

# Double Longitudinal Spin Asymmetry for Pion Production in 200 GeV p+p Collisions at STAR

Alan Hoffman (MIT)  
For the STAR collaboration  
University College, London  
April 7, 2008

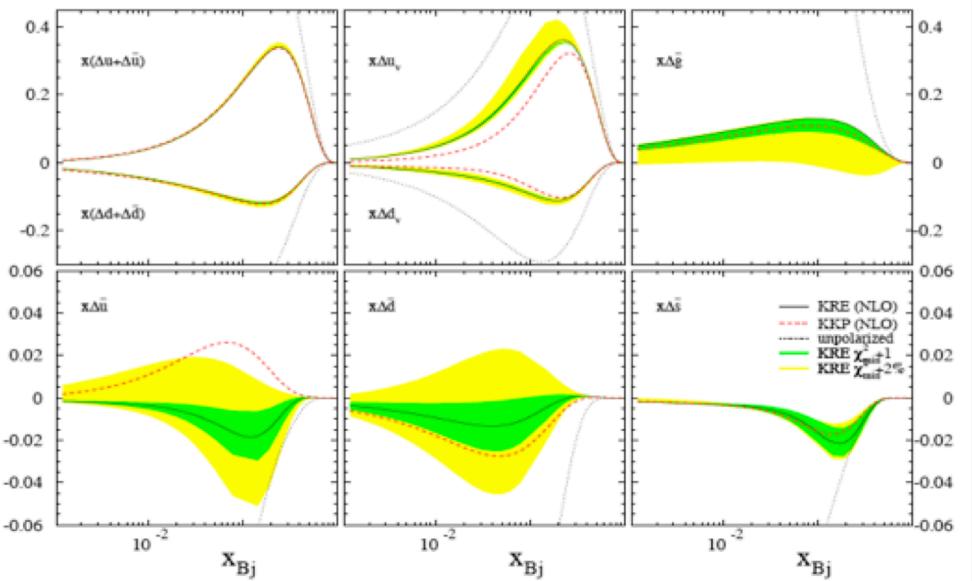
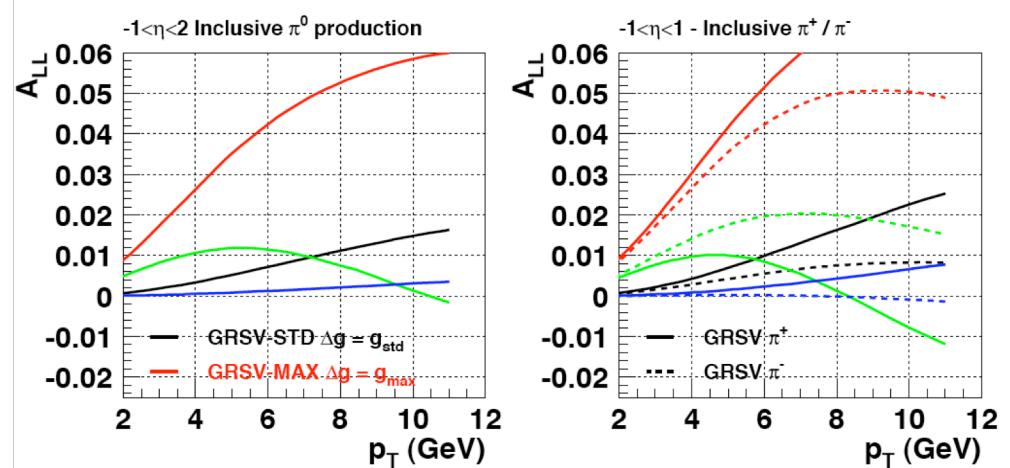
# Accessing $\Delta g$ at STAR



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

## Three Measurements:

- Polarizations
  - CNI and H polarimeters in RHIC rings
- Relative Luminosities
  - BBCs
- Spin Sorted Yields
  - Triggering on desired events
  - Final state reconstruction
  - Background identification



D. de Florian et al., Phys. Rev. D71, 094018 (2005).



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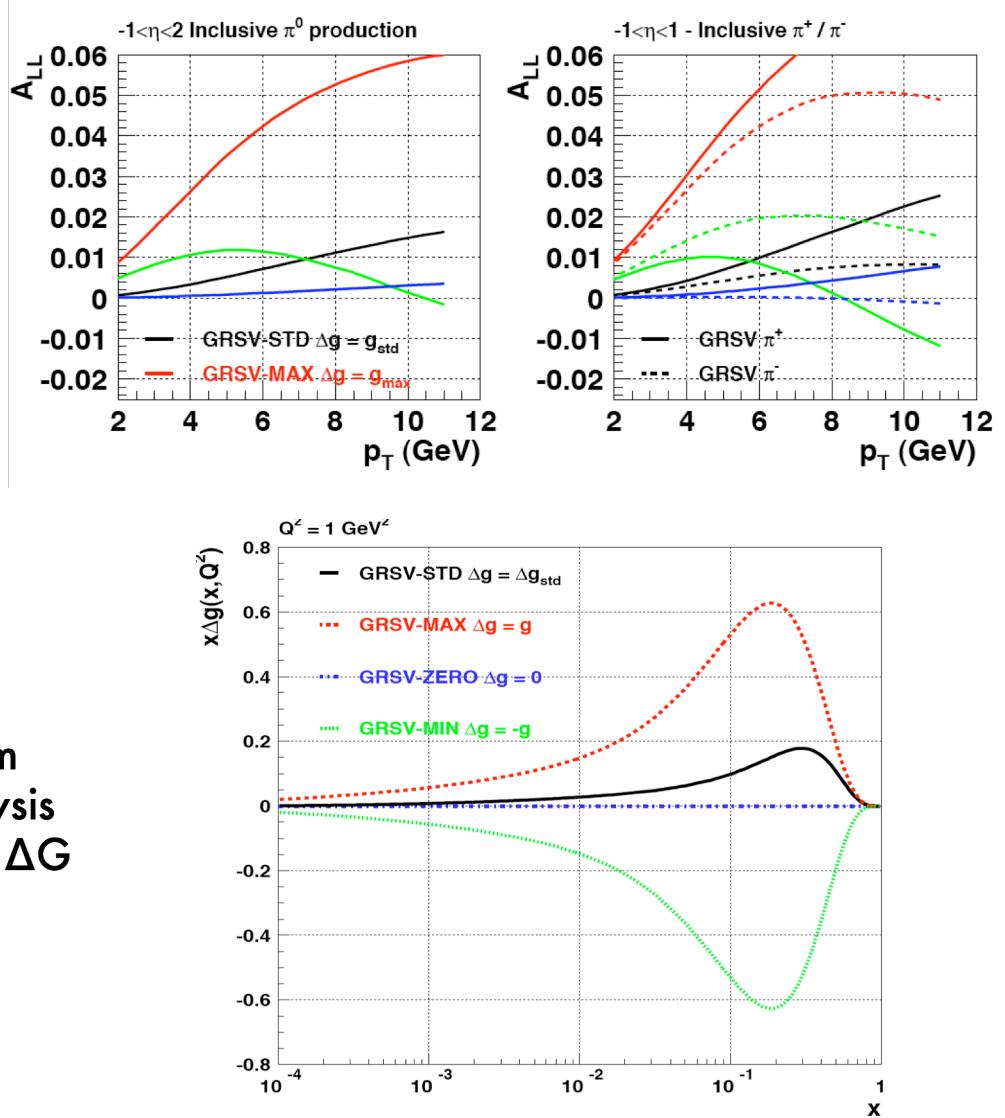
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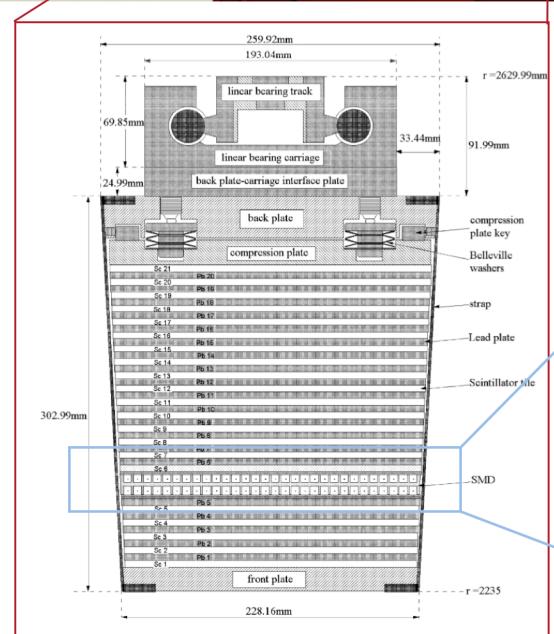
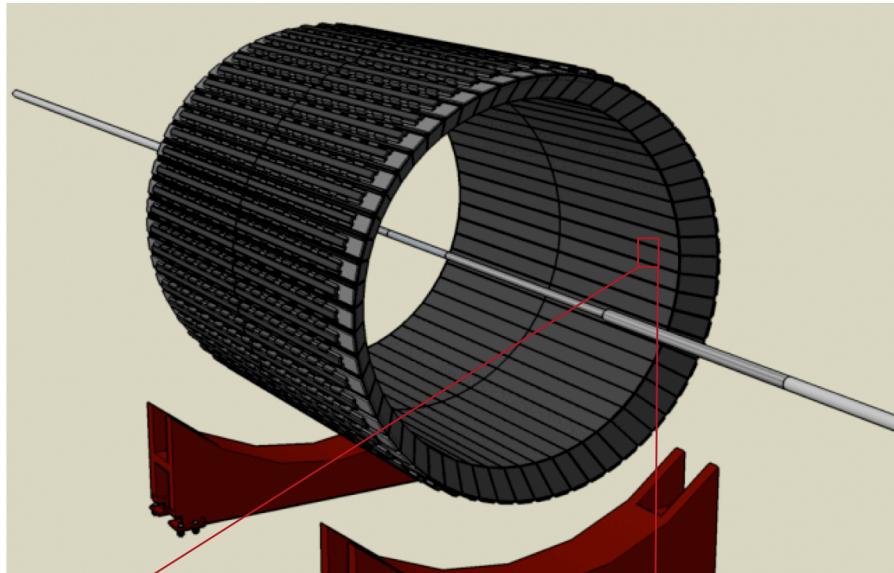
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## Why Pions?:

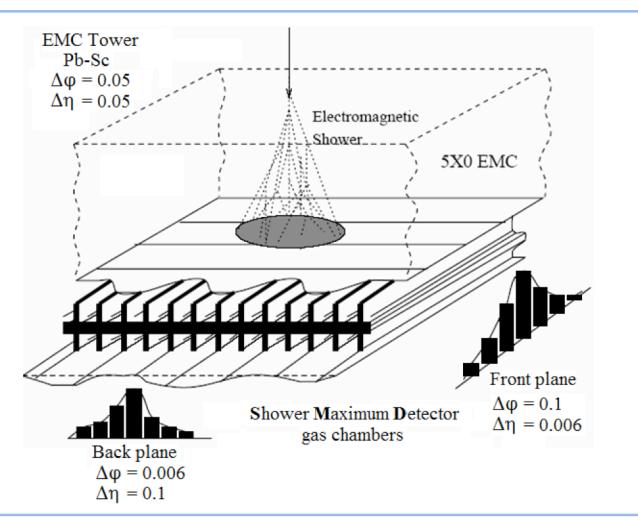
- Reconstruct all three species over a large  $P_T$  range.
- Independent (from jets) measurements of  $\Delta G$  with different systematic errors.
- Charged pions provide two complementary measurements with different contributions from polarized quark PDFs. Furthermore, an analysis of both species provides access to the sign of  $\Delta G$
- $\pi^0$  are largest background for direct photons



