Longitudinal Spin Measurements with Inclusive Hadrons in Polarized p+p Collisions at 200 GeV

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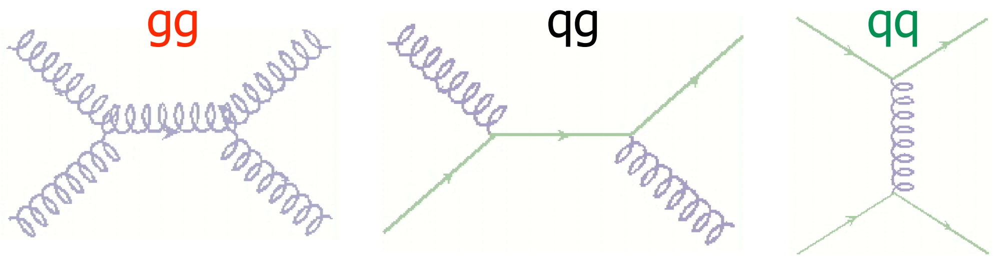
Outline

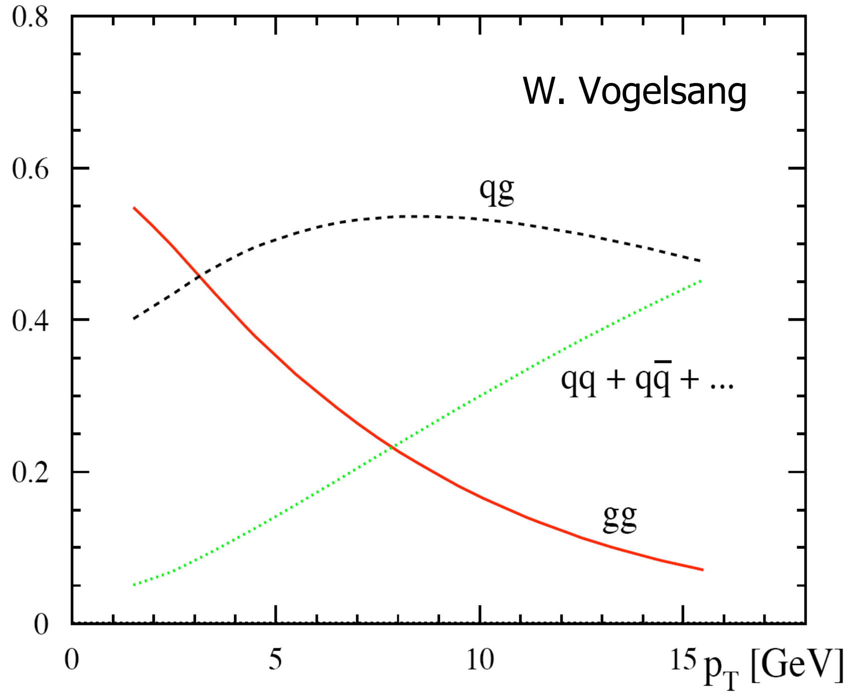
- Introduction
- Experimental Overview
- Inclusive Cross Sections
- Jet fragmentation
- Longitudinal Spin Asymmetries

Introduction

- Polarized p+p collisions provide sensitivity to gluon polarization in the nucleon
- With current statistics the focus is on inclusive measurements (Jets, Pions)
  - large contribution of gg and qg processes to overall cross section => good tool to study gluon polarization, but no constraint of event kinematics
  - Pions probe the same processes as jets, but with different experimental systematics and effects from fragmentation



relative contributions of subprocesses to inclusive π^0 production

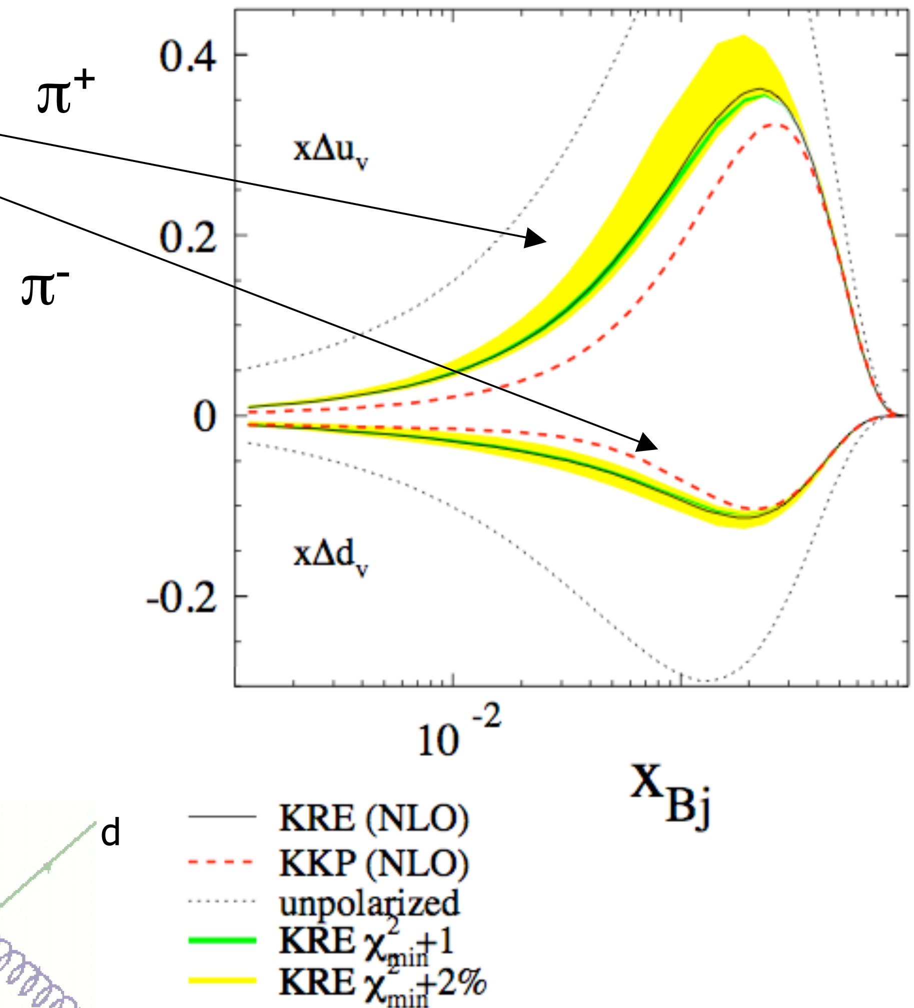


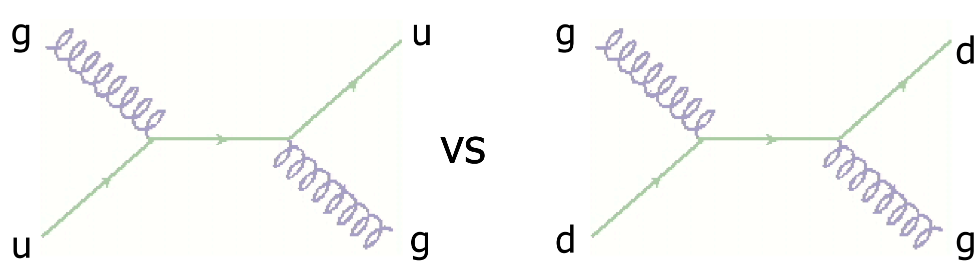
- Unpolarized measurements of inclusive hadrons are of considerable interest:
  - study fragmentation functions via NLO pQCD vs measured cross section comparisons: currently large uncertainty in gluon FF
  - study fragmentation directly: electromagnetic trigger selects jets with leading π^0

Introduction: Charged Pions

- Two complementary measurements with different contributions from polarized quark PDFs
- For qg processes, $A_{LL}(\pi^{+})$ - $A_{LL}(\pi^{-})$ tracks sign of ΔG
- STAR was designed for efficient reconstruction and identification of charged pions over a large range of transverse momenta

