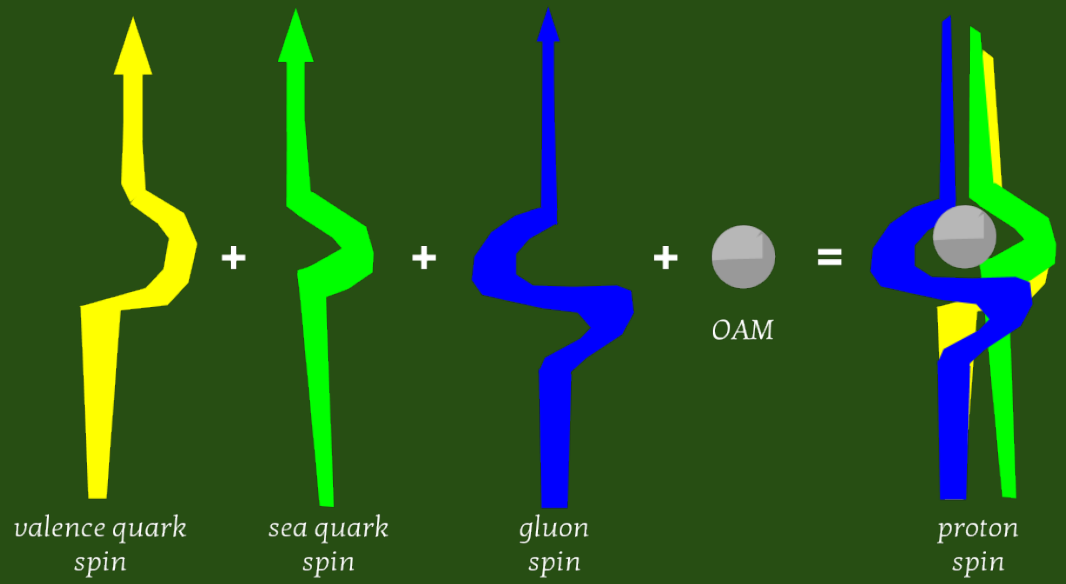
PHENIX Measurements of Double Longitudinal Spin Asymmetries to Study ΔG



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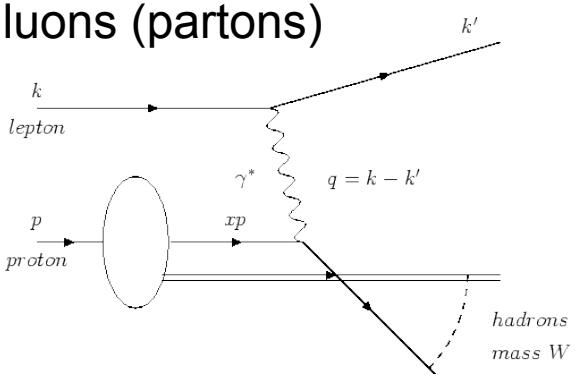
for the **PHENIX** *Experiment*

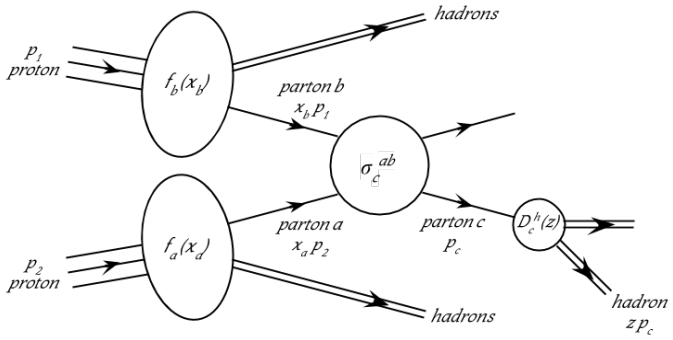
The 9th Circum-Pan-Pacific Symposium on High Energy Spin Physics
Shandong University, Ji'nan, China

Proton Sub-Structure & Parton Scattering

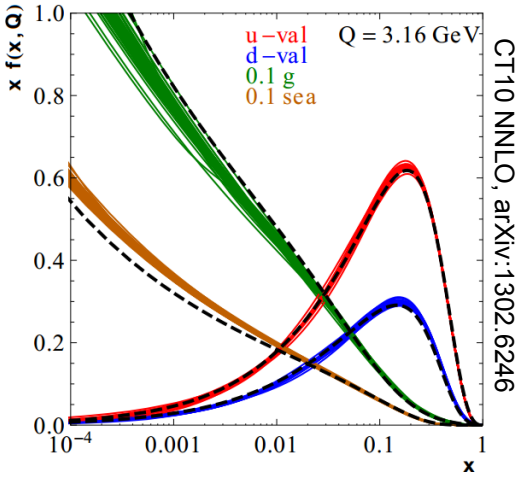
- High energy scattering with a nucleon (proton) probes the sub-structure
  - scattering with individual quarks, antiquarks, and gluons (partons)
- DIS:



- p+p:



- Parton Distribution Functions (PDFs), $f_i(x)$
  - describe statistical distribution of partons with momentum fraction *x*



- *polarized* PDFs, $\Delta f_i(x)$
  - take into account spin along proton's spin axis

Sum Rules

- Charge sum rule
  - assumes zero strangeness

$$Q_{proton} = 1 = \int_0^1 dx\ x\left(\frac{2}{3}[u(x) - \bar{u}(x)] - \frac{1}{3}[d(x) - \bar{d}(x)]\right)$$

- Momentum sum rule
  - quark term from neutrino, antinetrino x-section measurements
    - <50% of momentum
      - conclude that gluon contributes >50% of linear momentum

$$P_{proton} = P_{quark} + P_{gluon}$$
$$= \int_0^1 dx\ x\left([u(x) + \bar{u}(x)] + [d(x) + \bar{d}(x)] + [s(x) + \bar{s}(x)]\right) + \int_0^1 dx\ xg(x)$$

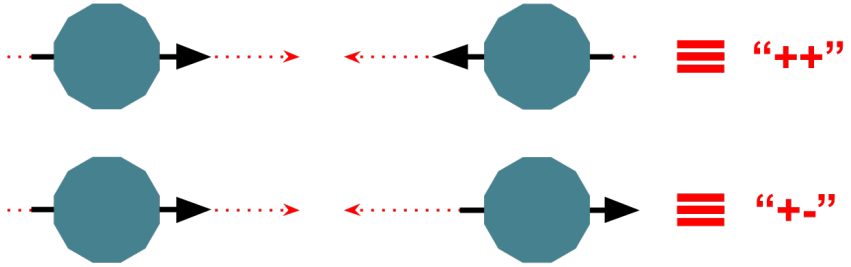
- Spin sum rule
  - quark spin, gluon spin, OAM
  - DIS experiments find quark spin contribution only 25-35%

$$S_{proton} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

$$\Delta G = \int_0^1 dx\ \Delta g(x), \quad \Delta\Sigma = \int_0^1 dx\ \left([\Delta u(x) + \Delta\bar{u}(x)] + [\Delta d(x) + \Delta\bar{d}(x)] + [\Delta s(x) + \Delta\bar{s}(x)]\right)$$

Double Longitudinal Spin Asymmetries

- In p+p scattering:
  - proton spin parallel (positive helicity) or antiparallel with its momentum vector:

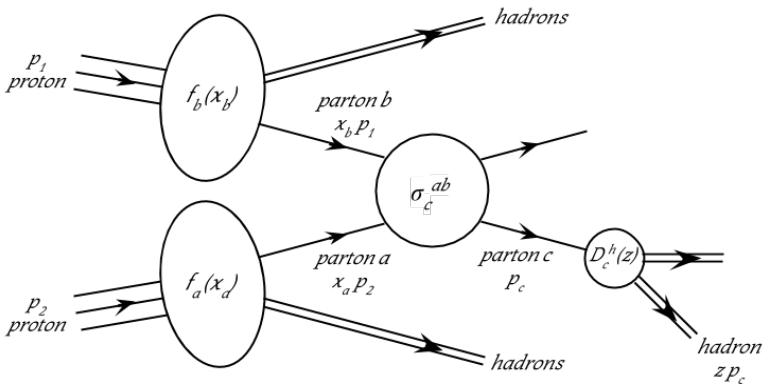


- "Double Longitudinal Spin Asymmetry" then defined in terms of cross-sections:

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

- Can be similarly defined for fixed target experiments

Factorization in p+p



- How to interpret A_{LL}?
- Known a priori:
  - parton-parton cross sections (calculable in pQCD)
  - *including gluon scattering!*
- Ingredients from other experiments:
  - Fragmentation functions (from e+e- scattering)
  - quark (p)PDFs
- Assume "factorization:"

polarized PDF

$$A_{LL} = \frac{\sum_{abc} \Delta f_a(x_1, \mu_F^2) \otimes \Delta f_b(x_2, \mu_F^2) \otimes \Delta\sigma^{a+b\to c+X}(x_1, x_2, p_c, \mu_F^2, \mu_R^2, \mu_{FF}^2) \otimes D_c^h(z, \mu_{FF}^2)}{\sum_{abc} f_a(x_1, \mu_F^2) \otimes f_b(x_2, \mu_F^2) \otimes \sigma^{a+b\to c+X}(x_1, x_2, p_c, \mu_F^2, \mu_R^2, \mu_{FF}^2) \otimes D_c^h(z, \mu_{FF}^2)}$$

