Local Polarimetry for Proton Beams with the STAR Beam Beam Counters

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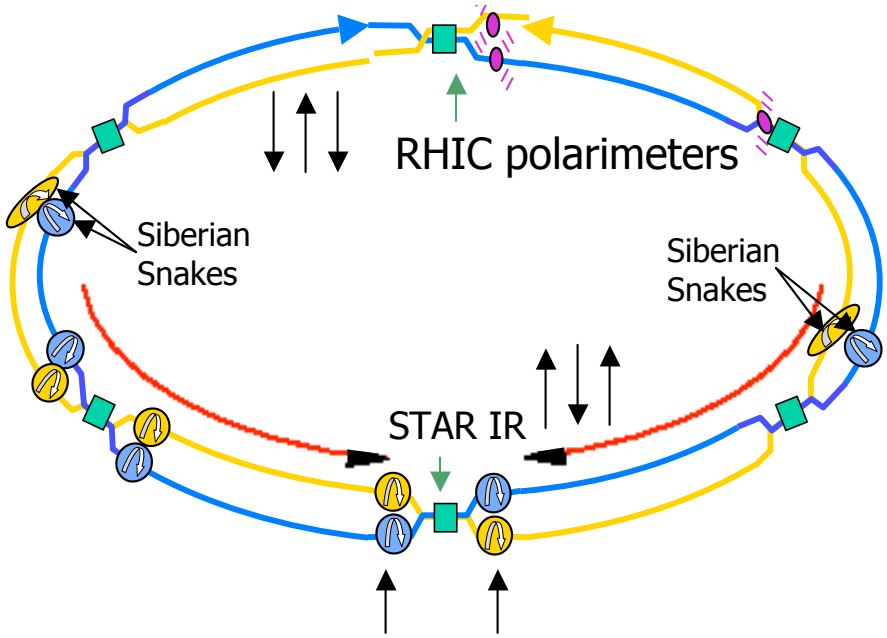
1. Motivation
2. Beam Beam Counters
3. Scaler boards
4. Single transverse spin asymmetries
5. Local polarimetry
6. Summary

Local Polarimetry at STAR - Motivation

RHIC (*Relativistic Heavy Ion Collider*) - polarized pp collider $\sqrt{s} = 200 - 500$ GeV



Spin Rotators

Off = transverse polarization
On = longitudinal polarization

- two siberian snakes in each ring:
  stable polarization direction at RHIC - vertical beam polarization measured by RHIC polarimeters
- a pair of spin rotators in each ring around STAR (and PHENIX) IR (Interaction Region):
  longitudinal polarization at two IRs for A_{LL} measurement to determine gluon polarization

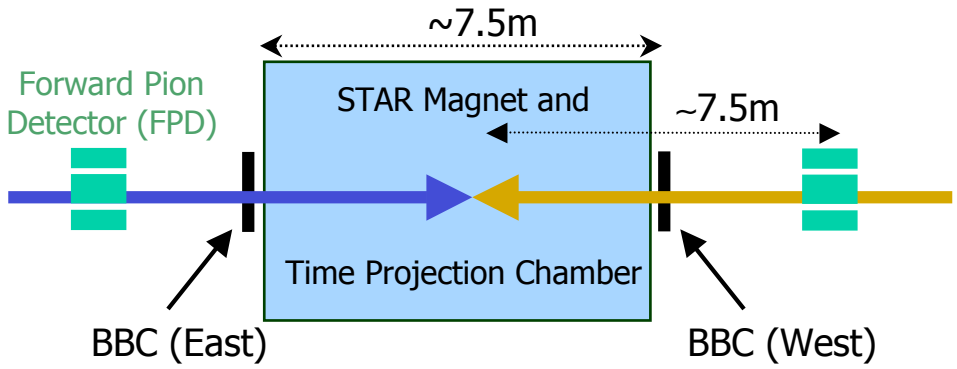
Need to measure polarization direction at IR
- Local Polarimetry

How?

- find a process with non-zero A_N at 200 GeV
- make fast (< hour) asymmetry measurement with ϕ-symmetric detector

Beam Beam Counters at STAR

- scintillator annulus installed around the beam pipe, on the east and west poletips of STAR magnet at ±3.74m from IR for detection of charged particles (no identification) in $2 < |\eta| < 5$

