UNIVERSITY OF BUCHAREST
VIRTUTE ET SAPIENTIA

Study of <p_T> scaling with m/n_q in relativistic heavy-ion collisions

Oana RISTEA[1], Diana Deara[1], Catalin RISTEA[1,2], Alexandru JIPA[1], Tiberiu ESANU[1,3], Marius CALIN[1]

1 University of Bucharest, Faculty of Physics, Bucharest-Magurele, Romania
2 Institute of Space Science, Bucharest-Magurele, Romania
3 National Institute of Nuclear Physics and Engineering Horia Hulubei, Bucharest-Magurele, Romania

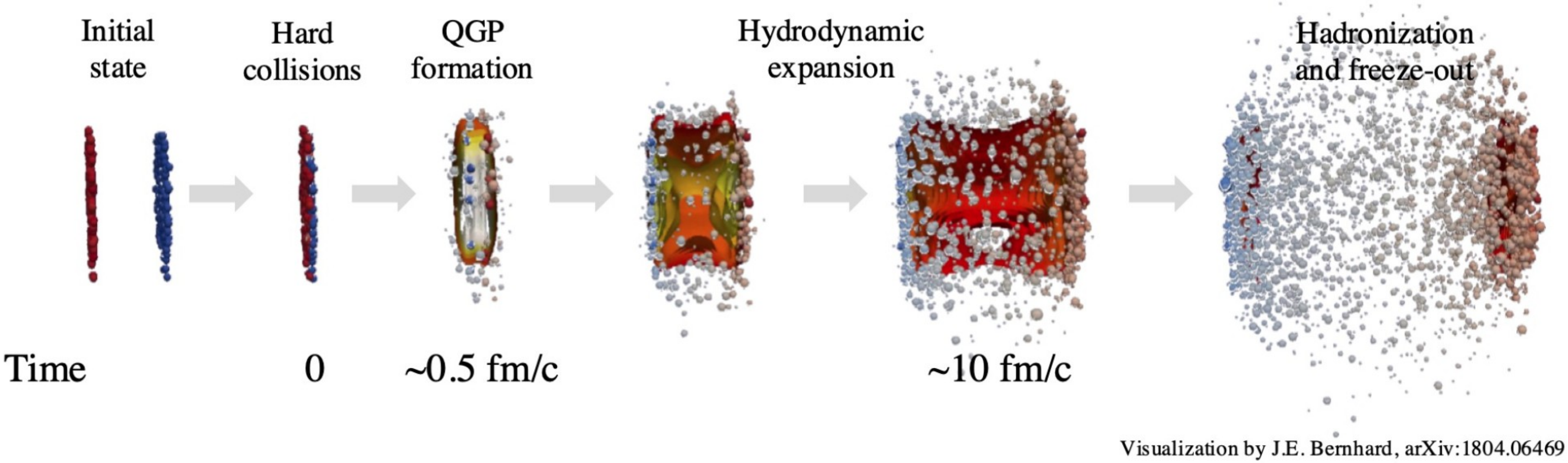
Outline

Motivation and data used

Results

Conclusions

Heavy-ion collision evolution



- thermal (kinetic) “freeze-out” (FO) --> kinetic FO temperature and average transverse flow velocity

- the collective transverse expansion of the system --> entirely generated and develops throughout the entire evolution of the system created in the collision

- the shape of the transverse momentum distributions of the identified charged hadrons --> sensitive to the dynamics of the nucleus-nucleus collisions.

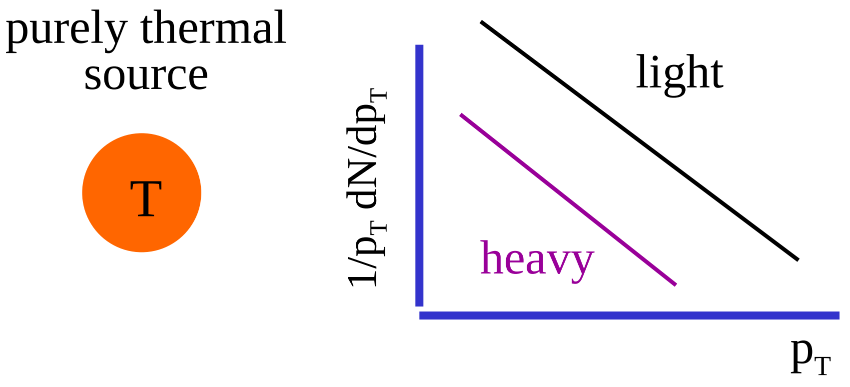
Particle source

Final state spectra → system properties at thermal freeze-out

Thermal source → spectrum slope reflects the temperature of the fireball

$$\frac{dN}{m_T dm_T} \sim e^{-m_T/T_{\rm slope}}$$

where $m_T \equiv \sqrt{p_T^2 + m^2}$

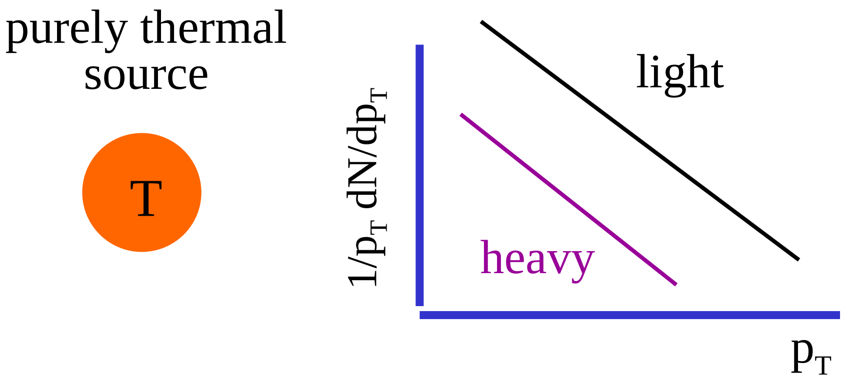


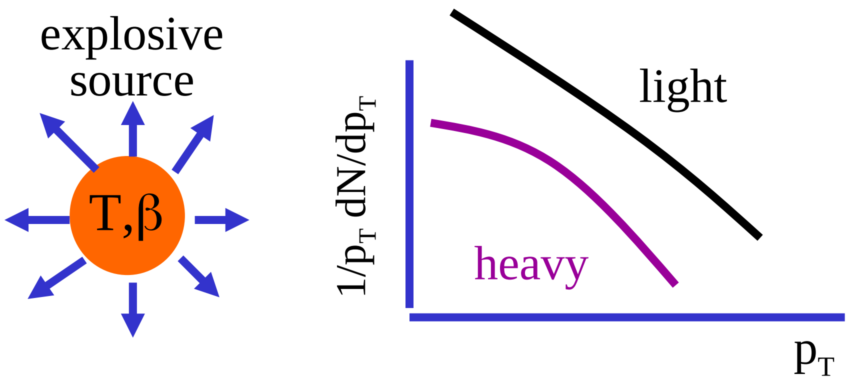
Particle source

Final state spectra → system properties at thermal freeze-out
Thermal source → spectrum slope reflects the temperature of the fireball

$$\frac{dN}{m_T dm_T} \sim e^{-m_T/T_{slope}}$$

where $m_T \equiv \sqrt{p_T^2 + m^2}$





Data → shape is different in p-p and A-A → stronger effect for heavier particles

Flow → collective motion of particles (due to high pressure arising from compression and heating of nuclear matter) superimposed on thermal motion

Data

STAR-BES Au-Au data at $\sqrt{s_{NN}}$ = 7.7, 11, 19.6, 27 and 39 GeV

The average transverse momentum:

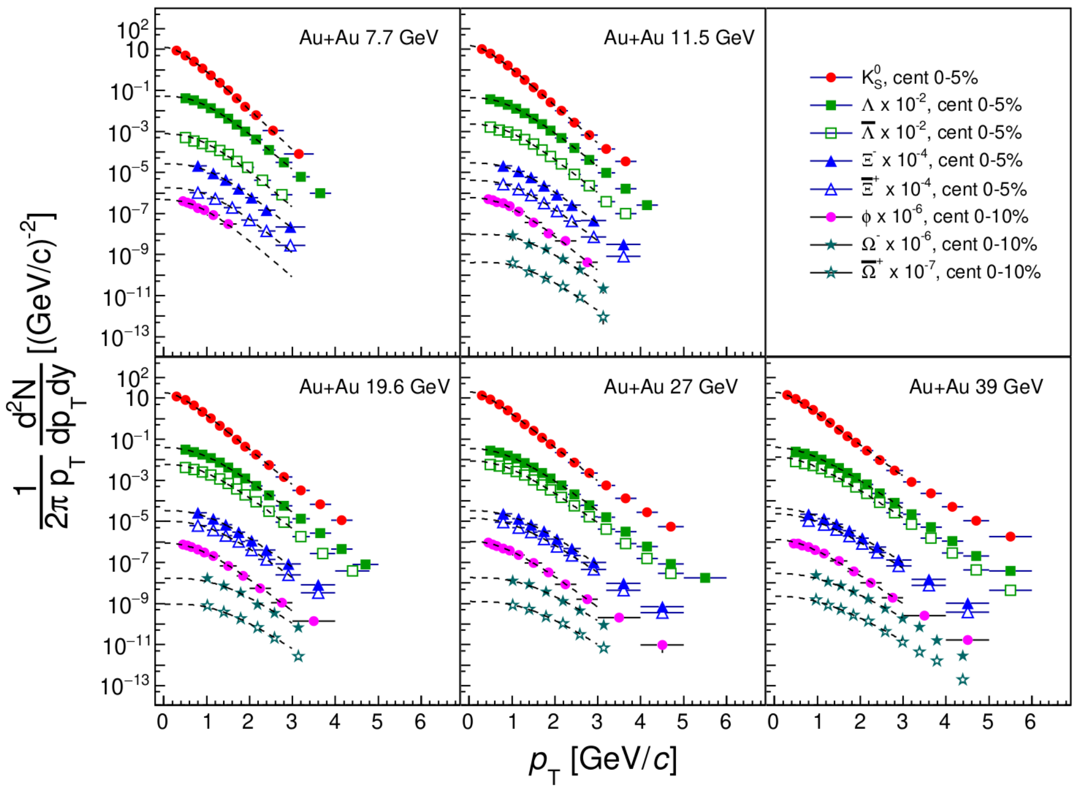
$$\langle p_T \rangle = \frac{\int_0^\infty p_T (2\pi p_T) f(p_T) dp_T}{\int_0^\infty (2\pi p_T) f(p_T) dp_T}.$$

For K^0_S, φ, Ω → an exponential function:

$$\frac{d^2N}{2\pi p_T dp_T dy} = A \exp\left(-\frac{m_T - m}{T}\right)$$

For Λ, Ξ → Boltzmann function:

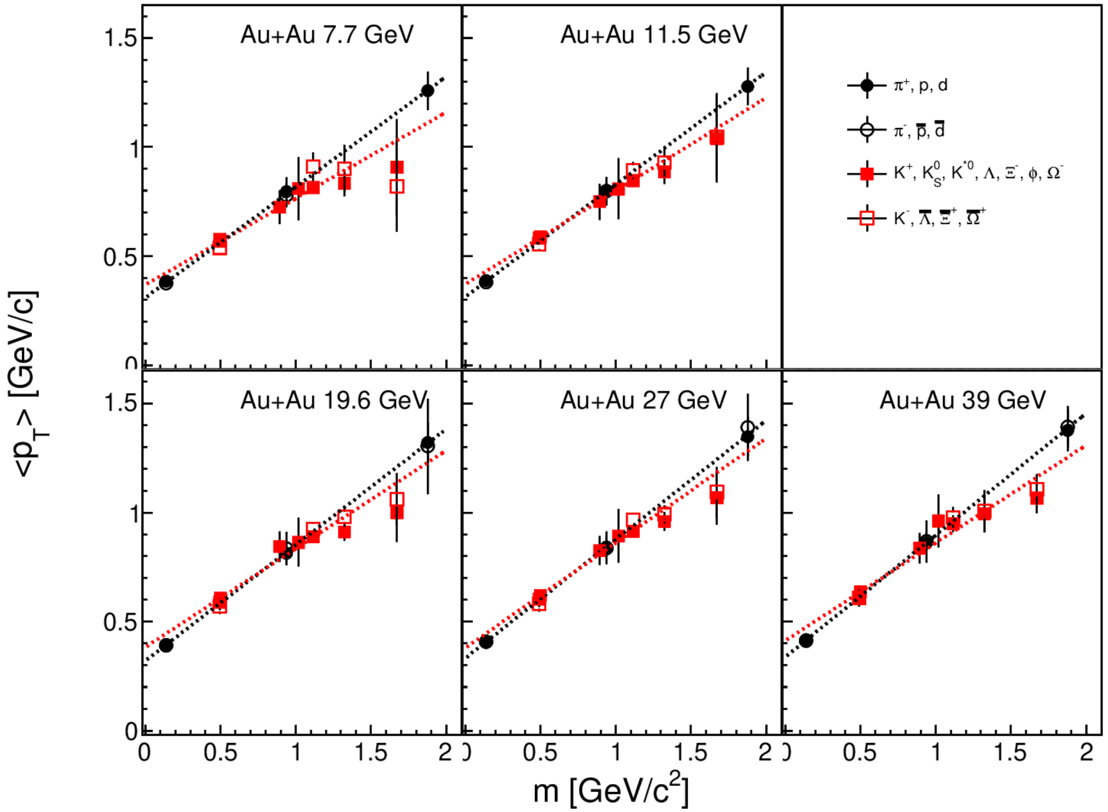
$$\frac{d^2N}{2\pi p_T dp_T dy} = A\, m_T \exp\left(-\frac{m_T - m}{T}\right)$$



J. Adam et al., STAR coll., Phys.Rev.C 102 (2020),034909;
L. Adamczyk et al., Phys. Rev. C 93, 21903 (2016)

Fit range: $0<p_T<2$ GeV/c (for K^0_S, φ, Λ) and $0<p_T<2.6$ GeV/c (Ξ, Ω)

Mean transverse momentum



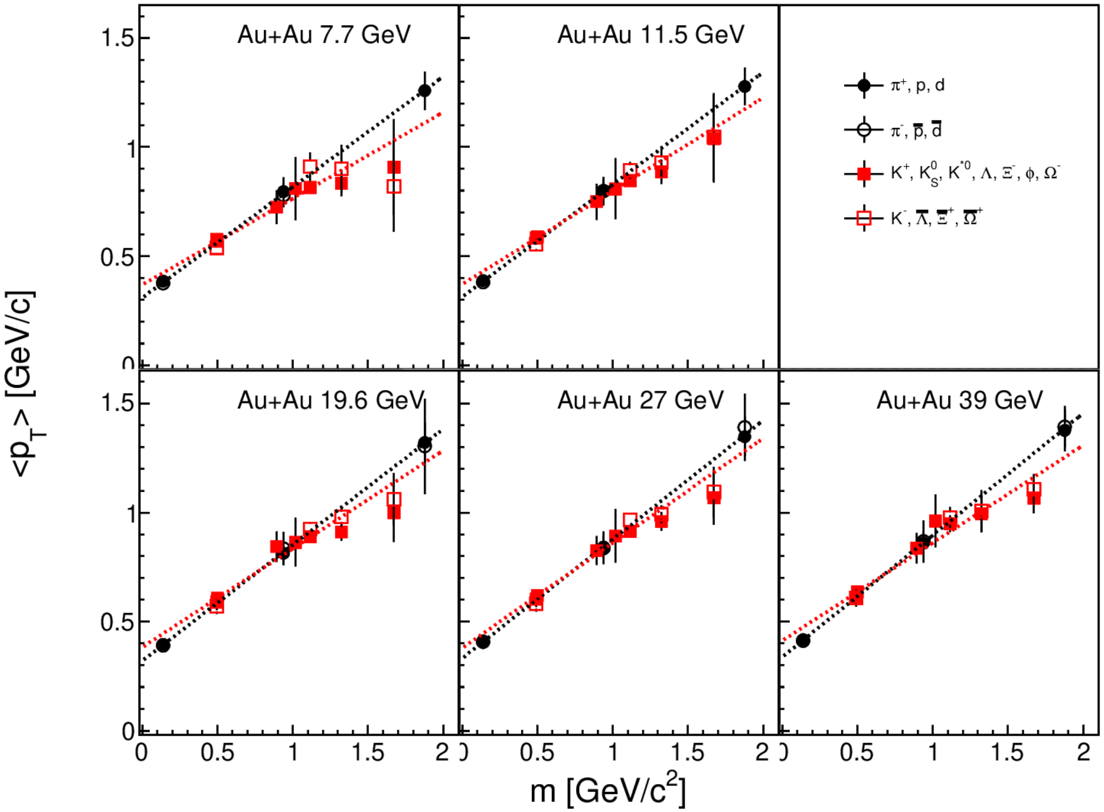
$\langle p_T \rangle$ reflects the slopes of the p_T spectra

$\langle p_T \rangle$ increases with the mass for all RHIC-BES energies

central Au-Au collisions (0-5%/0-10% centrality class)

J. Adam et al., STAR coll., Phys.Rev.C 102 (2020),034909; L. Adamczyk et al., Phys. Rev. C 96, 044904 (2017); L. Adamczyk et al., Phys. Rev. C 93, 21903 (2016); J. Adams et al, STAR coll., Phys. Rev. C 99, 064905 (2019), M. S. Abdallah et al., STAR coll., Phys. Rev. C 107 (2023) 34907

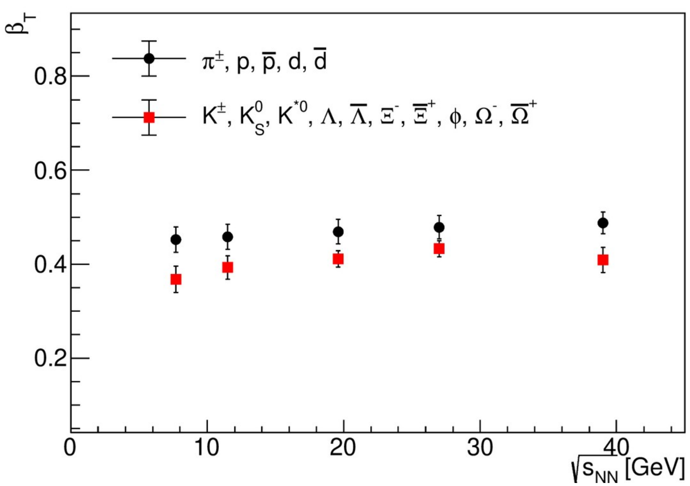
Mean transverse momentum



<p_T> reflects the slopes of the p_T spectra

<p_T> increases with the mass for all RHIC-BES energies

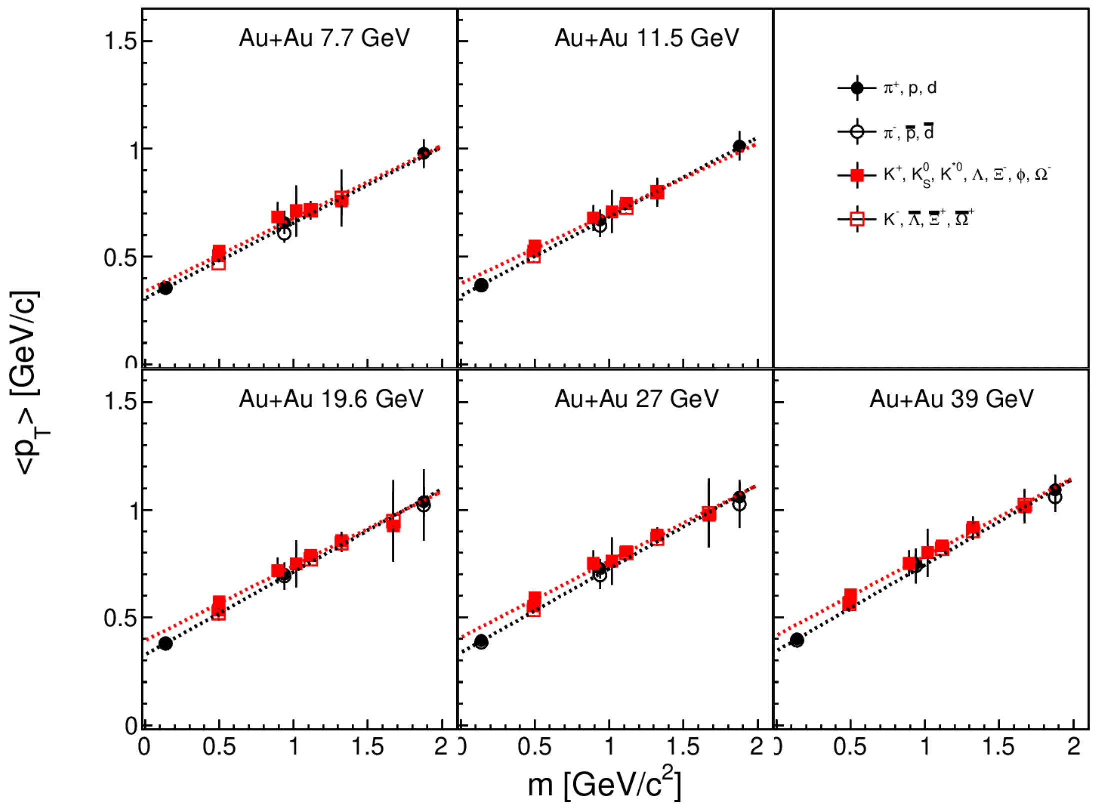
$$\langle p_T \rangle = C' + m\,\beta_T' = C' + m_0\gamma_T'\,\beta_T'$$



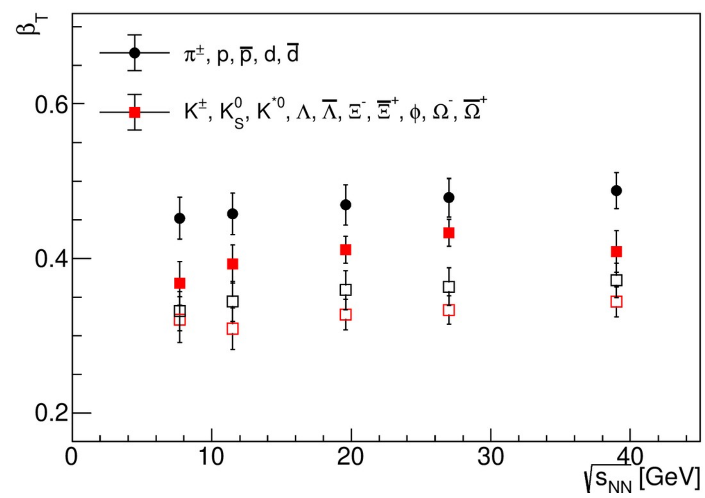
central Au-Au collisions
(0-5%/0-10% centrality class)

