STAR

Results on transverse spin asymmetries in the polarized proton-proton elastic scattering in the CNI region at STAR

Dmitry Svirida (ITEP) for the STAR Collaboration

International Workshop on Diffraction in High-Energy Physics,
Otranto, Italy, September 10-15, 2010

Diffraction 2010

Helicity amplitudes for spin ½ ½ → ½ ½

Matrix elements

$\phi_1(s,t) = \langle ++ | M | ++ \rangle$ 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

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

Formalism is well developed,
however not much data !
At high energy only A_N measured to some extent.

Observables: cross sections and spin asymmetries

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

$$\Delta\sigma_T = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow} = -\frac{8\pi}{s} \mathrm{Im}\{\phi_2\}_{t=0}$$

$$\Delta\sigma_L = \sigma^{\overleftarrow{\rightarrow}} - \sigma^{\overrightarrow{\rightarrow}} = \frac{8\pi}{s} \mathrm{Im}\{\phi_1 - \phi_3\}_{t=0}$$

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

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

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

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

also A_{SL}, A_{LL}

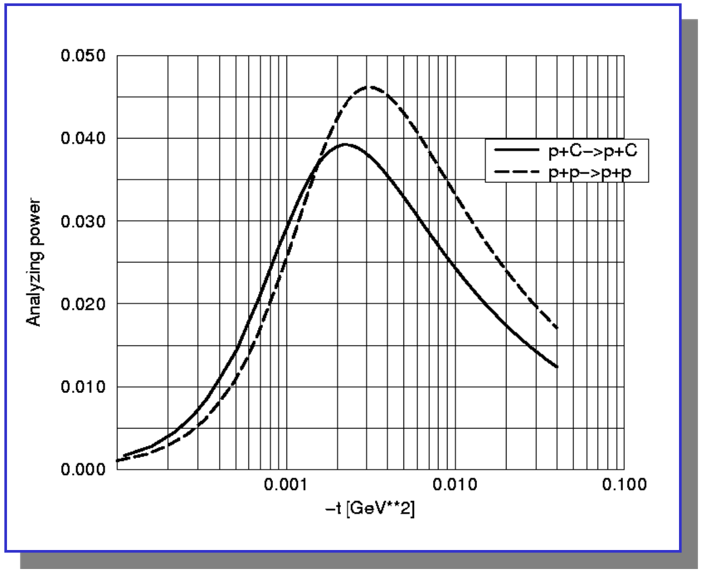
A_N & Coulomb nuclear interference

The left – right scattering asymmetry A_N arises from the interference of the spin non-flip amplitude with the spin flip amplitude (Schwinger)

$$A_N = C_1 \phi_{flip}^{em\,*} \phi_{non-flip}^{had} + C_2 \phi_{flip}^{had\,*} \phi_{non-flip}^{em}$$

$\propto(\mu-1)_p$ $\propto\sigma^{pp}_{tot}$

In absence of hadronic spin – flip Contributions A_N is exactly calculable (Kopeliovich & Lapidus)



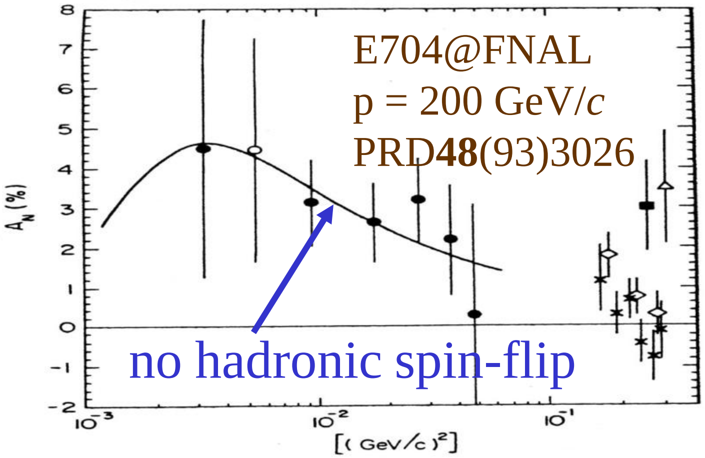
Hadronic spin- flip modifies the QED 'predictions'. Hadronic spin-flip is usually parametrized as:

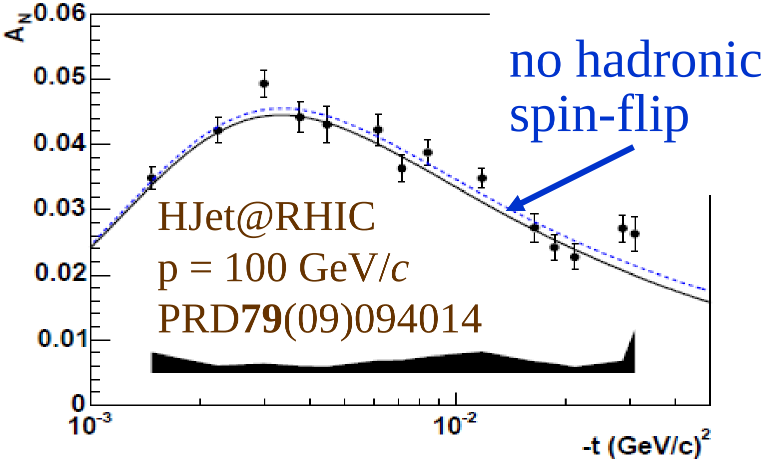
$$\phi_5^{had} = r_5 \frac{\sqrt{-t}}{m_p} \frac{1}{2} \mathrm{Im}\left(\phi_1^{had} + \phi_3^{had}\right)$$

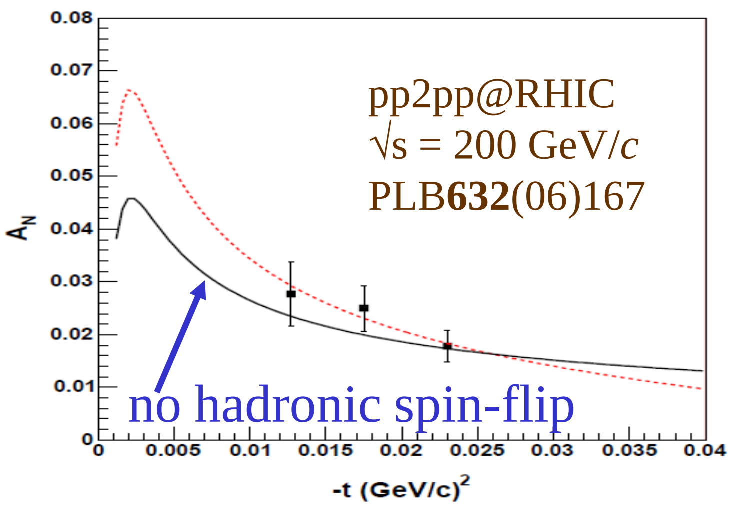
$$A_N(t) = \frac{\sqrt{-t}}{m} \frac{[\kappa(1-\rho\,\delta) + 2(\delta\,\mathrm{Re}\,r_5 - \mathrm{Im}\,r_5)]\frac{t_c}{t} - 2(\mathrm{Re}\,r_5 - \rho\,\mathrm{Im}\,r_5)}{\left(\frac{t_c}{t}\right)^2 - 2(\rho+\delta)\frac{t_c}{t} + (1+\rho^2)}$$

