Measurement of proton beam polarization in RHIC using *pC* elastic scattering

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On behalf of CNI Group (Polarimeter + Jet)

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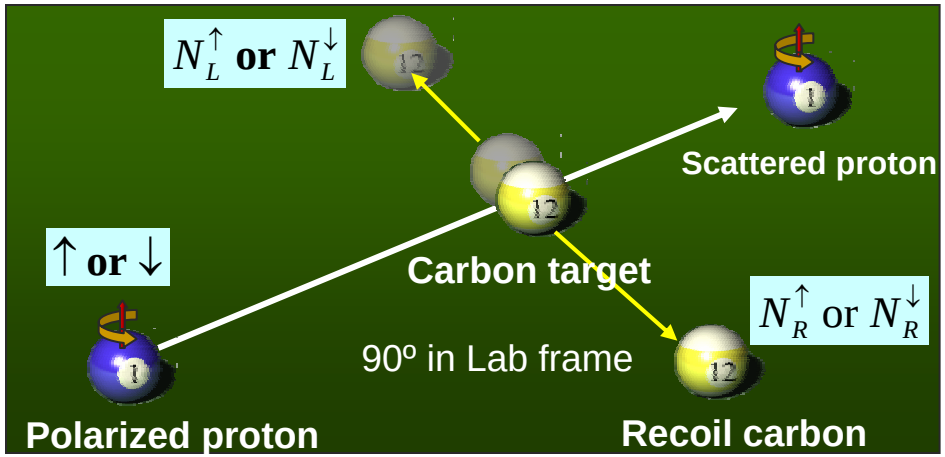
Elastic *pC*→*pC* scattering at very low –*t* range

- Elastic scattering of hadron-Nucleus at RHIC has an important physics information on spin-dependent hadronic amplitude in high energy
- Elastic scattering process is identified by detecting recoil Carbon (inelastic fraction~10^{-2})
- Use single transverse spin asymmetry A_N of *pC* for polarimetry at RHIC



$$t = (p_{out} - p_{in})^2 \approx -2M_C T_{kin} < 0$$
$$0.005 < |t| < 0.05\ (GeV/c)^2$$

A_N arises mainly from interference between ***EM spin-flip amplitude*** and ***hadronic non spin-flip amplitude*** (CNI = Coulomb – Nuclear Interference)

$$A_N = C_1 \phi_{em}^{flip}\, Im\phi_{had}^{nonflip} + C_2 \phi_{em}^{nonflip}\, \phi_{had}^{flip}$$

$\propto (\mu - 1)_p$ Pure CNI $\propto \sqrt{\sigma_{had}^{pp}}$

Regge poles /Pomeron exchange

A_N is also sensitive probe to hadronic spin flip amplitude

Helicity amplitude formalism and r_5 physics

Analogy to *pp* helicity amplitude formalism
pC process being described by two amplitudes

Non-flip $F_{+0}(s,t) = < +0|M|+0 >$

Spin flip $F_{-0}(s,t) = < +0|M|-0 >$

$$F_i = F_i^{em} + e^{i\delta} F_i^h \quad (i = +0, -0)$$

$$r_5^{pC}(t) = \frac{m F_{-0}^h}{\sqrt{-t}\ \mathrm{Im} F_{+0}^h}$$

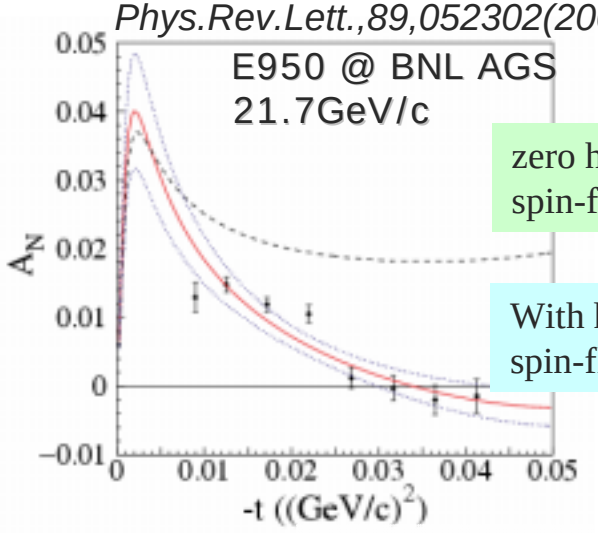
spin flip amplitude ratio, $r_5^{pC}(t)$ for *pC* is translated into parameter r_5 for *pp*

AN is described with two parameters

$$\mathrm{Re} r_5, \quad \mathrm{Im} r_5$$

s-dependence (E_B=24GeV, 100GeV)? phase?

