SSA's of Mid-rapidity Neutral Pions and Charged Hadrons at PHENIX

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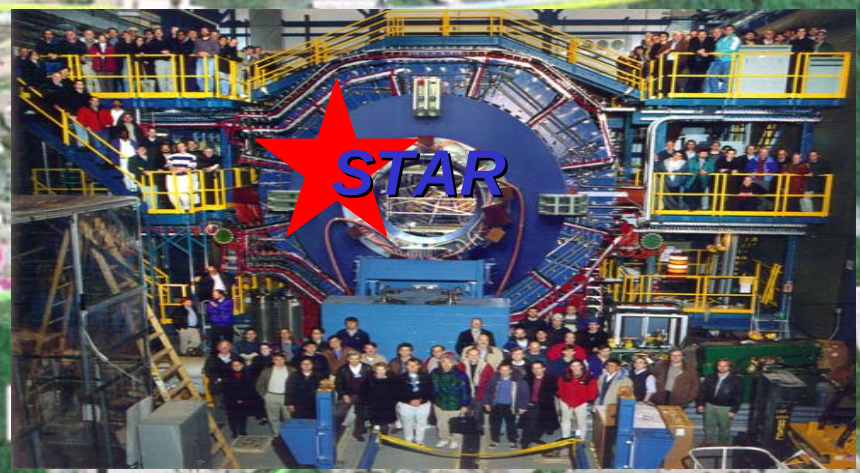
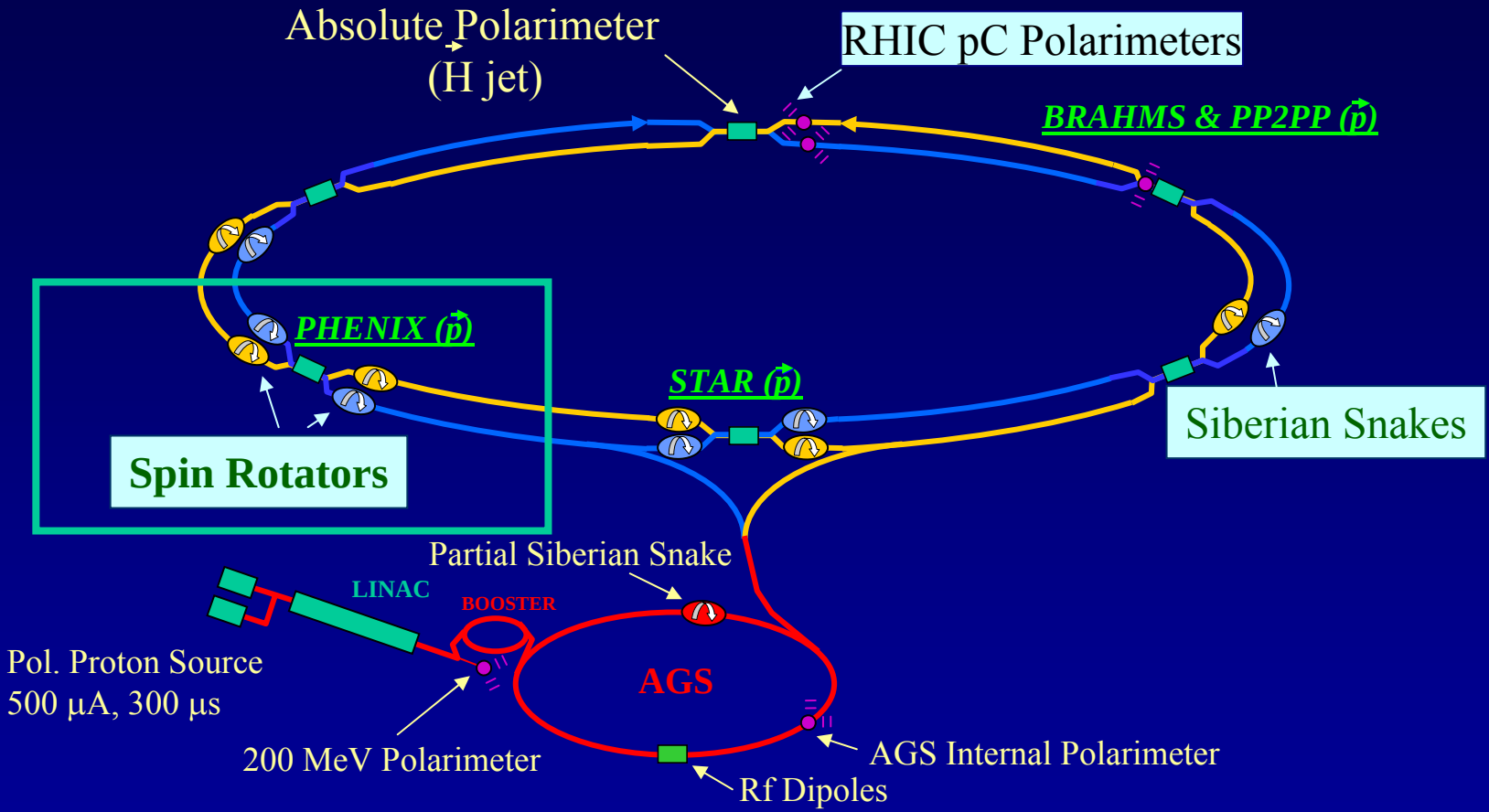
SSA Workshop, BNL
June 1, 2005

PHENIX

RHIC's Experiments



RHIC as a Polarized Proton Collider

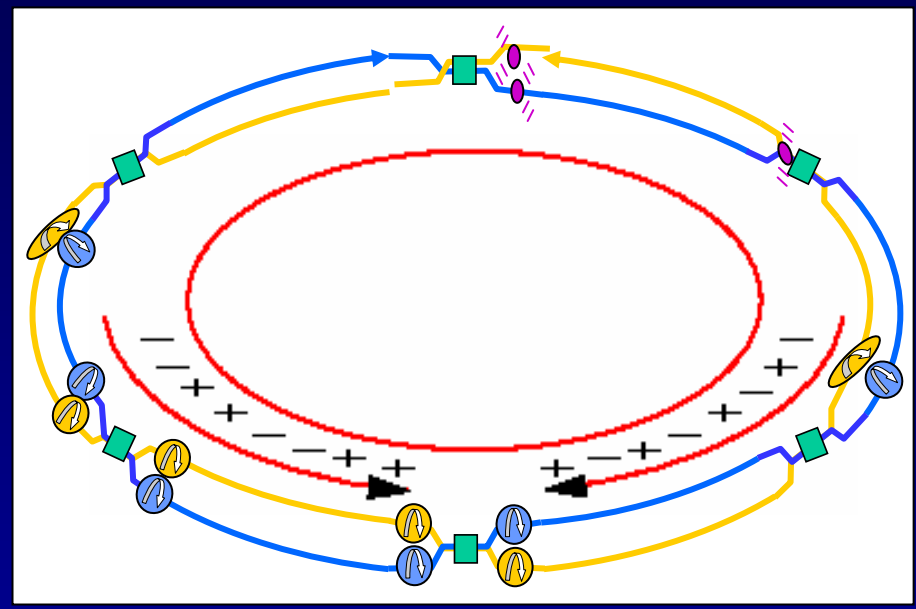


Must choose between transverse and longitudinal running time

The PHENIX Collaboration

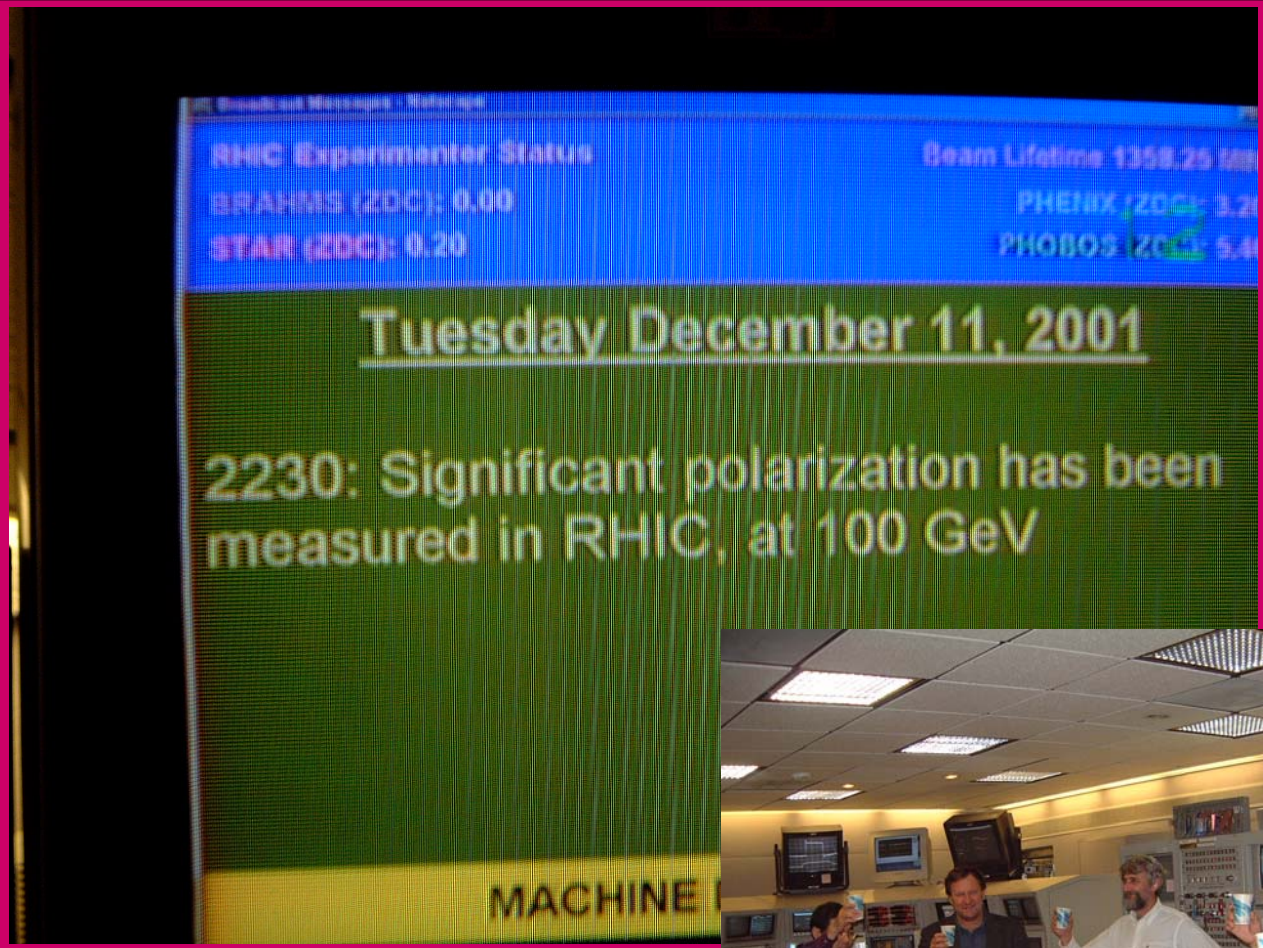
PHENIX Spin Running So Far

- 2001-2
  - ***Transversely*** polarized collisions
  - Average polarization 15%
  - Integrated luminosity 0.15 pb^{-1}
- 2003
  - ***Longitudinally*** polarized collisions
  - Average polarization 27%
  - Integrated luminosity 0.220 pb^{-1}
- 2004
  - 5 weeks commissioning
  - 4 days longitudinal physics data
  - Average polarization 40%
  - Integrated luminosity 0.075 pb^{-1}
- 2005
  - Long run (10 wks) currently underway!
  - P > 50% has been achieved
  - ~10% of total integrated luminosity will be transverse



