STAR Results from Polarized Proton Collisions at RHIC

- Long-term goals
- Polarized protons in RHIC
- STAR
- Results from first polarized proton collisions
- Summary

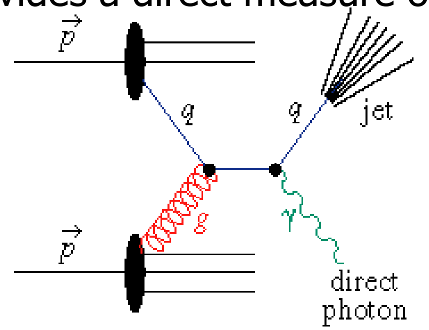
L.C. Bland, for the STAR collaboration
Brookhaven National Laboratory

Xth Workshop on High Energy Spin Physics
Dubna, September 16-20, 2003

STAR

Gluon Contribution to the proton's spin

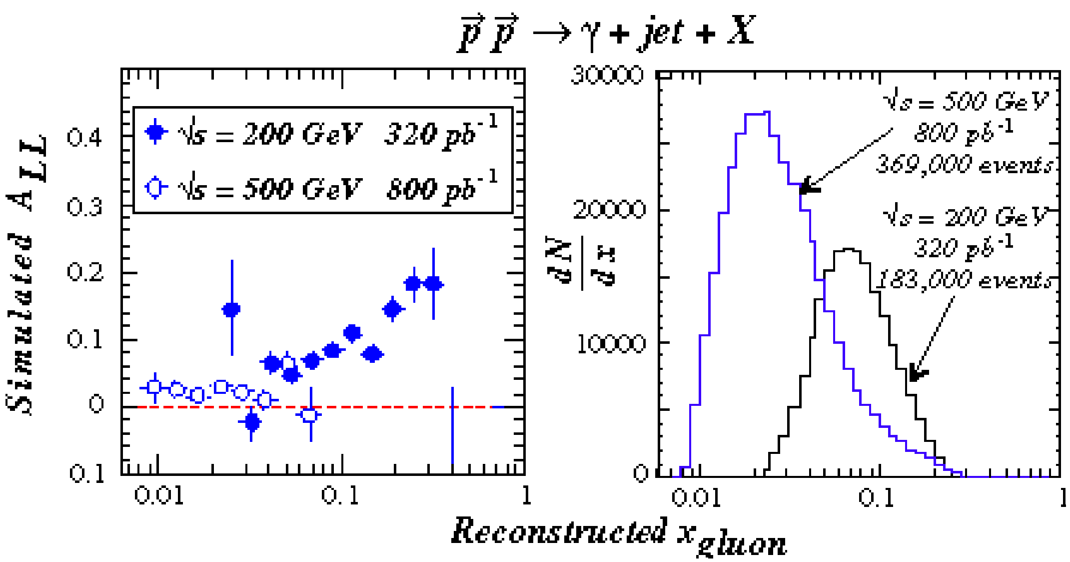
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$$\vec{p} + \vec{p} \rightarrow \gamma\,(+\,jet) + X$$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) with longitudinally polarized protons

$$P_{b1} P_{b2} A_{LL} = \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{b1(2)}$ — beam pol'n (~70%)

$N_{++(+-)}$ — equal (opposite) helicity yield

R — relative luminosity

Interpret measured asymmetry within leading-order pQCD

$$A_{LL} = \underbrace{P_{part.\,1}\, P_{part.\,2}}_{\text{parton pol'ns.}}\, \hat{a}_{LL} = \frac{\Delta f_1}{f_1}\frac{\Delta f_2}{f_2}\, \hat{a}_{LL}(\hat{s}, \hat{t}, \hat{u}) \xrightarrow{\text{QCD Compton}} \frac{\Delta G(x_g)}{G(x_g)}\, A_1^p(x_q)\, \hat{a}_{LL}$$

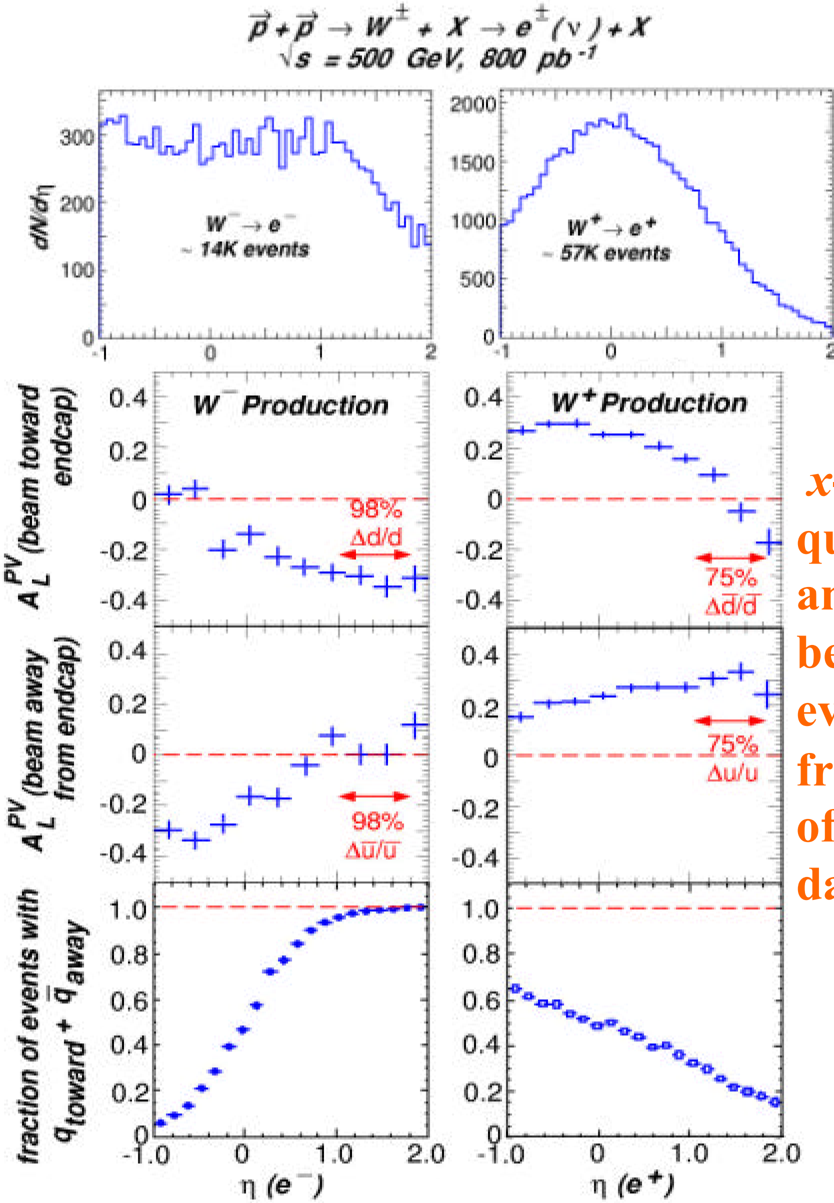
pol struct fncs. ($\Delta f_1, \Delta f_2$); unpol struct fncs. (f_1, f_2)

Measured in polarized deep-inelastic scattering ($A_1^p(x_q)$)

pQCD result for specific process ($\hat{a}_{LL}(\hat{s}, \hat{t}, \hat{u})$)

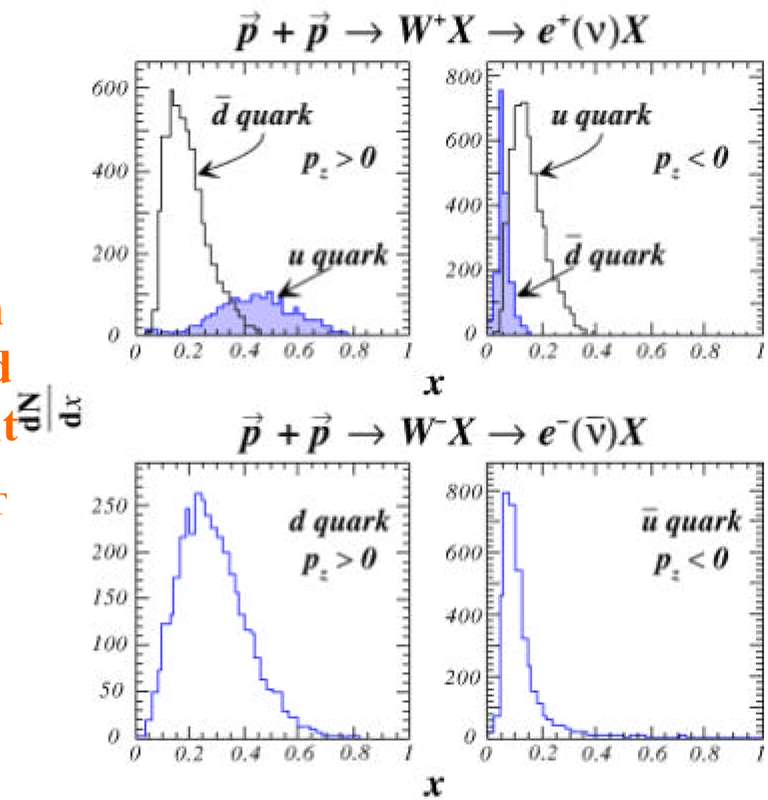
gluon polarization ($\Delta G(x_g)/G(x_g)$)

STAR Simulations of W Production



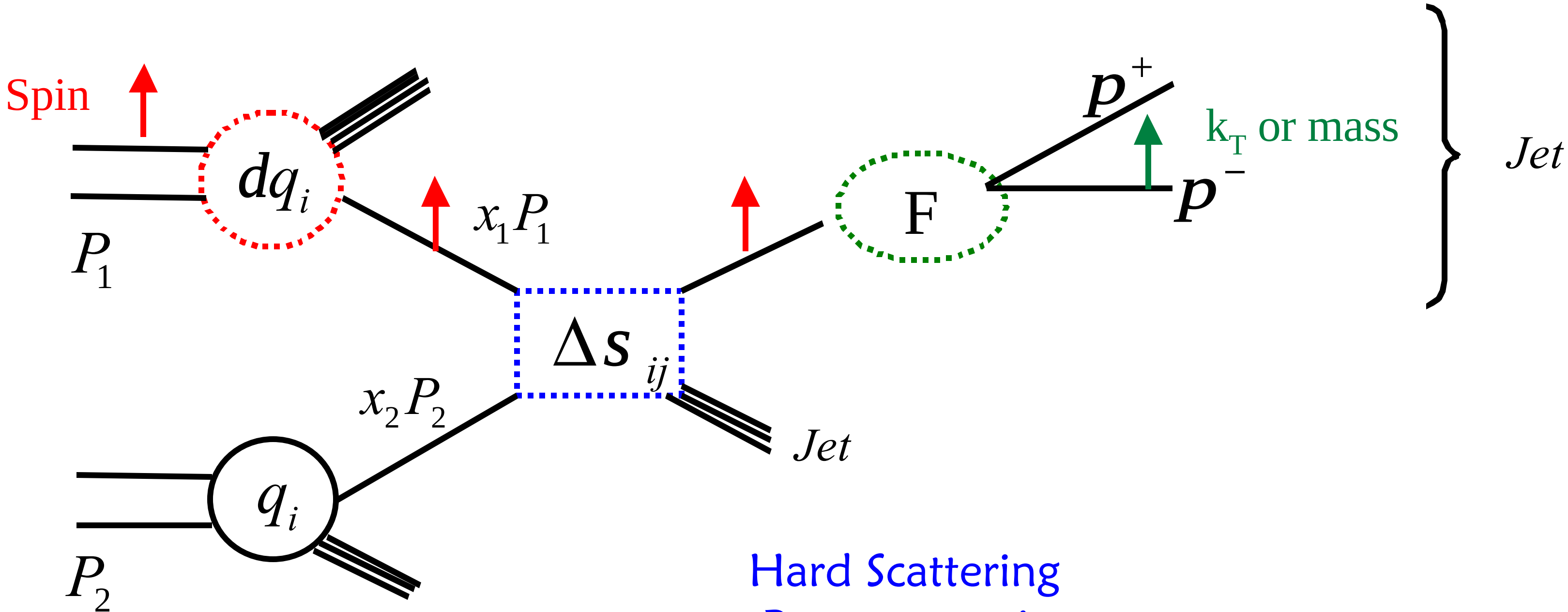
- ➢Different W^+ vs. W^- decay patterns Þ quite different h distributions for daughters
- ➢ Quark vs. antiquark polarization sensitivity are separated most cleanly for h > 1, especially for W^-

x-values of quark and antiquark can be determined event-by-event from h and p_T of detected daughter.



