↑ransverse Spin

phenomena in polarized p+p collisions

at

PHENIX

K. Oleg Eyser on behalf of the PHENIX collaboration

XV International Workshop
on Deep-Inelastic Scattering and Related Subjects

DIS 2007

Munich, Germany
April 18, 2007

Transverse Asymmetries

transversity δq

- Collins effect -

spin-dependent fragmentation functions

- Sivers effect -

transversely asymmetric k_t quark distributions

- Twist-3 -

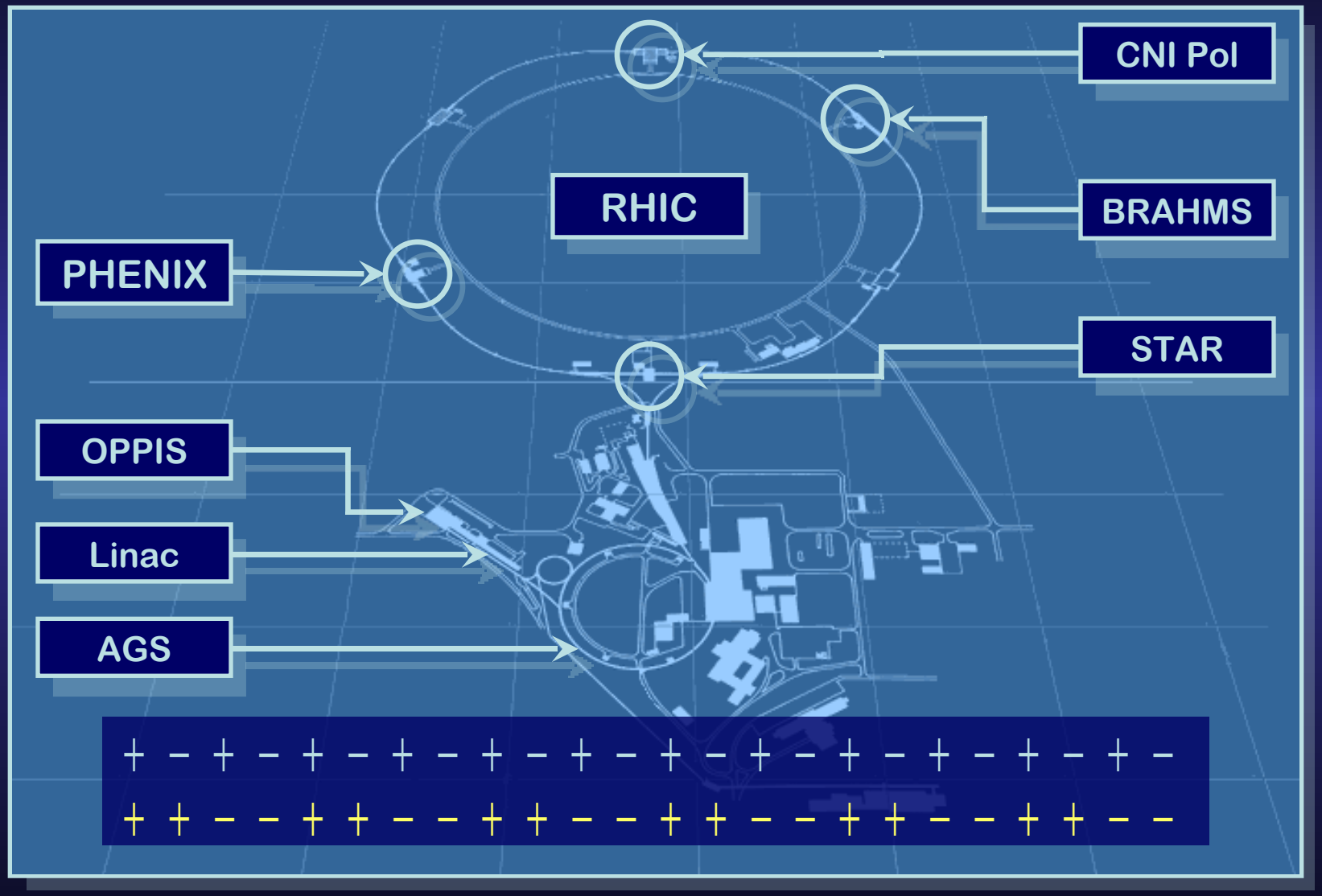