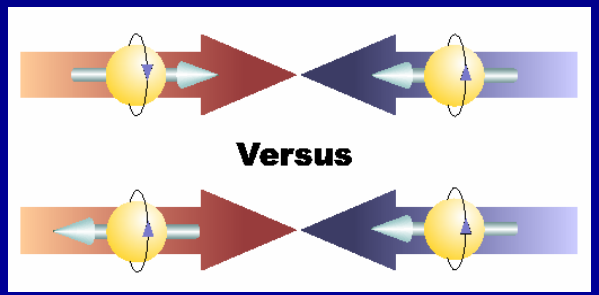
Flip spin of bunches every ~100 or 200 ns—controls systematics

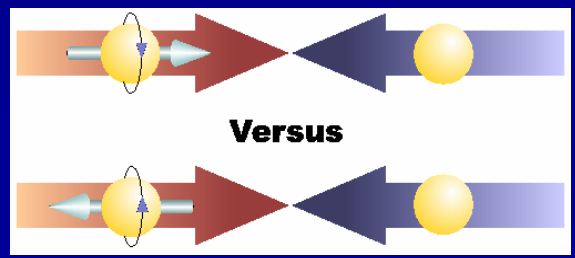
First Polarized Collisions at RHIC

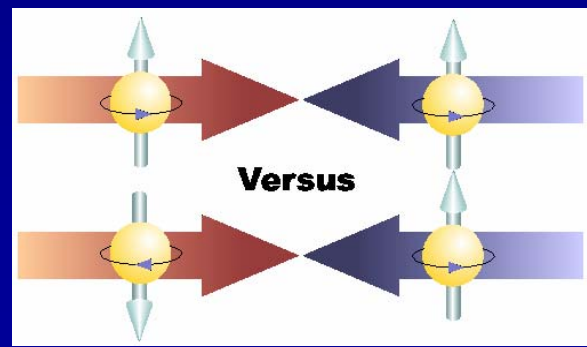


Measurement of Proton Spin Structure at PHENIX

Gluon Polarization ΔG	Flavor decomposition $\frac{\Delta u}{u}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta d}{d}, \frac{\Delta \bar{d}}{\bar{d}}$	Transverse Spin
π Production $A_{LL}(gg, gq \to \pi + X)$	**W Production**	**Transversity δq:**
Prompt Photon $A_{LL}(gq \to \gamma + X)$	$A_L(u + \bar{d} \to W^+ \to l^+ + \nu_l)$	π^+, π^- Interference fragmentation: $A_T(p_\perp p \to (\pi^+, \pi^-) + X)$
Heavy Flavors $A_{LL}(gg \to c\bar{c}, b\bar{b} + X)$	$A_L(\bar{u} + d \to W^- \to l^- + \bar{\nu}_l)$	Drell Yan A_{TT}
		Single Asymmetries A_N



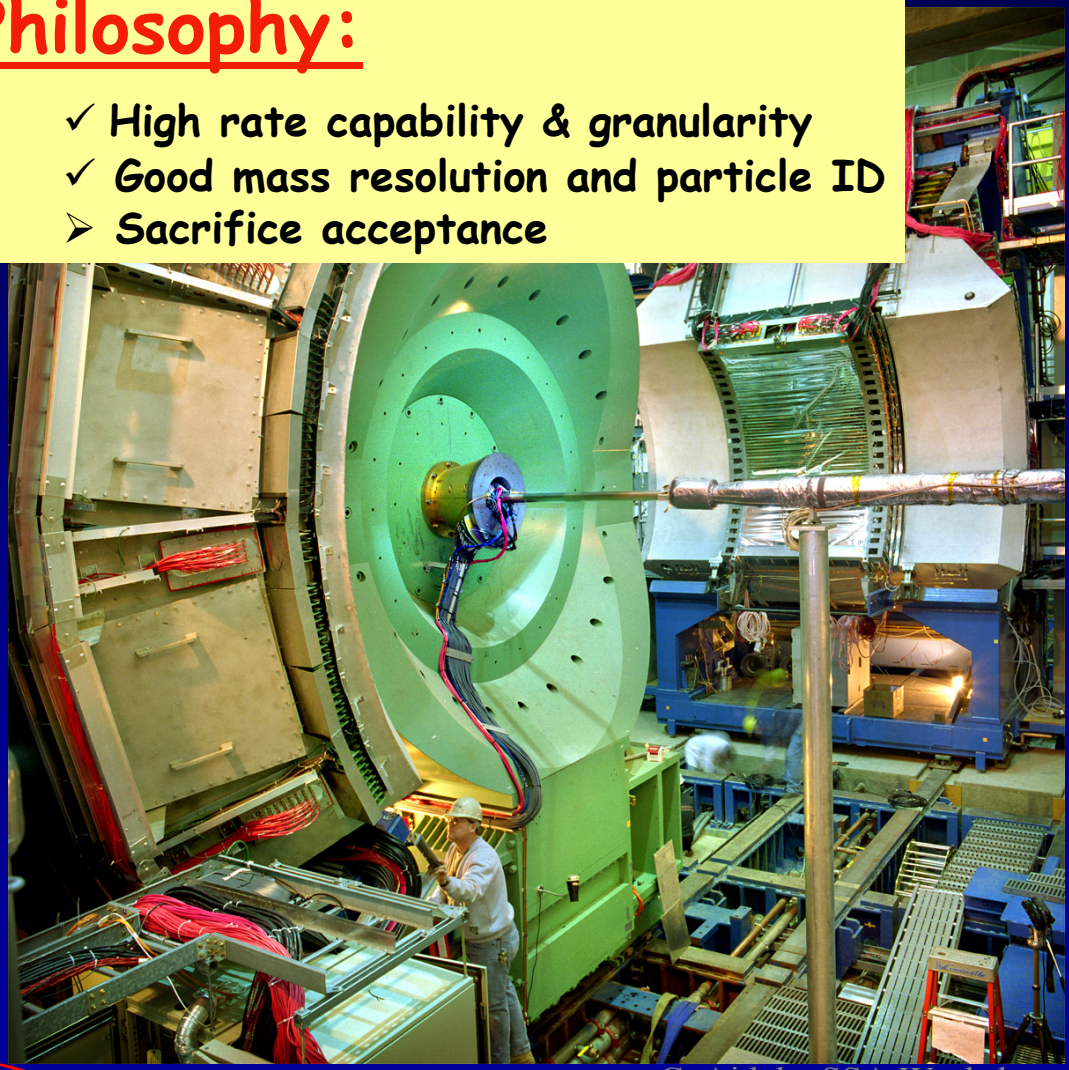




The PHENIX Detector

Philosophy:

- ✓ High rate capability & granularity
- ✓ Good mass resolution and particle ID
- ➢ Sacrifice acceptance



2 central spectrometers

- Track charged particles and detect electromagnetic processes

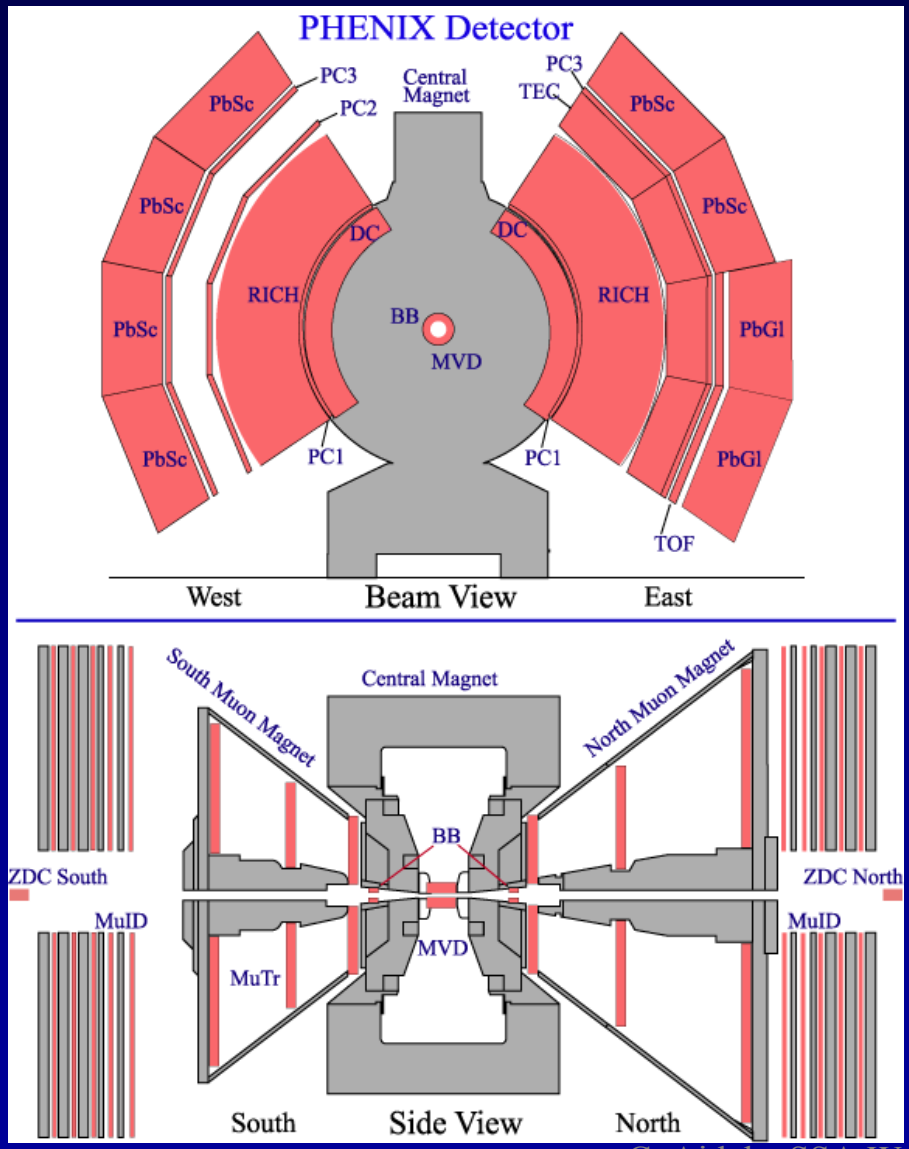
2 forward spectrometers

- Identify and track muons

3 global detectors

- Determine when there's a collision

The PHENIX Detector (cont.)