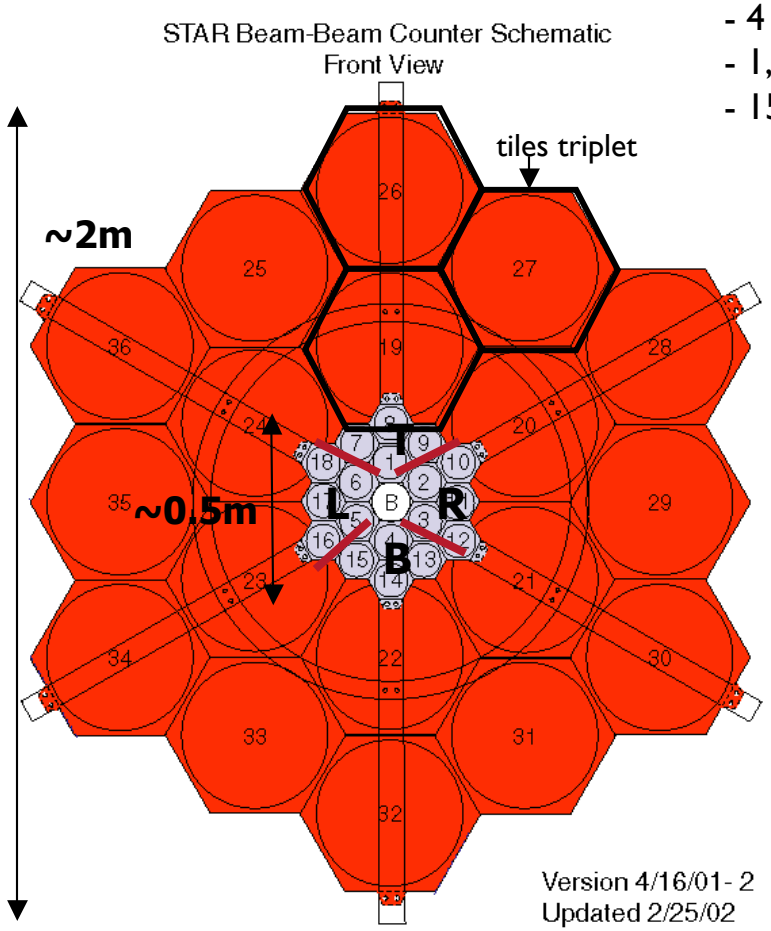


Schematic side view of the STAR detector

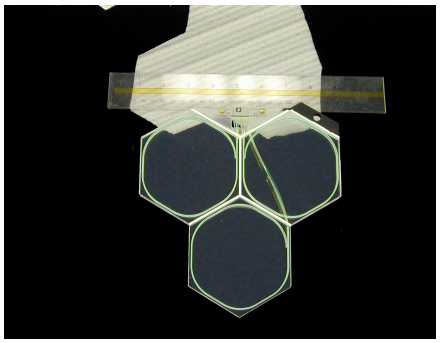
A coincidence condition between BBC East and West ($3.4 < |\eta| < 5$) suppresses beam-gas background and used for:

- triggering in pp (minimum bias, jet triggers)
- (relative) luminosity measurements for A_{LL}
- local polarimetery

Beam Beam Counters Instrumentation



- 1 cm thick scintillator
- 4 optical fibers for light collection
- 1,2 or 3 tiles connected to a PMT
- 15 photoelectron/MIP



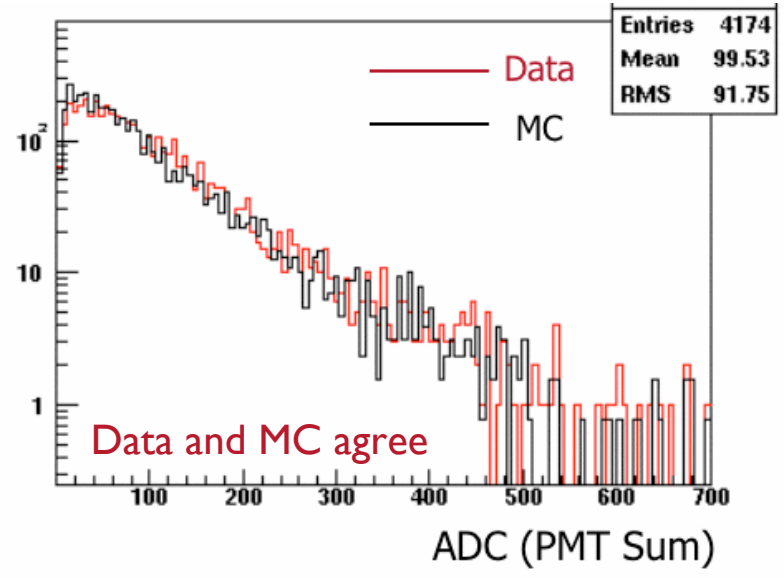
- Large hexagonal annulus:

- inner (outer) diameter 38cm (193cm);
- of 18 pixels, covering $2.1 < |\eta| < 3.3$ and $0<\phi<2\pi$;
- 8 PMT, no timing information

- Small hexagonal annulus:

- inner (outer) diameter 9.6cm (48cm);
- of 18 pixels, covering $3.3<|\eta|< 5.0$ and $0<\phi<2\pi$
- 16 PMT - feasible segmentation (i) two bins in η and (ii) azimuthal *Top/Bottom/Left/Right*, timing information

Beam Beam Counters - trigger data



Monte Carlo (MC) = Pythia+Geant for STAR

BBC response simulator:

- Light yield: dE/dE(MIP)x15 photoelectrons(MIP)= N photoel.
- Single photoelecton resolution = 30%
- PMT gain = 0.30 pC/photoelectron
- ADC bin = 0.25 pC
- Time resolution = 900 ps

pp minbias trigger condition = BBC East and West coincidence ($3.4 < |\eta| < 5$)

Cross section: $\sigma_{BBC} = \sigma_{tot}(pp) \times \underbrace{acc(BBC)}_{\text{from MC}} = 51\text{ mb} \times 0.53 \sim 27\text{ mb}$ (87% of $\sigma_{inelastic-s.diffraction}$)

In agreement with RHIC luminosity measurements (Van der Meer scans)

$L = Rate(BBC)/\sigma_{BBC}$ e.g. at $L = 10^{30}\,cm^{-2}\,s^{-1}$ the Rate(BBC) ~ 27 kHz

DAQ limitations - cannot take data at this rate

Solution: deadtimeless scaler boards -

- very useful when 'details' such as ADC information not needed, but statistics is an issue

