

STAR Highlights

Hiroshi Masui for the STAR collaboration

Lawrence Berkeley National Laboratory

Quark Matter 2011
Annecy, France, May 22-28, 2011



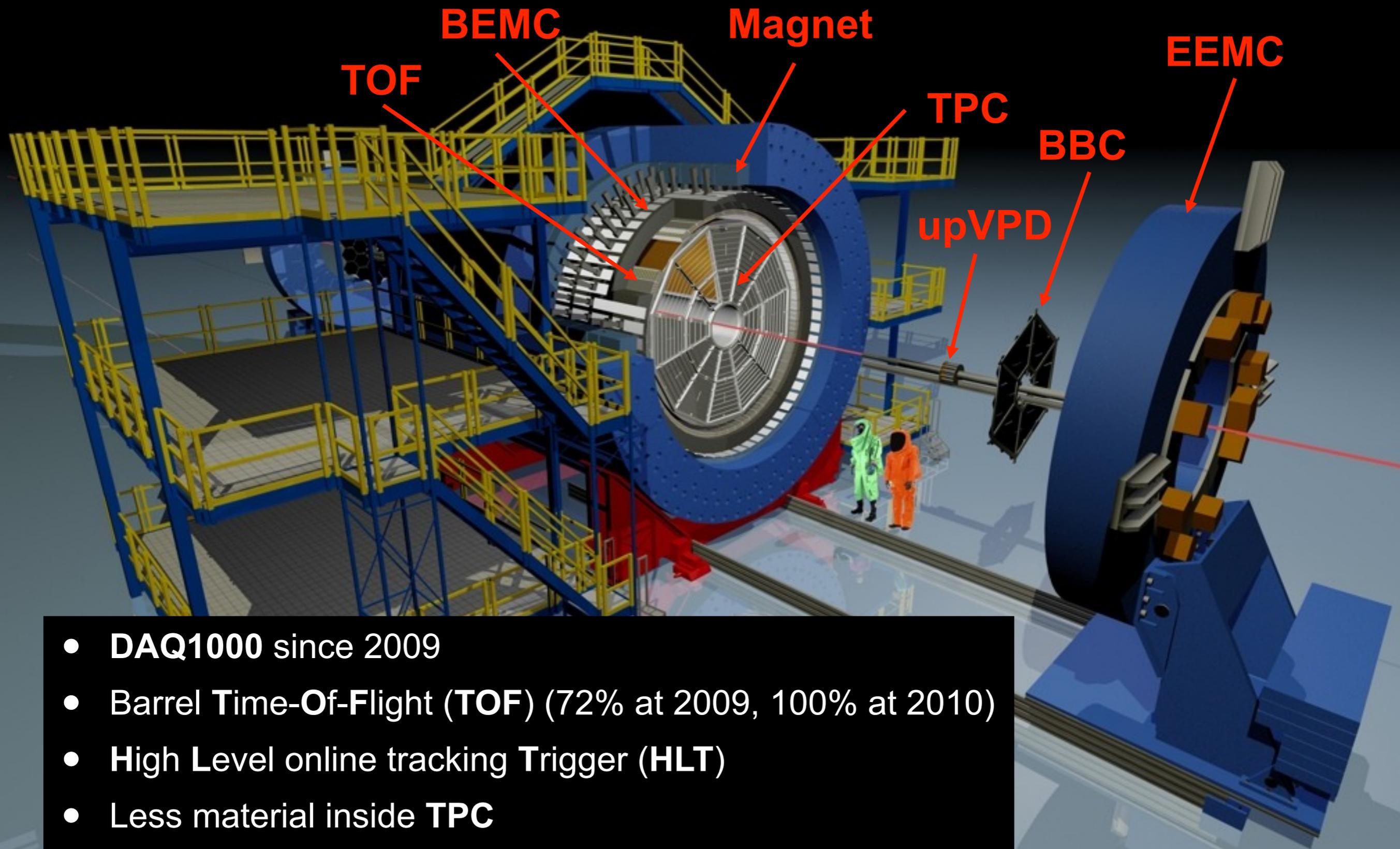
STAR physics focus in heavy ion collisions

Study structure of QCD phase diagram

- At top 200 GeV
 - Test **pQCD** in hot and dense medium
 - Study **medium properties**, **Equation of State**
- RHIC *Beam Energy Scan (BES)*
 - Search for the **QCD critical point**



STAR experiment



- DAQ1000 since 2009
- Barrel Time-Of-Flight (TOF) (72% at 2009, 100% at 2010)
- High Level online tracking Trigger (HLT)
- Less material inside TPC

STAR plenary talks

Wednesday 25/May 11:15 - Helen Caines (Yale)

STAR on reconstructed jets and jet-like correlations

Thursday 26/May 08:55 - Bedangadas Mohanty (VECC)

STAR: Results from the beam energy scan program

Thursday 26/May 12:00 - Paul Sorensen (BNL)

STAR correlations and fluctuations - v_n measurements

Outline

1. Jets & Heavy flavors

- Jet-hadron correlation, PID triggered correlations
- c & b cross section, spectra and R_{AA} for D mesons in Au + Au
- Quarkonium suppression R_{AA} , and J/ψ v_2

2. Electromagnetic & bulk probes

- Photoproduction of ρ^0 and J/ψ in the ultra-peripheral collisions
- Di-electron spectrum in p+p & Au + Au
- Discovery of anti- 4He
- Bulk correlation; triangular flow, dynamical charge correlation

3. Beam Energy Scan

- Azimuthal anisotropy v_2
- Higher moments of net-proton

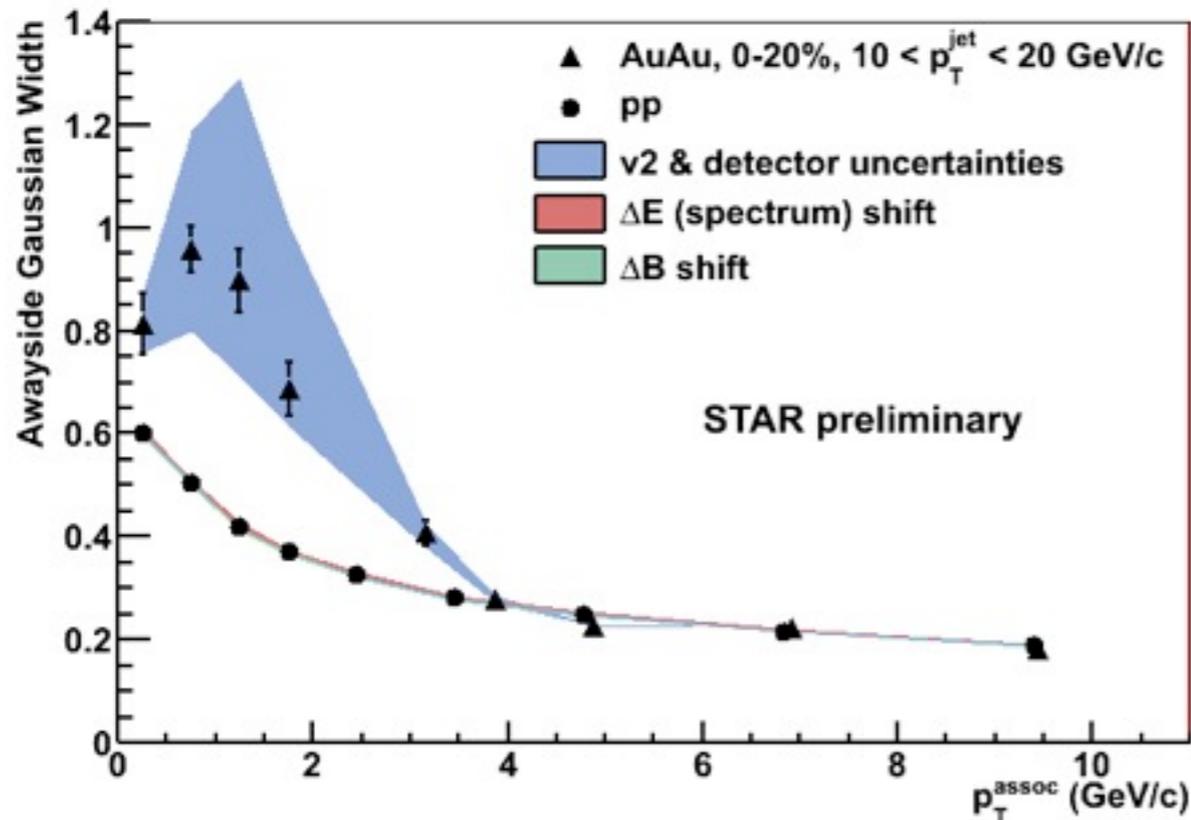
4. Summary

Jets & Heavy flavors

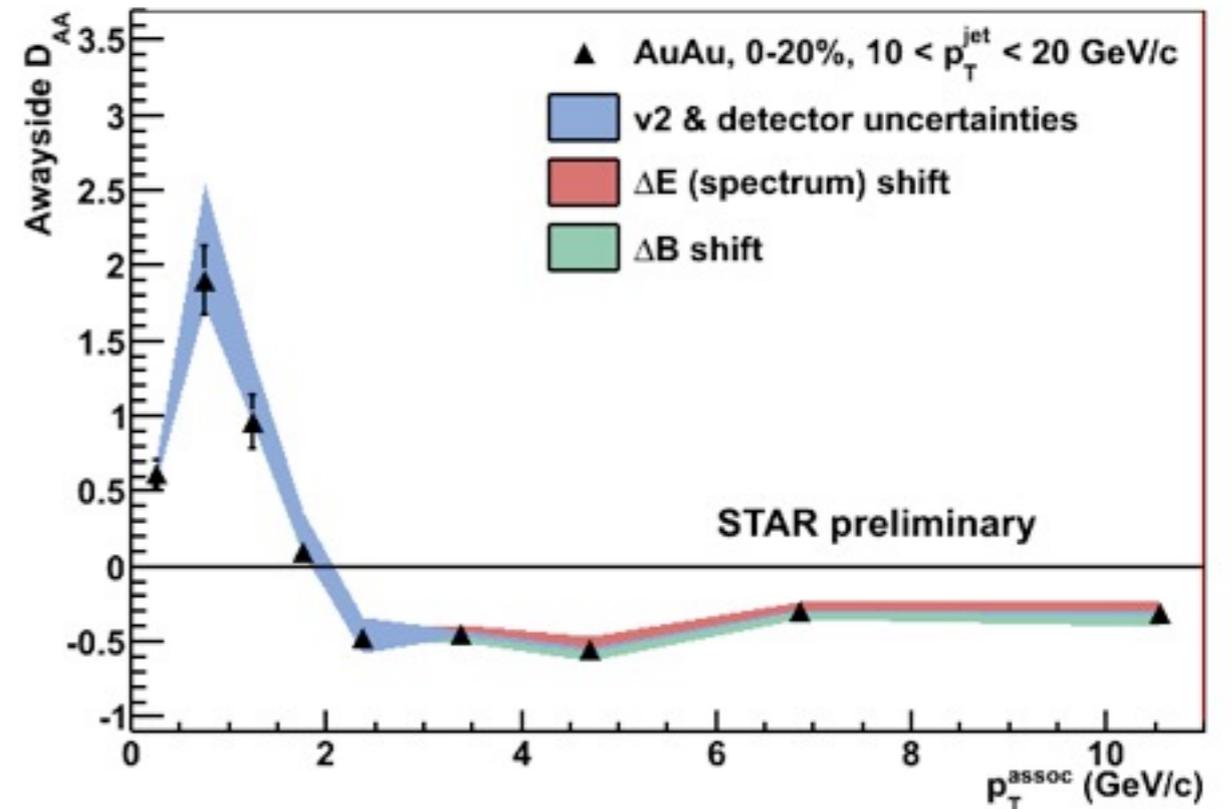
Jet-hadron correlation

Alice Ohlson, Fri/27 18:10

Away side Gaussian width



Away side energy balance



$$D_{AA}(p_T^{assoc}) = Y_{AA}(p_T^{assoc}) \cdot p_T^{assoc} - Y_{pp}(p_T^{assoc}) \cdot p_T^{assoc}$$

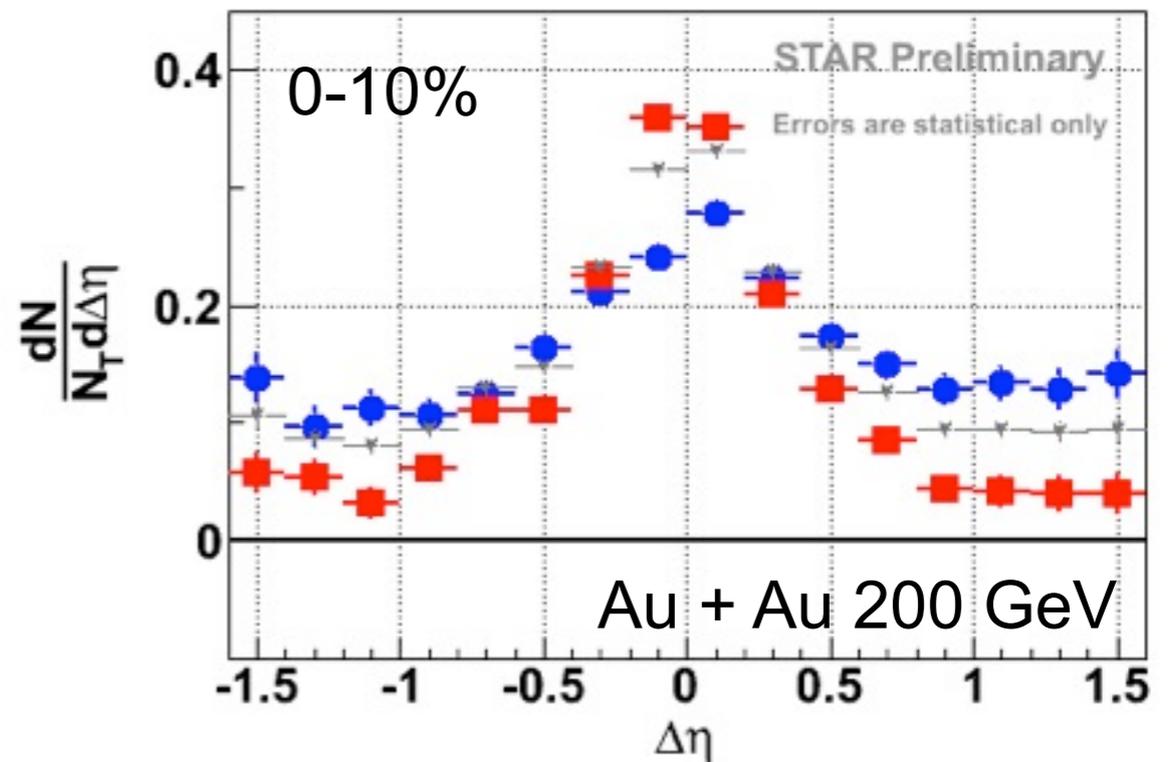
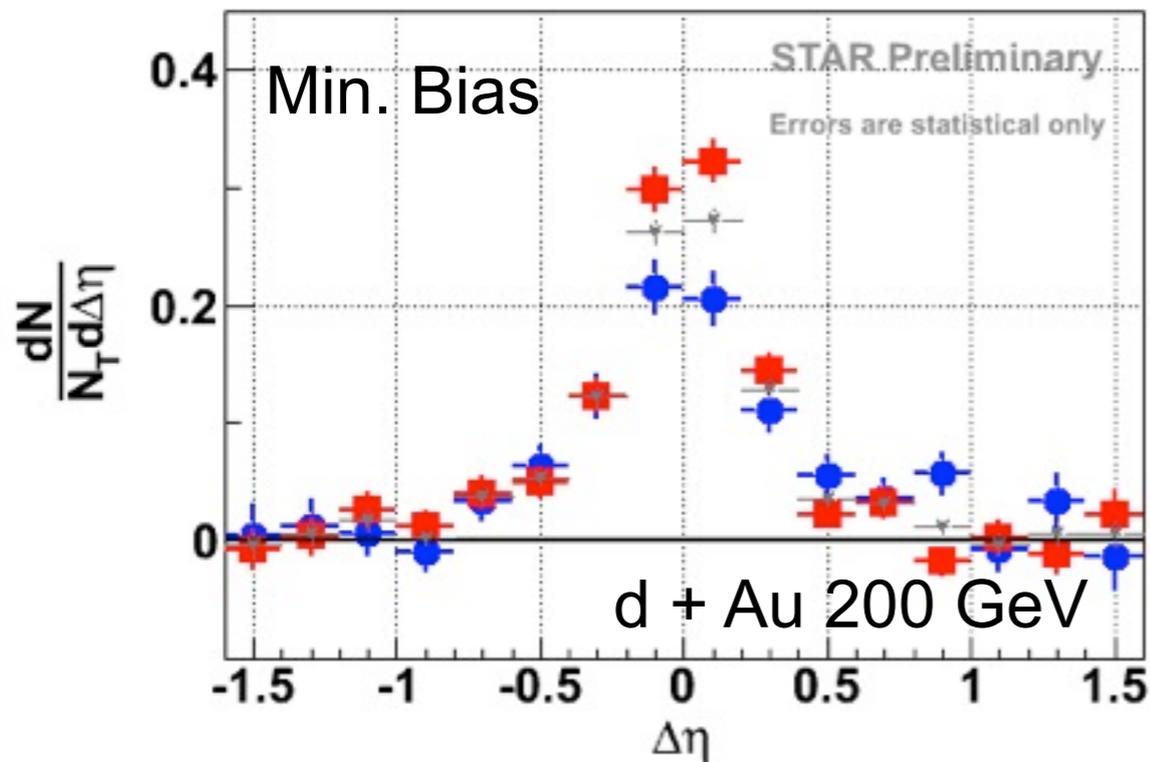
- Significant broadening and softening of jets in Au + Au
- High p_T suppression largely balanced at low p_T enhancement
- ➔ Seems to consistent with radiative energy loss picture

