Drell-Yan Single Transverse Spin Asymmetry at RHIC

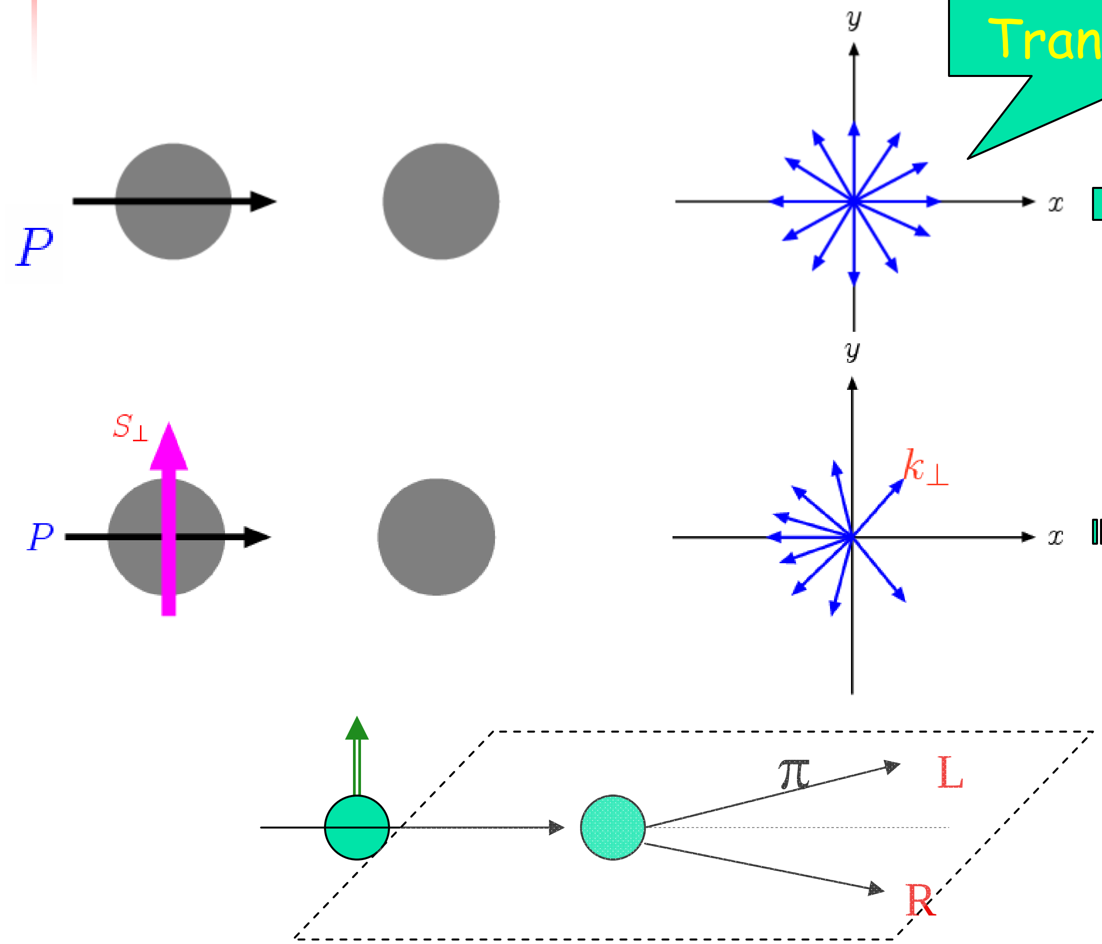
Ming Xiong Liu

Los Alamos National Lab

Thanks F. Yuan

What's Single Spin Asymmetry?

Transverse plane



Final state particle is Azimuthal symmetric

$$d\sigma \propto \vec{S}_\perp \cdot (\vec{P} \times \vec{K}_\perp)$$

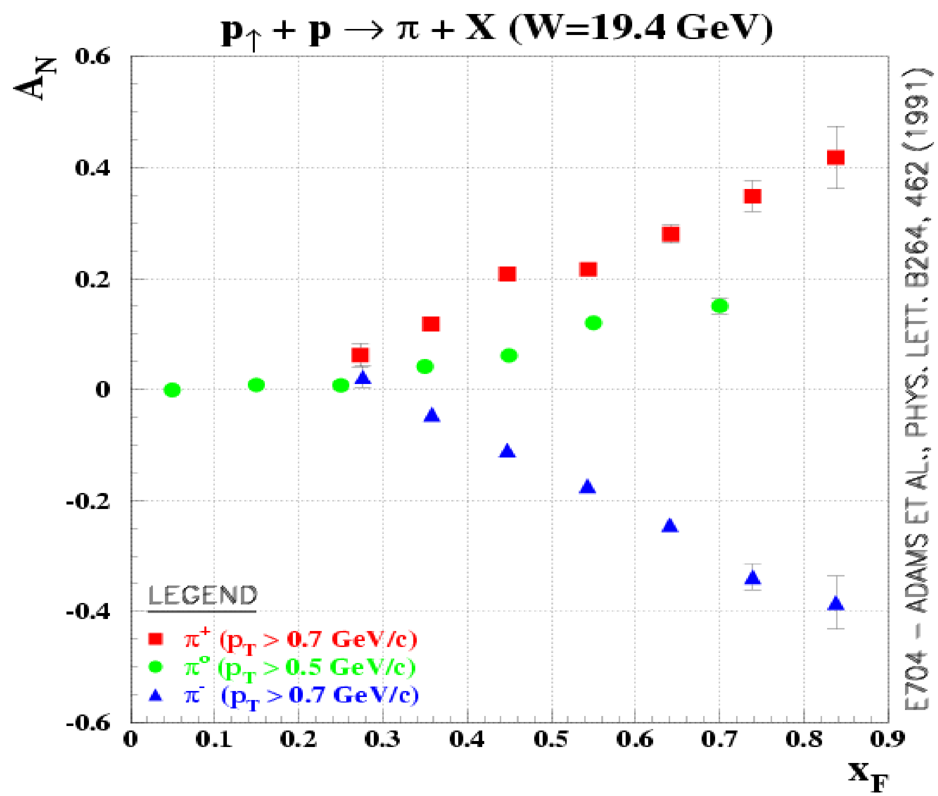
Single Transverse Spin Asymmetry (SSA)

$$A_N = \frac{L-R}{L+R}$$

Single Transverse Spin Asymmetry

E704/FNAL (1991)

- SSA is suppressed in naïve parton models ($\sim\alpha_s m_q/Q$)
- Large SSAs have been observed at forward rapidities in hadronic reactions



Models for the Large Single Spin Asymmetry (SSA)

- Models for SSA
  - Collins function
  - Sivers function
  - High twist
  - ...

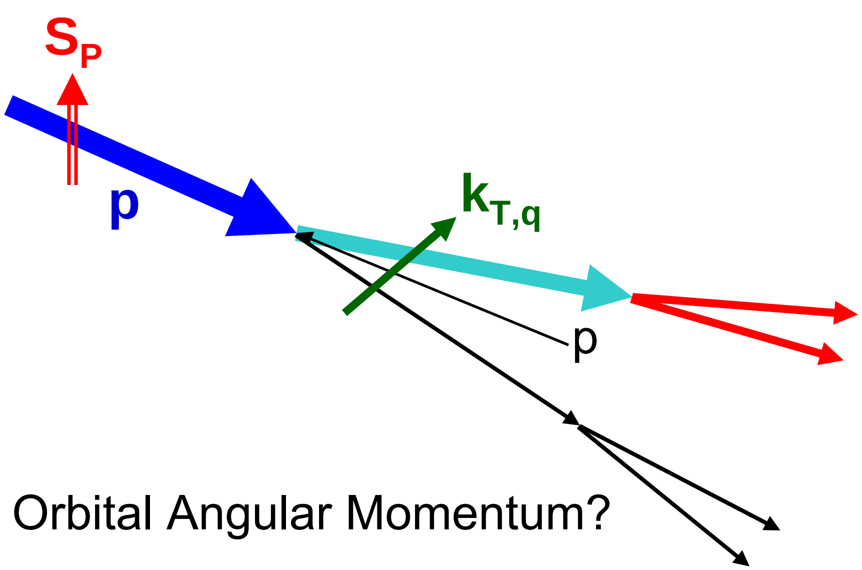
Two Examples ...

Sivers mechanism: Correlation between nucleon spin and parton k_T

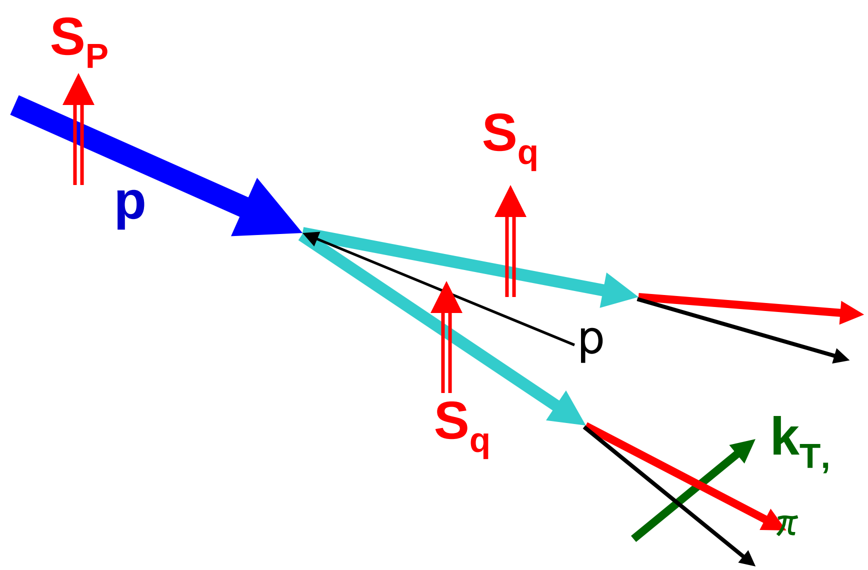
Phys Rev D41 (1990) 83; 43 (1991) 261

Collins mechanism: Transversity (quark polarization) * asymmetry in the jet fragmentation

Nucl Phys B396 (1993) 161

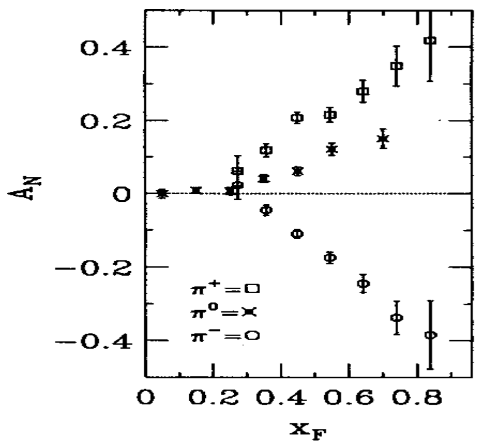


Orbital Angular Momentum?



