Local polarimetry at RHIC experiments

Manabu Togawa

RIKEN BNL Research Center

XIIIthInternational Workshop on Polarized Sources, Targets & Polarimetry, Sep. 7

Supported by RIKEN special postdoctoral researcher

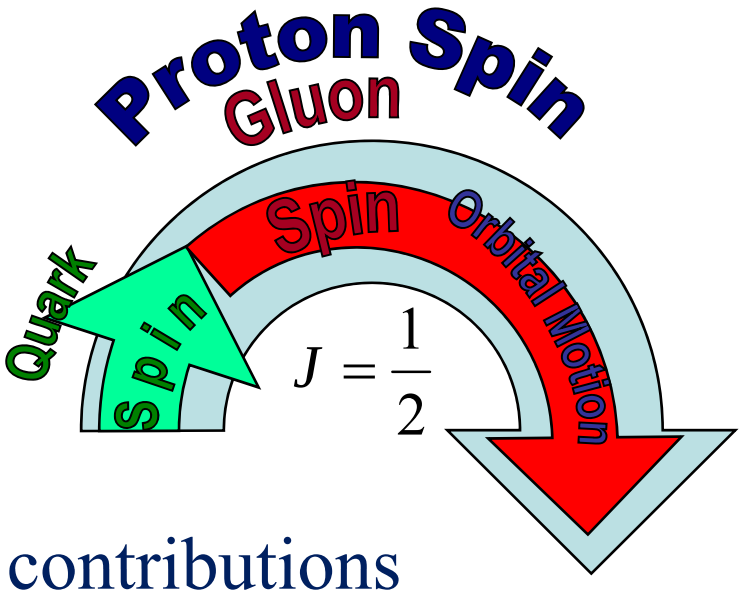
Outline

- RHIC spin program
- Local polarimetry
  - Performed by very forward neutron A_N (at PHENIX) and charged particles A_N (STAR)
- First polarized pp collision at $\sqrt{s} = 500$ GeV
  - So far $\sqrt{s} = 62$ and 200 GeV are performed
- Origin of these A_N
- Discussion
- Summary

RHIC spin program

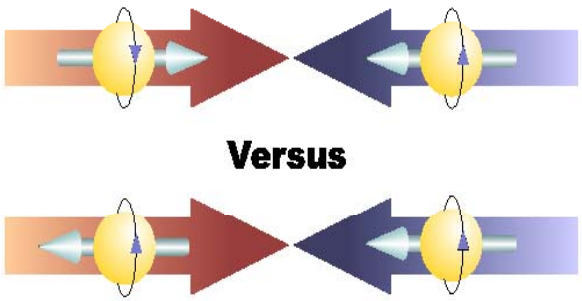
- Understanding of proton spin structure
  - Spin puzzle

$$\text{Proton spin}: \quad \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + \Delta L$$



  - Polarized DIS extracts quark contribution $\Delta\Sigma \sim 0.25$

- RHIC spin program : gluon and sea contributions

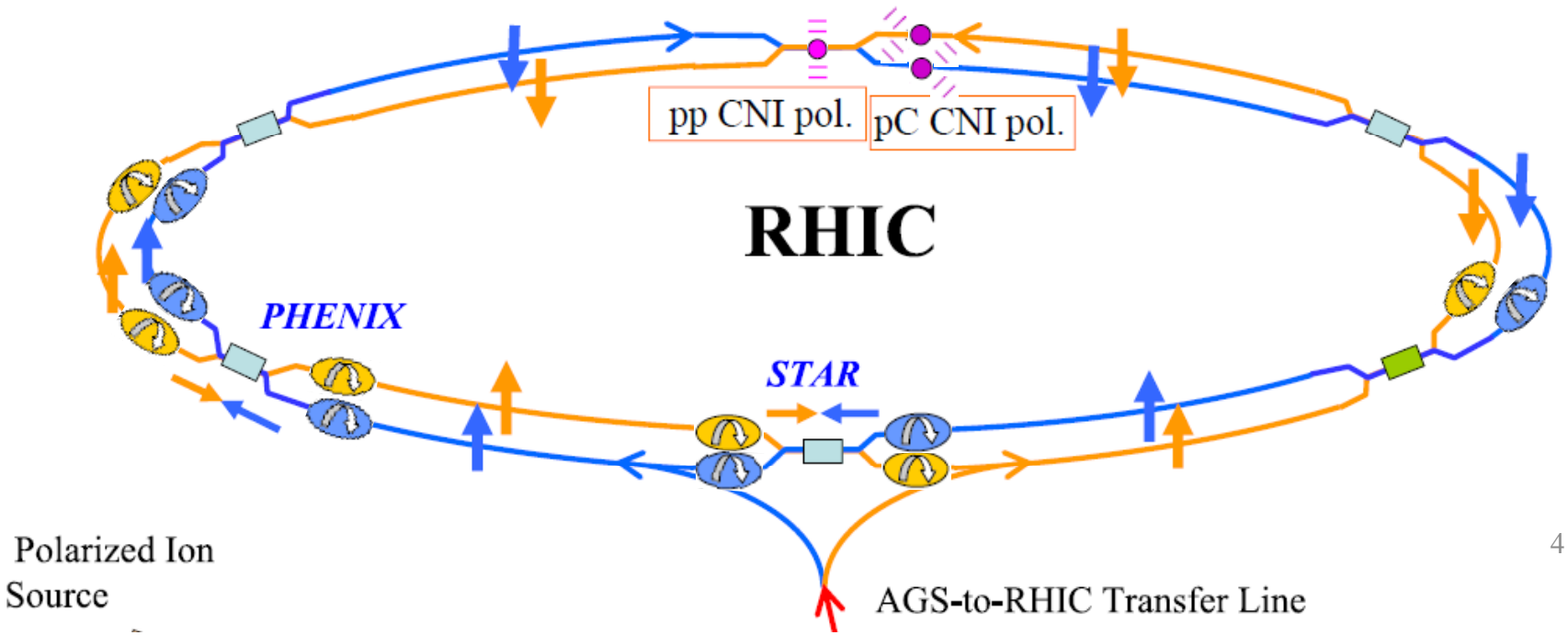


$$A_{LL} \equiv \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \qquad A_{LL}^{g+g} \sim \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{g+g}$$

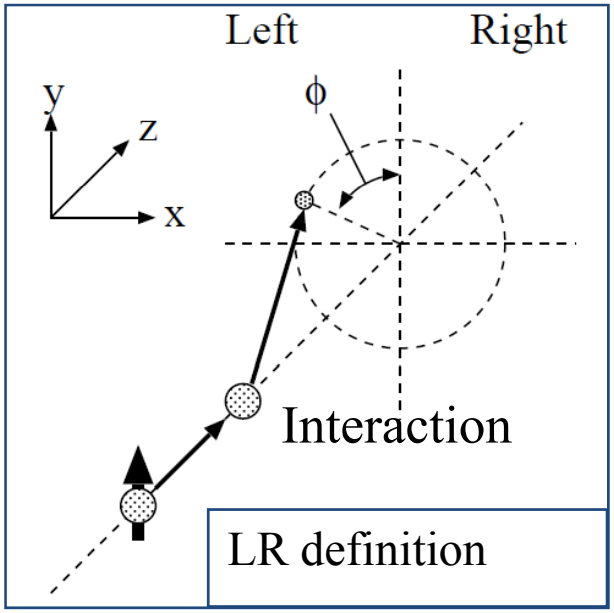
Needs longitudinal polarized beams

Polarized proton beams at RHIC

- Proton spin is keeping in transverse direction
  - Keeping by Siberian snake magnet
  - Polarization is measured by pC (pp) and CNI polarimeter.
- Spin is rotated to longitudinal at collision points
  - Rotated by Spin rotator magnet
  - Spin direction is monitored by Local polarimeter



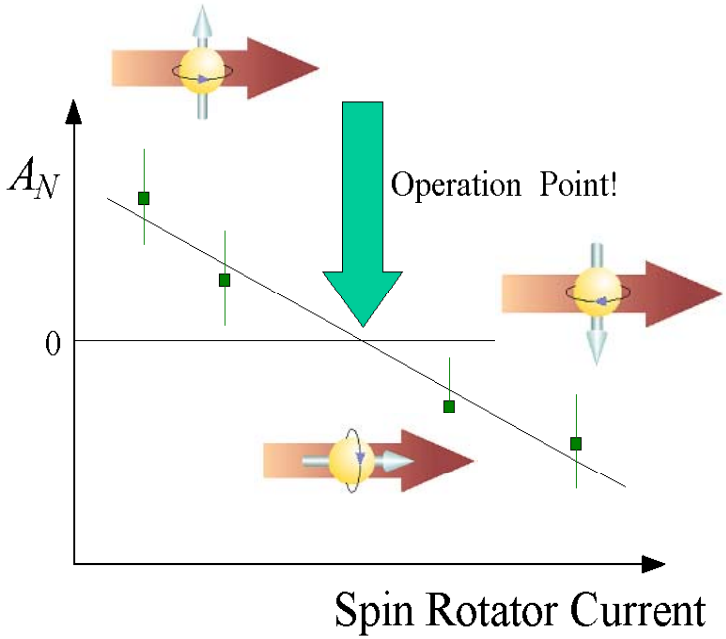
Local polarimetry



By measuring A_N

$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}, \quad A_N = \frac{1}{P} \cdot \varepsilon_N$$

in any produced particle from polarized proton collision,



Spin rotator OFF (Transverse run)
- pC CNI pol. → Finite A_N^{pC}
- Local pol → Finite A_N

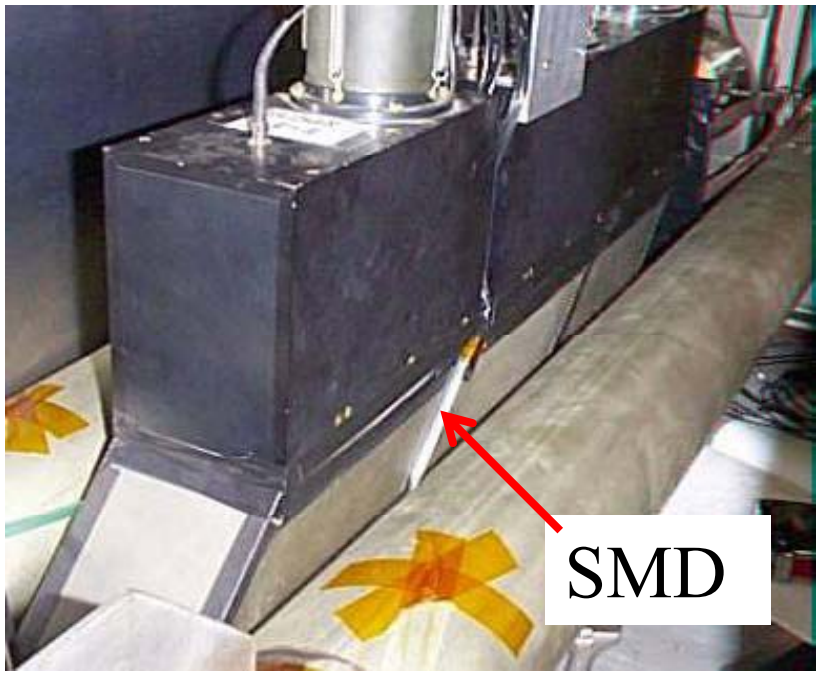
Spin rotator ON (Longitudinal run)
- pC CNI pol. → Finite A_N^{pC}
- Local pol → A_N=0