PID triggered correlation

Kolja Kauder, Fri/27 16:00

$$4 < p_{T,\text{trigger}} < 6 \text{ GeV}/c, p_{t,\text{assoc.}} > 1.5 \text{ GeV}/c$$
$$|\Delta\phi| < 0.73$$

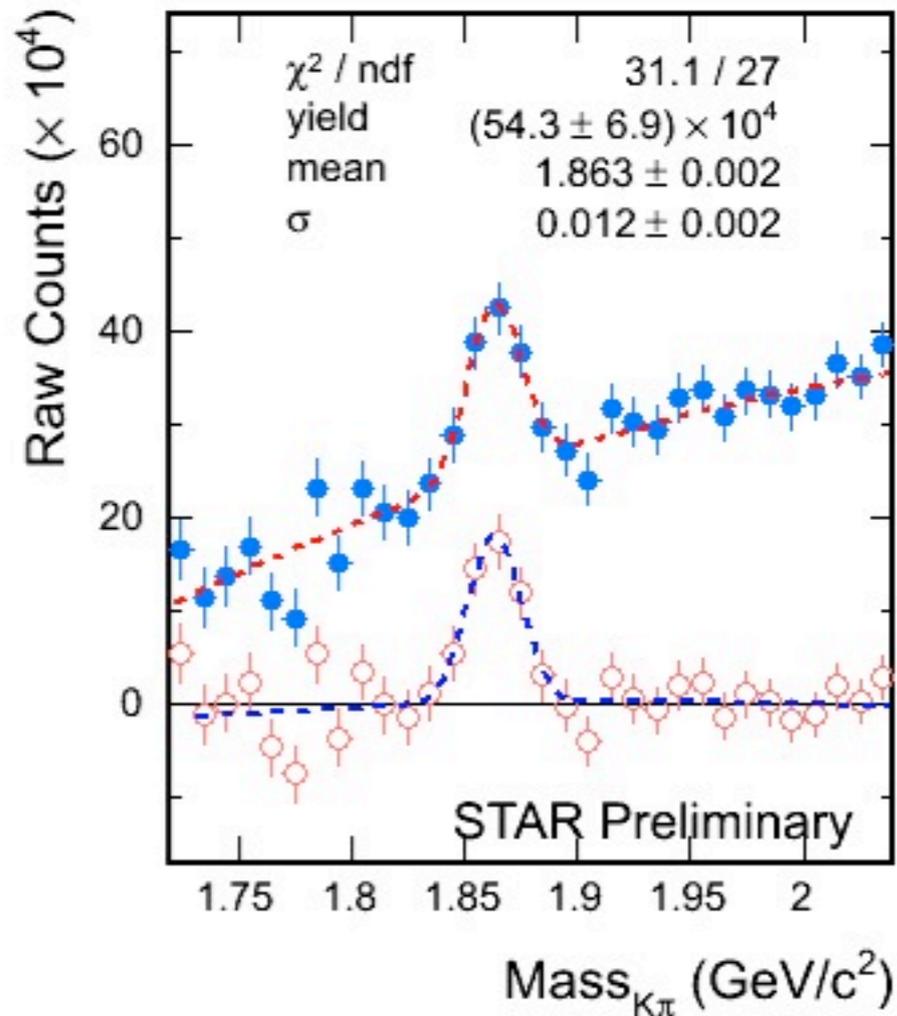
■ π trigger
● $p+K$ trigger



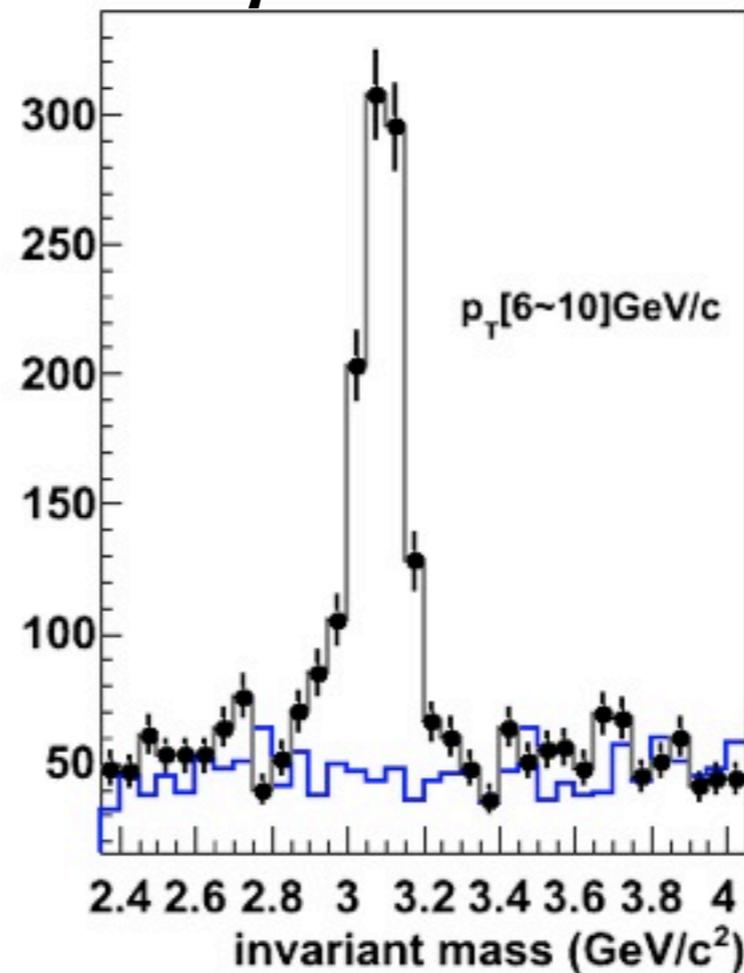
- Strong trigger-PID dependence of the ridge yield
- Near side peak: $\pi > p+K$, similarity in d+Au and Au + Au
- ➔ Consistent with no dilution of near side

STAR capability for heavy flavors

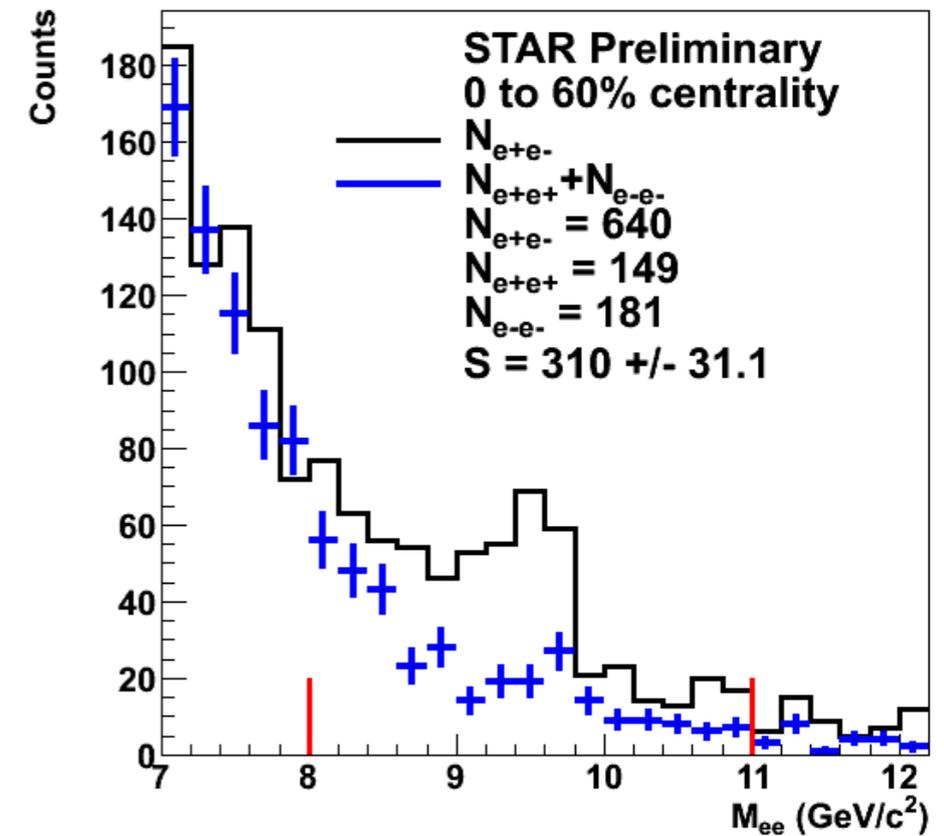
$$D^0 \rightarrow K^- \pi^+$$



$$J/\psi \rightarrow e^+ e^-$$



$$\Upsilon \rightarrow e^+ e^-$$



- Clear signal for D^0 mesons, J/ψ and Υ in Au + Au collisions

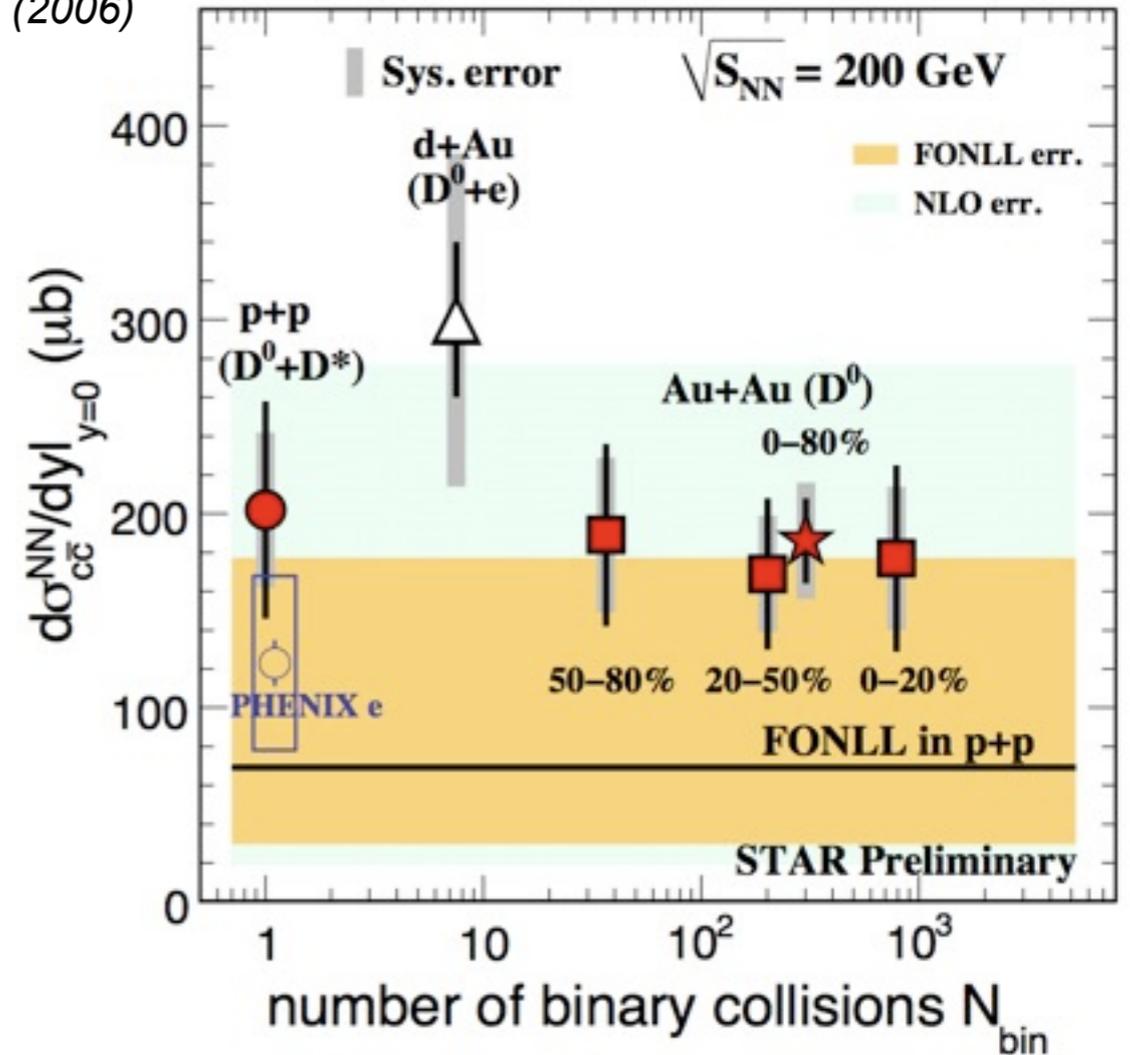
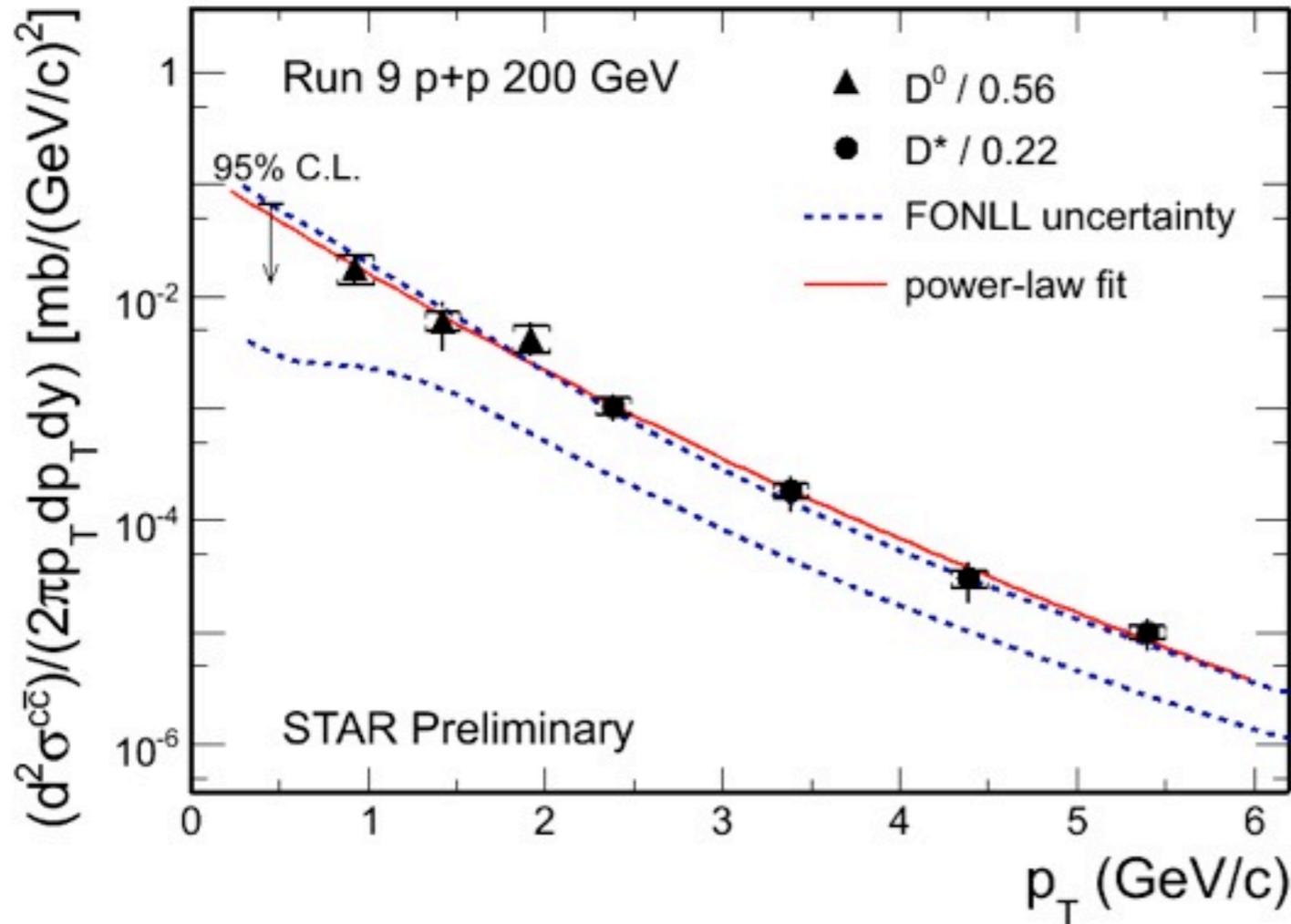
Charm cross section

FONLL: M. Cacciari et al, *PRL95*, 122001 (2005)

NLO: R. Vogt, *EPJ. ST 155*, 213 (2008)

d+Au: STAR, *PRL94*, 062301 (2005), electron: PHENIX, *PRL97*, 252002 (2006)