J. Adam et al., STAR coll., Phys.Rev.C 102 (2020),034909; L. Adamczyk et al., Phys. Rev. C 96, 044904 (2017); L. Adamczyk et al., Phys. Rev. C 93, 21903 (2016); J. Adams et al, STAR coll., Phys. Rev. C 99, 064905 (2019), M. S. Abdallah et al., STAR coll., Phys. Rev. C 107 (2023) 34907

Mean transverse momentum

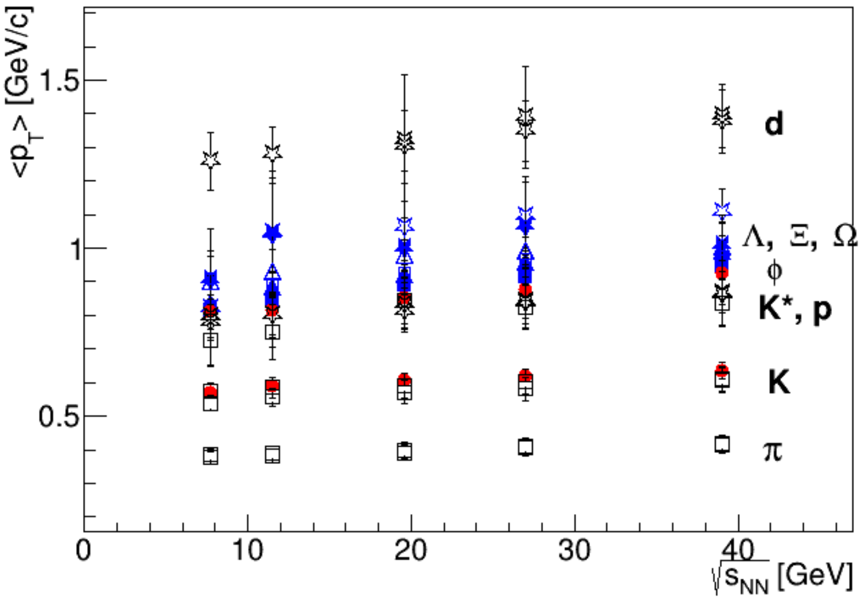


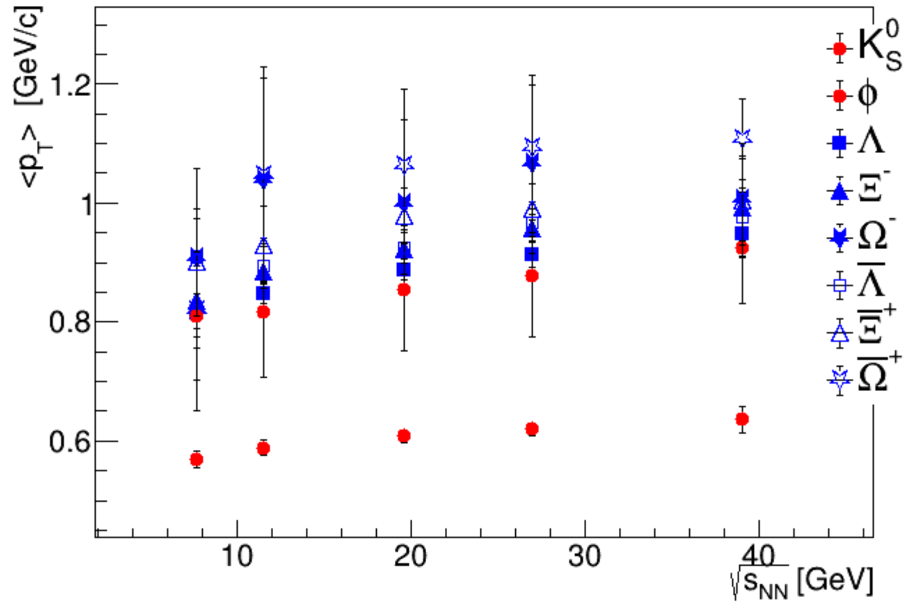
$<\beta_T>$ --> smaller in peripheral collisions --> weaker transverse collective flow



peripheral Au-Au collisions
(40-50%/40-60% centrality class)

$\langle p_T \rangle$ vs energy



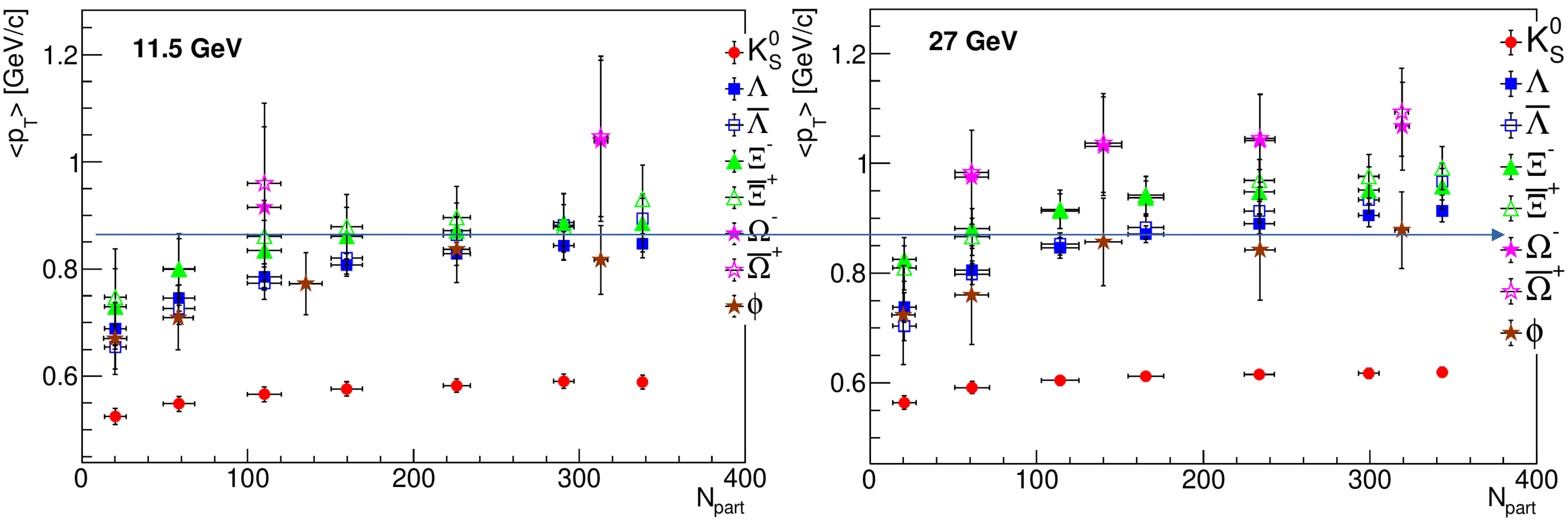


- mass dependence of $\langle p_T \rangle$ --> transverse collective flow --> larger p_T kick for particles with higher mass

- very weak energy dependence

J. Adam et al., STAR coll., Phys.Rev.C 102 (2020),034909; L. Adamczyk et al., Phys. Rev. C 96, 044904 (2017); L. Adamczyk et al., Phys. Rev. C 93, 21903 (2016); J. Adams et al, STAR coll., Phys. Rev. C 99, 064905 (2019), M. S. Abdallah et al., STAR coll., Phys. Rev. C 107 (2023) 34907

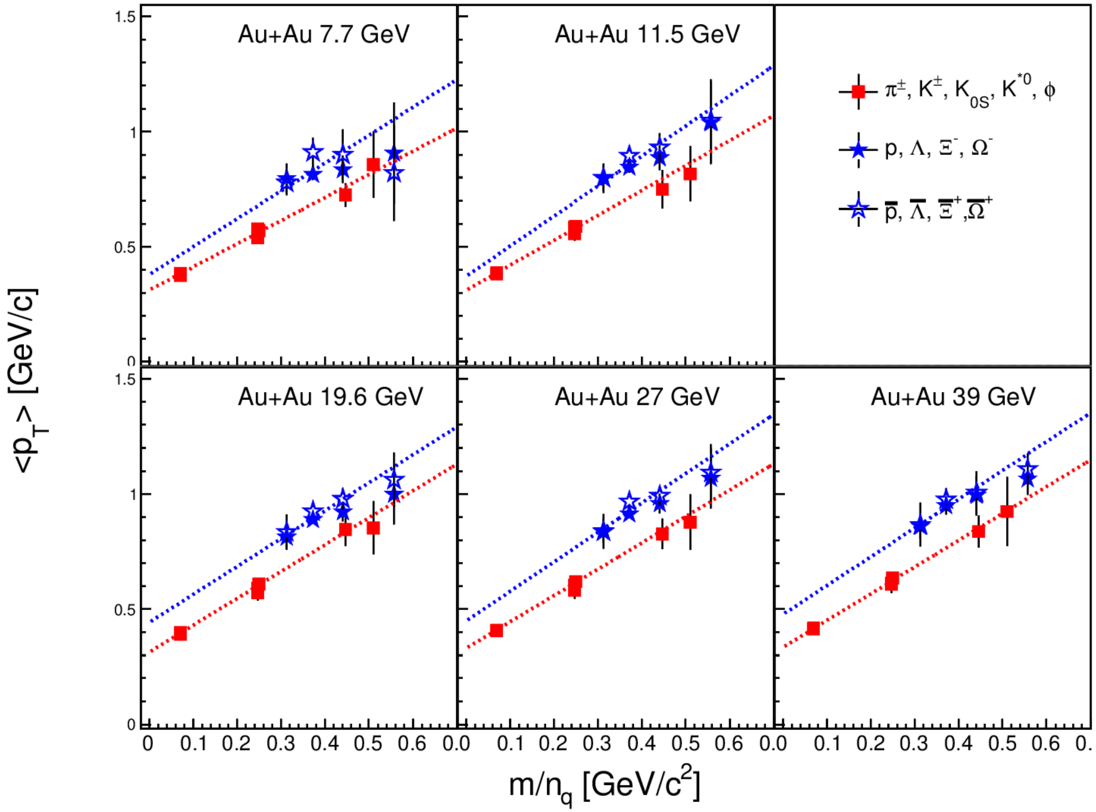
$\langle p_T \rangle$ vs centrality



- $\langle p_T \rangle$ increases with Npart for all energies --> gradual development of the transverse collective motion with increasing medium volume

- <pT> for K^0_S increases slightly with centrality, while for particles with higher mass, the increase is stronger --> contribution of the collective flow proportional with the particle mass

