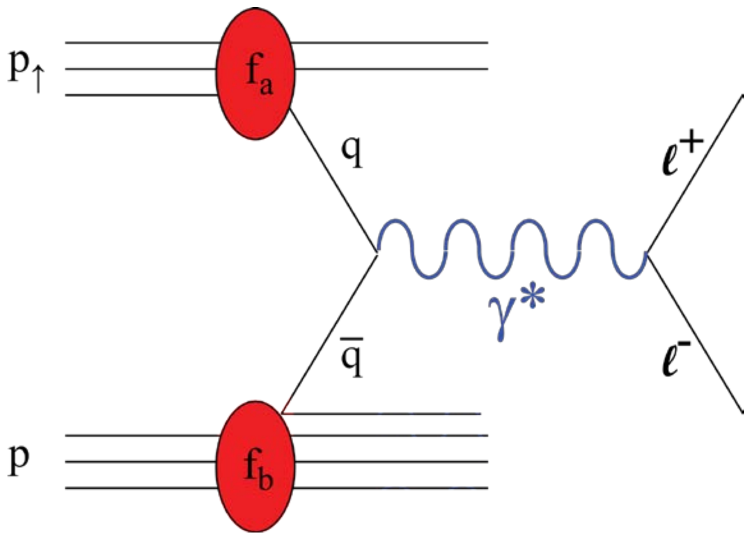
$A_N DY$

A proposal to measure analyzing power for Drell-Yan production



L.C. Bland, BNL

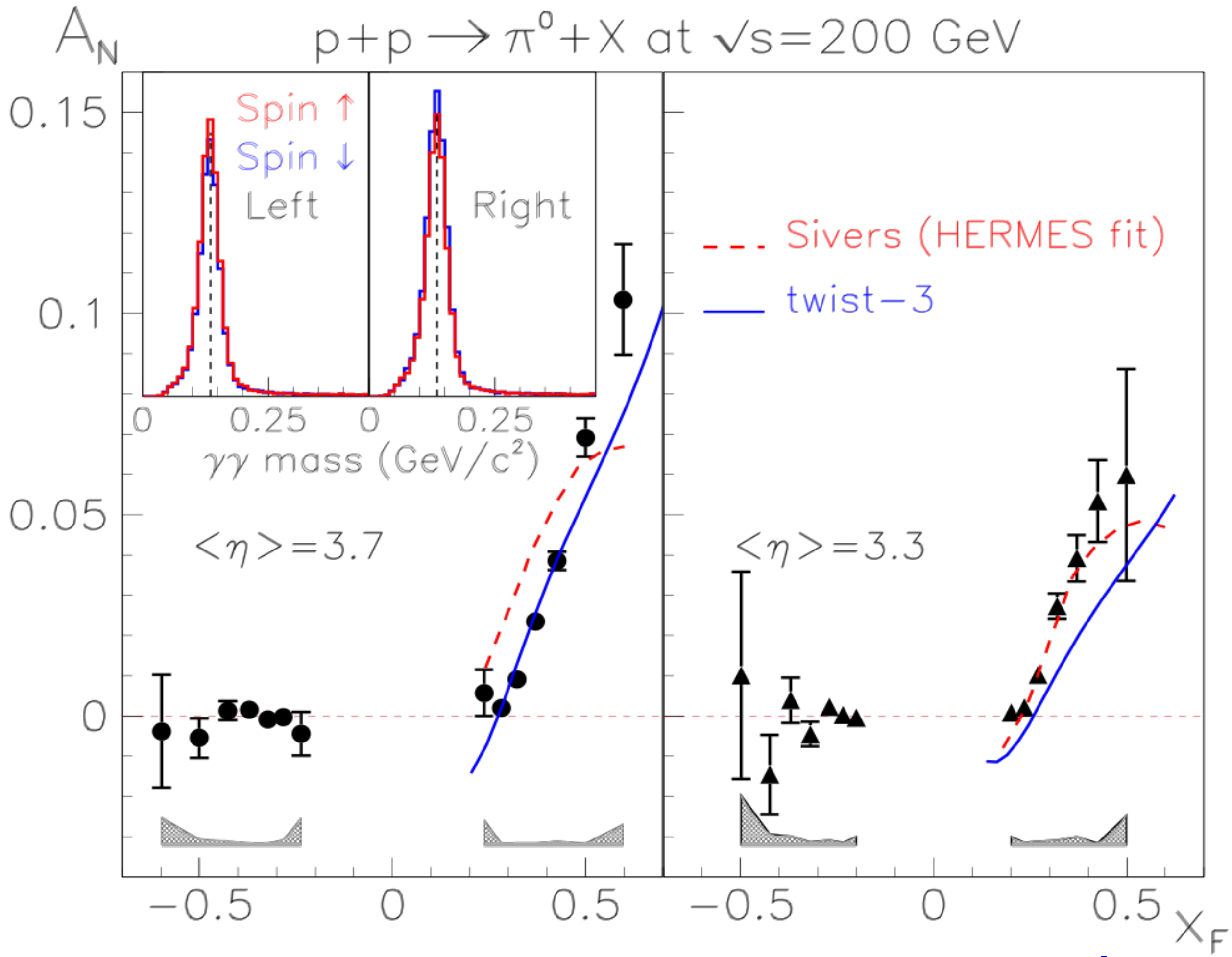
Program Advisory Committee

6 June 2011

x_F Dependence of Inclusive π^0 A_N

RHIC Run 6 with Forward Pion Detector

STAR



PRL 101, 222001 (2008)
arXiv:0801.2990 [hep-ex]

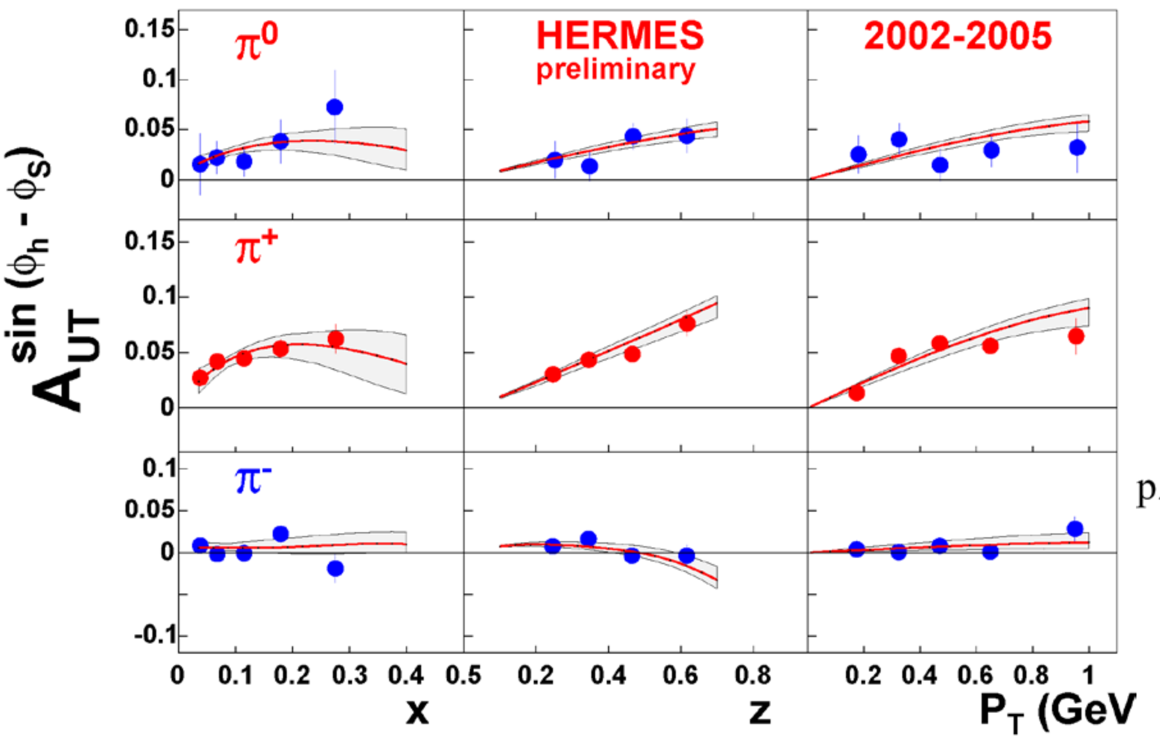
Fits to SIDIS (HERMES) ~~are~~ *were?* consistent with p+p→π+X data

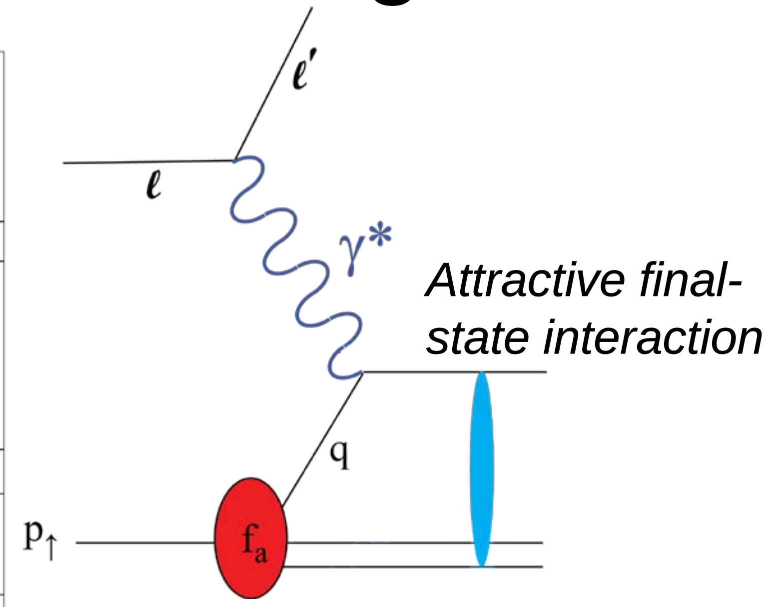
A_N at positive x_F grows with increasing x_F

U. D'Alesio, F. Murgia
Phys. Rev. D 70, 074009 (2004)
arXiv:hep-ph/0712.4240

C. Kouvaris, J. Qiu, W. Vogelsang, F. Yuan,
Phys. Rev. D 74, 114013 (2006).

Sivers Effect in Semi-Inclusive Deep Inelastic Scattering





$$\hat{S}_T \bullet \left(\hat{P} \times \hat{k}_\perp\right) f_{1T}^{\perp}(x, k_\perp)$$

final HERMES data: PRL 103 (2009) 152002 [arXiv:0906.3918] (Sivers asymmetry) and arXiv:1006.4221 (Collins asymmetry)

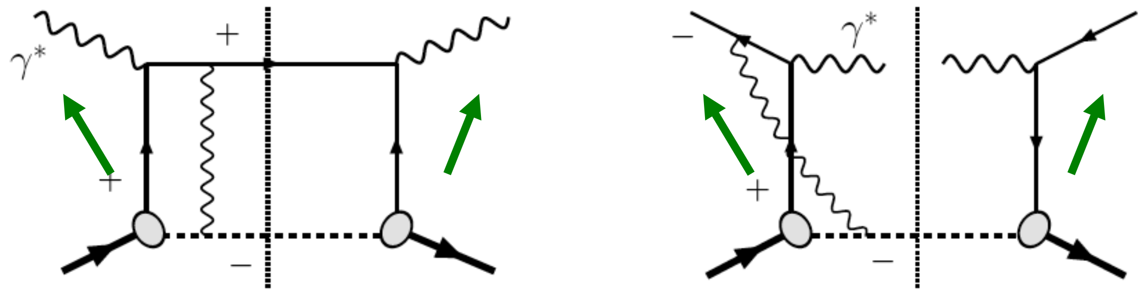
Phenomenological fits: M. Anselmino et al. EPJ A39 (2009) 89 [arXiv:0805.2677]

Final-state interaction: S.J. Brodsky, D.S. Hwang, I. Schmidt PL B530 (2002) 99 [hep-ph/0201296]

Attractive vs Repulsive Sivers Effects

Unique Prediction of Gauge Theory !

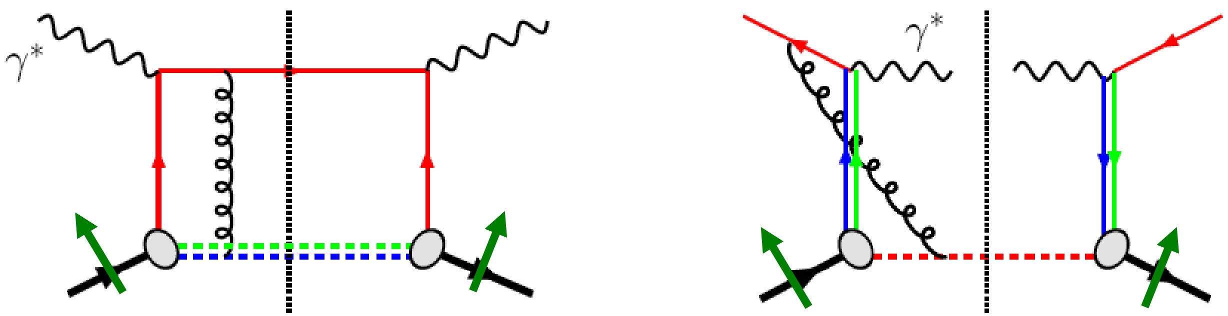
Simple QED example:



DIS: attractive

Drell-Yan: repulsive

Same in QCD:



As a result:

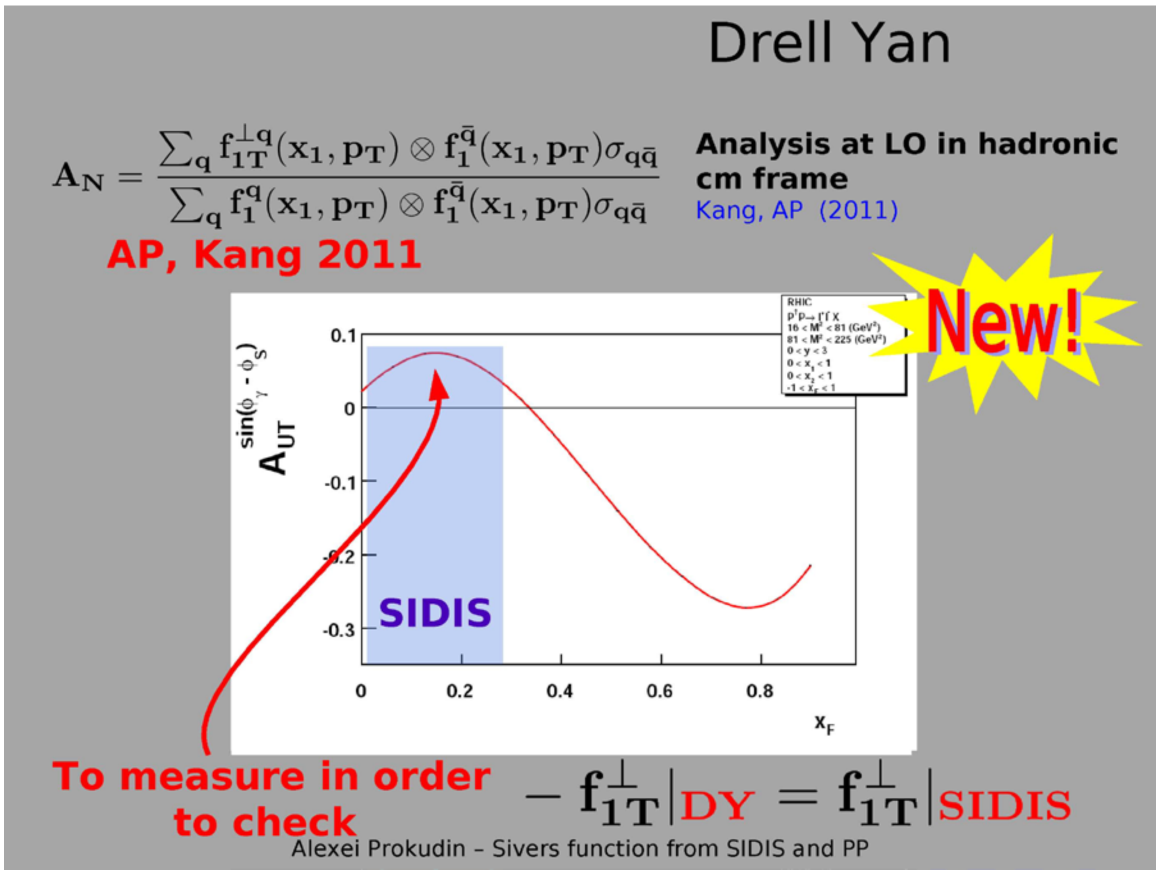
$$\boxed{\mathrm{Sivers}|_{\mathrm{DIS}} = -\mathrm{Sivers}|_{\mathrm{DY}}}$$

Transverse Spin Drell-Yan Physics at RHIC (2007)

http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf

New Developments

- *SIDIS and RHIC pion production do not overlap in momentum fraction (x)*
- *Attempts to describe both results in a sign “mismatch” conclusion [Kang, Qiu, Vogelsang, Yuan PRD83 (2011) 094001 and arXiv:1103.1591]*
- *Essential to test predicted sign change for DY in same kinematics as SIDIS*



Combined analysis of SIDIS and RHIC pion production leads to the conclusion that the u-quark Sivers function has a node at x~0.4

A. Prokudin, Z.B. Kang “Opportunities for Drell-Yan Physics at RHIC” workshop (May, 2011)

A$_N$DY

“Large Rapidity Drell Yan Production at RHIC”

Letter of Intent submitted 24 May 2010:

http://www.bnl.gov/npp/docs/pac0610/Crawford_LoI.100524.v1.pdf

PAC presentation:
http://www.bnl.gov/npp/docs/pac0610/aschenauer_DY-collider_june10.pdf

Proposal to 2011 PAC:
http://www.bnl.gov/npp/docs/pac0611/DY_pro_110516_final.2.pdf

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University of. California, Berkeley/Space Sciences Laboratory /Stony Brook University
A. Derevshchikov, N. Minaev, D. Morozov, L.V. Nogach
Institute for High Energy Physics, Protvino
G. Igo
University of California, Los Angeles
M. Grosse Perdekamp
University of Illinois
M.X. Liu
Los Alamos National Laboratory
H. Avakian
Thomas Jefferson National Accelerator Facility
E.J.Brash
Christopher Newport University and TJNAF
C.F.Perdrisat
College of William and Mary
V. Punjabi
Norfolk State University
Li, Xuan
Shandong University, China
Mirko Planinic, Goran Simatovic
University of Zagreb, Croatia
A. Vossen
Indiana University
G. Schnell
University of the Basque Country and IKERBASQUE,Spain
A. Shahinyan, S. Abrahamyan
Yerevan Physics Institute

6

Goals of A_NDY Project

- Demonstrate that large-x_F low-mass dileptons from the Drell-Yan process can be discriminated from background in $\sqrt{s}$=500 GeV $p^{\uparrow}$+p collisions

- Measure the analyzing power for Drell-Yan production with sufficient statistical precision to test the theoretical prediction of a sign change for DY in relation to semi-inclusive deep inelastic scattering

- Establish if robust detection of Drell-Yan dileptons at large x_F and low mass requires magnetic analysis $\Rightarrow$ critical for future facilities at RHIC

Staging/Scope

Assumptions:

1) polarized proton test run at $\sqrt{s}$=500 GeV in RHIC run 11

2) 12 week polarized proton W production run at $\sqrt{s}$=500 GeV in RHIC run 12

3) 12 week polarized proton W production run at $\sqrt{s}$=500 GeV in RHIC run 13

Planned Staging:

+ small ECal, courtesy of JLab

1) Hcal + newly constructed BBC at IP2 for RHIC run 11 with goals of establishing impact of 3IR operation and demonstrate calibration of Hcal to get first data constraints on charged hadron backgrounds

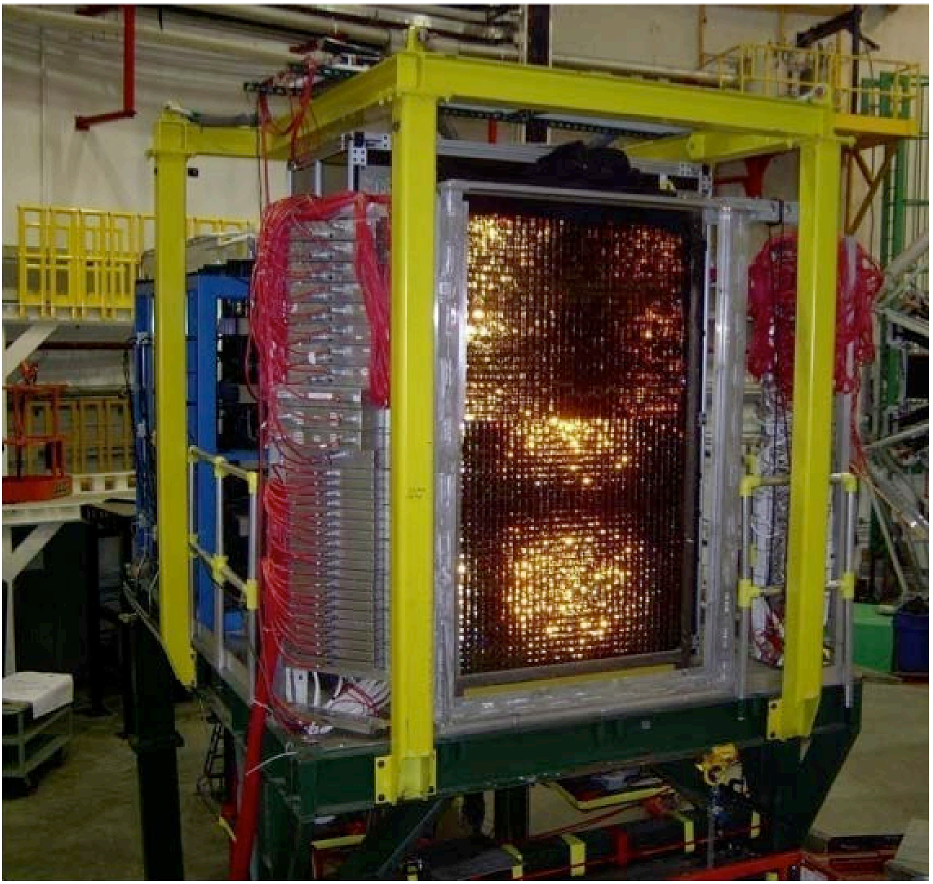
2) Hcal + EMcal + neutral/charged veto + BBC for RHIC run 12 with goals of zero-field data sample with L_{int}~150 / pb and P_{beam}=50% to observe dileptons from J/ψ, Υ and intervening continuum. Split-dipole tests envisioned.

