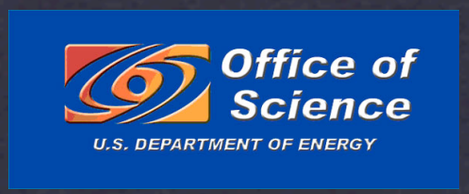
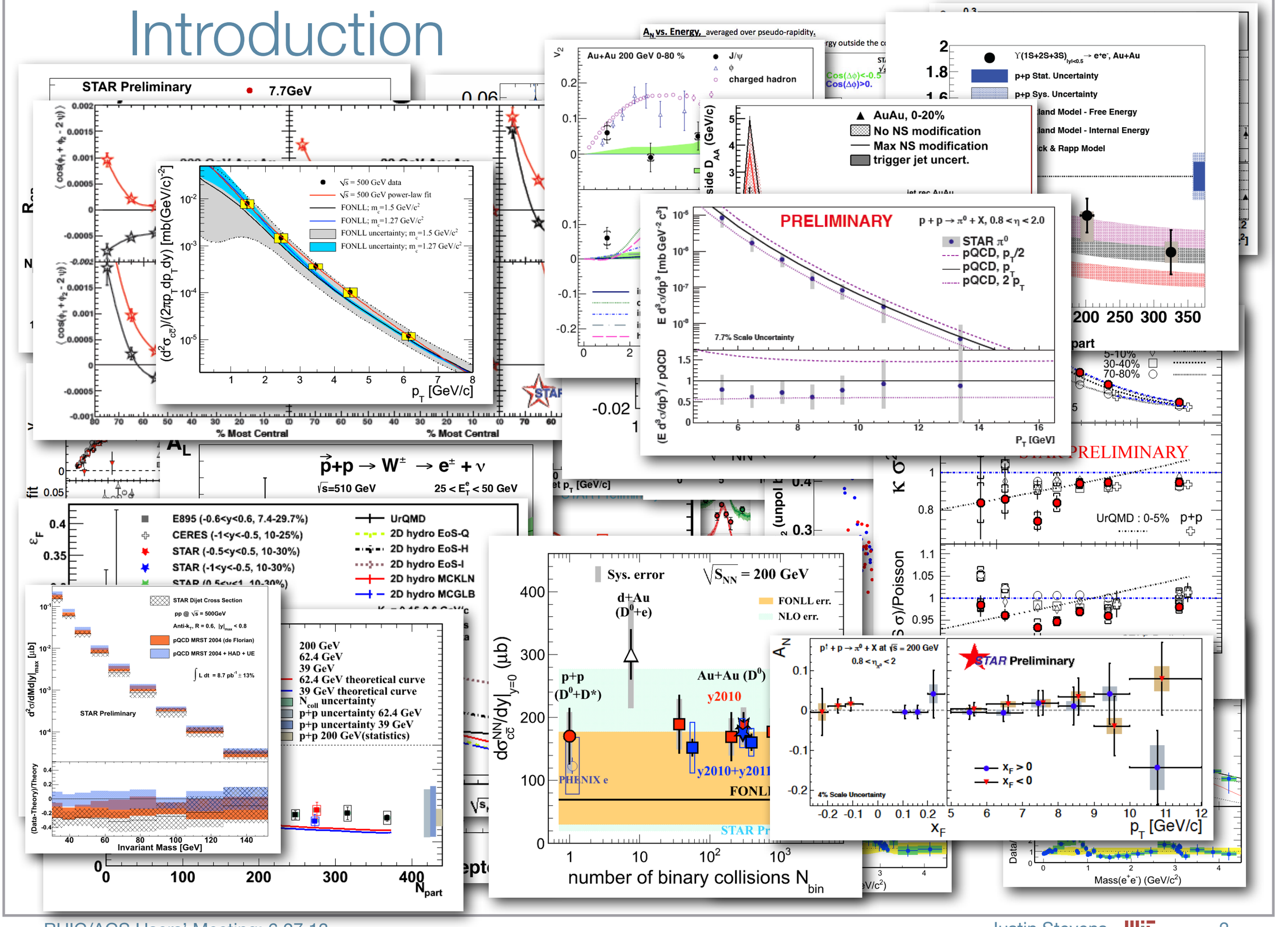
Summary of Recent STAR Results

Justin Stevens, MIT

RHIC/AGS Users' Meeting: 6.27.13



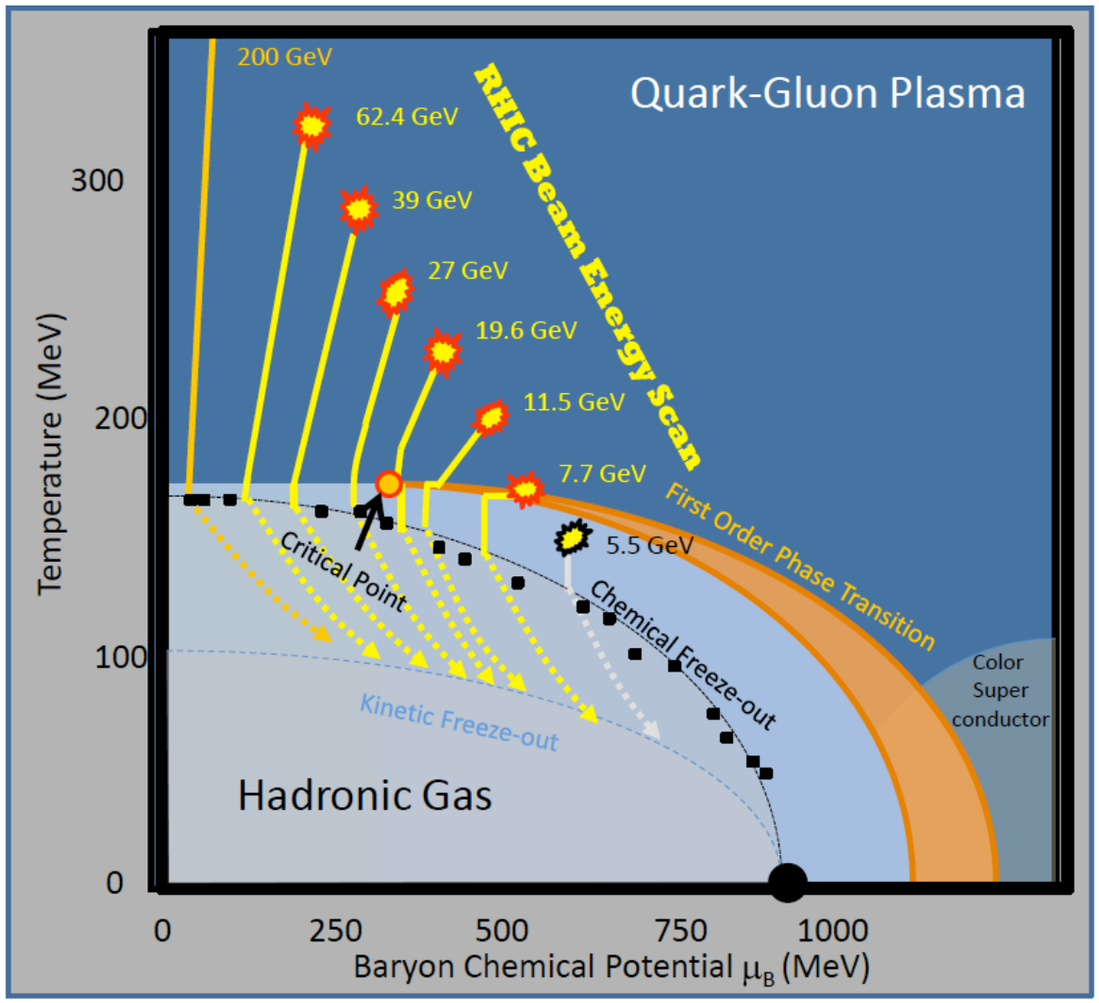
Introduction



Introduction

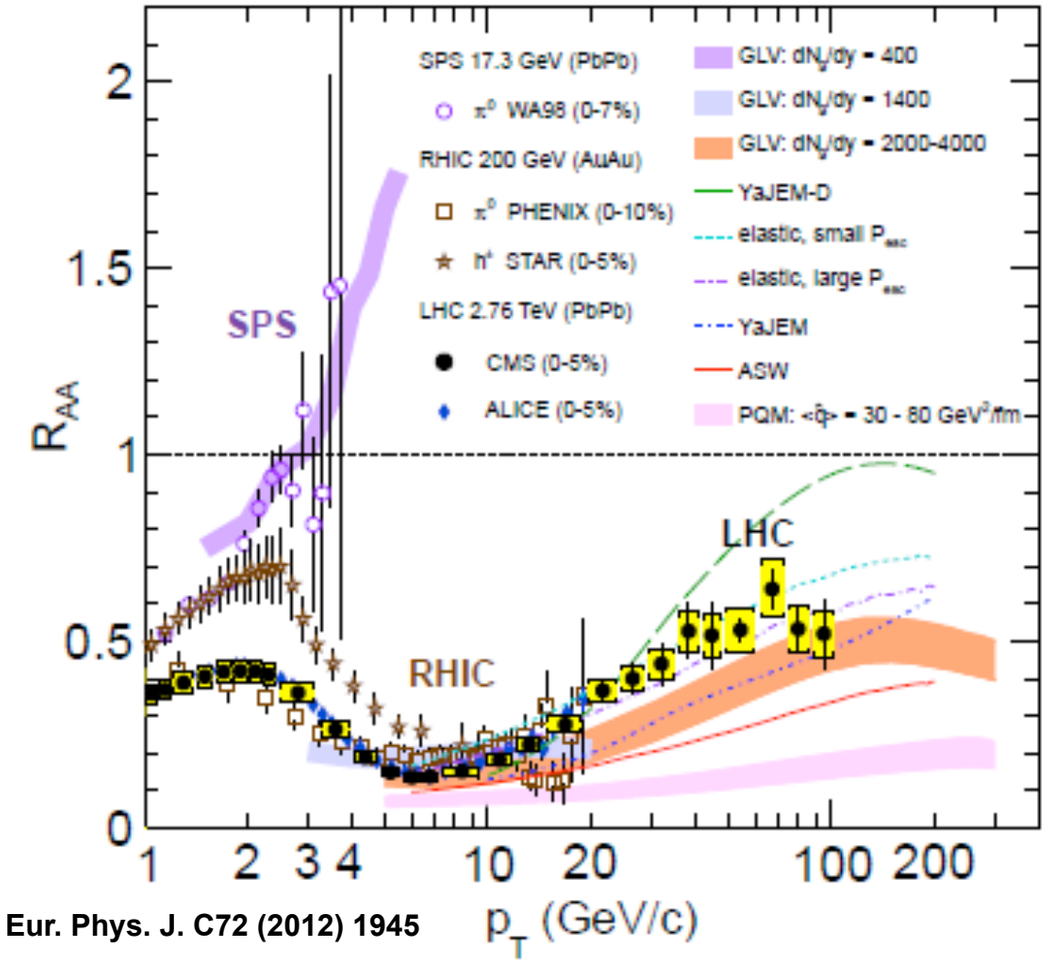
- Many exciting recent results addressing a broad range of physics topics
- For this talk focus on BES, U+U, Dilepton and Heavy Flavor probes, and proton spin

Beam Energy Scan (BES)

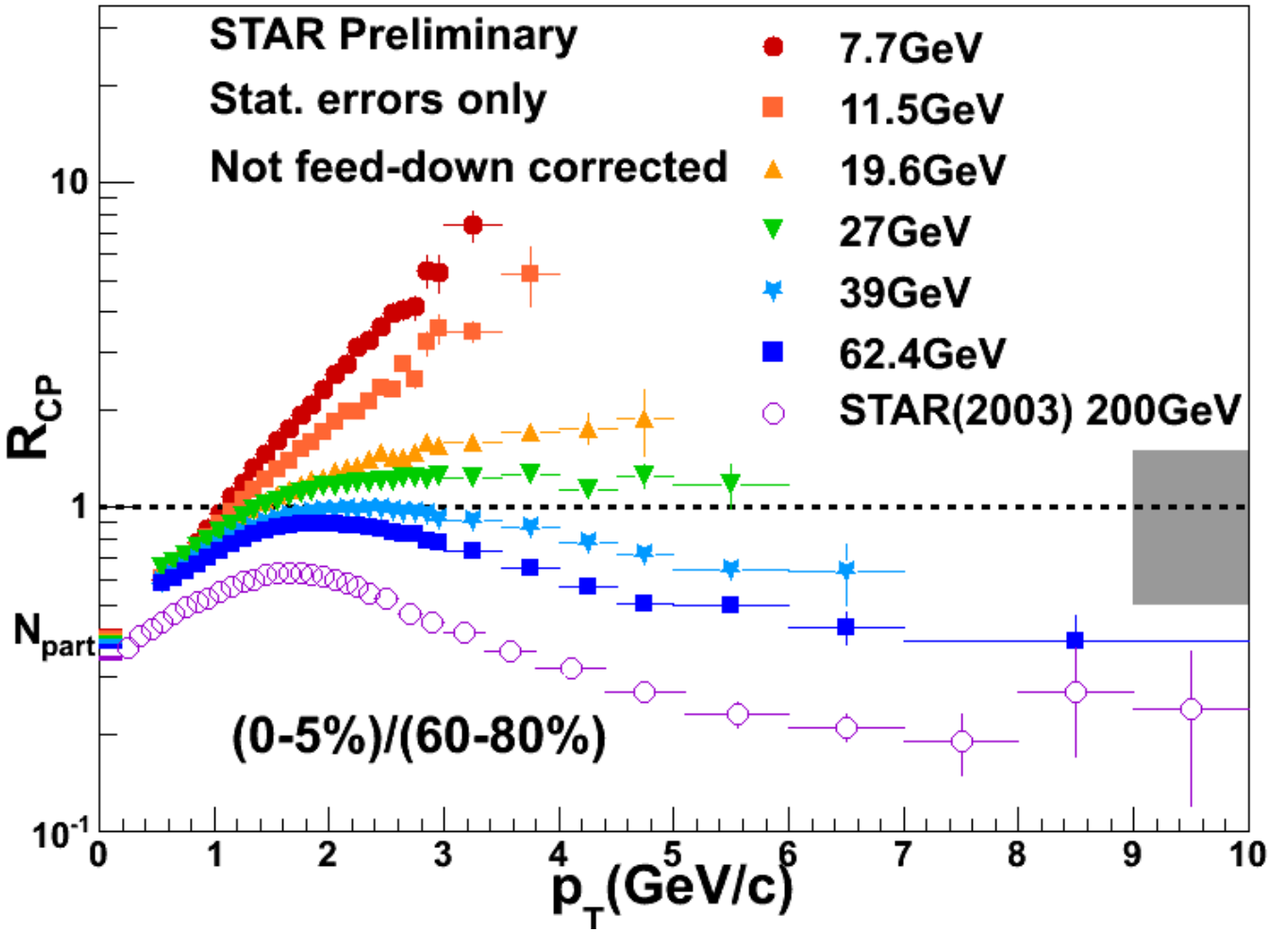


- Goal of the BES program to search for:
  - Turn-off of QGP signatures
  - 1st order phase transition
  - Critical point signatures
- Strategy:
  - Vary collision energy (T-μ_B) and search for non-monotonic behavior of key observables

R_{CP} Suppression



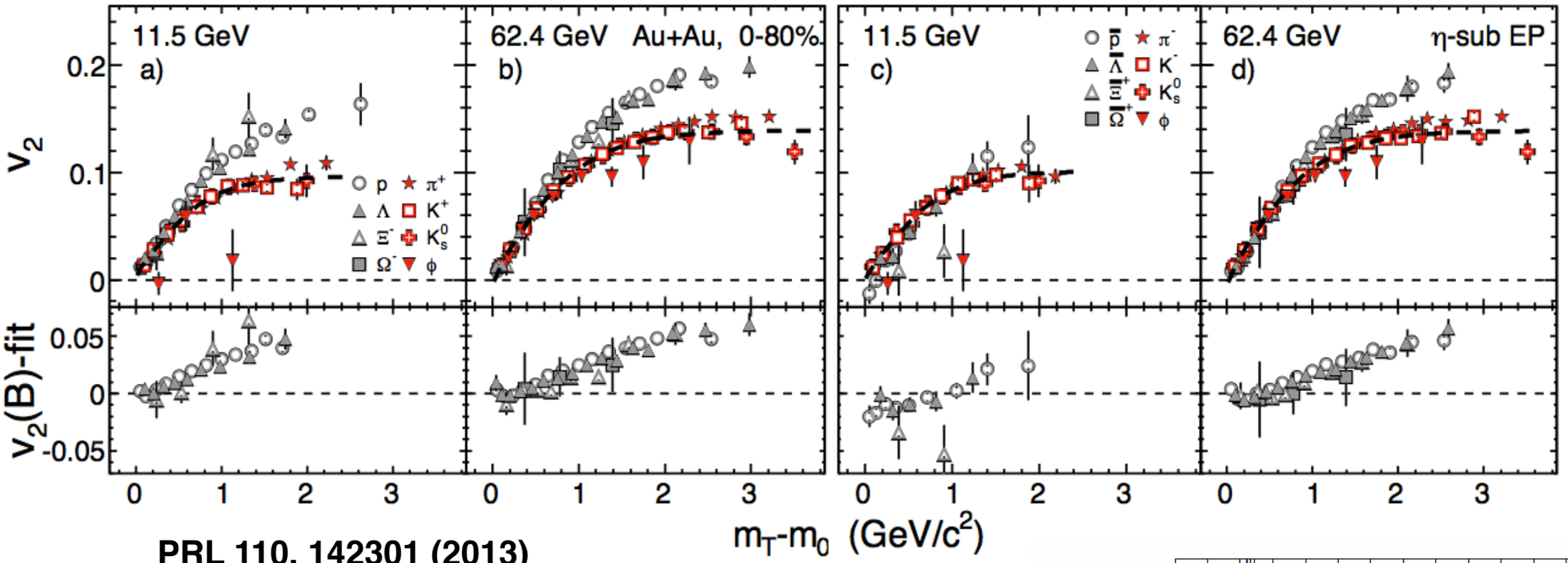
Eur. Phys. J. C72 (2012) 1945



- Observed suppression of high-p_T hadrons at full energy consistent with energy loss in the QGP medium
- R_{CP} suppression NOT seen at low energies, indicating the QGP signature is turned off

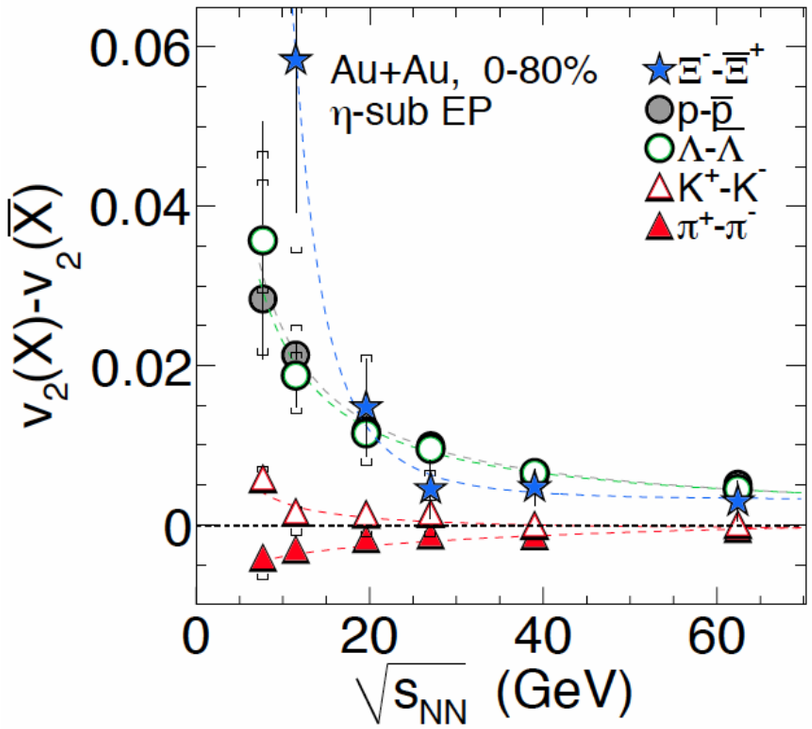
Breakdown of NCQ Scaling

Particles **Anti-particles**



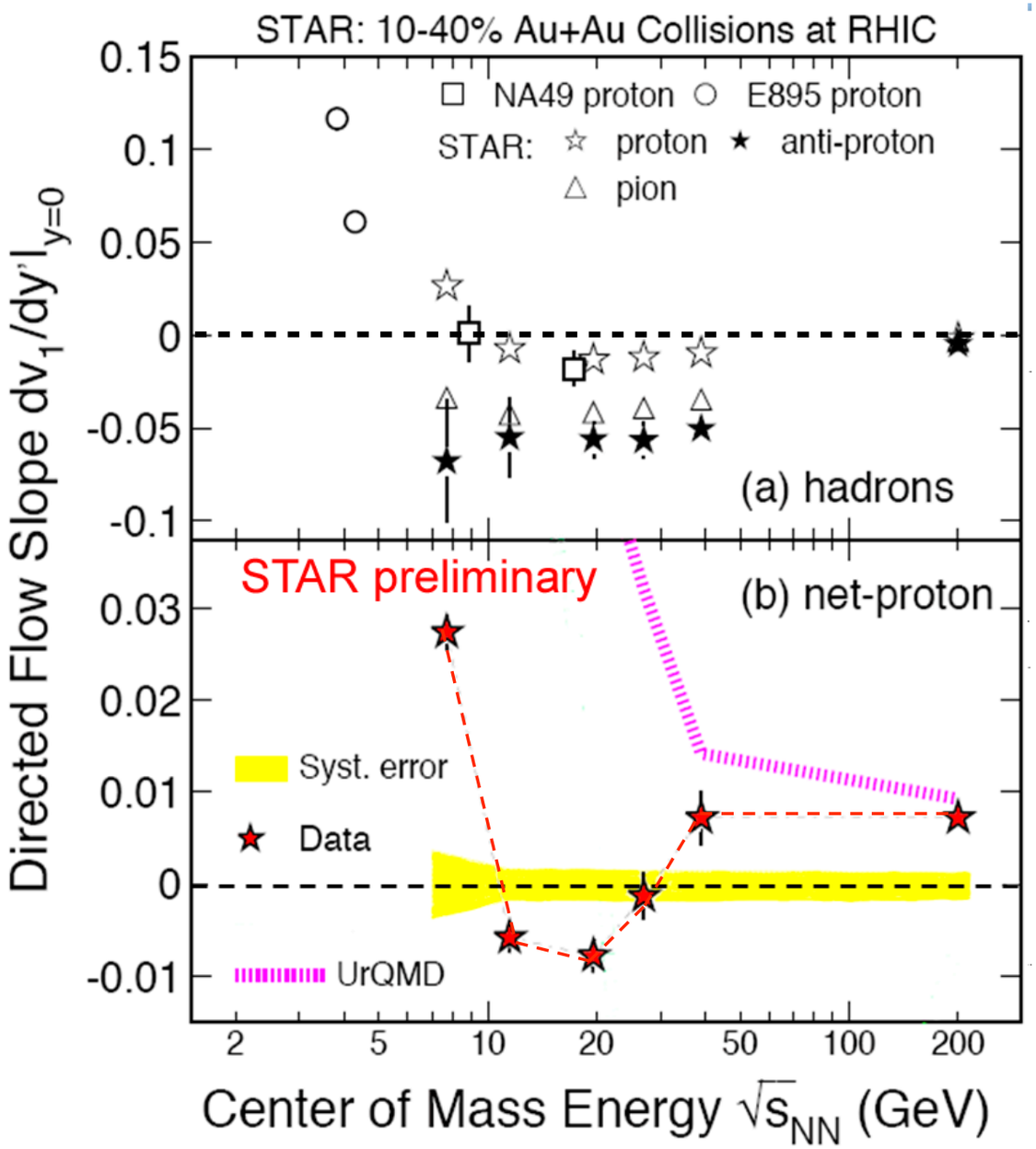
PRL 110, 142301 (2013)