Transversity at STAR

using spin dependent jet Fragmentation Function(FF)



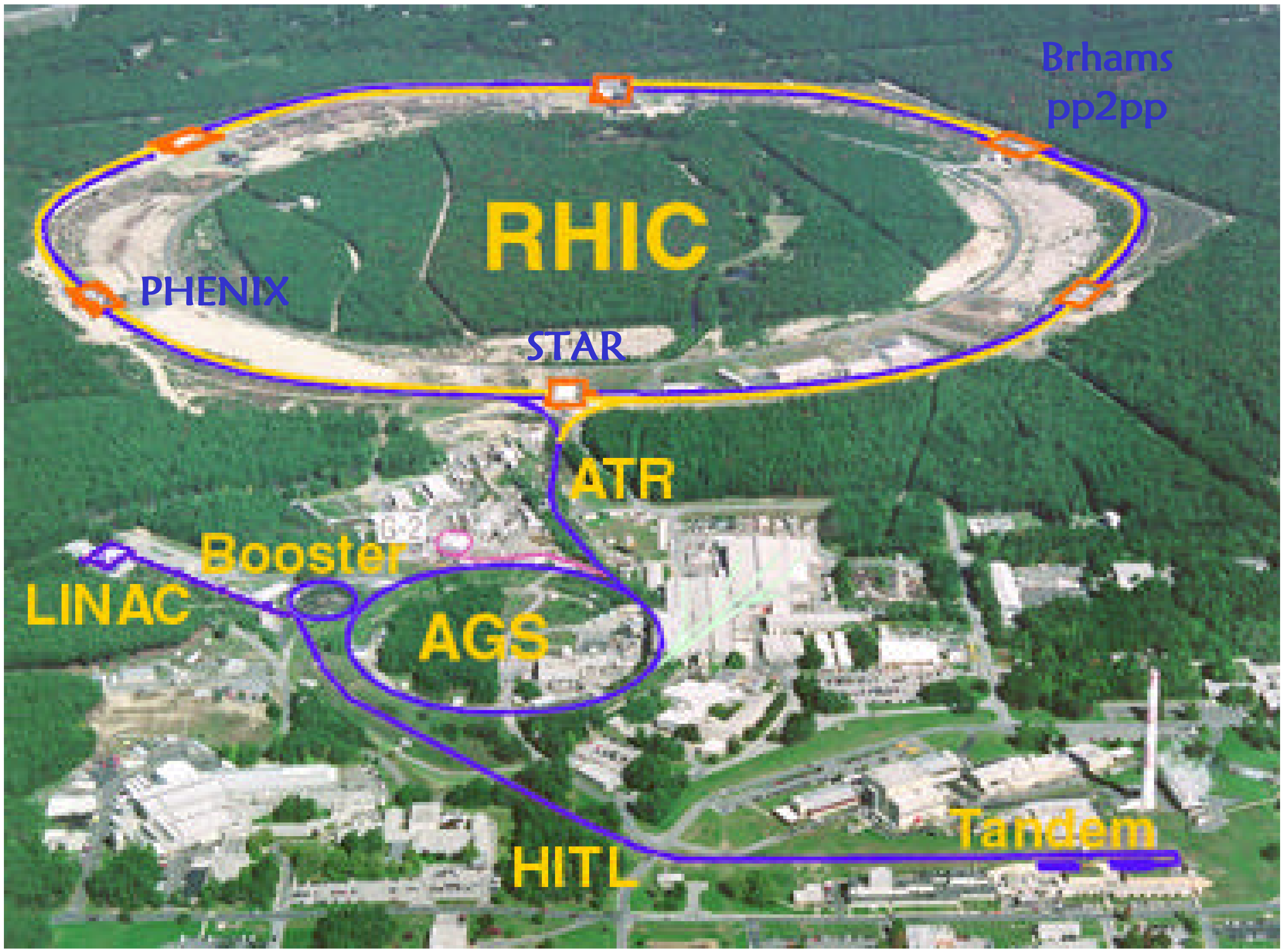
$$\frac{d^6\sigma_H\left(pp^{\uparrow}\rightarrow\pi^+\pi^-X\right)}{dx_1dx_2dtdzdm^2d\phi}\propto \delta q(x_1)\cdot q(x_2)\cdot\frac{d^3\sigma(q_1q_2\rightarrow q_3q_4)}{dx_1dx_2dt}\cdot\frac{d^3F}{dzdm^2d\phi}$$

Transversity

Hard Scattering Process xsection

Collins- Heppelmann FF
or
2 pion Interference FF

The **R**elativistic **H**eavy **I**on **C**ollider
at Brookhaven National Laboratory



R-HI

New state of matter

QGP

De-confinement

…

polarized proton

Nucleon Spin Structure

Spin Fragmentation

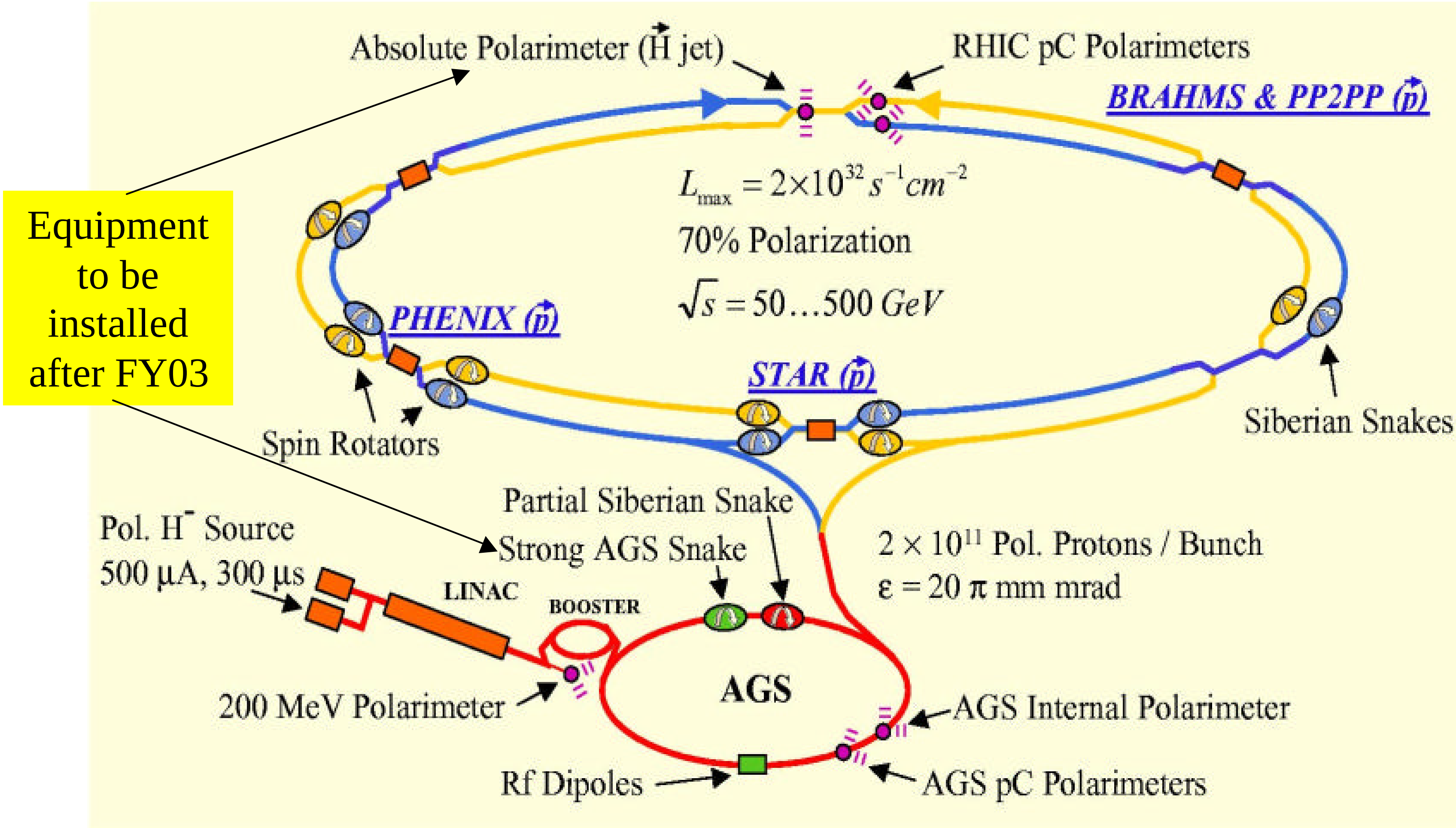
pQCD

…

RHIC is a QCD lab

BROOKHAVEN NATIONAL LABORATORY

Polarized Proton Operation at RHIC



Equipment/developments for runs 2 (1/02) and 3 (3/03 → 5/03)…

- Helical dipole snake magnets
- CNI polarimeters in RHIC,AGS
  → fast feedback
- β*=1m operataion
- spin rotators → longitudinal polarization

What is required for a spin experiment at RHIC?

(a summary of the multiple concurrent experiments)

Run 2 (12/01→1/02) Run 3 (3/03→5/03)

Stages of the RHIC-spin Project

Concept → Learning → Production

- Production of high-energy/intensity/polarization proton bunches that collide
  ⇒ A successful accelerator physics experiment employing 'snakes',rotators,etc.
  Rarest probes require P_{beam}=70% and $\int \mathcal{L}\, dt$ = 320(800) pb^{-1} at $\sqrt{s}$ = 200(500) GeV

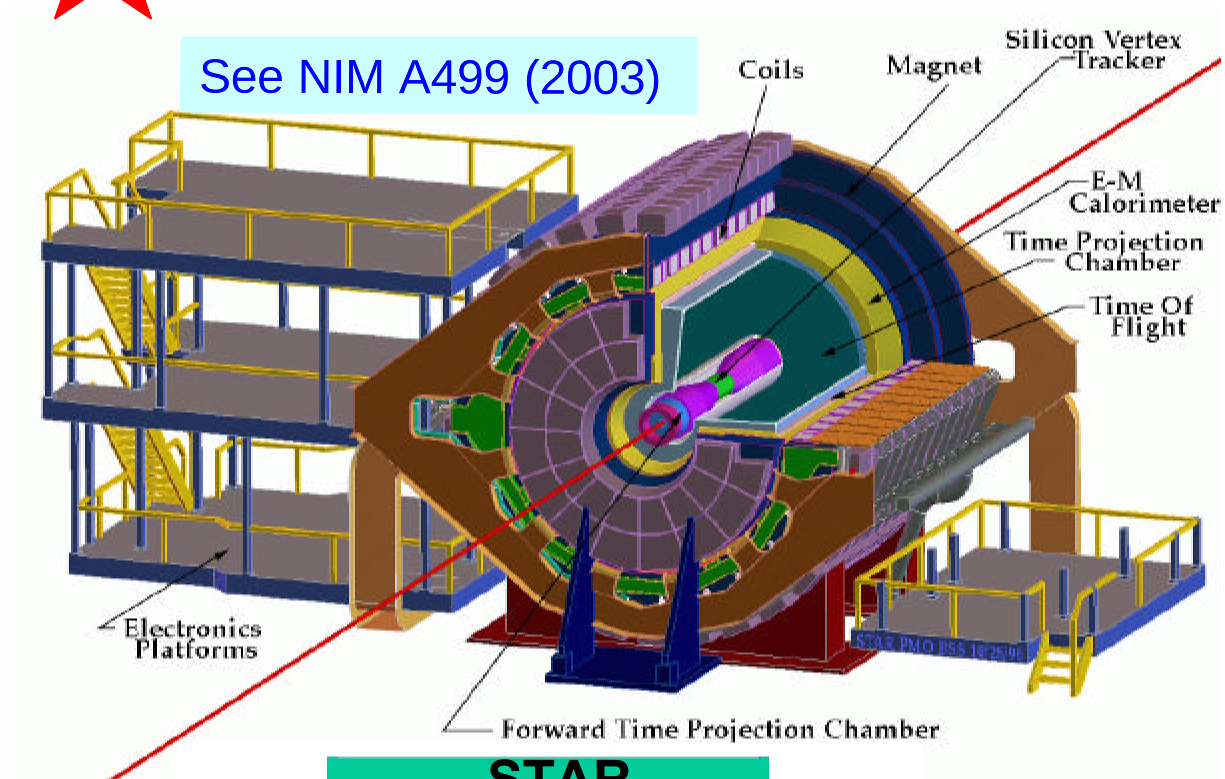
- Large experimental facilities capable of detecting hadrons/jets, γ, $e^{\pm}$,$\mu^{\pm}$ …
  ⇒ Experimental sophistication comparable to other colliders (Tevatron, HERA,…)

- Polarimeters to monitor polarization and establish its absolute magnitude
  ⇒ Coulomb-nuclear interference / polarized gas jet target / local polarimeters
  Require ΔP_{beam} / P_{beam} ~ 5%

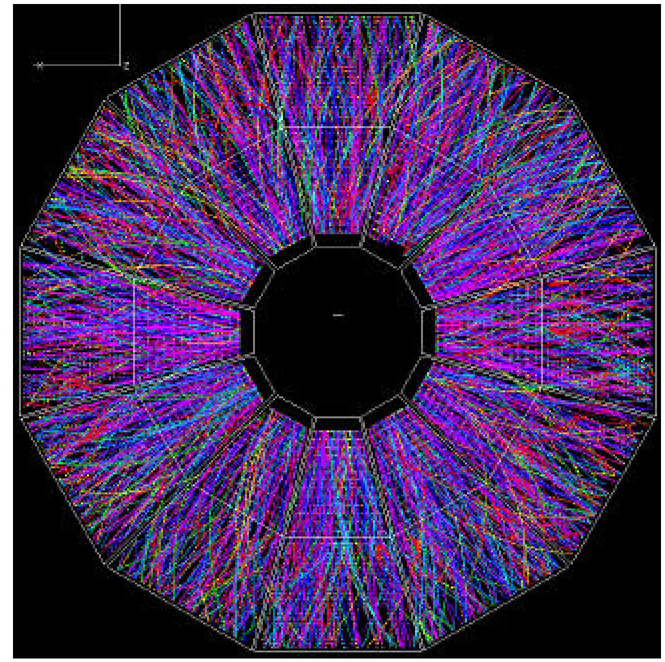
- Interaction-region monitors of spin-dependent relative luminosity
  ⇒ Precision experiments to minimize systematic errors in final answer

