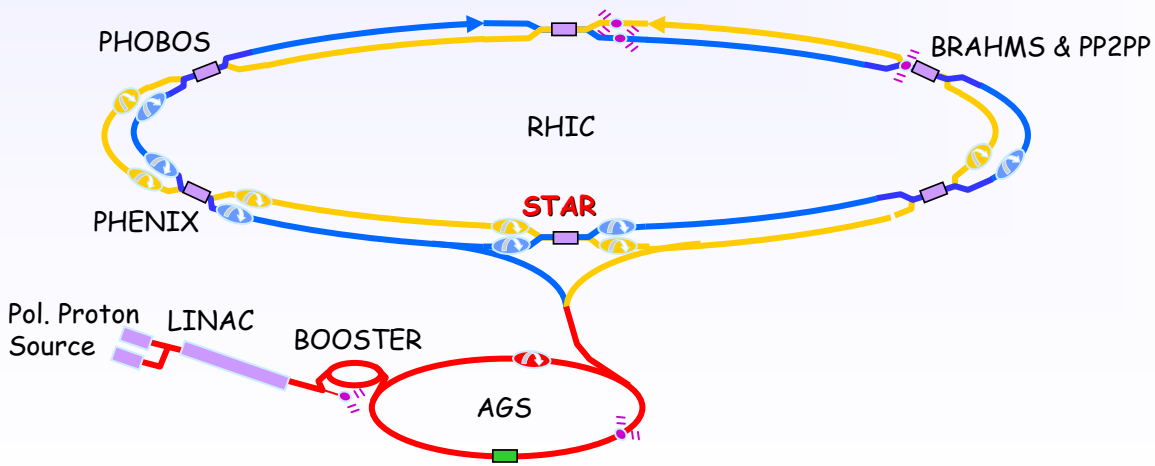
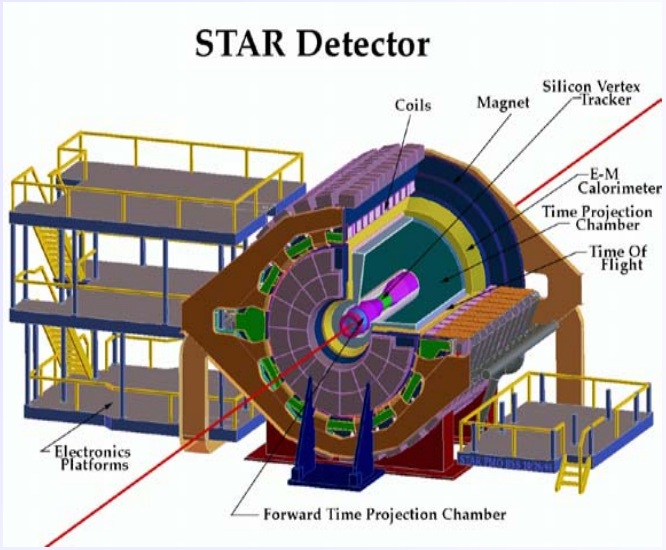
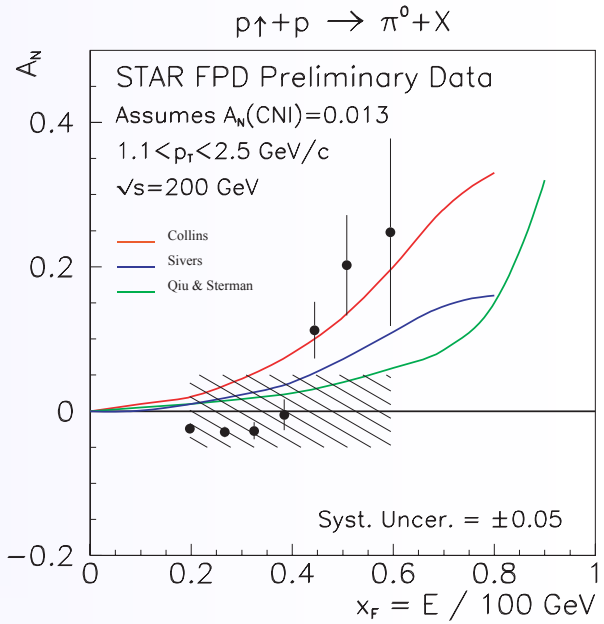
The First Collisions of Transverse Polarized Protons at the STAR experiment at RHIC

Bernd Surrow
BNL

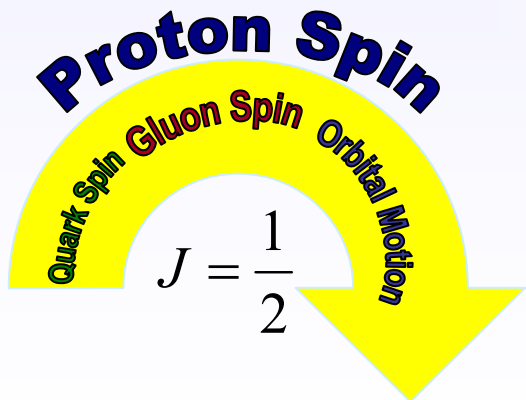


Outline





- STAR experiment
- Polarized proton collider RHIC
- First results in FY02
- Introduction
- Summary and Outlook



