LXX International conference "NUCLEUS – 2020. Nuclear physics and elementary particle physics. Nuclear physics technologies"

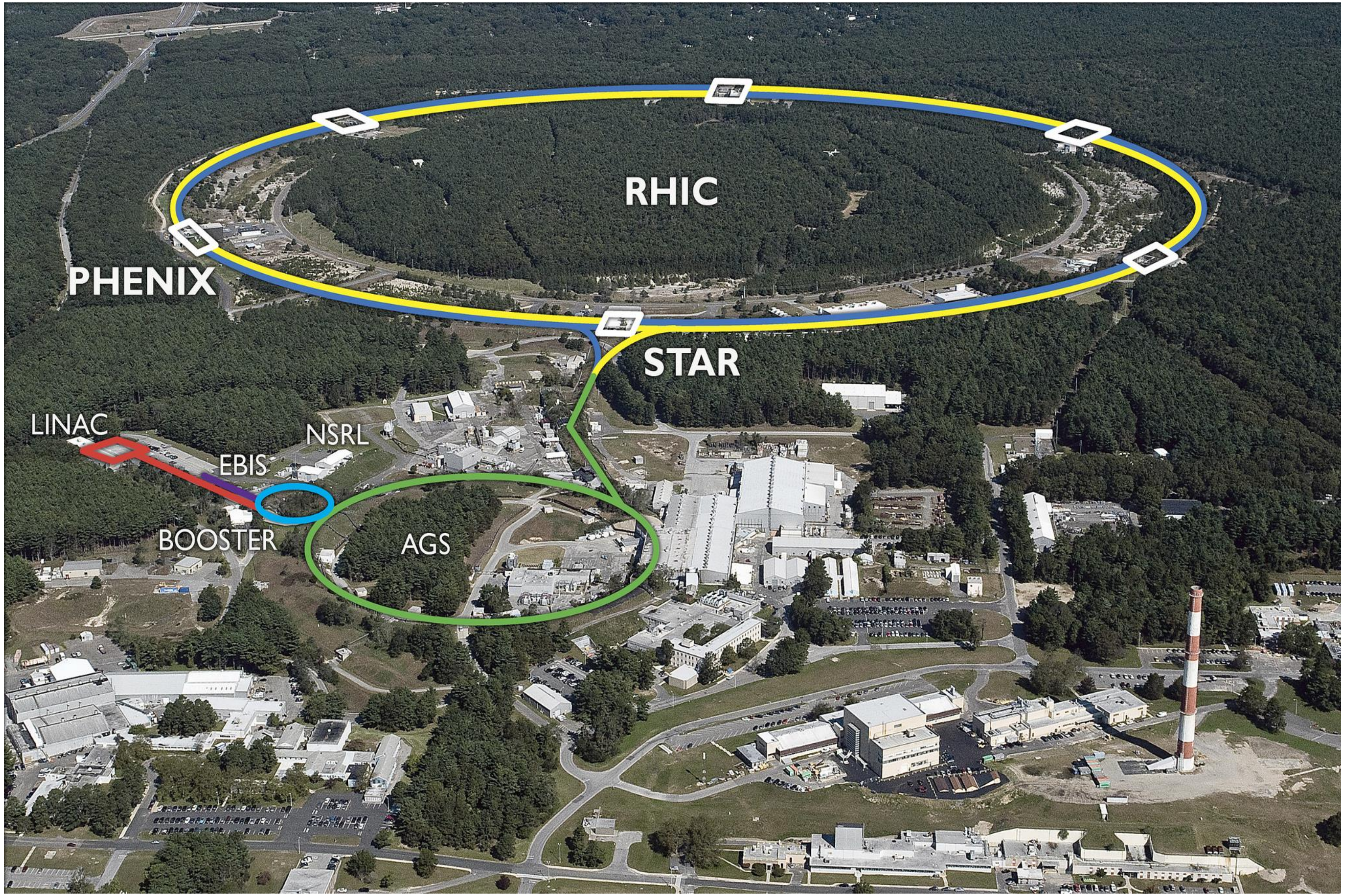
STAR

STAR recent results on heavy-ion collisions.

Alexey Aparin
for the STAR collaboration

Joint Institute for Nuclear Research

Relativistic Heavy Ion Collider



In operation since 1999

3.83 km circumference

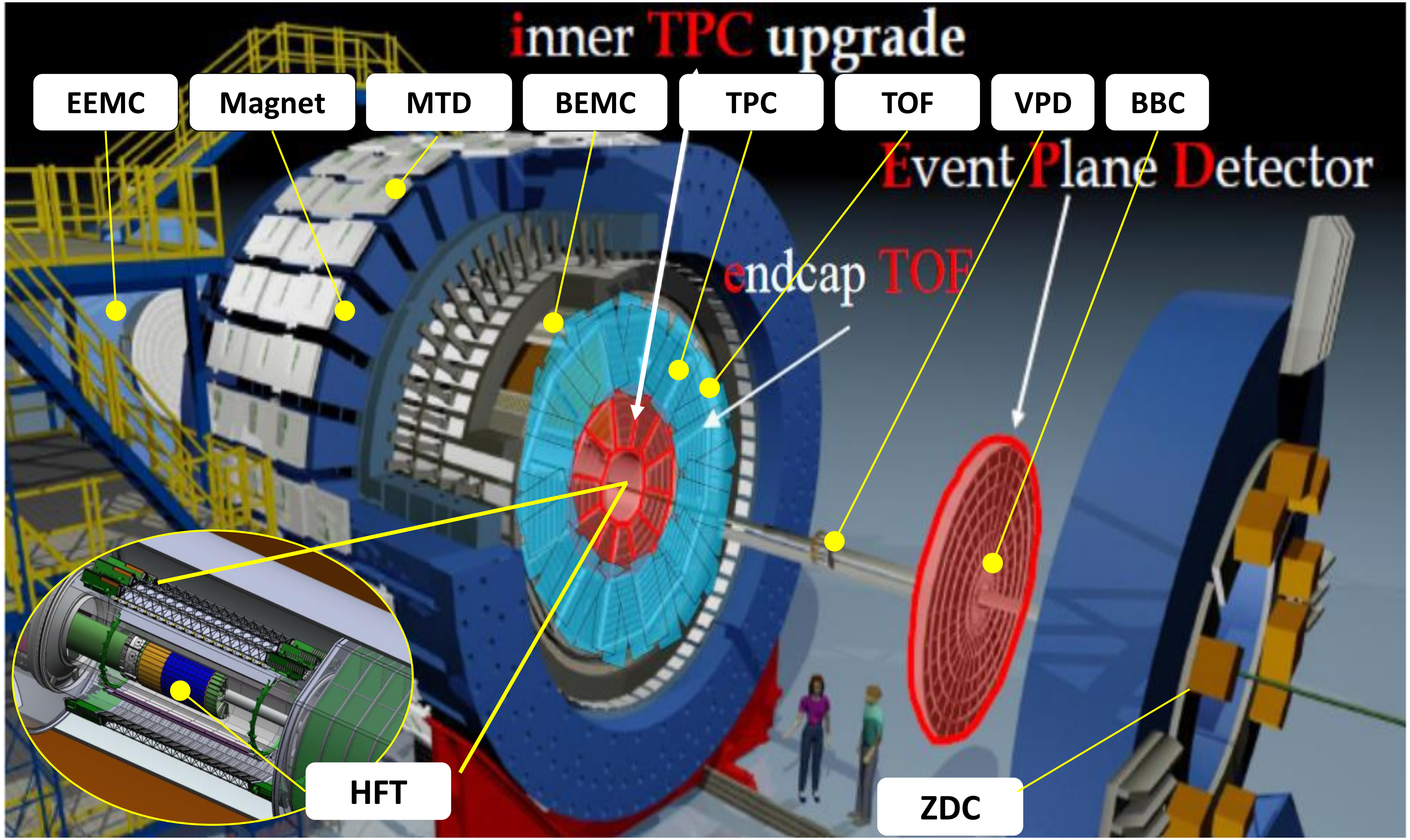
Suitable for p+p, p+A, A+A

Max. colliding energy:
200 GeV for Au+Au
510 GeV for p+p

Tuned for exploring QCD matter and its phase boundary in different colliding systems (Au+Au, U+U, p+Al, p+Au, d+Au, ^{3}He+Au, Cu+Au, Cu+Cu, Al+Au, Zr+Zr, Ru+Ru)

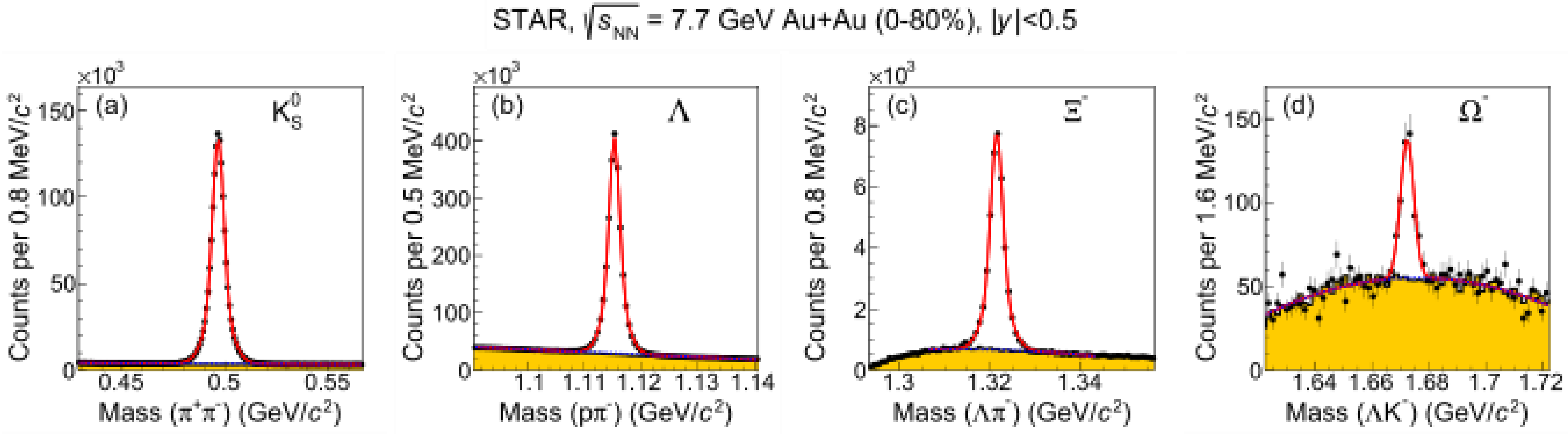
Spin physics on polarized proton-proton beam

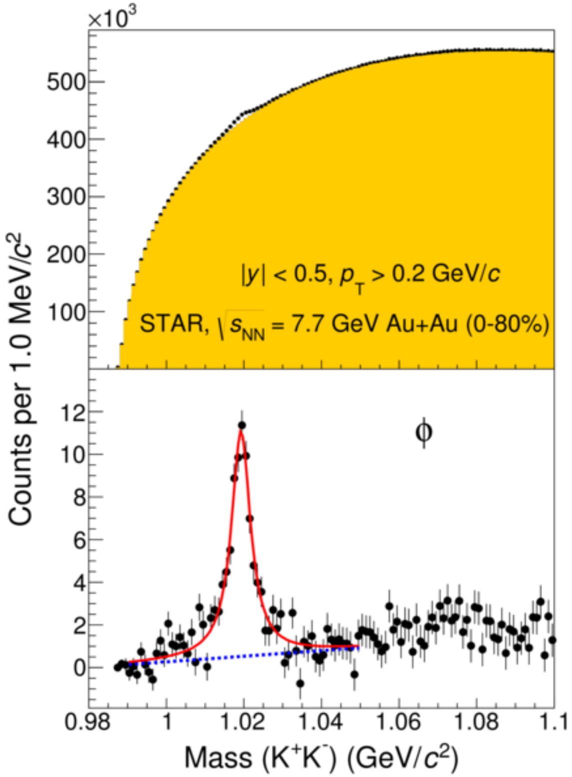
STAR detector



- Tracking and PID (full 2π)
  TPC: $|\eta| < 1$
  iTPC (2019+): $|\eta| < 1.5$
  TOF: $|\eta| < 1$
  eTOF (2019+): $-1.6 < \eta < -1$
  BEMC: $|\eta| < 1$
  EEMC: $1 < \eta < 2$
  HFT (2014-2016): $|\eta| < 1$
  MTD (2014+): $|\eta| < 0.5$
- MB trigger and event plane reconstruction
  BBC (before 2018): $3.3 < |\eta| < 5$
  EPD (2018+): $2.1 < |\eta| < 5.1$
  FMS (before 2017): $2.5 < |\eta| < 4$
  VPD: $4.2 < |\eta| < 5$
  ZDC: $6.5 < |\eta| < 7.5$
- Future upgrades (2022+)
  FCS: $2.5 < |\eta| < 4$
  FTS: $2.5 < |\eta| < 4$
  ECAL & HCAL: $2.5 < |\eta| < 4$

