Future Drell-Yan Experiments at RHIC

Relativistic Heavy Ion Collider

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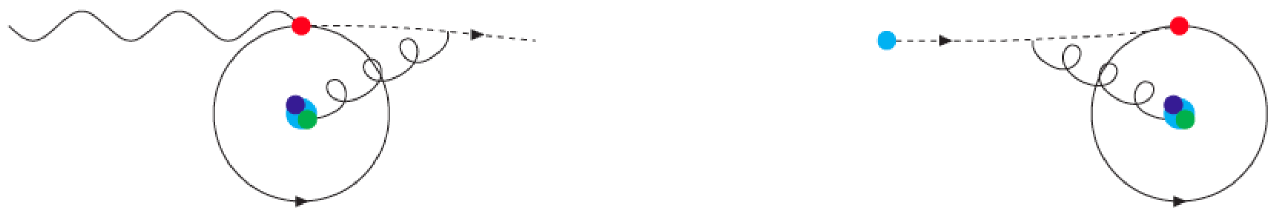
IWHSS Paris 2011

Contents

- Very short introduction
- DY at RHIC
- PHENIX decadal plan
- STAR decadal plan
- A_NDY @ IP2
- Internal target (FermiLab E906 @ BNL)
- Conclusions

The Sign Change

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



- 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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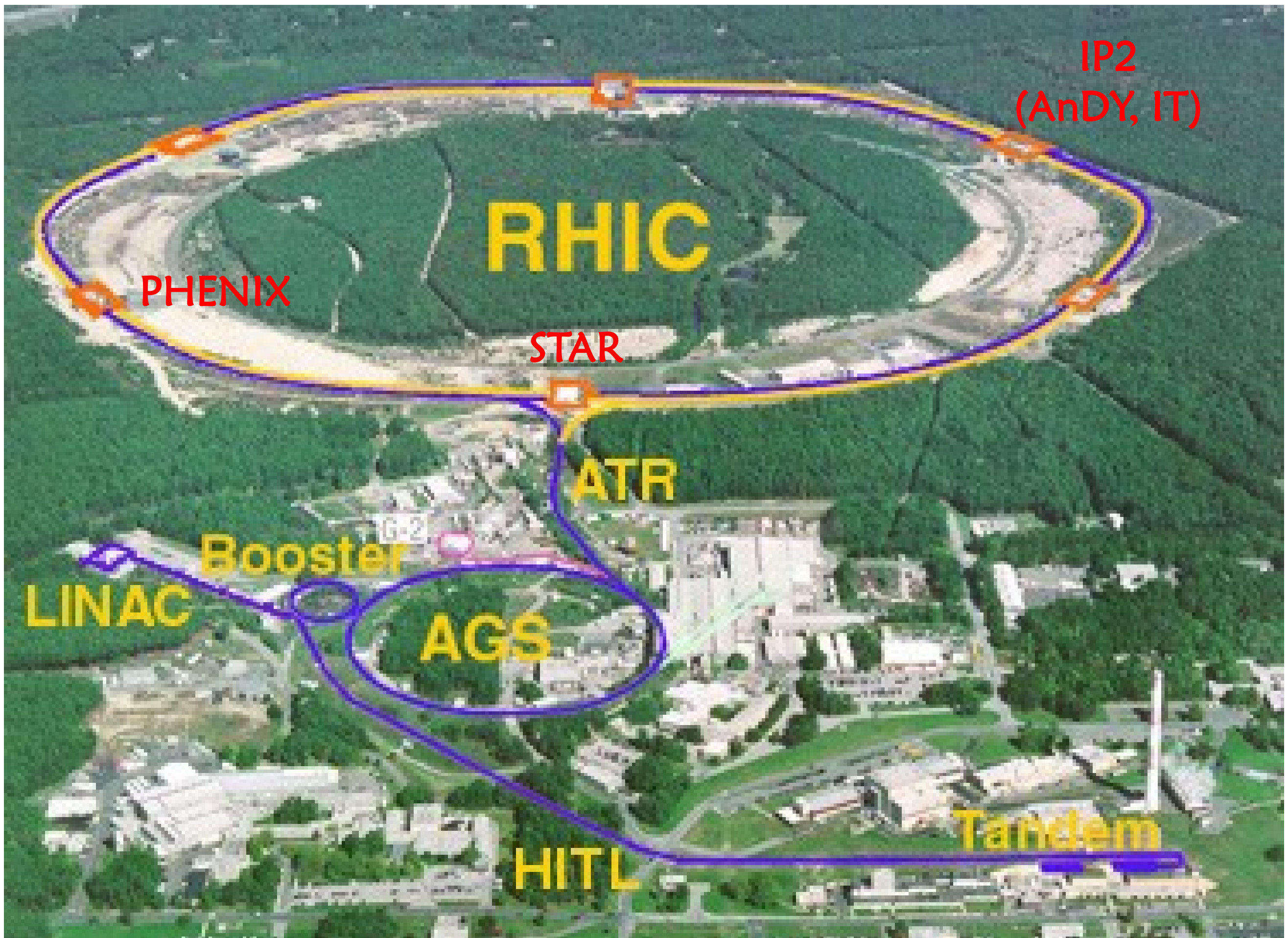
The Relativistic Heavy Ion Collider

BROOKHAVEN NATIONAL LABORATORY

RHIC Relativistic Heavy Ion Collider



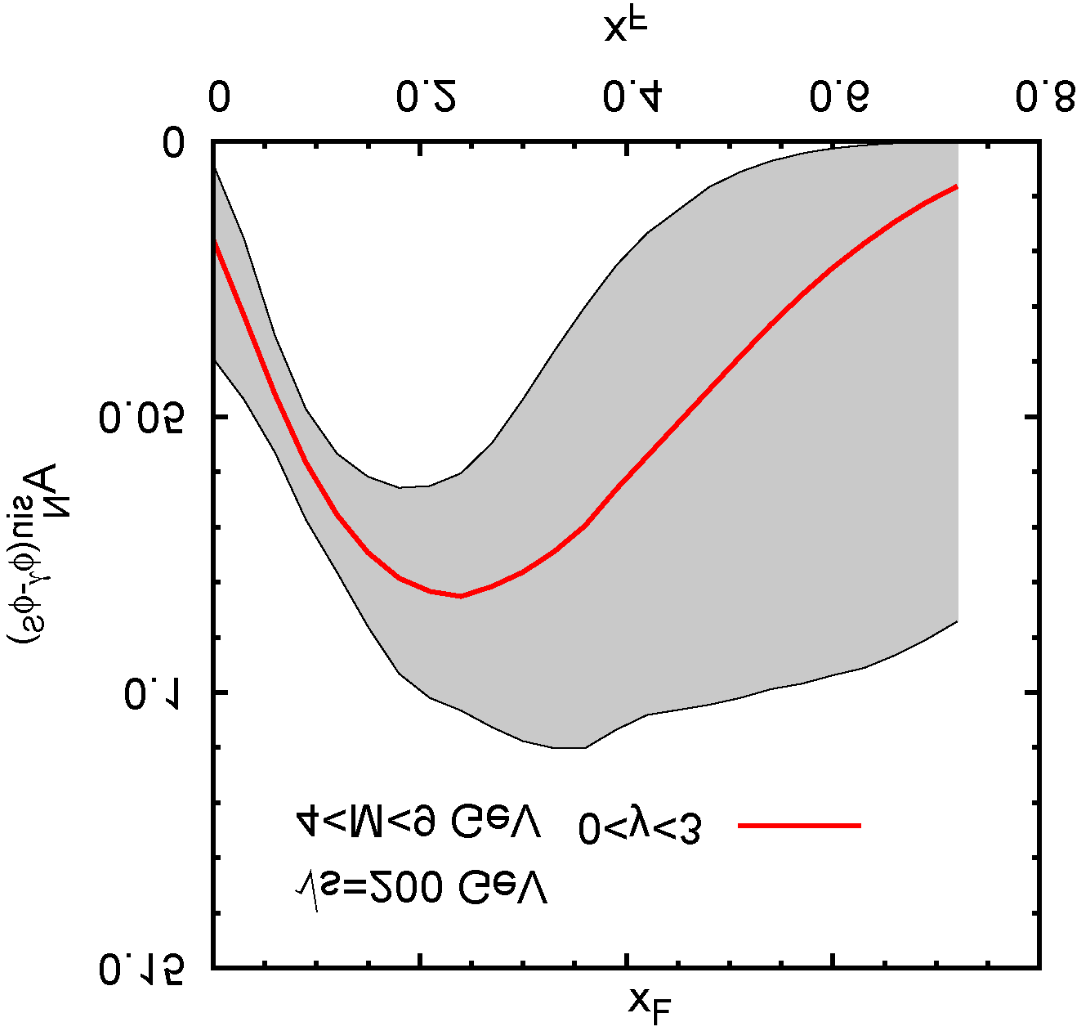
Au+Au

Polarized p+p

d+Au

RHIC is a QCD lab

DY Expectations – robust theory



- 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)

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

DY at Colliders? ⌠+⌠- or e+e- ?

p+p DY at ISR, $\sqrt{s}$=53,63 GeV (Phys. Lett. B91 (1980) 475)

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

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University of Athens, Athens, Greece

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

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Brookhaven National Laboratory [3], Upton, NY, USA

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

M. GOLDBERG, N. HORWITZ and G.C. MONETI
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and

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

Received 18 February 1980

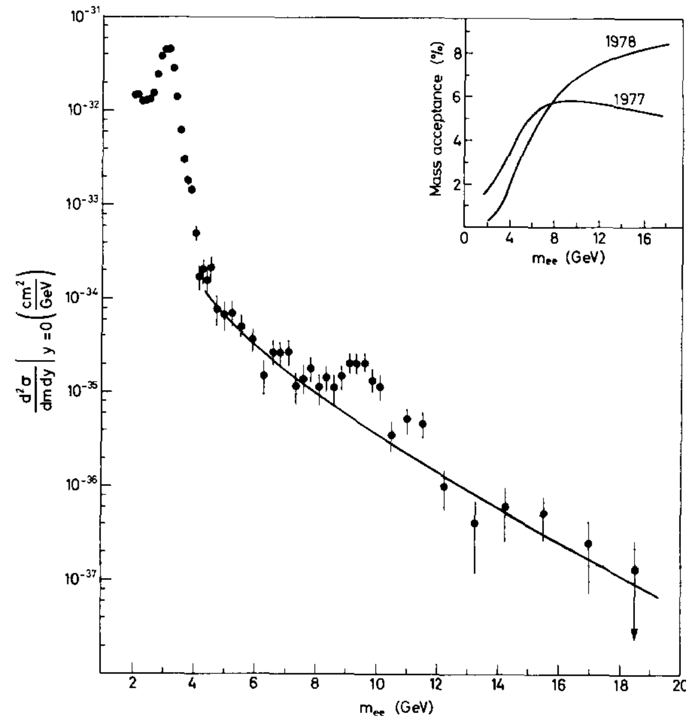


Fig. 1. The cross section $(d^2\sigma/dm\,dy)_{y=0}$ versus mass for the data at $\sqrt{s}$ = 53 and 63 GeV combined. The curve is a result of the fit to the continuum displayed in fig. 2. The inset show the mass acceptance for "1977" and "1978" triggers and geometrical configurations calculated for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

e+e- low-mass DY done at ISR and by UA2

[see review J.Phys. G19 (1993) D1]

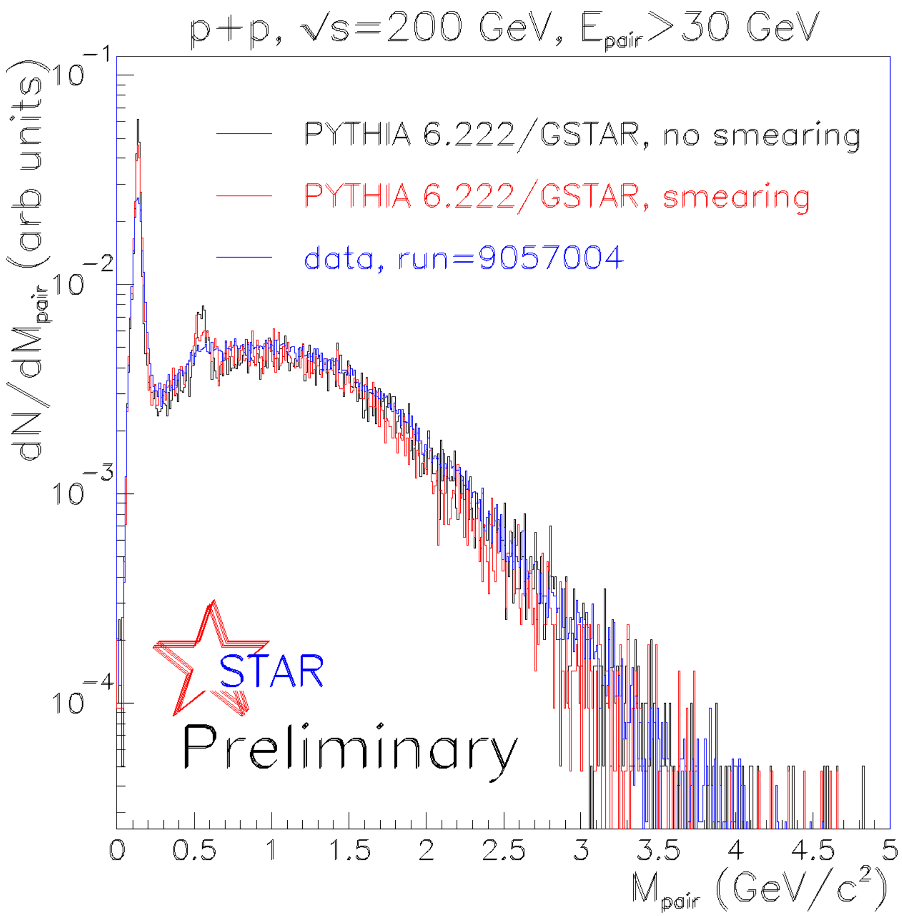
UA2 [PLB275 (1992) 202] did not use magnet

CCOR [PLB79 (1979) 398] did use magnet

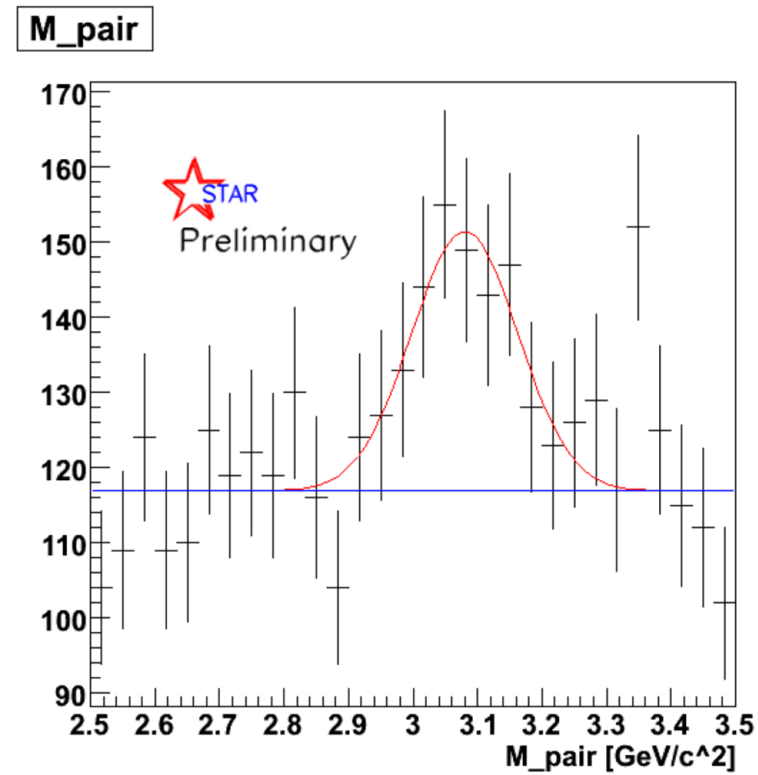
Most fixed target experiments done ⌠+⌠- DY

