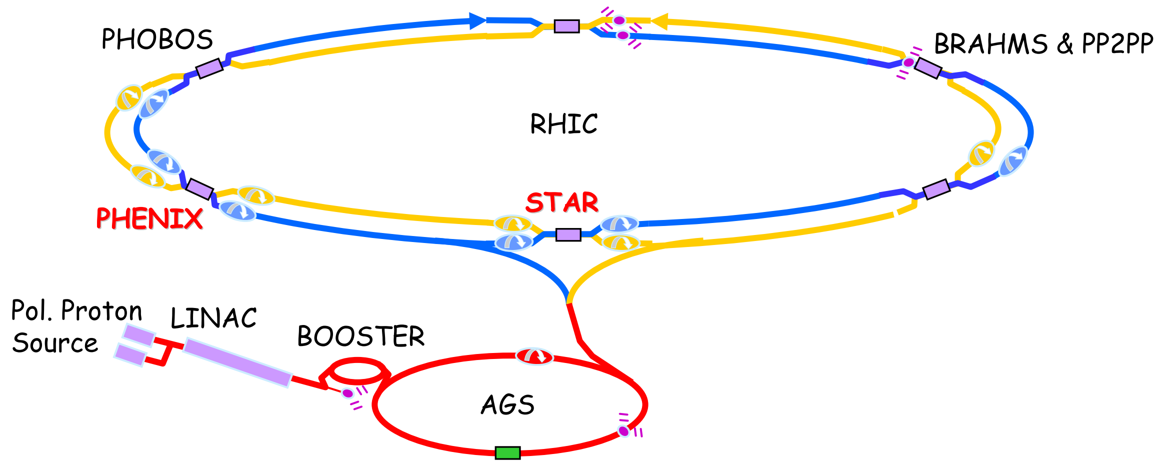
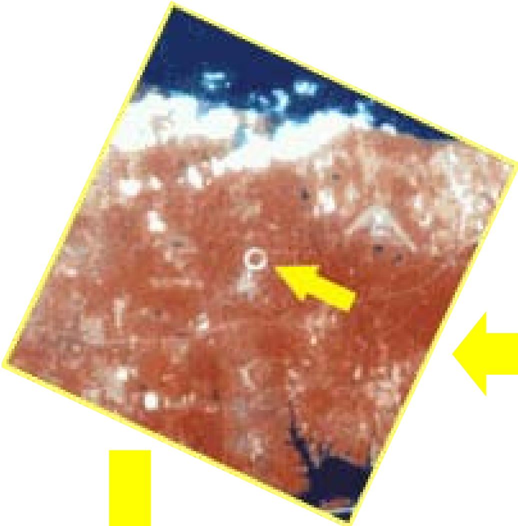
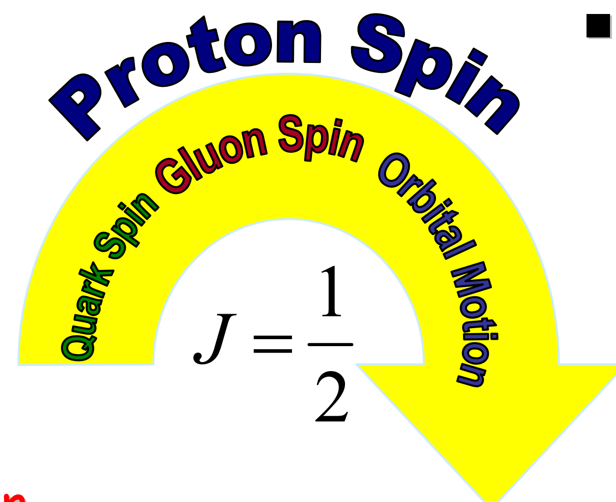
The First Collisions of Polarized Protons at RHIC and beyond

Bernd Surrow
BNL



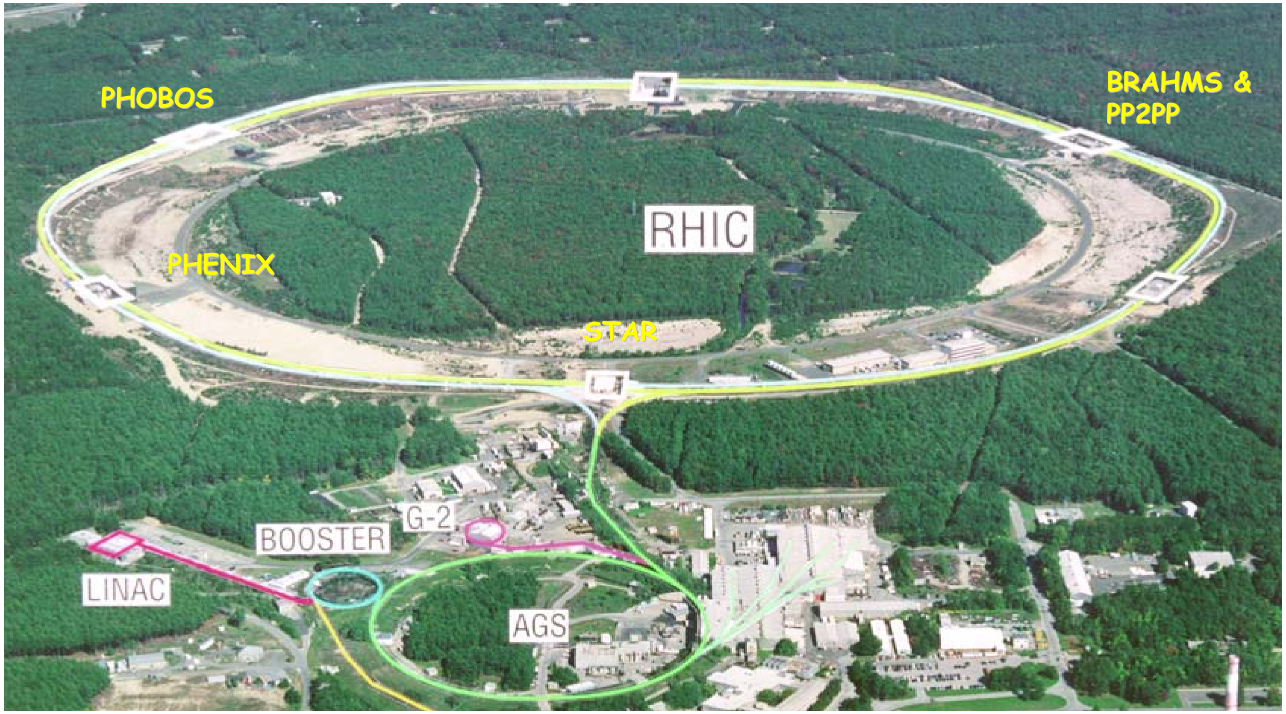
Outline





- Introduction
- Polarized proton collider RHIC
- STAR / PHENIX Experiments
- First RHIC SPIN results
- Proton structure at EIC
- Summary and Outlook

Introduction



- RHIC SPIN PYSICS effort of colliding polarized protons complements on-going relativistic-heavy ion program (Au-Au, Au-d) at RHIC

- **RHIC SPIN Collaboration**: Coordination of overall spin issues for RHIC accelerator and experiments (Spokesperson: Gerry Bunce)
  - ⇨ RHIC accelerator spin group
  - ⇨ RIKEN and RIKEN/BNL research center
  - ⇨ STAR and PHENIX experiments (Spin physics working groups)
  - ⇨ pp2pp experiment

Introduction

■ Cross-sections and Structure Functions (unpolarized)

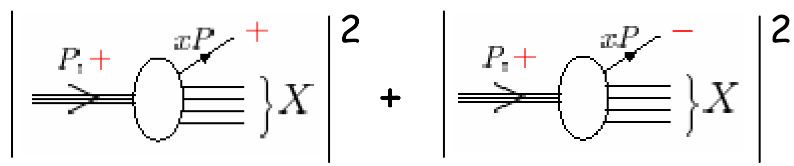
- Quantify spin-averaged structure of proton in terms of F_2 and F_L:

$$\left(\frac{d^2\sigma}{dE'd\Omega}\right) = \frac{\alpha^2}{Q^4}\left(\frac{E'}{E}\right) L_{\mu\nu}(l,q) W^{\mu\nu}(P,q)$$

In terms of kinematic variables:

$$\left(\frac{d^2\sigma}{dydQ^2}\right) = \frac{2\pi\alpha^2 Y_+}{Q^4 y}\left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)\right]$$

$Y_\pm = 1 \pm (1-y)^2$

q(x) = 

F_2 : structure function F_2

QPM: $F_2 = x\sum_q e_q^2 [q(x) + \bar{q}(x)]$

$F_L = F_2 - 2xF_1$: long. structure function F_L

QPM: $F_L = F_2(x) - 2xF_1(x) = 0$

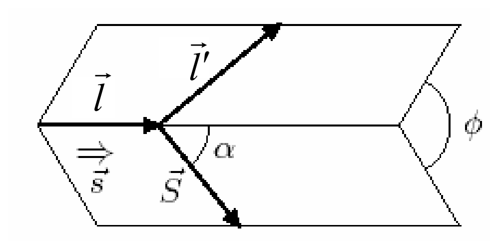
Quantify unpolarized structure of the proton!

Unpolarized parton distribution function q(x) (momentum distribution) $q(x)=f^+(x)+f^-(x)$:

Introduction

- Cross-sections and Structure Functions (polarized)

  - Quantify spin structure of proton in terms of g_1 and g_2:
    - Take difference of hadronic tensor: $W^{\mu\nu}(P,q,S) - W^{\mu\nu}(P,q,-S)$
    - Specialize to lepton with helicity λ and $\angle(\vec{l},\vec{S}) \equiv \alpha$



$$\left(\frac{d^2\sigma^{(\alpha)}}{dxdyd\phi}\right) - \left(\frac{d^2\sigma^{(\alpha+\pi)}}{dxdyd\phi}\right) = \frac{\lambda e^4}{4\pi^2 Q^2} \cdot \left\{\cos\alpha\left\{\left[1 - \frac{y}{2} - \frac{m^2x^2y^2}{Q^2}\right] g_1(x,Q^2) - \frac{2m^2x^2y^2}{Q^2} g_2(x,Q^2)\right\} - \sin\alpha\cos\phi\frac{2mx}{Q}\sqrt{\left(1 - y - \frac{m^2x^2y^2}{Q^2}\right)}\left(\frac{y}{2}g_1(x,Q^2) + g_2(x,Q^2)\right)\right\}$$

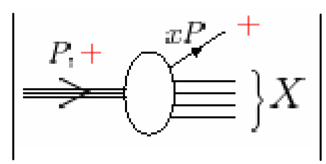
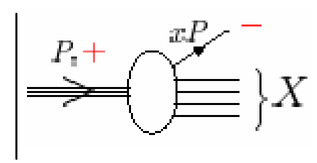
Quantify polarized structure of the proton!

⇨ For $\alpha=0$, g_1!
⇨ For $\alpha=\pi/2$, yg_1+2g_2 suppressed by m/Q!

g_1 : structure function g_1

QPM: $g_1 = \frac{1}{2}\sum_q e_q^2[\Delta q(x) - \Delta\bar{q}(x)]$

Polarized parton distribution function $\Delta q(x)$ (longitudinal spin distribution) $\Delta q(x) = f^+(x) - f^-(x)$:

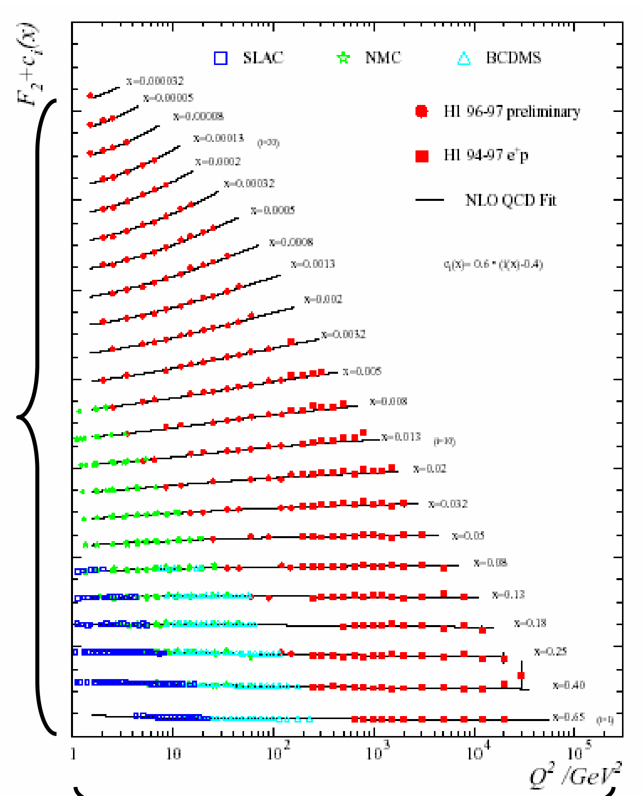
$\Delta q(x) =$  - 

Introduction

- Quantum Chromodynamics (DGLAP fits of F_2 and g_1 data)
  - NLO evolution according to DGLAP integro-differential equations:

⇨ F_2 results:

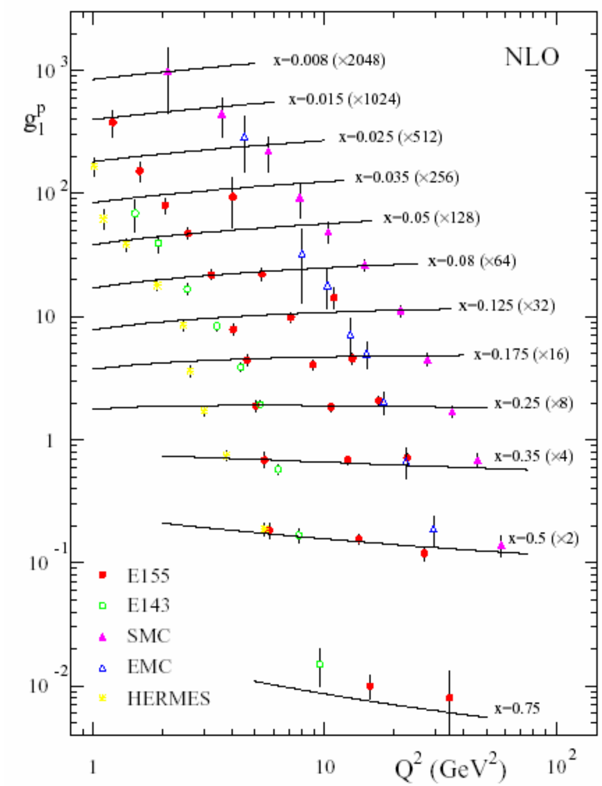
4 orders of magnitude in x!



4 orders of magnitude in Q^2!

- Good description of F_2/g_1 data by NLO DGLAP fits!
- HERA collider data extended kinematic region towards larger Q^2 and low x for F_2 (scaling violation clearly seen!)
- g_1 limited by fixed target data at low Q^2 and high x

⇨ g_1 results:



Limited range in x and Q^2!

