BES-II physics: the current status and future outlook (my personal view)

Initial and freeze-out conditions
Determining the EoS?
Understanding the emitting source(s)
Detecting the initial EM field
Understanding the nature of parton energy loss to QGP

Helen Caines (she/her),
Wright Lab, Yale University

RHIC-BES online seminar series - October 10 2023

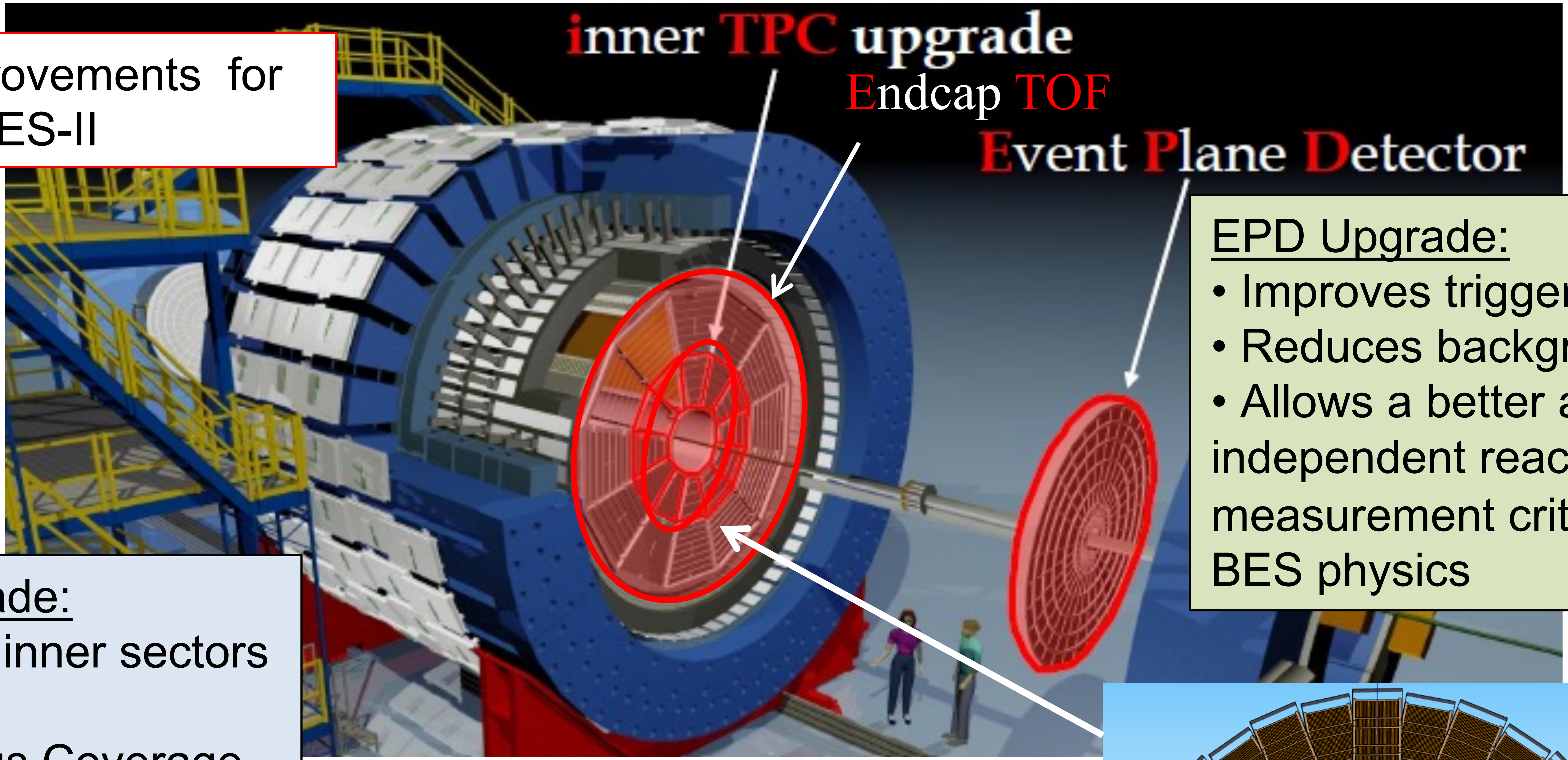
From the NSAC LRP 2023 - released Oct 4

Evidence for the dominance of either the QGP phase or the hadronic phase at different collision energies has been found in key observations, including critical fluctuations. At top RHIC energy, high moments of net-protons (a proxy for net-baryons) are consistent with lattice QCD predictions of a smooth crossover transition. Hydrodynamic calculations indicate that gold–gold collisions are above any critical point at center-of-mass energies above 20 GeV per nucleon pair. By contrast, at 3 GeV, hadronic interactions are evident from the measurements of moments of proton distributions, collective flow, and production of hadrons that contain strange quarks. This implies that the QCD critical point, if it exists, should be accessible in collisions with center-of-mass energies between 3 and 20 GeV.

US participation in … the CBM experiment…, will allow the US nuclear physics program to build on its successful exploration of the QCD phase diagram, use the expertise gained at RHIC to make complementary measurements, and contribute to achieving the scientific goals of the BES program.

Well known, but worth highlighting again

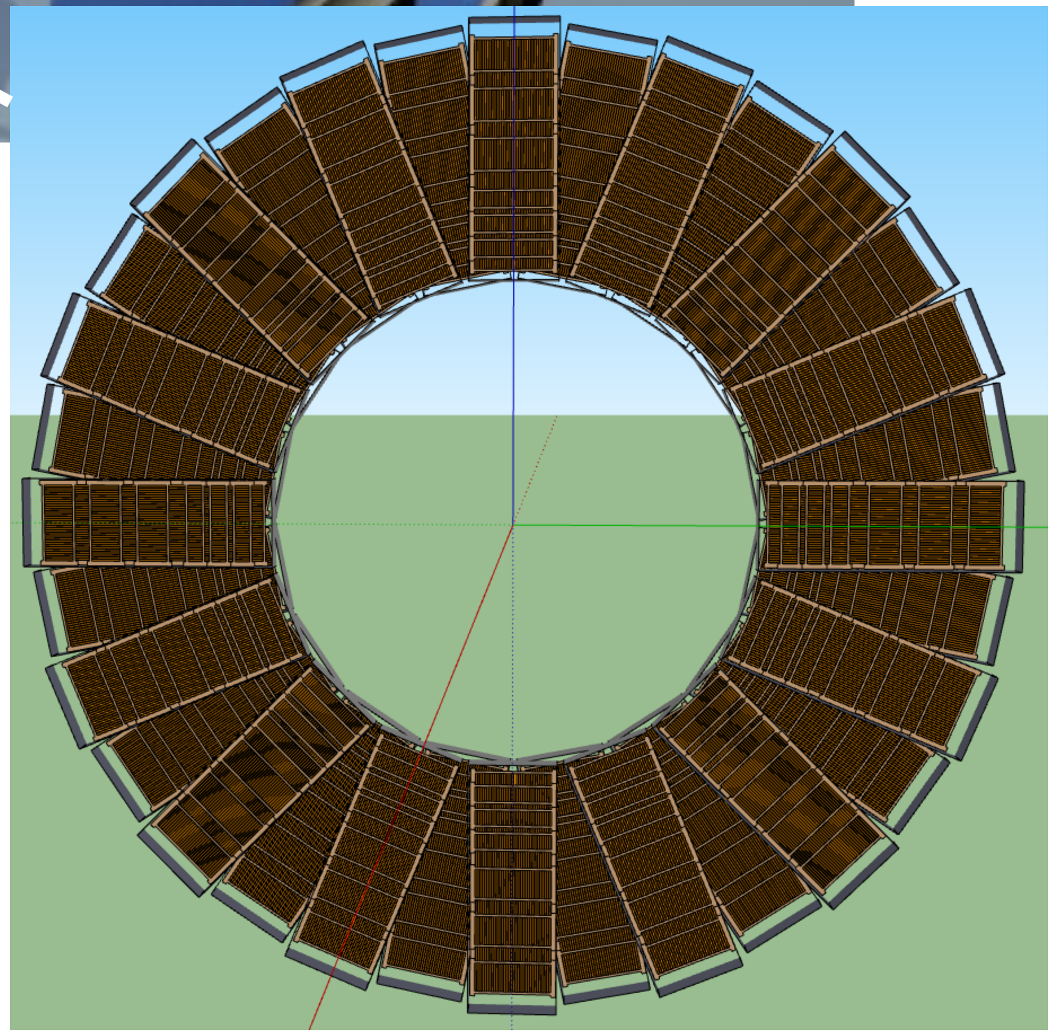
Major improvements for BES-II



EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

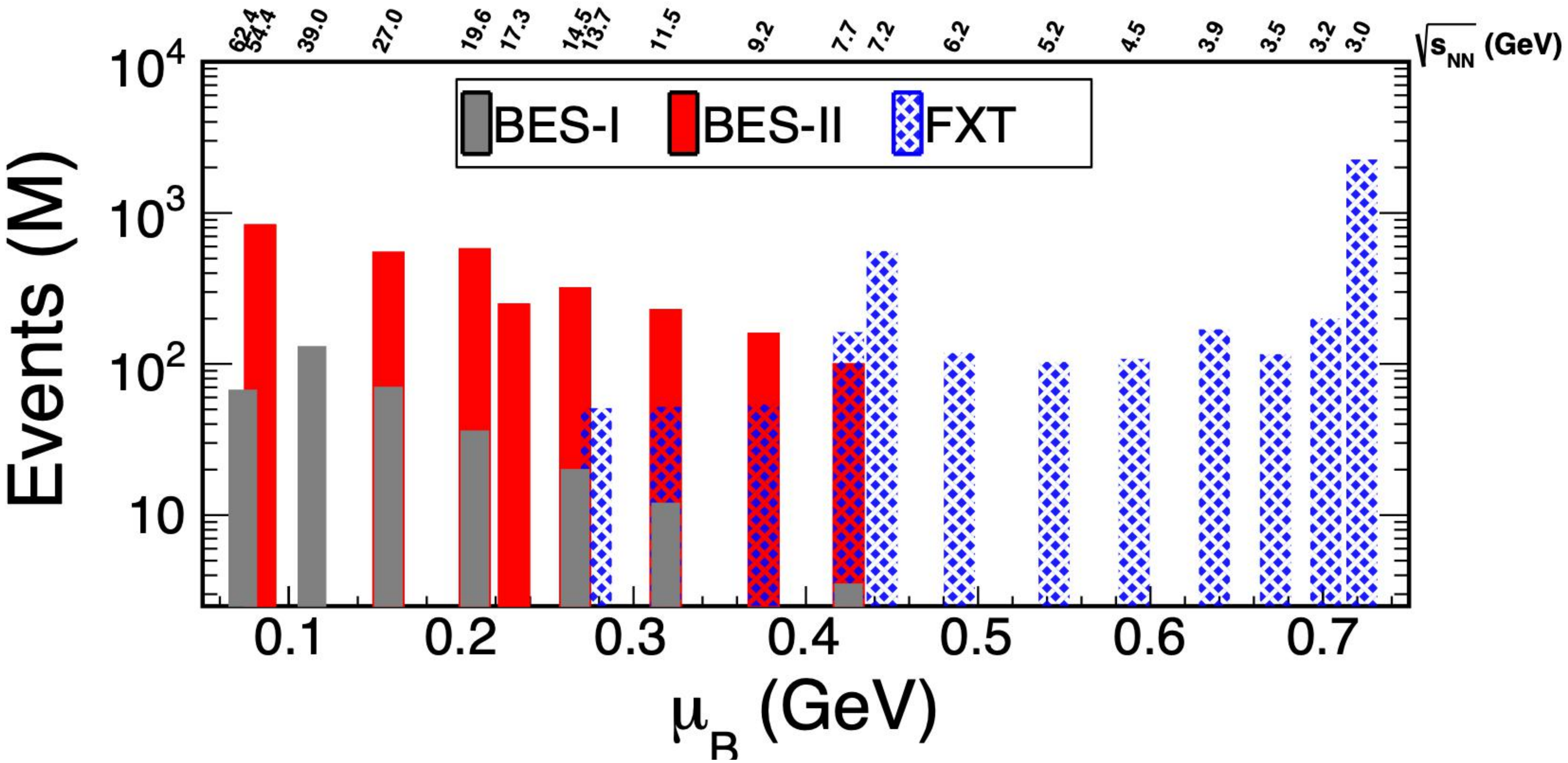
iTPC Upgrade:
- Replaced inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at η = 1 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR



All worked during BES-II

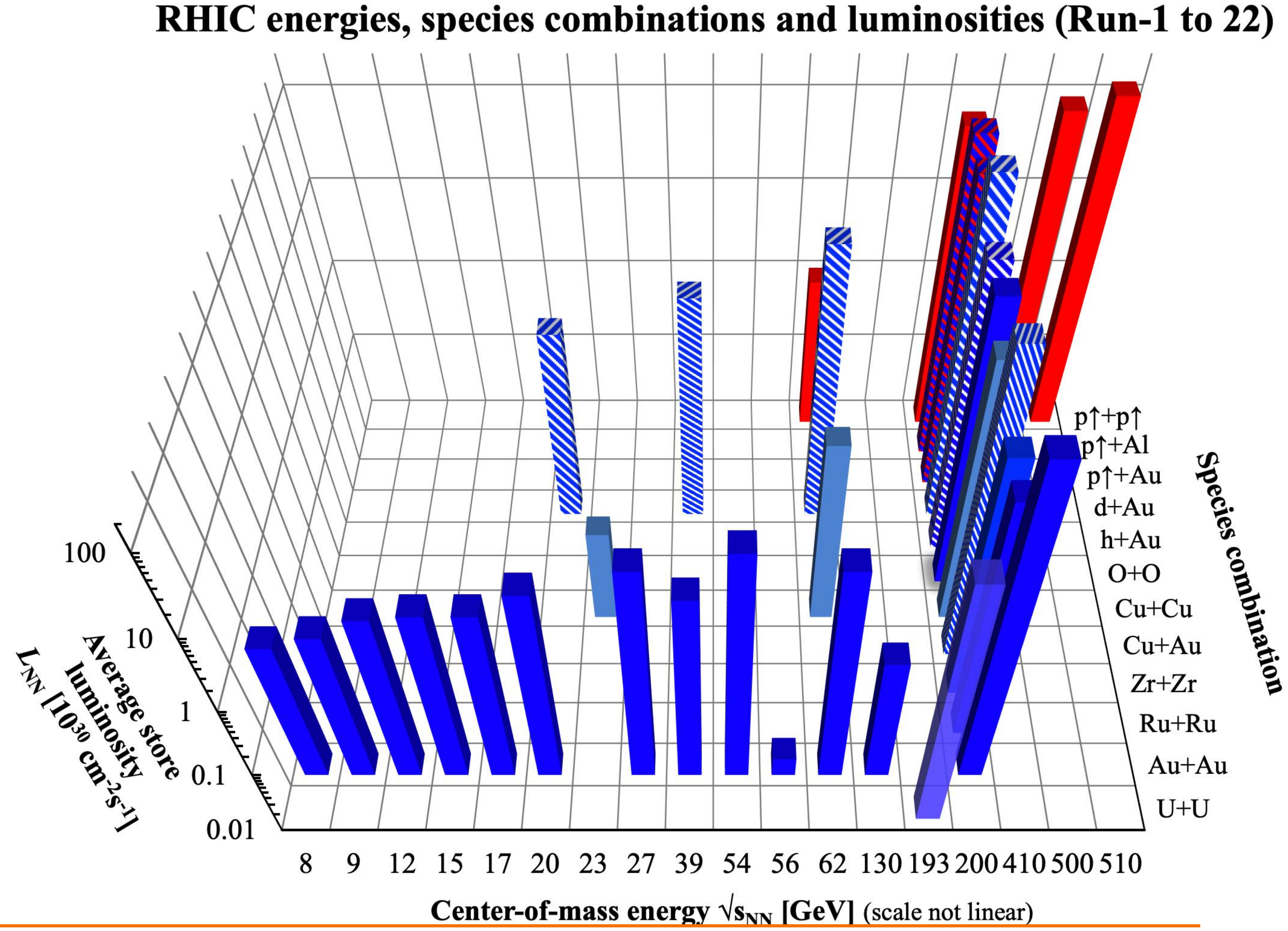
Datasets available



7 energies: 7.7 - 27 GeV (+54) (collider mode)

12 energies: 3.0 - 13.7 GeV (FXT mode)

L_{avg}(BES-II) >= 4 L_{avg}(BES-1)



Don’t forget also have different system sizes:

U+U, Au-Au, Ru+Ru, Zr+Zr, Cu+Cu, O+O,

Cu+Au, He^3+Au, d+Au, p+Au, p+Al, p+p

Wealth of data waiting to be analyzed

Critical Point search

No update from STAR on net-proton fluctuations in the BES-II data

Critical Point search

No update from STAR on net-proton fluctuations in the BES-II data

Analysis nearing completion and no major issues currently identified. Aiming for direct to publication results to be announced “soon”

Updates from theory

Experimentalists summary of their findings:

Disfavor QCD critical point at $\mu_B/T < 3$

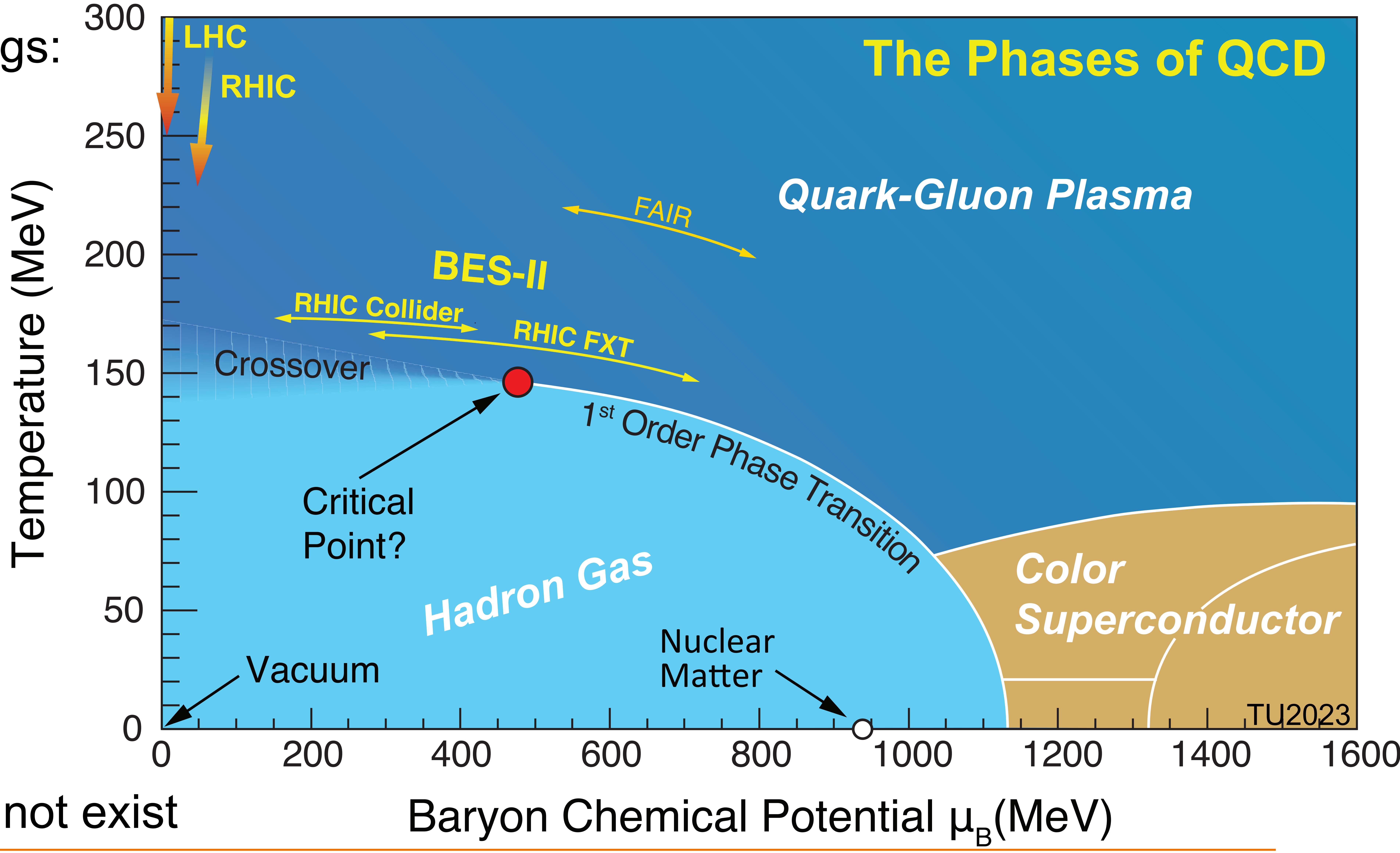
Significant progress in extrapolating off $\mu_B = 0$ axis

Several calculations settling on CP at

$T \sim 90\text{-}100$ MeV
$\mu_B \sim 500\text{-}600$ MeV

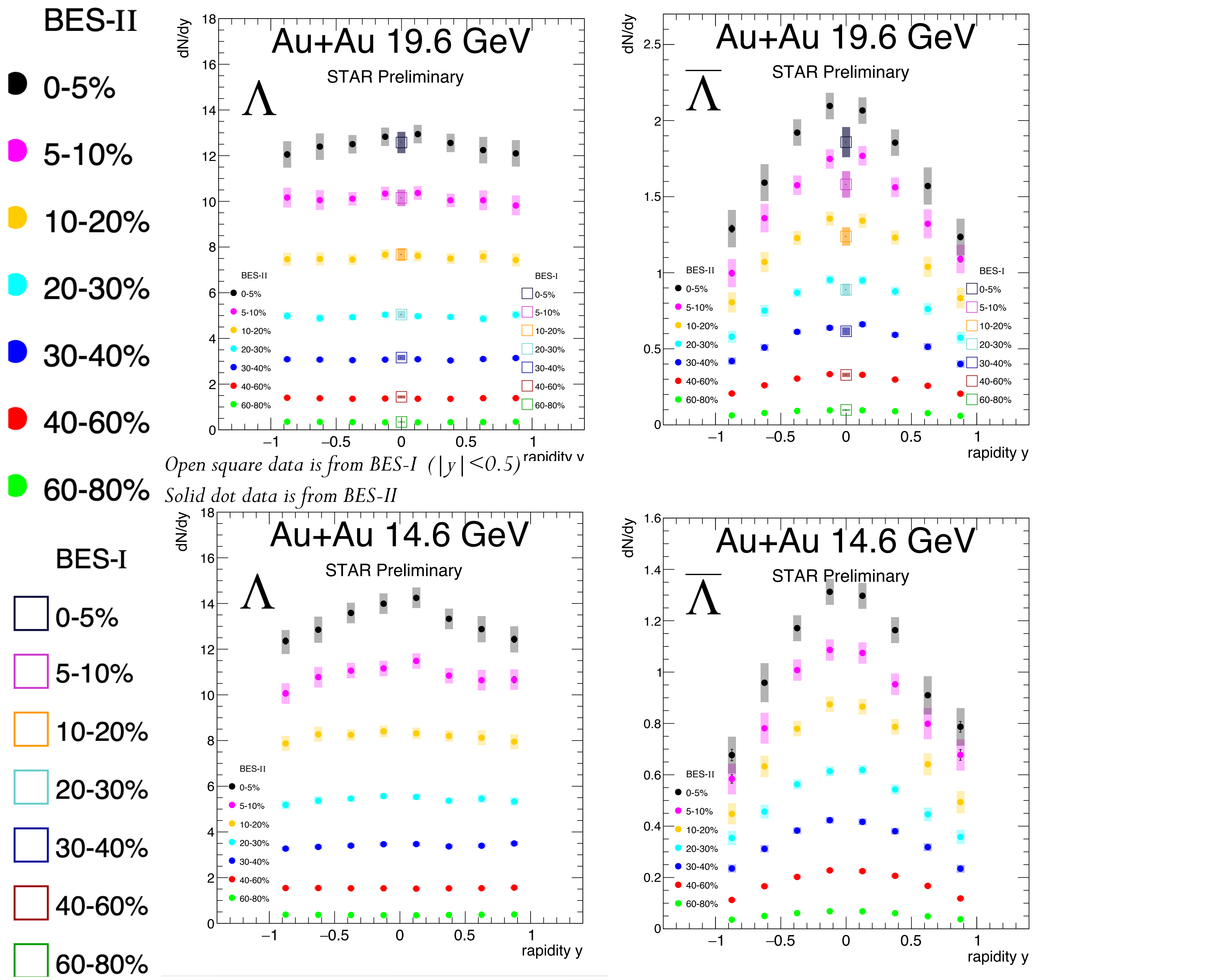
$\sqrt{s_{NN}} = 3\text{-}5$ GeV

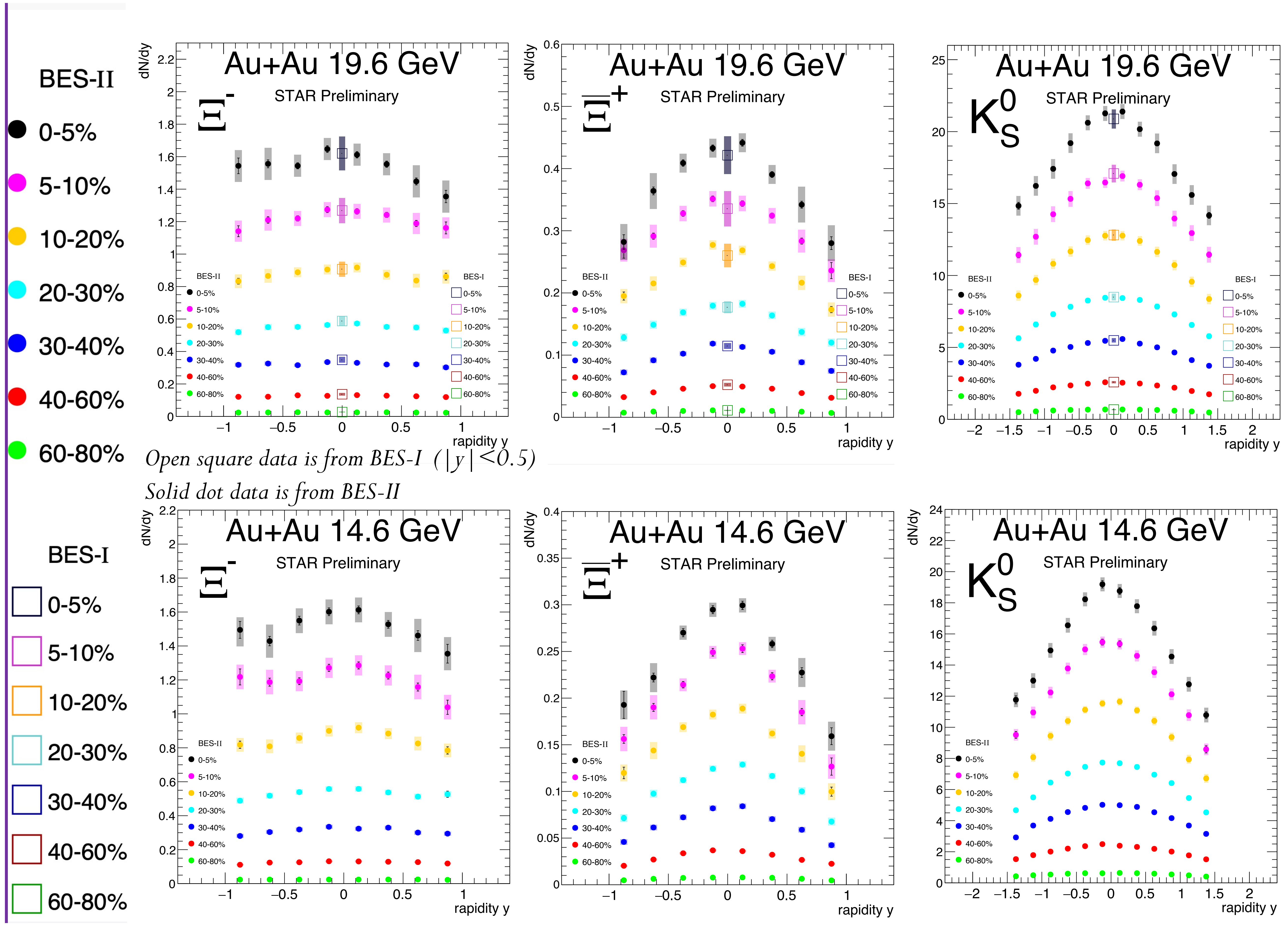
But still CP might also not exist



Initial and Freeze-out Conditions

Rapidity distributions



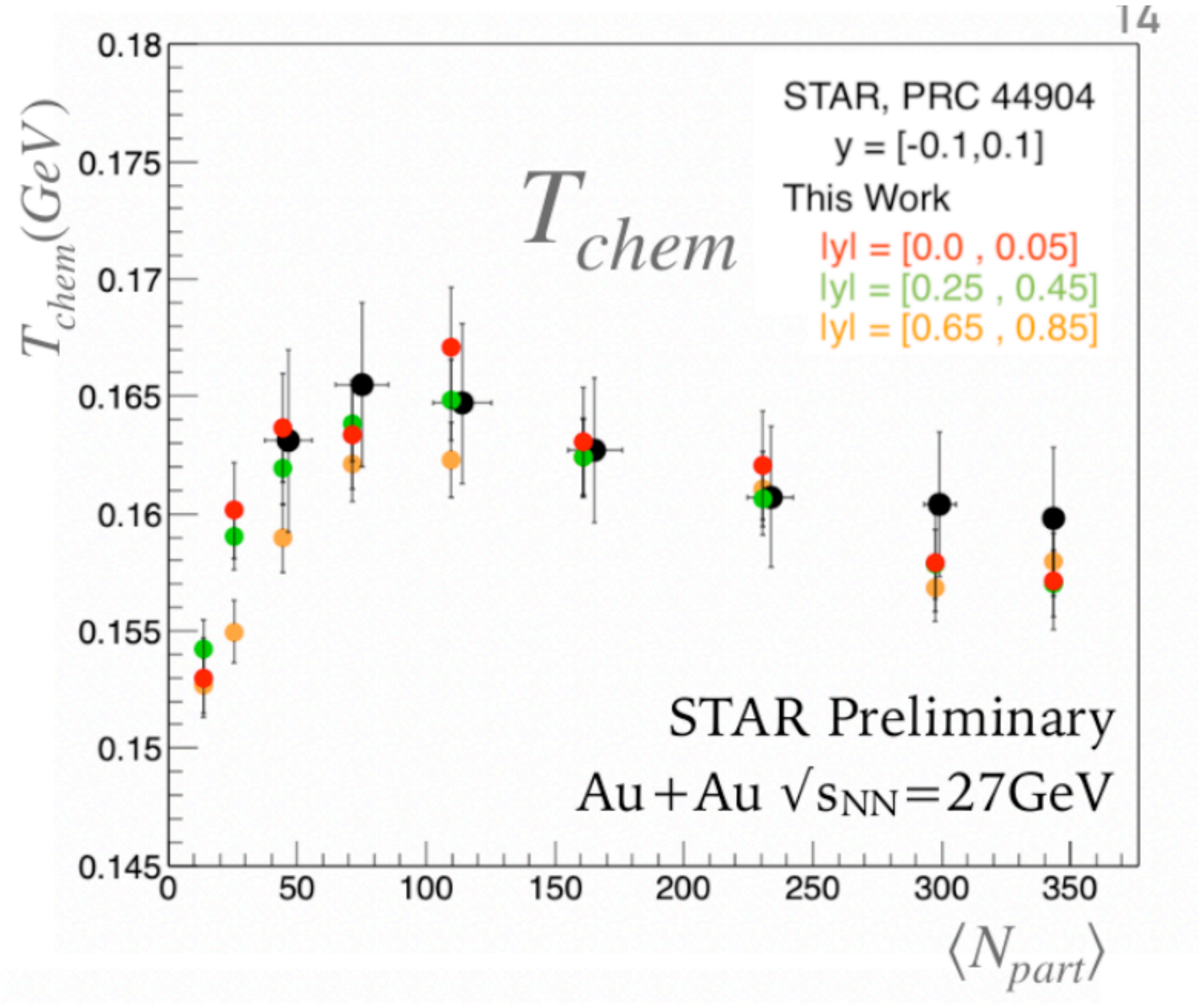


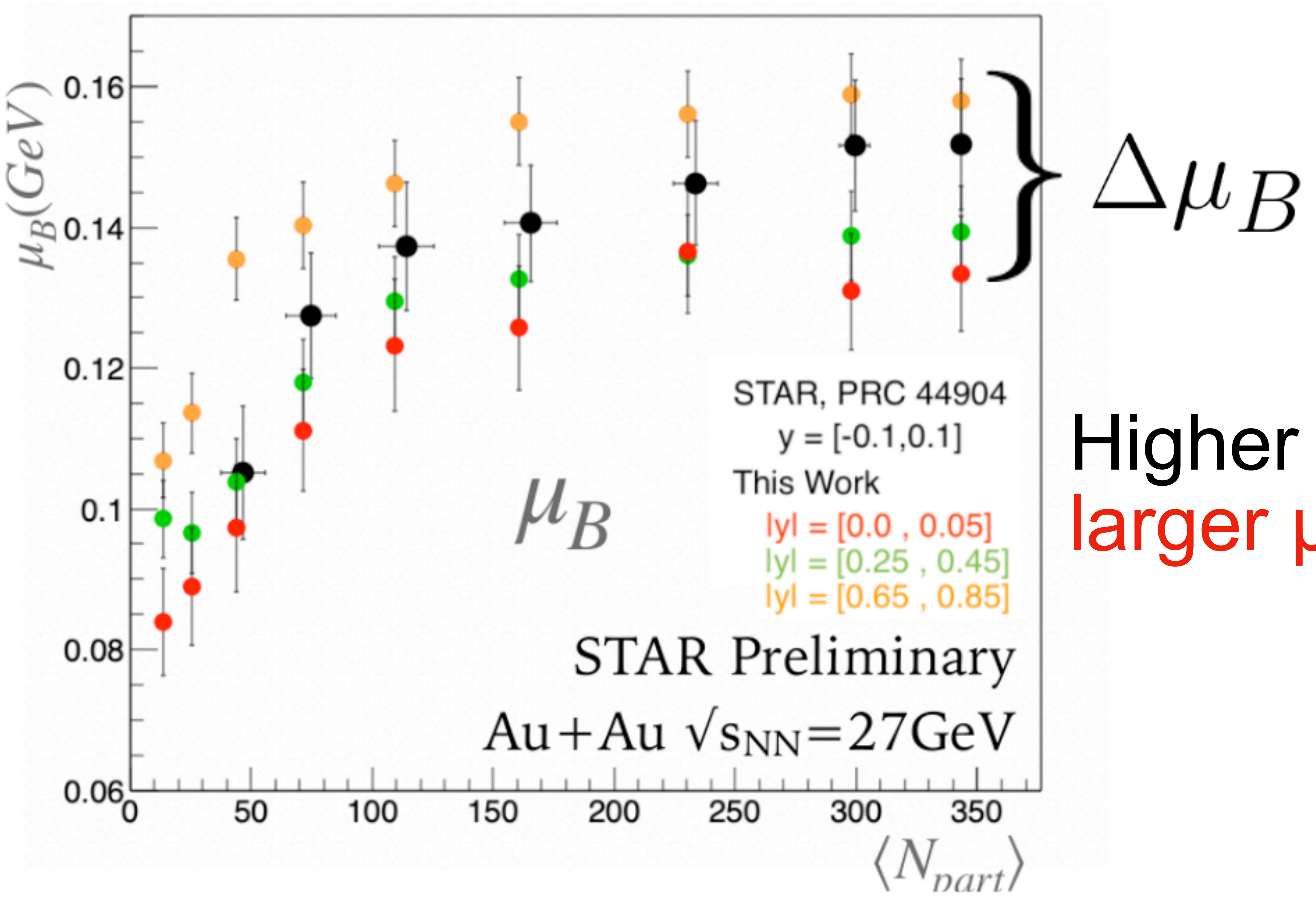
High statistics and iTPC acceptance on full display

Kaons and anti-baryons - Gaussian-like distributions

Stopping contribution clearly present in baryon distributions

Trajectory through the phase diagram?



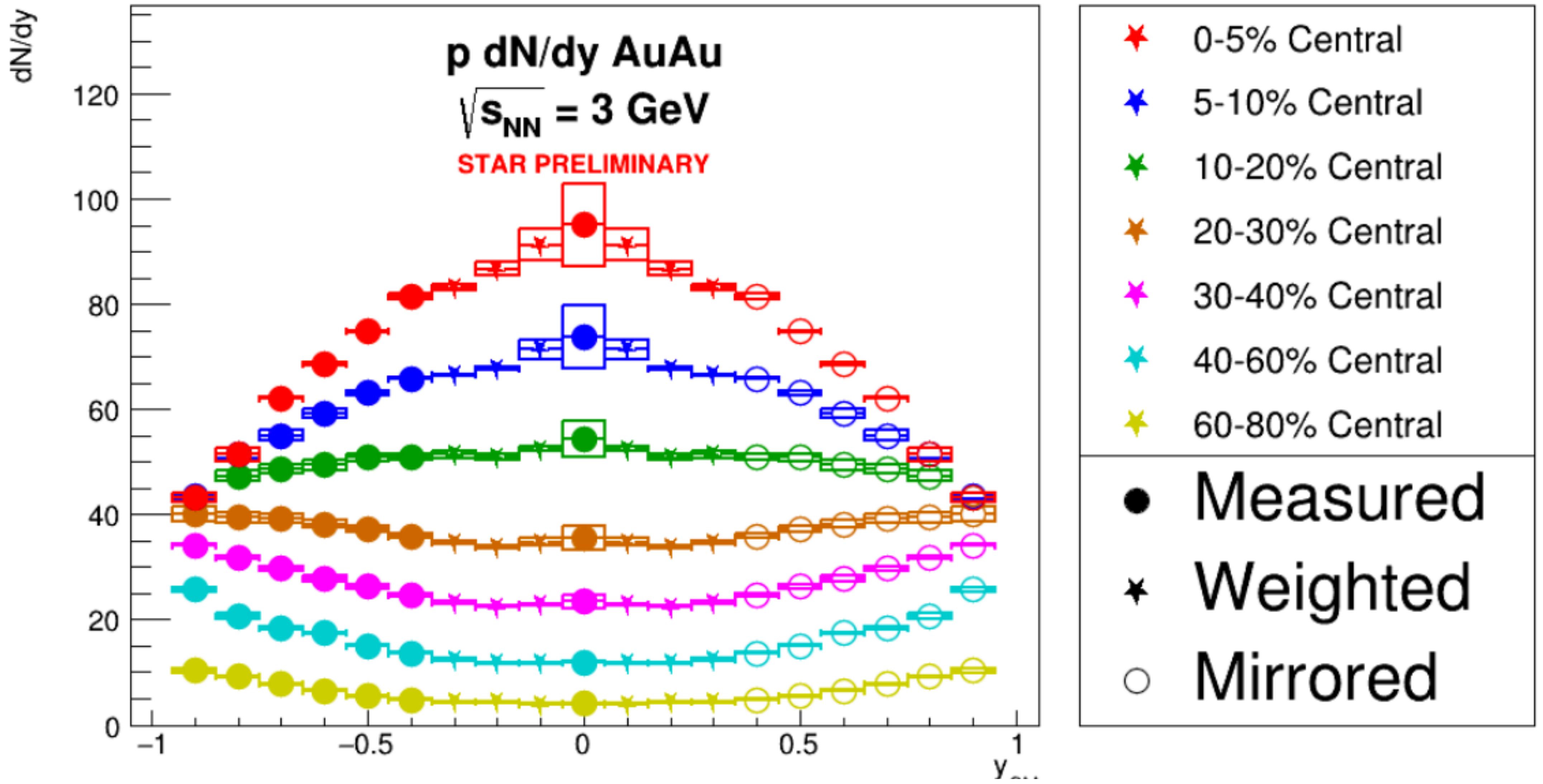


Higher rapidity —>
larger μ_B, similar T_{ch}

Next step: Compare mid-rapidity/low $\sqrt{s_{NN}}$ and high rapidity/high $\sqrt{s_{NN}}$

Chemical freeze-out parameters match but initial conditions differ.
Can we see the difference imprinted elsewhere?

