Elastic Polarized Proton Scattering at RHIC

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For the pp2pp Collaboration

- **Introduction**
- **Experimental Setup**
- **Results from 2002 Engineering Run**
- **Conclusions & Outlook**

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The Landscape of Elastic Scattering

Highest Energy so far in

pp: 63 GeV (ISR)

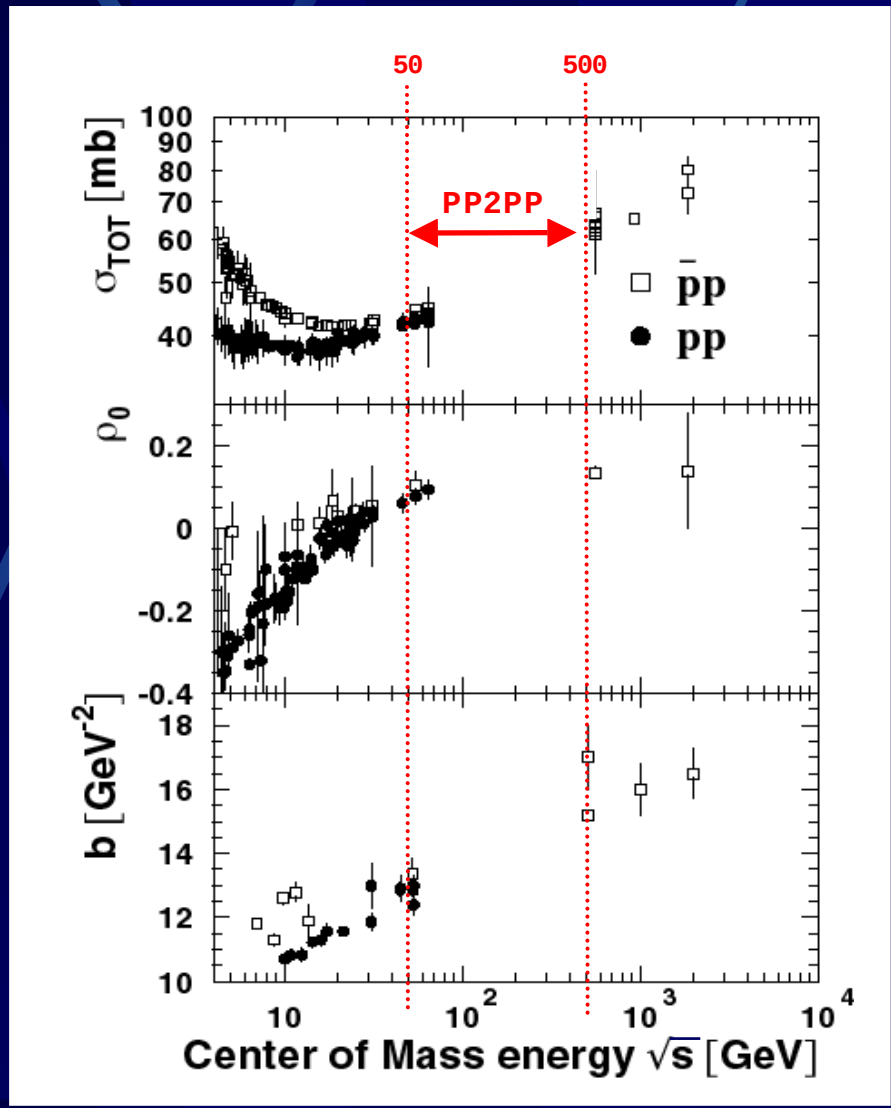
$p\bar{p}$: 1.8 TeV (Tevatron)

pp2pp Energy Range:

50 GeV $\leq \sqrt{s} \leq$ 500 GeV

pp2pp t-range (at $\sqrt{s} =$ 500 GeV)

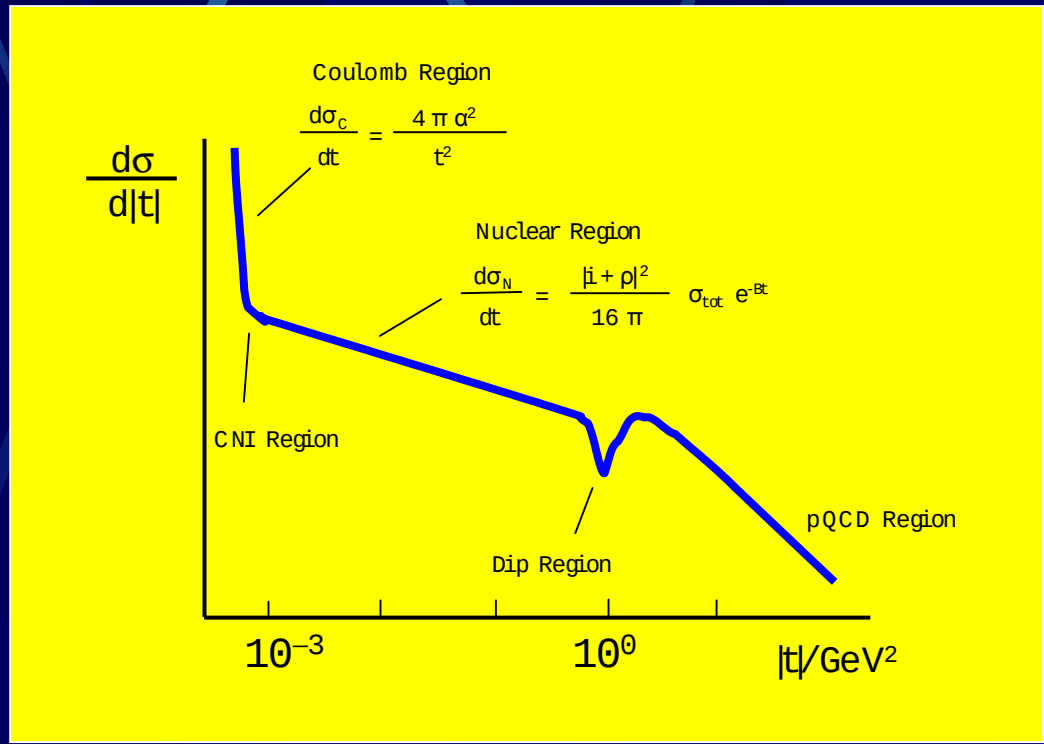
$4 \cdot 10^{-4}$ GeV$^2 \leq |t| \leq$ 1.3 GeV^2



Observables in Elastic Scattering

Measurement of Differential Cross Section to obtain:

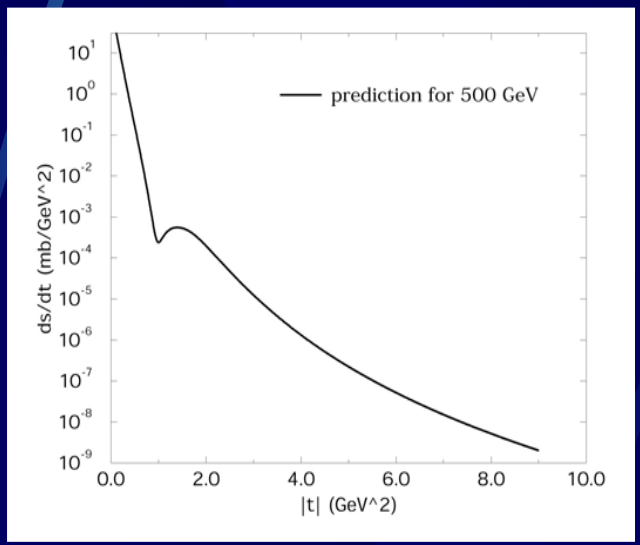
- Total cross section σ_{tot} need to know luminosity $\mathcal{L}$ $\rightarrow$ normalize by measuring in Coulomb region
- ρ parameter in CNI region
- Slope parameter B in nuclear region