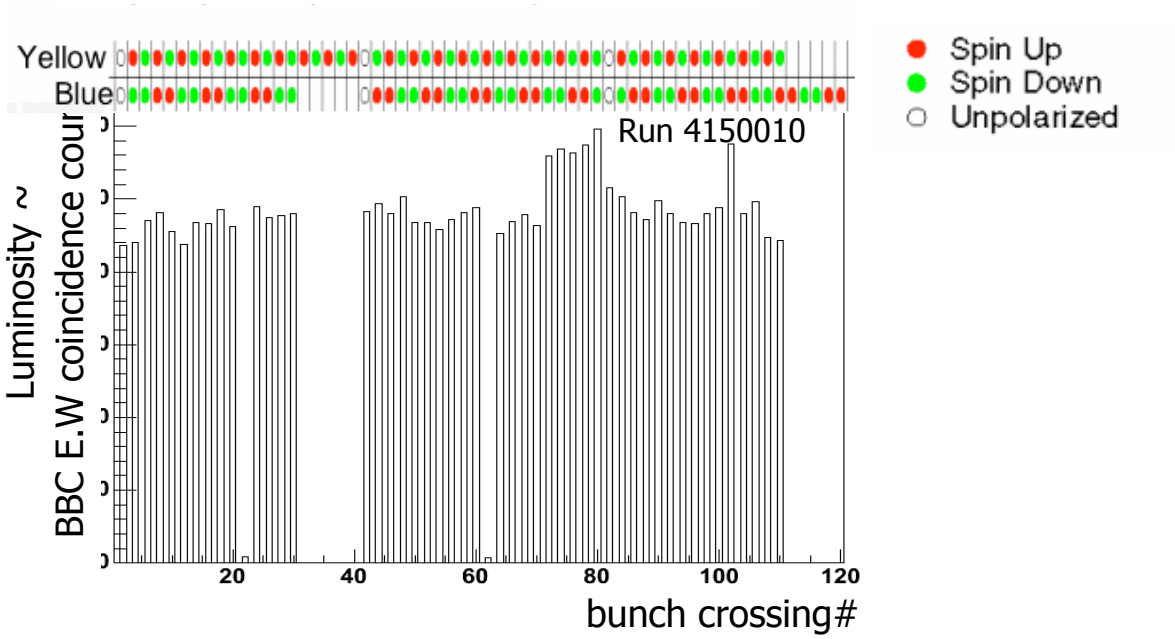
STAR Scaler Boards

The scaler board - 24 bit and 10 MHz VME memory module

It has 2^{24} cells, each cell 40-bit deep to keep continuous (deadtimeless) record for up to 24 hours operation at 10 MHz
(10 MHz clock corresponds to bunch crossing frequency at RHIC, 107 ns)

24 input bits = 7(bunch crossing) + 17(physics inputs)
$2^{17}=10^5$ combinations

Physics input bits = data from *fast* detectors e.g. BBC, which consists of discriminator outputs from individual PMTs as well as logic levels produced by the STAR Level 0 trigger electronics



Example of the BBC scaler bits

Bit#	Input	
1		BBC East PMT#i, i=1-16
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17	BBC E.W (Luminosity bit)	
18	BX1	Bunch crossing number
19	BX2	
20	BX3	
21	BX4	
22	BX5	
23	BX6	
24	BX7	

…and same for BBC West

BBC + Scaler Boards - Applications (1)

- Relative luminosity measurement for an asymmetry determination

e.g.

$$A_{LL}\left(\vec{p}+\vec{p}\rightarrow \text{jet}+X\right)=\frac{1}{P_1P_2}\times\frac{\left(N_{\uparrow\uparrow}+N_{\downarrow\downarrow}\right)-R\left(N_{\downarrow\uparrow}+N_{\uparrow\downarrow}\right)}{\left(N_{\uparrow\uparrow}+N_{\downarrow\downarrow}\right)+R\left(N_{\downarrow\uparrow}+N_{\uparrow\downarrow}\right)}$$

$P_{1(2)}$ -beam polarization, from CNI polarimetry at RHIC

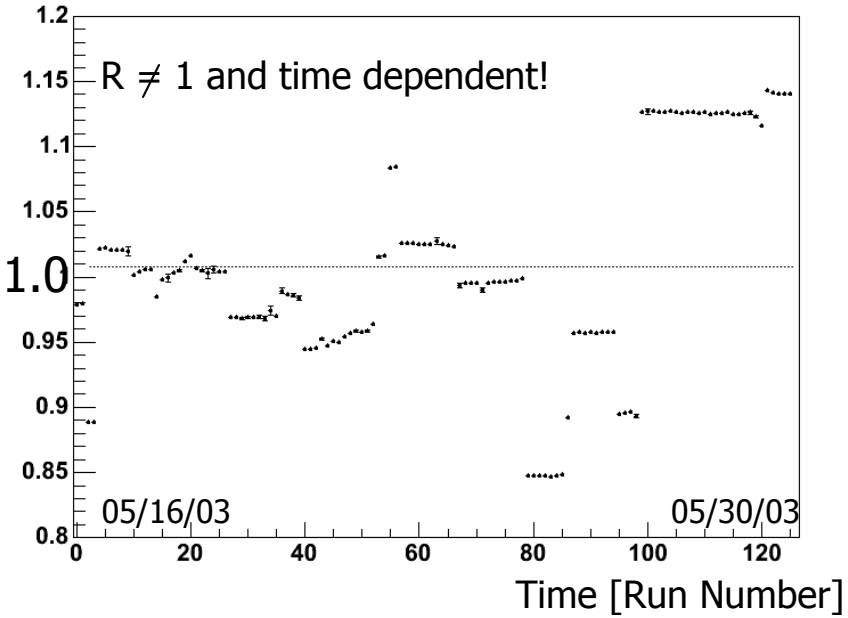
N_i where $i=\uparrow\uparrow,\uparrow\downarrow,\downarrow\uparrow,\downarrow\downarrow$ – spin dependent yields

