Triple high energy nuclear collisions - a new method to study QCD phase diagram at high baryonic densities

Oleksandr Vitiuk September 24th, 2022
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Uniwersytet Wrocławski

Article

Colliding and Fixed Target Mode in a Single Experiment—A Novel Approach to Study the Matter under New Extreme Conditions

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5. National Research Nuclear University (MEPhI), Kashirskoe Shosse 31, 115409 Moscow, Russia; zherebtsova.lisa@gmail.com
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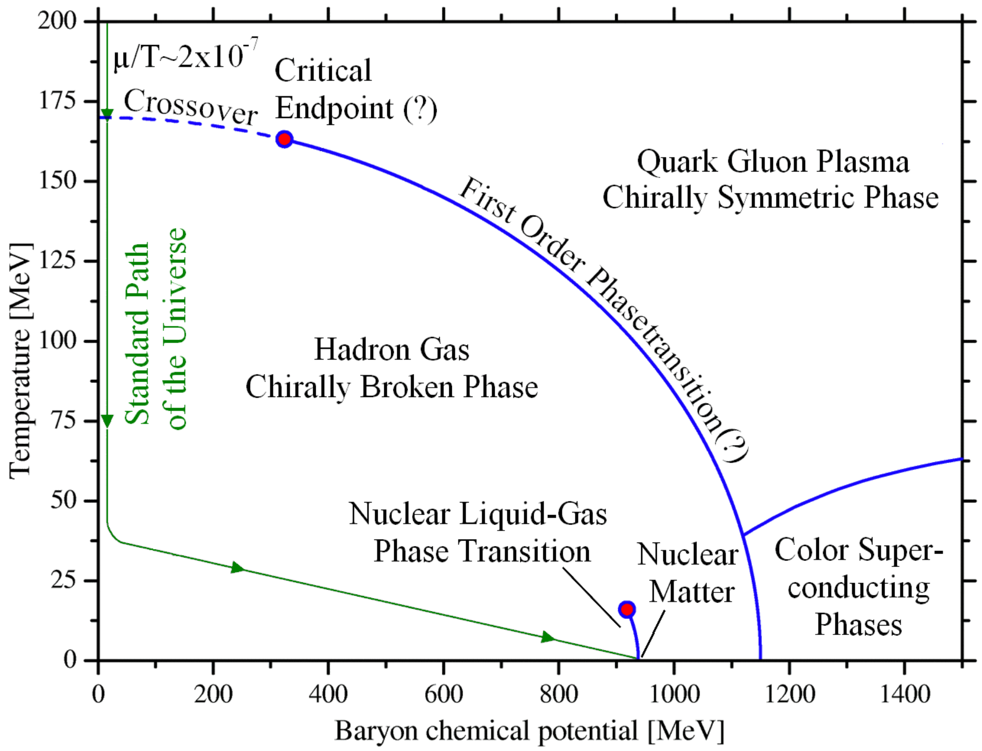
Introduction



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Exploring of the QCD phase diagram:

- Detect signals of deconfinement PT
- Detect signals of (partial) chiral symmetry restoration
- Locate (tri)critical endpoint(s) if such exists

[Credit: Universe 4 (2018) 52 & PoS (KMI 2013) 025]

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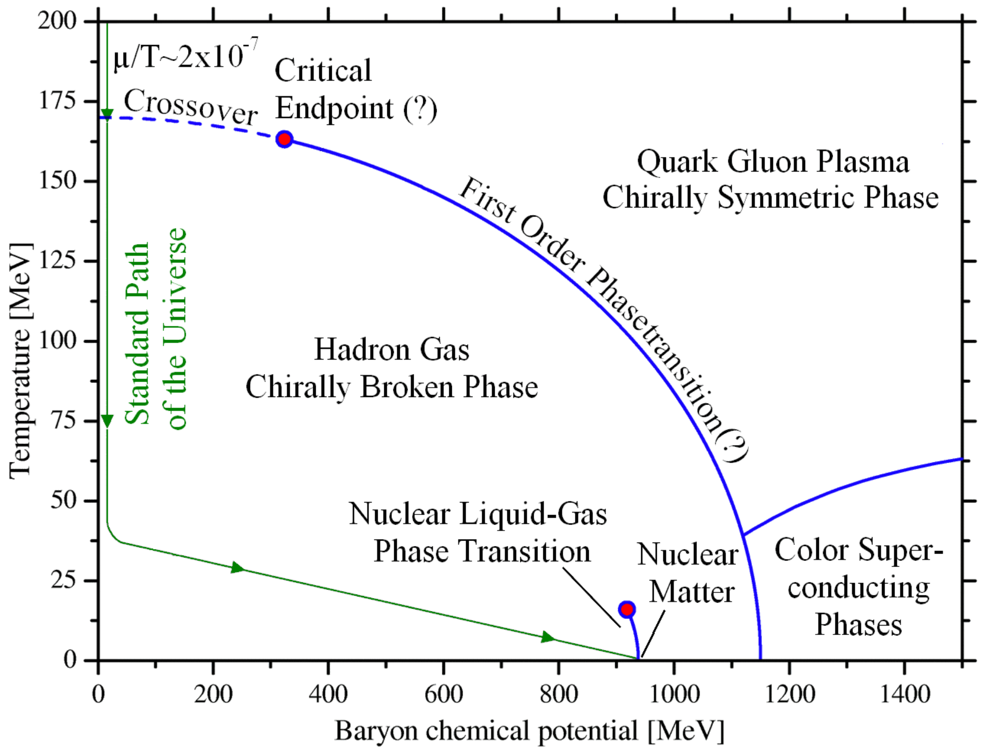

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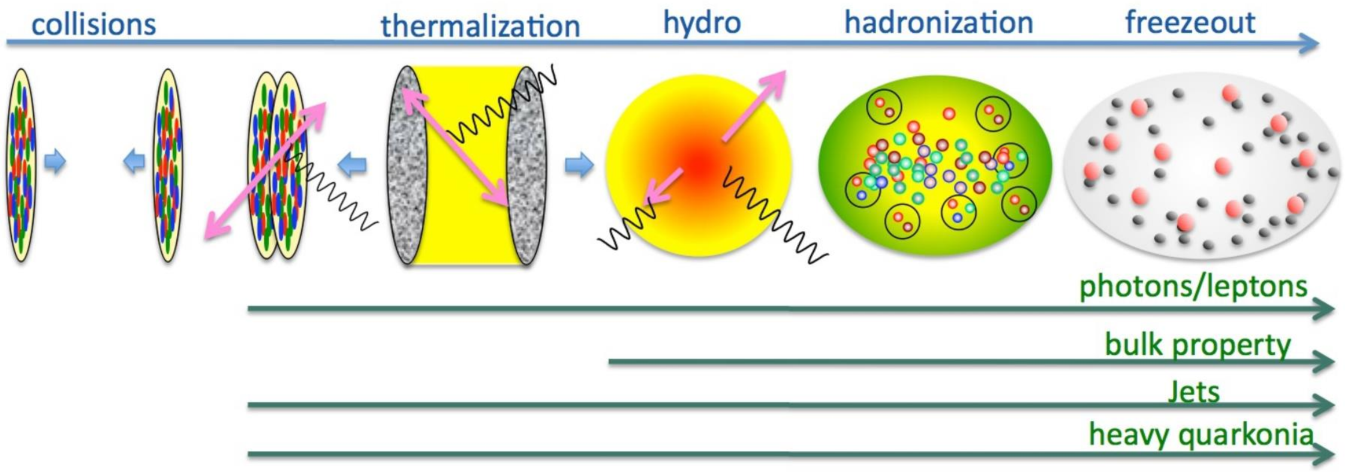

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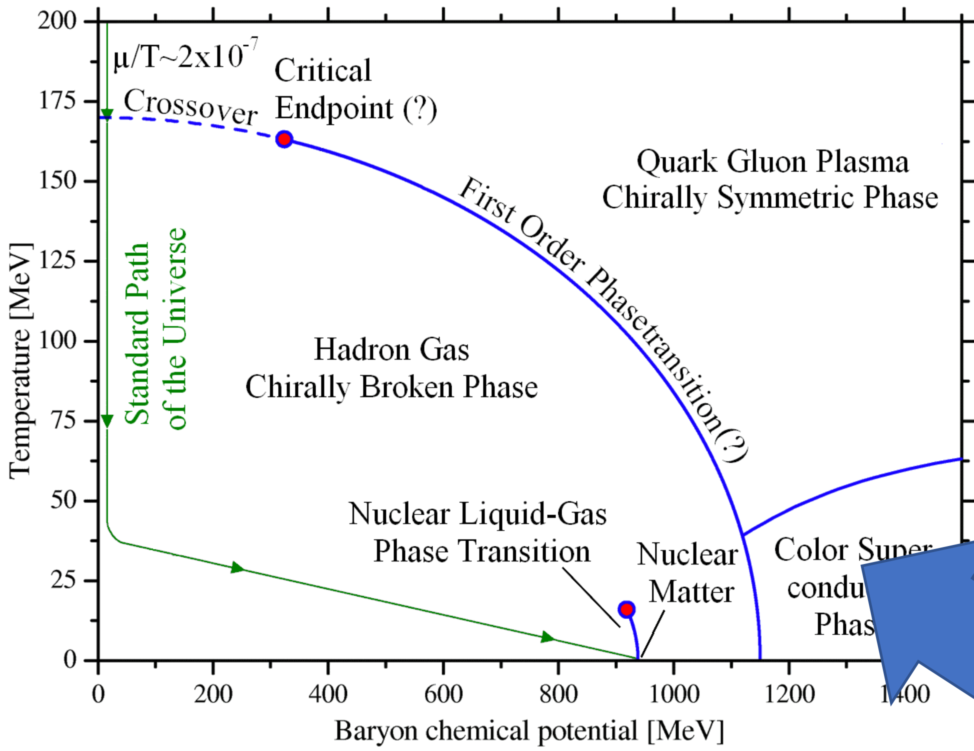