Introduction

Quantum Chromodynamics (General structure of $W^{\mu\nu}$)

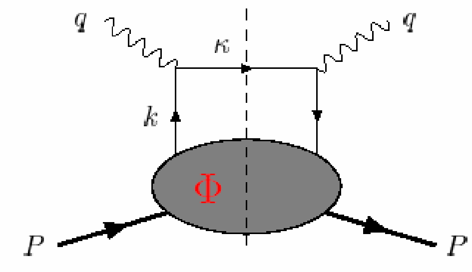
- Considered so far only fully inclusive DIS: f(x) and Δf(x) are accessible!
- General leading-twist structure of the proton (collinear approximation):

⇨ Leading-twist structure of proton in collinear approximation in terms of:

$$W^{\mu\nu} = \sum_q e_q^2 \int \frac{d^4k}{(2\pi)^4} \delta\left((k+q)^2\right) \mathrm{Tr}\left[\Phi \gamma^\mu (\not{k} + \not{q}) \gamma^\nu\right]$$

quark-quark correlation matrix:

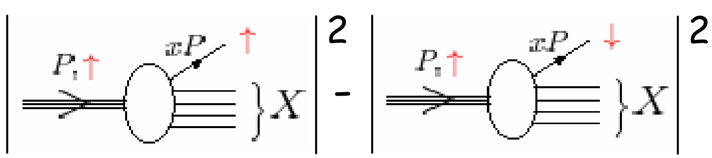
$$\Phi = \frac{1}{2}\left\{ f(x)\not{P} + \lambda_N \Delta f(x) \gamma_5 \not{P} + \delta f(x) \not{P} \gamma_5 \not{S}_\perp \right\}$$



Handbag diagram

Unpolarized long. Polarized (Helicity) trans. Polarized (Transversity) distribution functions!

- Transversity cannot be probed in fully inclusive DIS (Helicity conservation, δf is chiral odd), but in hadron-hadron collisions or semi-inclusive lepto-production (Pair of chiral odd effects required, e.g. $k_\perp$- dependent Collins fragmentation ⊗ δf)
- Additional distribution functions appear with inclusion of:
  - Quark transverse momentum $k_\perp$: six $k_\perp$ - dependent distribution functions (leading twist)
  - Higher twist

δq(x) =


Introduction

RHIC Spin program (e.g. ΔG)

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

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

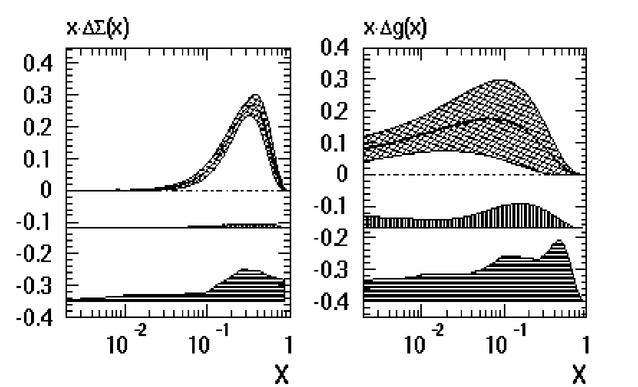
⇨ SMC result: Fraction of proton spin carried by quarks is small:

$$\Delta\Sigma_{(AB)} = 0.38^{+0.03+0.03+0.03}_{-0.03-0.02-0.05} \text{ at } Q^2 = 1\text{GeV}^2$$

⇨ Where is the spin of the proton then?

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

⇨ SMC QCD-fit:



- At present: ΔG is only poorly constrained from scaling violations in fixed target DIS experiments

$$\Delta G_{(AB)} = 0.99^{+1.17+0.42+1.43}_{-0.31-0.22-0.45} \text{ at } Q^2 = 1\text{GeV}^2$$

SMC, Phys. Rev. D58 (1998) 112002.

- Need: New generation of experiments to explore the spin structure of the proton: polarized proton collisions at RHIC which allows to access directly ΔG in polarized pp collisions!

RHIC spin program:

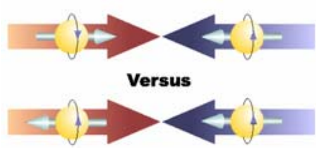
- Unique multi-year program which has just started...!
- Explore various aspects of the spin structure of the proton in a new domain:
  - ⇨ Spin structure of the proton (gluon polarization, flavor decomposition, transversity)
  - ⇨ Spin dependence of fundamental interactions
  - ⇨ Spin dependence of fragmentation
  - ⇨ Spin dependence in elastic polarized pp collisions

Introduction

Asymmetries

- Measurement of asymmetries (A): Principle approach to study spin effects
- Ultimately at RHIC, any combination of beam polarization (longitudinal (+/-) /transverse (↑/↓)) is possible, which allows to access different parts of the proton spin structure

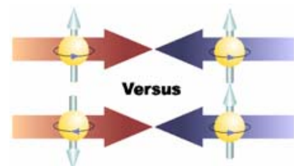
- Double longitudinal-spin asymmetry:



$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

⇨ Study helicity dependent structure functions!

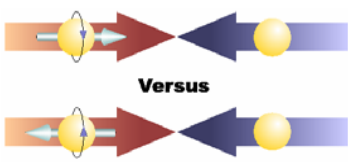
- Double transverse-spin asymmetry:



$$A_{TT} = \frac{(\sigma_{\uparrow\uparrow} - \sigma_{\downarrow\downarrow}) - (\sigma_{\uparrow\downarrow} + \sigma_{\downarrow\uparrow})}{(\sigma_{\uparrow\uparrow} + \sigma_{\downarrow\downarrow}) + (\sigma_{\uparrow\downarrow} + \sigma_{\downarrow\uparrow})}$$

⇨ Study transverse dependent structure functions!

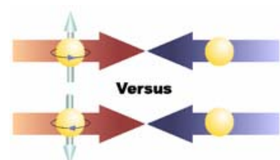
- Single longitudinal-spin asymmetry:



$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

⇨ Study parity violation effects!

- Single transverse-spin asymmetry:



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

⇨ Study left/right asymmetries!

- Statistical significance (FOM=figure-of-merit):

⇨ Single spin asymmetry: $^2 \cdot \int Ldt$

⇨ Double spin asymmetry: $P^4 \cdot \int Ldt$

Introduction

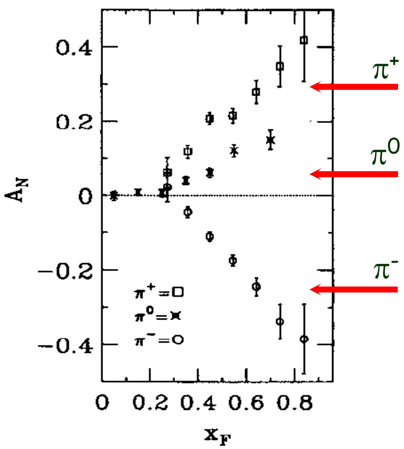
Experimental and theoretical remarks on A_N

- 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

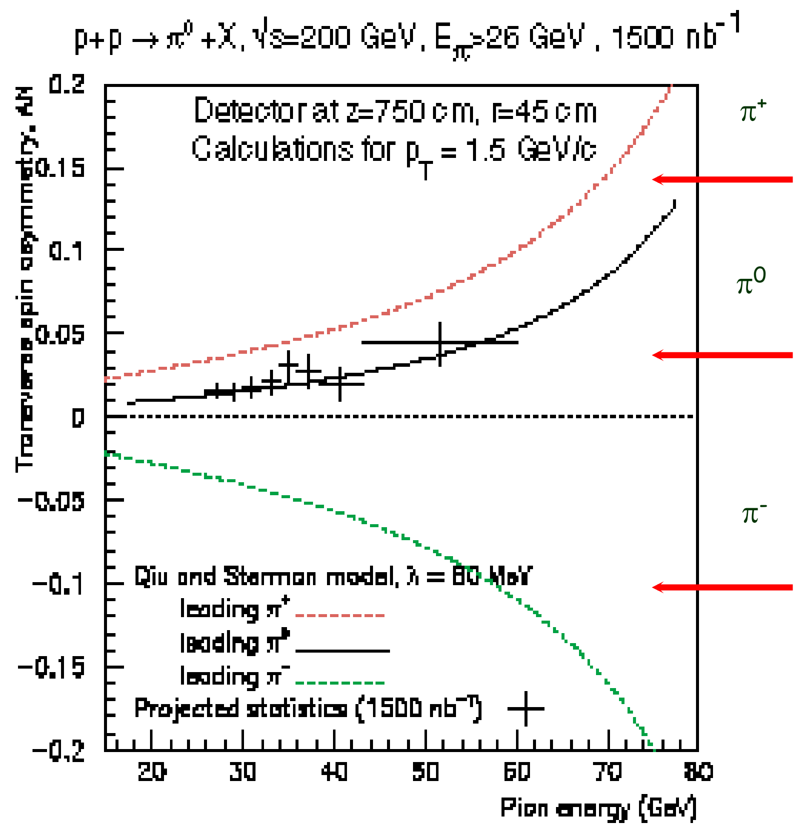
A_N E704 data



- 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



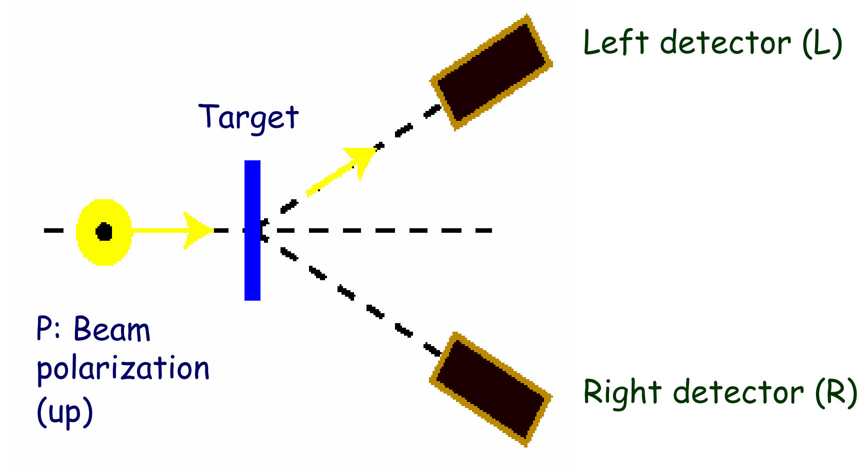
Introduction

Measurement of A_N

- Measurement of A_N for forward π^0 production:

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

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

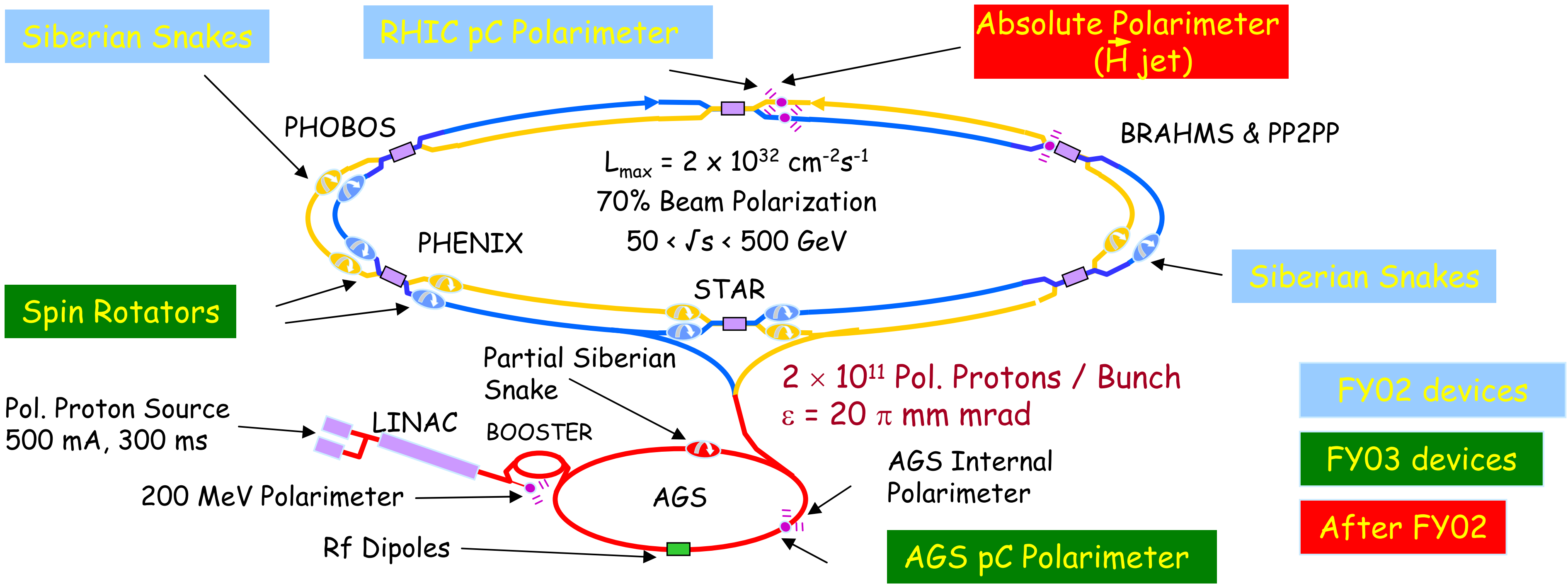
- Determination of A_N requires three measurements:
  1. Spin dependent event yield: $N_{\uparrow(\downarrow)}$
  2. Relative luminosity: $R=L_\uparrow/L_\downarrow$
  3. Beam polarization: P

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

- Reconstruction of $\pi^0 \rightarrow \gamma\gamma$ requires three basic measurements:
  1. Total π^0 energy: E_{tot}
  2. Energy sharing between two daughter photons: z_γ
     $z_\gamma=(E_{\gamma1} - E_{\gamma2})/(E_{\gamma1} + E_{\gamma2})$
  3. Opening angle between two daughter photons: $\Theta_{\gamma\gamma}$

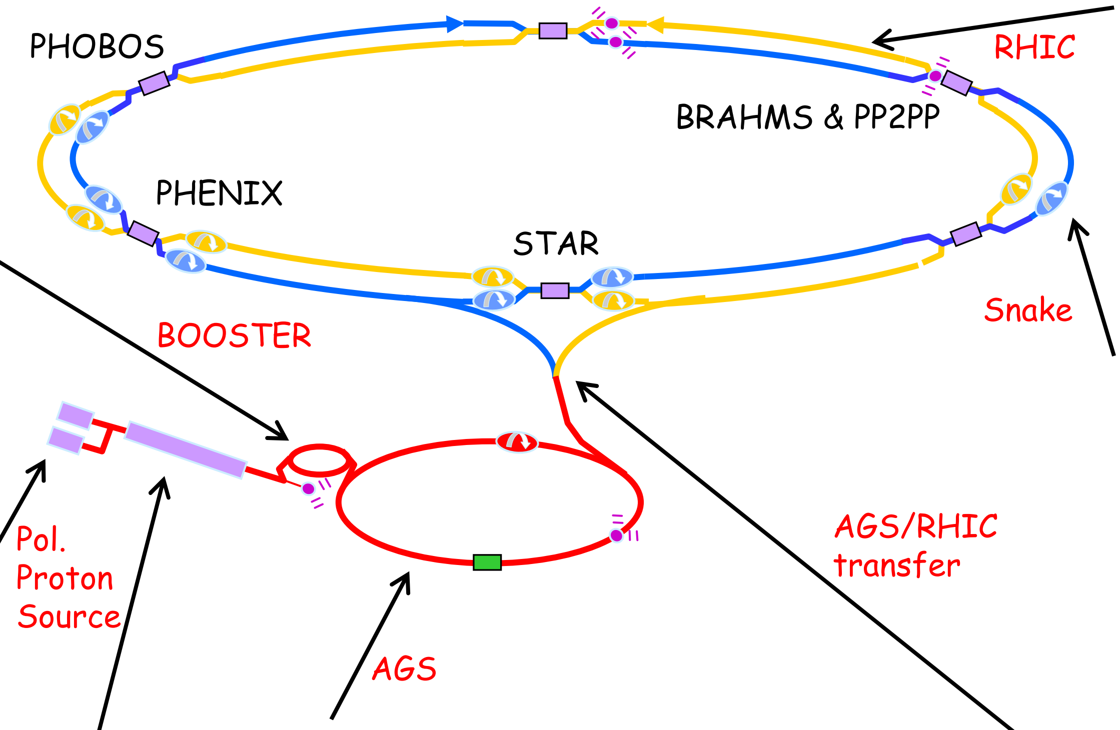
$$M_{\gamma\gamma} = E_{tot} \cdot \sqrt{1 - z_\gamma^2} \cdot \sin^2(\Theta_{\gamma\gamma}/2)$$

