

Update on STAR Analyses



Zhangbu Xu
(Brookhaven National Lab)

- Overview of STAR Analysis Activities
- Highlights of published and Preliminary results
- Blinding Analysis of isobar dataset
- Summary

Many results from [BES-I](#) and [Spin](#) will be covered in Helen Caines and Elke Eschenauer's talks



Collaboration Activities since June 2017



- 2 new institutions joined:
[Huzhou](#) University (China),
[Eotvos](#) University (Hungary)
- 13 PHD graduates
- Related to the isobar analysis
 - Form a CME focus group
co-chairs: Jiangyong Jia and Paul Sorensen
 - Form a Blind Analysis Committee
chaired by Jim Drachenberg
- Run 18 data-taking about to complete
- 11 papers published,
10 in journal review
- 25 paper committees in action
- 19 Quark Matter talks
- [STAR Collaboration Meeting
July 16-21, 2018, Lehigh University](#)
- [Pre-QM Meeting,
May 8-11, 2018,
Warsaw University of Technology](#)
- [STAR Collaboration Meeting
Jan. 24-28, 2018, LBL](#)
- [STAR Autumn 2017 Analysis Meeting
Nov. 2-4, 2017, BNL](#)
- [The 2nd CBM-STAR joint Workshop
Sep. 23, 2017, CCNU, Wuhan](#)
- [STAR Regional Meeting:
Heavy Quark Production,
Jets and Correlations
Jun. 27-29, 2017, Warsaw](#)

Notable Recognitions

- RHIC/AGS Users Thesis Awards in 2017:
Zilong Chang (TAMU)
Prashanth Shanmuganathan (KSU)
- APS Fellow:
Ernst Sichtermann (LBL)
- Humboldt Research Award:
Elke-Caroline Aschenauer (BNL)
- Yu-Gang Ma (SINAP) elected to
Chinese Academy of Sciences
- David Kapukchyan (UCR) best talk at
“BNL Early Career Researcher” Symposium
- James Brandenburg (Rice)
Quark Matter 2018 Flash Talk



Published Papers since June 2017



- **Dijet imbalance** measurements in Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

- Submit: 9/15/2016; Publish: 8/10/2017

- [Phys. Rev. Lett. 119 \(2017\) 062301](#)

Jet

- **Global Lambda hyperon polarization** in nuclear collisions: evidence for the most vortical fluid

- Submit: 01/21/2017; Publish: 08/02/2017

- [Nature 548 \(2017\) 62](#)

Bulk

- Measurement of **jet quenching** with semi-inclusive hadron+jet distributions in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV

- Submit: 02/02/2017; Publish: 08/14/2017

- [Phys. Rev. C 96 \(2017\) 024905](#)

Jet

- **Bulk properties** of the medium produced in relativistic heavy-ion collisions from the Beam Energy Scan program

- Submit: 01/24/2017; Publish: 10/13/2017

- [Phys. Rev. C 96 \(2017\) 044904](#)

Spectra

- **Coherent diffractive photoproduction** of ρ^0 mesons on gold nuclei at 200 GeV/nucleon-pair at the Relativistic Heavy Ion Collider

- Submit: 03/01/2017; Publish: 11/13/2017

- [Phys. Rev. C 96 \(2017\) 054904](#)

Spectra

11 published

- Azimuthal **transverse single-spin** asymmetries of inclusive jets and charged pions within jets from polarized-proton collisions at 500 GeV

- Submit: 8/23/2017; Publish: 2/2/2018

- [Phys. Rev. D 97 \(2018\) 032004](#)

Spin/CQCD

- Beam-energy dependence of **directed flow of Lambda**, Anti-Lambda, K plus, K minus, K0 short and phi in Au+Au collisions

- Submit: 8/23/2017; Publish: 2/6/2018

- [Phys. Rev. Lett. 120 \(2018\) 062301](#)

Bulk

- **Transverse spin-dependent azimuthal** correlations of charged pion pairs measured in $p^\uparrow + p$ collisions at $\sqrt{s} = 500$ GeV

- Submit: 10/27/2017; Publish: 3/10/2018

- [Phys. Lett. B 780 \(2017\) 332](#)

Spin/CQCD

- Measurement of **hypertriton lifetime** in Au+Au collisions at the Relativistic Heavy-Ion Collider

- Submit: 10/1/2017

- Phys. Rev. C (accepted)

Spectra

- Correlation measurements between **flow harmonics** in Au+Au collisions at RHIC

- Phys. Lett. B (accepted)

Bulk

- **Beam Energy Dependence of Jet-Quenching** Effects in Au+Au Collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39, \text{ and } 62.4$ GeV

Submitted Jul. 11, 2017, published 22 May 2018

Phys. Rev. C 97 (2018) 044909

Spectra/jet

Submitted & in journal review since June 2017

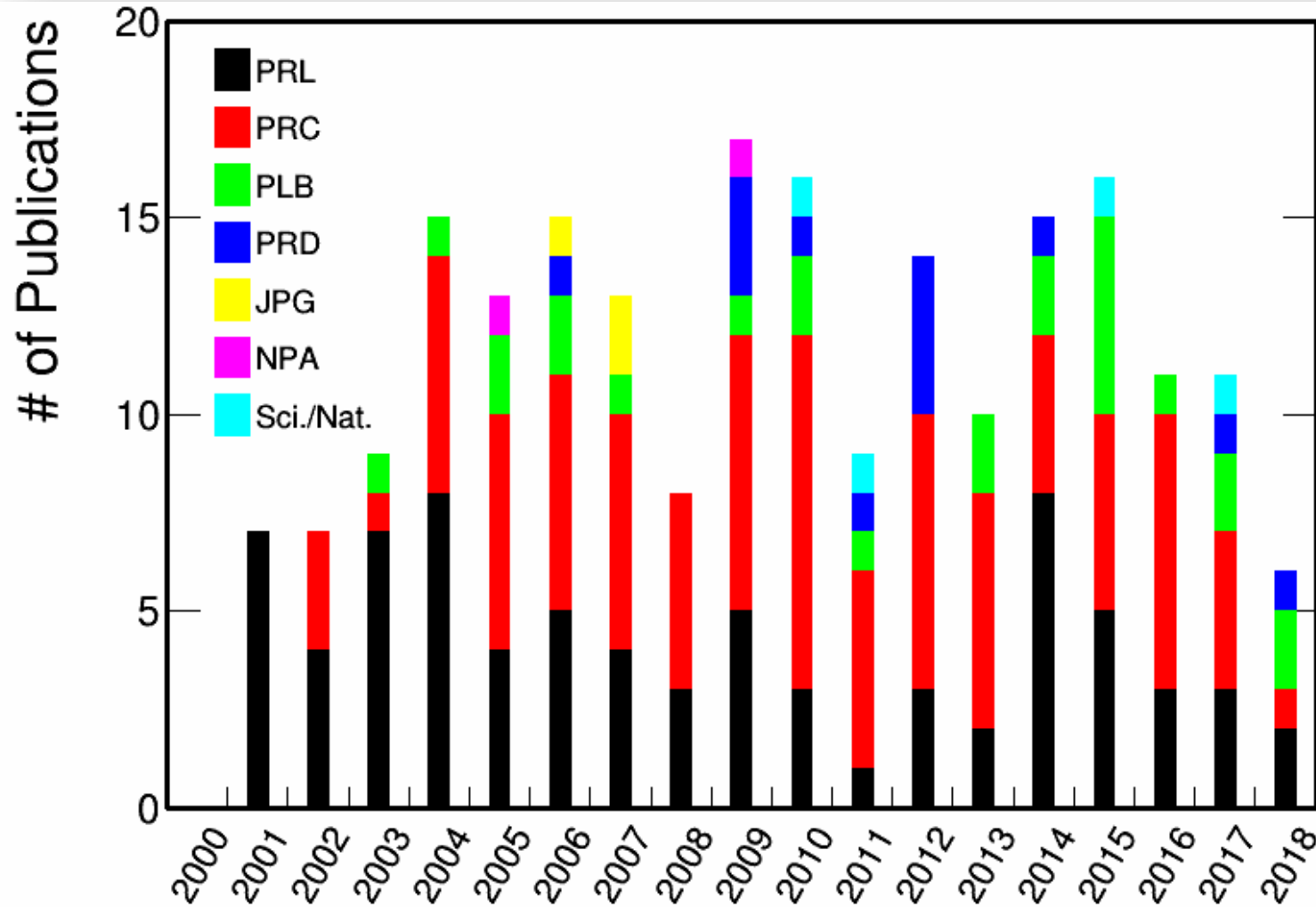


- **Collision Energy Dependence of Moments of Net-Kaon Multiplicity Distributions at RHIC**
Submitted Sep. 2, 2017
e-Print Archives (1709.00773) **Bulk**
- **Azimuthal anisotropy in Cu+Au collisions at 200 GeV**
Submitted Dec. 5, 2017
e-Print Archives (1712.01332) **Bulk**
- **Low-pT e+e- pair production in Au+Au and U+U collisions**
submitted June 7, 2018 **Spectra**

10 papers in journal review

- **Longitudinal Double-Spin Asymmetries for Dijet Production at Intermediate Pseudorapidity in Polarized pp Collisions at $\sqrt{s} = 200$ GeV**
Submitted May. 25, 2018
e-Print Archives (1805.09742) **Spin/CQCD**
- **Longitudinal double-spin asymmetries for π^0 s in the forward direction for 510 GeV polarized pp collisions**
Submitted May. 24, 2018
e-Print Archives (1805.09745) **Spin/CQCD**
- **Global polarization of Lambda hyperons in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV**
Submitted May. 11, 2018
e-Print Archives (1805.04400) **Bulk**
- **J/psi production cross section and its dependence on charged-particle multiplicity in p+p collisions at $\sqrt{s}=200$ GeV**
Submitted May. 11, 2018
e-Print Archives (1805.03745) **Heavy-Flavor**
- **Beam energy dependence of rapidity-even dipolar flow in Au+Au collisions**
Submitted Apr. 23, 2018
e-Print Archives (1804.08647) **Bulk**

STAR Publication History



- **2017**: 11 published
3 PRL, 2 PLB, 4 PRC, 1 PRD,
1 Nature
- **2018**: 3 published
3 accepted
2 PRL, 2 PLB, 1 PRC, 1 PRD
- 10 papers in journal review

STAR Citation Summary



Citesummary excluding self-citations or RPP citations

Generated on 2018-05-24

208 papers found, 208 of them citeable (published or arXiv)

Citation summary results

Total number of papers analyzed:

208

Total number of citations:

27,117

Average citations per paper:

130.4

Breakdown of papers by citations:

Renowned papers (500+)

11

Famous papers (250-499)

18

Very well-known papers (100-249)

42

Well-known papers (50-99)

49

Known papers (10-49)

72

Citeable papers

Citeable papers
excluding self cites

208

18,218

87.6

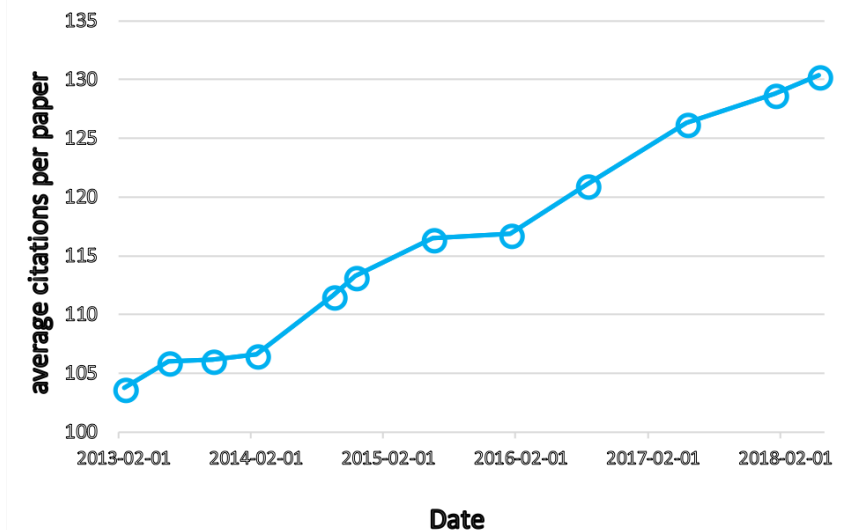
Citations (as per May 24 2018)

- 27,117 citations
- 208 peer-reviewed scientific papers
- 2005 white paper: 2713
- average citations/paper: 130.4

