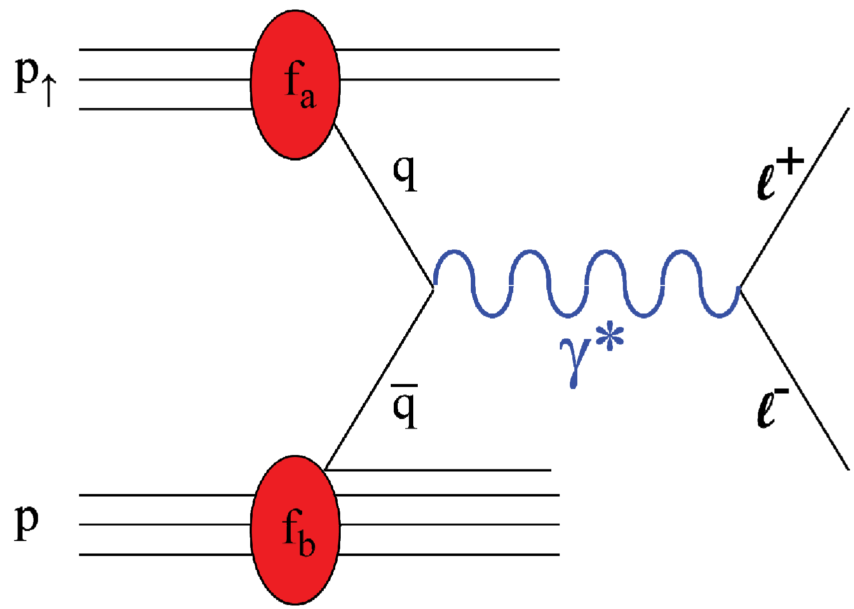
Transverse Spin Drell Yan Feasibility Study at RHIC



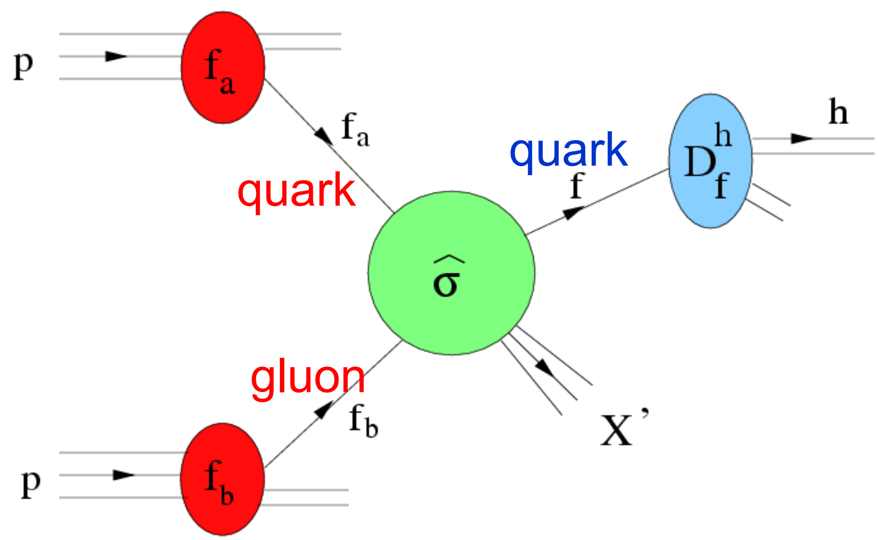
L.C. Bland, BNL

AGS/RHIC Users' Meeting Spin Workshop

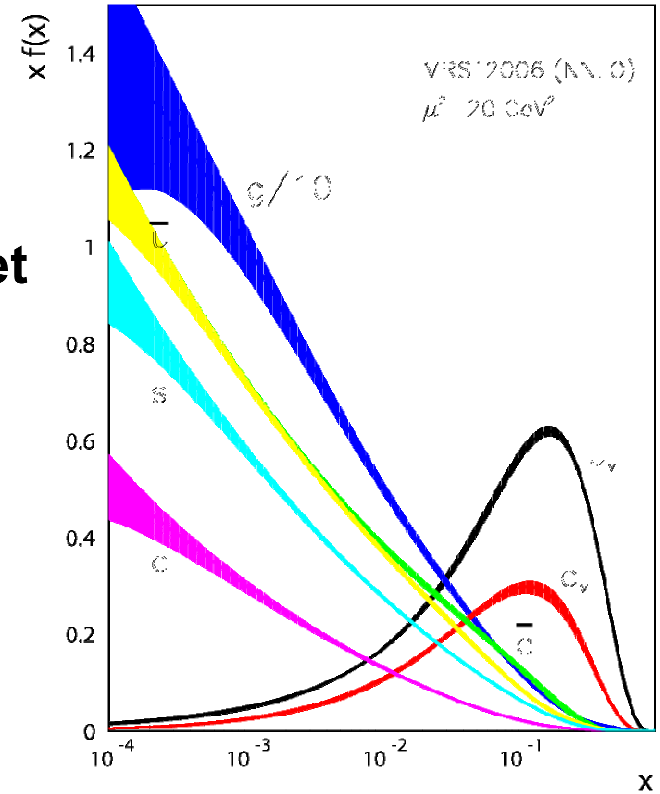
8 June 2010

RHIC Spin Probes

Proton collisions / collinear factorization



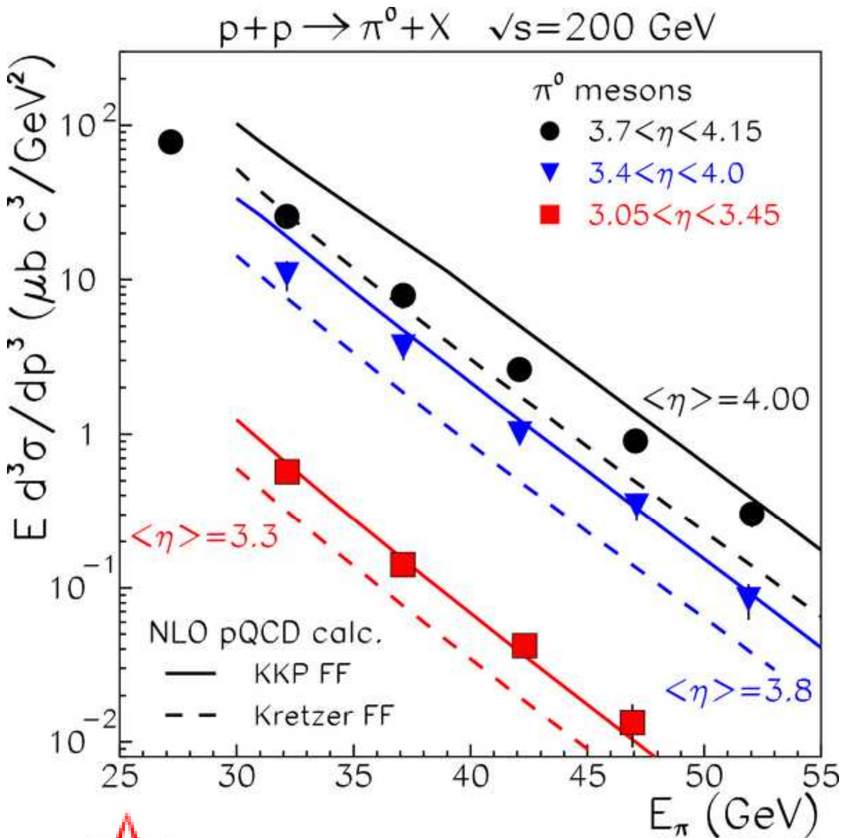
pion or jet



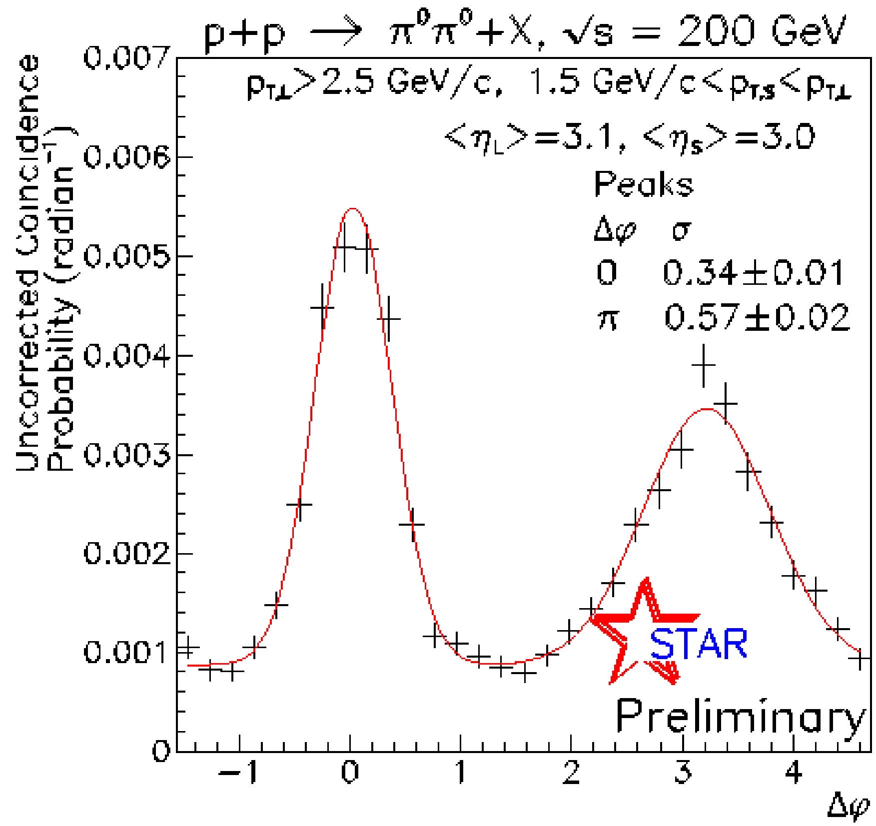
$$d\sigma_{\pi} = \sum_{a,b,c} \int dx_a \int dx_b \int dz_c \; f_a(x_a) f_b(x_b) D_c^{\pi}(z_c) d\hat{\sigma}_{ab}^{c}$$

Describe p+p particle production at RHIC energies (√s ≥ 62 GeV) using perturbative QCD at Next to Leading Order, relying on universal parton distribution functions and fragmentation functions

Forward Inclusive Pion Yields and Correlations



PRL **92** (2004) 171801



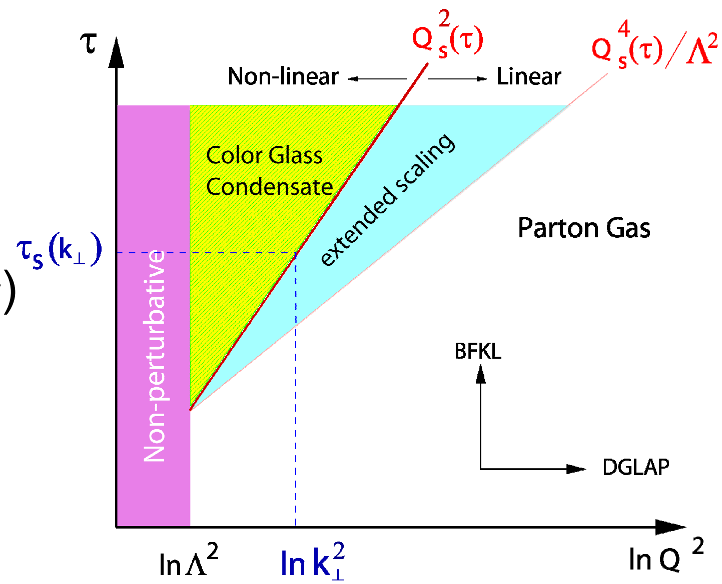
arXiv:1005.2378

- Inclusive π^0 cross sections agree with NLO pQCD
- Forward π^0-π^0 correlations show jet-like near-side and away-side peaks

Two Reasons to Go Beyond Collinear QCD

- **Low-x physics**: the gluon density cannot continue its growth as x→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.