Yifei Zhang, Fri/27 16:00

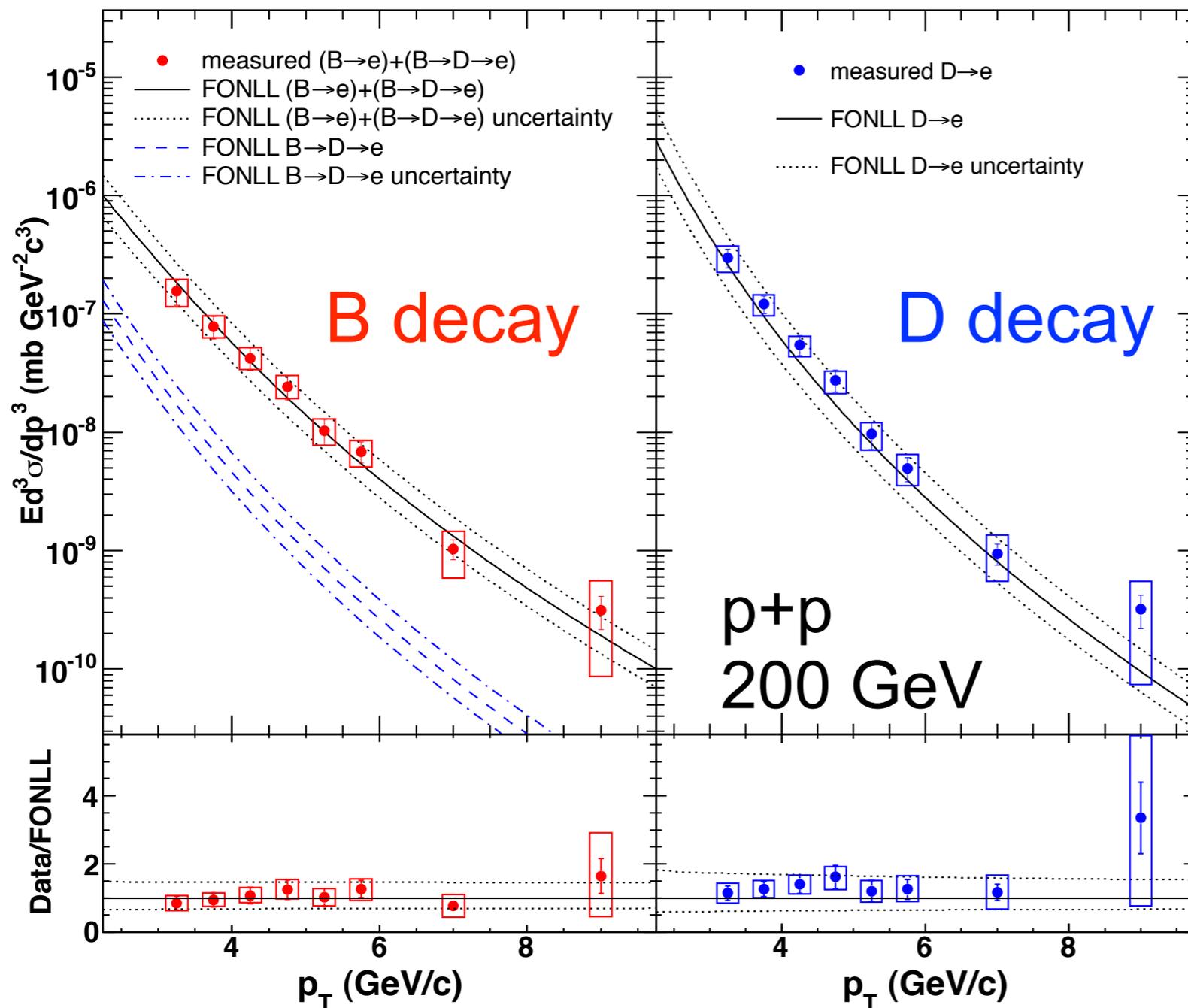


- Charm cross section is consistent with upper bound of FONLL calculation in p+p
- Charm cross section follows number of binary collision scaling
- ➔ Charm quarks are mostly produced by initial hard scattering

Bottom cross section

Xin Li, poster board 44, Thu/26

Wenqin Xu, Mon/23 17:30

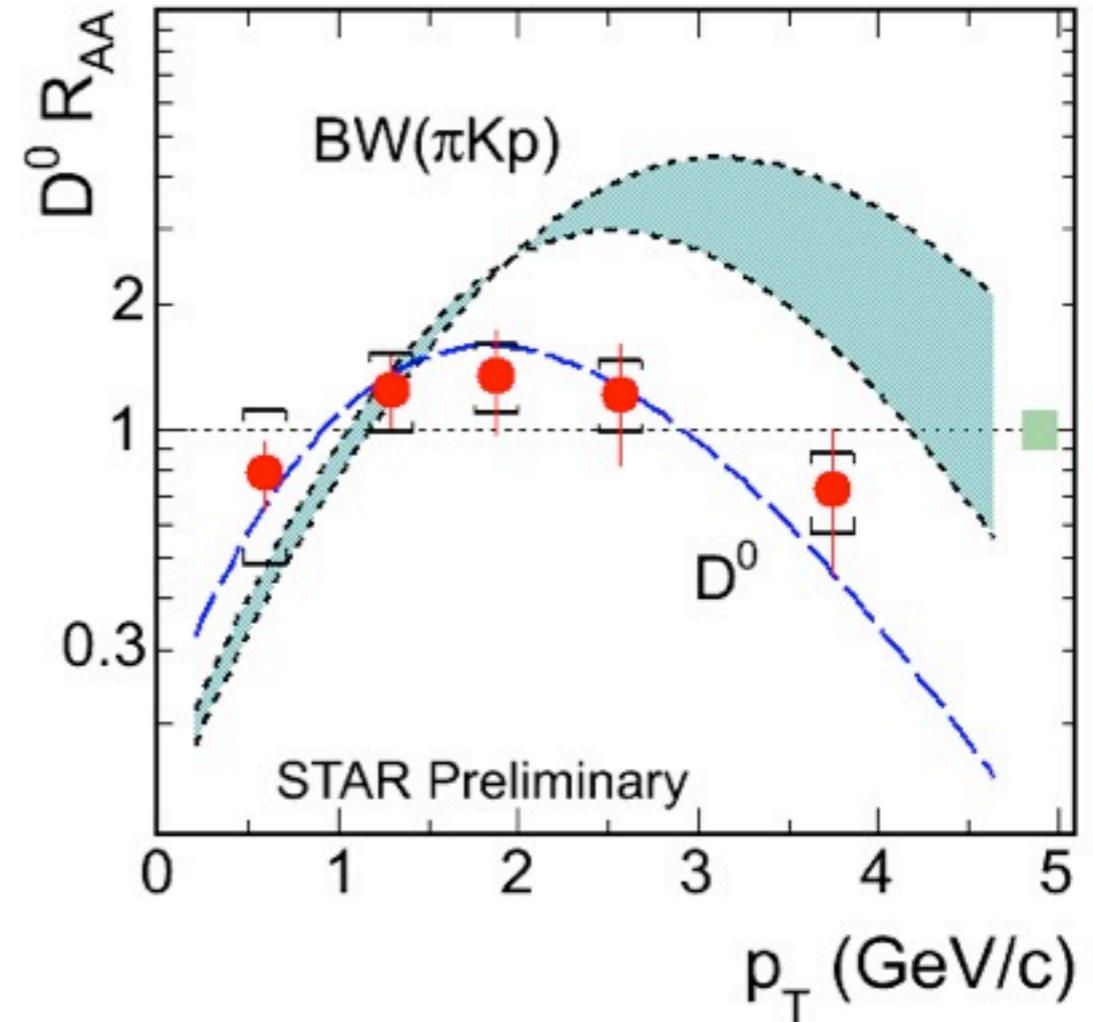
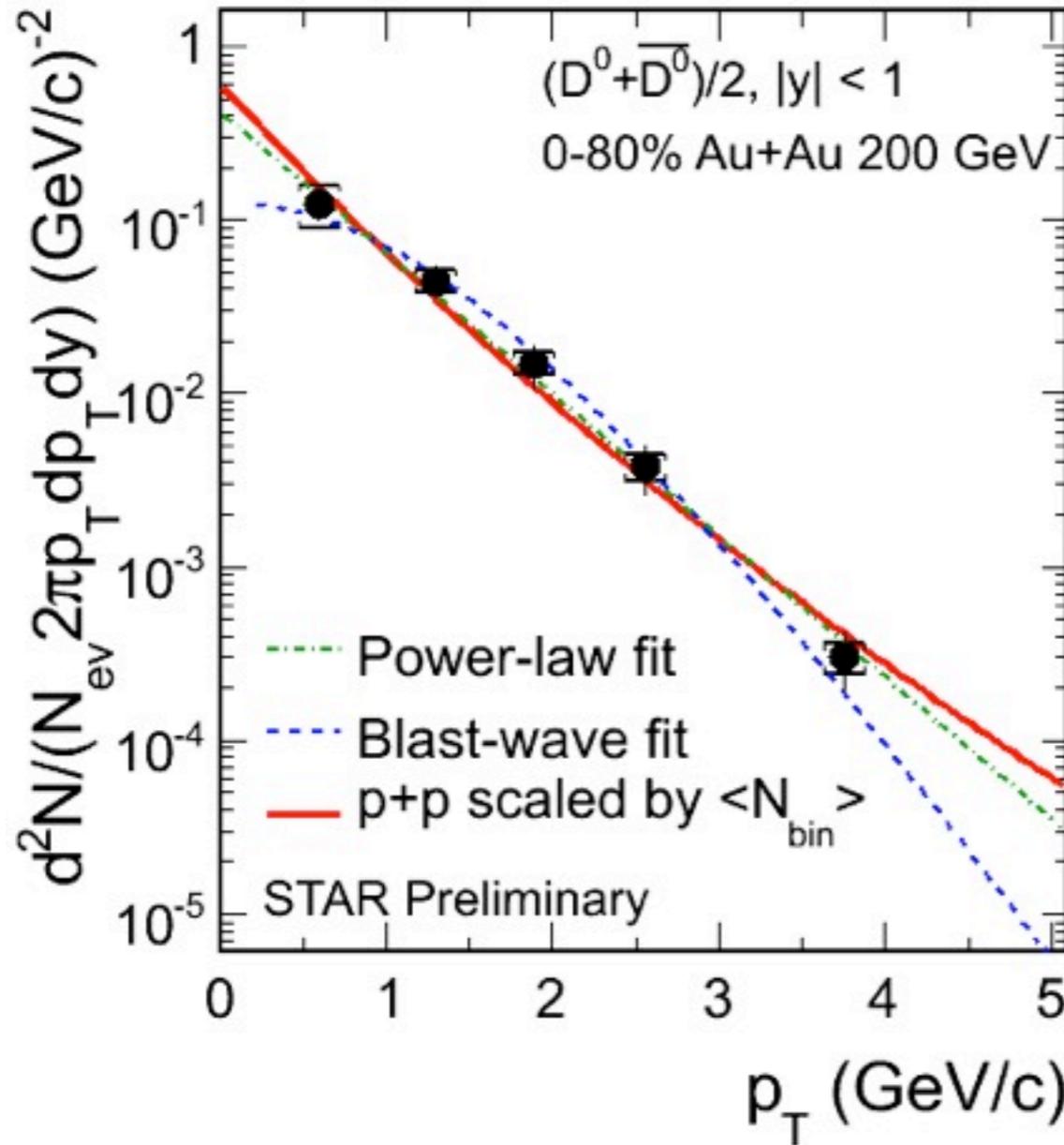


STAR, *PRD83*, 052006 (2011)
 FONLL, M. Cacciari et al, *PRL95*, 122001 (2005)
 M. Cacciari, R. Vogt, private communication

- Disentangle B decay contribution to non-photonic electron
- Bottom decay electrons consistent with FONLL calculation

$D^0 R_{AA}$

Yifei Zhang, Fri/27 16:00



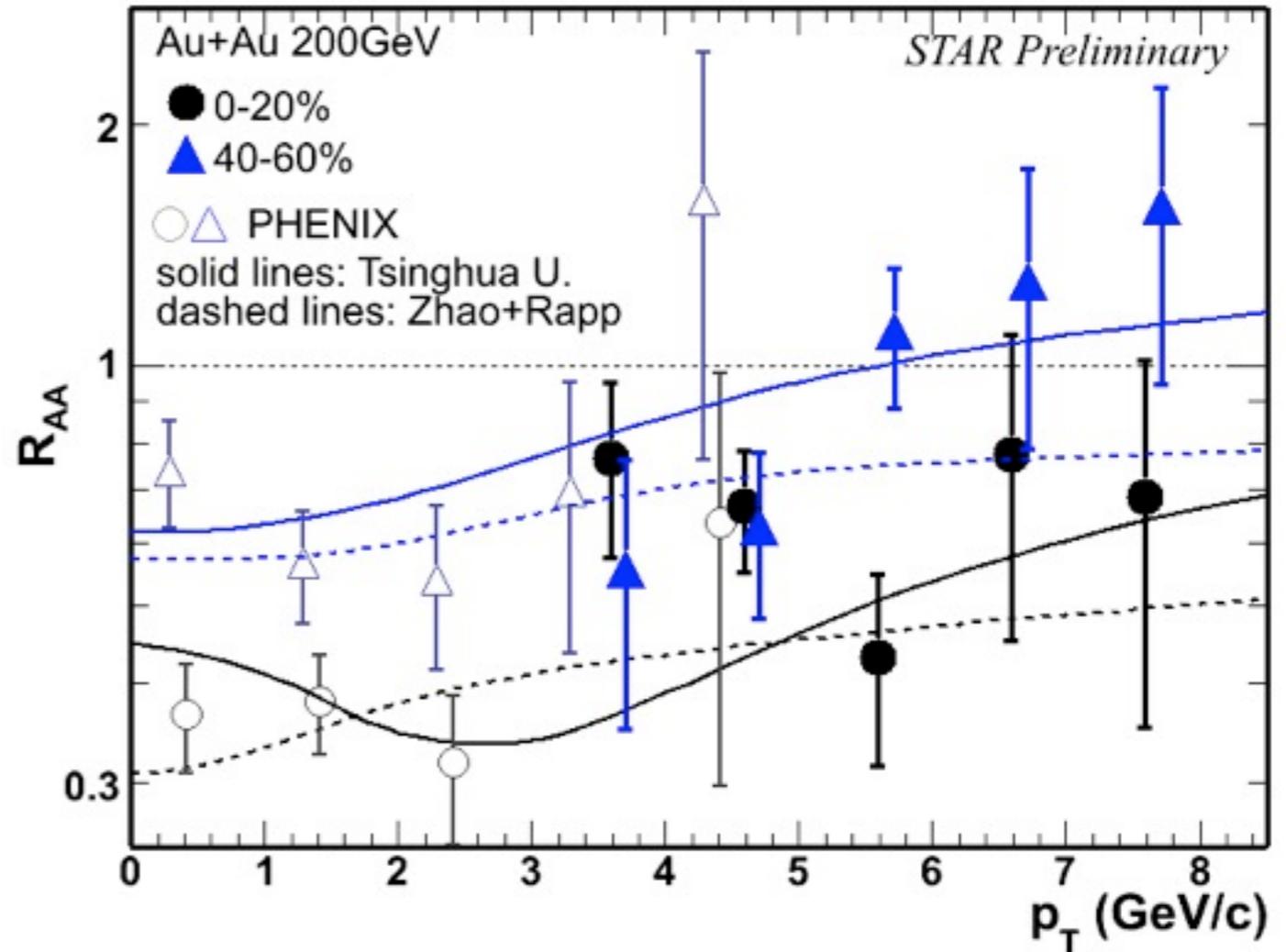
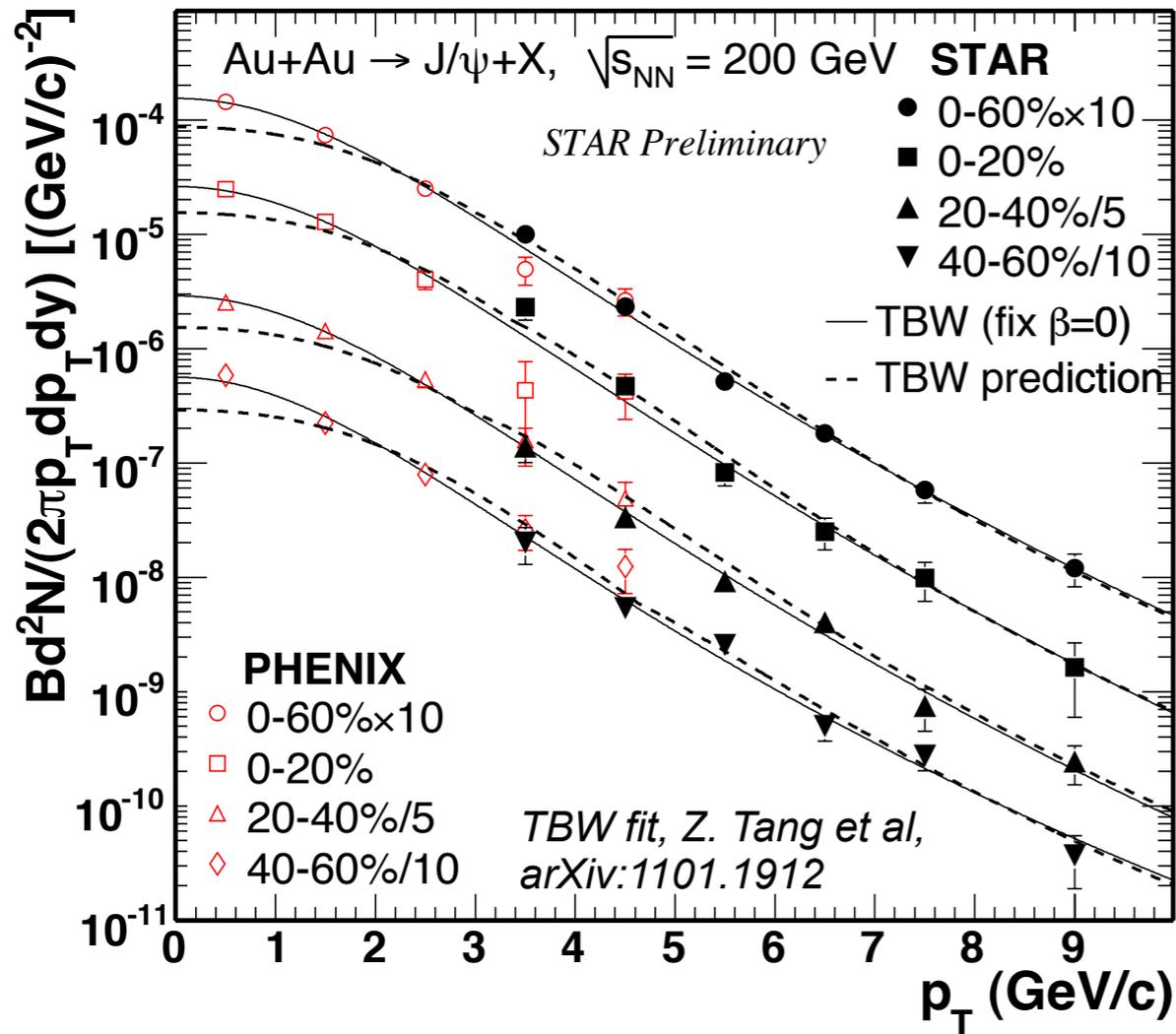
BW($\pi K p$) Blast-wave fit results, STAR, PRC79, 034909 (2009)