3) Hcal + EMcal + neutral/charged veto + BBC + split-dipole for RHIC run 13 with goals data sample with L_{int}~150 / pb and Pbeam=50% to observe dileptons from J/ψ, Υ and intervening continuum to address whether charge sign discrimination is required

A 3-year plan forced by timing of Coherent Electron Cooling and loan of BigCal

BigCal from JLab

1744 element lead-glass calorimeter



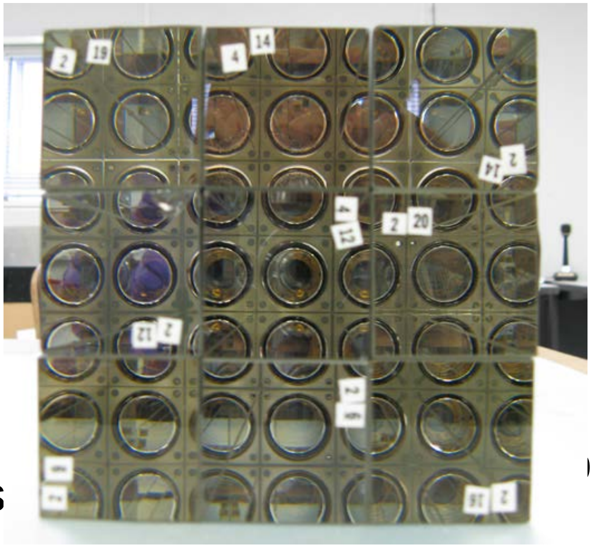
This is a picture of BigCal from a talk by Vina Punjabi at the Hall A collaboration meeting in June, 2010.

Protvino Glass
32 column × 32 row submatrix
38mm × 38mm ×45cm
TF1 glass from IHEP

Yerevan Glass
30 column × 24 row submatrix
40mm × 40mm × 40cm
TF1 glass from Yerevan Physics Institute.

Some people from BigCal have joined AnDY!

120 Yerevan cells from BigCal are now at BNL/IP2 and operated in two 7x7 stacks in run 11



3x3 test stack of fully assembled cells

Run-11 Implementation

A_NDY Goals
for RHIC run-11

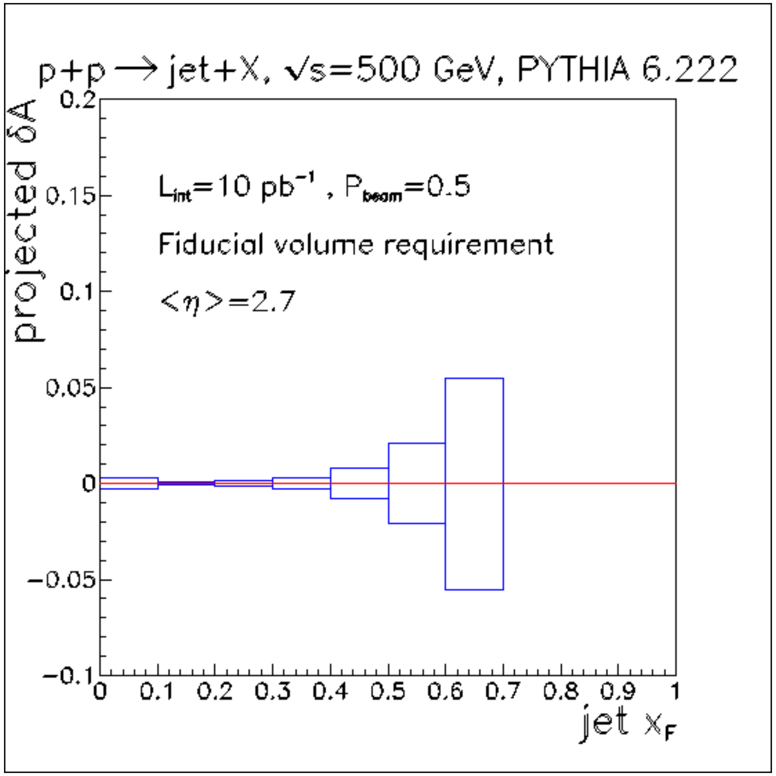
- Establish the impact of a third IR on RHIC performance for p+p collisions at $\sqrt{s}$=500 GeV - Demonstrate luminosity at IP2, as required for Drell-Yan sample in runs 12 (without magnet),13 (with magnet). Estimate that 150 / pb gives 10^4 large-rapidity di-electrons with M>4 GeV/c^2 for p+p at $\sqrt{s}$=500 GeV in "model 2". Is this possible in a 10-week run?

- Demonstrate calibration of HCal

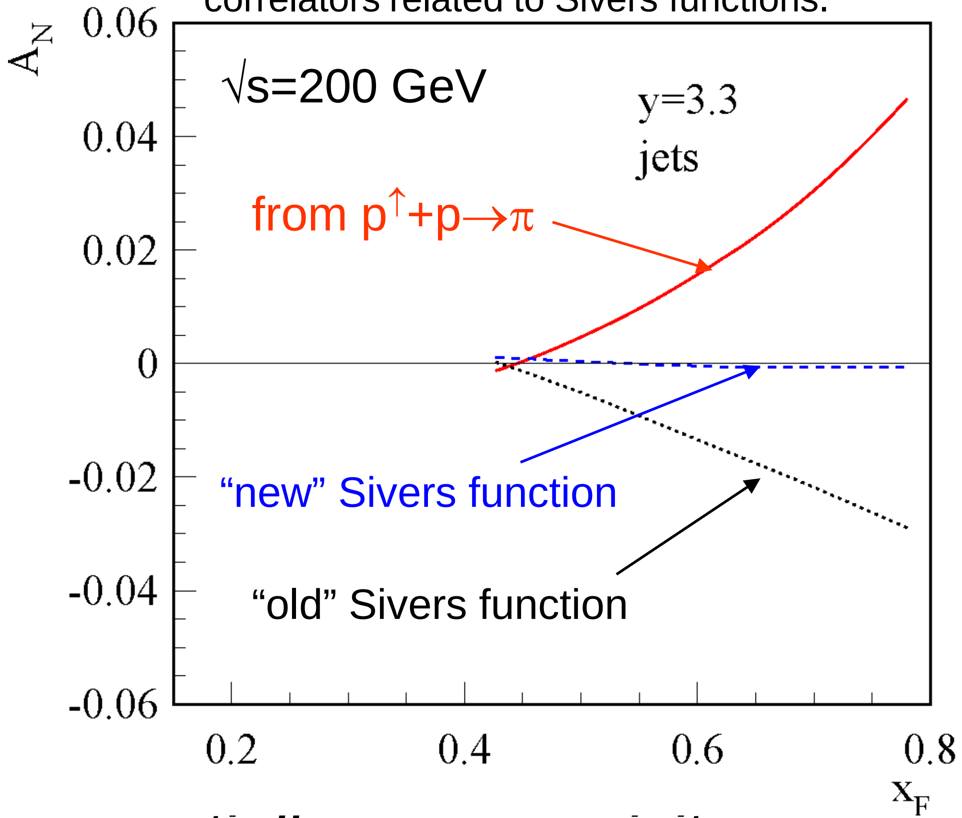
- Measure analyzing power for large x_F jet production. Non-zero A_N required for jets if Drell-Yan production has an analyzing power. Recent theoretical work establishes intrinsic interest in the jet analyzing power measurement. (Beyond the letter of intent)

Run11 A_N(Jet)

- Sivers effect only (no Collins effect contribution)
- Need A_N(Jet) measurements before DY
- With ~10/pb & P=50%, AnDY run11 can measure A_N(Jet)



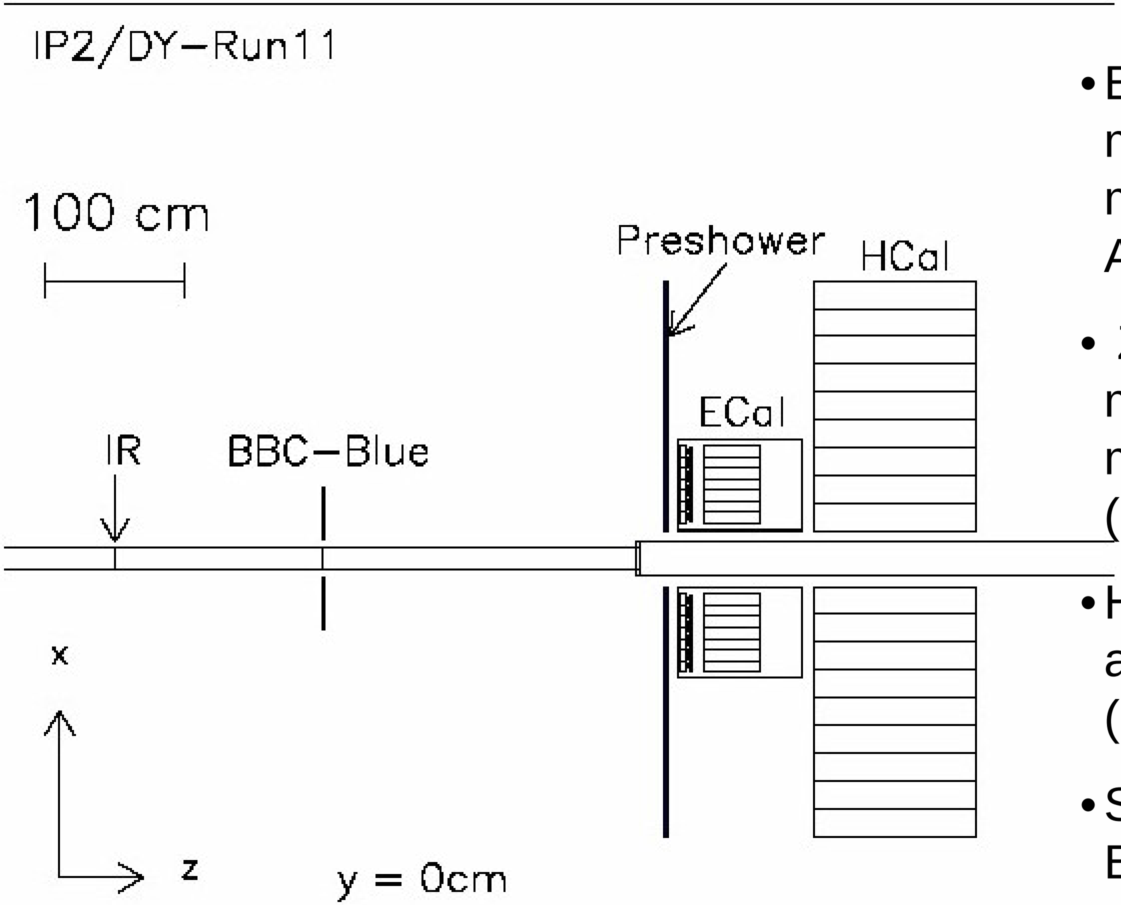
arXiv:1103.1591 jet A_N measurements are required to clarify signs of quark/gluon correlators related to Sivers functions.



Non-zero jet analyzing power essentially a prerequisite before proceeding to Drell Yan

Schematic of detector for Run-11

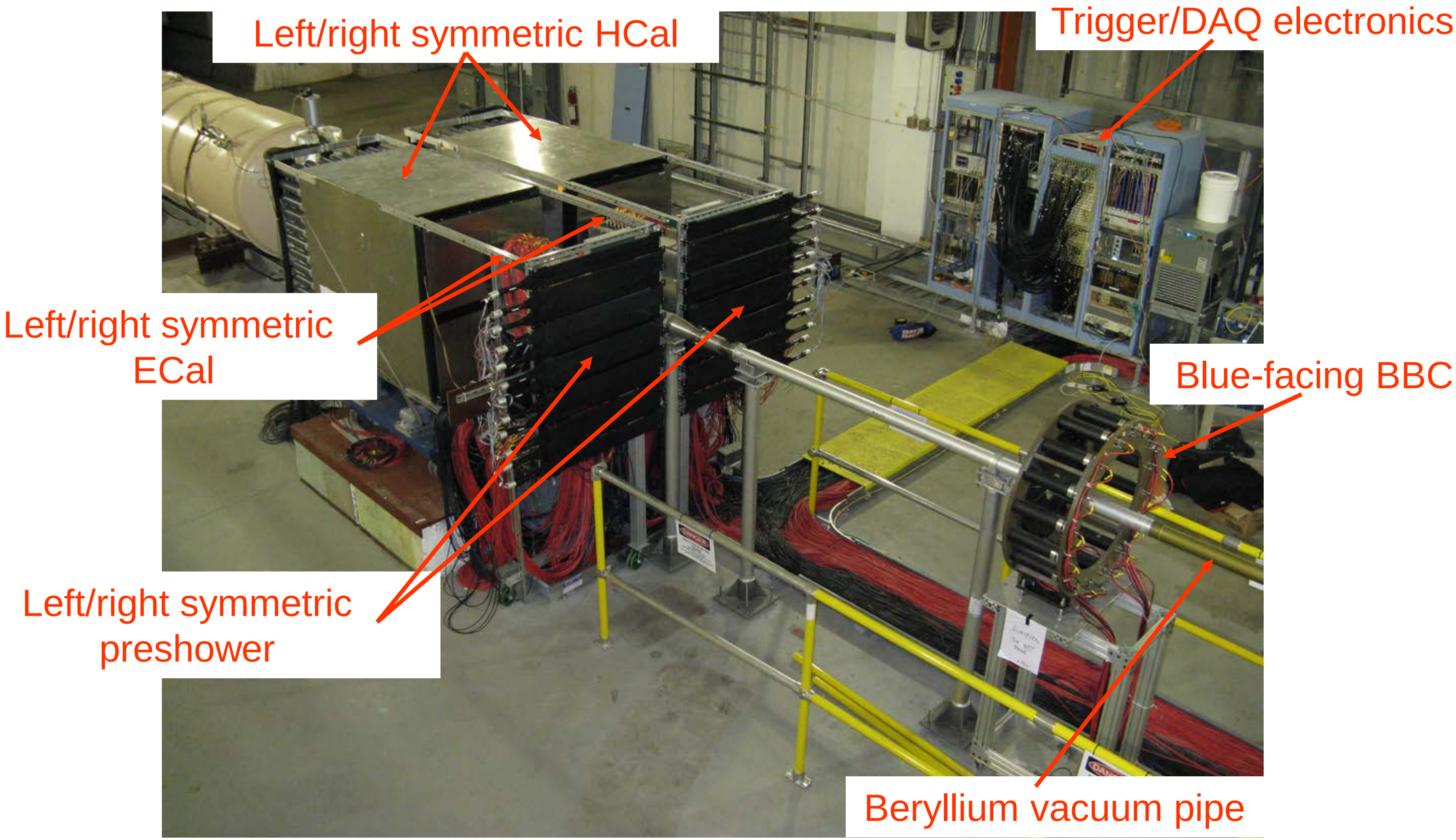
Polarized proton collisions at √s=500 GeV from February to April 2011



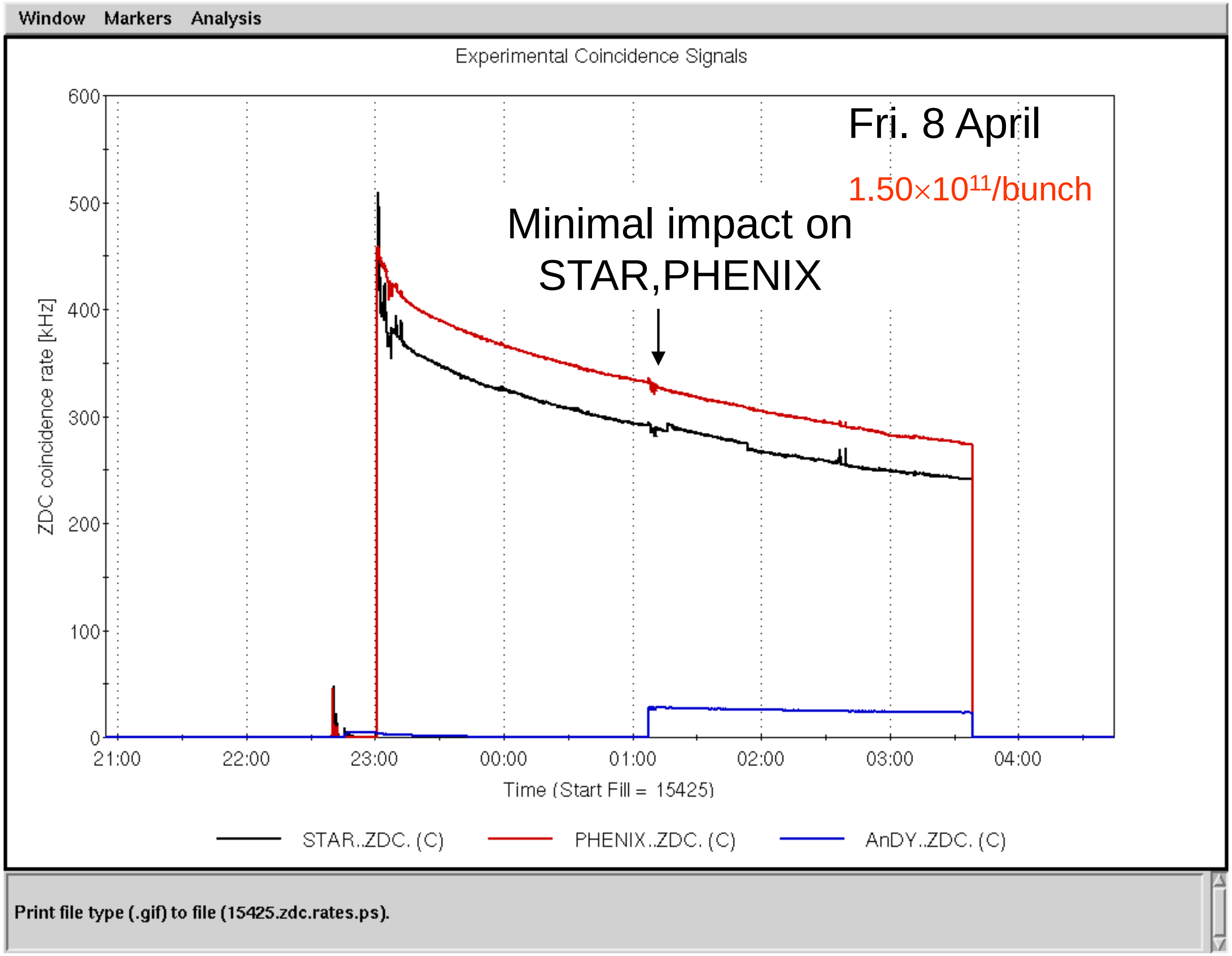
- Beam-beam counter (BBC) for minimum-bias trigger and luminosity measurement from PHOBOS [NIM A474 (2001) 38]
- Zero-degree calorimeter and shower maximum detector for luminosity measurement and local polarimetry (ZDC/ZDC-SMD, not shown)
- Hadron calorimeter modules (HCal) are 9x12 modules from AGS-E864 (NIM406,227)
- Small (~120 cells) ECal loaned from BigCal at JLab
- Pre-shower detector

13

IP2 in January, 2011

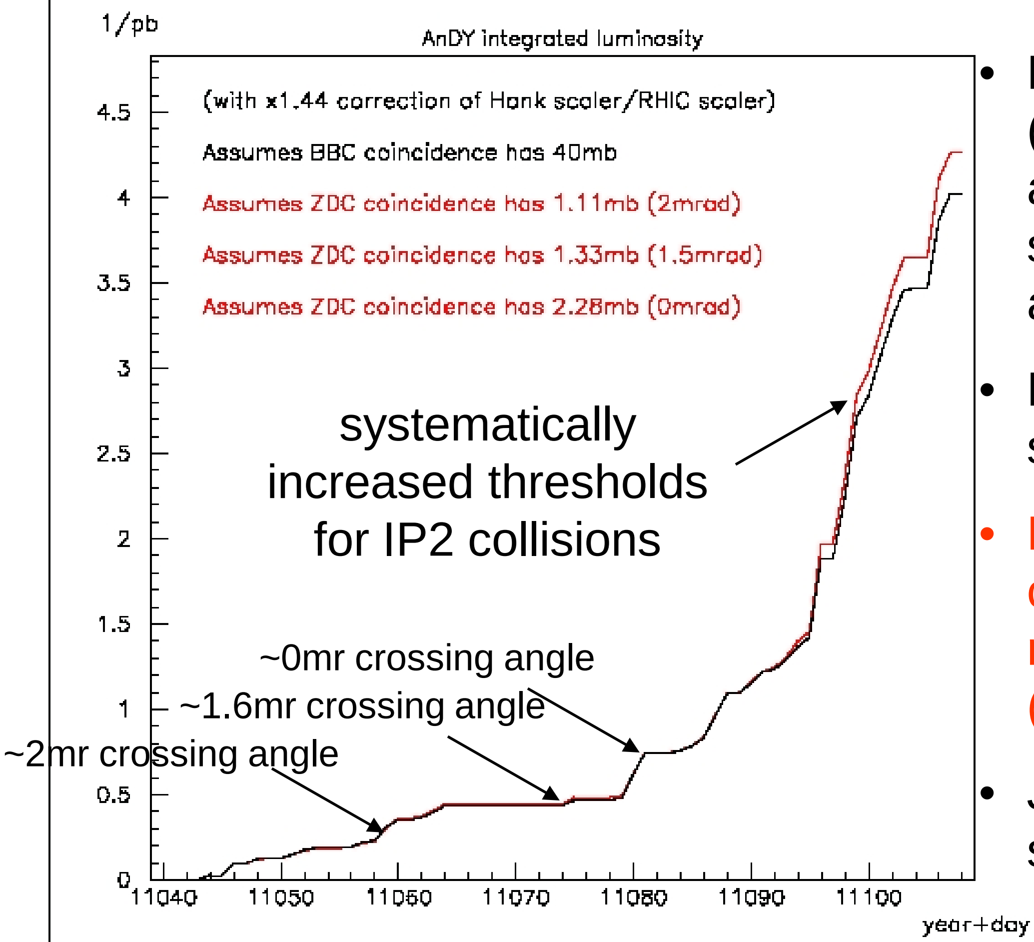


Impact of IP2 Collisions



IP2 collisions have begun <3 hours after physics ON with minimal impact on IP6,IP8

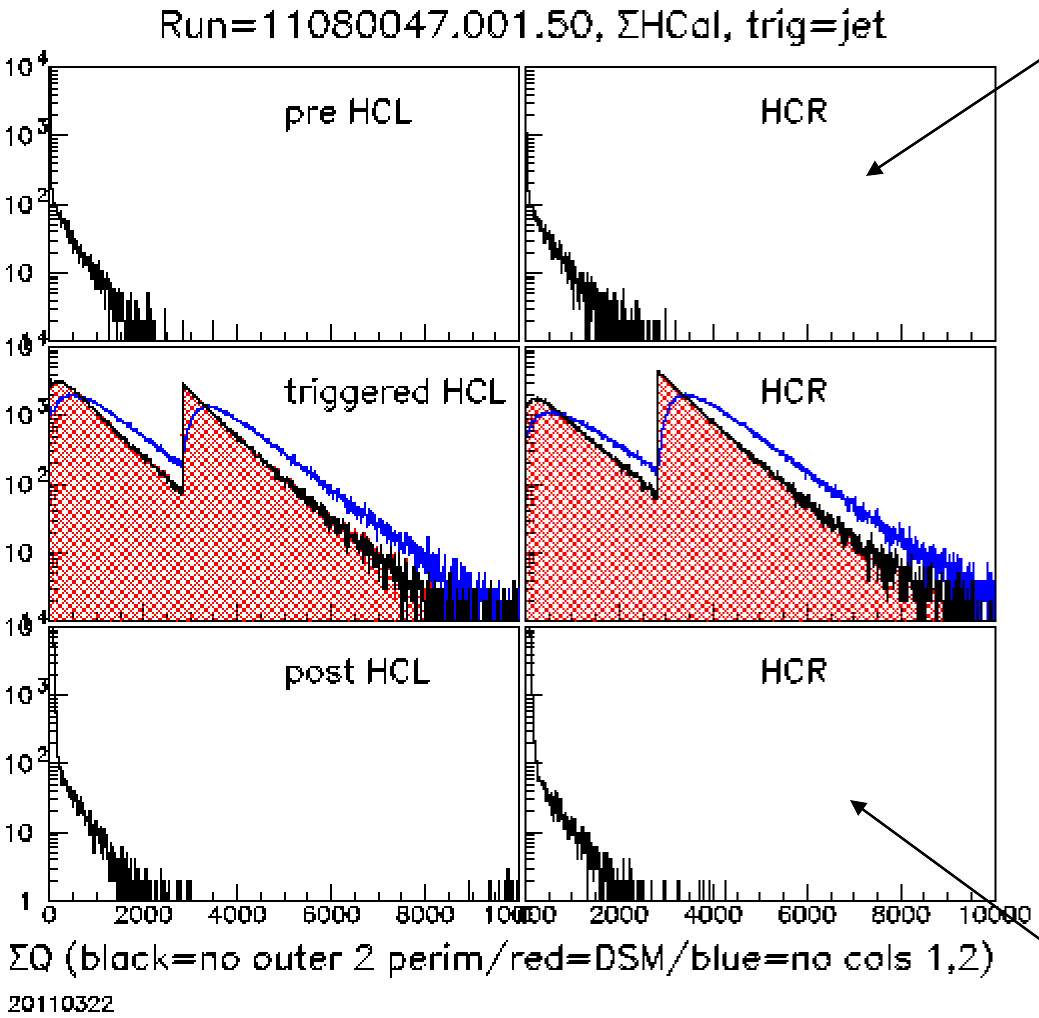
Integrated Luminosity in Run-11



- Presently, no accidentals correction (found to be large for ZDC). All rates are now scaled on bunch-crossing scalers, following 20110330 access and subsequent timing adjustments.
- Requires calibration of effective cross section for BBC via vernier scan.
- Need to reconcile assumptions about cross sections against vernier scan measurements in fill=15457 (underway)
- Jet analyzing power measurement sets goal of 10 / pb for run 11.