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

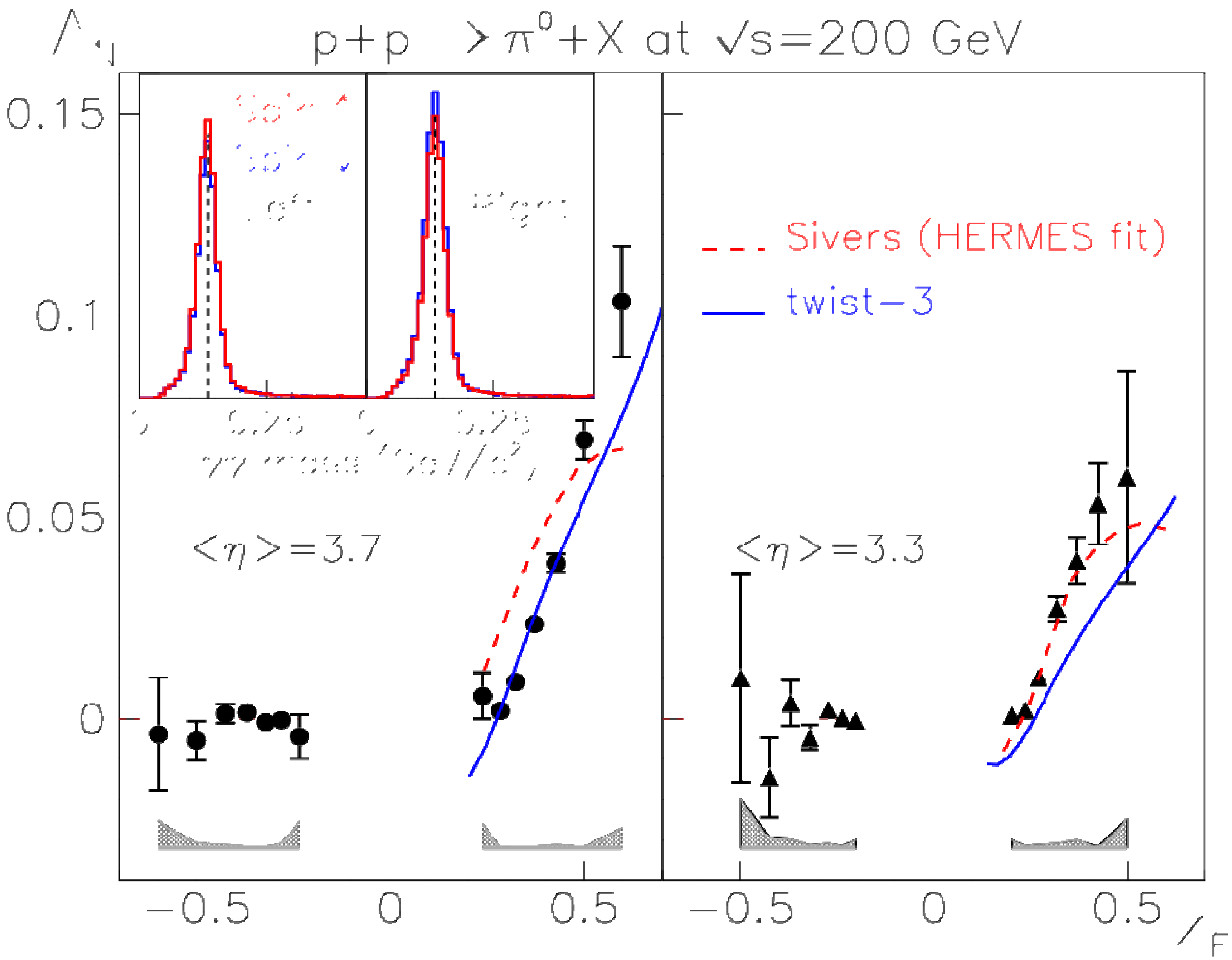


Iancu, Venugopalan
hep-ph/0303204

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

x_F Dependence of Inclusive π^0 A_N

RHIC Run 6 with FPD/FPD++



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

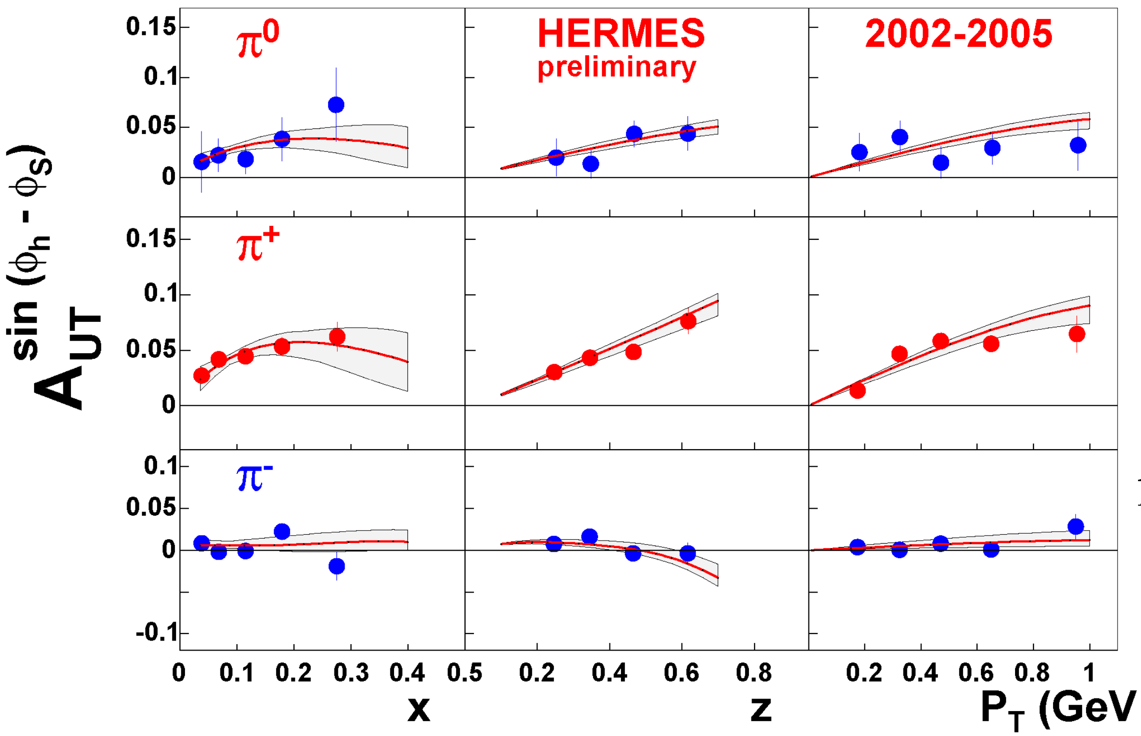
Fits to SIDIS (HERMES) are consistent with p+p→π+X data

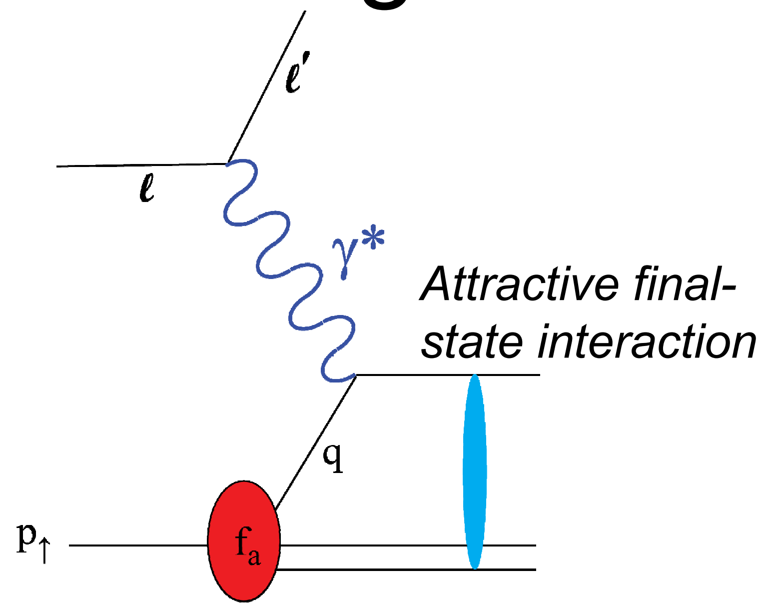
A_N at positive x_F grows with increasing x_F

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]

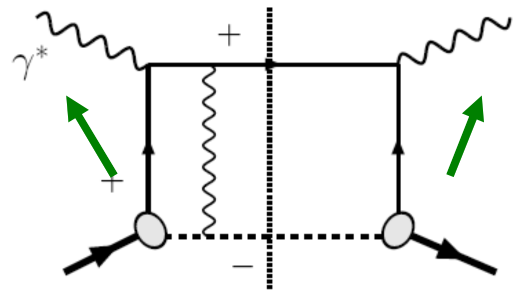
Phenomenological fits: M. Anselmino et al. EPJ A39 (2009) 89 [arXiv:0805.2677]

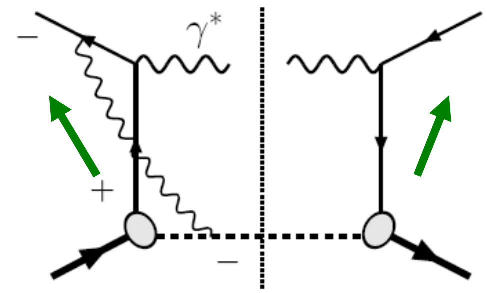
Final-state interaction: S.J. Brodsky, D.S. Hwang, I. Schmidt PL B530 (2002) 99 [hep-ph/0201296]

Attractive vs Repulsive Sivers Effects

Unique Prediction of Gauge Theory !

Simple QED example:

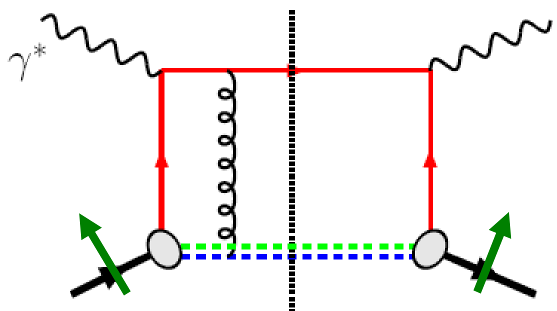


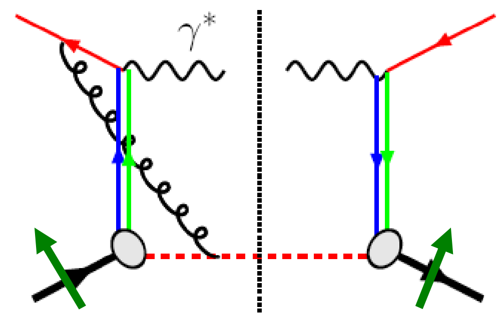


DIS: attractive

Drell-Yan: repulsive

Same in QCD:





As a result:

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

Transverse Spin Drell-Yan Physics at RHIC (2007)

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

Letters of Intent to 2010 Program Advisory Committee

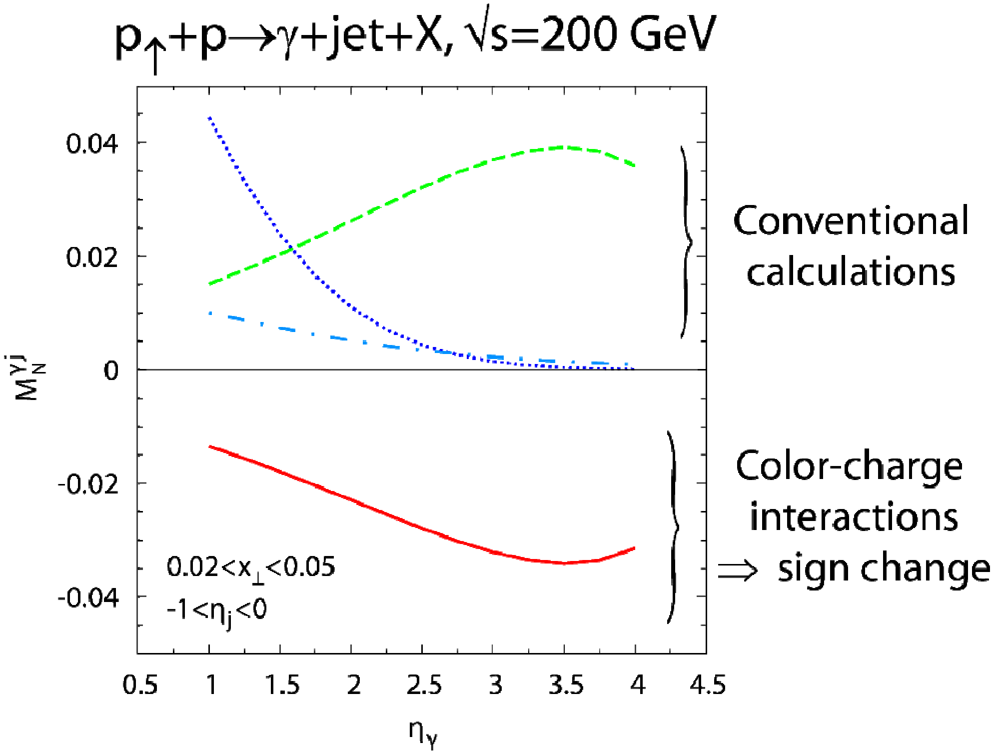
http://www.bnl.gov/npp/pac0610.asp

- *Measurement of Dimuons from Drell-Yan Process with Polarized Proton Beams and an Internal Target at RHIC* K.N. Barish, M.L. Brooks, A. Deshpande, N. Doshita, Y. Fukao, D.F. Geesaman, Y. Goto, M. Grosse Perdekamp, T. Iwata, X. Jiang, K. Kondo, G.J. Kunde, M.J. Leitch, M.X. Liu, P.L. McGaughey, Y. Miyachi, I. Nakagawa, K. Nakano, K. Okada, J.-C. Peng, P.E. Reimer, J. Rubin, N. Saito, S. Sawada, R. Seidl, T.-A. Shibata, A. Taketani, K. Tanida

- *Feasibility Test of Large Rapidity Drell Yan Production at RHIC* E.C. Aschenauer, A. Bazilevsky, L.C. Bland, A. Gordon, Y. Makdisi, A. Ogawa, P. Pile, T.G. Throwe, H.J. Crawford, J.M. Engelage, E.G. Judd, C.W. Perkins, A. Derevshchikov, N. Minaev, D. Morozov, L.V. Nogach, G. Igo, S. Trentalange, M. Grosse Perdekamp, A. Vossen, M.X. Liu, H. Avakian

The remainder of this talk focuses on the colliding-beam feasibility test.