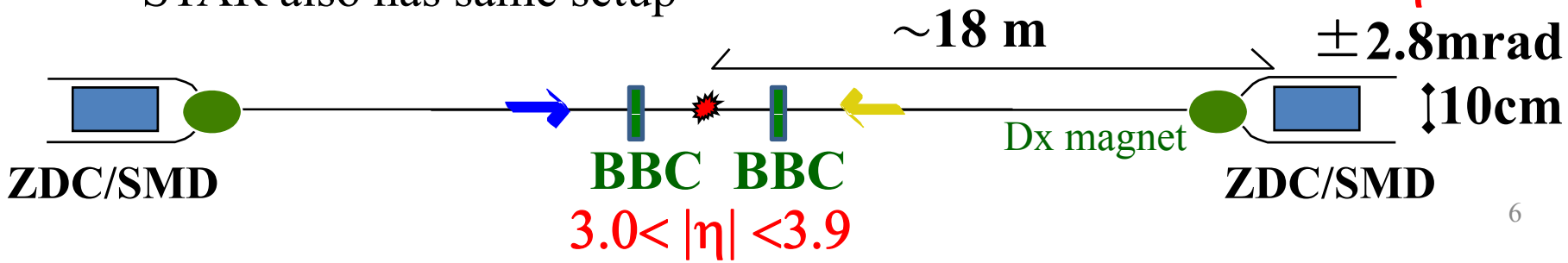
Local polarimetry is necessary in each experiment

What we measure at PHENIX

Very forward neutron A_N at ZDC

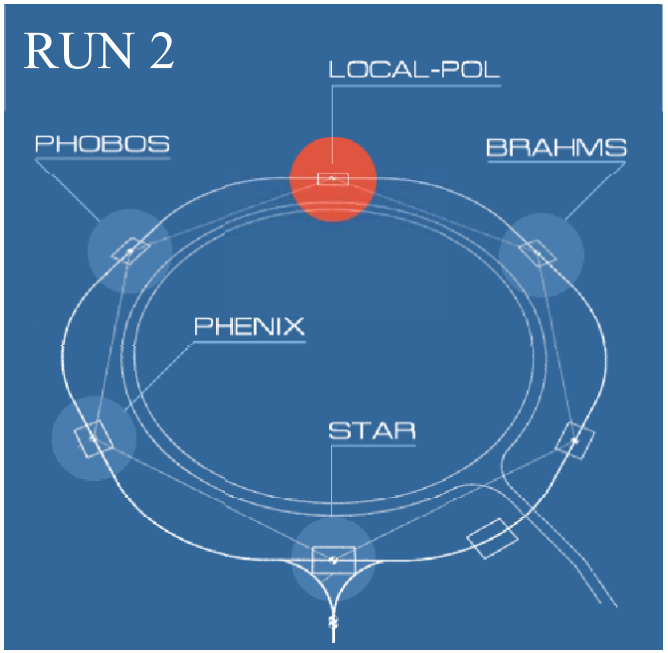
- ZDC (Zero Degree Calorimeter)
  - 3 modules : 5.1 λ_I
    (1.7 λ_I 50 X_0 for each module)
  - $\Delta E/E \sim 20\%$ for 100 GeV neutron
- SMD (Shower Max Detector)
  - Sintillator hodoscope in x and y
  - ~1 cm position resolution for 50 GeV neutron (by simulation)
- This is global detector at RHIC
  - STAR also has same setup



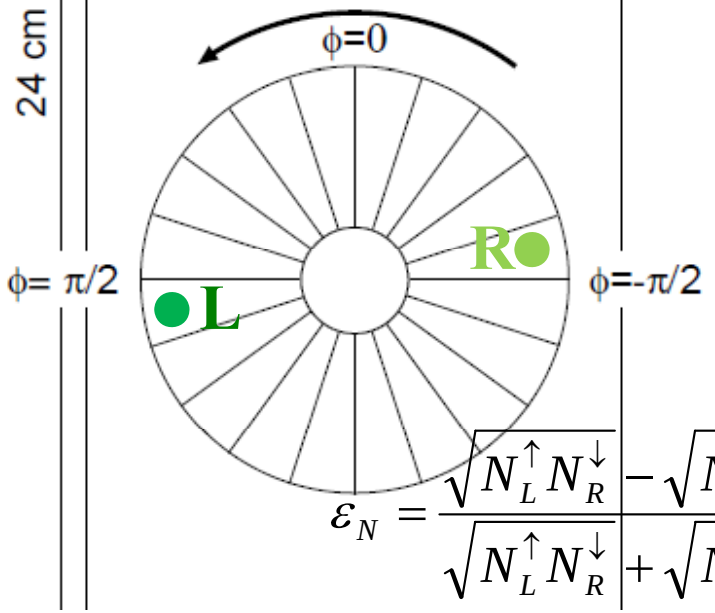


Very forward neutron A_N

- Discovered at RHIC-IP12 experiment (2001-2)
  - (First) pol. pp collision at $\sqrt{s}$ = 200 GeV
  - -10% in forward kinematics
  - Consistent with zero in backward

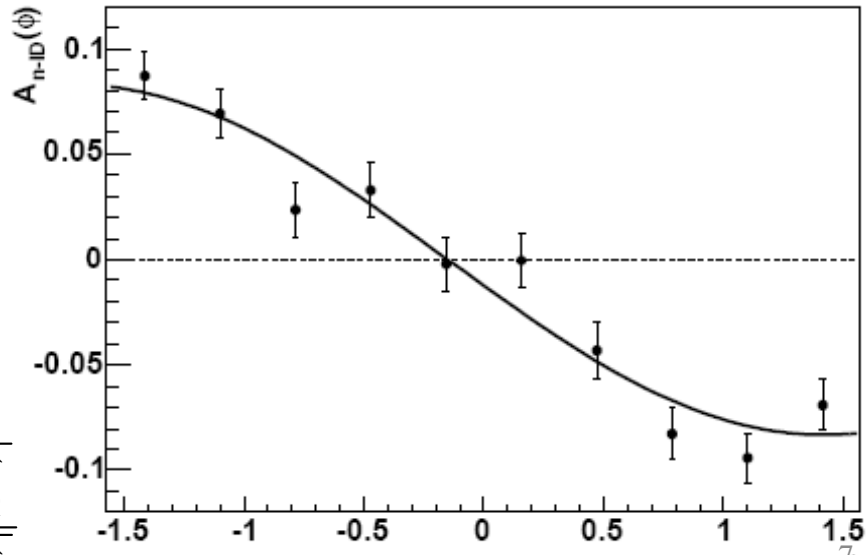


Detector acceptance



$$\varepsilon_N = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

Asymmetry for neutron ID sample



Phys. Lett. B650 : 325-330 (2007)

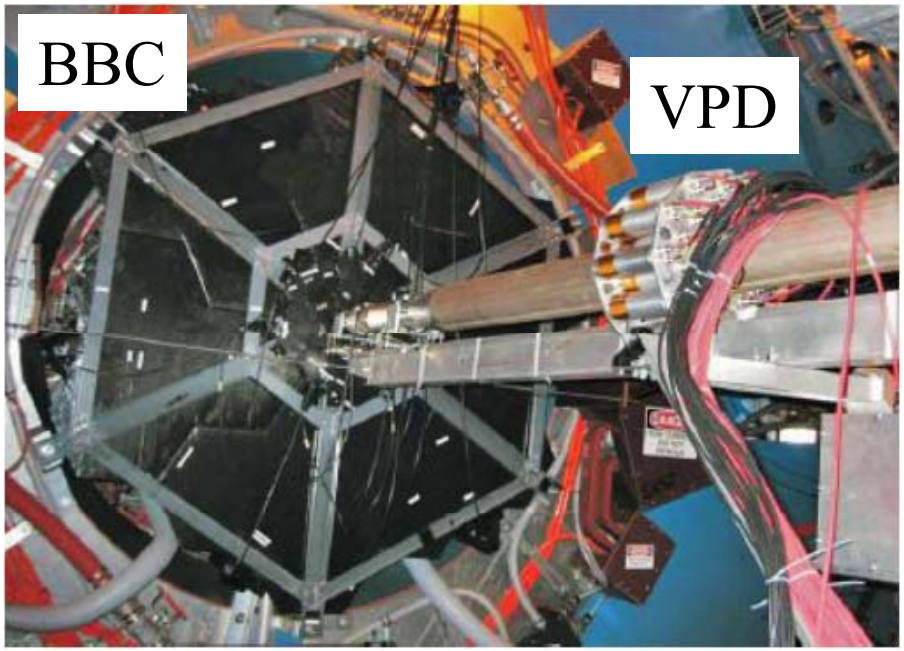
What we measure at STAR

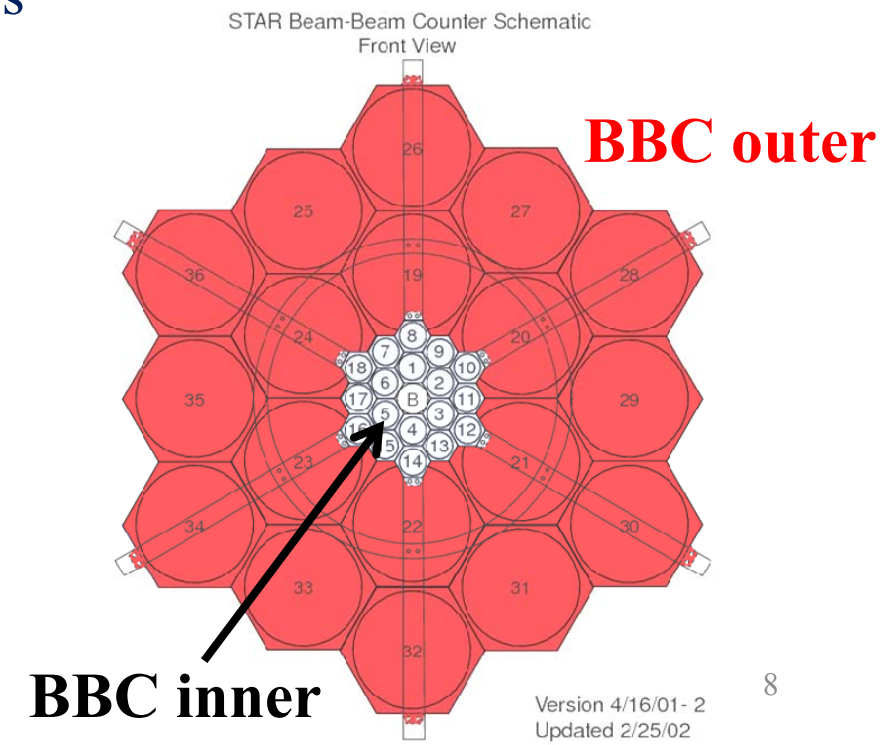
Forward charged particle A_N at BBC

- BBC (Beam Beam Counter)
  - Hexagonal scintillator
- VPD (Vertex Position Detector)
  - ¼ inch Cherenkov radiator

