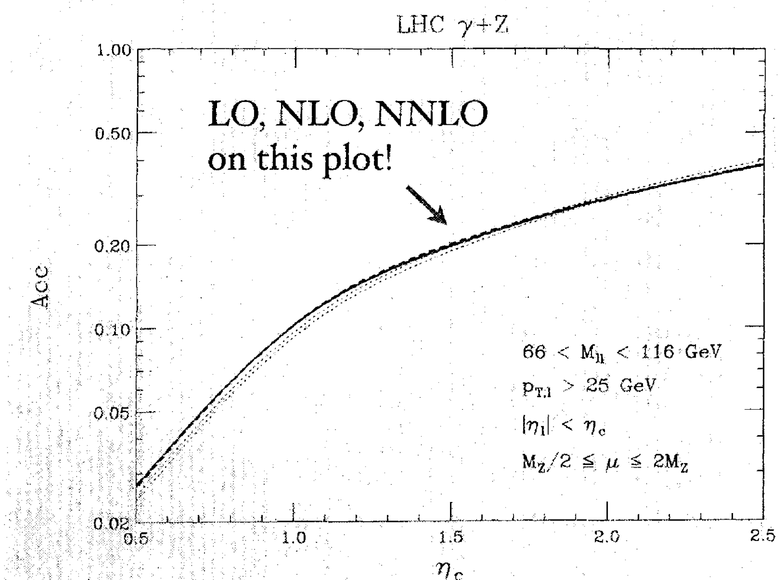
	Tevatron			LHC		
	LO	NLO	MC@NLO	LO	NLO	MC@NLO
Cut 1	0.409	0.385	0.383	0.524	0.477	0.485
Cut 1, no spin	0.413	0.394	0.394	0.553	0.510	0.515
Cut 2	0.356	0.340	0.336	0.058	0.129	0.133
Cut 2, no spin	0.389	0.374	0.370	0.075	0.150	0.157

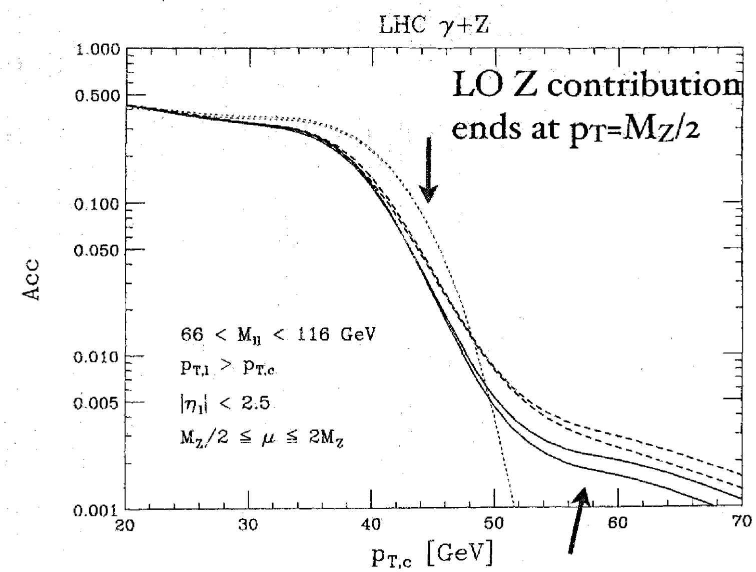
Frixione, Mangano hep-ph/0405130

Essential: fully differential NNLO with spin correlations, γ/Z interference

FEWZ

- ***FEWZ***: Fully exclusive W, Z production — Melnikov, FP hep-ph/0603182, 0609070



