Polarized Proton-Proton Elastic Scattering at RHIC

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For The STAR Collaboration

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Outline

- Proton-Proton Elastic Scattering
- Very-Forward Detectors at STAR Detector at RHIC
- Spin-Dependent Proton-Proton Elastic Scattering
- Simulation Results on Detector Acceptance
- Summary

Proton-Proton Elastic Scattering at RHIC

- RHIC provides polarized proton beams with a high average polarization of about **0.70** for each beam and a high luminosity reaching $\boldsymbol{L = 2 \cdot 10^{32}\ cm^{-2} sec^{-1}}$ at a cms energy range of **50 GeV ≤ $\sqrt{s}$ ≤ 500 GeV.**

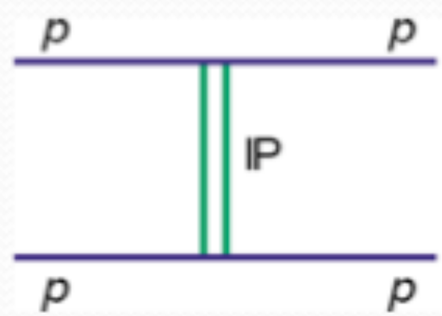
- PP2PP Experiment at RHIC
  - Past
    - Successful engineering run in **2002** (First Measurement of *p-p* Elastic Scattering at RHIC at $\sqrt{s}$ **= 200 GeV**)
    - Successful physics run in **2003** (Measurements of Spin Asymmetries at $\sqrt{s}$ **= 200 GeV**)
  - Present – The PP2PP setup has been integrated with STAR
    - Study elastic scattering and central production by using the STAR detector.
    - During run **2008** used a dedicated beam time during last 2 hrs of the run for Roman Pot and DAQ commissioning.
    - Integration with the accelerator and STAR trigger was successful
  - Future
    - Ready to take data with STAR during run **2009** and beyond

Proton-Proton Elastic Scattering

- In elastic scattering protons remain <u>intact</u>.

$$p + p \rightarrow p + p$$

- A *Pomeron* (IP) is exchanged.



- *Pomeron* exchange in PQCD consists of a color singlet combination of gluons (two gluons).

Detect protons in very forward direction by using Roman Pots

Differential *pp* Elastic Cross Section

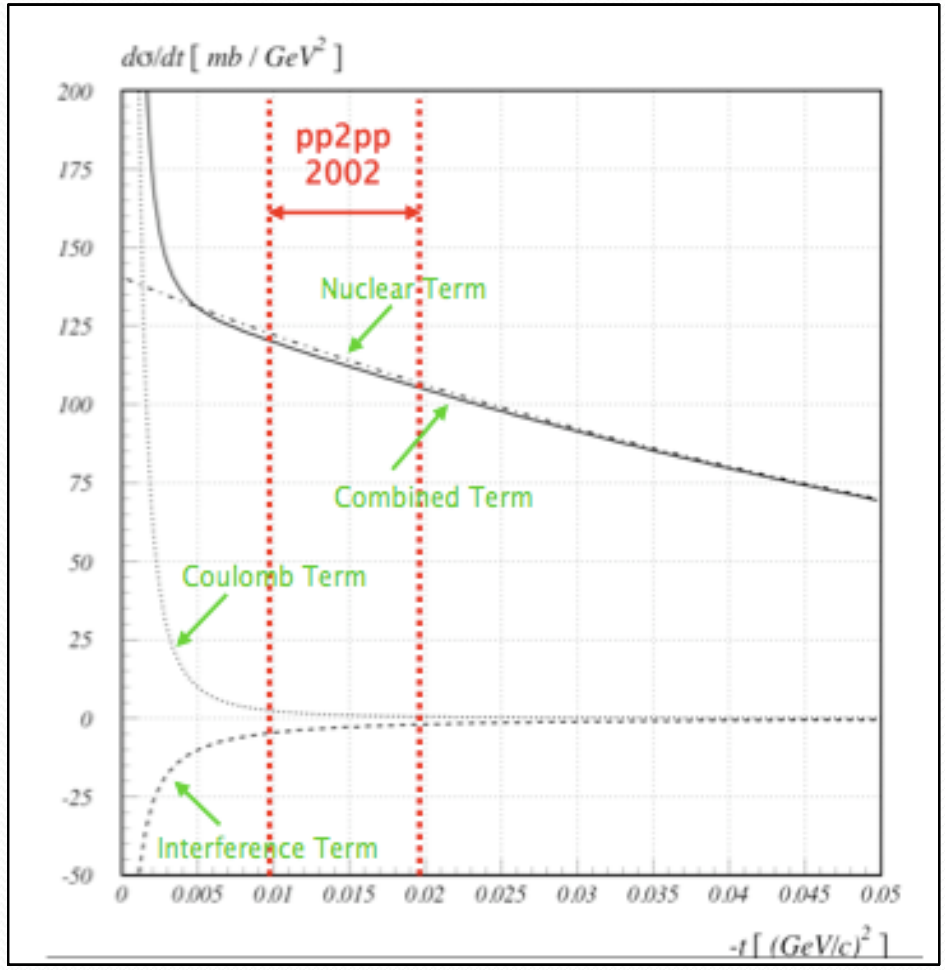
$$\frac{d\sigma_{el}}{dt} = 4\pi(\hbar c)^2\left(\frac{\alpha G_E^2}{t}\right)^2$$