- No baryon/meson splitting for antiparticle v_2 below 11.5 GeV
- Significant difference between particle-antiparticle v_2, especially at low energies



Search for 1st Order Phase Transition

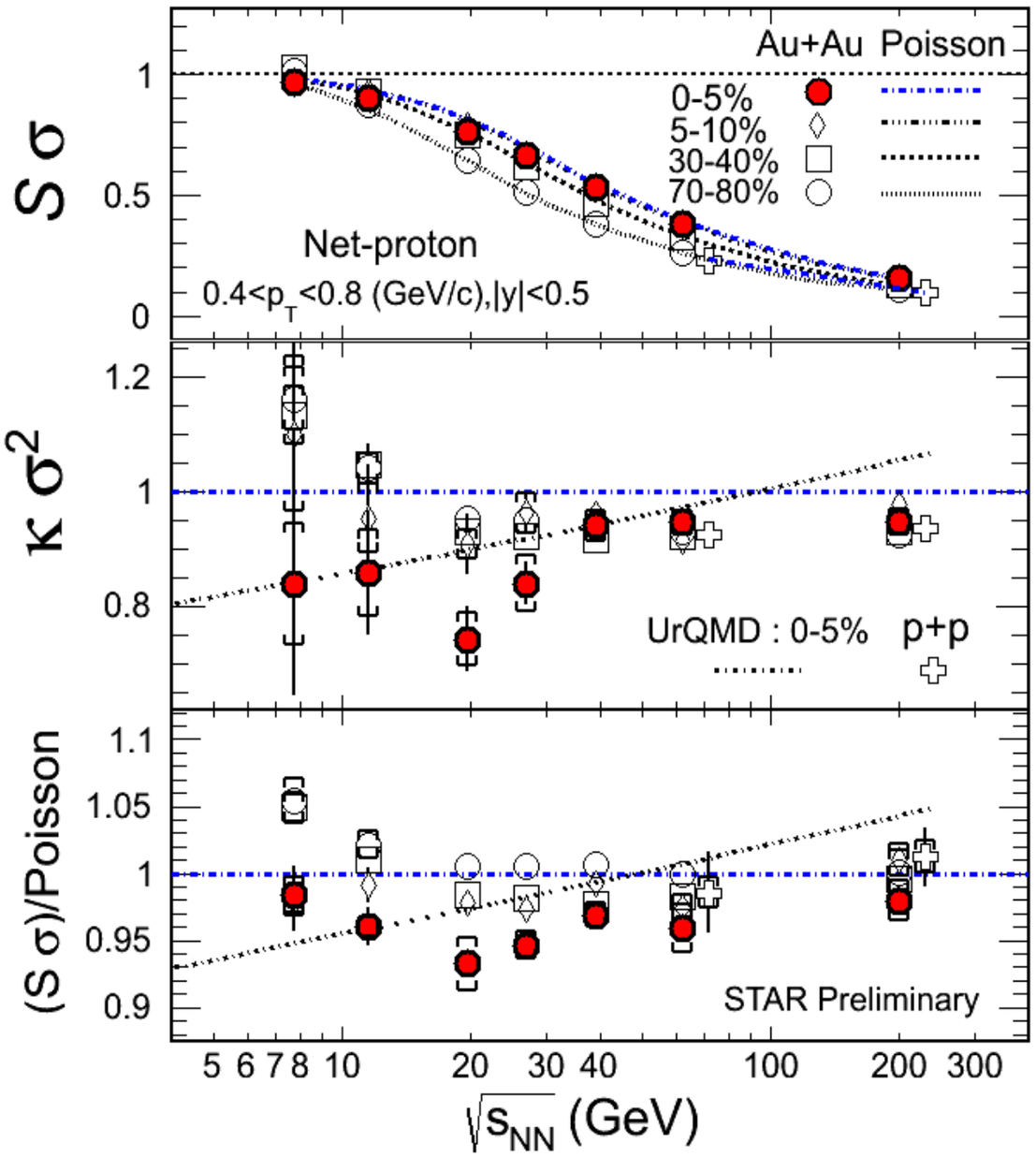
- Directed flow slope dv_1/dy:
  - Proton slope changes sign between 7.7 and 11.5 GeV
  - Net-proton slope shows a minimum between 11.5 and 19.6 GeV
- Other searches: Magnitude of elliptic flow, Azimuthal HBT



Search for the Critical Point

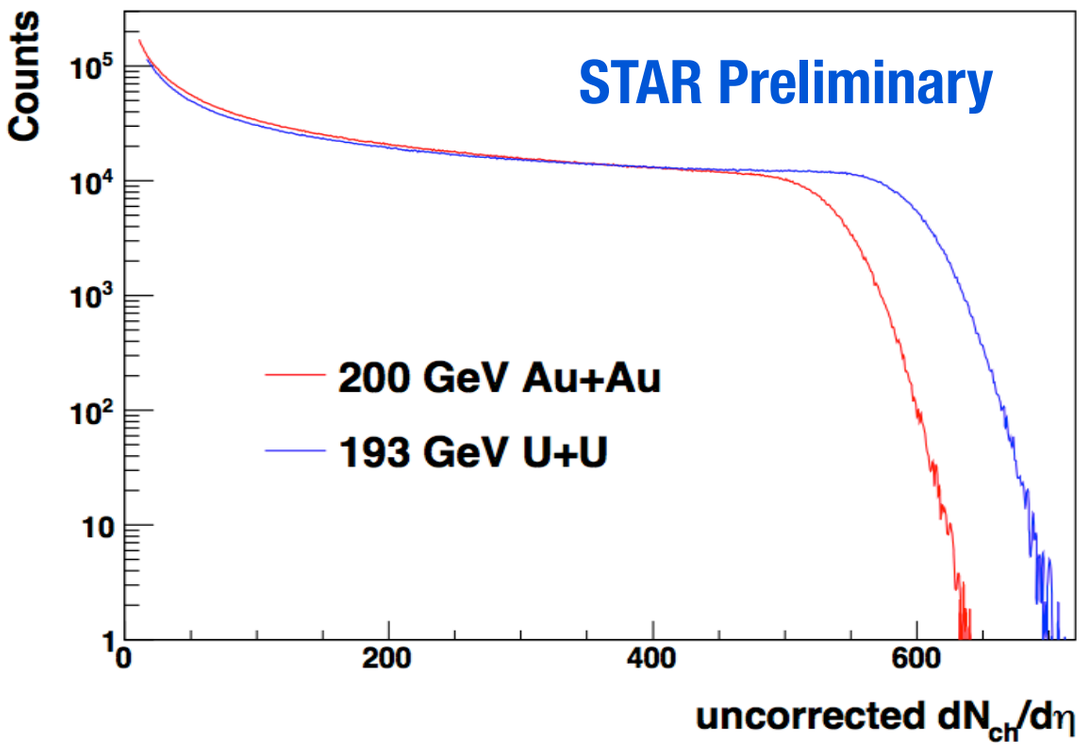
- Higher moments of net particle distributions are expected to be sensitive to fluctuations at the critical point
- Net-proton data are similar to the Poisson baseline for energies above 27 GeV
- Deviations observed for lower energies
- Need precision measurements at low energies and fill gap in μ_B at 15 GeV

$$\sigma^2 = \langle (N - \langle N \rangle)^2 \rangle$$
$$S = \langle (N - \langle N \rangle)^3 \rangle / \sigma^3$$
$$\kappa = \langle (N - \langle N \rangle)^4 \rangle / \sigma^4 - 3$$



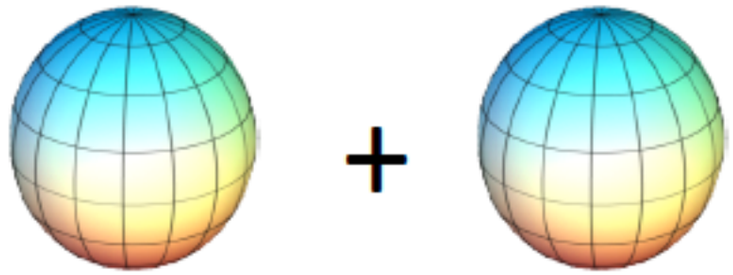
U+U Collisions

- Prolate shape of Uranium allows for the study of: particle production mechanism, anisotropic flow, Chiral Magnetic Effects, etc.
- Can we see differences between Au+Au and U+U?
  - Yes, larger system → higher multiplicity



Au+Au Collisions:

Oblate on average



U+U Collisions:

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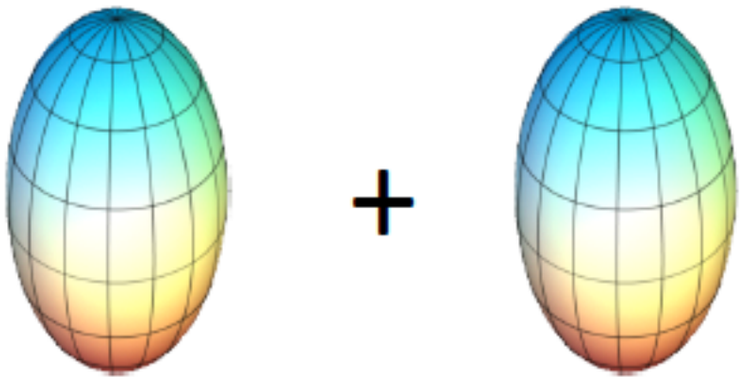
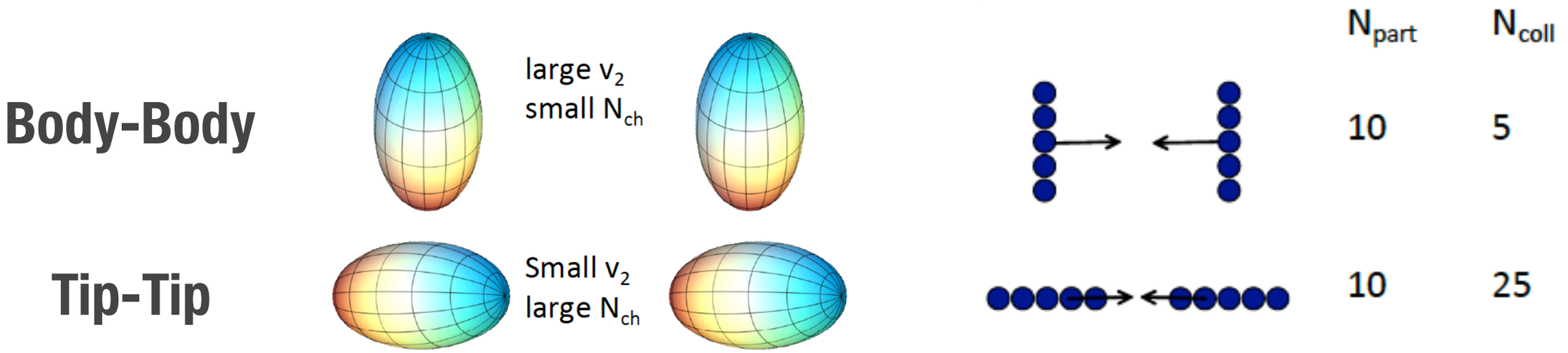


Can We Separate Tip-Tip and Body-Body?



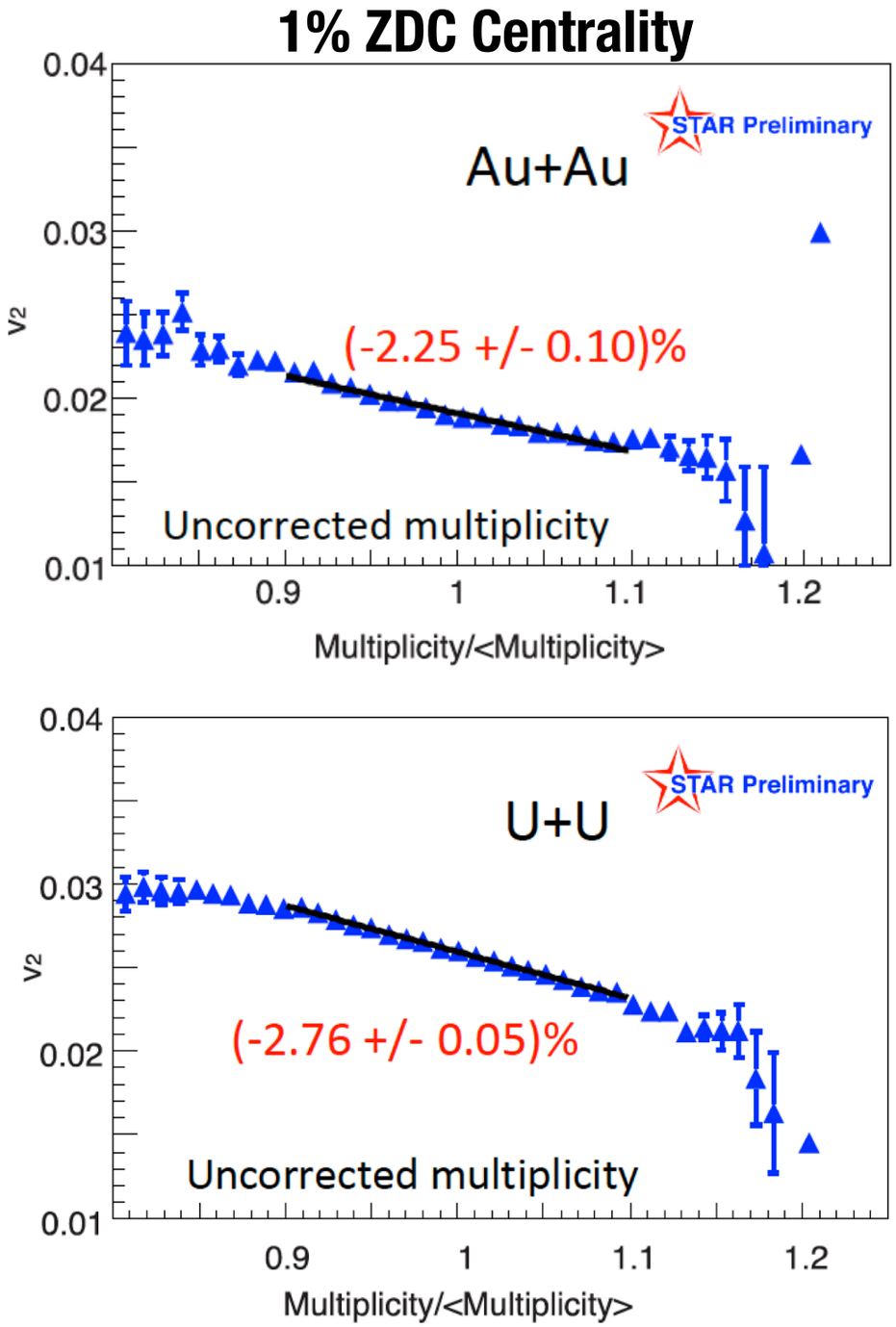
- Often assume that multiplicity depends partially on the number of participants and partially on the number of binary collisions

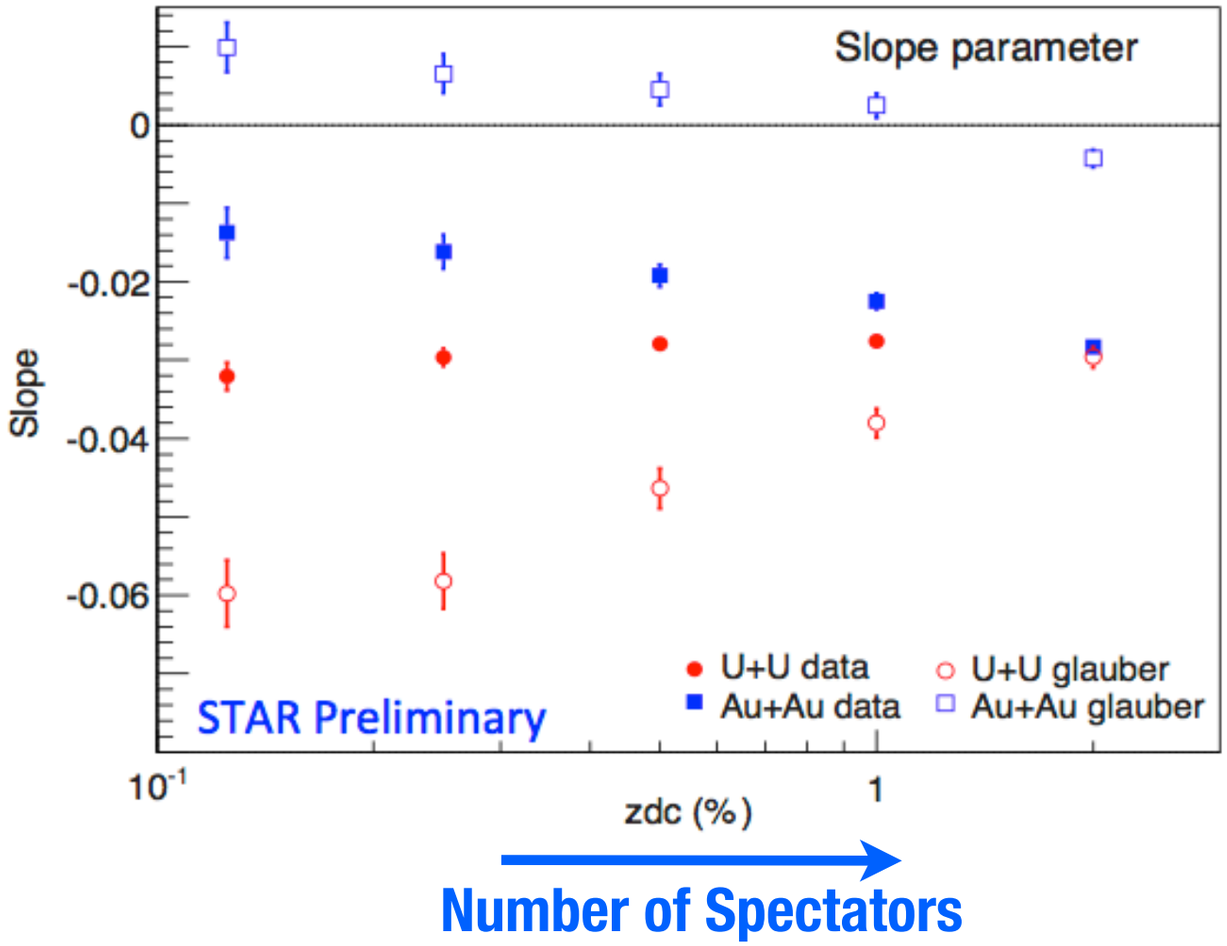
$$N_{ch} \sim (1-x)N_{part} + xN_{coll}$$

- Strategy: Select events where almost all nucleons collide (ie. high multiplicity and use ZDC to select events with very few spectators)

- Is larger v_2 associated with lower multiplicity?

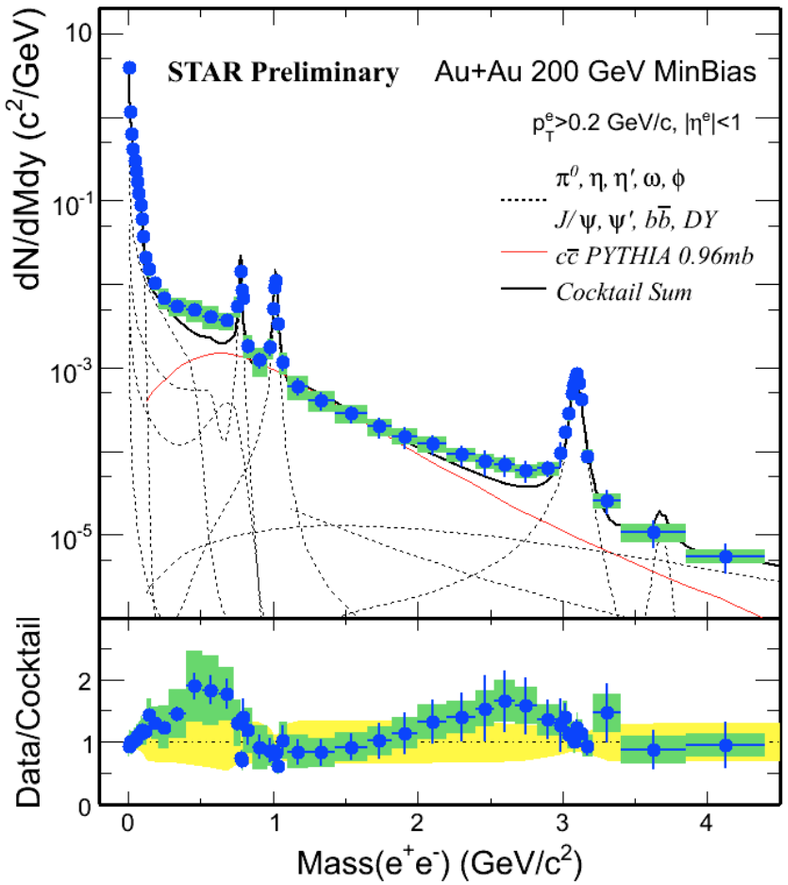
Can We Separate Tip-Tip and Body-Body?

