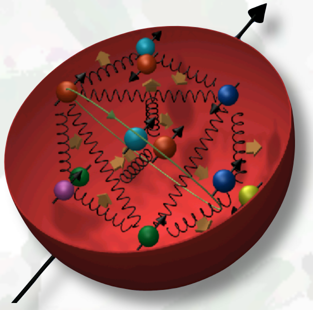
Recent STAR results on Charged Pion Production in Polarized proton-proton Collisions at $\sqrt{s}$ = 200GeV at RHIC

Bernd Surrow

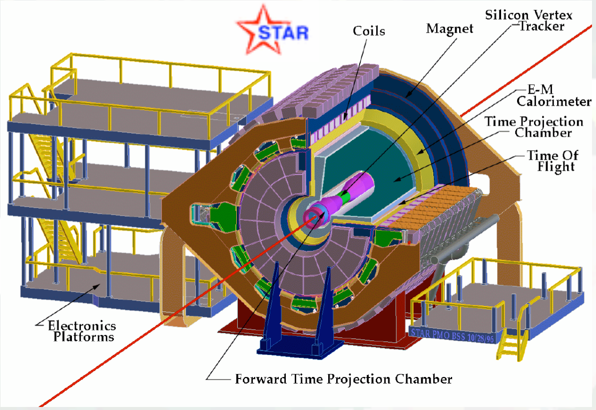
Massachusetts
Institute of
Technology

On behalf of the STAR Collaboration

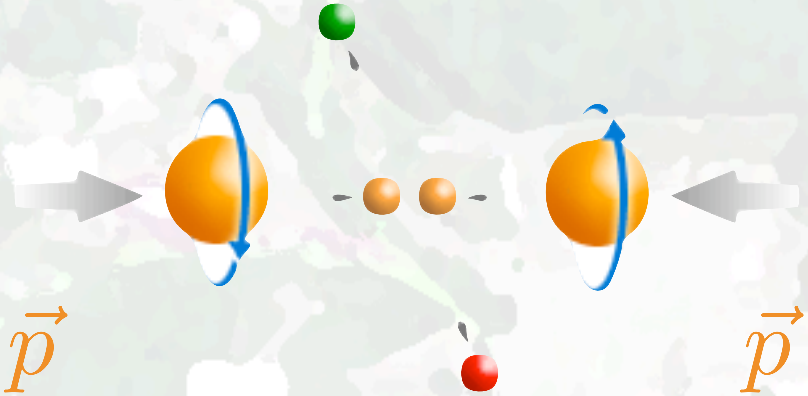


Outline

- ☐ Collider



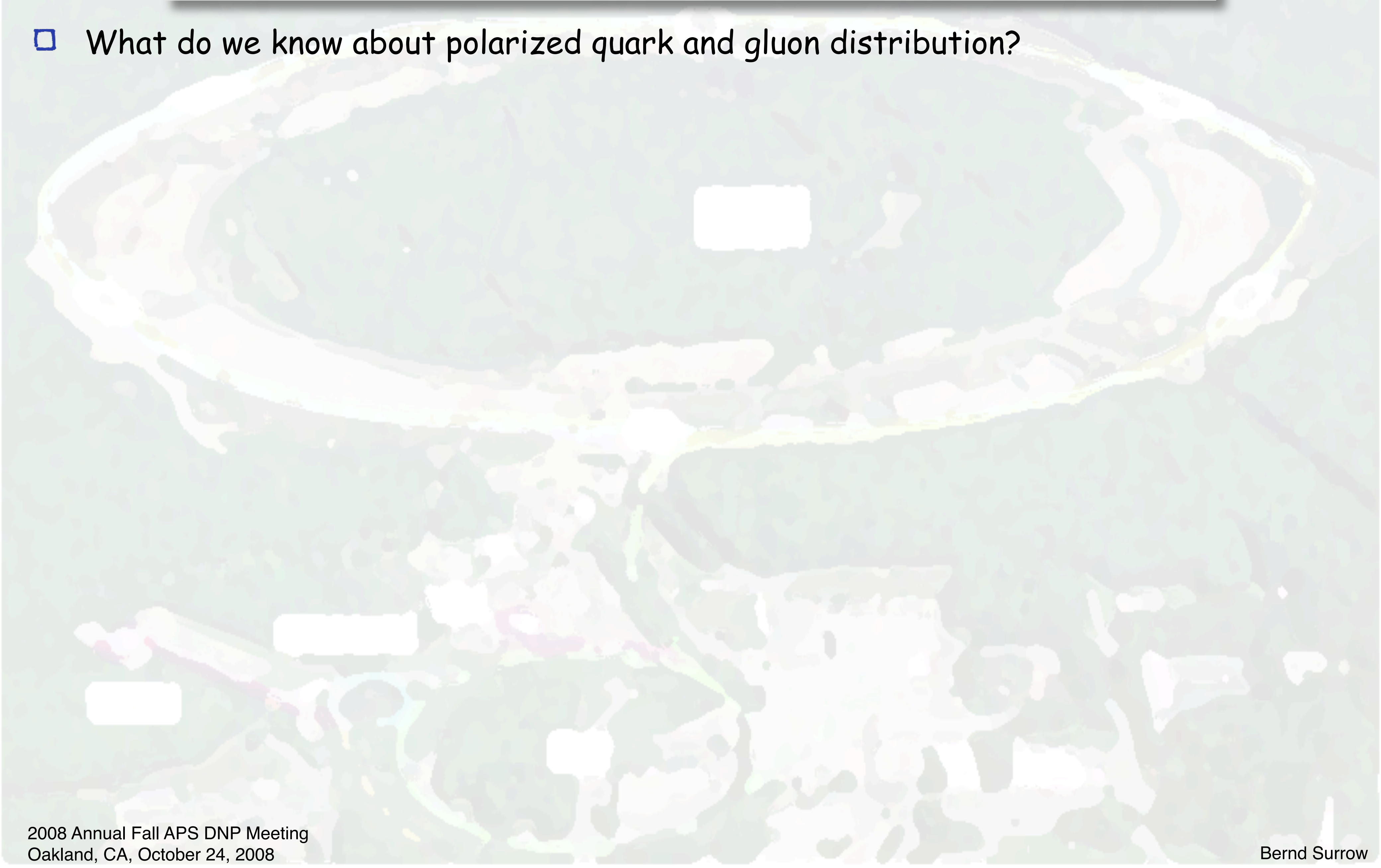
- ☐ Experiment
- ☐ Recent STAR Charged Pion A_{LL} results



- ☐ Theoretical foundation
- ☐ Summary and Outlook

Theoretical foundation

- ☐ What do we know about polarized quark and gluon distribution?



Theoretical foundation

- What do we know about polarized quark and gluon distribution?
  - Spin carried by quarks is very small (ΔΣ ~ 0.4)!

$$\boxed{\frac{1}{2} = \overbrace{\langle S_q \rangle}^{\frac{1}{2}\Delta\Sigma} + \underbrace{\langle S_g \rangle}_{\Delta G} + \langle L_q \rangle + \langle L_g \rangle}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

$$\boxed{\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx} \qquad \boxed{\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx}$$

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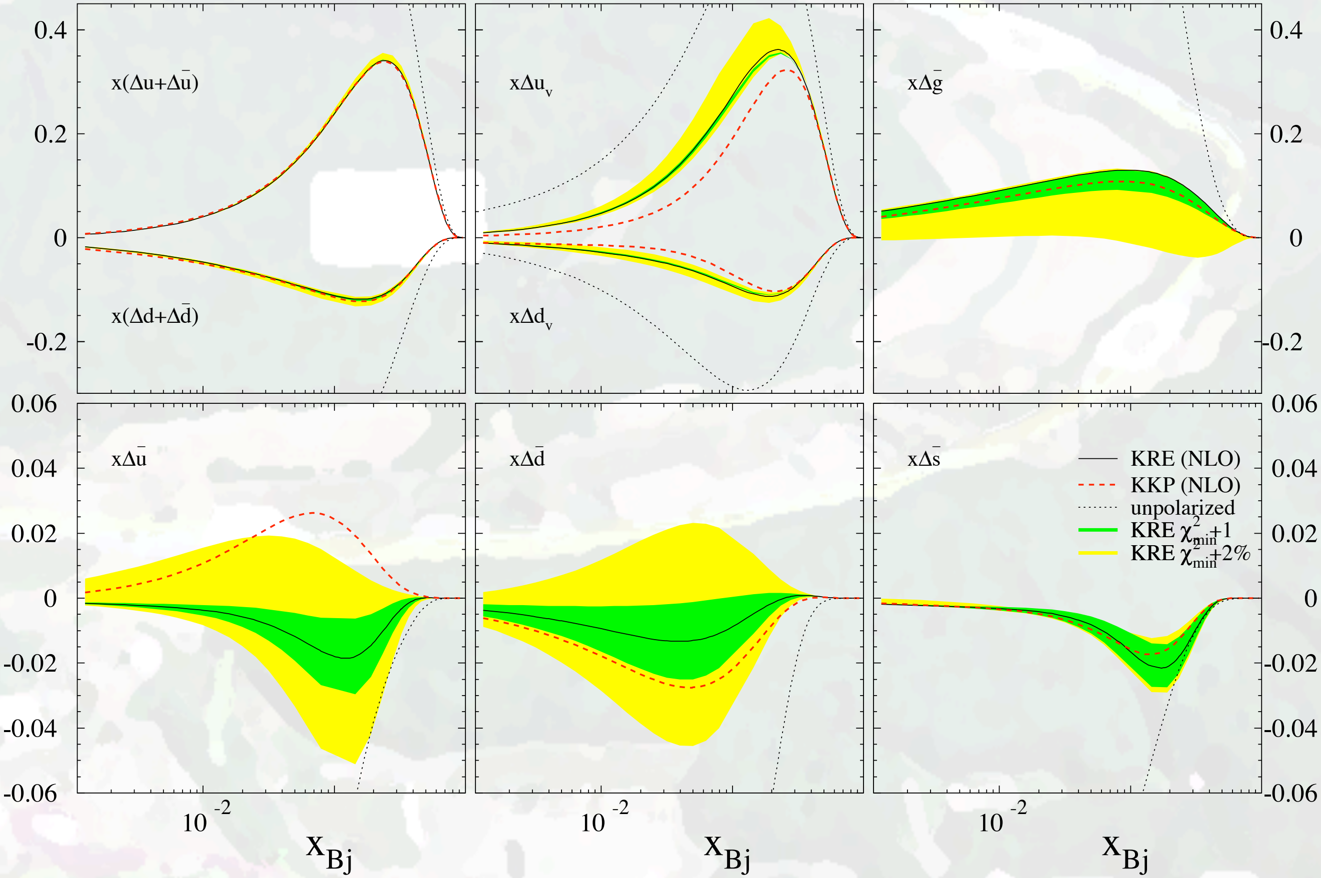