Introduction

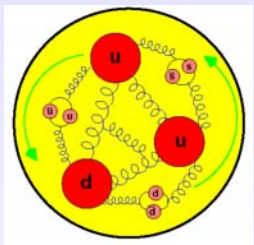
STAR spin

- Exploring the spin structure of the proton

  - SPIN: Fundamental property of elementary particles such as mass:

Proton:

SPIN J=1/2



Quarks and Gluons: Fundamental components of Theory of strong interaction – Quantum Chromo Dynamics (QCD)

  - Fundamental question: How is the proton spin made up?

$$J = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

⇨ Electron (e) / muon (μ) - proton (p) scattering experiments found that fraction of proton spin carried by quarks is small: $\Delta\Sigma \approx 1/3$

⇨ Where is the spin of the proton then?

$$\Delta G \text{ and } (L_z^q + L_z^g)$$

  - At present, the Gluon polarization, $\Delta G/G$, is only poorly constrained (only indirectly) from e/μ – p scattering experiments
  - Need: New generation of experiments to explore the spin structure of the proton: polarized proton collisions at RHIC which allows to access directly $\Delta G/G$!

RHIC spin program:

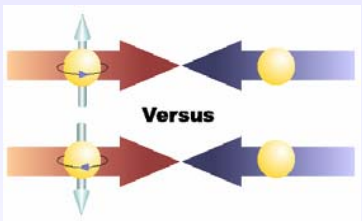
  - Unique multi-year program colliding polarized protons for the first time ever has just started...!
  - Explore various aspects of the spin structure of the proton in a new domain:
    - ⇨ Spin structure of the proton (e.g. role of gluon)
    - ⇨ Spin dependence of fundamental interactions
    - ⇨ Spin dependence of fragmentation
    - ⇨ Spin dependence in elastic polarized pp collisions

Introduction

STAR spin

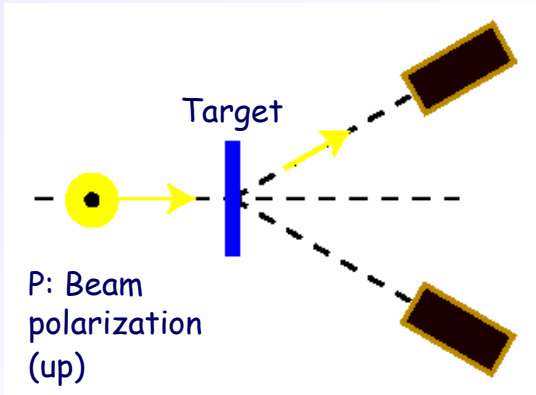
Asymmetries

- Measurement of asymmetries (A): Principle approach to study spin effects!
- An asymmetry quantifies the difference between different initial spin configurations for a particular process
- Example: Single transverse-spin asymmetry



$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$

⇨ Study left/right asymmetries!



- Ultimately at RHIC, any combination of beam polarization (longitudinal (+/-) /transverse (↑/↓)) is possible, which allows to explore different aspects of the proton spin structure
- First year (FY02): transverse (↑/↓) polarized collisions
- Second year (FY03): transverse (↑/↓) and longitudinal (+/-) polarized proton collisions

Introduction

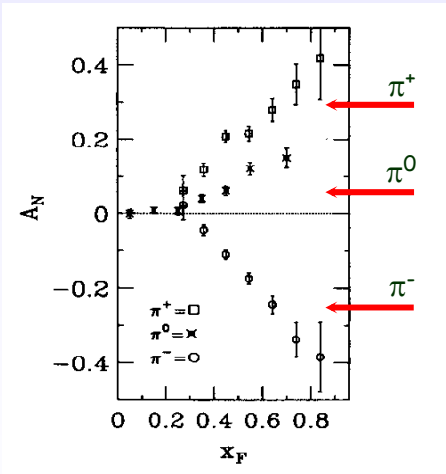
- Experimental and theoretical remarks on A_N