Large Asymmetries Persist at High $\sqrt{s}$

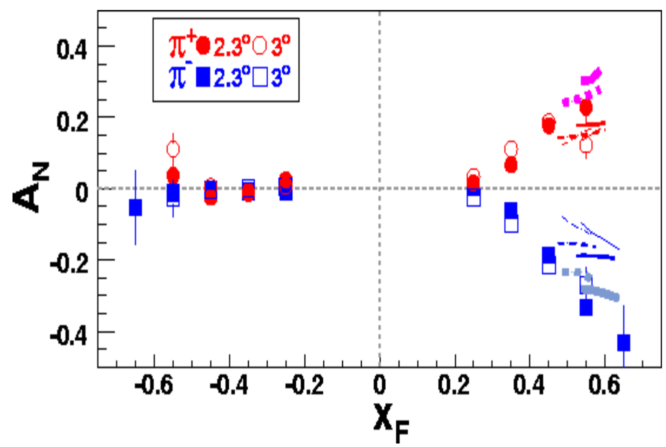
$p_{\uparrow} + p \to \pi + X$, $\sqrt{s} = 20$ GeV



π^0: E704, Phys.Lett. B261 (1991) 201.
$\pi^{+/-}$: E704, Phys.Lett. B264 (1991) 462.

Fermilab, E704, 1991

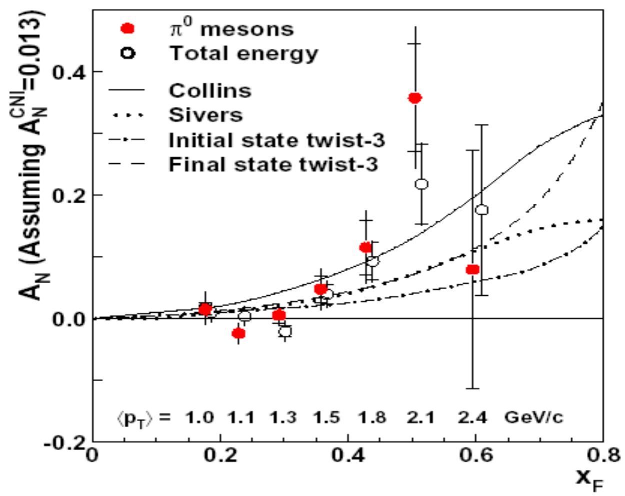
$p_{\uparrow} + p \to \pi^{\pm} + X$, $\sqrt{s} = 62$ GeV



Arsene et al. (BRAHMS), submitted to Phys. Rev. Lett. [arXiv:nucl-ex/0801.1078]

RHIC, Brahms, 2007

$p_{\uparrow} + p \to \pi^0 + X$, $\sqrt{s} = 200$ GeV

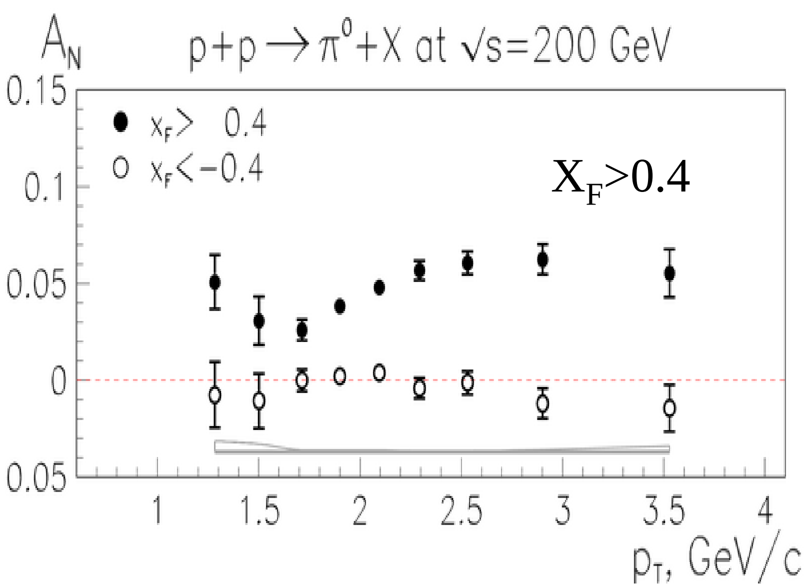


(STAR) Phys. Rev. Lett. **92** (2004) 171801

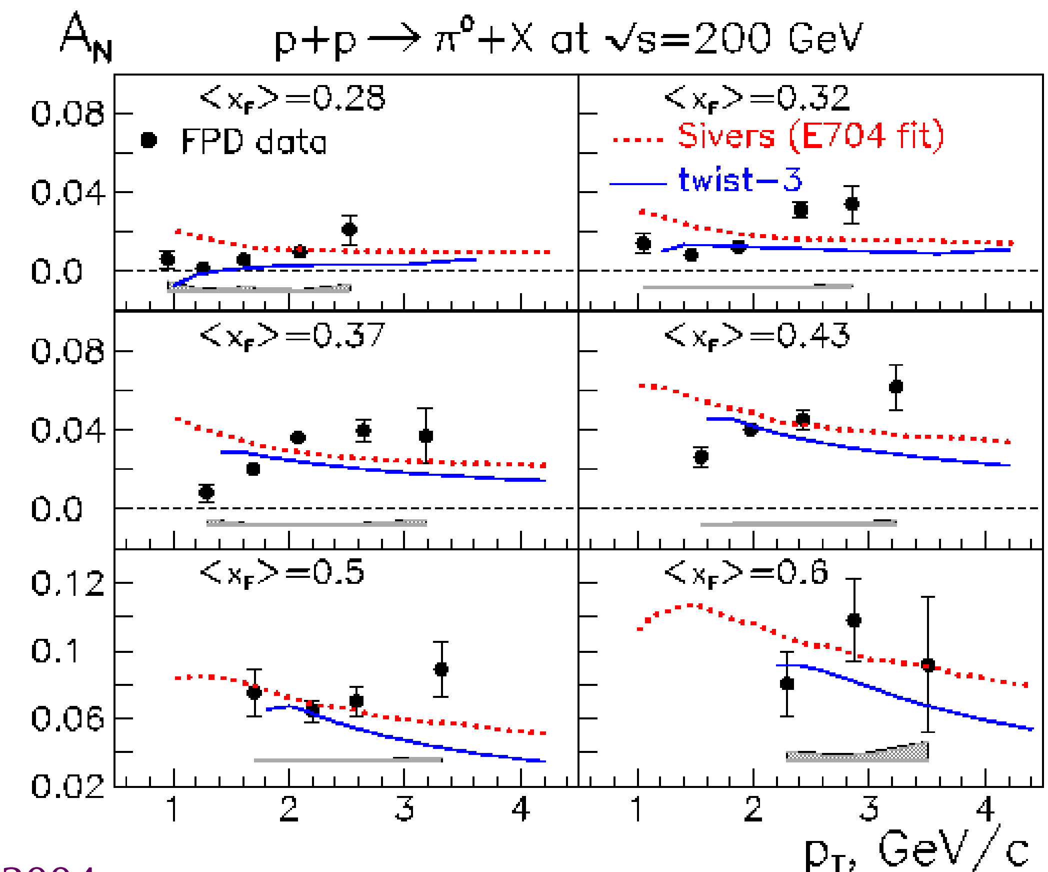
RHIC, STAR, 2004

Non-Perturbative cross section → Perturbative cross section

…but rising P_T dependence is not predicted by the same fits



B.I. Abelev et al. (STAR) [arXiv:hep-ex/0801.2990v1],), submitted to PRL



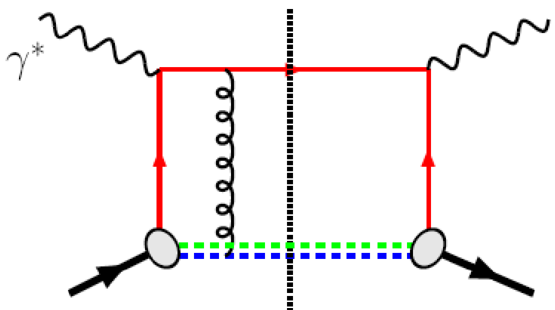
Admixture of Collins and Sivers?

RHIC, STAR, 2004

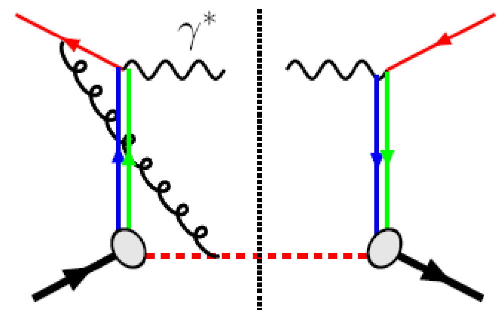
Attractive vs Repulsive "Sivers" Effects

Unique Prediction of Gauge Theory !