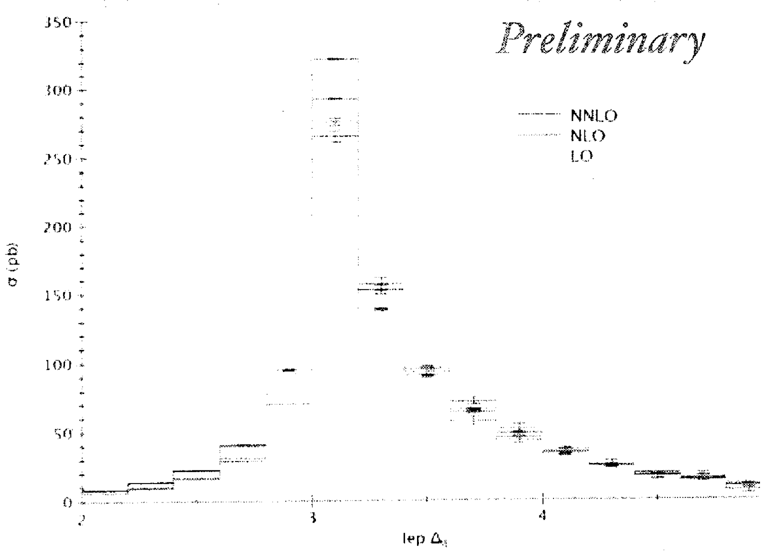


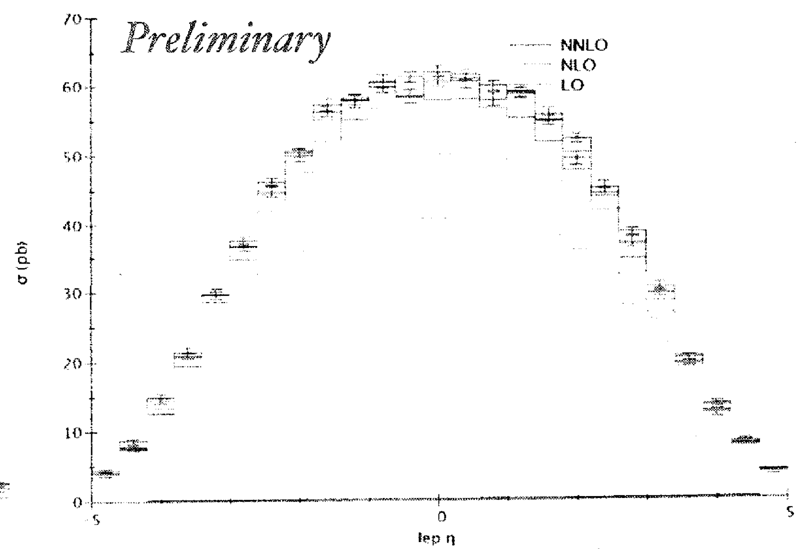
☑ Generally, percent-level predictions for acceptances

Need V+jet at NNLO for this region Boughezal, Gehrmann-de Ridder, Ritzmann 1001.2396

