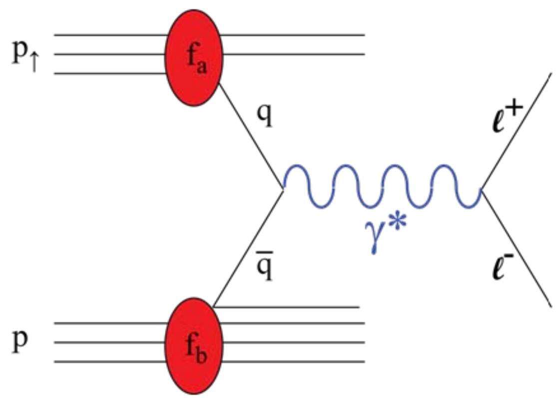
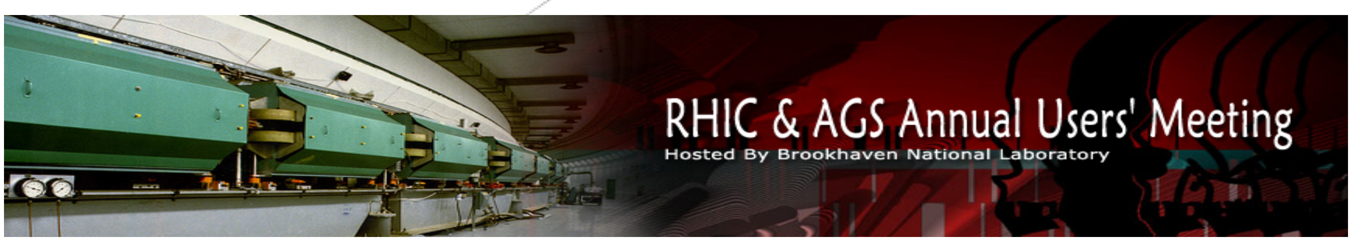
A_NDY Report



Akio Ogawa

BROOKHAVEN
NATIONAL LABORATORY



2011 June 23 @ BNL

A_NDY at IP2

"Feasibility Test of Large Rapidity Drell Yan Production at RHIC"

Letter of Intent to 2010 PAC:

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

2010 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 **APPROVED**

- Demonstrate that large-x_F low-mass dileptons from the DY process can be discriminated from background in $\sqrt{s}$=500 GeV $p^{\uparrow}$+p collisions.
- Measure the analyzing power for DY with sufficient statistical precision to test the theoretical prediction of a sign change for DY in relation to SIDIS

PHENIX and STAR decadal plan
Include e+e- DY for 2017-2020

- **Timeliness** – Run when STAR & PHENIX are doing W program (2012-13)
- **Acceptance/background rejection** – Severe space constraints at STAR and PHENIX require major changes in the forward direction to do DY
- **Is charge sign a requirement?** – feed back to STAR/PHENIX forward upgrade plans

A_NDY collaboration

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Indiana University
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University of the Basque Country and IKERBASQUE,Spain
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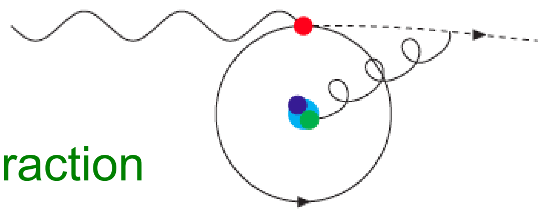
Yerevan Physics Institute

Collaborators new to RHIC activities from JLAB/BigCal and HERMES.

Siver's function - The Sign Change

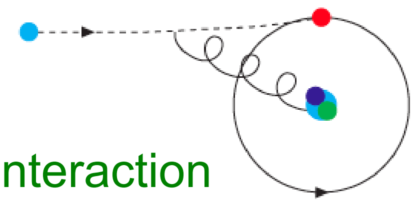
$$f_{1T}^{\perp}(x, \mathbf{k}_\perp)_{DY} = -f_{1T}^{\perp}(x, \mathbf{k}_\perp)_{SIDIS}$$

SI-DIS
Final state interaction
Attractive



a)

DY
Initial state interaction
Repulsive



b)

- time reversal: FSI $\leftrightarrow$ ISI

SIDIS: compare FSI for 'red' q that is being knocked out with ISI for an anti-red $\bar{q}$ that is about to annihilate that bound q

$\hookrightarrow$ FSI for knocked out q is attractive

DY: nucleon is color singlet $\rightarrow$ when to-be-annihilated q is 'red', the spectators must be anti-red

$\hookrightarrow$ ISI with spectators is repulsive

- test of this relation is a test of TMD factorization

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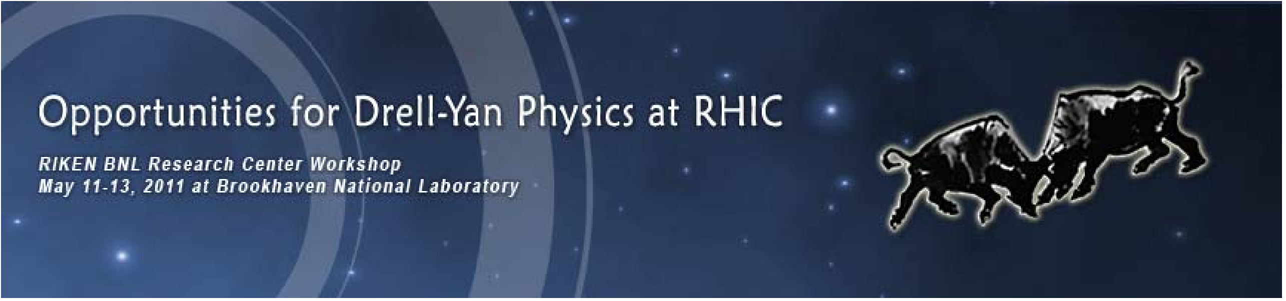


John Collins

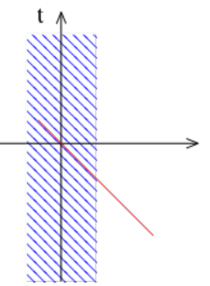
Reliability of theoretical framework

QCD

Kinematic approximations

Disentangle gluons into Wilson lines

Cancellation of spectator interactions



factorization

TMD, incl. Sivers

Cancellation of soft ints.

Collinear factorization

Any problems with Sivers function impact issues critical to all kinds of factorization.

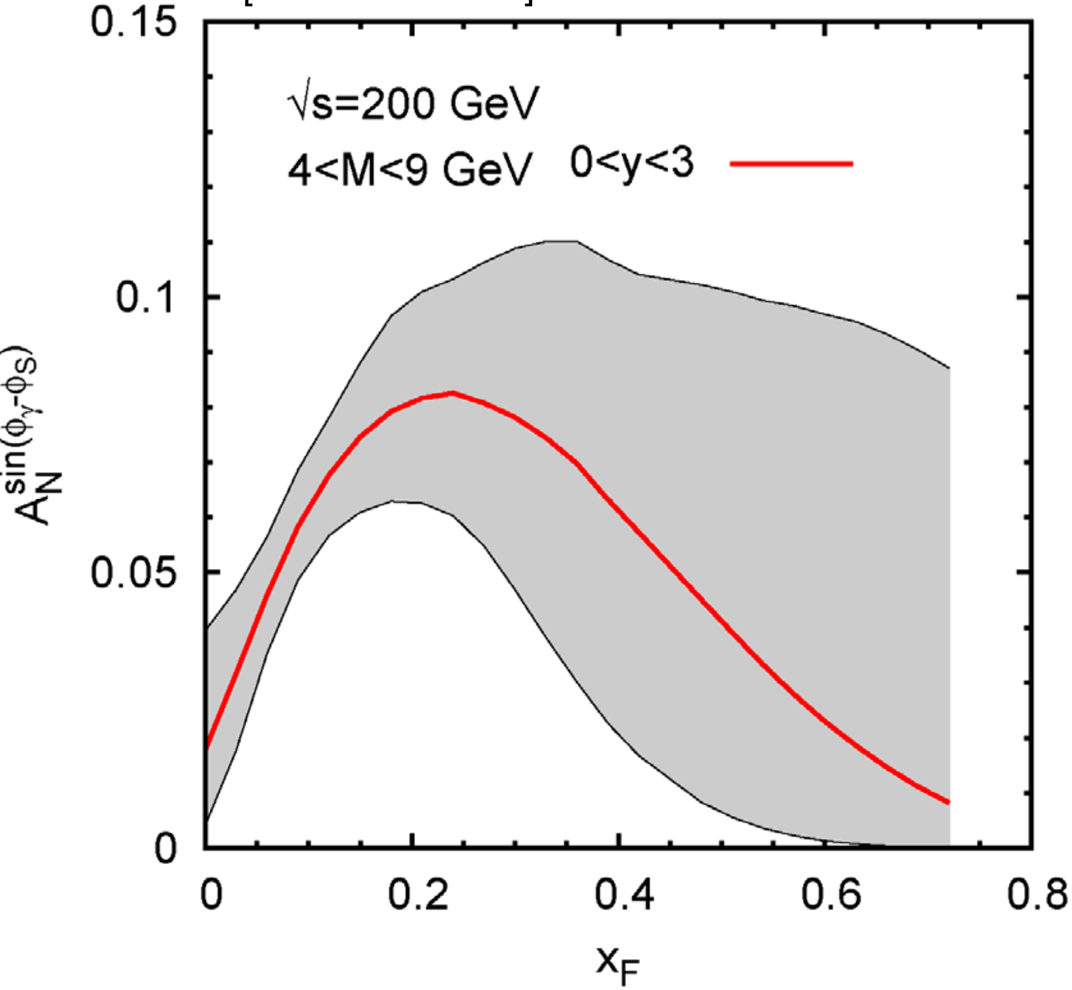
(Unpolarized) factorization survived many tests, so probability of failure is low.

Wilson lines encode space-time locations of color flow relative to hard scattering.

DY Expectations – robust theory

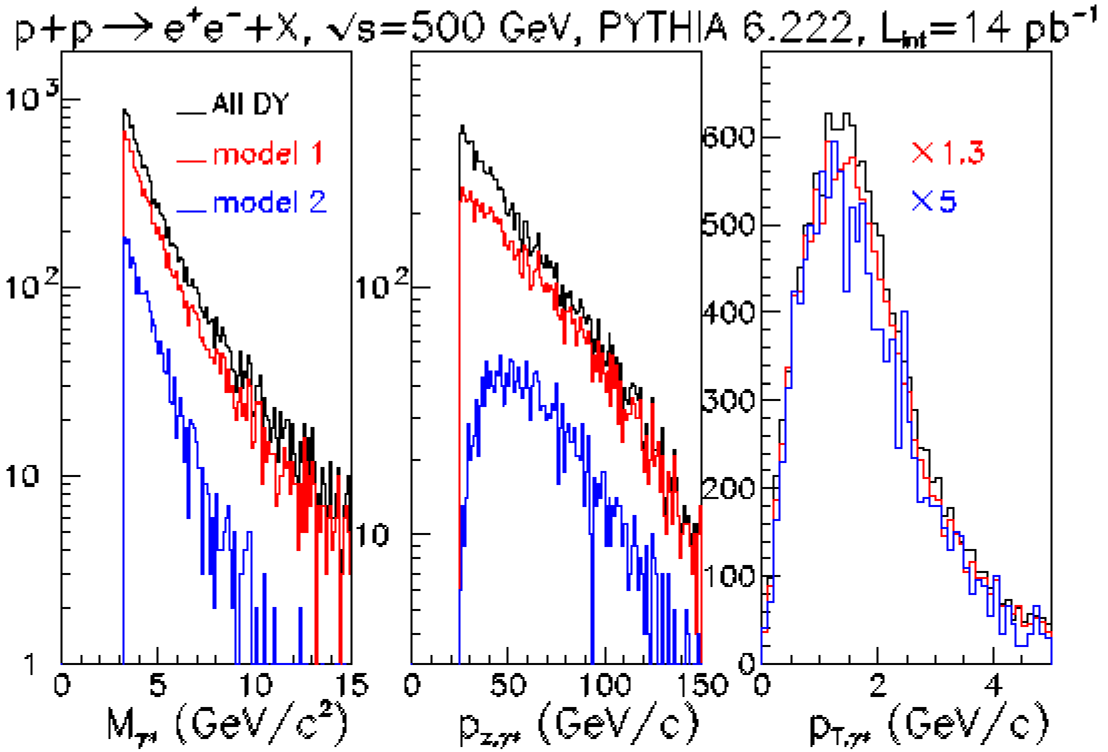
Anselmino, et al PRD 79 (2009) 054010

[arXiv:0901.3078]



