Transverse SSA Measured at RHIC

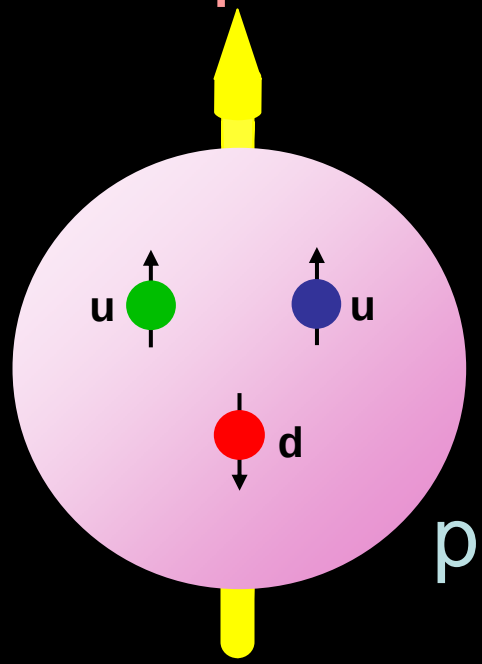
Jan Balewski, IUCF
Exclusive Reactions

May 21-24, 2007
Jefferson Lab

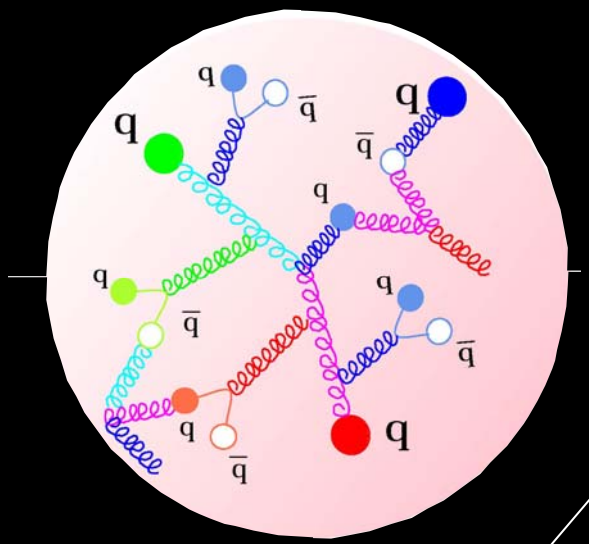
Where does the proton's spin come from?

p is made of 2 u and 1d quark

$$S = \tfrac{1}{2} = \Sigma\ S_q$$



Explains magnetic moment of baryon octet



BUT partons have an x distribution and there are sea quarks and gluons

Check via electron scattering and find quarks carry only ~1/3 of the proton's spin!

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Jets,pions,A_{LL}

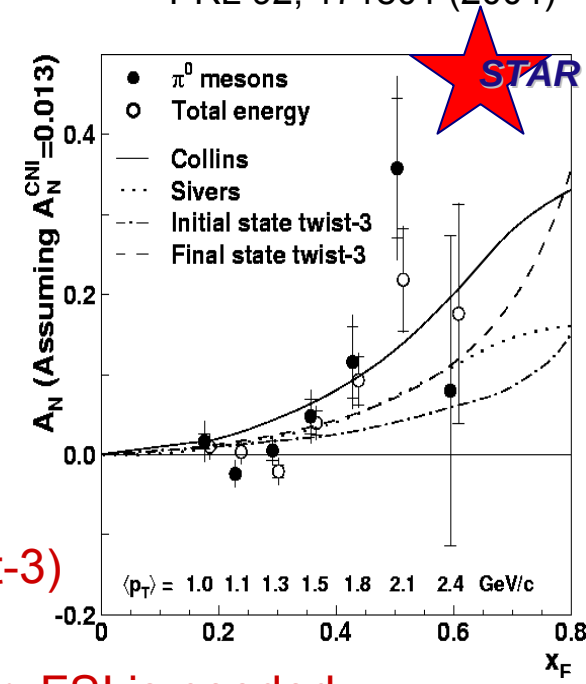
Di-jets, Sivers A_N

Transverse spin physics

PRL 92, 171801 (2004)

Basic, naïve QCD (leading-twist, zero quark masses) predicts:

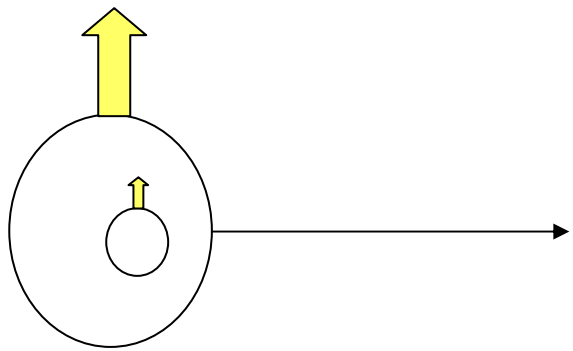
$$A_N \propto \frac{m_q}{\sqrt{s}} = 0$$



Experiments: E704(91), AGS(99), STAR(02) → A_N is large

Study of transverse spin effects:

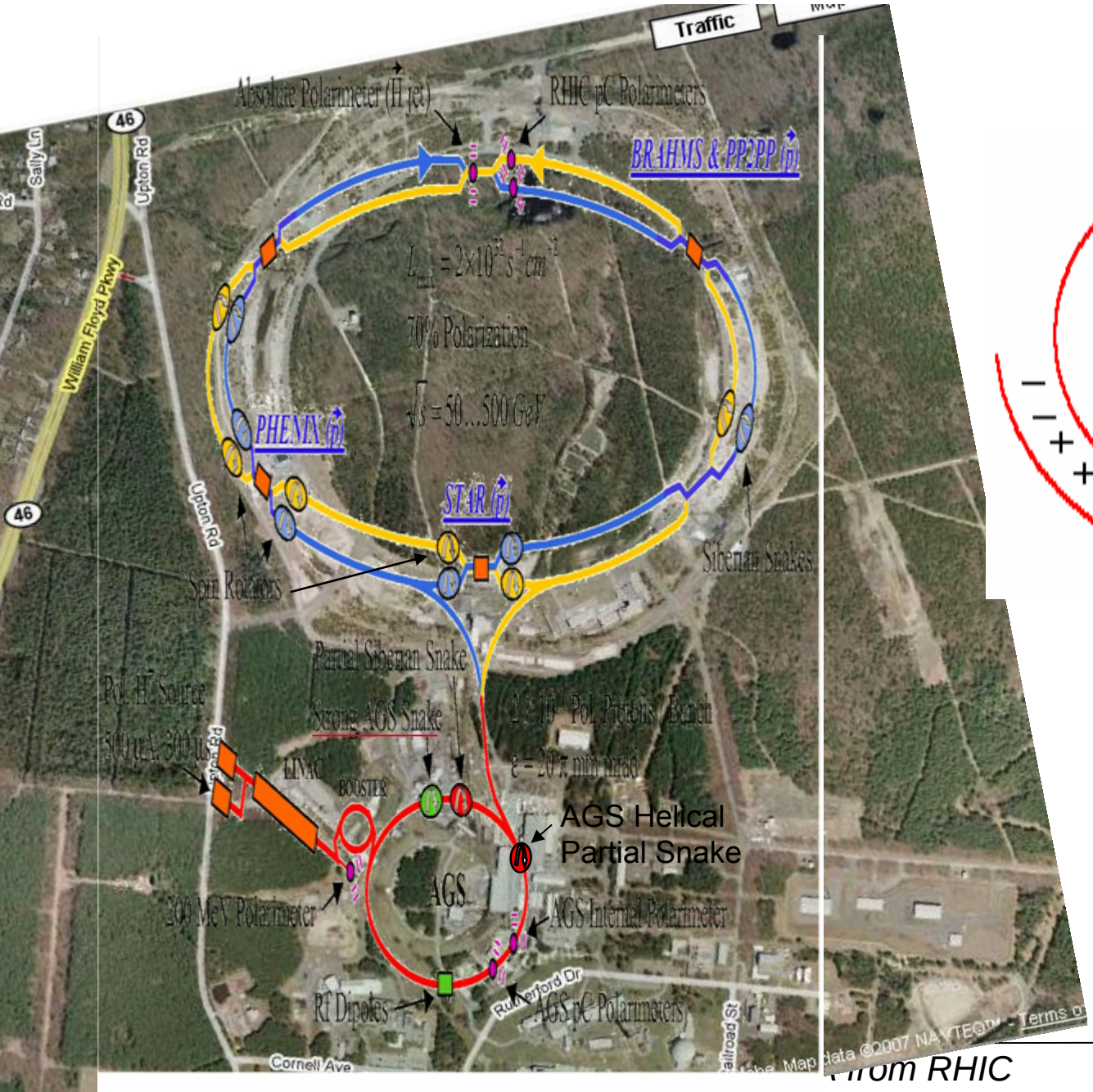
- Qui and Sterman (Initial-state twist-3), Koike (final-state twist-3)
  → **Quark & gluon field interference**
- **Sivers**: k_T in initial state correlates w/ proton spin, ISI and/or FSI is needed
  → depends on orbital momentum
- **Collins**: kT in final state correlates w/ spin of quark
  → depends on **transversity** $\delta q_i\left(x, Q^2\right)$

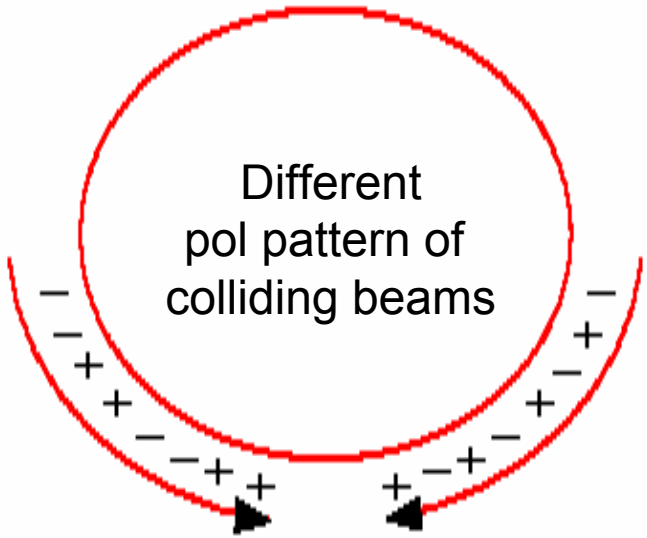


Fundamental **transverse spin sum rule**:

$$\frac{1}{2} = \frac{1}{2}\sum_{i=q,\bar{q}} \int dx \delta q_i\left(x, Q^2\right) + \sum_{i=q,\bar{q},g} \left\langle L_{S_T} \right\rangle_i \left(Q^2\right)$$