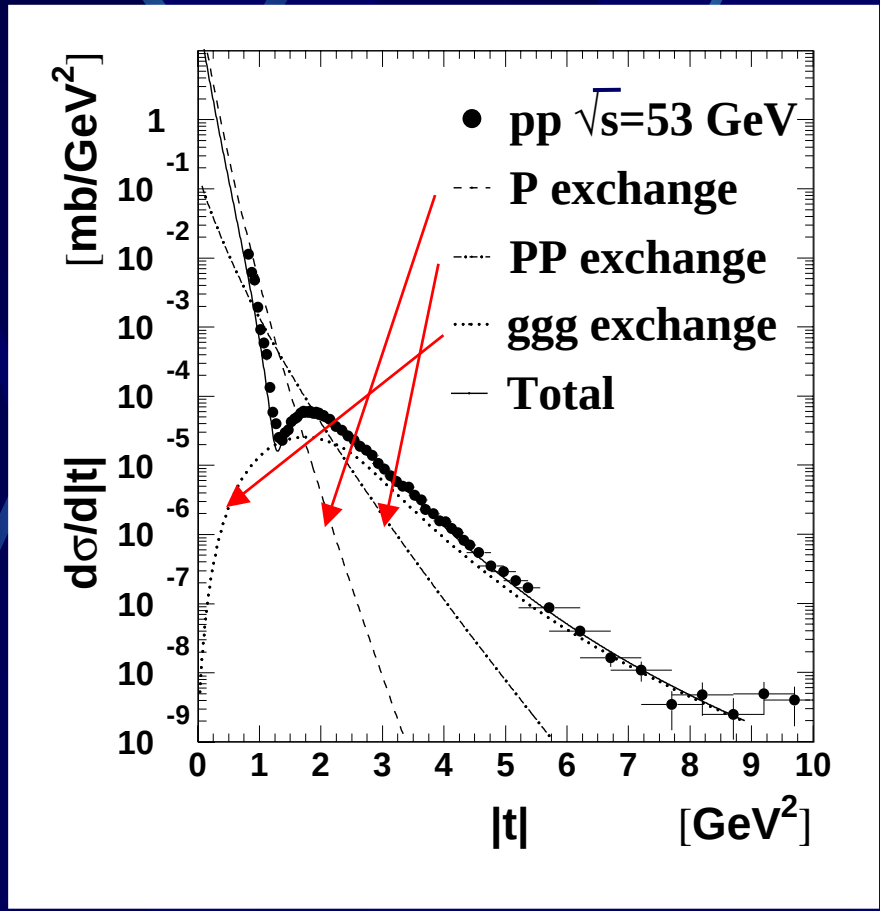
The Landscape of Elastic Scattering (2)

The dip region around $|t| \approx 1$ GeV^2 is determined by different exchange amplitudes:

- Pomeron exchange
- Double Pomeron exchange
- Triple Gluon exchange (C = -1)

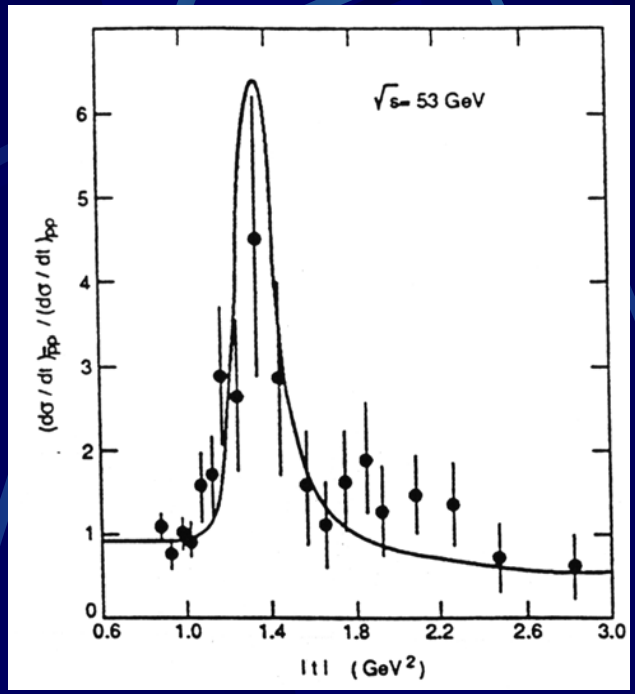


C. Tang, Ph.D. Thesis, Stony Brook 2001, using model by Donnachie & Landshoff (1984)



Model from:
A. Donnachie, P.V. Landshoff, NP B231 (1984) 189

The Landscape of Elastic Scattering (3)



P.V. Landshoff,
Proc. of the 1991 HEP Conference, Geneva, 1991.

$$\frac{d\sigma(p\bar{p})}{dt} \neq \frac{d\sigma(pp)}{dt}$$ at above $|t| \sim 1\,GeV^2$

Model by Donnachie & Landshoff predicts in this region dip in pp-, but not $p\bar{p}$-scattering

Odderon exchange amplitude has opposite sign in contribution to scattering amplitude:

$A_{pp} = A_P + A_O$

$A_{p\bar{p}} = A_P - A_O$

Spin Physics with pp2pp

The helicity amplitudes describe elastic proton-proton scattering

$\Phi_1(s,t) \propto \langle ++|M|++\rangle$

$\Phi_2(s,t) \propto \langle ++|M|--\rangle$

$\Phi_3(s,t) \propto \langle +-|M|+-\rangle$

$\Phi_4(s,t) \propto \langle +-|M|-+\rangle$

$\Phi_5(s,t) \propto \langle ++|M|+-\rangle$

$\Phi_n(s,t) \propto \langle h_3\ h_4|M|h_1\ h_2\rangle$

with h_x = s-channel helicity

$p_1 = -p_2$ incoming protons

$p_3 = -p_4$ scattered protons

$\Phi_+(s,t) = \frac{1}{2}\left(\Phi_1(s,t) + \Phi_3(s,t)\right)$

Measure $\sigma_{tot} = \frac{8\pi}{s} \mathrm{Im}\left[\Phi_+(s,t)\right]_{t=0}$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\left(|\Phi_1|^2 + |\Phi_2|^2 + |\Phi_3|^2 + |\Phi_4|^2| + 4|\Phi_5|^2\right)$$

$$\Delta\sigma_T = -\frac{8\pi}{s}\mathrm{Im}\left[\Phi_2(s,t)\right]_{t=0} = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}$$

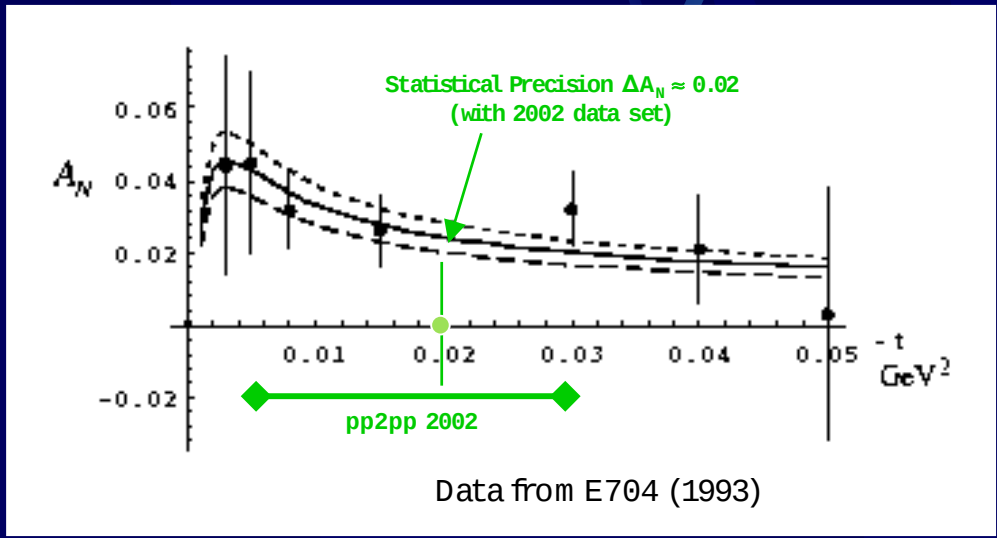
$$\Delta\sigma_L = \frac{8\pi}{s}\mathrm{Im}\left[\Phi_1(s,t) - \Phi_3(s,t)\right]_{t=0} = \sigma^{\leftarrow}_{\rightarrow} - \sigma^{\rightarrow}_{\rightarrow}$$

Spin Physics with pp2pp (2)

Single spin asymmetry A_N arises in CNI region from interference of hadronic non-flip amplitude with electromagnetic spin-flip amplitude

pp2pp : Measure t- and φ-dependence later also s-dependence

$$A_N(t) = \frac{1}{P_{blue} \cdot \cos\varphi} \frac{N_{\uparrow\uparrow}(t) + N_{\uparrow\downarrow}(t) - N_{\downarrow\downarrow}(t) - N_{\downarrow\uparrow}(t)}{N_{\uparrow\uparrow}(t) + N_{\uparrow\downarrow}(t) + N_{\downarrow\downarrow}(t) + N_{\downarrow\uparrow}(t)} \propto \frac{\mathrm{Im}\left[\Phi_5^{*}\,\Phi_+\right]}{d\sigma/dt} \quad \text{for small } t$$



Data from E704 (1993)

$N(t) = \frac{dN}{dt}$

φ = Azimuth

P_{blue} = Beam Polarization

N.H. Buttimore, B.Z. Kopeliovich, E. Leader, J. Soffer, T.L. Trueman, "The Spin Dependence of High-Energy Proton Scattering", PRD 59, 114010 (1999)