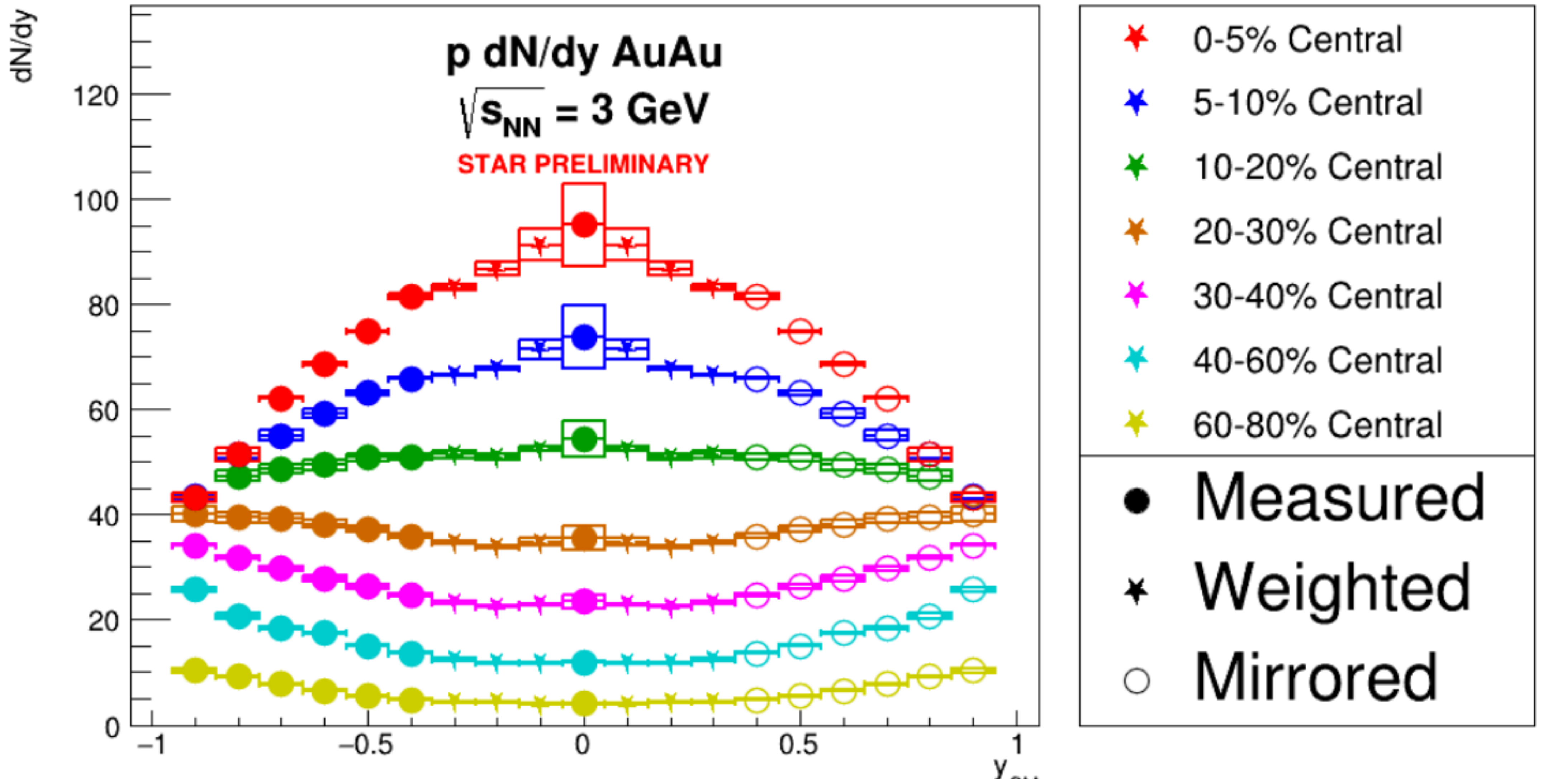
Baryon stopping



FXT data Au+Au $\sqrt{s_{NN}}$ = 3 GeV:
Centrality dependence of proton rapidity distribution width

Proton peak shifts away from mid-rapidity for more peripheral collisions
- less stopping

Baryon stopping



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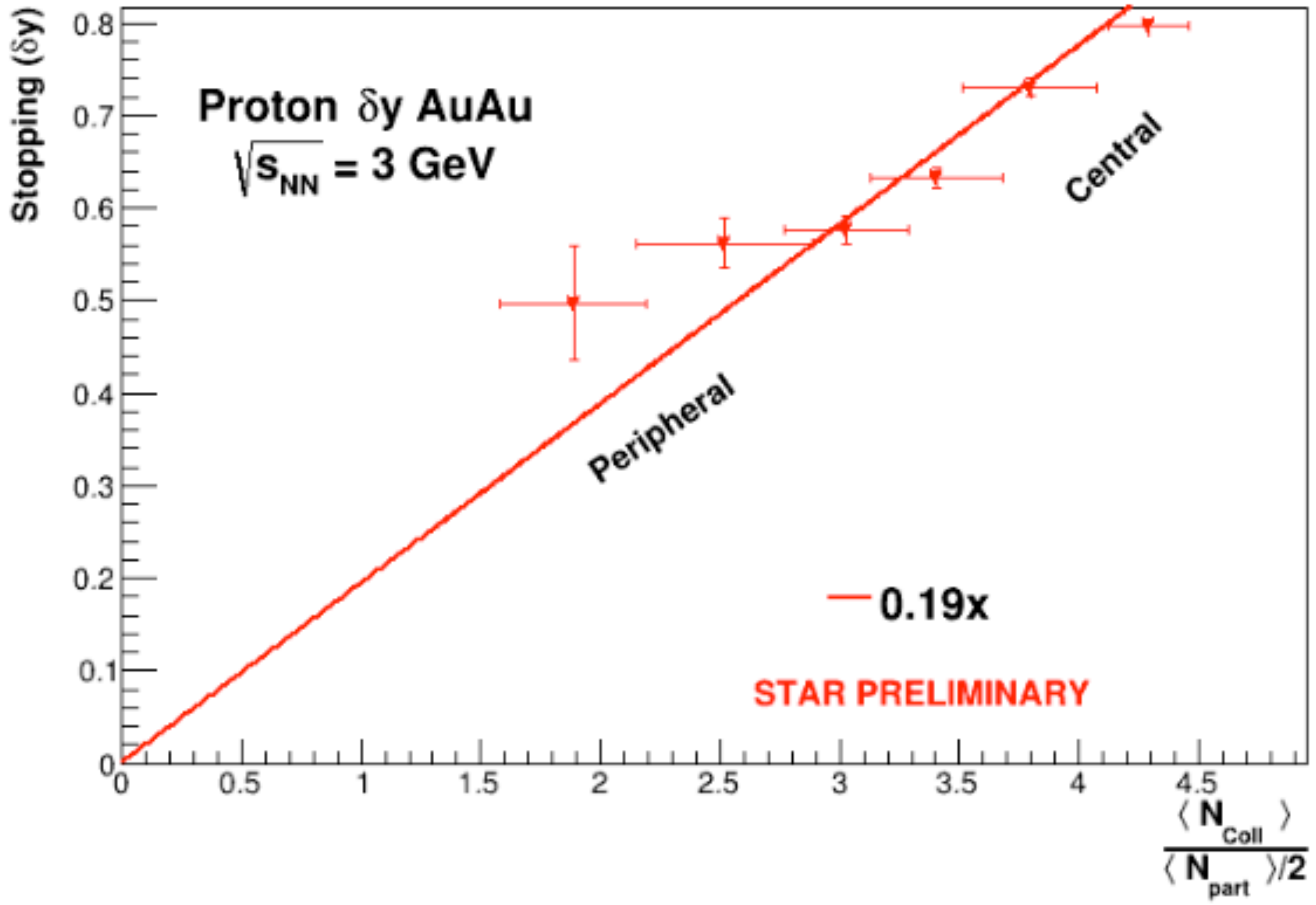
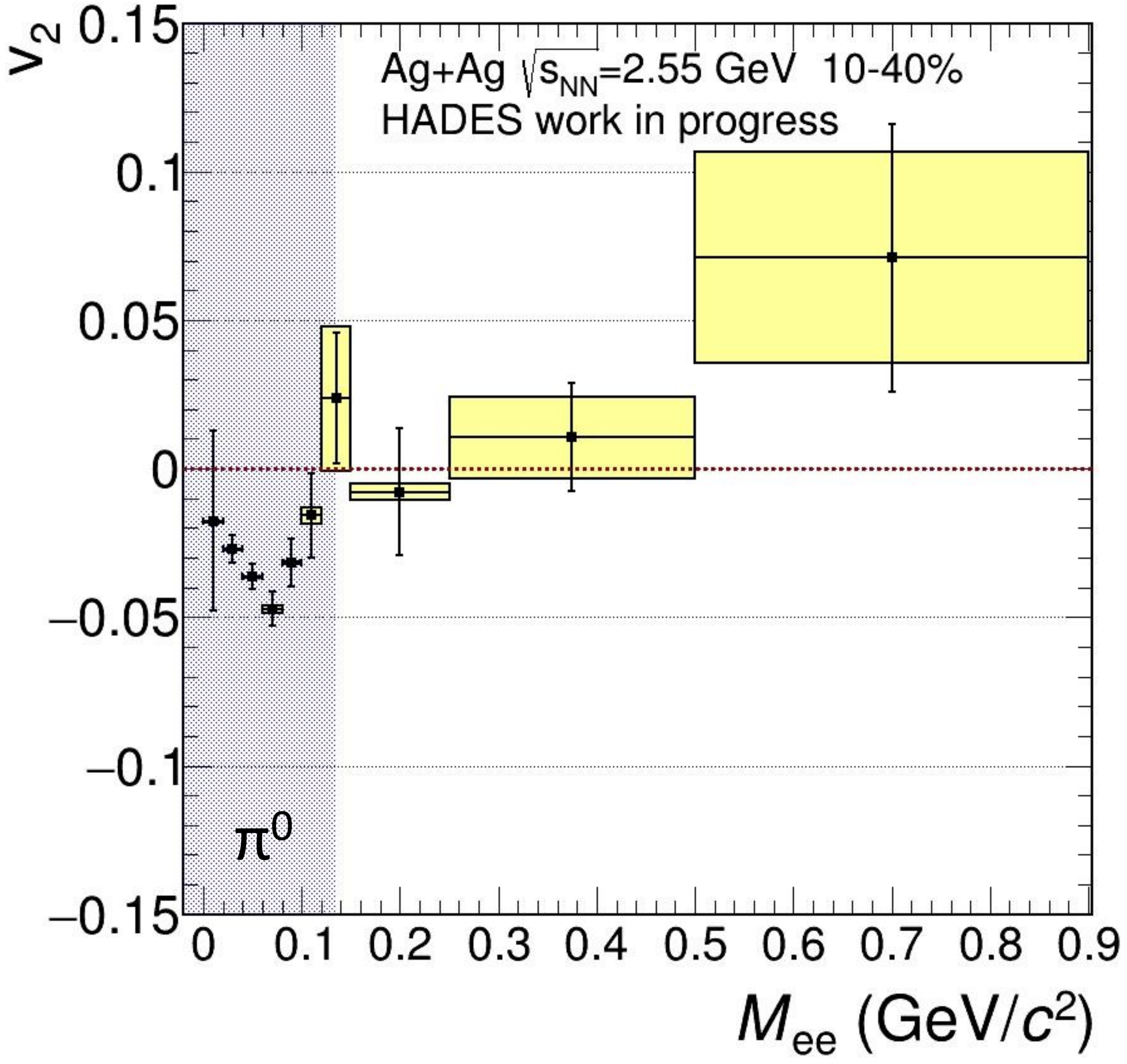


Define stopping, δy, via the shift of the participant proton peak from beam rapidity

Average loss of 0.19 ± 0.01 units of rapidity per nucleon-nucleon collision

consistency with other experiments at similar energies

Initial vs Freeze-out temperature

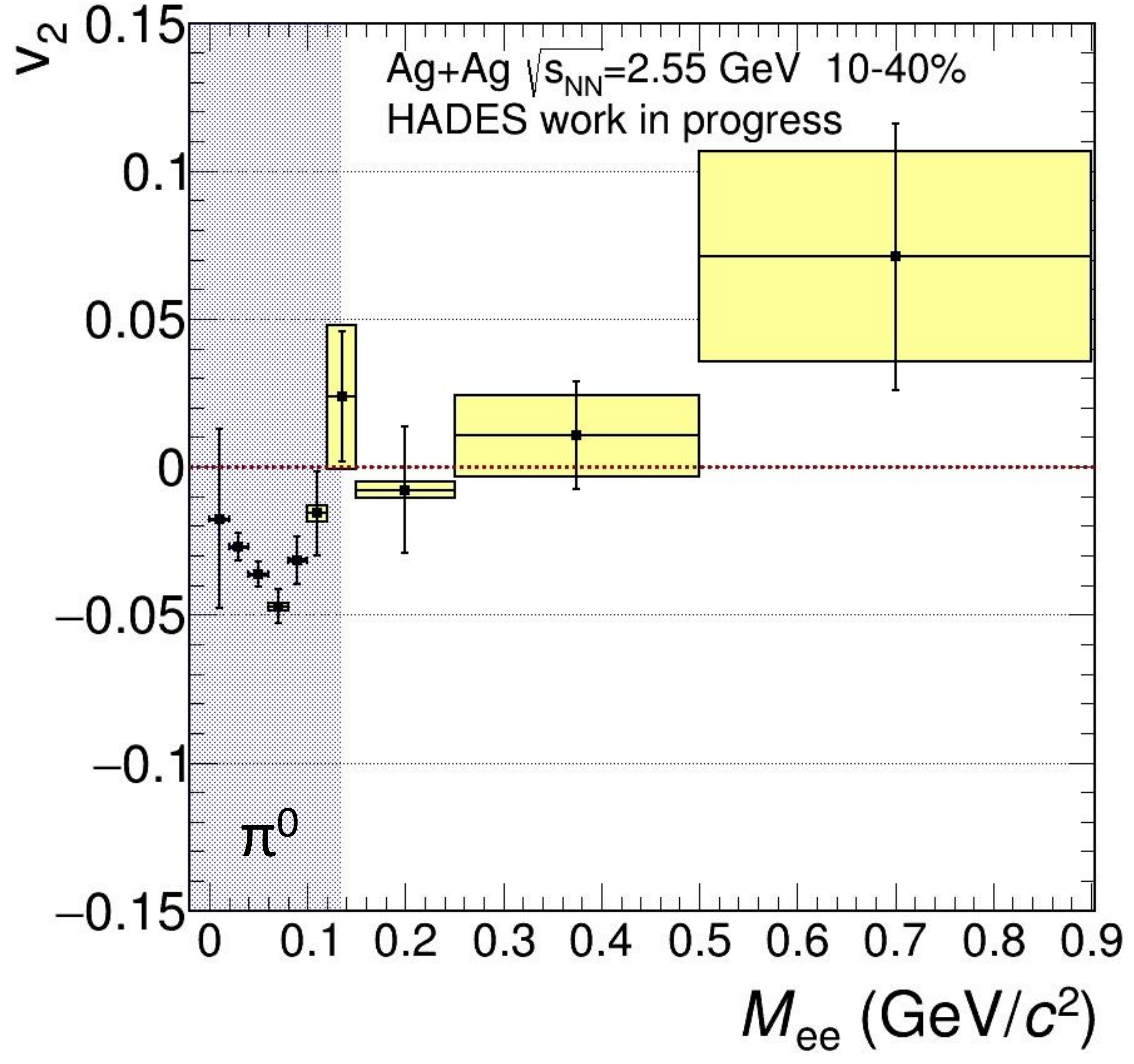


When M_{ee} above pion mass:

no collectivity exhibited —> a penetrating probe with no collective boost

N. Schild QM Poster

Initial vs Freeze-out temperature



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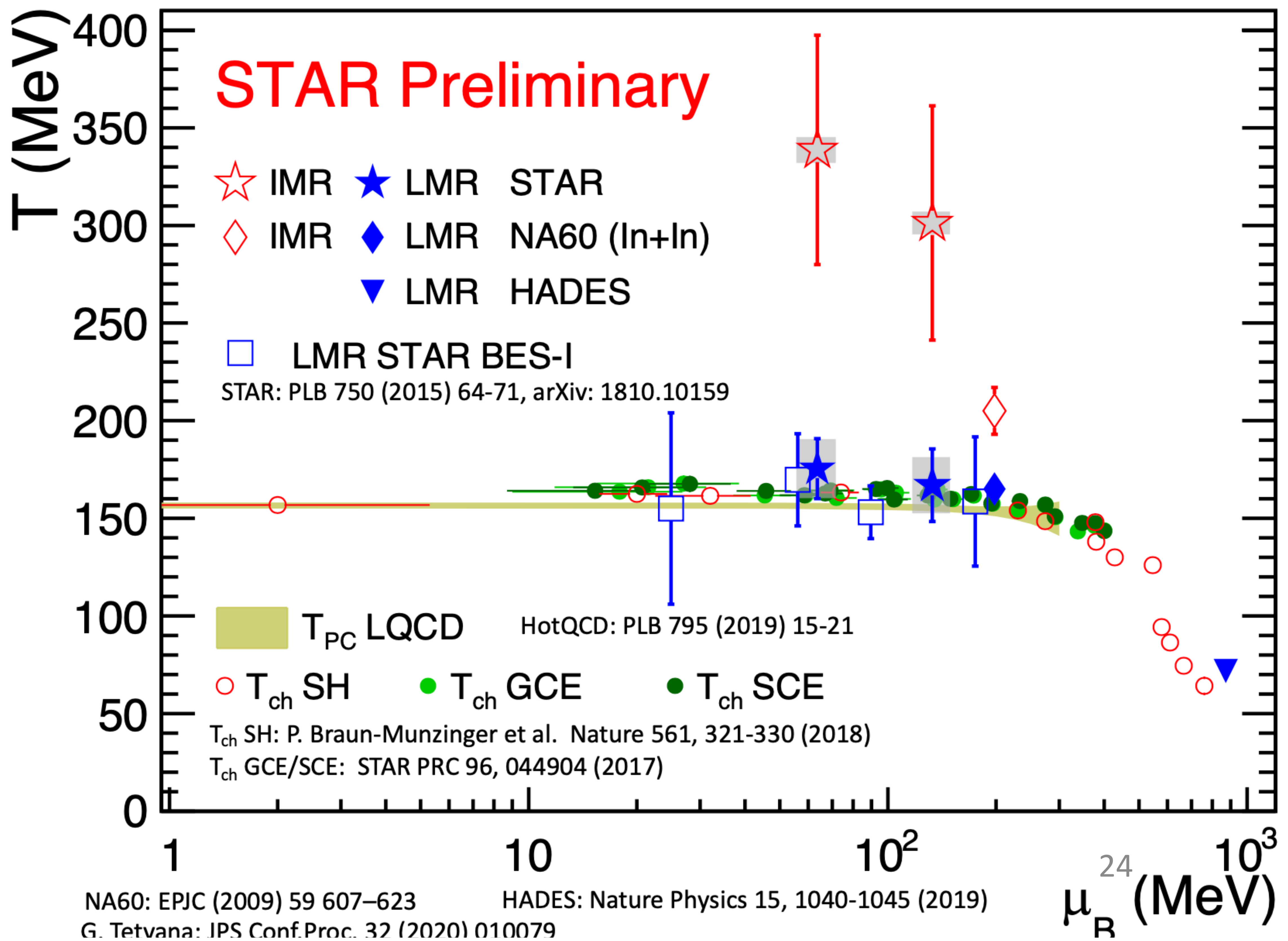

LMR : Extracted T in agreement with statistical model fits

IMR : Closer to initial T

Better ways to access early T?
Especially at low $\sqrt{s_{NN}}$

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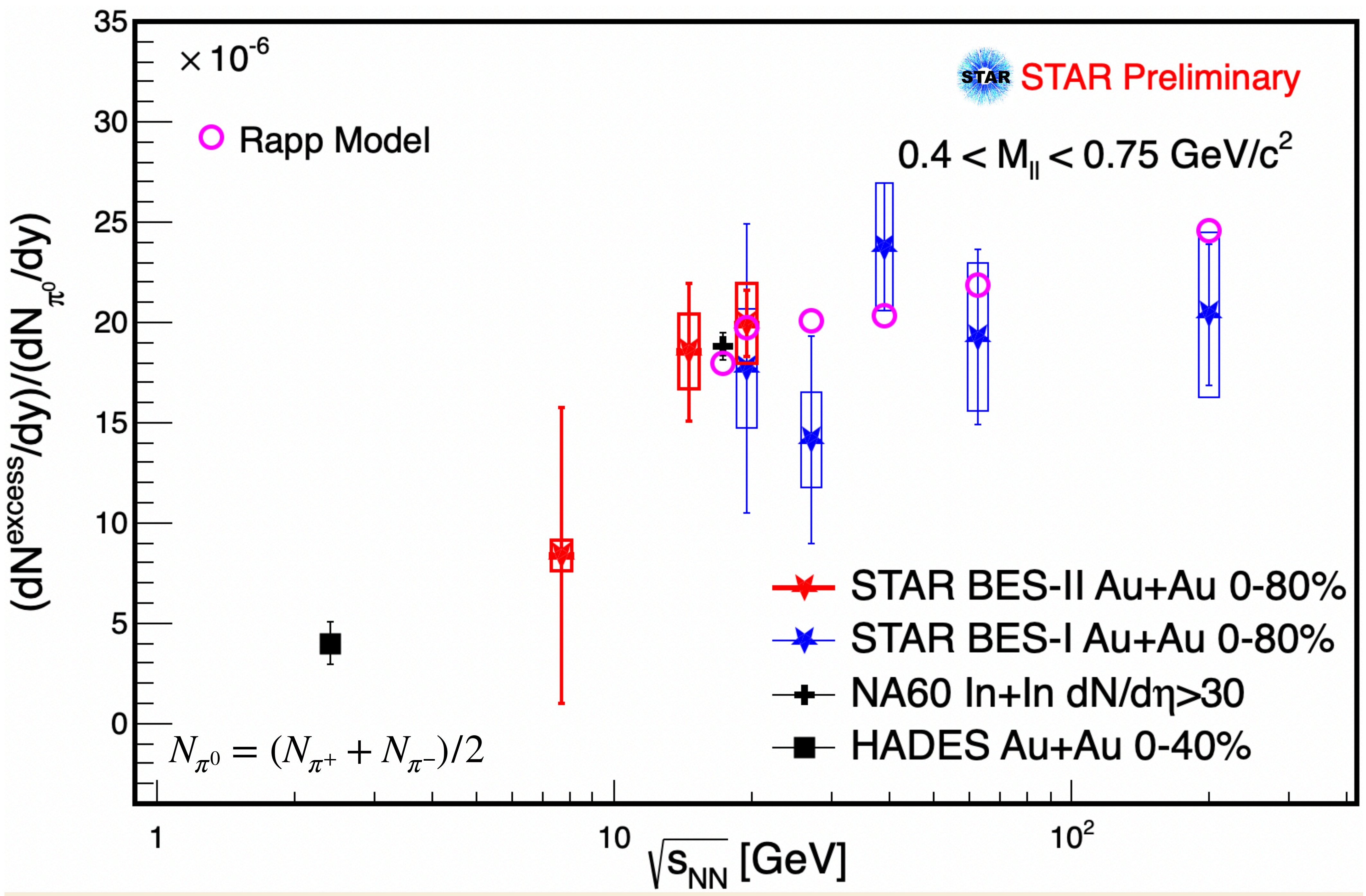
Normalized dilepton low mass excess



BES-I:
- No clear $\sqrt{s_{NN}}$ dependence
- Well described by in-medium ρ + QGP emission models

BES-II+ HADES
- Decrease below $\sqrt{s_{NN}}$ ~ 10 GeV

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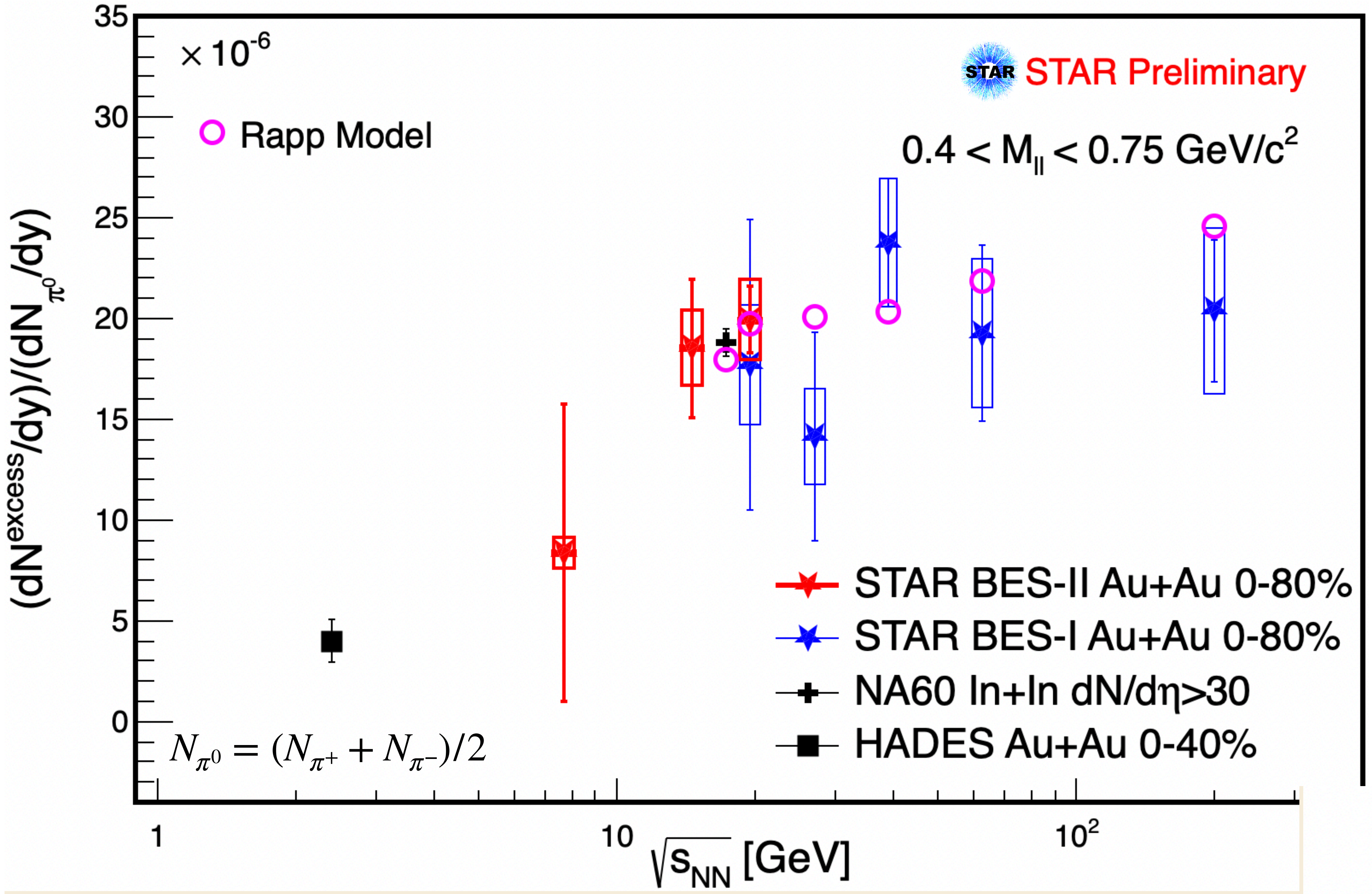

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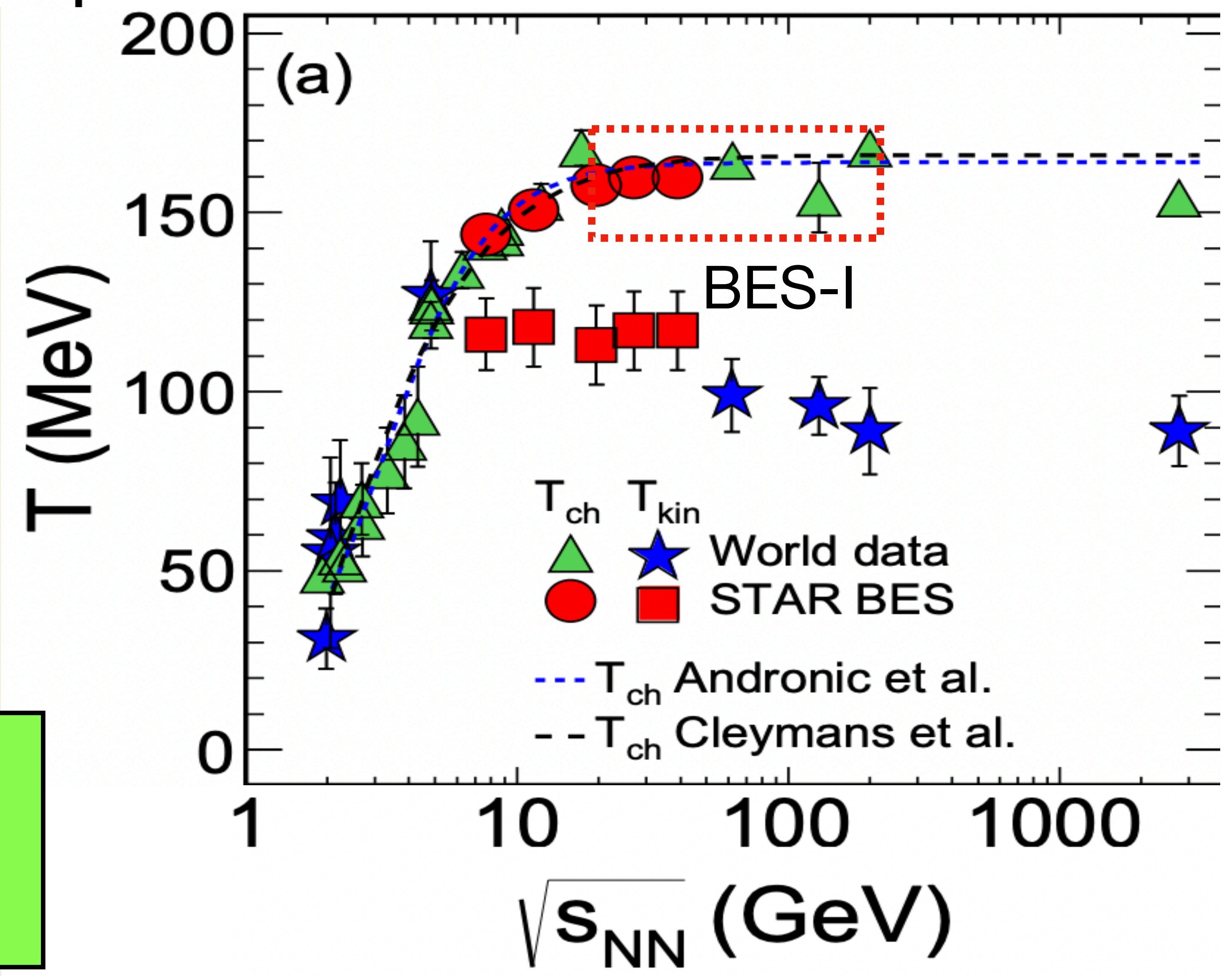
BES-II+ HADES

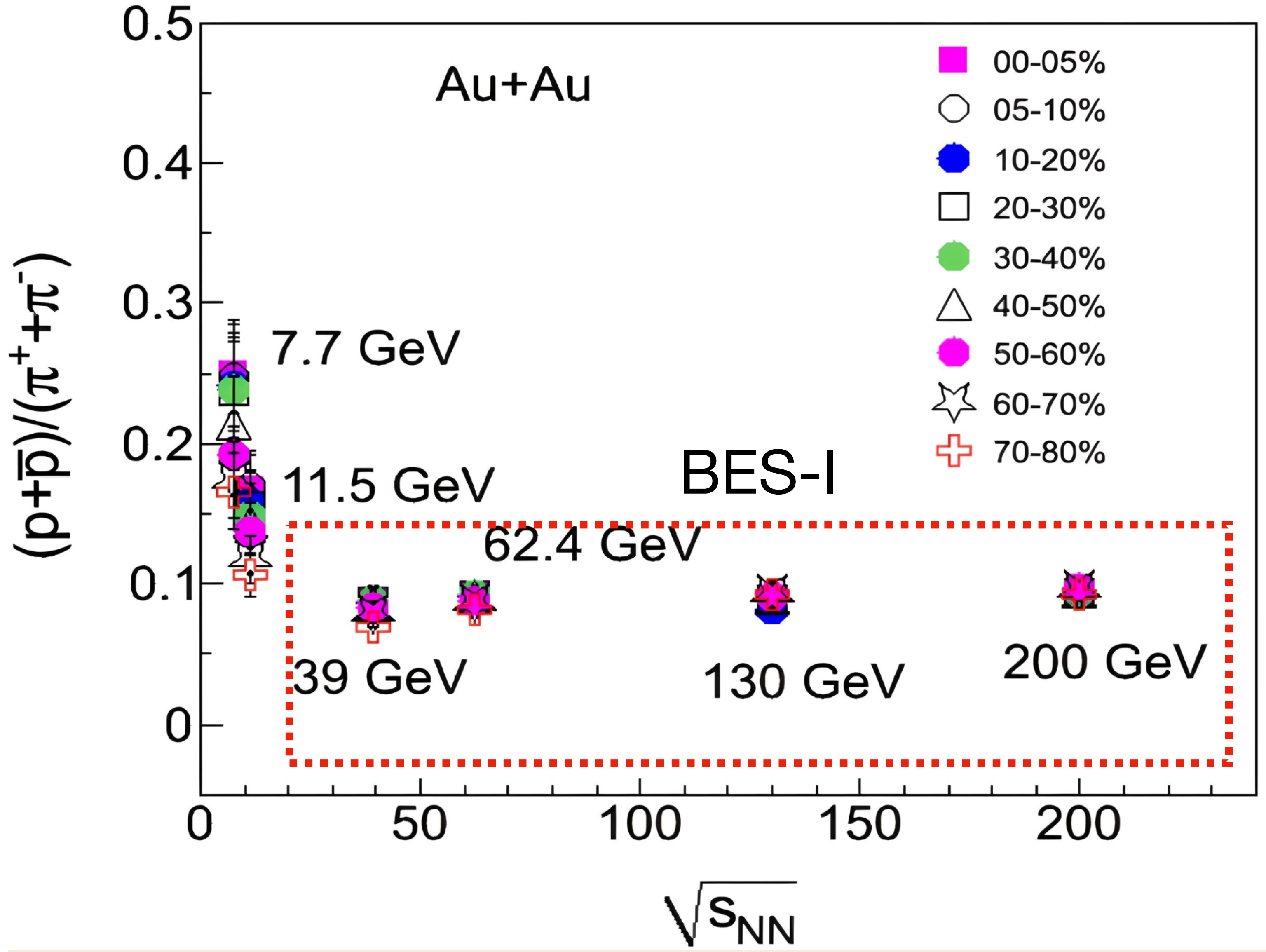
- Decrease below $\sqrt{s_{NN}}$ ~ 10 GeV

At about same location:

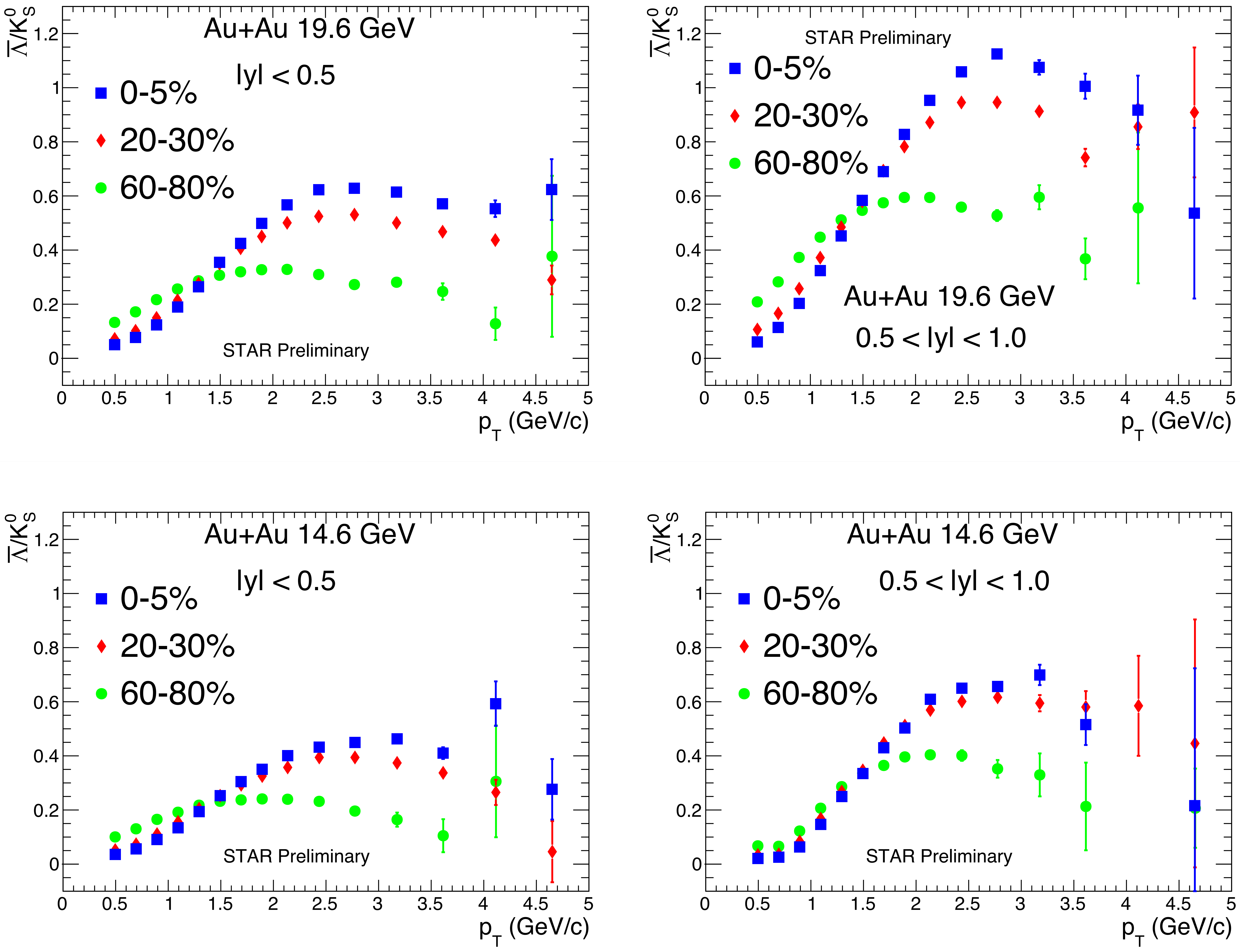
- Baryon density rises
- T_{ch} drops

Can we disentangle different medium effects on LME?