Large x_F DY at collider breaks new ground

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

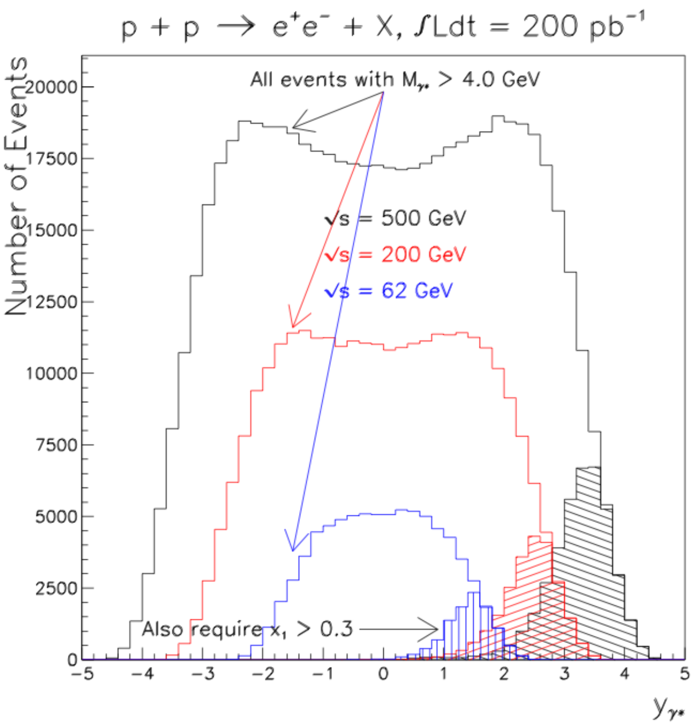
High luminosity ~>150/pb (similar to W program)

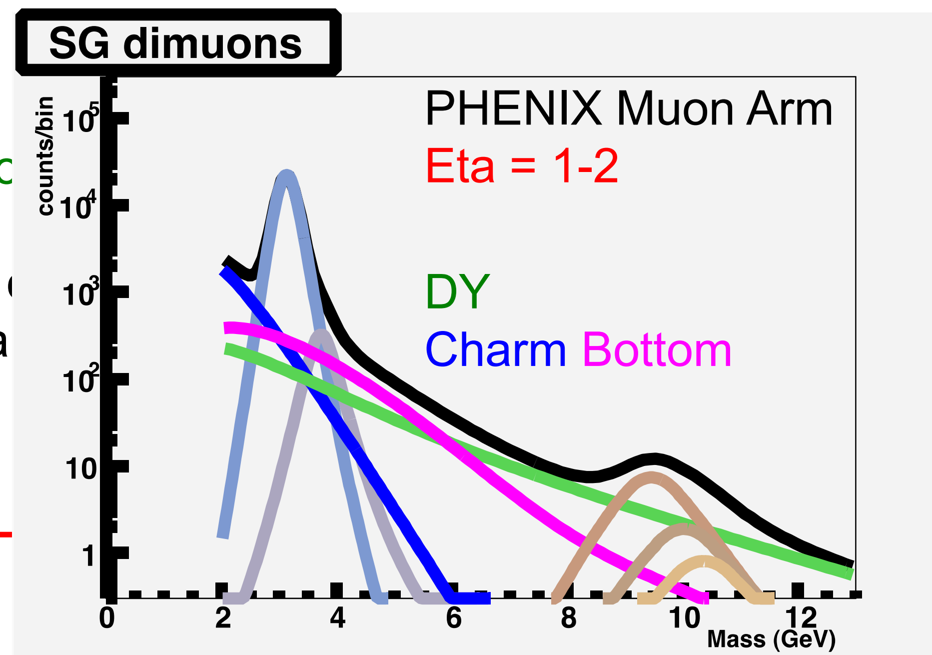
Prefer 500GeV over 200GeV

Forward (eta ~ 4) detector

Sizable A_N at high x_F

Less charm & bottom backgrounds



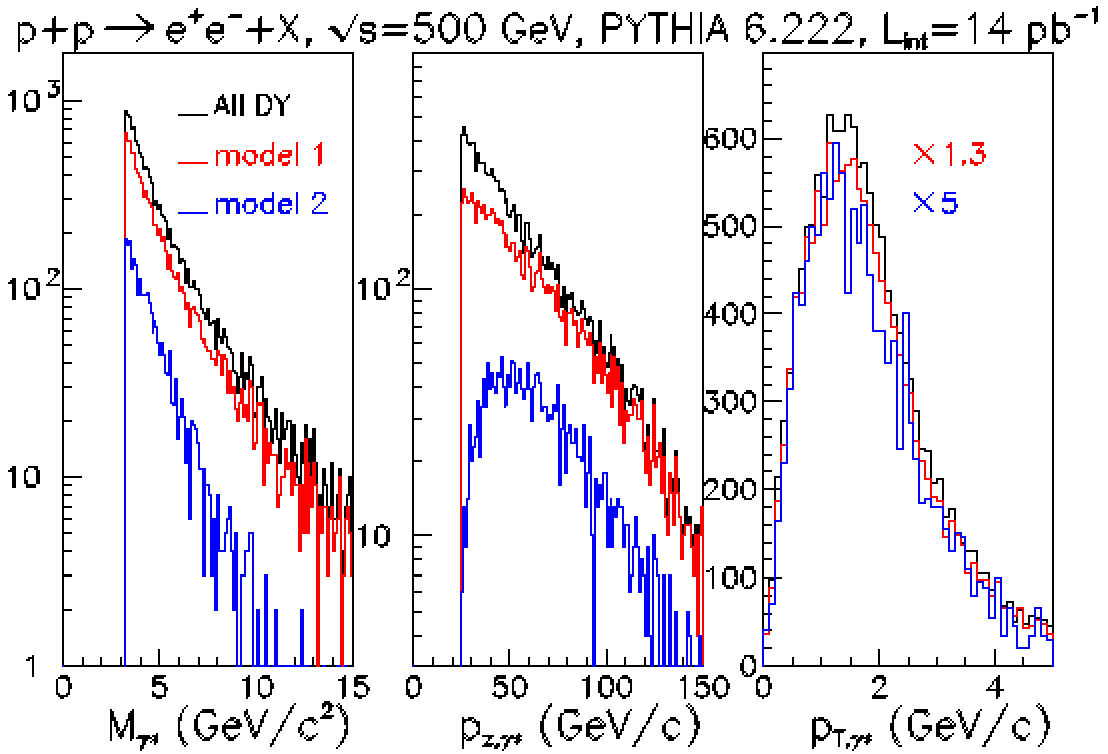


Go … on

Is … ign
pa…

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

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

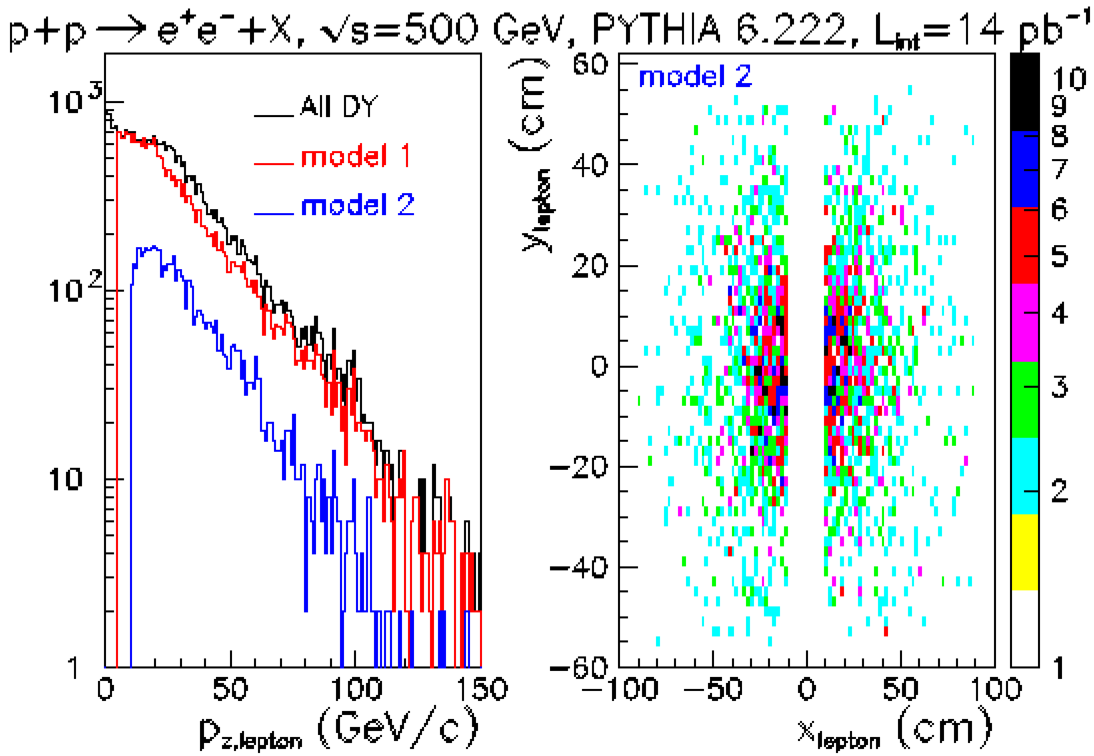
Reasonable efficiency can be obtained for large-x_F DY with existing equipment