D. de Florian et al., Phys. Rev. D71, 094018 (2005).

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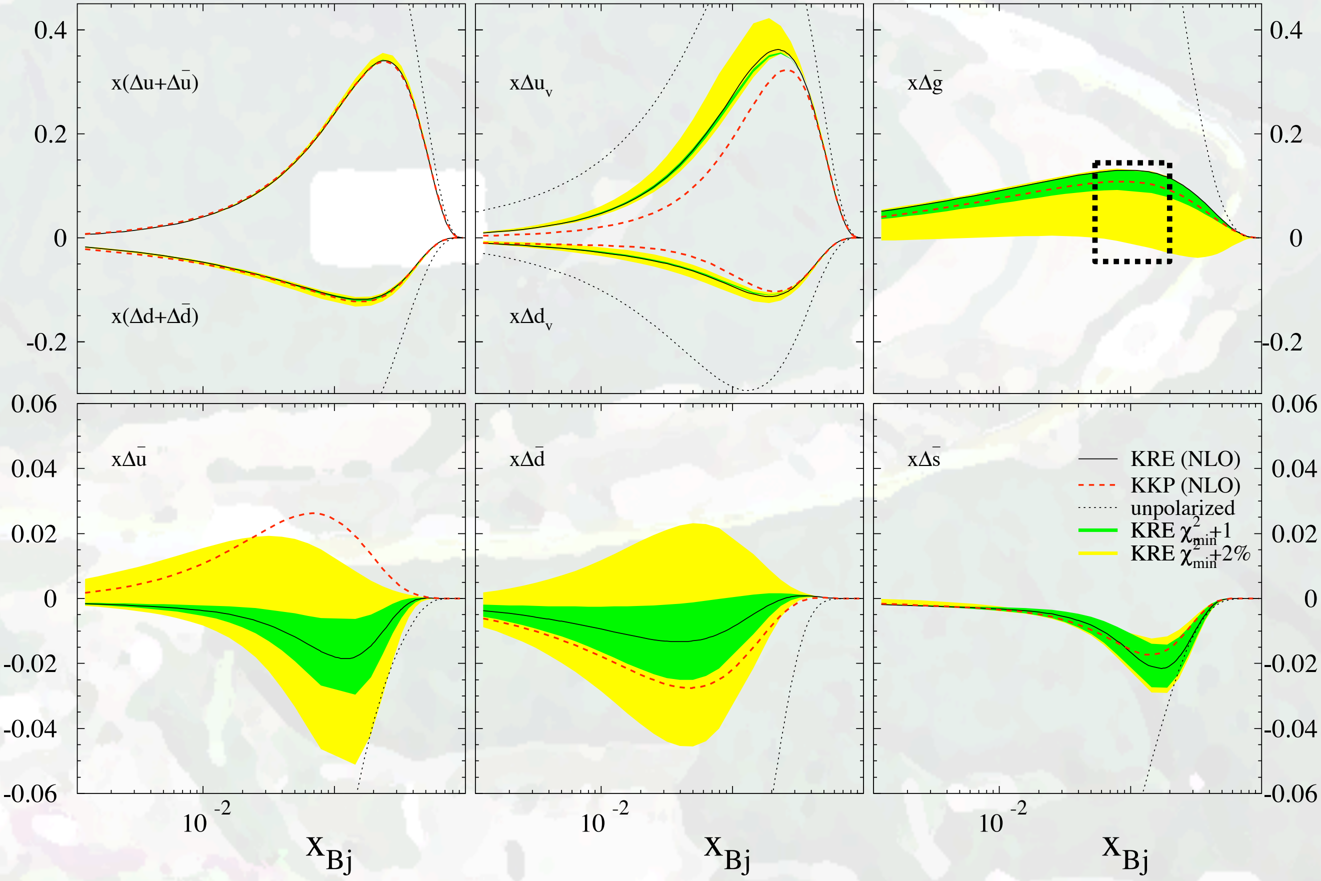

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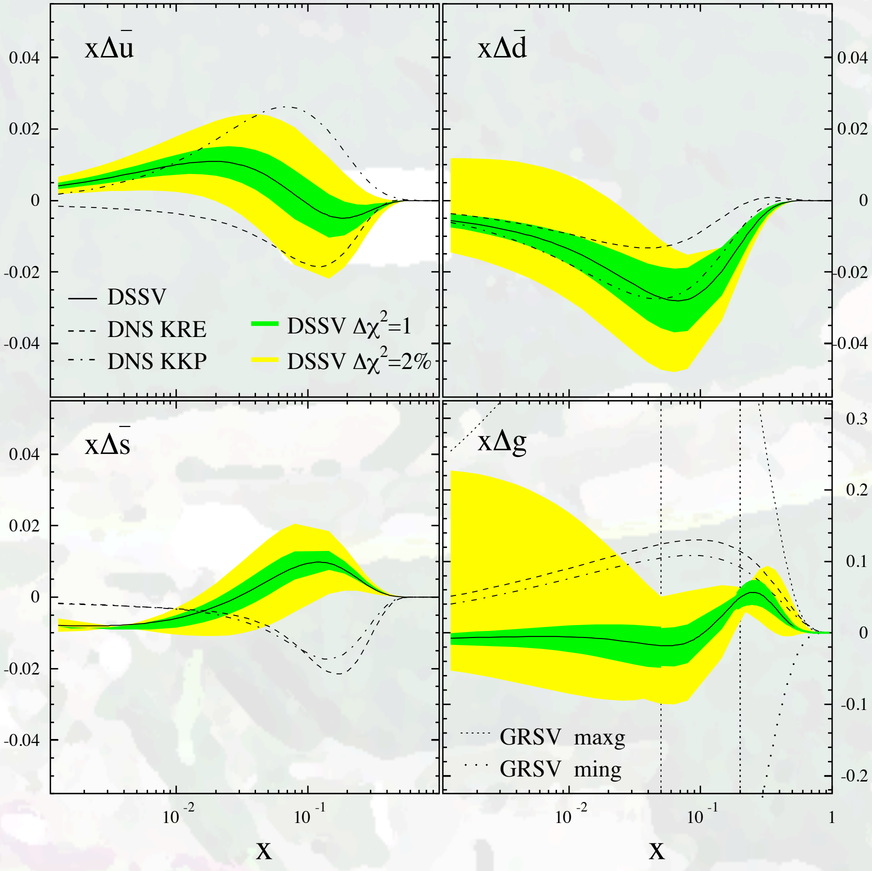

D. de Florian et al., hep-ph/0804.0422

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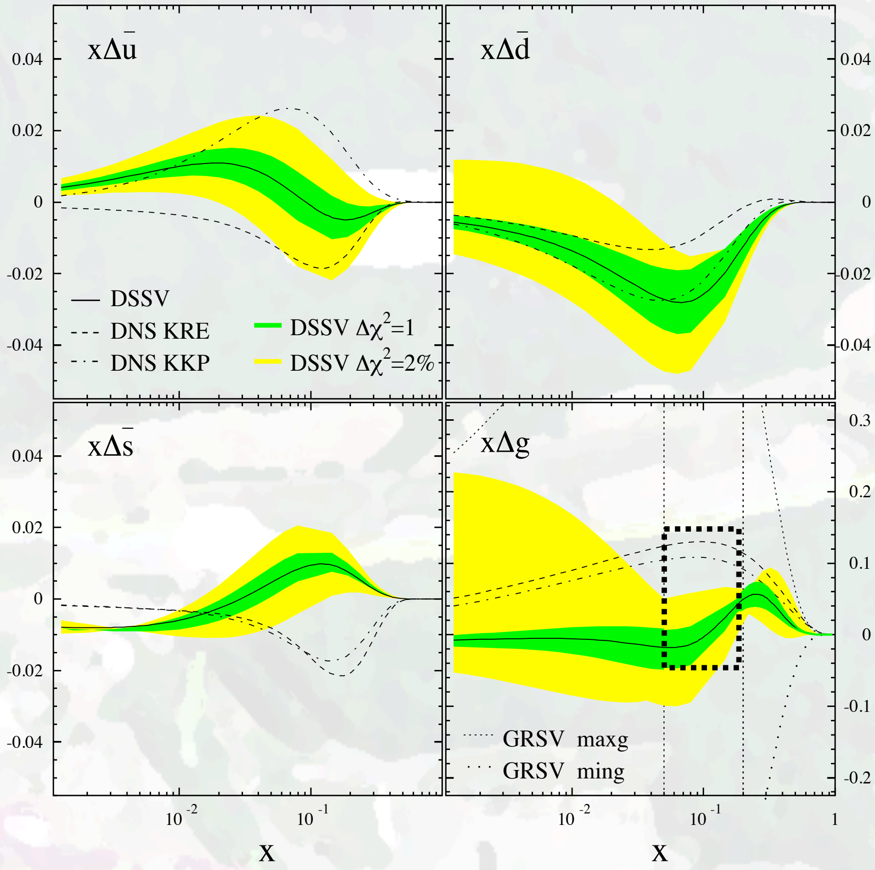

