# STAR spin Results

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for the STAR Collaboration

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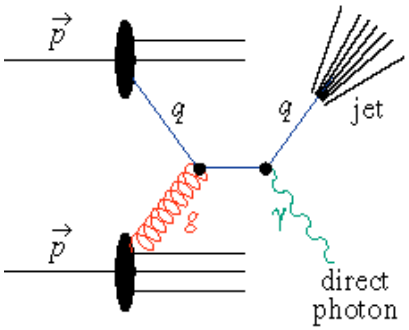
## Outline:

1. Long term program with rare probes
2. Short(er) term program
3. First results from pp at sqrt(s)=200GeV - analyzing power for
   - inclusive forward $\pi^0$ production
   - leading charged particle at midrapidity
   - charged hadrons in forward region ( local polarimetry )
4. Towards determination of gluon polarization $\Delta G$
   - status of $A_{LL}$ analysis for inclusive jet production from Run3
   - upgrades status of Barrel and Endcap calorimeters
5. Outlook

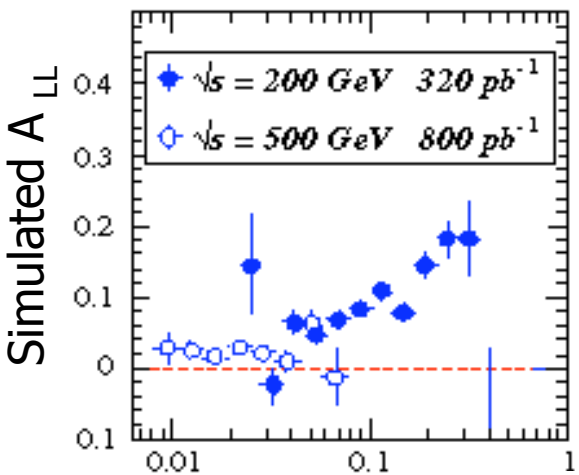
# Gluon polarization from Prompt Photon Production - Rare Probes at RHIC

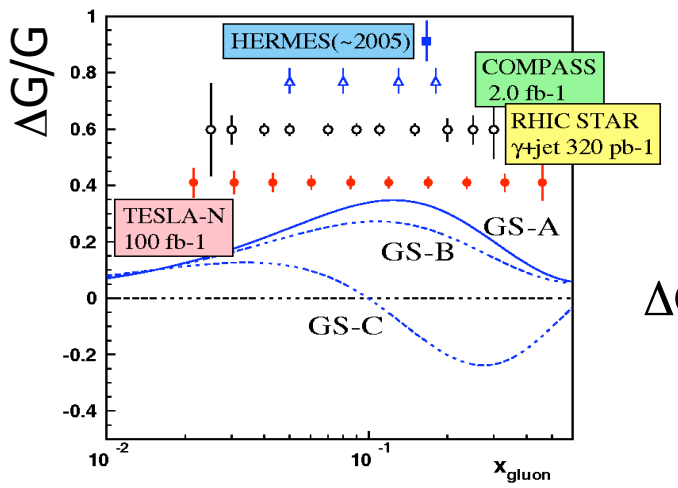



The asymmetry $A_{LL}$ for $\vec{p}\vec{p} \rightarrow \gamma$ + jet + X at Leading Order:

$$A_{LL} \approx \frac{\Delta g\,(x_g)}{g\,(x_g)} \cdot \underbrace{A_1^{\,p}(x_q)}_{\text{known from pDIS}} \cdot \underbrace{\hat{a}_{LL}^{\,\text{Compton}}(\cos\vartheta^*)}_{\text{calculable in pQCD, Scale } Q^2 \sim p_T^2 \text{ of } \gamma}$$

Direct measurement of gluon polarization



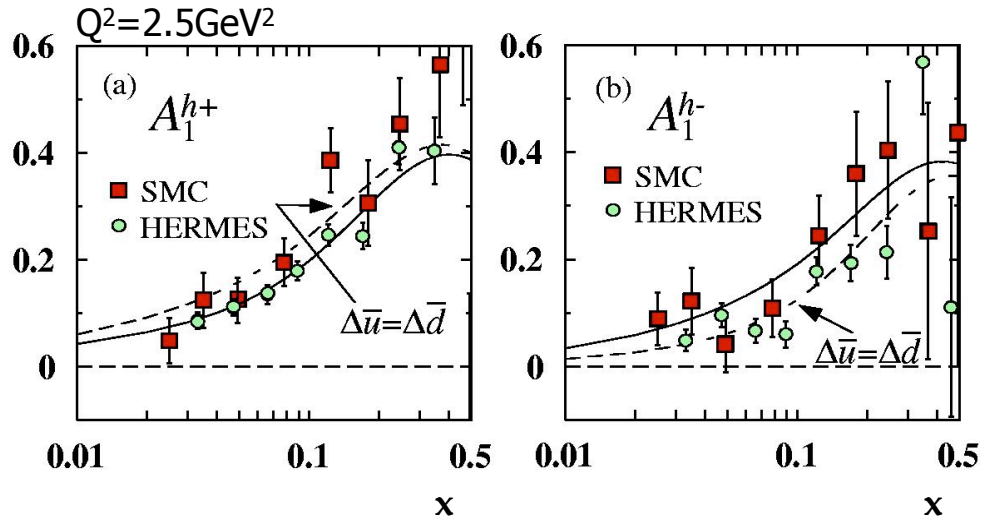

Reconstructed $x_g$

$$\Delta G\,(Q^2) = \int_0^1 \Delta G(x, Q^2)\,dx$$

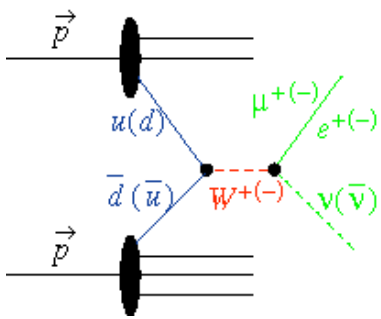
- A combined data sample from RHIC essential to minimize extrapolation errors in determining $\Delta G$
- The best determination of $\Delta G$ will result from a global analysis of the data from: RHIC (other channels, eg. STAR-inclusive jet or PHENIX heavy flavor production), pDIS (HERMES, COMPASS) and possibly eRHIC, Tesla

# Flavor Decomposition of the proton's spin from single spin asymmetry $A_L^{PV}$ in W boson production - Rare Probes at RHIC

- Semi-inclusive DIS - sensitivity reduced by fragmentation functions and $e_q^2$ weighting




- W boson production in pp collisions




$\sqrt{s}$ =500GeV

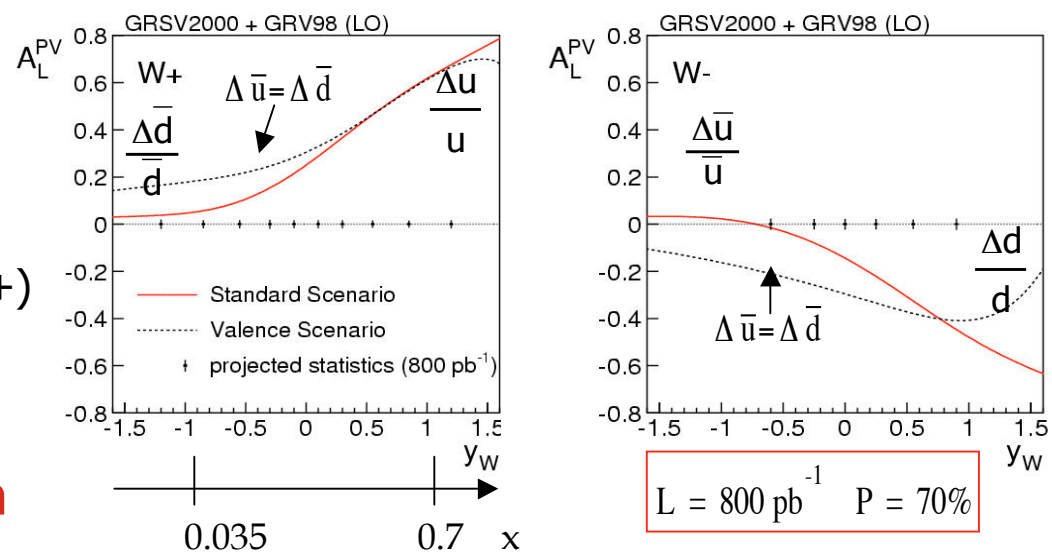
$Q^2=M_W^2$

Produced through V-A interaction, helicity of the quark and anti-quark are fixed:

$$A_L^{PV}(y_W) = \frac{\sigma_- - \sigma_+}{\sigma_- + \sigma_+}$$

at Leading Order:

$$= \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} \quad (W+)$$



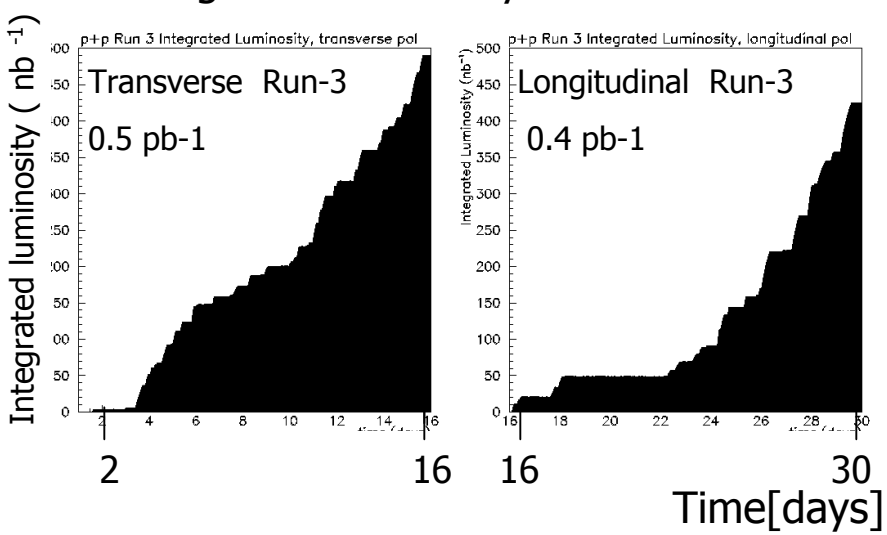

Ideal tool to study spin flavor structure of the proton

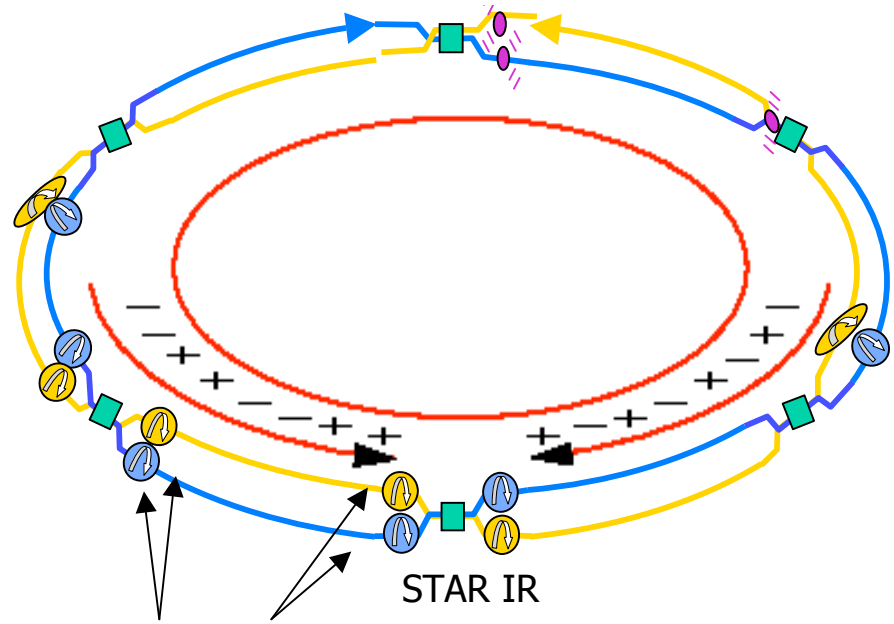
# Spin Running at RHIC - First Polarized pp Collider

## Luminosity and Beam polarization development at 200GeV

- 2001-2 Run-2 (5+3 weeks)
  - **Transverse** beam polarization P~15%
  - Luminosity = $5 \times 10^{29}$ $s^{-1}cm^{-2}$
  - Integrated luminosity at STAR = 0.15 $pb^{-1}$

- 2003 Run-3 (5+3 weeks)
  - **Transverse and Longitudinal** beam polarization of ~25%
  - Luminosity = $2 \times 10^{30}$ $s^{-1}cm^{-2}$
  - Integrated luminosity at STAR:

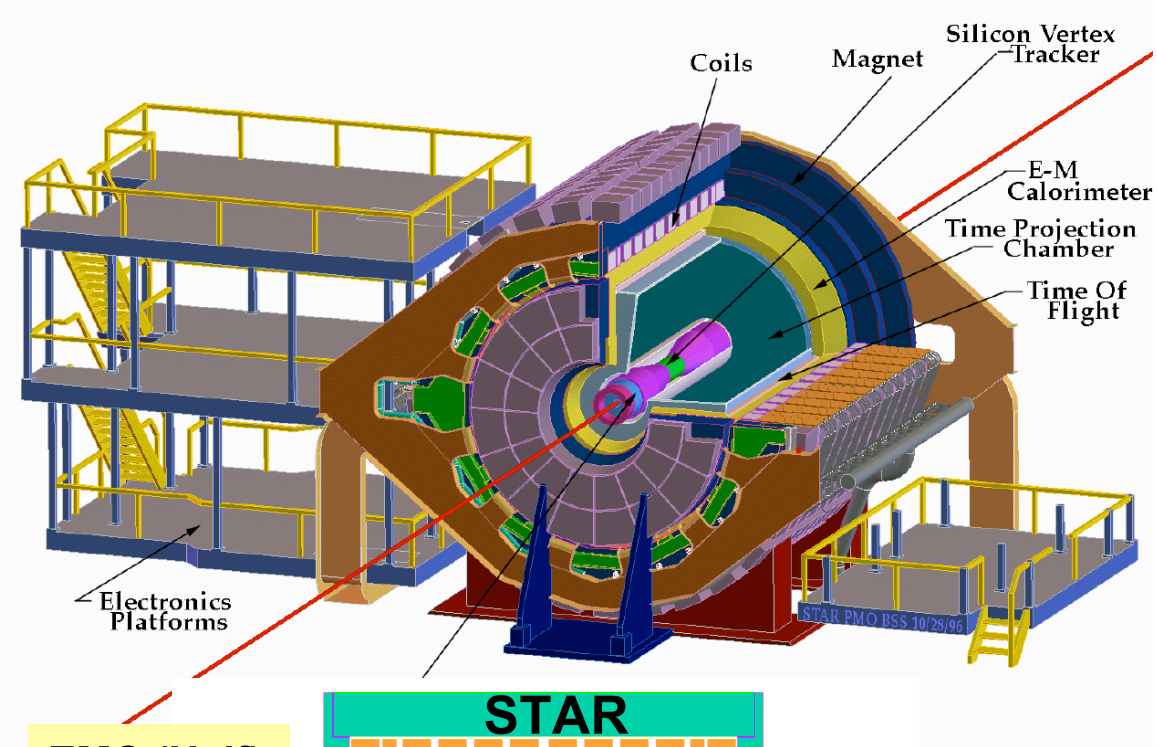


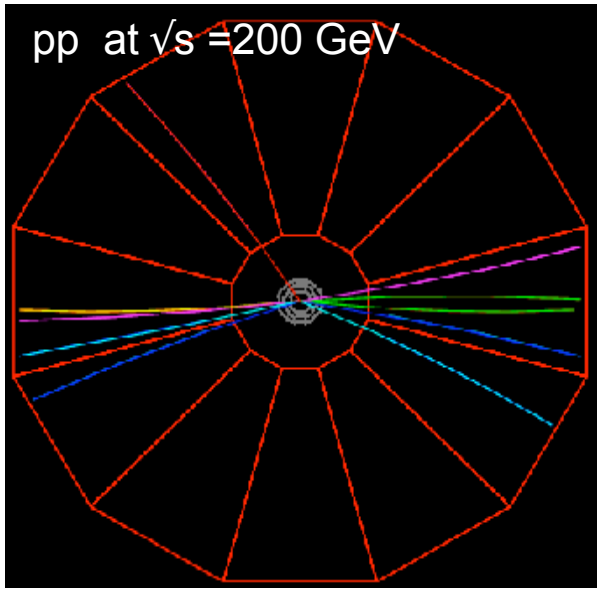



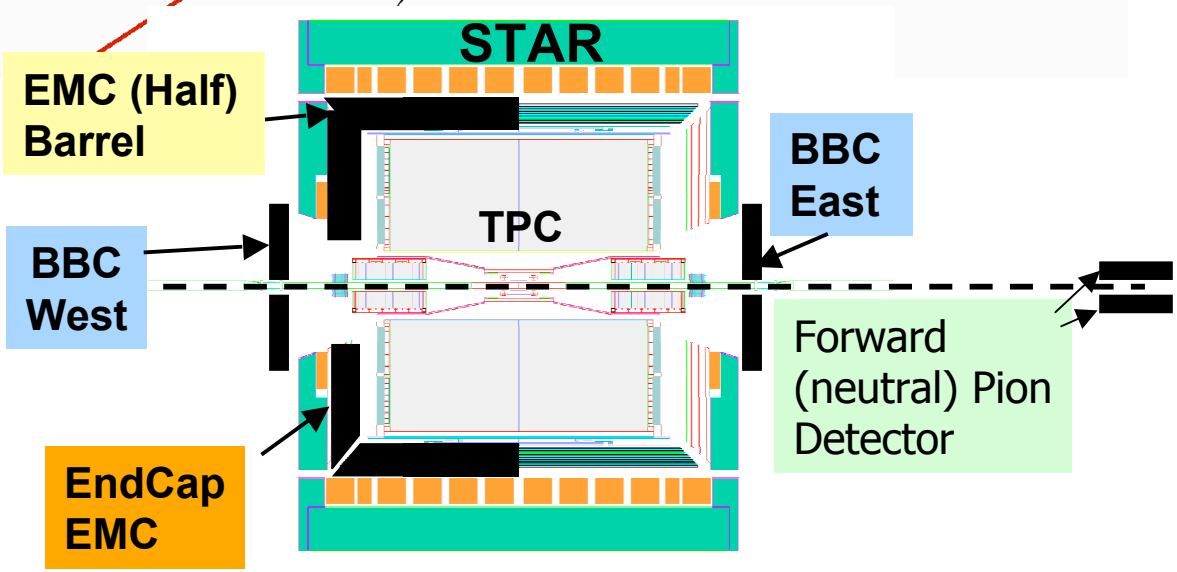

Rotators
Off = transverse polarization
On = longitudinal polarization

- 2004 Run-4 (6 weeks)
  - Machine commissioning - luminosity development - ongoing run
  - P>40% in both rings seen at RHIC flattop!

# STAR Upgrades for Spin




STAR is adding lots of EM calorimetry to detect high-energy $\gamma$, $e^{\pm}$, $\pi^0$

TPC+EMC for jet reconstruction

EMC's and FPD's partially implemented for 2004 run, will be completed before 2005.

Beam-Beam Counters for relative luminosity and polarization monitoring.