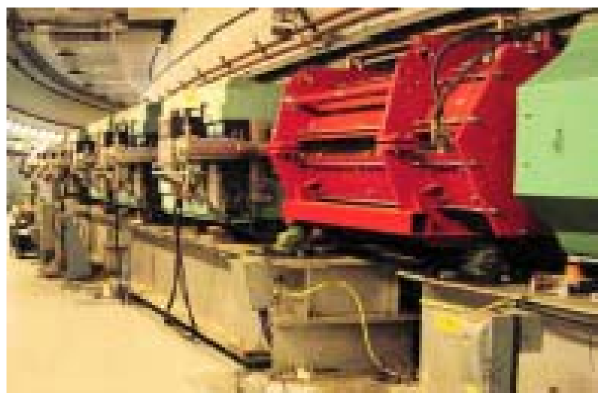
RHIC: Polarized pp facility

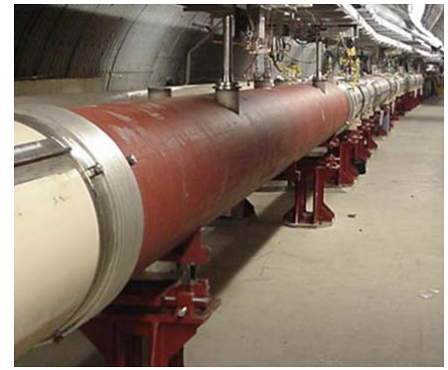


- RHIC performance in FY02:
  - ⇨ Beam energy: 100 GeV
  - ⇨ Inst. luminosity: ~ 1 • 10^{30} s^{-1} cm^{-2}
  - ⇨ Integrated luminosity: ~ 0.3pb^{-1}
  - ⇨ Bunch crossing time: 213ns
  - ⇨ Polarization: ~ 0.2 at injection approximately maintained at 100GeV (transverse)
- Expected RHIC performance in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

RHIC: Polarized pp facility

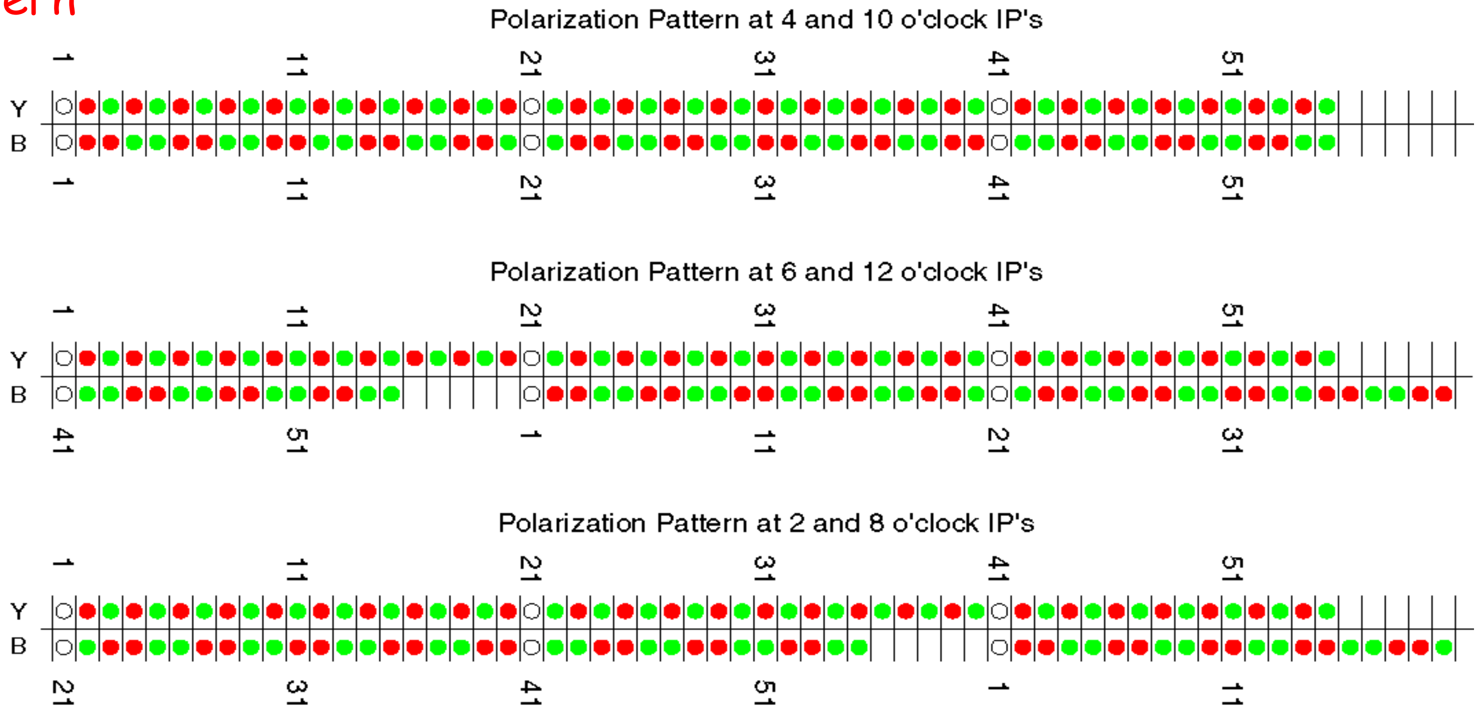






RHIC: Polarized pp facility

- Spin pattern

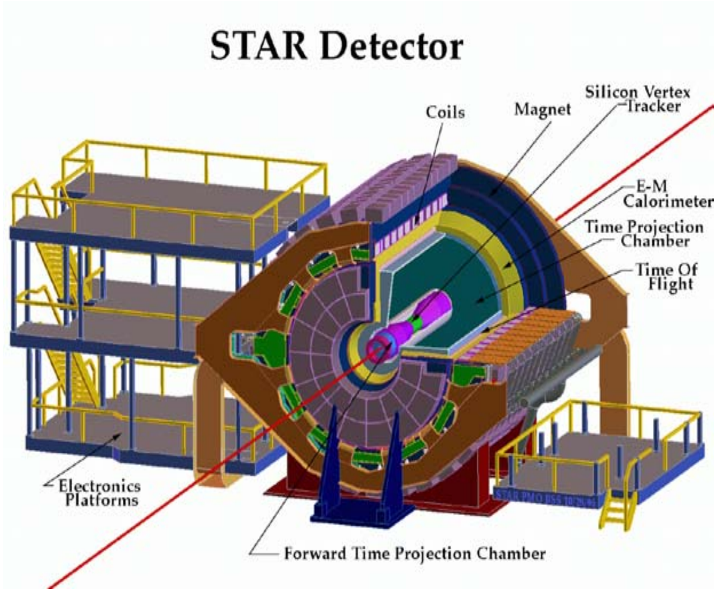


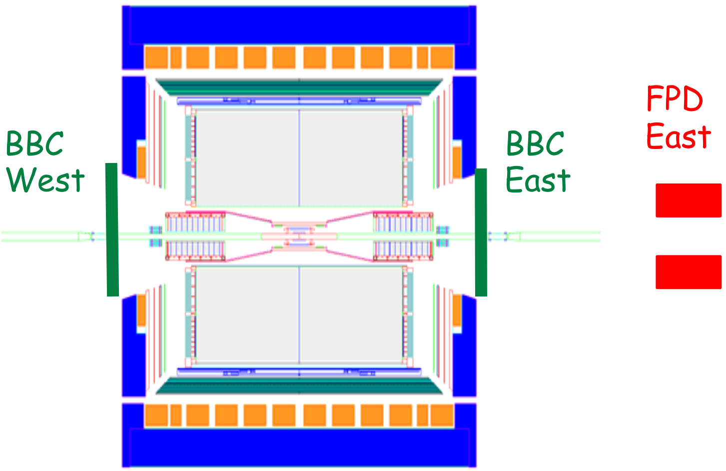
- Spin Up
- Spin Down
- Unpolarized

- Different spin combination every 214 ns
  ⇒ reduce systematic errors
- ~47 polarization reversals before RHIC injection
- Because of snake magnets, same bunch has opposite polarization at IP6 and IP12
  ⇒ 5×10^9 polarization reversals in RHIC for a ~10 hour store

- Requires extremely careful timing adjustments for both RHIC and experiments
- Essential to sort all data by which bunch pair interacts at experiments

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

STAR

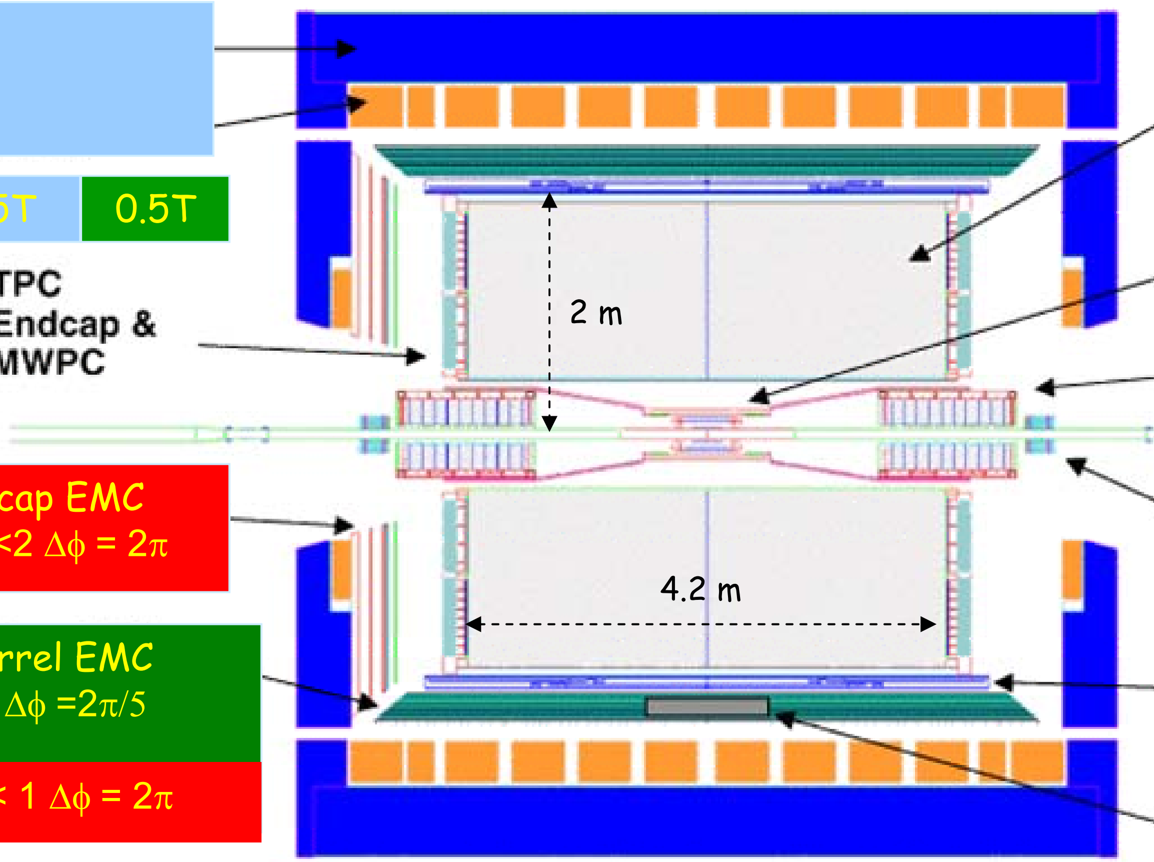
STAR Spin | Before FY02 | FY02 | FY03 and beyond

Magnet Coils

B=0.25T | 0.5T

TPC Endcap & MWPC

ZCal



Endcap EMC
$1 < \eta < 2$ $\Delta\phi = 2\pi$

Barrel EMC
$0 < \eta < 1$ $\Delta\phi = 2\pi/5$
$|\eta| < 1$ $\Delta\phi = 2\pi$

Time Projection Chamber $|\eta| < 1.5$

Silicon Vertex Tracker

Forward TPCs
$2.4 < |\eta| < 4.0$

Vertex Position Detectors

Central Trigger Barrel $|\eta| < 1$
TOF patch

RICH: $|\eta| < 0.3$, $\Delta\Phi = \pi/6$

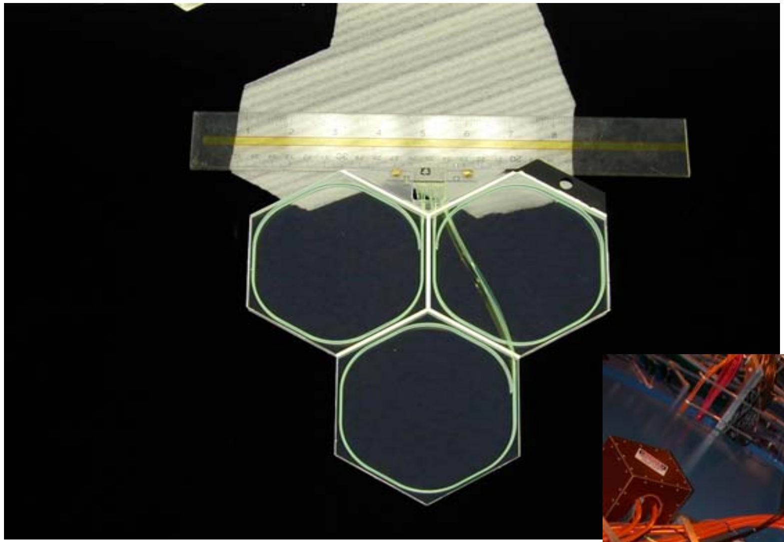
$$\eta = -\ln\left[\tan(\theta/2)\right]$$