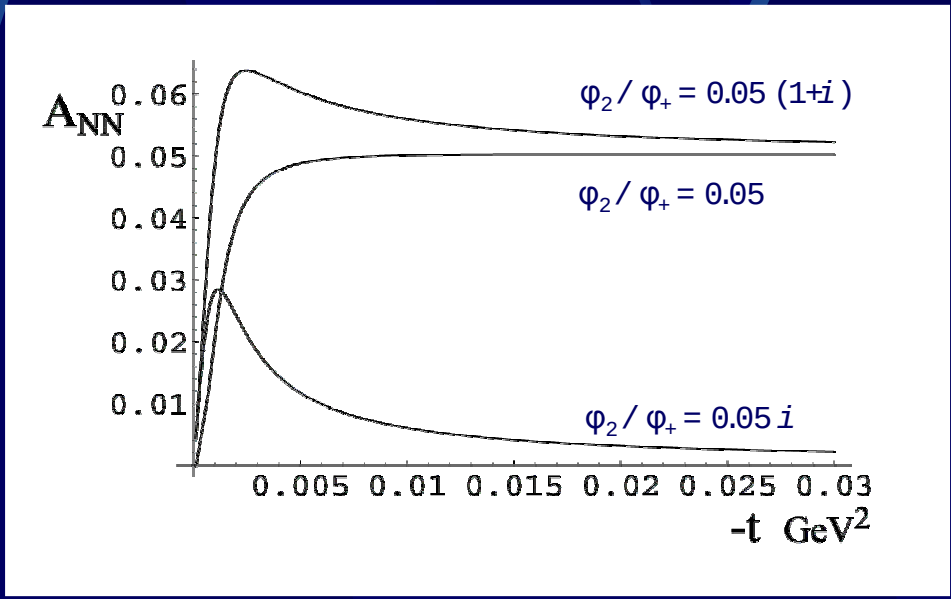
Spin Physics with pp2pp (3)

Measure A_{NN} to find limit on detectable Odderon contribution to interference between φ_1 and φ_2

Different phases ($\Delta \sim \frac{1}{2}\pi$) of Pomeron and Odderon at $t = 0$

$$A_{NN}(t) = \frac{1}{P_{blue} \cdot P_{yellow} \cdot \cos^2\varphi} \frac{N_{\uparrow\uparrow}(t) + N_{\downarrow\downarrow}(t) - N_{\uparrow\downarrow}(t) - N_{\downarrow\uparrow}(t)}{N_{\uparrow\uparrow}(t) + N_{\downarrow\downarrow}(t) + N_{\uparrow\downarrow}(t) + N_{\downarrow\uparrow}(t)} \propto \frac{\mathrm{Re}\left[\Phi_+ \Phi_2^*\right]}{d\sigma/dt}$$

for small t



$N(t) = \frac{dN}{dt}$

φ = Azimuth

P_{blue} = Beam Polarization

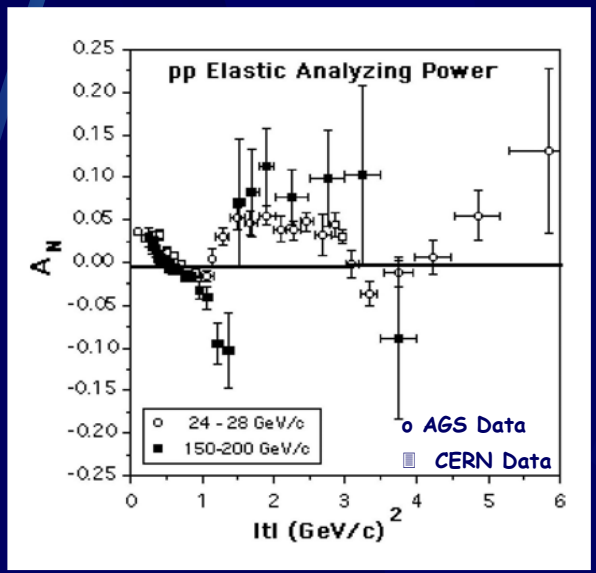
P_{yellow} = Beam Polarization

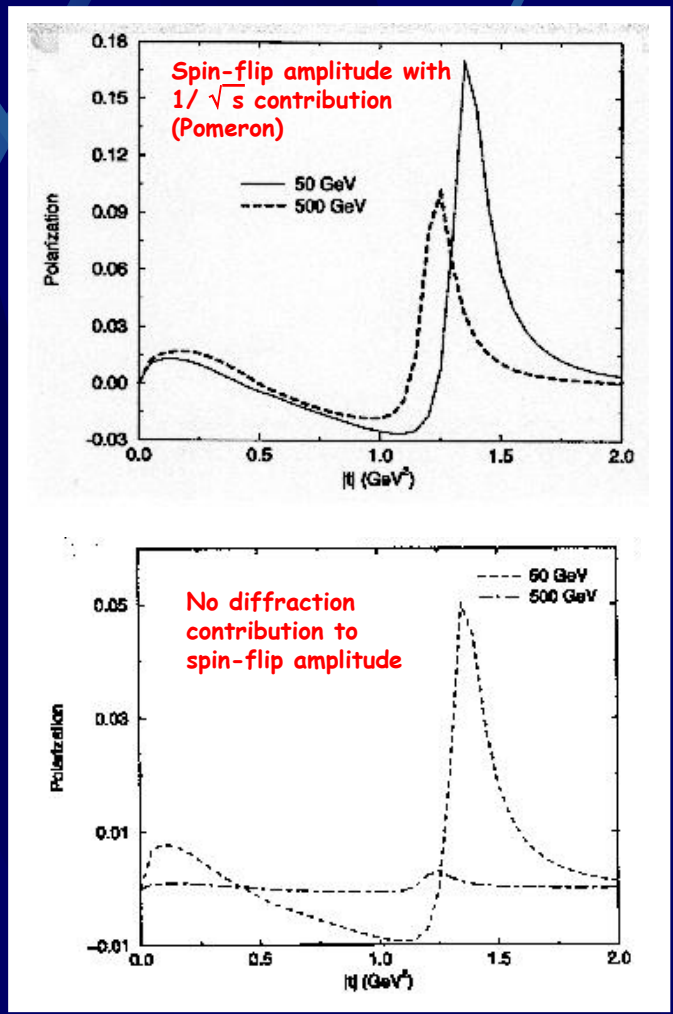
E. Leader, T.L. Trueman,
"The Odderon and Spin Dependence of High-Energy Proton-Proton Scattering",
PRD 61, 077504 (2000)

Spin Physics with pp2pp (4)

Single spin asymmetry in dip region shows sign change

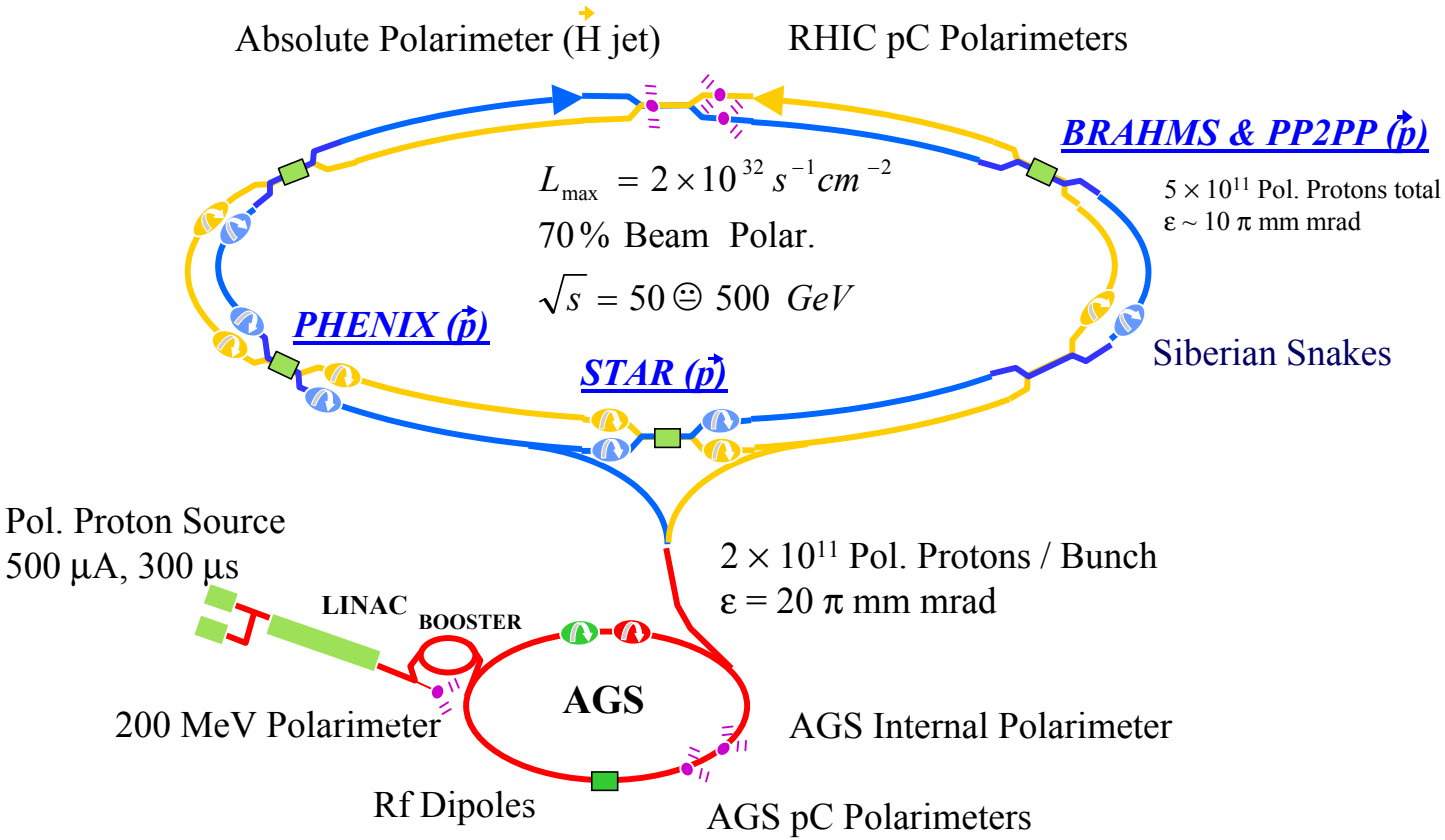
Prediction of large asymmetry even at $\sqrt{s} = 500$ GeV if Pomeron contributes to spin-flip amplitude





