New STAR results from RHIC Beam Energy Scan-II

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STAR

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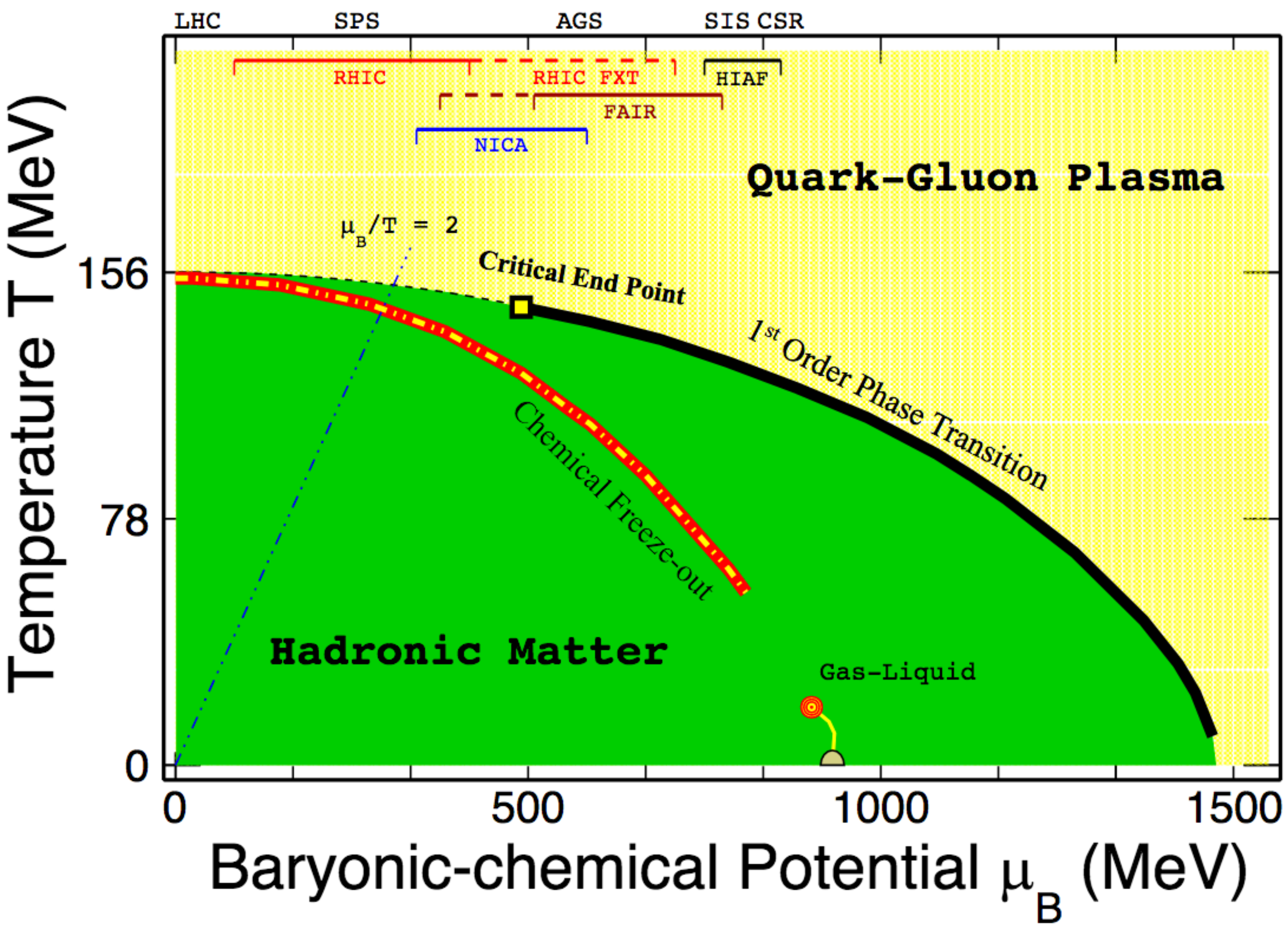
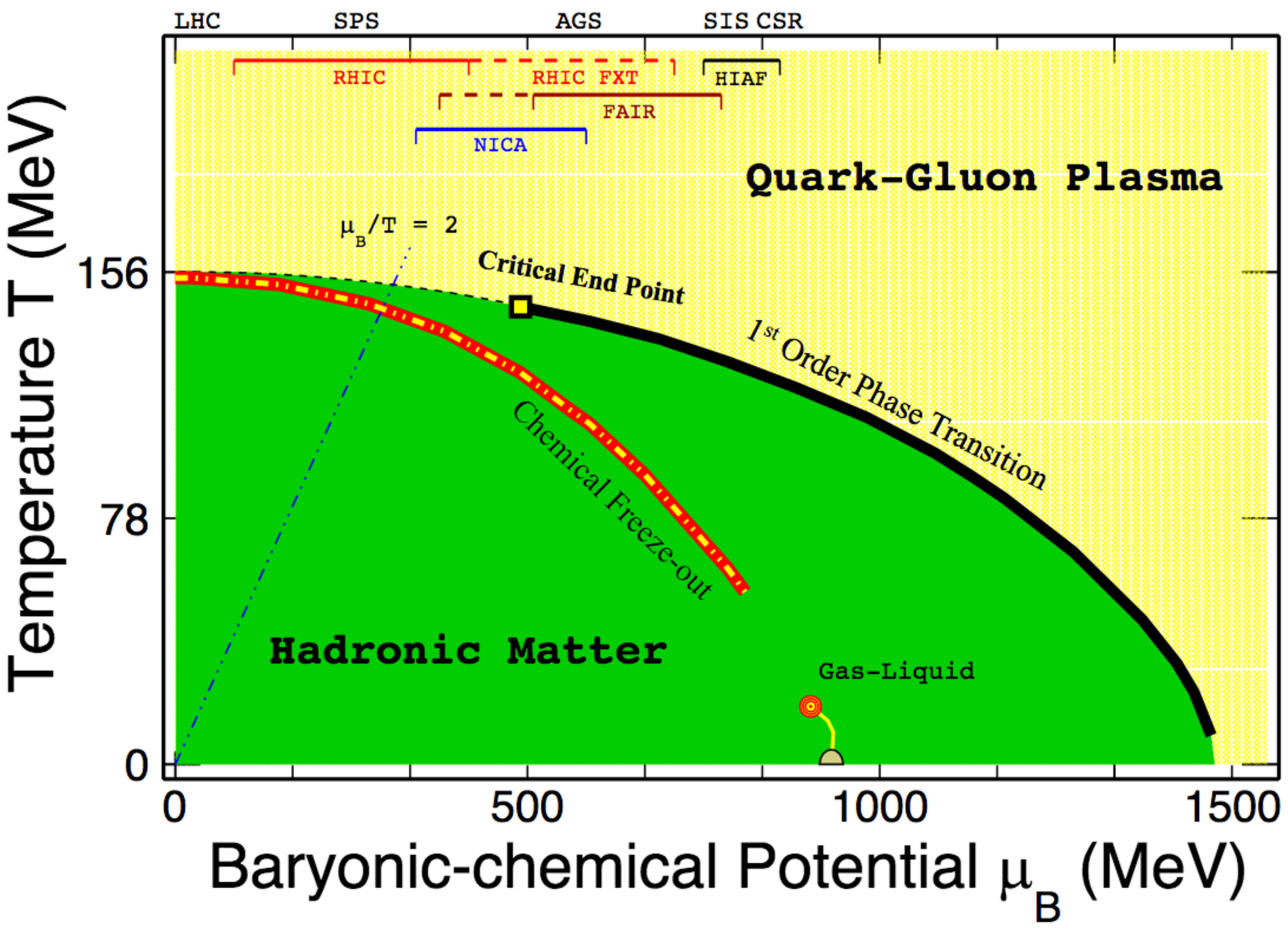


Outline of the talk

- Introduction
- STAR BES-II and FXT Programs
- New results on collectivity
- Strangeness production in high μ_B collisions
- Critical fluctuations
- Summary and Outlook



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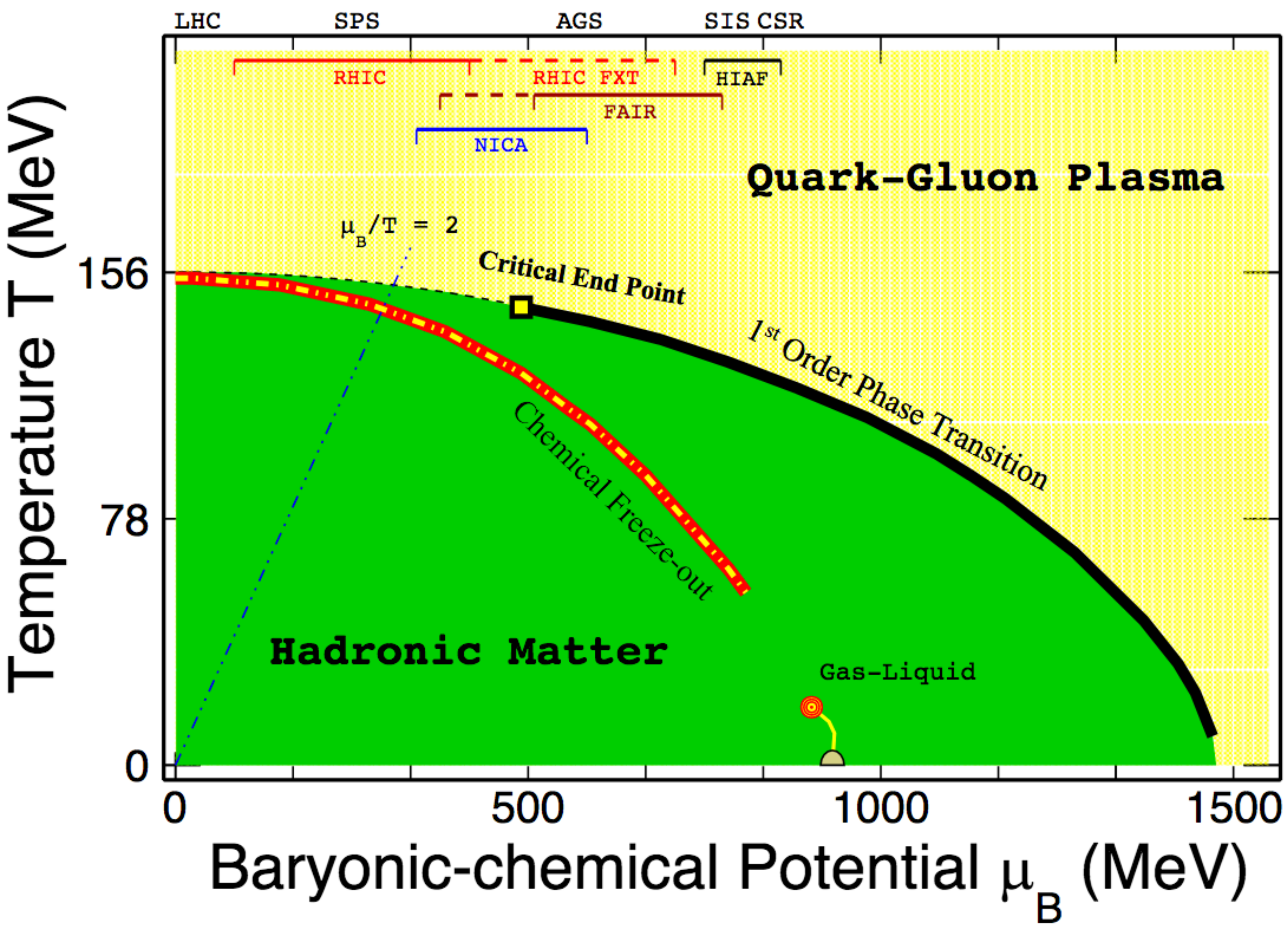
Exploring phase structure of QCD matter

