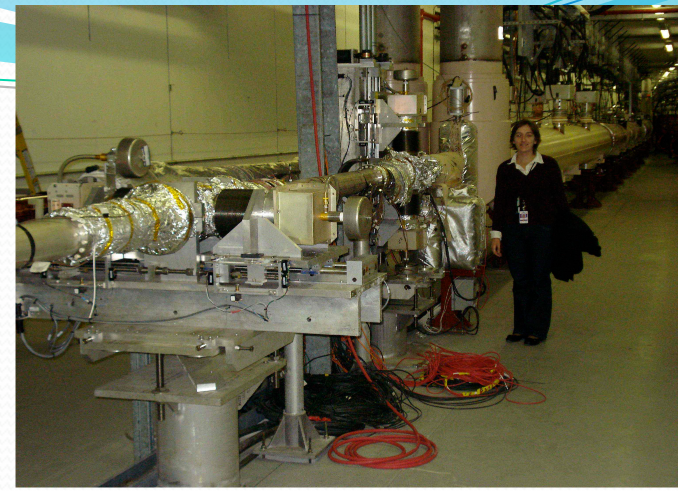
Performance of Silicon Detectors in Polarized Proton-Proton Elastic Scattering at RHIC



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For The STAR Collaboration

The 19th International Spin Physics Symposium

Forschungszentrum Jülich (Germany)

September 27 - October 2, 2010

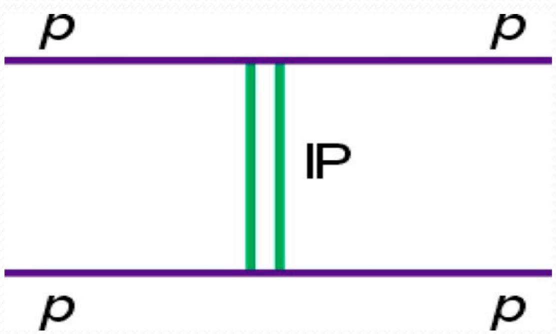
Outline

- Physics Program and Motivation
  - Physics with Tagged Forward Protons and the STAR detector
  - **Spin-Dependence** in Proton-Proton Elastic Scattering at RHIC
- Very-Forward Detectors at STAR (RHIC) - **Roman Pots at STAR**
  - Experimental Setup and **Detector Acceptance**
  - Data Collection during RHIC 2009 Run **(Run09)**
- **Detector Performance** during Run09
  - Survey and **Alignment** of the Silicon Detectors
  - Silicon Detector **Efficiency**
- Summary and Conclusion

Physics with Tagged Forward Protons and the STAR Detector

Elastic Scattering

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

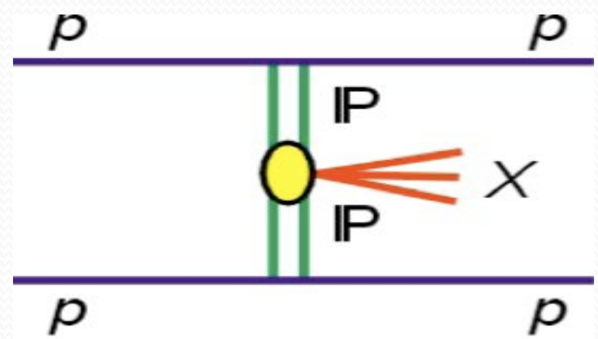


Detect protons in the very forward direction using Roman Pots

- In <u>elastic scattering</u> protons remain intact.
- A *Pomeron* (P) is exchanged.
- *Pomeron* exchange in pQCD consists of a color singlet combination of gluons.

Central Production

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



Need to use Roman Pots and the STAR detector to measure central system

- In <u>Double Pomeron Exchange</u> process, each proton *emits* a Pomeron and the two Pomerons interact producing a massive system M_X.
- Use STAR detector with **good acceptance and particle ID**, to measure <u>central system</u>.
  - TPC: $-1<\eta<1$, $-\pi<\phi<\pi$

Differential *pp* Elastic Cross Section

- Proton-Proton Scattering:
  - **Coulomb** Interaction
  - Strong (**Nuclear**) Interaction

$$\frac{d\sigma_{el}}{dt} = \left|F_c + F_n\right|^2$$

$$F_c = 4\pi(\hbar c)^2\left(\frac{\alpha G_E^2}{t}\right)^2$$

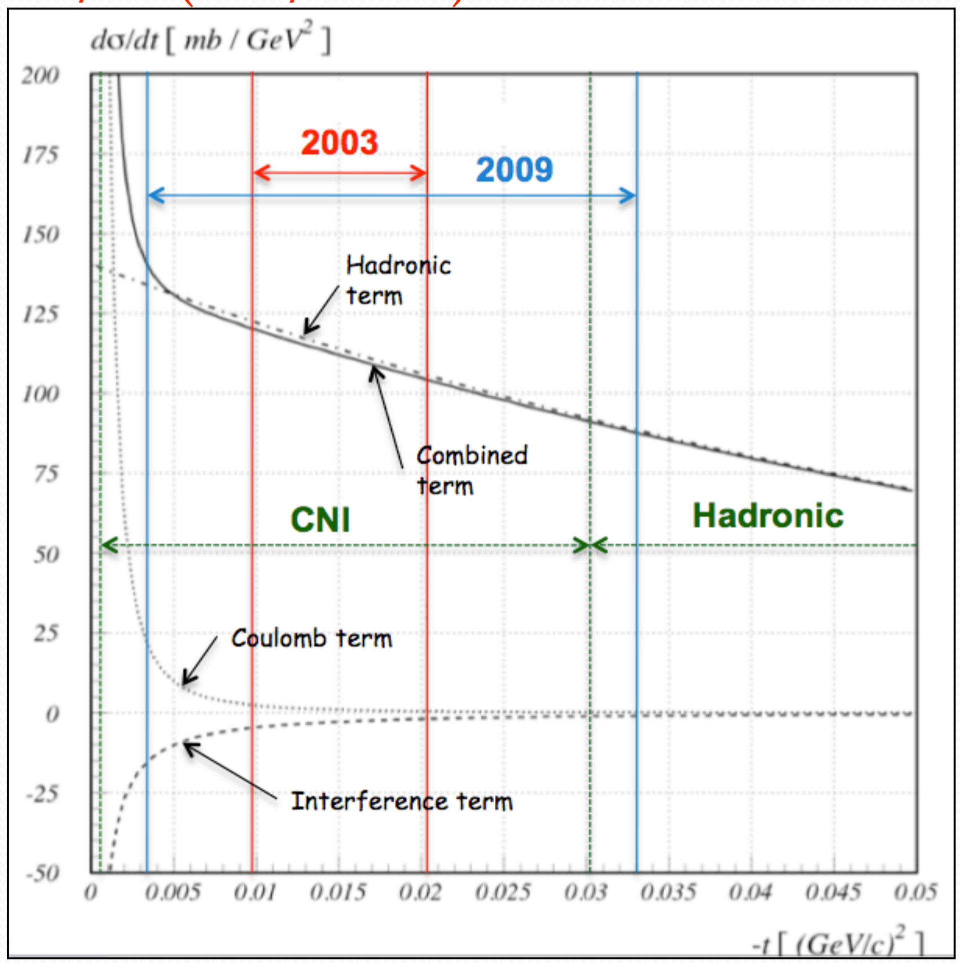
$$F_n = \frac{1+\rho^2}{16\pi(\hbar c)^2}\sigma_{tot}^2 e^{-b|t|}$$

