The 19th International Conference on Strangeness in Quark Matter

May 17-21, 2021, sponsored by Brookhaven National Laboratory, Upton, New York

SQM2021

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Updates on Flavor Production from STAR

Sooraj Radhakrishnan

(for the STAR Collaboration)

Kent State University/Lawrence Berkeley National Laboratory

STAR

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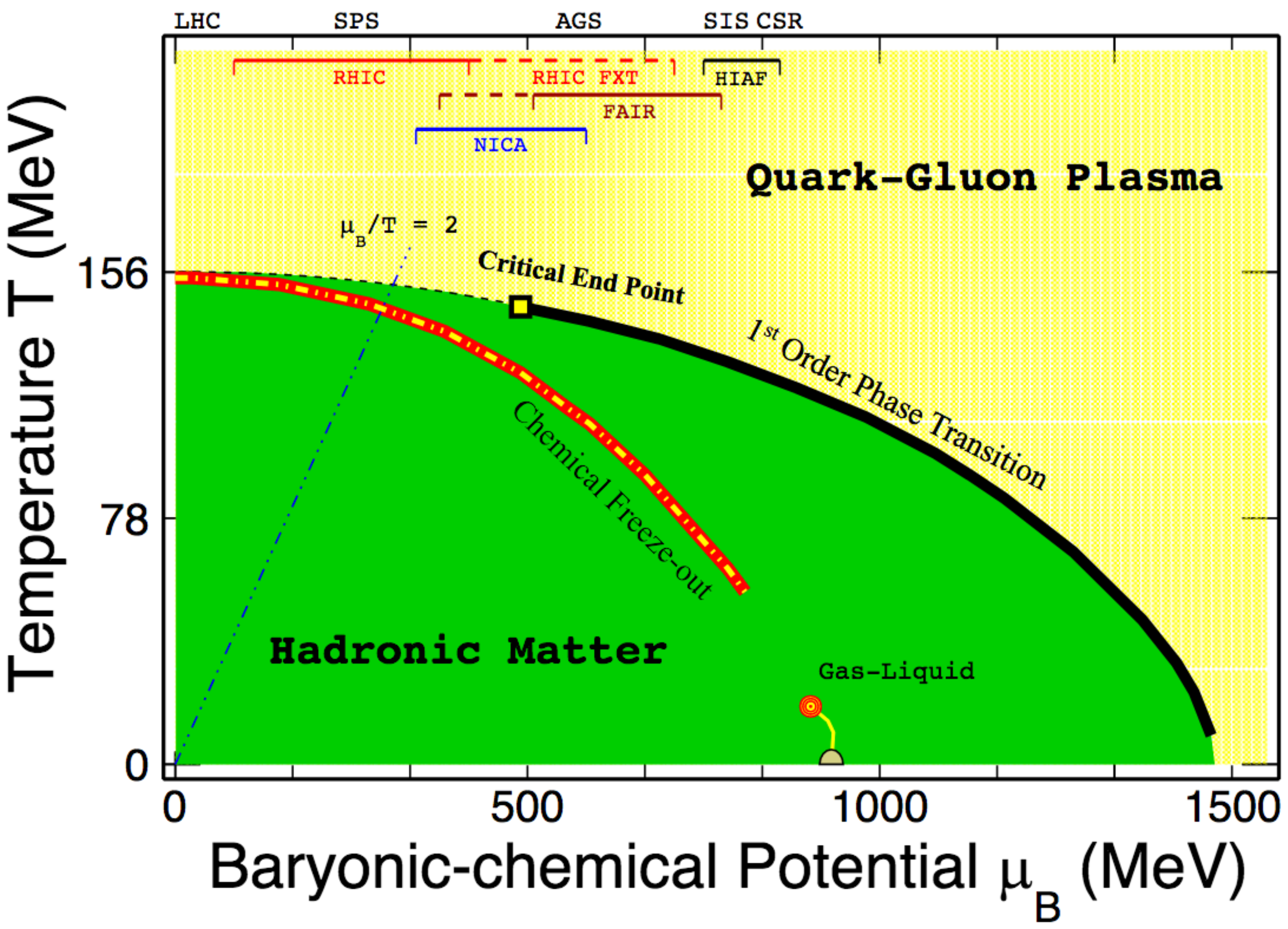
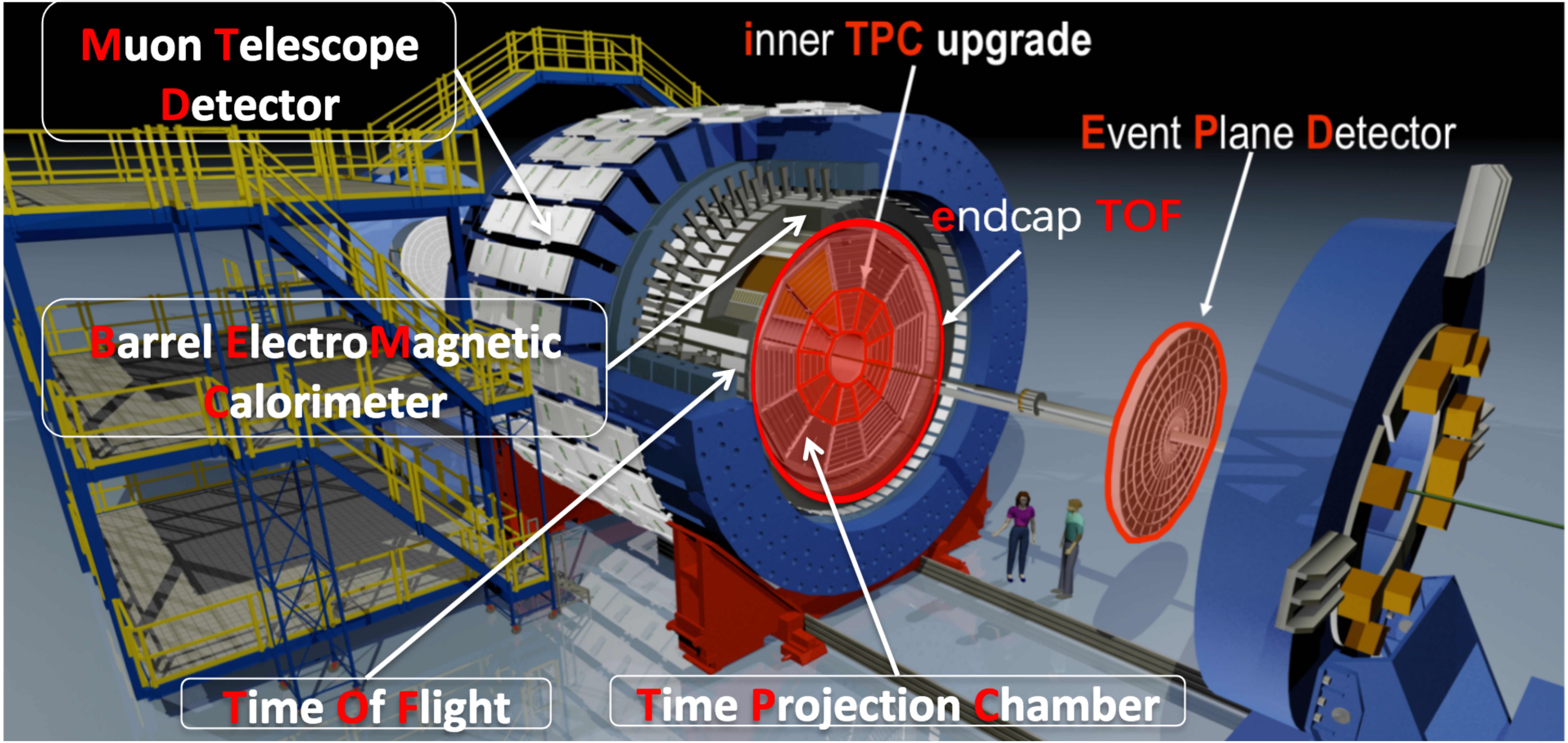
Flavor Production at STAR



STAR, arXiv:2001.02852

- Heavy flavor at top RHIC energies:
  - Probe Quark Gluon Plasma
- Light and strange flavor production in BES:
  - Nature of the produced medium
  - Canonical suppression of strangeness
- High μ_B region, hypernuclei production:
  - Hyperon contribution to nuclear EoS
  - Charge symmetry breaking

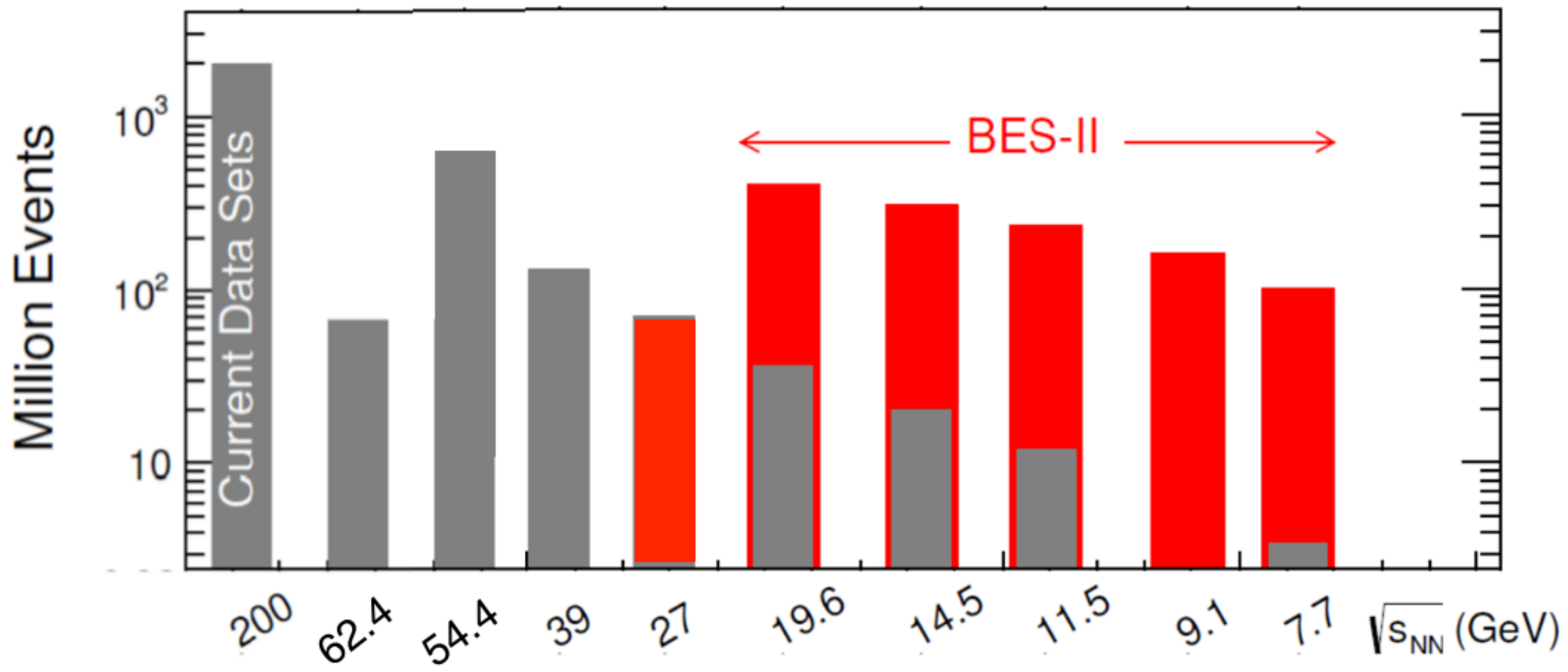
STAR Detector



Datasets and STAR BES-II

- Collision energies: 200 — 7.7 GeV, μ_B: 20 — 420 MeV
- Access with FXT to high baryon density regions with μ_B up to 720 MeV

Statistics comparison to BES-I



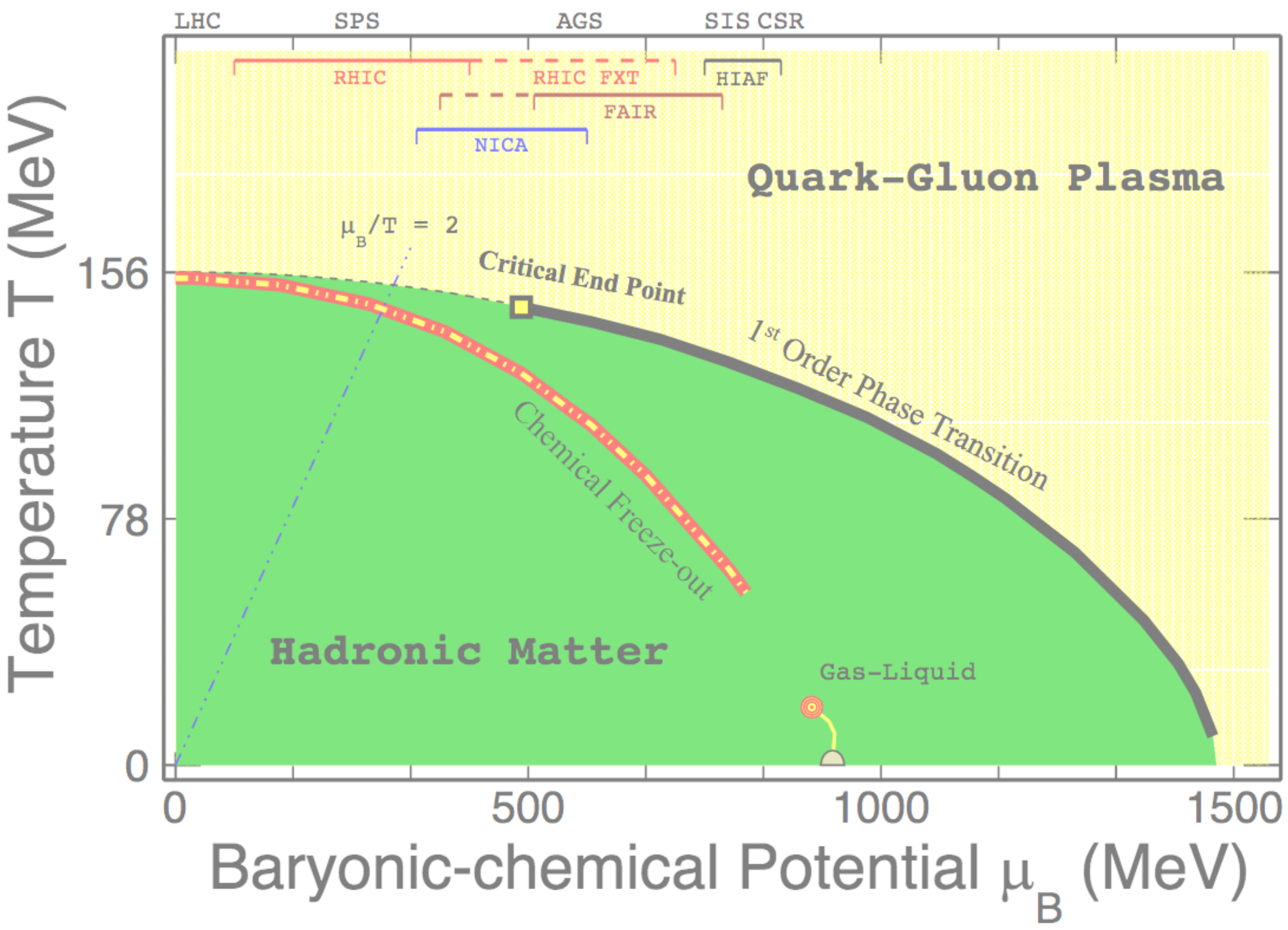
STAR BES-II, FXT data taking

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

STAR BES-II, Collider mode data taking

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

- Successful completion of BES-II and FXT data taking, thanks to excellent RHIC performance!