Lepton distributions

Z @ LHC @ 7 TeV

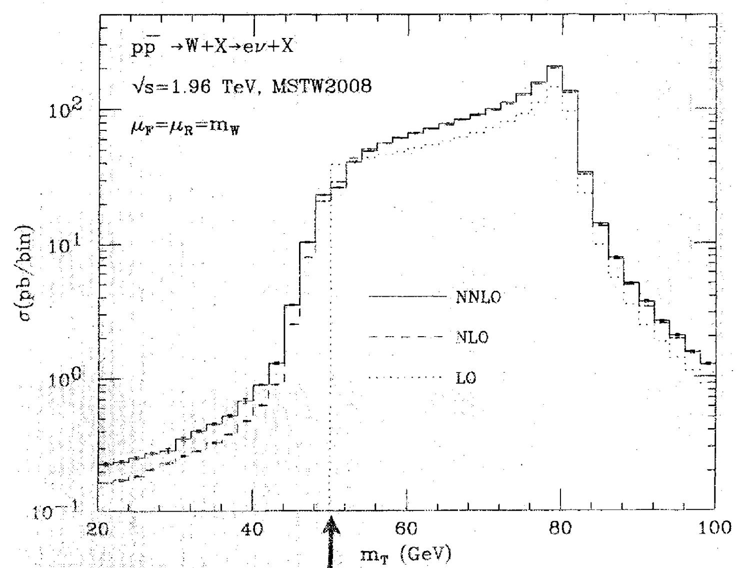




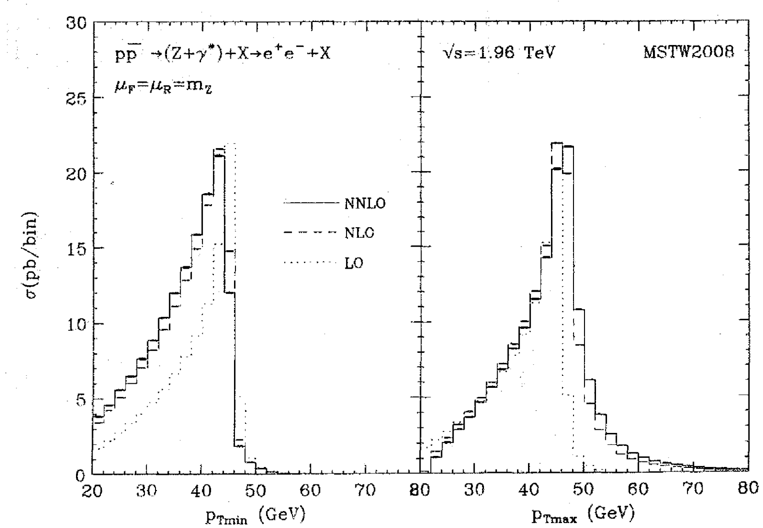
↑ LO boundary: leptons back-to-back in transverse plane

DYNNLO

- Alternative subtraction approach to handling IR singularities at NNLO Catani,Cieri, Ferrera, de Florian, Grazzini 0903.2120



LO boundary created by p_T^{miss} >25 GeV



The Physics of W and Z Bosons

June 24-25, 2010

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The Physics of W and Z Bosons

Brookhaven National Laboratory
Physics Department Large Seminar Room
June 24-25, 2010

Thursday 24 June 2010

09:00->*10:40* **Session I** [Convener: Jianwei Qiu (*BNL*)]

09:00	Welcome Remarks	Nick Samios (*RBRC*)
09:10	First Measurement of W+/W- Boson Production at STAR In Polarized pp Collisions at RHIC	Jan Balewski (*MIT*)
09:50	First Observations at PHENIX of W Production From Polarized pp Collisions at RHIC	David Kawall (*U. of Massachusetts, Amherst*)
10:30	Coffee	

10:50->*12:10* **Session II** [Convener: C.-P. Yuan (*MSU*)]

10:50	QCD Resummation on A_L of W p_T Distributions and PDFs	Pavel Nadolsky (*Southern Methodist U.*)
11:30	W Mass Measurements	Alessandro Vicini (U. of Milan)
12:10	Lunch at Berkner Hall	

13:30->*15:30* **Session III** [Convener: Abid Patwa (*BNL*)]

13:30	W/Z Physics from HERA	David South (*DESY*)
14:10	W Mass Measurements at D0	Junjie Zhu (*U. of Michigan*)
14:50	W Mass Measurements at CDF	Ashutosh Kotwal (*Duke U.*)
15:30	Coffee	

15:50->*17:50* **Session IV** [Convener: Kensuke Okada (*BNL/RIKEN*)]

15:50	Monte Carlo Modeling Issues for W Measurements	Jan Stark (*LPSC, Grenoble*)
16:30	Theoretical Issues in Monte Carlo Modelling for W Production	Jan Winter (*Fermilab*)
17:10	W Boson Physics and Global Analysis of PDFs	C. -P. Yuan (*Michigan State U.*)
18:30	Workshop Dinner: Cookout at Brookhaven Center	

Friday 25 June 2010

09:00->*10:20* **Session V** [Convener: Abhay Deshpande (*Stony Brook U*)]

09:00	Future Prospects of the STAR W Program in Polarized pp Collisions at RHIC	Joe Seele (*MIT*)
09:40	Prospects of the Forward W Measurement in Polarized pp Collisions at the RHIC-PHENIX Experiment	Yoshi Fukao (*RIKEN*)
10:20	Coffee	