$$+\frac{1+\rho^2}{16\pi(\hbar c)^2}\sigma_{tot}^2 e^{-b|t|}$$

$$-(\rho+\Delta\Phi)\frac{\alpha G_E^2}{|t|}\sigma_{tot}e^{-\frac{1}{2}b|t|}$$

1. Coulomb Term
2. Hadronic Term
3. Coulomb Nuclear Interference Term

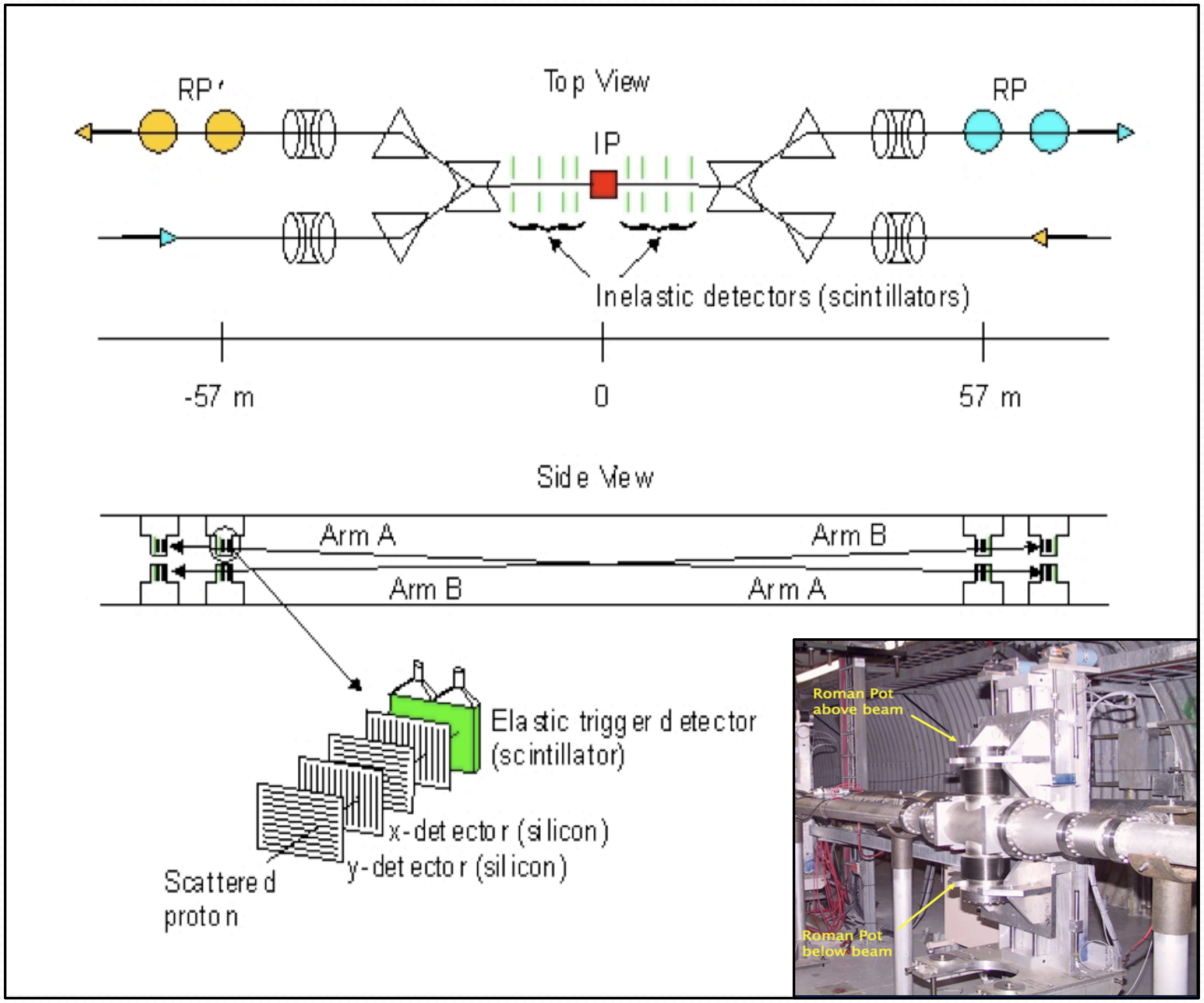
dσ/dt (mb/GeV²)