▸ **Heavy flavor at top RHIC energies:**

- Probe Quark Gluon Plasma

▸ Light and strange flavor production in BES:

- Nature of the produced medium
- Canonical suppression of strangeness

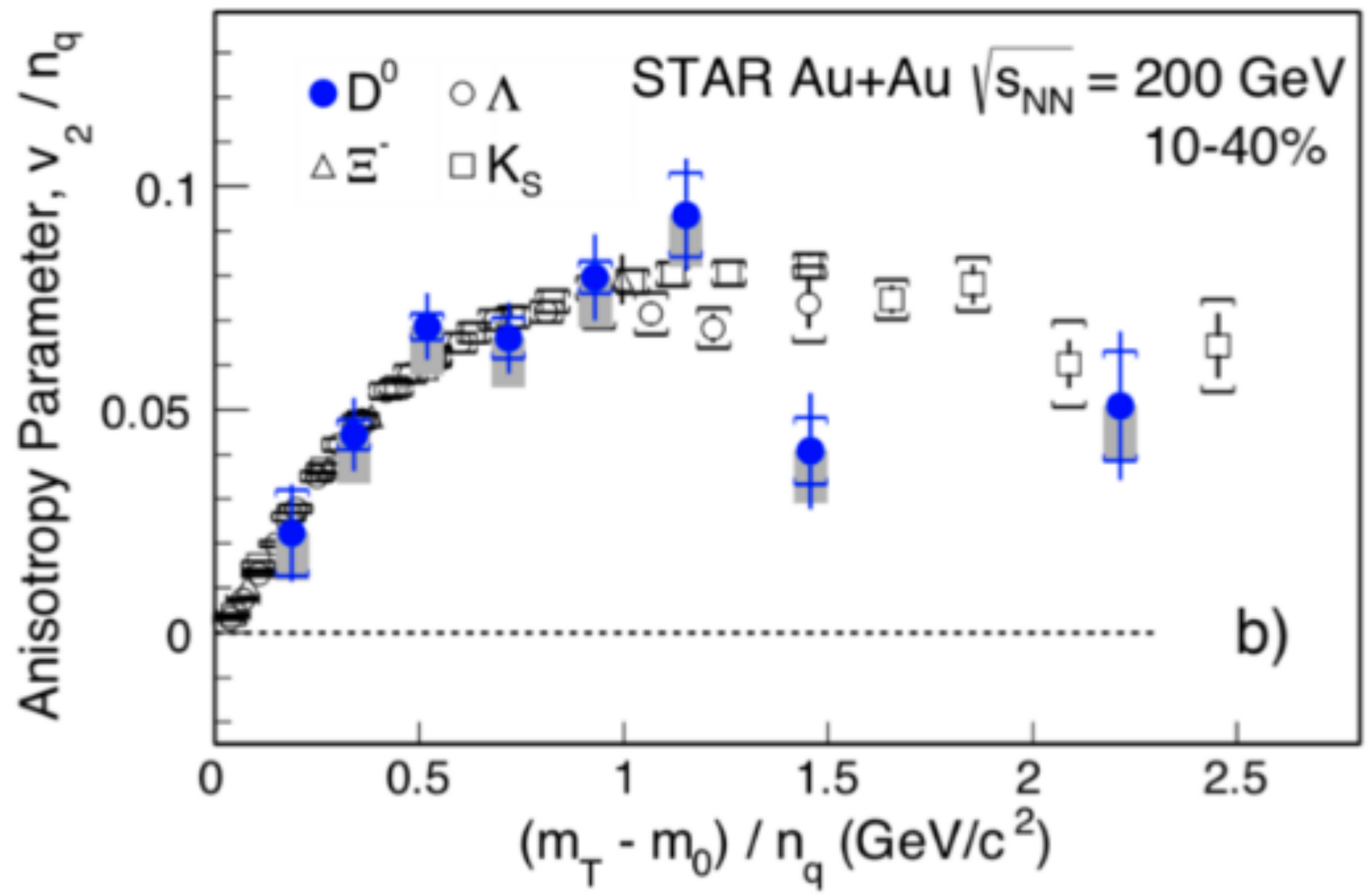
▸ High μ_B region, hypernuclei production:

- Hyperon contribution to nuclear EoS
- Charge symmetry breaking

Energy Dependence of HF Electron v_2

- Large v_2 for D mesons at 200 GeV, comparable to light hadrons
- HF flow at lower energies? Temperature dependence?
- High statistics data at 54.4 and 27 GeV

STAR: Phys.Rev.Lett. 118, 212301 (2017)



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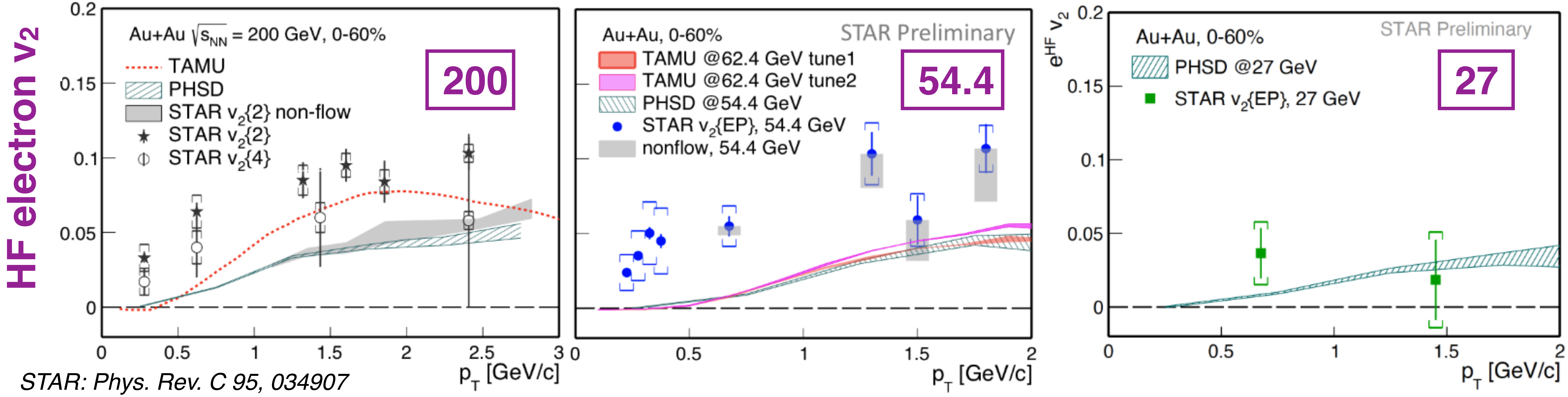


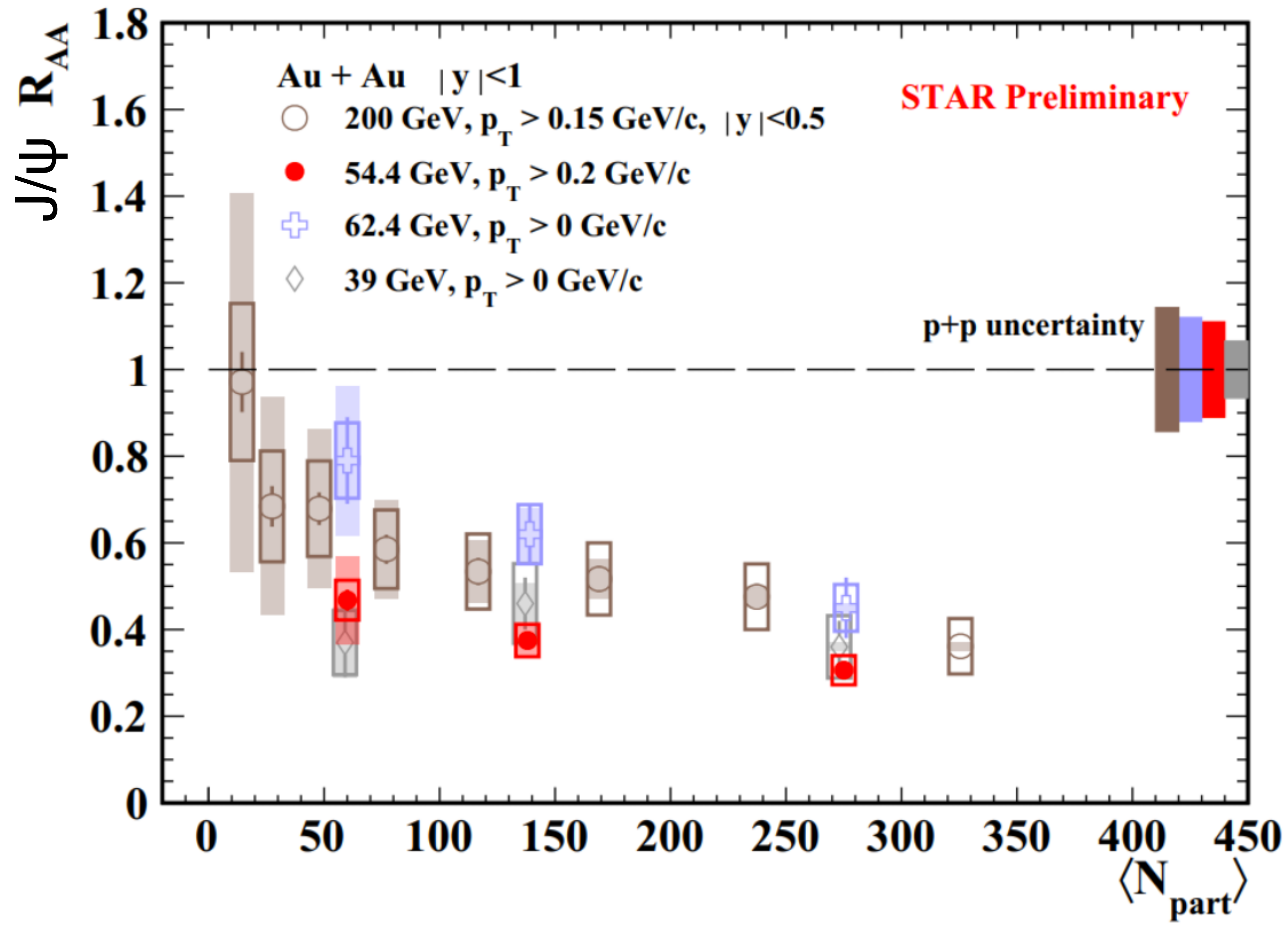
STAR: Phys. Rev. C 95, 034907

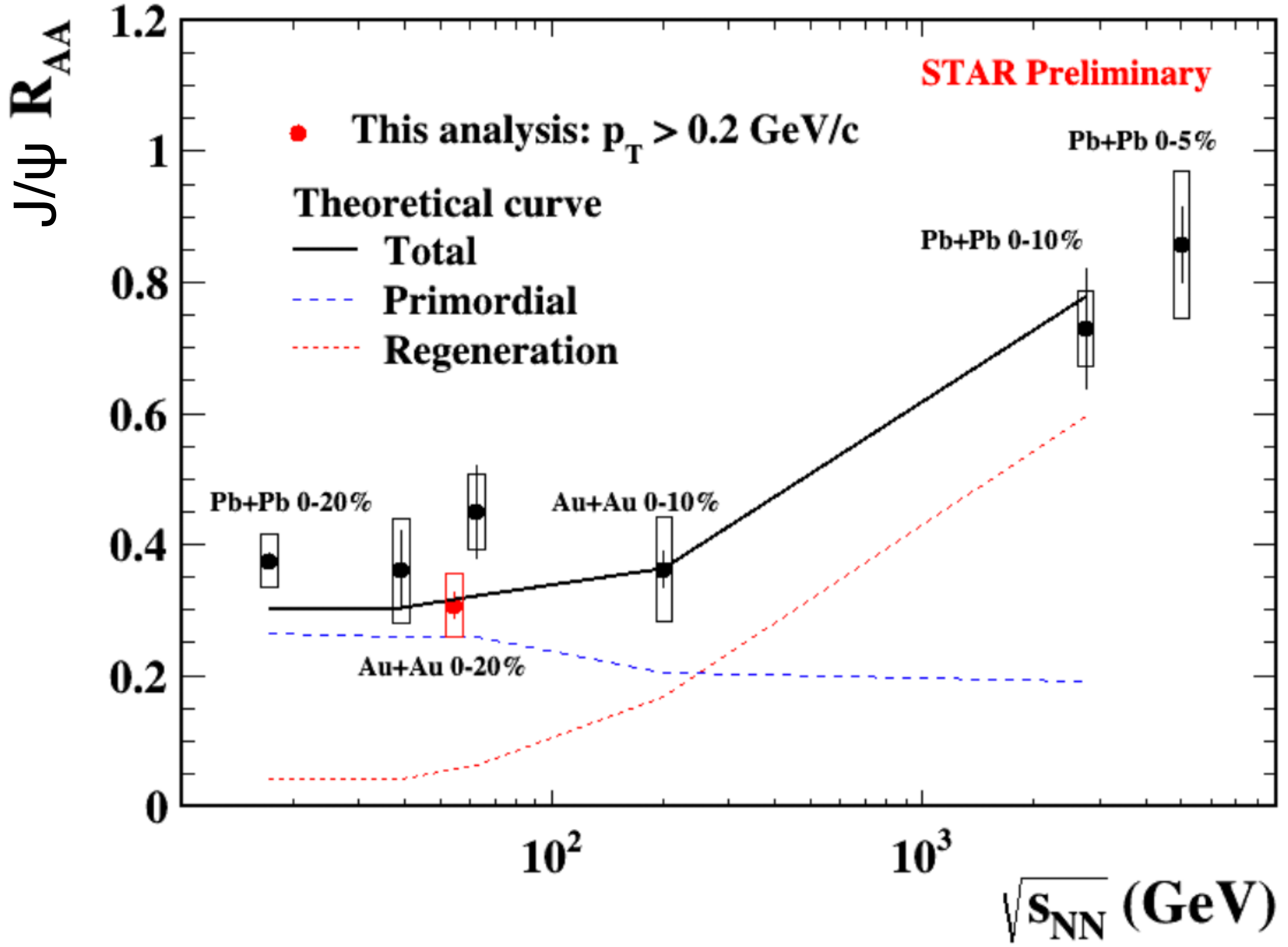
- Similar v_2 for HF electrons at 200 and 54.4 GeV, hint of smaller v_2 at 27 GeV
- Models fail describing data at low p_T (< 1.4 GeV/c) for 54.4 GeV

Talk by Shenghui Zhang: 19/05 Thu, 09.50 (D)

Energy Dependence of J/ψ Suppression

- J/ψ suppression: Interplay of color screening and regeneration
- 10x more data at 54.4 GeV than for previous measurements at 62.4 and 39 GeV





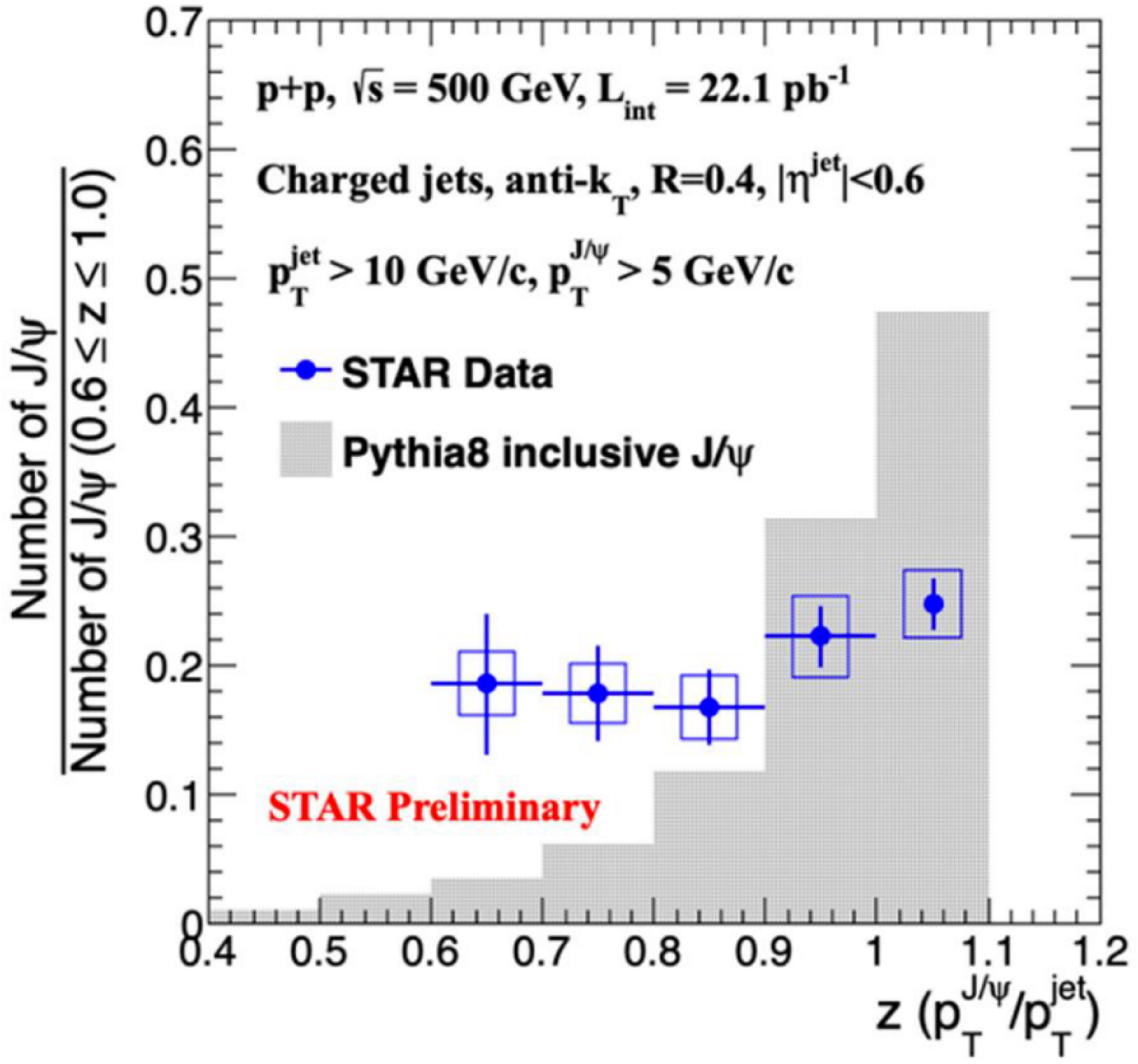
Theoretical curve:

R.Rapp et al Phys. Rev. C 82 (2010) 064905 (private communications)

