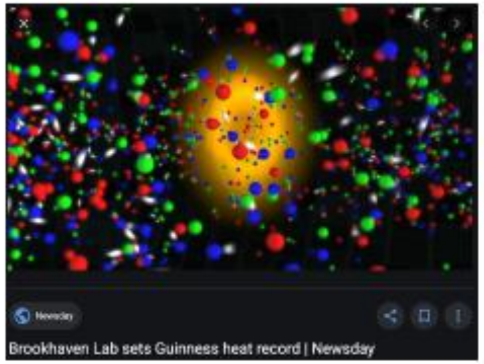
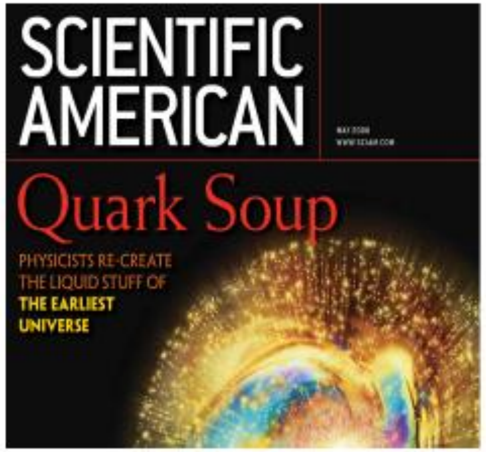
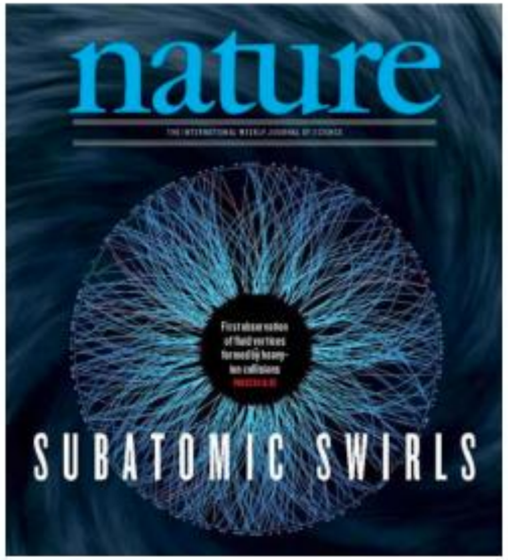


Hottest



Least viscous



Most vortical

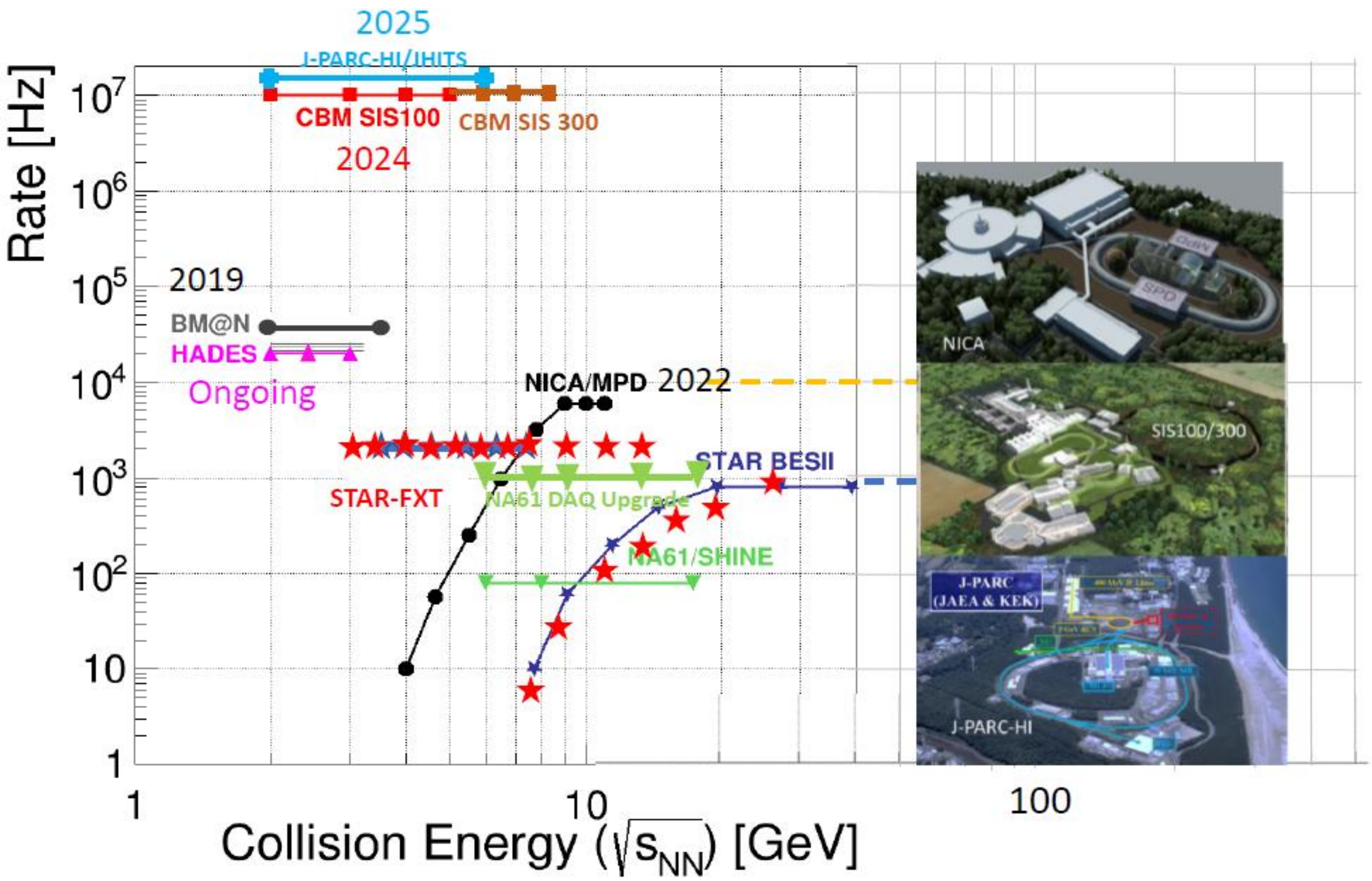
???