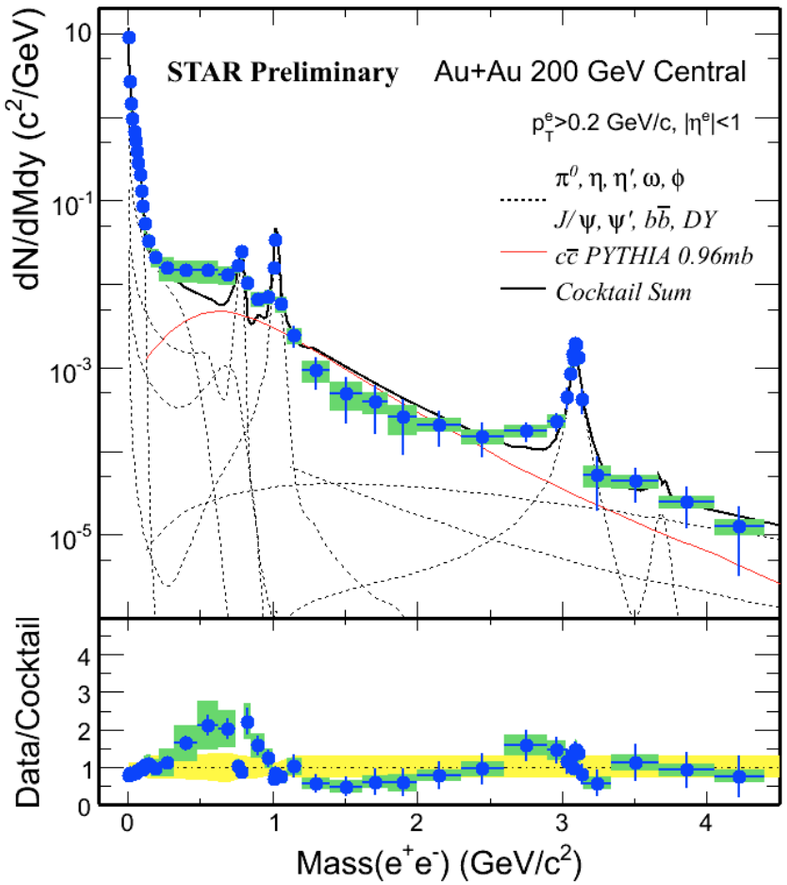




- Observe a clear difference in v_2 slope with multiplicity between Au+Au and U+U which is enhanced for more central collisions

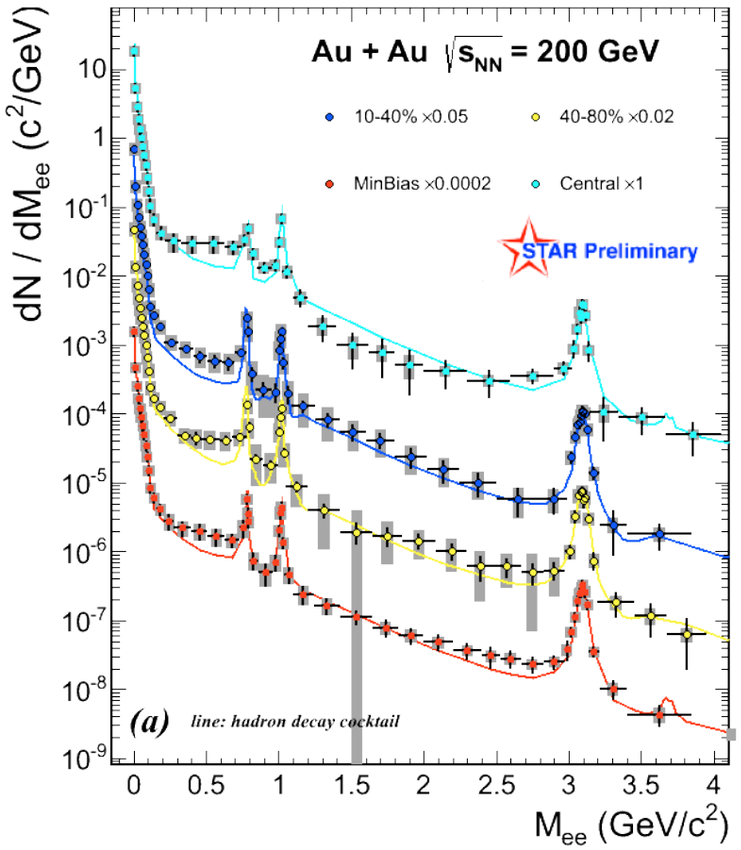
Dielectron Program

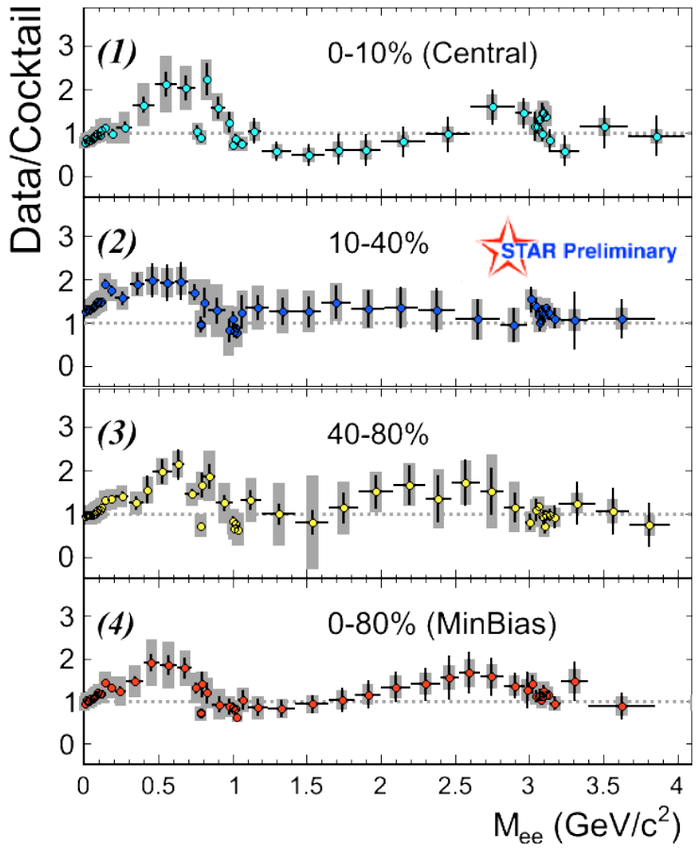


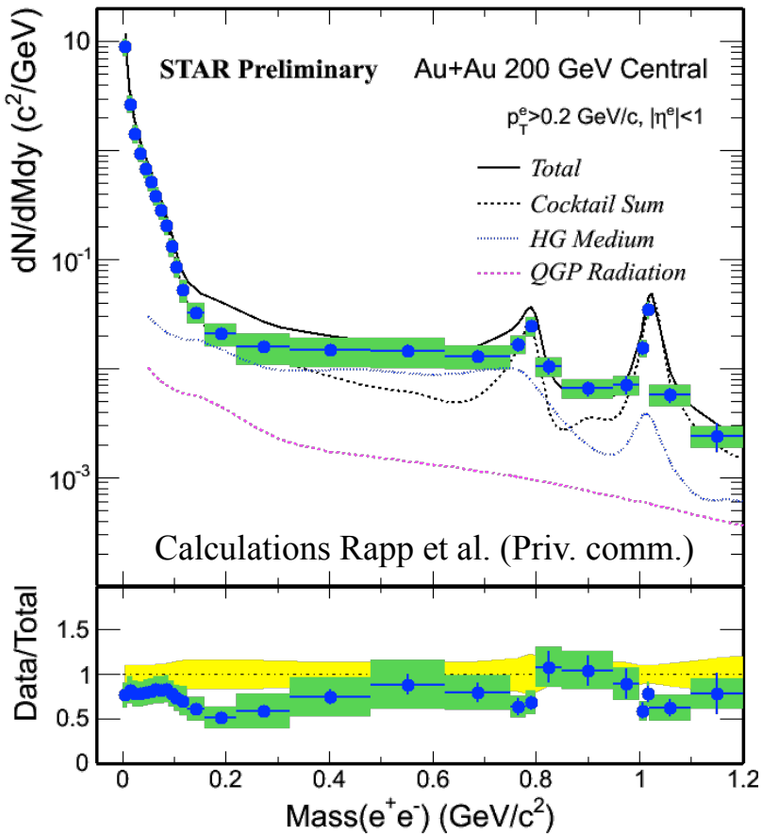


- Dileptons are an excellent penetrating probe at all time scales
- Systematic studies of dielectron production in Au+Au:
  - Comparisons to cocktail: low mass enhancement, possible intermediate mass suppression (charm modification?)
  - Dependence on mass, beam energy, p_T, centrality, and elliptic flow measurements

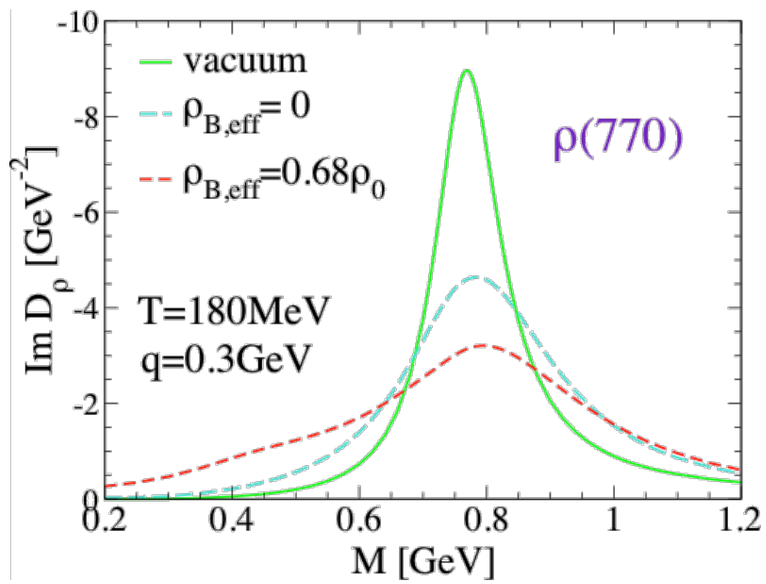
Low Mass Enhancement







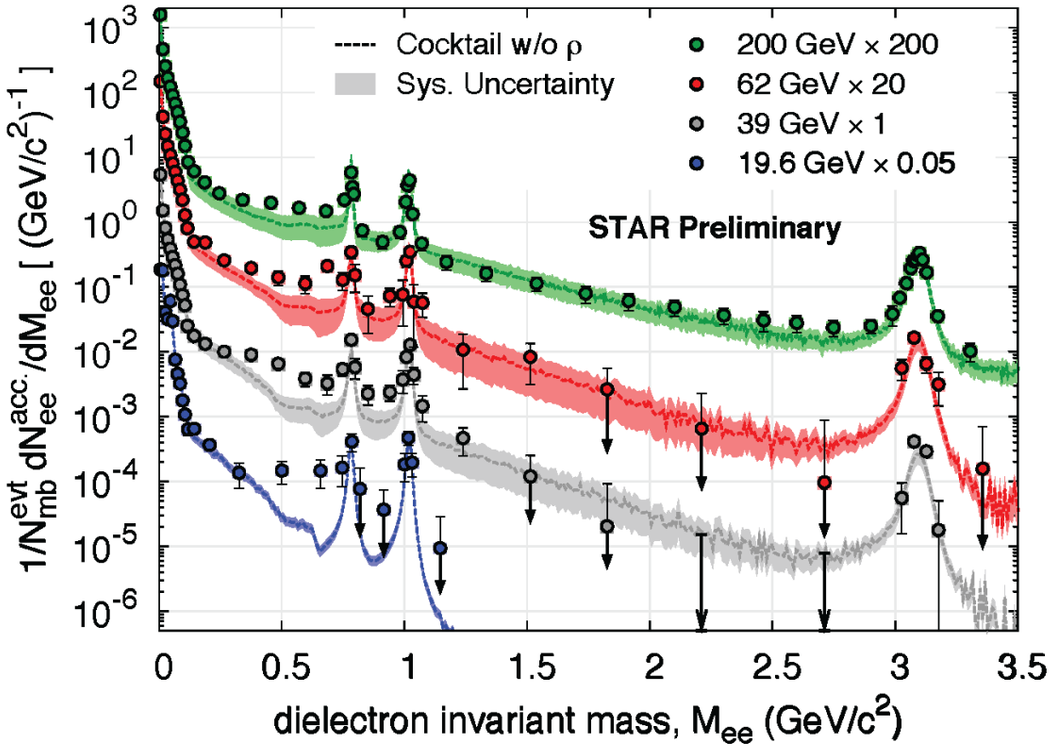
- Enhancement in low mass region compared to cocktail without ρ meson
- Observed excess consistent with models which include in-medium ρ broadening due to interactions with the hadronic medium

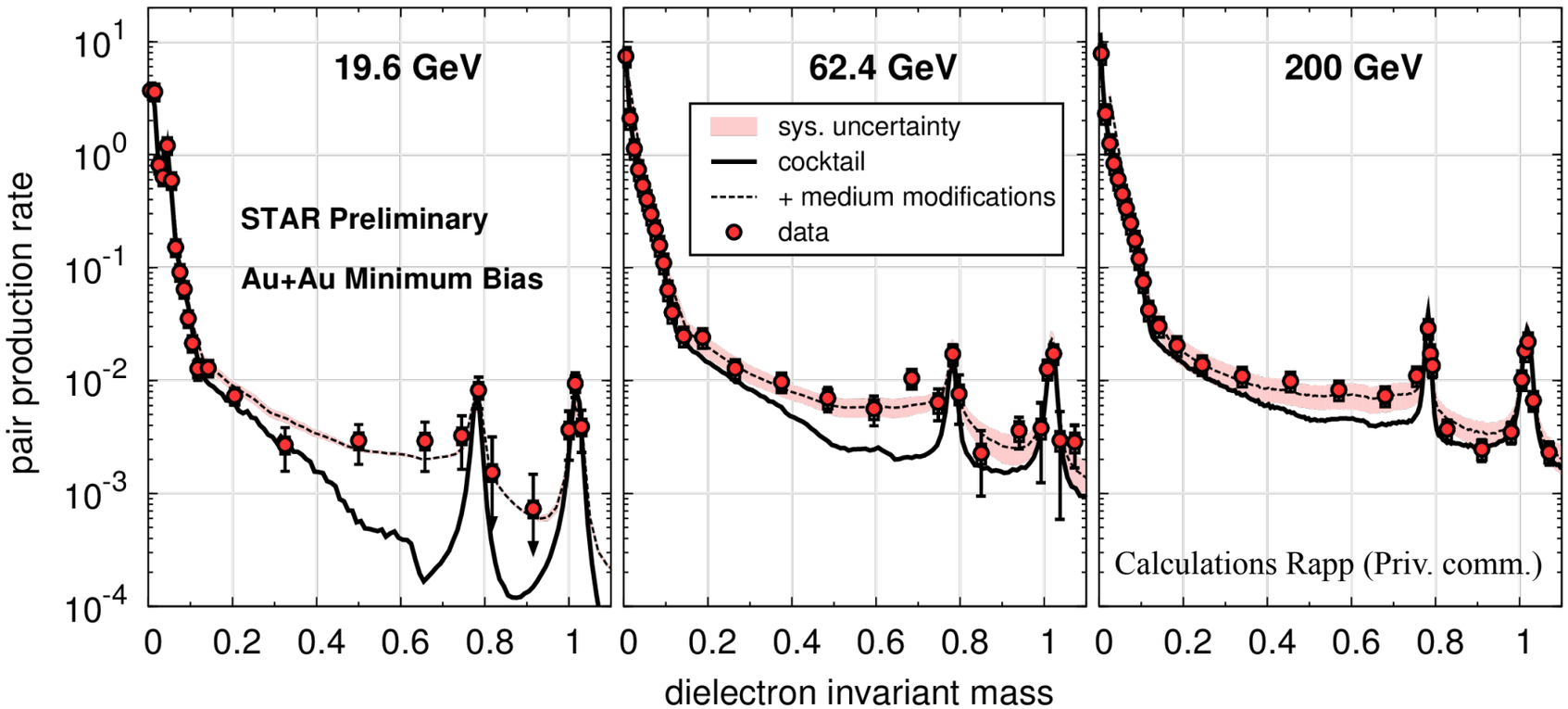


Rapp, Wambach, van Hees (arXiv:0901.3289)

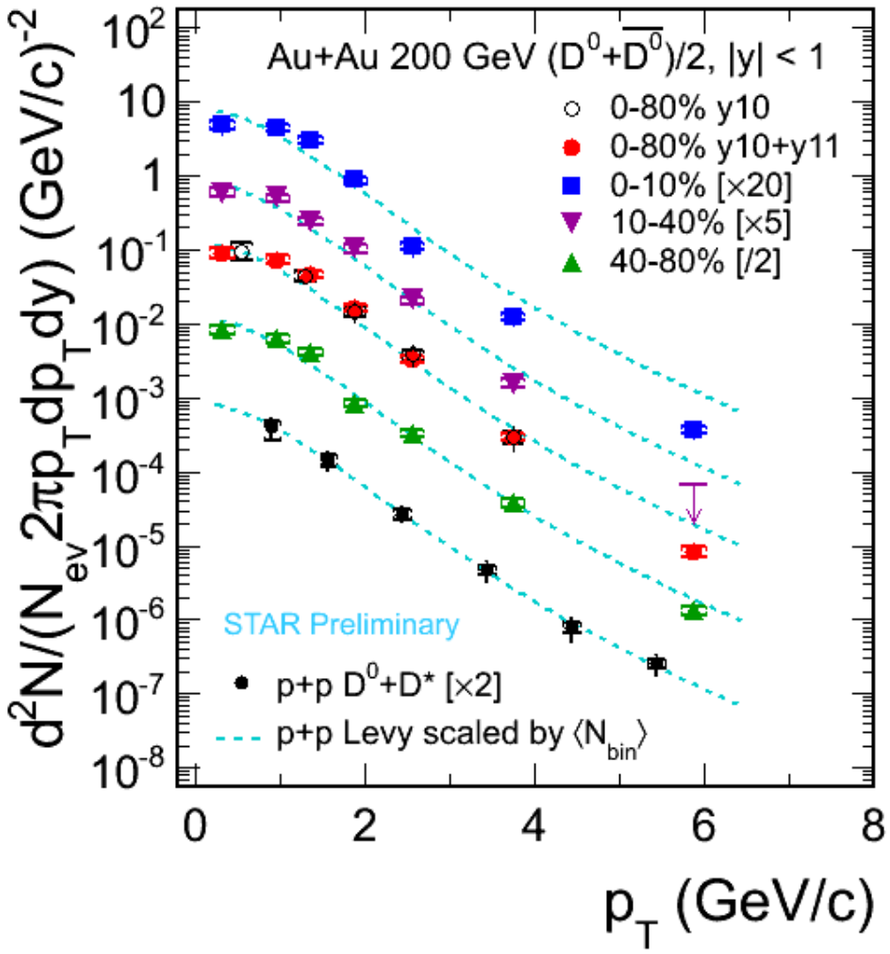
BES Dielectron Spectra

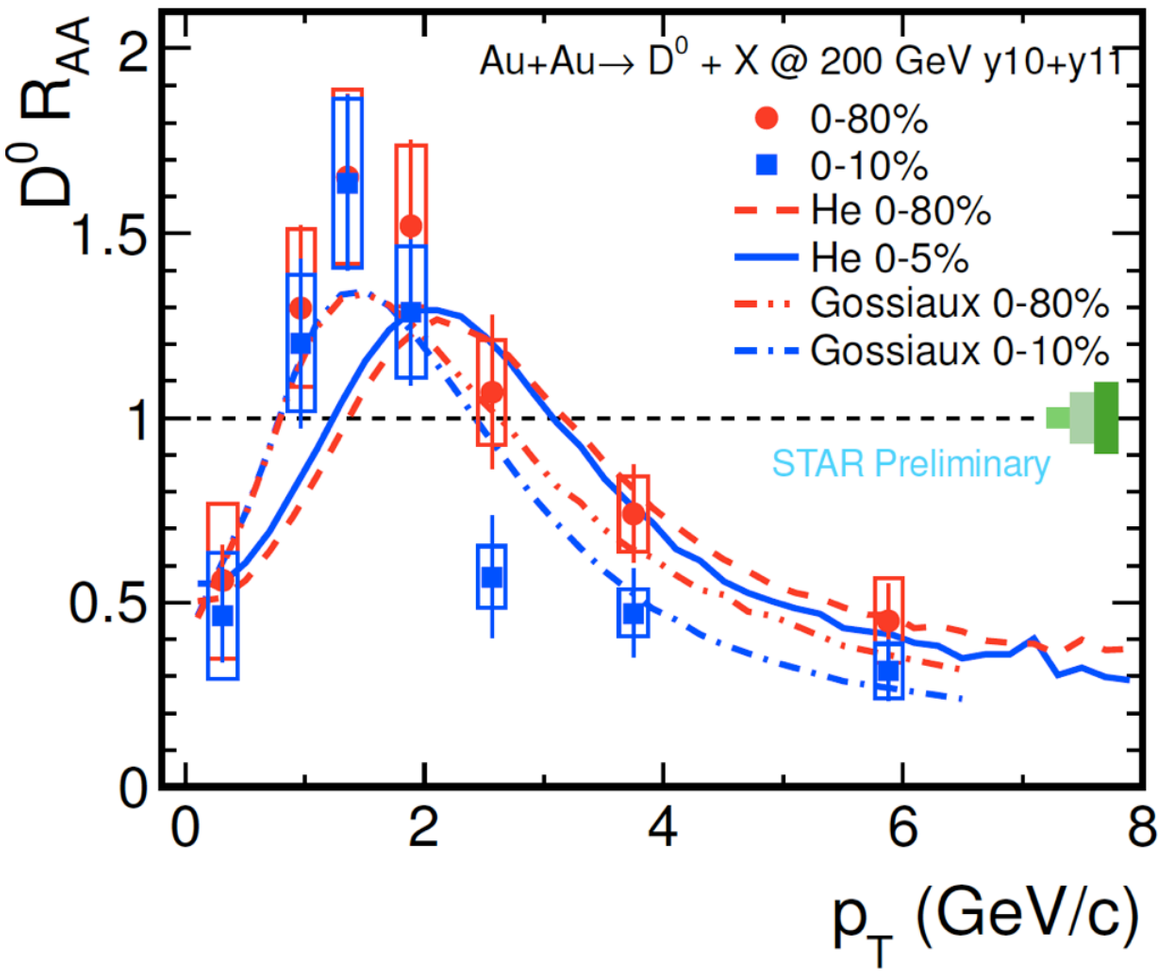
- Dielectron production systematically studied from 19.6 GeV to RHIC top energy
- Low mass enhancement observed for energies down to 19.6 GeV
- Measurements consistent with in-medium ρ broadening over a wide range of collision energies