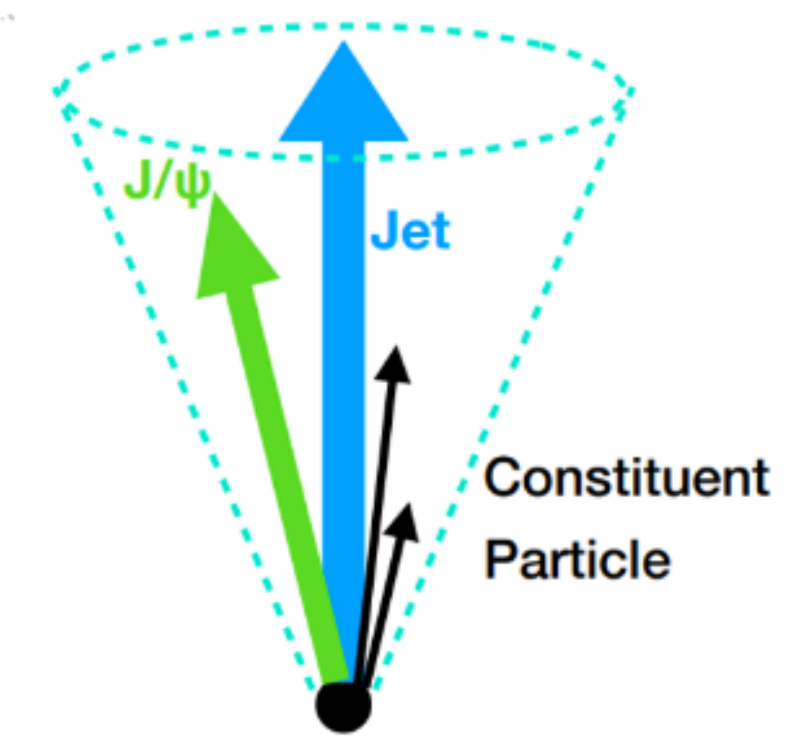
- Similar J/ψ R_{AA} values between 54.4 and 200 GeV
- Will help constrain the contributions from color screening and regeneration

J/ψ Production in Jet in p+p Collisions

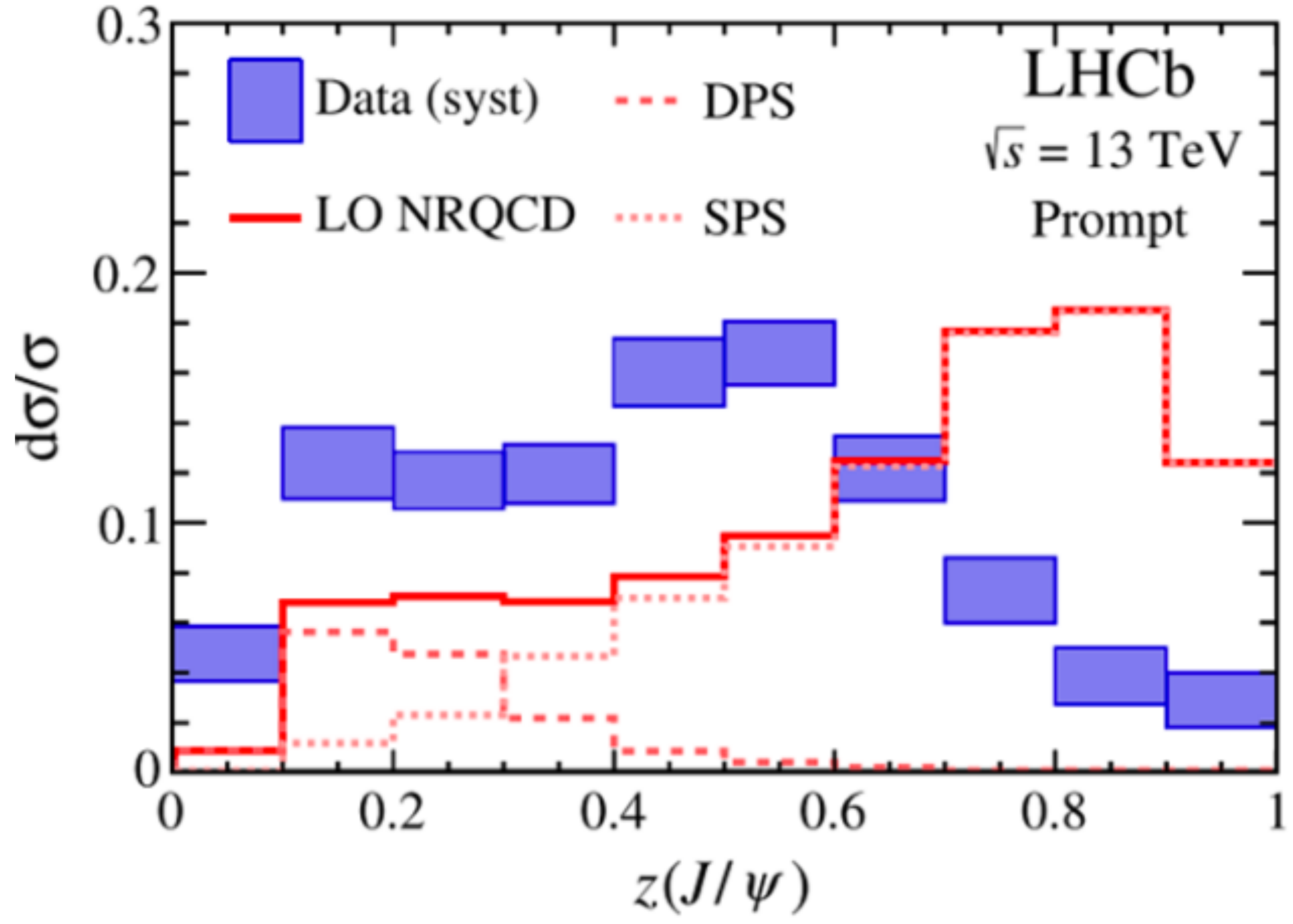
- J/ψ production mechanism in p+p collisions: also important to understand suppression in QGP
- Produced directly or in parton shower (associated with jets)?



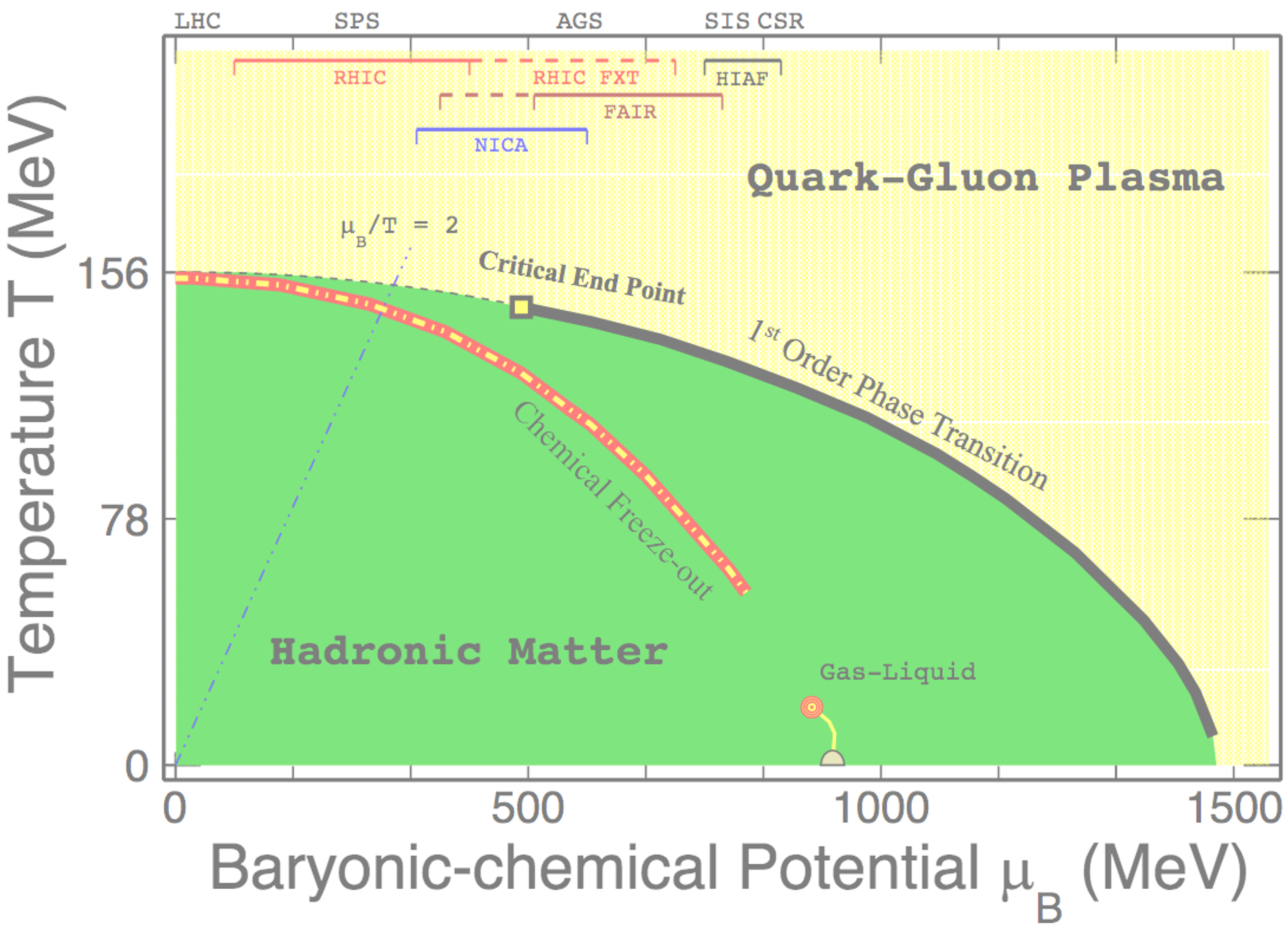
- First measurement of J/ψ production in jets at RHIC
- Less isolated production in data than in PYTHIA. Similar to observation at LHC



LHCb, PRL 118, (2017) 192001



Talk by Kaifeng Shen: 21/05 Fri, 10.10 (D)



- Heavy flavor at top RHIC energies:
  - Probe Quark Gluon Plasma
- **Light and strange flavor production in BES:**
  - Nature of the produced medium
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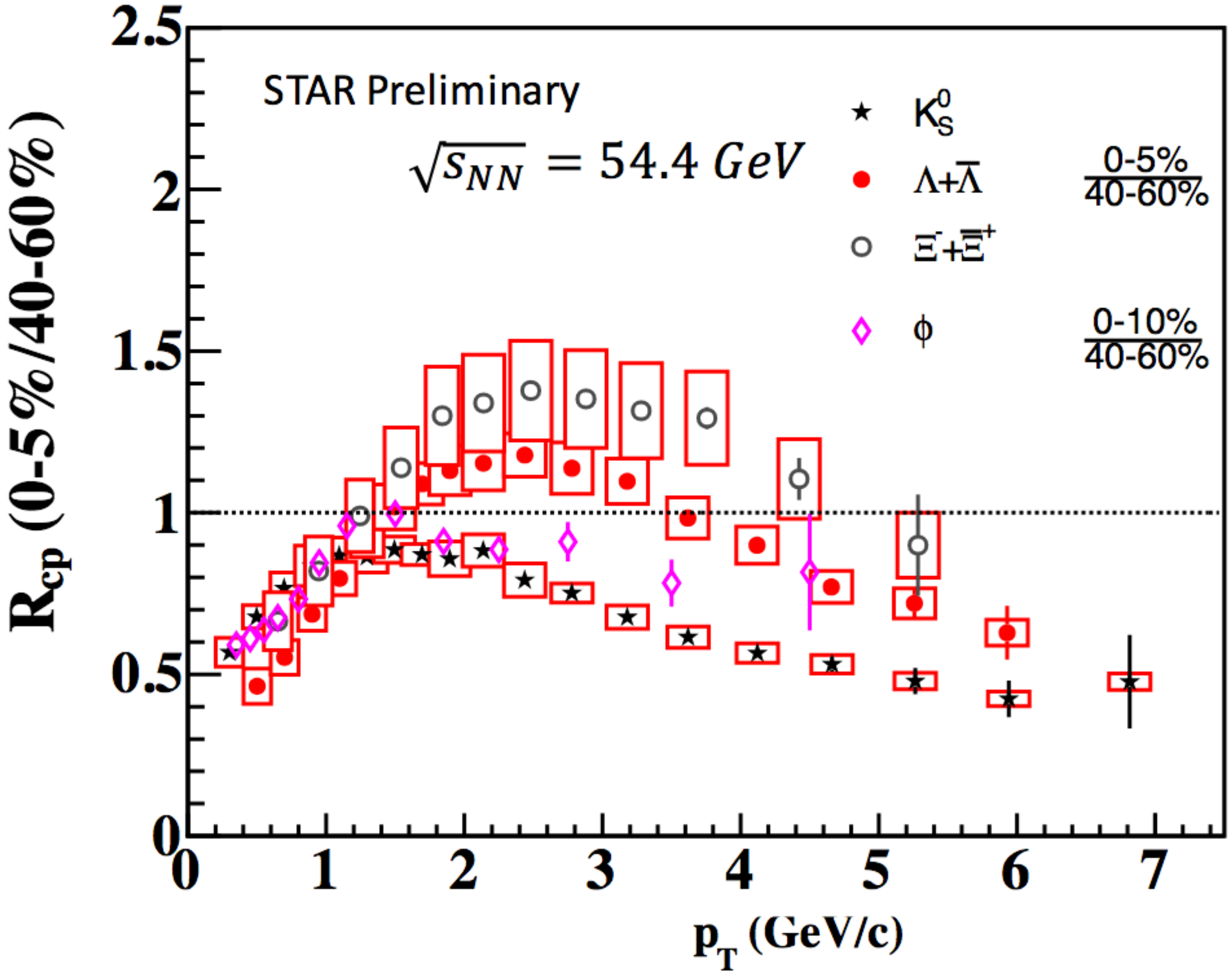
- High μ_B region, hypernuclei production:
  - Hyperon contribution to nuclear EoS
  - Charge symmetry breaking