Identified particle production at BES STAR

Alexey Aparin Joint Institute for Nuclear Research

X collaboration meeting MPD experiment

HIC facilities and experiments



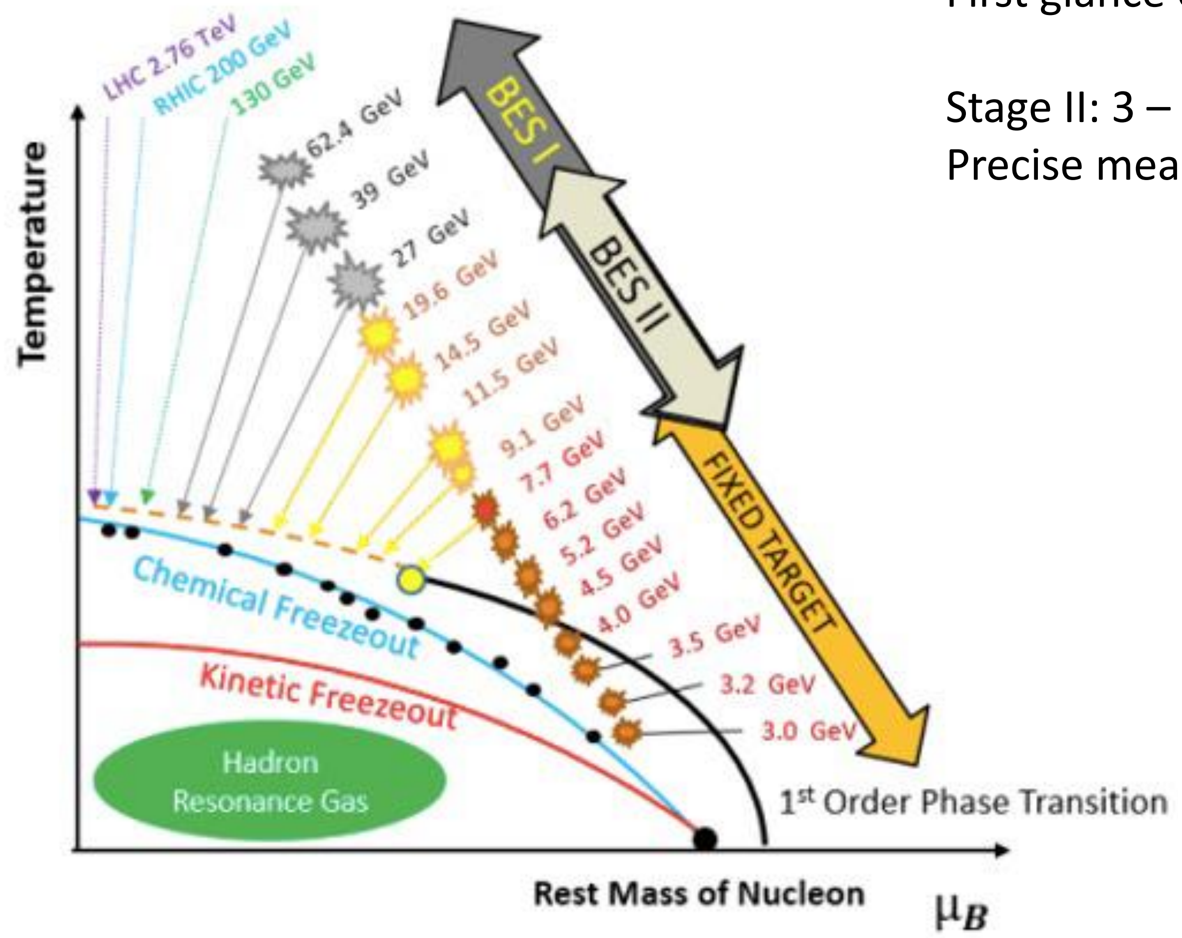
SPS up to 160 GeV

NICA/MPD is a Collider exp.
NICA single beam of about 10 GeV

Nuclotron reaches up to 3.5 GeV

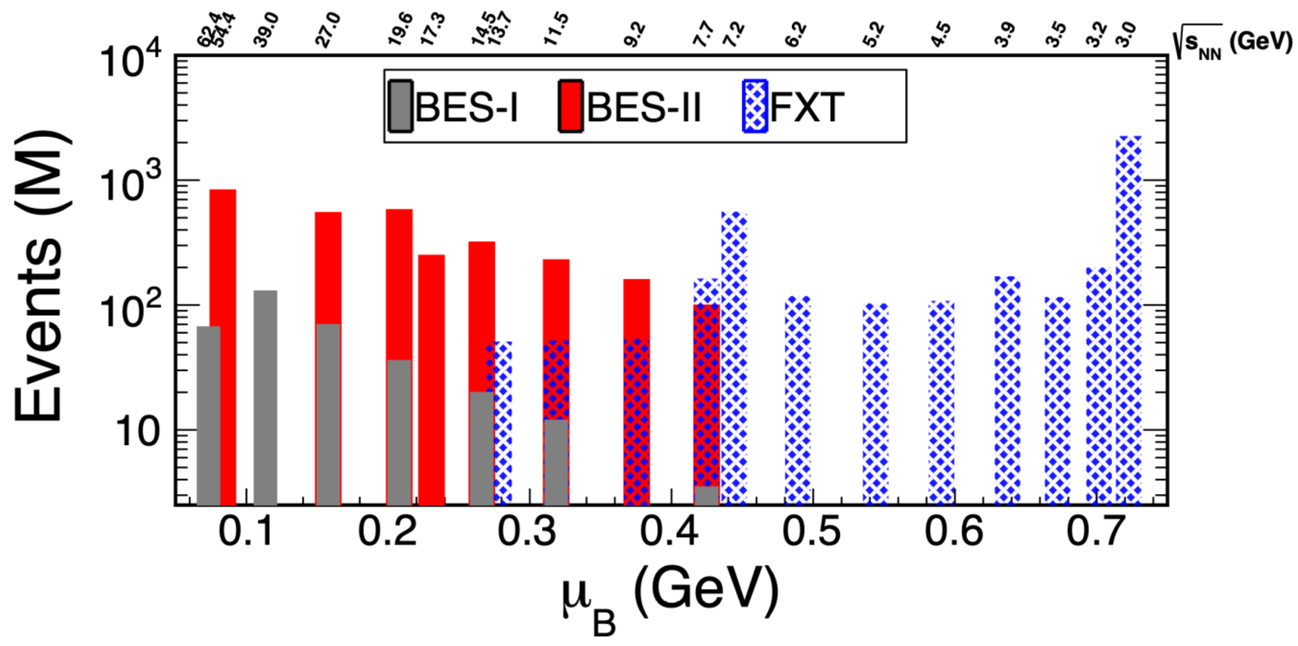
JPARC up to about 18 GeV

Beam Energy Scan to map the QCD phase diagram

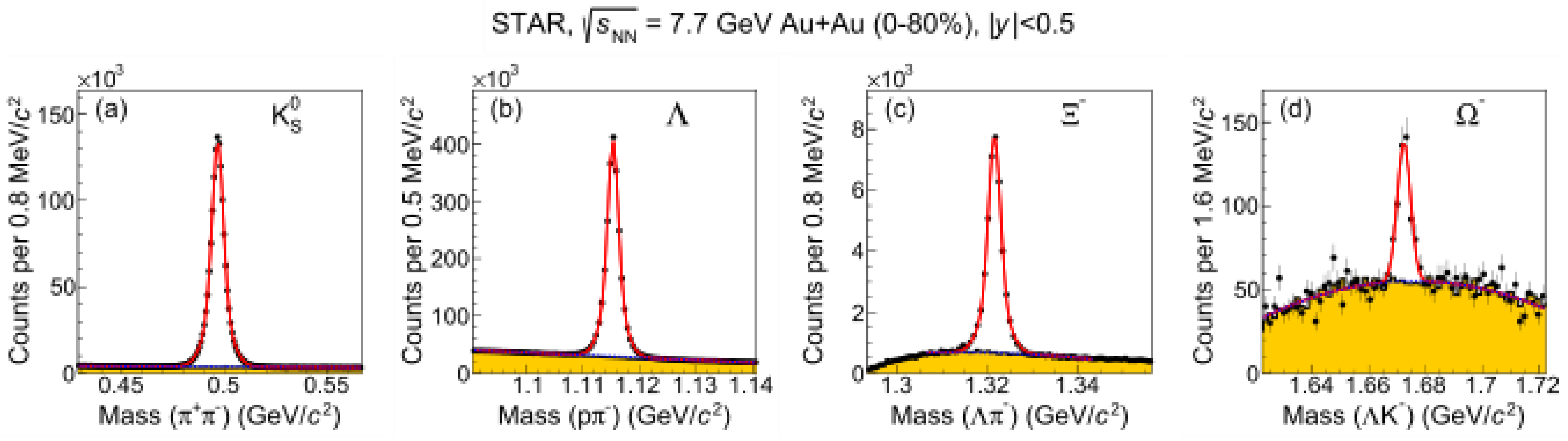


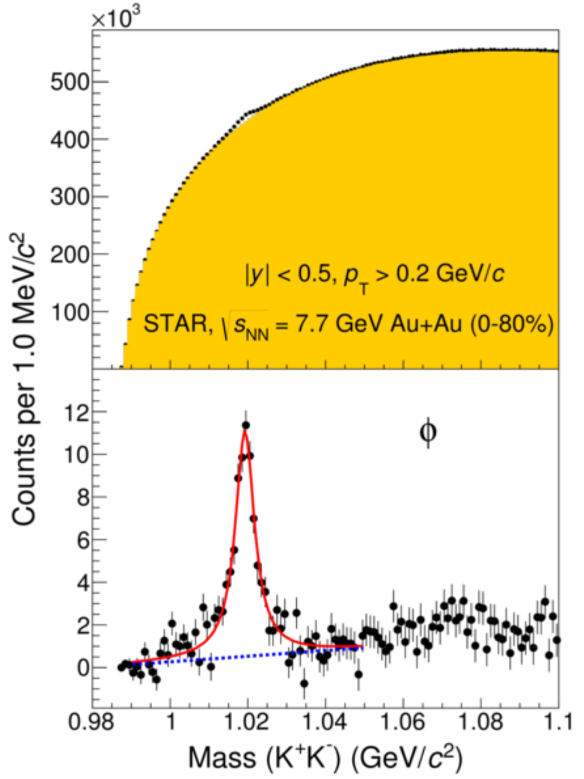
Two stages of Beam Energy Scan:
Stage I: 7.7 – 39 GeV 2010 – 2014
First glance on low energy region, rather low statistics

Stage II: 3 – 27 GeV 2018 – 2021
Precise measurements at low energies, sufficient statistics



Strange particle production at BES-I





$\sqrt{s_{NN}}$ (GeV)	z-vertex range (cm)	MB events (10^6)
7.7	[-70, 70]	4.4
11.5	[-50, 50]	12.0
19.6	[-70, 70]	36.3
27	[-70, 70]	72.8
39	[-40, 40]	134.3

$K^0_S \to \pi^+ + \pi^-$, 69.20%;

$\Lambda(\overline{\Lambda}) \to p(\overline{p}) + \pi^-(\pi^+)$, 63.9%;

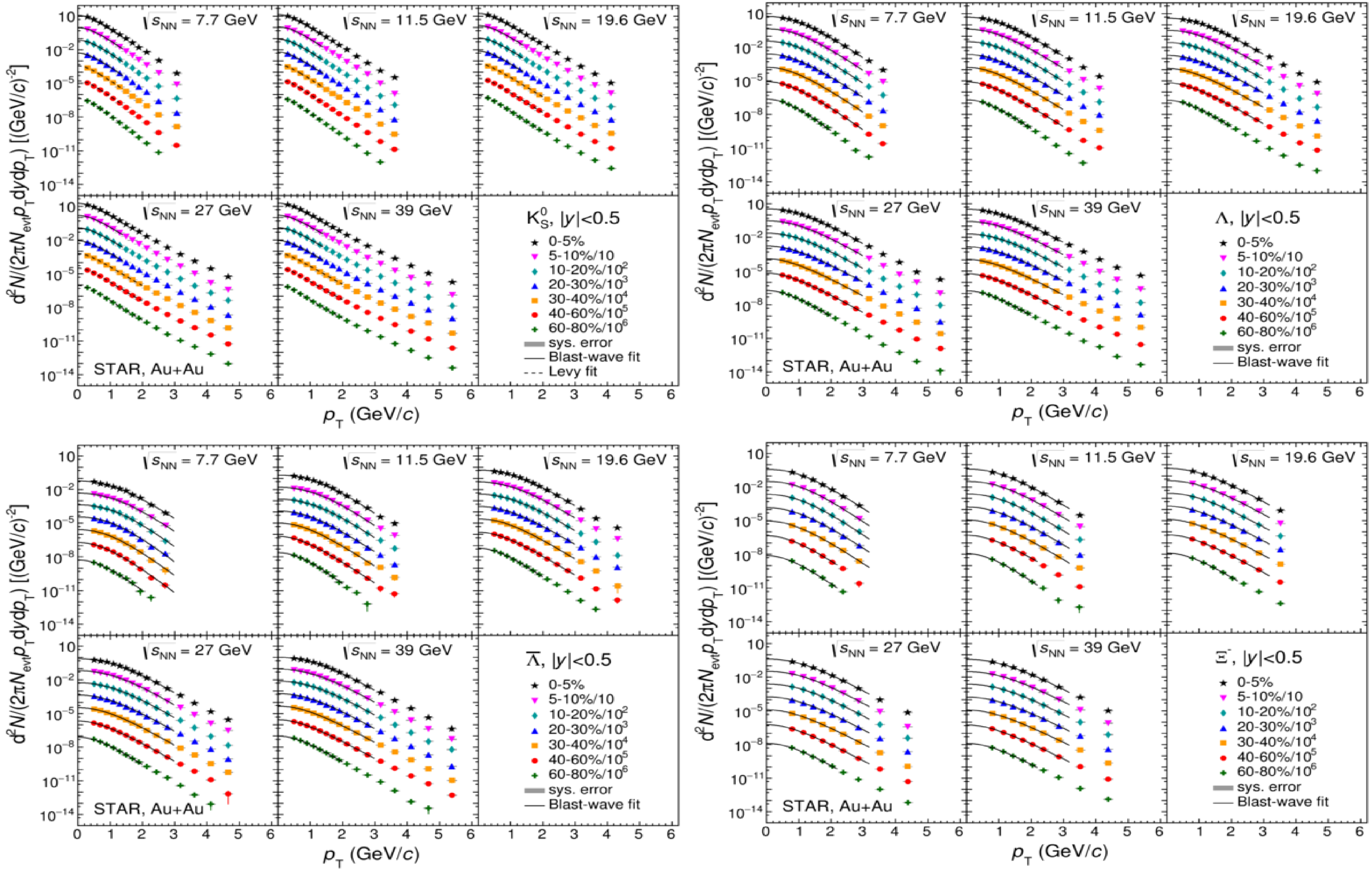
$\Xi^-(\overline{\Xi}^+) \to \Lambda(\overline{\Lambda}) + \pi^-(\pi^+)$, 99.887%;

$\Omega^-(\overline{\Omega}^+) \to \Lambda(\overline{\Lambda}) + K^-(K^+)$, 67.8%;