- First measurement of $D^0 R_{AA}$, $R_{AA} \sim 1$ in $p_T < 3$ GeV/c
- Blast-wave fit favors higher T_{kin} , smaller β_T for D^0 than light hadrons
- ➔ D^0 freeze-out earlier than light hadrons

J/ψ spectra & R_{AA}

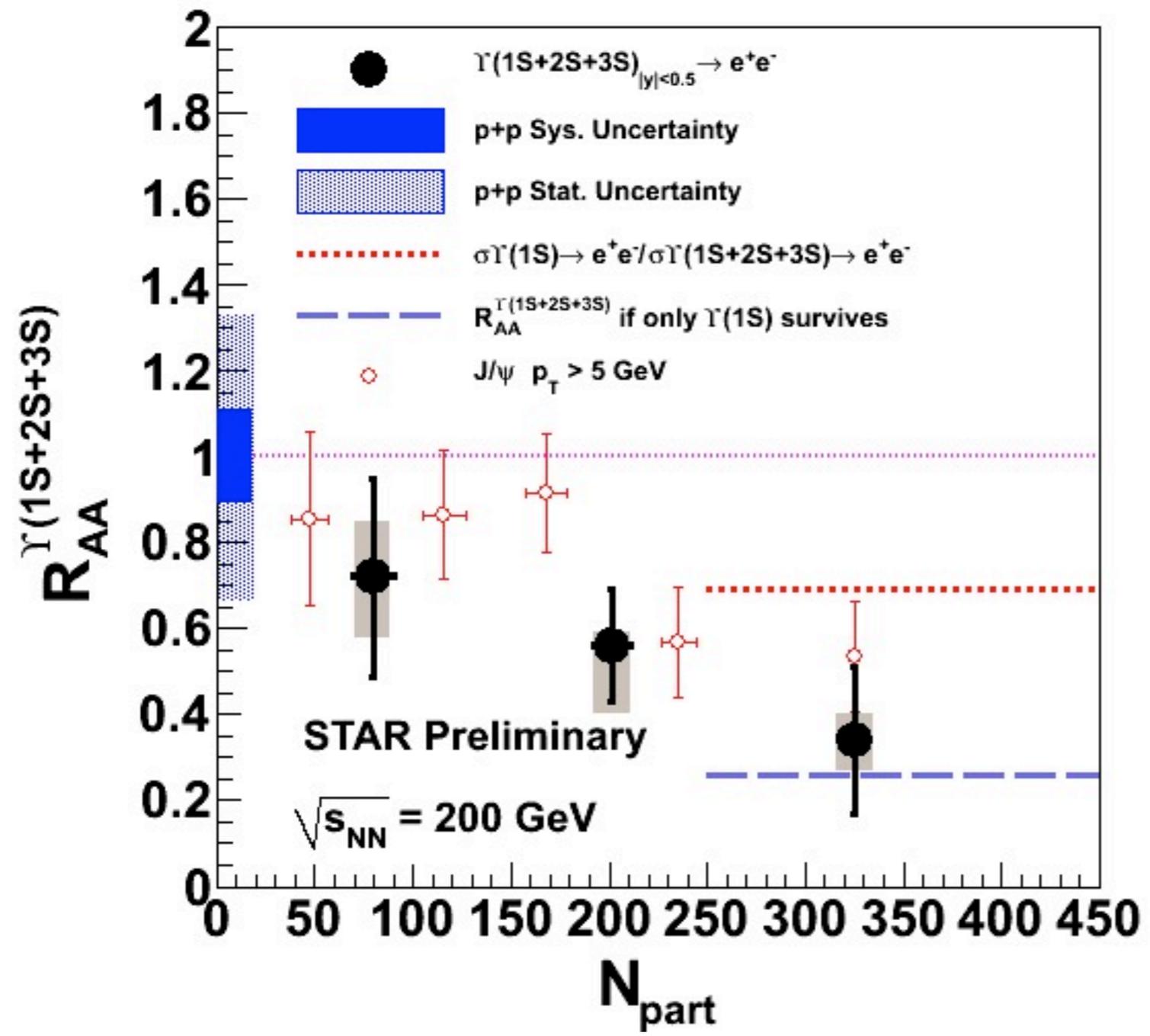
Zebo Tang, Tue/24 15:40

STAR CuCu: *PRC80*, 041902(R) (2009), PHENIX: *PRL98*, 232301 (2007)
 Y. Liu et al, *PLB678*, 72 (2009) and private communication
 X. Zhao and R. Rapp, *PRC82*, 064905(2010) and private communication



- Extend J/ψ spectra up to 10 GeV/c
- High p_T ($p_T > 5$ GeV/c) J/ψ suppression at central collisions

Rosi Reed, poster board 48, Thu/26



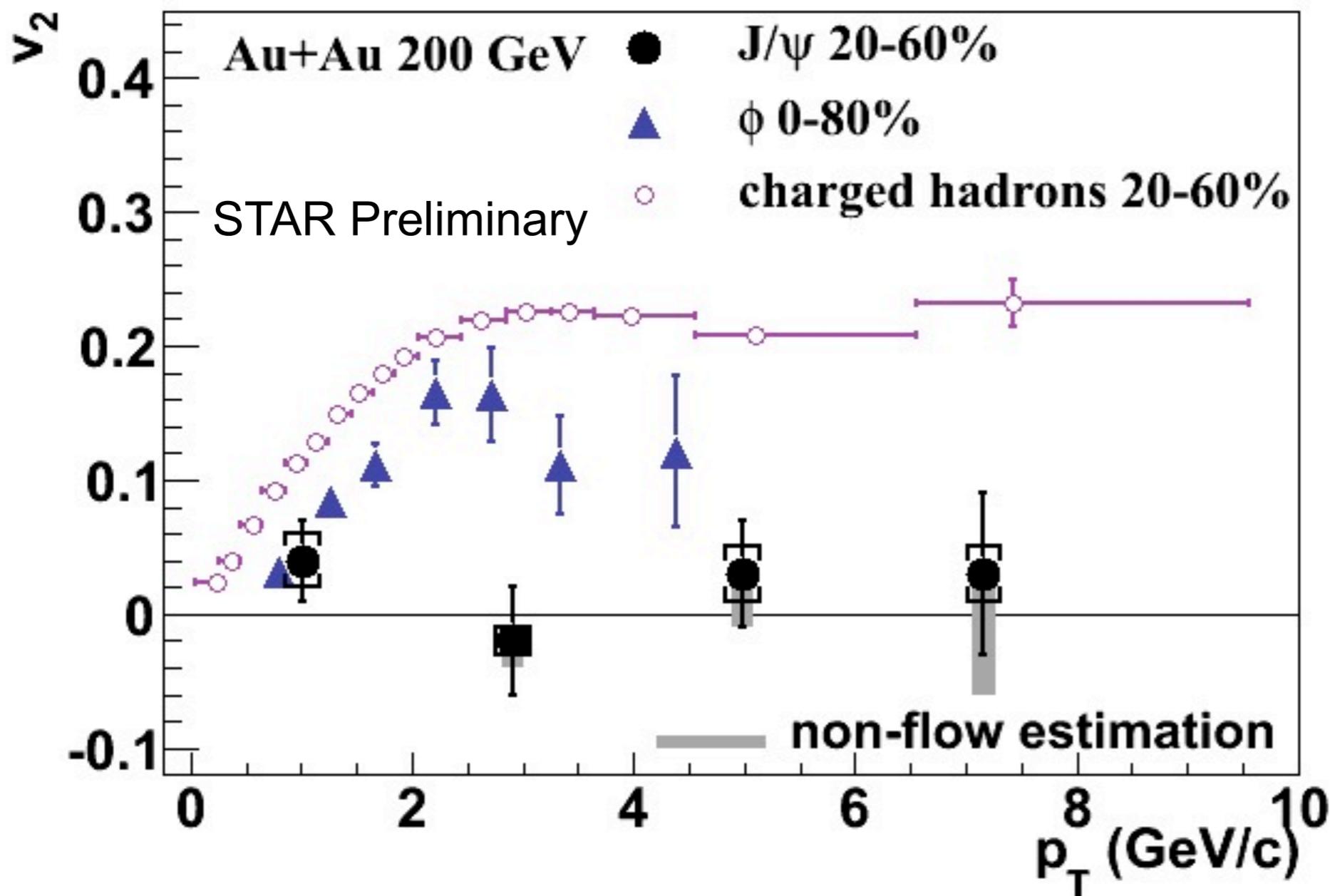
- $\Upsilon(1S+2S+3S)$ suppression at central collisions
 - Similar suppression with high p_T J/ψ
- First measurement of Υ suppression
- Statistical uncertainty will be improved by more than a factor of 2
 - $\times 3$ in p+p 2009
 - $\times 2$ in Au+Au 2011

J/ Ψ v_2

charged hadrons, STAR, *PRL*93, 252301 (2004)
 ϕ , STAR, *PRL*99, 112301 (2007)

Hao Qiu, poster
board 60, Thu/26

Zebo Tang, Tue/24
15:40

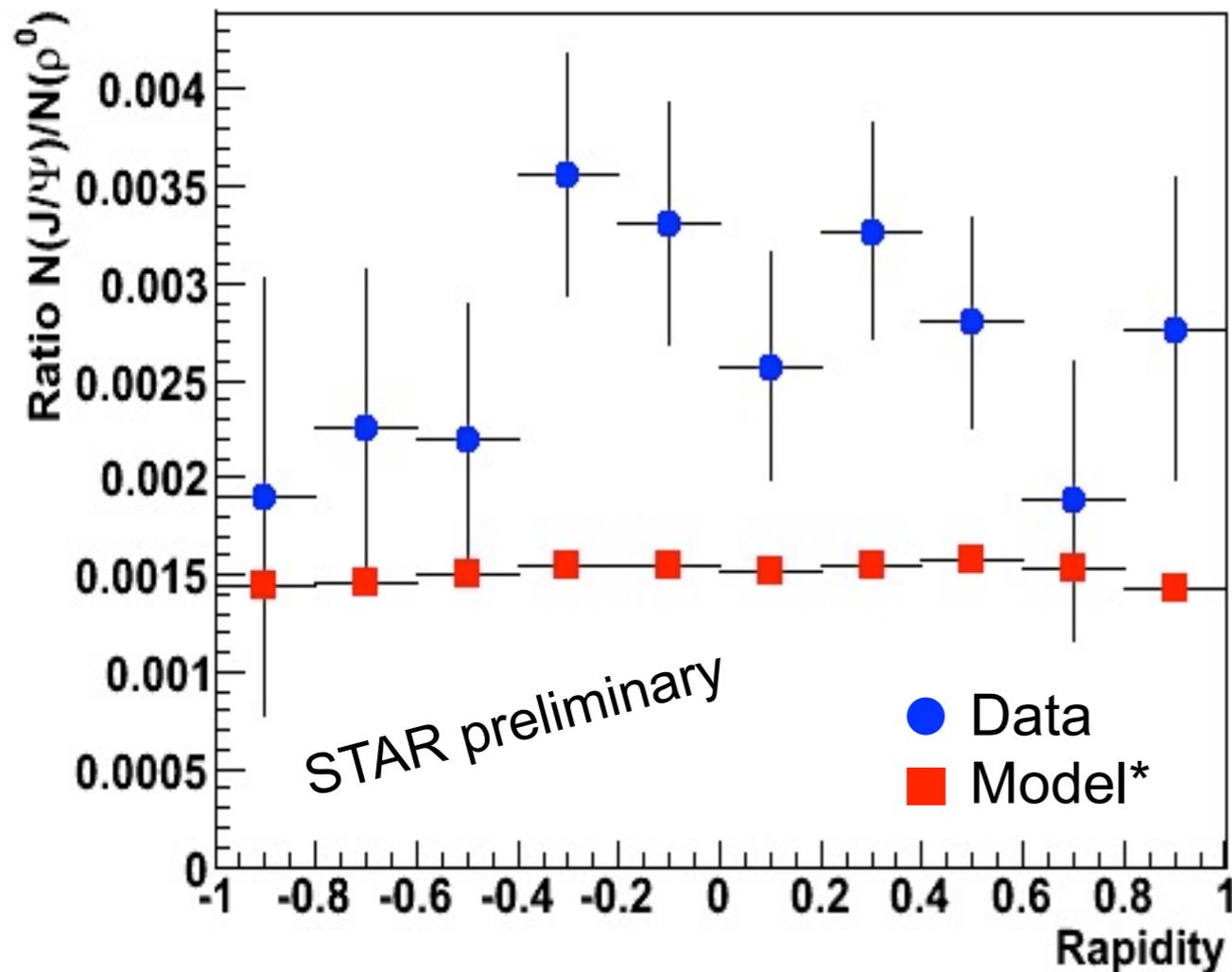
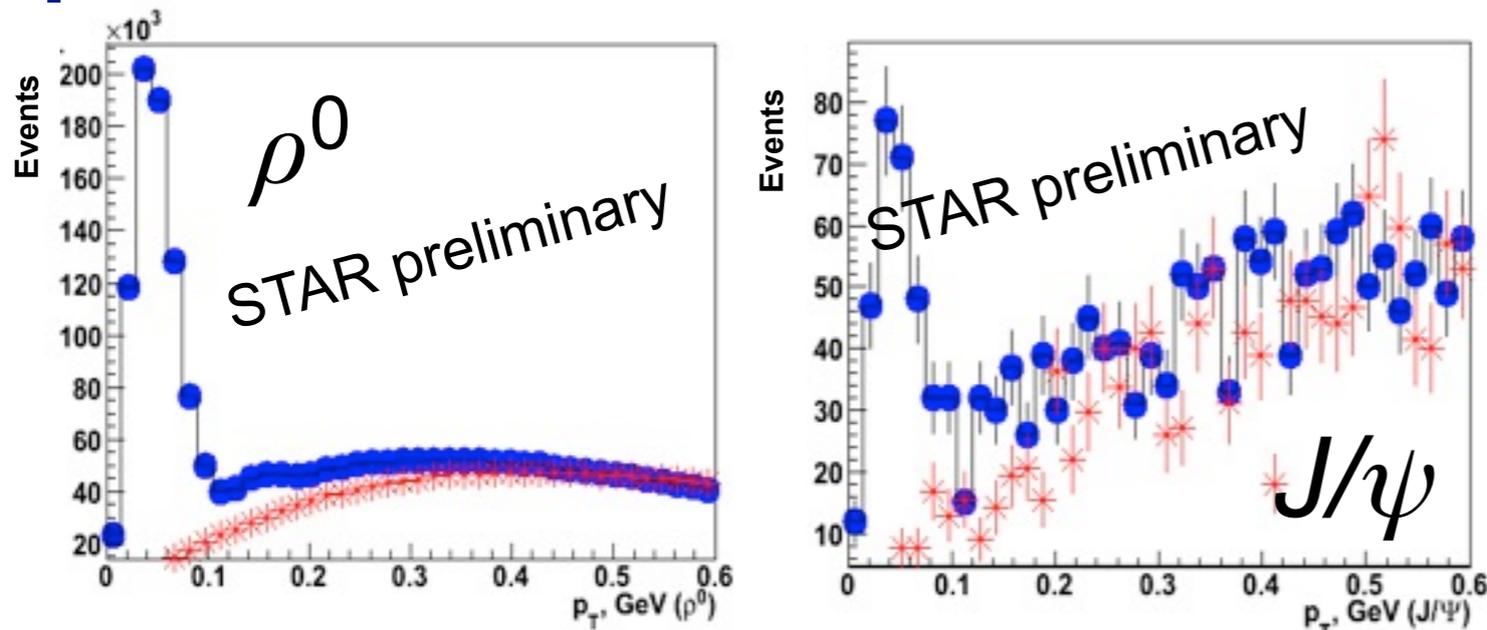


