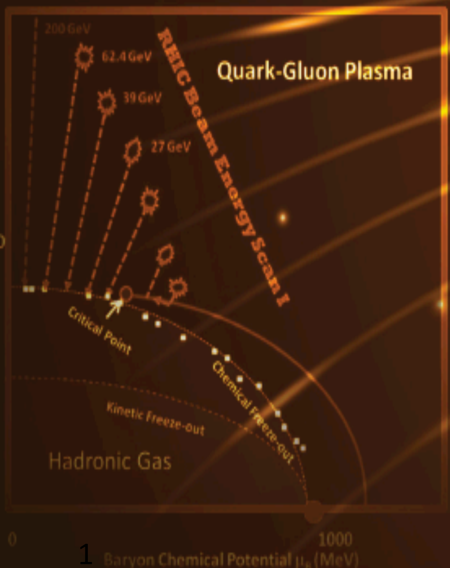
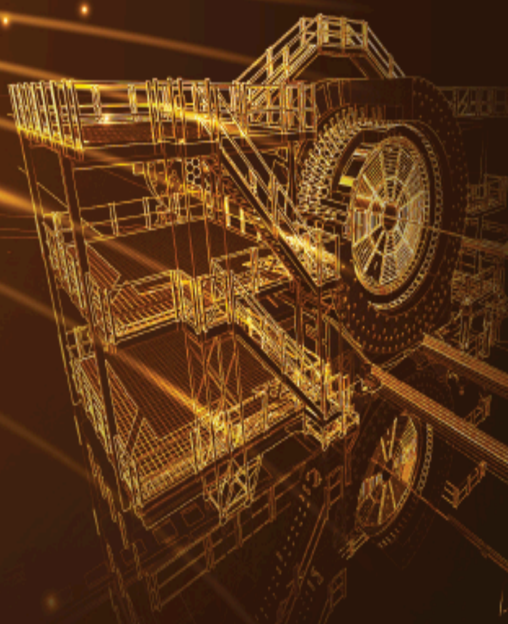
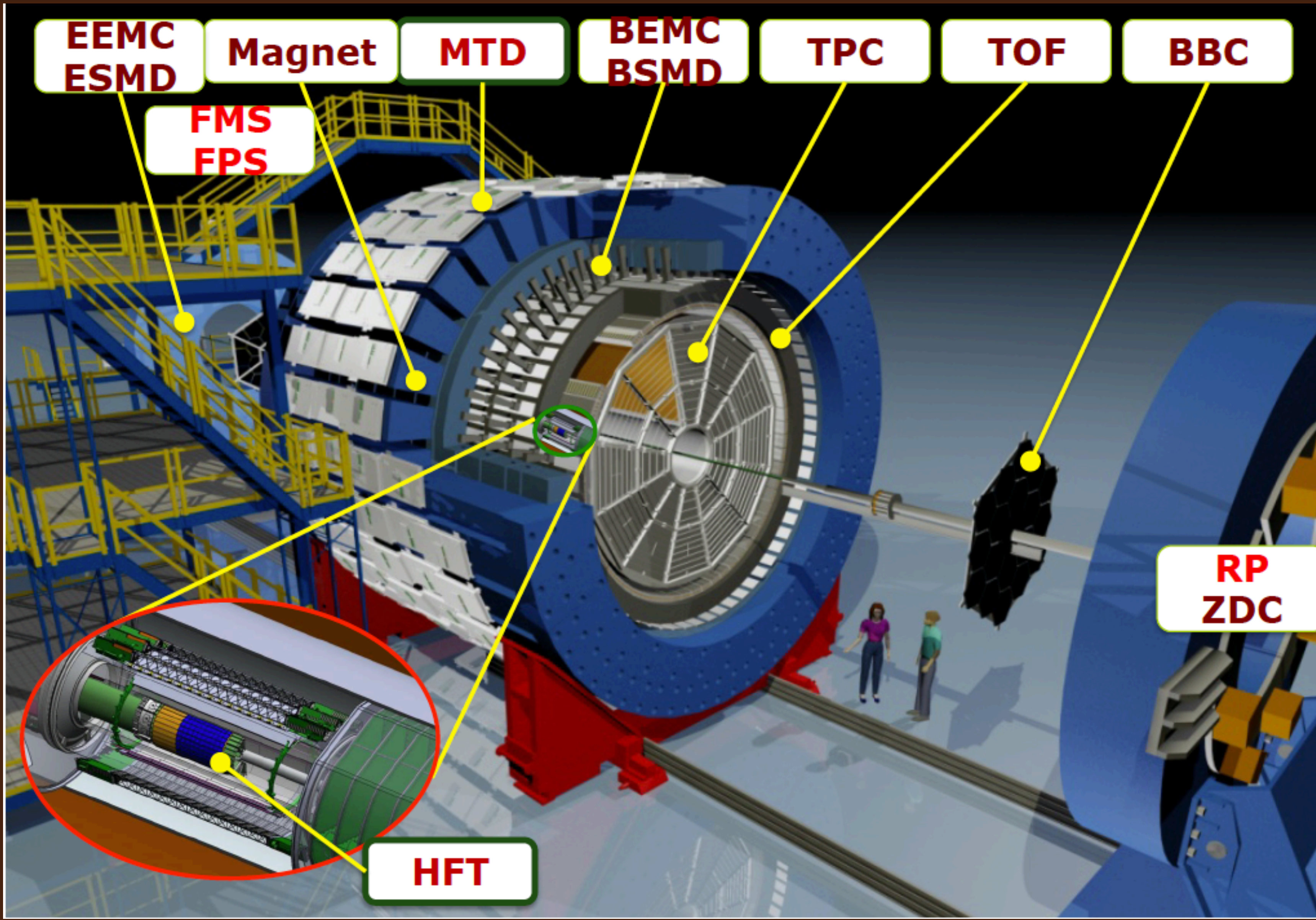
STAR Highlights





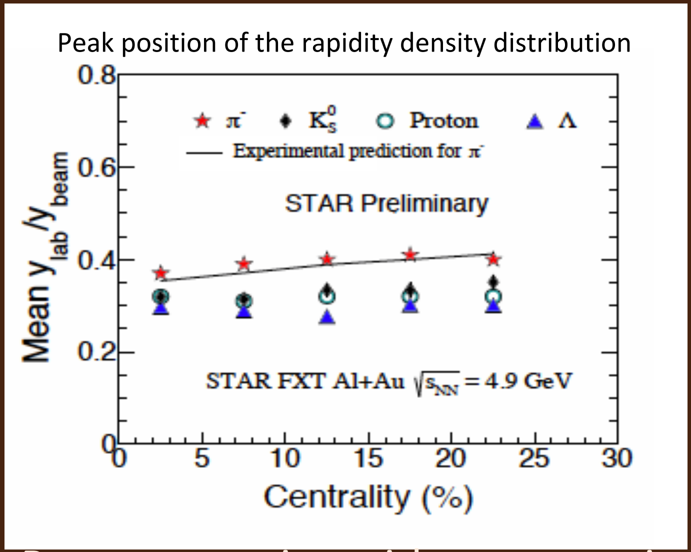
Amilkar Quintero
For the STAR collaboration
Temple University

The Solenoidal Tracker At RHIC



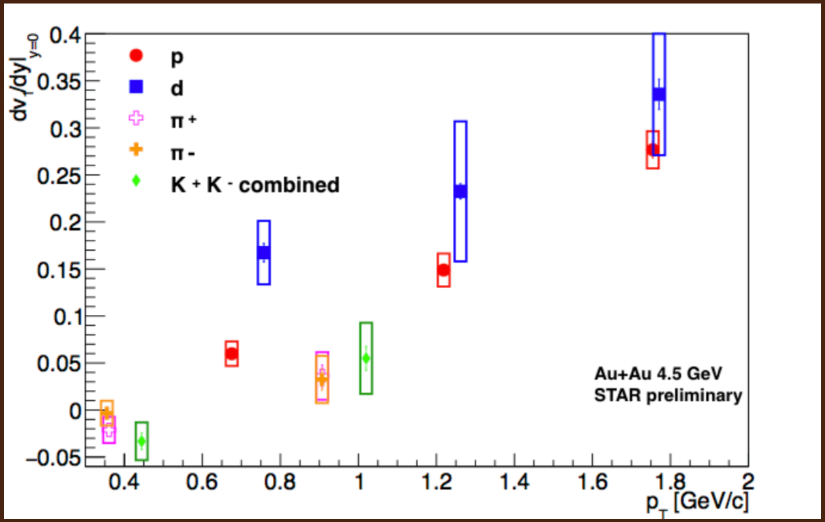
The Fixed-Target Program

Au target

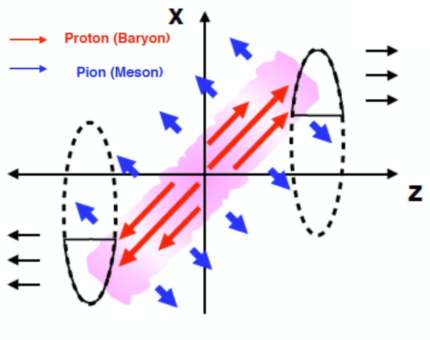


Baryon stopping with asymmetrical collisions → Consistent with the interaction zone rapidity.

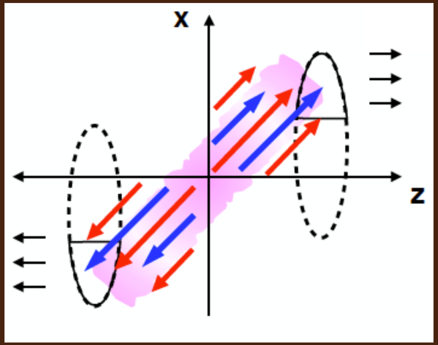
New baryons measurements at 4.5 GeV



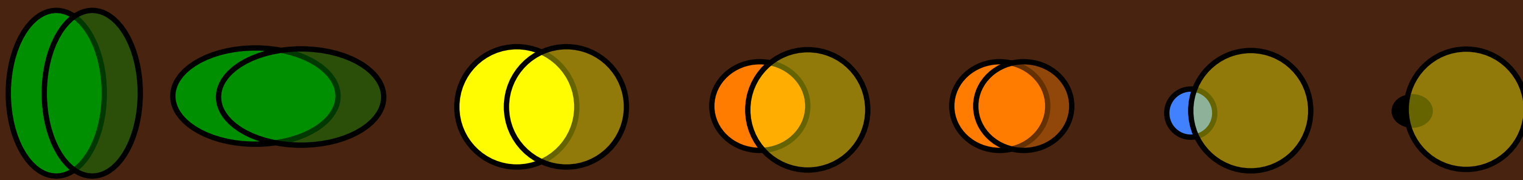
Low p_T
→ Shadowing



High p_T
→ Collective flow



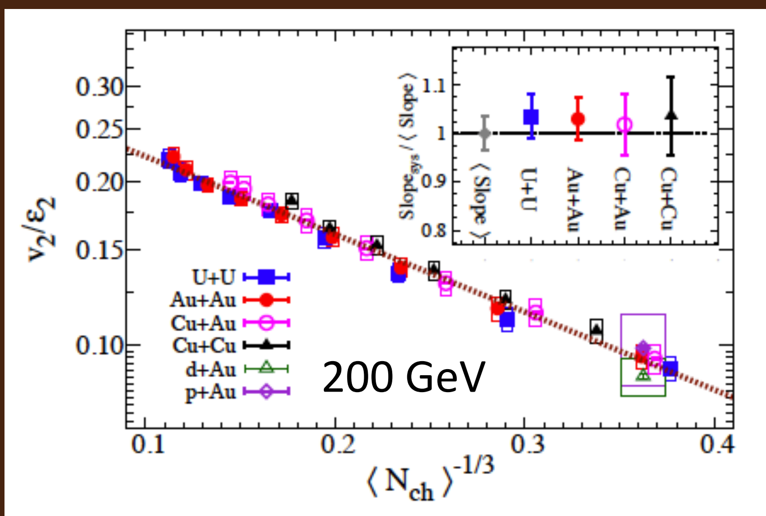
Small and Large Systems



U + U   Au + Au   Cu + Au   Cu + Cu   d + Au   p + Au

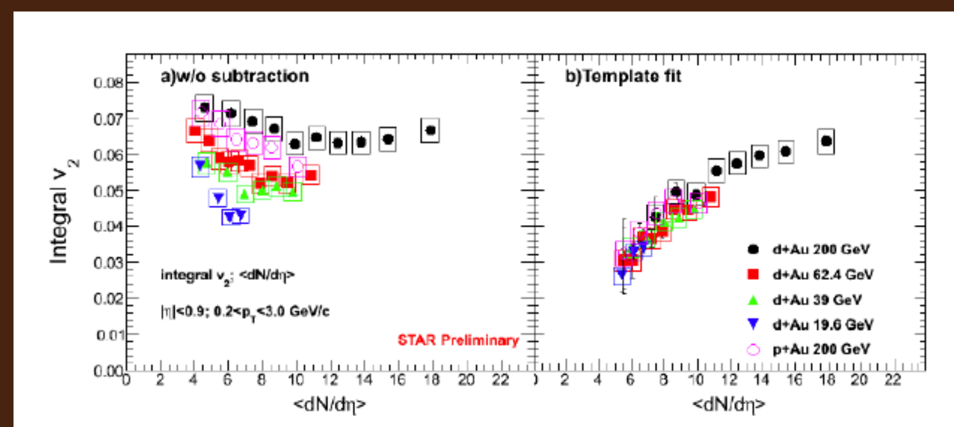
Different colliding species → initial state effects and transport coefficients.

STAR, Phys. Rev. Lett. 122 (2019) 172301

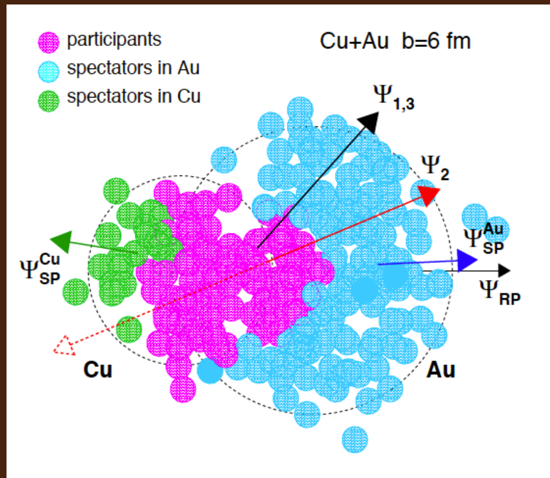


Shengli Huang
4 June @ 09:00

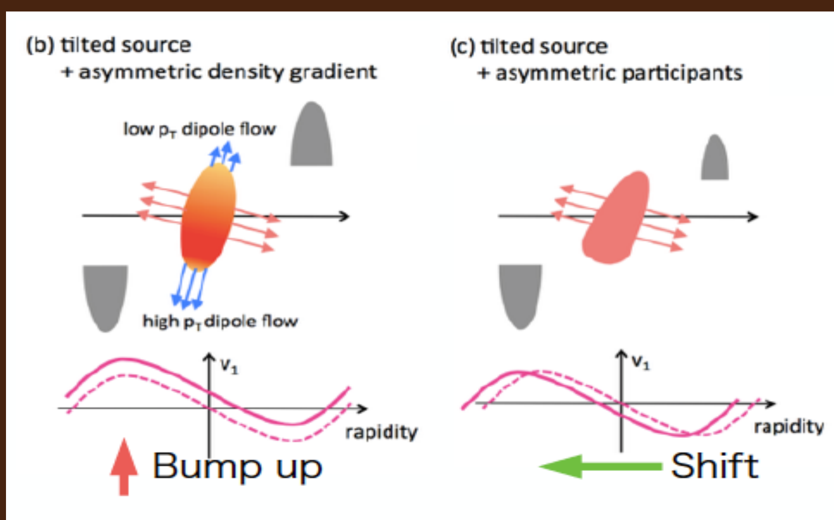
- Elliptic flow is system-dependent.
- Scale by system size after dividing by eccentricity → consistent with viscous attenuation damping (arXiv:1305.3341). Similar η/s for each system.
- Similar behavior for d+Au in BES after non-flow correction.