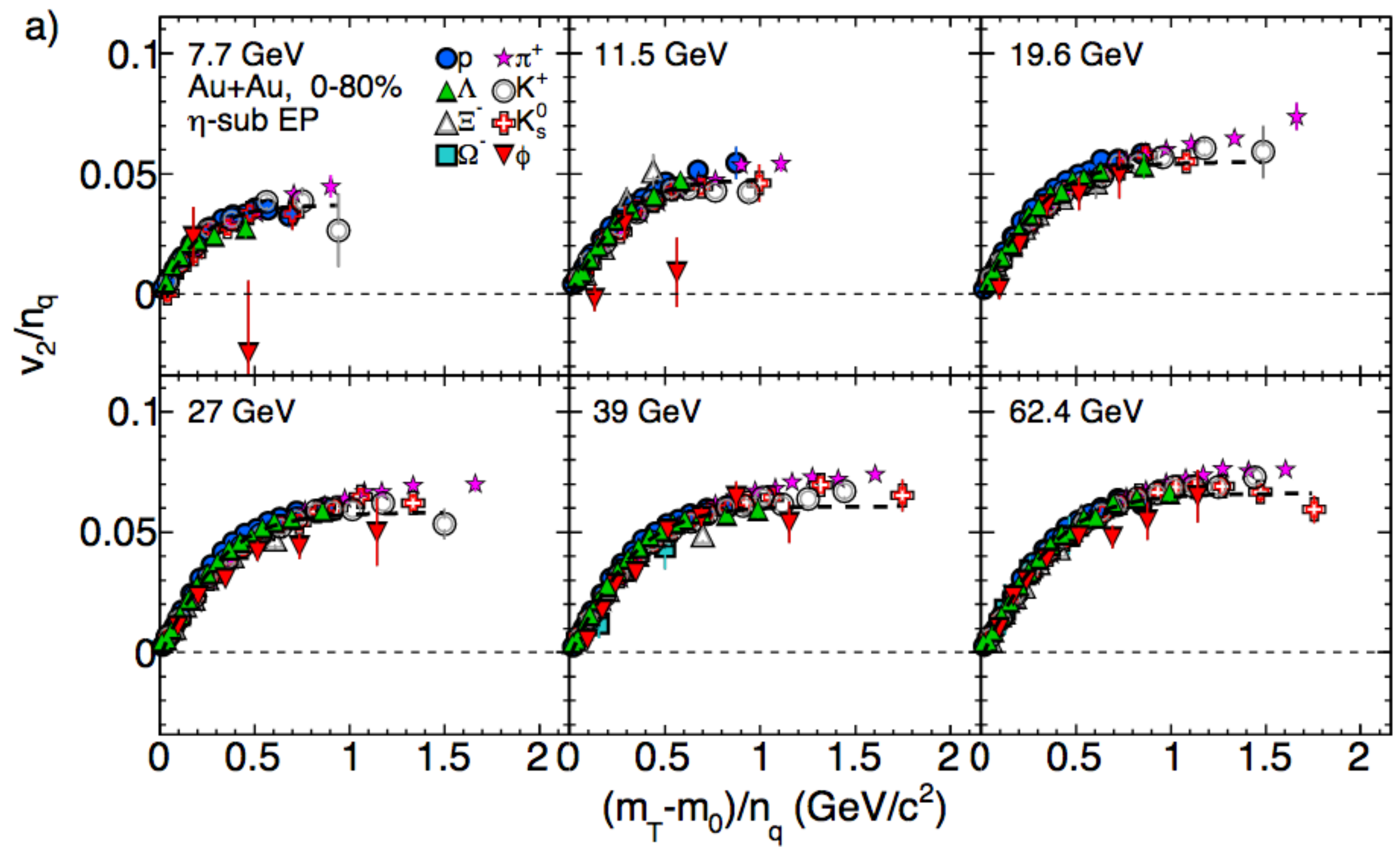


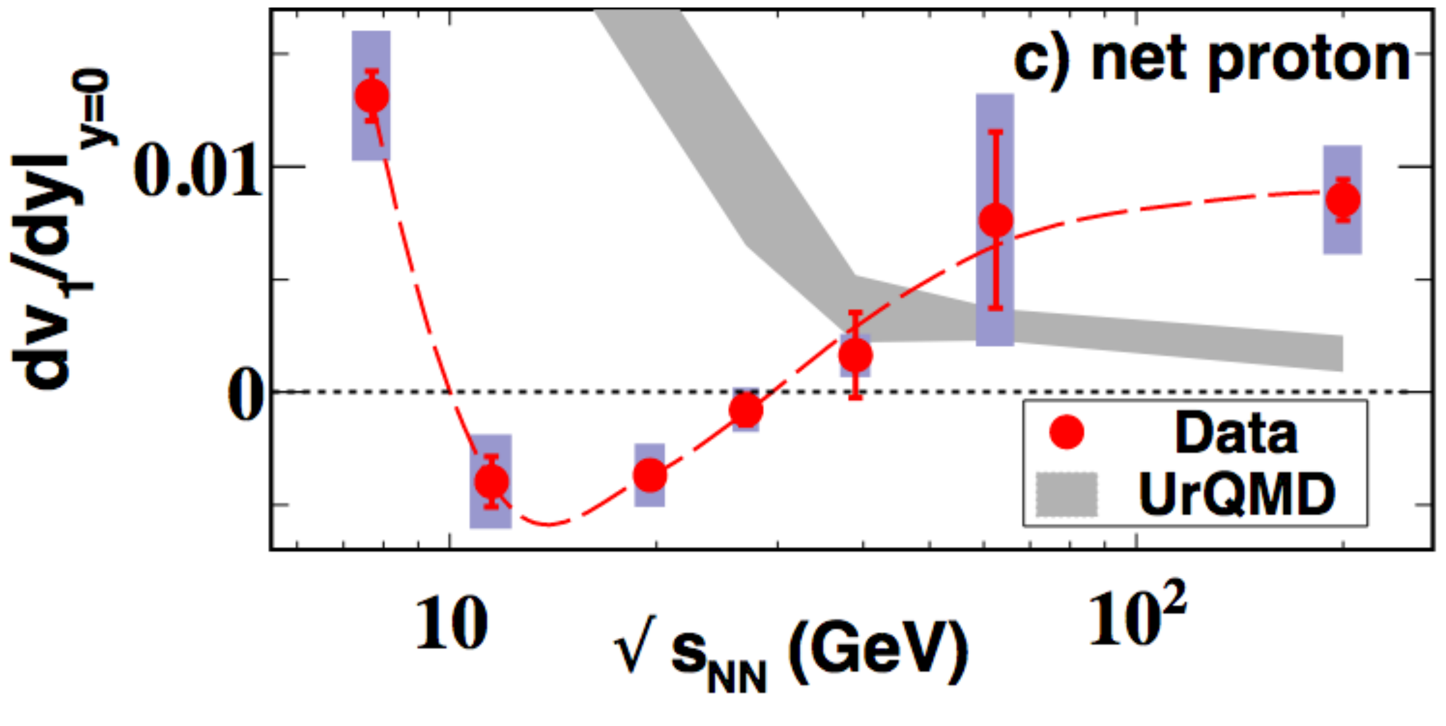
Conjectured QCD Phase diagram

- What is the phase structure of QCD matter?
- Crossover transition into QGP phase predicted by lattice QCD at $\mu_B = 0$
- Many models predict a first order transition at finite μ_B. Critical point?
- Beam Energy Scan Program at RHIC to provide experimental access to nuclear matter properties at finite μ_B

Beam Energy Scan at RHIC

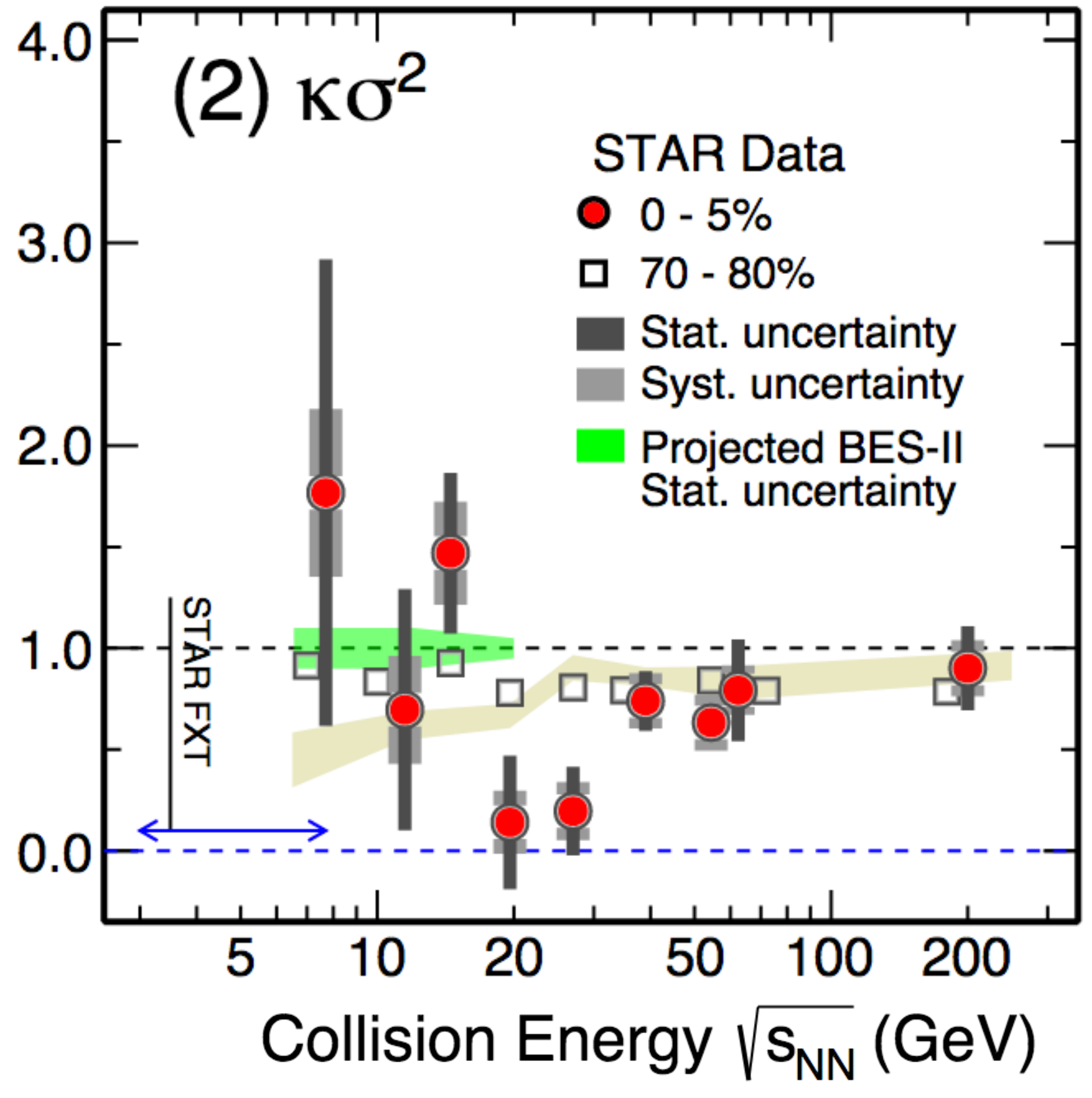
- Critical fluctuations, softening of EoS, disappearance of partonic collectivity/energy loss?
- STAR BES Phase-I (2009-10) Energies: 200 — 7.7 GeV, μ_B : ~20 — 420 MeV



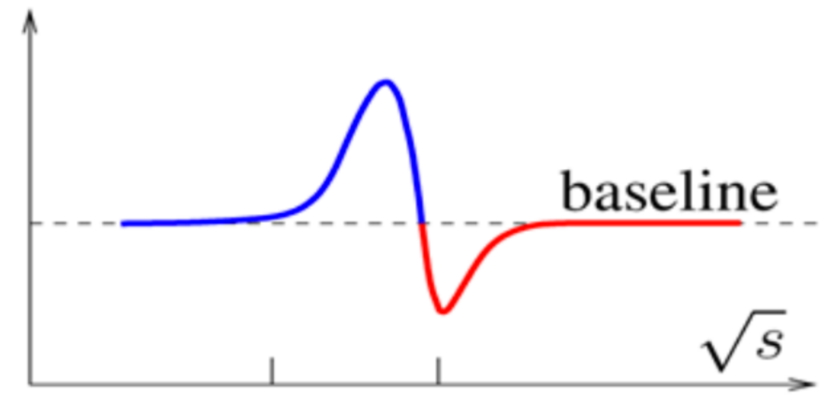


Au+Au, 10-40% Centrality

Net-protons



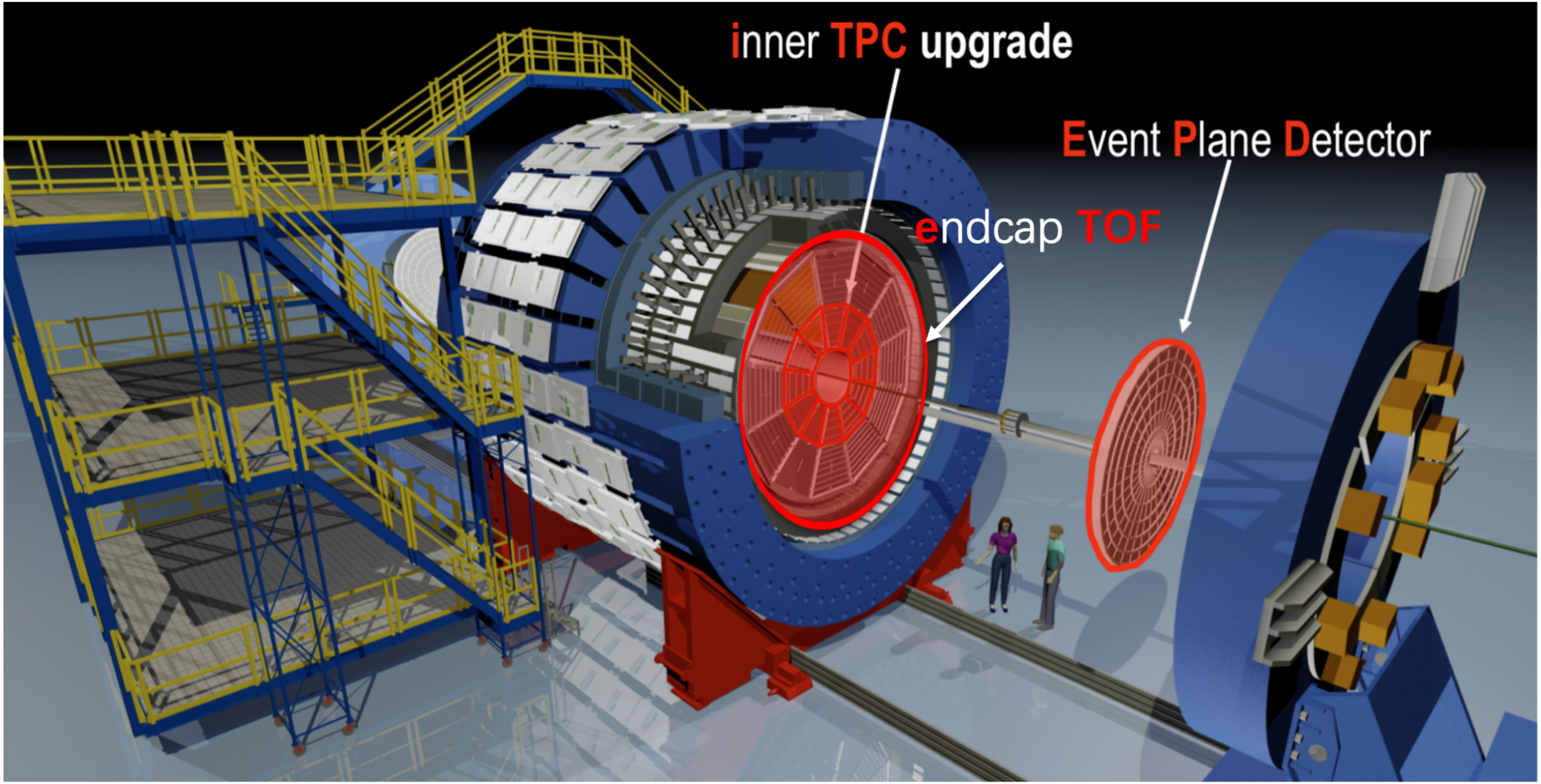
- Does collectivity turn off at lower energies?
- Hints of criticality, softening of EoS … at low beam energies/high μ_B
- STAR BES-II: Focus on high μ_B region with precision measurements
  - better statistics, acceptance, particle identification …



M.A.Stephanov, PRL 107, 052301 (2011)

STAR: Phys. Rev. C 93, 014907 , STAR: Phys. Rev. Lett. 112,162301, STAR: Phys. Rev. Lett 126, 92301