- Basic, "naive QCD calculations" (leading-twist, ignore masses of quarks) predict: A_N=0
- Non-zero values of A_N have been observed at the FNAL experiment E704 for:

$$\vec{p} + p \rightarrow \pi^0 + X$$

$\sqrt{s}$ = 20 GeV (10 X smaller than at RHIC), 0.5 < p_T < 2.0 GeV

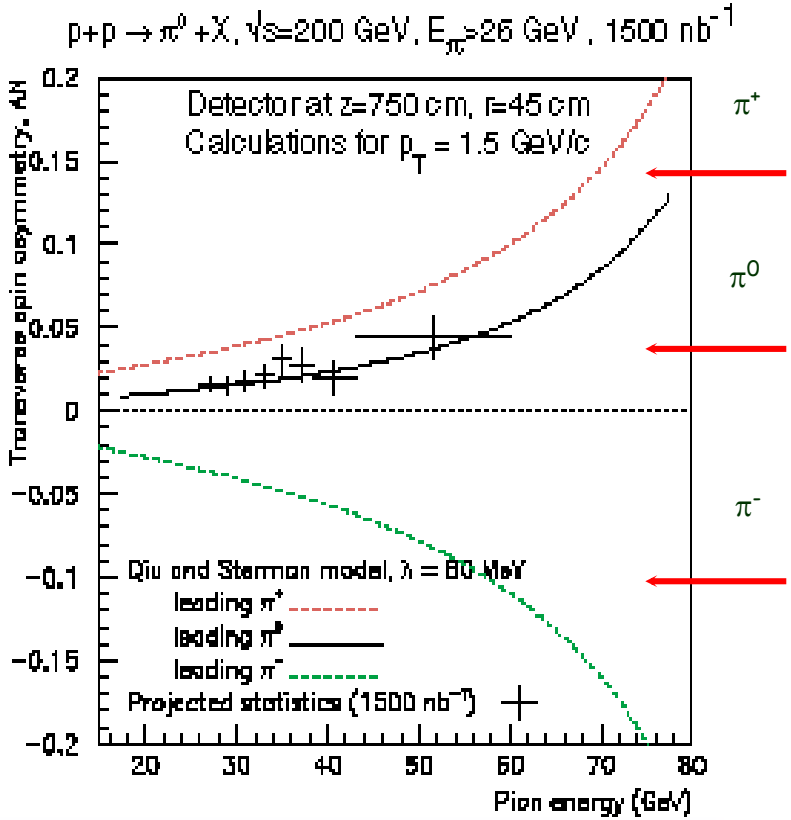
A_N E704 data



- Does the E-704 effect persist to RHIC energies?
- Challenge to theory community to explain this measured effect!

- Several approaches beyond the basic "naive QCD calculations" yield non-zero A_N values at RHIC energies:

A_N E704 simulation



Introduction

- First polarized proton run (12/20/01 - 01/24/02): transv. polarized proton beams

- Aim at STAR during first polarized proton run: ⇨ Exploratory measurement of a single transverse-spin asymmetry:

$$\vec{p} + p \rightarrow \pi^0 + X$$

Forward π^0 ($\pi^0 \rightarrow \gamma\gamma$) production

x_F ($\approx E_{\pi^0}/E_{beam}$) ~ 0.1 – 0.6 and p_T ~ 1 – 4 GeV

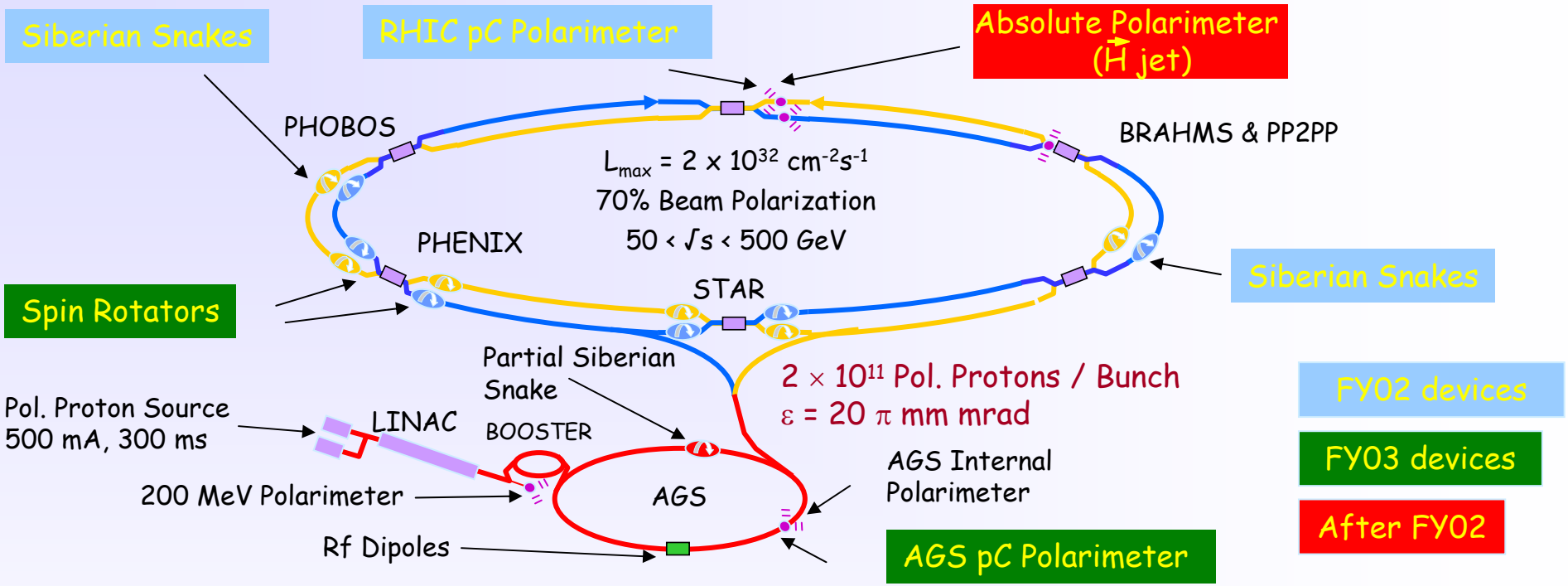
- Asymmetry:

$$\varepsilon = PA_N = \frac{N_\uparrow / L_\uparrow - N_\downarrow / L_\downarrow}{N_\uparrow / L_\uparrow + N_\downarrow / L_\downarrow} = \frac{N_\uparrow - R \cdot N_\downarrow}{N_\uparrow + R \cdot N_\downarrow}$$

- Determination of A_N requires three measurements:
  1. Spin dependent event yield: $N_{\uparrow(\downarrow)}$
  2. Relative luminosity: $R=L_\uparrow/L_\downarrow$
  3. Beam polarization: P

- A_N : DIFFERENCE over SUM – In general quite small ⇨ Require therefore:
  1. Statistical precision
  2. Control of systematic effects

Polarized Proton Collider RHIC



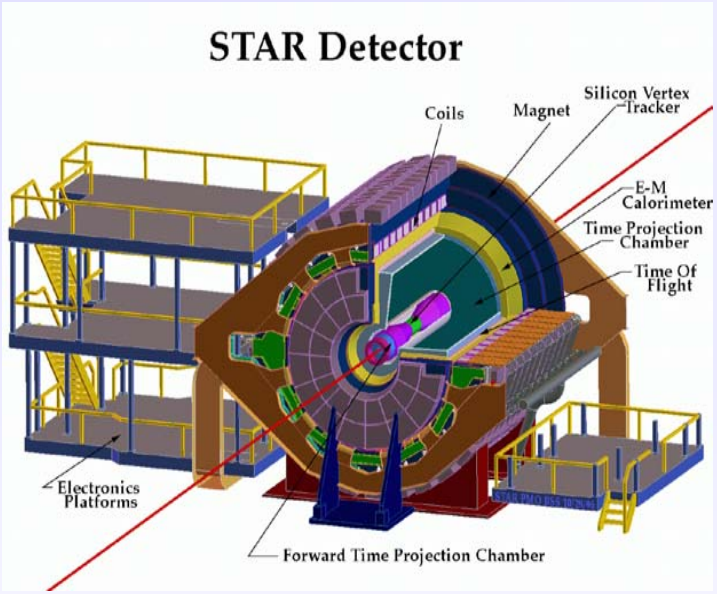
- RHIC performance in FY02:
  - ⇨ Beam energy: 100 GeV
  - ⇨ Inst. luminosity: ~ 1 • 10^{30} s^{-1} cm^{-2}
  - ⇨ Integrated luminosity: ~ 0.3pb^{-1}
  - ⇨ Bunch crossing time: 213ns
  - ⇨ Polarization: ~ 0.2 at injection approximately maintained at 100GeV (transverse)

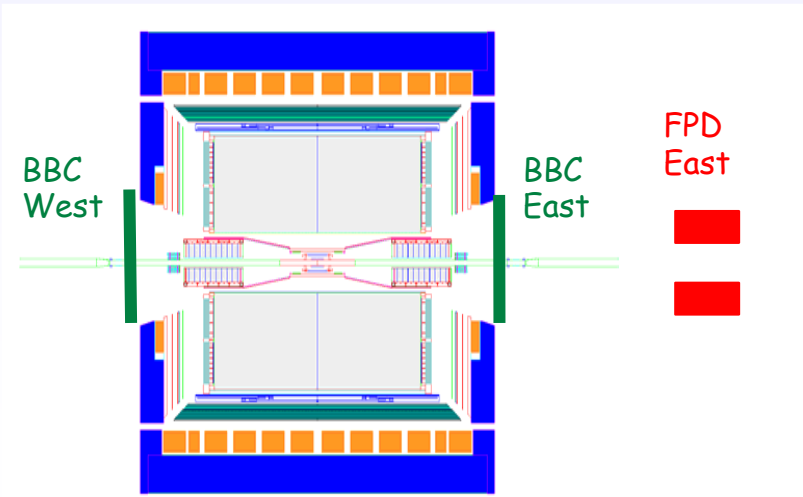
- Expected RHIC performance in FY03:
  - ⇨ Beam energy: 100 GeV
  - ⇨ Inst. luminosity: ~ 1 • 10^{31} s^{-1} cm^{-2}
  - ⇨ Integrated luminosity: ~ 3 pb^{-1} recorded at STAR (long. polarization)
  - ⇨ Bunch crossing time: 107ns
  - ⇨ Polarization: ~ 0.4 from AGS (trans. and long. at RHIC)