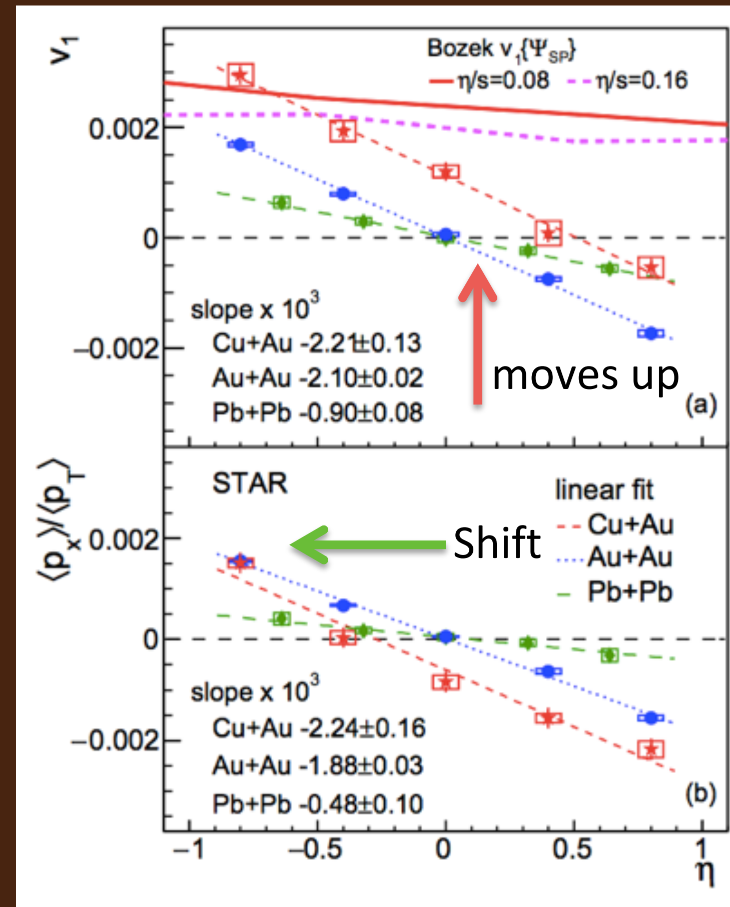
Flow in Cu+Au



1.- Asymmetric density gradient
2.- Different number of participants

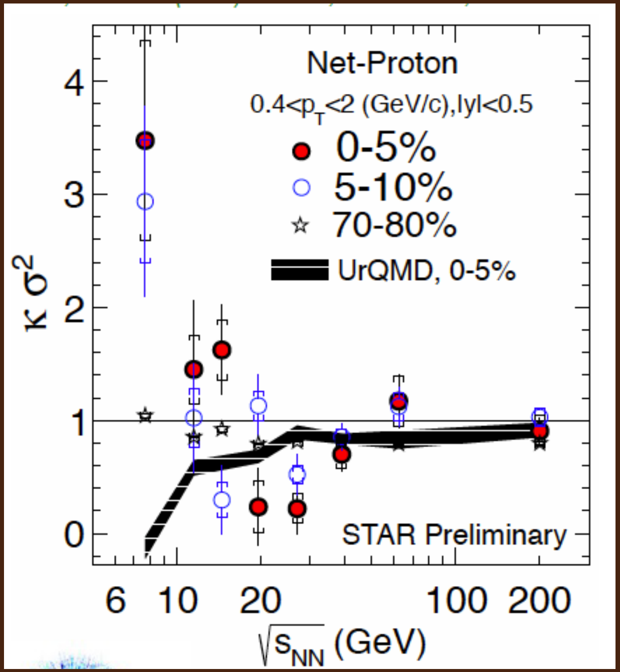


STAR, Phys. Rev. C 98 (2018) 014915

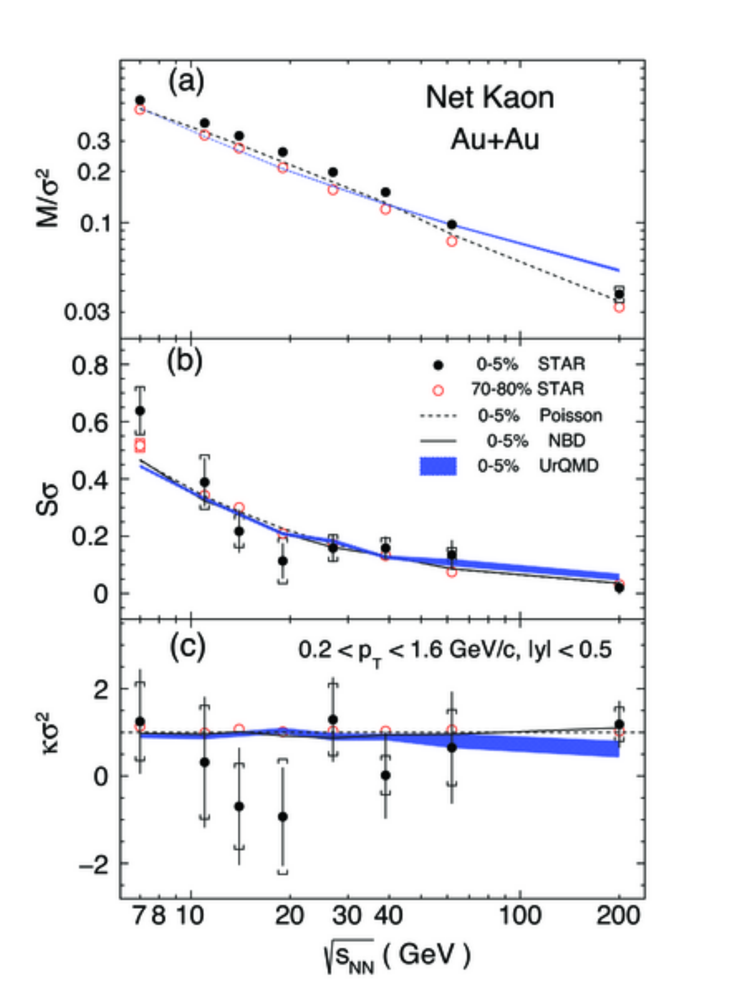


→ 1.- Increase directed flow signal.
→ 2.- Shift the directed flow to the center-of-mass rapidity.

Fluctuations of Conserved Quantities



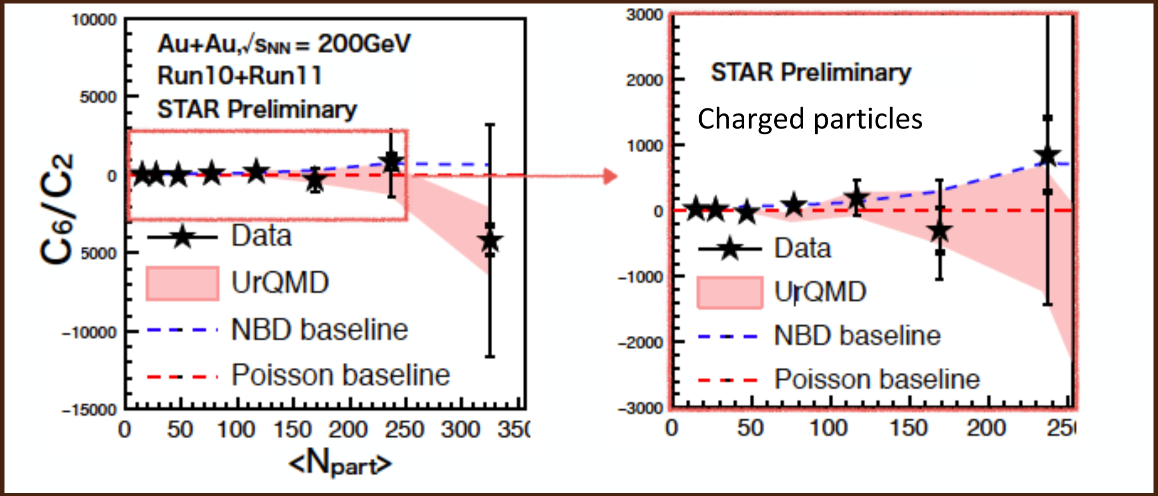
STAR, Phys. Lett. B 785 (2018) 551



- Non-monotonic energy dependence in the most central collisions for **Net-Proton** → A hint of a critical point region?
- UrQMD calculations for Sσ and κσ^2 are consistent with the data for **Net-Kaons**.
- Smaller statistical uncertainties expected in BES-II.

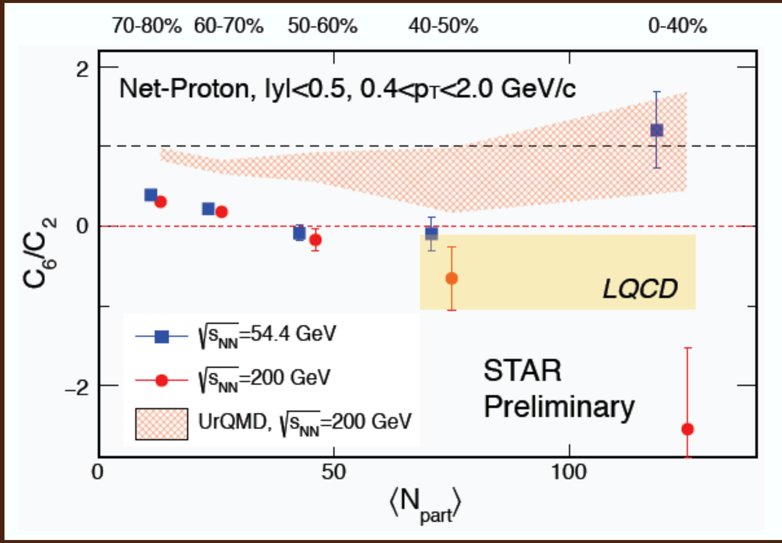
Sixth-order cumulants

- The 6th-order fluctuations are sensitive to the phase transition.
- QCD predictions suggest $C_6/C_2 < 0$ at beam √s > 60 GeV.



- Updated procedure for **charged particles** result → Individual efficiency calculation per particle. Still statistically limited.
- For **net protons**: $C_6/C_2 > 0$, at √s = 54.4 GeV
  $C_6/C_2 < 0$, at √s = 200 GeV

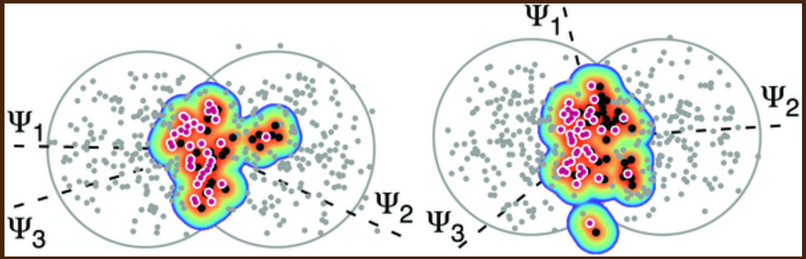
  → Cross over?



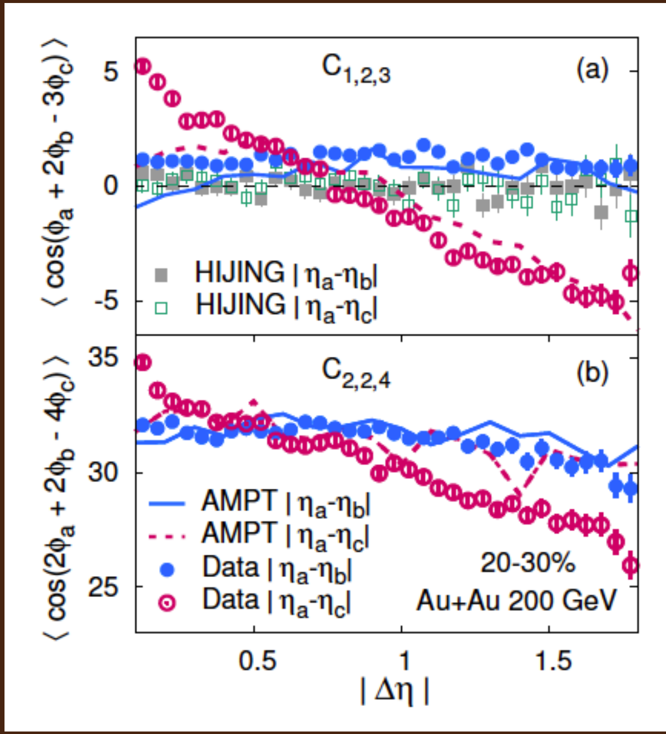
Three-particle correlation in BES

Three-particle correlation provide information of:

- The initial geometry.
- Non-linear hydrodynamic response.
- Constrain temperature dependence of η/s.

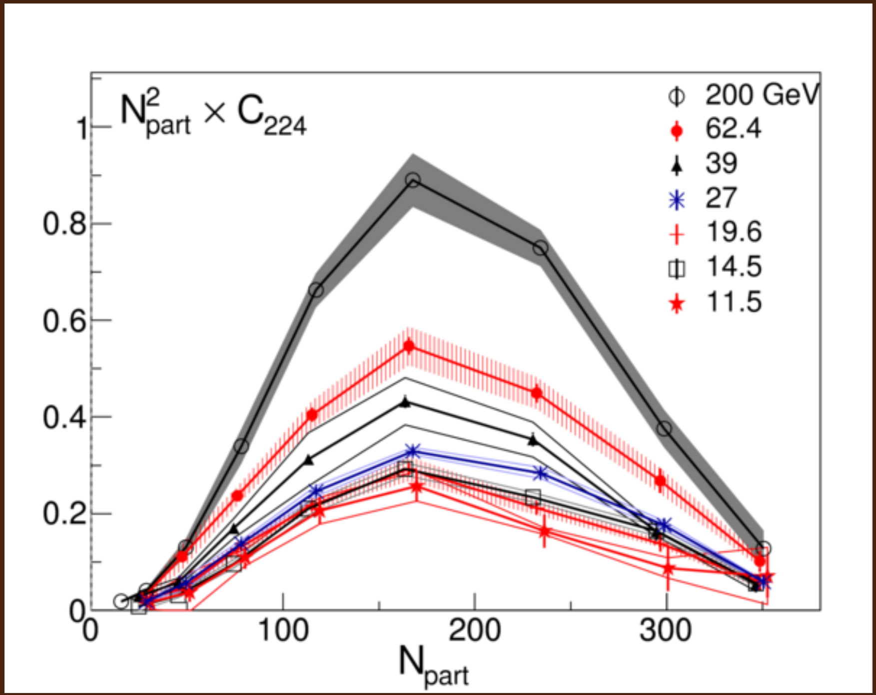


STAR, Phys. Lett. B 790 (2019) 81



$$C_{m,n,m+n} = \langle \cos(m\phi_a + n\phi_b - (m+n)\phi_c) \rangle$$

STAR, Phys. Rev. C 98 (2018) 34918



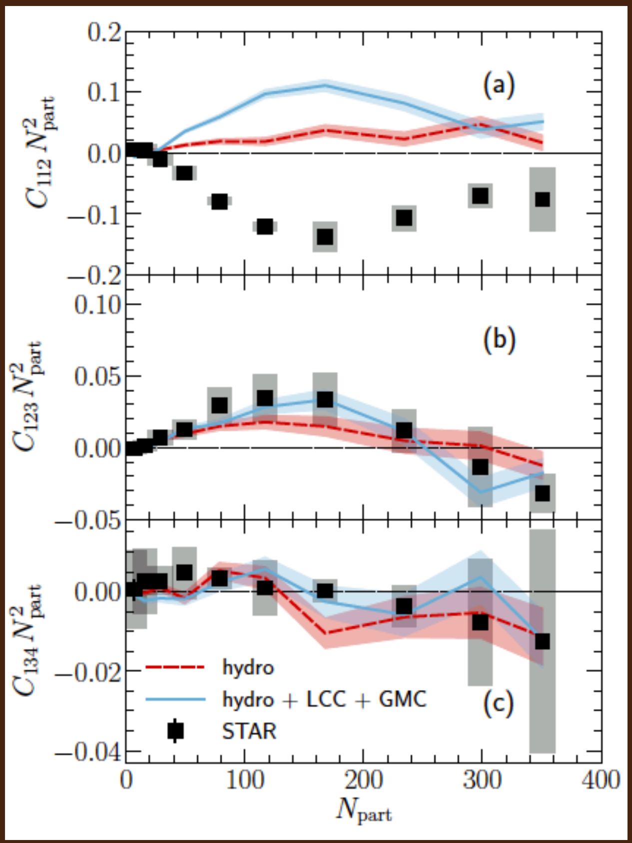
Evidence of coupling between directed, elliptic and triangular flow from initial geometry fluctuations.