Heavy Flavor Probes: Open Charm

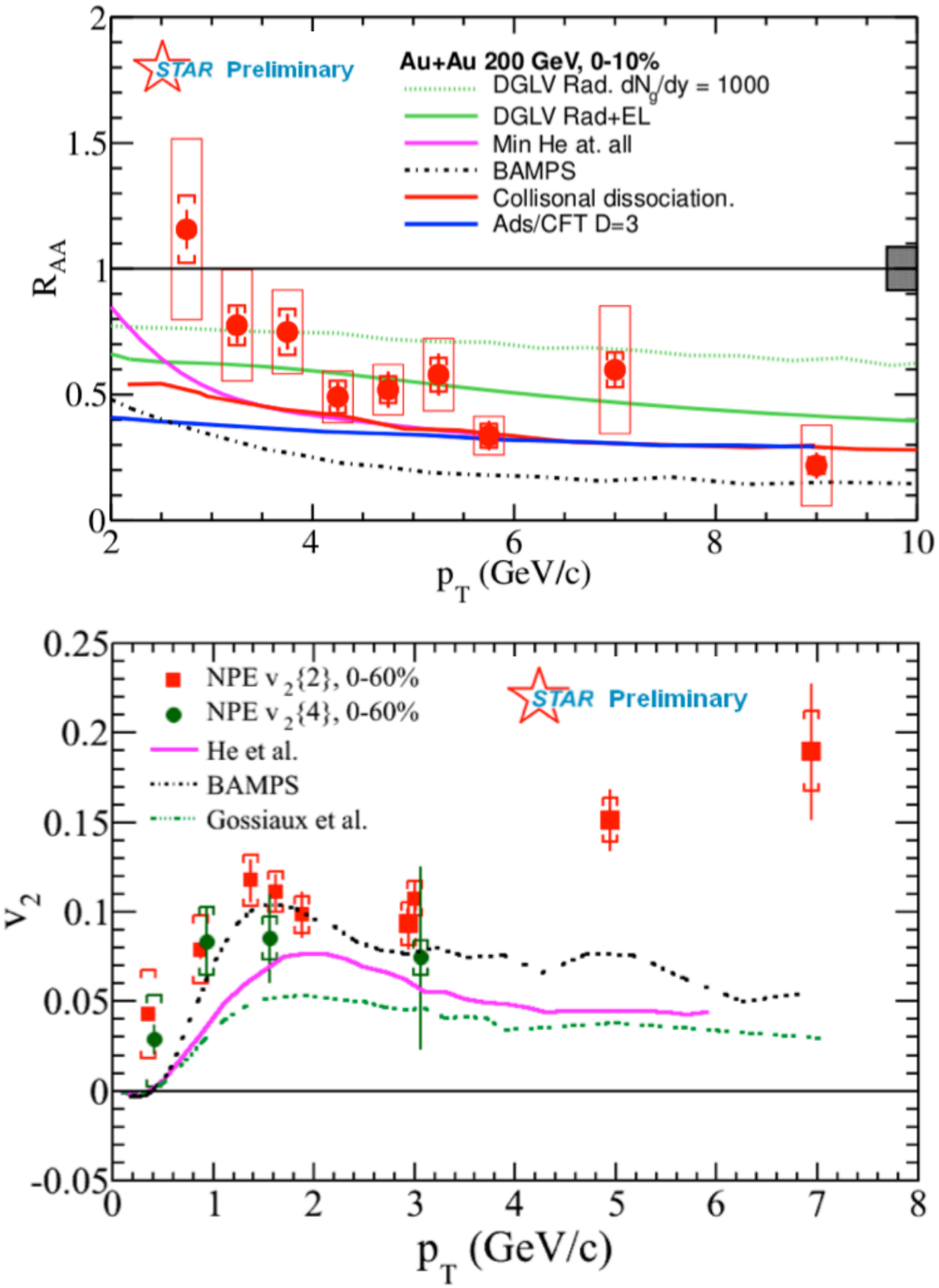




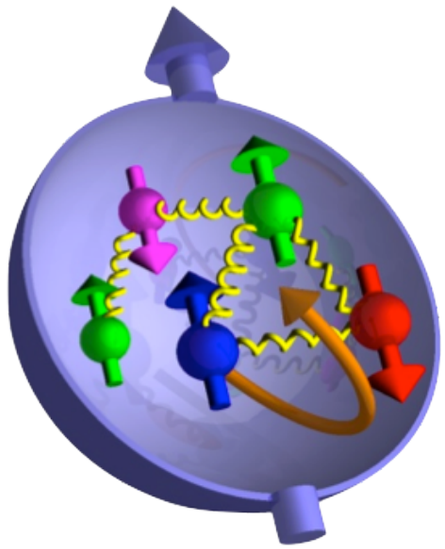
- Suppression of D^0 at high-p_T in central collisions, similar to that of light hadrons
- Enhancement at low p_T consistent with strong interactions between the charm quarks and the surrounding partonic medium

Heavy Flavor Probes: NPE

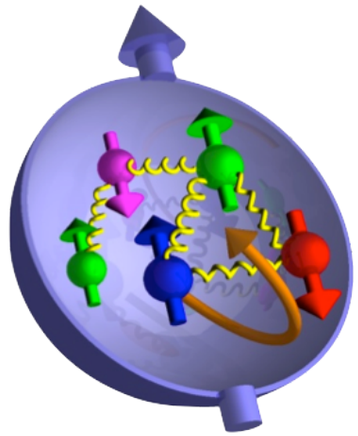
- NPE strongly suppressed in central collisions at high p_T
  - Disfavors radiative energy loss as the only energy loss mechanism for heavy quarks
- Finite v_2 at low and intermediate p_T, indicate charm quarks strong interaction with the medium
- HFT and MTD upgrades will allow future precision measurements with dilepton and heavy flavor probes



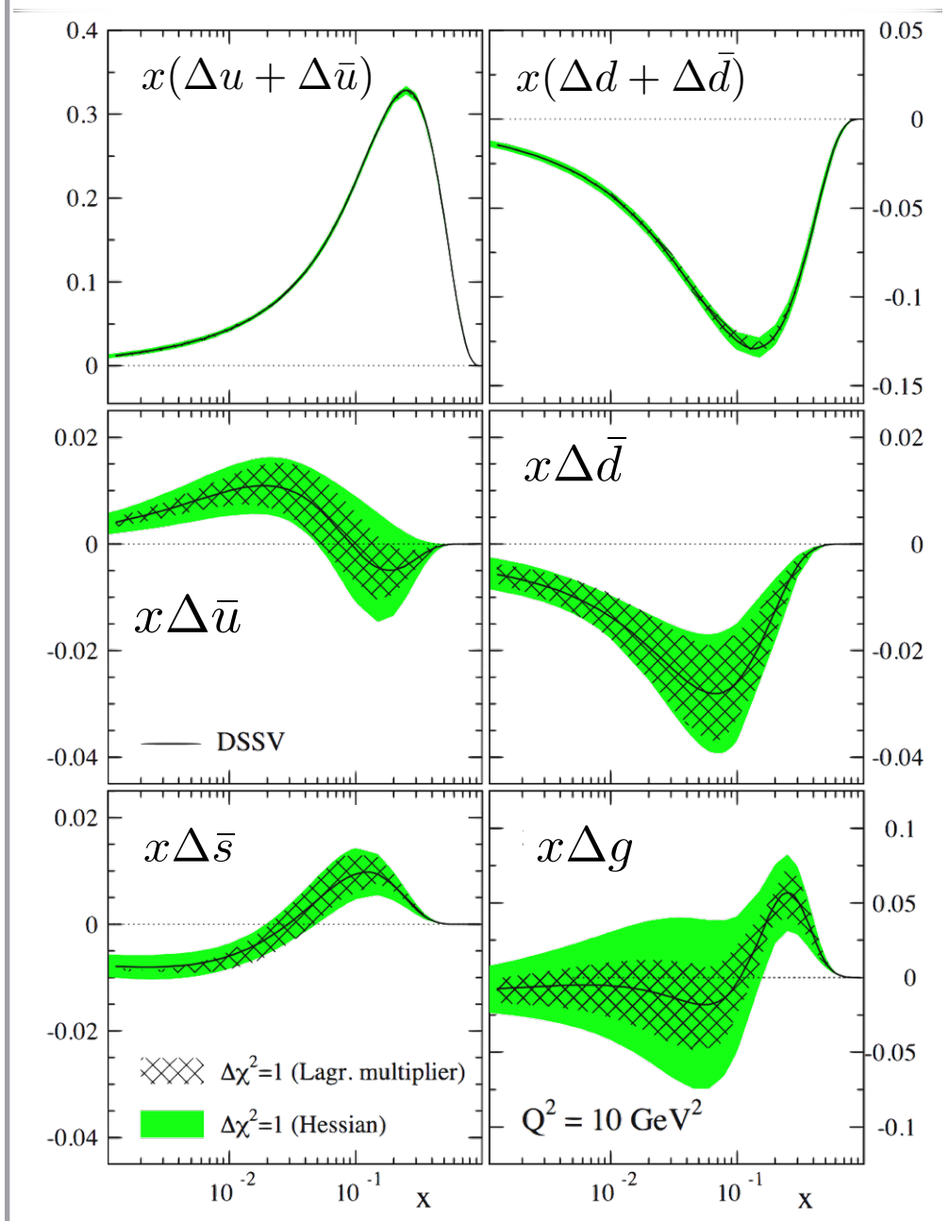
STAR Spin Results



Proton Spin Puzzle



DSSV Global Analysis



PRD **80**, 034030 (2009)

$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

$$\Delta\Sigma = \int \left(\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}\right) dx$$

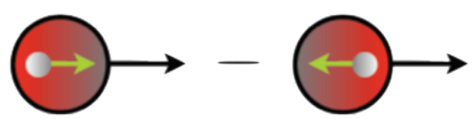
Integral of quark polarization is well measured in DIS to be ~30%, some info on decomposition from SIDIS but sea not well constrained

$$\Delta G = \int \Delta g\,(x)\, dx$$

Gluon polarization poorly constrained by DIS, and early RHIC data preferred a small contribution

Helicity PDF

$$\Delta f(x) =$$



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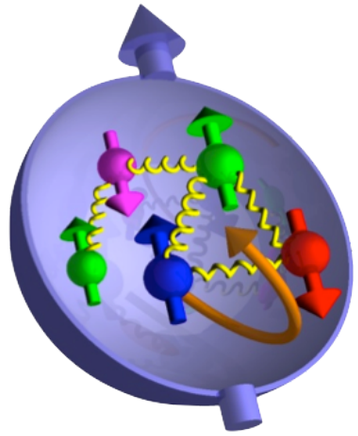

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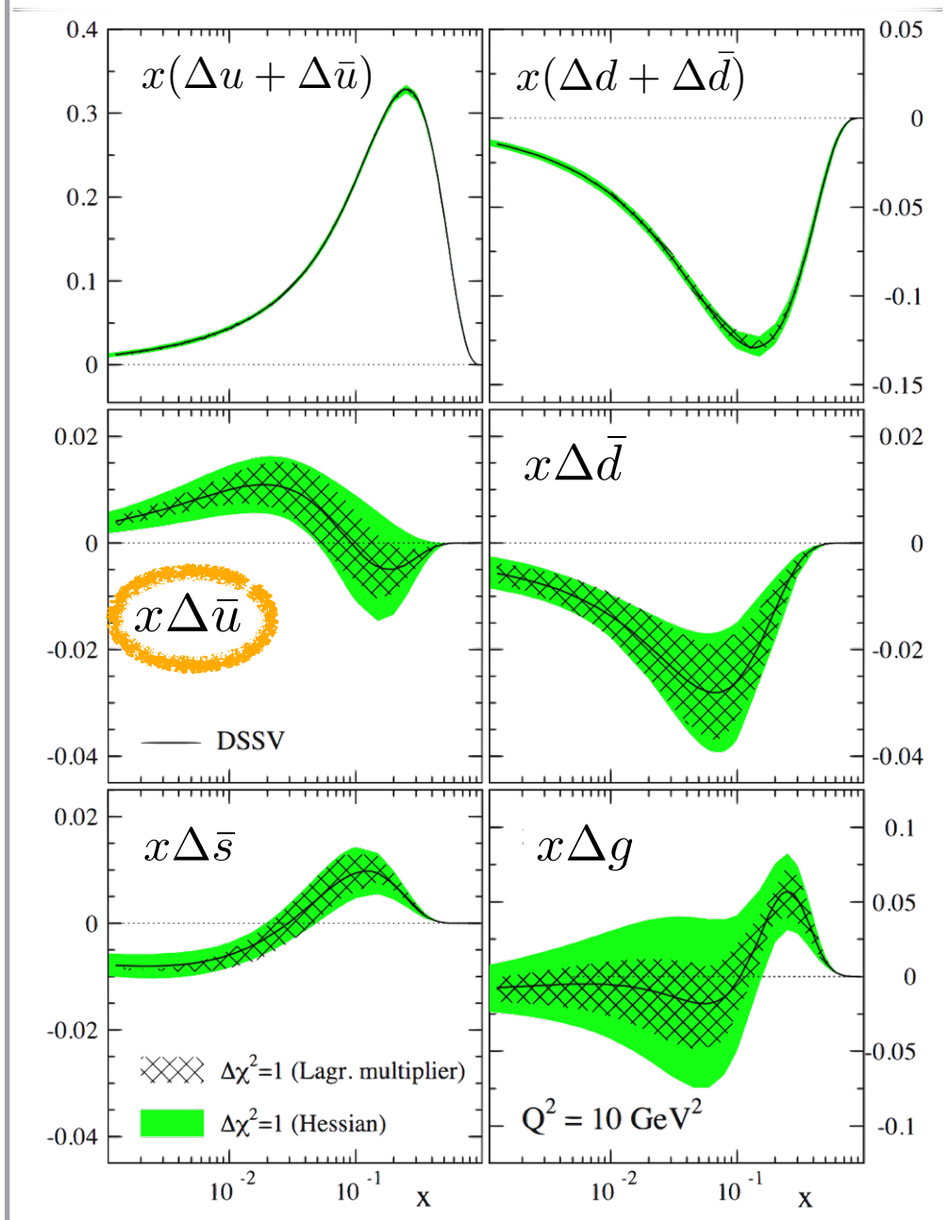

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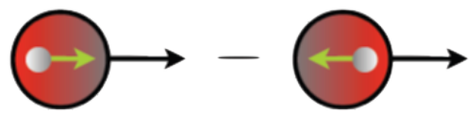

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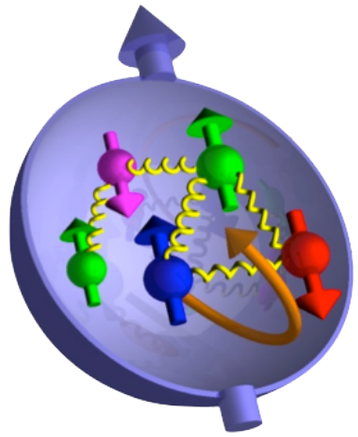

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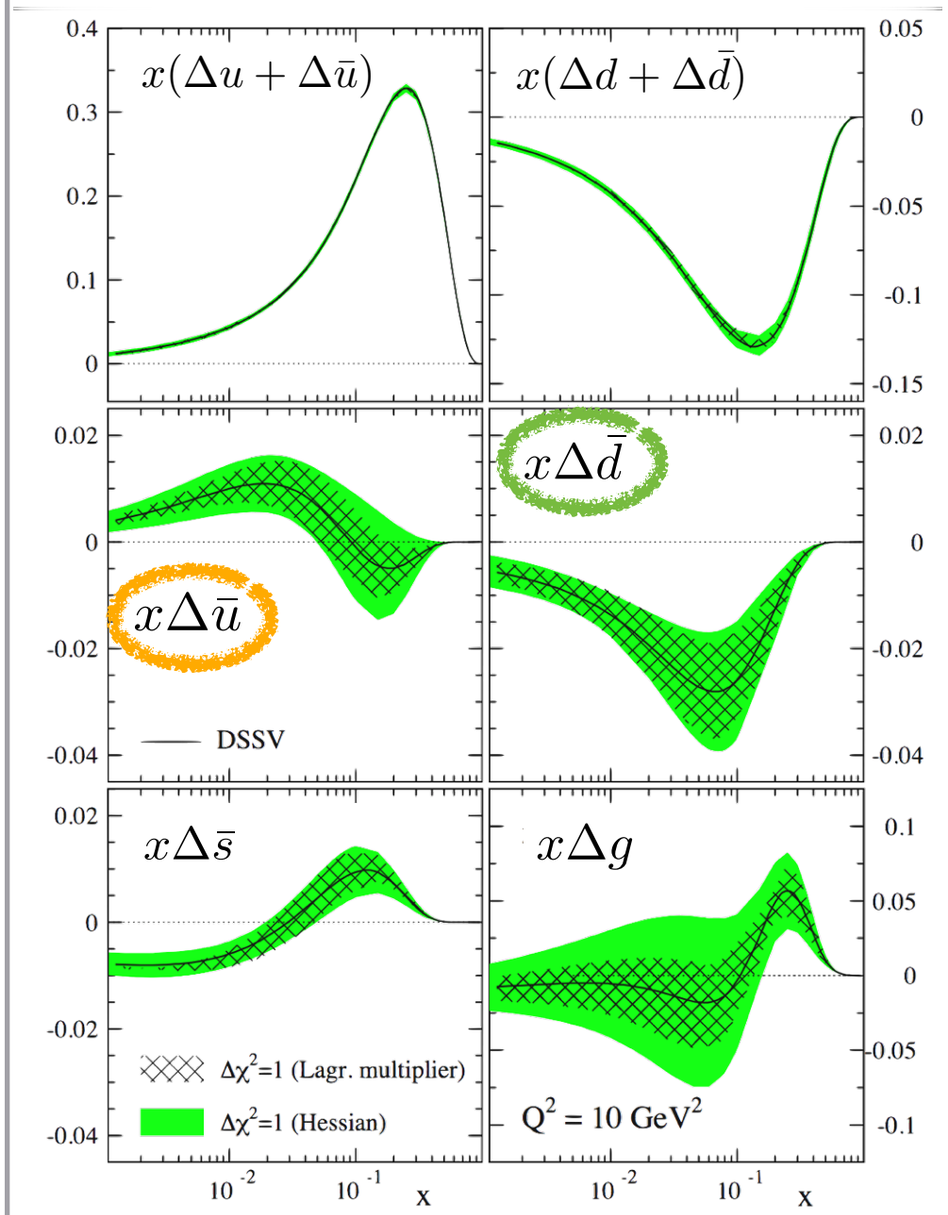

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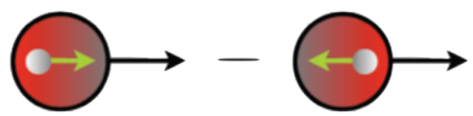

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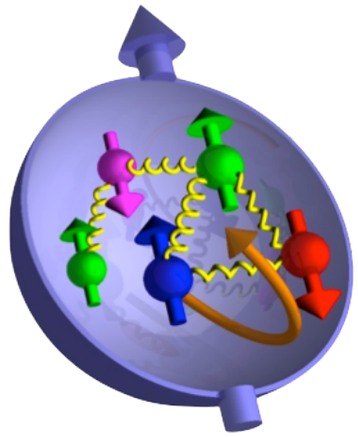