Strange hadron production at 54.4 GeV

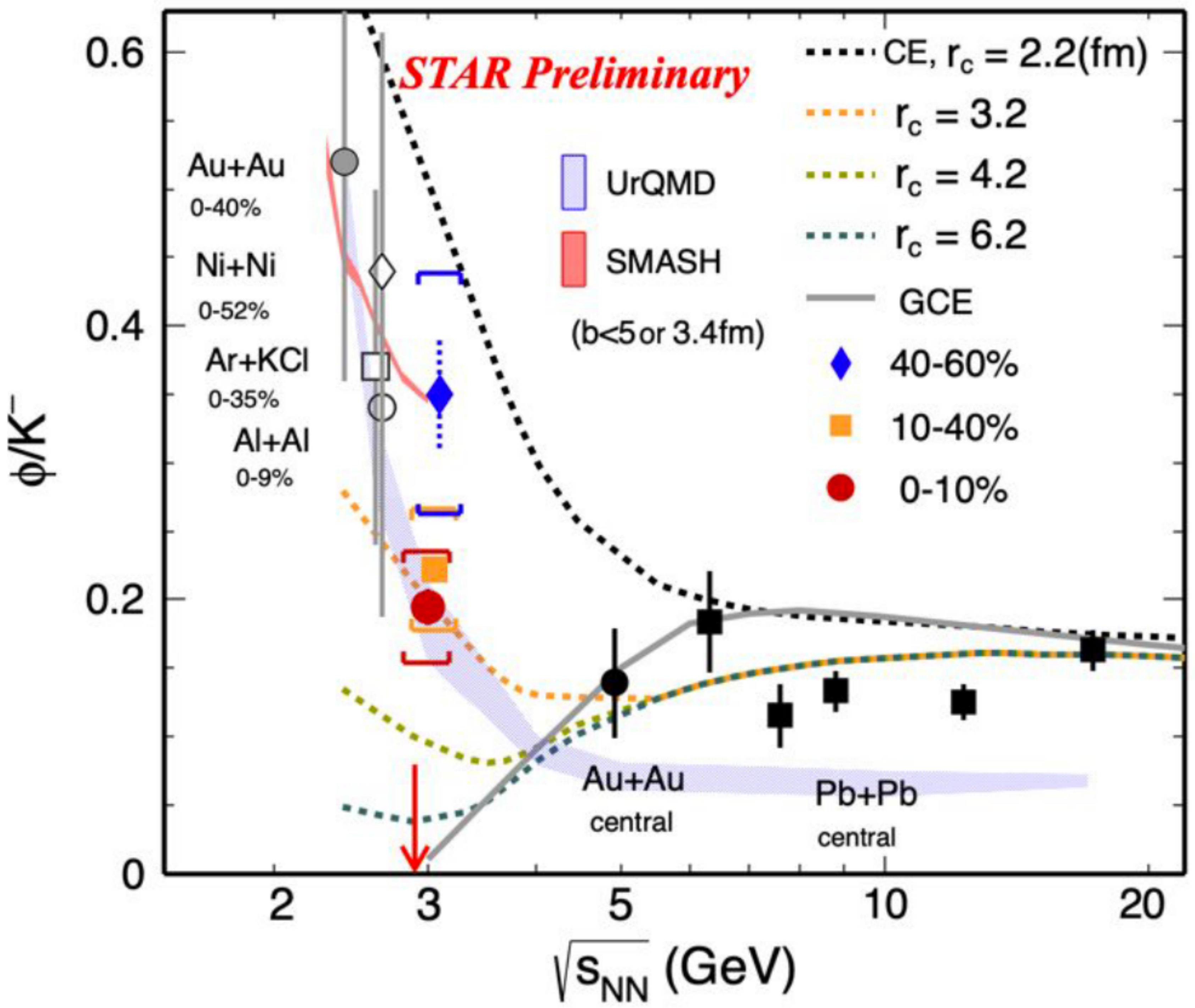


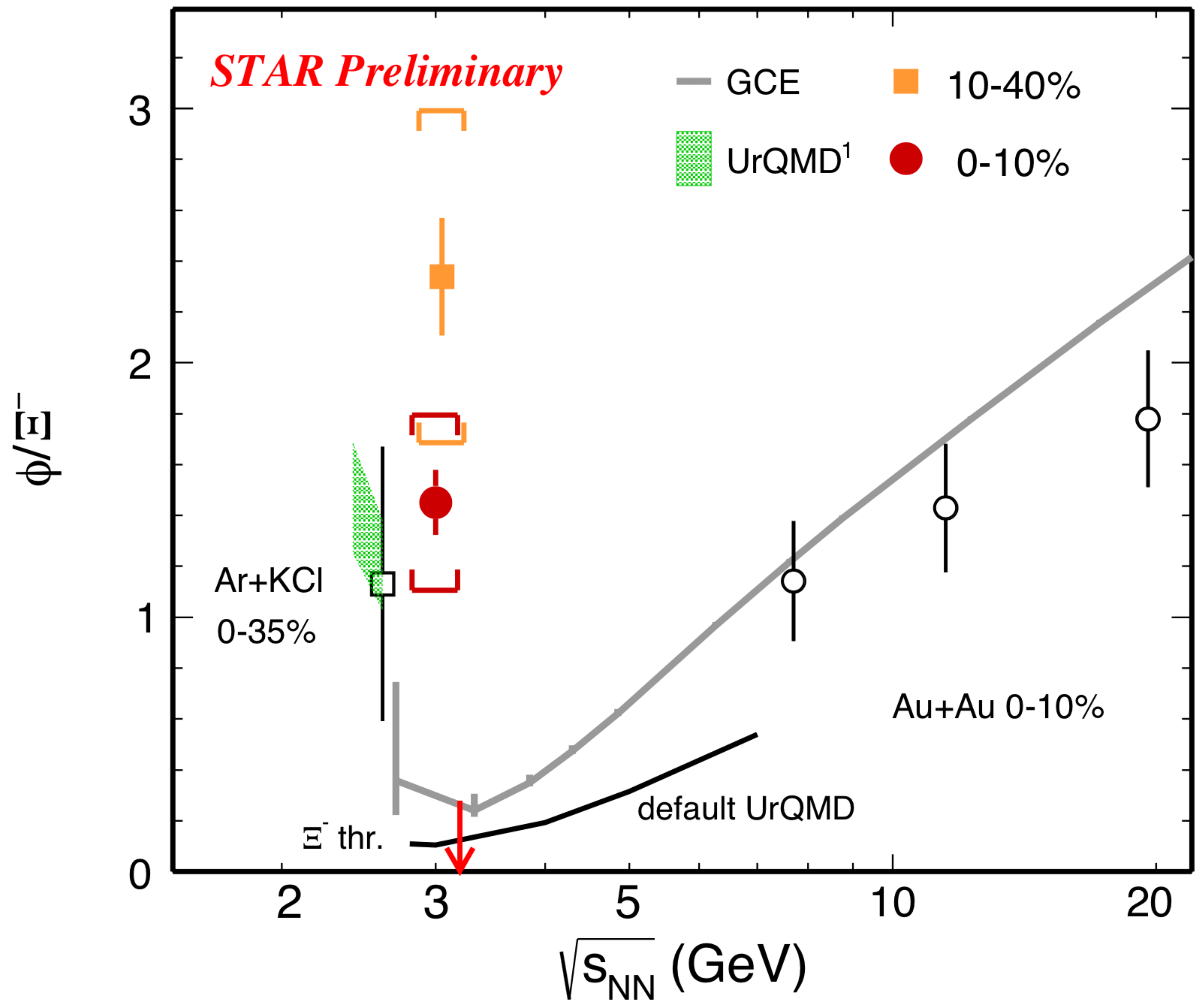
- Suppression at high p_T : Parton energy loss
- Separation between baryons and mesons at intermediate p_T ($2 < p_T < 6$ GeV/c): From coalescence hadronization

Talk by Yan Huang: 18/05 Wed, 09.30 (B)

Canonical Suppression: ϕ, Ξ Production at 3 GeV

- Low energies and/or small systems: Local strangeness conservation
- Canonical instead of Grand Canonical Ensemble describes statistical production





$$\phi(s\bar{s}), S = 0$$
$$K^-(s\bar{u}), S = 1$$
$$\Xi^-(dss), S = 2$$

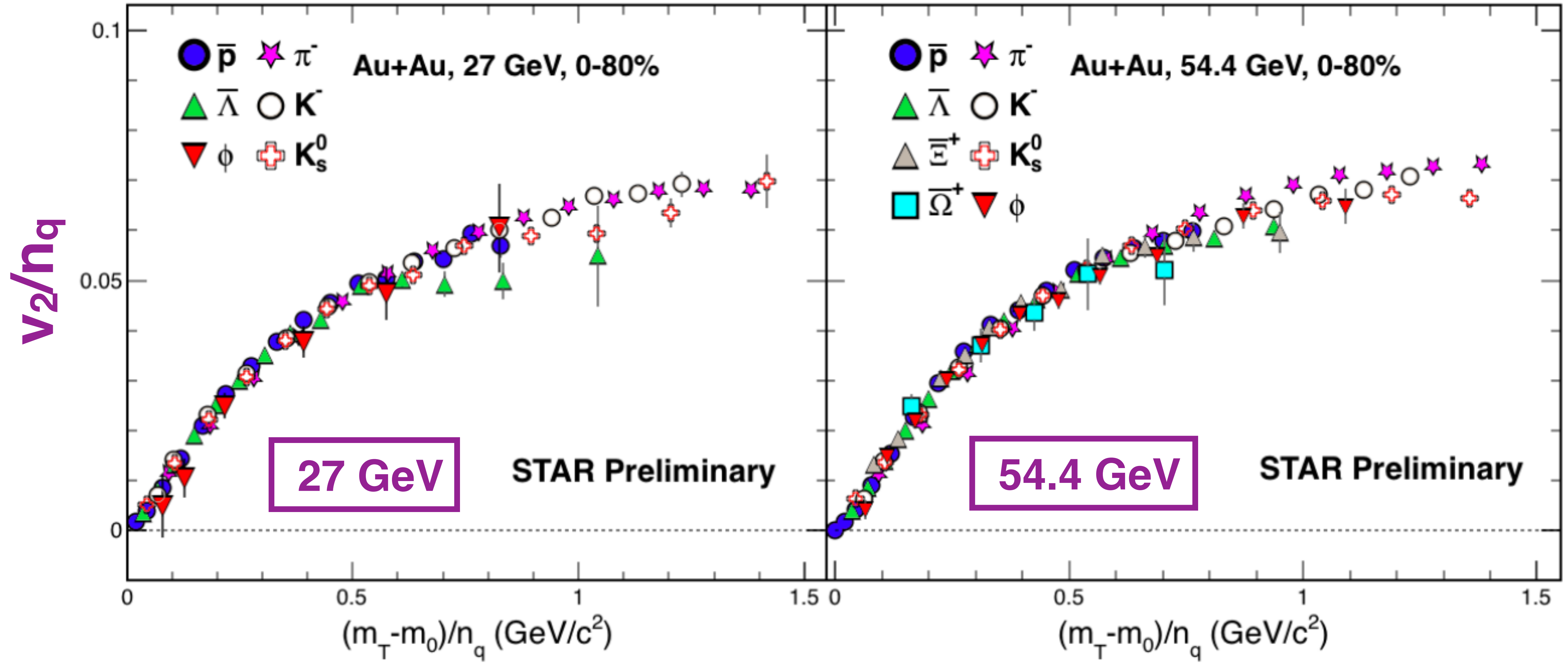
Statistical models:
A. Andronic et al, Nucl. Phys. A 772, 167;
J. Cleymans et al, Phys. Lett. B 603, 146

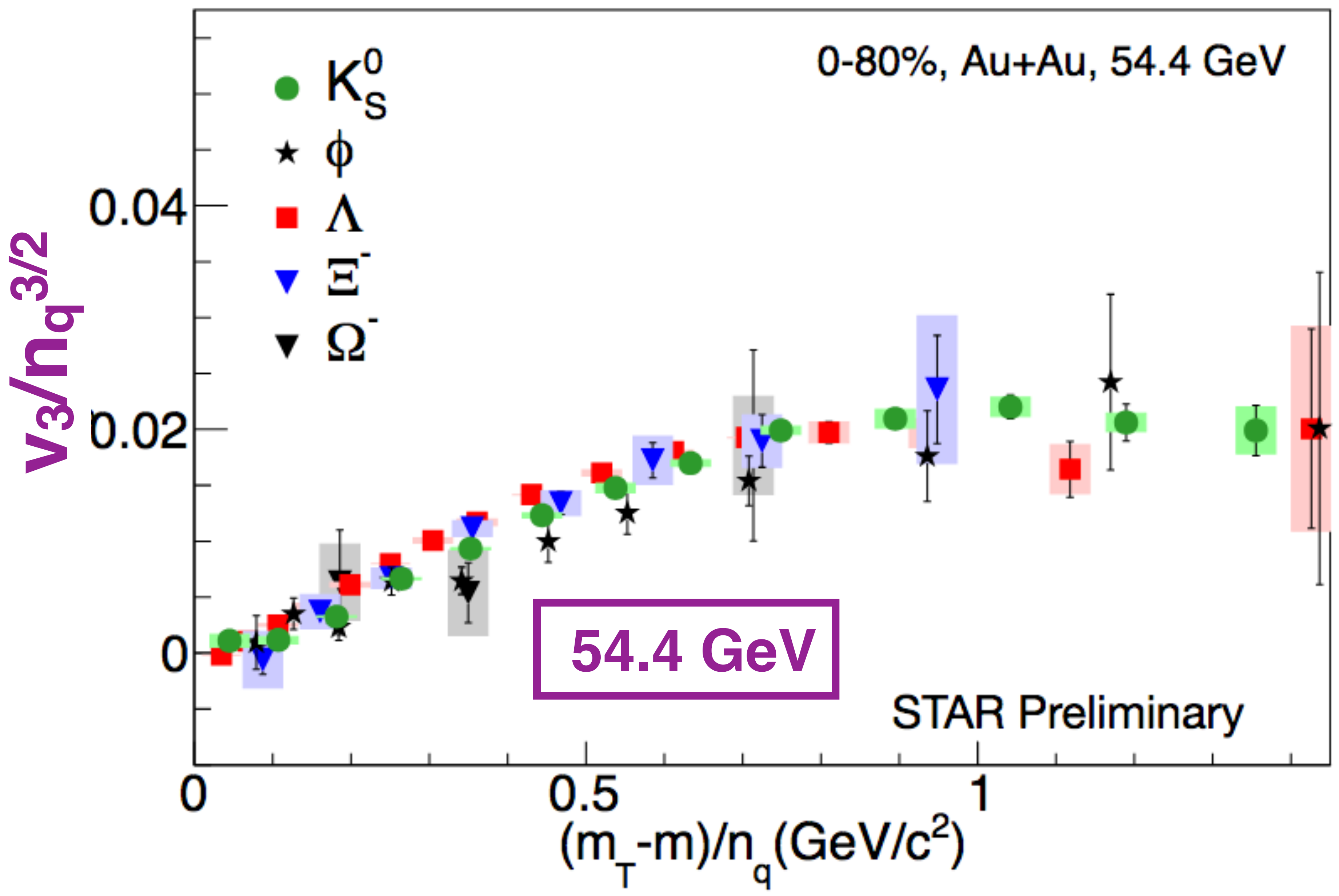
- ϕ/K^- and ϕ/Ξ^- measurements at 3 GeV strongly disfavor GCE

Talk by Guannan Xie: 18/05 Wed, 12.30 (B)

Partonic Collectivity: Strange Hadron Flow

- Strange hadrons: Small hadronic cross-section. Partonic vs hadronic contribution to flow

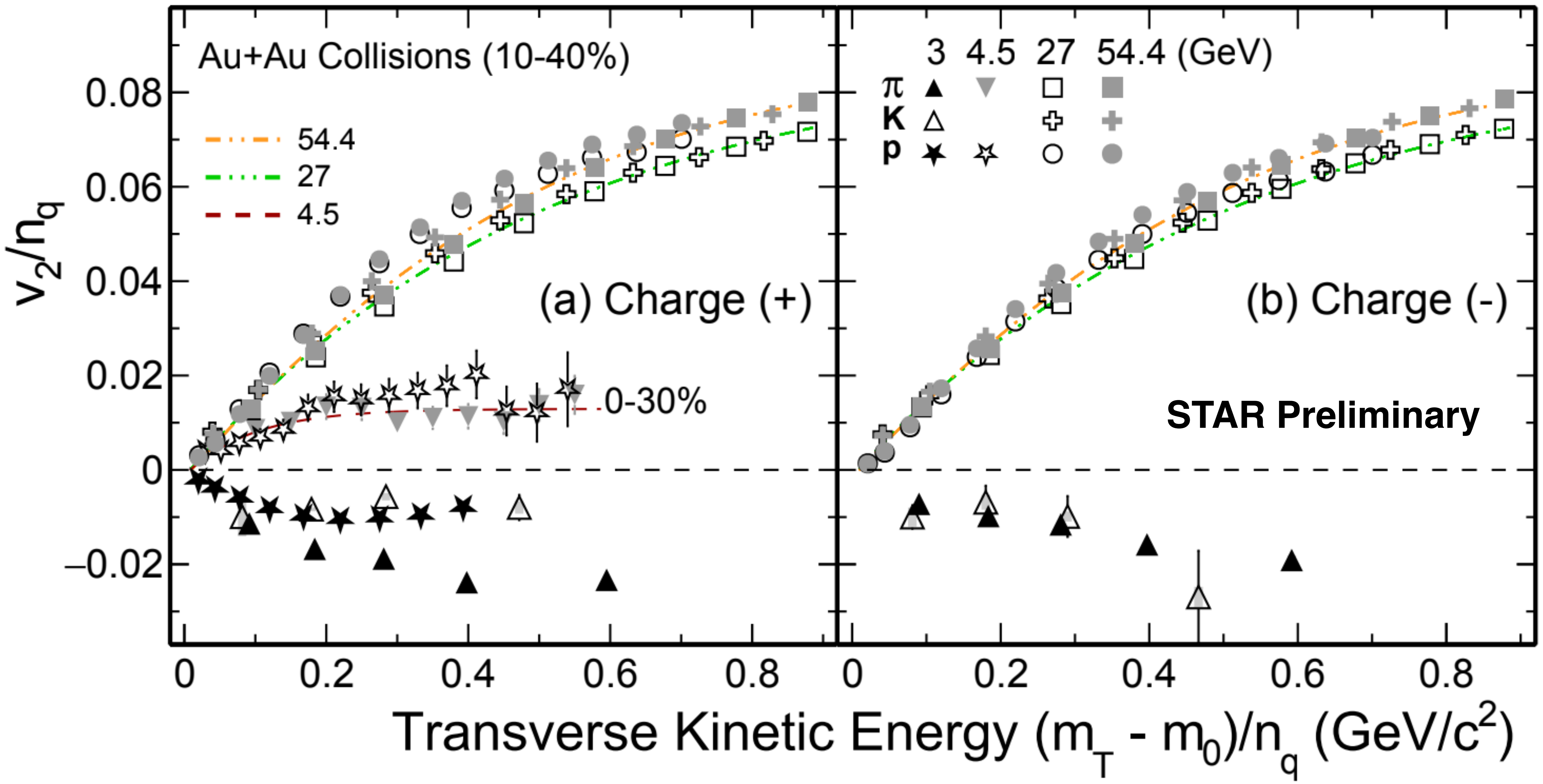




- NCQ scaling holds for strange hadrons at 54.4 and 27 GeV: Dominance of partonic collectivity