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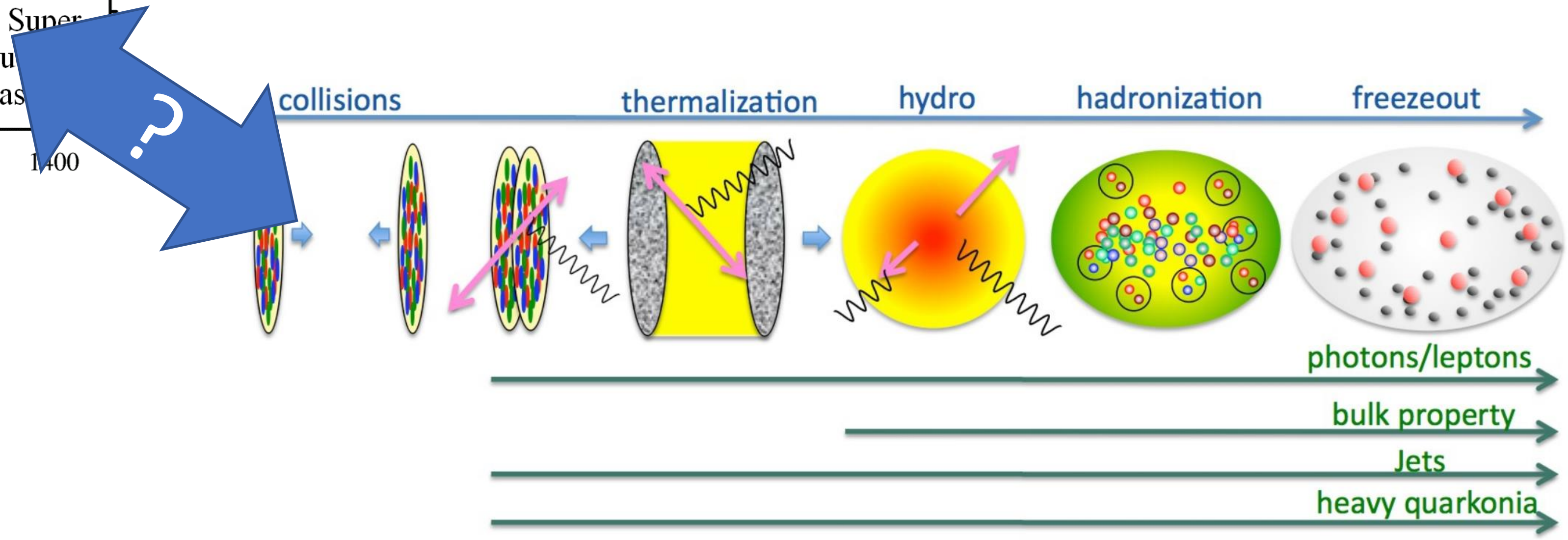

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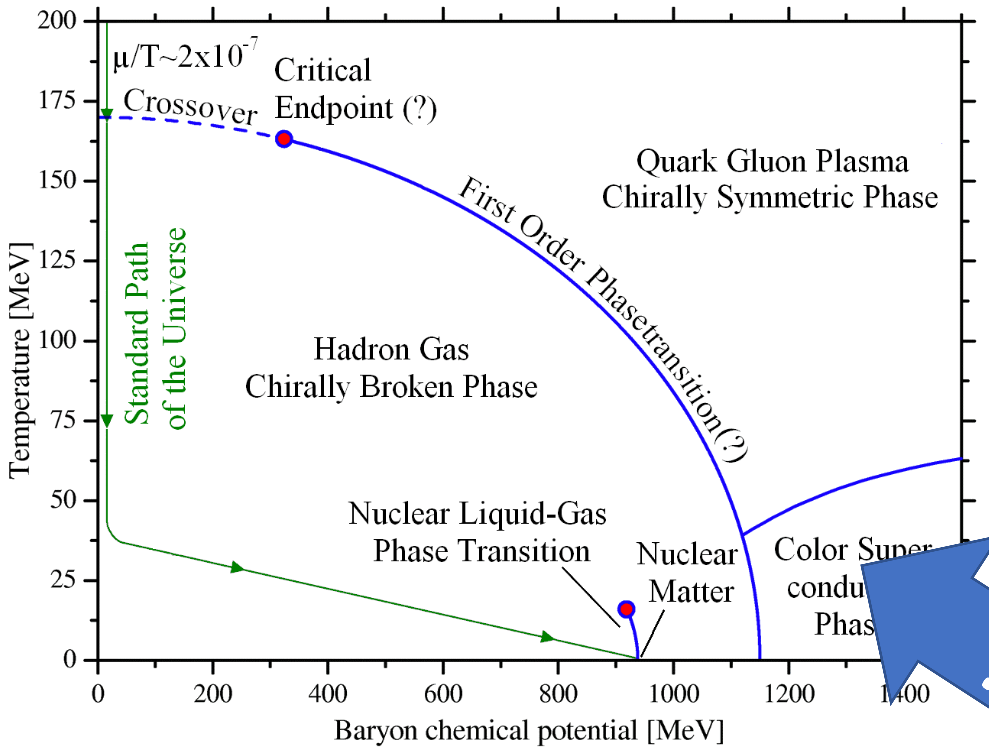

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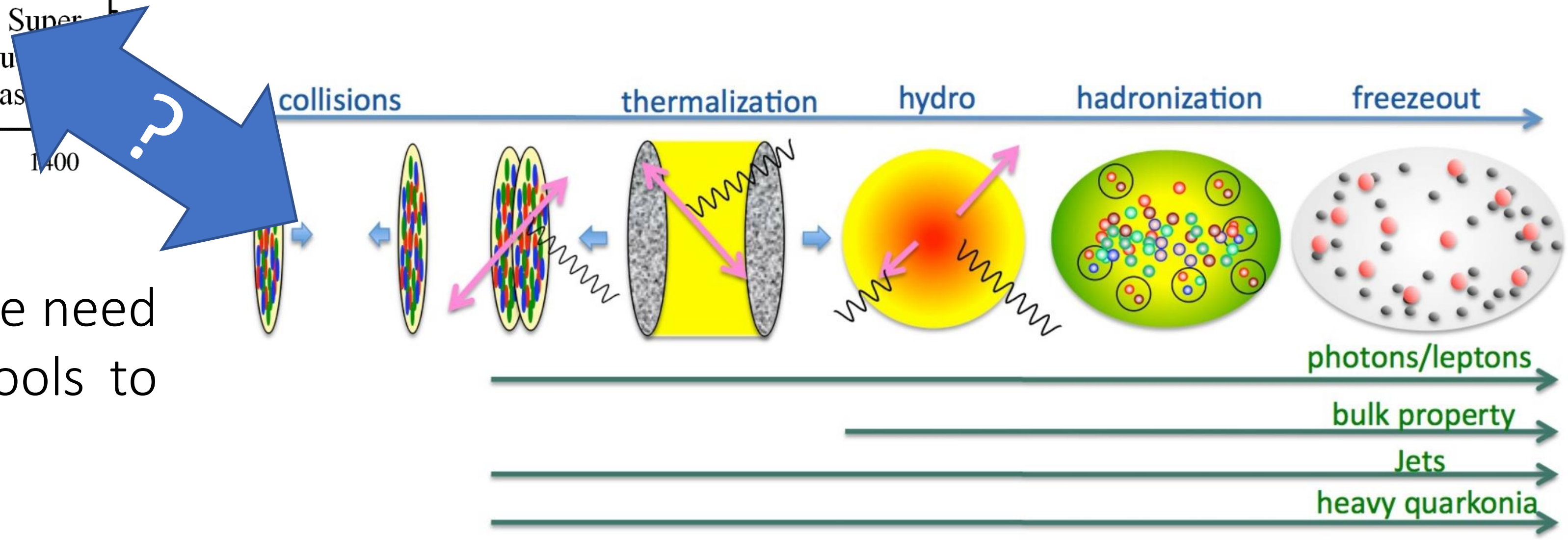


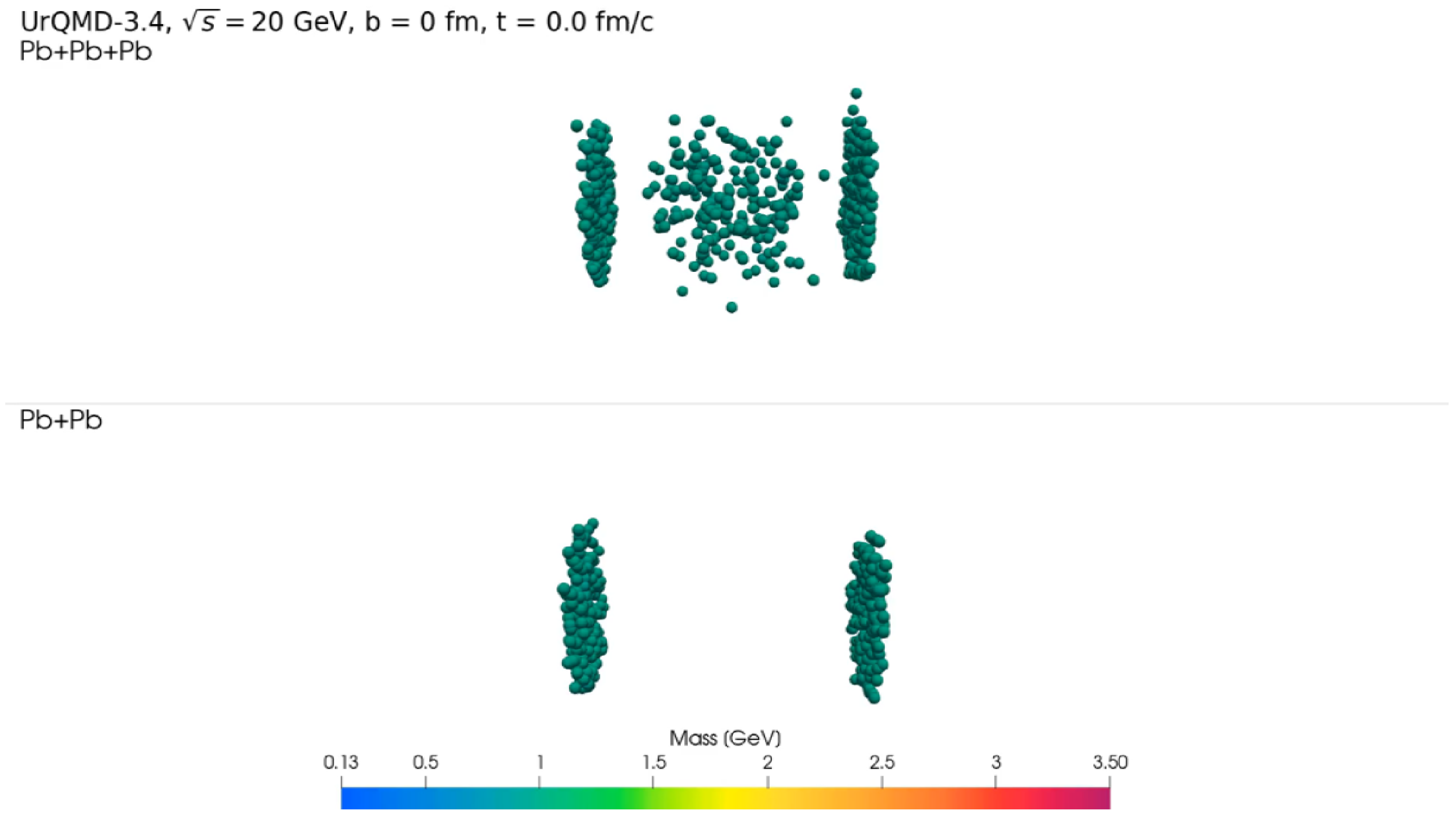
In order to resolve these tasks we need a very good observables and tools to analyse the data!