Forward Pion Detector $3.1 < \eta < 4.4$

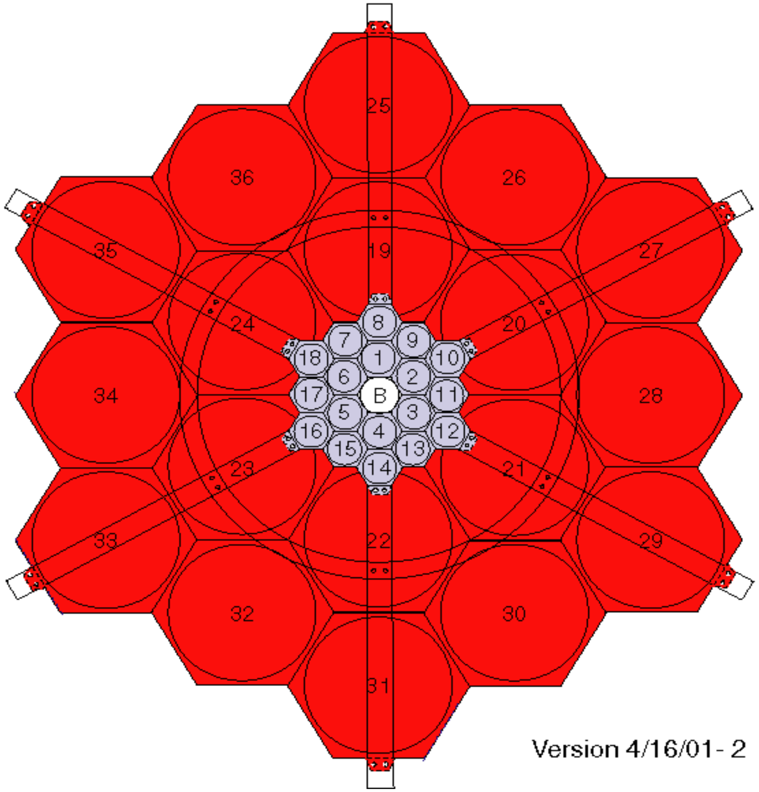
Beam-Beam Counters
$2 < |\eta| < 5$

STAR

- STAR Beam-Beam Counter (BBC)



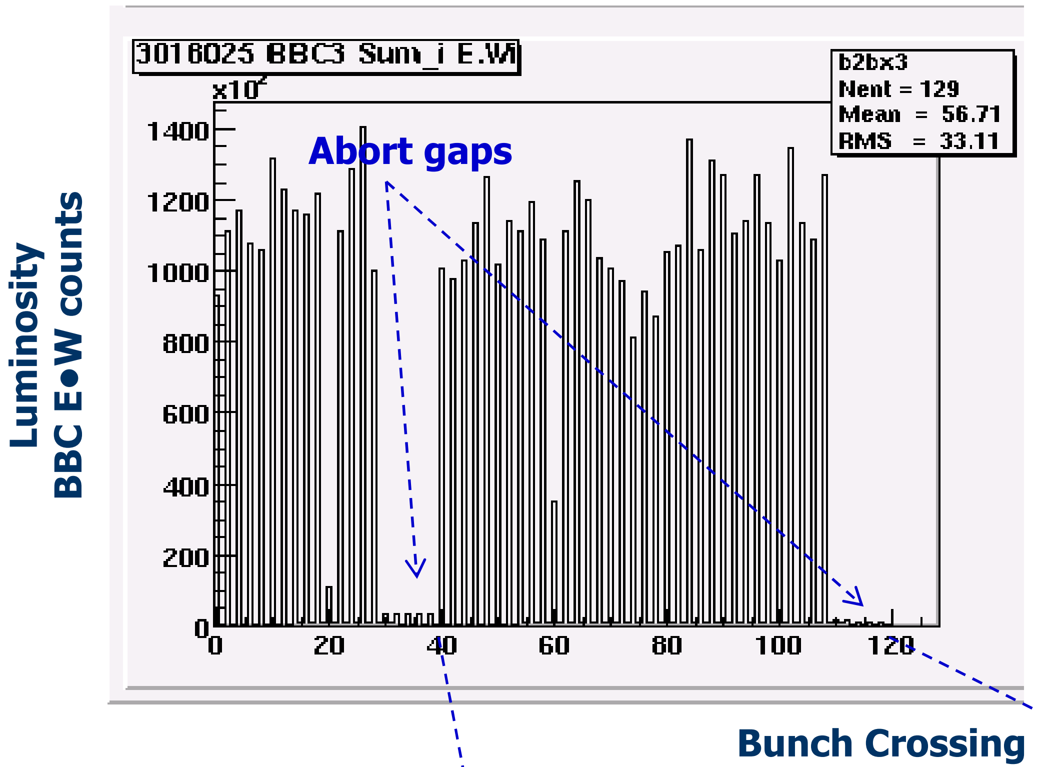
- Hexagonal scintillator array structure at ±3.5m from IP:
  - ⇨ Inner annulus: inner (outer) diameter 9.6cm (48cm) of 18 pixels
  - ⇨ Outer annulus: inner (outer) diameter 38cm (193cm) of 18 pixels

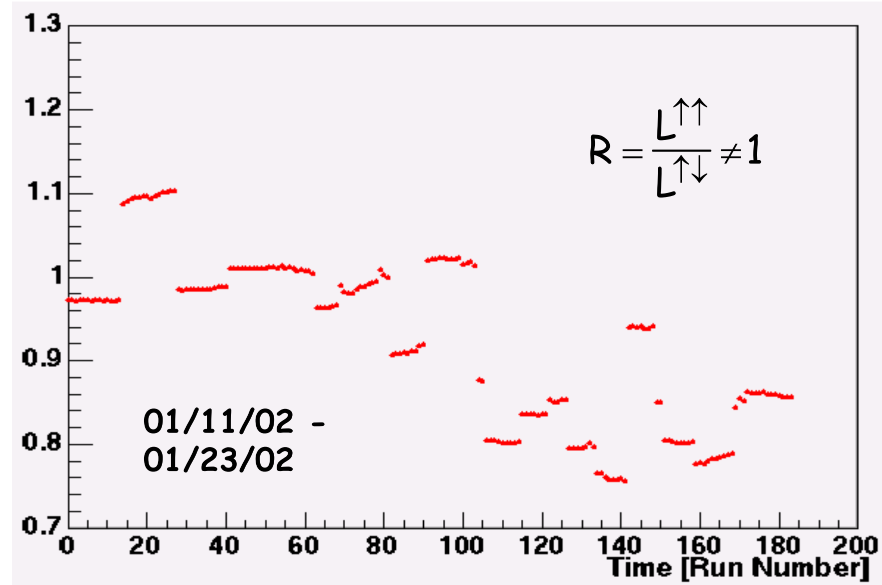


- Singe scintillator tile:
  - ⇨ 1 cm thick scintillator
  - ⇨ 4 optical fibres for light collection
  - ⇨ ~ 15 photoelectron/MIP

STAR

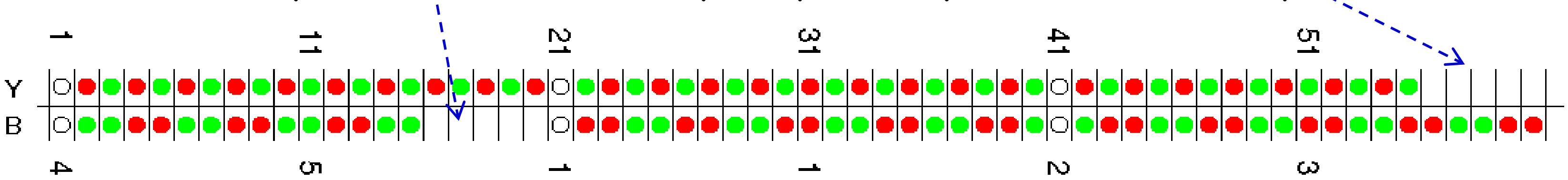
- STAR BBC luminosity monitoring





- Determine relative luminosity of bunch crossings with different polarization directions
- Abort gaps ⇒ beam-gas background

Polarization pattern at STAR: Spin Up ● Spin Down ● Unpolarized ○



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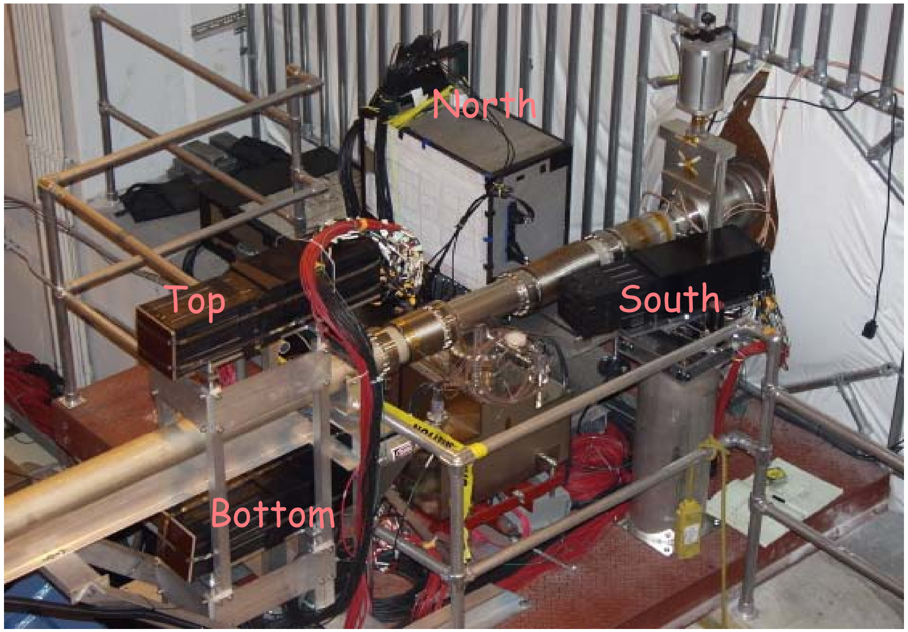
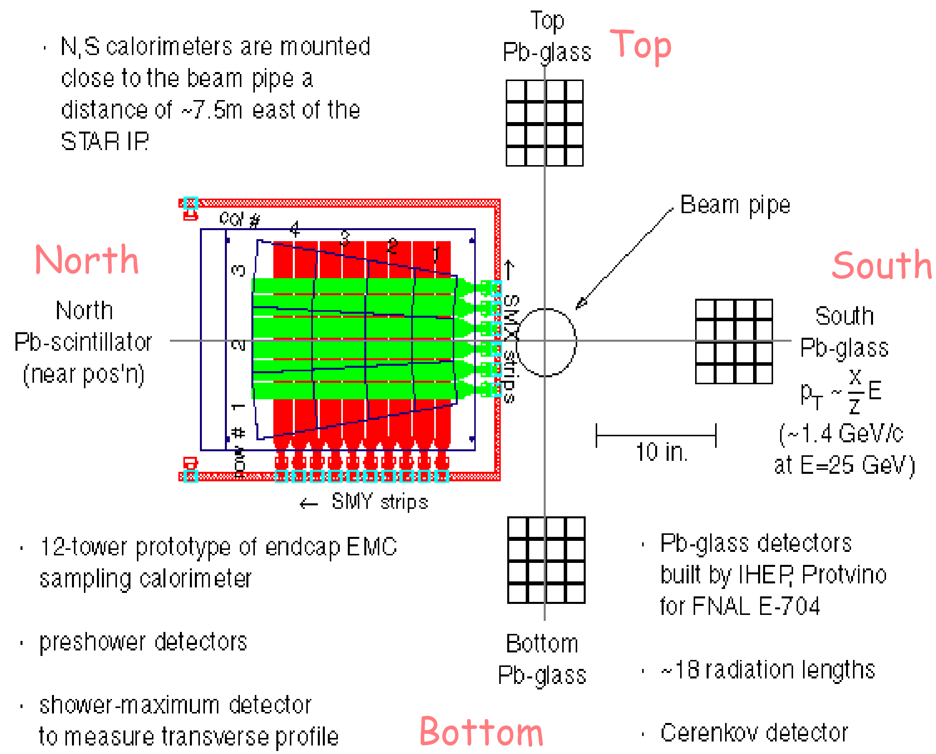
- Forward-Pion Detector (FPD)

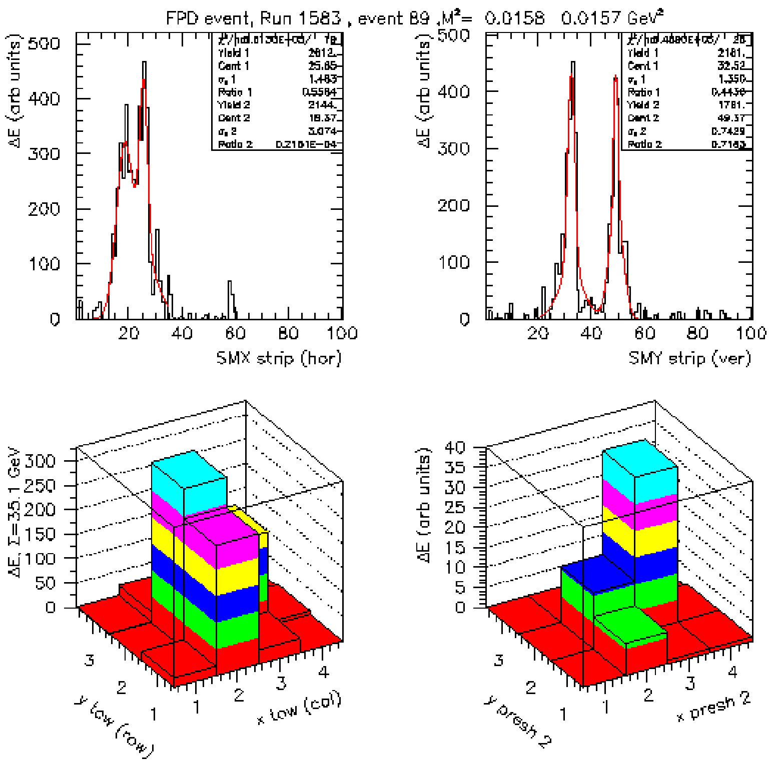




- N,S calorimeters are mounted close to the beam pipe a distance of ~7.5m east of the STAR IP.
- 12-tower prototype of endcap EMC sampling calorimeter
- preshower detectors
- shower-maximum detector to measure transverse profile
- extensively tested at SLAC
- Pb-glass detectors built by IHEP, Protvino for FNAL E-704
- ~18 radiation lengths
- Cerenkov detector

