STAR

Transverse spin asymmetries at low momentum transfer at STAR

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Amplitudes and observables

Amplitudes and observables

$\phi_1(s,t) = \langle ++ | M | ++ \rangle$ spin non–flip

$\phi_2(s,t) = \langle ++ | M | -- \rangle$ double spin flip

$\phi_3(s,t) = \langle +- | M | +- \rangle$ spin non–flip

$\phi_4(s,t) = \langle +- | M | -+ \rangle$ double spin flip

$\phi_5(s,t) = \langle ++ | M | +- \rangle$ single spin flip

$$\sigma_{tot} = \frac{4\pi}{s} \operatorname{Im}\{\phi_1 + \phi_3\}_{t=0}$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\left\{ |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2 \right\}$$

$$A_N(s,t)\frac{d\sigma}{dt} = \frac{-4\pi}{s^2} \operatorname{Im}\left\{ \phi_5^* \left(\phi_1 + \phi_2 + \phi_3 - \phi_4\right) \right\}$$

$$A_{NN}(s,t)\frac{d\sigma}{dt} = \frac{4\pi}{s^2}\left\{ 2|\phi_5|^2 + \operatorname{Re}\left(\phi_1^*\phi_2 - \phi_3^*\phi_4\right) \right\}$$

$$A_{SS}(s,t)\frac{d\sigma}{dt} = \frac{4\pi}{s^2} \operatorname{Re}\left\{ \phi_1\phi_2^* + \phi_3\phi_4^* \right\}$$

Coulomb nuclear interference

Each amplitude has hadronic and electromagnetic parts:

$$\phi_i(s,t) = \phi_i^{EM}(s,t) + \phi_i^{HAD}(s,t)$$

Main contribution to A_N $(\phi_1 \approx \phi_3 \gg \phi_2, \phi_4)$:

$$A_N(s,t)\frac{d\sigma}{dt} \approx \frac{-8\pi}{s^2} \operatorname{Im}\left\{ \phi_5^{EM*}\phi_+^{HAD} + \phi_5^{HAD*}\phi_+^{EM} \right\}$$

EM terms are calculable from QED

?

$$\phi_+^{HAD} = (\phi_1^{HAD} + \phi_3^{HAD})/2 \propto \sigma_{tot}$$

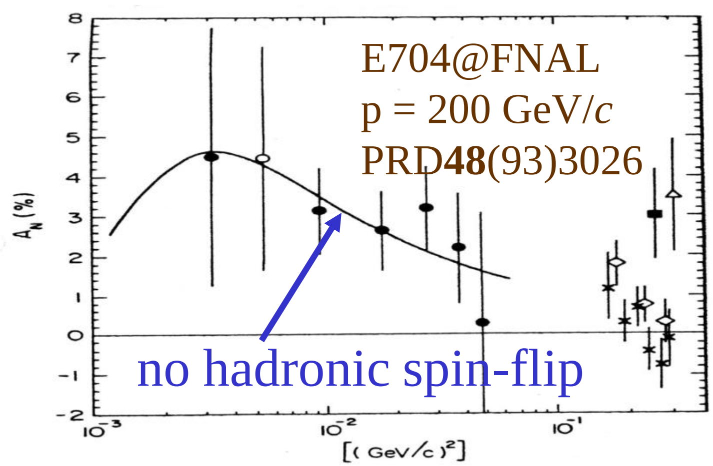
Parametrization: $\phi_5^{had} = r_5 \frac{\sqrt{-t}}{m_p} \operatorname{Im}\phi_+^{HAD}$

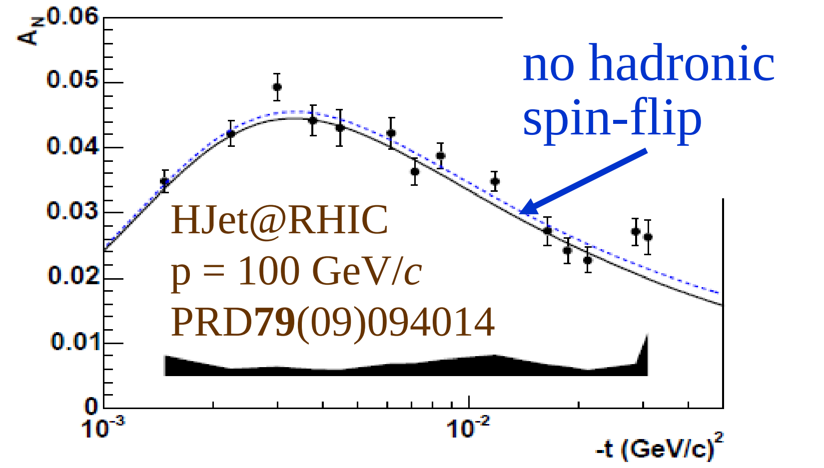
$$A_N(t) = \frac{\sqrt{-t}}{m} \frac{[(\mu-1)(1-\rho\,\delta) + 2(\delta \operatorname{Re} r_5 - \operatorname{Im} r_5)]\frac{t_c}{t} - 2(\operatorname{Re} r_5 - \rho \operatorname{Im} r_5)}{\left(\frac{t_c}{t}\right)^2 - 2(\rho+\delta)\frac{t_c}{t} + (1+\rho^2)}$$

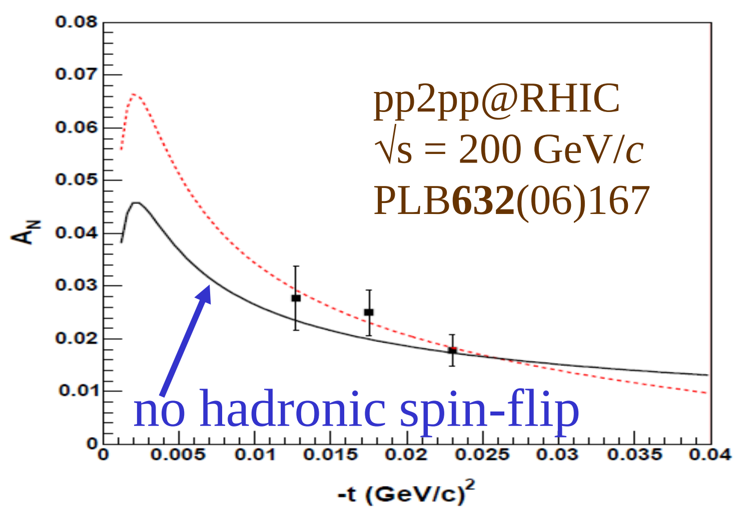
N. H. Buttimore *et. al*. Phys. Rev. D59, 114010 (1999)