D. de Florian et al., PRD 71, 094018 (2005)





The STAR Experiment

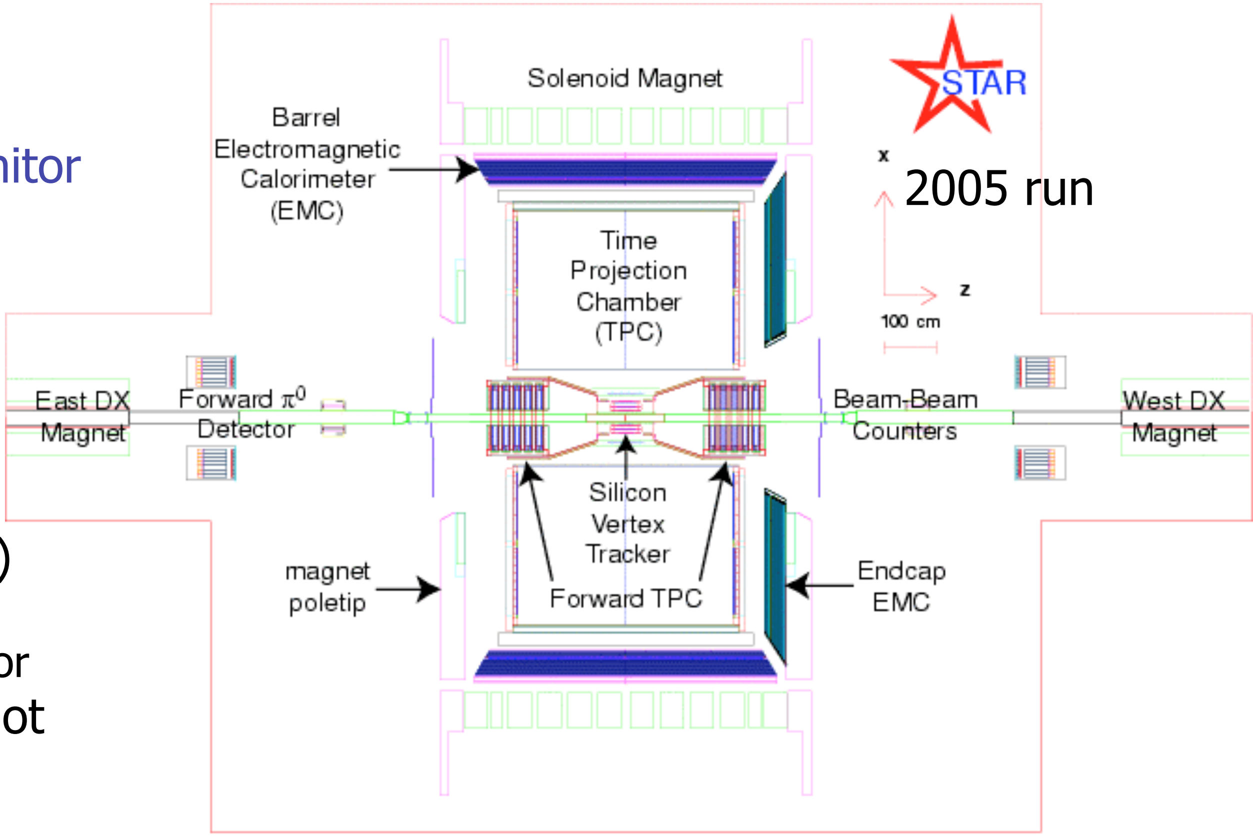
Magnet
- 0.5 T Solenoid

Triggering & Luminosity Monitor
- Beam-Beam Counters
  - $3.4 < |\eta| < 5.0$

Central Tracking
- Large-volume TPC
  - $|\eta| < 1.5$

Calorimetry
- Barrel EMC (Pb/Scintilator)
  - $|\eta| < 1.0$
  - Shower-Maximum Detector

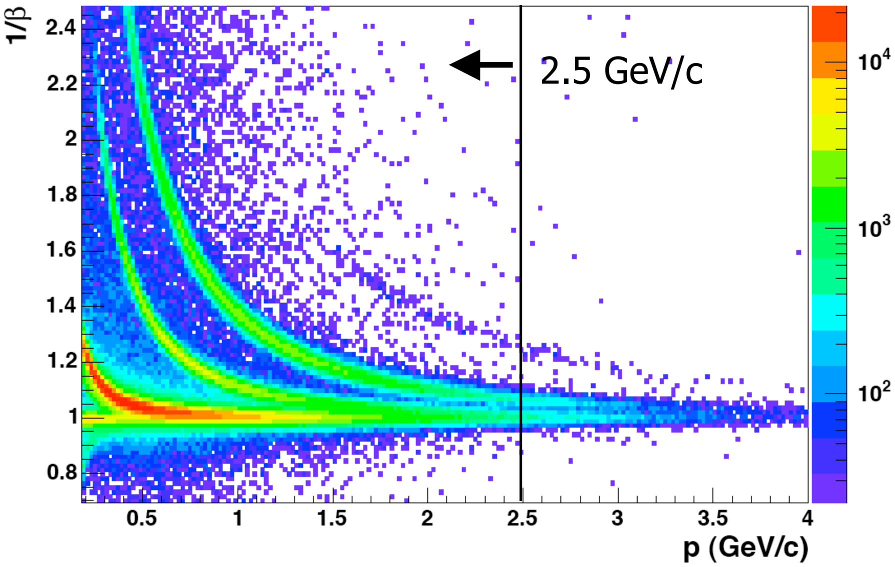
…and many other systems not used in the pion analysis



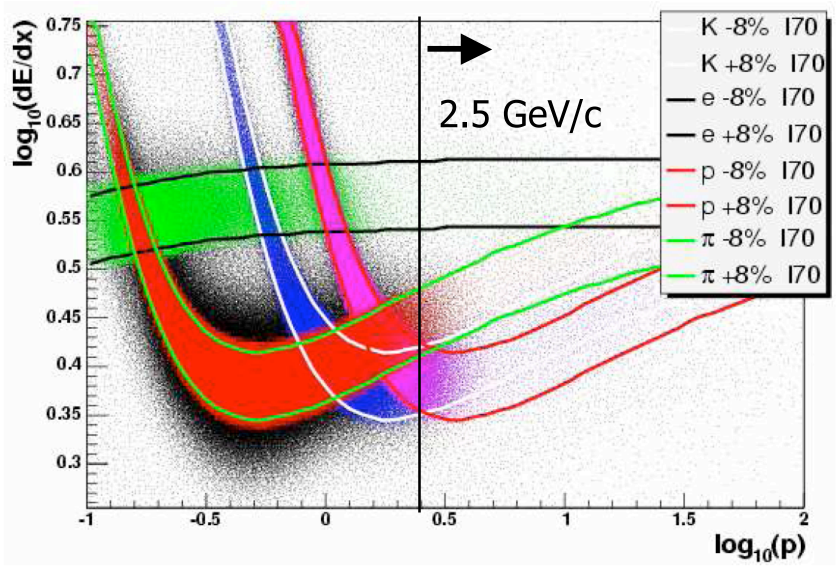
Used Triggers:
- Minimum Bias (MB): BBC Coincidence, highly prescaled
- High Tower 1 & 2 (HT1 / HT2): MB + one BEMC cell ($\Delta\eta x \Delta\phi$ = 0.05 x 0.05) above threshold (lower threshold trigger prescaled)
- Jetpatch Trigger: large BEMC area ($\Delta\eta x \Delta\phi$ = 1 x 1) above threshold

Charged Pions: Extraction

low p_t: particle ID via TOF

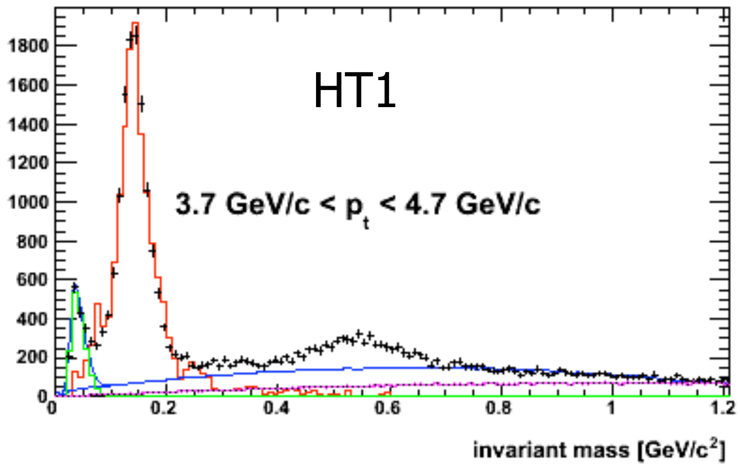


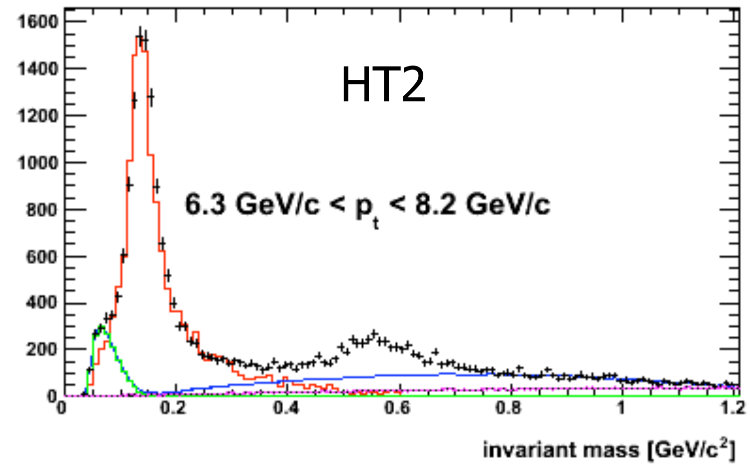
high p_t: particle ID via TPC dE/dx



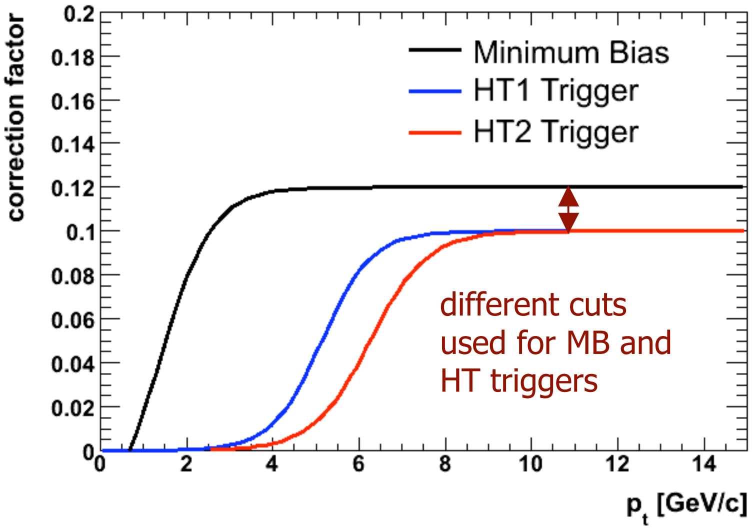
- Time of flight measurement used to separate π, K, p at low p_t (< 2.5 GeV/c), limited by time resolution
- Specific energy loss in the TPC can be used at high p_t to provide π, K, p separation (pt > 2.5 GeV/c) since the π dE/dx is higher than that for K and p in the relativistic rise region