quark gluon field interference

SSA

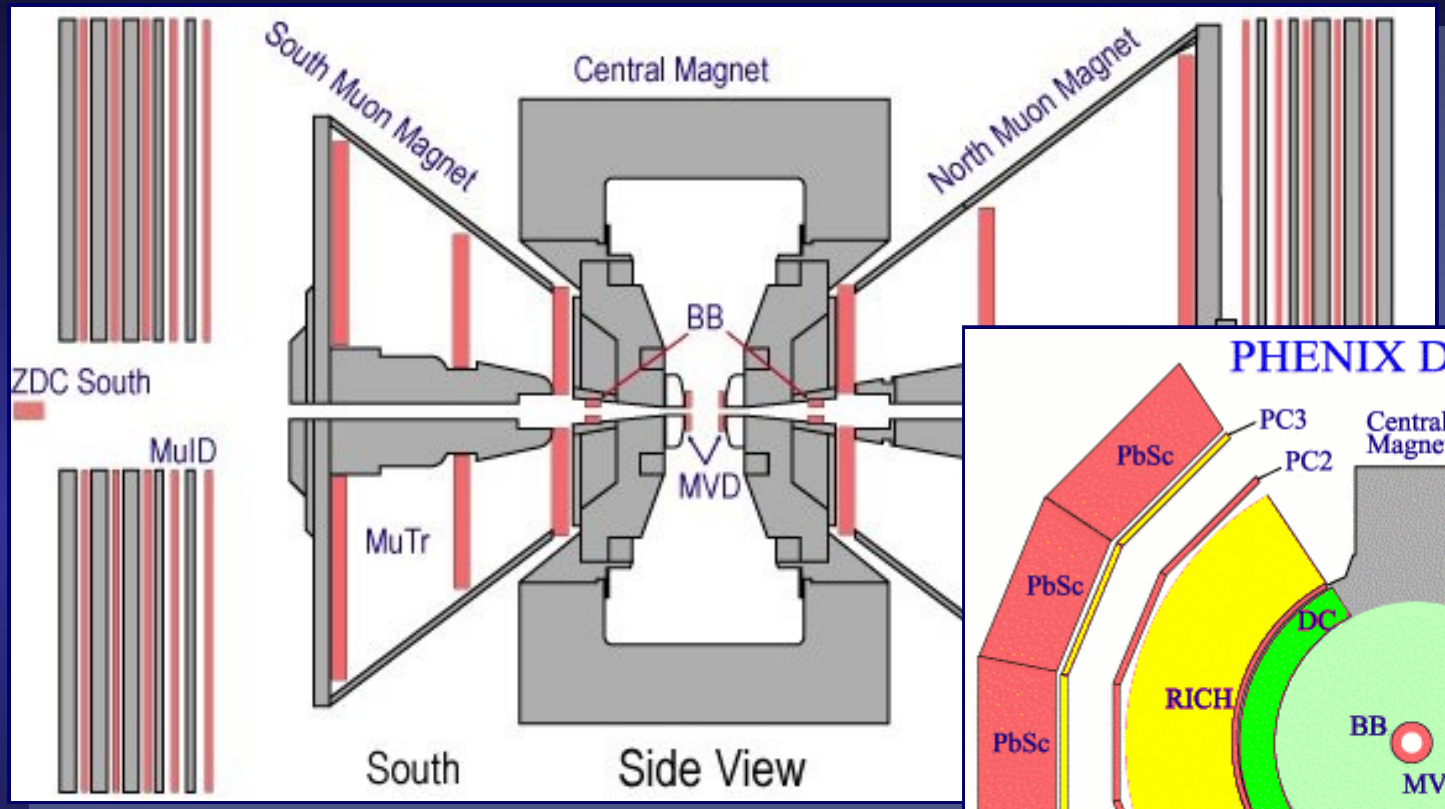
single spin asymmetries

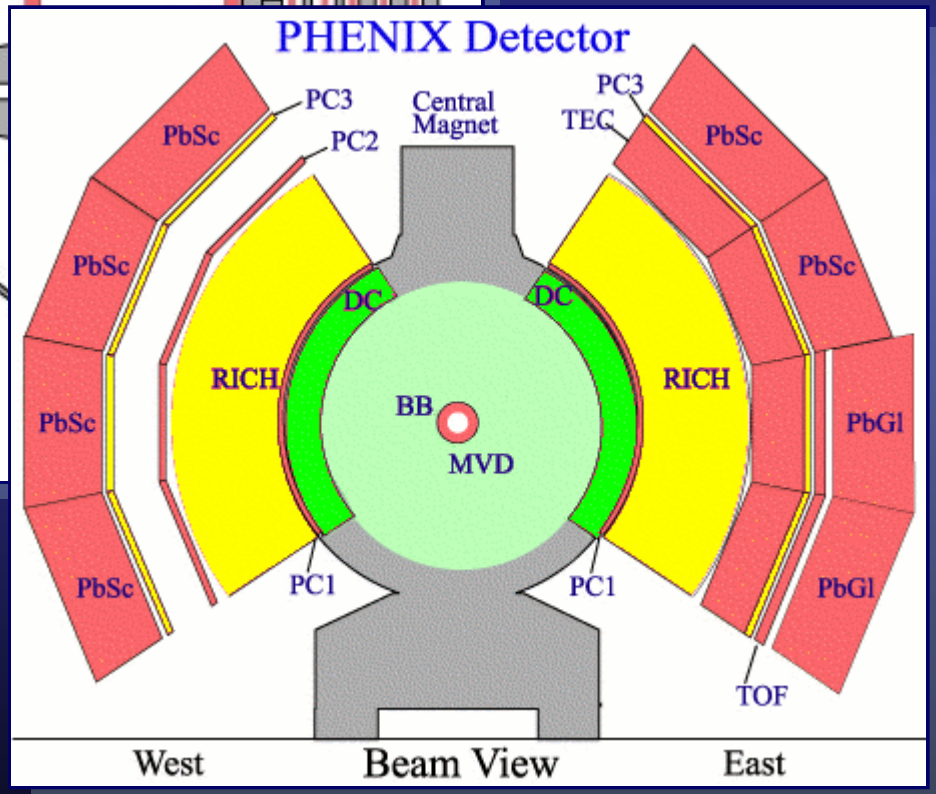
E704, BELLE, BRAHMS, COMPASS, HERMES, STAR, and PHENIX?

RHIC



PHENIX

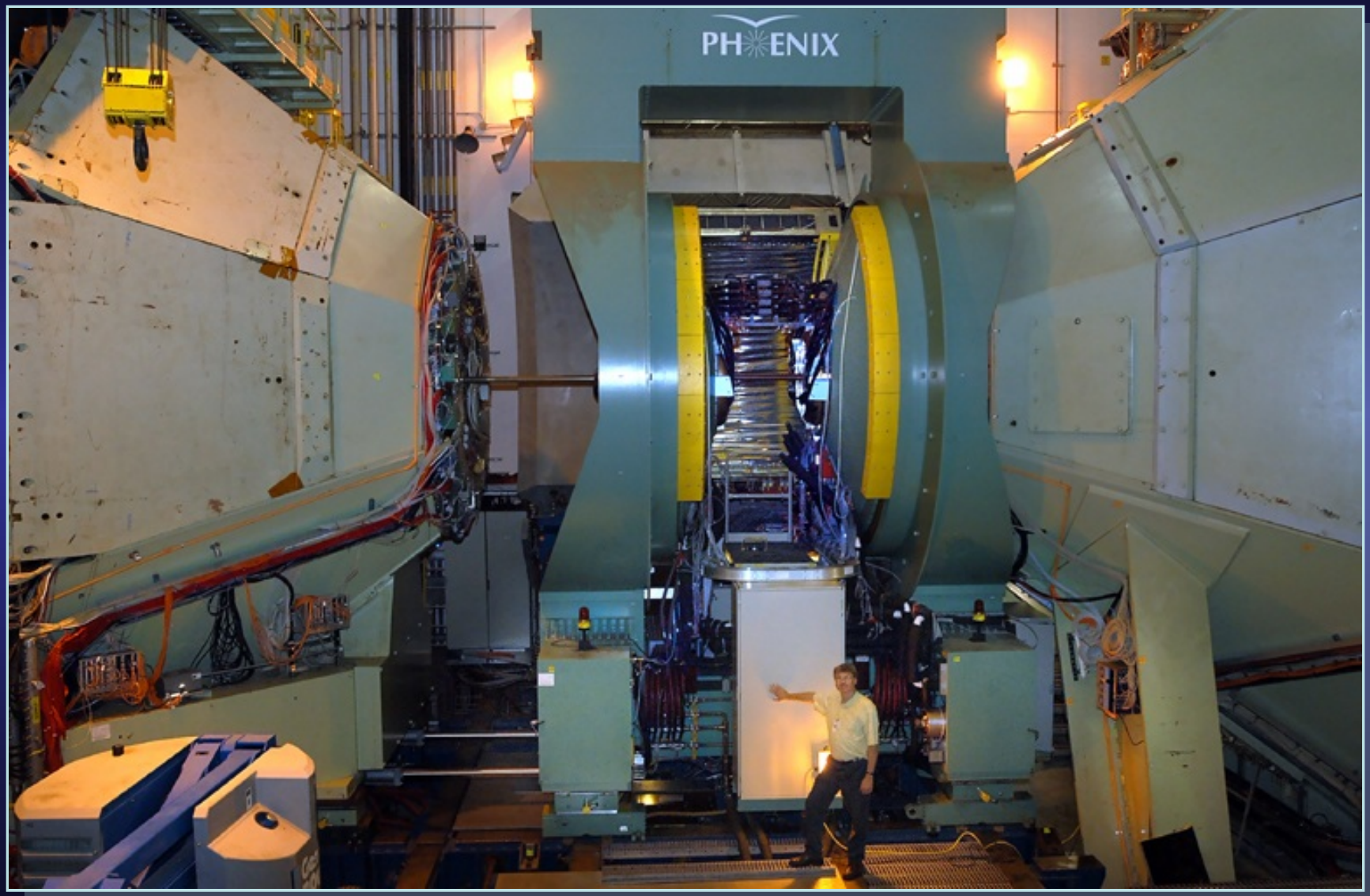




multi purpose detector:

central arms ($|\eta|<0.35$, $\Delta\varphi=2\times\pi/2$)
muon arms ($1.2<|\eta|<2.4$, $\Delta\varphi=2\pi$)
high DAQ bandwidth
multiple triggers