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

e+e- DY expectations at large x_F at □s=500 GeV



Note scale of signal for same L

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

Reasonable efficiency can be obtained for large-x_F DY with existing equipment

9400 DY-events (Model2)

with L=150/pb P=50% $M_{\gamma*}$ > 4 GeV, x_F > 25GeV, $p_{t,\gamma*}$ < 2GeV

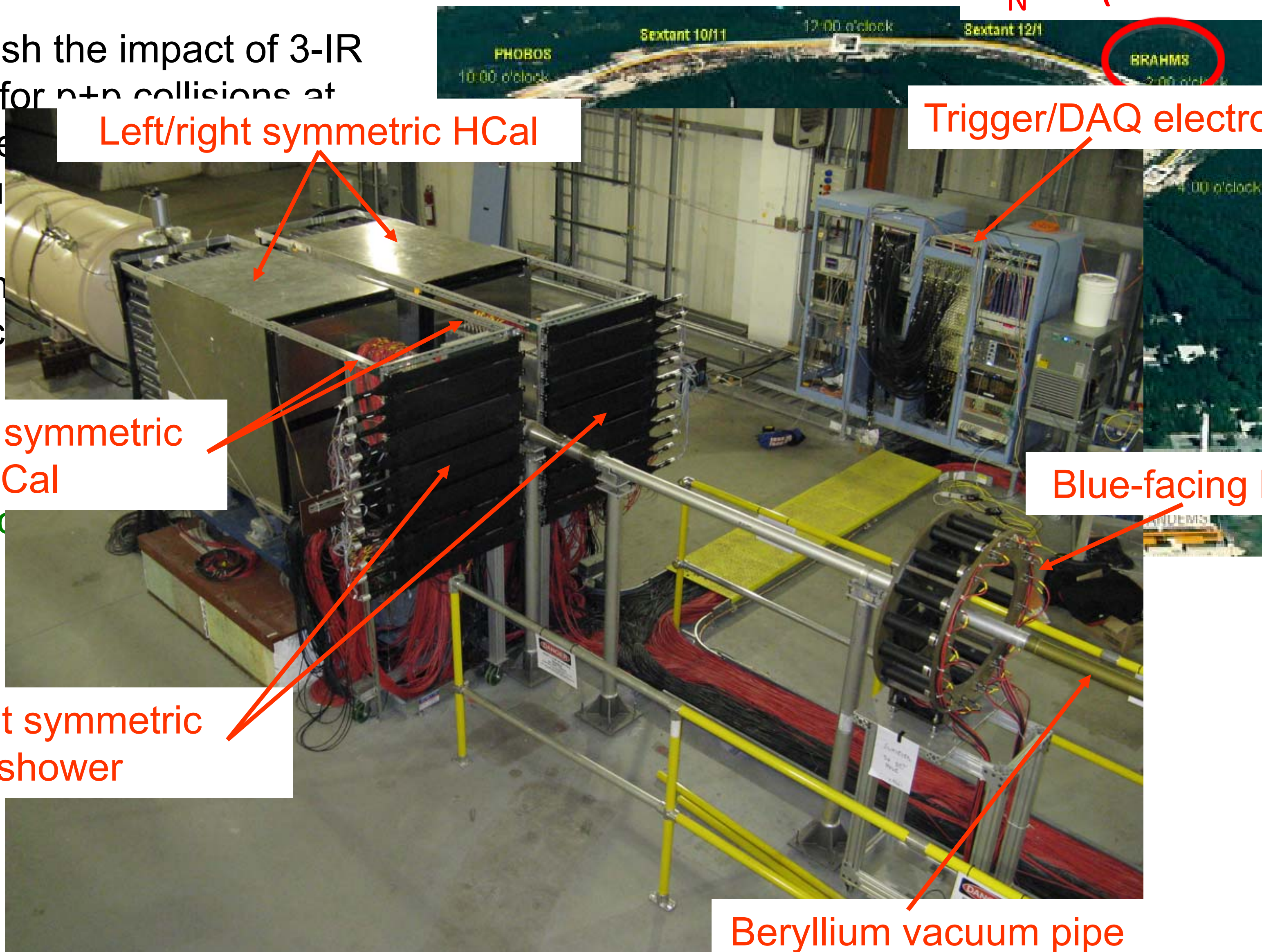
x_F=0.1~ 0.3 $|A_N|$ ~ 0.1 δA_N ~ 0.02

A_NDY Run11 Goals

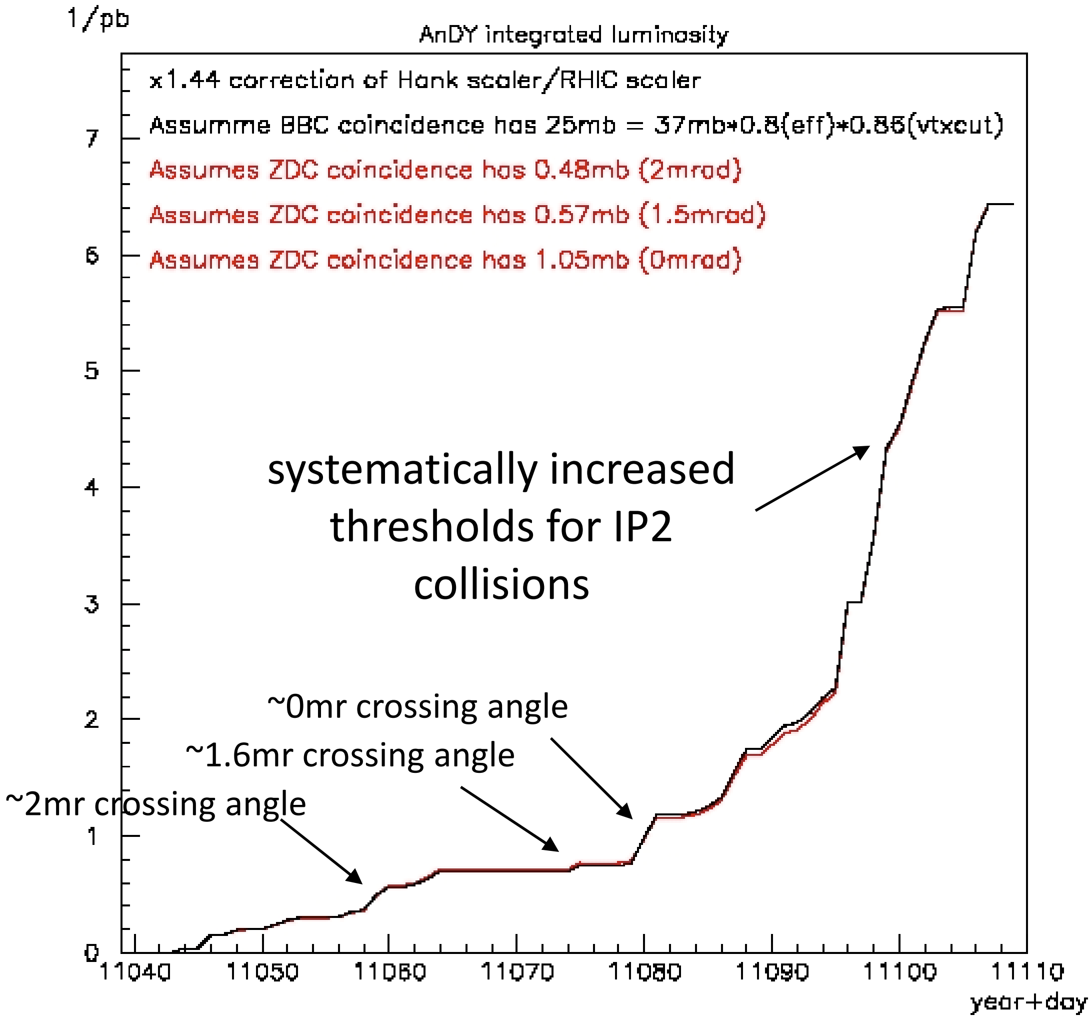
(1) Establish the impact of 3-IR operation for p+p collisions at √s=500 Ge
& STAR lu

(2) Demon
hadronic c

(4) Find E



Run11 Goal (1) – 3IR impact



Fri. 8 April

IP2 collisions have begun <3 hours after physics at 1.50×10^{11}/bunch

A_NDY got ~ 6.5/pb

in run11 with beta*=3m

(After recent BBC efficiency correction)

RHIC can operate 3IR with minimal impact on luminosity at STAR and PHENIX
With beta*=1.5m, RHIC can deliver ~10/pb/week in Run12/13 at ANDY

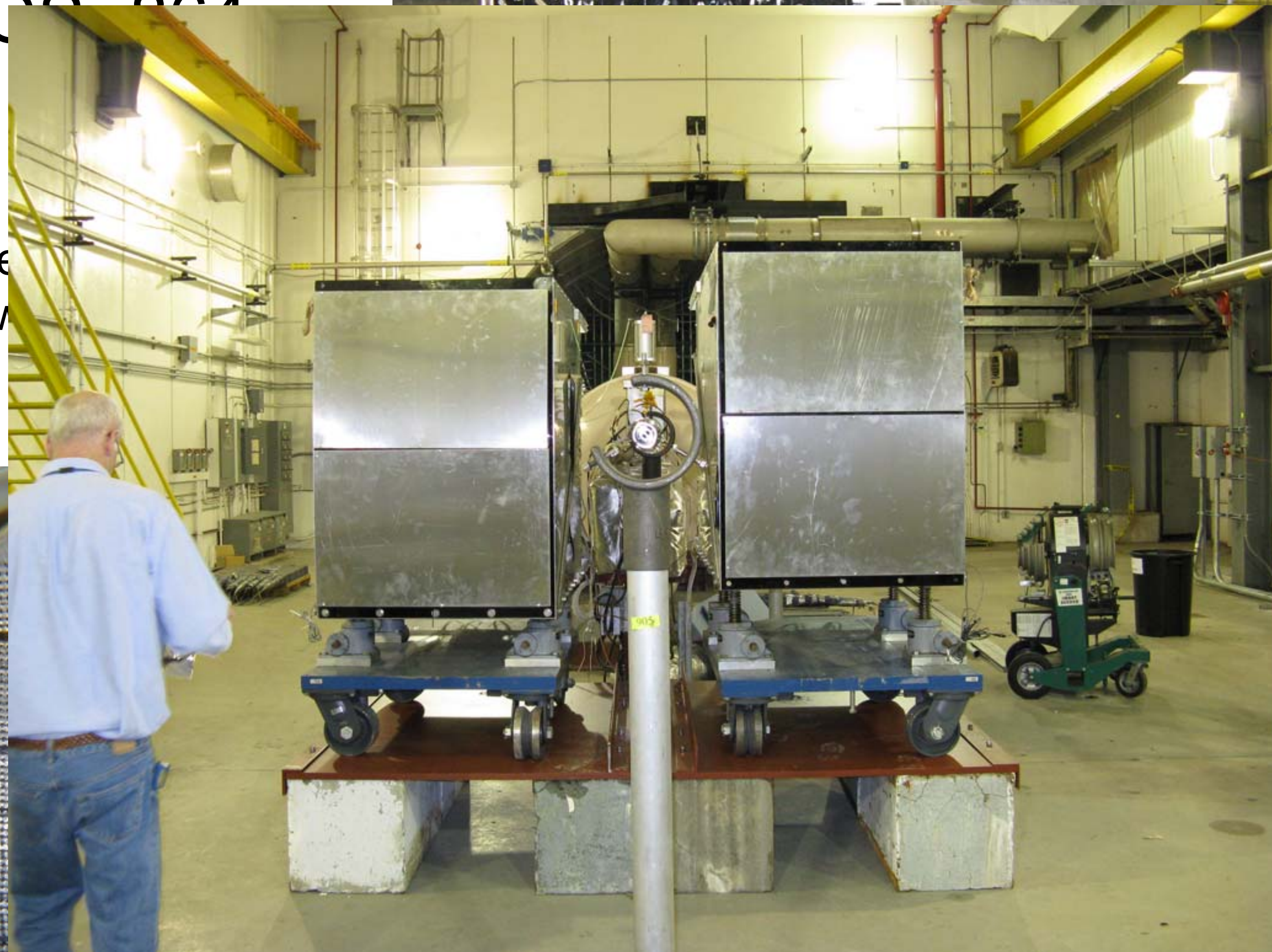
Run11 Goal (2)

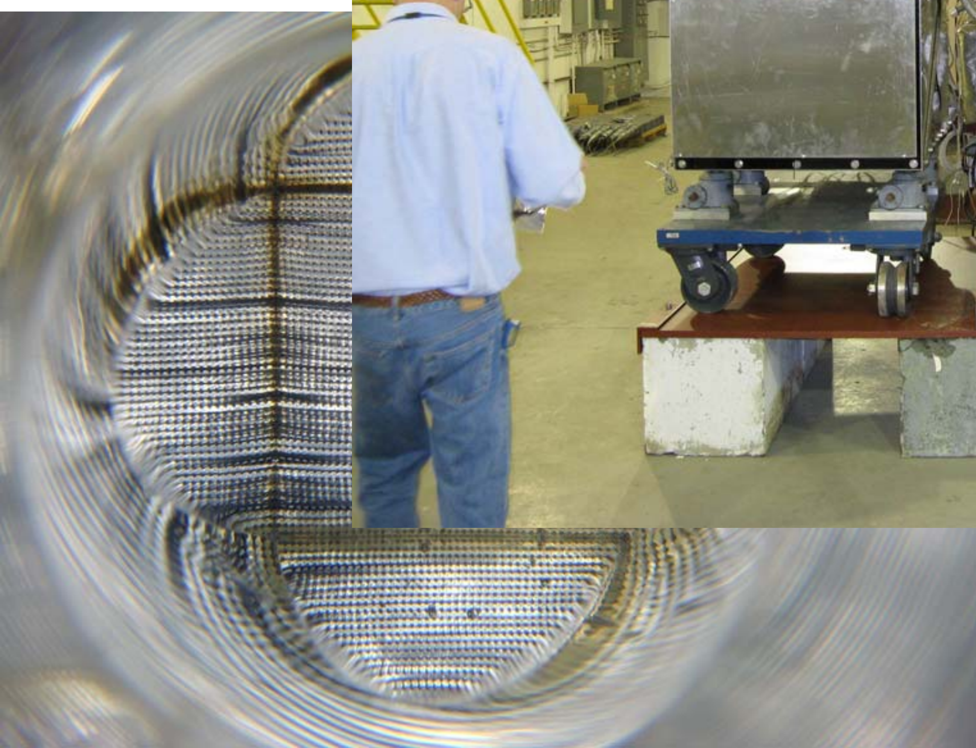
AnDY Hcal

from AC

Steel beam pipe

Be Beam pipe w





l module

ated by

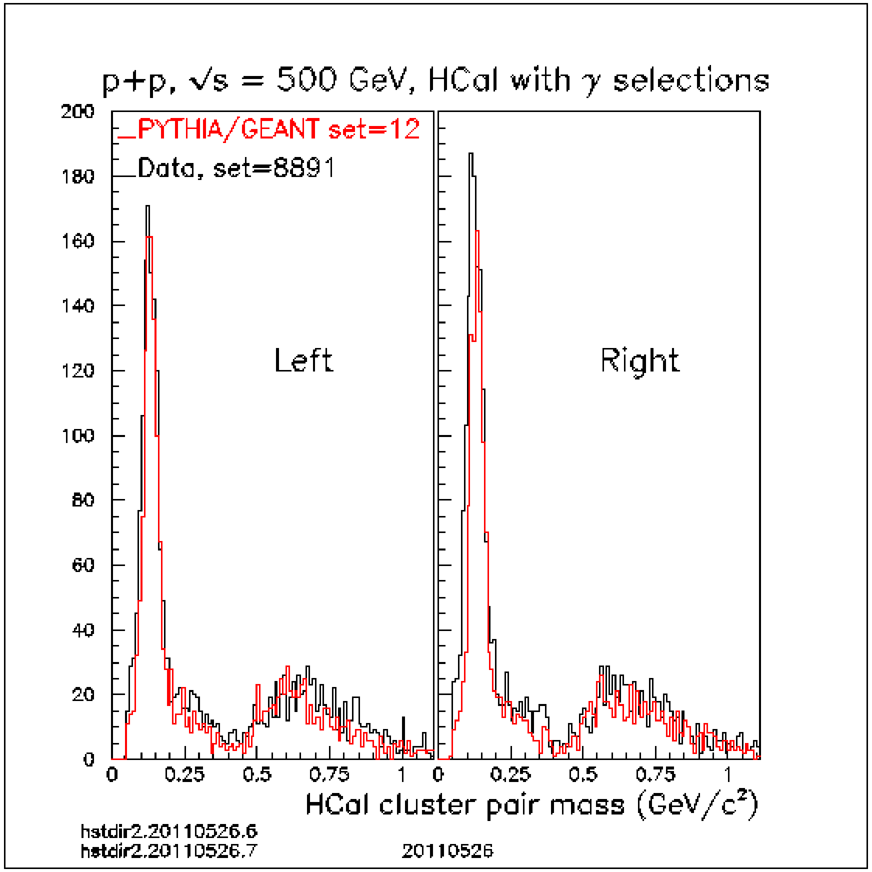
ay

View of single cell through light guide.