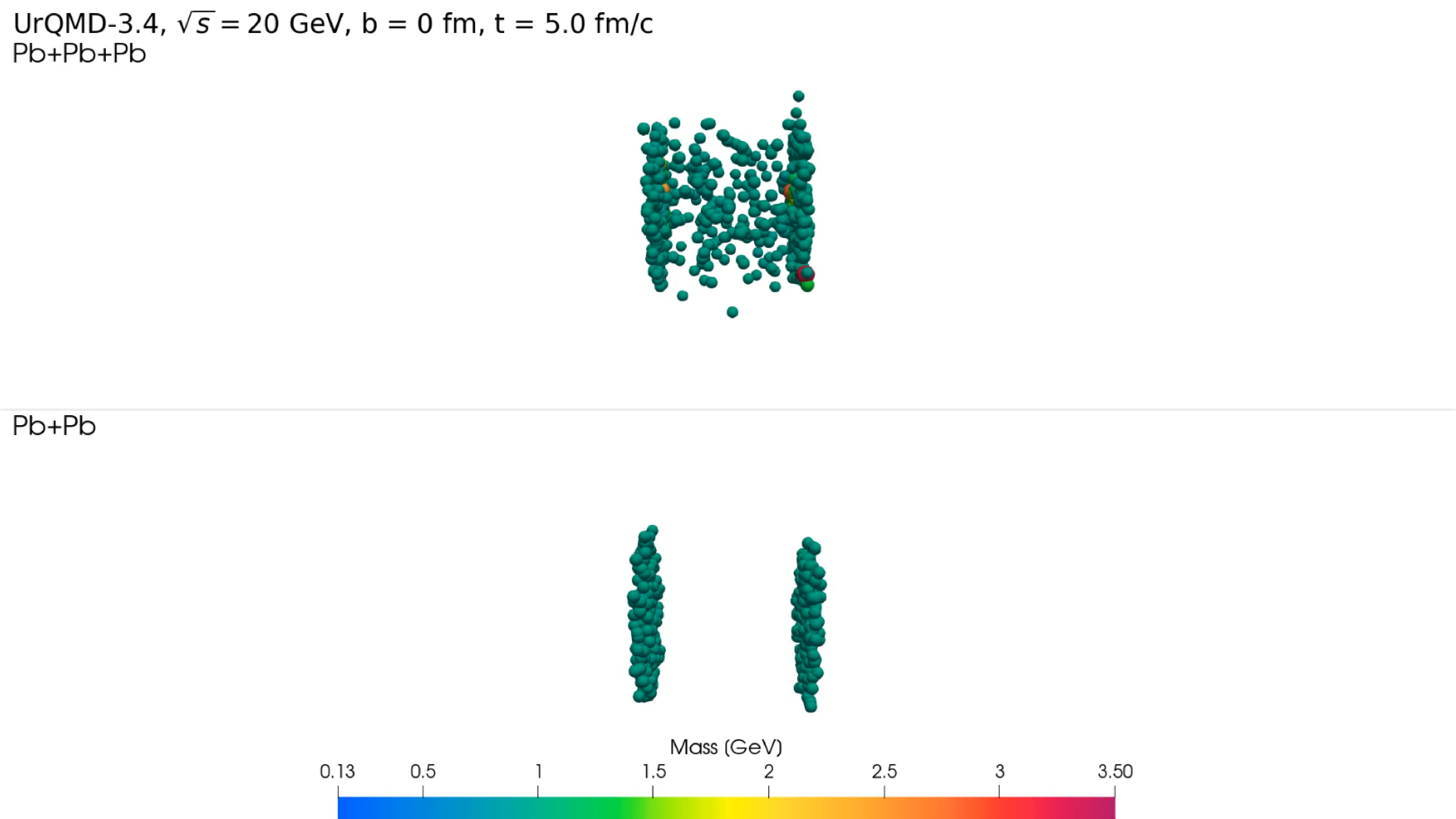
[Credit: Universe 4 (2018) 52 & PoS (KMI 2013) 025]

Ultrarelativistic Quantum Molecular Dynamics

- Represents a Monte Carlo method for the time evolution of the various phase space densities of particle species
- Based on the covariant propagation of all hadrons on classical trajectories, stochastic binary scatterings, resonance and string formation with their subsequent decay
- Provides the solution of the relativistic Boltzmann equation
- The collision criterion is a black disk approximation: $d < d_0 = \sqrt{\sigma(\sqrt{s}, type)/\pi}$
- 55 baryons and 32 mesons are included. All antiparticles and isospin-projected states are implemented
- Cross sections are taken from PDG where possible + additive quark model
- Resonances are implemented in Breit–Wigner form

[S. A. Bass et al, Prog. Part. Nucl. Phys. 41 (1998) 255-369,
M. Bleicher et al, J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859-1896]


UrQMD-3.4, $\sqrt{s} = 20$ GeV, b = 0 fm, t = 0.0 fm/c
Pb+Pb+Pb
Pb+Pb
Mass (GeV)
0.13
0.5
1
1.5
2
2.5
3
3.50


UrQMD-3.4, $\sqrt{s} = 20$ GeV, b = 0 fm, t = 5.0 fm/c
Pb+Pb+Pb
Pb+Pb
Mass (GeV)
0.13
0.5
1
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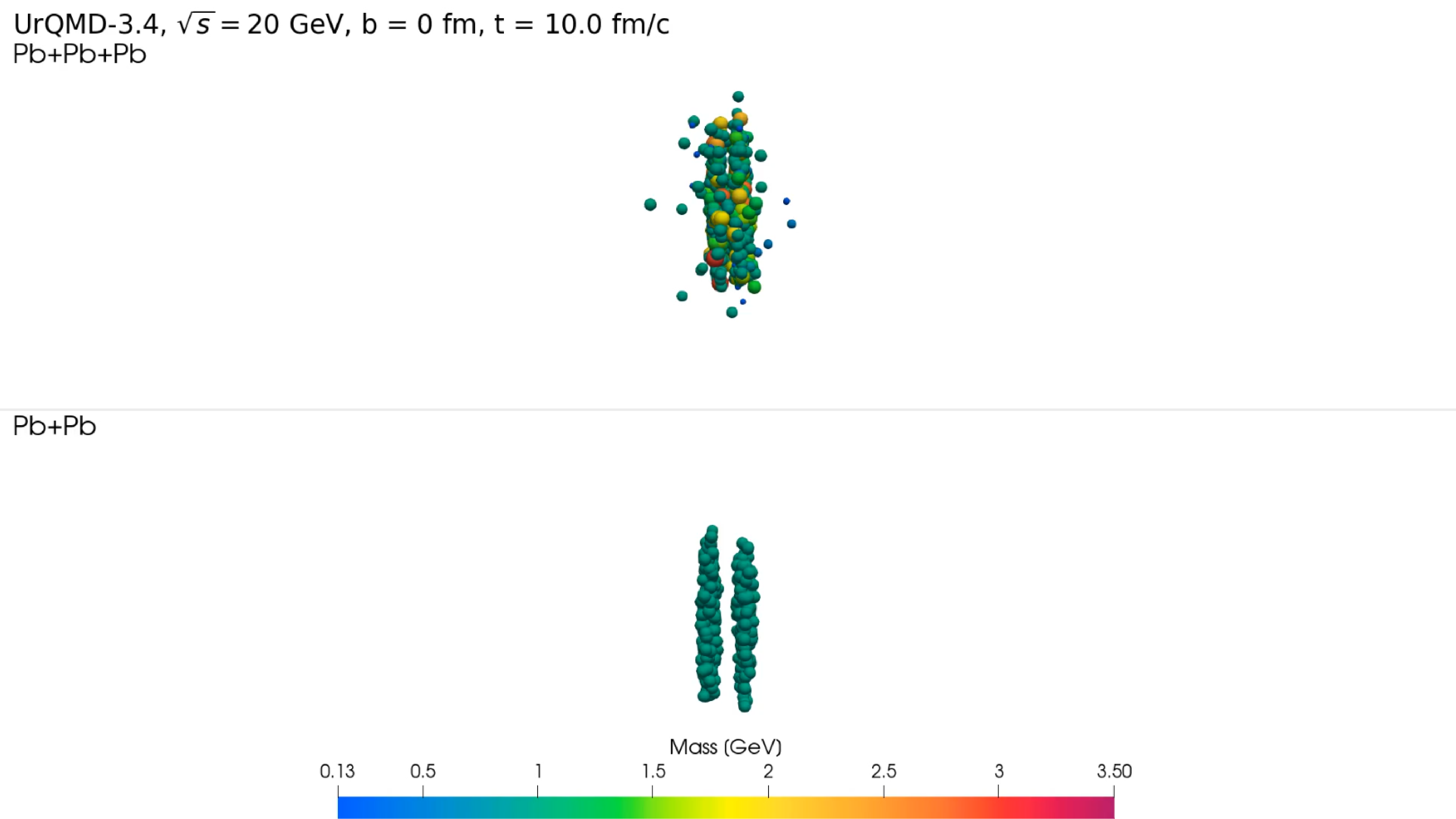
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Pb+Pb+Pb
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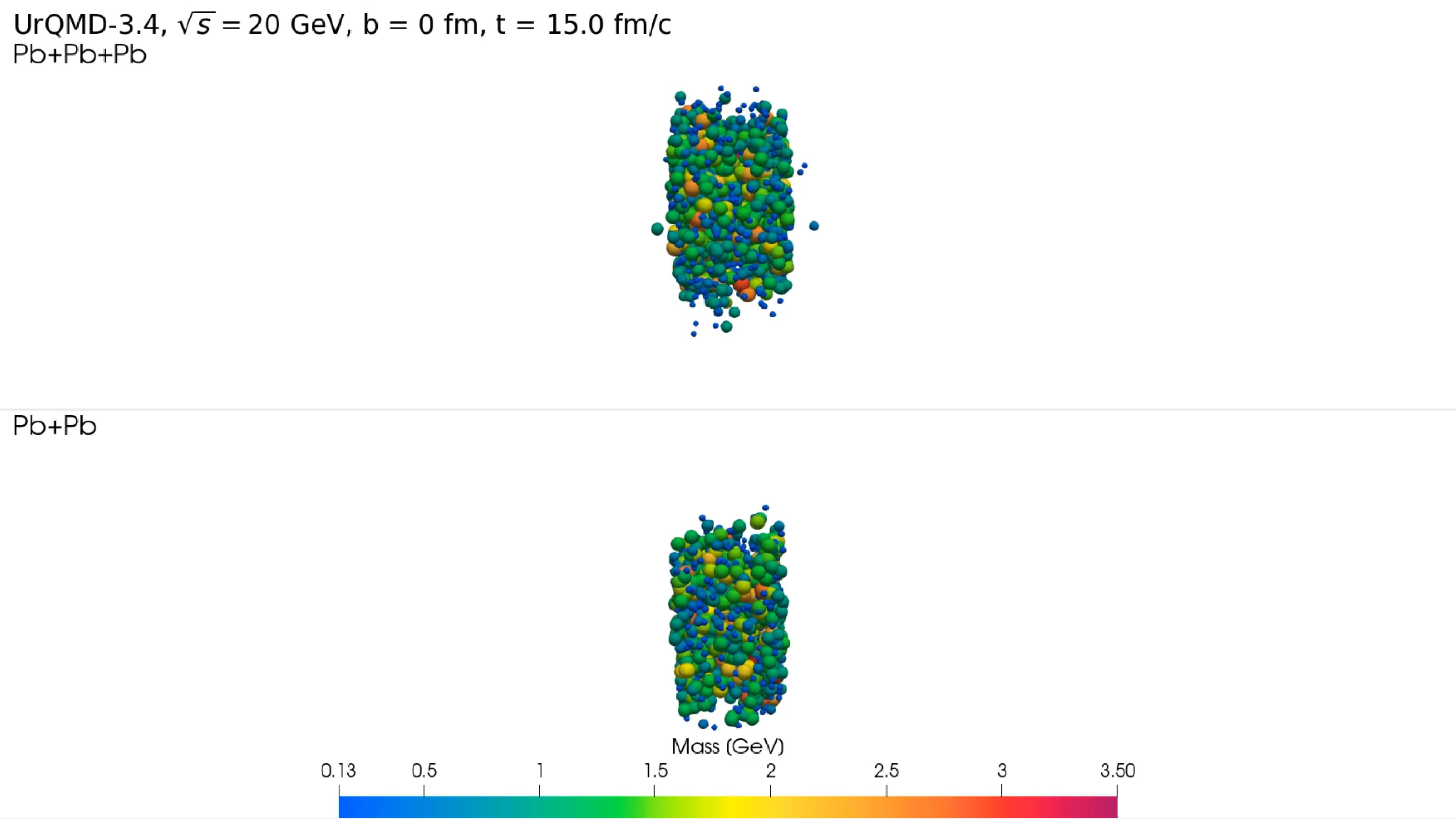

