BNL STAR Group Efforts

Biennial Science and Technology Review of RHIC

Lijuan Ruan, BNL

- Group composition and responsibilities
- Operation support
- Science highlights
- Upgrade involvement and leadership
- Research relevant to EIC science case
- Summary

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science

U.S. DEPARTMENT OF ENERGY

BNL STAR Heavy Ion Group

BNL STAR group dual mission:

- Support for the existing detector systems, operation, data taking and processing, along with development of new detector technology
- Ground-breaking scientific research to utilize these systems to their fullest potential, taking advantage of detailed expertise and knowledge of the detector capabilities
  - Ratio research : operations (8.2 FTE : 24.5 FTE)

BNL STAR group plays central and critical role to the success of the STAR experiment in all of these areas

The researchers and their roles at STAR

STAR Council
59 institutions,
12 countries
Chair: H. Huang
BNL Rep: F. Videbaek

STAR Spokesperson
Z. Xu
Deputy Spokespeople
Caines,Fatemi,Sichterman

STAR mgt
Geurts (PA)
Lauret (S&C)
Van Buren (S&C)
Christie (ops)
Videbaek (upgrade)

STAR Physics Working Groups
Physics Analysis Coordinator: Geurts
Bulk Correlations: Llope, Nigmatkulov,Xu
Heavy Flavor: Ma, Ye
Jet-like Correlations: Kauder, Schmah
Light Flavor Spectra: Kumar, Huang
Spin: Drackenberg, Vossen
UPC: Seger, Guryn

BES Focus Group: Sorensen, Keane, Odyniec
Tracking Focus Group: Tang, Margetis

STAR Group Leader: Z.Xu

Focus Groups:
Beam Energy Sscan: Sorensen, Keane, Odyniec
Tracking: Tang, Margetis, Fisyak, Chakabera, Ke

STAR Operations

Detector Support Group
Leader: Christie
DAQ: Ljubicic, Landgraf
TPC: Lebedev
Trigger: Crawford
HLT: Ke, Tang
Magnet: C-AD
Slow Controls: Cherney
BEMC: Tsai
EEMC: Jacobs
Laser: Lebedev
ZDC: Z. Xu, Tang
BBC: Ogawa
FMS: Trentalange
TOF : Ruan, Eppley
MTD: Ruan, Eppley
HFT : Ye, Thomas, Conti, Videbaek
RP: Guryn, Pak

Technical Support Group

S.Valentino	Head EE
Soja	MT
Sexton	MT
Scheblein	Designer
Kuzcewski	ET
Camerada	ET
Tkatchev	EE
Scheetz	EE, DAQ,iTPC
Hammond	ET

Software & Computing

Lauret	Leader
Van Buren	Co-Leader
Didenko	Production
Webb	Offline software coordinator
Perevotchikov	Simulation and tracking support
Arkhipkin	Online/Database
Smirnov	Vertexing and integration
Betts, Poat	Real Time Support
Zhu	Embedding
Witt, Fisyak	TPC software
Hajdu	Grid Development
Ke	HLT
Ogawa	Trigger Detector
Eyser	FMS/FPS
Ma	MTD

Team Scientific Staff;
Team Professional Staff;
Non-team Staff

STAR Operations Group

- Key experimental support in STAR Technical support Group
  - Essential for maintenance and installation of new detectors

  Leader: Christie (moved to CAD in 12/1/2015, 75% at STAR)

  Mechanical Engineer Sharma

  Facility Manager Soja

  Mechanical Tech Soja, Sexton (left in 10/1/2015)

  Mechanical Designer for modification new detectors Scheblein

- Electronics development, support and repair for STAR sub systems

  Electronics Engineers Valentino (head), Scheetz, Tkatchev

  Electronics Technicians: Camarada, Hammond, Kuzcewski (30% in 2015, 25% in 2016, 20% in 2017).

Electronics Group Activities

2016 & 2017 activities

- ❖New QT8 Prototype 2
- ❖QT8 Power Supply Board Production
- ❖STP Card Production – Trigger System
- ❖New QT32C (QT Motherboard)
- ❖Production of QT Motherboard with Point-to-Point Feature
- ❖QT Interface Card
- ❖Gating Grid Card Prototype 2
- ❖New TAC Card Production
- ❖EPD Prototype Electronics, Cables
- ❖RHICf Level Converter
- ❖FPost Electronics, Rack and Cabling
- ❖Differential to Single Ended Conversion Module
- ❖iTPC construction
  - Pad Plane
  - iFEE Card
  - iRDO Card
  - DEP Board
- ❖Jitter Cleaner PCB for RHIC Clock Signal

2015 Activities

- FPS Electronics, Rack and Cabling
- Replacement Digitizer Cards for BEMC
- Gating Grid Card Prototype 1
- iTPC R&D
  - Pad Plane
  - iFEE Card
  - iRDO Card
- New TAC Card
- New QT8 Card Prototype 1
- QT8 Power Supply Board Design

Software And Computing (S&C) Team Composition

Core team

- Leader: Lauret
- Co-Leader: Van Buren
- Offline software co-leaders: Webb, Perevoztchikov. and Smirnov
- Database Leader: Arkhipkin
- General offline software & sub-system software integration support: Smirnov
- Data production coordinator and software librarian: Didenko
- Distributed production, Grid technology and online tool support: Hajdu
- Real-time, Online and user support: Betts and Poat
- Grid Operation point of contact: Betts
- Web Master: Ke

Software And Computing (S&C) Responsibilities

- The S&C team is responsible for
  - The STAR specific infrastructure (online resources, online networking, Meta-Data archiving, …) in support of the data taking, run monitoring as well as STAR specific user support (real-time support)
  - The development of core framework components, tools and techniques in support of the scientific program. This includes framework development, simulation and modeling, global tracking, global calibration, efficient access to database, efficient retrieval of data from mass storage, …
  - The data reduction and production to physics usable quantities to sustain the experiment's Physics analysis (local and distributed data production)

- The Core team provides technical expertise critical for timely and correct physics results and to ensure data quality as it is recorded – it coordinates activities sustained by external workforce.

- Due to increase workload (more complex datasets, more sub-system), workforce was refocused on software support . With reduced staffing, the following activities are "best effort" basis only: Event Display and visualization, ROOT framework development, Grid activity overall coordination.

Activity Highlights

In addition to operational activities the S&C group members are involved in work aimed at improving efficiency, scalability, stability and precision. This work is crucial to keep up with the increasing demand on computing in the high luminosity RHIC era (and beyond). We focus on publishing our work ⇔ community benefit

- Planning for distributed workflows using Constraint Programing techniques. PhD in CS, Prague (advisor: J. Lauret) – *ACAT 2016* – optimized usage of distributed computing resources through global planning
- Leverage KISTI data production experience to outreach resources @ Dubna / JINR – *Grid 2016* – toward integration and utilization of remote resources into STAR production
- Deployment of distributed file system for online use – *ACAT 2016* –provisioning of large storage space at low (to no) cost, replacement for AFS online provides stability during run
- Use of modern configuration management and monitoring tools (CFEngine, Nagios, …) – *CHEP 2015* – managed and monitored reliable online infrastructure consistent with Cyber-Security (increasing) requirements
- Message Queuing system (MIRA framework) being worked on to extend with remote control capabilities – *ACAT 2014* – deliver modern and scalable online framework to sustain higher data taking demands, EPICS replacement for future experiments?
- Reconstruction R&D, optimized material accounting and hit inclusion for TPC+HFT tracking (*VERTEX2015*) and revisit of the Vertex Finding algorithms in diverse datasets (*submitted CHEP 2016*) - integration of HFT to meet performance deliverables, high precision primary track assignment & refined secondaries
- Simulation R&D, miss-aligned geometry framework – *submitted CHEP 2016* – high precision efficiency evaluation via realistic simulations (embedding)
- Calibration R&D, in-situ studies of the effects of alternative TPC gating grid operational modes on dynamical TPC distortions (viability of increasing event acquisition rates) & simulations of TPC multi-wire regions to understand ion leakage scenarios (reduce distortions in the iTPC upgrade and improve corrections at high luminosities)

Group Hardware Operational Responsibilities

TPC Hardware: Lebedev

Magnet: Christie

DAQ: Ljubicic, Landgraf

ZDC: Z.Xu, Tang

TOF- MTD: Ruan

HFT: Videbaek

HLT: Ke, Tang

RP-II: Guryn, Pak (moved to CAD on 10/1/2015)

HCAL pixelation R&D: Bland

Publication, Leadership & Awards

STAR had 15 publications in FY15, 12 in FY16 and 6 submitted.

The BNL group had 14 GPC members (including chairs), and 12 PA's on these papers

Chair of RHIC/AGS users group: Ruan

Co- Chairing of EIC science task force: Ullrich

Awards

- **F. Videbaek** recipient of 2015 BNL Science and Technology Award
- L. Ruan awarded 2016 BNL Sambamurti Award

Research Highlights

Tightly coupled responsibilities for hardware, software, and analysis provide the BNL STAR group a uniquely fertile ground for new uses of the STAR detector

Focus of local researchers

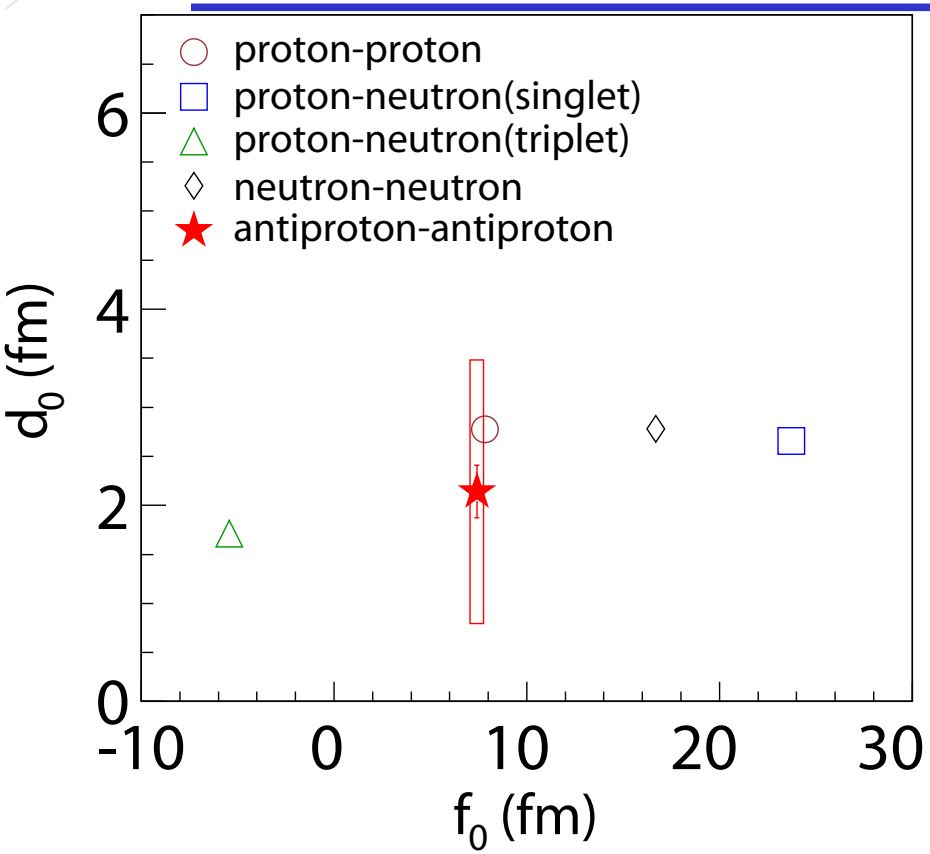
- Heavy flavor, exotics, and dileptons
  - Utilizing RHIC II luminosity and upgrades
    - Z. Xu, Tang, Ullrich, Ruan, Ma, Todoroki, Chakabera, Videbaek, Dunlop
- Flow and correlations: utilizing RHIC flexibility
  - Energy and beam species to constrain system properties with flow phenomena
  - Chiral Magnetic Effect/Wave
  - Initial state fluctuations, viscosity, equation of state

  Sorensen, Prithwish, Tang, Ke
- Elastic scattering, hard diffractive processes, UPC
  - Debbe (RIF 7/1/2016), Lee, Guryn

Extremely important for the collaboration:

Pool of local expertise for supervision of visiting students, post-docs

Measurement of interaction between antiprotons



Scattering length (f0) and effective range (d0) for (anti)nucleons.