A.F. Martini, E. Predazzi, PRD 66, 034029 (2002)

Polarized Protons at RHIC



Principle of Measurement

Elastically forward scattered protons have very small scattering angle θ^*

Beam transport magnets determine trajectory of beam and scattered protons

Study beam transport to find position along beam orbit where scattered protons are well separated from beam protons

Need Roman Pot to measure scattered protons close to beam

Beam transport equations relate measured position at detector to scattering angle

$x = a_{11}\, x_0 + L_{eff}\, \theta_x^* \rightarrow$ Optimize so that a_{11} small and L_{eff} large

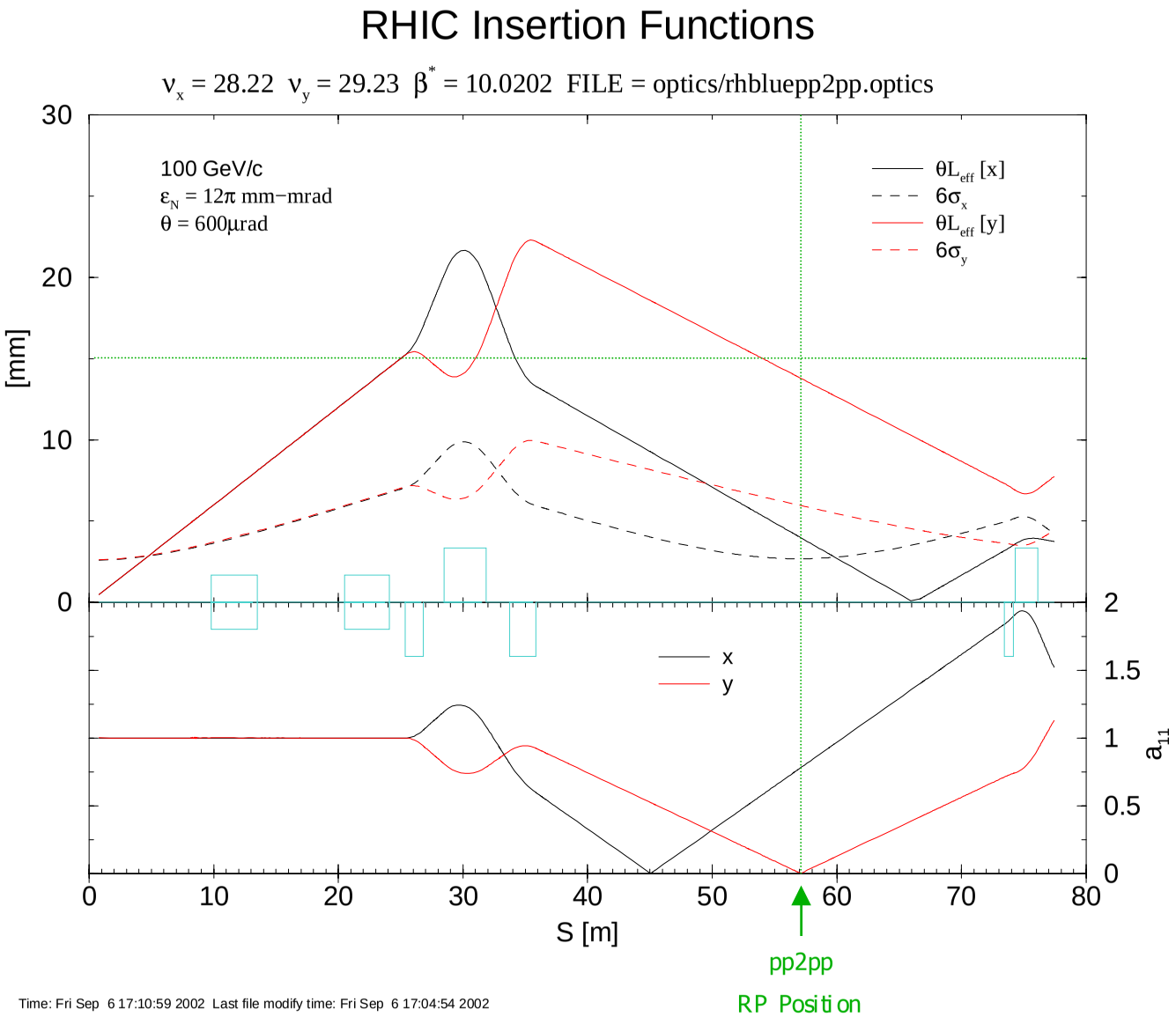
$\theta_x = a_{12}\, x_0 + a_{22}\, \theta_x^* \rightarrow$ x_0 can be eliminated by measuring θ_x

Similar equations for y-coordinate

Neglect terms mixing x- and y-coordinate in above equations

x : Position at Detector
θ_x : Angle at Detector
x_0 : Position at Interaction Point
θ_x^* : Scattering Angle at IP

Beam Transport

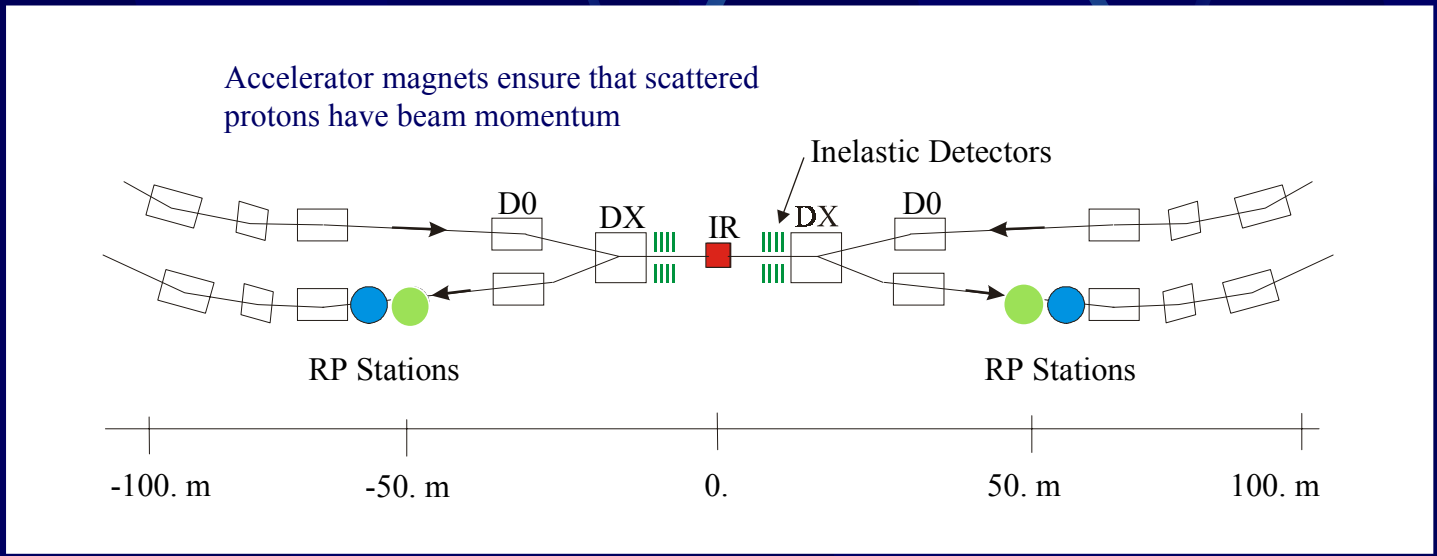


S. Tepikian

Experimental Setup at IR 2

- One Roman Pot station equipped with detector packages, placed downstream of interaction point (IP) on either side
  (Detectors arranged vertically above and below beam)