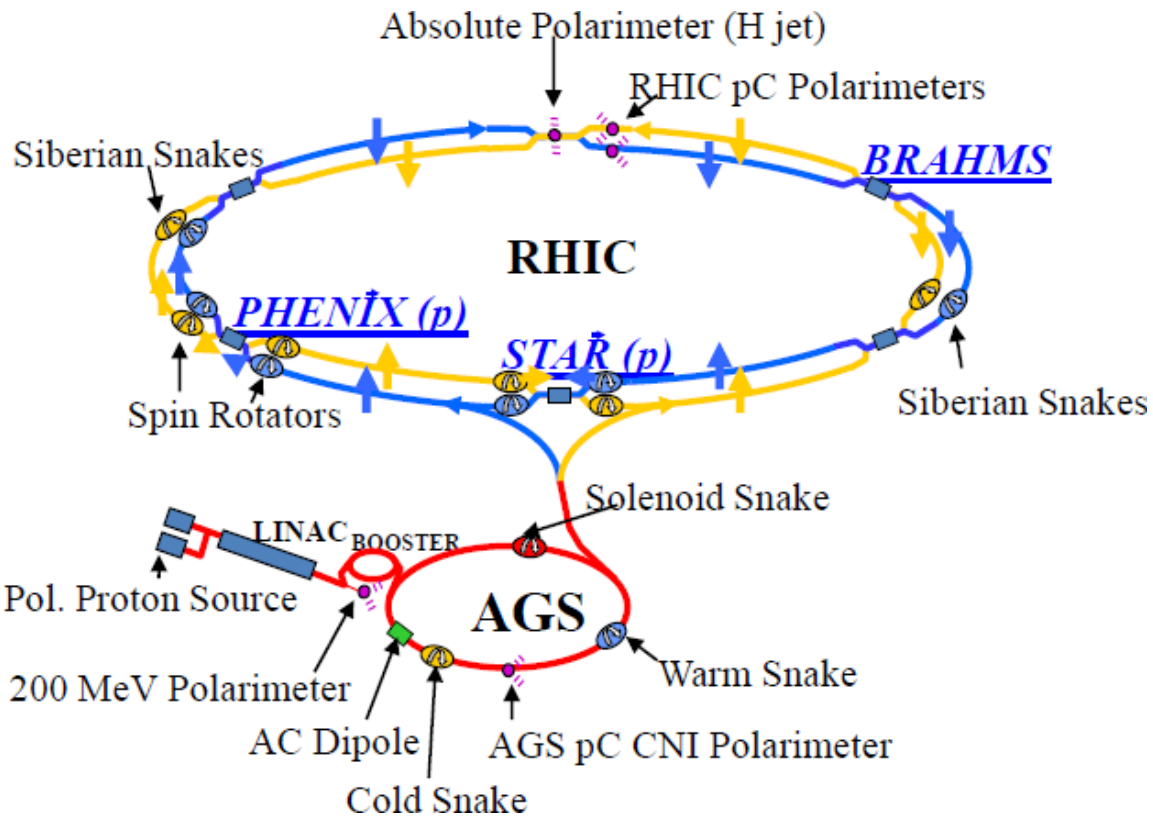
partonic reaction a+b -> c

partonic x-sect

fragmentation function

- Factorization tested in each case by checking denominator against absolute x-section

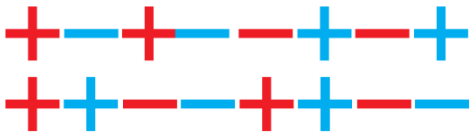
RHIC: Relativisitic Heavy Ion Collider



- Variable√s: **62.4**, **200**, **500** GeV

most of this talk

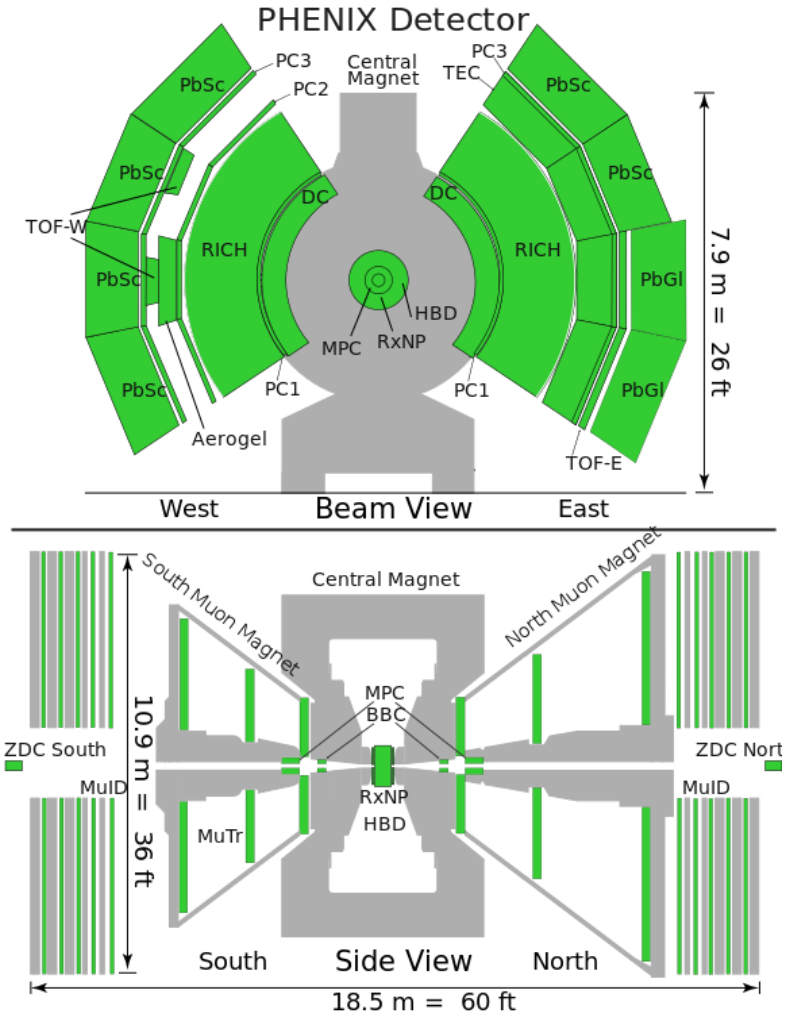
- Up to 120 proton bunches rotating in each ring
- Polarization can be chosen on a bunch-by-bunch basis, e.g.



- Spin Rotators allow polarization axis to be made transverse, longitudinal, or radial at different experiments
- Overall polarization P_B, P_Y, measured precisely by pCarbon polarimeters, and normalized to accurate Hydrogen-jet polarimeter meas.
- Polarization axis must be measured individually at each experiment