- J/ψ $v_2 \sim 0$ up to $p_T \sim 8$ GeV/c in mid-central 20-60%
- ➔ Disfavors coalescence from thermalized charm quarks

Electromagnetic & bulk probes

ρ^0 , J/ψ photoproductions

Janet Seger, poster board 55, Thu/26

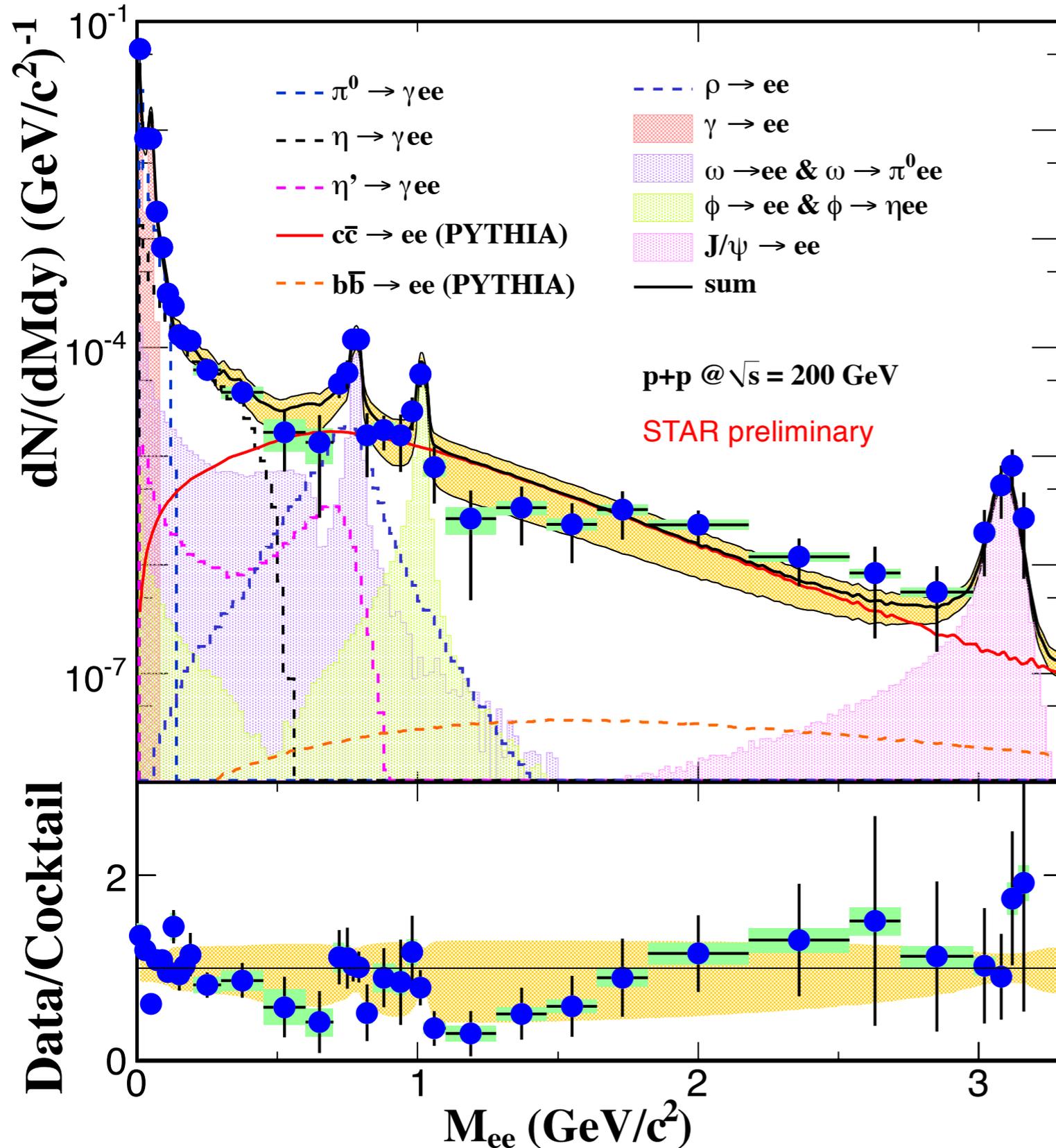


- Heavy vector mesons in ultra-peripheral collisions
 - Sensitive low x gluon distribution
 - ➔ Initial conditions
 - ρ^0 and J/ψ peak at low p_T
 - Consistent with expectations for coherent photoproductions
 - No significant rapidity dependence of cross section ratio $(J/\psi)/\rho^0$
 - Higher than Klein-Nystrand model calculations
- * S. R. Klein, J. Nystrand, *PRC60*, 014903 (1999)

Di-electron spectrum in p+p

Bingchu Huang, poster board 102, Thu/26

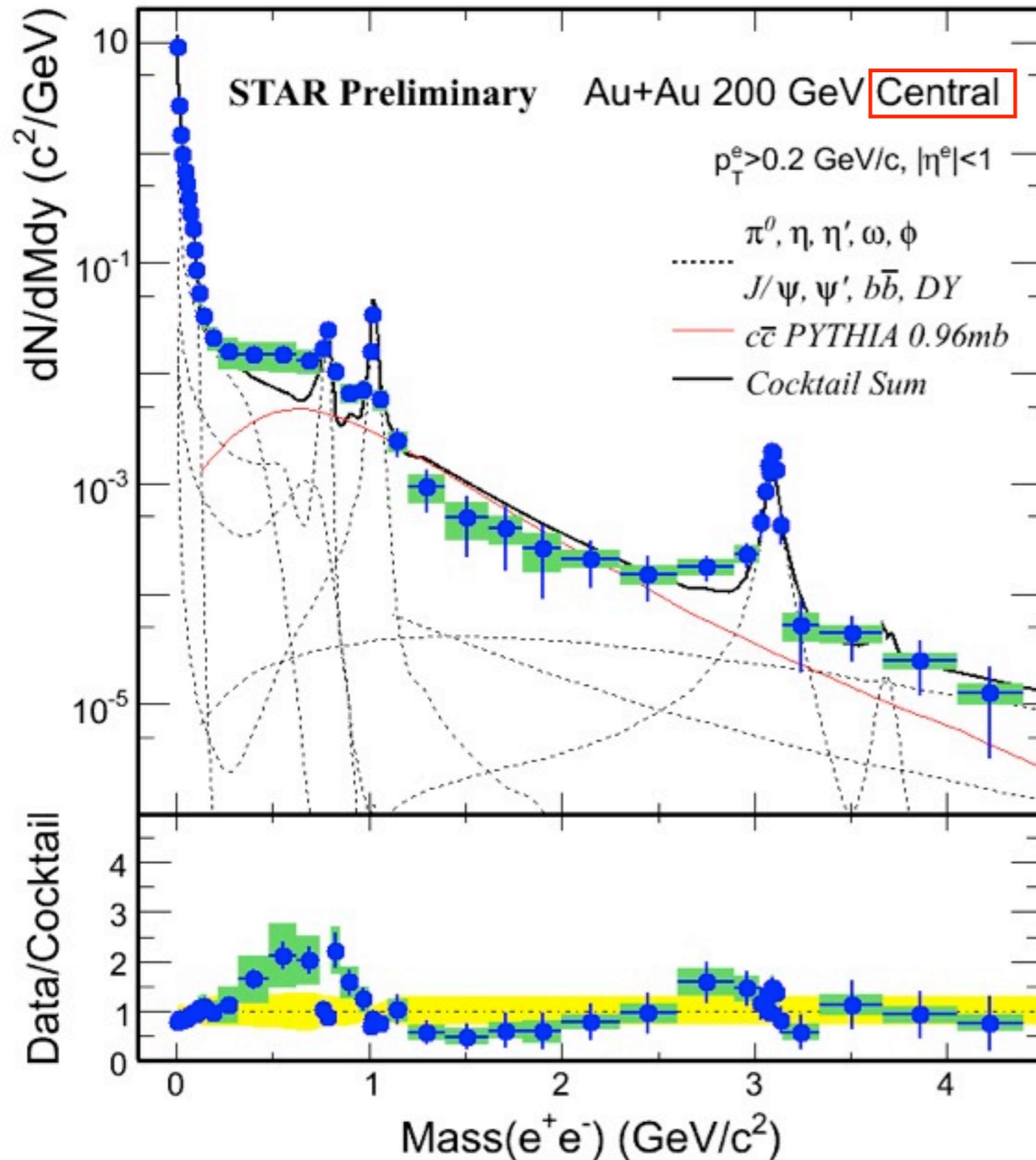
Jie Zhao, Thu/26 15:40



- Data is reproduced by cocktail simulations
- Provide a reference for Au + Au collisions

Di-electron spectrum in Au+Au

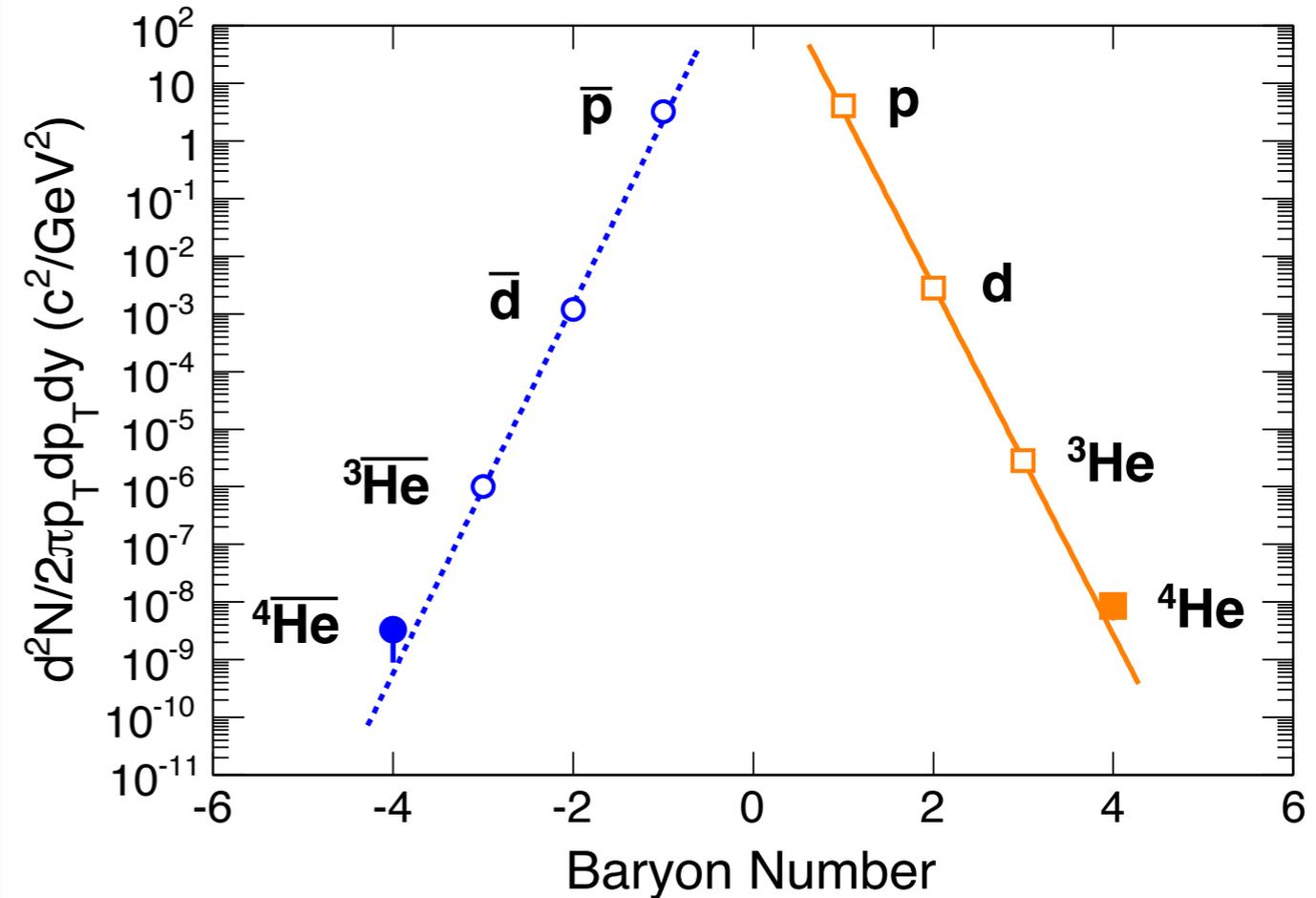
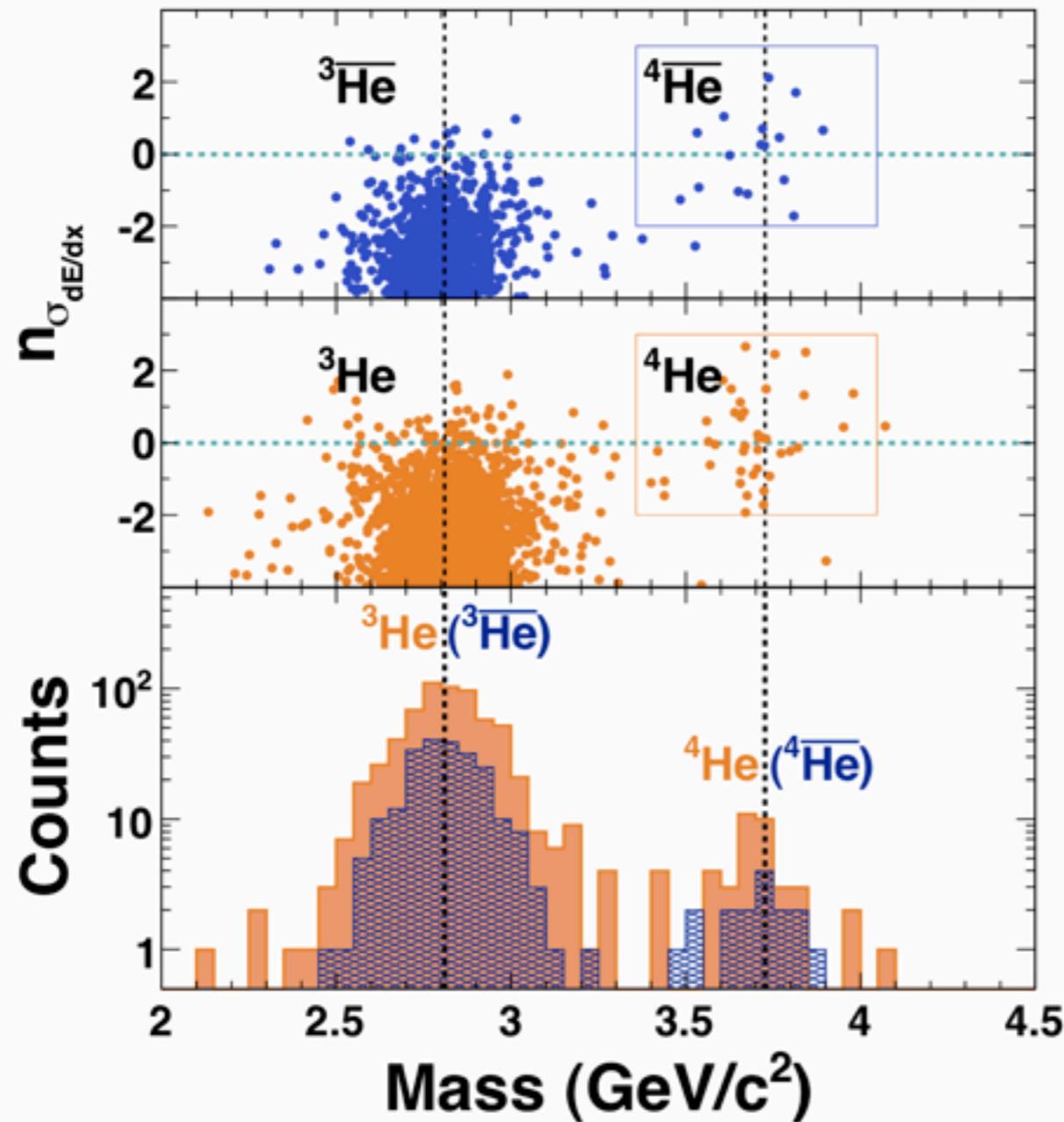
Jie Zhao, Thu/26 15:40



- Enhancement in low mass region at central 0-10%
 - ρ contribution not included in the cocktail
 - In-medium modification of ρ ?
- Charm contribution from PYTHIA $\times N_{\text{bin}}$ (0.96 mb) overestimate the data at intermediate mass region \rightarrow modification of charm ? thermal radiation ?