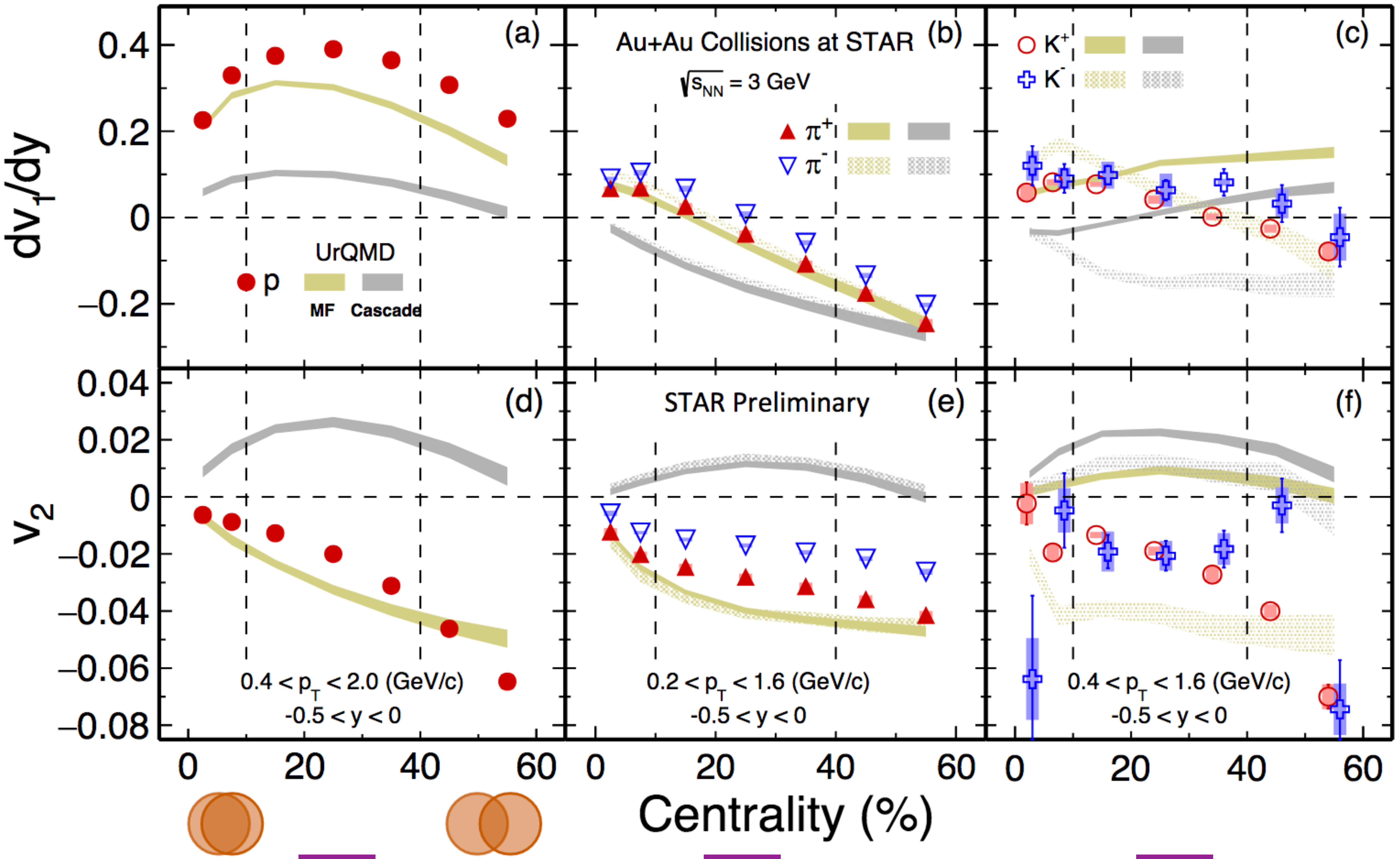
Mass ordering at very low $(m_T-m_0)/n_q$ <~ 0.4 GeV/c^2

Collectivity at 3 GeV



- 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
  — Medium less dominated by partonic interactions

Collectivity at 3 GeV

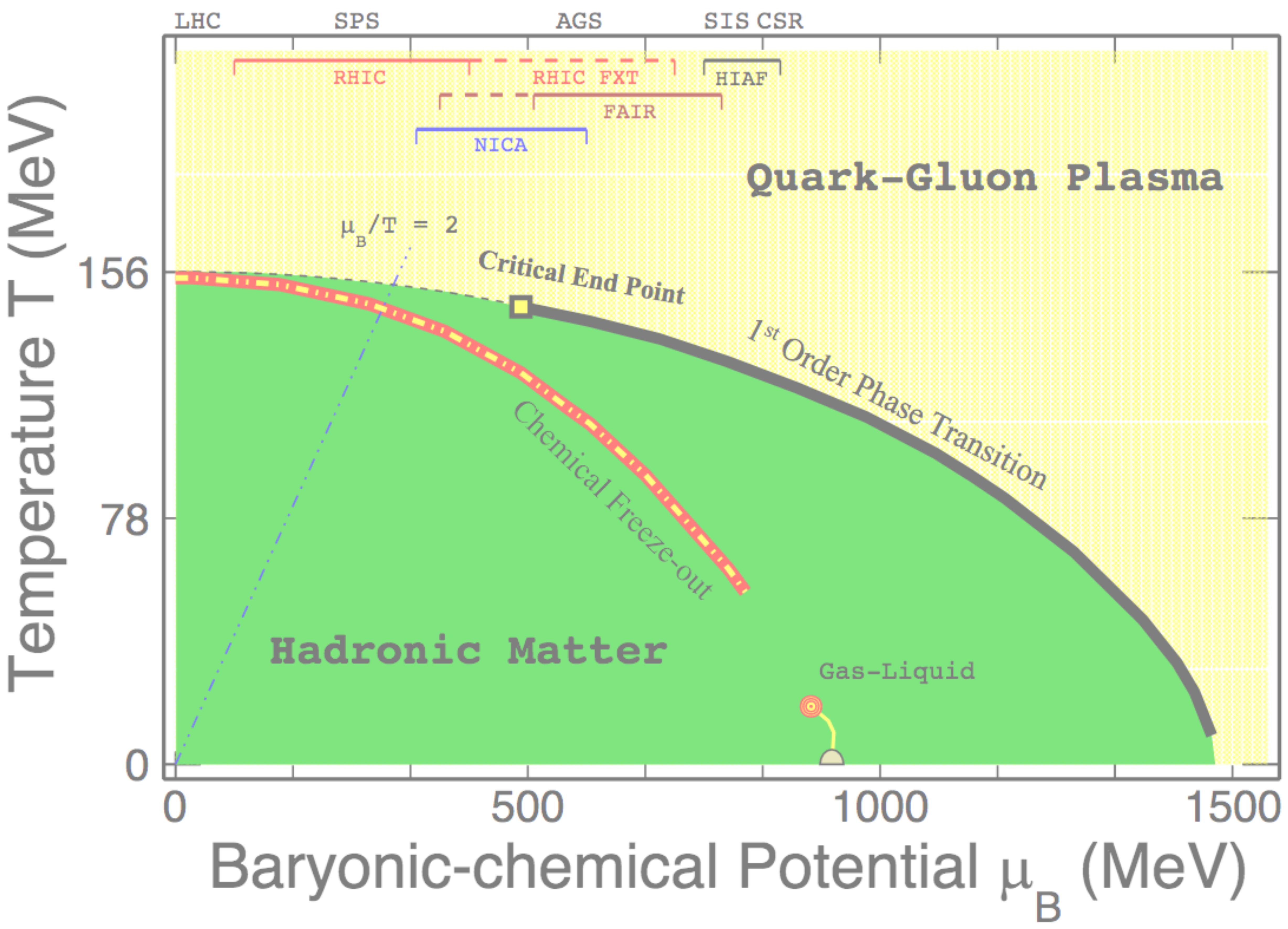


p π K

- UrQMD cascade mode fails to describe data
- Need baryonic mean field interactions to generate trends seen in data

- Medium dominated by baryonic interactions and nuclear EoS

Talk by Guannan Xie: 18/05 Wed, 12.30 (B)



- Heavy flavor at top RHIC energies:
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- Light and strange flavor production in BES:
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- **High μ_B region, hypernuclei production:**
  - Hyperon contribution to nuclear EoS
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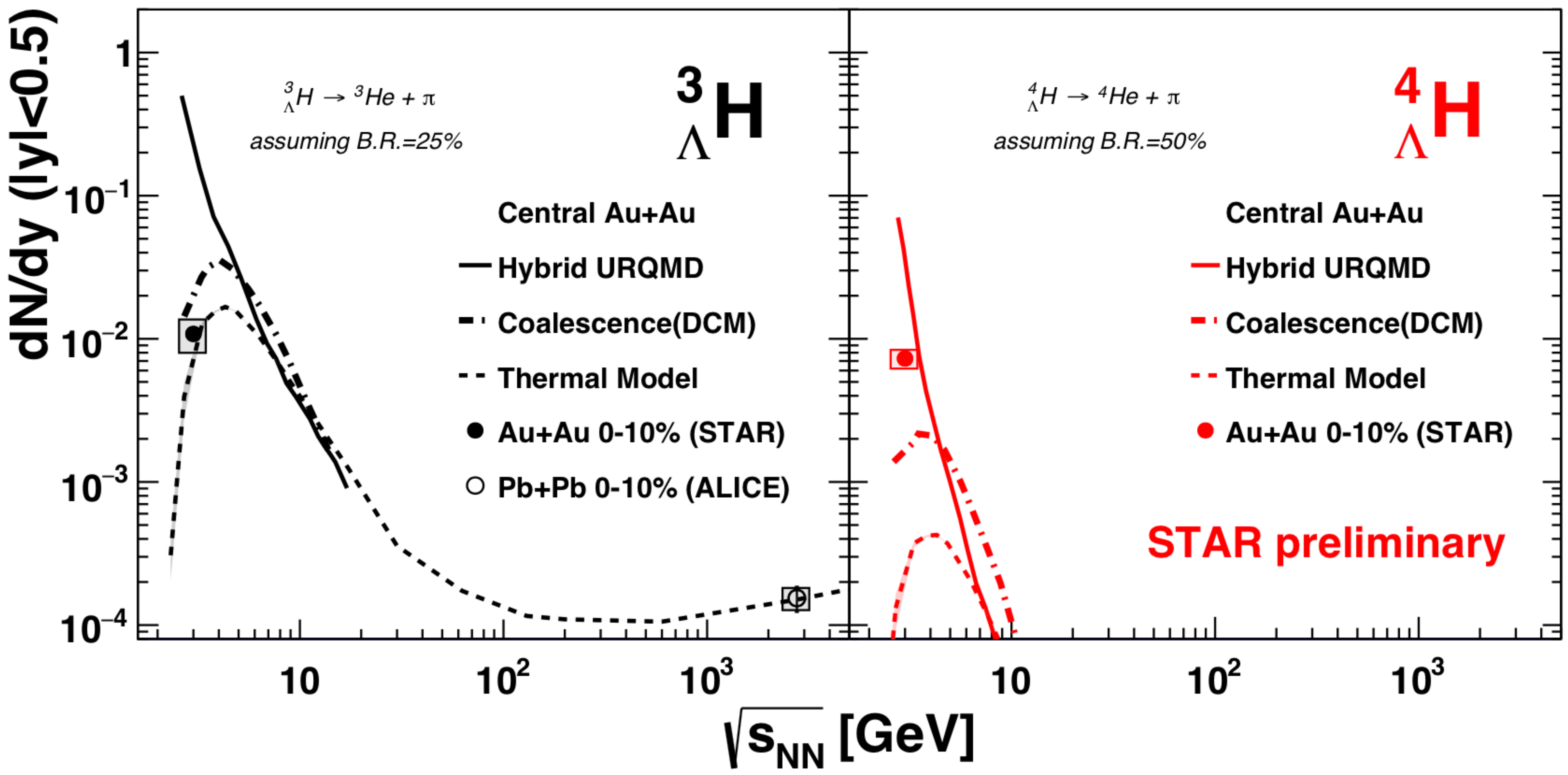
Hypernuclei Production at 3 GeV

- Lifetime, yield, flow of hypernuclei: Important to understand Y-N interactions and hyperon contribution to nuclear EoS
- Enhanced production of hypernuclei in high baryon density collisions

Hypernuclei Production at 3 GeV

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

Models: J. Steinheimer et al, Phys. Lett. B. 714,85; A. Andronic et al, Phys. Lett. B 697, 203 (Private communincations)
ALICE: Phys. Lett. B 754, 360



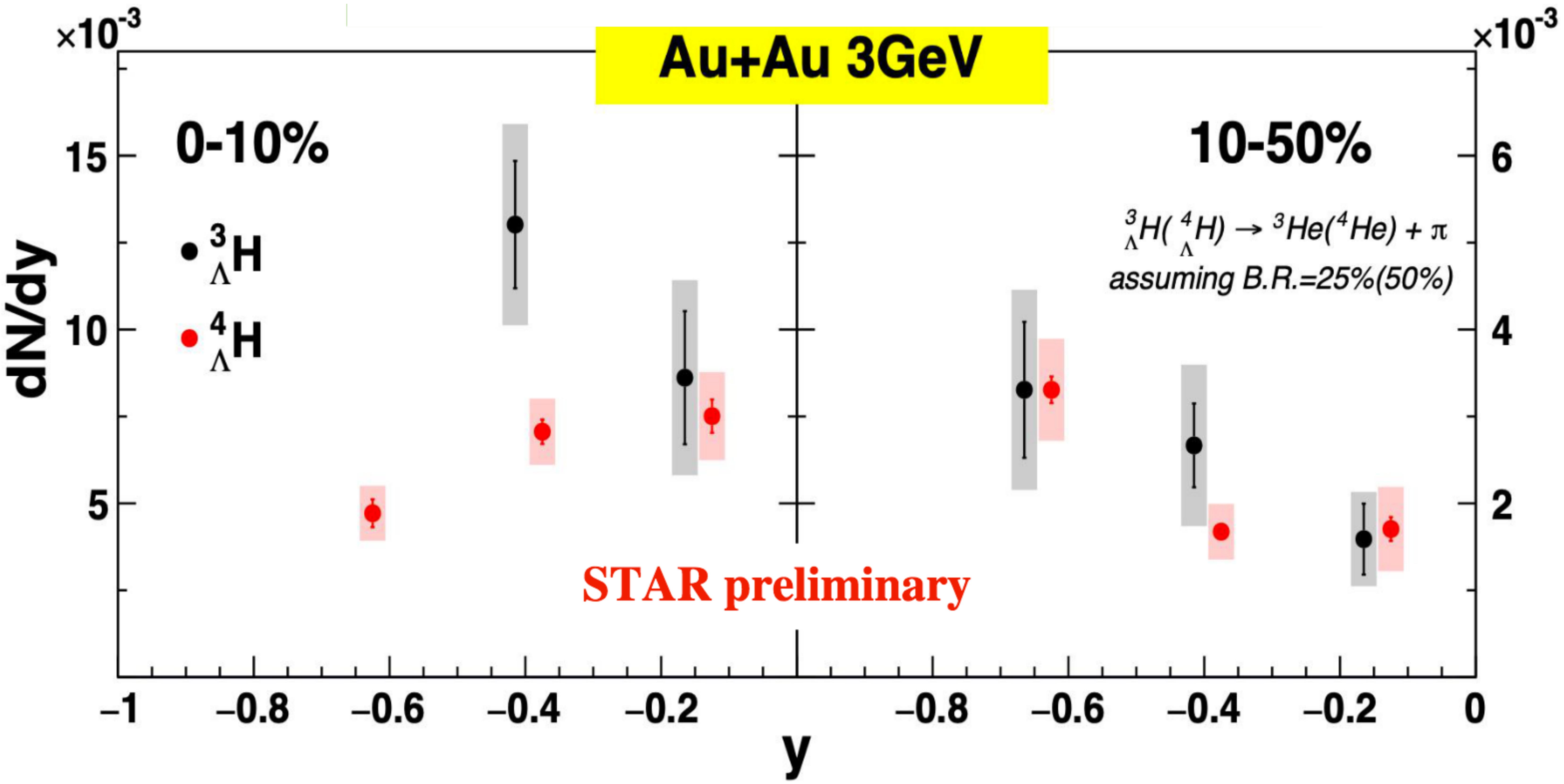
$$^3_\Lambda H : \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$$
$$^4_\Lambda H : \tau = 218.3 \pm 7.5(stat) \pm 11.8(syst)[ps]$$

- $^4_\Lambda$H lifetime measurement most precise to date

- Thermal (with canonical ensemble) and coalescence model calculations describe $^3_\Lambda$H yields, but lower than $^4_\Lambda$H yield

Talk by Chenlu Hu: 21/05 Fri, 10.30 (B)