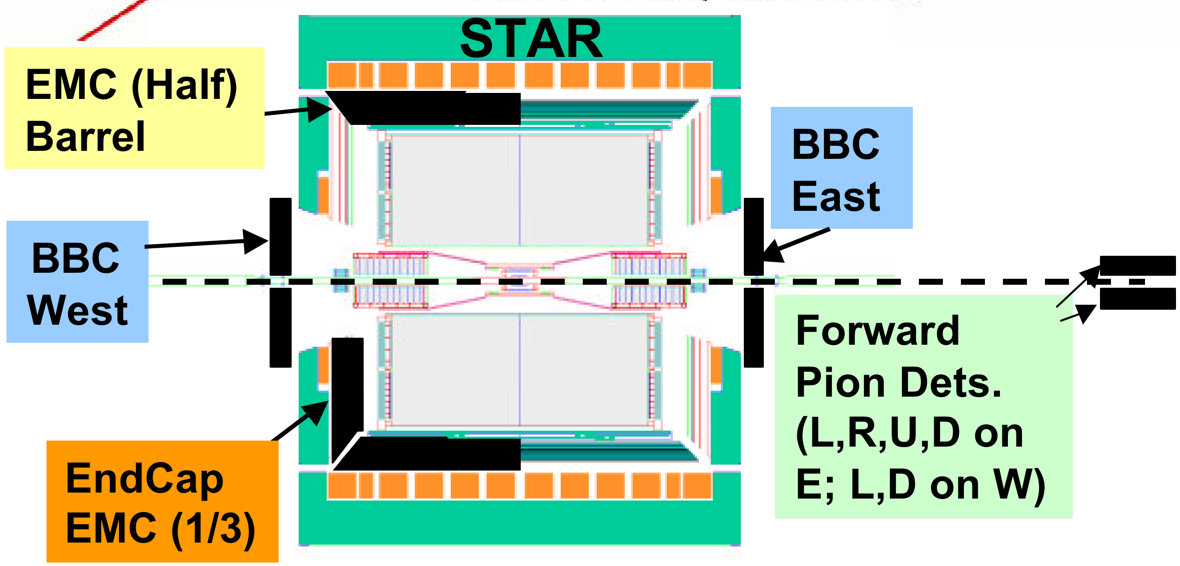
BROOKHAVEN NATIONAL LABORATORY

STAR Upgrades for Spin



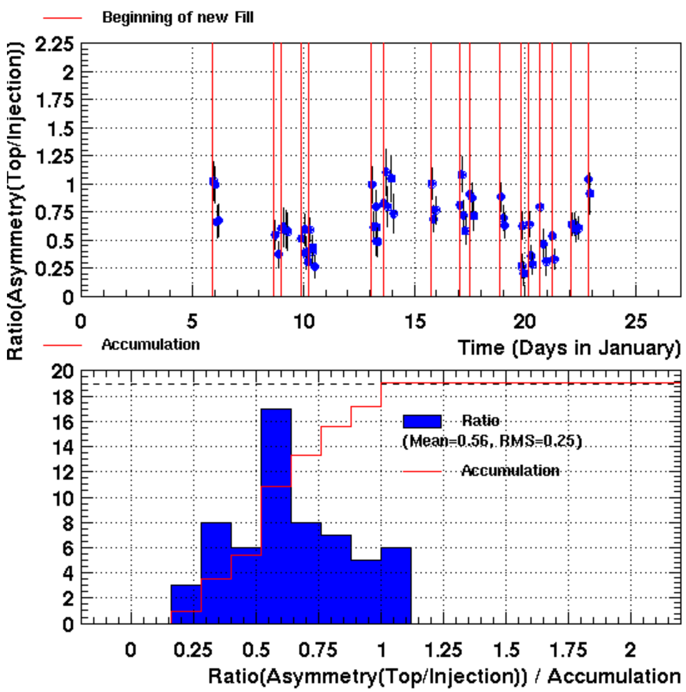
STAR Au+Au, $\sqrt{s_{NN}}$ = 200 GeV



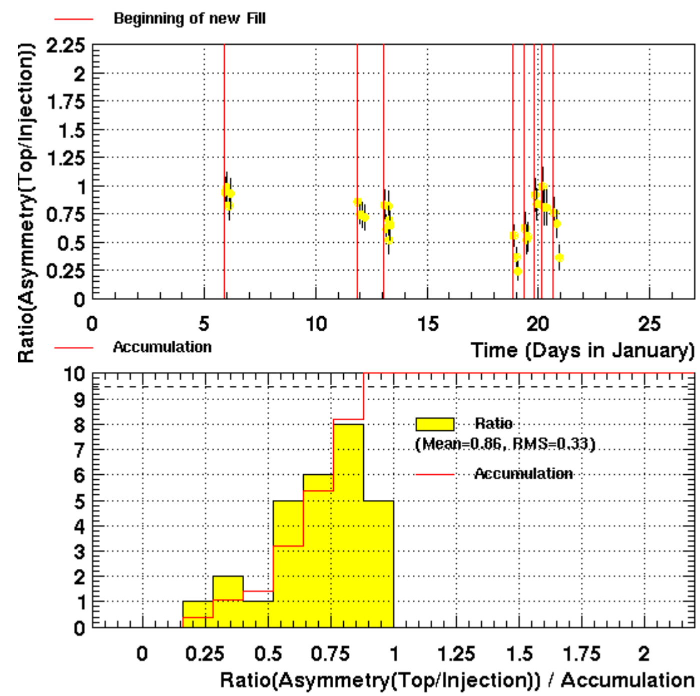


STAR adding lots of EM calorimetry to detect high-energy g, $e^{\pm}$, p^{0} plus Beam-Beam Counters for relative luminosity and polarization monitoring. EMC's and FPD's partially implemented for 2003 run, will be completed before 2005.

Run 2 Progress / Results



Siberian Snakes work to preserve polarization through acceleration and store.

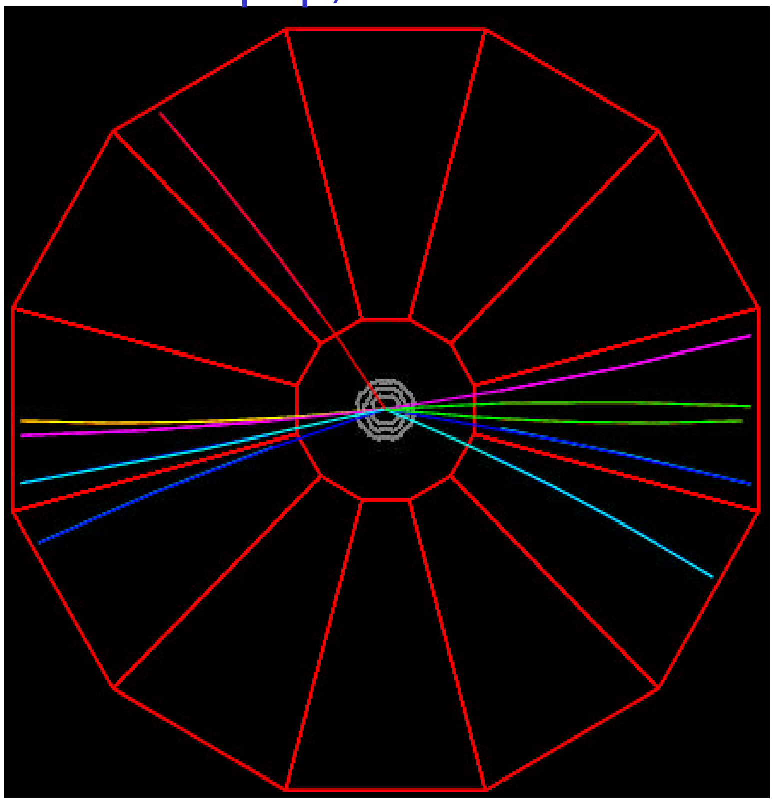


- $\int \mathcal{L}\, dt$ ~350 nb^{-1} and $\langle P_{beam} \rangle$ ~ 18% (Yellow) / 15% (Blue) delivered to experiments. Polarization limited by performance of AGS.
- STAR / PHENIX / pp2pp experiments commissioned for *pp* collisions at $\sqrt{s}$ = 200 GeV.
- Critical *pp* reference measurements for heavy-ion program completed providing important physics results.
- Transverse single-spin measurements completed providing physics results + local polarimeters for spin-rotator tuning in Run 3.

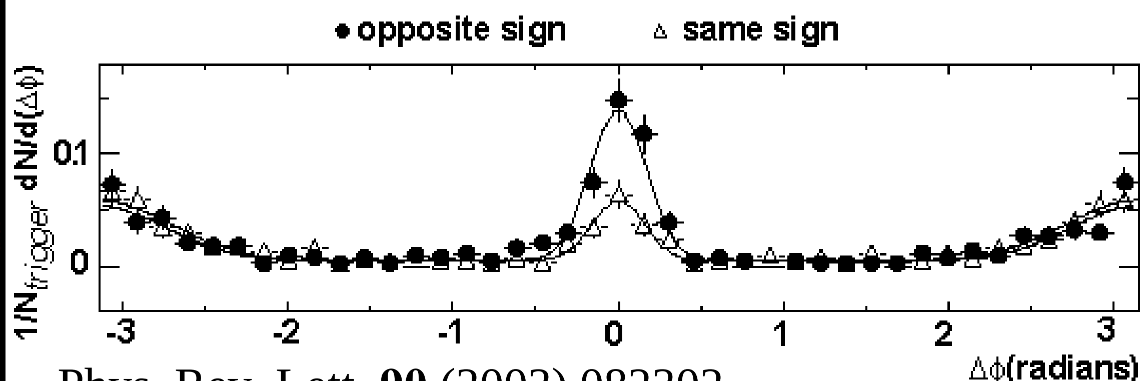
BROOKHAVEN NATIONAL LABORATORY

Di-jet Reference for Heavy-Ion Physics
(jet physics is central to spin program)

STAR p+p, $\sqrt{s}$ = 200 GeV



Hadronic high-p_T azimuthal correlations in *pp* collisions



Phys. Rev. Lett. **90** (2003) 082302

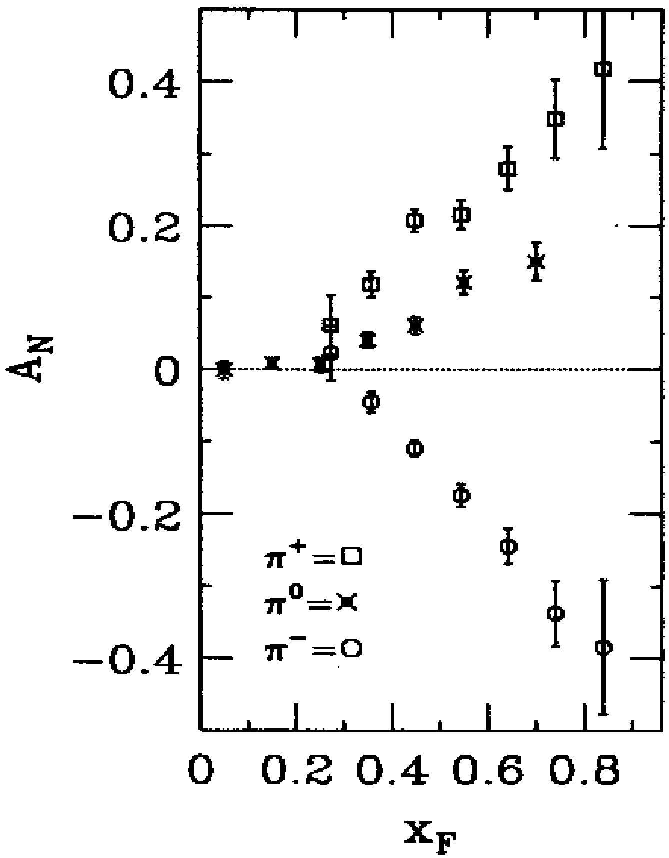
• di-jet events clearly observed in *pp* collisions at $\sqrt{s}$ = 200 GeV.

• di-hadrons serve as di-jet surrogates for heavy-ion collisions.

• clear near-side and away-side di-hadron correlations in *pp* collisions serve as contrast for central AuAu collisions where away-side correlations are strongly suppressed.