47x47 fiber scinti. array matrix in Pb.

Run11 Goal (2) – HCal calibration

HCal without ECal in front = π^0 in Hcal



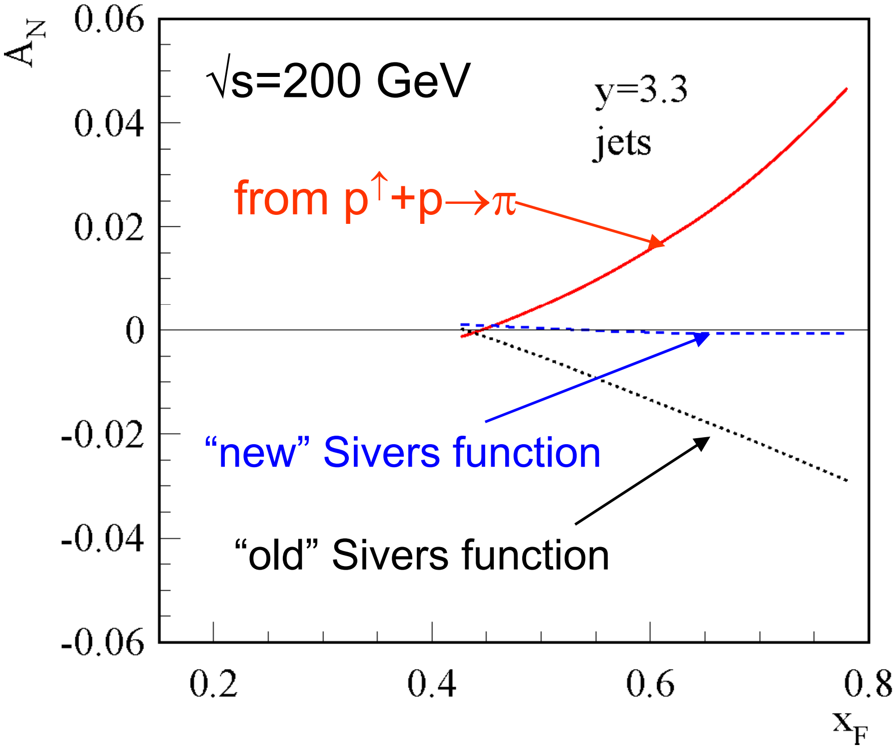
- 20M BBC collision data and 20M simulations events (PYTHIA+GEANT)
- Requirements:

  (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}<0.5.
- Hadronic response also under study with prospects for $\rho^{\pm}\rightarrow\pi^{\pm}\pi^{0}$ and $\omega\rightarrow\pi^{+}\pi^{-}\pi^{0}$ to correct h/γ differences

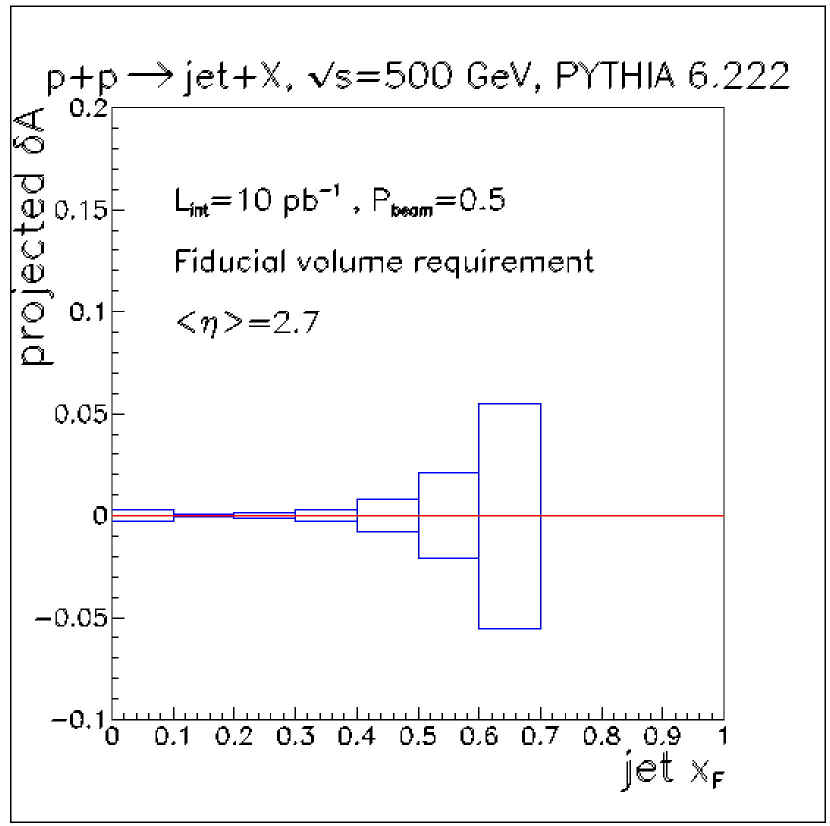
Data and simulation are in good agreement.

Run11 Goal (3) A_N for jets

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

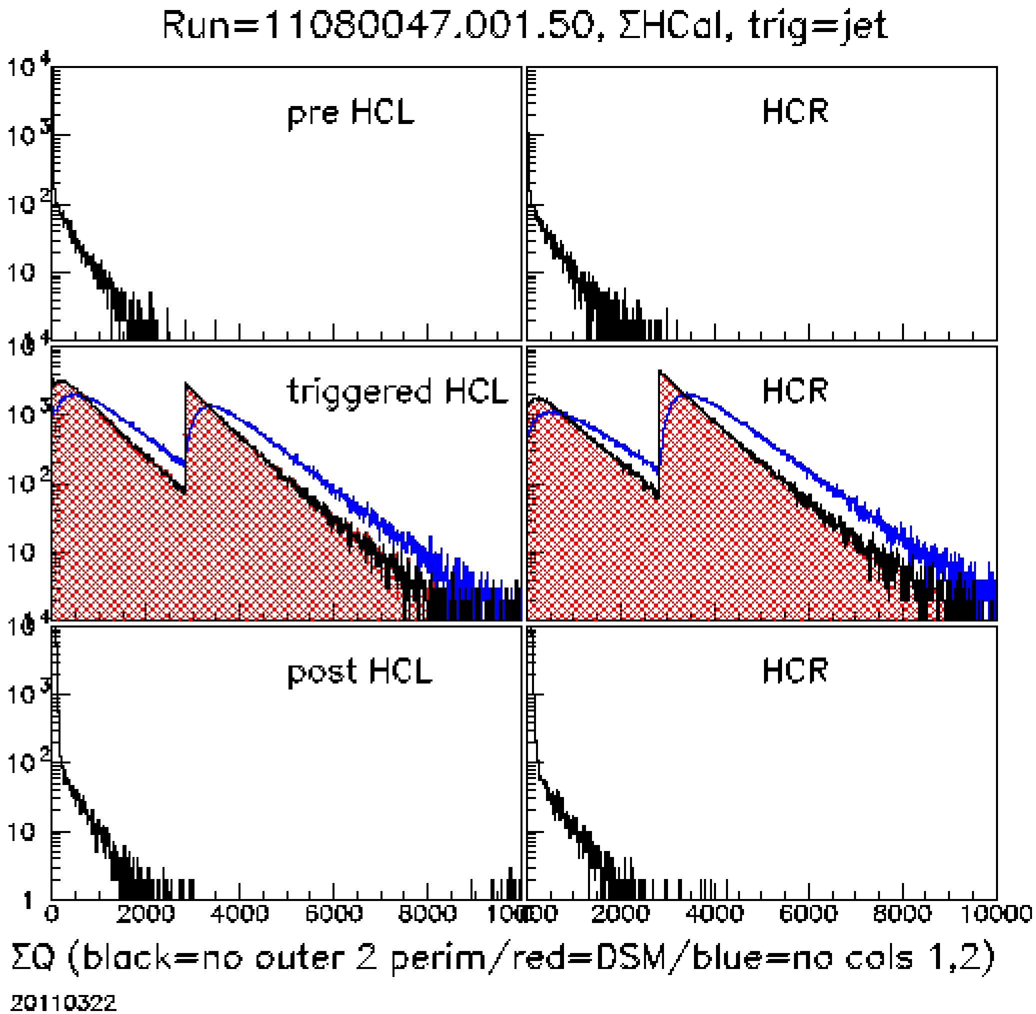


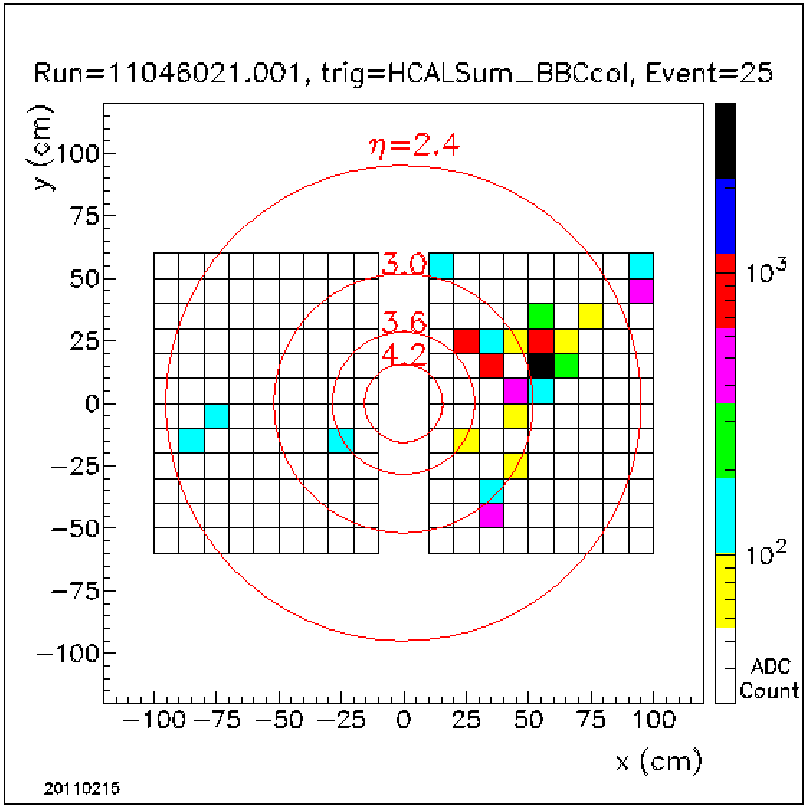
- With ~10/pb & P=50%, AnDY run11 can measure A_N(Jet).



Determine whether A_N(jet) is non-0 is a requirement for A_N(DY) sign-flip measurement

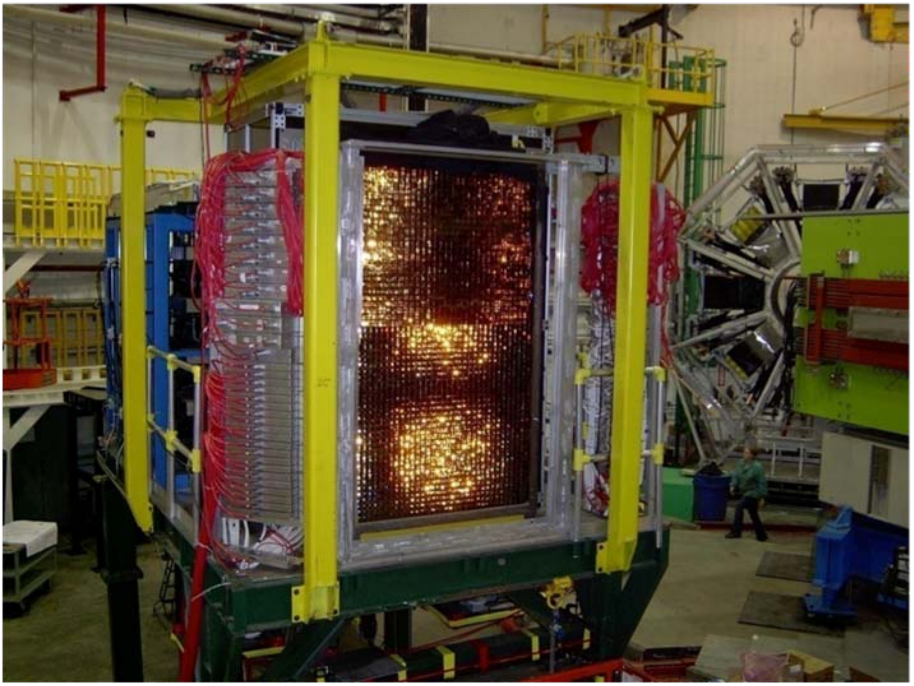
Run11 Goal (3) A_N for jets





More than 750M jet triggered events are recorded during Run11

Goal (4) - **BigCal @ JLAB to BNL**



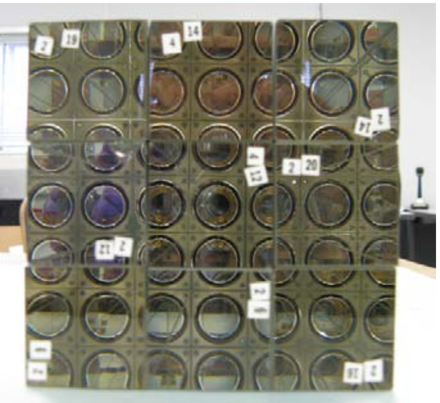
Some people from BigCal have joined AnDY!

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.