A_N measurements in the CNI region

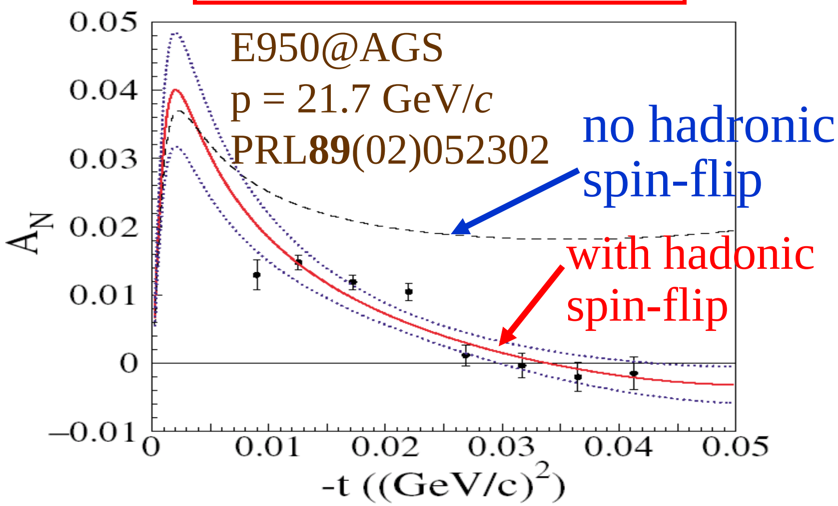
pp Analyzing Power



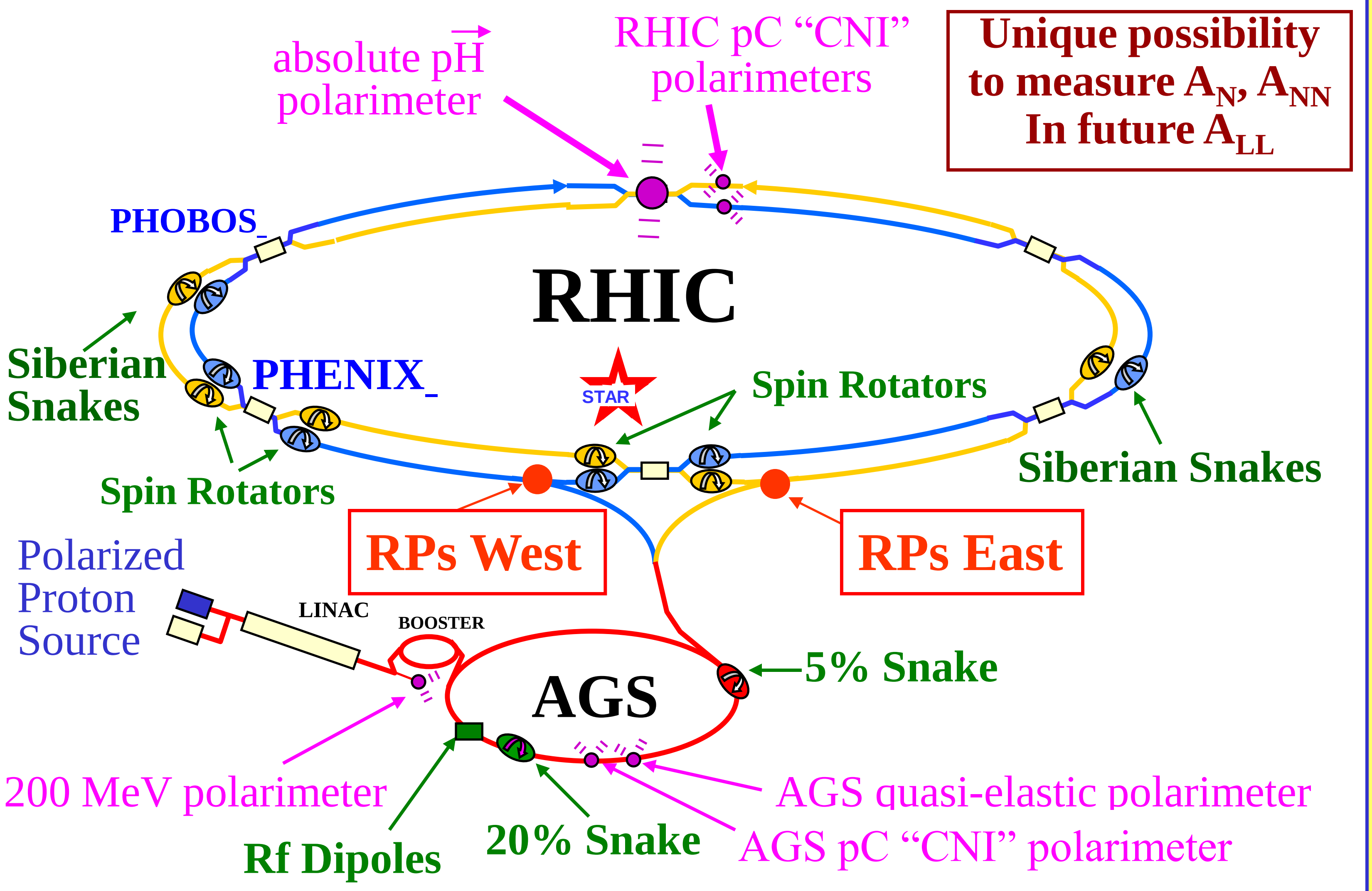




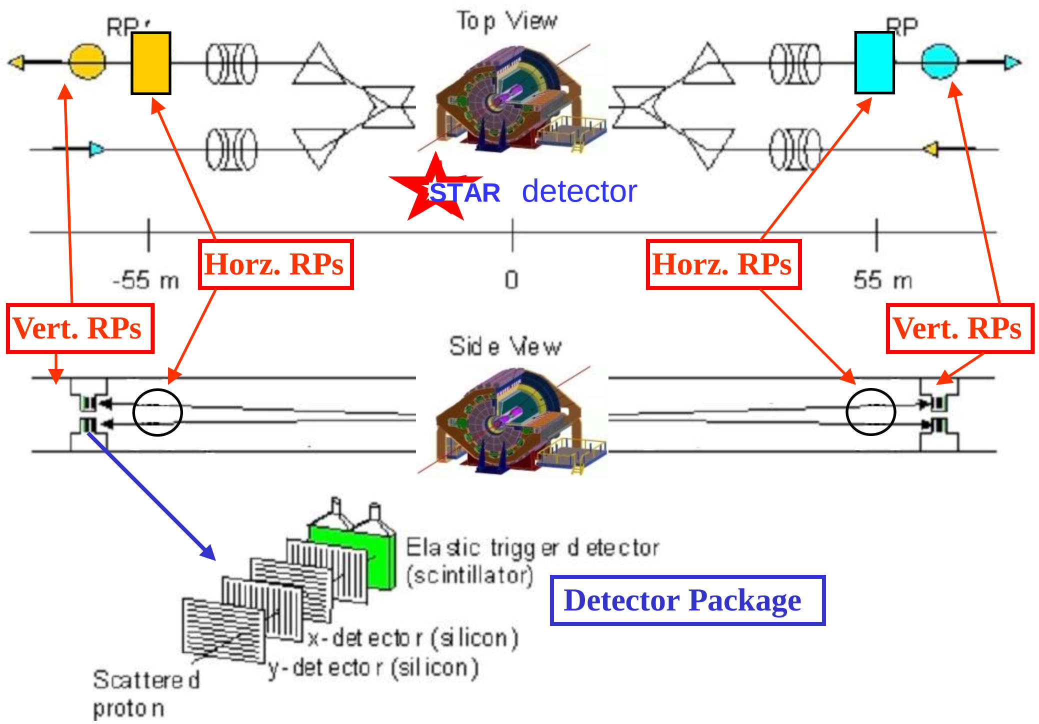
pC Analyzing Power



RHIC-Spin accelerator complex