$$R=\frac{\mathcal{L}_{\uparrow\uparrow}+\mathcal{L}_{\downarrow\downarrow}}{\mathcal{L}_{\uparrow\downarrow}+\mathcal{L}_{\downarrow\uparrow}}$$ - relative luminosity

Precision of relative luminosity measurement critical: for A_{LL} ~1% $\delta A_{LL}/A_{LL}$ ~5% if $\delta R/R\sim10^{-3}$

Requirements for a luminosity process/detector: - high rates (BBC + scaler boards)

- small measured background



Relative luminosities calculated for each STAR run using BBC scaler board data:

- statistical uncertainty $\delta R_{stat}\sim 10^{-4}-10^{-3}$

- systematic uncertainty (from comparison between BBC and ZDC,*Zero Degree Calorimeter*) $\delta R_{syst} < 10^{-3}$

BBC + Scaler Boards - Applications (2)

- BBC Transverse Single Spin Asymmetries

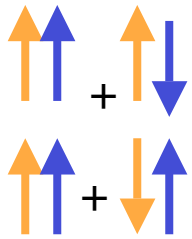
Single spin asymmetries measured for p+p -> A + X, where A – hit(s) in the BBC

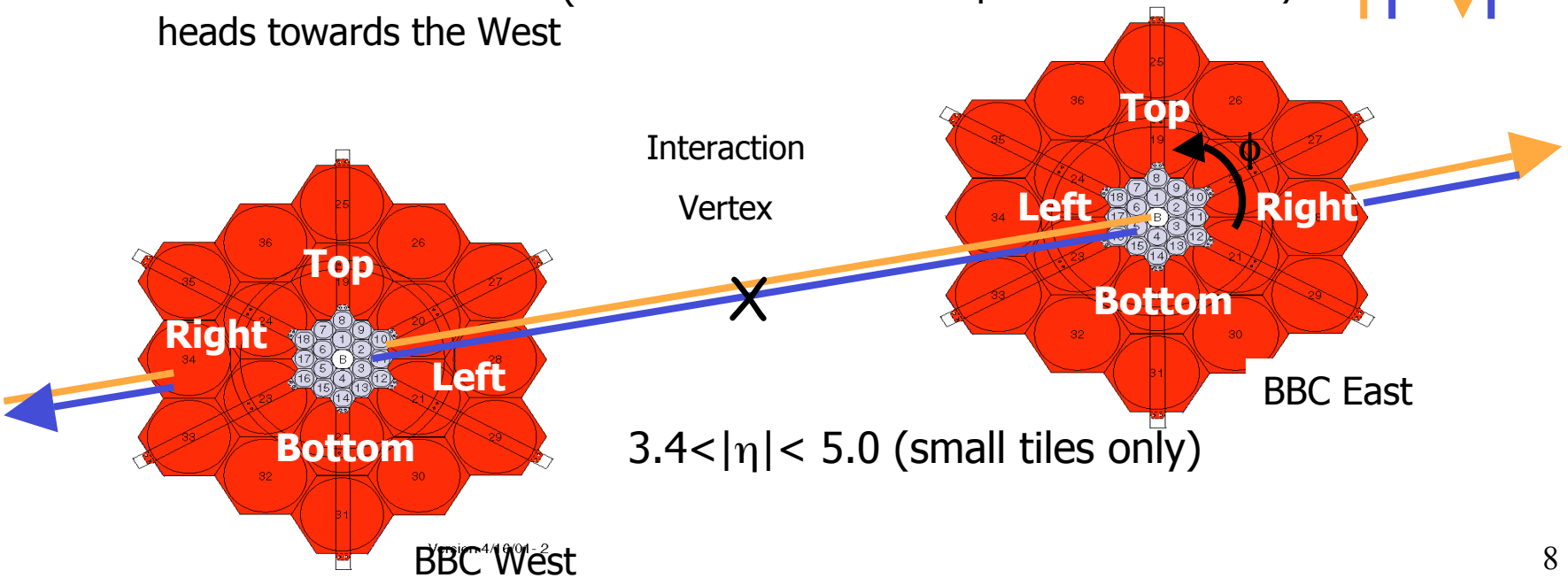
$$\varepsilon_{LR} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}} \sim \begin{cases} P_{beam}^{vert} \times A_N \times \langle \cos(\phi) \rangle & \text{Left-Right} \\ P_{beam}^{rad} \times A_N \times \langle \sin(\phi) \rangle & \text{Top-Bottom} \end{cases}$$

$N_{L(R)}$ – number of counts in BBC (East or West - small annuli) counted every bunch crossing by the scaler system