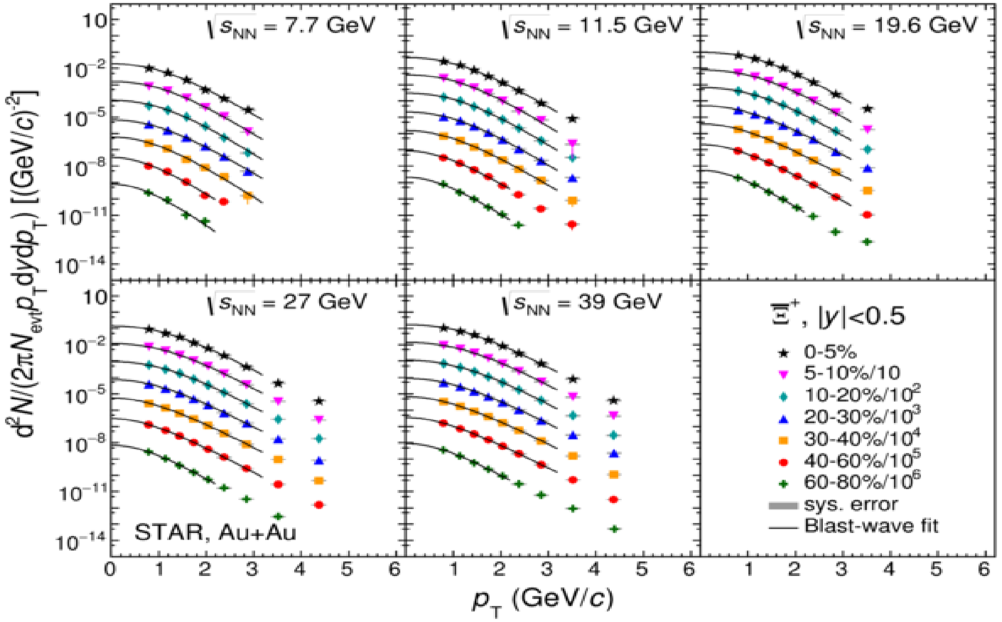
$\phi \to K^+ + K^-$, 49.1%.