Many thanks to C-A for IP2 collisions

Jet Trigger

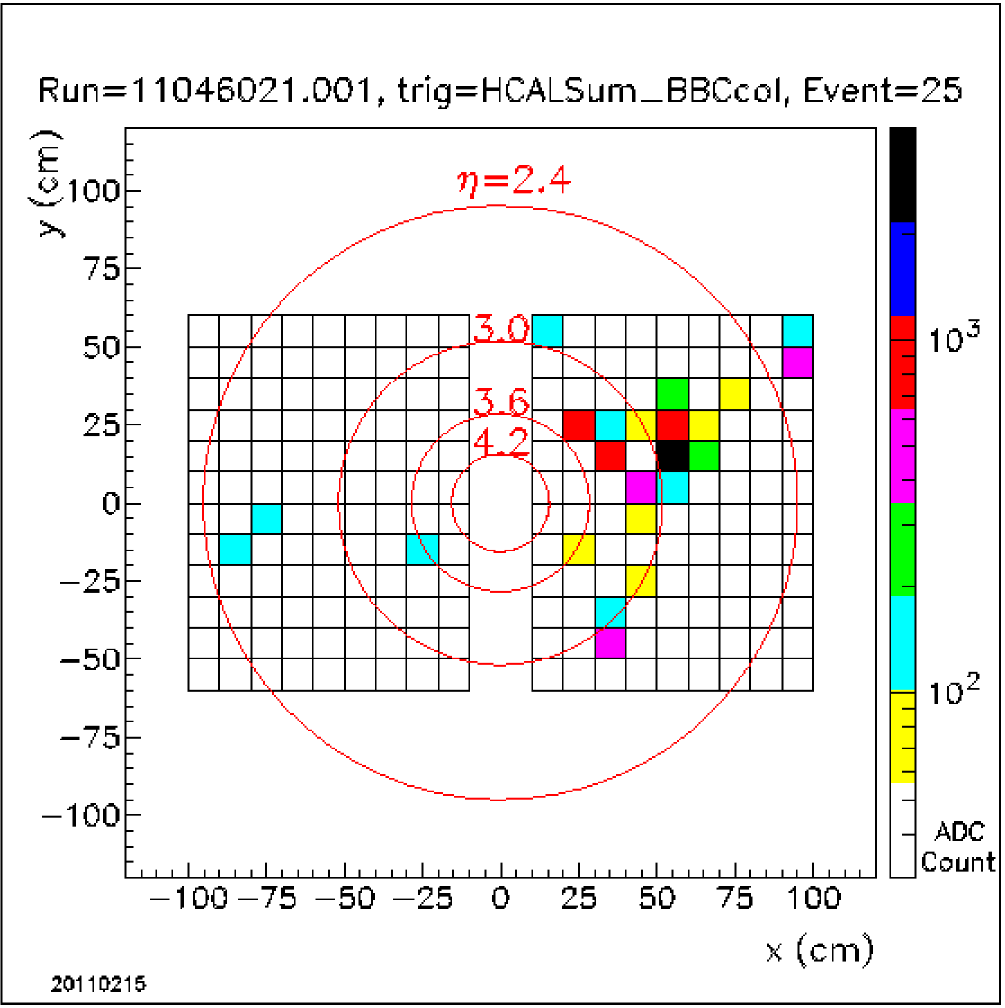


Hadron calorimeter is quiet ~107ns before jet event

- Jet trigger sums HCal response excluding outer two perimeters (rather than just two columns closest to beam)
- Definition is consistent with objective of having jet thrust axis centered in hadron calorimeter modules
- HCal energy scale is now determined

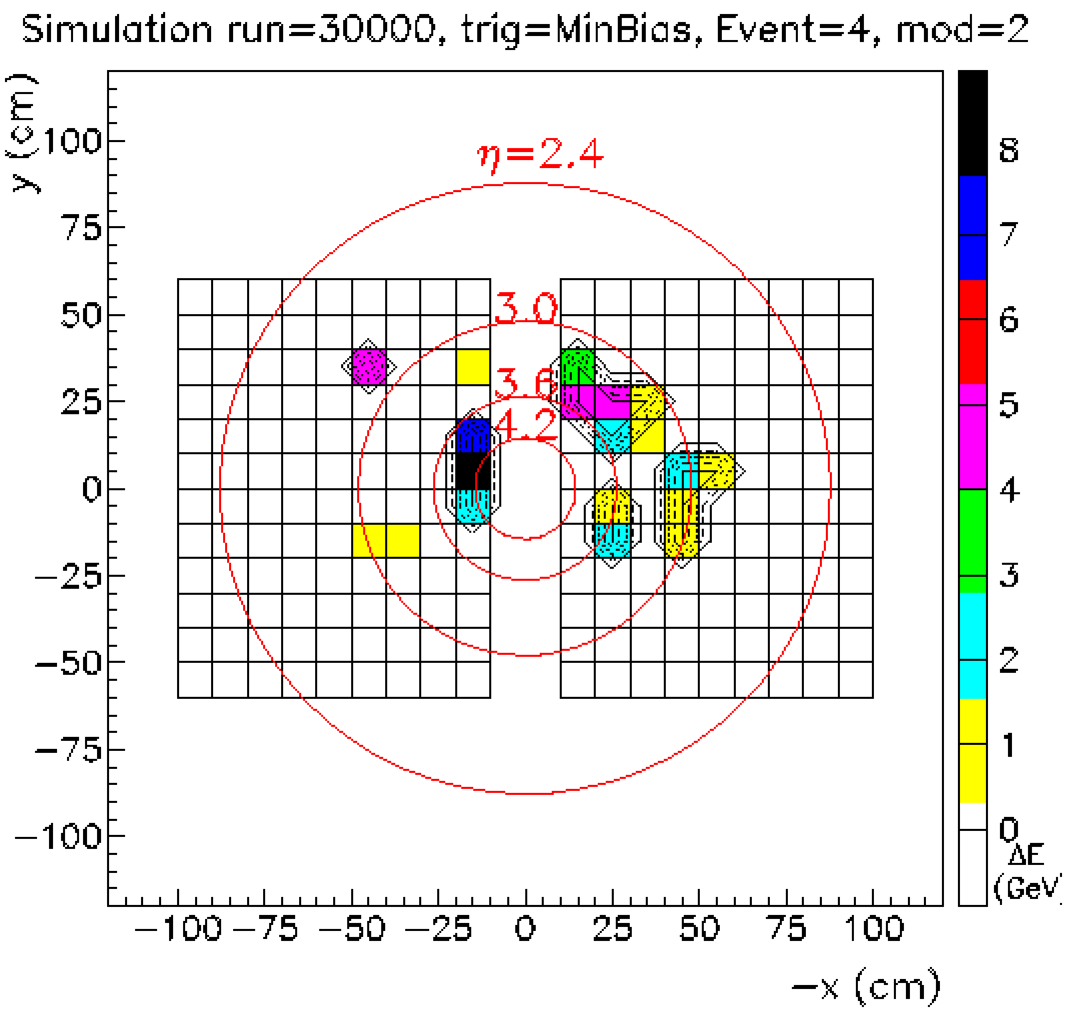
Hadron calorimeter is quiet again ~107ns after jet event

Jet Trigger Events



- Select from jet-trigger events for HCal “high-tower” to be centered in module
- Display for each detector of each module the ADC count as color scale (black=greatest count →yellow=lowest count)
- Events look “jetty”, as expected (and cosmic ray muons show expected tracks)
- In total, >750M jet events recorded during RHIC run 11.

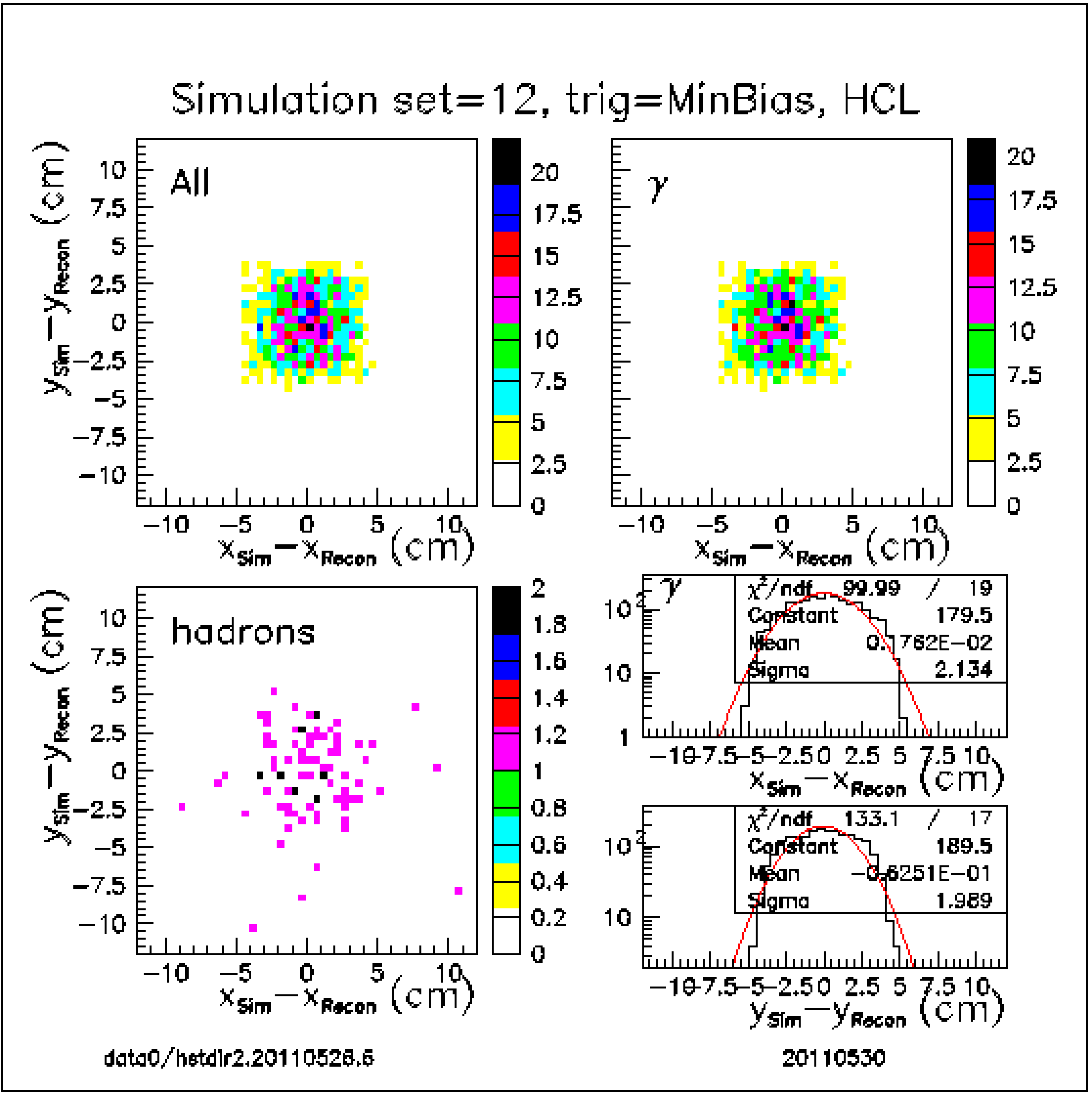
Clustering



- A cluster is a threshold-bounded set of connected detectors.
- Photons are primarily single-detector clusters
- Valid hadron showers have between 1 and ~12 detectors, although this depends on the cluster threshold
- Splitting/merging appears best with an event-dependent threshold (fraction of high-tower energy deposition)
- Find generally good agreement between data and PYTHIA/GEANT simulation

Simulated events with identified $\rho^{o} \rightarrow \pi^{+}\pi^{-}$ in acceptance

Association Results

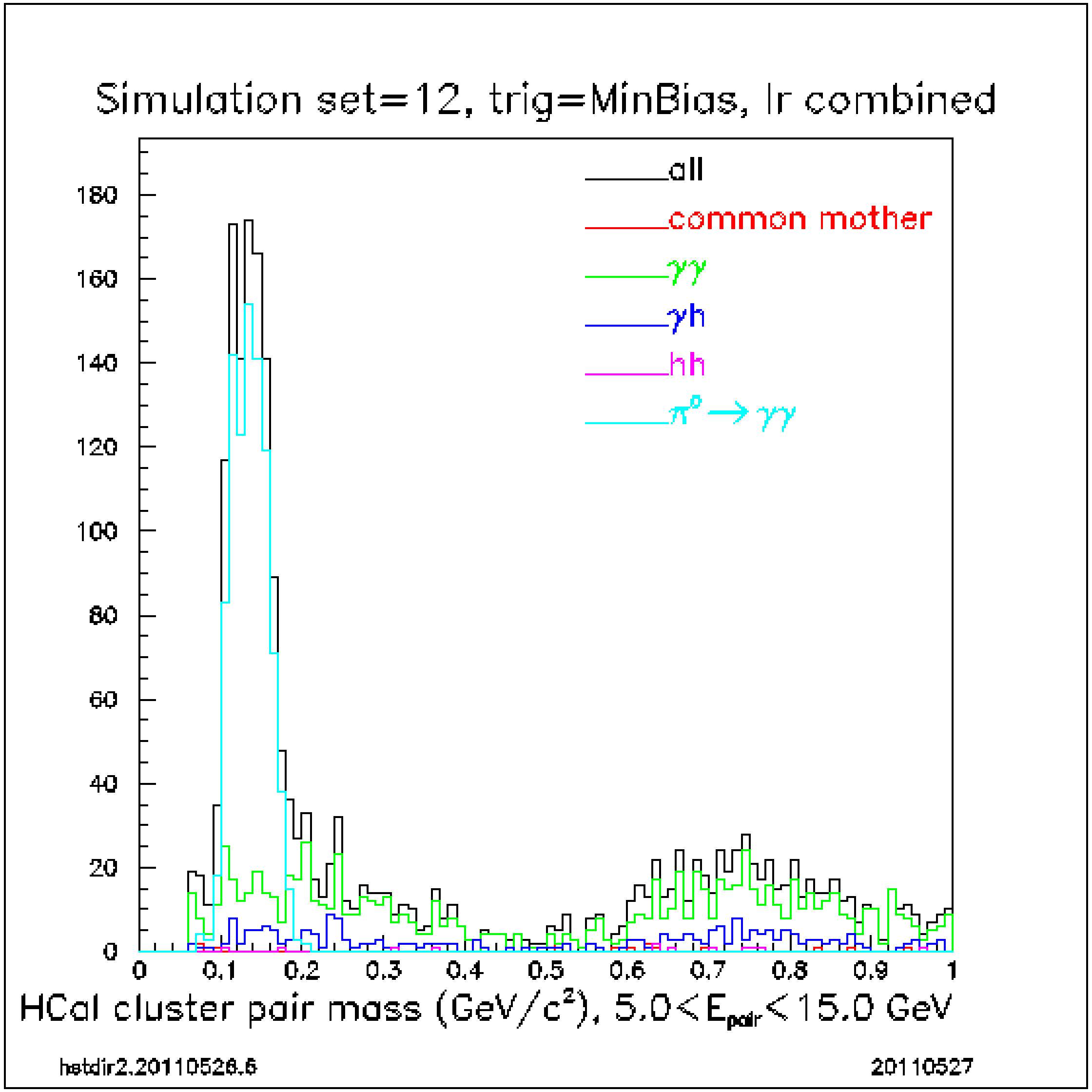


- Associations for clusters requiring: (1) 1-tower clusters; (2) E>1.8 GeV; (3) |x|>50 cm to avoid ECal shadow; (4) >1 clusters to form pairs; (5) E_{pair}>5 GeV; (6) M_{pair}<0.5 GeV; and (6) z_{pair}<0.5.

Findings…

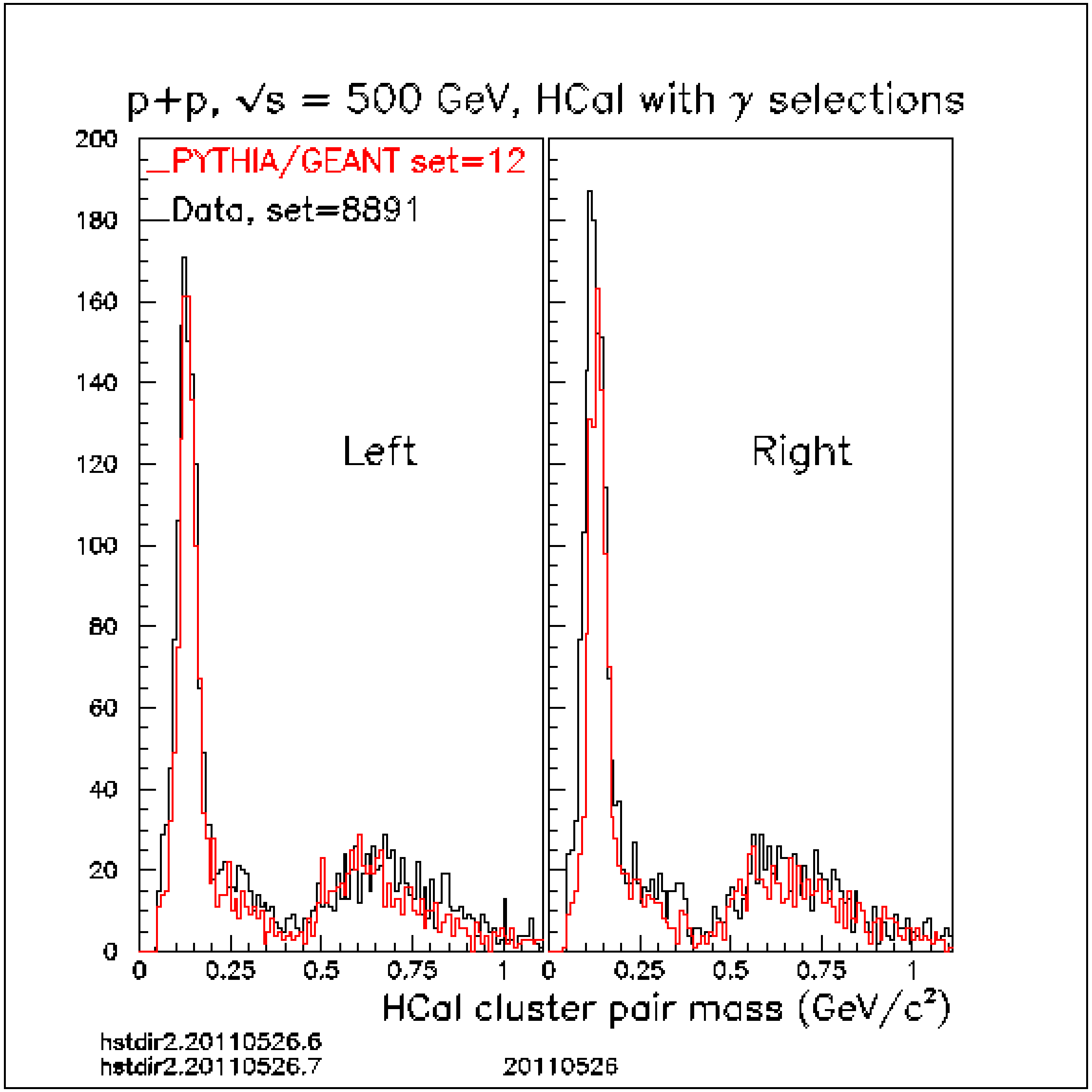
- Single-tower clusters in this energy range are dominated by photons
- Photon position resolution is ~1/5 cell-size