Discovery of anti- ^4He

Liang Xue, Mon/23 15:00



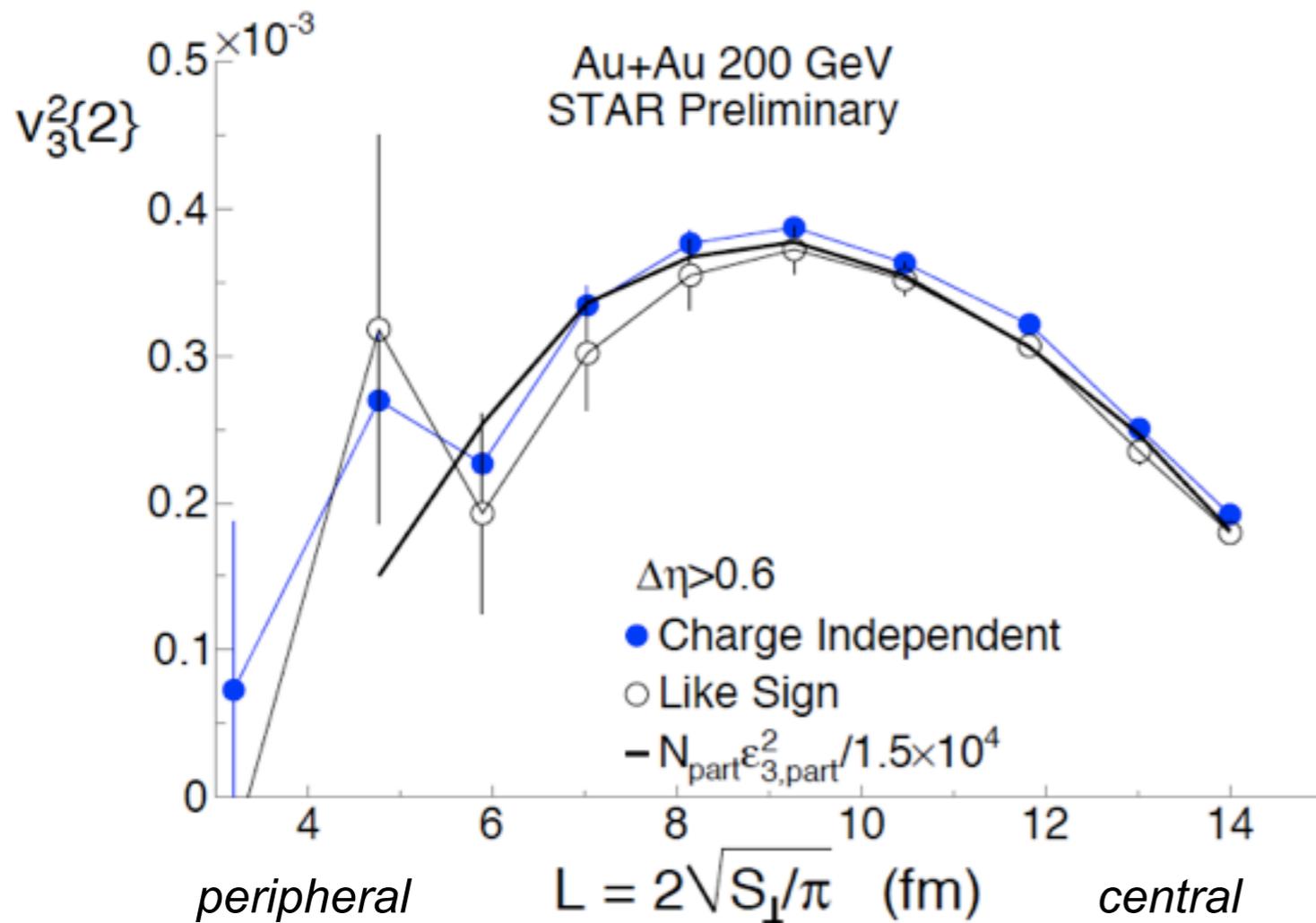
Nature 473, 353-356, (19 May 2011)
doi:10.1038/nature10079

- Discovery of 18 anti- ^4He based on **TPC+TOF+HLT**
- Consistent with thermal & coalescence model expectation

Triangular flow

Paul Sorensen, Thu/26, 12:00

$\cos 3(\phi_1 - \phi_2)$ for $|\Delta\eta| > 0.6$



Related posters

Tue/24

Li Yi, board 33

Jim Thomas, board 43

Thu/26

Chanaka De Silva, board 15

- v_3 observed. Peak at mid-central, similar to v_2
- Sensitive to the initial geometry, $v_3 \propto \epsilon_{3\text{part}}$

Dynamical charge correlation

Dhevan Gangadharan, Fri/27 15:40

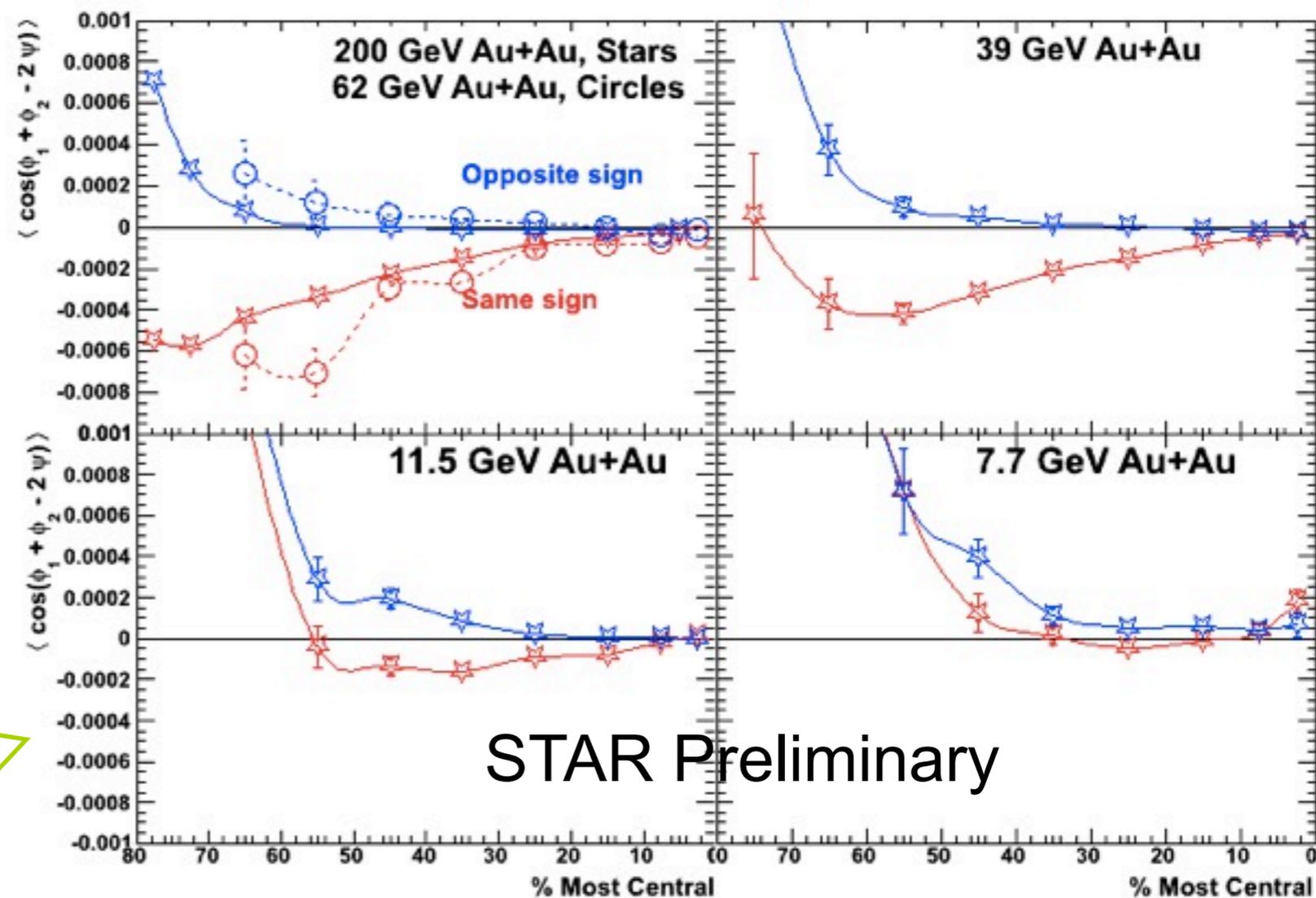
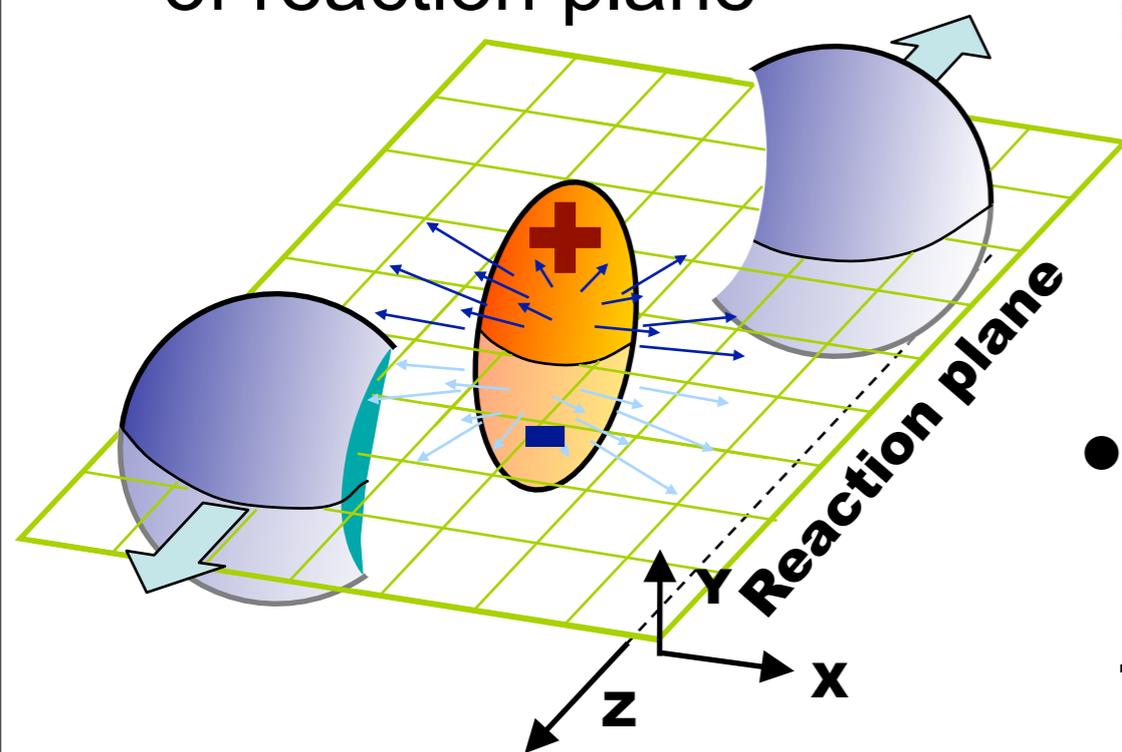
Related posters

Tue/24

Quan Wang, board 34

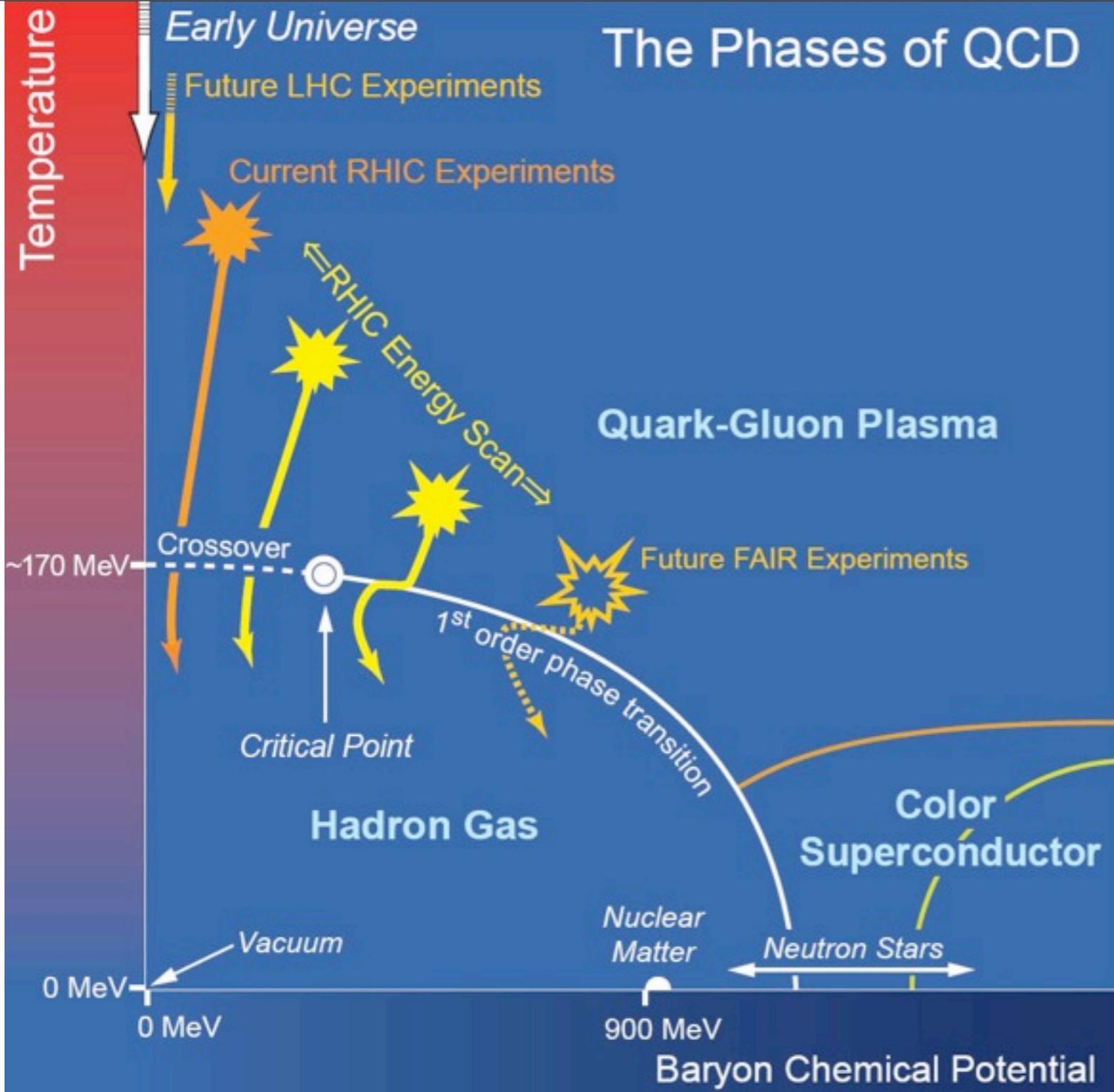
Hui Wang, board 95

Excess $+$ ($-$) charge
on one (another) side
of reaction plane



- Difference of opposite and same sign decreases with decreasing energy
- More details, different approaches in Dhevan's talk and related posters

The Phases of QCD



- Search for
 - ✓ Turn off signature of QGP
 - ✓ QCD Critical point
 - ✓ Signature for softening of EOS

Beam Energy Scan

RHIC Beam Energy Scan (BES)

► *Turn off signature of QGP*

NCQ scaling of v_2

suppression of R_{AA}

charge separation w.r.t reaction plane

...

► *QCD critical point*

higher moments of conserved quantities

particle ratio fluctuations

...