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 were 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

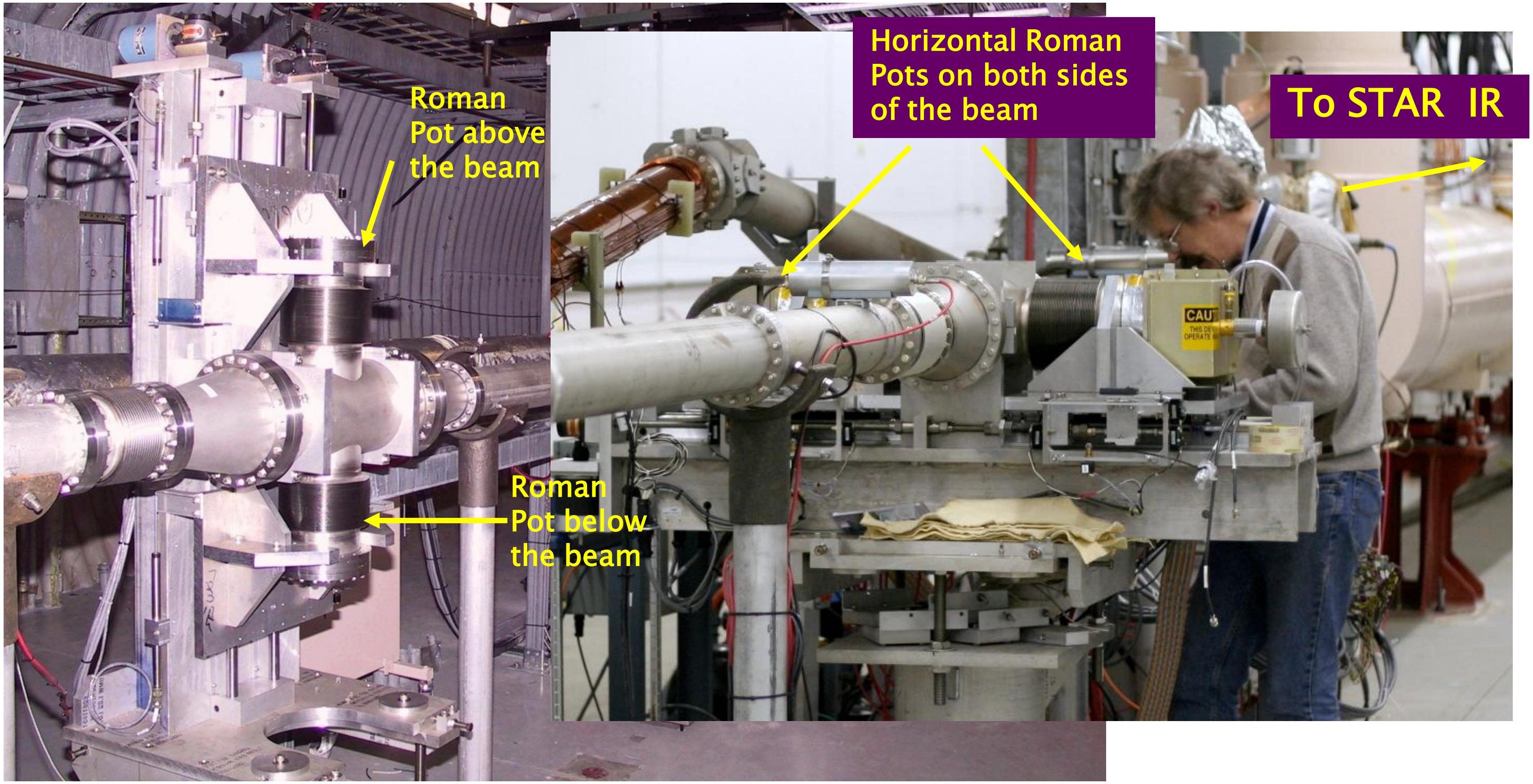
Θ^x_D, Θ^y_D : Angle at detector

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:

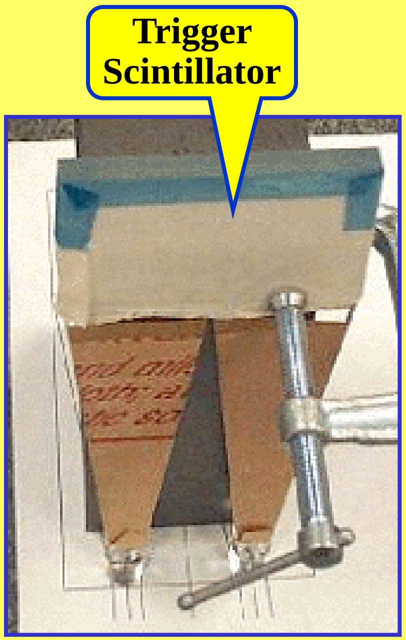
- STAR Trigger system
- STAR Data aqusition system
- STAR BBC or VPD for normalization

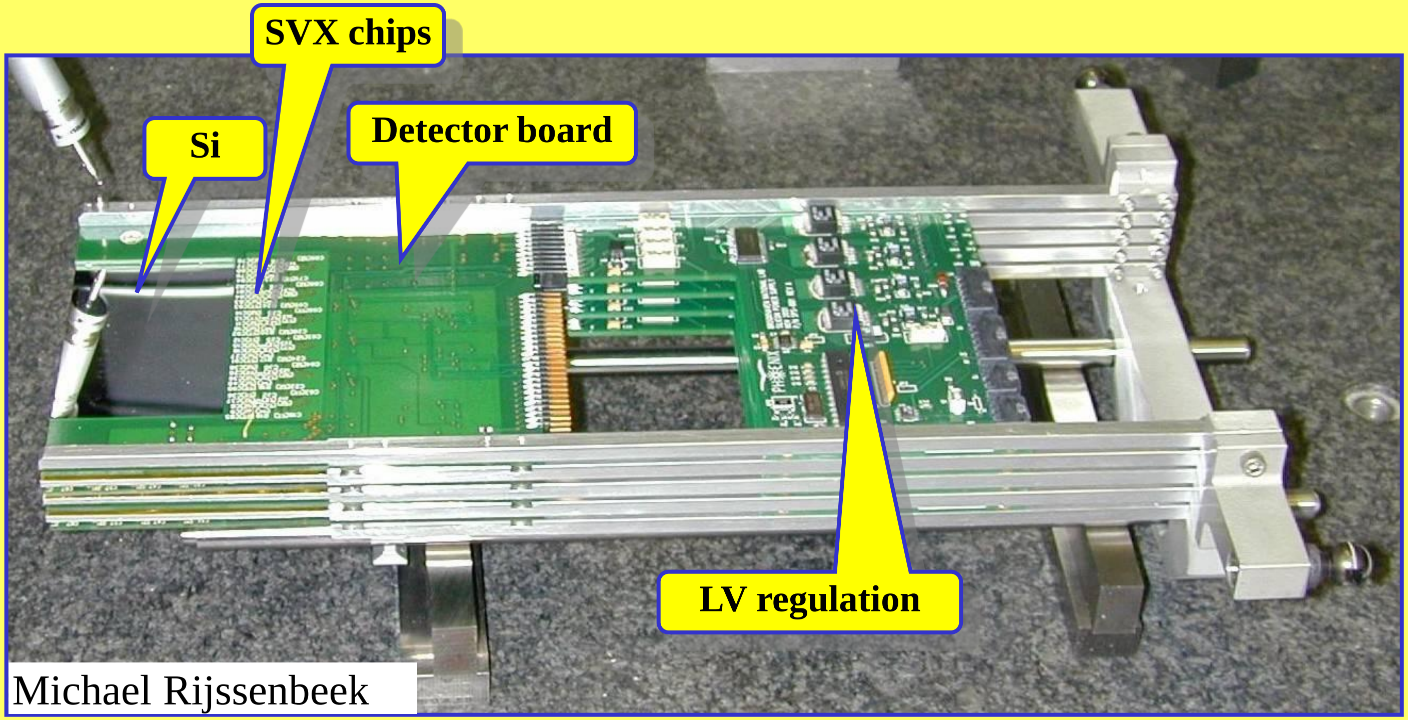
- Additional opportunities for other goals – central production etc. See the talk by W.Guryn at this conference

Si detector package

- **4 planes of 400 μm Silicon microstrip detectors:**
  - 4.5 x 7.5 cm^2 sensitive area
  - 100 μm strip pitch
  - Good resolution, low occupancy
  - Redundancy: 2X- and 2Y-detectors in each package
  - Closest proximity to the beam ~10 mm

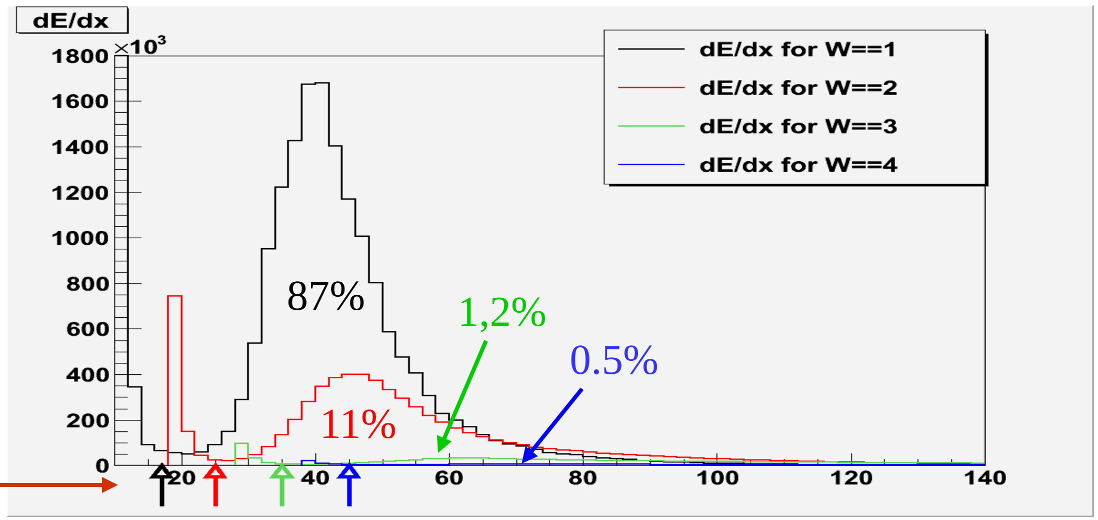
- 8 mm trigger scintillator with two PMT readout behind Silicon planes
- **Total 32 silicon planes by Hamamatsu Photonics in 8 packages**
- **Only 5 dead/noisy strips per ~14000 active strips.**