10:50->*12:10* **Session VI** [Convener: Frank Petriello (*Wisconsin*)]

10:50	A_N of W Production in Polarized pp Collisions	Zhong-Bo Kang (*RBRC*)
11:30	Precision Measurement of the W Mass and New Physics	Ulrich Baur (*U. at Buffalo*)
12:10	Lunch at Berkner Hall	

14:00->*16:00* **Session VII** [Convener: Sally Dawson (*BNL*)]

14:00	W Measurements and Prospects at ATLAS	Kevin Black (*Harvard*)
14:40	Current Status and Prospects for W & Z Cross Section Measurements at CMS	Carsten Magass (*RWTH Aachen*)
15:20	The Status of NNLO Tools for W/Z Boson Production at Hadron Colliders	Frank Petriello (*U. of Wisconsin*)

Additional RIKEN BNL Research Center Proceedings:

Volume 98 – Saturation, the Color Glass Condensate and the Glasma: What Have we Learned from RHIC?, BNL, May 10-12, 2010 – BNL-94271-2010
Volume 97 – RBRC Scientific Review Committee Meeting, October 21-22, 2009 – BNL-90674-2009
Volume 96 – P- and CP-Odd Effects in Hot and Dense Matter, April 26-30, 2010 – BNL-94237-2010
Volume 95 – Progress in High-pT Physics at RHIC, March 17-19, 2010 – BNL-94214-2010
Volume 94 – Summer Program on Nucleon Spin Physics at LBL, June 1-12, 2009
Volume 93 – PHENIX Spinfest School 2009 at BNL - July 1-31, 2009. BNL-90343-2009
Link: PHENIXSpinfestSchool2009@BNL
Volume 92 – PKU-RBRC Workshop on Transverse Spin Physics, June 30-July 4, 2008, Beijing, China, BNL-81685-2008
Volume 91 – RBRC Scientific Review Committee Meeting, November 17-18, 2008 – BNL-81556-2008
Volume 90 – PHENIX Spinfest School 2008 at BNL, August 4-8, 2008 - BNL-81478-2008
Volume 89 – Understanding QGP through Spectral Functions and Euclidean Correlators, April 23-25, 2008 – BNL-81318-2008
Volume 88 – Hydrodynamics in Heavy Ion Collisions and QCD Equation of State, April 21-22, 2008 – BNL-81307-2008
Volume 87 – RBRC Scientific Review Committee Meeting, November 5-6, 2007 – BNL-79570-2007
Volume 86 – Global Analysis of Polarized Parton Distributions in the RHIC Era, October 8, 2007 – BNL-79457-2007
Volume 85 – Parity-Violating Spin Asymmetries at RHIC-BNL, April 26-27, 2007 – BNL-79146-2007
Volume 84 – Domain Wall Fermions at Ten Years, March 15-17, 2007 – BNL 77857-2007
Volume 83 – QCD in Extreme Conditions, July 31-August 2, 2006 – BNL-76933-2006
Volume 82 – RHIC Physics in the Context of the Standard Model, June 18-23, 2006 – BNL-76863-2006