STAR Detector Upgrades for BES-II



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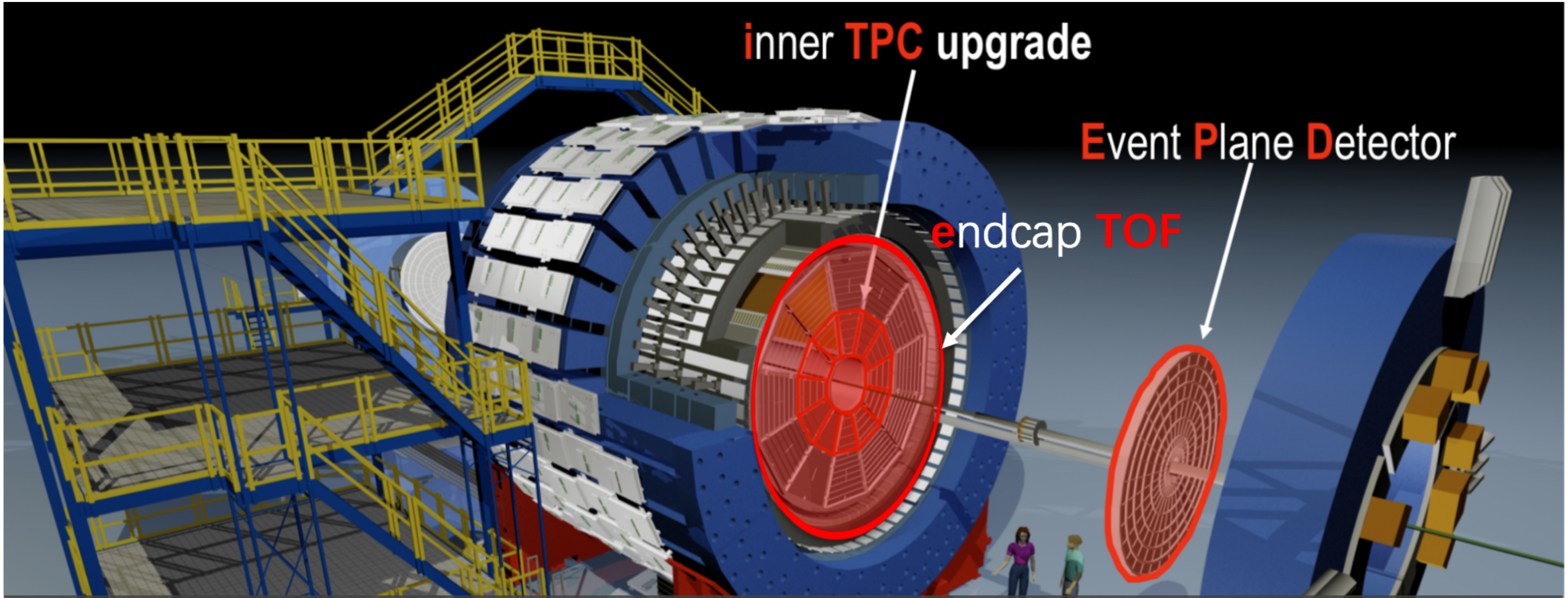
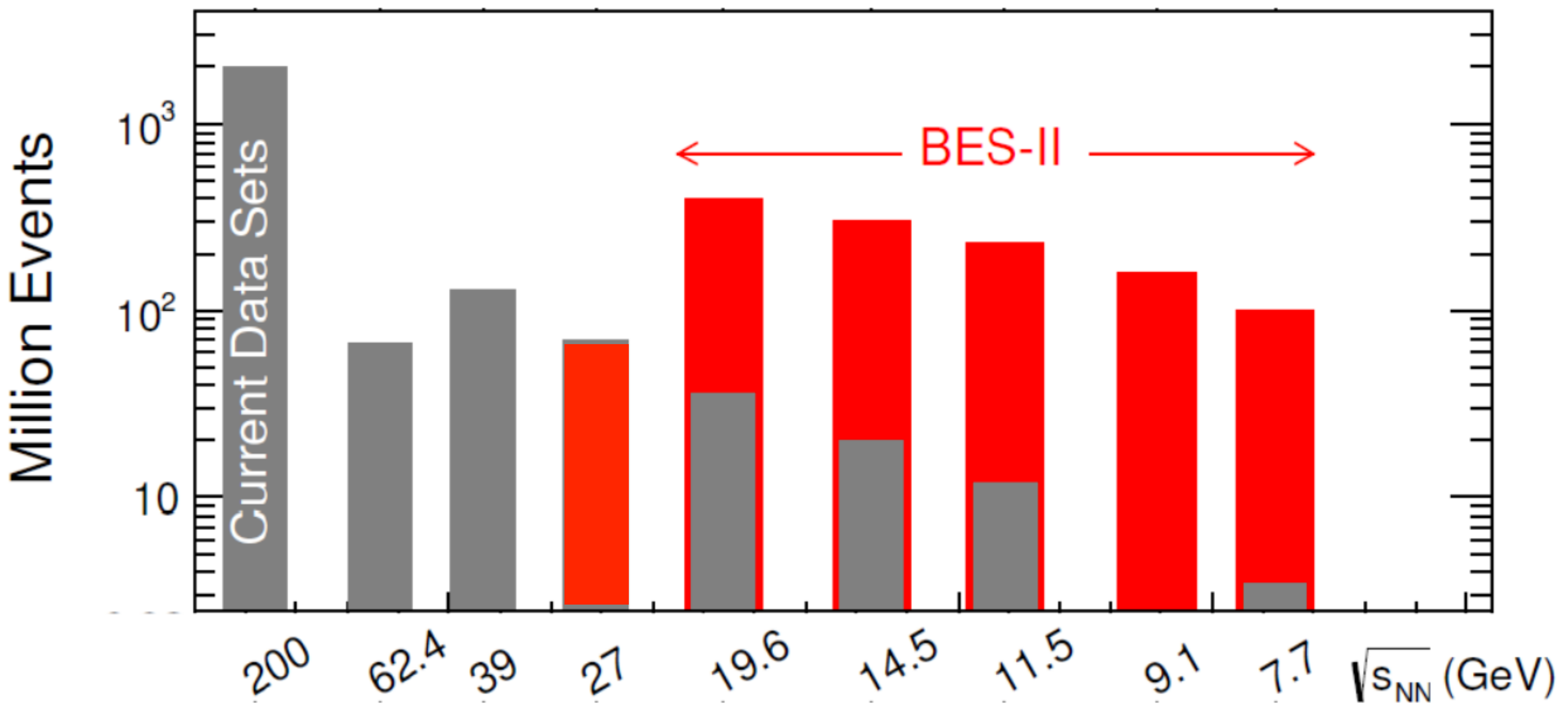


- ***iTPC:*** **Increased acceptance to |η| < 1.5, Better efficiency at low p_T, Improved dE/dx resolution**
- ***EPD:*** **Independent centrality detector, Improved EP resolution, Trigger**
- ***eTOF:*** **PID in the forward region**

STAR BES-II Status

- Order of magnitude more events in BES-II
- Collision energies: 27 — 7.7 GeV, μ_B: 206 — 420 MeV
- Finished taking data for energies down to 9.2 GeV. Run-21 ongoing

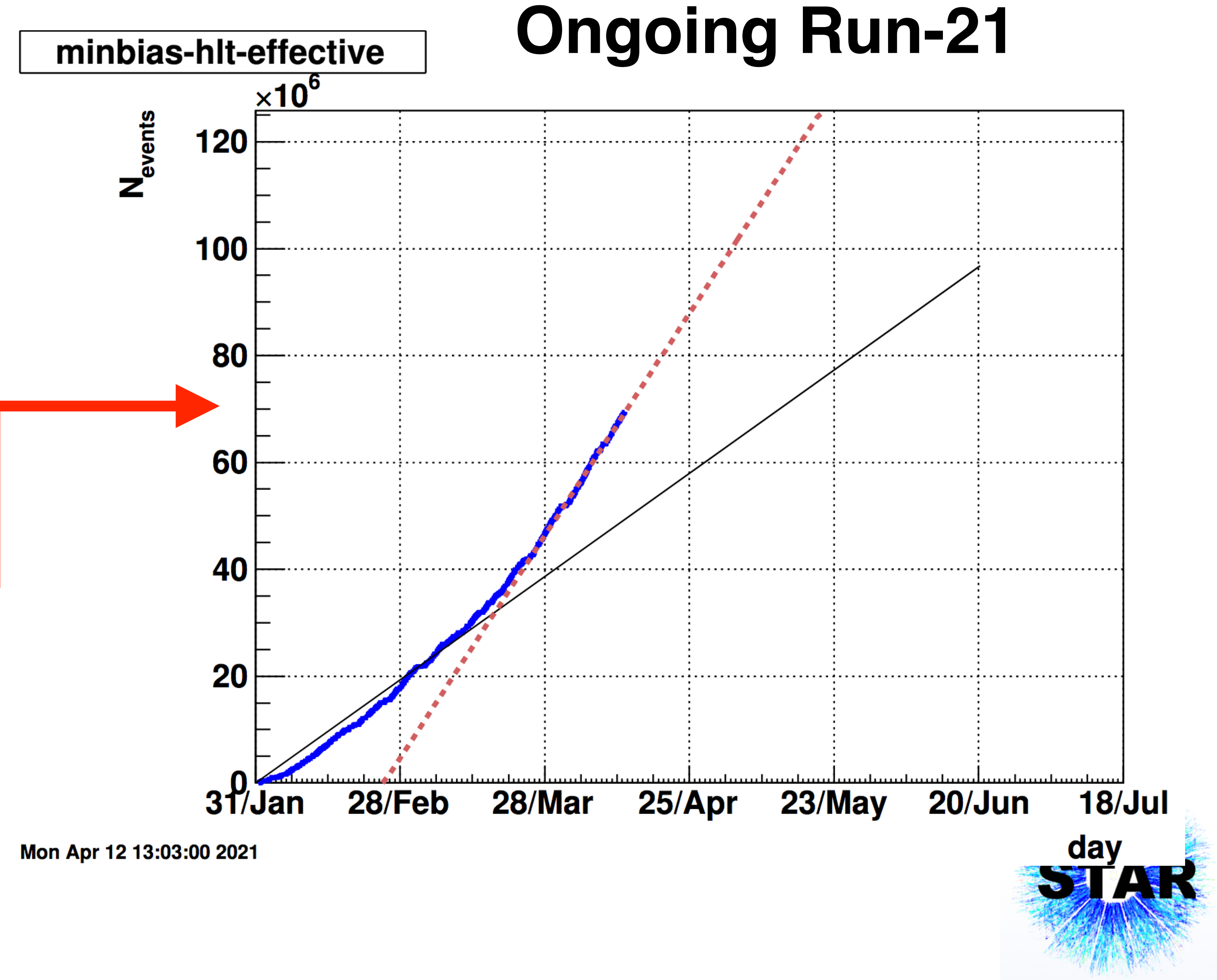
Statistics comparison to BES-I



BES-II data taking progress

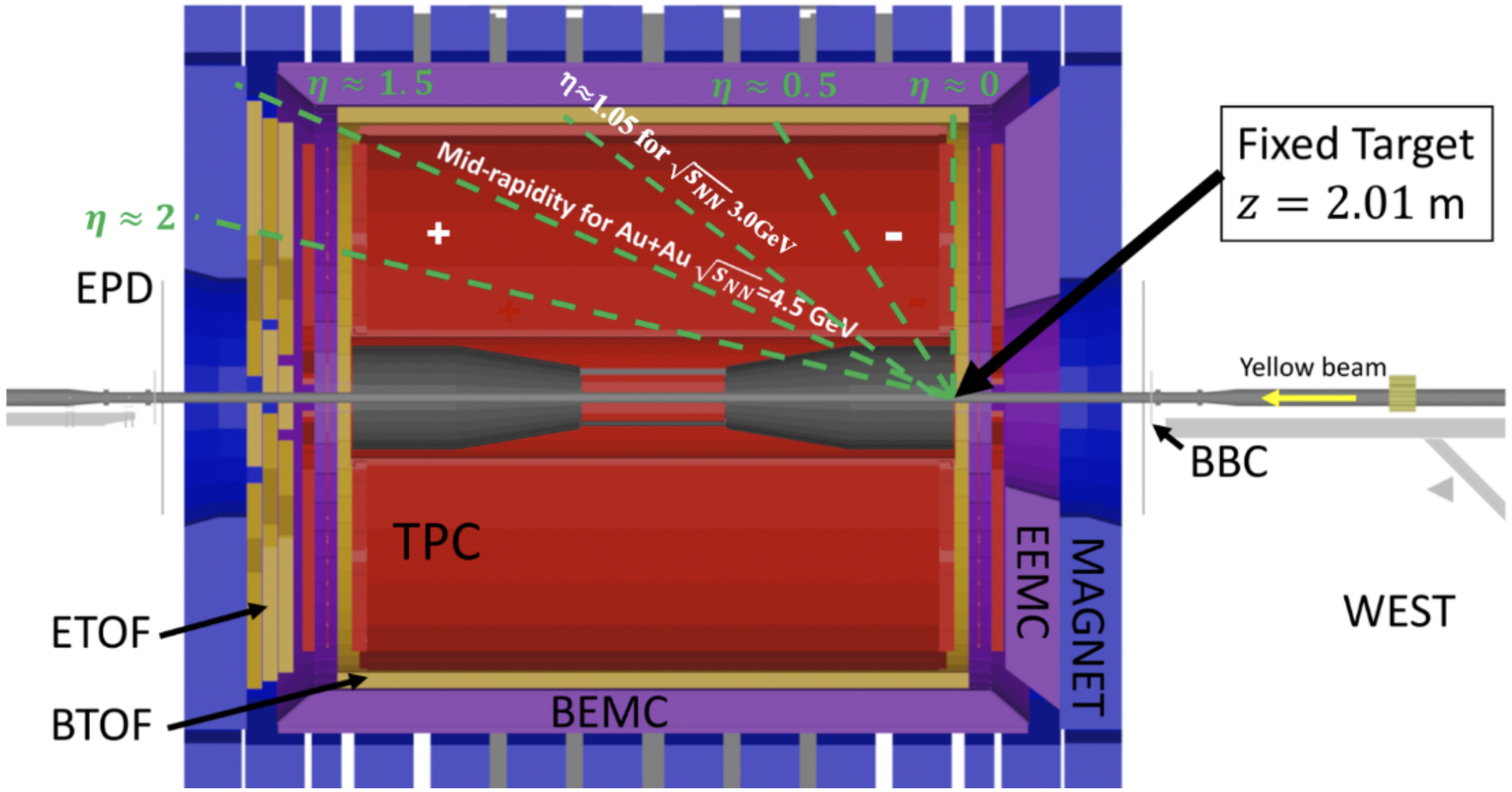
Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events Requested (Recorded)	Date Collected
13.5	27	156	24 days	(560 M)	Run-18
9.8	19.6	206	36 days	400 M (582 M)	Run-19
7.3	14.6	262	60 days	300 M (324 M)	Run-19
5.75	11.5	316	54 days	230 M (235 M)	Run-20
4.59	9.2	373	102 days	160 M (162 M)[1]	Run-20+20b
3.85	7.7	420	11-20 weeks	100 M (70 M)	Run-21[2]

Ongoing Run-21



- Further extend to lower energies with FXT runs

FXT Program at STAR BES-II



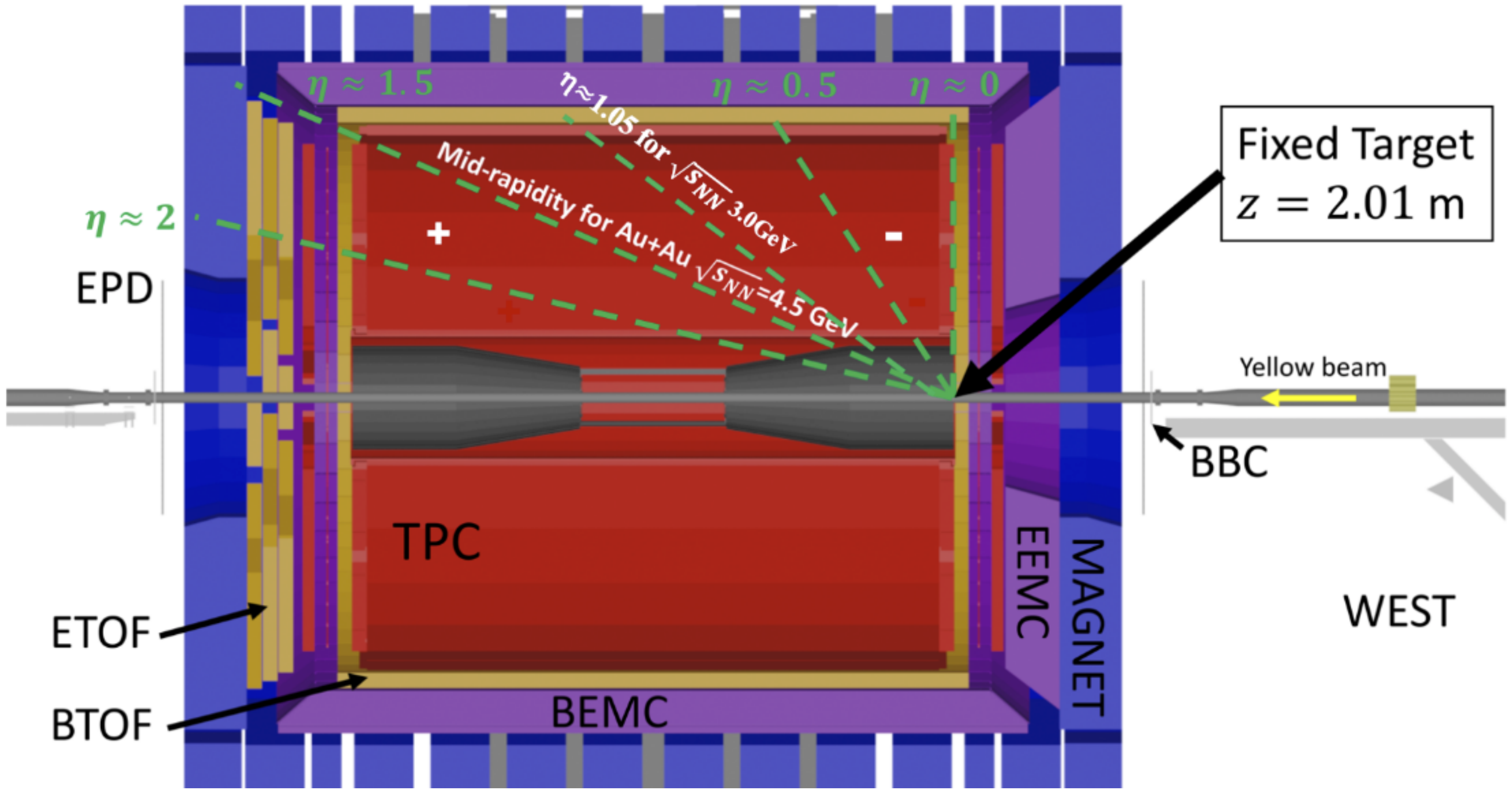
STAR in FXT mode

- Extends BES-II down to collision energy of 3 GeV and μ_B up to 720 MeV

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events Requested (Recorded)	Date Collected
31.2	7.7 (FXT)	420	0.5+1.1 days	100 M (50 M+112 M)	Run-19+20
19.5	6.2 (FXT)	487	1.4 days	100 M (118 M)	Run-20
13.5	5.2 (FXT)	541	1.0 day	100 M (103 M)	Run-20
9.8	4.5 (FXT)	589	0.9 days	100 M (108 M)	Run-20
7.3	3.9 (FXT)	633	1.1 days	100 M (117 M)	Run-20
5.75	3.5 (FXT)	666	0.9 days	100 M (116 M)	Run-20
4.59	3.2 (FXT)	699	2.0 days	100 M (200 M)	Run-19
3.85	3.0 (FXT)	721	4.6 days	100 M (259 M)	Run-18