UrQMD-3.4, $\sqrt{s} = 20$ GeV, b = 0 fm, t = 15.0 fm/c
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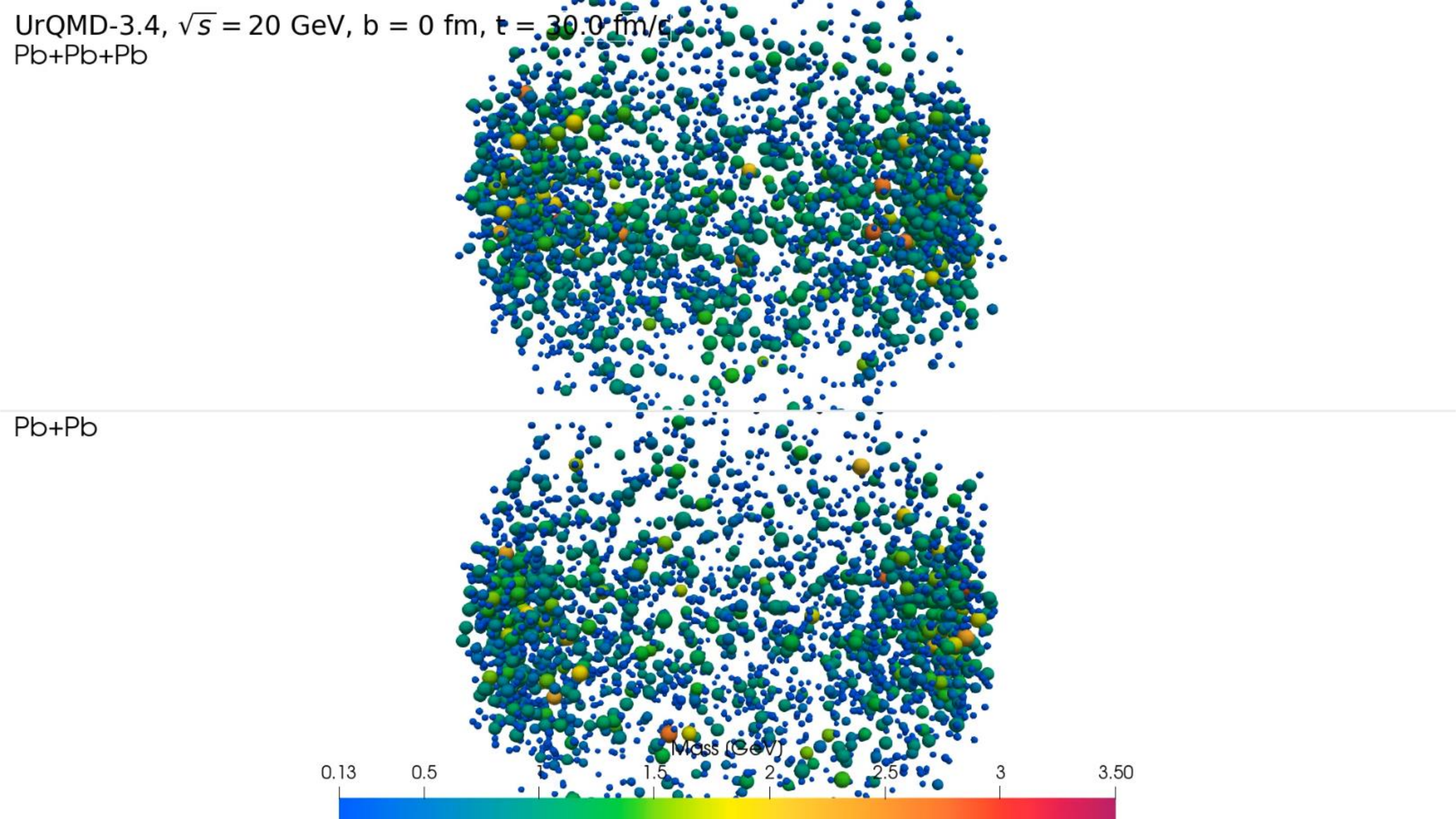
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Pb+Pb+Pb
Pb+Pb
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Model vs A+A data

- Main task is to study the properties of hadron production in TNC
- Main interest is the baryon production in most central collisions
- Pb+Pb+Pb @ $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$ & $\sqrt{s_{NN}} = 2.76\ \mathrm{TeV}$ considered

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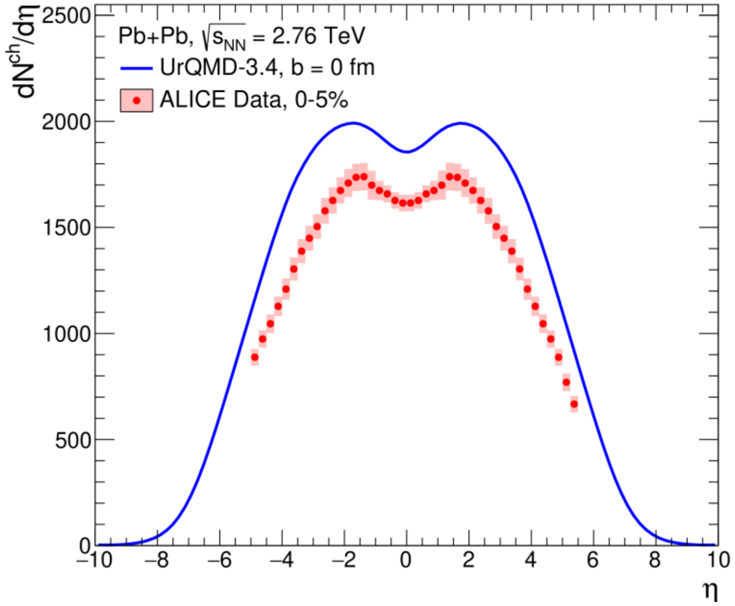