Transverse spin direct γ



Theory expects repulsive color charge interactions to result in an opposite sign to spin-correlated momentum imbalance for γ+jet.

Bacchetta et al., PRL 99, 212002
also Kouvaris,Qiu,Vogelsang and Yuan

and, Teryaev and Ratcliffe

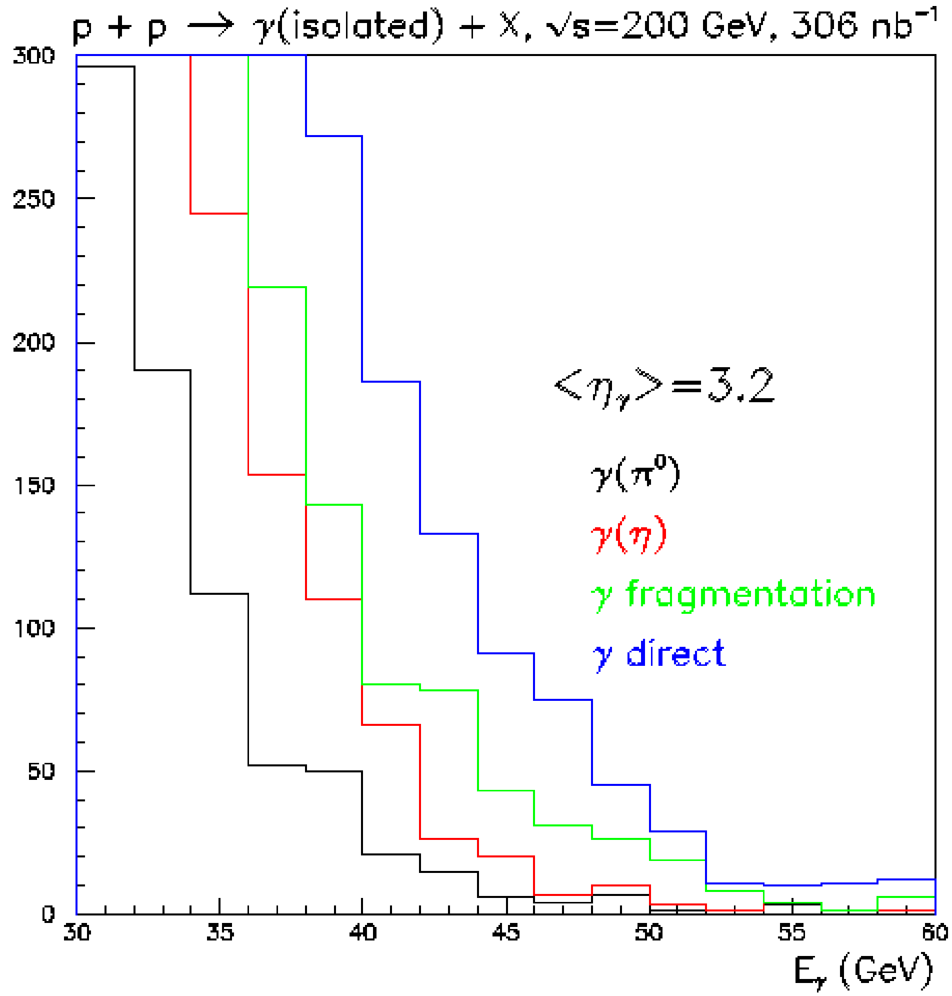
- Estimate that sign change is accessible with L_{int} = 30 pb^{-1} and P_{beam}=0.65
- Best done at $\sqrt{s}$ = 200 GeV for π^0 / γ separation
- Best done before removal for STAR Forward TPC

As part of the 2008 update to *Plans for the RHIC Spin Physics Program*

Future Opportunities

Transverse spin for forward γ+jet

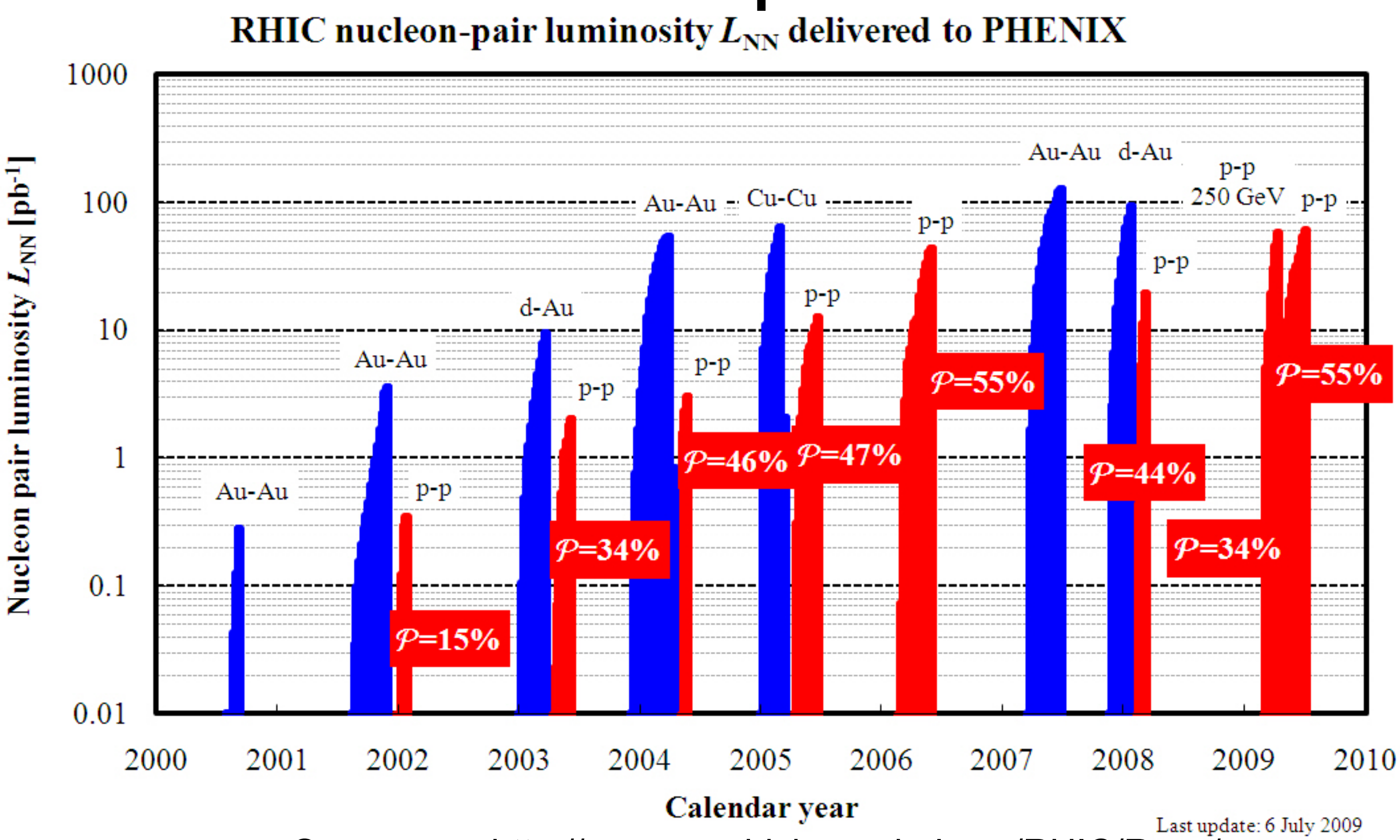
Test of predictive power of theory (A. Bacchetta et al. PRL **99** (2007) 212002)



Restricting the measurement of the forward photon to E_γ>35 GeV at $<\eta_\gamma>$=3.2 produces a signal:background ratio of 2.1.

As part of the 2008 update to *Plans for the RHIC Spin Physics Program*

RHIC is a Unique Collider…



Source: http://www.agsrhichome.bnl.gov/RHIC/Runs/

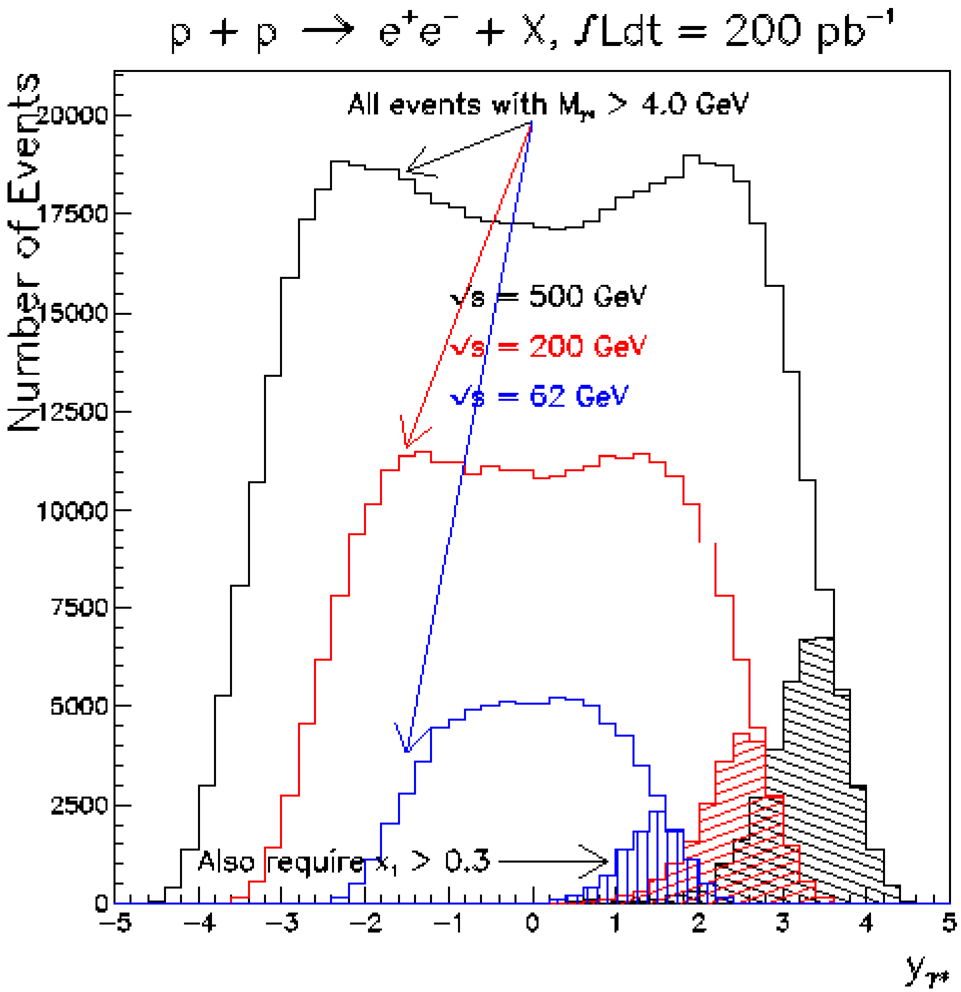
- …capable of colliding essentially all positive ions over a broad range of $\sqrt{s}$
- …with large L/$\sqrt{s}$, where L is free space at interaction region ⇒ large x_F possible
- …with a broad and diverse physics program aimed at important questions
  - What is quark-gluon plasma? ⇒ heavy-ion collisions
  - How does the proton get its spin? ⇒ polarized proton collisions
  - Does the gluon density saturate in a heavy nucleus? ⇒ d+Au/p+Au collisions

Status

- Luminosity gains projected for $\sqrt{s}$=200 GeV polarized proton collisons were not realized, so L_{int}=30 pb^{-1} and P_{beam}=65% for transverse spin direct photon would be challenging.
- Theory community has revisited whether color-charge interactions are robustly calculable [arXiv:1001.2977] for transverse single-spin asymmetries for processes *other than Drell Yan production*
- Low-x/saturation physics looks to be very interesting at RHIC collision energies. Non-universality of k_T dependent distribution functions for di-jets may impact small-x as well as transverse spin [arXiv:1003.0482]. This should not be the case for *low-x probed by Drell-Yan production*

$\Rightarrow$ establishing the requirements for a large-x_F Drell Yan production experiment will provide the most robust test of theory for transverse spin, and lead to future avenues that provide the most robust interconnections between low-x probed at RHIC and low-x probed at eRHIC.