F_c: Coulomb Term
α: fine structure constant
G_E: proton electric form factor

F_n: Nuclear Term
ρ, b, σ_{tot}: forward scattering parameters

- Accessible ***t*-region**: region dominated by the hadronic interaction (Measurement of slope parameter *b*) and the **CNI region (low-*t*)**.

dσ/dt (mb/GeV²)



t: four-momentum transfer squared (GeV²/*c*²)

Spin Dependence in *pp* Elastic Scattering
Polarized Proton Beam at RHIC

- Five independent **helicity amplitudes** describe ***p-p*** **elastic scattering:** (single, double or no spin-flip)

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

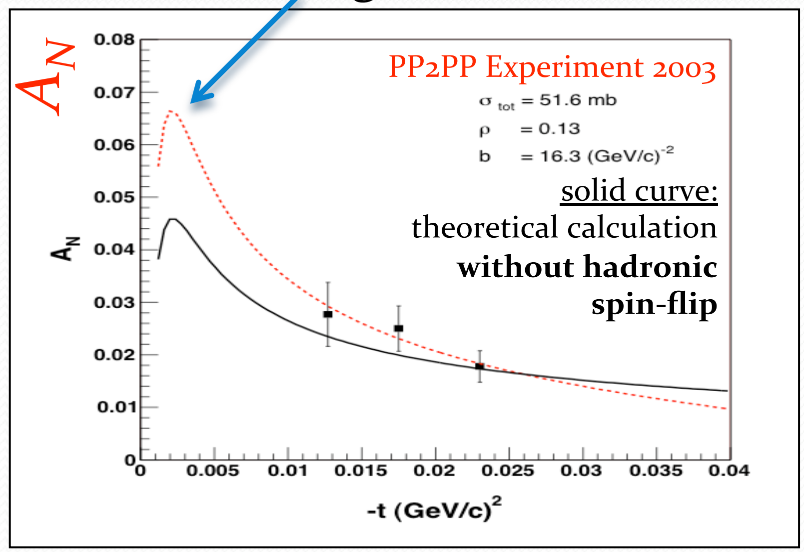
- Measurements of Spin-Dependent observables:
  - Cross Sections
  - Spin Asymmetries

- Sensitive to the **CNI region**, small-$|t|$ region where a measurable asymmetry A_N arises.

- Study A_N and its **$|t|$-dependence** to probe contribution from the **hadronic spin-flip amplitude**.

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

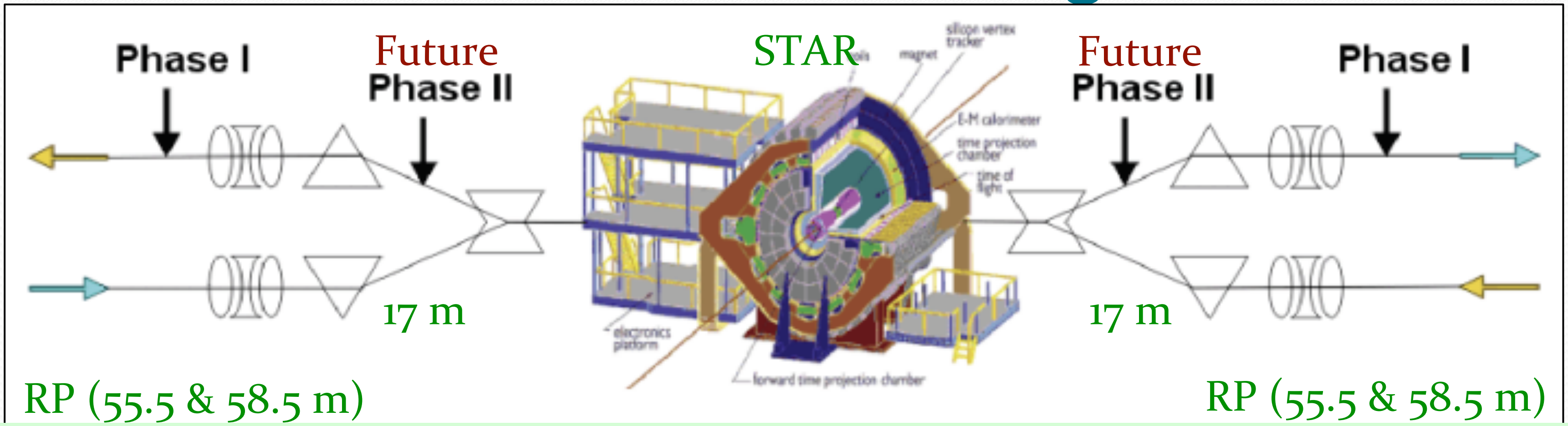
CNI region



$-t$ (GeV^2/c^2)

See SPIN-2010 talk on Thursday, by Igor Alekseev on recent Spin Asymmetry (STAR Preliminary) Measurements at $\sqrt{s}$ = 200 GeV, using Run09 data.