Neutral Pion Reconstruction

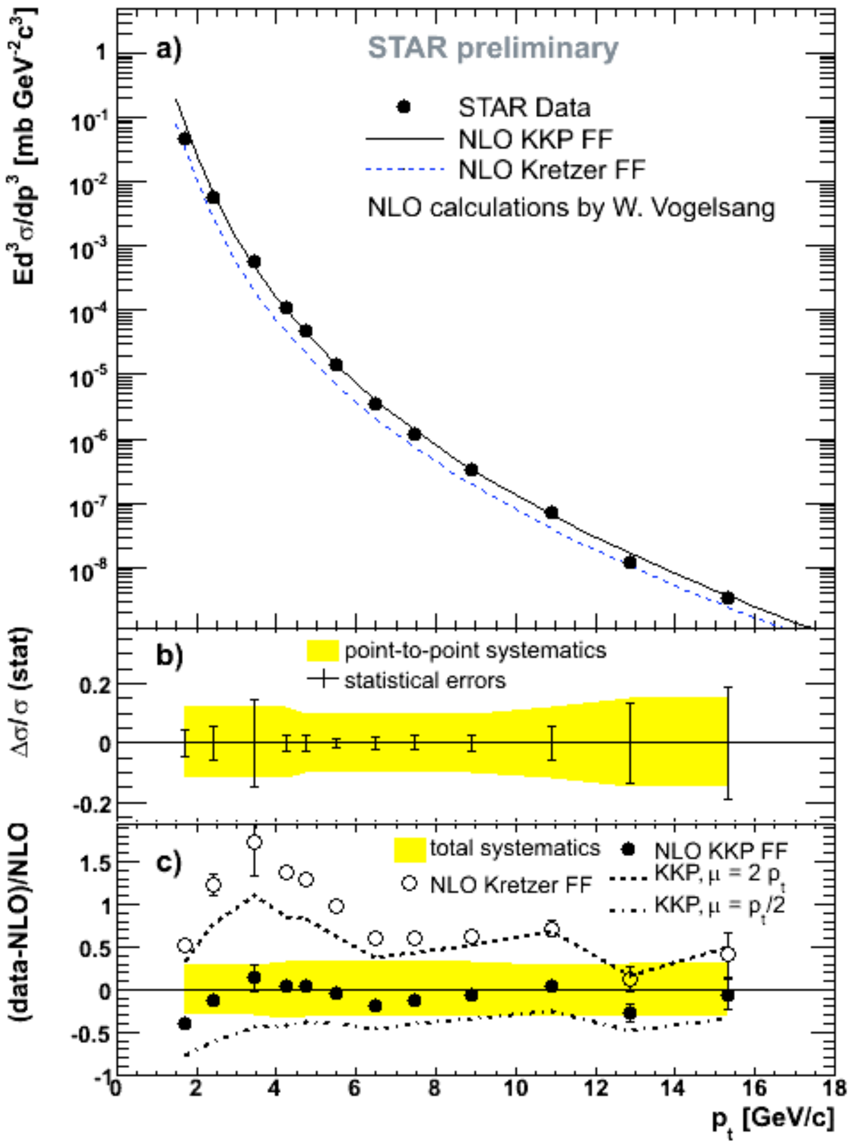




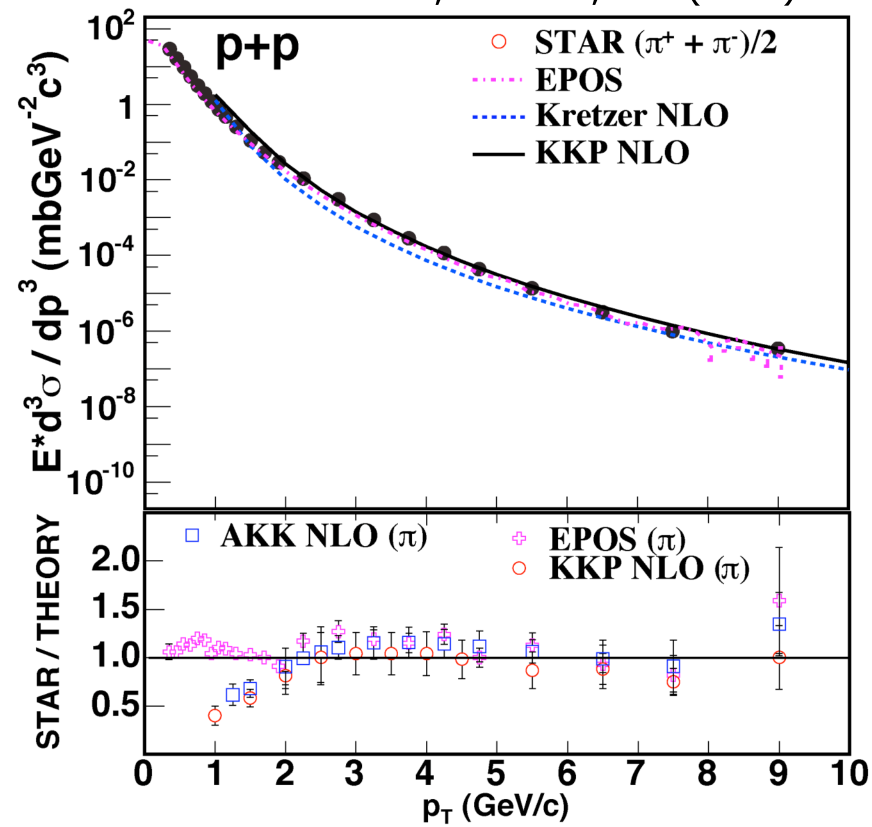
- $\gamma\gamma$ invariant mass spectrum near π^0 mass described by:
  - MC π^0 line shape
  - low invariant mass background (caused by cluster splitting in the SMD)
  - combinatoric background & residual fit
- Correction factor for cross section determination obtained from PYTHIA & HERWIG simulations



Inclusive Pions: Cross Section



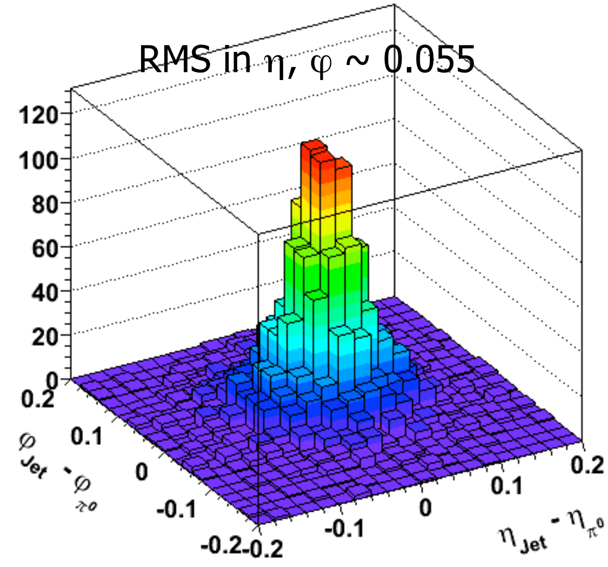
J. Adams et al., PLB 637, 161 (2006)