  → Both are counting charged particles

Detector	η range
BBC (outer)	3.3 – 3.9
BBC (inner)	3.9 – 5.0
VPD	4.2 – 5.0

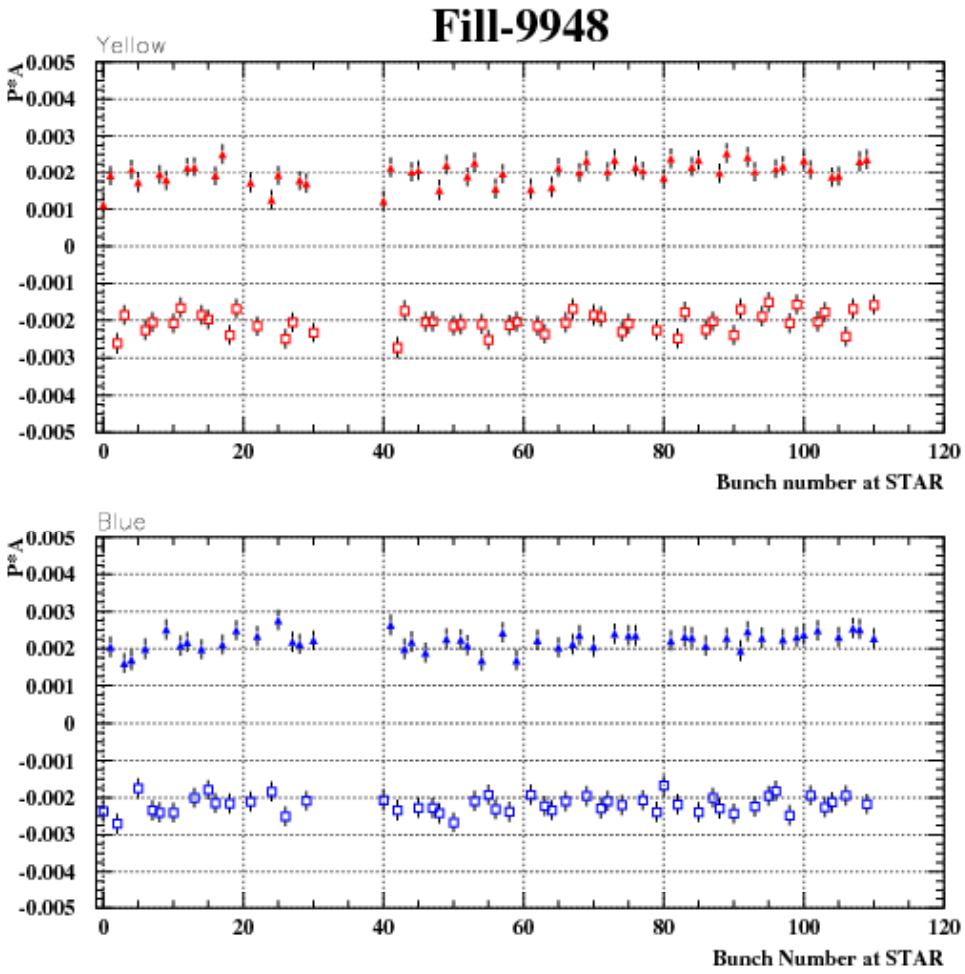




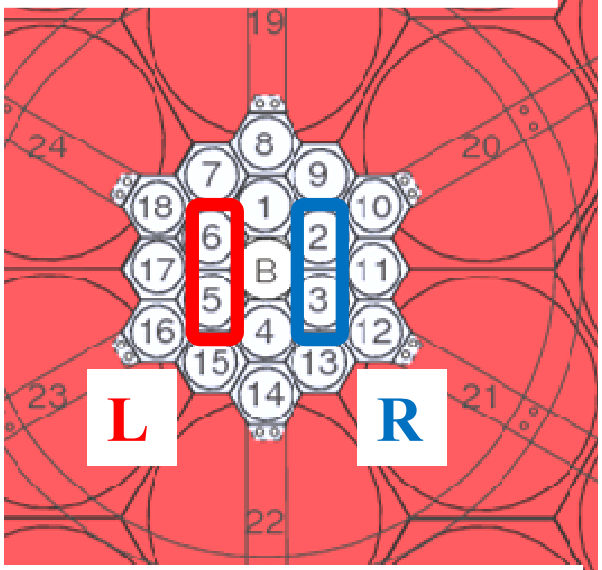
Charged particle A_N in BBC

Yellow beam

Blue beam



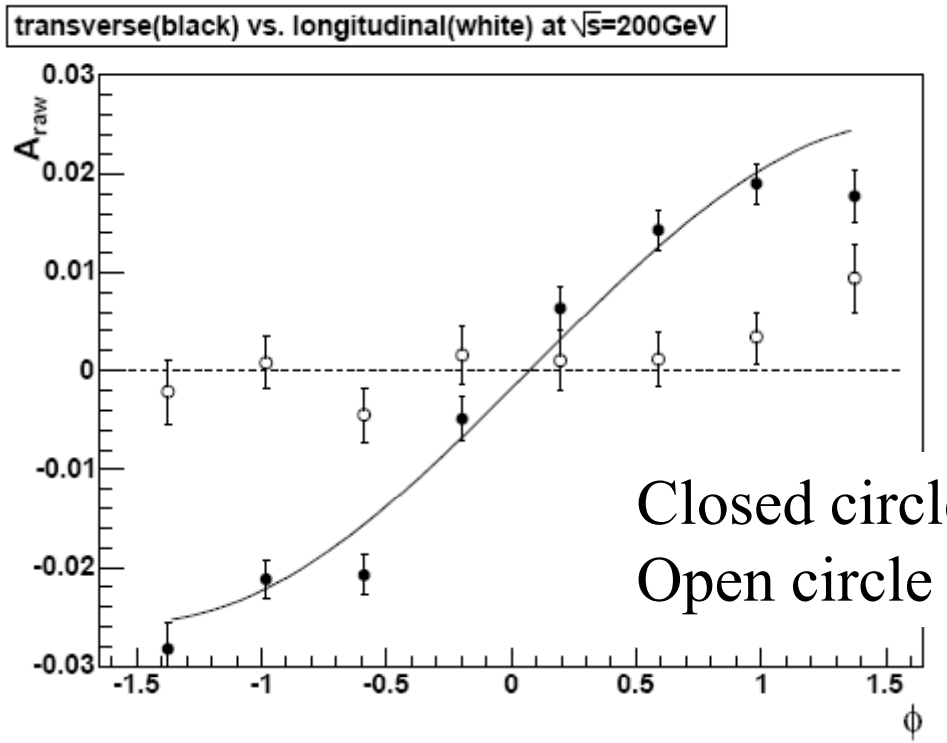
STAR measurement at RHIC run 2008 ($\sqrt{s}$ = 200 GeV)



$$\varepsilon_N = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

- Significant asymmetry bunch-by-bunch
  - Scaler mode : typically ~3.5 σ / bunch / hour
- Observed same level A_N at VPD

Local pol. operation at PHENIX



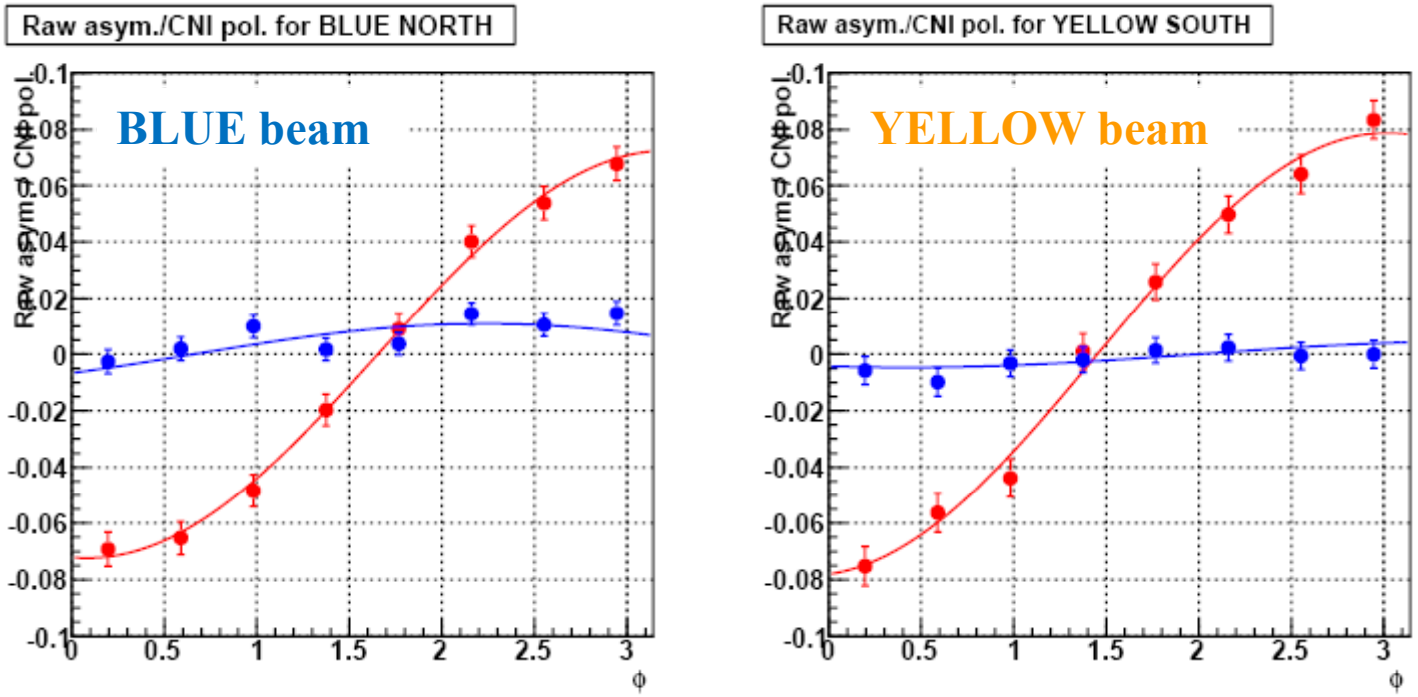
Neutron A_N at
RHIC RUN 2005

Closed circle : transverse RUN
Open circle : longitudinal RUN

- Significant raw A_N is observed at transverse RUN,
  while it is ~0 at longitudinal RUN.
- Beam polarizations during these period are almost same : 45-50%
- Calculate longitudinal component quantitatively
  - achieve 99% until RHIC 2008 run

Polarized pp collision @ √ s = 500 GeV

- In this year run, RHIC pol. beams were colliding at √ s = 500 GeV in PHENIX and STAR !
  - Average polarization ~ 35% (online value)
- PHENIX and STAR measured neutron asymmetry

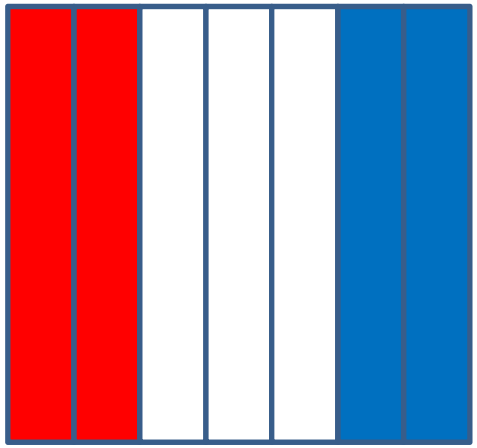


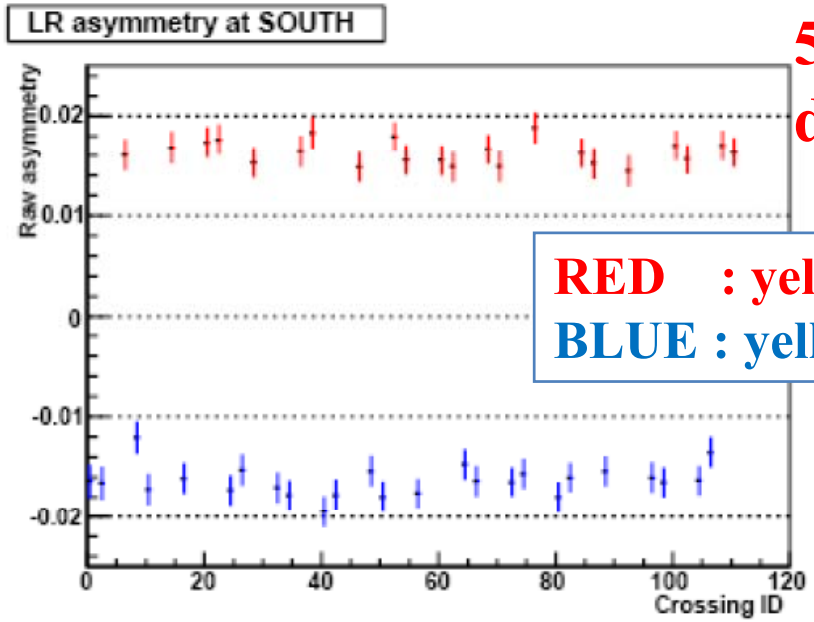
Red : Transverse run (Fill#10340)