Phys.Rev.Lett.,89,052302(2002)



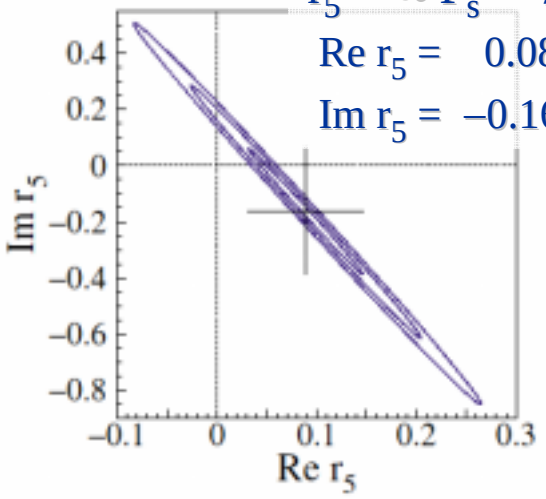
zero hadronic spin-flip

With hadronic spin-flip (E950)

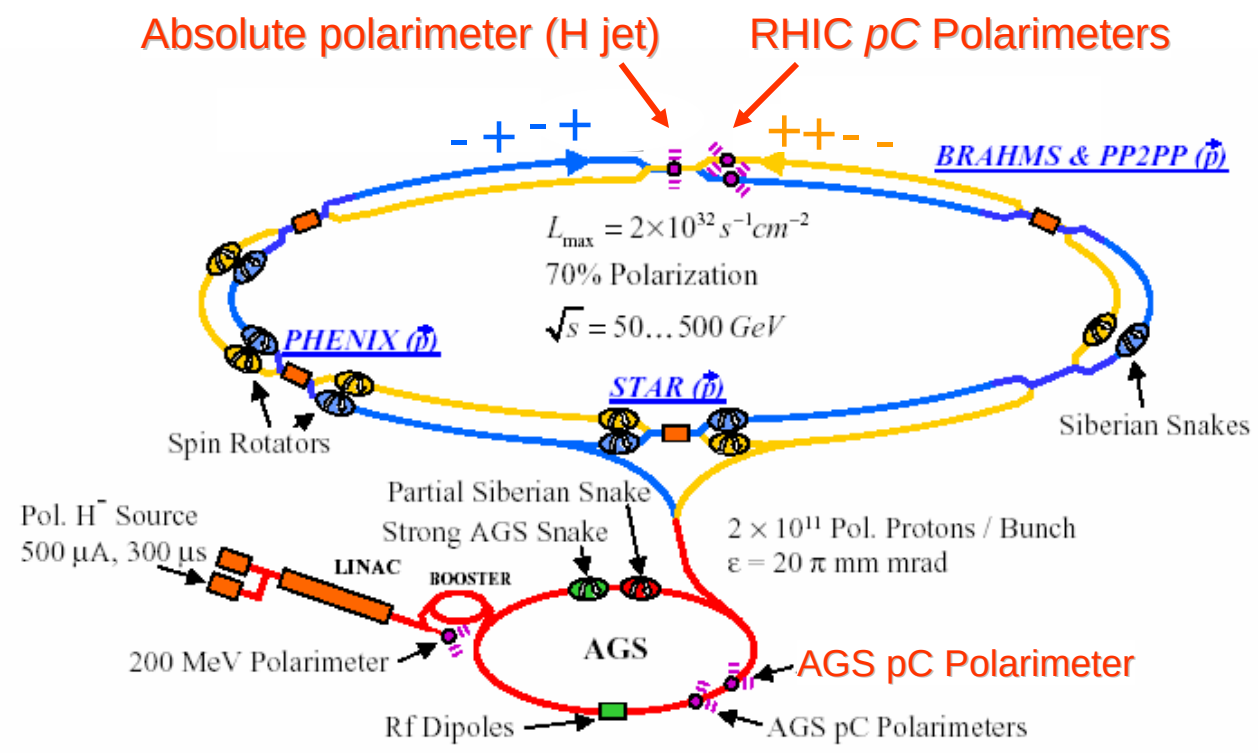
$r_5^{pC} \propto F_s^{had} / Im\ F_0^{had}$

Re r_5 = 0.088 ± 0.058

Im r_5 = –0.161 ± 0.226



RHIC Proton Polarization measurements



RHIC *pC* CNI Polarimeters :