RHIC - First Polarized pp Collider

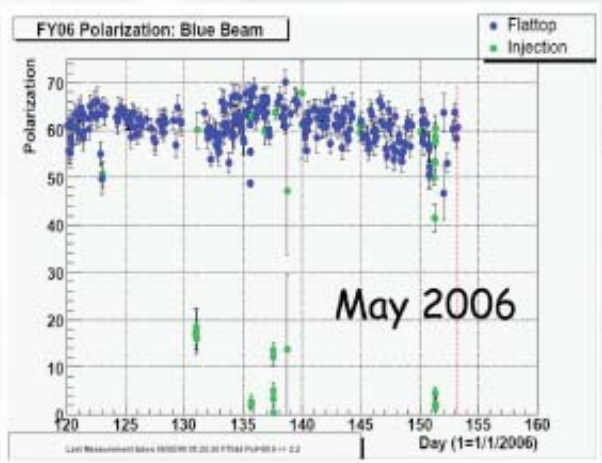


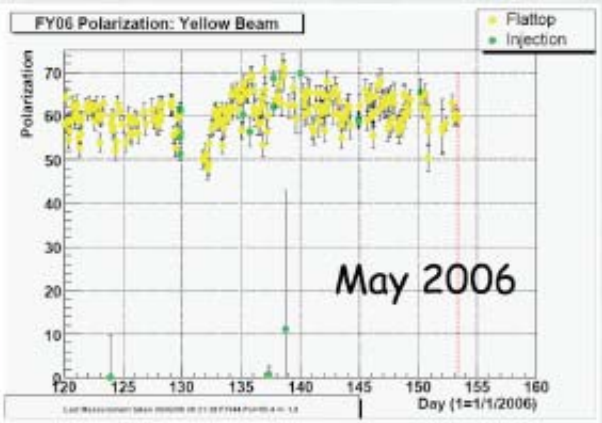


The polarized proton collider RHIC

- Luminosity and polarization performance
  - Overview of performance parameters

RHIC RUN	√s [GeV]	$L_{recorded}$ [pb^{-1}] (Transverse)	$L_{recorded}$ [pb^{-1}] (Longitudinal)	Polarization [%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.1	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60





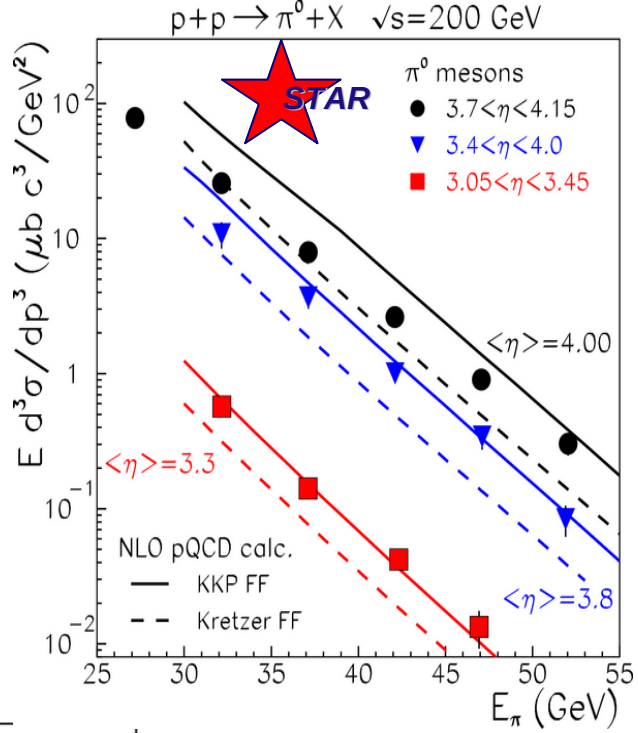
Yellow and Blue Beam polarization

- All RHIC polarized pp accelerator components are in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

SPIN2006, 17th International Spin Physics Symposium
Kyoto, Japan, October 02-07, 2006

Bernd Surrow

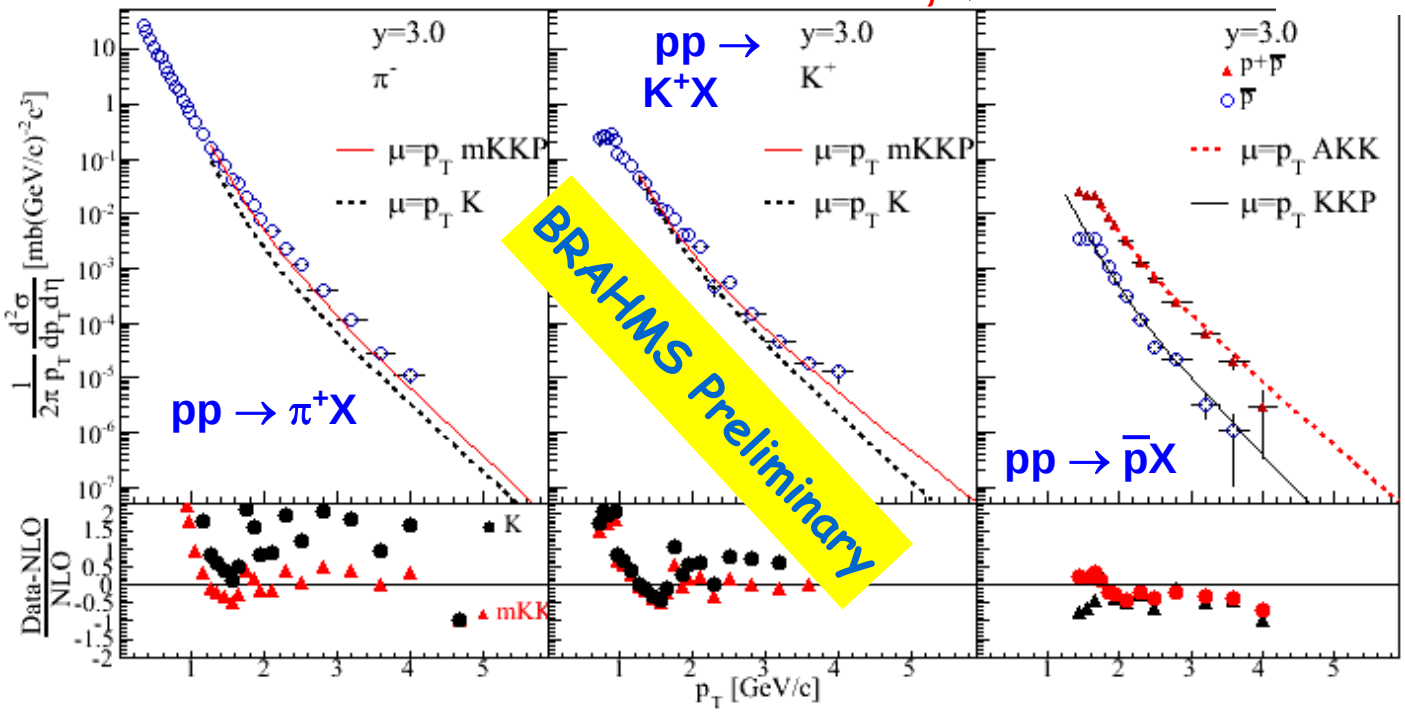
RHIC pp Absolute Cross Section Results Confirm Applicability of pQCD



PRL 97, 152302 (2006)

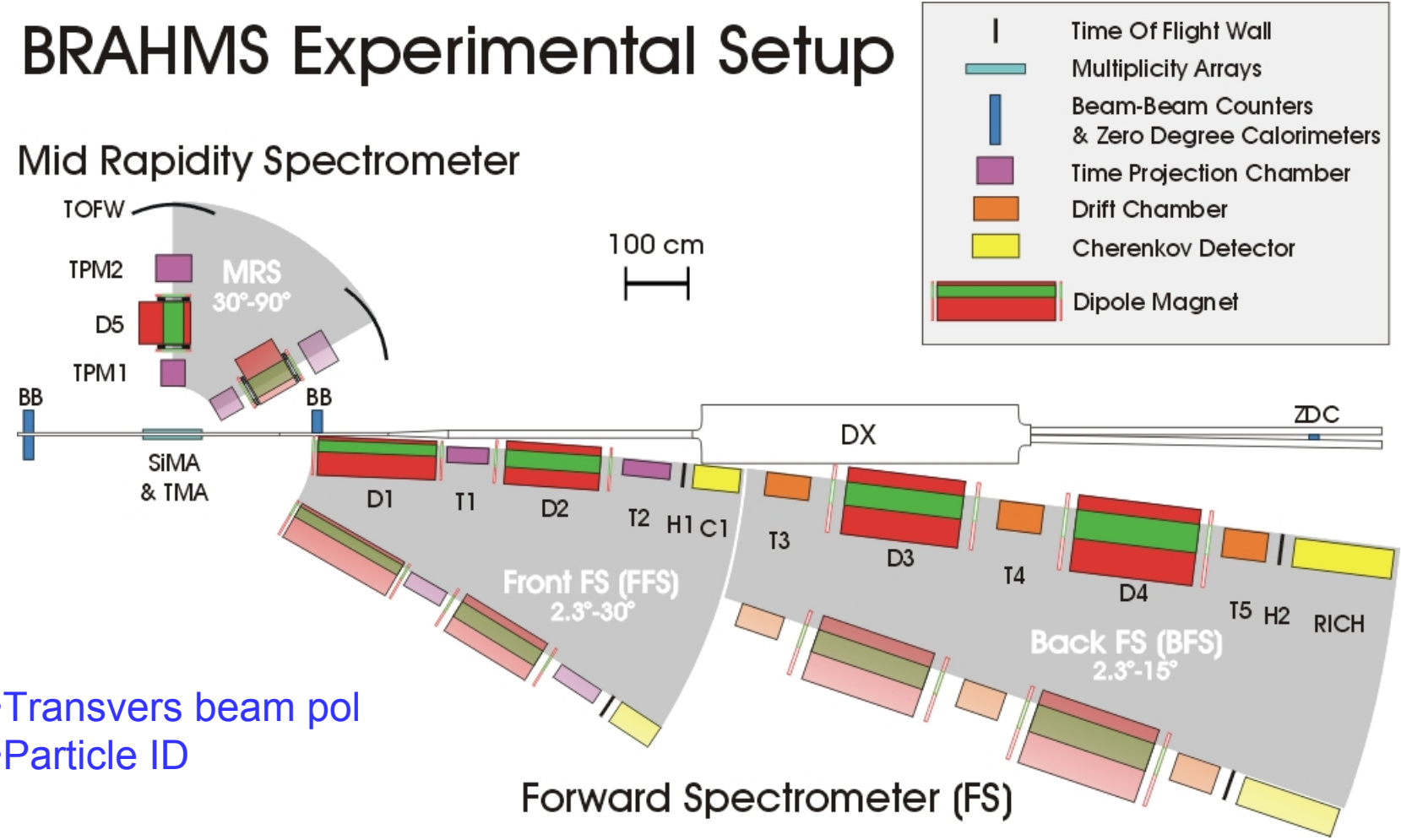
pQCD works! *Absolute cross sections for many channels -- p+p → π^0+X, jet + X, γ +X at $\sqrt{s}$ = 200 GeV – are well reproduced in NLO pQCD calcs. down to p_T ~ few GeV/c.*