Collision Energy Dependence of Drell Yan Production



Comments…

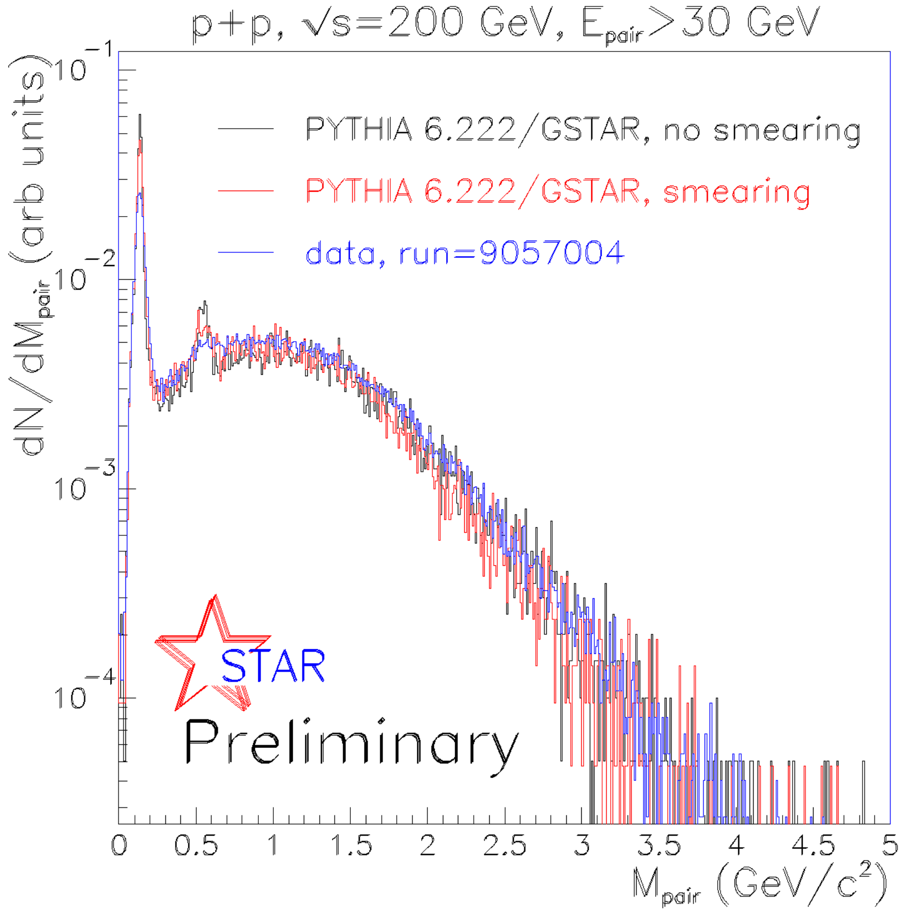
- $\bar{q}q \to \gamma^*$ has $\hat{\sigma} \propto 1/\hat{s}$
- partonic luminosities increase with $\sqrt{s}$
- net result is that DY grows with $\sqrt{s}$
- in any case, largest $\sqrt{s}$ probes lowest x

$\Rightarrow$ Consider large-x_F DY at $\sqrt{s}$=500 GeV

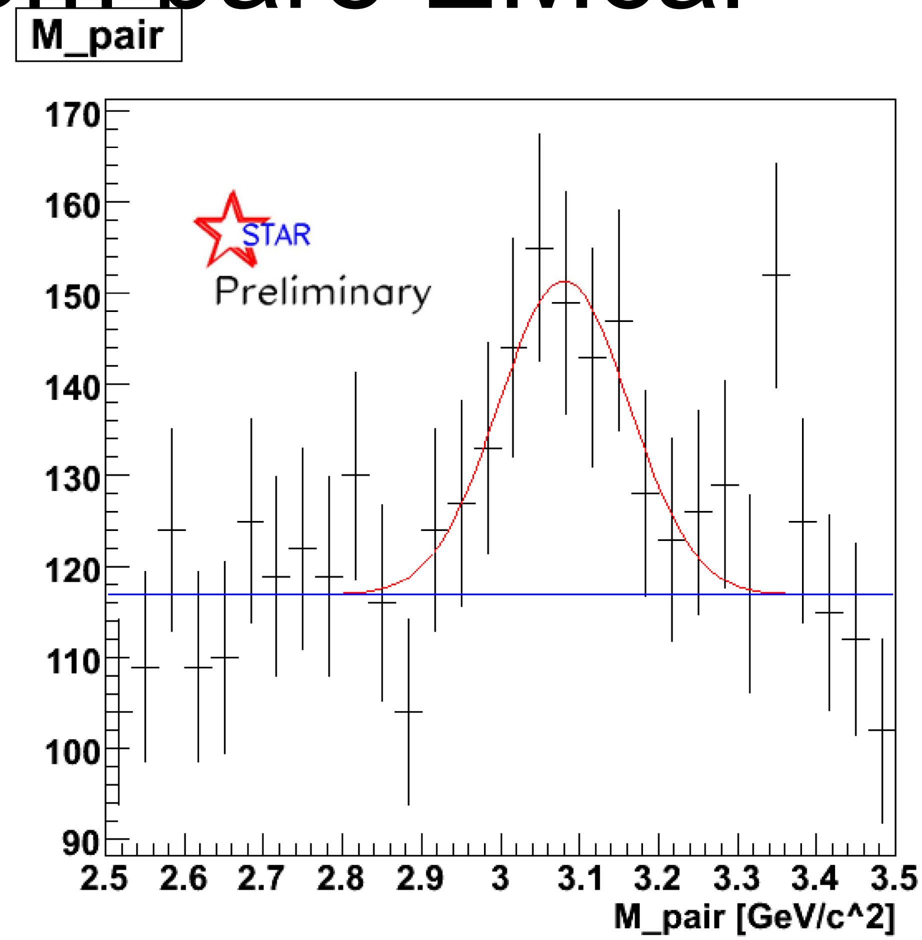
Transverse Spin Drell-Yan Physics at RHIC (2007)

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

Pair mass from bare EMcal



arXiv:0906.2332



arXiv:0907.4396

- pair mass backgrounds well modeled
- J/ψ→e+e- observation at <xF>~0.67 emboldens DY consideration

Motivations for DY Feasibility at IP2

2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering

Report to NSAC from the Subcommittee on Performance Measures (August, 2008)
http://www.sc.doe.gov/np/nsac/docs/PerfMeasEvalFinal.pdf

- **Timeliness** – HP13 milestone completion by 2015. This could be accomplished during W program if 3IR impact is acceptable.
- **Acceptance/background rejection** – severe space constraints at STAR and PHENIX require major changes in the forward direction. Space constraints are not present at IP2.
- **Is charge sign a requirement?**

Objective of DY feasibility test is to establish the **requirements for future major forward upgrades at STAR and PHENIX** that would be used in a future p+Au or d+Au run that would emphasize Drell Yan production to probe low-x through scaling violations or virtual photon p_T dependence.