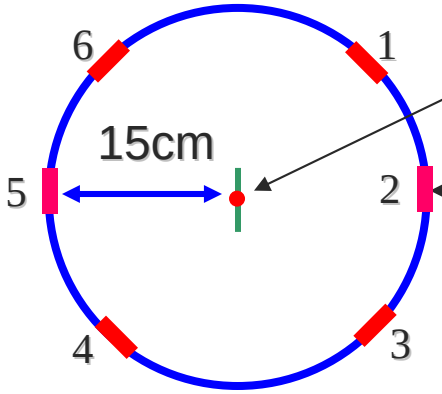
- quick polarimeters used since Run-02
- determine relative P
- need A_N calibration

H jet *pp* polarimeter : (→ next speaker)

- commissioned at Run-04
- absolute polarization measurement
- calibrate pC CNI polarimeters

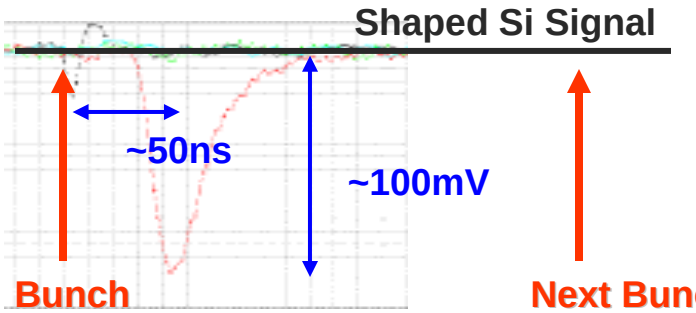
- Final goal is to achieve dP/P < 5%

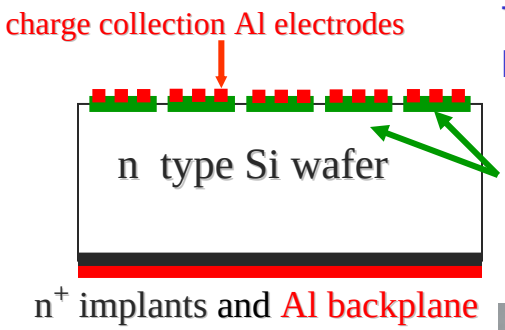
Detector setup + DAQ



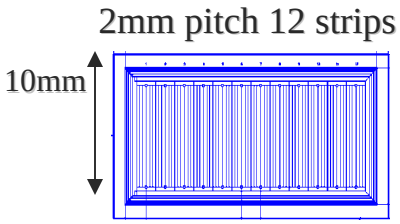
Ultra thin Carbon ribbon Target ($3.5\mu g/cm^2$)

Si strip detectors (TOF, E_C)

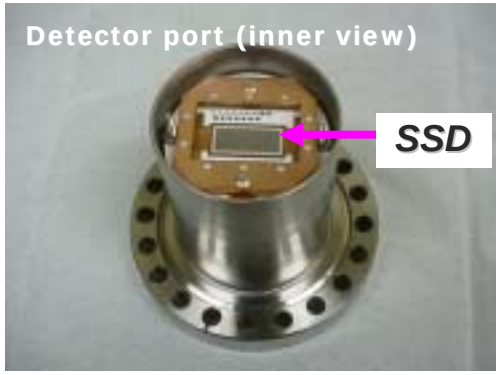




Thin dead layer for low energy spectroscopy



72 strips in total



Wave Form Digitizer (WFD)

20M events / 20sec

- Pulse Height
- TOF
- Bunch ID
- Integral (Q)

Select carbons at on-board LUT

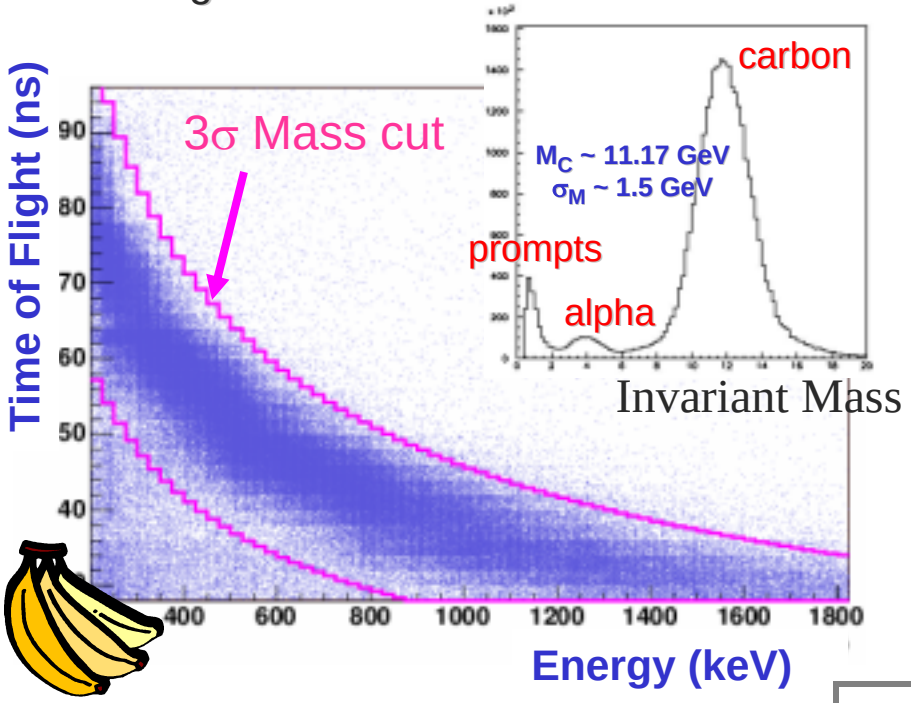
- Scaler data
- Asymmetry calculation
- Online results (to experiments)