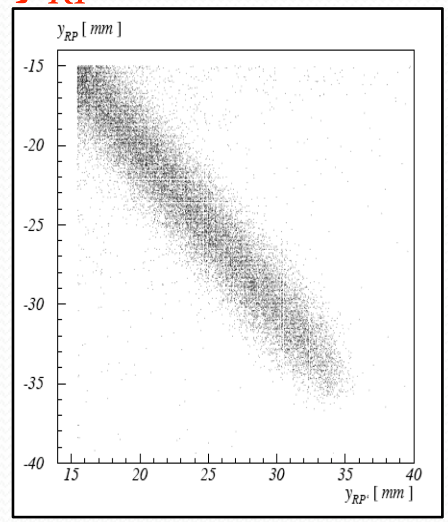
-t (GeV²/*c*²)

Experimental Layout

RP’ RP



$y_{RP'}$ (mm)



y_{RP} (mm)

Collinearity condition for elastic events

Measurement Technique

- Very forward detectors detect protons that scatter elastically at very small angles.
- Trajectories of scattered particles are determined by the beam transport equations: (* = at IP)

$$y = a_{11} y^* + L_{eff} \theta^*_y$$
$$\theta_y = a_{12} y^* + a_{22} \theta^*_y$$

- a_{11}, L_{eff}, a_{12}, a_{22} are the beam transport matrix elements
- Similar equations in *x*-coordinate
- Choose a_{11} to be small and L_{eff} very large, thus:

$$\boldsymbol{y \sim L_{eff} \theta^*_y}$$

Spin Dependent Elastic Scattering

- The scattering amplitude with **initial** $|h_1 h_2\rangle$ and **final helicity** $|h_3 h_4\rangle$ **states** of the interacting protons (1 & 2) with momenta $p_1 = - p_2$ and scattered protons (3 & 4) with momenta $p_3 = - p_4$ is of the form:

$$\phi_n(s,t) = \langle h_1 h_2 | M | h_3 h_4 \rangle = \phi_n^{em}(s,t) + \phi_n^{had}(s,t)$$

- The **helicity amplitudes** that describe ***pp*** **elastic scattering:**

$$\phi_1(s,t) = \langle ++ | M | ++ \rangle$$
$$\phi_2(s,t) = \langle ++ | M | -- \rangle$$
$$\phi_3(s,t) = \langle +- | M | +- \rangle$$
$$\phi_4(s,t) = \langle +- | M | -+ \rangle$$
$$\phi_5(s,t) = \langle ++ | M | +- \rangle$$

N.H. Buttimore et al, Spin dependence of high energy proton scattering, Phys. Rev. D, Volume 59, 114010 (1999)

- The **differential elastic cross section** and **the total cross section** are given as:

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

$$\sigma_{tot} = \frac{4\pi}{s}\,\mathrm{Im}\left[\phi_1(s,t) + \phi_3(s,t)\right]_{t=0}$$

Single Spin Asymmetry

- The interference between the hadronic non-flip and electromagnetic spin-flip amplitudes gives rise to the single spin asymmetry in the CNI region.

$$A_N(t) = \frac{1}{P\cos\phi_{azimuth}} \frac{N_{\uparrow\uparrow}(t) - N_{\downarrow\downarrow}(t) + N_{\uparrow\downarrow}(t) - N_{\downarrow\uparrow}(t)}{N_{\uparrow\uparrow}(t) + N_{\downarrow\downarrow}(t) + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}$$

$$A_N(t) \approx \frac{\mathrm{Im}\left(\phi_{flip}^{em*}\phi_{non-flip}^{had} + \phi_{flip}^{had*}\phi_{non-flip}^{em}\right)}{d\sigma/dt}$$