9400 DY-events (Model2)

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

x_{bj}=0.1~0.4 $|A_N| \sim 0.1$ $\delta A_N \sim 0.02$

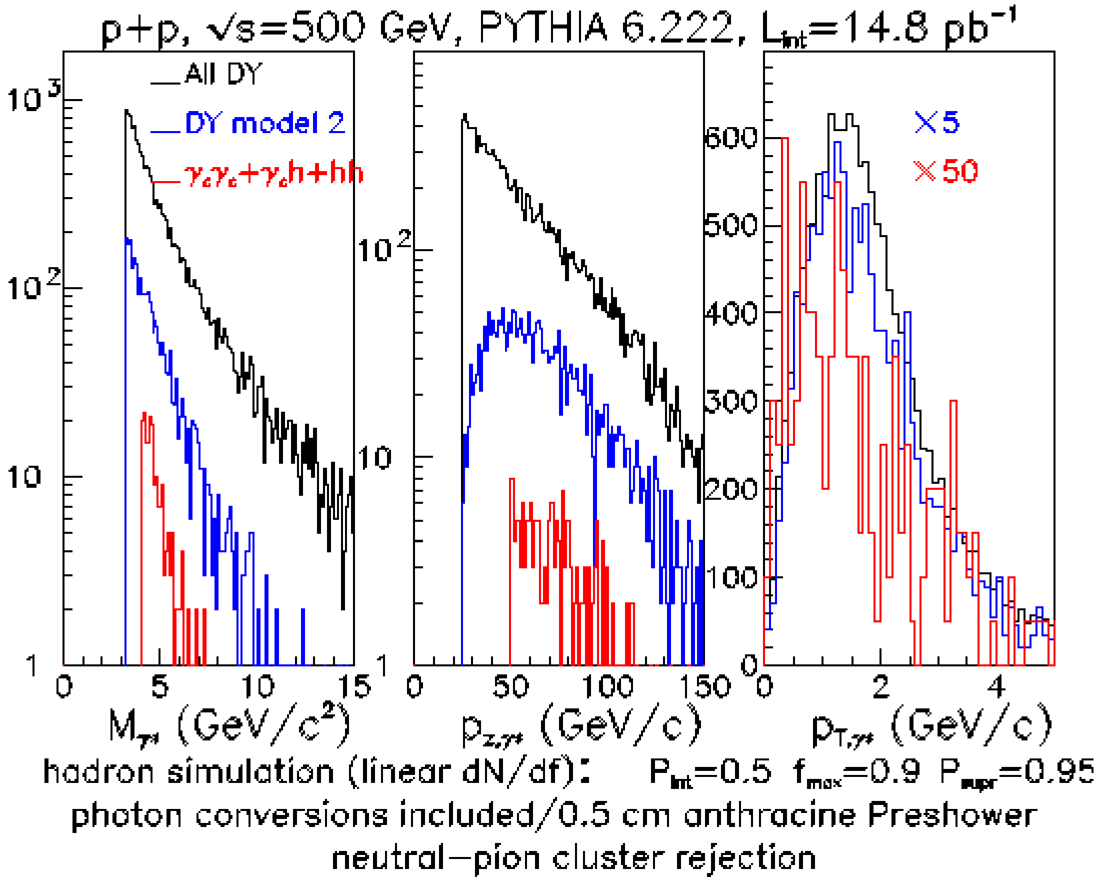
Lepton daughters from ©*



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



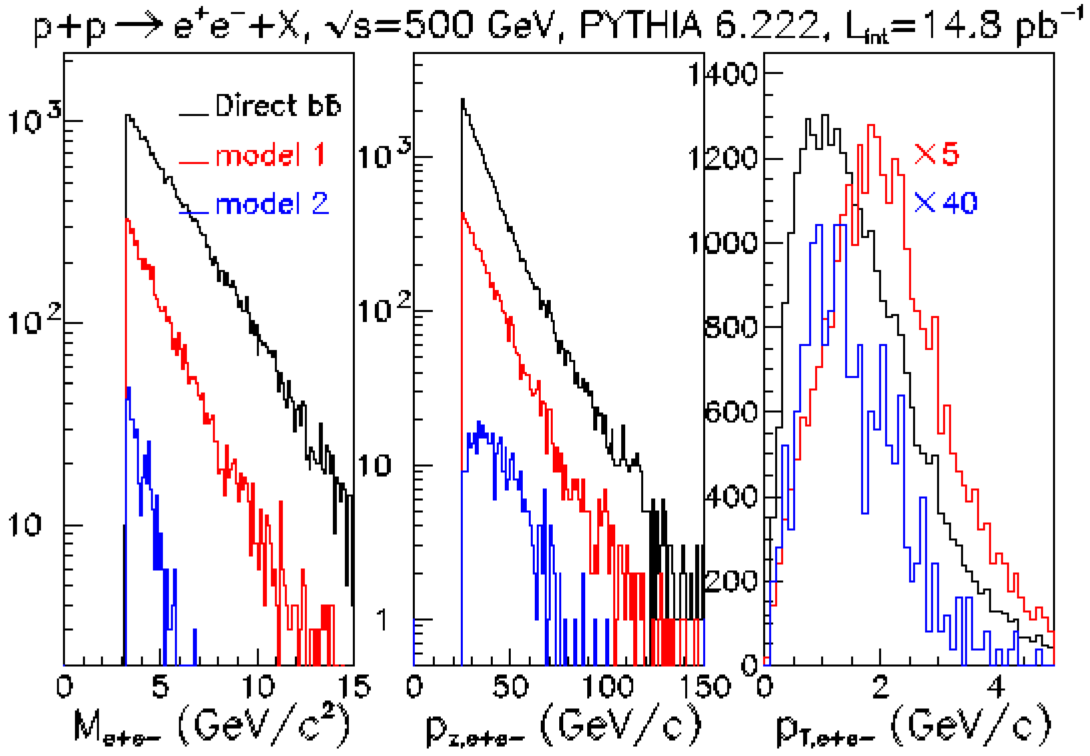
Note scale of bkgd

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

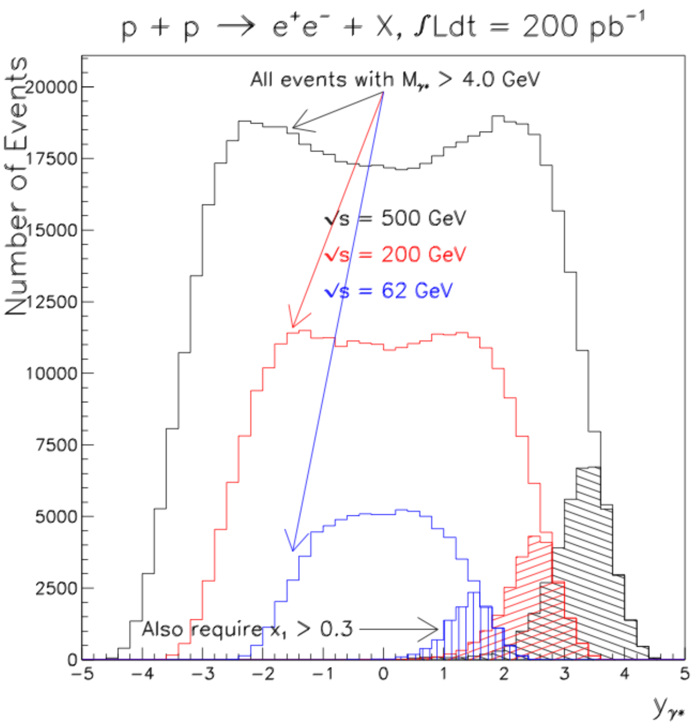


Model 1 = EMcal $(2m)^2$ / $(0.2m)^2$ beam hole at 10m / no magnetic field

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%

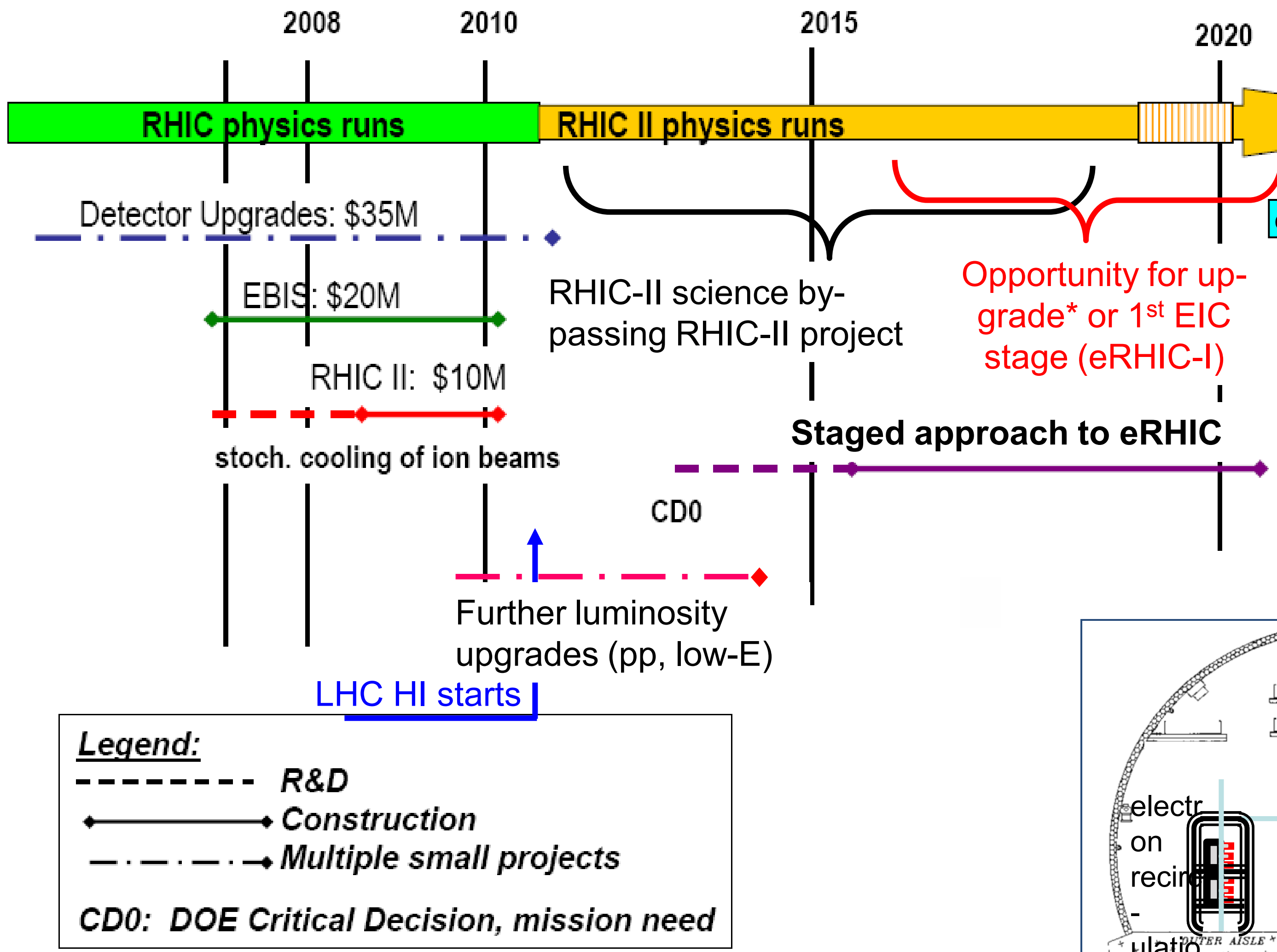
Good background (e/h and e/gamma) separation

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

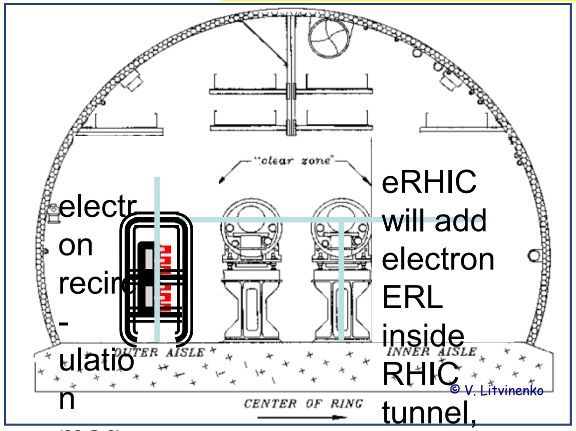
DY : ~7 x 10^{-5} mb @ 500GeV → (10^6) Hadronic : ~30mb

S. Vigdor

A Long Term (Evolving) Strategic View for RHIC



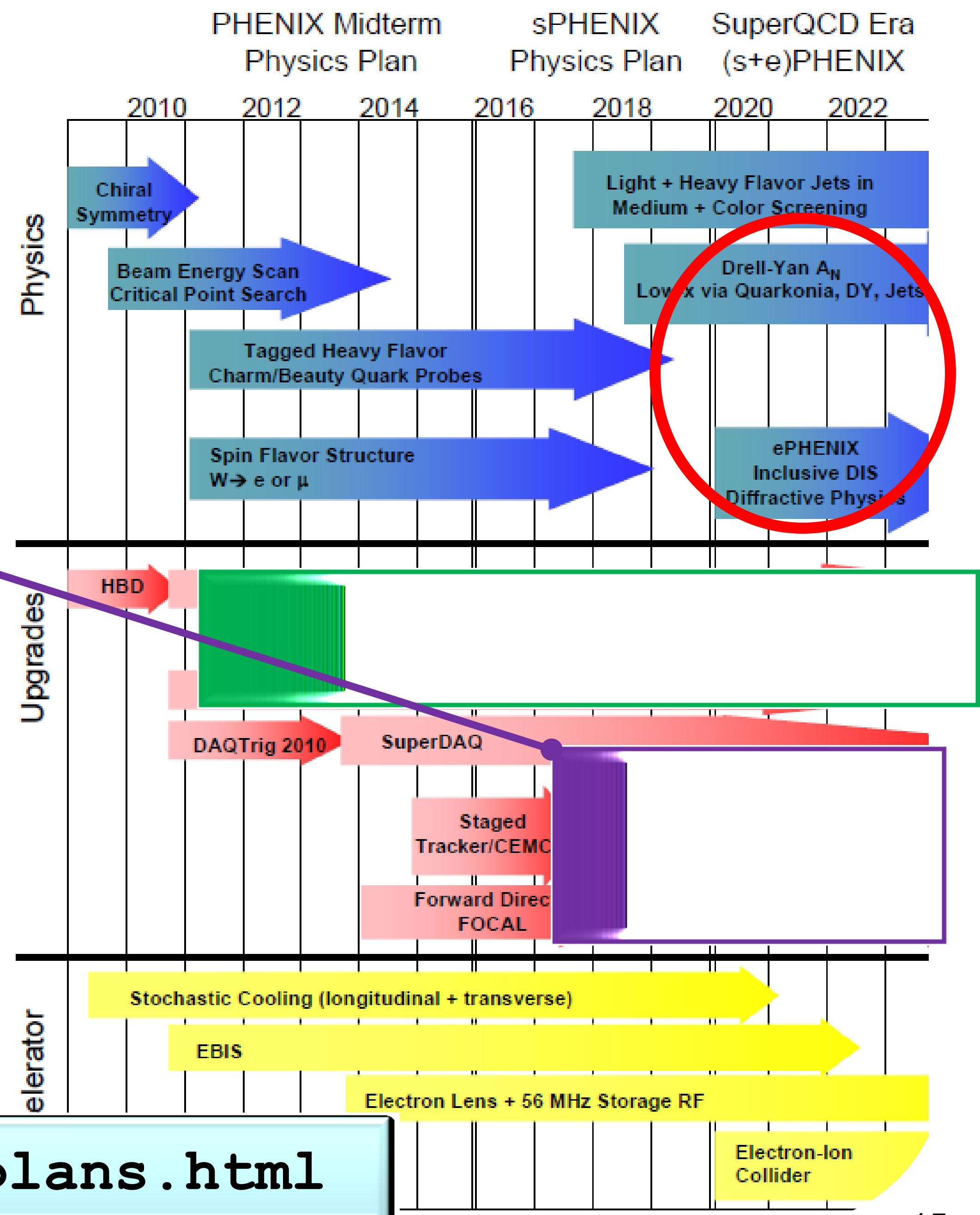
EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC



- New PHENIX and STAR Decadal Plans provide options for 2017-2022 with consideration of ePHENIX and eSTAR as early EIC detector

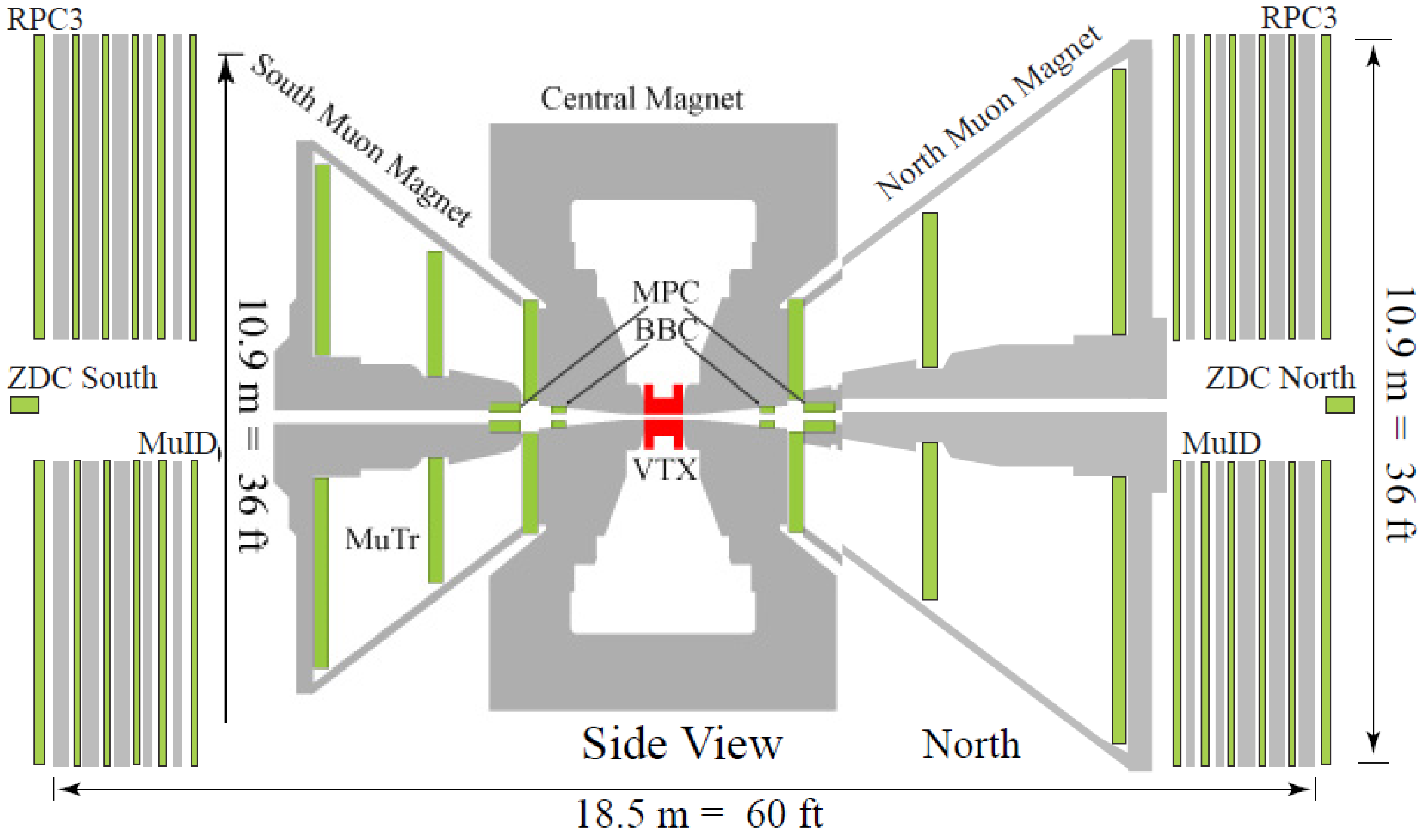
PHENIX Decadal Plan

- Long term evolution after 2015
  - Dynamical origins of spin-dependent interactions
  - *New probes of longitudinal spin effects*
  - *Measurement with polarized He^3 and increased energies*



www.phenix.bnl.gov/plans.html

sPHENIX detector



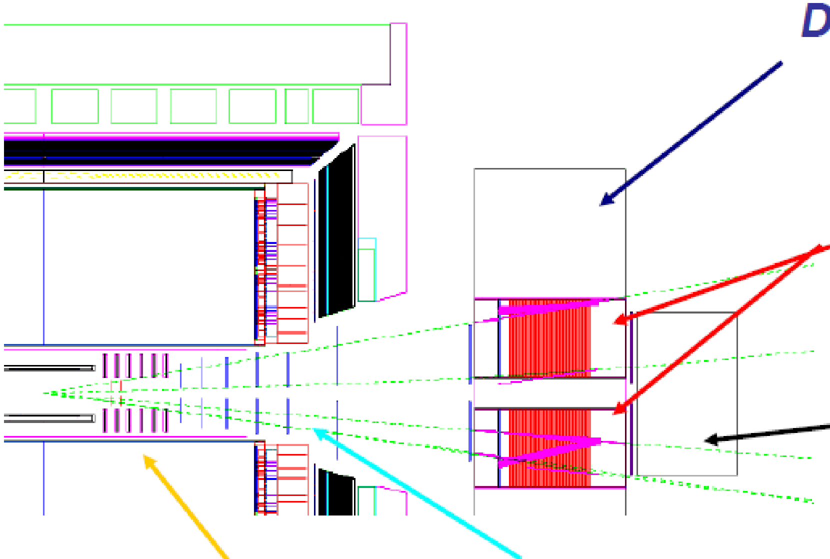
STAR Decadal Plan

	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	p+p, A+A	p+p, A+A	p+p, p+A, A+A, e+p, e+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \to ee$, m_{ee}, v_2	Υ, $J/\psi \to \mu\mu$, Charm v_2, R_{CP}, Charm corr, Λ_c/D ratio, μ-atoms	p+A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS, polarized SIDIS
(7) QCD beyond collinear factorization	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