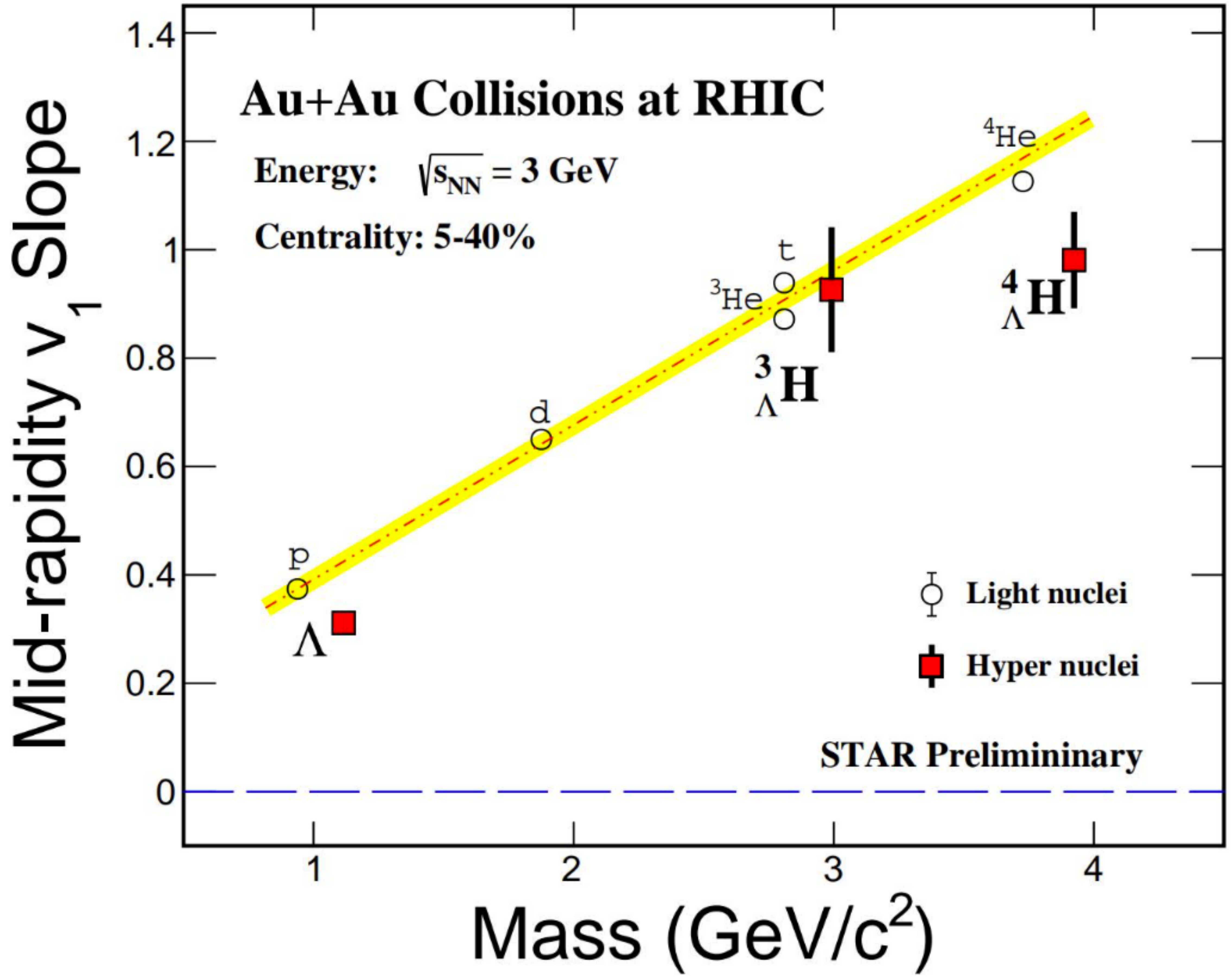
Hypernuclei Production: Rapidity Dependence



- Difference in rapidity distribution for $^{4}_{\Lambda}H$ between central and mid-central collisions
- Could be contributions from spectator reactions in $^{4}_{\Lambda}H$ production in non-central collisions

Hypernuclei Flow at 3 GeV

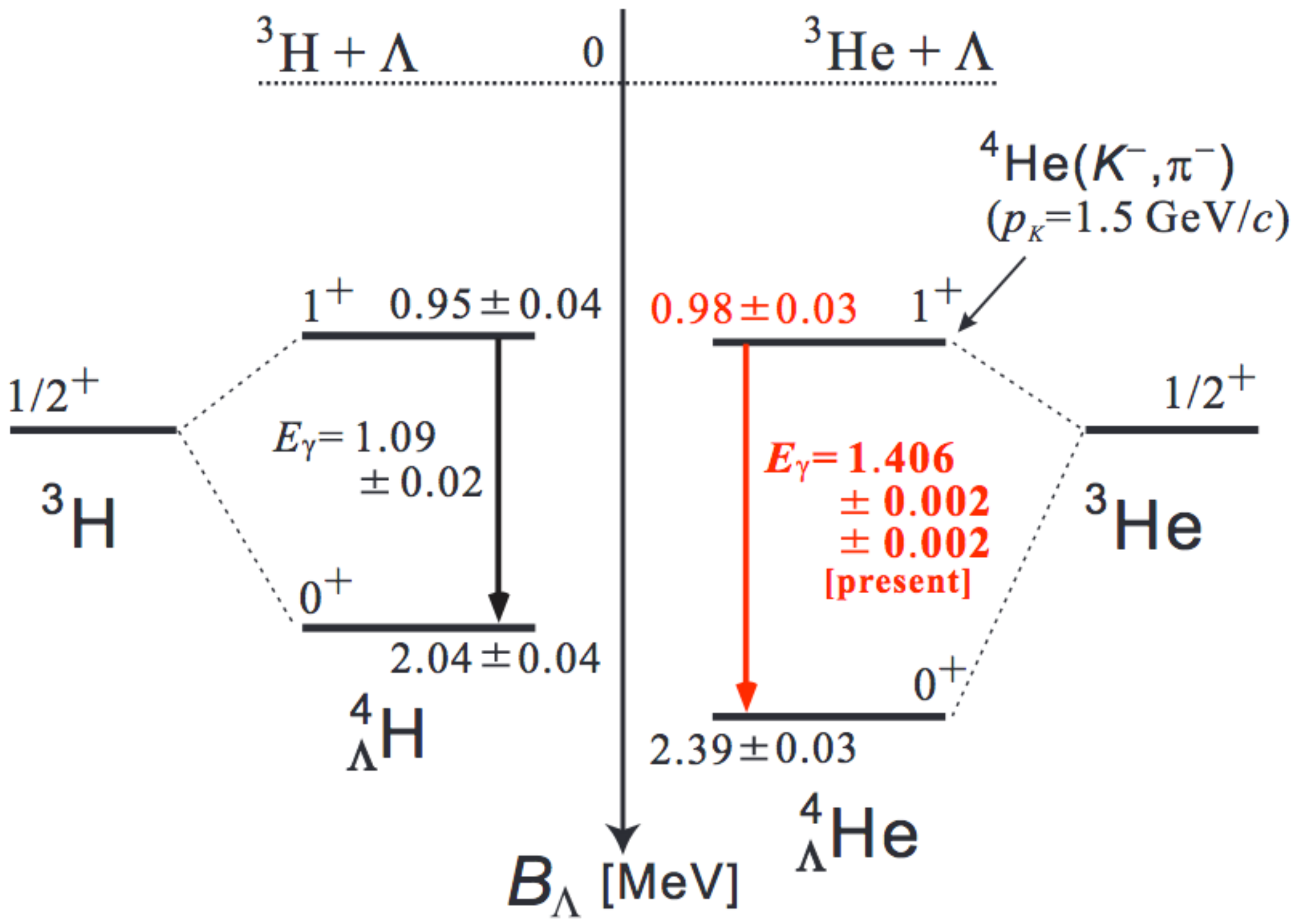
- Lifetime, yield, flow of hypernuclei: Important to understand Y-N interactions and hyperon contribution to nuclear EoS



- Directed flow of hypernuclei suggests mass number scaling
- Indicates a coalescence production of hypernuclei

Talk by Chenlu Hu: 21/05 Fri, 10.30 (B)

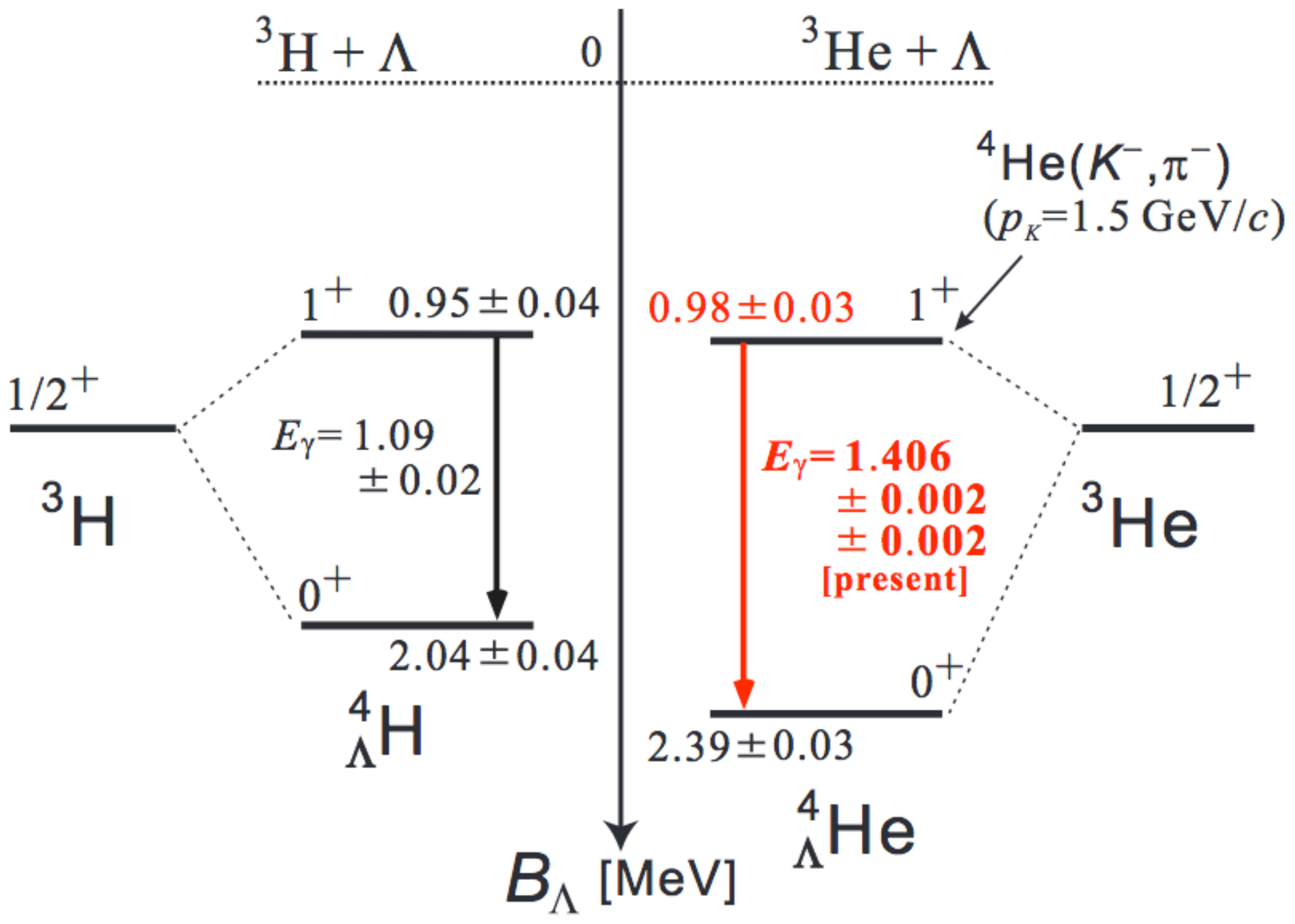
Study of Charge Symmetry Breaking



E13 Collaboration: Phys.Rev.Lett 115, 222501 (2015)

- Large binding energy difference between ground states of mirror hypernuclei
- Comparable BEs for excited states
- HIC data can offer independent experimental measurements

Study of Charge Symmetry Breaking



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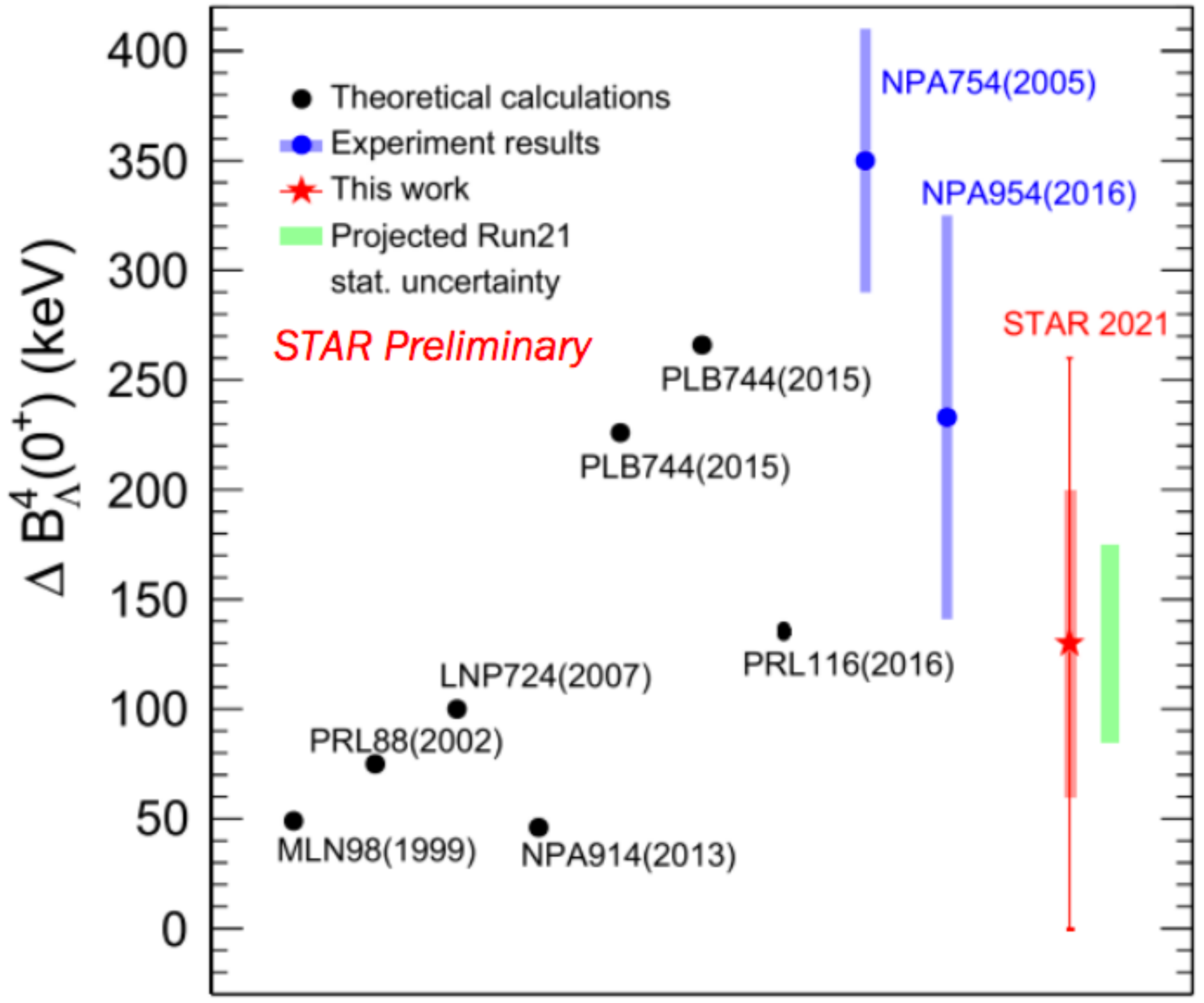
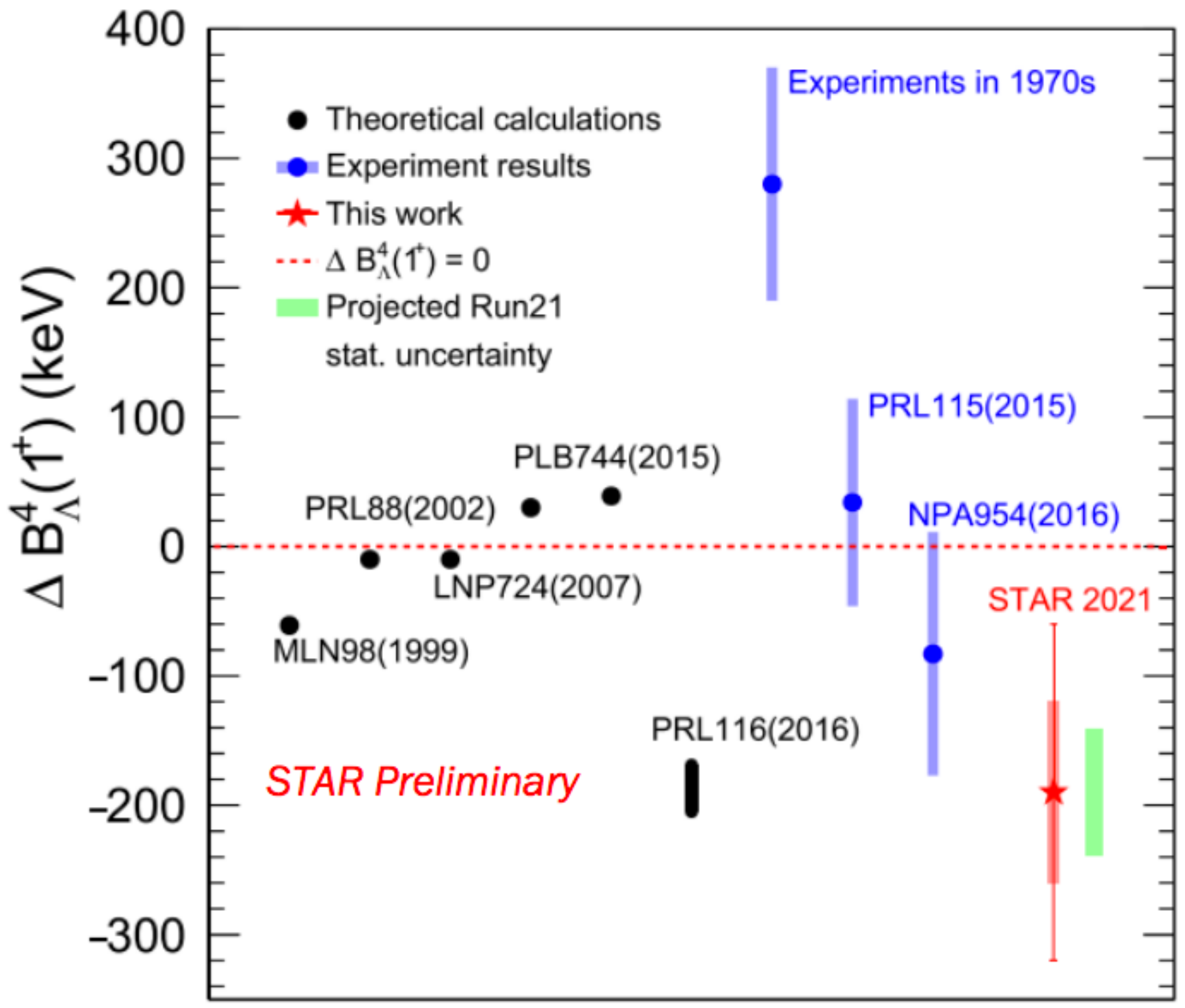




$$B_\Lambda = (M_\Lambda + M_{core} - M_{hypernucleus})c^2$$

- Potential to get better precision measurements with upcoming high statistics FXT datasets