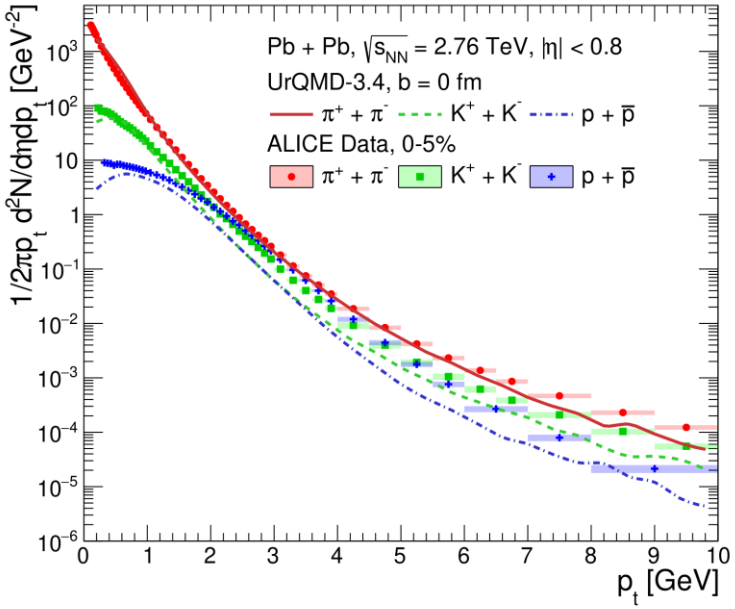

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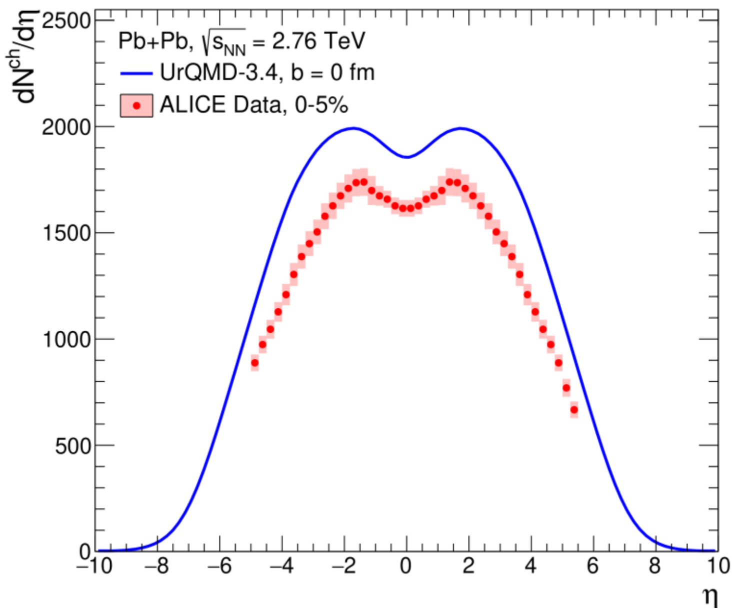

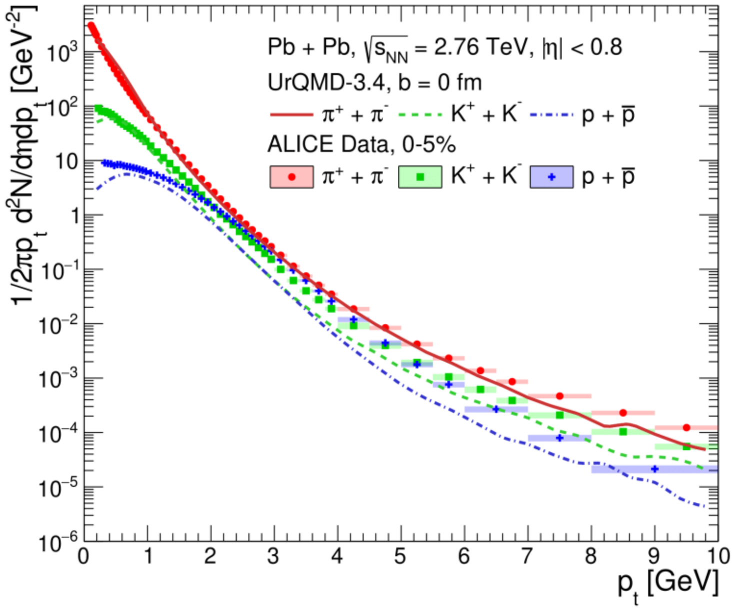

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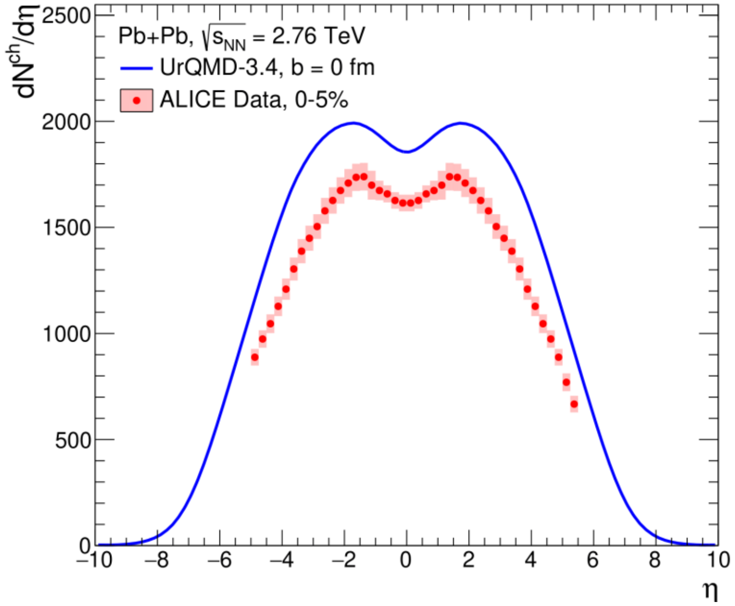

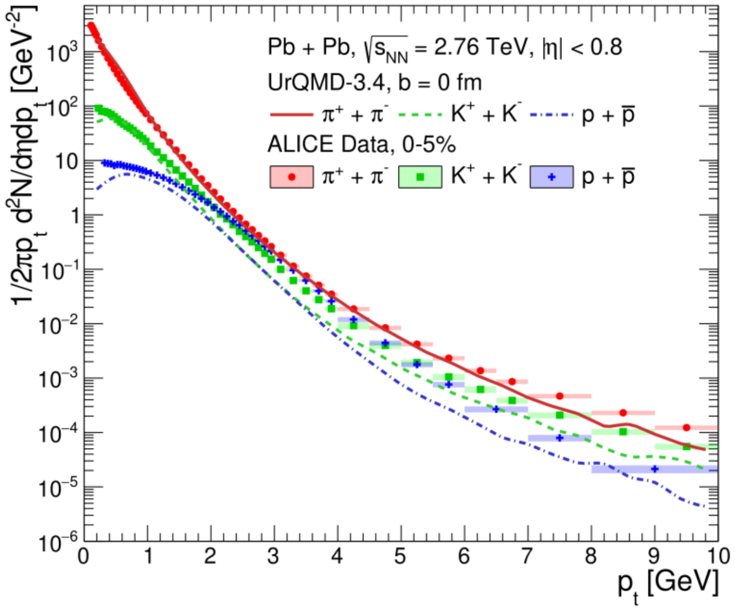

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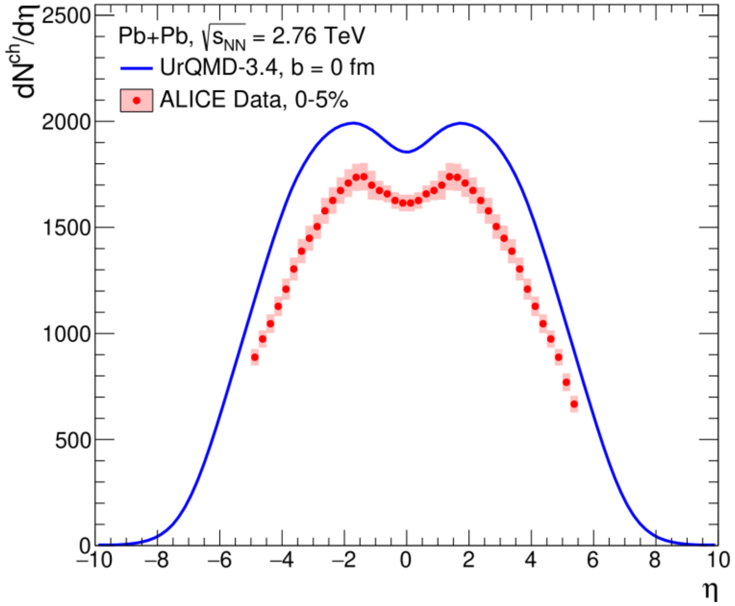

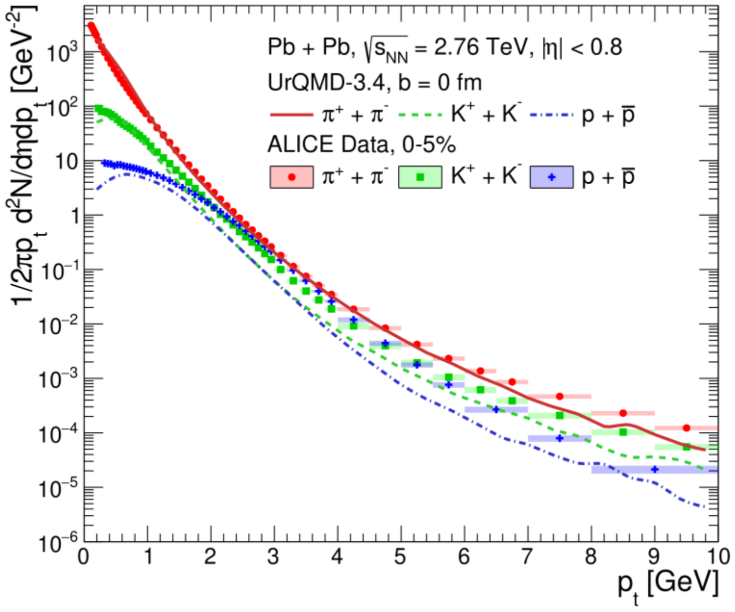

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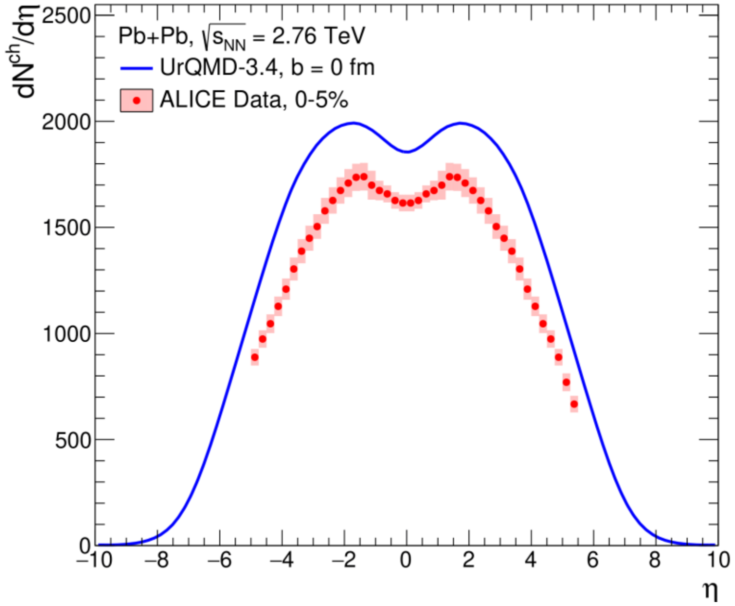