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

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

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

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

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

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

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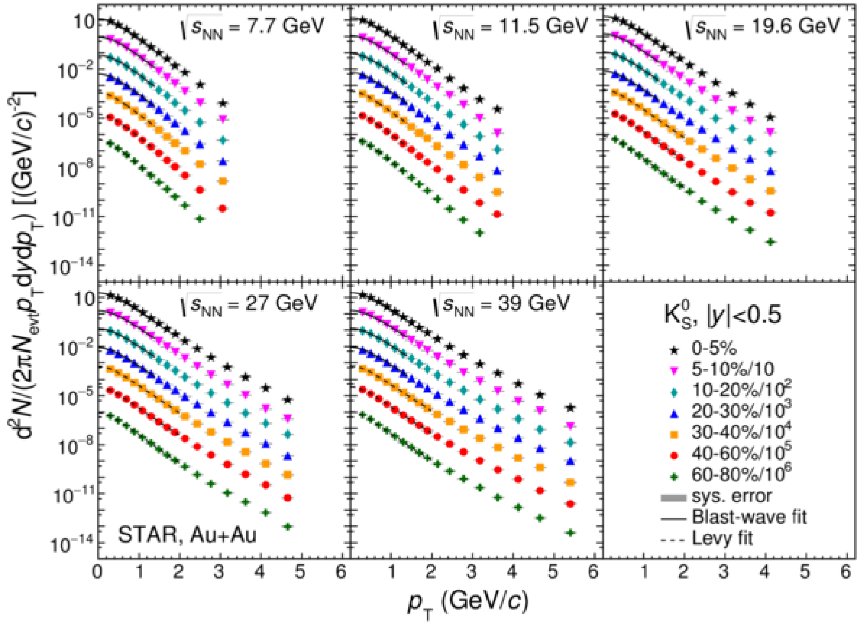
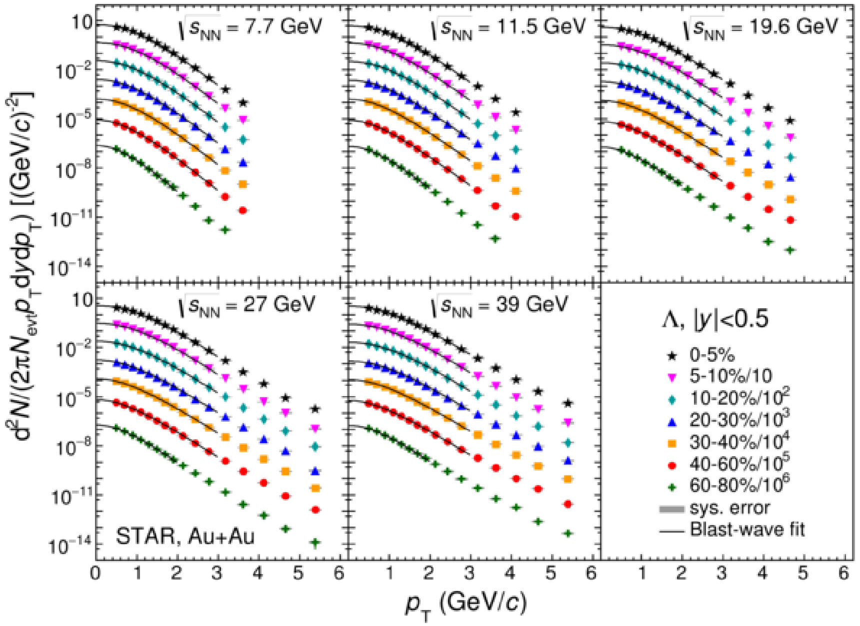
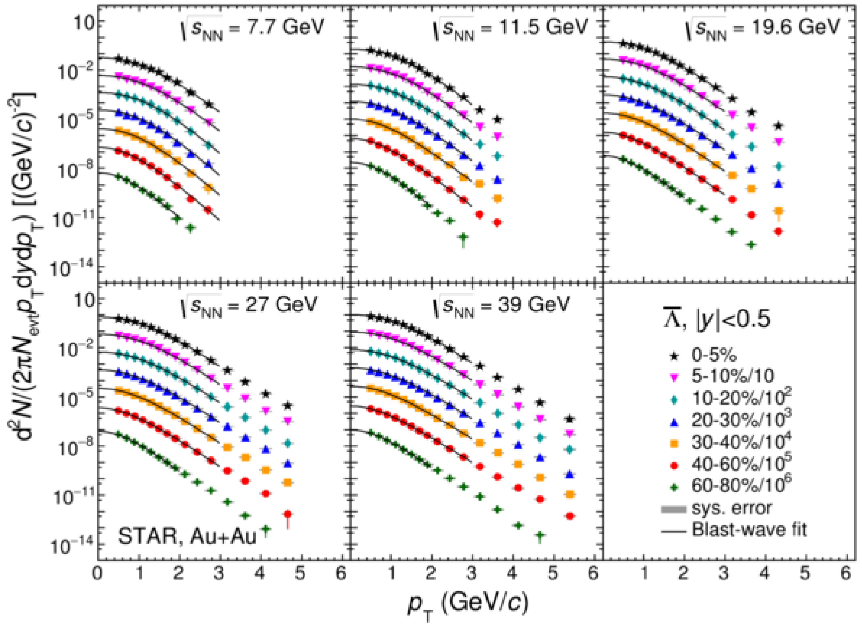
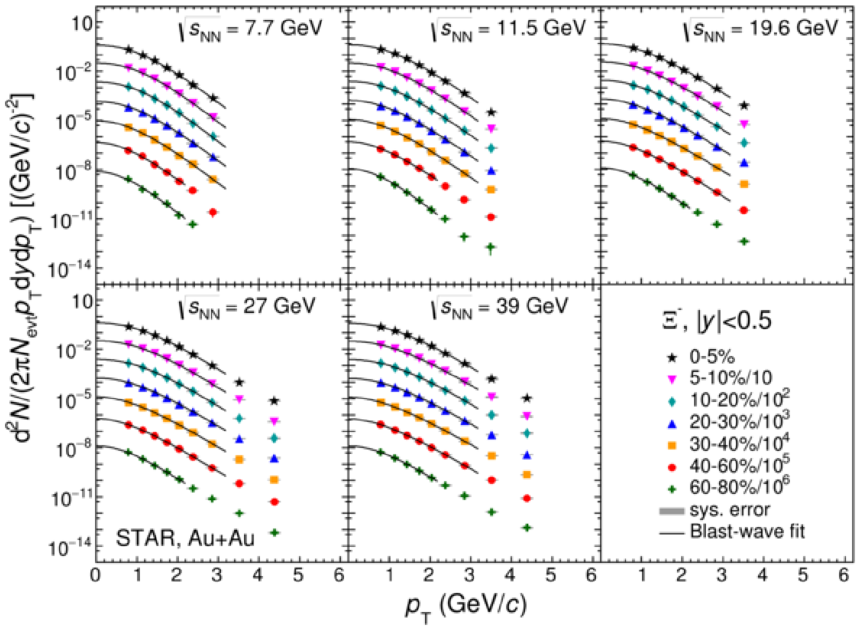
Momentum spectra of strange particles at BES-I









K^0_s, Λ, anti-Λ, Ξ^- transverse momentum spectra at midrapidity $|y| < 0.5$

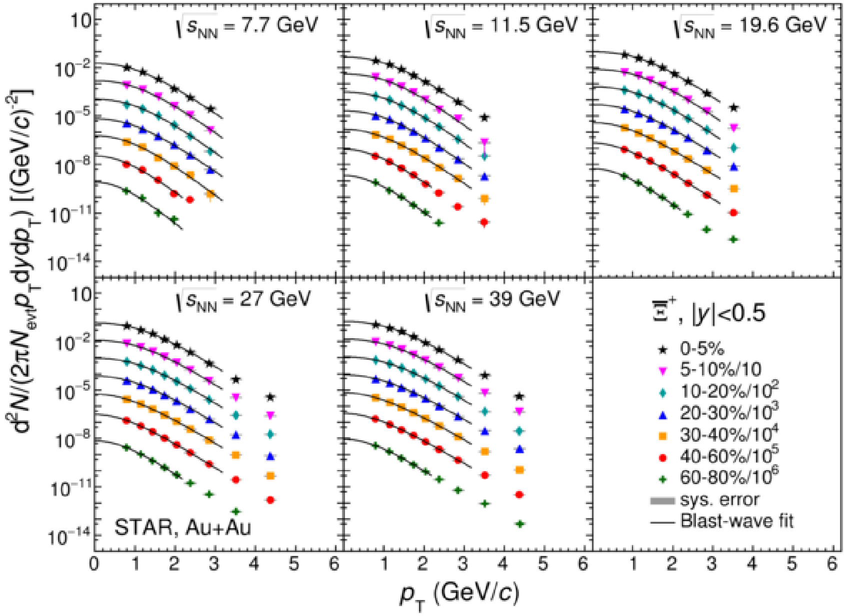
Levy fit

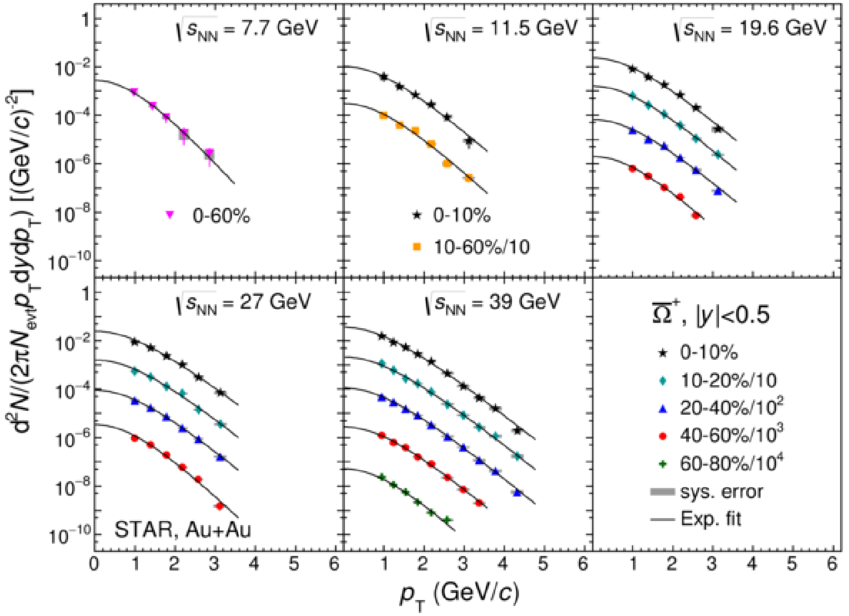
$$\frac{d^2N}{2\pi p_T dp_T dy} \propto \left(1+\frac{m_T - m_0}{nT}\right)^{-n}$$

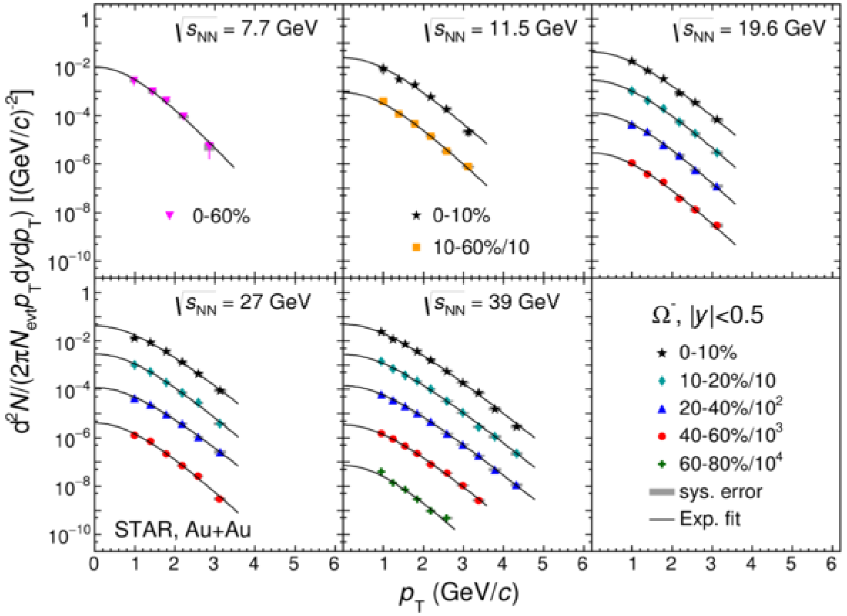
Blast-wave fit

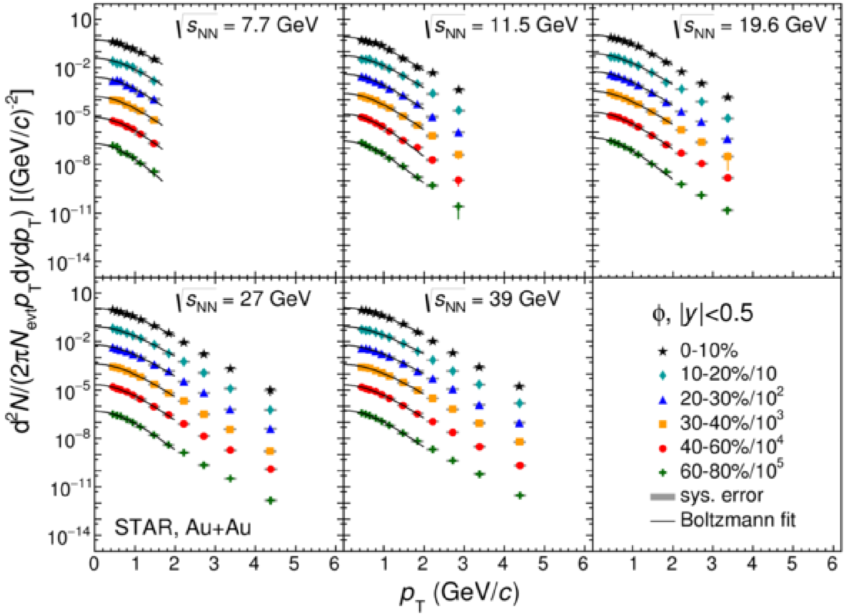
$$\frac{d^2N}{2\pi p_T dp_T dy} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho(r)}{T}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T}\right)$$