Pair Mass from Association



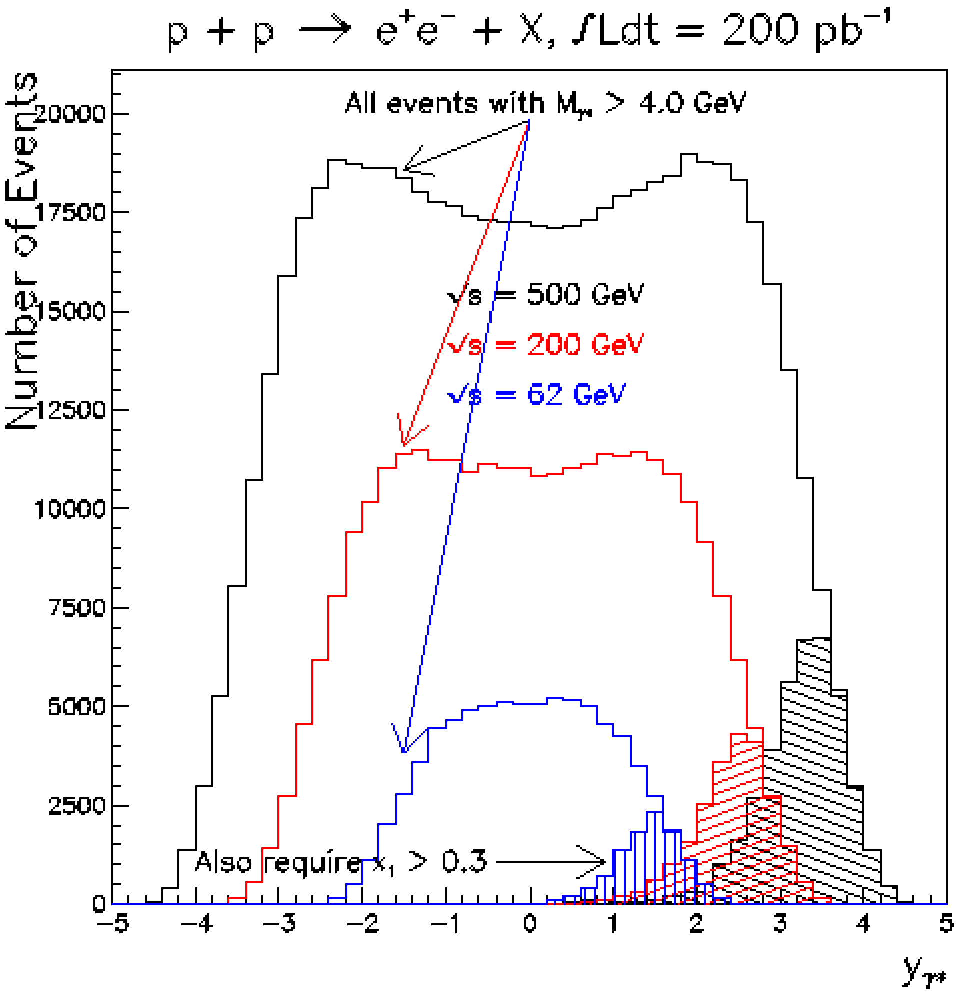
- Pair mass is computed subject to the requirements (1) 1-tower clusters; (2) E>1.8 GeV; (3) |x|>50 cm to avoid ECal shadow; (4) >1 clusters to form pairs; (5) E_{pair}>5 GeV; (6) M_{pair}<0.5 GeV; and (7) z_{pair}<0.4.
- The association analysis then allows identification of the origin of the clusters: i.e., $\pi^0 \to \gamma\gamma$ pairs; $\gamma_1\gamma_2$ combinatoric background; γh combinatoric background; etc.
- 916/1245 events with M_{pair}<0.22 GeV/c^2 are from $\pi^0 \to \gamma\gamma$ pairs

Data/Simulation Intercomparison



- require: (1) 1-tower clusters; (2) E>1.8 GeV; (3) |x|>50 cm to avoid ECal shadow; (4) >1 clusters to form pairs; (5) E_{pair}>5 GeV; (6) M_{pair}<0.5 GeV; and (7) z_{pair}<0.5.
- Apply to 20M BBCcol events in runs 11088023, 11088031, 11088039, 11088047, 11090004, 11091003, 11091015
- Apply to 20M PYTHIA events subjected to BBC charge sum trigger emulation (no vertex cut)
- Hadronic response also under study with prospects for $\rho \to \pi^{\pm}\pi^{0}$ and $\omega \to \pi^{+}\pi^{-}\pi^{0}$ to correct h/γ differences

Collision Energy Dependence of Drell Yan Production



Comments…

- partonic luminosities increase with √s
- net result is that DY grows with √s
- in any case, largest √s probes lowest x

⇒ Consider large-x_F DY at √s=500 GeV

$$\text{large } x_F \Rightarrow x_1 \approx x_F \text{ and } x_2 \approx \frac{M^2}{x_F s}$$

⇒ Forward DY production probes valence region for "beam" and $x_2 \approx 10^{-4}$ for "target" for √s=500 GeV (M>4 GeV/c^2)

Transverse Spin Drell-Yan Physics at RHIC (2007)

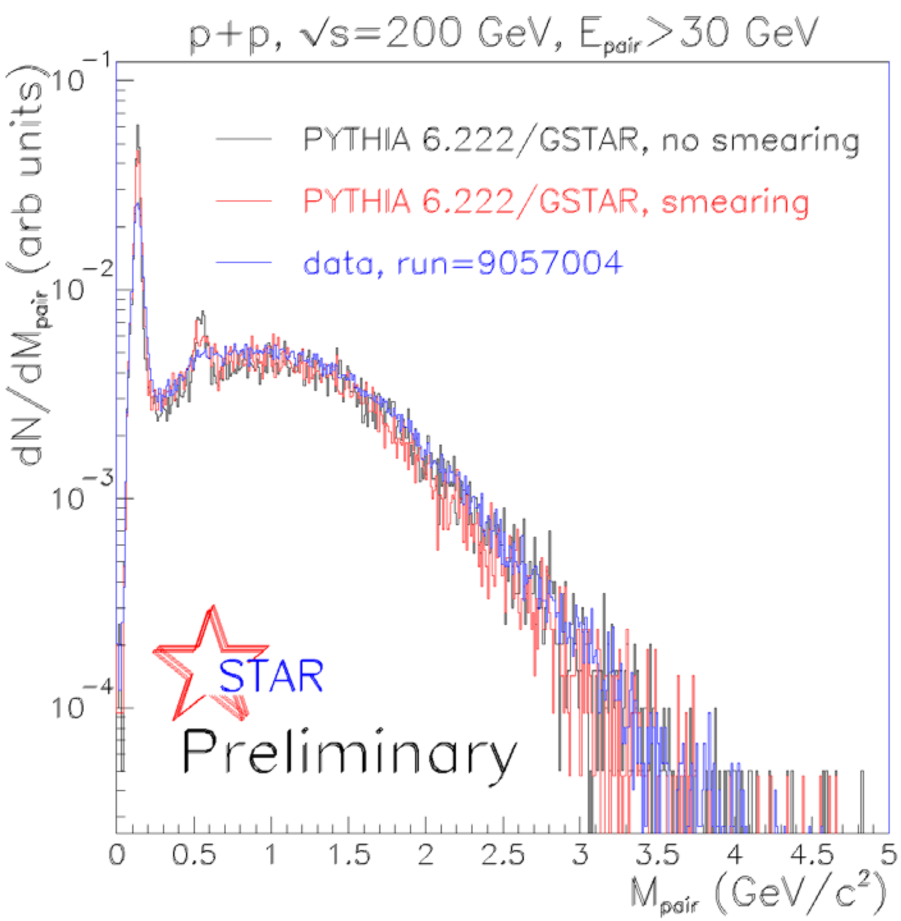
http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf

Requirements for DY

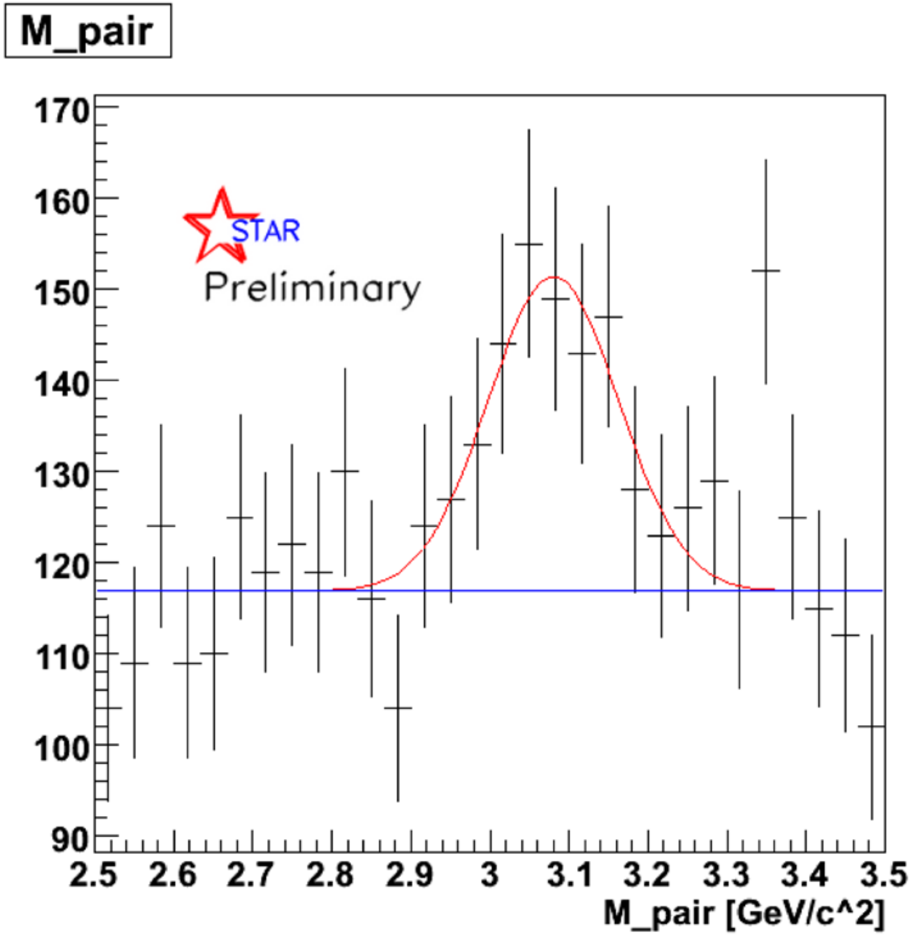
- Luminosity

- Background Reduction
  - electron/hadron discrimination / Q. What hadronic suppression required?
  - Charged/Neutral discrimination and photon conversion background
  - Open heavy flavor (c,b) production
  - Is charge sign discrimination required for like-sign pair subtraction?

Pair mass from bare EMcal



arXiv:0906.2332



arXiv:0907.4396

- pair mass backgrounds well modeled
- J/ψ→e+e- observation at $\langle x_F \rangle \sim 0.67$ emboldens DY consideration

Previous Work

p+p DY at ISR, √s=53,63 GeV
Phys. Lett. B91 (1980) 475

STUDY OF MASSIVE ELECTRON PAIR PRODUCTION AT THE CERN INTERSECTING STORAGE RINGS

C. KOURKOUMELIS and L.K. RESVANIS
University of Athens, Athens, Greece

T.A. FILIPPAS and E. FOKITIS
National Technical University, Athens, Greece

A.M. CNOPS, J.H. COBB [1], R. HOGUE, S. IWATA [2], R.B. PALMER, D.C. RAHM, P. REHAK and I. STUMER
Brookhaven National Laboratory [3], Upton, NY, USA

C.W. FABJAN, T. FIELDS [4], D. LISSAUER [5], I. MANNELLI [6], P. MOUZOURAKIS, K. NAKAMURA [7], A. NAPPI [6], W. STRUCZINSKI [8] and W.J. WILLIS
CERN, Geneva, Switzerland

M. GOLDBERG, N. HORWITZ and G.C. MONETI
Syracuse University [9], Syracuse, NY, USA

and

A.J. LANKFORD [10]
Yale University, New Haven, CT, USA

Received 18 February 1980

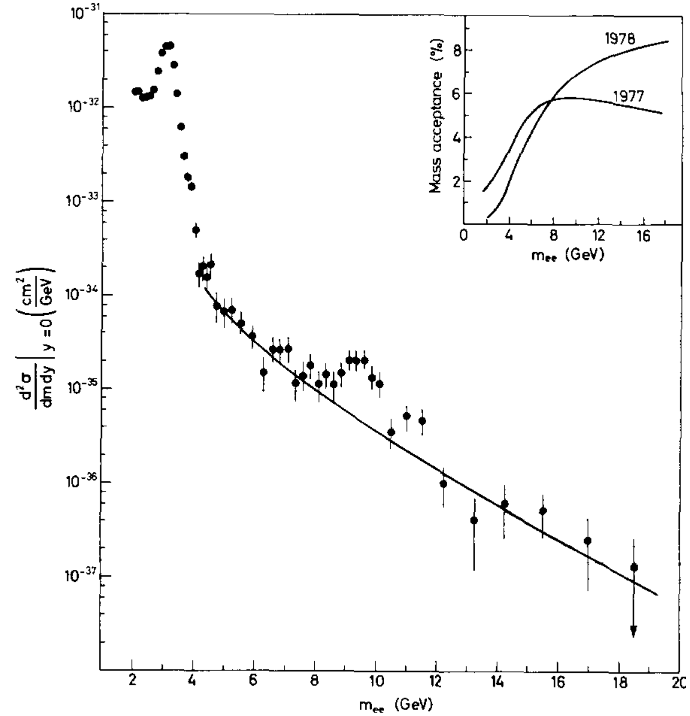


Fig. 1. The cross section $(d^2\sigma/dm\,dy)_{y=0}$ versus mass for the data at $\sqrt{s}$ = 53 and 63 GeV combined. The curve is a result of the fit to the continuum displayed in fig. 2. The inset show the mass acceptance for "1977" and "1978" triggers and geometrical configurations calculated for isotropic decay distributions and production uniform in rapidity with p_T dependence $d\sigma/dp_T^2 \sim \exp(-bp_T)$, where b = 1.4 GeV^{-1}. The mass acceptance changes by ± 15% when the helicity decay distribution follows $dN/d\cos\theta = 1 + \alpha\cos^2\theta$ when $\alpha = \pm 1$, where θ is measured in the s-channel helicity frame.

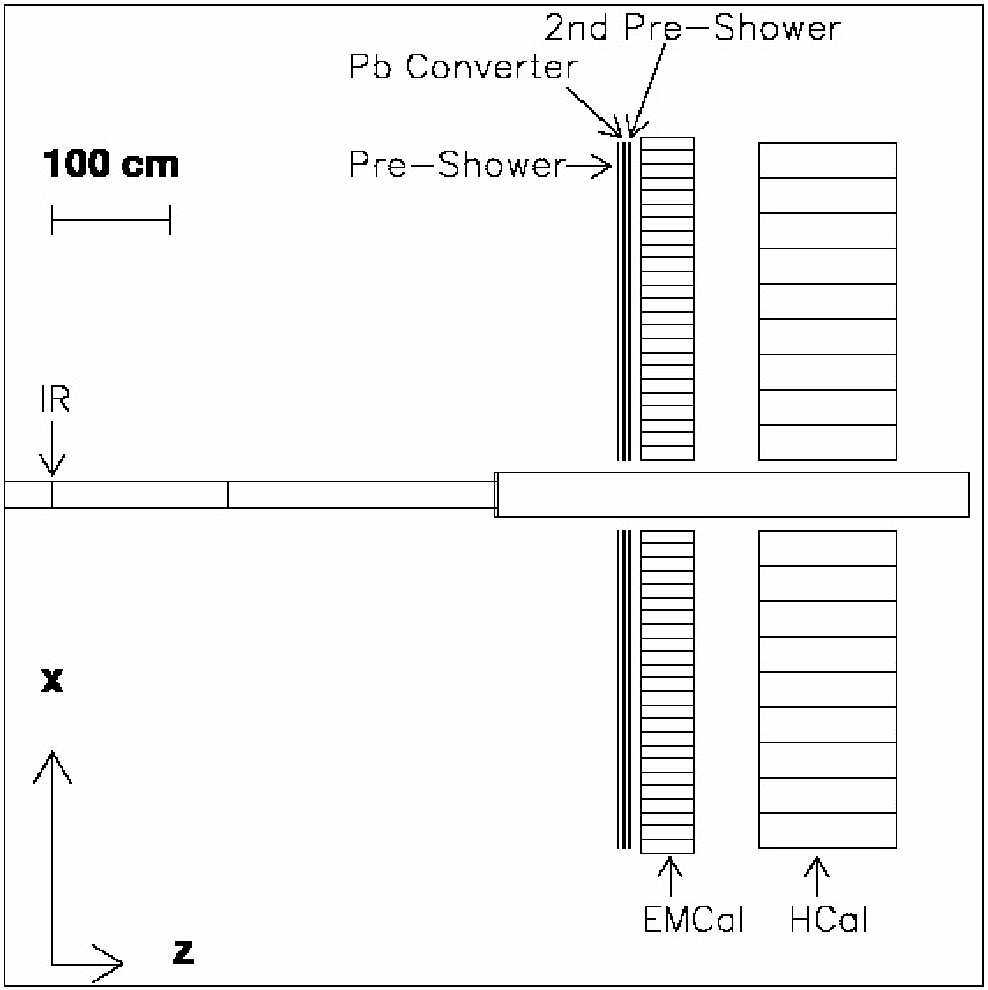
Comments (note: large x_F at collider breaks new ground)

- e+e- low-mass DY done at ISR and by UA2 [see review J.Phys. G19 (1993) D1]
- UA2 [PLB275 (1992) 202] did not use magnet / CCOR did [PLB79 (1979) 398]
- most fixed target experiments do μ+μ- DY

Schematic of detector considered

Run-12 configuration

(PHOBOS split-dipole expected to be in place, but not used)

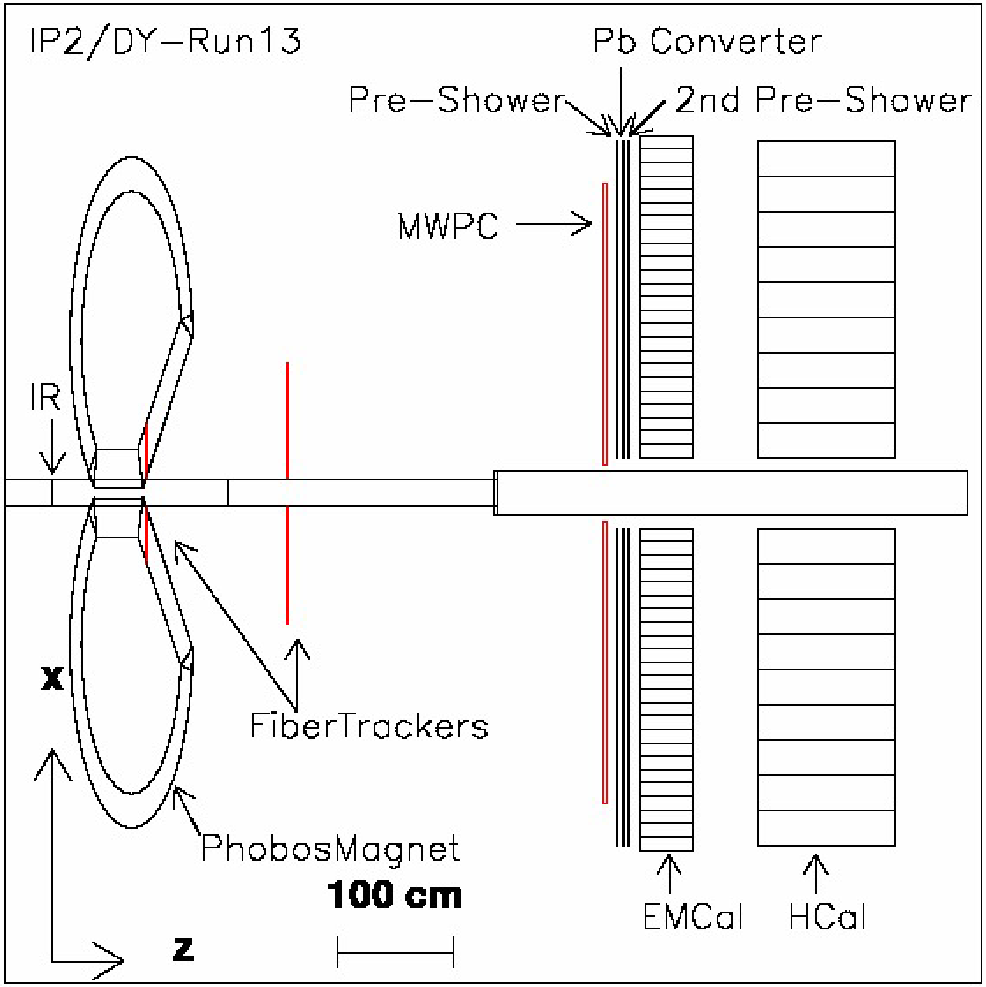


- Hcal is existing 9x12 modules from E864 (NIM406,227)
- EMcal is modeled as only $(3.8\text{cm})^2\text{x}(45\text{cm})$ lead glass
- Preshower would require construction

http://www.star.bnl.gov/~akio/ip2/topview2.jpeg

Schematic of detector considered

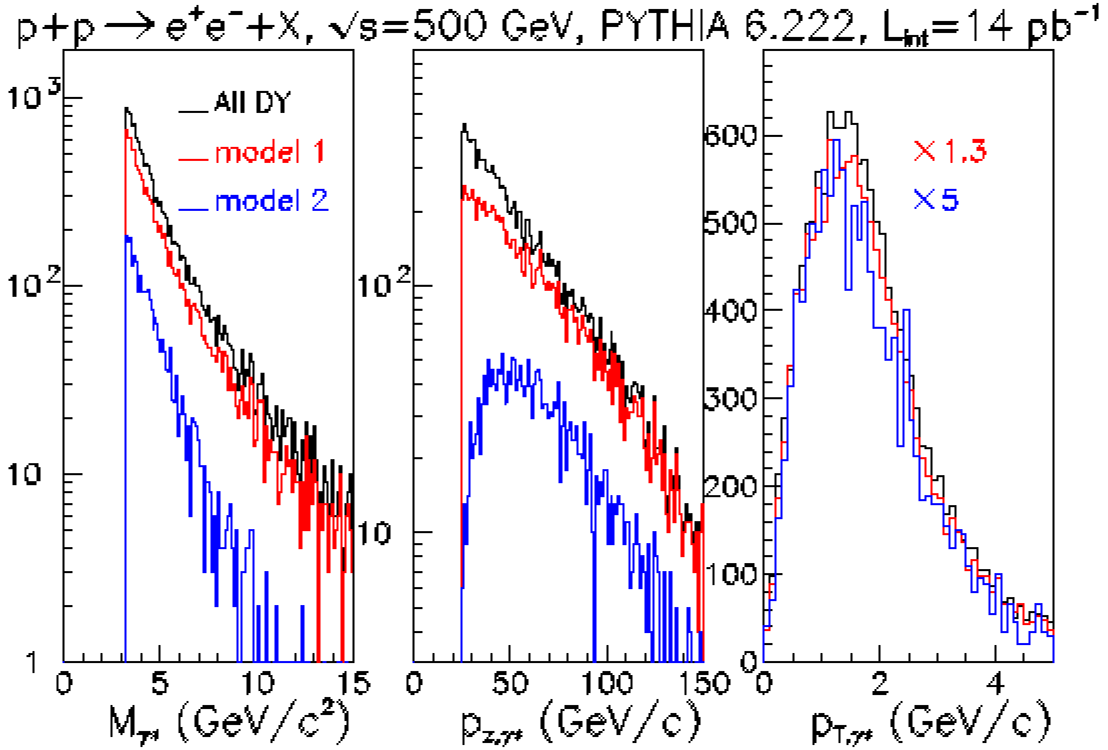
Run-13 configuration
(Uses PHOBOS Split Dipole for charge sign)