Event by event data

- Stored in on-board memory
- Used for offline detailed study

Recoil carbon PID → Asymmetry calculation

- Particle ID (banana cut)
  - Clear separation from backgrounds using TOF measurement



non-relativistic kinematics

$$tof = \sqrt{\frac{M_C}{2T_{kin}}}L$$

- Asymmetry calculation

$$\varepsilon_N^{\uparrow} = -\frac{N_L^{\uparrow} - N_R^{\uparrow}}{N_L^{\uparrow} + N_R^{\uparrow}} \quad \text{for up spin}$$

$$\varepsilon_N^{\downarrow} = -\frac{N_R^{\downarrow} - N_L^{\downarrow}}{N_R^{\downarrow} + N_L^{\downarrow}} \quad \text{for down spin}$$

With alternating spin pattern (+,-,+,-) square-root formula

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

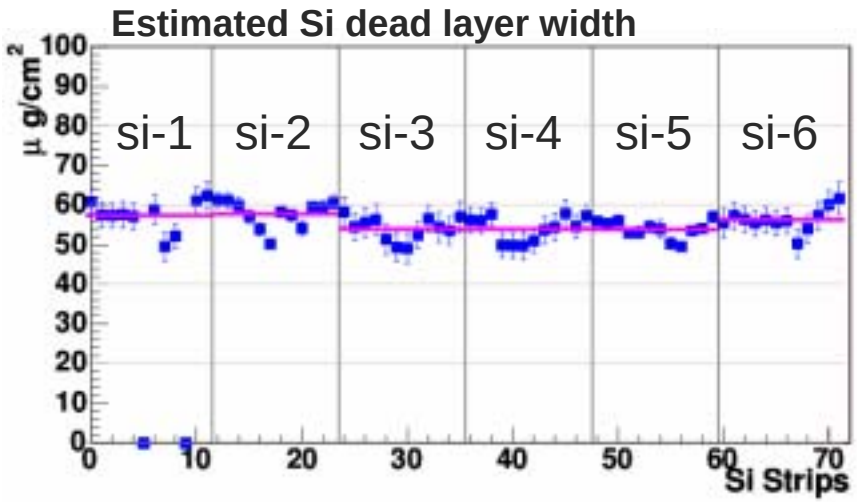
$$A_N = \varepsilon_N / P_{beam}$$

$\langle A_N \rangle$ is known to ±30% (E950 data at 22GeV)

H-jet target commissioning at 2004, the aim is to obtain ±10% calibration at 100GeV

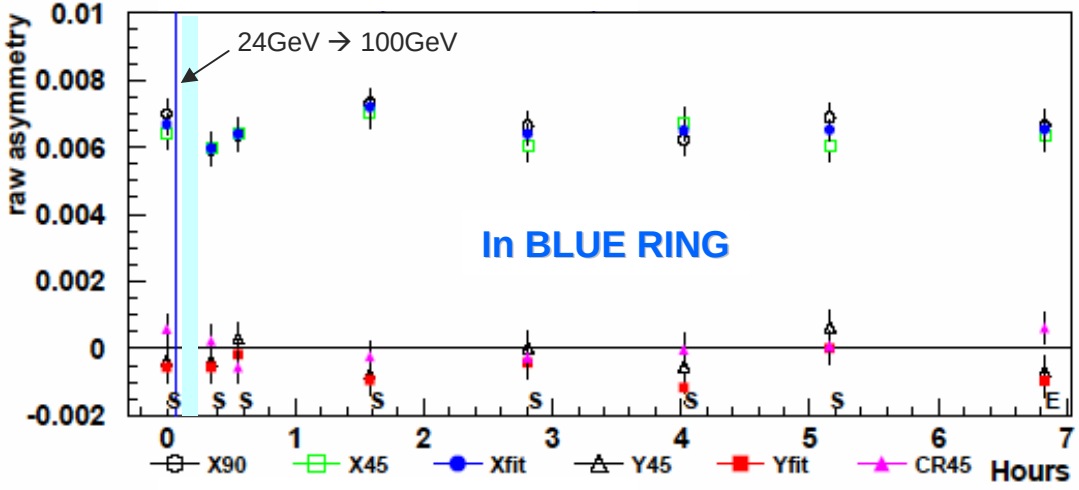
Offline analysis with event by event data