BRAHMS Inclusive Production, √s=200 GeV



Jan Balewski (IUCF)

BRAHMS Experimental Setup

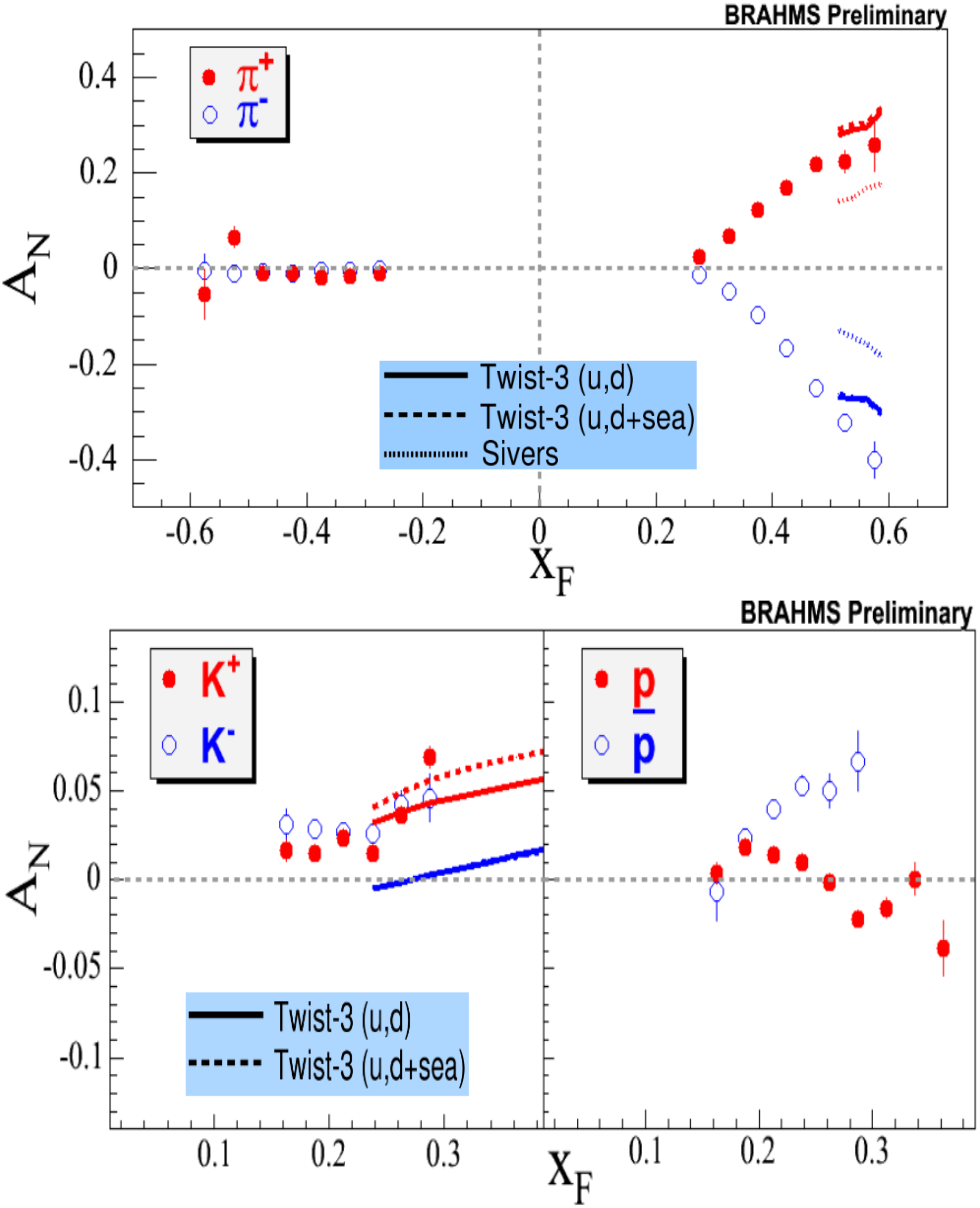


- Transvers beam pol
- Particle ID

BRAHMS measured A_N $\sqrt{s}$=62.4 GeV and 200 GeV

- Large xF dependent SSAs seen for pions and kaons
- Collinear factorization and (NLO) pQCD describe unpolarized cross-section at RHIC in wide kinematic region

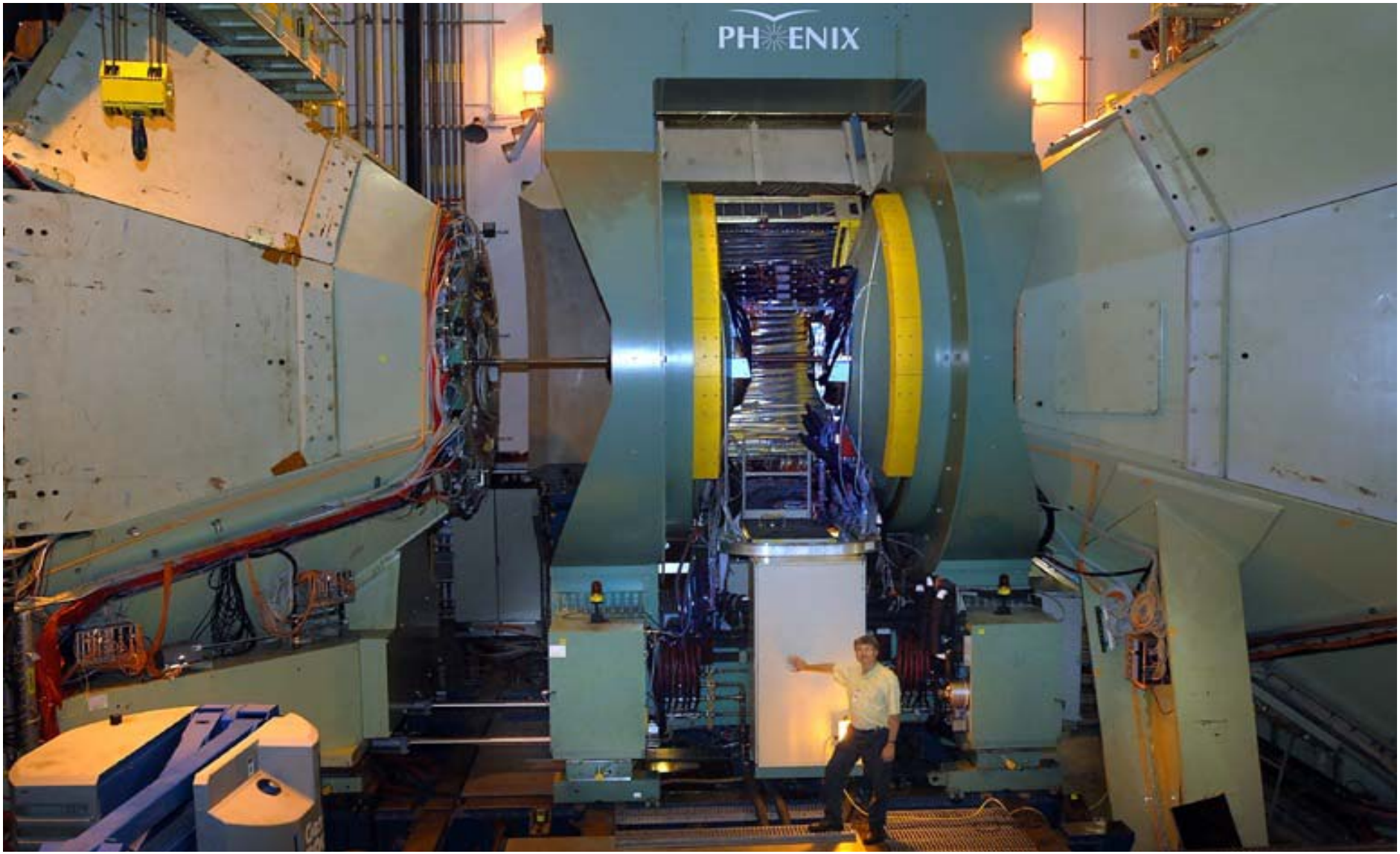
BRAHMS Transverse SSA



- TMD PDF (Sivers function) alone cannot describe polarized and unpolarized data
- Gluonic degree of freedom (Twist-3) is signicantly responsible for the large A_N
- Sea quark contributions not well understood: $A_N(K^{\pm})$,$A_N(p)$