Renowned and Famous Papers: 11 + 14

2017: 11+14; 2016: 11+11; 2015: 9+10; 2014: 6+9

AVERAGE CITATIONS PER PAPER by STAR: 2013-2018

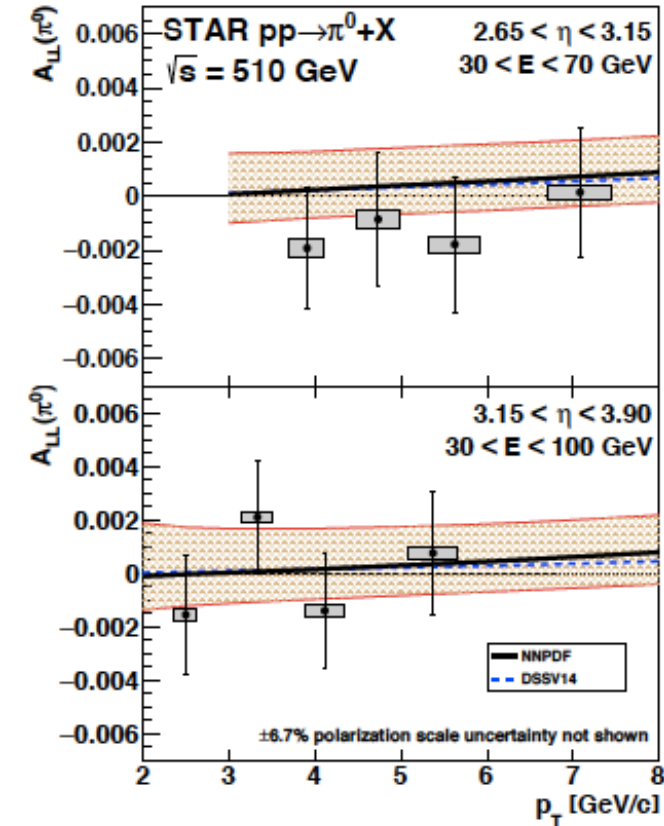
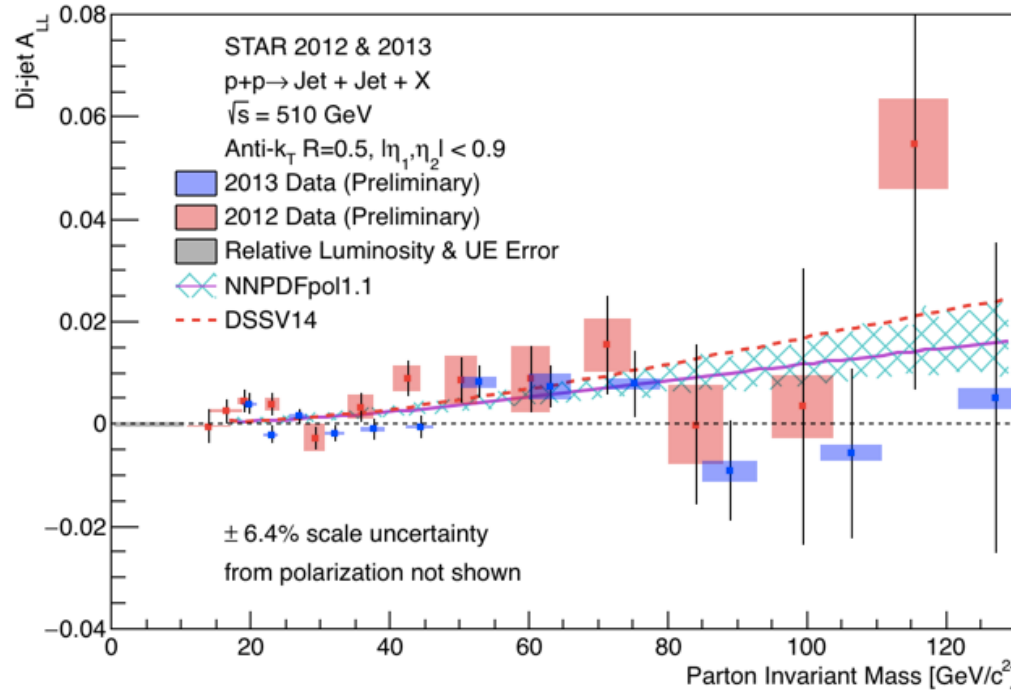
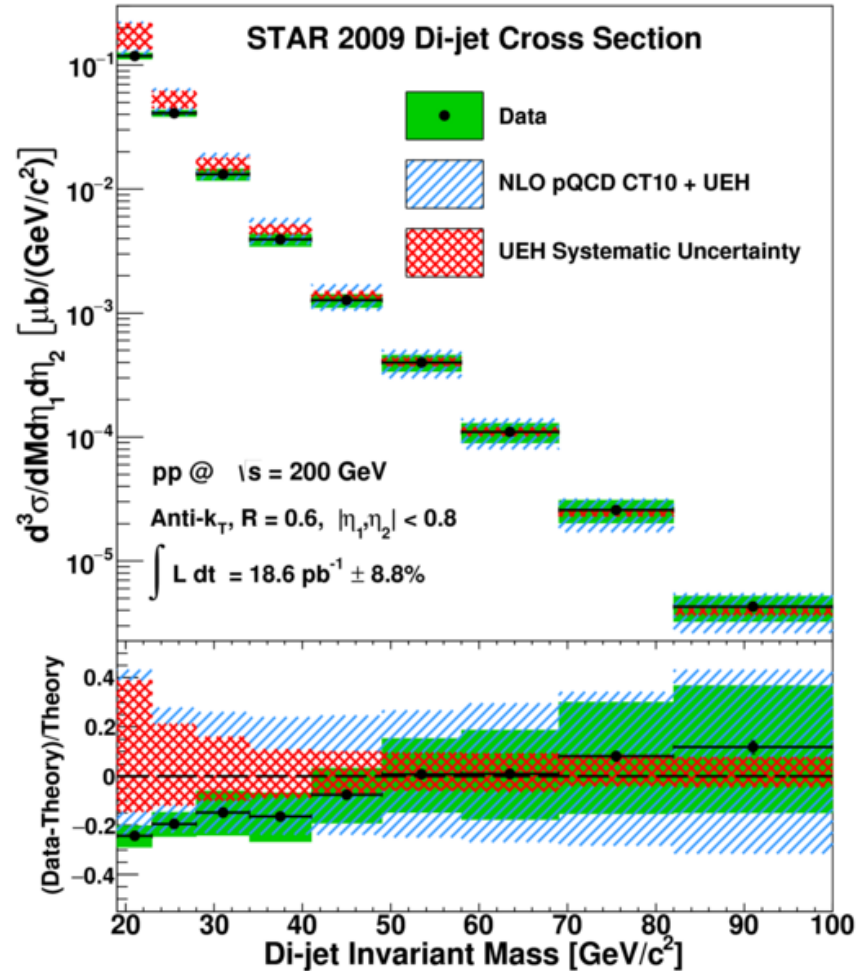


Longitudinal Spin Asymmetry (Gluon)



STAR Collaboration, PRD 95 (2017)

e-Print Archives (1805.09745)



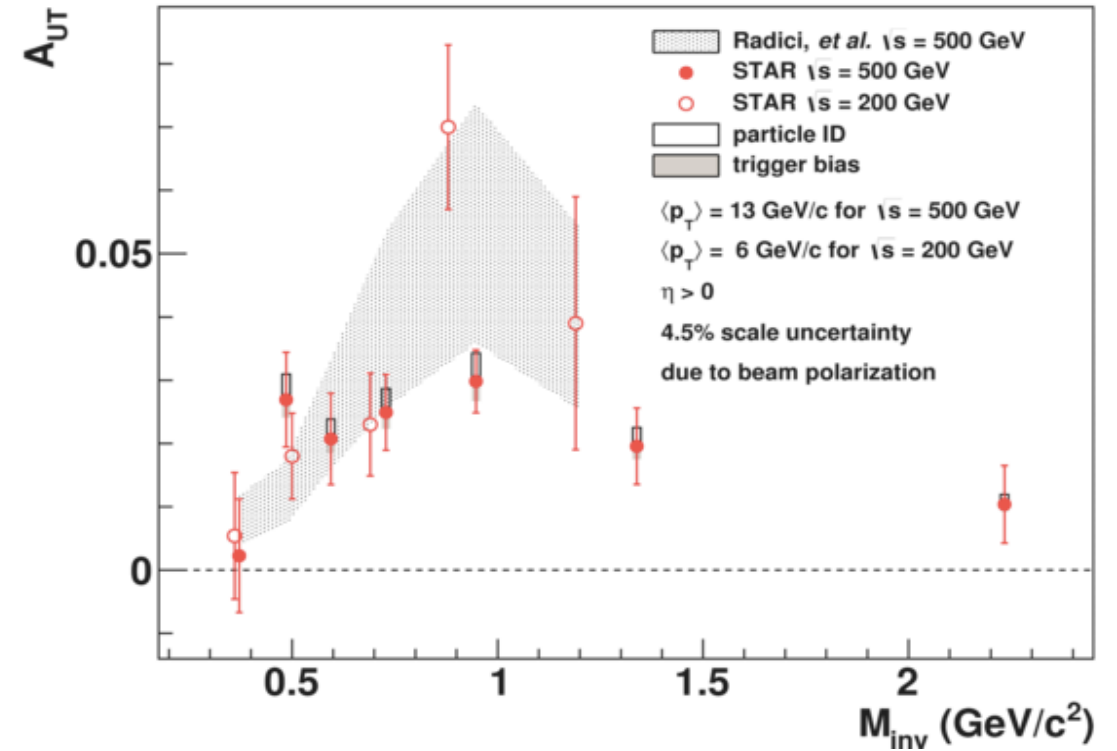
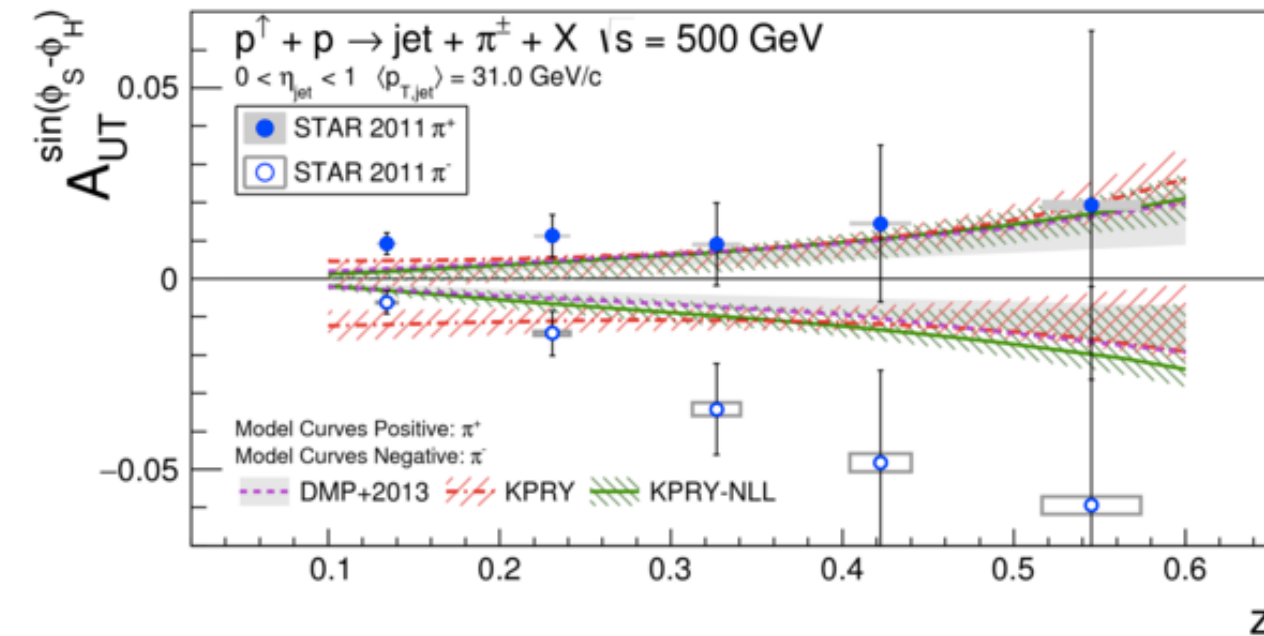
Precision Jet and dijet cross-section (up to 100GeV),
 comparison with pQCD calculations
 Double-Spin Asymmetry probes gluon spin in proton
 Run 2013 Forward π^0 A_{LL}

Transverse Spin Asymmetry



Phys. Rev. D **97** (2018) 32004

Phys. Lett. B **780** (2018) 332



universality and factorization:

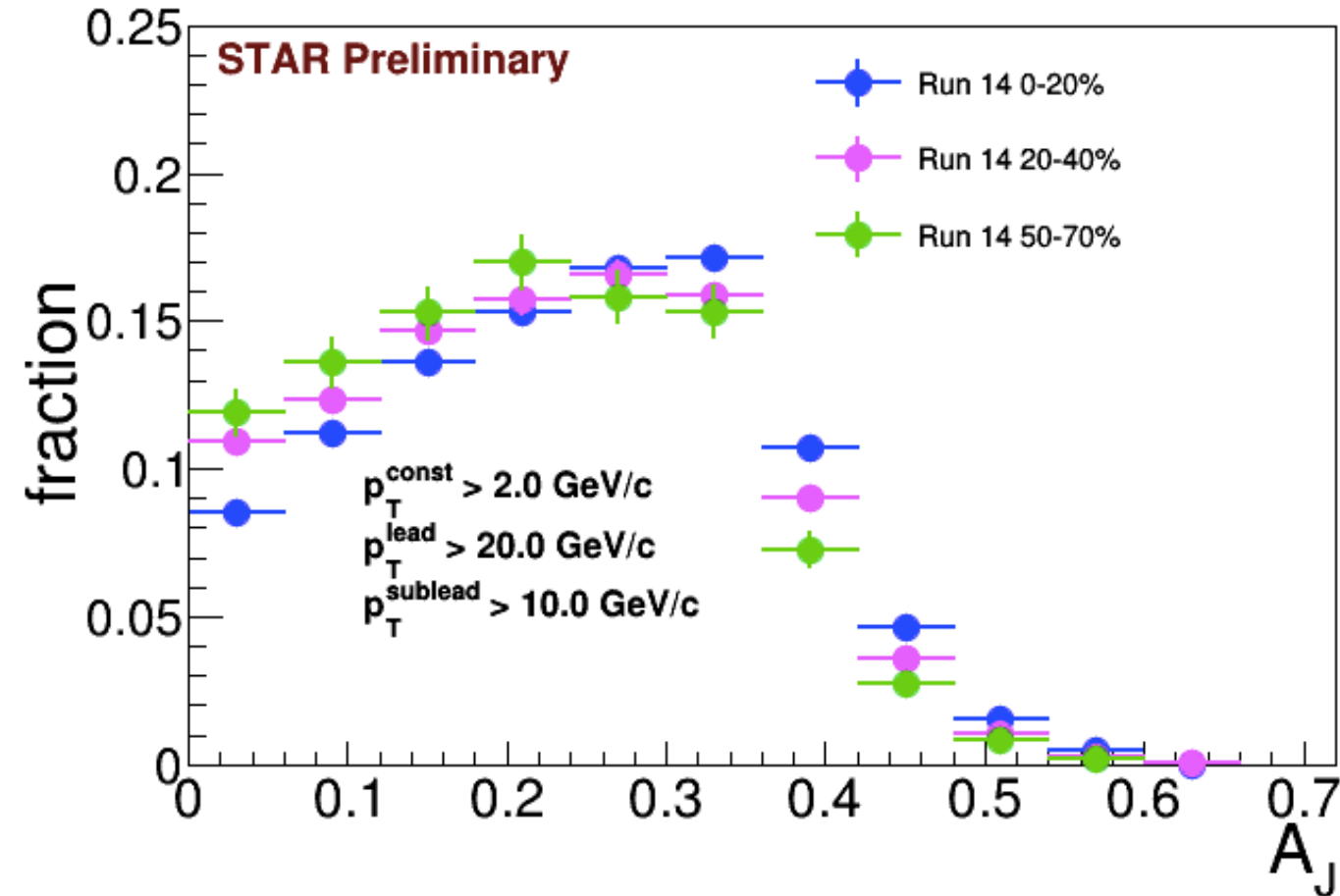
- First non-zero Collins Effect (Fragmentation) in p+p collisions
- First measurement (Collins-like) sensitive to gluon linear polarization
- Interference Fragmentation Function (first measure Transversity at high Q^2)

Run17 goals with forward DY/gamma and mid-rapidity W⁺⁻:
calibration and analyses on progress

Di-jet Imbalance in Au+Au collisions

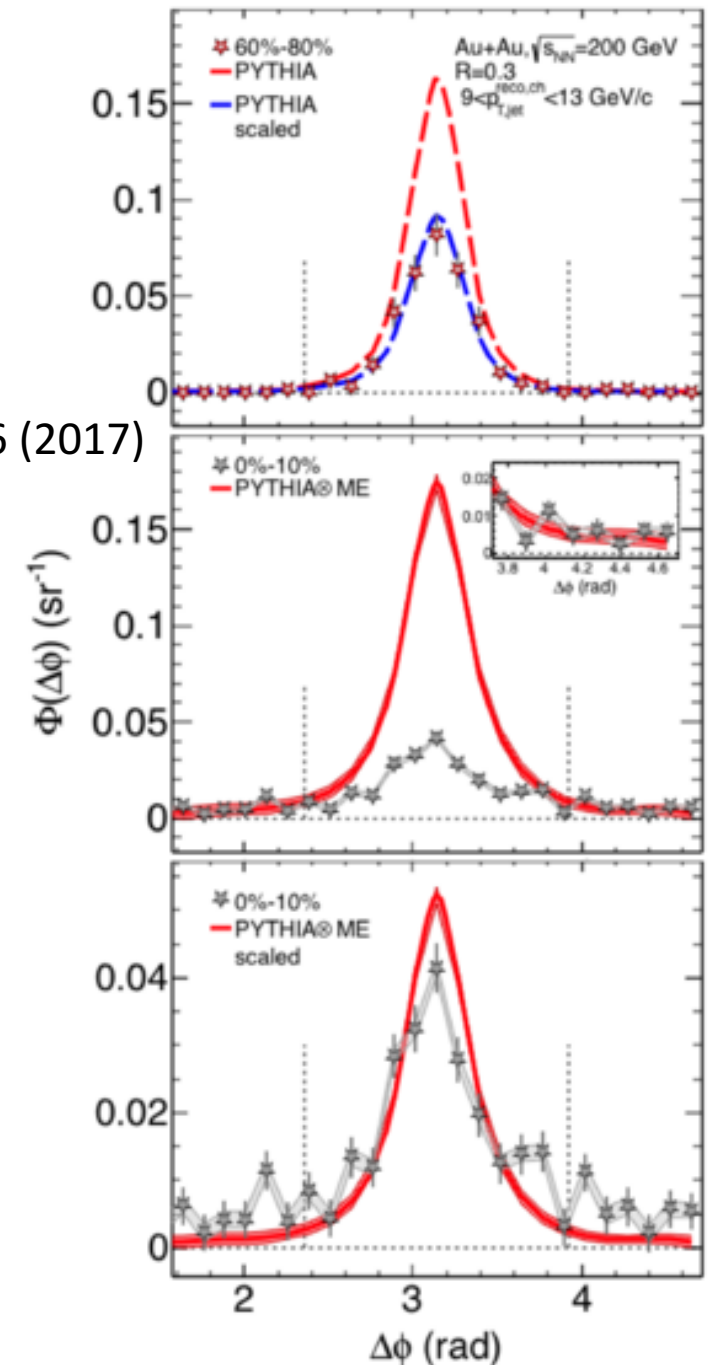


Run7 0-20%: STAR PRL 119, 062301 (2017)