The STAR experiment

STAR spin

- Upgrade of the STAR detector





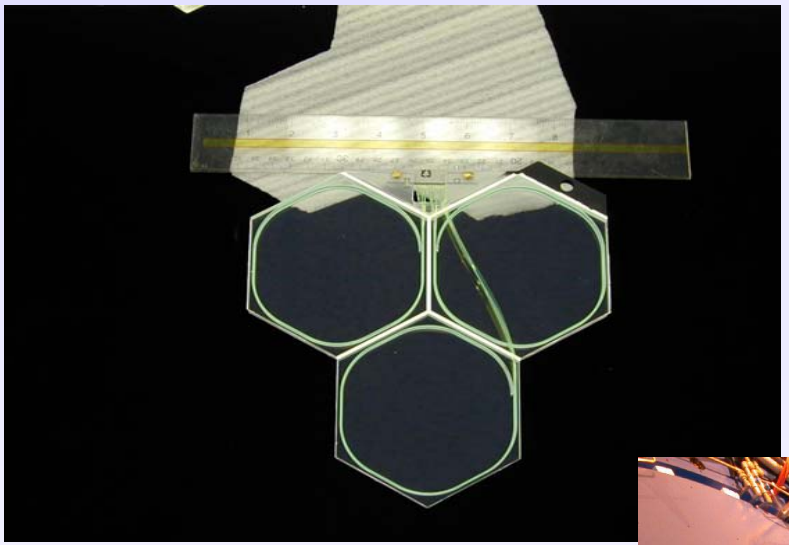
Upgrade program of the STAR experiment for the first polarized proton collisions:

- Beam-Beam Counter (BBC):
  - ⇨ Relative luminosity measurement
  - ⇨ Rejection of beam-gas event in pp collisions
  - ⇨ Minimum bias trigger
  - ⇨ Beam tuning to make collisions at STAR
  - ⇨ Luminosity monitor
- Forward-Pion Detector (FPD)
  - ⇨ Electromagnetic calorimeter system: Prototype setup of 3 Pb-glass arrays and 1 Pb-scintillator calorimeter
  - ⇨ Energy and shower profile measurement ($\pi^0 \rightarrow \gamma\gamma$)
  - ⇨ Event yield for Forward π^0 production
- Commissioning of EM-calorimeter (Barrel) modules and trigger
- Commissioning of spin scaler system

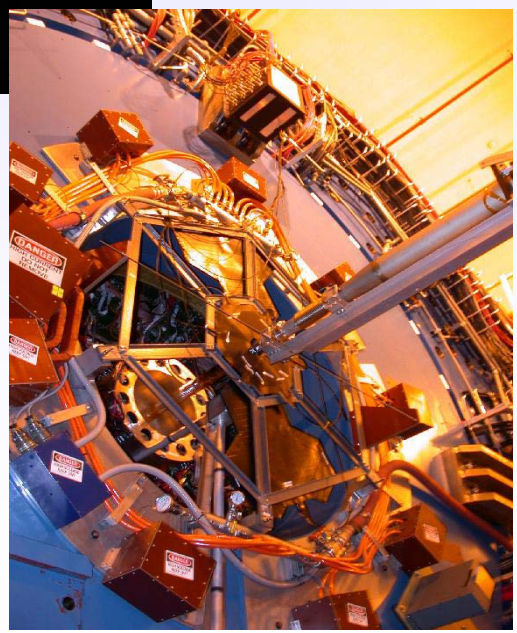
The STAR experiment

STAR spin

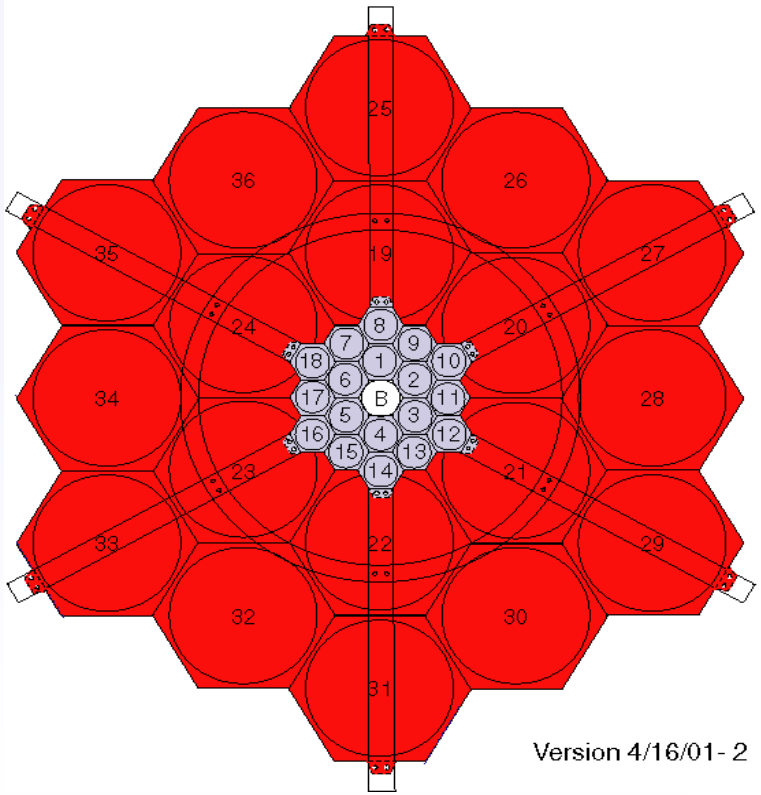
Beam-Beam Counter (BBC)