Substantial improvement for 0.05<x<0.2

Large uncertainties at low x

D. de Florian et al., hep-ph/0804.0422

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Theoretical foundation

- ☐ Gluon polarization - Extraction

Theoretical foundation

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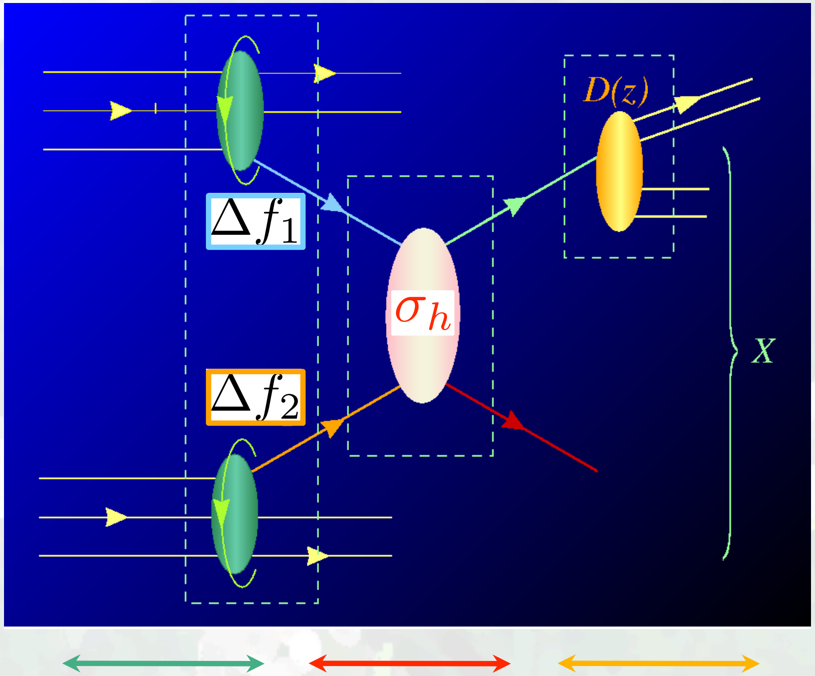
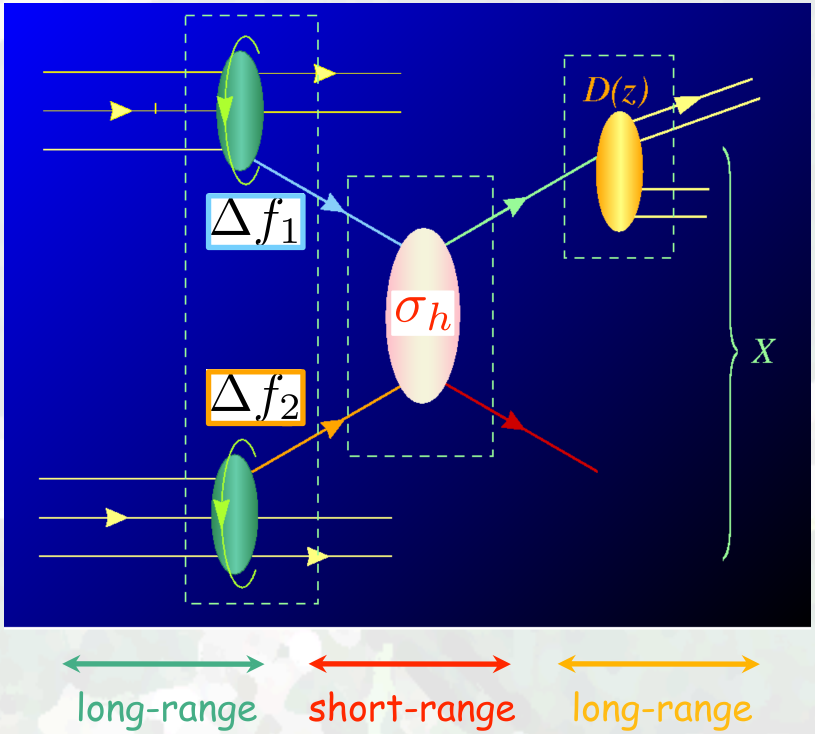


long-range short-range long-range

Theoretical foundation

- Gluon polarization - Extraction



$$\left.\boxed{\Delta f_1}\qquad \boxed{\Delta f_2}\qquad \boxed{a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}}\right\}\text{Input}$$

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} \propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Theoretical foundation

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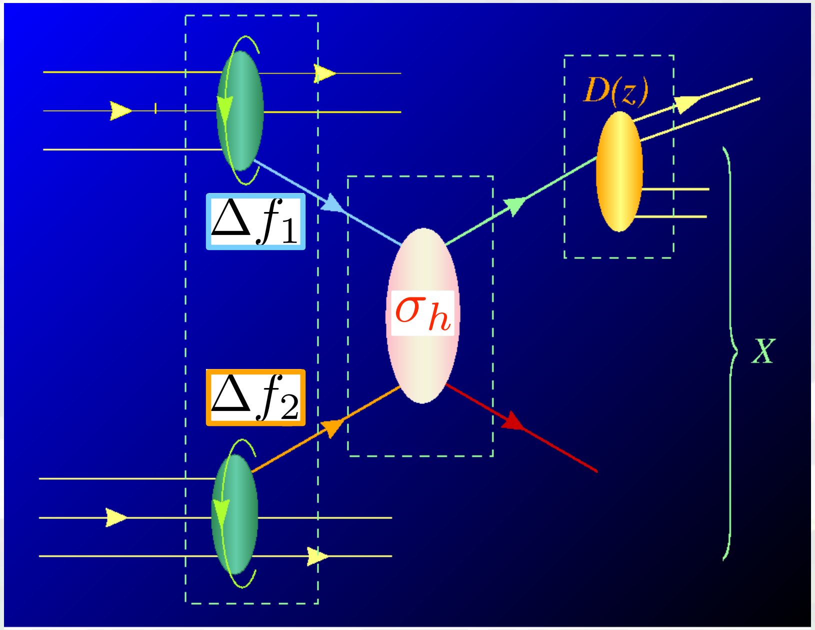

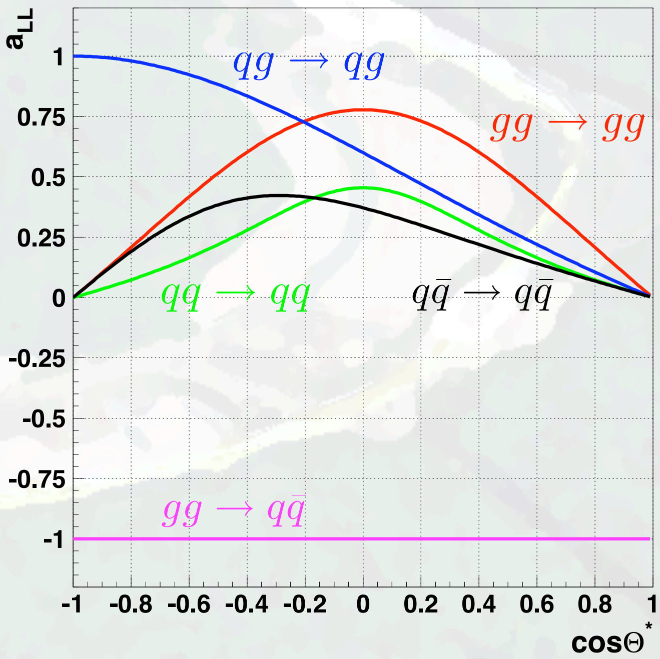

↔ long-range ↔ short-range ↔ long-range

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Theoretical foundation

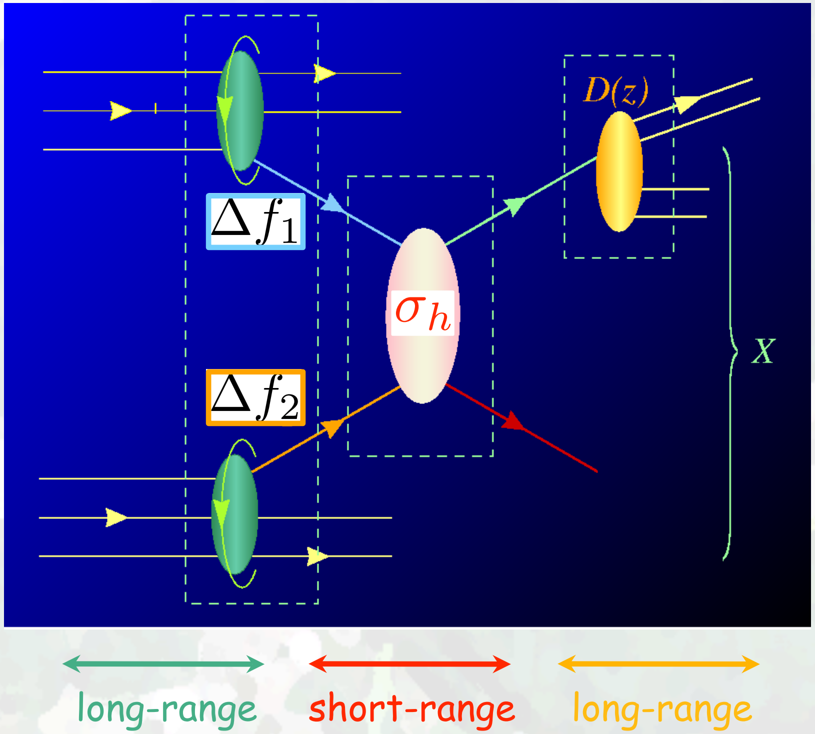
☐ Gluon polarization - Extraction

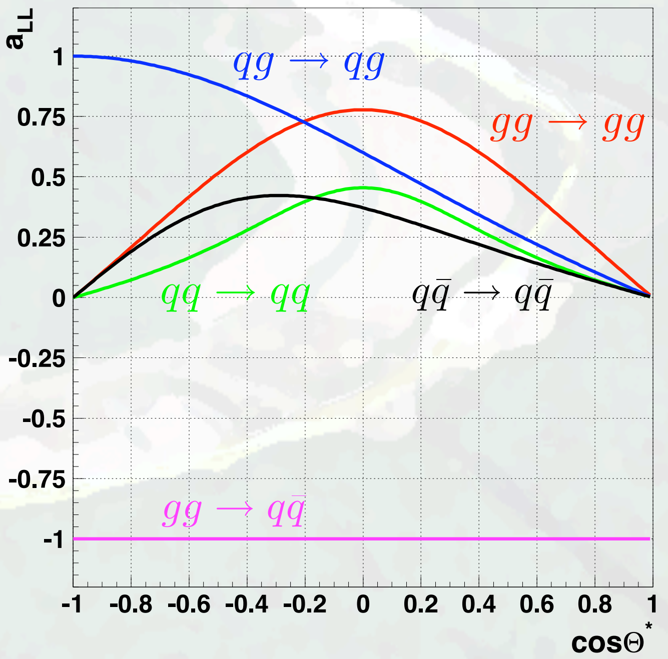
$$\boxed{\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx}$$

Extract Δg(x,Q²) through

Global Fit (Higher Order

QCD analysis)!