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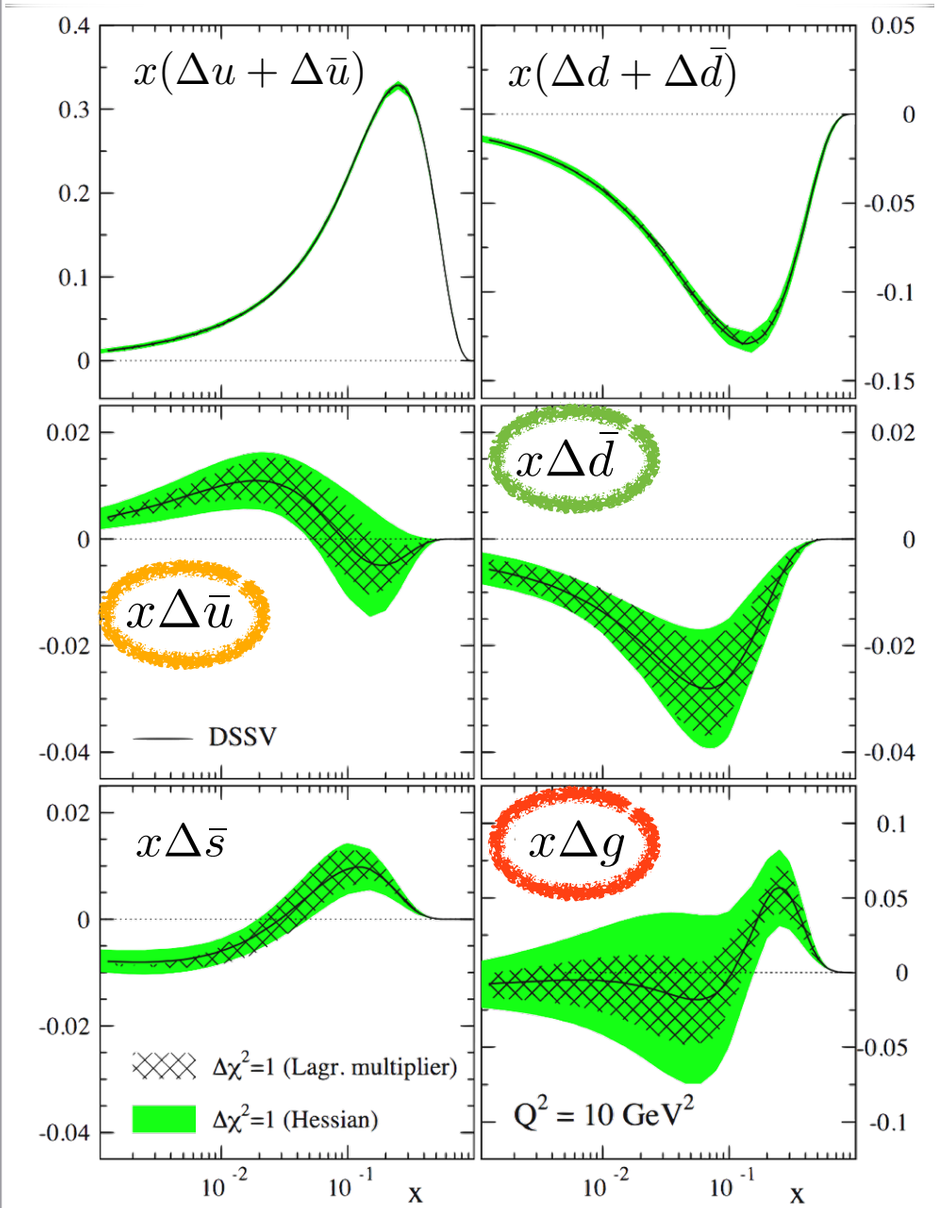

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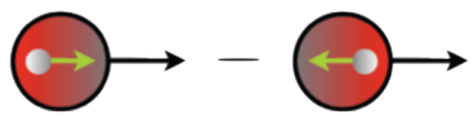

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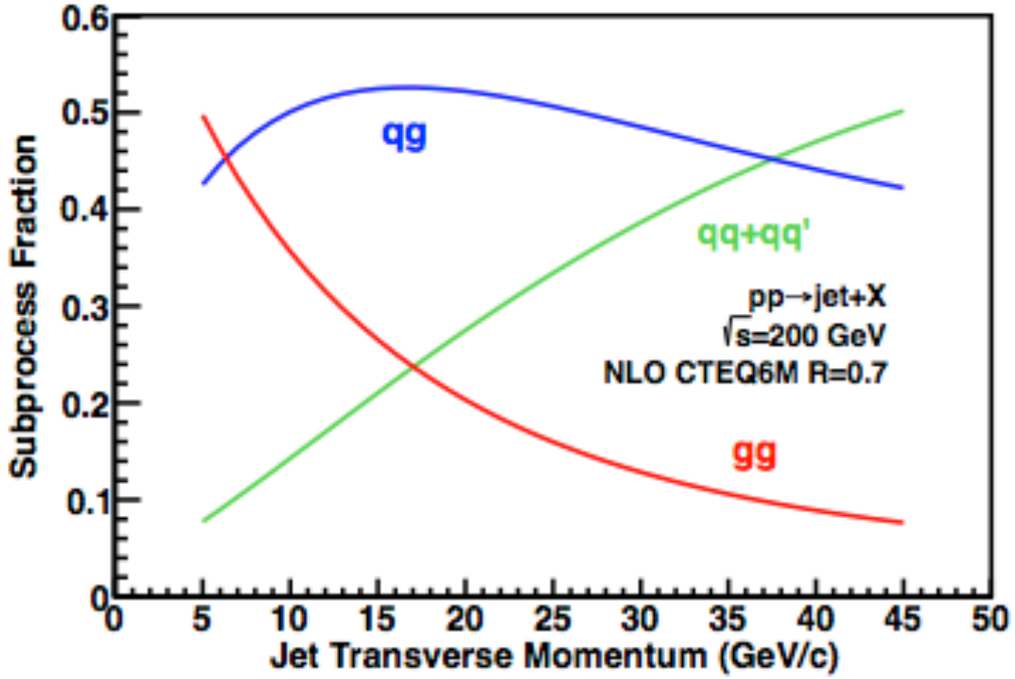
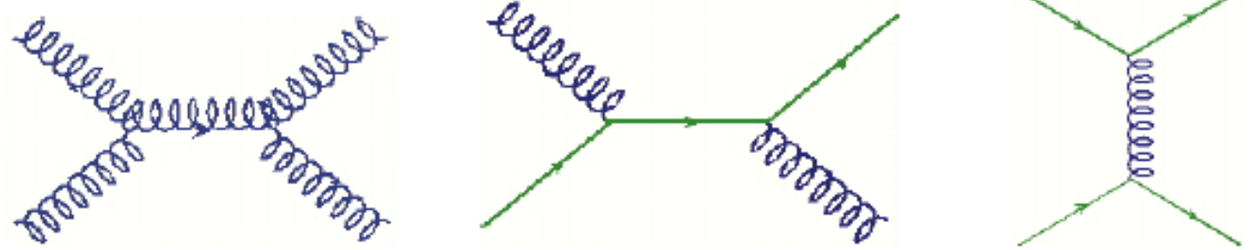
Gluon Polarization



$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

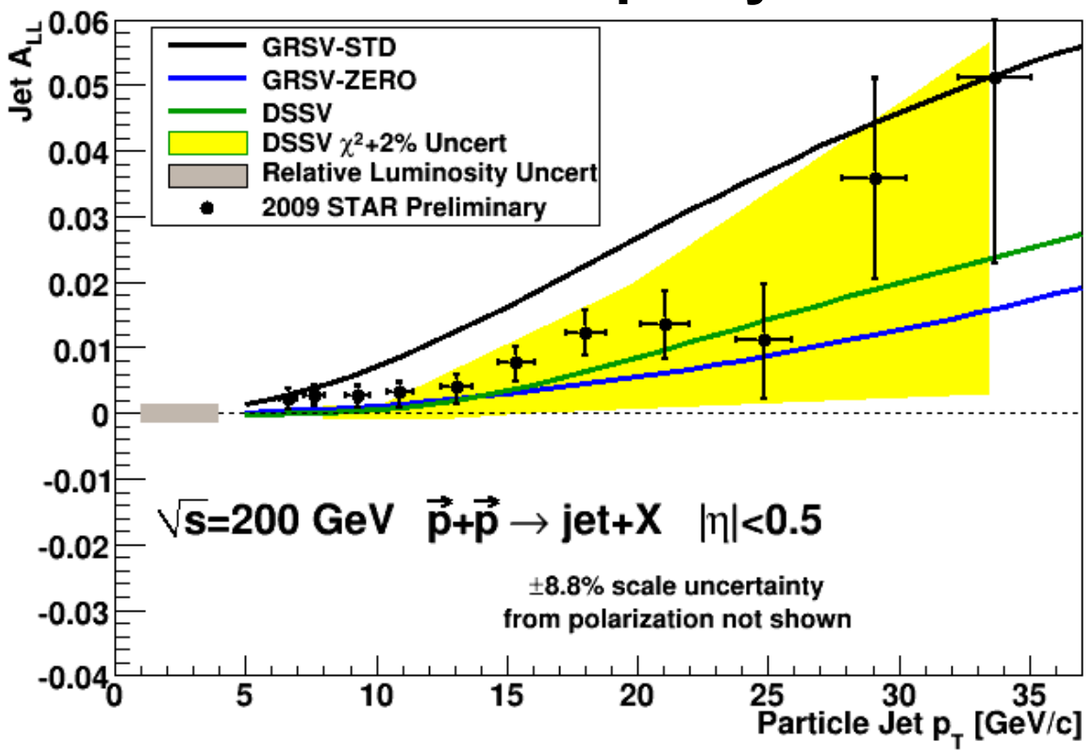
$\frac{\Delta G}{G}\frac{\Delta G}{G}$ $\frac{\Delta q}{q}\frac{\Delta G}{G}$ $\frac{\Delta q}{q}\frac{\Delta q}{q}$



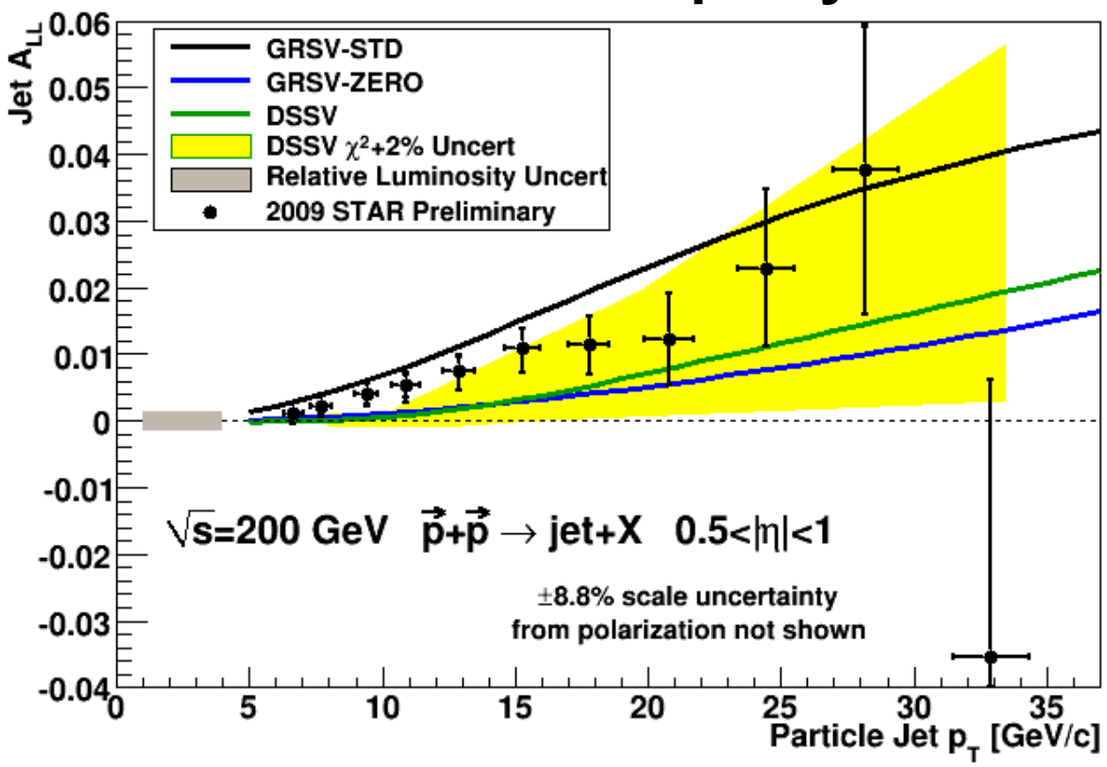
- For most of RHIC Kinematics qg and gg dominate
- A_{LL} for jets sensitive to gluon polarization
- Large acceptance of STAR makes it ideally suited for jet measurements

Inclusive Jet A_{LL}

Mid rapidity

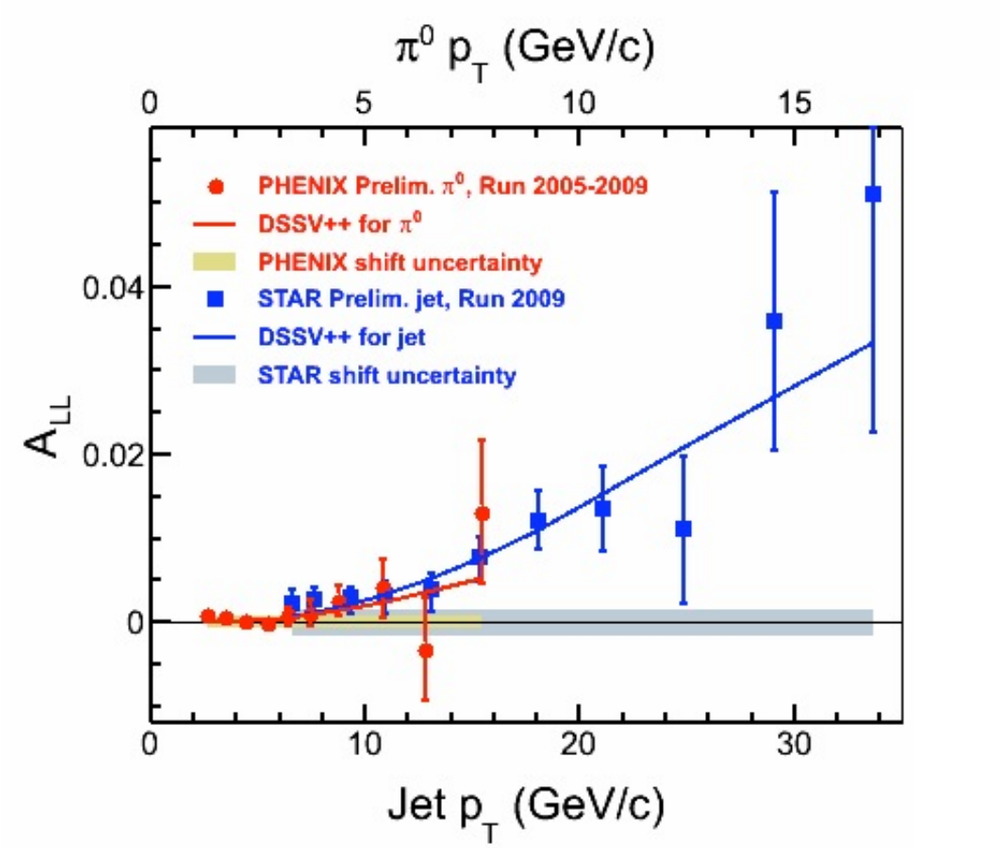


Forward rapidity



- A_{LL} separated into two pseudorapidity ranges preferentially sensitive to different partonic kinematics
- Data lie between predictions from **DSSV** and **GRSV-STD**

Global Analysis with 2009 RHIC Data



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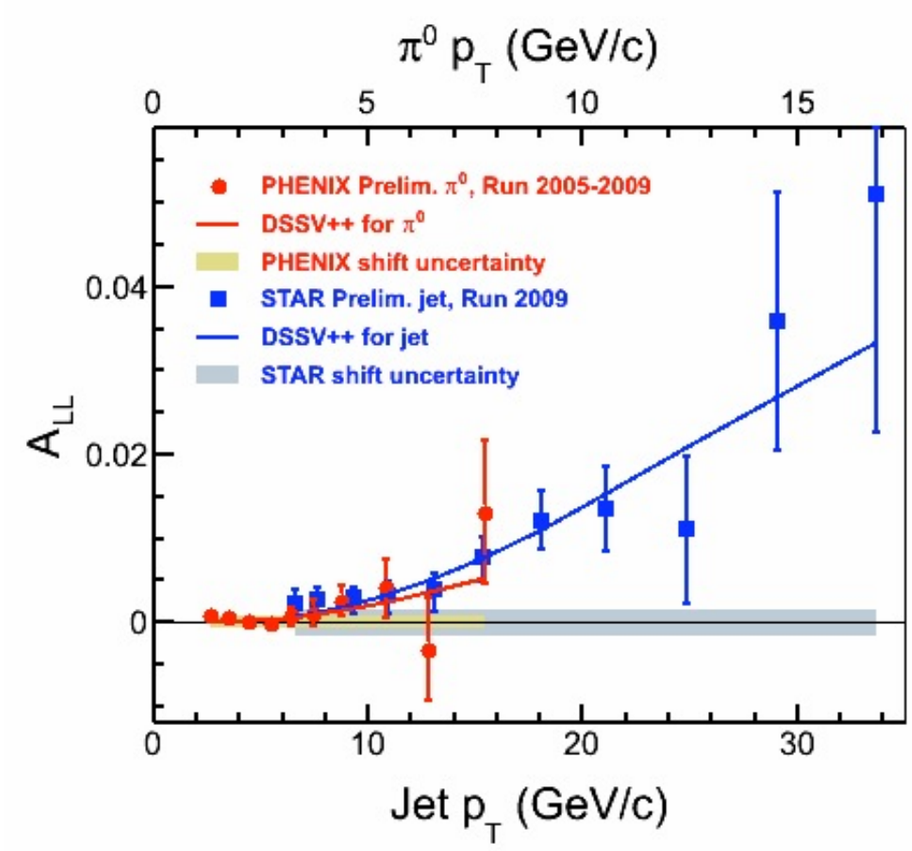
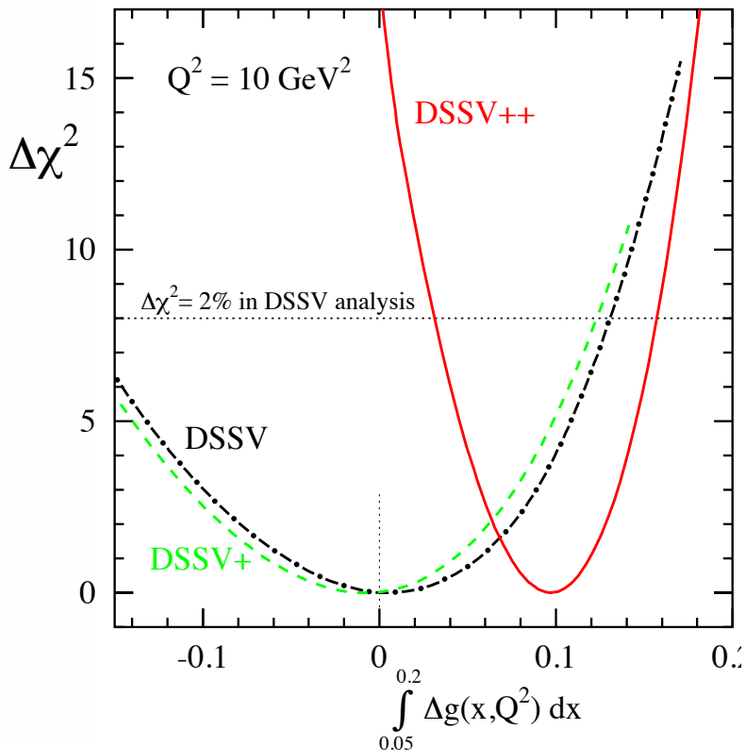


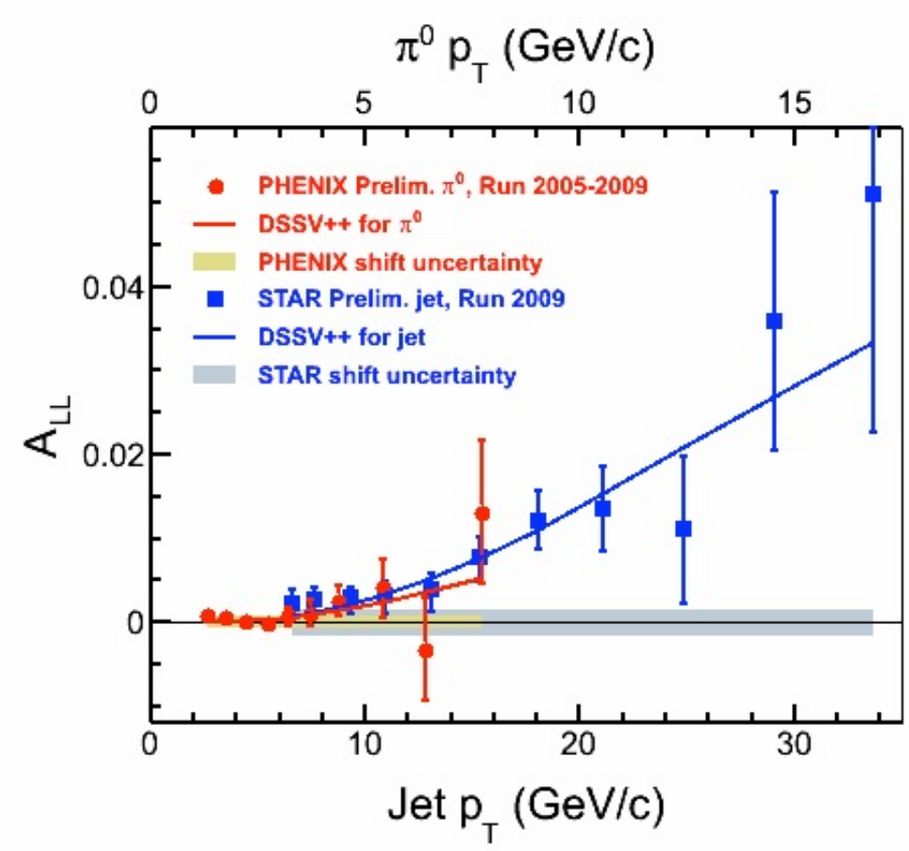


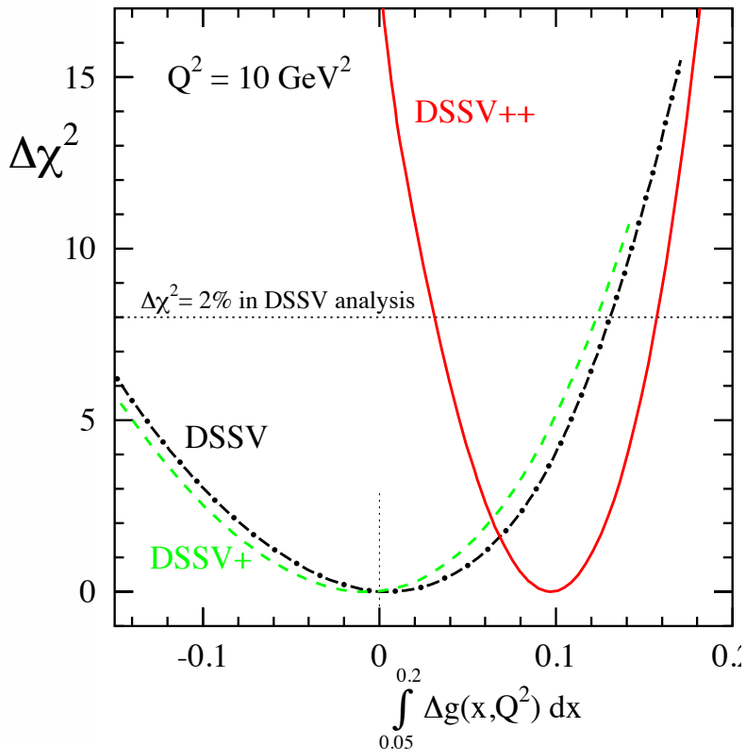
- DSSV++ is a new, preliminary global analysis from the DSSV group that includes preliminary 2009 A_{LL} measurements from PHENIX and STAR