- Hexagonal scintillator array structure at ±3.5m from IP:
  - ⇨ Inner annulus: inner (outer) diameter 9.6cm (48cm) of 18 pixels
  - ⇨ Outer annulus: inner (outer) diameter 38cm (193cm) of 18 pixels

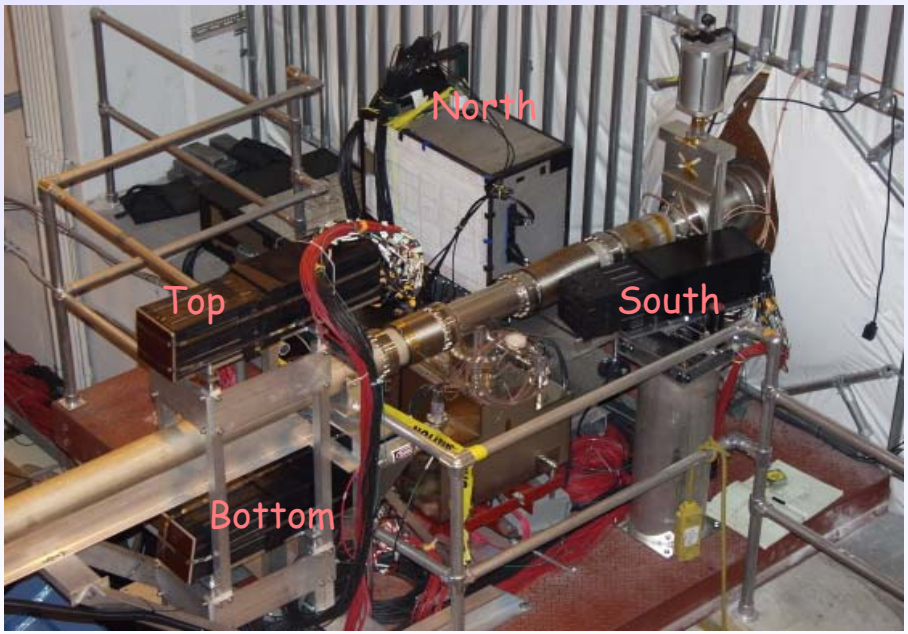


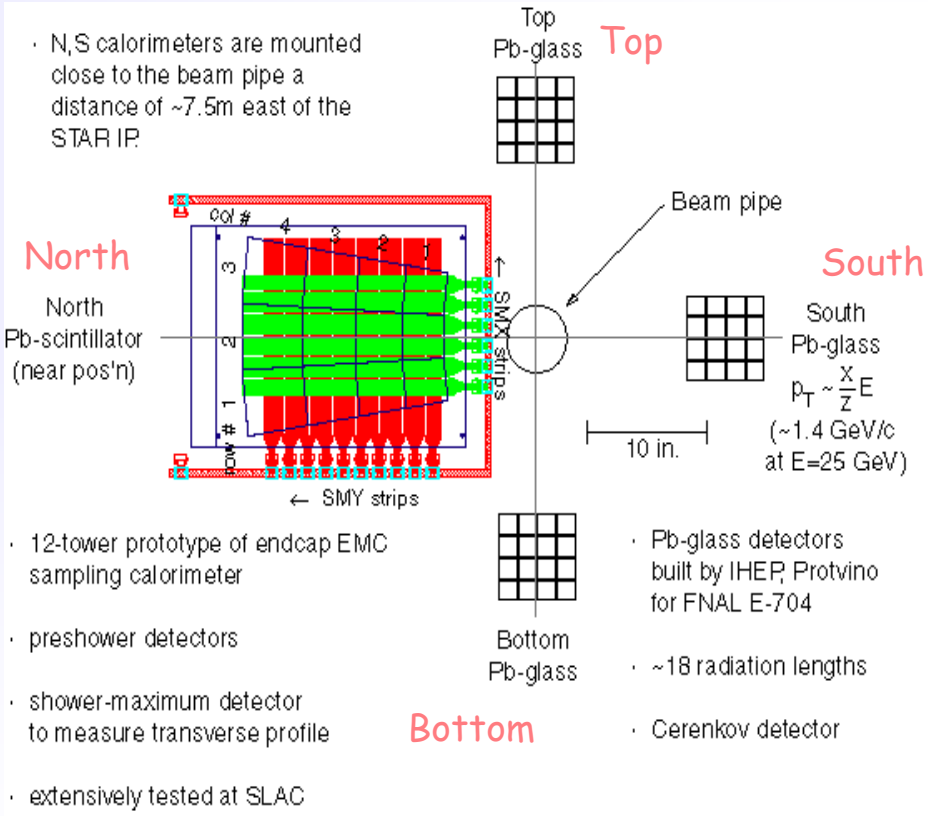
- Singe scintillator tile:
  - ⇨ 1 cm thick scintillator
  - ⇨ 4 optical fibres for light collection
  - ⇨ ~ 15 photoelectron/MIP