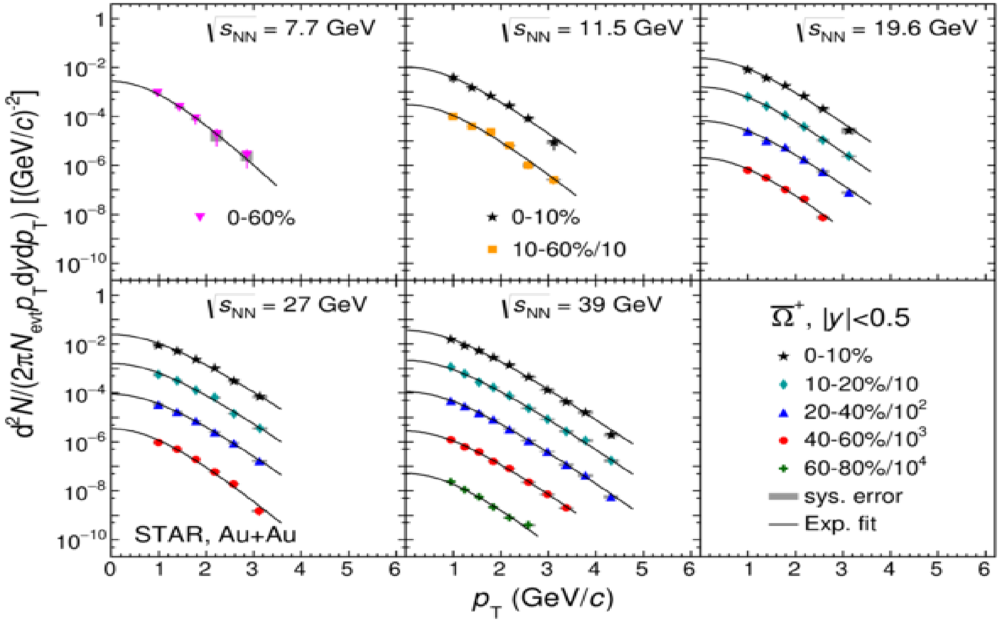
Phys. Rev. C **102** (2020) 34909

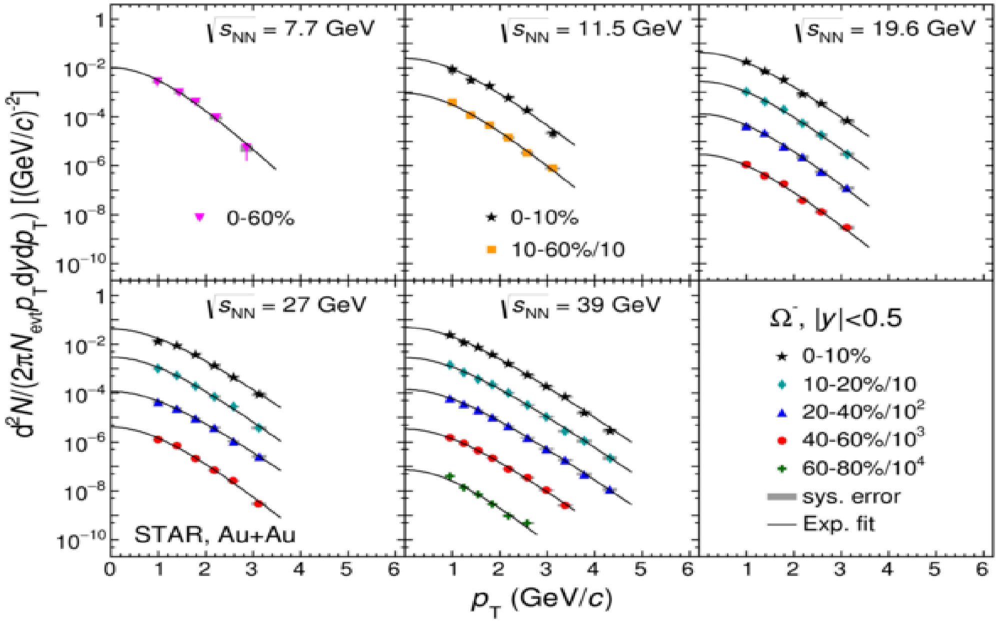
Strange particle production at BES-I

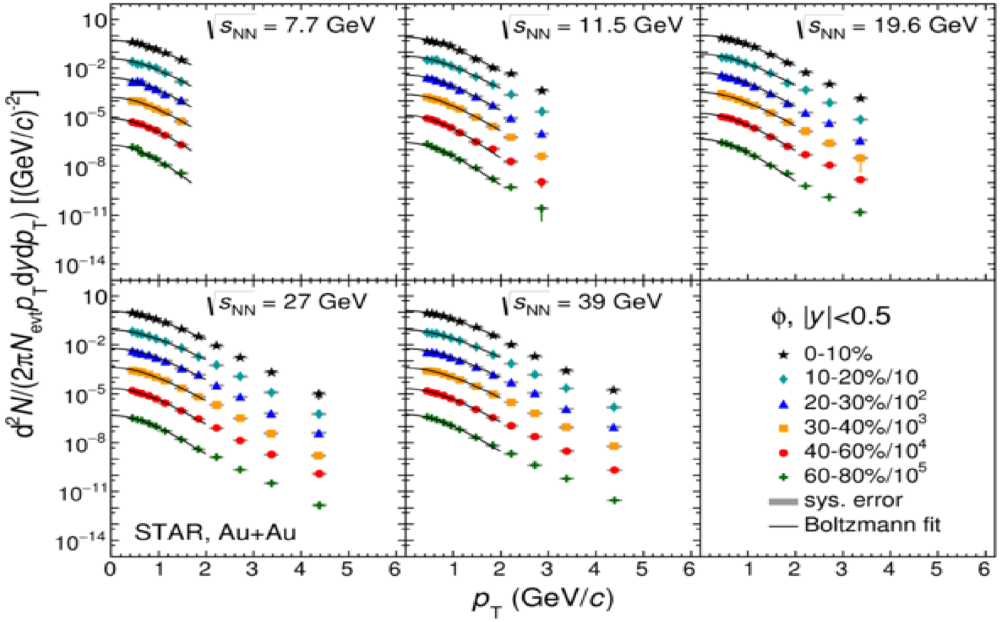


Strange particle production at BES-I

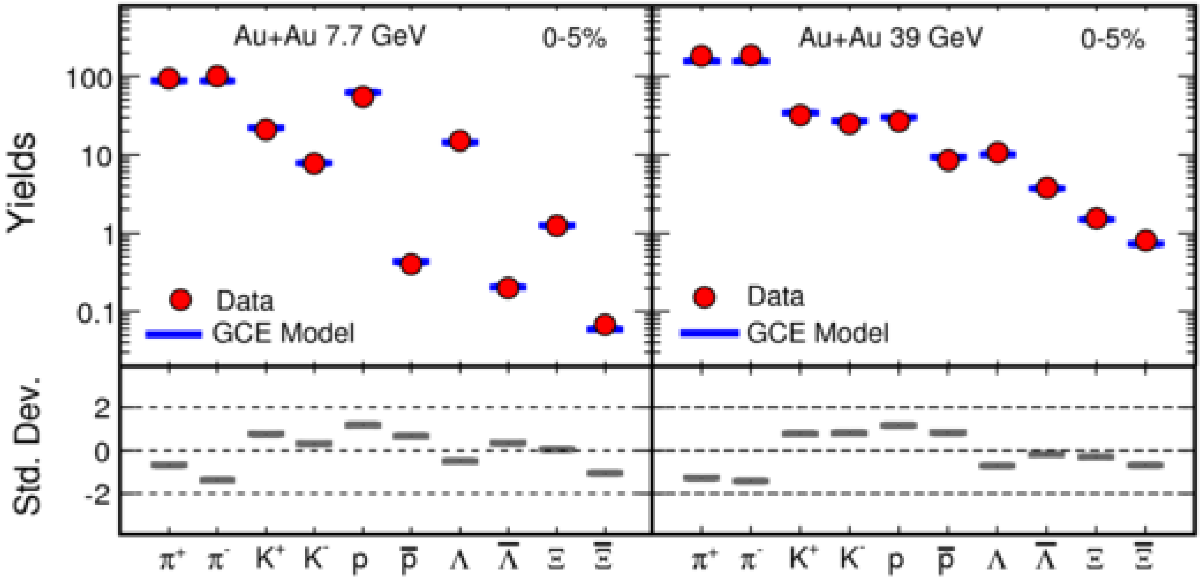


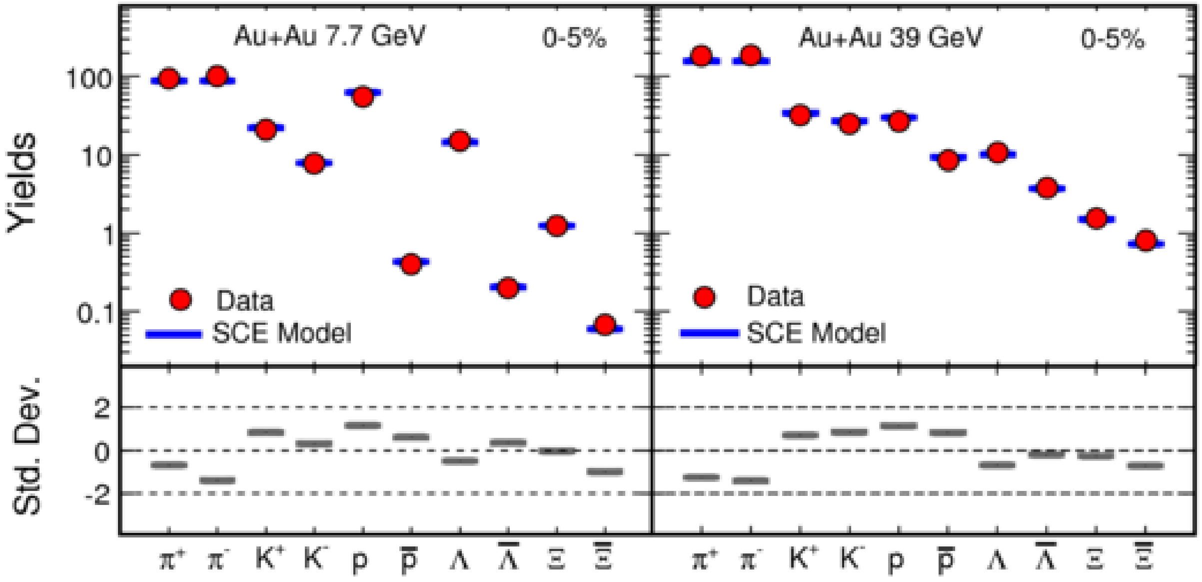






Thermal model predictions comparison



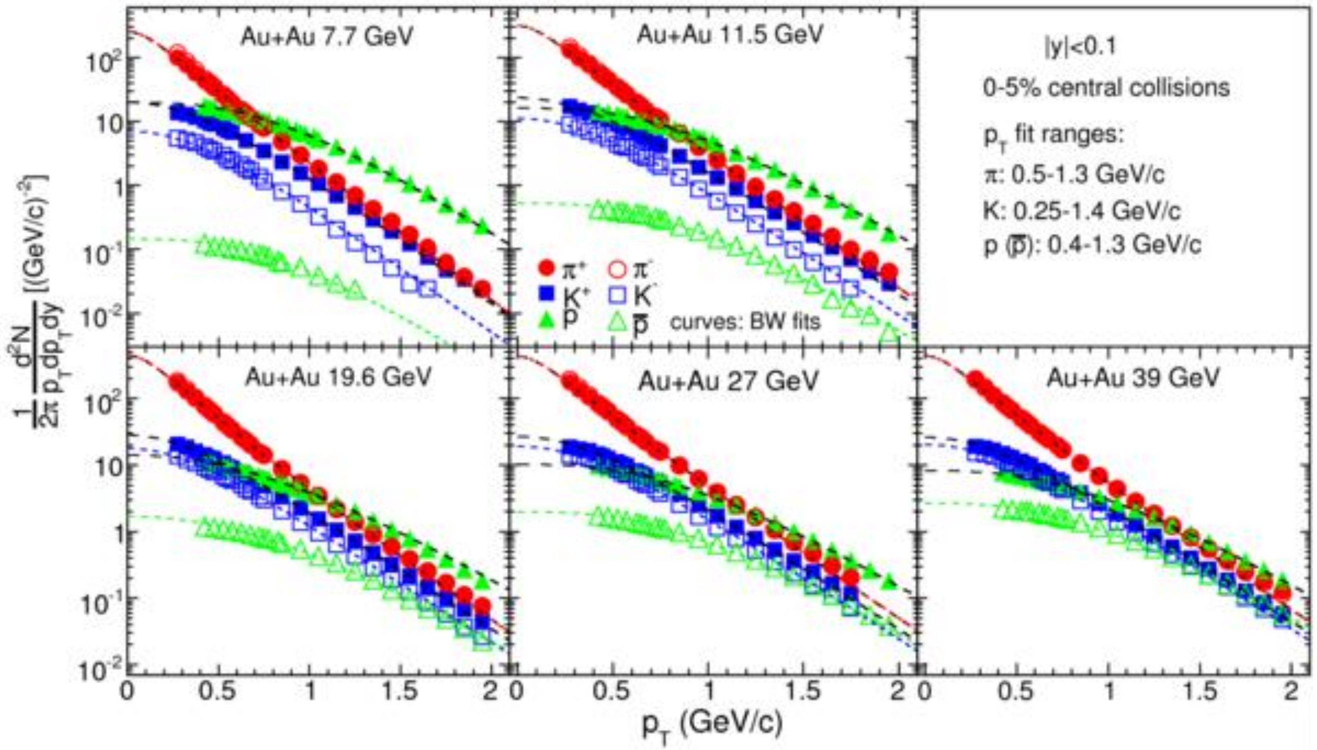


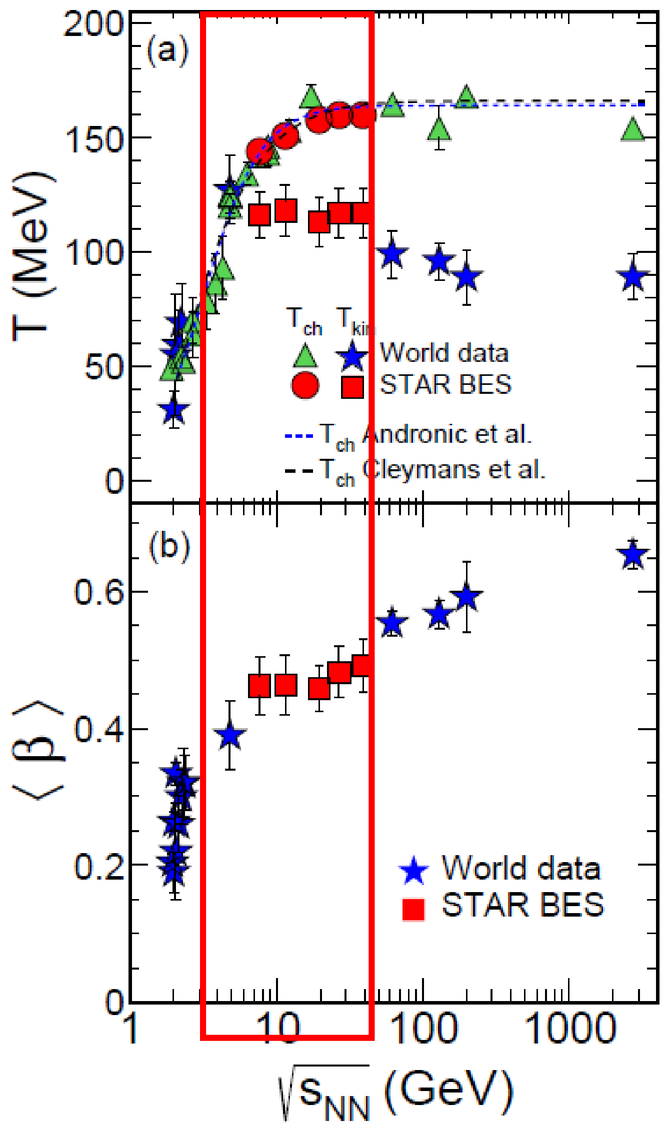
Blast-wave fits for particle spectra

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho(r)}{T}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T}\right)$$

Grand Canonical Ensemble – B, Q and S are conserved at average
Canonical Ensemble – exact conservation of B, Q and S
Strangeness Canonical Ensemble – exact conservation of S