Rapidity dependence of anti-baryon enhancement



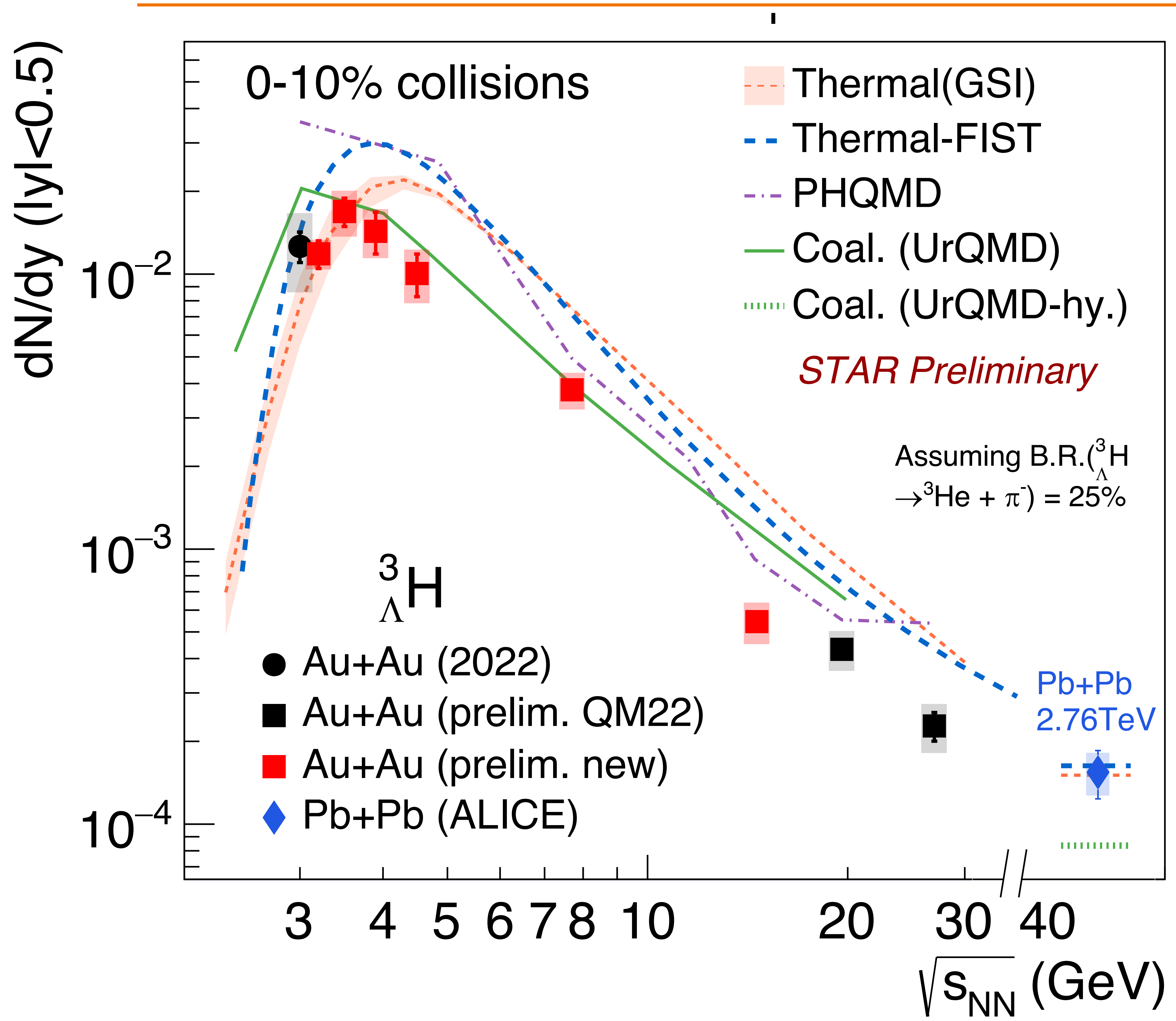
Anti-Baryon/Meson ratio increases with:

- collision energy
- centrality
- rapidity

Increased coalesence or fragments at higher rapidity?

Y. Fang: STAR QM Talk

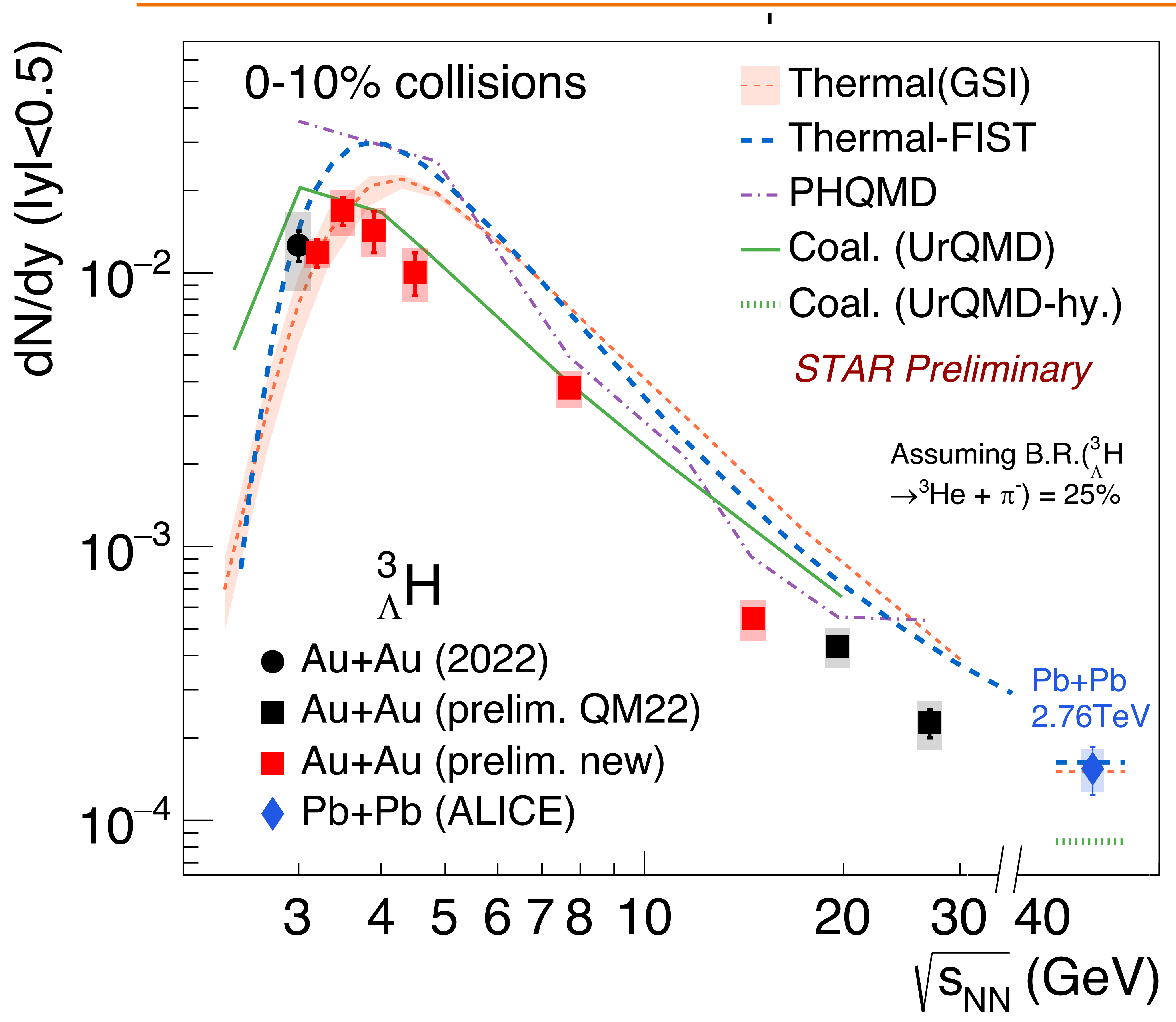
Light and Hypernuclei production



$^{3}_{\Lambda}$H yield maximum at $\sqrt{s_{NN}}$ =3-4 GeV -
Interplay of baryon stopping and strangeness suppression

Y.H. Leung, X. Li, Y. Jin: STAR QM Posters, Y. Ji STAR QM Flash Talk

Light and Hypernuclei production



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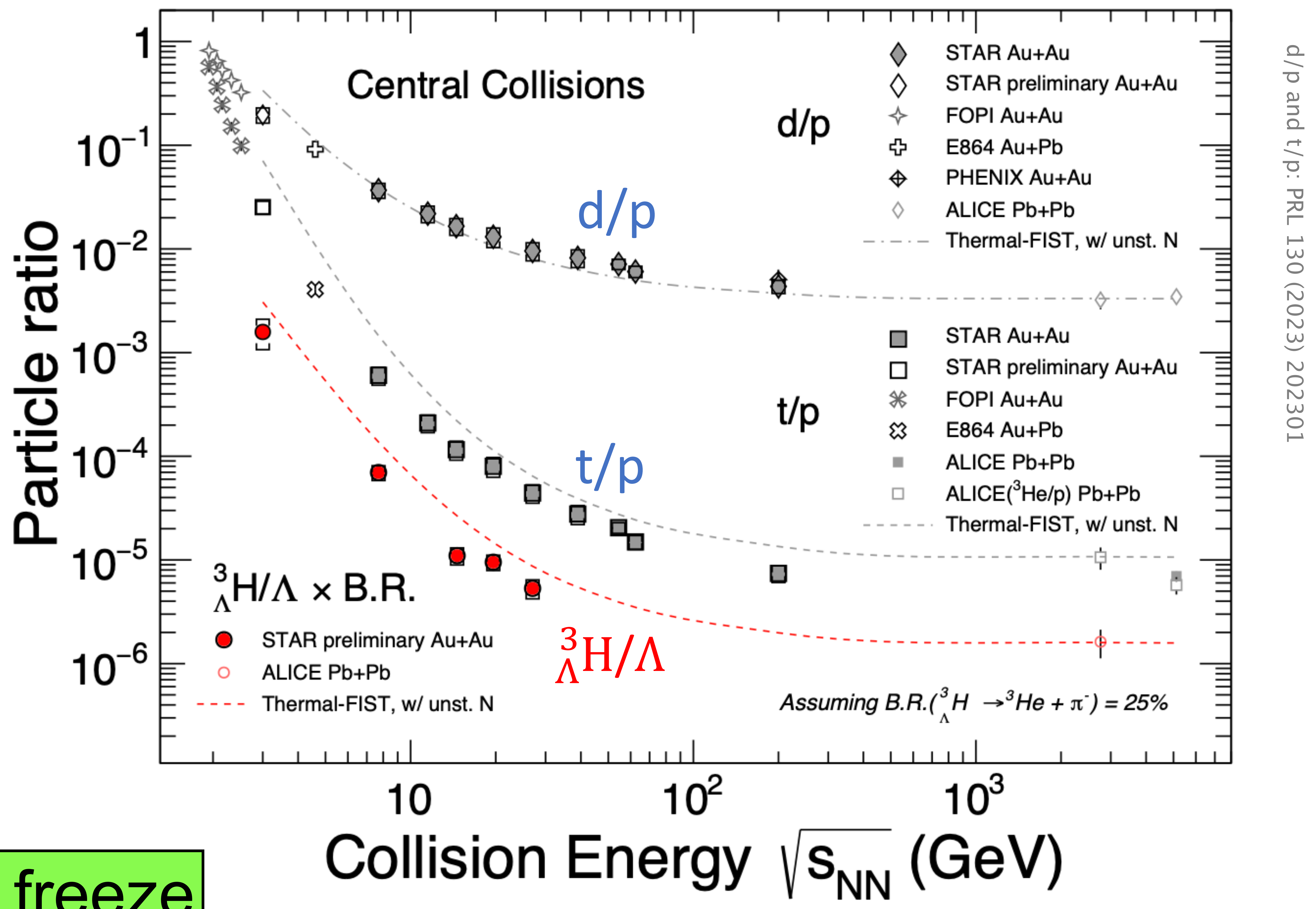


d/p - well described
t/p - overestimated by ~factor 2
$^3_\Lambda$H/Λ - overestimated by ~factor 2

(hyper)triton yields not fixed after chemical freeze

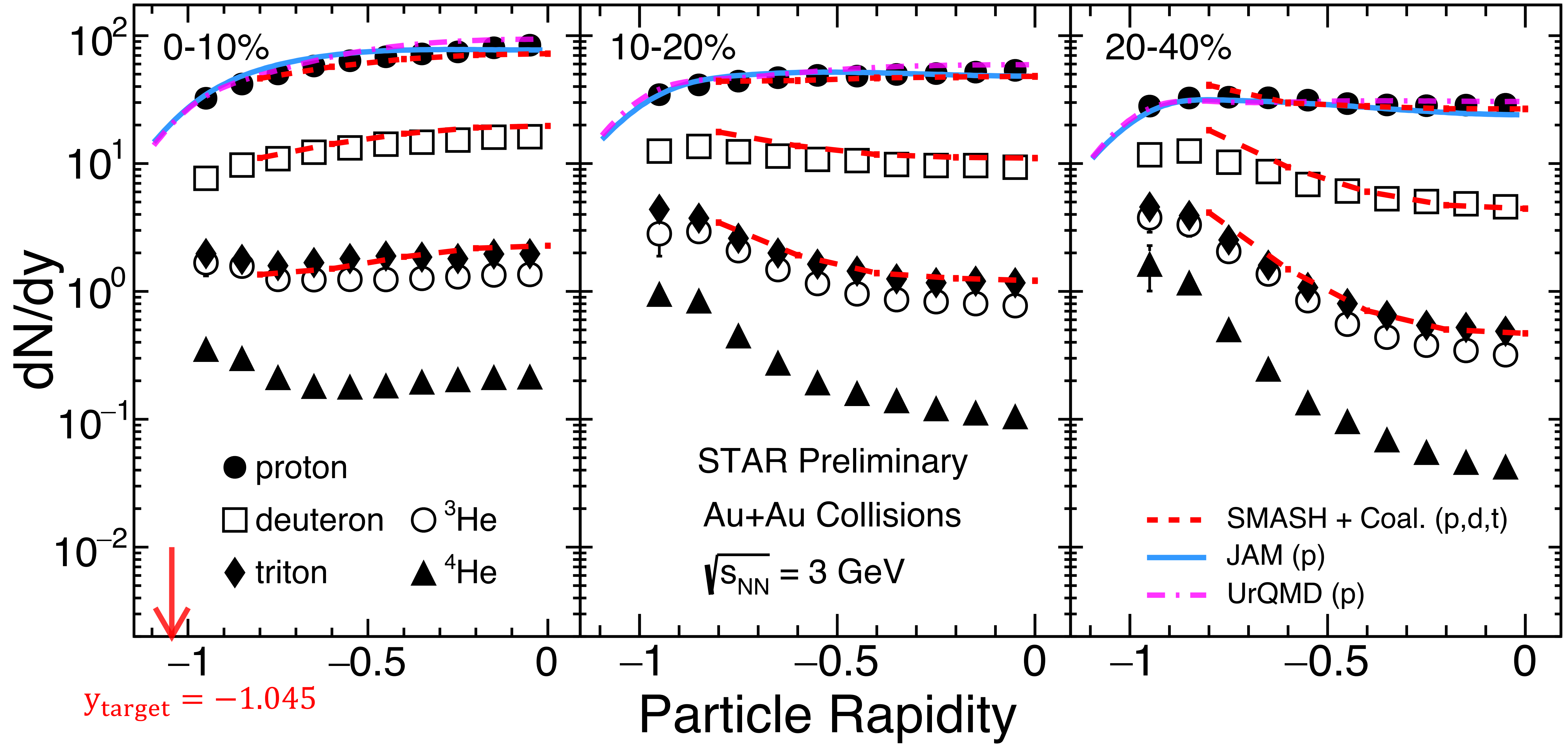
Y.H. Leung, X. Li, Y. Jin: STAR QM Posters, Y. Ji STAR QM Flash Talk

Kinetic freeze-out of light nuclei

At $\sqrt{s_{NN}}$ = 3 GeV

Yields of proton & light nuclei well described by models

Significant centrality and rapidity dependence



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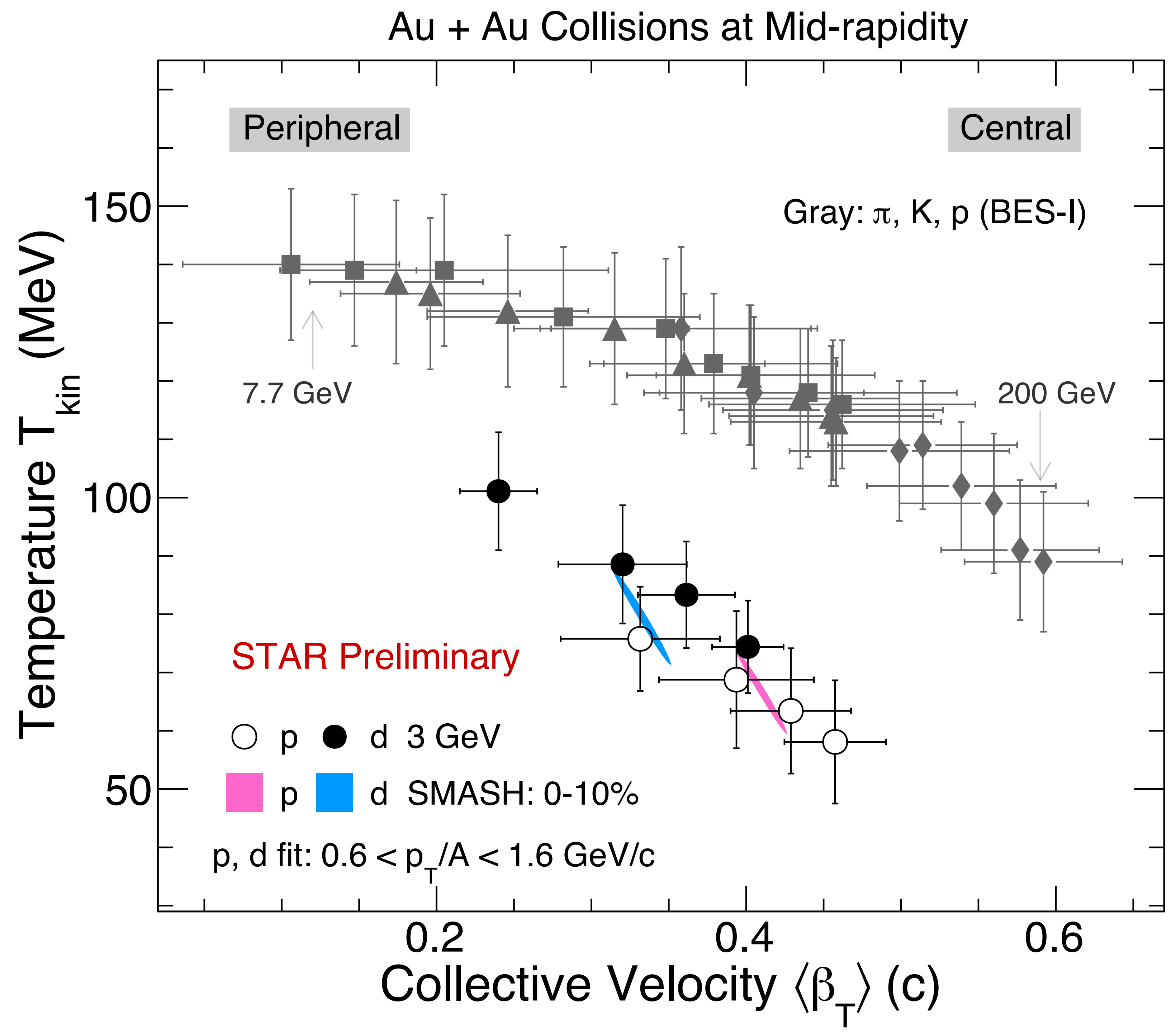
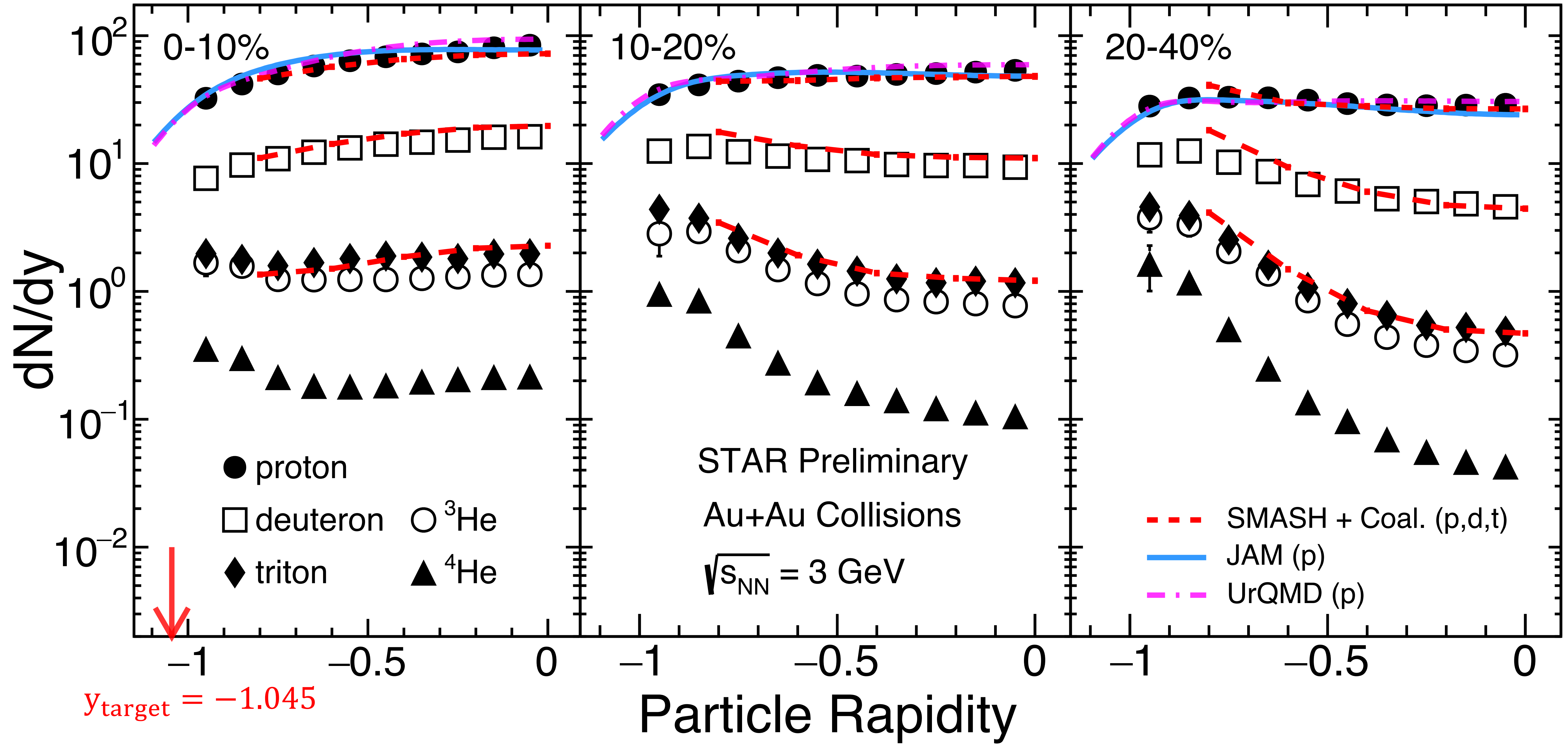


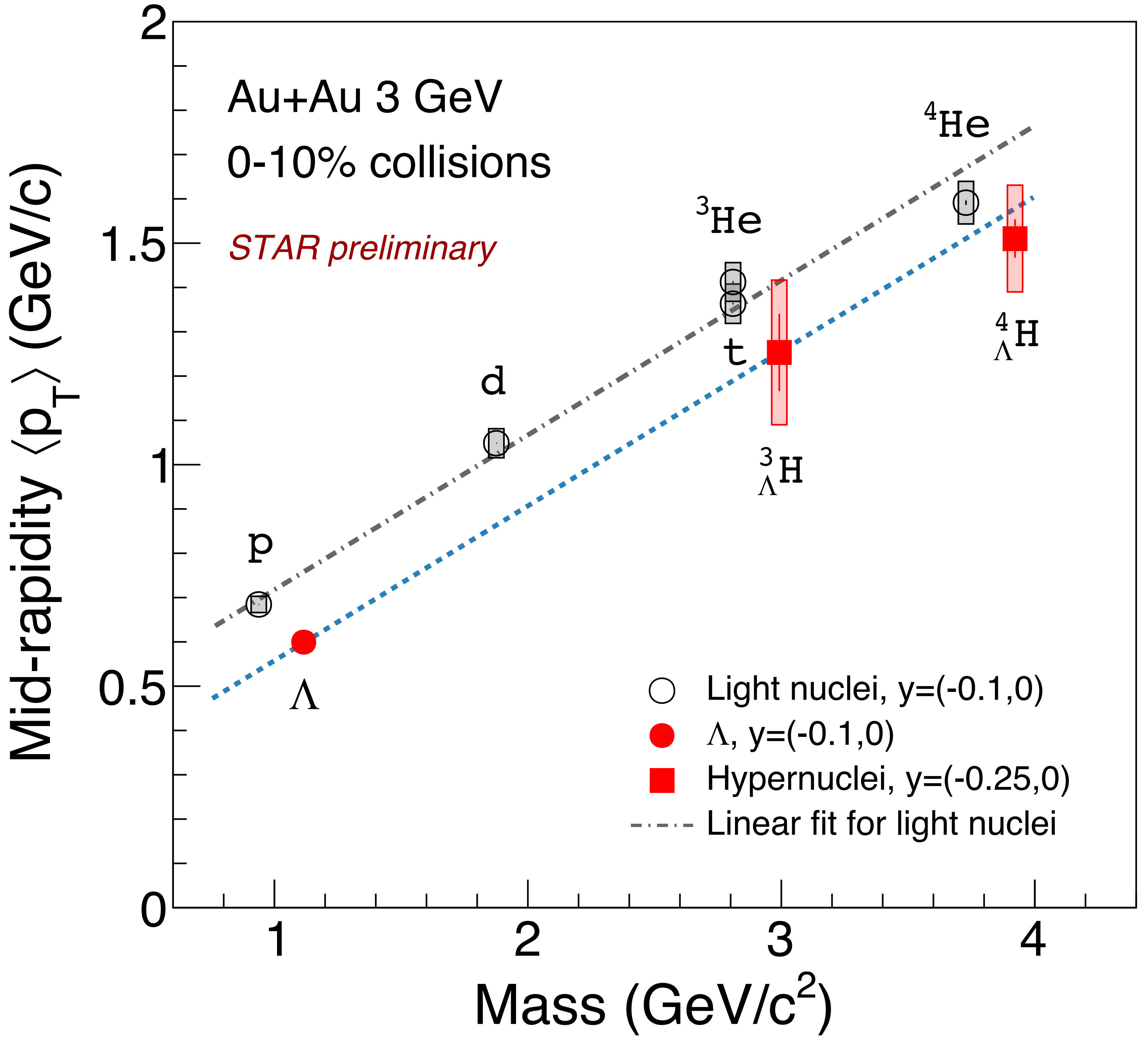


Effective average kinetic freeze out parameters extracted using cylindrical blast wave fits

$\sqrt{s_{NN}}$ = 3 GeV different trend to higher energies. Different EoS?

Effective $T_{kin}(d) > T_{kin}(p)$
$\beta_T(d) < \beta_T(p)$

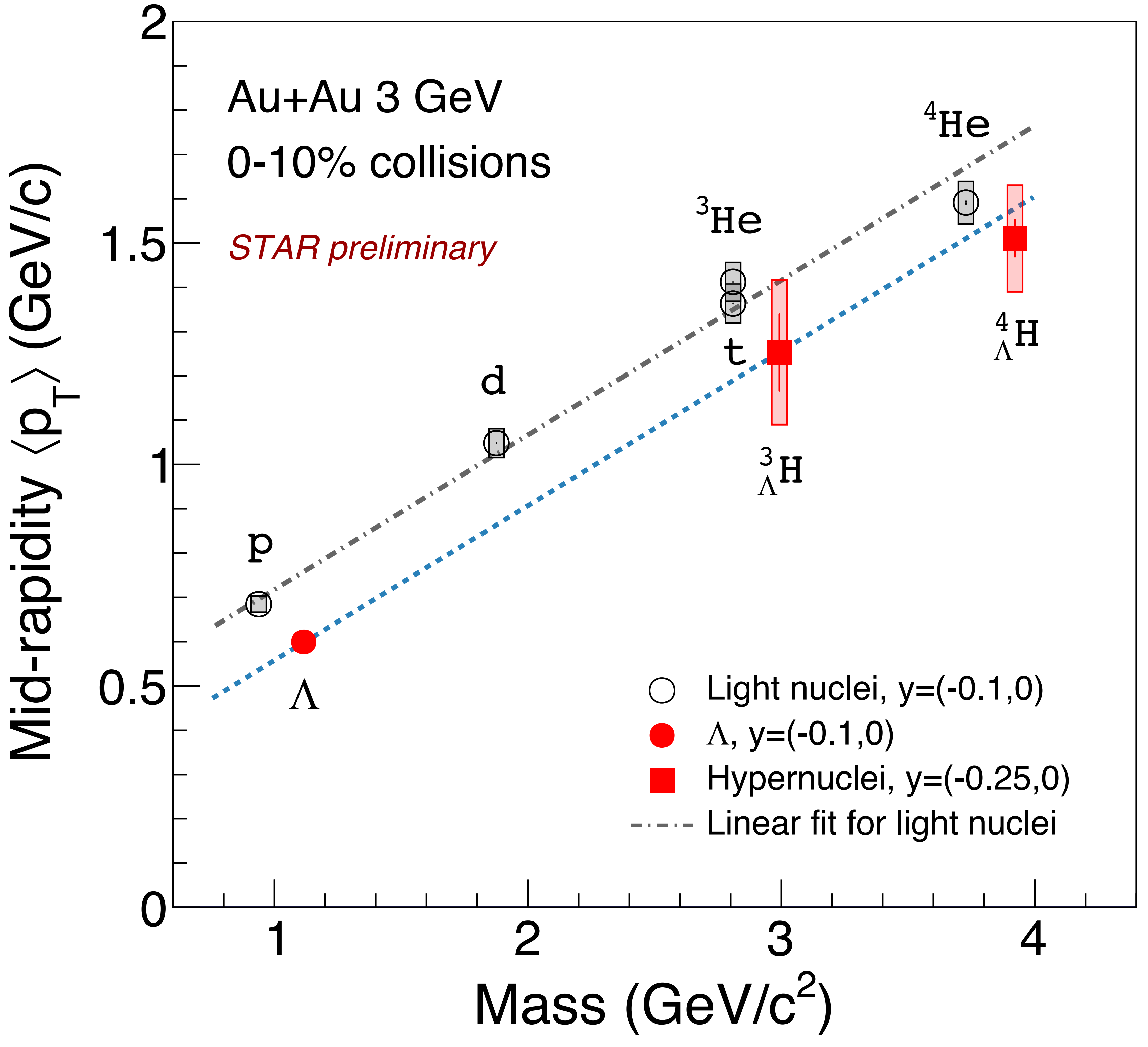
Hypernuclei kinematics

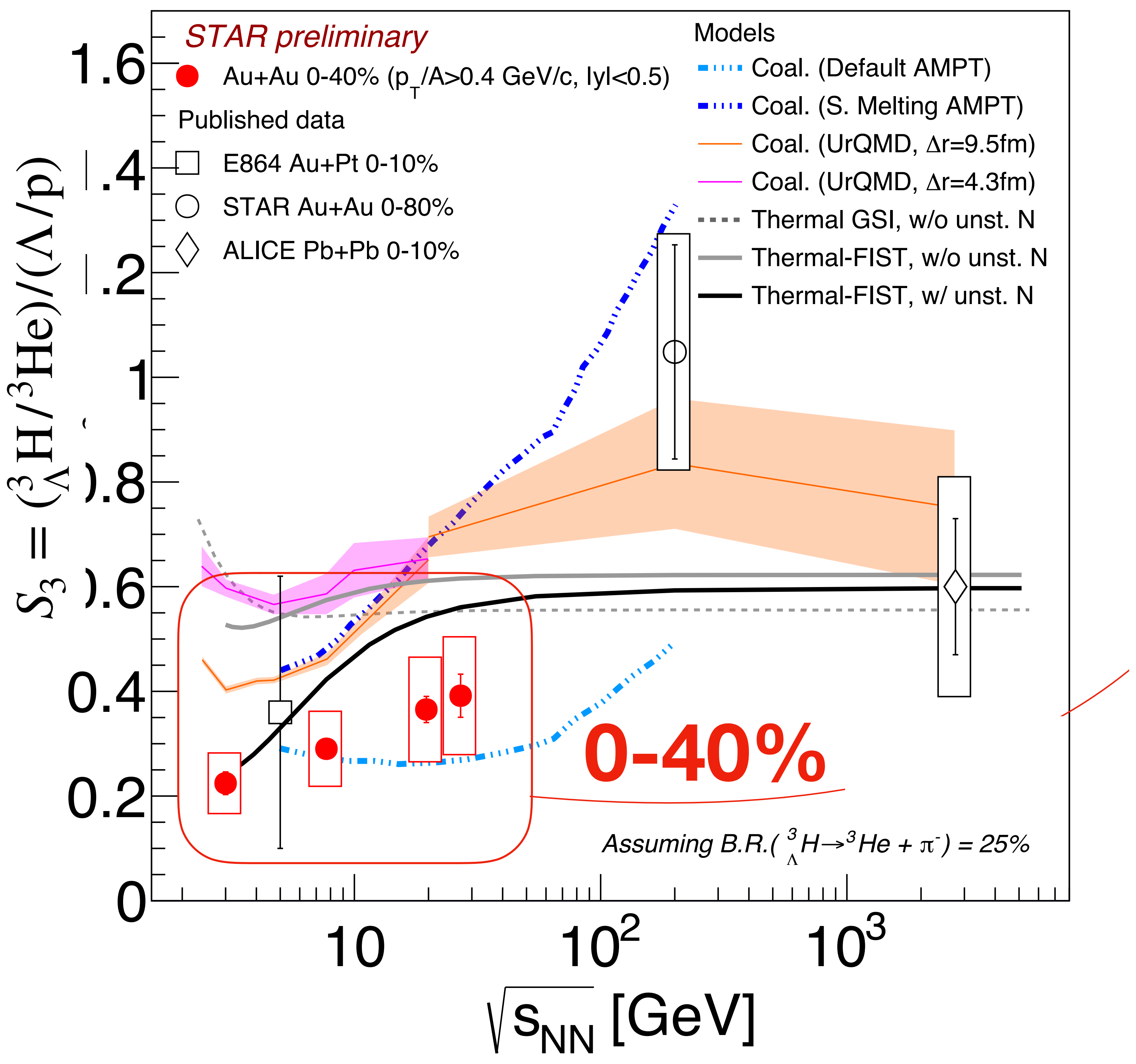


Including Λ reduces $<p_T>$

Mass number scaling preserved

Hypernuclei kinematics





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S_3 increases with $\sqrt{s_{NN}}$

Increasing feed-down to ^{3}He from unstable nuclei?

Suppression at low $\sqrt{s_{NN}}$?