PHENIX

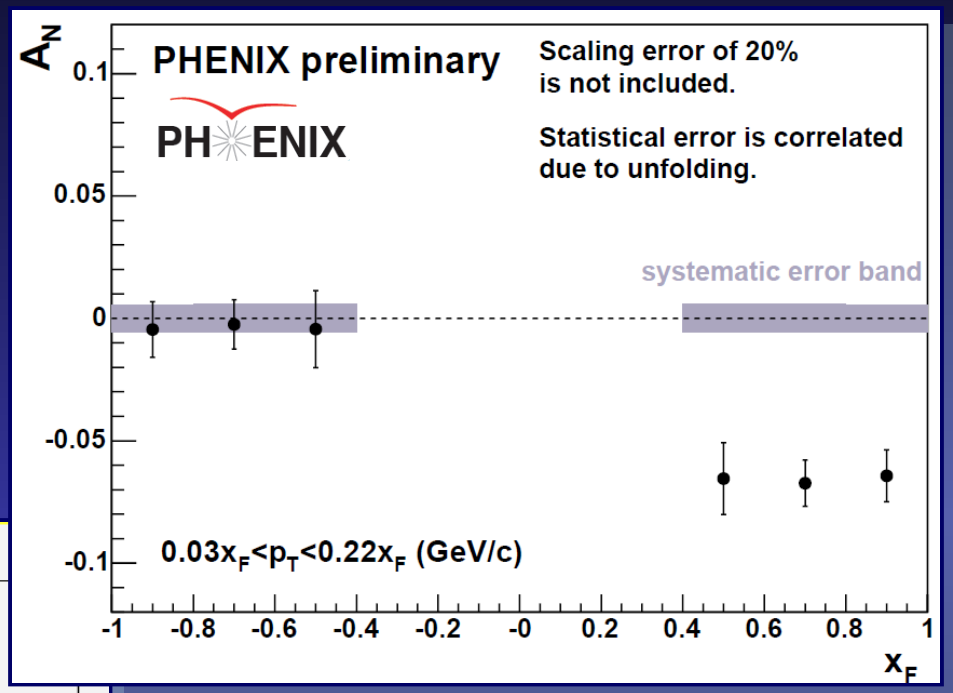


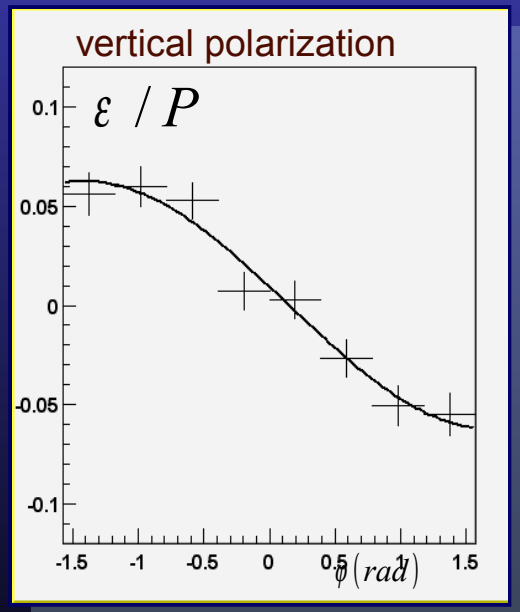
Forward Neutron Asymmetries

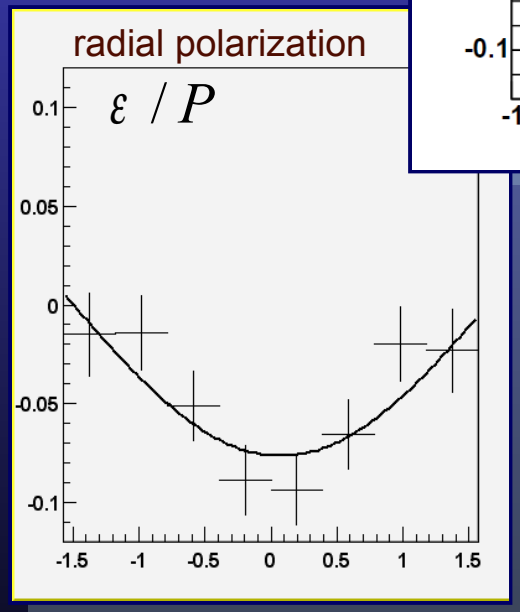
Zero Degree Calorimeter
behind Dx magnet

neutron → shower max

$$\varepsilon = \frac{\sqrt{N^{\uparrow}_{left} \cdot N^{\downarrow}_{right}} - \sqrt{N^{\downarrow}_{left} \cdot N^{\uparrow}_{right}}}{\sqrt{N^{\uparrow}_{left} \cdot N^{\downarrow}_{right}} + \sqrt{N^{\downarrow}_{left} \cdot N^{\uparrow}_{right}}}$$



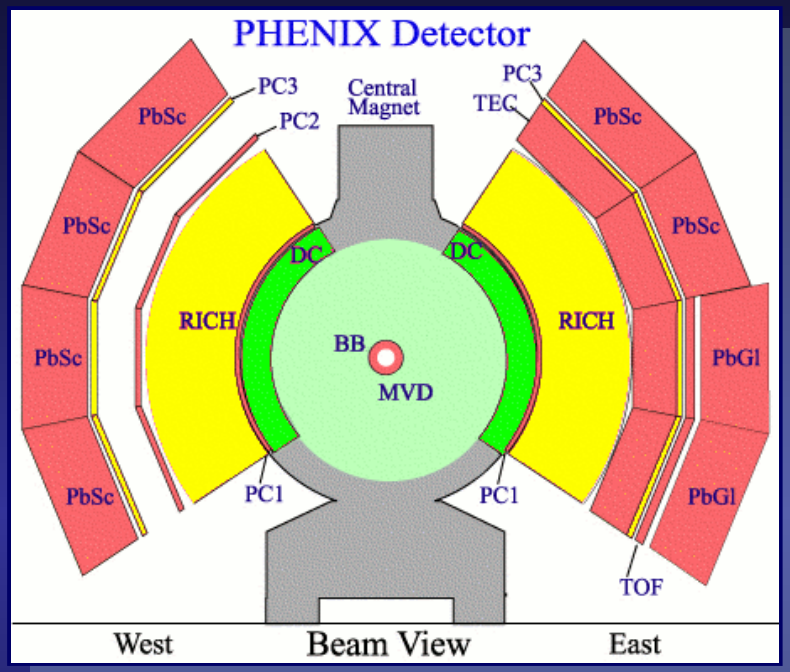


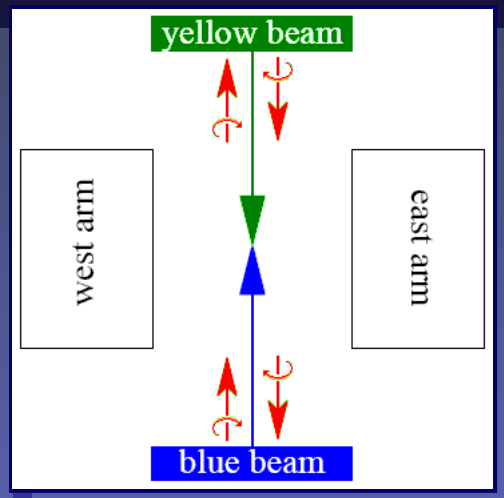


Local polarimetry:

- monitoring of polarization vector
- confirmation of spin rotator efficiency

Inclusive Measurements





data set:

2002:
L = 0.15 pb^{-1}, P ≈ 15%

2005:
same statistics, P ≈ 47%

2006: radial P ≈ 55%
3.3 pb^{-1}

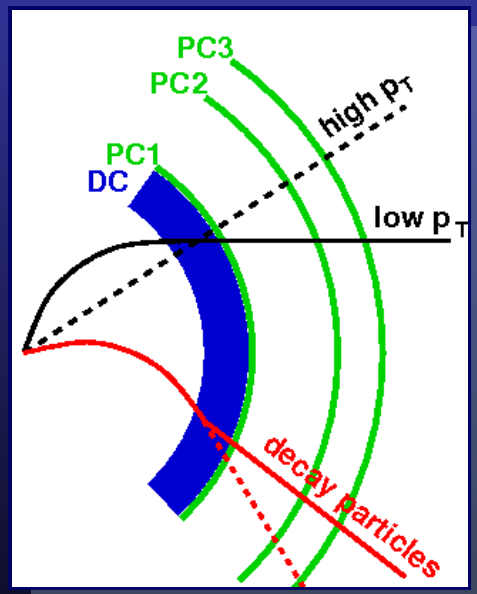
neutral pions: (→γγ)

calorimeters $\Delta\varphi \times \Delta\vartheta = 0.01 \times 0.01$
energy threshold
energy asymmetry
shower shape
charged track veto