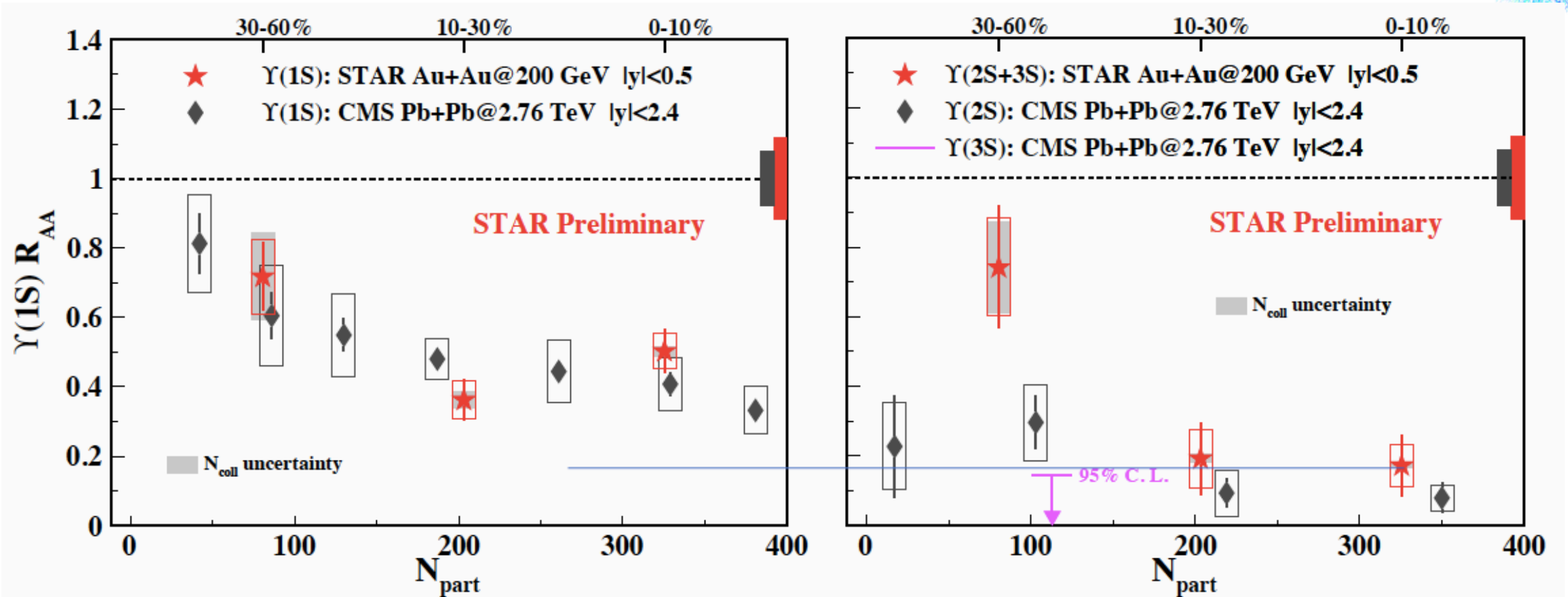


- First measurement of centrality dependence of A_J at RHIC
- Smaller di-jet imbalance in more peripheral collisions
- h-jet measurement Sensitive to large-angle deflection

PRC 96 (2017)



Suppression of Upsilon States

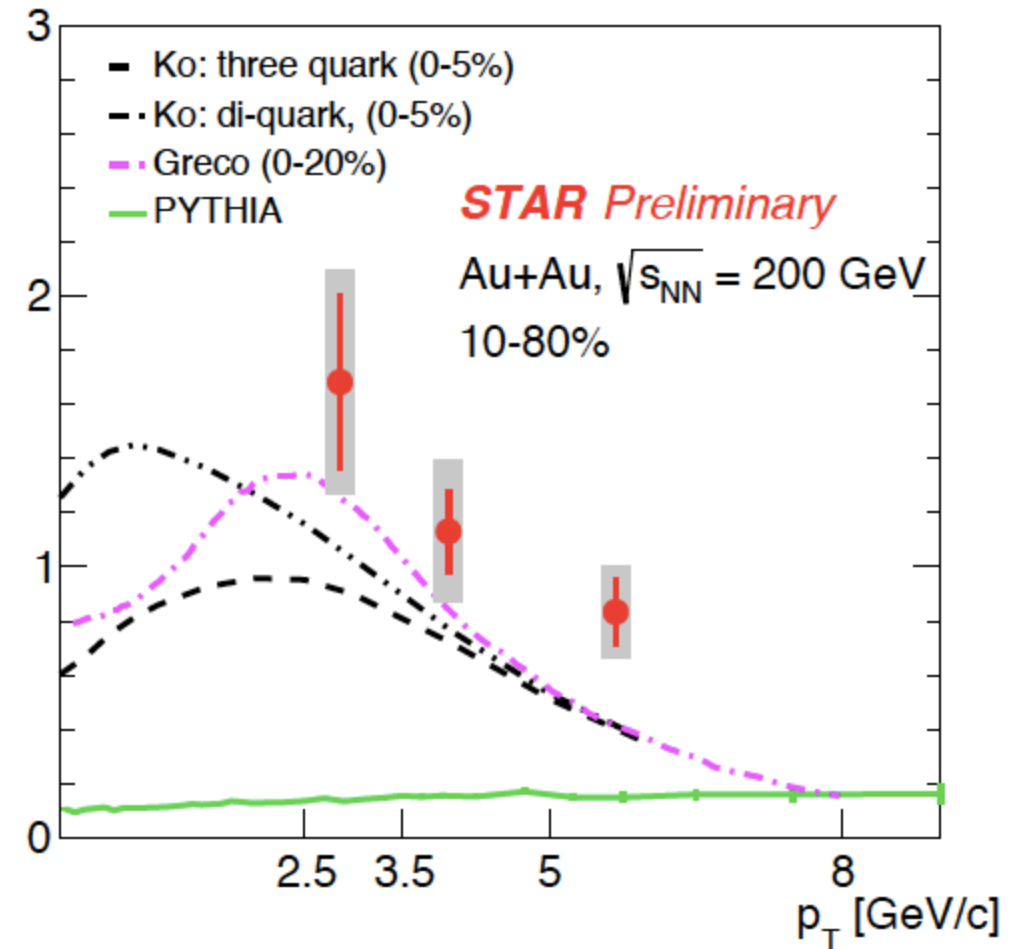
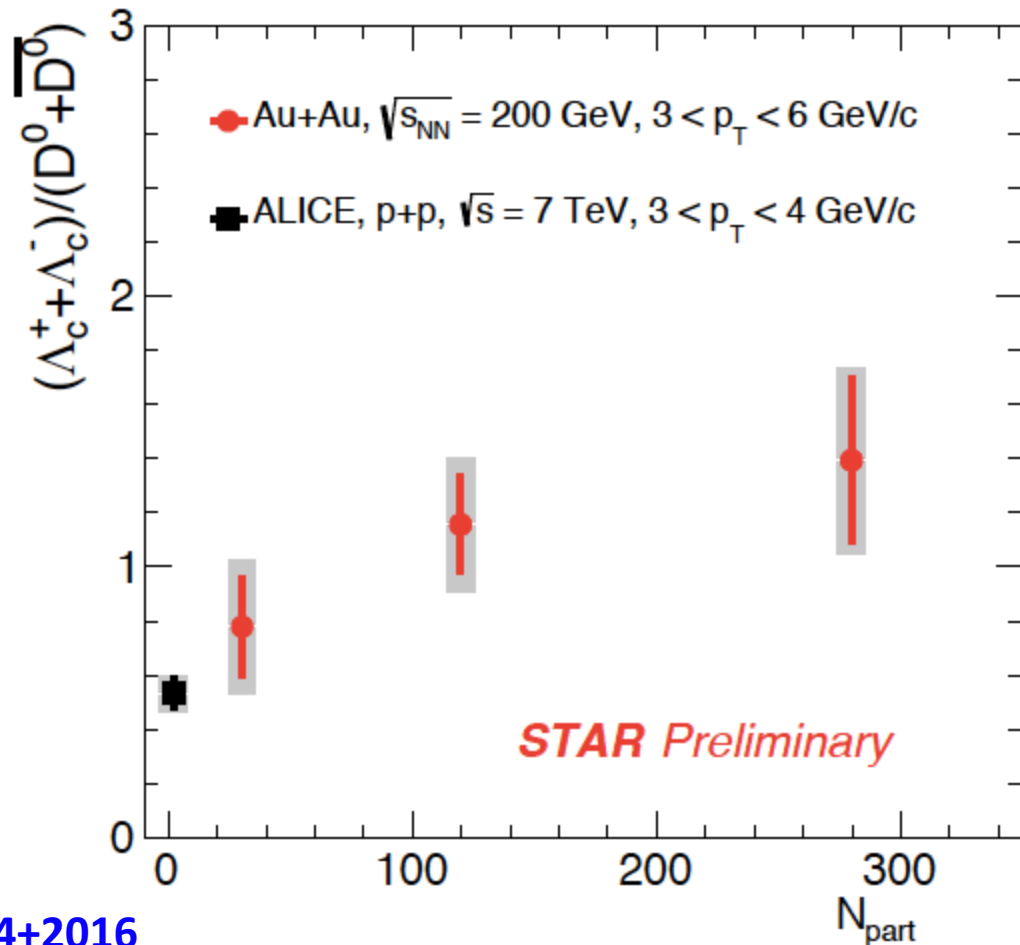


Consistent with Sequential Melting in QGP:

Combine 2011 dielectron
and 2014+2016 dimuon datasets

1. $Y(1S) R_{AA}$ similar at RHIC and LHC
2. $Y(2S+3S) R_{AA}$ smaller than $Y(1S)$ in 0-10%,
3. $Y(2S+3S) R_{AA}$ systematically larger than $Y(2S)$ at LHC

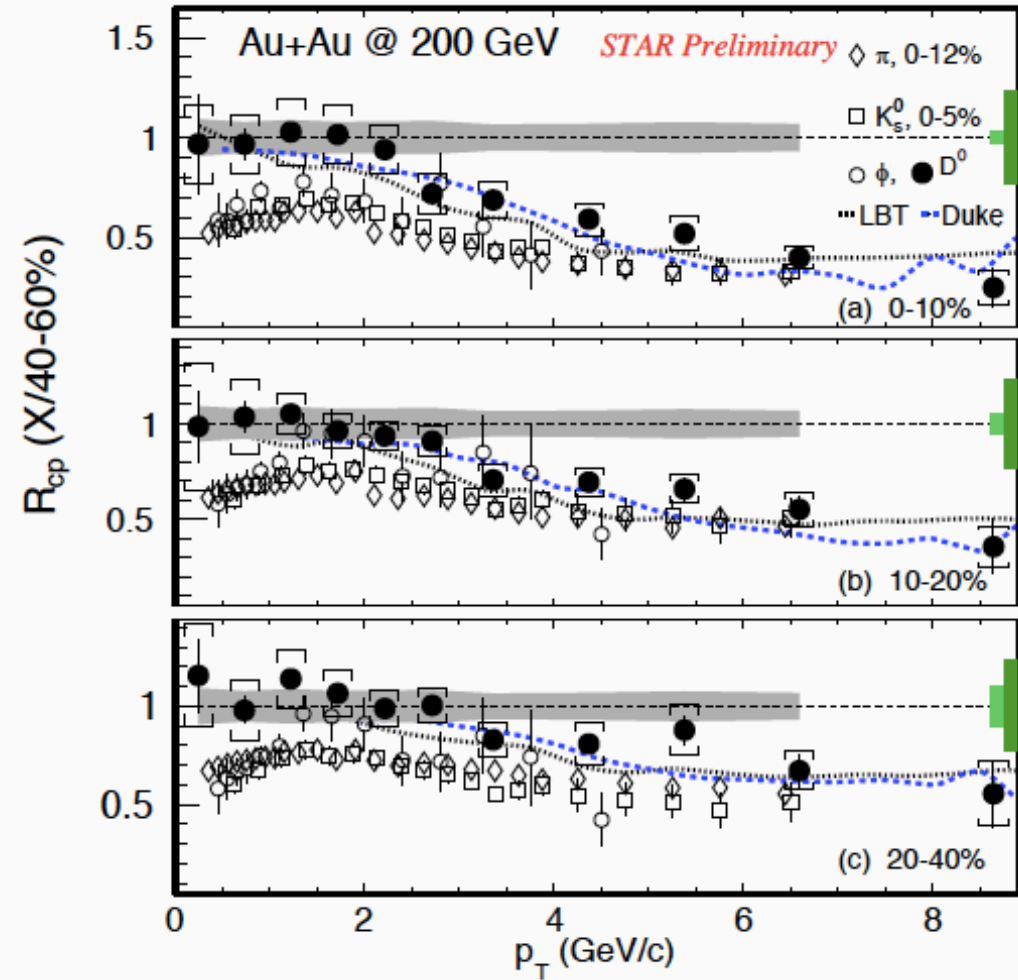
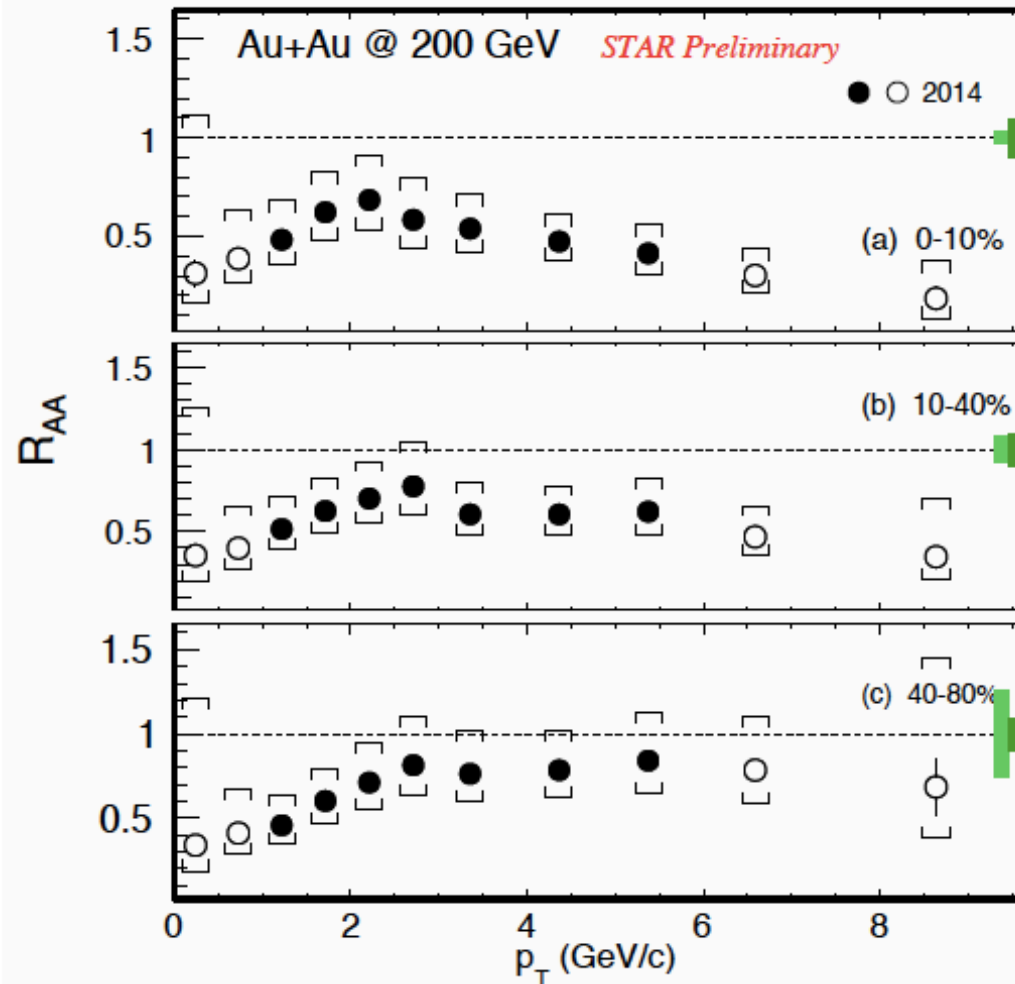
Charmed Baryon Enhancement