Y.H Leung: STAR QM Poster, Y. Ji STAR QM Flash Talk

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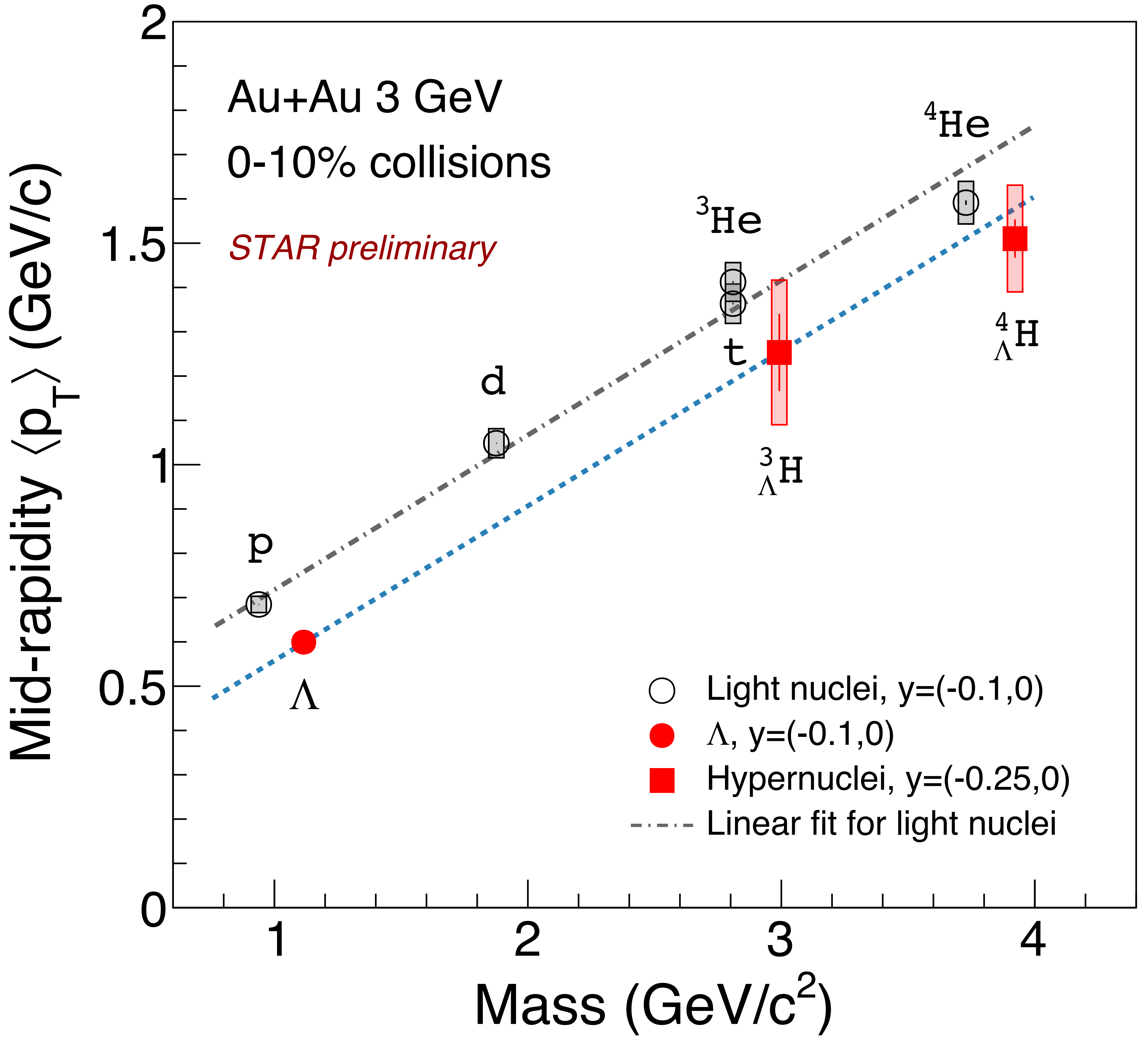

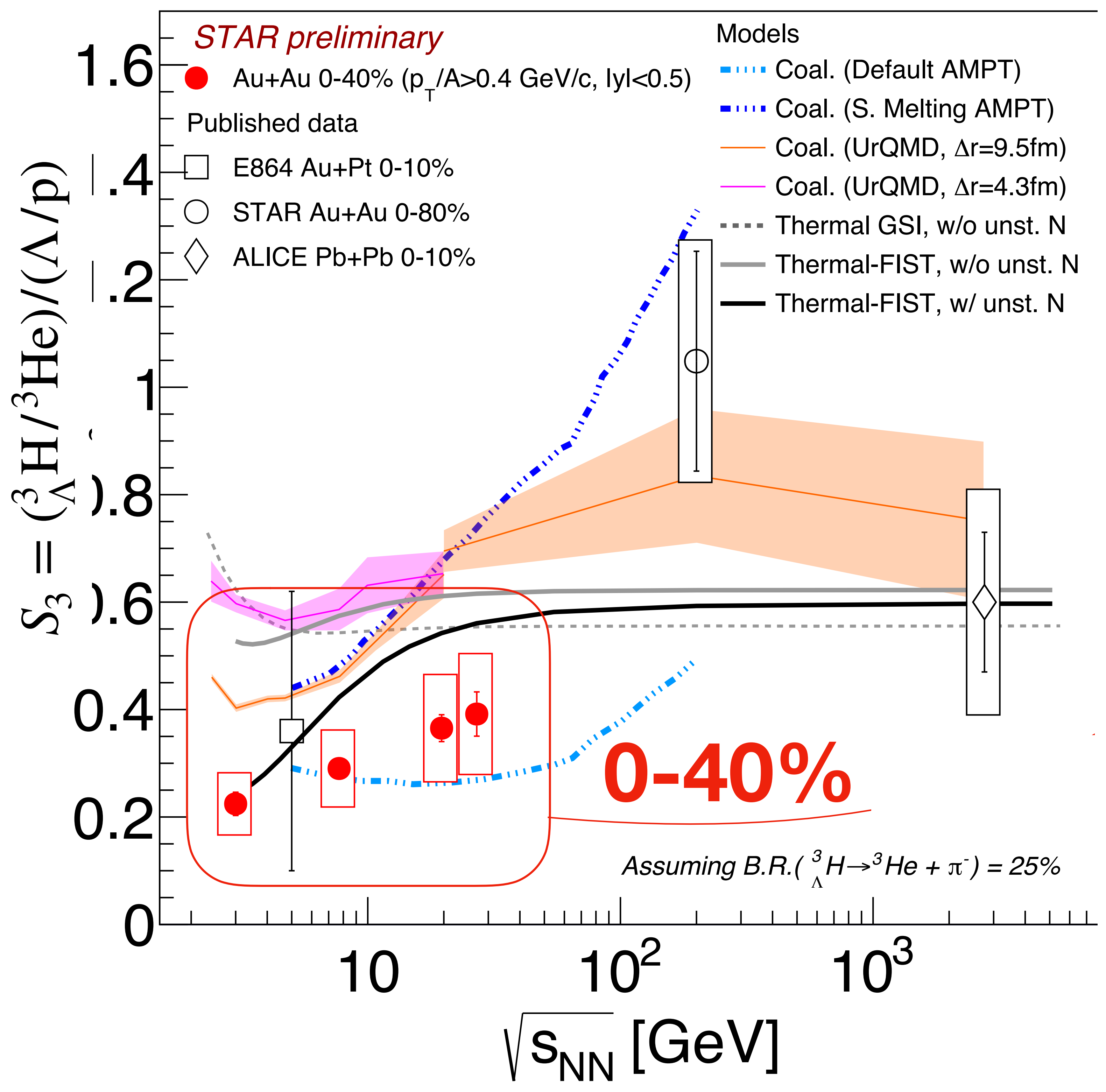

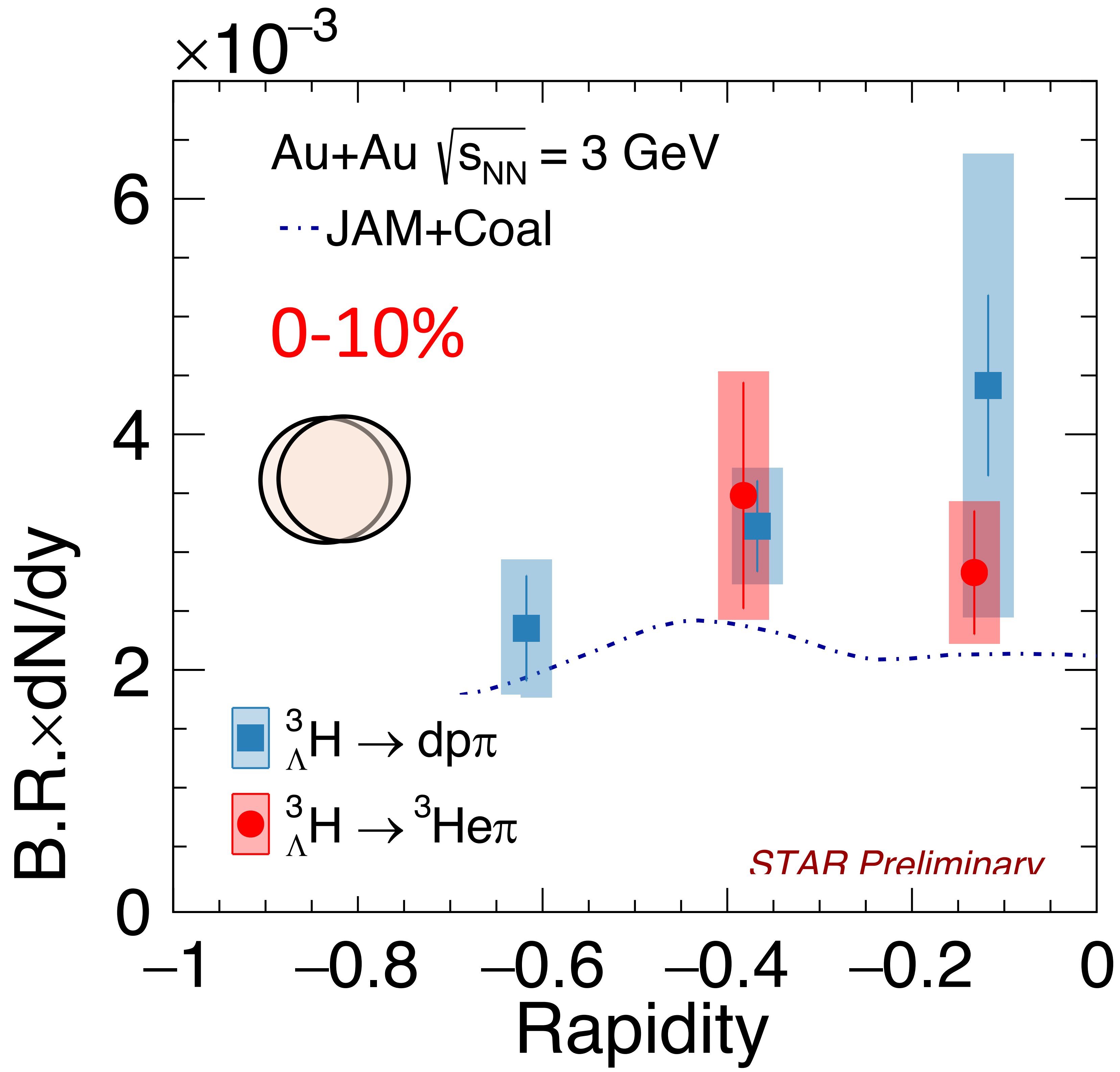

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S_3 increases with $\sqrt{s_{NN}}$

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Different decay channels give consistent distribution

JAM + Coalescence give reasonable description

Adding a hyperon enhances sensitivity

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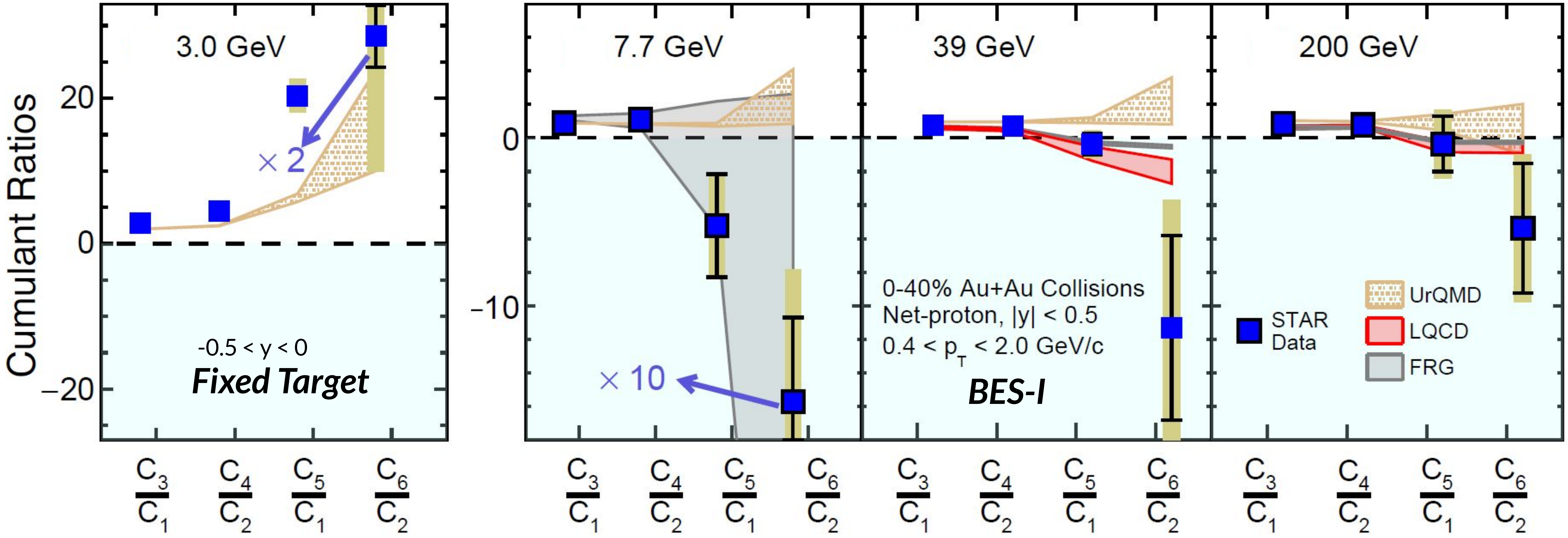
Determining the EoS?

Nature of medium produced

Cumulant ratios sensitive to nature of phase transition



$\sqrt{s_{NN}}$ =7.7-200 GeV: falling trend with rising order - trend predicted by Lattice

$\sqrt{s_{NN}}$ = 3 GeV (FXT): rising trend with rising order - trend in agreement with UrQMD

LQCD: HotQCD, PRD101,074502 (2020)
FRG: Wei-jie Fu et. al, PRD 104, 094047 (2021)
STAR: PRL 130, 082301 (2023)
STAR: PRL 127, 262301 (2021)
STAR: PRL 126, 092301 (2021)
STAR: PRC 104, 024902 (2021)

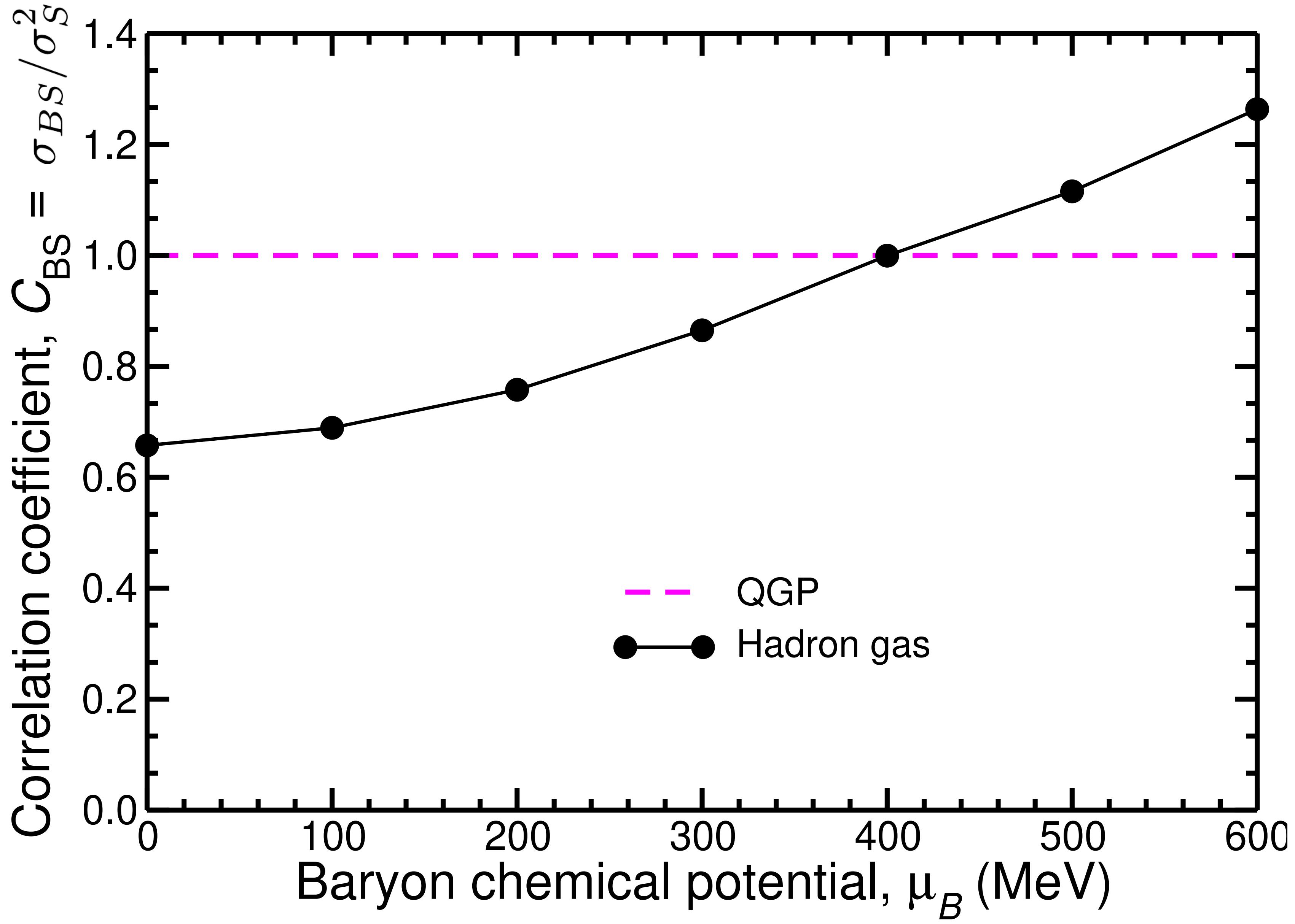
Eagerly awaiting BES-II data

Mixed correlations

Baryon-strangeness correlation coefficient:

$$C_{BS} = -3 * \frac{\langle BS \rangle_c}{\langle S^2 \rangle_c} = -3 * \frac{\langle BS \rangle - \langle B \rangle \langle S \rangle}{\langle S^2 \rangle - \langle S \rangle^2}$$

STAR uses: p, $K^{\pm}$, Λ



V. Koch et al: PRL95, 182301 (2005)
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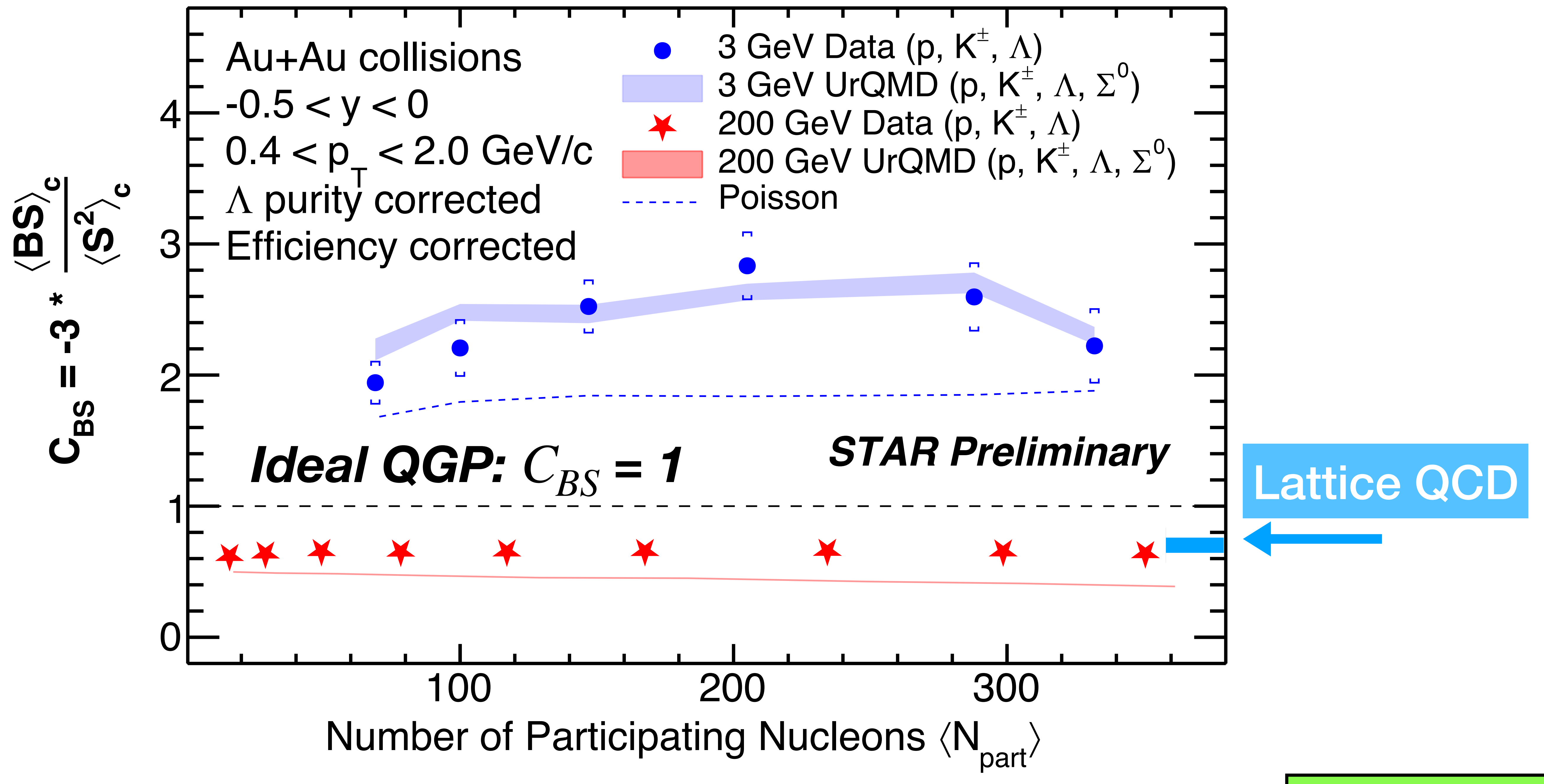

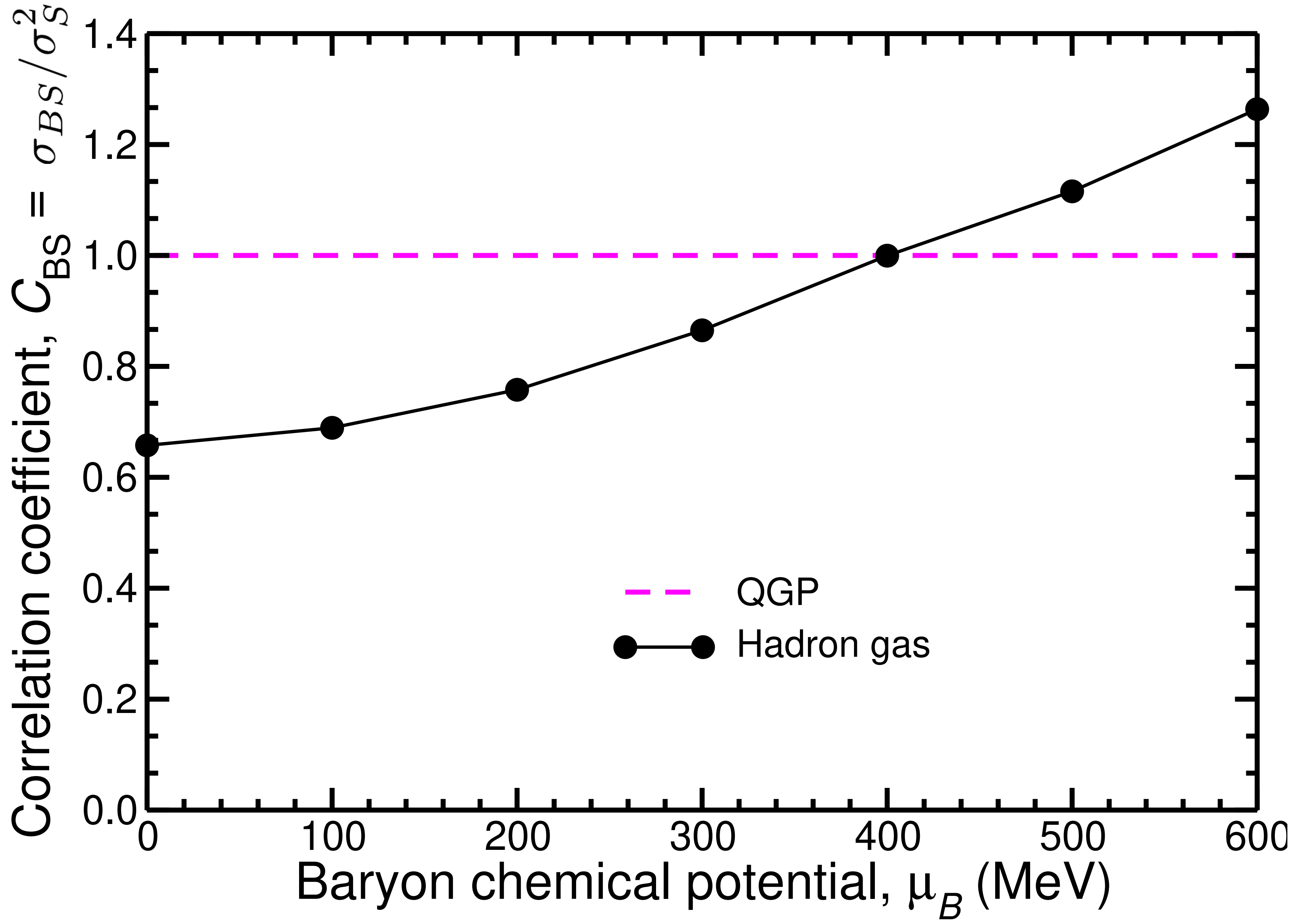

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LQCD: PRD 104, 074512 (2021)

T. Nonaka (ISMD 2023)

C_{BS} at 3 GeV

Well described by UrQMD - Hadronic interactions dominate

But BS_C and S^2 individually not well described

C_{BS} at 200 GeV:

Underestimated by UrQMD

Anti-correlation of strangeness and baryon production at $\sqrt{s_{NN}}$ = 3 GeV

Y. Zhang: STAR QM Poster

Softening of Equation of State

Fermi-Landau initial conditions with ideal hydro expansion : $c_s^2 = \partial P/\partial \varepsilon$

$c_s^2 = 0$ for a sharp phase transition

Softest Point: minimum in c_s^2

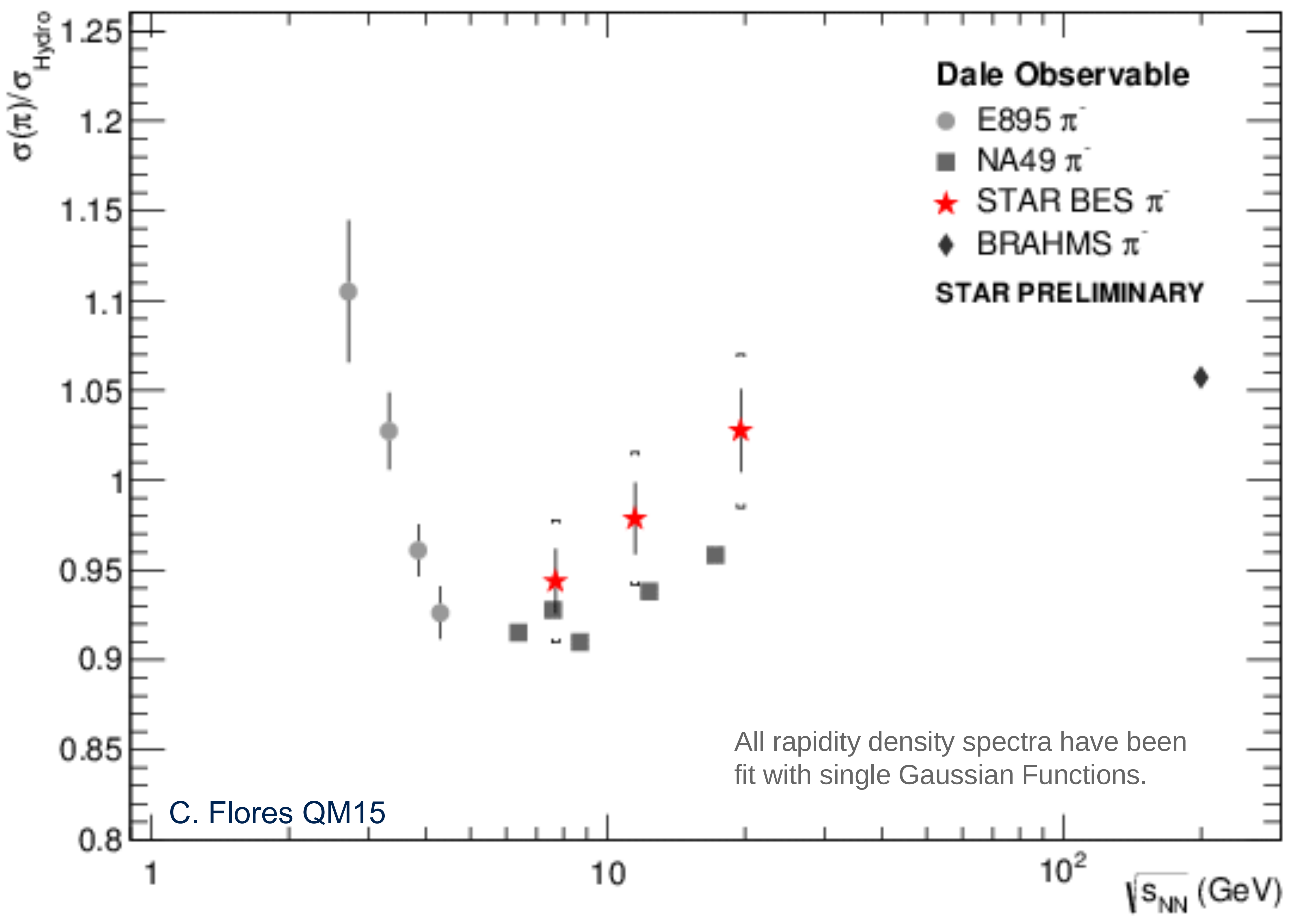
$$\frac{dn}{dy} = \frac{K s_{NN}^{1/4}}{\sqrt{2\pi\sigma_y^2}} e^{-\frac{y^2}{2\sigma_y^2}} \qquad \sigma_y^2 = \frac{8}{3}\frac{c_s^2}{1-c_s^4}\ln\left(\frac{\sqrt{s}}{2m_N}\right)$$

Minimum observed at √s = ~7 GeV

Minimum in the speed of sound?

$c_s^2 \sim 0.26$

Indication of softening of EoS?



E895: J. L. Klay et al, PRC 68, 05495 (2003)
NA49: S. V. Afanasiev et al. PRC 66, 054902 (2002)
BRAHMS: I.G. Bearden et al., PRL 94, 162301

NA61/SHINE see minima in similar place for pp data

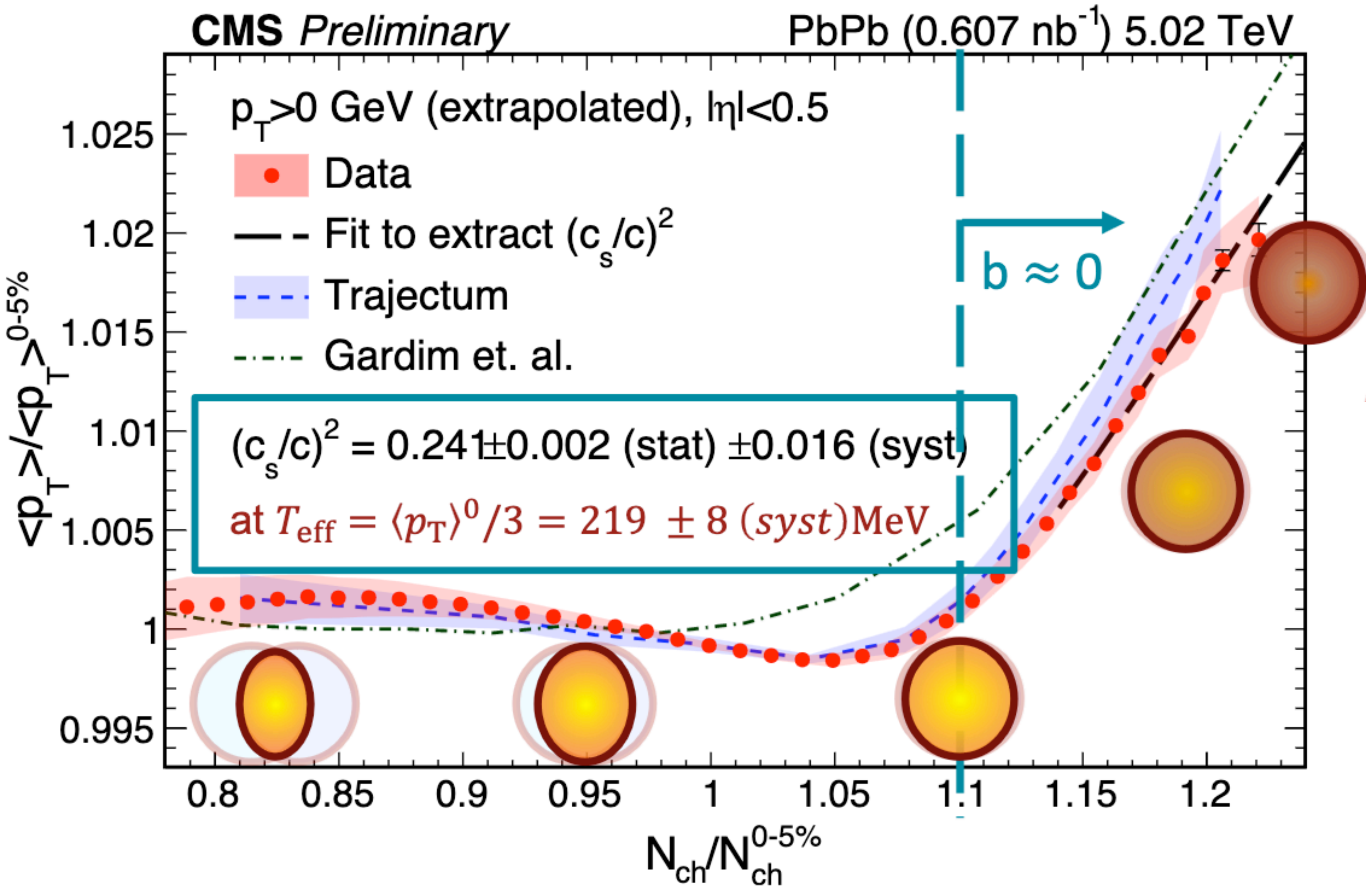
Confirm c_s in other ways?

Speed of Sound in QGP

Again relying on:

$$c_s^2 = \frac{dP}{d\varepsilon} = \frac{d\ln T}{d\ln s} = \frac{d\ln\langle p_T\rangle}{d\ln N_{ch}}$$

but focus on ultra-central events - avoids geometry fluctuations



C. Bernardes (Wed)

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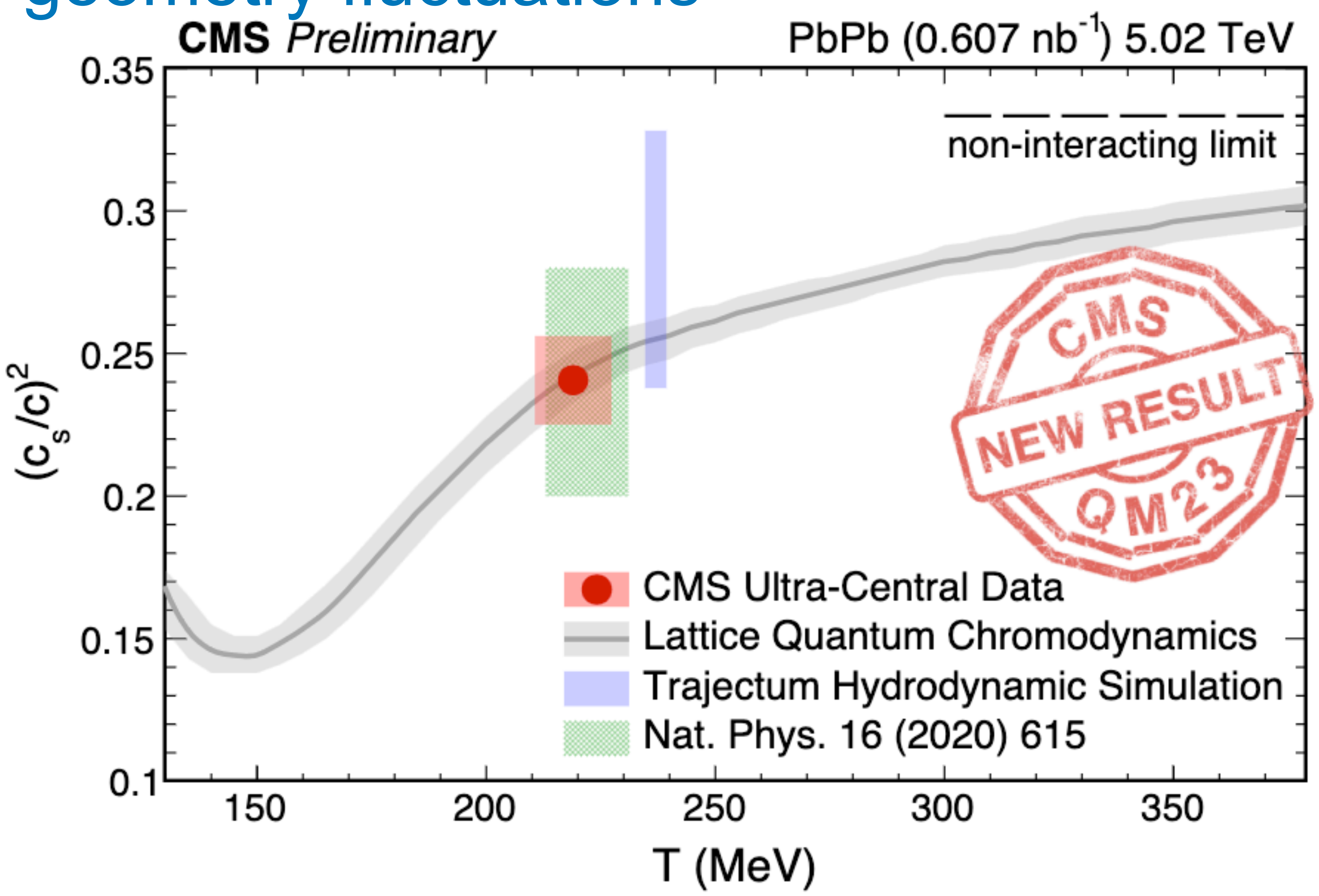
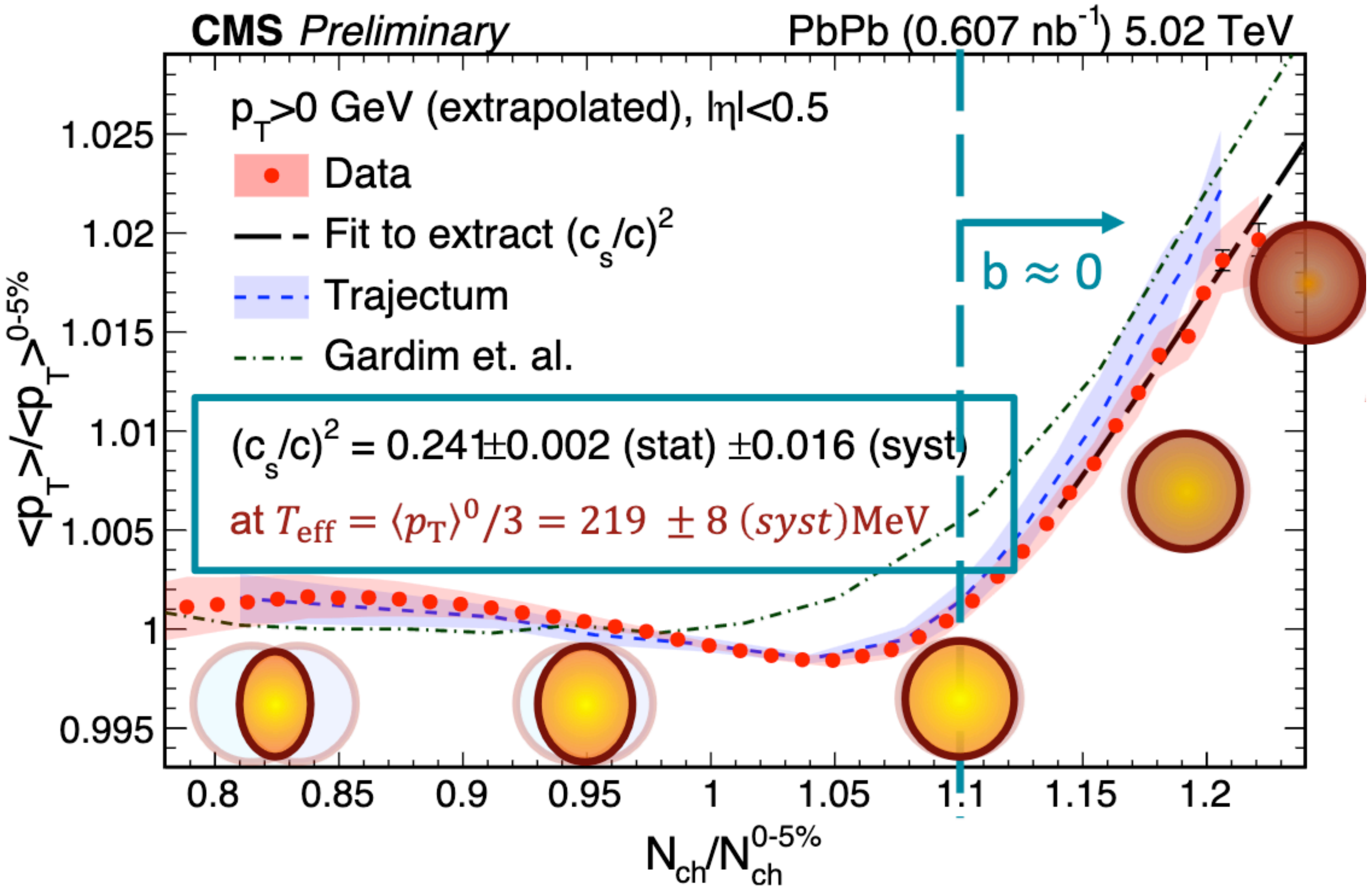




Impressive agreement with Lattice

Can this be done with BES data?