$N(t) = dN/dt$

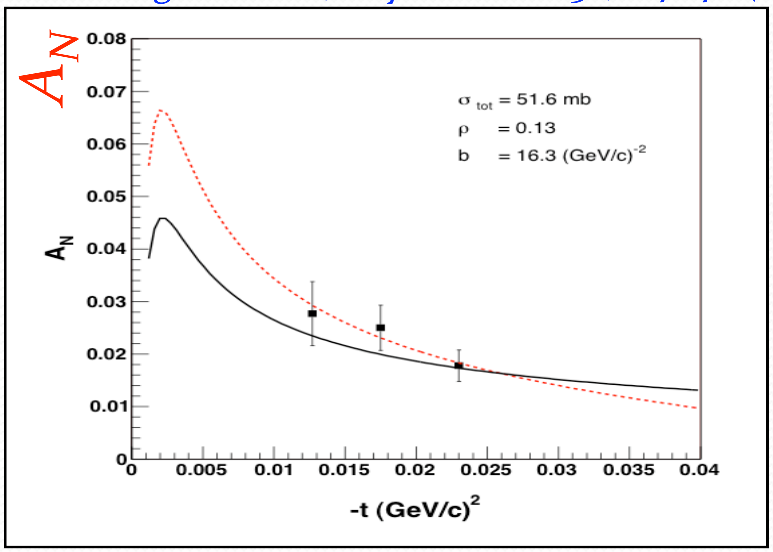
P: beam polarization

- The electromagnetic single-flip amplitude is real and calculable. Hence $\boldsymbol{A_N}$ can be calculated and compared to data.

- Study $\boldsymbol{A_N}$ and its **$|t|$-dependence** to probe the interference term between hadronic and Coulomb interactions.

Analyzing Power Measurement 2003

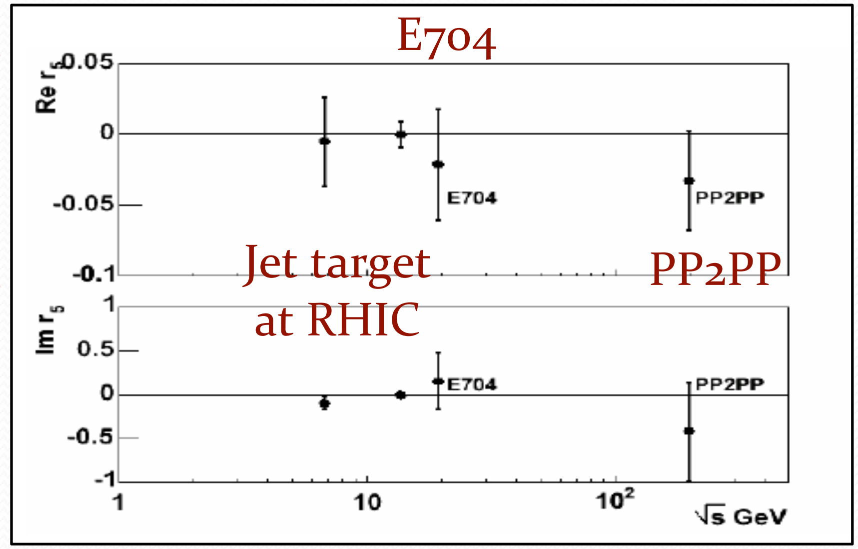
S. Bueltmann et al, "First Measurement of AN at √s = 200 GeV in Polarized Proton-Proton Elastic Scattering at RHIC", Phys. Lett. B 632, 167-172 (2006)



-t (GeV²/c²)

Re r_5

Im r_5



- $\sqrt{s}$ = 200 GeV
- 0.01 (GeV/c)² ≤ $|t|$ ≤ 0.03 (GeV/c)²
- solid curve: calculation without hadronic spin-flip amplitude

$$A_N = \mathbf{0.021 \pm 0.0023\ (stat.)}$$

$$\mathbf{\pm\ 0.0018\ (sys.) \pm 0.0036\ (beam)}$$

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

- A **possible hadronic single spin-flip amplitude** would alter A_N and its effect would depend on the ratio of the single spin-flip amplitude ϕ_5 to non-flip amplitudes ϕ_1 *and* ϕ_3.