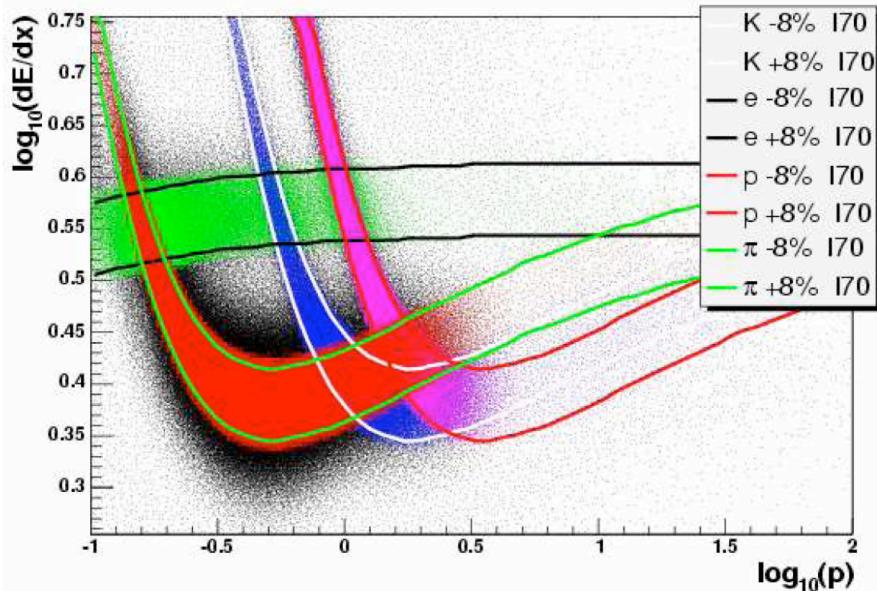
# Barrel EMC



- Lead-scintillator sampling calorimeter ( $\approx 20 X_0$ )
- $2\pi$  azimuthal coverage
- $-1 < \eta < 1$
- Segmented into 4800 towers, each tower covering  $.05 \times .05$  in  $\eta\phi$  space
- Nominal resolution:  
 $dE/E = 15\%/\sqrt{E[\text{GeV}]} \oplus 1.5\%$
- Shower Max Detector located  $5 X_0$  deep.

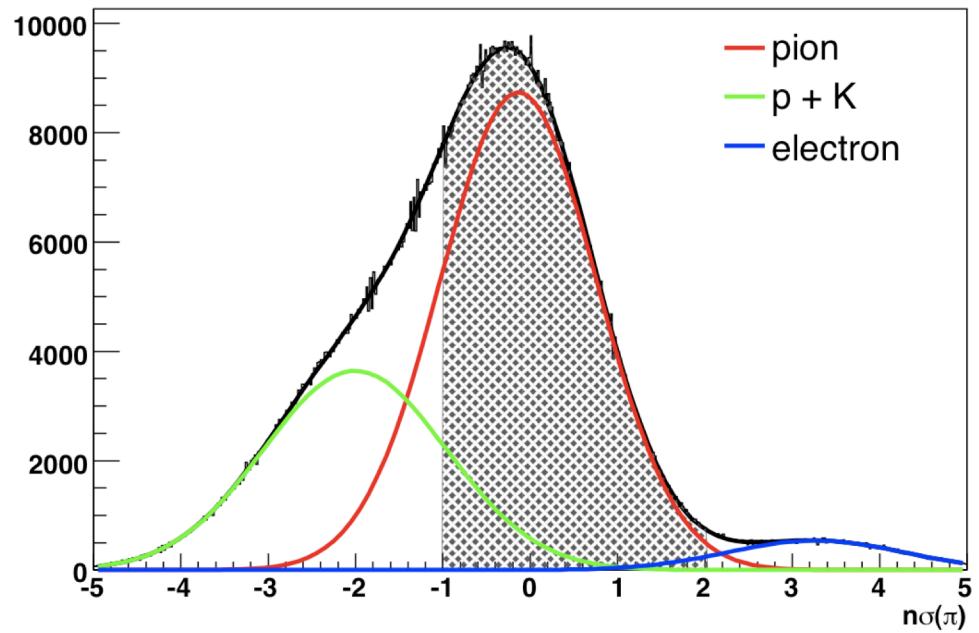


# Charged Pion Reconstruction

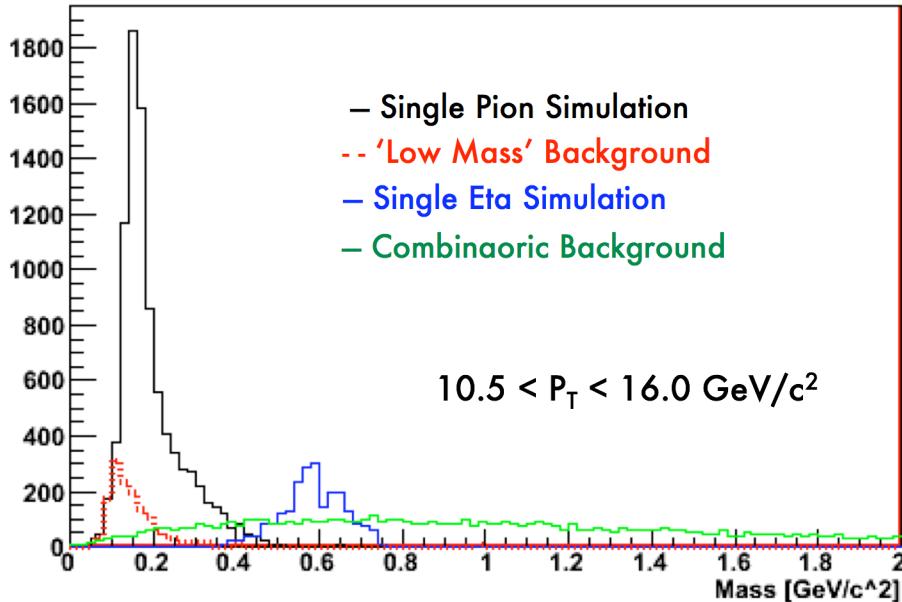


Plot track  $dE/dx$  in terms of standard deviation from mean of pion  $dE/dx$  band -  
Pion selection window:  $-1 < n\sigma < 2$

Specific energy loss ( $dE/dx$ ) in the TPC can be used at high  $p_T$  to provide  $\pi$ , K, p separation ( $P_T > 2 \text{ GeV}/c$ ) since the pion  $dE/dx$  is higher than that for K and p in the relativistic rise region



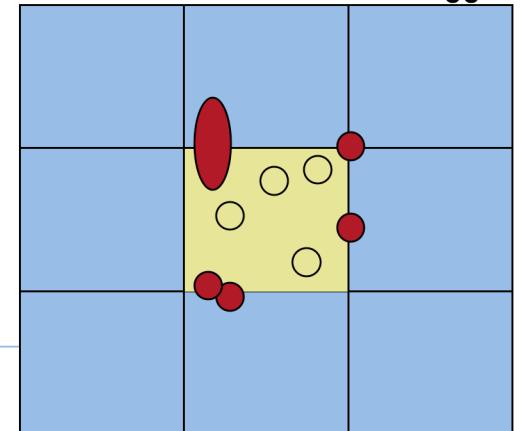
# Neutral Pion Reconstruction



- New trigger for run 6. Specifically designed to find more neutral pions.
- 2 stages: L0 High Tower + L2 Trigger Patch. Separate thresholds for high tower and 3x3 tower cluster centered on high tower.
- Average polarization  $\approx 55\%$

- Full barrel EMC available for the first time  
 $-1 < \eta < 1$  and  $0 < \phi < 2\pi$  (run 6)
- $\pi^0$  invariant mass:  $m_{inv}^2 = 2E_1E_2(1 - \cos\theta)$
- Diphoton invariant mass distribution well described by simulation.

Schematic of new trigger



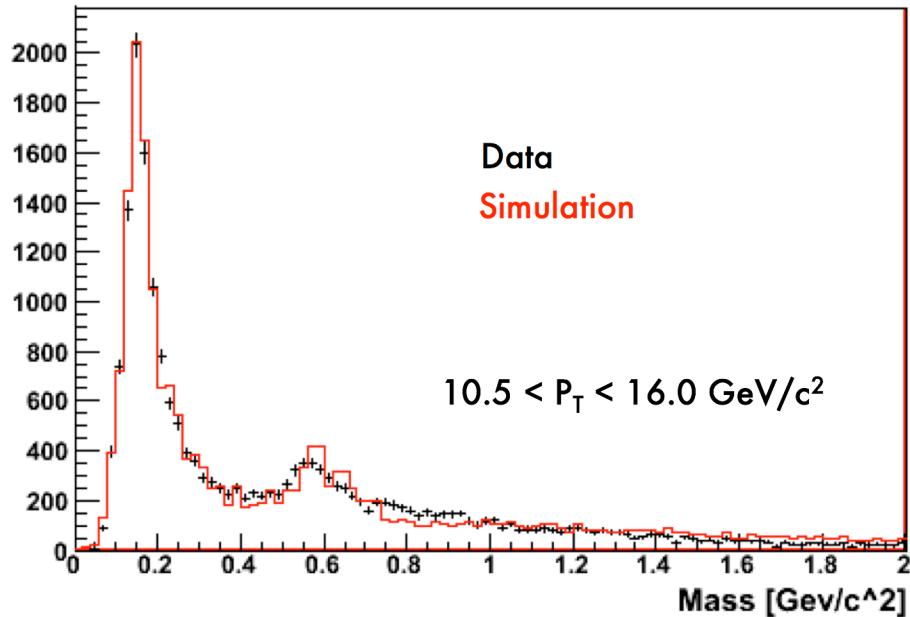
## Event Selection

- Satisfies hardware and software trigger
- Vertex found
- Require good SMD information in both planes
- Veto calorimeter hits with a charged track pointing to tower
- $\pi^0$  found w/  $P_T$  above  $5.2 \text{ GeV}/c$