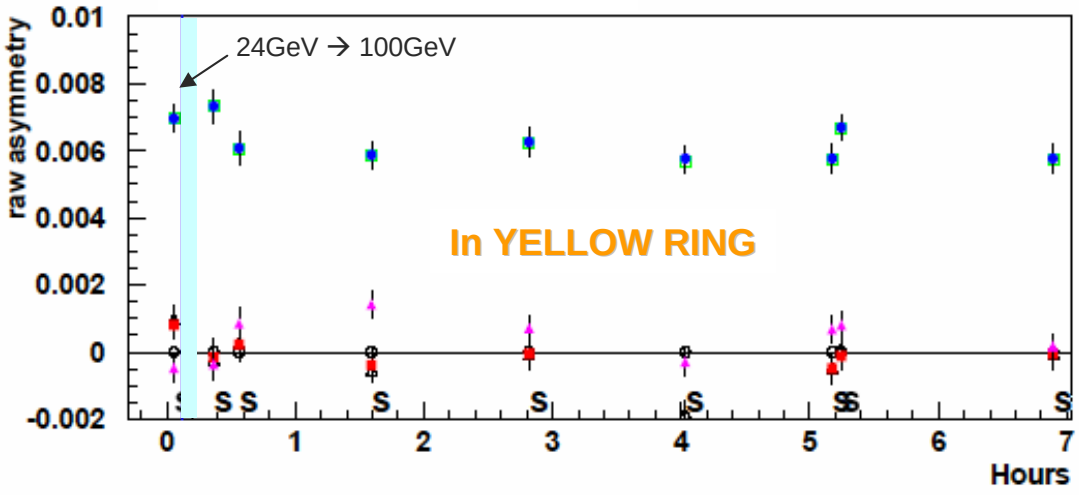
- Energy calibration
  - Tracking calibration constant with ^{241}Am (5.486MeV)
  - Stable within ± 2% through run period
- Correction for energy loss in silicon non-active layer on surface
  - Estimated from deformation of carbon kinetic curve (tof vs. energy)
    → 57 μg/cm^2 in average (±12 μg/cm^2)
  - 6 detectors - from same wafer
  - Small variation from strip to strip
- Event selection on invariant mass
  - Better S/N than timing cut
  - Mass resolution evolves during fills
  - 3σ cut applied



Typical Polarization measurements

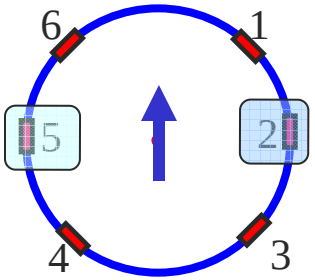
Online Results



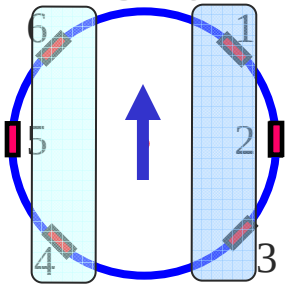


Physics asymmetry

90 deg Physics

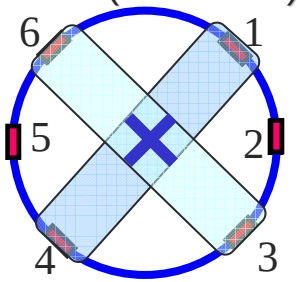


45 deg Physics

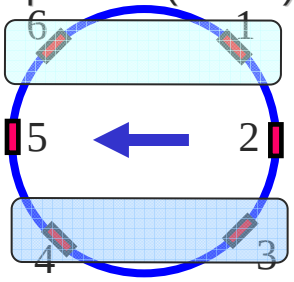


False asymmetry

Cross (Forbidden)