$\langle p_T \rangle$ vs m/n_q



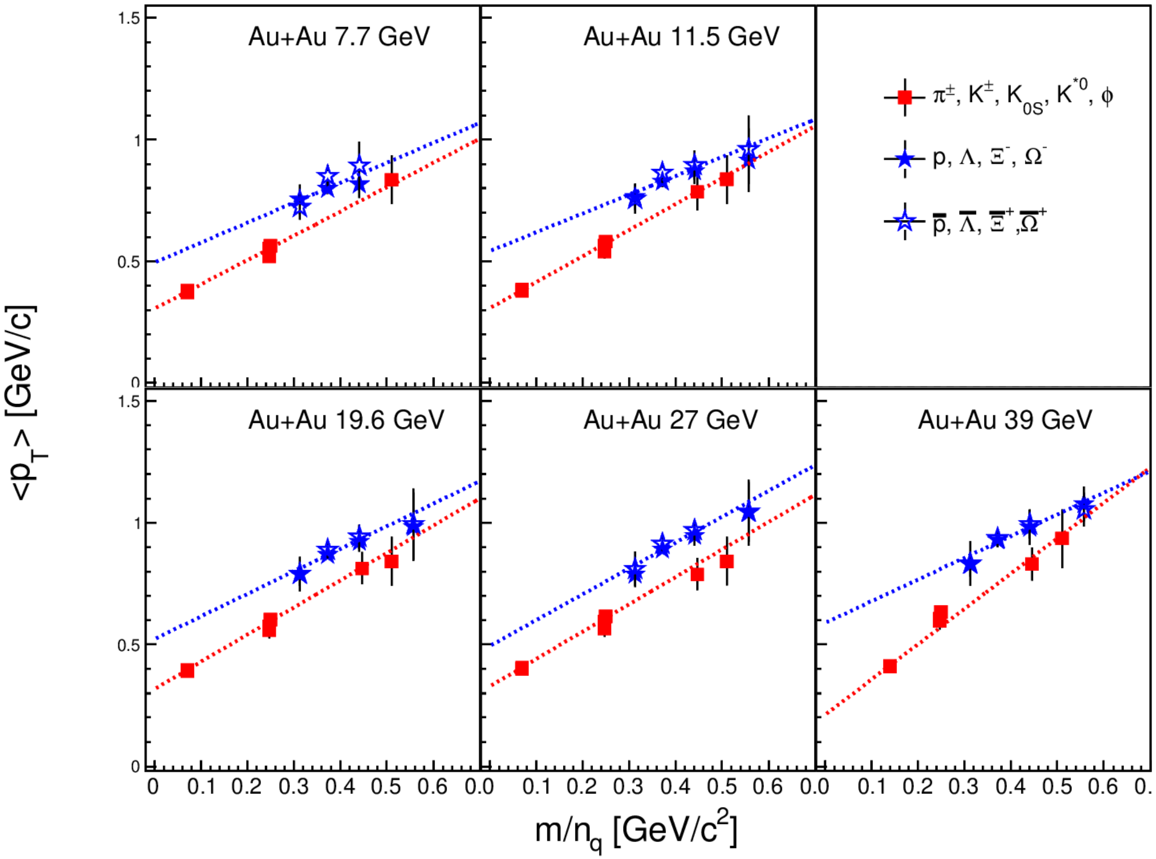
0-5%/0-10%

- 0-5%: π, $K^{+/-}$, K^0_S, p, Λ, Ξ
- 0-10%: φ (all energies), Ω , K^{*0} (11.5-39 GeV)
- 0-20%: K^{*0} (7.7 GeV)
- 0-60%: Ω (7.7 GeV)

- $\langle p_T \rangle$ of baryons as a function of reduced mass increases with a different slope compared with $\langle p_T \rangle$ of mesons

- for all energies, the average p_T for baryons is larger than for mesons

$\langle p_T \rangle$ vs m/n_q

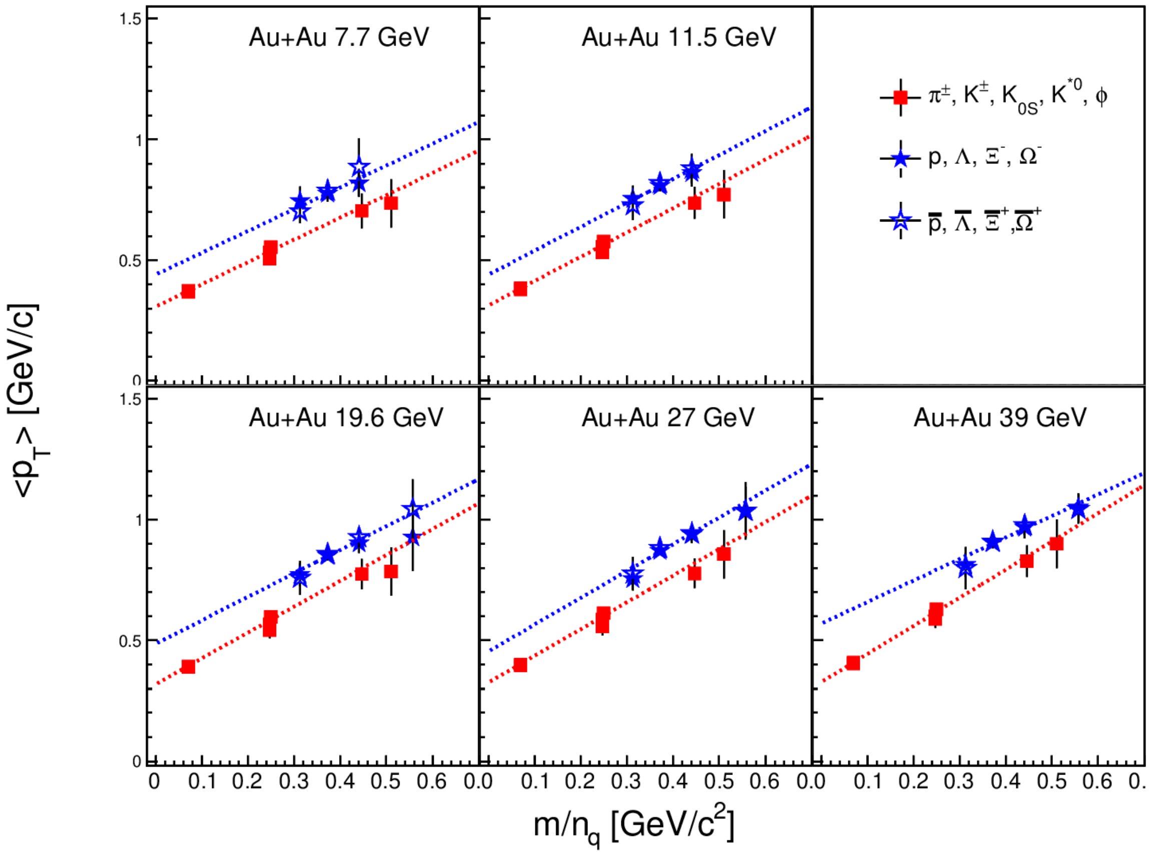


10-20%

- at 7.7 GeV, no Ω data in this centrality class

- at 11.5 GeV, 10-60% centrality class for Ω

$\langle p_T \rangle$ vs m/n_q

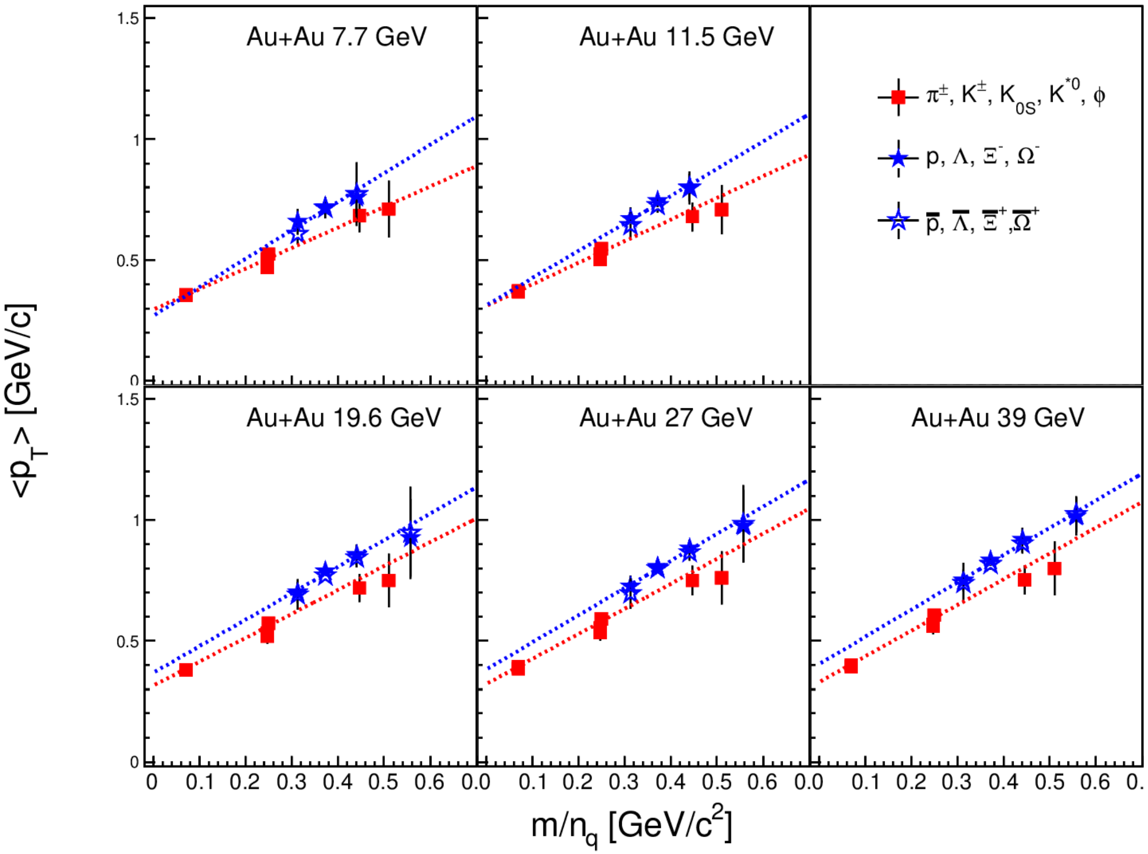


20-30%/20-40%

- 20-30%: π, $K^{+/-}$, K^0_S, K^{*0} , φ, p, Λ, Ξ

- 20-40%: K^{*0} (7.7 GeV), Ω (19.6-39 GeV)