Blue : Longitudinal run (Fill#10382)

Scaler mode (neutron asymmetry)

LR definition for SMD

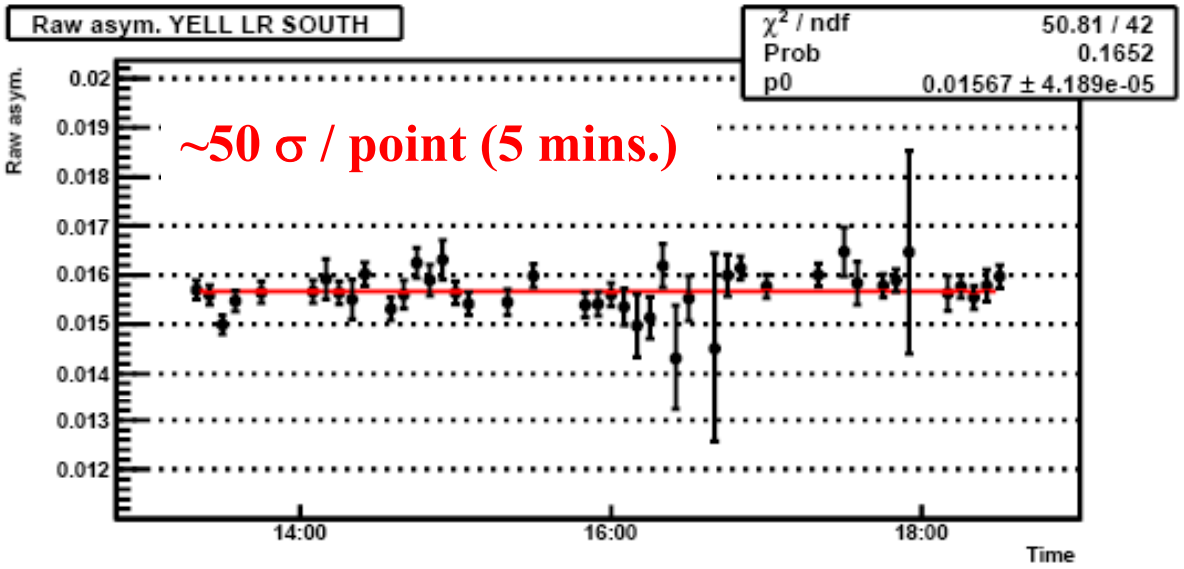




5 minutes data !

RED : yellow spin ↓
BLUE : yellow spin ↑

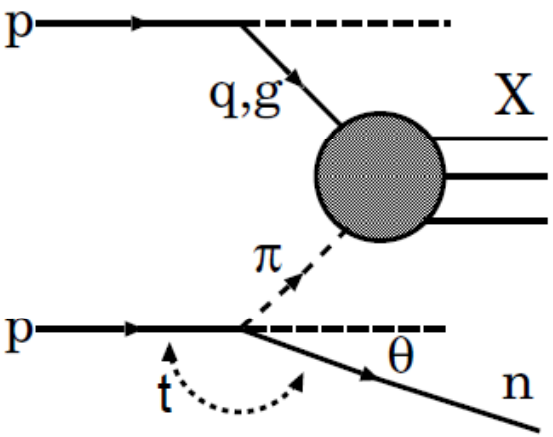
- PHENIX has scaler mode too.
  - Significant asymmetry bunch-by-bunch with only 5 mins. data!



~50 σ / point (5 mins.)

Physics : origin of neutron A_N

- Cross section measurements such very forward neutron production are already performed at ISR, NA49 (*pp*) and HERA (*ep*)
  - Large cross section at high x_F region (xF ~ 0.8)
  - No $\sqrt{s}$ dependence, scaled by x_F (claimed by ISR 31-63 GeV)
- These behaviors are explained by one pion exchange model.
  - A_N may be considered as this frame; it is generated by interference btw spin flip by pion exchange and non-spin flip amplitudes.
  - But not understand it quantitatively so far.



One pion exchange model

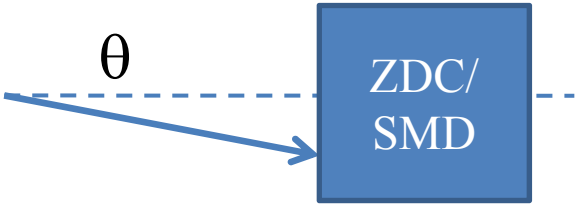
$$x_F = p_L/p_{L(max)} = E_n \cos\theta_n / E_p \sim E_n/E_p$$

$$p_T = E_n \sin\theta_n \sim x_F E_p \theta_n$$

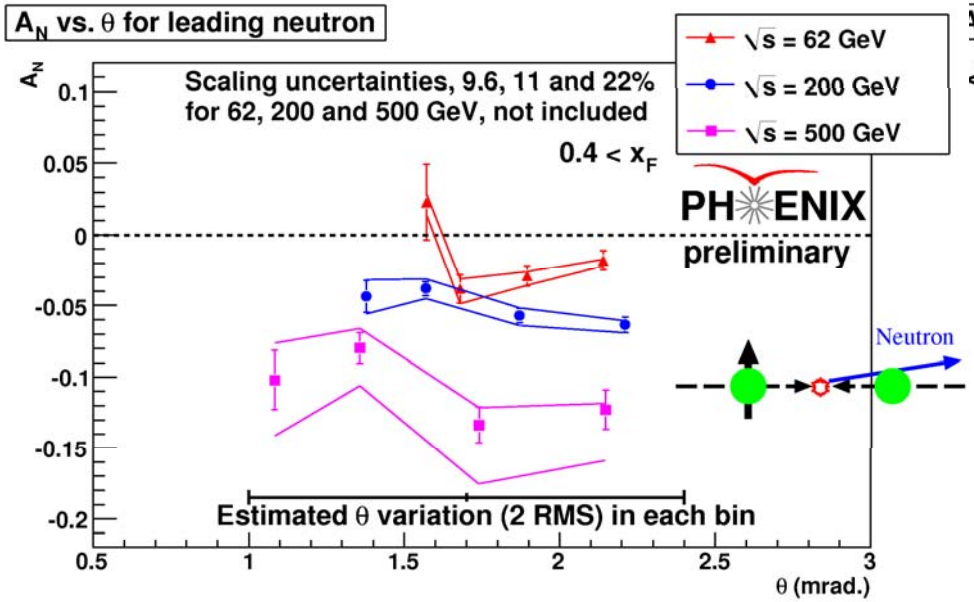
First calculation using OPE model : B.Z. Kopeliovich, I.K. Potashnikov, I. Schmidt and J.Soffer arXiv:0807.1449

θ dependent neutron A_N (inclusive neutron trigger)

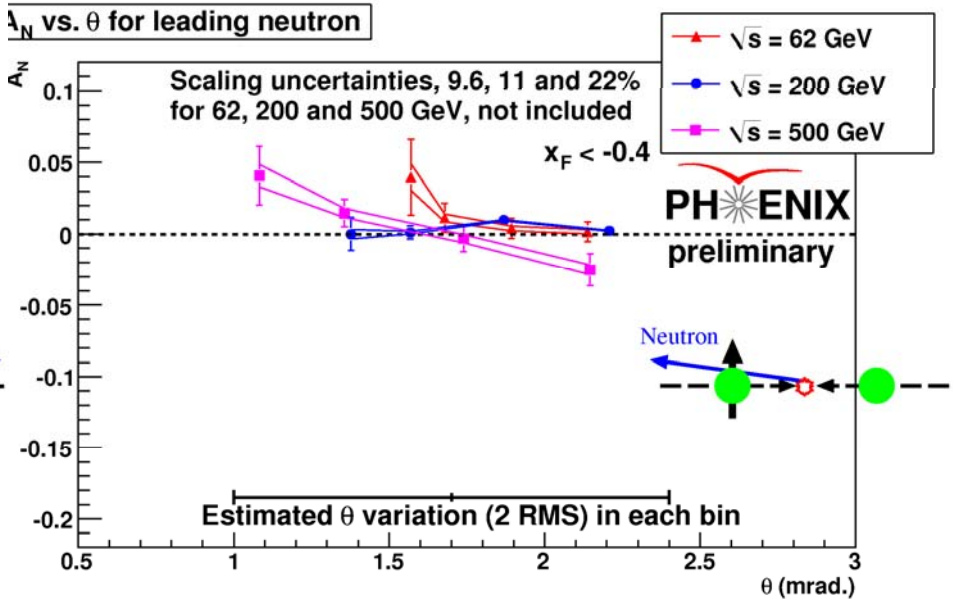
- Comparison A_N using various √ s
  - A_N grows with increasing θ
  - A_N grows with increasing √ s



Forward asymmetry

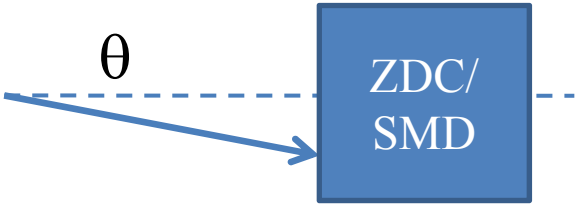


Backward asymmetry

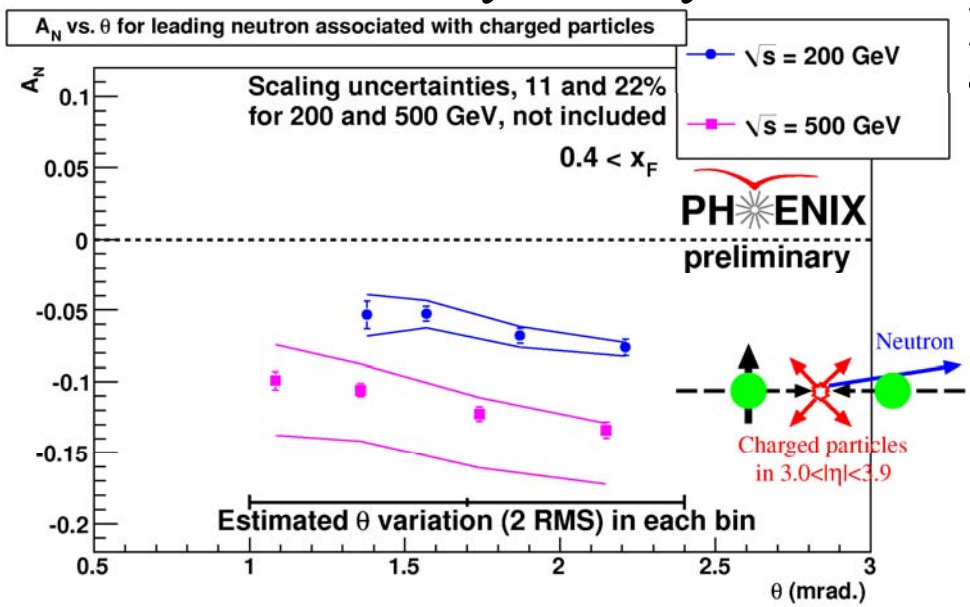


θ dependent neutron A_N (neutron with charged particles trigger)