Roman Pots at STAR
Phase I and Phase II Configurations



- **Phase I**: Existing setup with Roman Pots at ~60 m on each side of STAR (Run09 Configuration):
  - Vertical and Horizontal RP setup ($\Delta z = 3$ m), for a **complete ϕ coverage**.
  - Provides **low-*t* coverage.**
  - Requires special proton beam optics **(large β*)** and beam collimation, to reach small-*t* values.

- **Phase II:** Future upgrade. New construction of Roman Pots closer to IP, ~17 m on each side of STAR:
  - Will provide **higher-*t* coverage.**
  - Enables data taking without special running conditions, thus can provide larger data samples.

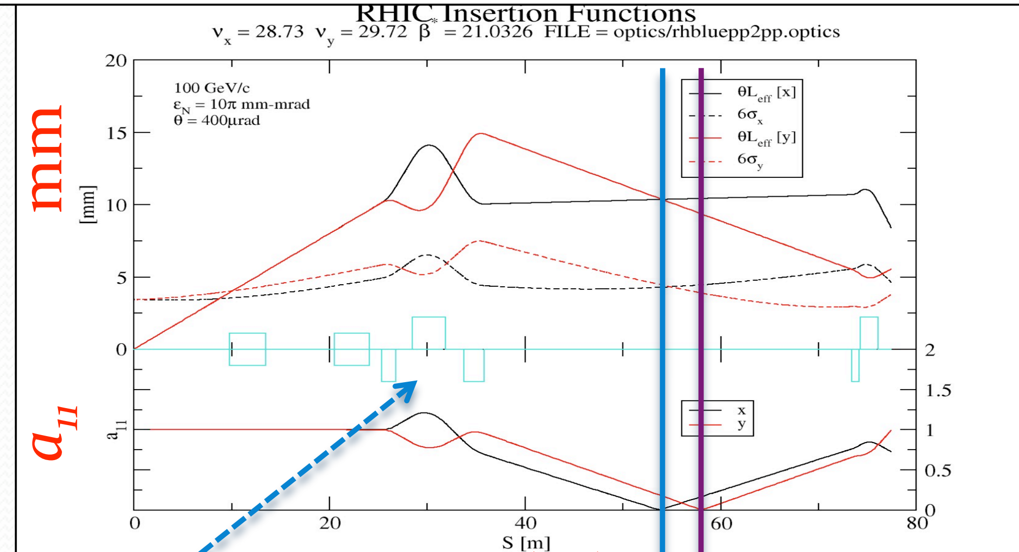
Experimental Technique (Phase I)

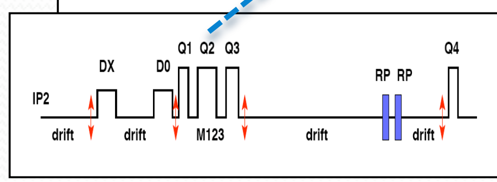
- Need Roman Pot to detect scattered protons **close to the beam** without breaking accelerator vacuum.

- The optimal position of the detectors is **where scattered protons are well separated from beam protons.**

- Elastically scattered protons have very small scattering angles Θ*, hence **beam transport magnets** determine their trajectory.

Beam Trajectory (Special Beam Optics $\beta^* = 21$m)