- Short run in 2015 at FXT 4.5 GeV demonstrating STAR FXT data taking capabilities *(Phys. Rev. C.103, 034908)*

FXT Program at STAR BES-II



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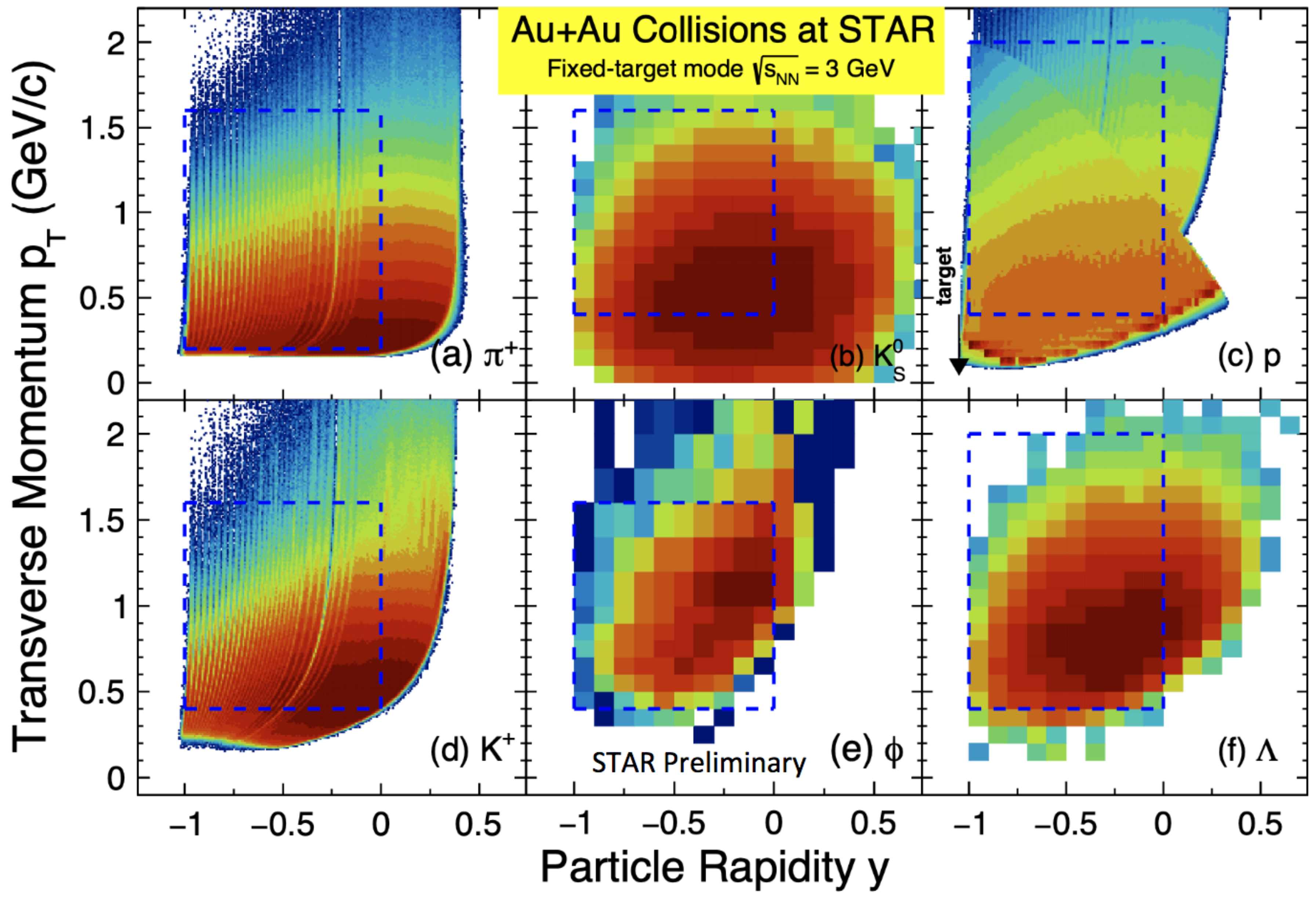
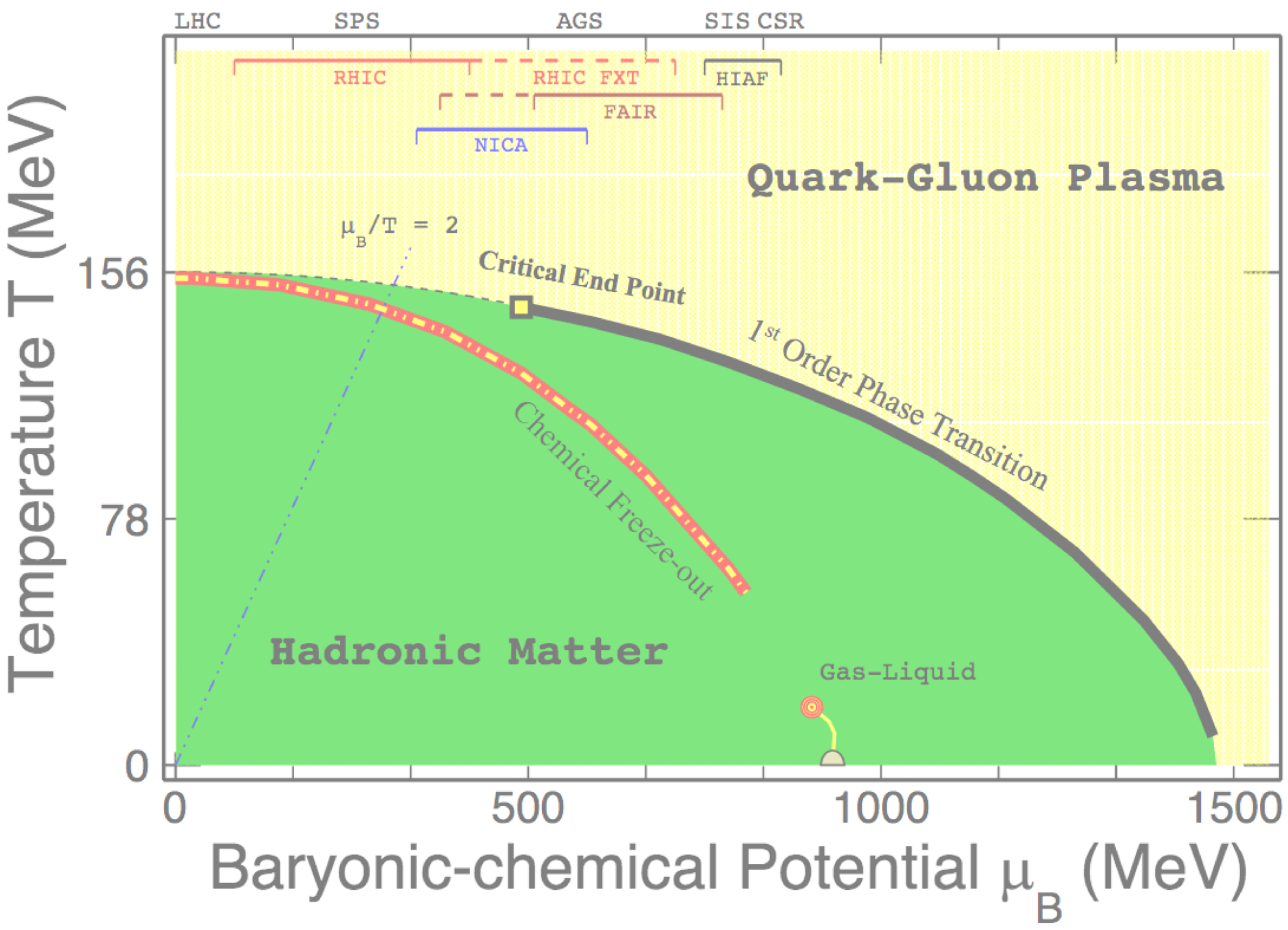
- Short run in 2015 at FXT 4.5 GeV demonstrating STAR FXT data taking capabilities *(Phys. Rev. C.103, 034908)*
- First of the BES-II FXT runs in 2018 @3 GeV
- Large data set and mid-rapidity acceptance





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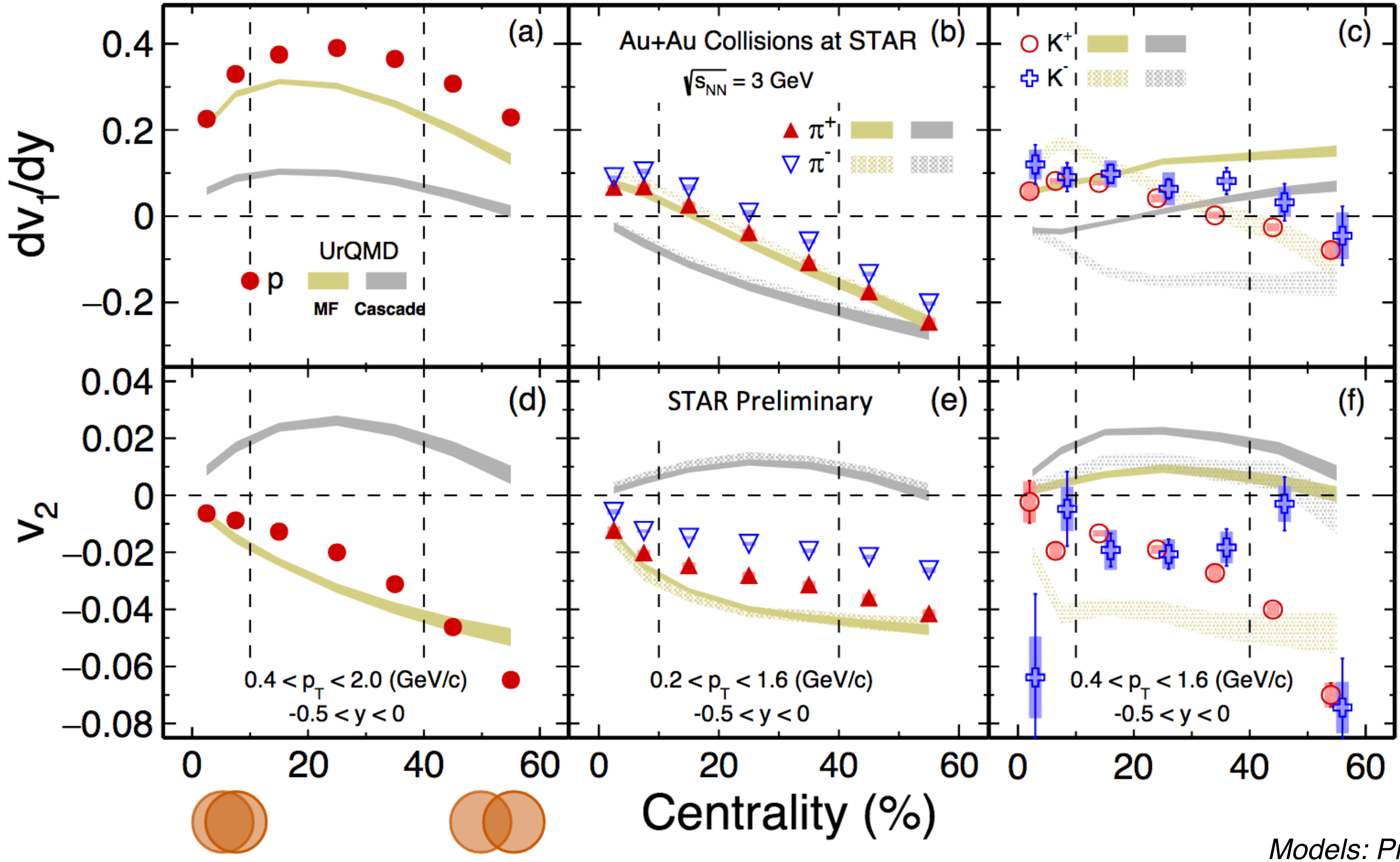
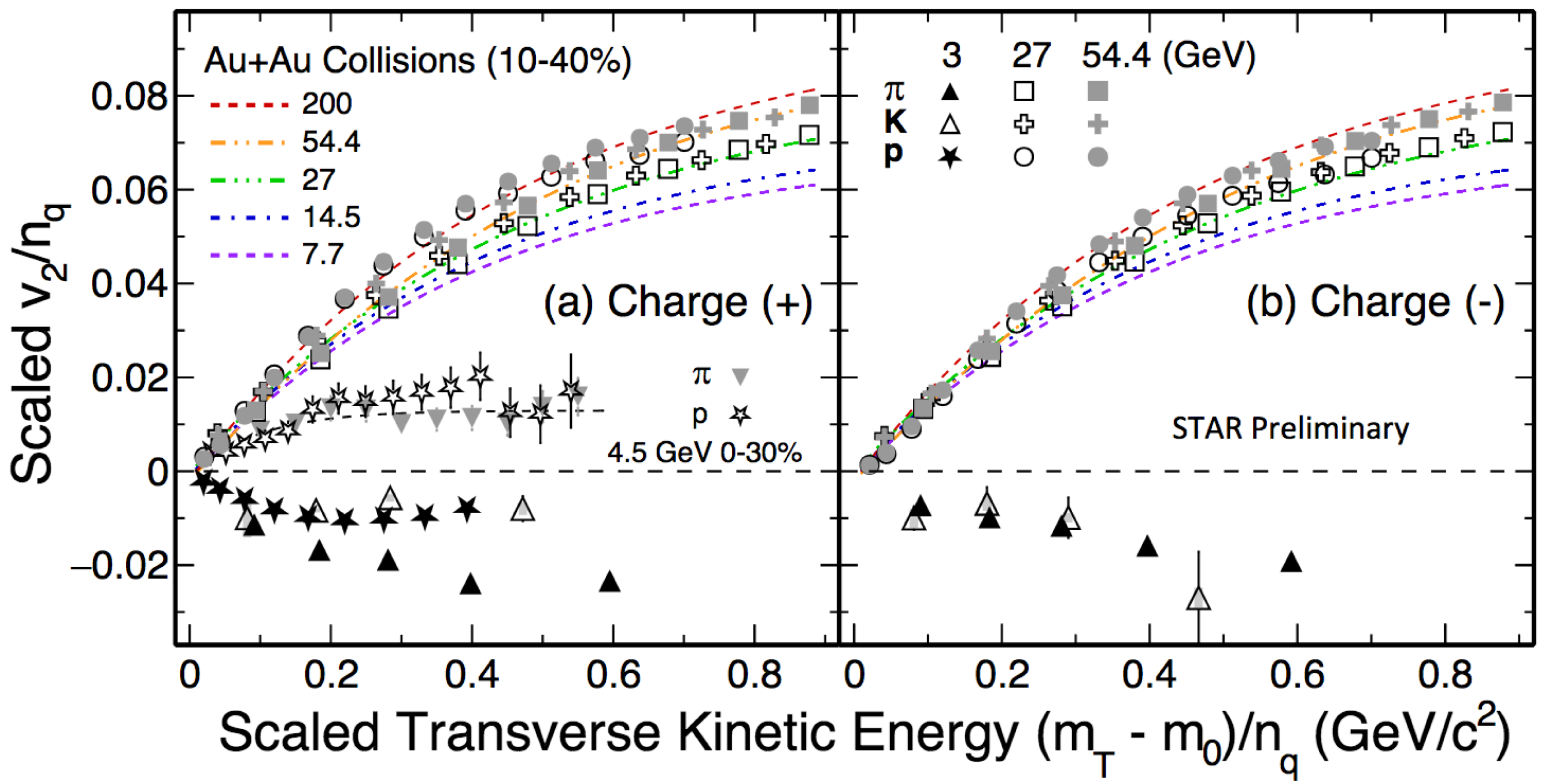
Identified hadron v_1 and v_2 at FXT 3 GeV