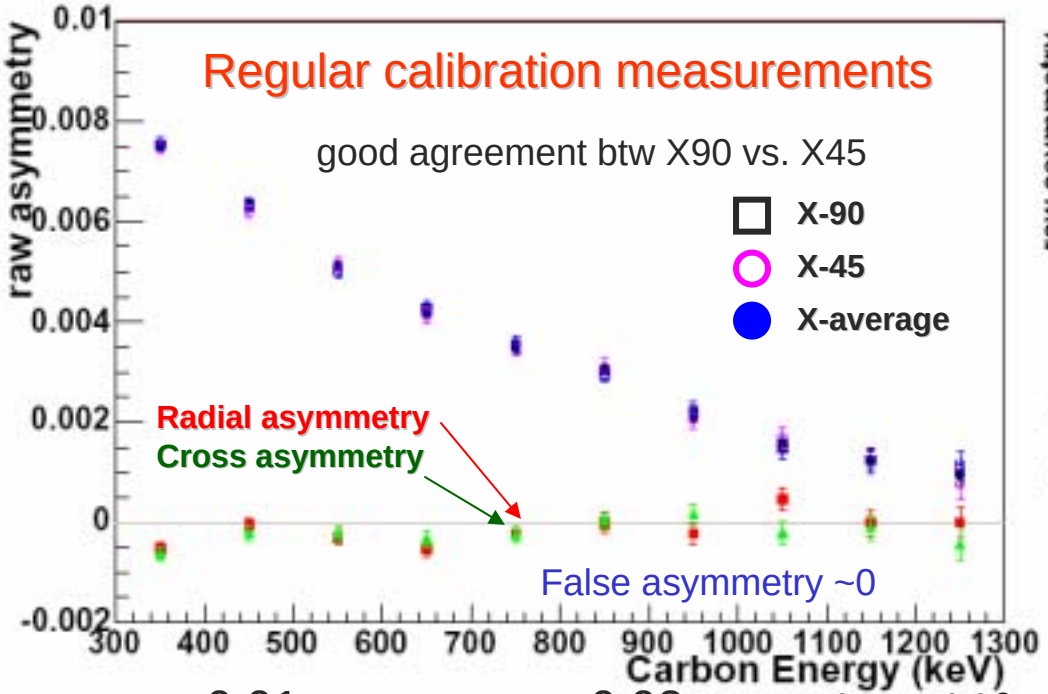
Up-Down (Radial)