Beam Transport

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

At detector

At IP

Optimize so that a_{11} small and L_{eff} large

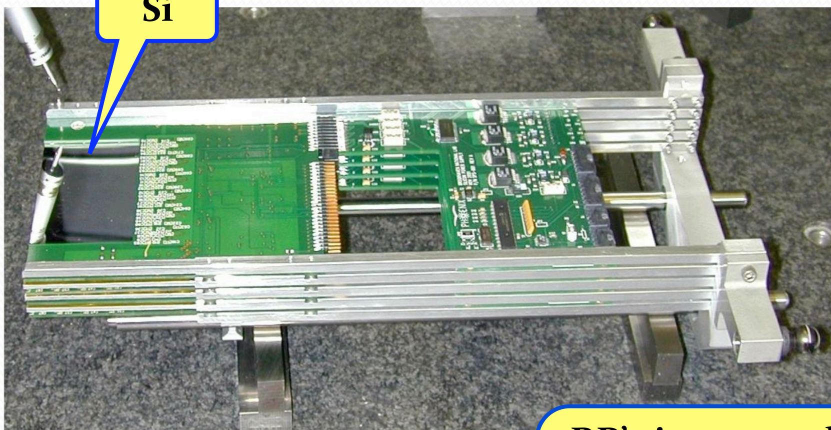
$$x_D \approx L_{eff}^x \theta_x^*$$

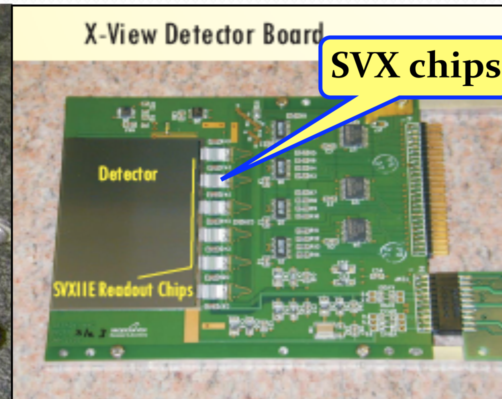
$$y_D \approx L_{eff}^y \theta_y^*$$

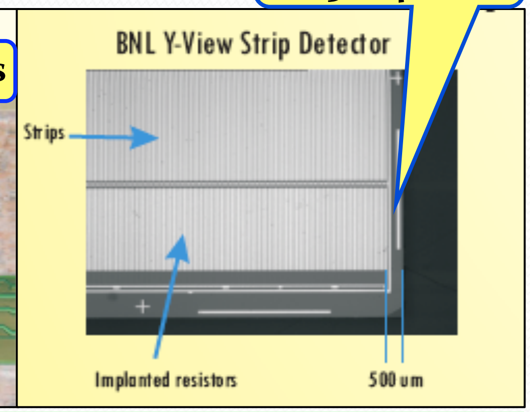
Silicon Microstrip Detectors

Silicon Detector Package for One Roman Pot

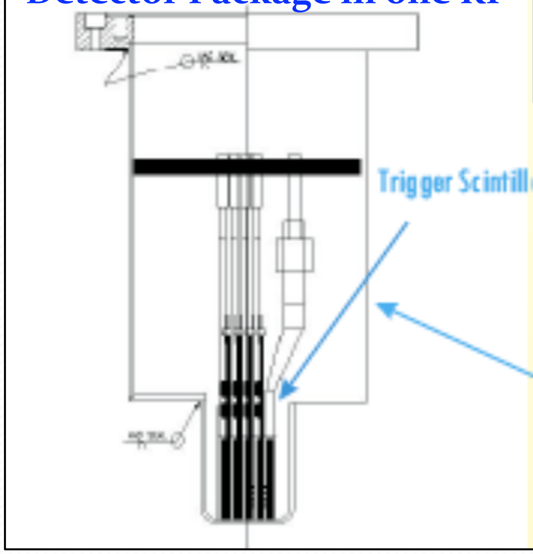
S. Bültmann *et al.*, *Nucl. Instr. Meth.* **A 535**, 415 (2004)







Detector Package in one RP

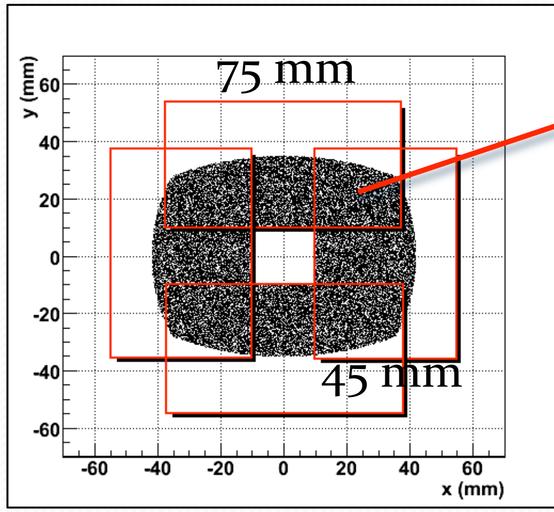


RP's integrated with STAR trigger and data acquisition systems (2008)

- **4 Planes of 400 μm Silicon Microstrip Detectors:**
  - 4.5 x 7.5 cm² **Sensitive Area**
  - **Good Resolution (100 μm strip pitch)**
  - **Redundancy**: 2X and 2Y-view detectors
  - 8 mm **Trigger Scintillator** with two PMT readout behind Silicon planes
- Total **32 silicon planes** (8 detector packages) by **Hamamatsu Photonics.**

Phase I Acceptance (55.5 m and 58.5 m)

Coordinates of Scattered Protons (y vs x in mm)



Overlapping Region Between Vertical and Horizontal Roman Pots

(3 m apart in the RHIC tunnel)

Simulation using Hector

$\beta^* = 21$ m

Special running conditions

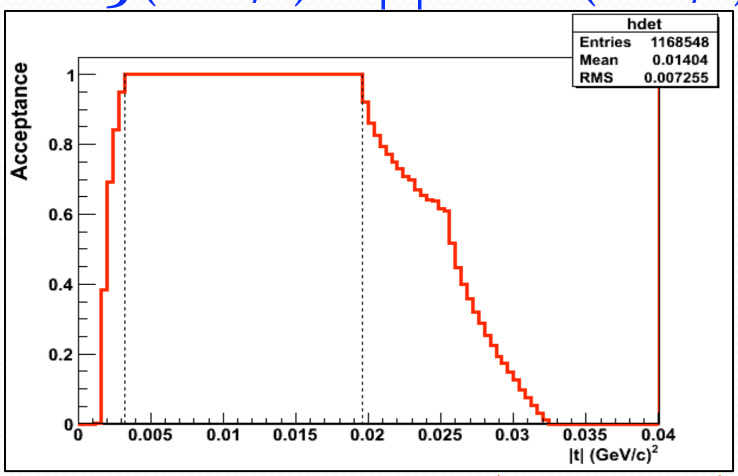
$\boldsymbol{p}$ **= 100 GeV/*c***

$d_{min} = 10\text{ mm} \approx 12\sigma_{beam} + d_o$

100% acceptance for elastic scattering

$0.003\ (\text{GeV}/c)^2 \le |t| \le 0.02\ (\text{GeV}/c)^2$

Acceptance



$|t|\ (\text{GeV}^2/c^2)$

accelerator constant optimized by beam scraping

beam size at the detection point

$$d_{\min} = k\sigma_D + d_0$$

detector dead space

$$|t_{\min}| = p^2\theta^2_{\min} \approx p^2\left(\frac{d_{\min}}{L_{eff}}\right)^2$$