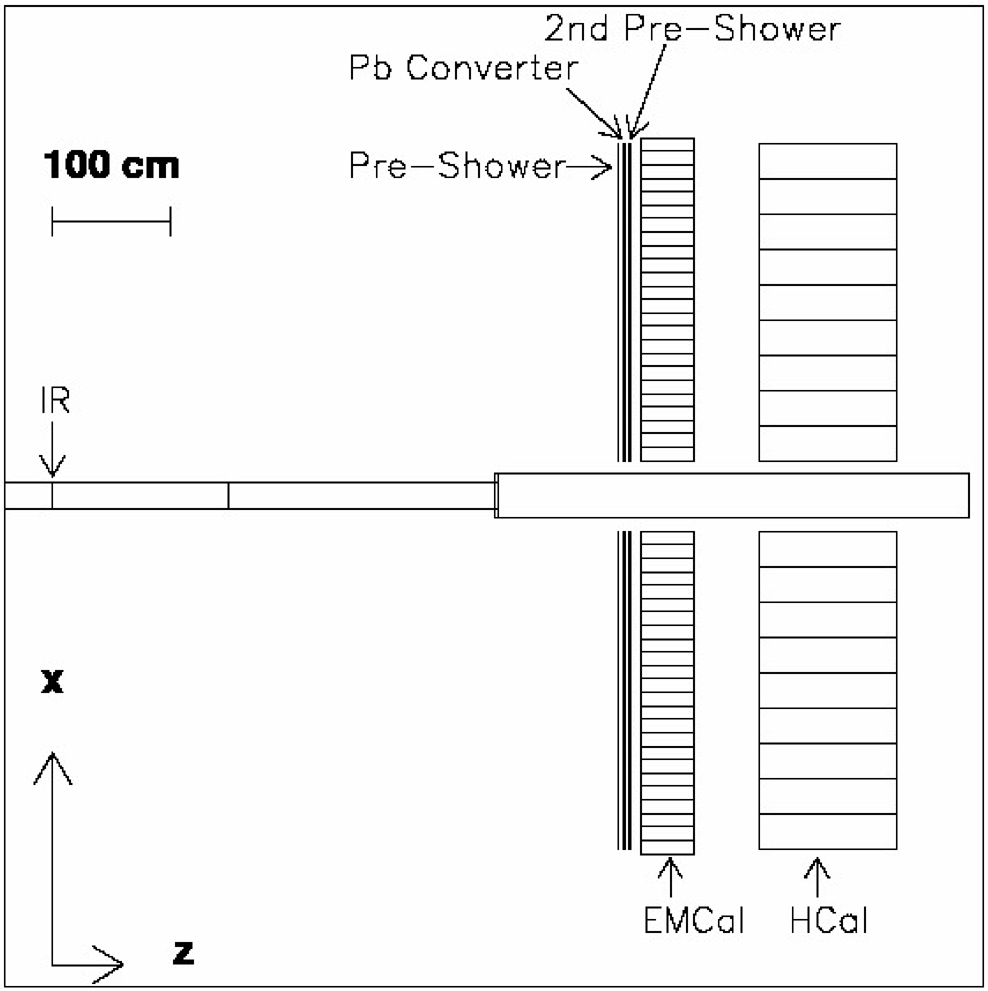
Requirements for DY

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

Schematic of detector considered

Run-12 configuration

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

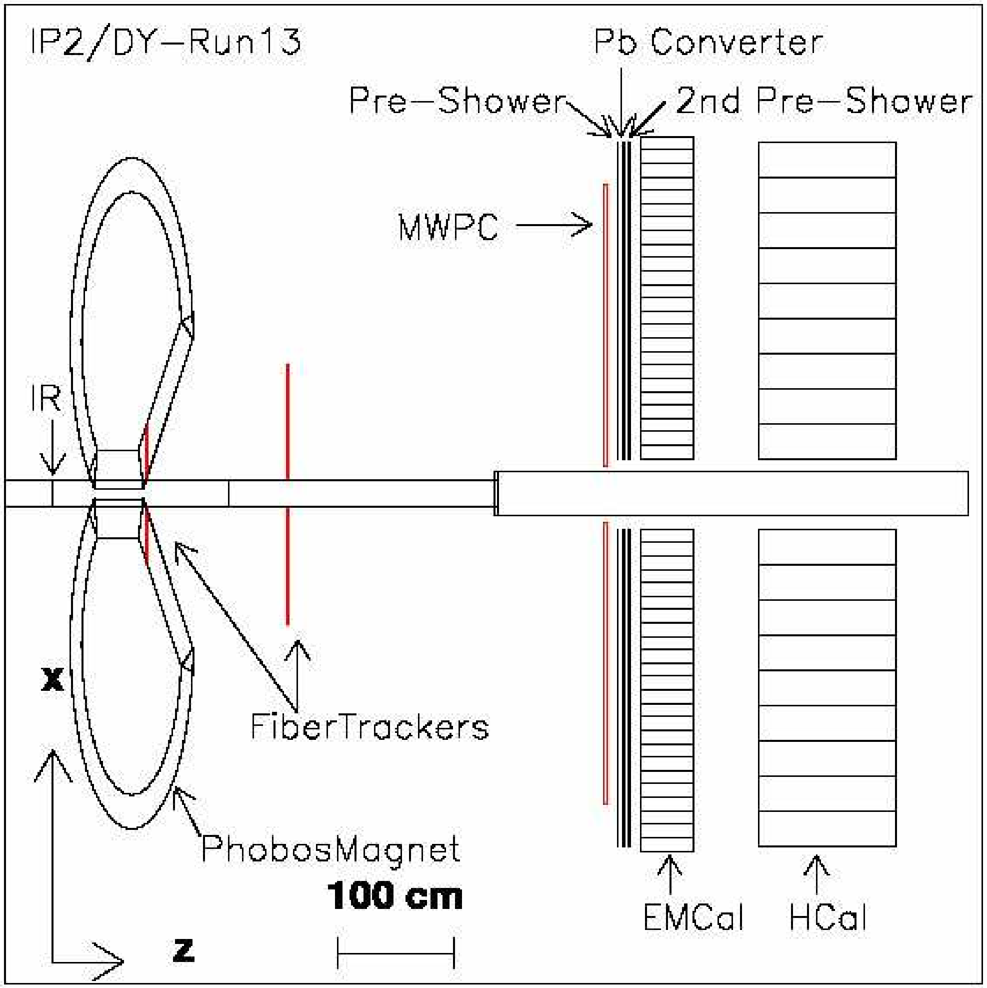


http://www.star.bnl.gov/~akio/ip2/topview2.jpeg

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

Schematic of detector considered

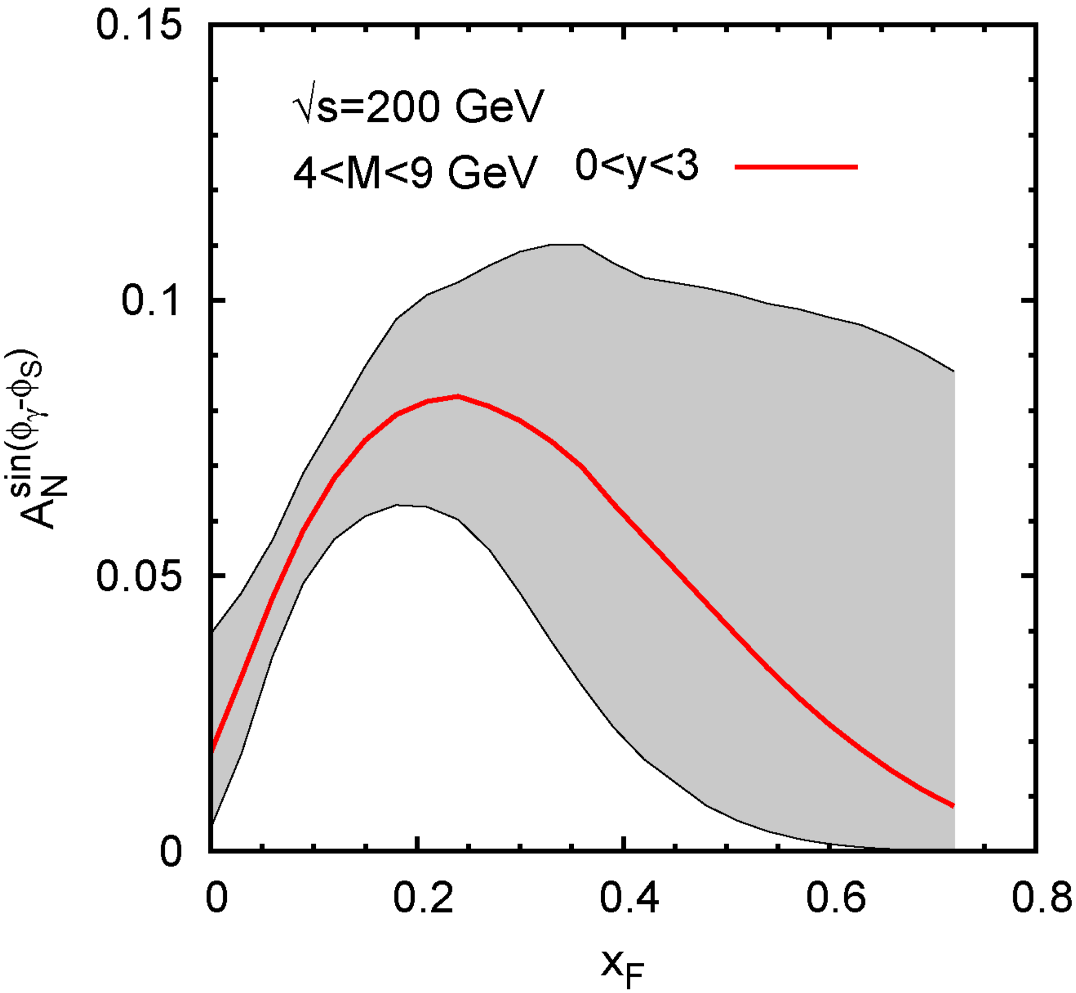
Run-13 configuration
(Uses PHOBOS Split Dipole for charge sign)



- Hcal is existing 9x12 modules from E864 (NIM406,227)
- EMcal is modeled as only $(3.8cm)^2$x(45cm) 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

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 δA_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]

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
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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

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Yale University, New Haven, CT, USA

Received 18 February 1980

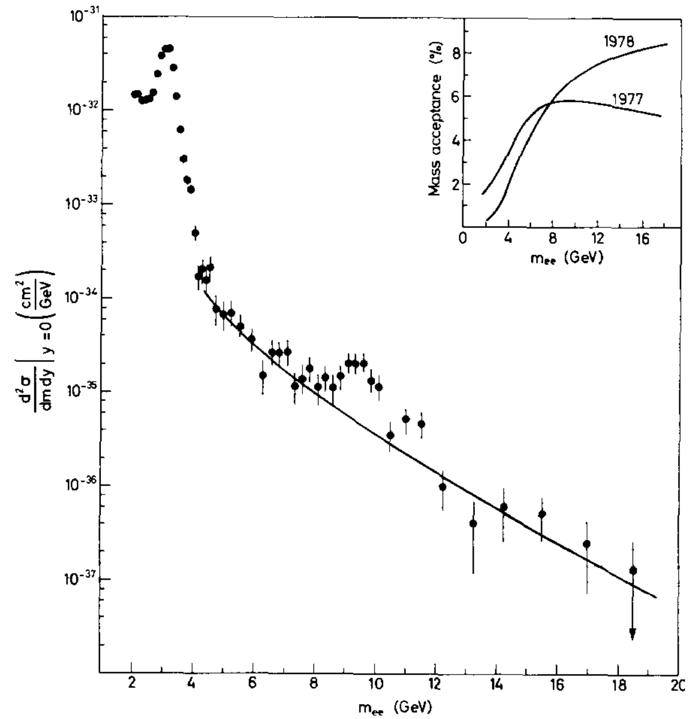
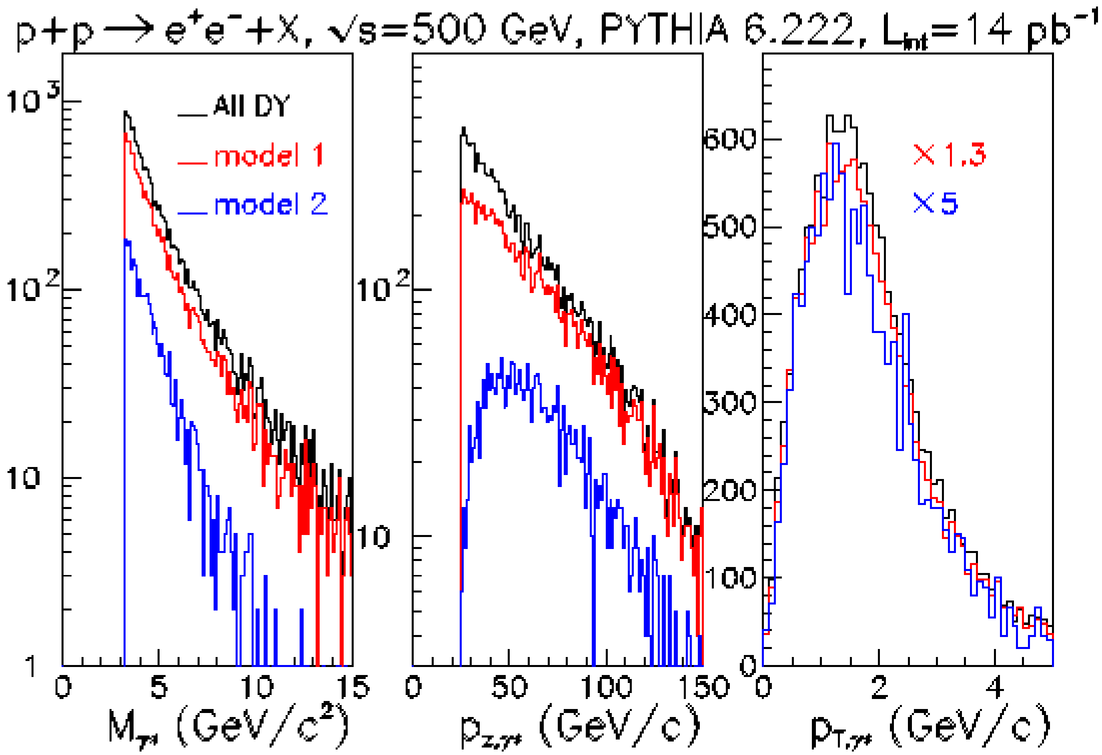


Fig. 1. The cross section $(d^2\sigma/dm\,dy)_{y=0}$ versus mass for the data at $\sqrt{s}$ = 53 and 63 GeV combined. The curve is a result of the fit to the continuum displayed in fig. 2. The inset show the mass acceptance for "1977" and "1978" triggers and geometrical configurations calculated for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

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



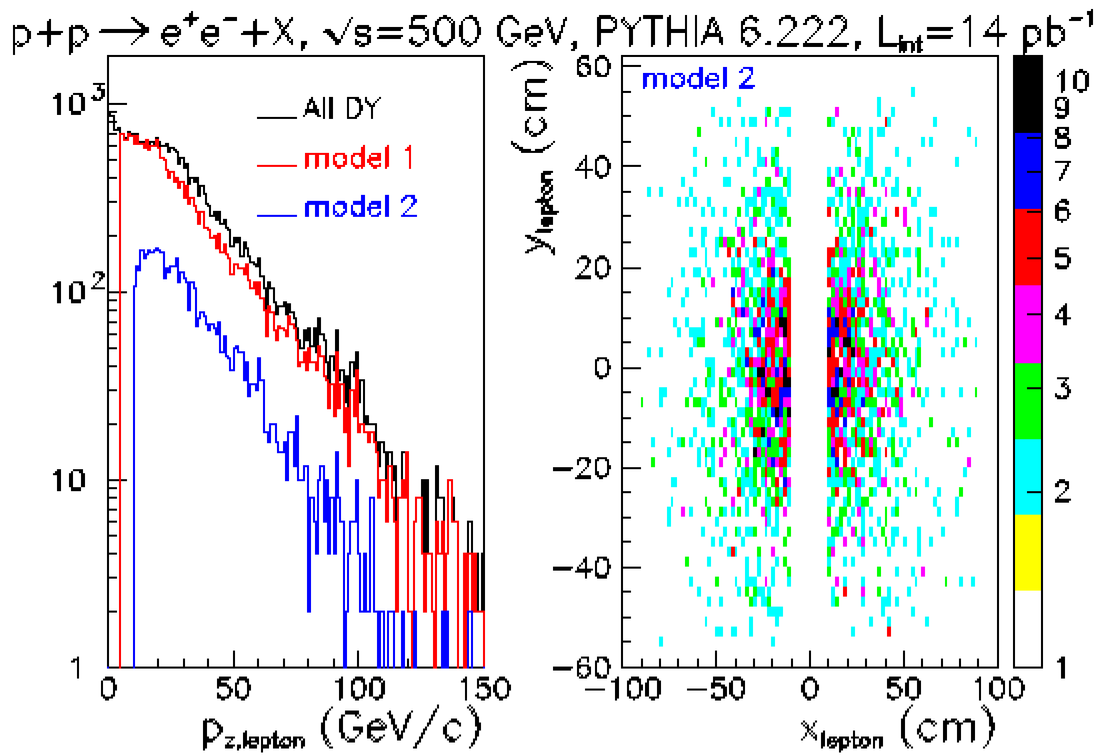
Model 1 = EMcal $(2m)^2$ / $(0.2m)^2$ beam hole at 10m / no magnetic field

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?