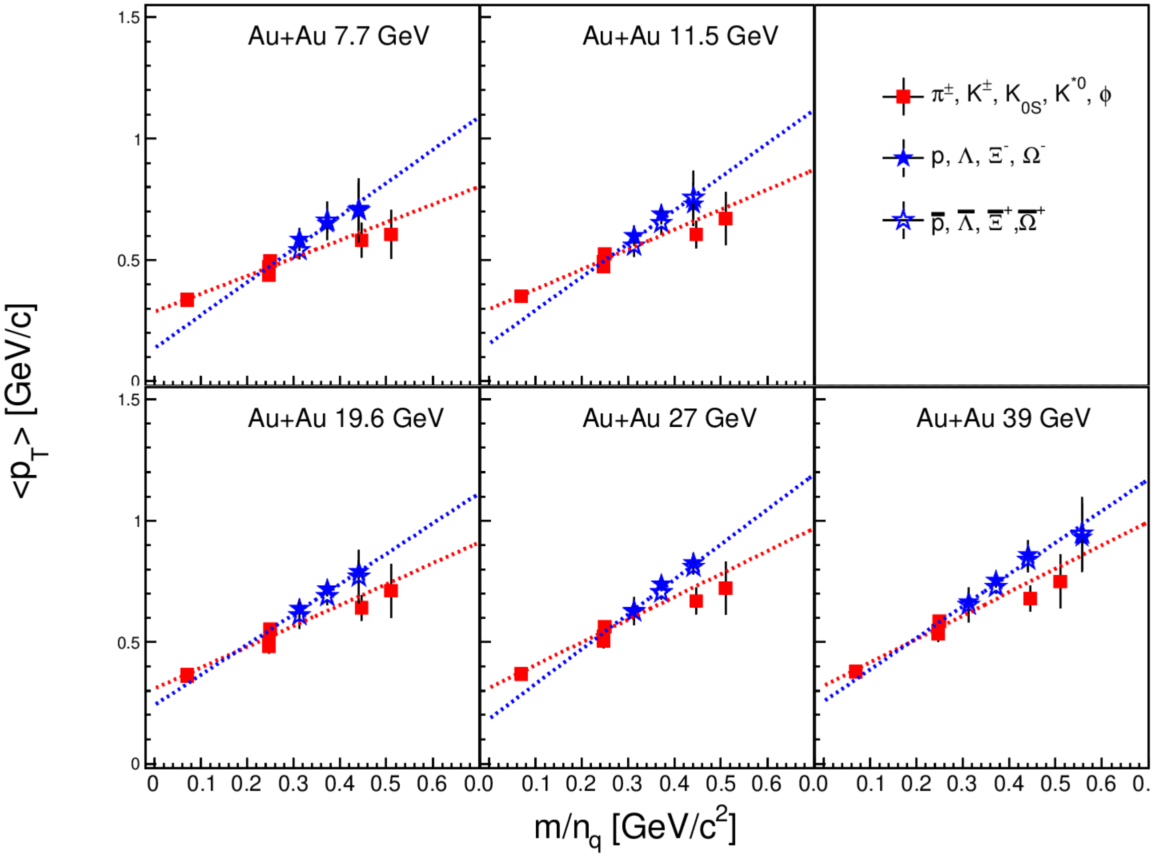
$<p_T>$ vs m/n_q



40-50%/40-60%

- 40-50%: π, $K^{+/-}$, p
- 40-60%: K^0_S, φ, Λ, Ξ, K^{*0}
- 40-60%: Ω (19.6-39 GeV)

$<p_T>$ vs m/n_q

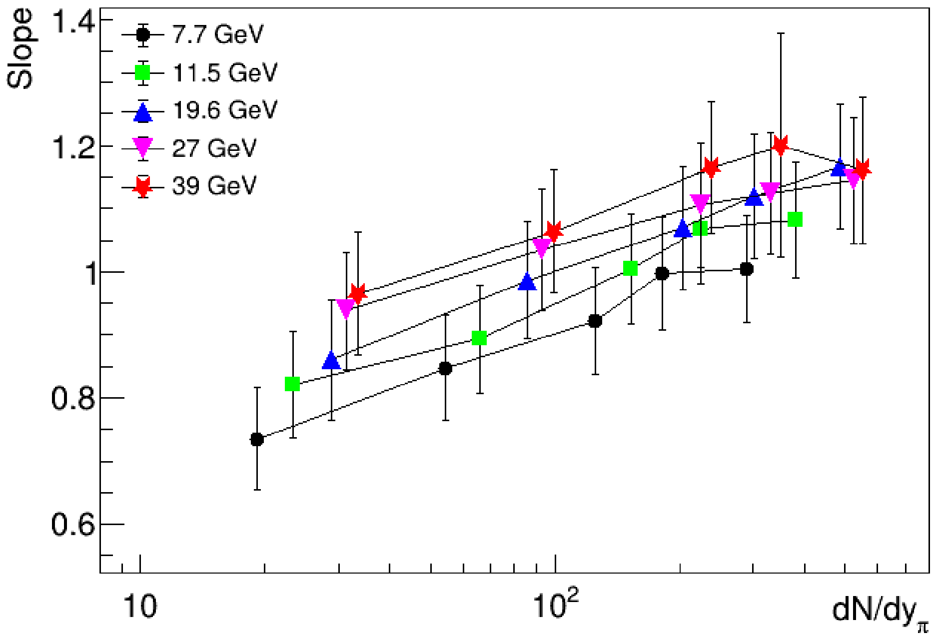


60-70%/60-80%

- 60-70%: π, $K^{+/-}$, p
- 60-80%: K^0_S, φ, Λ, Ξ, K^{*0}
- 60-80%: Ω (39 GeV)

- the differences in $<p_T>$ values between the baryons and mesons are smaller in peripheral collisions

Meson slopes



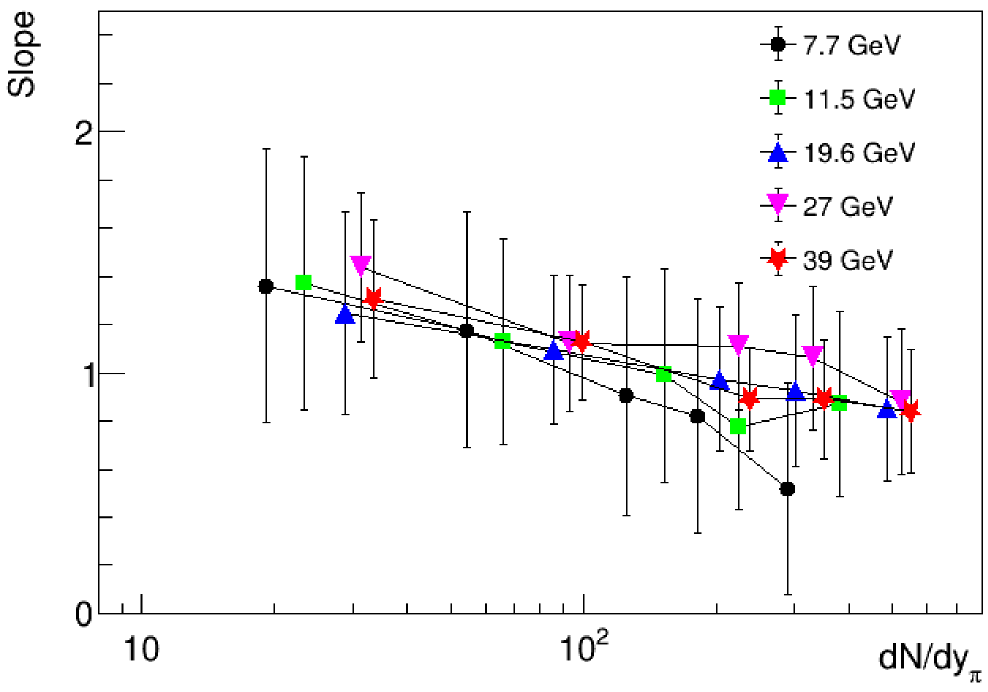
- the slopes of <p_T> = f(m/n_q) for mesons extracted from linear fits

- pion multiplicities are taken from L. Adamczyk et al., STAR Collaboration, Phys. Rev. C 96, 044904 (2017)

$$dN/dy_\pi = 1.5 \cdot (dN/dy_{\pi^+} + dN/dy_{\pi^-})$$

- for all energies, the slope increases with pion multiplicity from peripheral to semi-central collisions, while for central collisions seems to saturate

Baryon slopes

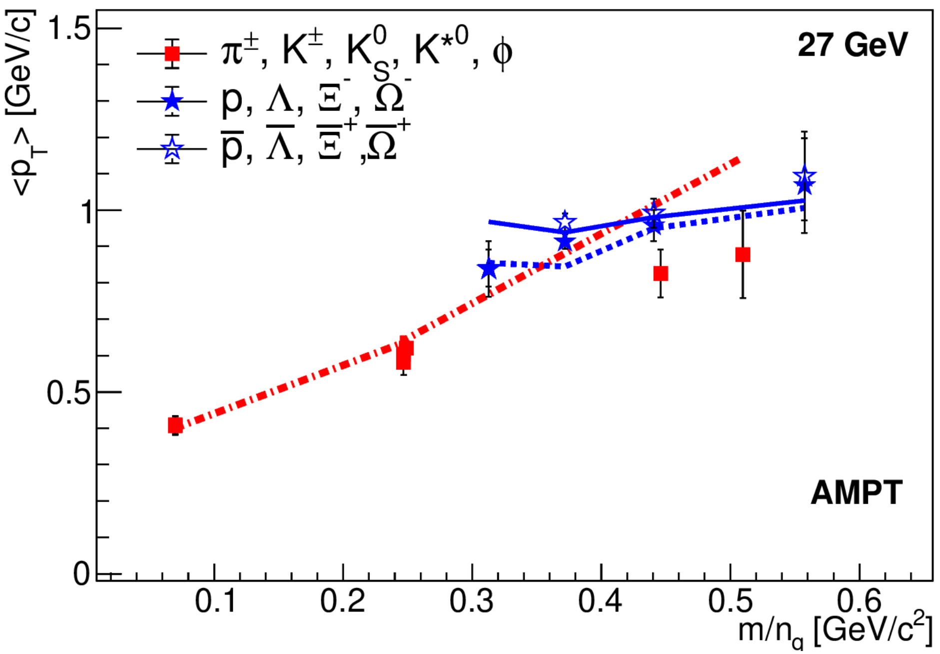


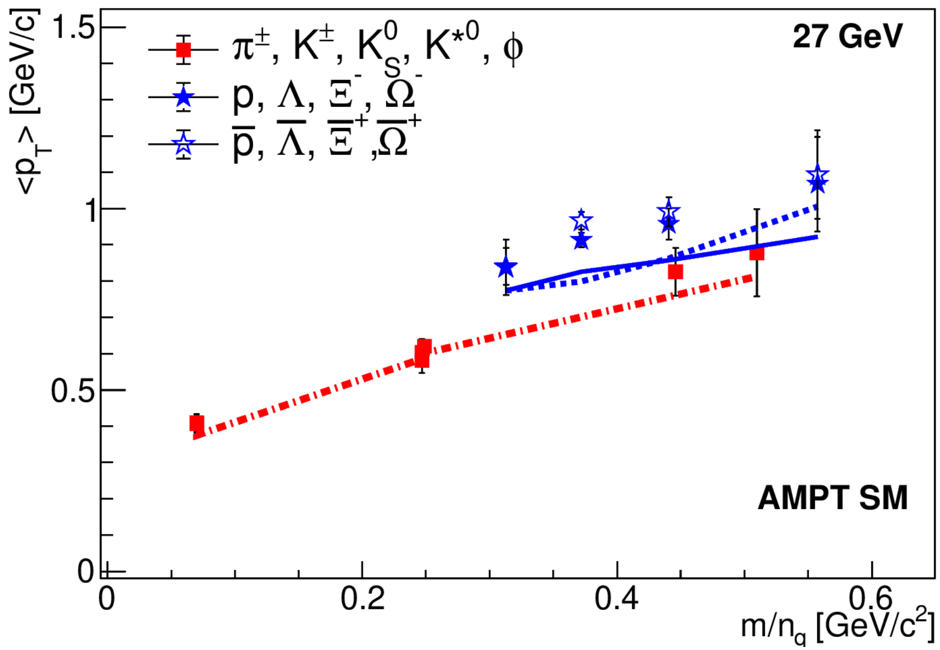
- for baryons, the $<p_T> = f(m/n_q)$ dependence is fitted with a 1st degree polynomial