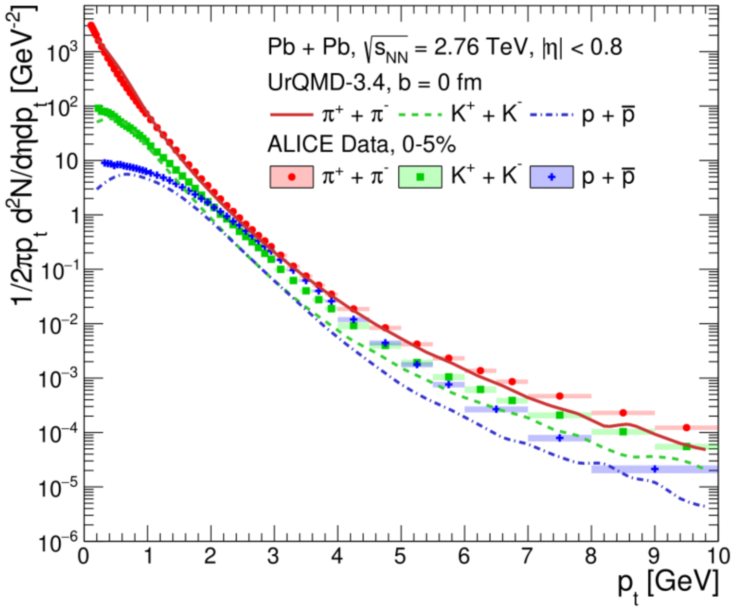

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$$R_{32}(y) = \left(\frac{dN}{dy}\right)_{TNC} \Big/ \left(\frac{dN}{dy}\right)_{BC} \qquad R_{32}(p_T) = \left(\frac{d^2N}{p_T dp_T dy}\right)_{TNC} \Big/ \left(\frac{d^2N}{p_T dp_T dy}\right)_{BC}$$

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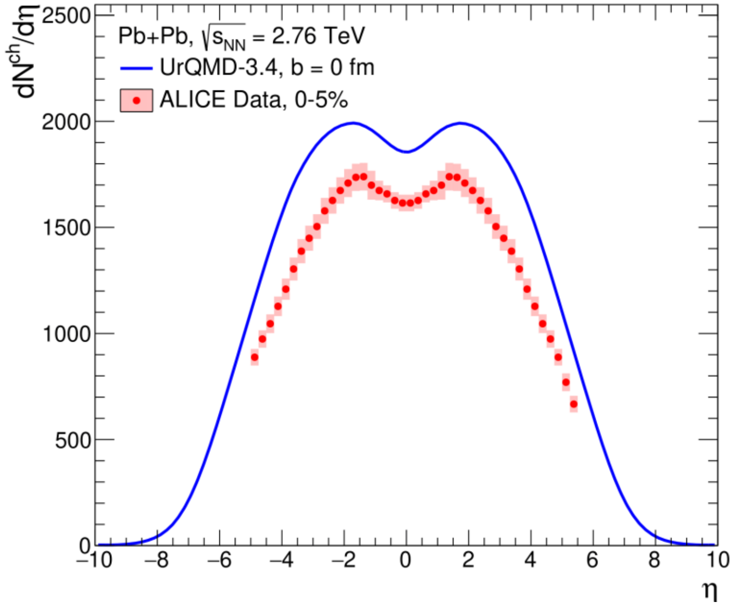

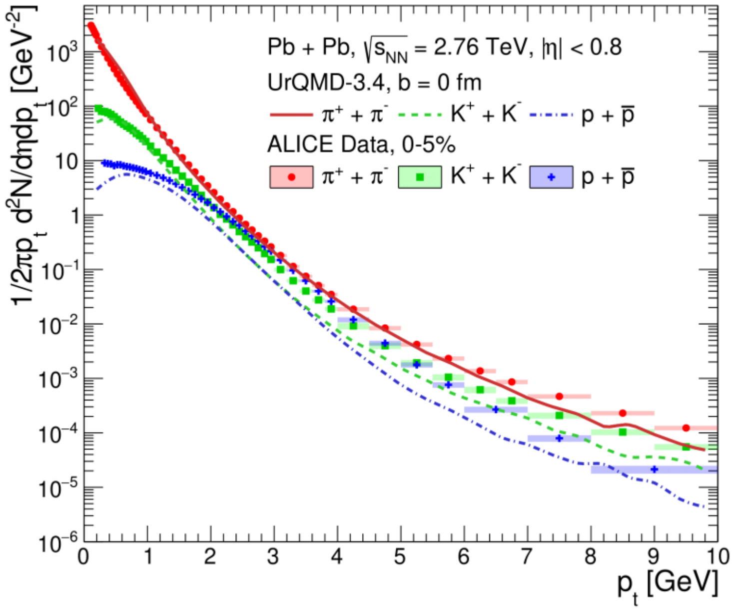

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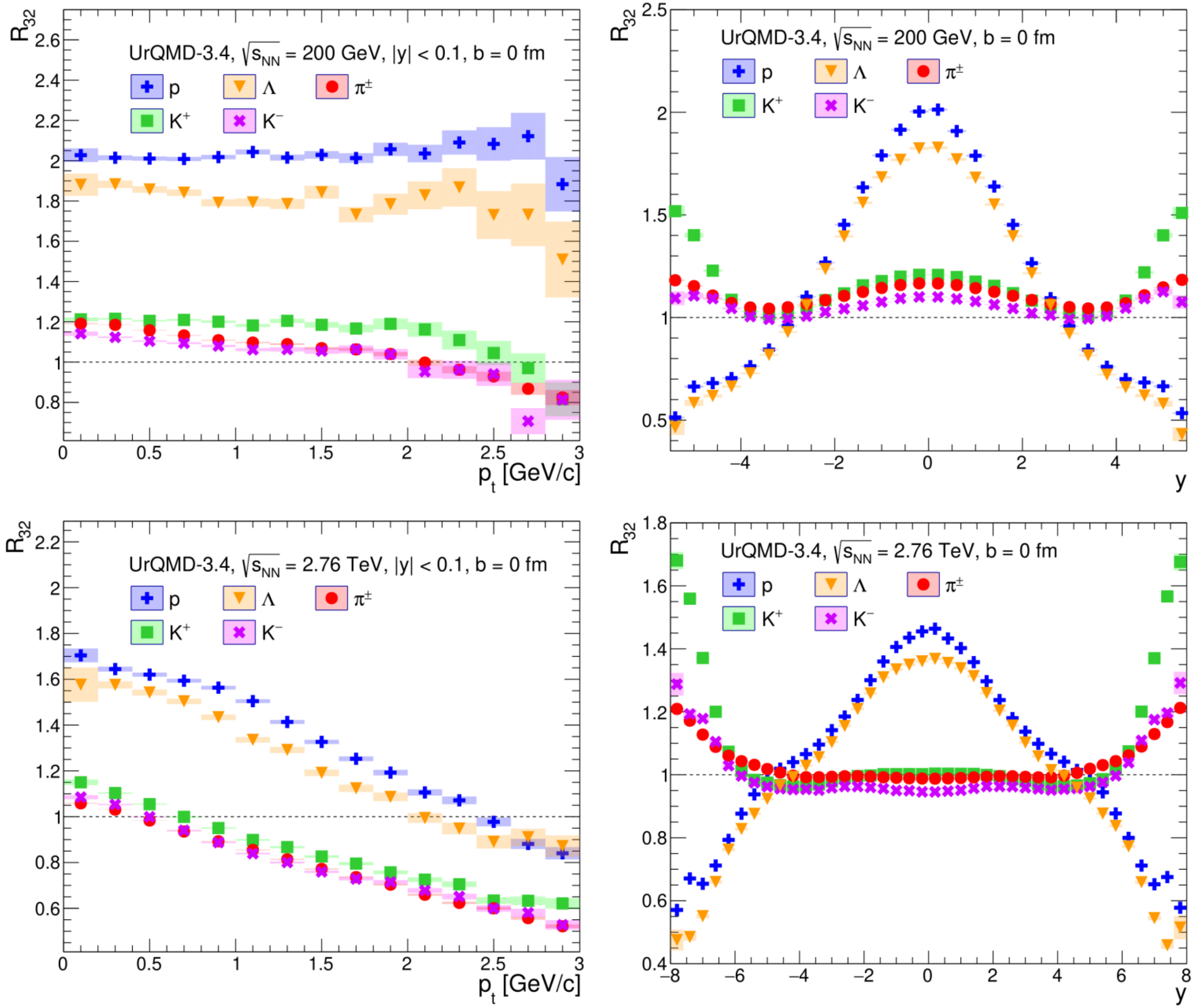
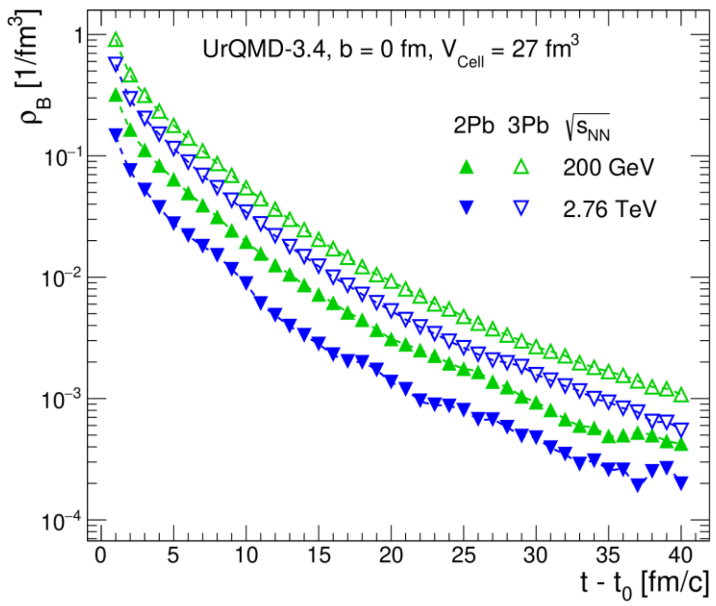
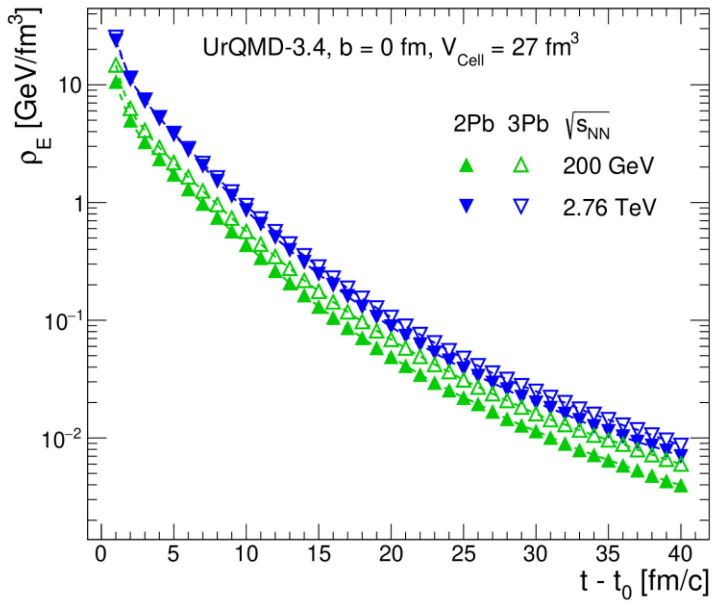
Results: $R_{32}(y)$ & $R_{32}(p_t)$