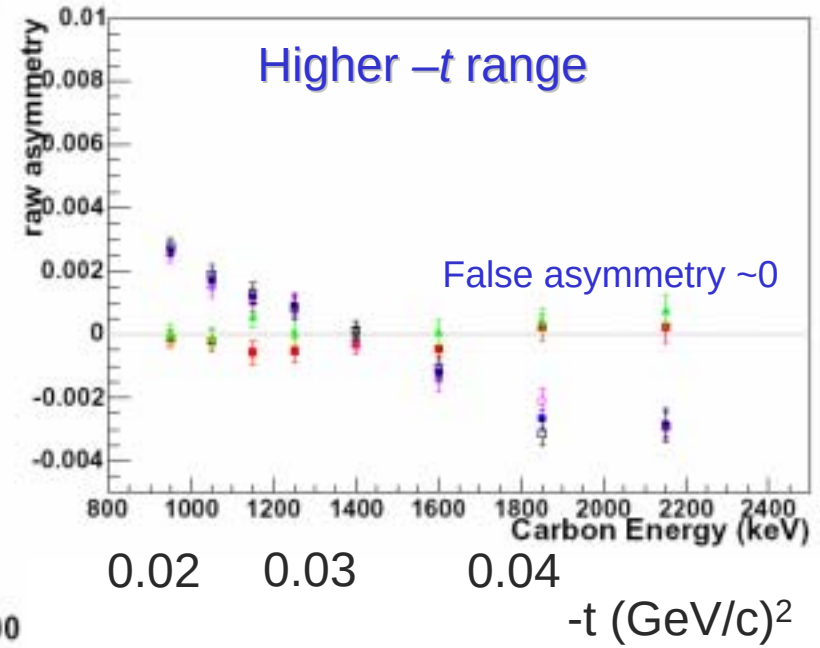


Size of systematic error

(unit in P)	BLUE	YELLOW
Cross asymmetry	-2.2%	1.2%
Up-Down asymmetry	0.4%	1.1%

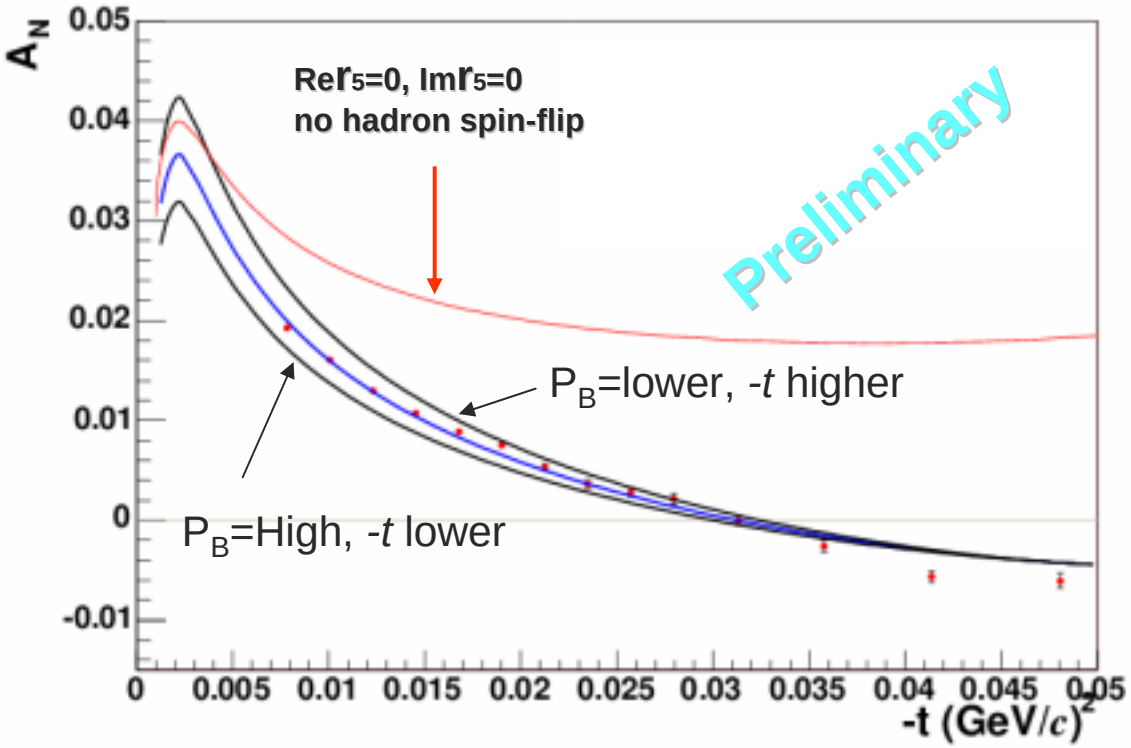
Raw asymmetry (*t*) in wide range





- Regular polarimeter runs
  - Measurements taken with running Jet-target in parallel
  - very clean asymmetry values
- Polarimeter dedicated runs (high -*t*)
  - Signal attenuation (x1/2) to reach higher –*t*
  - Normalized at overlap region to regular runs
  - *Zero crossing measured with large significance*