2014+2016

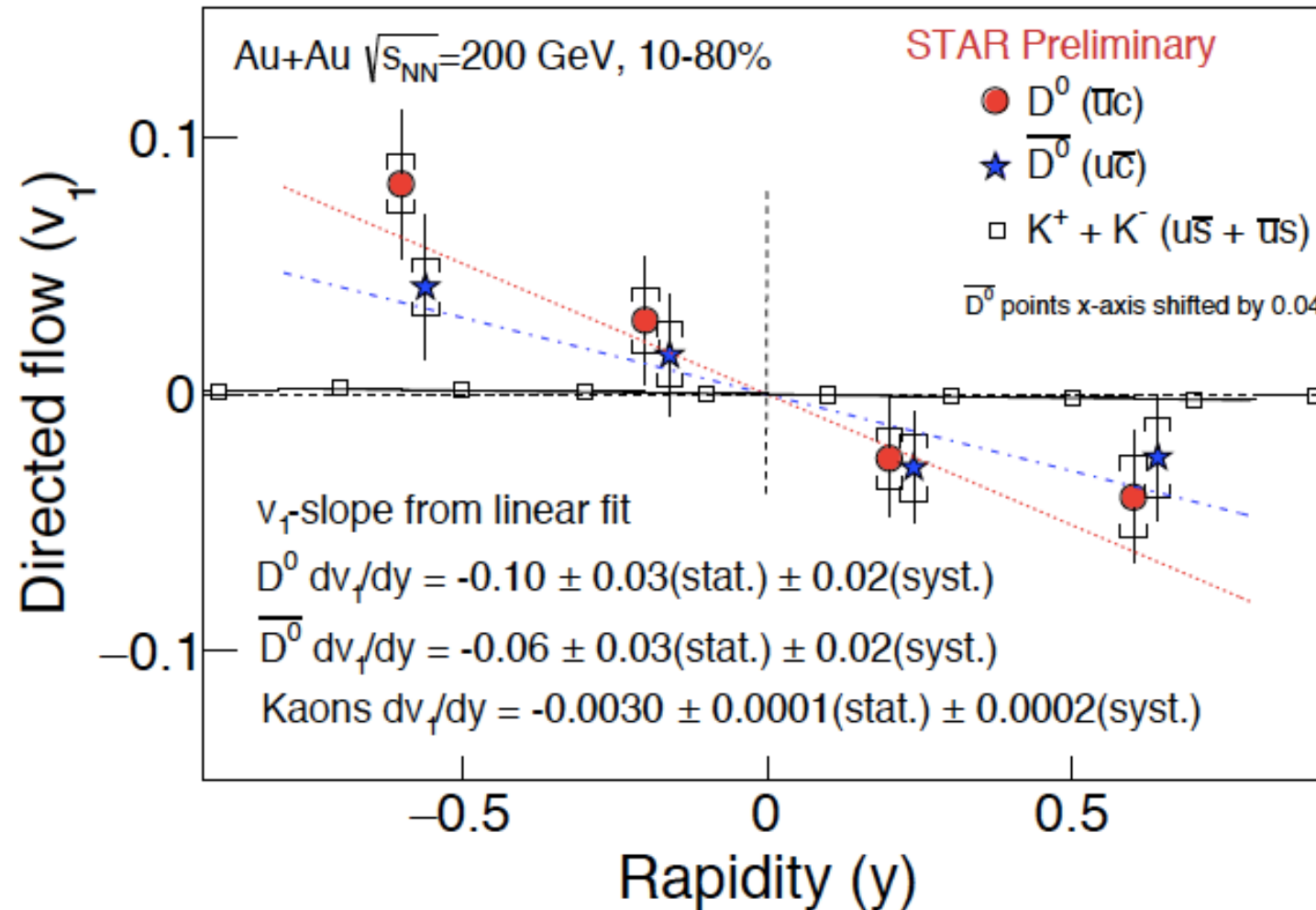
- Λ_c enhancement increases towards more central Au+Au collisions
- Large Λ_c contribution to the total charm cross-section in HI collisions

D^0 Nuclear Modification Factor with centrality



- Significant suppression at low p_T with no strong centrality dependence
- Suppression at high p_T decreases towards more peripheral collisions

D^0 Directed Flow in Au+Au

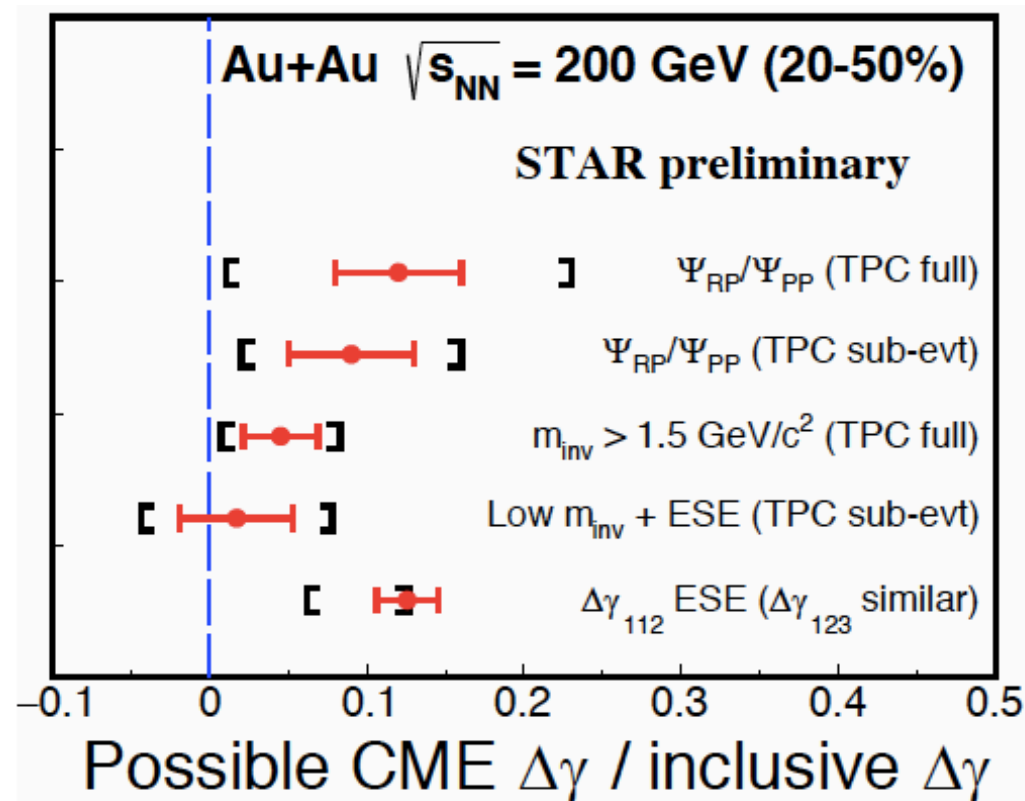
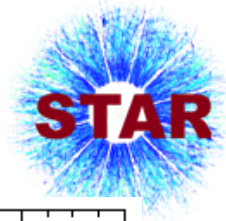


- First evidence for non-zero $D^0 v_1$ from 2014+2016 Heavy Flavor Tracker (HFT) data

$$D^0 + \bar{D}^0 dv_1/dy = -0.081 \pm 0.021(\text{stat.}) \pm 0.017(\text{syst.})$$

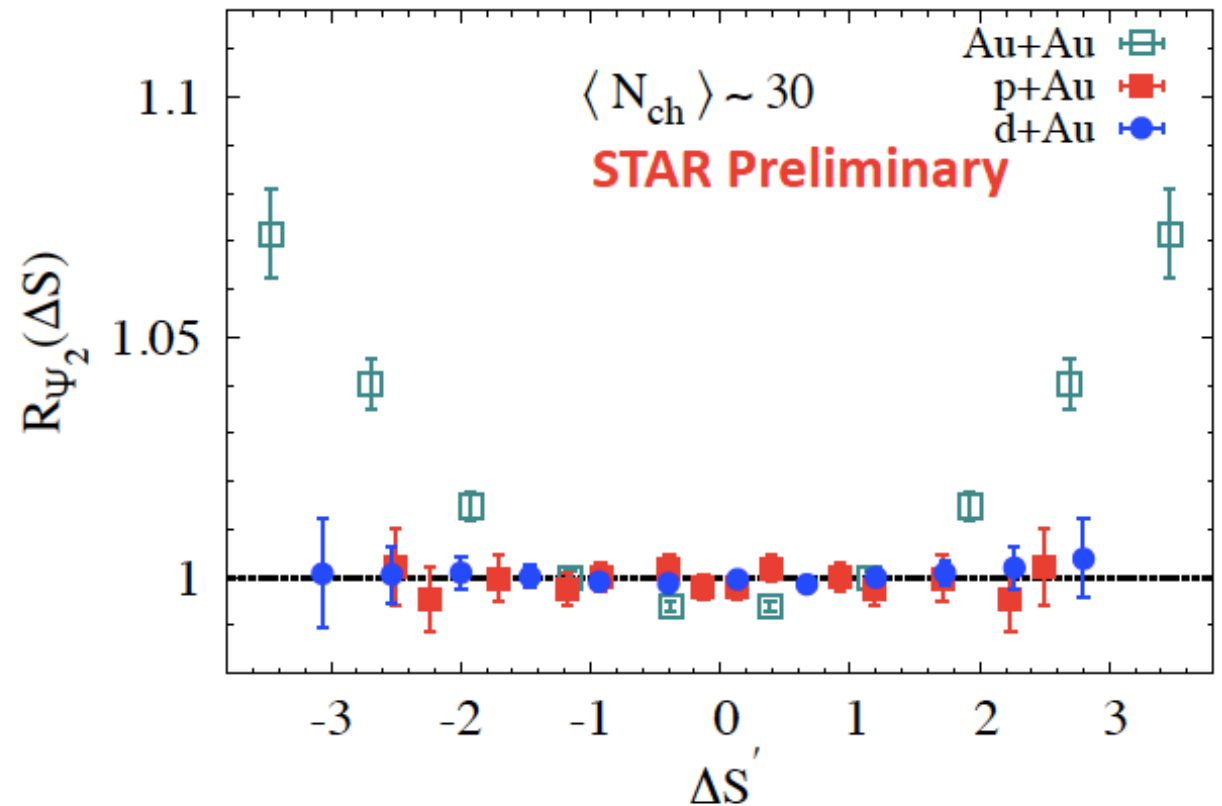
probe the initial tilt of the source and the initial EM field