Momentum spectra of strange particles at BES-I









Ξ^+, Ω^-, Ω^+, φ transverse momentum spectra at midrapidity $|y| < 0.5$

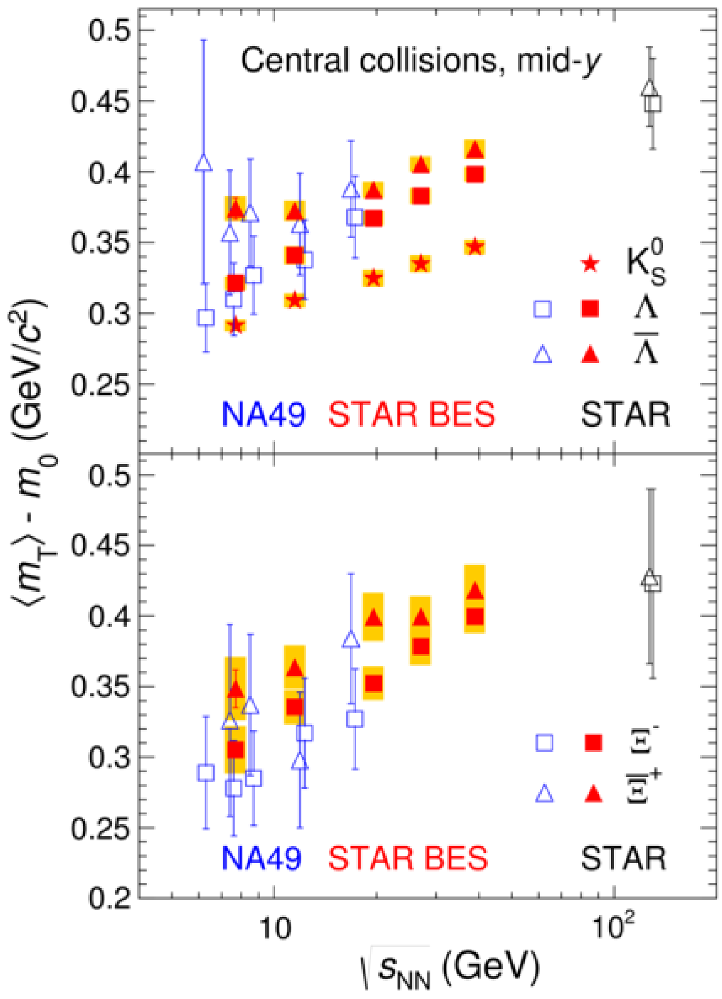
Exponential fit

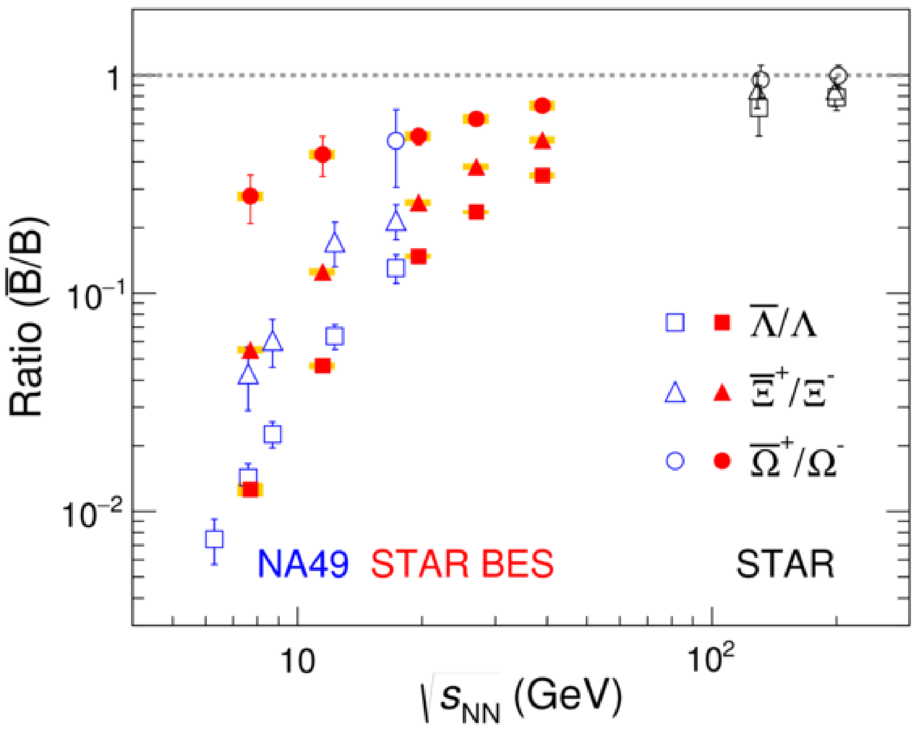
$$\frac{d^2N}{2\pi p_T dp_T dy} \propto e^{-\frac{m_T}{T}}$$

Boltzmann fit

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto m_T e^{-\frac{m_T}{T}}$$

Energy dependence of particle production





Data are consistent with results previously obtained by NA49 and STAR with better precision

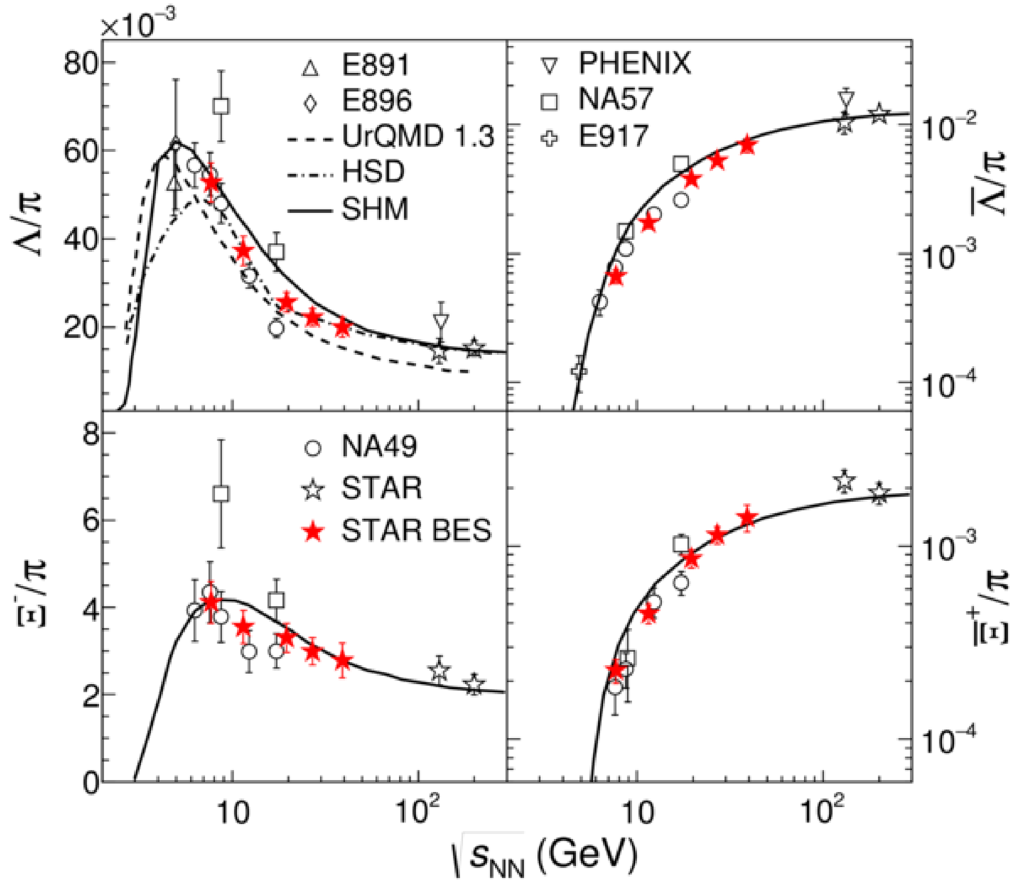
Anti-baryon to baryon ratio follows the hierarchy for all energies

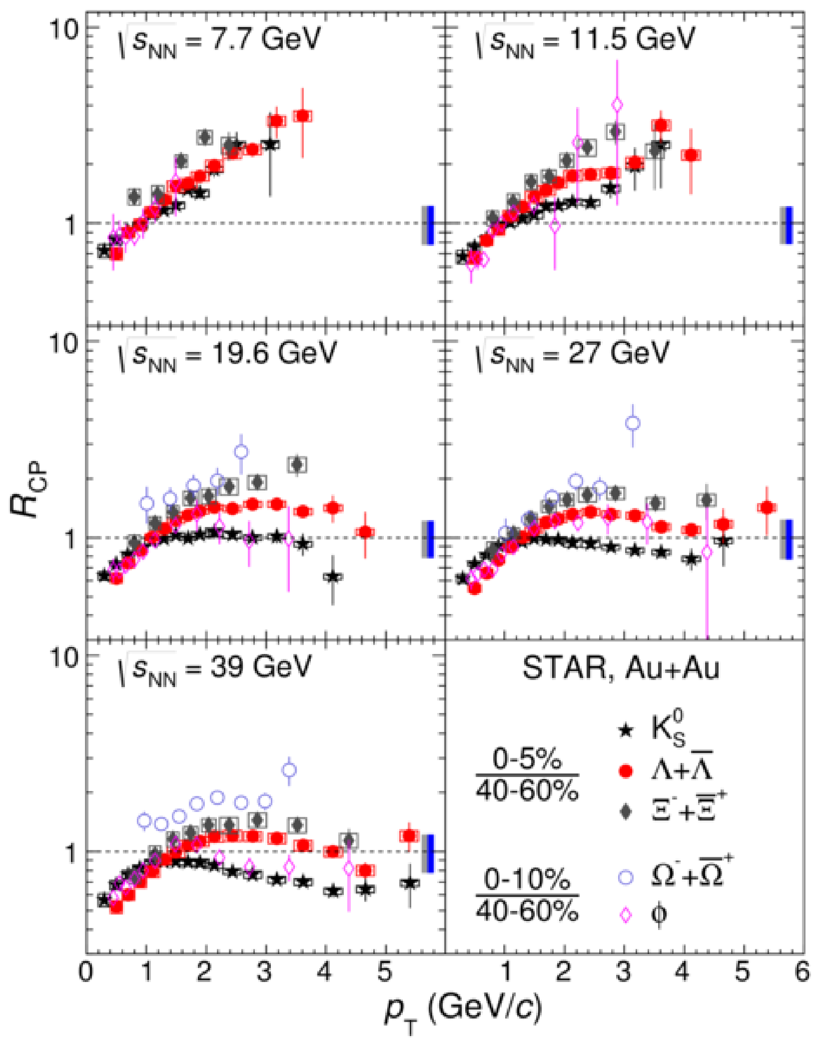
$$\overline{\Omega}^+/\Omega^- > \overline{\Xi}^+/\Xi^- > \overline{\Lambda}/\Lambda$$

which is consistent with the predictions from the statistical thermal model

Possible hints of the onset of deconfinement

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





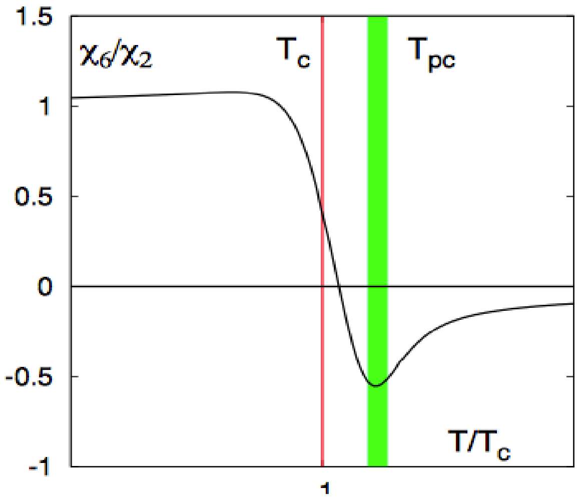
$$\pi = 1.5 \cdot (\pi^- + \pi^+)$$

Data are consistent with previous measurements

Maximum in production of Λ, Ξ^- at energies ~ 10 GeV

Net-kaon cumulants measurements

High order cumulants of conserved number distributions are sensitive to critical phenomena, related to the correlation length and susceptibilities.