- Hcal is existing 9x12 modules from E864 (NIM406,227)
- EMcal is modeled as only $(3.8\text{cm})^2\text{x}(45\text{cm})$ lead glass
- Preshower would require construction
- PHOBOS split-dipole magnetic field in GEANT model
- Fiber tracker stations and MWPC require construction

http://www.star.bnl.gov/~akio/ip2/topview_run13.jpeg

e+e- DY expectations at large x_F at $\sqrt{s}$=500 GeV



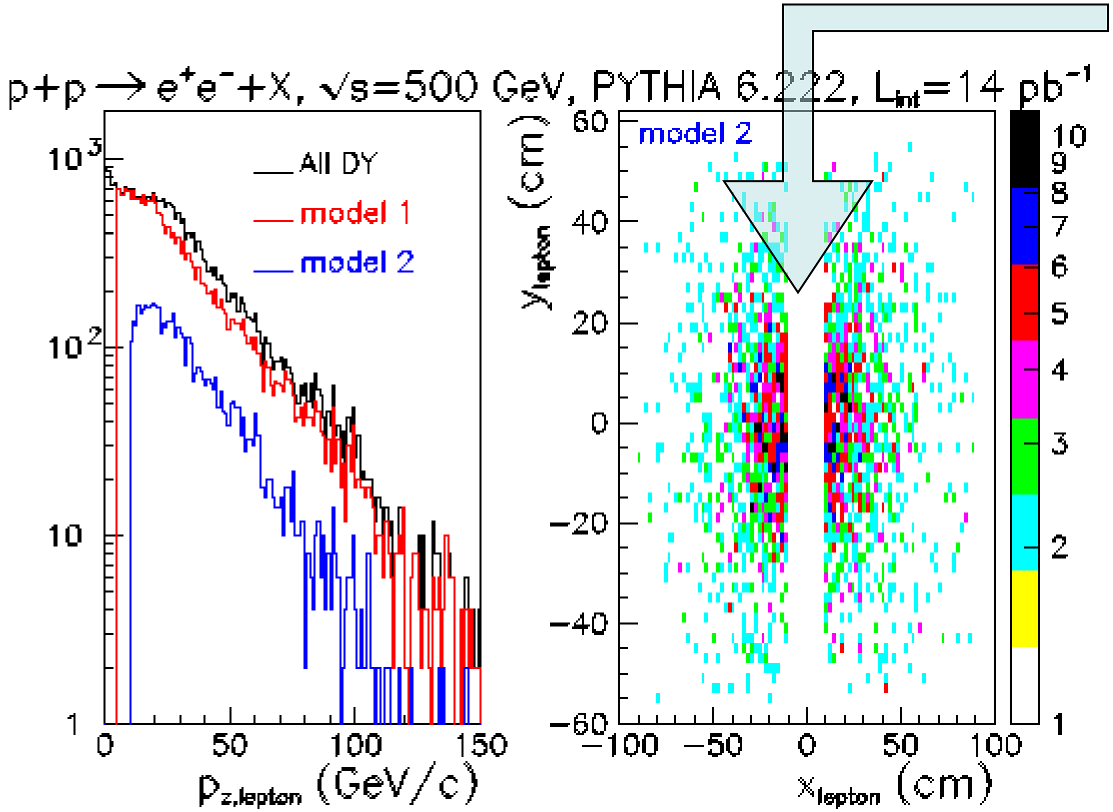
Model 1 = EMcal $(2m)^2$ / $(0.2m)^2$ beam hole at 10m / no magnetic field

Model 2 = L/R modular EMcal (0.9mx1.2m) at 5m / no magnetic field

Comments…

- reasonable efficiency can be obtained for large-x_F DY with existing equipment
- final estimates of DY yield must follow estimates of background rejection
- critical question for decadal planning: is charge sign discrimination required?

Lepton daughters from γ^*

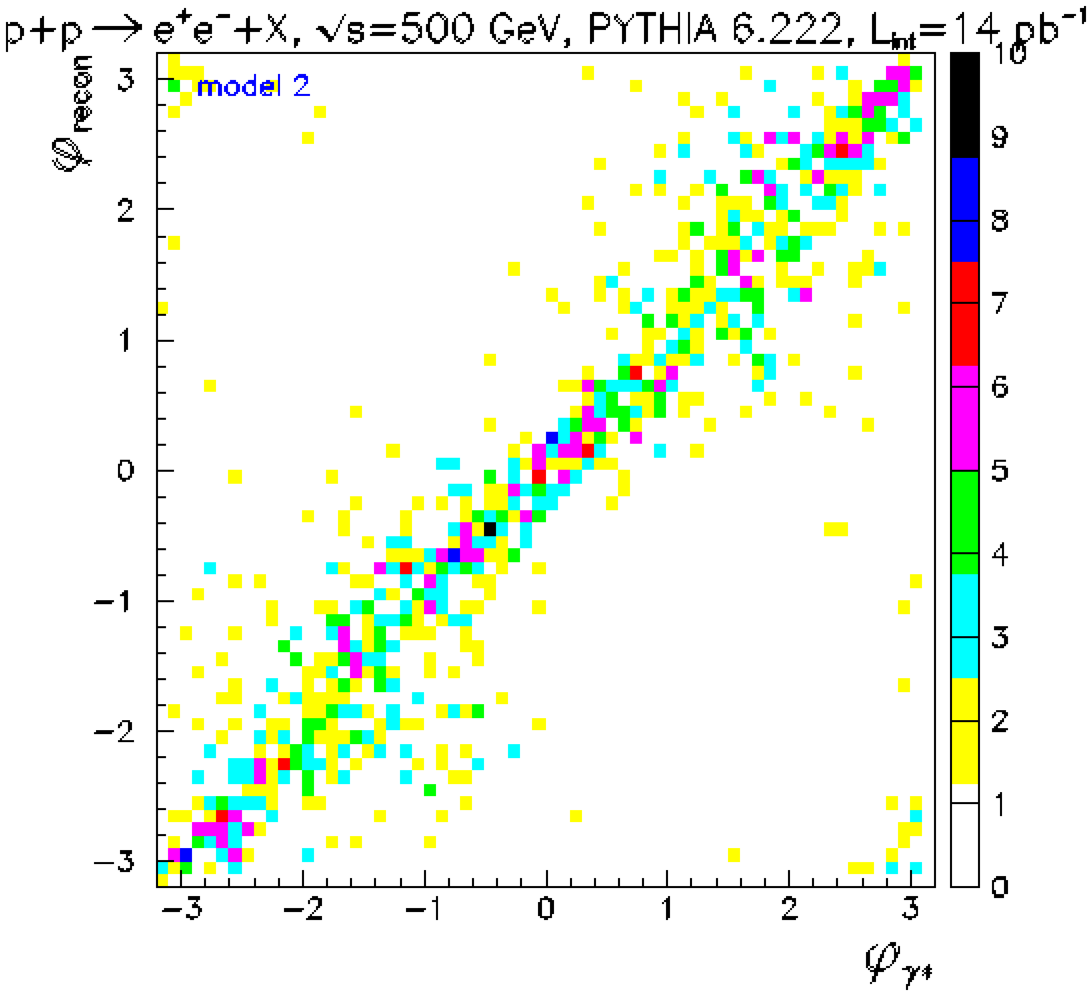


Model-1 acceptance is increased by closing gap between halves

Most important contributions for γ^* x_F>0.1 at $\sqrt{s}$=500 GeV …

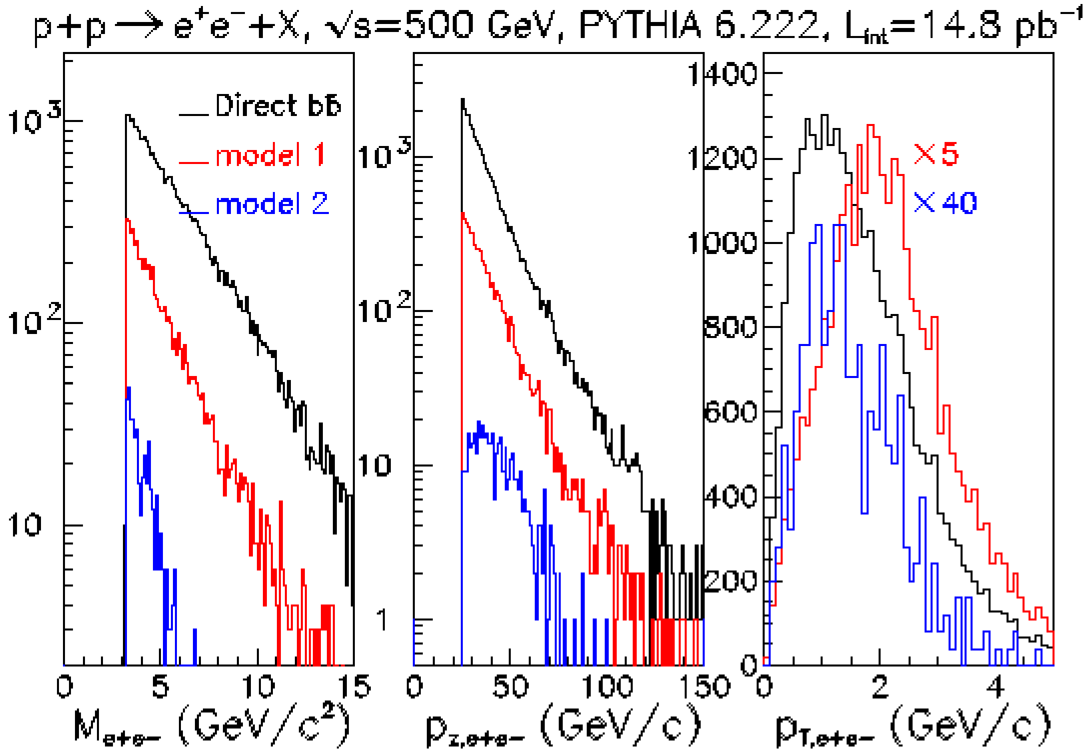
- high energy electrons and positrons (E>10 GeV)
- require detection at very forward angles
- e+(e-) from γ^* little affected by "modest" isolation (20mr half-angle cone)
- best solution for charge sign would be a dipole magnet (difficult for any collider)

Azimuthal angle for $\gamma^* \rightarrow e+e-$



- e+ and e- in separate modules except when γ^* has large p_T
- Azimuthal angle required for analyzing power measurement
- Resolution is primarily from measuring energies of e+ and e-
- Model 2 covers full azimuth despite modular coverage

Dileptons from open beauty at large x_F



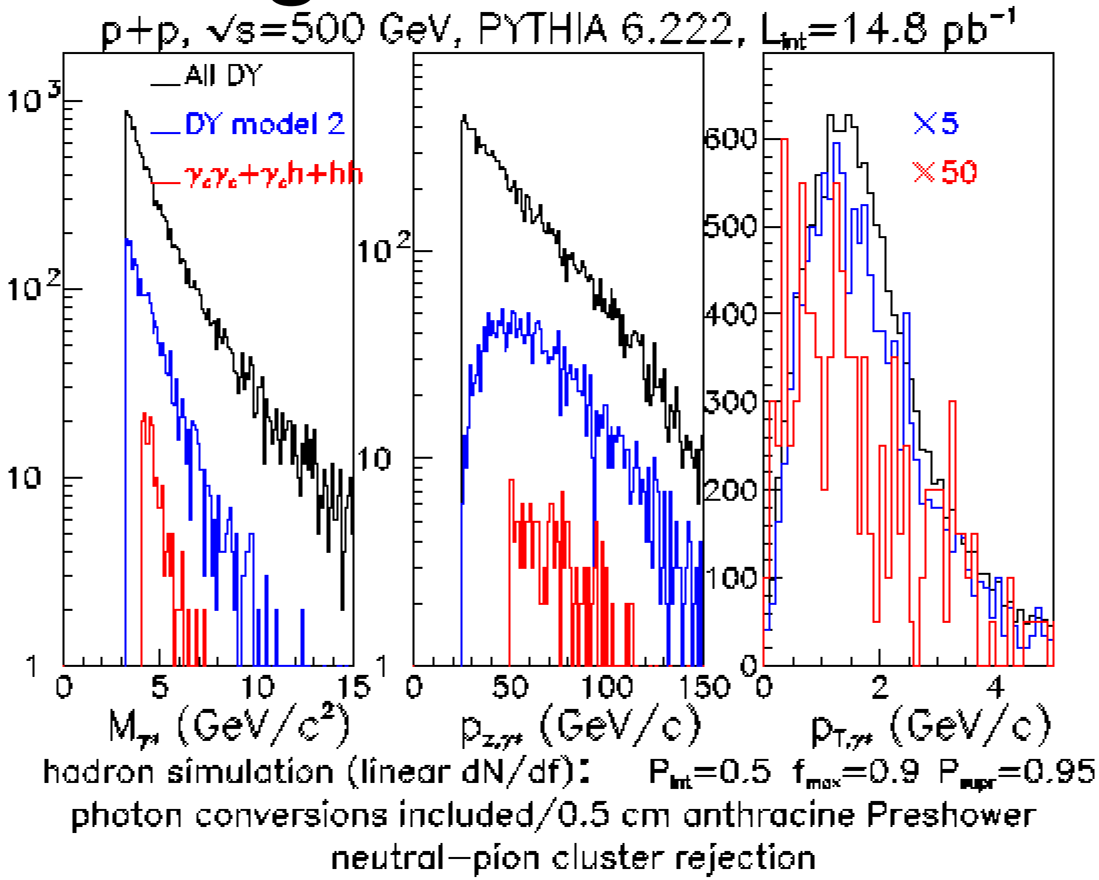
Model 1 = EMcal $(2m)^2$ / $(0.2m)^2$ beam hole at 10m / no magnetic field

Model 2 = L/R modular EMcal (0.9mx1.2m) at 5m / no magnetic field

Comments…

- open beauty dileptons are a background 2x larger than DY for PHENIX $\mu+\mu-$
- direct production of open beauty results in ~15% background at large x_F
- large forward acceptance for the future would require discrimination (isolation)

Background Estimate

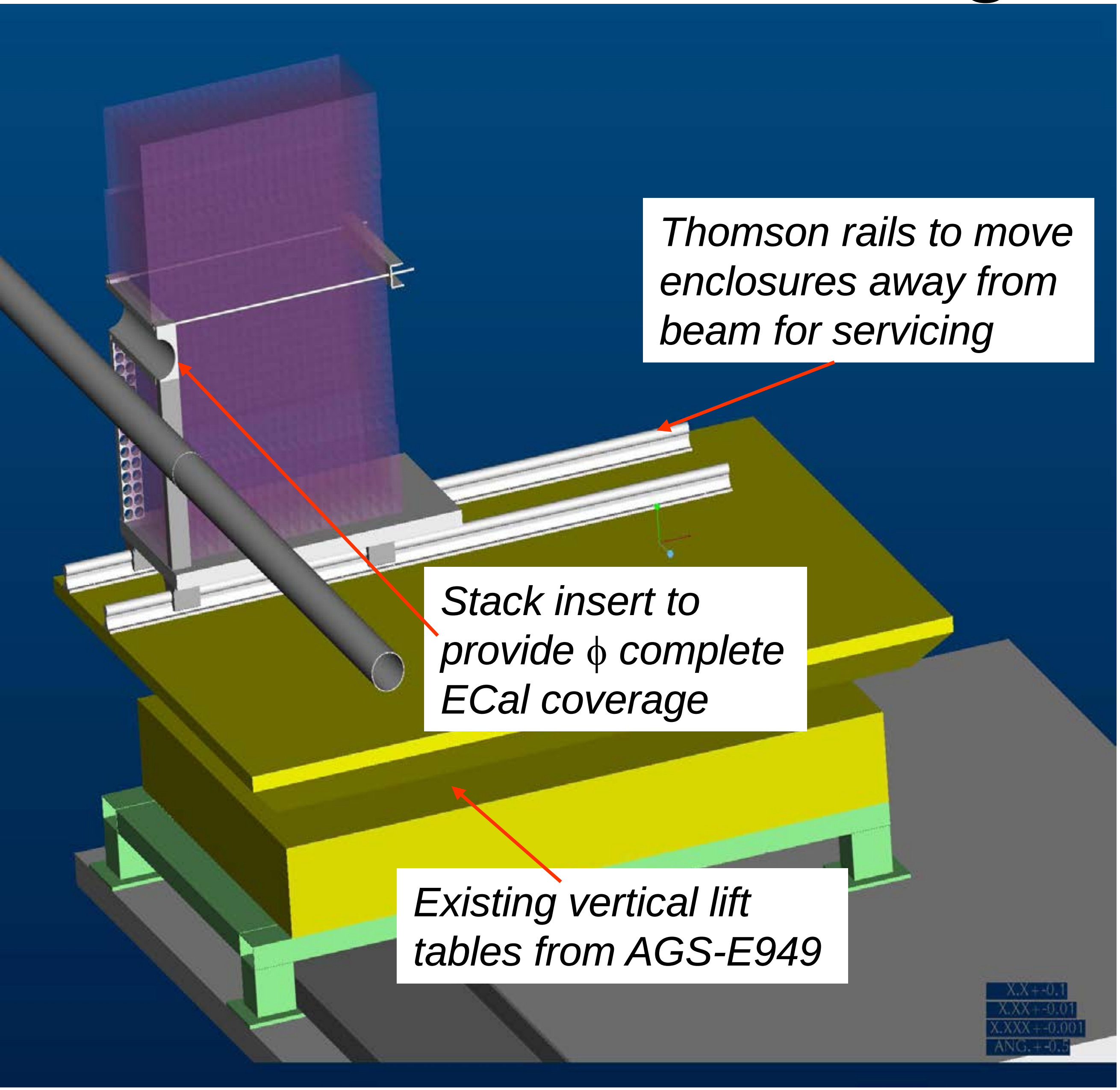


Comments:

- Conversion photons significantly reduced by $\pi^0 \rightarrow \gamma\gamma$ veto
- Preshower thickness tuned, although perhaps is not so critical given photon veto
- Linearly decreasing dN/df (fast-simulation model for hadronic response of ECal) estimates smaller hadronic background $\Rightarrow$ increased sophistication needed for reliable estimates, although other model uncertainties could easily dominate.

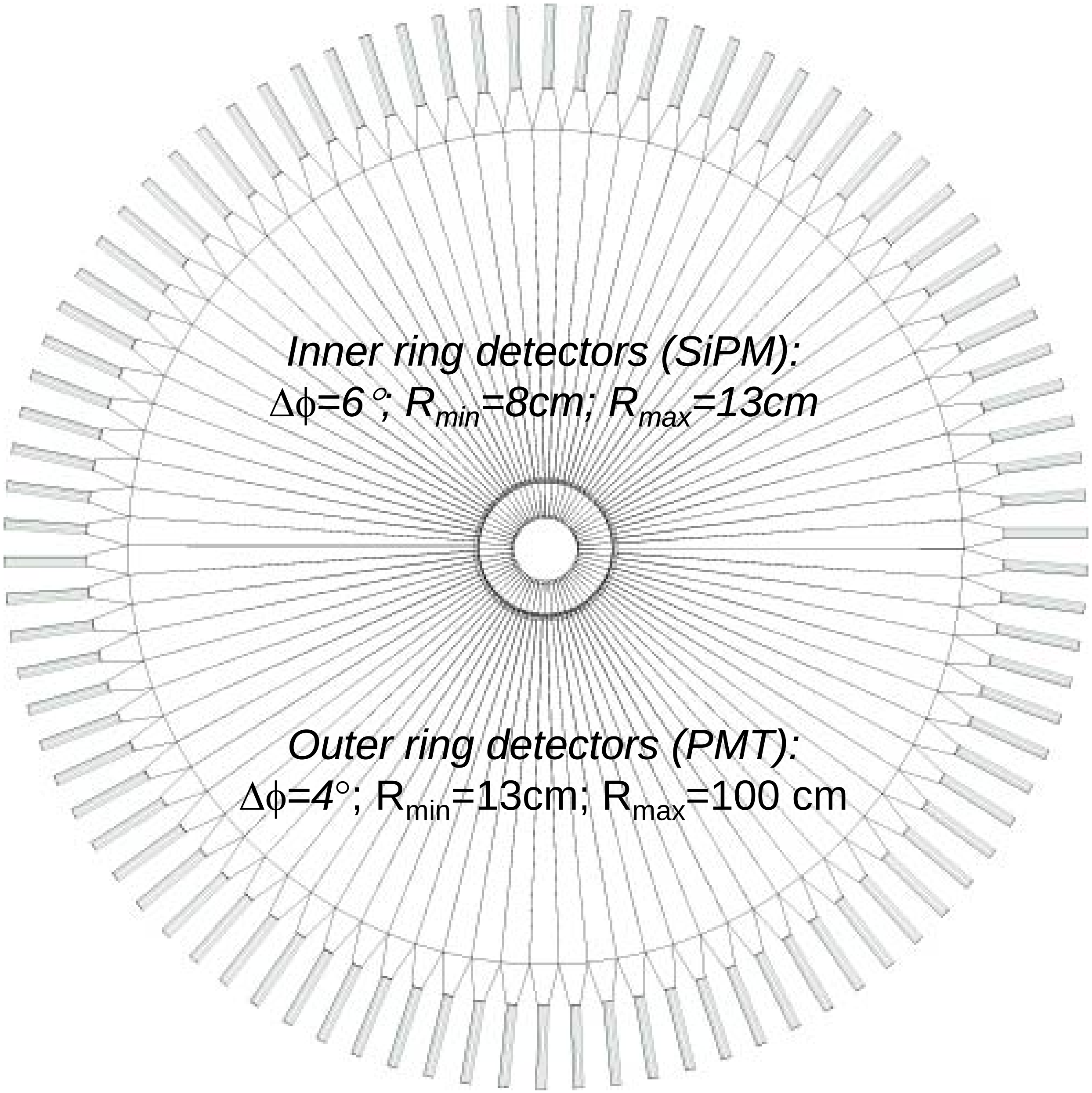
C. Folz

ECal Design for Run 12



- *Major mechanical design for ECal installation in IP2 well advanced by C. Folz.*
- *Enclosure and cable management plans underway following visit to JLab/BigCal on 17 May.*
- *Plans for BigCal unstacking/packing also well developed, with goal of completed relocating of BigCal to BNL prior to end of July.*
- *Azimuthal coverage of ECal design is closer to "model 1" acceptance, thereby reducing L_{int} requirements for 10K DY events*

Preshower Detector Concept for Run 12



- *e /h/γ discrimination relies heavily on preshower detectors (PSD) and converter for longitudinal shower profiling*
- *particle multiplicity for p+p collisions at $\sqrt{s}=500$ GeV requires segmented PSD to realize $e^{\pm}/h/\gamma$ discrimination*
- *Loan of 400 XP2972+CW bases for outer ring PSD keeps project costs within original estimates*
- *Use SiPM for inner ring detector for low mass readout*
- *Separated halves to allow mounting to ECal halves*