Central Arms

$|\eta| < 0.35$

$\Delta\phi = 180$ degrees

Photons

(EMCal: Lead-glass and lead scintillator)

Charged tracks

(Beam-Beam, Drift Chamber, Pad Chambers)

+ RICH rings

+ EMCal clusters

Forward Muon Arms

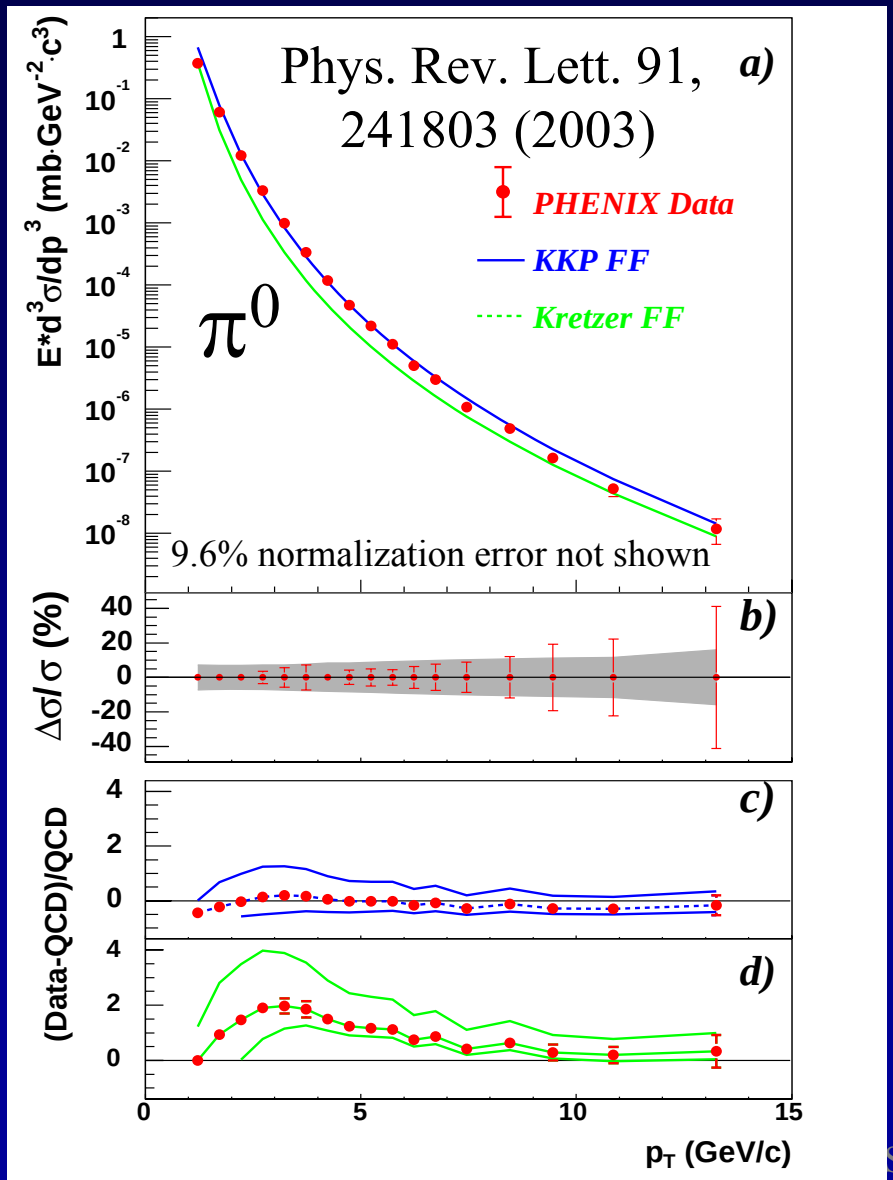
$1.2 < |\eta| < 2.4$

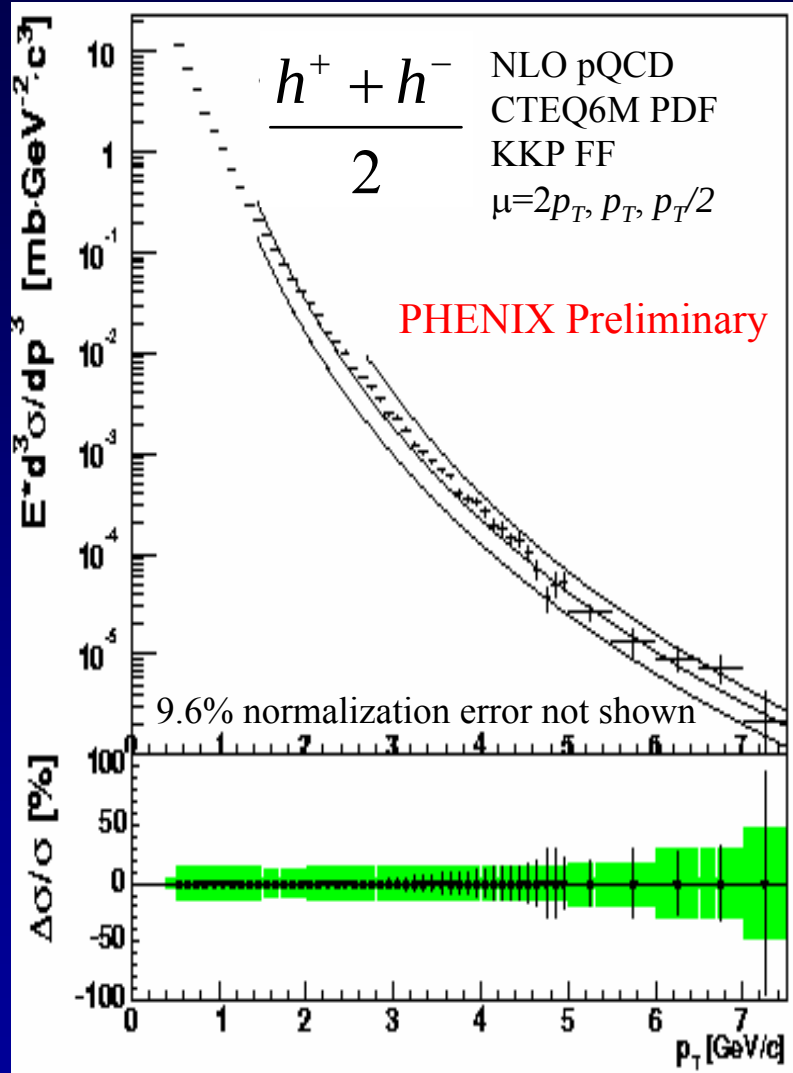
$\Delta\phi = 2\pi$

Beam-Beam Counters (BBC's)

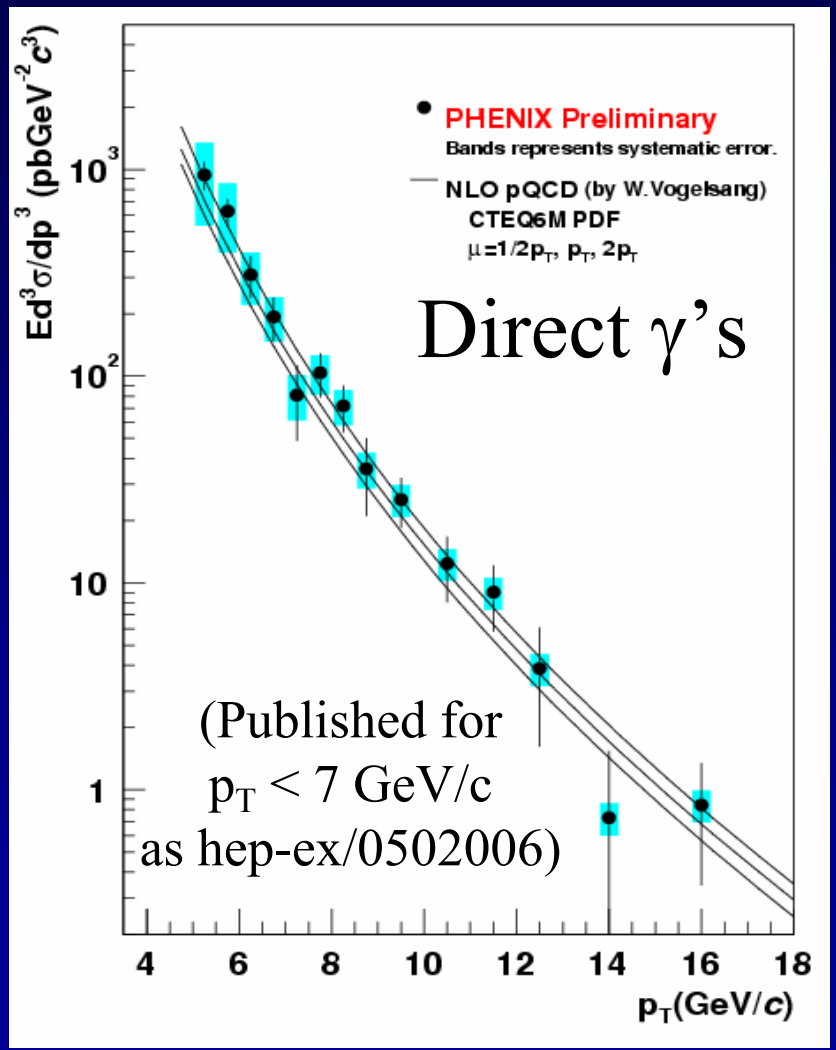
- Quartz Cherenkov detectors—sensitive to forward charged particles
- 2π azimuthal coverage
- $3.0 < |\eta| < 3.9$
- Serve as minimum-bias (MB) trigger
- Determine event vertex (resolution ~2 cm)
- Used to measure absolute luminosity, necessary for cross-section measurements
  - See ~50% of total inelastic p+p cross section
- Used to measure *relative luminosity* between bunches with up and down polarization

Cross Section Measurements



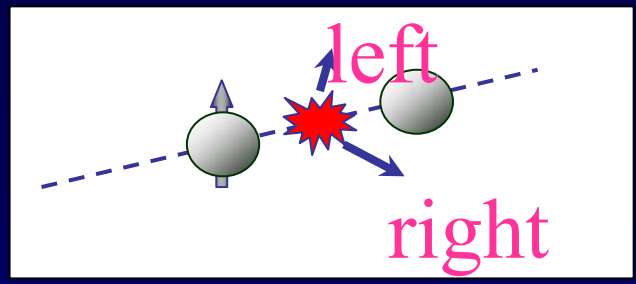


Cross Section Measurements (cont.)



- Cross sections have been measured by PHENIX for mid-rapidity π^0's, charged hadrons, and direct photons
- Good agreement with pQCD calculations for $p_T > \sim 2$ GeV/c
- Important confirmation of theoretical foundation of RHIC spin program
  - Will be able to use NLO pQCD to extract *polarized* pdf's

Why Measure A_N of Different Particle Species at Mid-rapidity in PHENIX?



- Significant asymmetry observed by STAR for forward π^0's with $x_{quark} \geq 0.6$
- Significant [illegible] observed at RHIC in forward neutron pr[illegible]
- A_N measu[illegible] kinematic
- Cross sect[illegible]

➢ Measuring A_N at RHIC for different particle species in different kinematic regions will help to separate contributions from transversity and Sivers

➢ PHENIX central arm spectrometers designed to measure a variety of particle species at mid-rapidity

Measuring A_N

- Two methods of calculation
  - "Square-root" formula
    - Combine yields from up and down bunches, left and right sides of beam, such that differences in luminosity of up and down bunches cancel

$$A_N = \frac{1}{P^{Beam}} \frac{\sqrt{N^{\uparrow}_{Left} N^{\downarrow}_{Right}} - \sqrt{N^{\uparrow}_{Right} N^{\downarrow}_{Left}}}{\sqrt{N^{\uparrow}_{Left} N^{\downarrow}_{Right}} + \sqrt{N^{\uparrow}_{Right} N^{\downarrow}_{Left}}}$$

  - "Luminosity" formula
    - Must measure relative luminosity (R) of up and down bunches
    - Used for double-longitudinal measurements
    - Separately for left and right of beam in single-transverse case