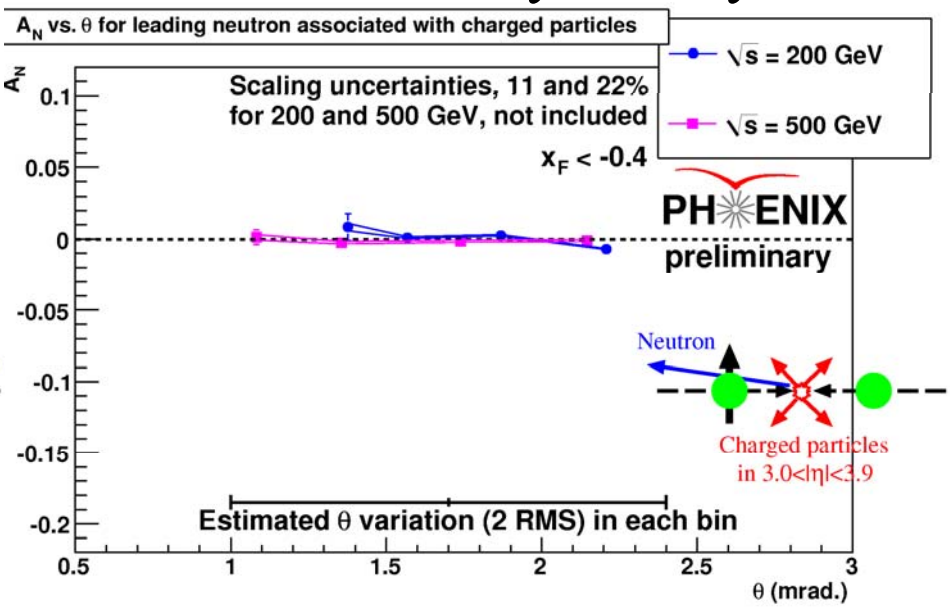
- Same behaviors are observed
  - A_N is larger with association of charged particles
- This trigger sample is used for polarimetry



Forward asymmetry

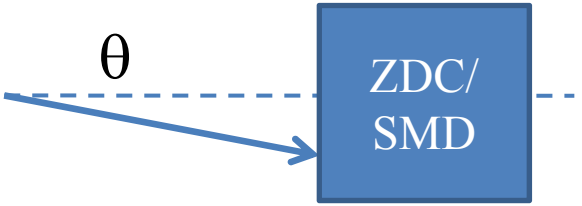


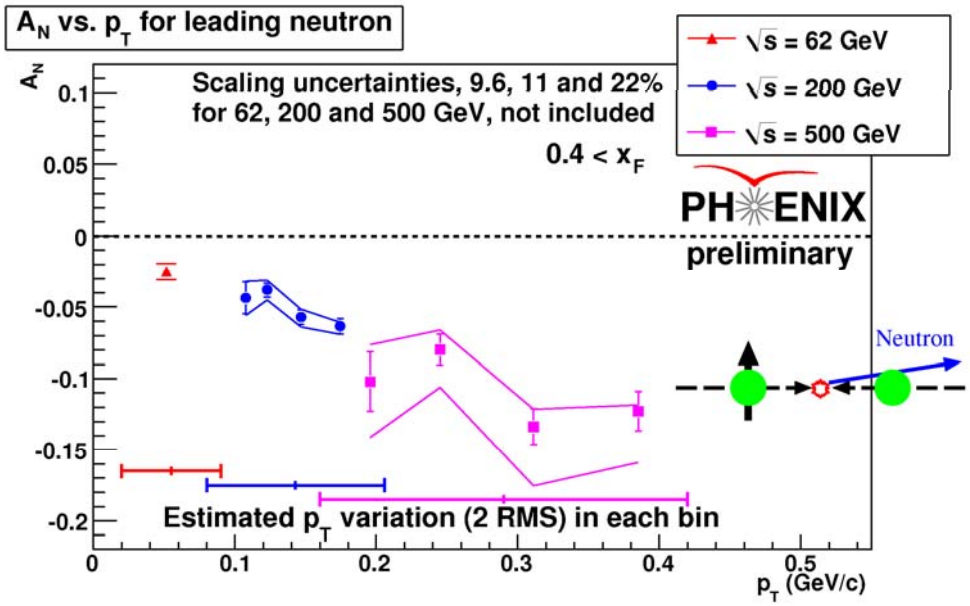
Backward asymmetry

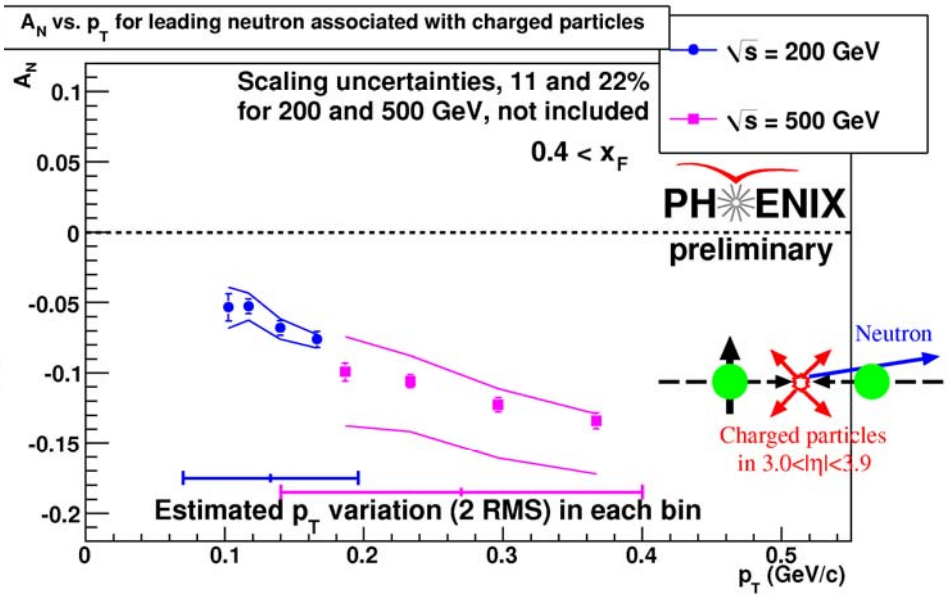


(trial) p_T dependent neutron A_N

- p_T is estimated assuming ISR p_T shape
  - In this kinematics, $\mathbf{p_T \sim x_F * Ep * \theta}$
  - A_N is showing p_T dependence; amplitude grows up !



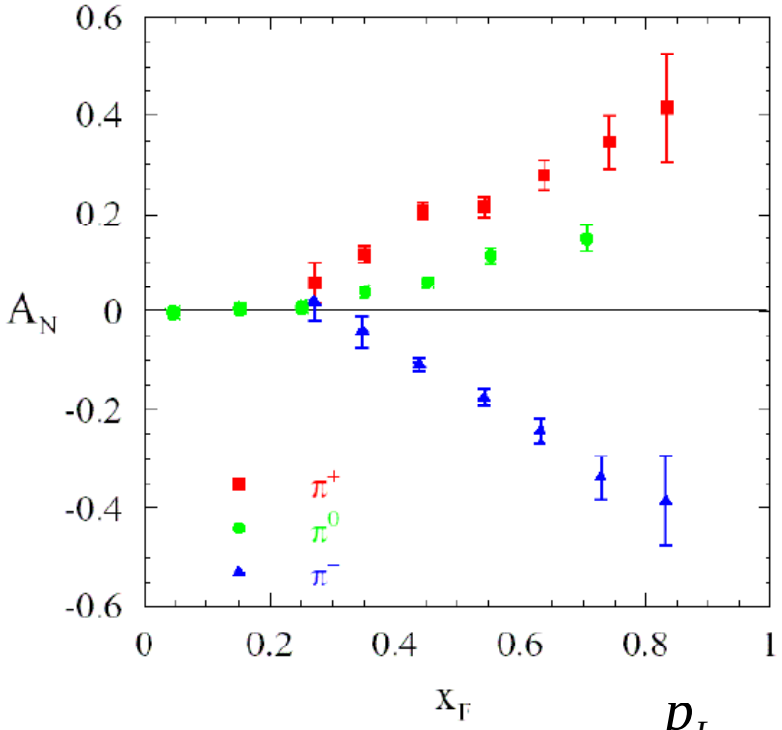




Origin of charged particle A_N

E704 experiment at Fermilab

$pp \rightarrow \pi^{\pm 0} X$
$\sqrt{s} = 19.4$ GeV
$0.2 < p_T < 2.0$ GeV/c



$$x_F \equiv \frac{p_L}{p_L^{\max}}$$

Phys. Lett. B264 462 (1991).

- Could be considered as mixing of charged particles A_N
  - $A_N(\pi^+)>0$, $A_N(\pi^-)<0$
  - $A_N(K^+)>0$, $A_N(K^-)>0$
  - $A_N(\bar{p})>0$, $A_N(p)\sim 0$

  → Will be positive A_N in total

at RHIC energy

What we learn from $\sqrt{s}$ = 62, 200 and 500 GeV

- Very forward neutron A_N
  - $A_N(62) < A_N(200) < A_N(500)$
  - Trigger rate for 62 GeV really low.. (due to narrow p_T acceptance)
- Charged particle A_N
  - PHENIX BBC ($3.0<|\eta|<3.9$) measured finite A_N at 62 GeV
    - While $A_N \sim 0$ at 200 GeV → $A_N(62) > A_N(200)$
  - It will depend on η range. Analyses for 62 GeV and 500 GeV at STAR are ongoing
    - STAR has large acceptance, $3.3<|\eta|<5.0$

- Local polarimetry at RHIC,
  - prefers very forward neutron A_N for 500 GeV
  - (would) prefer charged particles A_N for 62 GeV

Summary

- RHIC spin program needs local polarimetry in each experiment and has been developed independently
  - PHENIX : by very forward neutron A_N
  - STAR : by forward charged particles A_N