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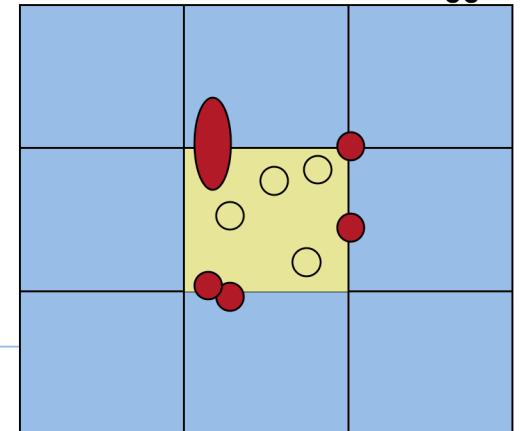
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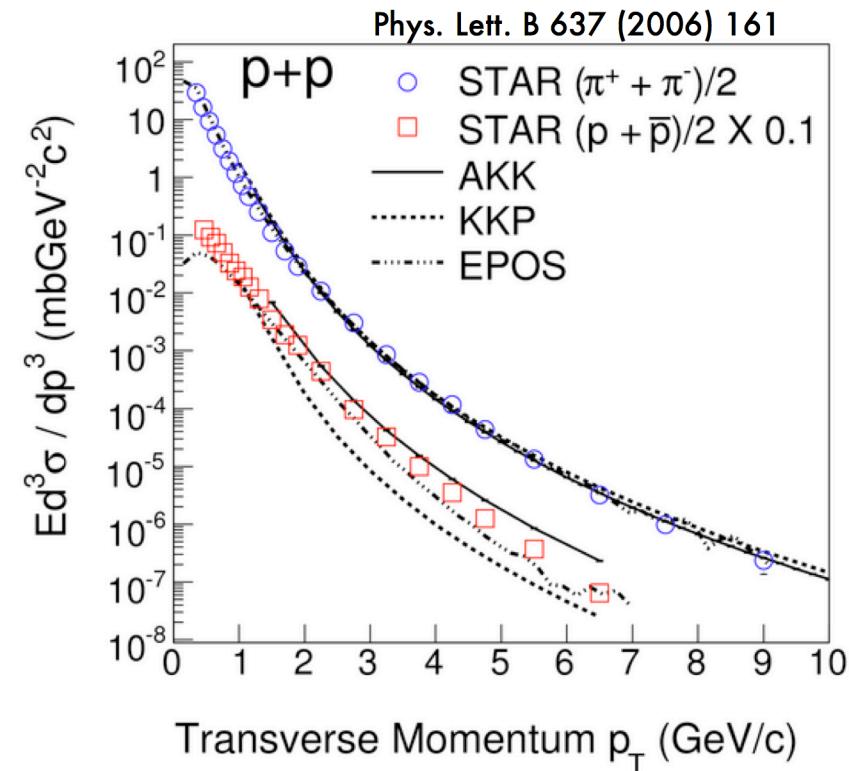
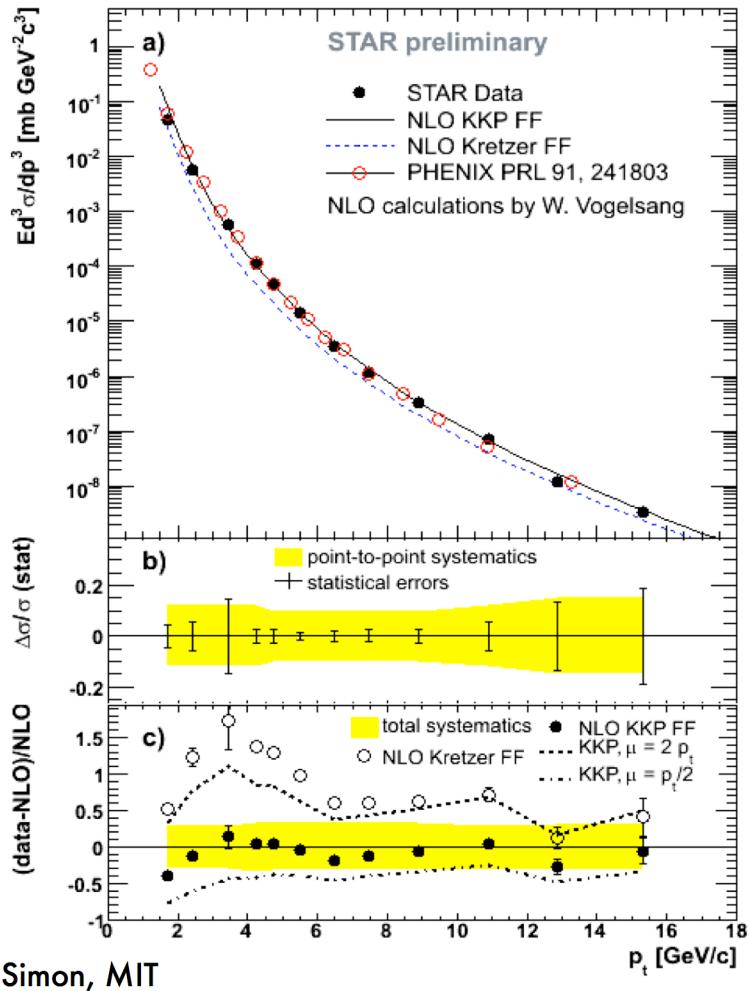


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# Pion Cross Sections



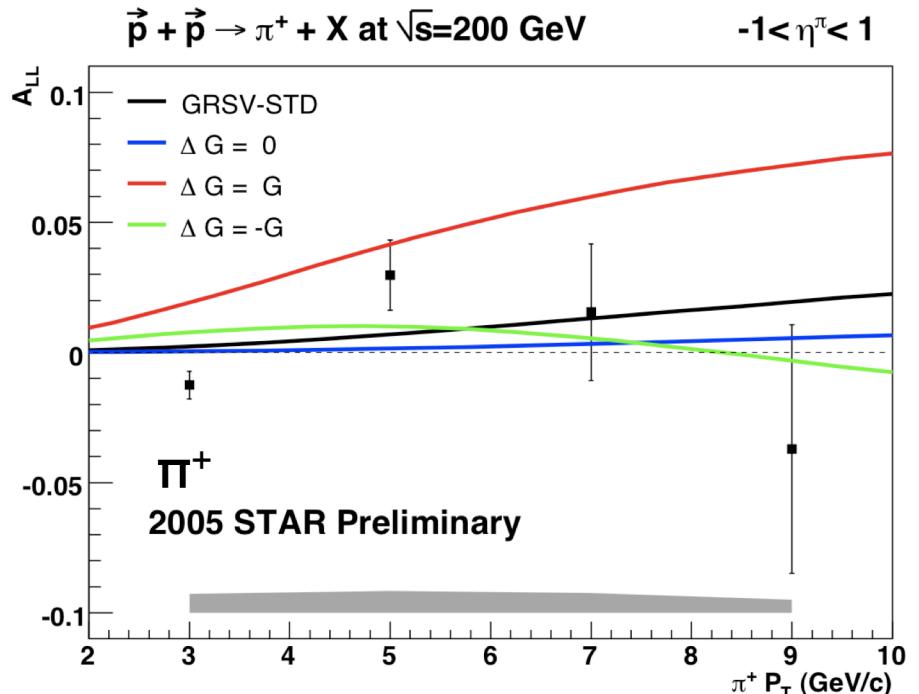
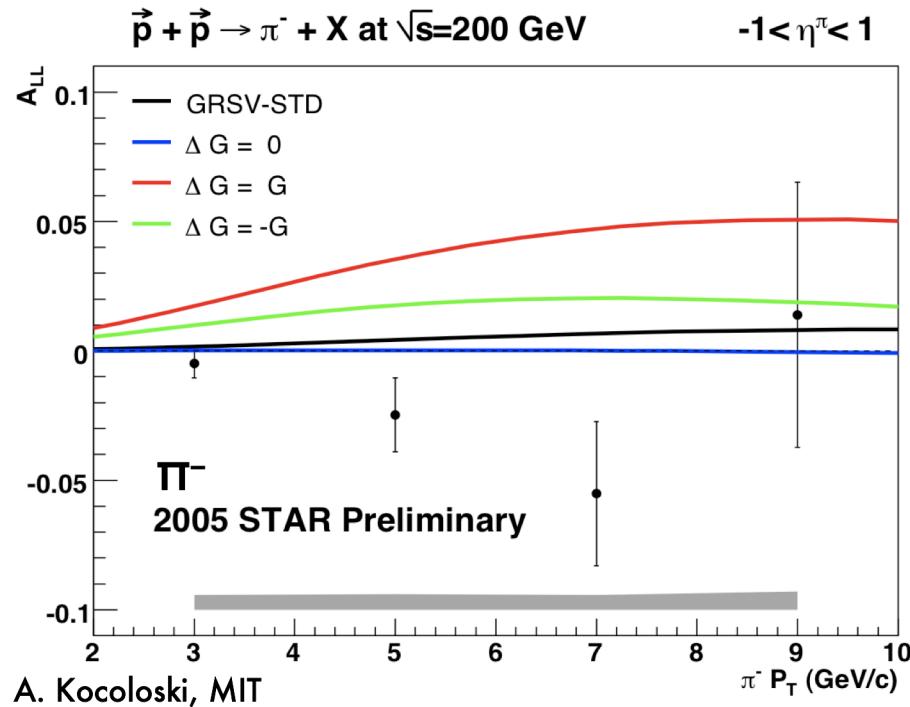
$$E \frac{d^3\sigma}{dp^3} = \frac{1}{2\pi p_T \Delta p_T \Delta y} c \frac{N^\pi}{L_{sampled}}$$



- Cross sections have been measured and reported.
- Measurement compared to pQCD predictions using different fragmentation functions.
- Good Agreement with NLO predictions over a large range in  $P_T$