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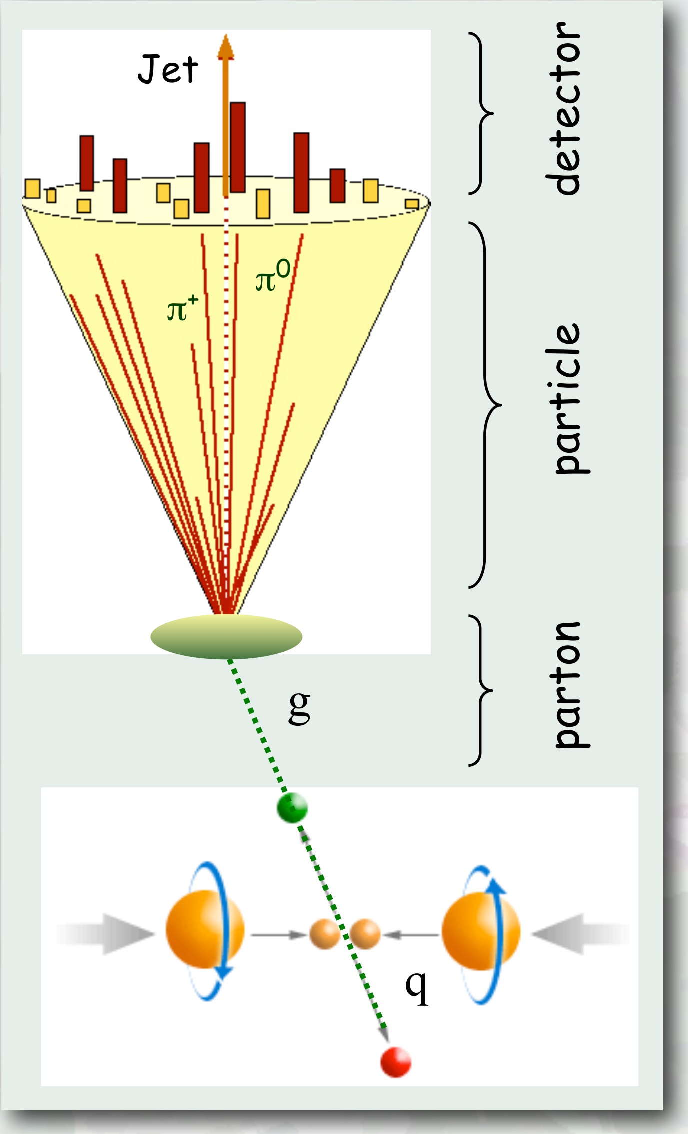
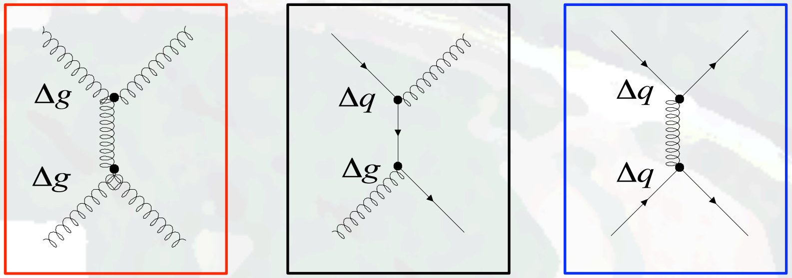
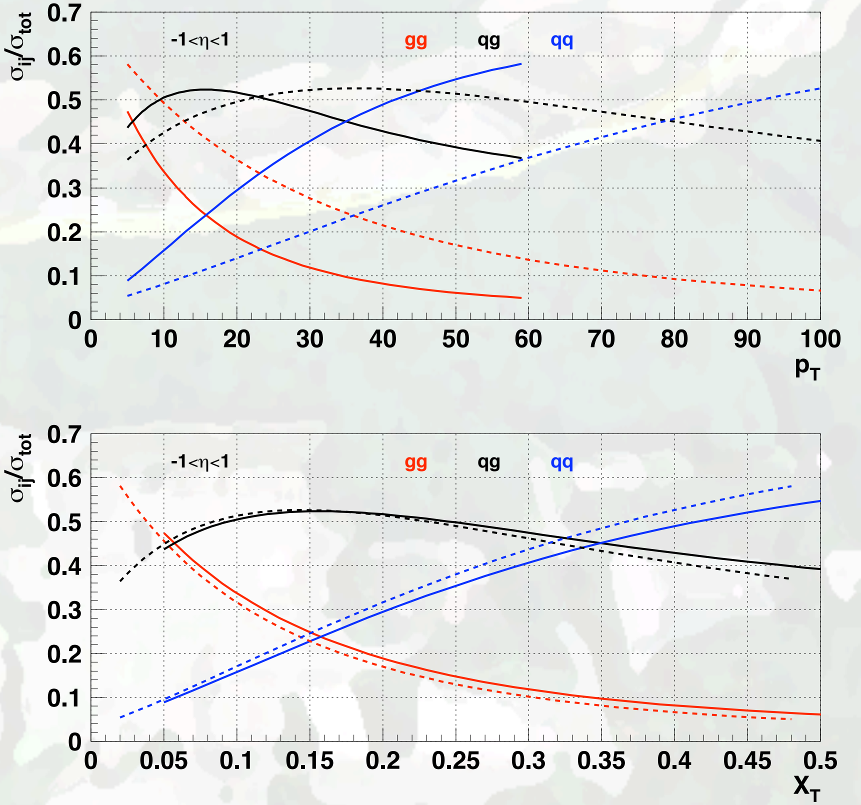
Theoretical foundation

- Gluon polarization - Inclusive Measurements





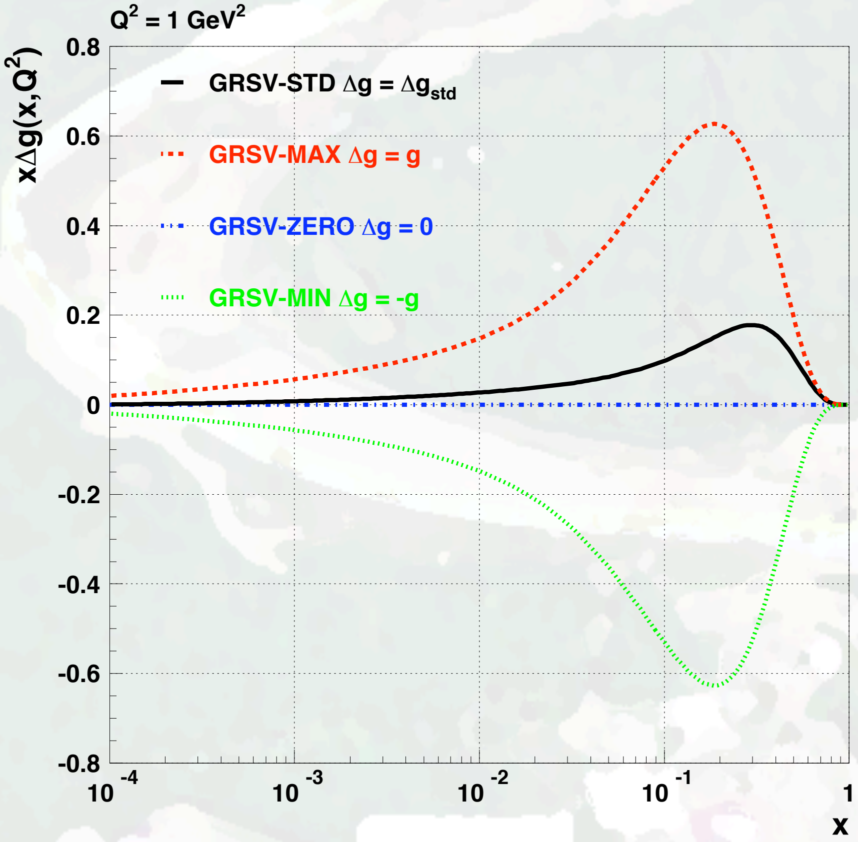
Inclusive Jet production (200GeV: Solid line / 500GeV: Dashed line)

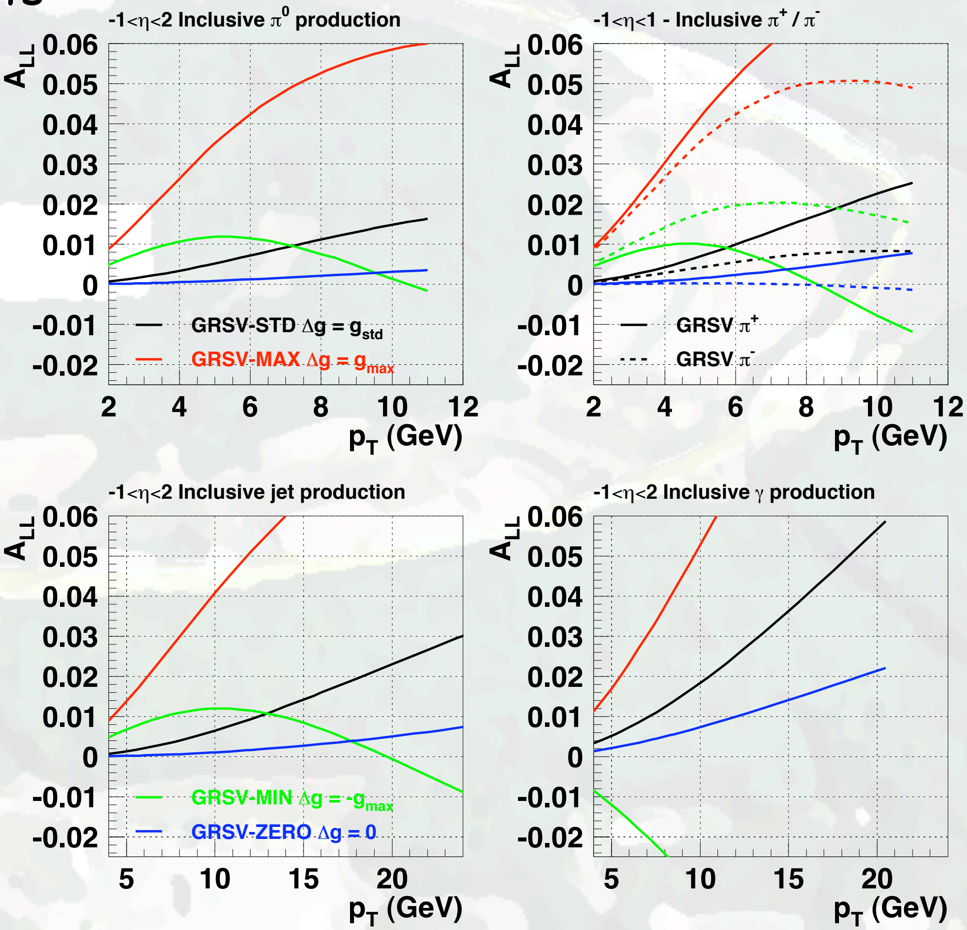


$$x_T = 2p_T/\sqrt{s}$$

Highlights of recent results and achievements

☐ Gluon polarization - Inclusive Measurements





- Examine wide range in Δg: $-g < \Delta g < +g$

- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

$$x_{\text{parton}} \simeq 2p_T/\sqrt{s}$$

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

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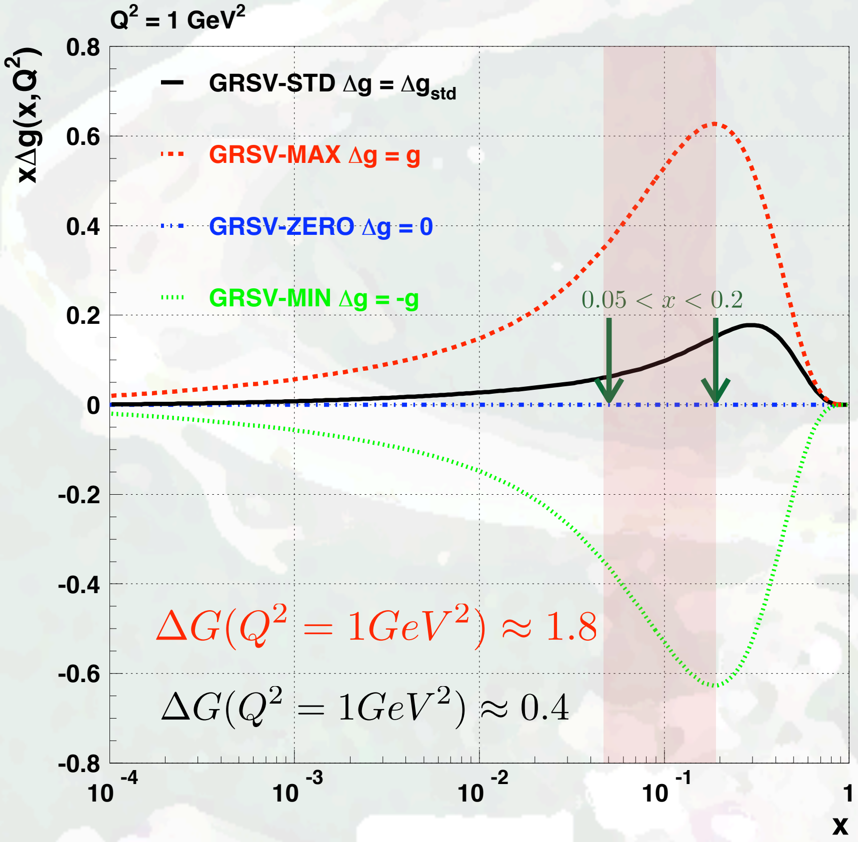