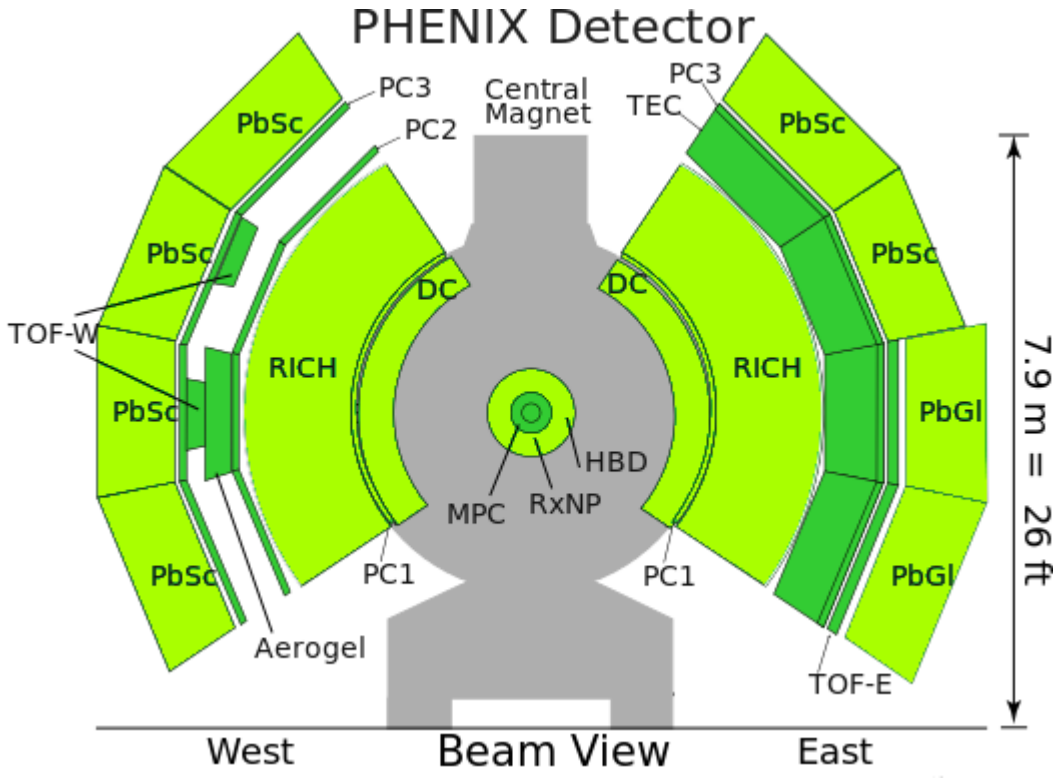
The PHENIX Experiment at RHIC

- **Central arms**
  - |η| < 0.375, Δφ = (π/2) x 2
  - Tracking
    - **D**rift **C**hamber (Multi-Wire Proportional)
    - **P**ad **C**hambers
  - Particle ID
    - **R**ing **I**maging **Ch**erenkov detector
    - **H**adron **B**lind **D**etector (Gas Electron Multiplier) in '09 and '10
  - EM Calorimetry
    - Two separate technologies for cross-check
    - Lead-Scintillator (**PbSc**)
      - sampling calorimeter
    - Lead-Glass (**PbSc**)
      - Cherenkov radiation calorimeter
- **Forward arms**
  - Tracking, Calorimetry, Muon Identification
  - Minbias detectors
    - **Z**ero **D**egree **C**alorimeter:
    - Δη = ±(3.1 to 3.9), |z| = 18m
      - outside of bending field, sees neutrals
    - **B**eam-**B**eam **C**ounter: |Δη| = > 6, |z| = 1.4m
      - reconstruct collision z-vertex online with ~5cm resolution



Final-state Probes for A_{LL}

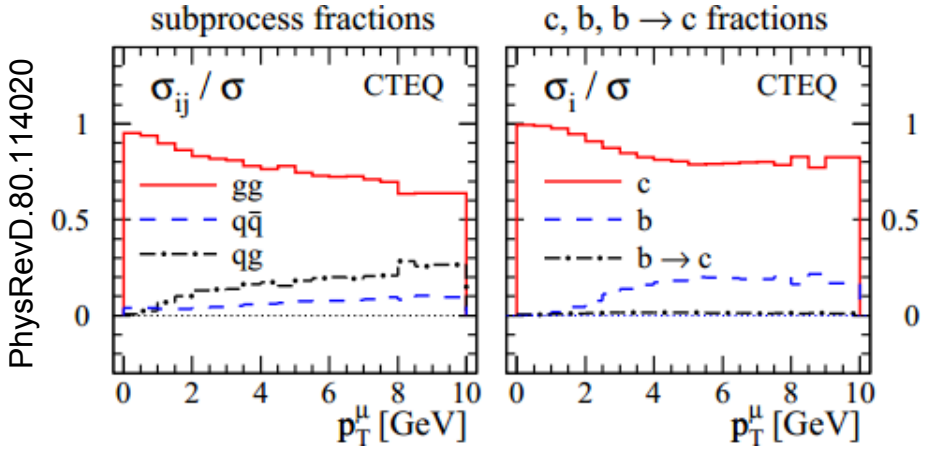
- PHENIX is a versatile detector that allows A_{LL} measurements from a variety of complementary probes, including:
  - Single electrons from heavy flavor decays
    - dominated by gluon-gluon scattering
  - Electromagnetic clusters at forward rapidity
    - low Bjorken-*x* reach
  - Identified charged pions
    - sensitivity to sign of ΔG
  - Neutral meson decays
    - statistically powerful probe
  - π^0 pairs
    - improved *x* resolution through correlation



Probe: Heavy Flavor Decays

Probe: Heavy Flavor Decays

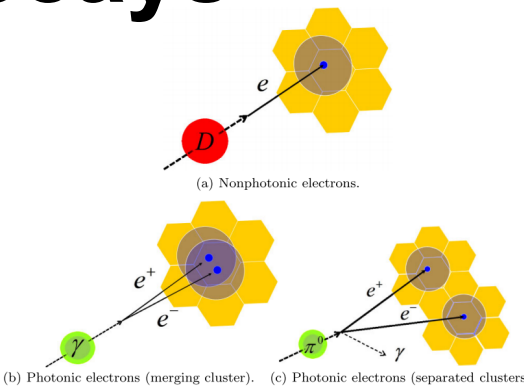
- Analysis of electrons (positrons) from Heavy Flavor Decays
- Dominated by gluon-gluon scattering resulting in a c-cbar pair



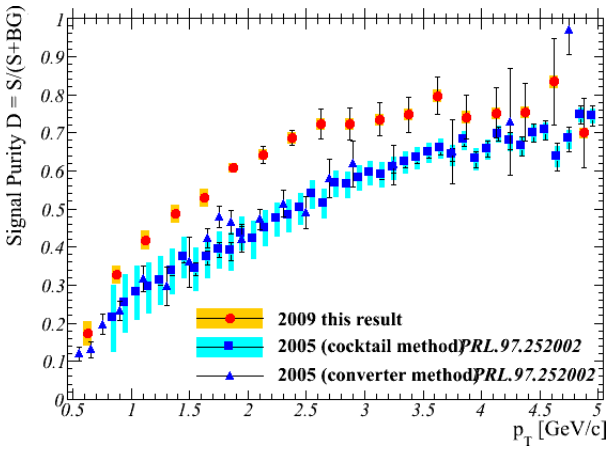
PhysRevD.80.114020

- Measure electron from decay of heavy flavor meson
  - e.g.

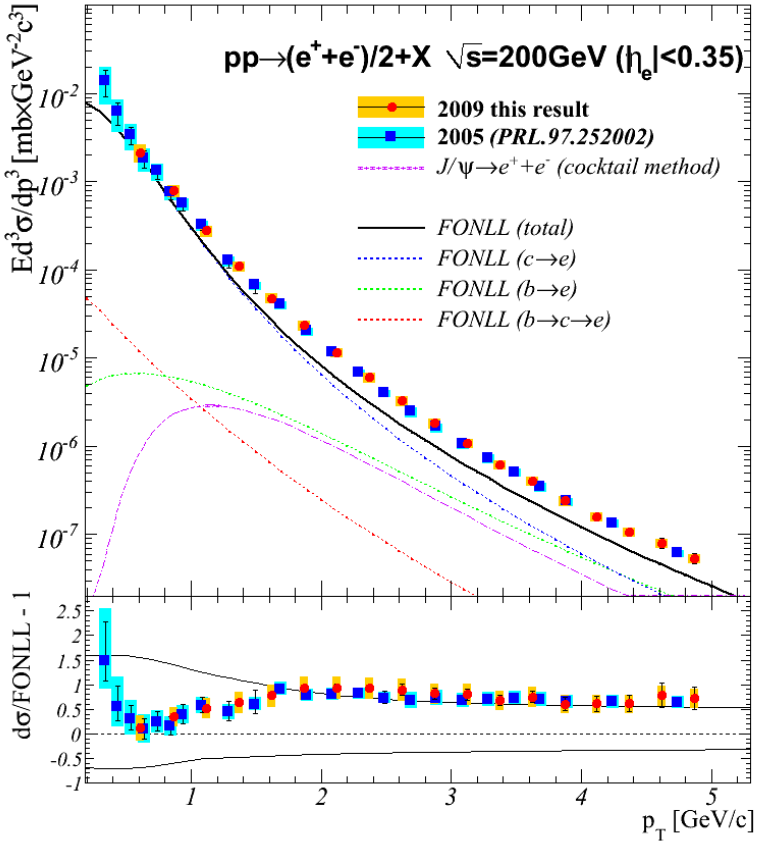
$$D^+ \rightarrow \bar{K}^0 \nu_e e^+$$



- Improved BG rejection with Hadron Blind Detector in Run9
  - Cherenkov Radiator/GEM detector, 50 cm from IR
  - 6.2 cm^2 pads, circle from electron rad. slightly larger than 1 pad