Extracting transport properties

Model based on: IP-Glasma initial state, Music (viscous hydrodynamics dynamics simulations) and UrQMD.
B. Schenke, C. Shen and P. Tribedy, arXiv:1901.04378.

Correlations of flow harmonics is sensitive to transport properties.

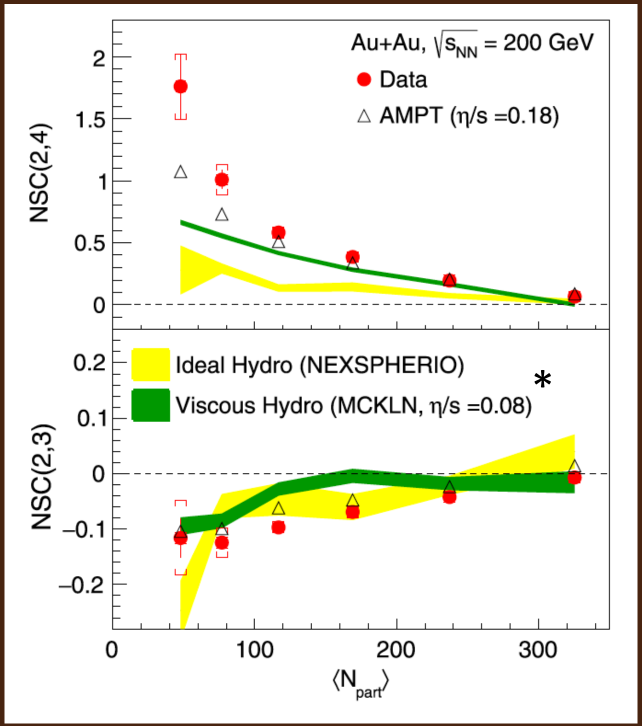
STAR, Phys. Lett. B 783 (2018) 459



Data from: STAR, Phys. Lett. B **790** (2019) 81

Reproduces data

Predictions for the Isobar run in 2018

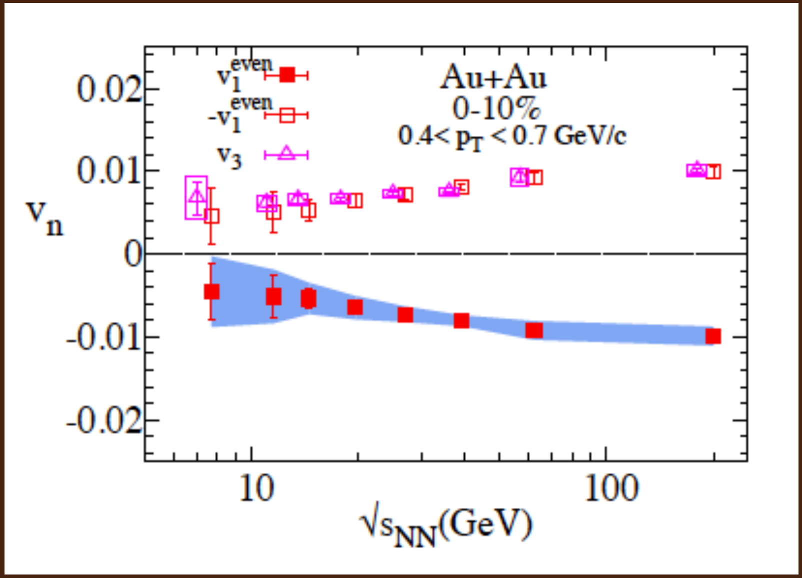


First RHIC measurements of inclusive four particle symmetric cumulants.
*Hydro models from F. G. Gardim et al. Phys. Rev. C 95, 034901 (2017)

Two-particle correlation

Anisotropic flow coefficients

STAR, Phys. Lett. B 784 (2018) 26



- Correlation function:

$$C_r(\Delta\phi, \Delta\eta) = \frac{(dN/d\Delta\phi)_{same}}{(dN/d\Delta\phi)_{mixed}},$$

- New measurement to constrain initial state models and temperature dependence of shear viscosity.

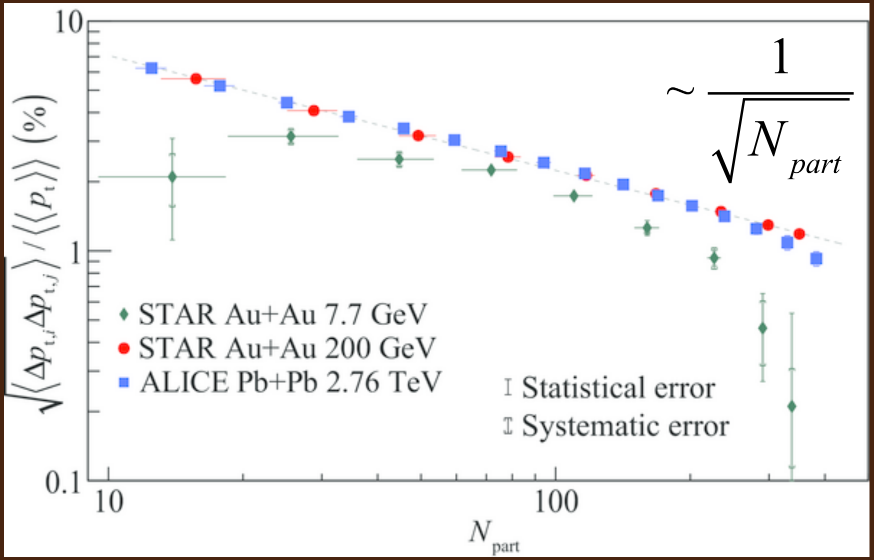
Study thermalization with p_T correlation

$$\langle \Delta p_{t,i} \Delta p_{t,j} \rangle = \frac{1}{N_{event}} \sum_{k=1}^{N_{event}} \frac{C_k}{N_k (N_k - 1)}$$

where

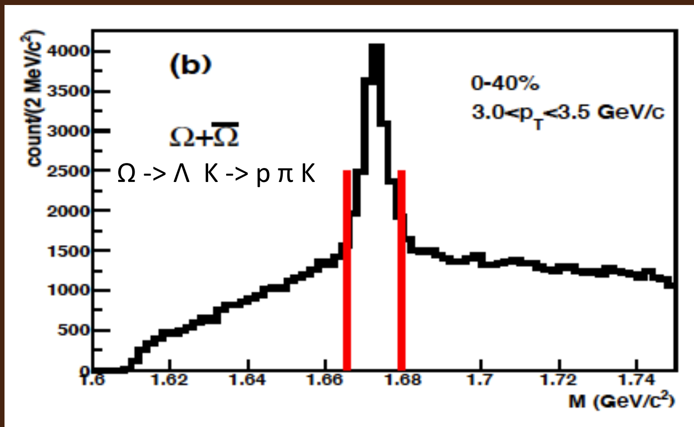
$$C_k = \sum_{i=1}^{N_k} \sum_{j=1, i \neq j}^{N_k} \left(p_{t,i} - \langle\langle p_t \rangle\rangle\right)\left(p_{t,j} - \langle\langle p_t \rangle\rangle\right)$$

STAR, Phys. Rev. C 99 (2019) 44918

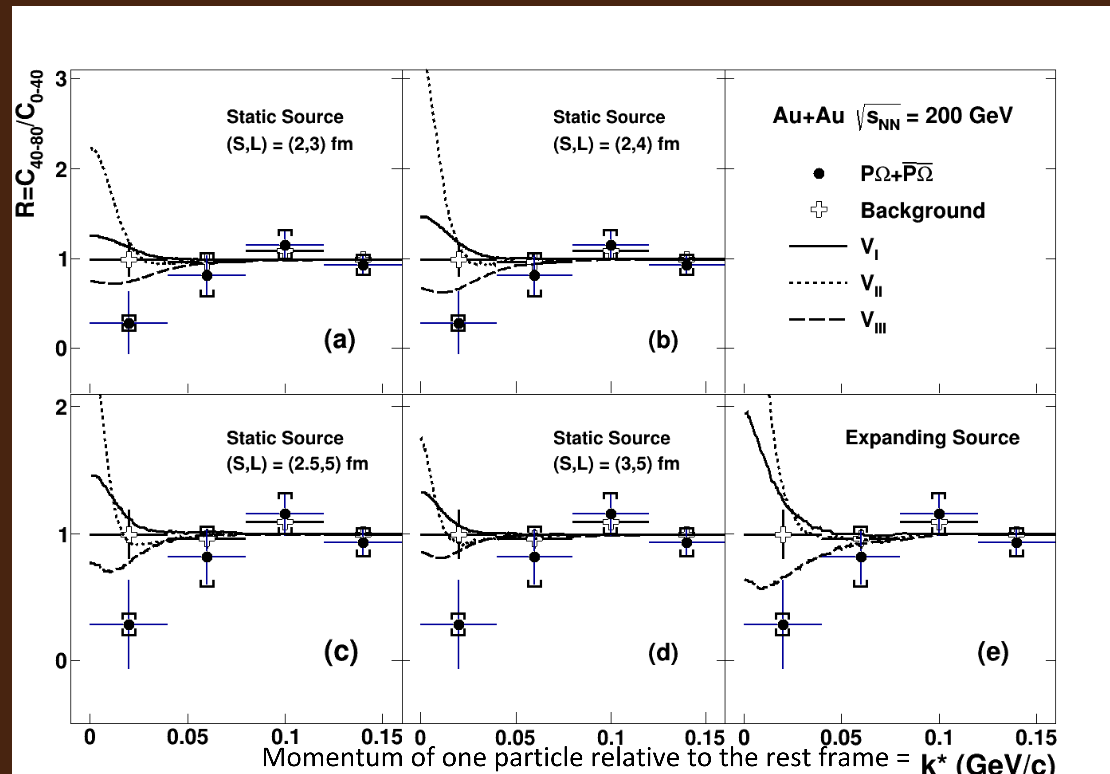


- Power law dependence consistent between 200 GeV Au+Au and 2.76 TeV Pb+Pb but breaks for 7.7 GeV.

Proton Omega correlations in Au+Au



STAR, Phys. Lett. B 790 p490-497 (2019)



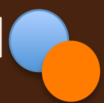
Prediction from lattice QCD for proton- Ω interaction potentials, Phys. Rev. C 94, 031901 (2016) .

Spin-2 pΩ potentials	V_I	V_{II}	V_{III}
E_b (MeV)	-	6.3	26.9
a_0 (fm)	-1.12	5.79	1.29
r_{eff} (fm)	1.16	0.96	0.65

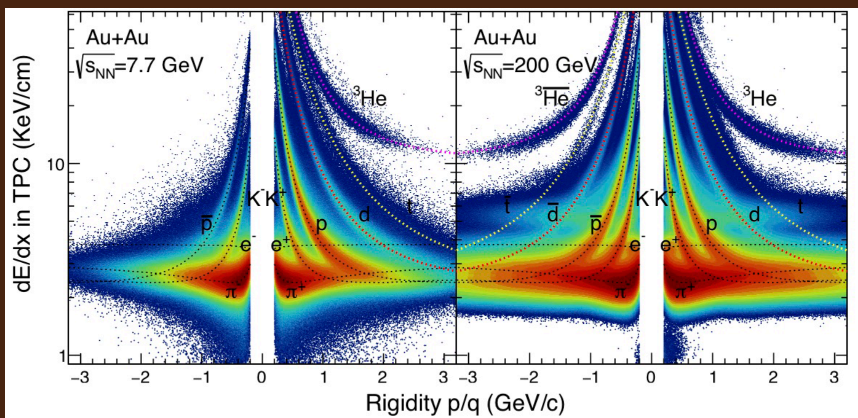
- **First measurement of the proton-Omega correlation function in Au+Au collisions.**
- The results slightly favors a binding energy ~ 27 MeV (limited statistics).

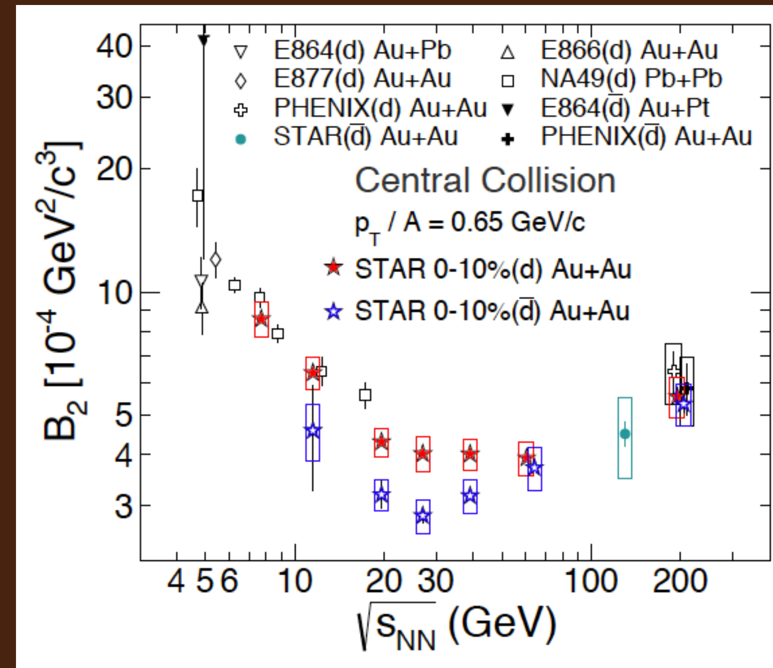
Energy Dependence of Deuteron Production

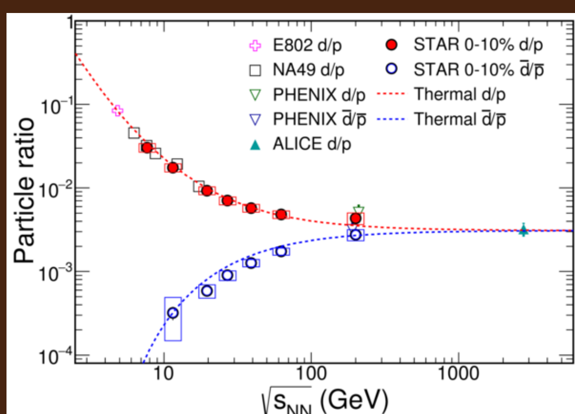
STAR, arvix:1903.11778, accepted by PRC

^2H 

Light nuclei may serve as probes of space-momentum density and correlation of nucleons at freeze-out.