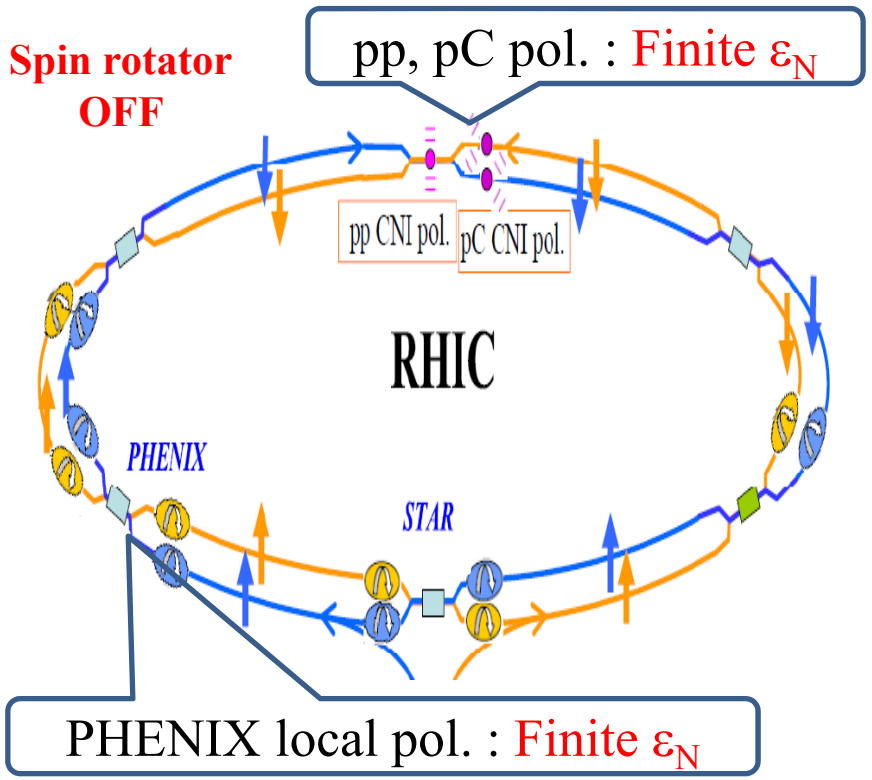
    ← Successfully monitored spin direction for 62 and 200 GeV run.
- In this year, first 500 GeV polarized pp run was performed
  - We also measured large A_N for leading neutron production
- We learned that need to monitor both A_N to cover all center-of-mass energy range ($\sqrt{s}$ = 62, 200 and 500 GeV).
  - A_N amplitudes are changed due to the physics kinematics.

bakup

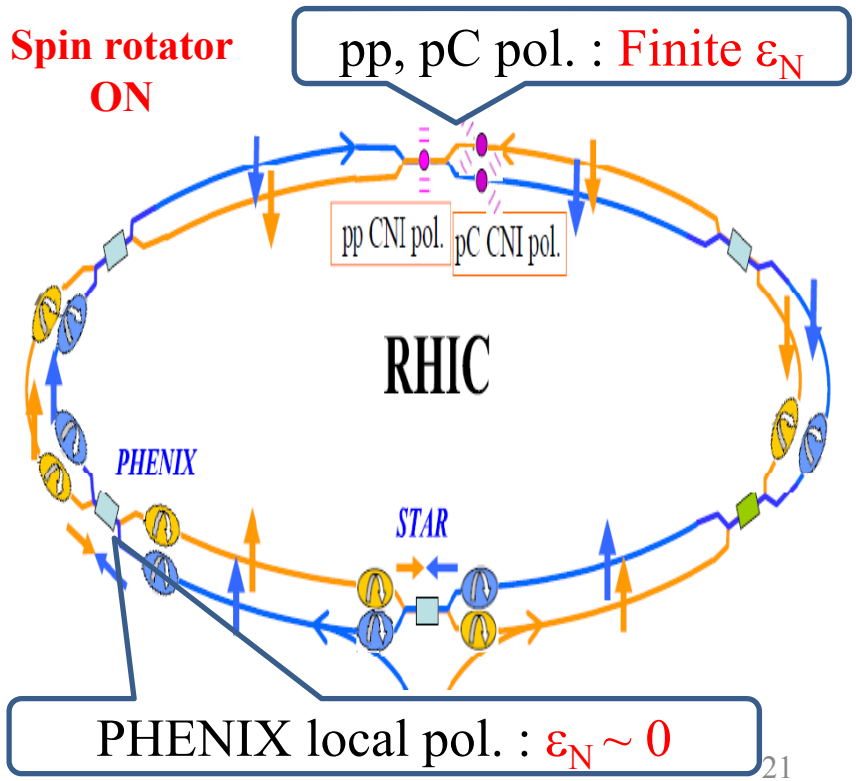
Local polarimeter

- Measurement of spin direction of proton beams at collision point as function of spin rotator operation

- Transverse RUN setting



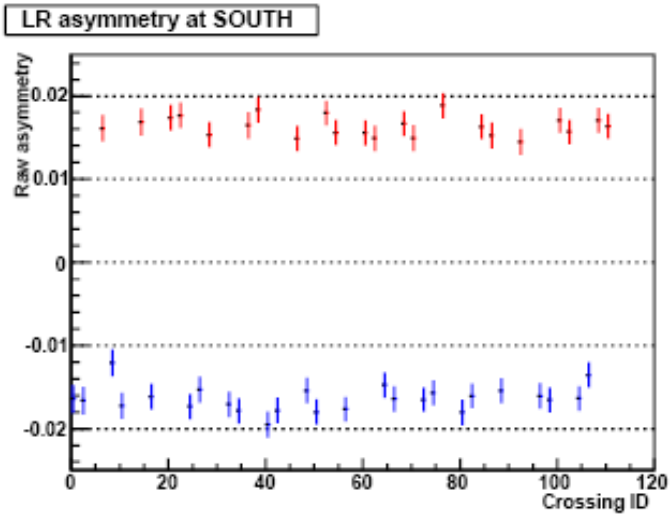
- Longitudinal RUN setting

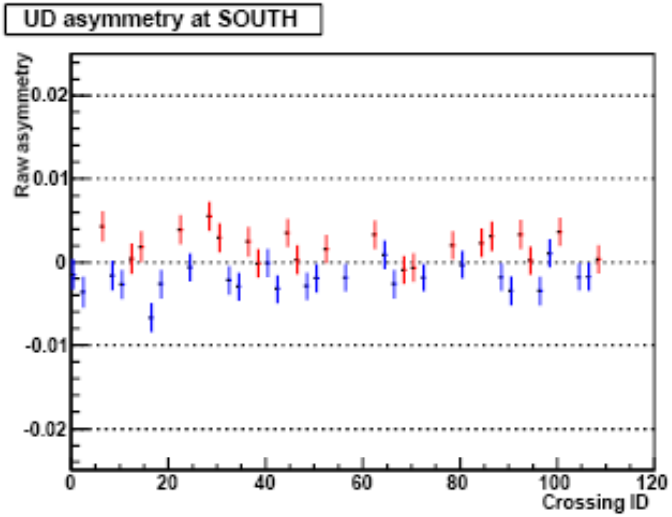


		BLUE beam		Yellow beam	
RUN	$\sqrt{s}$ (GeV)	p_T/p	p_L/p	p_T/p	p_L/p
3	200	0.119 ± 0.067	$0.995\ ^{+0.003}_{-0.013}$	0.223 ± 0.075	$0.975\ ^{+0.012}_{-0.019}$
4	200	0.094 ± 0.047	$0.997\ ^{+0.002}_{-0.007}$	0.074 ± 0.045	$0.998\ ^{+0.002}_{-0.008}$
5	200	0.100 ± 0.010	0.997 ± 0.001	0.147 ± 0.012	0.989 ± 0.002
6	62	0.107 ± 0.151	$1.000 - 0.034$	0.112 ± 0.119	$1.000 - 0.025$
6	200	0.125 ± 0.024	0.993 ± 0.004	0.111 ± 0.023	0.994 ± 0.003

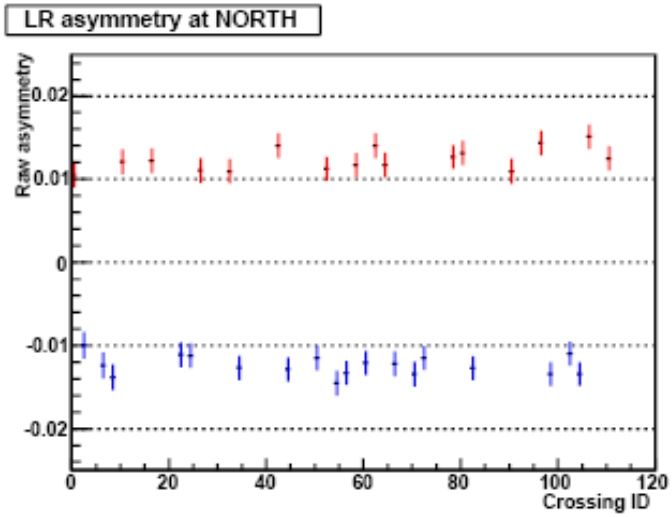
Scaler mode : Fill#10371 (transverse pol.)

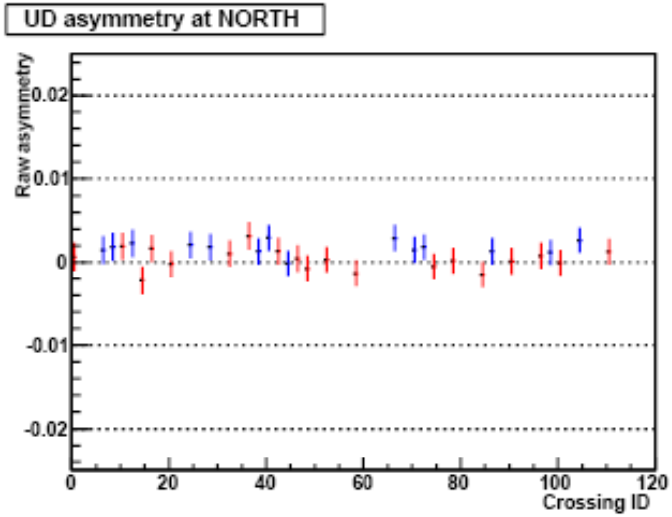
RED : yell pol. ↑ BLUE : yell pol. ↓





RED : blue pol. ↑ BLUE : blue pol. ↓





5 mins data

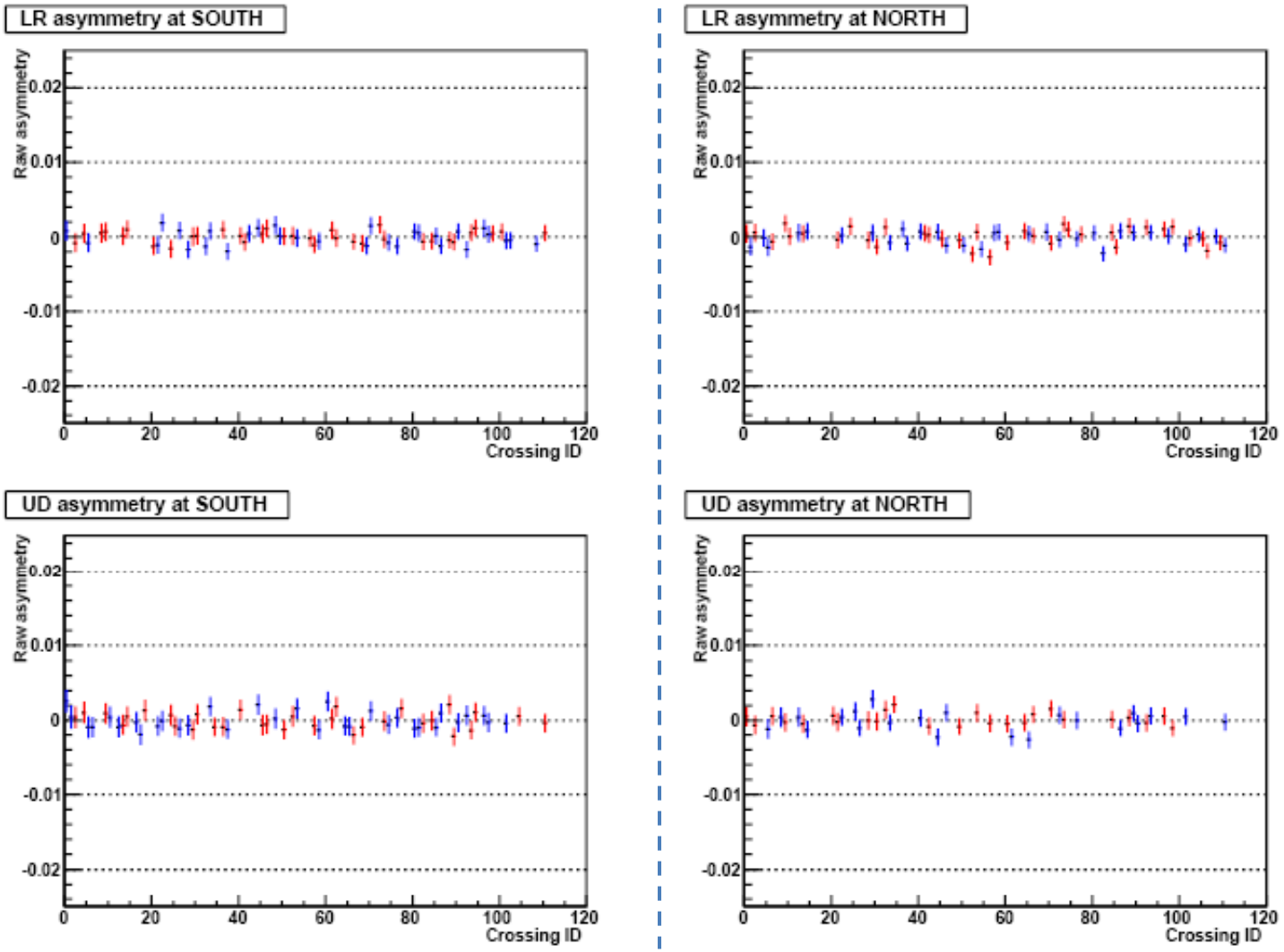
Significant asymmetry bunch-by-bunch !