Data Collection during Run09

Run Conditions

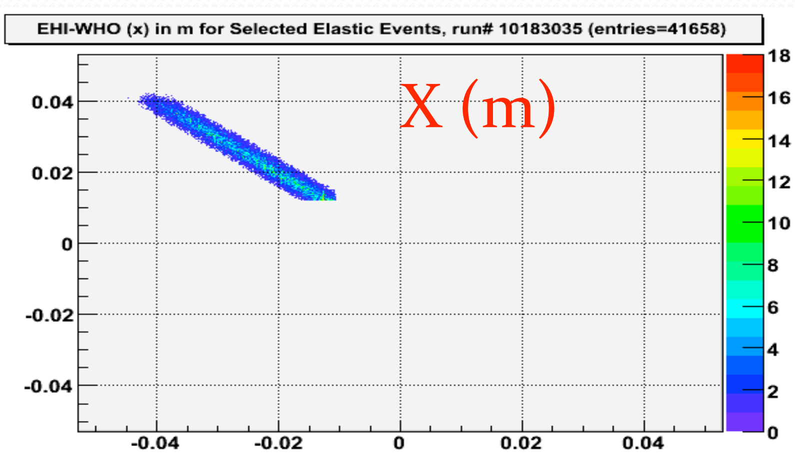
- Proton beam **momentum** = 100 GeV/*c*
- Beam **Polarization** (average for 4 fills):

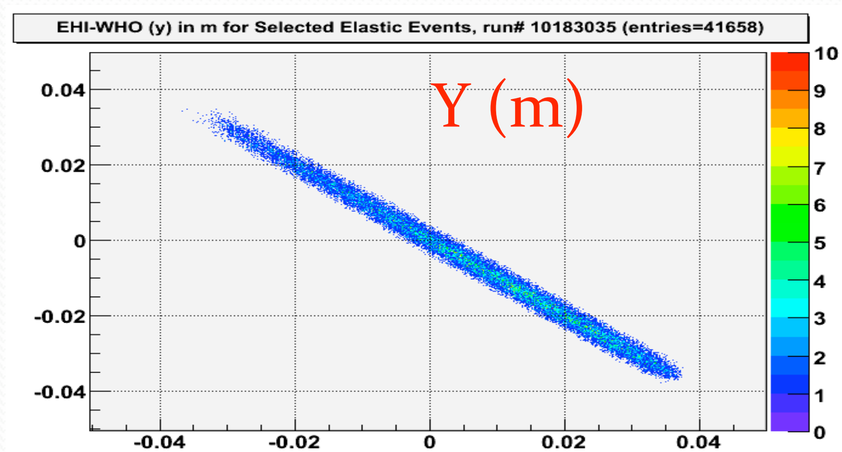
  $P_B \sim 0.60 \qquad P_Y \sim 0.62$
- **Luminosity** ~ $1.5 \cdot 10^{29}$ cm^{-2} sec^{-1}
- Good data sample (see collinearity plots)

- **40 hrs of data taking**
- $35 \cdot 10^6$ Elastic Triggers Recorded
- Elastic trigger using **Roman Pot co-linearity** (four elastic arms)**:**
  - Vertical (up $\wedge$ down) (down $\wedge$ up)
  - Horizontal (left $\wedge$ right) (right $\wedge$ left)

East-West Collinearity for Selected Elastic Events

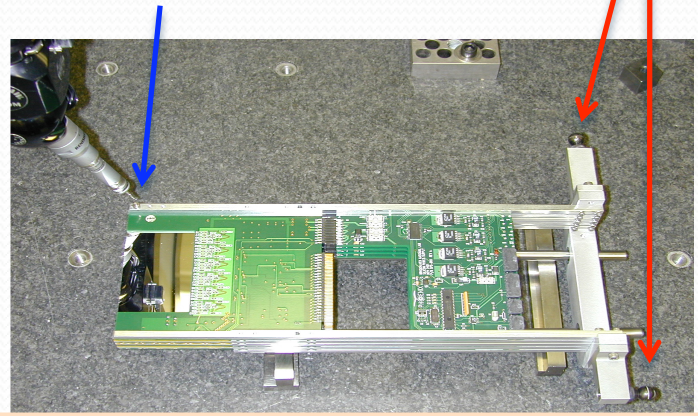
with elastic trigger condition and after all cuts applied (explained in slide 13)





Survey and Alignment of the Silicon Detectors

- Detector packages were surveyed in the lab and in the actual setup in the RHIC tunnel. (Combined survey precision ~ 100 μm)
- Positions of fixed survey tools on the package were measured relative to a ref. point on the package and the beampipe center.
- Used survey information to calculate:
  - Tilt angle of each detector plane in *x*-*y* plane (largest angle~2.5 mrad).
  - **(x,y) Positions of the 1st Si strip in each detector plane (32 planes)** relative to the center of the outgoing beampipe at STAR.



Detector Package being Surveyed

(x,y) Positions of the 1st Si strip are needed to translate **positions of the detected particles** from Si strip# notation to (x,y) coordinates relative to the beampipe center.

Survey and Alignment of the Silicon Detectors

Alignment Issues:

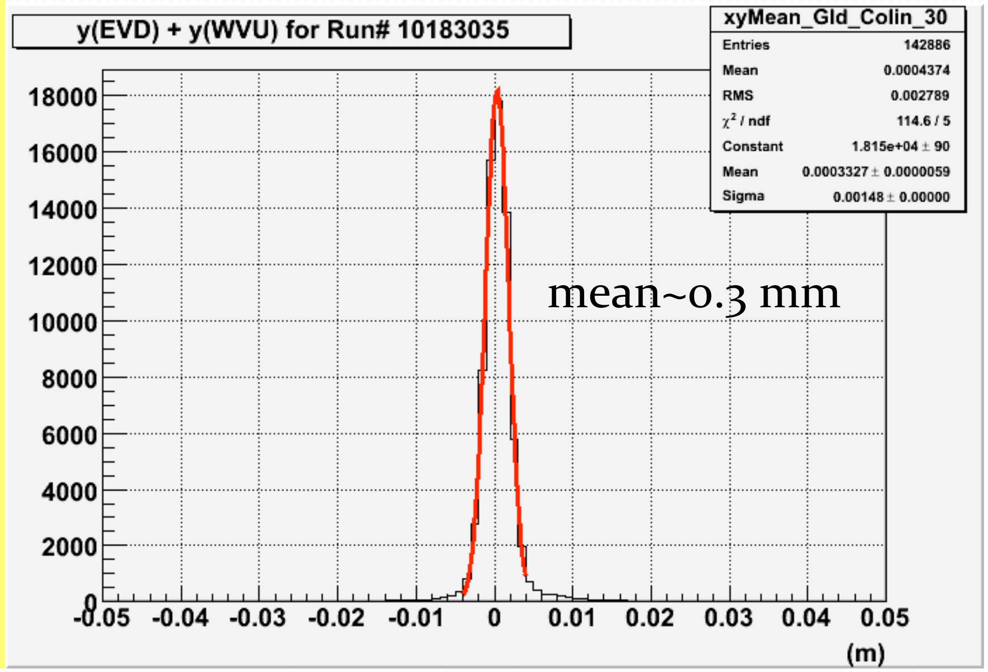
1. **Alignment using survey**:
   Determination of the 1st Si strip position relative to the beam-line center, using survey.
2. **Alignment using data**:

➢ Use over-constrained elastic events that fall in the overlapping regions of the RP's, to do relative alignment of the detectors.

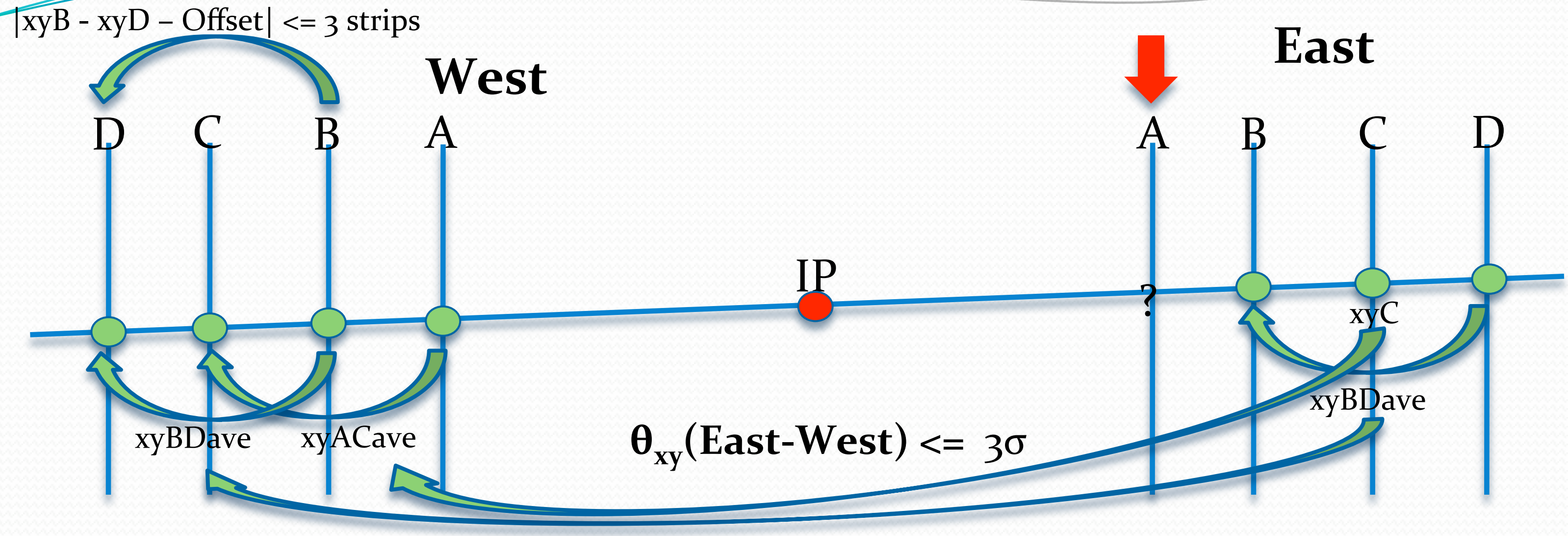
➢ **Beam Position:**
Use hit distributions to align detectors with respect to the beam: Measured **collinearity of events** sensitive to actual **beam position** *(measured to be drifting by **several 100 μm** during one store)*

Collinearity plots
after alignment using survey
Position difference between two sides of STAR

y(Top RP in East) + y(Bottom RP in West)



Silicon Detector Efficiency



Studying efficiency of plane A in the East (repeat for other planes):

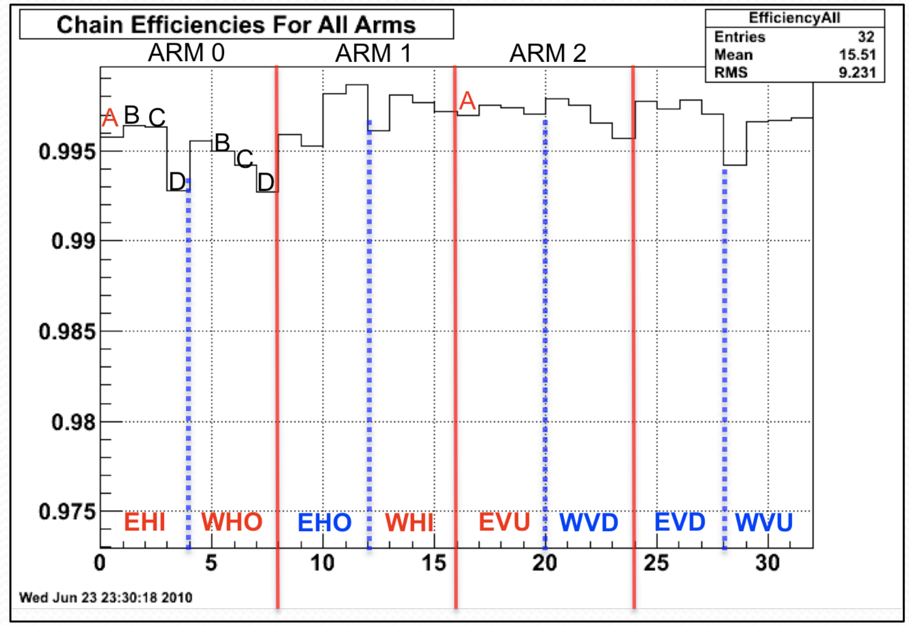
- Single cluster (*Cluster Definition*: Particle deposits energy on several neighbor Si strips) in all other 7 Si planes in the same collinear pair of detectors:
  - Valid hit/Si strip with energy: ADC > (Pedestal per channel) + $5\sigma_{pedestal}$
  - max width ≤ 4 consecutive strips; with total energy ≥ 20ADC (charge cut depends on cluster width)
  - Cluster Matching: Clusters of the same coordinate in planes A-C, B-D are within 3*strip pitch distance.
- Measured xy-positions translated into angles at IP using transport matrix.
- Collinearity Cut: Hits on each side, with scattering angles θ_x or θ_y within 3σ angle distribution, θ_{xy}(East-West), combined into one track.