Nature 527 345 (2015)

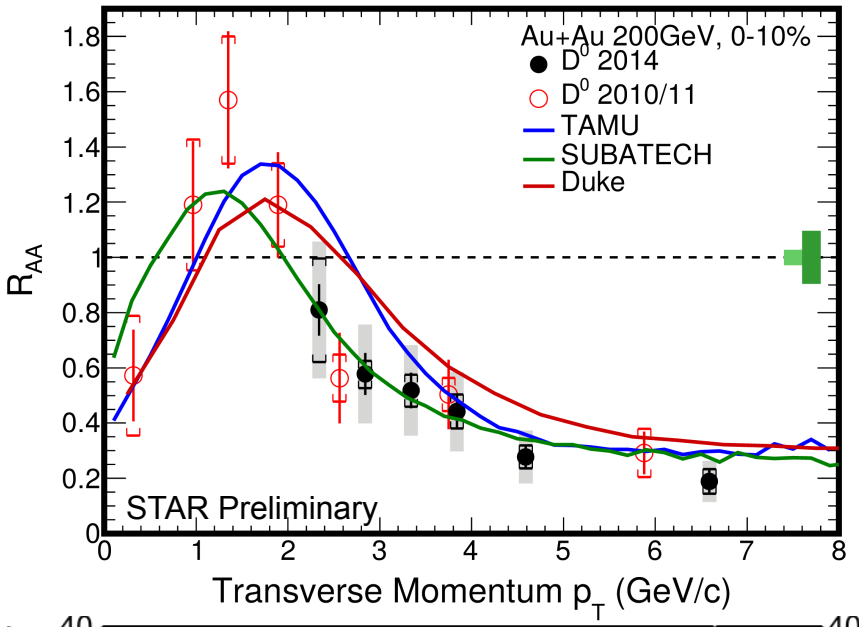
Tang

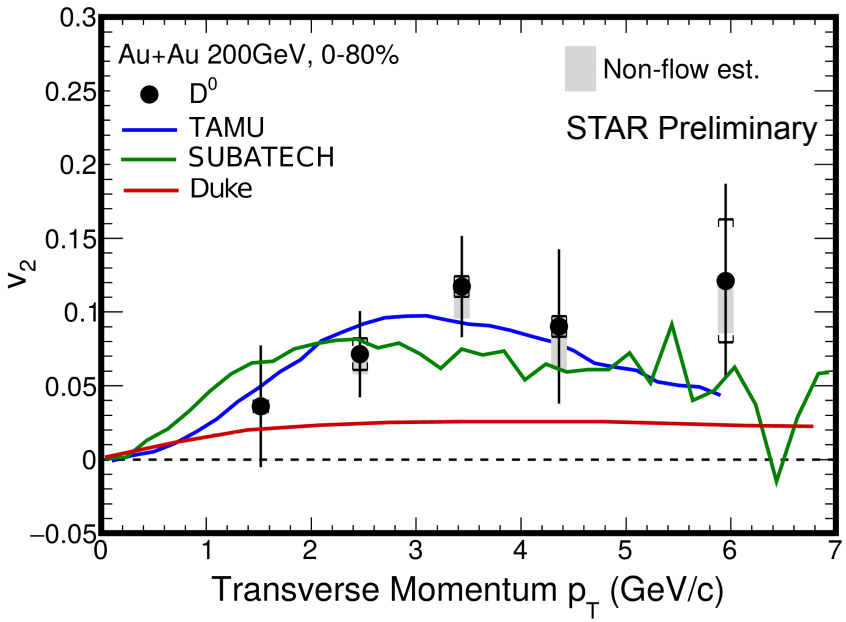
Two key parameters that characterize the strong interaction between anti-nucleons.

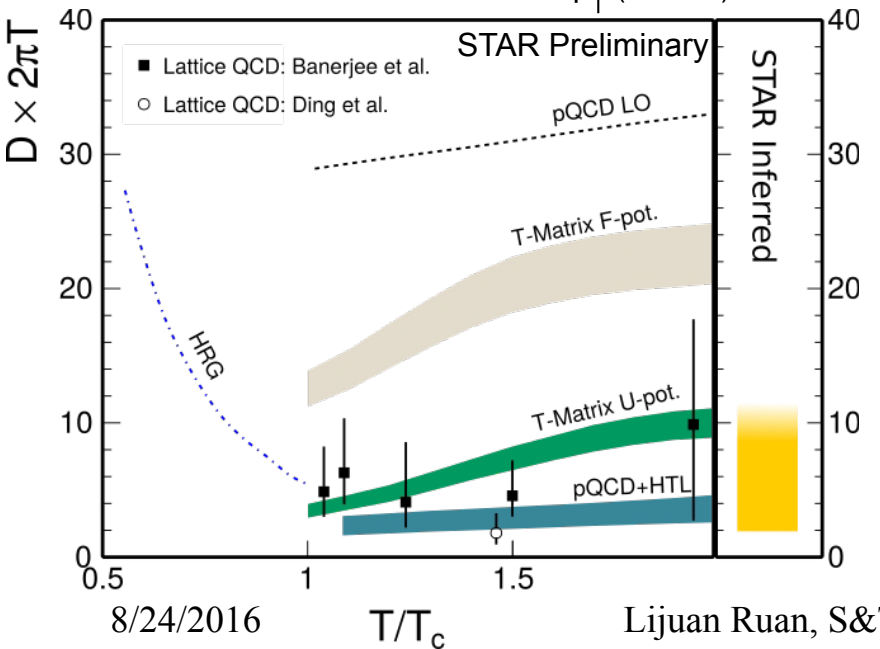
Fundamental ingredient for understanding the structure of more complex antinuclei and their properties.

Independent CPT verification.

Open charm with the HFT







Charm quark flows, interacts with medium strongly.

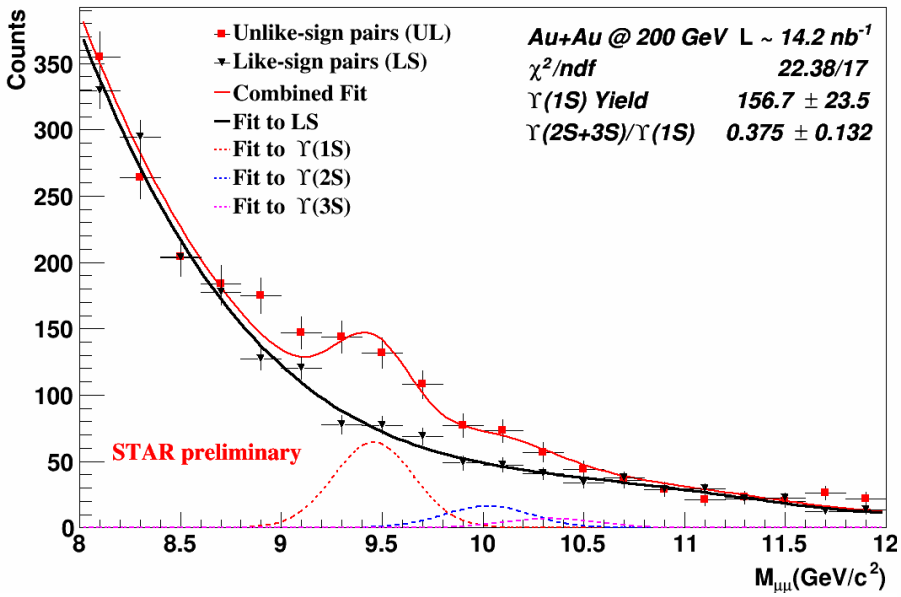
Models with charm diffusion coefficient ($D\times2\pi T$) of 2-10 describe STAR R_{AA} and v_2 data.

Videbaek

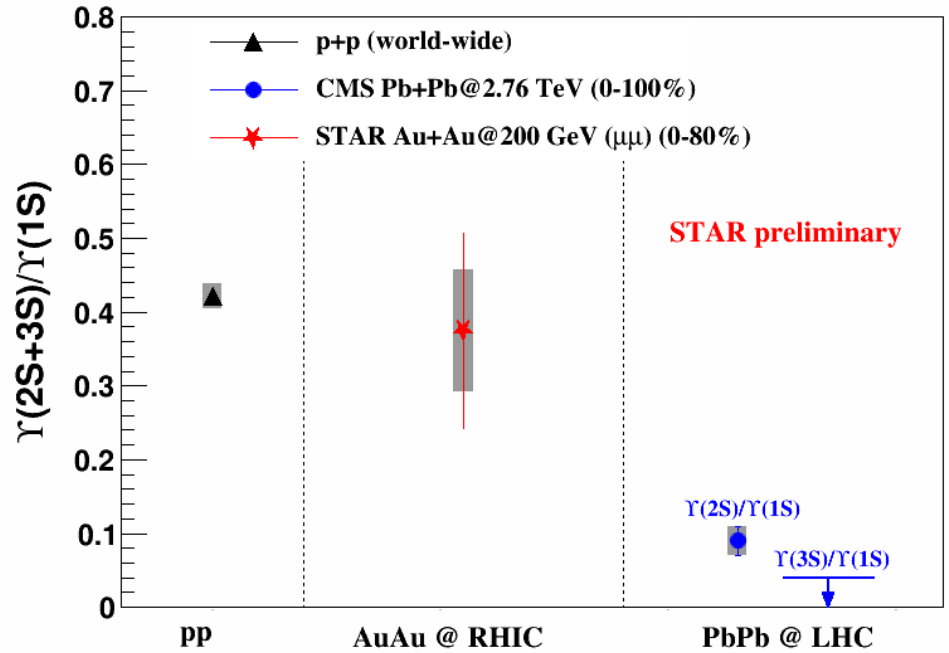
STAR Collaboration, QM2015

Quarkonium with the MTD

STAR Collaboration, SQM2016



Ruan, Ma, and Todoroki



0.28, 0.56, 0.78 fm for Υ(1S), Υ(2S), Υ(3S).

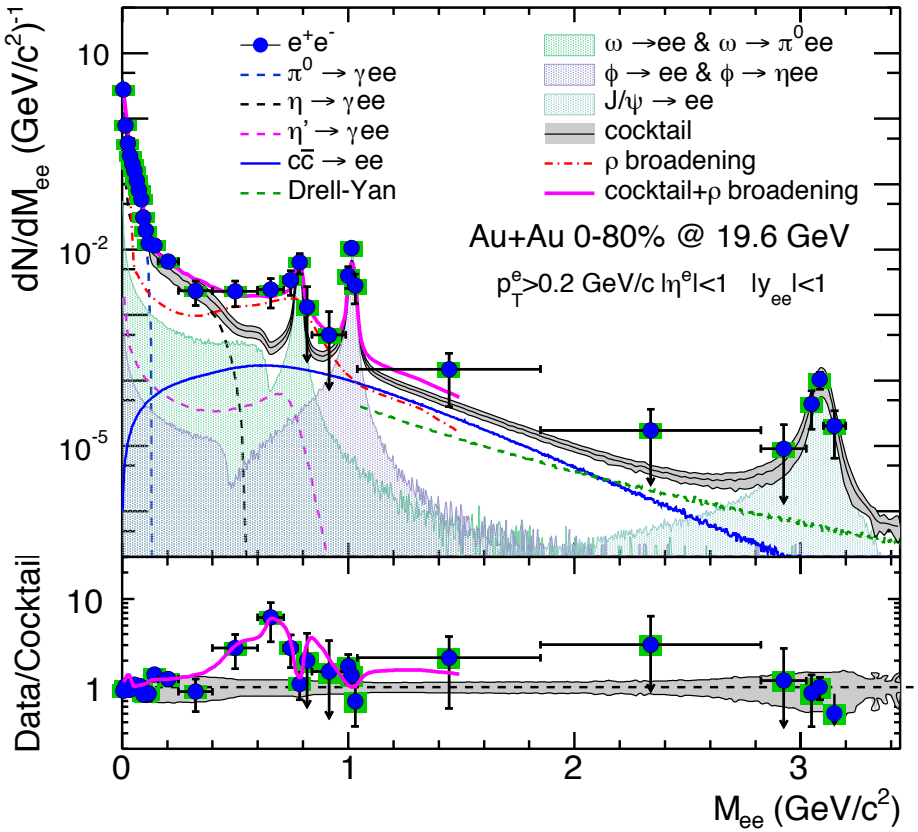
Negligible contribution from b and bbar recombination at RHIC

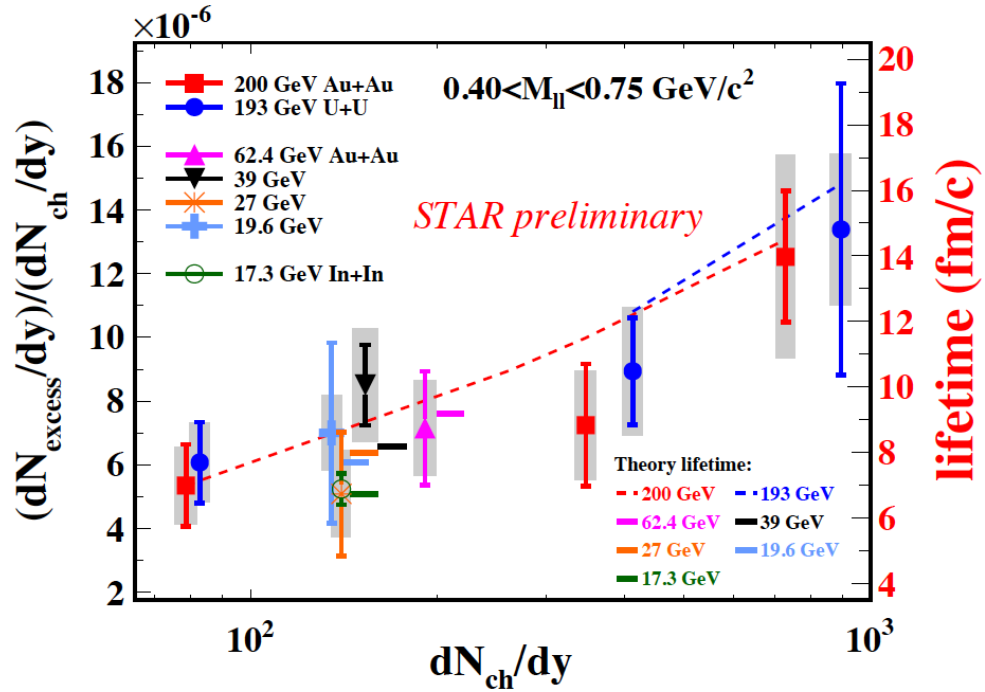
A better probe to study color-screening feature of QGP.

A hint of Υ(2S+3S) less suppressed at RHIC than at LHC!