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

120 Yerevan cells from BigCal at BNL/IP2 and used during run11

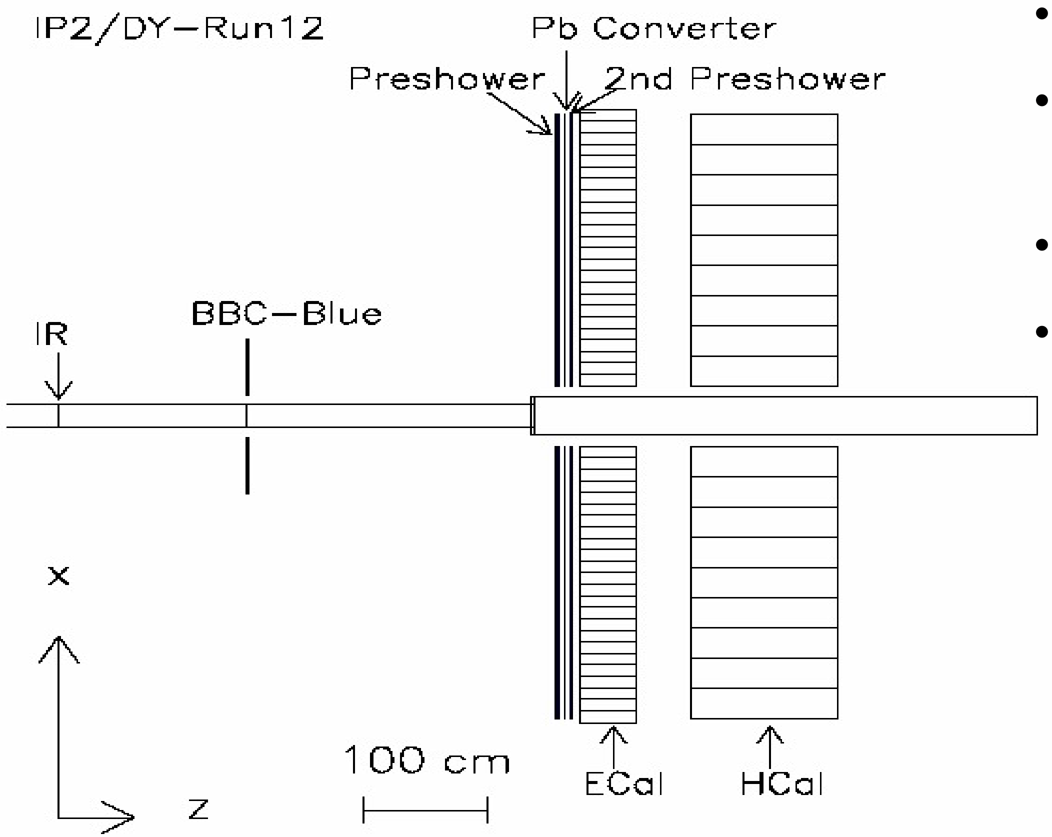


3x3 test stack of fully assembled cells
Two 7x7 modules installed at IP2 for run11

JLAB-BNL loan agreement signed
~600 coming to BNL next week.
Plan to complete moving all ~1700 cells by end of July
Plan to make new CW base

Schematic of detector for Run-12

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



- BBC and ZDC/ZDC-SMD
- HCal is existing 9x12 modules/side from E864 (NIM406,227)
- Full Ecal wall (lead glass)
- Full Pre-shower detector

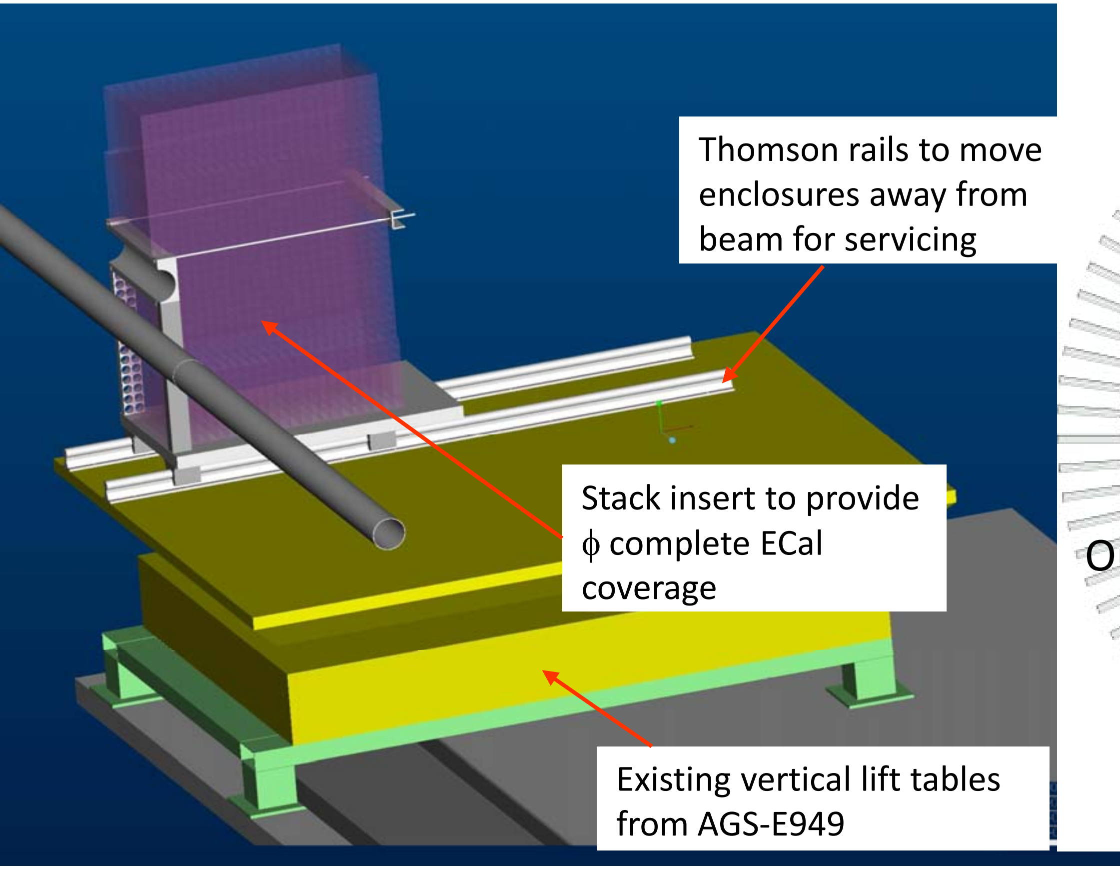
Goal:
1. Reconstruct J/ψ and Y
2. Measure continuum between them
3. Integrate 100 pb-1 recorded to see if we can measure A_N(DY) without magnet

9400 DY-events
$|A_N| \sim 0.1$ $\delta A_N \sim 0.02$

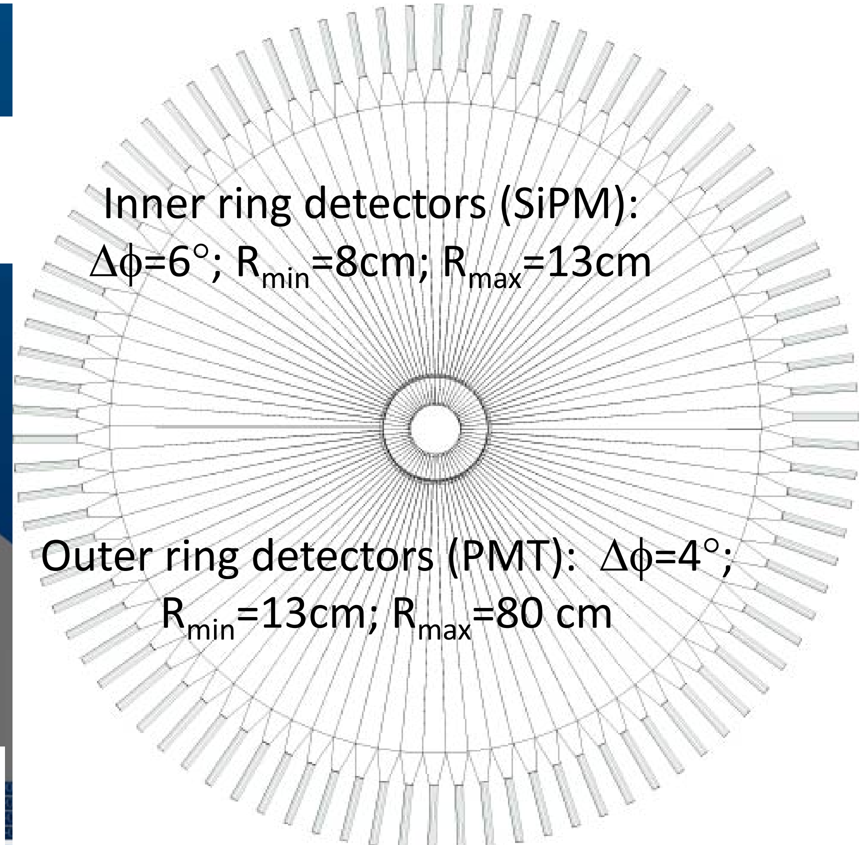
http://www.star.bnl.gov/~akio/ip2/topview2.jpeg

Run12 plan

- ~1700 EM calorimeter lead glass cells from “Bigcal”.
- Pre-shower detector



Ecal stand concept for run12



A pre-shower concept for run12

AnDY costs – Run 12

detector	ECal	PS	HCal
mechanical	$ 11k	$ 58k	$5K
readout electronics	$256k	$ 48k	$5k
HV and bases	$218k (CW bases)	$ 9k (control)	$3k (control)
cables	$ 80k	$ 26k	$2k
total	$555k	$141k	$15k

Investment for RHIC/Jlab Future

- Ecal's new CW bases will be compatible with Jlab future program
- Hcal/PS/Electronics will likely be used in STAR after run13

Funding proposal & BNL review in coming months

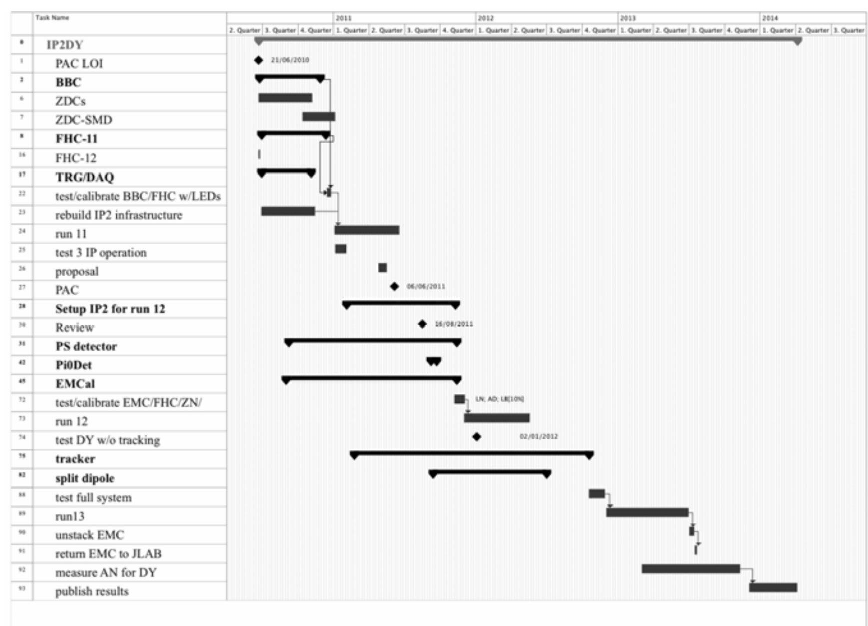
AnDY Timeline

Run12 data taking with no magnet

Run13 data taking with magnet

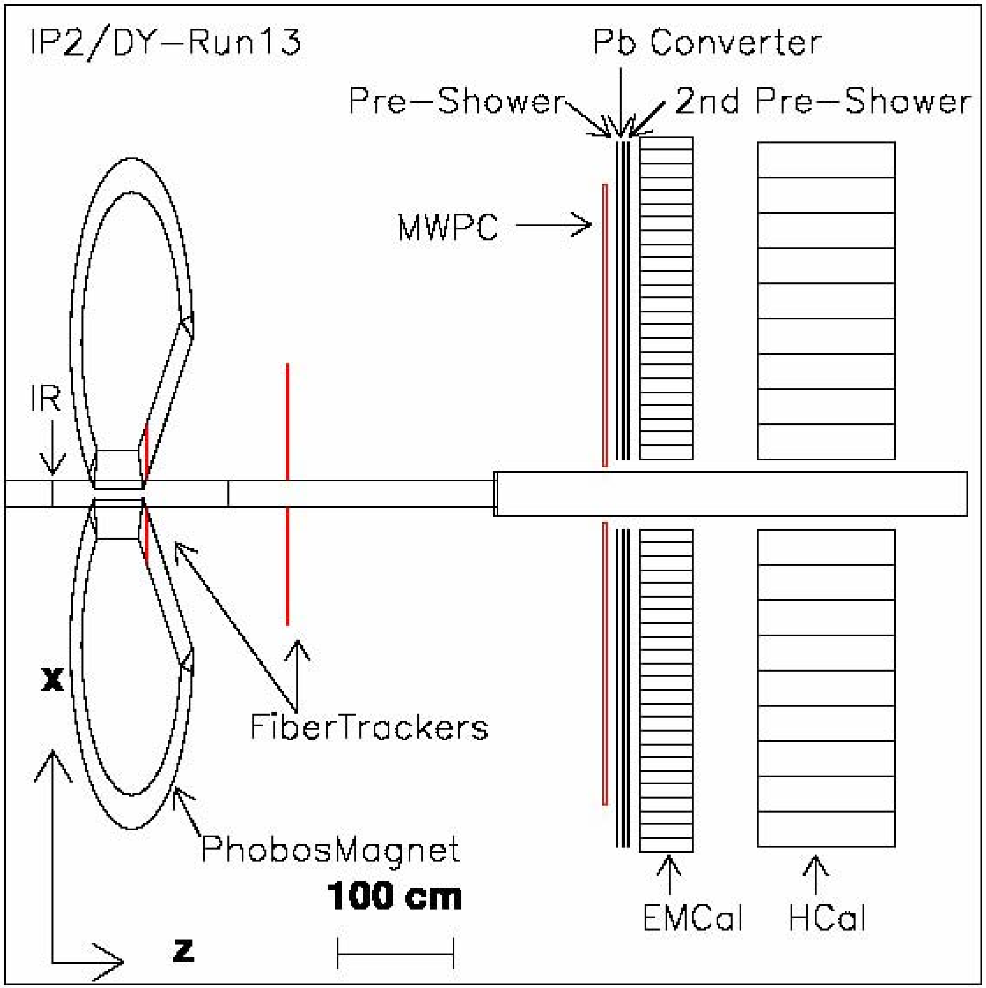
Return BigCal by 2014

Electron Cooling at IP2 2014~



Schematic of detector for Run-13

(Uses PHOBOS Split Dipole for charge sign)



- BBC and ZDC/ZDC-SMD
- Hcal is existing 9x12 modules from E864 (NIM406,227)
- Ecal (lead glass)
- Pre-shower detectors
- PHOBOS split-dipole magnetic field in GEANT model
- Fiber tracker stations and MWPC require construction

Goal:

Integrate 150 pb-1 recorded to see whether tracking significantly improves signal/background for A_N(DY)