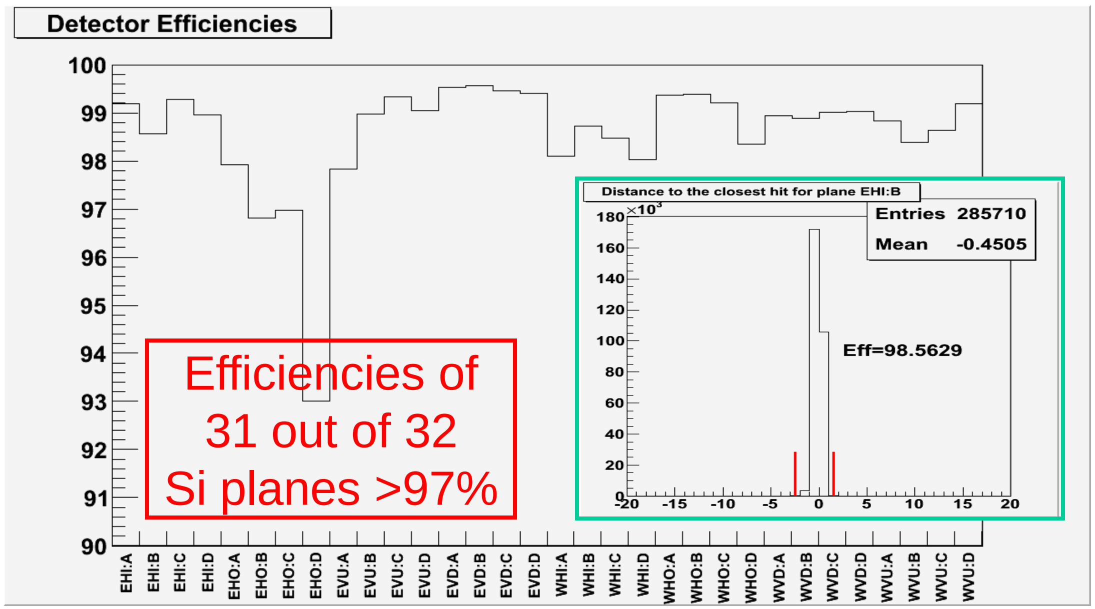




Hit selection and Detector performance

- Pedestals and pedestal spreads σ_P calculated for each strip
- Signal beyond $5\sigma_P$ is a signal candidate
- Look for adjacent strips with signals to form a cluster
- Reject cluster with >4
- Apply cluster charge cut based on cluster width
- Planes with >5 clusters rejected in given event
- Clusters in the planes of the same coordinate in a package are combined into one hit if closer than 2 strips (~200 um) or left as separate clusters otherwise
- All possible X-Y hit pairs are taken (not more than 20 per package)



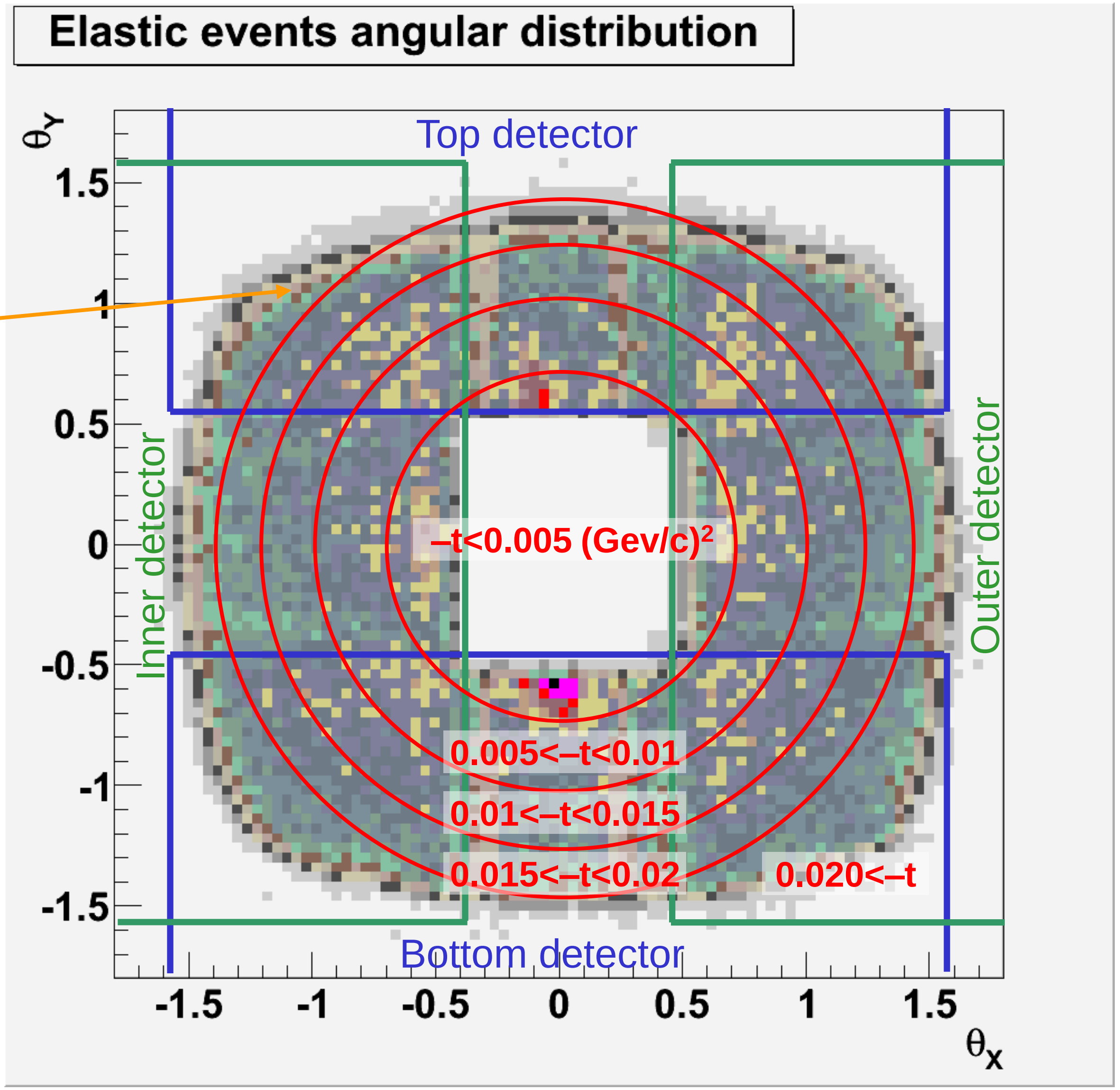


System acceptance and –t ranges

- Hits on each side translated into angles at IP using transport matrix and alignment data (both in x and y directions)
- Hits on each side with angles in x and y within 0.06 mrad combined into one track (intersection regions)
- Number of hits in each track is counted