A_N measurements in the CNI region

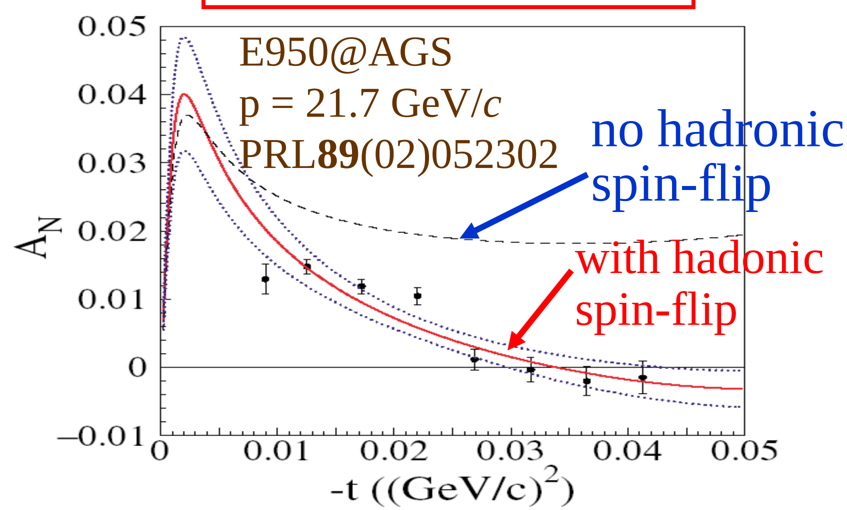
pp Analyzing Power



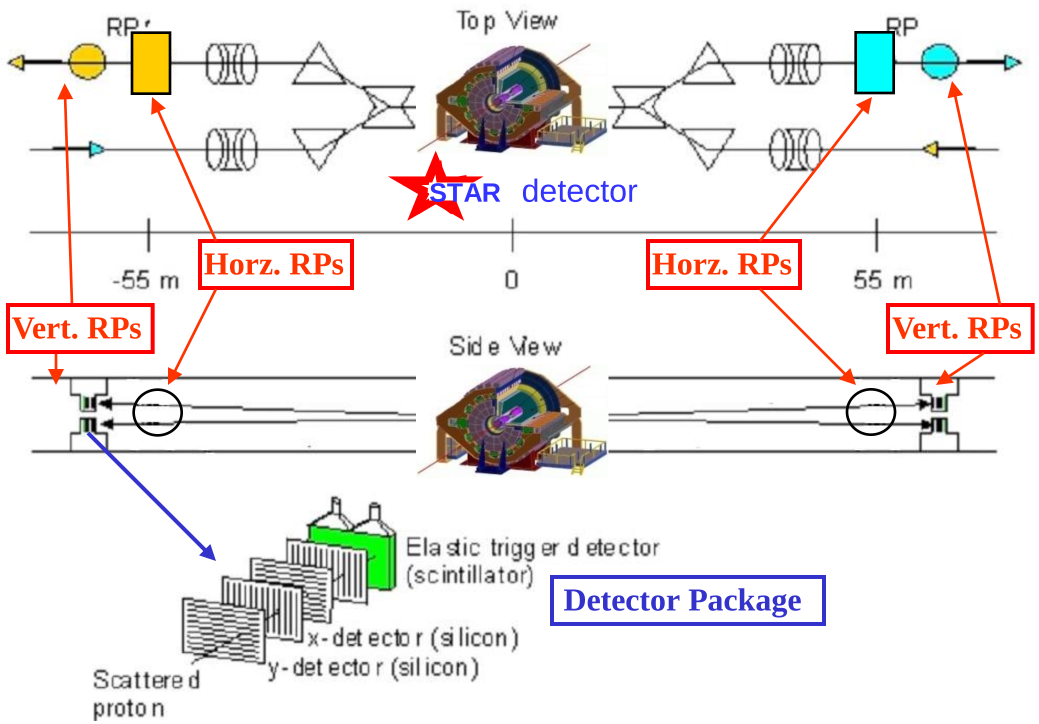




pC Analyzing Power



Roman pots at STAR



- Scattered protons have very small transverse momentum and travel with the beam through the accelerator magnets
- Roman pots allow to get very close to the beam without breaking accelerator vacuum
- Optimal detector position is where scattered particles are already separated from the beam and their coordinate is most sensitive to the scattering angle through the machine optics

Beam transport equations **relate measured position at the detector to the scattering angle**.