► *Softening of EOS*

azimuthal HBT

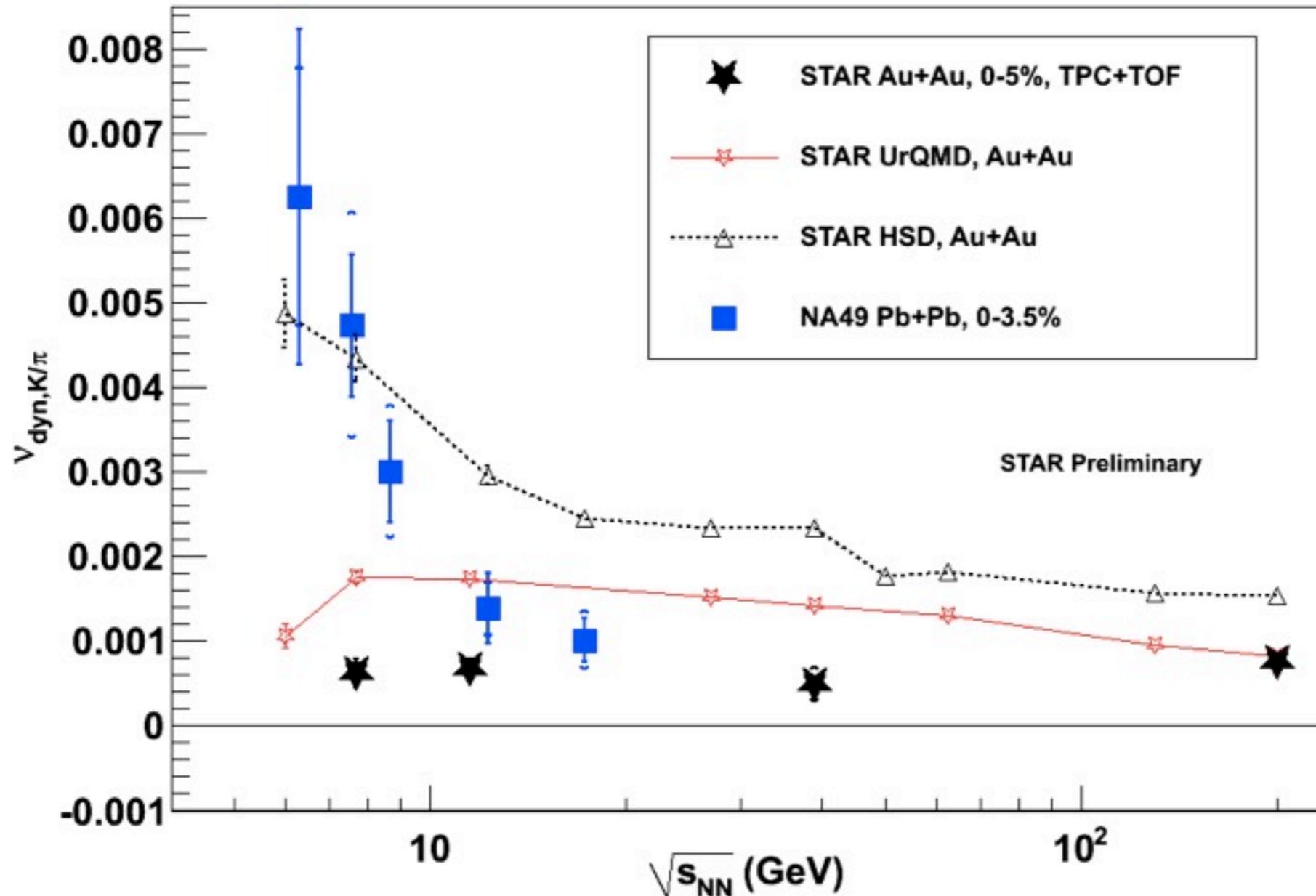
azimuthal anisotropy v_1, v_2, \dots

...

<i>Year</i>	$\sqrt{s_{NN}}$ (GeV)	<i># of good events</i>
2010	7.7	~5M
	11.5	~11M
	39	~170M
2011	19.6	~17M
2011	5	-
2012	27	-

Particle ratio fluctuations

Terence Tarnowsky,
Mon/23 16:00



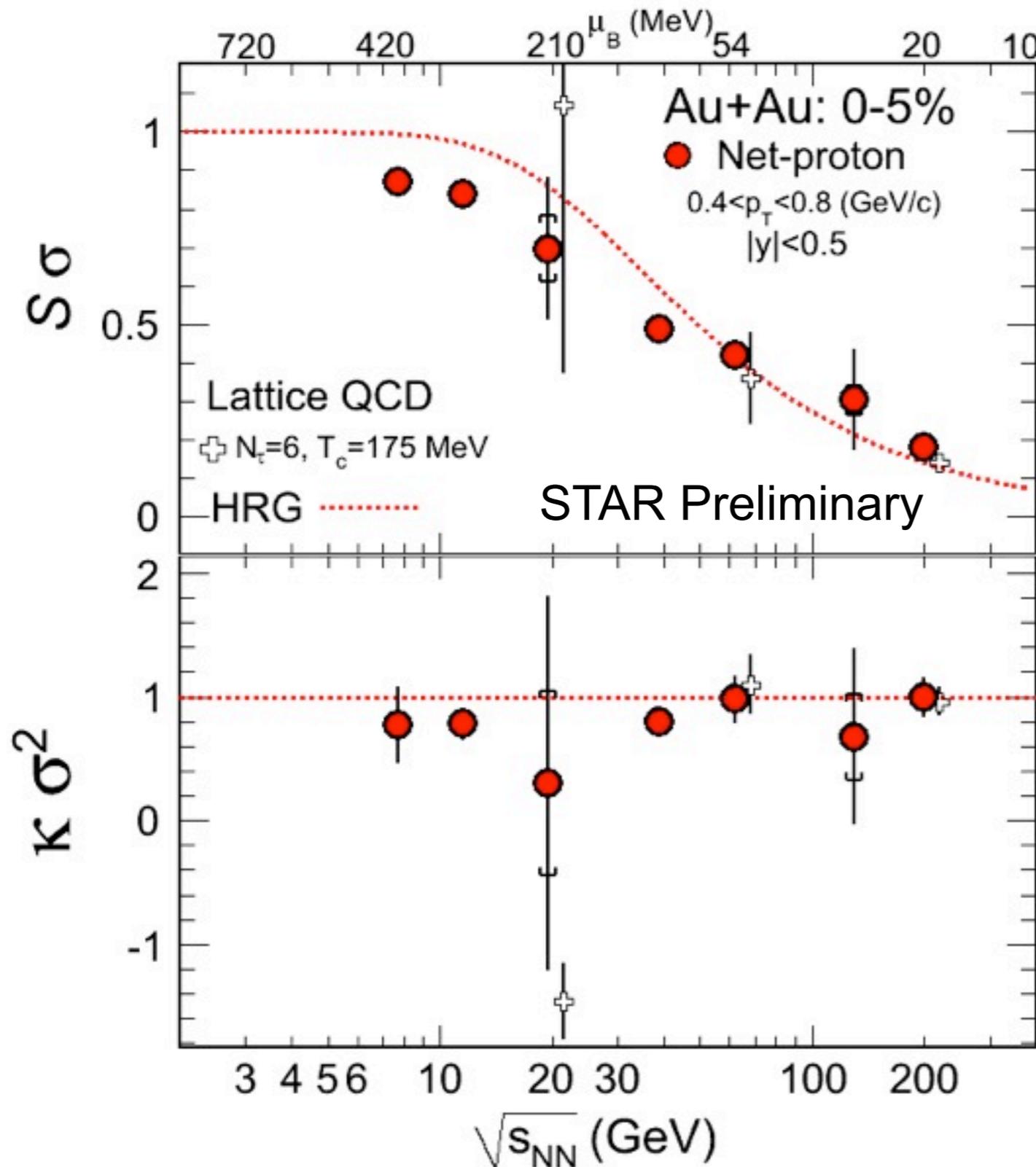
STAR TPC+TOF
 π : $0.2 < p_T < 1.4$ GeV/c
K; $0.2 < p_T < 1.4$ GeV/c

- No strong energy dependence of K/ π fluctuations in central 0-5% Au + Au collisions from STAR data

Higher moments of net-proton

Xiaofeng Luo, poster board 141, Thu/26

Terence Tarnowsky, Mon/23 16:00



19.6, 62.4 and 200 GeV: STAR, *PRL*105, 022302 (2010)

$$S\sigma = \chi_B^{(3)} / \chi_B^{(2)}$$

$$\kappa\sigma^2 = \chi_B^{(4)} / \chi_B^{(2)}$$

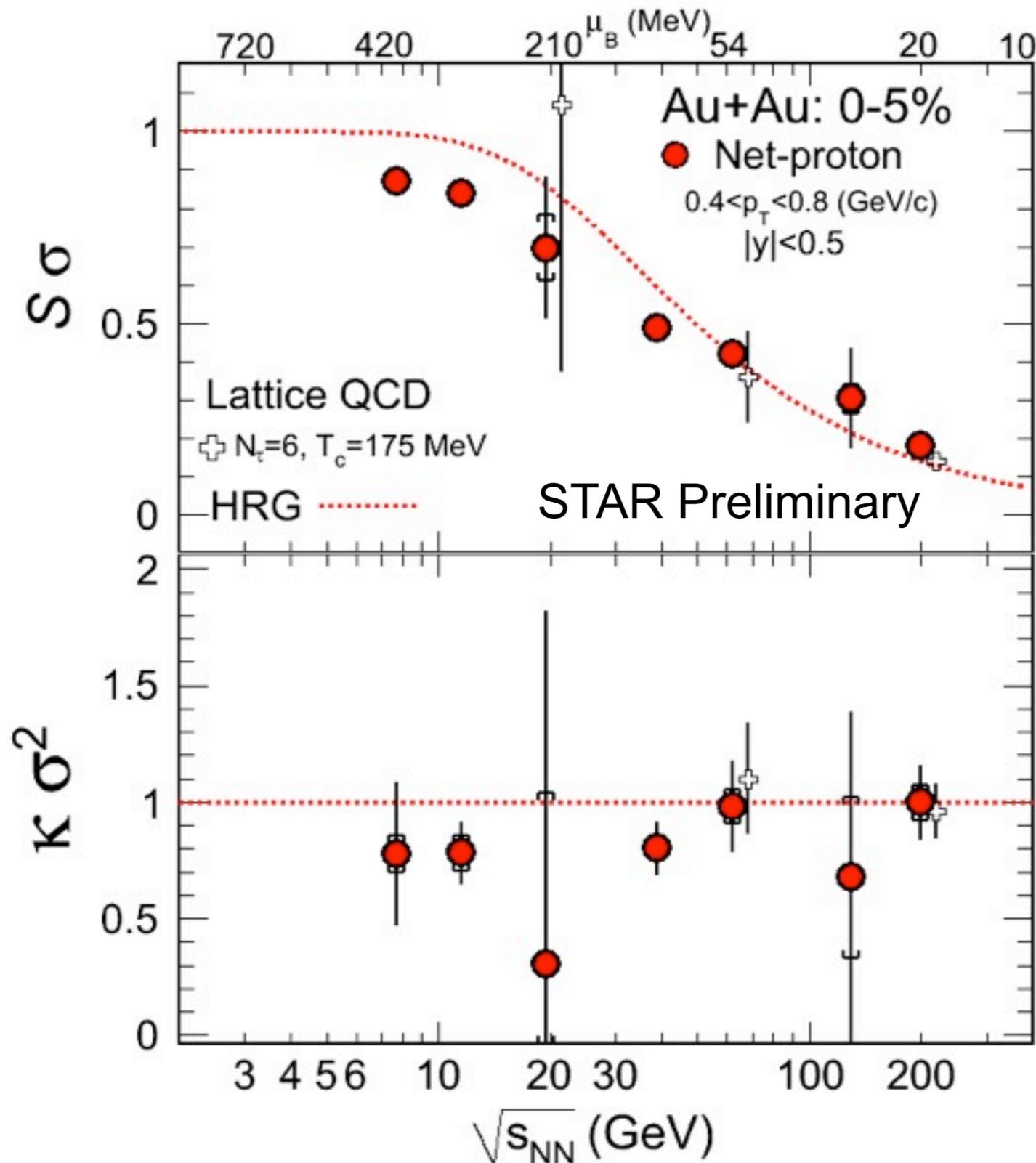
1. Connection to susceptibilities
2. Higher order, more sensitivity to the correlation length

- Consistent with Lattice QCD and Hadron Resonance Gas (HRG) model at higher energies
- Start deviating from HRG model at 39 GeV

Higher moments of net-proton

Xiaofeng Luo, poster board 141, Thu/26

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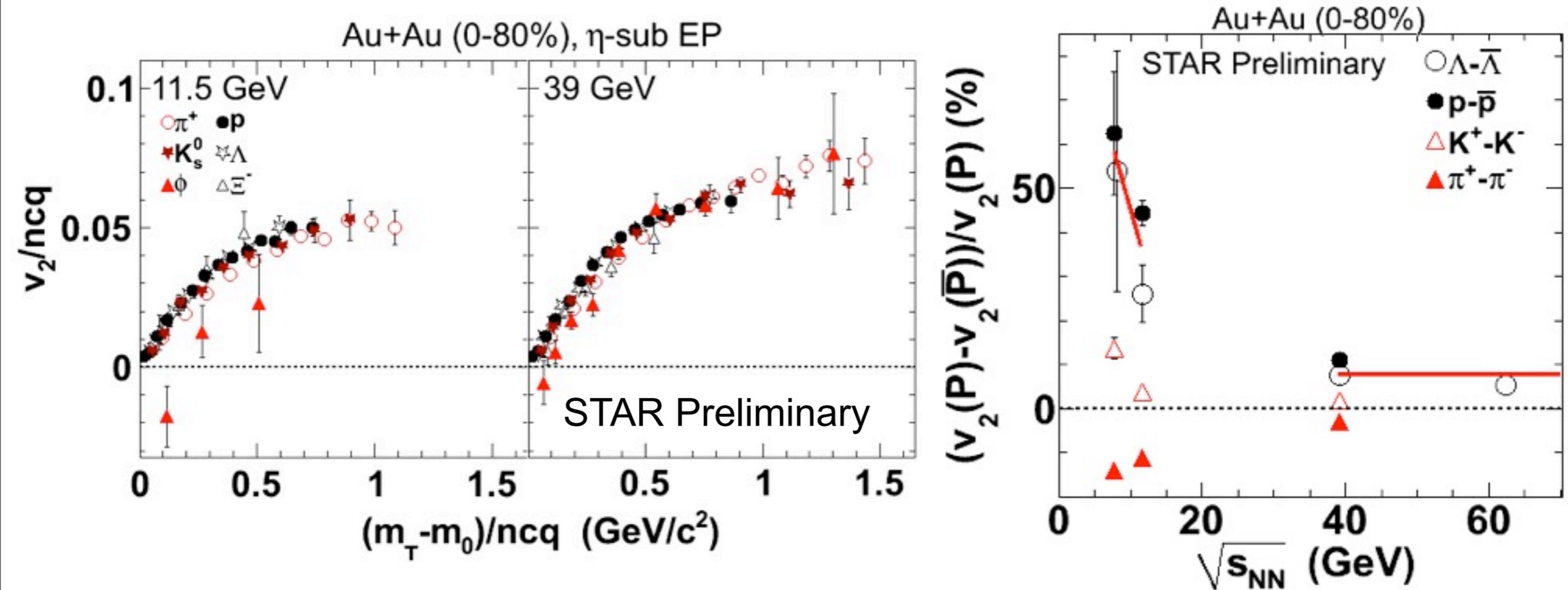
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Azimuthal anisotropy v_2

62.4 GeV Λ - $\bar{\Lambda}$: STAR, PRC75, 054906 (2007)

Alexander Schmah,
Mon/23, 18:50



- $v_2(\phi)$ does not follow the trend for other hadrons at 11.5 GeV
- Significant difference of v_2 between baryon and anti-baryon at 7.7 and 11.5 GeV

Summary (i)

- Jet-hadron correlation
 - Appears to be consistent with radiative energy loss picture
- PID triggered correlation
 - Strong trigger-PID dependence of the ridge yields
 - No dilution of near-side peak → challenge to simple recombination picture
- **More results in Helen's talk on Wed/25 11:15**
- Charm and bottom cross section are consistent with FONLL
- First measurement of $D^0 R_{AA}$
 - Blast-wave model fit suggests D^0 freeze-out earlier than light hadrons
- Quarkonium R_{AA} at central collisions
 - High p_T J/ψ suppression, first measurement of $\Upsilon(1S+2S+3S)$ suppression
- J/ψ $v_2 \sim 0$ up to 8 GeV/c
 - Disfavors coalescence from thermalized charm quarks

Summary (ii)

- Enhancement of low mass di-electron spectrum at 0-10% central collisions
 - In-medium modification of ρ ? Charm modification ?
- Discovery of anti- ^4He
 - Consistent with thermal & coalescence model expectation
- $v_3 \propto \varepsilon_{3,\text{part}}$, sensitive to the initial geometry. **More results in Paul's talk on Thu/26 12:00**
- Difference of opposite and same sign correlations decreases with decreasing energy
- Success of RHIC Beam Energy Scan program in 2010.
 - Presented selected results; particle ratio fluctuations, higher moments of net-proton, v_2
- **More results (azimuthal HBT, v_1 , p_T spectra, particle ratio, ...) in Bedanga's talk on Thu/26 8:55**

STAR parallel talks

Global and Collective Dynamics

- Mon. 23, 18:50 Alexander Schmah (LBNL) - Event anisotropy $v_{\{2\}}$ of identified hadrons and light nuclei in Au+Au collisions at $\sqrt{s_{\{NN\}}}$ = 7.7, 11.5 and 39 GeV with STAR
Fri. 27, 15:40 Dhevan Gangadharan (OSU) - Search for Local Strong Parity Violation in STAR Using Multiple Observables

Jets

- Fri. 27, 16:00 Kolja Kauder (UIC) - Leading hadron PID effects in di-hadron angular correlations in STAR
Fri. 27, 18:10 Alice Ohlson (Yale) - Jet-Hadron Correlations in STAR

Hadron thermodynamics and chemistry

- Mon. 23, 15:00 Liang Xue (SINAP/BNL) - Observation of the antimatter helium-4 nucleus