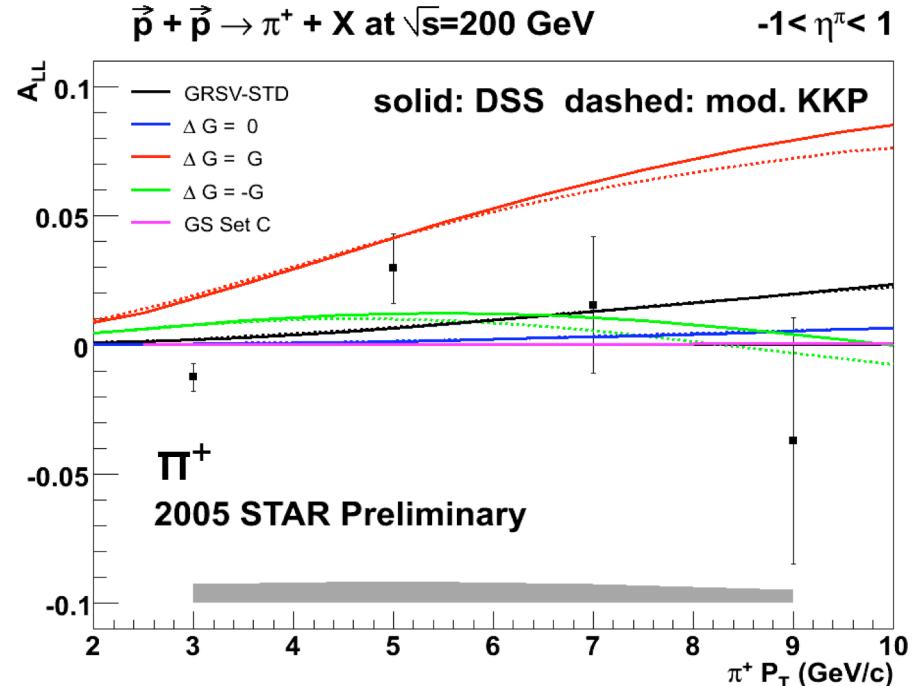
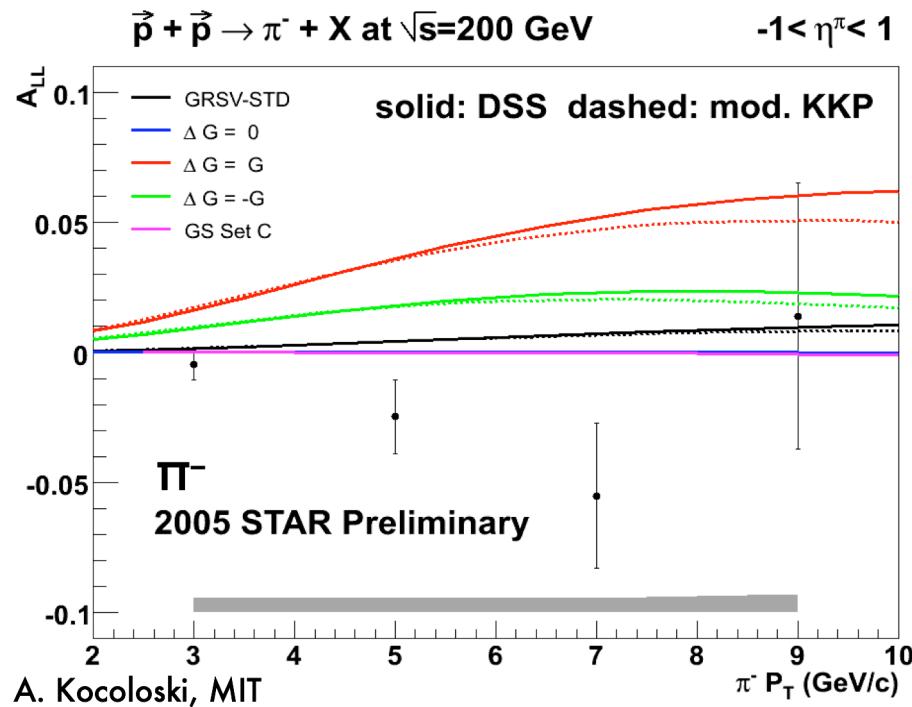


# Charged Pion Preliminary $A_{LL}$



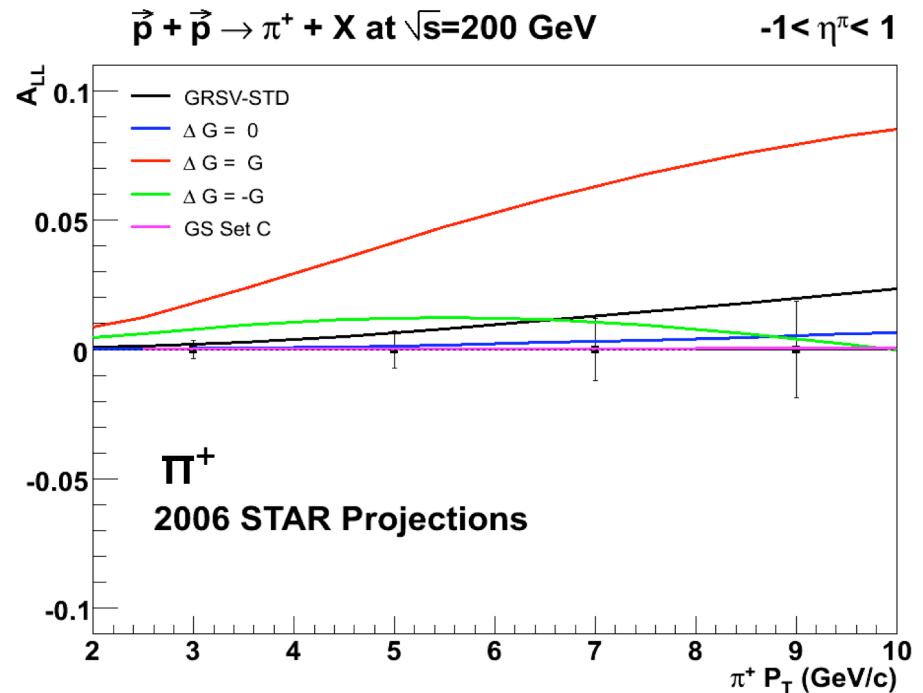
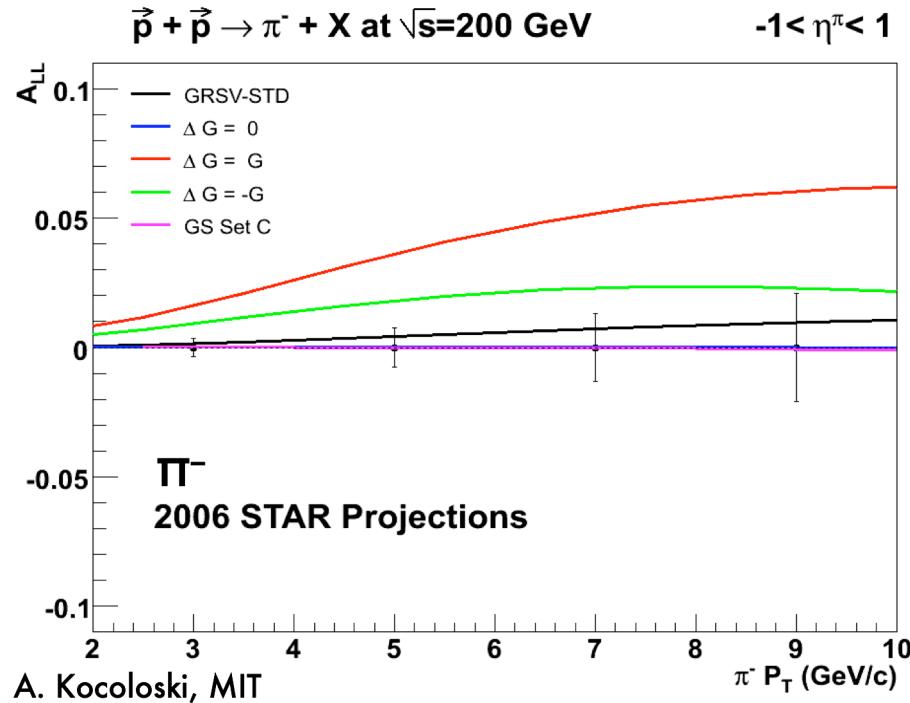
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- Improved precision with Run 6 data
  - Increased polarization: 45% to 55%
  - Increased Luminosity

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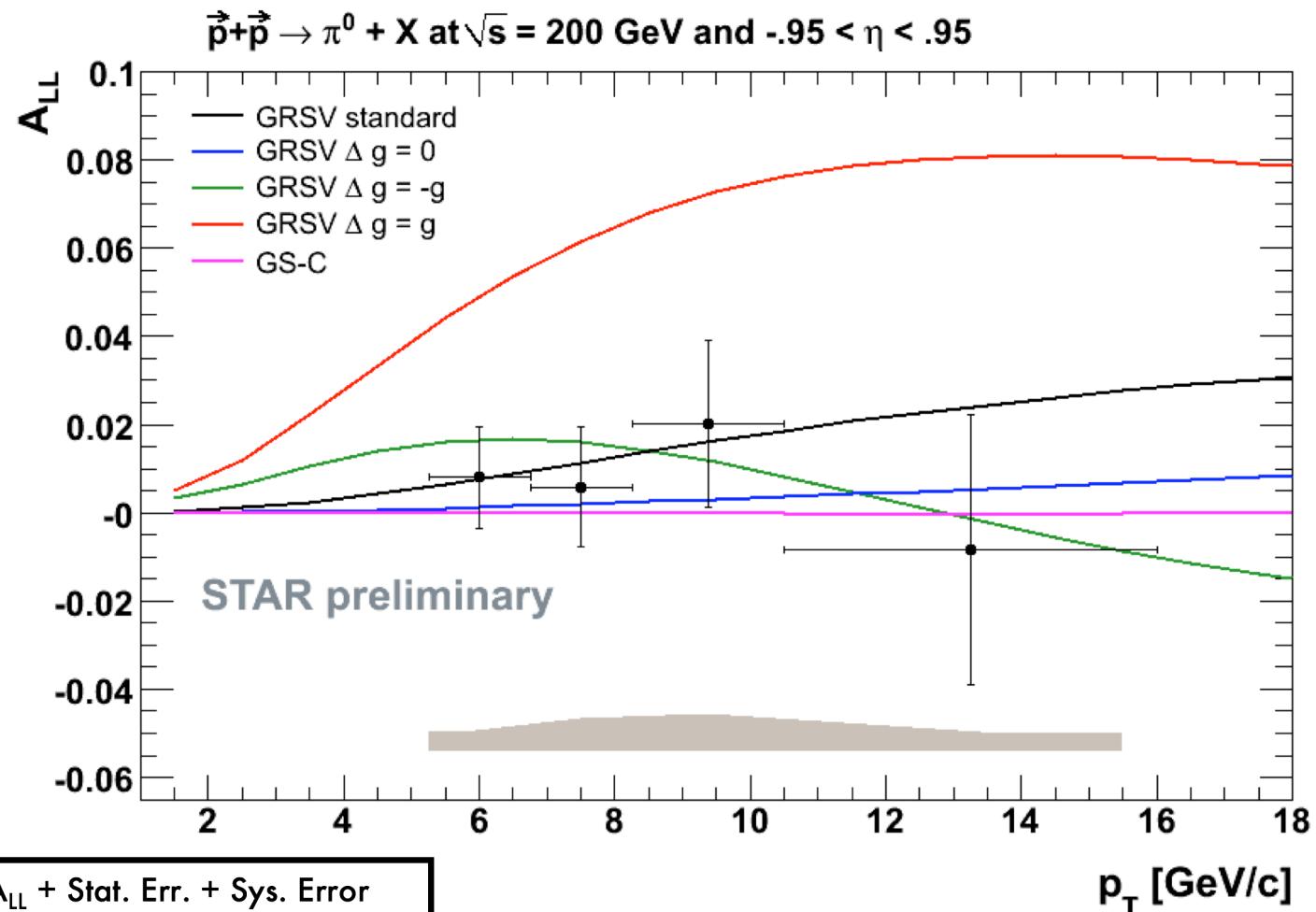
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# A<sub>LL</sub> for Run 6 Neutral Pions



$\chi^2/\text{ndf}$  for NLO Models:

GRSV Std: 0.3  
 GRSV Max: 11.4  
 GRSV Min: 0.3  
 GRSV Zero: 0.4  
 GS-C: 0.5



Pt Range [GeV/c]	$A_{LL} + \text{Stat. Err.} + \text{Sys. Error}$
5.2 - 6.75	$0.0080 + 0.0115 + 0.0023$
6.75 - 8.25	$0.0058 + 0.0136 + 0.0038$
8.25 - 10.5	$0.0203 + 0.0189 + 0.0043$
10.5 - 16.0	$-0.0084 + 0.0306 + 0.0020$