$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{pmatrix}$$

x_0, y_0 : Position at interaction point

Θ^*_x , Θ^*_y : Scattering angle at IP

x_D, y_D : Position at detector

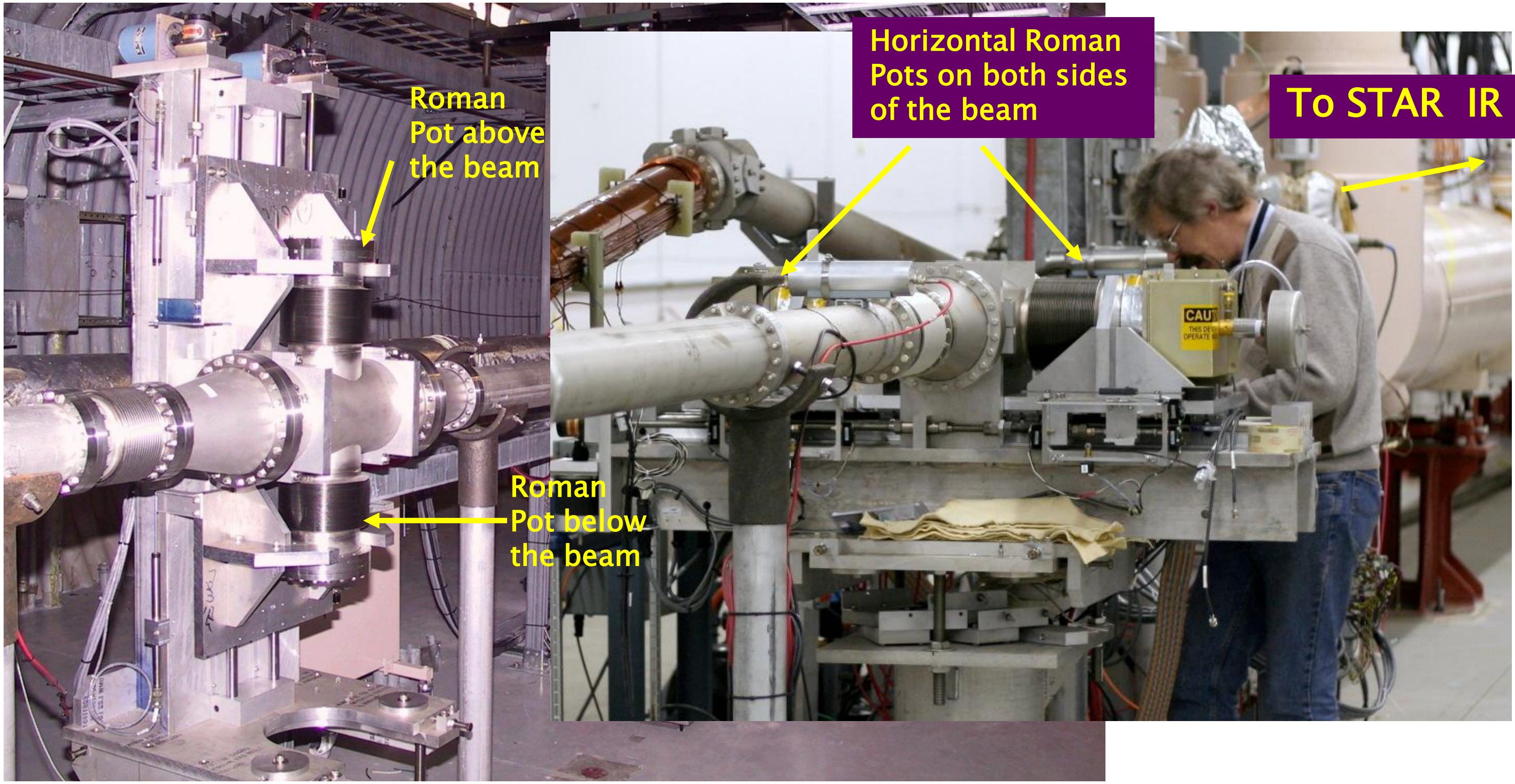
Θ^x_D, Θ^y_D : Angle at detector

The most significant matrix elements are L_{eff}, so that approximately

$x_D \approx L^x_{eff}\,\Theta_x^*$

$y_D \approx L^y_{eff}\,\Theta_y^*$

In the tunnel



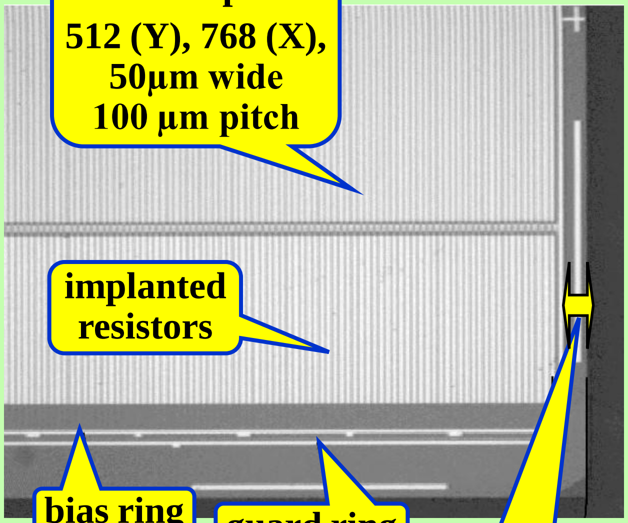
Integration of RPs with STAR for RUN-2009:

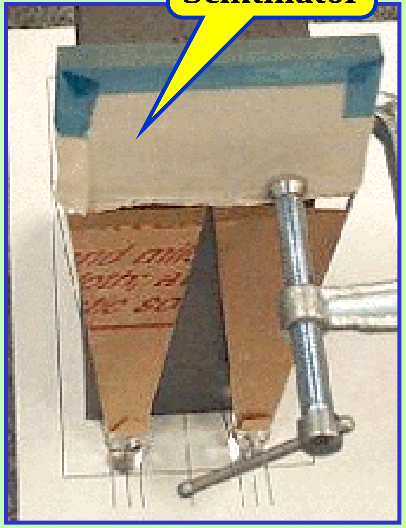
- STAR Trigger system
- STAR Data aqusition system
- STAR BBC or VPD for normalization

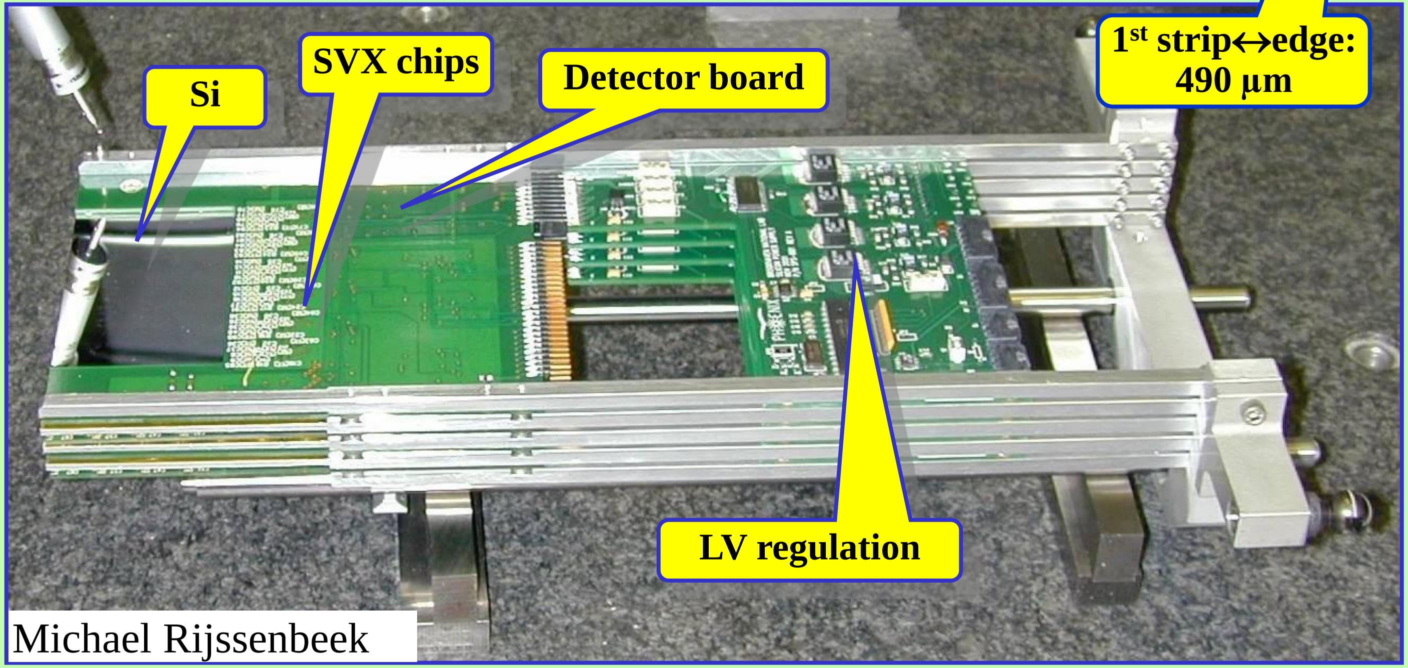
- Additional opportunities for other goals – central production etc.