DIS: attractive

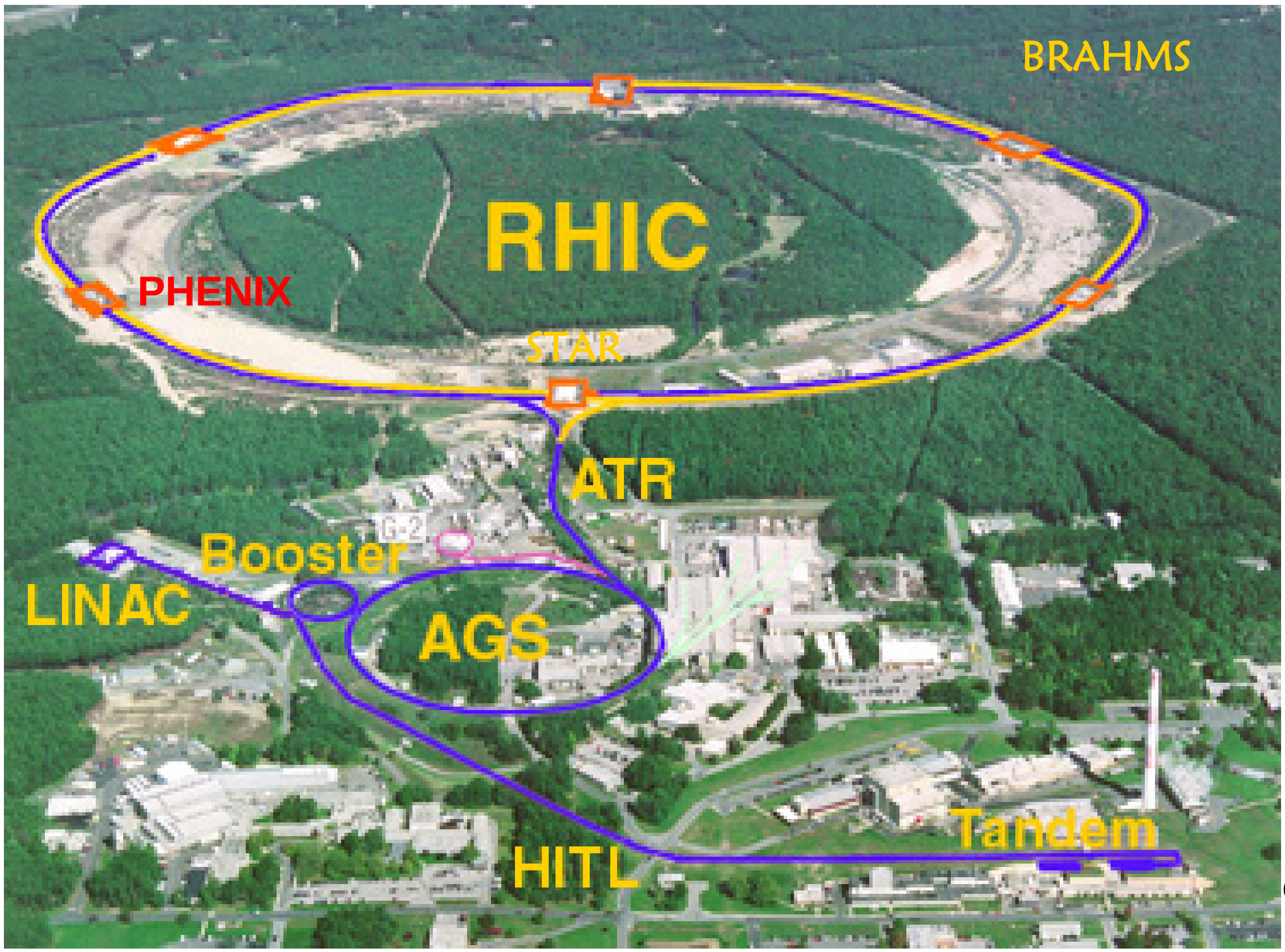


Drell-Yan: repulsive



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

The Relativistic Heavy Ion Collider at Brookhaven National Laboratory



R-HI

New state of matter

QGP

De-confinement

…

polarized proton

Nucleon Spin Structure

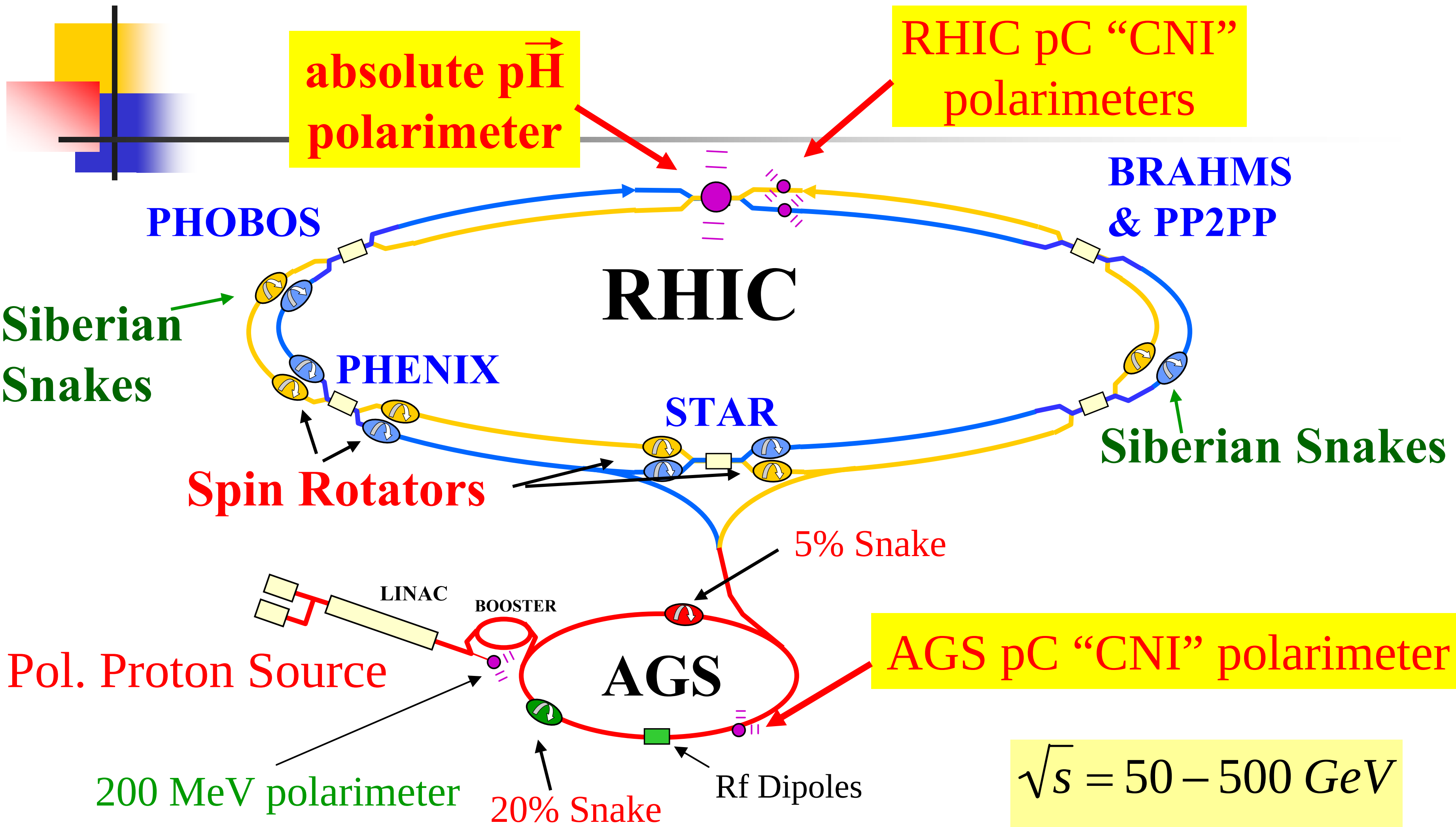
Spin Fragmentation

pQCD

…

RHIC is a QCD lab

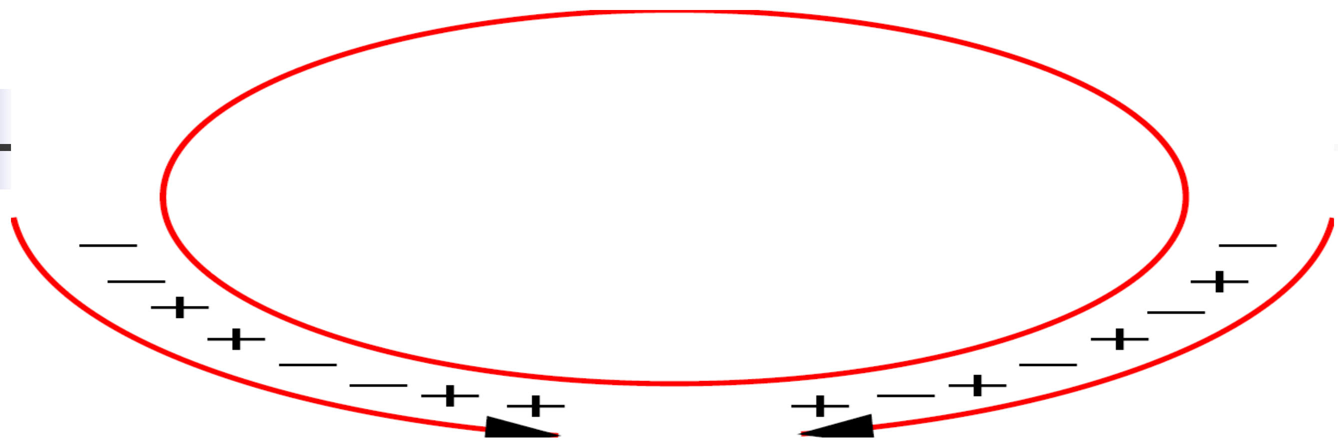
RHIC *pp* Accelerator Complex



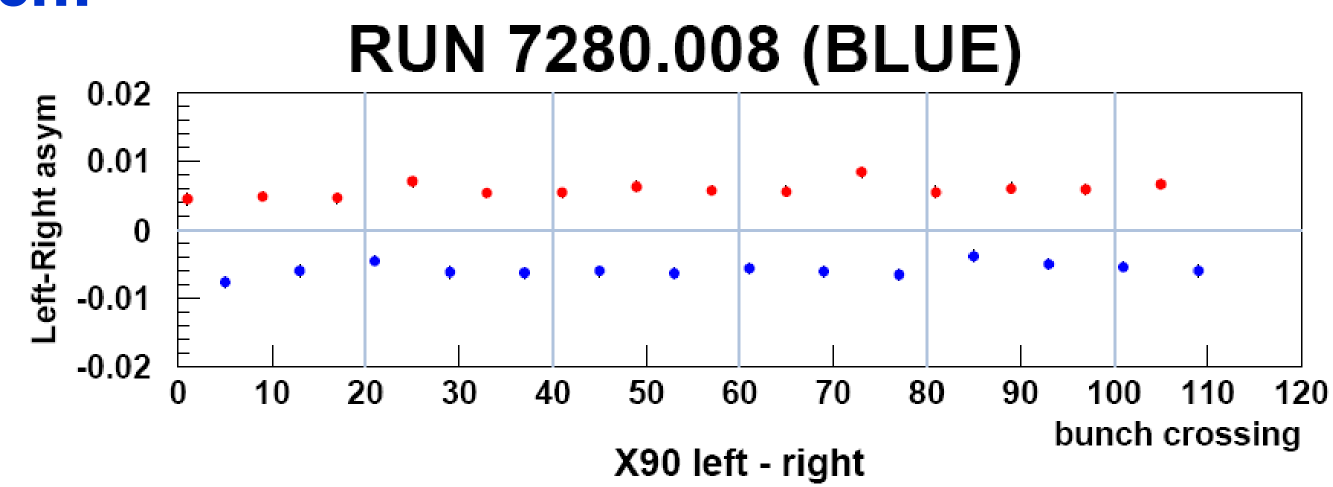
$$\sqrt{s} = 50 - 500\ GeV$$

$$Pol. = 70\%$$

Exquisite Control of Systematics



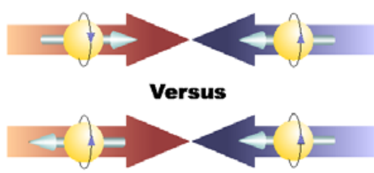
Raw asymmetries from carbon polarimeter by bunch:



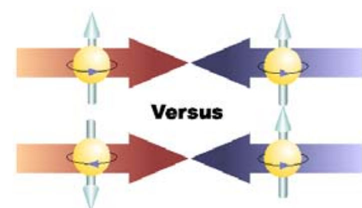
Experimental Observables

- Asymmetries
  - PHENIX and STAR: all
  - BRAHMS: transverse beams only

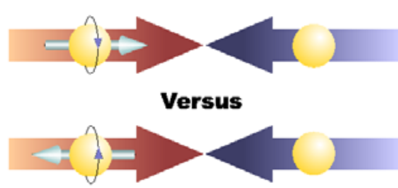
$$A_{LL} = \frac{\sigma(++)-\sigma(+-)}{\sigma(++)+\sigma(+-)}$$



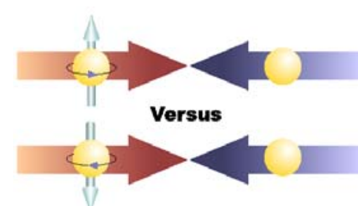
$$A_{TT} = \frac{\sigma(\uparrow\uparrow)-\sigma(\uparrow\downarrow)}{\sigma(\uparrow\uparrow)+\sigma(\uparrow\downarrow)}$$



$$A_{L} = \frac{\sigma(+)-\sigma(-)}{\sigma(+)+\sigma(-)}$$



$$A_{T} = \frac{\sigma(\uparrow)-\sigma(\downarrow)}{\sigma(\uparrow)+\sigma(\downarrow)}$$



The PHENIX detector

Philosophy:

High rate capability to measure rare probes, limited acceptance.

- 2 central spectrometers
  - Track charged particles and detect electromagnetic processes

$|\eta| < 0.35$

$90^\circ + 90^\circ$ azimuth

- 2 forward muon spectrometers
  - Identify and track muons

$1.2 < |\eta| < 2.4$

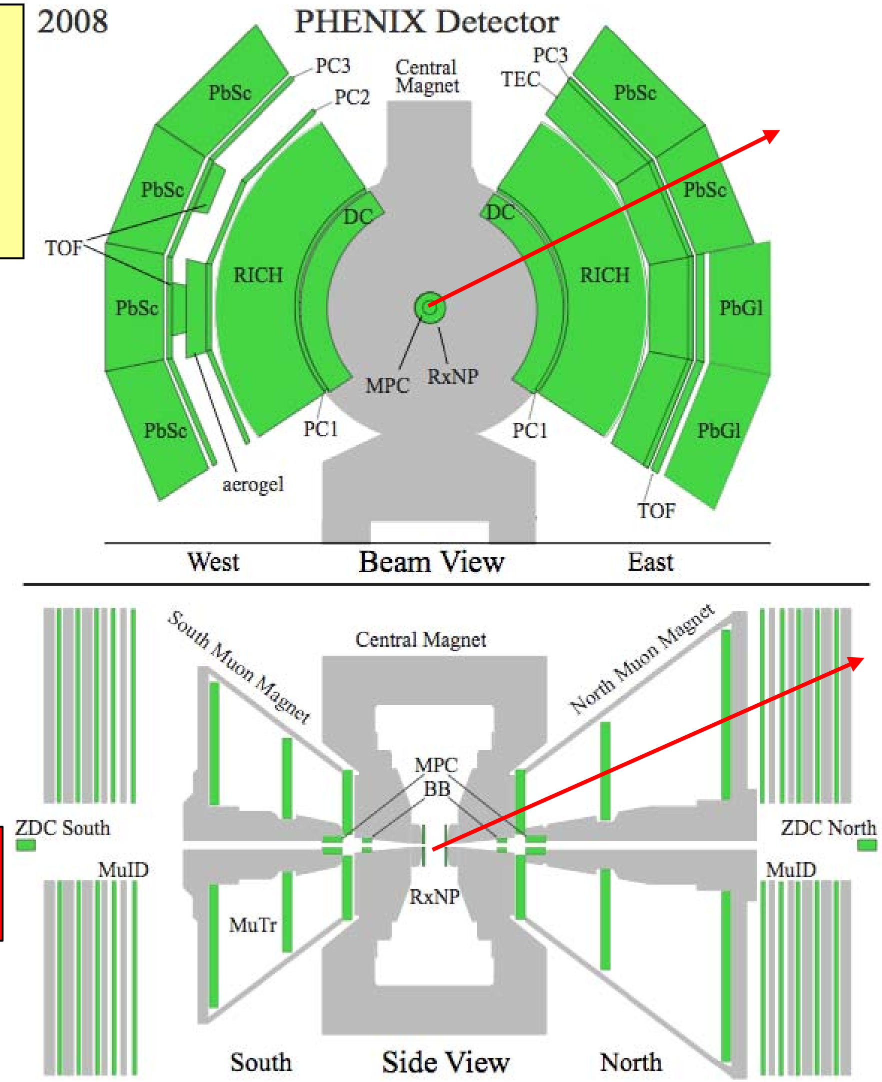
2π azimuth

- 2 forward calorimeters (as of 2007!)
  - Measure forward pions

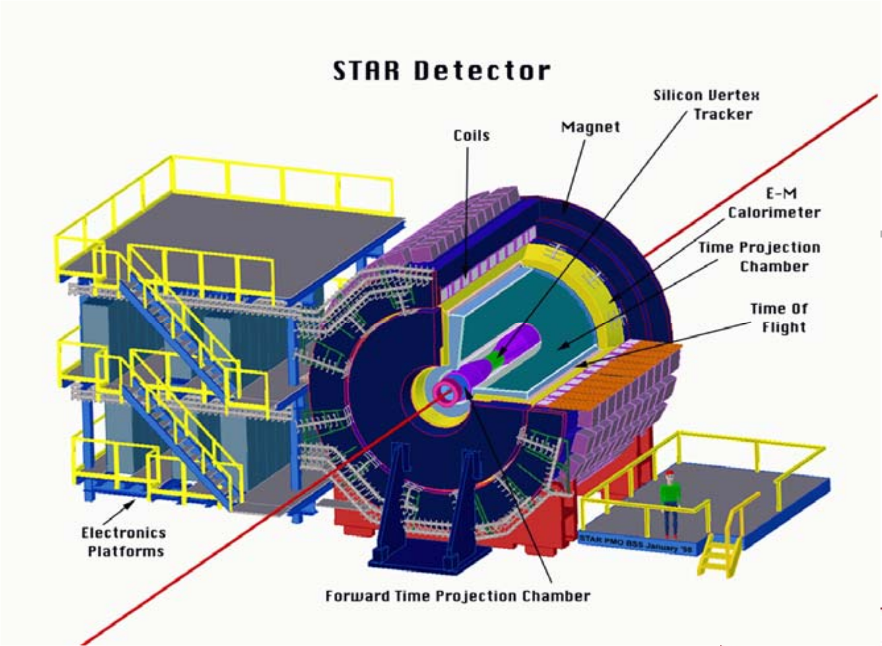
$3.1 < |\eta| < 3.7$

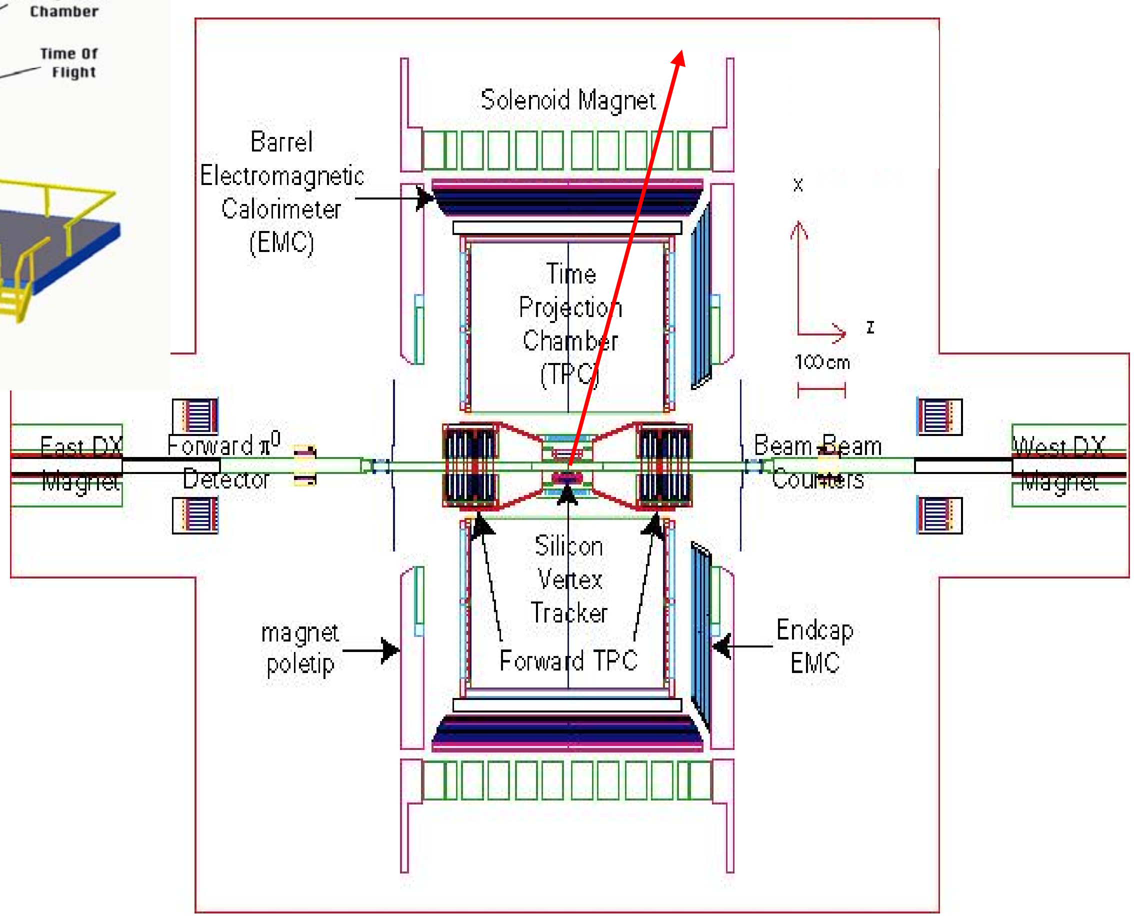
2π azimuth

- Relative Luminosity
  - Beam-Beam Counter (BBC)
  - Zero-Degree Calorimeter (ZDC)