Talk by Tianhao Shao: 21/05 Fri, 09.30 (B)

Summary and Outlook

- Comparable J/ψ suppression and HF flow at 54.4 and 200 GeV
  - Can help constrain temperature dependence of heavy quark dynamics in QGP

- Light flavor and strangeness production:
  - Canonical suppression of strangeness at 3 GeV
  - Medium dominated by baryonic interactions and nuclear EoS in 3 GeV collisions

- Hypernuclei production:
  - Thermal and coalescence models describe ${}^{3}_{\Lambda}\mathrm{H}$ yields, but not ${}^{4}_{\Lambda}\mathrm{H}$ yields
  - Directed flow of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$ suggests mass number scaling and coalescence production

Data from BES-II and FXT at other energies being analyzed on flavor production, flow …
Look forward to more exciting results from STAR

STAR Beam Use Request 2021

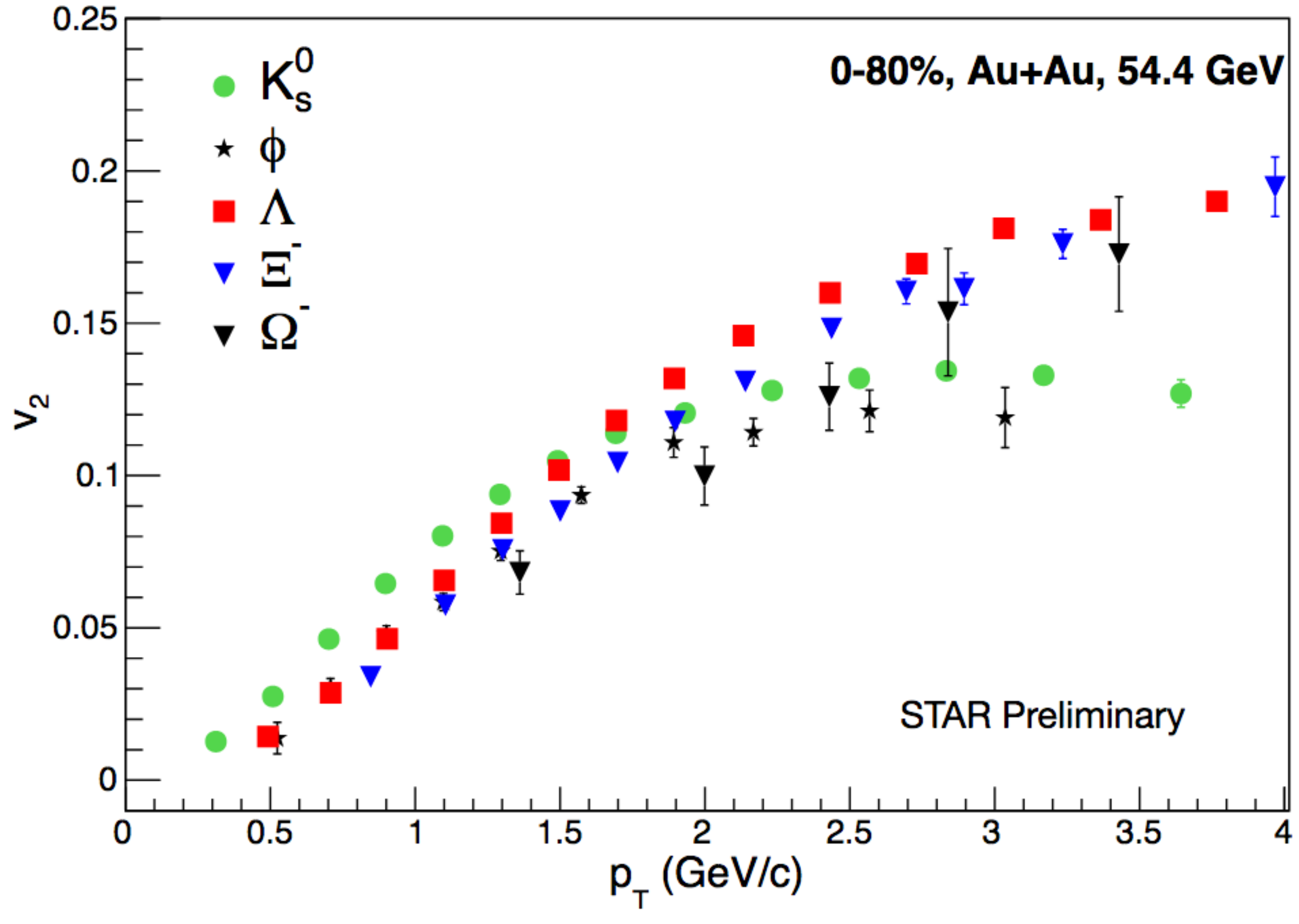
Single-Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority
3.85	7.7	11-20 weeks	Au+Au	100 M	1
3.85	3 (FXT)	3 days	Au+Au	300 M	2
44.5	9.2 (FXT)	0.5 days	Au+Au	50 M	2
70	11.5 (FXT)	0.5 days	Au+Au	50 M	2
100	13.7 (FXT)	0.5 days	Au+Au	50 M	2
100	200	1 week	O+O	400 M 200 M (central)	3 a
8.35	17.1	2.5 weeks	Au+Au	250 M	3 b
3.85	3 (FXT)	3 weeks	Au+Au	2 B	3 c

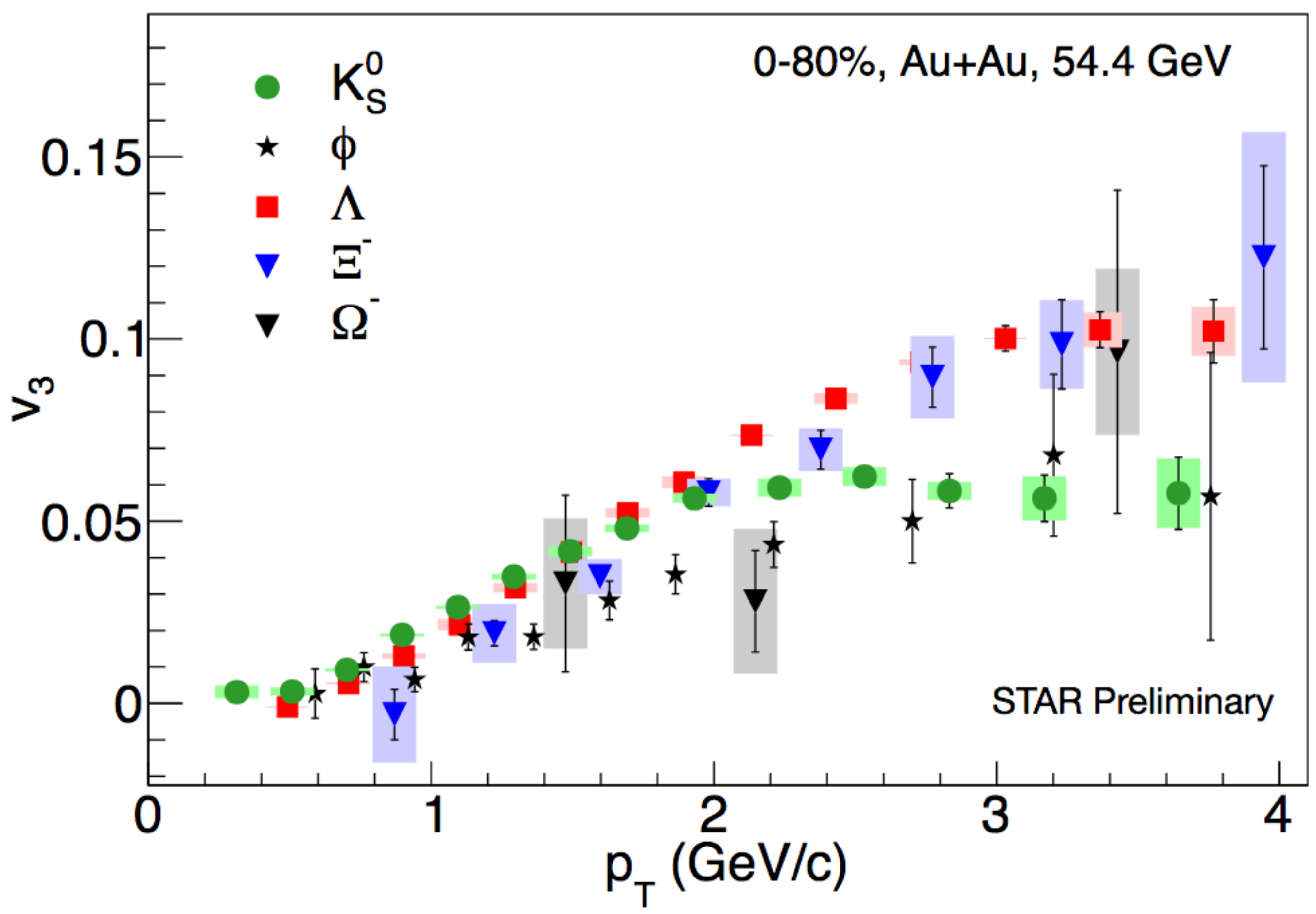
Successfully completed data taking for BES-II

O+O run and high statistics (2B events) FXT data taking at 3 GeV to finish this year's run

Back Up

Strangeness flow at 54.4 GeV

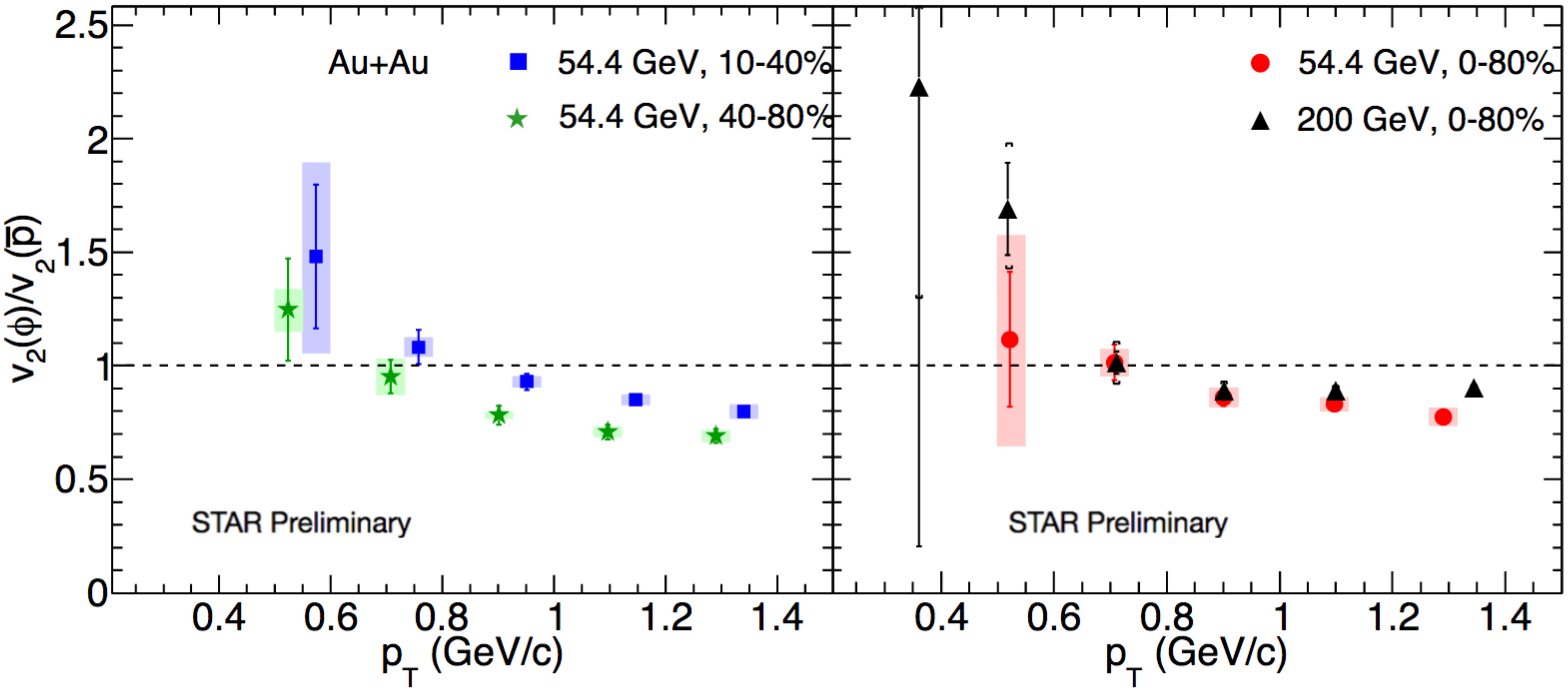




- Transverse momentum dependence of v_n

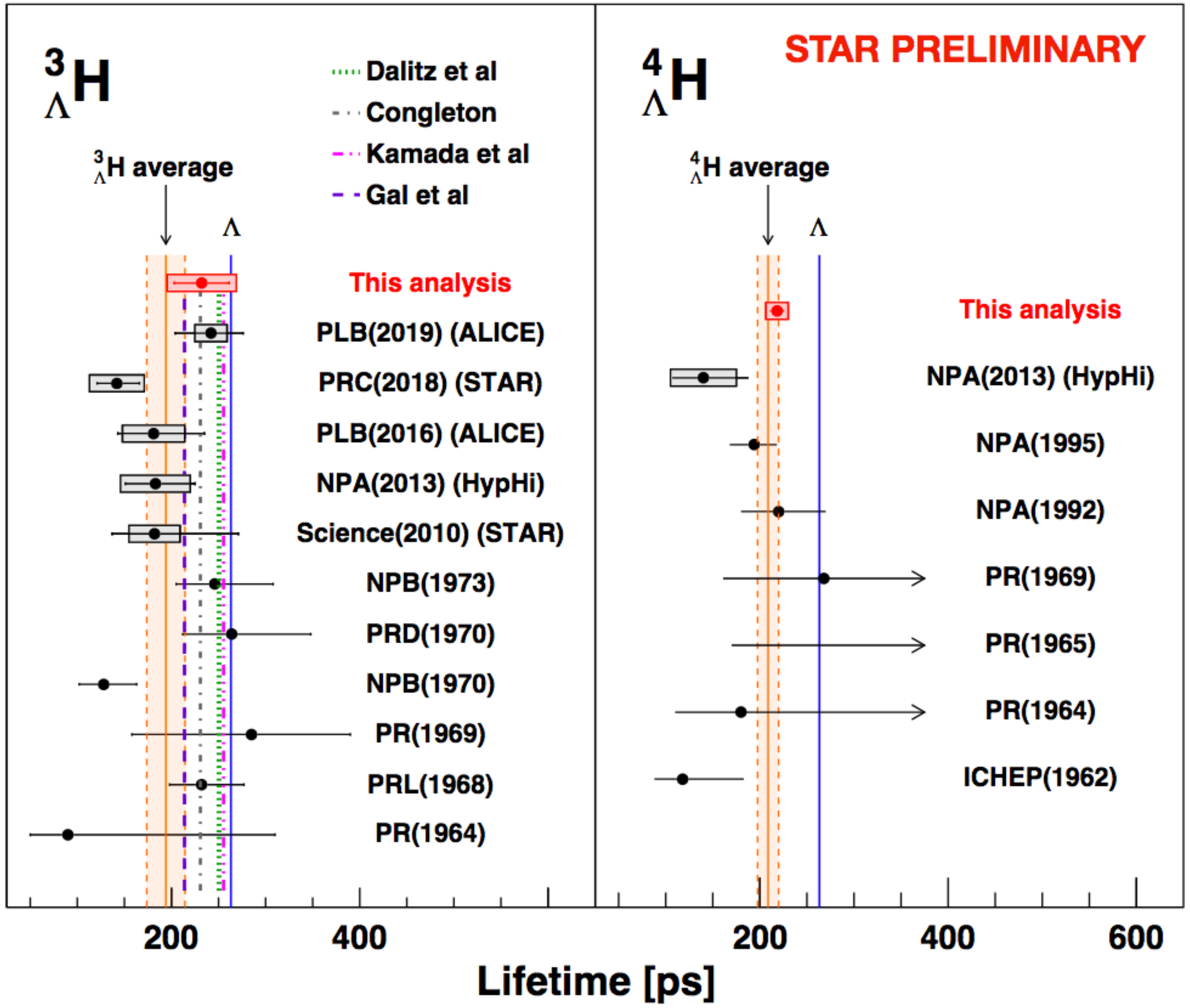
Partonic collectivity: Strange hadron flow