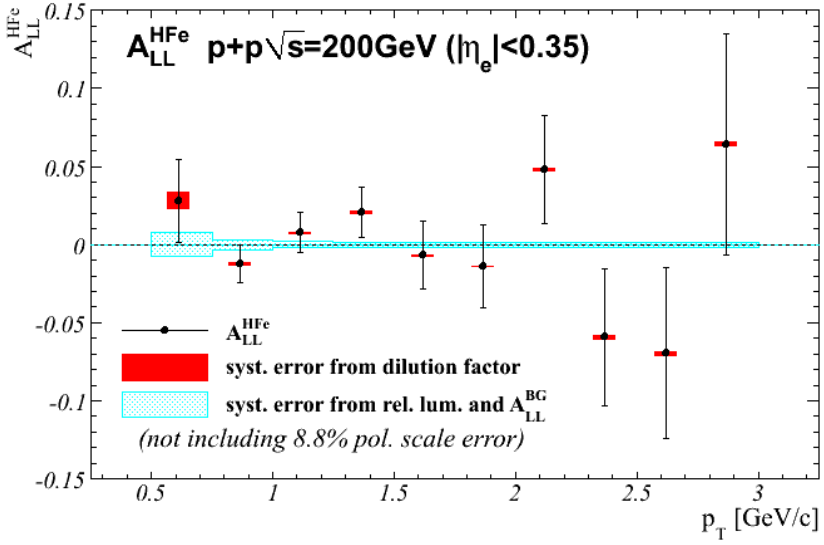


Probe: Heavy Flavor Decays



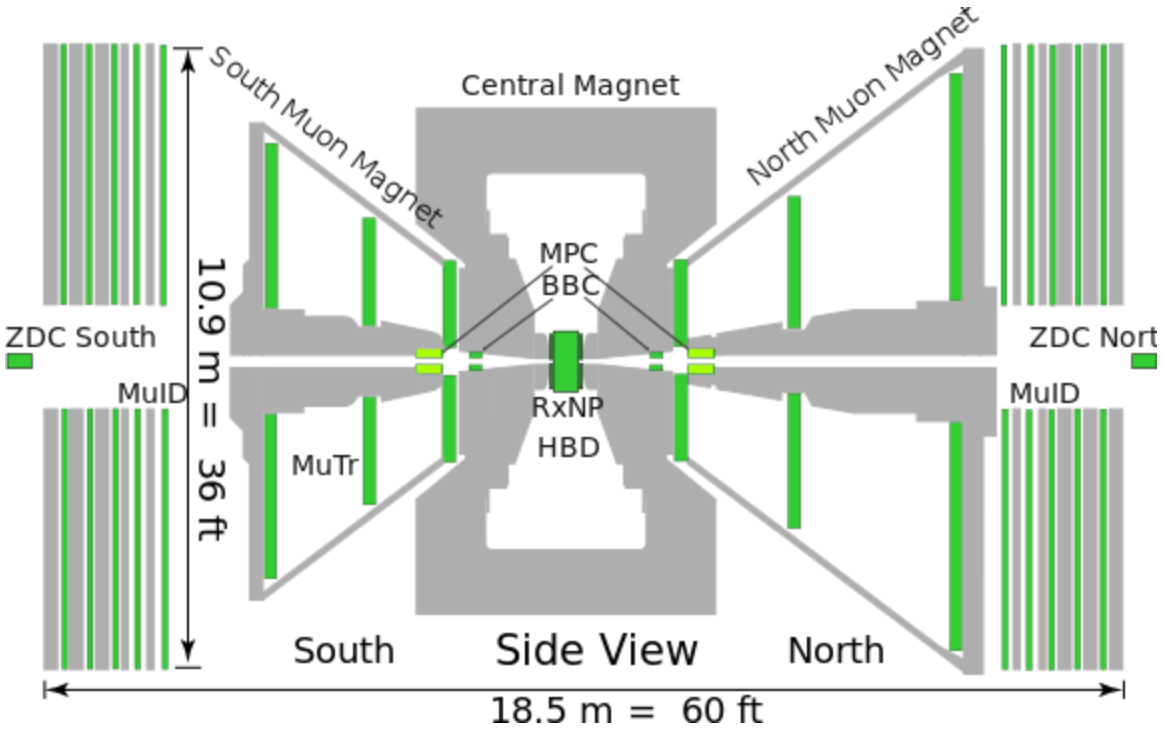
- cross section measurement at upper limit of theory uncertainty

- gluon-gluon scattering:
  - sensitive to magnitude of Δg
  - negligible quark scattering contribution to asymmetry



- resultant constraint:

$$|\Delta G^{[0.01,0.08]}| < 0.85\ (1\sigma), \mu = 1.4\ \mathrm{GeV}/c^2$$



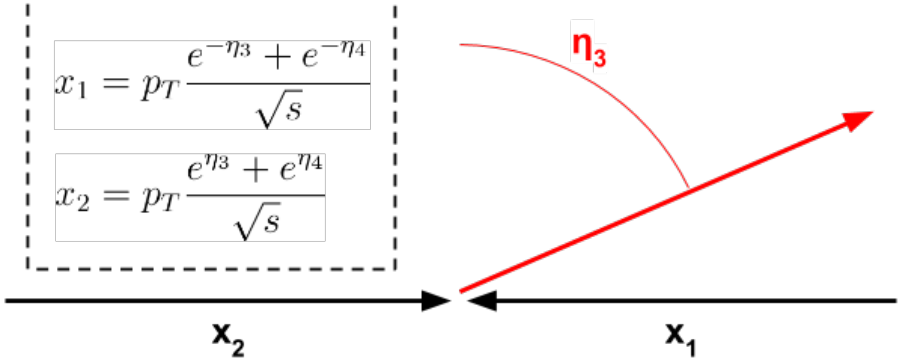
Probe: EM Clusters at Forward Rapidity

Probe: EM Clusters at Forward Rapidity

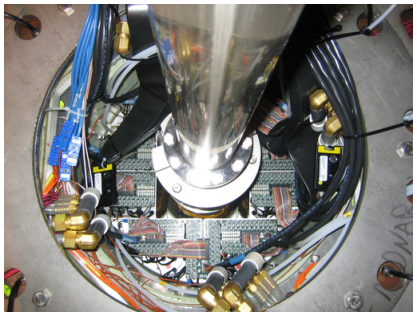
- Forward A_{LL} allows access to lower Bjorken-x
  - for partonic reaction 1+2 → 3+4 :

$$x_1 = p_T \frac{e^{-\eta_3} + e^{-\eta_4}}{\sqrt{s}}$$

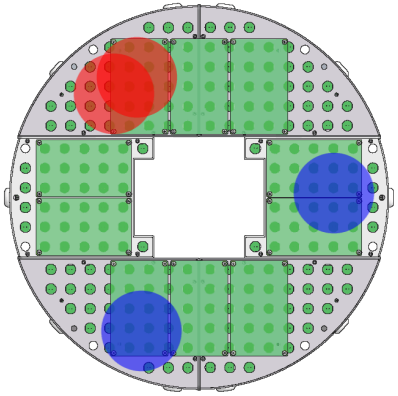
$$x_2 = p_T \frac{e^{\eta_3} + e^{\eta_4}}{\sqrt{s}}$$



- Measurement of high statistics forward π^0 production
- Can extend PHENIX ΔG reach down to x ~ 0.002
  - central arm π^0 down to x ~ 0.02



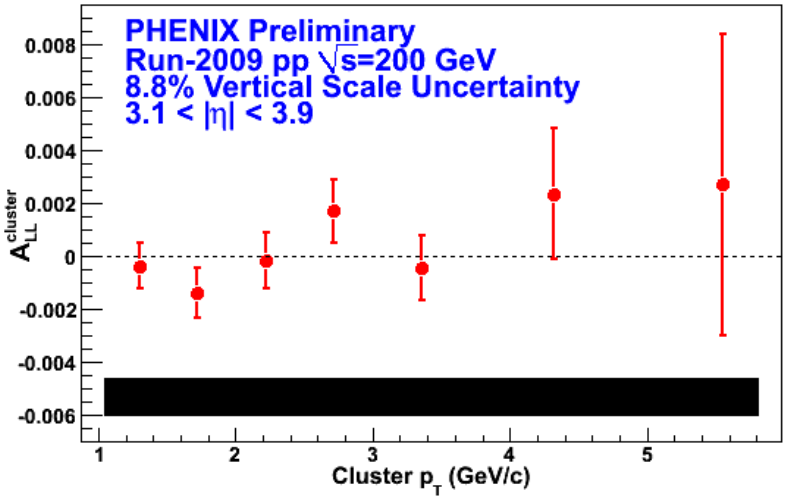
- Muon Piston (EM) Calorimeter
  - 3.1 < |η| < 3.9, Δϕ = 2π
  - 4.8 cm^2 towers
  - $\pi^0 \rightarrow \gamma\gamma$ measurement limited by merging at $p_T \gtrsim 2$ GeV/c
    - analyze unidentified electromagnetic “clusters”



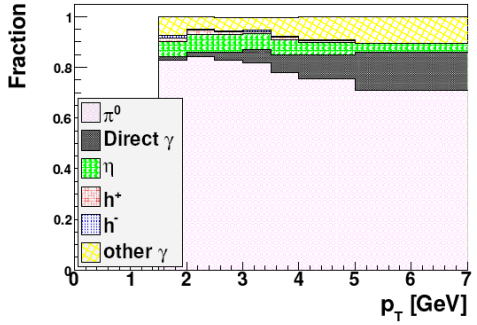
π^0 meson decay
η meson decay

Probe: EM Clusters at Forward Rapidity

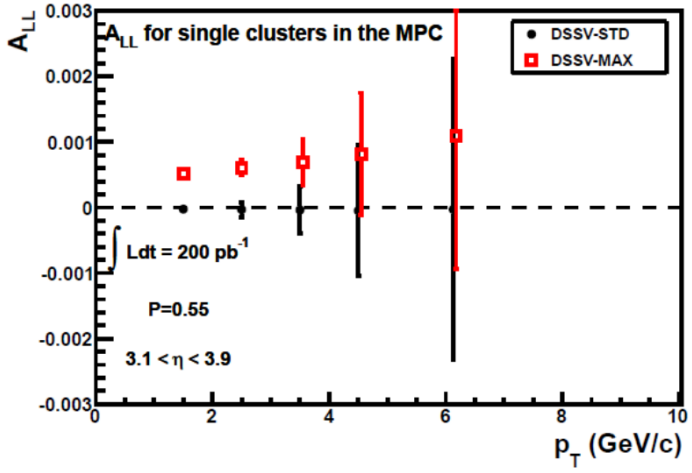
- Preliminary result for cluster asymmetry at √s = 200 GeV