Electron positron mass spectrum

STAR Collaboration, Phys. Lett. B. 750 (2015) 64; QM2015





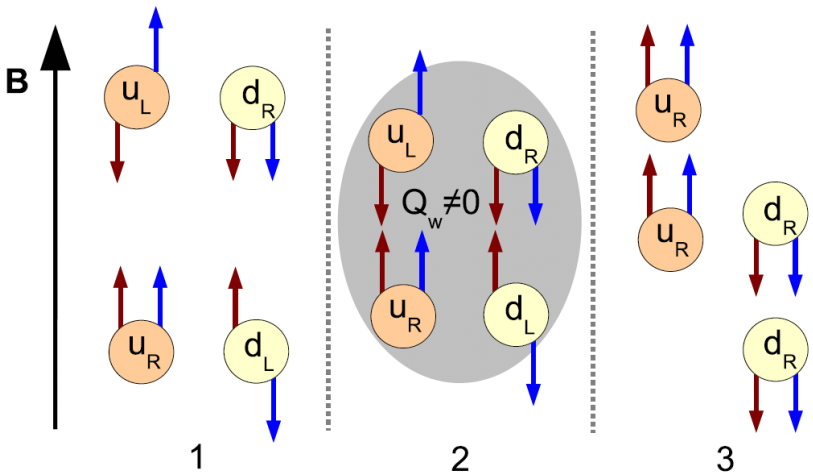
Ruan

Significant excess is observed in $0.3<M_{ee}<0.8$ GeV/c^2, described by a broadened ρ spectral function.

Low-mass electron-positron production, normalized by dN_{ch}/dy, is proportional to the life time of the medium from 17.3 to 200 GeV.

Detecting the Chiral Anomaly in U+U

charge separation caused by anomaly induced chiral imbalance

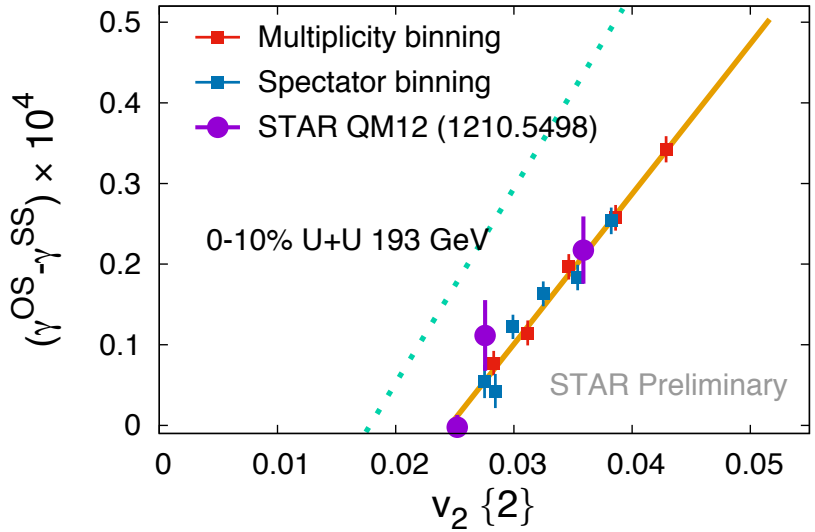


$$\vec{J}_V = \frac{eN_C}{2\pi^2}\mu_A\vec{B}$$

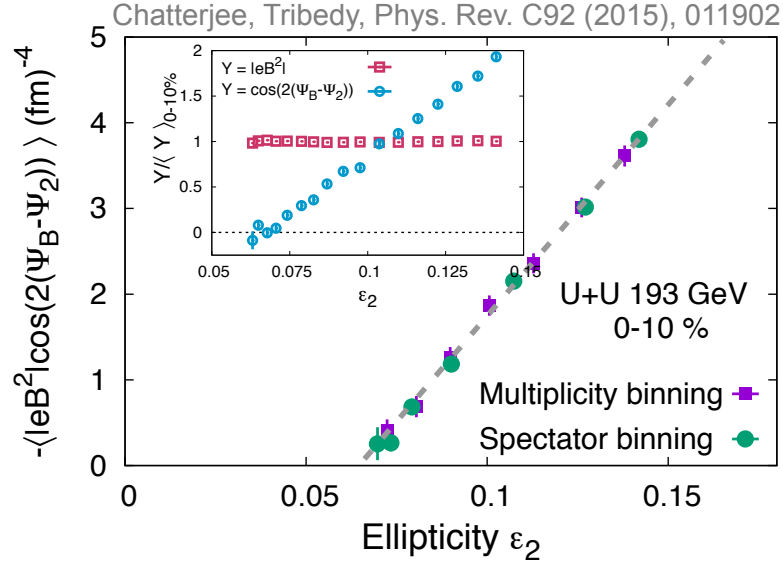
Charge separation in central collisions follows projected B-Field, not v_2

Evidence pointing to charge separation caused by the chiral anomaly of QCD

P. Tribedy, UCLA Chirality Workshop 2016



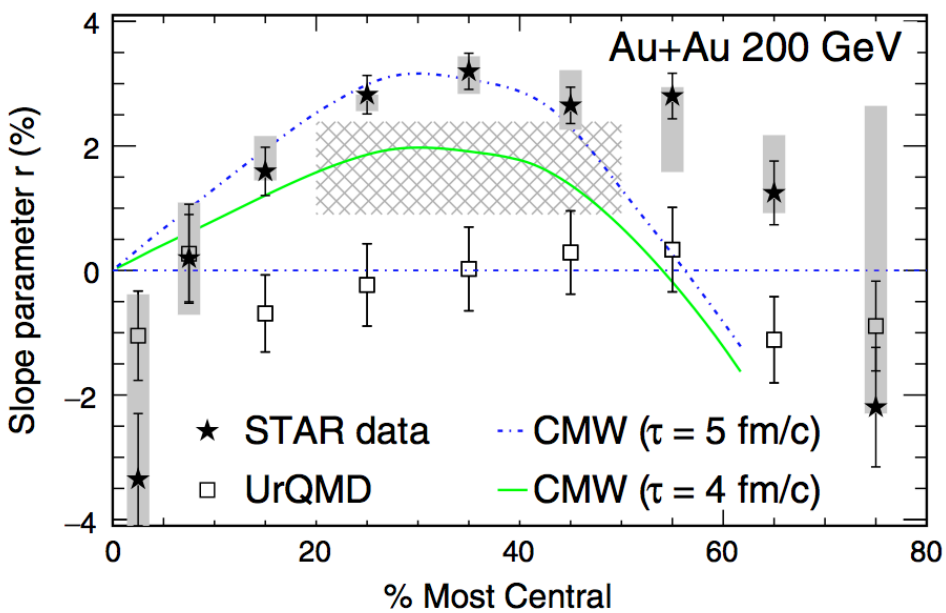
Chatterjee, Tribedy, Phys. Rev. C92 (2015), 011902



Sorensen and Tribedy

Chiral Magnetic Wave : Fundamental QCD phenomena

$$\vec{J}_V = \frac{eN_C}{2\pi^2}\mu_A\vec{B} \qquad \vec{J}_A = \frac{eN_C}{2\pi^2}\mu_V\vec{B}$$



v_2 splitting as a function of charge asymmetry between π+ and π- is consistent with CMW prediction.

Imply that both Chiral Magnetic Effect and Chiral Separation Effect are at work.

Imply chiral restoration.

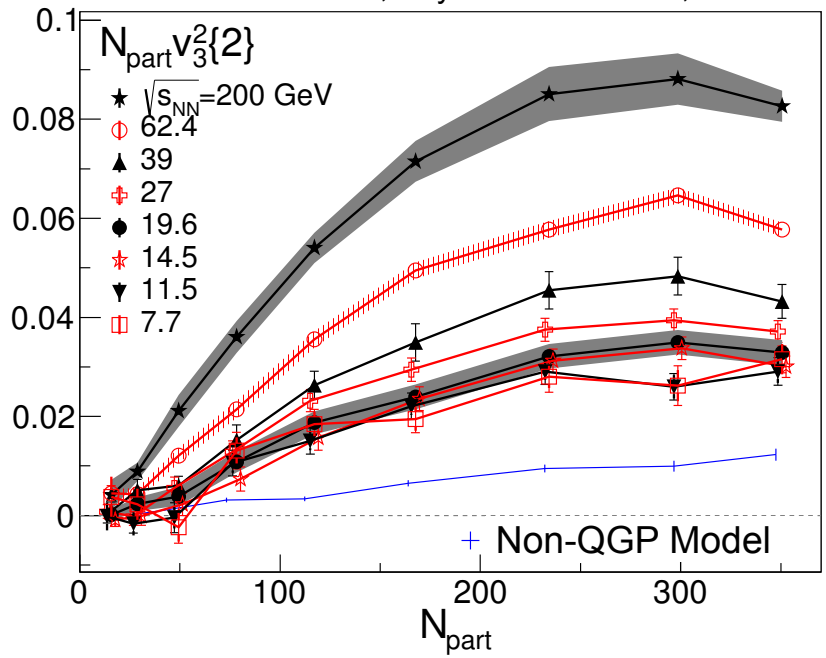
STAR-BNL group continues to study the phenomena differentially (kaons, rapidity separation between Ach and v_2, splitting in v_3 etc.).

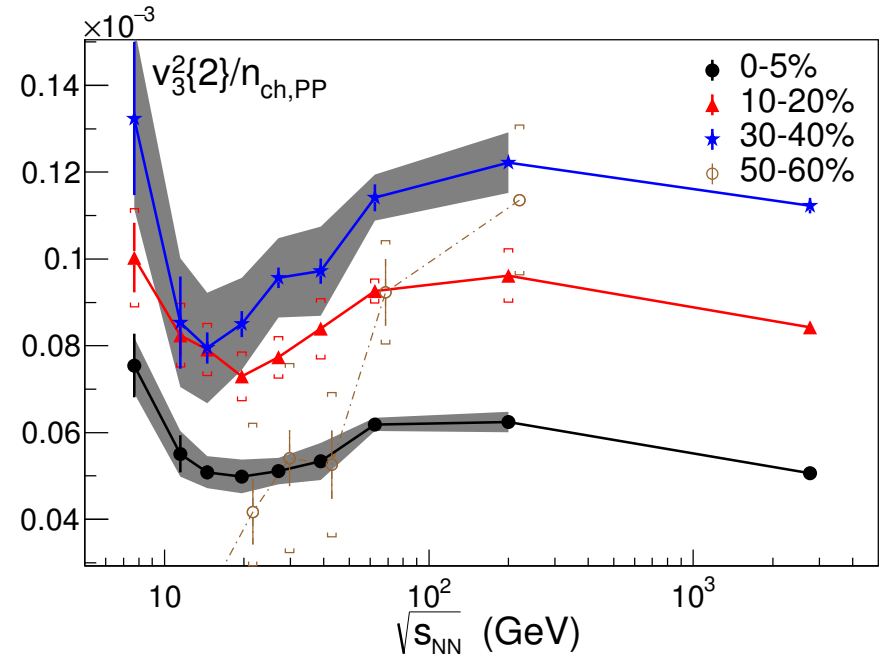
Ke and Tang

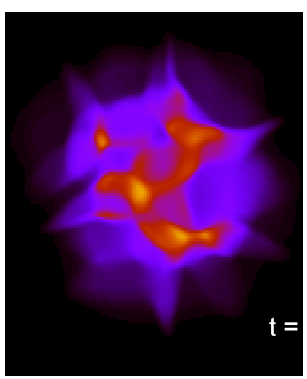
Phys. Rev. Lett. 114, 252302 (2015), Editor's suggestion

Mapping the Phase Diagram: Higher Harmonics

STAR Collaboration, Phys. Rev. Lett. **116**, 112302







Models show that higher harmonic ripples are sensitive to the presence of a QGP: v_3 goes away when the QGP goes away

In more central collisions, v_3 is present at the lowest energies, but disappears at lower energies for N_{part}<50 (turn-off of QGP)

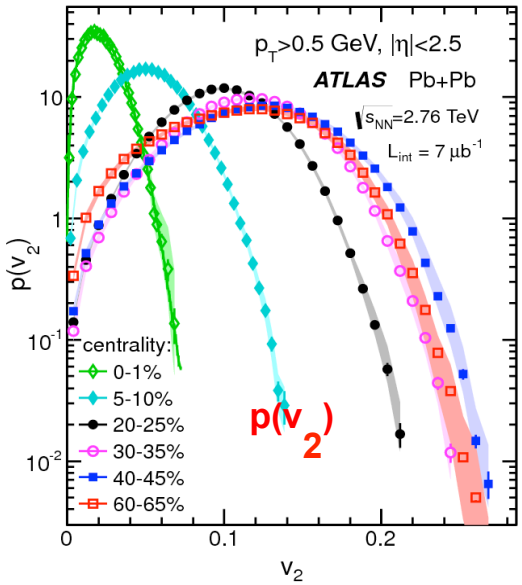
Sorensen

When scaled by entropy density, v_3 shows a minimum near 15 GeV consistent with an increased bulk viscosity and decreased effective pressure

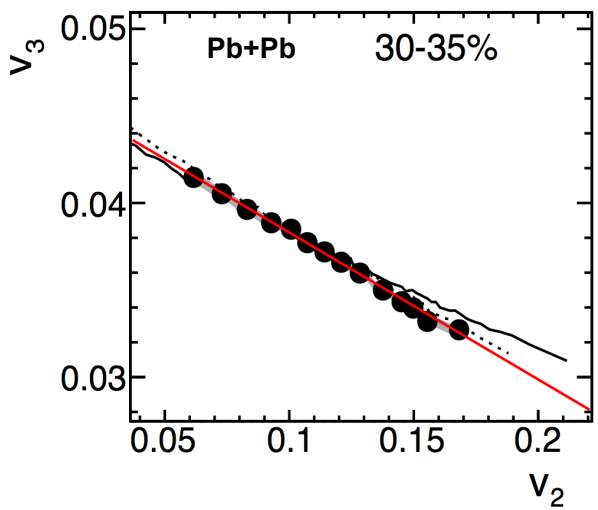
Transverse flow fluctuations and longitudinal dynamics

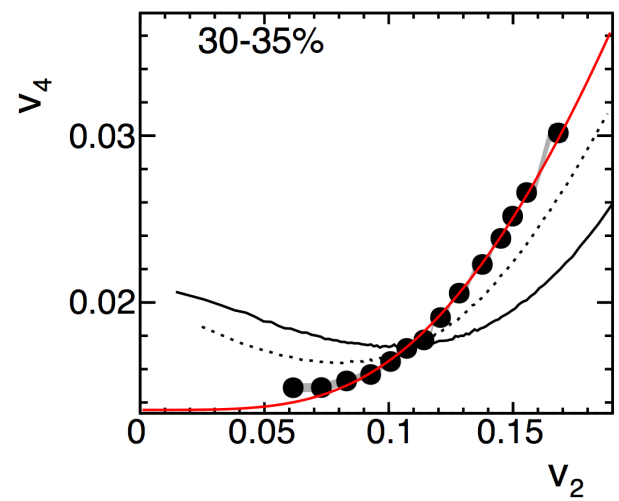
- Probe initial condition and final state non-linear response
  - via $p(v_n)$ and event-shape engineering at LHC

ATLAS: Jia 1305.2942



ALTAS: Jia 1504.01289





Plan to do similar measurements in U+U & Au+Au collisions at STAR

- Expect different $p(v_2)$ distri. in ultra-central U+U collisions.
- Energy/temperature dependence of non-linear response

Carried out flow longitudinal decorrelation analysis

Scientific case discussed in a RBRC workshop organized by Sorenson, Tribedy and Jia, list of interesting measurements identified.