The STAR experiment

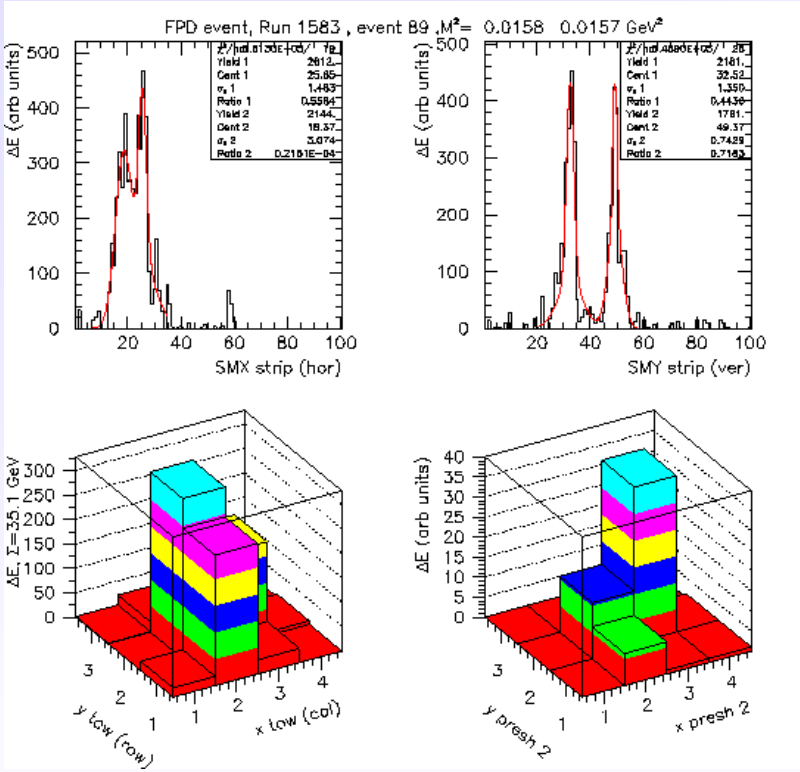
- Forward-Pion Detector (FPD)





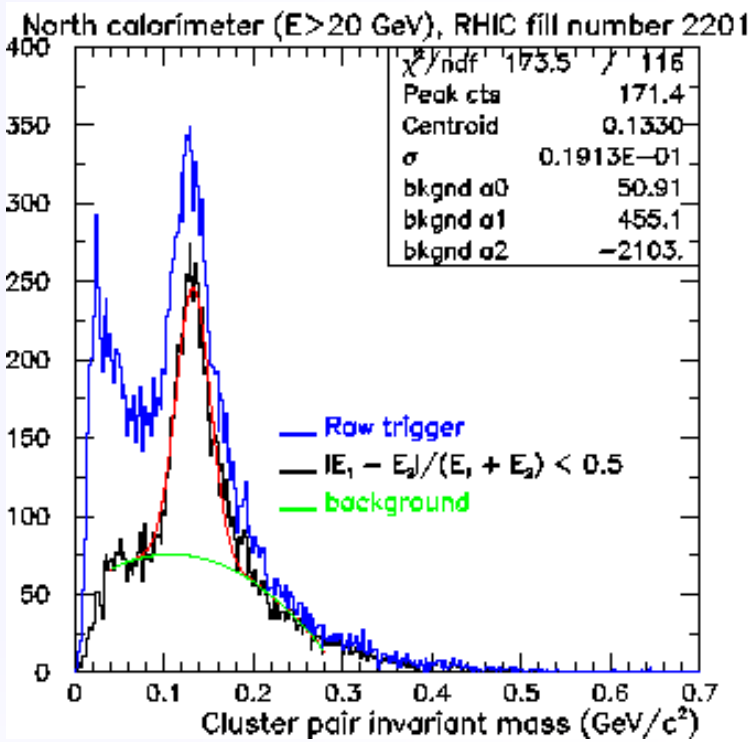
First results (FY02)