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

Summary

- A_NDY is the first attempt to access forward rapidity Drell-Yan process at polarized p+p collisions at RHIC.
- Successful Run11
  - RHIC can operate 3IR with minimal impact on PHENIX/STAR
  - RHIC can deliver 10/pb/week at IP2
  - Hcal calibrated
  - BigCal (EMCal) on the way to BNL/IP2
  - Jet Analyzing power measurement
- PAC approval for A_NDY
  - Funding proposal & BNL review in coming months
- Run12 & 13 to get ~100/pb each at 500GeV to observe J/ψ,ϒ and dilepton continuum between them
  - Important feedback to PHENIX & STAR decadal plans and EIC for transverse spin physics as well as low-x physics

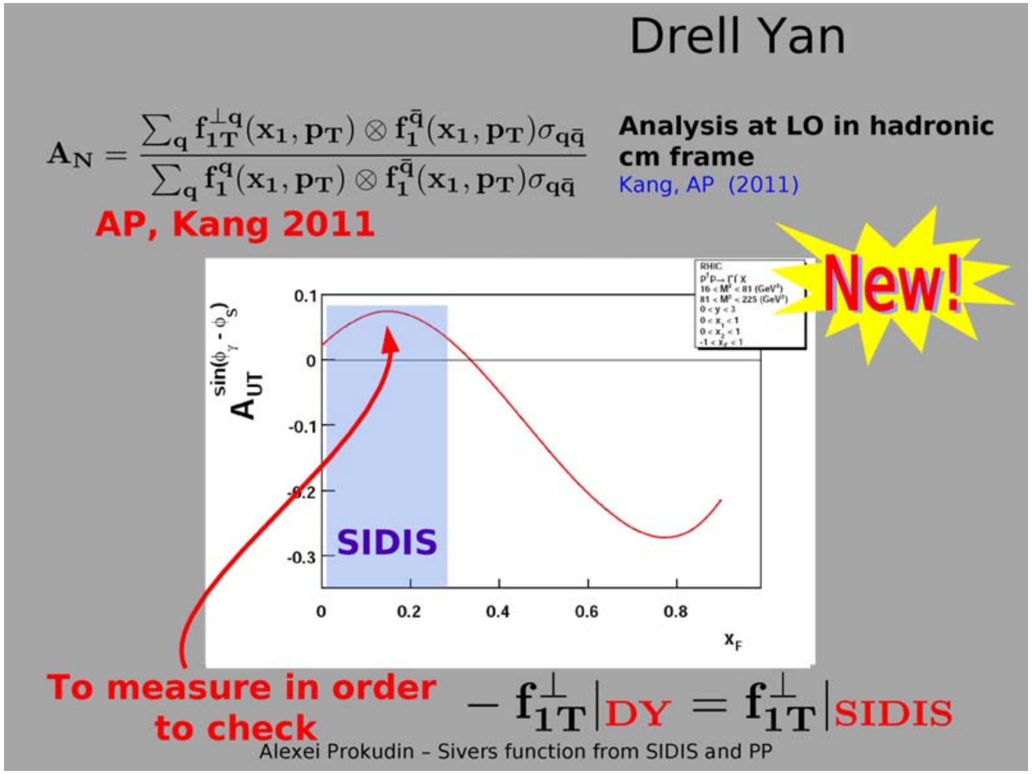
Backup

Theory prediction for Drell-Yan process

- New development

•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

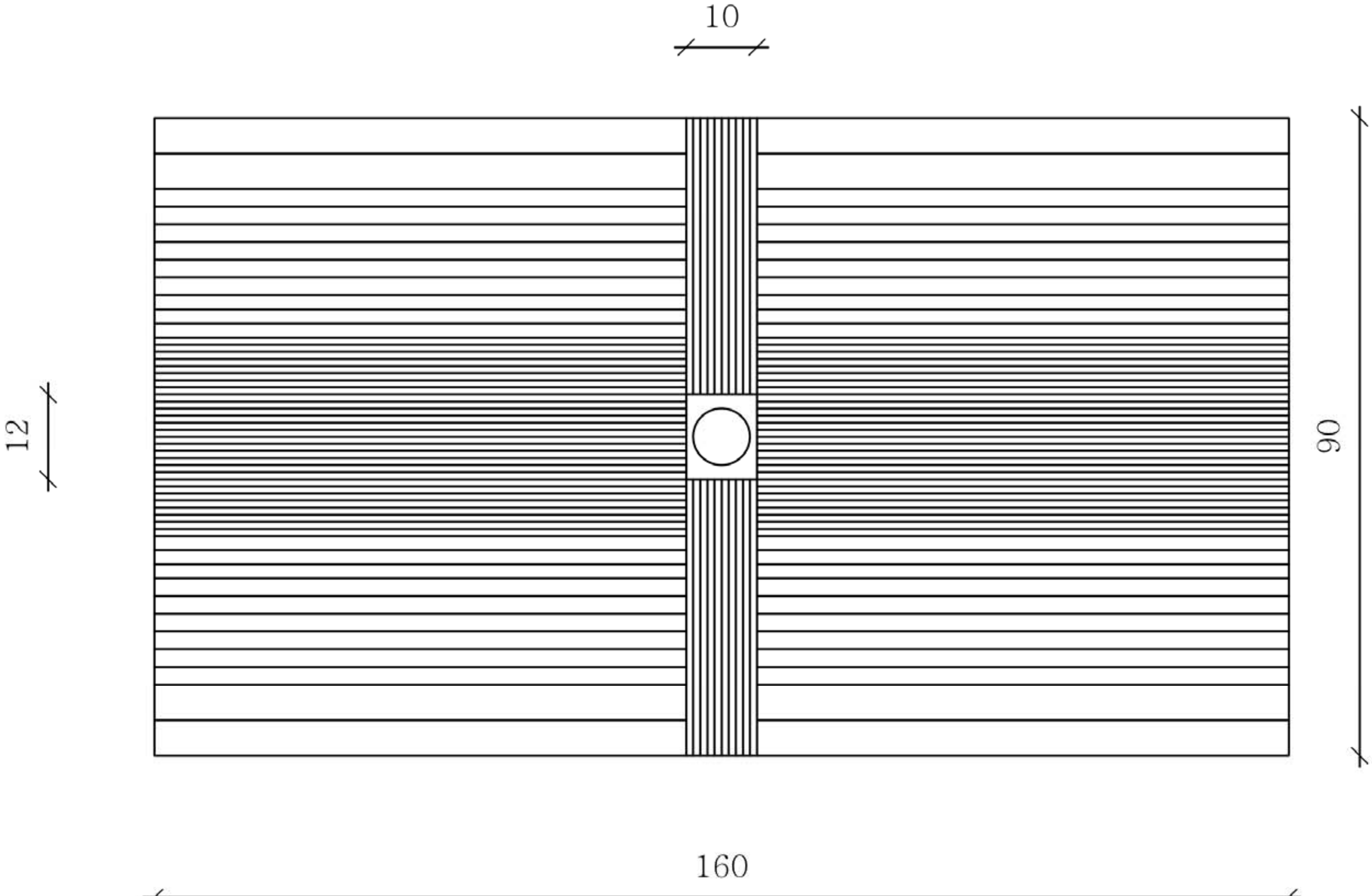


Combined analysis of SIDIS and RHIC pion production leads to the conclusion that the u-quark Sivers function has a node at x~0.4

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

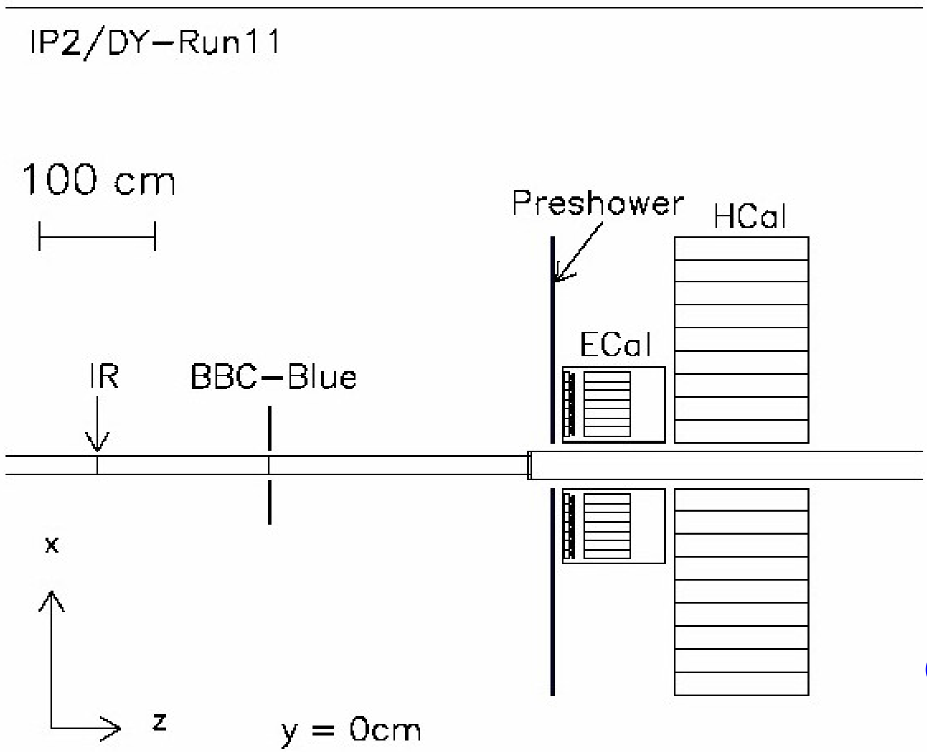
Essential to test Dell-Yan process in this region

Another Pre-shower concept



Schematic of detector for Run-11

Happening right now



- BBC and ZDC/ZDC-SMD
- HCal is existing 9x12 modules from E864 (NIM406,227)
- Small (~120 cells) Ecal
- Pre-shower detector

Goal:

1. Establish impact of 3 IR operation on PHENIX and STAR luminosity
2. Calibrate Hcal absolute energy scale with ρ.
3. Measure hadronic background to bench mark MC further
4. A_N for jet ?

DY at Colliders? ⌠+⌠- or e+e- ?

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

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Received 18 February 1980

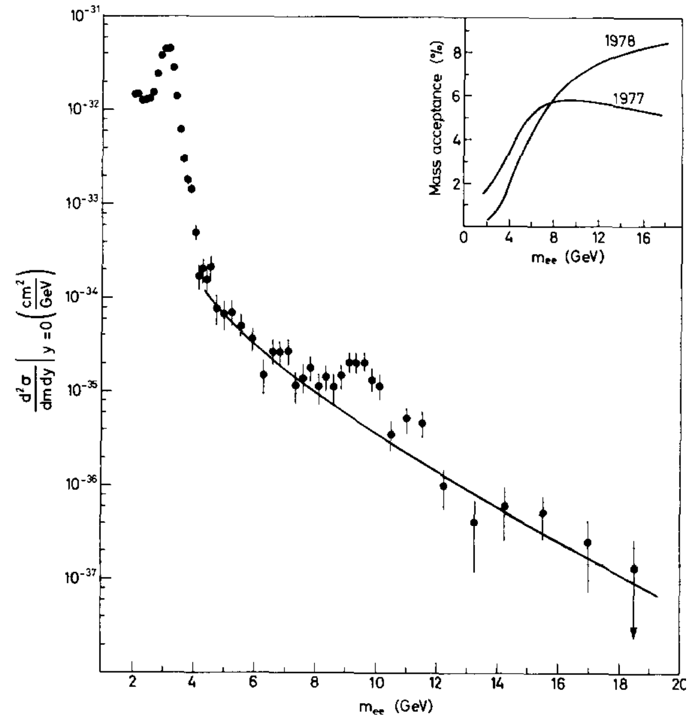


Fig. 1. The cross section $(d^2\sigma/dm\,dy)_{y=0}$ versus mass for the data at $\sqrt{s}$ = 53 and 63 GeV combined. The curve is a result of the fit to the continuum displayed in fig. 2. The inset show the mass acceptance for "1977" and "1978" triggers and geometrical configurations calculated for 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.

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 [PLB79 (1979) 398] did use magnet

Most fixed target experiments done ⌠+⌠- DY

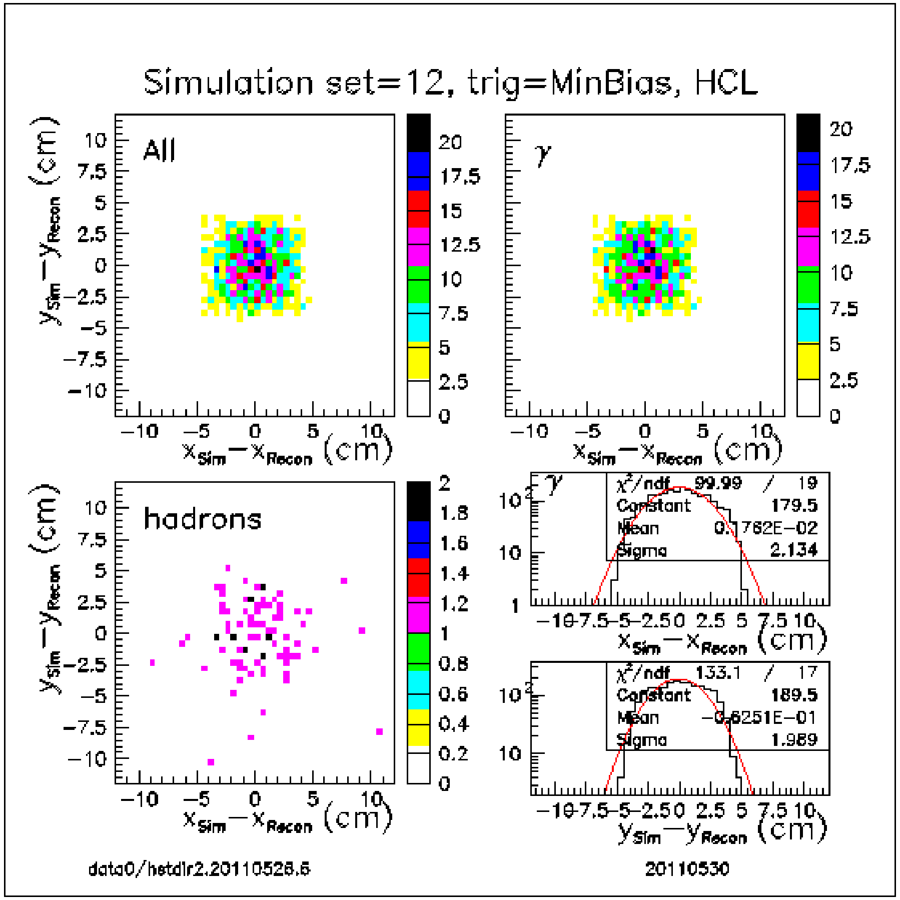
Large x_F DY at collider breaks new ground

IP2 in August, 2010

Remnants of the BRAHMS Experiment

Hadronic calorimeter calibration

- Association studies in PYTHIA+GEANT simulation.