# STAR Spin Program

| | |
|---|---|
| Short term - Run-2 | 200 GeV |
| Short term - Run-3 and Run-5 | 200 GeV |
| Long term - Rare Probes | 500 GeV |

## Single Spin

### Transverse $A_N$

$$p^{\uparrow} + p \rightarrow \pi^0 + X$$

$$p^{\uparrow} + p \rightarrow h^{\pm} + X$$

$$p^{\uparrow} + p \rightarrow h_1 + (h_2^{\pm}) + X$$

$$p^{\uparrow} + p \rightarrow jet_1 + jet_2 + X$$

### Longitudinal $A_L$

$$\vec{p} + p \rightarrow W + X \rightarrow e + X$$

$$\frac{\Delta u}{u} \quad \frac{\Delta d}{d} \quad \frac{\Delta \bar{u}}{\bar{u}} \quad \frac{\Delta \bar{d}}{\bar{d}}$$

## Double Spin

### Longitudinal $A_{LL}$

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

$$\vec{p} + \vec{p} \rightarrow \pi^0 + X$$

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

$$\Delta G$$

### Transverse $A_{TT}$

$$p^{\uparrow} \ p^{\uparrow} \rightarrow (di) - jets + X$$

$$\Delta q_T \cdot \Delta \bar{q}_T$$

STAR spin program requires charged particle tracking and identification of electrons, pions, photons and jets

# Spin Asymmetry Measurements

## Single Transverse

$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{1}{P} \times \frac{N_\uparrow - R_1 N_\downarrow}{N_\uparrow + R_1 N_\downarrow}$$

## Double Longitudinal

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - R_2 N_{+-}}{N_{++} + R_2 N_{+-}}$$

Statistical significance: $P^{2(4)} \cdot \int \mathcal{L} dt$

## Require concurrent measurements:

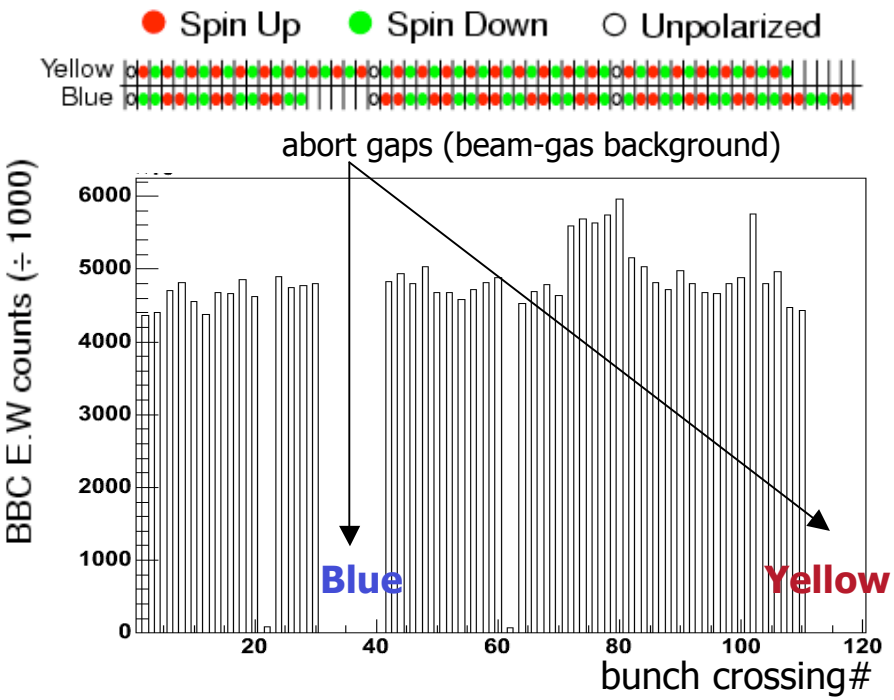
- magnitude of beam polarization, $P_{1(2)}$ pC CNI polarimeter (RHIC)
- direction of polarization vector at interaction point
- relative luminosity of bunch crossings with different spin directions:

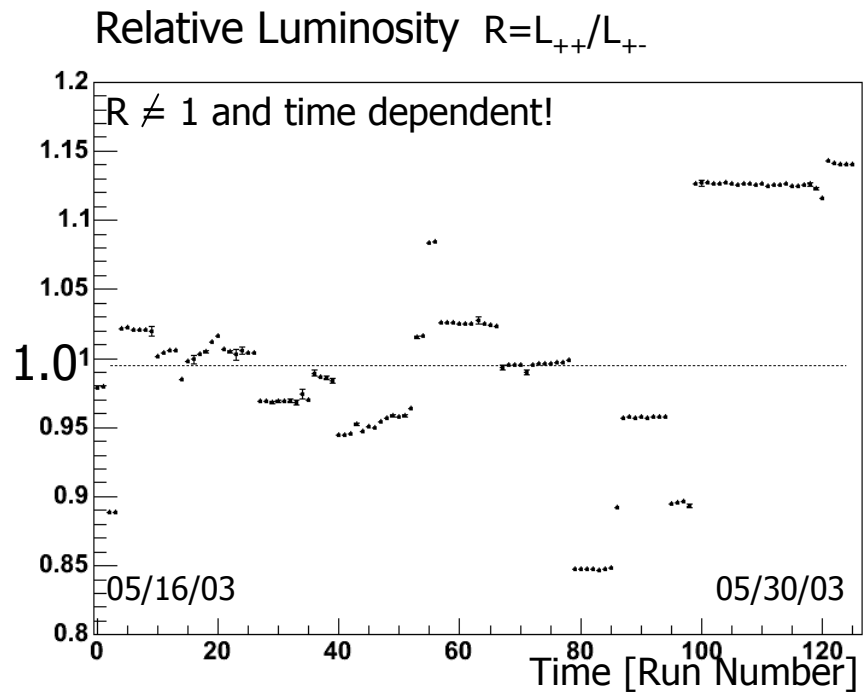
$$R_1 = \frac{L_\uparrow}{L_\downarrow} \quad \text{and} \quad R_2 = \frac{L_{++}}{L_{+-}}$$

- spin dependent yields of process of interest: $N_i$ and $N_{ij}$

# Relative Luminosity Measurement (BBC-Run3)

- Precision of relative luminosity monitoring critical: for $A_{LL}$ ~1% $\delta A_{LL}/A_{LL}$ ~5% if $\delta R/R \sim 10^{-3}$
- Luminosity ~ BBC coincidence rate ( large cross section of ~27mb)
- RHIC stores up to 120 bunches per ring - different bunches injected with different spin orientation
  - collision luminosity can vary with spin combination

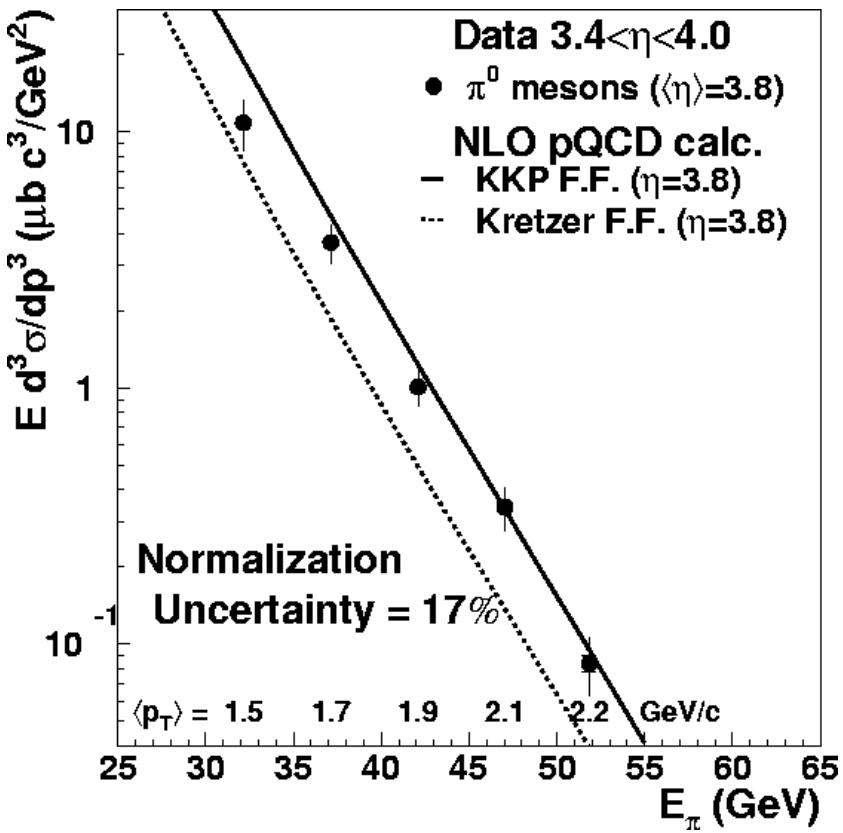


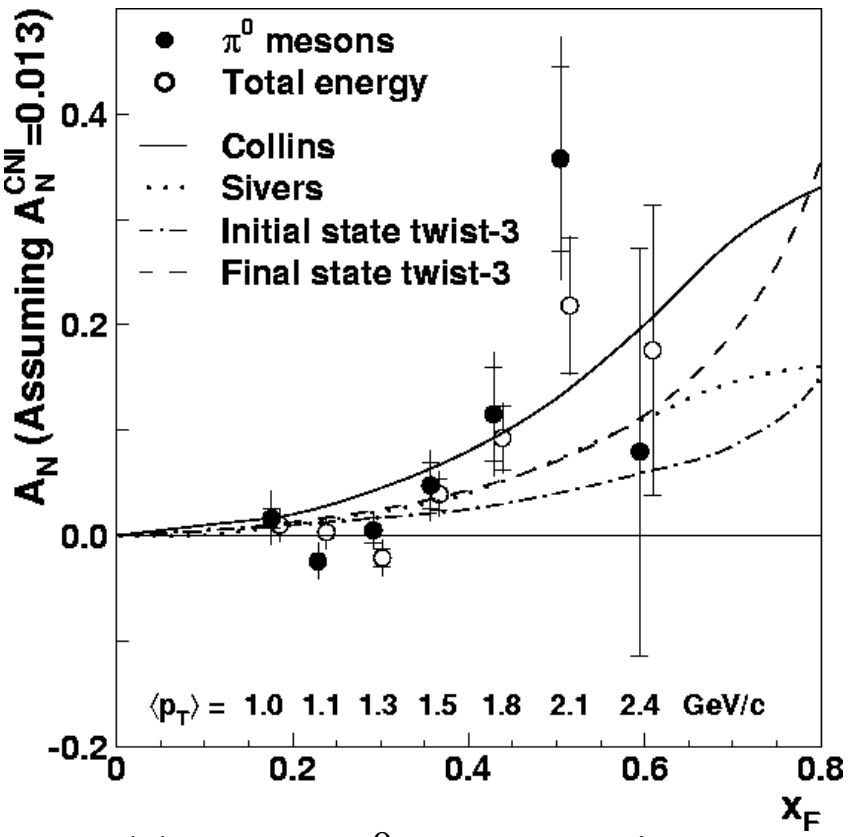




- relative luminosities calculated for each STAR run, statistical uncertainty $\delta R_{stat} \sim 10^{-4} - 10^{-3}$
- systematic uncertainty $\delta R_{syst} < 10^{-3}$