J.H.Lee, SPIN06

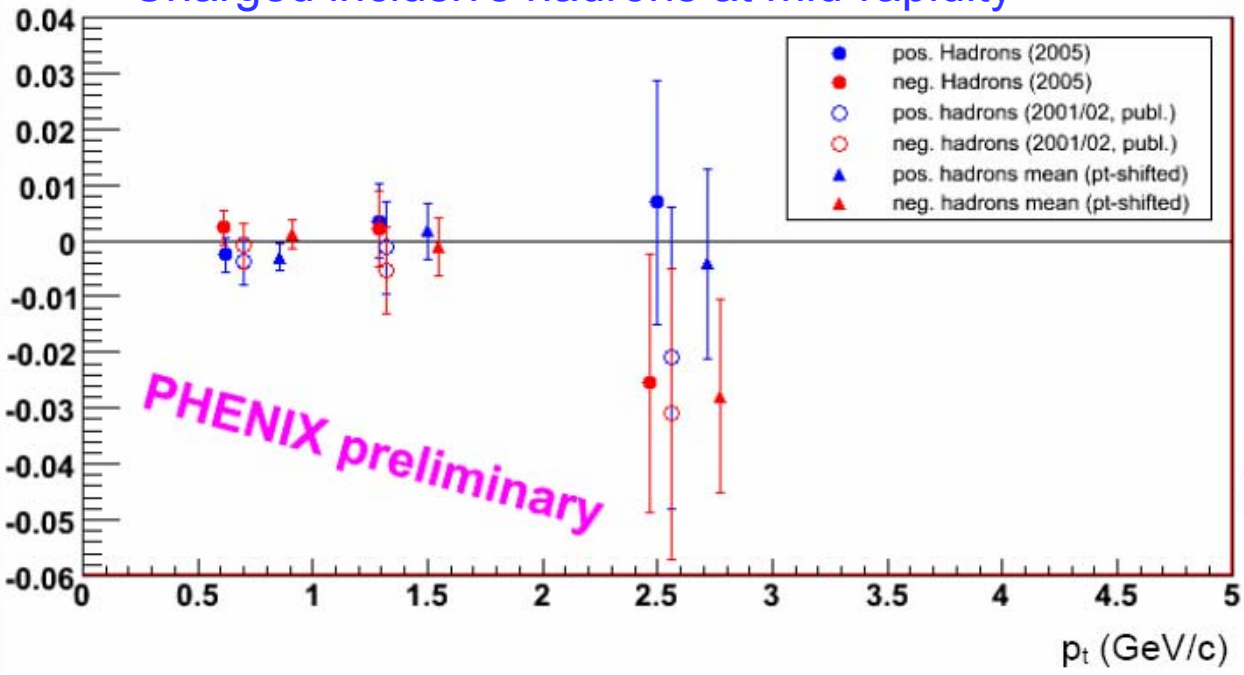
Phenix



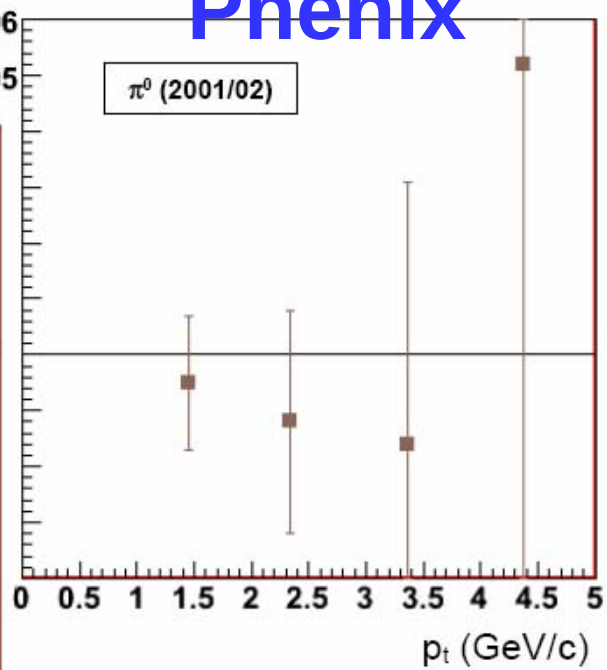
Inclusive Single Spin Asymmetries

[Phys. Rev. Lett. **95**, 202001 (2005)]

Charged inclusive hadrons at mid-rapidity



Phenix



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

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

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

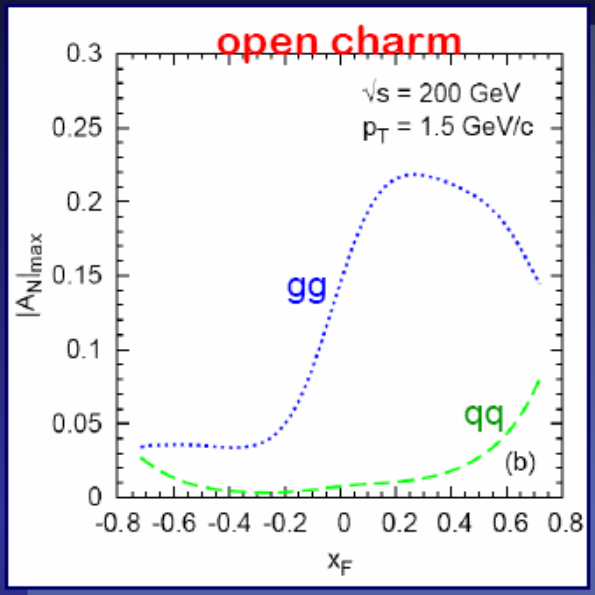
residual polarization in *unpolarized* beam:
< 10% and small A_N

helps constrain gluon Sivers:

Anselmino et al., PRD74:094011 (2006)

Heavy Flavor

Phenix



Anselmino et al.[hep-ph/0407100]

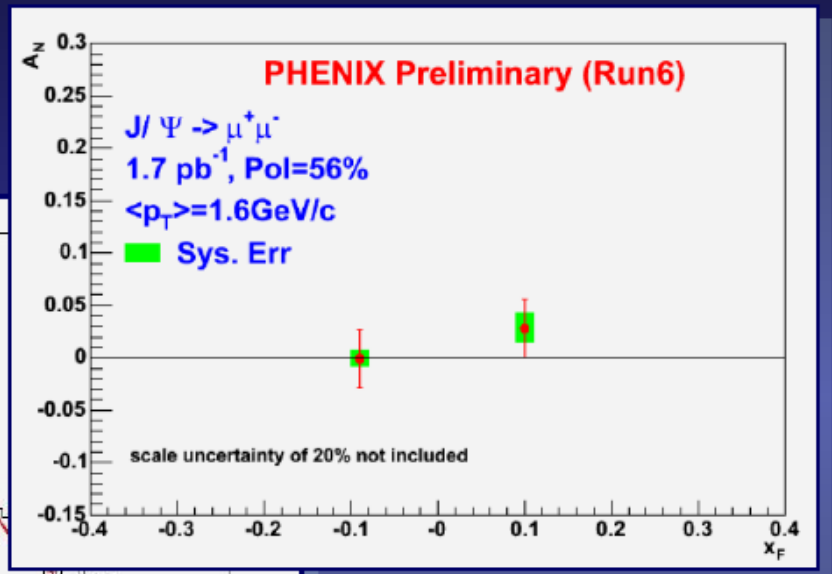
gluon dominance
minimized Collins
Sivers $\rightarrow A_N$