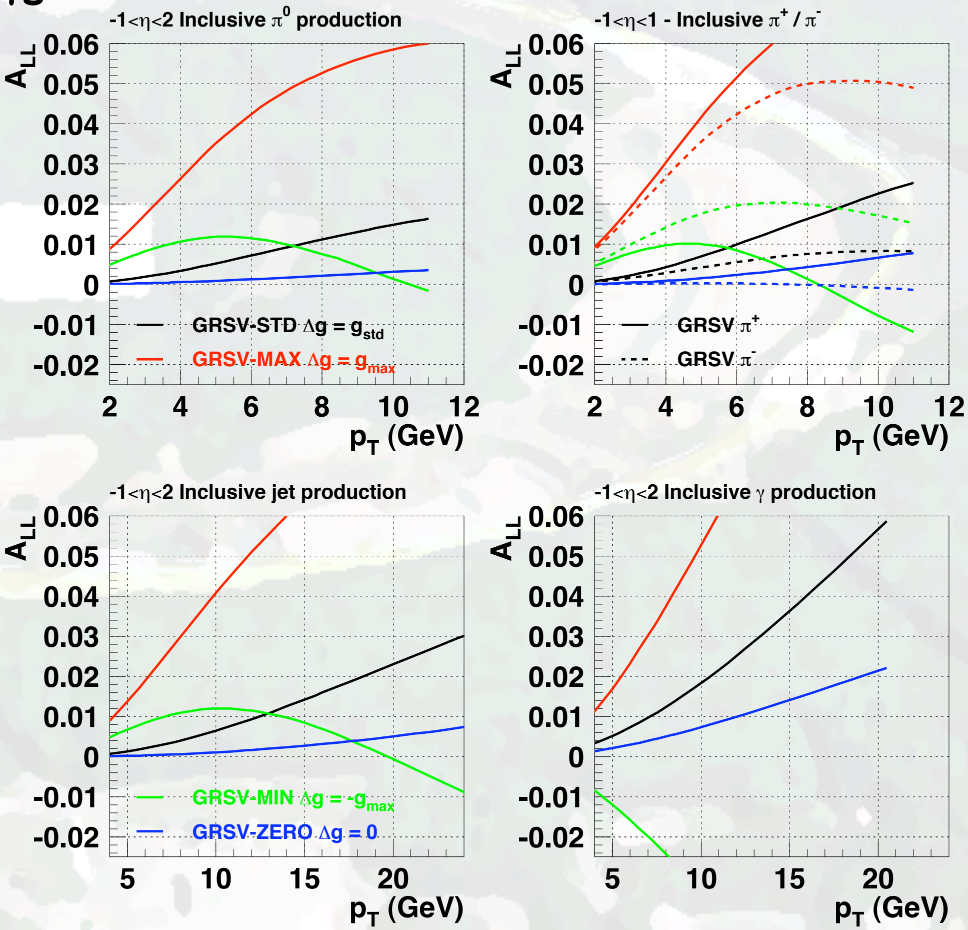

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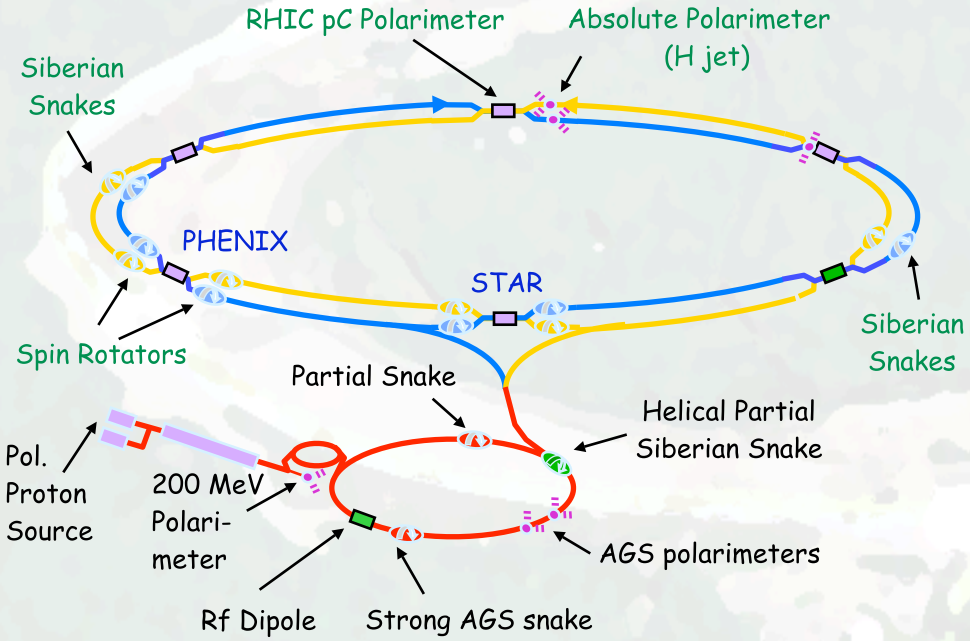
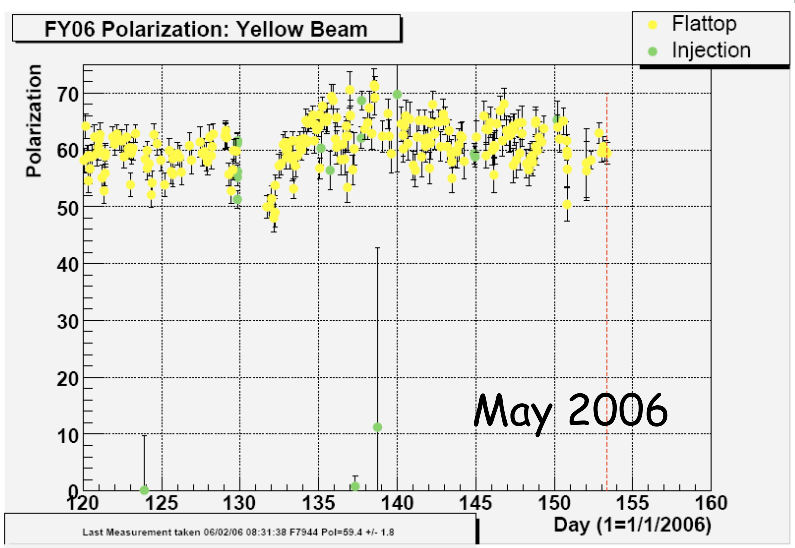
Collider: The First polarized p+p collider at BNL

Performance



RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (trans.)	$L_{recorded}$ [pb^{-1}] (long.)	Polarization[%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60

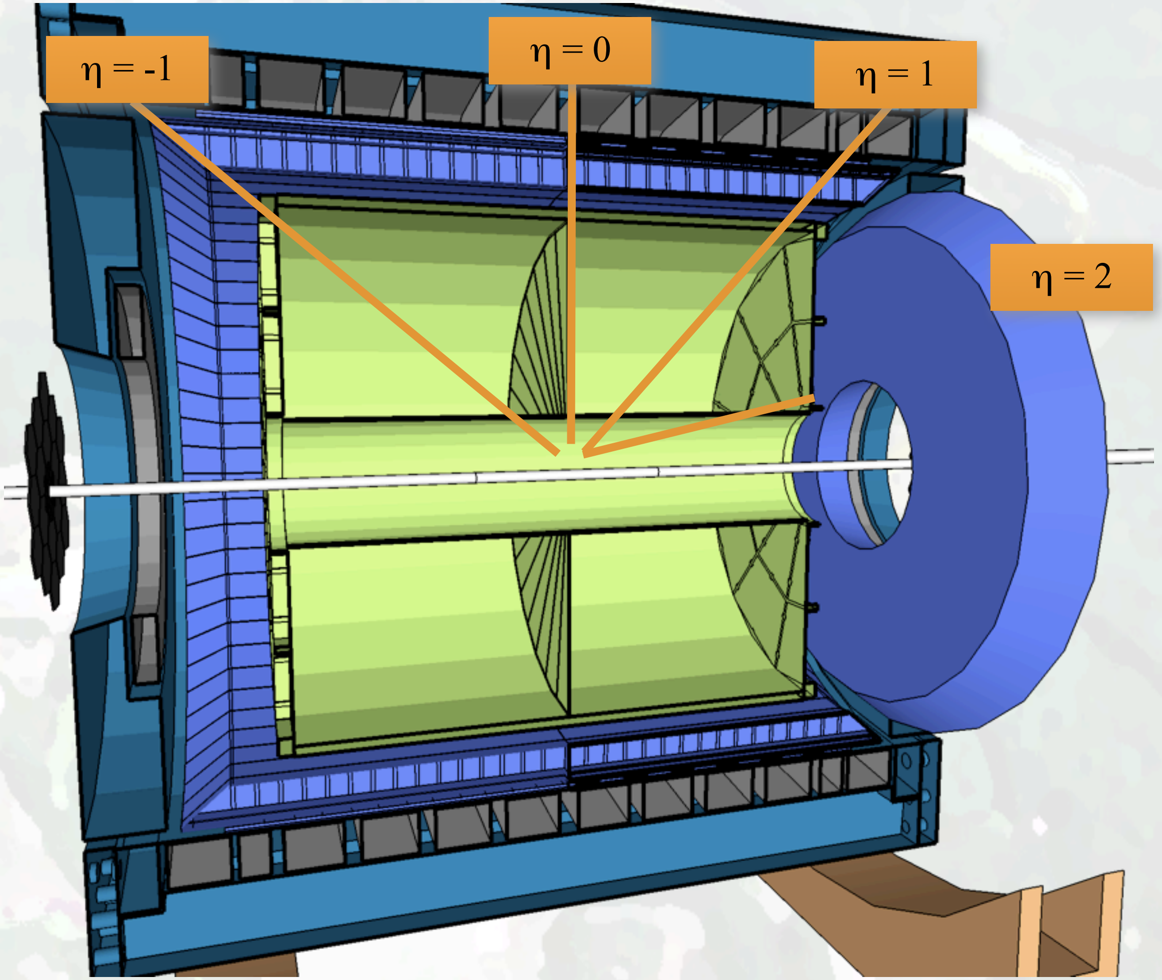
- All RHIC polarized pp accelerator components in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