STAR Forward upgrade ideas

Dipole magnet; B=(0 – 1.4 T)

TPC + gas RICH Or TRD tracker



EMCal

GEM based Pre-Shower detector + SPALCAL

Forward Tracking; Si + GEMs

FGT
(under construction, to be installed summer 2011)

SPACAL =
Tg powder + scintillating fibers

A_NDY at IP2

"Feasibility Test of 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

- **Timeliness** – Run when STAR & PHENIX is 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

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Shandong University, China

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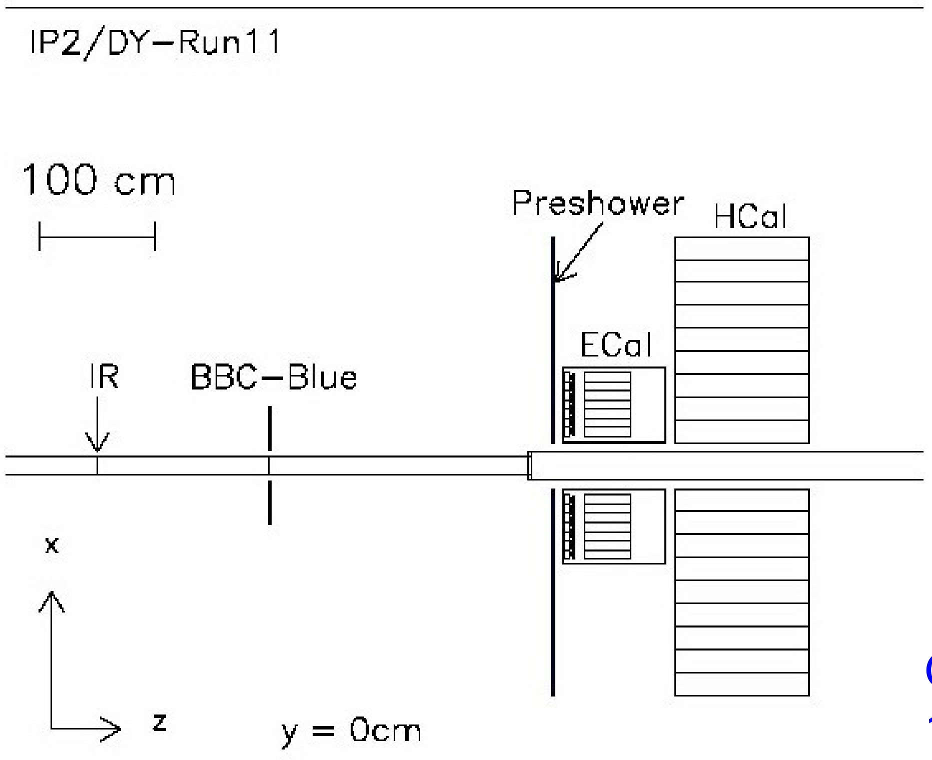
Schematic of detector for Run-11

Happening right now



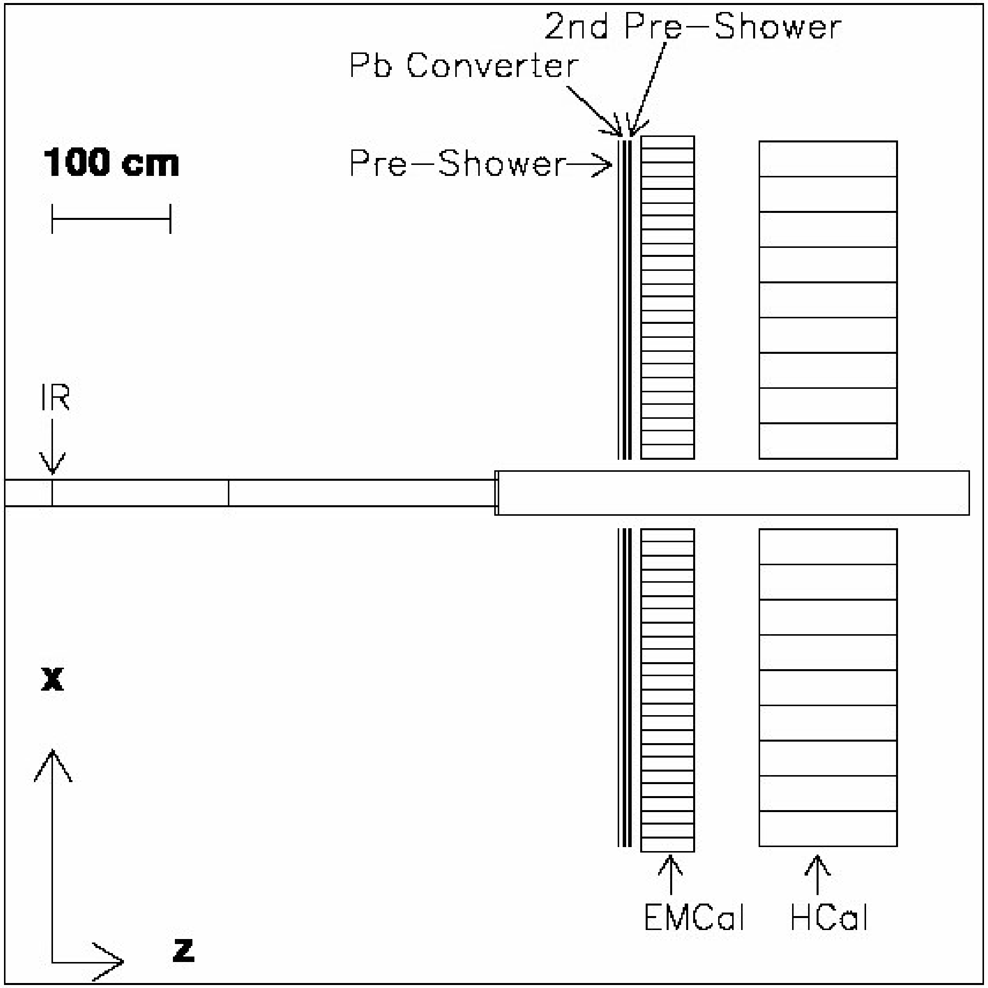
- BBC and ZDC/ZDC-SMD
- HCal is existing 9x12 modules from E864 (NIM406,227)
- Small (~120 cells) Ecal
- Pre-shower detector

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 ?

Schematic of detector for Run-12

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



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

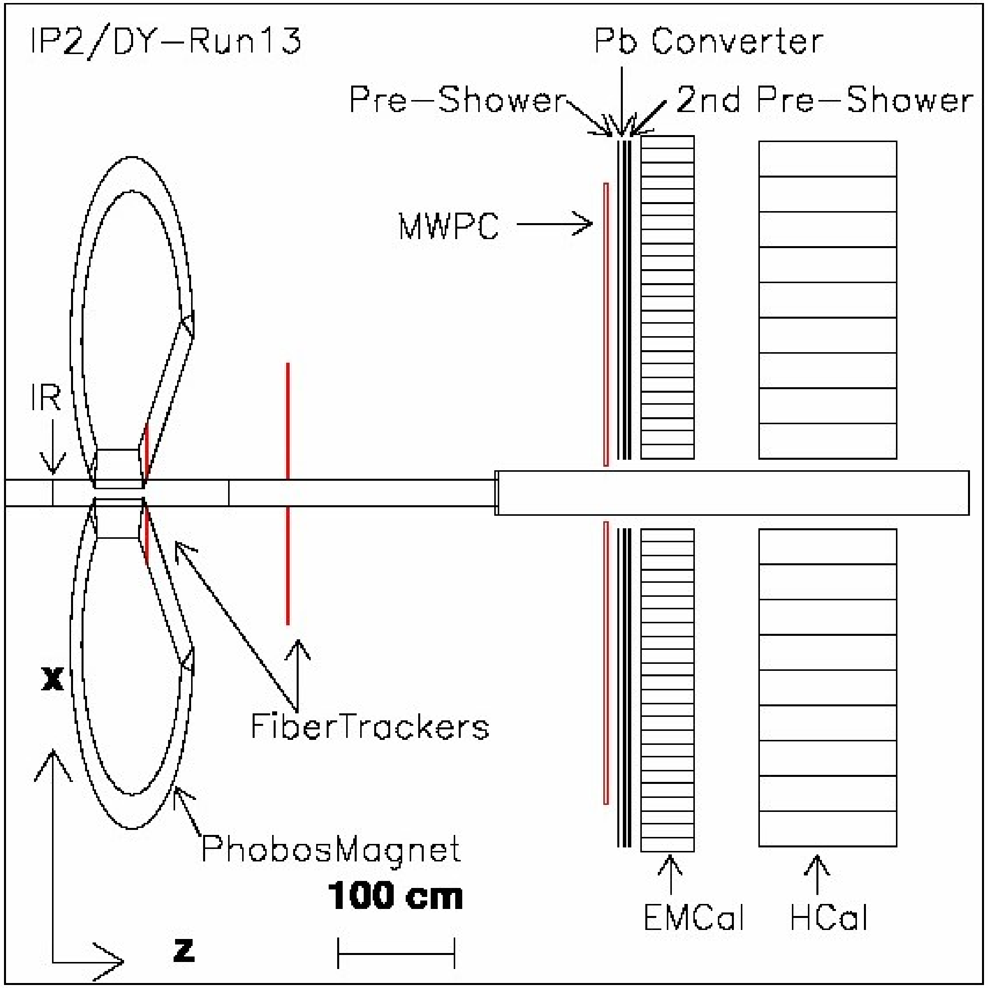
- BBC and ZDC/ZDC-SMD
- HCal is existing 9x12 modules from E864 (NIM406,227)
- Full Ecal wall (lead glass)
- Pre-shower detector

Goal:
1. Reconstruct J/ψ and Y
2. Measure continuum between them
3. Integrate 150 pb-1 recorded to see if we can measure A_N(DY) without magnet

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

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

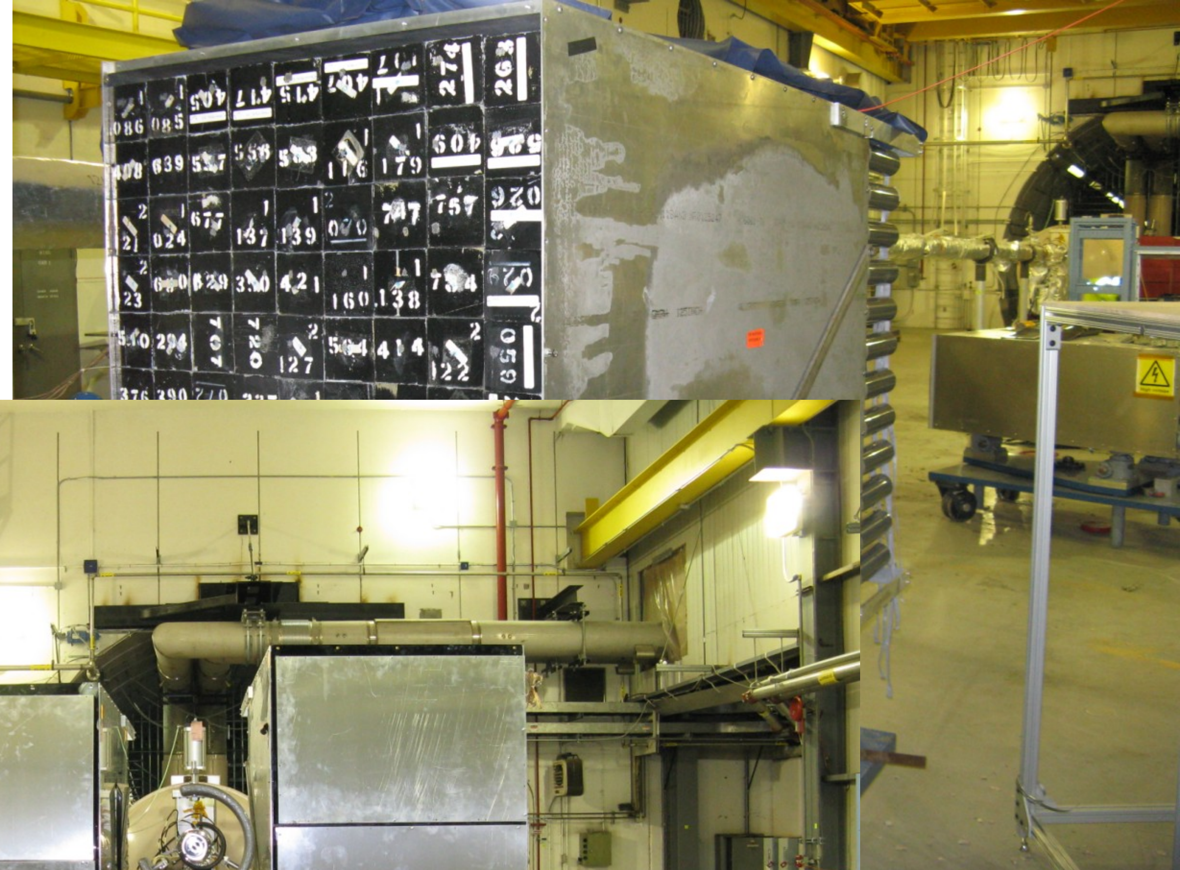
Goal:

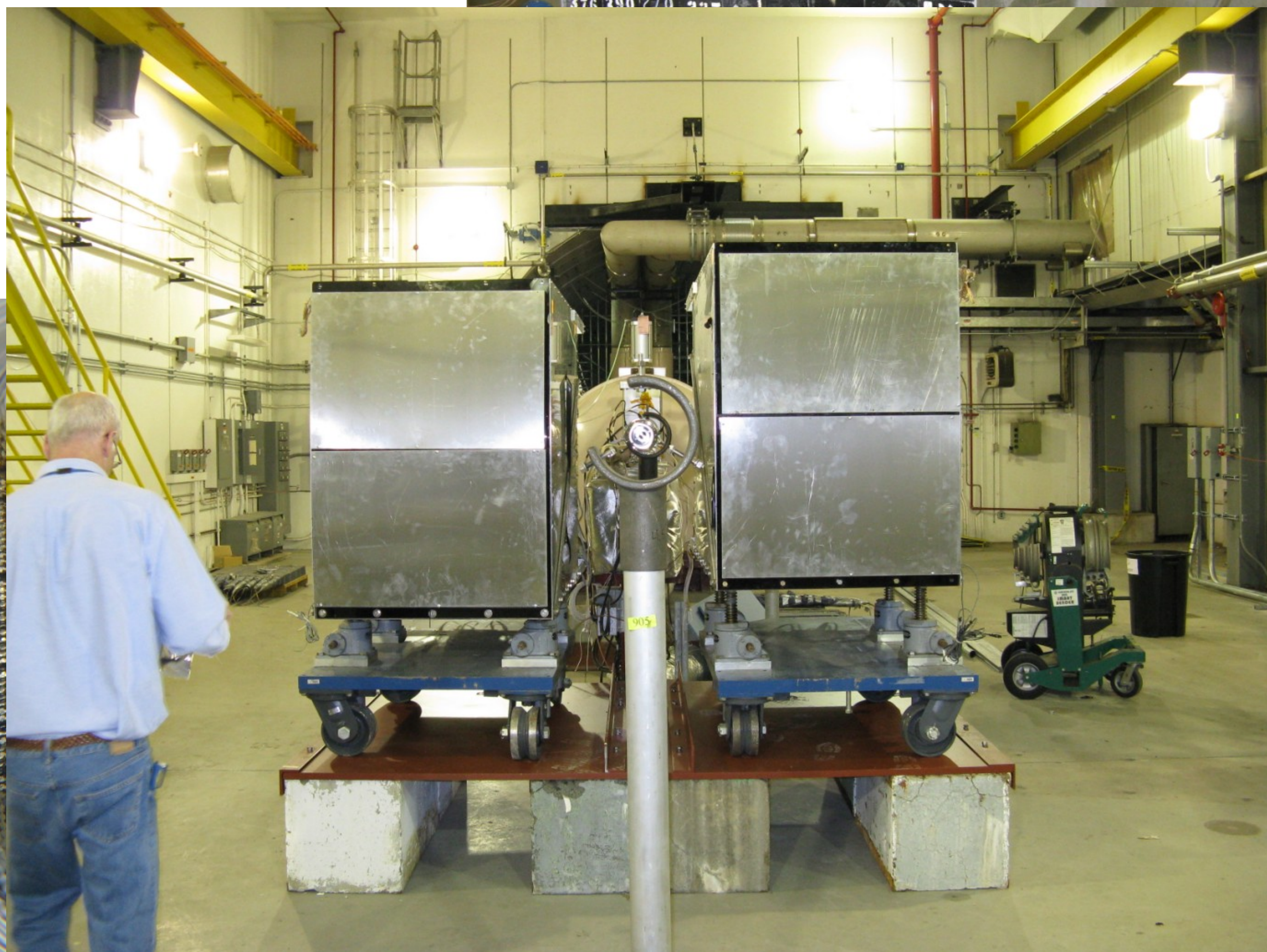
Integrate 150 pb-1 recorded to see whether tracking significantly improves signal/background for A_N(DY)

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

AnDY Hcal from AGS -864

Steel beam pipe removed
Be Beam pipe will be installed

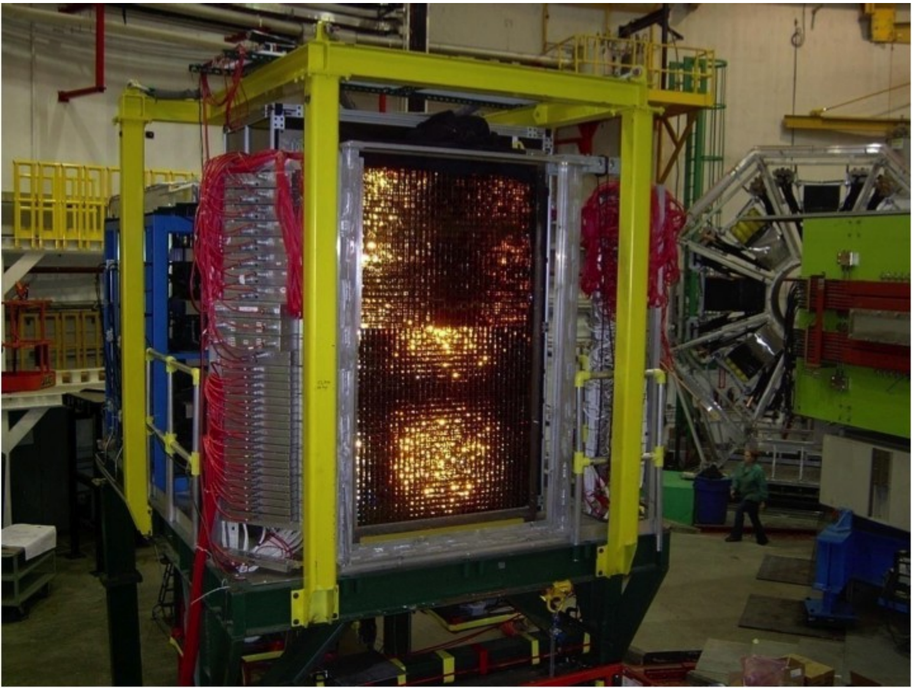




Hcal module

light guide.
atrix in Pb.

BigCal @ JLAB to BNL



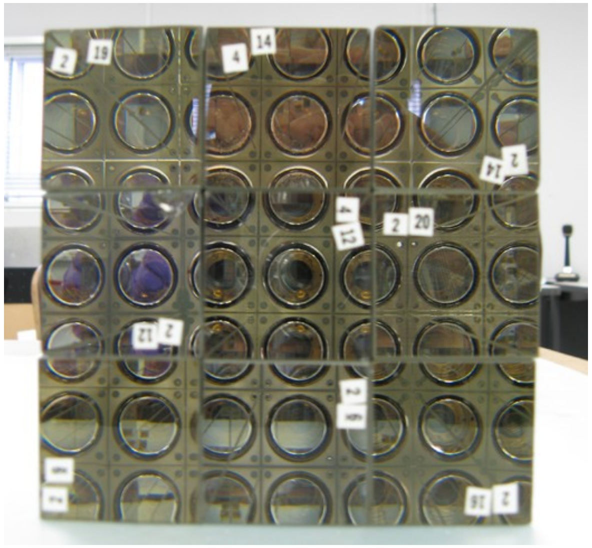
Some people from BigCal has joined AnDY!