- Positive v_1 slope and negative v_2 for all particles in central collisions
- UrQMD cascade mode cannot describe data
- Need baryonic mean field interactions to generate trends seen in data

Models: Prog. Part. Nucl. Phys. 41, 225-370
J. Phys. G: Nucl. Part. Phys. 25, 1859-1896
Eur. Phys. J. A1 15, 1-16

Disappearance of quark number scaling

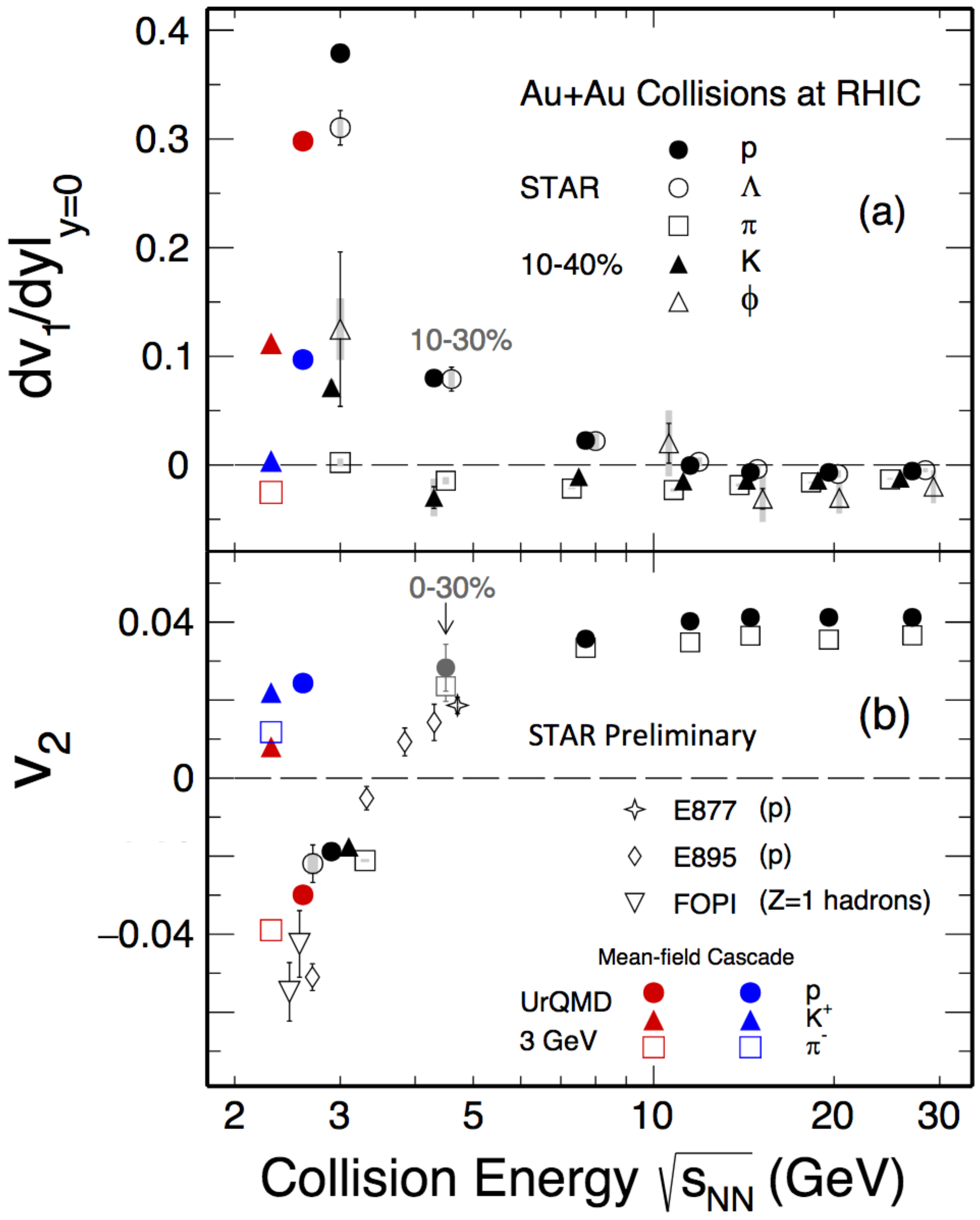


- NCQ scaling holds for energies from 200 down to 4.5 GeV collisions
  — Partonic collectivity
- v_2 values are negative and NCQ scaling breaks down at 3 GeV
  — indicative of medium without partonic degrees of freedom

Measurements from new data at 27 and 54.4 GeV

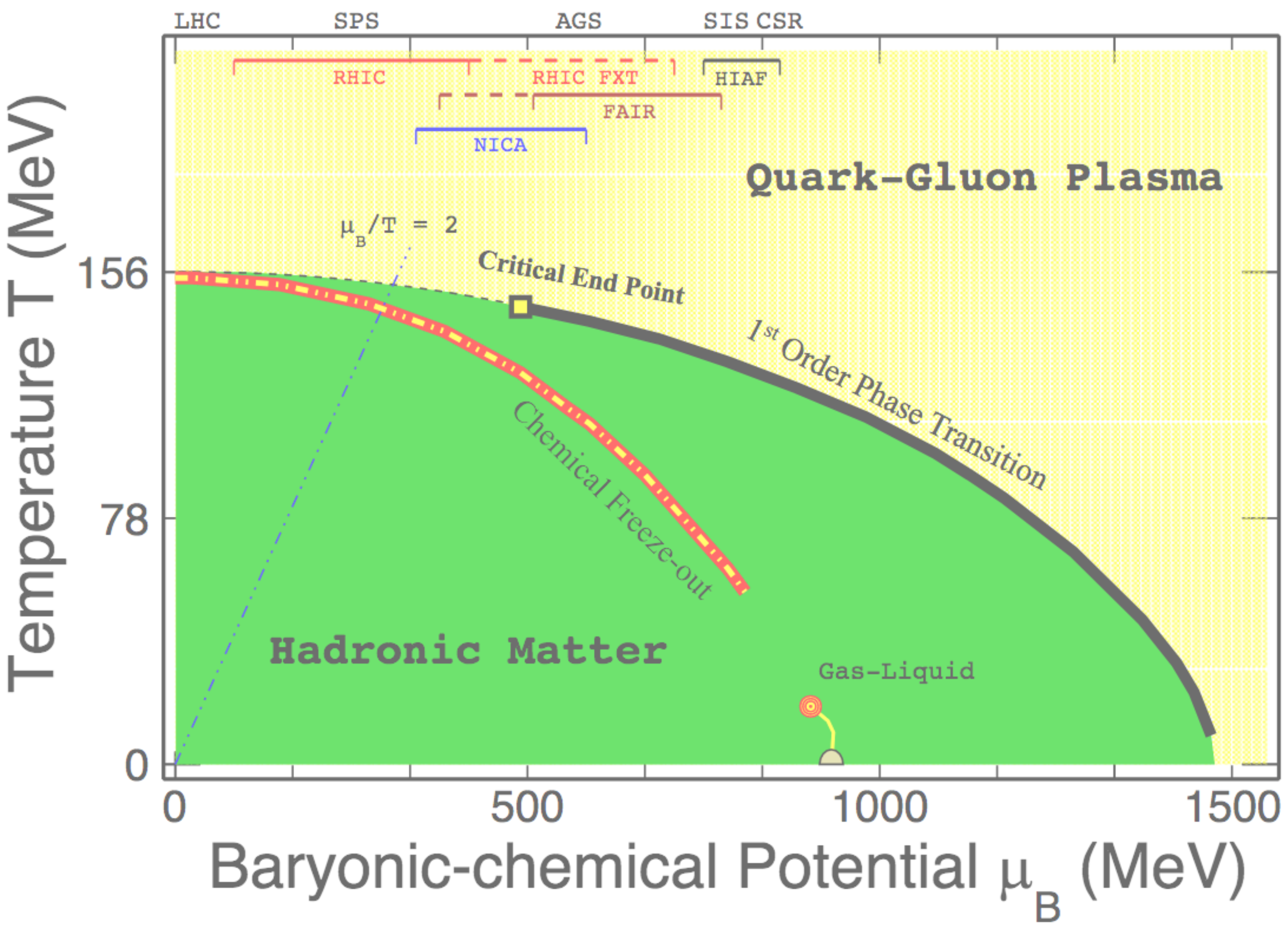
STAR: Phys. Rev. C88149020
STAR: Phys. Rev. C.103, 034908
X. Dong et al. Phys. Lett. B 597 328-332

Energy dependence of v_1 and v_2



- Negative v_1 slope and large positive v_2 at high energy collisions
- Positive v_1 slope and negative v_2 for all measured particles in 3 GeV collisions
- Positive v_1 slope observed for kaons and Φ mesons for the first time
- Results from UrQMD with baryonic mean-field interactions qualitatively describe the data
- EoS dominated by baryonic interactions at 3 GeV

E877: Phys. Rev. C 56, 3254-3264
E895: Phys. Rev. Lett.85, 940
FOPI: Phys. Lett. B612, 173



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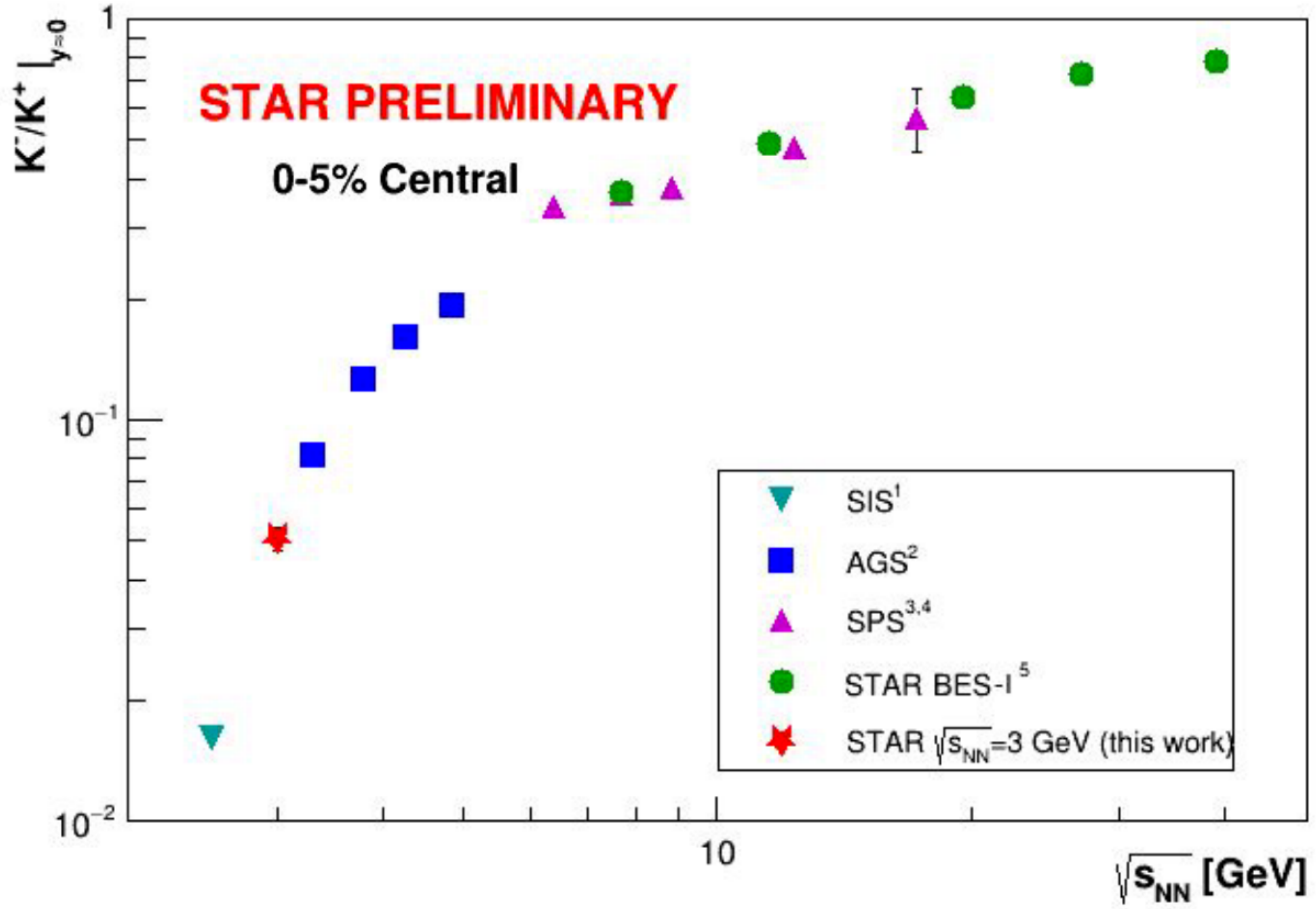
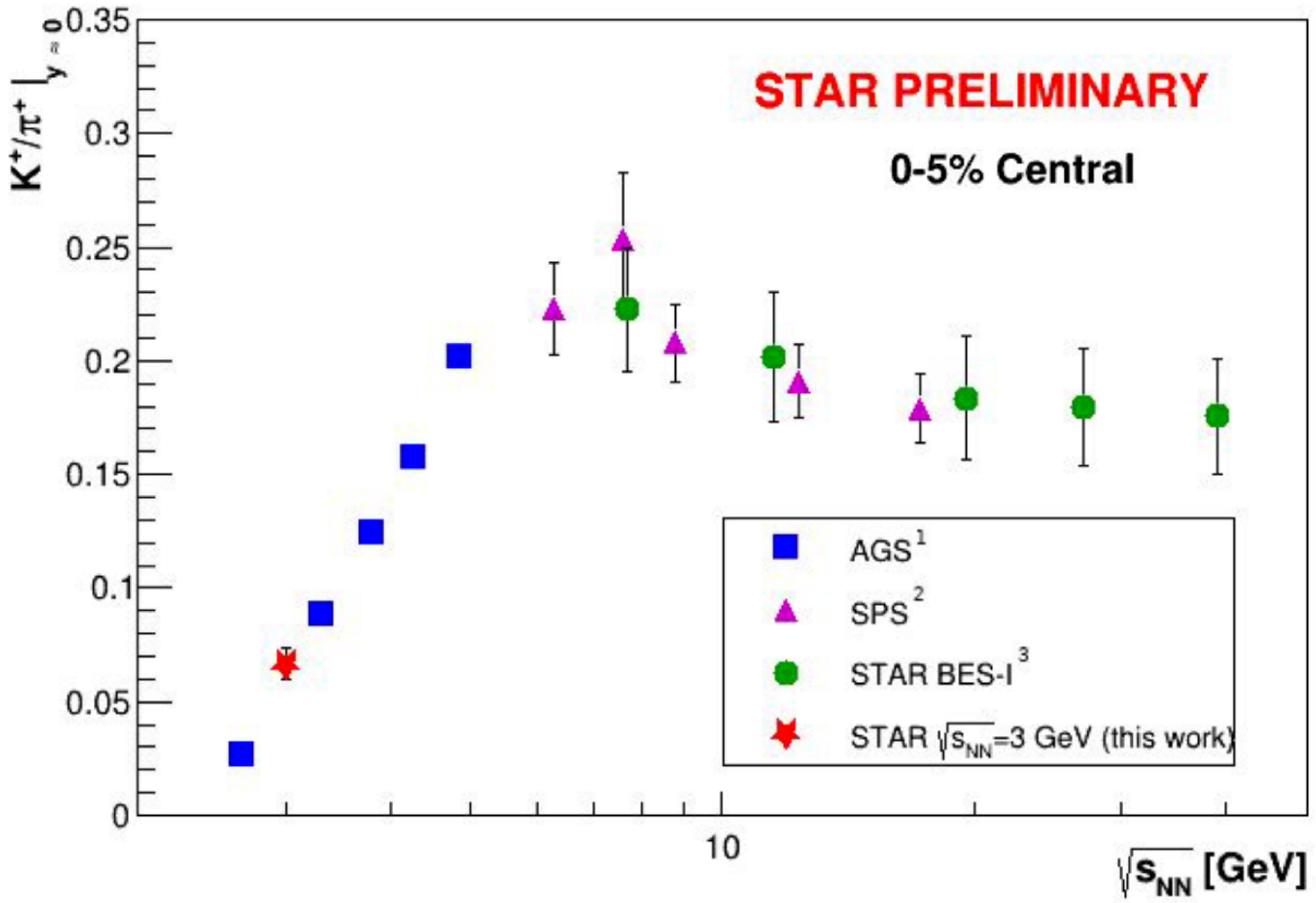
Strangeness production: K^-/K^+, K^+/π^+ ratios