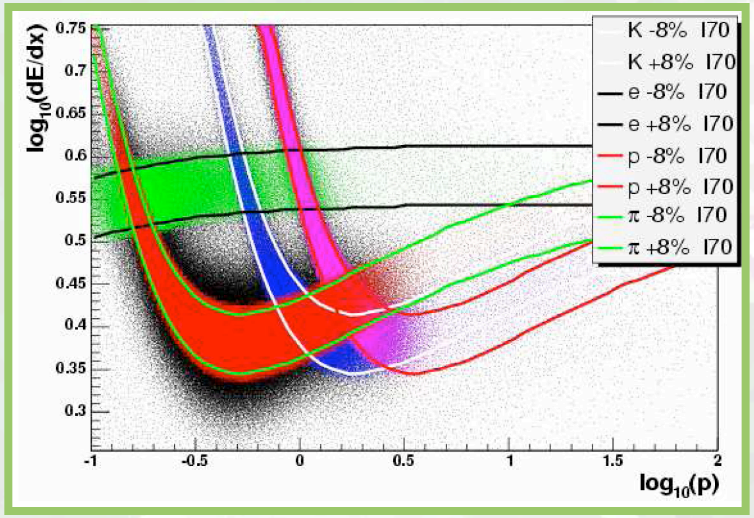


May 2006

Experiment: The STAR detector

- Overview
  - **BBC**: Relative luminosity / Minimum bias trigger
  - **BEMC**: Jet patch trigger sums energy over fixed $\Delta\eta \times \Delta\Phi = 1.0 \times 1.0$ regions
  - **TPC**: Tracking and PID using dE/dx for $|\eta| < 1.3$ and $p_T < 15$ GeV/c

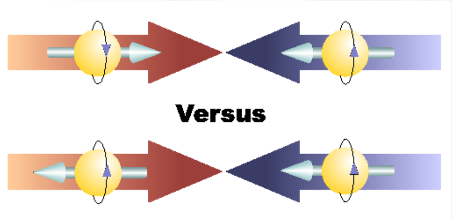




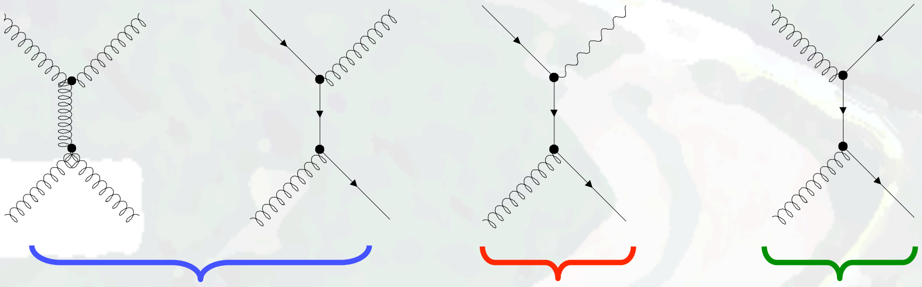
- Sophisticated TPC (dE/dx) calibrations improve precision at high p_T (arXiv:0807.4303-physics)

Recent result on Charged Pion production

- What is required experimentally to measure the gluon spin contribution?
  - Double longitudinal-spin asymmetry: A_{LL}



$$\vec{p} + \vec{p} \rightarrow$$



$\boxed{\text{jets} + X}$ $\boxed{\gamma + X}$ $\boxed{c\bar{c}\,(b\bar{b}) + X}$

- Study helicity dependent structure functions (Gluon polarization)!

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

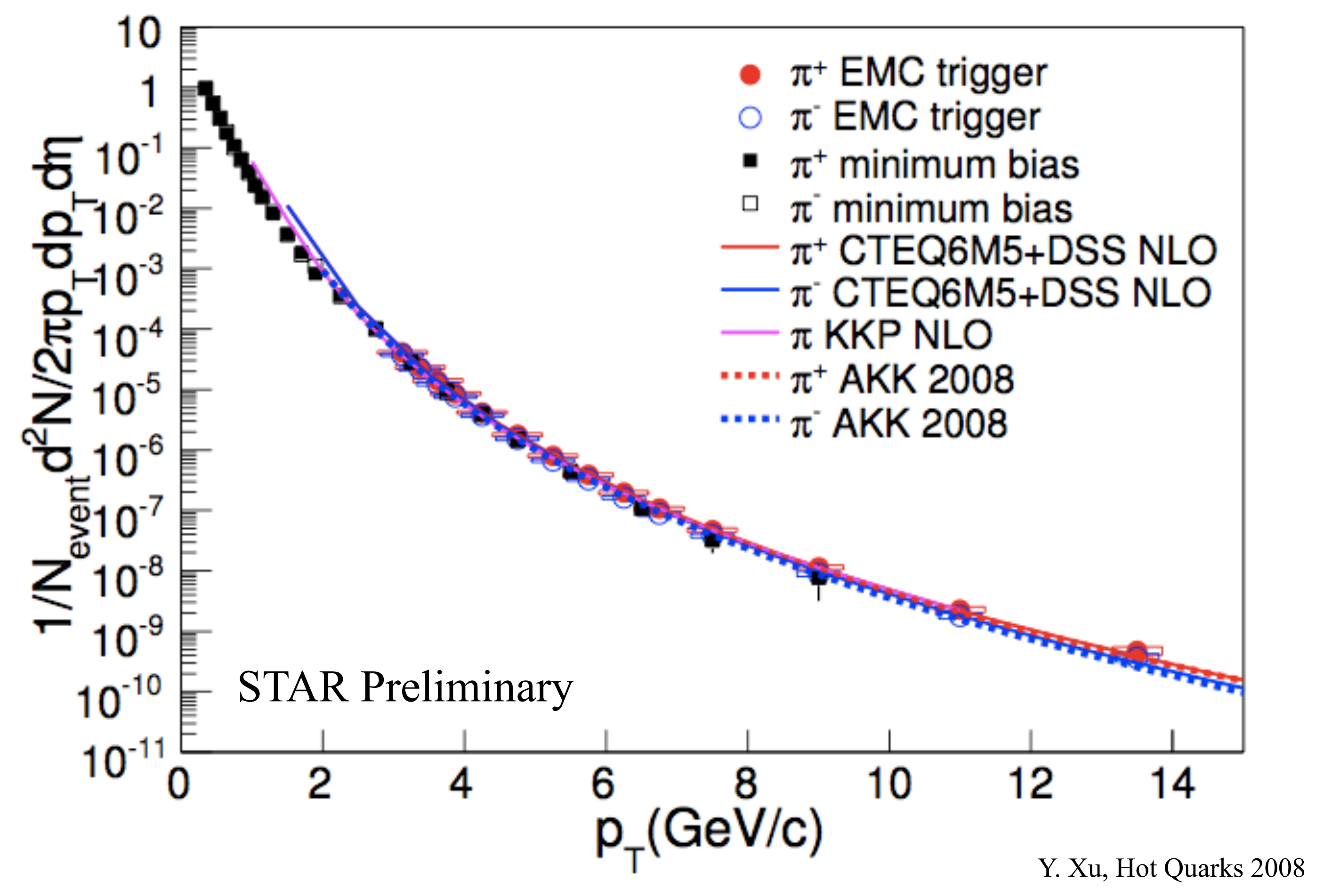
- Require concurrent measurements:
  - Magnitude of beam polarization, $P_{1(2)}$ RHIC polarimeters
  - Direction of polarization vector
  - Relative luminosity of bunch crossings with different spin directions
  - Spin dependent yields of process of interest N_{ij}

} RHIC polarimeters

} STAR experiment

Recent result on Charged Pion production

- STAR Run 5 Cross section result: Mid-rapidity charged pion production



Y. Xu, Hot Quarks 2008

- Good agreement between data and NLO calculations for charged pion production ($3<p_T<15$GeV/c) incl. cross-section ratios (π^-/π^+) for $|\eta|<0.5$

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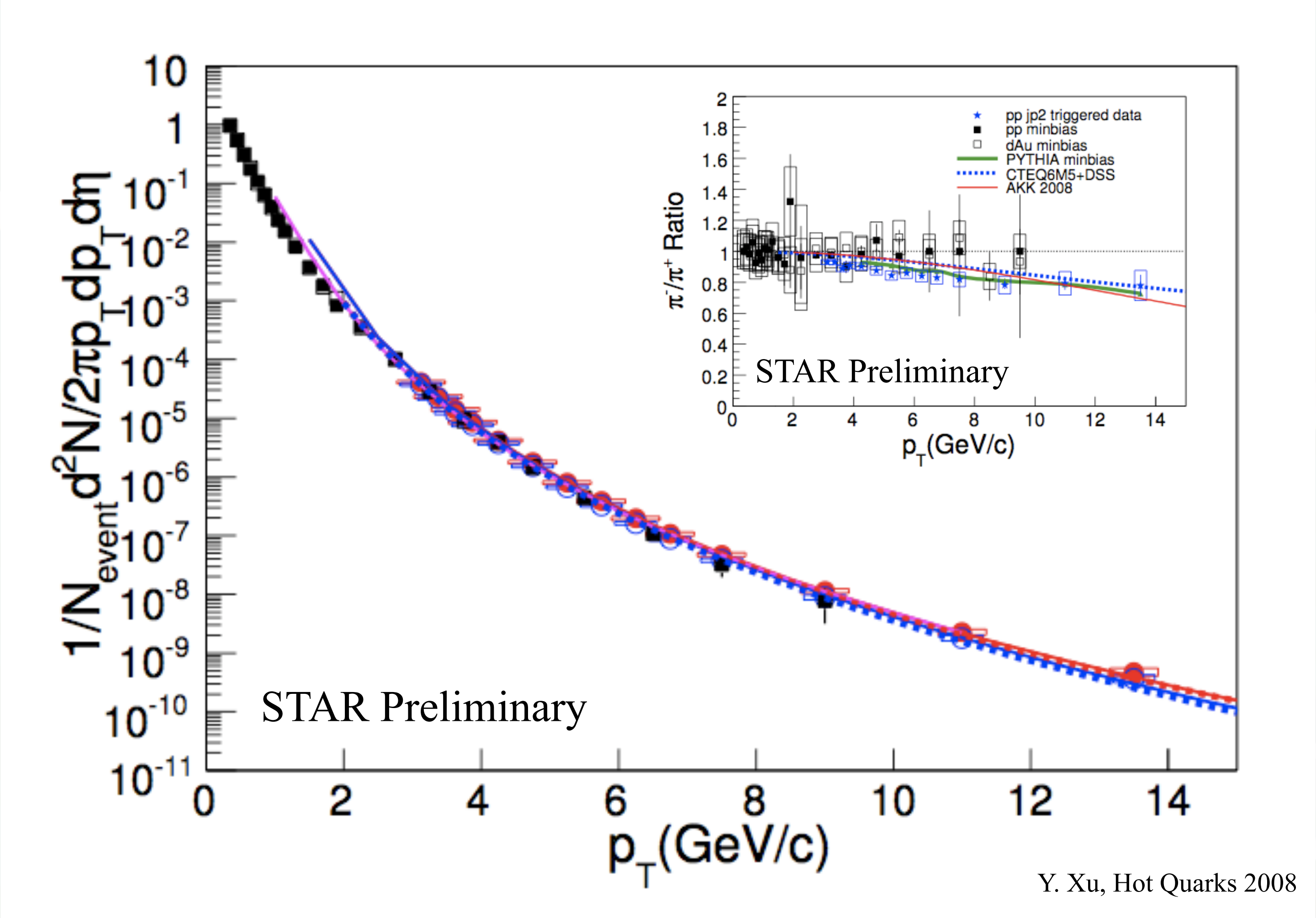