High Level Trigger (HLT) development

Tang and Ke

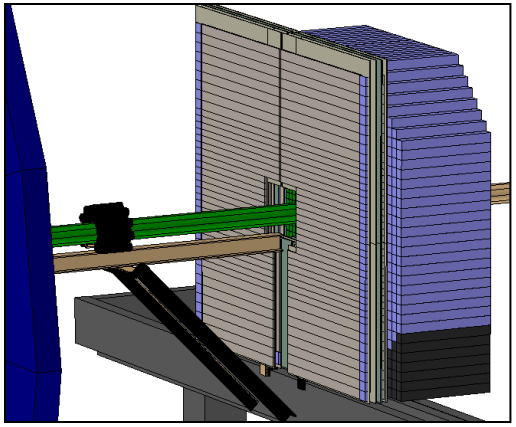
Expanded with 18 new powerful computers with a contribution of ~160k$ from China (NSFC). In total 1192 cpu cores and 44 Xeon Phi coprocessors.

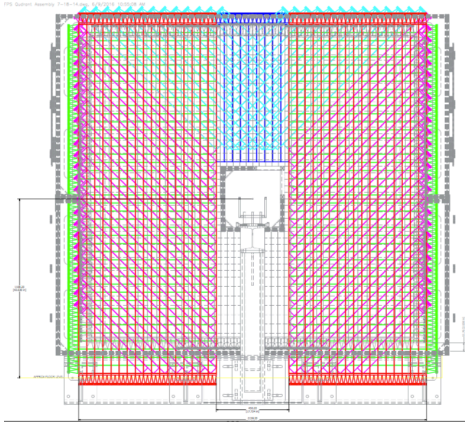
Monitored background collisions and provided live feedback to collider for optimizing beam condition.

Selected a small quarkonium-rich sample by matching TPC tracks to MTD hits.

Upgrades for run-17

- The Forward Meson Spectrometer (FMS) is being refurbished with UV LEDs for in situ curing of Pb Glass arrays.
- A post shower is add to the FMS for additional hadron suppression for the DY measurements in pp 500. This is constructed by the BNL medium energy group, and integration by STSG.





iTPC upgrade for BES-II

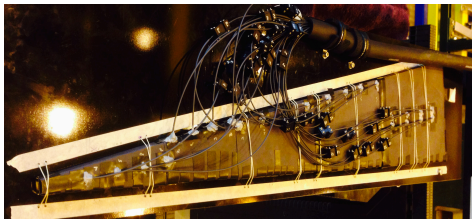
- The iTPC is now and approved project as of February 2016 , and the construction has started.
- The group was involved the iTPC proposal, and is a leading force in the construction
  - Project Manager Videbaek
  - Integration and Installation Pak (moved to CAD on 10/1/2015), Sharma, Lebedev, STSG
  - Electronics development Ljubicic, Scheetz
  - Collaboration with Shandong U., USTC Z.Xu
  - Simulations Chakaberia, Fisyak

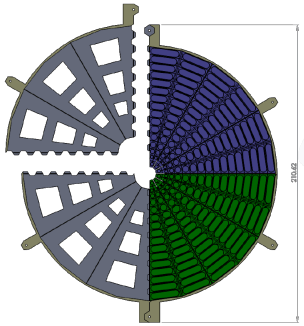
Project consist of upgrade of 24 inner sectors and associated electronics

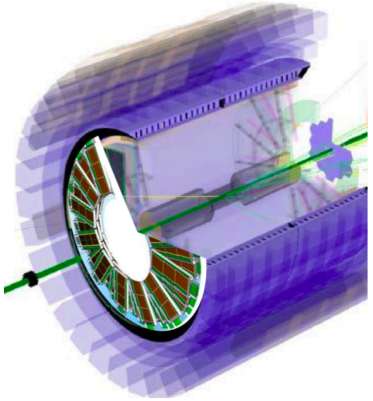
Other upgrades for BES II

- Event Plane Detector
  - Improved EP resolution
- 1 sector prototype successfully deployed in run 16
- 1/8th EPD installation run 17 for detector commissioning
- Integration STSG

- Endcap TOF. STAR - CBM TOF collaboration
  - Improved PID at $-1.6 < \eta < -1.1$
- Single module prototype to be installed for run-17 STSG







Research relevant to EIC science

- Strong involvement in BNL EIC task force
  - Ullrich (co-leader with Aschenauer)
  - Lamont (left 10/15)
  - Lee
- Strong collaborative effort with Medium Energy Group
- Research Efforts
  - Structure function particular in eA, F^A_L
  - Diffractive Physics
  - Di-Hadron correlations
  - Gluon Sivers
  - Tagging event geometry in eA
  - Ridge in eA

Summary

BNL STAR group dual mission:

- Support for the existing detector systems, operation, data taking and processing, along with development of new detector technology
- Ground-breaking scientific research to utilize these systems to their fullest potential, taking advantage of detailed expertise and knowledge of the detector capabilities

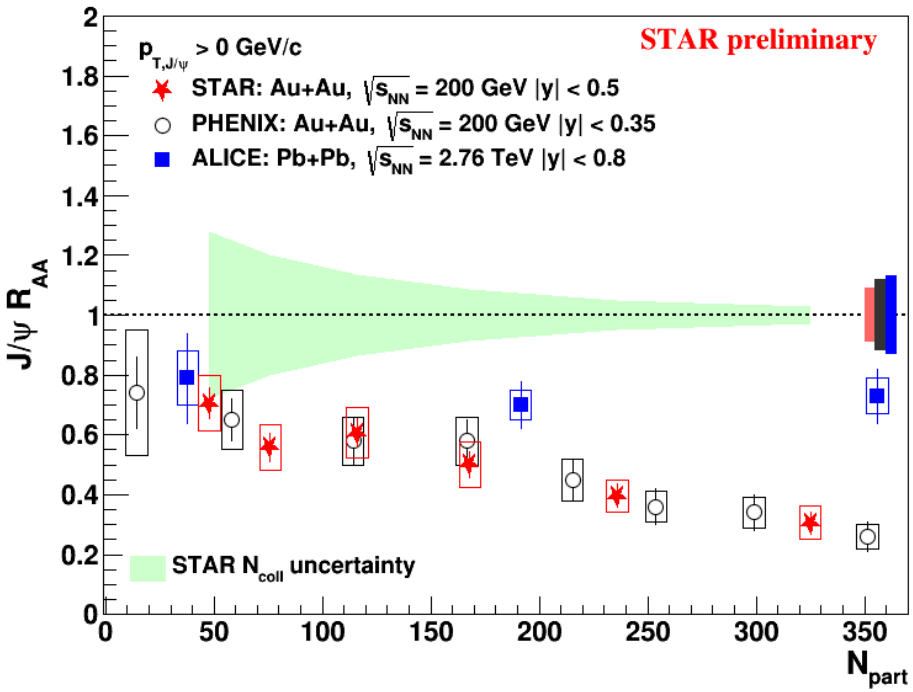
BNL STAR group plays central and critical role to the success of the STAR experiment in all of these areas