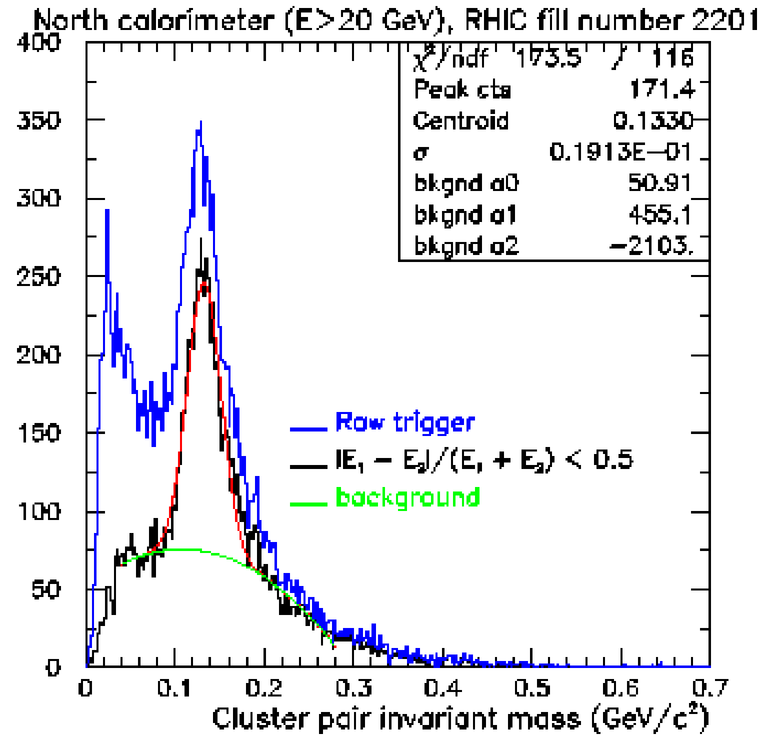
STAR

- Measurement of forward π^0 production at RHIC



Transverse shower profile response of shower maximum detector

Calorimeter and Preshower detector response

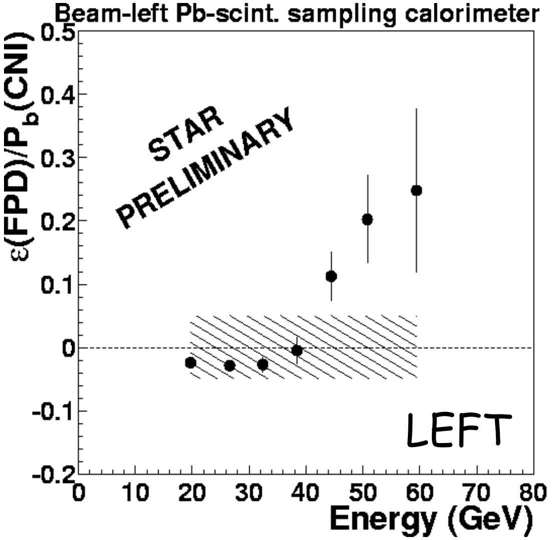


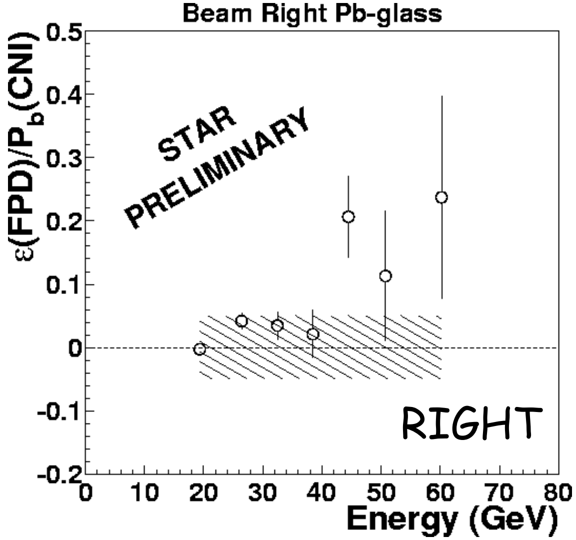
⇨ Cluster separation in shower maximum detector and measured calorimeter energy serves as input to the π^0 mass determination!

⇨ Clearly identified π^0 mass peak!

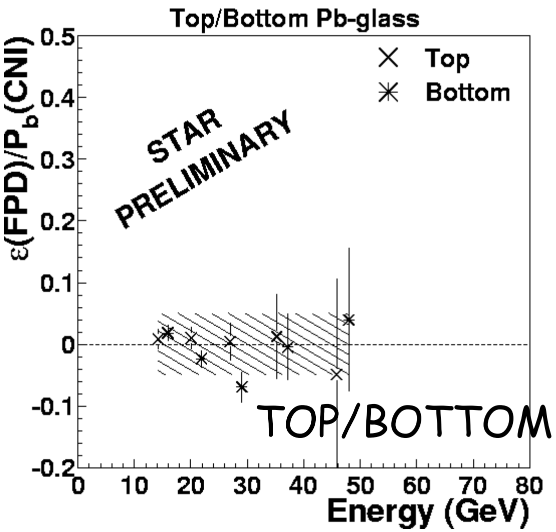
First results (STAR)

- FPD Asymmetry results:





LEFT = RIGHT as expected for vertical polarization!

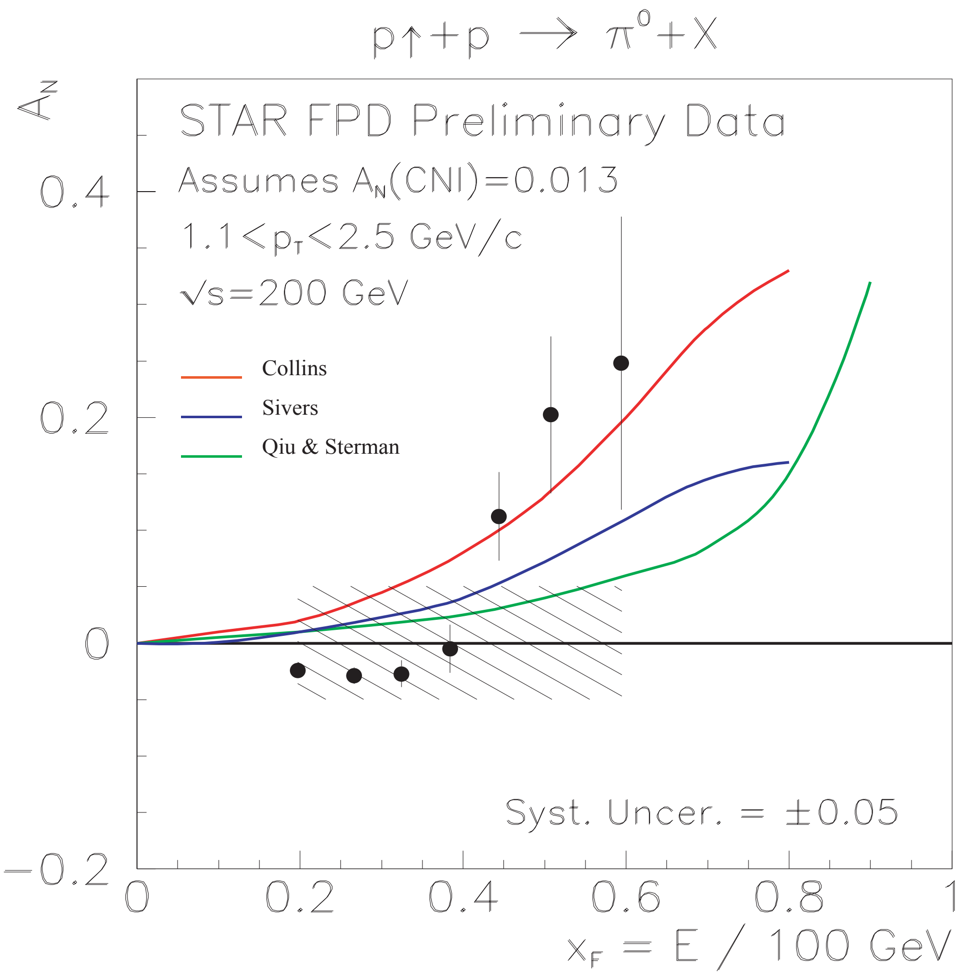


Top = Bottom = 0 as expected for vertical polarization!

Assuming A_N(CNI)=0.013 (25 GeV) at 100 GeV!

First results (STAR)

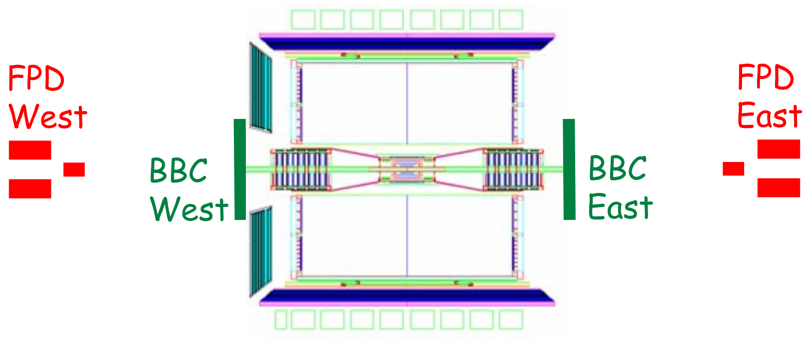
- First measurement of A_N for forward π^0 production at RHIC

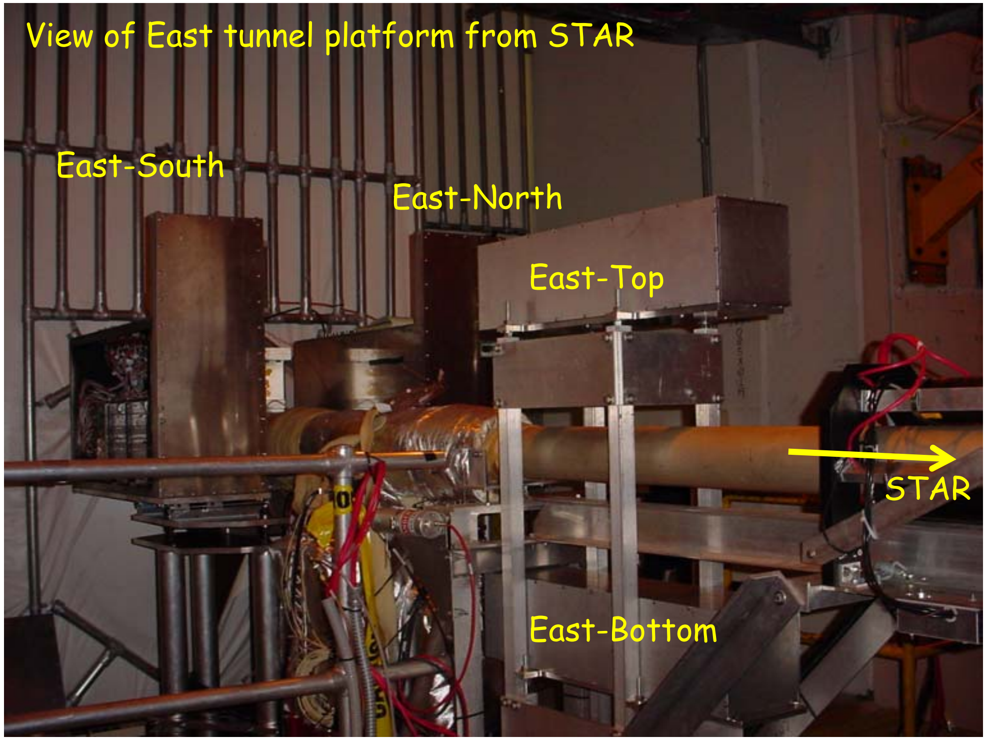


- Several approaches beyond the basic "naive QCD calculations" yield non-zero A_N values at RHIC energies:
  - ⇨ Sivers: include intrinsic transverse component, $k_\perp$, in initial state (before scattering takes place)
  - ⇨ Collins: include intrinsic transverse component, $k_\perp$, in final state (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

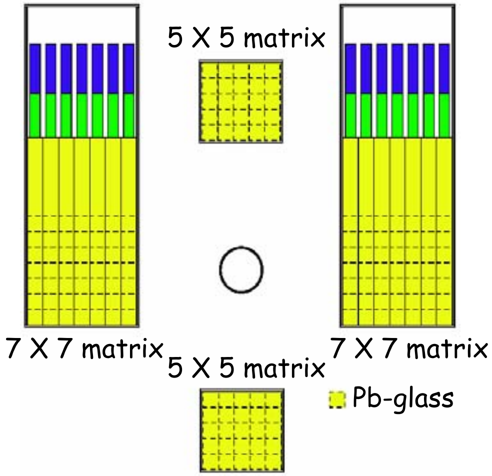
STAR

■ FPD upgrade





- Physics motivation:
  - A_N measurement for $\vec{p}+p \rightarrow \pi^0 + X$ expect FOM to increase by factor 40!
  - Tuning of STAR spin rotator (Local polarimeter)
  - Gluon density in heavy nuclei: $d + Au \rightarrow \pi^0 + X$

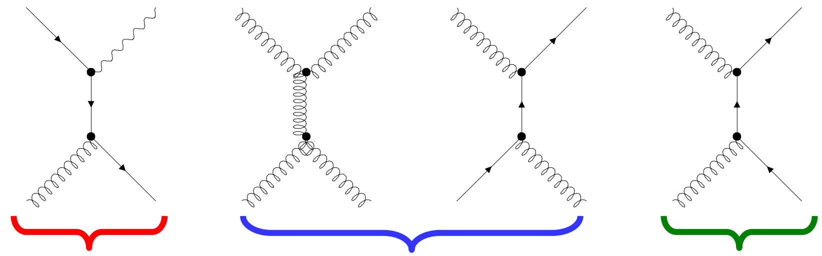


- Acceptance:
  - Forward rapidity: $3 < \eta < 4$
  - High x_F: $x_F > 0.2$
  - Moderate p_T: $1 < p_T < 4$ GeV

STAR

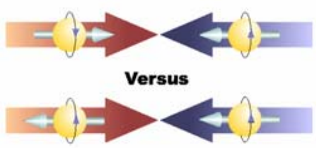
Access ΔG in polarized pp collisions

- ΔG sensitivity in polarized pp collisions
  - ⇨ High-p_T (prompt) photon production
  - ⇨ Jet production
  - ⇨ Heavy-flavor production



$\vec{p}\,\vec{p} \rightarrow \gamma\, X$ | $\vec{p}\,\vec{p} \rightarrow \mathrm{jet}(s)\, X$ | $\vec{p}\,\vec{p} \rightarrow c\bar{c}X, b\bar{b}X$

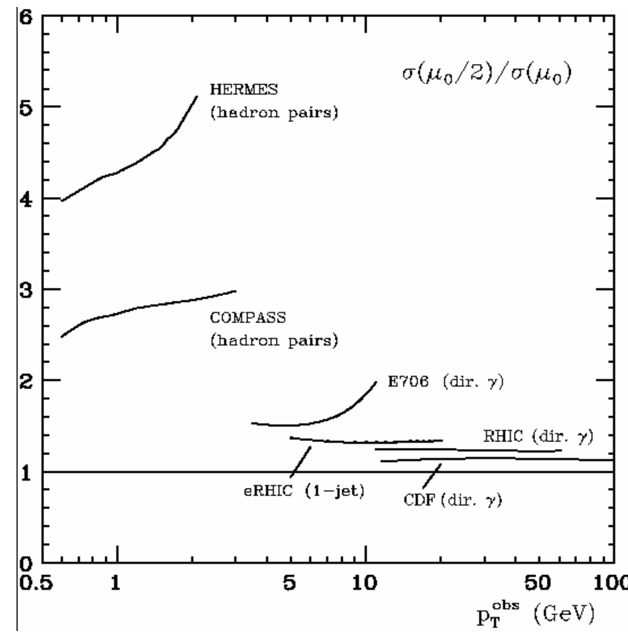
- Access ΔG: Double longitudinal-spin asymmetry A_{LL}



$$A_{LL} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

⇨ Study helicity dependent structure functions!

- Theoretical advantage of RHIC:



W. Vogelsang, M. Strattmann

⇨ Smaller scale dependence at RHIC compared to HERMES/COMPASS!