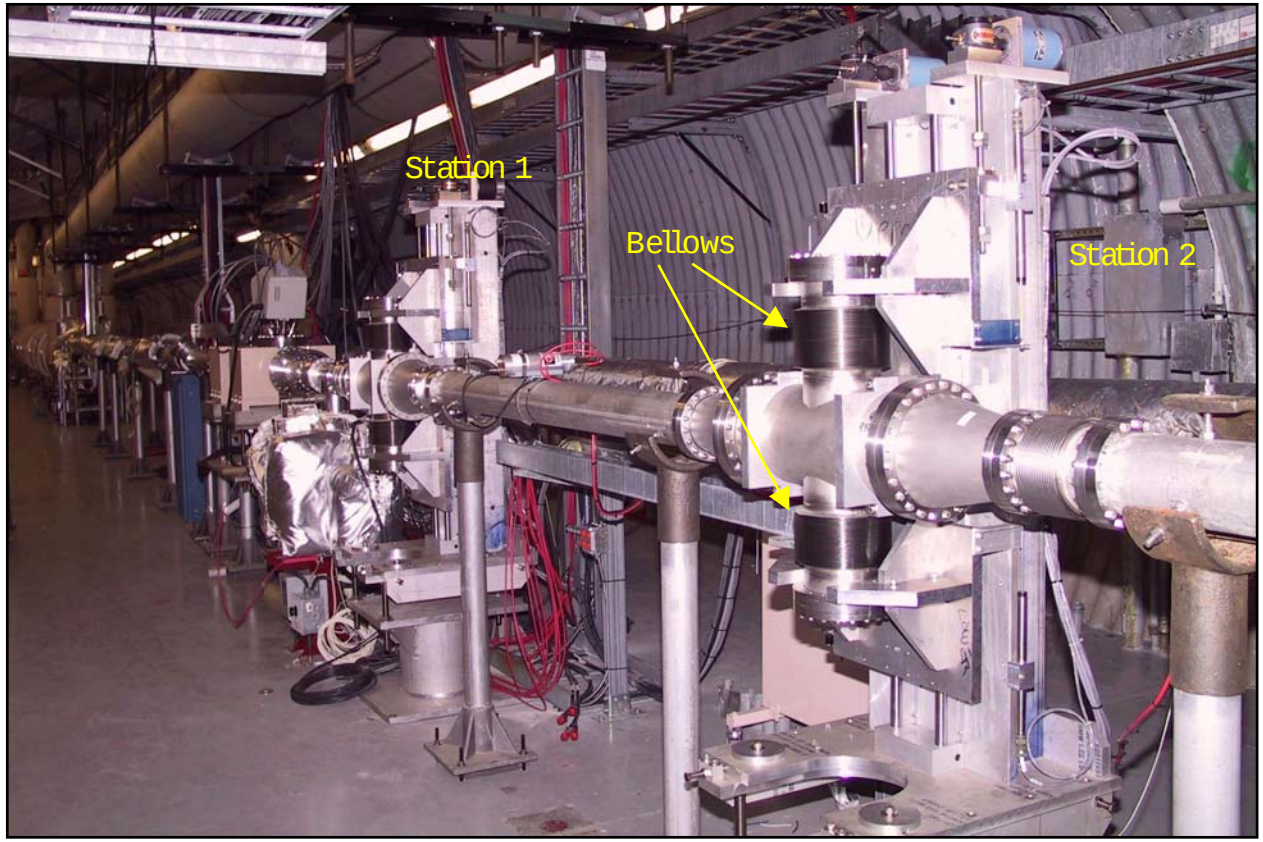
- 4 planes of inelastic scintillation counters on either side of IP
  (Kinematic coverage $2.4 \leq |\eta| \leq 5.3$)



Roman Pot Stations at RHIC

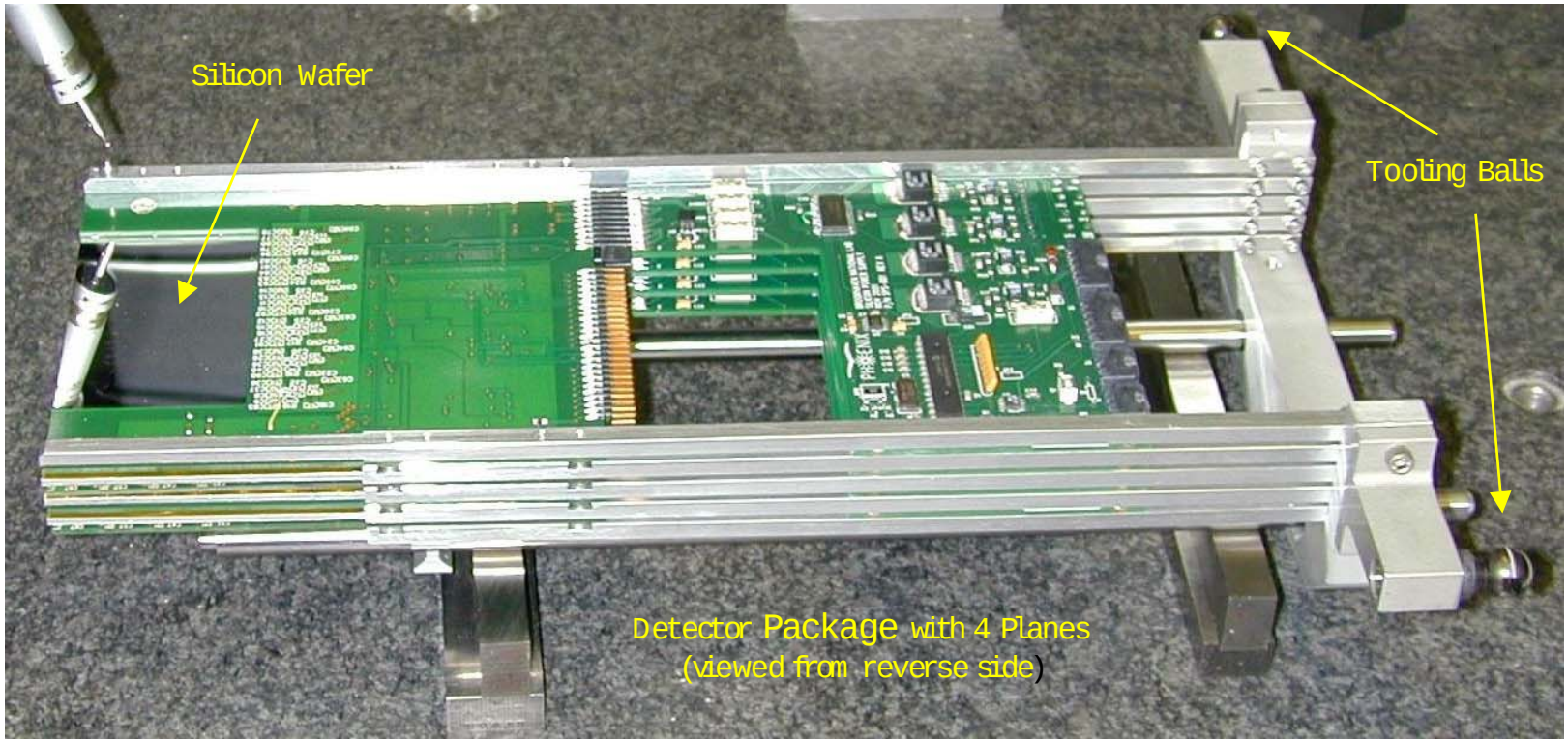
Detector Package
consists of
2 x-silicon planes
2 y-silicon planes
1 trigger scintillator

Active area of silicon
covers 7.5 x 4.5 cm^2



Two Roman Pot Stations installed in each Sector
One Station was equipped with a detector package
in top and bottom Roman Pot

Silicon Detector Assembly



Running Conditions in 2002

Running conditions during a pp2pp, 14 hour dedicated run:

Beam momentum $p = 100\ \mathrm{GeV}/c$

Number of bunches per beam $N_B = 55$ used 35 bunches

Beam scraped to emittance $\varepsilon \approx 12\ \pi \cdot 10^{-6}$ m

and intensity $I \leq 5 \cdot 10^{11}$ protons in each beam

Beam tune used $\beta^* = 10$ m

Beam polarization (working #) $P_b = 0.24 \pm 0.02$ O. Jinnouchi, Polarimetry Session Tuesday