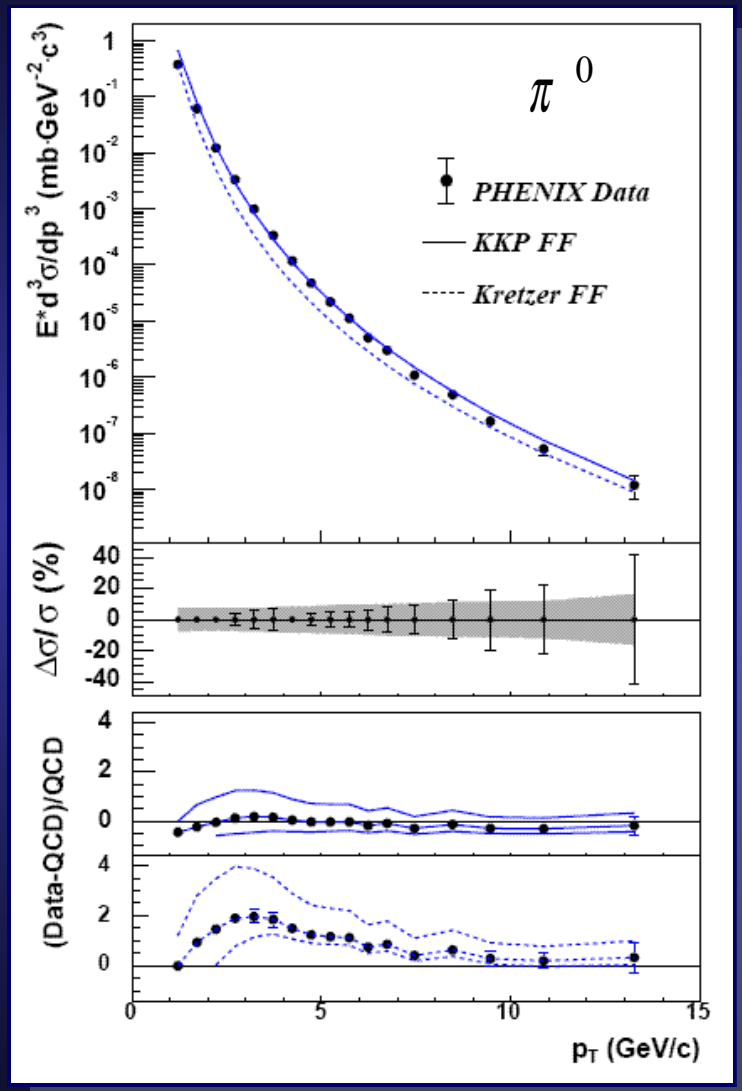
charged hadrons:

central magnetic field
drift chamber

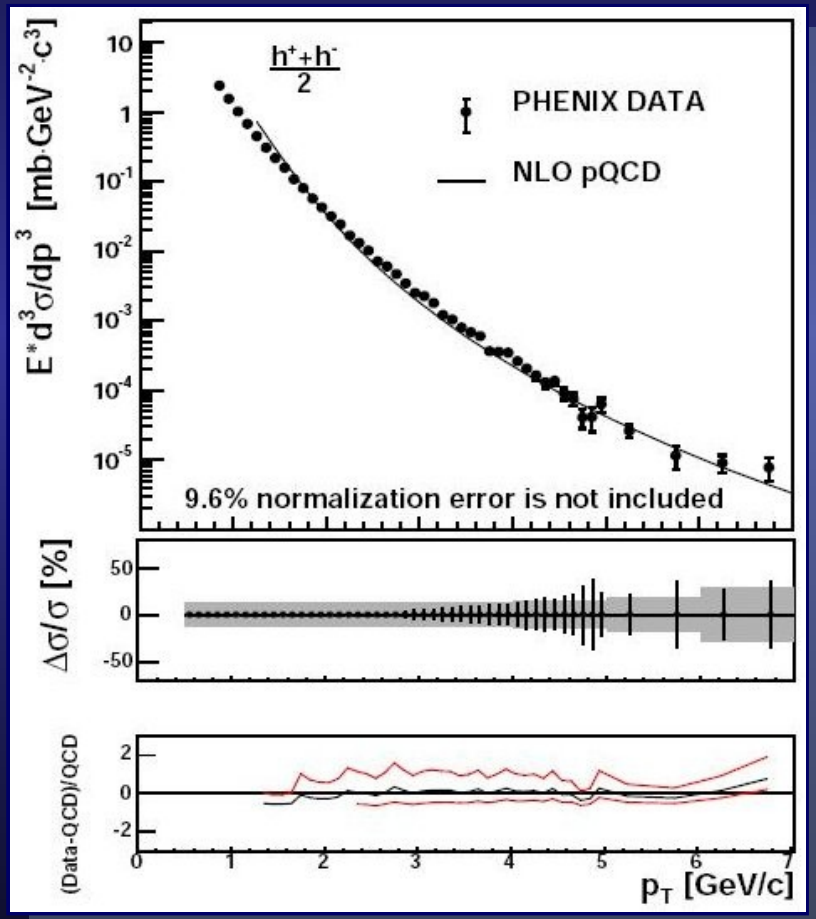
vertex
track quality
DC zed position
RICH nPMT
PC matching



Cross Sections



in good agreement with NLO pQCD over 5-8 orders of magnitude



Raw Asymmetries

$$\frac{d\sigma}{d\Omega} \propto 1 + A_N \cdot P \cdot \cos\varphi$$

$$N \propto L \cdot \Delta\Omega \cdot E(\Delta\Omega) \cdot (1 + A_N \cdot P < \cos\varphi >)$$

efficiency (left / right)

luminosity ($P_\downarrow$ / $P_\uparrow$)

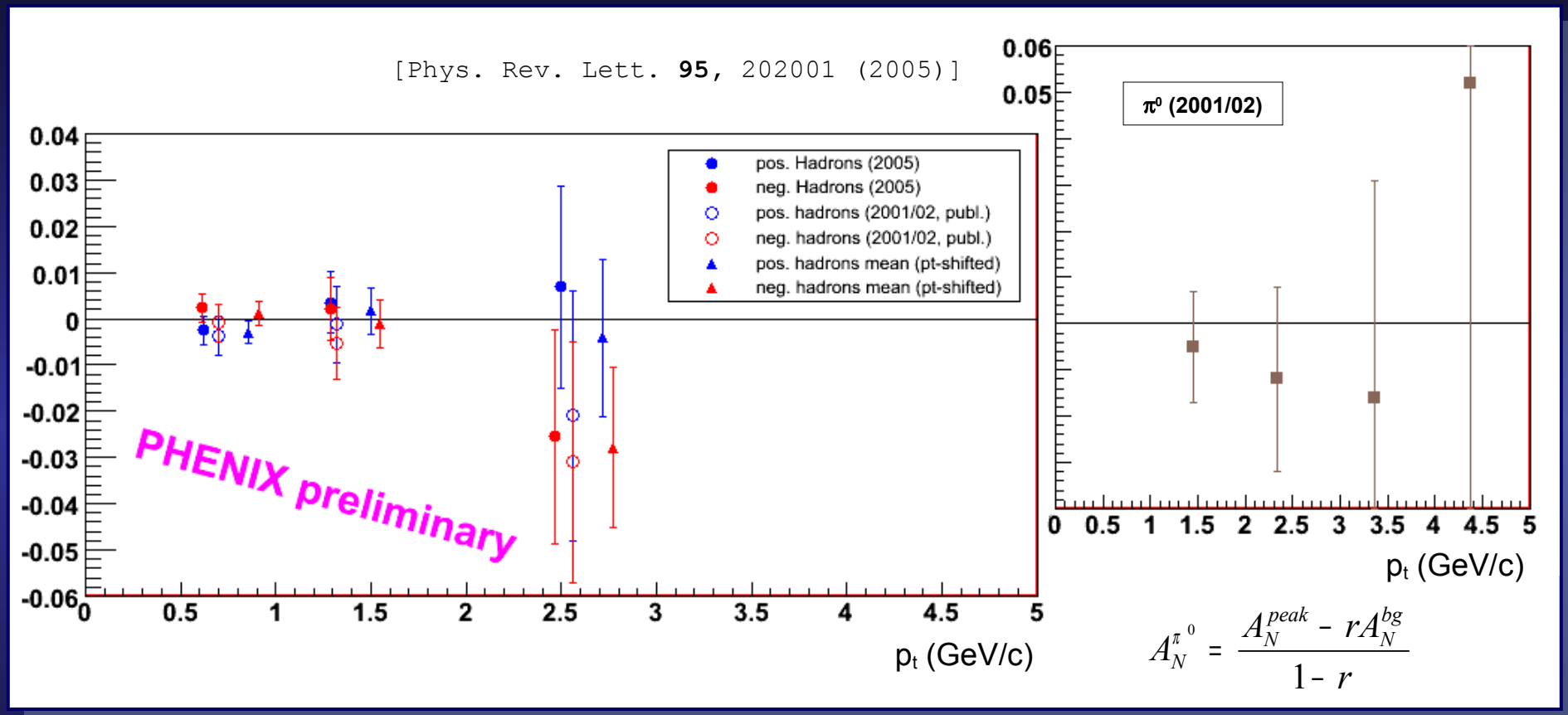
acceptance (p_t / charge / left / right)