Spin asymmetries in π^0 production: $p_{\uparrow} + p \rightarrow \pi + X$

Non-zero A_N measured in E704 at Fermilab at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:

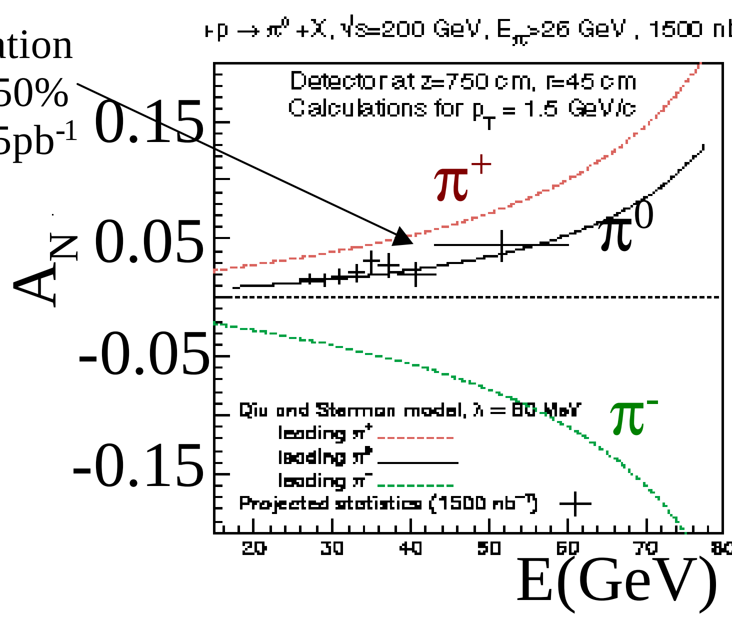


π^0 - D.L. Adams, et al., Phys. Lett. B261(1991)201.

$\pi^{+/-}$ - D.L. Adams, et al., Phys. Lett. B264(1991)462.

Predictions by different theorists expect non-zero A_N values, attributed to different dynamics, to persist at RHIC energies: $\sqrt{s}$=200 GeV...

Simulation w/P_b=50% and 1.5pb^{-1}



Qiu and Sterman, Phys. Rev. D59 (1998) 014004.

See also:

Anselmino, et al., Phys. Lett. B442 (1998) 470.; Anselmino, et al., PRD 60 (1999) 054027.

...Non-zero analyzing power expected to persist up to RHIC collision energies...

STAR Forward π^0 Detector

24 layer Pb-scintillator sampling calorimeter

2 orthogonal planes of finely segmented triangular scintillator strips (Shower-Maximum Detector, or SMD)

2 Preshower layers

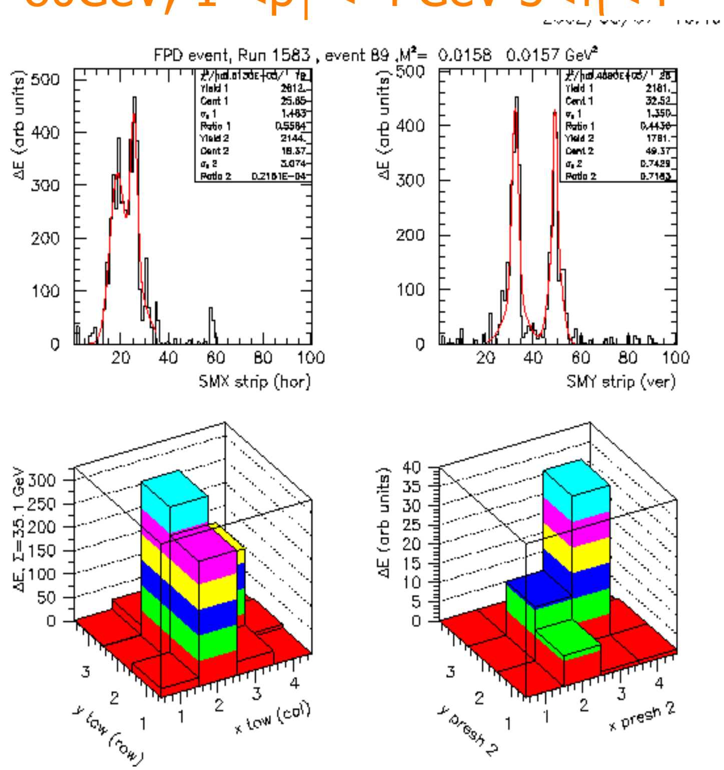
π^0 reconstruction at

$E=20\sim80$GeV, $1 < p_T < 4$ GeV $3<\eta<4$

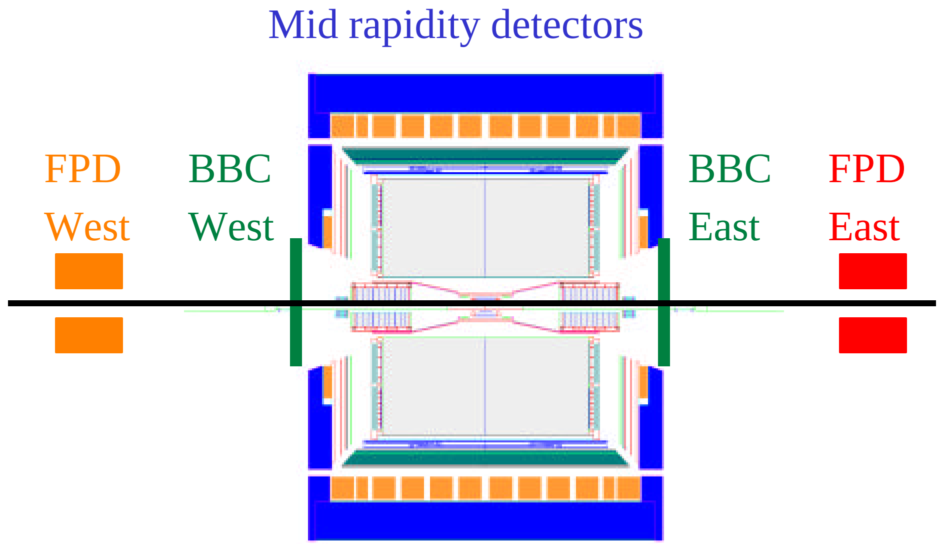
Event Display

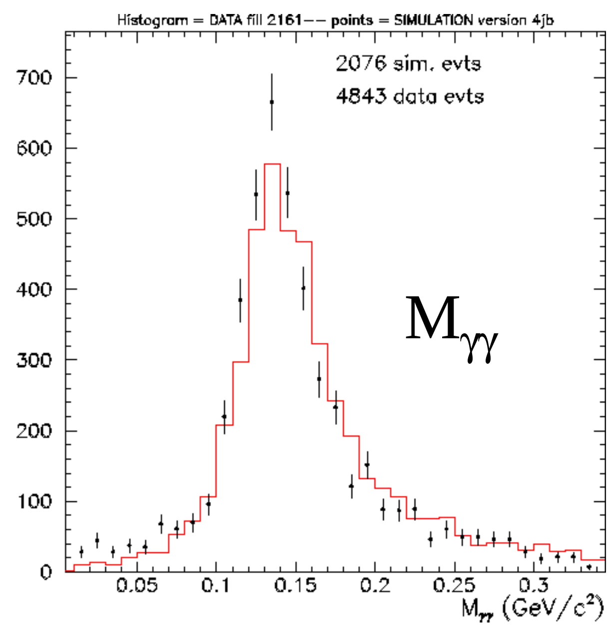
SMD

EMC



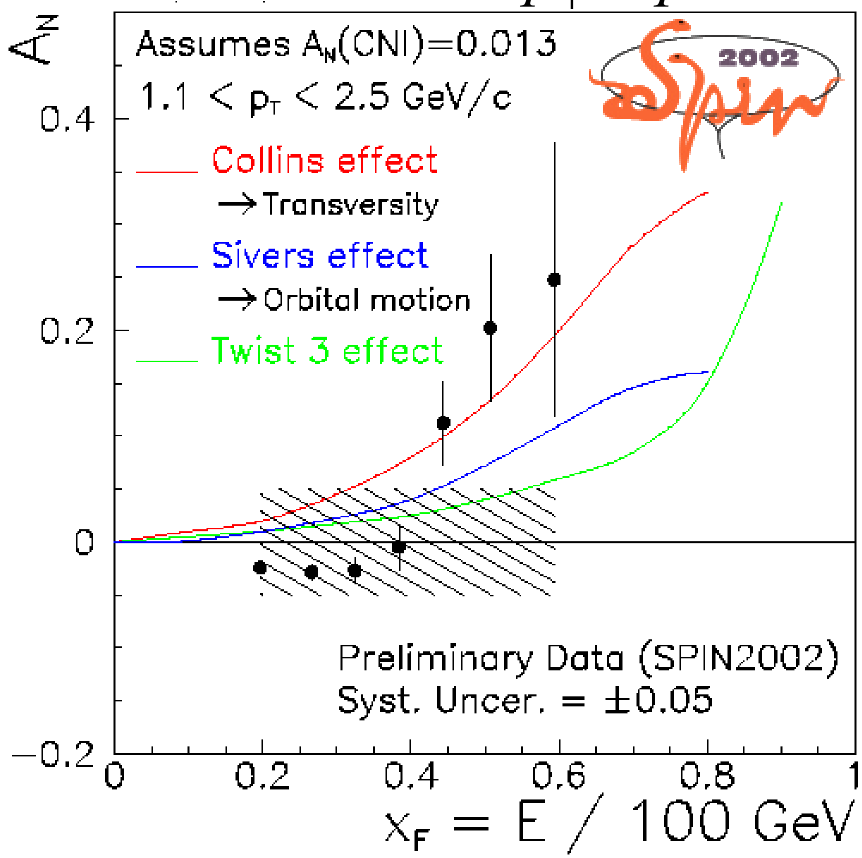
Located east of STAR detector at z=750cm