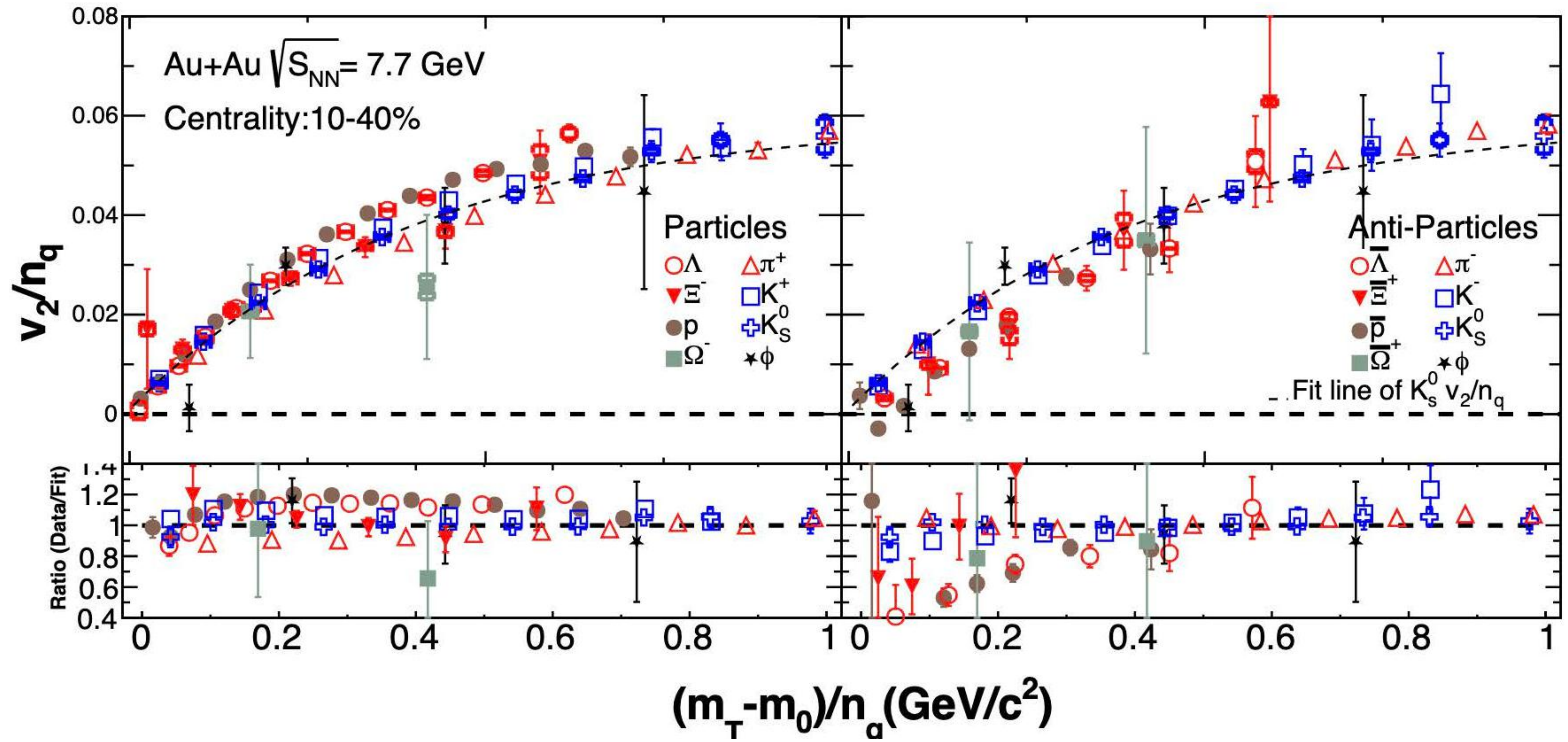
iTPC: Less p_T extrapolation

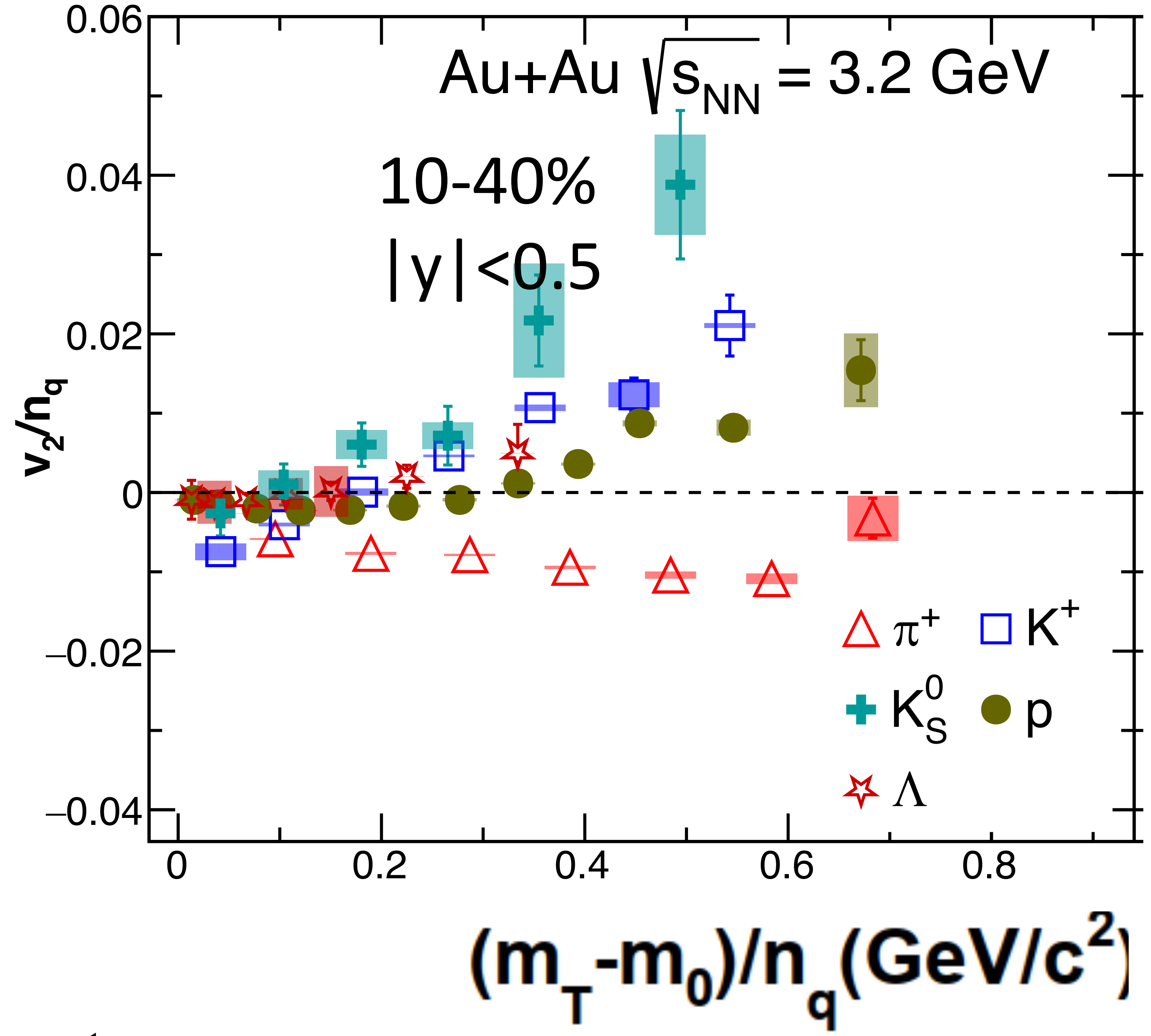
Probe particle species effects?

Also suggestions to use HBT and/or flow

C. Bernardes (Wed)

NCQ of elliptic flow





Using BES-II data high precision now available for multi-strange

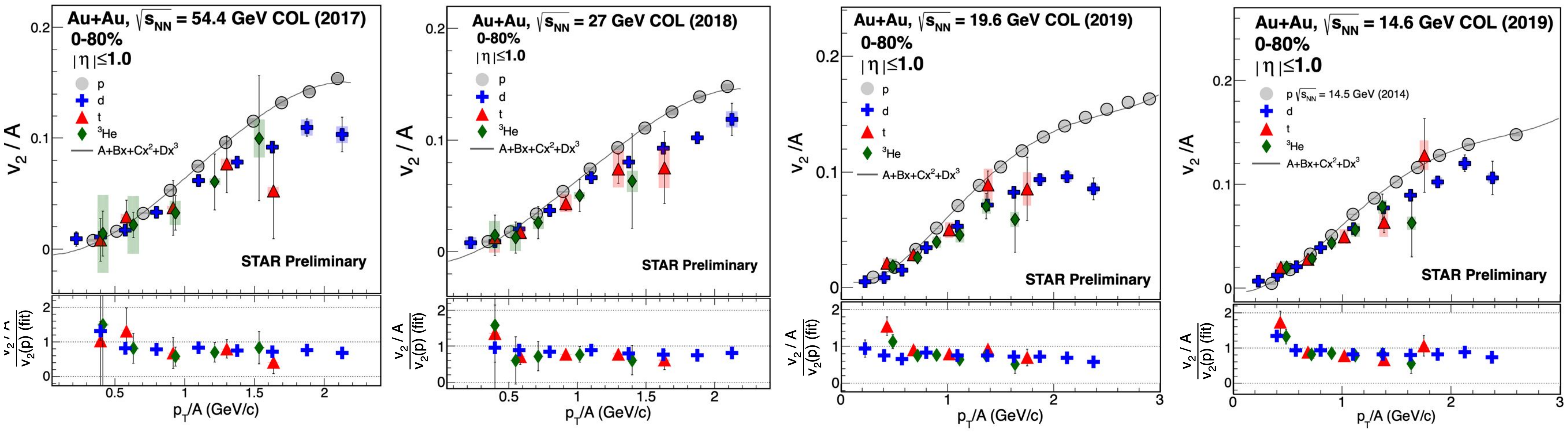
NCQ scaling holds at $\sqrt{s_{NN}}$ = 7.7 GeV and above
Better for anti-particles (~10%) than particles (~20%)
Similar trends observations for v_3

NCQ scaling fails at $\sqrt{s_{NN}}$ = 3.2 GeV and lower

Partonic for $\sqrt{s_{NN}}$ = 7.7 and above

Hadron dominated below $\sqrt{s_{NN}}$ = 3.2

Light nuclei collective motion



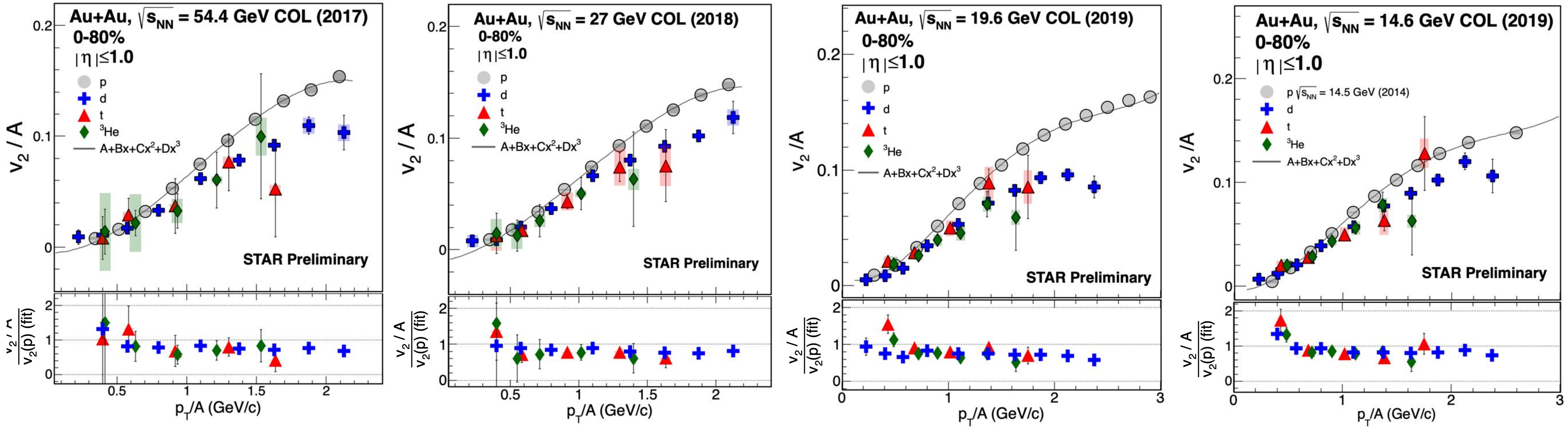
A-scaling:

v_2 for $\sqrt{s_{NN}}$ = 54-14.6 GeV

(also for v_3)

X. Liu and R. Sharma: STAR QM Talks

Light nuclei collective motion



A-scaling:

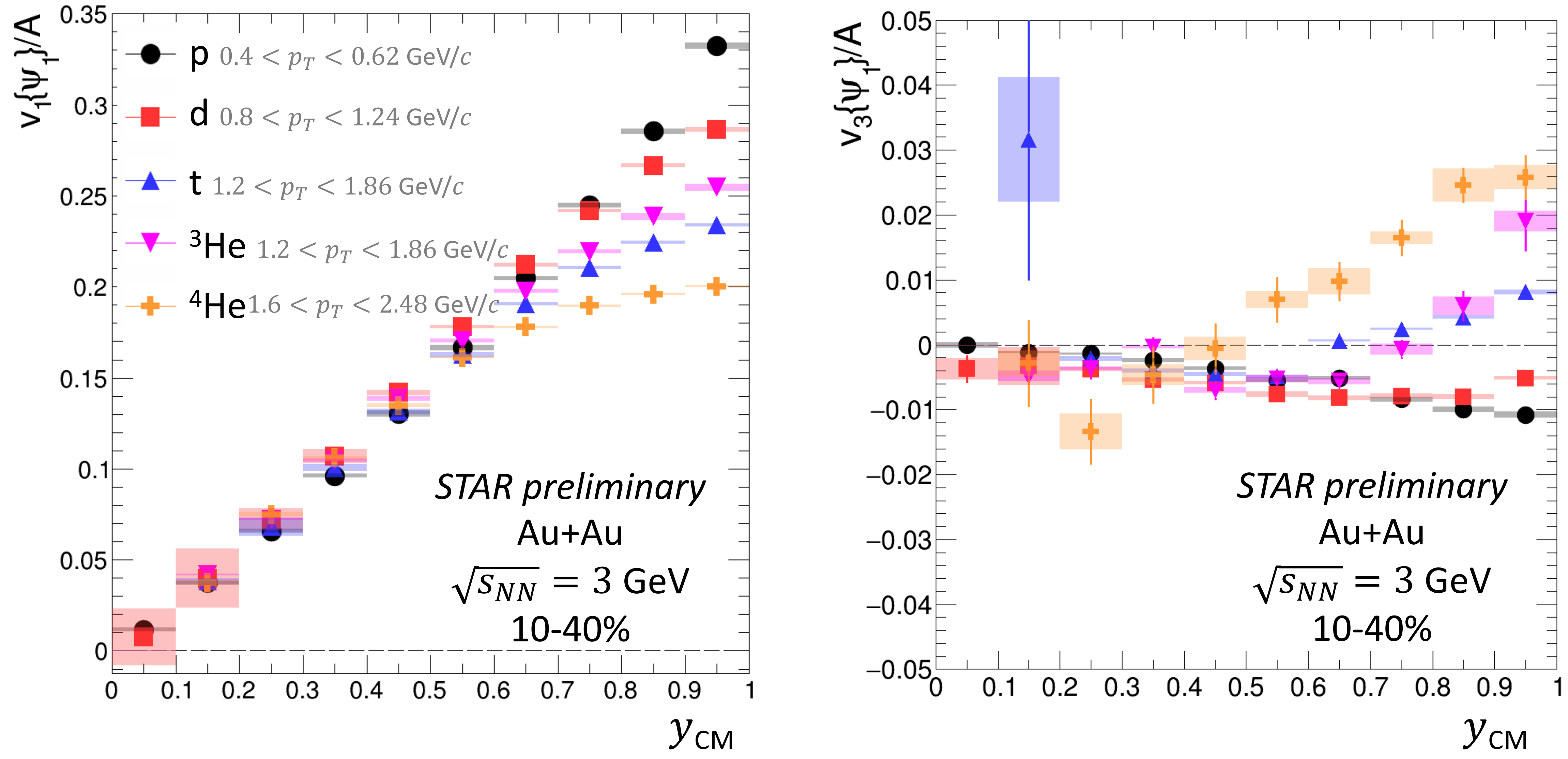
v_2 for $\sqrt{s_{NN}}$ = 54-14.6 GeV

(also for v_3)

A-scaling at $\sqrt{s_{NN}}$ = 3 GeV

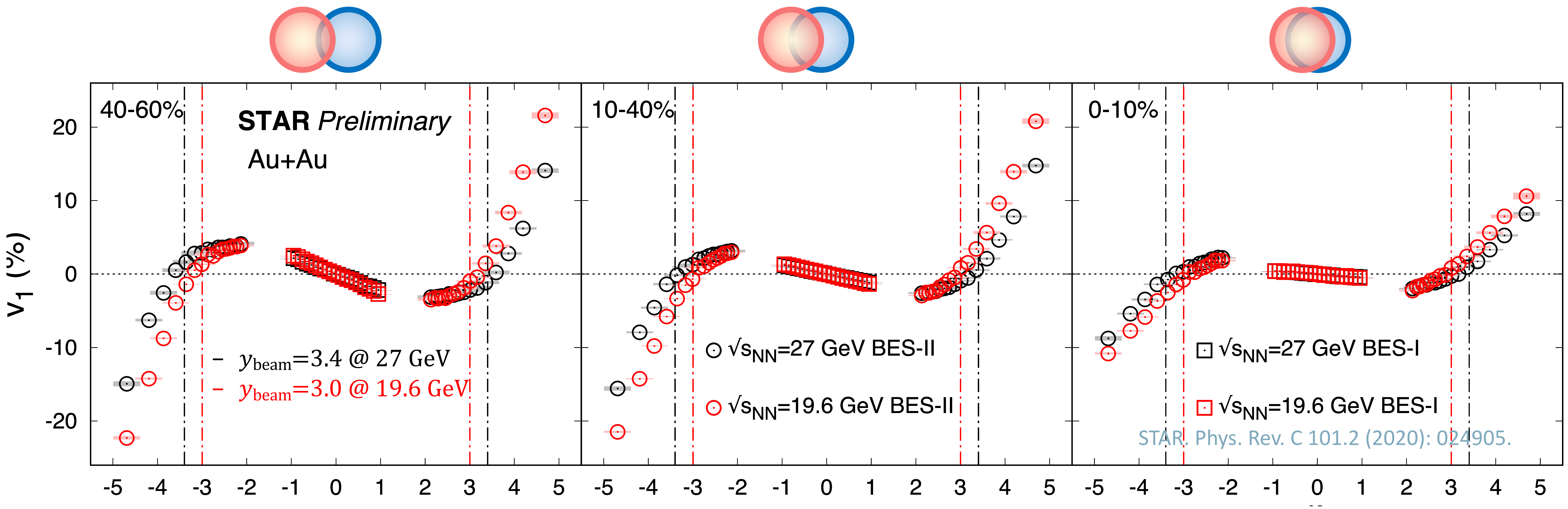
Reasonable for v_1 and $v_3\{\Psi_1\}$ at $y_{cm}<0.5$
Breaks for v_1 and $v_3\{\Psi_1\}$ $y_{cm}>0.5$

v_1 of hypernuclei similar trend

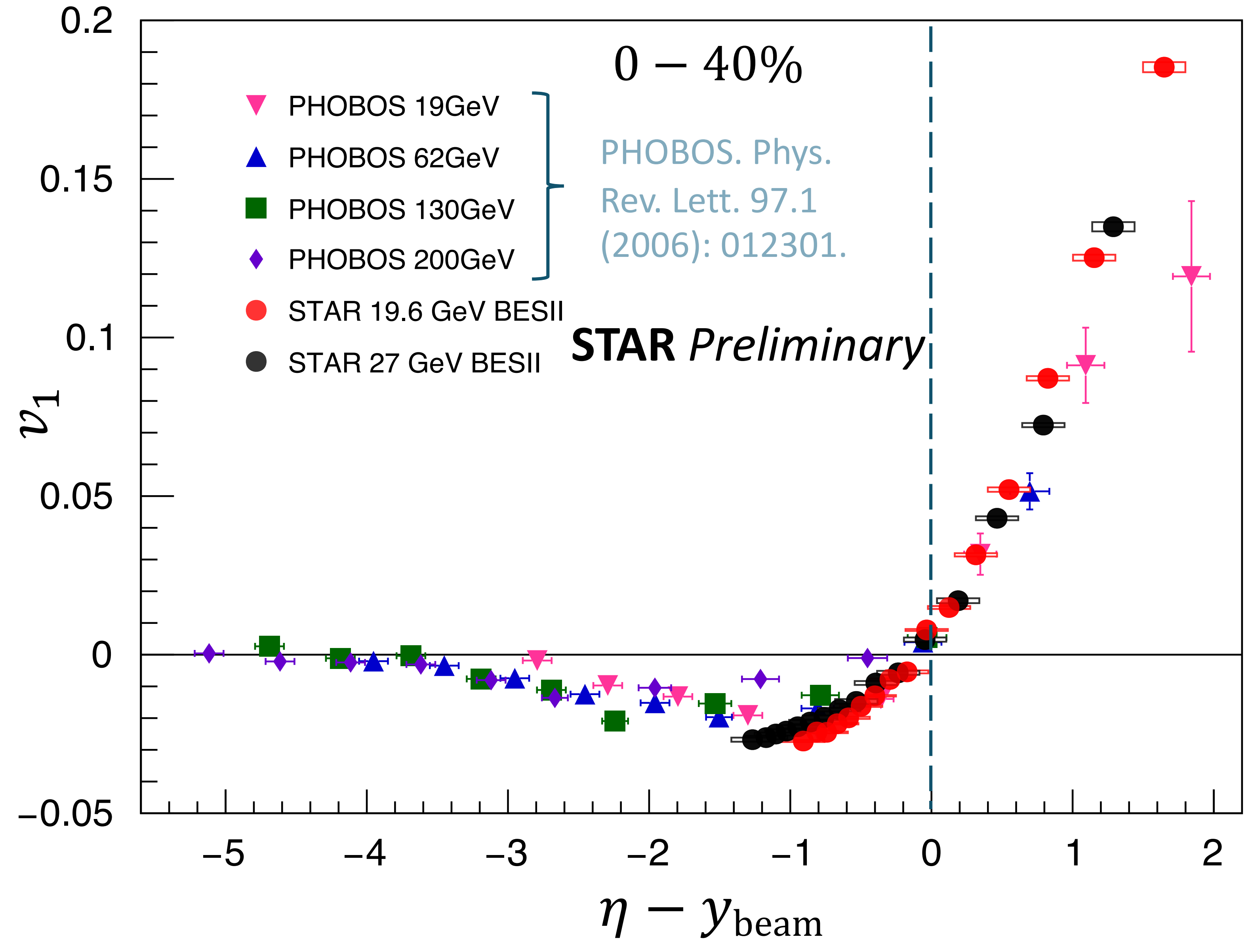


Consistent with late-stage coalescence
- high y nuclear fragments

Limiting fragmentation



Results extended to more centralities



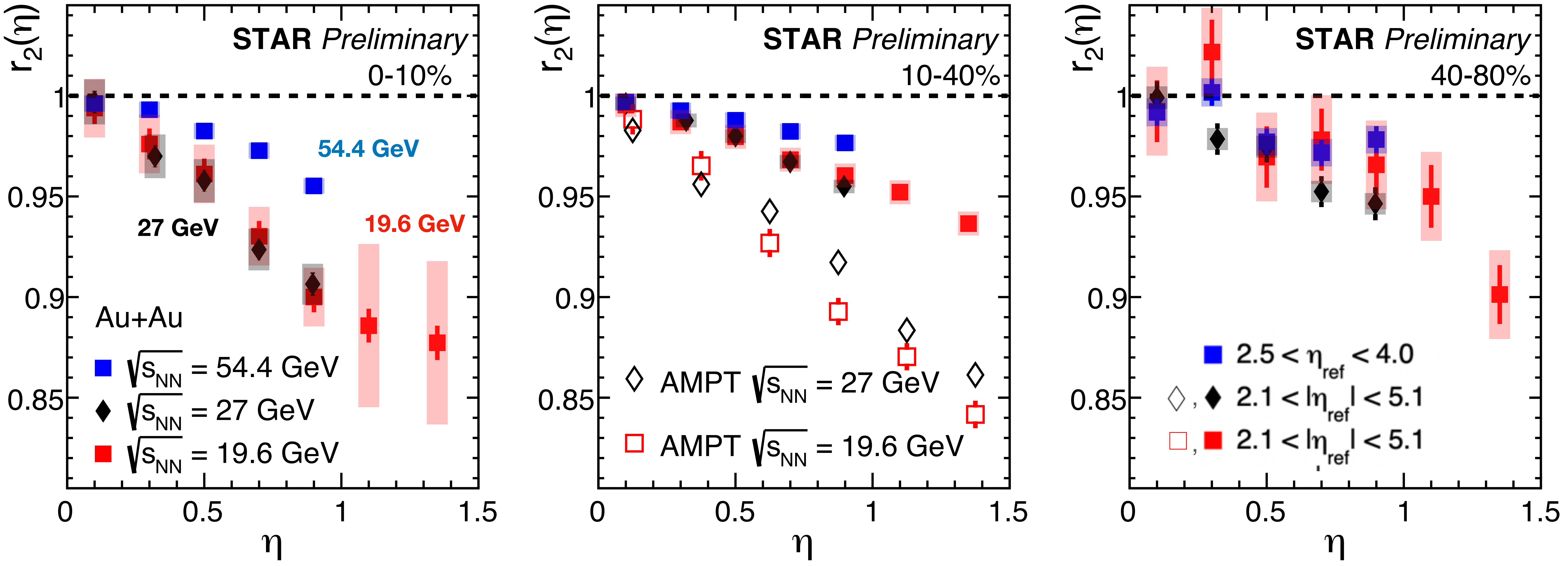
Scaling of v_1 observed for all centralities

Nuclei fragments contribute to v_1

"Limiting fragmentation" a dynamical phenomenon

X. Liu: STAR QM Talk

Longitudinal decorrelation



Strong decorrelation at RHIC energies (even stronger for r_3)

Strongest in central events

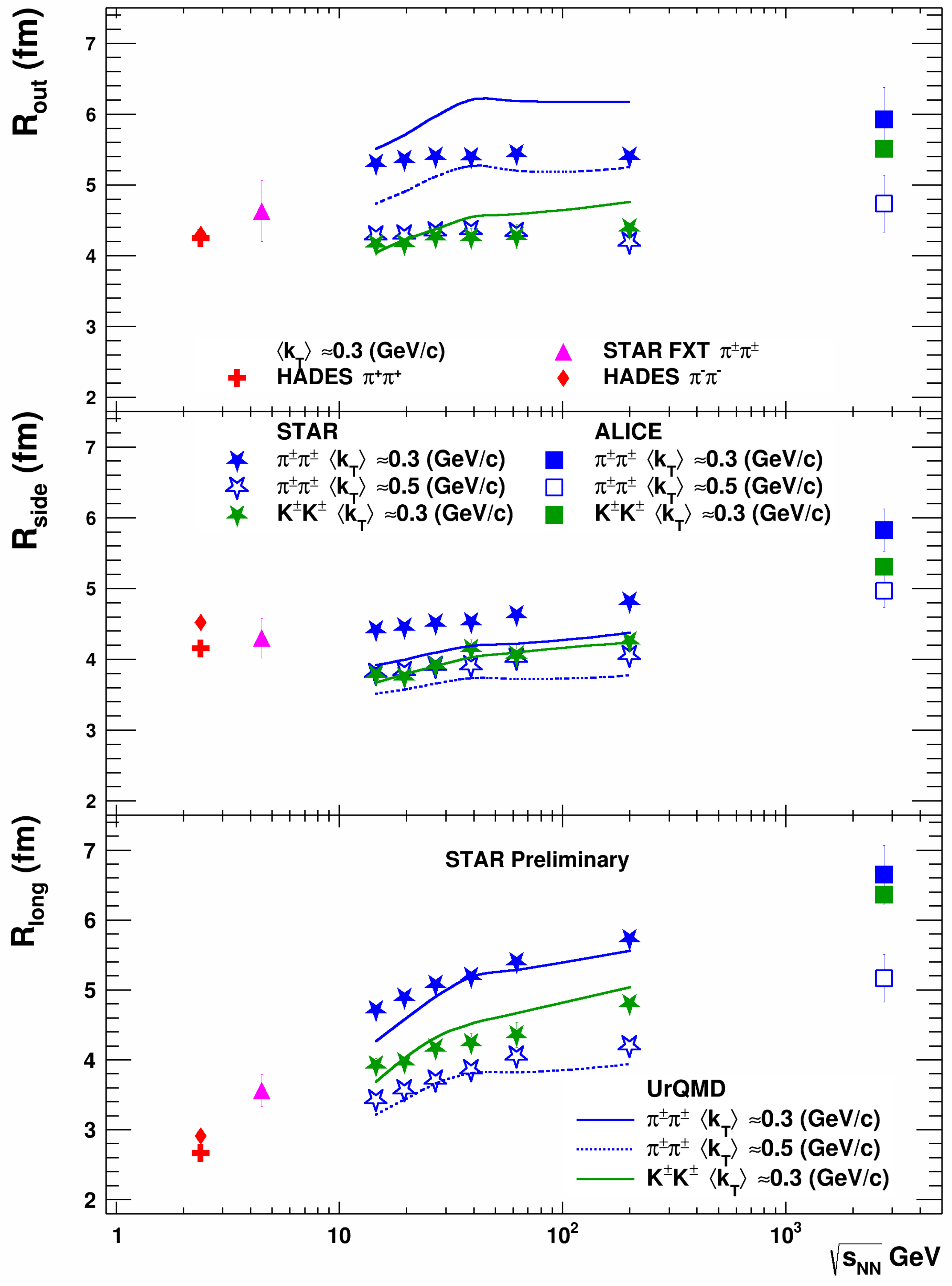
Increasing with decreasing collision energy

AMPT too strong

3D dynamics important

Understanding the Emitting Source(s)

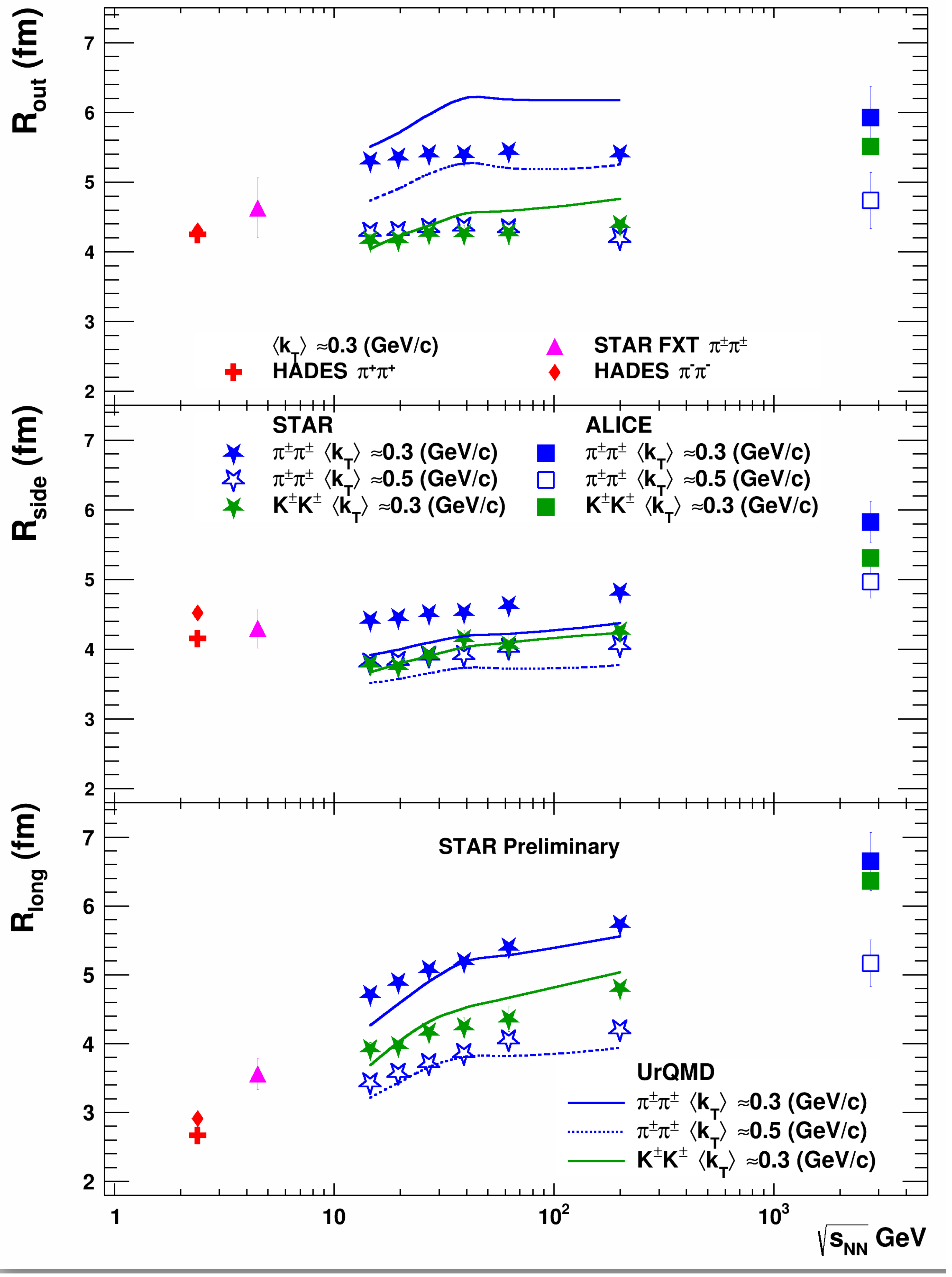
HBT - 3D femtoscopy

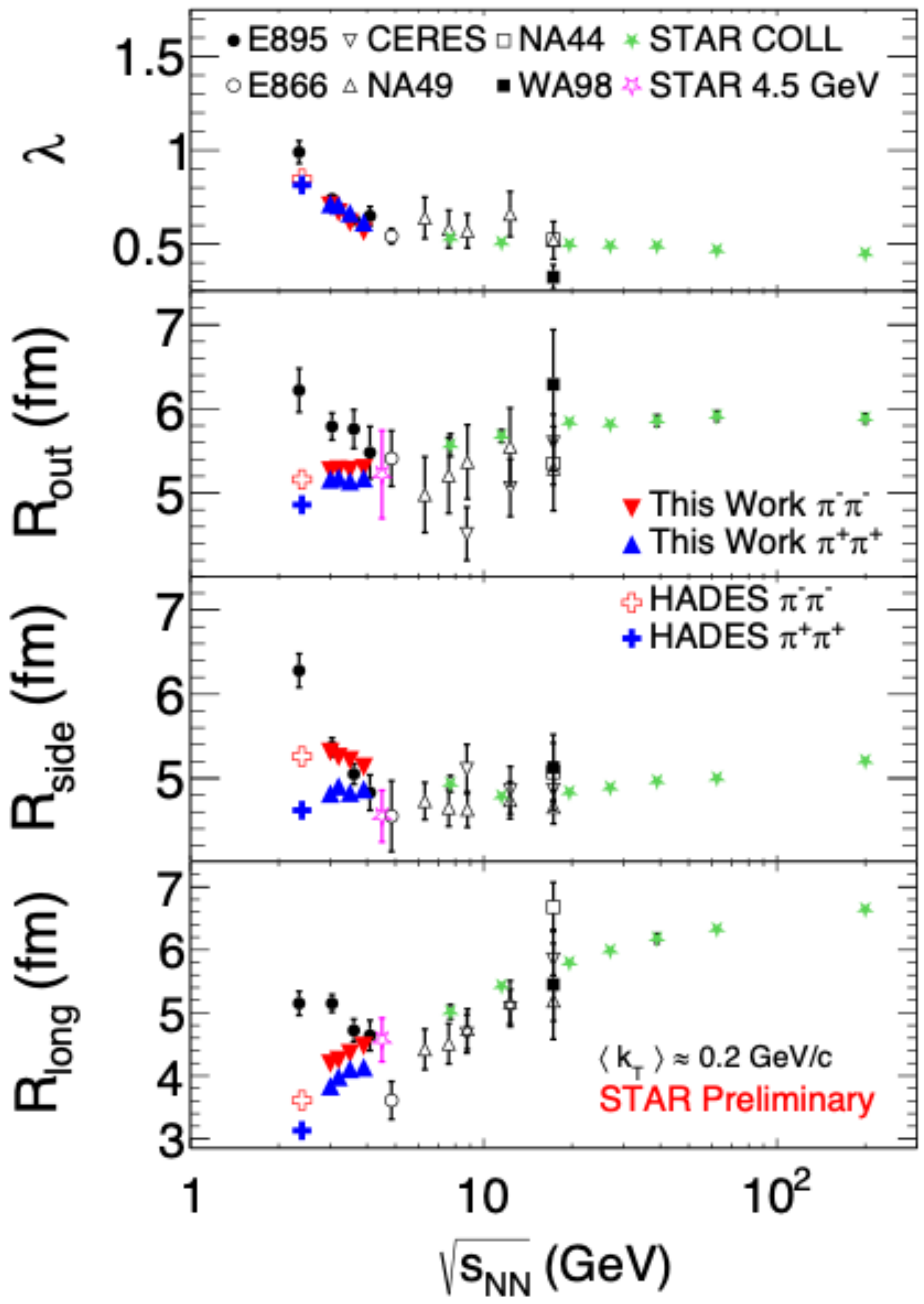


Radii:
- Increase with collision energy
- Decrease with transverse mass
- Larger for π than K
- UrQMD reasonable agreement