Volume 81 – Parton Orbital Angular Momentum (Joint RBRC/University of New Mexico Workshop) February 24-26, 2006 – BNL-75937-2006
Volume 80 – Can We Discover the QCD Critical Point at RHIC?, March 9-10, 2006 – BNL-75692-2006
Volume 79 – Strangeness in Collisions, February 16-17, 2006 – BNL-79763-2008
Volume 78 – Heavy Flavor Productions and Hot/Dense Quark Matter, Dec 12-14, 2005 – BNL-76915-2006
Volume 77 – RBRC Scientific Review Committee Meeting – BNL-52649-2005
Volume 76 – Odderon Searches at RHIC, September 27-29, 2005 – BNL-75092-2005
Volume 75 – Single Spin Asymmetries, June 1-3, 2005 – BNL-74717-2005
Volume 74 – RBRC QCDOC Computer Dedication and Symposium on RBRC QCDOC, May 26, 2005 – BNL-74813-2005
Volume 73 – Jet Correlations at RHIC, March 10-11, 2005 – BNL-73910-2005
Volume 72 – RHIC Spin Collaboration Meetings XXXI(January 14, 2005), XXXII (February 10, 2005), XXXIII (March 11, 2005) – BNL-73866-2005
Volume 71 – Classical and Quantum Aspects of the Color Glass Condensate – BNL-73793-2005
Volume 70 – Strongly Coupled Plasmas: Electromagnetic, Nuclear & Atomic – BNL-73867-2005
Volume 69 – RBRC Scientific Review Committee – BNL-73546-2004
Volume 68 – Workshop on the Physics Programme of the RBRC and UKQCD QCDOC Machines – BNL-73604-2004
Volume 67 – High Performance Computing with BlueGene/L and QCDOC Architectures
Volume 66 – RHIC Spin Collaboration Meeting XXIX, October 8-9, 2004, Torino Italy – BNL-73534-2004
Volume 65 – RHIC Spin Collaboration Meetings XXVII (July 22, 2004), XXVIII (September 2, 2004), XXX (December 6, 2004) – BNL-73506-2004
Volume 64 – Theory Summer Program on RHIC Physics – BNL-73263-2004
Volume 63 – RHIC Spin Collaboration Meetings XXIV (May 21, 2004), XXV (May 27, 2004), XXVI (June 1, 2004) – BNL-72397-2004
Volume 62 – New Discoveries at RHIC, May 14-15, 2004 – BNL- 72391-2004
Volume 61 – RIKEN-TODAI Mini Workshop on "Topics in Hadron Physics at RHIC", March 23-24, 2004 – BNL-72336-2004
Volume 60 – Lattice QCD at Finite Temperature and Density – BNL-72083-2004
Volume 59 – RHIC Spin Collaboration Meeting XXI (January 22, 2004), XXII (February 27, 2004), XXIII (March 19, 2004)– BNL-72382-2004
Volume 58 – RHIC Spin Collaboration Meeting XX – BNL-71900-2004
Volume 57 – High pt Physics at RHIC, December 2-6, 2003 – BNL-72069-2004