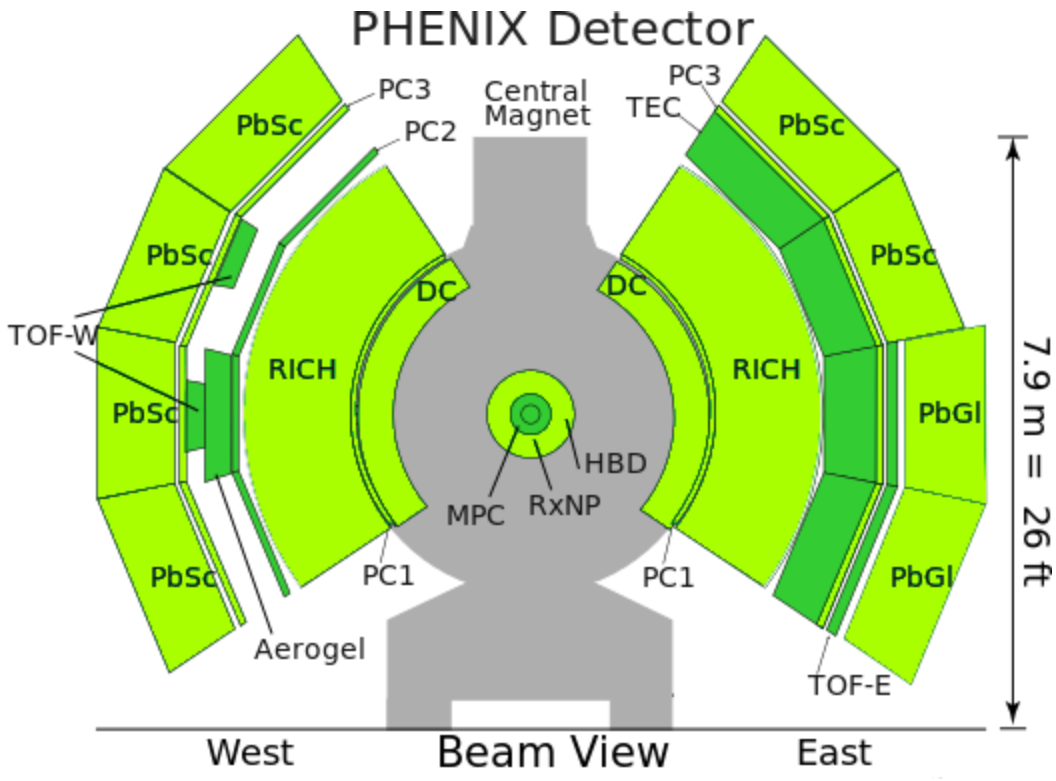


- Approximate cluster composition (from PYTHIA):



- Analysis of √s = 500 GeV datasets underway
- Readout electronics and trigger upgrade for Run12
  - purity of trigger improved by factor 4
- Expected statistical uncertainty on cluster A_{LL} from *existing* 500 GeV data expected to be ~1e^{-4}

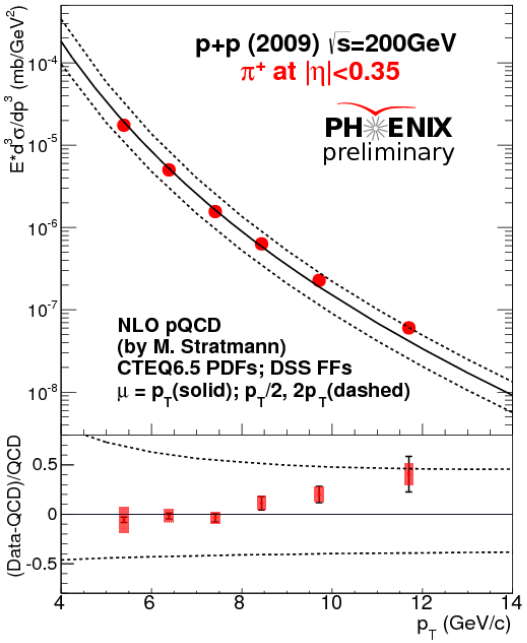


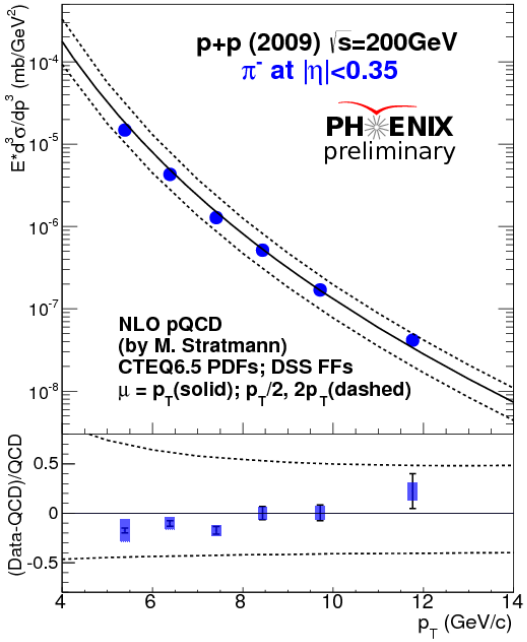


Probe: Charged Pions

Probe: Charged Pions

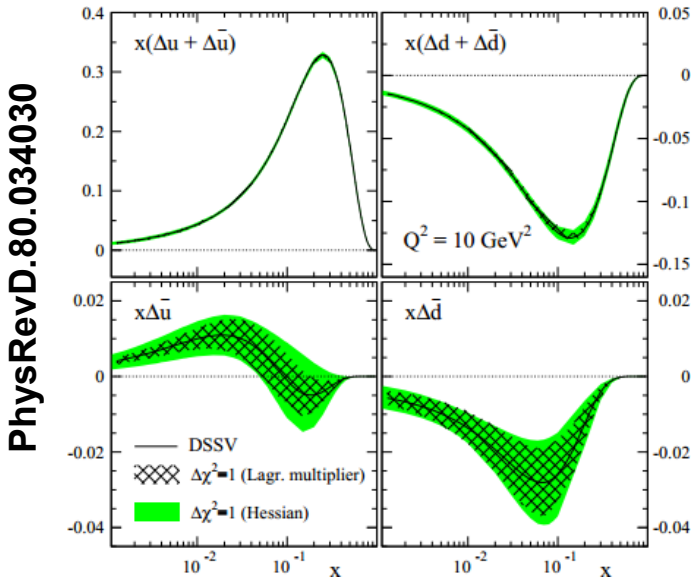
- Identified π^+, π^-
  - Ring Imaging Cherenkov Detector
    - electrons: 0.017 GeV/c
    - muons: 3.5 GeV/c
    - pions: 4.7 GeV/c
- Main source of BG:
  - conversions before DC, look like high p_T tracks
- Matching to HBD hit brings background to ~1% level
  - enables high pT cross section measurement



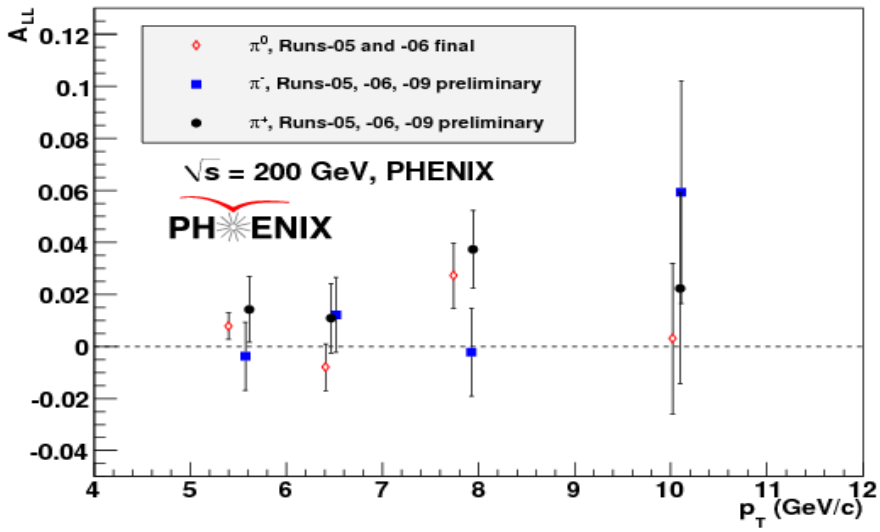


Probe: Charged Pions

- Valence quark content:
  $\pi^+ = u\bar{d} \quad \pi^- = d\bar{u}$
- Plus large polarizations for u and d quarks:



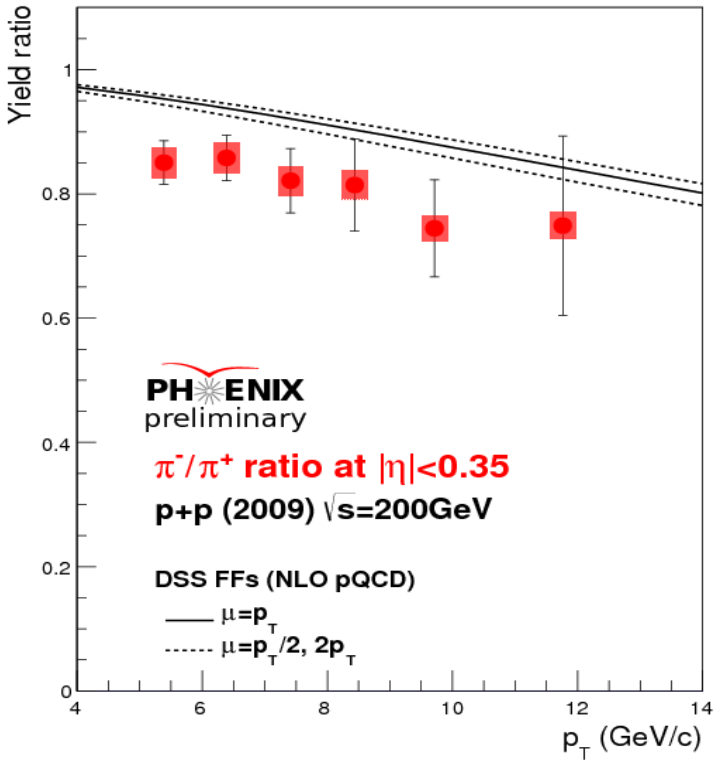
- Result without HBD
  - Tight EMCal shower shape and other cuts alleviate BG problem

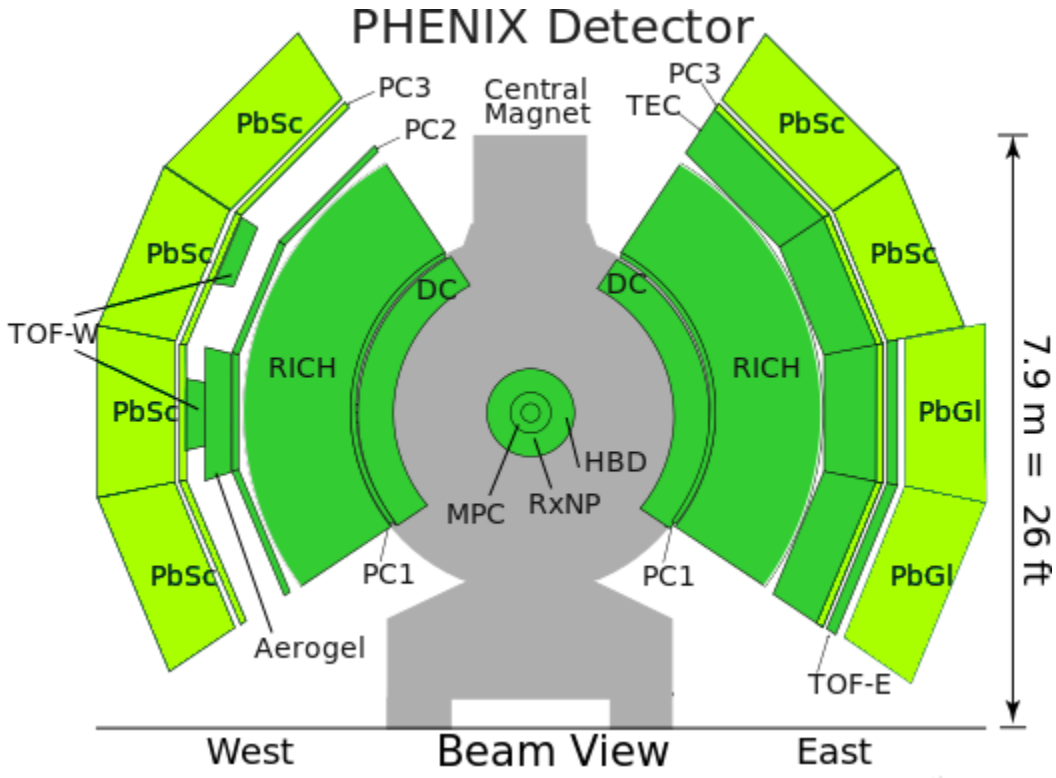


- Leads to ΔG sign sensitivity:
  $A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-} \Rightarrow \Delta G > 0$
  $A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-} \Rightarrow \Delta G < 0$

Probe: Charged Pions

- Inclusion of "charge neutralized" average of charged pion A_{LL}s in global analysis already possible
  - lose sensitivity to sign of ΔG
- For full inclusion, fragmentation functions need to be updated to account for π^+, π^- cross sections
  - global analyses needs to include high-p_T p+p cross section measurements





Probe: Neutral Mesons (π^0 and η)

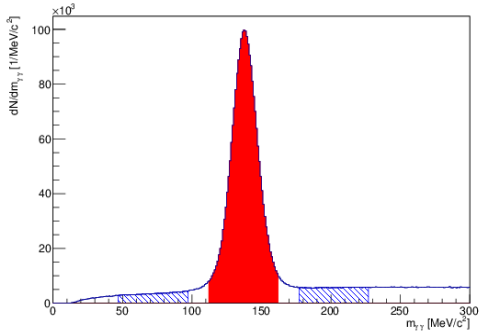
Probe: Neutral Mesons

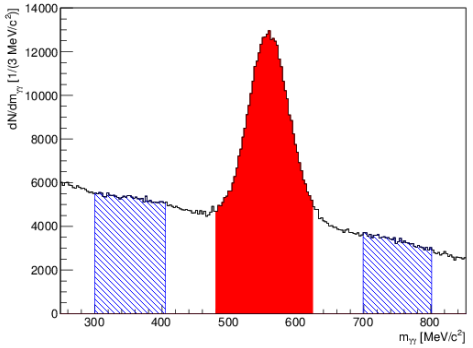
- Analyze through the γγ decay channel
  - PHENIX EMCal
    - Δη ~ 0.01, Δφ ~ 0.01 rad. segmentation
  - B.R. 99%for π^0, 39% for η
- Count signal region (red) and sideband region (blue) counts in ++ and +- helicity crossings:

$$A_{LL} = \frac{1}{P_B P_Y}\left(\frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}\right),\ R \approx \frac{N^{++}_{BBC}}{N^{+-}_{BBC}}$$

- Relative Luminosity R is measured using minbias BBC scalars
  - largest systematic uncertainty from confidence that BBC sees zero asymmetry
- Interpolate combinatorial B.G. shape under peak to get background fraction "r"

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{signal} - rA_{LL}^{sides}}{(1-r)}$$

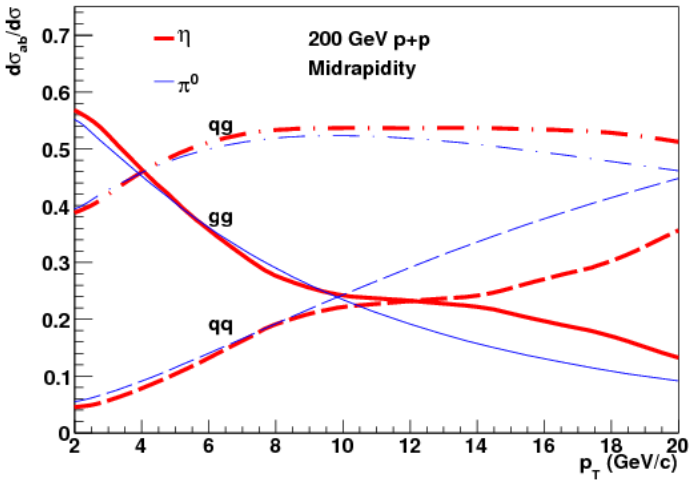




Advantage:

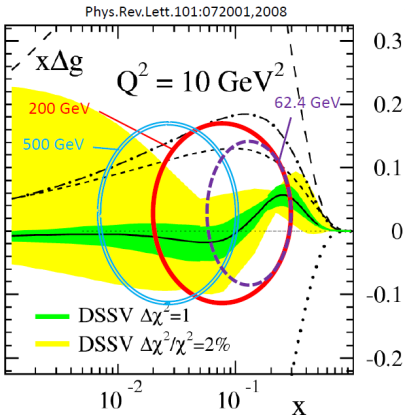
- identifiable mass peak
- choose cuts to minimize total uncertainty