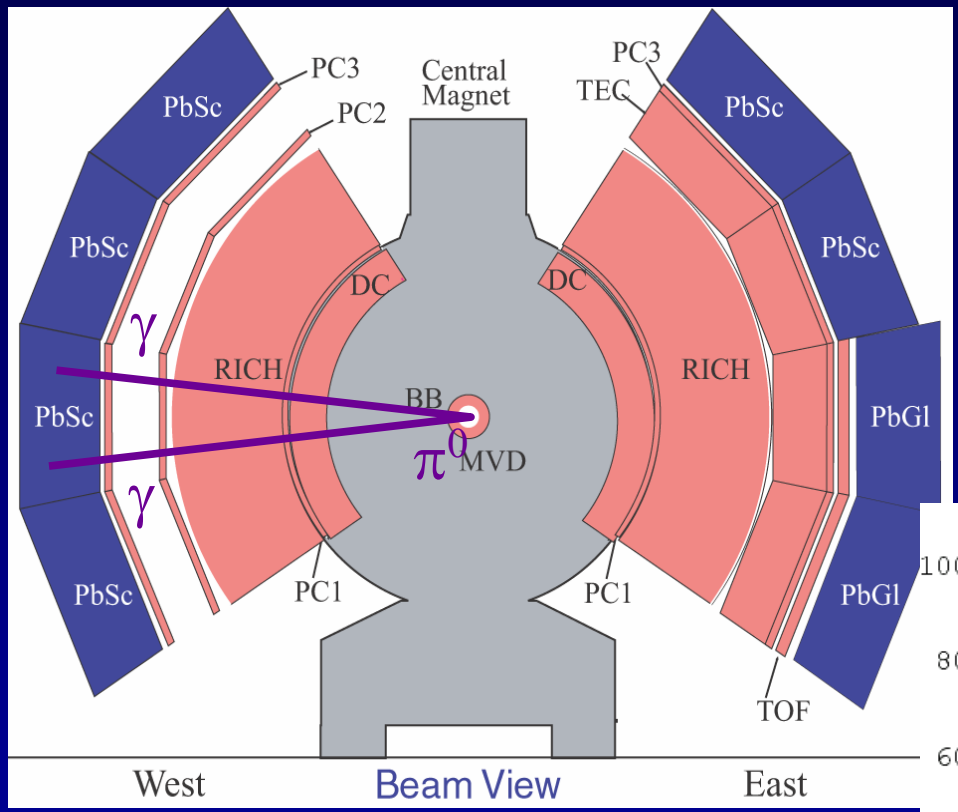
$$A_N^{Left} = \frac{1}{P^{Beam}} \frac{\left(N^{\uparrow,Left} - RN^{\downarrow,Left}\right)}{\left(N^{\uparrow,Left} + RN^{\downarrow,Left}\right)}, R = \frac{L^{\uparrow}}{L^{\downarrow}} \approx 1.09$$

Obtaining the Polarization

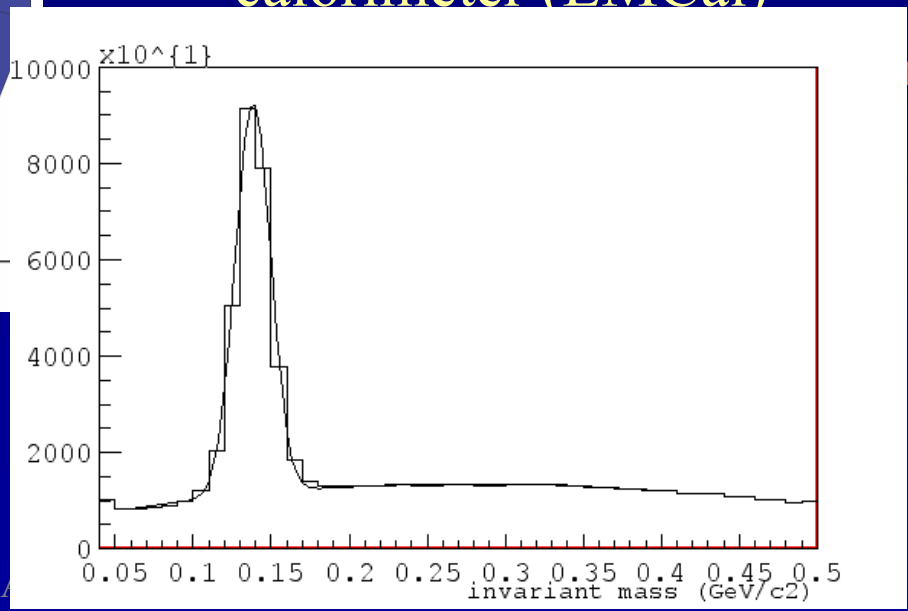
- Polarimeter uses proton-carbon elastic scattering in the Coulomb-nuclear interference (CNI) region
- ~30% total uncertainty due to uncertainty in the original measurement of the analyzing power at 22 GeV and uncertainty on energy dependence between 22 and 100 GeV

Note that any uncertainty on the polarization becomes a scale uncertainty on A_N, affecting asymmetries and statistical uncertainties in the same way, preserving each point's significance from zero

Obtaining the (Spin-Dependent) π^0 Yields



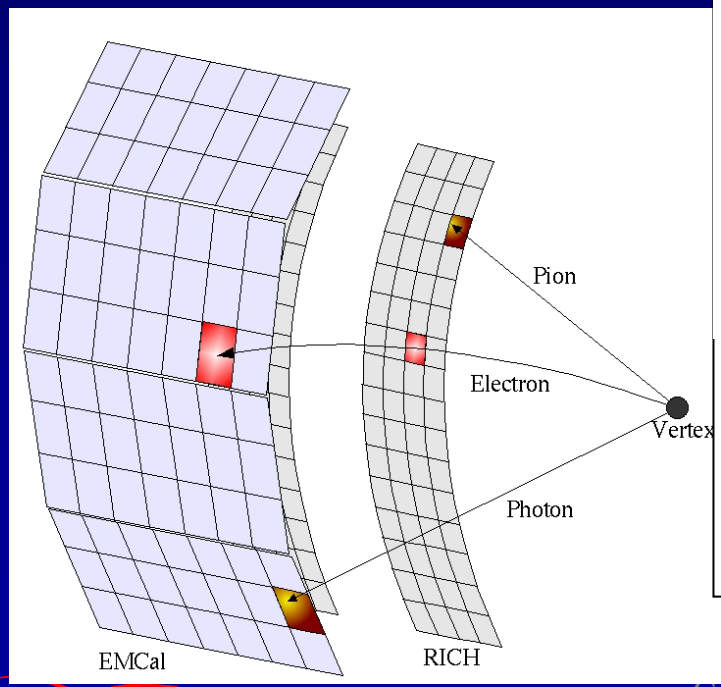
- 18M events used
- Central spectrometer arms $|\eta| < 0.35$
  - γ, π^0 via $\pi^0 \rightarrow \gamma\gamma$
  - Electromagnetic calorimeter (EMCal)



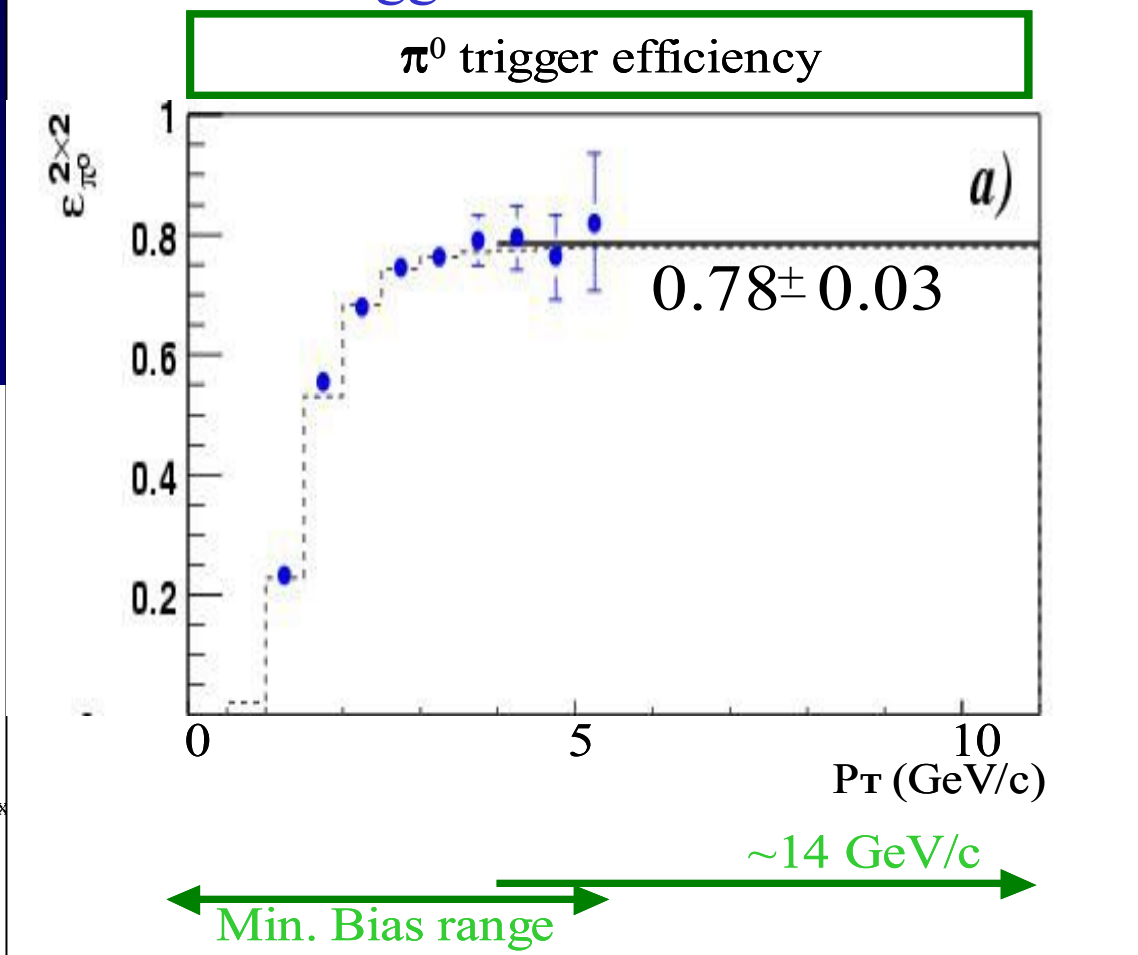
π^0 width ~10-15 MeV/c^2

EMCal-RICH Trigger

- 2x2 tower non-overlapping energy sum
- Threshold ~ 0.8 GeV
- Also used in conjunction with RICH to form an electron trigger

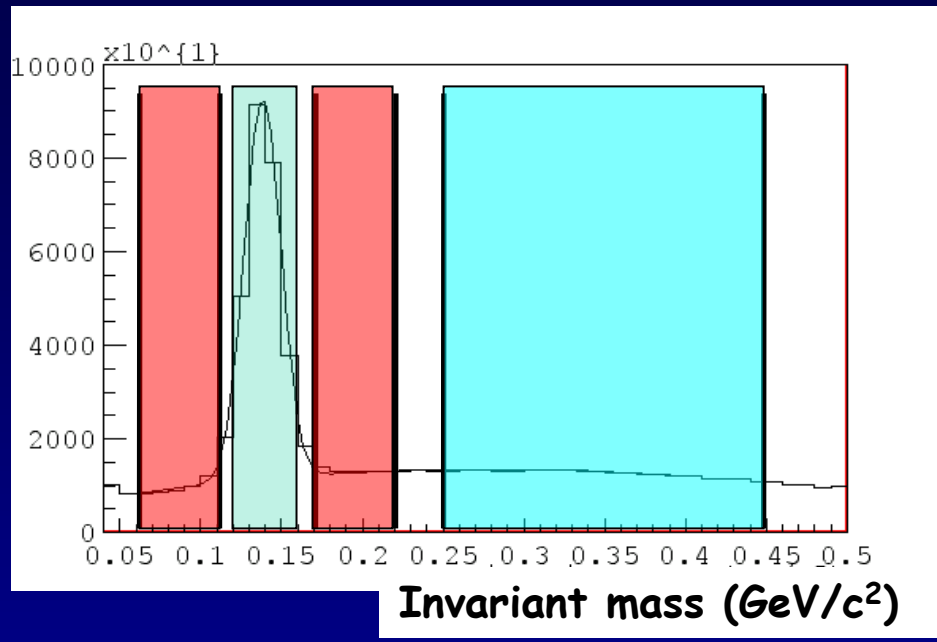


2x2 Trigger in 2001-2002 run.