- Particle ratios:

→ Well described by thermal model.

→ consistent with the world data.

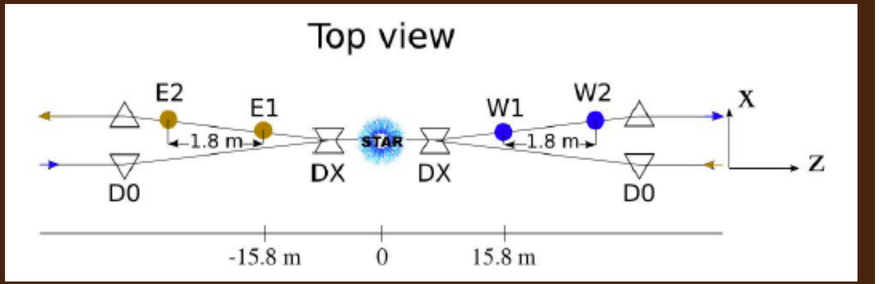
- Coalescence parameter B_2:

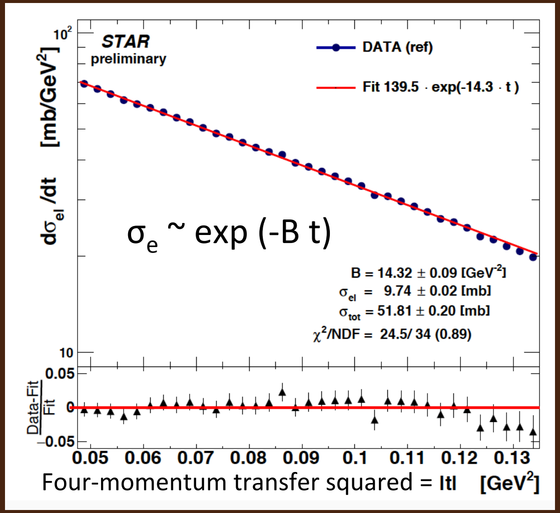
→ Minimum at 20 GeV - change in EOS?

→ Differences between central and peripheral collisions.

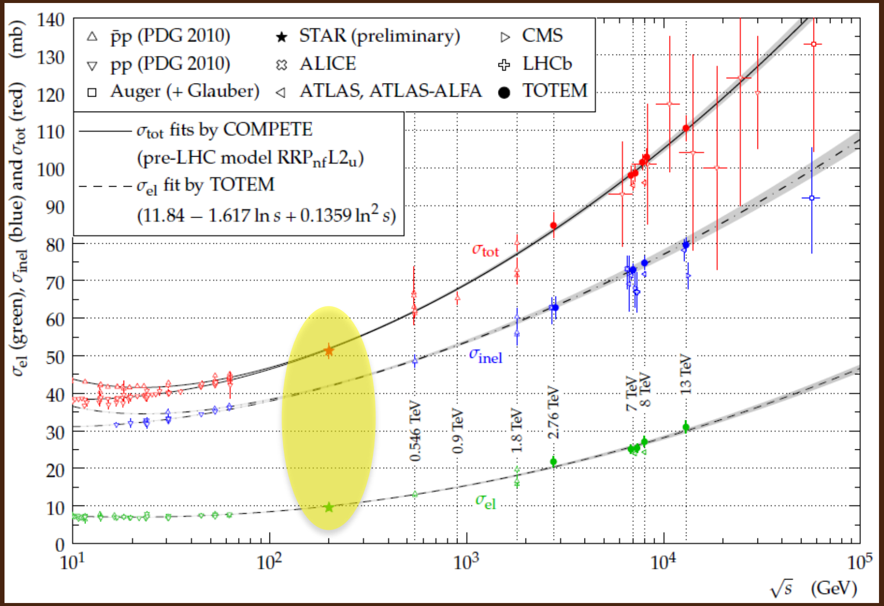
Elastic cross section in proton collisions

Roman Pot Vessel





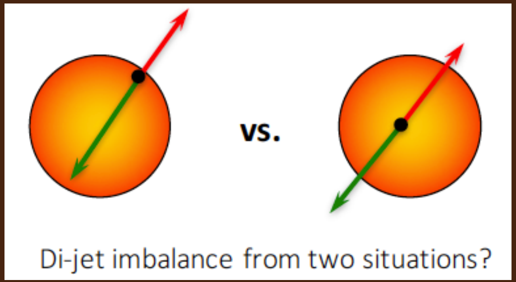
First high-statistics measurement of elastic cross section with the Roman Pot at RHIC.



Also preliminary results with RP of:

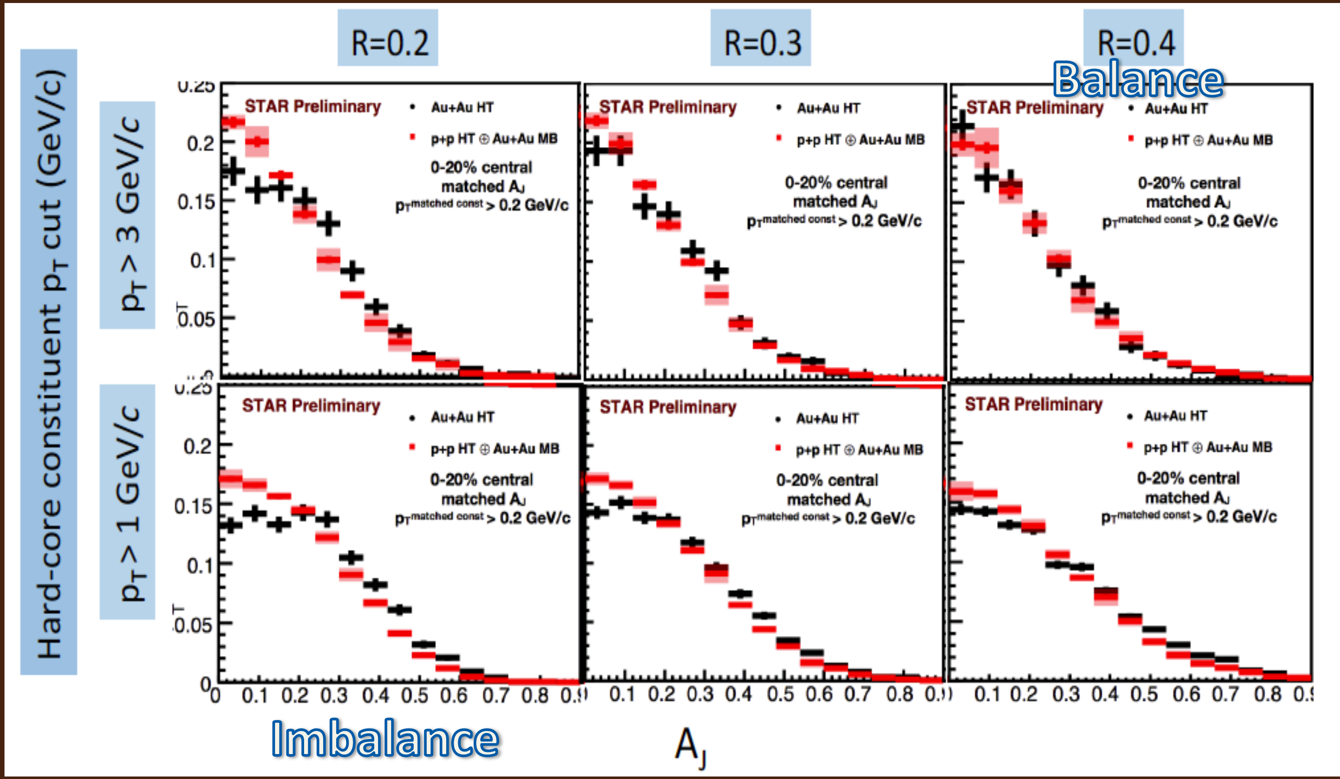
- Particle spectra in diffractive p+p collisions.
- Central exclusive production.

Di-jet imbalance



Varying the jet definition to control the path length of jets in the medium.

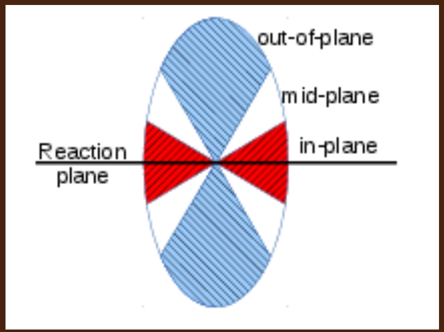
$$A_J = \frac{p_T^{\text{Lead}} - p_T^{\text{SubLead}}}{p_T^{\text{Lead}} + p_T^{\text{SubLead}}}$$

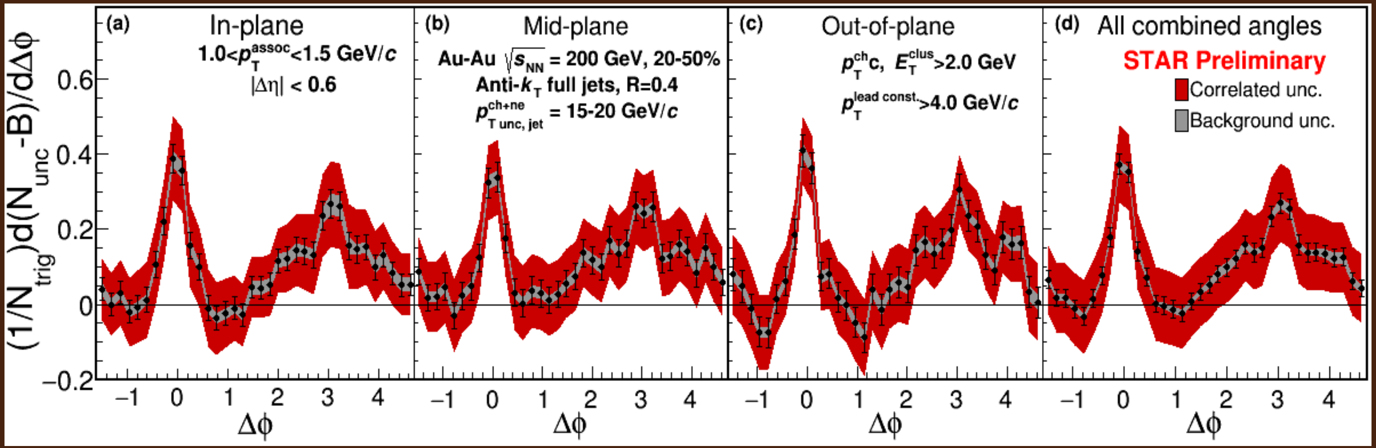


- Imbalance at small resolution parameters.
- Balance restored with increased R (≈ 0.35) when soft particles are included.
- Capability to control the extent of the energy loss using jet kinematic cuts → Jet Geometry Engineering.
- Also new preliminary results of fully unfolded jet substructure in p+p.

Seahanseul Oh
4 June @ 16:30

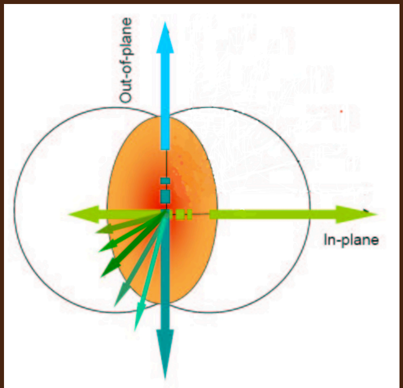
Correlations dependence on the Event Plane

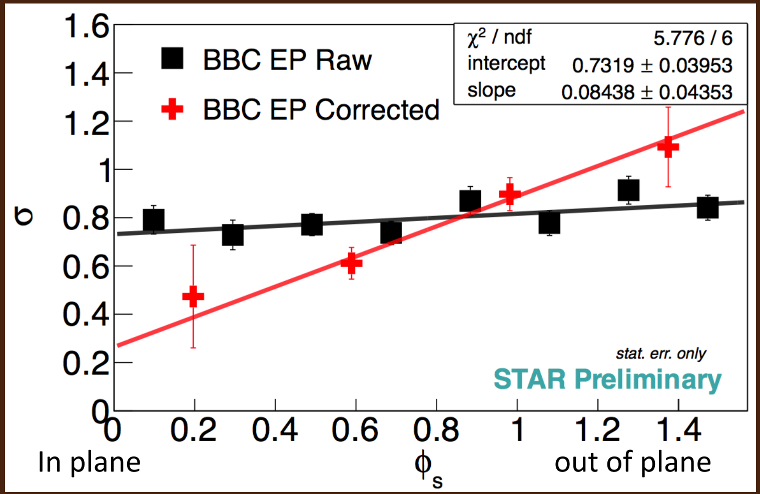




Jet-Hadron correlation:
- Differential measurements using the trigger jet angle with respect to the event plane.
- No significant event plane dependence is observed within uncertainties.

- Di-hadron correlations indicate different away-side widths after correcting for the EP resolution.
→ Indication of jet-medium interaction + path-length dependence.