A_N (t) at 100GeV and fit result with theoretical function



$$A_N(t) = \frac{\varepsilon_N(t)}{P_{beam}}$$

- 1.2 x 10^9 events are collected with P_B known from jet-target

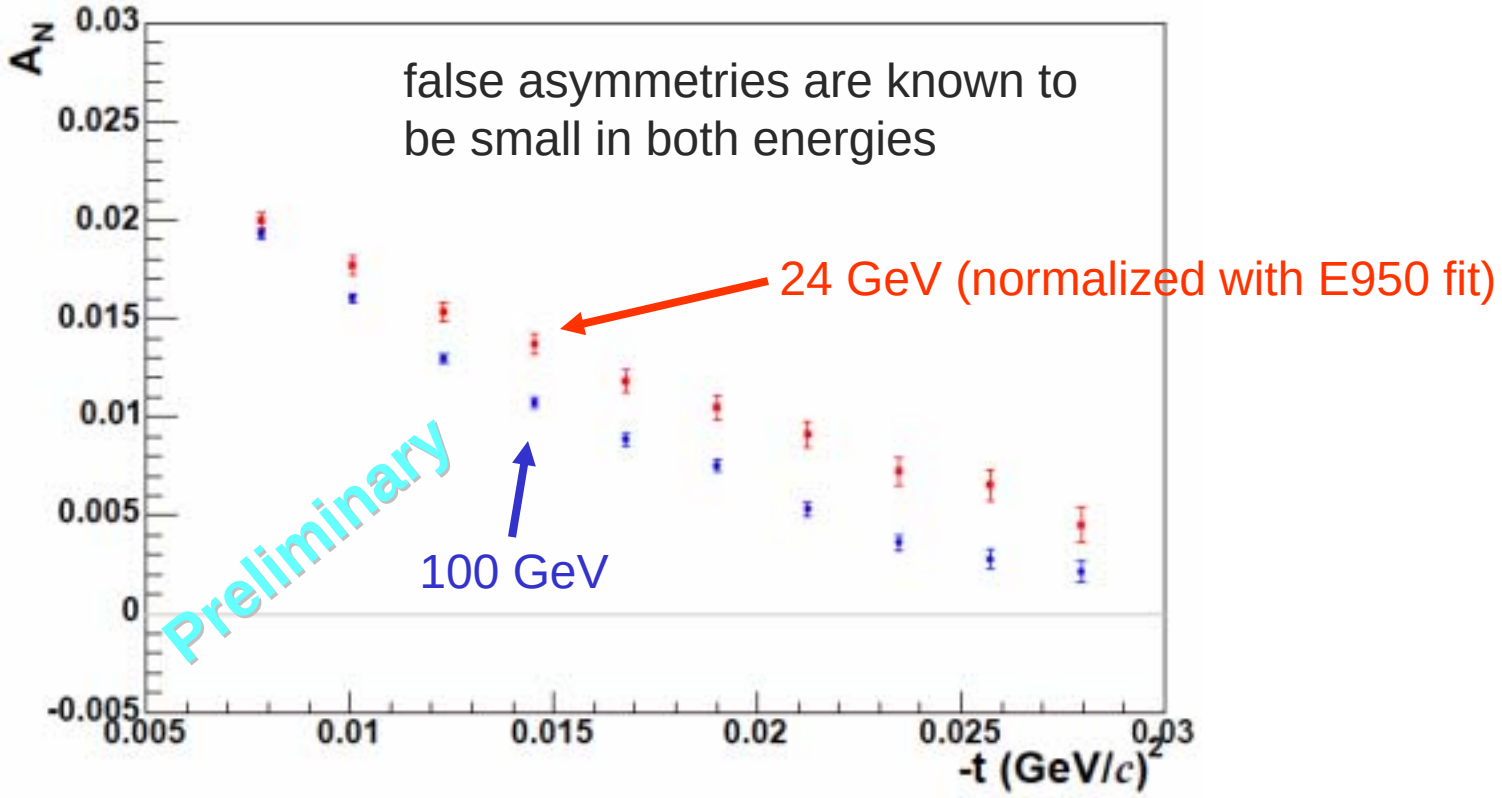
  $P_B = 0.386 \pm 0.030$

- Fit with CNI theory function (hep-ph/0305085)
- Major sources for sys errors
  - Si dead layer on $-t$ ($\pm 12 \mu g/cm^2$)
  - Propagation from error on P_B
  - The effects are scaling or shifting

Only BLUE ring has Jet-Target for Run-04

Hadron spin-flip term is still significant at 100GeV

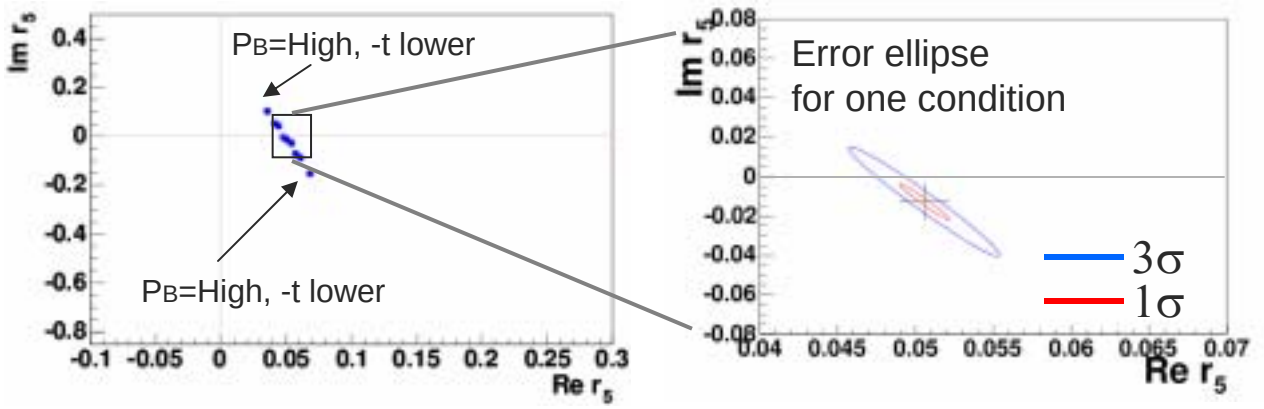
$A_N(t)$ comparison between 24GeV vs. 100GeV



- Raw asymmetry for 24GeV data is available (Not calibrated yet)
- Raw asymmetries at 24GeV are normalized by $A_N(t)$ theory fit function to E950

Discussion & Summary

- *pC* polarimeters used to measure beam polarizations in RHIC
- A_N measurement of *pC* elastic scattering was carried out at E_B=100GeV with Jet-Target for P_B
- In high -*t* range at 100GeV, zero crossing of A_N is observed
- The shapes of $A_N(t)$ are different btw 24GeV and 100GeV
- r_5 parameter was measured at E_B=100GeV
  - Strong correlation (Im vs. Re)
  - Small (zero consistent) Im r5



- A_N Calibration at E_B=24GeV is in progress