Si detector package

- **4 planes of 400 µm Silicon microstrip detectors:**
  - ➢ 4.5 x 7.5 cm^2 sensitive area
  - ➢ 100 um pitch => good resolution, low occupancy
  - ➢ Redundancy: 2X- and 2Y-detectors in each package
  - ➢ Closest proximity to the beam ~10 mm
  - ➢ 8 mm trigger scintillator with two PMT readout
- **Total 32 silicon planes by Hamamatsu Photonics in 8 packages**
- **Only 5 dead/noisy strips per ~14000 active strips.**

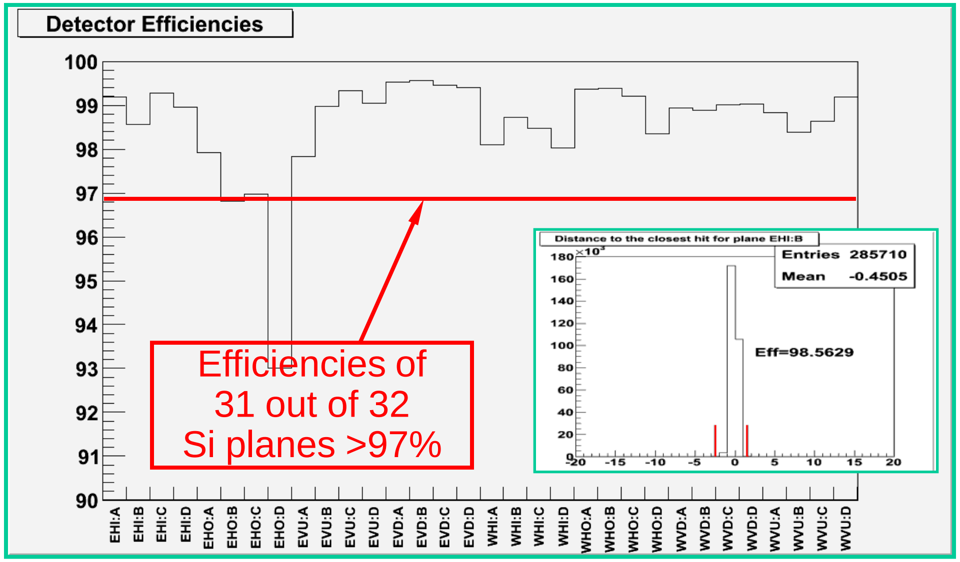




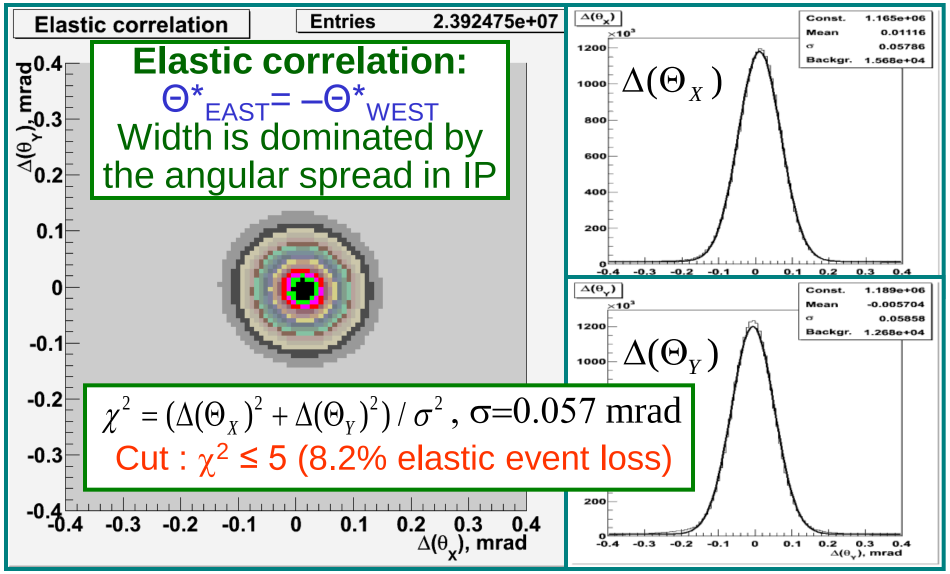


Detector performance and Elastic cuts

- Accurate hit cluster selection based on individual channel pedestals, cluster width and total charge
- Excellent signal/noise ratio ~20, high detector efficiency >97%
- Combine clusters in different planes of each side into tracks using alignment data from overlapping regions
- Convert track coordinates to IP angles using transport matrix
- Analyze the event for elasticity based on χ^2 , number of tracks and number of contributing planes