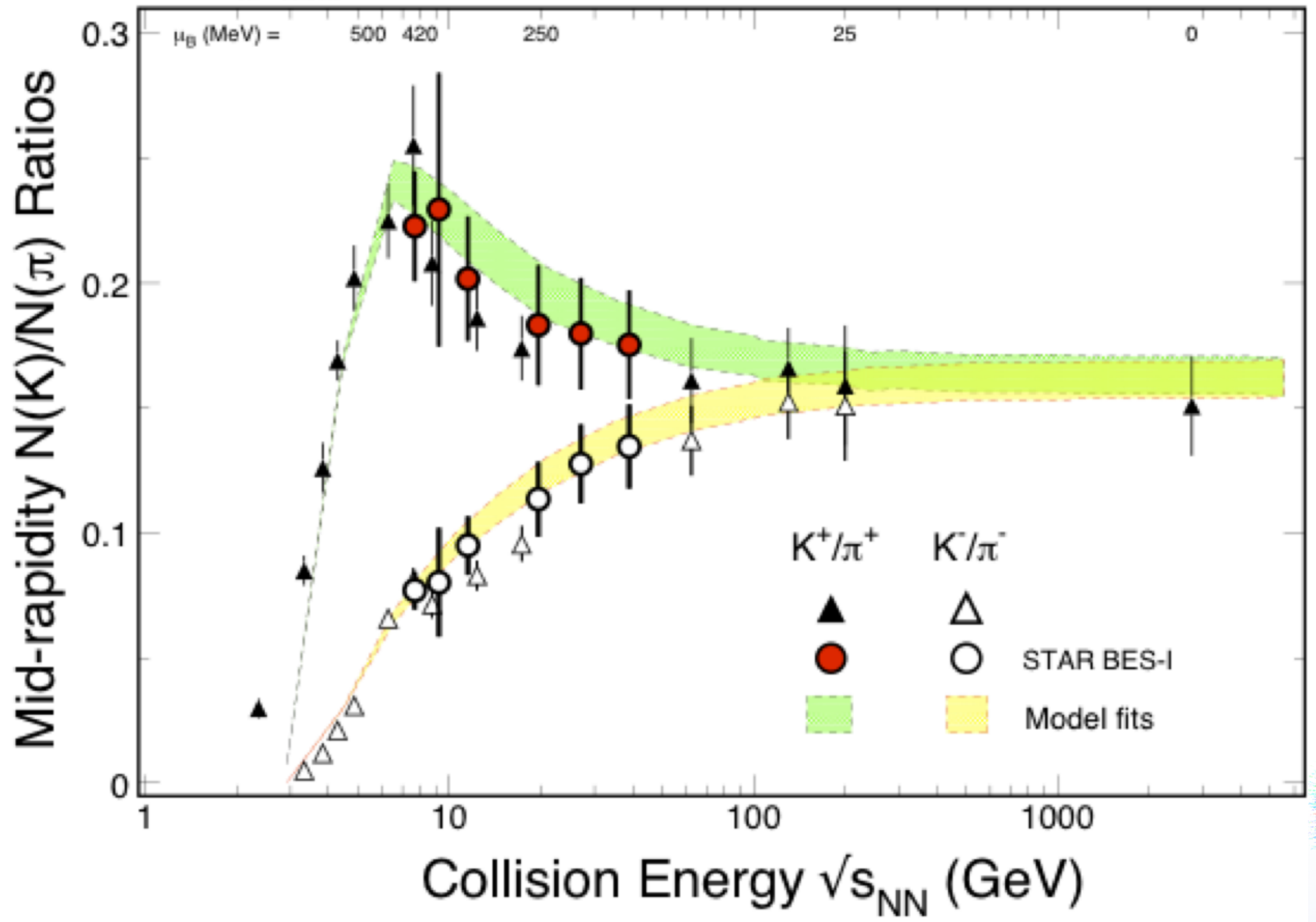
- Beam energy dependence of strangeness production

SIS: J. Phys. G 28, 2011
AGS: Phys. Lett. B 490, 53;
Phys. Lett. B 476, 1
SPS: Phys. Rev. C 77, 024903;
Phys. Rev. C 66, 054902;
Phys. Rev. C 77, 024903
STAR: Phys. Rev. C 96, 044904



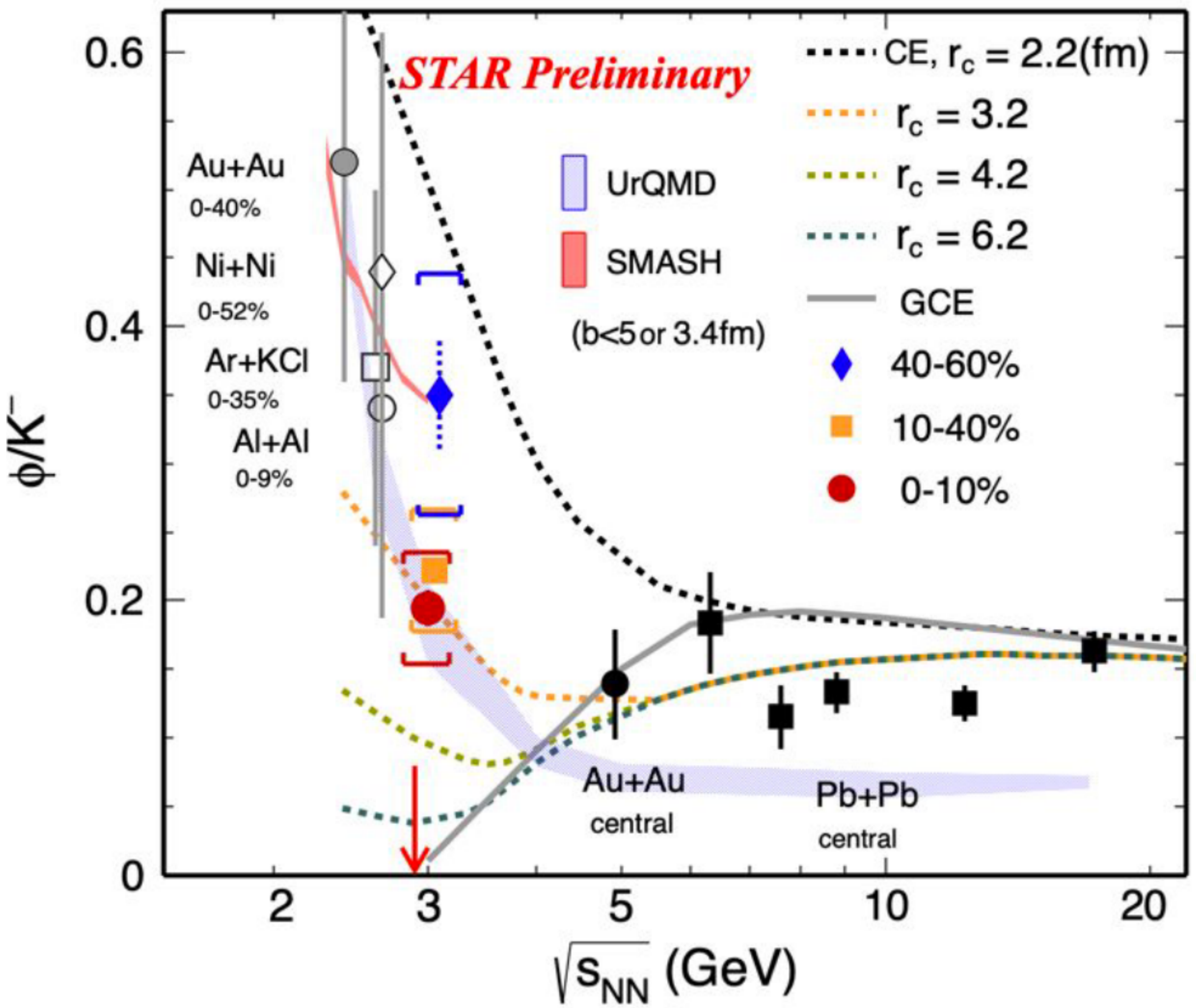


- K^+/π^+ and K^-/K^+ ratios follow world trend
- Statistical models describe K^+/π^+ beam energy dependence
- K^-/K^+ ratio drops at lower energies from associated production of K^+ ($N + N \longrightarrow N + \Lambda + K$)



Strangeness production: Φ/K ratio

- Beam energy dependence of strangeness production



- Low energies, small systems: local strangeness conservation
- Canonical instead of Grand Canonical Ensemble describe statistical production —> reduced phase space —> "Canonical suppression"

- Data favors a CE calculation with a correlation length r_c = 3.2 fm

World data: Phys. Lett. B 778, 403-407, Phys. Rev. C. 80.025209; Phys. Rev. C. 69.054901; Phys. Rev. C 78, 044907; Phys. Rev. C 77, 024903, Phys. Rev. C 66, 054902

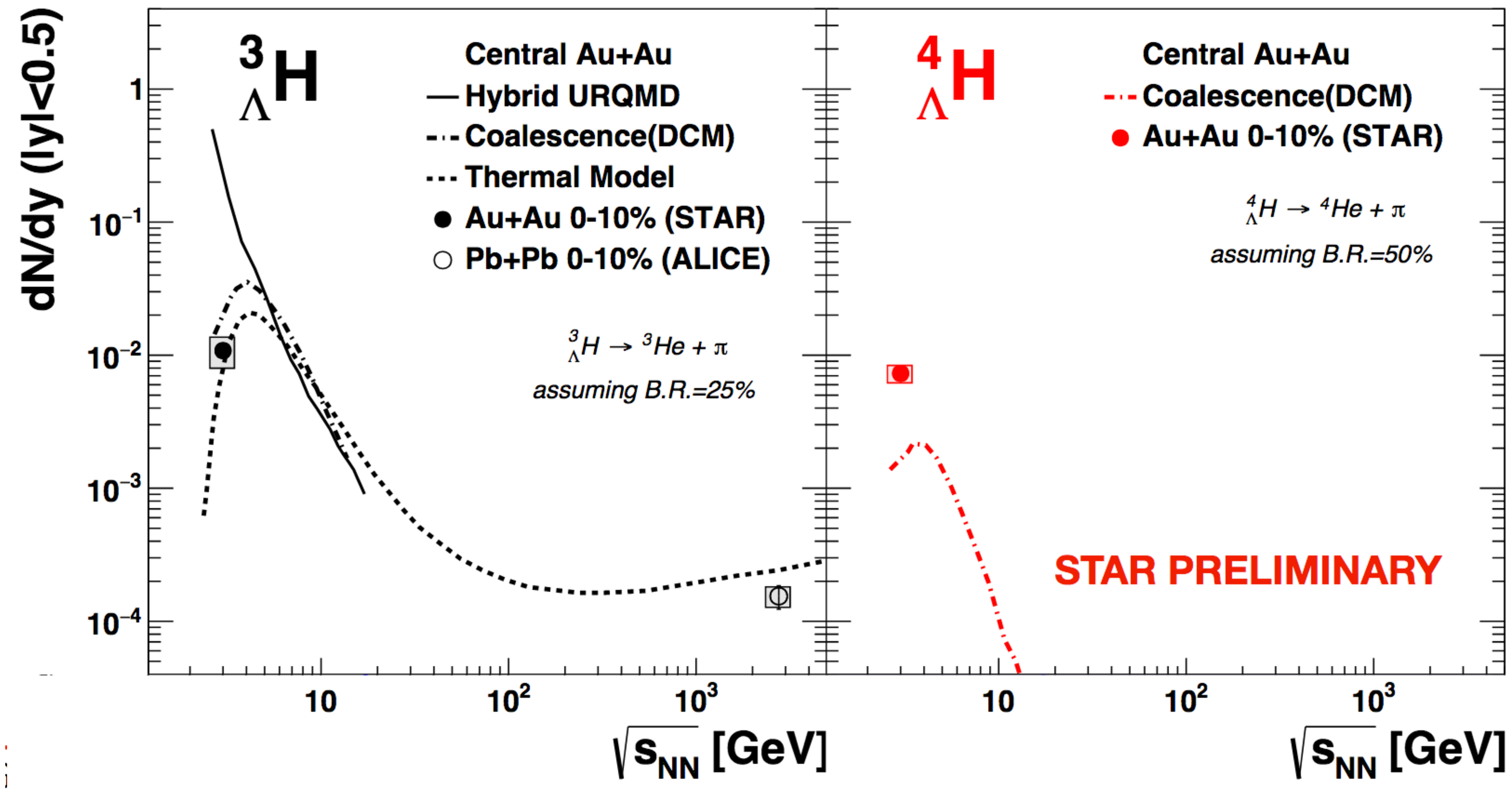
- STAR data at 3 GeV strongly disfavors GCE, results ~5σ away from zero (for 0-10%)