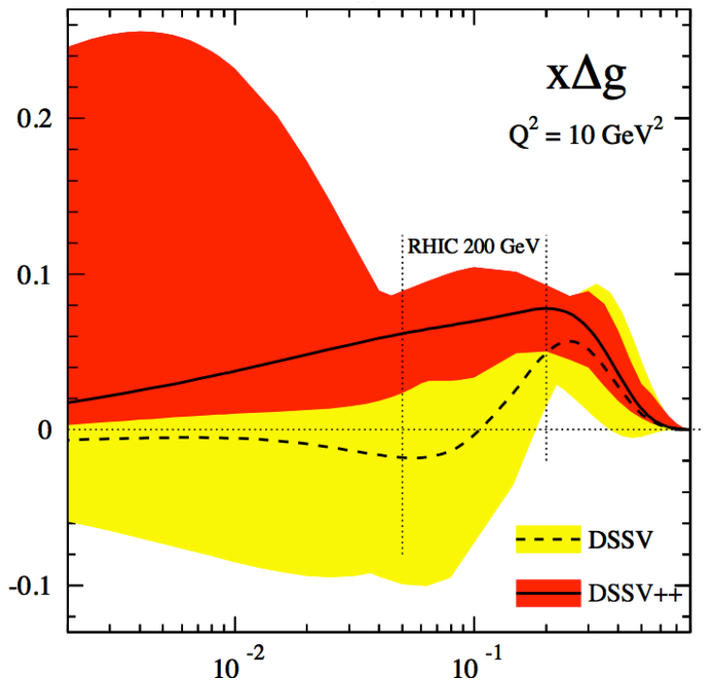
$$\int_{0.05}^{0.20} \Delta g(x, Q^2 = 10\ \mathrm{GeV}^2)\, dx = 0.10^{+0.06}_{-0.07}$$

- First experimental evidence for non-zero gluon polarization in the RHIC range ($0.05 < x < 0.2$)

Global Analysis with 2009 RHIC Data







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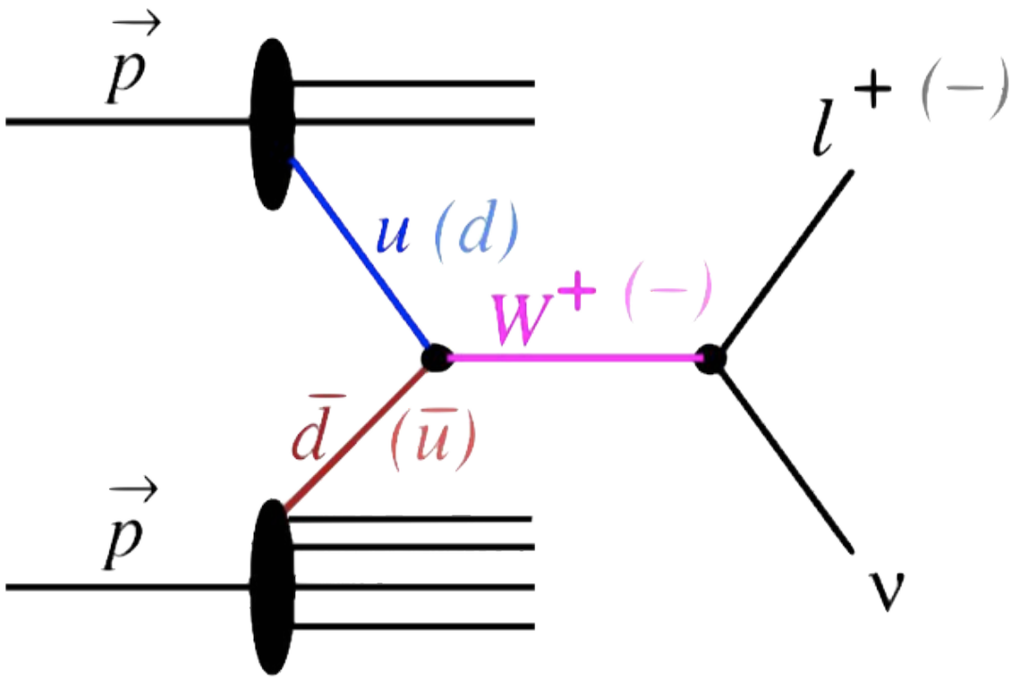
Antiquark Polarization: W Production



$$u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$$

$$d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}$$

- Ws couple directly to the quarks and antiquarks of interest
- Detect Ws through e+/e- decay channels
- V-A coupling of the weak interaction leads to perfect spin separation

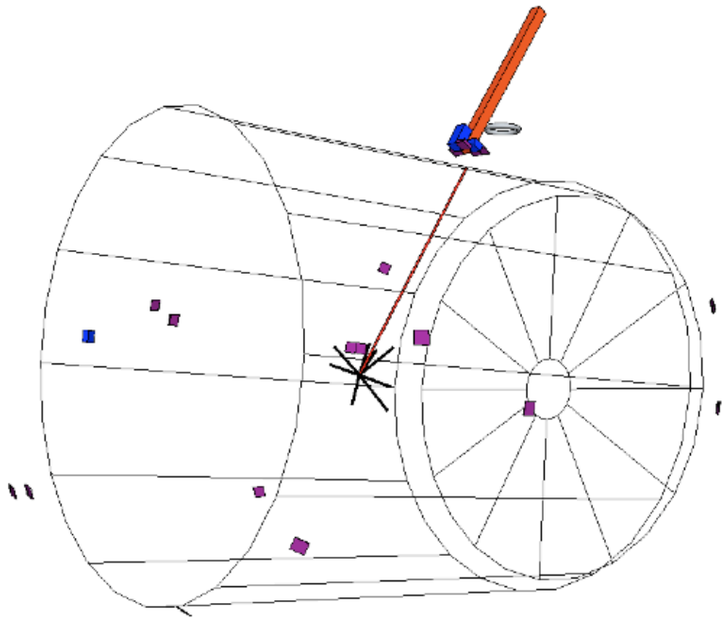
Measure parity-violating single-spin asymmetry: $A_L = \dfrac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$

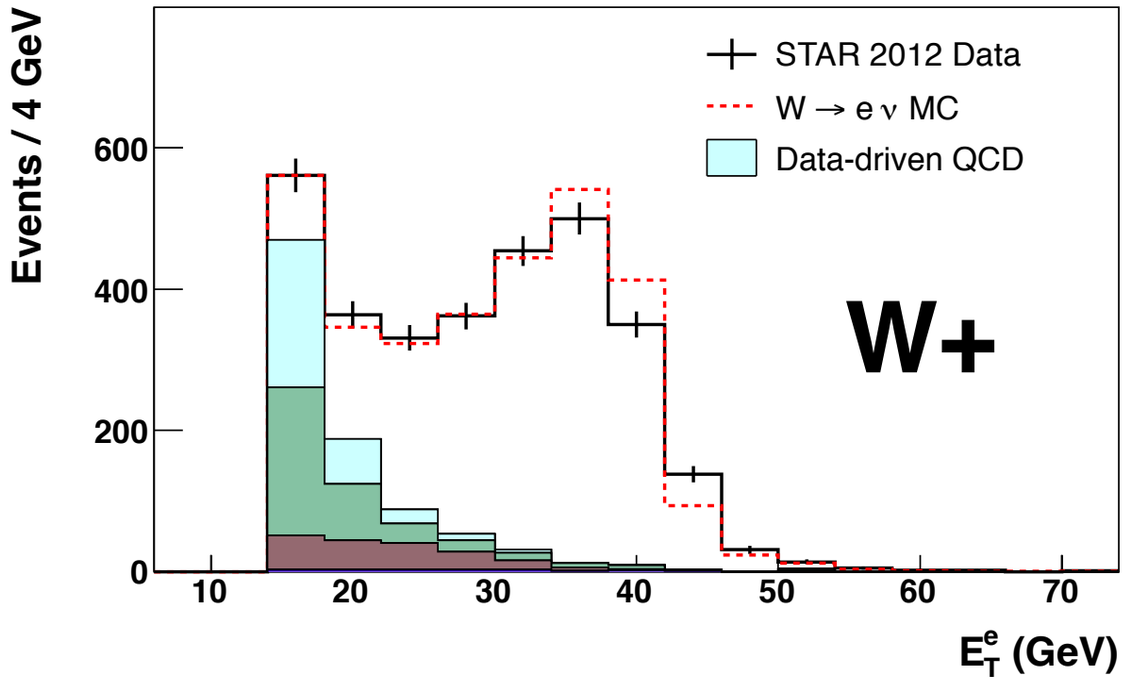
(Helicity flip in one beam while averaging over the other)

$$A_L^{W-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)} \qquad A_L^{W+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

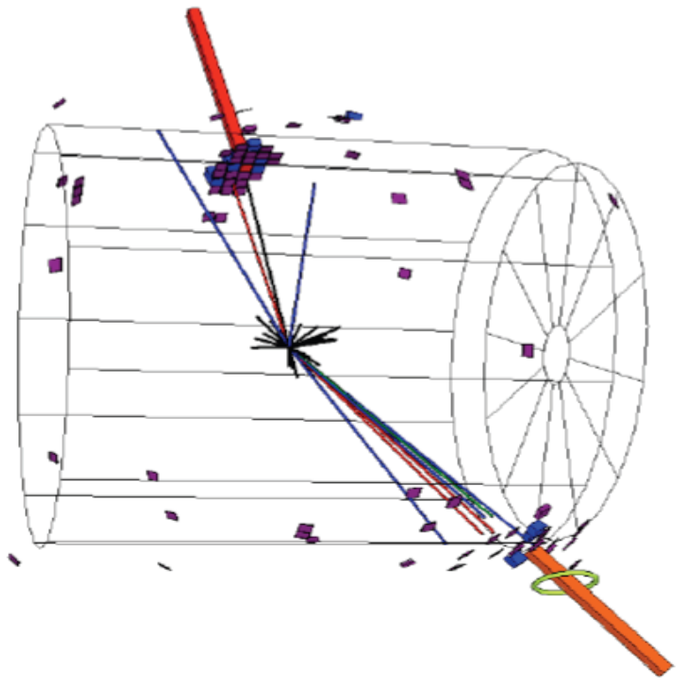
What do W decays look like?