Collectivity and temperature of the medium



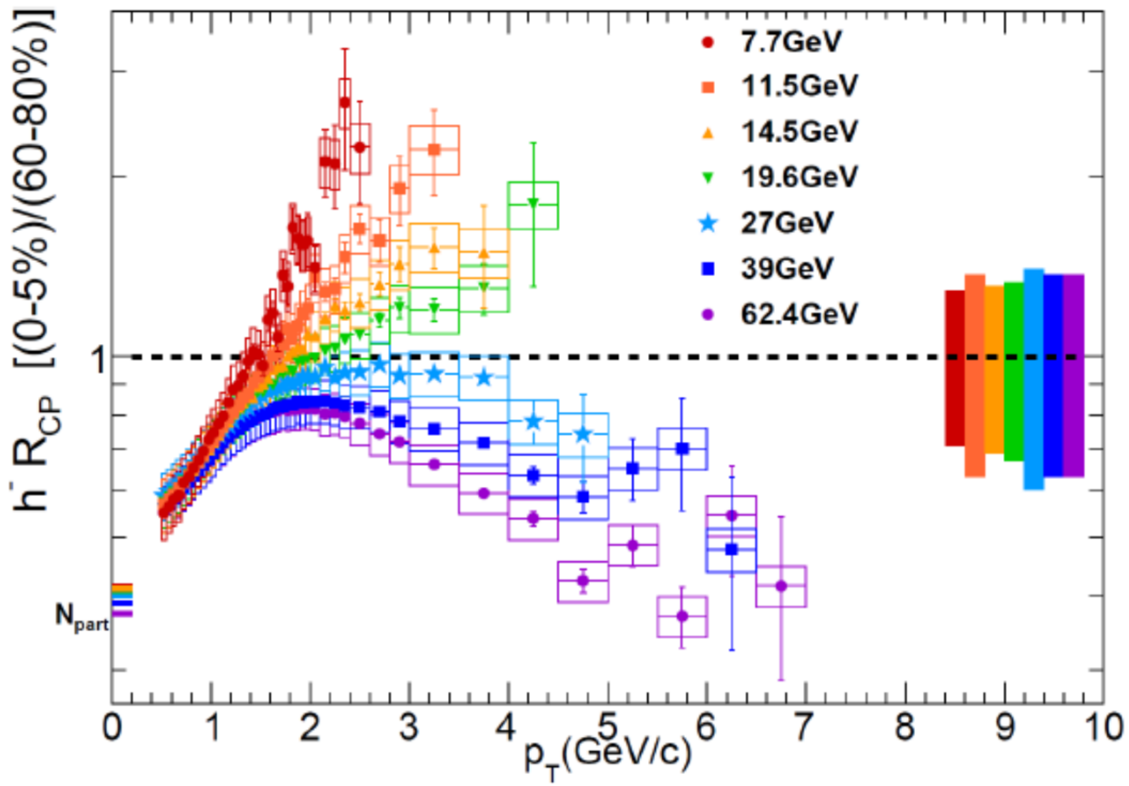


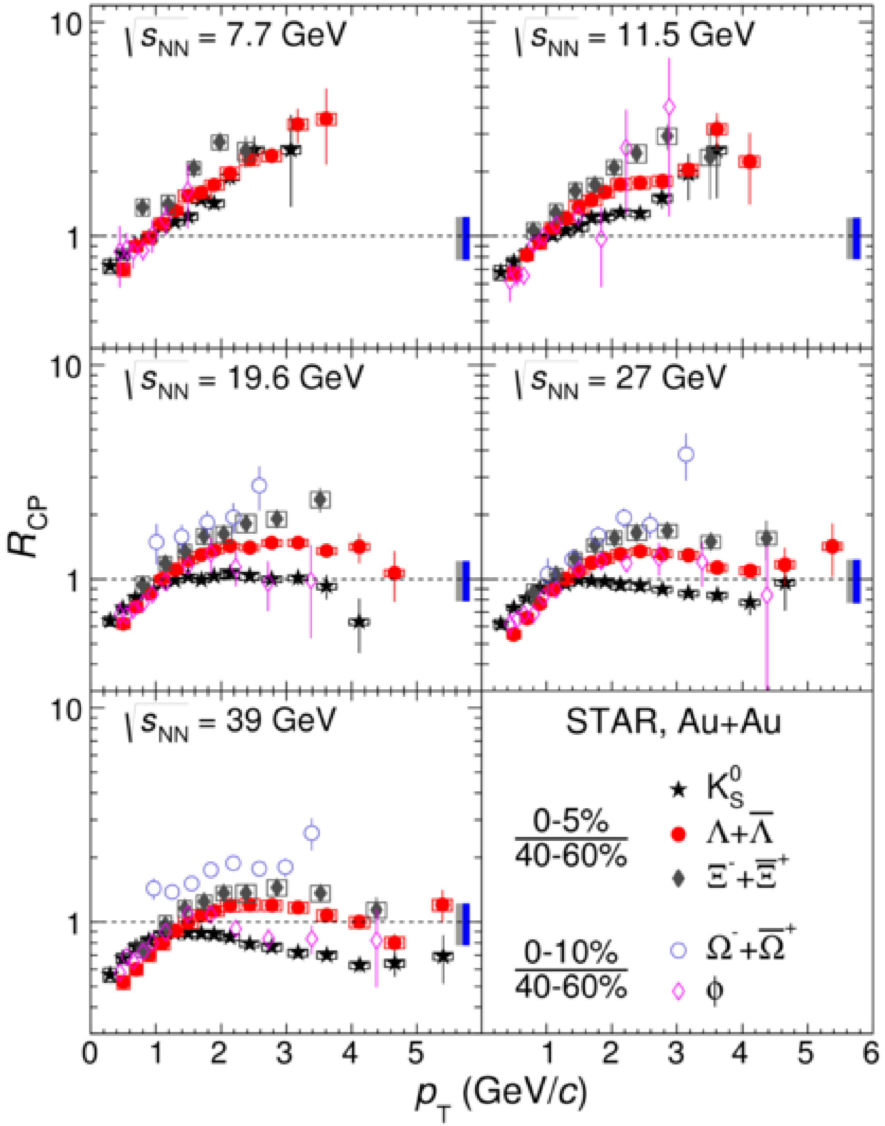
Parameters: Temperature (T_{kin}) and transverse radial velocity (β) obtained by fitting the momentum distribution of particles.

Phys. Rev. C **96** (2017) 44904

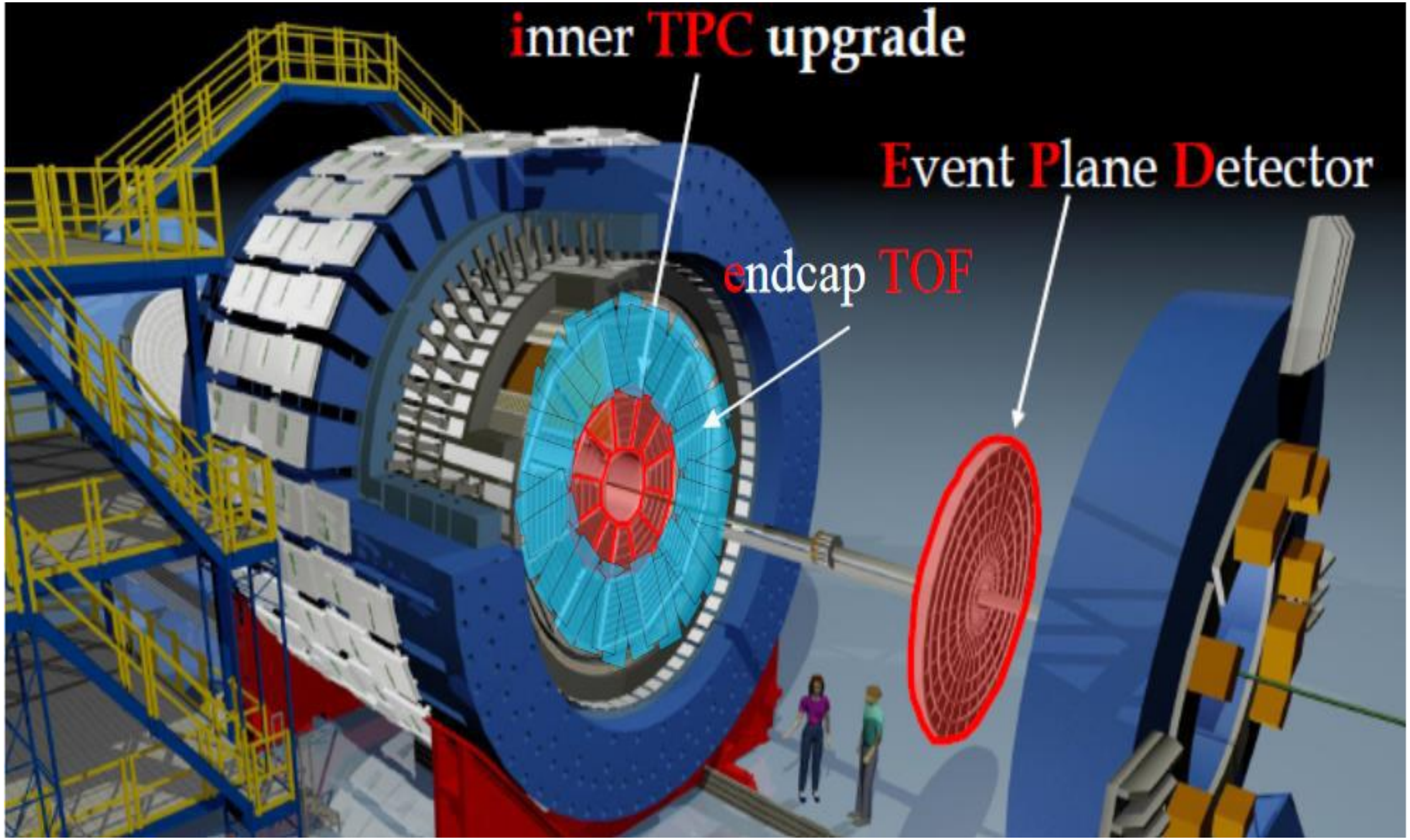
Nuclear modification in the medium

$$R_{cp} = \frac{d^2Ndp_t d\eta / <N_{coll}> (central)}{d^2Ndp_t d\eta / <N_{coll}> (peripheral)}$$





STAR detector upgrades



- **Tracking and PID (full 2π)**
  TPC: |η| < 1
  iTPC (2019+): |η| < 1.5
  TOF: |η| < 1
  eTOF (2019+): -1.6 < η < -1
  BEMC: |η| < 1
  EEMC: 1 < η < 2
  HFT (2014-2016): |η| < 1
  MTD (2014+): |η| < 0.5

- **MB trigger and event plane reconstruction**
  BBC (before 2018): 3.3 < |η| < 5
  EPD (2018+): 2.1 < |η| < 5.1
  FMS (before 2017): 2.5 < |η| < 4
  VPD: 4.2 < |η| < 5
  ZDC: 6.5 < |η| < 7.5

- **Future upgrades (2022+)**
  FCS: 2.5 < |η| < 4
  FTS: 2.5 < |η| < 4
  ECAL & HCAL: 2.5 < |η| < 4

STAR event with new sub-detectors

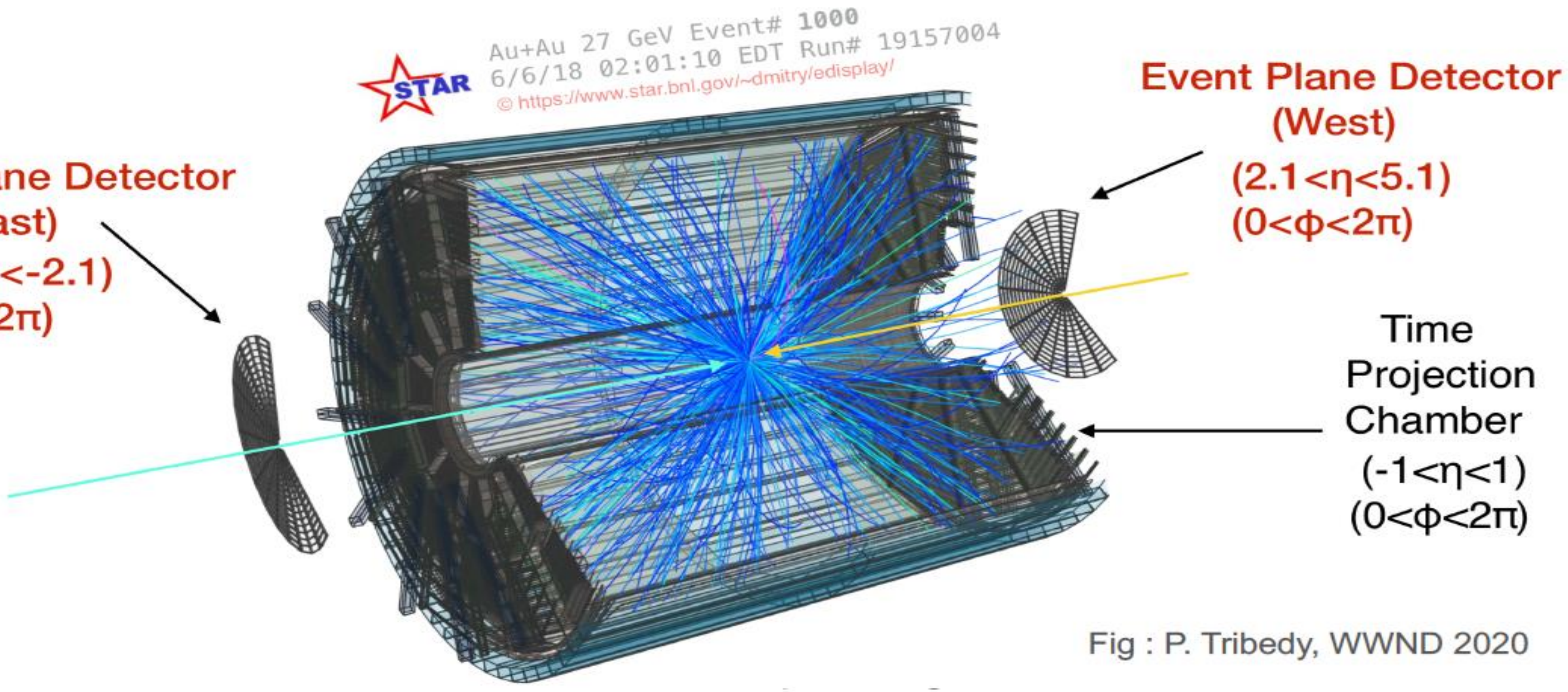
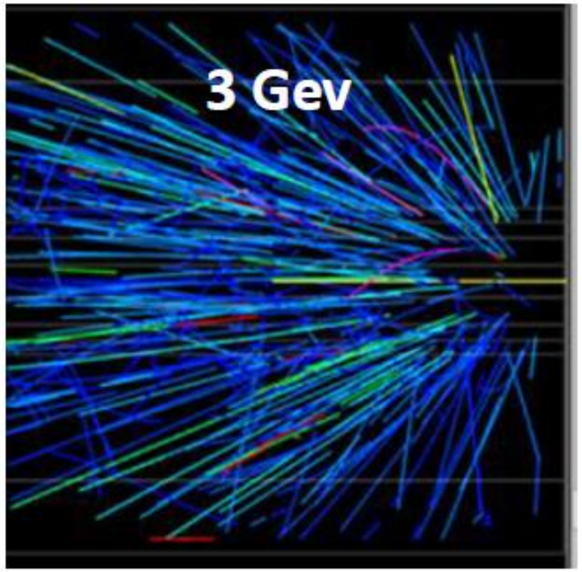