Susceptibility ratios fluctuations near the CP

Phys. Lett. B **785** (2018) 551

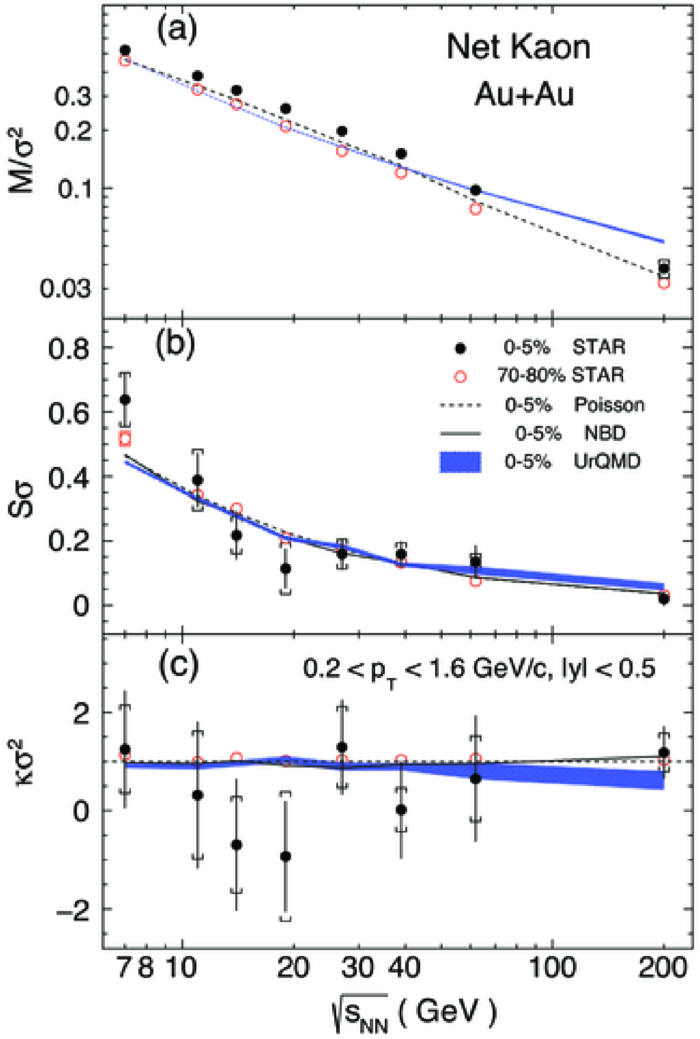
Cumulants

$$C_1 = \langle N \rangle$$
$$C_2 = \langle (\delta N)^2 \rangle$$
$$C_3 = \langle (\delta N)^3 \rangle$$
$$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$$

Moments

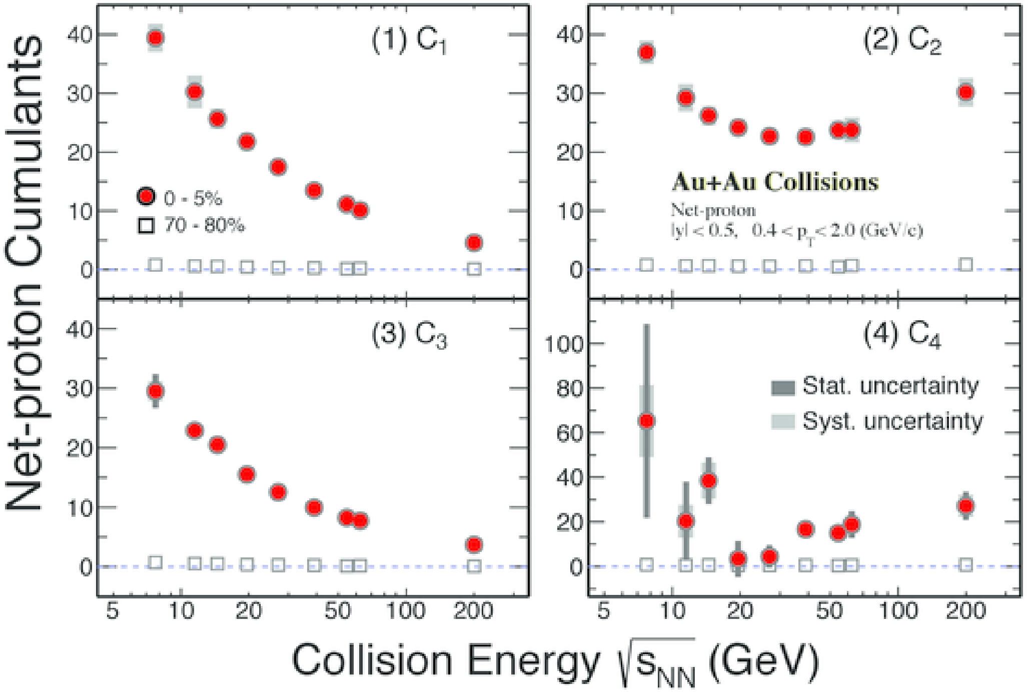
$$M = C_1, \sigma^2 = C_2, S = \frac{C_3}{(C_2)^{\frac{3}{2}}}, \kappa = \frac{C_4}{(C_2)^2}$$

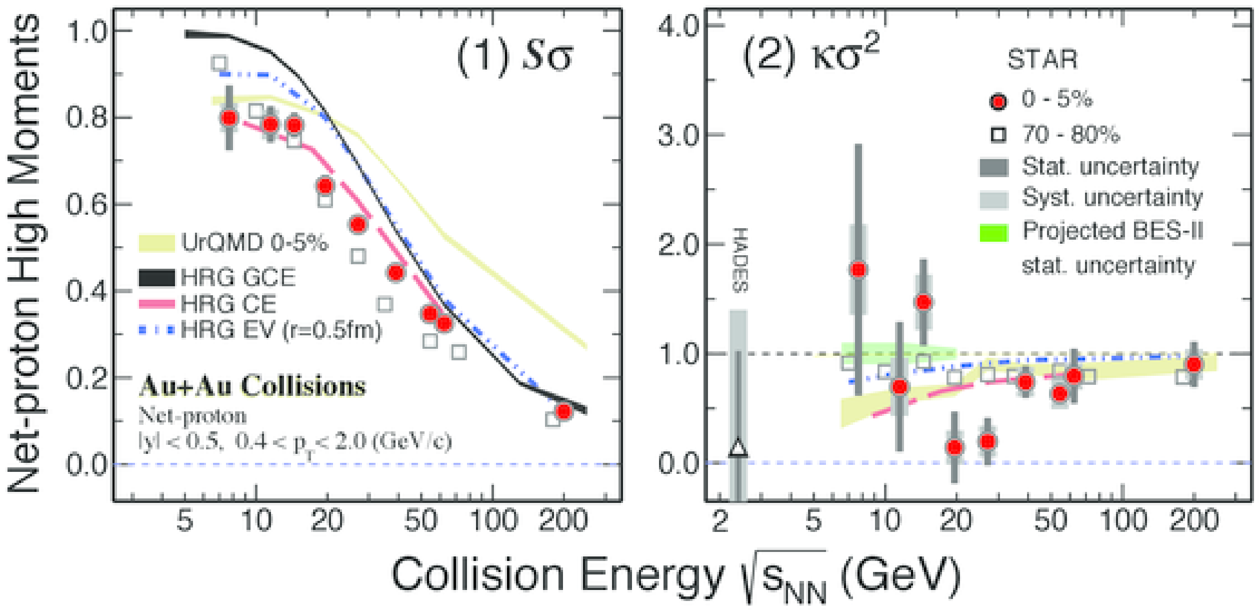
$$\frac{C_2}{C_1} = \frac{\sigma^2}{M} \qquad \frac{C_3}{C_2} = S\sigma \qquad \frac{C_4}{C_2} = \kappa\sigma^2$$



Energy dependence of net-proton cumulants

Non-monotonic behavior for higher order cumulants.