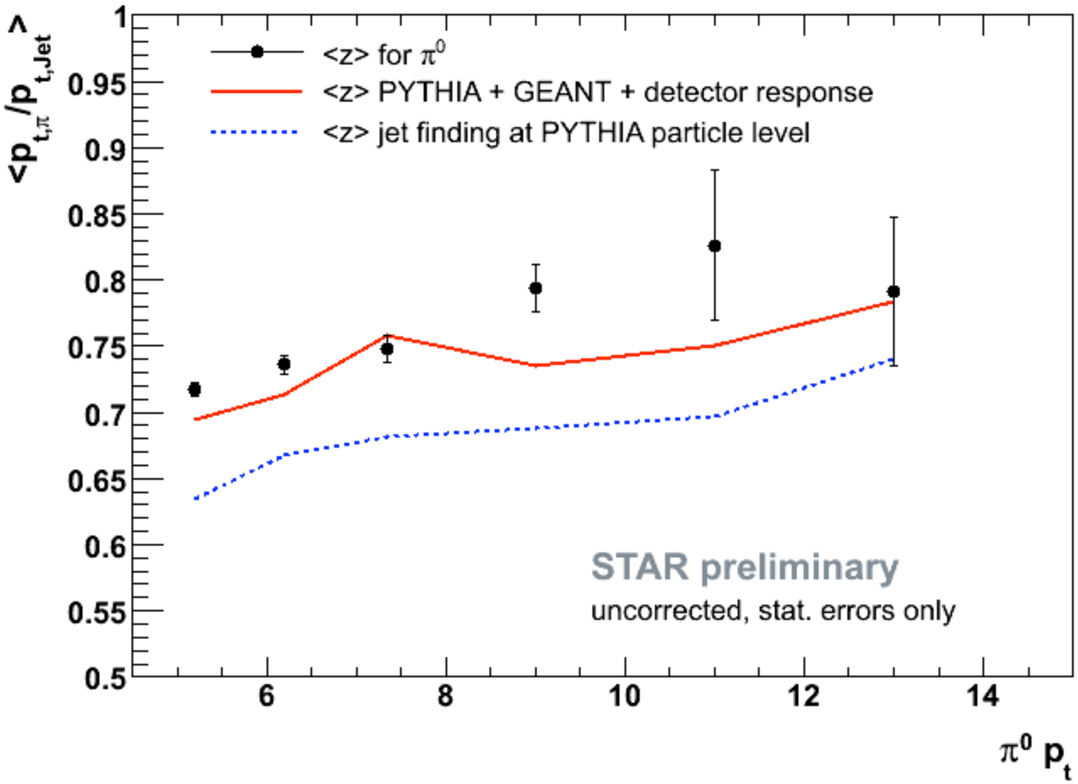


- excellent agreement with NLO pQCD
- charged and neutral pions favor KKP fragmentation functions over Kretzer set
- considerable scale uncertainty in theory

Neutral Pions in Jets

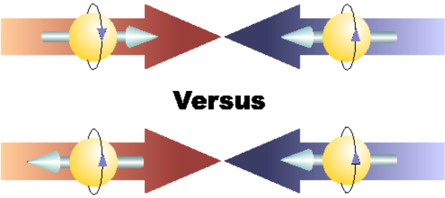
- STAR is capable of full Jet reconstruction
- reconstructed π^0 are associated with Jets (HT triggered) if the π^0 lies within the Jet cone (0.4 in η, φ)
- π^0 direction is strongly correlated with the Jet axis:
  - leading π^0 typically within 5° of the Jet axis





- $\langle z \rangle = \left\langle \frac{p_t^{\pi^0}}{p_t^{jet}} \right\rangle$
- Depends on p_t evolution of cross section and z dependence of the fragmentation function

Asymmetry: Overview



$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \text{ FOM} \sim P_1^2 P_2^2 \cdot \int \mathcal{L} dt$$

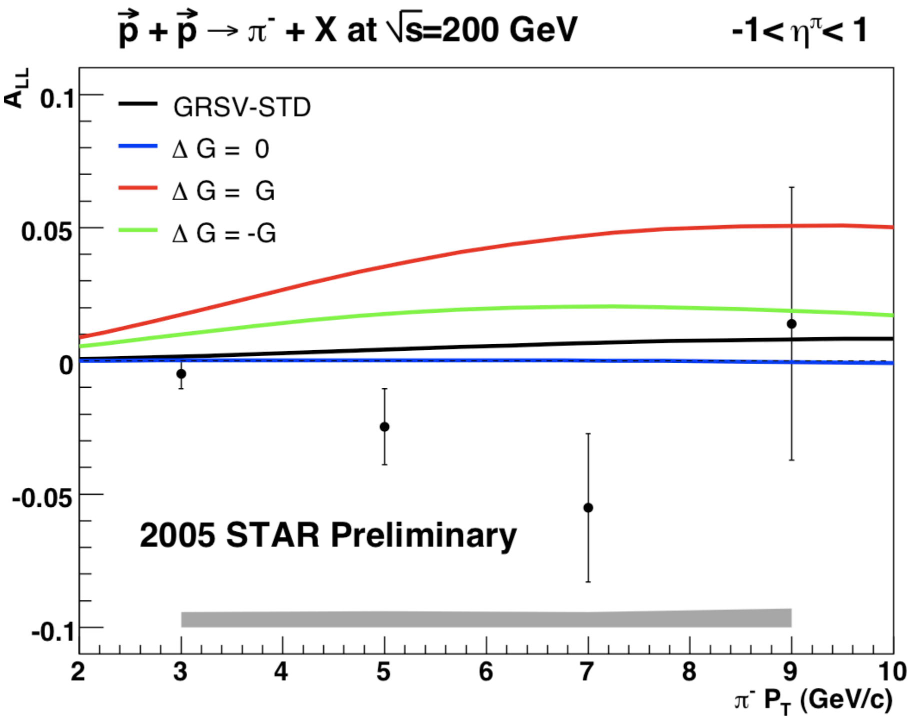
Ingredients:

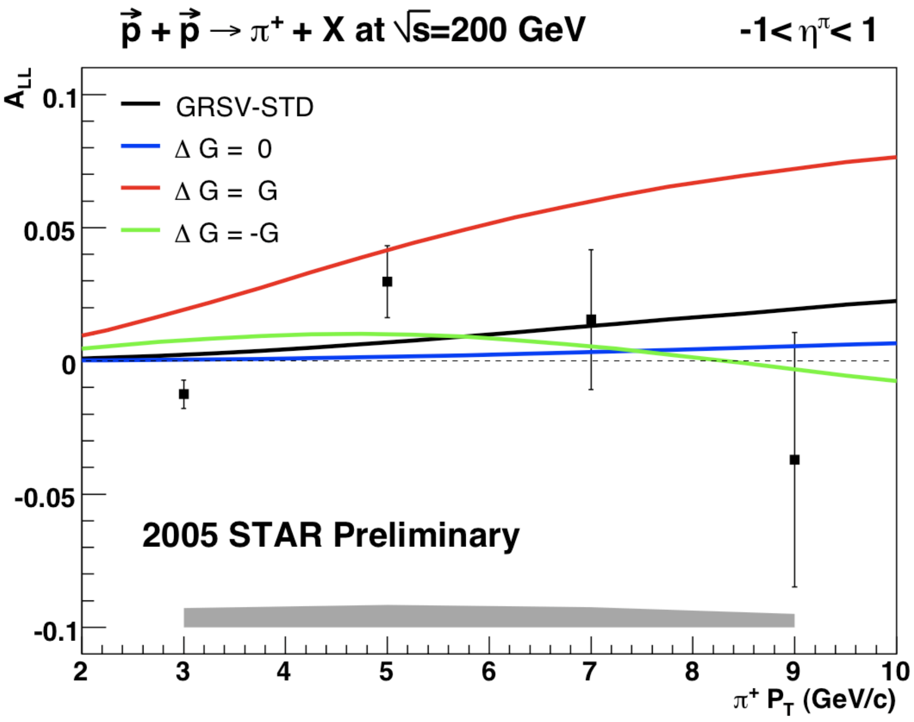
- Polarization: measured by RHIC polarimeters
- Relative Luminosity *R* measured with the STAR BBC & scaler system (relative luminosities for each bunch crossing available)

$$R = \frac{L_{++}}{L_{+-}}$$

- Spin dependent yields N_{++}, N_{+-} : number of detected particles for a given combination of beam polarization directions
- Spin direction in the interaction region verified by the STAR BBCs

Inclusive $\pi^{+/-}$ A_{LL}





GRSV polarized PDFs:

M. Glück, E. Reya, M. Stratmann, W. Vogelsang, PRD63, 094005 (2001).
B. Jäger, M. Stratmann and W. Vogelsang, PRD70, 034010 (2004).