- pion multiplicities are taken from L. Adamczyk et al., STAR Collaboration, Phys. Rev. C 96, 044904 (2017)

- different behaviour for baryons compared to meson slopes

AMPT model comparison – central collisions





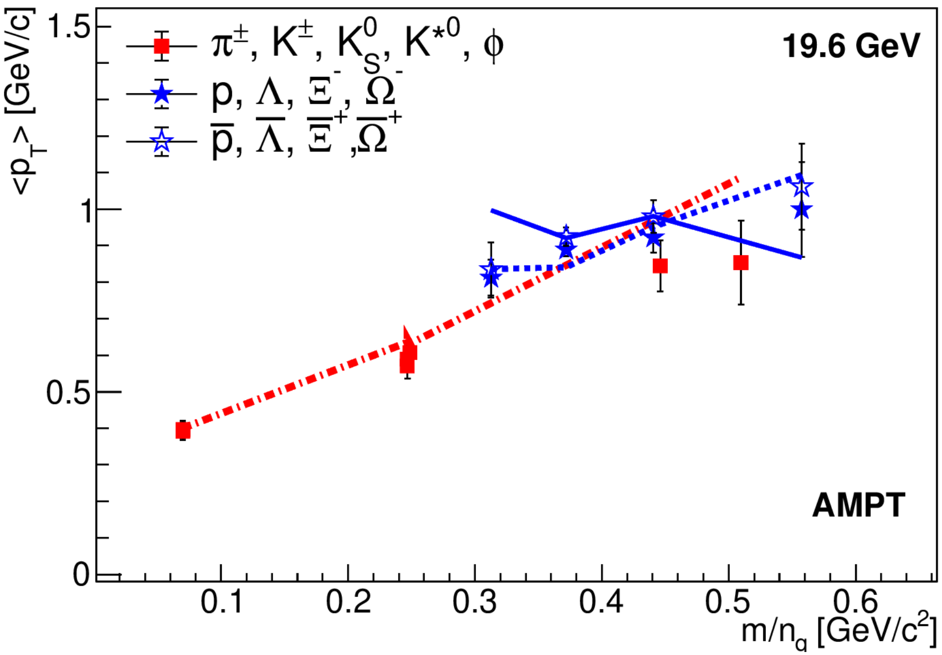
- 0-5%/0-10% centrality

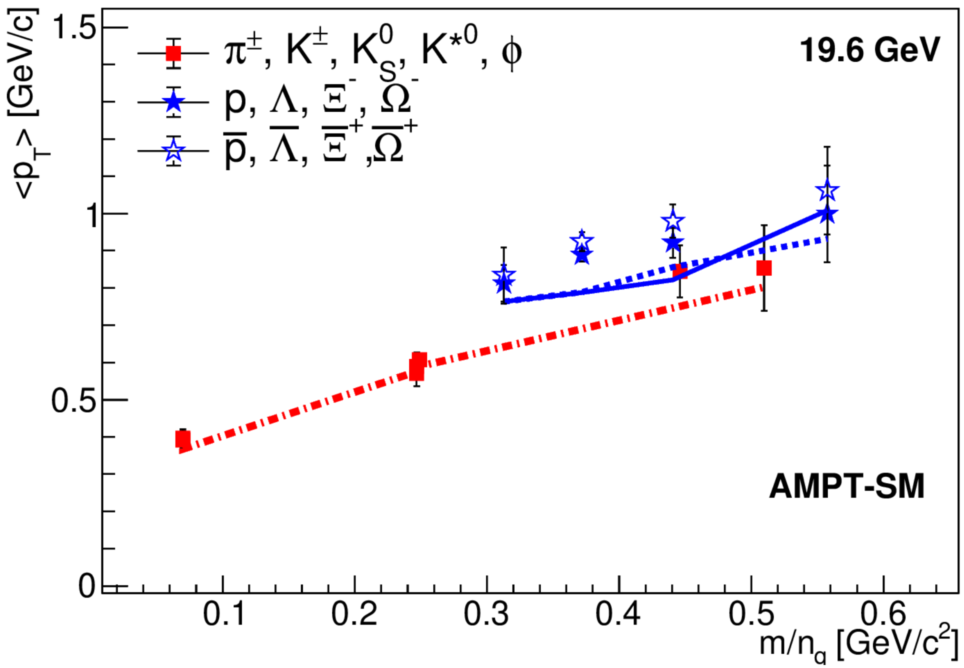
- A Multi-Phase Transport (AMPT) --> a Monte Carlo transport model for heavy-ion collisions at relativistic energies --> includes both initial partonic and final hadronic interactions, and the transition between these two phases of matter.

- AMPT-default describes better the (anti)baryon $<p_T>$; but overestimates the φ $<p_T>$

- AMPT-SM underestimates the $<p_T>$ for baryons and for φ

Model comparison – central collisions



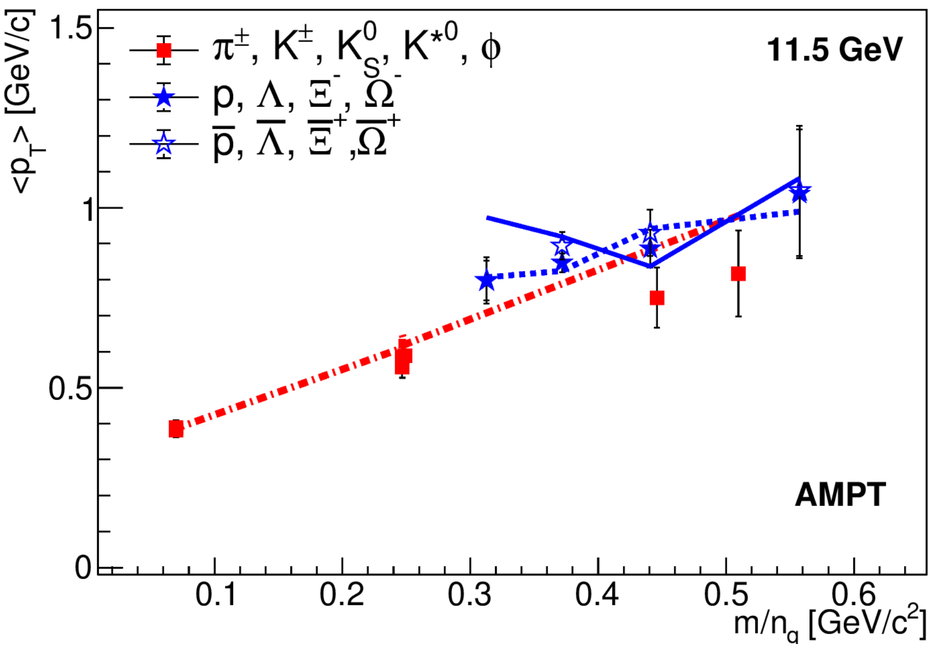


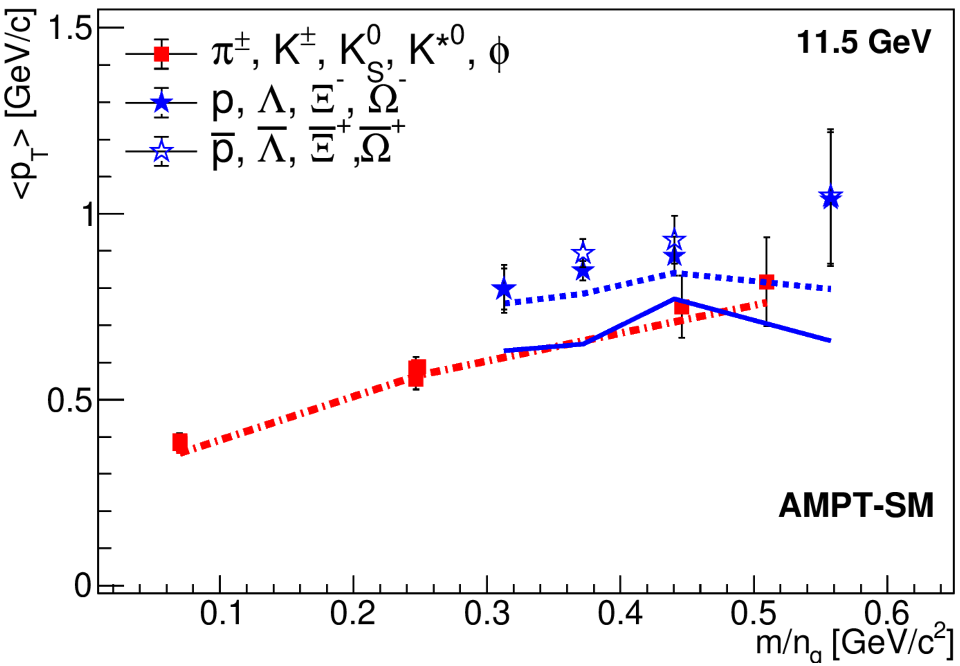
- 0-5%/0-10% centrality

- AMPT-default describes better the (anti)baryon $<p_T>$; but overestimates the φ $<p_T>$