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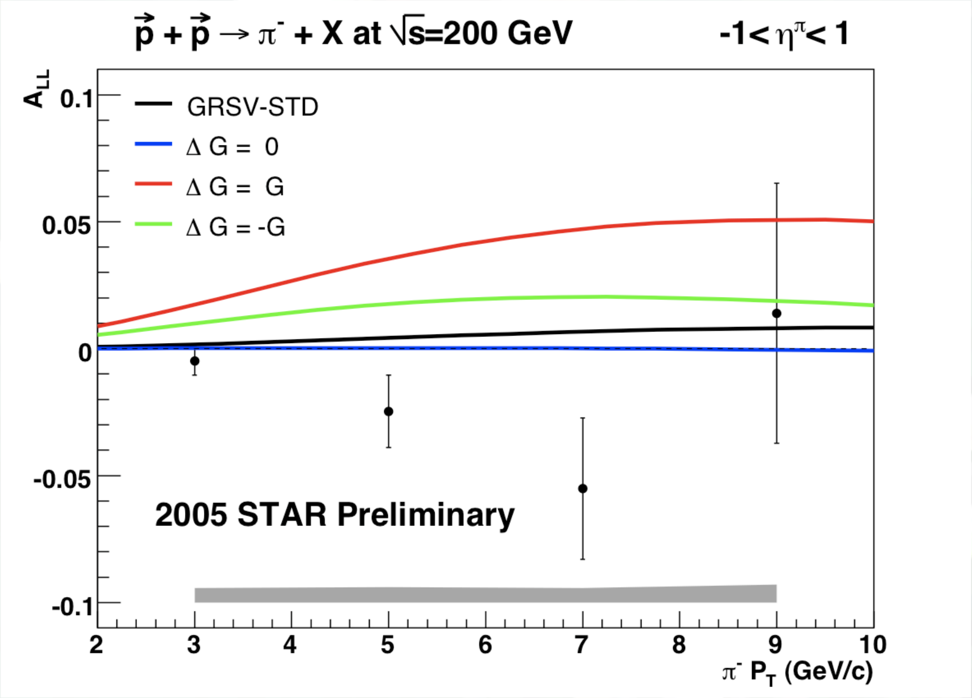
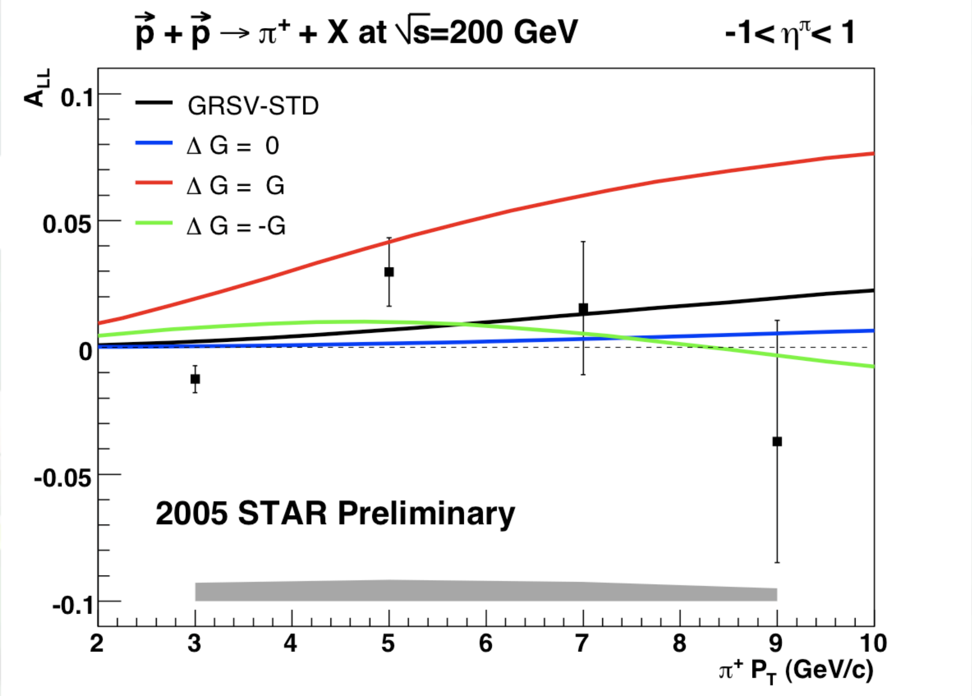
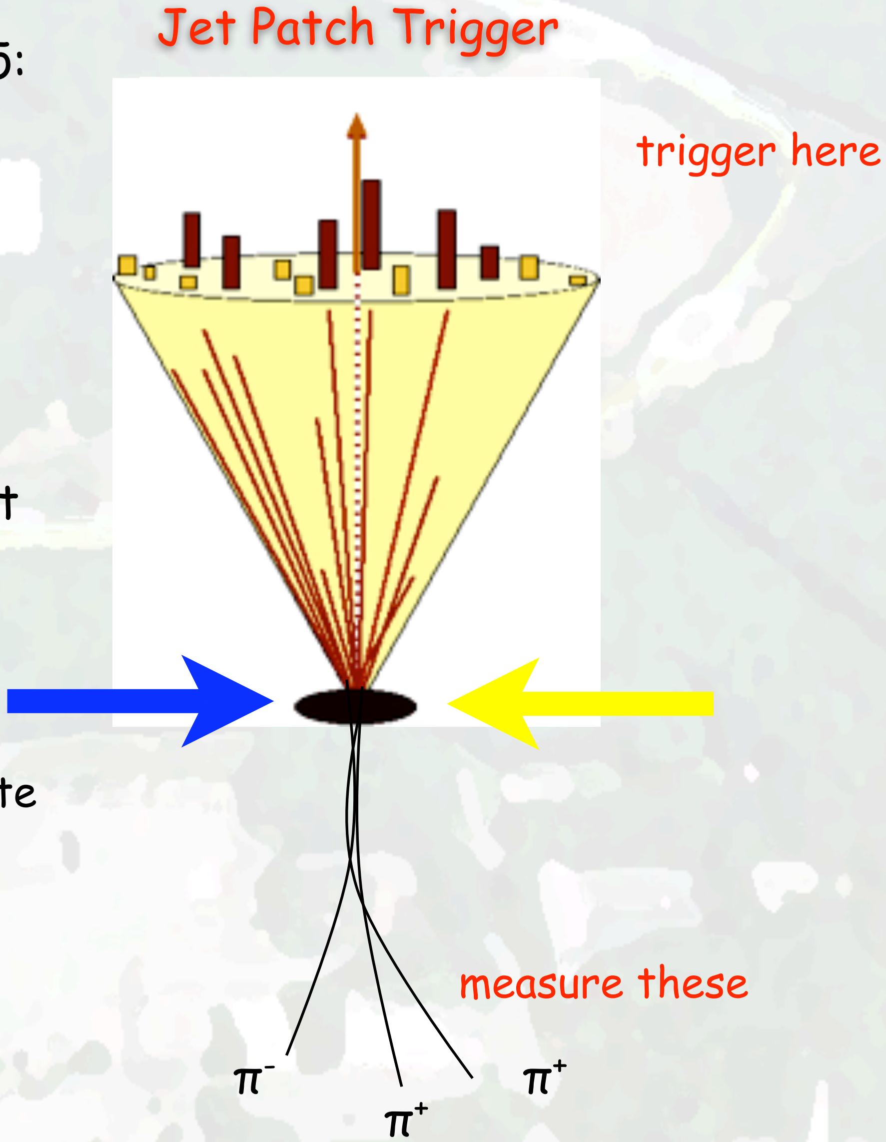




- Luminosity: 1.6 pb^{-1} / Beam polarization: 45-50%
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Dominant systematic uncertainty arises from use of jet patch trigger which samples partonic subprocesses in a non-uniform fashion and suppresses high-z fragmentation

Recent result on Charged Pion production

- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production
  - Significant improvements compared to Run 5:
    - 50% ⇒ 60% beam polarization
    - 1.6 pb^{-1} ⇒ 5.4 pb^{-1}
    - BEMC η acceptance [0,1] ⇒ [-1,1]
  - But ... increased JP trigger thresholds result in strong fragmentation bias for charged pions in trigger jet
    - Limit bias by measuring charged pions opposite a trigger jet
    - Plot asymmetry versus $z \equiv p_T(\pi) / p_T(\text{trigger jet})$ to cleanly isolate favored fragmentation