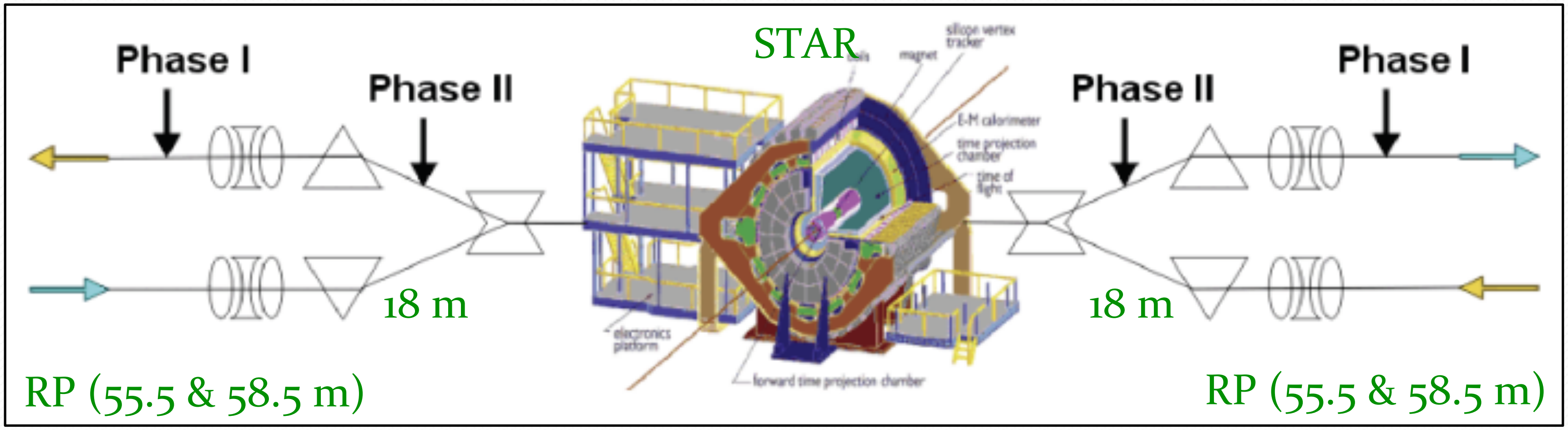
Goals for the Future

Expected uncertainties for elastic scattering (for three-four days of data taking and luminosity = $2 \cdot 10^{29}$ cm^{-2} sec^{-1}):

1. In the small $|t|$, Coulomb-Nuclear Interference (CNI) region measure:
   - σ_{tot} and $d\sigma_{el}/dt$ and study their dependence on $\sqrt{s}$
   - Nuclear slope parameter b
   - Ratio of real and imaginary part of forward elastic scattering amplitude ρ
   - The analyzing power A_N
   - The transverse double spin asymmetries A_{NN} and A_{SS}
2. In the intermediate $|t|$ region, $|t| \leq 1.5$ (GeV/c)^2
   - Study the correlation between the position of the dip and the single spin asymmetry A_N crossing zero at the same $|t|$ value

Uncertainty	Previous	Expected
$\Delta\sigma_{tot}$	-	3 mb
Δb	1.6 (GeV/c)$^{-2}$	0.3 (GeV/c)$^{-2}$
$\Delta\rho$	-	0.01
ΔA_N	0.0023	0.0017
ΔA_{NN}	0.017	0.0053
ΔA_{SS}	0.008	0.0053

Plan of the Experiment



Phase I (existing Roman Pots around 58 m)

- Requires special data taking run with **special proton beam tune** to reach small-*t* values.
- Run at $\sqrt{s}$ =200 GeV with β^* = 20 m and at $\sqrt{s}$ = 500 GeV with β^* = 20 m

Phase II (additional Roman Pots at 18 m)

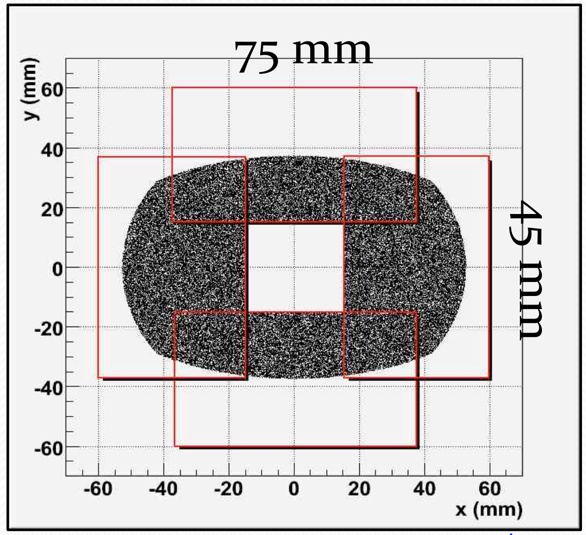
- Install additional Roman Pots between dipole magnets (18 m)
- Will extend the kinematic $|t|$-range. For example at $\sqrt{s}$ = 500 GeV to $-t < 1.5$ $(\mathrm{GeV}/c)^2$
- **No special running conditions** required (use standard proton beam tune $\beta^* \leq 1$ m)
- Beam pipe between dipole magnets needs to be rebuilt.