Additional RIKEN BNL Research Center Proceedings:

Volume 56 – RBRC Scientific Review Committee Meeting – BNL-71899-2003
Volume 55 – Collective Flow and QGP Properties – BNL-71898-2003
Volume 54 – RHIC Spin Collaboration Meetings XVII, XVIII, XIX – BNL-71751-2003
Volume 53 – Theory Studies for Polarized pp Scattering – BNL-71747-2003
Volume 52 – RIKEN School on QCD "Topics on the Proton" – BNL-71694-2003
Volume 51 – RHIC Spin Collaboration Meetings XV, XVI – BNL-71539-2003
Volume 50 – High Performance Computing with QCDOC and BlueGene – BNL-71147-2003
Volume 49 – RBRC Scientific Review Committee Meeting – BNL-52679
Volume 48 – RHIC Spin Collaboration Meeting XIV – BNL-71300-2003
Volume 47 – RHIC Spin Collaboration Meetings XII, XIII – BNL-71118-2003
Volume 46 – Large-Scale Computations in Nuclear Physics using the QCDOC – BNL-52678
Volume 45 – Summer Program: Current and Future Directions at RHIC – BNL-71035
Volume 44 – RHIC Spin Collaboration Meetings VIII, IX, X, XI – BNL-71117-2003
Volume 43 – RIKEN Winter School – Quark-Gluon Structure of the Nucleon and QCD – BNL-52672
Volume 42 – Baryon Dynamics at RHIC – BNL-52669
Volume 41 – Hadron Structure from Lattice QCD – BNL-52674
Volume 40 – Theory Studies for RHIC-Spin – BNL-52662
Volume 39 – RHIC Spin Collaboration Meeting VII – BNL-52659
Volume 38 – RBRC Scientific Review Committee Meeting – BNL-52649
Volume 37 – RHIC Spin Collaboration Meeting VI (Part 2) – BNL-52660
Volume 36 – RHIC Spin Collaboration Meeting VI – BNL-52642
Volume 35 – RIKEN Winter School – Quarks, Hadrons and Nuclei – QCD Hard Processes and the Nucleon Spin – BNL-52643
Volume 34 – High Energy QCD: Beyond the Pomeron – BNL-52641
Volume 33 – Spin Physics at RHIC in Year-1 and Beyond – BNL-52635
Volume 32 – RHIC Spin Physics V – BNL-52628
Volume 31 – RHIC Spin Physics III & IV Polarized Partons at High Q^2 Region – BNL-52617
Volume 30 – RBRC Scientific Review Committee Meeting – BNL-52603
Volume 29 – Future Transversity Measurements – BNL-52612
Volume 28 – Equilibrium & Non-Equilibrium Aspects of Hot, Dense QCD – BNL-52613
Volume 27 – Predictions and Uncertainties for RHIC Spin Physics & Event Generator for RHIC Spin Physics III – Towards Precision Spin Physics at RHIC – BNL-52596
Volume 26 – Circum-Pan-Pacific RIKEN Symposium on High Energy Spin Physics – BNL-52588
Volume 25 – RHIC Spin – BNL-52581
Volume 24 – Physics Society of Japan Biannual Meeting Symposium on QCD Physics at RIKEN BNL Research Center – BNL-52578
Volume 23 – Coulomb and Pion-Asymmetry Polarimetry and Hadronic Spin Dependence at RHIC Energies – BNL-52589
Volume 22 – OSCAR II: Predictions for RHIC – BNL-52591
Volume 21 – RBRC Scientific Review Committee Meeting – BNL-52568
Volume 20 – Gauge-Invariant Variables in Gauge Theories – BNL-52590
Volume 19 – Numerical Algorithms at Non-Zero Chemical Potential – BNL-52573
Volume 18 – Event Generator for RHIC Spin Physics – BNL-52571
Volume 17 – Hard Parton Physics in High-Energy Nuclear Collisions – BNL-52574
Volume 16 – RIKEN Winter School - Structure of Hadrons - Introduction to QCD Hard Processes – BNL-52569
Volume 15 – QCD Phase Transitions – BNL-52561
Volume 14 – Quantum Fields In and Out of Equilibrium – BNL-52560
Volume 13 – Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project First Anniversary Celebration – BNL-66299
Volume 12 – Quarkonium Production in Relativistic Nuclear Collisions – BNL-52559
Volume 11 – Event Generator for RHIC Spin Physics – BNL-66116
Volume 10 – Physics of Polarimetry at RHIC – BNL-65926
Volume 9 – High Density Matter in AGS, SPS and RHIC Collisions – BNL-65762

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Volume 7 – RHIC Spin Physics – BNL-65615
Volume 6 – Quarks and Gluons in the Nucleon – BNL-65234
Volume 5 – Color Superconductivity, Instantons and Parity (Non?)-Conservation at High Baryon Density – BNL-65105
Volume 4 – Inauguration Ceremony, September 22 and Non-Equilibrium Many Body Dynamics –BNL-64912
Volume 3 – Hadron Spin-Flip at RHIC Energies – BNL-64724
Volume 2 – Perturbative QCD as a Probe of Hadron Structure – BNL-64723
Volume 1 – Open Standards for Cascade Models for RHIC – BNL-64722

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RIKEN BNL RESEARCH CENTER

The Physics of W and Z Bosons

June 24-25, 2010

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

Speakers:

Jan Balewski
Yoshi Fukao
Ashutosh Kotwal
Francis Petriello
Jan Stark
C.-P. Yuan
Ulrich Baur
Zhongbo Kang
Carsten Magass
Joseph Seele
Alessandro Vicini
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Jan Winter

Organizers: S. Dawson, K. Okada, A. Patwa, J. Qiu and B. Surrow