Y. Khyzhniak and Y. Qi: STAR QM Posters

HBT - 3D femtoscopy

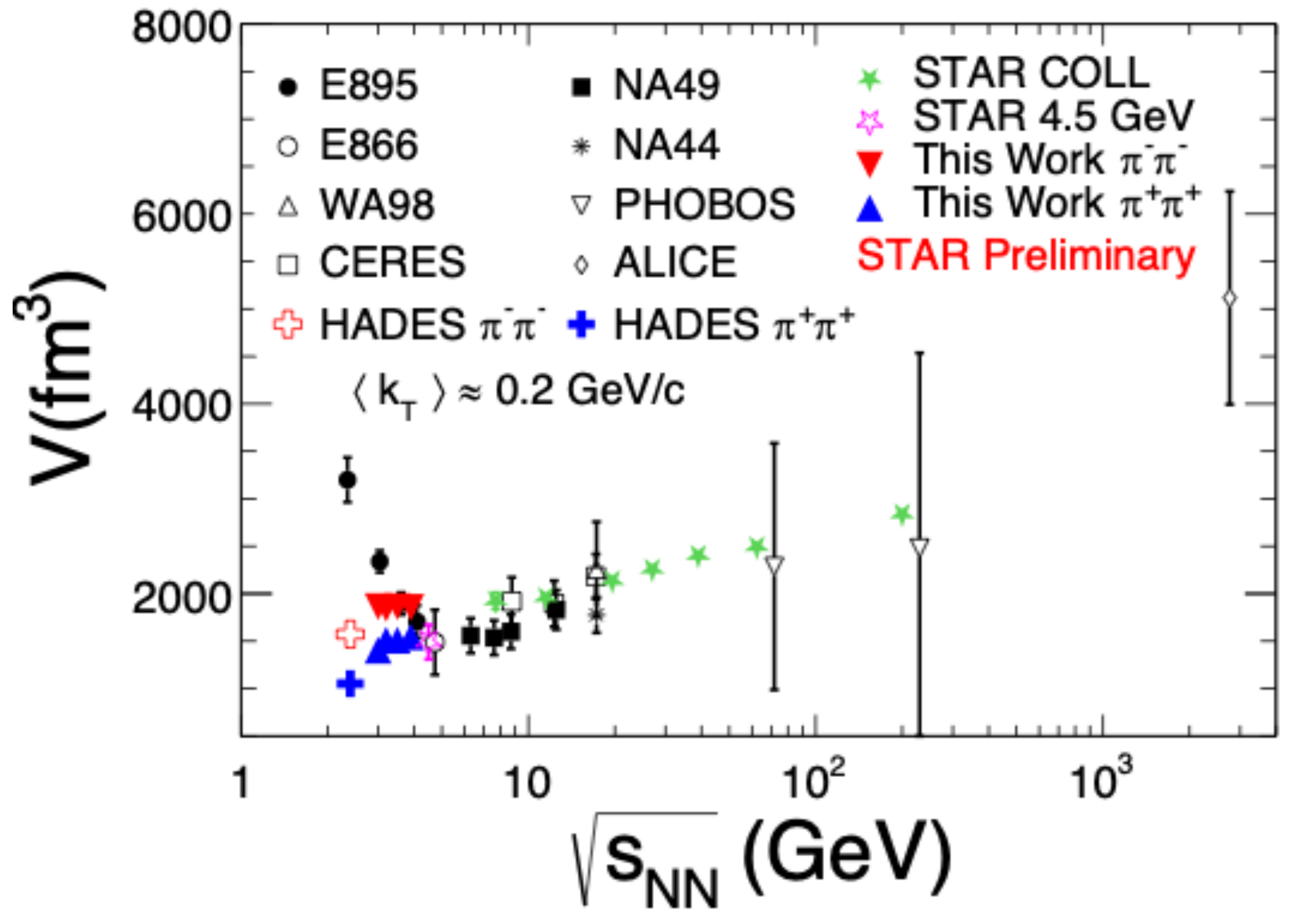




Radii:

- Increase with collision energy
- Decrease with transverse mass
- Larger for π than K
- UrQMD reasonable agreement

Tension emerging with E895



Slowly increasing volume from STAR and HADES

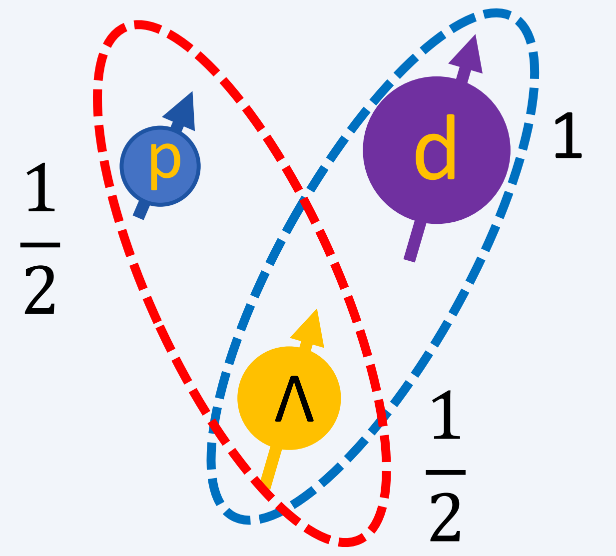
Y. Khyzhniak and Y. Qi: STAR QM Posters

Correlations with hyperons

p-Λ and d-Λ correlations explore:
N-(-N)Y interactions and hyper nuclei structure

R_G : Spherical Gaussian source size
f_0 : scattering length
d_0 : effective range

Expect different f_0 and d_0 from difference spin states



Singlet State	$^1S_0$	(S)
Triplet State	$^3S_1$	(T)
Doublet State	$^2S_{1/2}$	(D)
Quartet State	$^4S_{3/2}$	(Q)

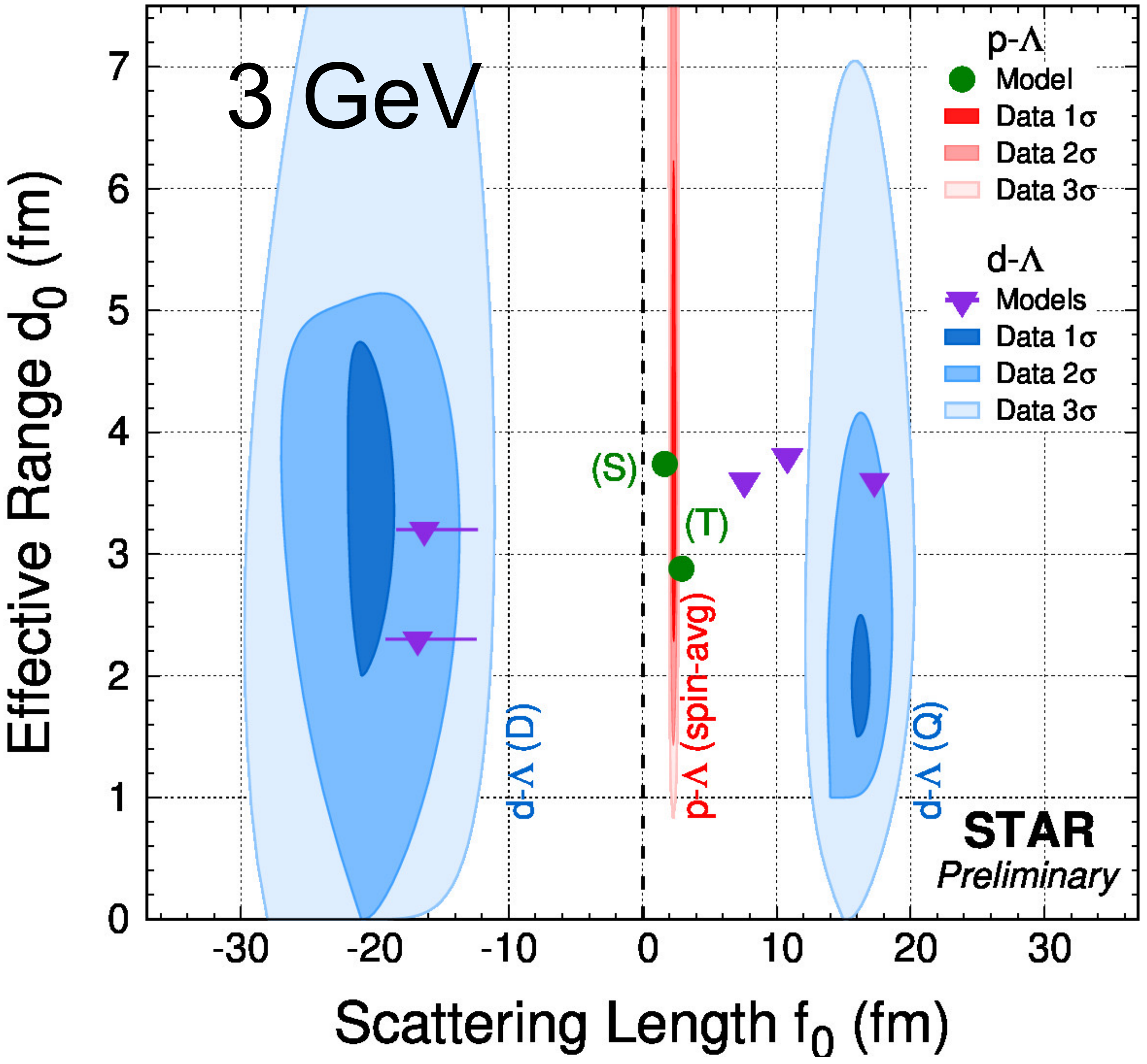
Separating source size and FSI

R_G ~ 2-3 fm

$R_G^{central} > R_G^{peripheral}$

$R_G^{(p-\Lambda)} > R_G^{(d-\Lambda)}$

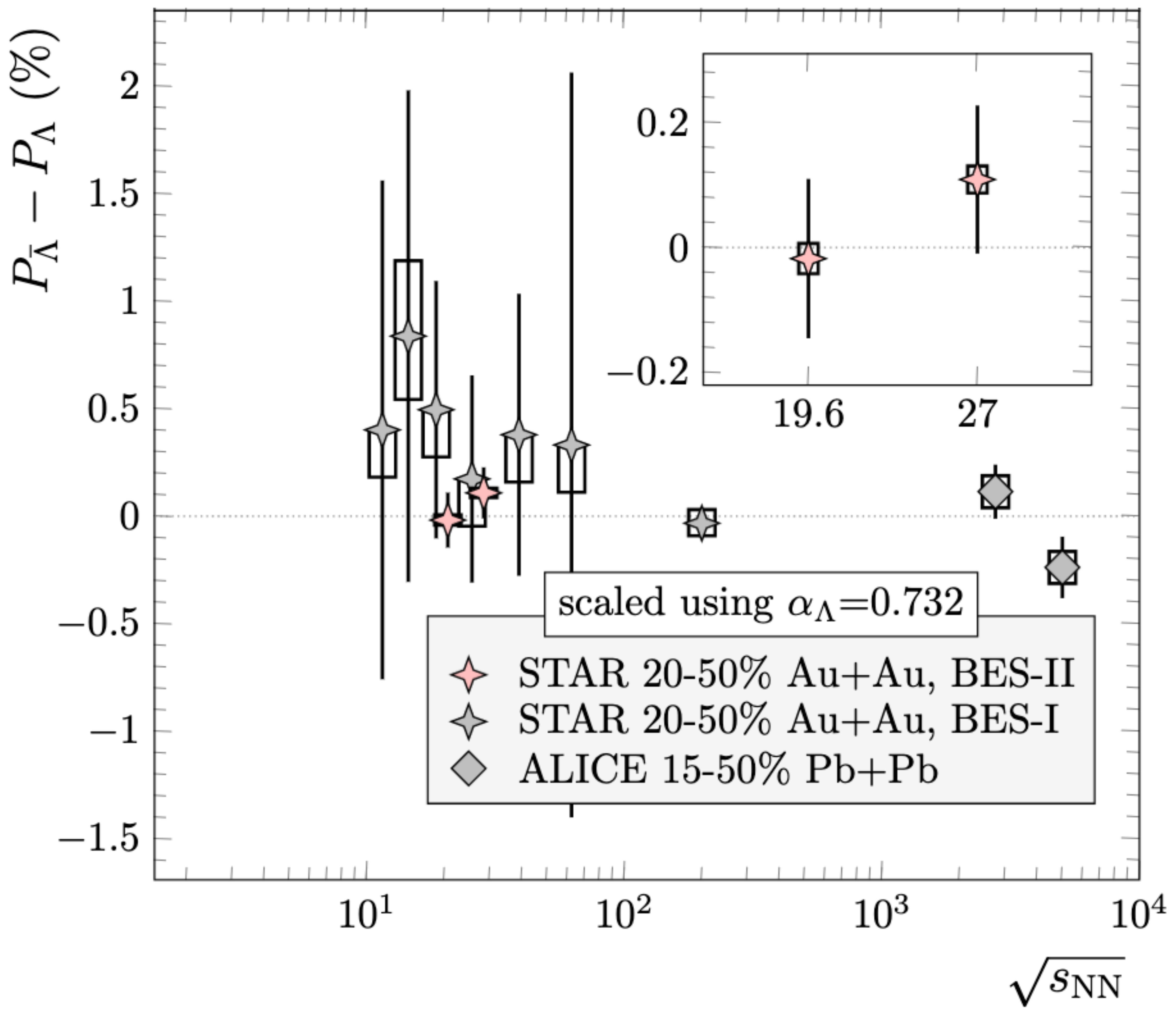
10x stats still to come



- Spin-avg for f_0 & d_0 p- system
- $f_0 = 2.32^{+0.12}_{-0.11}$ fm, $d_0 = 3.54^{+2.7}_{-1.3}$ fm
- Separate two spin states in d-Λ
- $f_0(D) = -20^{+3}_{-3}$ fm, $d_0(D) = 3^{+2}_{-1}$ fm
- $f_0(Q) = 16^{+2}_{-1}$ fm, $d_0(Q) = 2^{+1}_{-1}$ fm

Detecting the Initial EM Field

Splitting of hyperon polarization



Late stage magnetic field should cause splitting in (anti)Λ polarization

No splitting observed over wide range of beam energies

None in Isobar data either

At 95% confidence level late stage magnetic field (Initial field 10^{14}-10^{16} T)

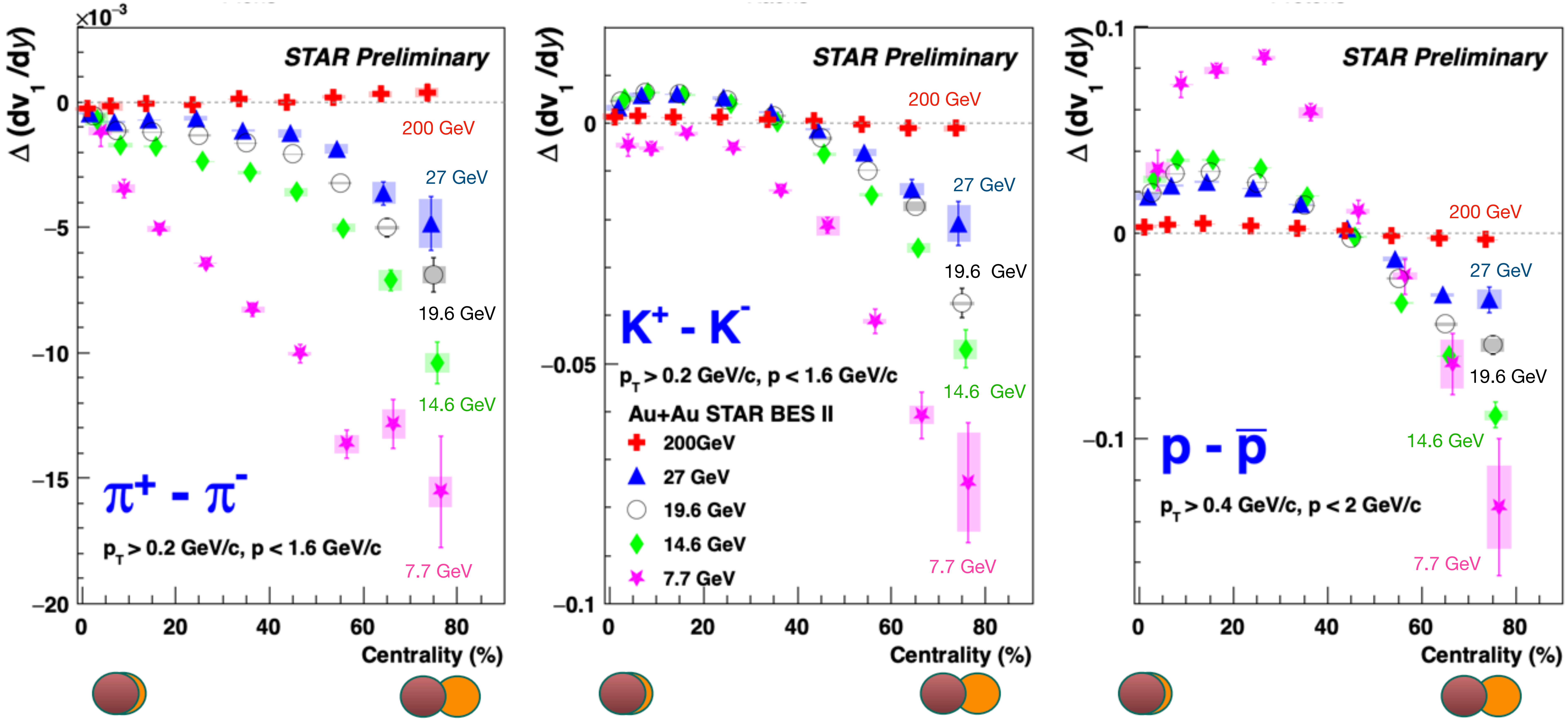
B(19.6 GeV) < 9.4×10^{12} T

B (27 GeV)< $1.4\text{x}10^{13}$ T

Does magnetic field die away too quickly?
Can we probe at earlier time?

X. Gou : STAR QM Talk

Directed flow difference



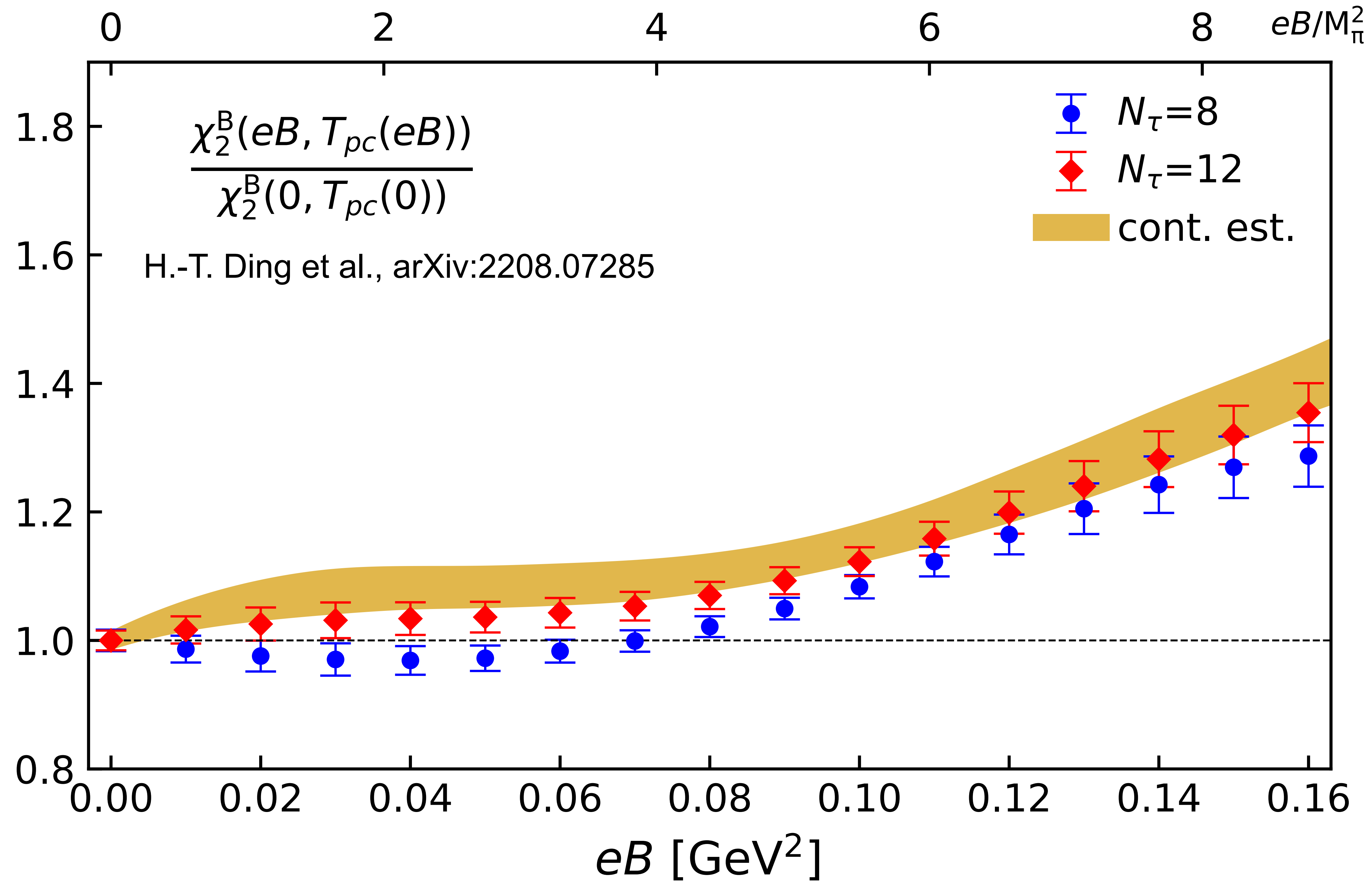
Different effects can/do dominate in different regimes - Have precision to hopefully disentangle

Difference in particle-anti-particle slope:

- Increases with decreasing centrality - Higher B-field
- Increases with decreasing beam energy - Increasing crossing time
- Has species dependence - transported vs created quarks

Net-proton cummulants at LHC

Lattice calculations suggest susceptibilities sensitive to initial EM field



I. Fokin: QM Poster

Net-proton cummulants at LHC

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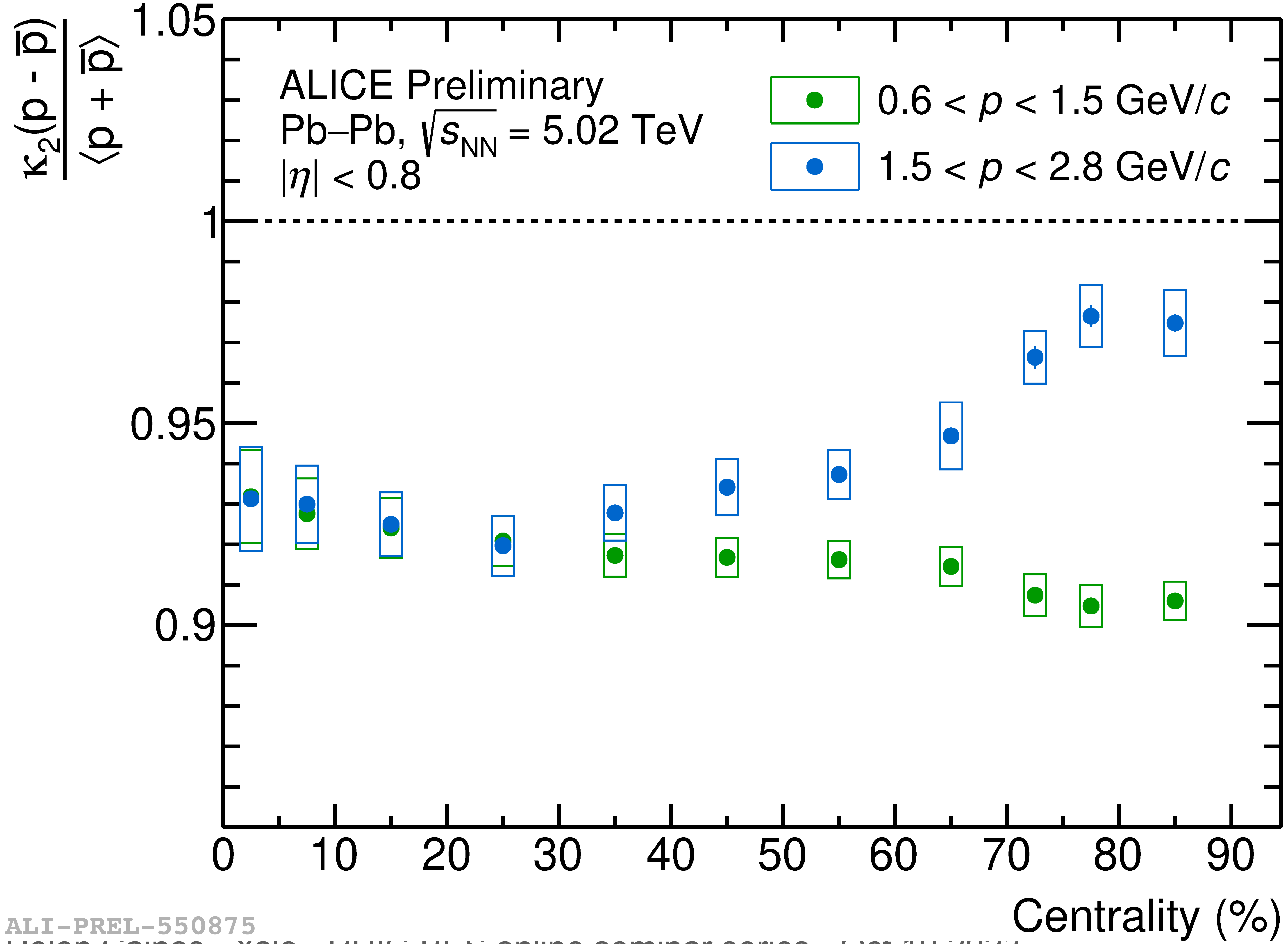
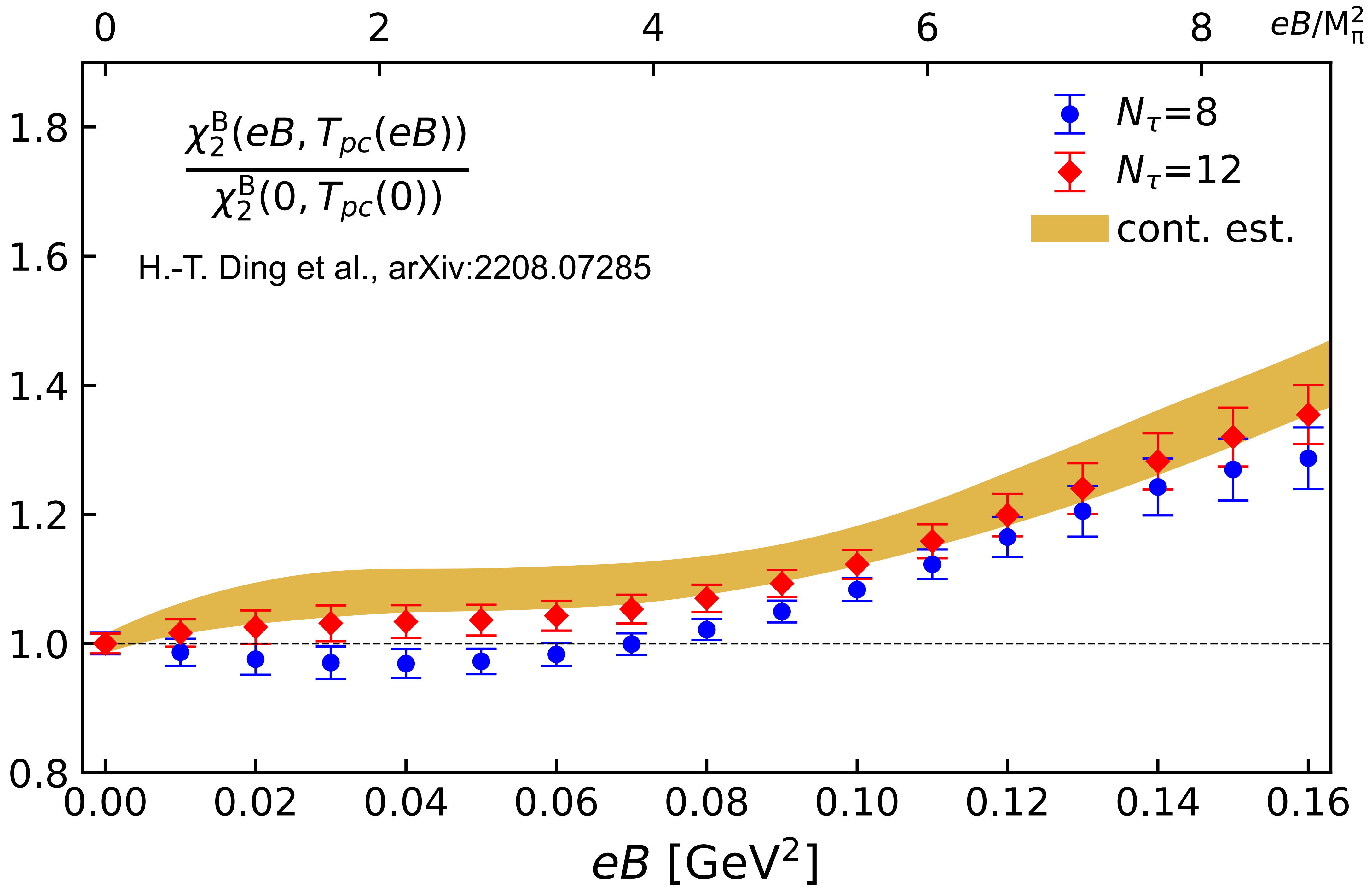




First measurement above 2 GeV/c

Fluctuation in high p range increases in peripheral events - B-field largest

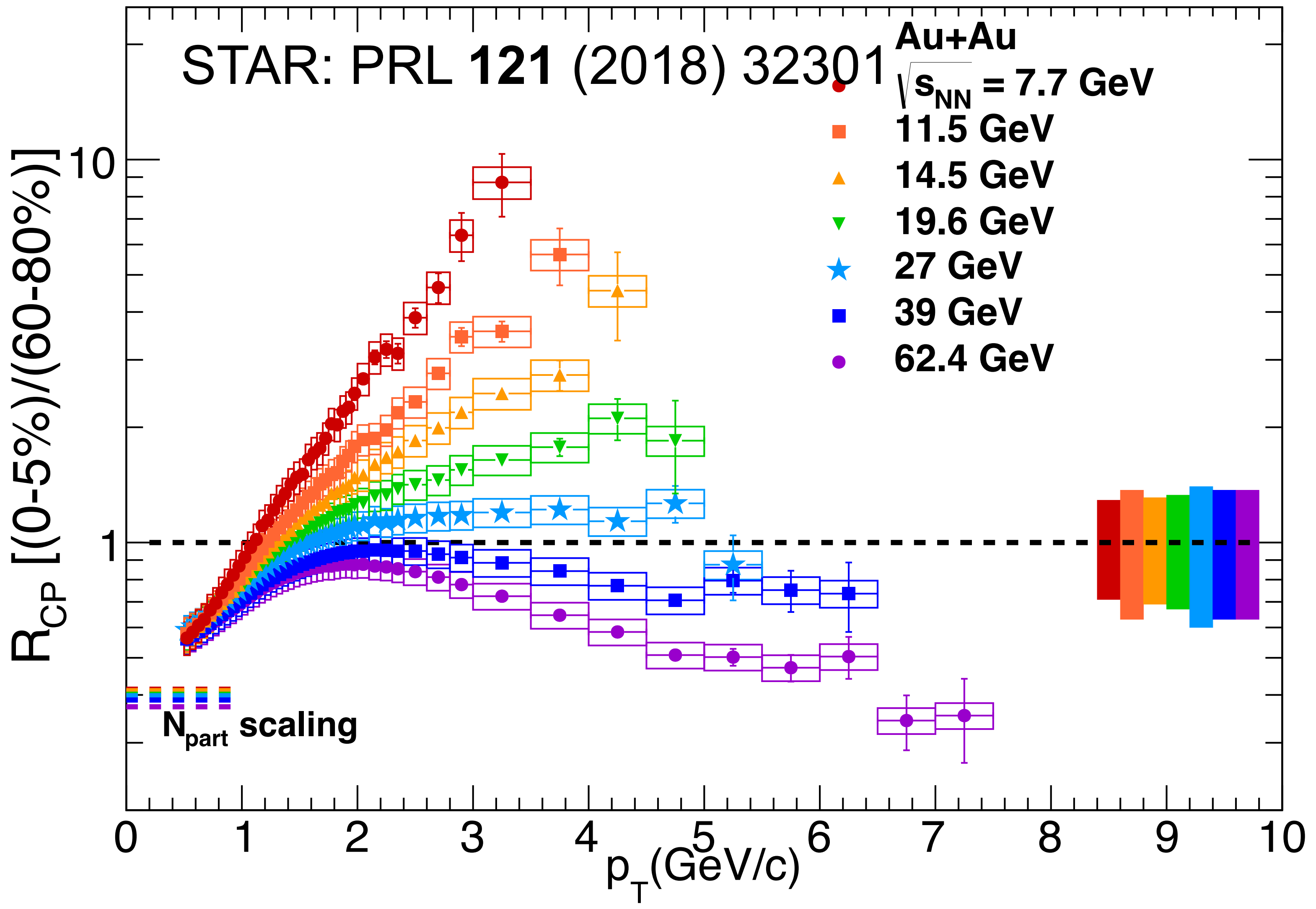
More discussion with theory and measurement in pp needed

Can this be done at RHIC?