- 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;

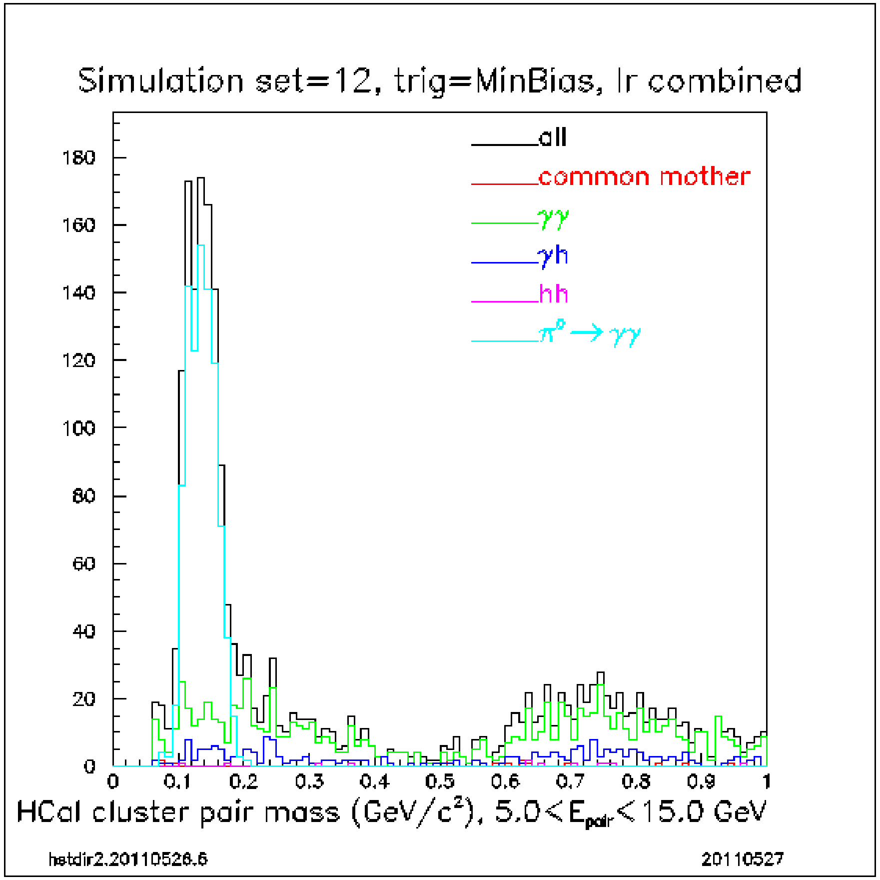
(6) M_{pair}<0.5 GeV;

(7)(6) z_{pair}<0.5.

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

Hadronic calorimeter calibration

- Pair mass from photon-like clusters in Hcal (simulation).



- 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;

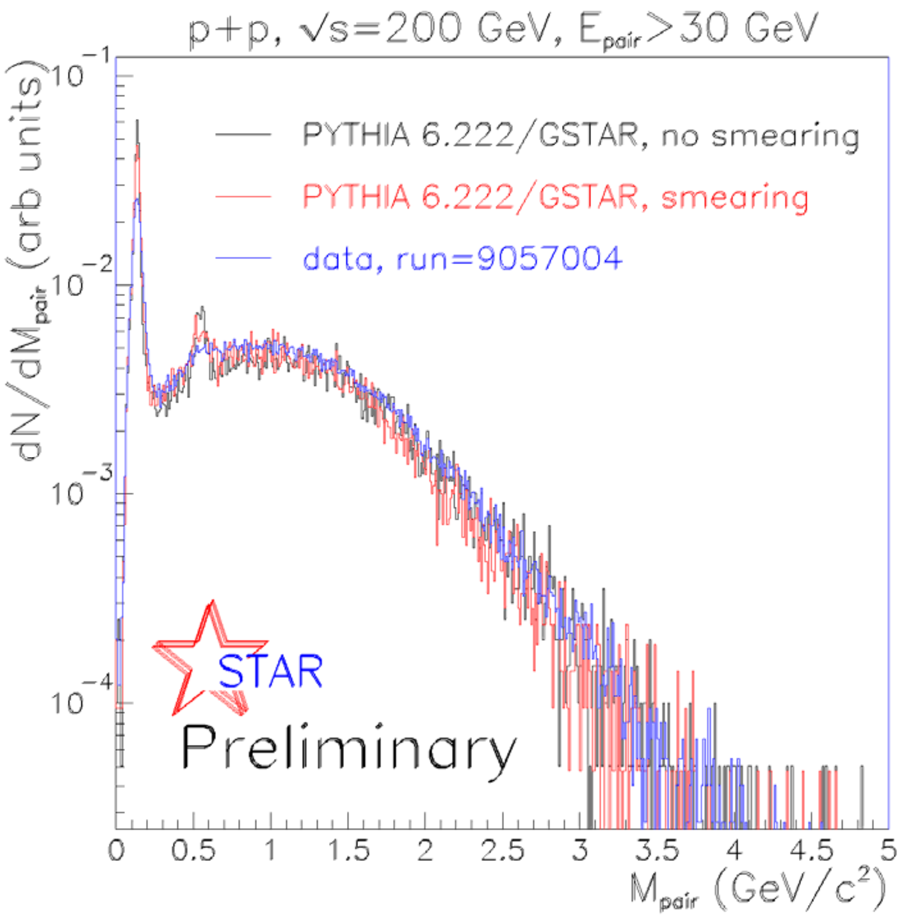
(5) E_{pair}>5 GeV;

(6) M_{pair}<0.5 GeV;

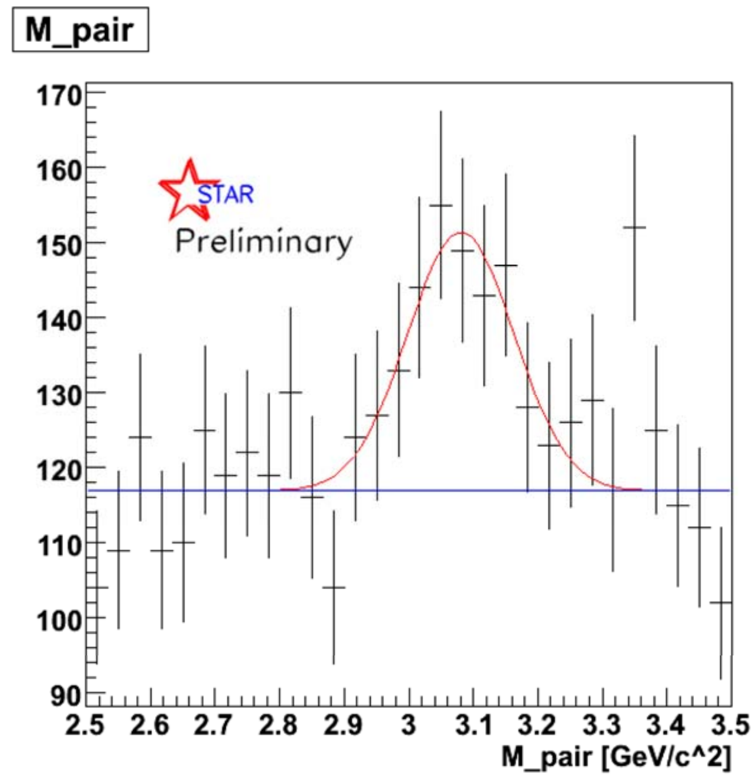
(7) z_{pair}<0.4.

916/1245 events with M_{pair}<0.22 GeV/c^2 are from $\pi^0\rightarrow\gamma\gamma$ pairs.

e^+e^- pairs: we can see J/ψ in bare Ecal at STAR



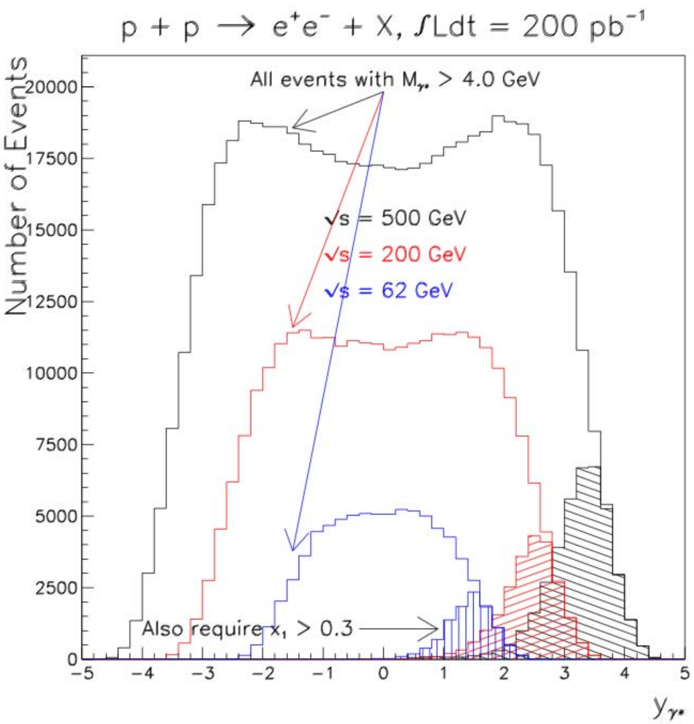
arXiv:0906.2332



arXiv:0907.4396

- pair mass backgrounds well modeled (small sample here)
- J/ψ→e+e- observation at $<x_F>\sim0.67$ emboldens DY consideration

Requirements for e+e- DY at RHIC



High luminosity ~>150/pb (similar to W program)