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

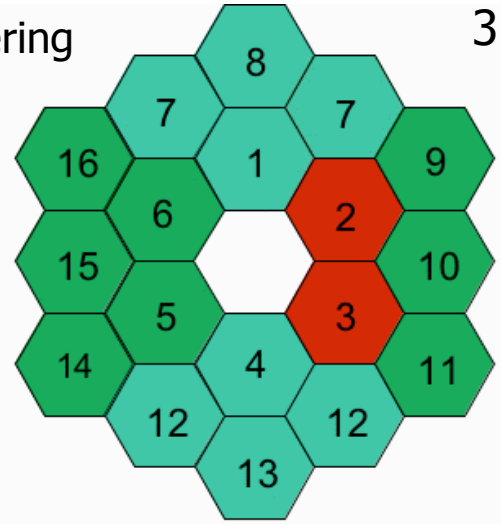
1. **Polarized Yellow beam** (sum over Blue beam polarization states) heads towards the East
2. **Polarized Blue beam** (sum over Yellow beam polarization states) heads towards the West





BBC Event Selection for Asymmetry Measurement

Right scattering

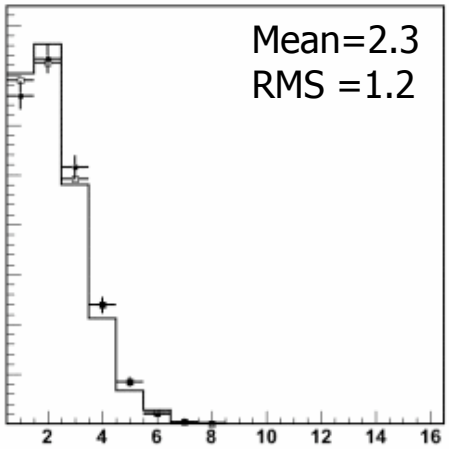


At least one tile hit

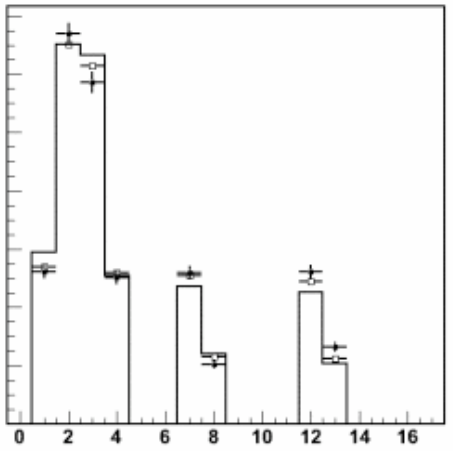
Tile can be hit

Tile is not hit

$3.9 < \eta < 5.0$



Number of hits

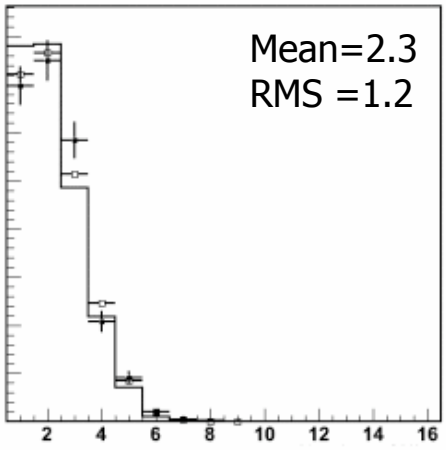