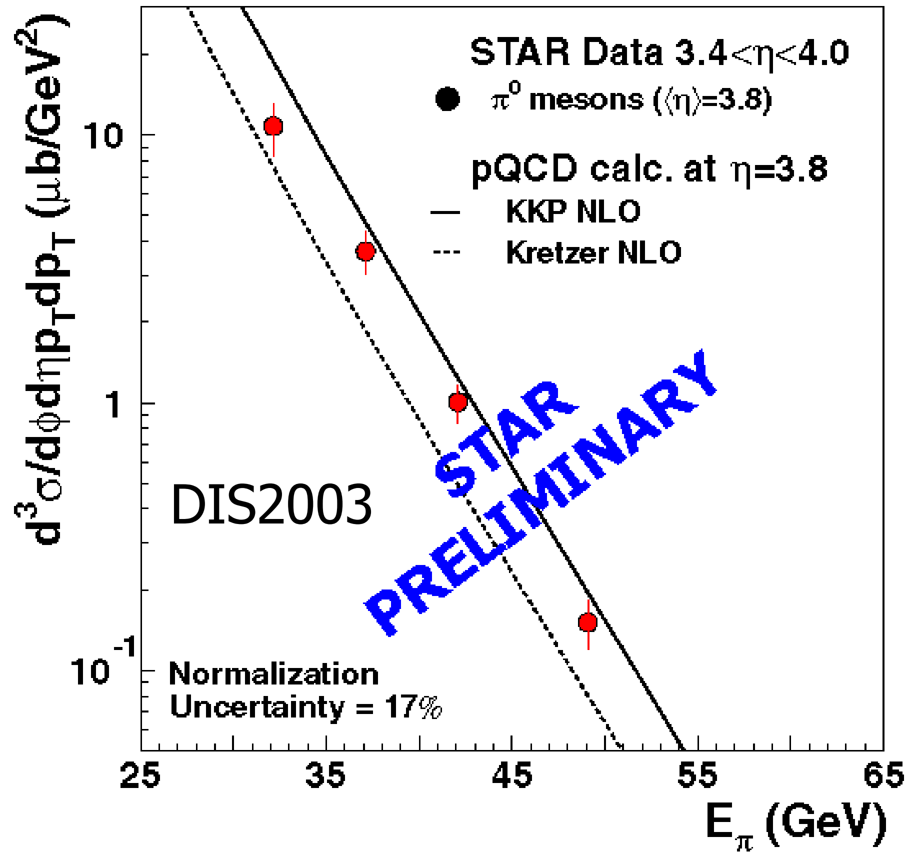




STAR-Spin Results from Run 2

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



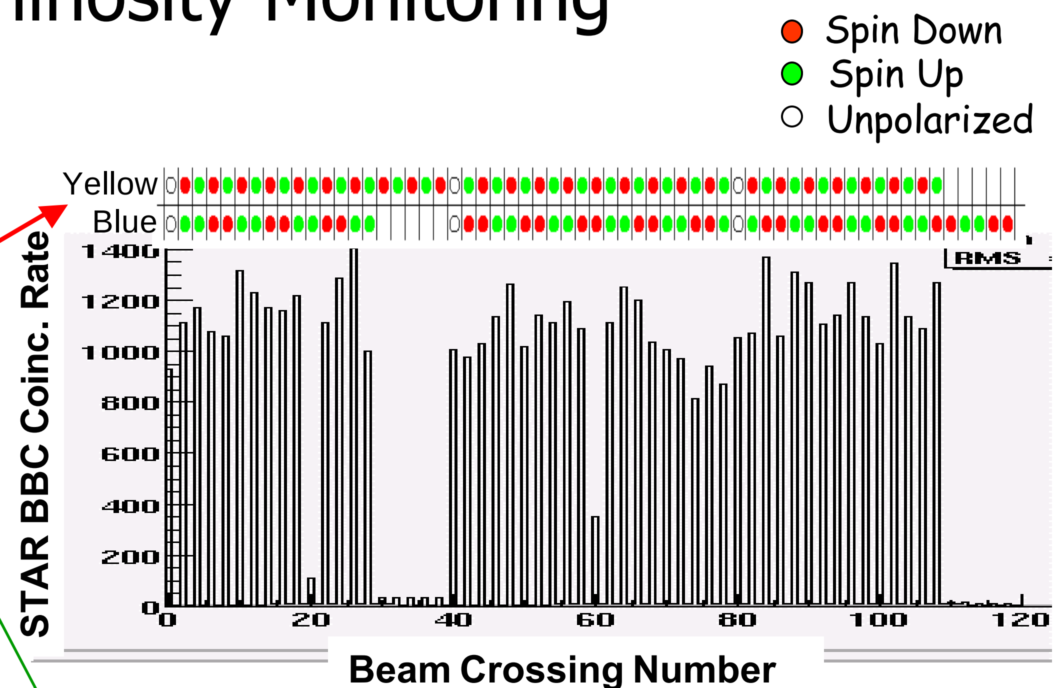


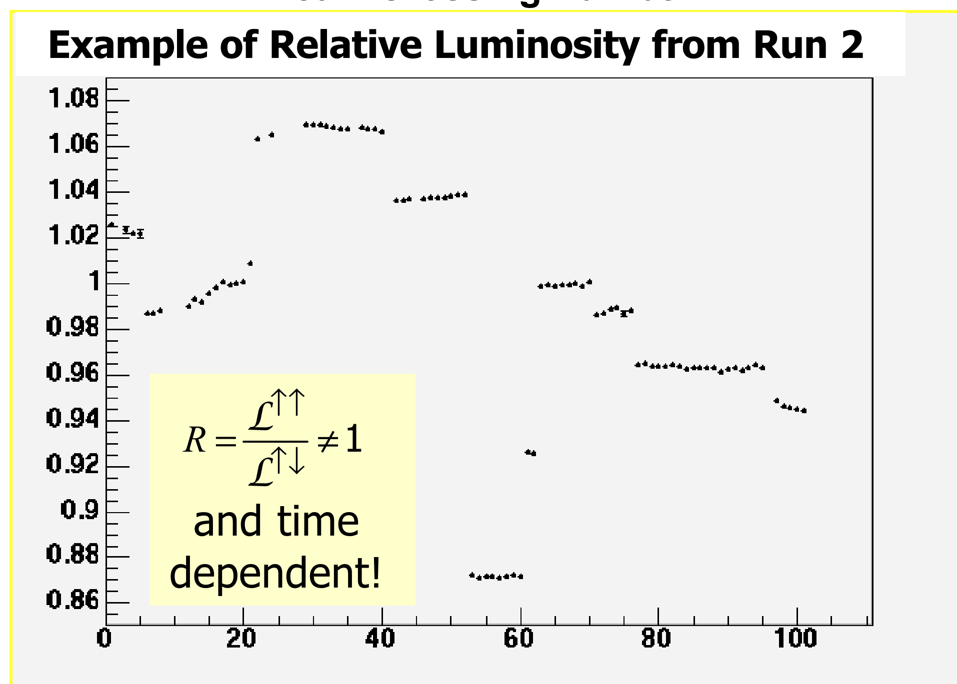
- Measured cross sections consistent with pQCD calculations
- Large spin effects observed for $\sqrt{s}$ = 200 GeV *pp* collisions

Status: final analysis complete / paper in preparation

Relative Luminosity Monitoring

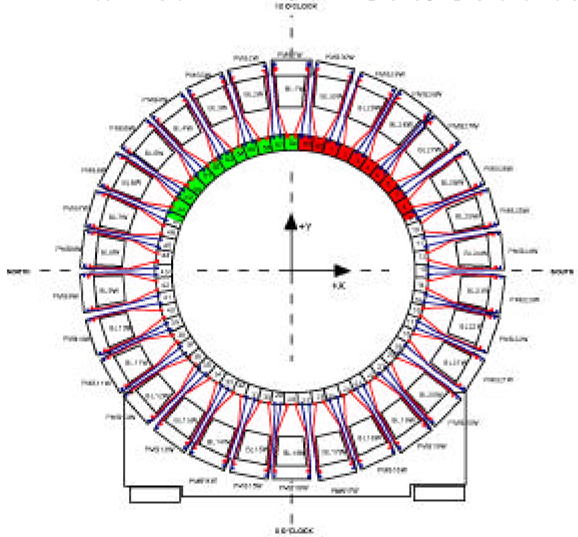
- ➢ RHIC stores up to 120 bunches per ring
- ➢ Different bunches injected with different spin orientation
- ➢ Collision luminosity can vary significantly with spin combination
- ➢ Precision of relative luminosity monitoring critical – demonstrated better than 10^{-3} in 2002 run
- ➢ Special problem for A_{LL} measurements: asymmetry f-independent, shows up <u>only</u> as yield change per integrated luminosity unit
- ➢ Must demonstrate that ℒ monitor reaction does not have its own A_{LL} of magnitude comparable to physics of interest Þ comparisons of different ℒ monitors

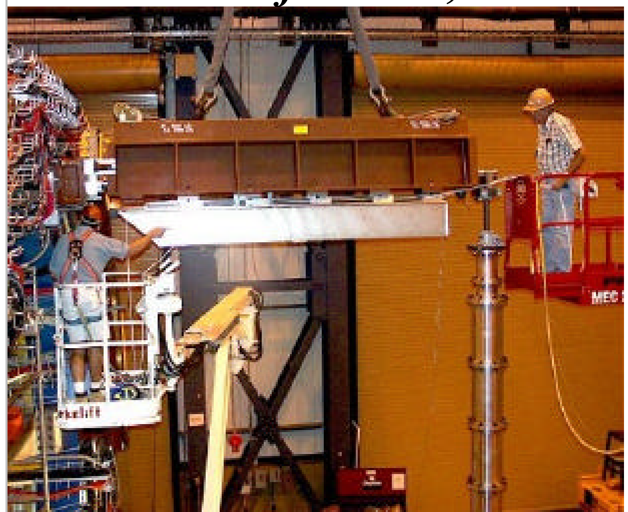


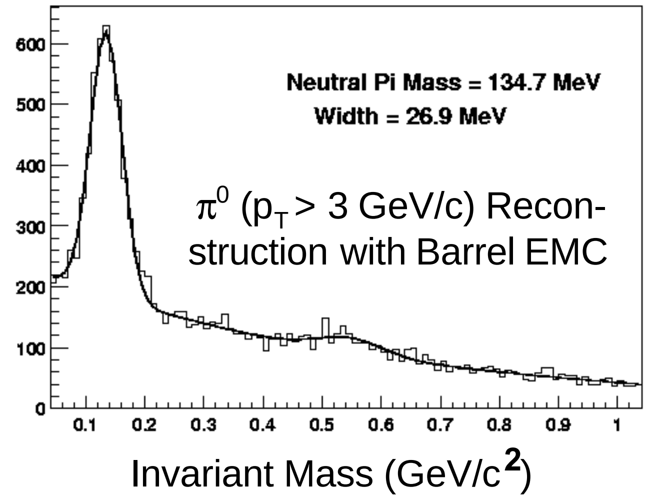


STAR Electromagnetic Calorimeters

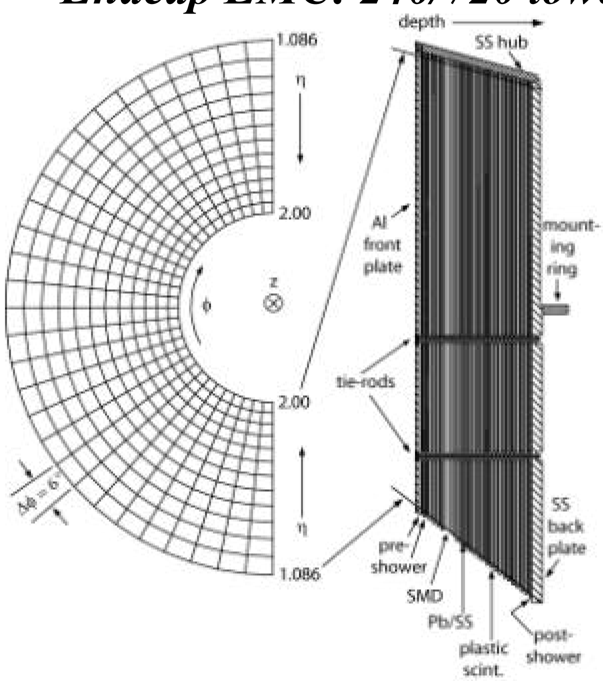
Barrel EMC: 2400/4800 towers installed for 2003, with SMD but not yet preshower readout

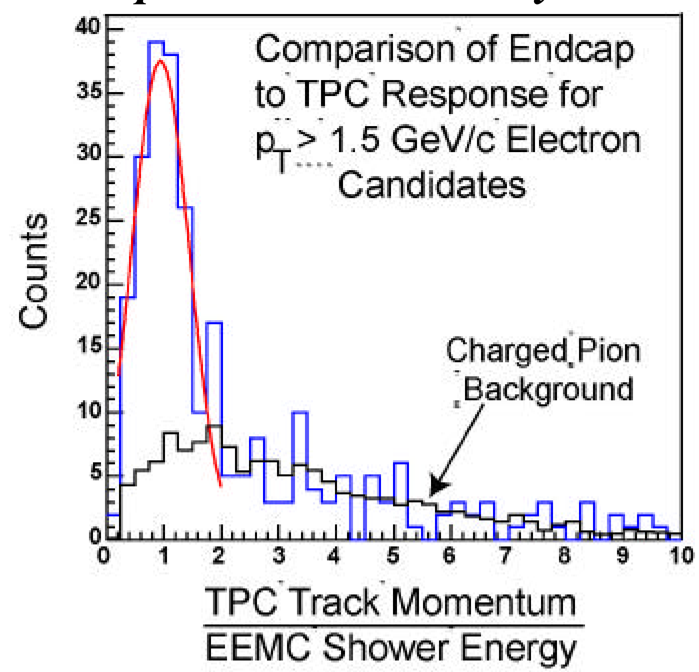






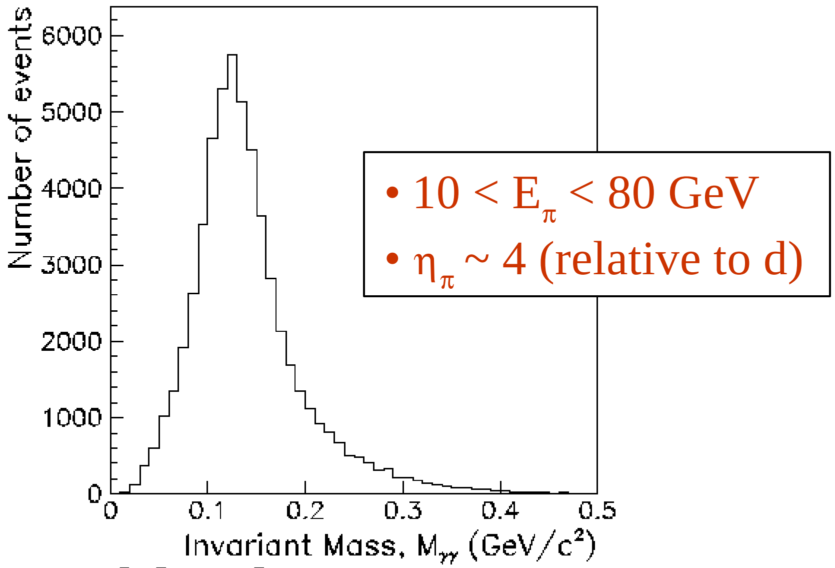
Endcap EMC: 240/720 towers installed; no SMD, preshower or postshower readout yet

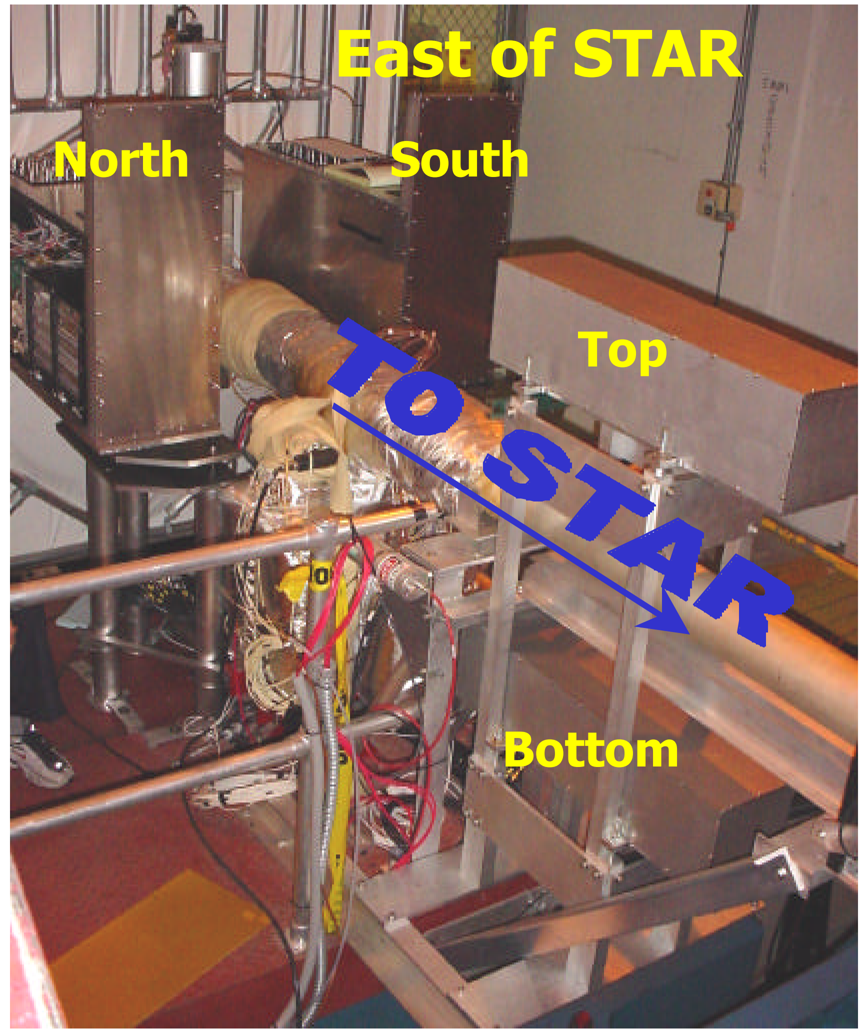




STAR Forward Pion Detector
(Construction for Run 3)