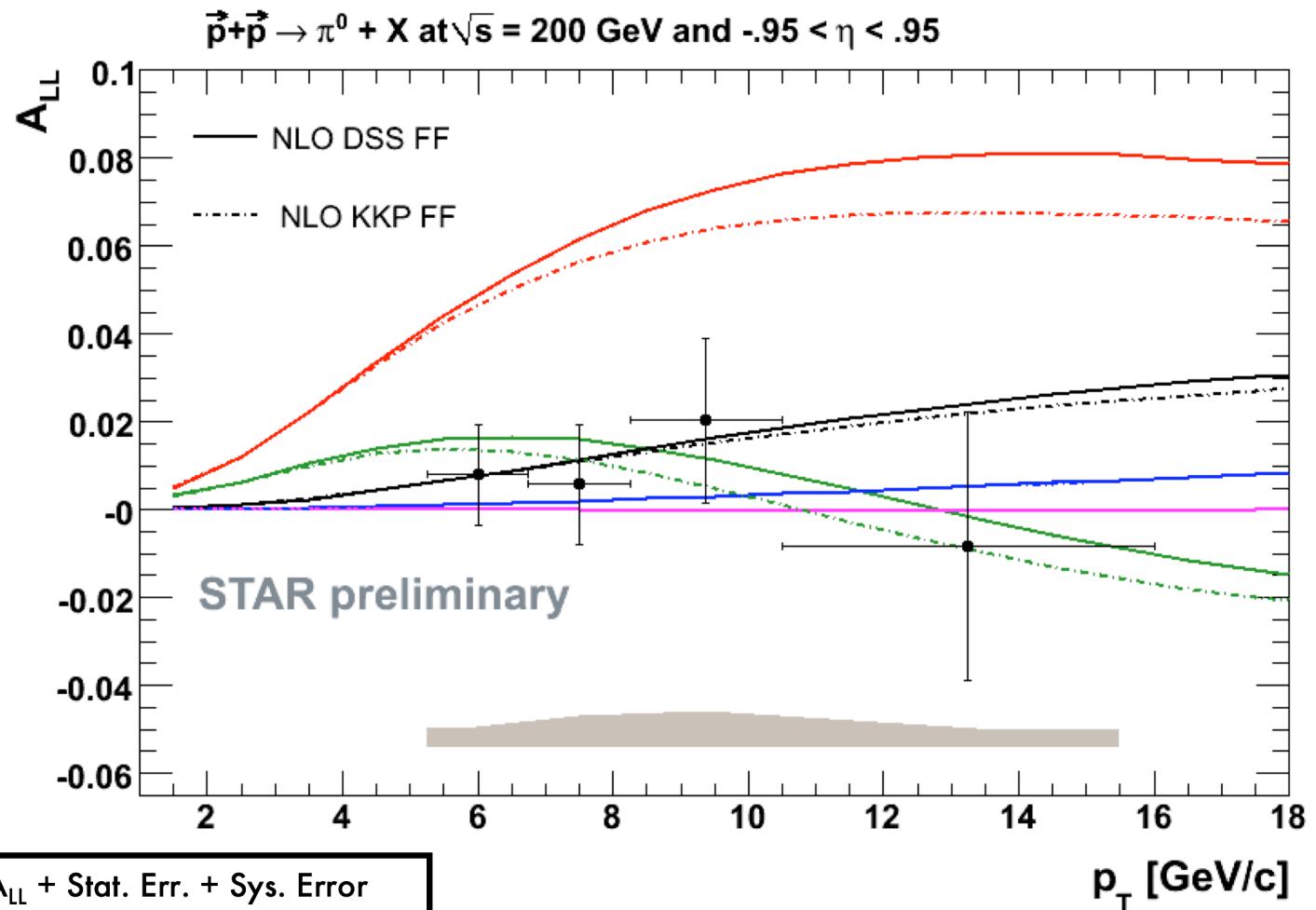


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# $A_{LL}$ Systematic Errors



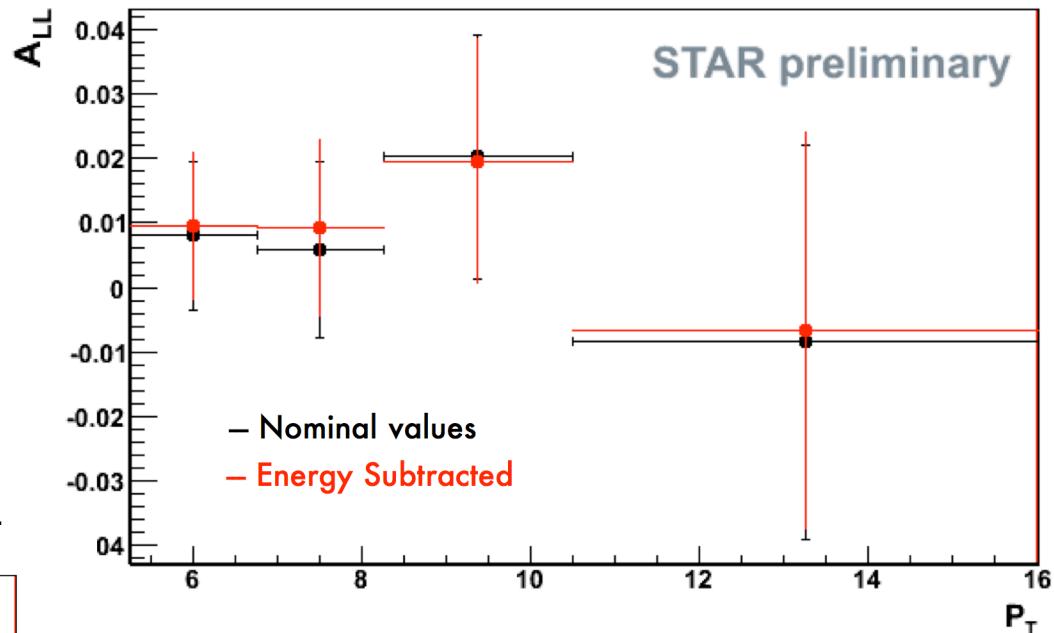
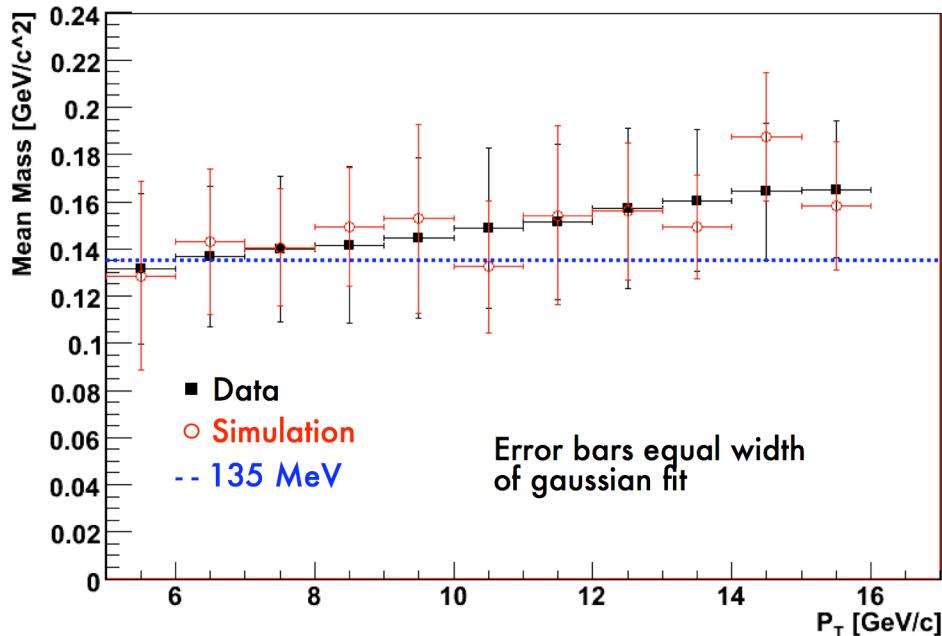
- Systematic Errors Assigned in Run 6  $\pi^0 A_{LL}$  Analysis (all errors  $\times 10^{-3}$ )
  - Non-Longitudinal Beam Components: 0.9
  - Photon Energy Uncertainty:  $P_T$  Dependent from 0.7 to 3.4
  - Backgrounds (from split clusters and combinatorics):  $P_T$  Dependent from 1.1 to 4.1
- Systematic Errors Assigned in Run 5  $\pi^\pm A_{LL}$  Analysis (all errors  $\times 10^{-3}$ )
  - Non-Longitudinal Beam Components: 3.0
  - Trigger Bias:  $P_T$  Dependent from 3.0 to 7.3
  - Relative luminosity: 2.0
  - Particle ID: 1.7
  - Beam Background: 0.7



# Photon Energy Uncertainty



- Reconstructed Pion mass is  $P_T$  dependent.
  - Artificially increasing opening angle.
  - Jet Background adding to  $E_\gamma$
  - Readily reproduced in simulation
- Reconstructing individual  $E_\gamma$  high.
- Systematic estimated by subtracting out "extra" energy and examining effect on  $A_{LL}$