Handling Background in the π^0 Asymmetry

- Eliminate as much background as possible using EMCal cluster shower shape cut and charged veto
- Calculate asymmetry of (signal + background) in the π^0 mass window
- Calculate the asymmetry of two different background regions
- Subtract the asymmetries

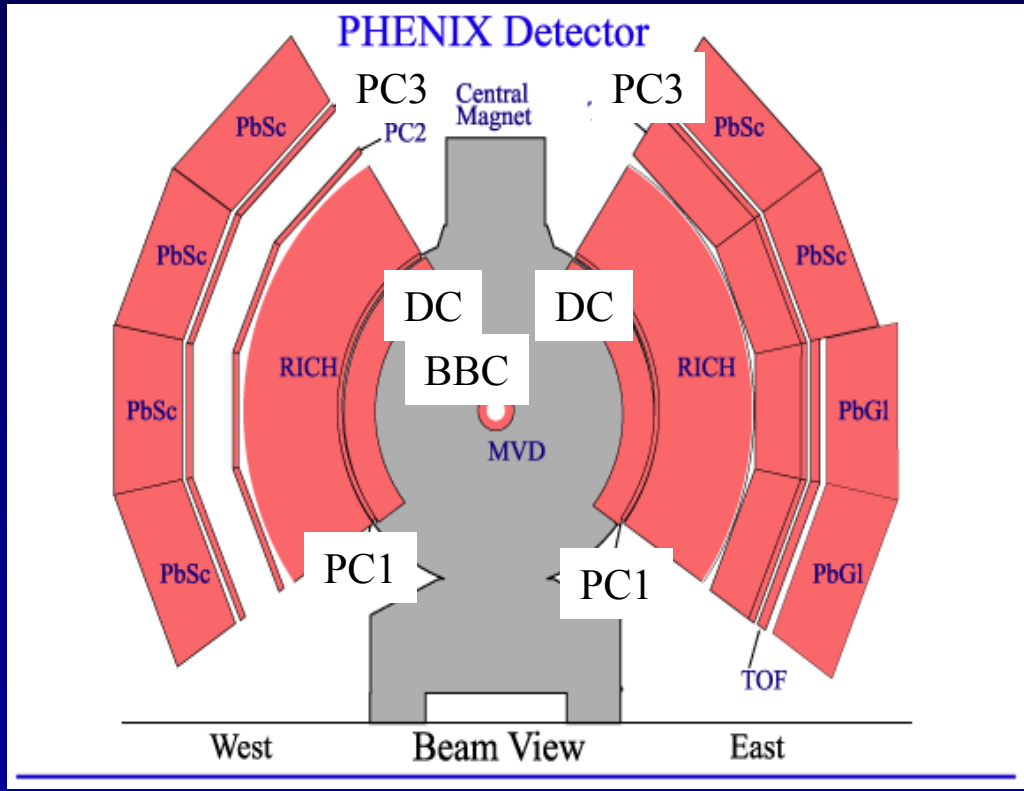


- 50-MeV/c^2 windows around the π^0 peak (60-110 and 170-220 MeV/c^2)
- 250-450 MeV/c^2 (between π^0 and η)

$$A_N^{\pi^0} = \frac{A_N^{\pi^0+bkg} - rA_N^{bkg}}{1-r}$$

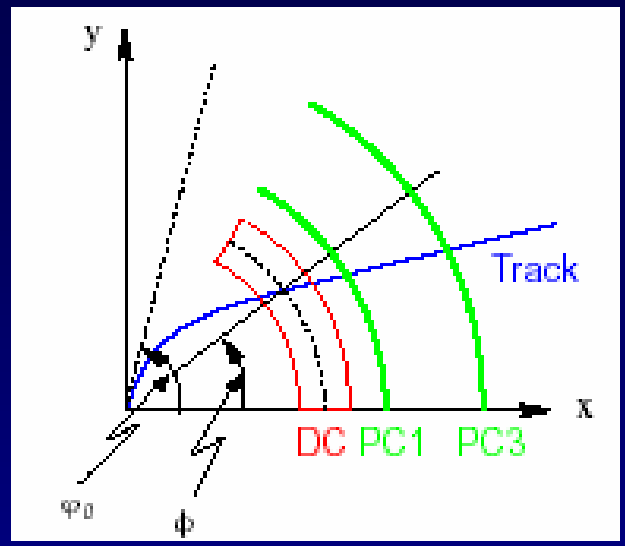
Obtaining Charged Hadron Yields

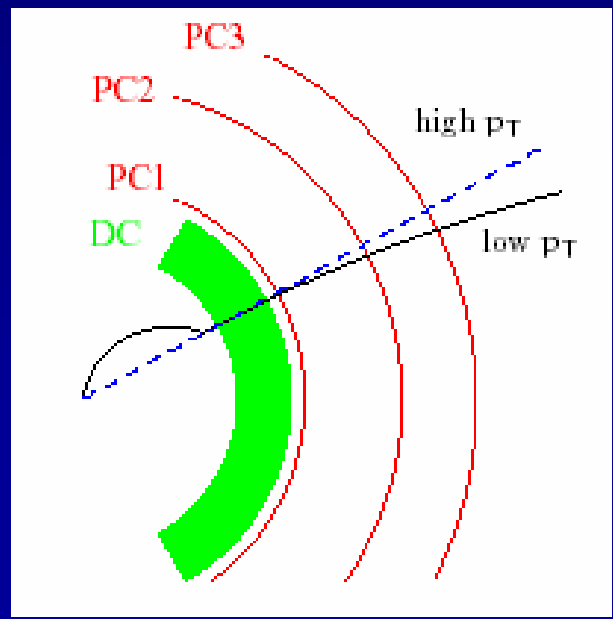
- 13M events used
- Event vertex from BBC's
- Track reconstruction from
  - vertex
  - drift chamber
  - pad chambers



Background in h^+/h^- Sample

- Note that tracking detectors in PHENIX are *outside* the magnetic field
- Assume track originates at event vertex, then measure momentum based on deflection angle observed at drift chamber
- Low-momentum tracks that don't originate from the vertex may be misreconstructed with higher momentum
  - Conversion electrons
  - Decay products from long-lived particles (K^{+-}, K^0_L)



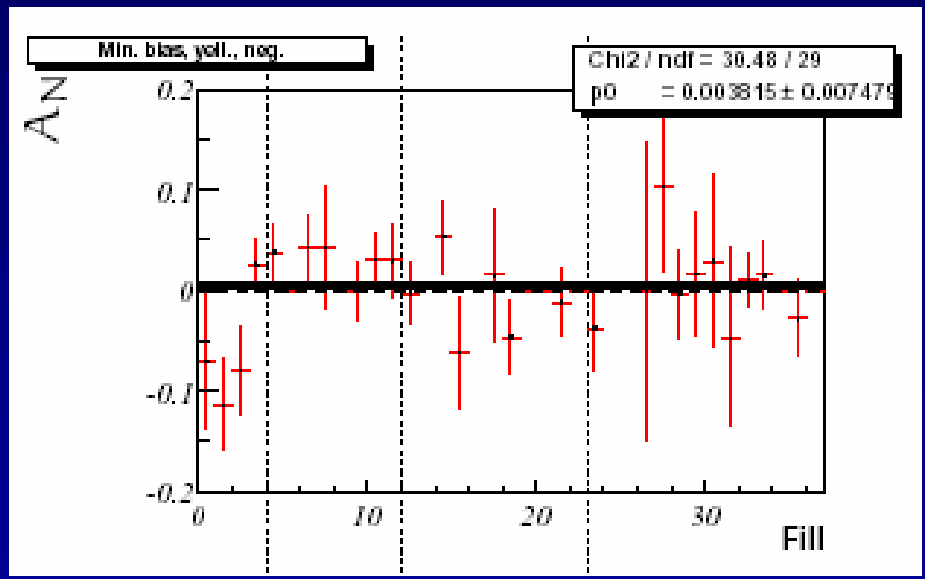


Background in h^+/h^- Sample (cont.)

- RICH veto to eliminate electrons
  - Electron threshold 0.017 GeV/c
  - Pion threshold 4.7 GeV/c
  - < 1% electron contamination in final sample
- Estimate decay background from long-lived particles from tracks with reconstructed $p_T > 9$ GeV/c but that didn't produce a hit in the RICH
  - < 5% in final sample

From Yields to Asymmetries

- Keep track of fill-by-fill polarization for each beam
- Polarization-corrected asymmetries obtained fill by fill, then averaged over all fills



- Also correct for the range in azimuthal coverage of the central spectrometer arms by a factor of $\frac{1}{\langle \cos\varphi \rangle}$

A_N of Neutral Pions and Charged Hadrons: Systematic Checks

- Independent results from two polarized beams
- Independent results from two detector arms (luminosity formula)
- Comparison of square-root and luminosity formulas
- Fill-by-fill stability of asymmetry
- Effects of background on π^0 asymmetry
  - Integrate over different ranges of photon-pair invariant mass
  - Measure asymmetry of two different background invariant mass regions

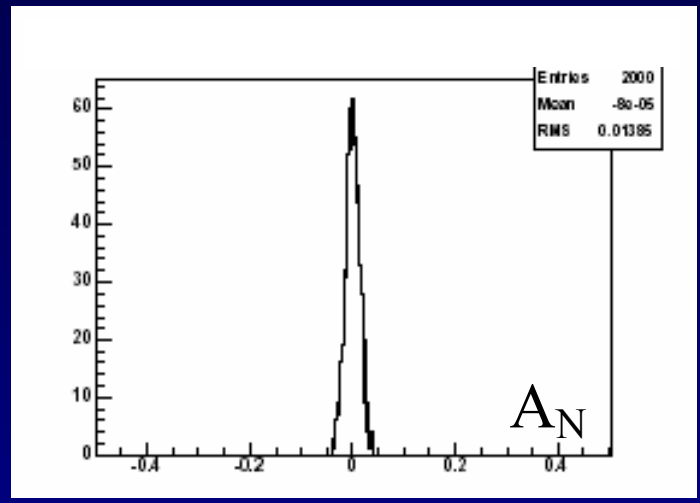
Bunch Shuffling to Check for Systematic Errors

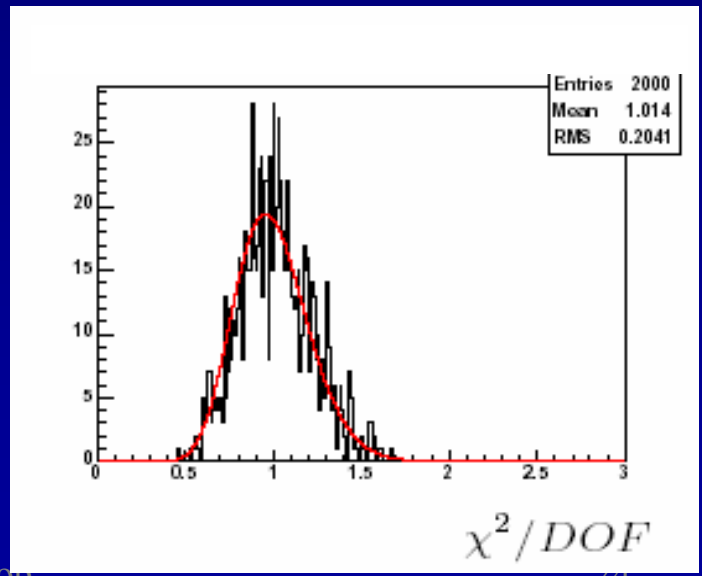
- Randomly assign helicity sign for each bunch