PMT number

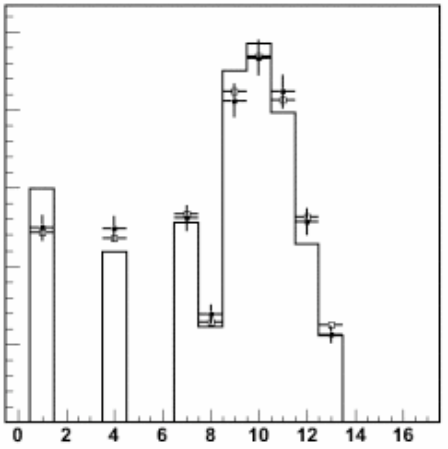
Monte Carlo simulation

• Data

$3.4 < \eta < 3.9$



Number of hits

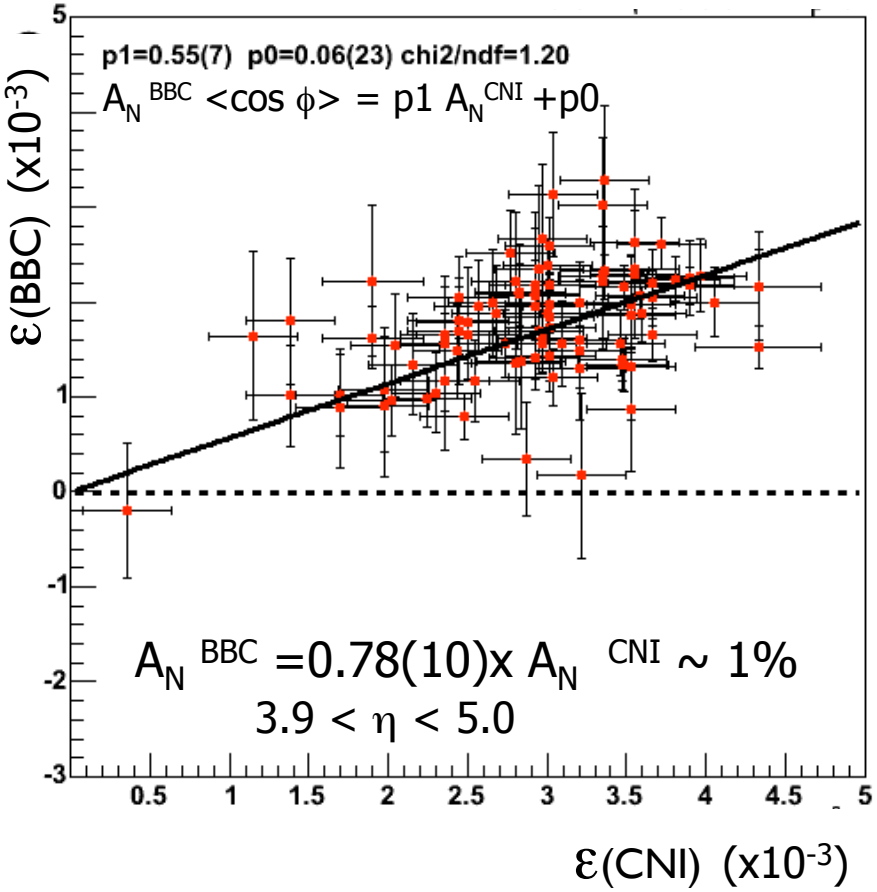


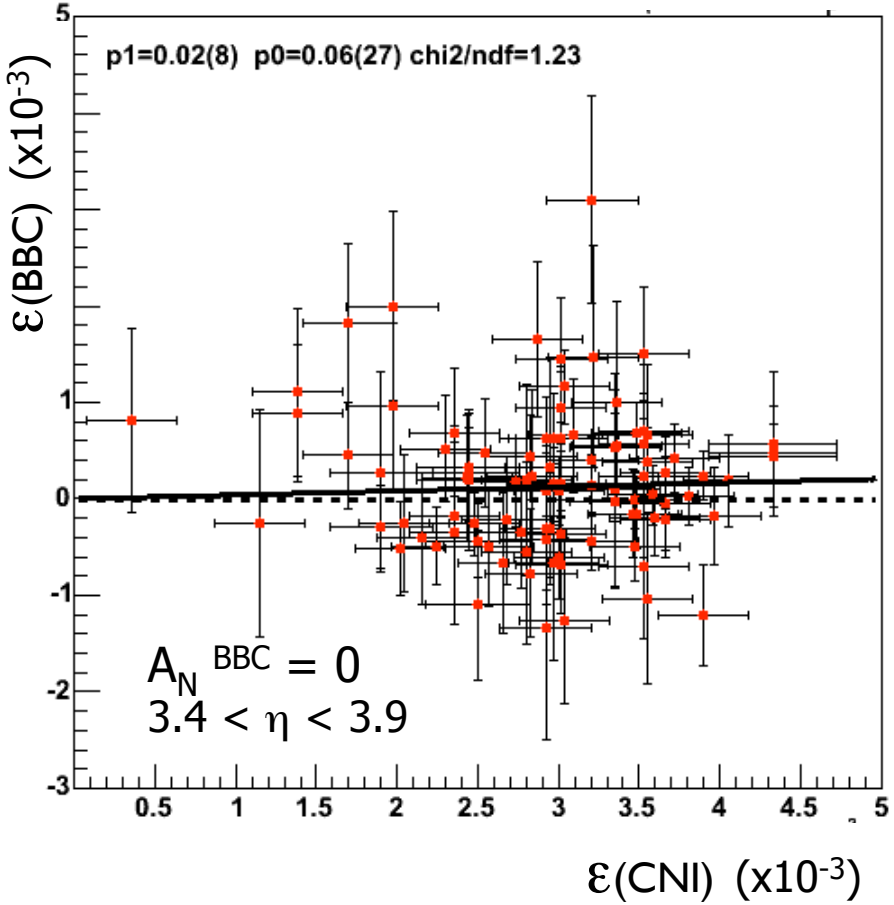
PMT number

Transverse Single Spin Asymmetries
BBC (Preliminary) Results

$$\varepsilon^{BBC} = \mathbf{P}_{\mathbf{beam}}^{\mathbf{vert}} \times \mathbf{A}_{\mathbf{N}}^{\mathbf{BBC}} \times \langle \cos(\phi) \rangle$$

$$\mathbf{P}_{\mathbf{beam}}^{\mathbf{vert}} = \varepsilon^{CNI} / \mathbf{A}_{\mathbf{N}}^{\mathbf{CNI}}$$