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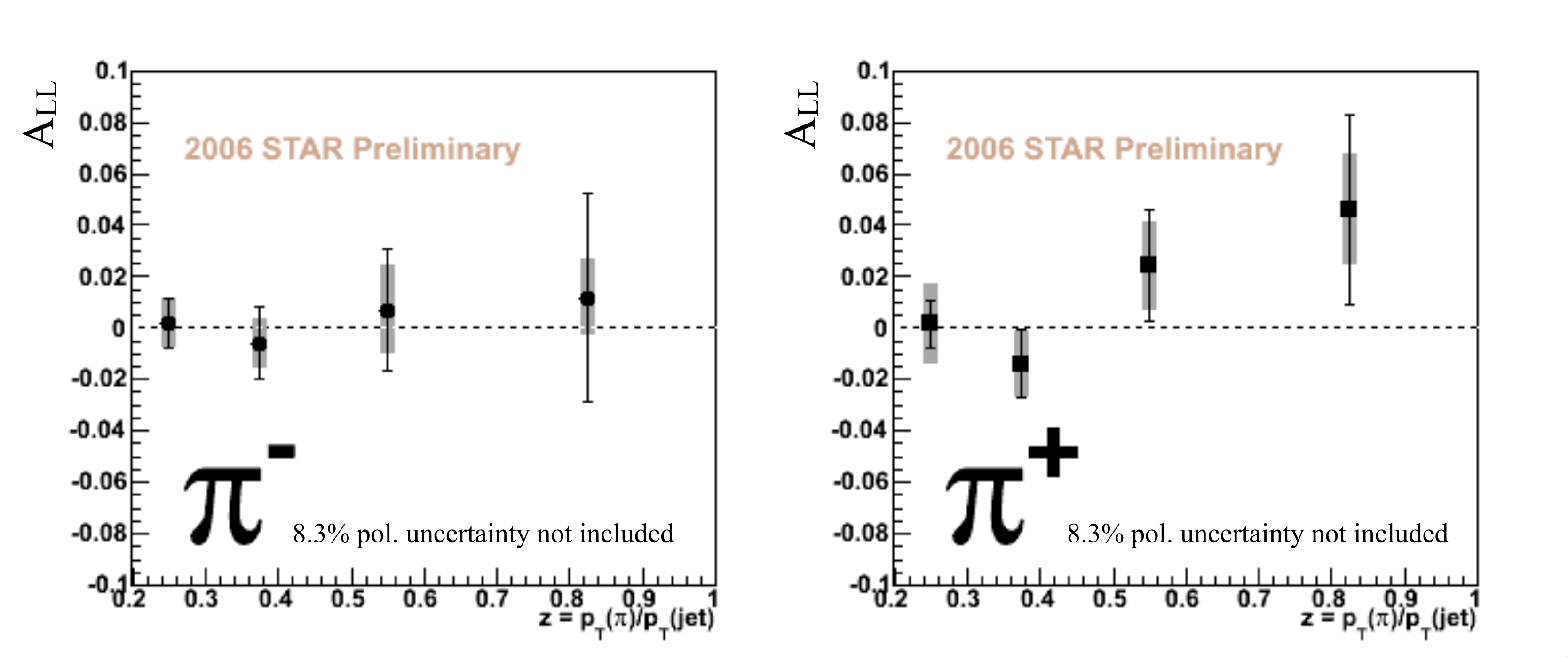

- Conservative systematic uncertainties are evaluated for:
  - Trigger bias (6 - 15 x 10^{-3})
  - PID background contamination (2 - 10 x 10^{-3})
  - Uncertainty on the jet p_T shift (3 - 16 x 10^{-3})
  - Non-longitudinal components, relative luminosity (small)

Recent result on Charged Pion production

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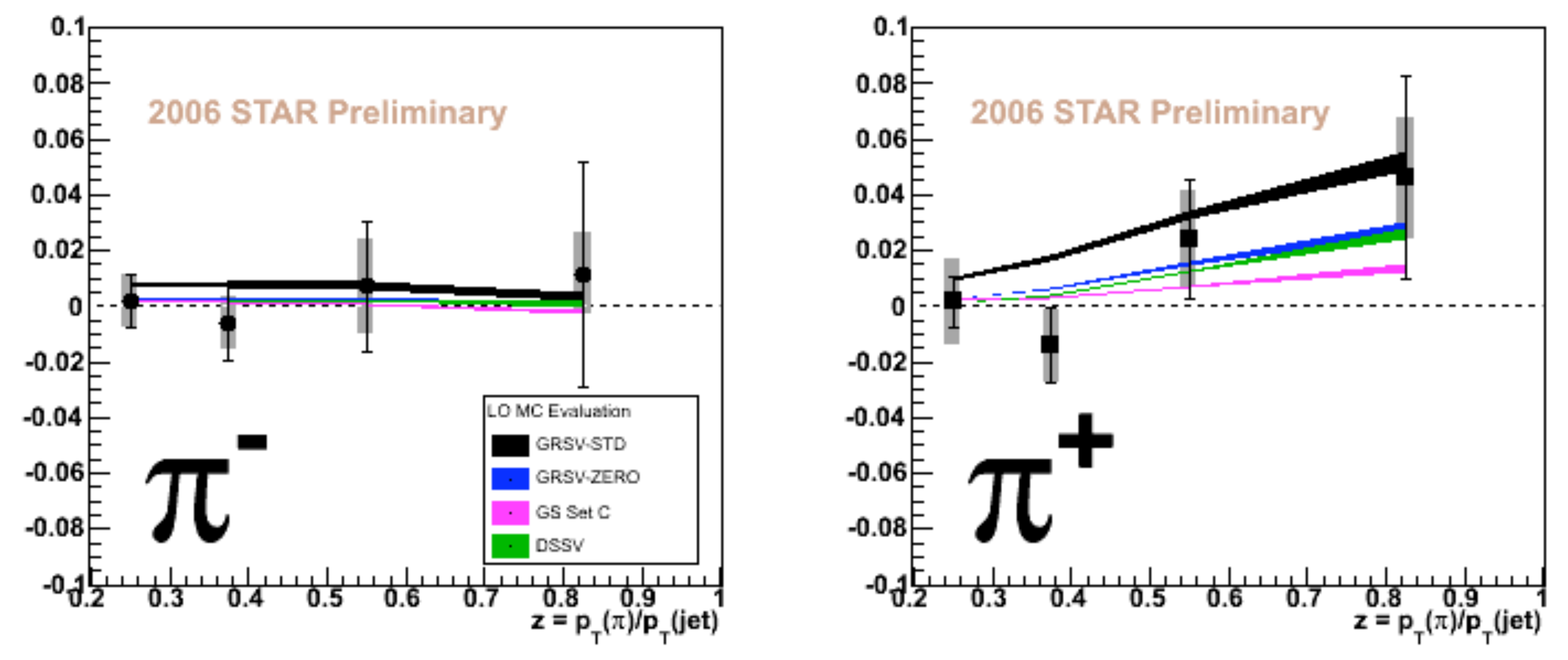
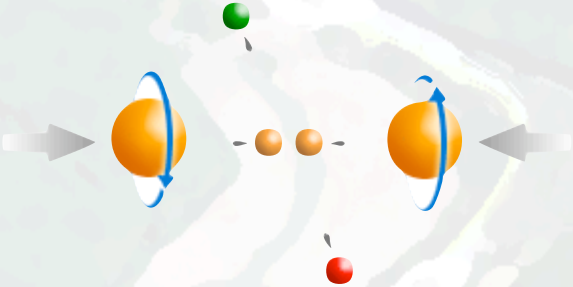


  - Full NLO pQCD predictions are not yet available for this measurement
  - These curves generated by sampling a_{LL} and parton distribution functions at kinematics of PYTHIA event.
  - π^+ offers significant sensitivity at high z

Summary and Outlook

- Summary
  - pQCD: Critical role to interpret measured asymmetries
  - 2005 result: first spin asymmetry for inclusive charged pion production at STAR
  - 2006 measurement focuses on charged pions opposite a trigger jet to minimize fragmentation bias
  - Measurement versus z allows favored fragmentation to improve π^+ analyzing power at high z
  - Theoretical predictions for A_{LL} are forthcoming, and future RHIC runs will allow for additional precision at high z



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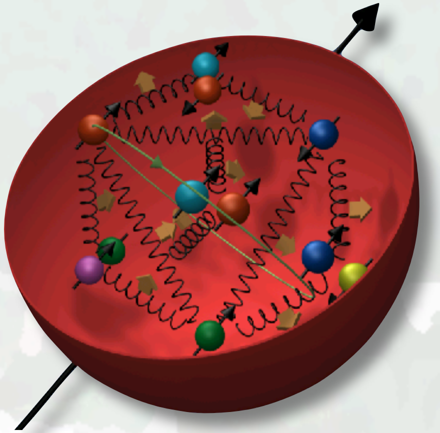
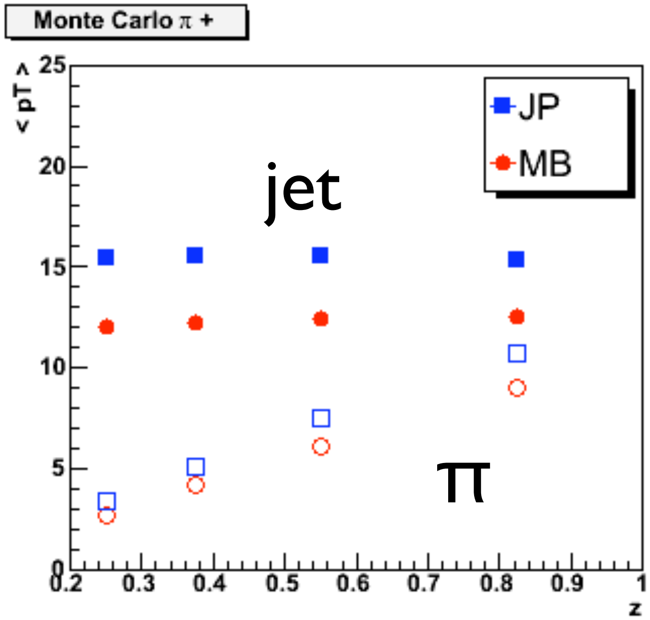
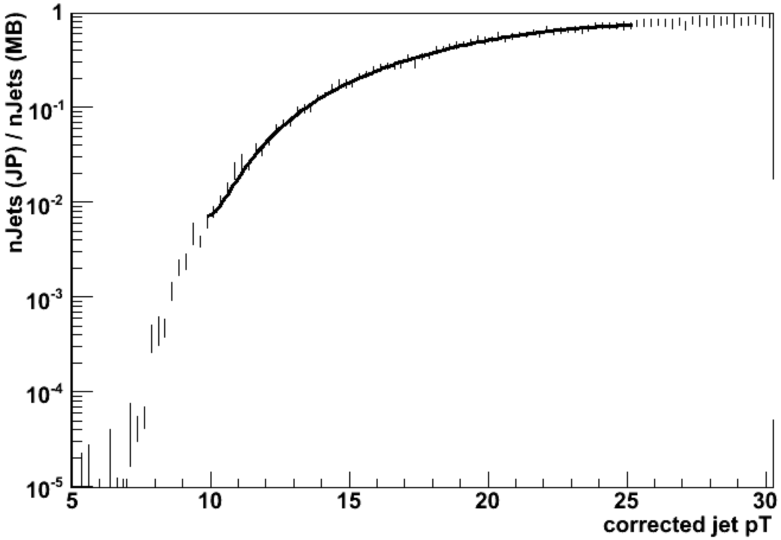


Trigger Bias

- Jet patch trigger samples subprocesses non-uniformly
- Traditionally, LO MC evaluation of A_{LL} is used to assign model-dependent systematic
- This measurement integrates over a wide range in jet p_T, so triggered dataset samples different kinematic range too
- Factor out the difference in <jet p_T> by reweighting the Monte Carlo
- Bias assigned assuming GRSV-STD





PID Background Asymmetry

- use triple Gaussian fits to estimate p/K background at 10%
- Select sideband starting at -2σ and calculate its A_{LL}
- Systematic assigned as

$$\delta A_{LL} = f_{bg} \times (A_{LL}^{meas} - A_{LL}^{bg})$$