- Baryon yields are strongly enhanced in the midrapidity region
- p_t-spectra show enhancement of slow hadrons and deficit of fast ones
  1. Density trap
  2. Transverse momentum redistribution effect
- Different p_t behavior of 3-to-2 nuclei enhancement factor at RHIC and LHC energies
  1. $\approx const.$ at RHIC energy for particles with $p_t \leq 2$ GeV/c
  2. Decreasing function of p_t at LHC energy

Results: Central Cell Evolution





UrQMD

$$n_B = \frac{1}{V} \sum_{\vec{r}_k \in V} B_k$$

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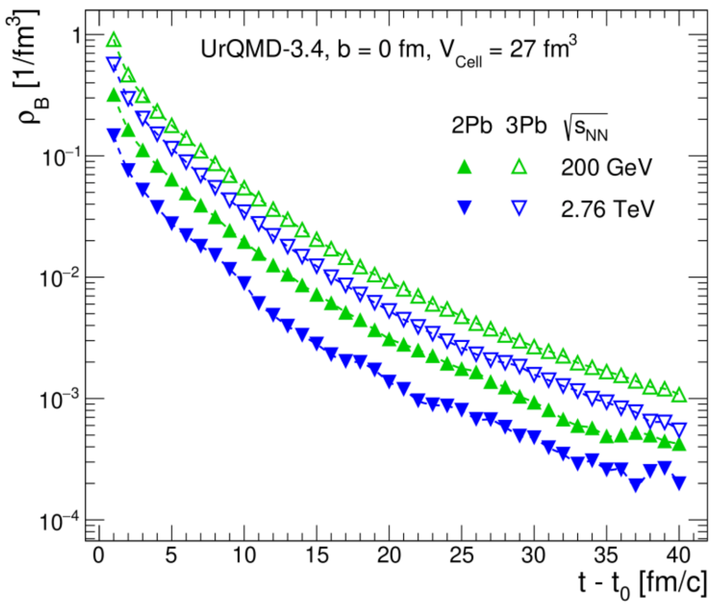

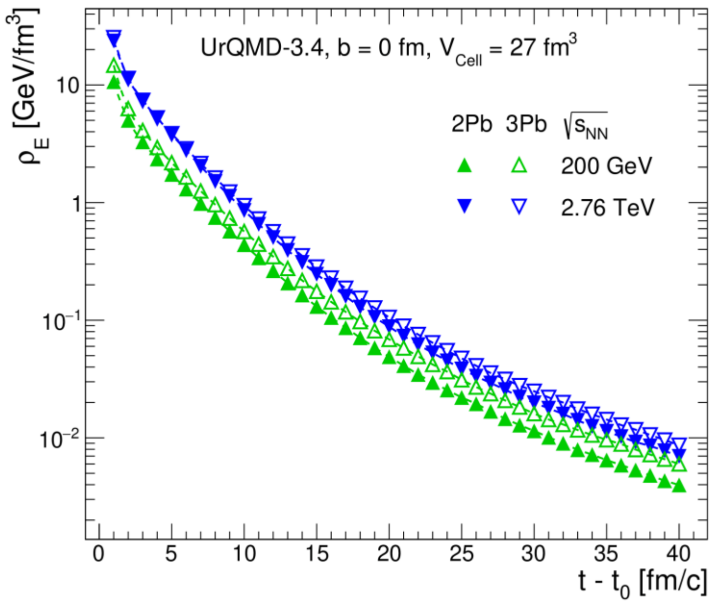

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Bag Model EoS

$$p = \frac{19}{36}\pi^2 T^4 + \frac{1}{6}\mu_B^2 T^2 + \frac{\mu_B^4}{108\pi^2} - B_{vac}$$

$$\varepsilon = \frac{19}{12}\pi^2 T^4 + \frac{1}{2}\mu_B^2 T^2 + \frac{\mu_B^4}{36\pi^2} + B_{vac}$$

$$n_B = \frac{\mu_B}{3}\left(T^2 + \frac{\mu_B^2}{9\pi^2}\right), B_{vac}^{1/4} = 206 \text{ MeV}$$

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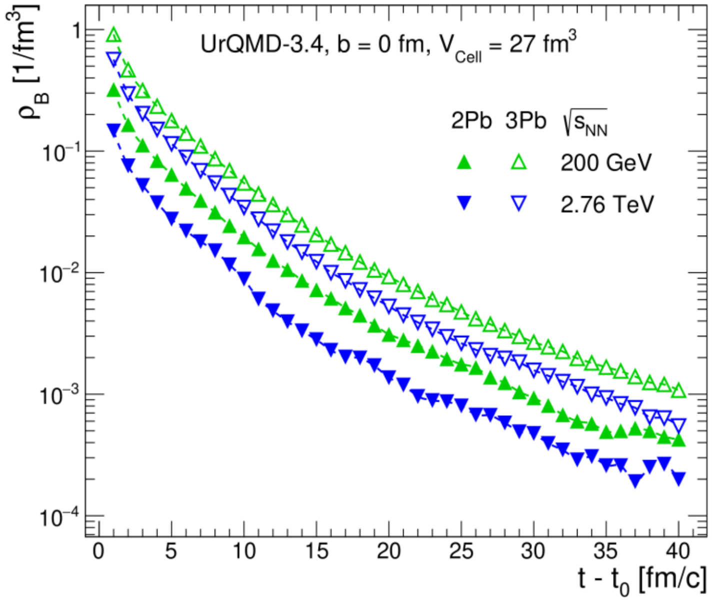

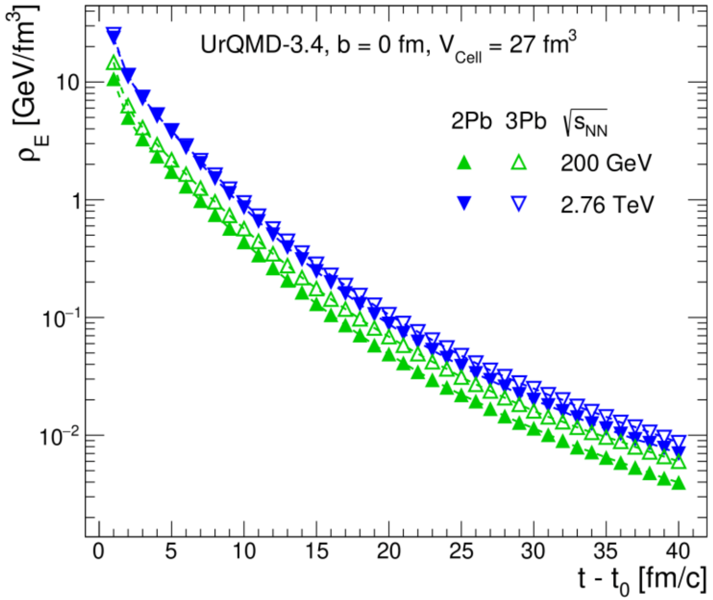

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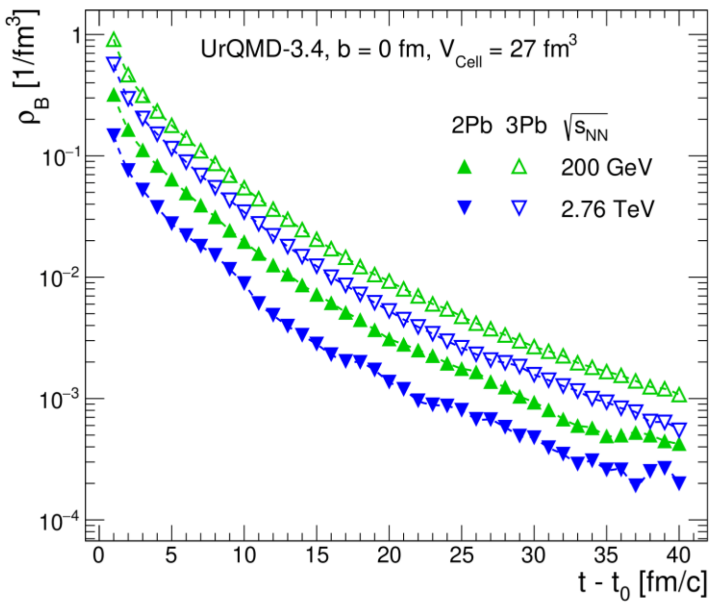