$d+Au \rightarrow \pi^0+X, \sqrt{s_{NN}} = 200$ GeV

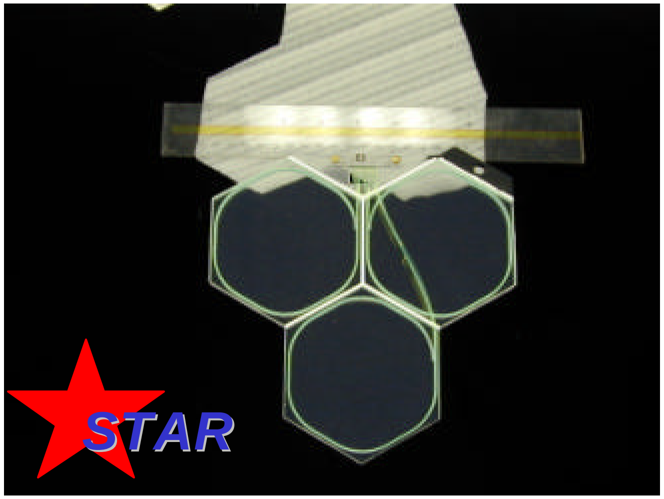




Run 3 Objectives:

- probe of Color Glass Condensate in d+Au
  - $\Rightarrow p_T$ dependence of large η yield
- improve understanding of dynamical origin of A_N in $p_\uparrow+p \rightarrow \pi^0+X \Rightarrow$
  - Collins effect $\rightarrow$ sensitivity to transversity
  - Sivers effect $\rightarrow$ sensitivity to orbital motion
  - twist-3 effect $\rightarrow$ quark/gluon correlations
- serve as local polarimeter at STAR IR

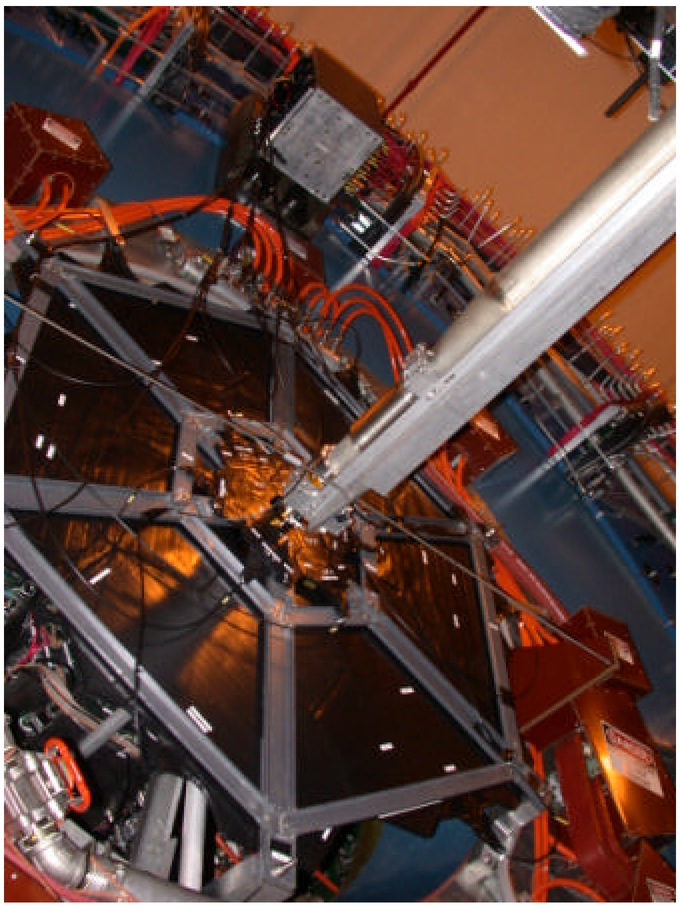
BNL, Penn State, IHEP-Protvino, UC Berkeley/SSL, UCLA, ANL

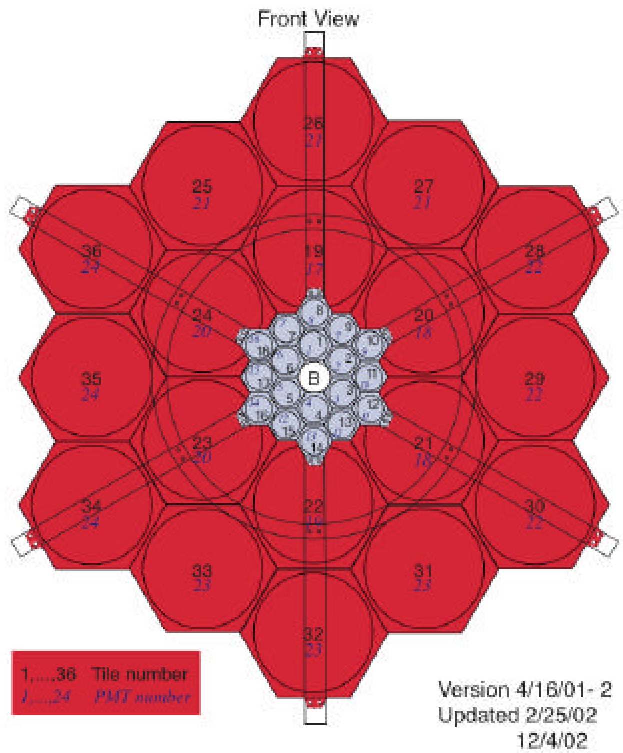


Beam Beam Counter

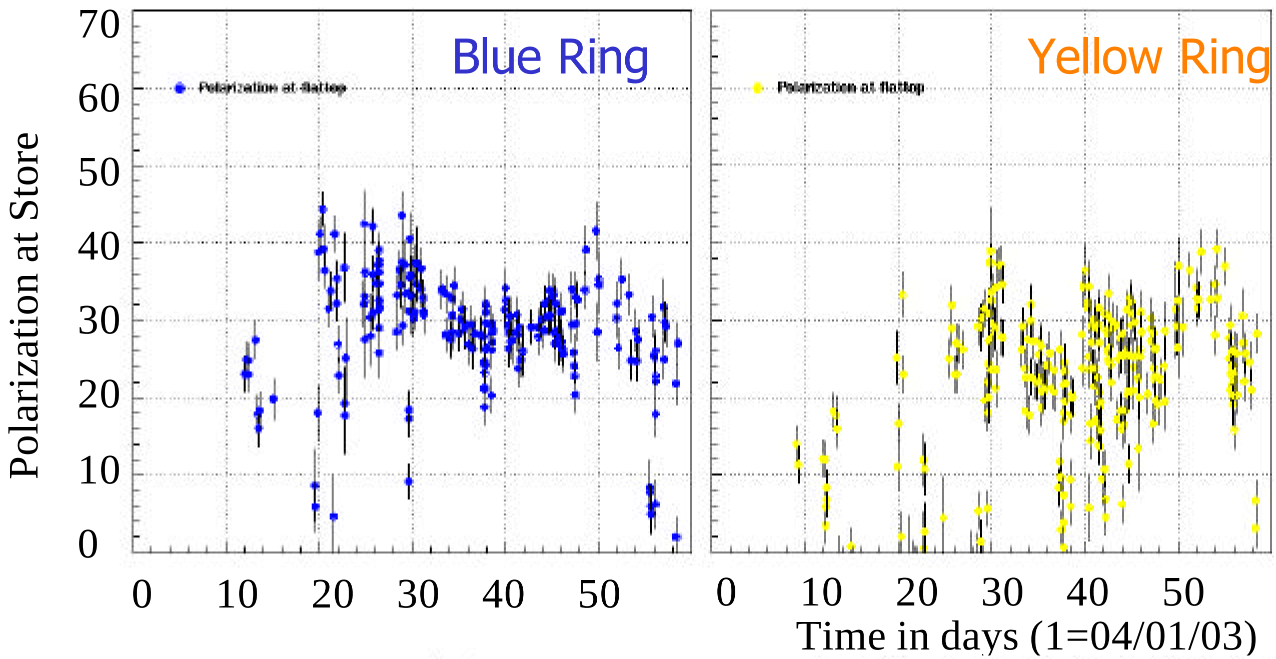
1cm thick scintillator hex tiles with PMT readout (2.1<|η|<5)

- Feed back to RHIC to make collision at STAR
- Measure relative luminosity ~10^{-3} level
- Measure absolute luminosity ~ 15% level
- Minimum bias trigger (covers ~50% of total σ)
- Reject beam gas events from biased trigger
- Measure multiplicity at forward rapidity
- A_N for forward charged particles