Number of events in each *–t*-range

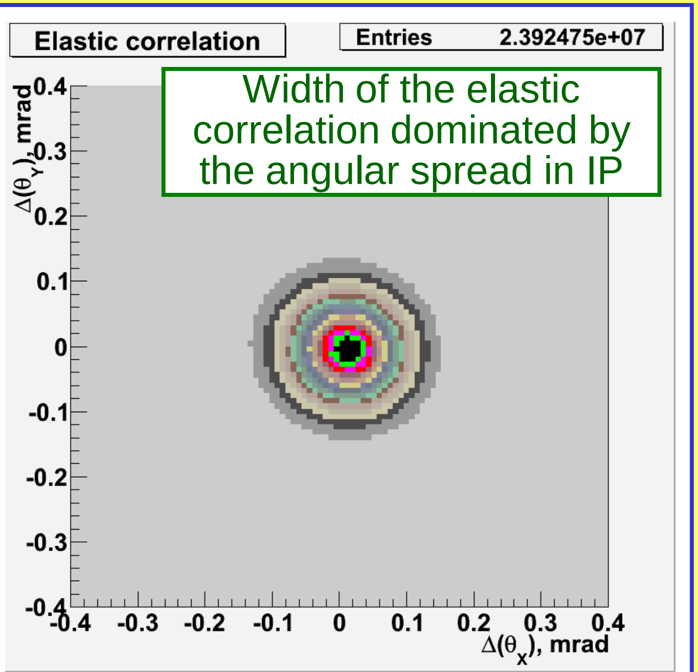
Range -t	<-t>	Events
0.005 > -t	0,0040	890434
0.005 – 0.010	0,0077	4104266
0.010 – 0.015	0,0125	5241353
0.015 – 0.020	0,0174	4854983
-t > 0.020	0,0234	4186571



Elastic events selection

- On each side, if there is more than one track, only tracks with 4 or more contributing planes left (noise reduction)
- Require exactly 1 track on each side

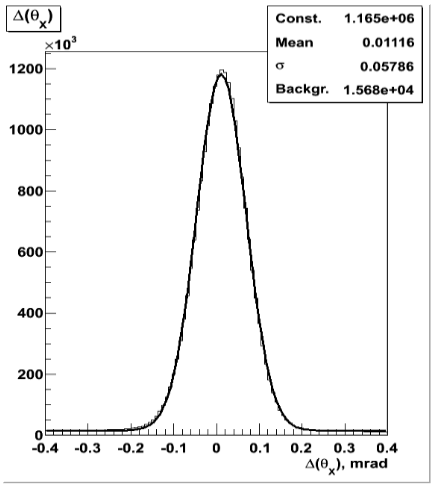
- For elastic events $\Theta^*_{EAST} = -\Theta^*_{WEST}$ – elastic correlation
- For each East-West track pair calculated $\chi^2 = (\Delta(\Theta_X)^2 + \Delta(\Theta_Y)^2) / \sigma^2$; σ=0.057 mrad
- Final event selection: number of planes contributed >= 6 and $\chi^2 \leq 5$ (8.2% elastic event loss)

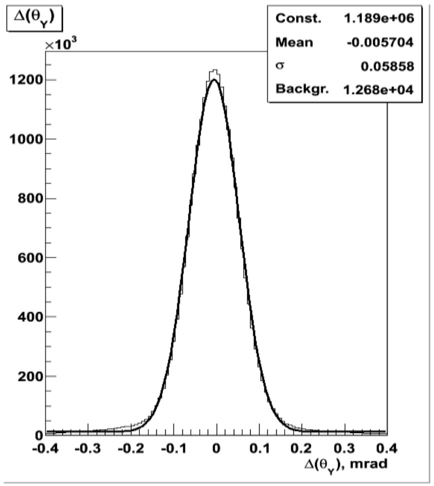


Additional cuts:

- Bunches in abort gaps rejected

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





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

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

- Both beams polarized – half of the statistics, but effect ~ (P_B+P_Y)

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

- One beam polarized, the other 'unpolarized' – full statistics, but effect is only ~P_B (or P_Y)

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

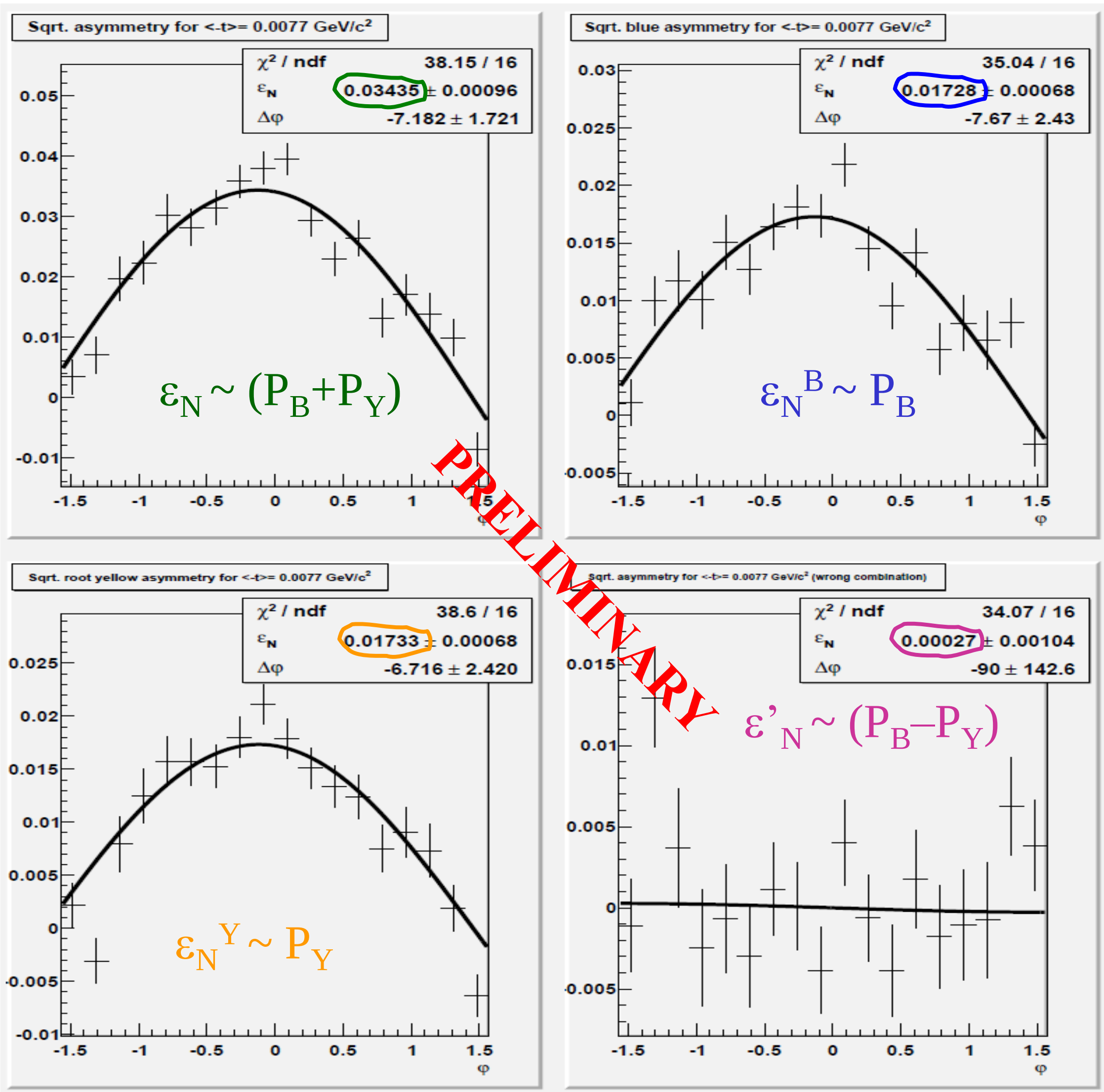
- Opposite relative polarization – effect ~ $(P_B–P_Y)$ should be close to 0 – systematics check