Widths of shuffled A_N distributions consistent with statistical errors assigned to physics A_N

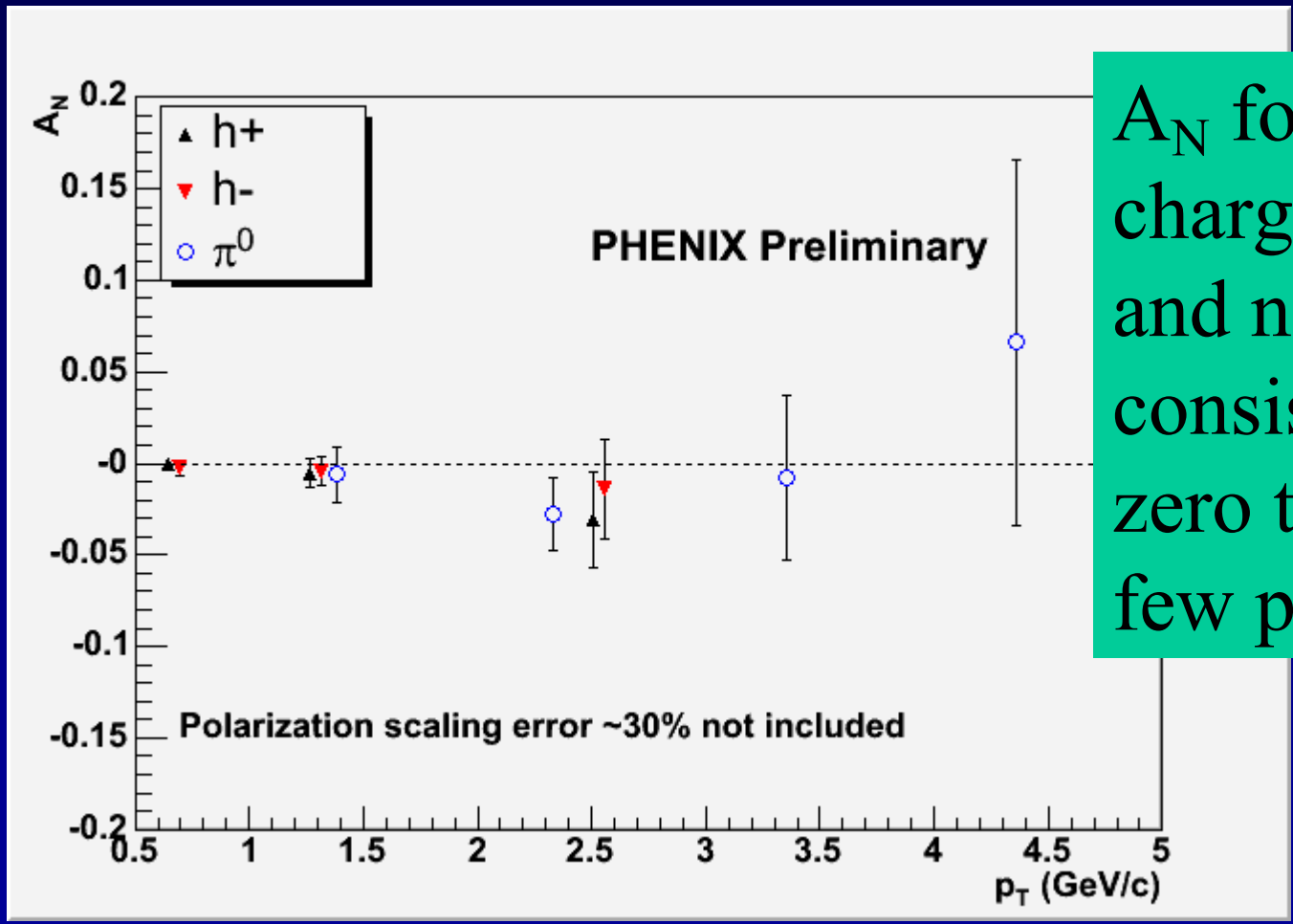
➢Indicates that uncorrelated systematic errors are smaller than statistical errors

distributions for fitted A_N and χ^2





A_N of Neutral Pions and Non-Identified Charged Hadrons: Results

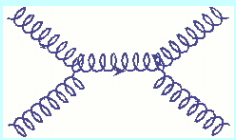


A_N for both charged hadrons and neutral pions consistent with zero to within a few percent.

Sensitivity to Partonic Processes

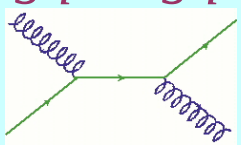
- Neutral pion as well as charged hadron production in the current p_T range dominated by gg and gq scattering
- Contributions to A_N from transversity suppressed

$gg \rightarrow gg$



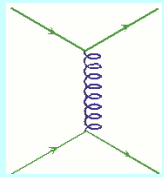
$\propto \frac{\Delta G}{G}\frac{\Delta G}{G}$

$gq \rightarrow gq$

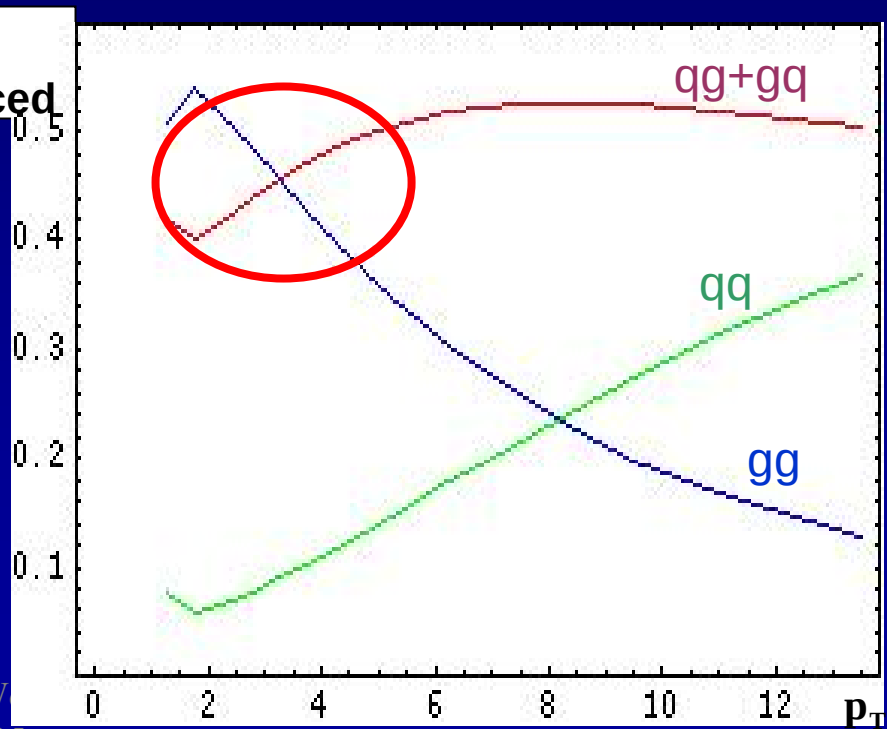


$\propto \frac{\Delta q}{q}\frac{\Delta G}{G}$

$qq \rightarrow qq$



$\propto \frac{\Delta q}{q}\frac{\Delta q}{q}$



Summary

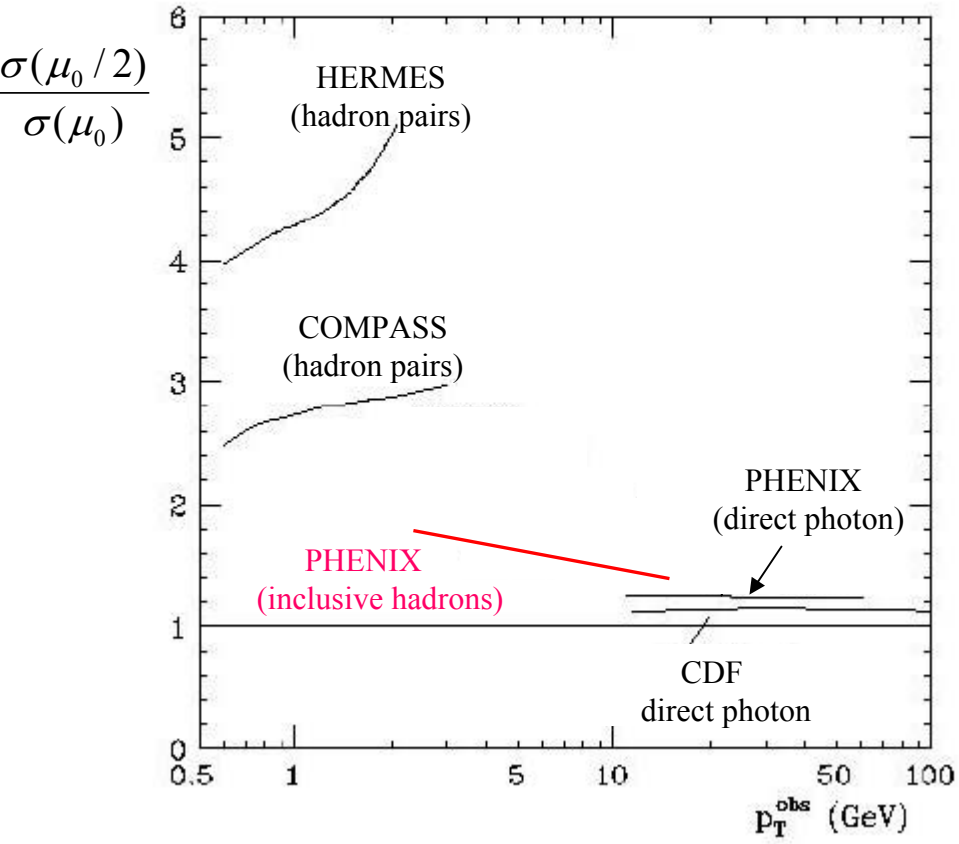
- A_N of neutral pions and charged hadrons measured for $0.5 < p_T < 5$ GeV/c and $|\eta| < 0.35$
- Asymmetries consistent with zero to within a few percent
- Results may provide information on gluon-Sivers
- Expect an improved measurement from data to be taken this month
  - High-statistics data will eventually allow measurement of A_N for a variety of other particle species at mid-rapidity
- Check the preprint server for final 2002 results in a couple weeks!