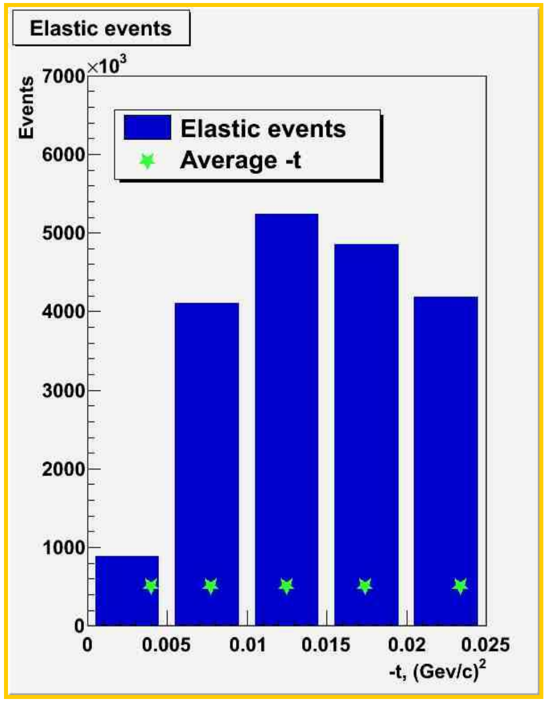
Event counting (45 runs)	
Total in files	58344907
Elastic triggers in files	32916916
Tracks in both sides	25028096
Single track on both sides	23924753
Selected elastic events	19277607

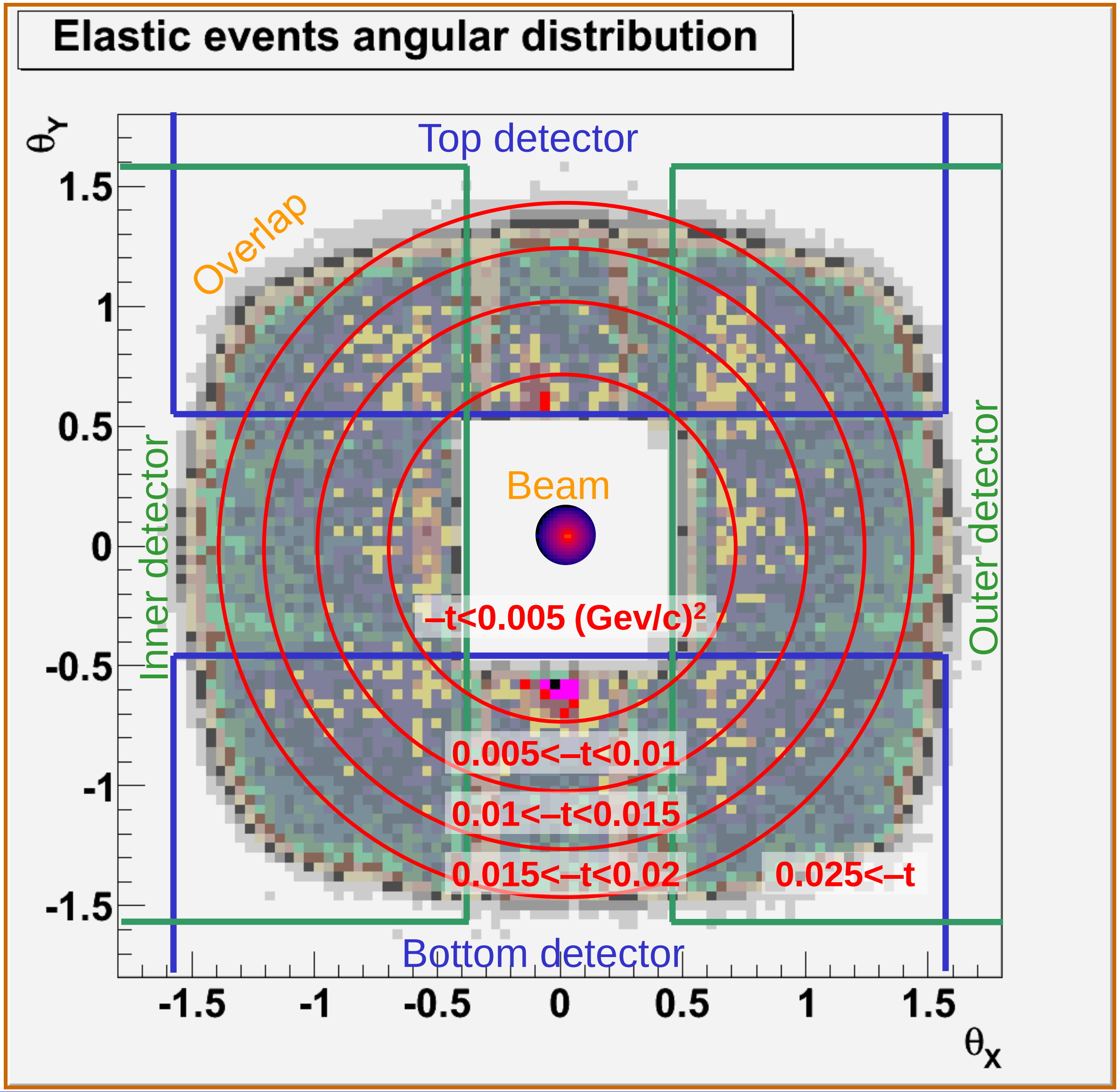


System acceptance and –t ranges

- Full 2π acceptance in azimuth angle
- 5 (–*t*) ranges up to 0.03 (GeV/c)^2

Number of events in each –*t*-range





Calculation of asymmetry A_N

Square root formula: don't need external normalization, acceptance asymmetry and luminosity asymmetry cancel out

We have all bunch polarization combinations: ↑↑, ↑↓, ↓↑, ↓↓ -- can build various asymmetries

$$\varepsilon_N(\varphi) = \frac{(P_B + P_Y) A_N \cos\varphi}{1+\delta(\varphi)} = \frac{\sqrt{N^{++}(\varphi)N^{--}(\pi+\varphi)} - \sqrt{N^{--}(\varphi)N^{++}(\pi+\varphi)}}{\sqrt{N^{++}(\varphi)N^{--}(\pi+\varphi)} + \sqrt{N^{--}(\varphi)N^{++}(\pi+\varphi)}}$$

$$\varepsilon_N^B(\varphi) = P_B A_N \cos\varphi = \frac{\sqrt{N_B^{+}(\varphi)N_B^{-}(\pi+\varphi)} - \sqrt{N_B^{-}(\varphi)N_B^{+}(\pi+\varphi)}}{\sqrt{N_B^{+}(\varphi)N_B^{-}(\pi+\varphi)} + \sqrt{N_B^{-}(\varphi)N_B^{+}(\pi+\varphi)}}$$