- AMPT-SM underestimates the $<p_T>$ for baryons

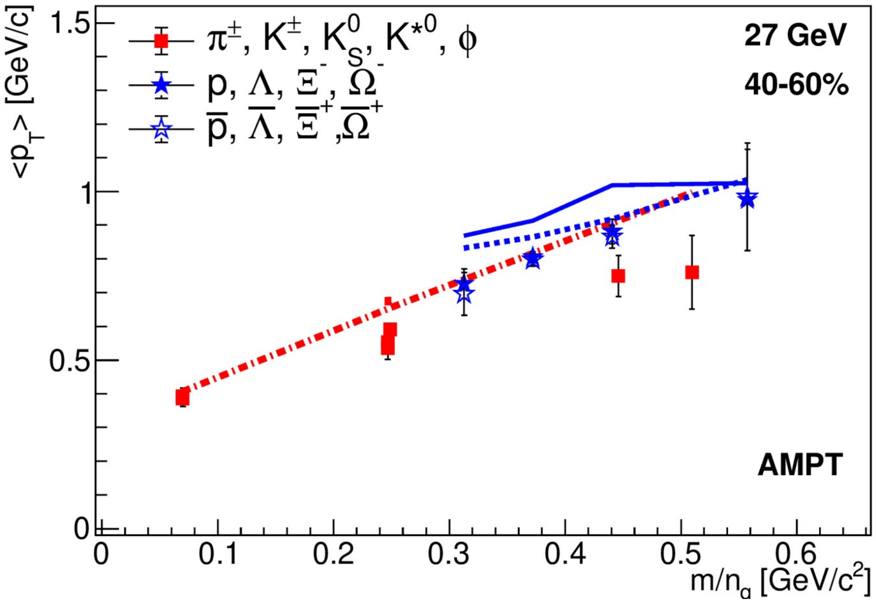
Model comparison – central collisions

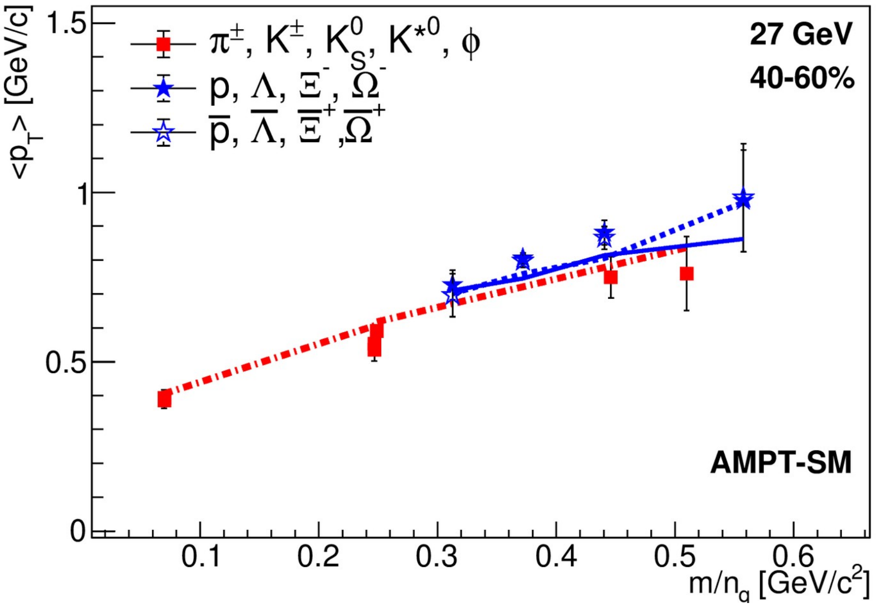




- 0-5%/0-10% centrality
- AMPT-default describes better the (anti)baryon $<p_T>$; but overestimates the φ $<p_T>$
- AMPT-SM describes $<p_T>$ for mesons; smaller values of baryon $<p_T>$ compared to antibaryons

Model comparison – peripheral collisions



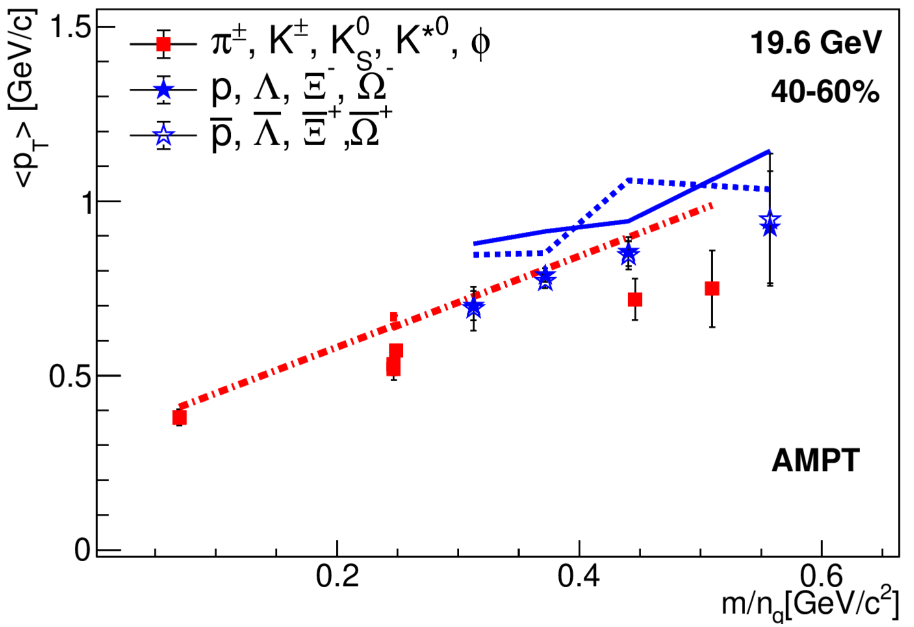


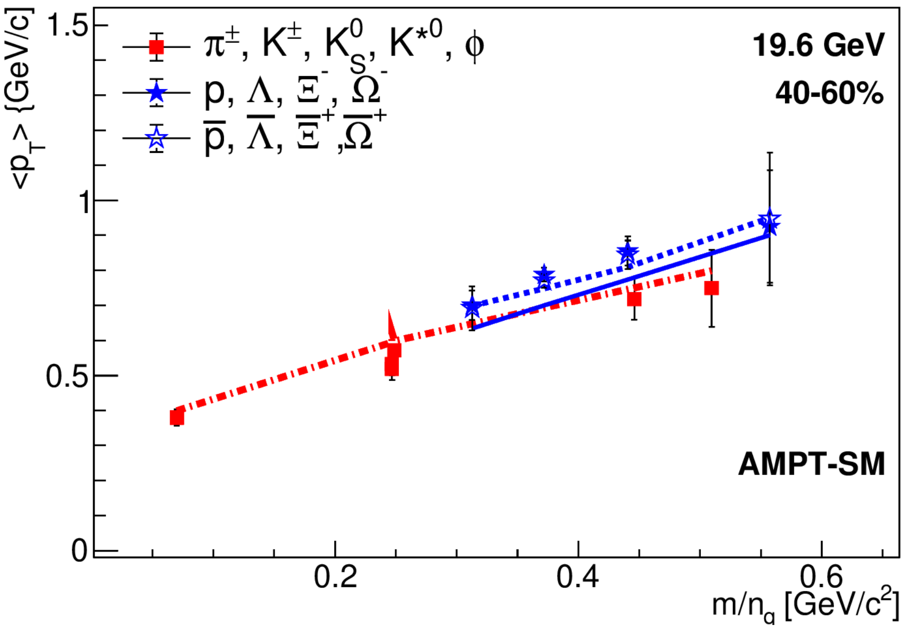
- 40-05%/40-60% centrality

- AMPT-default overestimates the (anti)baryon and meson $\langle p_T \rangle$

- AMPT-SM describes better $\langle p_T \rangle$ for mesons and baryons

Model comparison – peripheral collisions



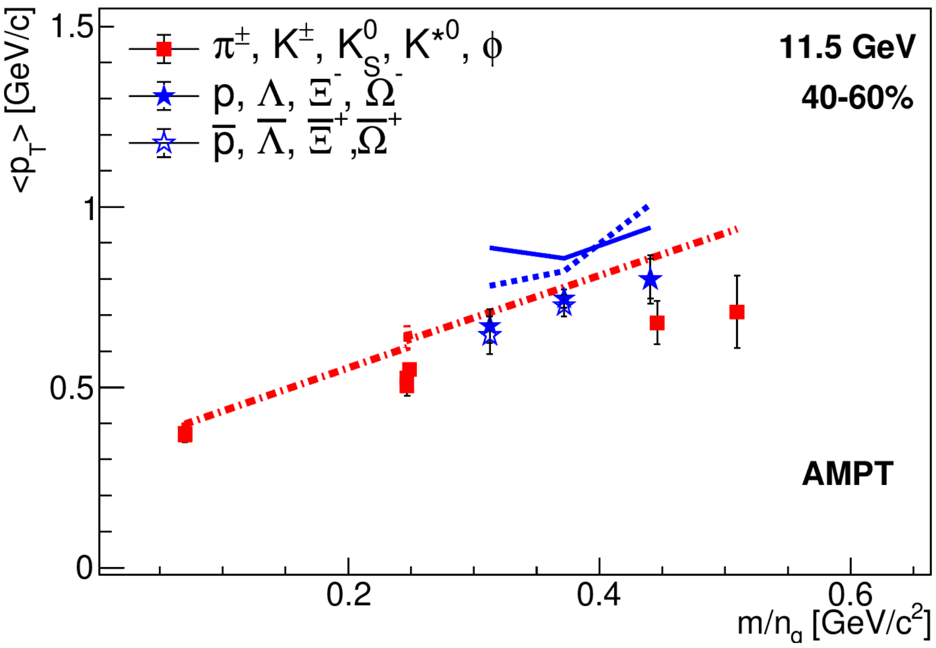


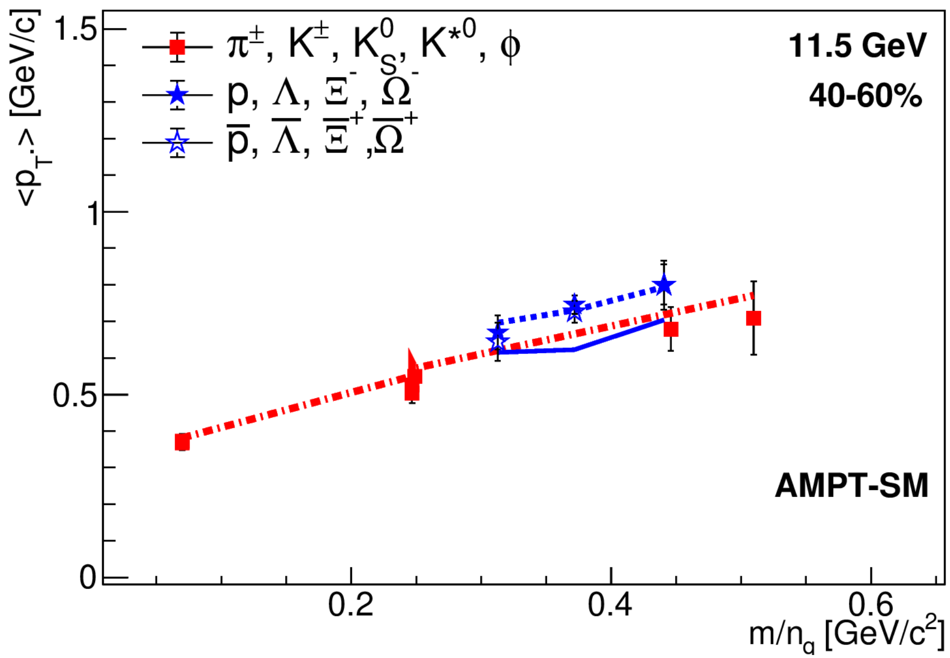
- 40-05%/40-60% centrality

- AMPT-default overestimates the (anti)baryon and meson $\langle p_T \rangle$

- AMPT-SM describes better $\langle p_T \rangle$ for mesons and baryons

Model comparison – peripheral collisions





- 40-05%/40-60% centrality

- AMPT-default overestimates the (anti)baryon and meson <p_T>

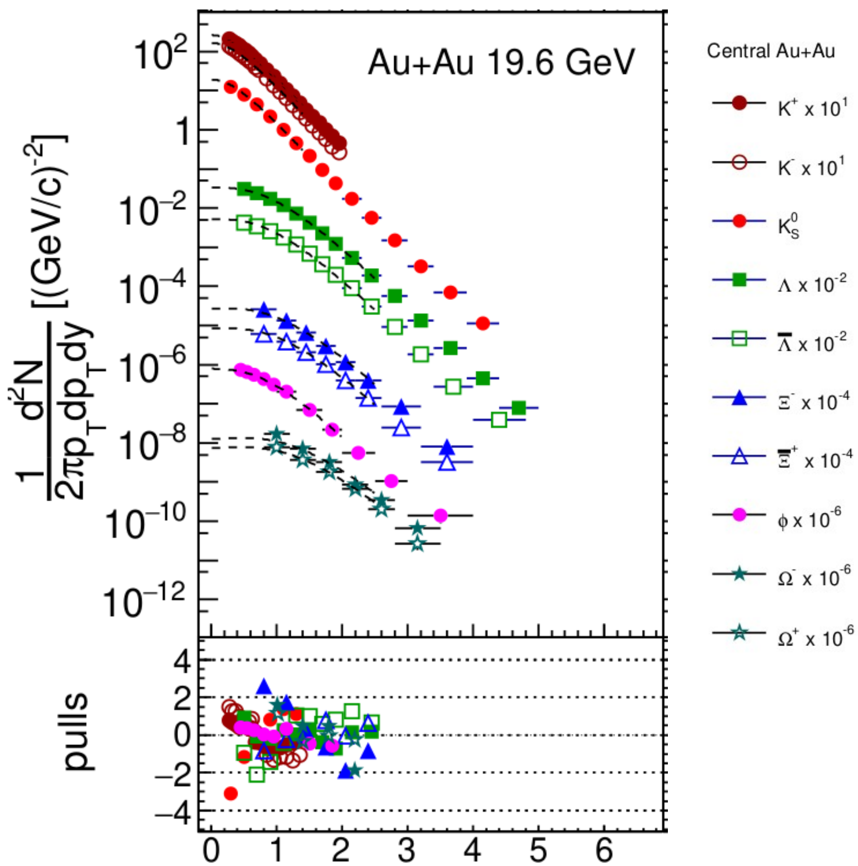
- AMPT-SM describes better <p_T> for mesons and baryons; the <p_T> for antibaryons is larger that of baryons