Phase I Acceptance (55.5 m and 58.5 m)

Coordinates of Scattered Protons (y versus x in mm)

β^* = 21 m
Special running conditions

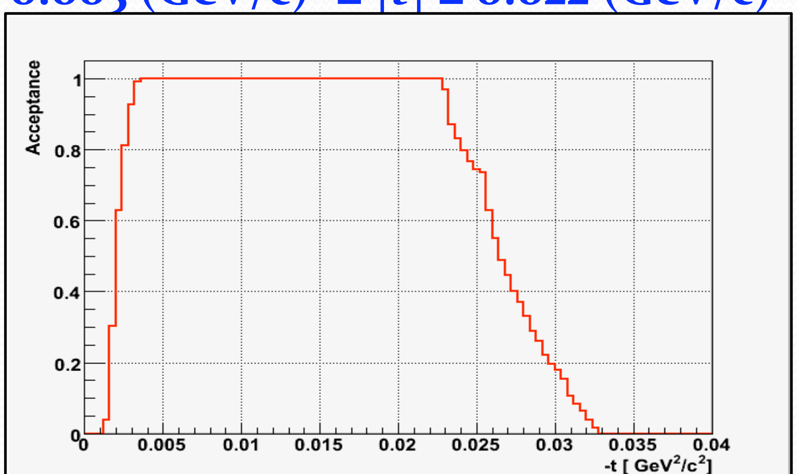
p **= 100 GeV/*c***
d_{min} = 10 mm ≈ 12 σ_{beam}
100% acceptance for elastic scattering
0.003 (GeV/c)² ≤ |*t*| ≤ 0.022 (GeV/c)²



J. de Favereau, X. Rouby, K. Piotrzkowski, Hector, a fast simulator for the transport of particles in beamlines, arXiv: 0707.1198 [physics.acc-ph] (2007)

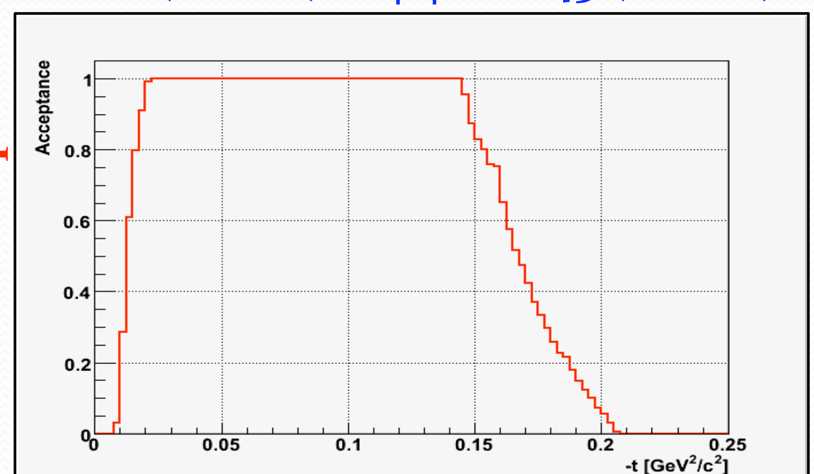
p **= 250 GeV/*c***
0.02 (GeV/c)² ≤ |*t*| ≤ 0.145 (GeV/c)²

Acceptance



|*t*| (GeV²/c²)

Acceptance



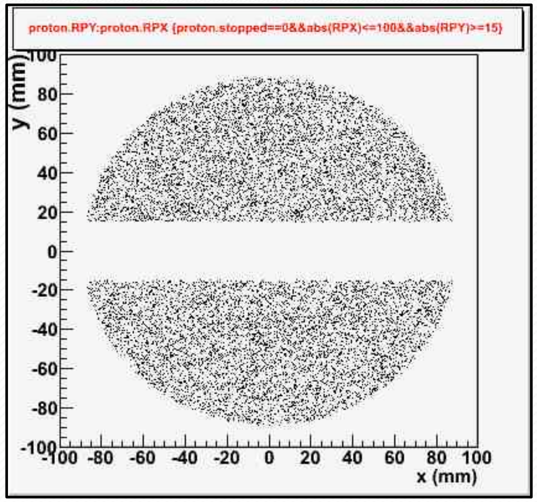
|*t*| (GeV²/c²)

Phase II Acceptance (18 m)

Coordinates of Scattered Protons (y versus x in mm)

Can run under normal running conditions

$\beta^* \leq 1$ m



Area of Detectors (one RP station)