Models: Nucl. Phys. A 772, 167; Phys. Lett. B 603, 146
J. Phys. G: Nucl. Part. Phys. 43 (2016) 015104
Phys. Rev, C 99, 064908

Hypernuclei production at FXT 3 GeV

- Lifetime, yield, flow of hypernuclei important to understand Y-N interactions and hyperon contribution to EoS

Models: Phys. Lett. B. 714,85;
Phys. Lett. B 697, 203
ALICE: Phys. Lett. B 754, 360



$^{3}_{\Lambda}H : \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$

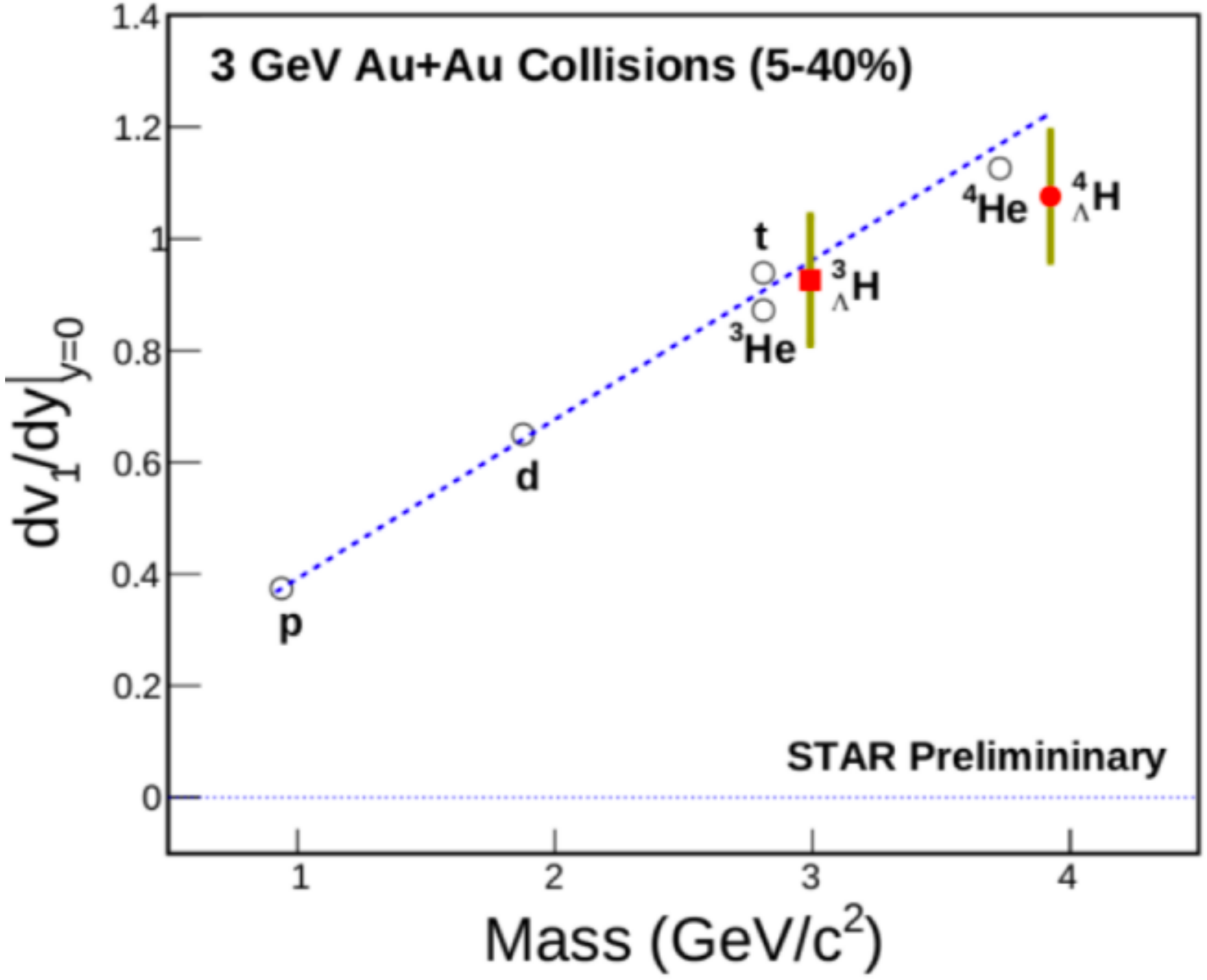
$^{4}_{\Lambda}H : \tau = 218.3 \pm 7.5(stat) \pm 11.8(syst)[ps]$

- $^{3}_{\Lambda}$**H** lifetime close to that of Λ (263 ± 2 ps), low binding energy

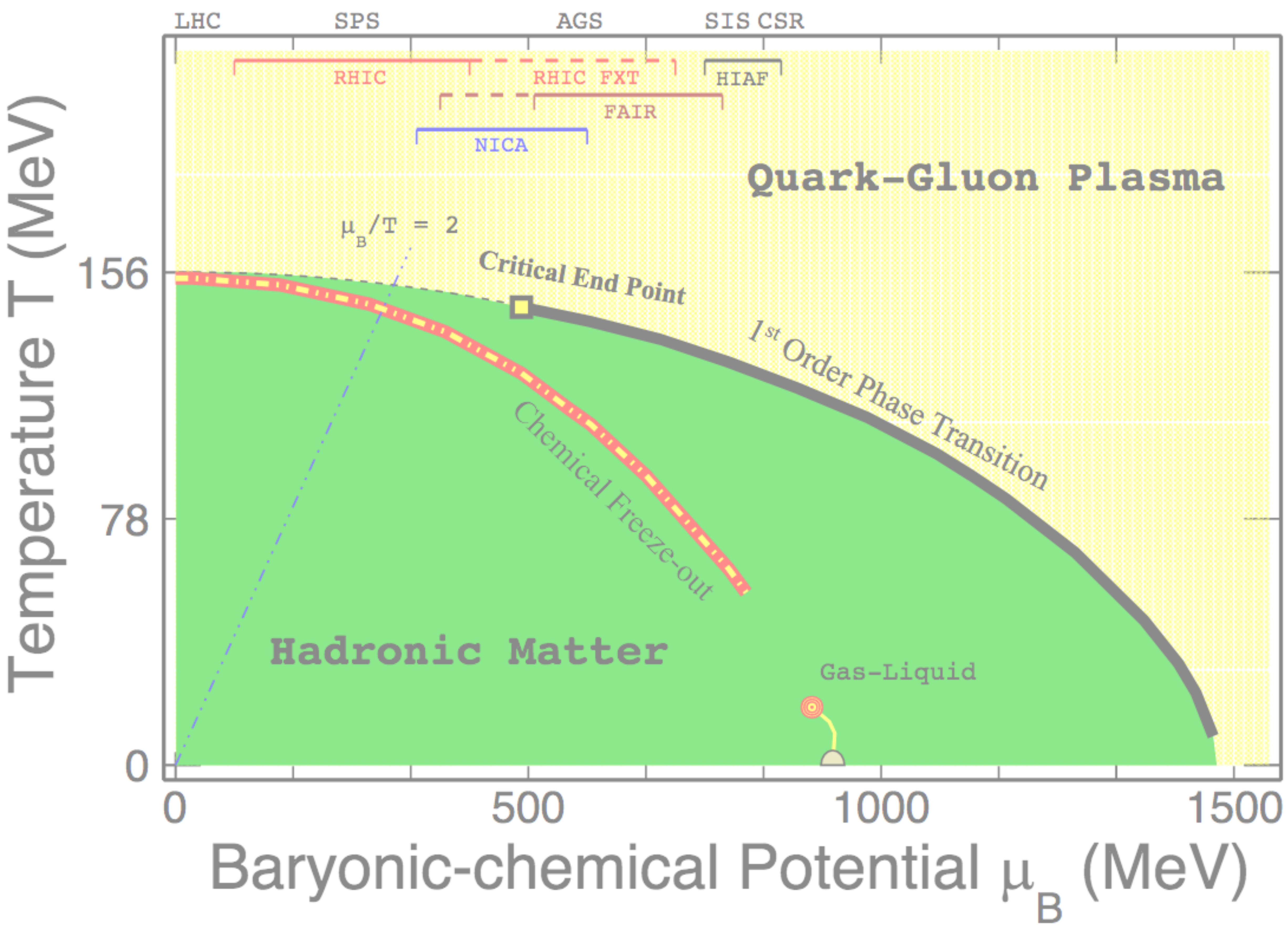
- Thermal (with canonical ensemble) and coalescence model calculations describe $^{3}_{\Lambda}$**H** yields
- $^{4}_{\Lambda}$**H** yield much higher than from coalescence model calculations

Hypernuclei flow at FXT 3 GeV

- Lifetime, yield, flow of hypernuclei important to understand Y-N interactions and hyperon contribution to EoS



- Directed flow of hypernuclei follow baryon number scaling
- Consistent with coalescence production of hypernuclei



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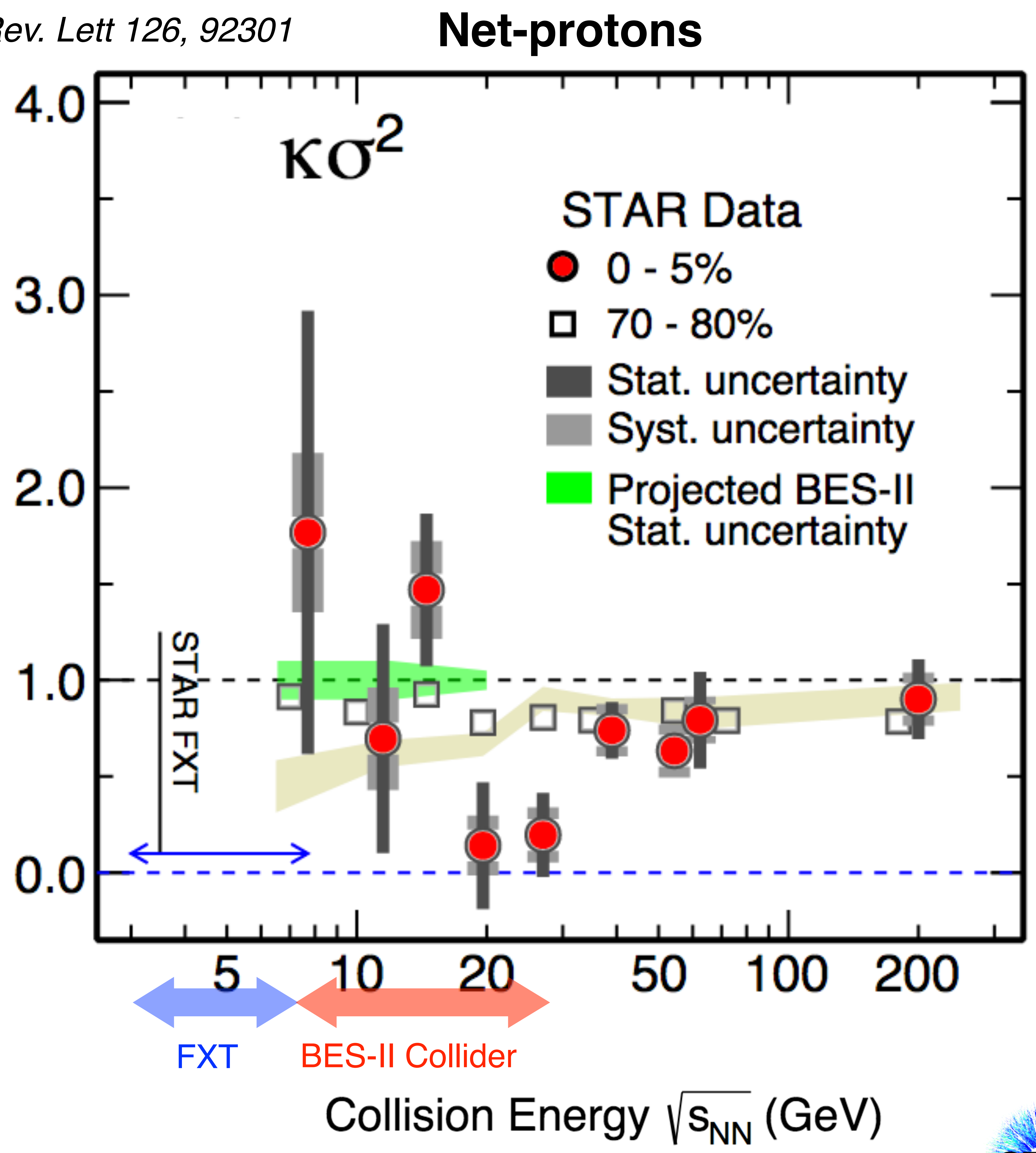
Net-proton cumulant measurements

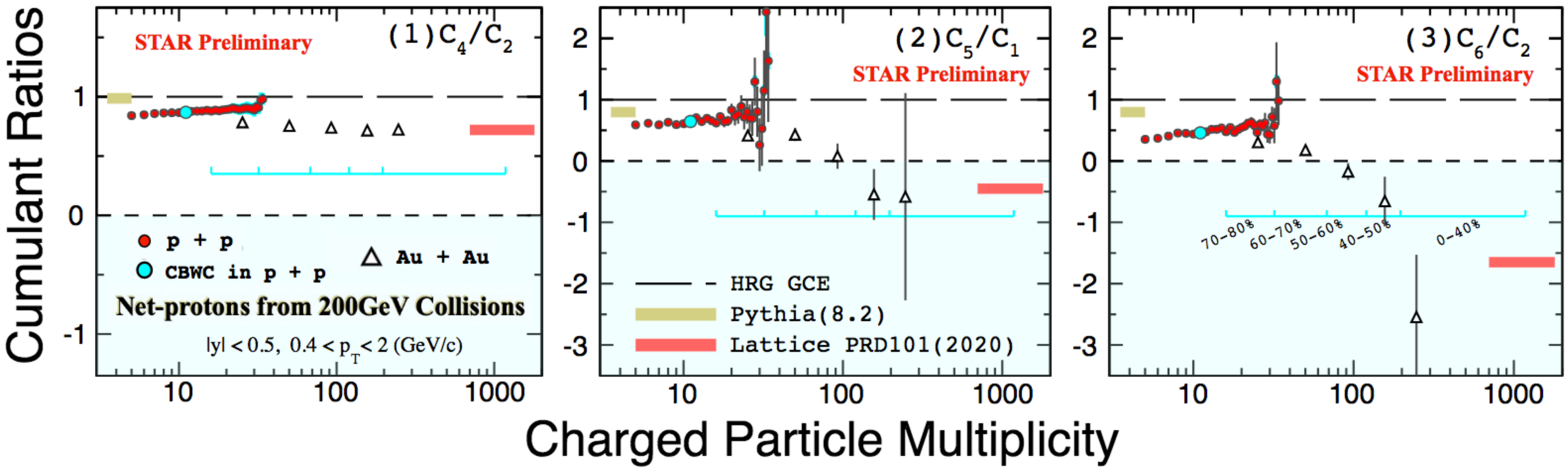
- Non-monotonic variation of net-proton kurtosis x variance vs collision energy (at 3.1σ significance)
- Qualitatively consistent with models involving a critical point