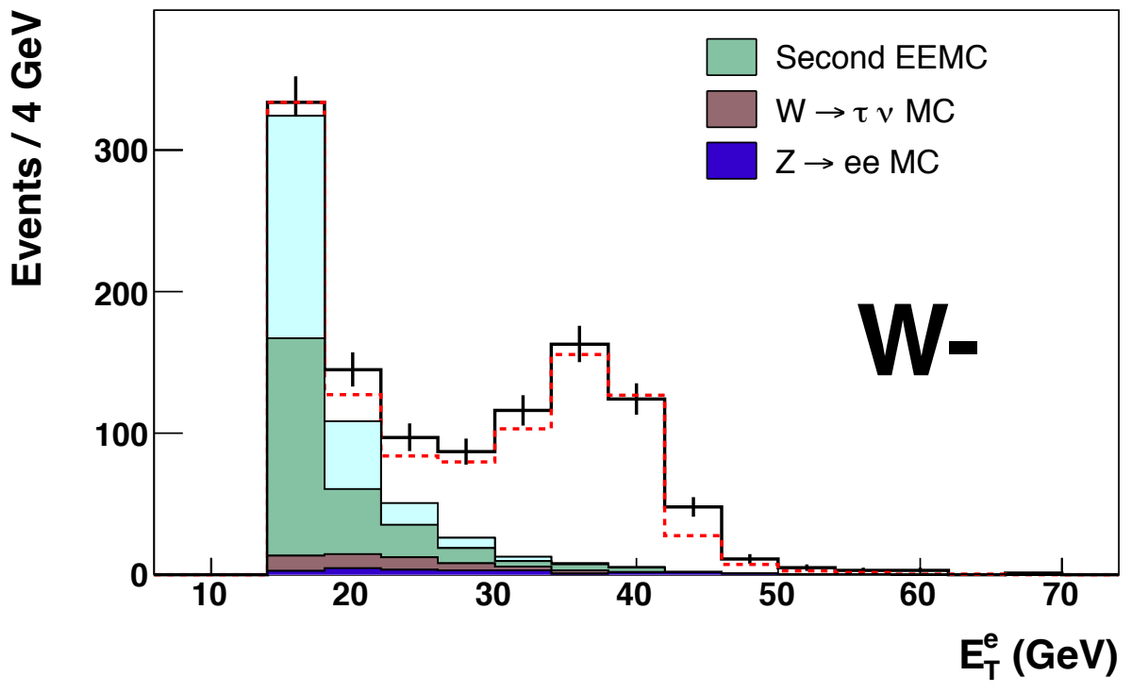
$W \rightarrow e + \nu$ Candidate Event



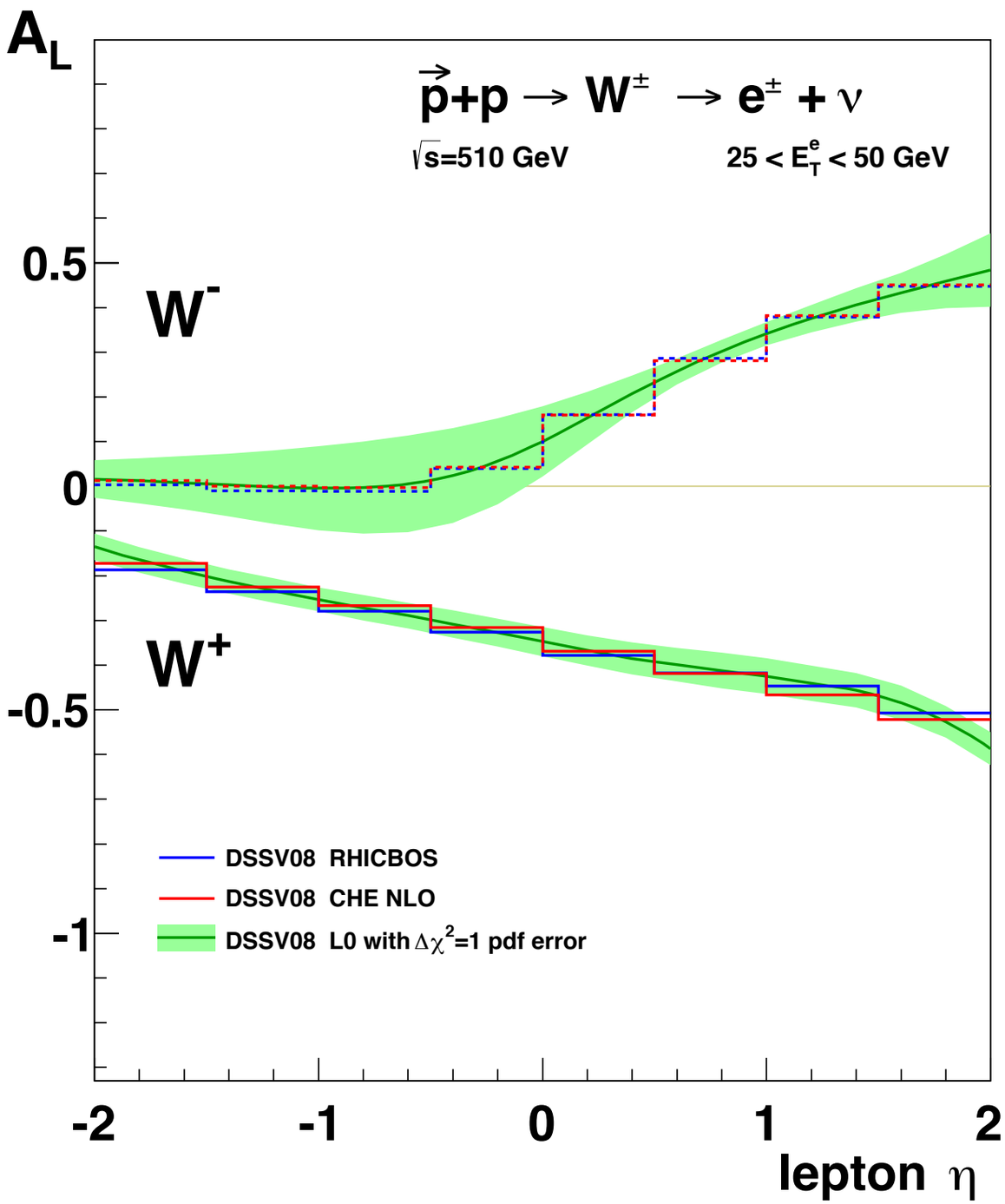


Di-jet Background Event

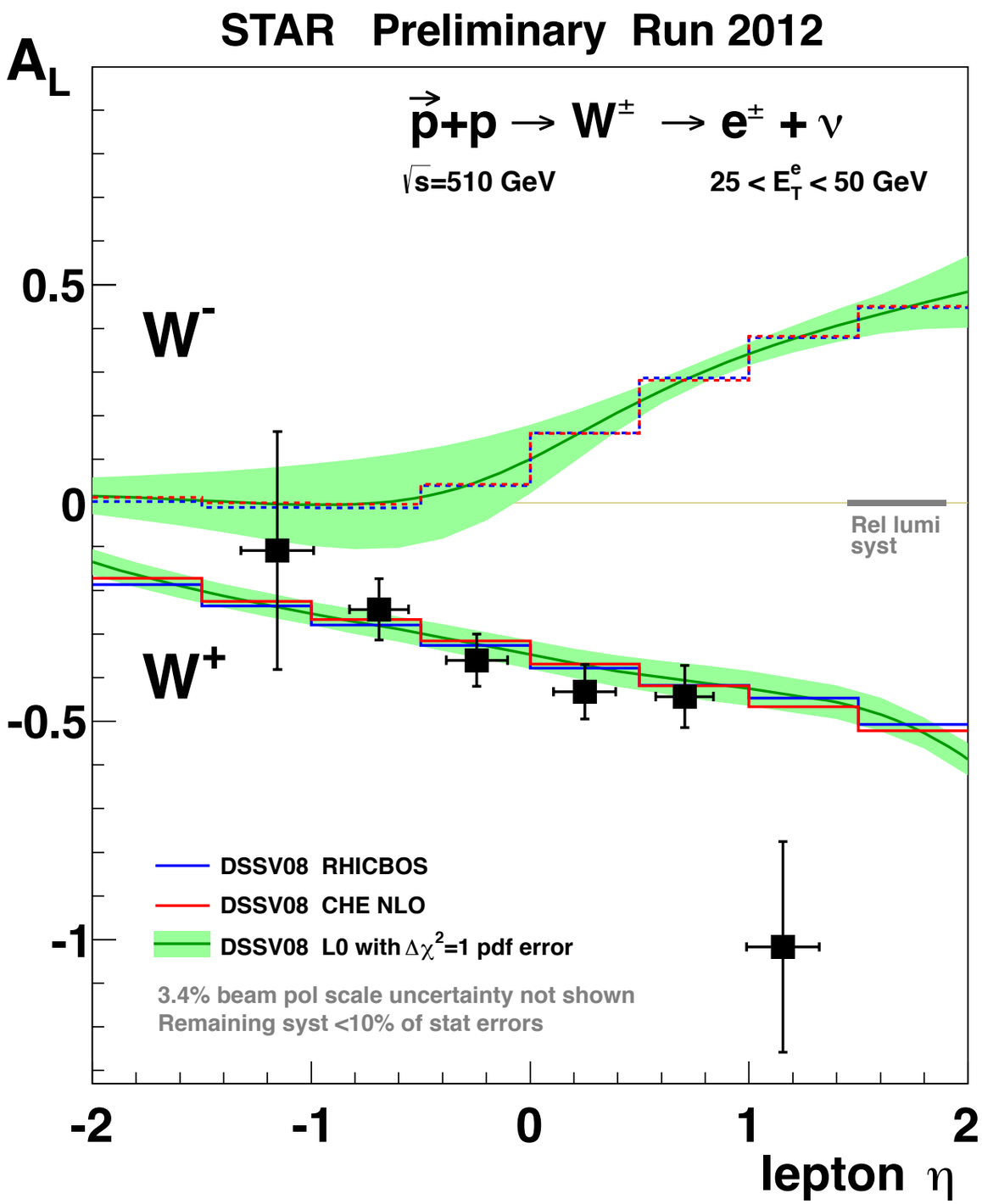




2012 W $A_L(\eta)$

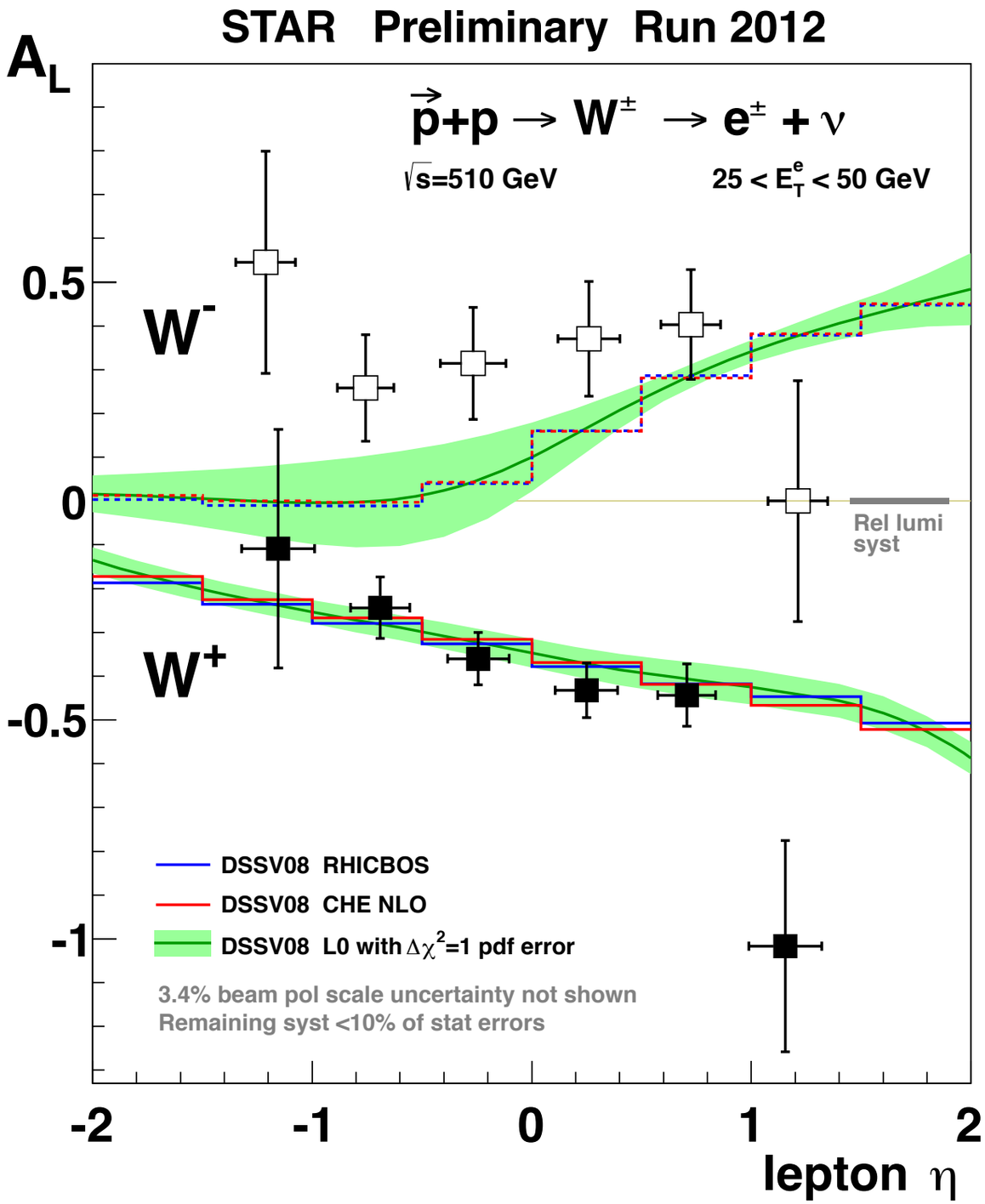

A_L
p⃗+p → W± → e± + ν
√s=510 GeV
25 < E_T^e < 50 GeV
W-
W+
0.5
0
-0.5
-1
-2
-1
0
1
2
lepton η
DSSV08 RHICBOS
DSSV08 CHE NLO
DSSV08 L0 with Δχ²=1 pdf error

2012 W $A_L(\eta)$



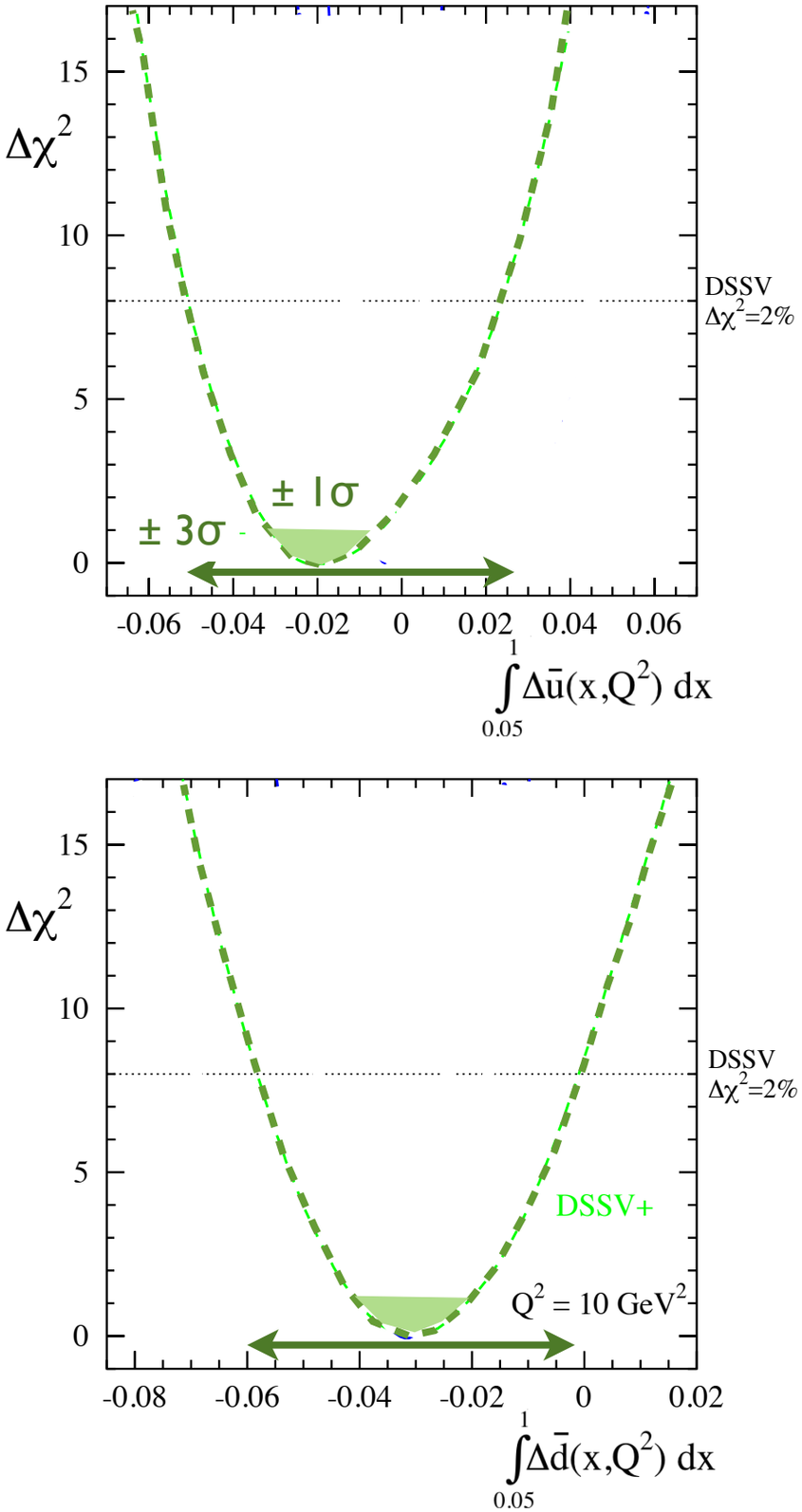
- $A_L(W+)$ is consistent with theoretical predictions using the DSSV polarized PDFs
- The systematic uncertainties for A_L are well under control for $|\eta_e| < 1.4$

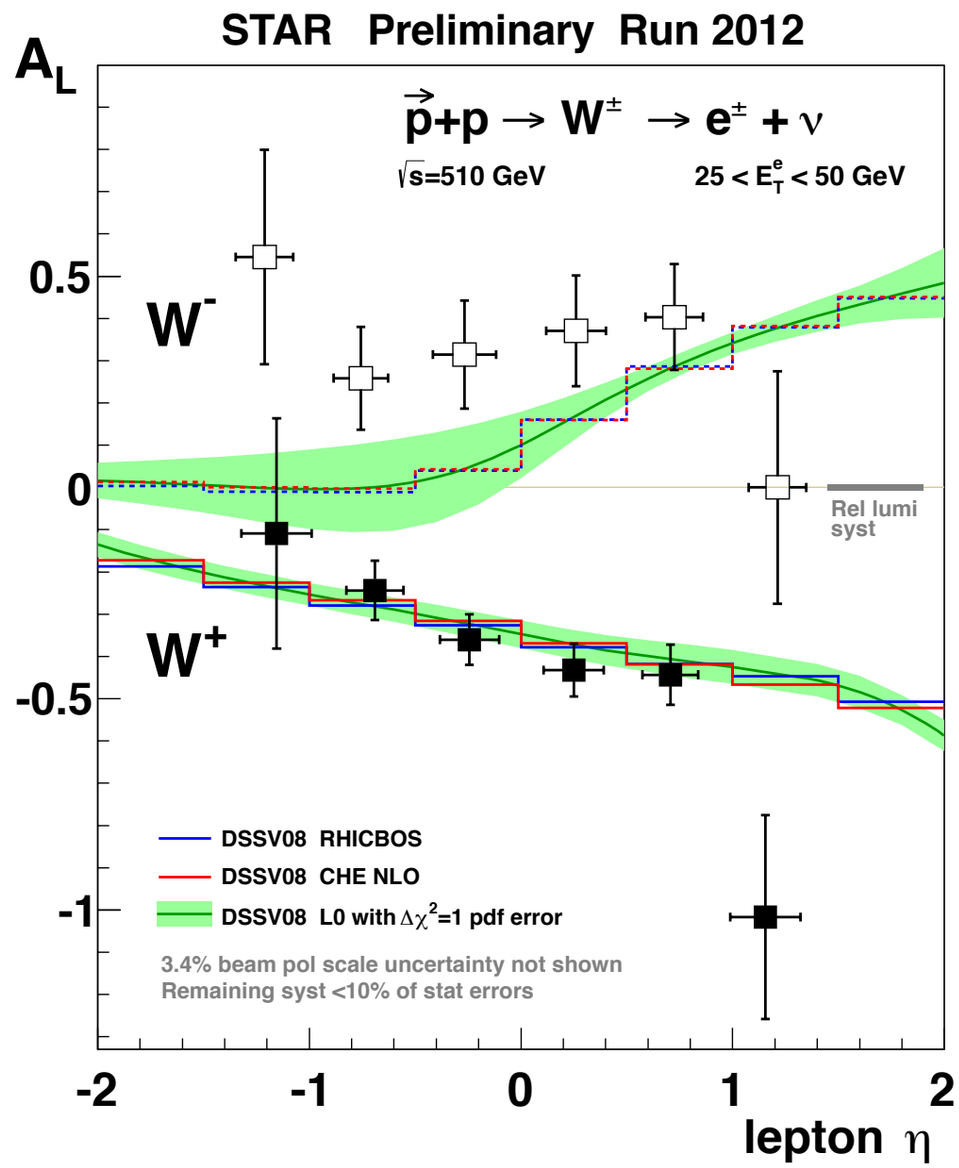
2012 W $A_L(\eta)$



- $A_L(W^-)$ is systematically larger than the DSSV predictions
  - The enhancement at $\eta_e<0$, in particular, is sensitive to the $\Delta\bar{u}$ antiquark helicity distribution
- $A_L(W^+)$ is consistent with theoretical predictions using the DSSV polarized PDFs
- The systematic uncertainties for A_L are well under control for $|\eta_e| < 1.4$

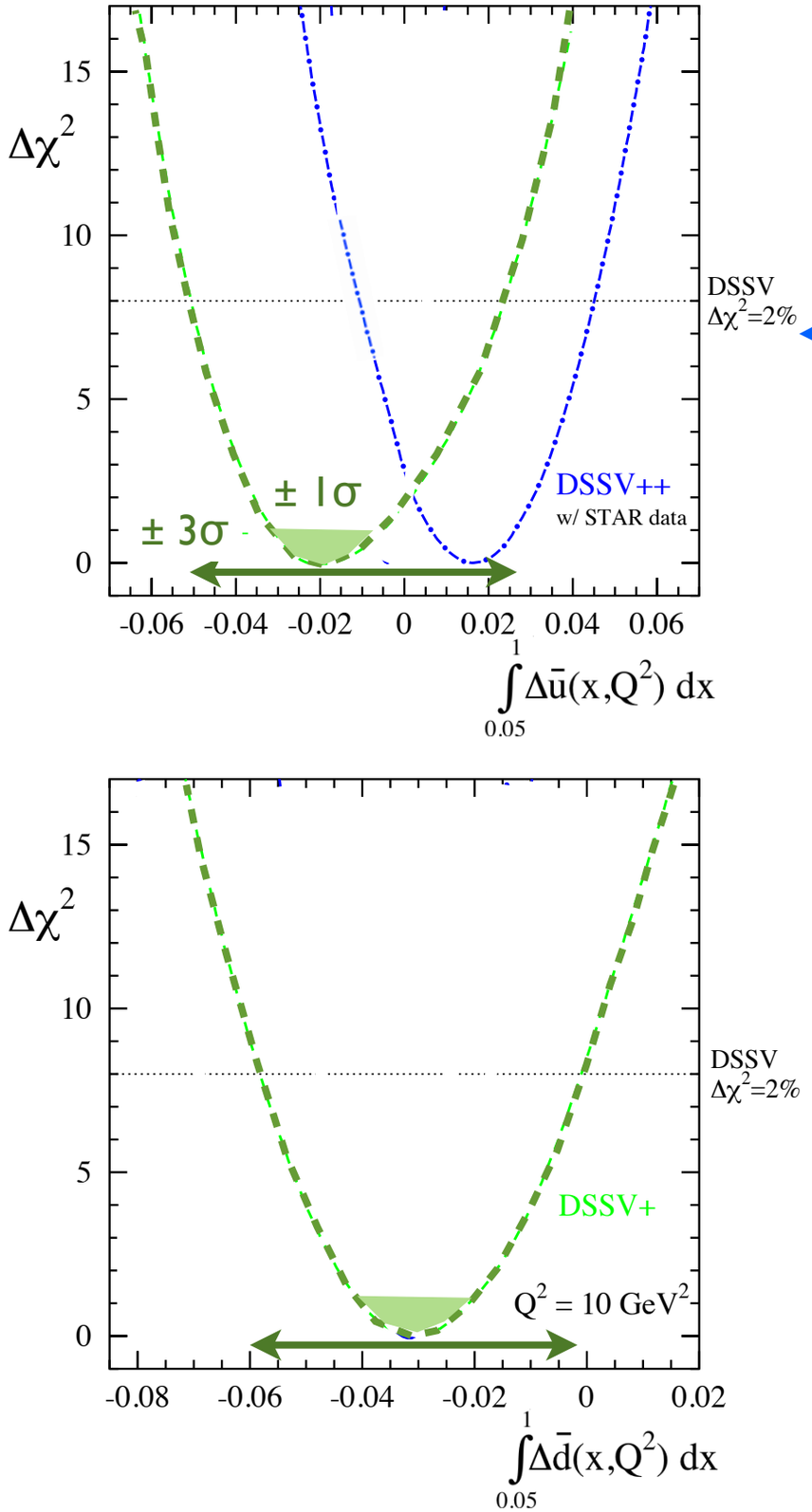
Global Analysis with 2012 STAR Data



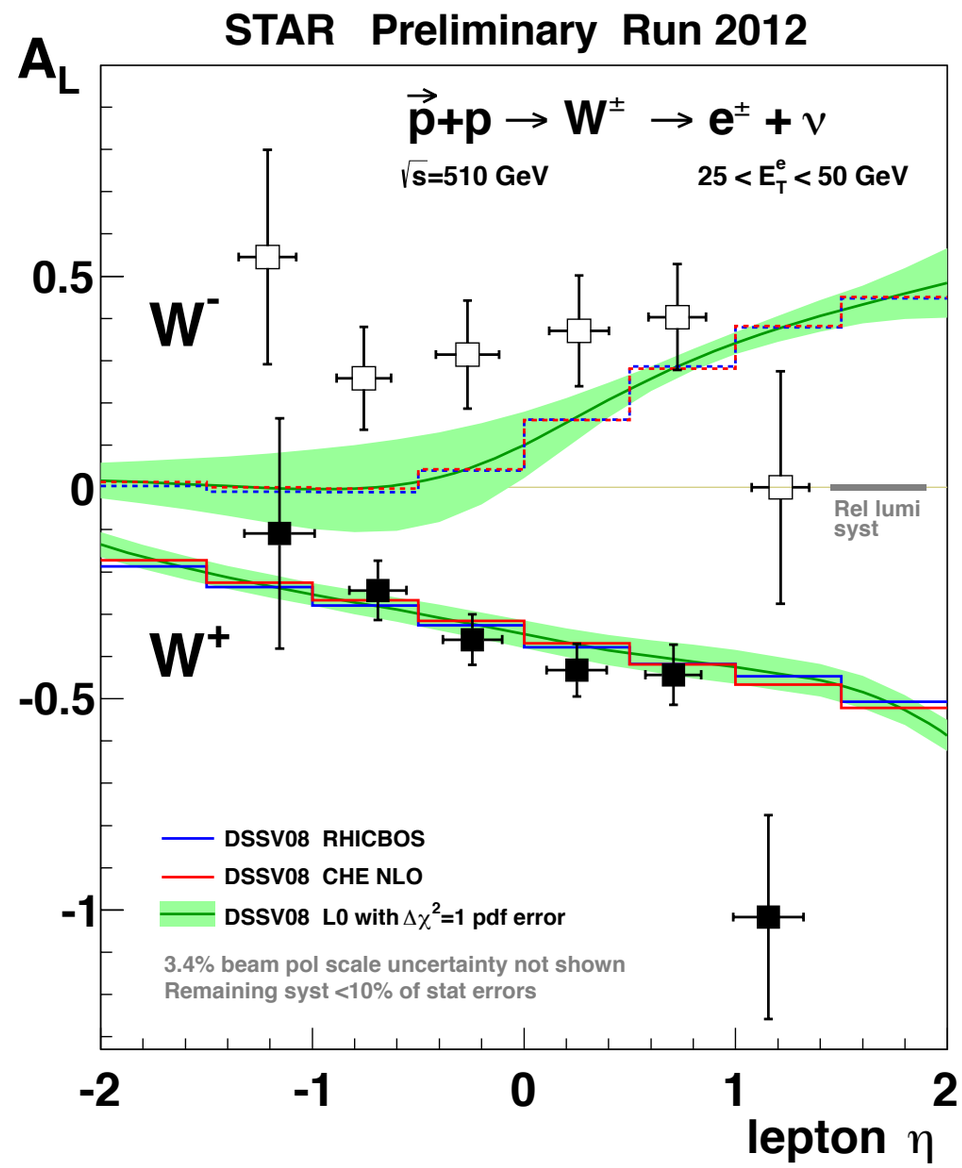


- New fit prefer sizable polarized flavor asymmetry: $\Delta\bar{u}(x) - \Delta\bar{d}(x)$