200*100 mm²

$d_{min} \approx 12\ \sigma_{beam}$

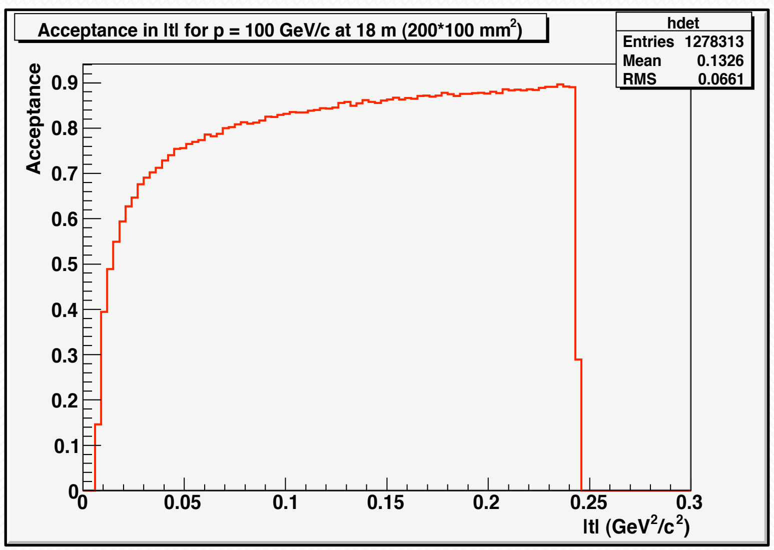
p **= 100 GeV/*c***

$-t \leq 0.246\ (GeV/c)^2$

p **= 250 GeV/*c***

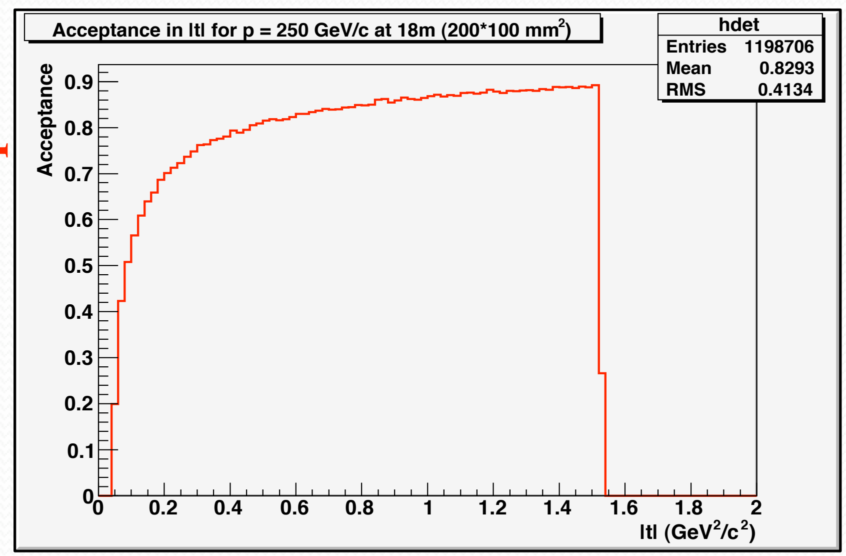
$-t \leq 1.5\ (GeV/c)^2$

Acceptance



$|t|\ (GeV^2/c^2)$

Acceptance



$|t|\ (GeV^2/c^2)$

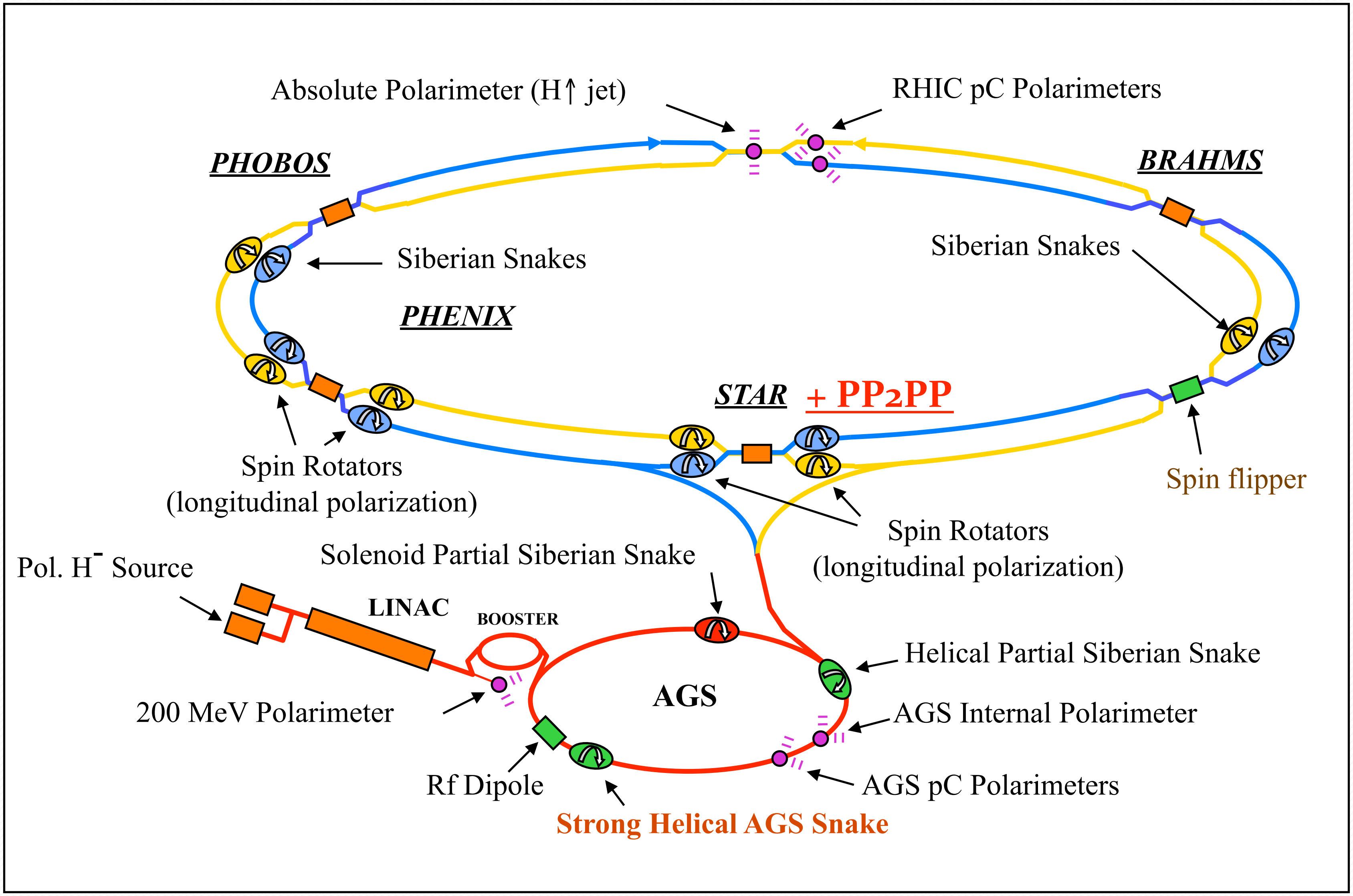
Summary

- **Phase I (RP region)**
  - Study **elastic** scattering by using only the existing Roman Pots on each side of STAR.
  - **$0.003\ (\text{GeV}/c)^2 \leq |t| \leq 0.022\ (\text{GeV}/c)^2$ for $\sqrt{s} = 200$ GeV**
  - **$0.02\ (\text{GeV}/c)^2 \leq |t| \leq 0.145\ (\text{GeV}/c)^2$ for $\sqrt{s} = 500$ GeV**
  - Requires special data taking run with **special proton beam tune.**
  - Study **inelastic** scattering with STAR as a central detector. STAR has a good acceptance and particle ID to measure the central system.

- **Phase II (18 m)**
  - Install additional Roman Pots in the region between dipole magnets (18 m)
  - **Will extend the kinematic $|t|$ range at:**
    - **$\sqrt{s} = 200$ GeV to $-t \leq 0.246\ (\text{GeV}/c)^2$**
    - **$\sqrt{s} = 500$ GeV to $-t \leq 1.5\ (\text{GeV}/c)^2$**
  - **No special running conditions** required.
  - Beam pipe between dipole magnets needs to be rebuilt.

Thank You

RHIC at BNL



Absolute Polarimeter (H↑ jet)
RHIC pC Polarimeters
PHOBOS
BRAHMS
Siberian Snakes
Siberian Snakes
PHENIX
STAR
+ PP2PP
Spin Rotators
(longitudinal polarization)
Spin flipper
Spin Rotators
(longitudinal polarization)
Pol. H⁻ Source
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Helical Partial Siberian Snake
AGS
200 MeV Polarimeter
AGS Internal Polarimeter
Rf Dipole
AGS pC Polarimeters
Strong Helical AGS Snake