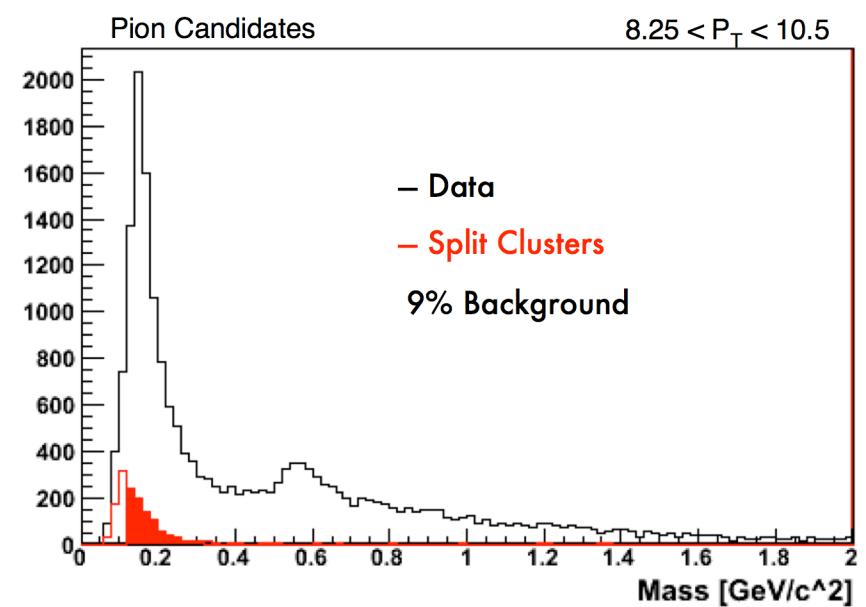
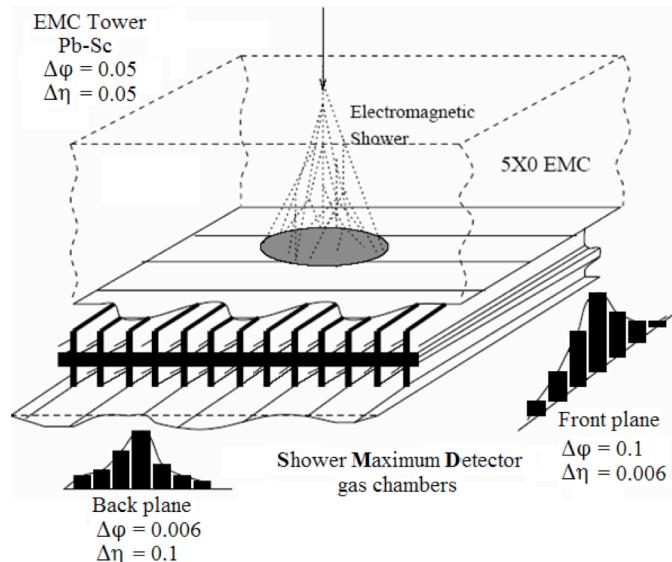
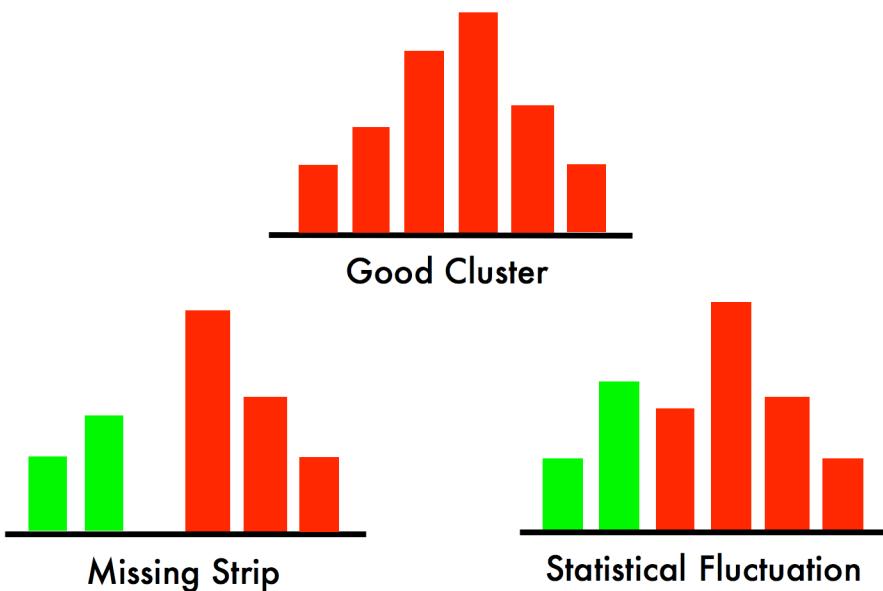


- Consistent with statistical effect
- Systematic error assigned (equal to observed shift) to be conservative

$P_T$ Range [ $\text{GeV}/c$ ]	Error $\times 10^{-3}$
5.2 - 6.75	1.5
6.75 - 8.25	3.4
8.25 - 10.5	0.7
10.5 - 16.0	1.5

# Background: Low Mass Cluster Splitting

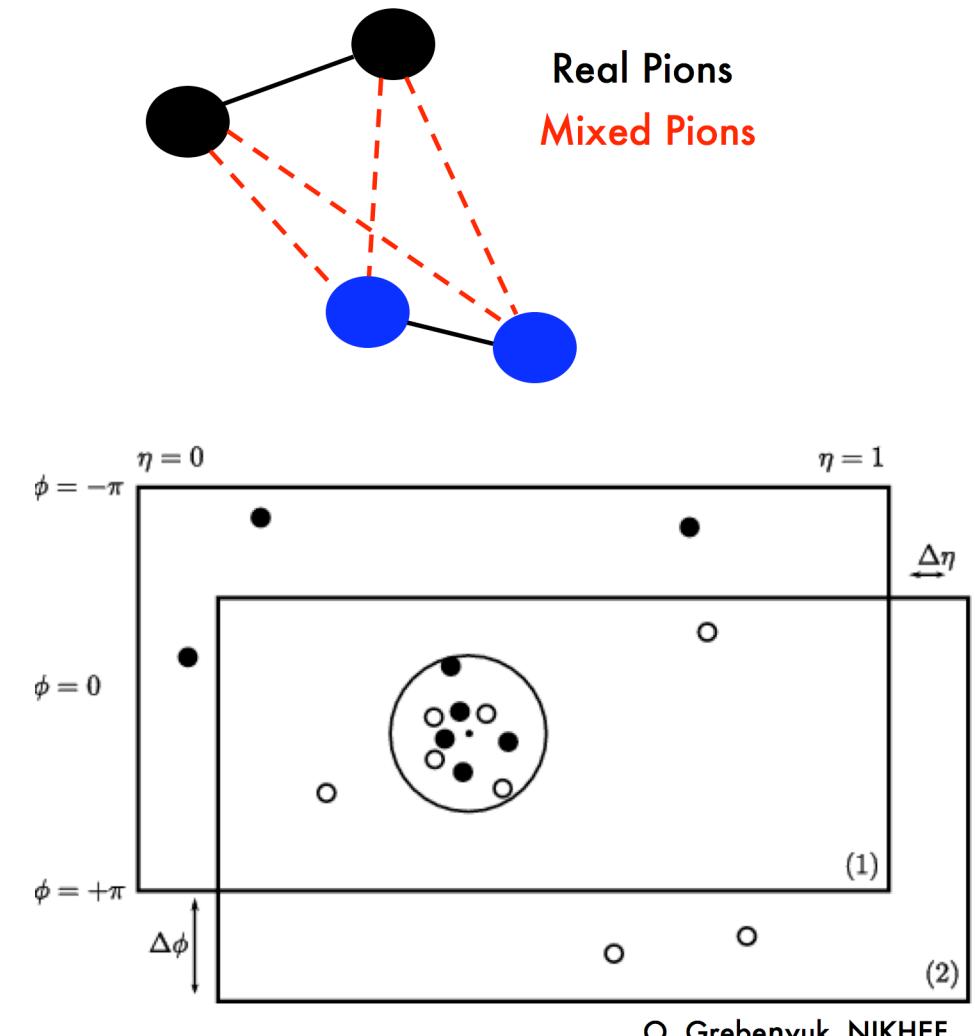
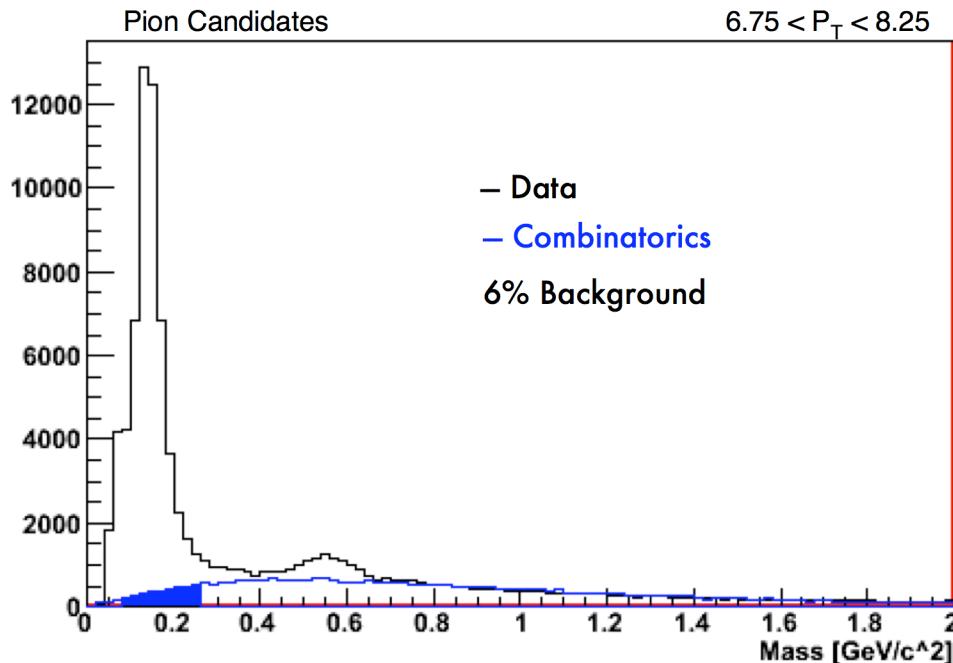
- Above 5 GeV/c pions, rely on SMD to separate and reconstruct decay photons.
- Split photons come from SMD hardware inefficiencies and strip energy fluctuations.
- Modeled with single particle MC, looking for split clusters.



# Background: Combinatorics

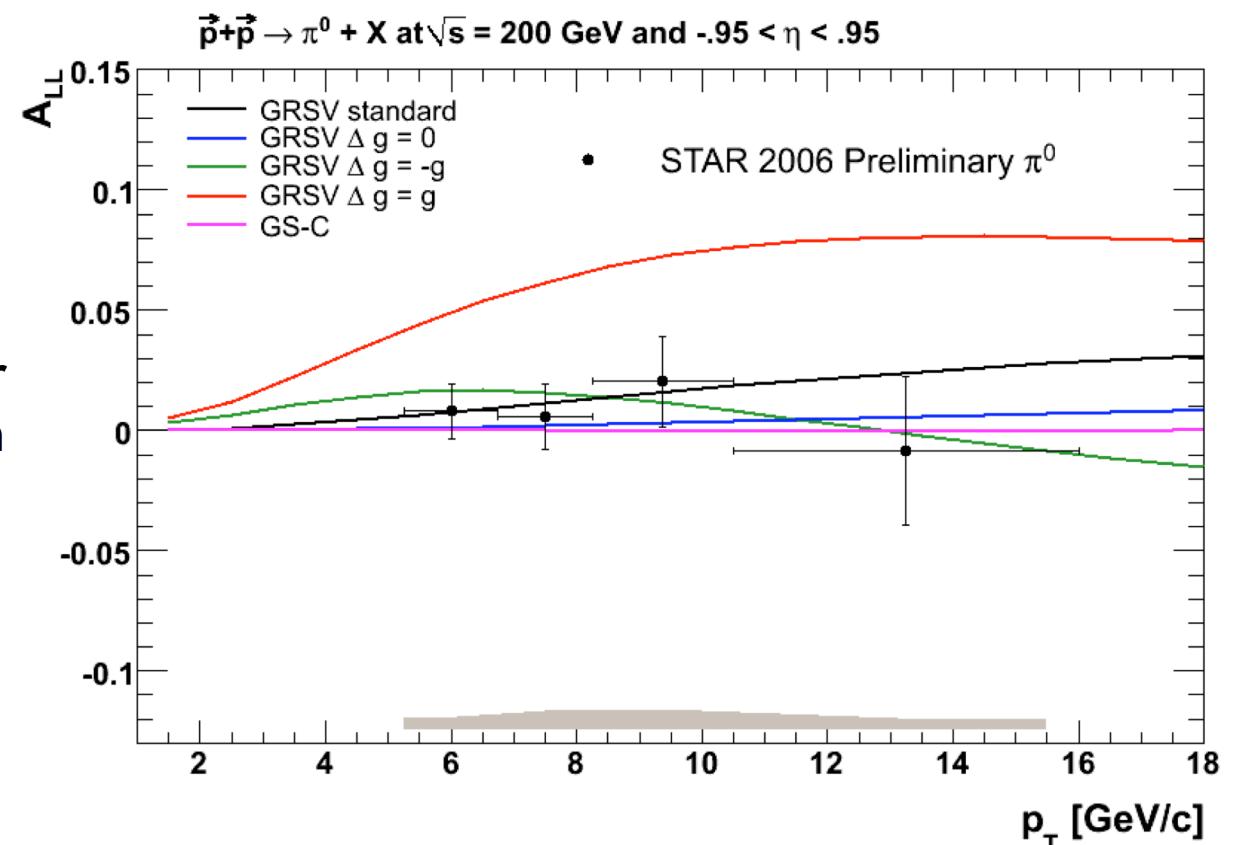


- Comes from two uncorrelated photons
- Modeled by mixing events (data)
- Careful about event topology
  - Rotating jets
  - Similar in jet  $\eta$  and z vertex