RHIC performance during run 3



Polarization

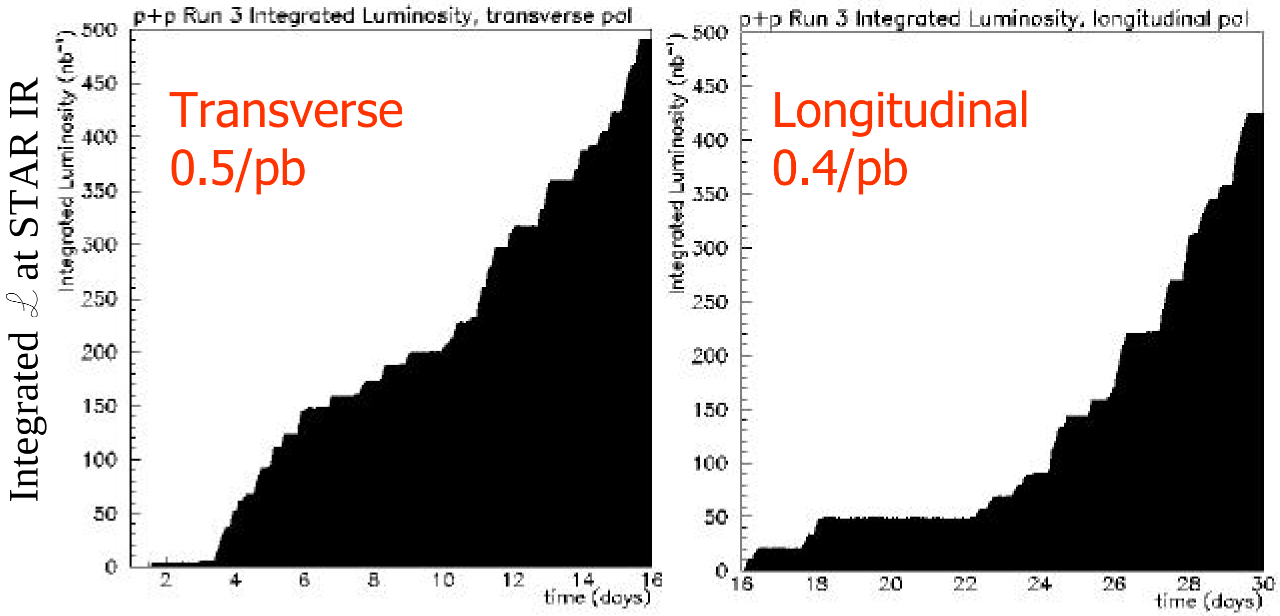
•Maximum at injection: ~50%,

•Maximum at 100GeV: ~40%

•Average P ~25%

•Improved by factor of two compared to run 2

•Yellow ring affected by problem with snake magnet



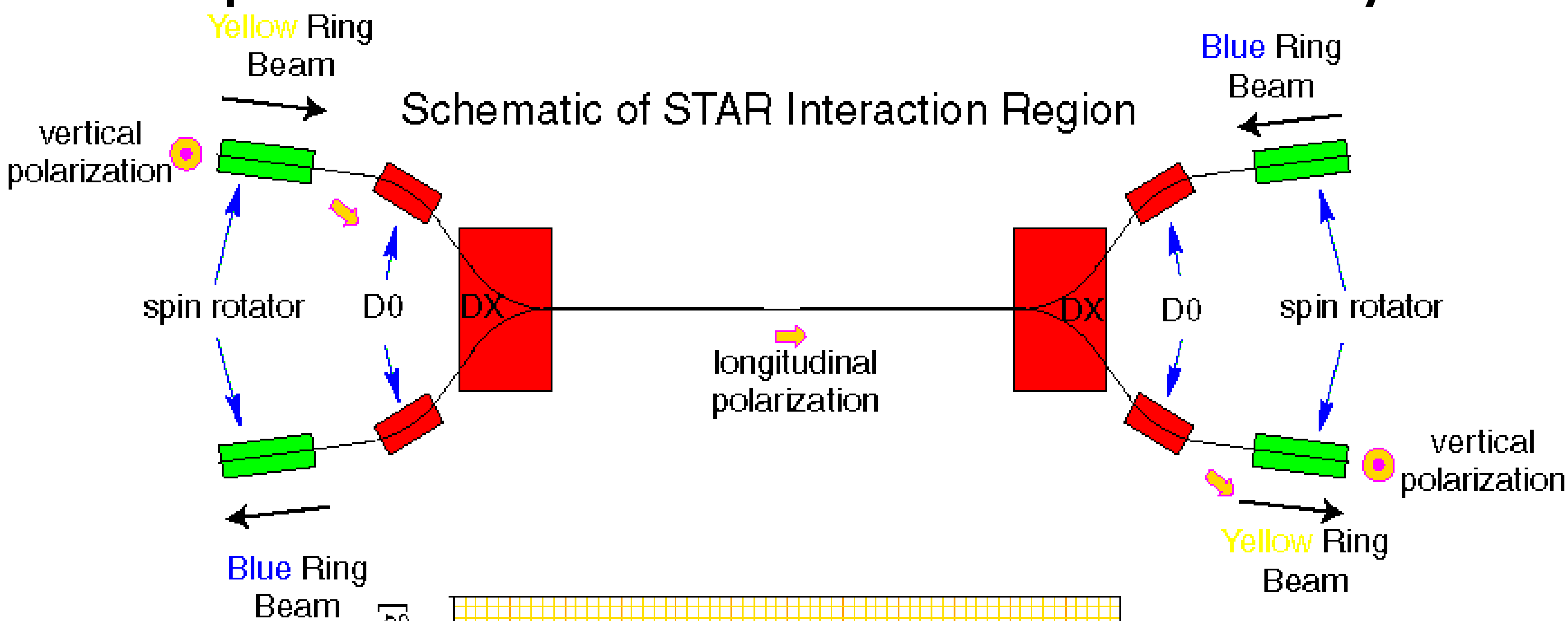
Luminosity

•New problem 'beam-beam tune shift' surfaced, limiting luminosity

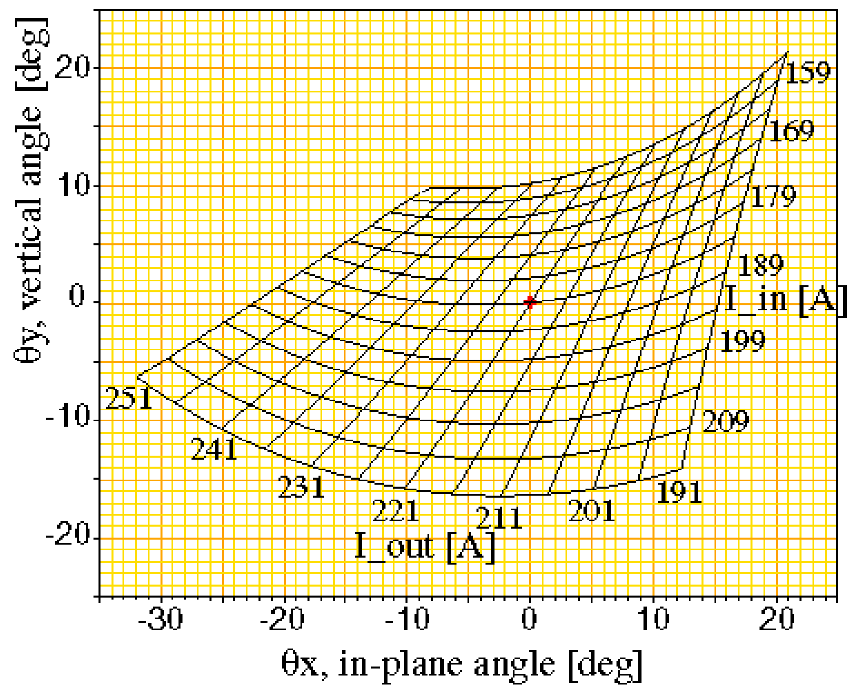
•Adequate to accomplish physics goals from Run 3.

BROOKHAVEN NATIONAL LABORATORY

Spin Rotators and Local Polarimetry



Calculations establish a working point and the dependence of transverse polarization components on spin rotator currents.

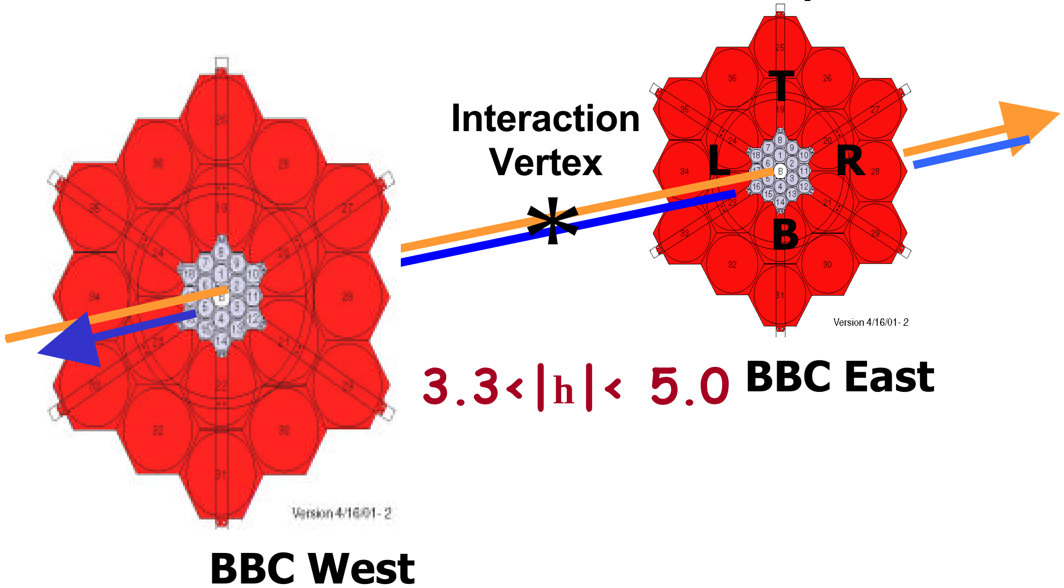


Local polarimeters are needed to measure vertical,radial polarization components at interaction region.

BROOKHAVEN NATIONAL LABORATORY

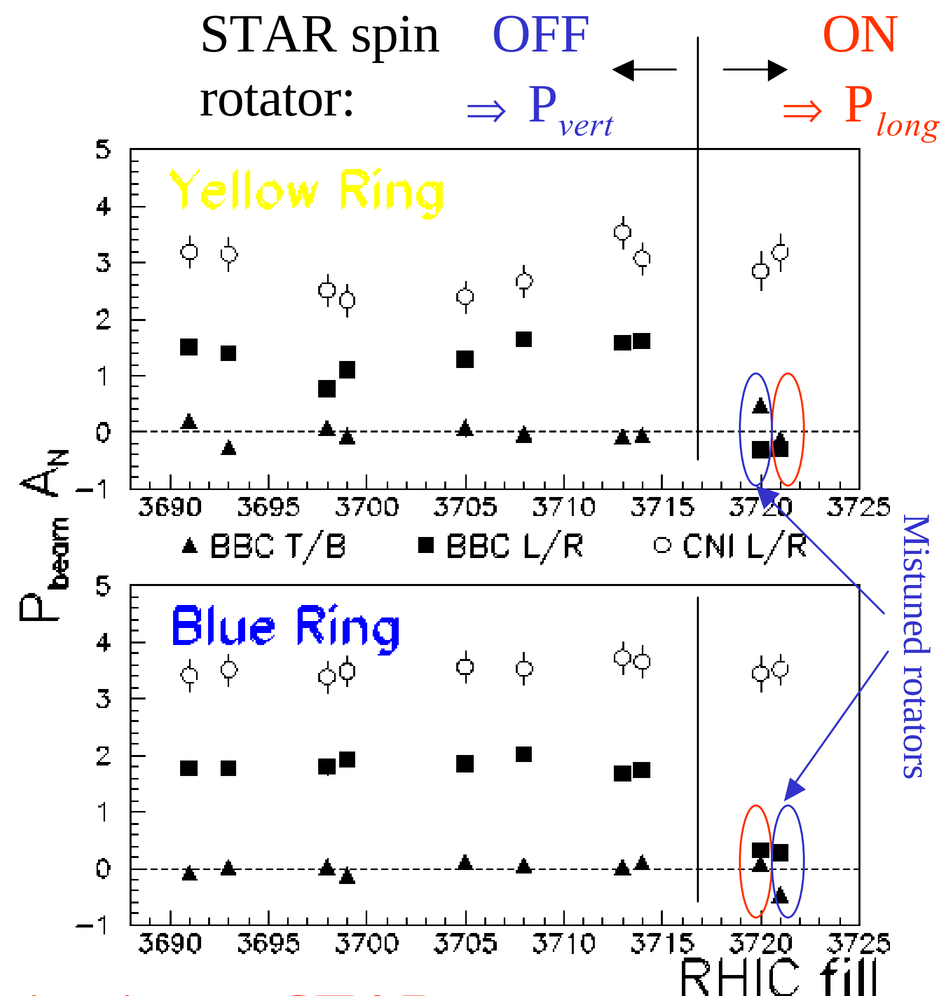
STAR Spin Rotator Magnet Tuning

(Run 3 Result)



• *RHIC polarimeter* (CNI) establishes polarization *magnitude.*

• *Local polarimeter* (BBC) establishes polarization *direction* at STAR.



• use segmentation of inner tiles of BBC as a *Local Polarimeter* monitoring *pp* collisions.

• Rotators OFF ⇒ BBC L/R spin asymmetries comparable to RHIC polarimeter (CNI).

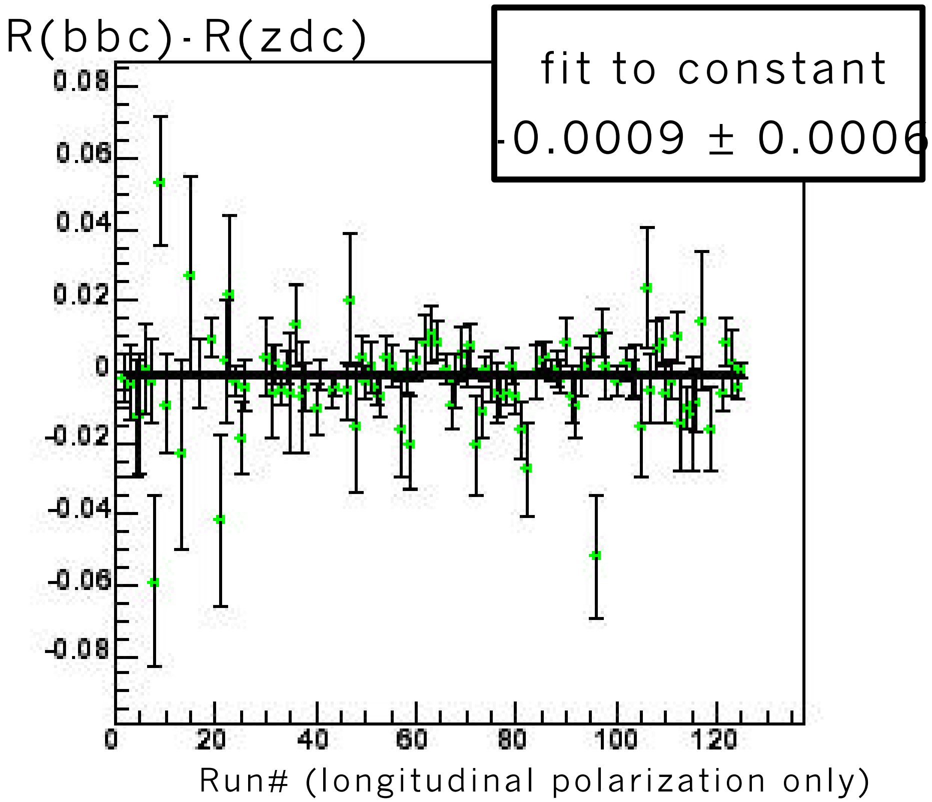
• Rotators ON ⇒ adjust rotator currents to minimize BBC L/R and T/B spin asymmetries.