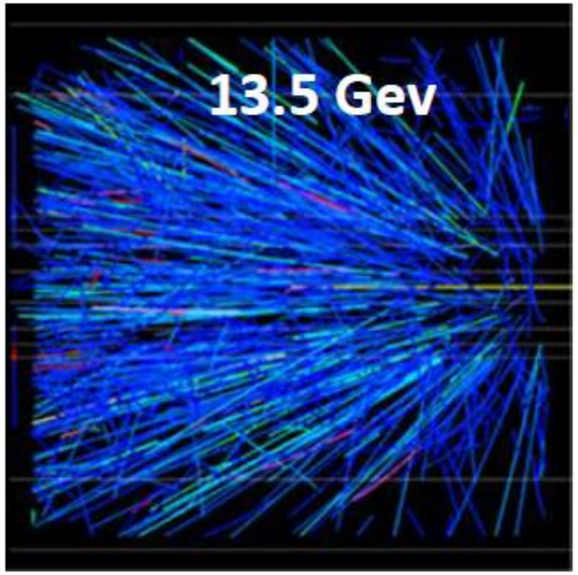
Fig : P. Tribedy, WWND 2020

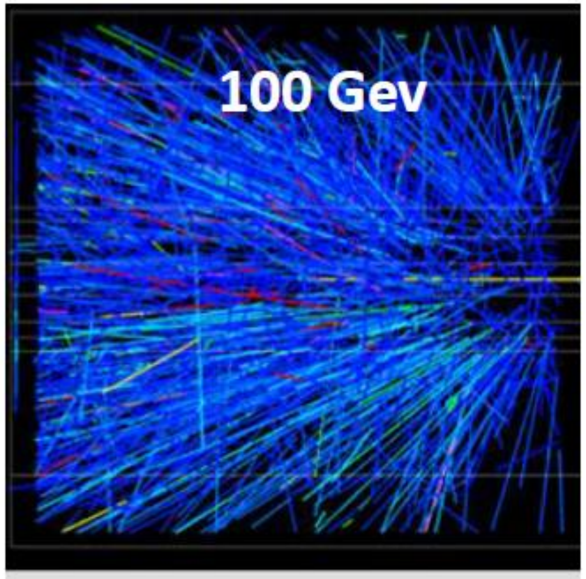
Full azimuthal coverage
Large separation in η between TPC and EPD

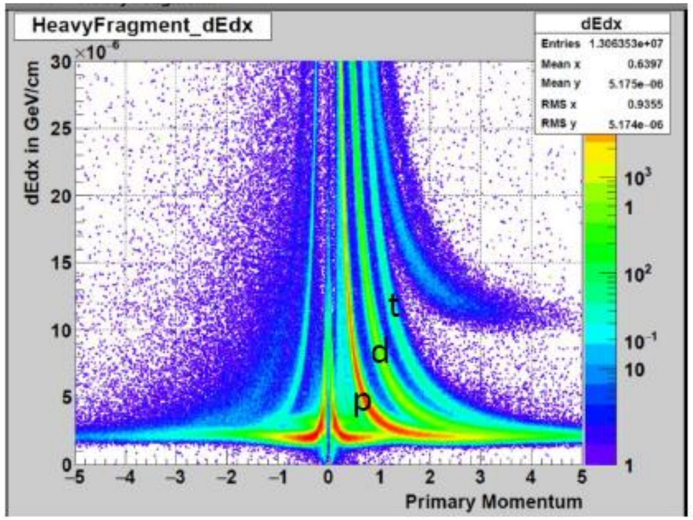
J. Adams et al. Nucl. Instrum. Meth. A 968 (2020)