$$\varepsilon_N = \frac{N_{L(B)} - N_{R(T)}}{N_{L(B)} + N_{R(T)}}$$

Scaler mode : Fill#10372 (unpol.)

RED : yell pol. ↑ BLUE : yell pol. ↓

RED : blue pol. ↑ BLUE : blue pol. ↓



5 mins data

Consistent with unpol.

$$\varepsilon_N = \frac{N_{L(B)} - N_{R(T)}}{N_{L(B)} + N_{R(T)}}$$

STAR BBC configuration

Require

East-West coincidence

Keeps ~5% of all bunch crossings. (Backgrounds from single beam accidentals less than ~1% of sample after this requirement.)

Top and bottom of inner tiles clean to reduce dilution of asymmetry

Keeps 20% of the 5%=1% of all crossings pass both requirements.

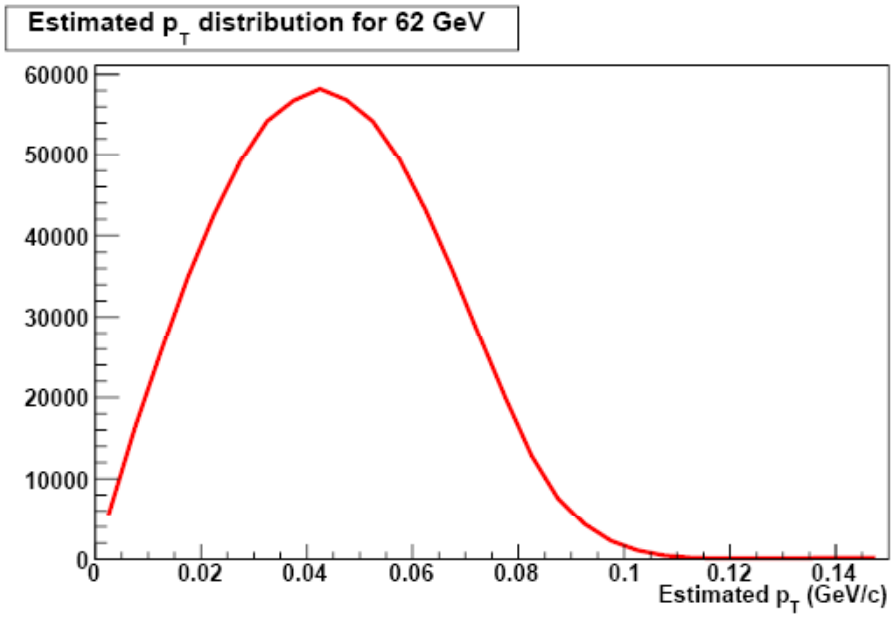
Use tiles 5+6 for Left, tiles 2+3 for Right

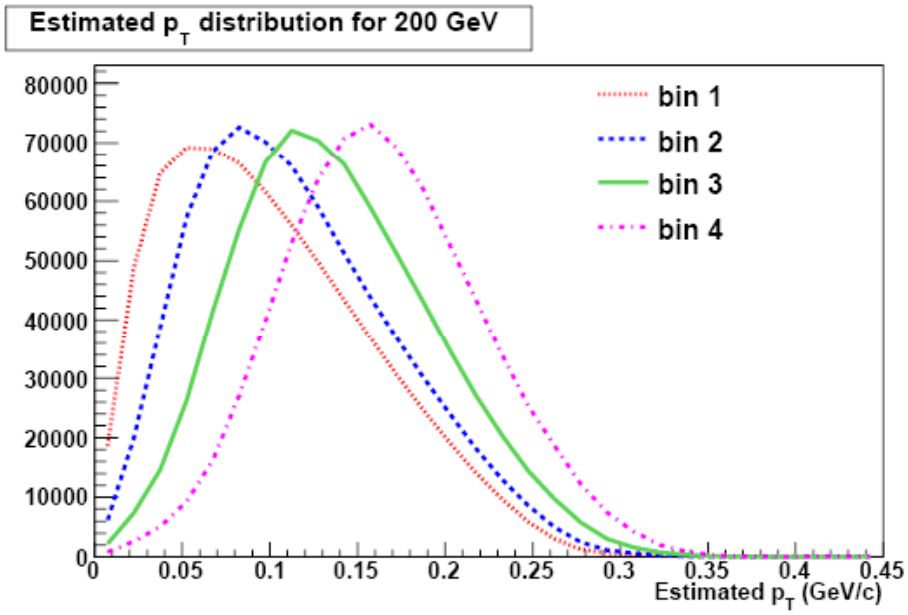
Typical numbers on the order of

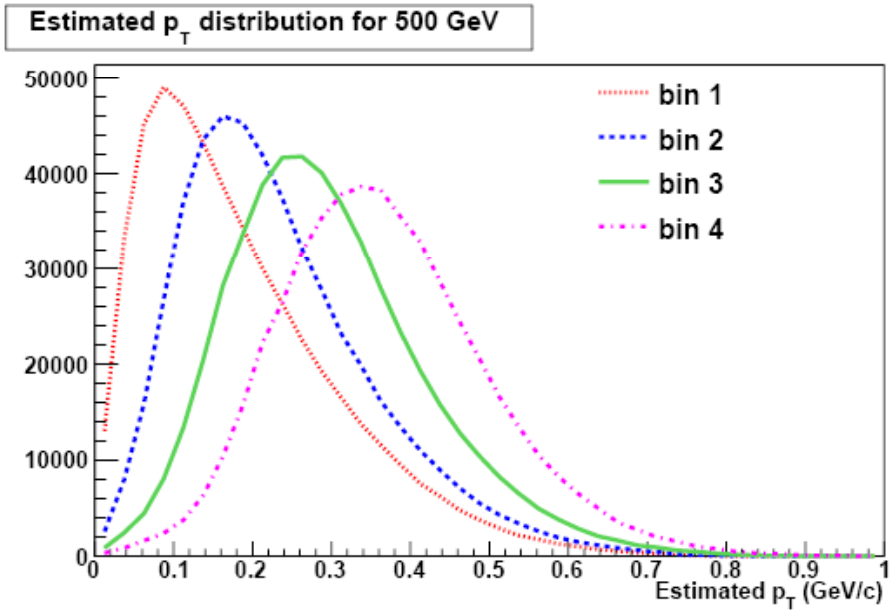
~3M events per bunch per hour

~3.5 σ (statistical) measurement of polarization per bunch per hour

Estimated p_T distributions



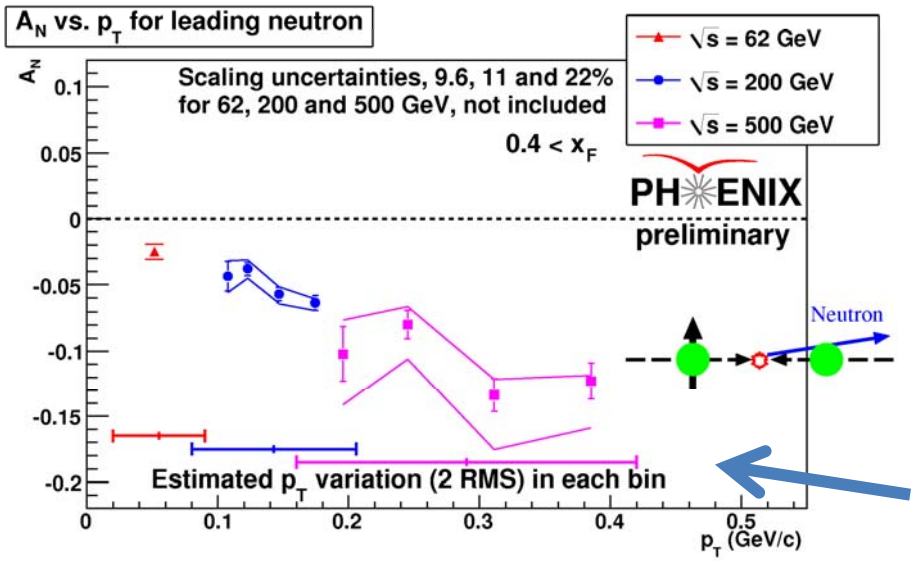




These pictures for backup

Will make BBC scaler ?