# Forward $\pi^0$ Production

Run-2 STAR collaboration, PRL **92**, 171801 (2004)



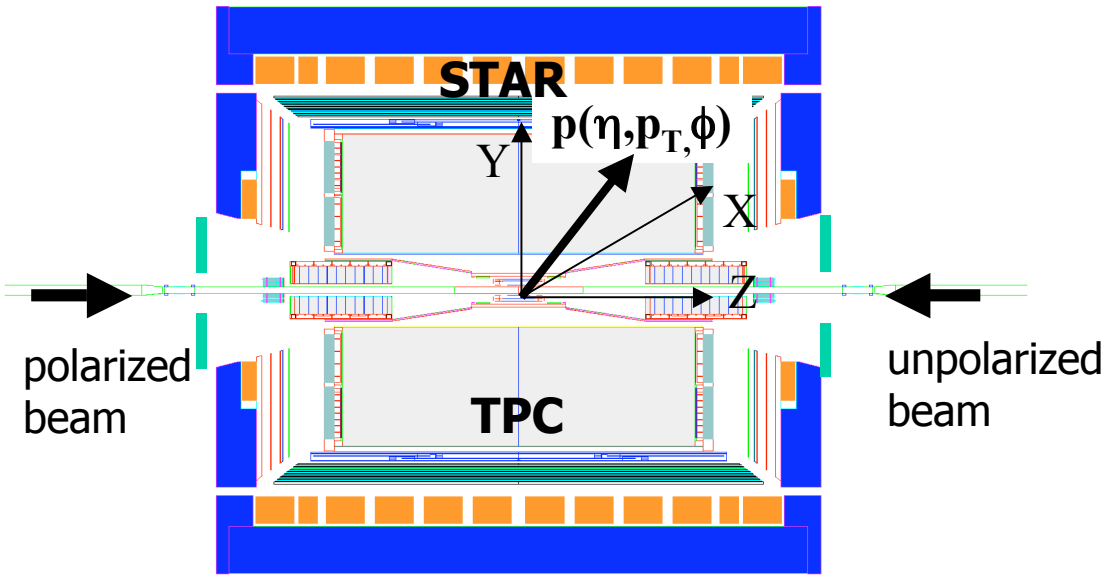




- pQCD calculations consistent with measured large-η $\pi^0$ cross sections
- Large transverse single-spin effects observed for $\sqrt{s}$ = 200 GeV *pp* collisions

Collins effect ⇒ transversity  Sivers effect ⇒ orbital angular momentum

Additional measurements required to disentangle contributions

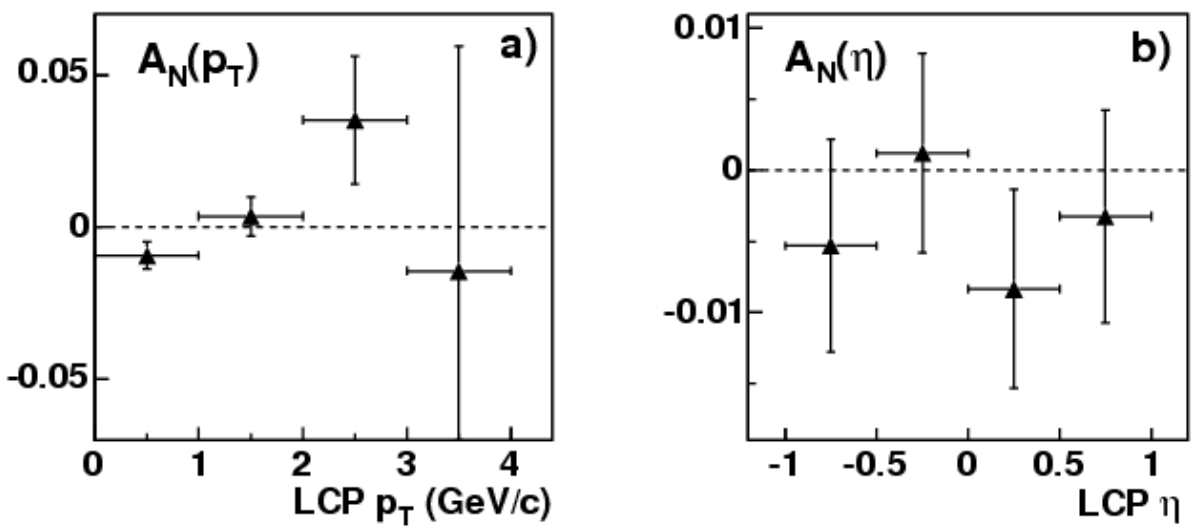
# Leading Charged Particle Production at Midrapidity




Leading Charged Particle ( LPC ) :

- charged particle reconstructed in TPC for $|\eta| < 1.0$ and $\Delta\phi = 2\pi$ with largest $p_T$ $0.4 < p_T < 5$GeV

Run-2 (Preliminary) Results




$A_N$ consistent with 0

- true also for charge separated LCP

# BBC Transverse Single Spin Asymmetries

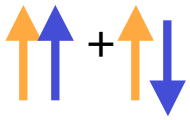
Single spin asymmetries measured for p+p -> A + X, where A – hit(s) in the BBC

$$\varepsilon = P_{beam} \times A_N \approx \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

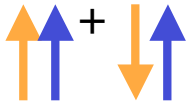
L(R) – number of counts in Left (Right) or Top (Bottom) in the BBC East or BBC West (small annuli) counted every bunch crossing by the scaler system

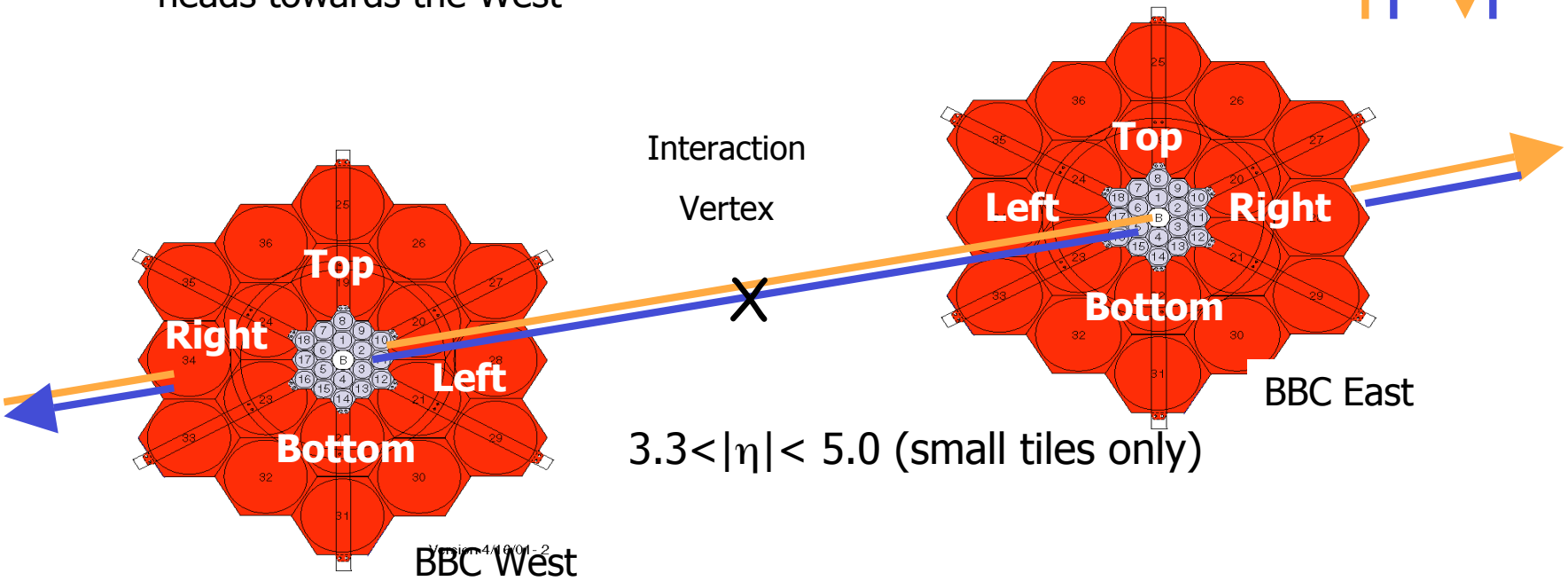
The BBC East and West data sets sorted by beam polarization states:

1. **Polarized Yellow beam** (sum over Blue beam polarization states) heads towards the East