$$N_L^\uparrow \propto L^\uparrow \cdot E_L \cdot (1 + A_N \cdot P \cdot c_L)$$
$$N_R^\uparrow \propto L^\uparrow \cdot E_R \cdot (1 - A_N \cdot P \cdot c_R)$$
$$N_L^\downarrow \propto L^\downarrow \cdot E_L \cdot (1 - A_N \cdot P \cdot c_L)$$
$$N_R^\downarrow \propto L^\downarrow \cdot E_R \cdot (1 + A_N \cdot P \cdot c_R)$$

$$\frac{N_L^\uparrow \cdot N_R^\downarrow}{N_L^\downarrow \cdot N_R^\uparrow} = \frac{(1 + A_N \cdot P \cdot c_L) \cdot (1 + A_N \cdot P \cdot c_R)}{(1 - A_N \cdot P \cdot c_L) \cdot (1 - A_N \cdot P \cdot c_R)}$$

$$\varepsilon = \frac{(N_\uparrow^2 + N_\downarrow^2) \cdot (c_L + c_R) \pm \sqrt{(N_\uparrow^2 + N_\downarrow^2)^2 \cdot (c_L + c_R)^2 - 4 \cdot c_L \cdot c_R \cdot (N_\uparrow^2 - N_\downarrow^2)^2}}{2 \cdot c_L \cdot c_R \cdot (N_\uparrow^2 - N_\downarrow^2)}$$

Inclusive Single Spin Asymmetries



$$A_N^{\pi^0} = \frac{A_N^{peak} - rA_N^{bg}}{1 - r}$$

P = 15% in 2002, P = 47% in 2005

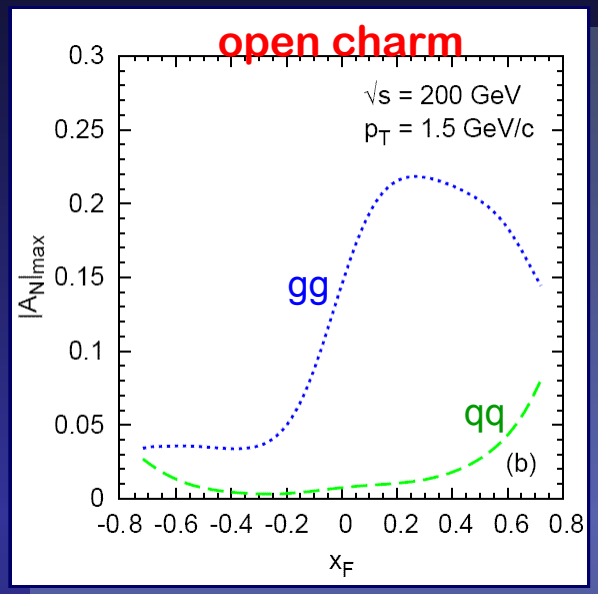
polarization scaling uncertainty: 30%(2002), ≈ 20%(2005)

residual polarization in *unpolarized* beam:
< 10% and small A_N

helps constrain gluon Sivers:

Anselmino et al., PRD74:094011 (2006)

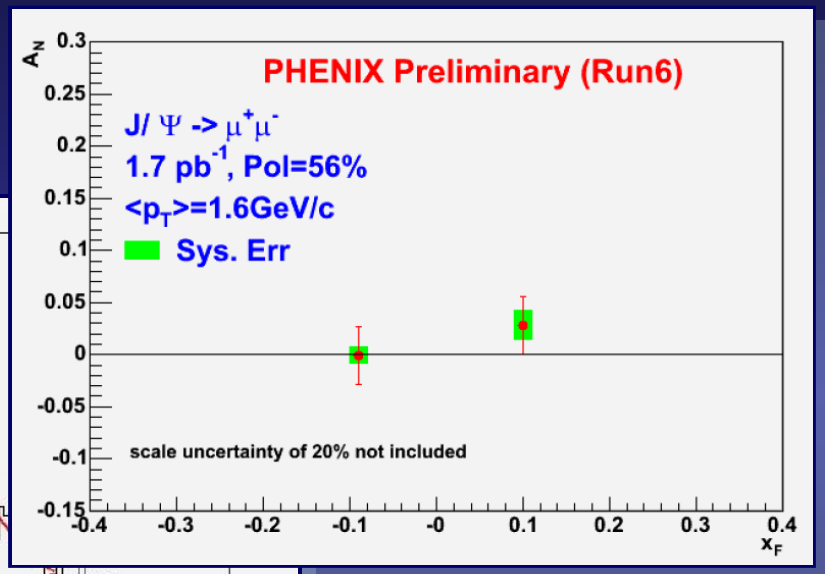
Heavy Flavor

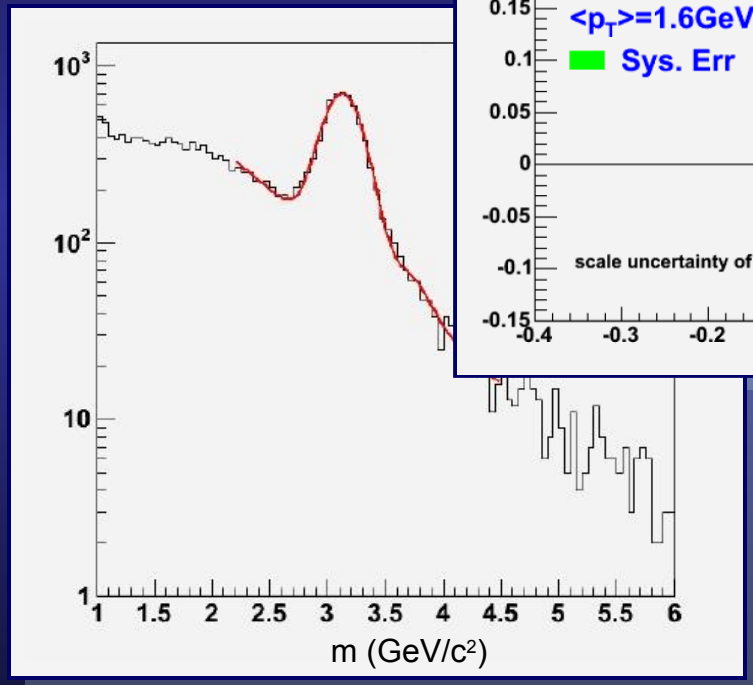


Anselmino et al.[hep-ph/0407100]

J/Ψ di-muon decay: muon spectrometers

- large rapidities
- full azimuth





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

gluon dominance
minimized Collins
Sivers $\rightarrow A_N$

2005: 0.15 pb^{-1}

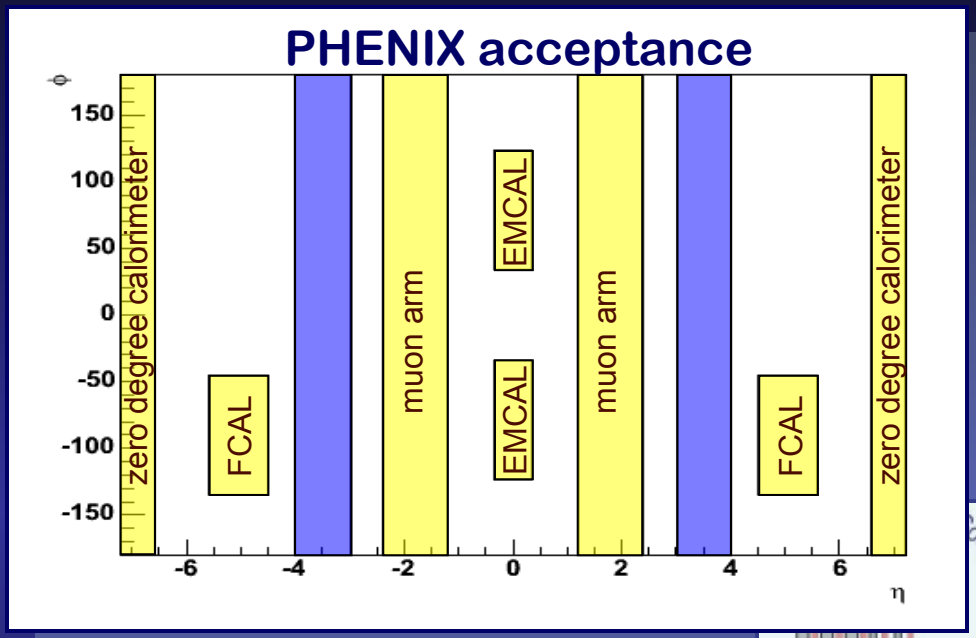
2006: 2.7 pb^{-1}

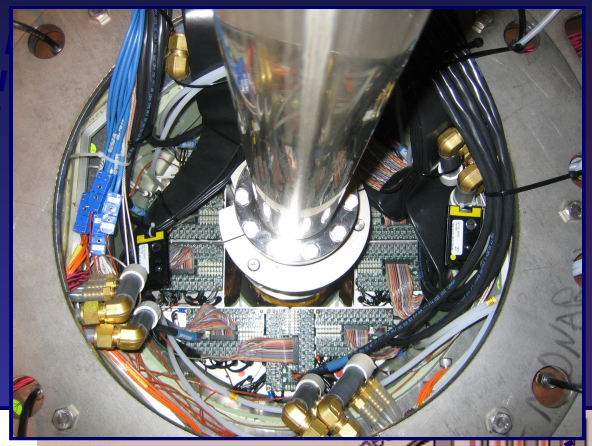
bg. asymmetry:

- side-bands
- like-sign spectrum

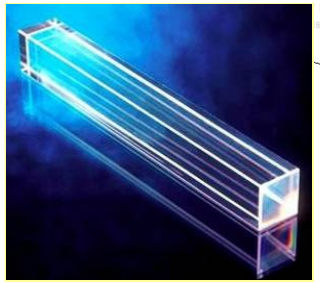
$$A_N^{J/\Psi} = \frac{A_N^{peak} - r A_N^{bg}}{1 - r}$$

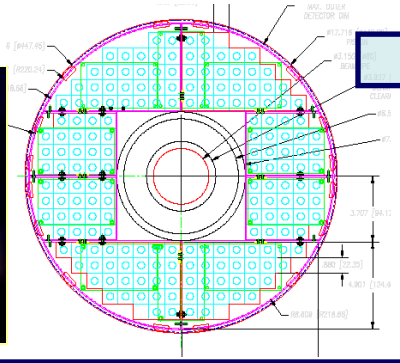
The Muon Piston Calorimeter

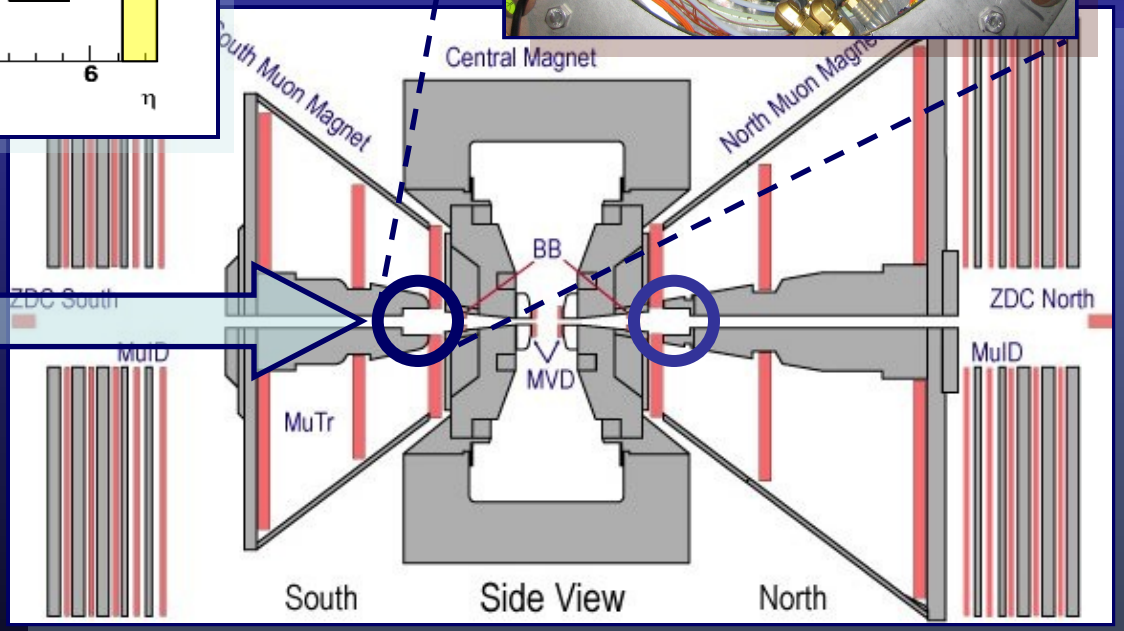




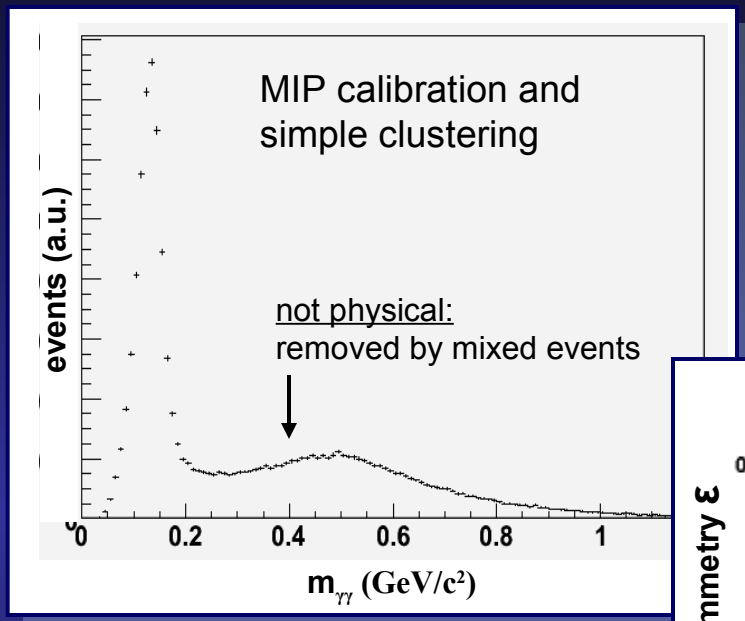
array of ≈ 220 $PbWO_4$ crystals







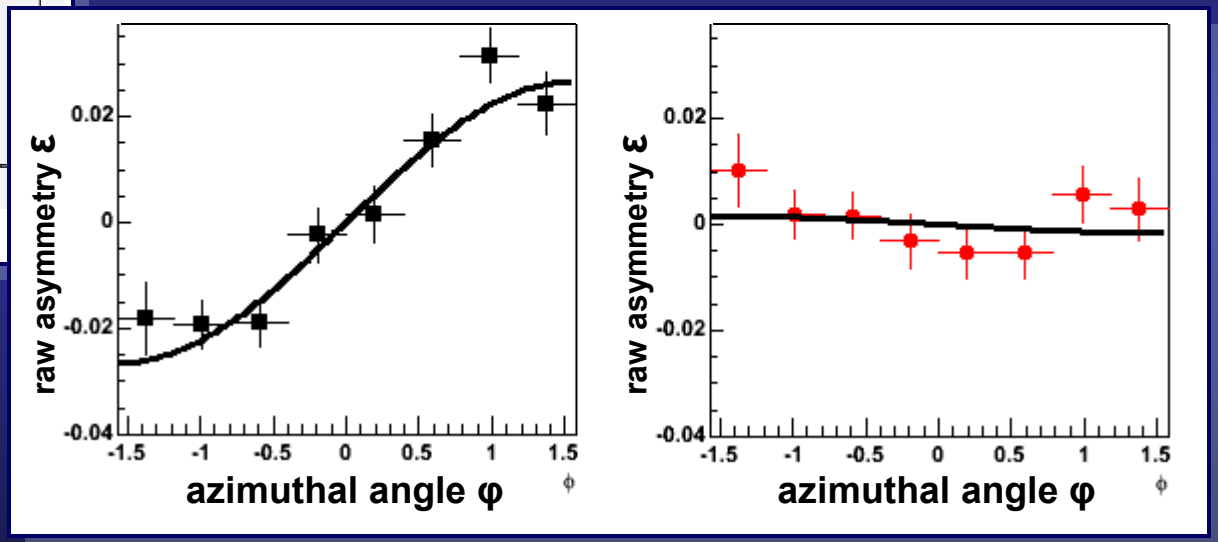
Forward Neutral Pions



asymmetries in forward direction

- energy (x_F) dependent
- no asymmetry in backward direction (x_F<0)

on-going analysis, waiting for final data production



2006:

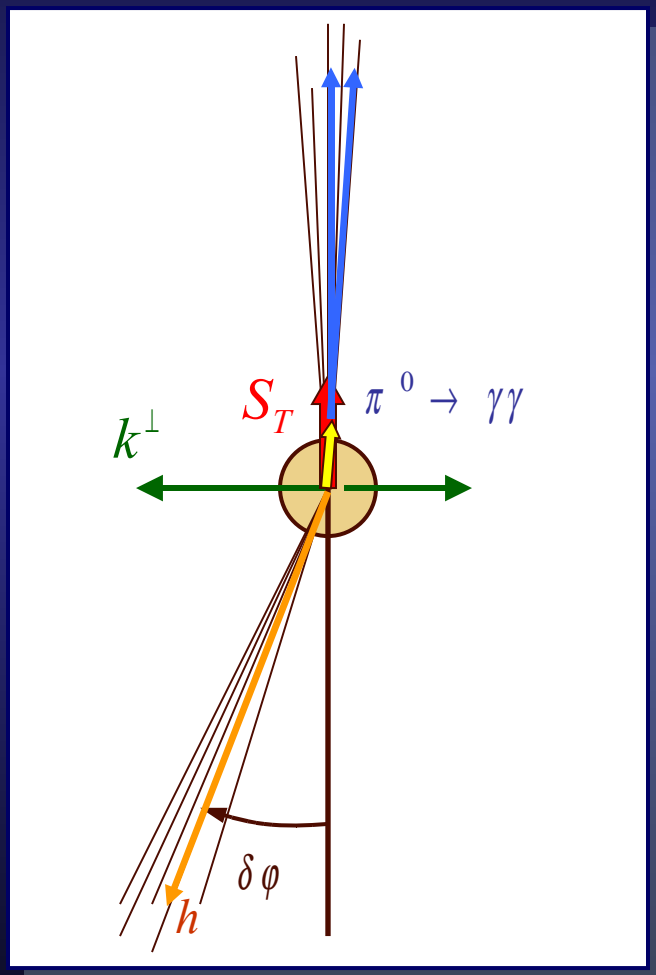
- commissioning during 200 GeV transverse
- 20 nb^{-1} at 62.4 GeV transverse
- add. local polarimeter (200 GeV longitudinal)

more about PHENIX upgrades:
J. Lajoie in *Spin Physics 9* on Thursday

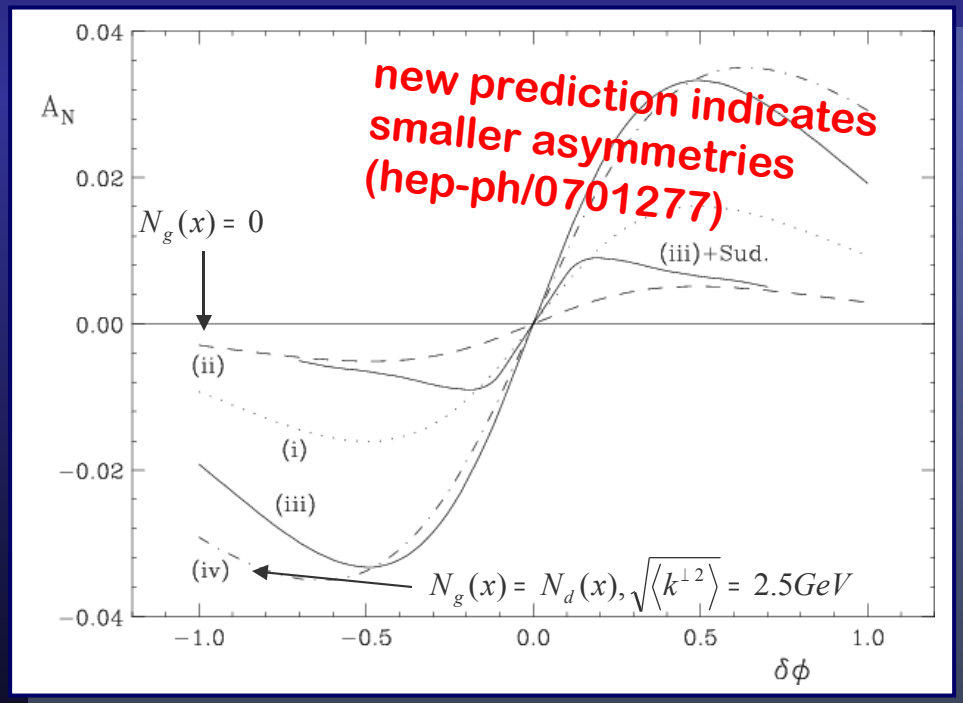
Two-Jet back-to-back Correlations

D. Boer and W. Vogelsang,
Phys. Rev. D **69**, 094025 (2004)

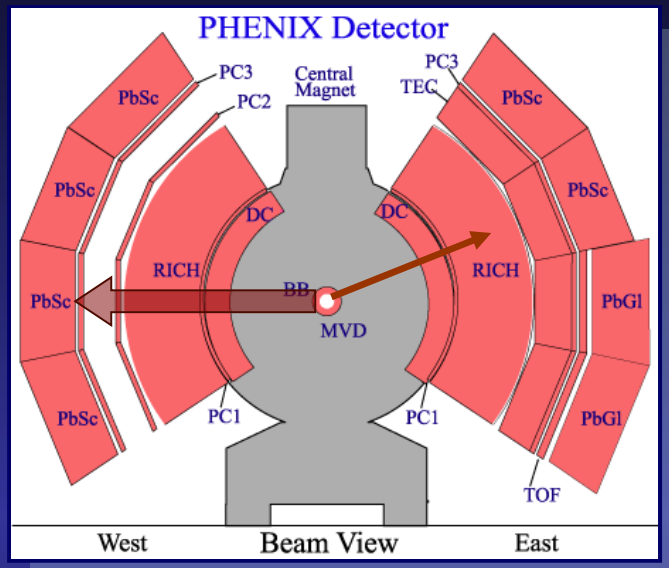
$$\hat{f}(x,k^{\perp},S_T) = f(x,k^{\perp}) + \tfrac{1}{2}\Delta^N f(x,k^{\perp})\frac{S_T\cdot(P\times k^{\perp})}{|S_T||P||k^{\perp}|}$$

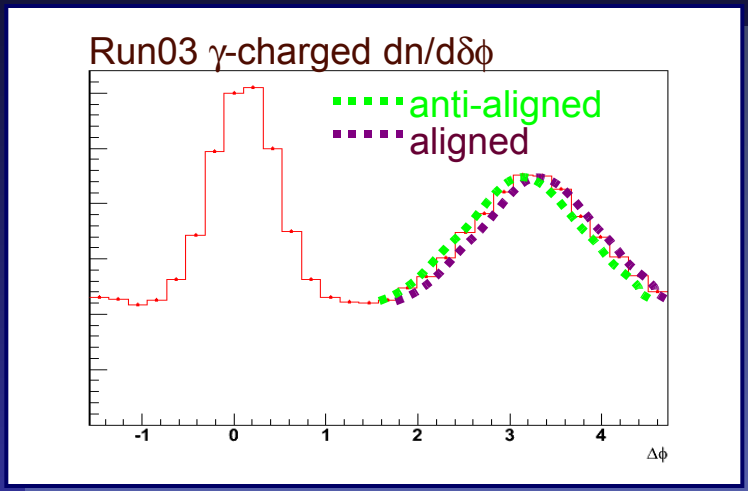


$$A_N = \frac{\sigma^{\uparrow}(\delta\varphi) - \sigma^{\downarrow}(\delta\varphi)}{\sigma^{\uparrow}(\delta\varphi) + \sigma^{\downarrow}(\delta\varphi)} \qquad \delta\varphi = \varphi_{jet1} - \varphi_{jet2} + \pi$$