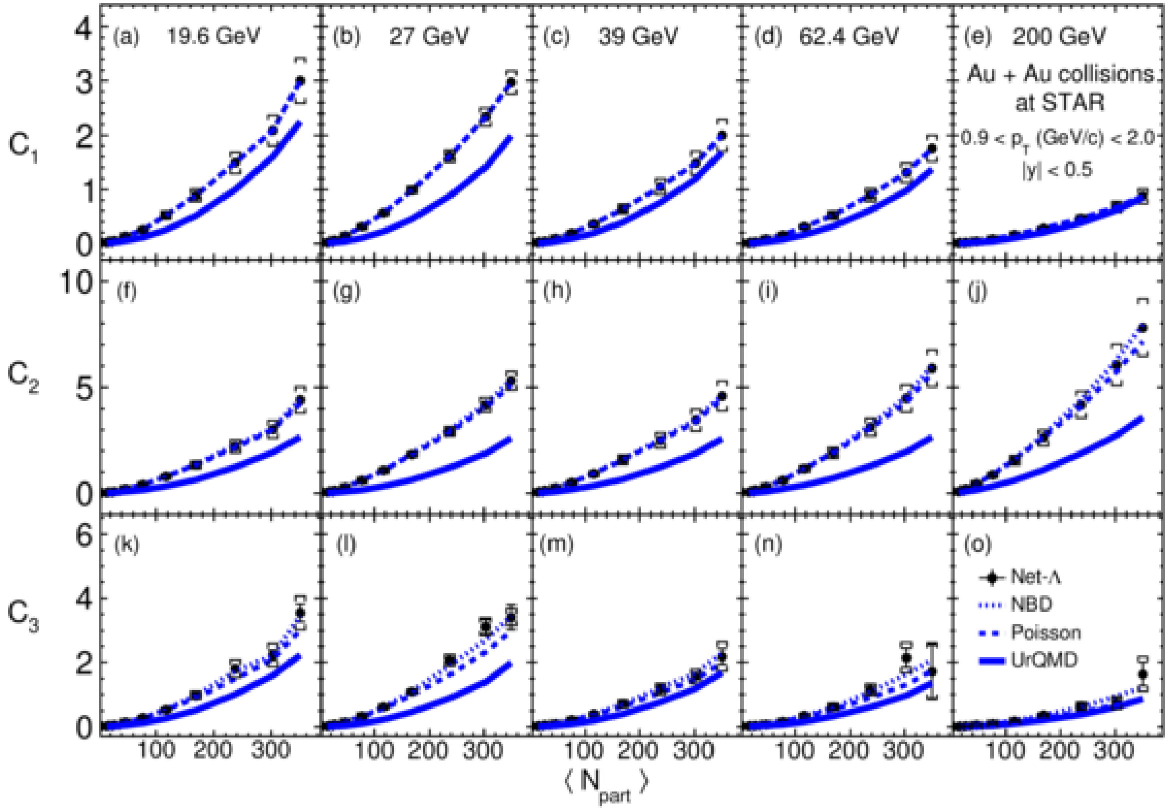


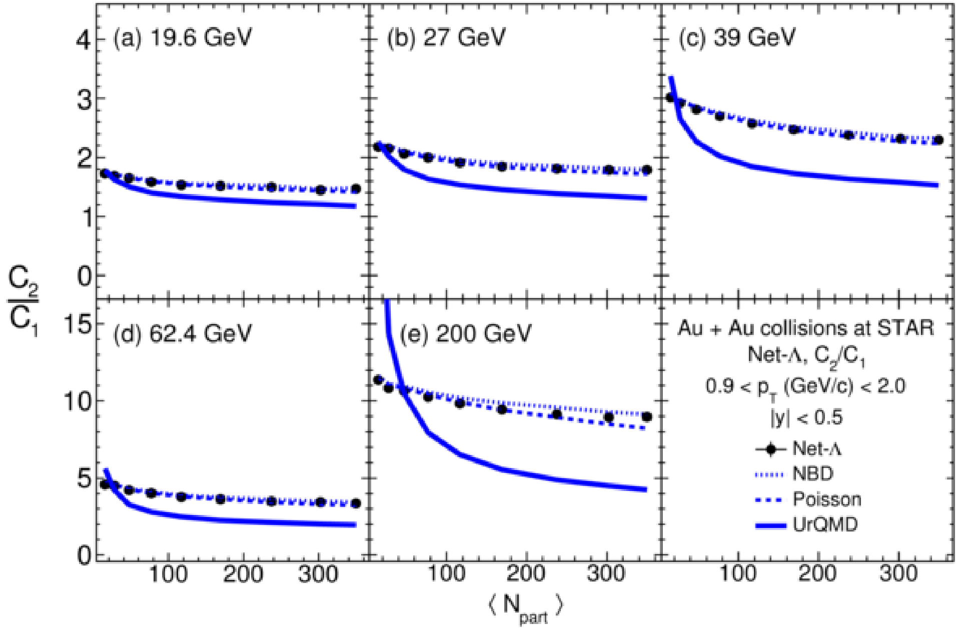


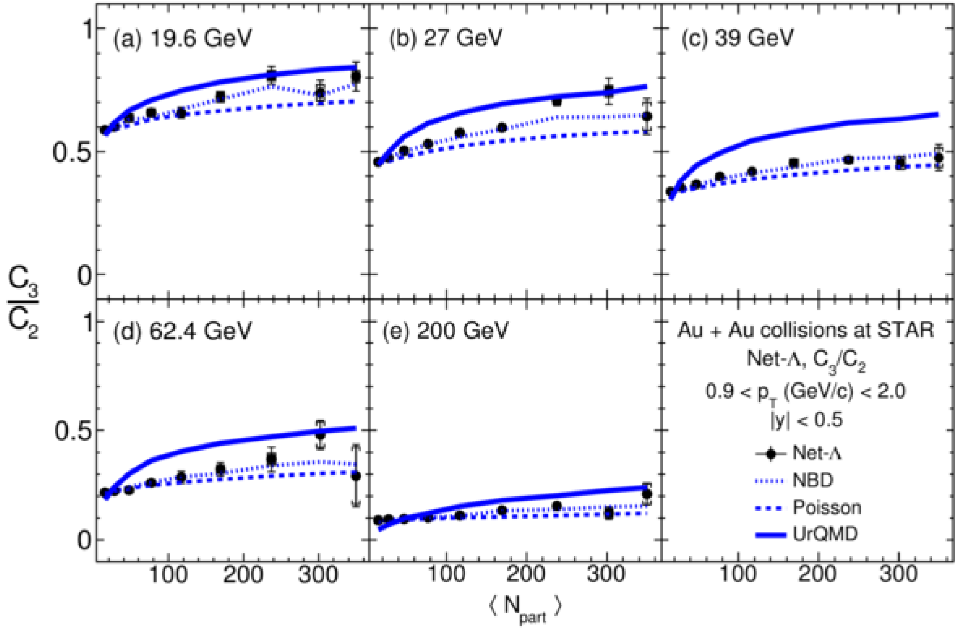
Large values of C_3 and C_4 for central events show that distributions have non-Gaussian shape. It may suggest for the enhanced fluctuations arising from a possible critical point.

arXiv:2001.02852v2

Λ cumulants measurements







Λ cumulants are measured for energy range from 19.6 to 200 GeV

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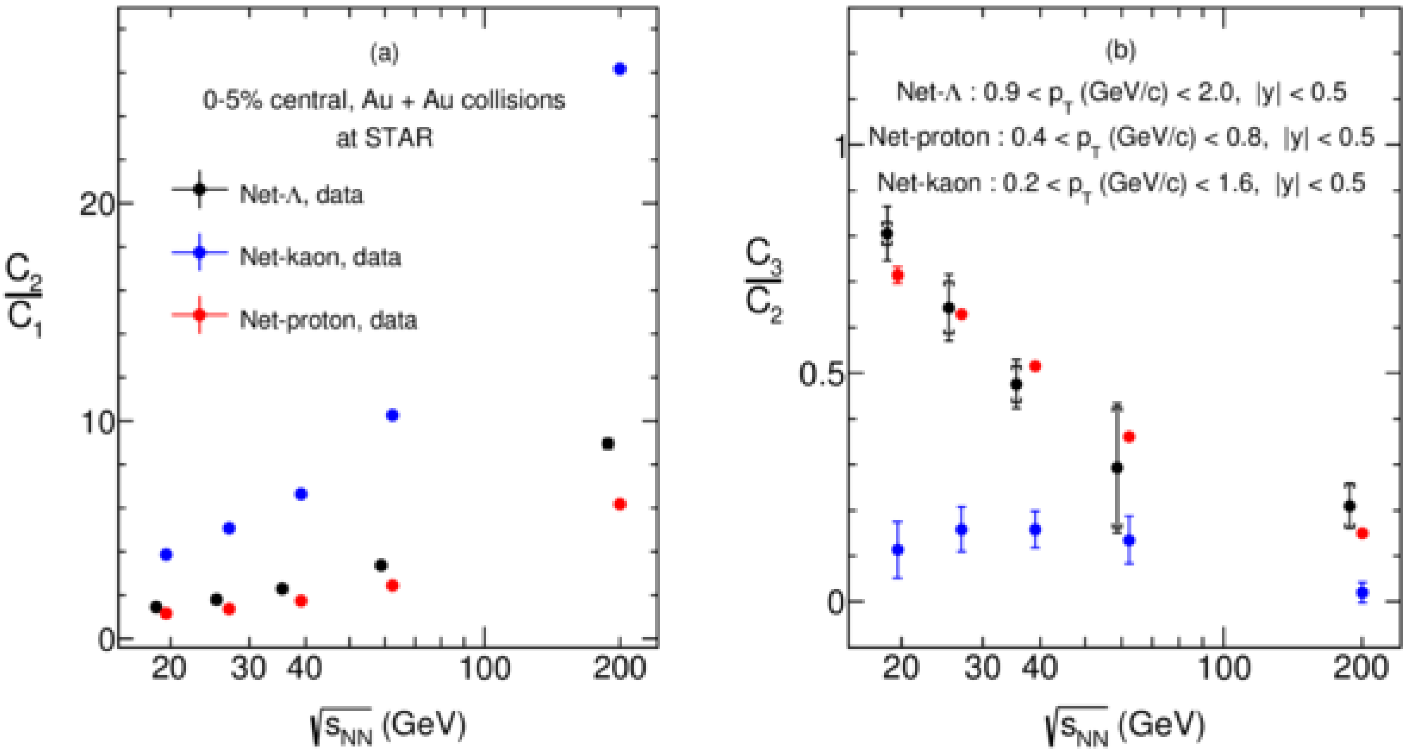
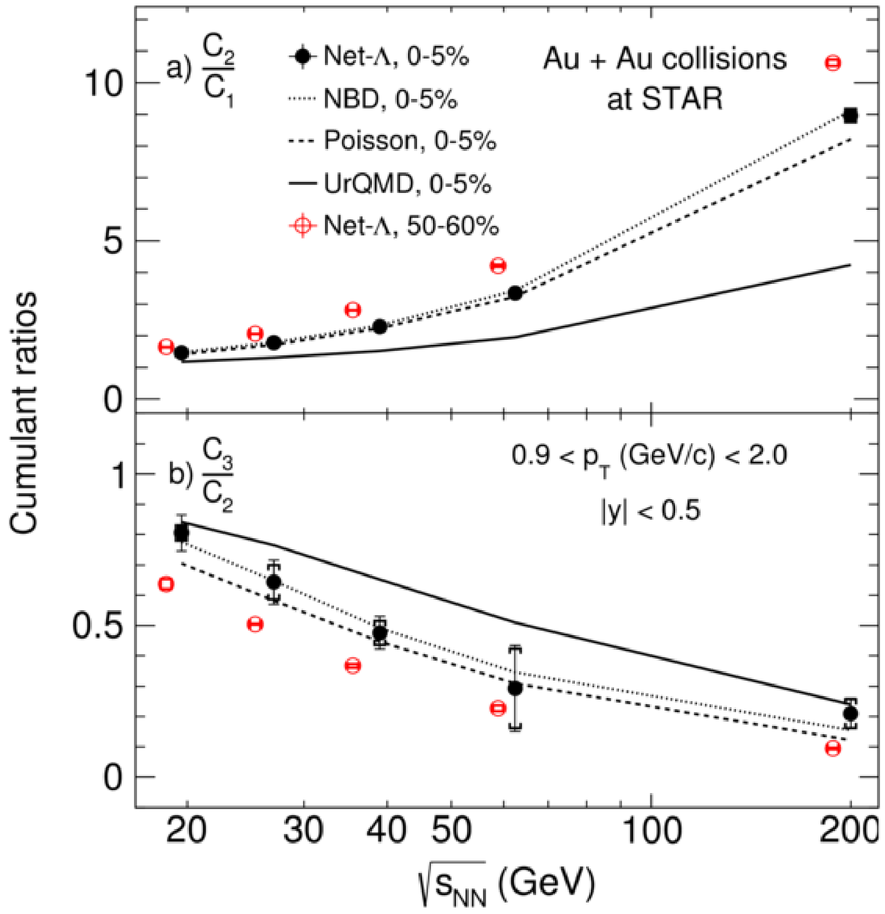
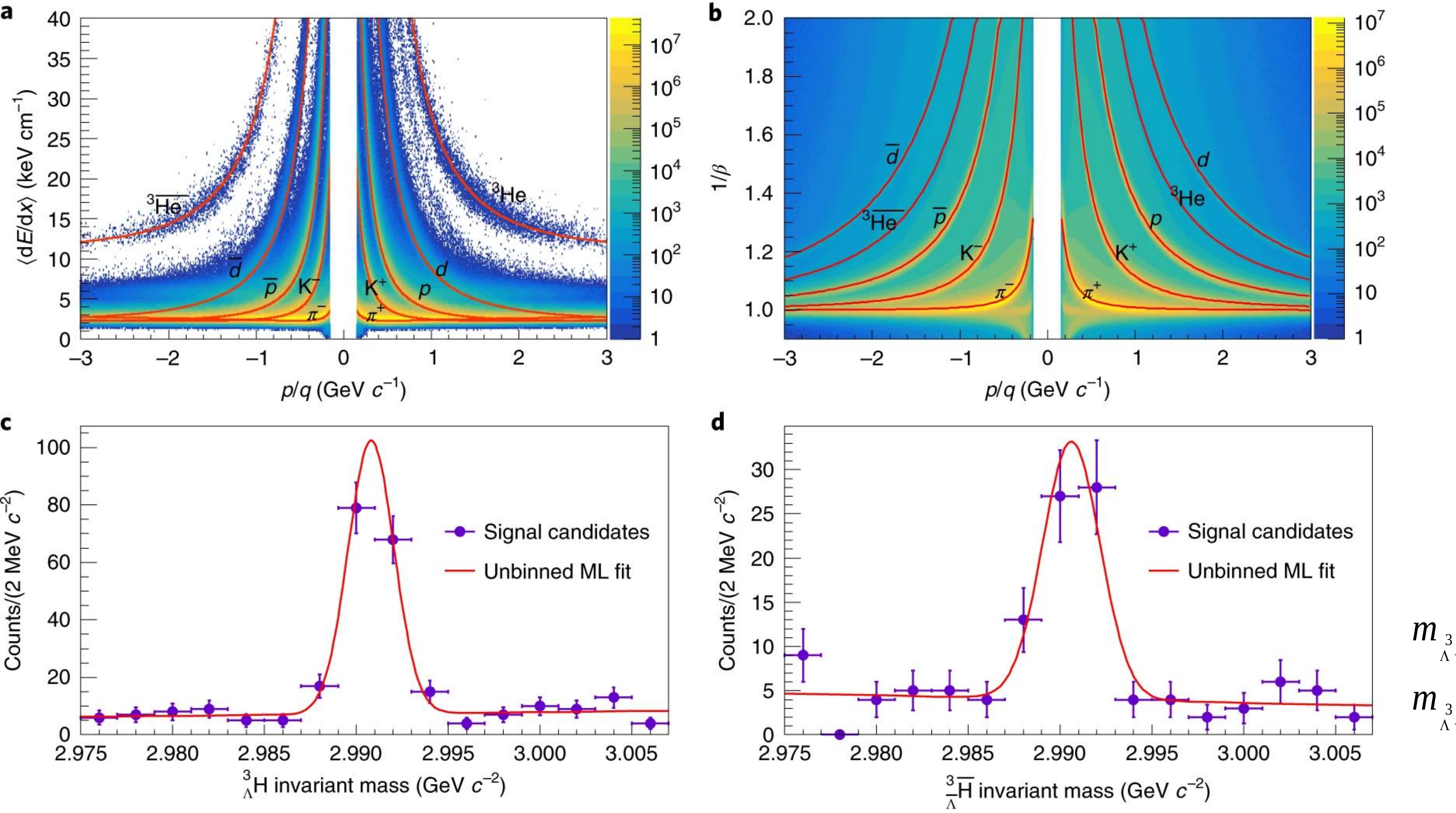
Baryon and meson cumulants ratios





Net-proton and net-Λ cumulants ratios are similar for central collisions at all energies.