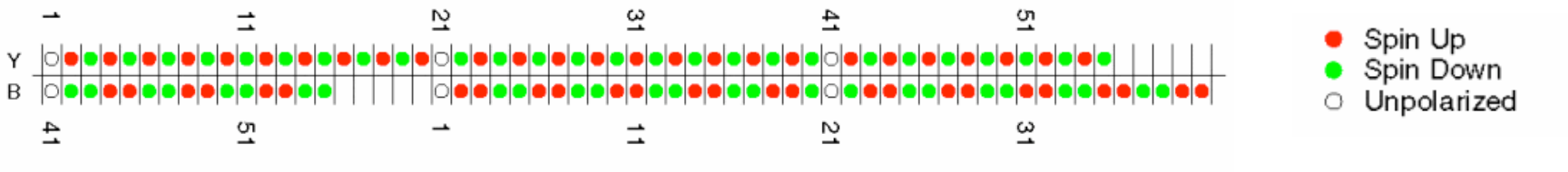




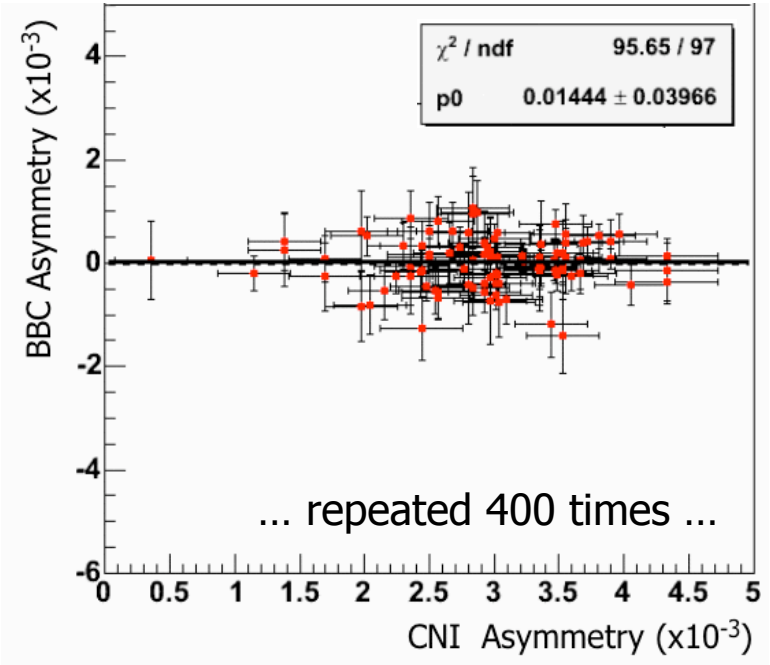
- Unexpected A_N of unknown origin measured with the BBC
- Strong pseudorapidity dependence of A_N for $x_F>0$ and $A_N = 0$ for $x_F<0$
- $\delta\varepsilon(\text{syst}) < \delta\varepsilon(\text{stat})$ (next slide)

Systematic Study - Random Fill Pattern Analysis

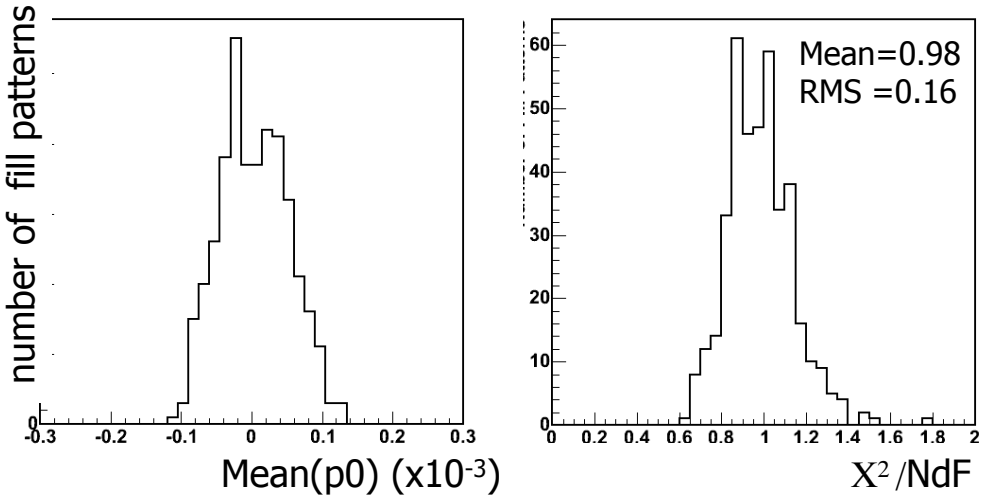
1. Method: take true fill pattern and mix assignment of spin up and down bunches (red and green points) to the bunch crossing number



2. Result for one random fill pattern

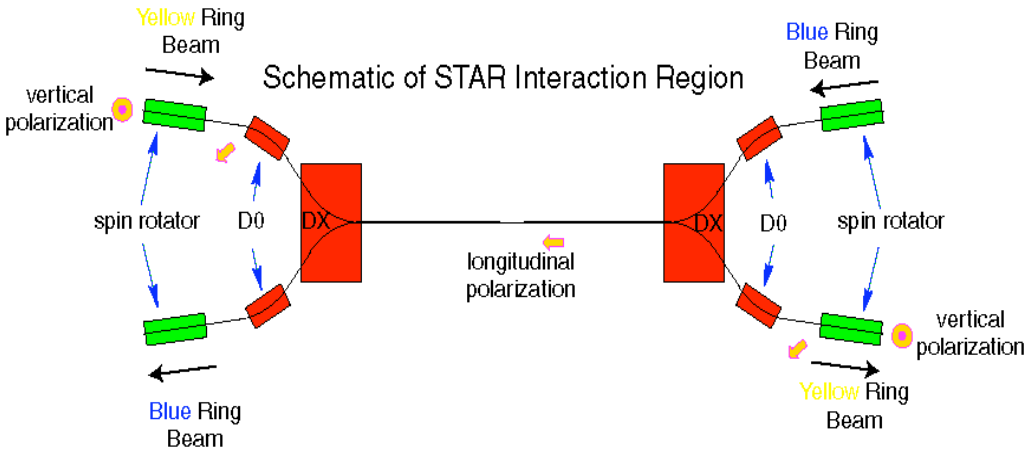


3. 400 random fill patterns



- Mean=10^{-5}
- RMS=5×10^{-5} ← $\delta\varepsilon$(syst)