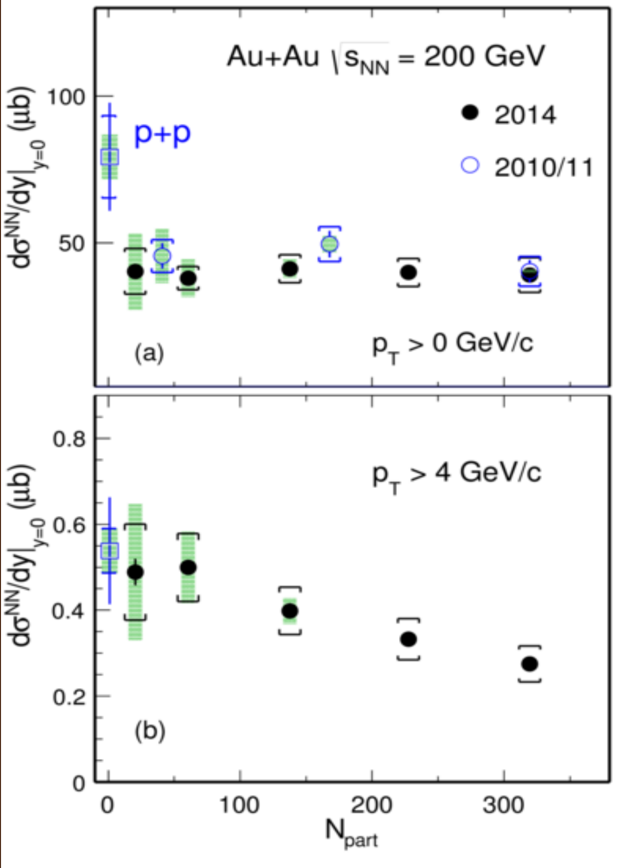


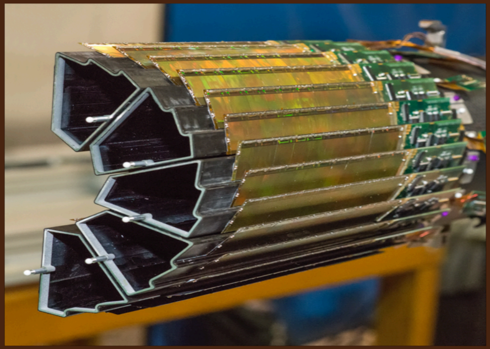


Seahanseul Oh
4 June @ 10:50

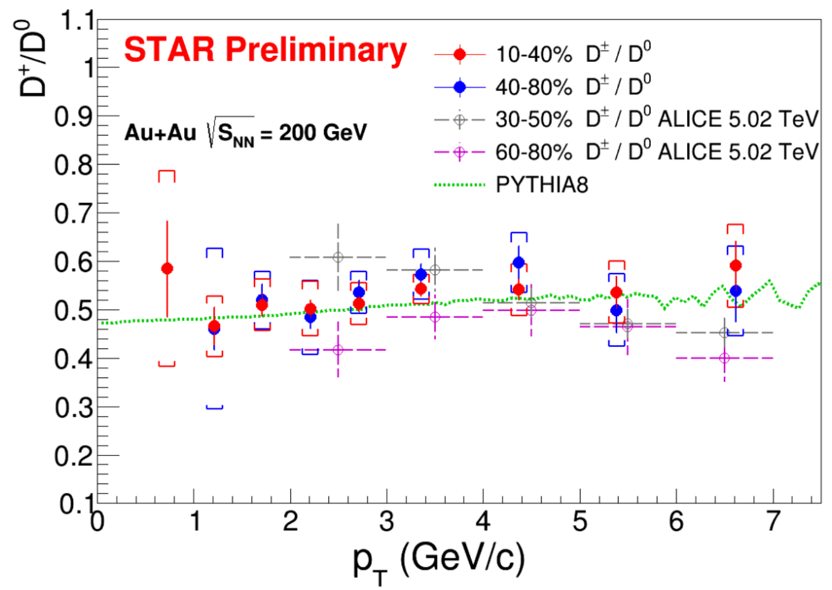
D^0 Nuclear modification factors

STAR, Phys. Rev. C 99 (2019) 034908





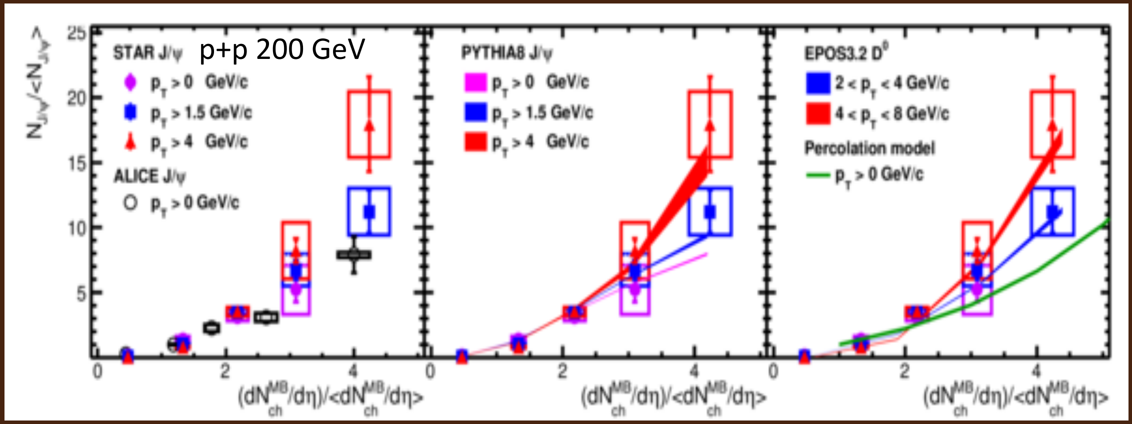
Sooraj Radakrishnan
4 June @ 9:00



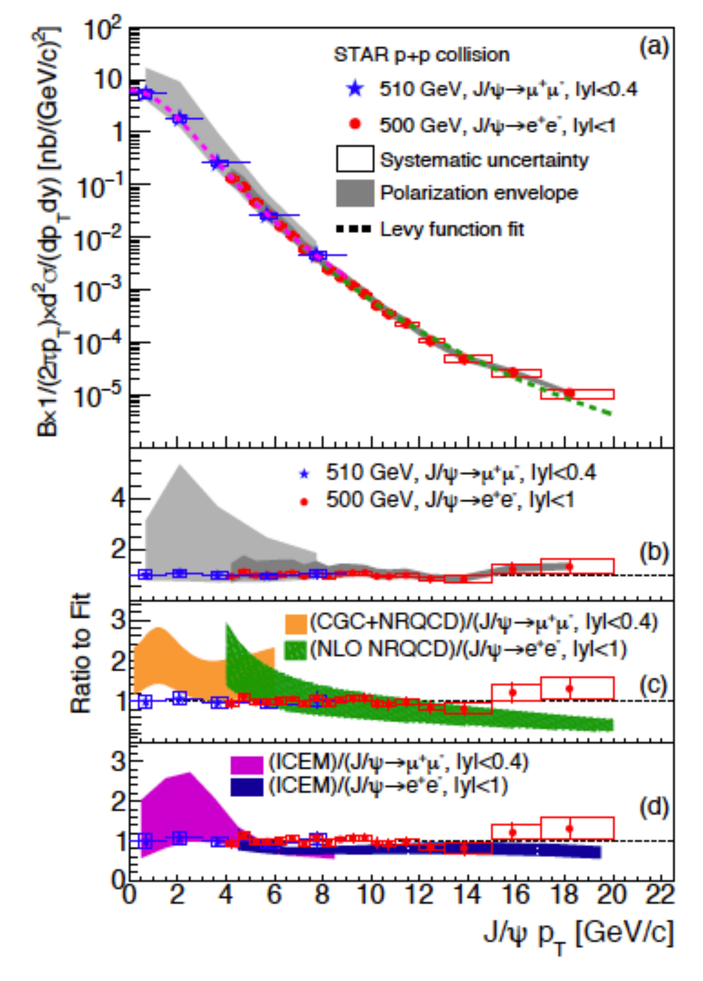
- Cross section in Au+Au smaller than in p+p. Decreasing trend vs. N_{part} for p_T > 4 GeV/c.
- No modification to $D^{+/-}/D^0$ ratio compared to PYTHIA, indicates similar R_{AA}.
- Improved presicion for several open charm measurements with multi-variative techniches.

Quarkonium in p+p

STAR, Phys. Lett. B 786 (2018) 87



STAR, arvix:1905.06075, submitted to PRD



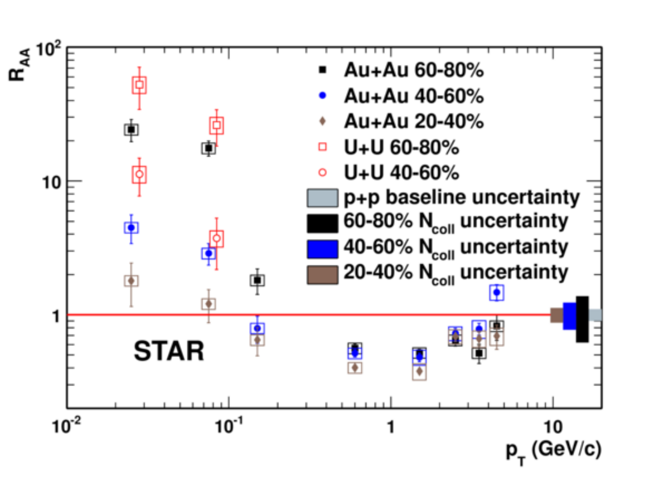
- Precision measurement of J/ψ production cross-sections at 200 GeV and 500/510 GeV .
- PYTHIA, EPOS3 and Percolation model can qualitatively describe the rising trend of J/ψ yield vs charged-particle multiplicity.
- Measured cross-section at 500/510 GeV with two lepton channels can be described by model calculations.

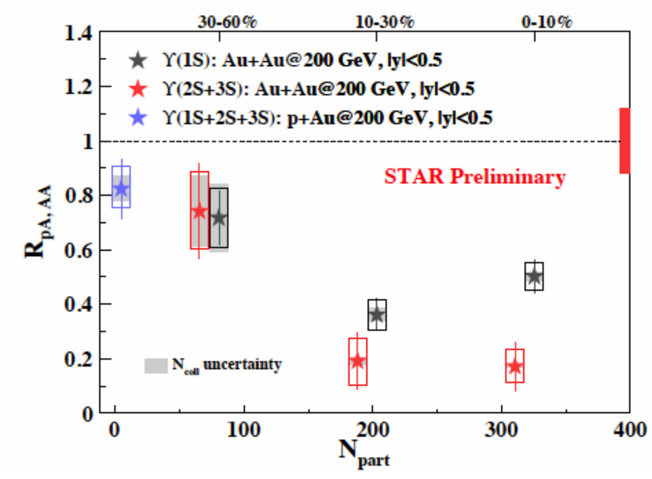
Pengfei Wang
4 June @ 9:00

Te-Chuan Huang
poster

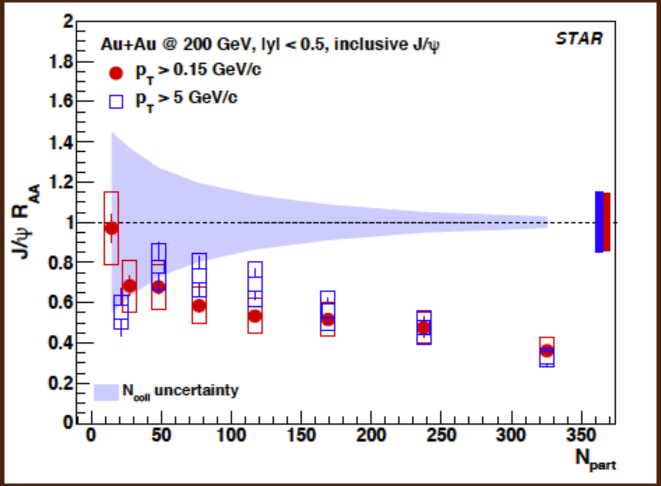
Suppression in quarkonium

STAR, arvix:1904.11658, submitted to PRL





STAR, arvix:1905.13669, submitted to PLB



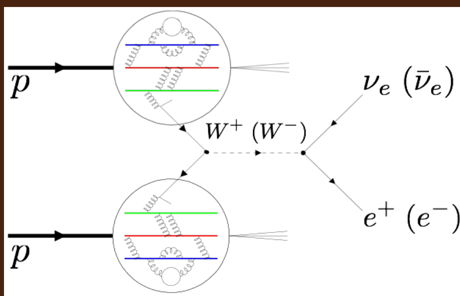
- Significant excess of J/ψ yield at low p_T for peripheral collisions → originated from coherent photon-nucleus interactions.
- Increasing J/ψ suppression towards central collisions → (dissociation, regeneration, CNM, formation time).
- ϒ(1S) less suppress than ϒ(2S+3S) → sequential suppression.
- ϒ(1S+2S+3S) from p+Au → indicates CNM effects.

Pengfei Wang
4 June @ 9:00

Constraining Sea Quark

Matt Posik
Poster

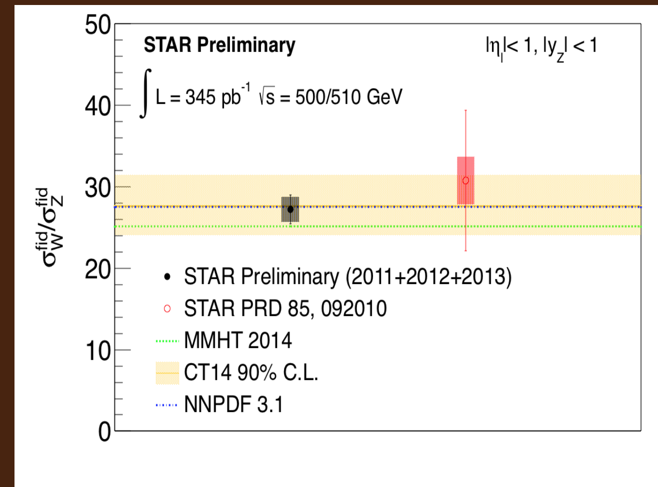
W/Z cross section measurements.

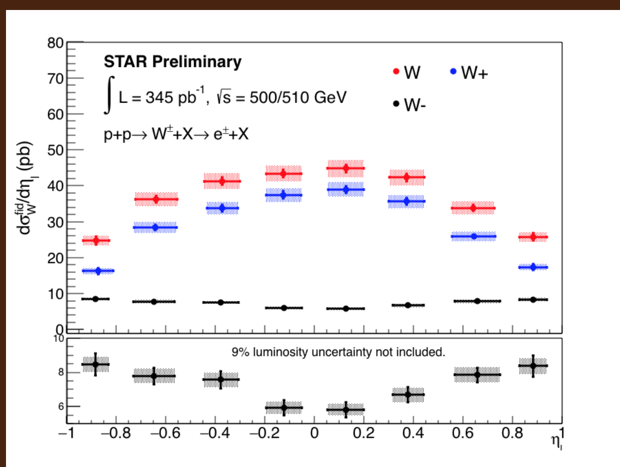


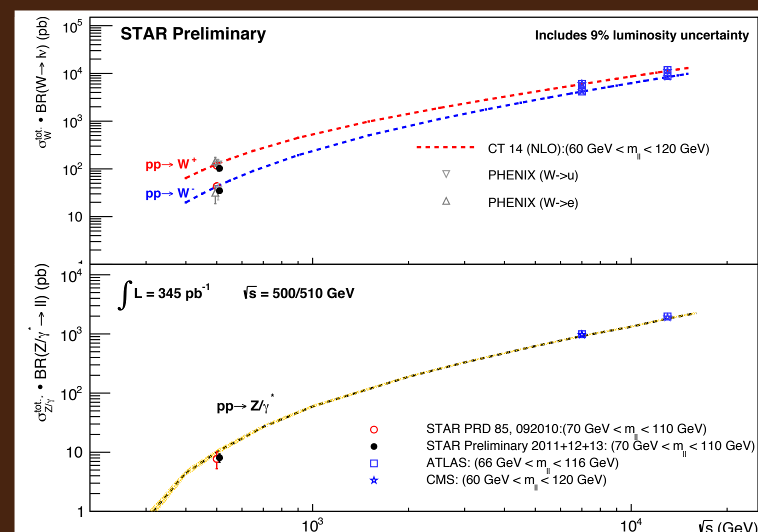
$$q + \bar{q} \to Z/\gamma^* \to e^+ + e^-$$

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

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

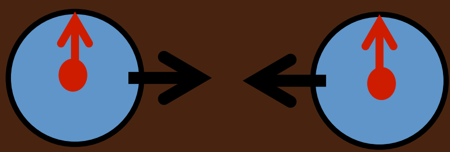


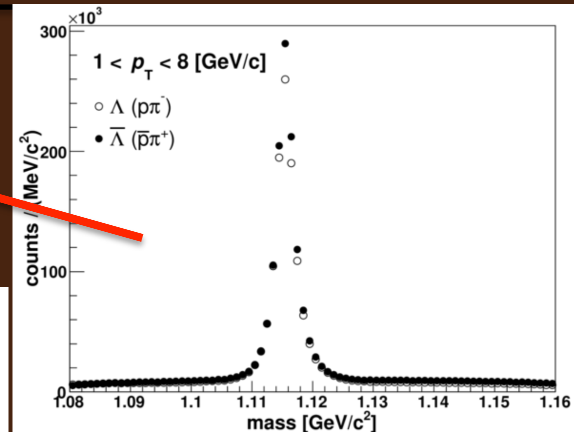




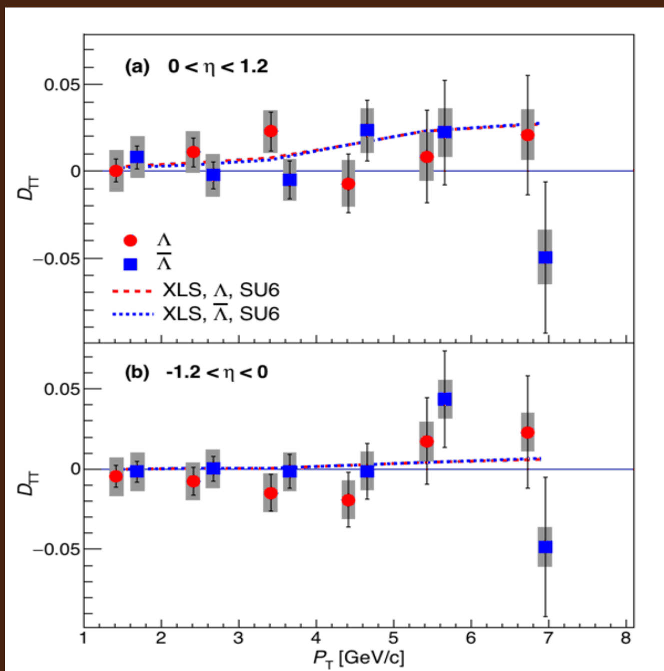
Ongoing analysis from run 2017 data will double the statistics.