Chiral Magnetic Effect in Au+Au



H.-J. Xu et al. arXiv:1710.07265

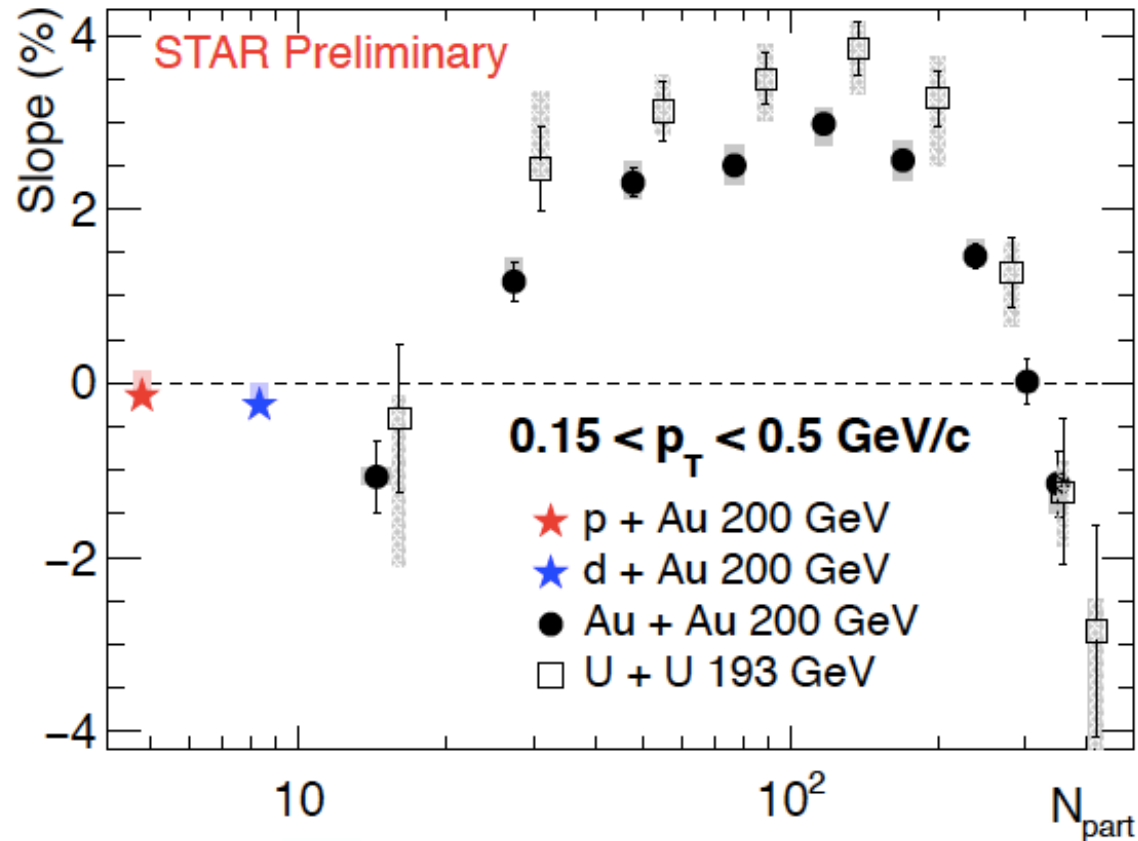
J. Zhao et al. arXiv:1705.05410



N. Magdy, et al., arXiv:1710.01717

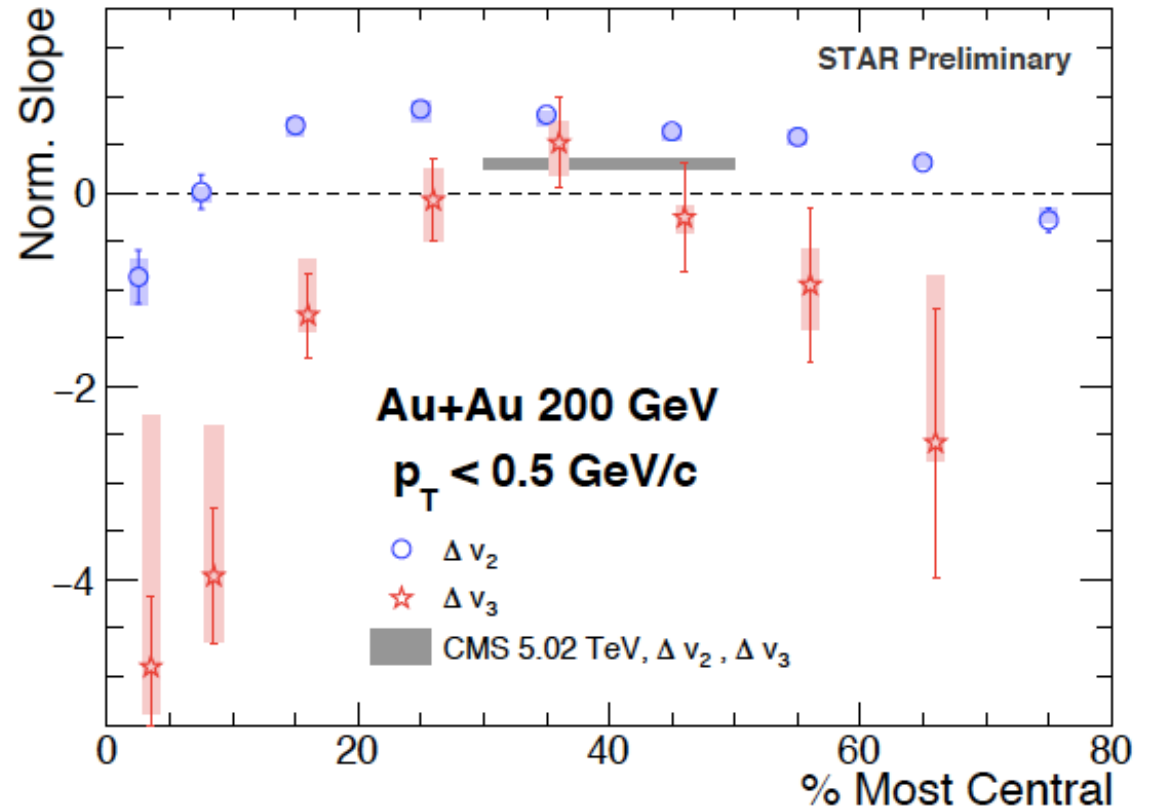
- Isolate possible CME signal in inclusive $\Delta\gamma$ by different methods
- New observable $R_{\Psi_2}(\Delta S)$ shows difference between p(d)+Au and peripheral Au+Au collisions
- Dedicated isobar run this year completed, blind analyses for CME studies being conducted

Study related to Chiral Magnetic Wave (CMW)



$$A_{\text{ch}} \equiv (\bar{N}_+ - \bar{N}_-) / (\bar{N}_+ + \bar{N}_-)$$

$$\Delta v_2 = v_2^- - v_2^+ \approx r A_{\text{ch}}$$



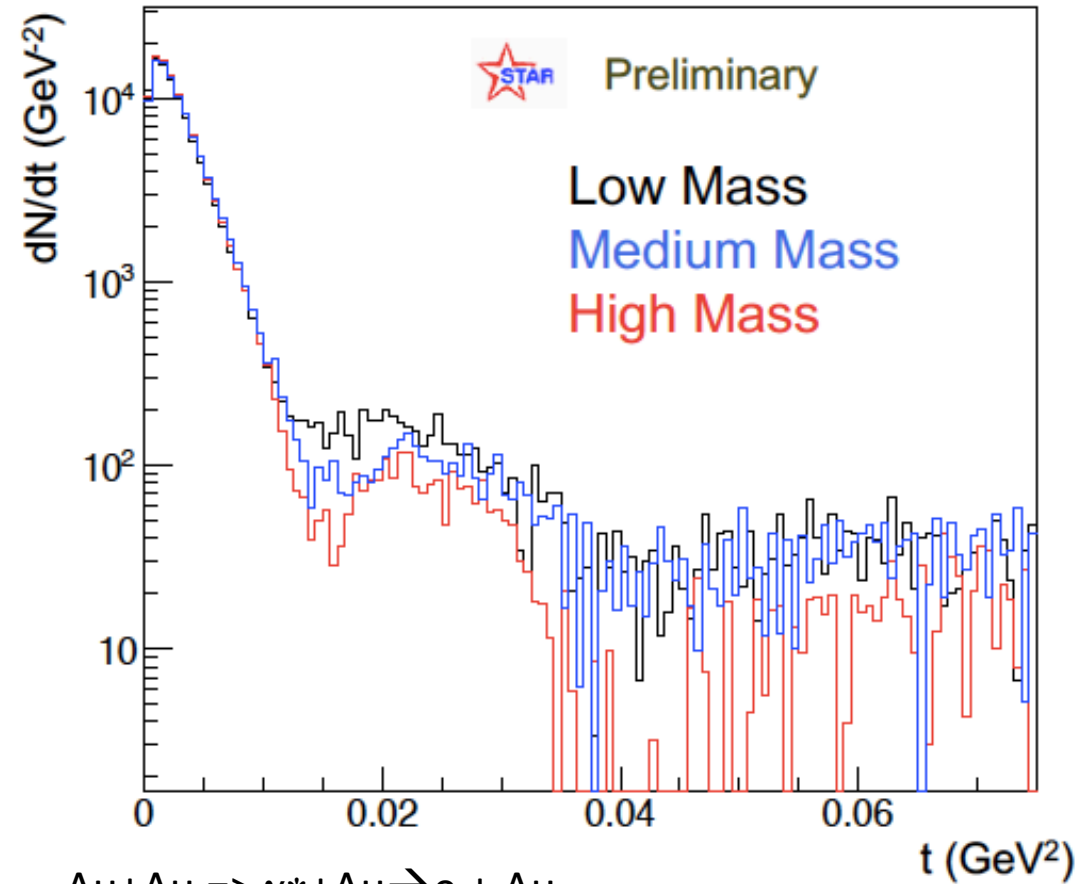
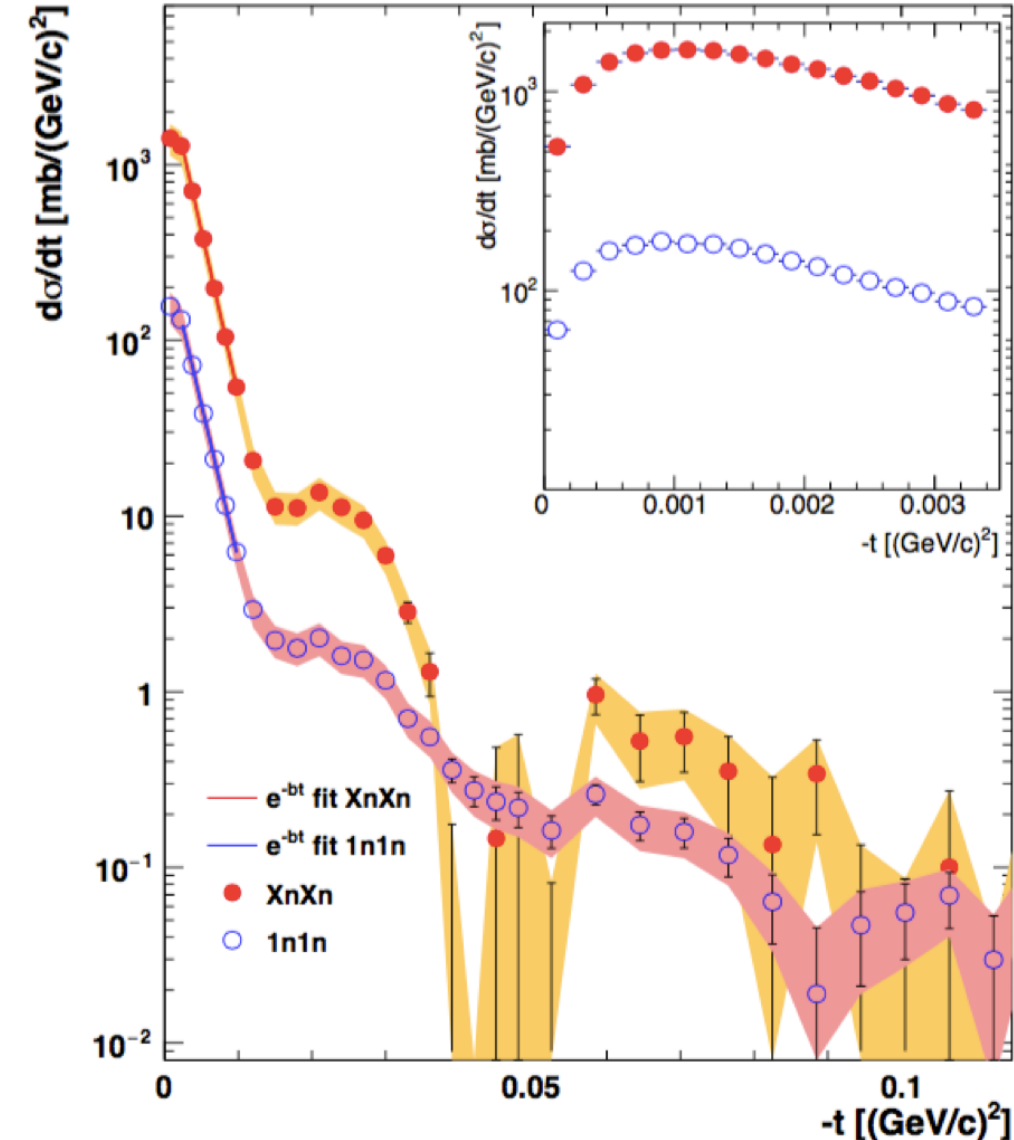
$$\text{Norm.} \Delta v_n = 2 \frac{v_n^- - v_n^+}{v_n^- + v_n^+}$$

- Differences in slope (r) among p/d+Au, Au+Au and U+U consistent with CMW expectation
- Difference between normalized Δv_2 and Δv_3 in most central and peripheral collisions

Coherent Diffractive as probe of nuclear shape



PRC 96 (2017)



$$\text{Au+Au} \Rightarrow \gamma^* + \text{Au} \rightarrow \rho + \text{Au}$$

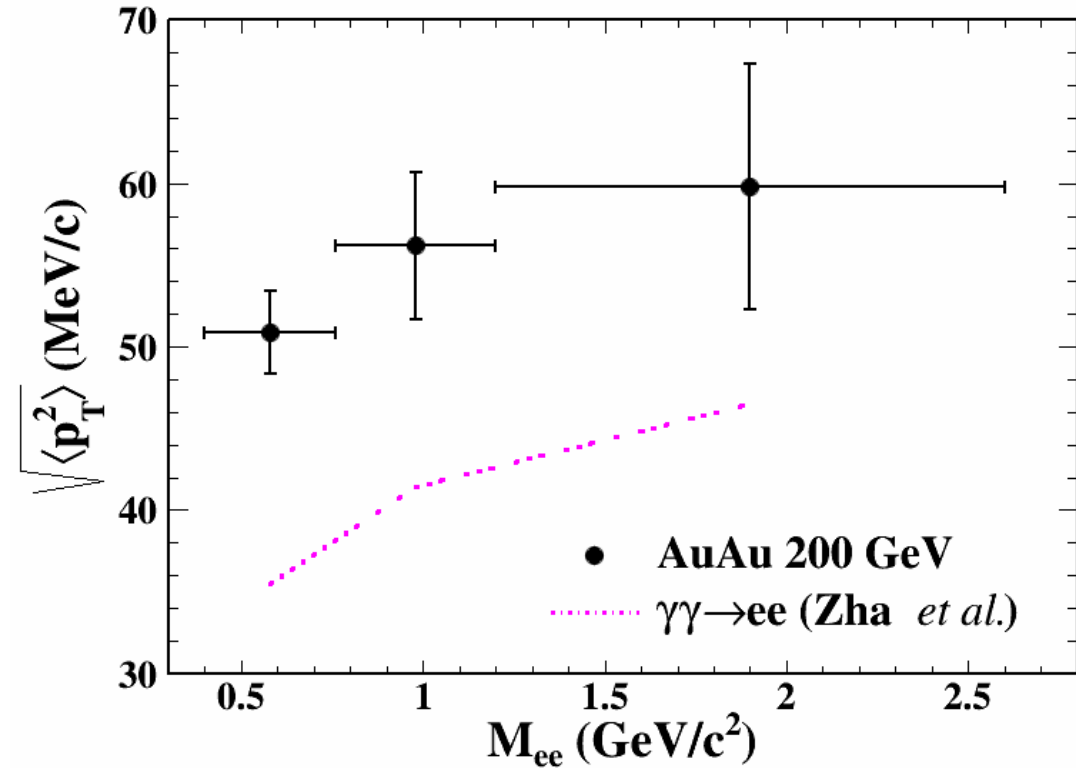
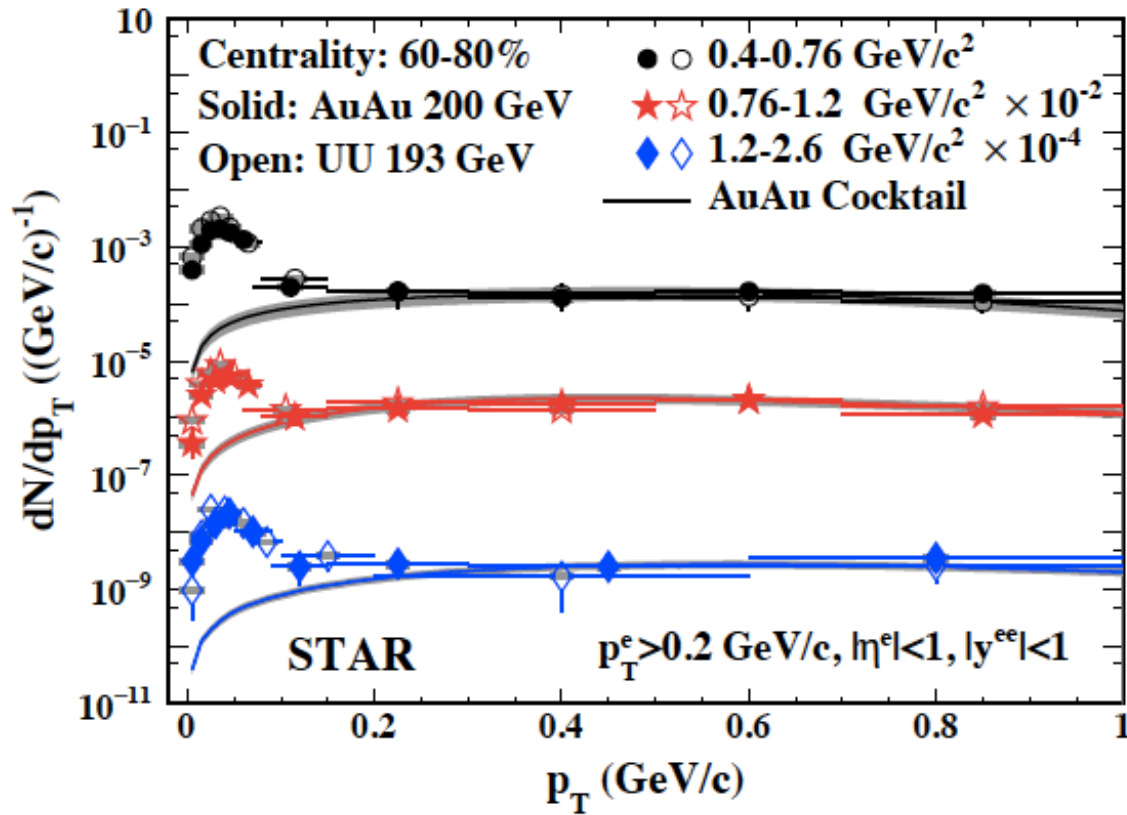
$$\rho \rightarrow \pi^+ \pi^-$$

Strong electromagnetic fields generated by passing nuclei
 At an EIC, we can directly control (x, Q^2) to probe gluon distribution
 Tool developments and inclusive measurements can be done at RHIC NOW.