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

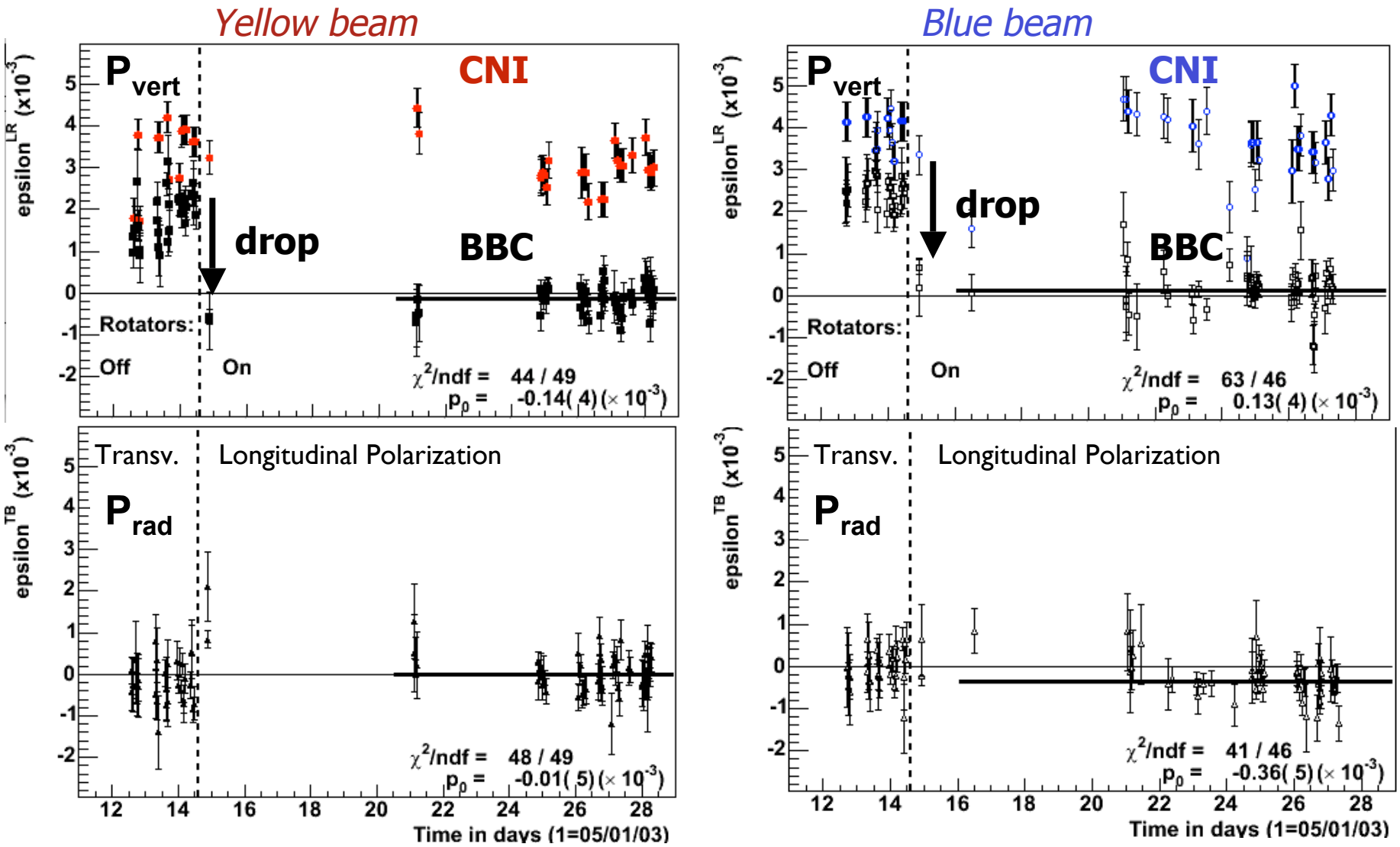
BBC - local polarimeter at STAR

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

BBC - local polarimeter at STAR



- Vertical and radial polarization components smaller than 5%
- *Longitudinal beam polarization at STAR*

Summary

1. Unexpected A_N of unknown origin measured with the Beam Beam Counters

   $p^{\uparrow} + p \rightarrow A + X$ where $A - \text{hits(s)}$ in the BBC

   - Strong pseudorapidity dependence of A_N for $x_F>0$

     $3.9 < \eta < 4.9$ $A_N(BBC)=0.78(10)xA_N(CNI)$ ~1% with $A_N(CNI)=0.0118(10)$

     $3.4 < \eta < 3.9$ $A_N(BBC)=0$

   - A_N (BBC)= 0 for $x_F<0$

2. The BBC was used to:

   - tune spin rotators needed to get longitudinally polarized beams at STAR IR
   - monitor on-line transverse and radial beam polarization components. They are found to be small: $P_{rad(vert)} < 5\%$.

   The BBC worked very well as a fast, non-distructive polarimeter

3. Other applications of the BBC+scaler boards - to monitor luminosity and measure relative luminosities R of colliding proton beams (critical for the measurement of A_{LL} /ΔG)
   R - known at the level of 10^{-3} ($\delta R_{stat}=10^{-3}$ - 10^{-4} and $\delta R_{syst}<10^{-3}$)

Institutions participating in this project: BNL, MIT, Penn State, UC Berkeley, UCLA