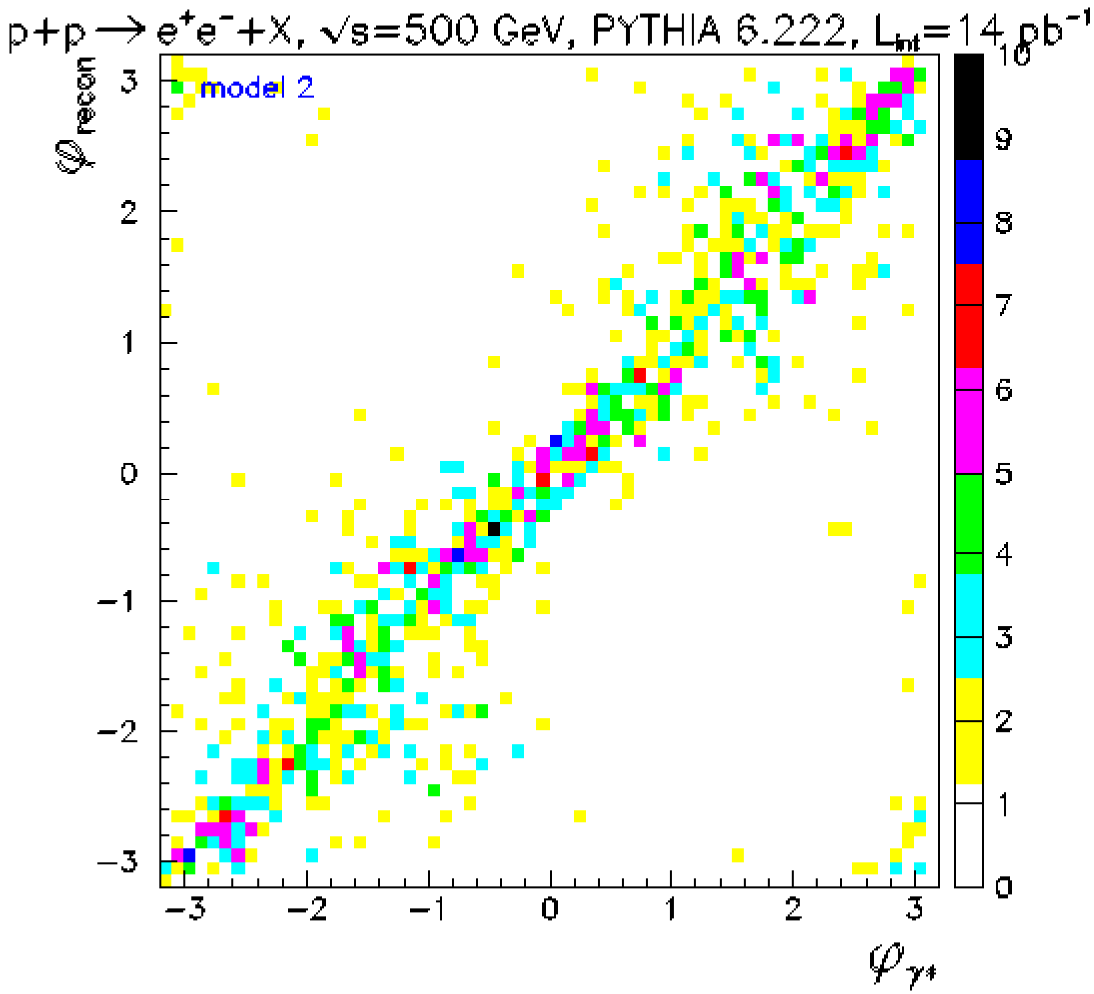
Lepton daughters from γ^*



Most important contributions for γ^* x_F>0.1 at √s=500 GeV …

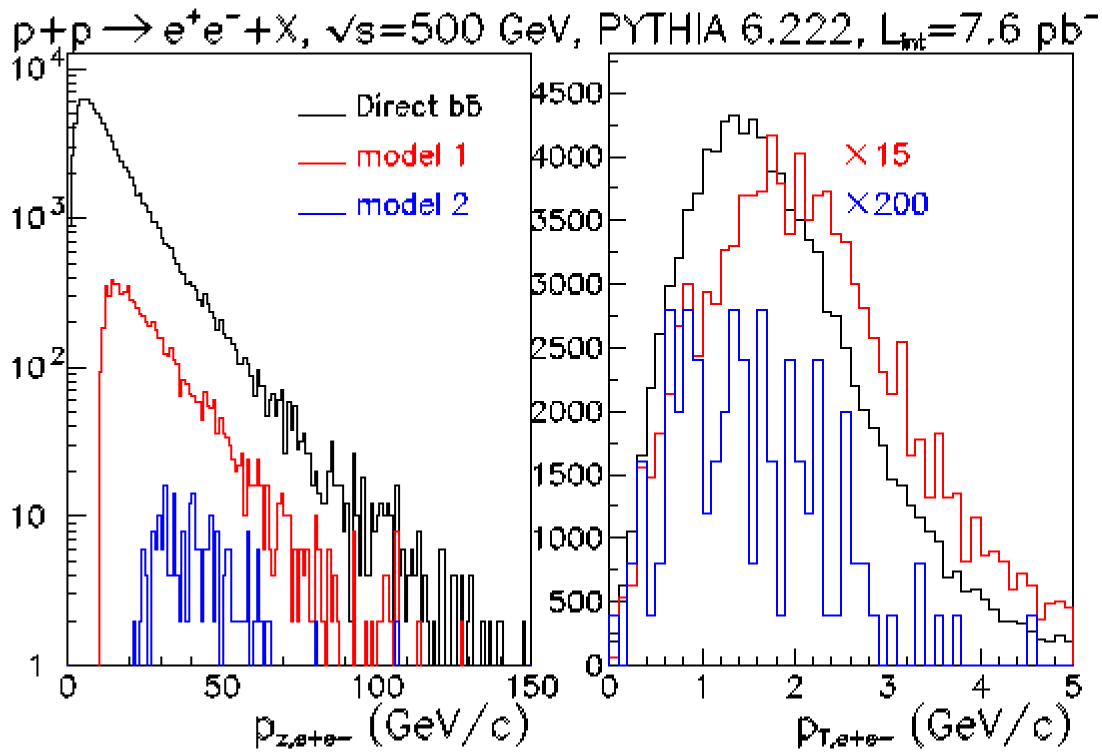
- high energy electrons and positrons (E>10 GeV)
- require detection at very forward angles
- e+(e-) from γ^* little affected by "modest" isolation (20mr half-angle cone)
- best solution for charge sign would be a dipole magnet (difficult for any collider)

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

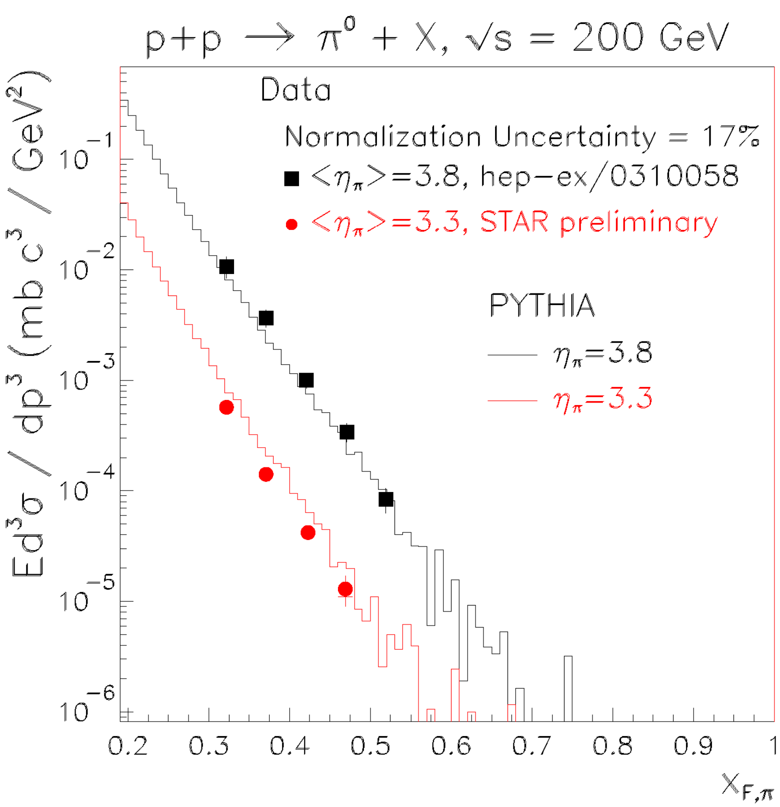


Comments…

- 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 xF
- large forward acceptance for the future would require discrimination (isolation)

Backgrounds

- $h^{\pm}/e^{\pm}$ discrimination – requires estimates of p+p collisions and EMcal response
- charged/neutral discrimination
- photon conversion background – requires estimates of p+p collisions and materials