Coherent $\gamma+\gamma \rightarrow e^+e^-$ as probe of QGP?



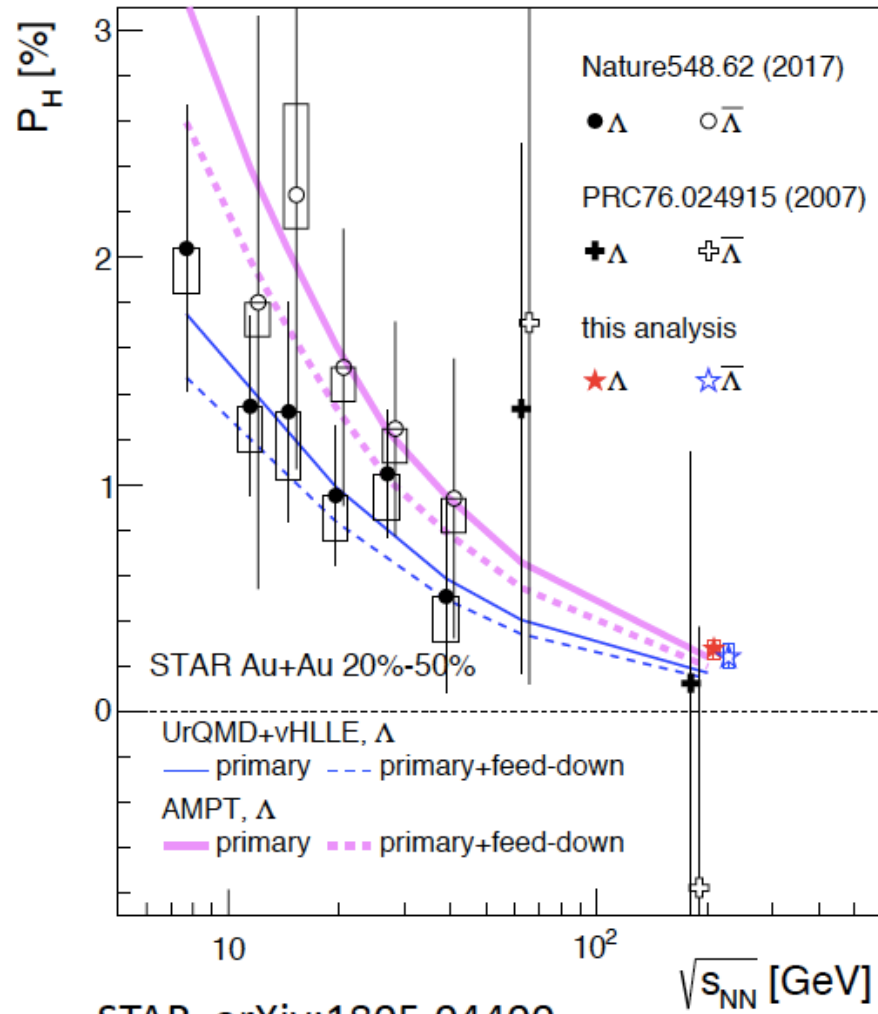
arXiv:1806.02295, submitted to PRL



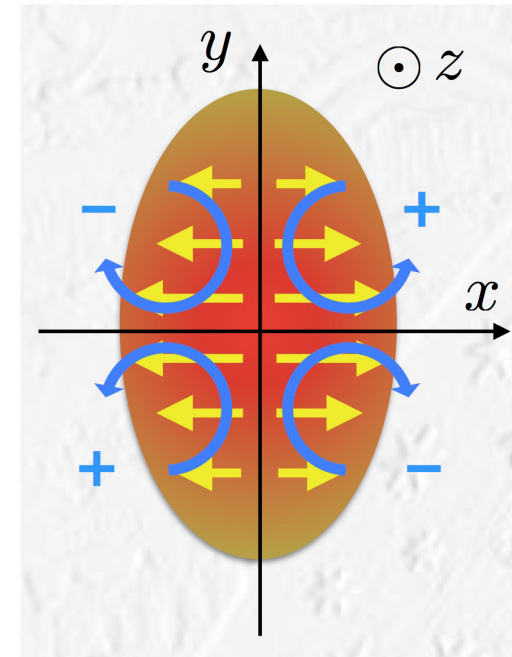
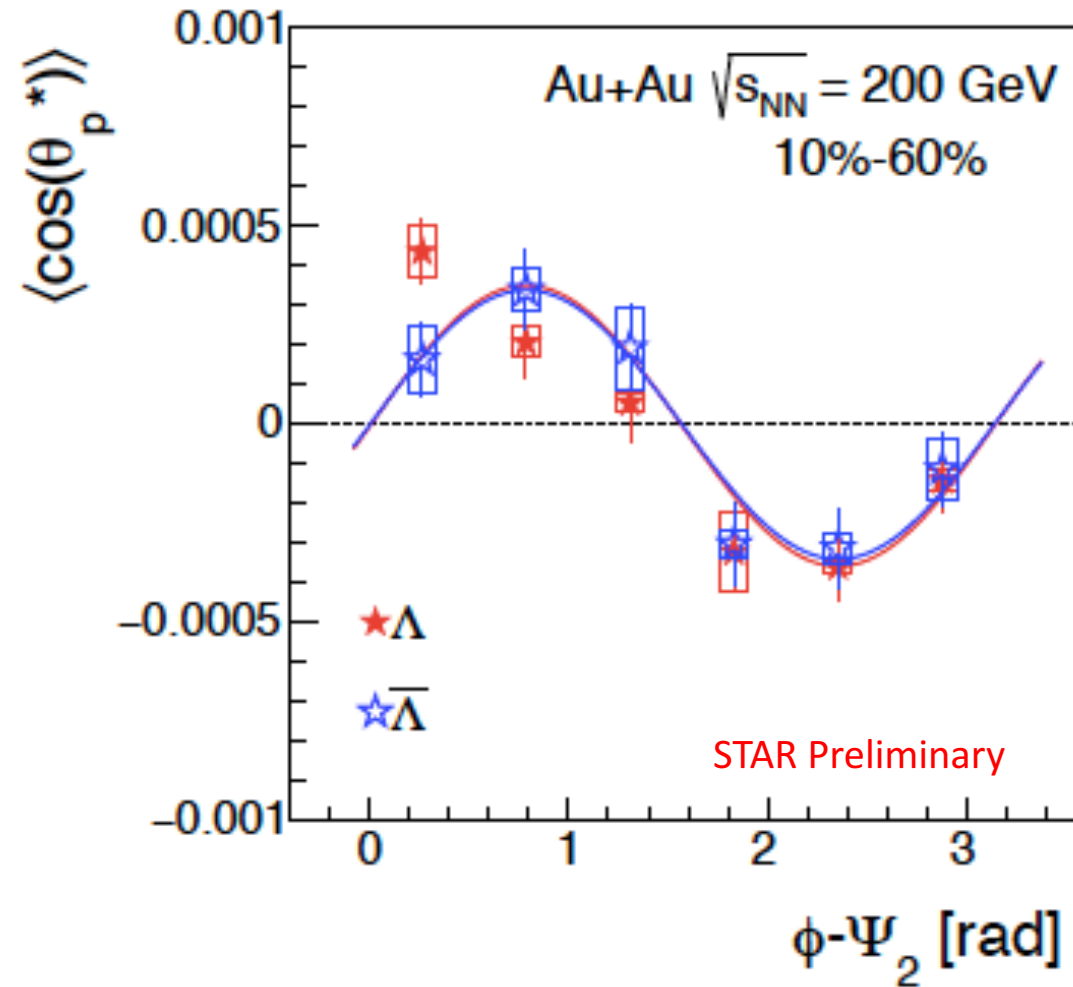
Zha, *et al*, PLB 781 (2018) 182

- Coherent Light-light interaction in non-central Au+Au collisions
- Characteristic low- p_T and Large excess over hadronic cocktail and hot-medium models
- p_T broadening compared to $\gamma+\gamma$ models, which explains well yields and UPC collisions

Global Polarization and Vorticity



STAR, arXiv:1805.04400

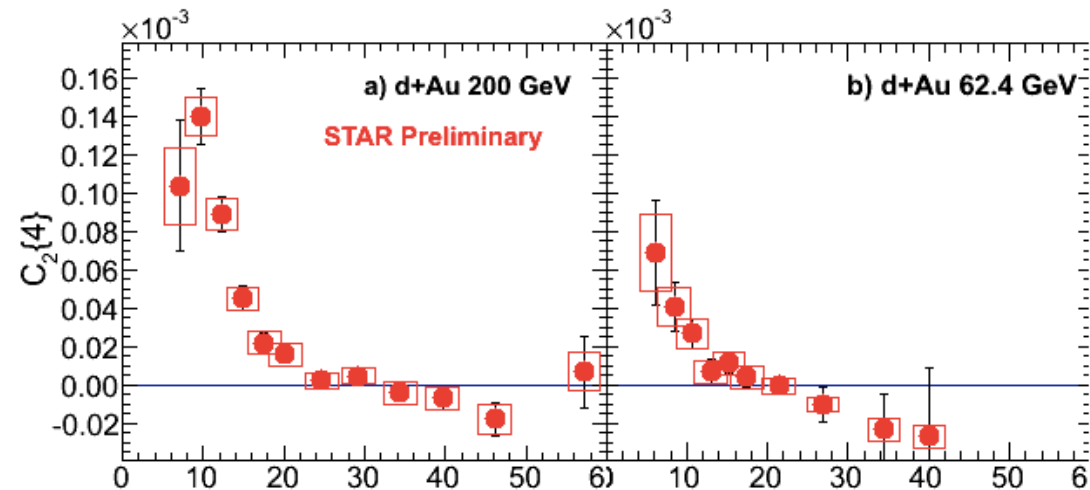
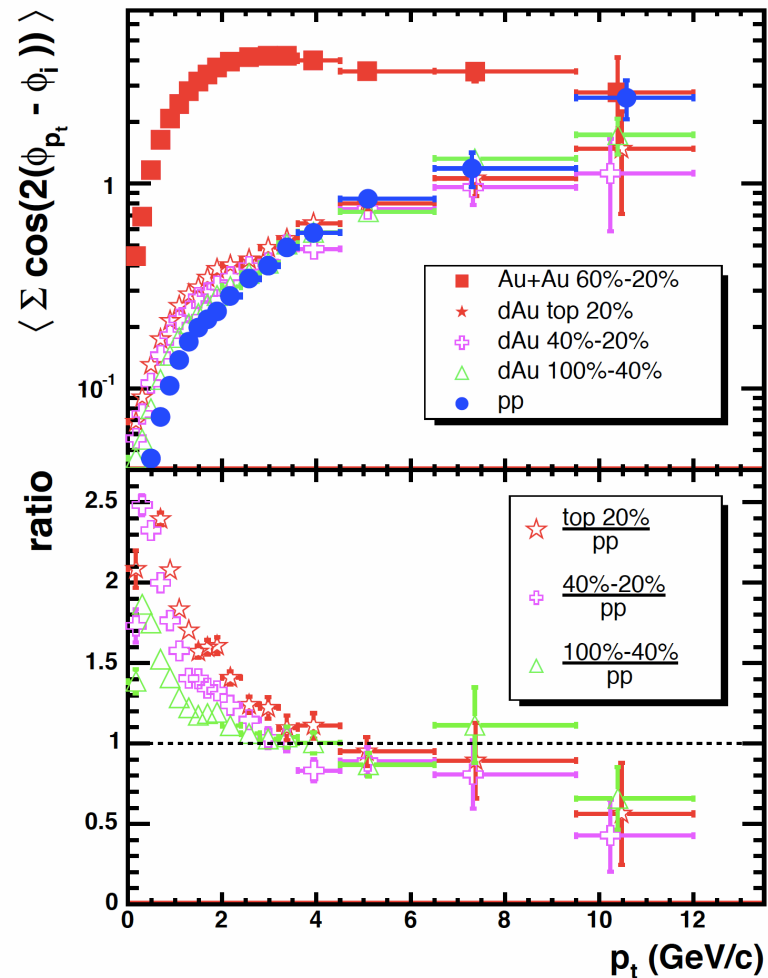


- First observation of Λ global polarization at 200 GeV
- First observation of quadrupole structure of Λ polarization along beam direction