Backup

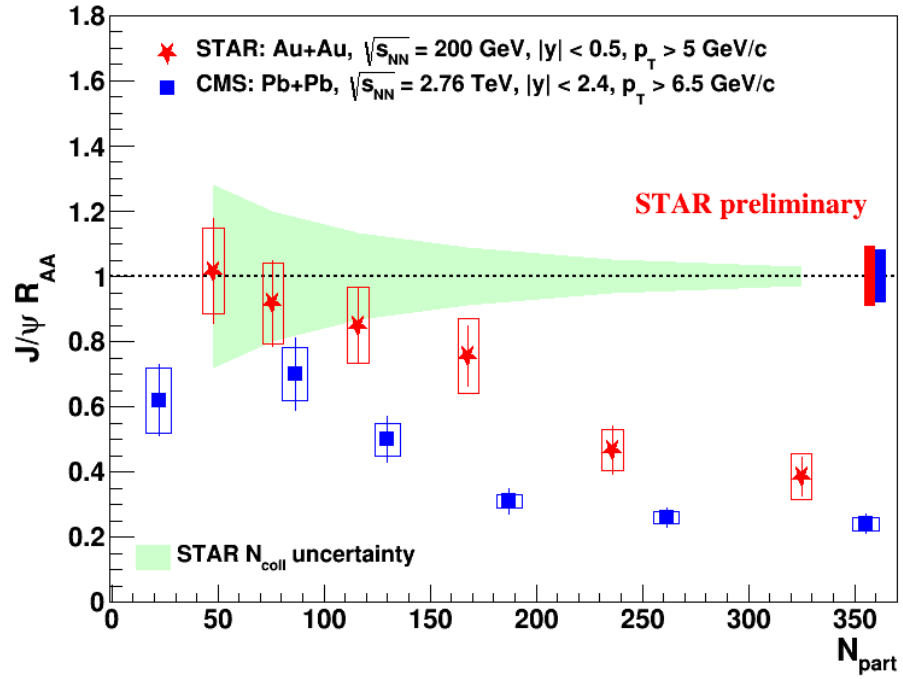
Quarkonium with the MTD

Different quarkonium states: heavy but small, different dissociation temperature

J/ψ through its dileptonic decay: indicator of deconfinement

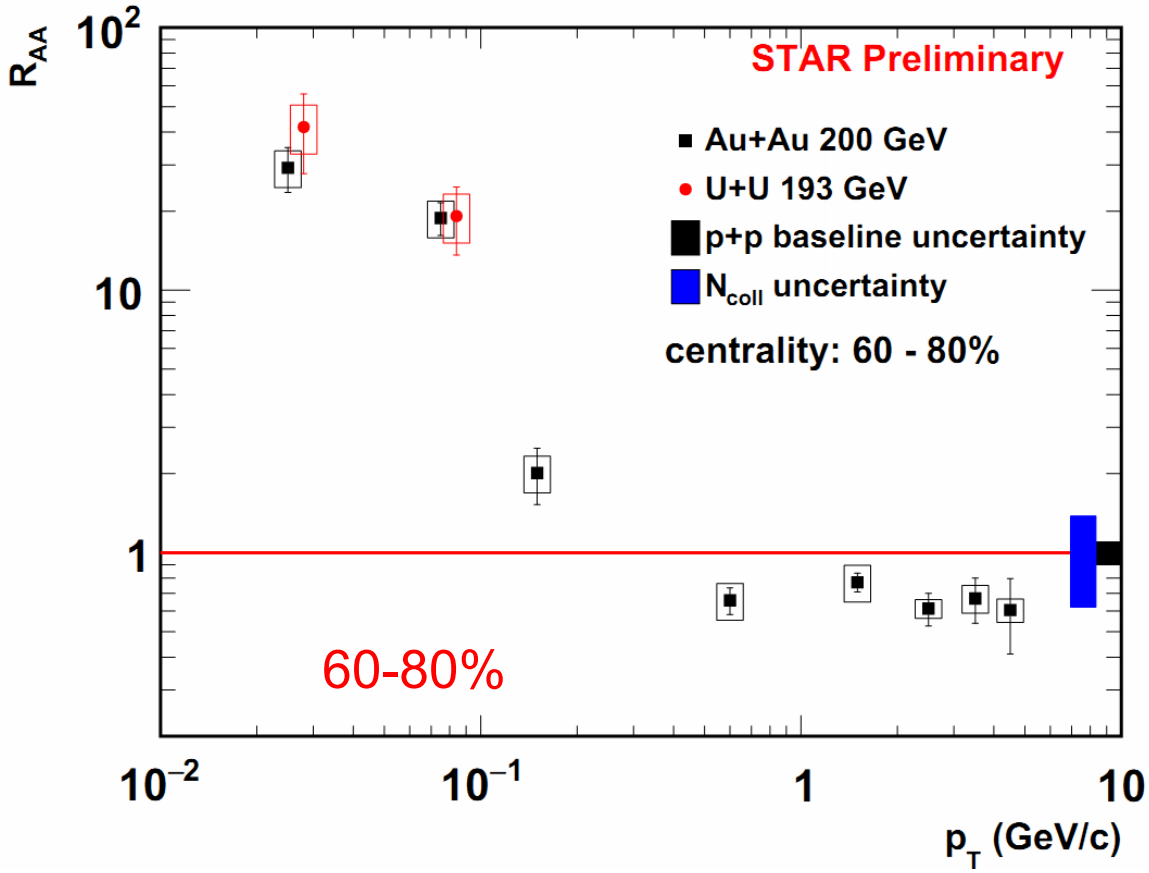


STAR Collaboration, SQM2016



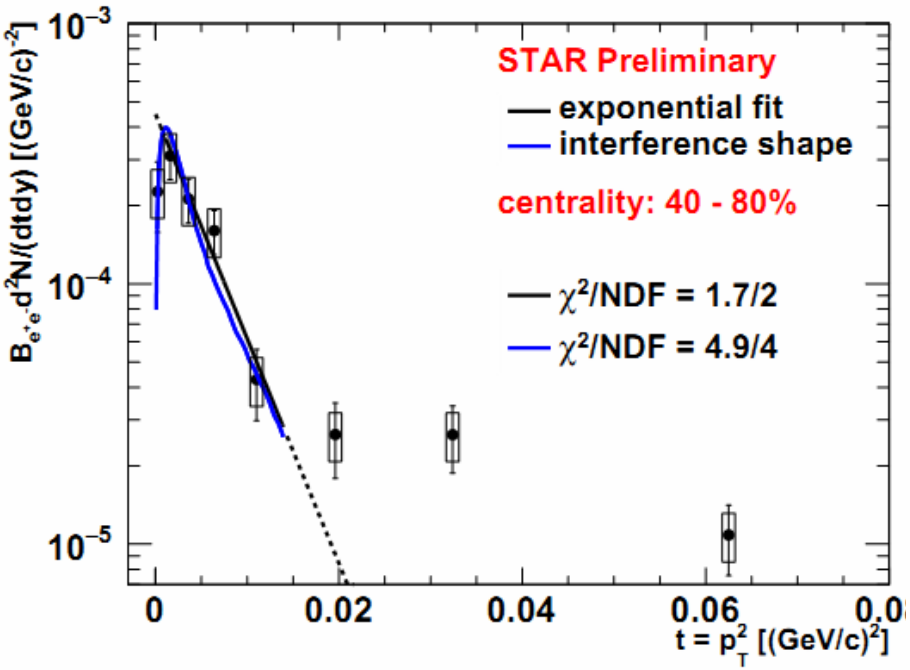
Ruan, Ma, and Todoroki

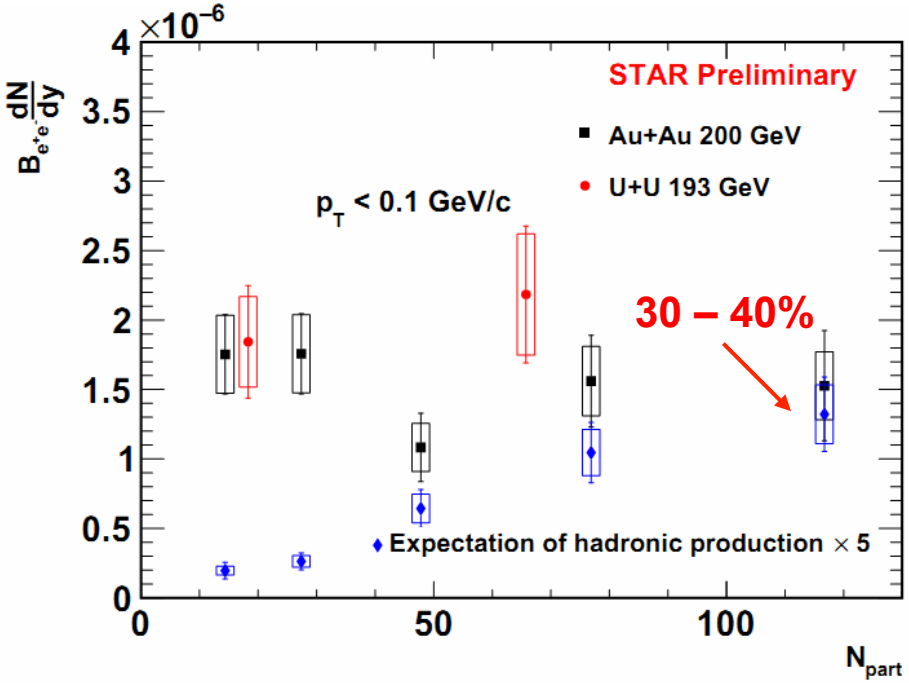
Very low pt J/ψ: largely enhanced!



Significant enhancement of J/ψ yield observed: R_{AA}~ 20 at p_T < 0.1 GeV/c for peripheral collisions (60 – 80 %) Au+Au and U+U !

J/ψ yield :$t=p_T^2$ and centrality dependence



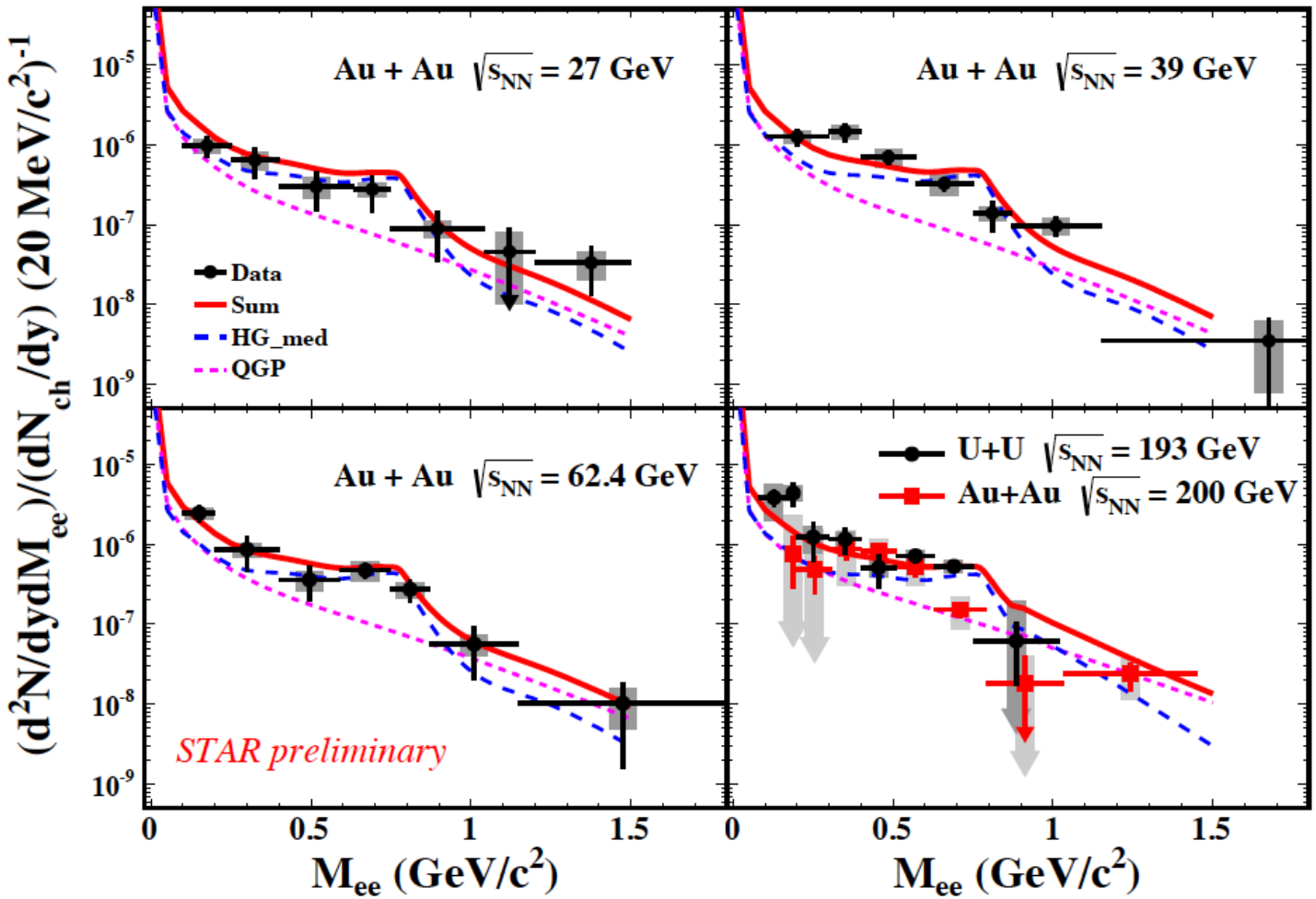


Slope parameter consistent with the size of the Au nucleus. Interference structure observed. Coherent photon-nucleus interactions?

No significant centrality dependence of the excess yield! Interplay between photon flux cancellation in the overlapped area and the distance of the spectators of the two nuclei?

Simulations ongoing and need theoretical inputs!

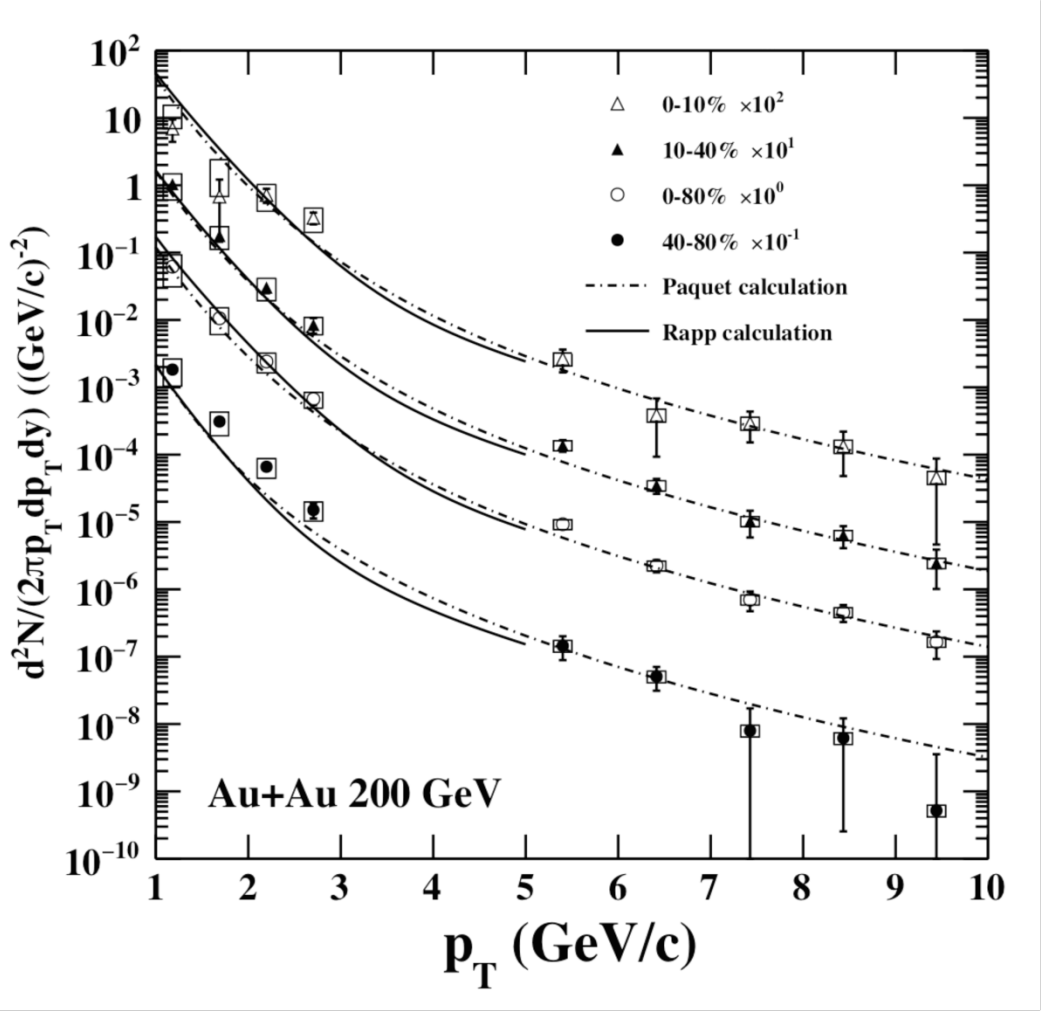
The ρ resonance spectral function: broadened



Ruan

A broadened ρ spectral function consistently describes the low mass electron-positron excess for all the energies 19.6-200 GeV.

Direct virtual photon production



Direct virtual photon production in 200 GeV Au+Au collisions can be described by models including contributions from hot, dense medium

STAR Collaboration, arXiv: 1607.01447, submitted to Phys. Lett. B.