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 are now at BNL/IP2



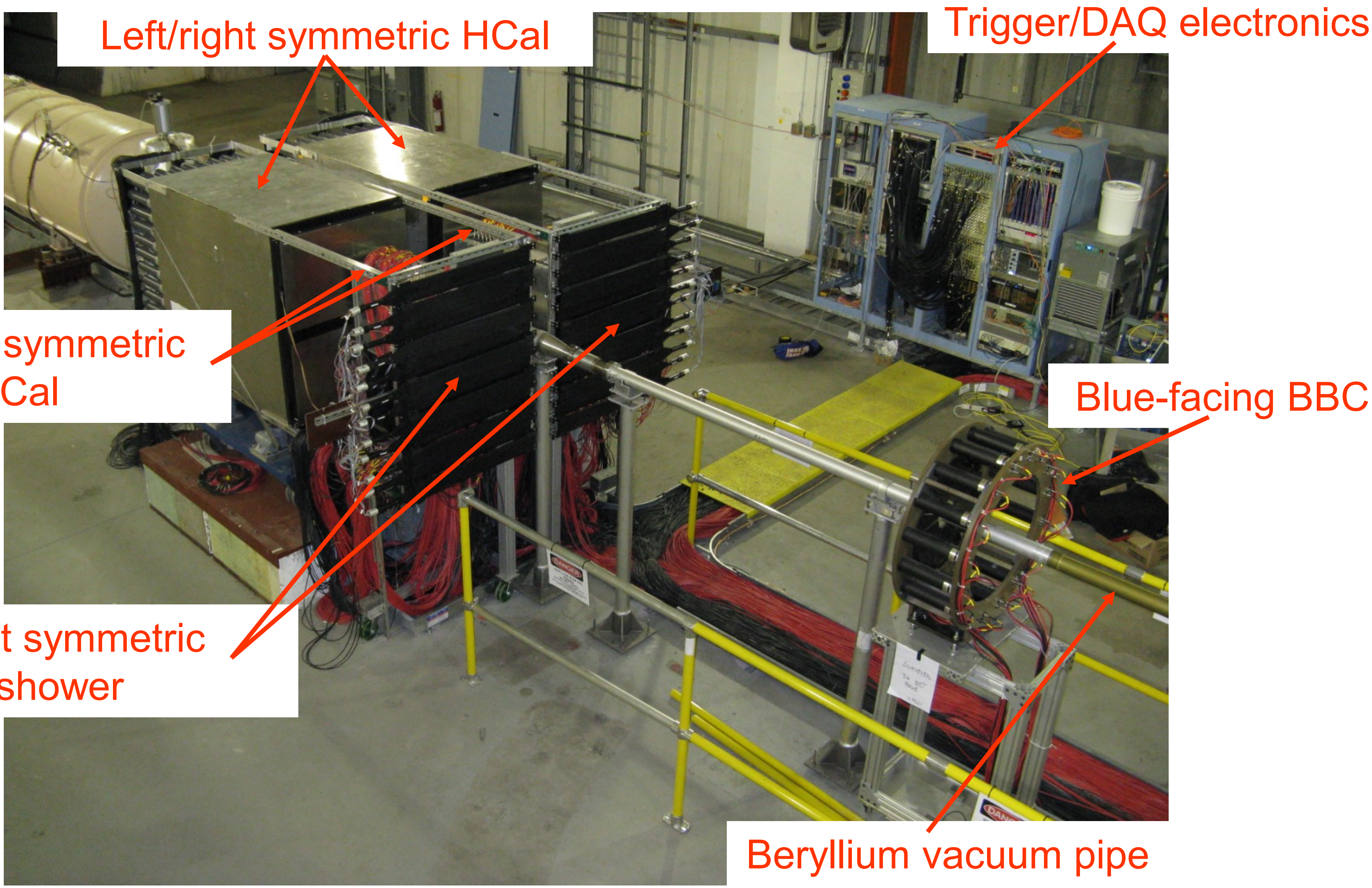
3x3 test stack of fully assembled cells

Two 7x7 modules installed at IP2 for run11

IP2 in August, 2010

Remnants of the BRAHMS Experiment

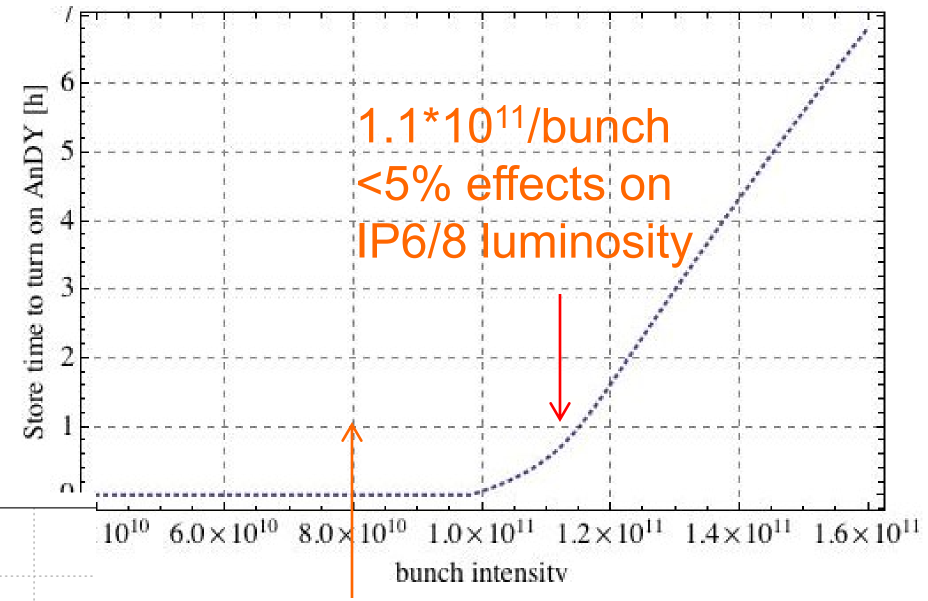
IP2 in January, 2011

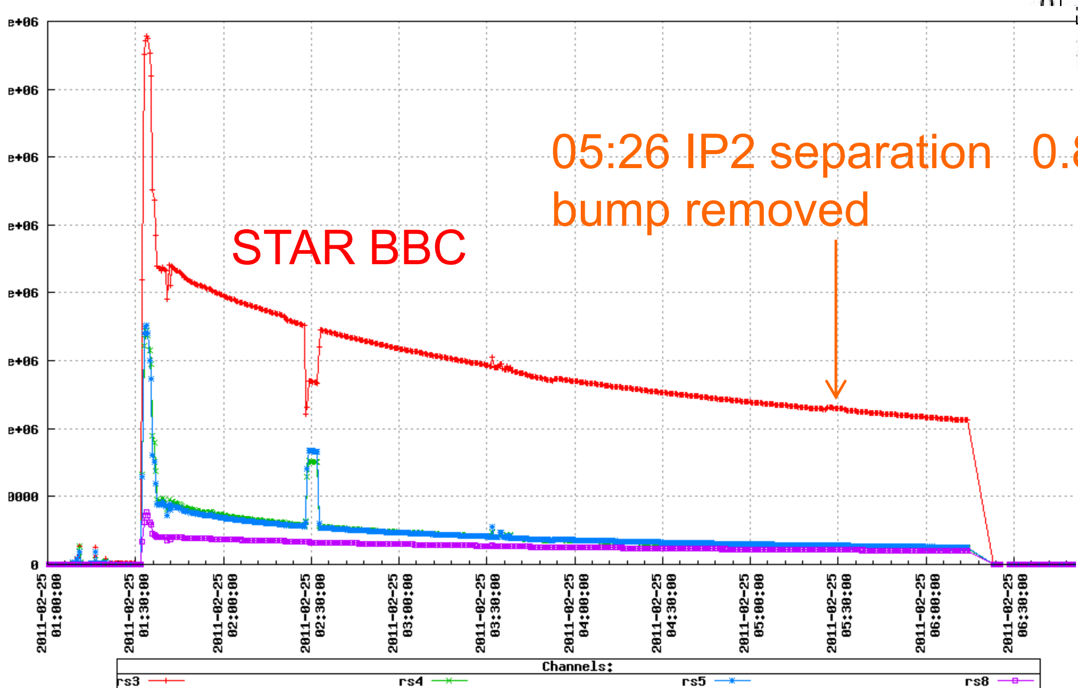


Impact of 3 IP operation

Beam-beam effect is expected to limit luminosity at high intensity

Time in a fill to turn on AnDY to have
no impact on STAR and PHENIX luminosity

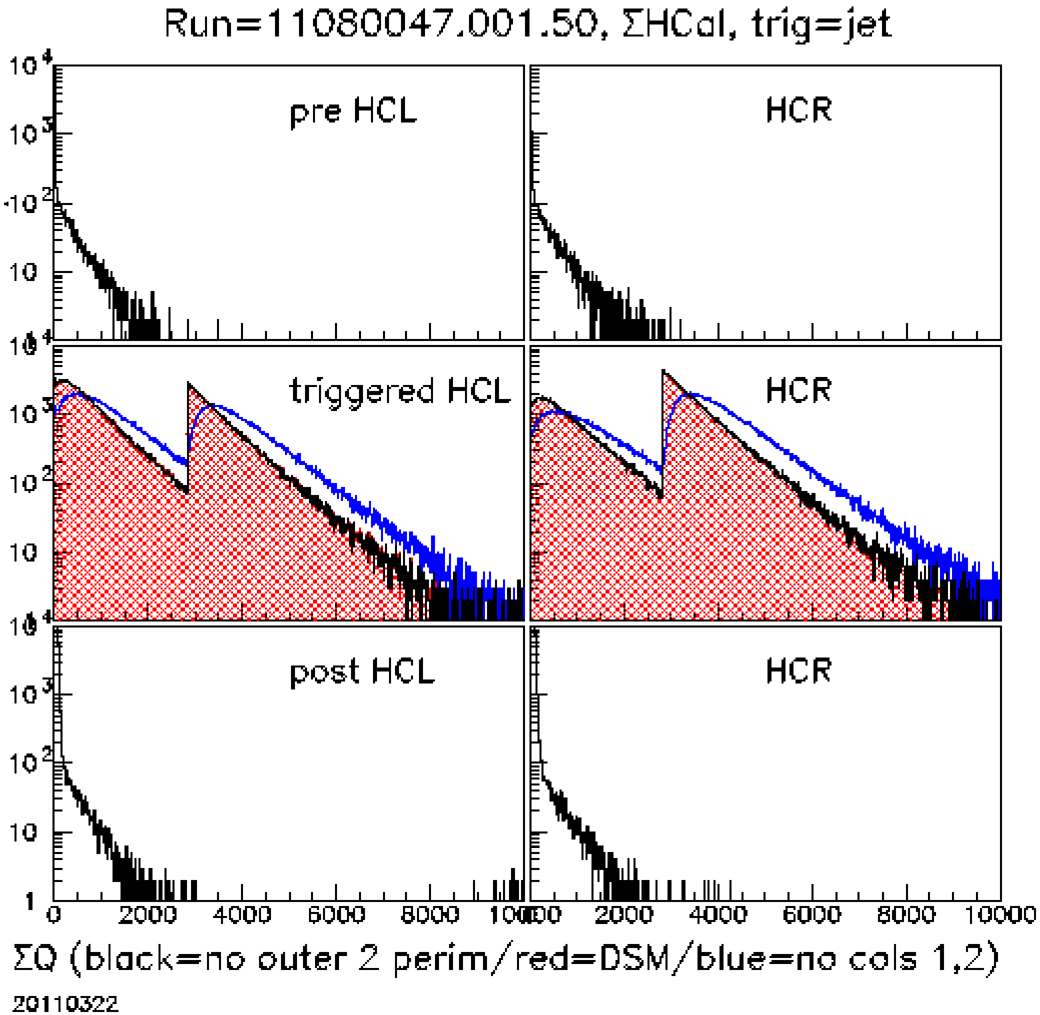


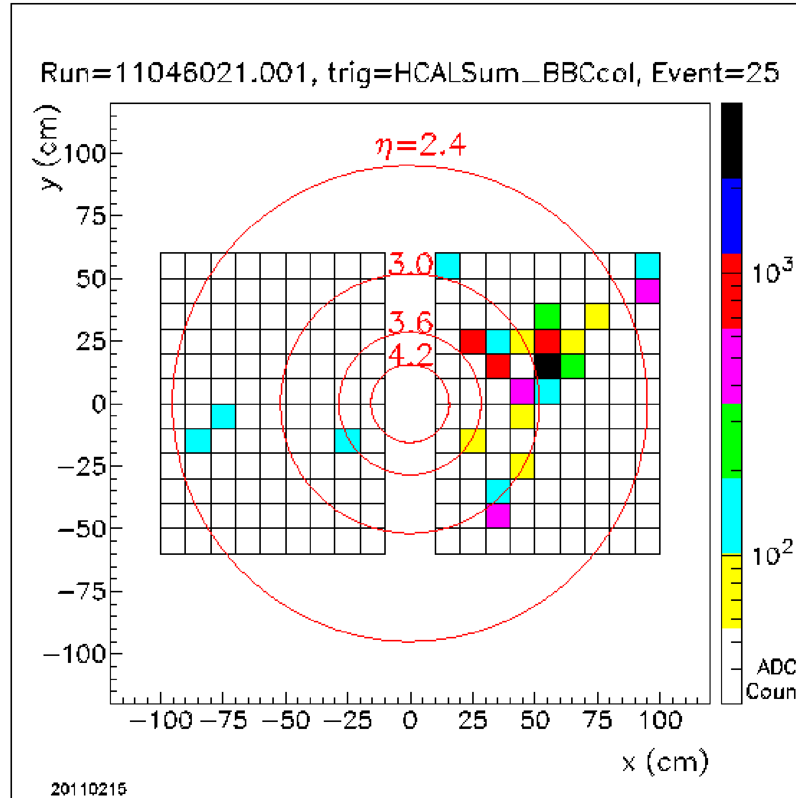


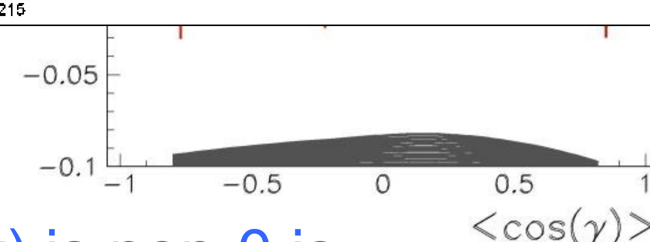
Goal in Run11 is to find the impact
On IP6/8 luminosity

Next PAC to judge if it is
“acceptable impact”

A_N for jets







A_NDY is taking HCal jet trigger right now (~500M jet trigger events as of last week)

We have ~1/pb as of last week

Need >5x more (possible in 1 week if 3IP collisions from start of fill)

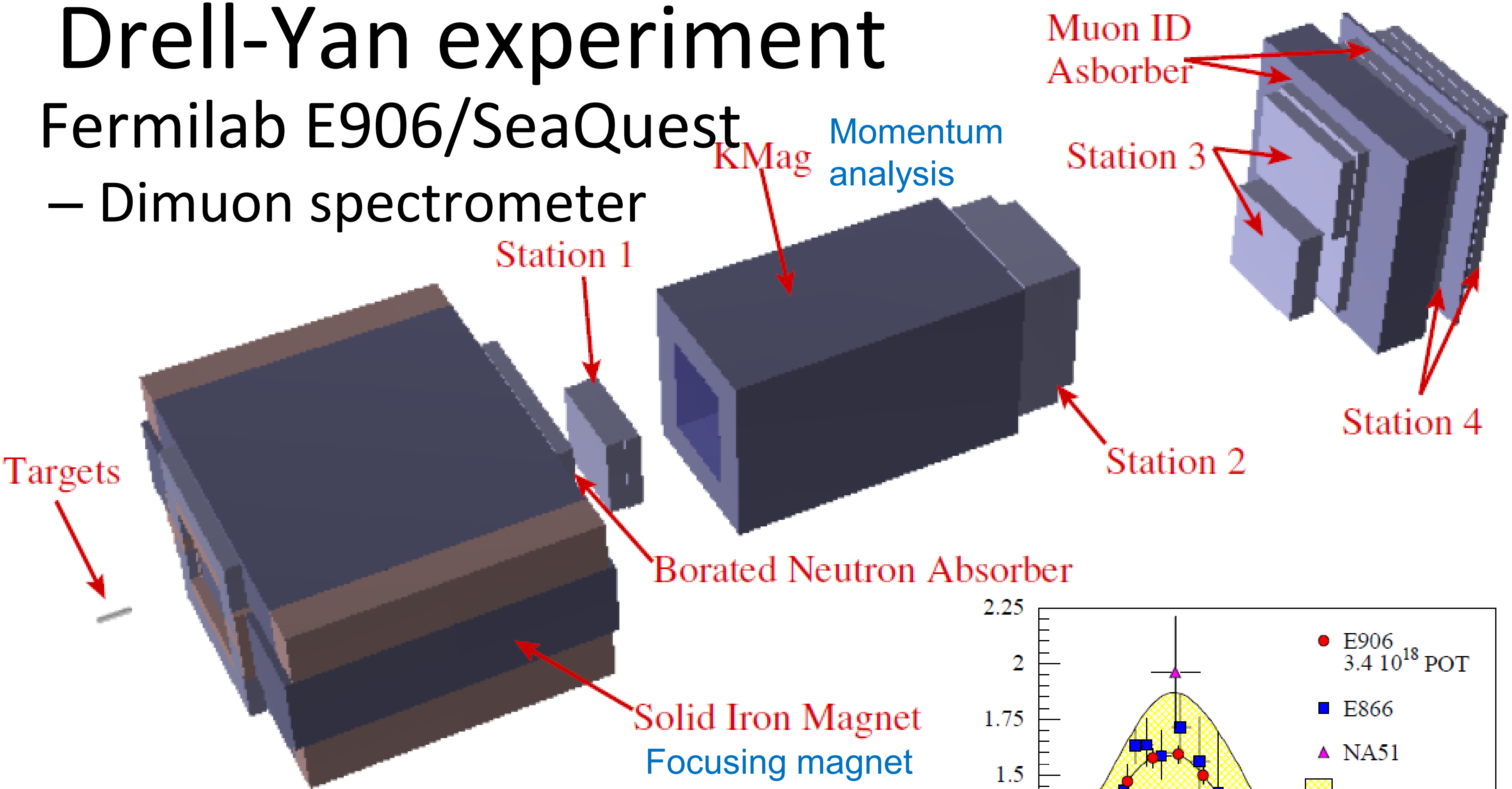
Determine whether A_N(jet) is non-0 is a requirement for A_N(DY) sign-flip measurement

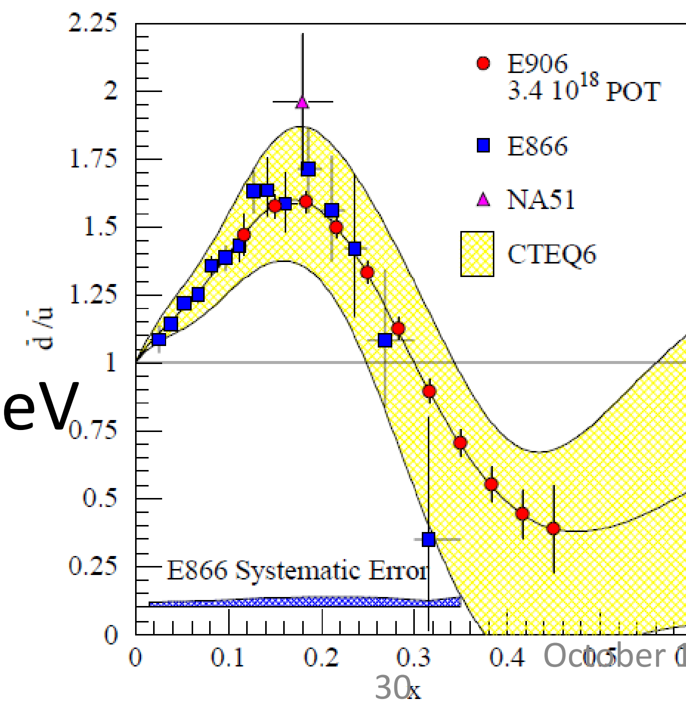
Letter of Intent: Measurement of Dimuons from Drell-Yan Process with Polarized Proton Beams and an Internal Target at RHIC

- http://www.bnl.gov/npp/docs/pac0610/Goto_rhic-drell-yan.pdf
- Academia Sinica (Taiwan): W.C. Chang
- ANL (USA): D.F. Geesaman, P.E. Reimer, J. Rubin
- UC Riverside (USA): K.N. Barish
- UIUC (USA): M. Groose Perdekamp, J.-C. Peng
- KEK (Japan): N. Saito, S. Sawada
- LANL (USA): M.L. Brooks, X. Jiang, G.L. Kunde, M.J. Leitch, M.X. Liu, P.L. McGaughey
- RIKEN/RBRC (Japan/USA): Y. Fukao, Y. Goto, I. Nakagawa, K. Okada, R. Seidl, A. Taketani
- Seoul National Univ. (Korea): K. Tanida
- Stony Brook Univ. (USA): A. Deshpande
- Tokyo Tech. (Japan): K. Nakano, T.-A. Shibata
- Yamagata Univ. (Japan): N. Doshita, T. Iwata, K. Kondo, Y. Miyachi

Drell-Yan experiment

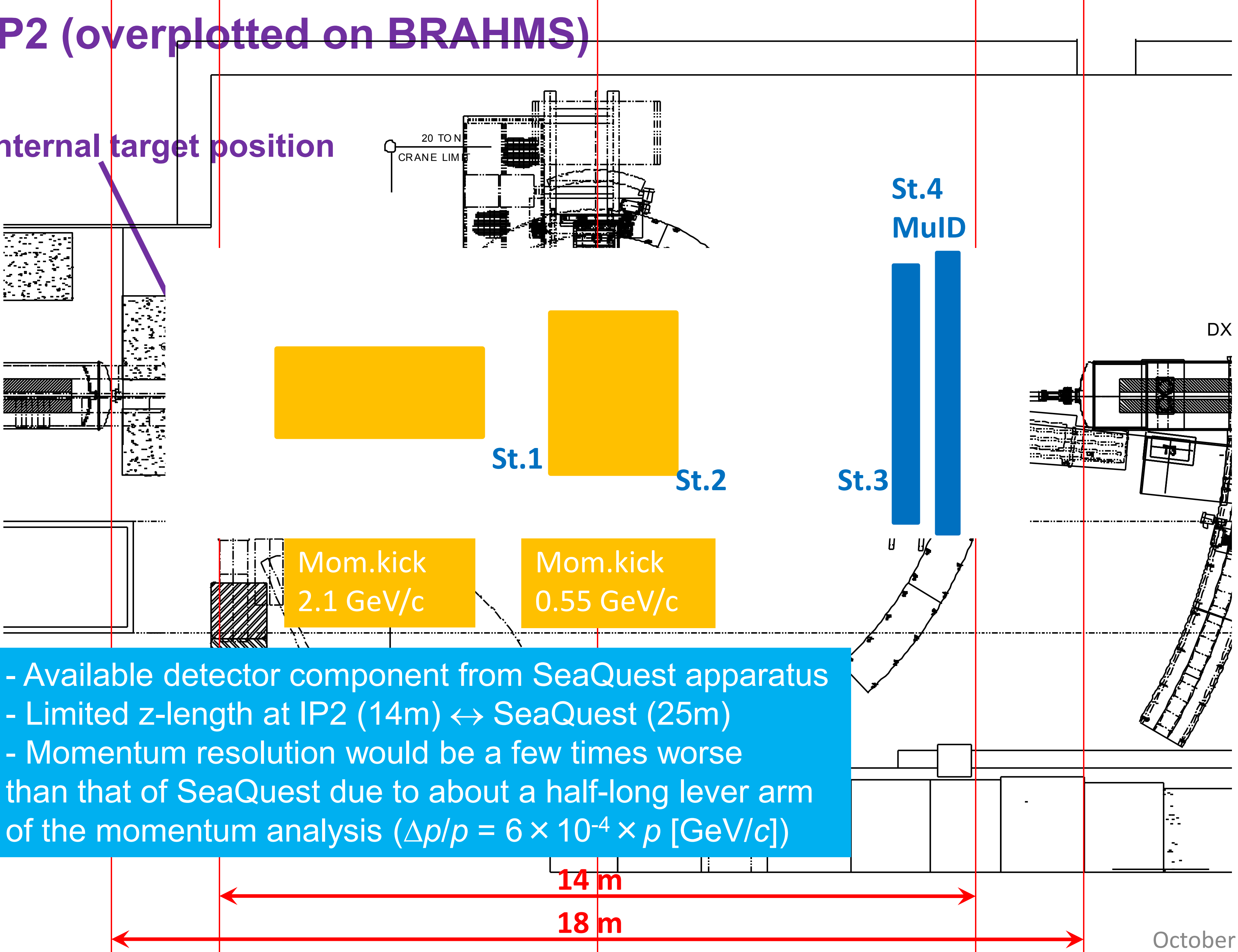
- Fermilab E906/SeaQuest
  - Dimuon spectrometer