Heavy flavors

- Mon. 23, 17:30 Wenqin Xu (UCLA) - STAR Measurements of Bottom to Charm ratio and Heavy Quark Interaction with the QCD Medium through Non-Photonic Electron-Hadron Correlations
Tue. 24, 15:40 Zebo Tang (USTC) - J/Psi production and correlation in p+p and $R_{\{AA\}}$ at high-pt in Au+Au collisions
Fri. 27, 16:00 Yifei Zhang (LBNL) - Open charm hadron measurement in p+p and Au+Au collisions at $\sqrt{s} = 200$ GeV in STAR

Electromagnetic probes

- Thu. 26, 15:40 Jie Zhao (SINAP/LBNL) - Dielectron Continuum Production from $\sqrt{s_{\{NN\}}} = 200$ GeV p+p and Au+Au collisions at STAR

Correlation and fluctuations

- Mon. 23, 16:00 Terence Tarnowsky (MSU) - Dynamical $K\pi$, $p\pi$, and K/p Fluctuations in $\sqrt{s_{\{NN\}}} = 7.7-200$ GeV Au+Au Collisions

Energy Scan

- Fri. 27, 15:00 Lokesh Kumar (KSU) - Identified Hadron Production from the RHIC Beam Energy Scan Program in the STAR experiment
Fri. 27, 16:00 Christopher Anson (OSU) - Energy dependence of the freeze out eccentricity from azimuthal dependence of HBT at STAR

Future Facilities and Experiment Upgrades

- Thu. 26, 16:40 Carl Gagliardi (Texas A&M) - STAR Science for the Coming Decade

STAR posters (Session1)

Tue/24, 17:20

Board/Poster	Author	Title
16/281	ShuSu Shi	Inclusive charged hadron elliptic flow in Au + Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5$ and 39 GeV
17/284	Yadav Pandit	Directed flow of Identified Particles in Au+Au Collisions at $\sqrt{s_{NN}} = 39, 11.5$ and 7.7 GeV from the STAR Experiment
19/291	Michael Mitrovski	Elliptic Flow of charged particles in Au+Au collisions at 7.7, 11.5 and 39 GeV from STAR
23/392	Prabhat Pujahari	Elliptic Flow (v_2) of ρ^0 vector-meson in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR at RHIC
33/520	Li Yi	Triangular Flow and Nonflow by 2-, 4-, and 6-Particle Cumulants from STAR
34/583	Quan Wang	Measurement of Charge Multiplicity Asymmetry Correlations to Search for Chiral Magnetic Effect in Heavy Ion Collisions
43/576	Jim Thomas	Three Particle Correlations as a Probe of Eccentricity Fluctuations
61/395	Shikshit Gupta	Charged Particle Ratios for p+p Collisions in $\sqrt{s} = 62.4$ GeV at RHIC
89/332	Michael Skoby	Forward-Backward Multiplicity Correlations for Identified Particles at STAR
93/362	Amal Sarkar	Higher moments of Net Kaon Fluctuation in the Beam Energy Scan of STAR
95/381	Hui Wang	Local Parity Violation or Local Charge Conservation/Flow? A Reaction-Plane-Dependent Balance Function
127/274	Aihong Tang	A High Level Online Tracking Trigger for the STAR experiment at RHIC
129/335	Liuan Luan	A Novel and Compact Muon Telescope Detector at STAR for Midrapidity Di-lepton Physics at RHIC

STAR posters (Session 2)

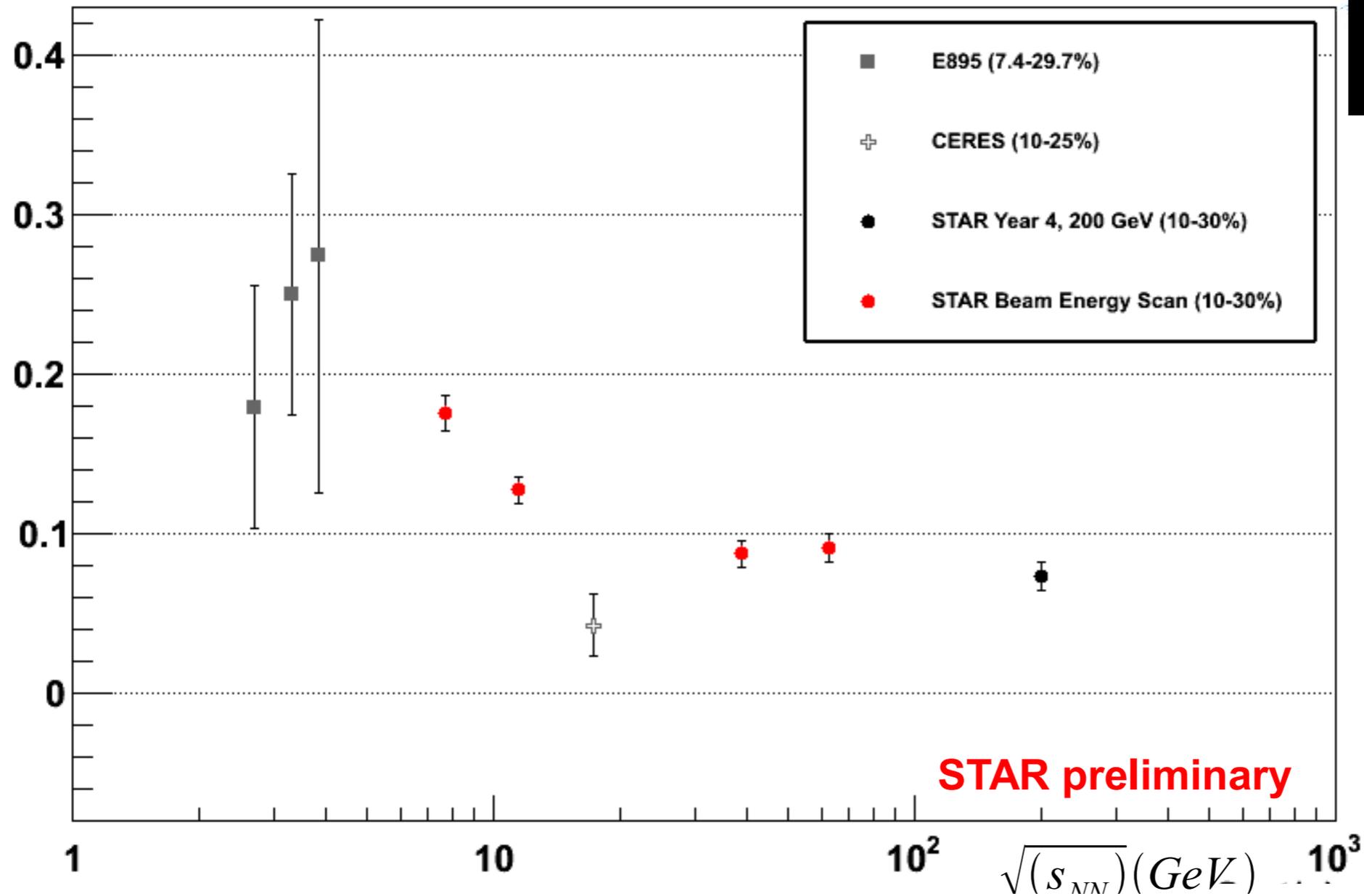
Thu/26, 17:20

Board/Poster	Author	Title
14/231	Mriganka Mouli Mondal	Jet properties in \sqrt{s} p+p and their possible modification in cold nuclear matter in STAR
15/255	Chanaka De Silva	Investigating jet and non-jet contributions to long range pseudo-rapidity correlations in di-hadron measurements from STAR
18/407	Jana Bielcikova	Underlying event studies in d+Au collisions at $\sqrt{s_{NN}}=200$ GeV from STAR
19/428	Jan Kapitan	Jet studies in 200 GeV d+Au collisions from the STAR experiment at RHIC
43/235	Wei Li	Non-Photonic Electron and Charged Hadron Azimuthal Correlation in 500 GeV p+p Collisions at STAR
44/241	Xin Li	Measurements of Non-photonic Electron Spectra in p+p Collisions from STAR at RHIC
48/254	Rosi Reed	First Measurement of Υ Suppression
55/328	Janet Seger	Ratio of J/ψ to ρ Photoproduction Cross Sections at the Relativistic Heavy Ion Collider with STAR
49/373	Barbara Trzeciak	J/ψ polarization in p+p collisions at $\sqrt{s} = 200$ GeV at STAR
60/401	Hao Qiu	Measurement of J/ψ elliptic flow in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV in STAR
94/375	Neha Shah	Study of $\Lambda\Lambda$ correlations and search for the H-dibaryon with the STAR detector at RHIC
97/238	Patrick Huck	Dielectron production in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV at STAR
102/292	Bingchu Huang	Low-mass meson production through di-leptonic decays in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from STAR
103/295	Christina Markert	Leptonic decay of $\phi(1020)$ meson measured with the STAR experiment
141/260	Xiaofeng Luo	Higher moments of Event-by-Event Net-proton Multiplicity distributions at RHIC
146/348	Lizhu Chen	Mix-ratios of Higher Order Moments of Proton and Kaon for QCD Critical Point search at RHIC
151/398	Nihar Sahoo	Search for the QCD critical point by higher moments of the net-charge multiplicity distribution

Back up

Azimuthal HBT correlation

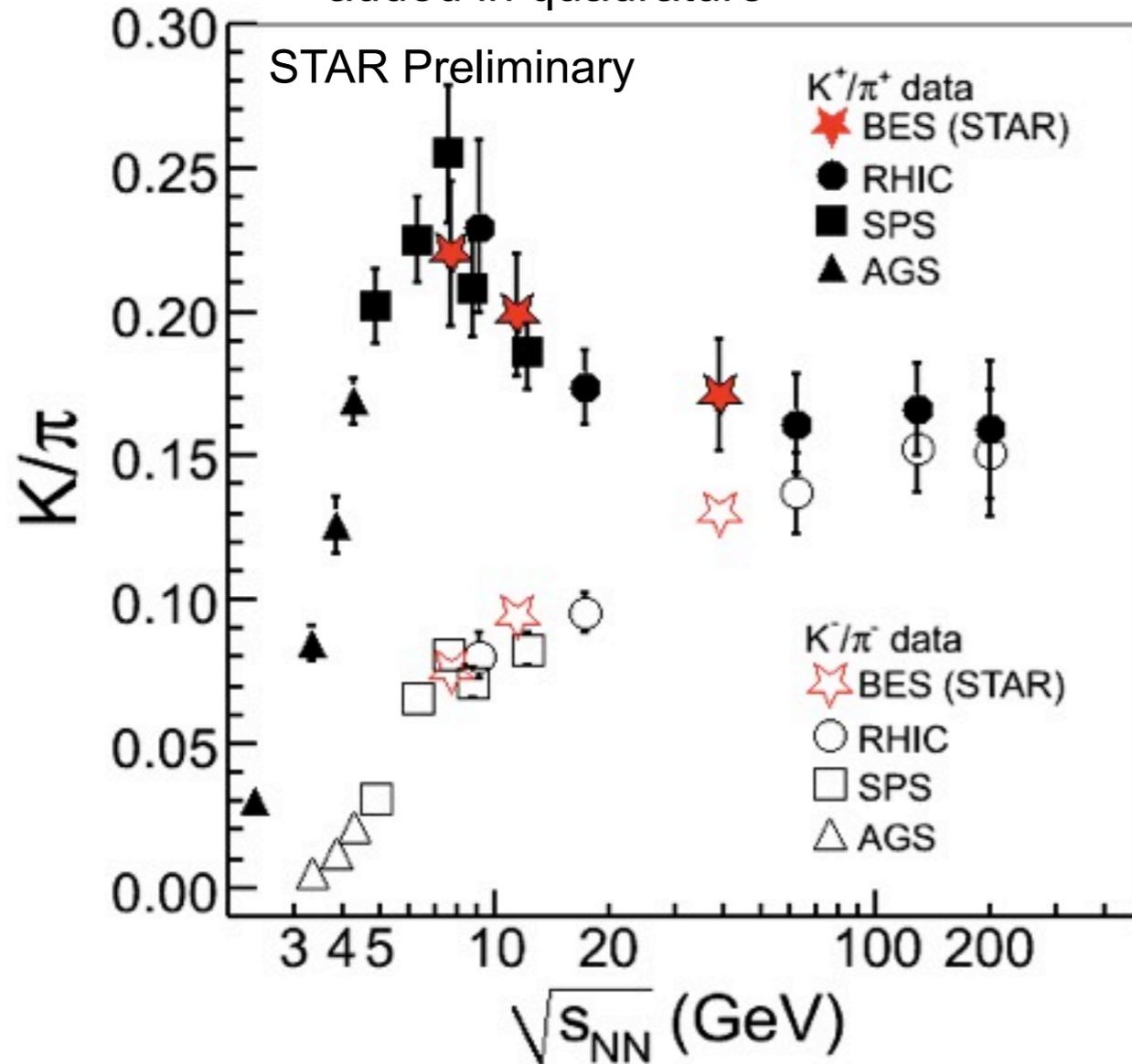
Christopher Anson,
Fri/27 16:00



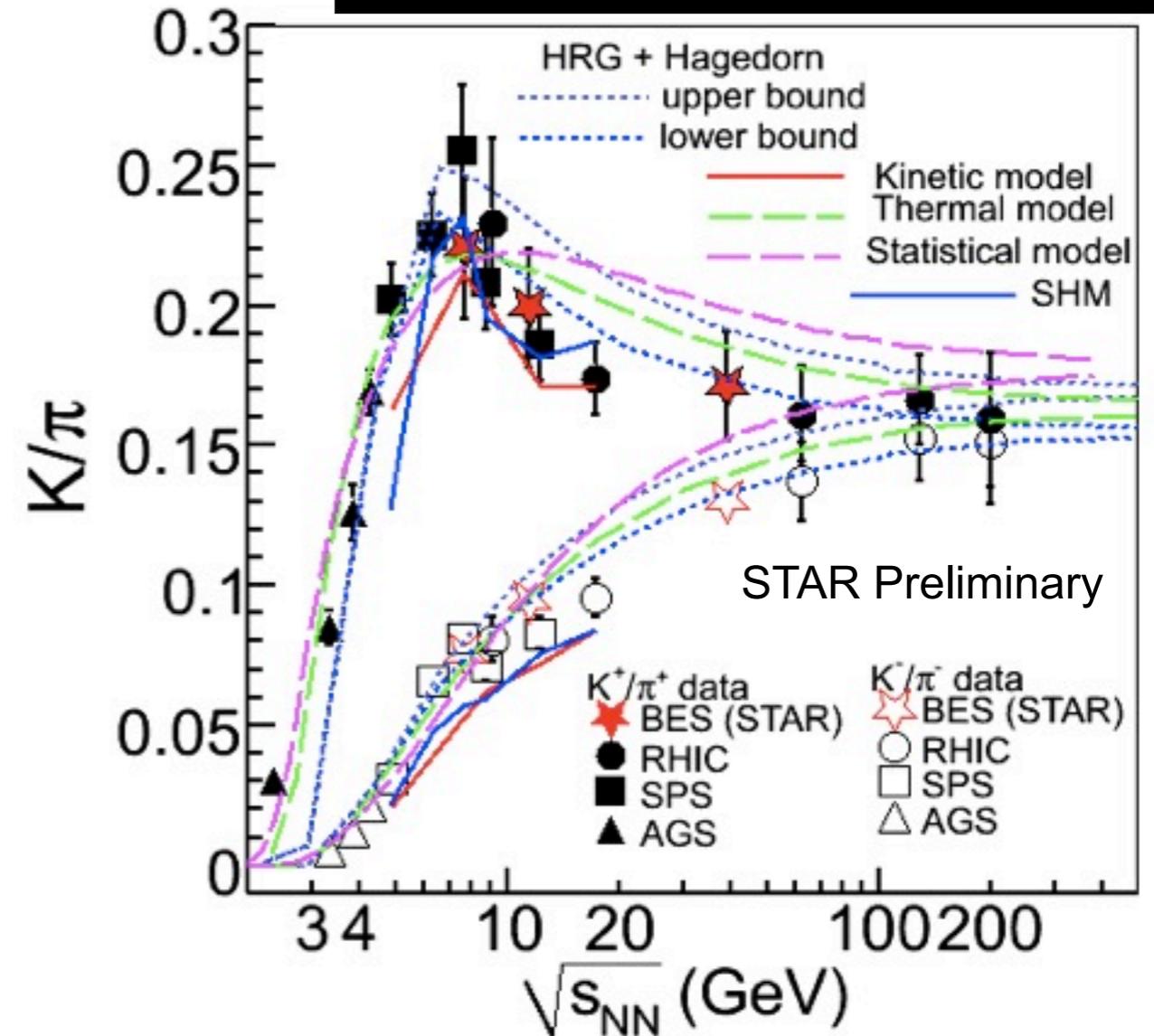
- Excitation function of freeze-out eccentricity from STAR is consistent with a monotonic decrease

K/π ratio

Statistical and systematic error added in quadrature



Lokesh Kumar, Fri/27 15:00



- K/π consistent with published results \rightarrow strangeness enhancement
- K^+/π^+ is best explained by HRG + Hagedorn model