- Measurement of forward π^0 production at RHIC



Transverse shower profile response of shower maximum detector

Calorimeter and Preshower detector response

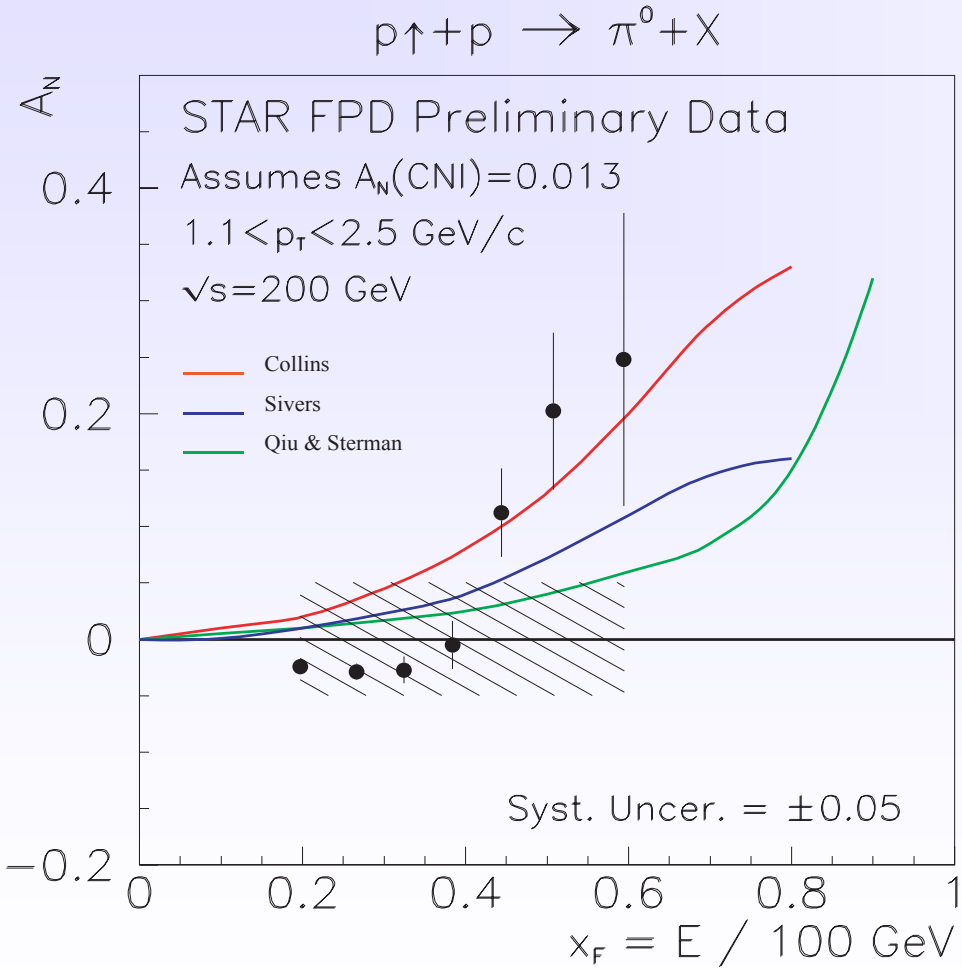


⇨ Cluster separation in shower maximum detector and measured calorimeter energy serves as input to the π^0 mass determination!

⇨ Clearly identified π^0 mass peak!

First results (FY02)

- First measurement of A_N for forward π^0 production at RHIC



- Several approaches beyond the basic "naive QCD calculations" yield non-zero A_N values at RHIC energies:
  - ⇨ Sivers: include intrinsic transverse component, $k_\perp$, in initial state (before scattering takes place)
  - ⇨ Collins: include intrinsic transverse component, $k_\perp$, in final state (after scattering took place)
  - ⇨ Qiu and Sterman: more "complicated QCD calculations" (higher-twist, multi-parton correlations)
- A_N is found to increase with energy similar to E704 result
- This behavior is also seen by several models which predict non-zero A_N values

Summary and outlook

Summary

- First polarized proton collisions ever at STAR experiment at RHIC!
- Successful upgrade and commissioning of various new STAR components for the first polarized proton run at RHIC:
  - ⇨ Beam-Beam Counter (Relative luminosity measurement < 10^{-3})
  - ⇨ Forward-Pion Detector (Total event sample: $3.5 \cdot 10^6$)
  - ⇨ EM calorimeter modules and trigger (Total event sample: $0.8 \cdot 10^6$)
  - ⇨ Spin scaler system
- First measurement of single transverse-spin asymmetries A_N for forward π^0 production at RHIC (⇨ Probe new domain in QCD)!

Outlook

- Various upgrade programs are underway at STAR
  - ⇨ Beam-Beam counter / Forward-Pion Detector
  - ⇨ Electromagnetic calorimetry (Endcap/Barrel)
- First collisions of longitudinally polarized protons expected for FY03!

⇨A very exciting time is ahead of us to explore the spin structure of the proton at RHIC!

Thank you!

- BNL directorate
- STAR Collaboration
- Gerry Bunce
- Les Bland
- Joanna Kiryluk, Akio Ogawa and Greg Rakness!