Spin Transfer to Lambda Hyperons





STAR, Phys. Rev. D 98 (2018) 112019

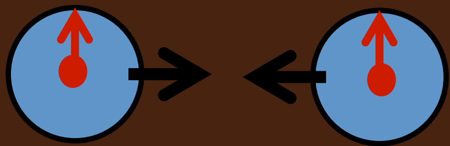


Rene Fatemi
4 June @ 14:00

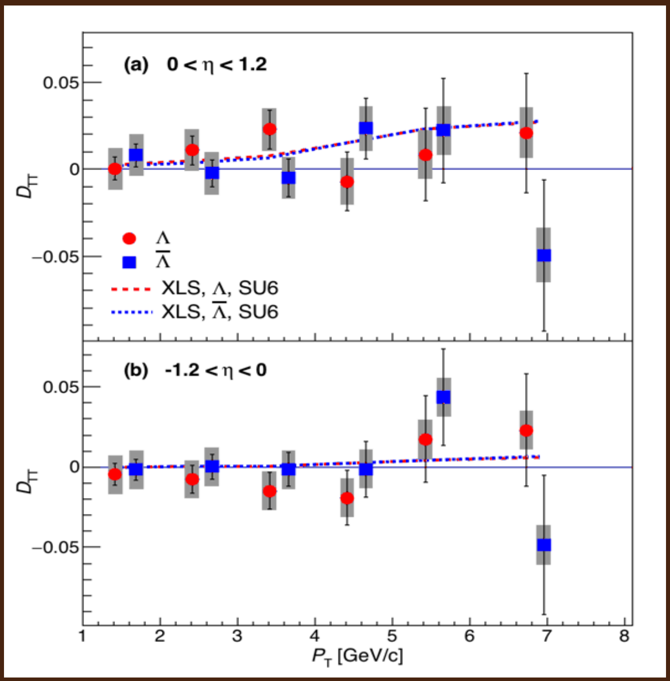
- First measurement of transverse spin transfer in proton collisions at RHIC.

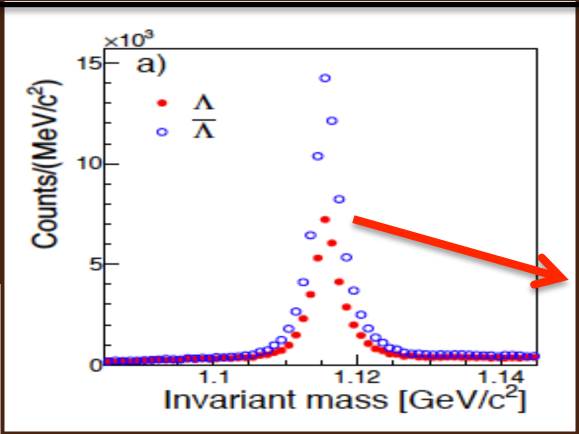
- The results are consistent with the model prediction and also with zero.

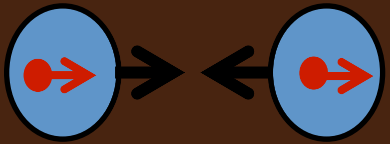
Spin Transfer to Lambda Hyperons



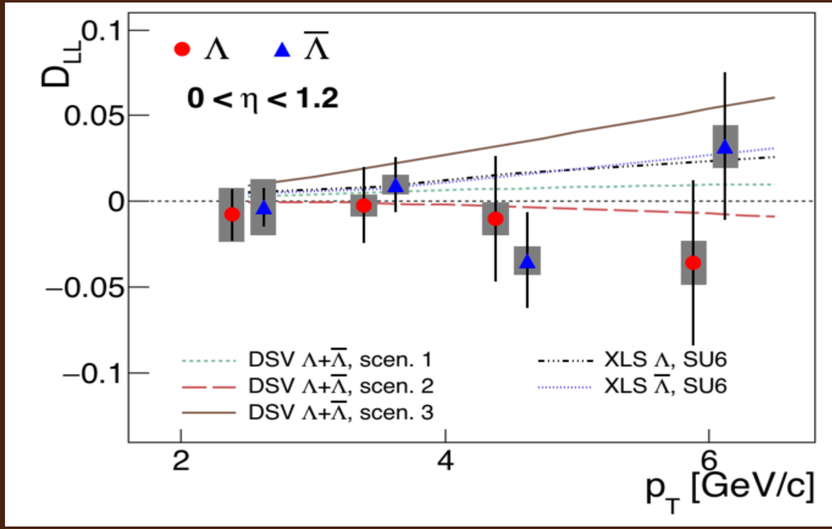
STAR, Phys. Rev. D 98 (2018) 112019







STAR, Phys. Rev. D 98 (2018) 091103



- First measurement of transverse spin transfer in proton collisions at RHIC.

- The results are consistent with the model prediction and also with zero.

- No conclusive evidence for a spin transfer signal D_{LL}.
- Not possible to rule out theory models.
- Ongoing analyses with run 2015 data.

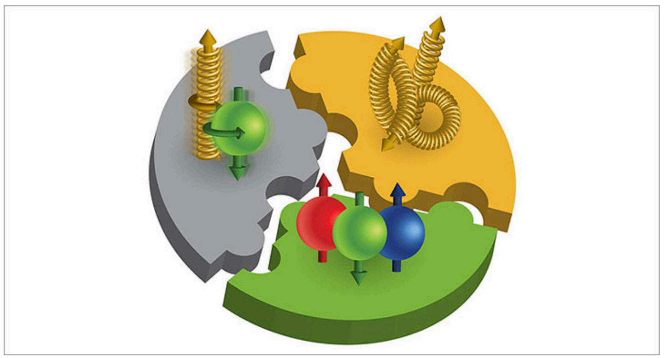
Constraining polarized PDF

$$< S_p >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Sea Quark Surprise Reveals Deeper Complexity in Proton Spin Puzzle

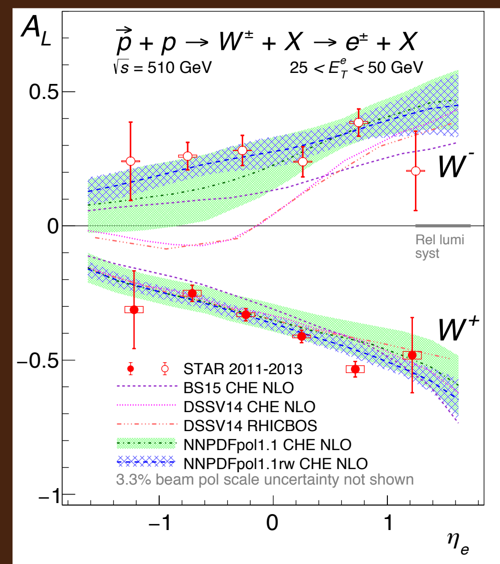
New results from STAR experiment show antiquarks' contribution to proton spin depends on "flavor"—and in a way that's opposite to those flavors' relative abundance

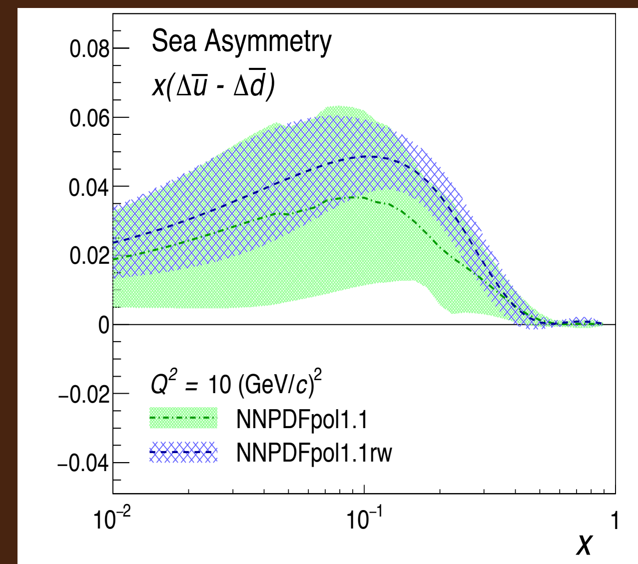
March 14, 2019



The proton spin puzzle: Scientists want to know how different constituents of the proton contribute to its spin, a fundamental property that plays a role in how these building blocks give rise to nearly all visible matter in the universe. Pieces of the puzzle include the orbital angular momentum of quarks and gluons (top left), gluon spin (top right) and quark and antiquark spin (bottom). The latest data from RHIC reveal that the antiquarks' contribution is more complex than previously thought. + ENLARGE

STAR, Phys. Rev. D 99 (2019) 051102



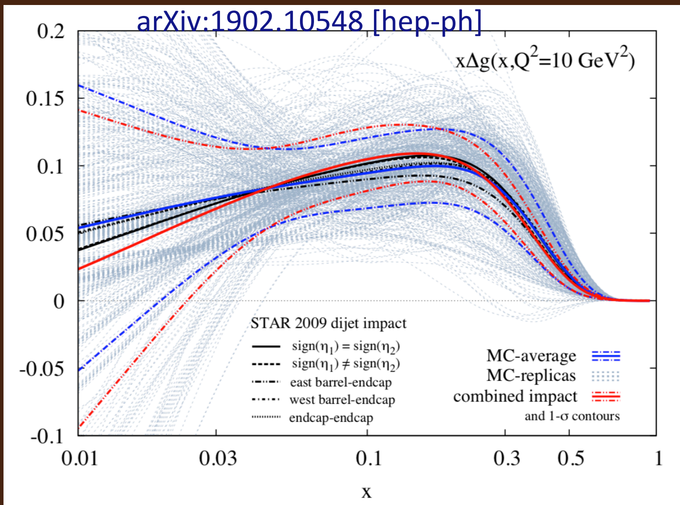


Jinlong Zhang
4 June @ 9:00

- Most precise W A_L results from 2013 dataset.
- Consistent with 2011+2012 published results, with 40% uncertainty reduced.
- First clear evidence of the flavor asymmetry in the polarized quark sea.

Constraining polarized PDF

$$< S_p > = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$



√s	Run	Central Jets (|η|<1)	Central Di-jets (|η|<1)	Forward Di-jets (0.8 < η < 1.8)
200	2009	Published x > 0.05	Published x > 0.05	Published x > 0.01
200	2015	In Progress x > 0.05	In Progress x > 0.05	
510	2012	Submitted x > 0.02	Submitted x > 0.02	In Progress x > 0.004
510	2013	Preliminary x > 0.02	Preliminary x > 0.02	In Progress x > 0.004

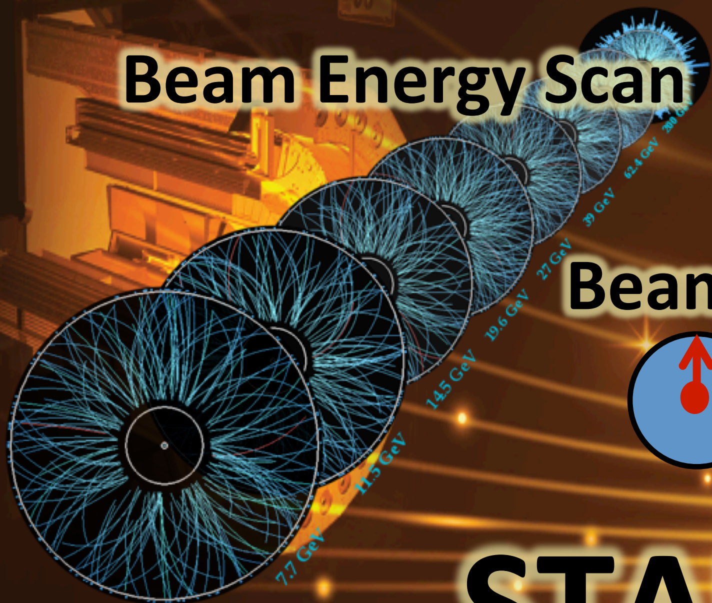
- All 2009 results were recently included in a global fit, reducing the uncertainty in the probe region.
- Data on tape will increase current precision (~2).
- Time to move "forward".

AQ
4 June @ 10:30

Neutral pions measurement at √s = 510 GeV for the data 2012 and 2013 (published) allowed reaching the lowest x ($\sim 10^{-3}$) values at STAR.

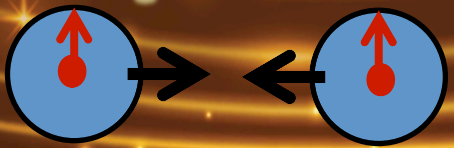
STAR Highlights

Beam Energy Scan

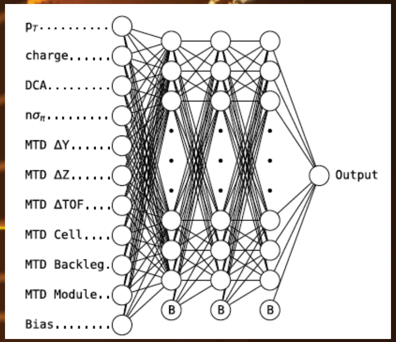


Different species

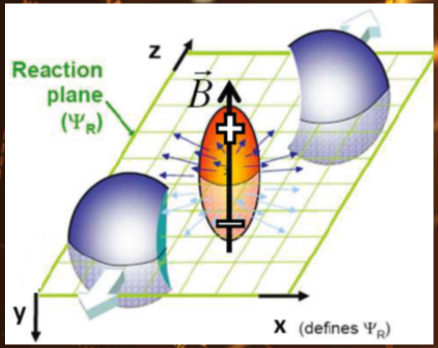
Beam polarization



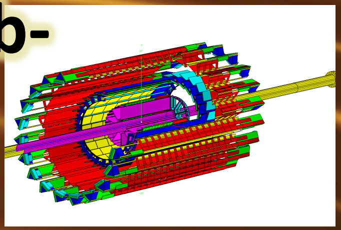
New techniques

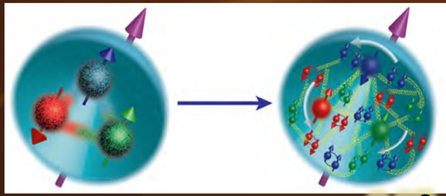


Robust procedures



Multiple sub-systems





High precision

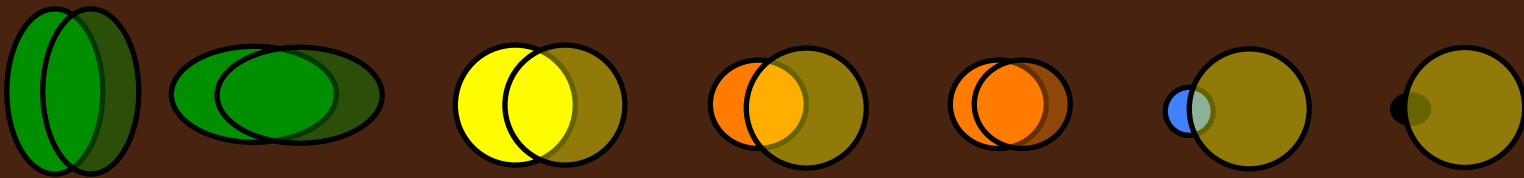
Bright future

Backup

Summary

- Great variety of measurement from the Beam Energy Scan I.
- Different energies and collision system studied.
- Data recorded and analyzed with several sub-systems.
- Well established procedures from previous analyses.
- New techniques developed.
- Measurements are reaching an outstanding level of precision.