- Measurement of A_{LL} requires:

$$A_{LL} = \frac{1}{P_1 P_2} \cdot \frac{N_+ - RN_-}{N_+ + RN_-}$$

$$\delta A_{LL} = \frac{1}{P_1 P_2} \cdot \sqrt{\frac{1-(P_1 P_2 A_{LL})^2}{N_+ + RN_-}}$$

1. $N_{+(-)}$: Spin dependent event yield
2. R: Relative luminosity
3. P: Beam polarization

- FOM (= Figure-Of-Merit):

⇨ A_N/A_L: $P^2 \cdot \int Ldt$ ⇨ A_{LL}/A_{TT}: $P^4 \cdot \int Ldt$

The golden channel at RHIC: Quark-Gluon Compton scattering

- A_{LL} for QGC scattering interpreted in LO QCD: $gq \rightarrow \gamma g$

$$A_{LL} \cong \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}_{LL}^{(g+q\rightarrow\gamma+q)}(\cos\vartheta^*)$$

Gluon polarization

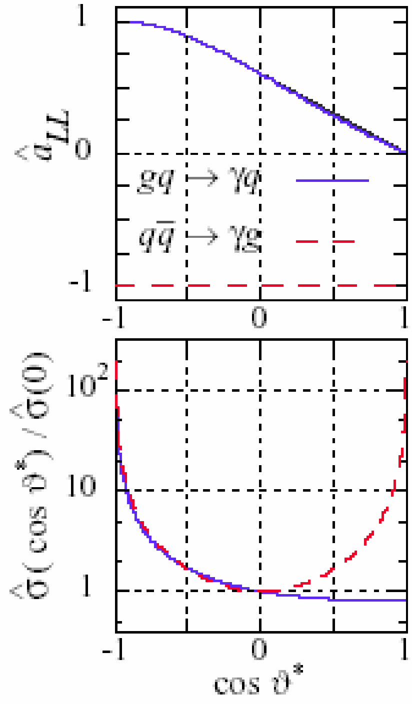
Measured asymmetry from polarized DIS

pQCD result for QGC scattering

⇨ Note: QGC scattering dominates over competing background process: $q\bar{q} \rightarrow \gamma g$

⇨ Polarized cross-section is strongly peaked when photon is emitted in direction of incident quark

⇨ Best determination of ΔG for: final-state photon || to initial-state quark



- Reconstruction of initial-state partonic kinematics:

⇨ Event-by-event determination of $p_{T,\gamma}$ (photon energy), η_γ (photon direction) and η_{jet} (jet direction) allows to reconstruct:

$$x_{1(2)} \cong \frac{p_{T,\gamma}}{\sqrt{s}}\left(e^{\pm\eta_\gamma} + e^{\pm\eta_{\mathrm{jet}}}\right)$$

$$x_q^{recon} = \max[x_1, x_2]$$

$$x_g^{recon} = \min[x_1, x_2]$$

⇨ Large x quark (large quark polarization) analyzes small-x gluons (gluon-rich)

⇨ Asymmetric QGC scattering (forward boost in direction of incident quark)

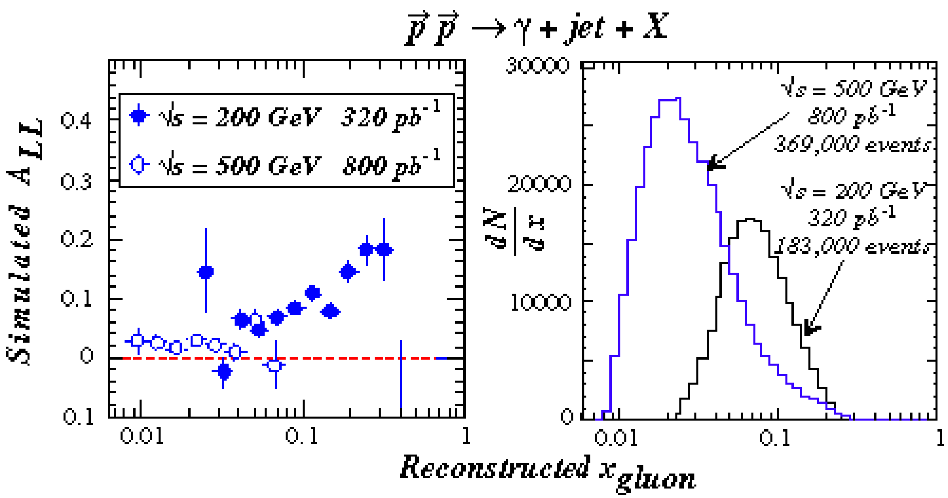
- Background:

⇨ $\pi^0(\eta^0) \rightarrow \gamma\gamma$: $\pi^0(\eta^0)/\gamma$ discrimination needed

⇨ Isolation cone requirement

Quark-Gluon Compton scattering: Prospects at STAR

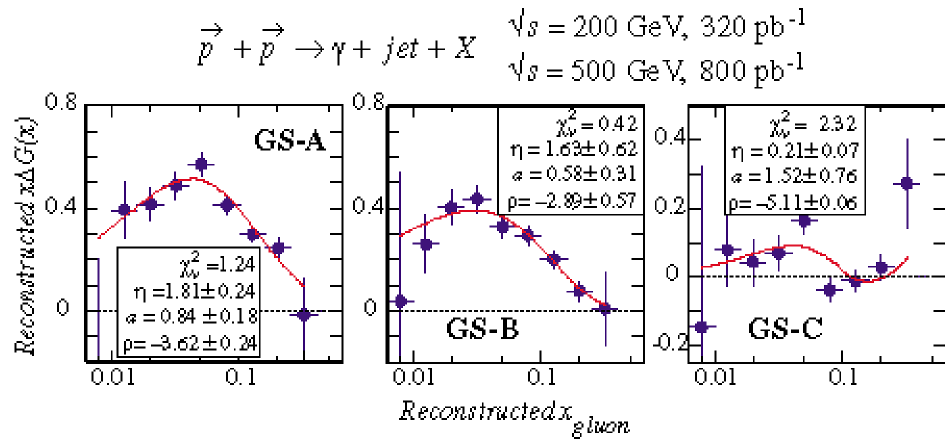
- Simulated A_{LL} at two different RHIC center-of-mass energies:



⇨ Multi year program at RHIC which requires:

1. High luminosity
2. High polarization
3. $\sqrt{s}$ = 200 / 500GeV

$$A_{LL} \cong \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}_{LL}^{(g+q\rightarrow\gamma+q)}(\cos\vartheta^*)$$



⇨ Combined data sample at 200 GeV and 500 GeV is essential to minimize extrapolation errors in determining ΔG:

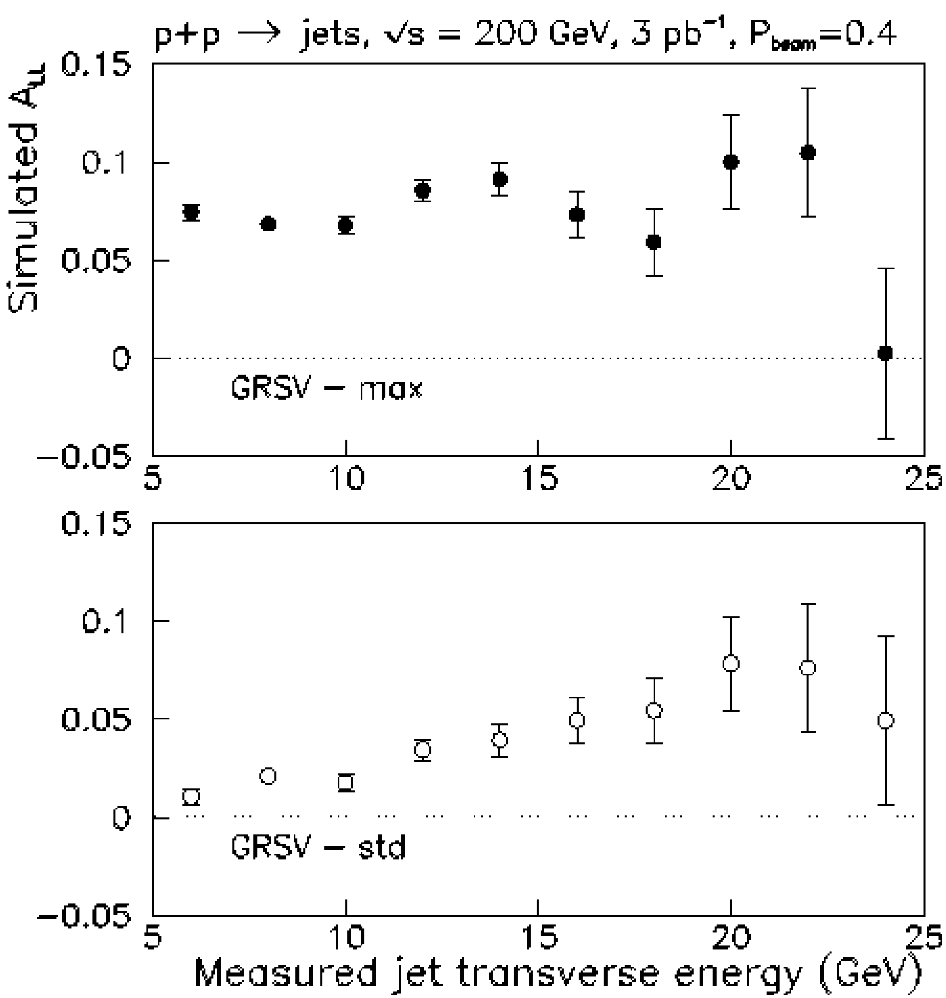
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)\,dx$$

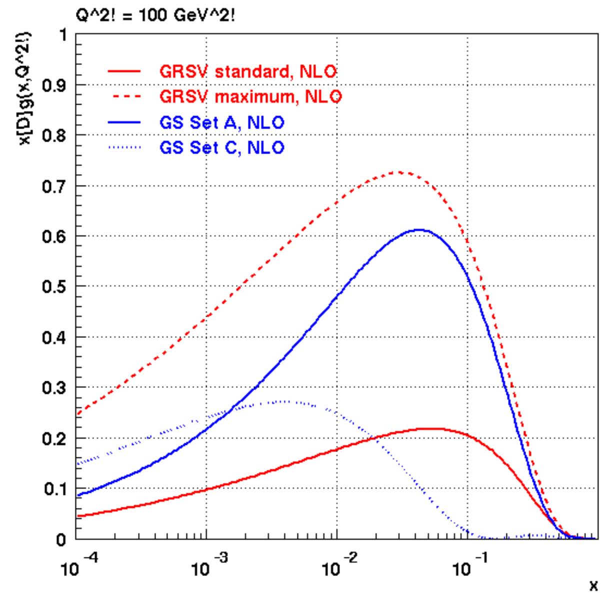
Accuracy: 0.5

⇨ Ultimately: Global analysis of various ΔG!

STAR

- Prospects on constraining ΔG from inclusive jet production in RUN III





- Simulation based on Pythia including trigger and and jet reconstruction efficiencies
- Assume: Coverage of EMC (barrel) ⇨ $0 < \Phi < 2\pi$ and $0 < \eta < 1$
- Jet Trigger: $E_T > 5$ GeV over at least one "patch" $(\Delta\eta = 1) \times (\Delta\Phi = 1)$
- Jet reconstruction: Cone algorithm (seed = 1GeV, R = 0.7)

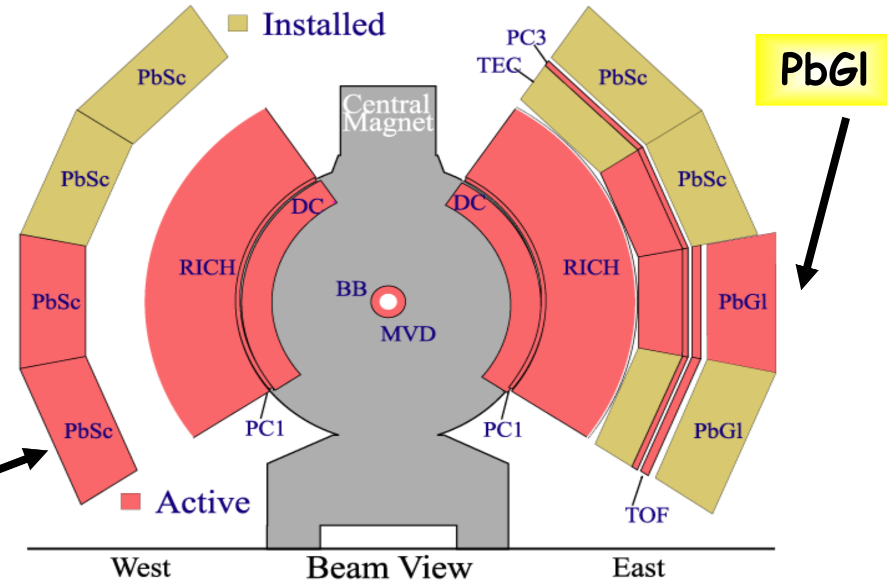
(B.S. at SPIN 2002)

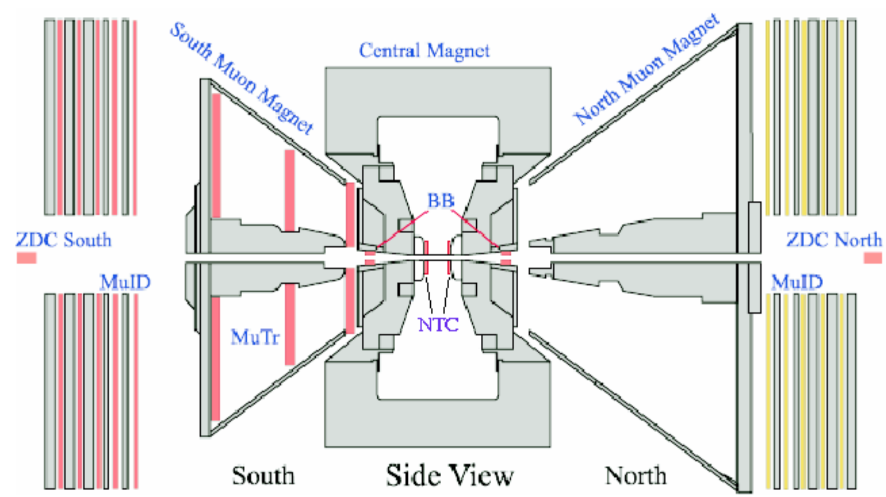
PHENIX

- **Status during the first pp run**
  - Commissioning of spin scaler system and relative luminosity monitor
  - Calorimeter components
    - Lead Scintillator (PbSc)
      - 6 sectors (15552 channels)
    - Lead Glass (PbGl)
      - 2sectors (9216 channels)
  - Calorimeter coverage
    - $|\eta| < 0.38$
    - $\phi = 180°$
  - First run coverage:
    - $\phi = 45° + 90°$ are active
      - 2 sectors PbSc
      - 1 sector PbGl

⇨ Crucial component for the first π^0 production cross-section measurement in polarized pp collisions!