J. Engelage, H.J. Crawford

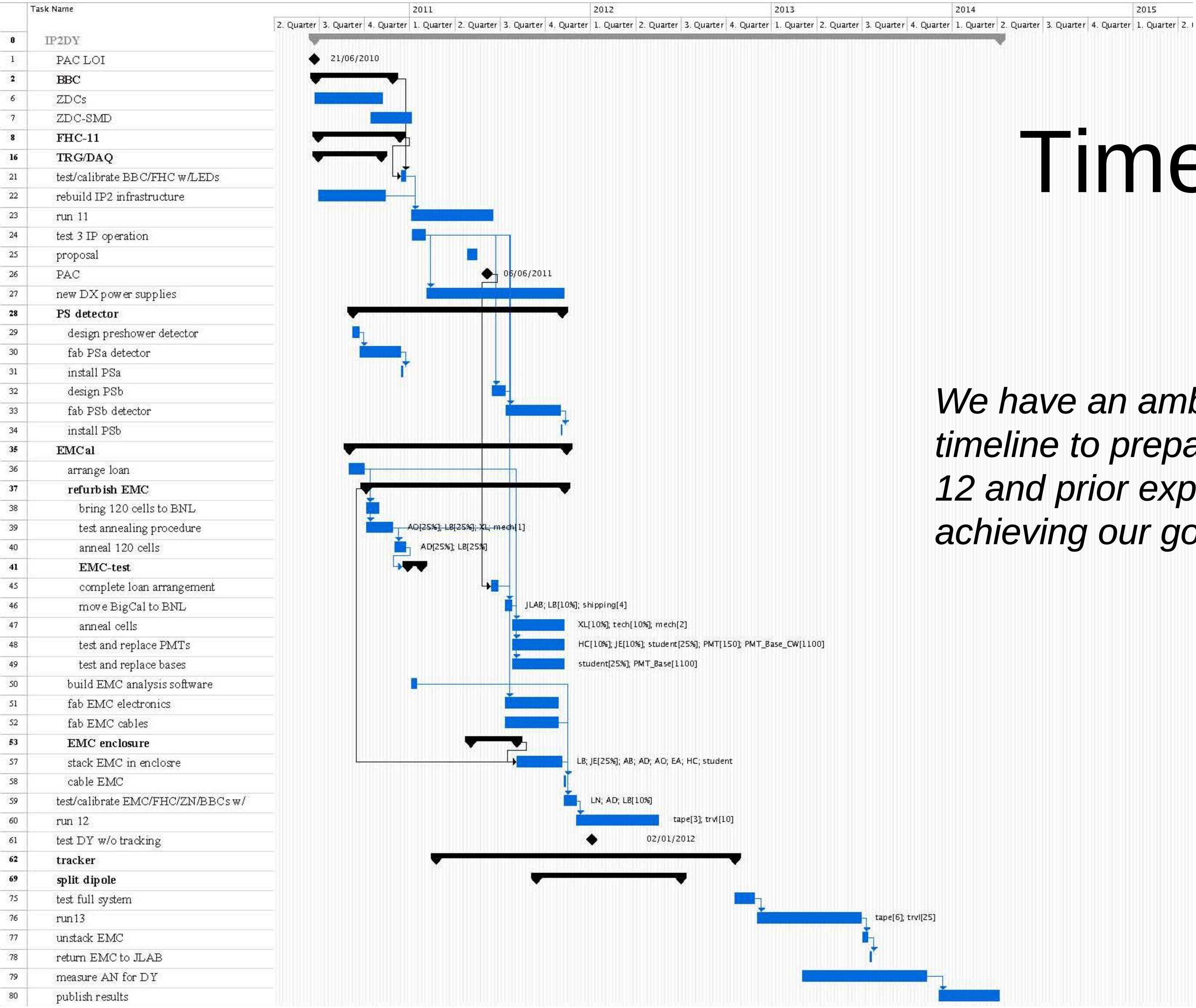
Run-12 Project Responsibilities

ECal project

- *Unstacking/packing – Brash, Perdrisat, Punjabi*
- *Design – Folz*
- *Detector preparations/stacking – Li, Simatovic, Minaev, Abrahamyan, Bland, Ogawa*
- *Cable orders – Engelage*
- *HV – Crawford*
- *Electronics – Crawford, Engelage, Perkins*
- *Integration/testing – Perkins, Bland, Ogawa*

Preshower project

- *Design – Folz, Engelage*
- *Scintillator order – Bland, Crawford*
- *SiPM and PMT – Crawford*
- *Fabrication – Schnell*
- *Cable orders – Engelage*
- *Electronics – Crawford, Engelage, Perkins*
- *Integration/testing – Bland, Ogawa*

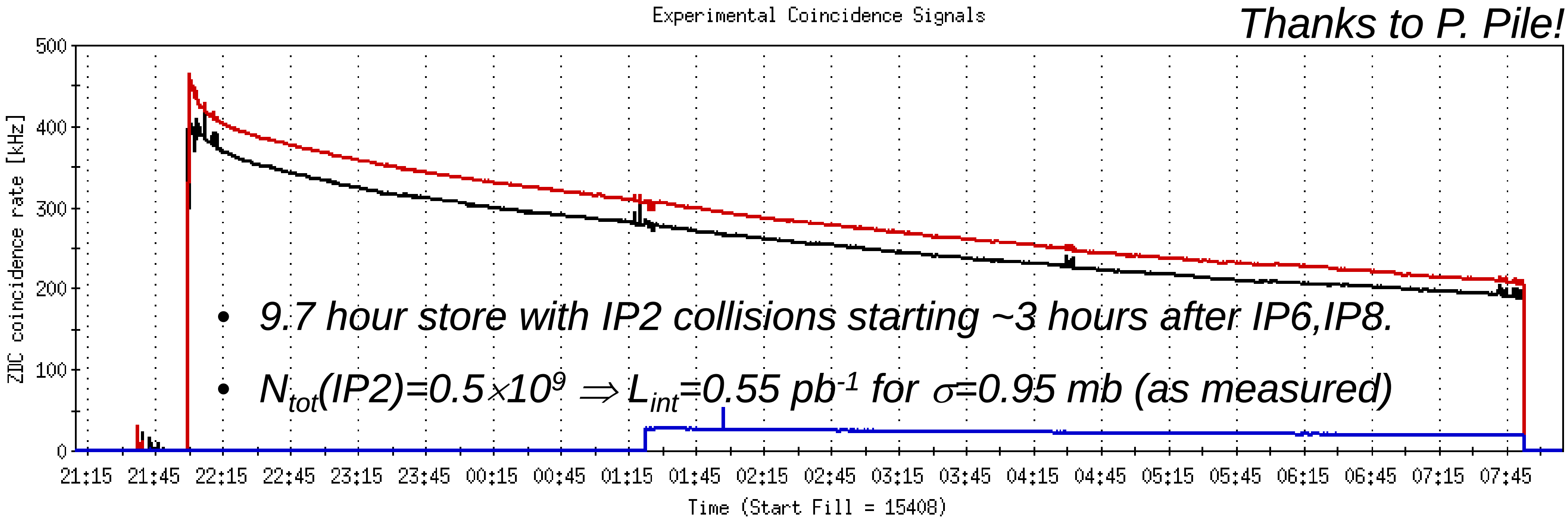


Timeline

We have an ambitious timeline to prepare for run 12 and prior experience in achieving our goals.

Luminosity Estimate for Run 12

Thanks to P. Pile!



- *9.7 hour store with IP2 collisions starting ~3 hours after IP6,IP8.*
- *$N_{tot}(IP2)=0.5\times10^9 \Rightarrow L_{int}=0.55\ pb^{-1}$ for $\sigma=0.95$ mb (as measured)*

- With 2:00 β^* = 1.5 meters
  - AnDY fraction of store 15403 would have been 2x18%=36%

  - using Fischer et.al. 11 May 2010 Table 7 lumi projections for Run12

Physics Weeks	Max Lumi	Min Lumi	AnDY Est (1.5 m β^*)
8	276 pb^{-1}	98 pb^{-1}	35-99 pb^{-1}
10	388 pb^{-1}	134 pb^{-1}	48-140 pb^{-1}
12	500 pb^{-1}	170 pb^{-1}	61-180 pb^{-1}

→ 100 pb^{-1} is not an unreasonable expectation for a 10-12 week run

Summary

- *Collisions can occur at IP2 in polarized proton operation at $\sqrt{s}$=500 GeV without significant impact on operations at IP6,IP8. Integrated luminosity projected for runs 12,13 is sufficient for a significant measurement of the analyzing power for Drell Yan production.*

- *Calibration of HCal has been accomplished. Further work on hadronic response is needed to establish a jet energy scale for the run-11 data. Significant integrated luminosity was acquired during run 11 to allow for measurement of the jet analyzing power.*

- *The additions of ECal (BigCal from JLab) and preshower and ~100 / pb of integrated luminosity for $p^{\uparrow}+p^{\uparrow}$ collisions at $\sqrt{s}$=500 GeV will allow AnDY to address in RHIC run 12 the goal…*
  - *to observe* J/ $\psi \rightarrow$*e+e- and* $\Upsilon \rightarrow$*e+e- and the dilepton continuum between these two signals as a clear benchmark for DY feasibility*

Backup

STAR Results vs. Di-Jet Pseudorapidity Sum

Run-6 Result

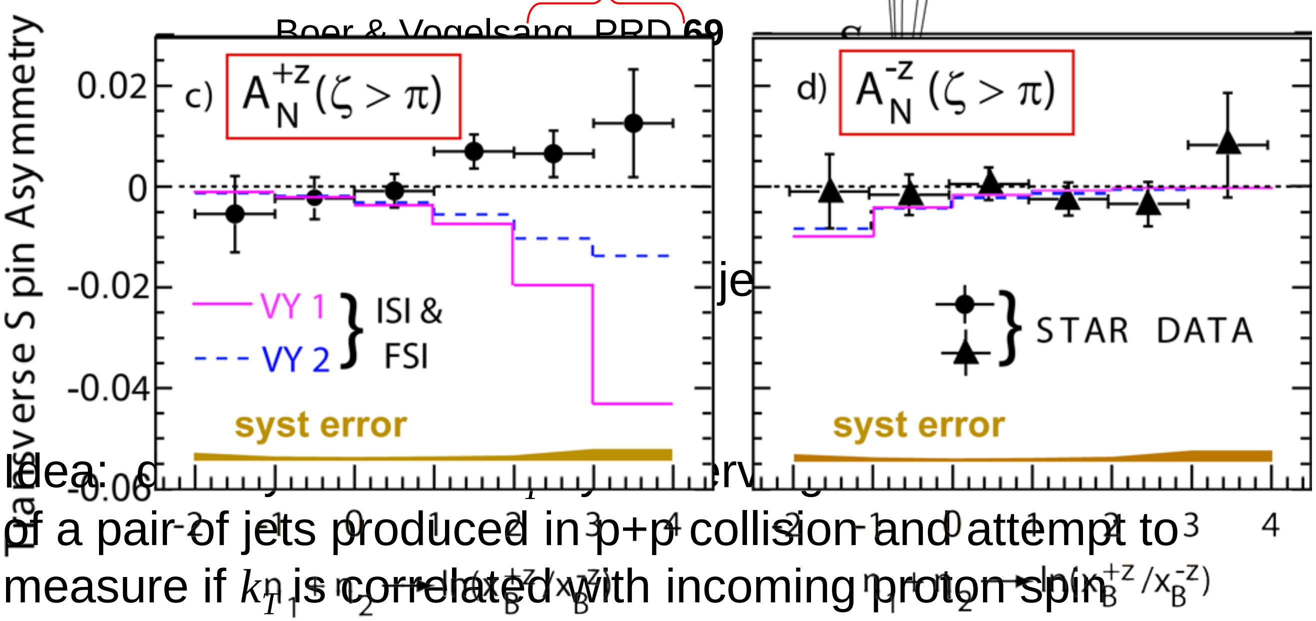
VY 1, VY 2 are calculations by
Vogelsang & Yuan, PRD **72** (2005) 054028

$$A_N \propto p_{beam} \bullet (k_T \times S_T)$$

Emphasizes (50%+) **quark** Sivers

jet

Boer & Vogelsang, PRD **69**



Idea: ... of a pair of jets produced in p+p collision and attempt to measure if k_T is correlated with incoming proton spin

A_N consistent with zero

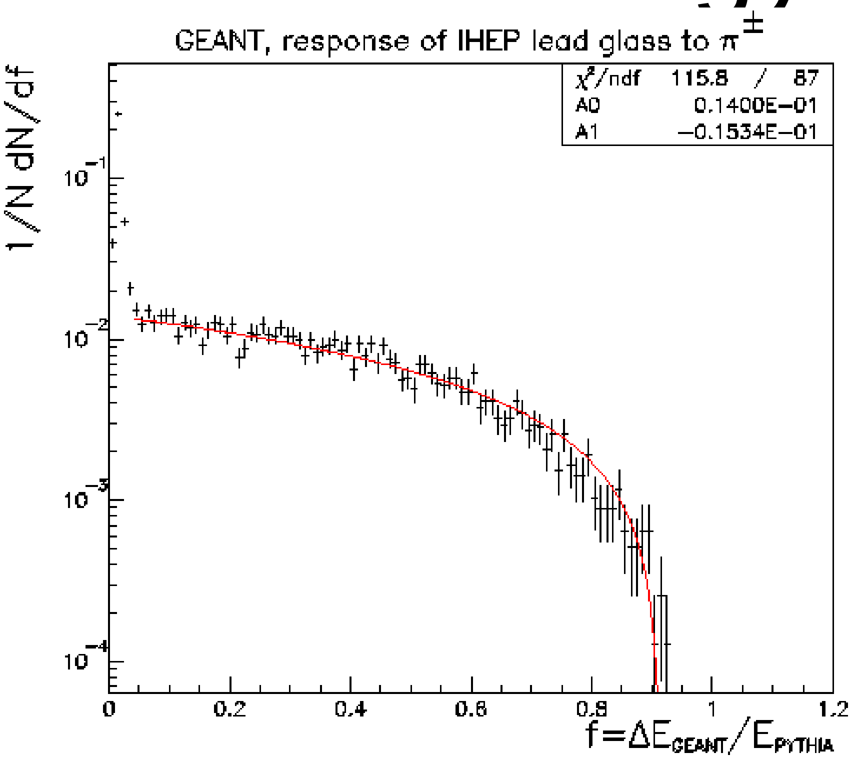
⇒~order of magnitude smaller in pp → di-jets than in semi-inclusive DIS quark Sivers asymmetry!

PRL 99 (2007) 142003

IP2 in August, 2010

Remnants of the BRAHMS Experiment

Strategy for estimates



GEANT simulation of EMcal response to E>15 GeV π from PYTHIA 6.222 incident on $(3.8\text{cm})^2$x45cm lead glass calorimeter. GEANT response not so different from 57-GeV pion test beam data from CDF [hep-ex/0608081]

~10^{12} p+p interactions in 50 / pb at $\sqrt{s}$=500 GeV $\Rightarrow$ full PYTHIA/GEANT not practical

Parameterize GEANT response of EMcal and use parameterized response in fast simulator applied to full PYTHIA events

Estimate rejection factors from GEANT for hadron calorimeter and preshower detector (both critical to h /e discrimination)

Explicit treatment in fast simulator to estimate pathlengths through key elements (beam pipe and preshower), to simulate photon conversion to e+e- pair

- Estimate effects from cluster merging in EMcal ($d < \varepsilon d_{cell}$ / use ε=1 for estimates)
- Estimate/simulate EMcal cluster energy and position resolutions. σ_E=15%/$\sqrt{E}$ and $\sigma_{x(y)}$=0.1d_{cell}, used to date for $\pi^0\rightarrow\gamma\gamma$ rejection.

Analysis Procedure

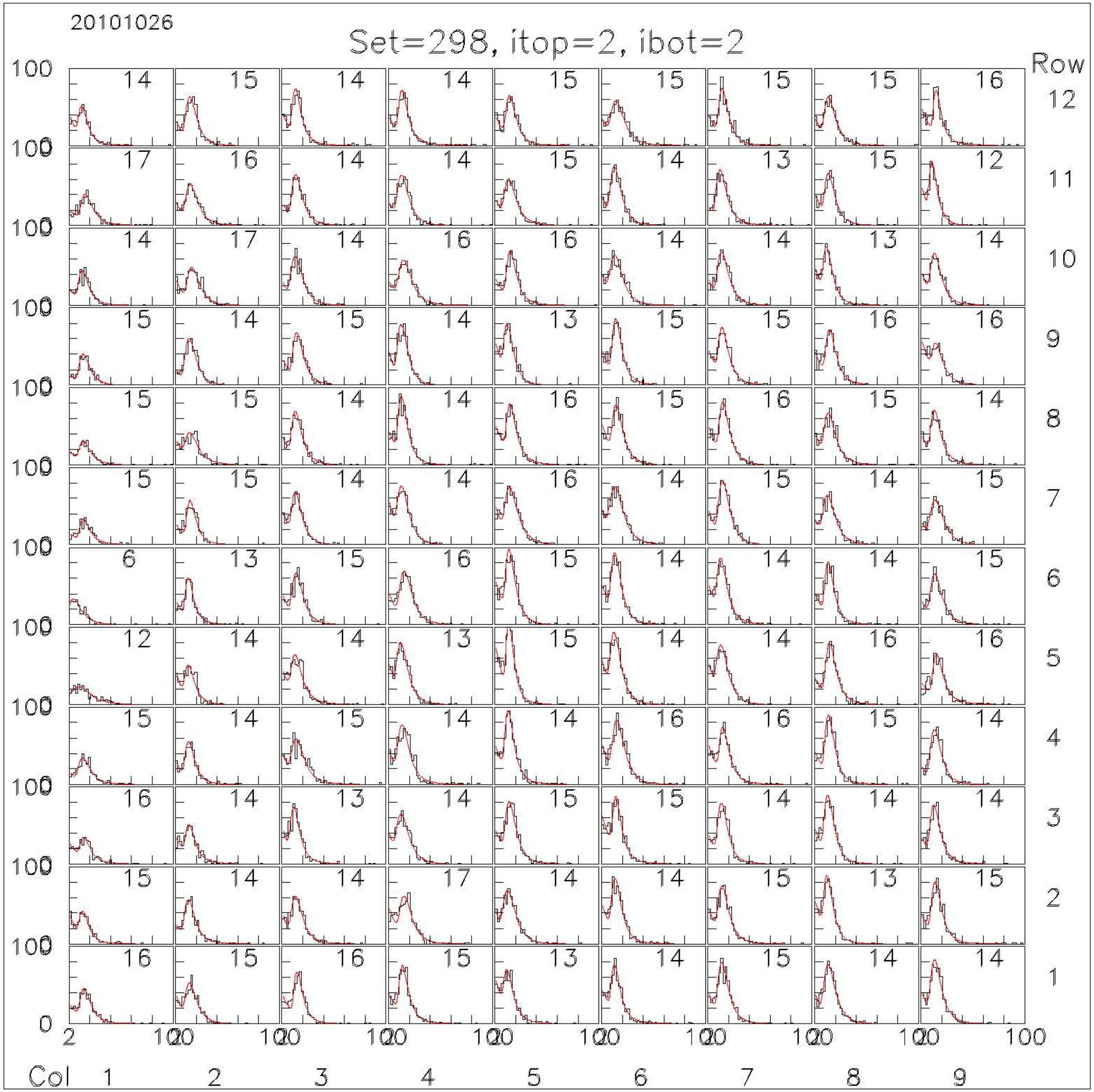
- Pedestal corrected ADC value is scaled by factor (g) to yield ΔE for a detector.
- Threshold-bounded clusters are found in each HCal module.
- Requirements are placed on clusters and other attributes of the event.
- The summed ΔE for each cluster is converted into total relativistic energy via $E=f\Delta E+E_0$. The f,E_0 values depend on the origin of cluster: e.g., photon assumption uses $E_0=0$; hadron assumption uses $E_0=\langle m_h c^2\rangle+\delta E$, where $\langle\delta E\rangle$ represents averaged upstream energy loss and $\langle m_h c^2\rangle$ is the rest energy averaged over all hadrons (dominantly π).
- The x,y position of cluster is converted into polar and azimuthal angles, using fixed displacement of the HCal from the average vertex location.
- The momentum vector is reconstructed using assumed mass (taken to be zero for photons) to obtain p from E
- Invariant mass (M_{pair}) is then computed from cluster pairs, as is pair energy (E_{pair}) and energy-sharing ($z_{pair}=|E_1-E_2|/E_{pair}$)

Association

- 4×10^7 non-elastic, non-singly diffractive PYTHIA 6.222 p+p collision events at $\sqrt{s}$=500 GeV have been generated and run through the fiber-model of the run-11 IP2 GEANT. Energy deposition from GEANT is digitized using the inverse of calibration factors used for data. Digitized simulation is then reconstructed using the same coding as used for data.
- Intercomparisons of reconstructions of digitized PYTHIA/GEANT events and data show reasonable agreement.