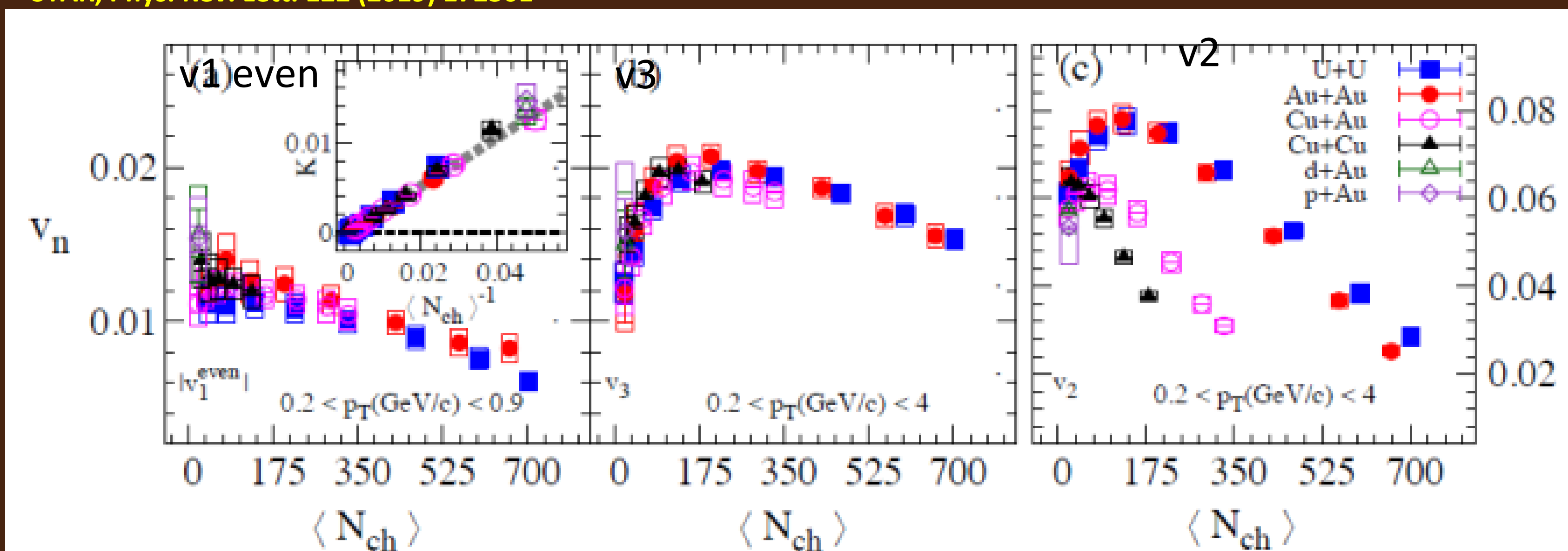
Small and Large Systems



U + U   Au + Au   Cu + Au   Cu + Cu   d + Au   p + Au

Different colliding species → initial state effects and transport coefficients

STAR, Phys. Rev. Lett. 122 (2019) 172301

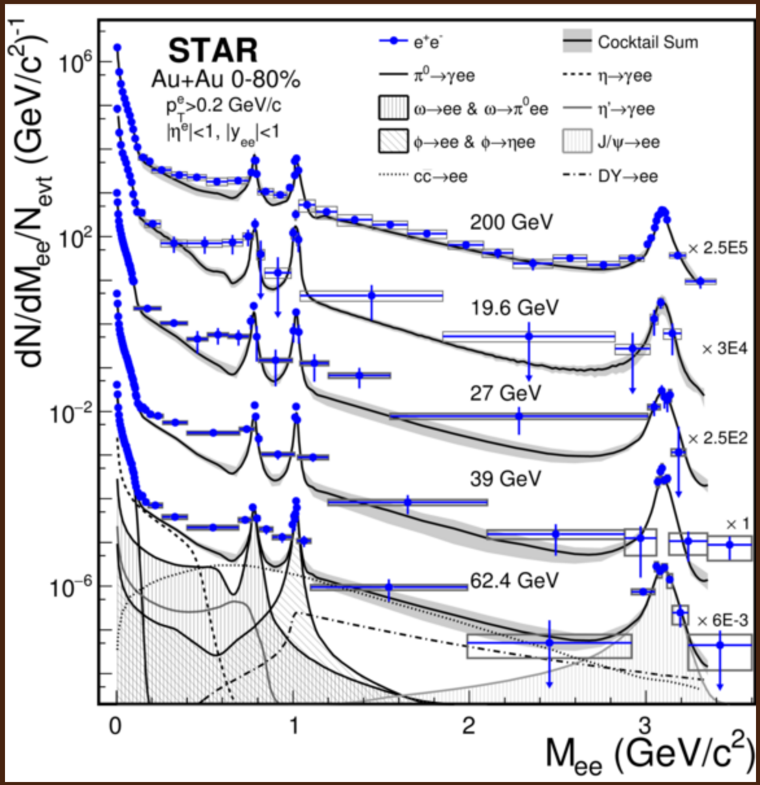


Shengli Huang
4 June @ 09:00

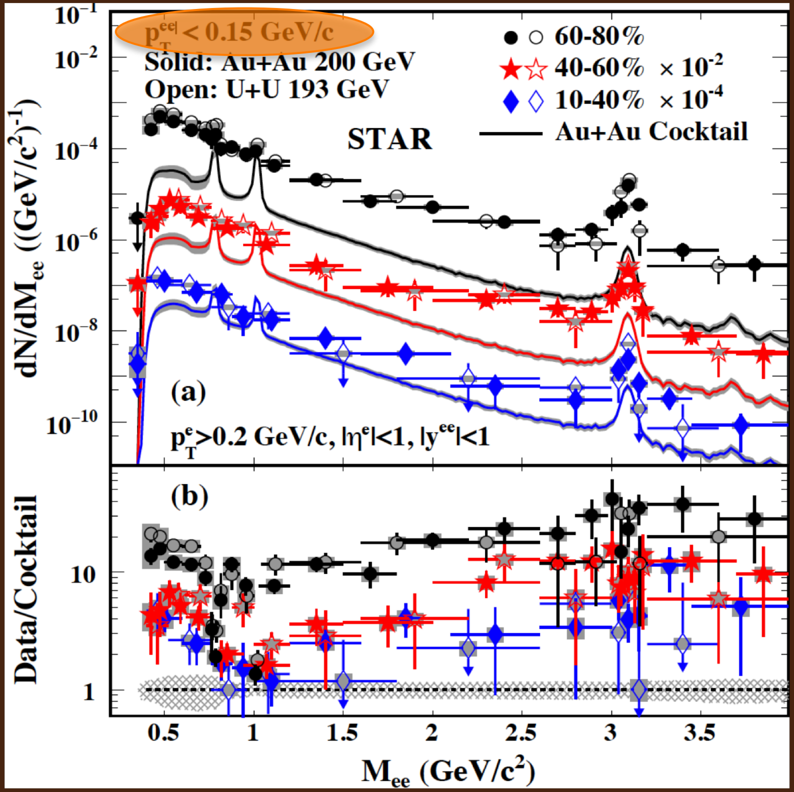
- v_1 even and v_3 are independent.
- v_2 is system dependent.

Di-electron production in Au+Au and U+U

STAR, arXiv:1810.10159 submitted to PRL



STAR, Phys. Rev. Lett. 121 (2018) 132301



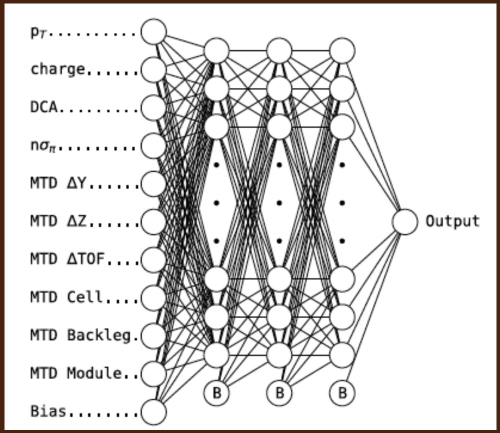
- Complementing measurements from BES-I.
- No significant collision-energy dependence and consistent with ρ broadening scenario.
- More clear pictures of the excesses in BES-II

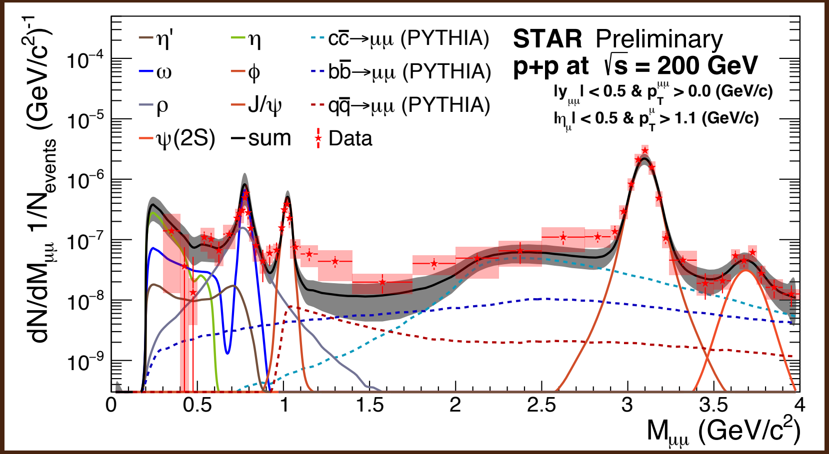
-Coherent photon-photon and photon-nucleon interaction.
- Challenge to theory on the understanding of coherent interactions.
- It will be measured in in di-muon channel.

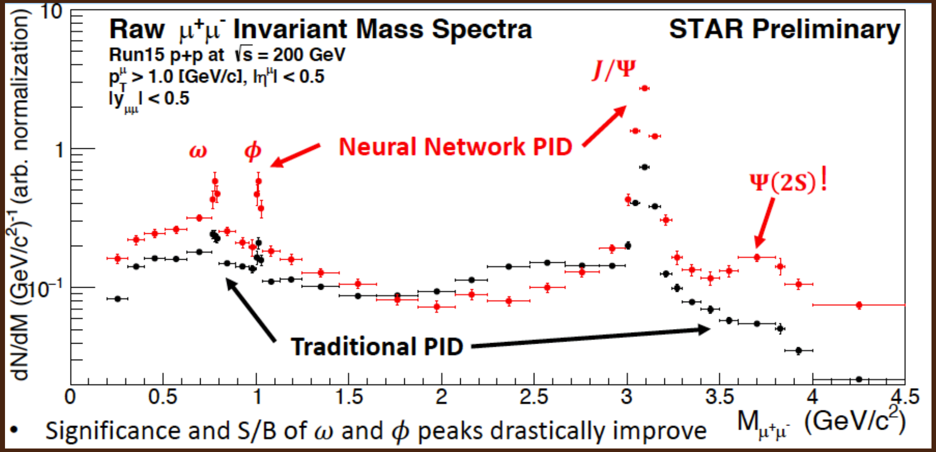
Di-muon production in p+p and p+Au

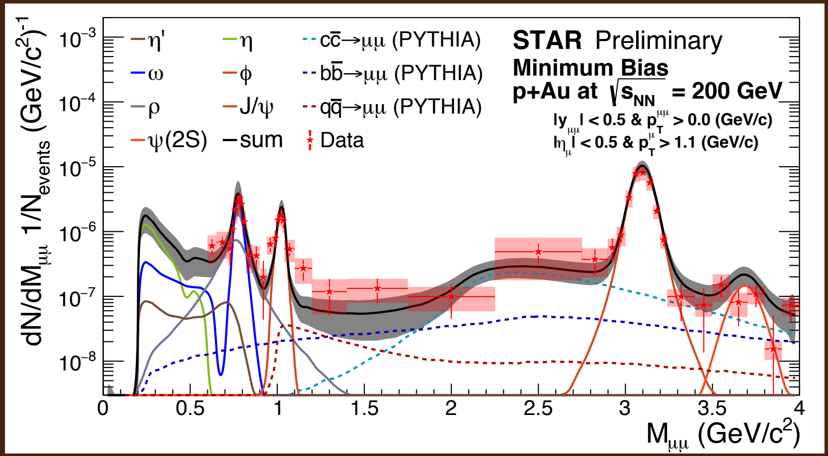
Muon identification with a deep neural network

Background:
π, K, p



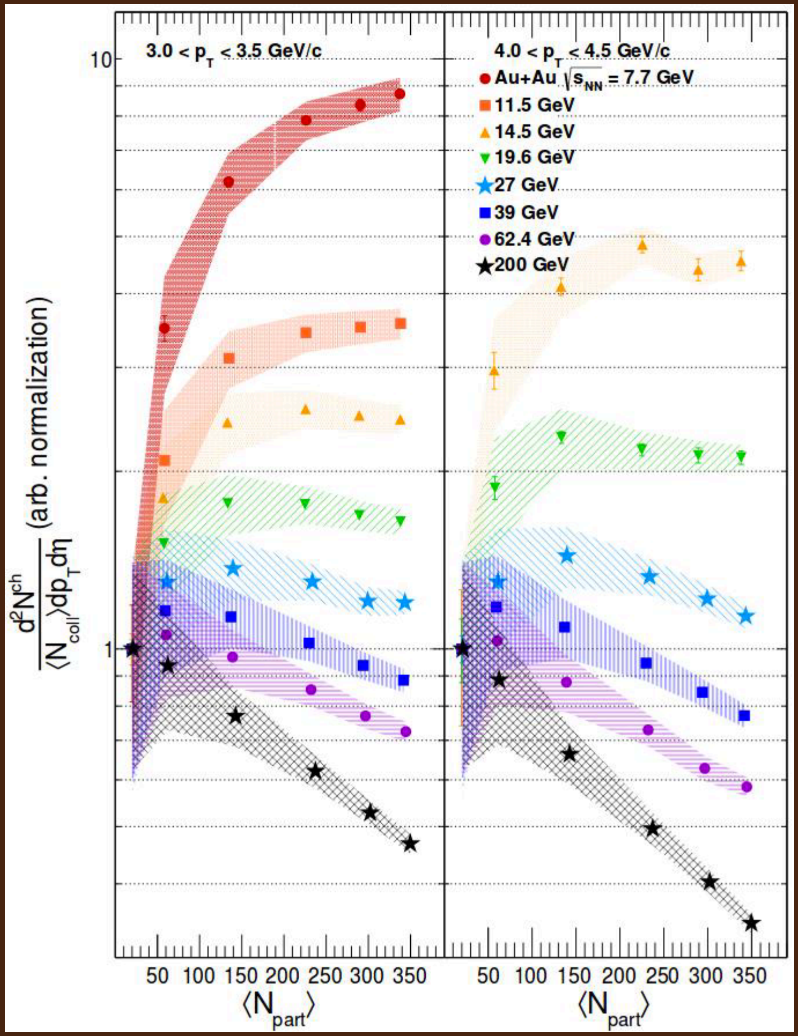




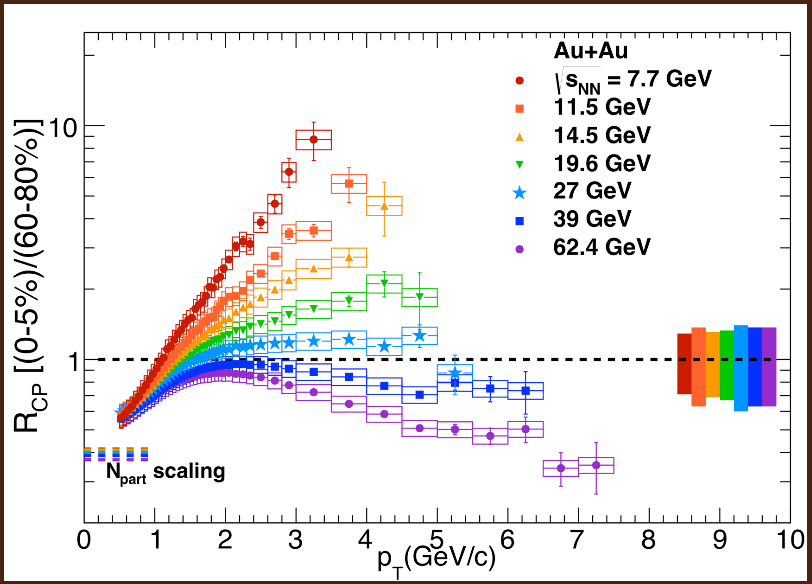


First measurement of the $\mu^+ \mu^-$ invariant mass spectra over large range and ϕ channel by STAR.