I. Fokin: QM Poster

Understanding the Nature of Parton Energy Loss to QGP

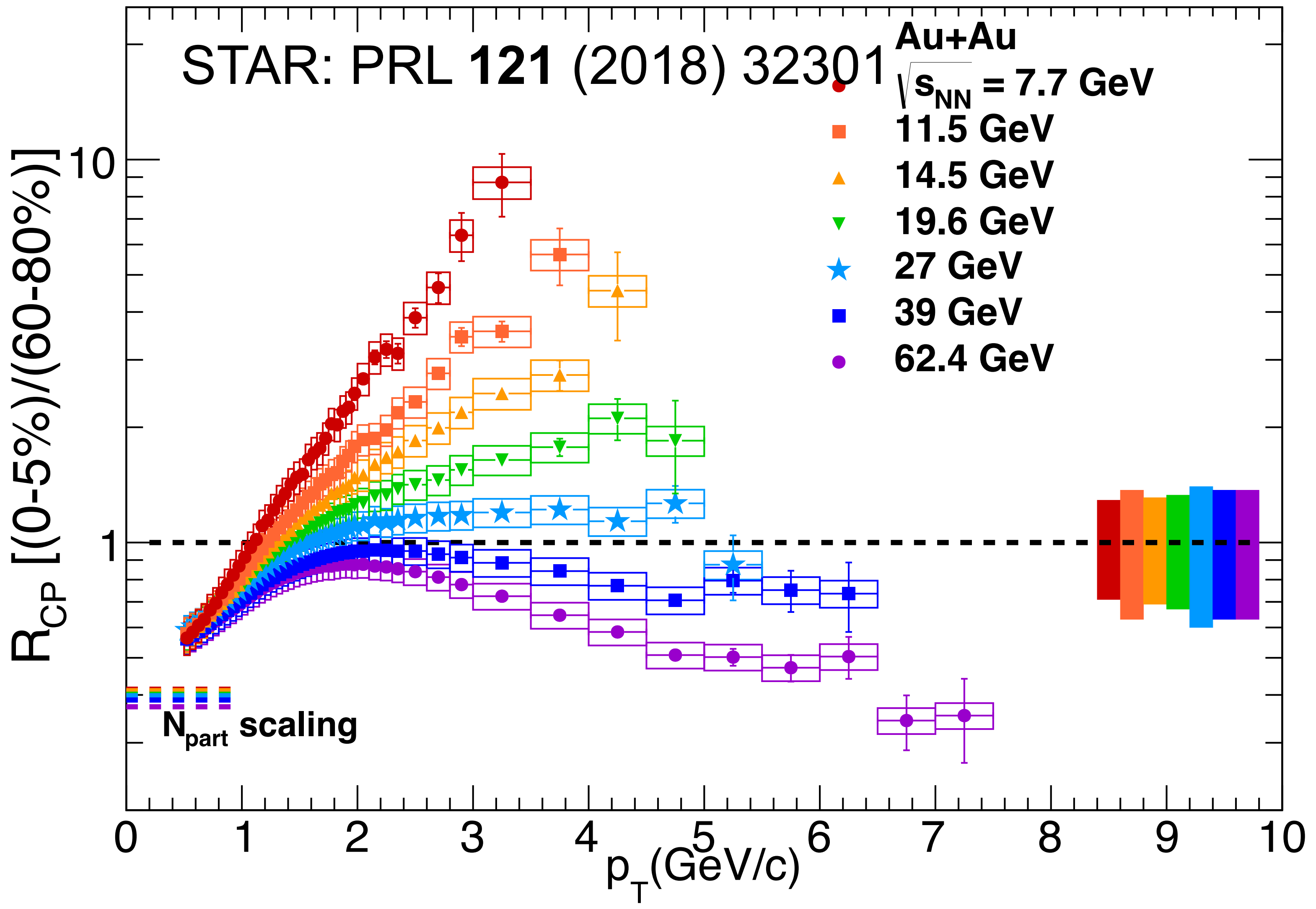
Nuclear modification of light species

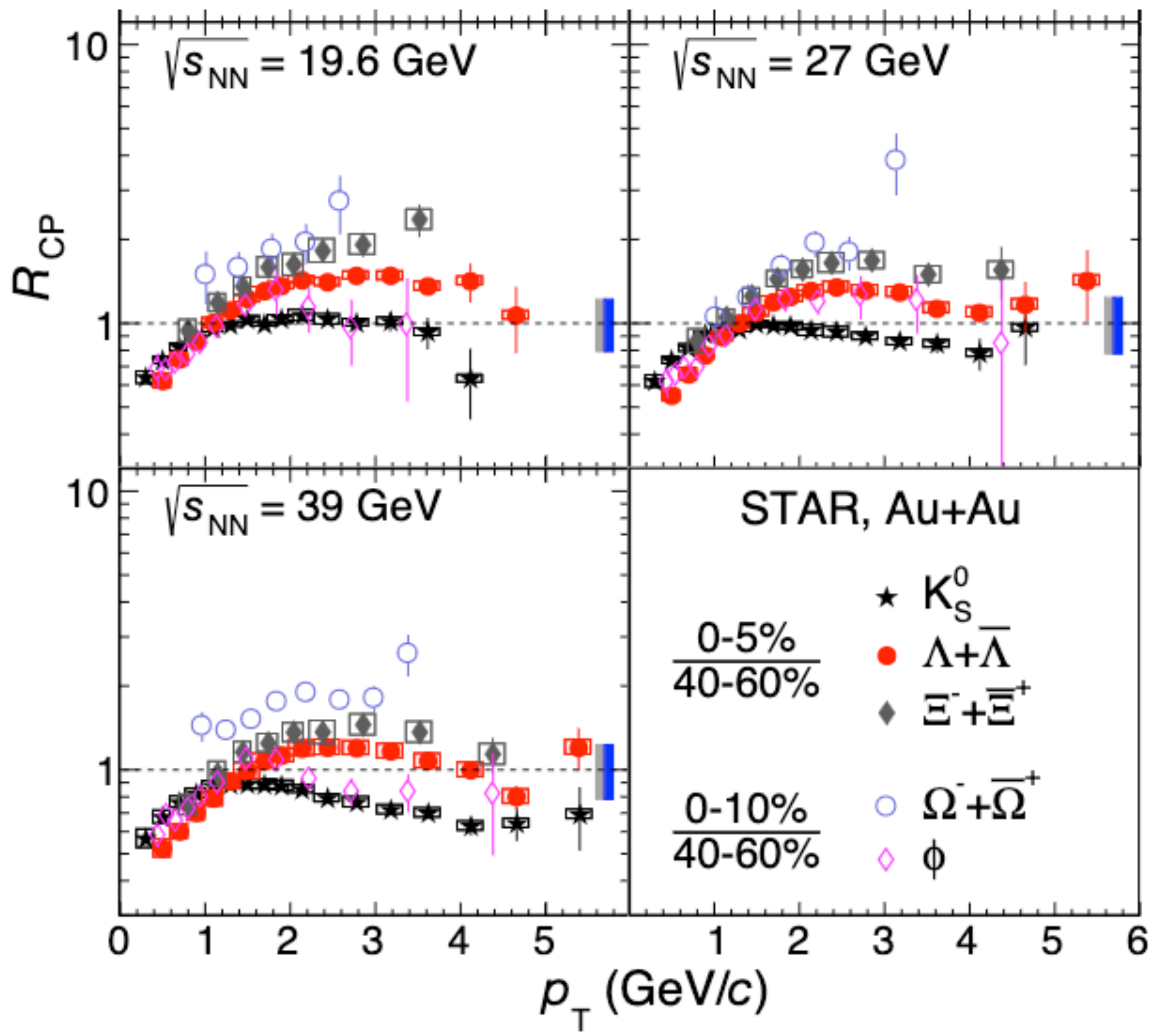


For $\sqrt{s_{NN}}$ > 27 GeV suppression observed

Y. Fang: STAR QM Talk, W. Yuan STAR QM Poster

Nuclear modification of light species



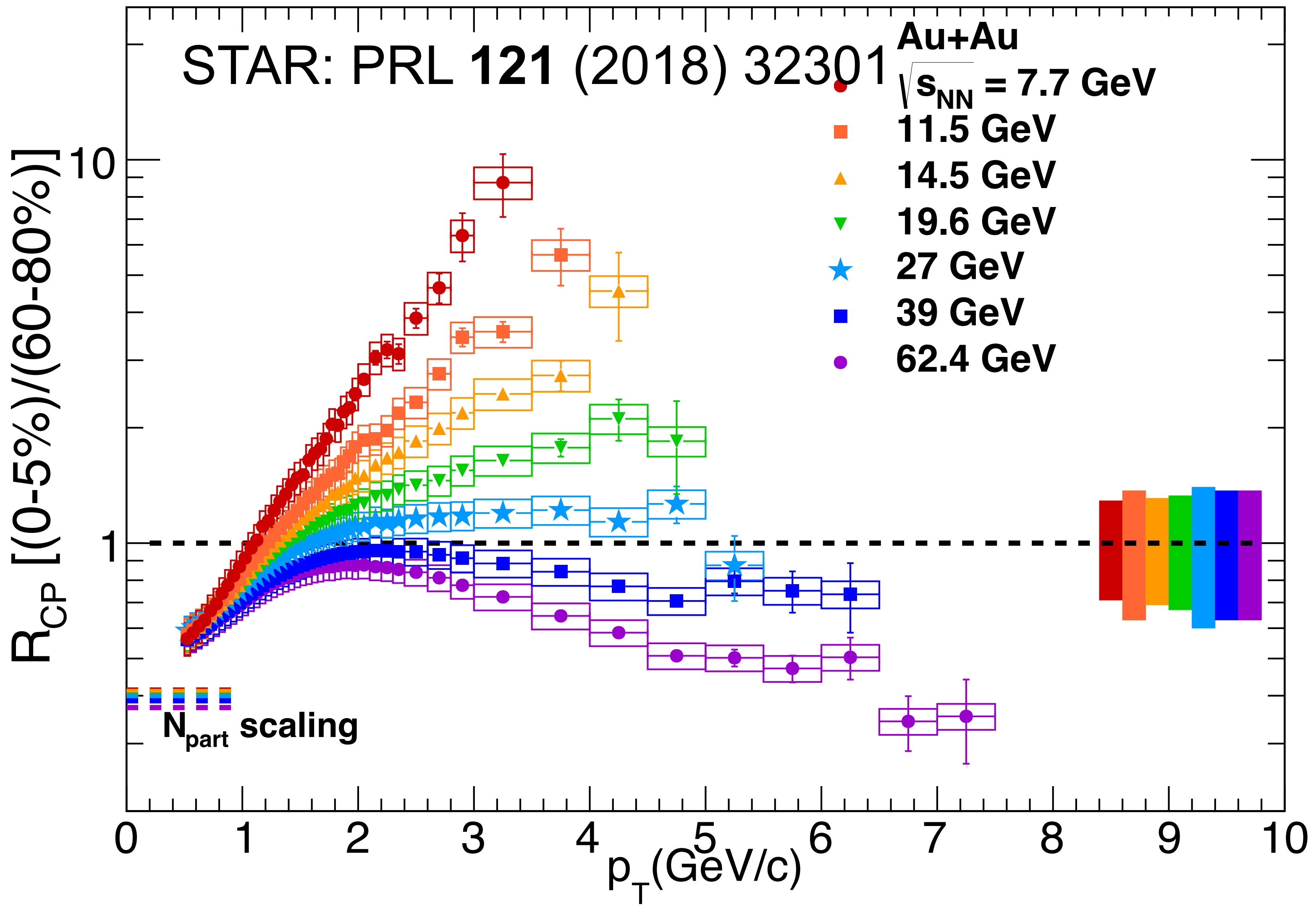


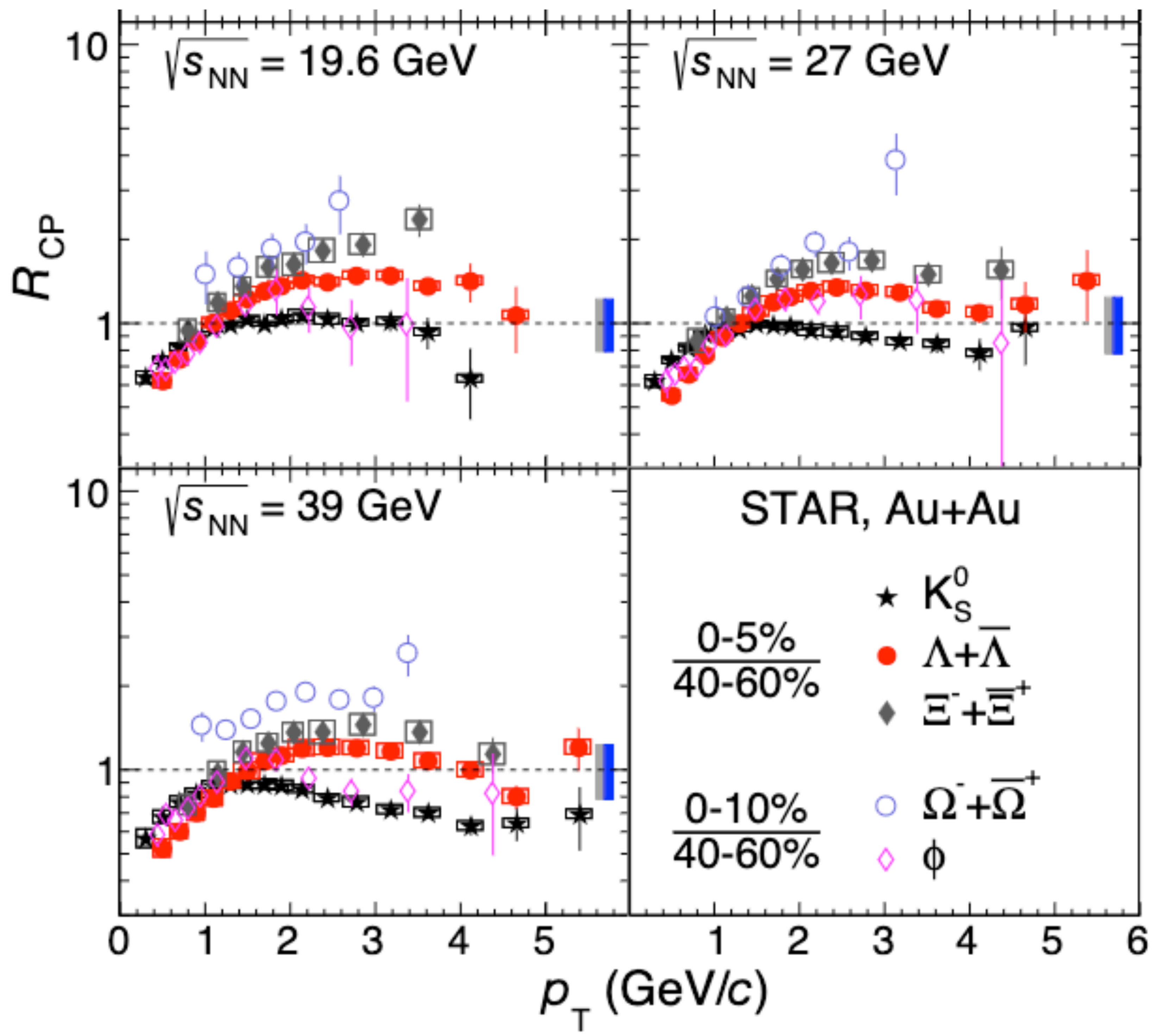
For $\sqrt{s_{NN}}$ > 27 GeV suppression observed

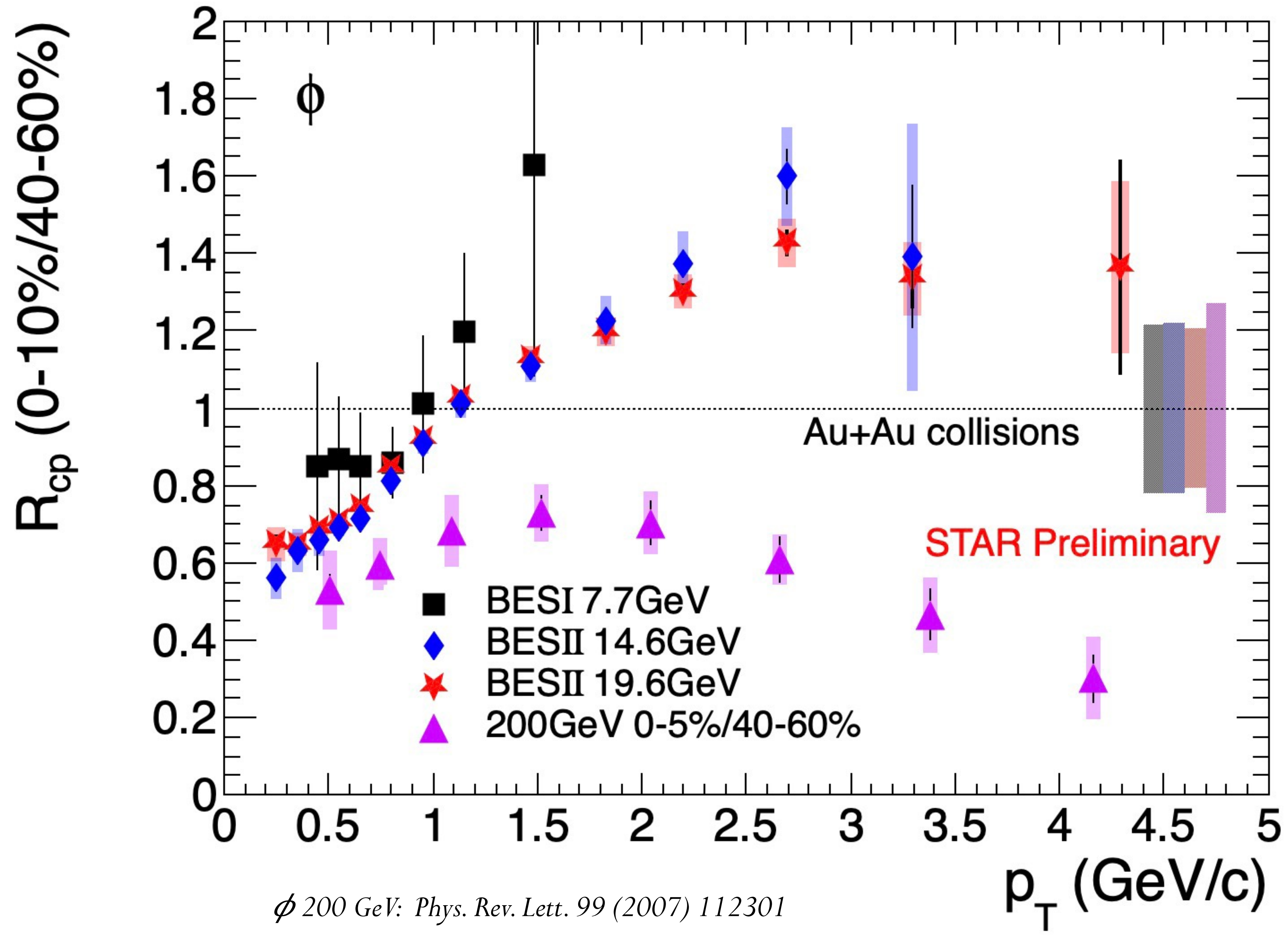
Differences for baryons and mesons

Y. Fang: STAR QM Talk, W. Yuan STAR QM Poster

Nuclear modification of light species







For $\sqrt{s_{NN}}$ > 27 GeV suppression observed

Differences for baryons and mesons

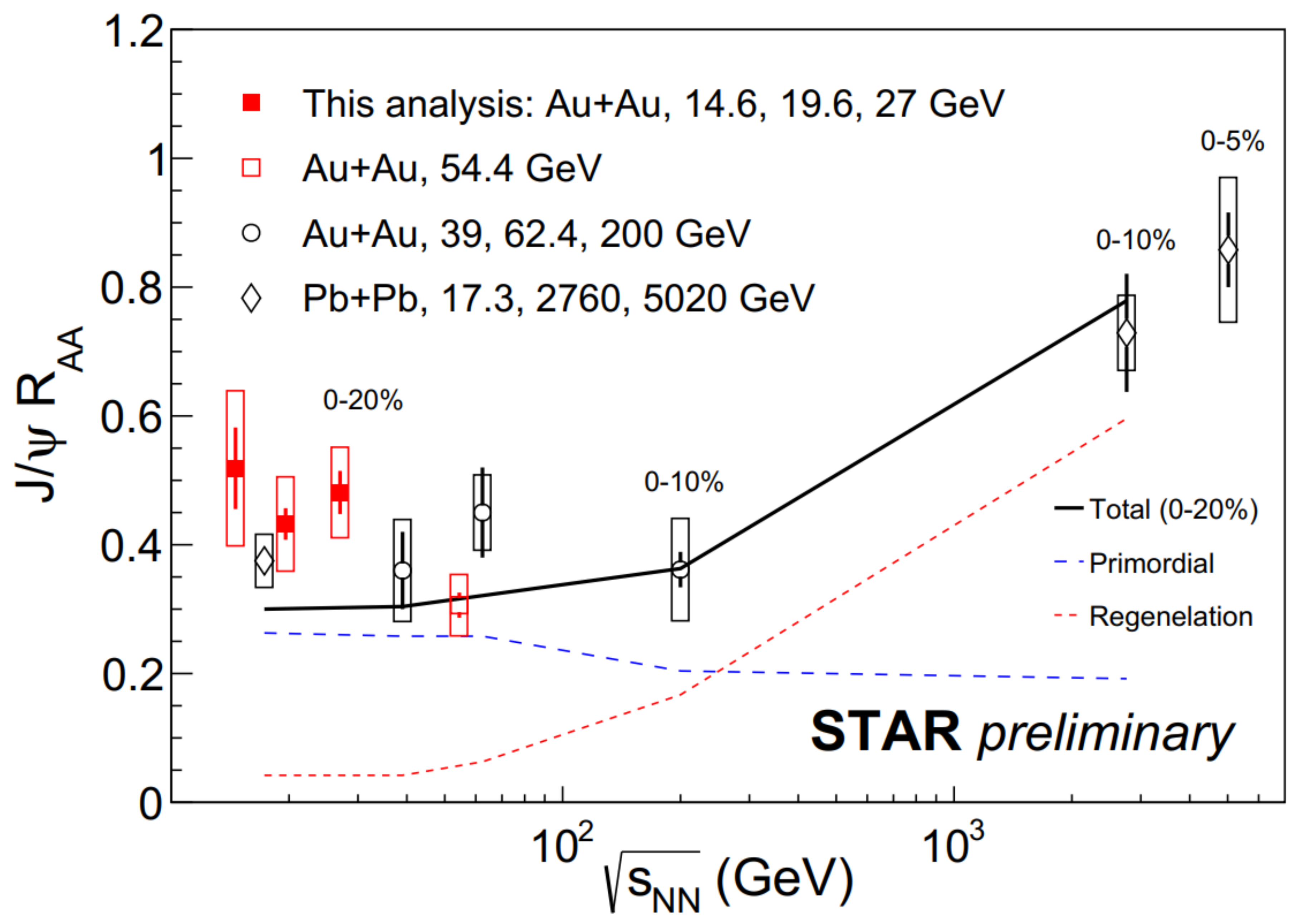
New ϕ data indicate mass not baryon/meson effect?

Is flow hiding E_{loss}?

How to disentangle?

Y. Fang: STAR QM Talk, W. Yuan STAR QM Poster

Medium modification of J/ψ



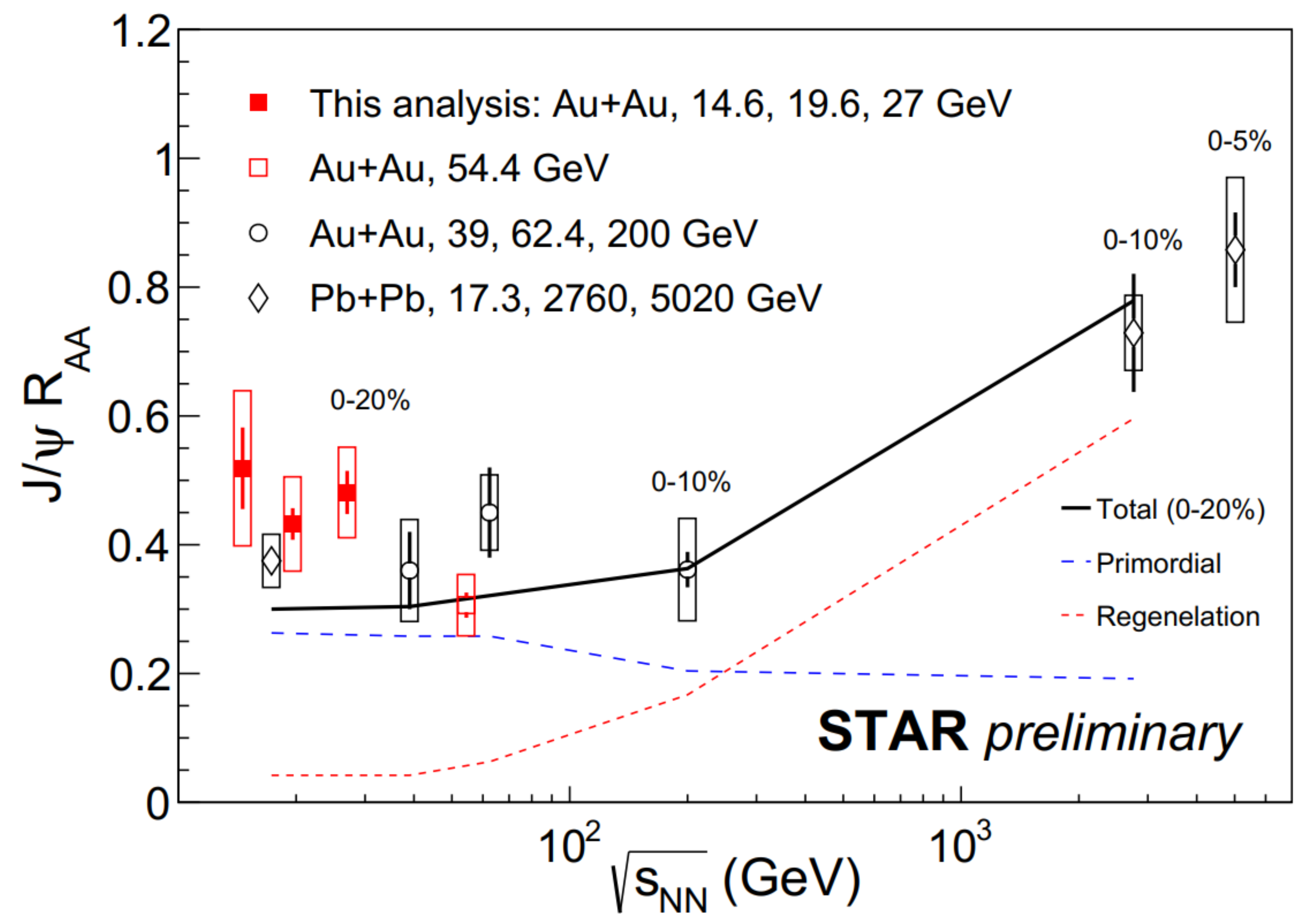
New data at 14.6, 19.6 and 27:

Confirm no significant energy dependence at RHIC energies

Interplay of dissociation, regeneration, CNM, spectra shape

Y. Wang: STAR QM Talk, W. Zhang STAR QM Poster

Medium modification of J/ψ

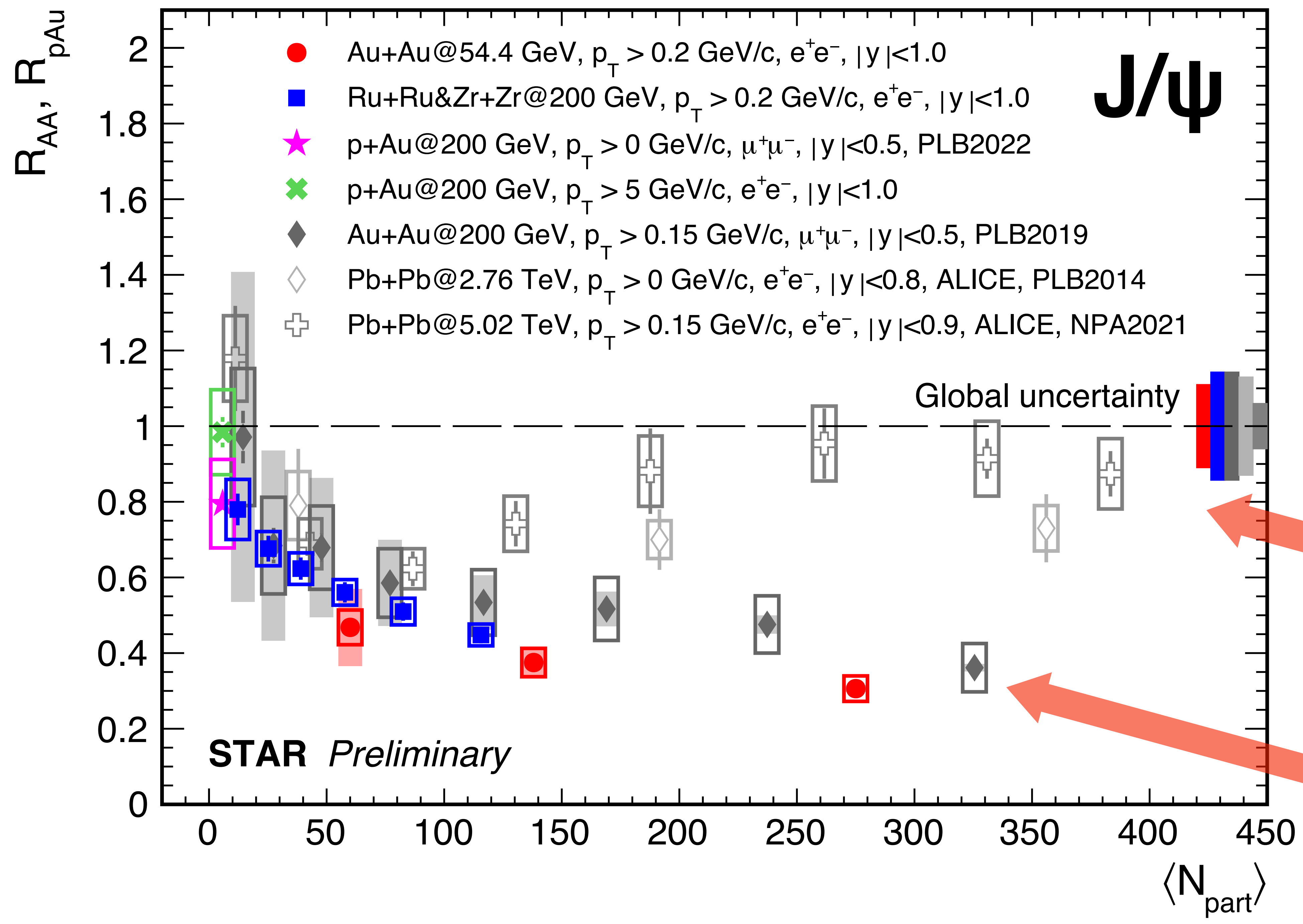


New data at 14.6, 19.6 and 27:

Confirm no significant energy dependence at RHIC energies

Interplay of dissociation, regeneration, CNM, spectra shape

Suppression at RHIC that scales with N_{part}



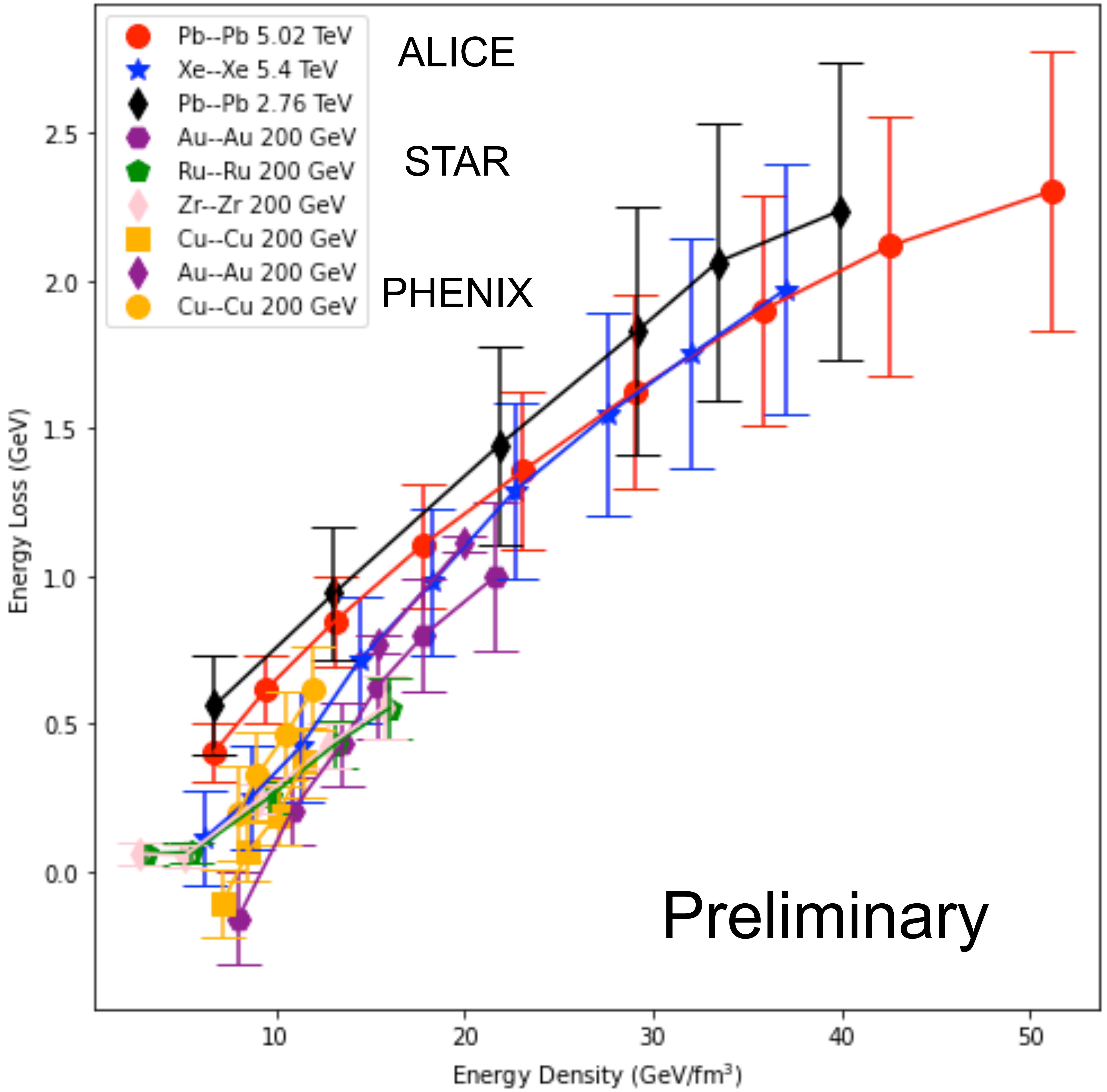
LHC

RHIC

More suppression at RHIC due to much less regeneration in the medium

Y. Wang: STAR QM Talk, W. Zhang STAR QM Poster

Energy loss vs energy density



E_{Loss} from: shift of p_T spectra

Approximate energy density from:

$dN_{ch}/d\eta$ —> dS/dy —> $s_f\,\tau_f = dS/dy/A_T = s_{init}\,\tau_{init}$

$\varepsilon_{init} = 3/4\ s_{init}\,T_{int}$

Given number of approximations reasonable correlation between E_{Loss} and ε_{init} over different species and collision energies
Down to what energy does this work?

Link between entropy and charged particle density very sensitive to viscosity

More careful calculation needed

More details on estimates see 2308.05743 J. Harris & B. Muller

Summary

Already a wealth of results available from across whole BES-II datasets

- Much more to come!

As large amount of data becomes available need to perform Bayesian/global analyses of all results to fully exploit full power of BES-II

- JETSCAPE working to include BES physics, building off of work by BEST and others

Future data from CBM/FAIR, HADES, SHINE

- NA60+ and Fixed target at EIC?

Summary

Already a wealth of results available from across whole BES-II datasets

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Future data from CBM/FAIR, HADES, SHINE

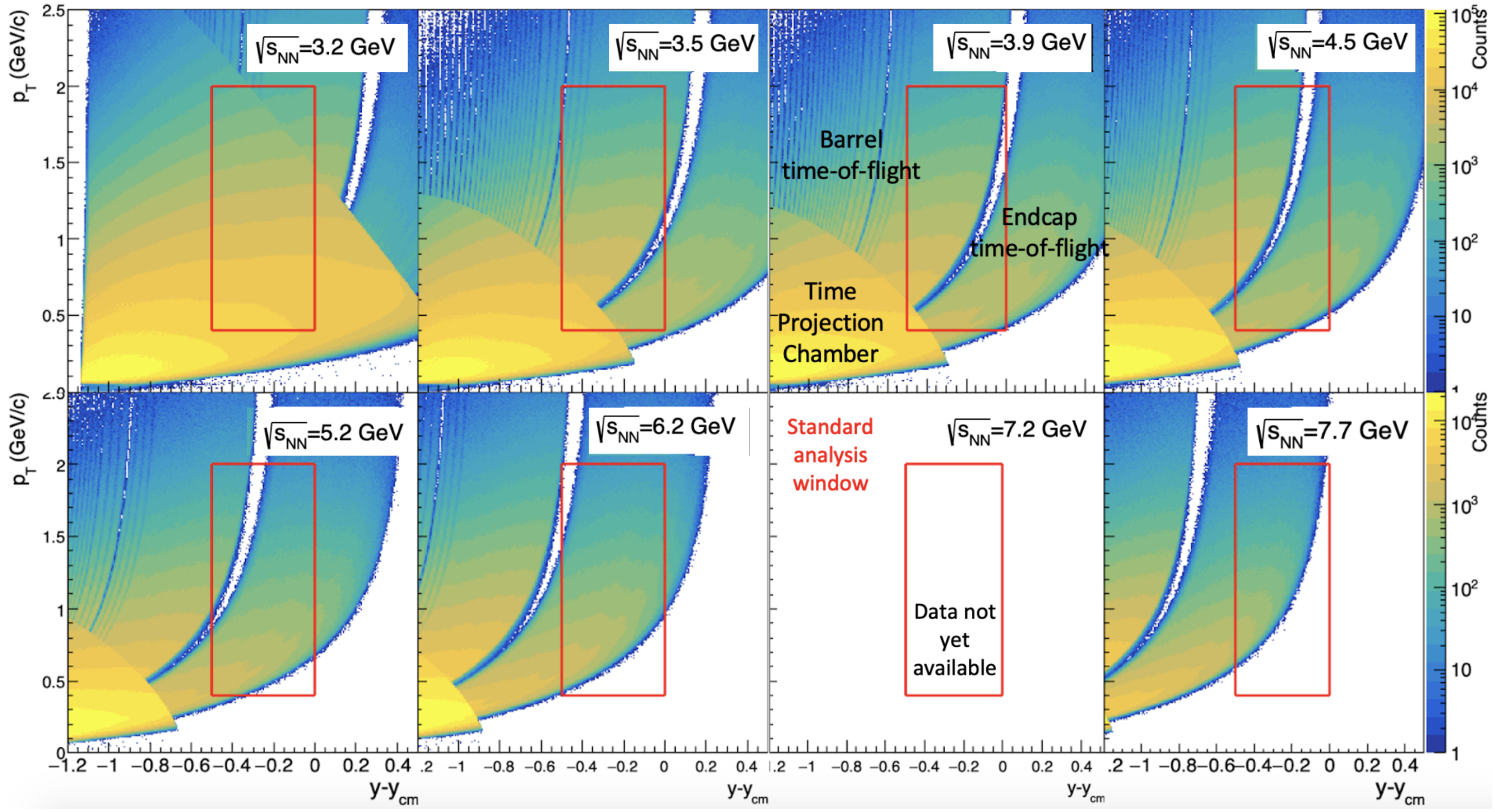
NA60+ and Fixed target at EIC?