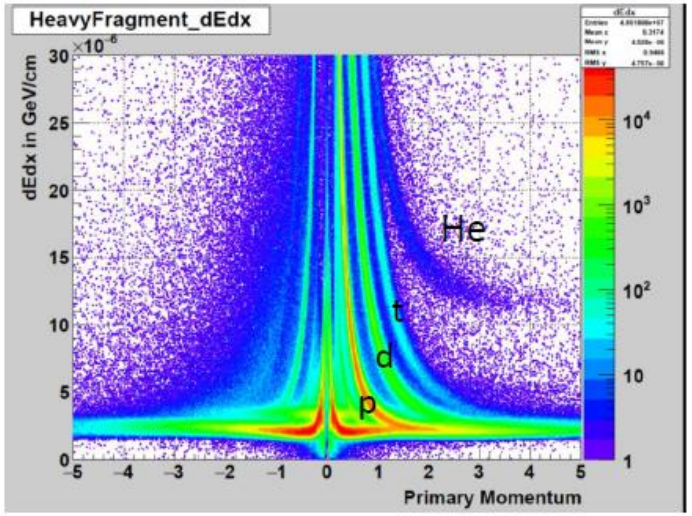
TPC coverage at FXT energies

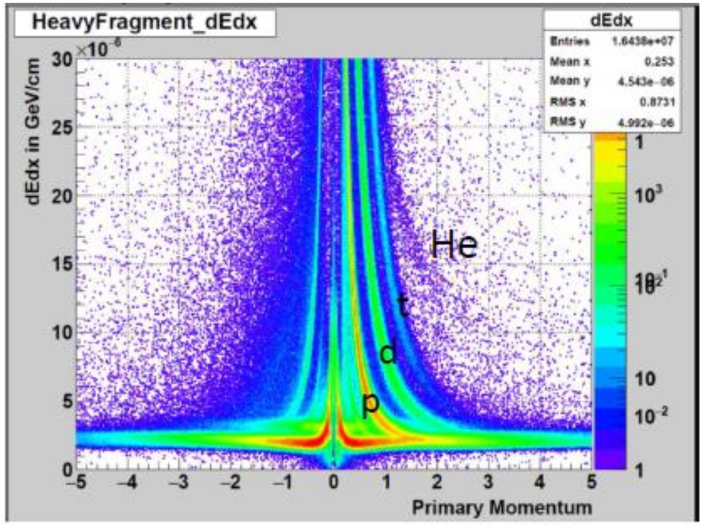




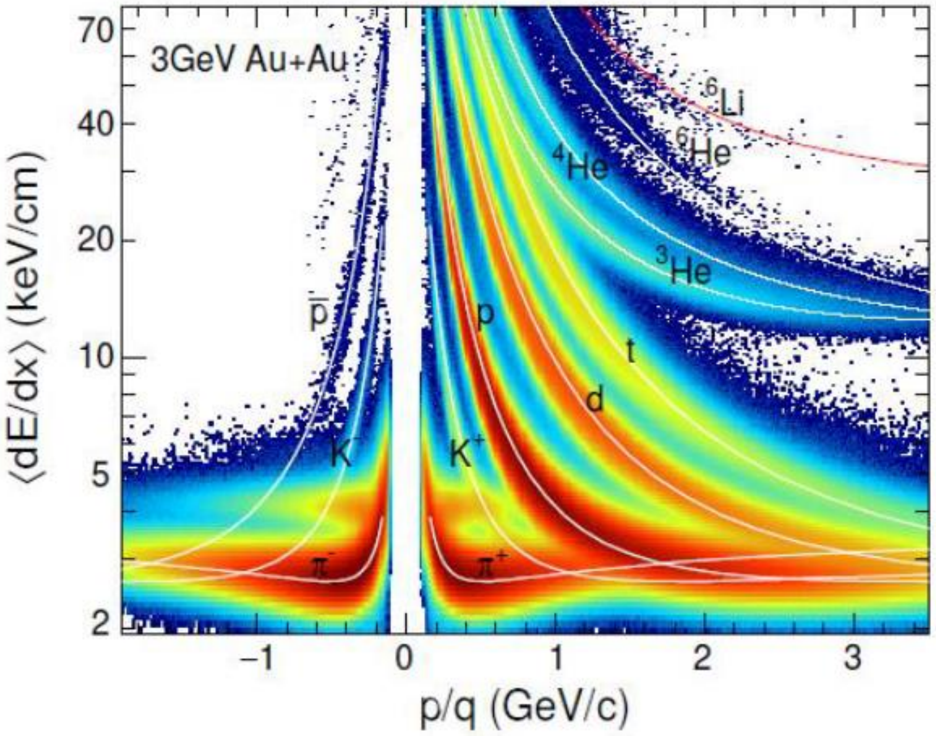


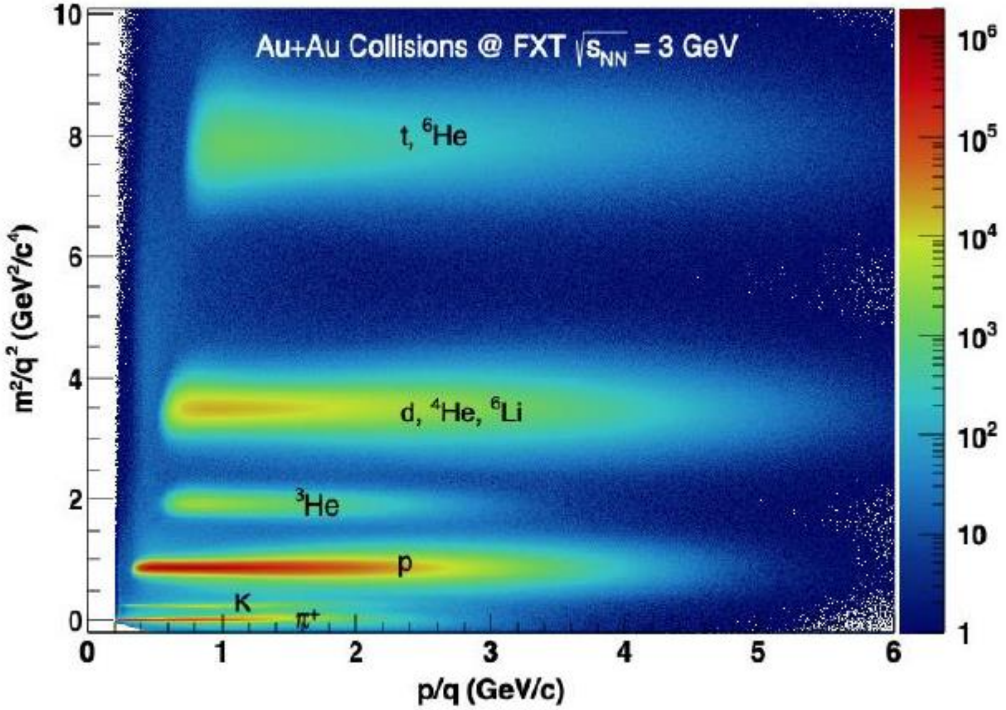






Particle identification at 3 GeV





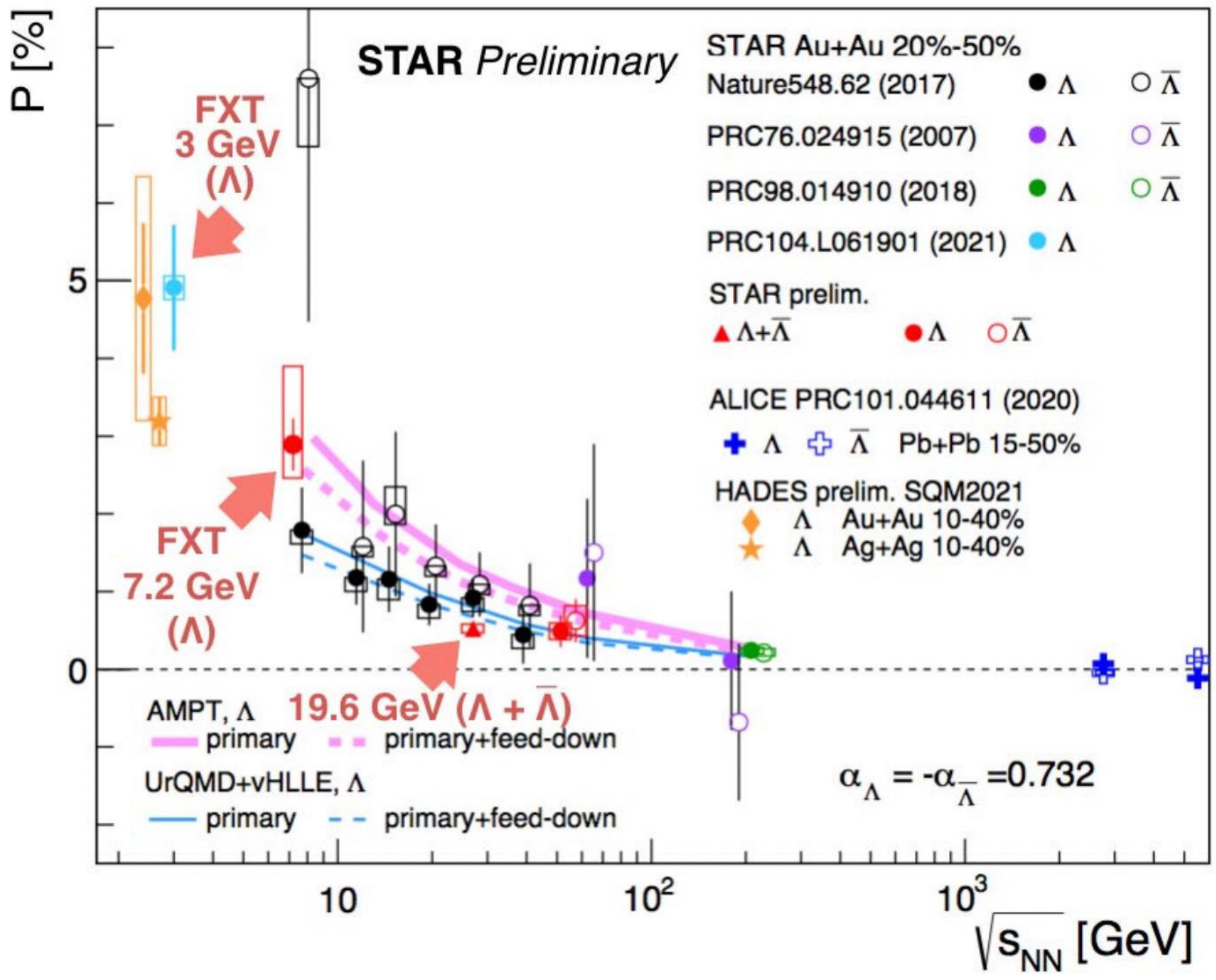
Detects Particles in the $0 < \eta < 2$ range

π, K, p, d, t, h, α through dE/dx and TOF

K^0_s, Λ, Ξ, Ω, ϕ, $^3_\Lambda H$, $^4_\Lambda H$ through invariant mass

Only ~ 15% of full statistics analyzed (300M)

Global polarization measurements



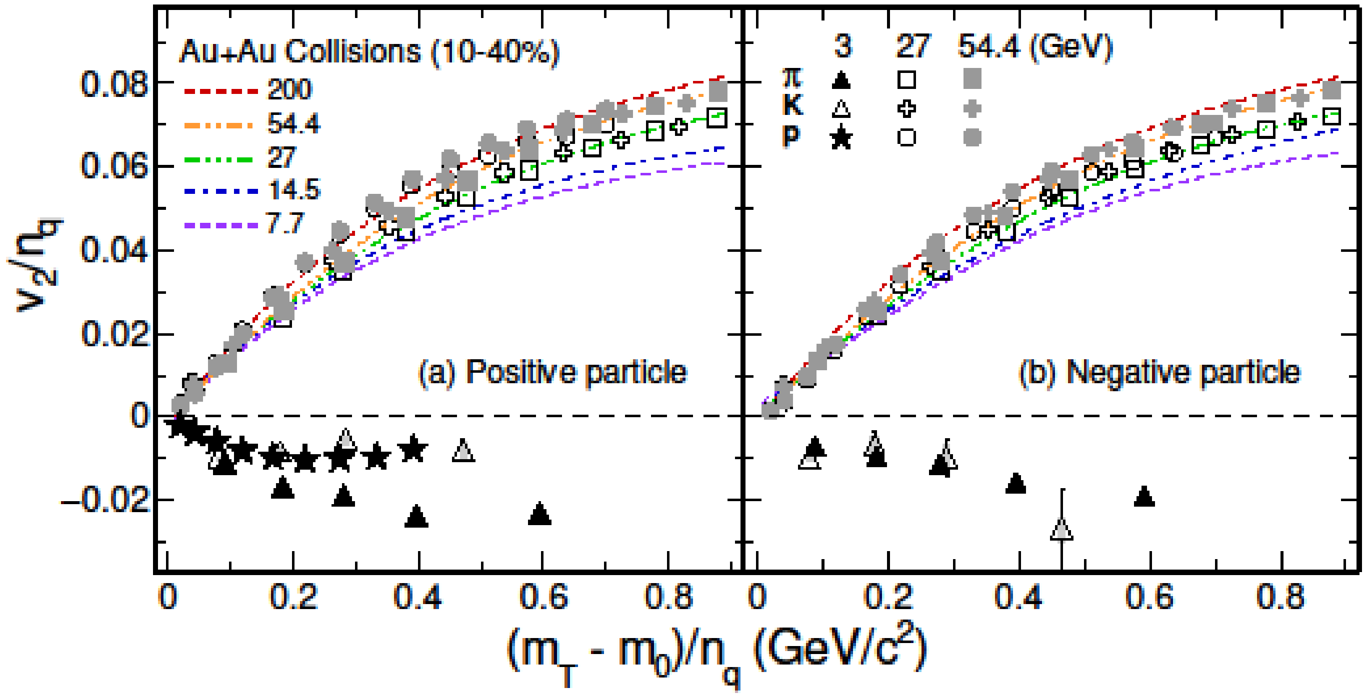
Global hyperon polarizationovera large range of collision energywas recently measured and successfully reproduced by hydrodynamic and transport models with intense fluid vorticity of the QGP

The observation of substantial polarization in these collisions may require a reexamination of the viscosity of any fluid created in the collision, of the thermalization timescale of rotational modes, and of hadronic mechanisms to produce global polarization.

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1+\alpha_H|\vec{\mathcal{P}}_H|\cos\theta^*\right)$$

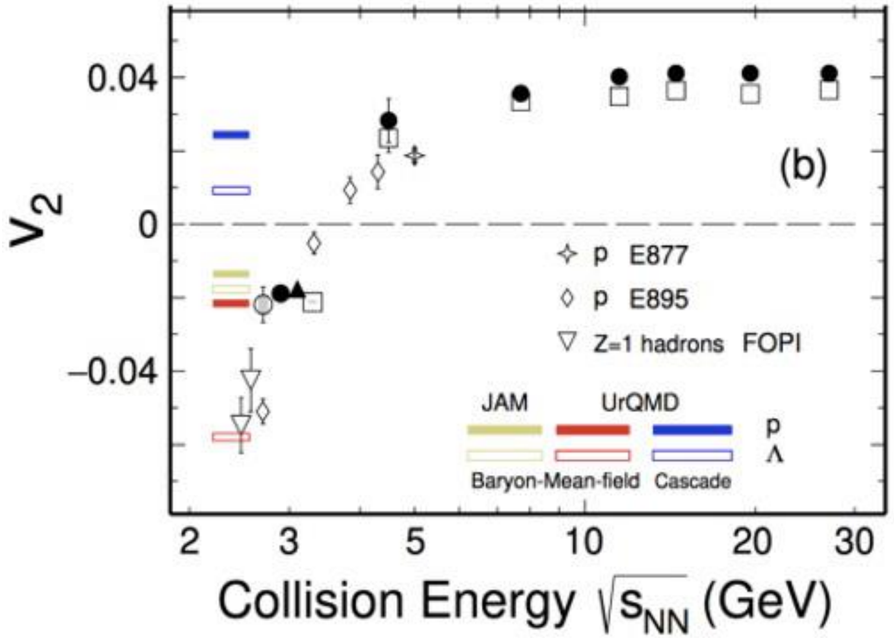
Nature 548 (2017) 62,
PRC 104 (2021) 061901,
arXiv: 2204.02302