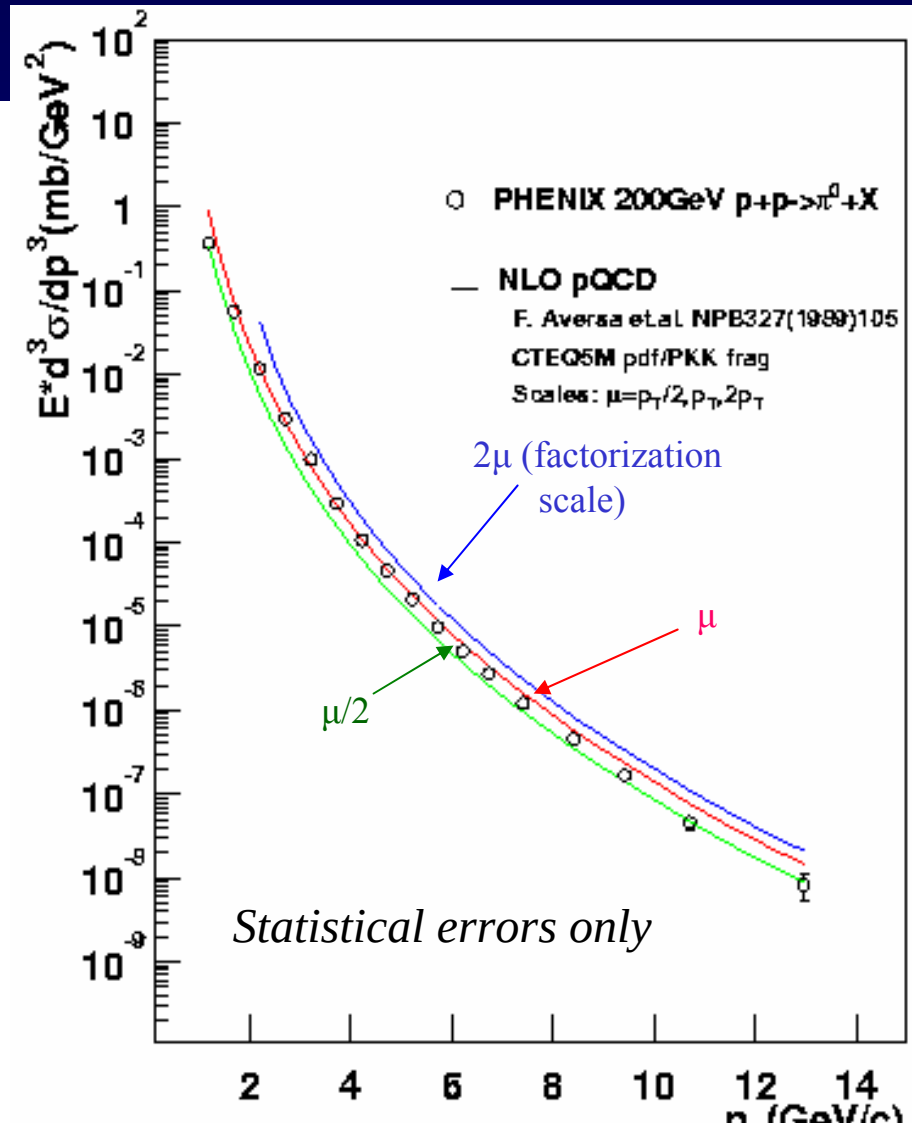
Extra Slides

pQCD Scale Dependence at RHIC

Theoretical uncertainty of pQCD calculations in various channels:

π^0 data vs pQCD with different factorization scales:



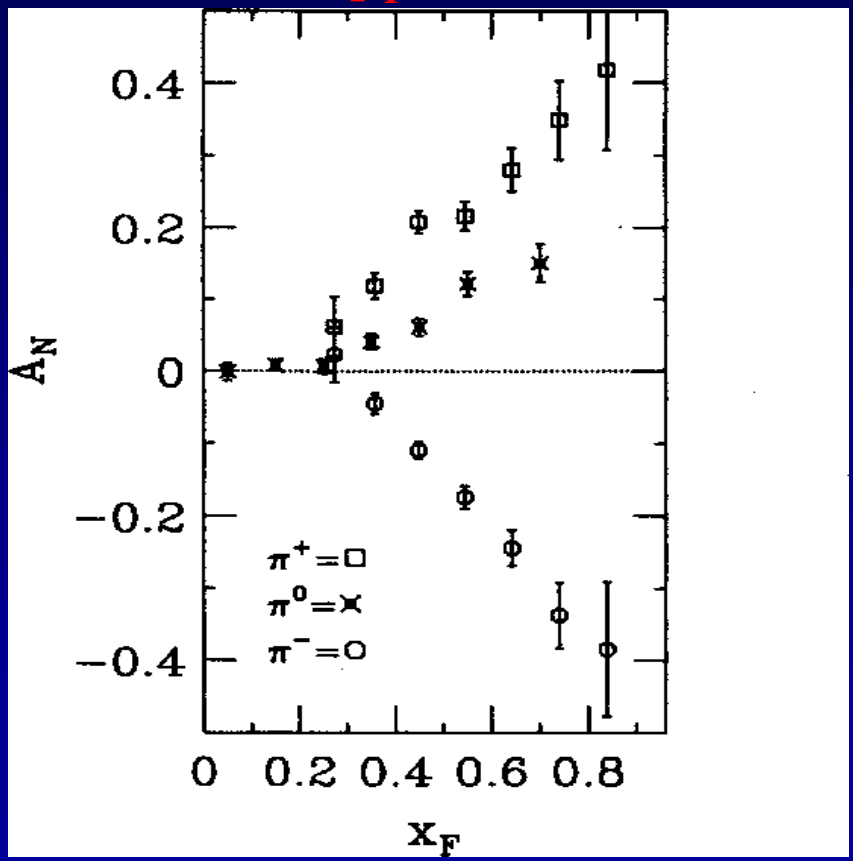


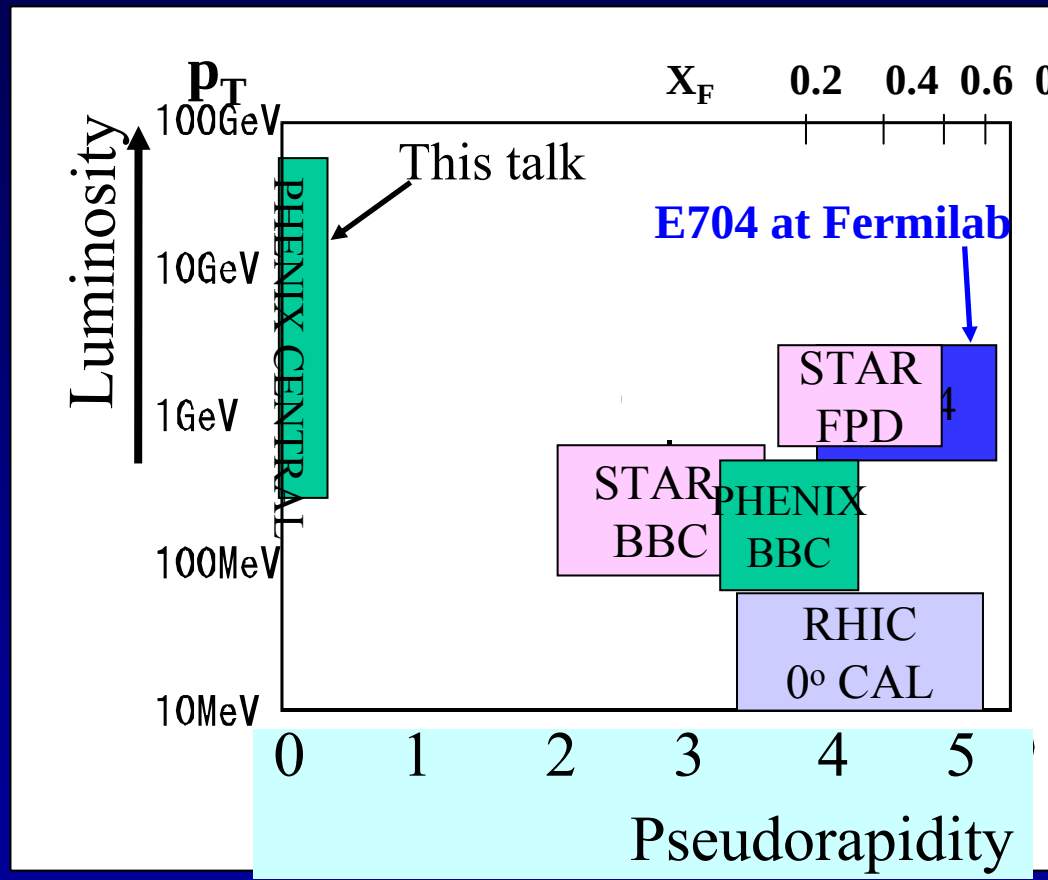
Single spin asymmetries: L-R

Essential for proton spin orientation information at IPs

E704 at Fermilab

at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:

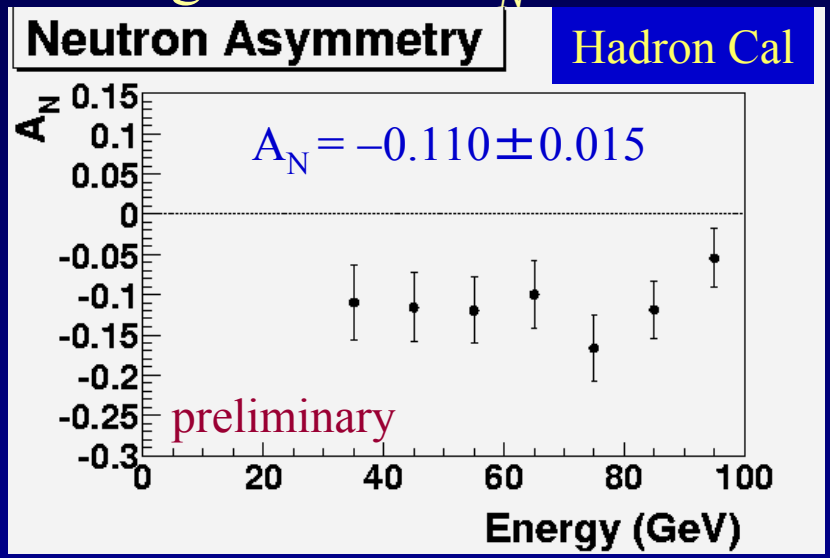


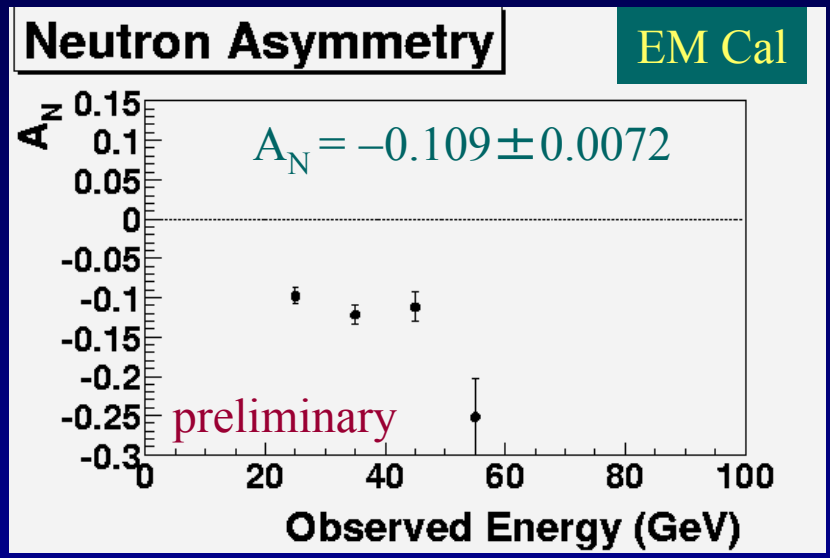


Neutron A_N at IP12

- A_N measurement at IP12
  - large neutron A_N was discovered

Y. Fukao



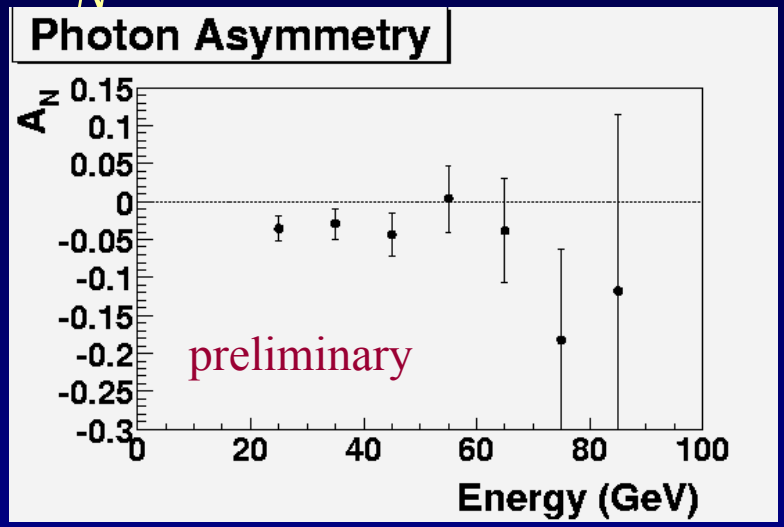


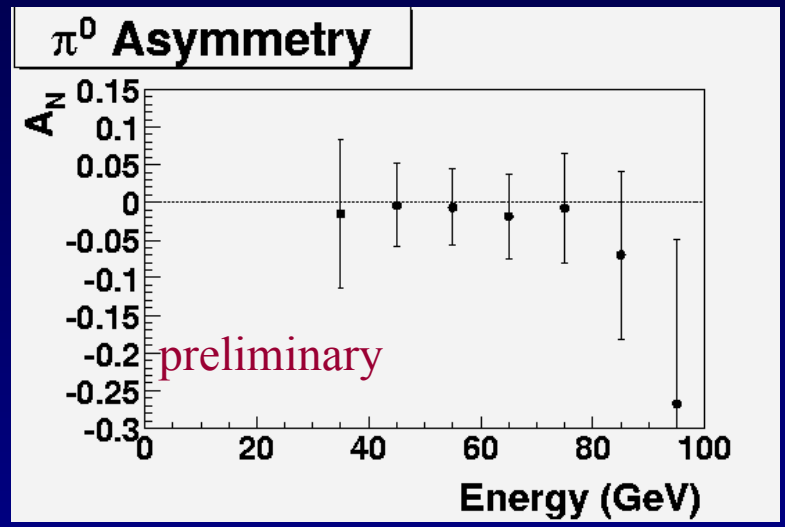
➔ Local polarimeter at PHENIX

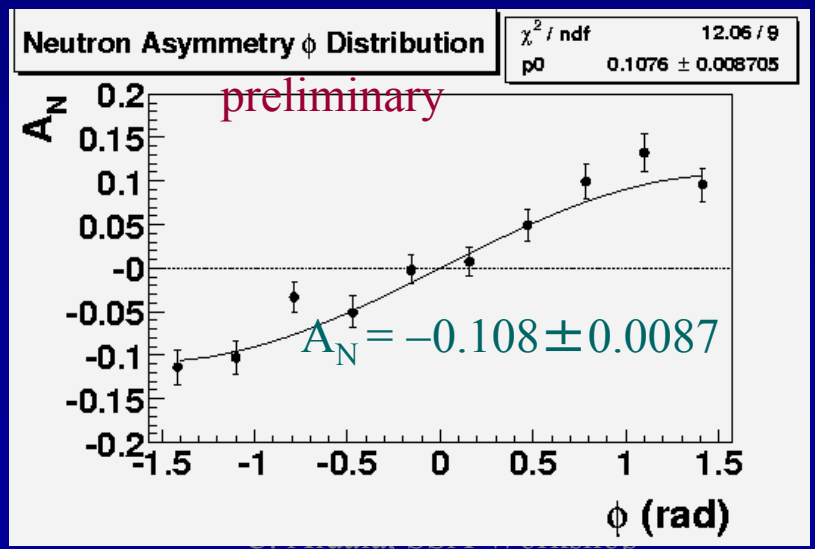
- ZDC + position sensitive counters to measure the neutron A_N
- 8-ch hodoscopes for both X- and Y-directions at the shower maximum position of the ZDC (between 1st and 2nd modules)

A_N at IP12

- A_N measurement at IP12

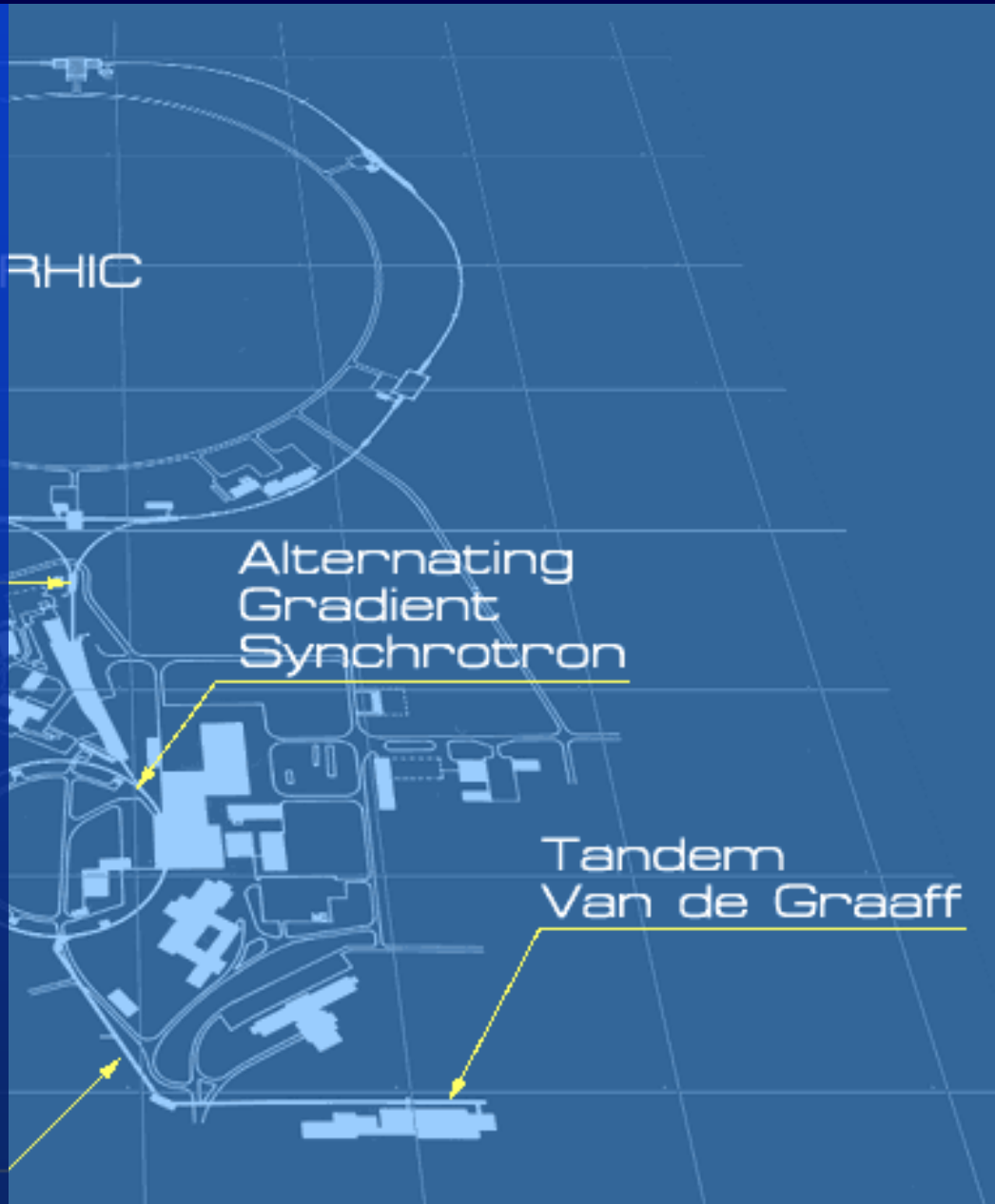




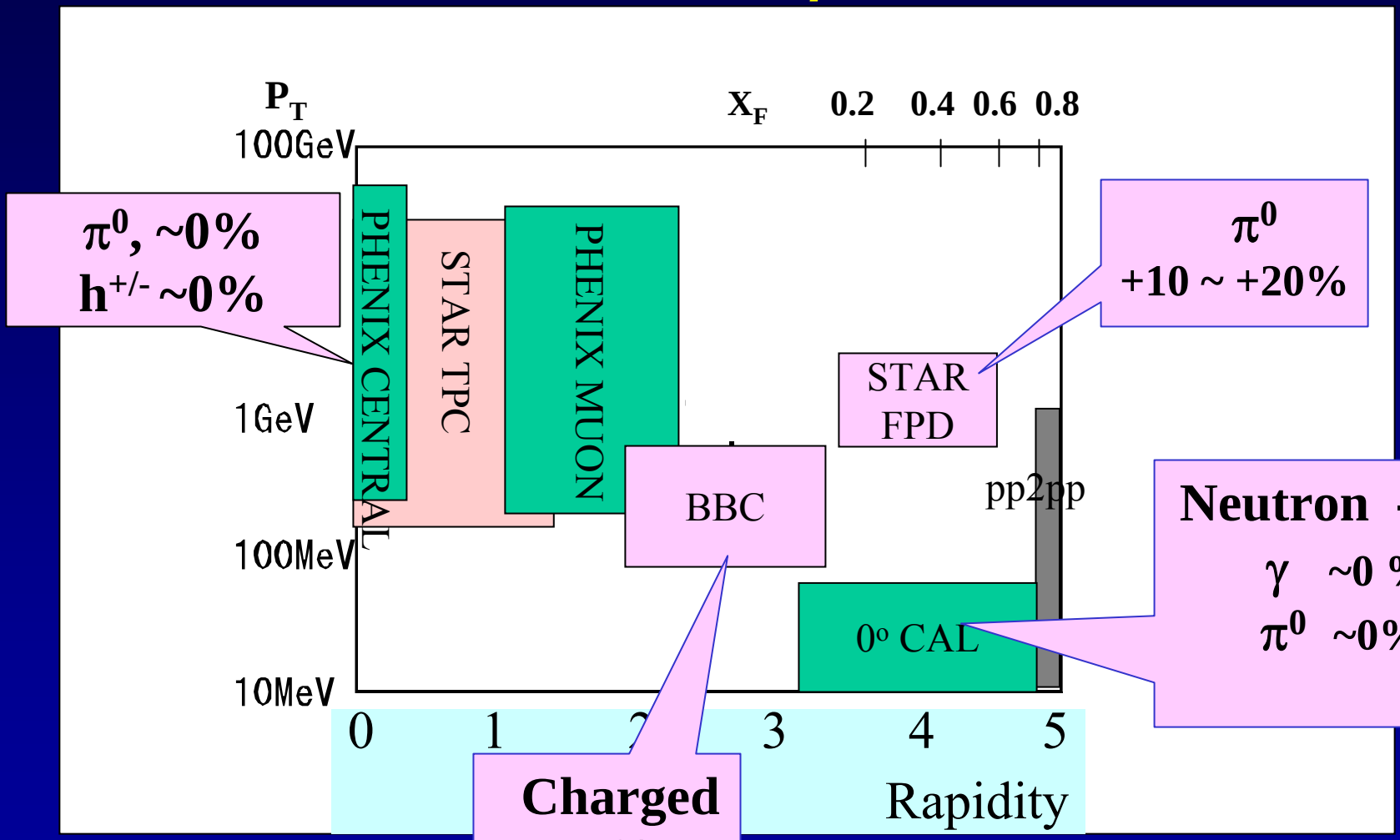


RHIC Specifications

- 3.83 km circumference
- Two independent rings
  - Up to 120 bunches/ring
  - 106 ns crossing time
- Energy:
  - ➔Up to 500 GeV for p-p
  - ➔Up to 200 GeV for Au-Au (per N-N collision)
- Luminosity
  - Au-Au: 2 x 10^{26} cm^{-2} s^{-1}
  - p-p : 2 x 10^{32} cm^{-2} s^{-1} (*polarized*)



Single-spin asymmetries seen at RHIC so far…



PHENIX

- University of São Paulo, São Paulo, Brazil
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