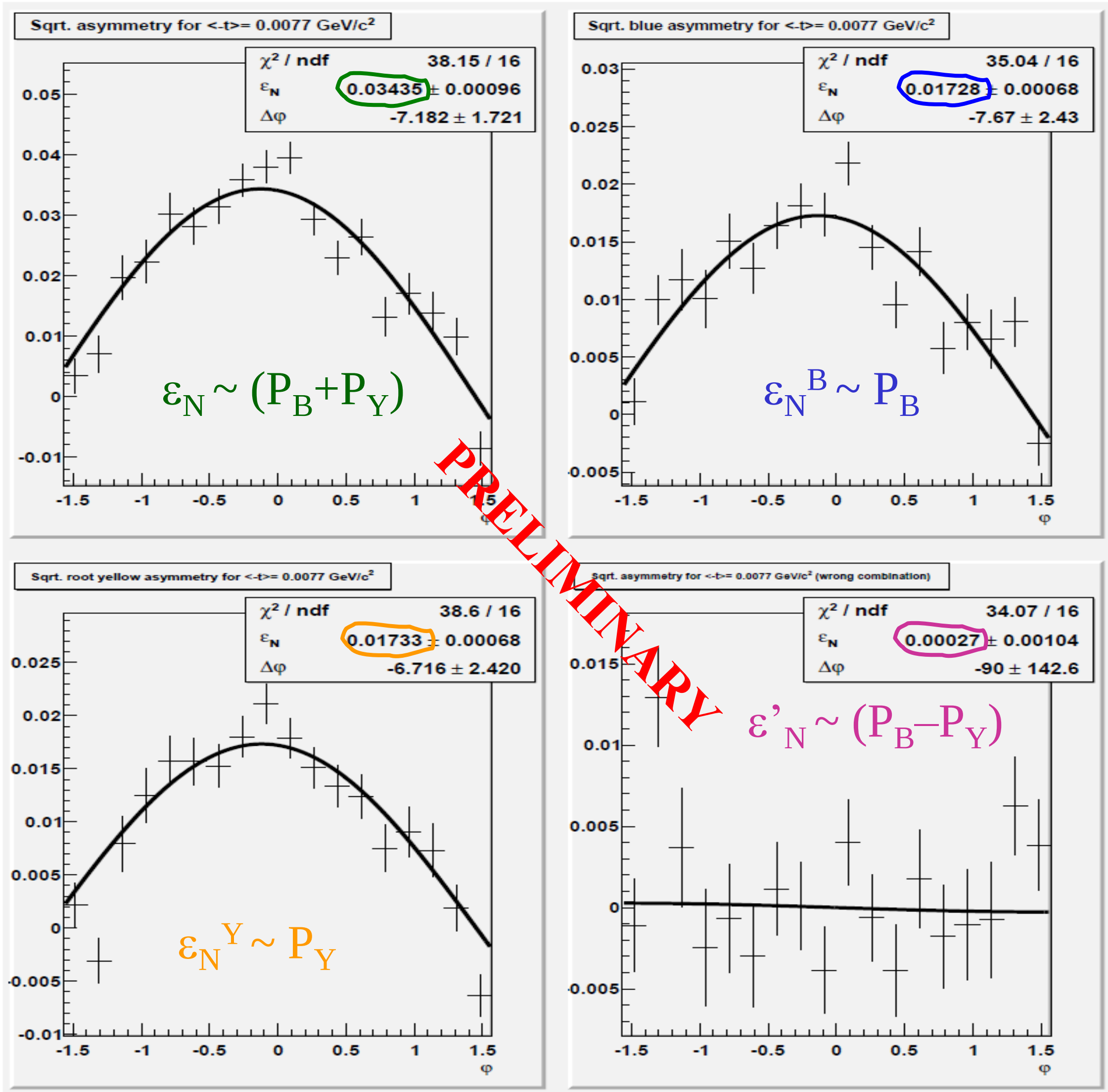
$$\varepsilon_N'(\varphi) = \frac{(P_B - P_Y) A_N \cos\varphi}{1-\delta(\varphi)} = \frac{\sqrt{N^{+-}(\varphi)N^{-+}(\pi+\varphi)} - \sqrt{N^{-+}(\varphi)N^{+-}(\pi+\varphi)}}{\sqrt{N^{+-}(\varphi)N^{-+}(\pi+\varphi)} + \sqrt{N^{-+}(\varphi)N^{+-}(\pi+\varphi)}}$$

where $\delta(\varphi) = P_B P_Y (A_{NN} \cos^2\varphi + A_{SS} \sin^2\varphi) < 0.01 << 1$

- Both beams polarized – half of the statistics, but effect ~ (P_B+P_Y)
- One beam polarized, the other 'unpolarized' – full statistics, but effect is only ~P_B (or P_Y)
- Opposite relative polarization – effect ~ $(P_B–P_Y)$ should be close to 0 – systematics check

Beam polarization: P_B= 0.602±0.026 P_Y= 0.618±0.028 P_BP_Y= 0.372±0.023
(P_B+P_Y) = 1.221±0.038, $(P_B – P_Y)$ = –0.016±0.038 = $0.013(P_B+P_Y)$