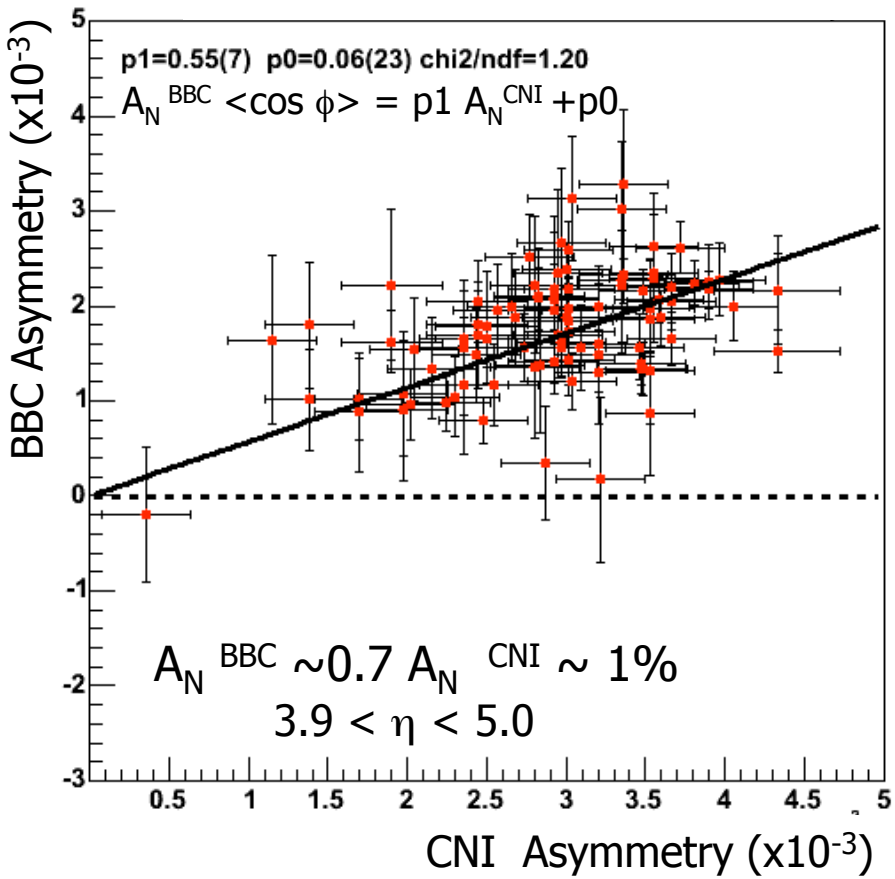


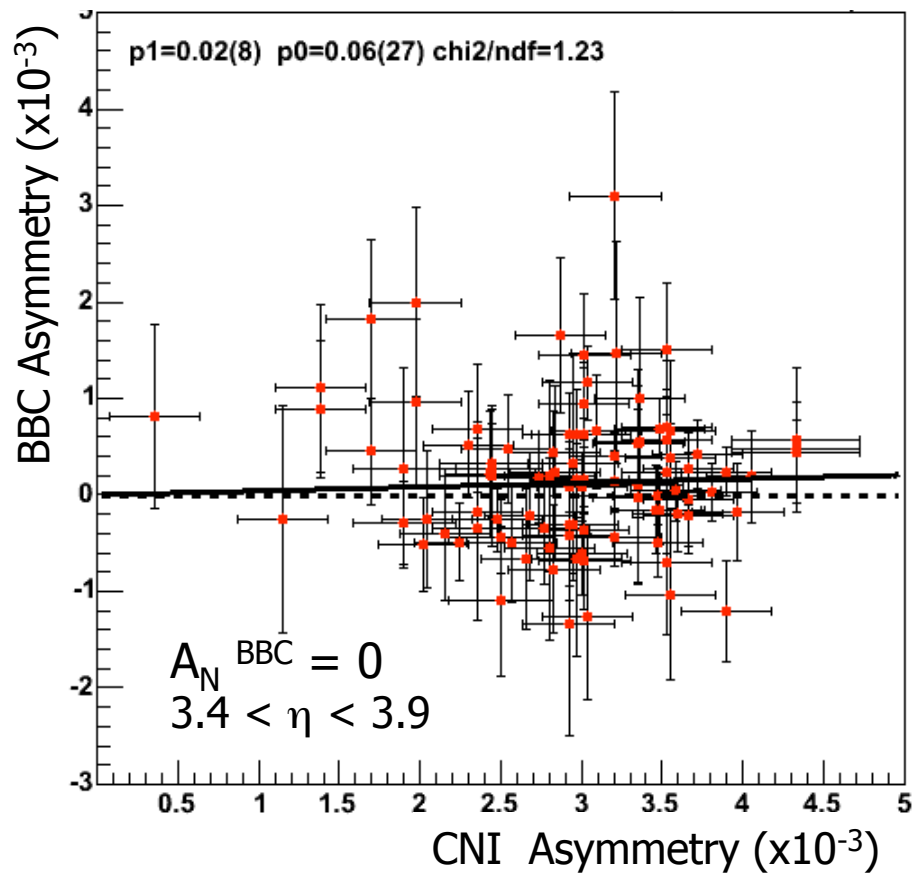
2. **Polarized Blue beam** (sum over Yellow beam polarization states) heads towards the West





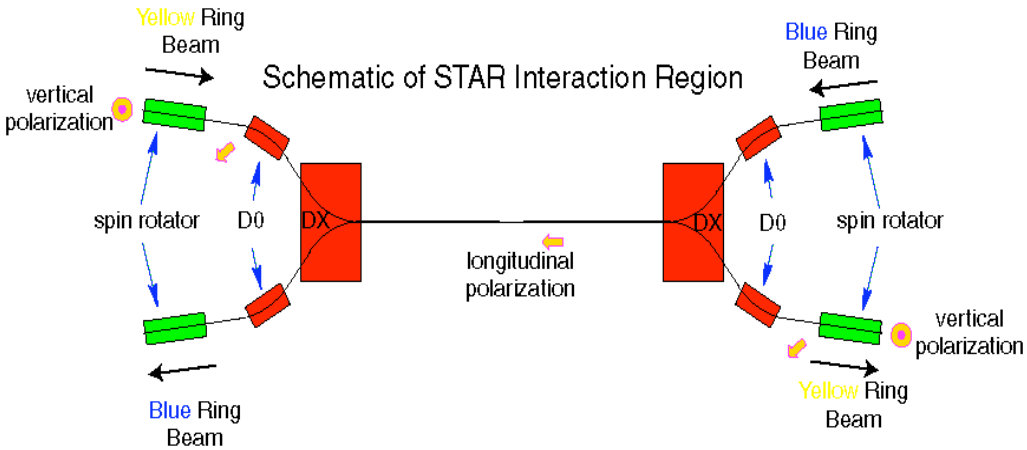
# Transverse Single Spin Asymmetries BBC Run-3 (Preliminary) Results




- Unexpected $A_N$ of unknown origin measured with the BBC
- Strong pseudorapidity dependence of $A_N$ for $x_F>0$ and $A_N = 0$ for $x_F<0$
- BBC - fast local polarimeter at STAR

# How do we get longitudinal polarization?




- Stable spin direction at RHIC is vertical
- Spin Rotater brings to almost radial
- D0/DX magnet causes spin precession
- Longitudinal at IR
- DX/D0/Spin Rotater put back to vertical

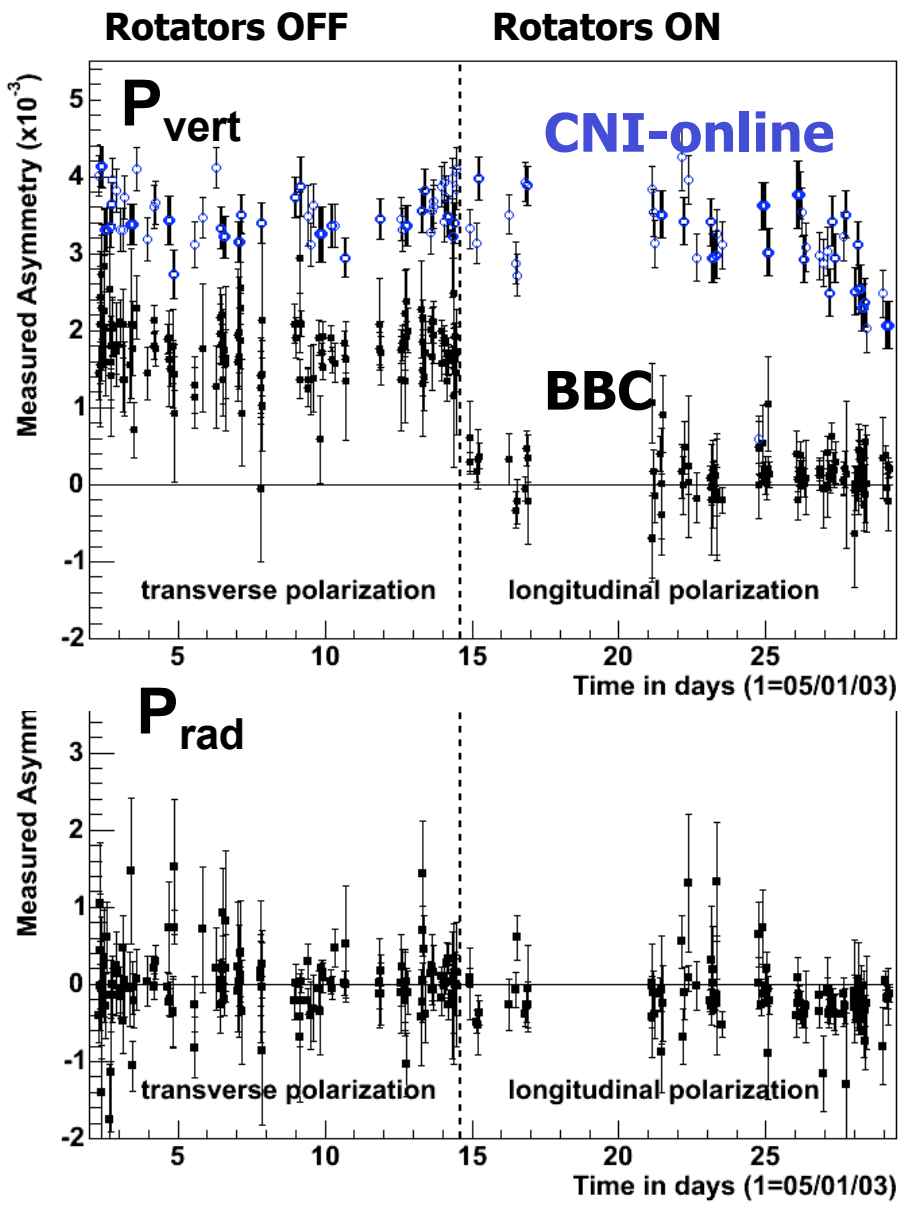
# BBC - local polarimeter at STAR

$\text{asymmetry}_i \sim A_N P_i$

Left-Right asymmetry - sensitive to verical polarization

Top-Bottom asymmetry - sensitive to radial polarization

| Rotators | | OFF | ON |
|---|---|---|---|
| CNI polarimeter | | non-zero | non-zero |
| BBC Left-Right | ( vertical ) | NON_ZERO | ZERO |
| BBC Top-Bottom | ( radial ) | zero | zero |