- Strange hadrons: Small hadronic cross-section. Partonic vs hadronic contribution to flow



- Hint of violation of mass ordering, at very low p_T
- Potentially from hadronic contribution to anti-proton v_2

Hypernuclei life time



- 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

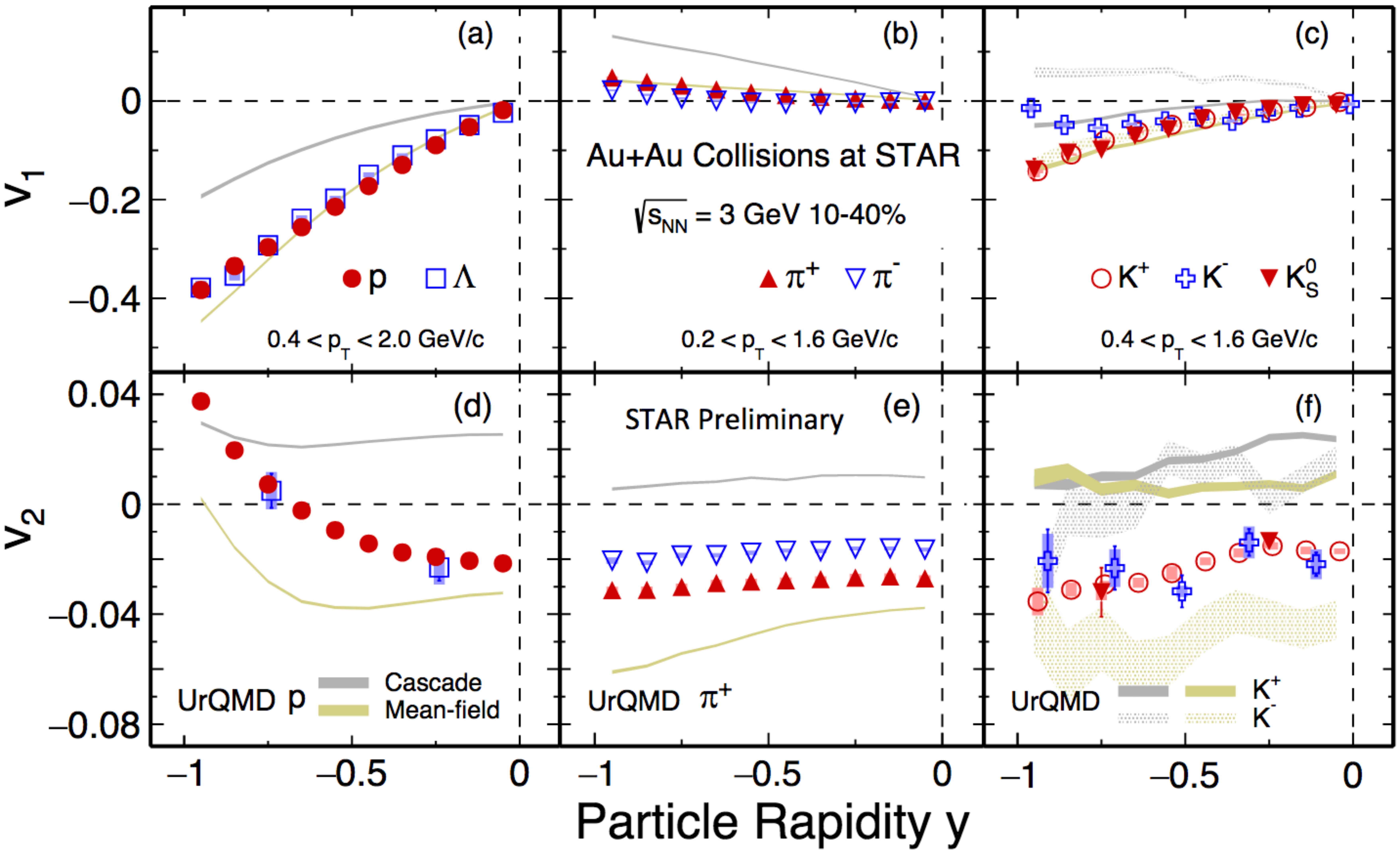
$$^{3}_{\Lambda}\mathrm{H} : \tau = 232.1 \pm 29.2(\mathrm{stat}) \pm 36.7(\mathrm{syst})[\mathrm{ps}]$$

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

STAR $^{3}_{\Lambda}H$ Lifetime measurements

STAR 2021 Preliminary: 232 +- 29(stat) +- 37(syst) [ps]
STAR(2019): 142 +24-21(stat) +- 31(syst) [ps]
STAR(science): 182 +89-45(stat) +- 27(syst) [ps]

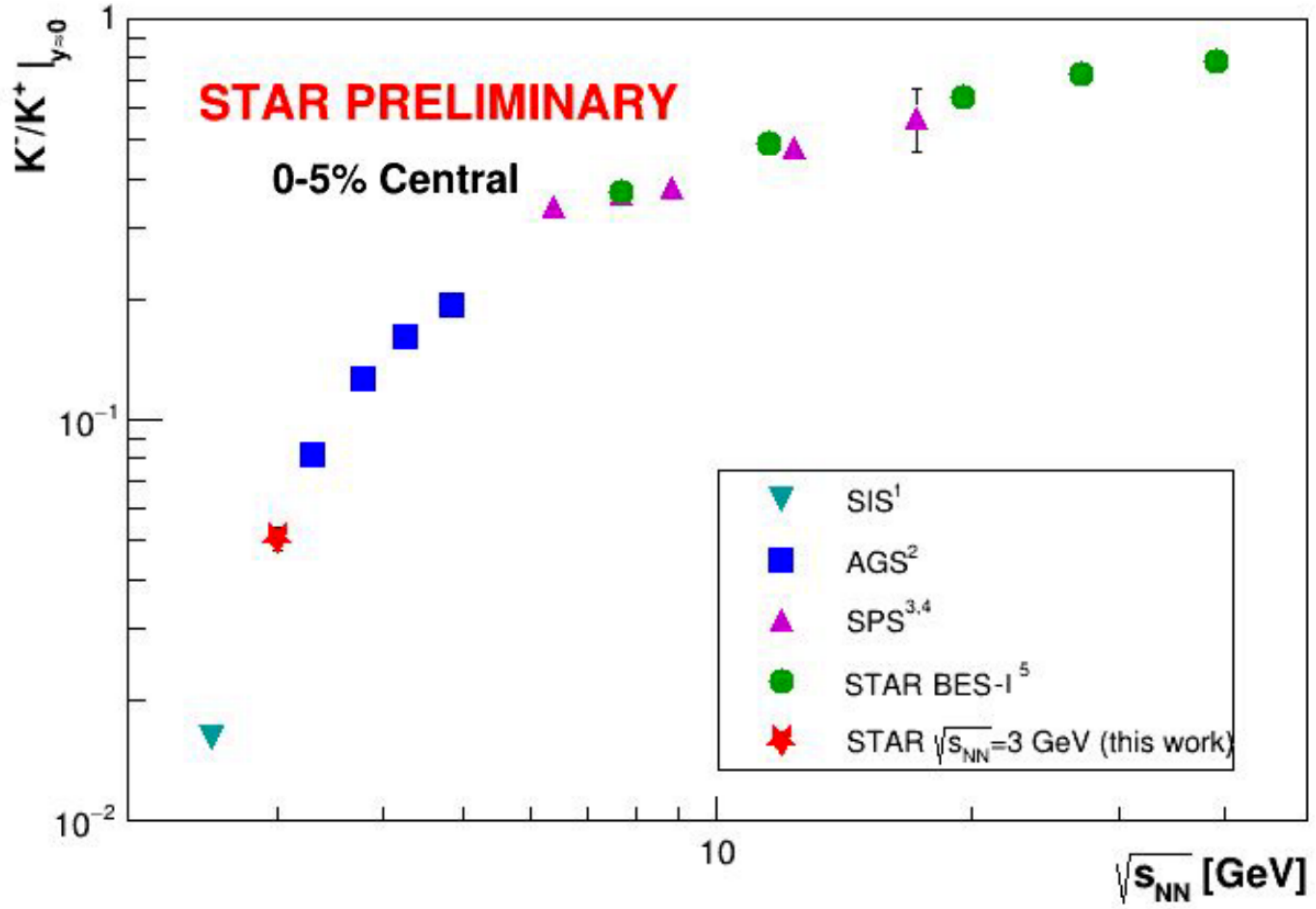
Identified hadron v_1 and v_2 at 3 GeV: Rapidity dependence

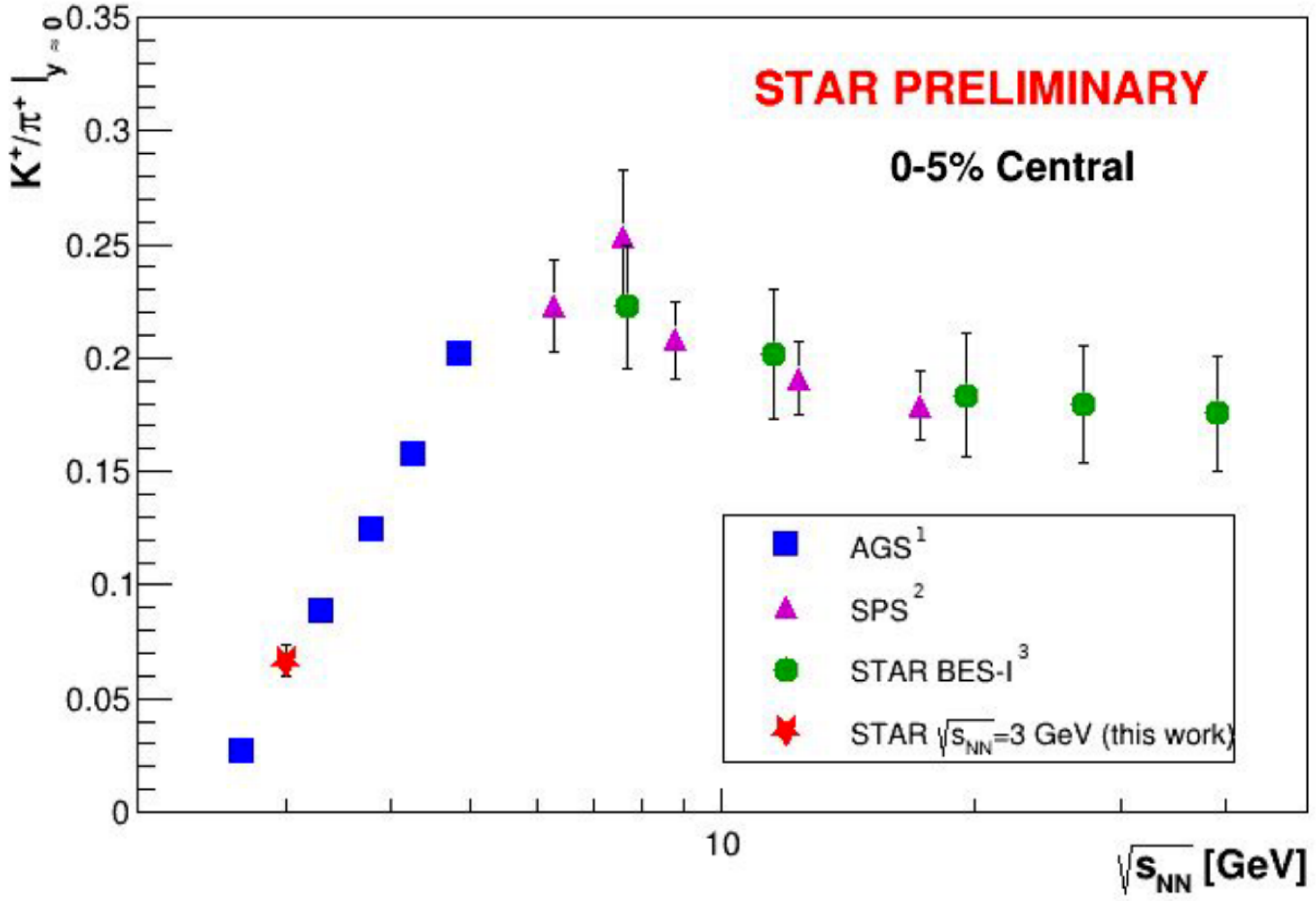


K^-/K^+, K^+/π^+ yield ratios at 3 GeV

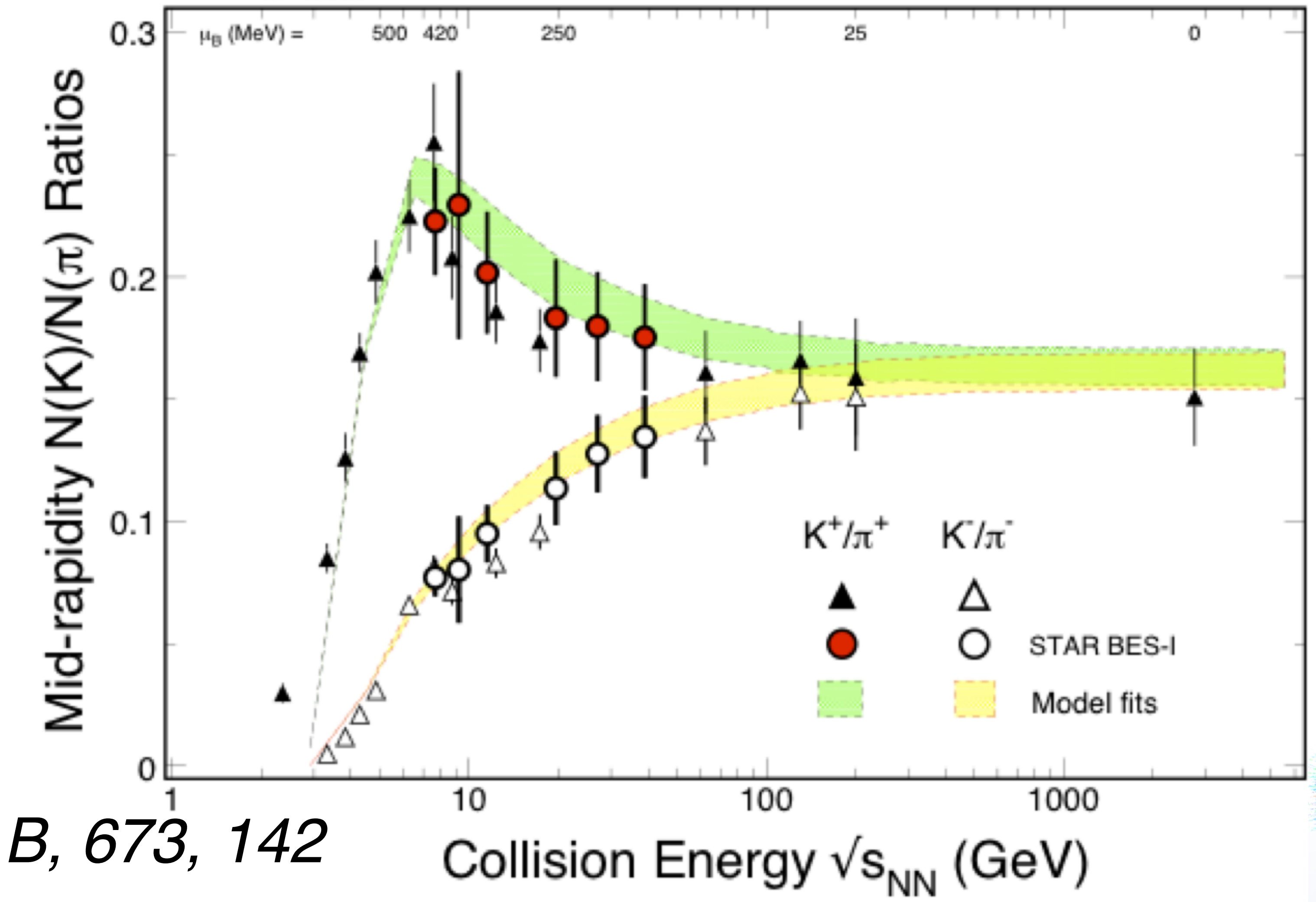
- Flavor production in the high baryon density region

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^+ ($N + N \rightarrow N + \Lambda + K$)



Phys. Lett. B, 673, 142