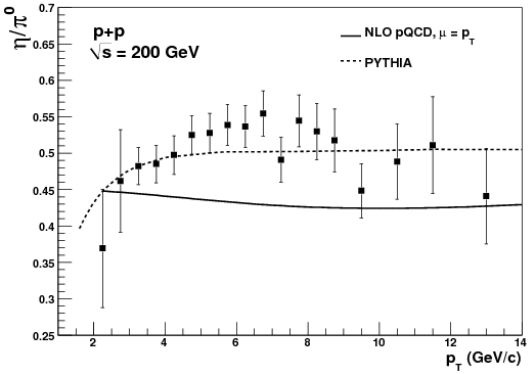
Probe: Neutral Mesons



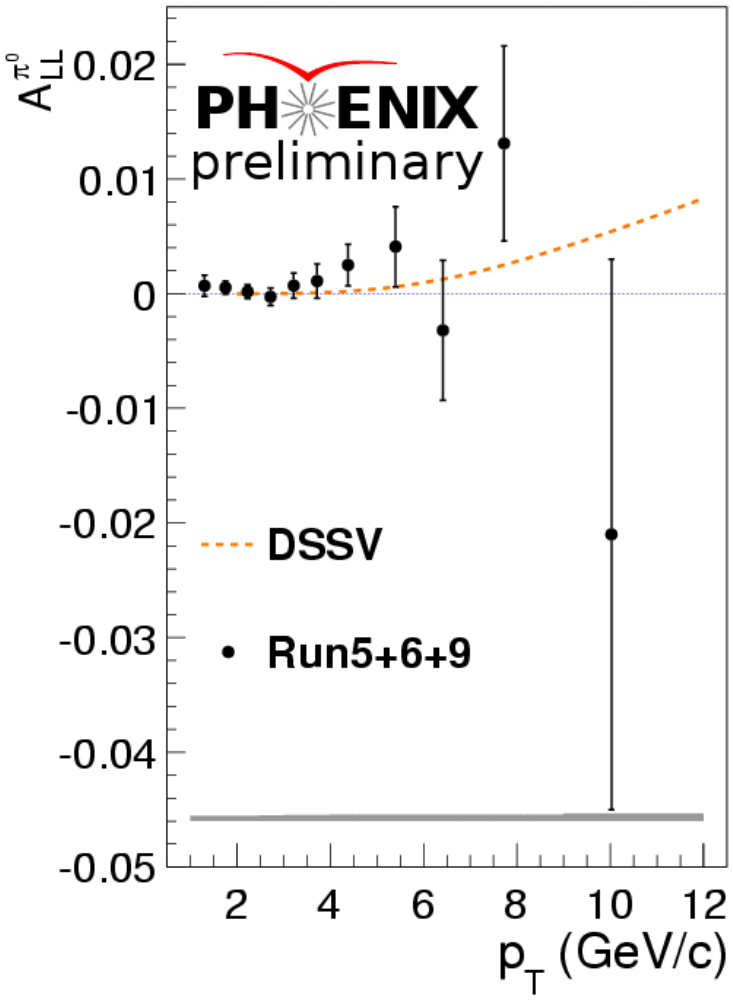
- q-g and g-g sub-processes at low p_T
- π^0 is the highest statistics PHENIX central arm probe
  - excellent constraint of ΔG
- η has larger decay opening angle, measurable to higher p_T
  - π^0 decays merge ~10 GeV/c
  - η at ~ 20 GeV/c

- $\sqrt{s}$ = 200, 62.4 GeV PHENIX π^0 currently used in global analysis
- $\sqrt{s}$ = 500 GeV data under analysis
- inclusion of η requires more well-determined fragmentation functions in global analysis