Net-proton fluctuations coming soon
But BES-II physics **MUCH** more than that

BACK Up

$\sqrt{s_{NN}}$ (GeV)	Beam Energy (GeV/nucleon)	Collider or Fixed Target	$y_{center\ of\ mass}$	μ_B (MeV)	Run Time (days)	No. Events Collected (Request)	Date Collected
200	100	C	0	25	2.0	138 M (140 M)	Run-19
27	13.5	C	0	156	24	555 M (700 M)	Run-18
19.6	9.8	C	0	206	36	582 M (400 M)	Run-19
17.3	8.65	C	0	230	14	256 M (250 M)	Run-21
14.6	7.3	C	0	262	60	324 M (310 M)	Run-19
13.7	100	FXT	2.69	276	0.5	52 M (50 M)	Run-21
11.5	5.75	C	0	316	54	235 M (230 M)	Run-20
11.5	70	FXT	2.51	316	0.5	50 M (50 M)	Run-21
9.2	4.59	C	0	372	102	162 M (160 M)	Run-20+20b
9.2	44.5	FXT	2.28	372	0.5	50 M (50 M)	Run-21
7.7	3.85	C	0	420	90	100 M (100 M)	Run-21
7.7	31.2	FXT	2.10	420	0.5+1.0+ scattered	50 M + 112 M + 100 M (100 M)	Run-19+20+21
7.2	26.5	FXT	2.02	443	2+Parasitic with CEC	155 M + 317 M	Run-18+20
6.2	19.5	FXT	1.87	487	1.4	118 M (100 M)	Run-20
5.2	13.5	FXT	1.68	541	1.0	103 M (100 M)	Run-20
4.5	9.8	FXT	1.52	589	0.9	108 M (100 M)	Run-20
3.9	7.3	FXT	1.37	633	1.1	117 M (100 M)	Run-20
3.5	5.75	FXT	1.25	666	0.9	116 M (100 M)	Run-20
3.2	4.59	FXT	1.13	699	2.0	200 M (200 M)	Run-19
3.0	3.85	FXT	1.05	721	4.6	259 M -> 2B(100 M ->	Run-18+21

FXT proton acceptance



Red box: Standard analysis window

$0.4 < p_T < 2$ GeV/c

$-0.5 < y - y_{cm} < 0$

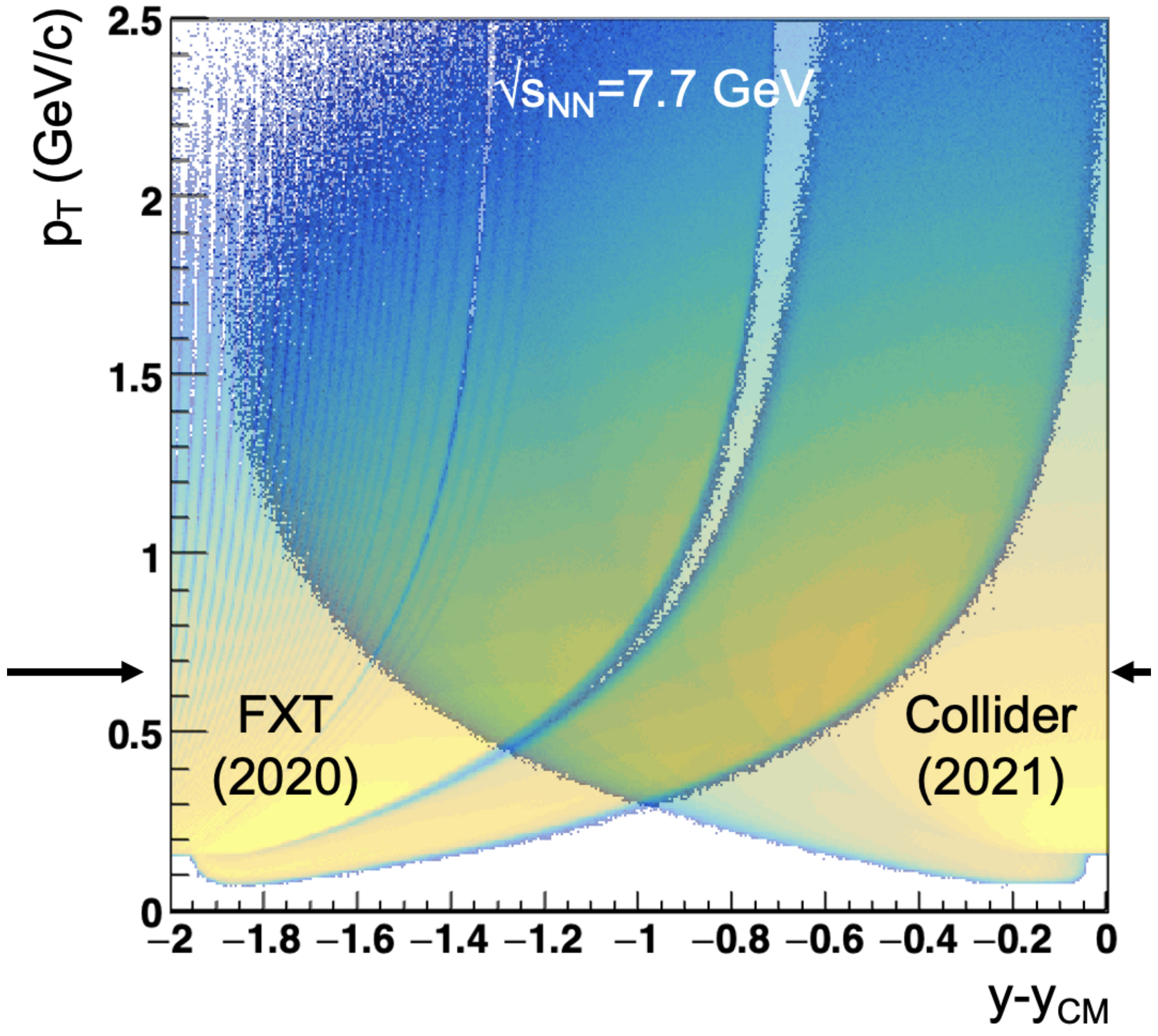
Near-full acceptance to 4.5 GeV

Top energies need to move away from mid-rapidi

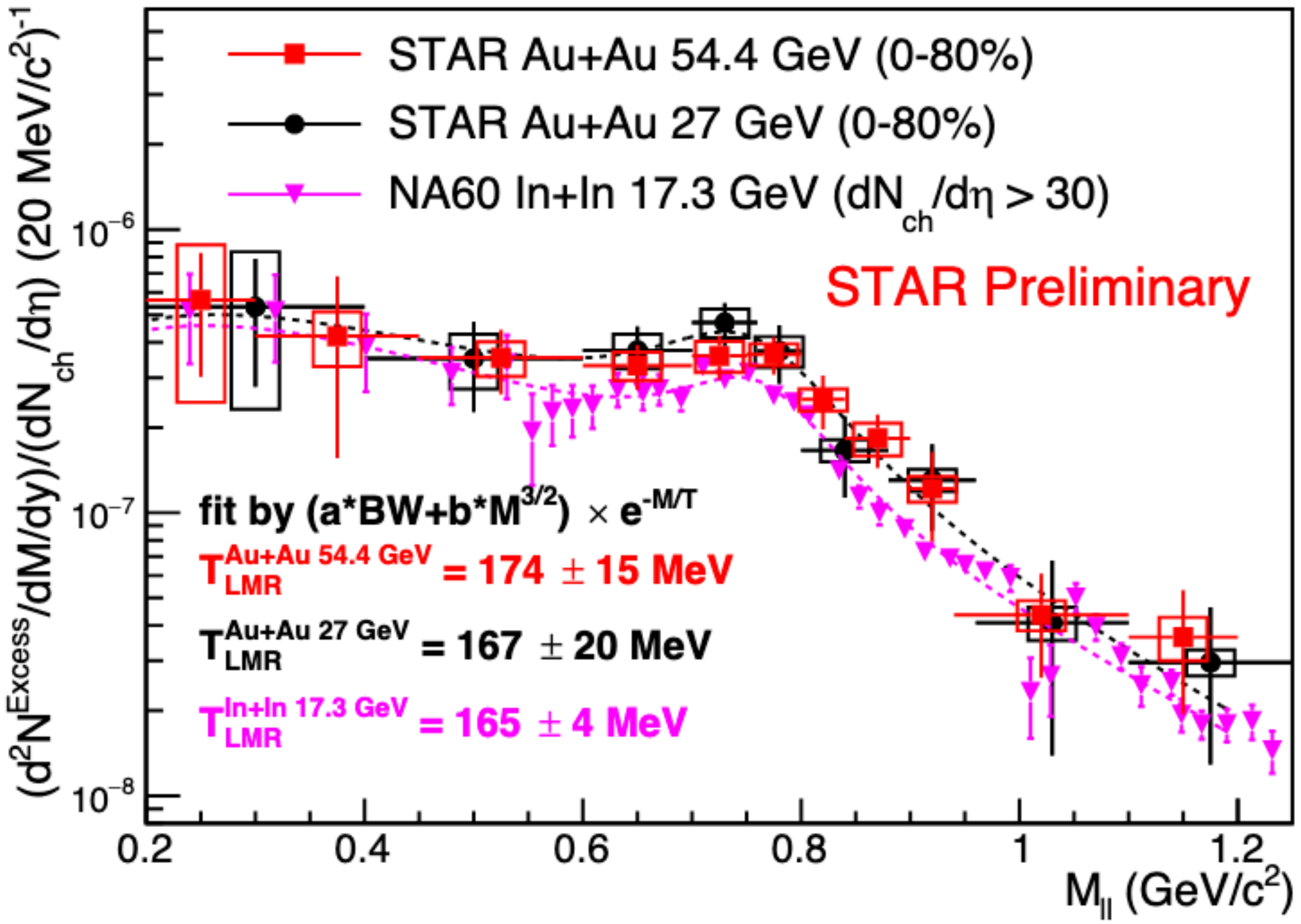
7.7 taken in both FXT and collider mode

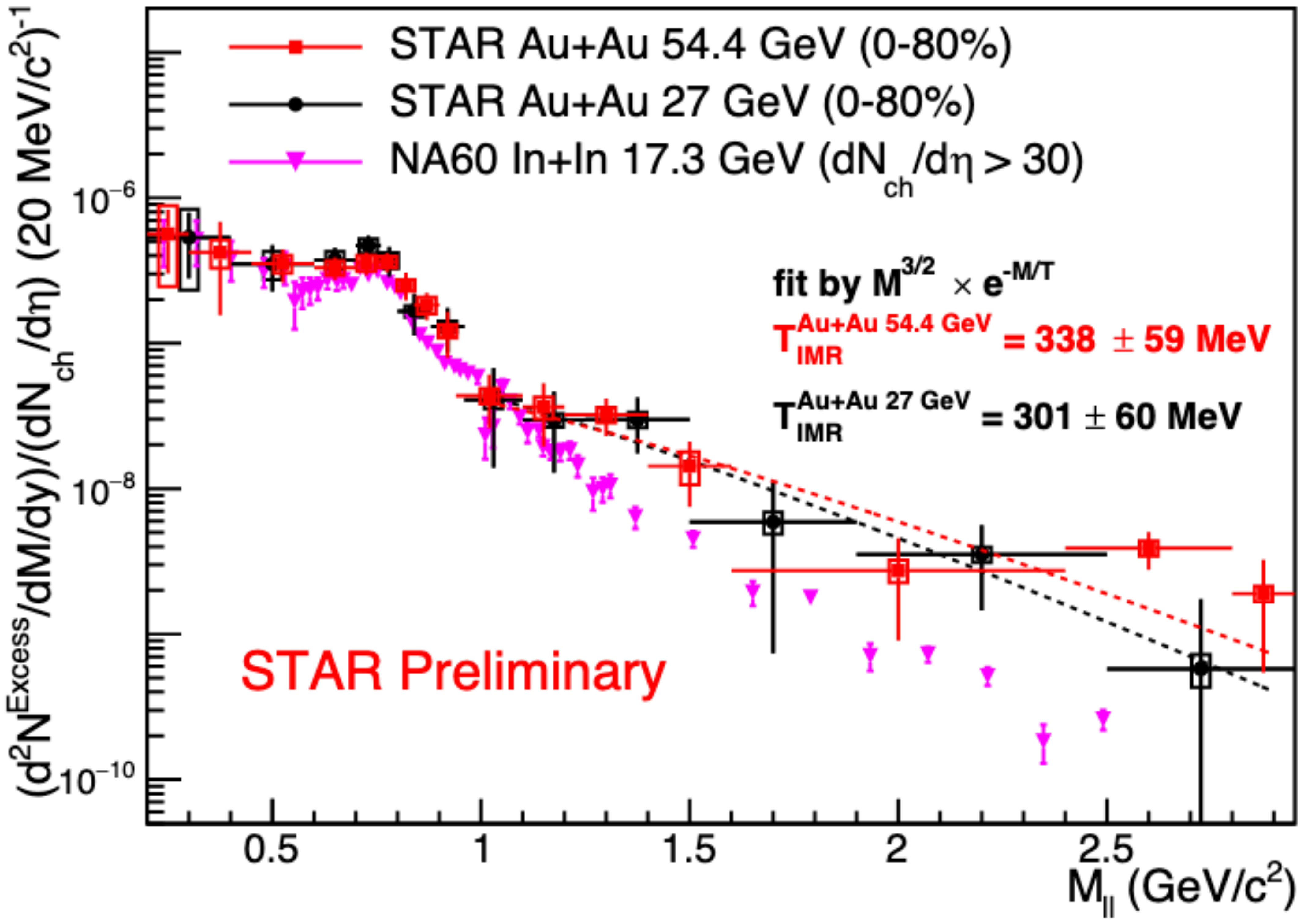
Good overlap in acceptance

Critical for methodology comparison



Extracting the temperatures





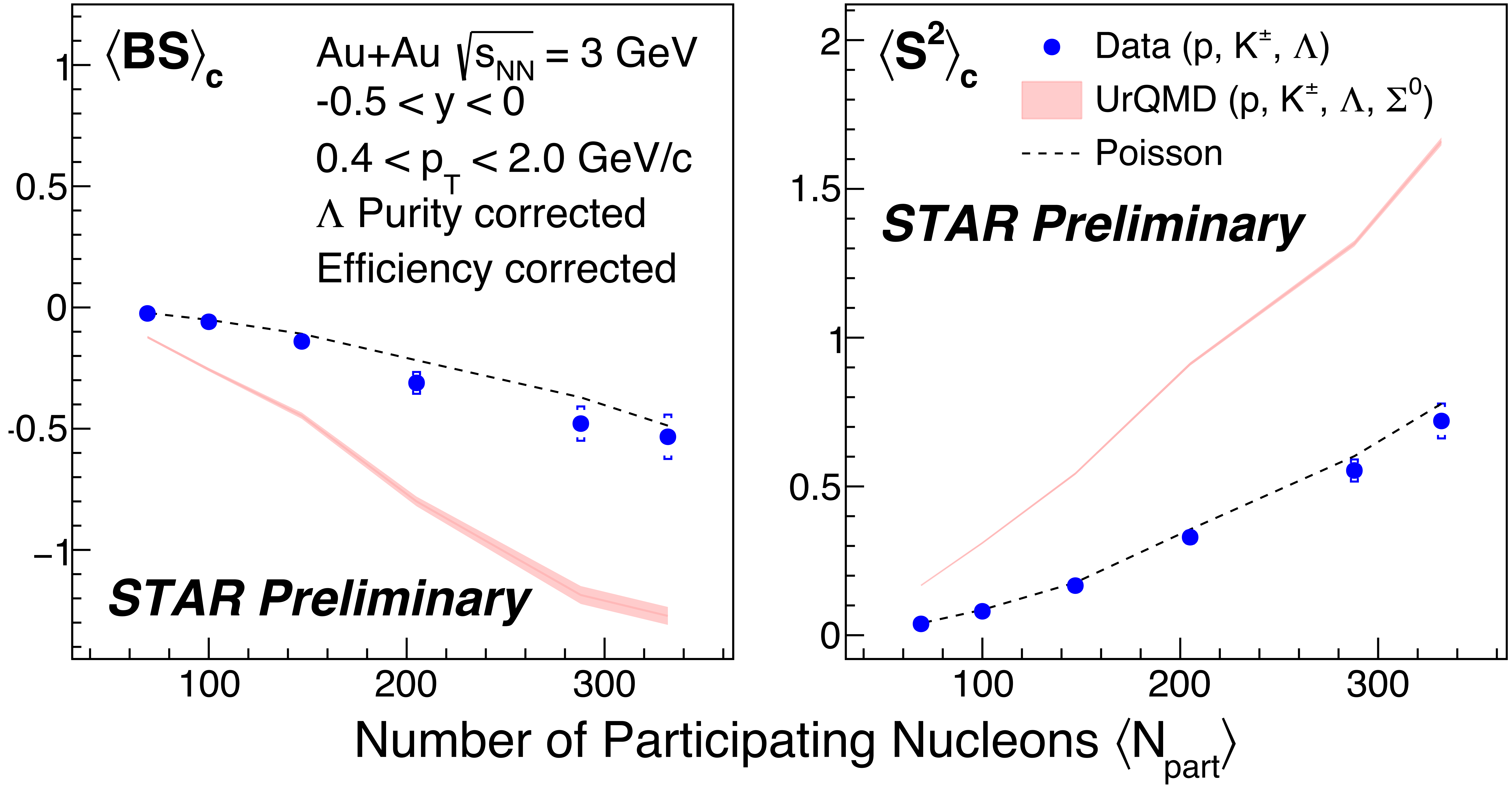
Low mass range: Similar mass spectrum, similar T,
in-medium ρ produced and broadened in similar heat bath from $\sqrt{s_{NN}}$ =17-56 GeV

Intermediate mass range: T($\sqrt{s_{NN}}$ =54.6) = 338± 59 MeV ~ T($\sqrt{s_{NN}}$ =27) = 301±60 MeV
T($\sqrt{s_{NN}}$ =17) ~ 246 MeV

Clearly create QGP at these energies

Something different starts to happen below 20 GeV

Baryon-strangeness correlations



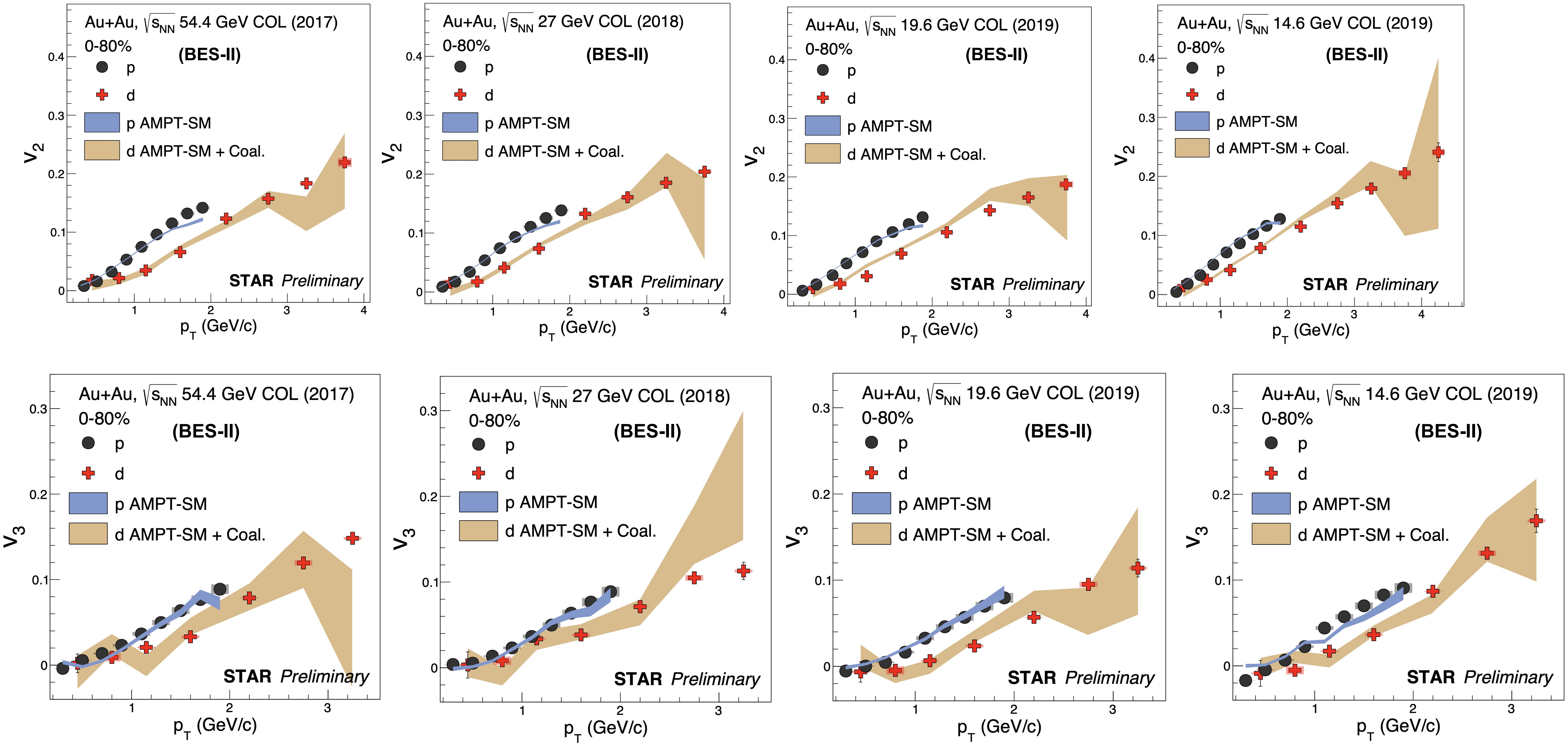
- The negative $\langle BS \rangle_c$ in all centralities indicates negative correlation between baryon and strangeness.

Y. Zhang: STAR QM Poster

v_2 light nuclei

1) Light-Nuclei elliptic flow v_2 measurements in 10-40% mid-central Au+Au Collisions at $\sqrt{s_{NN}}$= 3.0, 3.2, 3.5, 3.9 GeV
2) Mid-rapidity elliptic flow results indicate an out-of-plane expansion ($v_2 < 0$) at the lowest collision energy, whereas in-plane expansions ($v_2 > 0$) are evident at higher collision energies

Flow of light nuclei from coalescence - AMPT



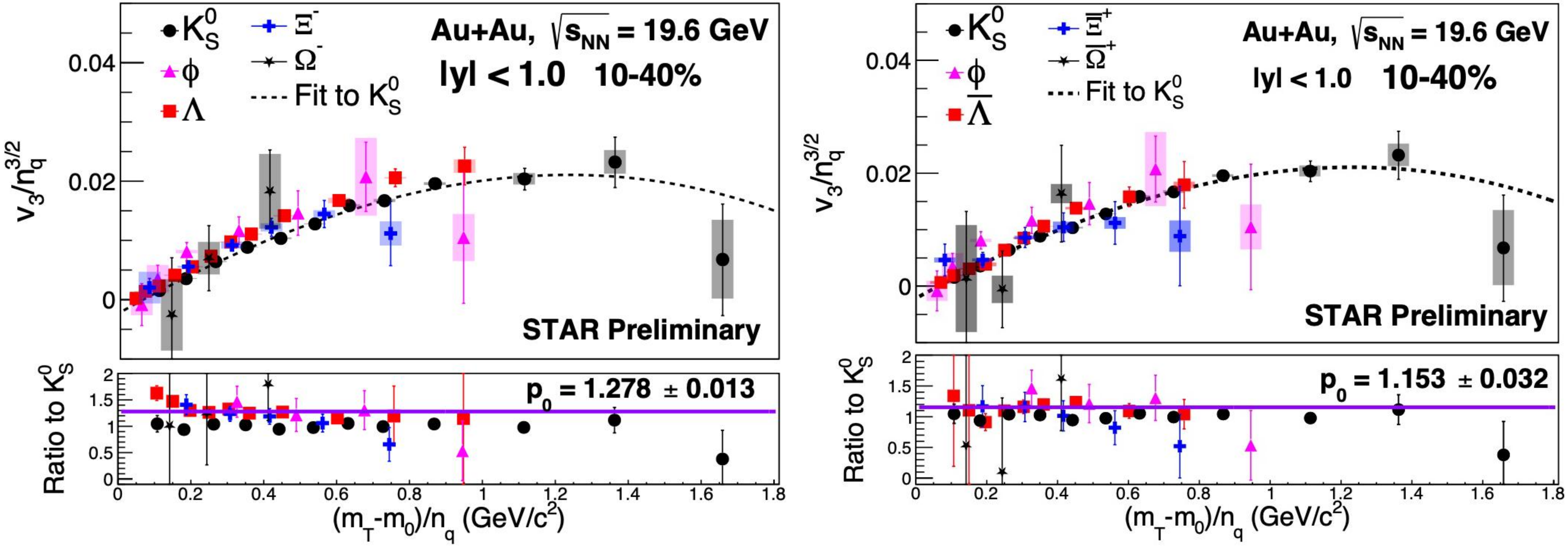
R. Sharma: STAR QM Talks

Flow of light nuclei from coalescence

➢ $v_3(p_T)$ of *d* shows a good agreement with mass number scaling within ~10%

NCQ v_3

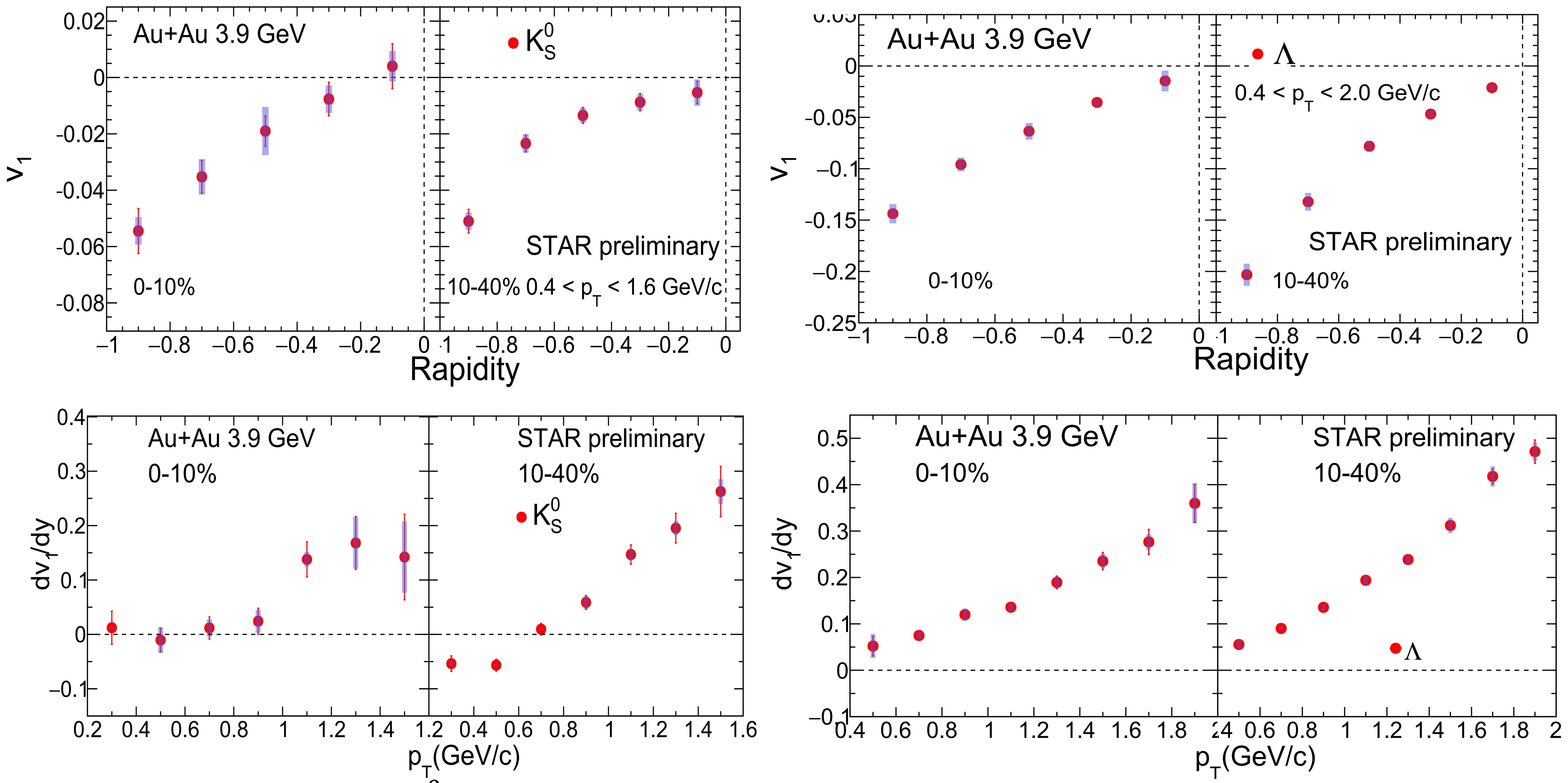
BES II



- Strange and multi-strange v_3 studied systematically in Au+Au collisions at BES-II energy $\sqrt{s_{NN}} = 19.6$ GeV.
- NCQ scaling of v_3 holds better for anti-particles (~15%) than the particles (~30%).
- Observation of NCQ scaling of identified hadron v_2
  → Indicate partontic collecitivity

v_1 and v_2 flow of strangeness 3.9

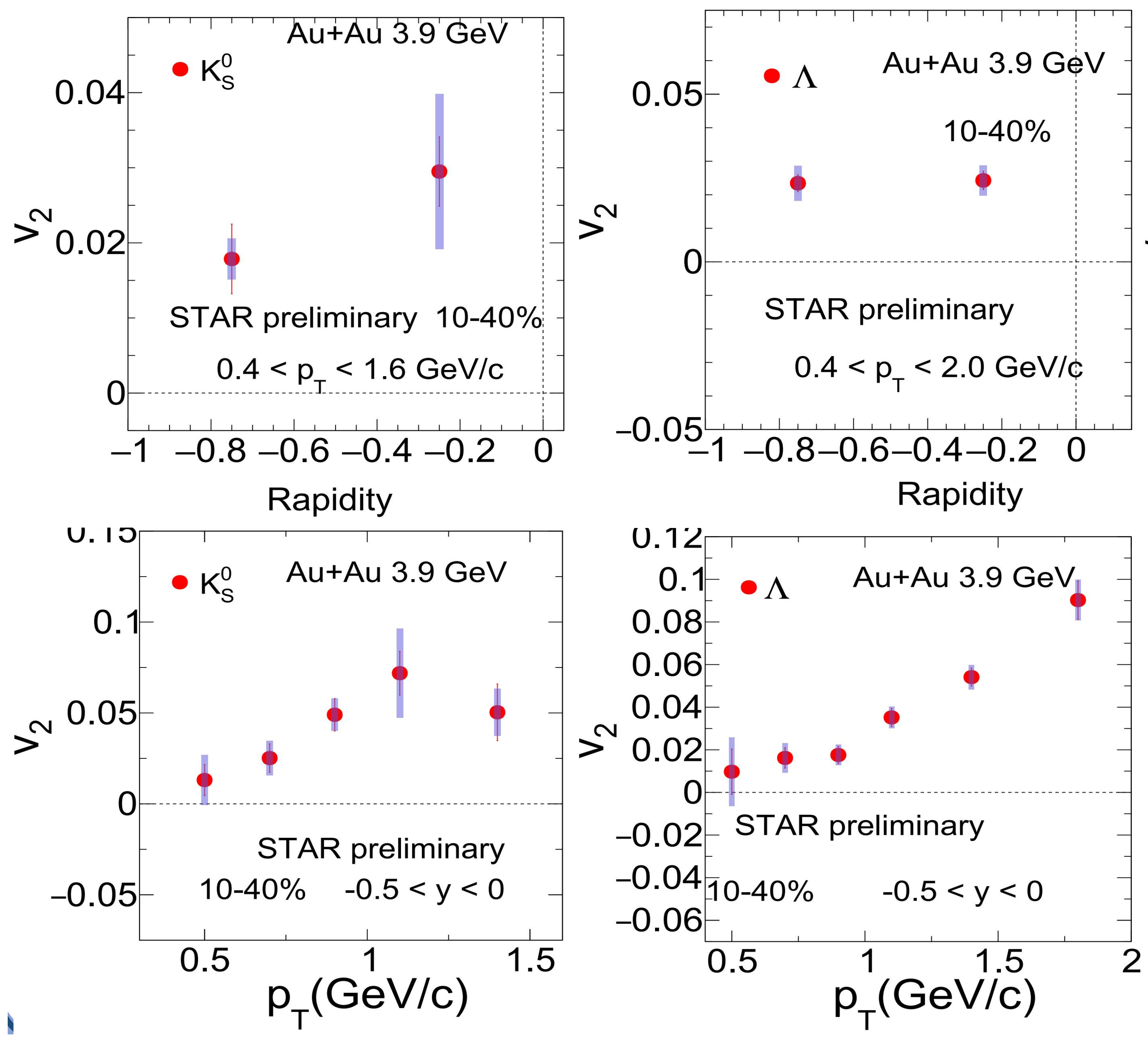
v_1 Results

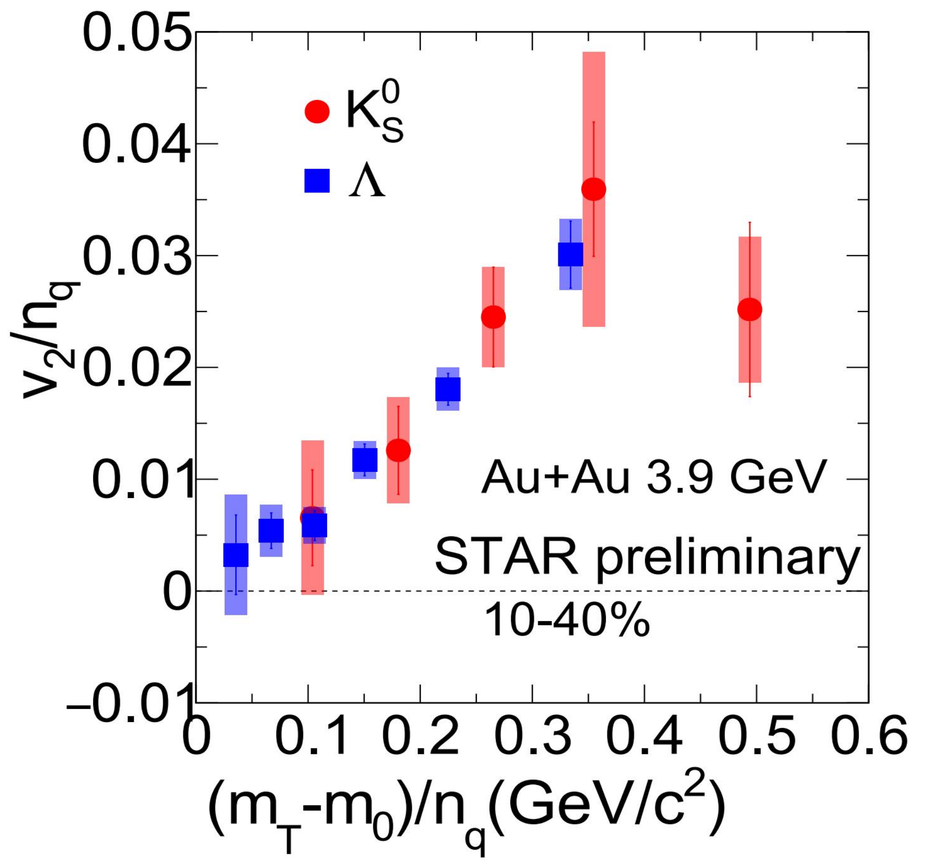


- ➢ Small anti-flow for K_S^0 at low p_T (< 0.7 GeV), positive slope at higher p_T.
- ➢ Λ v_1 slope is positive at all p_T.

Hint of NCQ at 3.9

v_2 Results





- ➢ Positive v_2 for both K_S^0 and Λ at all measured p_T and rapidity at 3.9 GeV.
- ➢ K_S^0 and Λ v_2 shows NCQ scaling at 3.9GeV.

X. Wu: STAR QM Poster

v_1 and EM Fields

Quarks in the expanding medium experience different forces due to

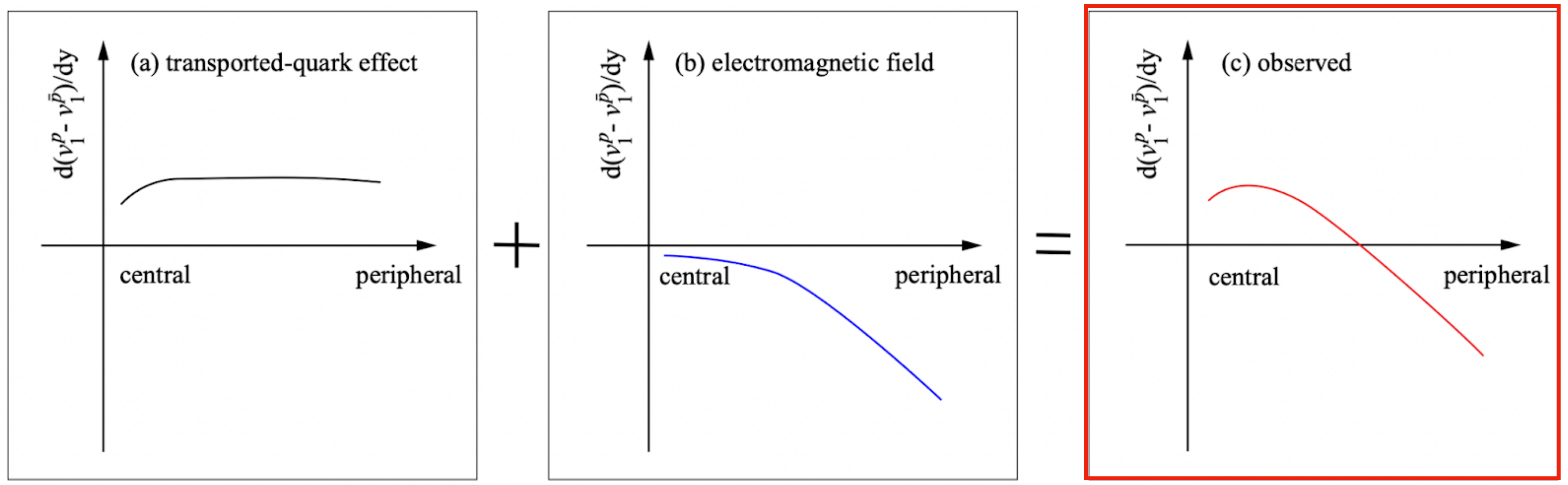
1. **Hall Effect**: **F**= q(**v**×**B**)
2. **Coulomb Effect**: **E** generated by spectators
3. **Faraday Induction**: Generated by decreasing magnetic field as spectators fly away

[U. Gürsoy et al. PRC 98,055201, PRC 89 054905]

These EM forces give opposite v_1 to particles with opposite charges and thus $v_1(h^+)$-$v_1(h^-)$ is sensitive to EM fields

Transported quark effect: Quarks transported from incoming nuclei can have different v_1 than that of quarks produced in the interaction region. **It can affect hadrons having u and d quarks.**

Demonstration for protons



$\Delta dv_1/dy = dv_1(h^+)/dy - dv_1(h^-)/dy$

[STAR, arXiv:2304.03430]