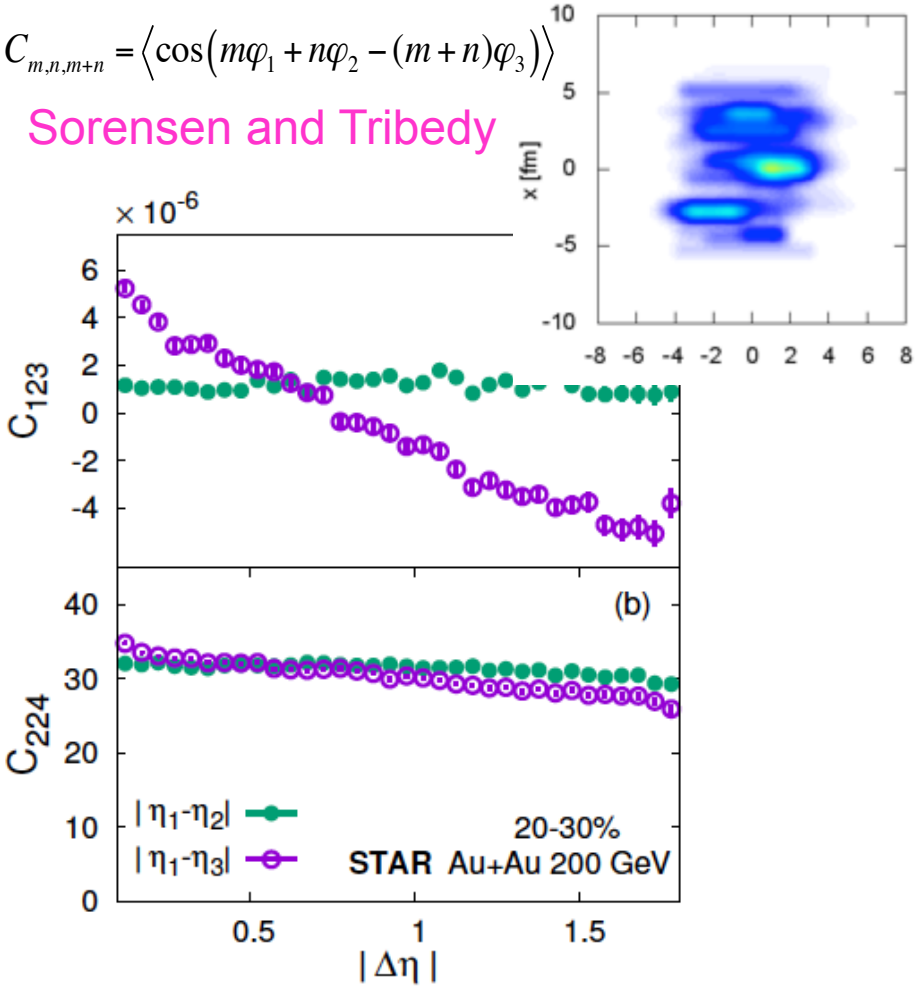
Ruan

Road Map to Constraining η/s(T)

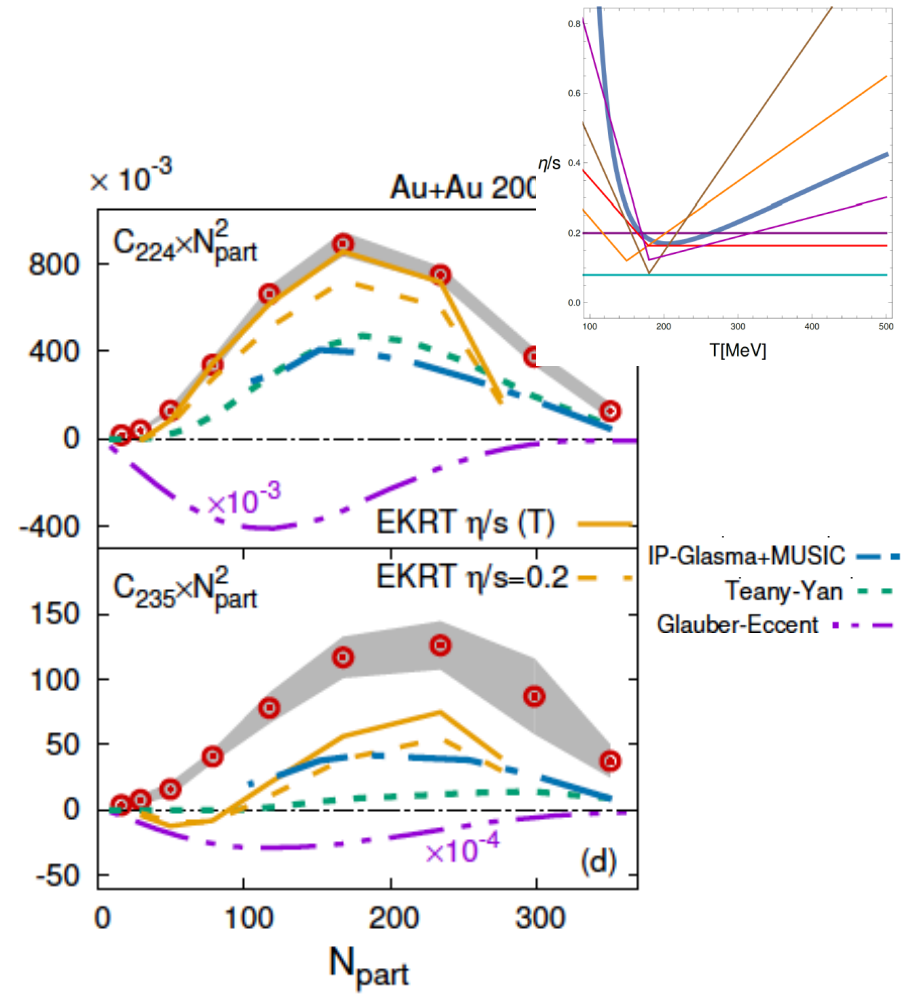
Δη dependence maps 3-D initial state

$$C_{m,n,m+n} = \left\langle \cos\left(m\varphi_1 + n\varphi_2 - (m+n)\varphi_3\right)\right\rangle$$

Sorensen and Tribedy



3-D models will constrain η/s(T)

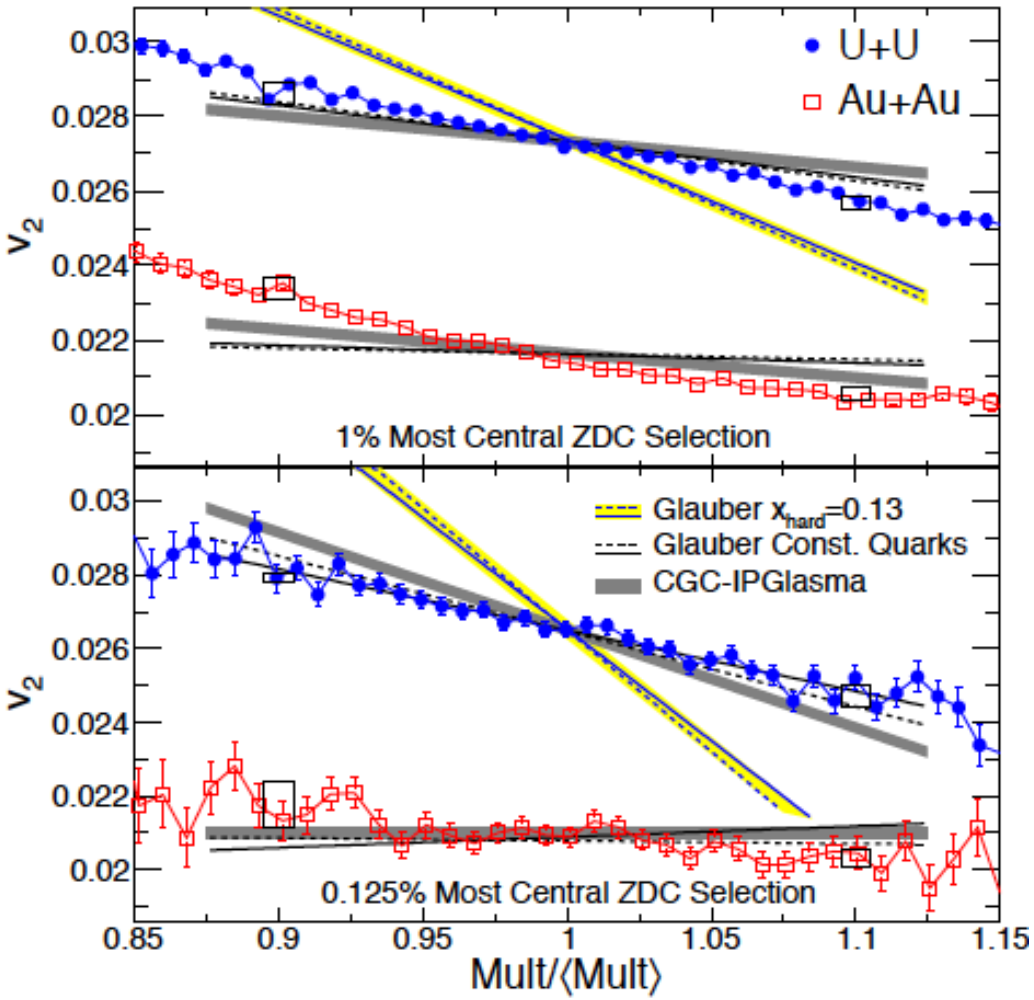


Understanding the initial state in 3-D required to constrain η/s(T)

Data on 3-particle correlations shows the way to do both

Uranium Collisions

STAR Collaboration, Phys. Rev. Lett. **115** (2015) 222301

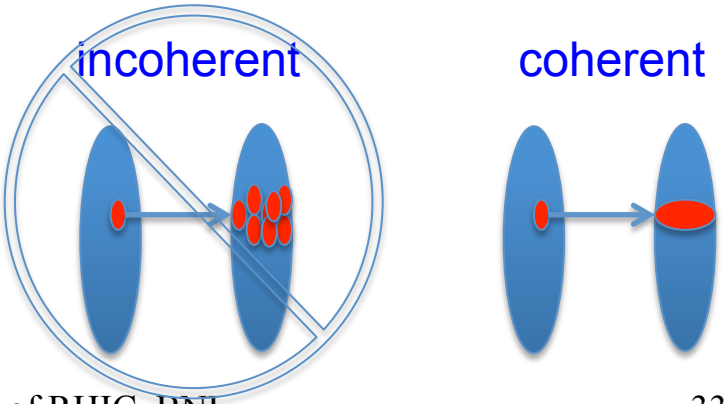


Sorensen

Redefining our understanding of particle production

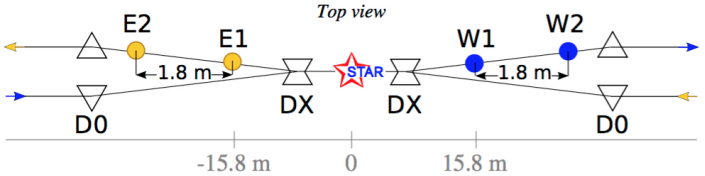
Data require models with most coherence: such as gluon-saturation or quark-participant

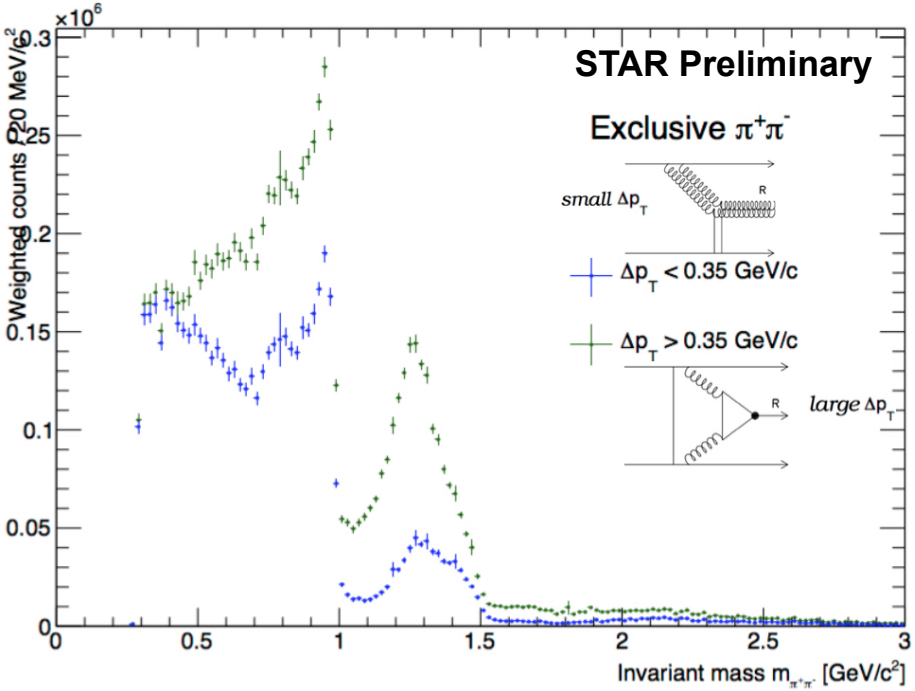
Coherence: the colliding constituents don't see all the other individual constituents



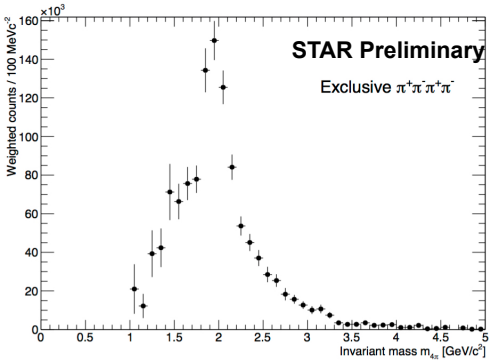
Spectroscopy in Central Exclusive Diffractive Process through Double Pomeron Exchange

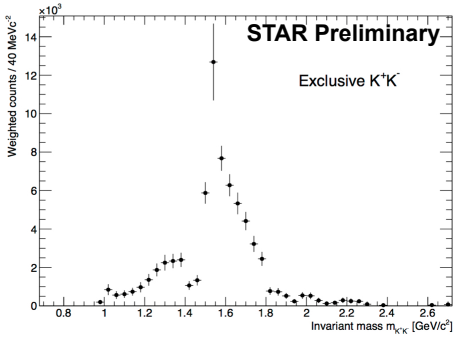
- First measurement of dynamics of Pomeron-Pomeron coupling with high statistics in polarized pp at RHIC
- RHIC Run15 with new Roman Pot configuration at STAR
- $p_1 p_2 \rightarrow p_1, M_X p_2$, $M_X \rightarrow \pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$, K^+K^-
- In QCD, Pomeron is considered to be made of two gluons: natural place to look for gluonic bound state - Lattice cal.: Lightest glueball $M(0^{++})$=1.5-1.7 GeV/c^2