Prefer 500GeV over 200GeV

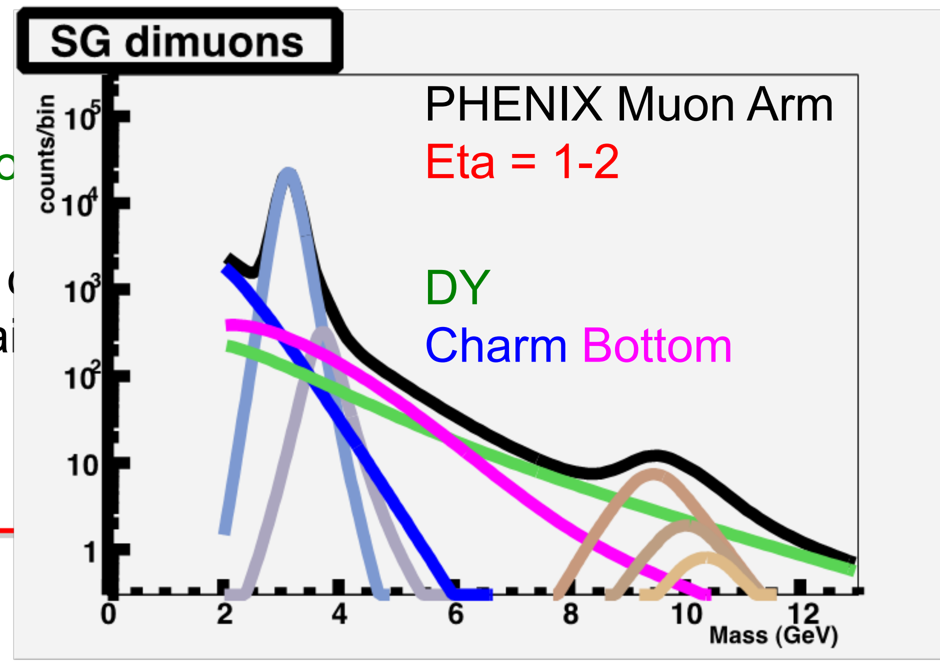
Forward (eta ~ 4) detector

Sizable A_N at high x_F

Less charm & bottom backgrounds

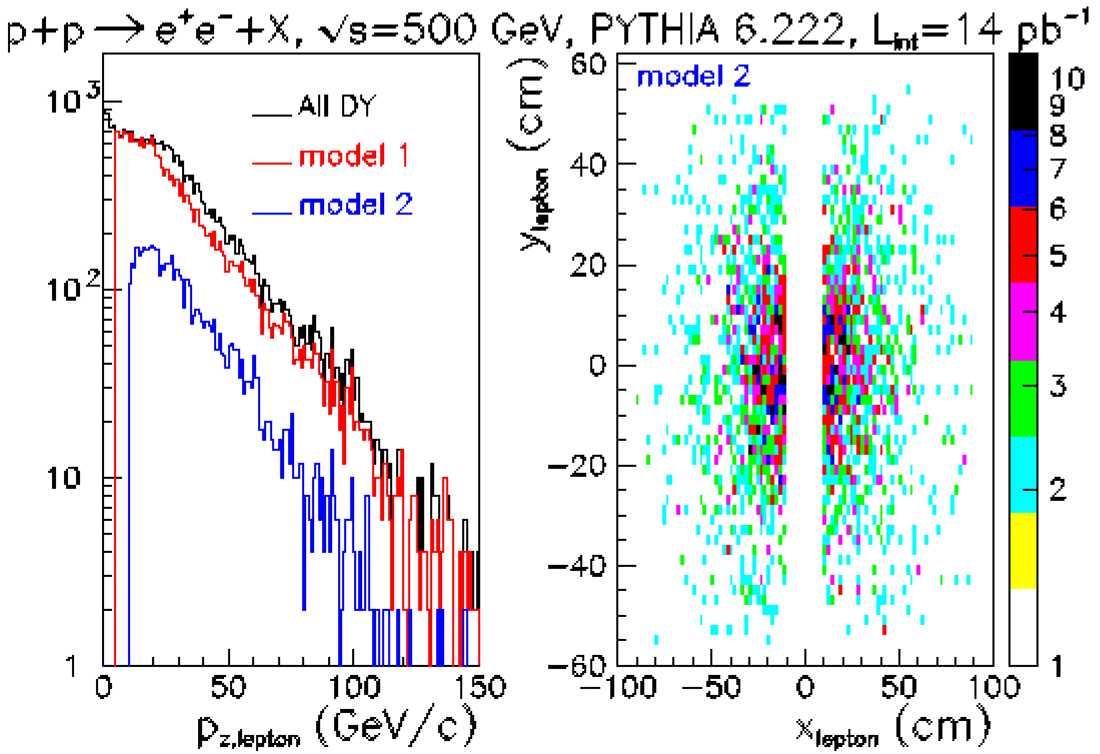
Go … on

Is (… ign
pai



DY : ~7 x 10^{-5} mb
@ 500GeV

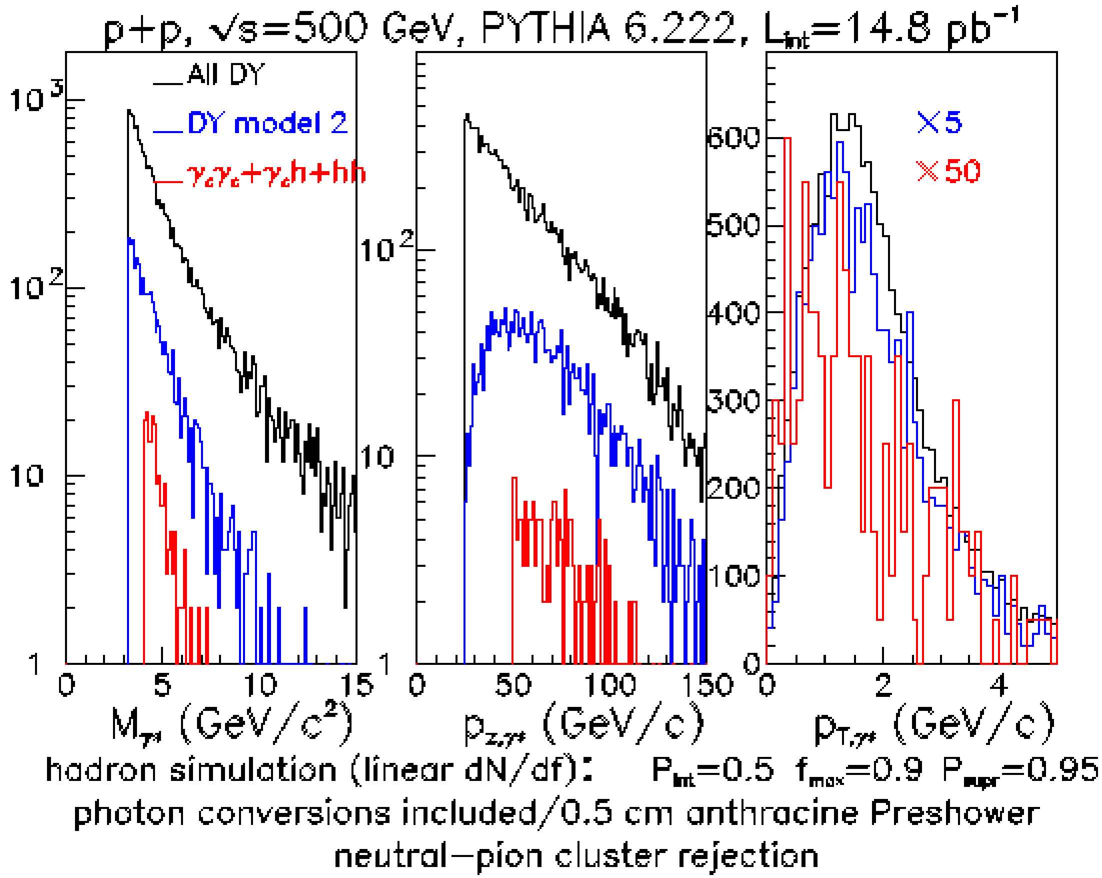
Lepton daughters from ©*



Most important contributions for ©* at x_F>0.1 at □s=500 GeV …

- high energy electrons and positrons (E>10 GeV)
- require detection at very forward angles (eta ~ 4)
- $e^+(e^-)$ from ©* little affected by “modest” isolation (20mr half-angle cone)
- best solution for charge sign would be a dipole magnet (difficult for collider)

Hadron Background Estimate



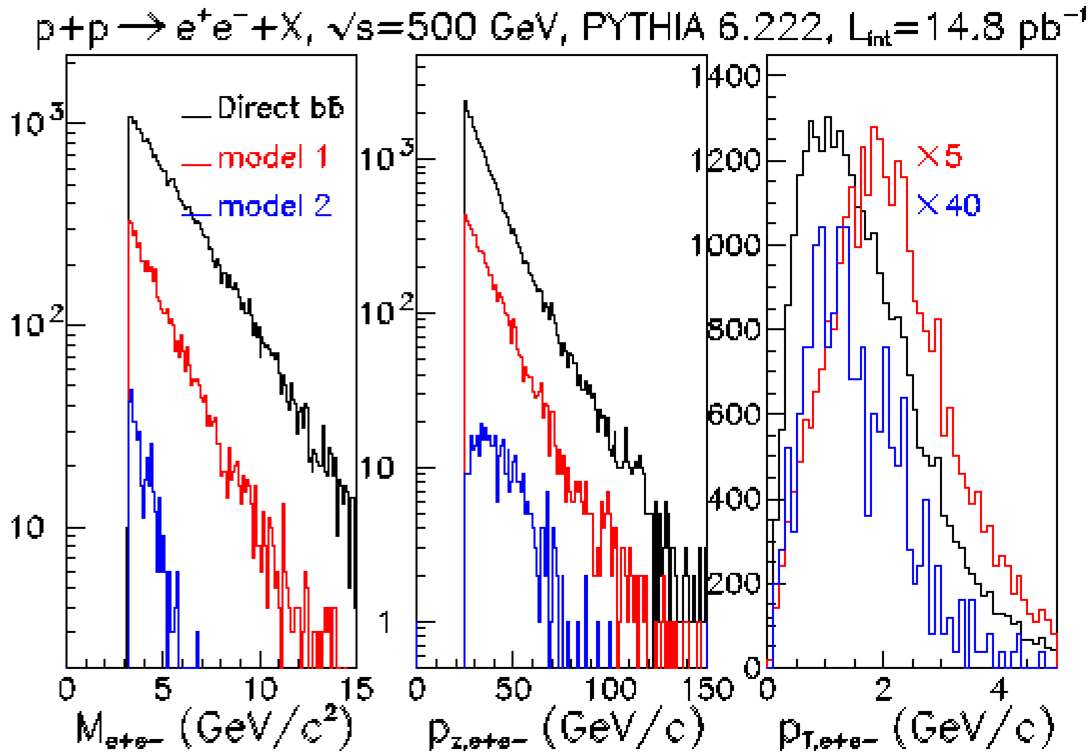
Note scale of bkgd

Simulation with PYTHIA + fast detector response simulation (tuned by GEANT)

- Conversion photons significantly reduced by □0□©© reconstruction in ECAL / veto
- 2 layer Pre-shower detector for e/h and e/gamma identification
- Hcal veto for e/h identification

e+e- bkgd from open beauty at large x_F

Note scale for same L

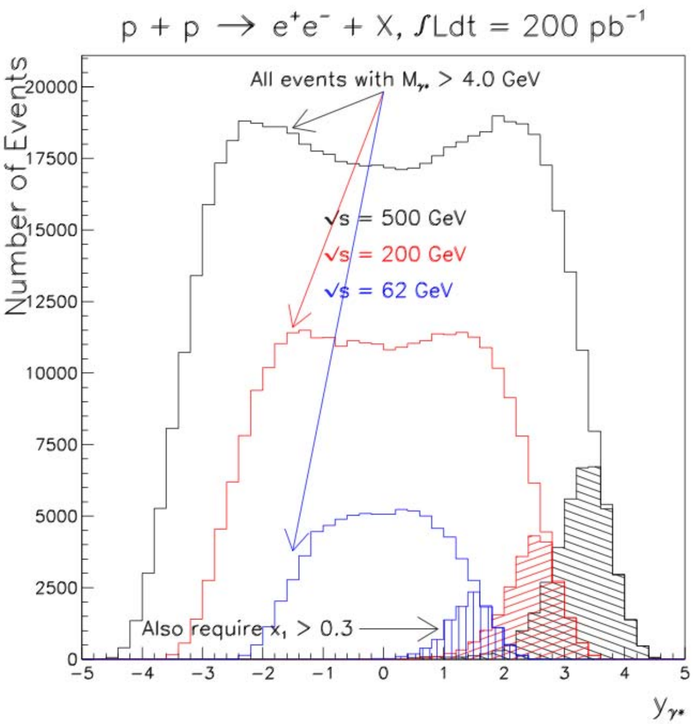


Model 1 = EMcal $(2m)^2$ / $(0.2m)^2$ beam hole at 10m / no magnetic field

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

- open beauty dileptons are a background 2x larger than DY for PHENIX ⌠+⌠□
- direct production of open beauty results in ~15% background at large x_F

e+e- DY at RHIC seems possible



High luminosity ~>150/pb (similar to W program)

Prefer 500GeV over 200GeV

Forward (eta ~ 4) detector

Sizable A_N at high x_F

Less charm & bottom backgrounds ~15%

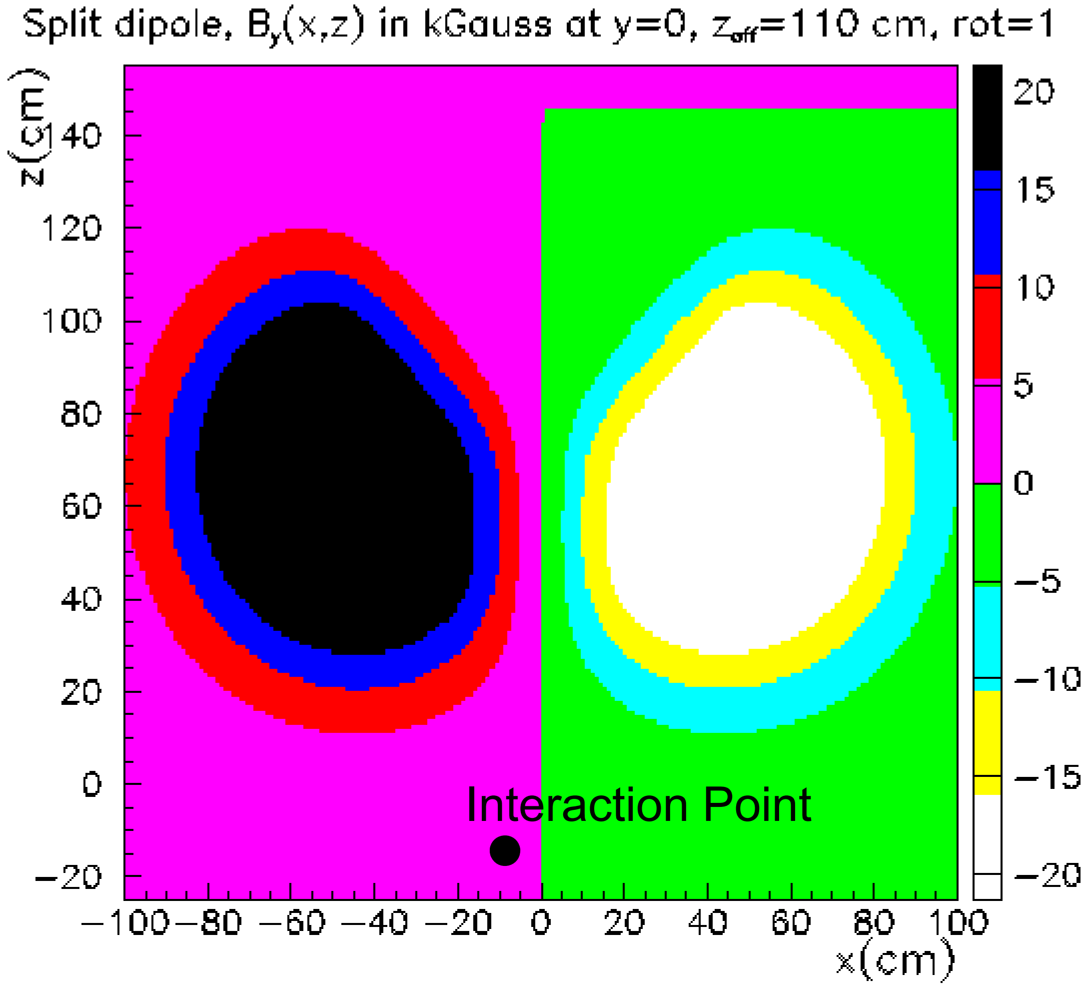
Less QCD backgrounds <15%

Good background (e/h and e/gamma) separation

Is charge sign discrimination required for like-sign pair subtraction?

DY : ~7 x 10^{-5} mb @ 500GeV → 10^6 → Hadronic : ~30mb

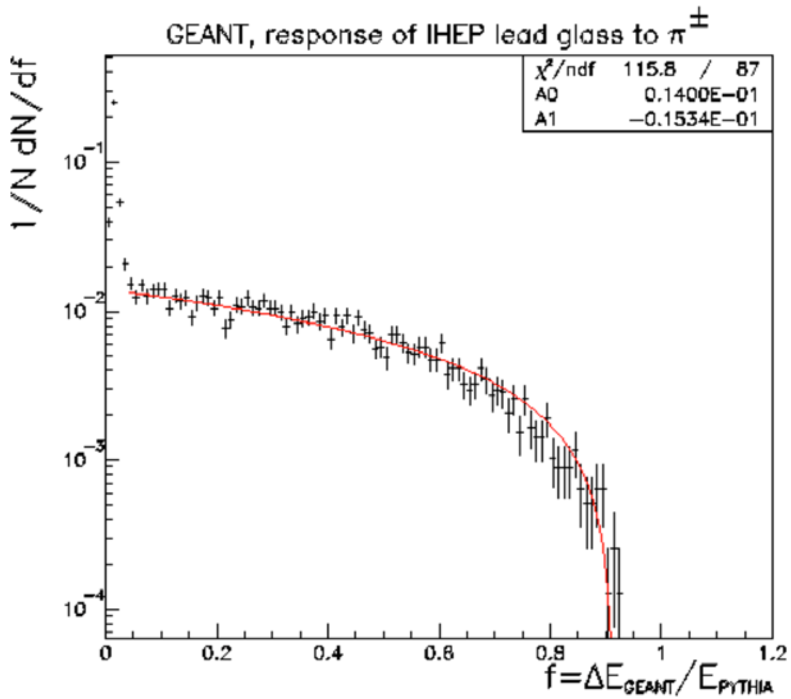
Magnetic Field Used for Charge Sign Simulations