Hypertriton and anti-hypertriton measurements



Decay channels:

$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi$

$^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{p} + \pi$

$S/\sqrt{(S+B)} = 11.4\ ({}^{3}_{\Lambda}\mathrm{H})$

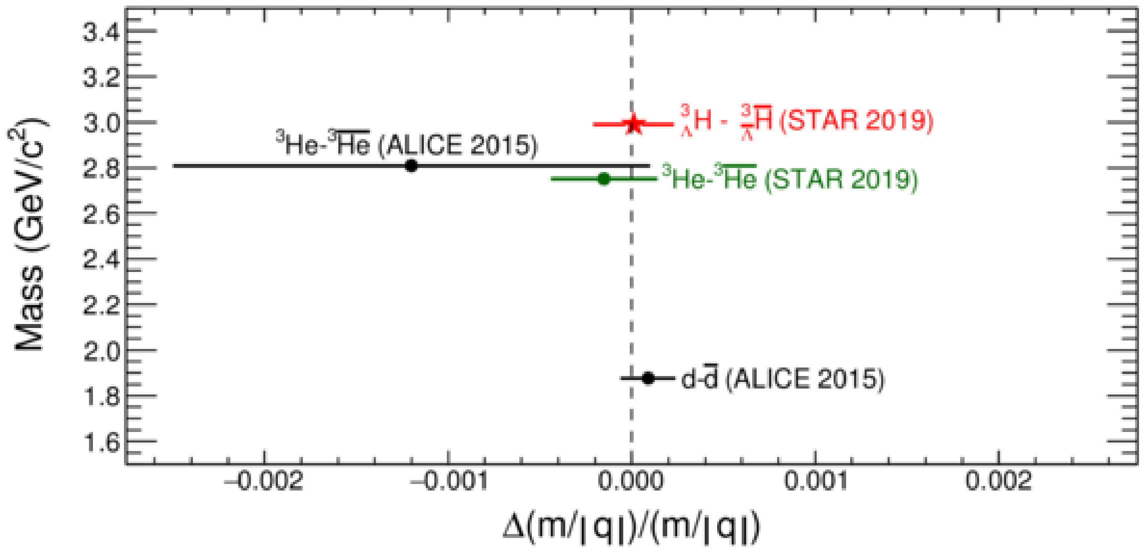
$S/\sqrt{(S+B)} = 6.4\ ({}^{3}_{\Lambda}\overline{\mathrm{H}})$

$m_{^{3}_{\Lambda}H} = 2990.95 \pm 0.13(stat.) \pm 0.11(syst)$

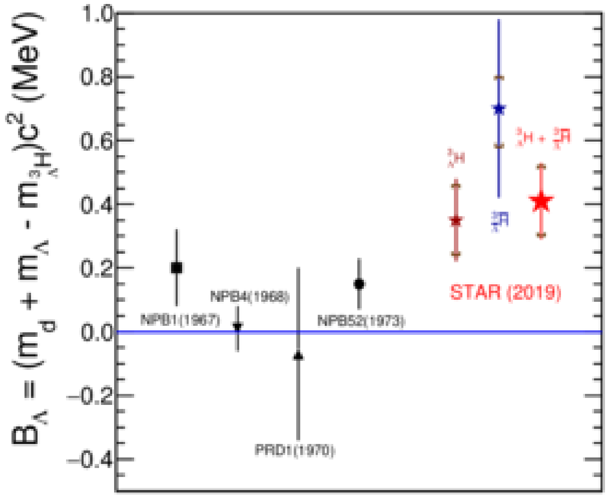
$m_{^{3}_{\Lambda}\overline{H}} = 2990.60 \pm 0.28(stat.) \pm 0.11(syst)$

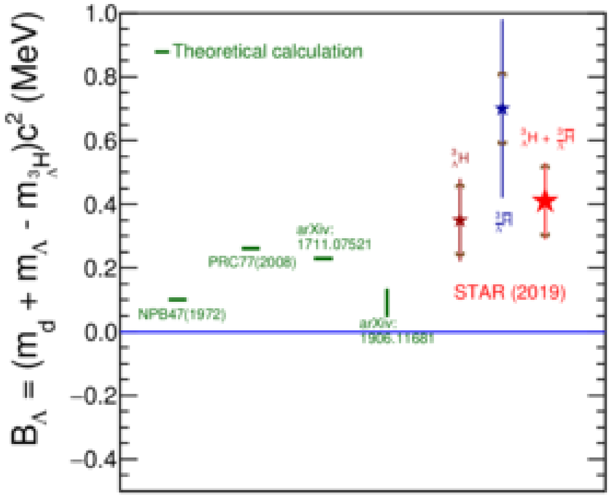
Nature Physics **16** (2020) 409

Hypertriton and anti-hypertriton measurements



$$\frac{m_{^3_\Lambda H} - m_{^3_{\bar\Lambda}\bar{H}}}{m} = (0.1 \pm 2.0(\text{stat.}) \pm 1.0(\text{syst.})) \times 10^{-4}$$

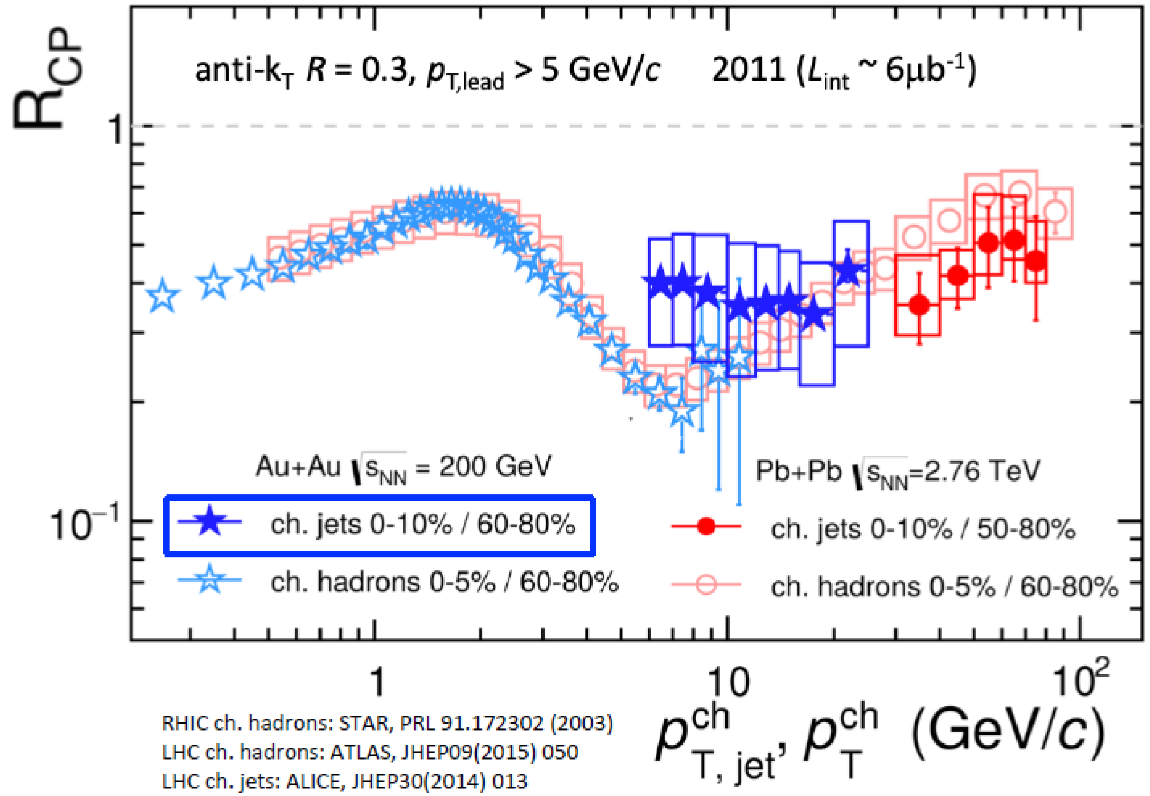




$$B_\Lambda = 0.41 \pm 0.12(stat.) \pm 0.11(syst.) MeV$$

Analysis of $^4{}_\Lambda$H and $^4{}_\Lambda$He is ongoing
More results are coming!

Jet probes



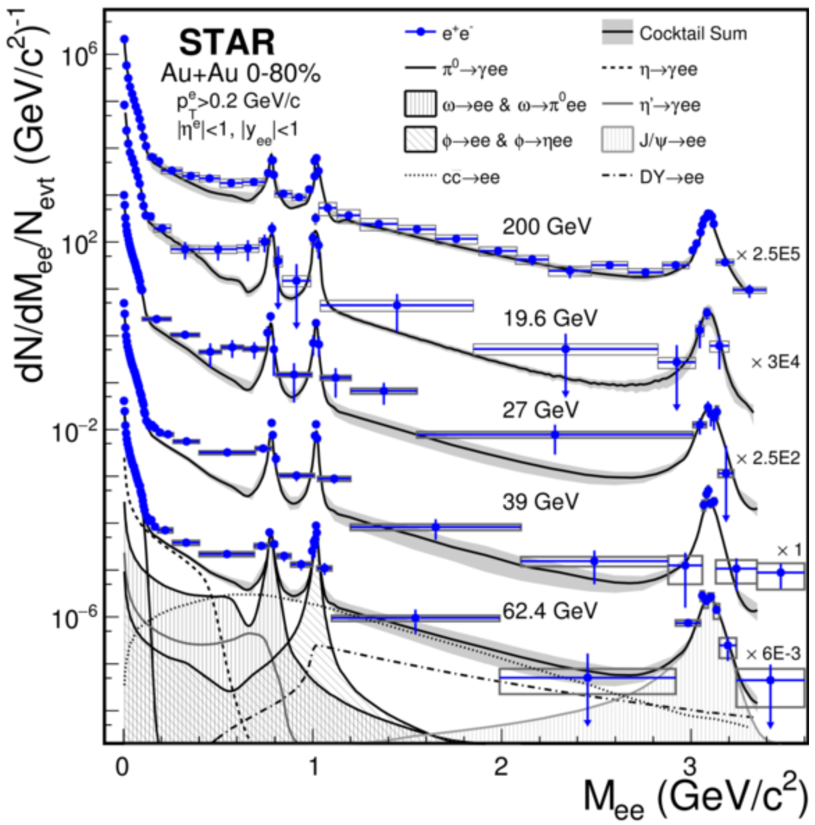
RHIC ch. hadrons: STAR, PRL 91.172302 (2003)
LHC ch. hadrons: ATLAS, JHEP09(2015) 050
LHC ch. jets: ALICE, JHEP30(2014) 013

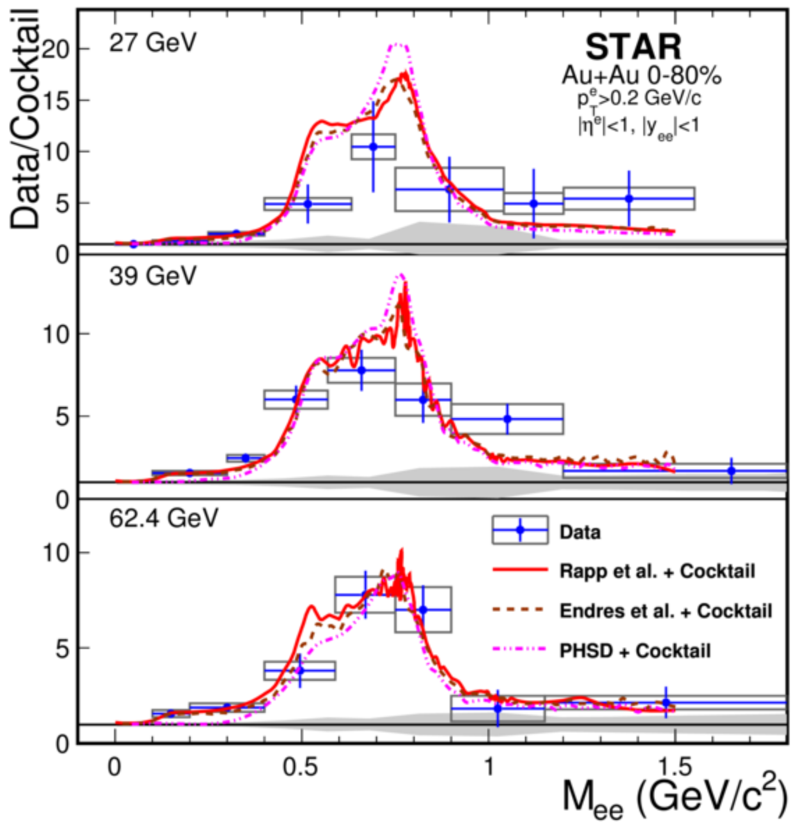
First measurement of inclusive jet R_{CP} at RHIC

Significant suppression in central collisions with respect to peripheral collisions

Results are consistent with those for hadrons (RHIC&LHC) and jets (LHC) data. Possibly different p_T dependence for charged hadrons and jets