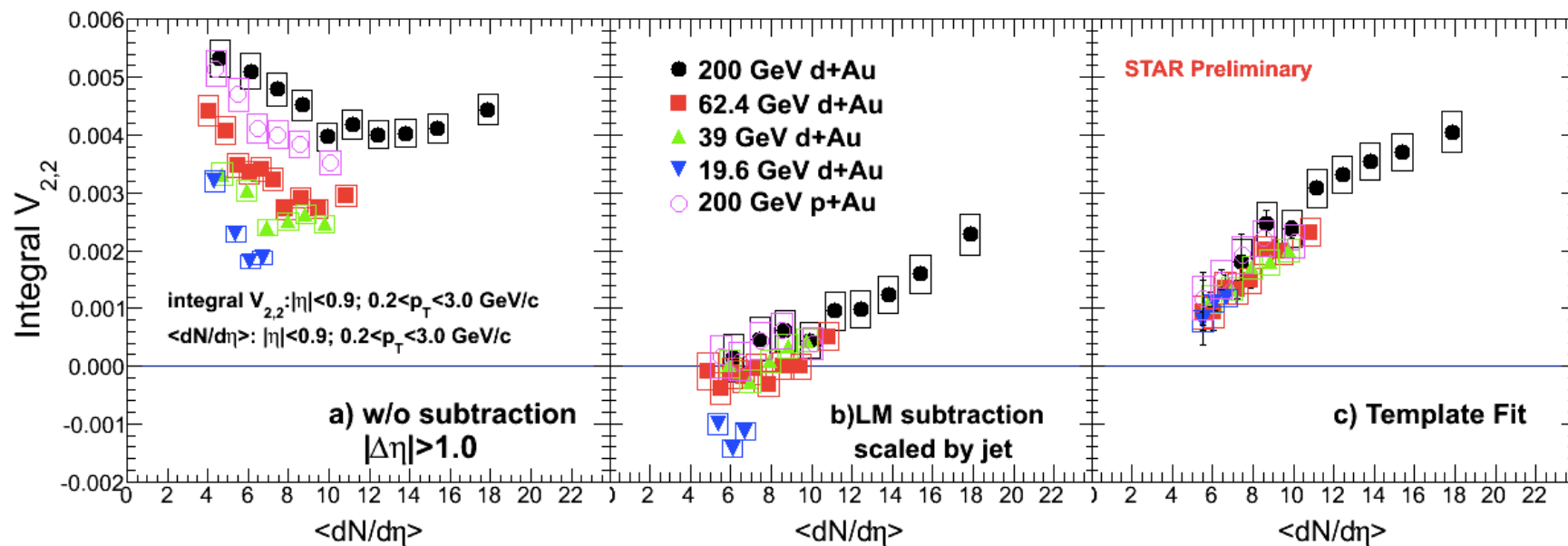
Small-system Azimuthal Correlation analyses



STAR, PRC 72 014904 (2005)

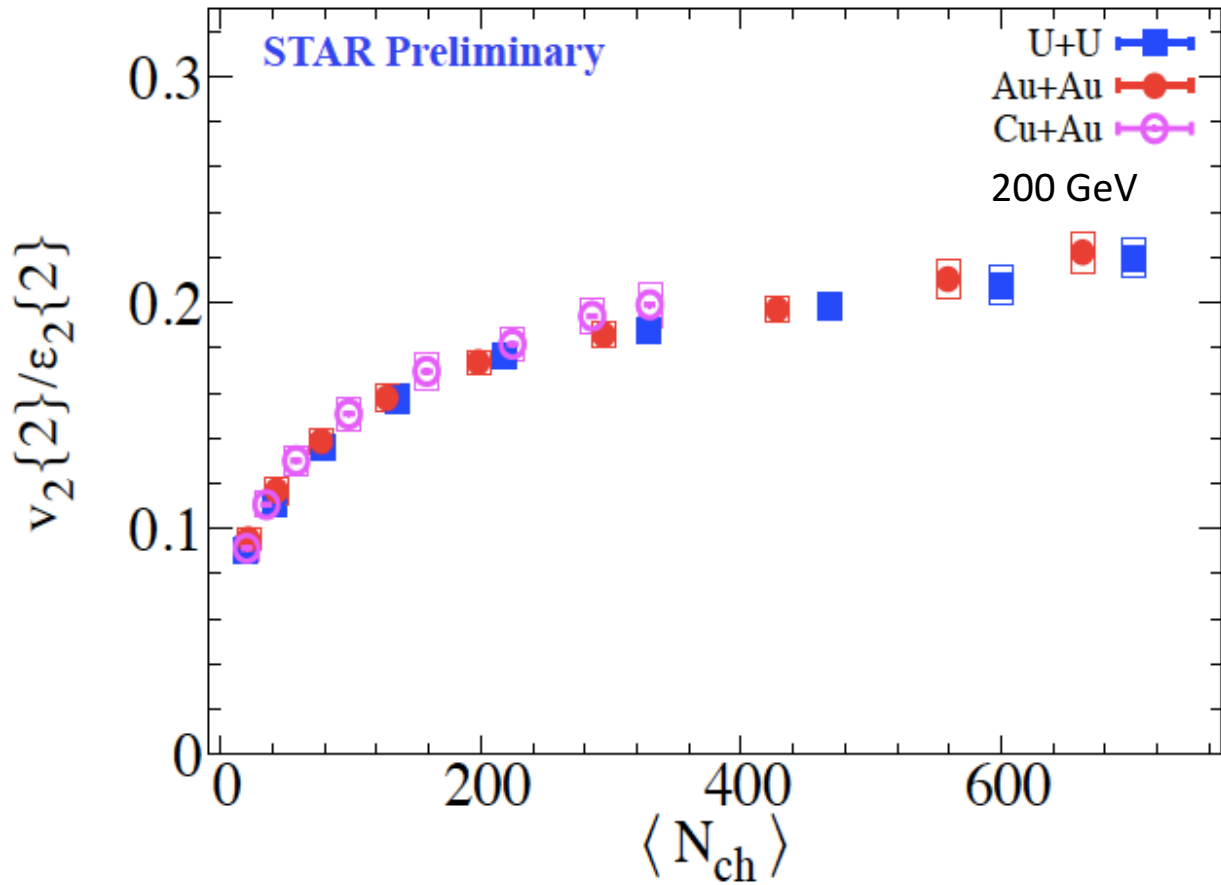


Smooth progression from pp/dAu toward Au+Au, seem to scale with Nch



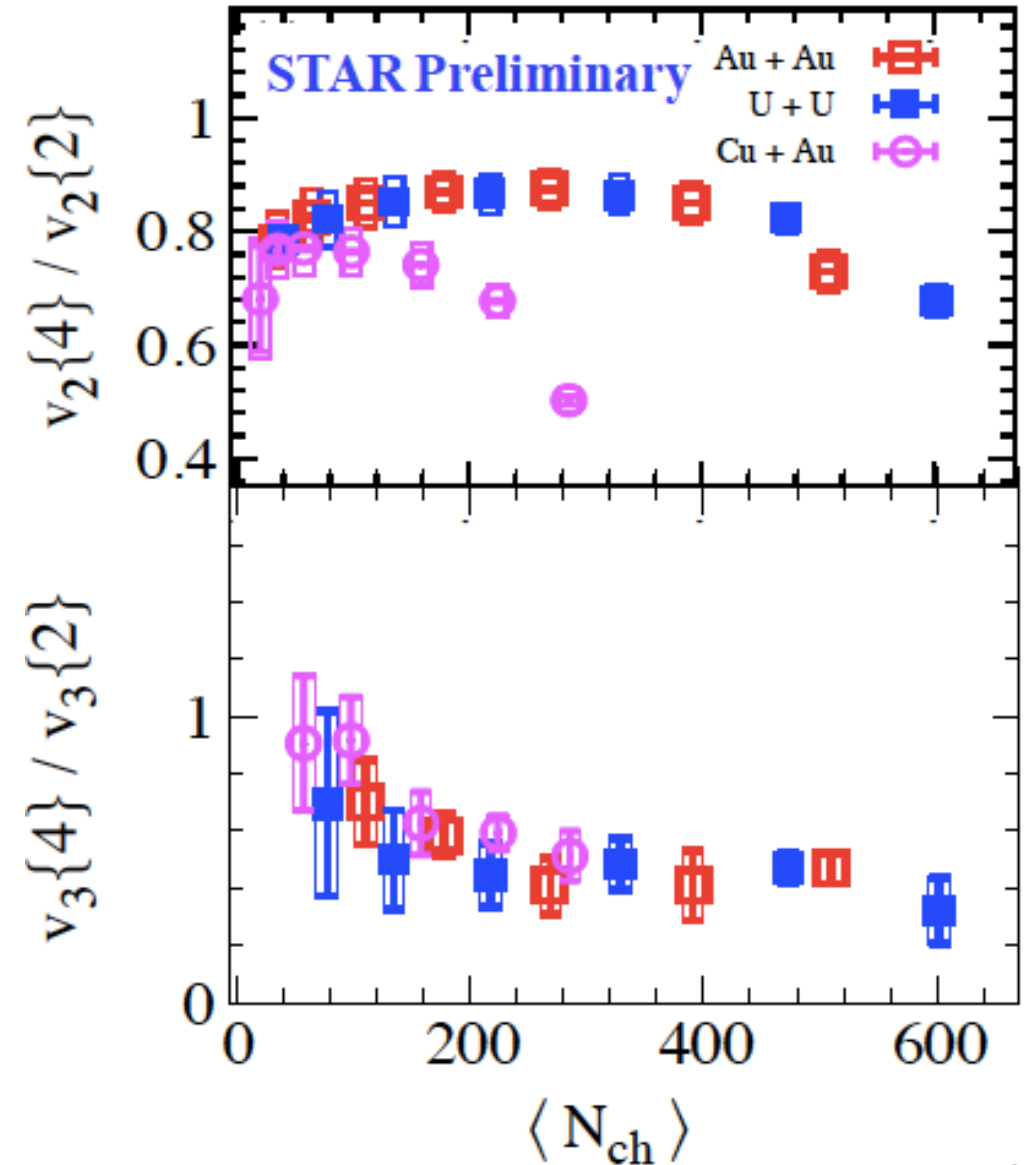
Different $V_{2,2}$ from different methods to correct for non-flow background in p/dAu collisions. Be careful about the assumptions of the methods.

Flow and Fluctuation scaling in multiple systems

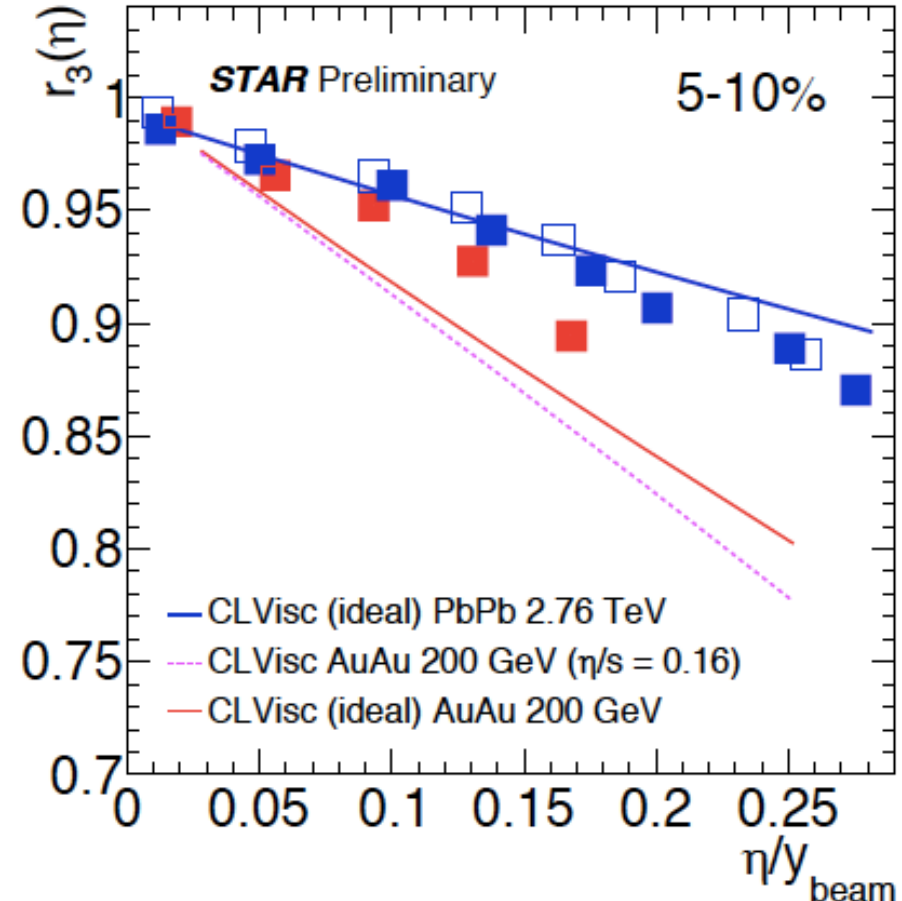
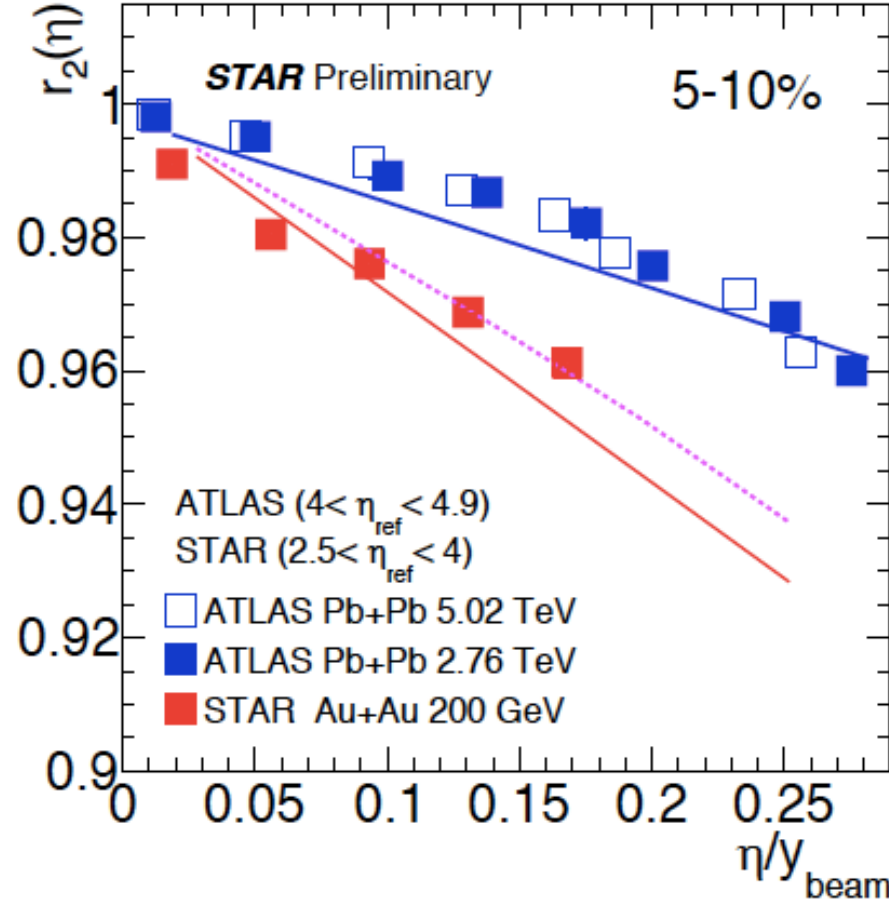


$v_2\{2\}/\text{geometry}$ follow N_{ch} scaling

Ratio of $v_2\{4\}/v_2\{2\}$ is sensitive to flow fluctuations.