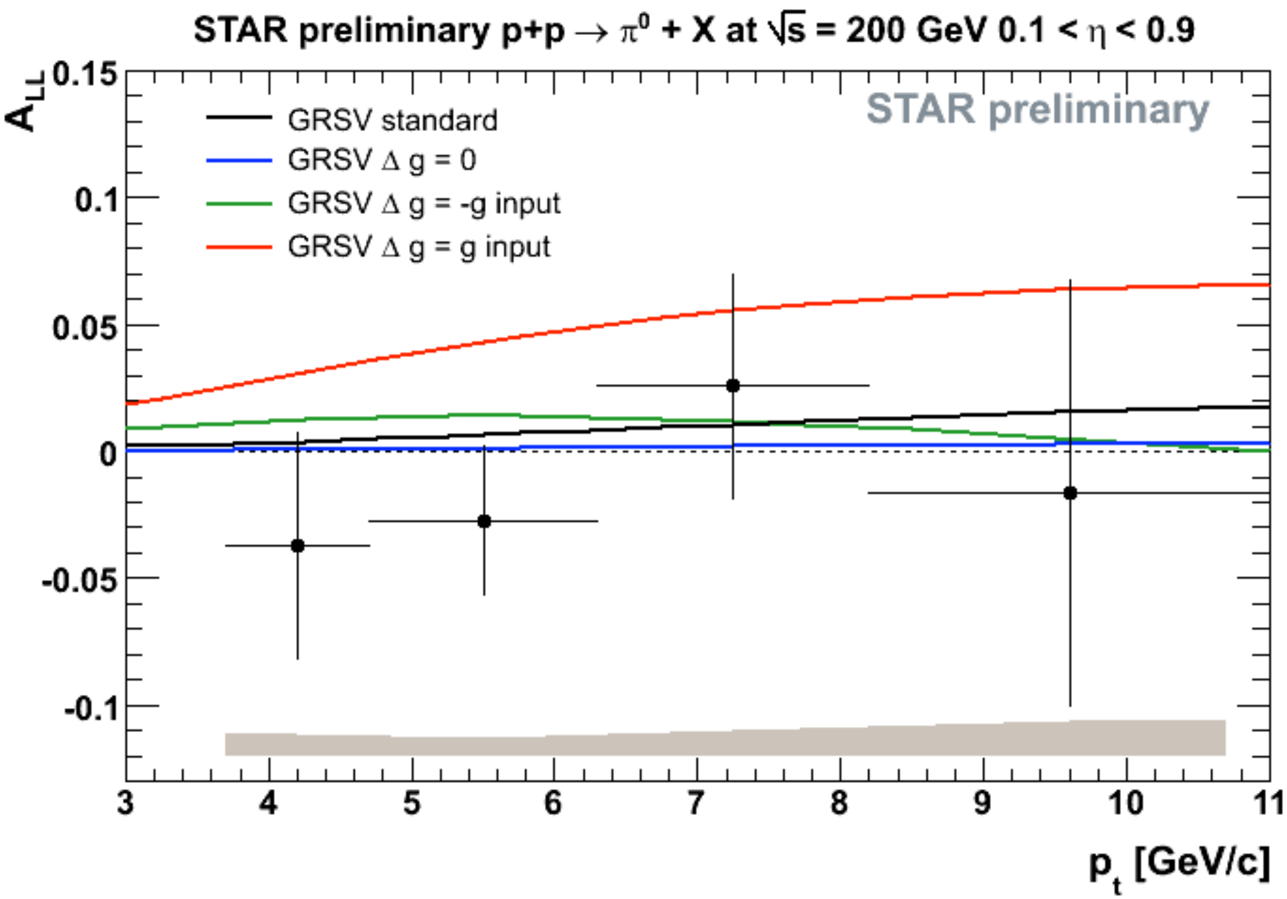
Fragmentation functions modified from KKP:

B. A. Kniehl, G. Kramer and B. Pötter, Nucl. Phys. B582, 514 (2000).

KKP modification:

Charge-separated versions of KKP pion fragmentation functions obtained by multiplying favored partons by (1+z) and unfavored by (1-z).

Inclusive π^0 A_{LL}



χ^2/ndf compared to NLO calculations (ignoring systematic errors):

- GRSV Std: 0.8
- GRSV Max: 2.5
- GRSV Min: 0.8
- GRSV Zero: 0.4

⇨ GRSV max scenario disfavored

overall scale uncertainty from beam polarization measurement not included

A_{LL} Systematic Studies & Errors

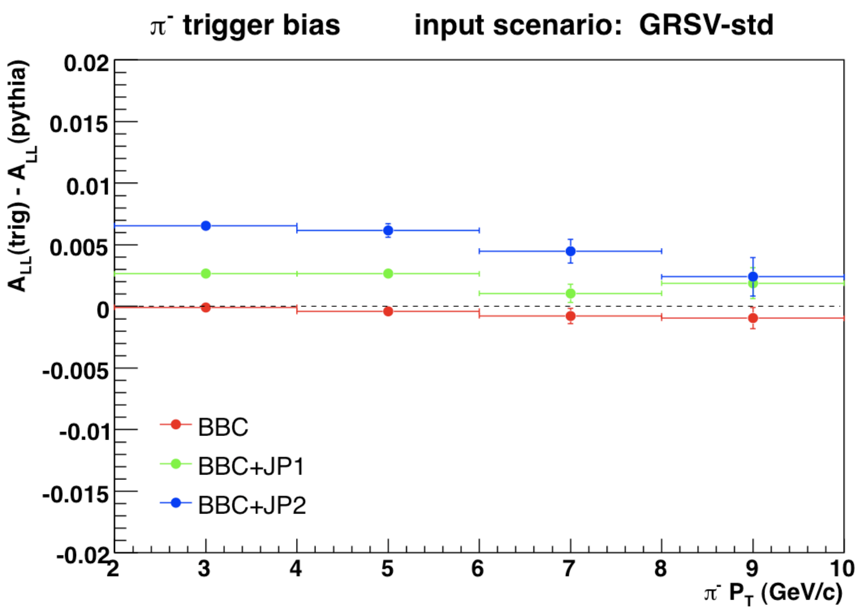
- Parity-Violating Single Spin Asymmetries
  - Come in through the weak interaction, and are limited to less than 10^{-4}, so they should be consistent with zero at the present level of statistics
  - no significant single spin asymmetries observed
- Random Pattern Analysis
  - Asymmetries calculated with randomized bunch patterns
  - no indication of non-statistical effects found

- Systematic Errors assigned for
  - non-longitudinal spin components in beams 3×10^{-3}
  - relative luminosities 2×10^{-3}
  - Analysis specific for neutral pions:
    - remaining Background (from beam background, not removed invariant mass background) p_t dependent from 5×10^{-3} to 11×10^{-3}
    - yield extraction (normalization of background model) from 3×10^{-3} to 7×10^{-3}
  - Analysis specific for charged pions
    - particle identification: 2×10^{-3}
    - trigger bias: from 3×10^{-3} to 7×10^{-3}

Trigger Bias for charged pions

- Majority of pions are sub-leading particles in trigger jet
  - Significant statistics from "away-side", untriggered jet as well
- PYTHIA afterburner used to construct "polarized" event generator
- Calculate A_{LL} in simulation with and without trigger requirement
- Bias estimated using average of GRSV-min and GRSV-std scenarios

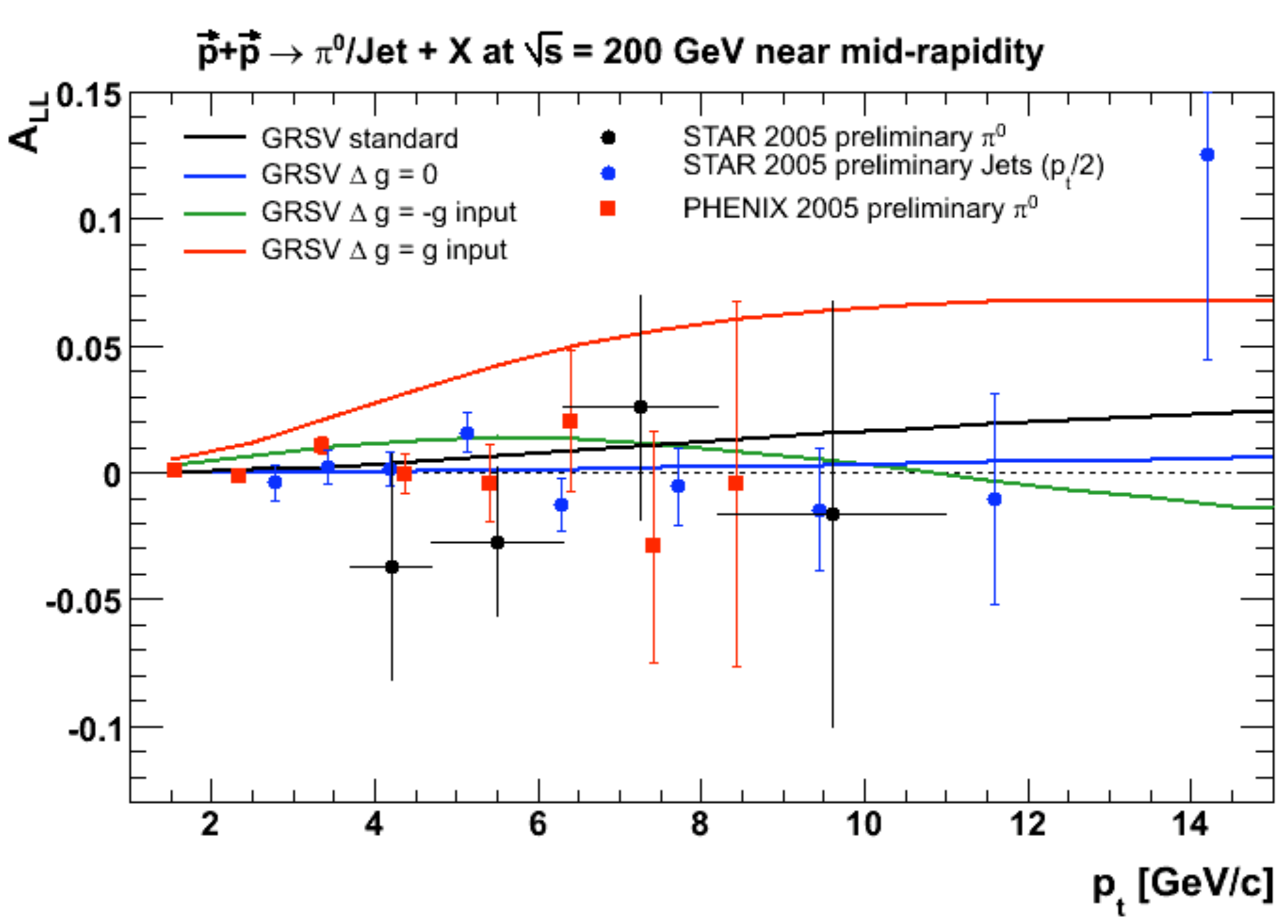
- 3.0 - 7.3 x 10^{-3} as a function of p_T and charge sign