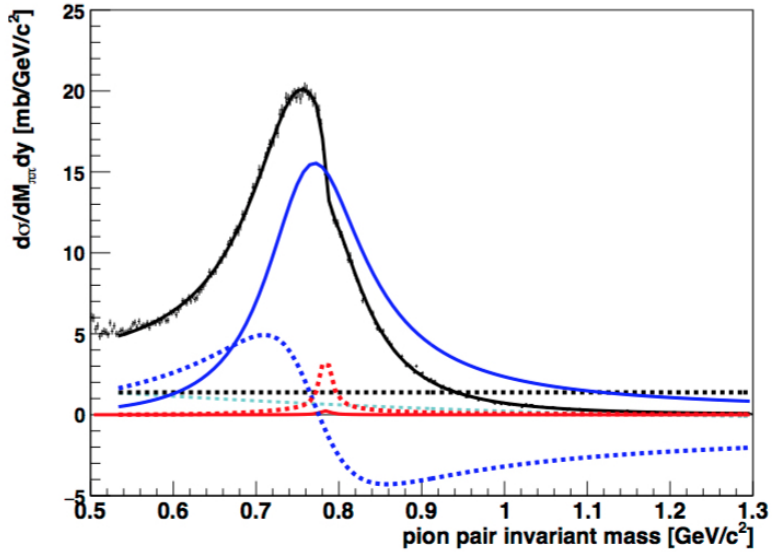


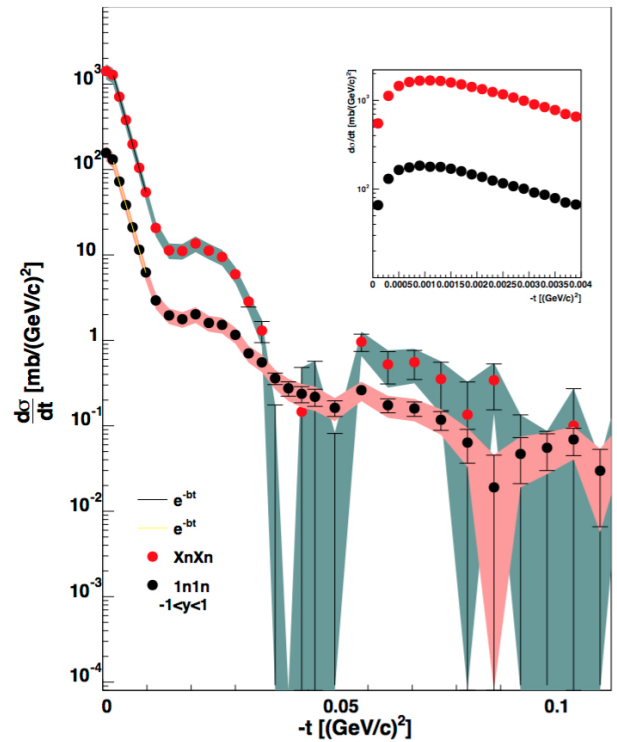
Lee and Guryn





Coherent diffractive photoproduction of ρ mesons on Au





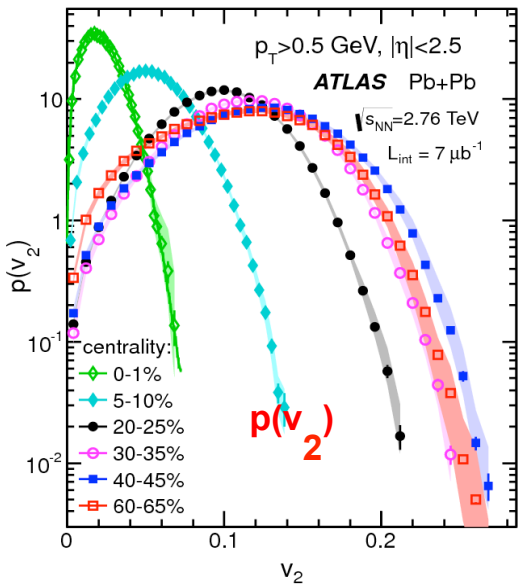
- The π+π− invariant-mass distribution for all selected ππ candidates: Curves show ρ0 (blue solid), ω(red dotted), and interference between non-resonant pion pairs and ρ0 (blue dotted).

- Fully normalized coherent diffraction patterns for ρ0 mesons detected in exclusive any number of neutrons (XnXn: red) events and in single neutron (1n1n: black) events. The insert showsthe effects of the destructive interference between photoproduction with the photon emitted by any of the two ions.

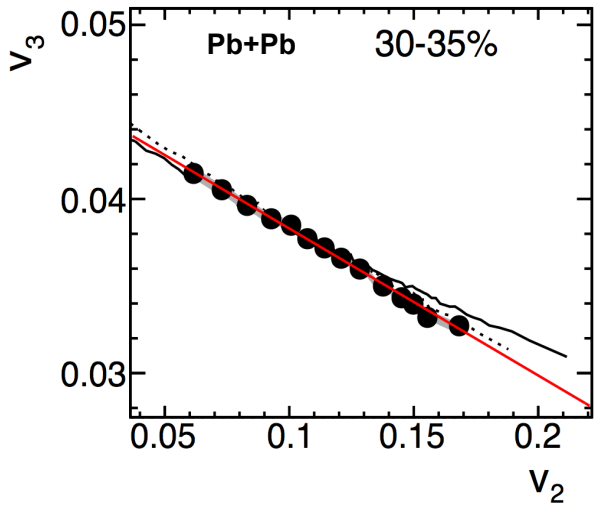
Transverse flow fluctuations

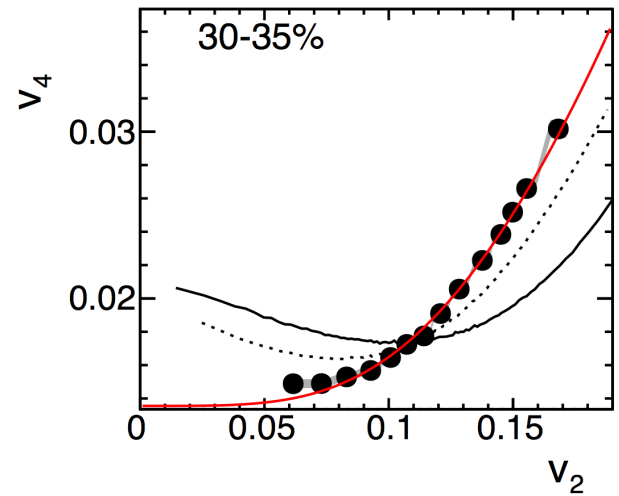
- Probe initial condition and final state non-linear response
  - via $p(v_n)$ and event-shape engineering at LHC

Jia 1305.2942



Jia 1504.01289



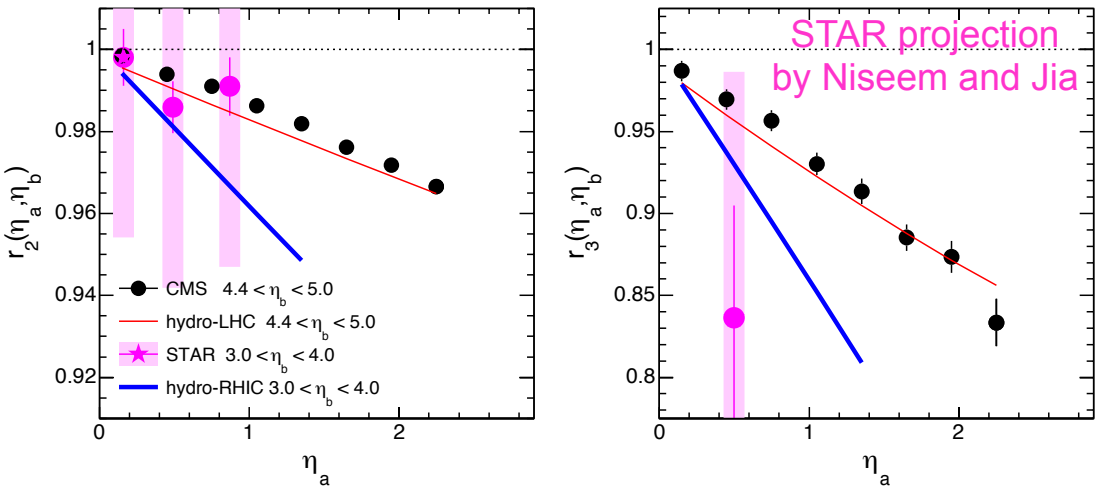


- Similar measurements in U+U & Au+Au collisions at RHIC
  - Expect different $p(v_2)$ distri. in ultra-central U+U collisions.
  - Energy/temperature dependence of non-linear response

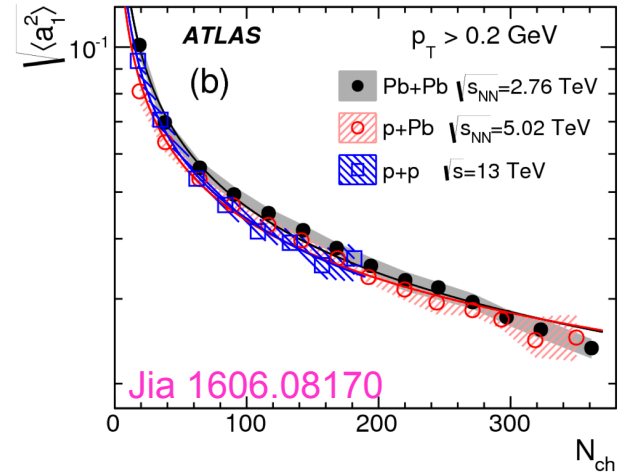
Longitudinal dynamics

- Initial condition is not boost-invariant event-by-event
  - Leading to flow decorrelation and forward-backward multiplicity fluctuation

Flow decorrelation



FB asymmetry

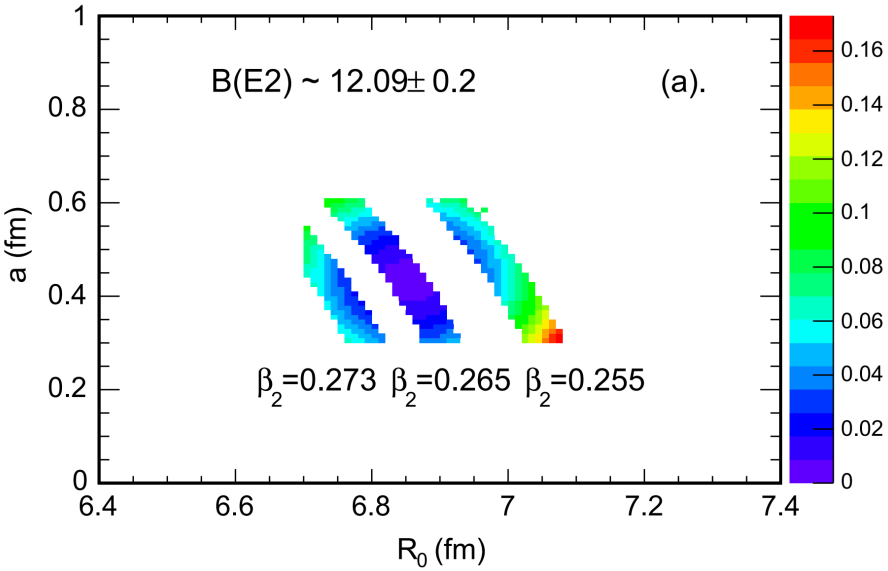


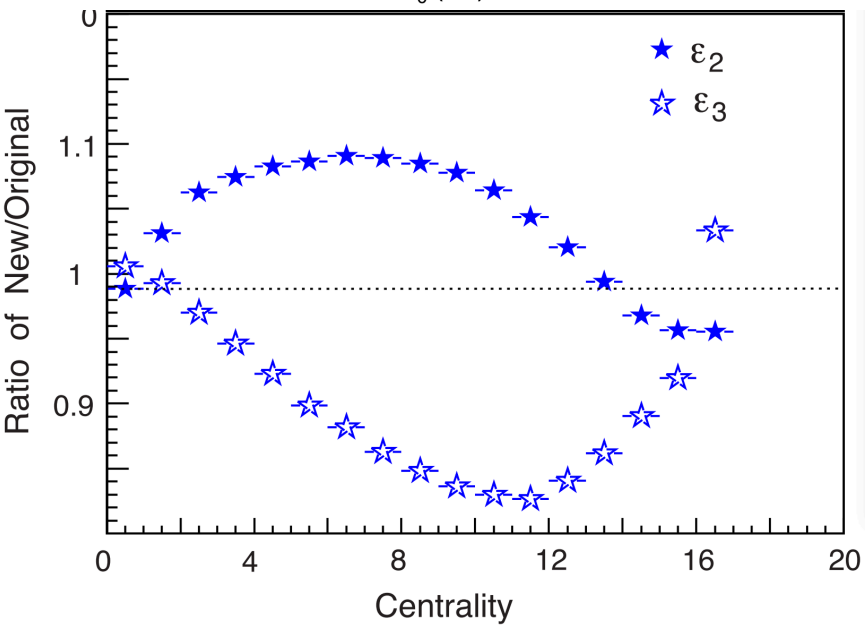
$$r_n(\eta,\eta_{ref}) = \frac{V_{n\Delta}(-\eta,\eta_{ref})}{V_{n\Delta}(\eta,\eta_{ref})}$$

$$\frac{N(\eta)}{\langle N(\eta)\rangle} \approx 1 + a_1\eta$$

- Much stronger effects expected at RHIC energy.
  - Interesting to do similar measurement at RHIC→benefit from EPD upgrade
  - Constraints on the rapidity dependence of initial condition
- Scientific case discussed in a RBRC workshop organized by Sorenson, Tribedy and Jia, list of interesting measurements identified.