Closest approach of first detector strip to beam about

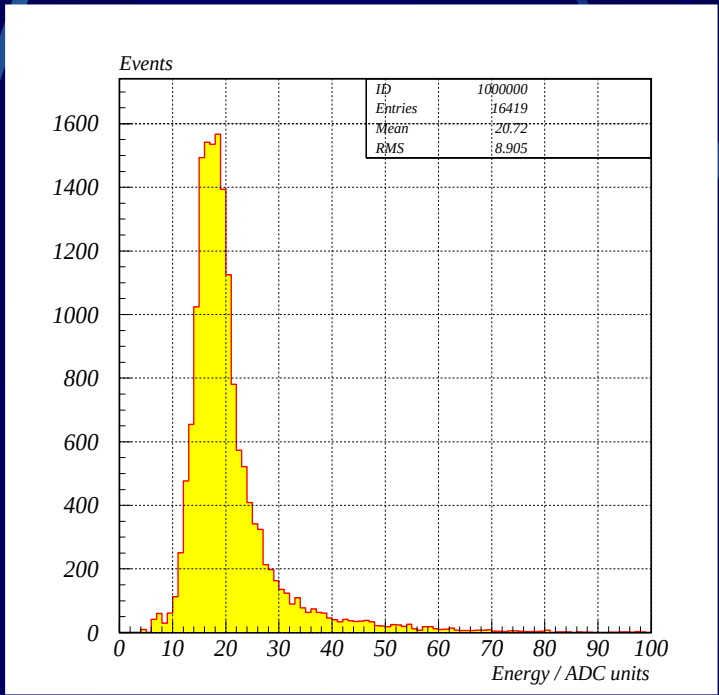
15 mm $\rightarrow t_{min} = -4 \cdot 10^{-3}$ GeV^2

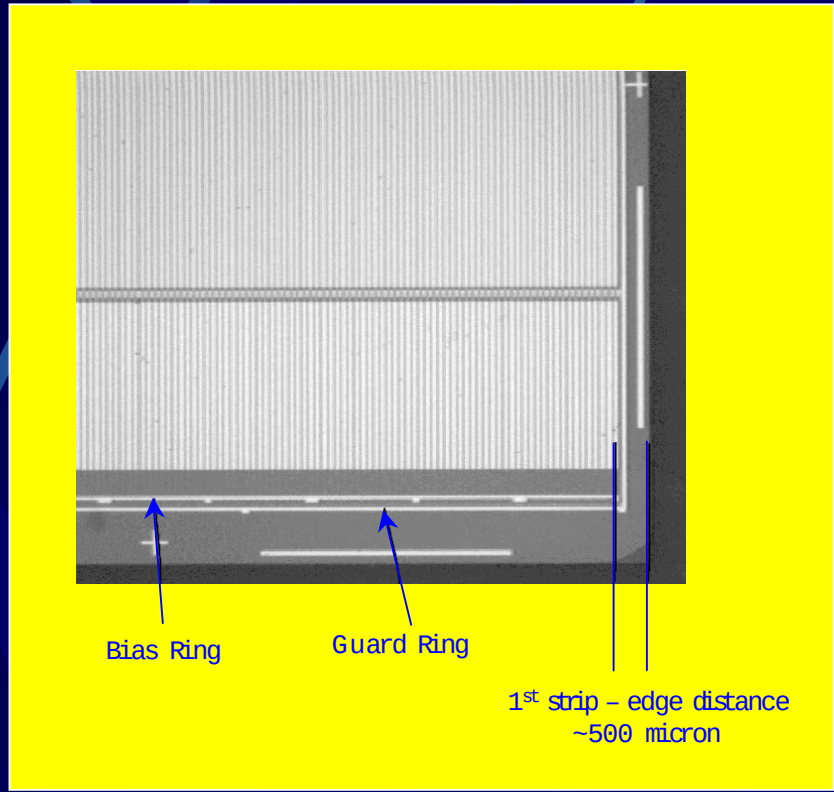
Collected ~1 million events of which >30 % are elastic

Silicon Microstrip Detector

100 GeV proton looses about 200 keV in silicon (~58,000 electron-hole pairs)

SN ratio ≈ 11





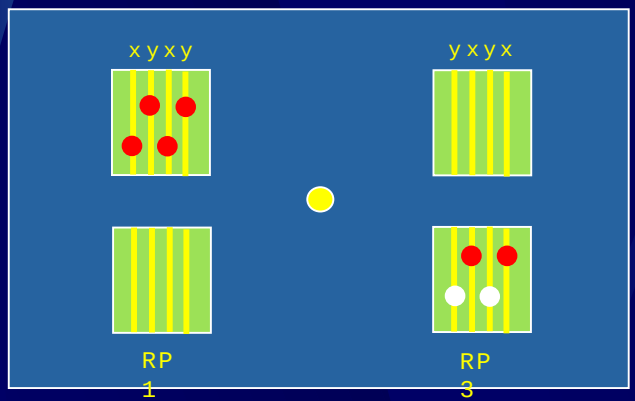
400 micron thick Silicon

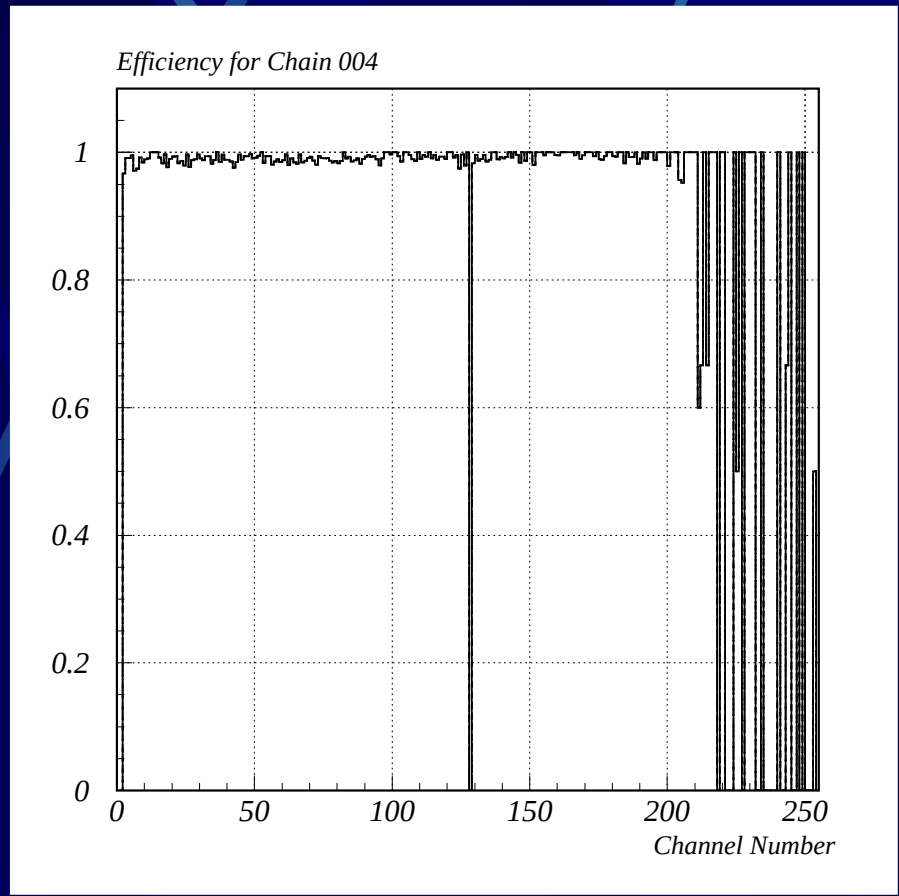
Good Position Resolution with Strip Pitch ~100 micron

Silicon Microstrip Detector Efficiency

First order efficiency calculated for combination of two x- or y-planes inside any given Roman Pot

14 out of 16 total silicon detectors have an average efficiency > 0.98





Collected Data Sample 2002

Inelastic events	40 %	
Elastic events	24 %	
Elastic triggers excluded by cuts Good track inside RP Collinearity between protons	26 %	
Elastic triggers without hits in silicon detector	10 %	Due to readout problem for certain bunches

Bunch Interaction Pattern

Two beams of 55 bunches each

Bunches filled with transversely polarized protons

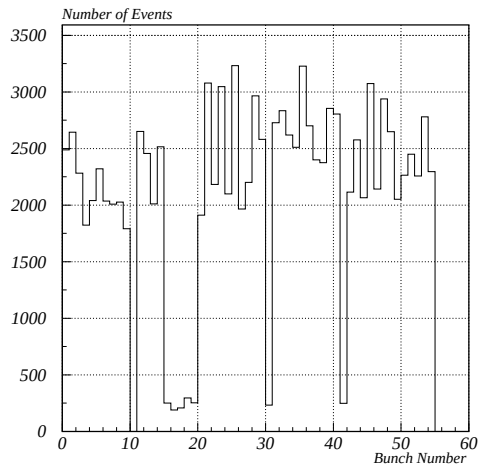
Polarization state, up or down, was selected on Bunch-By-Bunch basis for each beam separately