Other Cross-Checks

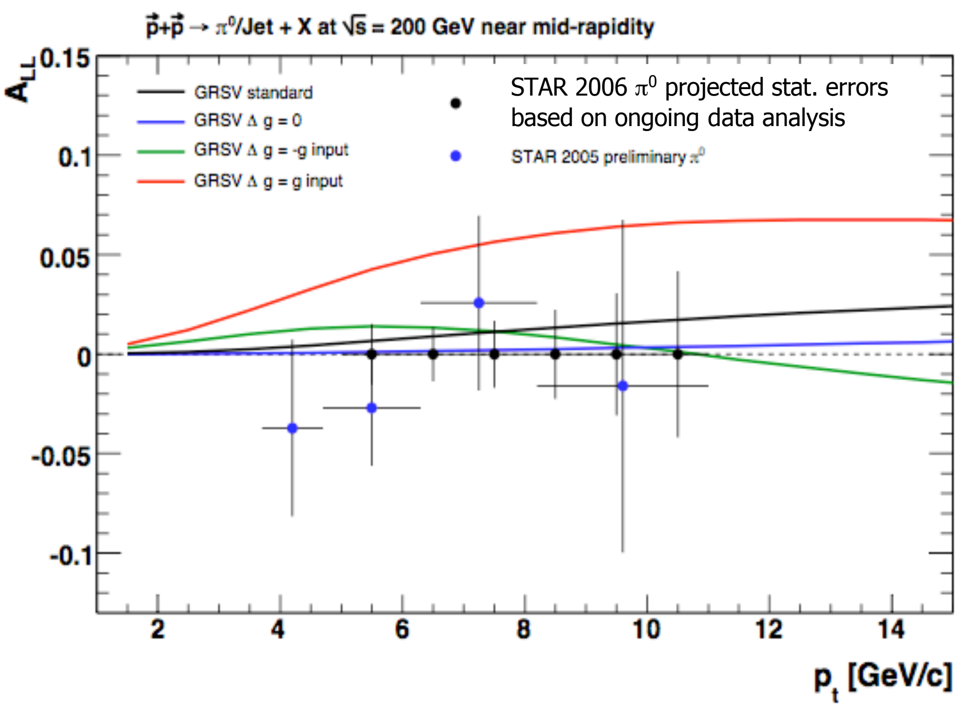
- Charge-summed asymmetry consistent with neutral pions
- "Near-side" and "away-side" asymmetries consistent with each other

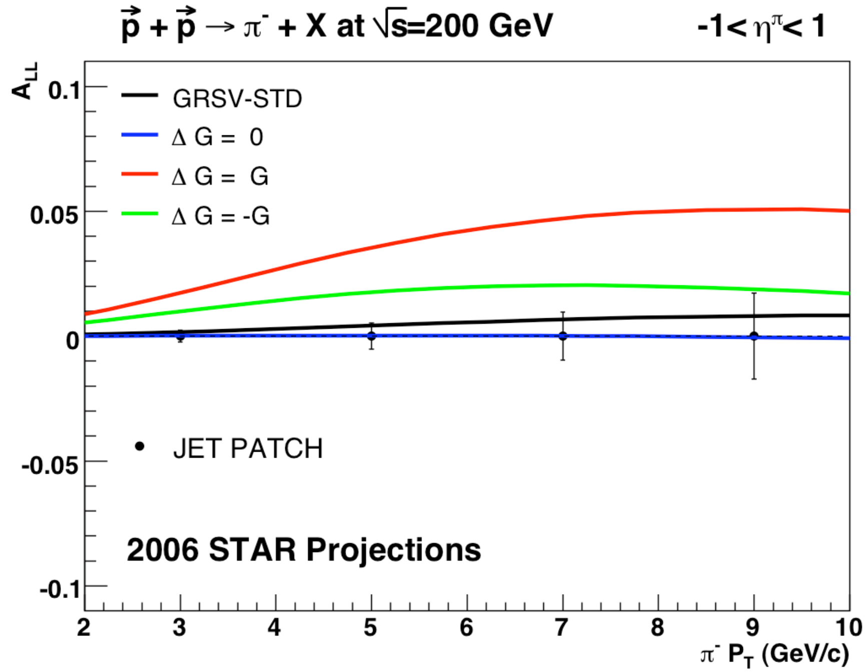
Neutral Pions: How do they fit in?



- Comparison with other RHIC run 2005 results:
  - STAR inclusive Jets, p_t divided by 2
  - PHENIX inclusive π^0

Projections for 2006 Data





- Significant increase in sampled luminosity
- Polarization typically ~60%
- acceptance in BEMC increased by a factor of 2

⇨ significant increase in figure of merit!

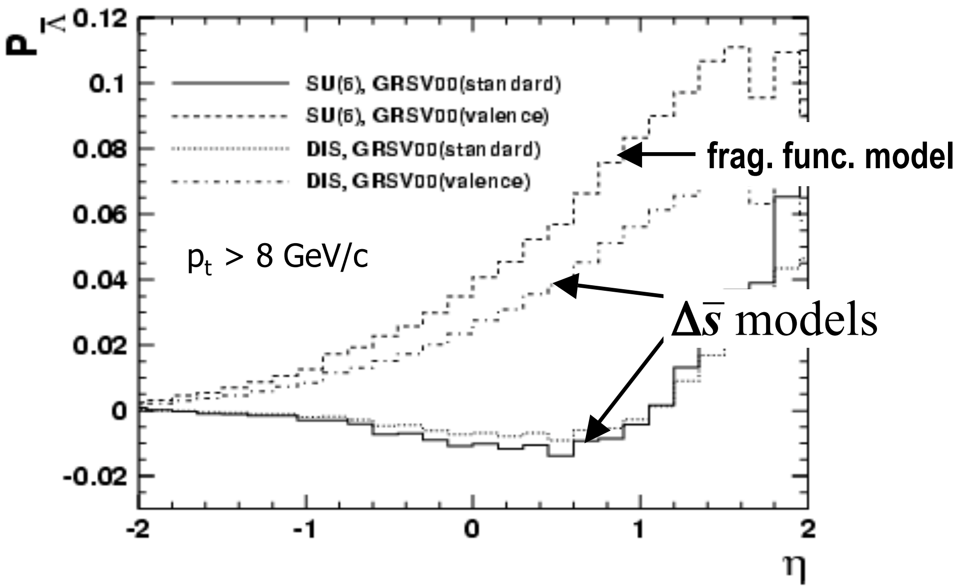
Beyond Gluons

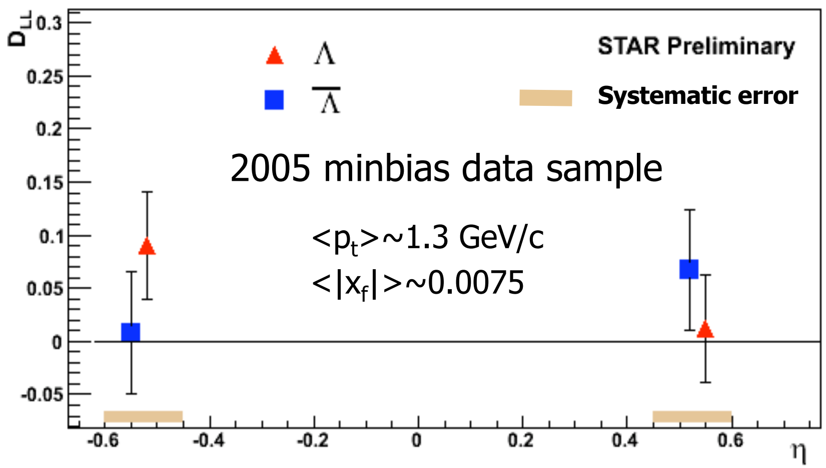
- Spin of Anti-Λ dominated by anti-s quark
  - Polarization of Anti-Λ contains information of anti-s quark polarization in the proton

$$D_{LL} \equiv \frac{\sigma_{p^+p\to\Lambda^+X} - \sigma_{p^+p\to\Lambda^-X}}{\sigma_{p^+p\to\Lambda^+X} + \sigma_{p^+p\to\Lambda^-X}}$$