PbSc



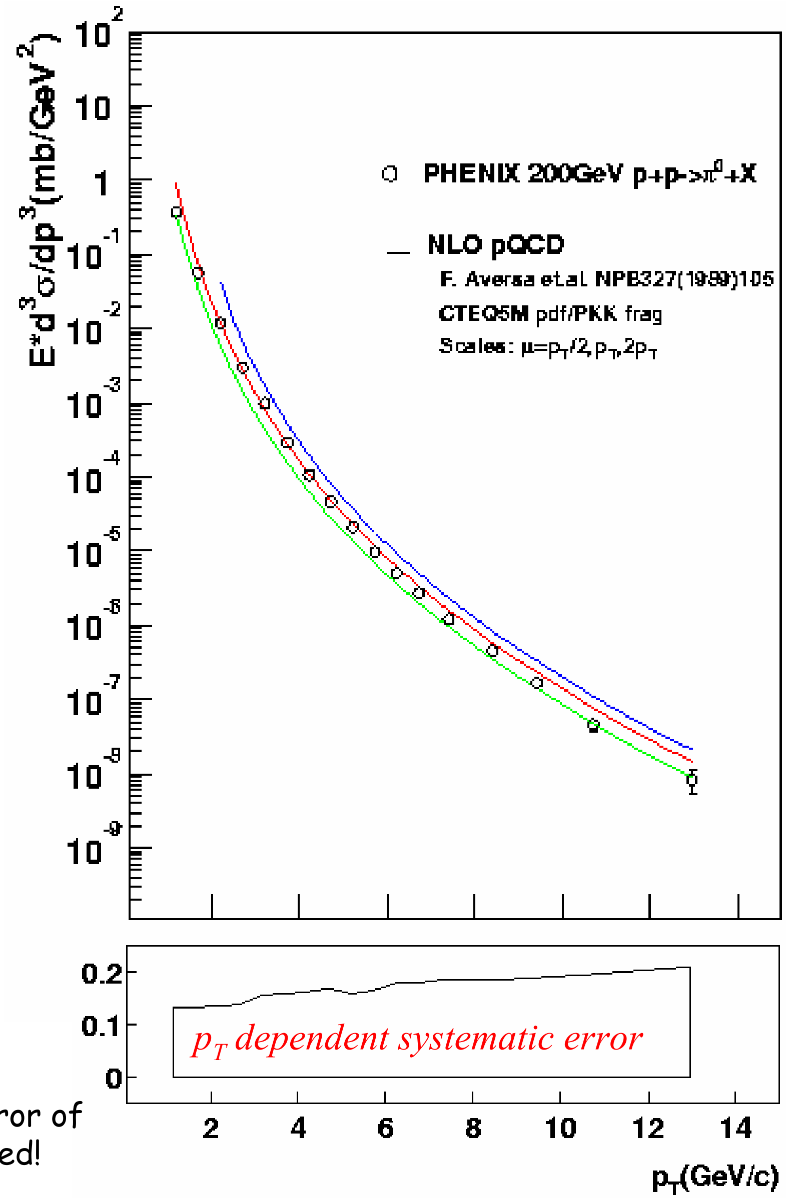


First results (PHENIX)

- PHENIX π^0 production cross section
  - Data covers over 8 orders of magnitude
    - $p_T = 1 - 13$ GeV/c
    - based on combining minimum bias trigger and EMCal trigger data
  - NLO pQCD calculation is consistent with data
    - CTEQ5M PDF + PKK FF
    - with a scale variation: $\mu = p_T/2$ and $2p_T$

⇨ Confidence in understanding subprocesses

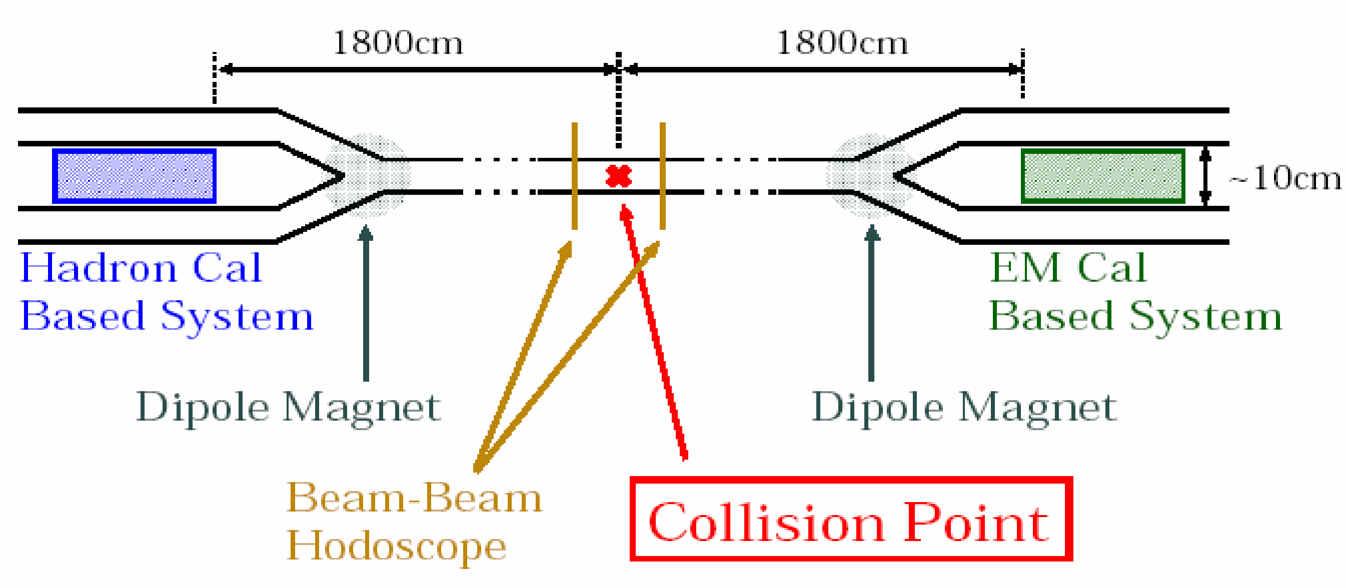
⇨ Solid basis for future polarized pp asymmetry measurements

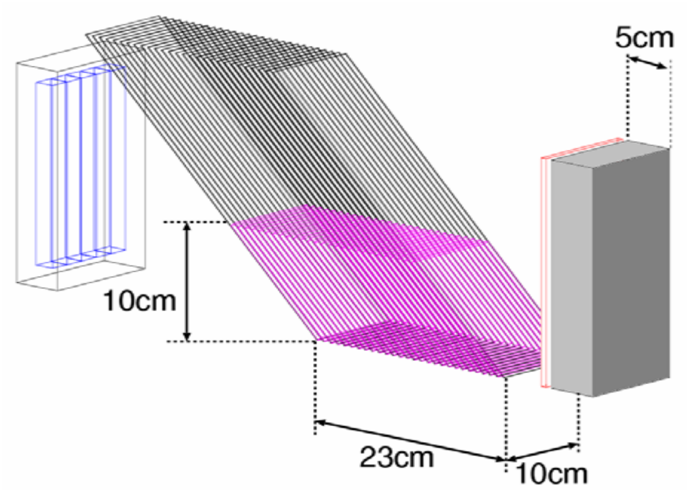


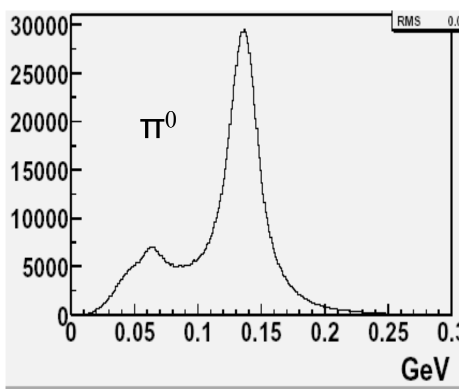
Normalization error of 30% is not included!

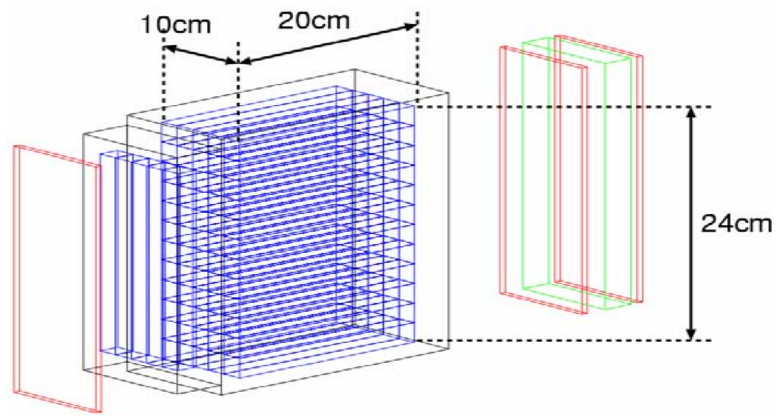
PHENIX

- Local polarimeter development: IP12 ⇨ PHENIX test setup



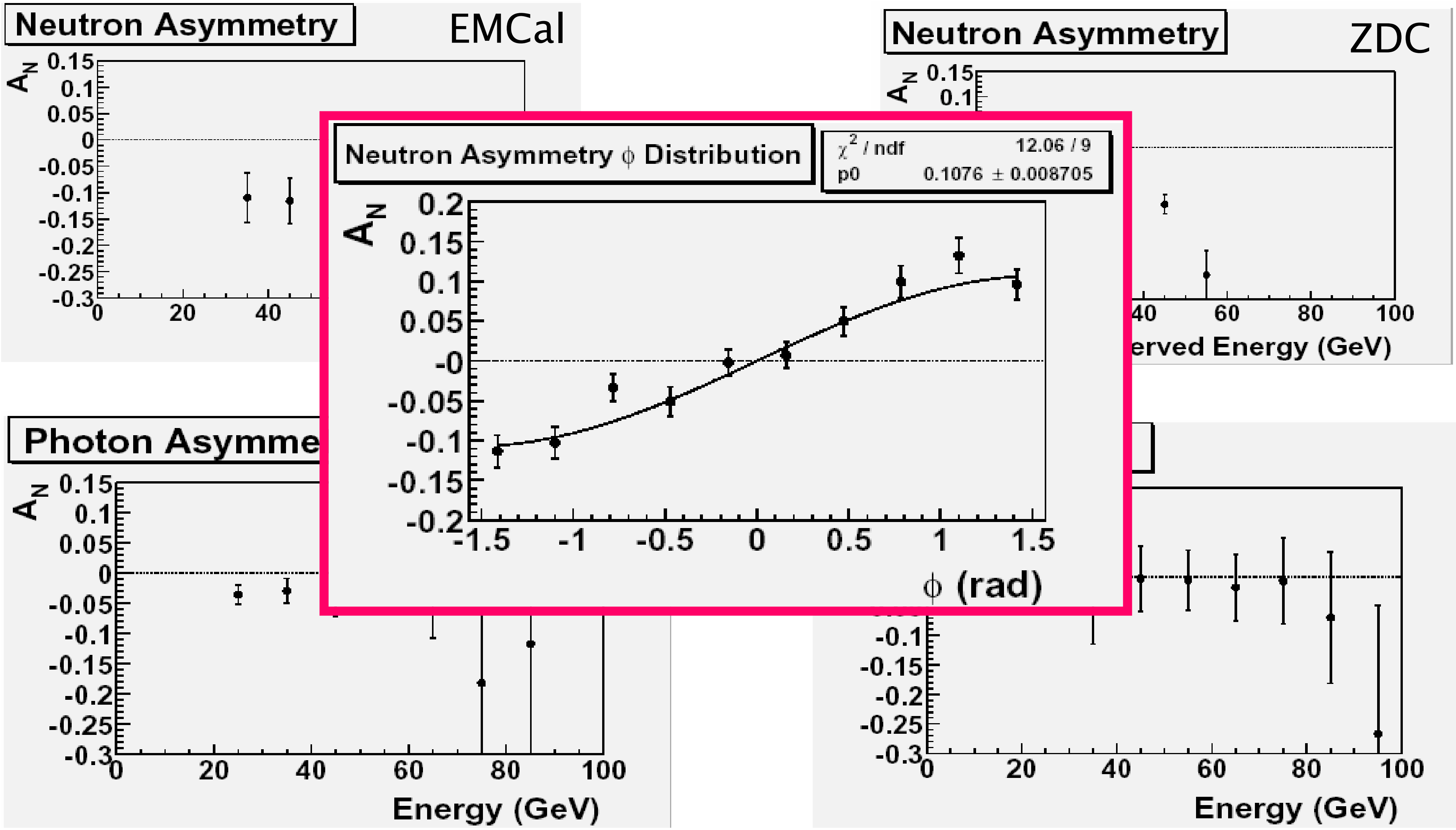






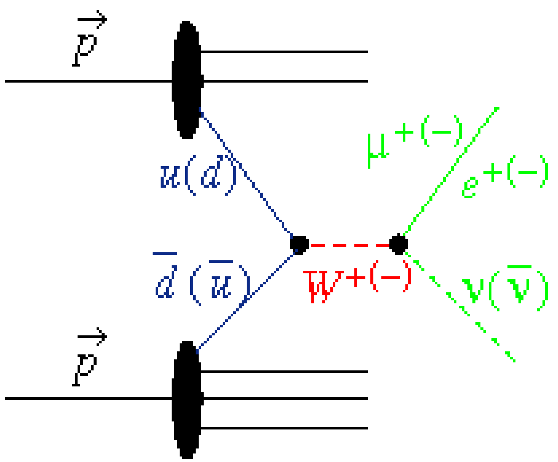
First results (PHENIX)

- Asymmetry results



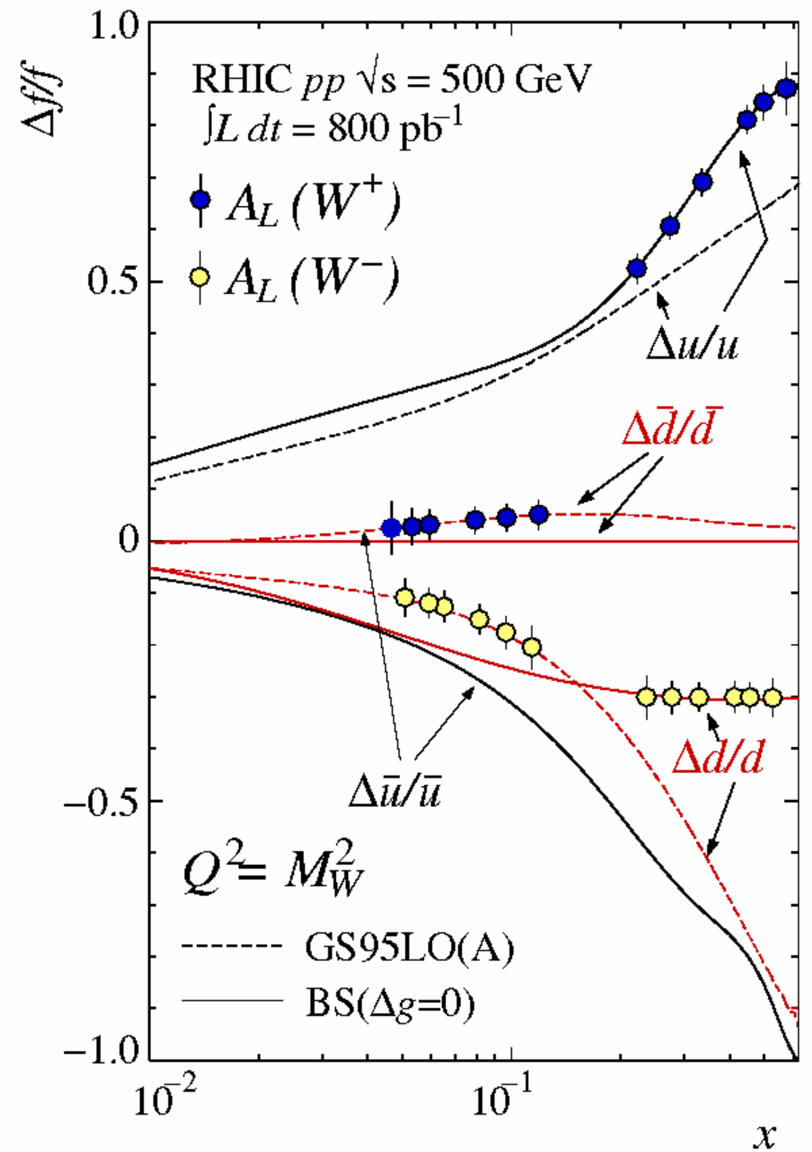
PHENIX

- Flavor decomposition
  - Explore spin structure of sea is crucial:
    - Is polarization of sea shared by quarks and anti-quarks?
    - Is there any flavor dependence?
  - $W^{\pm}$ production in pp collisions probes flavor structure analogous to deep-inelastic scattering
  - Polarized proton beams allow the measurement of (the expected large) parity violation in $W^{\pm}$ production
  - Forward e/μ detection gives direct access to probe the underlying quark (anti-quark) polarization which is dominated at RHIC by u/d quarks