$\Rightarrow$ Apply association analysis to reconstructions of PYTHIA/GEANT events

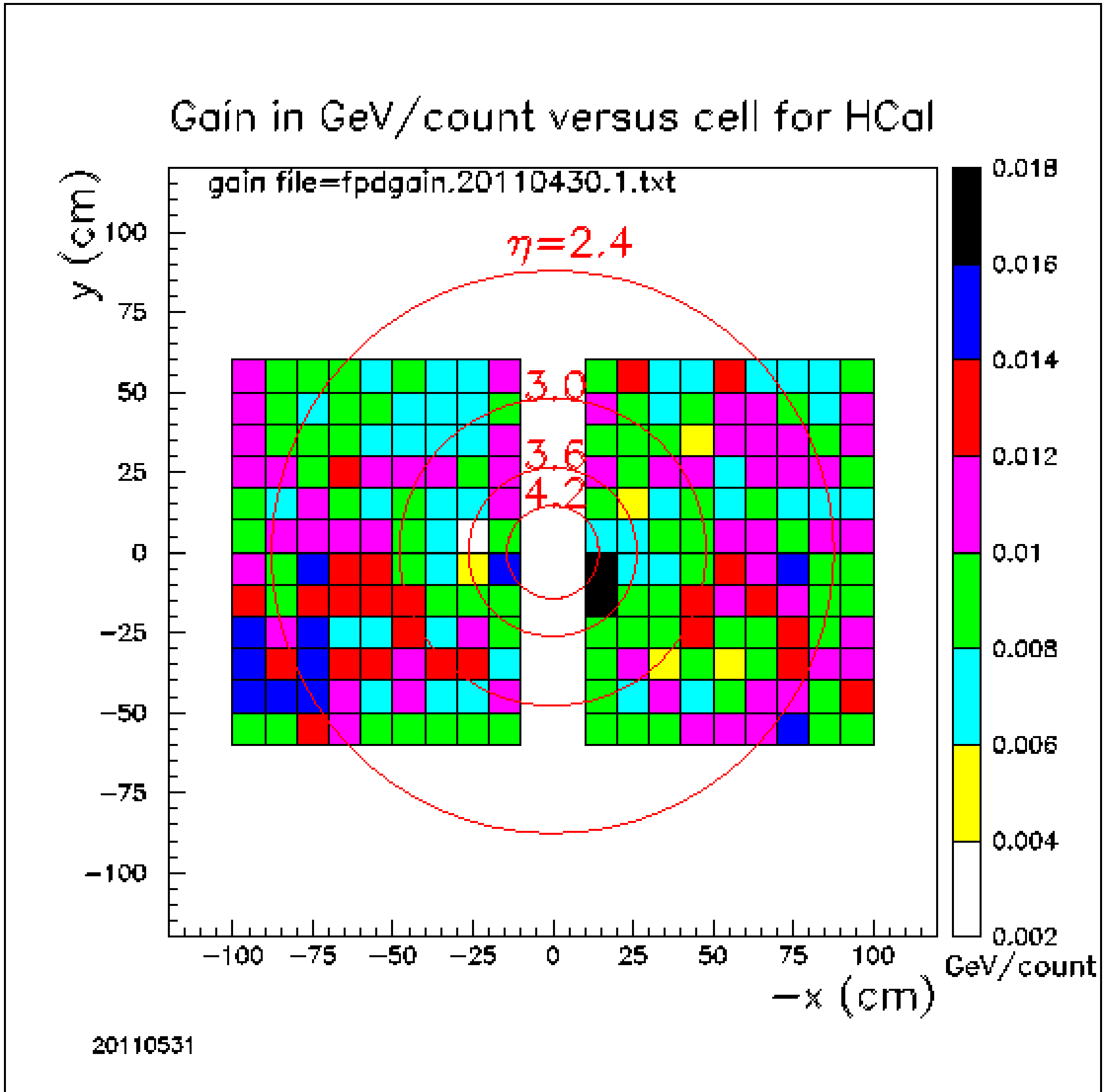
- Project PYTHIA primary from collision point to HCal
- Compute distance in x,y plane from projected position to reconstructed cluster
- Declare association for minimum distance that is smaller than HCal cell size (10cm)
- If proximity match is not found for reconstructed cluster, identify primary that leads to largest contribution to high tower of cluster and declare match



Cosmic Ray Muon Calibrations

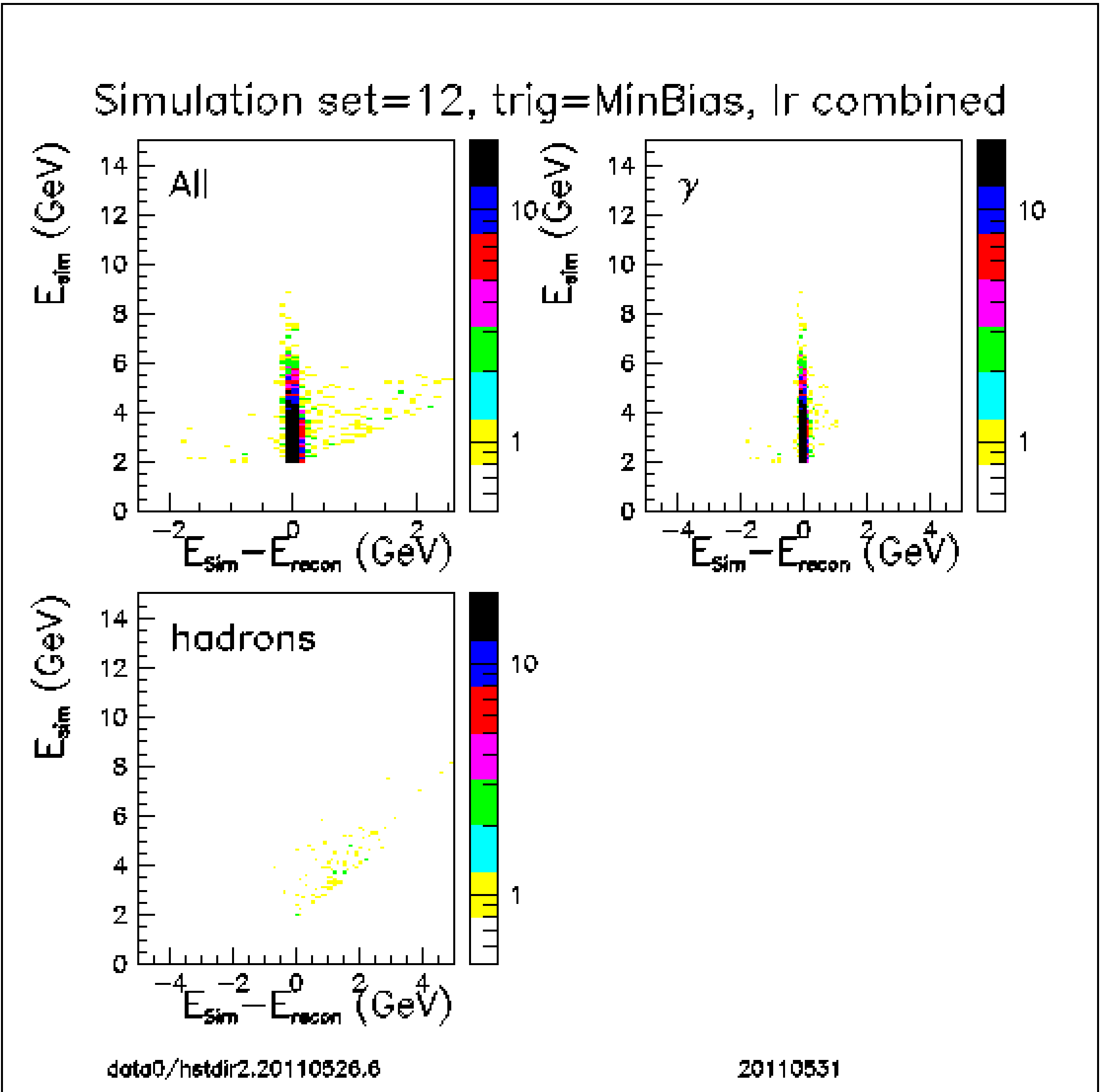
- *Prior to run 11 operation, HCal modules had relative PMT gains set by cosmic-ray muon response.*
- *Triggering enabled verification of scintillating fiber attenuation length in each detector*
- *ADC data from beam-left module with fits to Landau distribution (centroid shown) + exponential background*

Gain



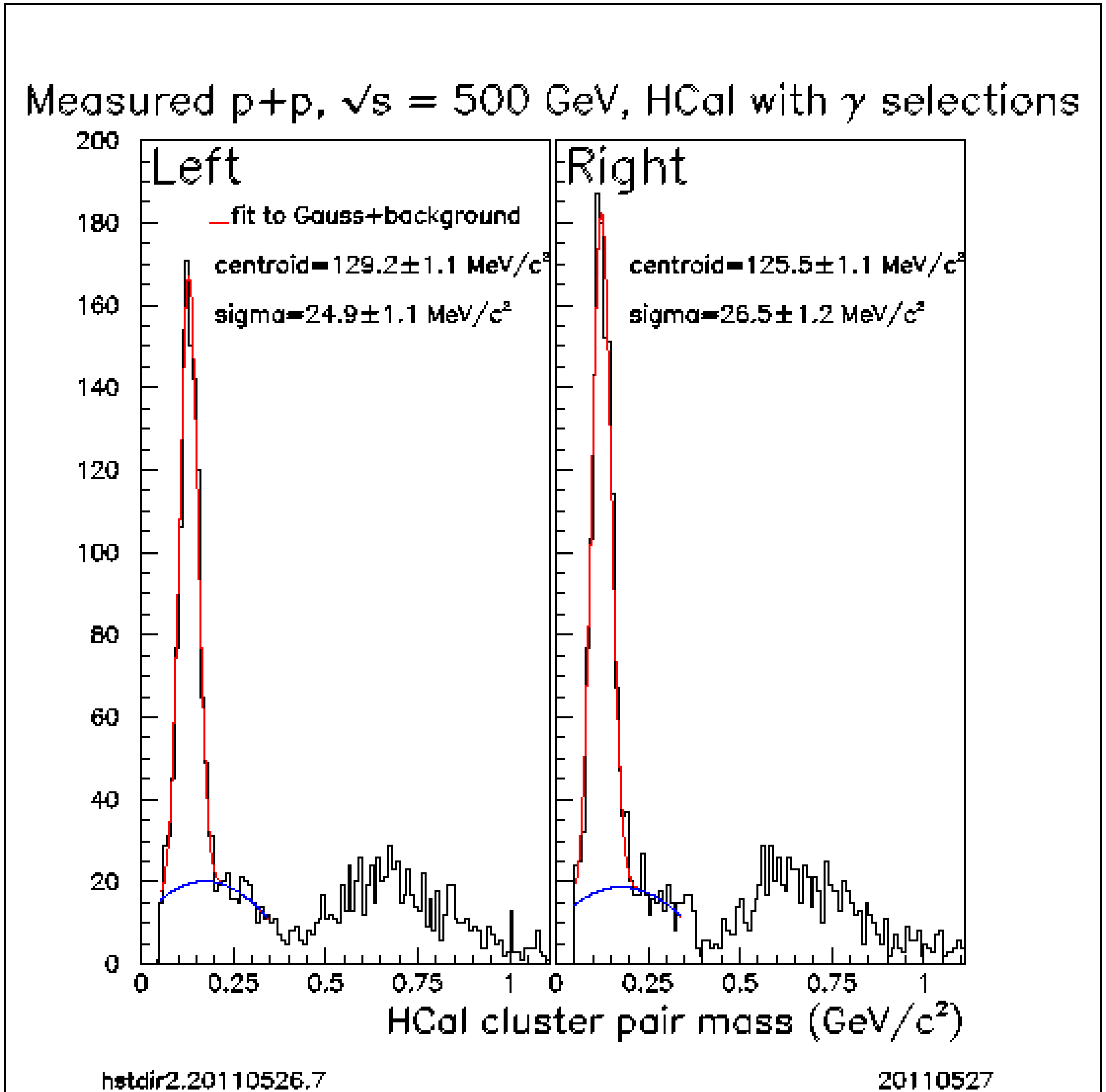
- Individual detector f*g factors in GeV/count used for reconstruction of data
- Inverse of g used for digitizing simulations. f=1.85 used to convert cluster energy deposition to total relativistic energy. This factor depends on simulation model, whereas f*g does not for photons.

Reconstructed Energy from Simulation



- Photon assumption used to convert cluster energy deposition into total relativistic energy
- Associations for clusters requiring: (1) 1-tower clusters; (2) E>1.8 GeV; (3) |x|>50 cm to avoid ECal shadow; (4) >1 clusters to form pairs; (5) E_{pair}>5 GeV; (6) M_{pair}<0.5 GeV; and (7) z_{pair}<0.5.
- Find $\sigma_{\delta E}$~0.02 GeV from analysis of projected δE distribution summed over energy.

Centroids



- Neutral pion peak centroid is fitted for the data using a Gaussian distribution for the peak and a quadratic polynomial background.
- Peak centroids are somewhat lower than PDG value for $m_{\pi 0}$, and likely reflect present quality of gain and geometry calibrations
- Association of neutral pion peak with individual detectors for the leading photon have been done and can be used to tune gain calibration.

Conclusions and Outlook

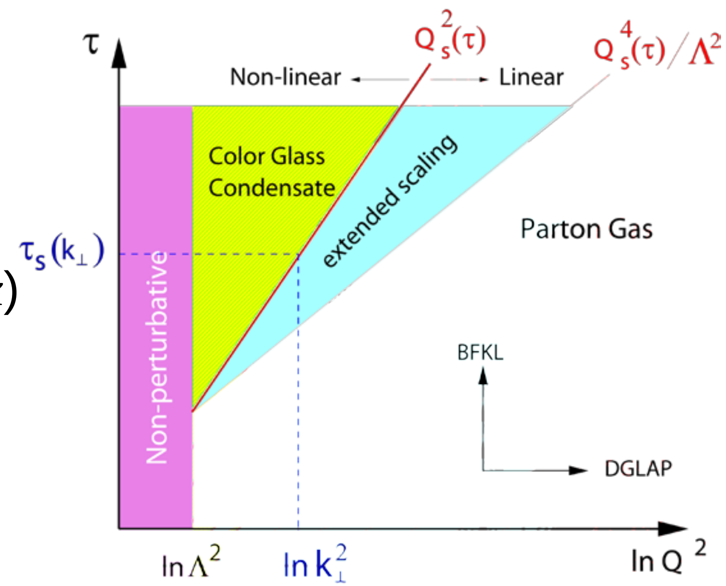
- One of the primary objectives for run 11 has been achieved. The energy scale of the hadron calorimeter used by A_NDY has been determined from $\pi^0\to\gamma\gamma$ reconstruction.
- Extension of photon finding to lower energies has begun. First look at efficiencies find them to be roughly consistent with acceptance area for single-tower clusters.
- Scale and offset factors for hadronic response are being investigated through hadronic decays $\rho^0 \to\pi^+\pi^-$; $\rho \to\pi\ \pi^0$; $\eta,\omega\to\pi^0\pi^+\pi^-$ Combinatoric backgrounds are the dominant feature to these 2-cluster and 3-cluster mass distributions. Improved cluster tagging likely to help.

Two Reasons to Go Beyond Collinear QCD

- **Transverse spin physics**: present understanding requires spin-correlated transverse momentum in distribution functions (Sivers effect) and fragmentation functions (Collins effect)

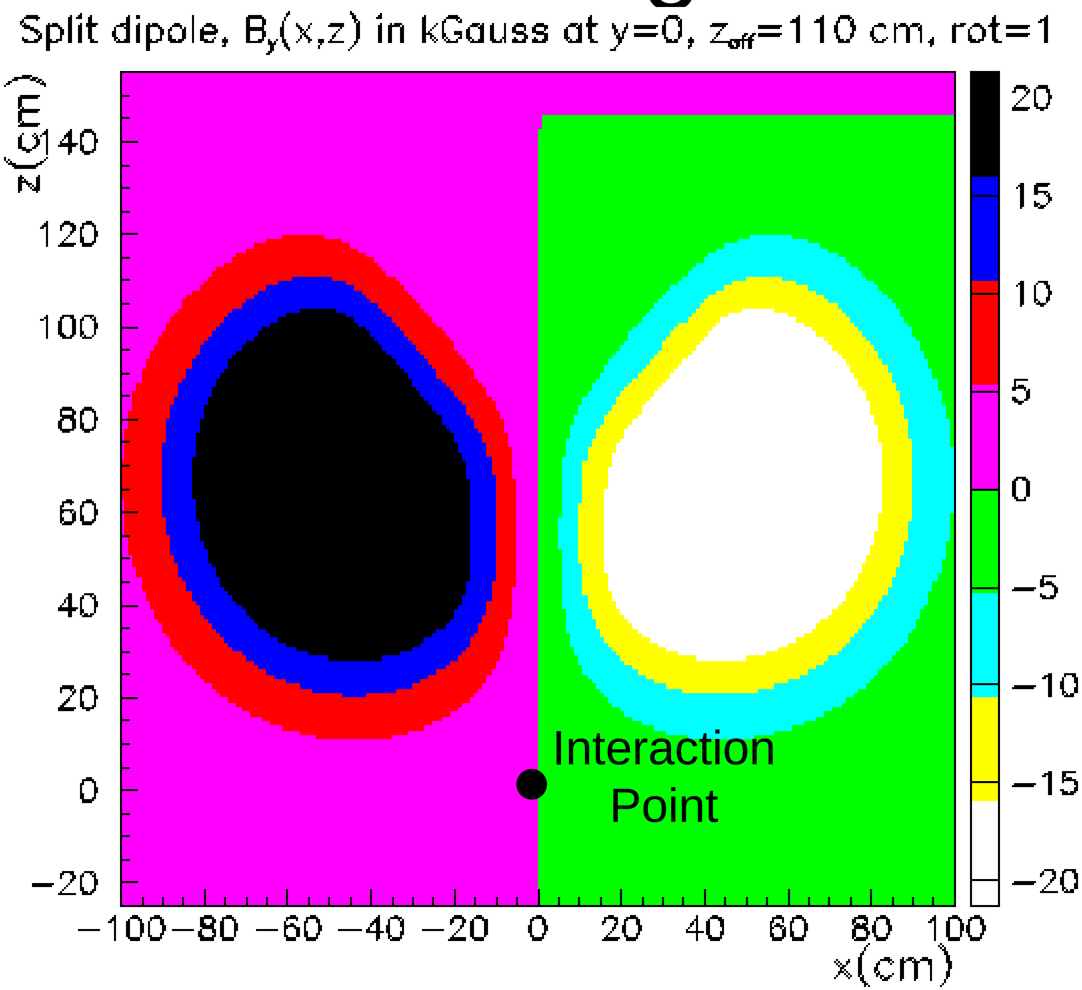
- **Low-x physics**: the gluon density cannot continue its growth as $x \to 0$. This is a major focus of a future electron-ion collider [see Ann. Rev. Nucl. Part. Sci 55 (2005) 165]. Universality aspects can be probed at RHIC, especially with Drell Yan production.

$\tau = \ln(1/x)$



Iancu, Venugopalan
hep-ph/0303204

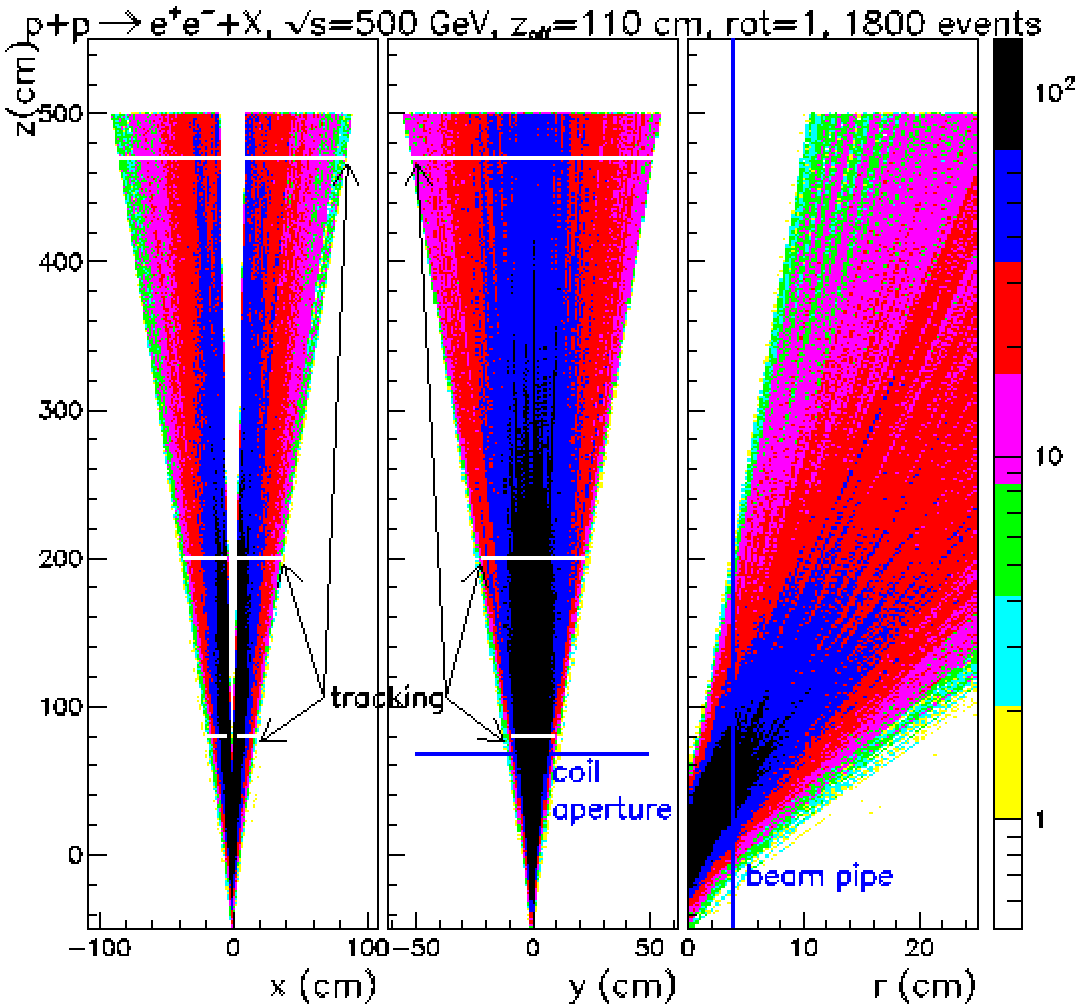
Magnetic Field Used for Charge Sign Simulations



Vertical component of B versus x,z at y=0 from PHOBOS split-dipole magnet

- The plan is to reuse the split-dipole magnet at IP2 designed, built and operated by the PHOBOS collaboration.
- PHOBOS provided their field map and geometry files for GEANT for simulation studies.
- Compared to use at IP10, split-dipole is rotated by 180º around vertical axis, to move aperture restriction from coils close to IP.