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

Beam polarization: $P_B = 0.602 \pm 0.026$ $P_Y = 0.618 \pm 0.028$ $P_B P_Y = 0.372 \pm 0.023$

$(P_B+P_Y) = 1.221 \pm 0.038$, $(P_B - P_Y) = -0.016 \pm 0.038 = 0.013(P_B+P_Y)$

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

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:

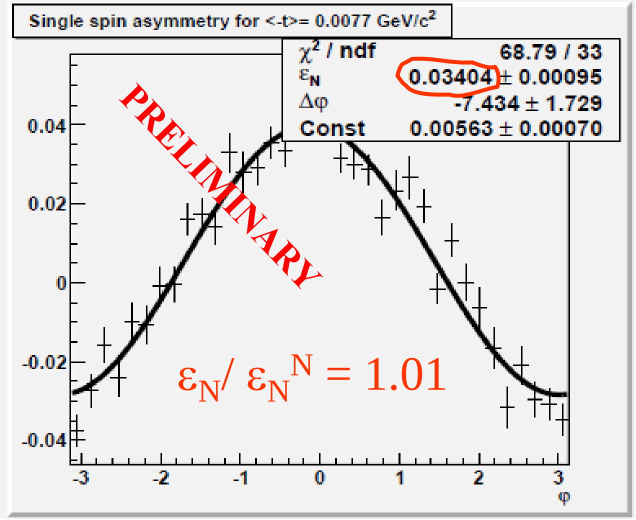
  BBC – beam-beam counters　　VPD – vertex position detector

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

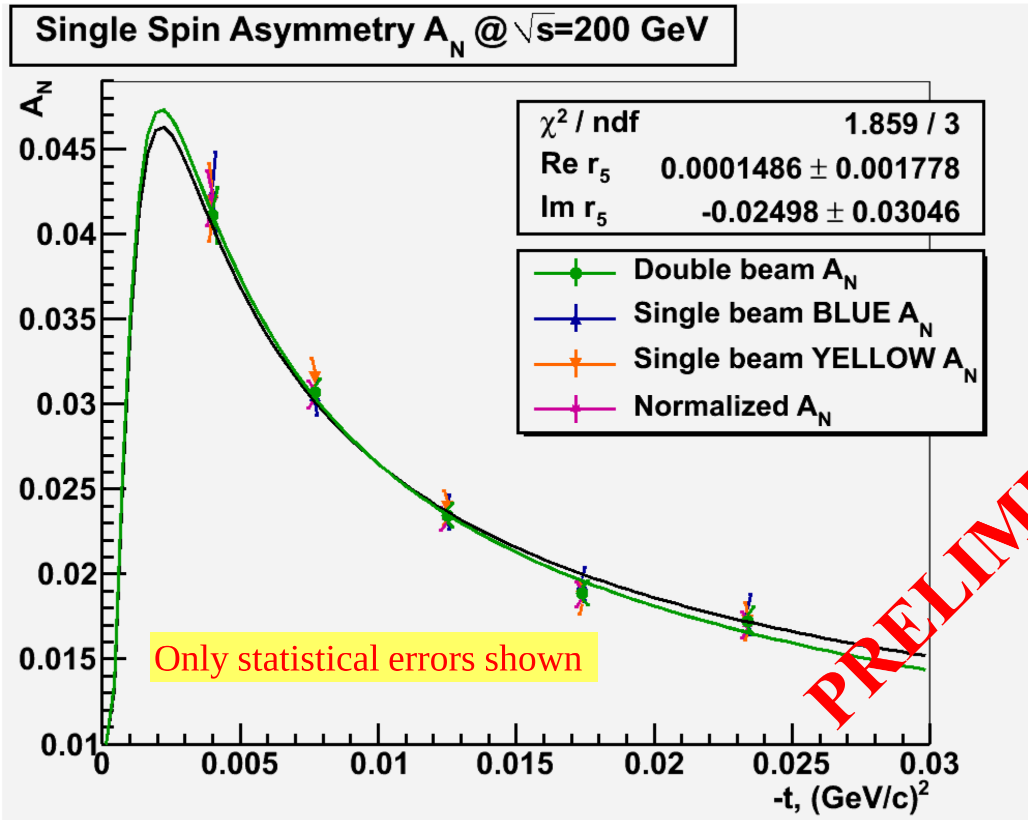
	statistics	++	+-	-+	--	stat σ
VPD	38246243	0.24544	0.24676	0.24940	0.25839	0.00007
BBC	449686340	0.24512	0.24595	0.25028	0.25864	0.00002
average		0.24528	0.24636	0.24984	0.25852	