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

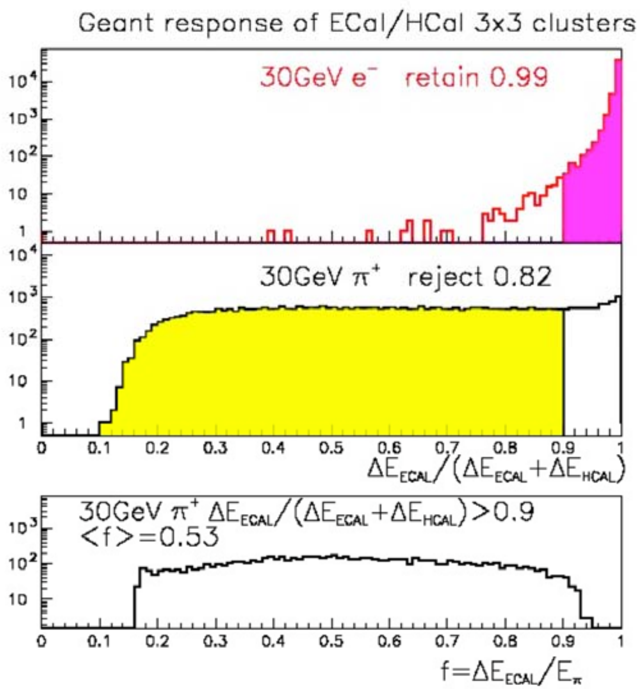
- The plan is to reuse the split-dipole magnet at IP2 designed, built and operated by the PHOBOS collaboration.
- PHOBOS provided their field map and geometry files for GEANT for simulation studies.
- Compared to use at IP10, split-dipole is rotated by 180^o around vertical axis, to move aperture restriction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

GEANT response of PbGl for sims



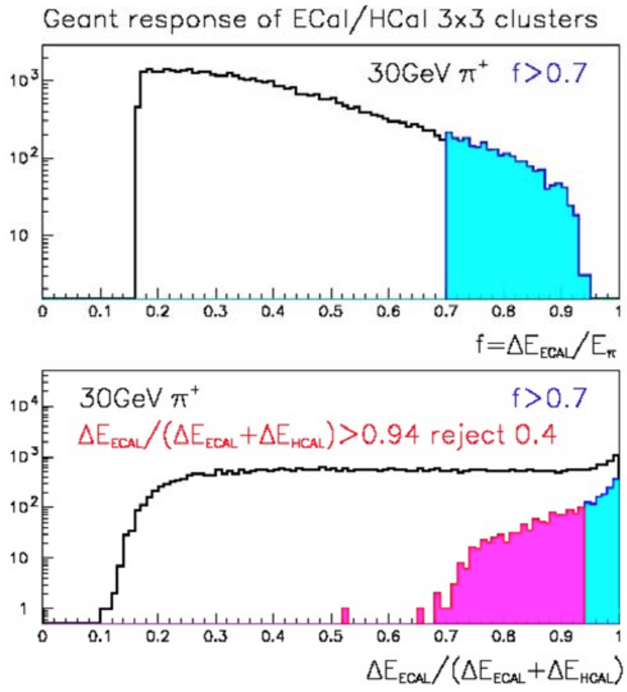
GEANT simulation of energy deposited in an EMcal built from 3.8 cm × 3.8 cm × 45 cm lead glass bars. Charged pions with E>15 GeV are used in this simulation. The fraction of the incident pion energy deposited in the EMcal is *f*. The dN/d*f* distribution is well represented by a linear function of *f*, at values larger than the peak from minimum-ionizing particles.

Ecal and Hcal response - cuts



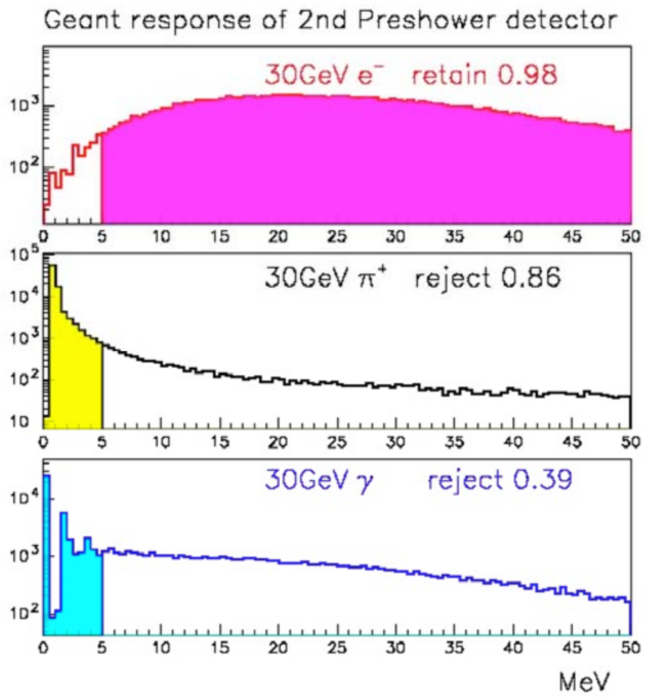
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV electrons and charged pions. A 3x3 cluster sum of deposited energy forms the ratio R=DE(EMcal)/(DE(EMcal)+DE(Hcal)) shown in top plot. With R>0.9 cut, EMcal+Hcal can reject 82% of hadrons while retaining 99% of electrons. The bottom plot shows distribution of f for hadrons that survive R>0.9 cut.

Ecal and Hcal Response - cuts



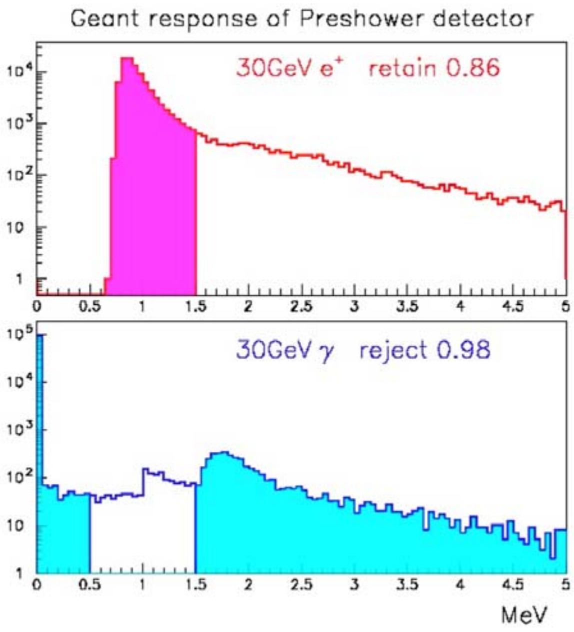
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV charged pions. The top plot shows the distribution of f in EMcal 3x3 clusters around the high tower. The bottom plot shows the ratio R=DE(EMcal)/(DE(EMcal)+DE(Hcal)). Blue shaded area is for hadrons surviving cut f>0.7. Red shaded area is hadrons which can be identified using Hcal by R>0.94 cut. This gives 40% hadron rejection for hadrons with f>0.7.

Preshower Cuts



GEANT simulation of 2nd pre-shower detector made of 0.5cm thick plastic scintillation counter placed after 1cm Pb converter. Responses for 30GeV electrons, charged pion and photons are simulated. A cut of energy deposit in the 2nd pre-shower above 5MeV will retain 98% of electrons, while rejecting 85% of pions and 39% of photons.

Preshower cuts

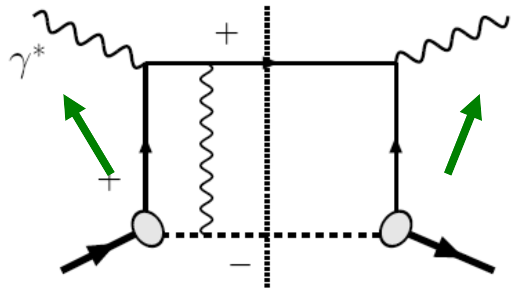


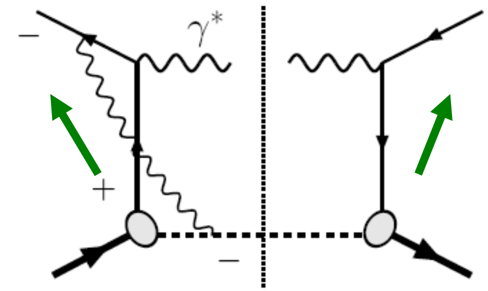
GEANT simulation of a pre-shower detector made of 0.5cm thick plastic scintillation counter. Responses for 30GeV electrons and photons are simulated. A cut of 0.5MeV < dE < 1.5MeV will retain 86% of electrons, while rejecting 98% photons including ones converted to e+e- pairs in beam pipe and preshower detector itself.

Attractive vs Repulsive Sivers Effects

Unique Prediction of Gauge Theory !
originally predicted by Collins!

Simple QED example:

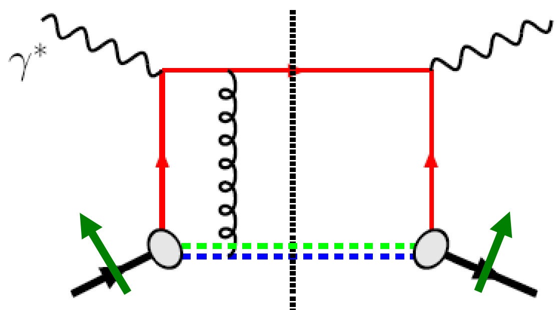


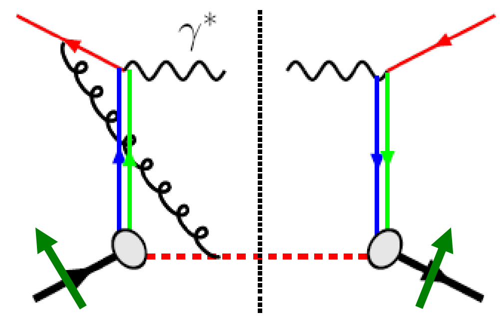


DIS: attractive

Drell-Yan: repulsive

Same in QCD:





As a result:

$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

Transverse Spin Drell-Yan Physics at RHIC (2007)

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

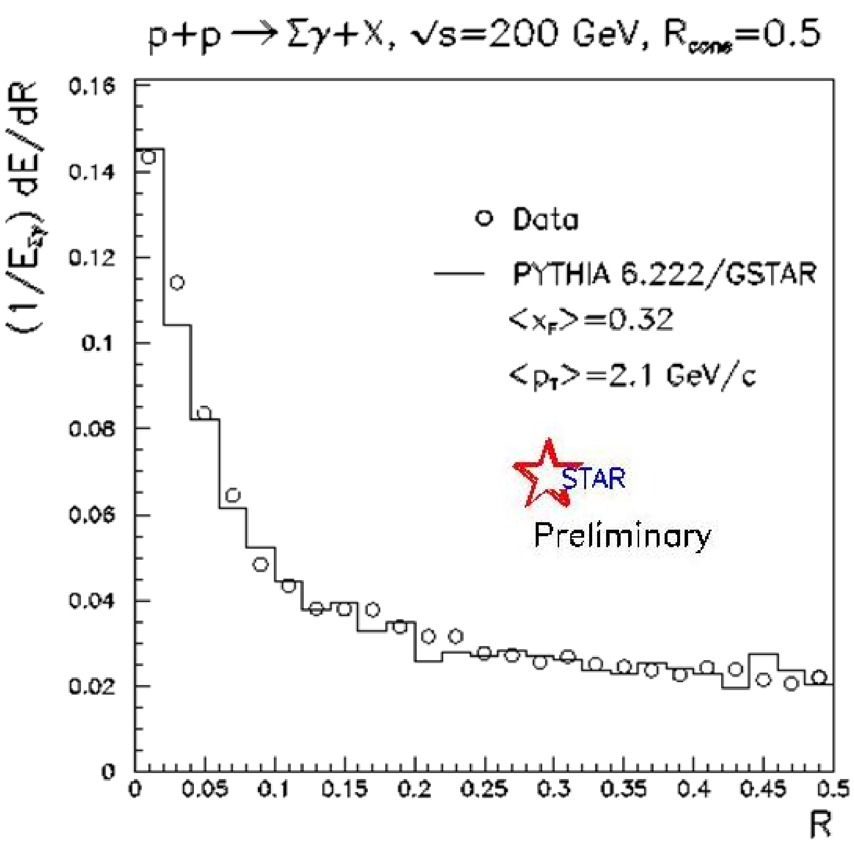
"jet-like" event measurements

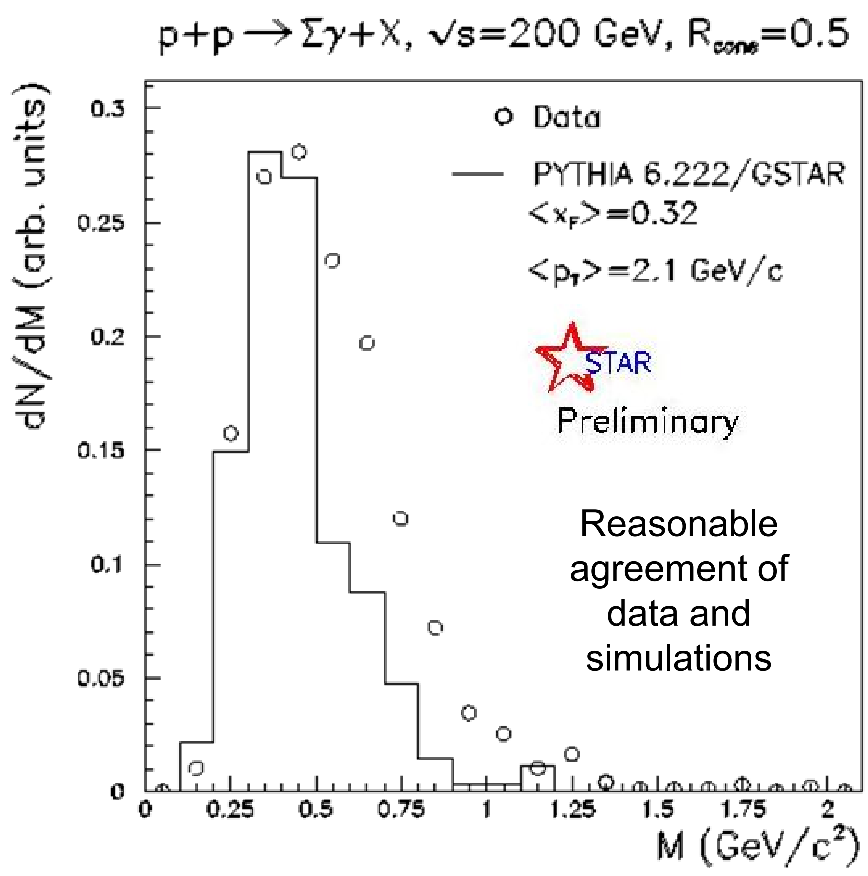
Obtained with the FMS; event selection done with:

- >15 cells with energy > 0.4GeV in the event (no single pions in the event sample)
- cone radius = 0.5 (eta-phi space)
- "Jet-like" p_T > 1 GeV/c ; x_F > 0.2
- 2 perimeter fiducial volume cut (small/large cells)

arXiV:0901.2828

N. Poljak for the STAR collaboration





Reasonable agreement of data and simulations