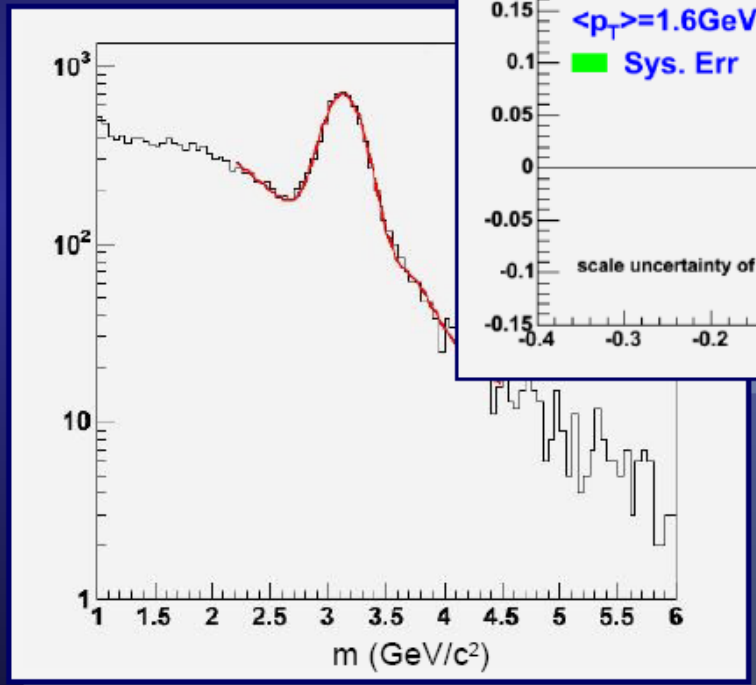
2005: 0.15 pb^{-1}

2006: 2.7 pb^{-1}

J/Ψ di-muon decay: muon spectrometers

- large rapidities
- full azimuth





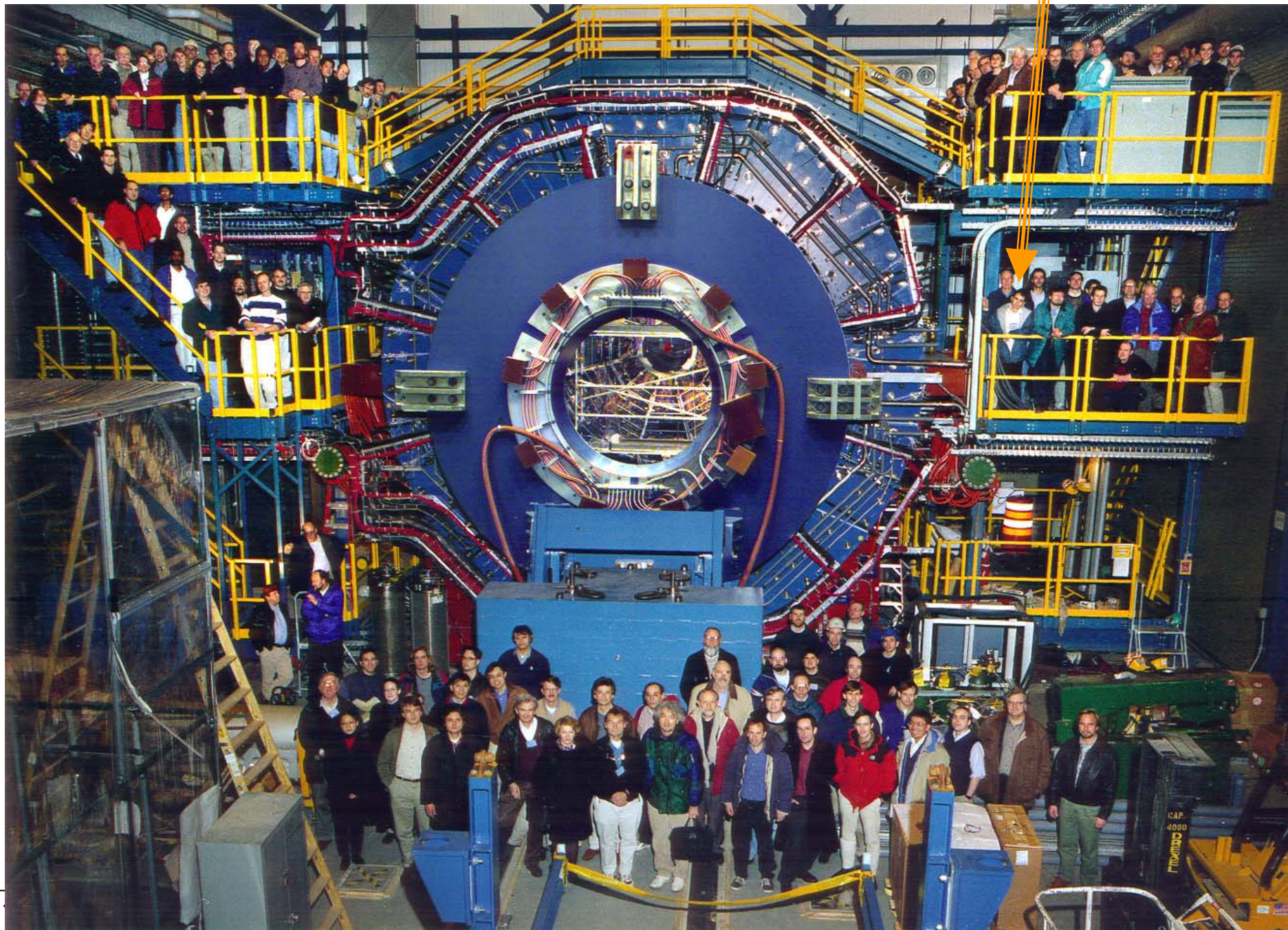
$$\frac{dN}{dM} = A \cdot e^{-K \cdot M} + N \cdot \frac{1}{2\pi\sqrt{\sigma}} e^{-\frac{(M-M_{J/\Psi})^2}{2\sigma^2}} + N' \cdot \frac{1}{2\pi\sqrt{\sigma}} e^{-\frac{(M-M_{\Psi'})^2}{2\sigma^2}}$$

bg. asymmetry:

- side-bands
- like-sign spectrum

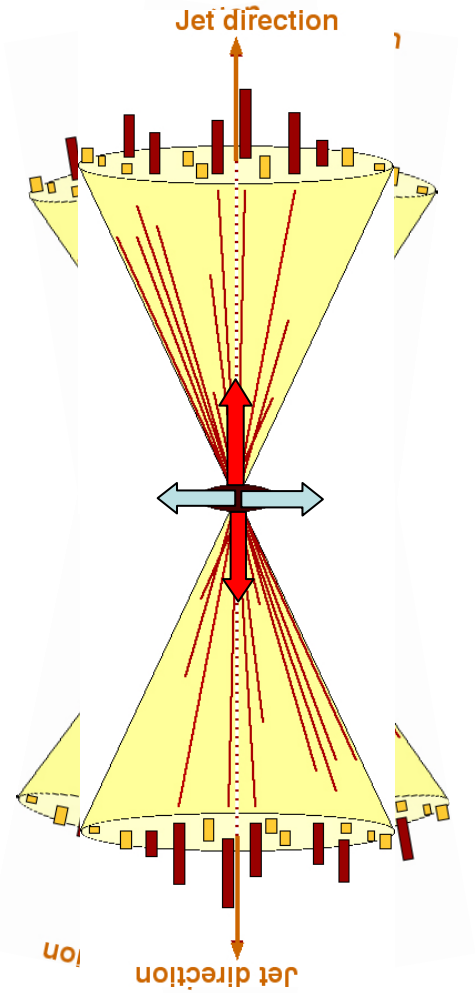
$$A_N^{J/\Psi} = \frac{A_N^{peak} - r A_N^{bg}}{1 - r}$$

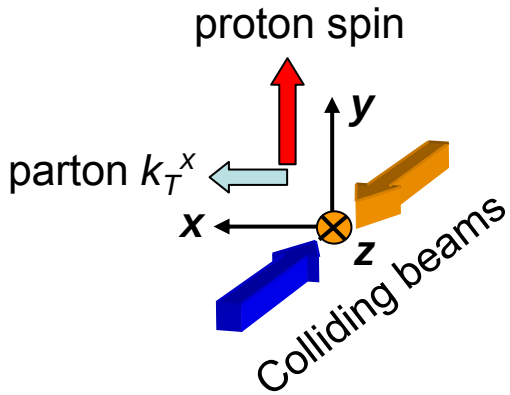
STAR



Motivation for pp → Di-Jet Measurement

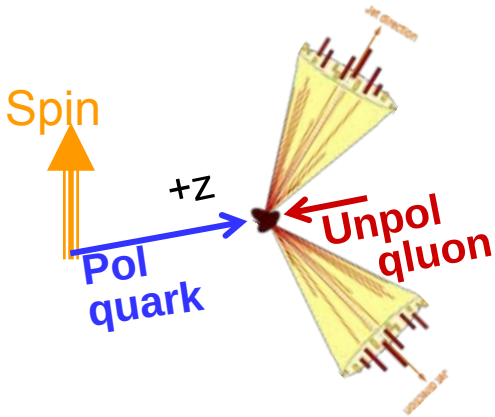
- *HERMES transverse spin SIDIS asymmetries ⇒ u and d quark Sivers functions of opposite sign, different magnitude.*
- *Sivers effect in pp ⇒ $\vec{s}$pin-dependent sideways boost to di-jets, suggested by Boer & Vogelsang (PRD 69, 094025 (2004))*
- *Both beams polarized, $x^{+z} \neq x^{-z} \Rightarrow$ can distinguish q vs. g Sivers effects.*
- *Do we observe q Sivers consistent with HERMES? Tests universality.*
- *First direct measurement of gluon Sivers effects.*

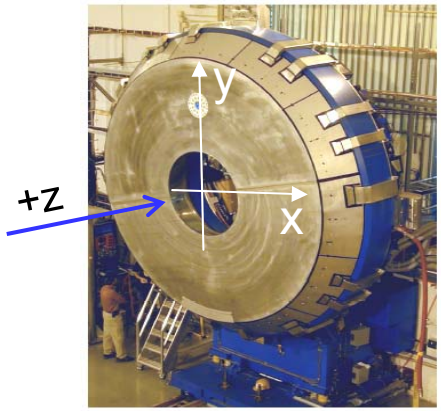




$$A_N \propto \vec{p} \cdot \left(\vec{k}^{\perp} \times \vec{S}_T \right)$$

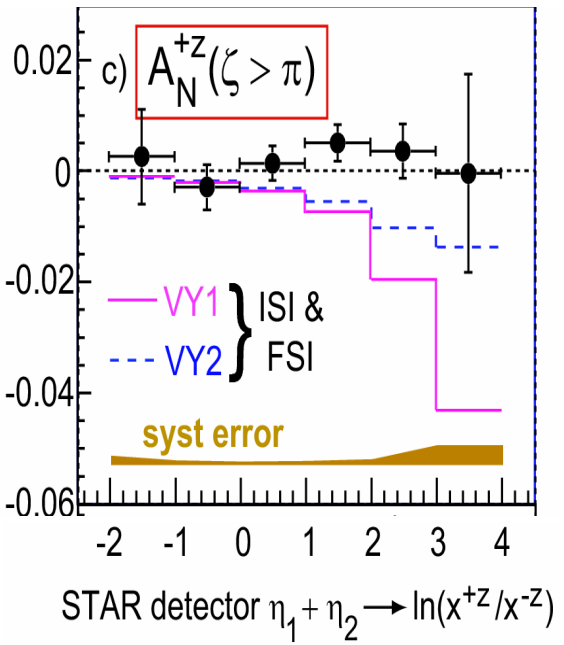
STAR Results vs. Di-Jet Pseudorapidity Sum

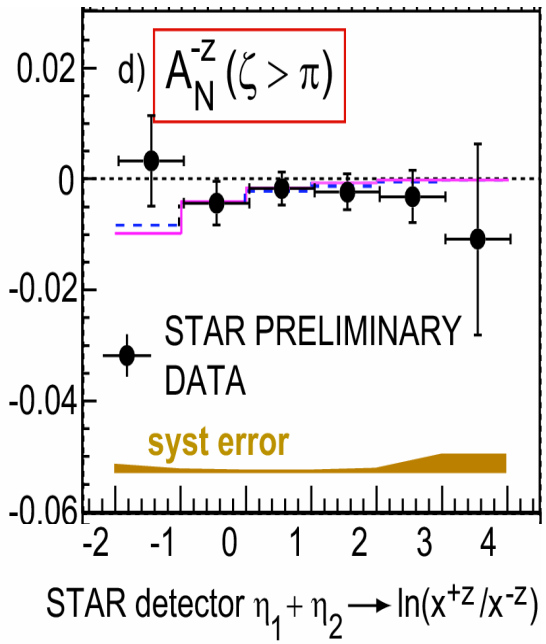




V&Y calcs. include:

- ***no hadronization***
- ***$5 < p_T^{parton} < 10$ GeV/c***
- ***STAR η acceptance***
- ***HERMES-fitted q Sivers***
- ***no gluon Sivers fcns.***