Bunch interaction patterns

↑↑ ↓↓ ↑↓ ↓↑ ↑0 ↑ ↓

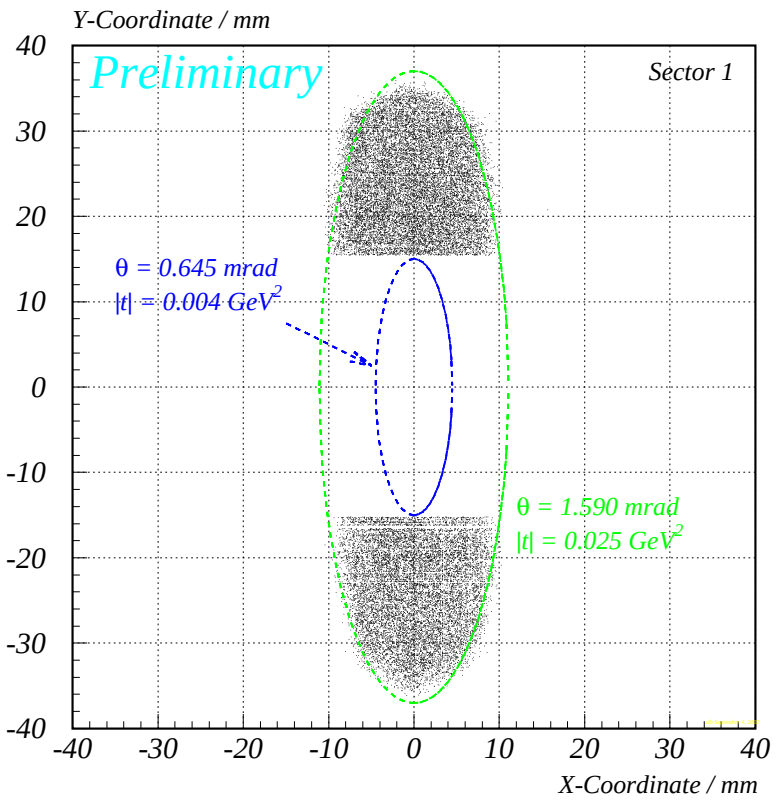
Crossings with empty bunches were used for background estimates

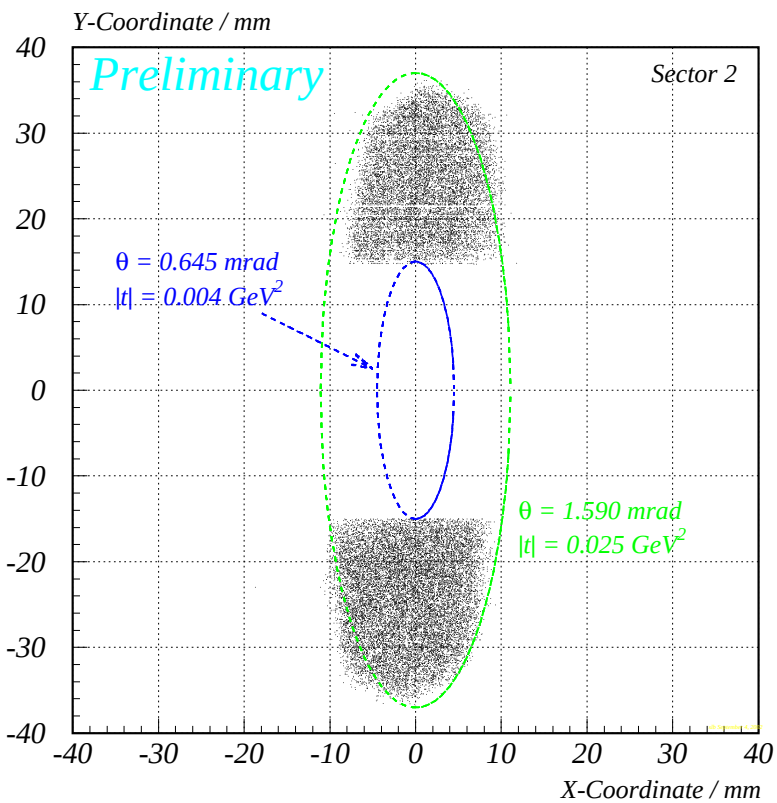
Bunch dependent inelastic count rate can be used for relative normalization of elastic count rate in asymmetry calculation



Elastic Hit Pattern

Raw hit distribution of scattered protons as seen on either side of the interaction region (sectors 1 and 2) by the detectors above and below the beam