Dielectron production



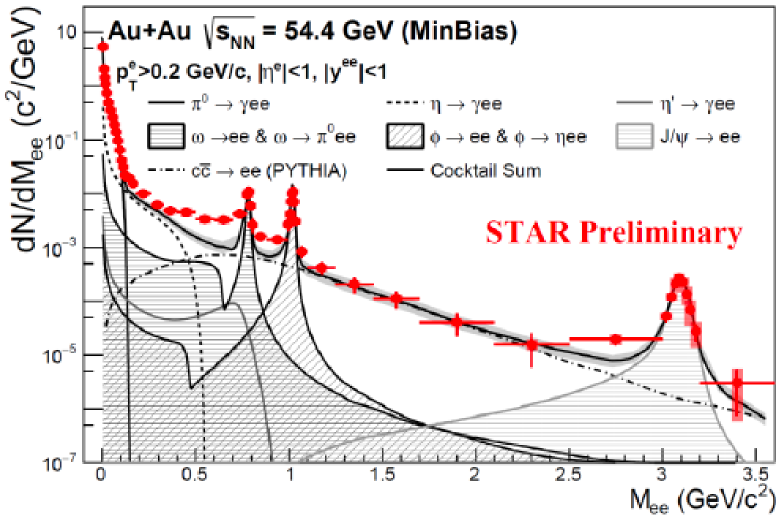


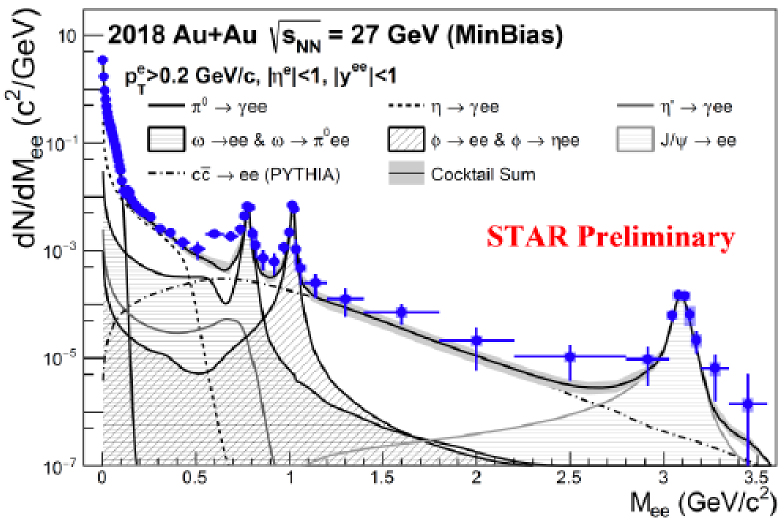
New data on dielectron production for 27, 39 and 62.4 GeV confirm a significant excess in the yields of dielectrons in the low mass region previously observed.

Data are consistent with model calculations

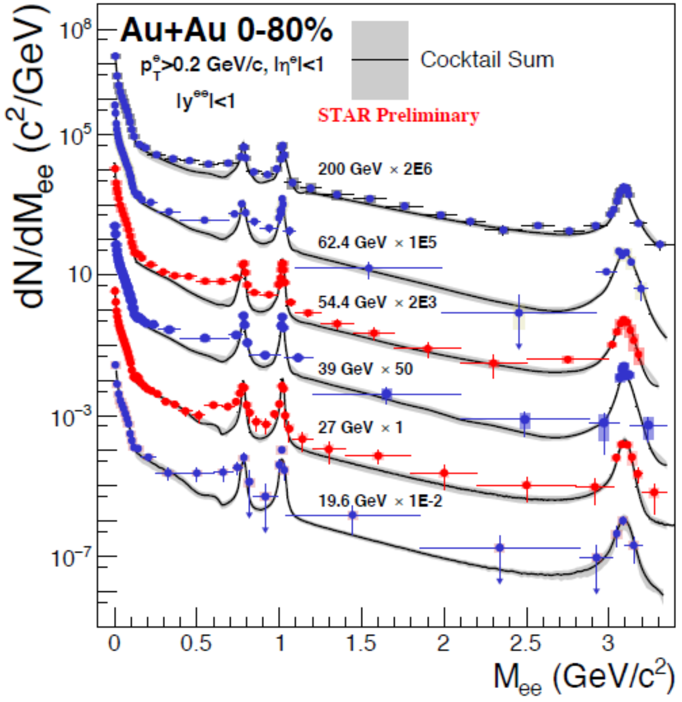
arXiv:1810.10159v1

Dielectron production





A hint of excess in the intermediate mass region can be observed in both $\sqrt{s_{NN}}$ = 27 and 54.4 GeV measurements



- New data from BES-II have enough statistics for differential measurements vs. centrality, p_T, etc.
- Reduced charm cross section enhances sensitivity to thermal radiation in the intermediate mass region
- Systematically study energy dependence of low mass region excess at $\sqrt{s_{NN}}$ = 7.7 and 19.6 GeV

Isobar Blind Analysis : Procedure

From the talk by James Dunlop

Cartoon : P. Tribedy, WWND 2020

Phase-I Blinding

- **Mock data challenge** — Test data Structure (27 GeV files)
- **Isobar-Mixed Analysis** — QA, physics & code freezing (One run is Ru+Zr)

Establish all procedures

Phase-II Blinding

- **Isobar-Blind Analysis** — Run-by-run QA, Full analysis (One run is Ru/Zr)
- **Mass Data production** ~ 3 months
- **Isobar-Unblind Analysis** — Full analysis (Ru and Zr Separated)

Act "blindly" on all procedures

STAR, arXiv:1911.00596 (2019)

- The most difficult step
- PAC mtg in May
- We are here
- End of 2020

STAR BES-II program so far

STAR Beam Use Request for Run20

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number "Good" Events requested / collected
9.8	19.6	205	4.5 weeks	400M 582M
7.3	14.5	260	5.5 weeks	300M 324M
5.75	11.5	315	9.5 weeks	230M
4.55	9.1	370	9.5 weeks	160M
3.85	7.7	420	12 weeks	100M
31.2	7.7 (FXT)	420	2 days	100M 51M
19.5	6.2 (FXT)	487	2 days	100M
13.5	5.2 (FXT)	541	2 days	100M
9.8	4.5 (FXT)	589	2 days	100M
7.3	3.9 (FXT)	633	2 days	100M 53M
5.75	3.5 (FXT)	666	2 days	100M
4.55	3.2 (FXT)	699	2 days	100M 201M
3.85	3.0 (FXT)	721	2 days	100M 3.7M+300M (run18)

Run20 (rows 5.75 and 4.55)

Run20 (FXT rows 31.2 to 5.75)

Despite the unprecedented situation with COVID-19 limitations STAR continues to collect data.

All plans for Run 20 were achieved/exceeded
Final data for BES-II will be taken in Run 21

STAR forward upgrade

Forward-rapidity $2.5<\eta<4$

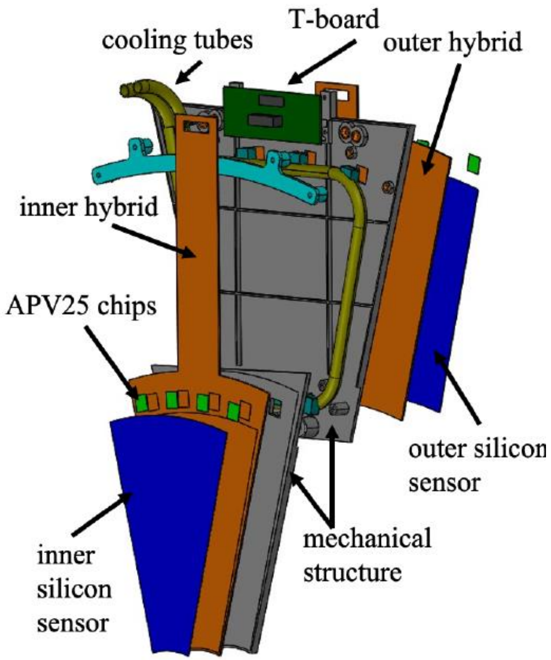
pp, pA	Au+Au
Beam: 500 GeV: p+p 200 GeV: p+p and p+A	**Beam:** 200 GeV: Au+Au
Physics Topics: ▪ TMD measurements at high x transversity → tensor charge ▪ Improve statistical precision for Sivers through Drell-Yan ▪ $\Delta g(x, Q^2)$ at low x through Di-jets ▪ Gluon PDFs for nuclei ➢ R_{pA} for direct photons & DY ▪ Test of Saturation predictions through di-hadrons, g-Jets	**Physics Topics:** ▪ Temperature dependence of viscosity through flow harmonics up to h~4 ▪ Longitudinal decorrelation up to h~4 ▪ Global Lambda polarization → Test for strong rapidity dependence

Observables:
- Inclusive jets and di-jets
- Hadrons in jets
- Direct photons
- Drell-Yan *e+e-*
- Lambda's
- Mid-forward & forward-forward
- rapidity correlations

Requirements:
- Good *e/h* separation
- Hadrons, photons, π^0 identification

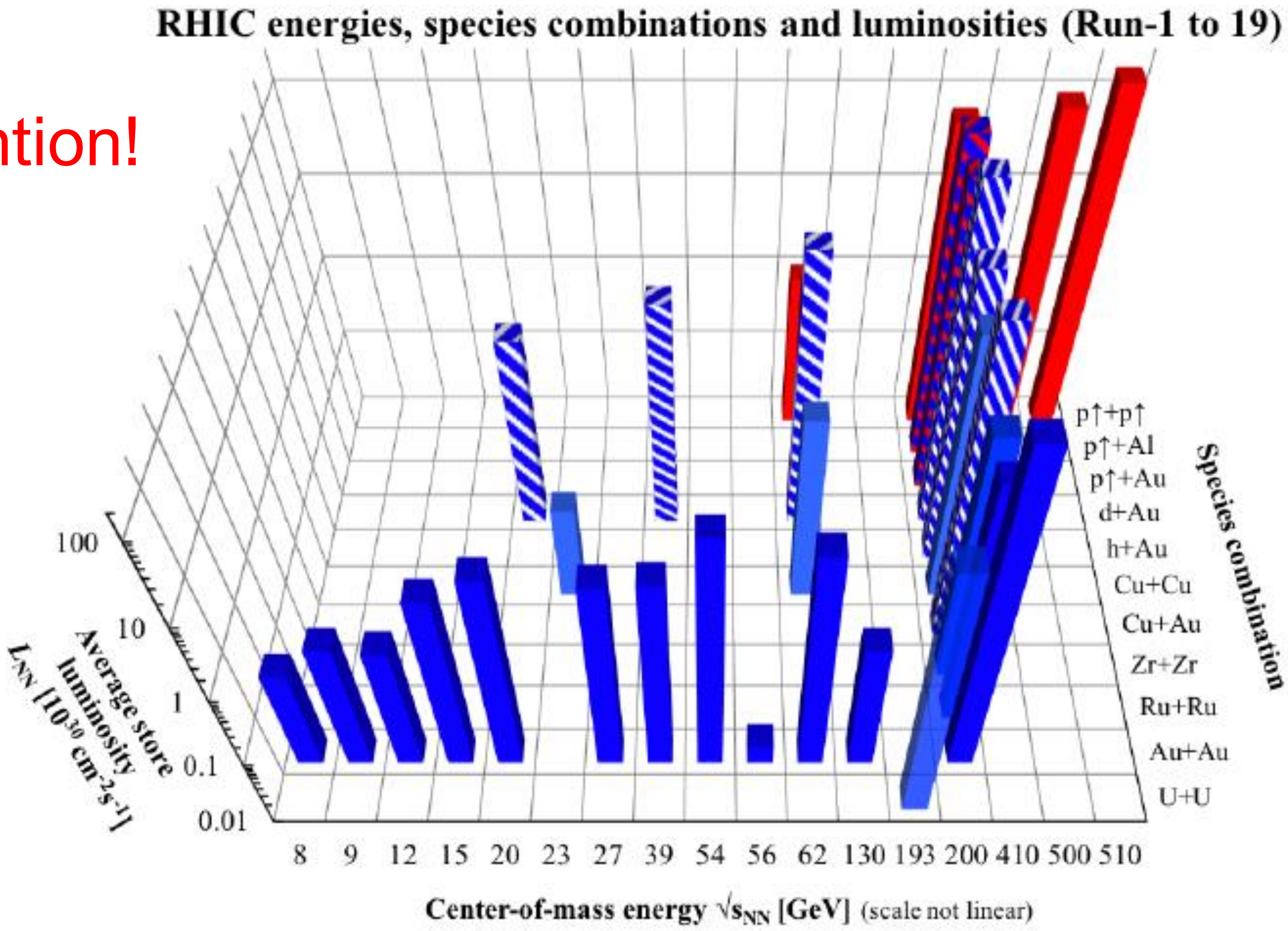
2021/22: 500 GeV polarized pp run

Additional pp, pA, and AA data taking in parallel to the sPHENIX campaign



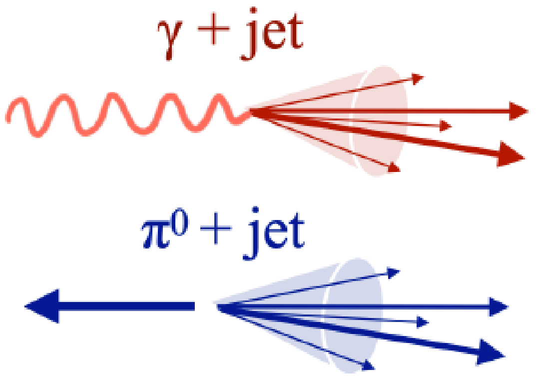
3 layers of silicon microstrip detectors
4 layers of Small-strip Thin Gap Chambers
combined with forward ECAL and HCAL

Thank you for the attention!