  - Main injector beam E_{beam} = 120 GeV
  - Higher-x region: x = 0.1 – 0.45
  - Beam time: 2010 – 2013

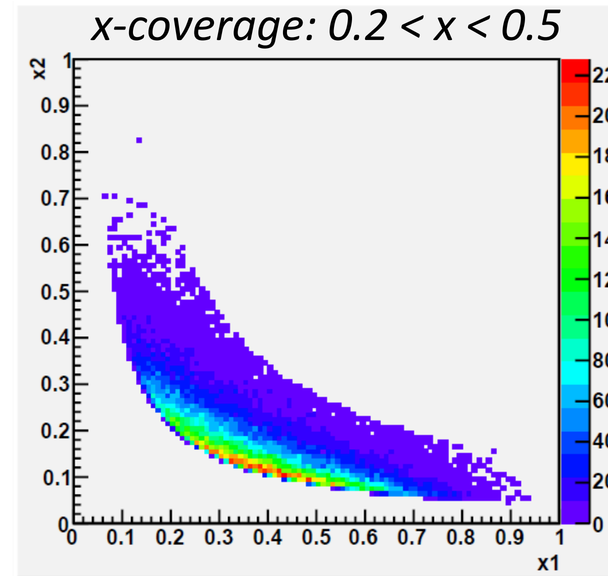
IP2 (overplotted on BRAHMS)



- Available detector component from SeaQuest apparatus
- Limited z-length at IP2 (14m) ↔ SeaQuest (25m)
- Momentum resolution would be a few times worse than that of SeaQuest due to about a half-long lever arm of the momentum analysis ($\Delta p/p = 6 \times 10^{-4} \times p$ [GeV/c])

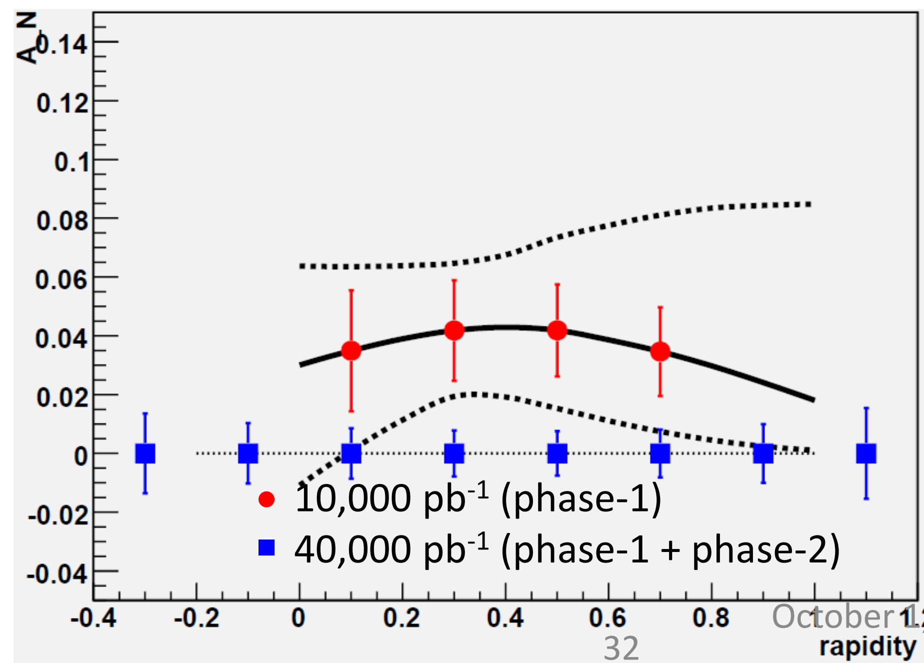
Experimental sensitivities

- Phase-1 (parasitic operation)
  - L = 2×10^{33} cm^{-2}s^{-1}
  - cluster-jet or pellet target ~10^{15}atoms/cm^2
  - 10,000 pb^{-1} with 5×10^6 s
  - 3 years (10 weeks $\times$ 3) of beam time
- Phase-2 (dedicated operation)
  - L = 3×10^{34} cm^{-2}s^{-1}
  - pellet or solid target 10^{16}/cm^2
  - 30,000 pb^{-1} with 10^6 s
  - 8 weeks of beam time



Theory calculation:
U. D'Alesio and S. Melis, private communication;
M. Anselmino, et al., Phys. Rev. D79, 054010 (2009)

Measure not only the sign of the Sivers function but also the shape of the funcion



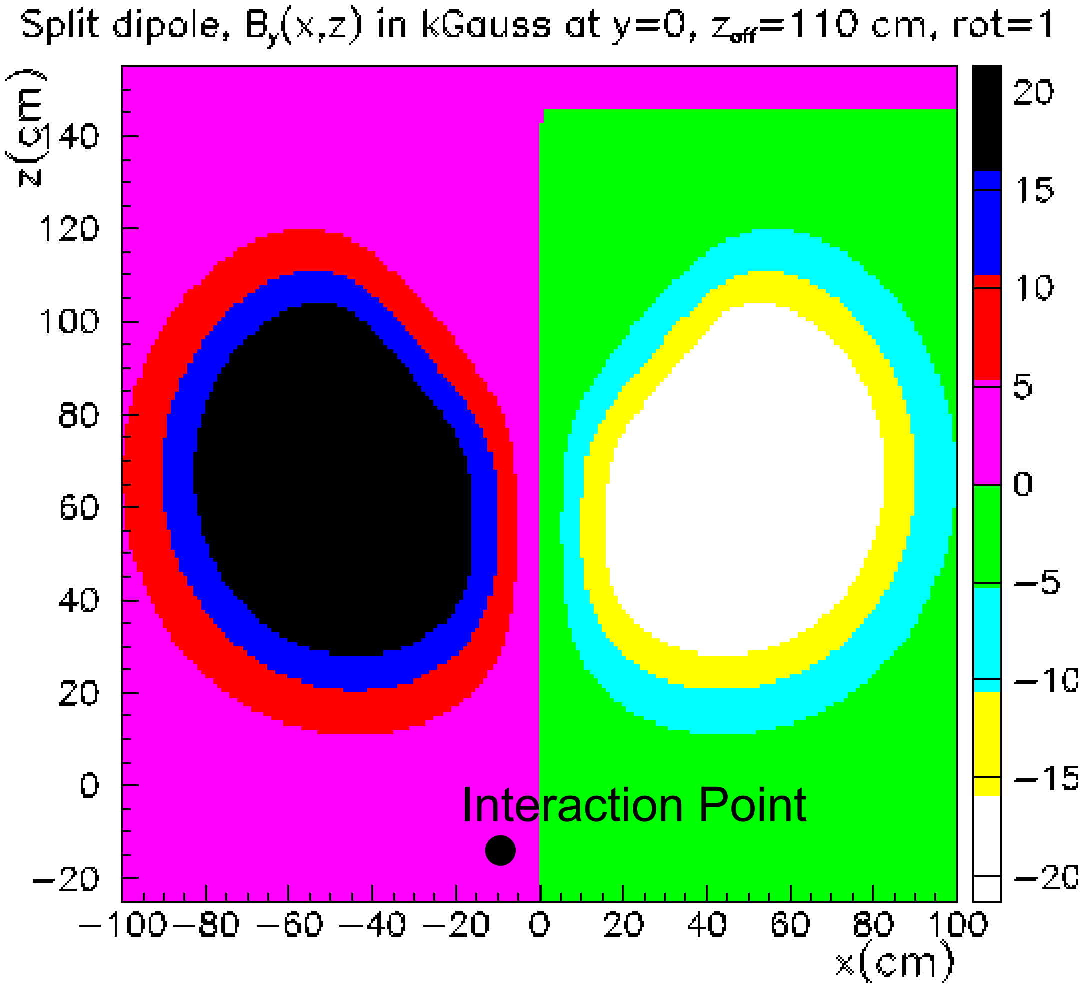
Conclusions

- RHIC is forming a long range plan, which includes DY measurements
  - PHENIX plan - collider, e^+e^- 2017-2022
  - STAR plan - collider, e^+e^- 2017-2022
  - Internal target – fixed target, mu^+mu^- 2015-2017
- A_NDY - collider, e^+e^- 2011-2013
  - Test run underway
  - Possibly A_N(Jet) from current (2011) run
  - Proposal in next PAC(June) to run 2012-2013
- DY workshop at BNL - May11-13

http://www.bnl.gov/dpworkshop/

Backup

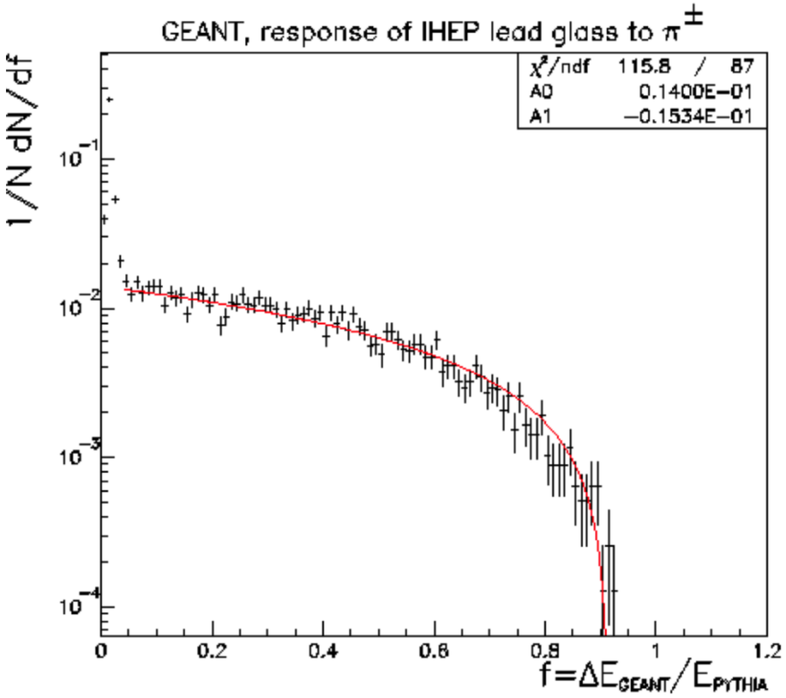
Magnetic Field Used for Charge Sign Simulations



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

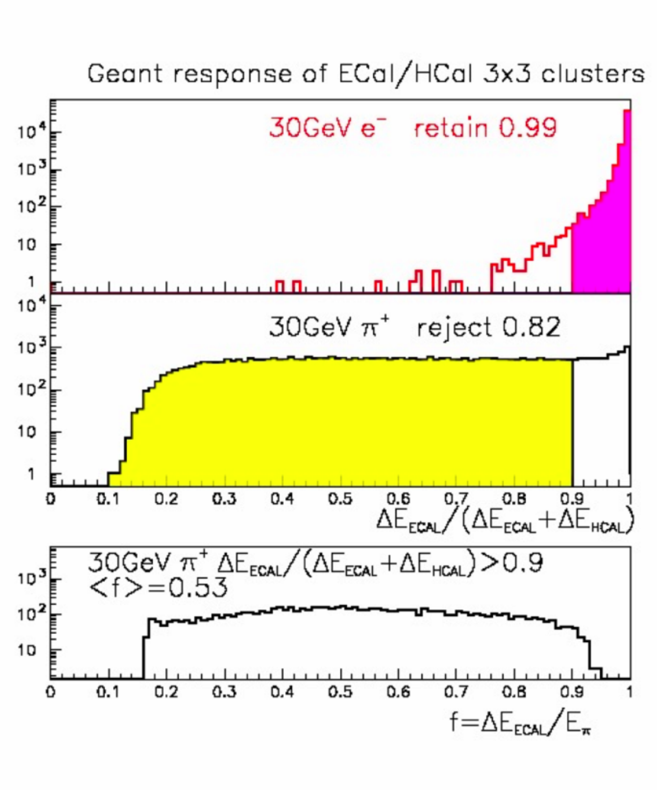
- The plan is to reuse the split-dipole magnet at IP2 designed, built and operated by the PHOBOS collaboration.
- PHOBOS provided their field map and geometry files for GEANT for simulation studies.
- Compared to use at IP10, split-dipole is rotated by 180^o around vertical axis, to move aperture restriction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

GEANT response of PbGl for sims



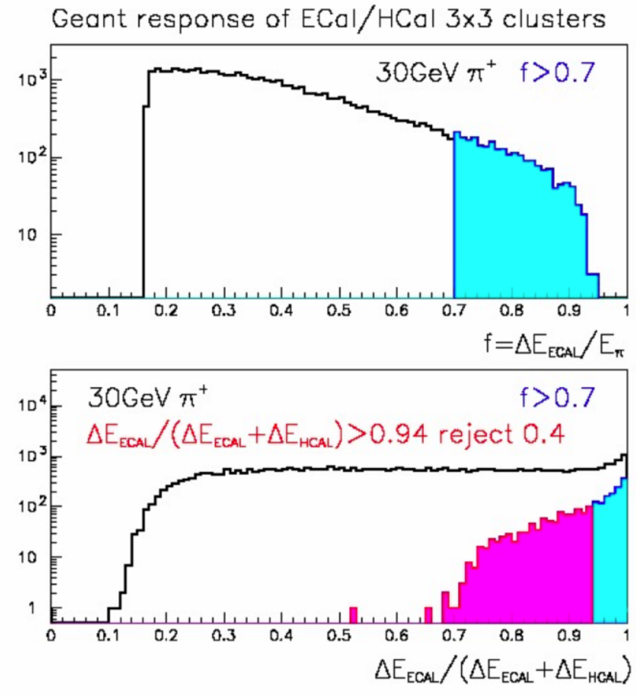
GEANT simulation of energy deposited in an EMcal built from 3.8 cm × 3.8 cm × 45 cm lead glass bars. Charged pions with E>15 GeV are used in this simulation. The fraction of the incident pion energy deposited in the EMcal is *f*. The dN/d*f* distribution is well represented by a linear function of *f*,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