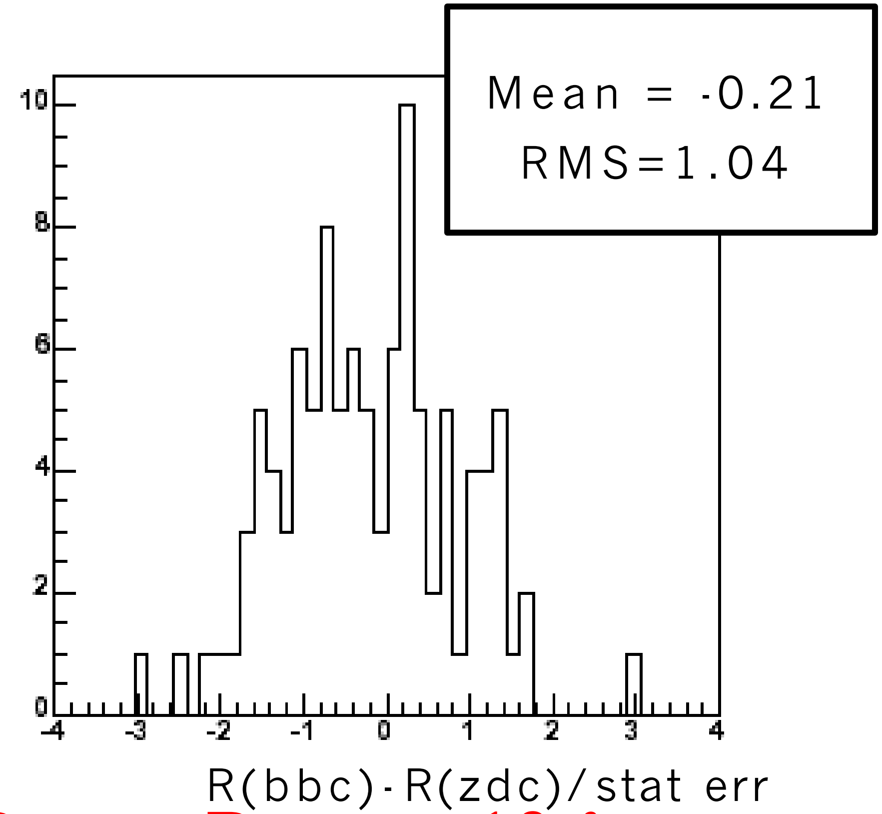
⇒ Longitudinal Polarization at STAR

BBC & ZDC for relative luminosity monitor

Is there A_{LL} in Relative Luminosity ($R=N_{++}/N_{+-}$) measurement?

BBC sees ~50% of total cross section (~87% of inelastic, non-diffractive cross section). ZDC sees ~0.5% of total cross section.



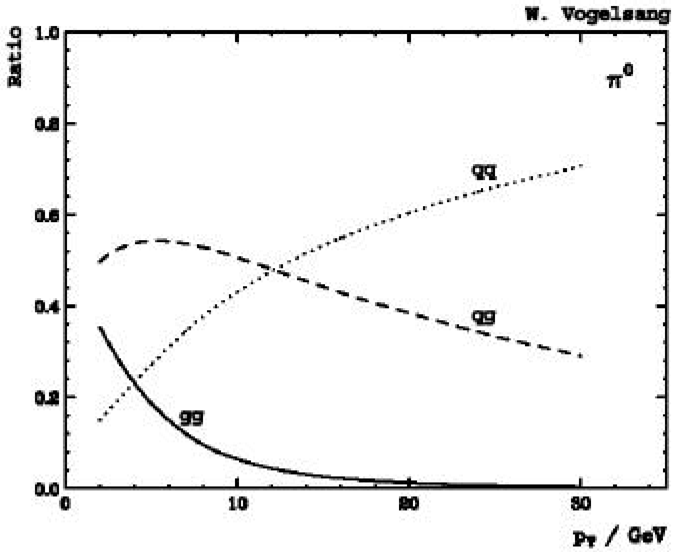


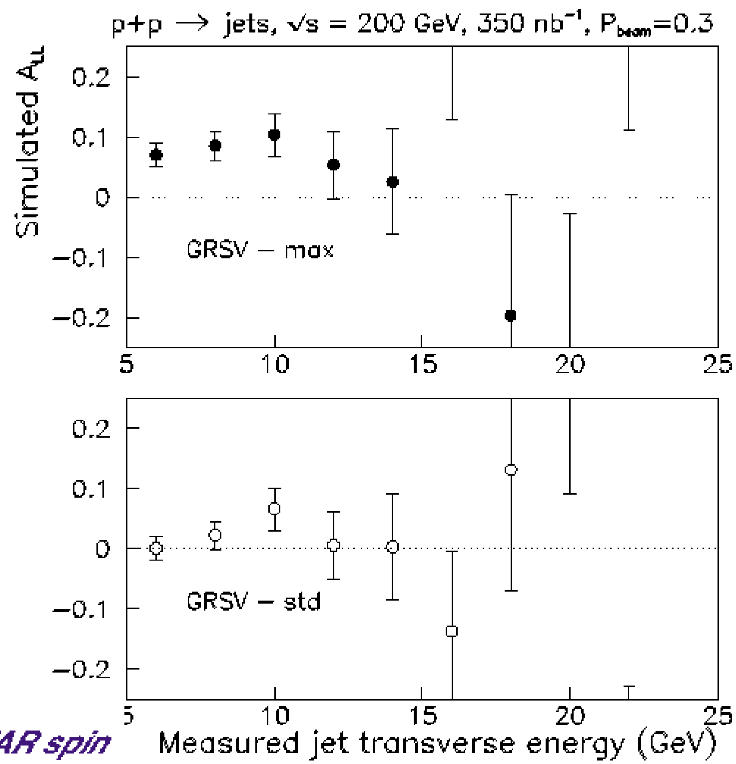
$$A_{LL(BBC)} - A_{LL(ZDC)} \sim R_{(BBC)} - R_{(ZDC)} \leq 10^{-3}$$

Green light for A_{LL} measurements

STAR spin

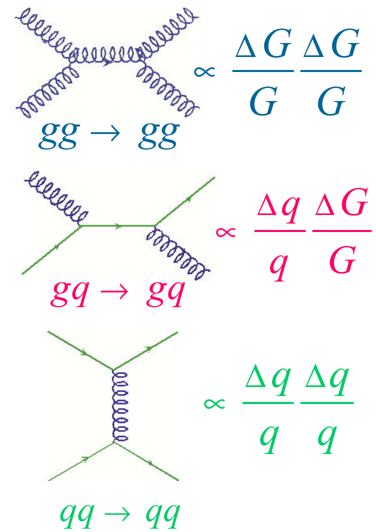
Projections for Sensitivity to ΔG from Run 3





Longitudinal spin asymmetry (A_{LL}) for mid-rapidity jet production

⇒ first measurements sensitive to gluon polarization



Status:

- data analysis underway
- understand trigger bias
- understand jet yields

STAR spin

Possible Timeline for STAR Spin Program

RHIC RUN YEAR	NEW EQUIPMENT TO BE COMMISSIONED	STAR/RHIC SPIN MEASUREMENTS
FY04	New AGS warm snake; $\vec{H}$ gas jet; rf spin flipper; BEMC preshower; EEMC SMD + preshower; completed FPD	Test $\mathcal{L}$ improvement schemes; calibrate P_{beam} to 10%; continue A_{LL}(jets)
FY05	New strong AGS cold snake; Completed BEMC, EEMC (incl. postshower); forward hadron calorimeter?	Calibrate P_{beam} to 5%; improve $\mathcal{L}$; Collins frag. with forward π^0's; more A_{LL}(jets); first look at γ+jet
FY06+07	Whatever is needed to achieve full design $\mathcal{L}$ and P_{beam} ; $\sqrt{s}$ = 500 GeV polarized collisions;	$A_{LL}(\gamma$ + jet), transversity measurements at mid-rapidity, at $\sqrt{s}$ = 200 GeV
FY08+09	Improved STAR forward tracker ($1<\eta<2$)	$A_{LL}(\gamma$ + jet), $A_L(W^{\pm})$ at $\sqrt{s}$ = 500 GeV

Summary

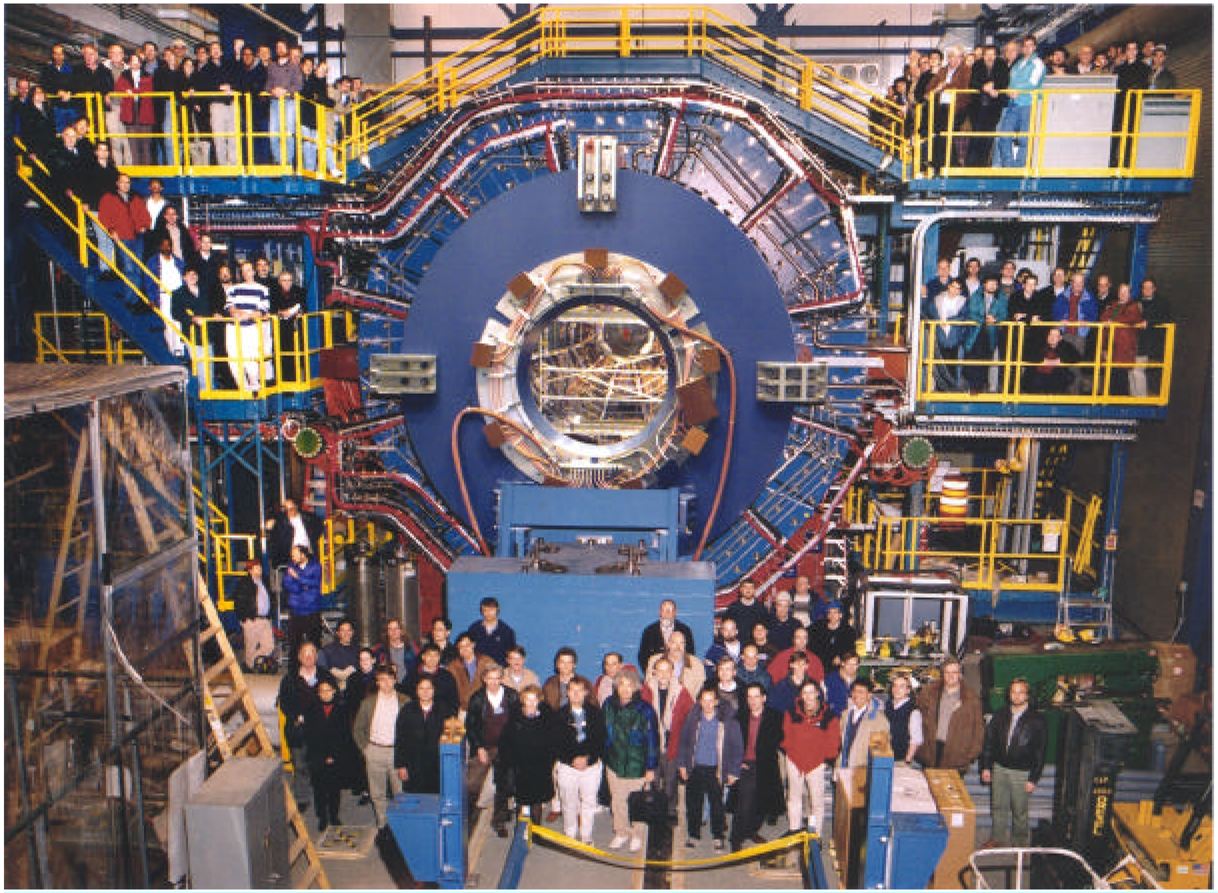
1) STAR spin program well under way. Essential equipment and procedures commissioned during RHIC runs 2,3: snakes, rotators, polarimeters, accurate relative luminosity monitors; STAR EMC's, FPD, BBC's.

2) 1st pp collisions with transversely polarized beams in run 2 $\Rightarrow$ large analyzing power in hard scattering at $\sqrt{s}$ = 200 GeV. Additional data on A_N(fwd. π^0) in run 3, including correlations with midrapidity tracks, negative Feynman-x spin asymmetry.

3) 1st pp collisions with longitudinally polarized beams in run 3 $\Rightarrow$ begin search for ΔG sensitivity in jet production.

4) For next ~2 years, STAR spin physics focus on ΔG via A_{LL}(jets) and A_N(fwd. π^0) vs. Collins angle from jet axis, while $P^4 \mathcal{L}$ brought to ~design goals.

5) High priority programs on A_{LL}(γ + jet), A_L^{PV}($W^{\pm}$) and transversity via mid-rapidity jet fragmentation likely to take rest of decade to complete.



The STAR Collaboration

~ 500 collaborators
48 institutions
12 countries

Note strong new STAR spin interest from:
CalTech, LBNL, MIT, Valparaiso U., Zagreb

Brazil: Sao Paolo
China: IHEP-Beijing, IMP-Lanzhou, Shanghai INR, Tsinghua, USTC, IPP-Wuhan
Croatia: Zagreb
Czech Republic: Nuclear Physics Institute-AS-CR
England: Birmingham
France: IReS - Strasbourg, SUBATECH-Nantes
Germany: Frankfurt, MPI-Munich
India: Bhubaneswar, Jammu, IIT, Panjab, Rajasthan, VECC-Kolkata
Netherlands: NIKHEF
Poland: Warsaw U. of Technology
Russia: JINR - Dubna, IHEP – Protvino, MEPHI - Moscow
U.S.: Argonne, Berkeley, Brookhaven National Laboratories
UC Berkeley, UC Davis, UCLA, CalTech, Creighton, Carnegie-Mellon, Indiana, Kent State, MIT, Michigan State, CCNY, Ohio State, Penn State, Purdue, Rice, Texas, Texas A&M, Valparaiso, Washington, Wayne State, Yale Universities