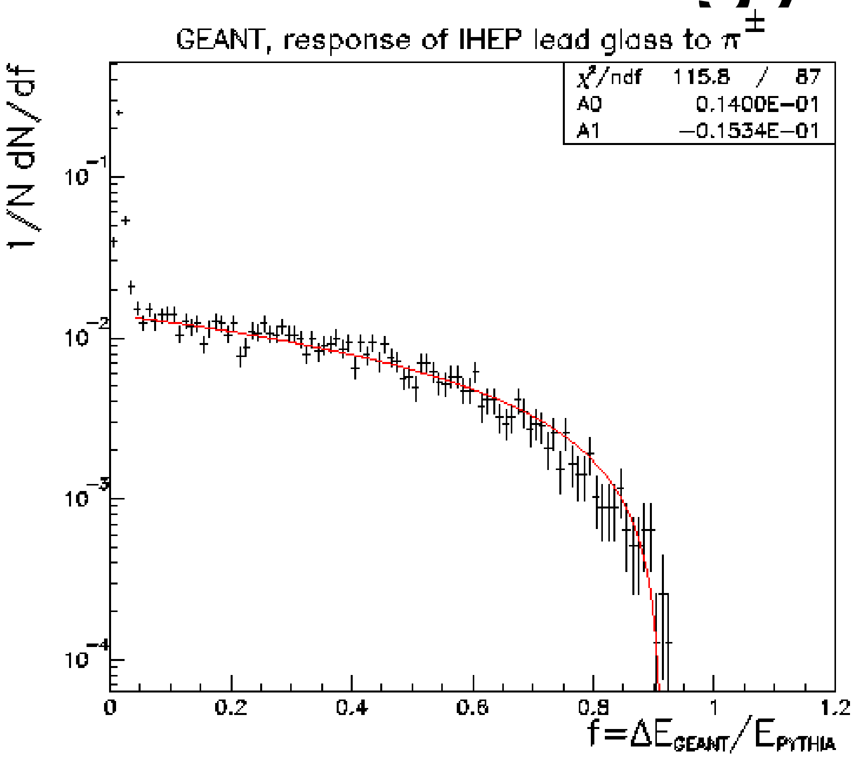


hep-ex/0403012

- 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

⇒ Stick to PYTHIA 6.222 for estimates

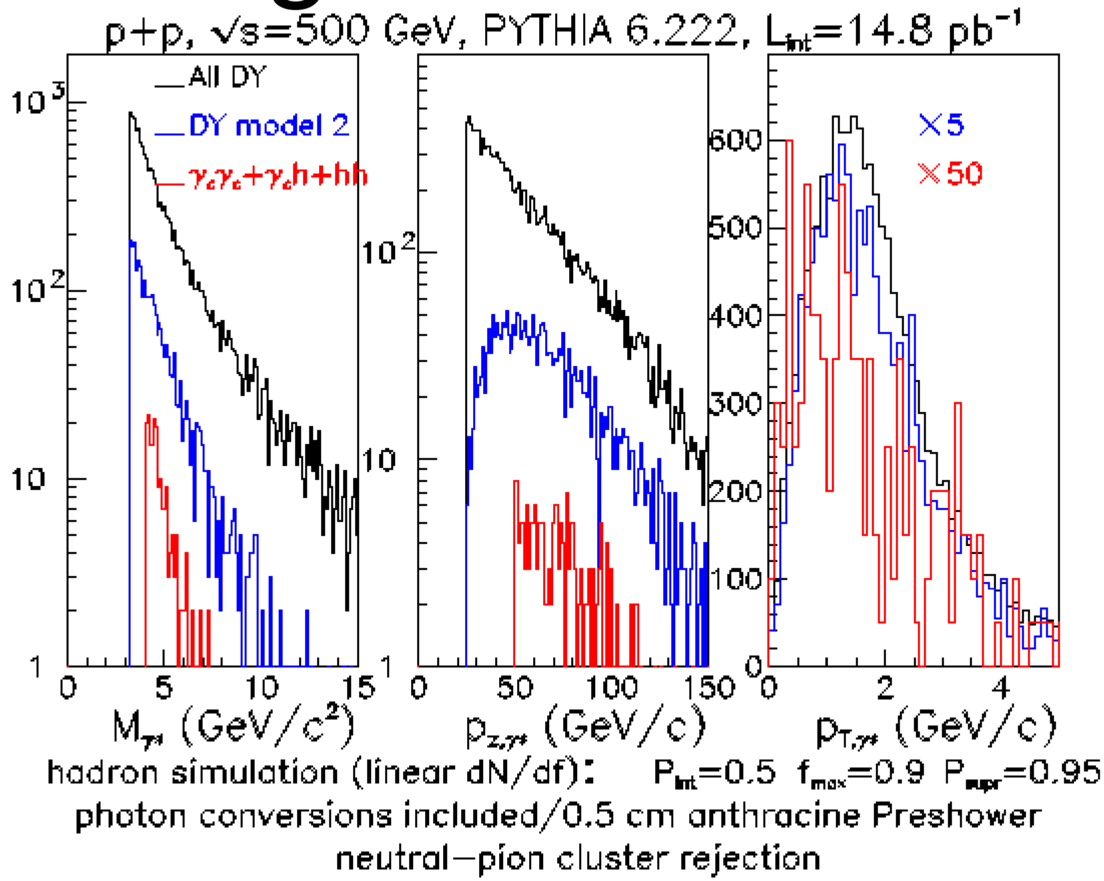
Strategy for estimates



GEANT simulation of EMcal response to E>15 GeV $\pi^{\pm}$ 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 ⇒ 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 $h^{\pm}/e^{\pm}$ 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. $\sigma_E=15\%/\sqrt{E}$ and $\sigma_{x(y)}=0.1d_{cell}$, used to date for $\pi^0\rightarrow\gamma\gamma$ rejection.

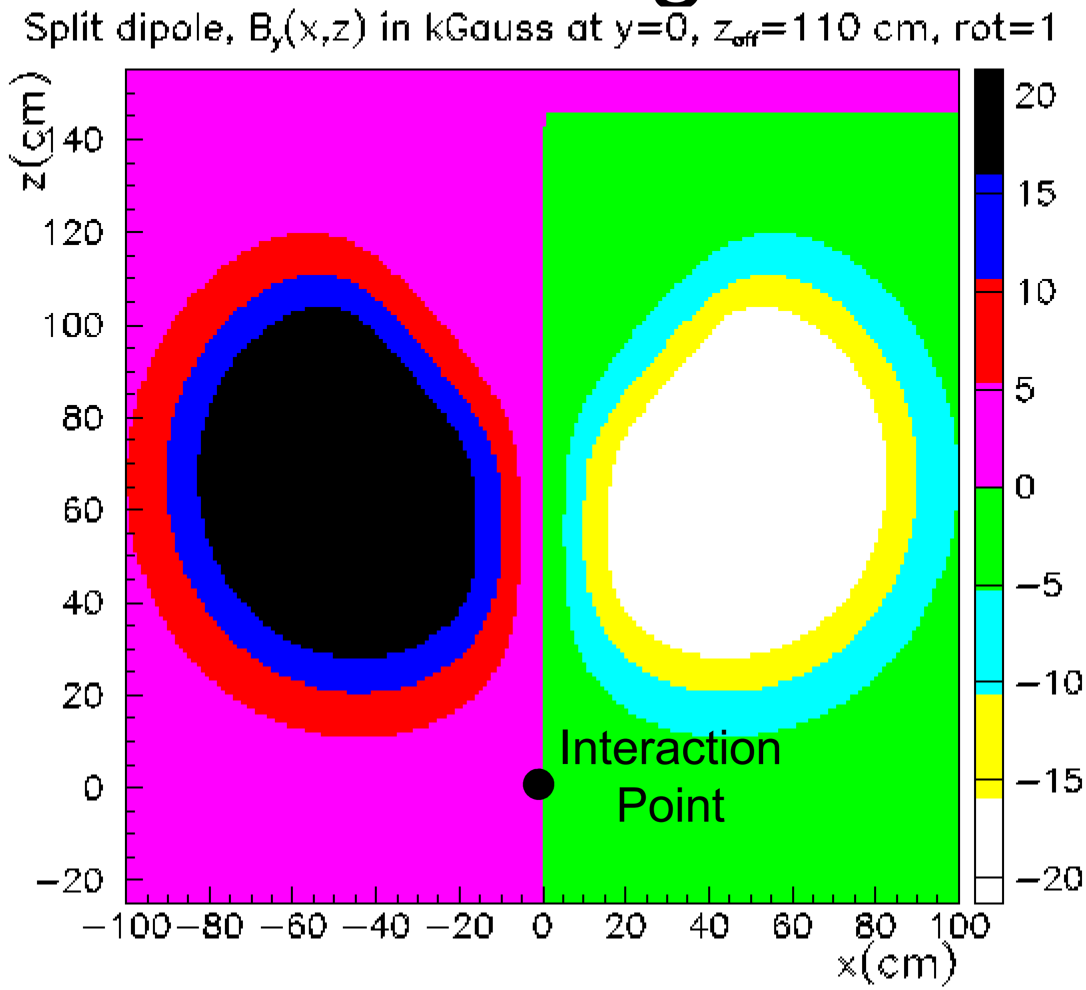
Background Estimate



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 estimates smaller hadronic background ⇒ increased sophistication needed for reliable estimates, although other model uncertainties could easily dominate.

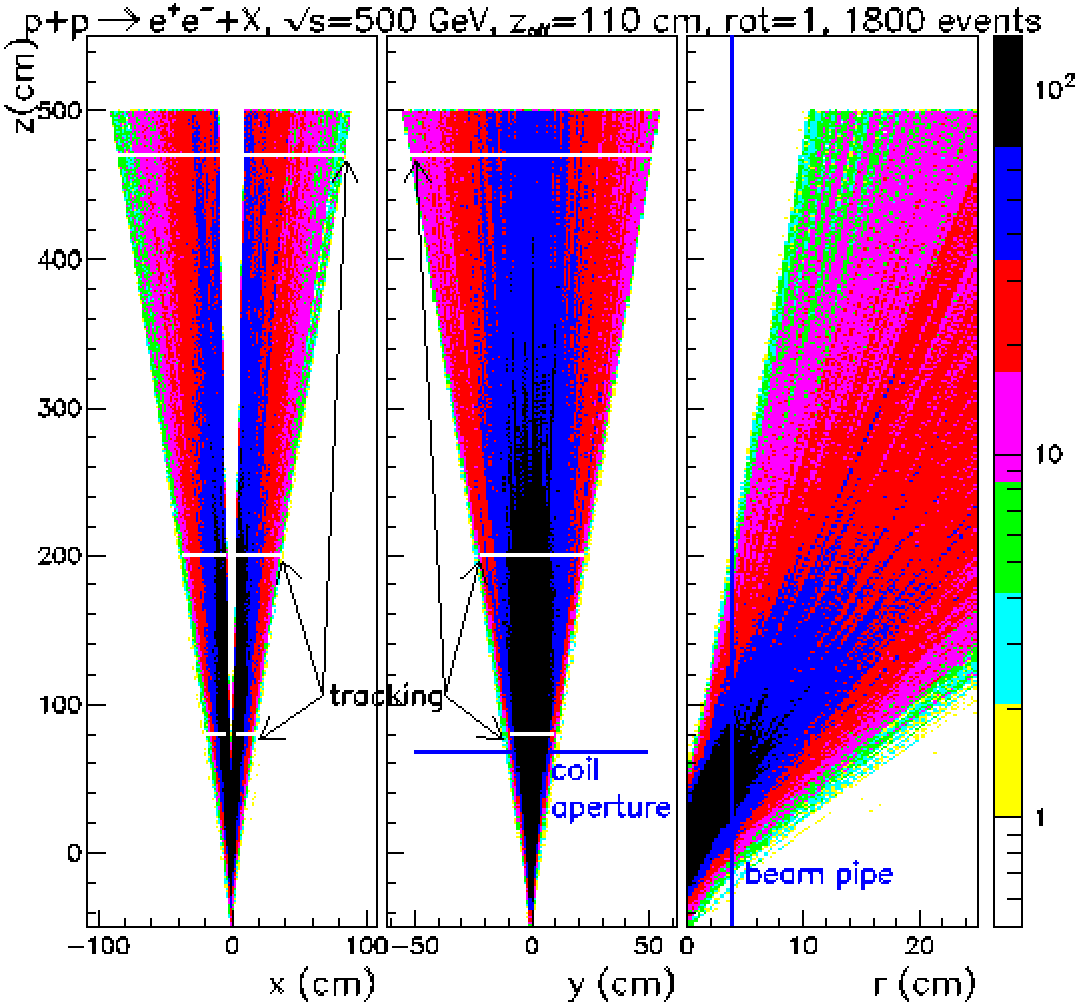
Magnetic Field Used for Charge Sign Simulations



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° around vertical axis, to move aperture restriction from coils close to IP.

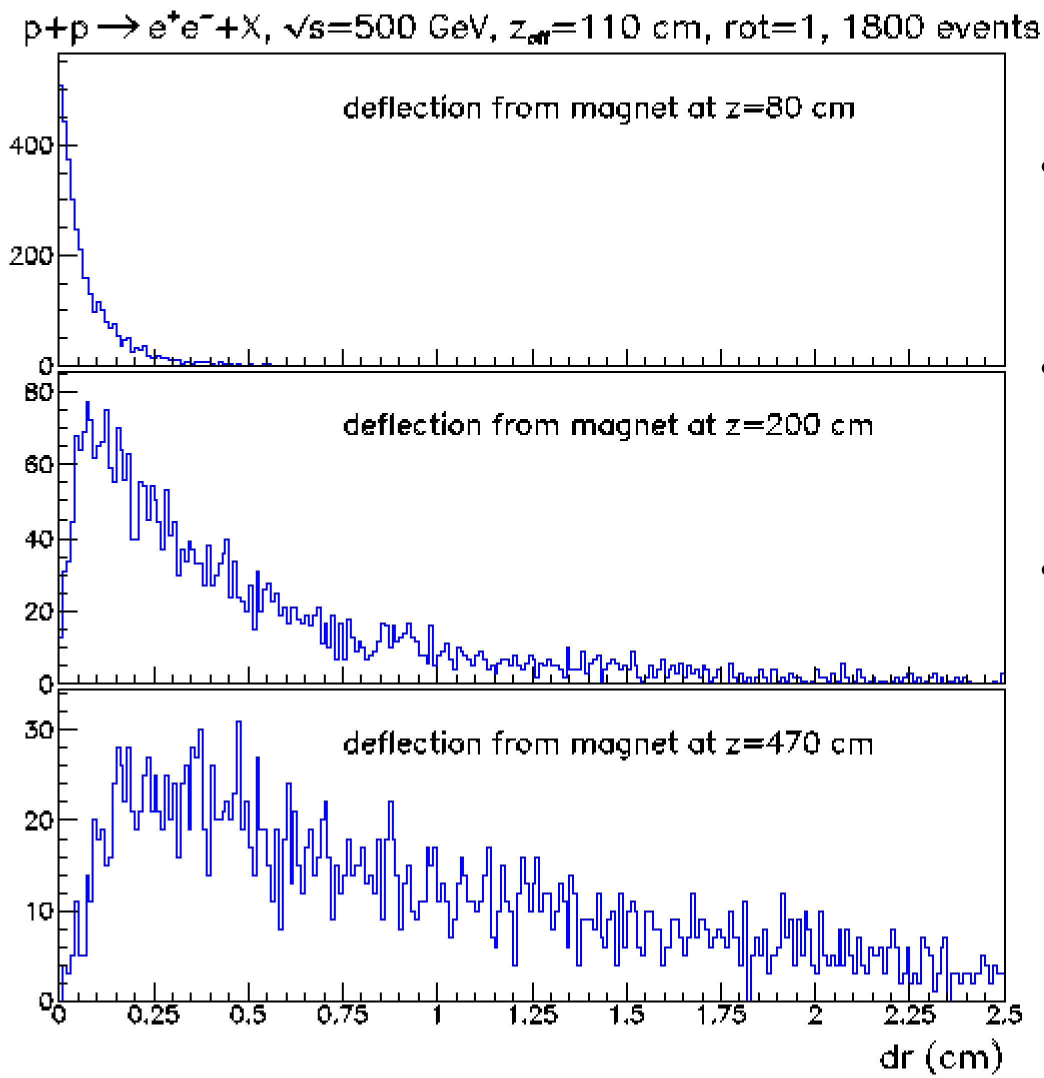
Raytracing DY di-electrons through apparatus



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

- 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

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

Staging

Assumptions:

1) ~4 week 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:

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}>50 / 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 Lint>50 / pb and Pbeam=50% to observe dileptons from J/ψ, Υ and intervening continuum to address whether charge sign discrimination is required

Conclusions

- Acceptance with existing modular apparatus looks adequate for feasibility experiment
- Estimates show that DY can dominate over hadronic, conversion photon and open beauty backgrounds
- Requirements for charge sign determination in run-13 stage of DY feasibility experiment have been established, and will require construction of fiber tracking stations and MWPC.