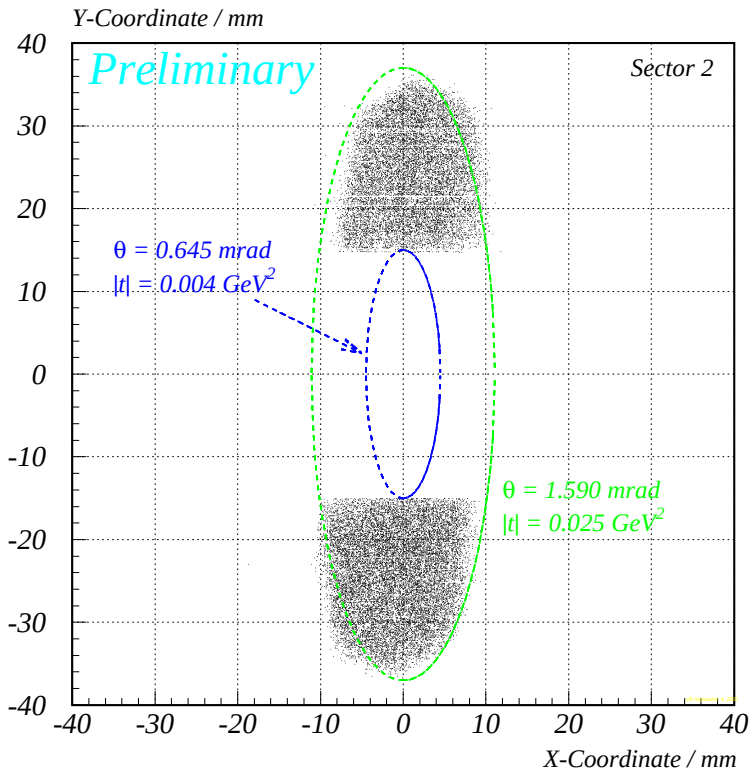


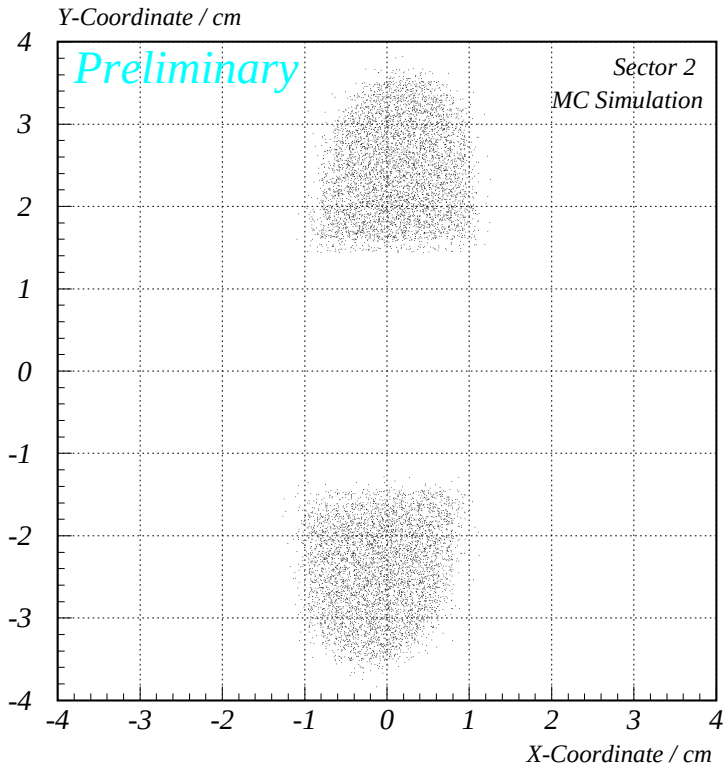


Comparison with MC Simulation

Raw hit distribution in sector 2

Simulated hit distribution in sector 2

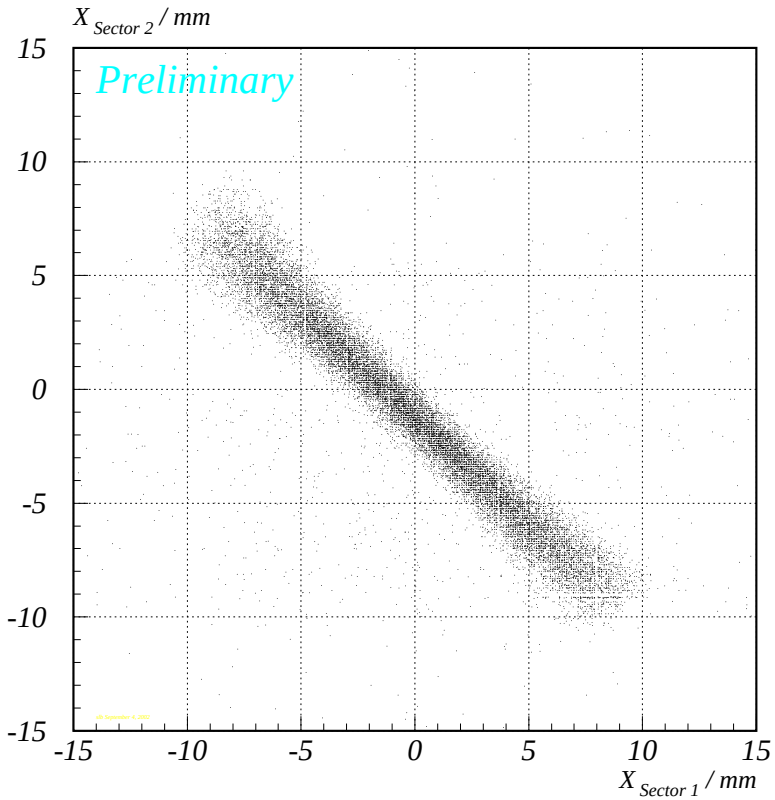


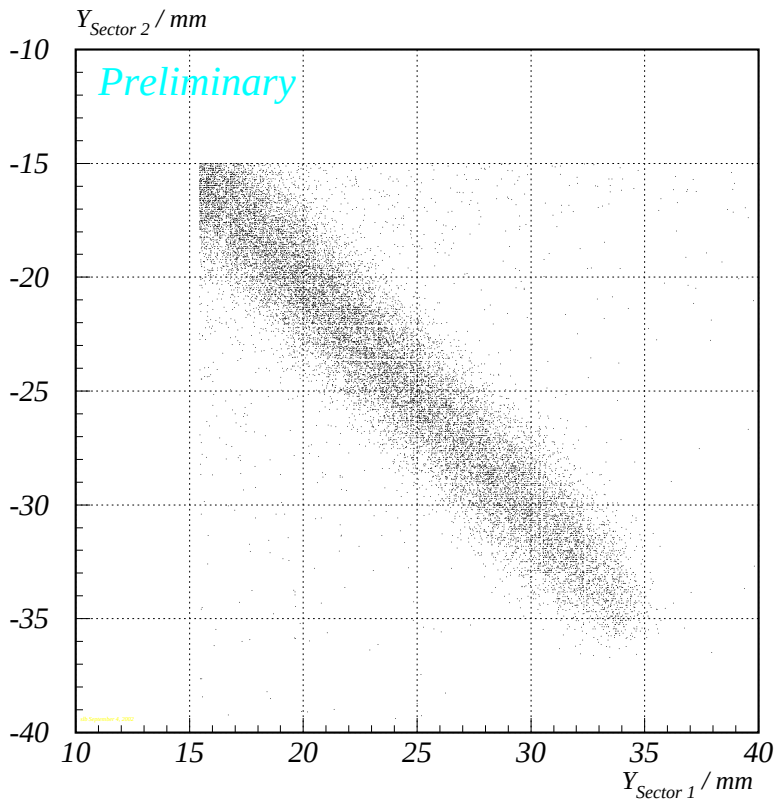


N. Öztürk

Collinearity Plots

Correlation plots for the *x*- and *y*-coordinates of scattered protons as measured to the left and right of the interaction region





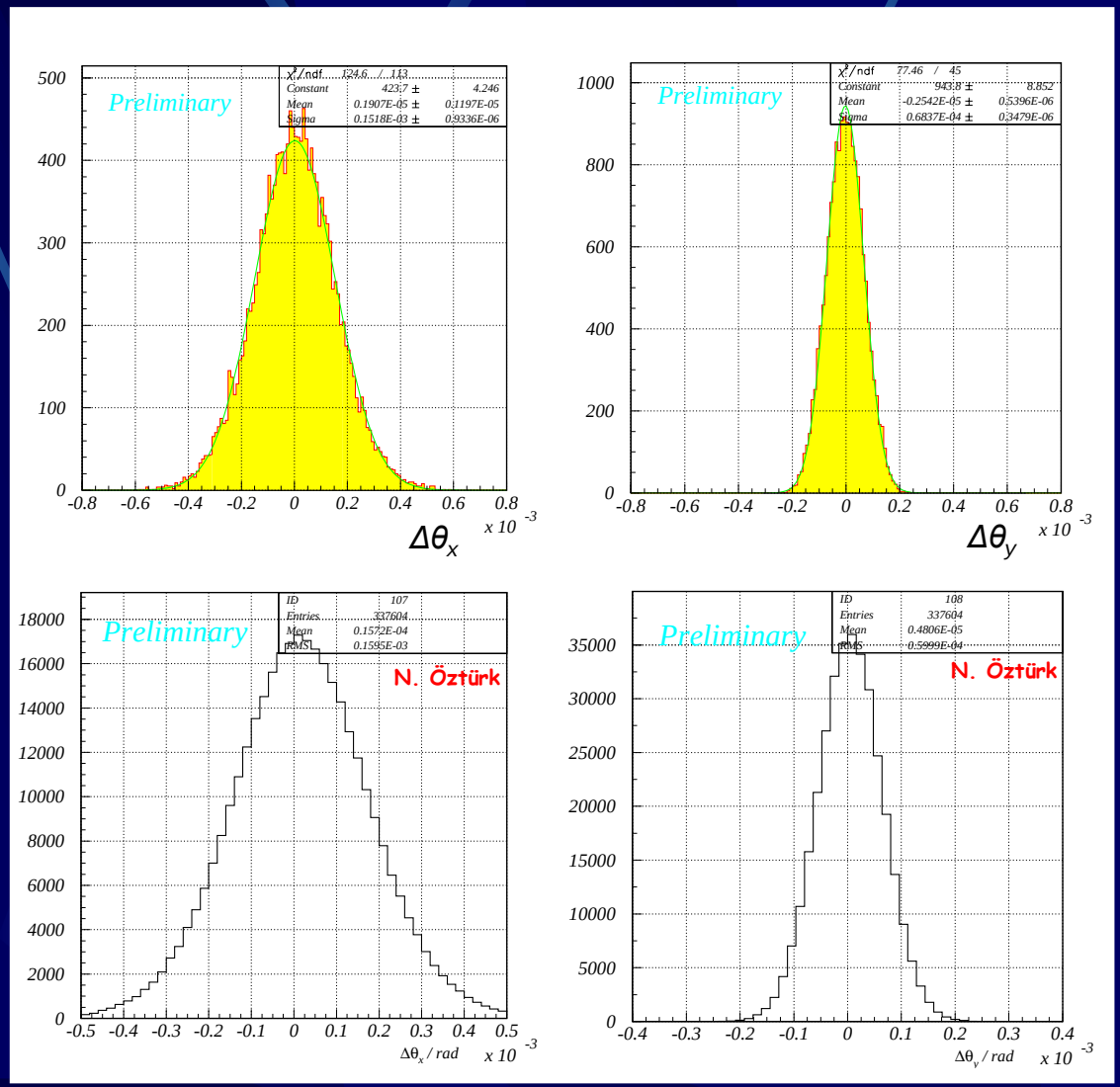
Beam Angular Divergence

Good agreement between width of θ_x and θ_y distributions for measured and simulated events with emittance of

$$\varepsilon = 12\ \pi \cdot 10^{-6}\ \text{m}$$

$$\Delta\theta_x \approx 150\ \mu\text{rad}$$

$$\Delta\theta_y \approx 70\ \mu\text{rad}$$



Conclusions

We had a successful engineering run in 2002

- Beam was set up efficiently for pp2pp running conditions
- Detectors worked efficiently
- MC Simulation reproduces features of the data

We are working on:

- **Determination of systematic effects on elastic event reconstruction due to the beam transport and collision point uncertainties**
- **Calculation of detector acceptance**
- **Calculation of silicon detector efficiency**

This will result in determination of spin asymmetries and slope parameter *B*

Steps to be taken for run in 2003

- Install detector packages in two remaining Roman Pot Stations not to depend on vertex position (in x_0 and y_0) in calculation of scattering angles
- Measure beam tune under pp2pp running conditions to reduce systematic uncertainty in beam transport calculation
- Include Van der Meer beam scans for luminosity determination
- Run longer to improve statistics in view of physics goals (and also systematic uncertainties)

Outlook

The Future beyond 2003

- Measure in CNI region with special beam tune and upgrades to machine (power supplies)

  $0.0004\ \mathrm{GeV}^2 < |t| < 1.3\ \mathrm{GeV}^2$

- Add Roman Pot Stations between DX and D0 magnets to measure at higher $|t|$-region

  $1.3\ \mathrm{GeV}^2 < |t| < 5\ \mathrm{GeV}^2$

- Measure at different beam energies

  $p < 250\ \mathrm{GeV}/c$

- Measure with different nuclei, like $^1H + ^2H$, ...