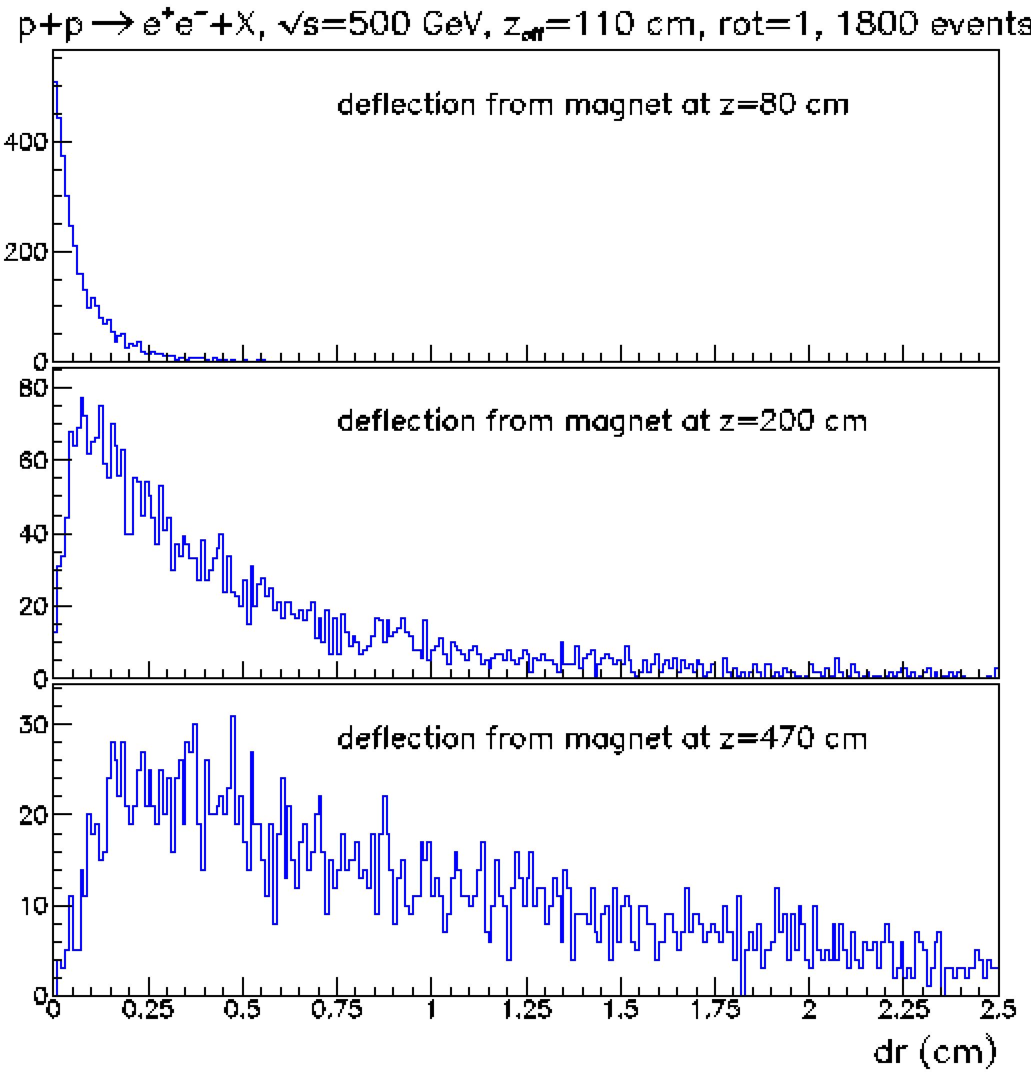
Raytracing DY di-electrons through apparatus



- Assumes vertex distribution with σ_z=20 cm ⇒ relies on 9MHz RF system to reduce the diamond size. The z location of beam-pipe crossings would be broadened otherwise
- 2-mm square scintillating fibers are assumed for tracking stations at z=80 and 200 cm.
- MWPC assumed for tracking station at z=470 cm

x-z , y-z and r-z views of trajectories through apparatus planned for run 13, including split-dipole field, used for charge-sign determination

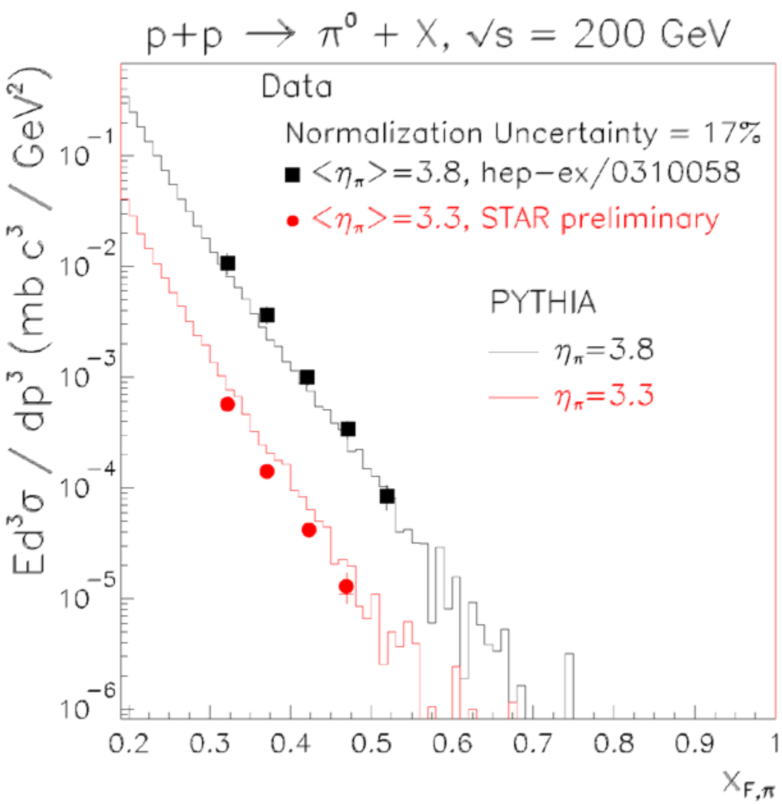
Deflections from split-dipole field



- dr is distance in x-y plane at tracking station between zero-field track intercept and full-field track intercept
- difference between positive and negative charged particles produced in collisions is twice larger
- Strategy to determine charge sign is to measure impulse delivered by magnet by measuring deviation of point at z=470 cm from line fitted to vertex and z=80,200 cm space points

QCD Backgrounds

- h /e discrimination – requires estimates of p+p collisions and EMcal response
- charged/neutral discrimination
- photon conversion background – requires estimates of p+p collisions and materials



- PYTHIA 5.7 compared well to √s=200 GeV data [PRL 97 (2006) 152302]
- Little change until "underlying event" tunings for LHC created forward havoc

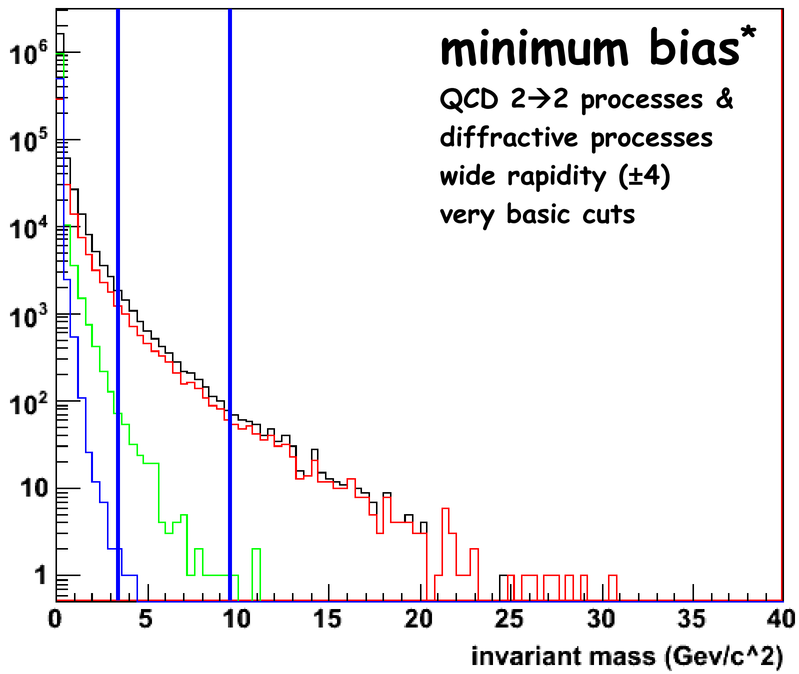
$\Rightarrow$ Stick to PYTHIA 6.222 for estimates

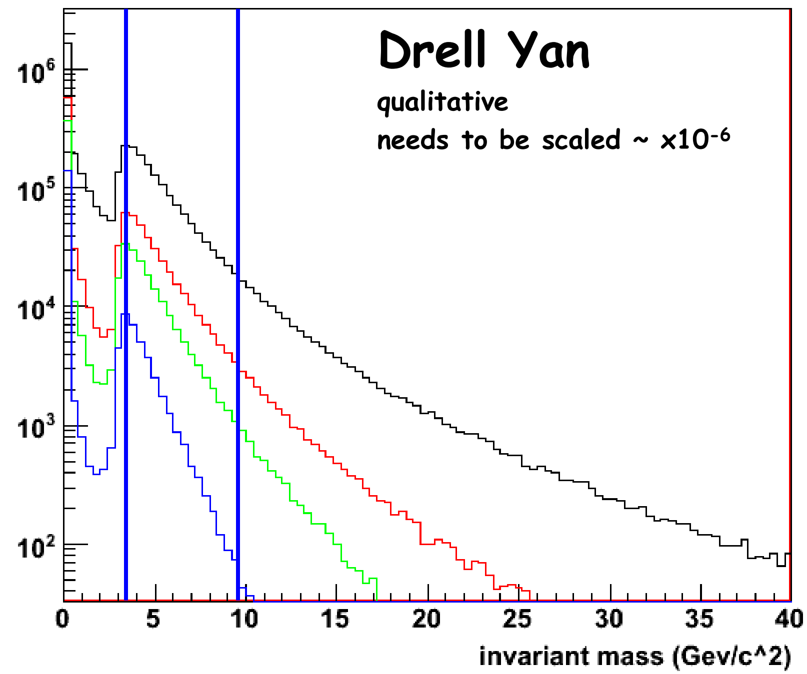
hep-ex/0403012

√s=500 GeV Simulation

Electron pairs in different rapidity ranges

central (|y|<1), forward (|y|>2), very forward (|y|>3)



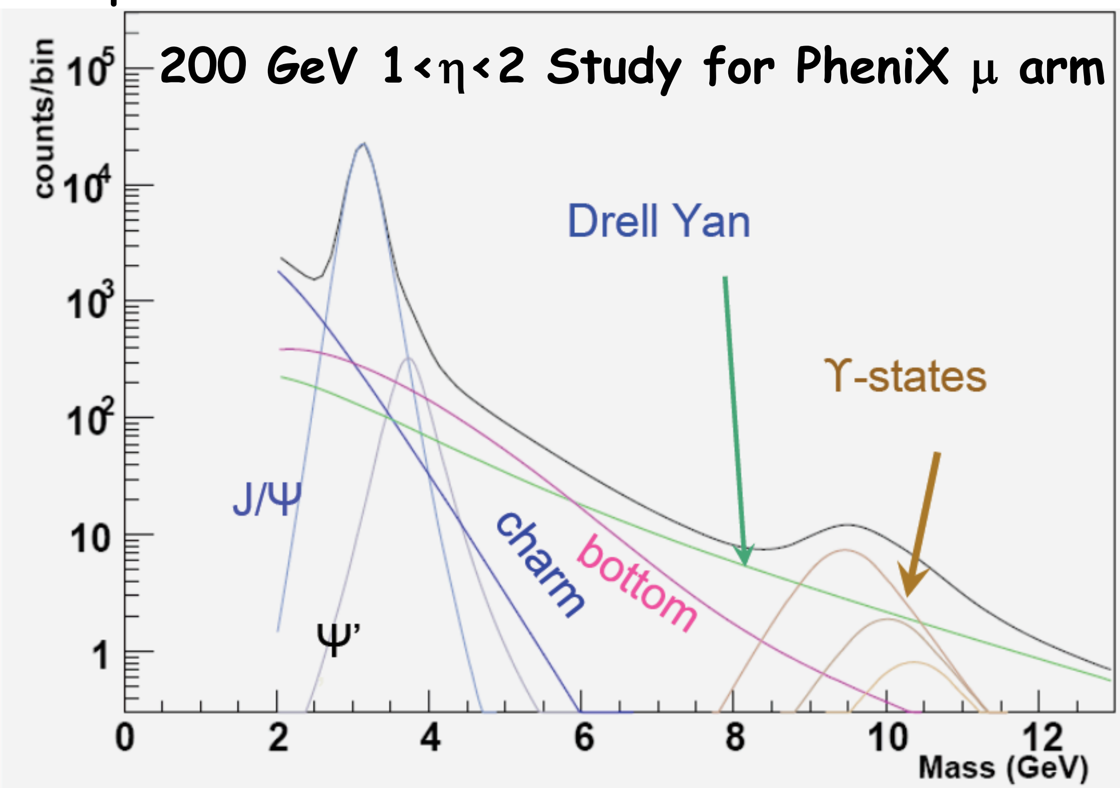


Background decreases faster than signal at forward η

What are the biggest background contributions?

Background to e+e- DY pairs:

- hadronic background from QCD 2→2
  - →$h^{\pm}/e^{\pm}$ discrimination – requires estimates of p+p collisions and EMcal response
  - → charged/neutral discrimination
- photon conversion in beam-pipe and other material
- Open Beauty
- Open Charm

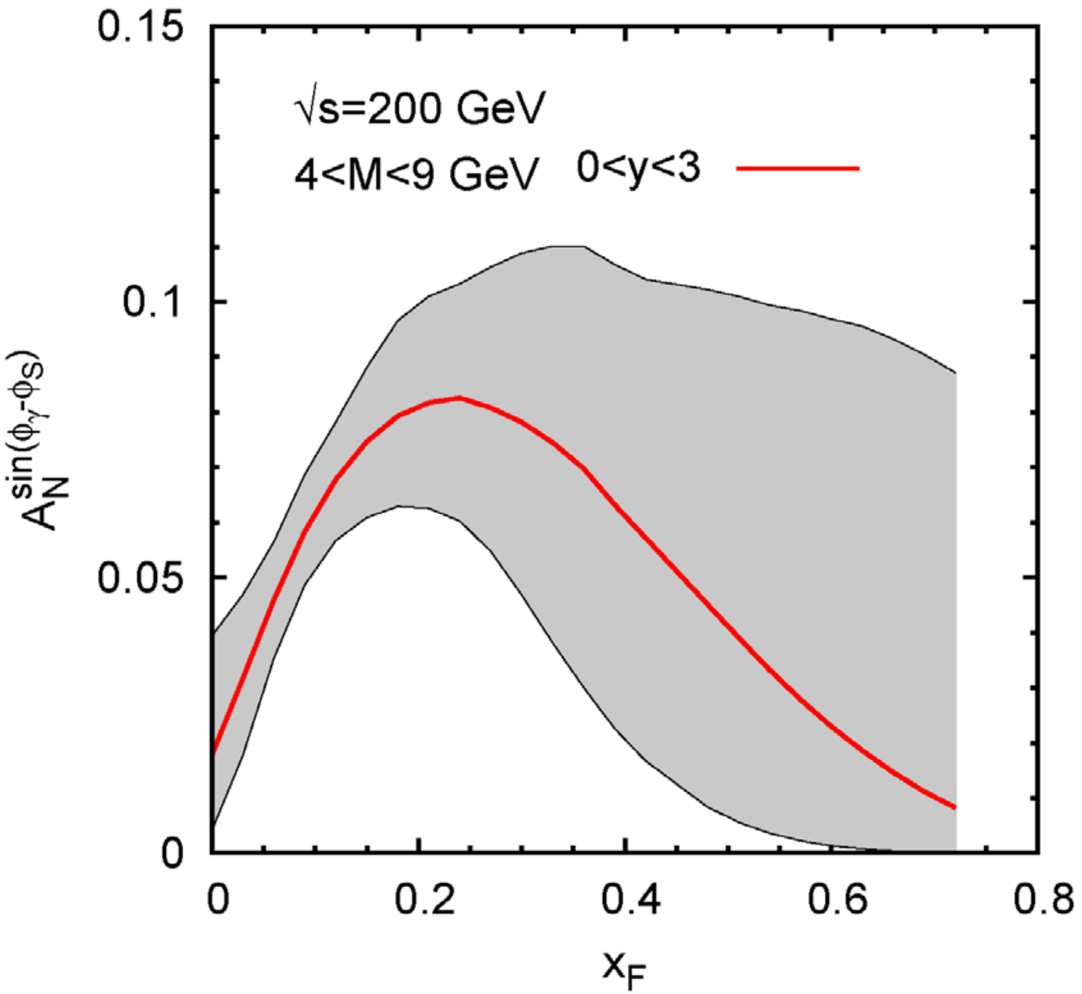


Charm even further reduced going to $\eta > 3$

Transverse Spin Drell-Yan Physics at RHIC (2007)

http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf

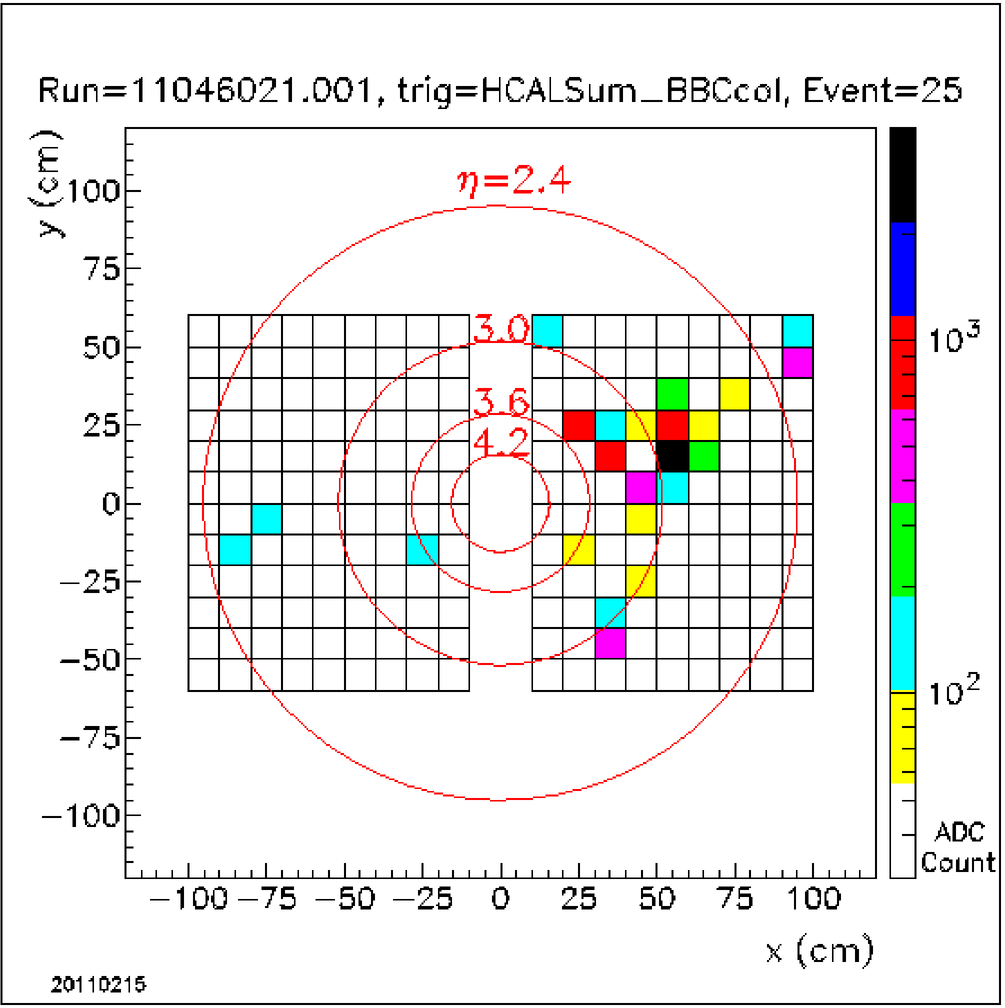
DY Expectations



- Non-zero A_N expected at moderate to large x_F
- Measurement with accuracy $\delta A_N<0.02$ should be of great interest
- With P_{beam}=50%, require 10K events for $\delta A_N=0.02$
- Uses Sivers function from EPJ A39 (2009) 89, that fits preliminary HERMES results and COMPASS deuteron results
- $\sqrt{s}$=500 GeV predictions very similar, since $x_F=x_1-x_2$ is the relevant parameter (private communication)

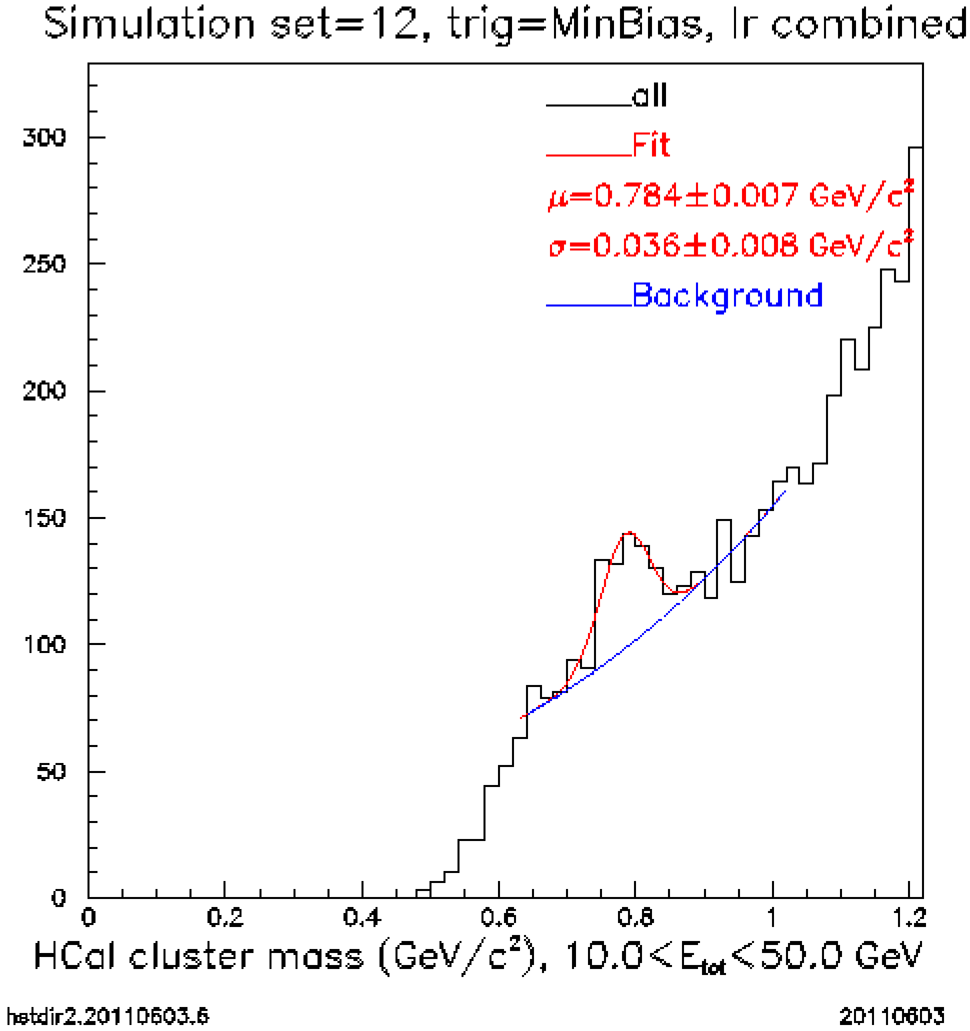
Anselmino, et al PRD 79 (2009) 054010 [arXiv:0901.3078]

HCal Events



- Cosmic ray trigger is essentially the same as jet trigger, except that the threshold on the summed calorimeter response is set at 5 pC (20 counts)
- This is a trigger that will work without beam. We have other cosmic-ray triggers that will work with beam, when commissioned, for continuous monitoring.
- The tracks test noise, patterns, etc.

Status of Hadronic Response of HCal



- *HCal detectors are not fully compensated, meaning h/γ response corrections required*
- *Hadronic response focused on meson reconstruction, to assess calibration via mass peak.*
- *Likely the best solution will be combining clusters from ECal and HCal, but this awaits GEANT simulations with survey geometry*
- *For now, focus on $\omega \to \pi^+\pi^-\pi^0 \to \pi+\pi-\gamma\gamma$, with all clusters in HCal (separately "photon" tagged and "hadron" tagged)*
- *Reconstruction from 20M PYTHIA/GEANT events looks promising*

Summary of A_NDY Reports to C-A During Run 11

11 Jan 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110111/AnDY.ppt

1 Feb 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110111/AnDY.ppt

8 Feb 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110208/AnDY.ppt

15 Feb 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110215/AnDY.ppt

22 Feb 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110222/AnDY.ppt

1 Mar 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110301/AnDY.ppt

8 Mar 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110308/AnDY.ppt

15 Mar 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110315/AnDY_2.ppt

22 Mar 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110322/AnDY.ppt

29 Mar 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110329/AnDY.ppt

5 Apr 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110329/AnDY.ppt

12 Apr 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110412/AnDY.ppt

19 Apr 2011 Time Meeting - http://www.c-ad.bnl.gov/esfd/Scheduling_Physicist/Time_Meetings/tm110412/AnDY.ppt