Elliptic flow at 3 GeV



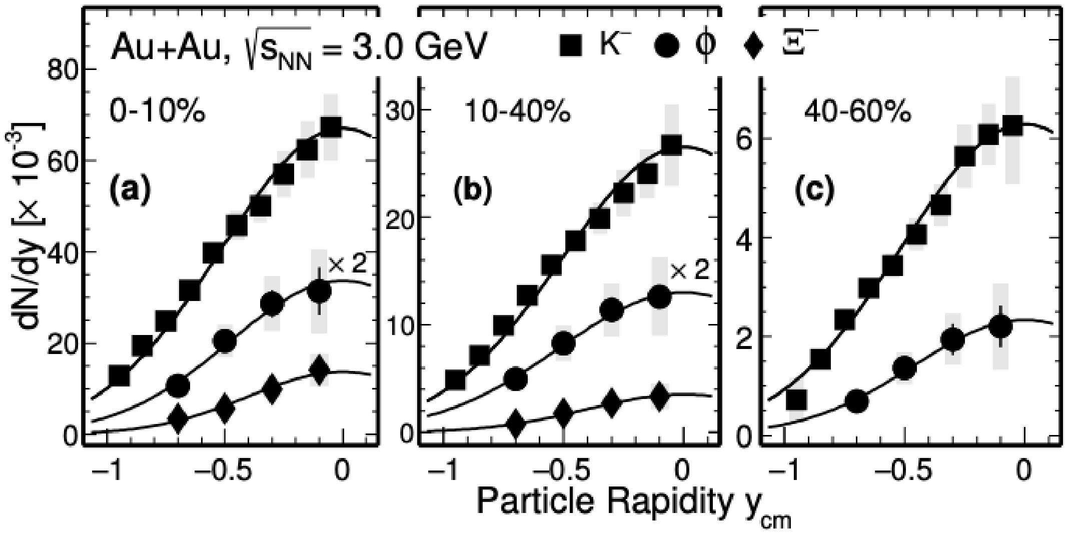
Elliptic flow is negative (squeeze-out) at 3 GeV, as expected from the previous AGS data

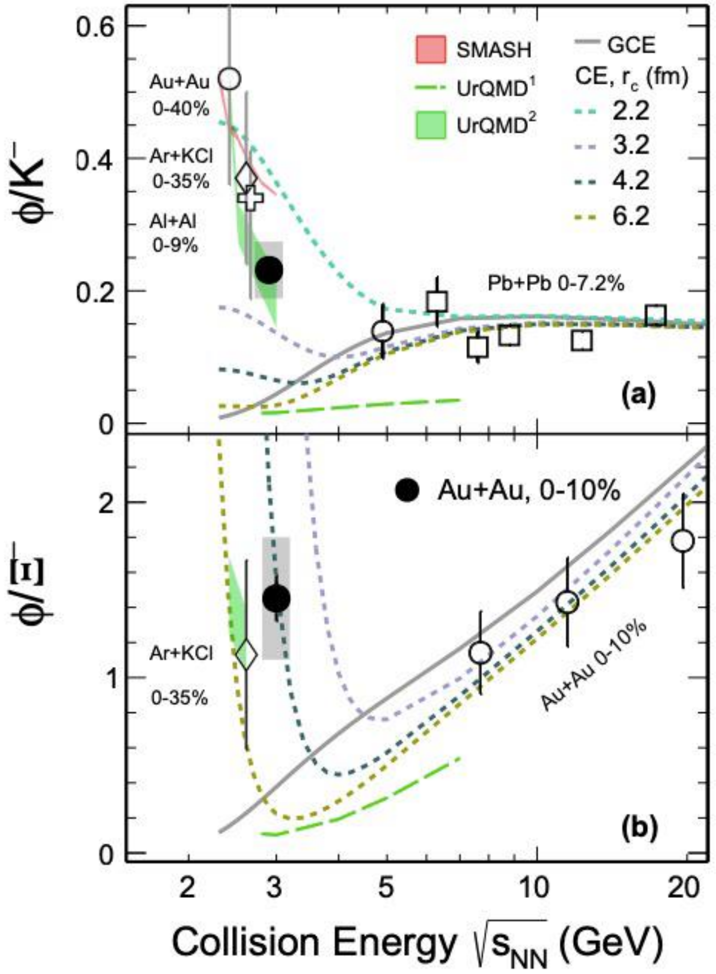
The quark number scaling has been used at higher energies as a signature of the QGP. At 3 GeV, the scaling is broken down e.g. hadronic gas (not QGP).



Phys. Lett. B **827**(2022) 137003

Hidden vs. open strangeness production





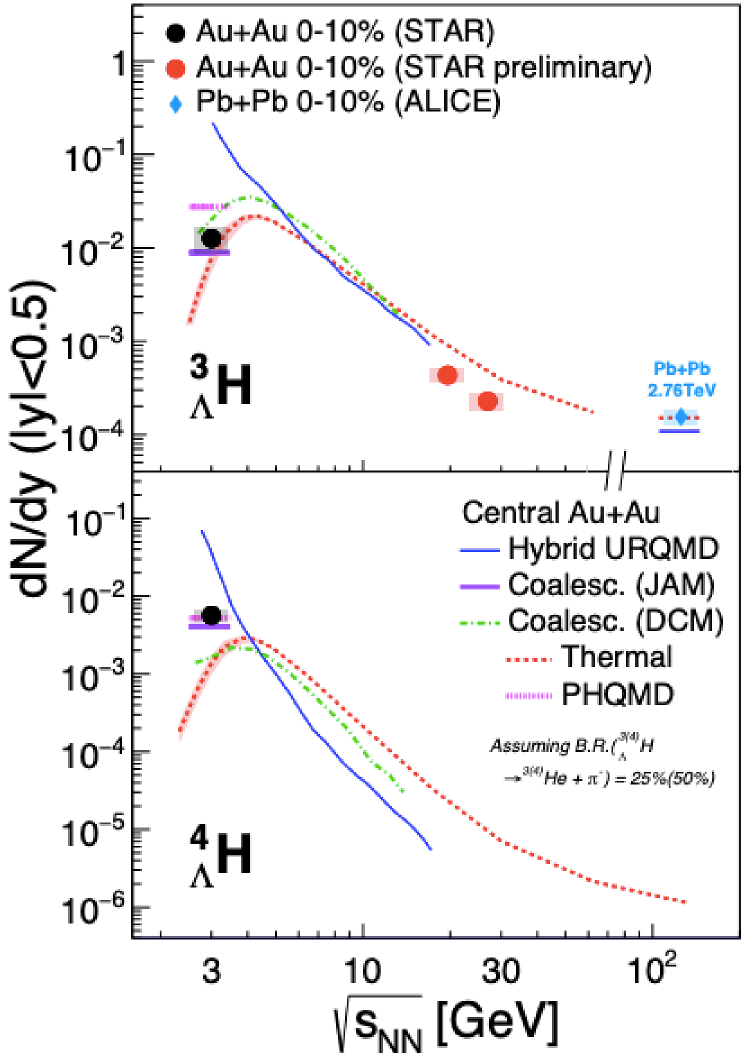
The thermal model with grand canonical ensemble (GCE) under-predicts the ratios

The canonical ensemble (CE) calculations reproduce the ratios with correlation lengths of 3-4 fm

These observations imply that the fmeson is produced in a system of high baryon density causing the small correlation length

Phys. Lett. B **831**(2022) 137152

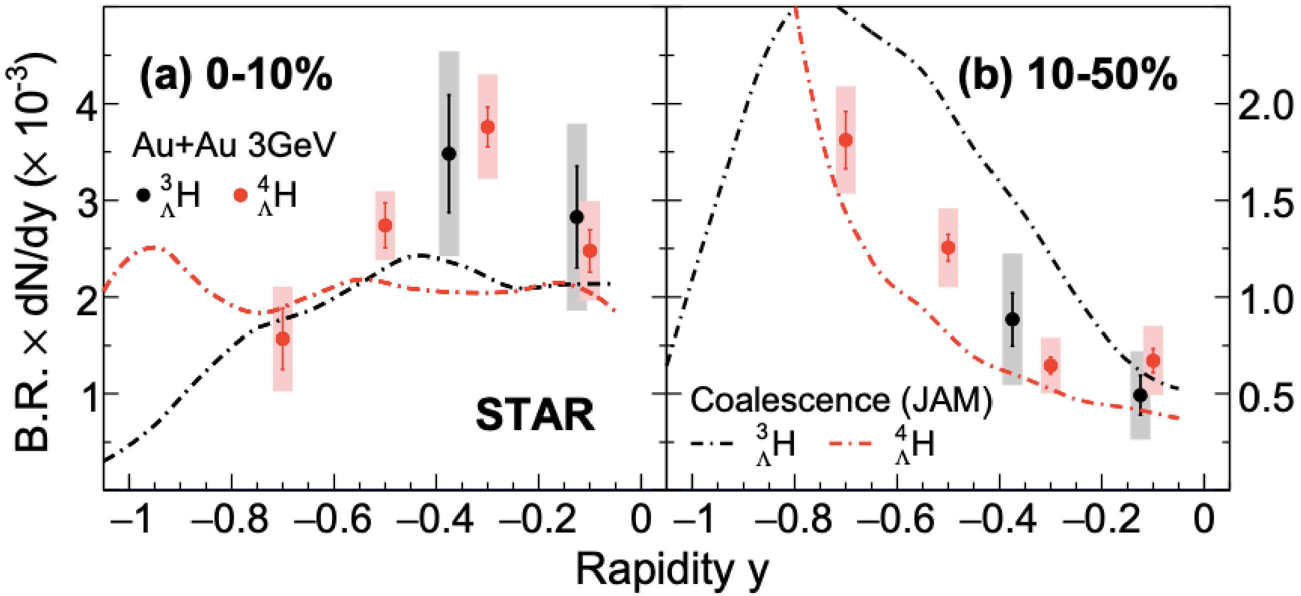
Hypernuclei production



Hyper-triton yields follow the thermal model predictions

Hyper-H4 yields are under predicted by thermal models

Lifetime measurements are consistent with previous measurements and have higher precision



PRL 128 (2022) 202301

Summary

- ✓ BES-I results are mostly analyzed and published
- ✓ BES-II has increased statistics and collision energy coverage
- ✓ BES-II data were taken after several detector upgrades
- ✓ Previous energy scans had demonstrated the liquid - gas phase transition and the evolution from systems dominated by the attractive part of the inter nucleon potential to those dominated by repulsive interactions
- ✓ The first results are from the lowest energy FXT system and these demonstrate that the system is clearly in the hadronic gas phase (as expected)
- ✓ Data taking has been very successfully completed and analysis is underway

Backup slides

BES-I statistics and run time

$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year	μ_B (MeV)	T_{CH} (MeV)
200	350	2010	25	166
62.4	67	2010	73	165
54.4	1200	2017	90	
39	39	2010	112	164
27	70	2011	156	162
19.6	36	2011	206	160
14.5	20	2014	264	156
11.5	12	2010	315	152
9.2	0.3	2008	355	140
7.7	4	2010	420	140

BES-II statistics and run time

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
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
3.85	7.7	420	11-20 weeks	100 M	Run-21[2]

New acceptance