Backup slides

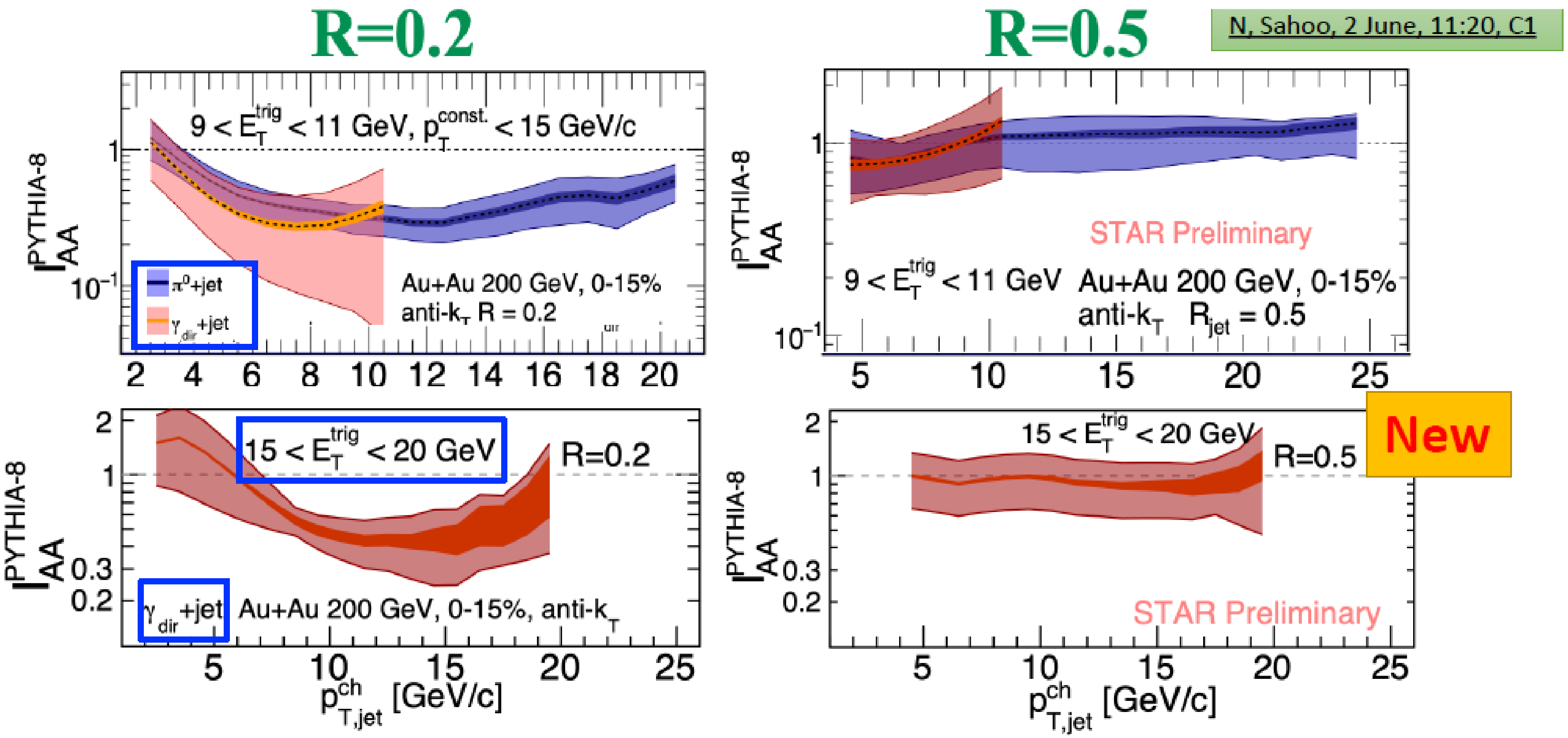
Jet probes



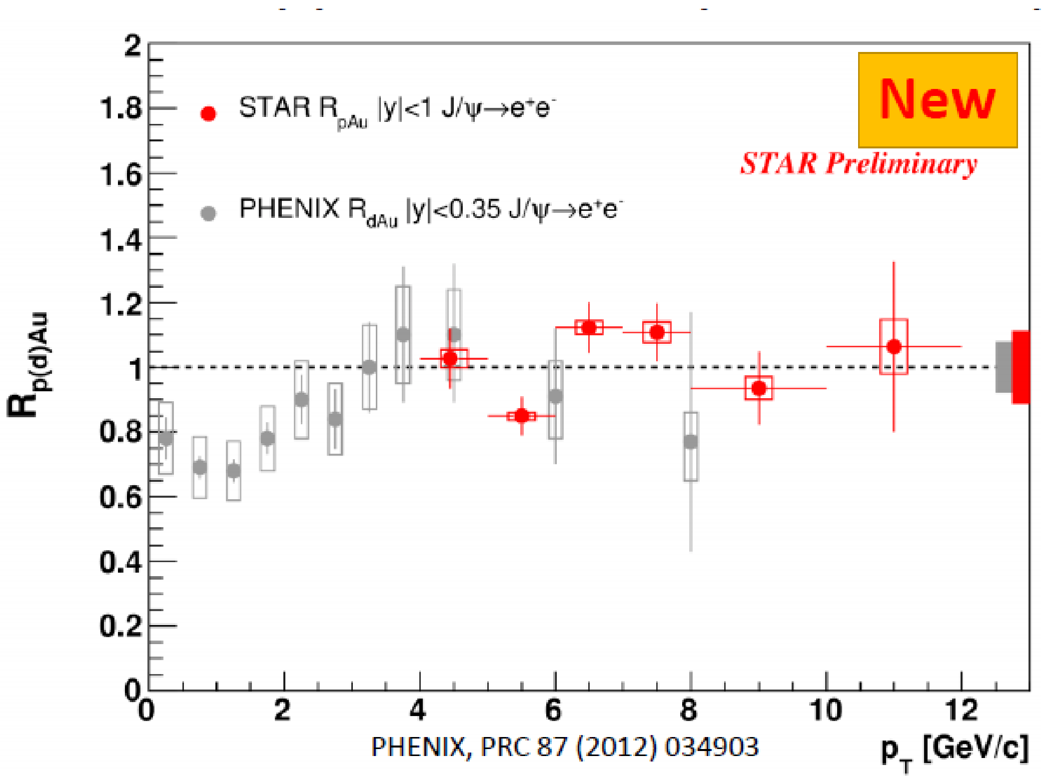
Vary:

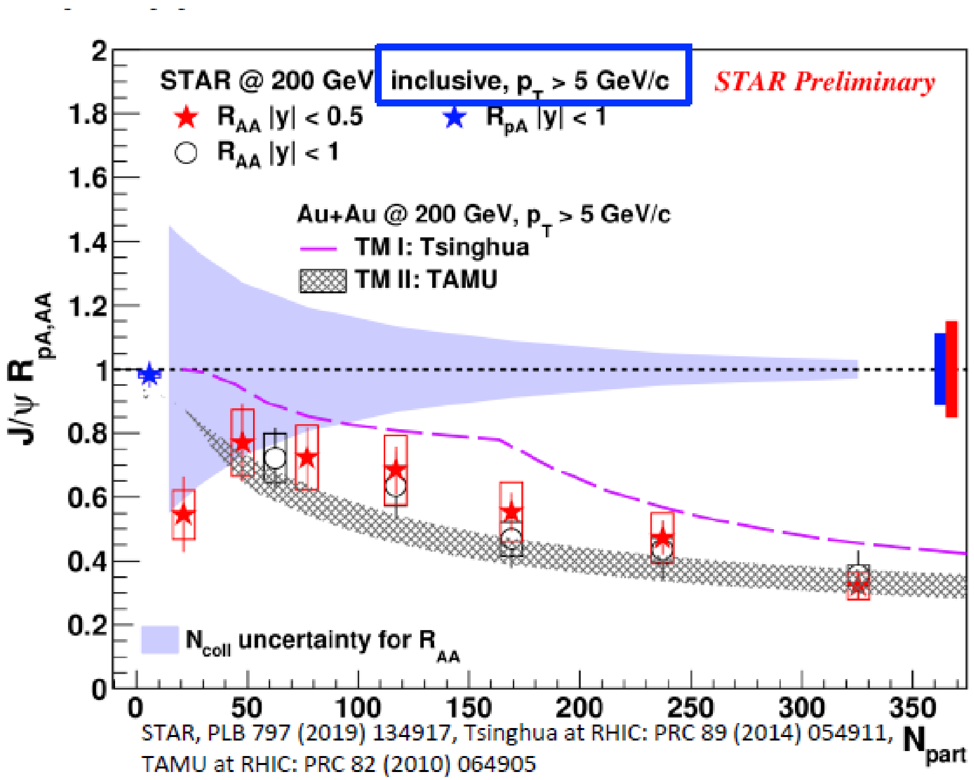
- quark vs. gluon of recoil jets
- <path length>

$$I_{AA}(p^{ch}_{T,jet}) = \frac{Y(p^{ch}_{T,jet})^{Au+Au}}{Y(p^{ch}_{T,jet})^{p+p}}$$



J/psi supression



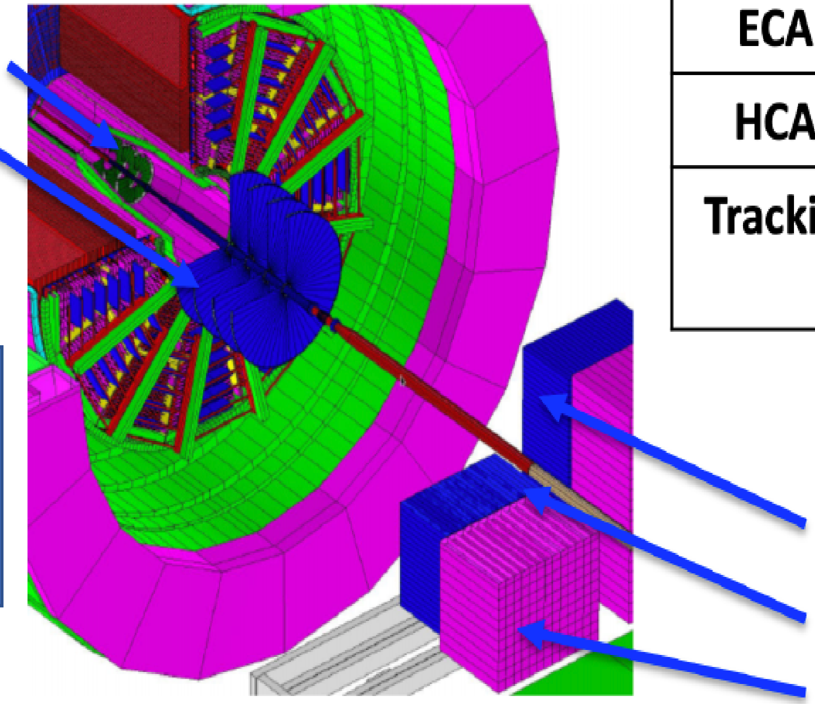


STAR Beyond BES-II

D. Brandenburg, 4 June, 11:55, G4

- **Detectors from BES-II upgrade (iTPC and EPD) will keep going**
- The forward (2.5 < η < 4) upgrade includes **Trackers** (silicon microstrip tracker **&** small-strip Thin Gap Chamber) and **Calorimeters (ECAL & HCAL)** dedicated to study nuclear structure, QGP.

Forward Tracker
- 3 silicon disks
- 4 sTGC layers



Detector	pp and pA	AA
ECAL	~10%/$\sqrt{E}$	~20%/$\sqrt{E}$
HCAL	~60%/$\sqrt{E}$	---
Tracking	Charge separation Photon suppression	$0.2 < p_T < 2$ GeV/c with 20 – 30% $1/p_T$

Preparing for data-taking from **2021+**

Forward Calorimeters
- Pre/post-shower: scintillator
- ECAL: PbSc towers (18 X_0)
- HCAL: FeSc plates (4.5 λ)