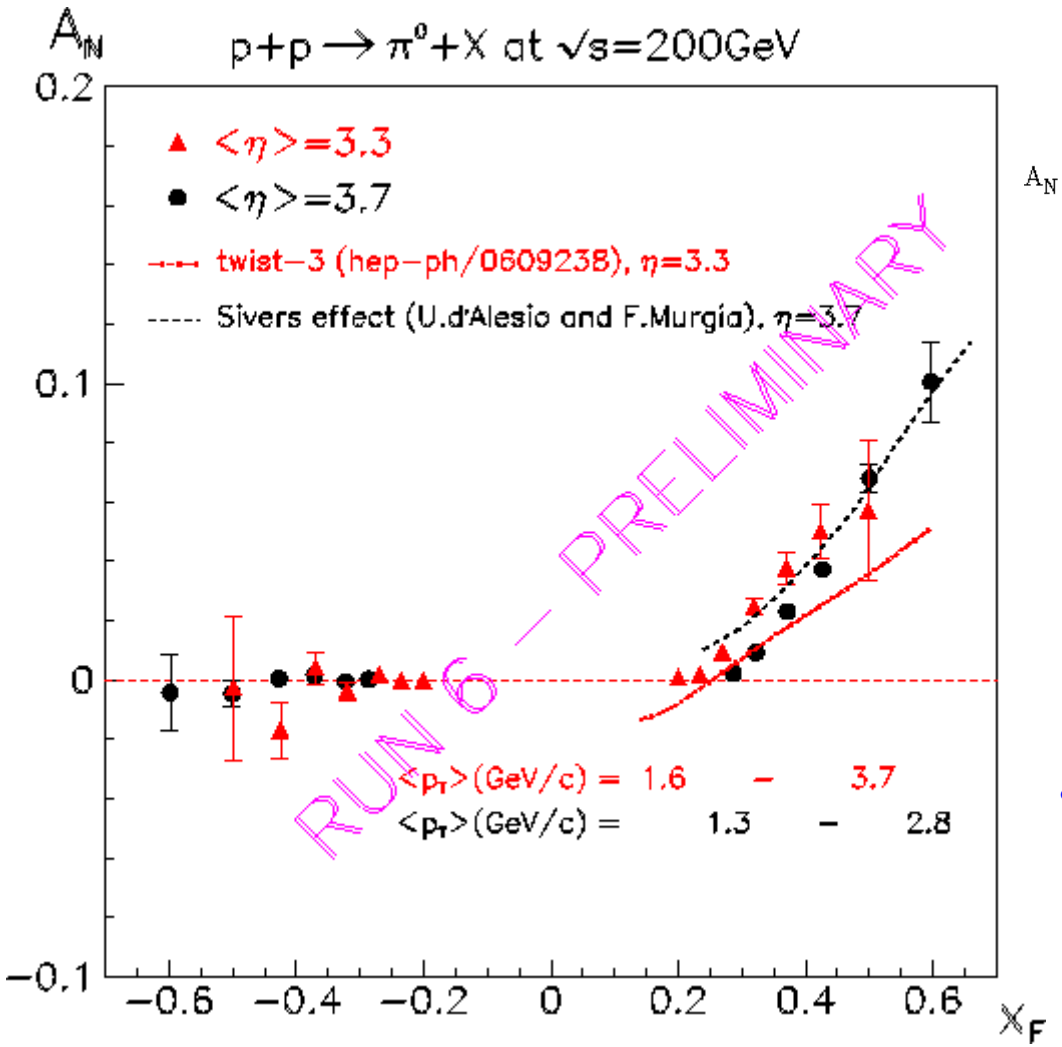
A_N consistent with zero

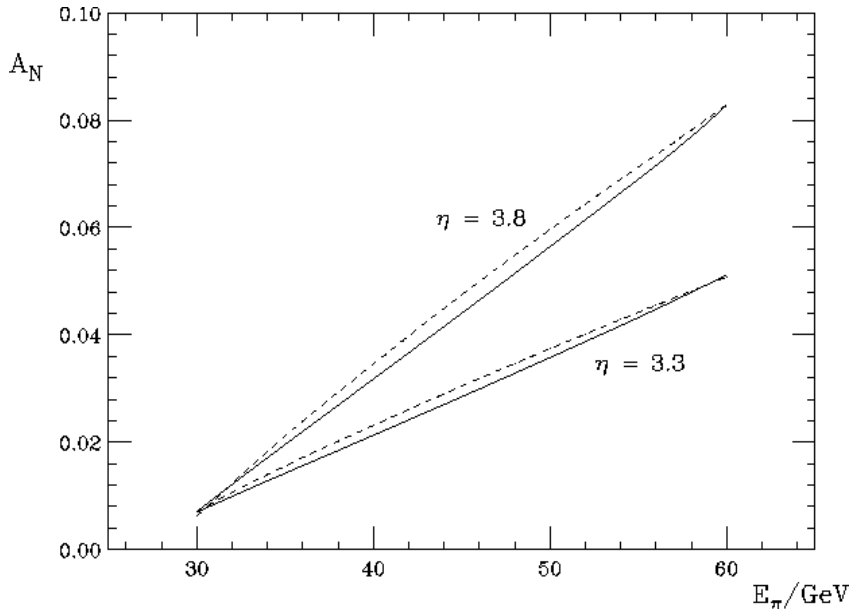
⇒both quark and gluon Sivers
⇒~order of magnitude smaller in pp → di-jets than in SIDIS quark Sivers asym.

hep-ex/0612036

STAR: Forward Pion Detector++

π^0 A_N at $\sqrt{s}$=200 GeV – x_F-dependence

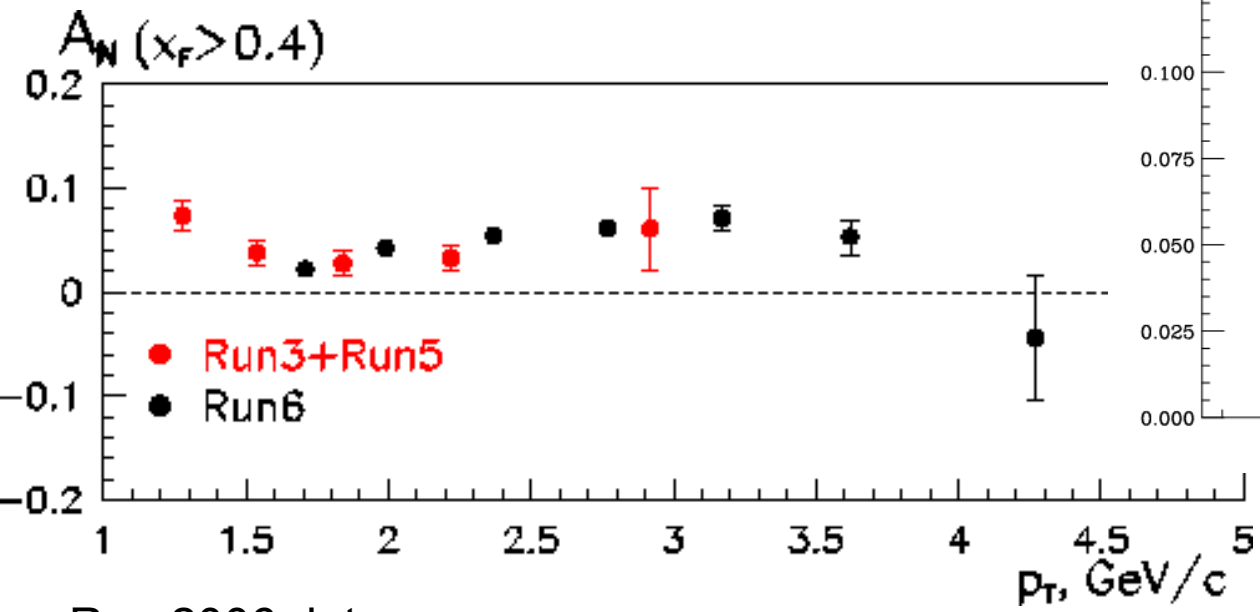


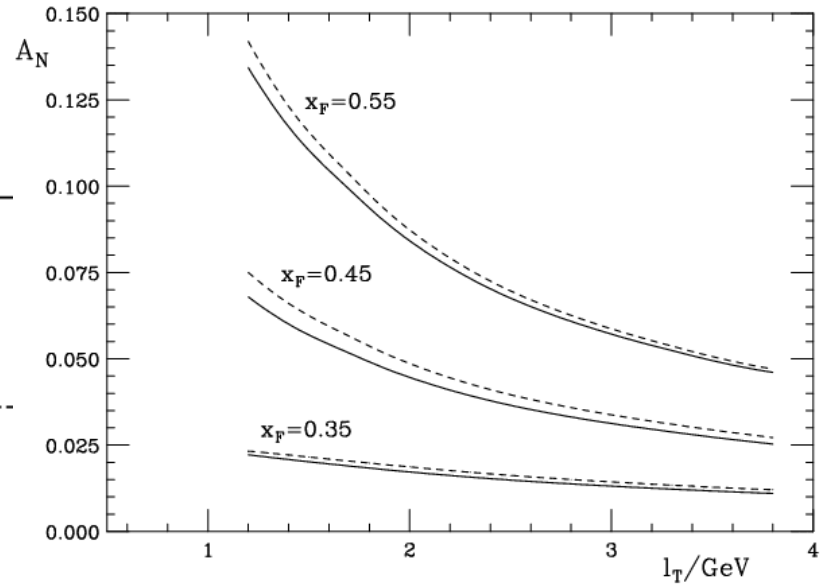


- Small errors of the data points allow quantitative comparison with theory predictions
  - Theory expects the reverse dependence on η

L.Nogach, SPIN06
hep-ex/0612030

STAR: Forward Pions $A_N(p_T)$ at $x_F > 0.4$





Run 2006 data:

- more precise measurements
- consistent with the previous runs in the overlapping p_T region
- jet-like events → can discriminate Collins and Sivers A_N

residual x_F-dependence?
→ $A_N(x_F,p_T)$ mapping in planed

L.Nogach, SPIN06
hep-ex/0612030

Summary

Transverse SSA Measured at RHIC

- Large A_N at forward rapidity (Brahms, STAR)
- Consistent w/ zero A_N at mid-rapidity (Phoenix, STAR)
  → related to Sivers A_N

Implication for theory

•Measured in p+p quark Sivers A_N differs from non-zero HERMES results for π^+ → universality of Sivers fcn.?