- BES-II and FXT measurements for cumulant ratios ongoing
  - Higher statistics
  - FXT measurements will help explore the nature of fluctuations at lower energies

Phys. Rev. Lett 126, 92301



Higher order cumulants of net-proton @ 200 GeV



- Measurements in 200 Gev Au+Au an p+p collisions
- C_6/C_2 values decrease with multiplicity in Au+Au collisions
- Negative C_6/C_2 in central Au+Au collisions, consistent with LQCD calculations with a cross-over transition to the QGP phase
- p+p results consistent with peripheral Au+Au, and weak multiplicity dependence

Summary and Outlook

- Collectivity measurements in FXT 3 GeV collisions
  - Change from a medium dominated by partonic interactions to one dominated by nuclear EoS

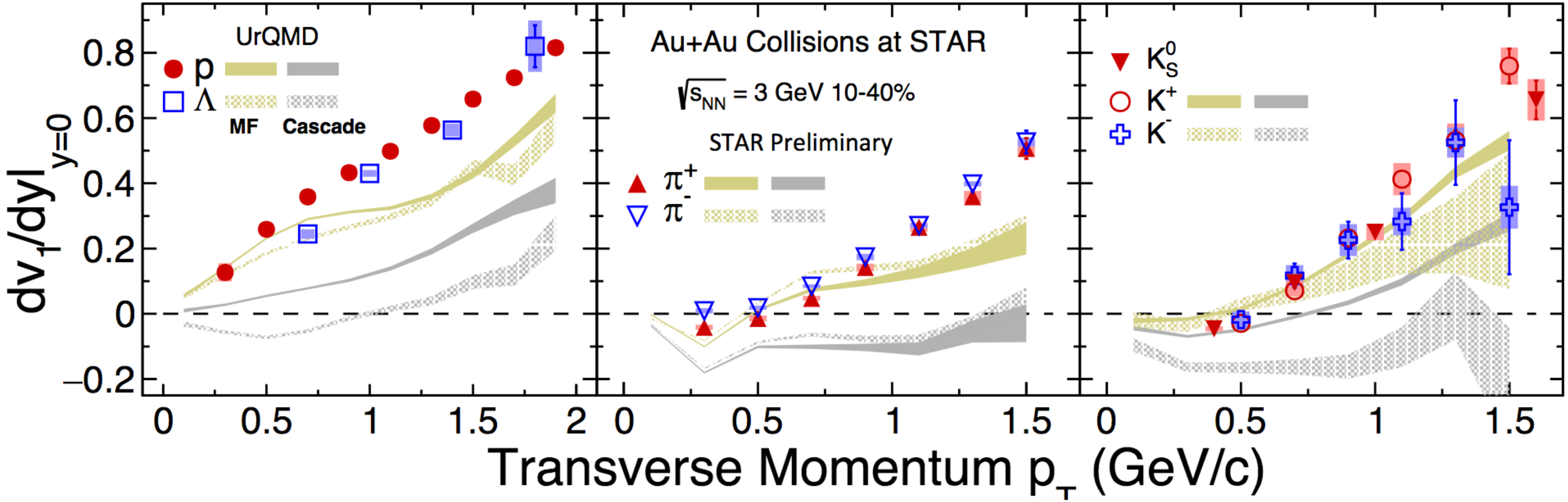
- Strangeness production vs beam energy
  - Strongly disfavors statistical models with Grand Canonical Ensemble
  - Strange hadron and hypernuclei production consistent with models with Canonical Ensemble

- Critical fluctuations
  - Higher order cumulant ratios consistent with a cross-over transition in 200 GeV collisions

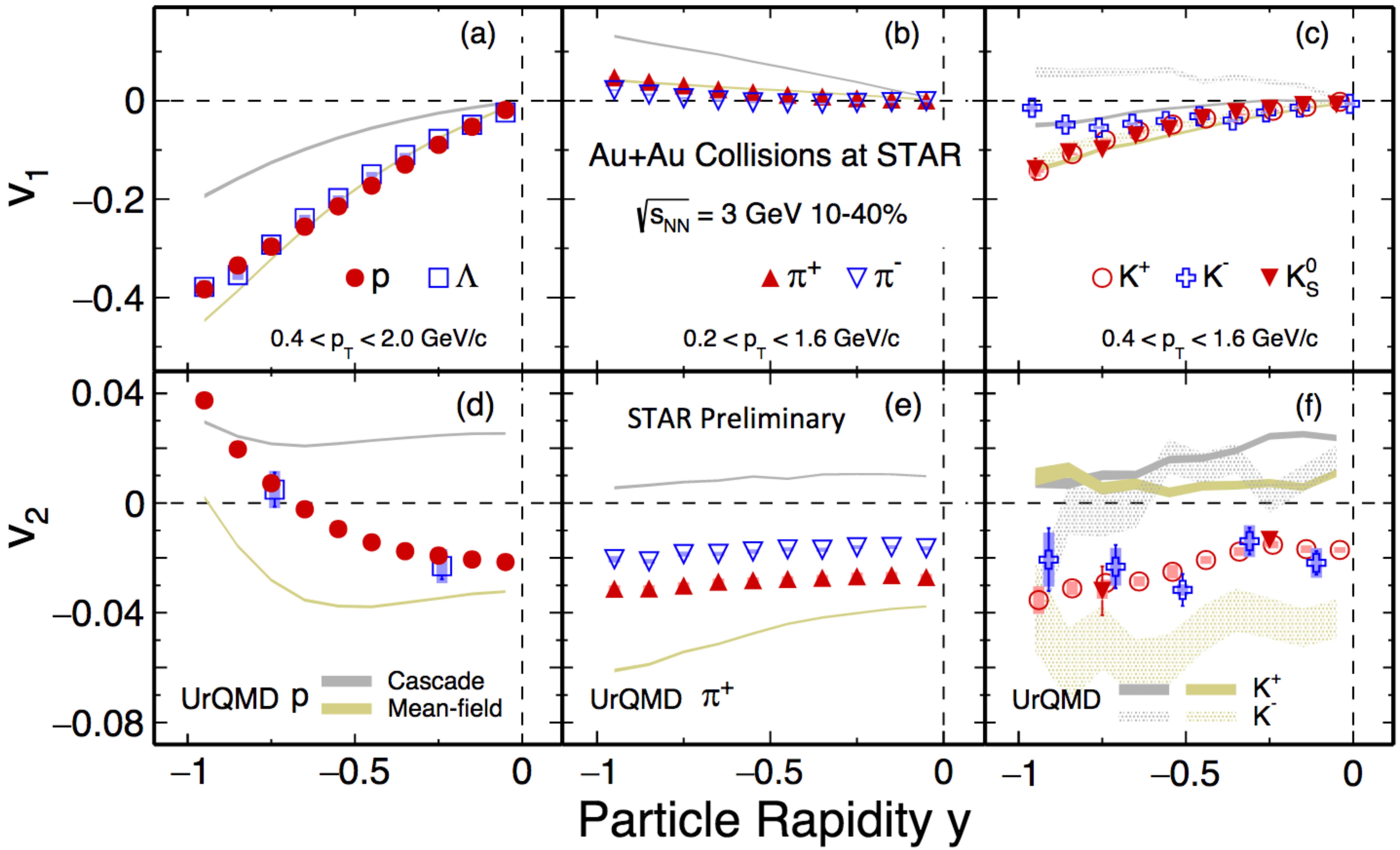
BES-II and FXT measurements on critical fluctuations, femtoscopy, flow,…. ongoing.
Look forward to more exciting results from STAR

Back Up

Identified hadron v_1 and v_2 at FXT 3 GeV: p_T dependence

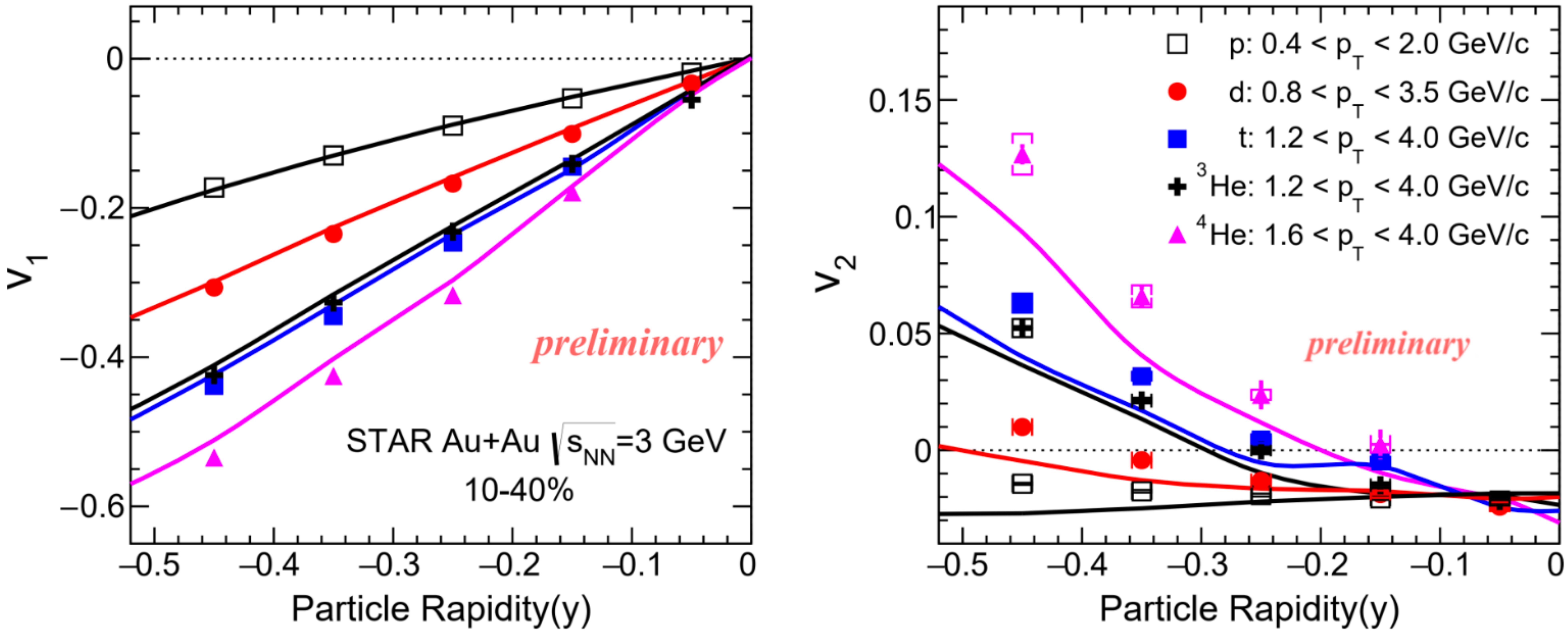


Identified hadron v_1 and v_2 at FXT 3 GeV: Rapidity dependence



Sooraj Radhakrishnan (for STAR Collaboration)

Light nuclei v_1 and v_2 at FXT 3 GeV

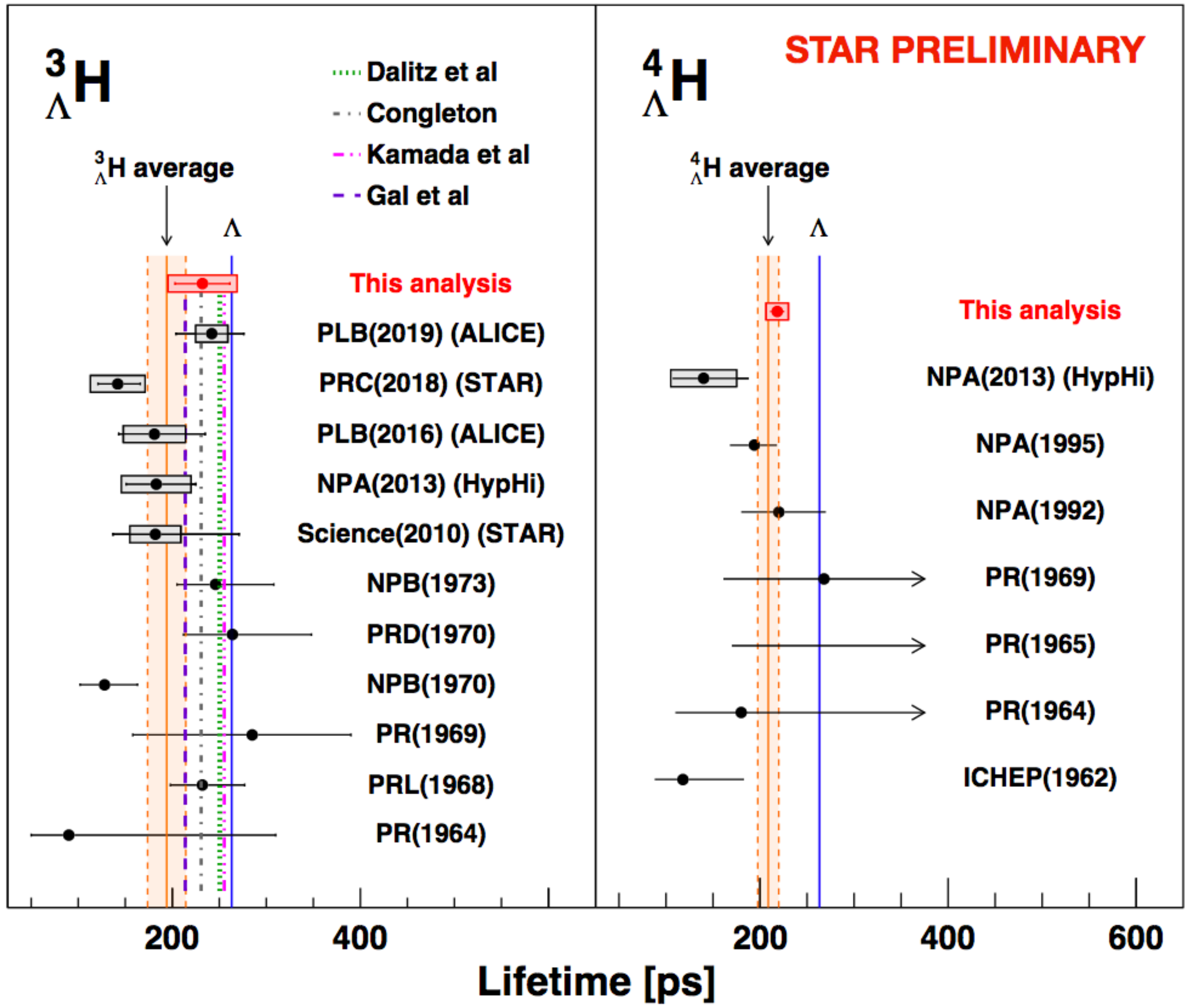


JAM: Phys. Rev. C. 97. 064913

- Lines from JAM model calculation with coalescence production for light nuclei
- Describes data qualitatively —> coalescence production of light nuclei

Hypernuclei production at FXT 3 GeV

- Lifetime, yield, flow of Hypernuclei important to understand Y-N interactions and hyperon contribution to EoS
- High μ_B at low energies —> large yields for hypernuclei



- Increased precision for lifetime measurements for $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H
- $^{3}_{\Lambda}$H lifetime close to that of Λ as expected due to the low binding energy

$$^{3}_{\Lambda}H : \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$$
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