$W^- \rightarrow d + \bar{u}$

$W^+ \rightarrow u + \bar{d}$



STAR/PHENIX spin physics topics

- Topics
  - Gluon polarization
    - Direct photon (STAR/PHENIX) + jet production (STAR)
    - Hadron production (STAR/PHENIX)
    - Inclusive jet production and di-jet production (STAR)
    - Heavy-flavor production (STAR/PHENIX)
  - Quark/Anti-quark polarization and flavor decomposition
    - W production (STAR/PHENIX)
  - Transversity and transverse spin effects
    - Single-transverse spin asymmetries (STAR/PHENIX)
    - Transversity via Drell-Yan (PHENIX)
  - Physics beyond the SM
    - Varity violating asymmetries (STAR/PHENIX)

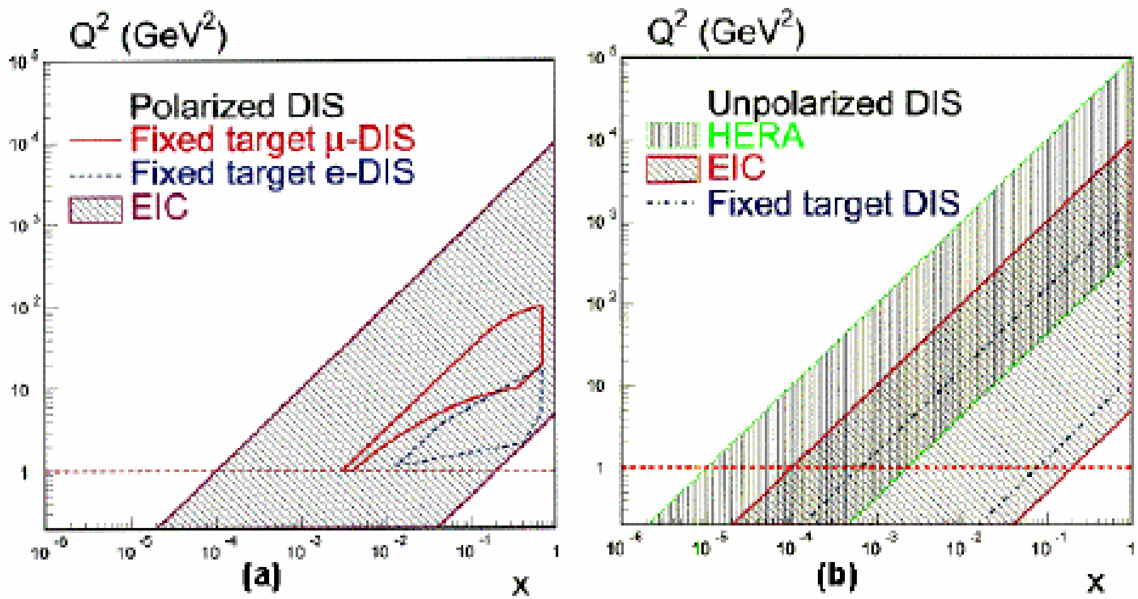
New opportunities in SPIN physics!

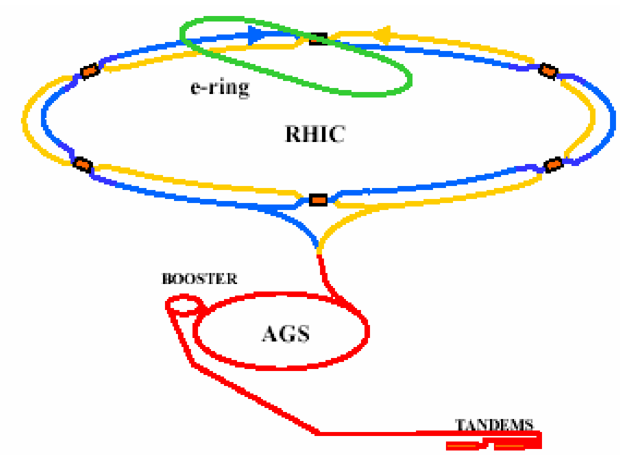
STAR/PHENIX spin physics timeline

- **Timeline**
  - FY02:
    - First polarized proton run and
    - First polarization observable measurement at RHIC in transverse polarized pp collisions
  - FY03:
    - Continue with measurements on transverse-single spin asymmetries with upgraded STAR FPD
    - Confirm tuning of spin rotator magnets via absence of left/right and up/down spin asymmetries (STAR/PHENIX)
    - A_{LL} for mid-rapidity inclusive jet production (STAR) and hadron production (PHENIX) as a first probe on the gluon polarization at RHIC
    - Continue commissioning of RHIC for polarized proton running ($L = 10^{31}$ $cm^{-2}s^{-1}$ and $P = 0.4$)
  - FY04:
    - Installation of polarized gas jet target for CNI polarimeter calibration
    - Commissioning of $\sqrt{s}$ = 500 GeV and first run
  - FY05 and beyond:
    - Strong snake in AGS for improved polarization
    - Improved luminosity
    - Embark on γ and W physics and heavy flavor production

Completion and upgrade of STAR/PHENIX

General comments on a future Electron-Ion Collider (EIC)





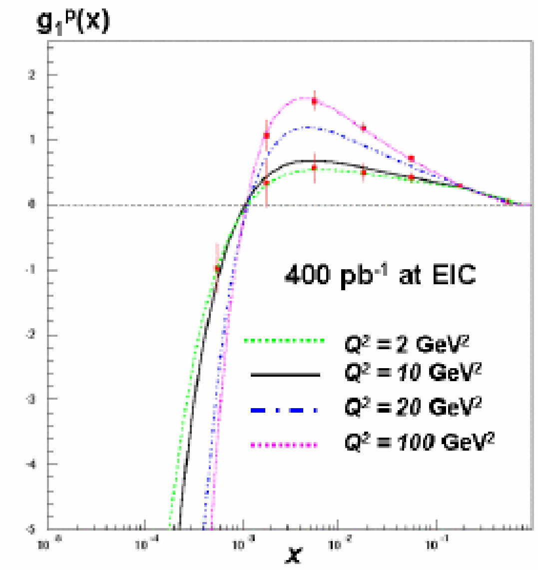
- Explore new QCD regime in eA scattering and polarized ep scattering in collider mode beyond the fixed target DIS era
- Complement current physics program at RHIC (AA/pp ⇨ eA/ep)

- Essential features for new EIC facility:
  - High luminosity: > 10^{33} cm^{-2} sec^{-1}
  - High polarization: ≈ 70%
  - High energy: $E_e \approx 10$ GeV, $E_p \approx 250$GeV
  - Variable center-of-mass energy: 25 – 60 GeV
  - Optimal detector for physics to be explored at EIC (Lessons from HERA!)

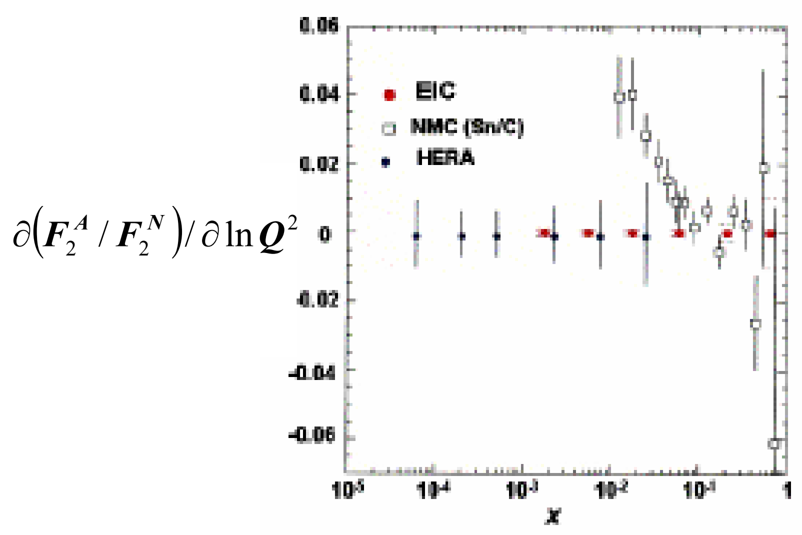
EIC

Physics program

- **Unpolarized ep scattering:**
  - Longitudinal structure function F_L
  - Flavor separation
  - Precise direct measurement of the gluon (0.001 < x < 0.5-1)
  - Exclusive reactions
  - Transition region ($Q^2 \rightarrow 0$)
- **Polarized ep scattering:**
  - Polarized structure function of the proton
  - Gluon polarization (Complement effort at RHIC, COMPASS, HERMES)
  - Exclusive reactions
  - Deeply-virtual Compton scattering (Orbital angular momentum of quarks)
- **eA scattering:**
  - Influence of nuclear medium within nucleon/nucleus: F_2^A/F_2^D
  - Gluon distribution within nucleus
  - Parton saturation at low-x



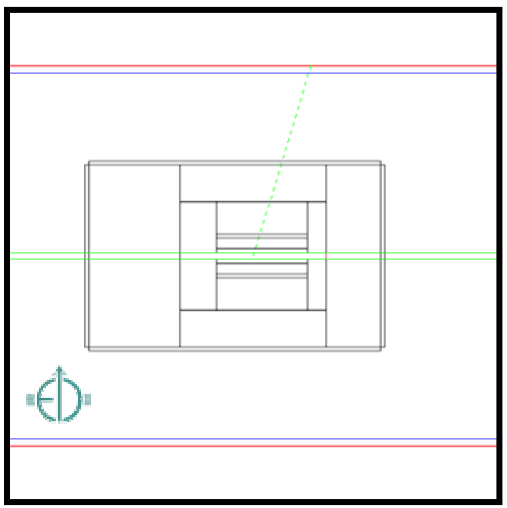
EIC White paper, BNL-68933



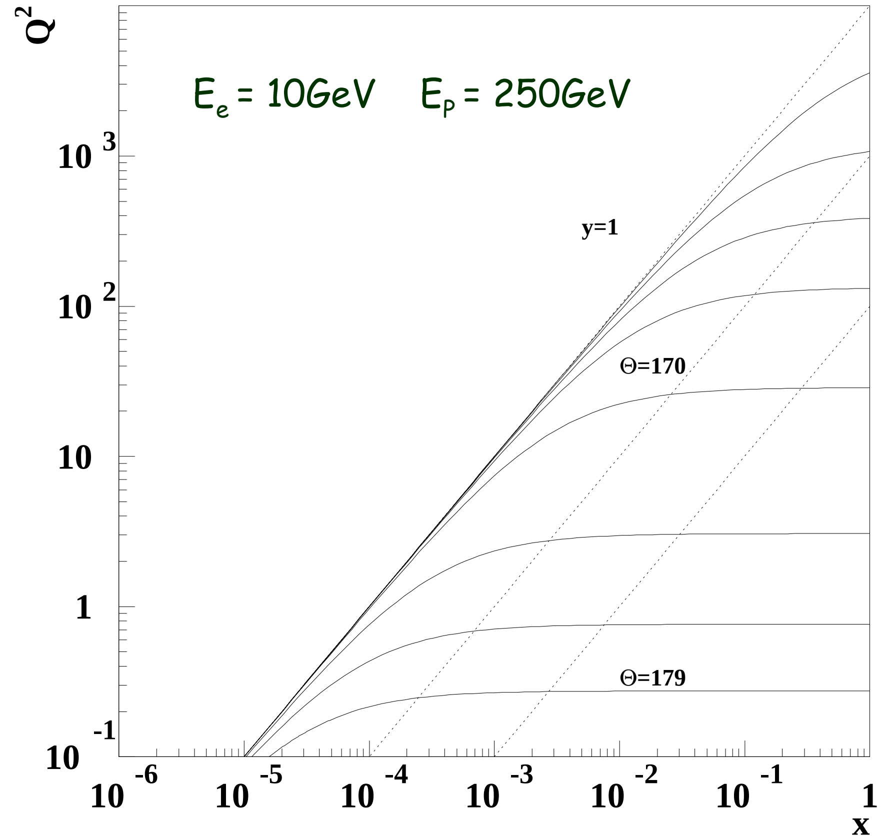
EIC White paper, BNL-68933

Requirements on a future EIC detector

- Basic requirements:
  - Measure precisely scattered electron (Kinematics of DIS reaction)
  - Tag electrons under small angles (Study of transition region)
  - Measure hadronic final state (Kinematics, jet studies, flavor tagging, fragmentation studies)
  - Zero-degree photon detector to control radiative corrections
  - Missing E_T for events with neutrinos in the final state
  - Tagging of forward particles (Diffraction)



GEANT detector simulation work has started!



EIC x-Q^2 acceptance!

EIC

- **Past:**
  - Series of workshops
  - Before 2001:
    - Indiana/MIT: EPIC
    - eRHIC
  - Merge to EIC: EIC = eRHIC + EPIC (Sept. 2000)
  - White paper (March 2001)
  - EIC workshop (Febr. 2002)
  - Result of submission: NSAC 2002/2003: Formal project in long-range plan

- **Present:**
  - Next large-scale project at BNL beyond RHIC
  - Beam cooling for RHIC already within EIC machine budget
  - Strong intention to have a dedicated EIC group at BNL from 2004 onward
  - WWW-page: http://www.bnl.gov/EIC

- **Future:**
  - Series of CDR's (CDR0: 2005) (rough institutional responsibility and interests, functionality of detector)
  - Start of construction (CDR3=TDR) in 2008

Summary and Outlook

- RHIC Spin program at BNL
  - First successful polarized proton collisions ever at RHIC
  - Successful upgrade and commissioning of various new STAR components for the first polarized proton run at RHIC
  - First measurement of single transverse-spin asymmetries A_N for forward π^0 production at RHIC (⇨ Probe new domain in QCD)
  - Unique opportunity to explore the spin structure of the proton in a new unexplored regime at RHIC over the next years:
    - Gluon polarization
    - Flavor decomposition
    - Transverse spin effects and transversity
  - This requires various accelerator, polarimeter and detector components to be completed (High polarization and luminosity)!
- Future EIC program at BNL
  - Explore new QCD regime in eA (high parton density - saturation phenomena) and polarized ep scattering (complement ongoing RHIC physics activities)
  - Unique opportunity to establish such a QCD facility at BNL!

⇨ A very exciting time is ahead of us to explore the spin structure of the proton at RHIC and to establish a new ep/eA facility at BNL!