measures the spin transfer from beam to Λ

Q. Xu, E. Sichtermann, Z. Liang, PRD 73,2006





⇨ proof of principle

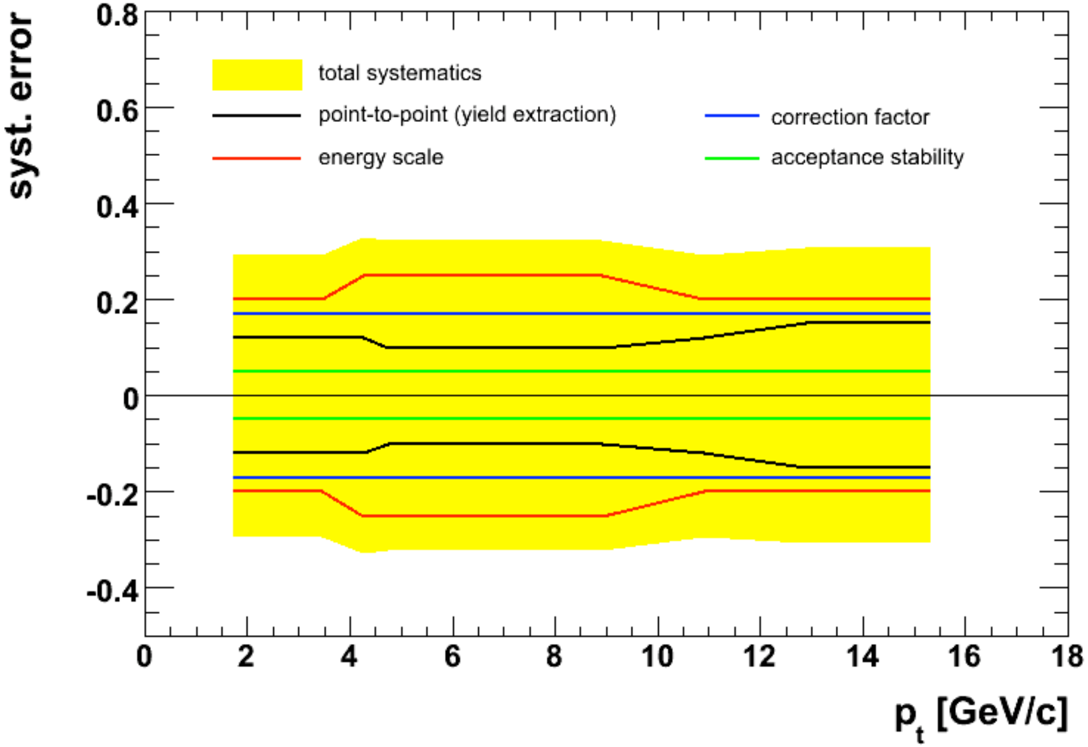
⇨ dedicated triggers needed to reach high p_t

Summary

- **Inclusive hadron spin results from the STAR Experiment**
- Inclusive cross sections consistent with NLO pQCD calculations
  - KKP fragmentation functions favored over Kretzer set
  - scale uncertainty of pQCD of comparable size as preliminary systematics
- Energetic π^0 carry a significant fraction of the total transverse momentum of their associated jet
- Double longitudinal spin asymmetry for charged and neutral pions disfavors large positive gluon polarization
  - consistent with previous observations with jets and π^0
  - result limited by statistics
- Significant increase in figure of merit with the already recorded 2006 data set, new possibilities open up for charged pions
- First proof of principle of Λ polarization measurement to access Δs

Backup

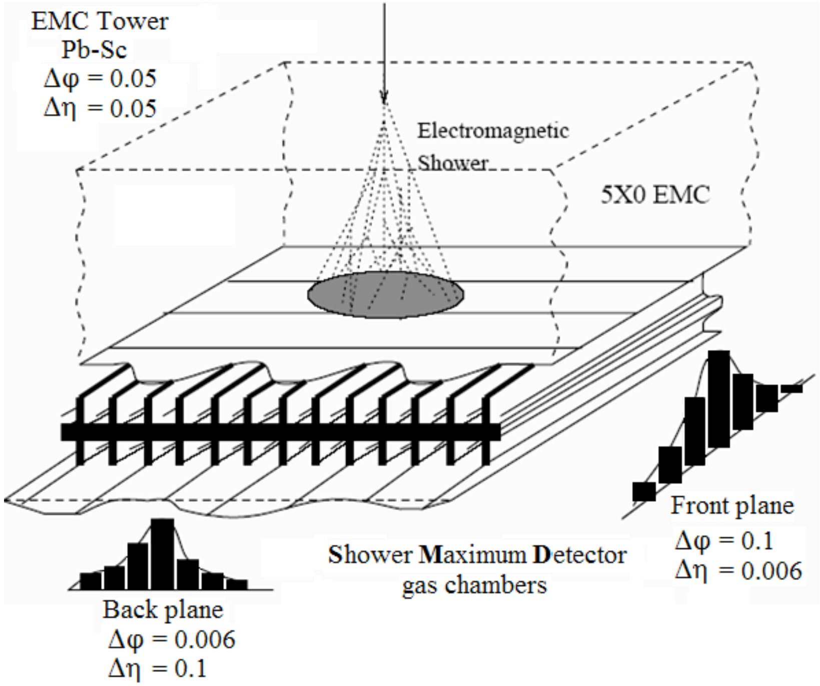
Backup: Systematics: Cross Section



- Point-to-Point (yield extraction, background subtraction)
- Energy scale (5% uncertainty on BSMD gain calibration)
- Correction factor (variation of cuts, uncertainty in SMD gain (to a large extend built into MC, additional uncertainties included in systematics), statistical limitation of MC dataset)
- Acceptance Stability (changes in electronics status, modeling in MC)

Backup: Neutral Pion Reconstruction

- 2005 p+p dataset (after rigorous quality cuts): ~ 1.7 pb^{-1}
- Trigger & shower maximum detector in 2005 operational only for $0 < \eta < 1$, full acceptance $-1 < \eta < 1$ available for 2006 data



tower size ($\Delta\phi$ x $\Delta\eta$) 0.05 x 0.05

π^0 invariant mass: $m_{inv}^2 = 2E_1E_2(1-\cos\theta)$

⇨ SMD becomes crucial for π^0 reconstruction for p_t ~ 5 GeV/c (photon separation equal to tower size)

veto calorimeter hits that have a charged track leading to them

- π^0 candidates accepted for $0.1 < y < 0.9$
- π^0 has to be able to fire the trigger (but does not have to be the triggering particle)
- rejection of beam background found with pattern recognition code

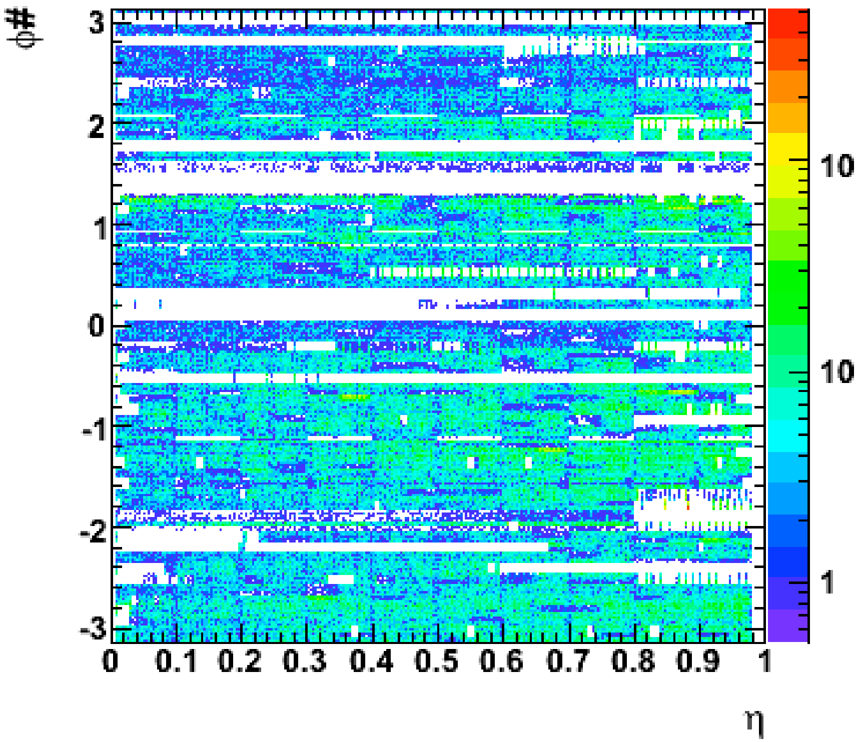
Backup: Systematic Errors on A_{LL}

Bin	remaining Background	Yield Extration	relative Luminosity	non-long. Effects	Total Systematic	stat. Error
1	0.0052	0.0062	0.0022	0.003	0.0089	0.0443
2	0.0052	0.0032	0.0022	0.003	0.0072	0.0291
3	0.0082	0.0047	0.0022	0.003	0.0102	0.0439
4	0.0112	0.0069	0.0022	0.003	0.0137	0.0836