The STAR Detectors





- Time Projection Chamber $|\eta|<1.6$
- Forward TPC $2.5<|\eta|<4.0$
- Silicon Vertex Tracker $|\eta|<1$
- Barrel EMC $|\eta|<1$
- Endcap EMC $1.0<\eta<2.0$
- Forward Pion Detector $3.3<|\eta|<4.1$

Drell-Yan Production @RHIC

- Rapidity and Collision Energy Dependence

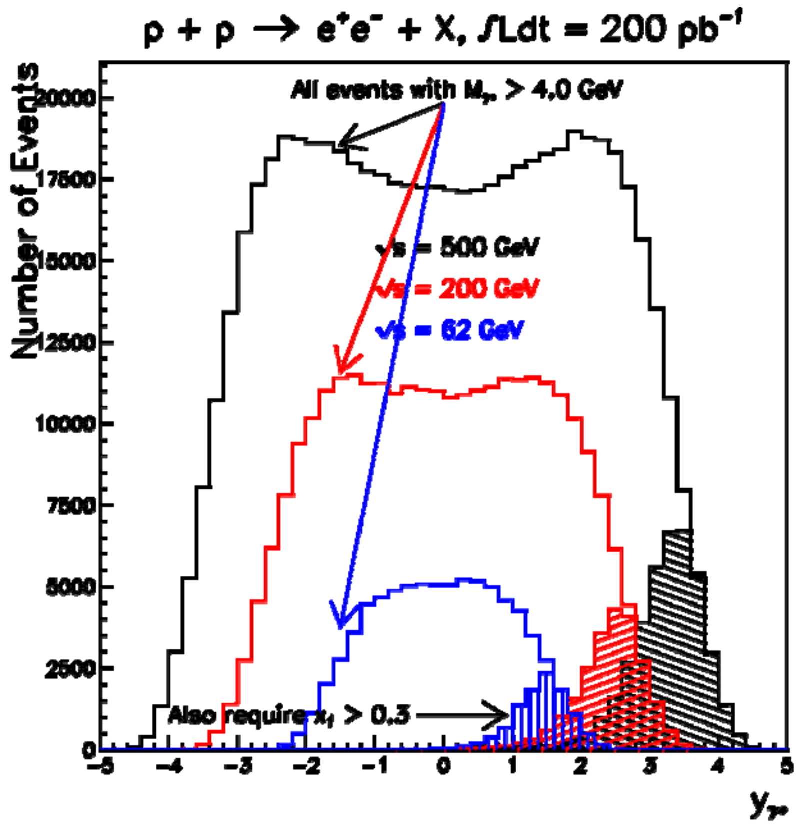
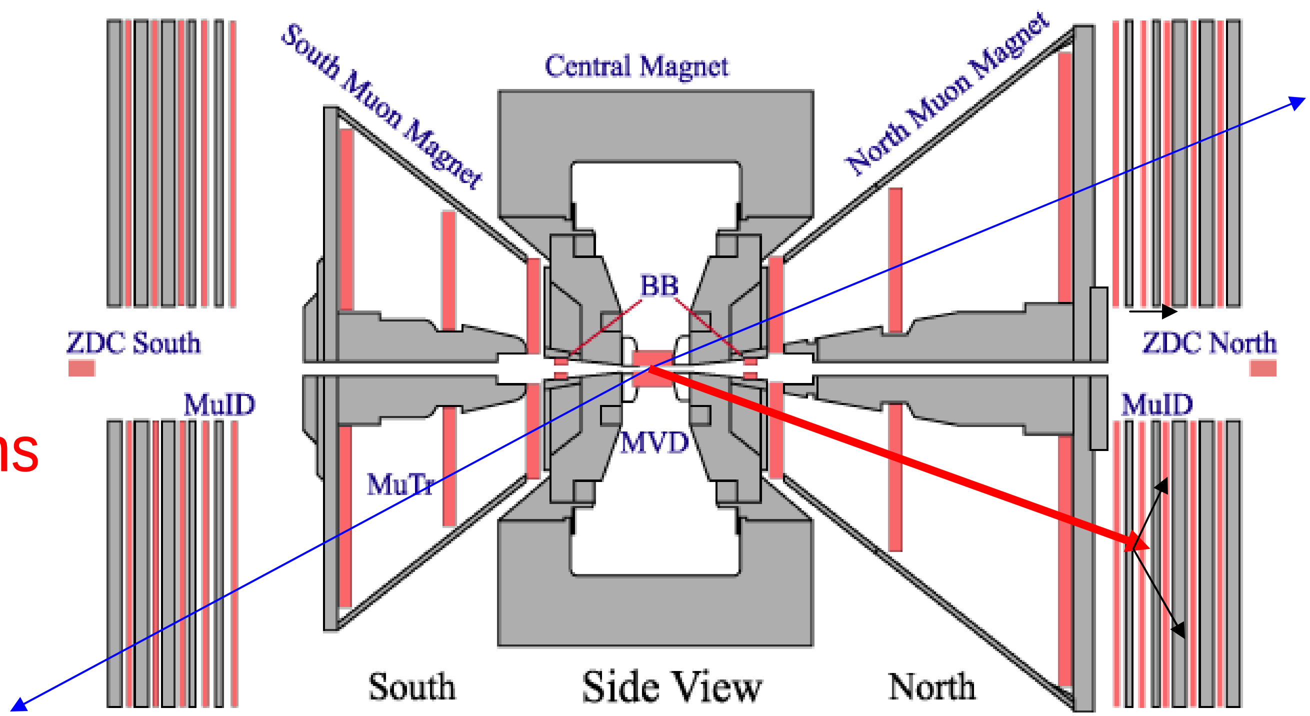


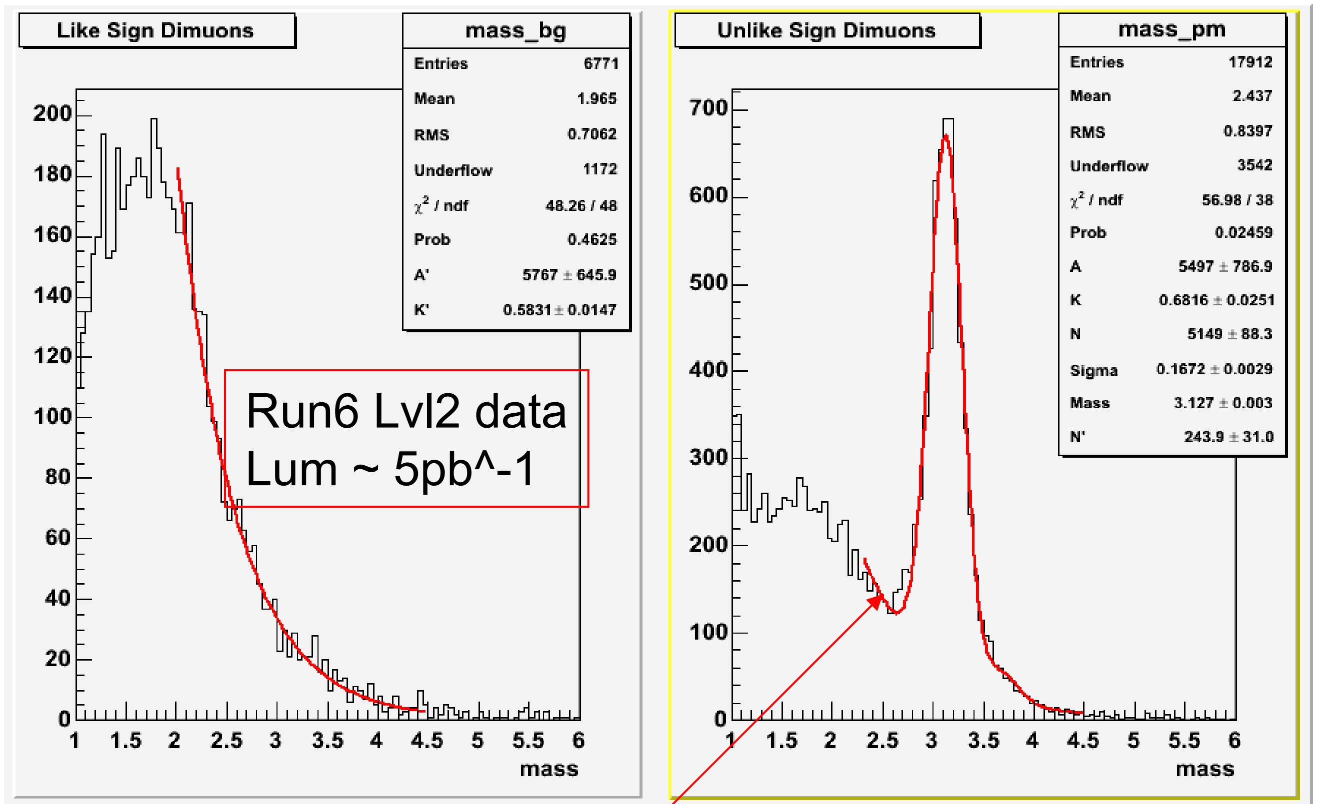
Figure 5: *PYTHIA simulation of the rapidity distribution of $e^+ e^-$ dileptons produced through the Drell-Yan process. The importance of large rapidity to probe the valence region is illustrated by selecting events with* $x_1 > 0.3$.