Silicon Detector Efficiency

- Exclude all edge clusters and all identified hot/dead Si strips.
  - Not critical due to redundancy: 2 Si planes for each coordinate (x,y)
- Only 5 dead/noisy strips per ~14000 active strips (Active area limited by acceptance)

- **Overall plane efficiency above 99%.**

Run# 10183035



After excluding clusters (**3 strips from the edge**) + all **hot/dead** strips

Summary and Conclusion

- Use of Roman Pots at STAR, provides measurements in the **low-*t* region**.
- **Unique opportunity** for *Spin-Dependent Measurements* at RHIC
- Run09 Performance:
  - **~20·10^6 Elastic Events** (after all cuts applied) and **700k CP triggers** recorded in 5 days, at $\sqrt{s}$=200 GeV and with β^*=21 m.
  - Excellent detector performance provided **very clean data set**.
  - Alignment: Physical alignment of the Si detectors is completed. Elastic events can be used to make alignment corrections.
  - Si Detector Inefficiency: Mainly due to the dead/noisy Si channels (~0.04% of the channels excluded from analysis).
- Analysis: Analysis is in progress. **First preliminary results on spin asymmetries** are available, see talk by Igor Alekseev at SPIN-2010.

In addition:

- Roman Pots integration with the STAR system, allows study of both **elastic and diffractive scattering** in *pp* collisions at RHIC.
- Analysis of **central production** data from Run09 is in progress.
- Future Upgrade (Phase II): Roman Pots closer to IP. Phase II setup will not require special running conditions.

Additional Slides

Spin Dependence in *pp* Elastic Scattering (Polarized Proton Beam at RHIC)

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

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

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

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**:

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

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

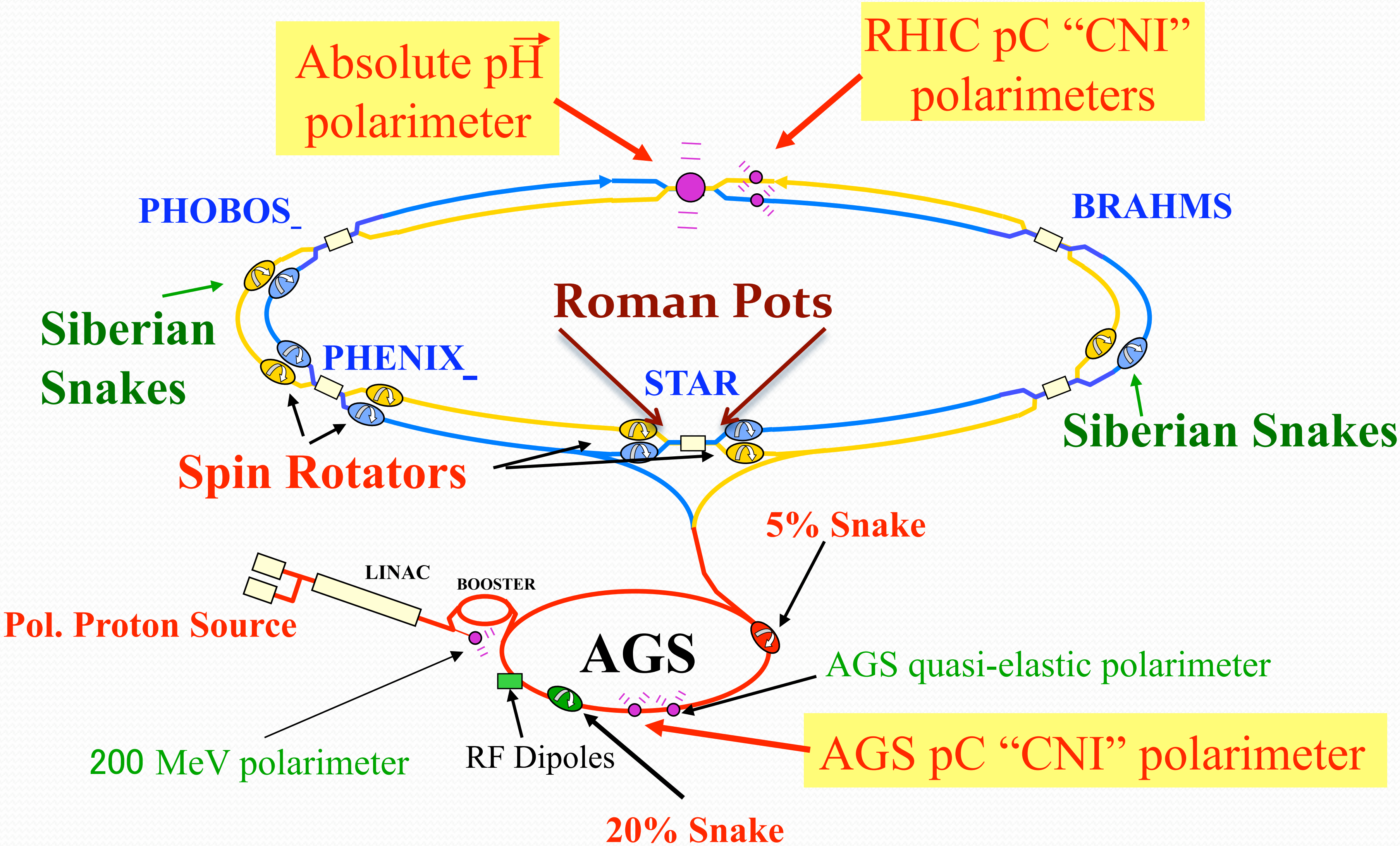
- The **analyzing power A_N** and the **double spin asymmetries, A_{NN} and A_{SS}**:

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

T.L. Trueman, "Spin asymmetries for elastic proton scattering and the spin-dependent couplings of the Pomeron" PRD 77, 054005 (2008)

$$2\pi\frac{d^2\sigma}{dt\,d\phi} = \frac{d\sigma}{dt}\left[1 + (P_B + P_Y)A_N\cos^2\phi + P_B P_Y\left(A_{NN}\cos^2\phi + A_{SS}\sin^2\phi\right)\right]$$

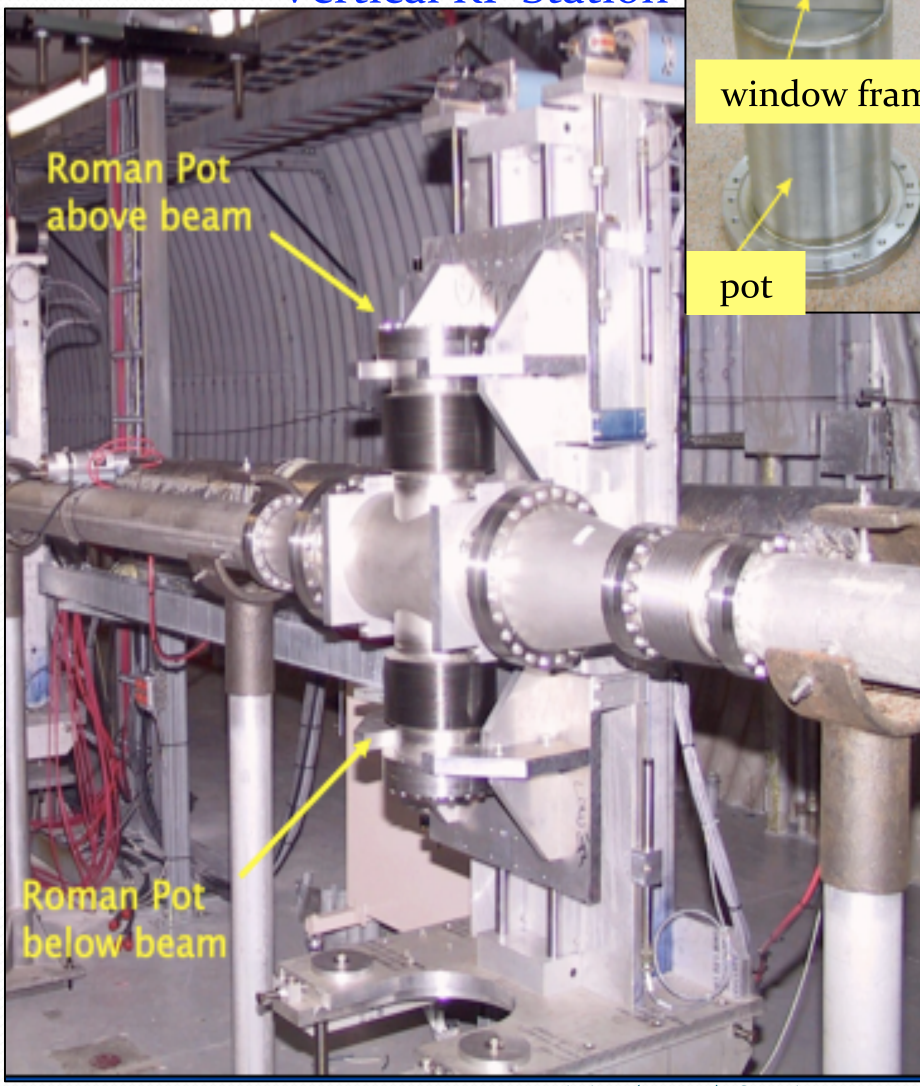
RHIC at BNL

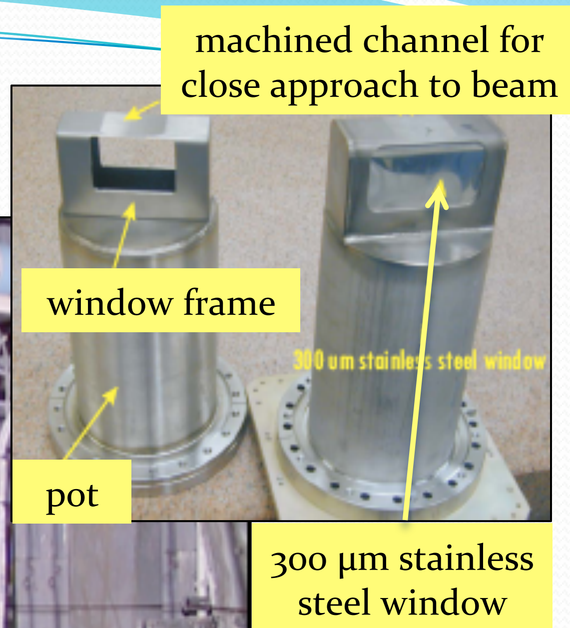


Absolute p$\vec{H}$ polarimeter
RHIC pC "CNI" polarimeters
PHOBOS
BRAHMS
Roman Pots
Siberian Snakes
PHENIX
STAR
Siberian Snakes
Spin Rotators
5% Snake
LINAC
BOOSTER
Pol. Proton Source
AGS
AGS quasi-elastic polarimeter
200 MeV polarimeter
RF Dipoles
AGS pC "CNI" polarimeter
20% Snake

Roman Pots

Vertical RP Station





- Cylindrical vessels that house the detectors.
- Can be inserted close to the beam for data taking.
- RP's integrated with STAR trigger and data acquisition systems (2008).