Raw single spin asymmetry $\varepsilon_N = A_N * P$

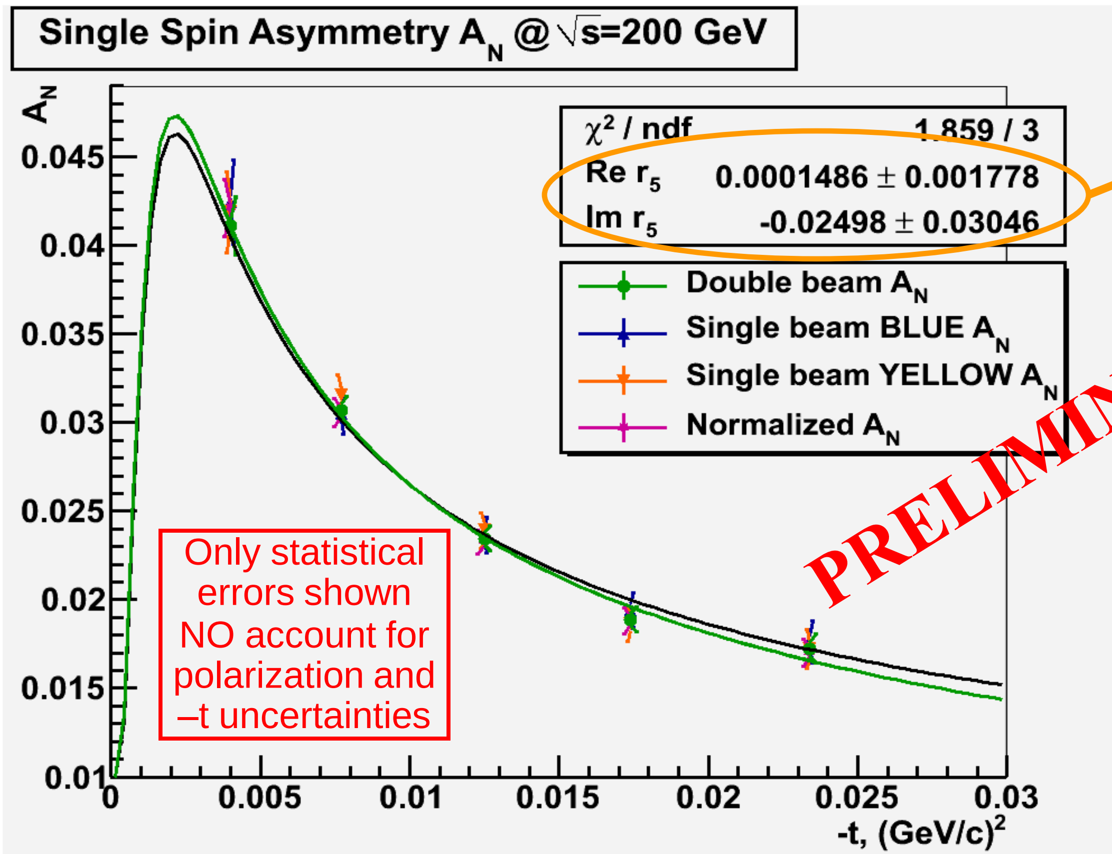


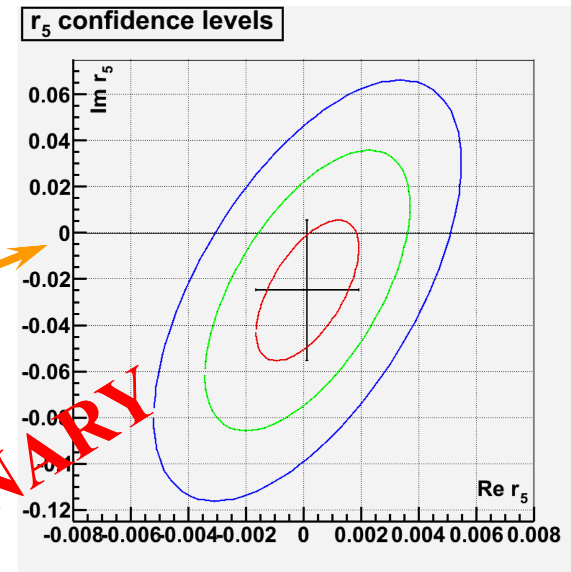
- Typical result for a single *t*-range
- As expected,

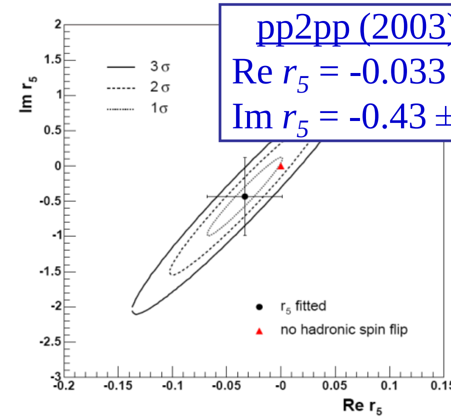
$$\frac{\varepsilon_N}{\varepsilon_N^B} \approx \frac{\varepsilon_N}{\varepsilon_N^Y} \approx 2.0$$

- Low statistical errors 2-3%
- Single beam asymmetries use the same statistics, but independent polarization variables – can be combined
- ε'_N is consistent with 0 – proof of 2 statements:
  - $(P_B - P_Y) \sim 0$ and
  - Low systematic shifts
- $\Delta\varphi$ reflects small deviation of the beam spin from vertical direction – the same by all calculations

A_N results and r_5 estimates







pp2pp (2003) result
Re r_5 = -0.033 ± 0.035
Im r_5 = -0.43 ± 0.56

- No significant contribution of hadronic spin-flip amplitude: $r_5 \sim 0$
- Accuracy improved ~20 times compared to pp2pp (2003)

Normalization and ε_N systematics checks

- Normalization is based on “inelastic” event counts assuming their negligible polarization dependence
- Two independent STAR subsystems, both having 2π acceptance for forward particles in east and west:

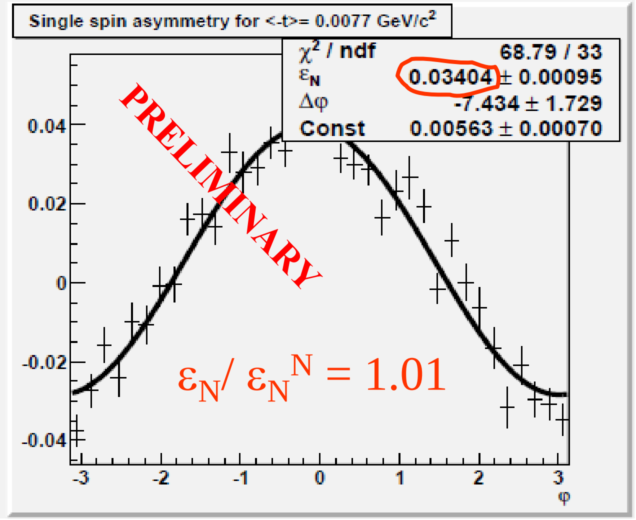
  BBC – beam-beam counters　　　VPD – vertex position detector

- Normalized counts: $K^{+/-} = N^{+/-}/V^{+/-}$, $N^{+/-}$ -- elastic event counts for a certain spin combination, $V^{+/-}$ -- normalization factor from BBC/VPD