An Example: PHENIX Muon Detectors

- Muon arms
  - $1.2<|\eta|<2.4$
  - $\Delta\varphi=2\pi$
  - P>2GeV/c
  - Triggers
- "Muons"
  - Stopped hadrons
  - Light meson decays
  - Heavy & DY decays



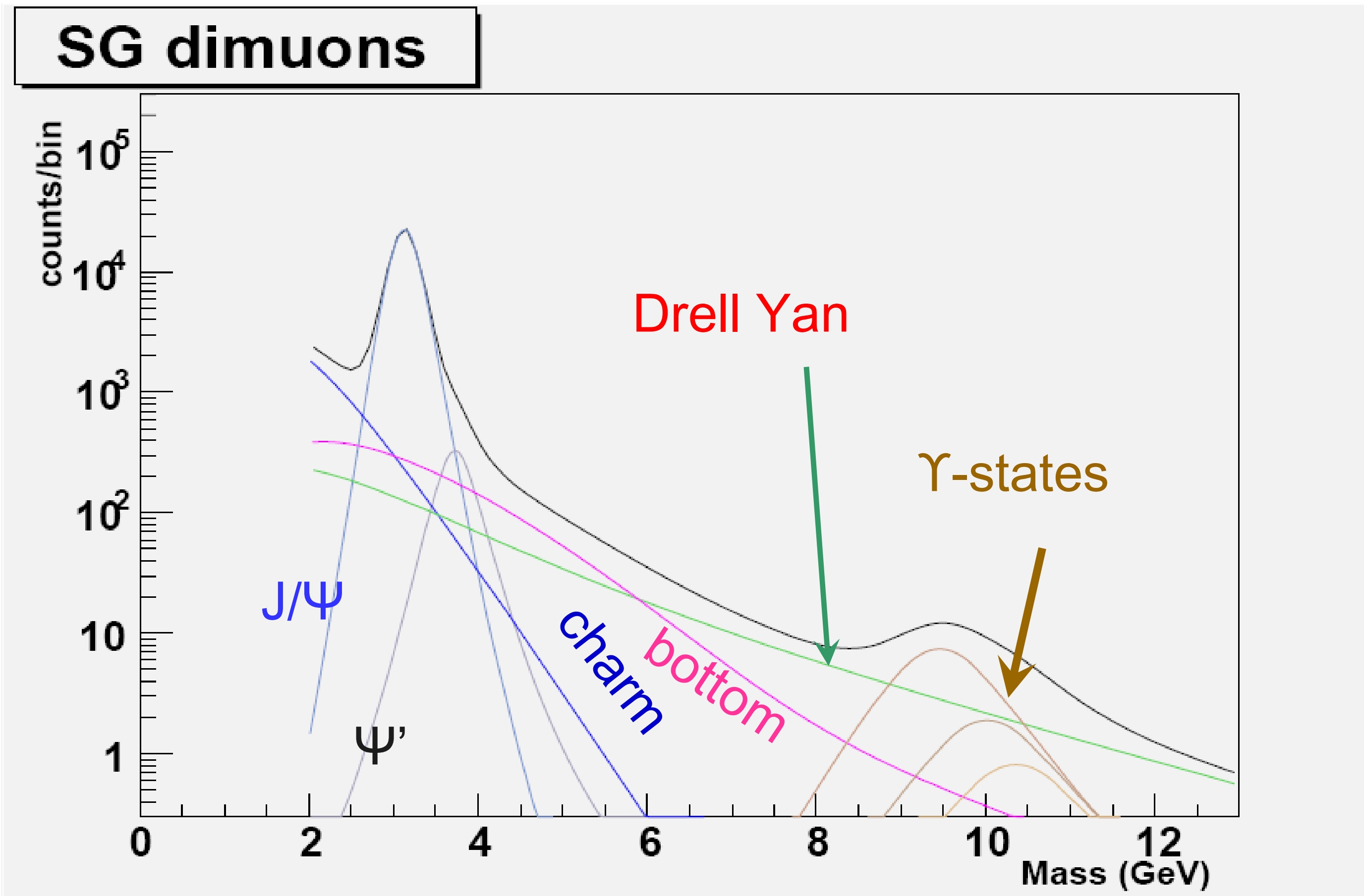
Dimuon Mass Spectra from PHENIX @200GeV



$$\frac{dN}{dM} = A \cdot e^{-K \cdot M} + N \cdot \frac{1}{2\pi\sqrt{\sigma}} e^{-\frac{(M - M_{J/\psi})^2}{2\sigma^2}} + N' \cdot \frac{1}{2\pi\sqrt{\sigma}} e^{-\frac{(M - M_{\psi'})^2}{2\sigma^2}}$$

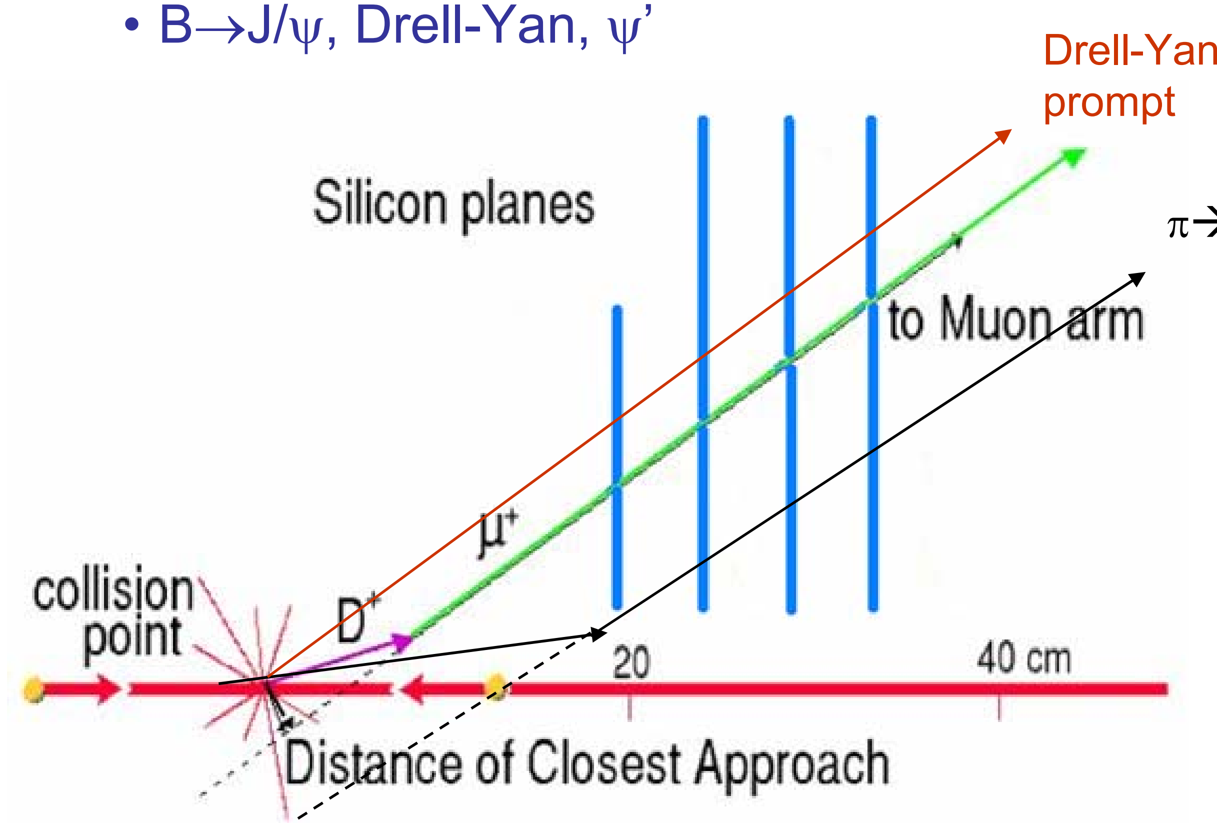
DY Background @200GeV

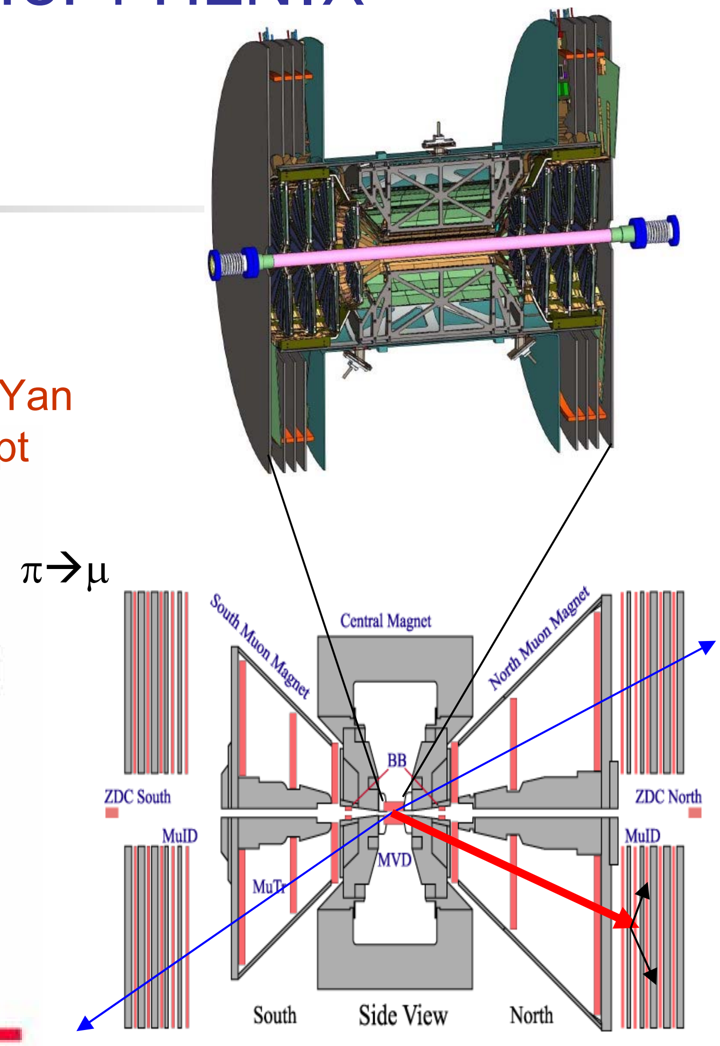
(PYTHIA Simulation benchmarked to PHENIX Data)



Silicon VerTeX Detector Upgrade for PHENIX (available 2011)

- Precision Charm/Beauty Measurements
- B→J/ψ, Drell-Yan, ψ'