Ecal and Hcal response - cuts



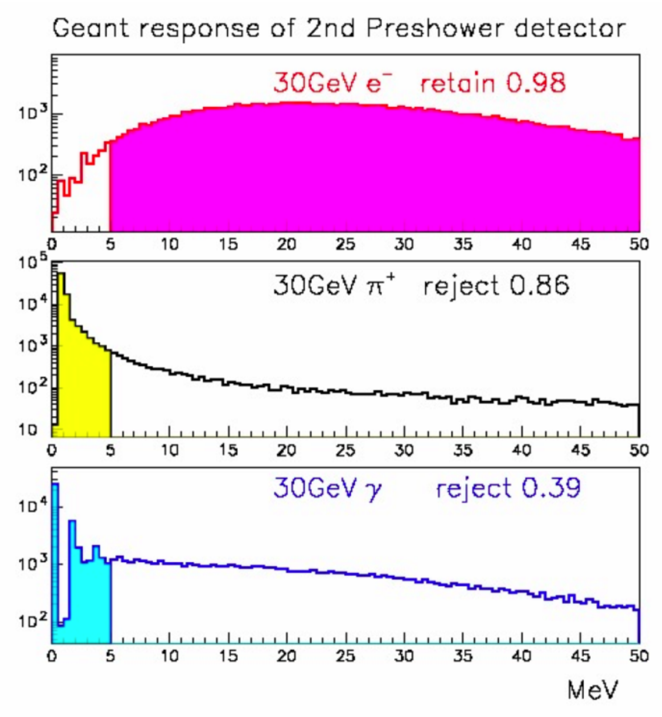
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV electrons and charged pions. A 3x3 cluster sum of deposited energy forms the ratio R=DE(EMcal)/(DE(EMcal)+DE(Hcal)) shown in top plot. With R>0.9 cut, EMcal+Hcal can reject 82% of hadrons while retaining 99% of electrons. The bottom plot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

Ecal and Hcal Response - cuts



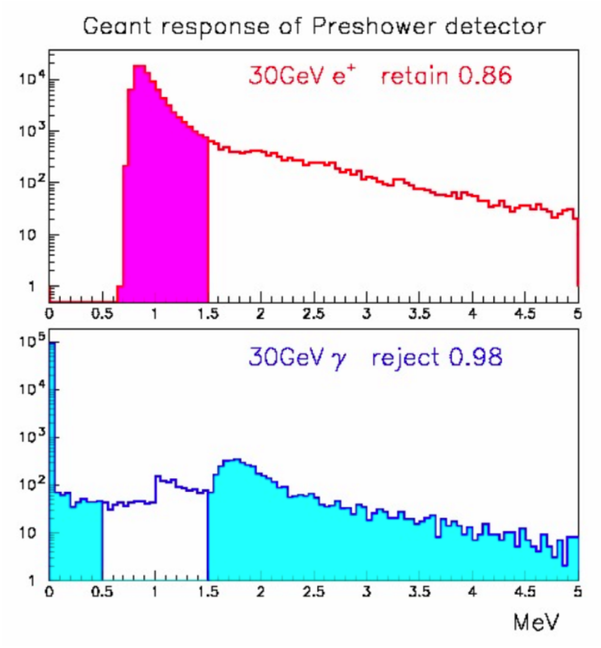
GEANT simulation for energy deposit in an EMcal and Hcal for 30GeV charged pions. The top plot shows the distribution of f in EMcal 3x3 clusters around the high tower. The bottom plot shows the ratio R=DE(EMcal)/(DE(EMcal)+DE(Hcal)). Blue shaded area is for hadrons surviving cut f>0.7. Red shaded area 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

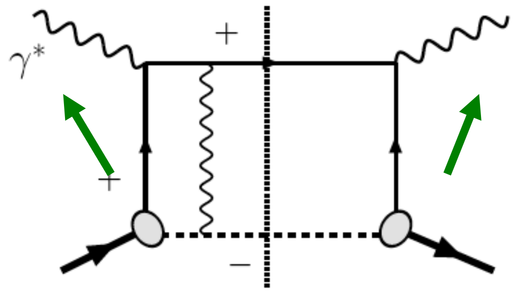


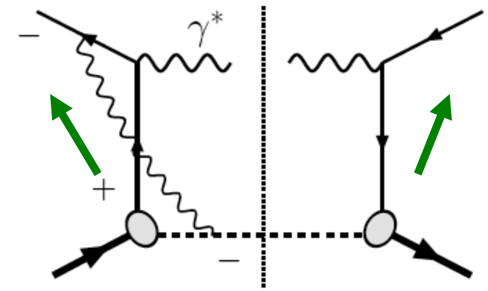
GEANT simulation of a pre-shower detector made of 0.5cm thick plastic scintillation counter. Responses for 30GeV electrons and photons are simulated. A cut of 0.5MeV < dE < 1.5MeV will retain 86% of electrons, while rejecting 98% photons including ones converted to e+e- pairs in beam pipe and preshower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

Attractive vs Repulsive Sivers Effects

Unique Prediction of Gauge Theory !
originally predicted by Collins!

Simple QED example:

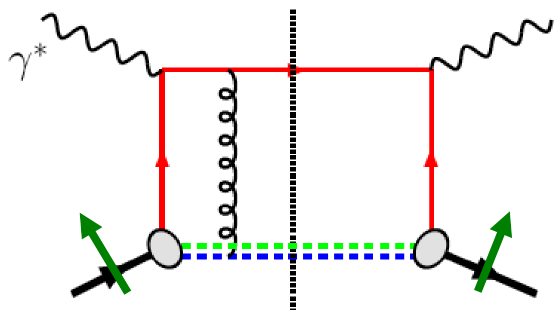


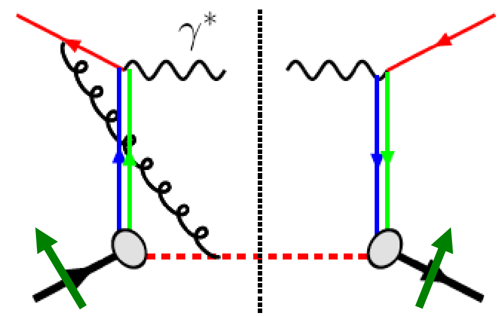


DIS: attractive

Drell-Yan: repulsive

Same in QCD:





As a result:

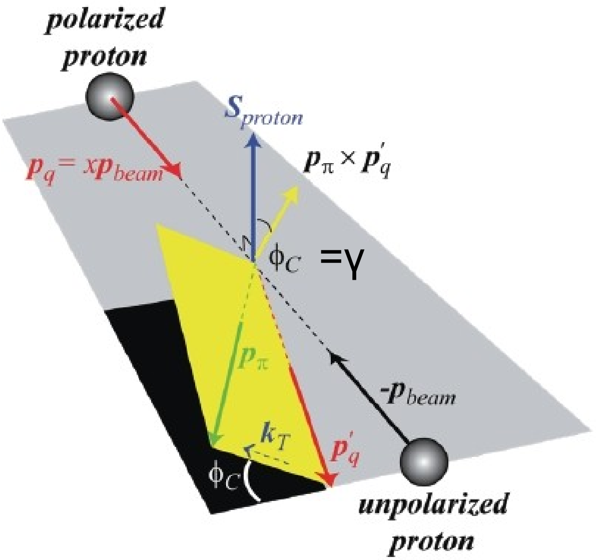
$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

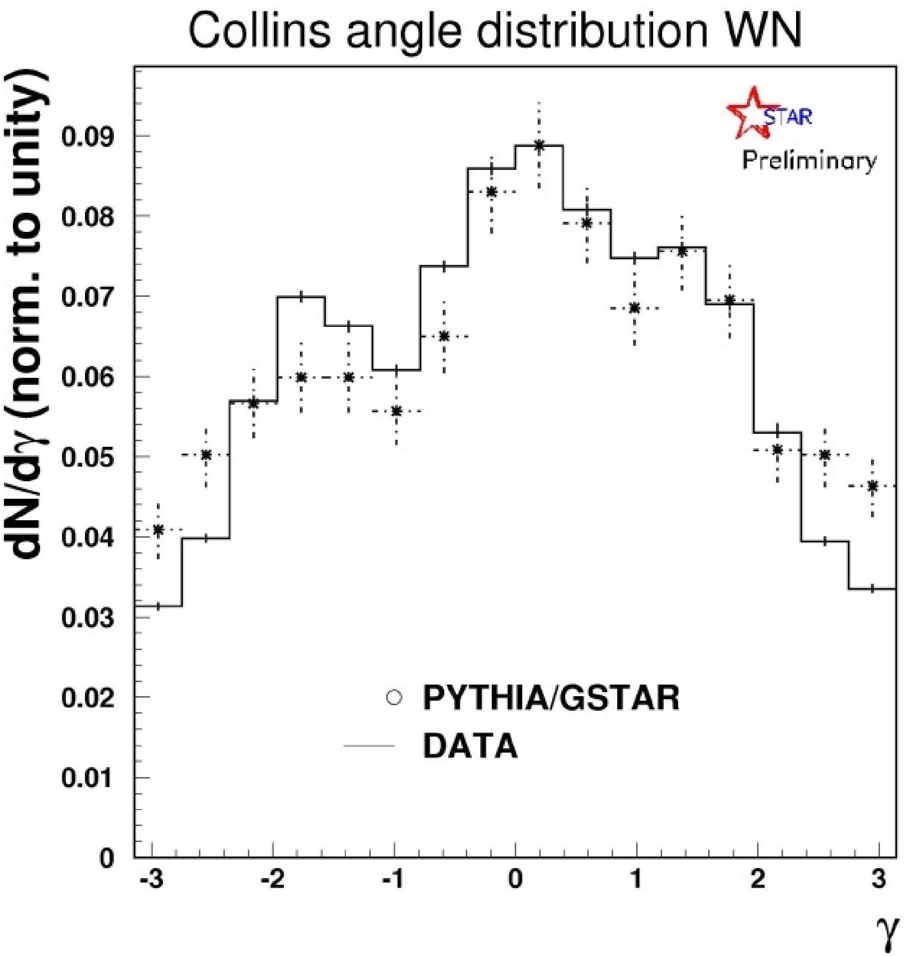
Transverse Spin Drell-Yan Physics at RHIC (2007)

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

Collins angle – definition and results

- The angle which the plane defined by the leading pion and the fragmenting quark closes with the reaction plane
- Defined mirror symmetrically around the axis of symmetry of the detector system (here parallel to S_{proton}), with 0 away from the beam and $\pm\pi$ towards the beam





- Collins angle well reconstructed as confirmed by association analysis
- The pion carries most of the transverse momentum of an event, so it is expected that the distribution will be peaked near small angles

The Collins angle distributions show agreement in data/simulations and are behaving as predicted.

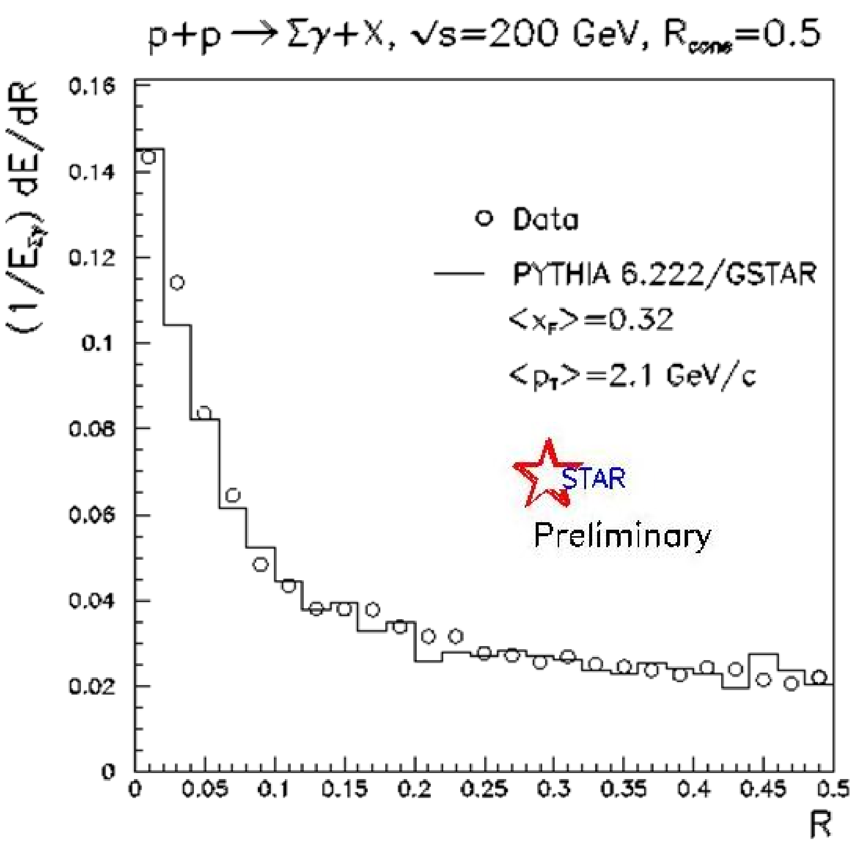
“jet-like” event measurements

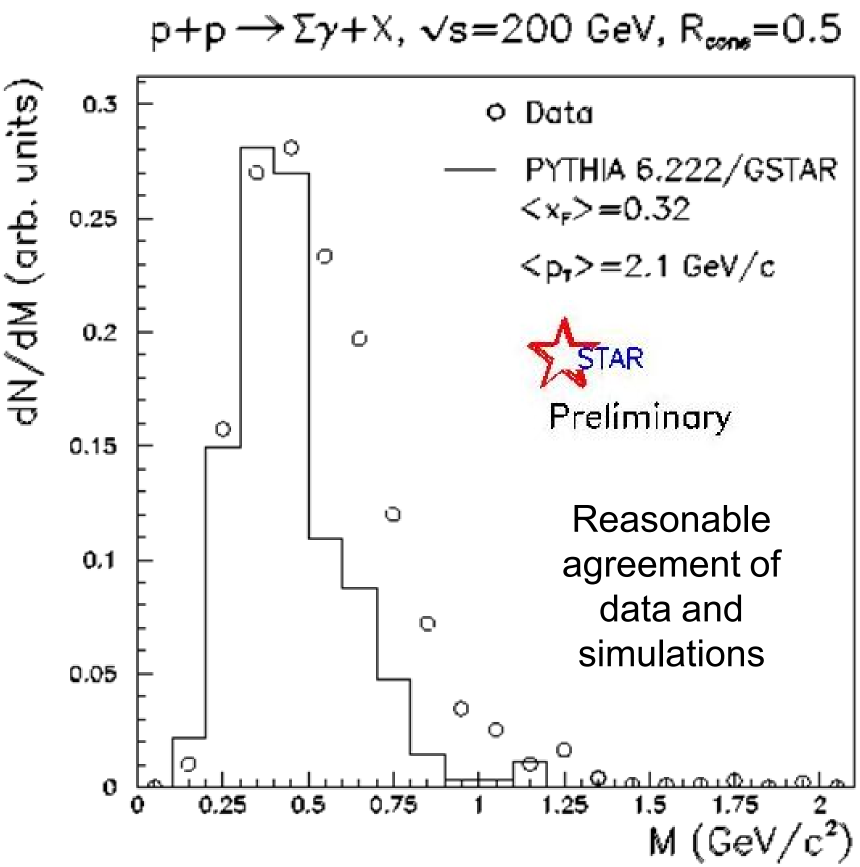
Obtained with the FMS; event selection done with:

- >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