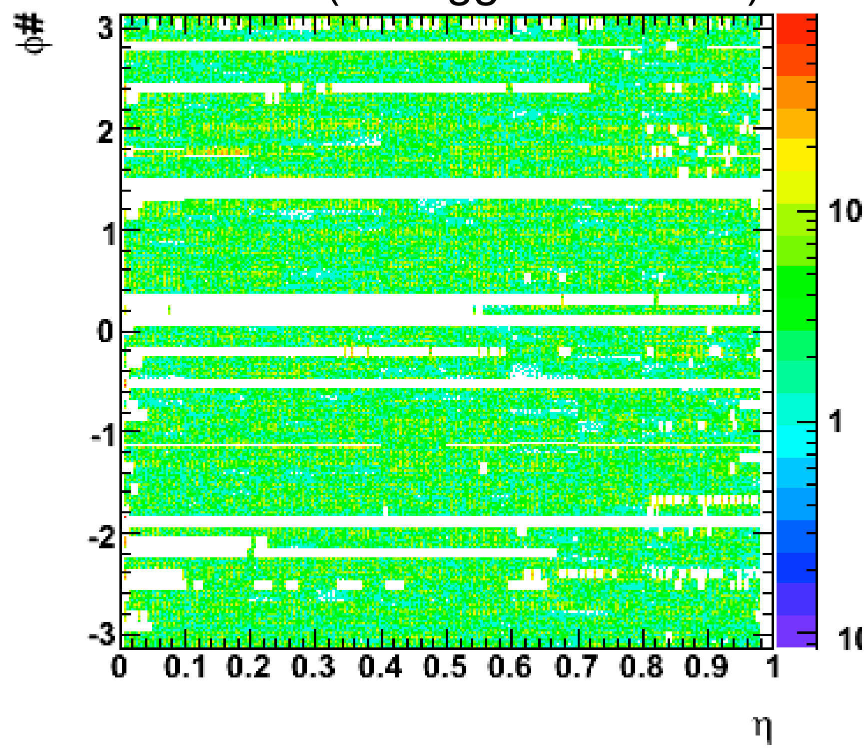
Backup: BEMC π^0 Acceptance

- Photon Candidates (Calorimeter Hits) above 1 GeV requiring information from both SMD planes: Data vs MC

Data (all triggers)

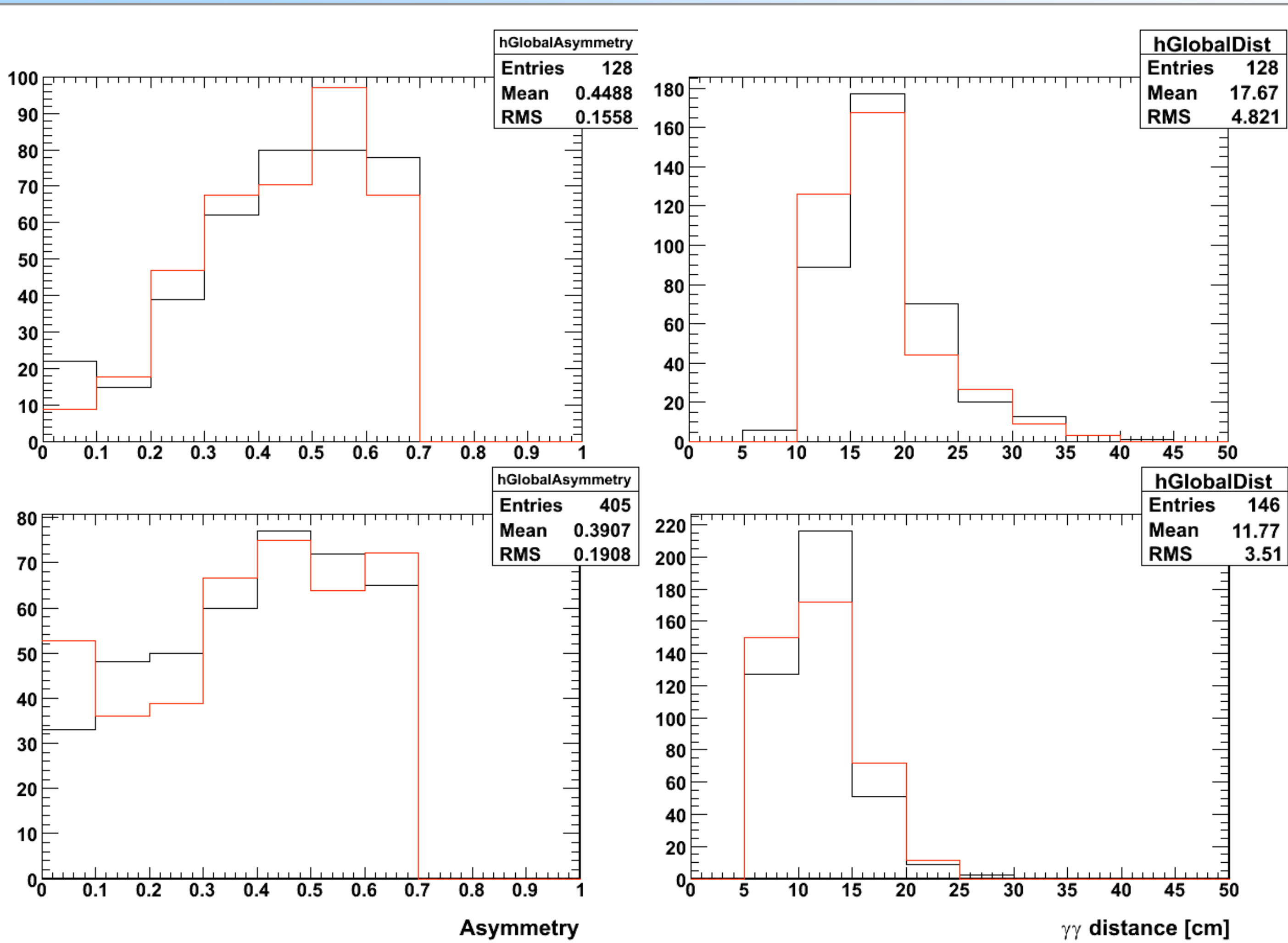


PYTHIA (no trigger selection)



- Data histogram integrates over a running time of 12 days, MC takes the detector status at one specific time within that period
- Overall good agreement, detector acceptance reasonably modeled in MC

Backup: BEMC π^0 Data/MC Comparison



HT1 triggers

4.5 GeV/c < π^0 p_t < 4.6 GeV/c

black: data

red: Pythia

HT2 triggers

7.0 GeV/c < π^0 p_t < 7.2 GeV/c

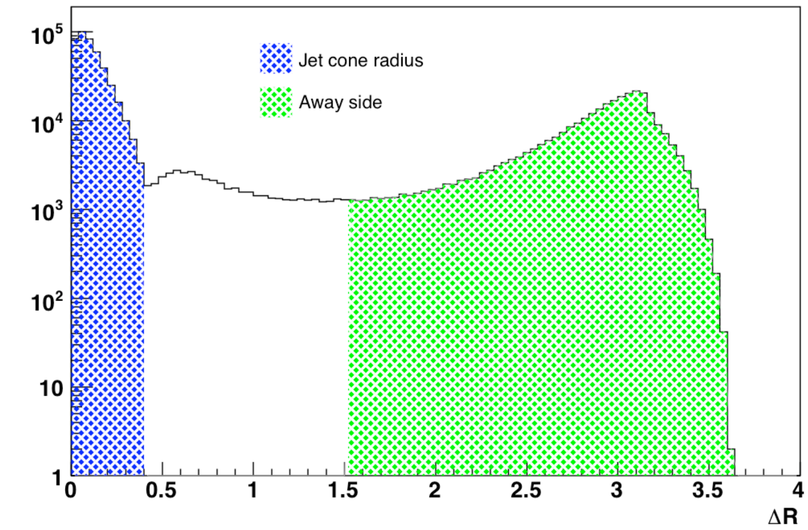
black: data

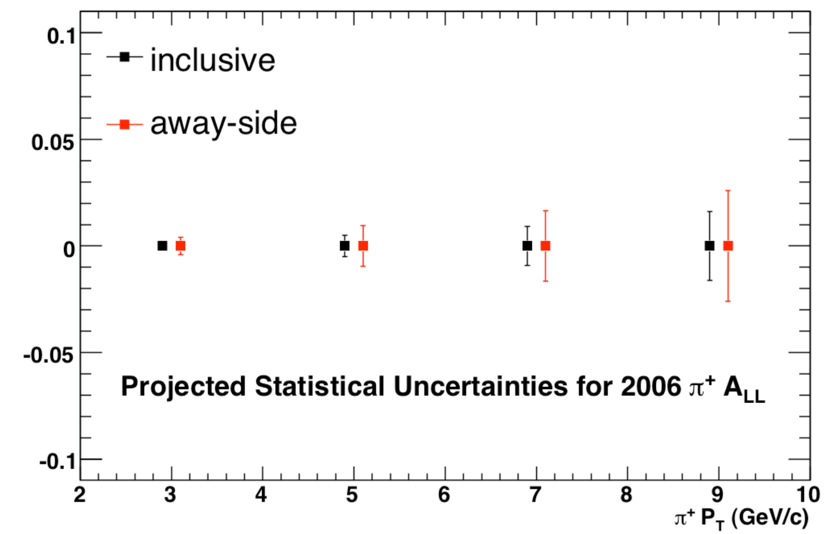
red: Pythia

- Preliminary! Limited MC Statistics!
- π^0 properties well reproduced in MC for different p_t and triggers

Backup: Charged Pions Away-side A_{LL}

- Calculate $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ for each pion relative to trigger jet
- Originally motivated by trigger bias studies
  - "away-side" sample free from fragmentation bias
- Reasonable statistical precision
- Needs theoretical guidance





Backup: Charged and Neutral Pions