Blast-wave model

- A cylindrical expanding fireball in local thermal equilibrium, in which the particles are locally thermalized at a kinetic freeze-out temperature and are moving with a common transverse collective flow velocity (E. Schnedermann et. al, PRC48 (1993) 2462).

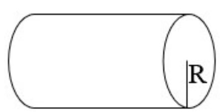
- The p_T spectrum of produced particles described by:

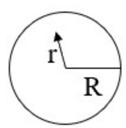
$$\frac{dN}{p_T\,dp_T} \propto \int_0^R r\,dr\,m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{\rm kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{\rm kin}}\right),$$



- The radial flow velocity profile parametrized as:

$$\beta_T(r) = \beta_s\left(\frac{r}{R}\right)^n$$

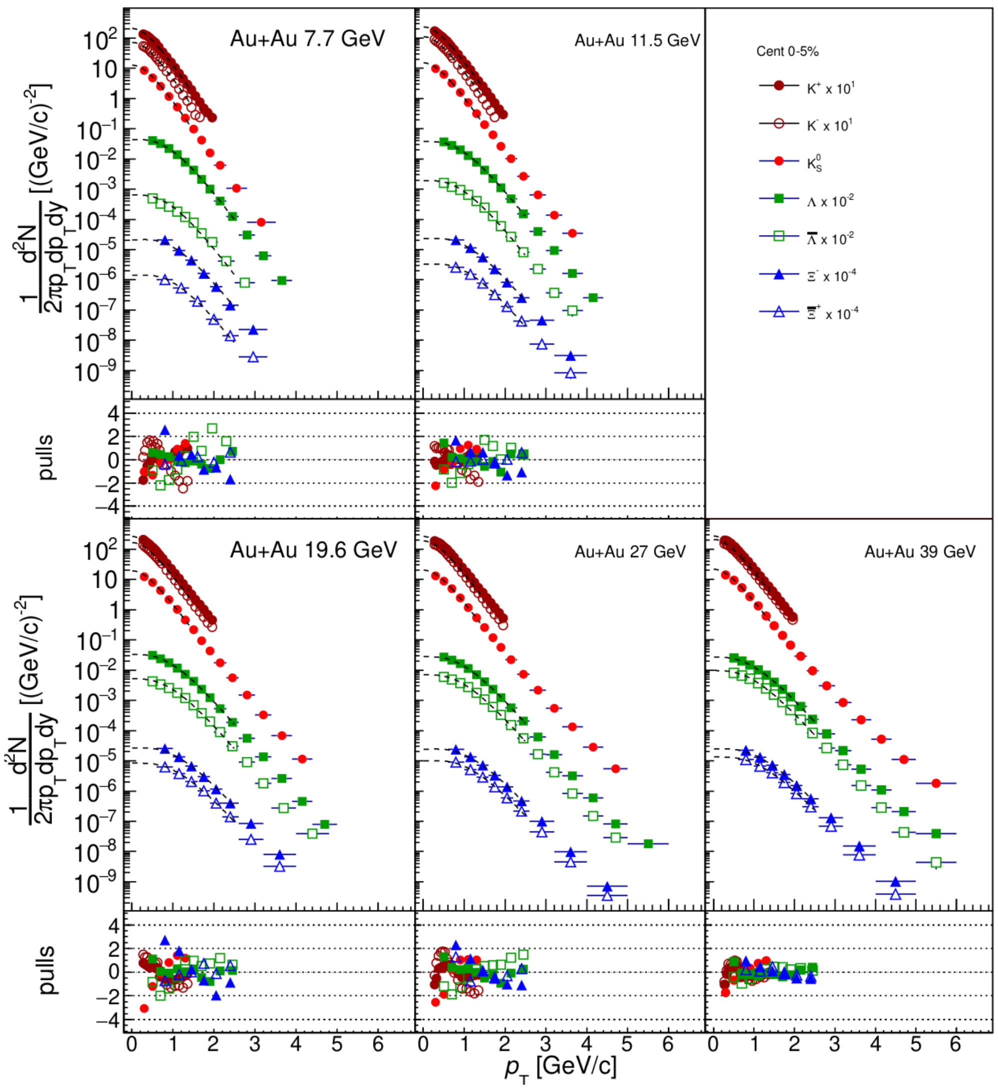




- The average transverse radial flow velocity is:

$$\langle\beta_T\rangle = \frac{2}{n+2}\beta_s$$

Blast-wave analysis of strange hadron spectra



--> BW fits on the p_T spectra of strange hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 GeV from the STAR experiment

--> standard BW analyses -->π^+, π^-, K^+, K^-, p and anti-p spectra fits

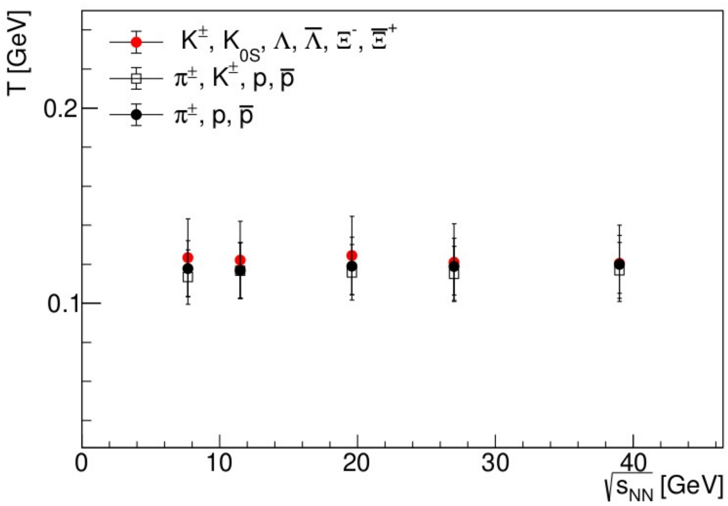
--> fit ranges: for kaons p_T<1.4 GeV/c; for strange baryons p_T<2.5 GeV/c

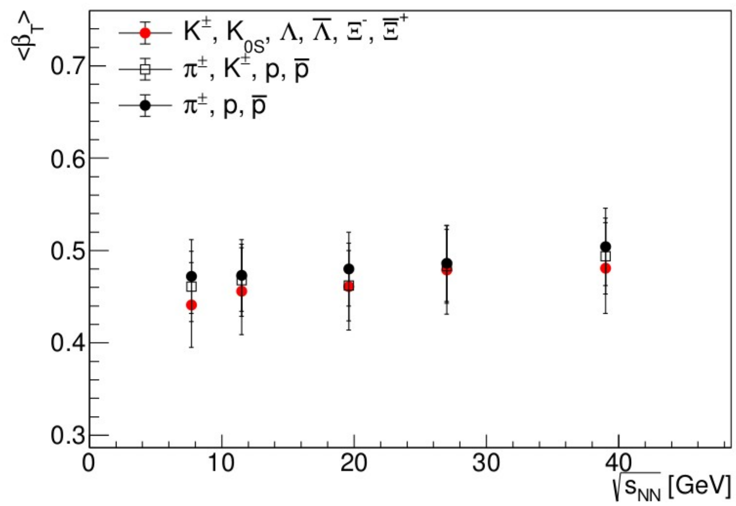
--> pulls distributions calculated as:

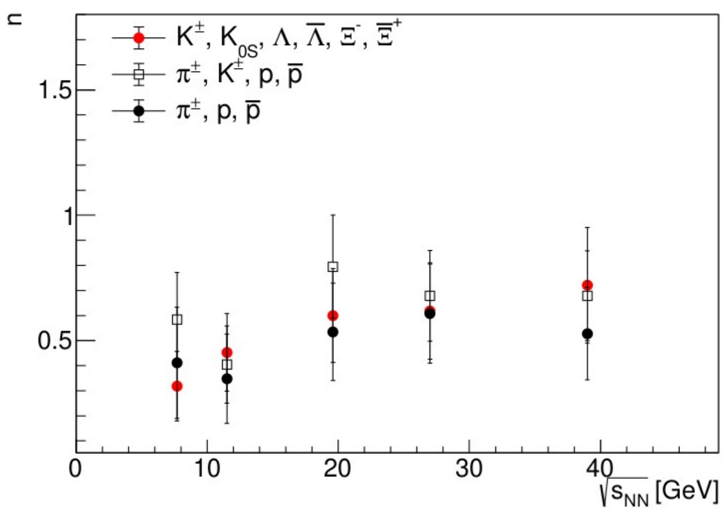
(data – fit value)/data error

J. Adam et al., STAR coll., Phys.Rev.C 102 (2020),034909; L. Adamczyk et al., Phys. Rev. C 96, 044904 (2017); L. Adamczyk et al., Phys. Rev. C 93, 21903 (2016)

Energy dependence







--> in most central Au-Au collisions, similar T and $\langle\beta_T\rangle$ within errors in this energy range for strange, non-strange and bulk hadrons --> indicate common freeze-out conditions for the strange/non-strange hadrons

--> very weak energy dependence of T and $\langle\beta_T\rangle$ parameters

--> n increases slowly with energy

Conclusions

- in Au+Au collisions at RHIC-BES energies, <p_T> increases with particle mass indicating the presence of the radial flow in the system → two different linear trends can be observed for non-strange hadrons and strange hadrons separately.

- <p_T> of each studied particle species increases with N_{part} at all RHIC-BES energies, indicating a stronger collective motion in more central collisions

- weak energy dependence for the analyzed energy range

- different behaviour of <p_T> as a function of m/n_q for mesons and baryons

- for central collisions, the default AMPT is generally better than the SM version to describe <p_T> for mesons and baryons, while peripheral collisions <p_T> are better described by AMPT-SM

- the values of strange particles freeze-out T and <β_T> are similar within errors with the corresponding parameter values extracted from BGBW fits on bulk and non-strange particles p_T spectra.