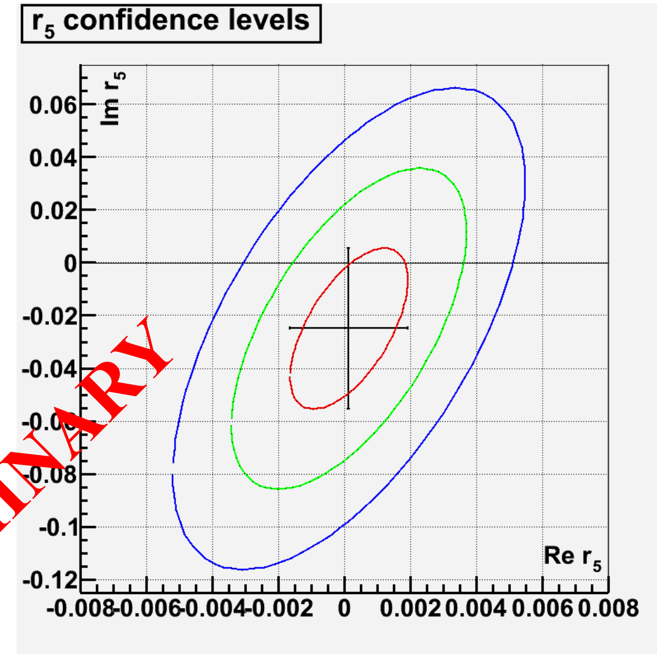
$$\varepsilon_N^N(\varphi) = \frac{(P_B + P_Y) A_N \cos\varphi}{1 + \delta(\varphi)} = \frac{K^{++}(\varphi) - K^{--}(\varphi)}{K^{++}(\varphi) + K^{--}(\varphi)}$$

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



A_N results and r_5 estimates





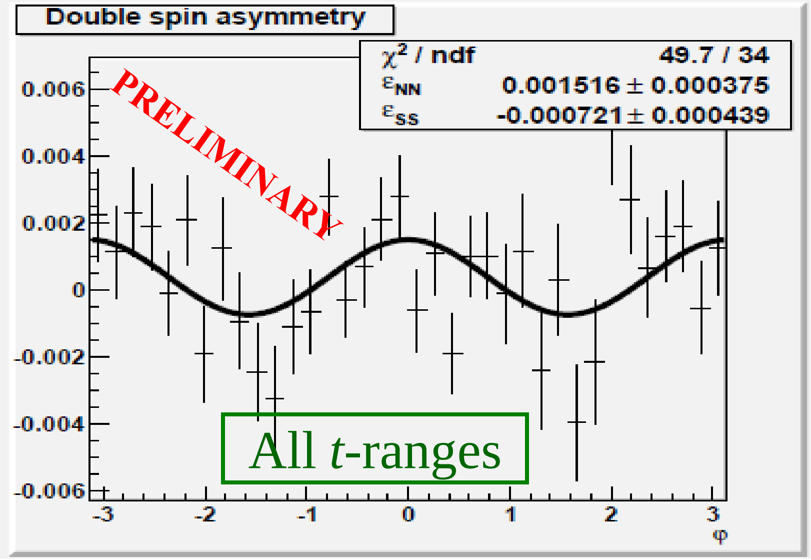
NO account for polarization and –t uncertainties

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

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

$t_c = -8\pi\alpha / \sigma_{tot}$; κ is anomalous magnetic moment of the proton;

A_{NN} and A_{SS}

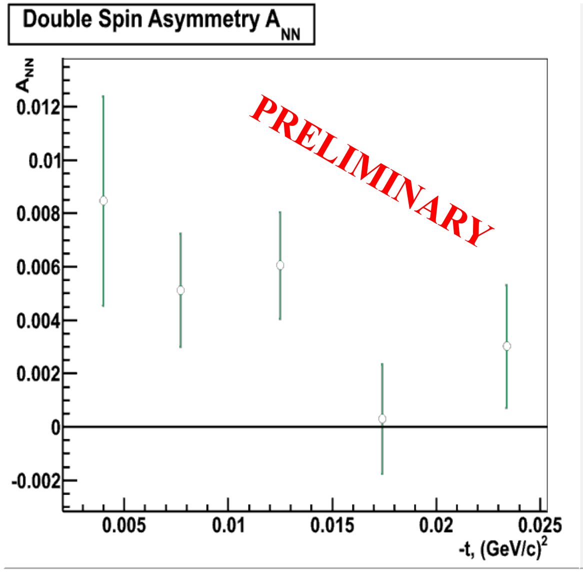


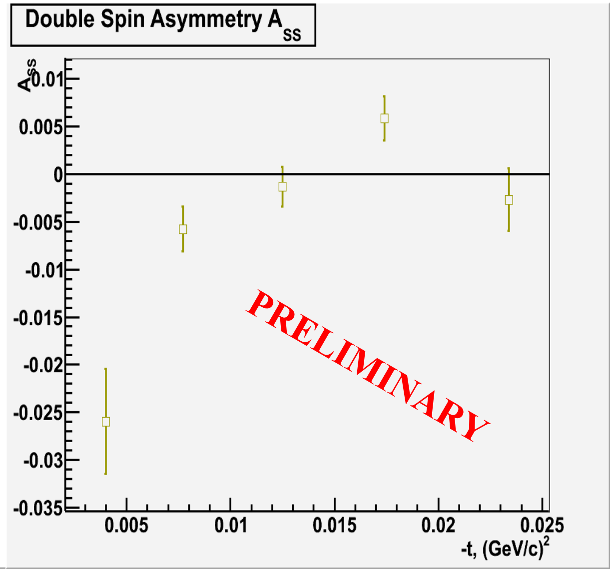
- Cannot use square root formula – have to rely on normalized counts $K^{+/-}$

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

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

- 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

- Roman Pots installed at STAR IR and integrated into STAR detector for low *t* studies
- ~$20 \cdot 10^6$ 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 studies

THE PATH TO THE FINAL RESULT

- Finalize detector alignment using data
- Constraint several transport matrix elements using data
- More systematic error studies: random polarization, forbidden asymmetries, acceptance asymmetries etc.
- Advance r_2 and r_4 estimates from double spin asymmetry studies

NEAREST FUTURE IN 2011

- Plan to run 1 week at $\sqrt{s}$=500 GeV with the same physics goals

FURTHER PLANS

- Measurements with longitudinal polarization – A_{LL} – possible with STAR spin rotators