Recent theory development for p+p:

- **u & d-quark Sivers fcn cancel**
  Bomhof, Mulders, Vogelsang, Yuan, hep-ph/0701277
- **factorization is violated** for back-to-back hadrons
  Collins,Qiu, hep-ph/0705.2141

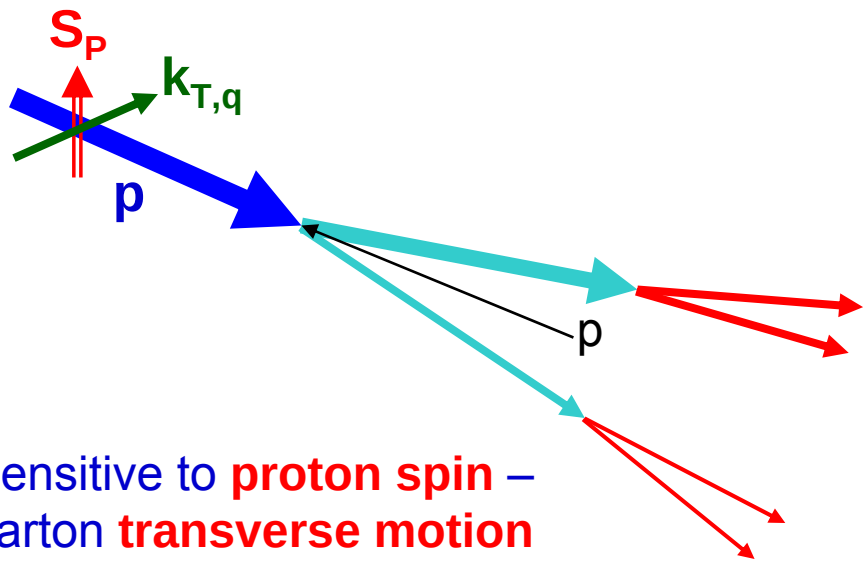
Future RHIC plans:

- jet back-to-back → Sivers fcn
- two hadrons correlations → Sivers and Collins→transversity