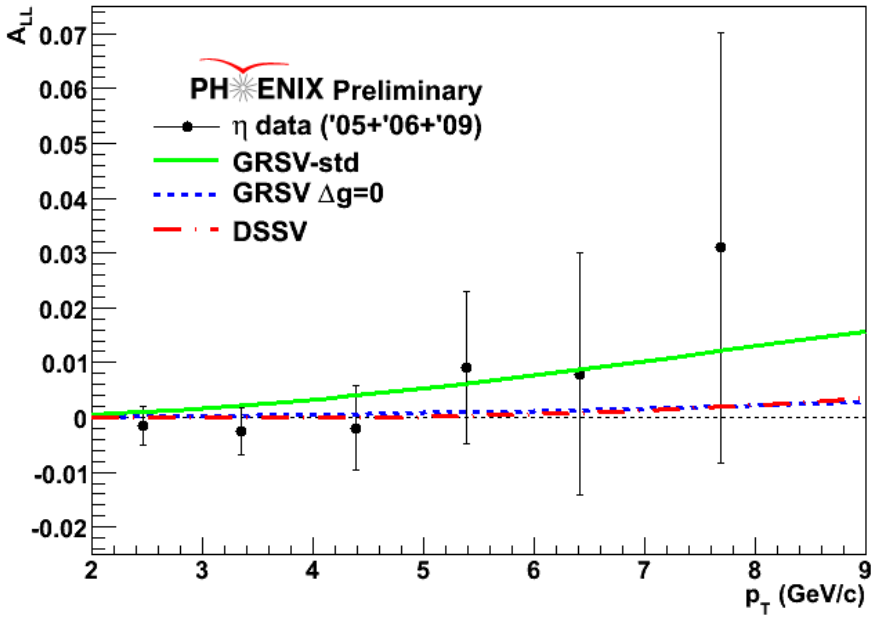




Probe: Neutral Mesons

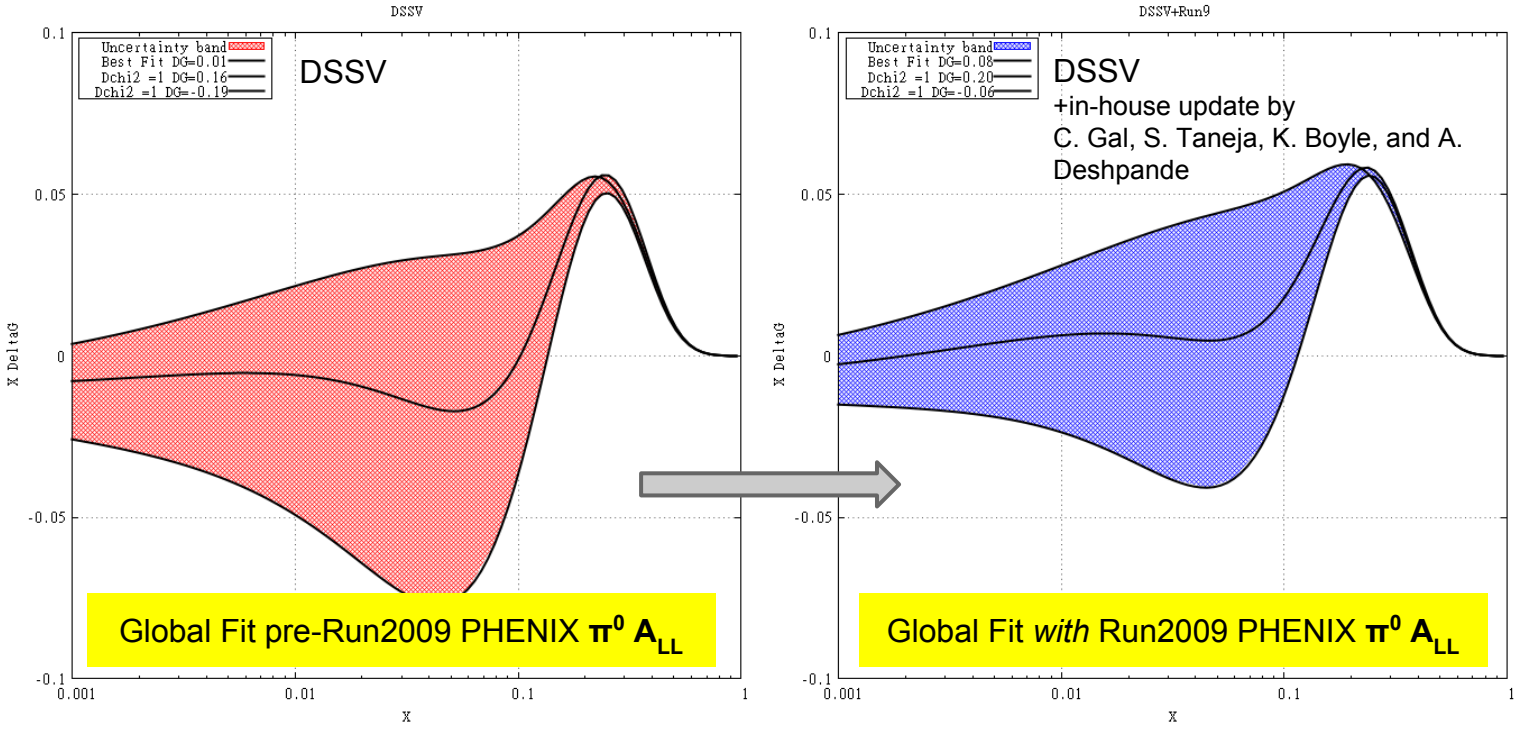


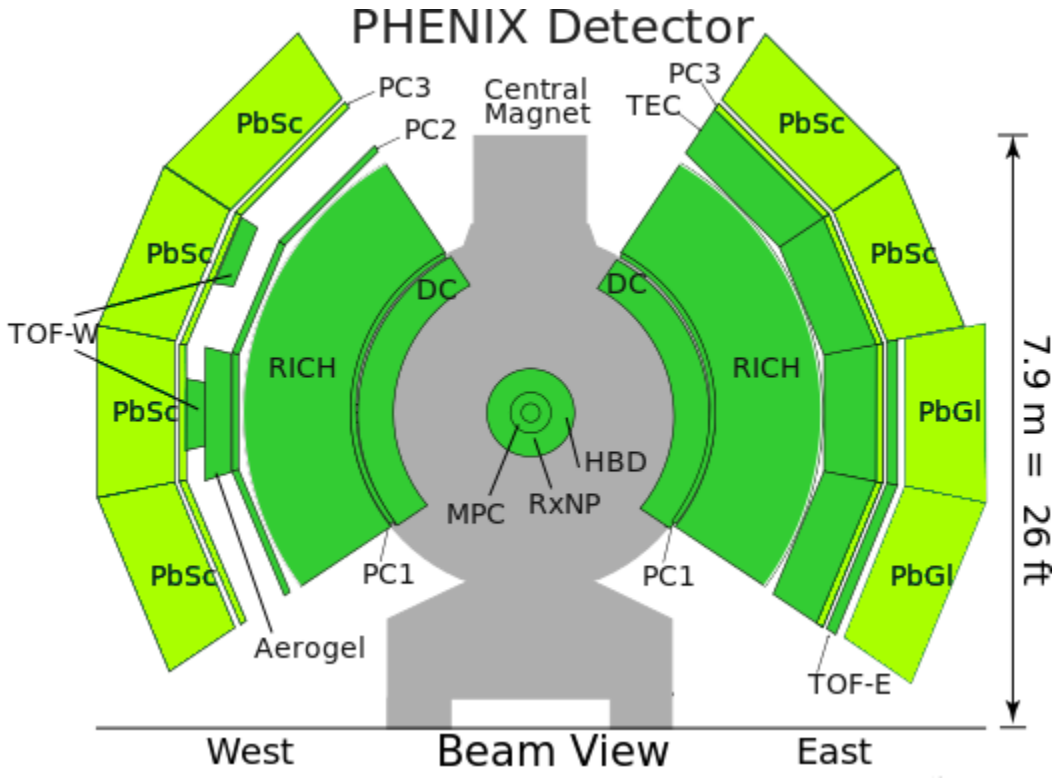
- PHENIX Run9 Prelim. results @ √s = 200 GeV
- Final results out soon
  - refinement of cuts
  - addition of 12-15 GeV/c pT bin for π^0



Probe: Neutral Mesons

- Inclusion of Run9 A_{LL} π^0 in DSSV08 Global Analysis (PhysRevD.80.034030)
  - Central curve also affected by update of Run6 values to final
    - Finalization of Run9 data will move curve down slightly
  - ΔG in "RHIC" range [0.05,0.2] consistent with small or zero
  - Systematic uncertainty treatment lacking
    - DSSV does not include p_T correlation

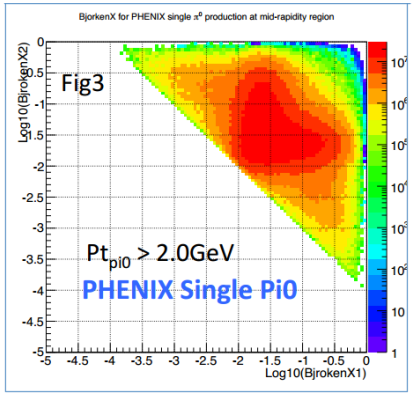


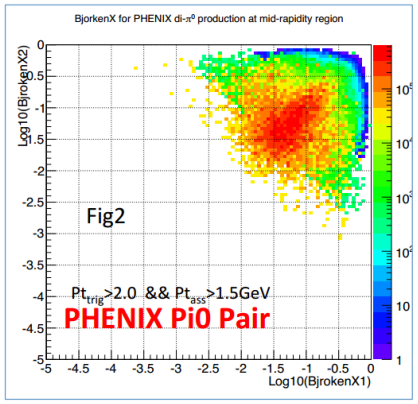


Probe: π^0 pairs

Probe: π^0 Pairs

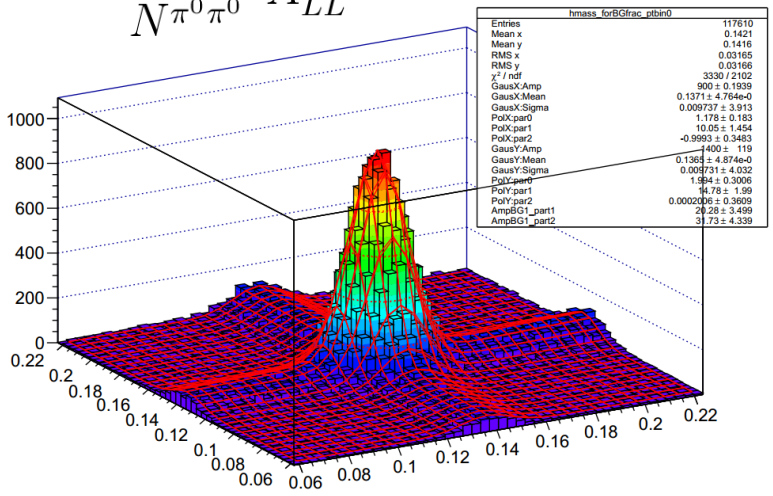
- π^0-π^0 correlation gives better Bjorken-x determination:



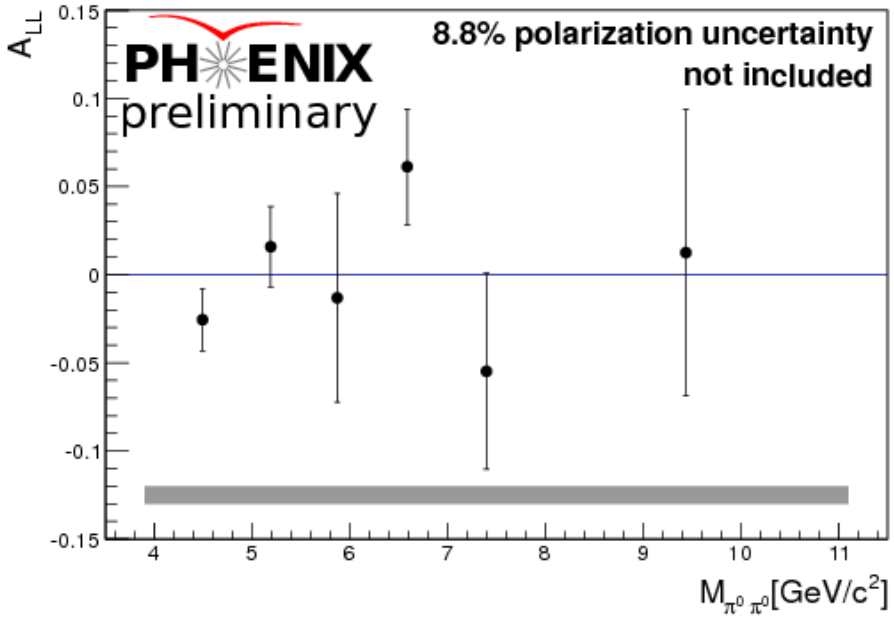


- Analysis similar to single inclusive π^0 with an added dimension

$$A_{LL}^{\pi^0\pi^0} = \frac{N^{\pi^0\pi^0+\pi^0 BG+BGBG}}{N^{\pi^0\pi^0}} A_{LL}^{\pi^0\pi^0+\pi^0 BG+BGBG} - \frac{N^{\pi^0 BG}}{N^{\pi^0\pi^0}} A_{LL}^{\pi^0 BG} - \frac{N^{BGBG}}{N^{\pi^0\pi^0}} A_{LL}^{BGBG}$$



Probe: π^0 Pairs



- Statistics limited
- First pair correlation A_{LL} measurement in PHENIX
- Possible extensions to
  - π^0 + hadron
  - central arm π^0 + forward cluster

Summary & Outlook

- Summary:
  - PHENIX measures a variety of probes that give complementary information about ΔG
  - Significant constraints on Δg(x) from p+p scattering
    - PHENIX π^0 data consistent with small or zero ΔG in measured region
    - Plenty of measurements not yet included in global analysis
- Outlook:
  - $\sqrt{s}$ = 500 GeV datasets to being analyzed
    - high luminosity, lower *x*-reach
    - A_L measurements of central W->e and forward W→μ
      - constrains anti-quark spin
  - Heavy flavor asymmetry measurements with VTX
  - sPHENIX upgrade
    - enhanced di-jet asymmetry capabilities