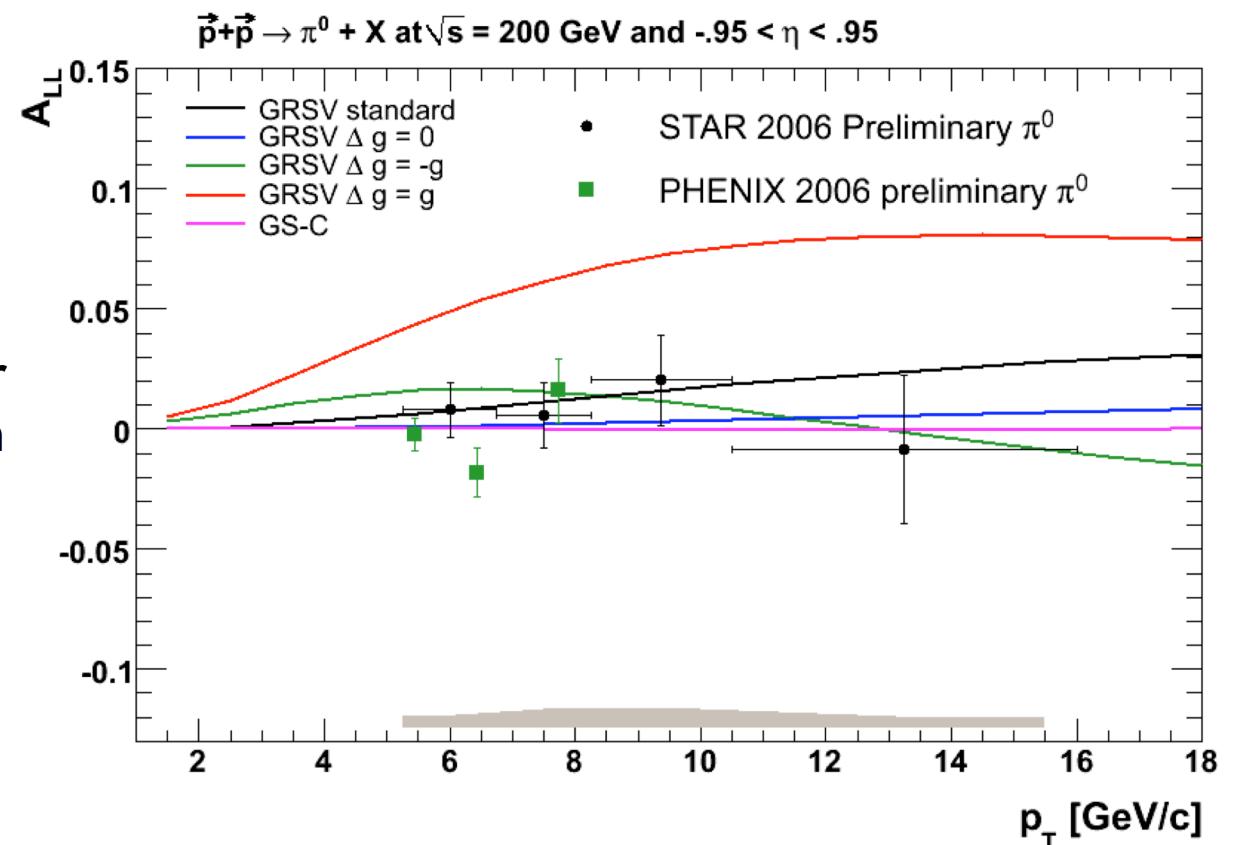
# Summary

- Most recent measurements of  $A_{LL}$  for inclusive neutral and charged pion production have been presented.
- Systematic uncertainties from backgrounds and energy resolution have been estimated and are smaller than statistical uncertainties.
- Results consistent with PHENIX 2006 preliminary
- The run 6  $\pi^0$  result sees a significant increase in statistical precision as well as a greater reach in  $P_T$  compared to run 5. Similar results are expected for run 6  $\pi^\pm$ .
- STAR is planning for a long pp run in Run 9. Expecting large increase in FOM with 60% polarization and 50  $\text{pb}^{-1}$



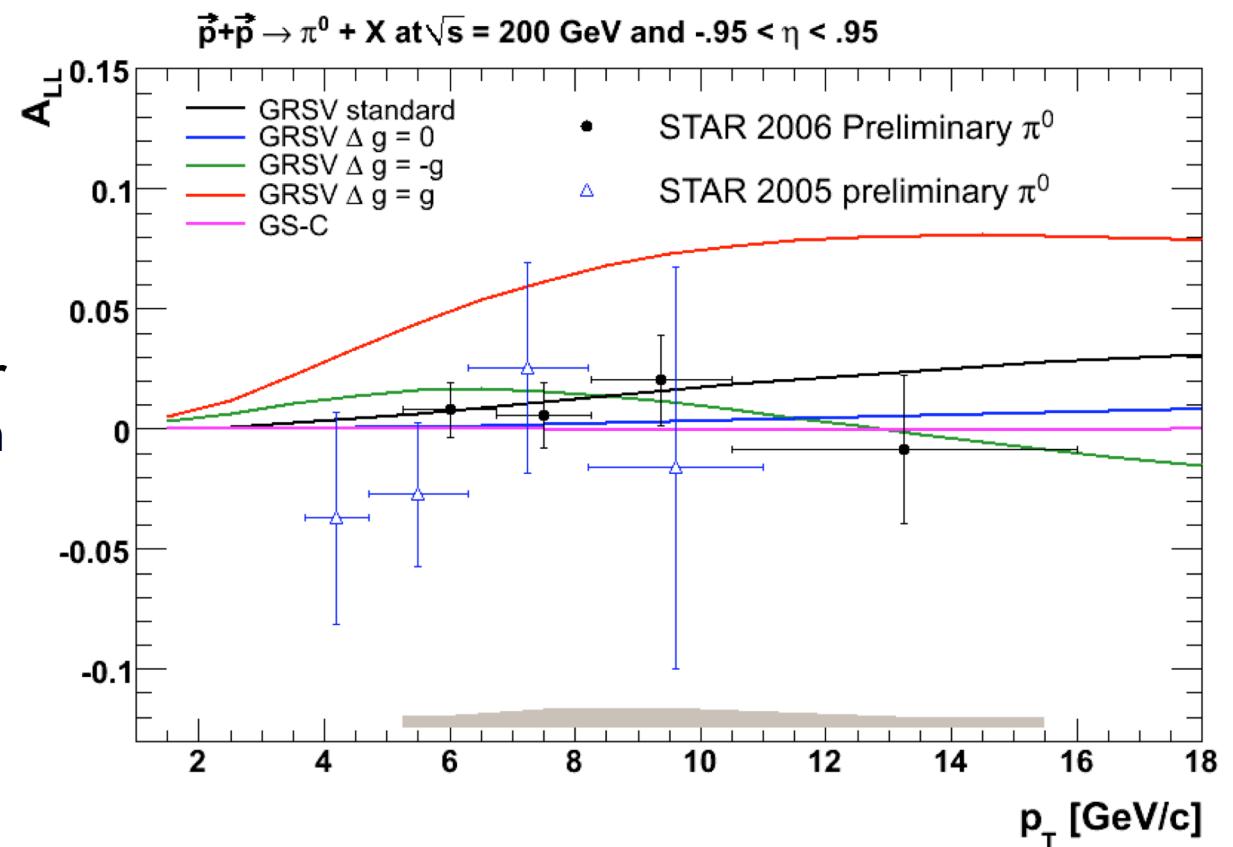
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# Backup and/or replacement slides

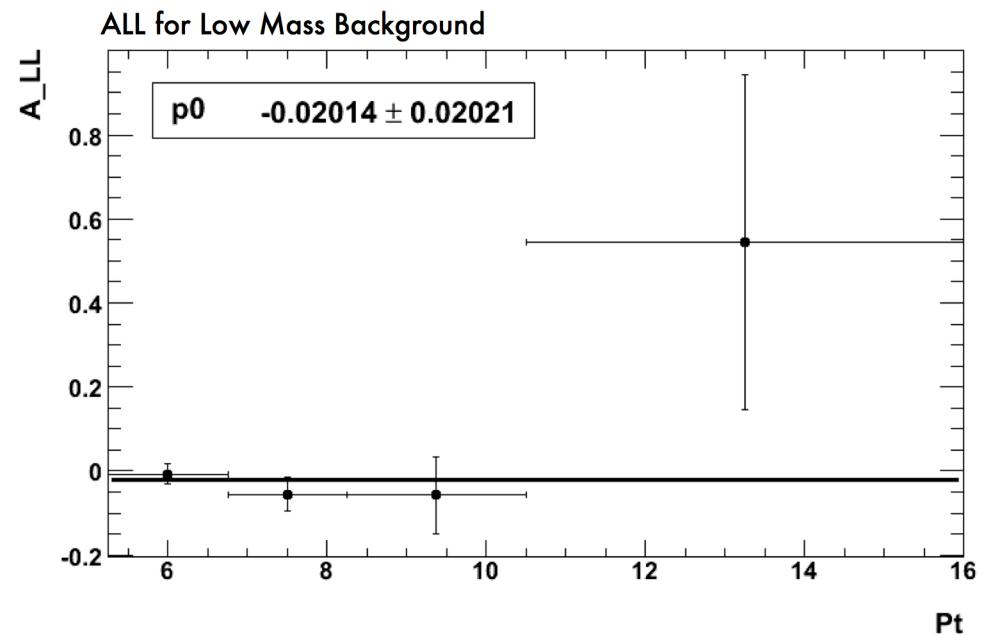
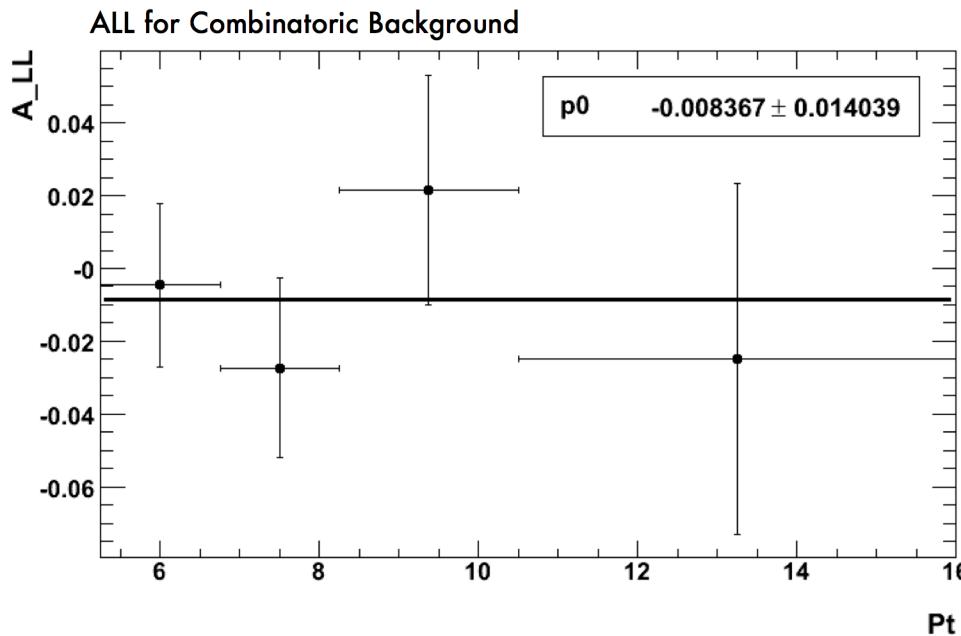