Parameterization of deformed nuclei for Glauber modeling





Determine parameterization of deformed nuclei (U), by matching the reduced electric quadrupole transition probability (B(E2)↑) to that measured in electron scattering experiments.

The procedure uses appropriate density profiles for protons and neutrons (instead of point-like).

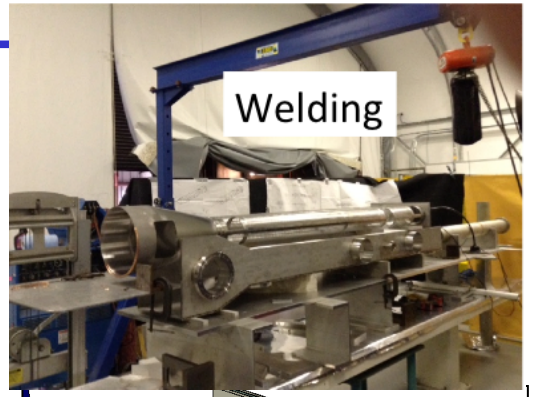
ε_2 and ε_3, which play important roles in interpreting the data and extracting η/s, are both affected by the new parameterization.

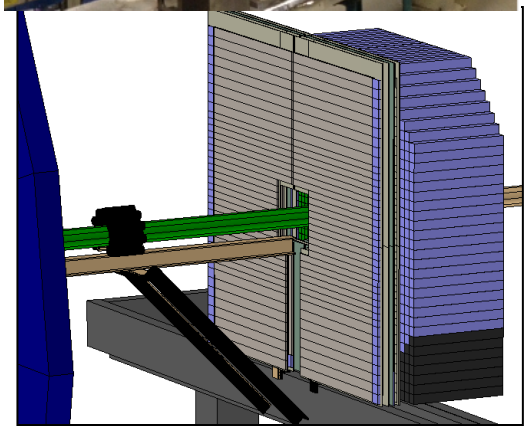
Phys. Lett. B 749 215 (2005),
P. Sorensen, A. Tang, F. Videbaek and H. Wang

Completed STAR Upgrades

Roman Pot Phase-II*

- Modest upgrade, extending t range and allowing concurrent operation with high luminosity operation for A_N and exotic states
- Testing ground for applications at the EIC
- Star HI Group Guryn, Debbe, Lee + STSG+ (BNL MES
- successfully operated in run-15, data analysis ongoing and will be used for run-17 pp 500 GeV

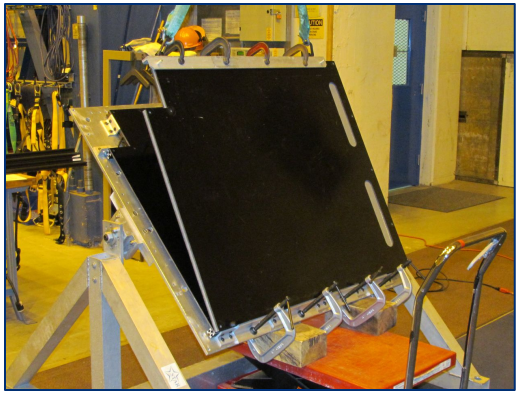




FMS is being refurbished for run-17

FMS pre-shower

- Direct photon measurements at forward rapidities
- 3 layer hodoscope. BNL Medium Energy group and STSG
- Successfully operated in run-15 and will be utilized in Run-17



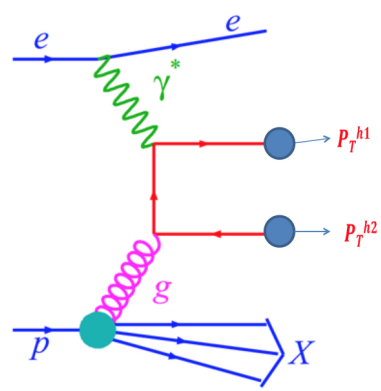
Forward upgrades at STAR

- Group is involved in work for the forward upgrades at STAR beyond 2020
- We have produced a two-page write-up and a proposal with group efforts from Ruan, Sorensen, Jia, Tribedy, Z.Xu, Videbaek, and Lee. Simulation efforts from the S&C core team members: Webb, Ogawa, Perev, Lauret, Van Buren.
- Proposal disapproved by BNL management.

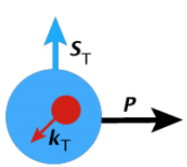
3D imaging of partonic structure of nucleon - accessing Gluon Sivers at EIC

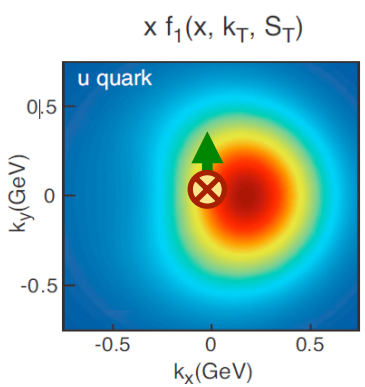
- Gluon TMDs is ingredient of complete 3D imaging of nucleon, and can be uniquely measured at EIC by measuring gluon Sivers function

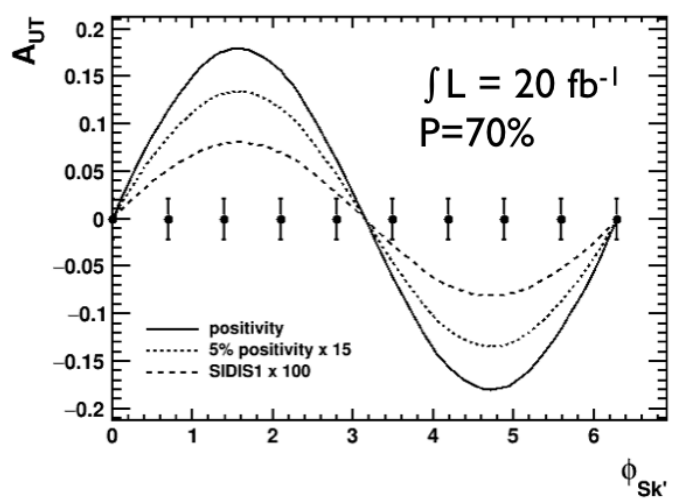
- Gluon Sivers can be accessible and constrained in a wide kinematic range via photon-gluon coupling - D0 pair, K+K-, h+h- within EIC's machine and detector reach



$$ep^{\uparrow} \to e' c\bar{c} X$$



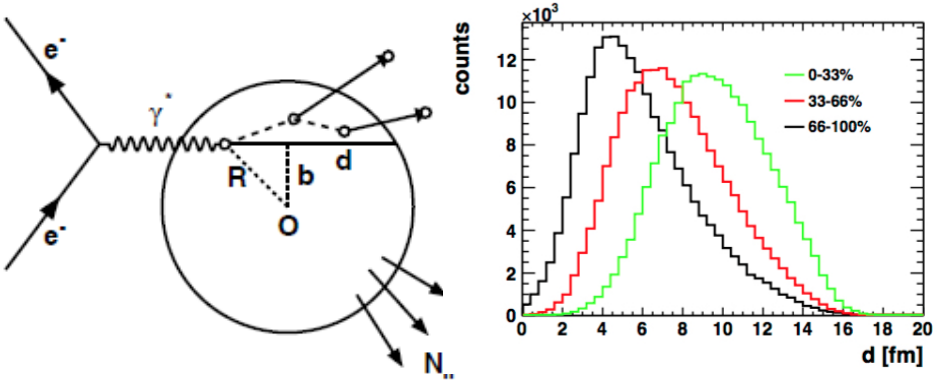




Zheng,Aschenauer,Lee,Xiao: RHIC Users Meeting (2016), EIC Users Meeting (2016)

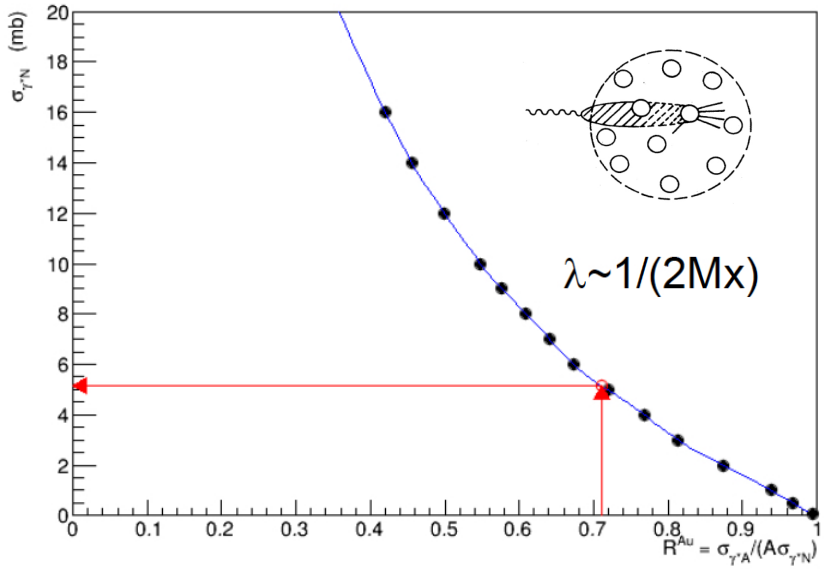
Event characterization for eA in the Saturation Regime

- Modeling DIS for eA including multinuclear / shadowing effect
- Extending existing model for eA: DPMJetHybrid (Aschenauer, Lee, Zheng) to simulate
  - Geometry tagging in eA
  - Multi nucleonic recoil of intrinsic k_T (Qs)
- Key input for detector configuration for event tagging in saturation regime in EIC



EPJA 50 189 Zheng,Aschenauer, Lee

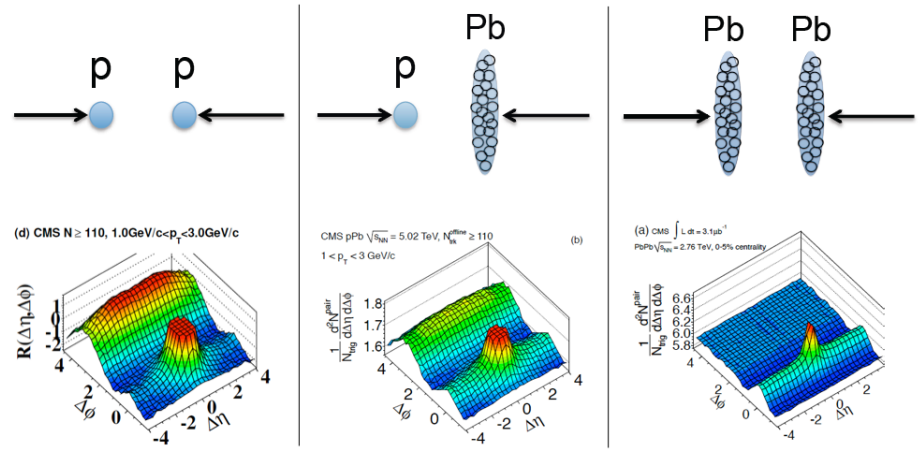
Map for λ >> R



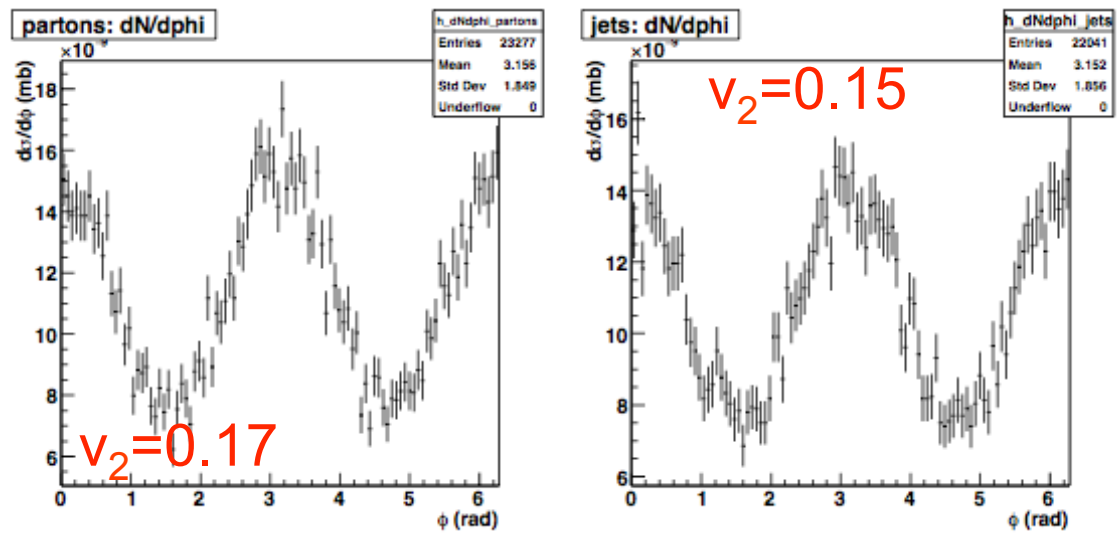
eRD17 (2016-2017) Baker, Aschenauer, Lee, Zheng

The Ridge in e+A

TMD factorization in *e*+A in the Color Glass Model predicts cos2φ asymmetries (v_2) in dijet production.
Dumitru, Lappi, Skokov, PRL 115 (2015), 252301 and arXiv: 1605.02739



Theory gives partons only! Feasibility study to see if after parton showering, detector effects, and jet finding the asymmetries are still visible
⇒ studies so far are very encouraging



Ullrich, Skokov, and Dumitru

Standard QCD generators show no such effect