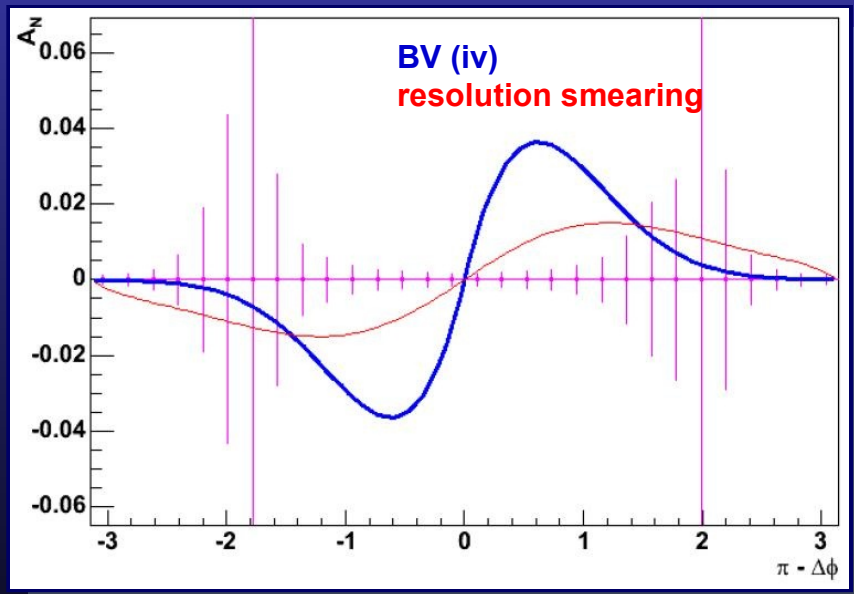


Two-Hadron back-to-back Correlations





$$\delta\varphi = \varphi_\pi - \varphi_h + \pi$$



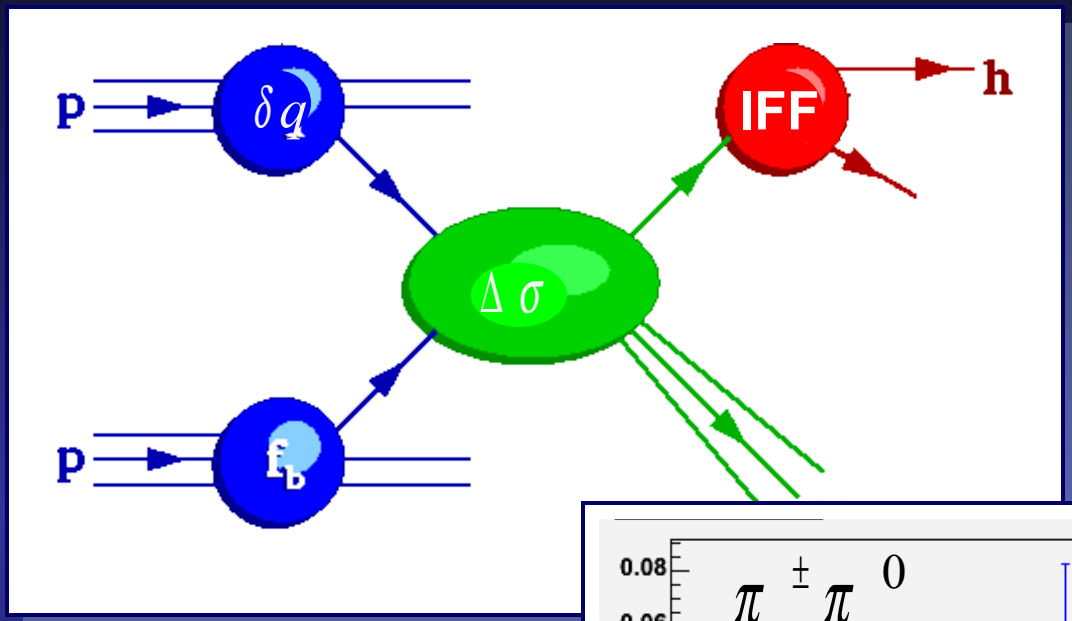
direction of central arms
→ ***radial*** polarization

radial polarization component in 2005
P_{blue} = 8%, P_{yellow} = 15%

→ σ_{stat} = 5% in away-side peak

2006:
radial polarization, 2.7 pb^{-1} at P = 55%

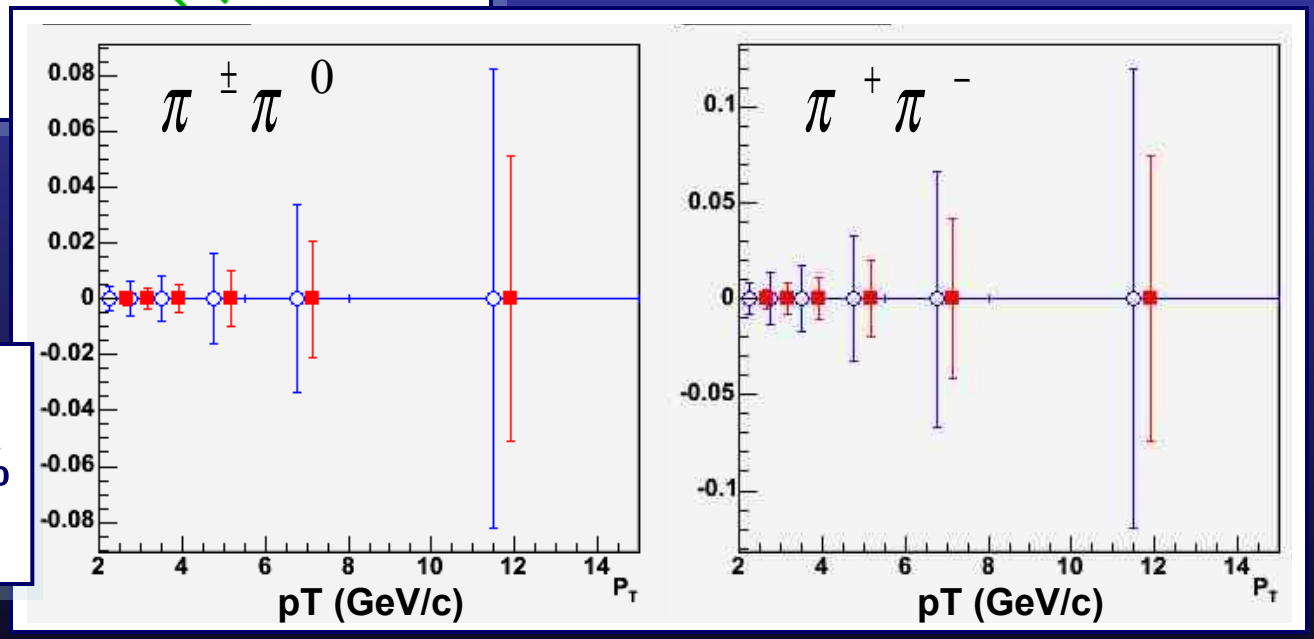
Interference Fragmentation Function



$$pp^{\uparrow} \rightarrow hhX$$

$$A_{UT} \propto \delta q \otimes IFF$$

$$A_{UT}(\varphi) = \frac{1}{P} \cdot \frac{N^{\uparrow}_{\pi\pi}(\varphi) - R \cdot N^{\downarrow}_{\pi\pi}(\varphi)}{N^{\uparrow}_{\pi\pi}(\varphi) + R \cdot N^{\downarrow}_{\pi\pi}(\varphi)}$$



projections:

2006: 2.7 pb^{-1} at 55%

5.0 pb^{-1} at 65%

Summer-y

- **single spin asymmetries at midrapidity consistent with 0**
  data from 2001/2 and 2005
  2006 *radial* polarization:
  reduced asymmetry due to acceptance (< ½),
  but large integrated luminosity and increased polarization
- **single spin asymmetries at forward rapidities**
  energy dependence in forward direction
  no asymmetry in backward direction
  J/ψ asymmetry consistent with zero
- **on-going analysis of two-hadron b2b asymmetries**
  first look with *residual radial* polarization (2005)
  mid-rapidity correlations (central arms)
  forward region correlations (new calorimeter, $3 < \eta < 4$)
- **transversity from interference fragmentation function**
  extraction using BELLE IFF
- **large negative forward neutron asymmetry**
  no backward asymmetry, monitoring of polarization alignment

PHENIX
OVER ONE BILLION SERVED
Thank you !!!