Global Analysis with 2012 STAR Data



$\Delta\bar{u}$



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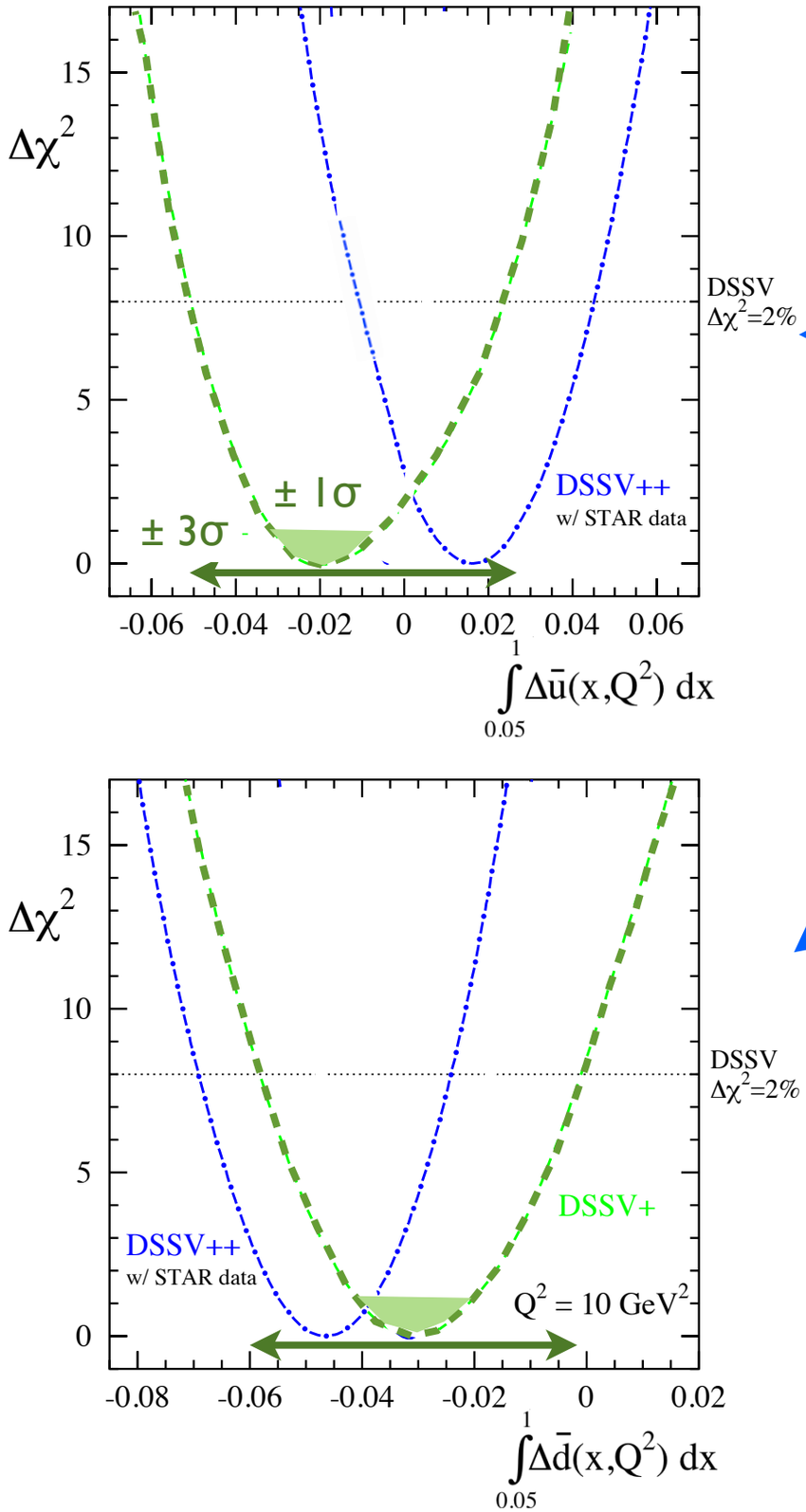
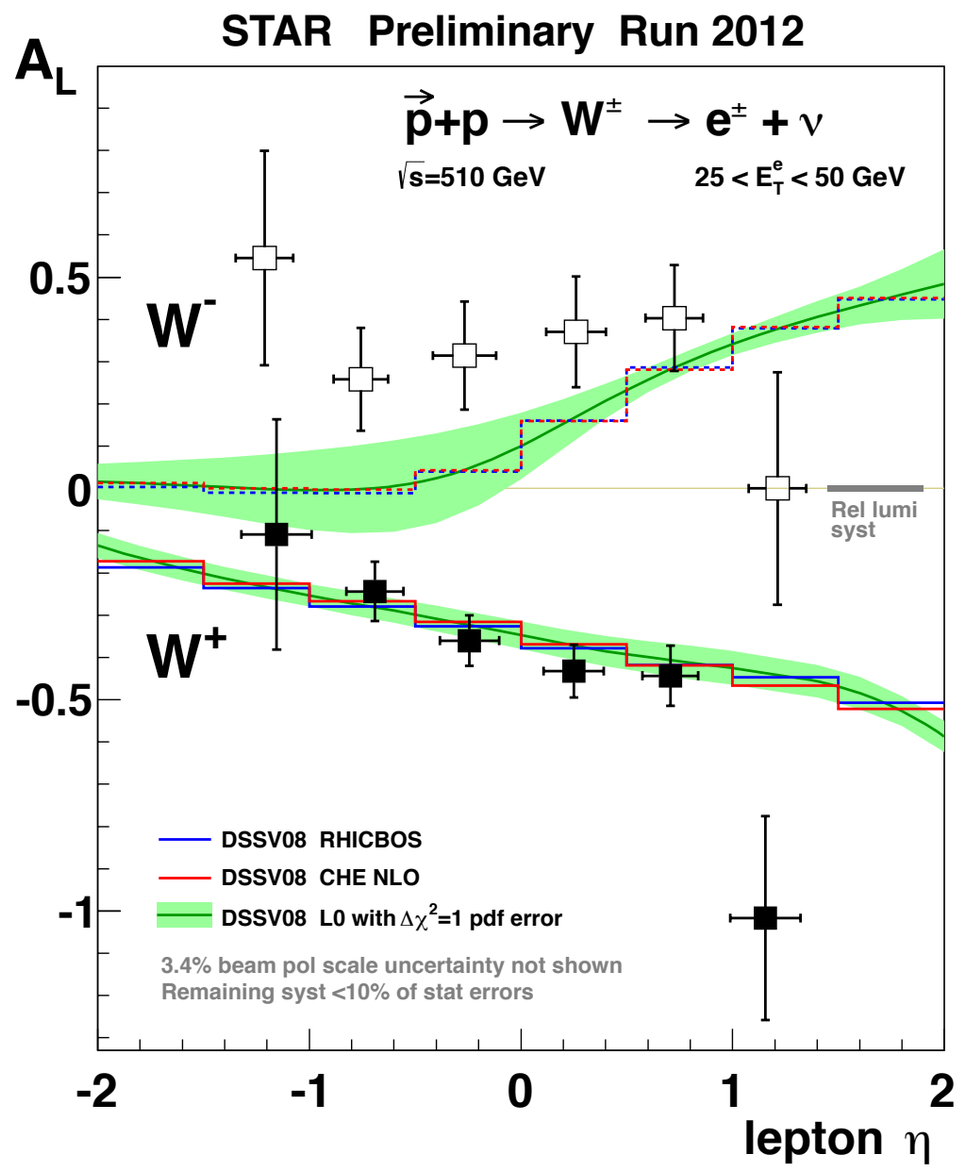
Global Analysis with 2012 STAR Data



$\Delta\bar{u}$

$\Delta\bar{d}$



- New fit prefer sizable polarized flavor asymmetry: $\Delta\bar{u}(x) - \Delta\bar{d}(x)$

Summary

- Turn-off of QGP signatures at low energy
- Searches for 1st order phase transition and critical point show some interesting features, but more data needed
- Interesting features in U+U, needs further investigation
- Studies of dielectron production dependence on mass, beam energy, p_T, centrality as well as elliptic flow
- Strong suppression of heavy quark production through NPE and D^0 at RHIC top energy
- Evidence for non-zero gluon and antiquark polarization from jet A_{LL} and W A_L measurements

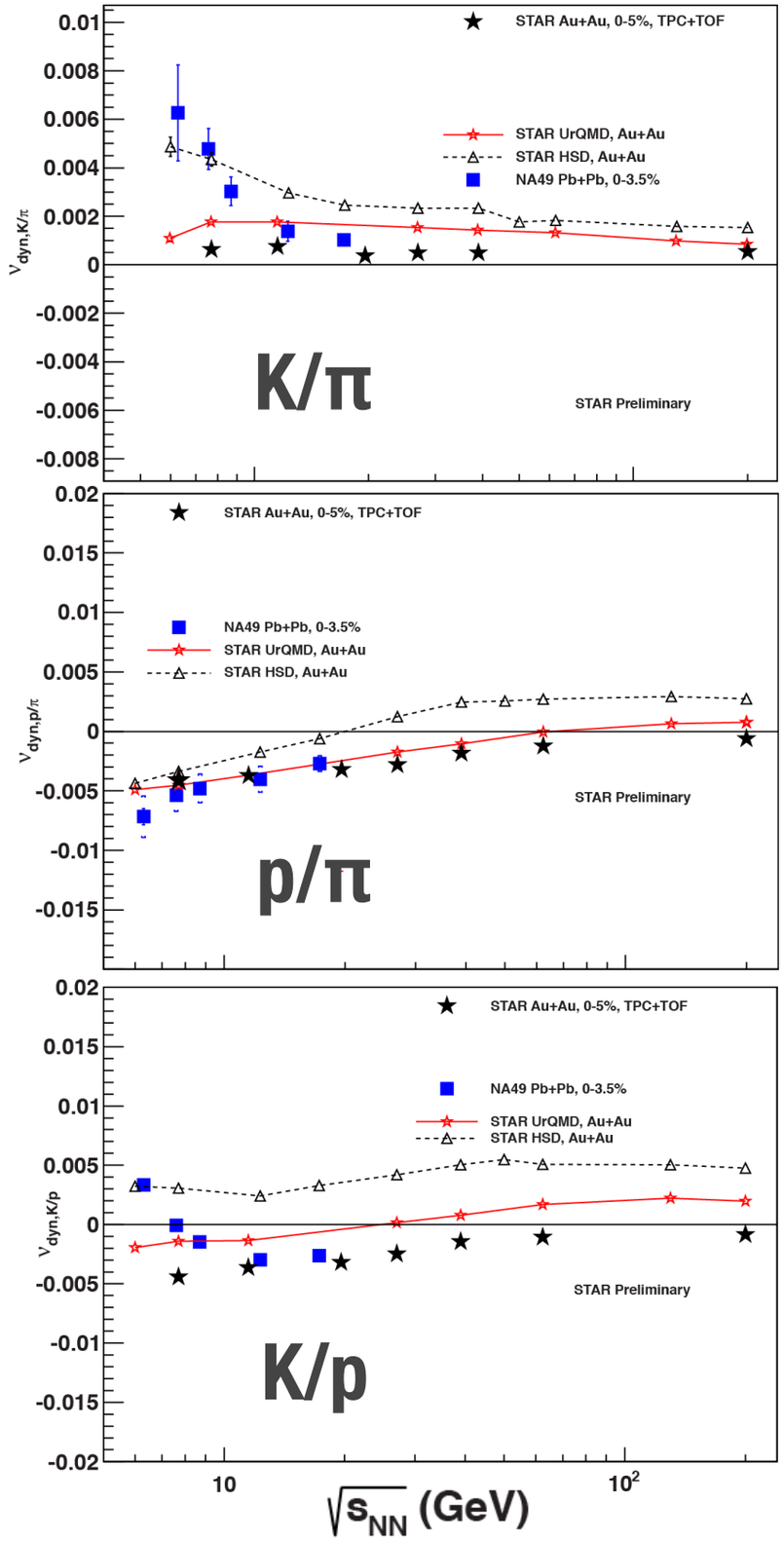
Backup

Search for the Critical Point

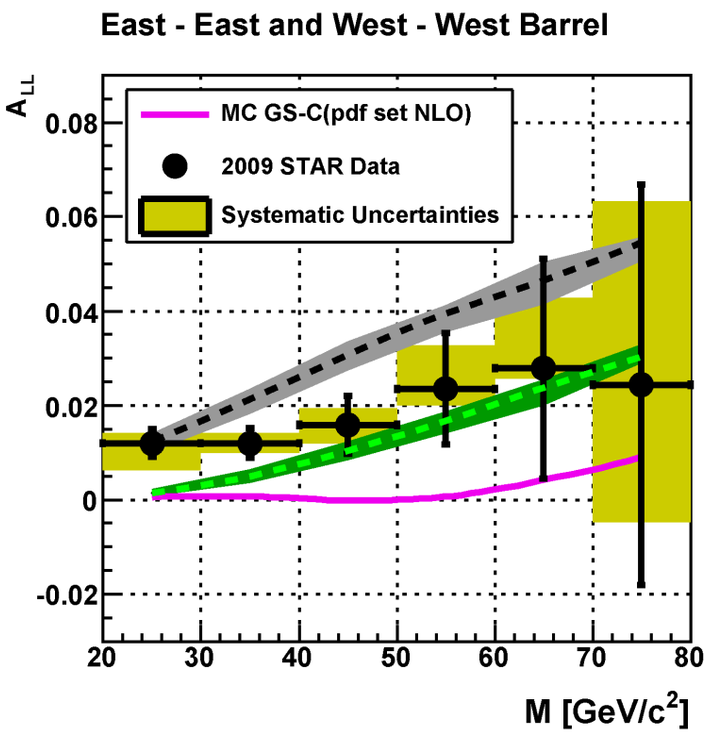
- Particle ratio fluctuations, look for non-monotonic behavior with incident energy

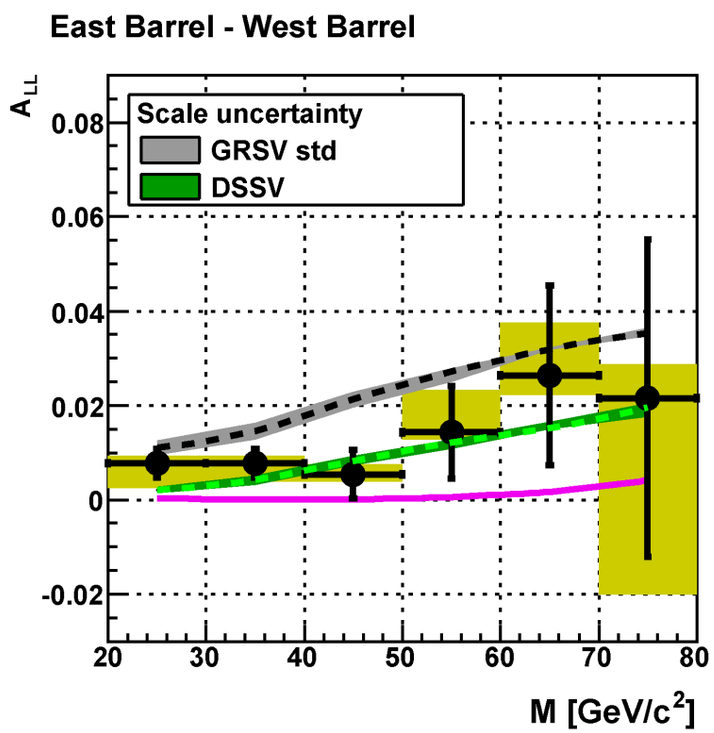
$$\nu_{\mathrm{dyn},K\pi} = \frac{\langle N_K(N_K-1)\rangle}{\langle N_K\rangle^2} + \frac{\langle N_\pi(N_\pi-1)\rangle}{\langle N_\pi\rangle^2} - 2\frac{\langle N_K N_\pi\rangle}{\langle N_K\rangle\langle N_\pi\rangle}$$

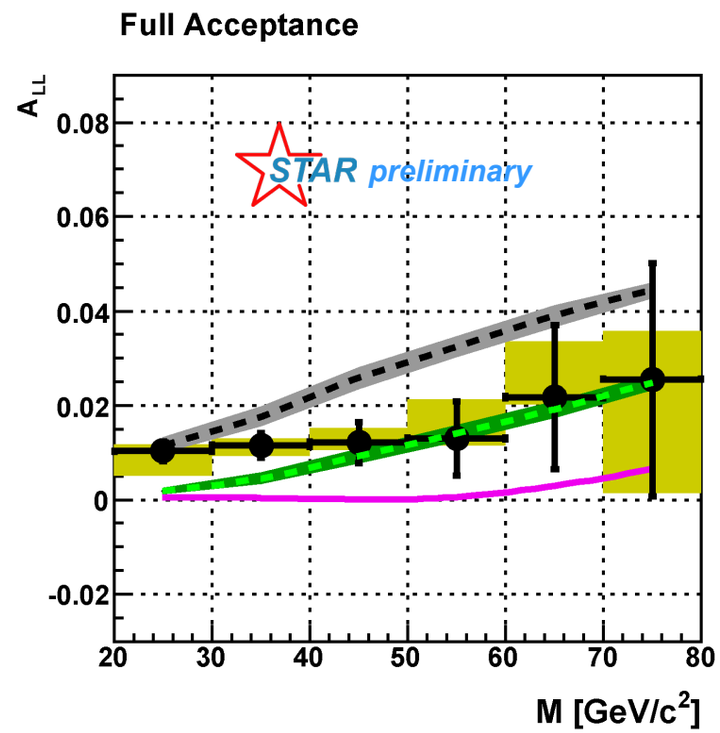
- K/π show no significant energy dependence
- Smooth evolution with energy for p/π and K/p
- No non-monotonic behavior with collision energy observed
- Other searches: Higher moments of net-proton and net-charge

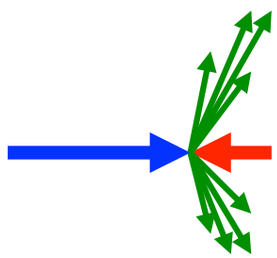


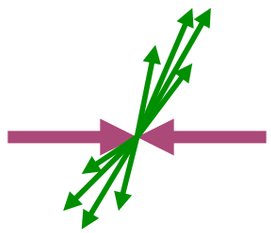
Di-jet A_{LL}





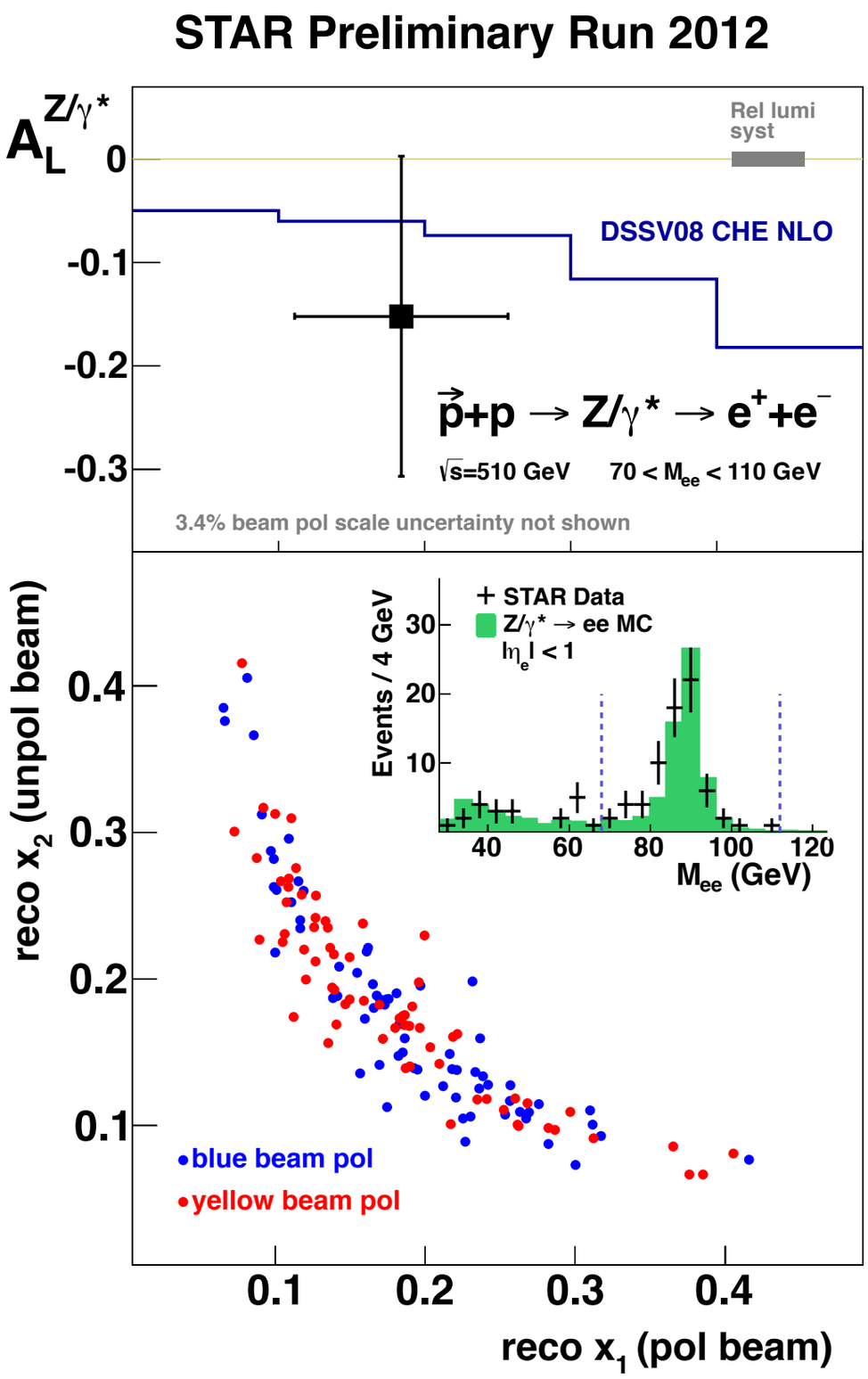


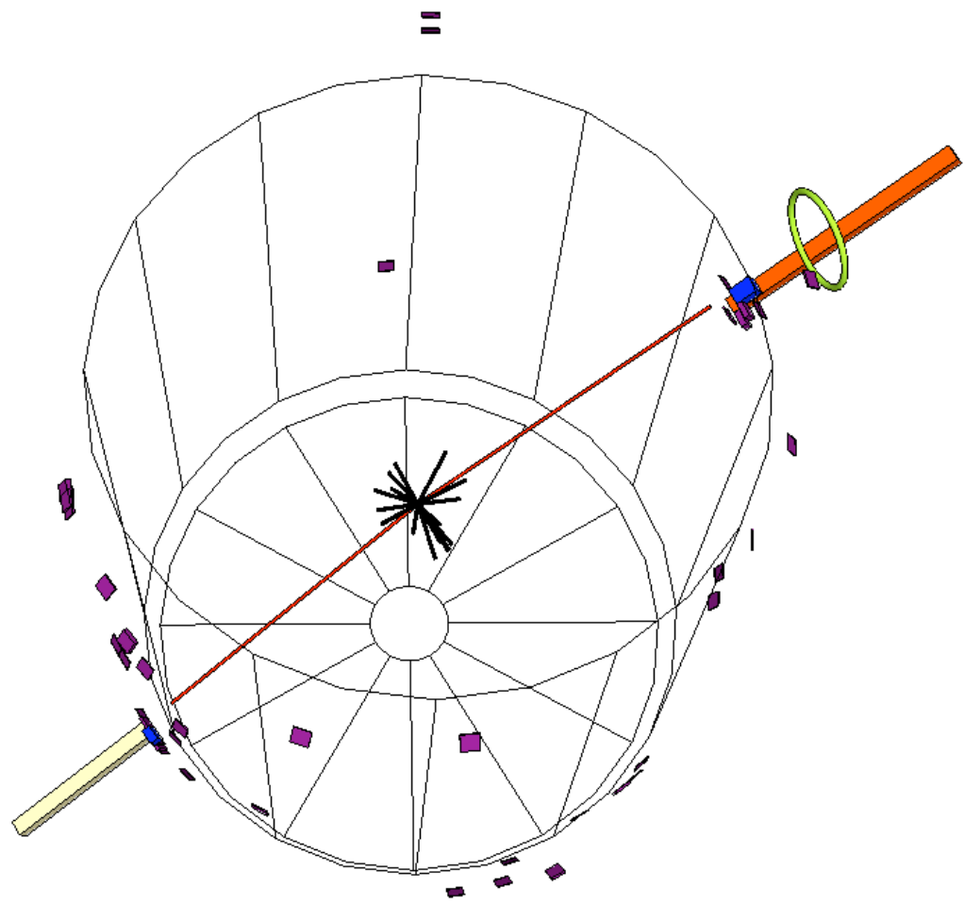




- Access to different partonic kinematics through di-jet topology
- Data lie between predictions from **DSSV** and **GRSV-STD**, consistent with inclusive jet results

2012 Z A_L





Reconstruct initial state kinematics at leading order