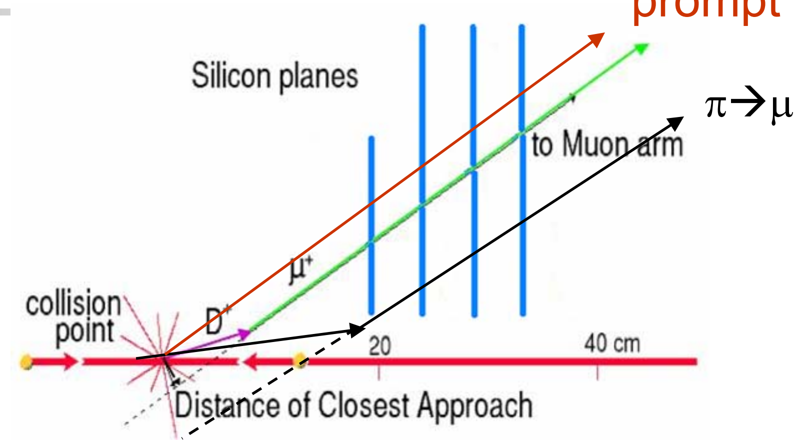


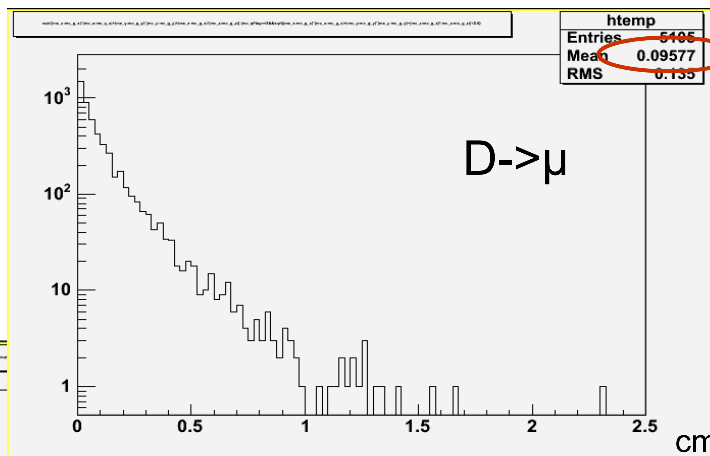


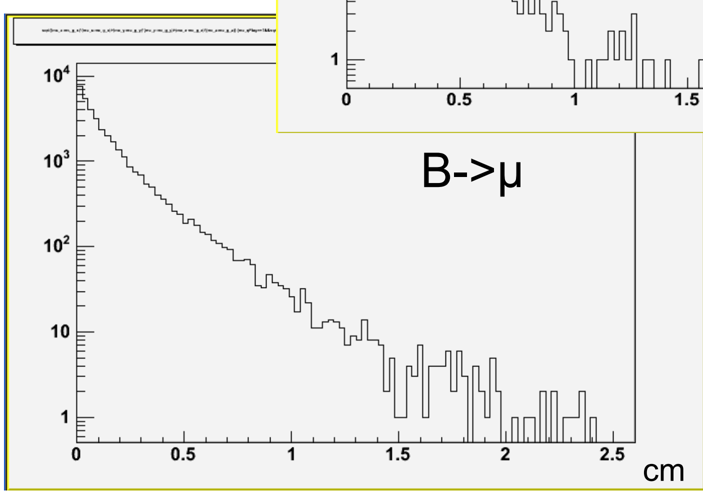
Impact Parameters for muons from D,B and DY

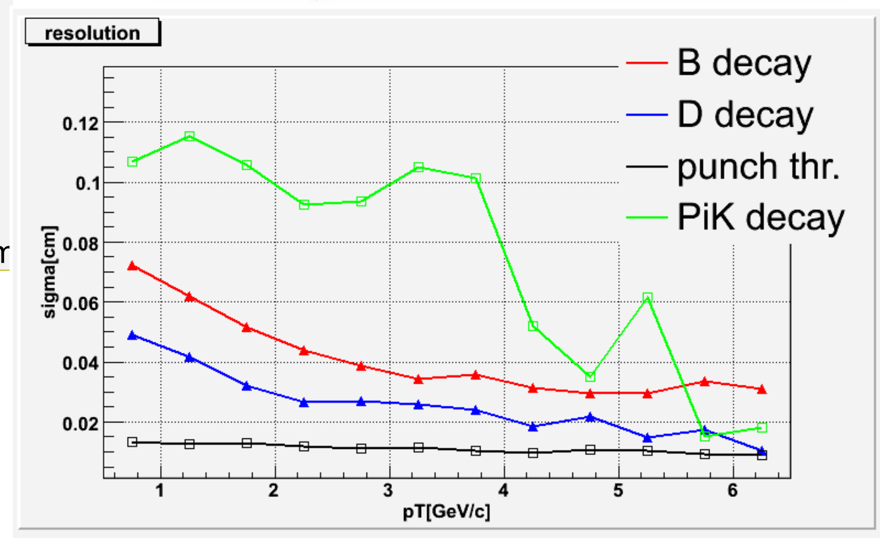
Measuring Charm and Beauty

- D, B mesons travel ~1 mm (with boost) before semi-leptonic decay to muons
- By measuring DCA to primary vertex, can separate D and B from prompt particles and long-lived decays like π, K



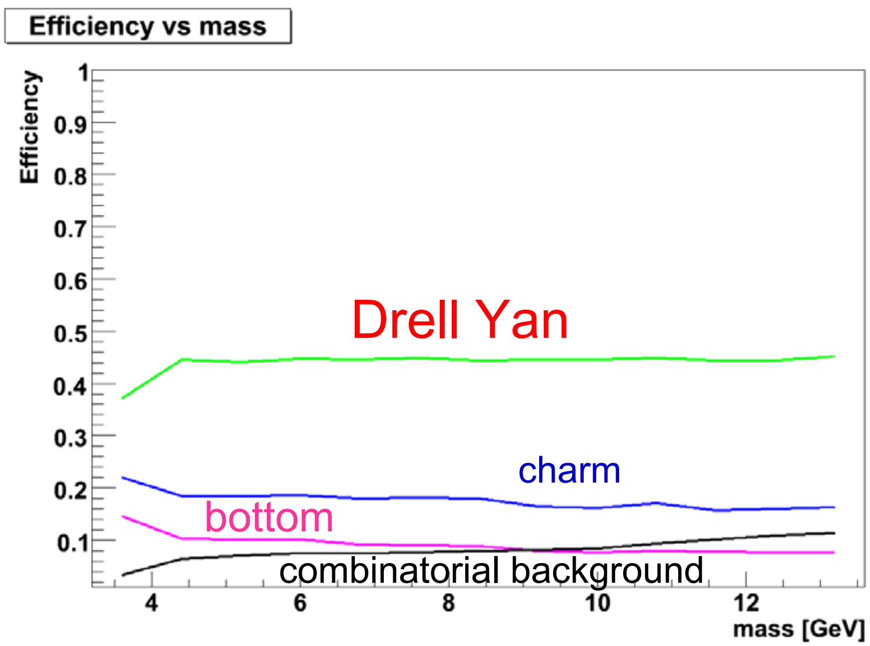




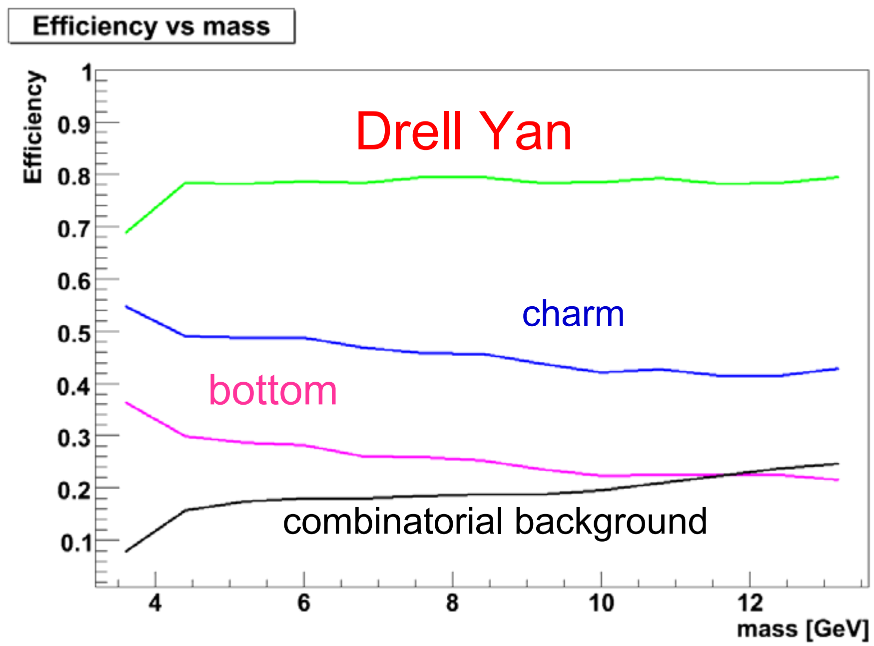


Reduce Heavy Quark Background by DCA cut

DCA < 1 σ cut:
Increase DY/bb ~ 5



DCA < 2 σ
Increase DY/bb ~ 3



PYTHIA vs NLO

- PYTHIA w/ CTEQ5l
- NLO w/ CTEQ6M

Dimuon physics continuum simulation (2)

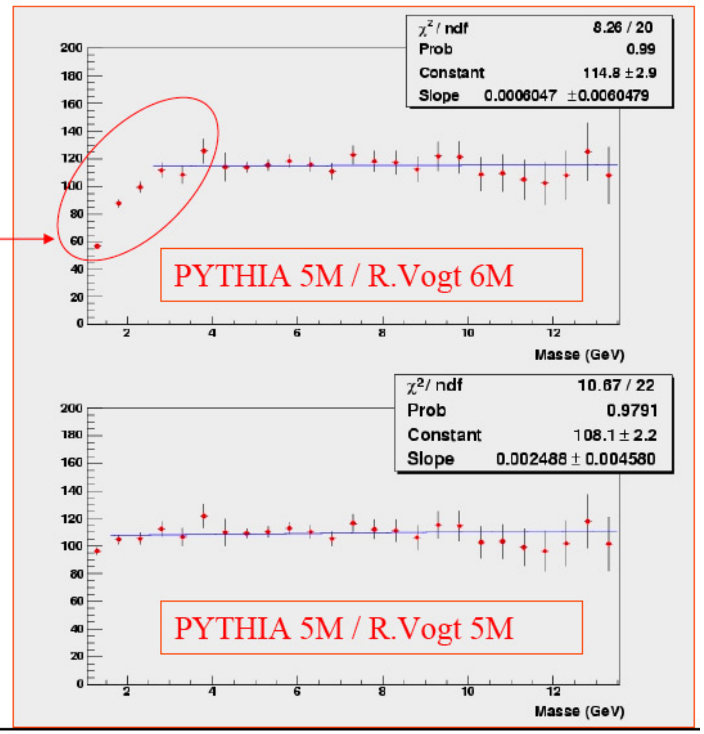
Drell-Yan: reproduction as best as possible of theoretical predictions from R. Vogt (NLO calculation with CTEQ6M)

Comparison:
$(dN/dm)_{Pythia} / (dN/dm)_{R.Vogt}$

This is due to a different behaviour of the two PDFs at low x

(R. Vogt)