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# Background Systematics



First the background asymmetries and background fractions are calculated. For the low-mass this means between 0 and .7 GeV/c<sup>2</sup>. For the high mass tail this means between 1.2 and 2.0 GeV/c<sup>2</sup>. We fit these asymmetries with a flat line (in P<sub>T</sub>). We assume that any asymmetry will not be P<sub>T</sub> dependent.



$$\Delta A_{LL} = F_{bg} * (A_{LL}^{bg} - A_{LL}^{meas.})$$

Where  $F_{bg}$  is the background fraction.

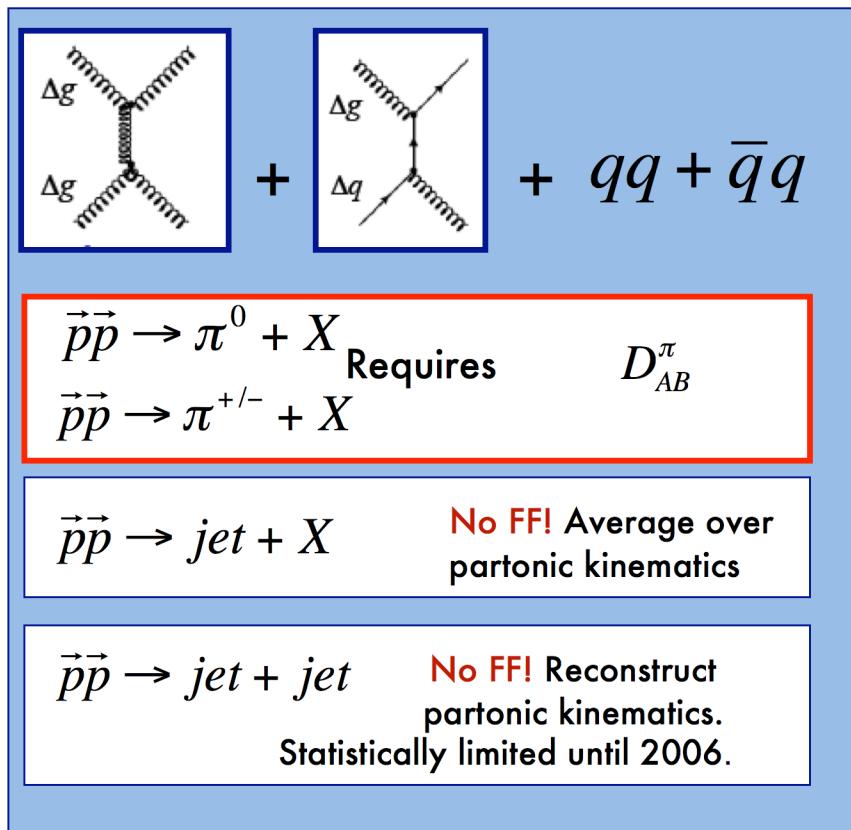


# Accessing $\Delta G$ at STAR (theorist version)



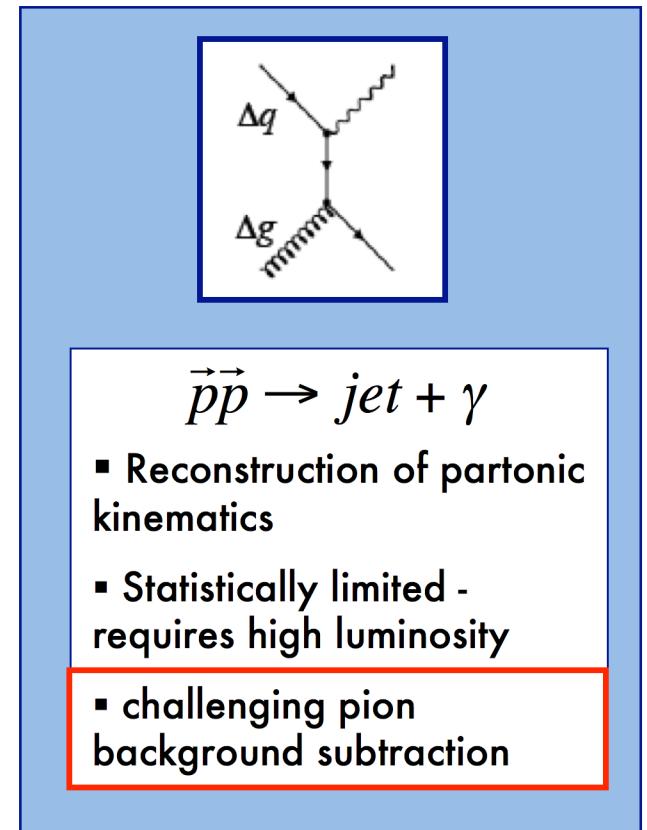
$$A_{LL} \approx \frac{\sum_{a,b} \Delta a \otimes \Delta b \otimes d\hat{\sigma}^{ab \rightarrow cX'} \cdot \hat{a}_{LL}^{ab \rightarrow cX'} \otimes D_c^F}{\sum_{a,b} a \otimes b \otimes d\hat{\sigma}^{ab \rightarrow cX'} \otimes D_c^F}$$

Inclusive measurements have contributions from several sub-processes



Understanding of inclusive channels necessary for analysis of clean jet + photon channel

Golden Channel



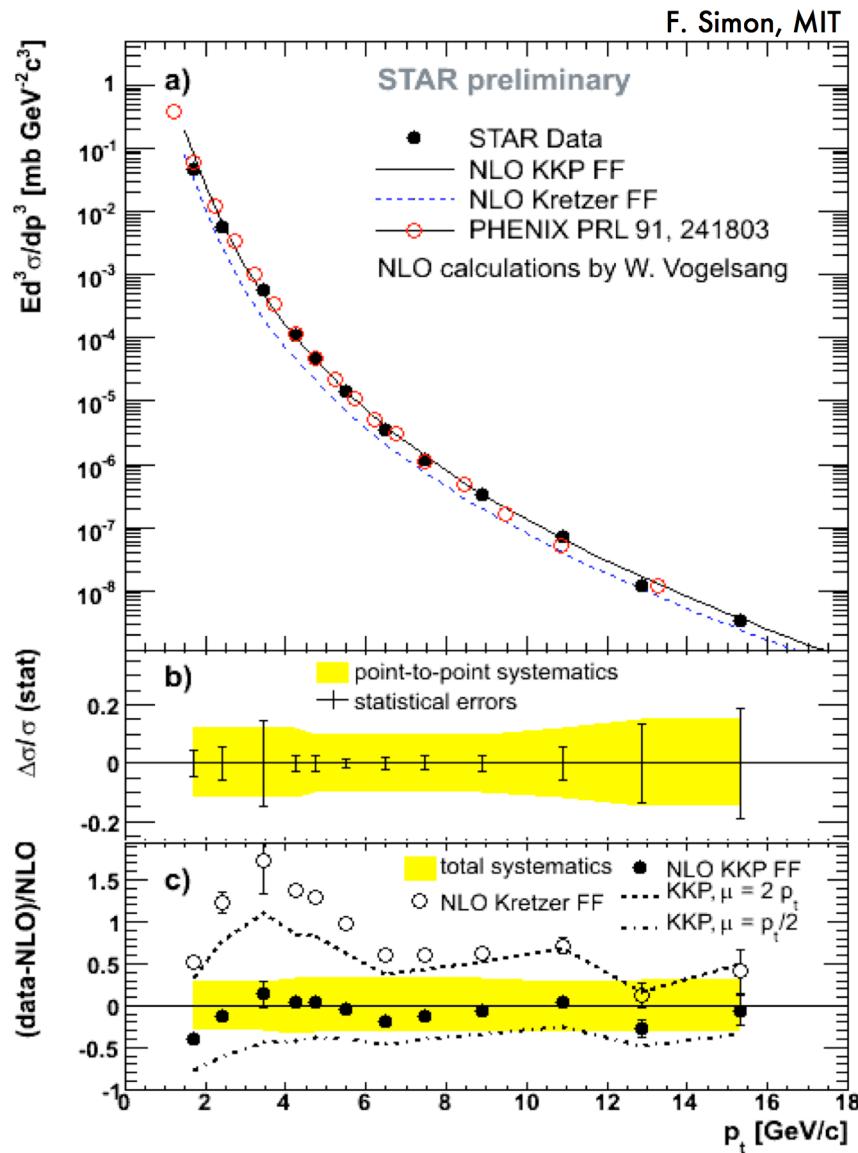
# Systematics



Effect	Uncertainty {Binwise} ( $\times 10^{-3}$ )
Backgrounds	{1.4; 1.4; 4.1; 1.0}
Photon Energy Uncert.	{1.5; 3.4; 0.7; 1.5}
Relative Luminosity	0.94
Non Long. Contribution	0.03
Quad. Sum	{2.25; 3.8; 4.3; 2.0}



# 2005 Neutral Pion Cross Section



Invariant cross section:

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{2\pi p_T \Delta p_T \Delta y} c \frac{N^\pi}{L_{\text{sampled}}}$$

- $L_{\text{sampled}}$ : 0.4 pb-1 (HT triggers), 44 mb-1 (MB)
- Point-to-point systematics from yield extraction
- Total systematics dominated by 5% uncertainty in BEMC energy scale, significant contribution from correction factor uncertainty
- Compared to NLO pQCD (CTEQ6M pdfs) using KKP and Kretzer fragmentation func.
- better agreement with KKP
- large scale uncertainties in pQCD calculations, indicated by choosing different scales for KKP calculations