# Beam-Beam Counters
# - local polarimeter at STAR

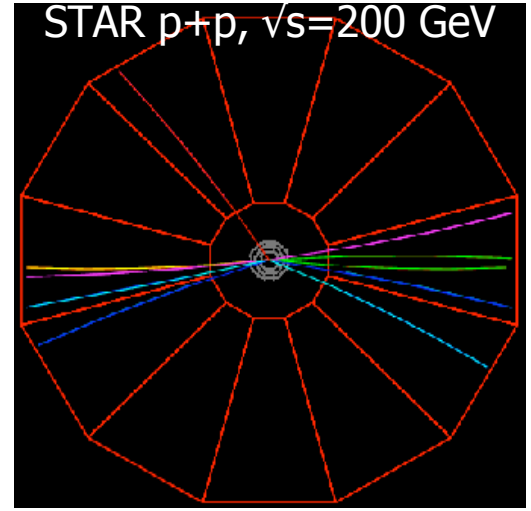
BBC worked very well as a local polarimeter. In Run3
vertical and radial polarizations < 3%

Longitudinal polarization at STAR -

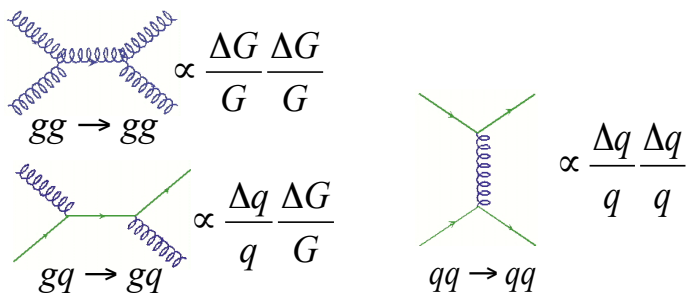
first step to $A_{LL}$ measurement

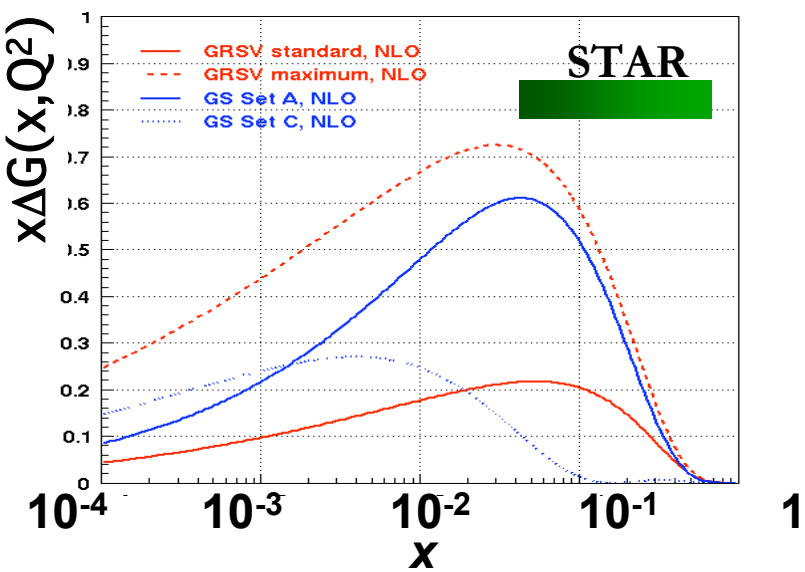
# ΔG from inclusive jet production

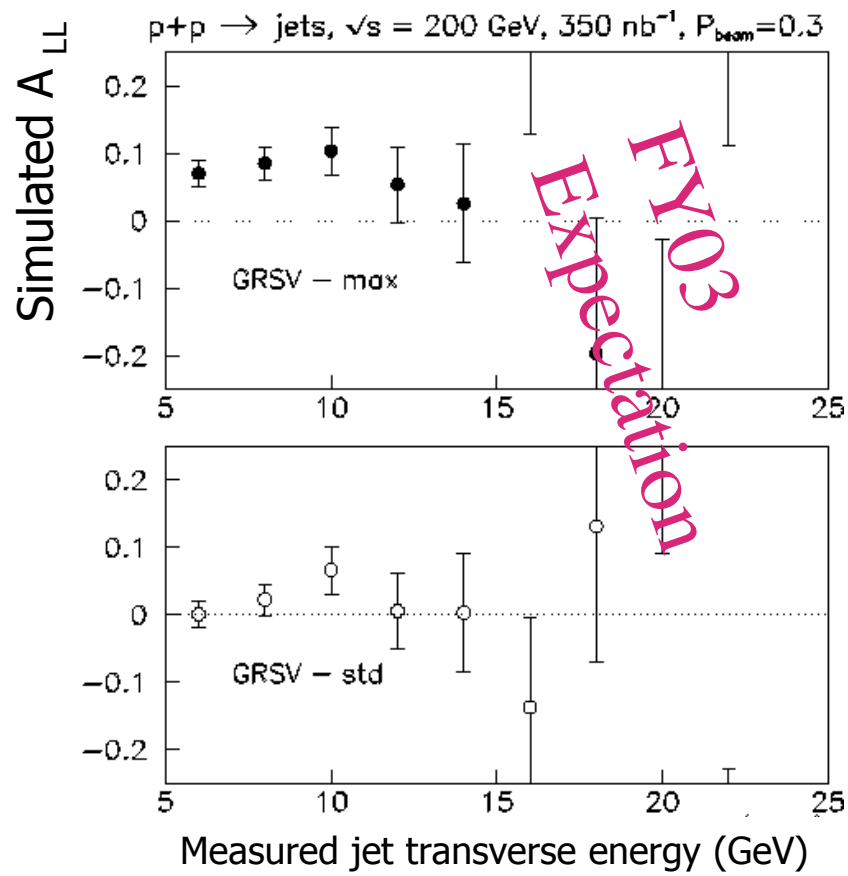
$$\vec{p} + \vec{p} \rightarrow jet(s) + X \quad \text{at } \sqrt{s} = 200 \text{ GeV}$$



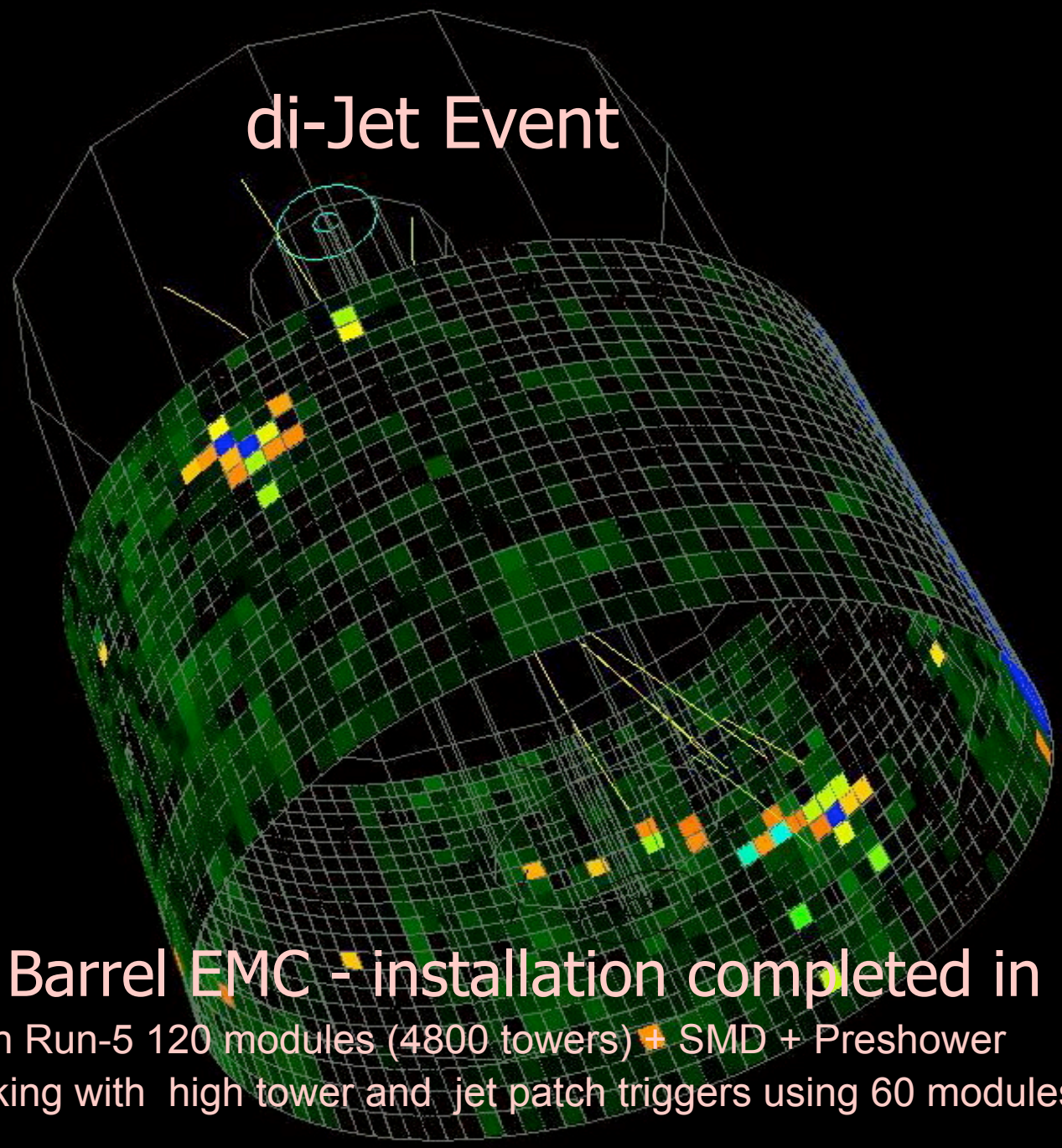

- STAR reconstructs jets via TPC $p_T$ for charged hadrons + EMC $E_T$ for em showers.
- Simulations under approximately realized conditions show sensitivity to ΔG.