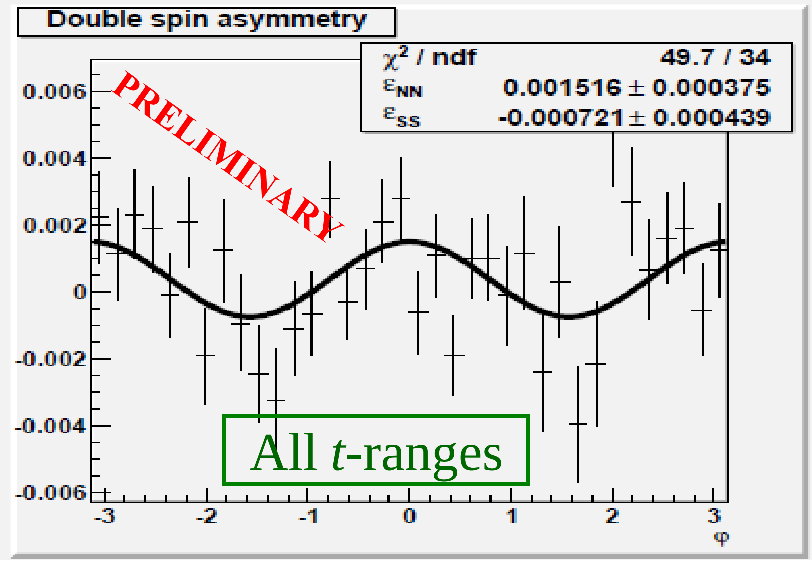
	statistics	V^{++}	V^{+-}	V^{-+}	V^{--}	stat σ
VPD	38246243	0.24544	0.24676	0.24940	0.25839	0.00028
BBC	449686340	0.24512	0.24595	0.25028	0.25864	0.00008
average		0.24528	0.24636	0.24984	0.25852	

$$\varepsilon_N^N(\varphi) = \frac{(P_B + P_Y)A_N \cos\varphi}{1+\delta(\varphi)} = \frac{K^{++}(\varphi) - K^{--}(\varphi)}{K^{++}(\varphi) + K^{--}(\varphi)}$$

- $V^{+/-}$ differs beyond statistical error (0.25%) for VPD/BBC – two different physics processes ⇒ average
- Asymmetry value in good agreement ⇒
  - Small systematic errors
  - High normalization quality – but may not be good enough for A_{NN} & A_{SS}



A_{NN} and A_{SS}

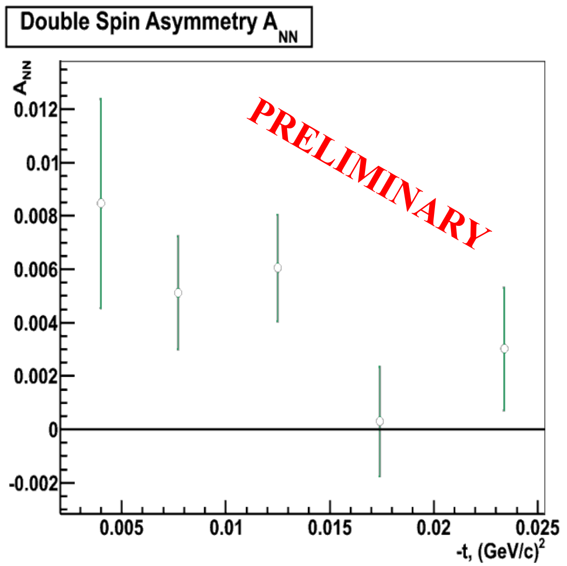


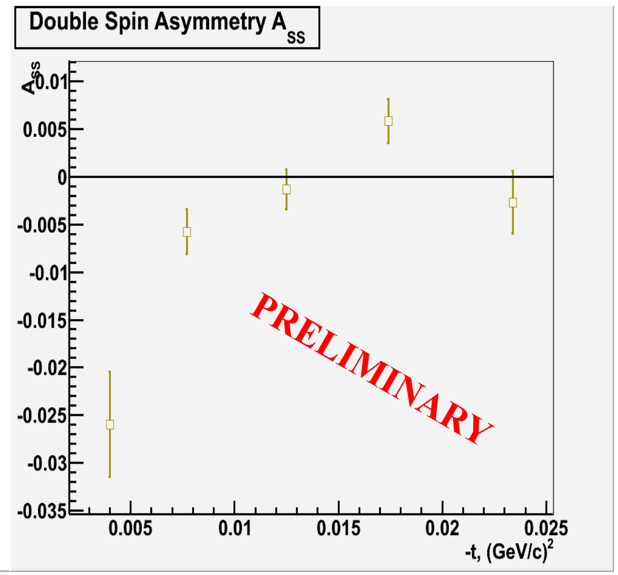
- Cannot use square root formula – have to rely on normalized counts $K^{+/-}$

$$\varepsilon_{NN}(\varphi) = P_B P_Y (A_{NN} \cos^2 \varphi + A_{SS} \sin^2 \varphi) =$$

$$= \frac{(K^{++}(\varphi) + K^{--}(\varphi)) - (K^{+-}(\varphi) + K^{-+}(\varphi))}{(K^{++}(\varphi) + K^{--}(\varphi)) + (K^{+-}(\varphi) + K^{-+}(\varphi))}$$

- Double spin effects are seen and not consistent with 0





- Both A_{NN} and A_{SS} are very small ~10^{-3} (except for the lowest *t*-range where larger systematic shifts may occur)
- Need better systematic error studies – current normalization uncertainties are of the order of the effect

Conclusions and plans

SUMMARY

- Roman Pots installed at STAR IR and integrated into STAR detector for low *t* studies
- ~$20\cdot10^6$ elastic events recorded in 40 hours of data taking in 5 days with RPs in 2009 at $\sqrt{s}$=200 GeV and special machine optics β^*=21 m
- Excellent detector performance provides extremely clean data set
- Single spin asymmetry A_N obtained with unprecedented 2% accuracy in 5 *t*-ranges
- No significant contribution of hadronic spin-flip amplitude seen: $r_5 \sim 0$
- Double spin effects are seen, but need more accurate normalization studies

THE WAY TO THE FINAL RESULT

- Accurate MC simulations of transport and comparison with data – done
- Finalize detector alignment based on data and MC – done
- Derive final values of systematic uncertainties in $-t$, A_N, r_5 – in progress
- Normalization studies for double spin asymmetries – in progress.

FURTHER PLANS

- Measurements of A_{LL} at $\sqrt{s}$=200 GeV – longitudinal polarization is possible with STAR spin rotators
- Measurements at $\sqrt{s}$=500 GeV: σ_{TOT}, diffraction cone slope b, A_N (expect r_5~0)