Jet quenching in BES



STAR, Phys. Rev. Lett. **121** (2018) 32301



- Charged hadrons suppression in central collisions, evolving to net enhancement at lower energies.

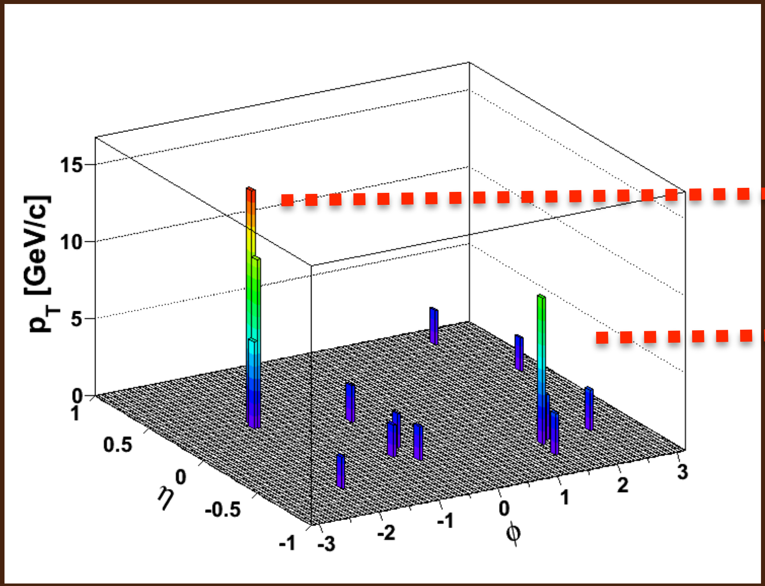
- Enhancement effects compete against suppression effects

- Most central data are suppressed (turnover) for √s ≥ 14.5 GeV

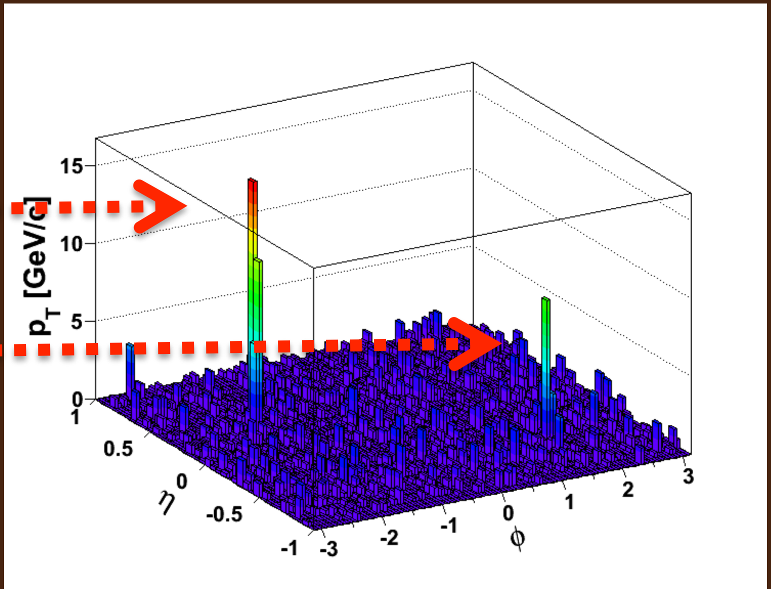
Di-jet selection in heavy ions collision

Selection initially developed in STAR, PRL 119 062301 (2017)

Hard-core jets
$p_T^{const} > 2$ GeV/c



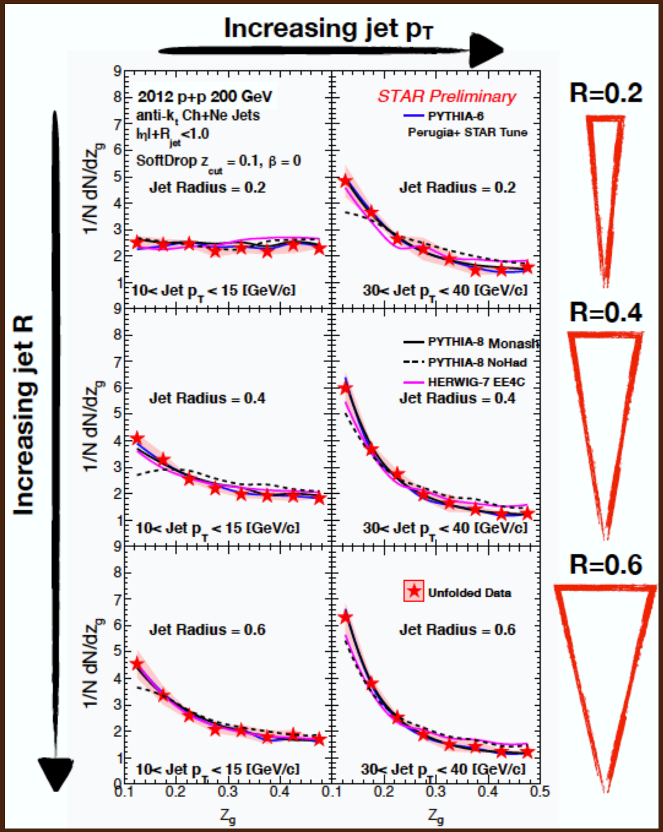
Matched jets
$p_T^{const} > 0.2$ GeV/c



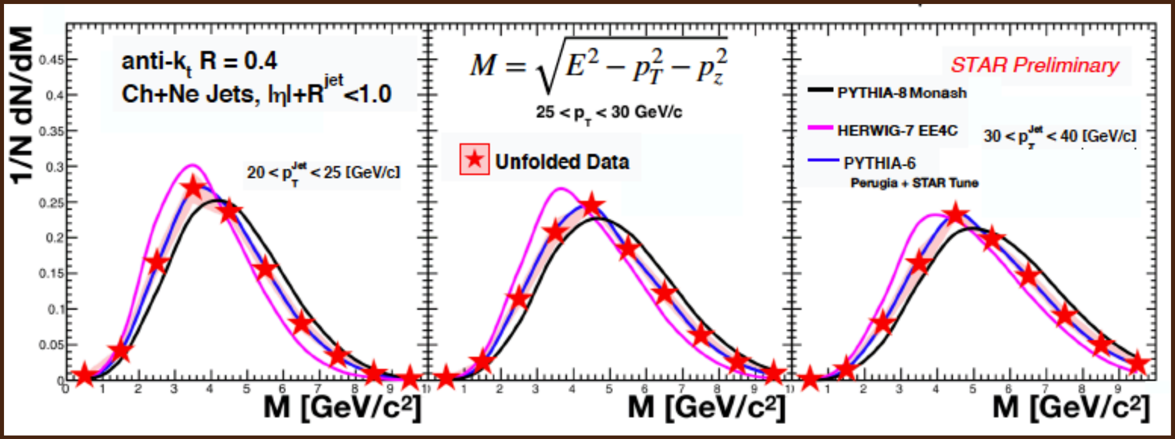
- Removes almost all background.
- No combinatory jets.
- No information about soft constituents.

- Geometrically matched to hard-core jets.
- No combinatory jets.
- Recovers all constituents.

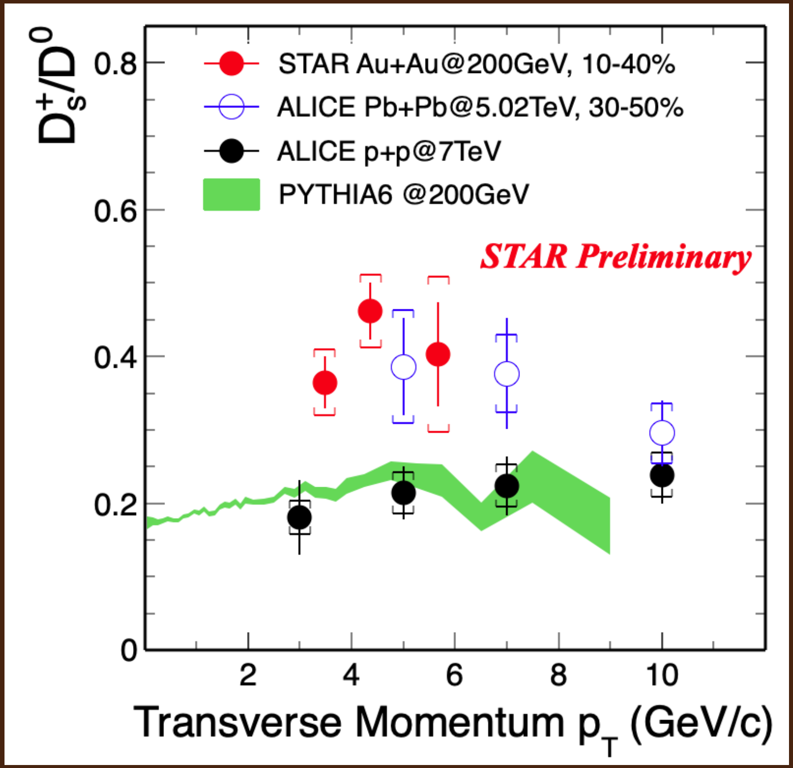
Jet Substructure

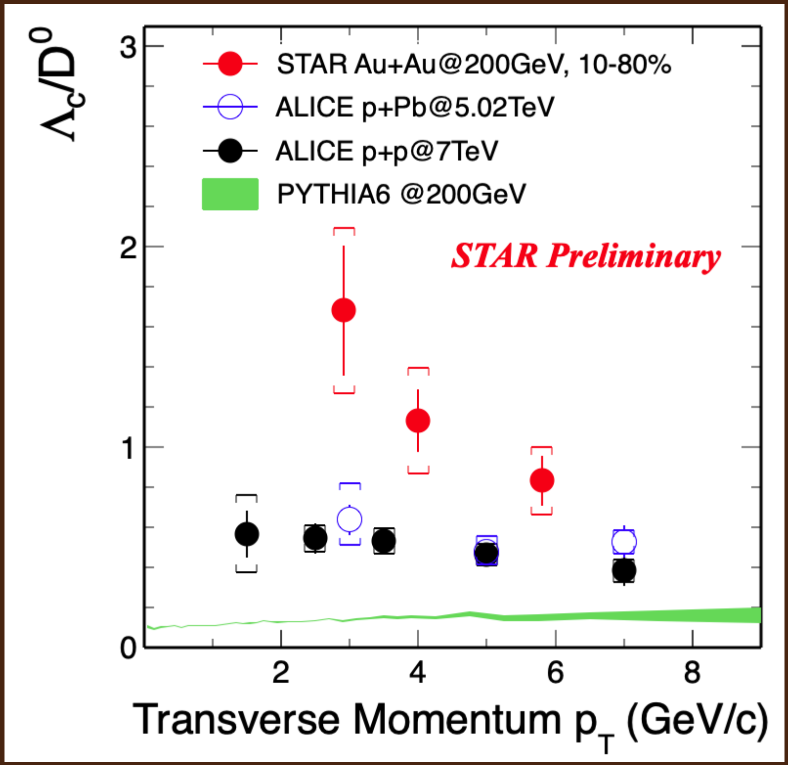


-Shapes of z_g, R_g in p+p collisions at RHIC are reproduced by LO-MC event generators
- PYTHIA6 tuned to STAR data - excellent prediction of jet substructure.
- Jet mass sensitive to description of shower and MC parameters.
- Interaction of the jet with the medium could depend on the resolution scale.



Charm quark hadronization



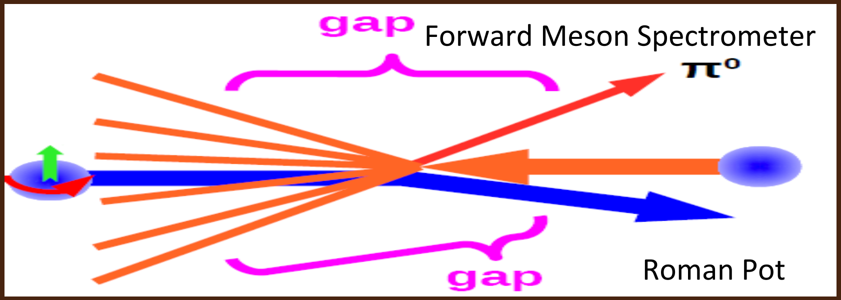


- D_s/D^0 and Λ_c/D_0 significantly higher than p+p collisions → charm quark hadronization through coalescence with light flavor quarks.
- Improvement of presicion for several open charm measurement due to multi variative analysis techniches.

Sooraj Radakrishnan
4 June @ 9:00

TSSA for $p^{\uparrow}+p \rightarrow p+\pi_0+X$

- Incident proton transverse spin may be correlated with proton+pion angular momentum
- Study asymmetries modulated by proton and pion azimuthal angles
- Rare process (5/9000) but observed at STAR, despite acceptance limitations.

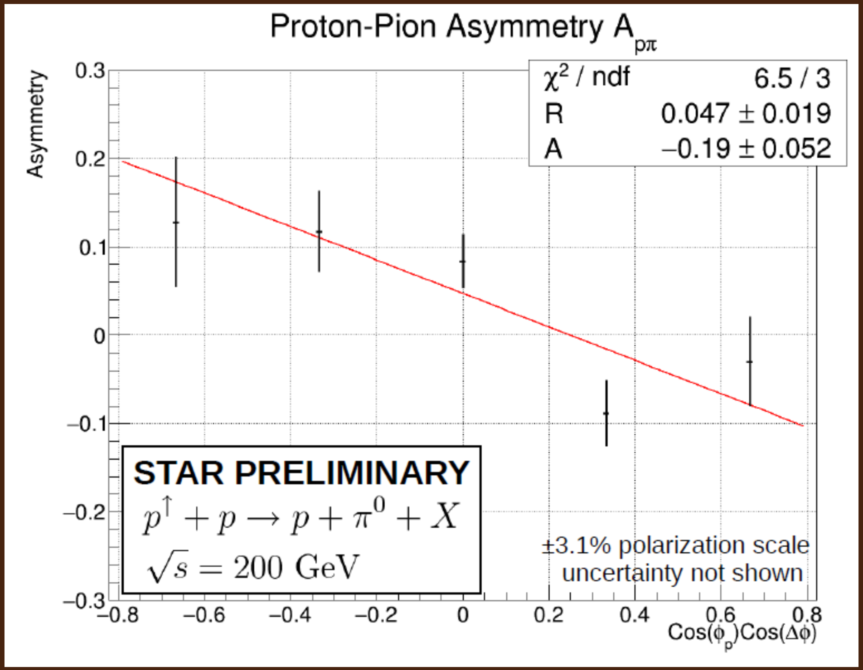


The observed asymmetry seems to be modulated by:

$$\frac{1}{\langle P \rangle} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} = R + A \cos\phi_p \cos\Delta\phi$$

Spin up/down

Pion in the proton plane



The mechanism remains open to interpretation