# di-Jet Event

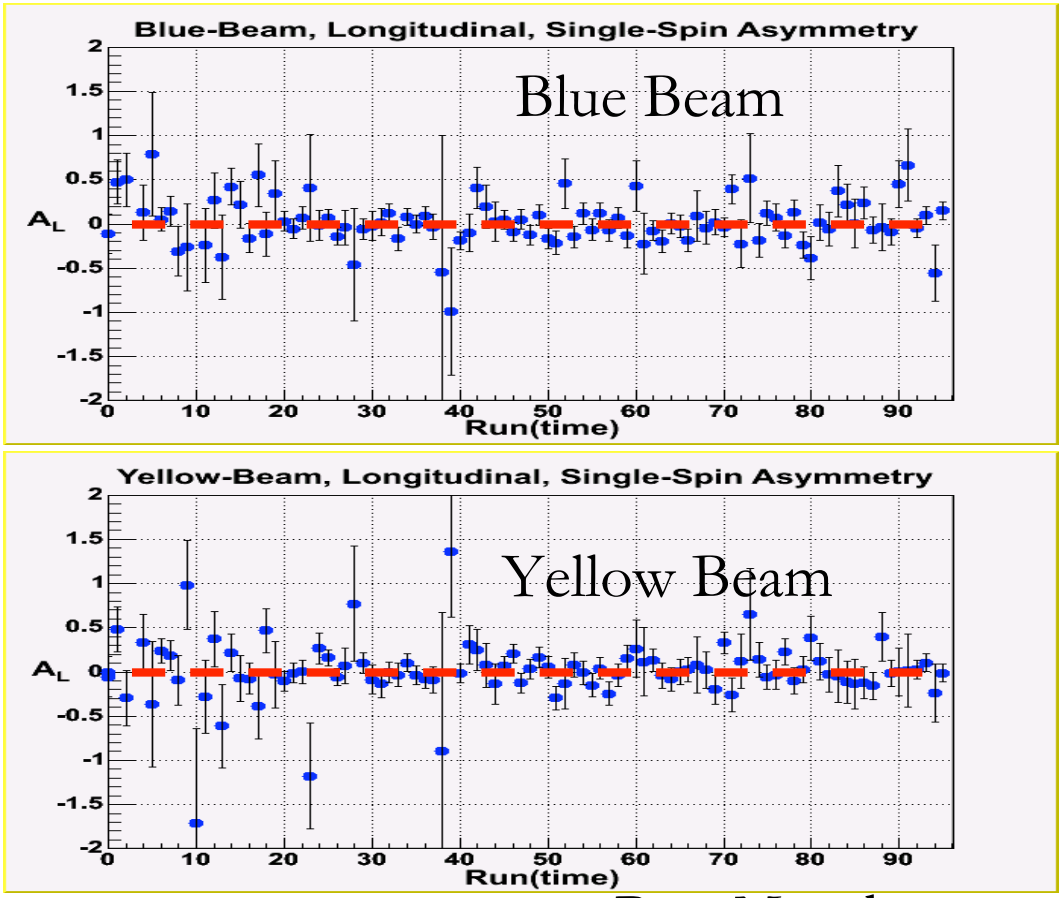


## Full Barrel EMC - installation completed in 2005

In Run-5 120 modules (4800 towers) + SMD + Preshower

Run-4 data taking with high tower and jet patch triggers using 60 modules of BEMC

# Diagnostic Tools: Parity-Violation Single Longitudinal Spin Asymmetries for Inclusive (charged*) Jet Production




$\langle A_L^B \rangle = 0.001(16)$
$\chi^2/\mathrm{dof} = 1.12$

$\langle A_L^Y \rangle = 0.022(16)$
$\chi^2/\mathrm{dof} = 1.06$

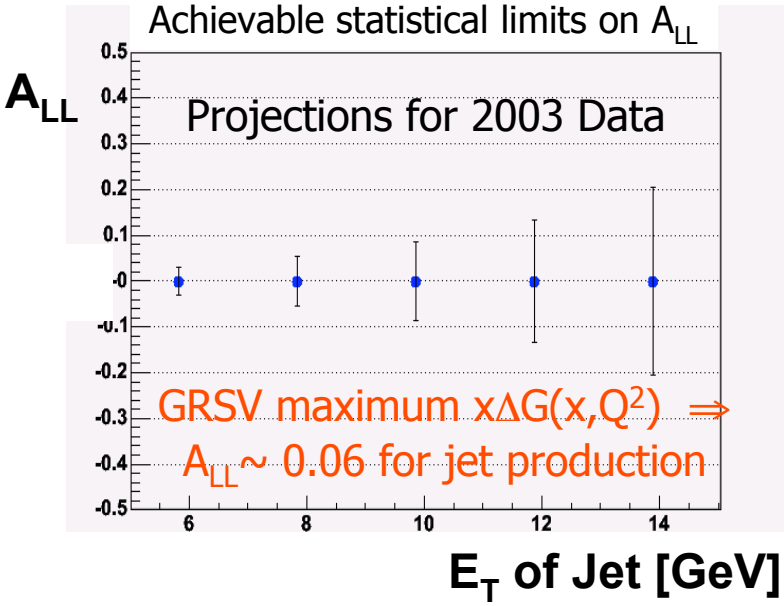
$A_L$'s consistent with 0
( as expected )

*Full jet reconstruction using BEMC waiting final calibration of the calorimeter - coming soon

# Statistical Precision

Achieved in 2003:

- Ave Polarization / Beam ~ 0.25
- RHIC Delivered Integrated Luminosity ~ 0.4 $pb^{-1}$




MORE DATA NEEDED

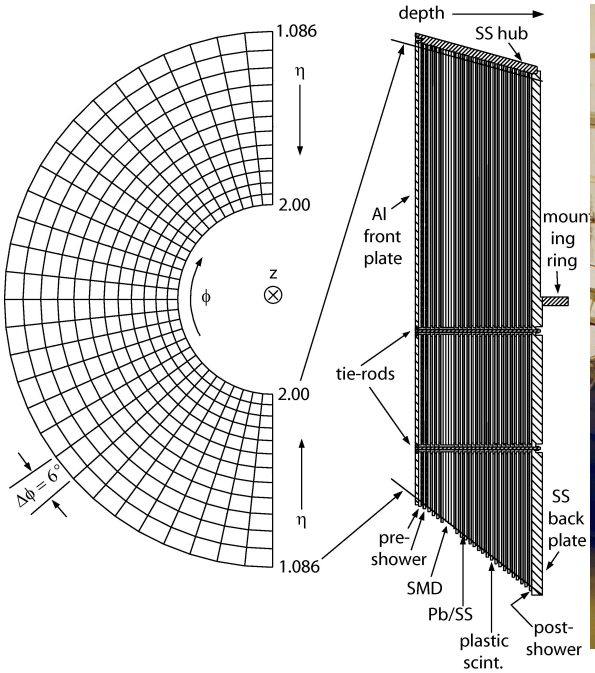
Goal for 2005

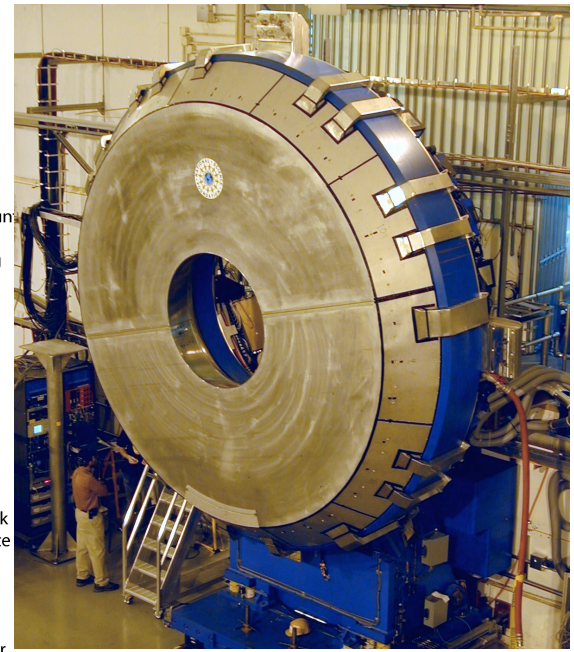
- Ave Polarization / Beam ~ 0.40
- RHIC Delivered Integrated Luminosity ~ 5 $pb^{-1}$

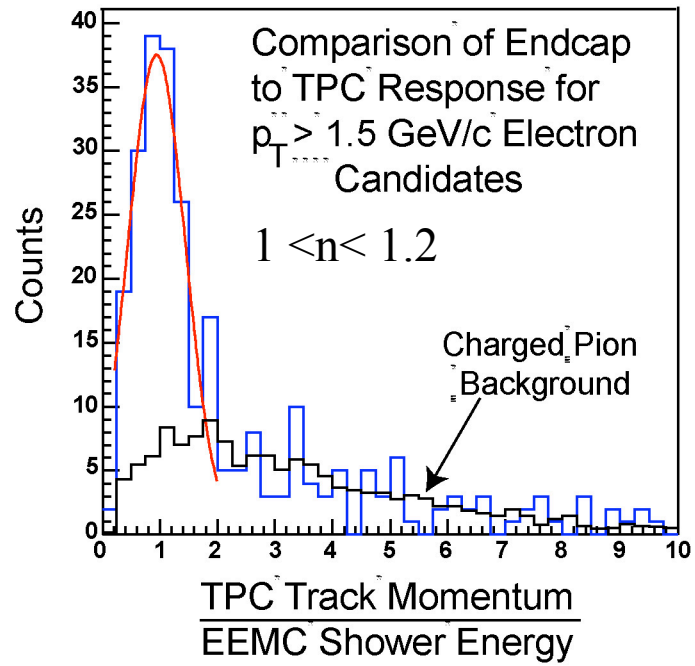
-

# Endcap Electromagnetic Calorimeter - status of upgrades

- 12 sectors of towers, SMD and Pre- and Post-shower detector installed
- Full electronic readout for all 720 towers, 4 sectors of SMD and Pre/Post (~3000 chns)
- 8 remaining sectors of SMD and Pre- and Post-shower electronics will be installed for Y2005






- First EEMC data taking with High Tower trigger (commisioning of jet-patch trigger)
- 4 methods of tower callibration: $\pi^0$ mass reconstruction, MIP tracks, electron tracks and from maching slopes of ADC spectra; relative calibration of SMD from cluster finder
- Present analysis - single and di- photons reconstruction

From $\pi^0$ and jets heading towards photon physics in forward region (rare probes)

# Summary and Outlook

1) STAR spin program well under way. Essential equipment/procedures commissioned during 2002-2003: rotators, local polarimetry, accurate relative luminosity monitors; STAR detector upgrades: EMC's, BBC's, FPD.