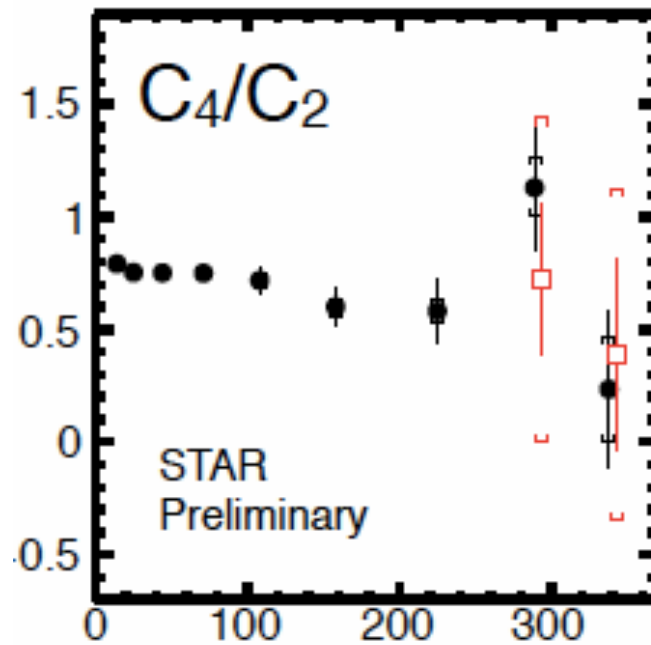
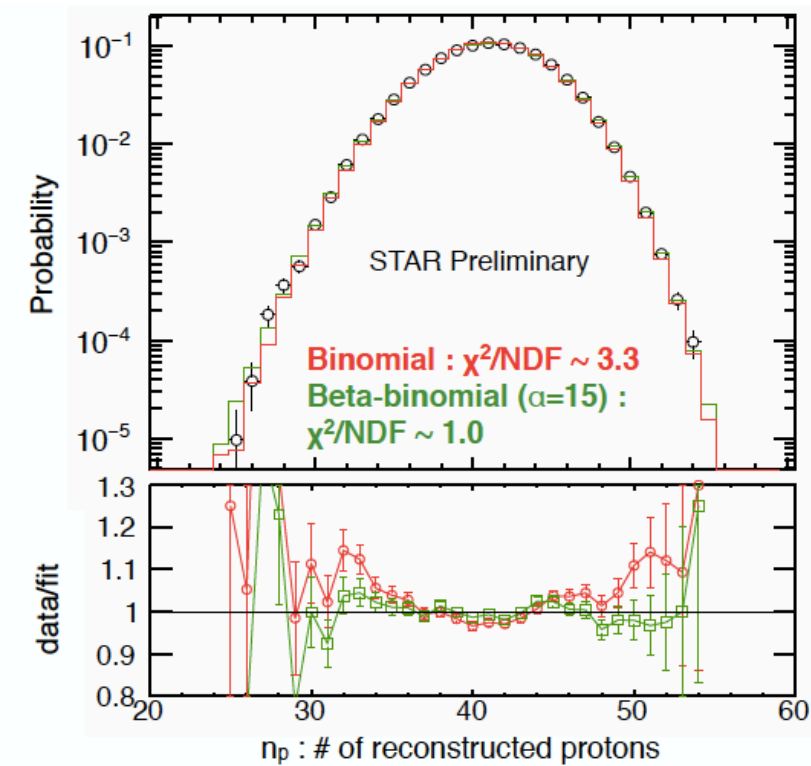
Longitudinal Flow Decorrelation



$$r_n(\eta) = \frac{\langle v_n(-\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}{\langle v_n(\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}$$

- Stronger longitudinal flow decorrelation at RHIC than at LHC
- Hydro calculations can not simultaneously describe LHC and RHIC data

High Moments

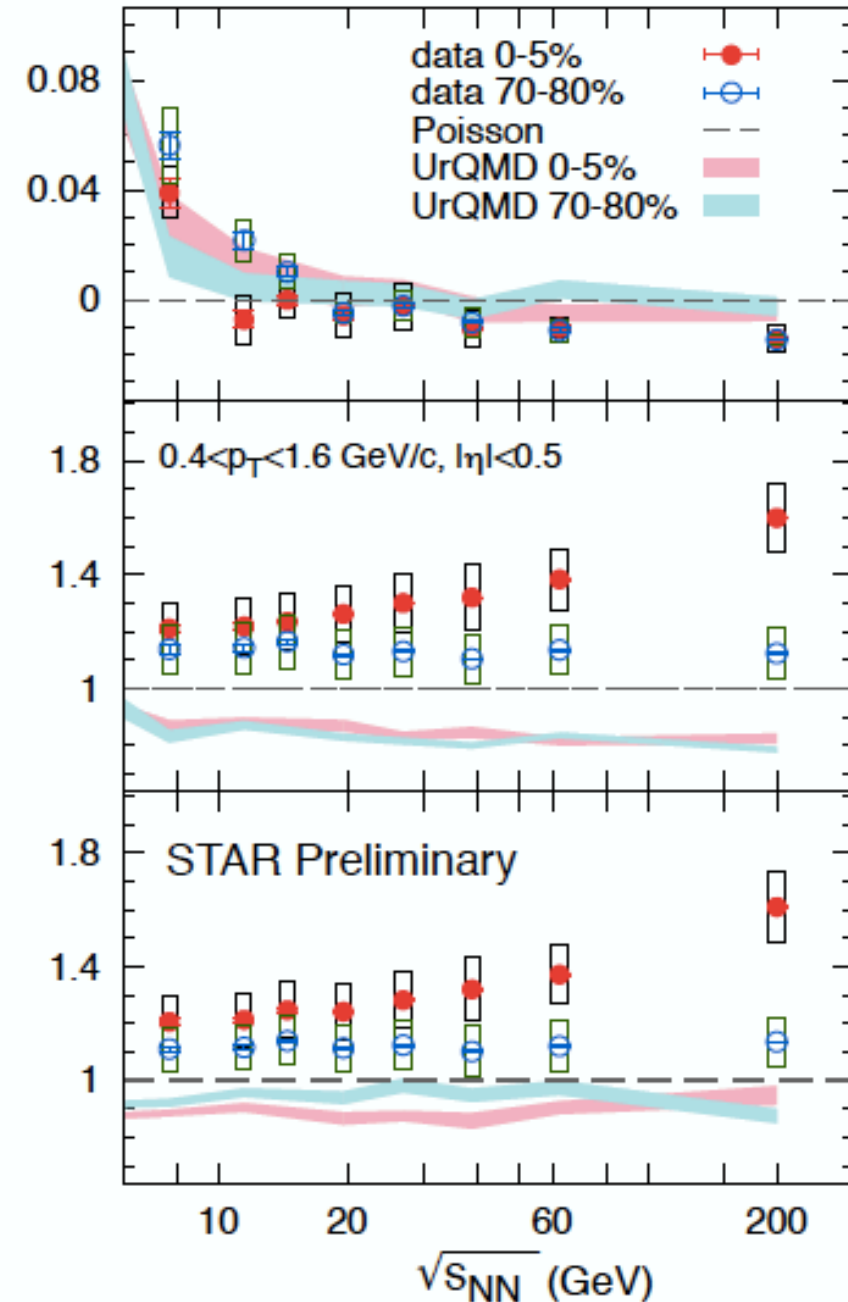


Efficiency correction shows beta-binormal
 Progress toward applying the correction to data
 Off-diagonal correlations measured to be above Poisson or UrQMD

$$C_{p,k} = (\sigma_{p,k}^{1,1} / \sigma_k^2)$$

$$C_{Q,k} = (\sigma_{Q,k}^{1,1} / \sigma_k^2)$$

$$C_{Q,p} = (\sigma_{Q,p}^{1,1} / \sigma_p^2)$$

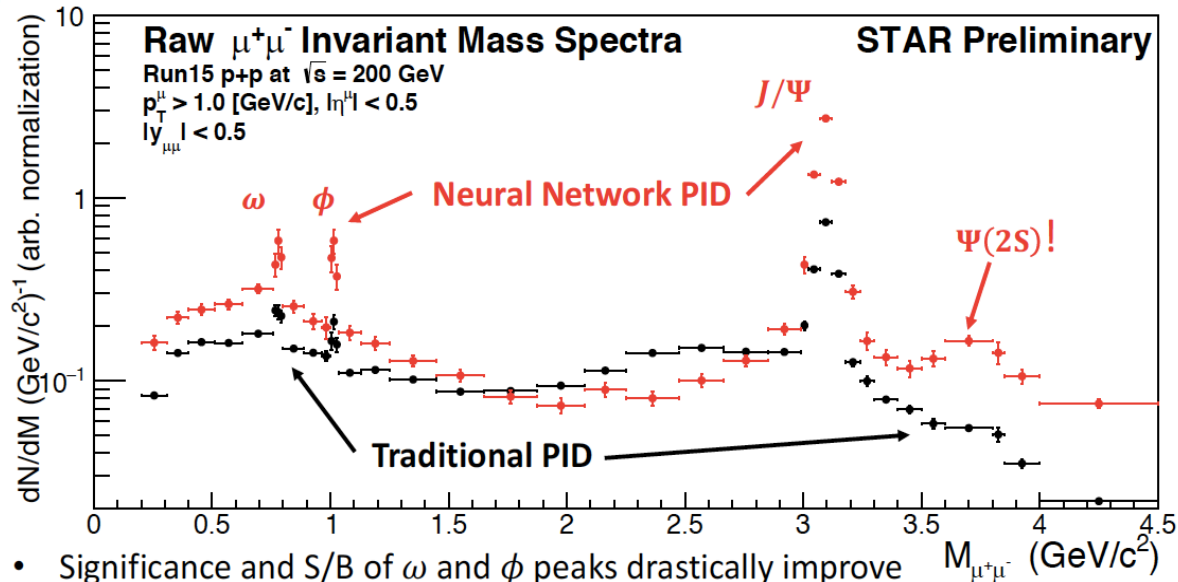
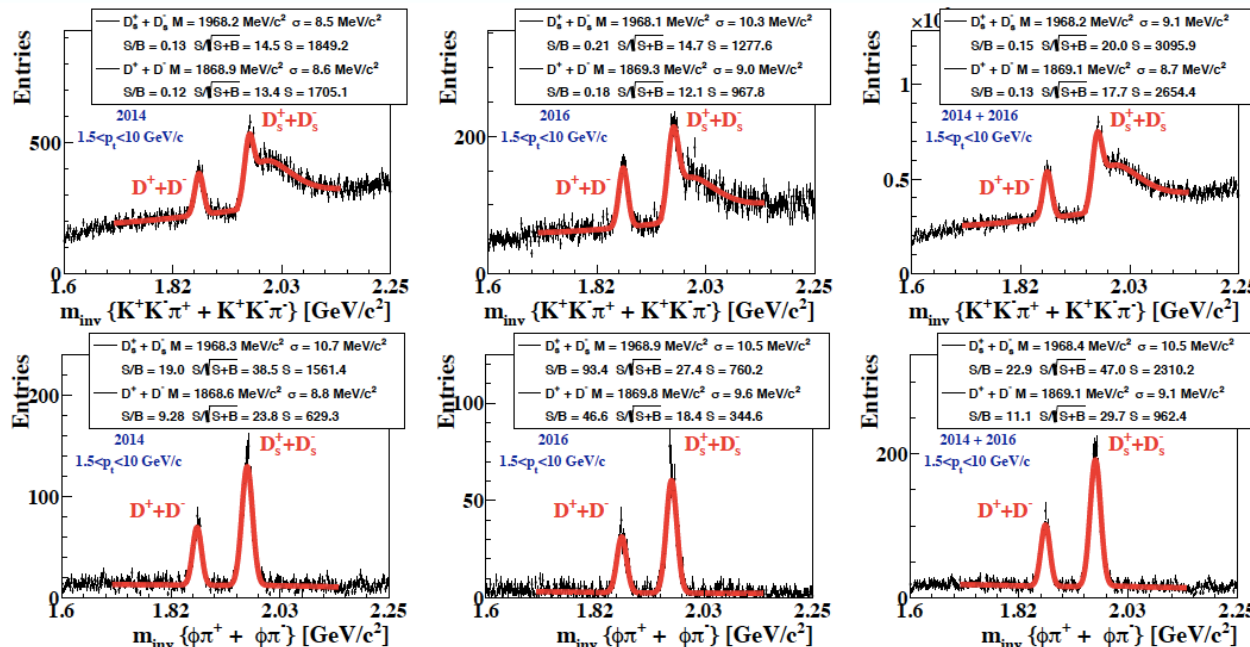


Improvements and new analysis tools

KF Particle with Kalman Filter Particle finder

Many new decay channels and particles

Neural network on muon identification



- Significance and S/B of ω and ϕ peaks drastically improve
- Measurement of $\Psi(2S)$ possible with neural net PID

Isobar Blinding Procedure for CME Analyses



Current Status

- CME analysts actively working with members of S&C and blinding committee on blind Q/A of isobar data and to finalize list of variables needed for physics analysis
- After analysts and committee satisfied, S&C will produce a “blinded” test sample, e.g. from existing 200 GeV Au+Au, utilizing techniques intended for isobar data
- Following completion of “mock data challenge,” blind isobar data samples will be provided in two-step process:

Step-1:

- Provided output files composed of events from a **mix** of the two species
- **Analysis code** and **time-dependent Q/A** tuned, committed to CVS, and frozen

Step-2:

- After analysis of the step-1 data, do a “partial un-blinding”
- Provide files that obscure true runnumber—and therefore isobar species—but do **not** mix events across different runs
- Only run-by-run corrections and code alteration directly resulting from these corrections are allowed

After review of Step-2 complete, fully un-blinded data released

Cold QCD/Spin Datasets and Analyses



- 2015/2017
large datasets

- Calibration and
Analyses
on progress

- Major topics:
forward correlation from pp/pA
 W^{+-} at mid-rapidity,
Forward DY and γ

Year	$\sqrt{s}$ (GeV)	Recorded Luminosity (pb^{-1})	Spin Orientation	B/Y $\langle P \rangle$
2009	200	25	Longitudinal	55
2009	500	10	Longitudinal	39
2011	500	12	Longitudinal	48
2011	500	25	Transverse	48
2012	200	22	Transverse	61/56
2012	510	82	Longitudinal	50/53
2013	510	300	Longitudinal	51/52
2015	200	52	Transverse	53/57
2015	200	52	Longitudinal	53/57
2017	510	320	Transverse	55

**Requests to DOE for supplementary
grant to support more analysis efforts
on RHIC Cold QCD/Spin (STAR and PHENIX)**

Offline Production Summary



- Production status
 - Past datasets produced
 - 2017 datasets ~ 3-4 months from now
 - Thanks to the NERSC/Cori resources and efficient use of Grid and local resources
 - picoDST (x7 smaller than MuDST) in use past datasets being converted
- Other Analysis related updates
 - Embedding workflows showed to work smoothly on NERSC/Cori @ 25k slots
 - most embedding for QM 2018 at NERSC/Cori
 - Grid workflows used for picoDST production/conversion
 - end-to-end efficiency: 98.2%
 - Combining online resources whenever available
 - HFT embedding successful with realistic misalignment framework
- Planned obsolescence of NERSC/PDSF
 - Timeline - no new user accounts NOW, April 2019 closing
 - migration of user analysis from PDSF to BNL storage significant: 170 TB of space
 - picoDST production and storage at RCF
- Storage
 - Will continue to be a challenge
 - SBIR Phase I award: “Next-Generation Technology for the Extremely Efficient Storage, Distribution, and Processing of Nuclear Physics Data”
 - Investigating LOSSLESS data compression (over ROOT methods)
 - Intelligent compression up to x5 (TBC), best x10

Summary



- 2 new institutions joined
- 13 PHD graduates
- 11 papers published,
10 in journal review
- 25 paper committees in action
- 19 Quark Matter talks

- Request supplementary fund for **Cold QCD/Spin** Analyses
- the **isobar** production and analyses progressing well
- **Run 18** about to complete successfully
- **Data production** completed before 2017
- Migration from PDSF to RCF
- **Embedding** progress smoothly
- Addressing **storage** challenge
- **New analysis** methods and measurements

Another very productive year