Backup

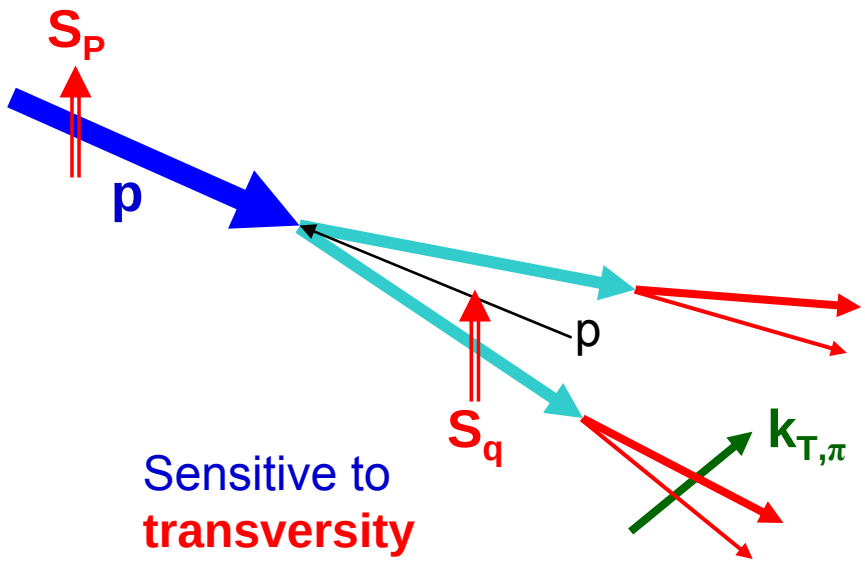
Separating Sivers and Collins effects

Sivers mechanism: asymmetry in the forward jet or γ production



Sensitive to **proton spin** – parton **transverse motion** correlations

Collins mechanism: asymmetry in the forward jet fragmentation

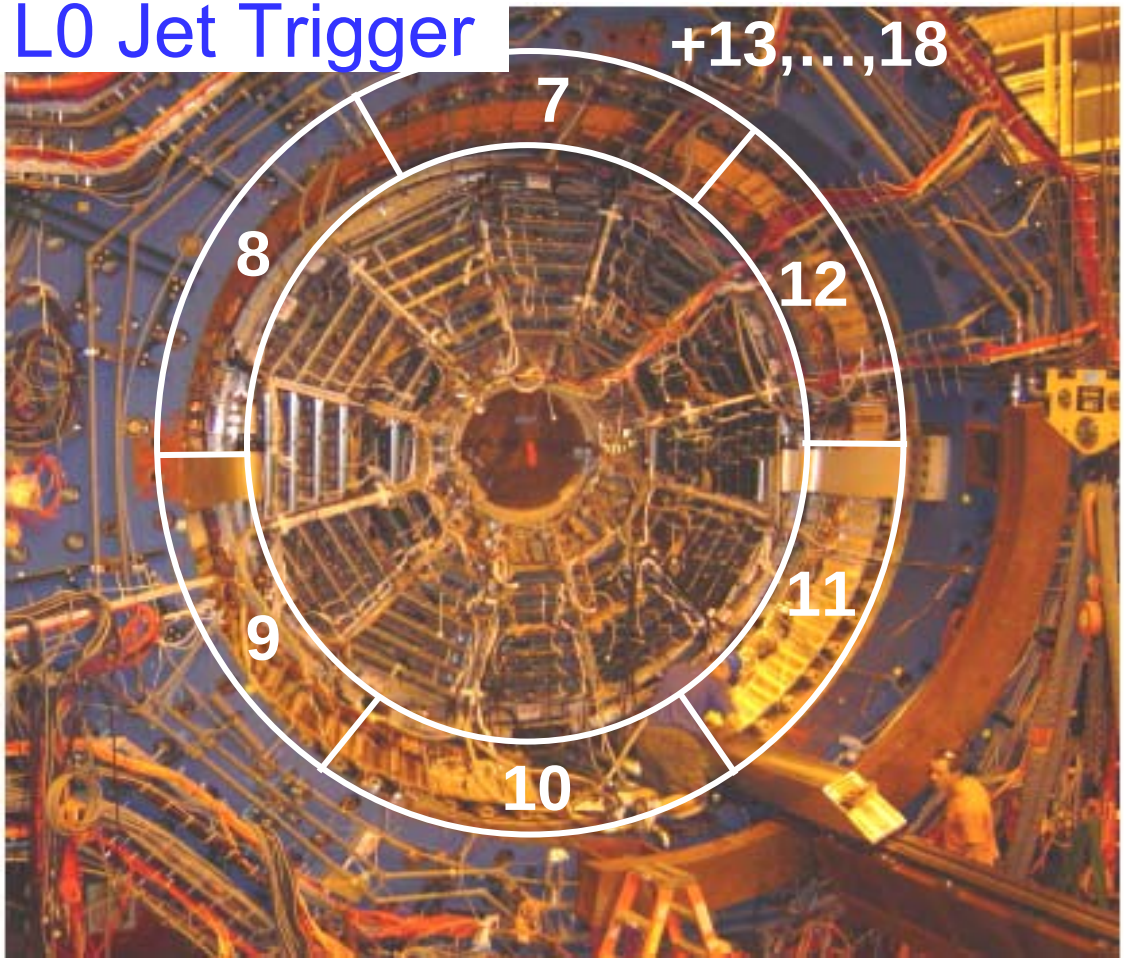


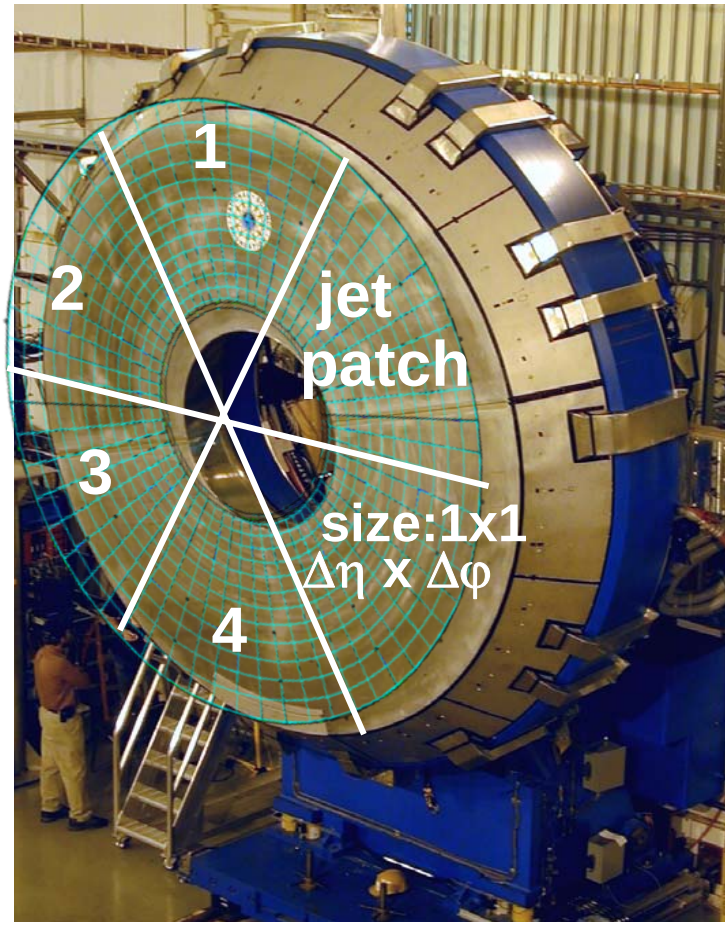
Sensitive to **transversity**

Need to go beyond π^0 detection to **jets** and **direct photons**

STAR

L0 Jet Trigger

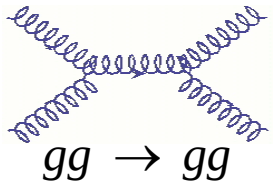


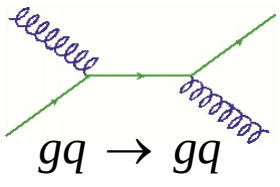


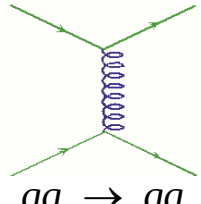
Luminosity $3*10^{31}/cm^2/s$

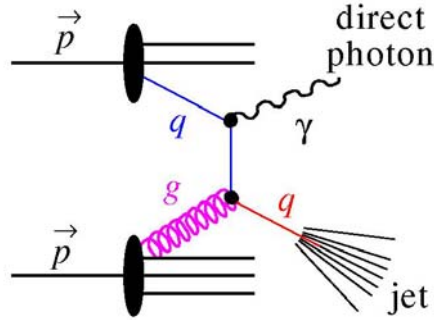
Di-Jet Rate to tape: 15 Hz

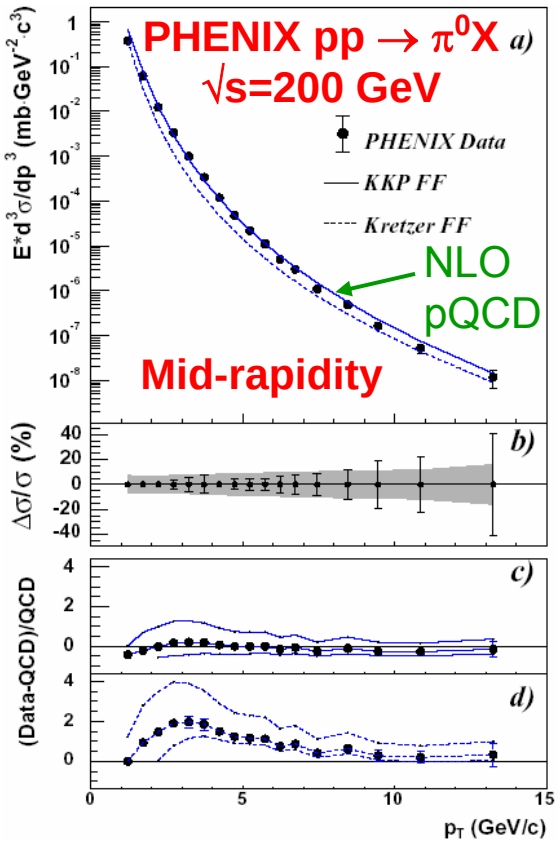
RHIC pp Absolute Cross Section Results at Mid-Rapidity…





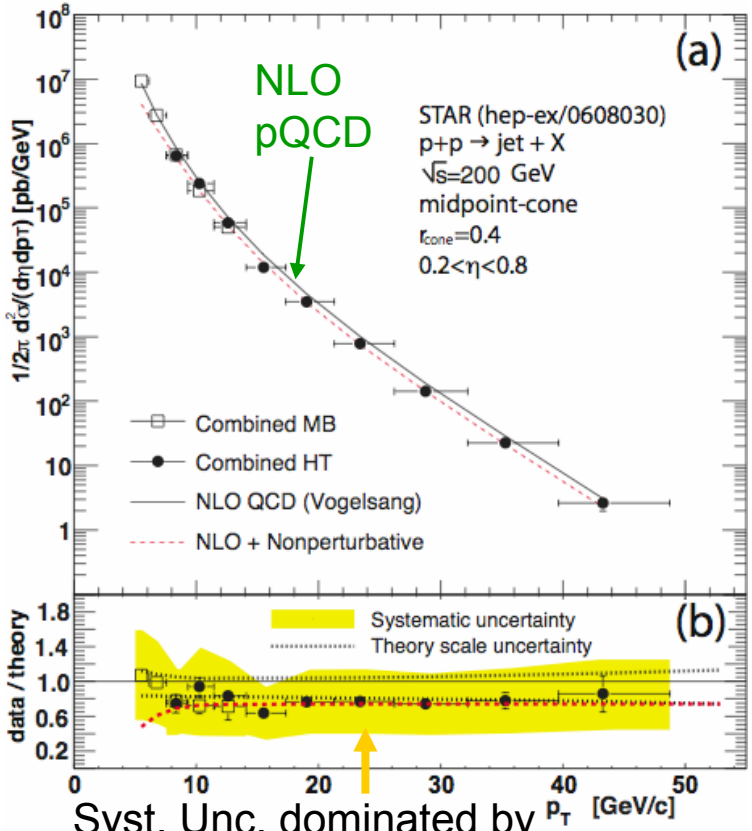






PRL 91, 241803 (2003)

STAR pp → jet+X, √s=200 GeV

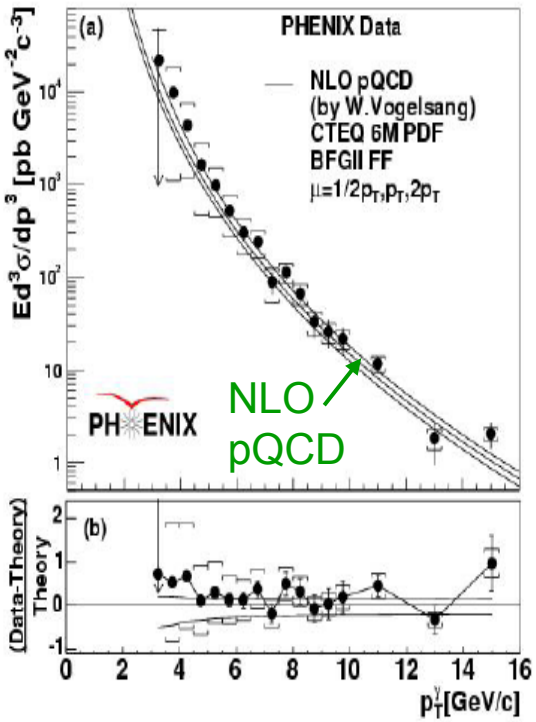


Syst. Unc. dominated by jet E scale uncertainty

PRL 98, 252001 (2006)

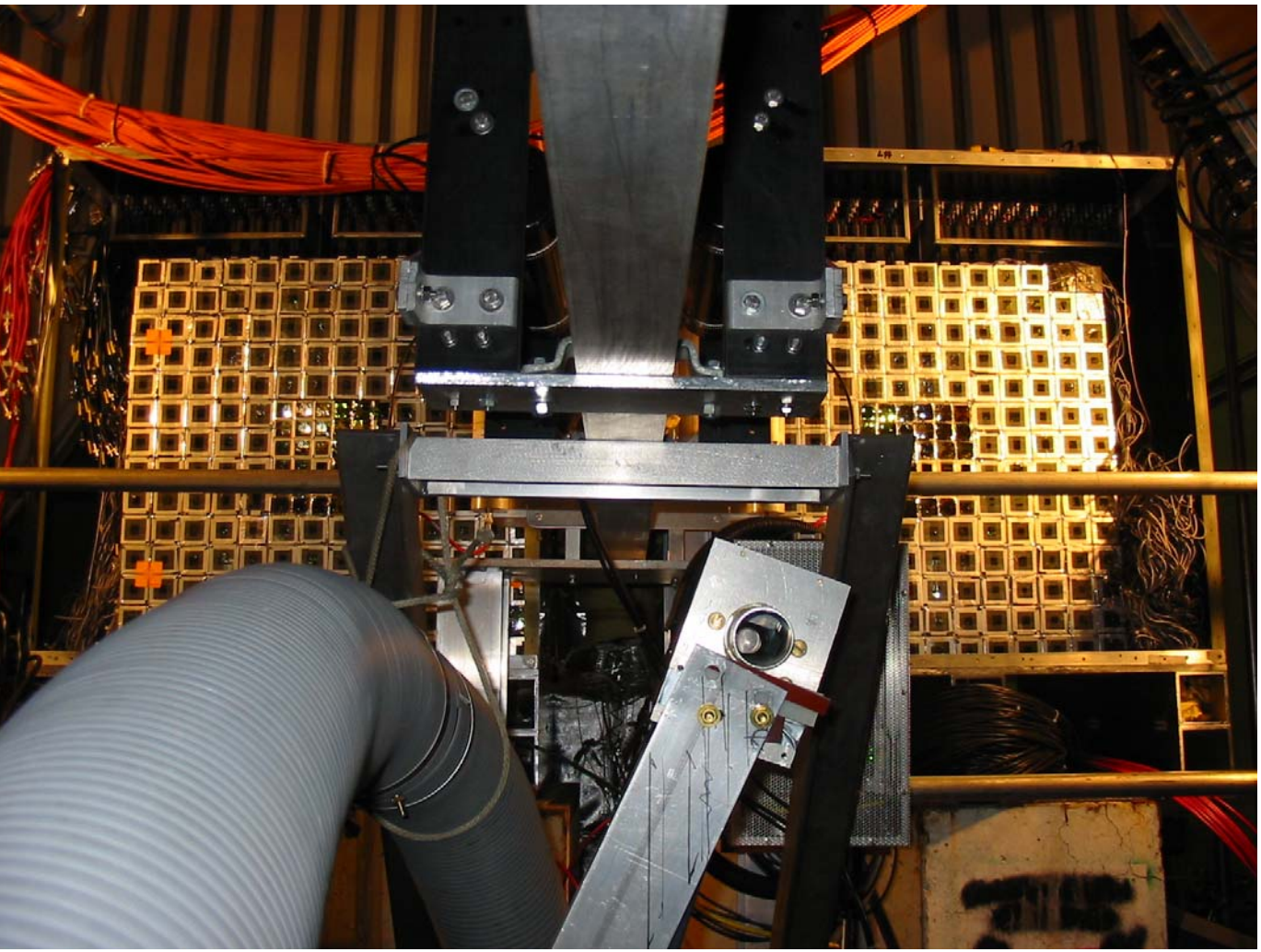
pp → γ X : PHENIX

√s = 200 GeV



PRL 98, 012002 (2007)

STAR: Forward Pion Detector ++



TPC: $-1.0 < \eta < 1.0$

FTPC: $2.8 < |\eta| < 3.8$

BBC : $2.2 < |\eta| < 5.0$

EEMC: $1 < \eta < 2$

BEMC: $-1 < \eta < 1$

FPD++/FPD:

$\eta \sim 3.3/-3.7$

FPD++: engineering test of the Forward Meson Spectrometer

L.Nogach, SPIN06

STAR $pp \rightarrow \pi^0 X$, $\sqrt{s}$=200 GeV High rapidity