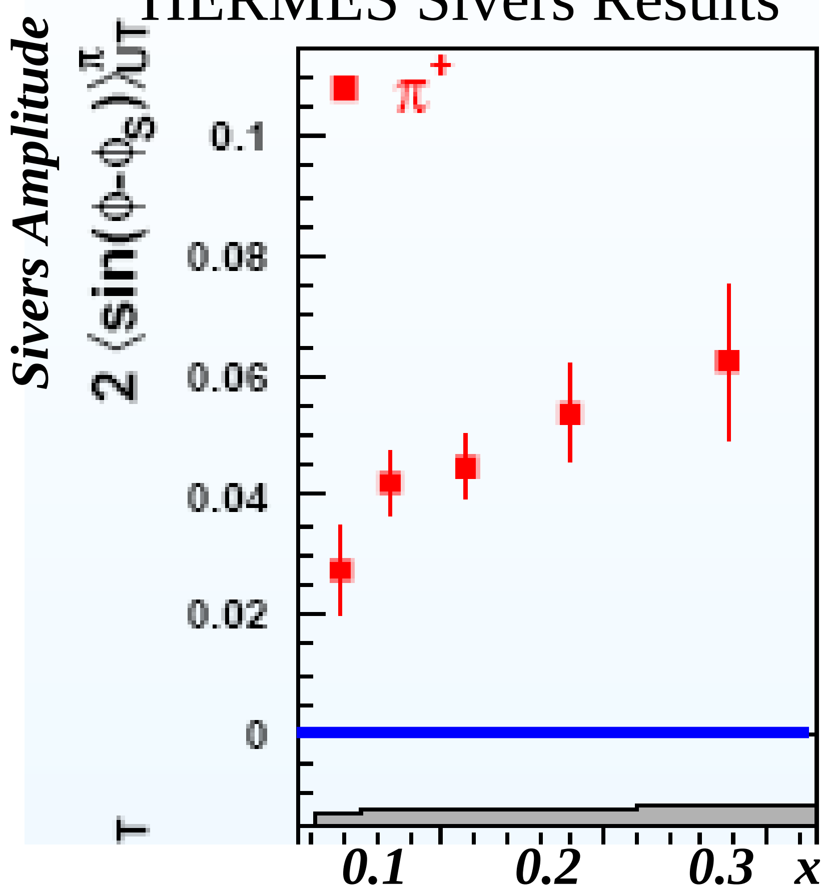
Good agreement between Pythia and QCD@NLO Prediction with same PDF



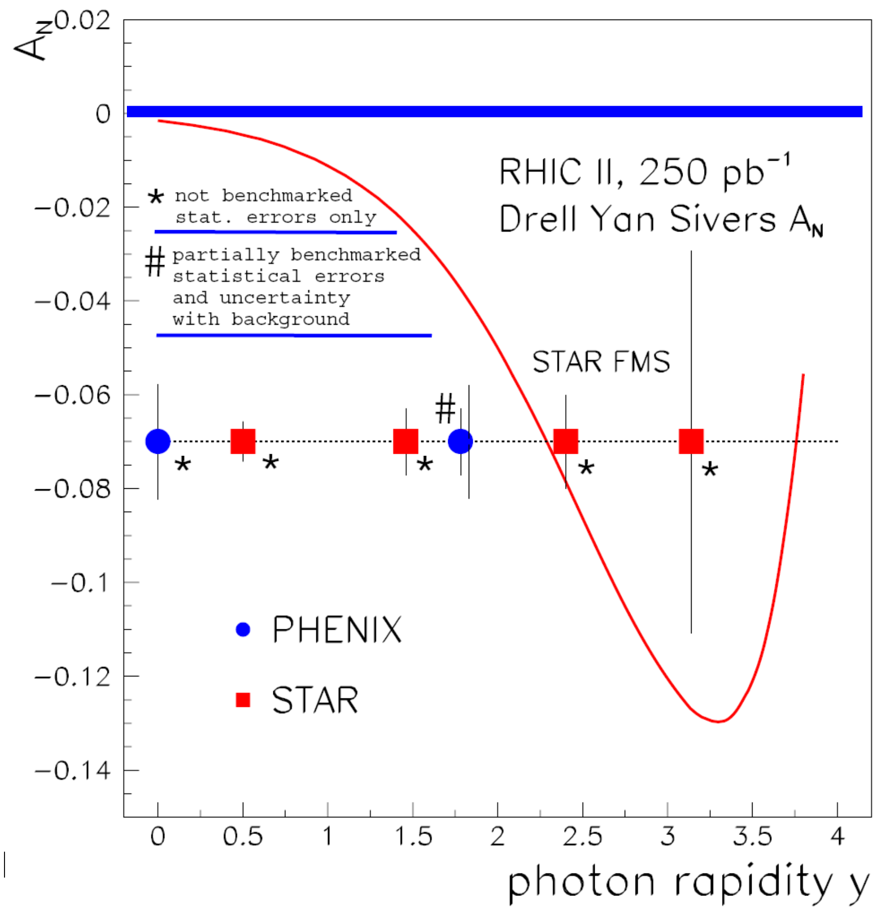
Experiment SIDIS vs Drell Yan: Sivers$|_{DIS}$= − Sivers$|_{DY}$

*** Probes QCD attraction and QCD repulsion ***

HERMES Sivers Results



RHIC II Drell Yan Projections

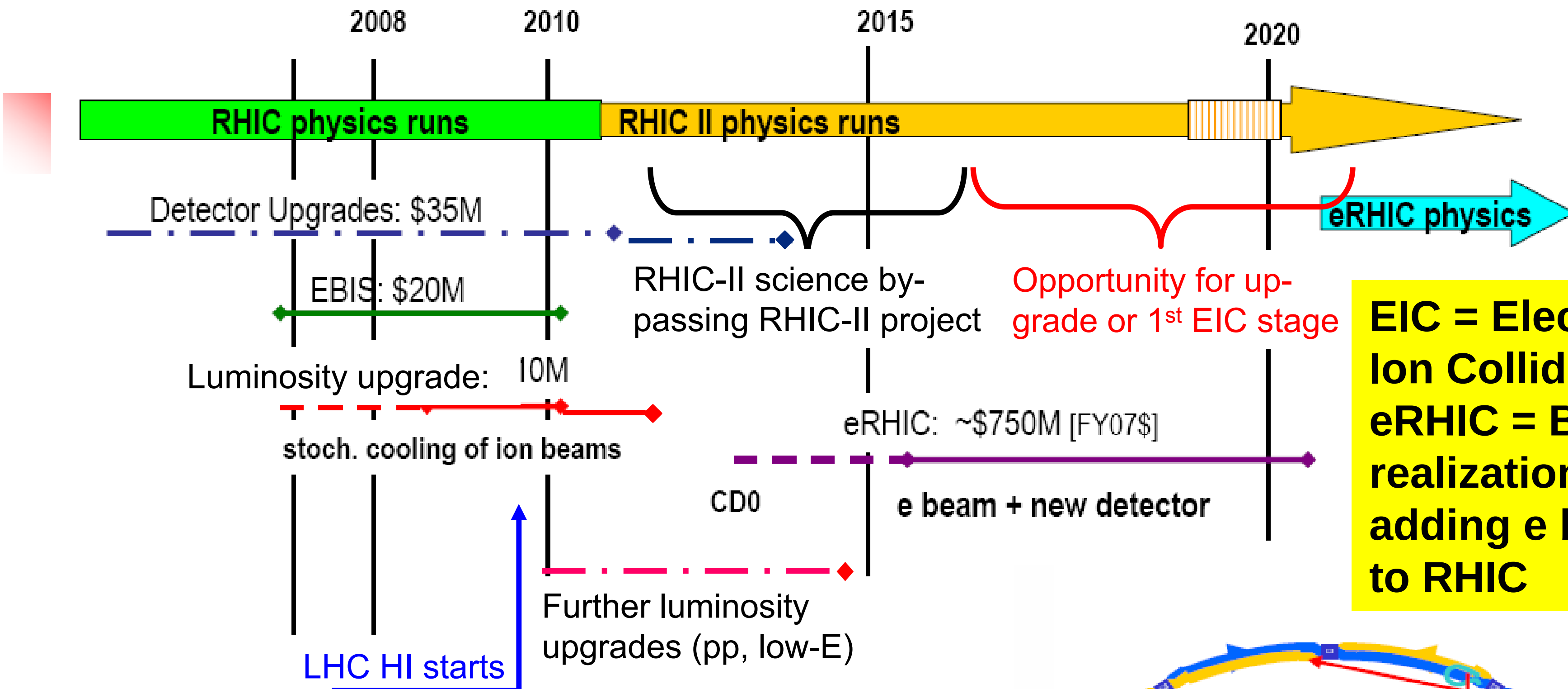


Transverse Spin Drell Yan at RHIC vs Sivers Asymmetry in Deep Inelastic Scattering

- Important test at RHIC of recent fundamental QCD predictions for the Sivers effect, demonstrating...
attractive vs repulsive color charge forces

- Possible access to quark **orbital angular momentum**
- Requires very high luminosity (RHIC II)
- Both STAR and PHENIX can make important, exciting, measurements
- Discussion available at http://spin.riken.bnl.gov/rsc/

A Long Term (Evolving) Strategic View for RHIC



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

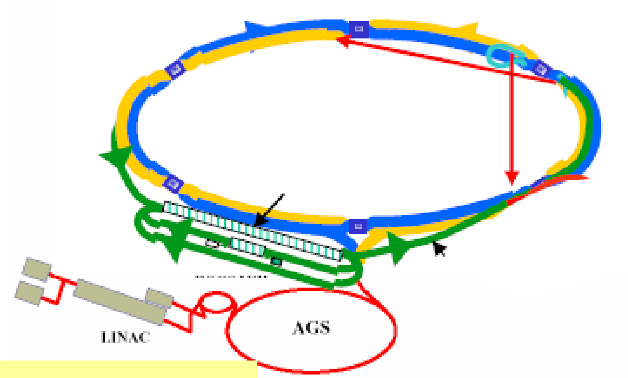
Legend:

R&D

Construction

Multiple small projects

CD0: DOE Critical Decision, mission need



RHIC, RHIC-II, LHC-HI and EIC science share a common theme…

Summary

- Exciting Physics
  - A new fundamental test of QCD prediction
- Experimentally challenge
  - Need RHIC-II luminosity
  - Detector Upgrade
- Can do it at RHIC!

backups

X range seen by the PHENIX Muon Spectrometer