2) Run-2: 1st pp collisions with transversly polarized beams
$\Rightarrow$ single transverse spin asymmetries: $A_N(\pi^0$, FPD), $A_N(h^{+/-}$,TPC) and $A_N$(BBC)

3) Run-3: 1st pp collisions with longitudinally polarized beams
$\Rightarrow$ BBC worked well as local polarimeter in STAR
$\Rightarrow$ $\Delta G$ sensitivity in jet production

4) Run-5 goal: $\Delta G$ determination from $A_{LL}$ measurements in mid-rapidity jet production and $\pi^0$ at $\eta>1$ (STAR unique!)

Long term plan:
( continuous effort for luminosity and beam polarization development needed )

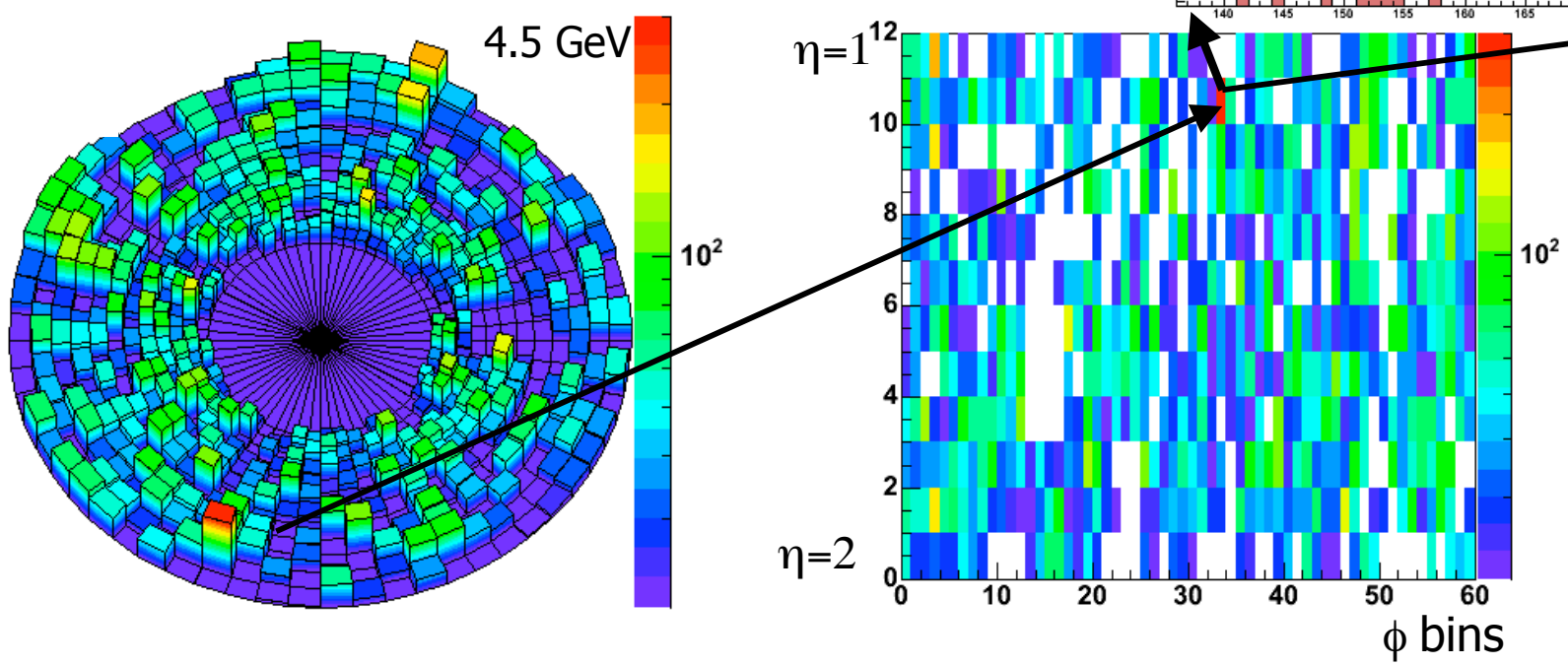
Measurements with rare probes: $A_{LL}(\gamma$ + jet), $A_L^{PV}(W^{\pm})$
and transversity via mid-rapidity jet fragmentation

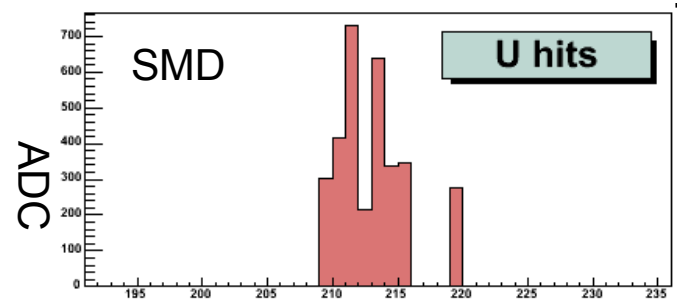
# Cluster Finder under Development

## to start of $\gamma/\pi^0$ reconstruction

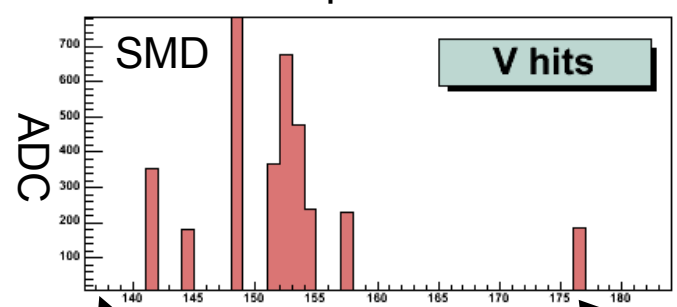
Au-Au event from Run-4
( EEMC HighTower trigger )

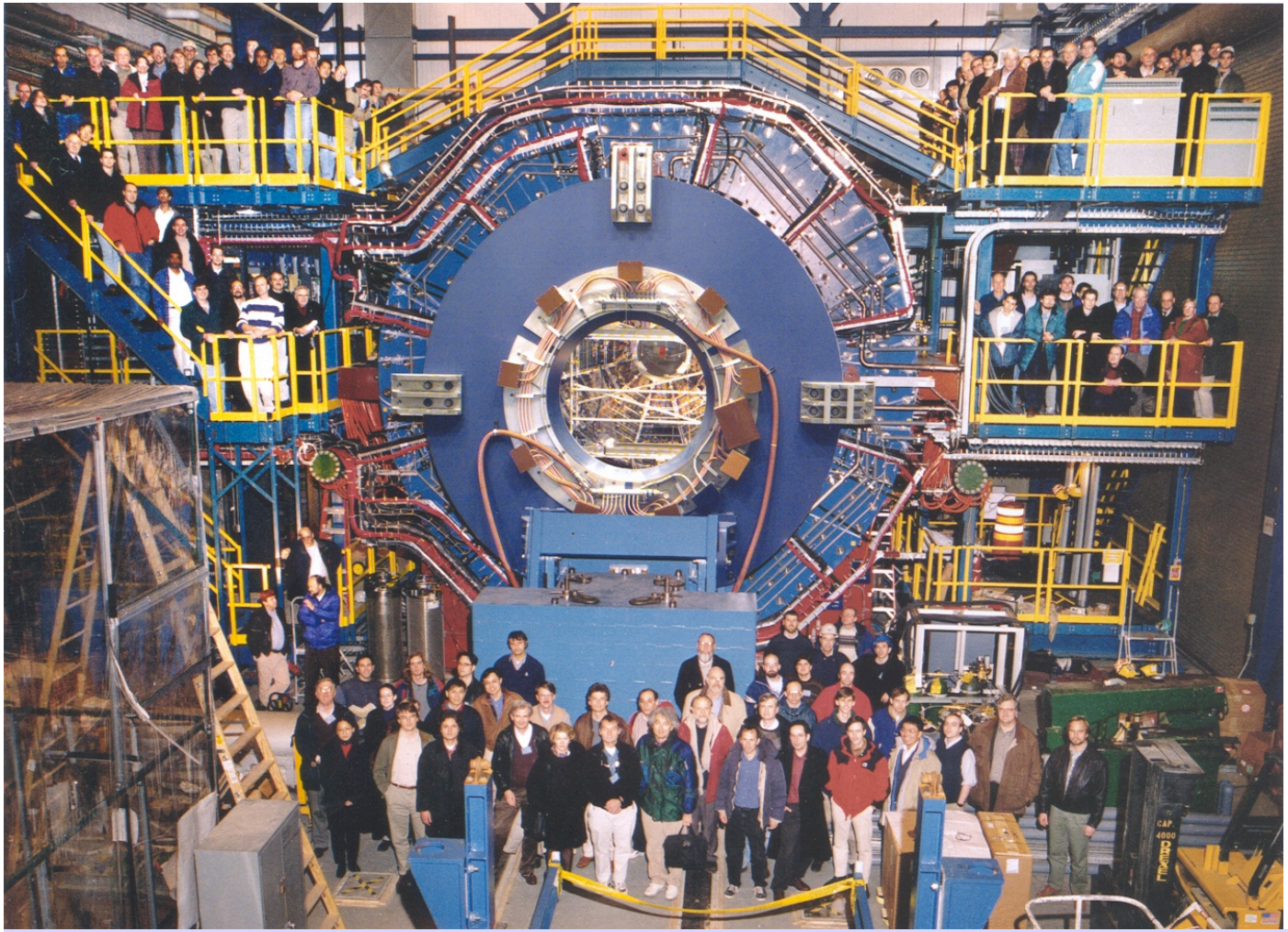
ADC - pedestal corrected




Strip # - within tower





# The STAR Collaboration

**~ 400 collaborators**
**34 institutions**
**8 countries**

**Strong new STAR spin interest from:**
***CalTech, LBNL, MIT, Valparaiso U., Zagreb***

**Brazil:** Sao Paolo
**England:** Birmingham
**Germany:** Frankfurt, MPI - Munich
**China:** IHEP - Beijing, IPP - Wuhan
**France:** IReS - Strasbourg, SUBATECH-Nantes
**Poland:** Warsaw University of Technology
**Russia:** MEPHI - Moscow, JINR - Dubna, IHEP - Protvino

**U.S.:** Argonne, Berkeley, Brookhaven National Laboratories
UC Berkeley, UC Davis, UCLA, Creighton, Carnegie-Mellon, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas, Texas A&M, Washington, Wayne, Yale Univ.