- Luminosity → 62 : 200 : 500 ~ 1 : 10 : 25
- BBC cross section → 62 : 200 : 500 ~ 14 : 24 : 30 (mb)
  - 62& 200 : Analysis note 688 500 : Amaresh's presentation at W meeting (2009/06/12) : not final these values
- ZDCN|S ratio relative to BBC → 62 : 200 : 500 ~ 24 : 36 : 67
- Total count rate for ZDCN|S → 62 : 200 : 500 ~ 1 : 25 : 150
- Total $A_N/\Delta A_N$ → 62 : 200 : 500 ~ 1 : 15 : 75



Typical rate for ZDCN|S relative to BBC

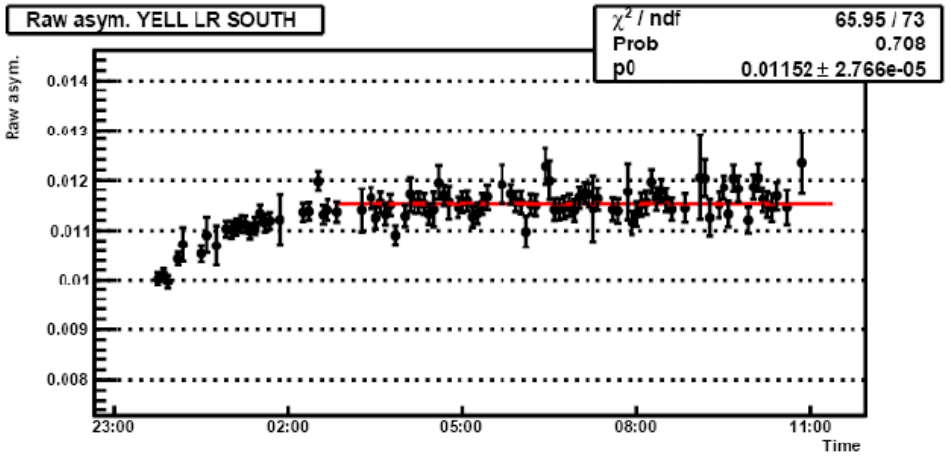
√ s	BBCLL1(NoVtx)	ZDCN|S
62	13.5 kHz	3.3 kHz (24%)
200	171 kHz	62 kHz (36%)
500	859 kHz	573 kHz (67%)

A_N 62 : 200 : 500 ~ 2 : 6 : 12 (%)

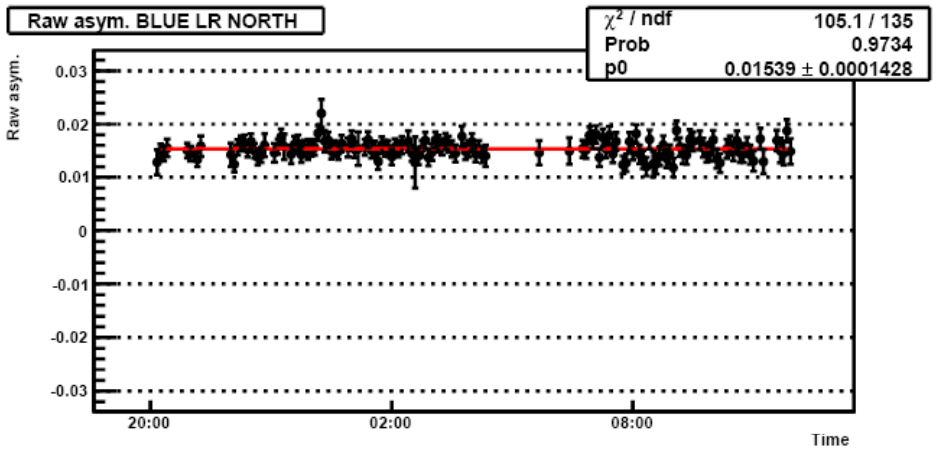
Estimation for scaler

- Total $A_N/\Delta A_N$ → 62 : 200 : 500 = 1 : 15 : 75
  - 62 GeV → 0.7 σ / point (5 mins) → 3.5 σ / 2 hours.
  - In addition, BG from charged particles are very high.
    - From pythia simulation, only 14% is neutron while ~25-33% for 200 and 500 GeV (with 5 GeV threshold).

* Need to consider polarization, rate.



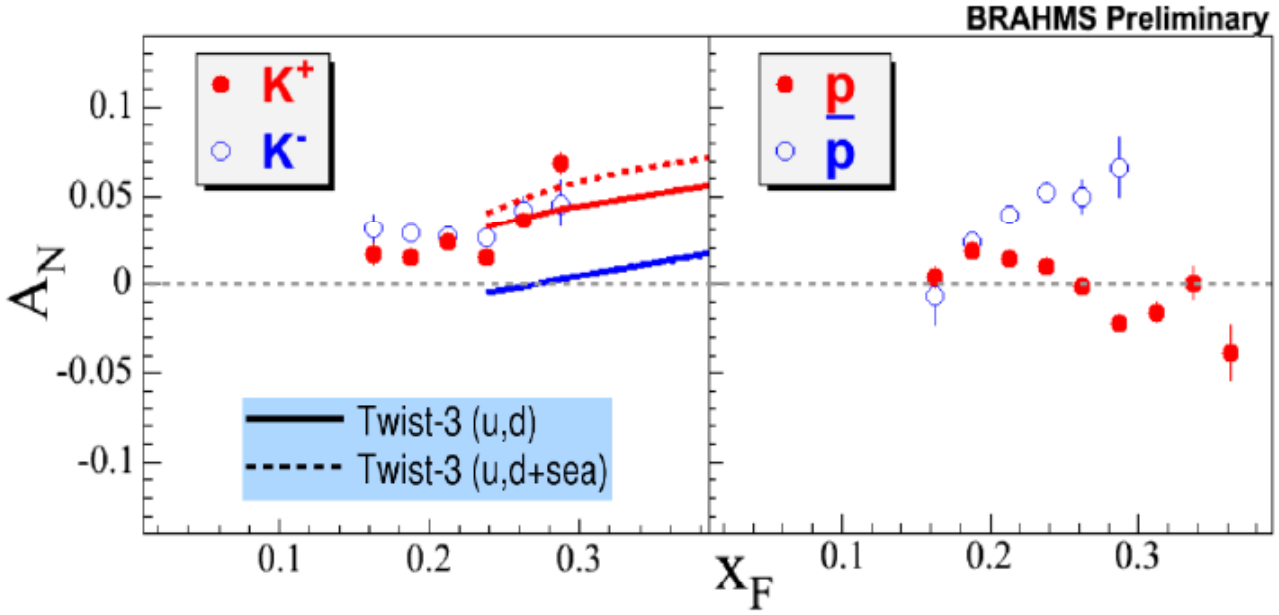
500 GeV : ~50 σ / point (5 mins.)



200 GeV : ~10 σ / point (5 mins.)

RHIC A_N results (BRAHMS)

Detector：Forward Spectrometer (FS)　$3.3<\eta<5.25$



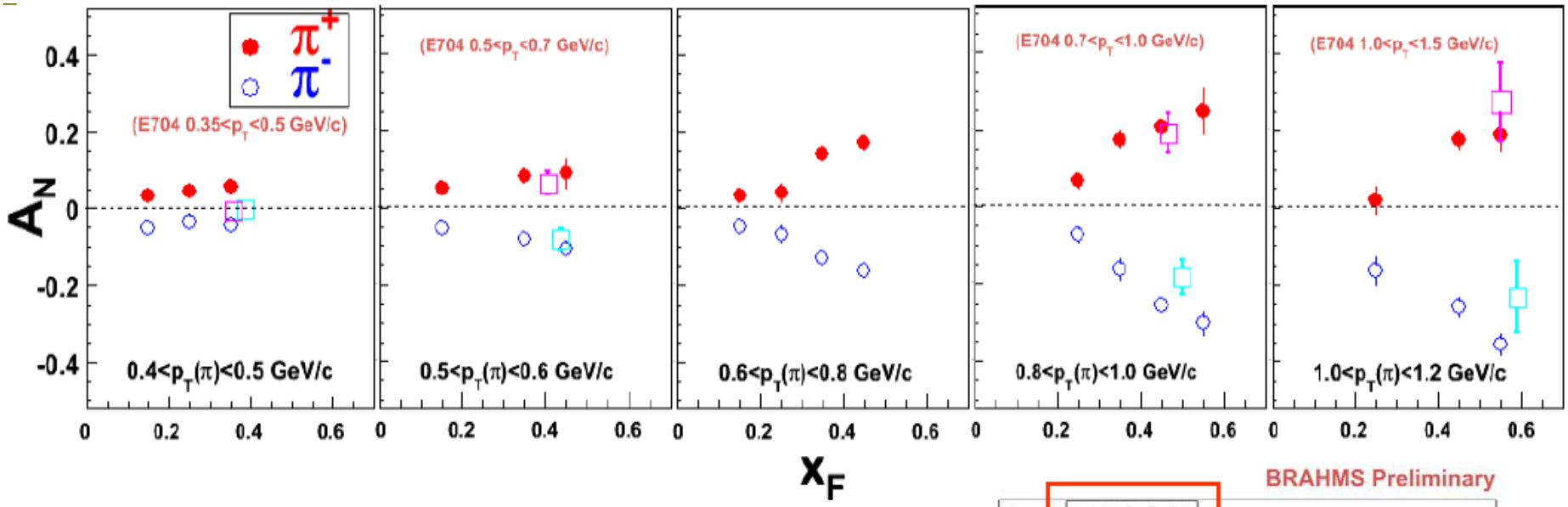
- $A_N(K^+)\sim A_N(K^-)$
  - $K^+(u\bar{s})$ vs. $K^-(\bar{u}s)$ why they are same ?
- $A_N(p\_bar)>0$, while $A_N(p)\sim 0$
  - Large A_N for anti-proton ?

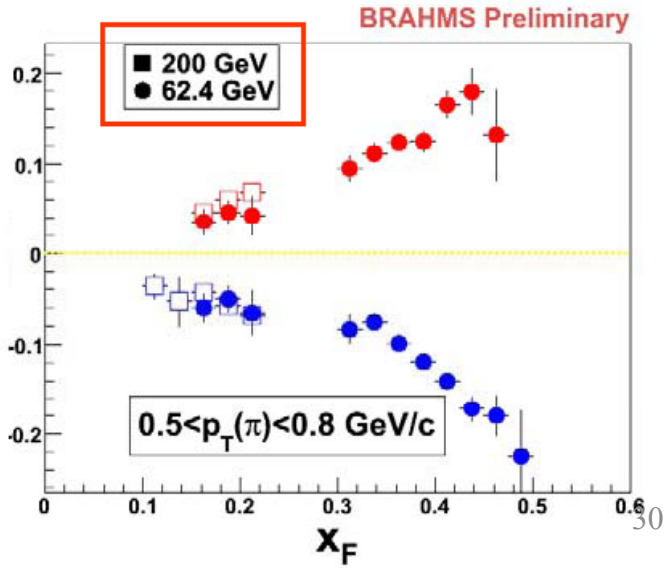
→ Key is NOT valence quark in transverse physics?

RHIC A_N results (BRAHMS)

●π^+ ○π^- : BRAHMS 62.4 GeV RPL 101 042001 (2008)

□π^+ □π^- : E704 19.4 GeV RPL 77 2626 (1996)





- **x_F scaling, not in $\sqrt{s}$**
  - **NOT origin of quark ?**

But BRAHMS experiment was finished..
No 500 GeV data

PHENIX LP until RUN8

- Calculate longitudinal component via vertical component

$$\frac{P_L}{P} = \sqrt{1 - \left(\frac{P_T}{P}\right)^2}, \qquad \frac{P_T}{P} = \frac{A_N^{Longitudinal}}{A_N^{Transverse}}.$$

- Spin direction is extracted through the run.
  - Data rate is 100-200 Hz during physics run in PHENIX DAQ
- STAR also has performed LP work using BBC asymmetry

Local results are shown for longitudinal runs.

Achieved 99 % longitudinal beams !

		BLUE beam		**Yellow beam**	
RUN	$\sqrt{s}$ (GeV)	p_T/p	p_L/p	p_T/p	p_L/p
3	200	0.119 ± 0.067	$0.995\ ^{+0.003}_{-0.013}$	0.223 ± 0.075	$0.975\ ^{+0.012}_{-0.019}$
4	200	0.094 ± 0.047	$0.997\ ^{+0.002}_{-0.007}$	0.074 ± 0.045	$0.998\ ^{+0.002}_{-0.008}$
5	200	0.100 ± 0.010	0.997 ± 0.001	0.147 ± 0.012	0.989 ± 0.002
6	62	0.107 ± 0.151	$1.000 - 0.034$	0.112 ± 0.119	$1.000 - 0.025$
6	200	0.125 ± 0.024	0.993 ± 0.004	0.111 ± 0.023	0.994 ± 0.003

RUN8 : transverse run only