$\Rightarrow$ Letter of Intent to June,2010 program advisory committee for DY feasibility test aimed at running in parallel with W measurement, pending demonstration that impact of third IR is acceptable

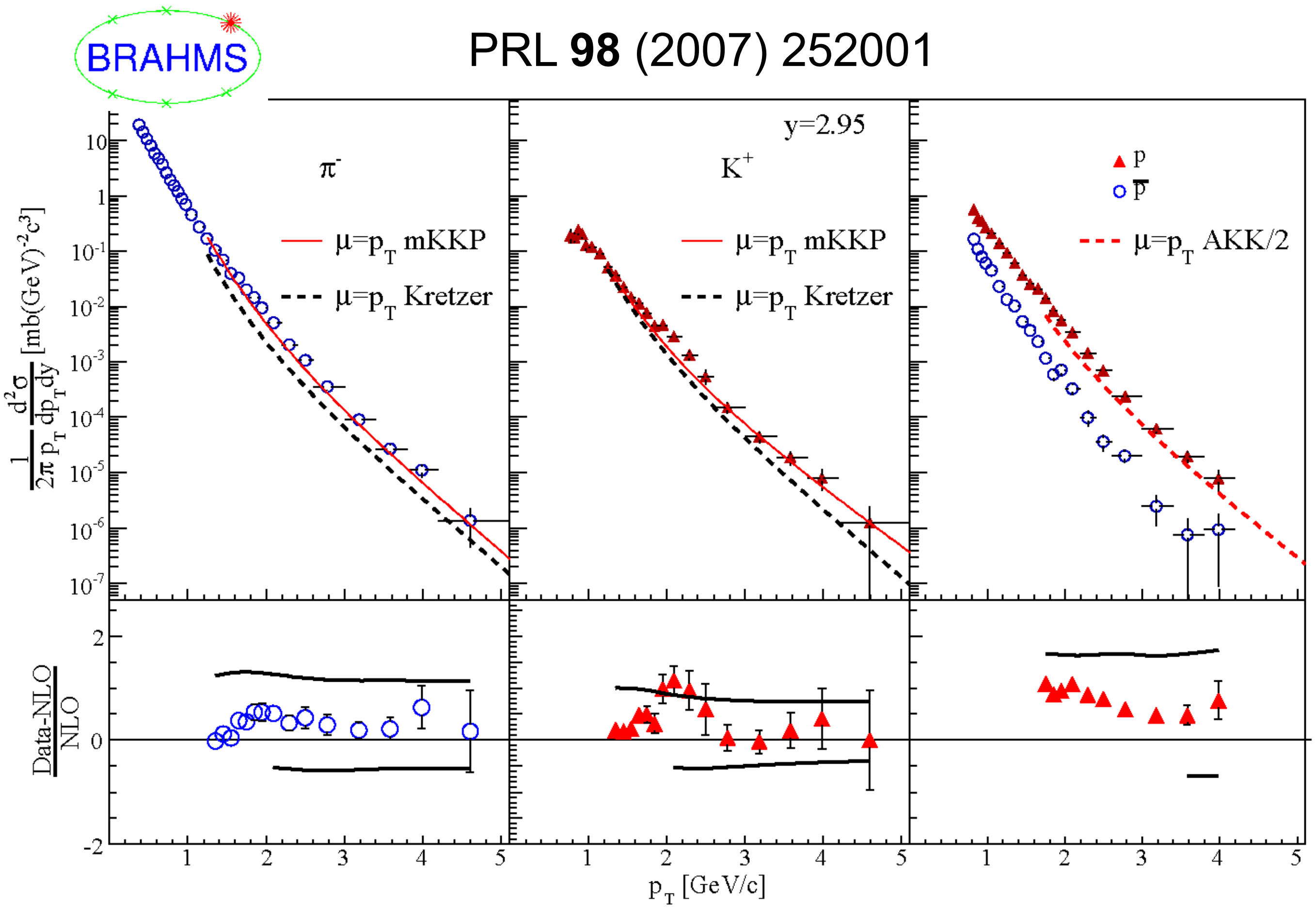
Backup

RHIC Spin Probes - II

Unpolarized cross sections as benchmarks and heavy-ion references

Large rapidity π,K,p cross sections for p+p, $\sqrt{s}$=200 GeV

PRL **98** (2007) 252001



Good agreement between experiment and theory

⇒ calibrated hard scattering probes of proton spin

STAR Results vs. Di-Jet Pseudorapidity Sum

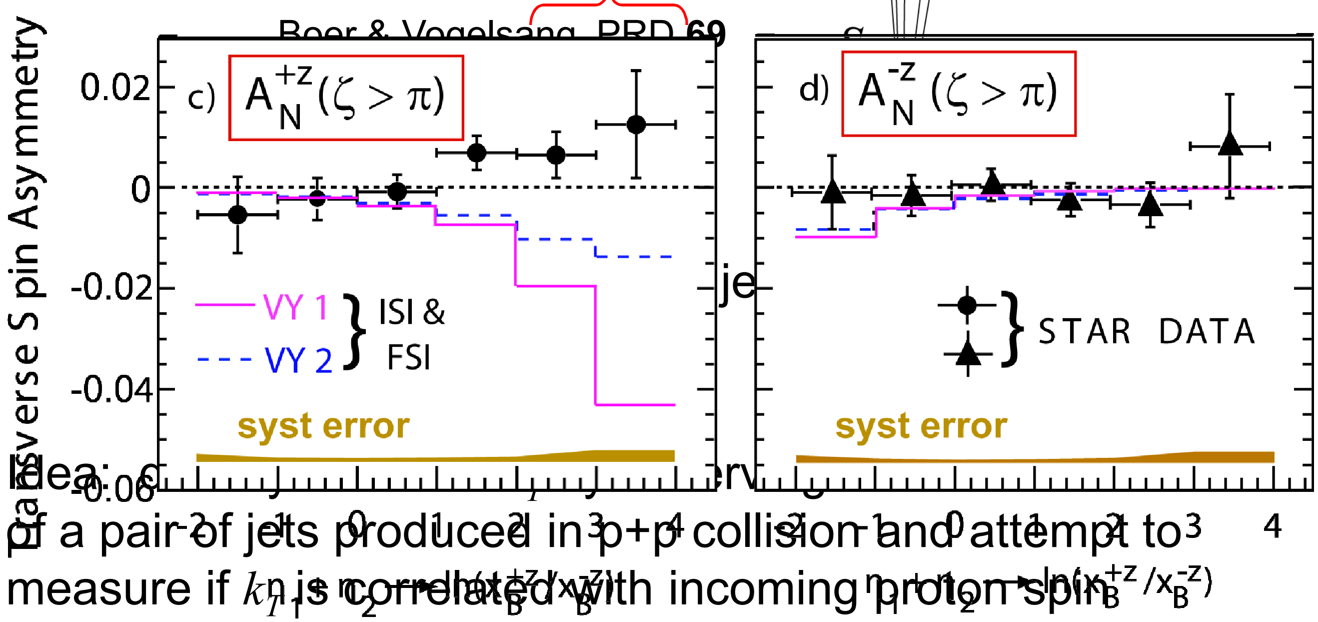
Run-6 Result

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

$A_N \propto \mathbf{p}_{beam} \bullet (\mathbf{k}_T \times \mathbf{S}_T)$ jet

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

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

<u>A_N consistent with zero</u>

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

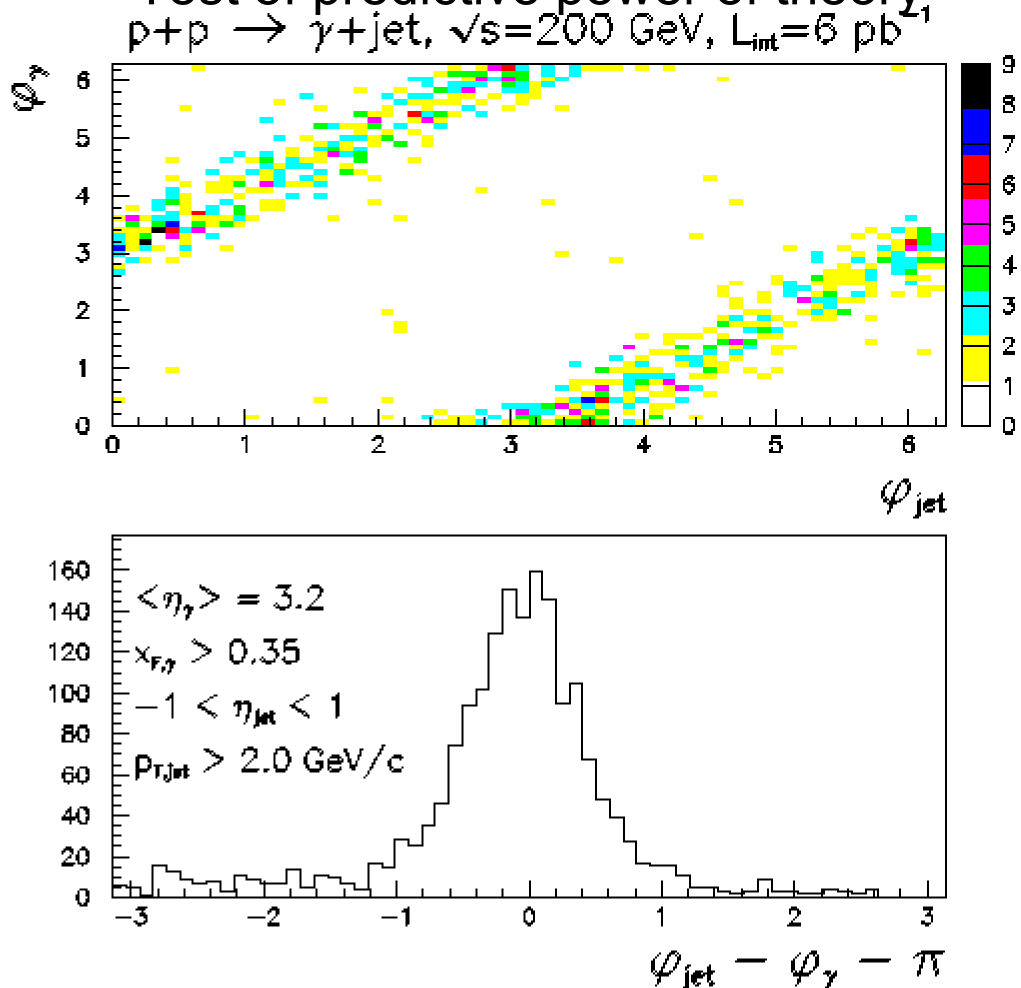
PRL 99 (2007) 142003

STAR

Future Opportunities

Transverse spin for forward γ+jet

Test of predictive power of theory



10^4 useable forward photon + jet coincidences are expected in a 30 pb^{-1} data sample with 60% beam polarization

As part of the 2008 update to *Plans for the RHIC Spin Physics Program*