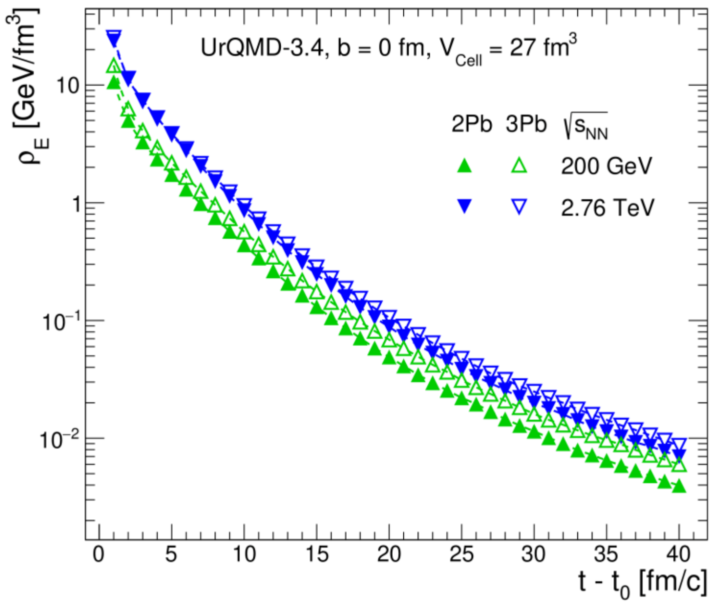

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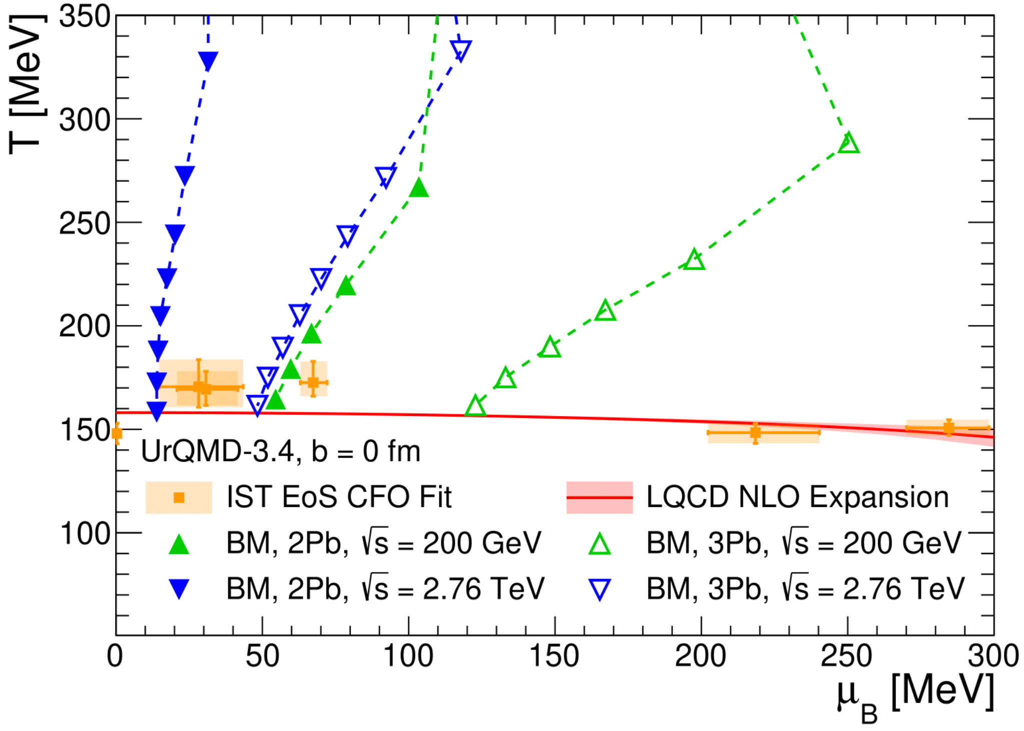
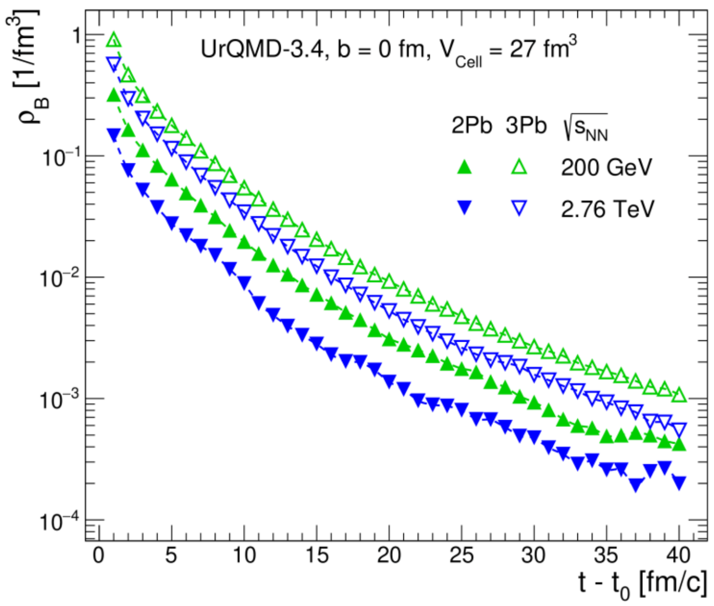
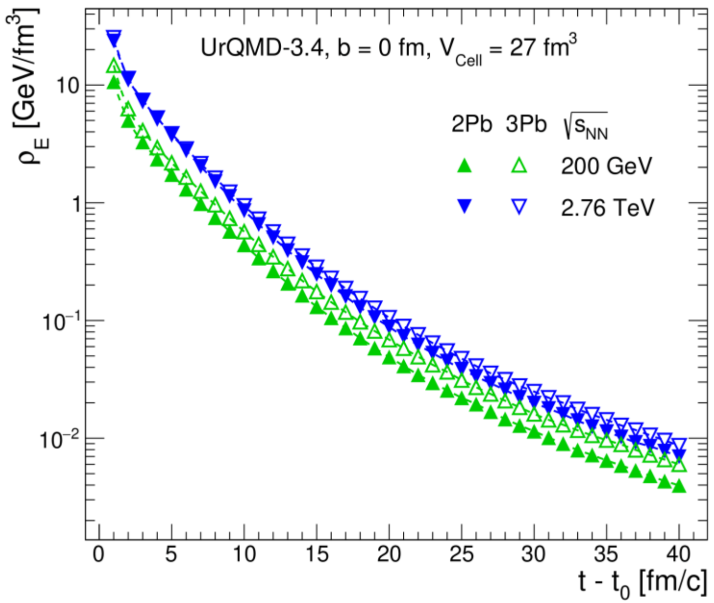
$$n_B = \frac{\mu_B}{3}\left(T^2 + \frac{\mu_B^2}{9\pi^2}\right), B_{vac}^{1/4} = 206 \text{ MeV}$$



Results: Central Cell Evolution





UrQMD

$$n_B = \frac{1}{V}\sum_{\vec{r}_k \in V} B_k$$

$$\varepsilon = \frac{1}{V}\sum_{\vec{r}_k \in V} E_k$$

Bag Model EoS

$$p = \frac{19}{36}\pi^2 T^4 + \frac{1}{6}\mu_B^2 T^2 + \frac{\mu_B^4}{108\pi^2} - B_{vac}$$

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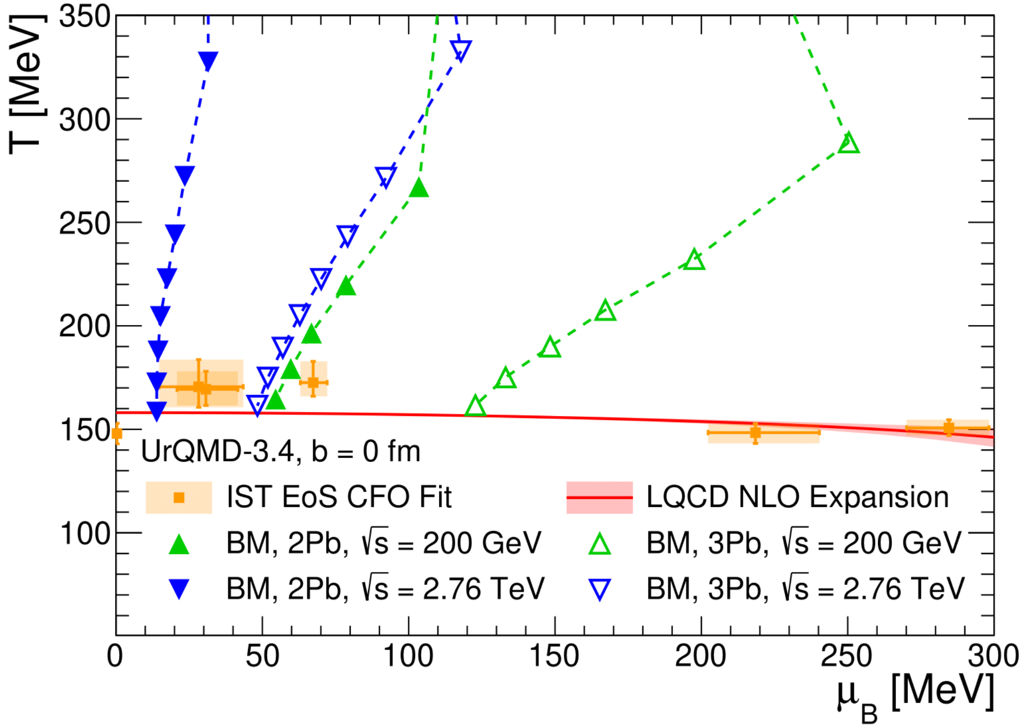
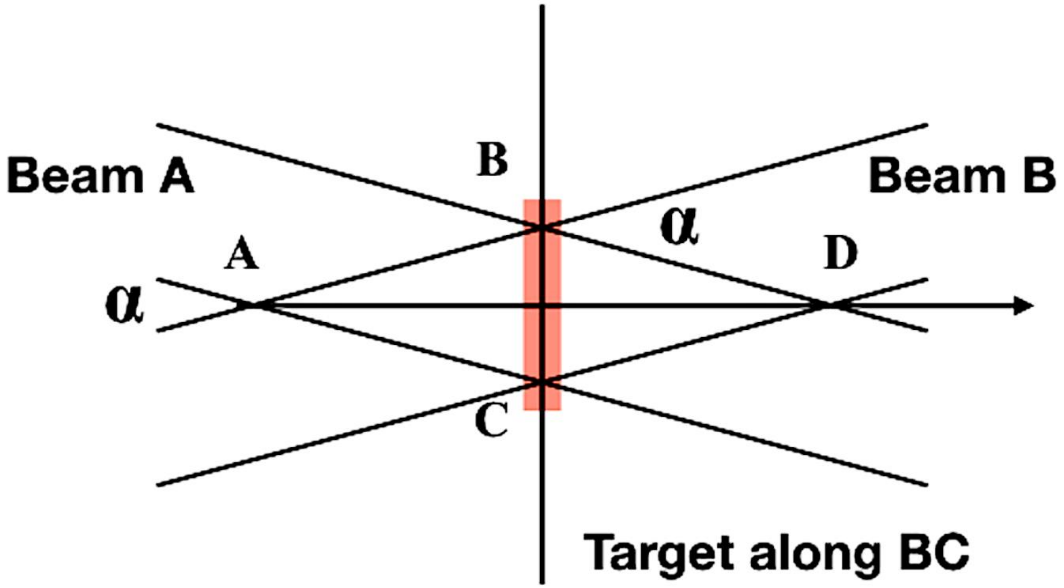
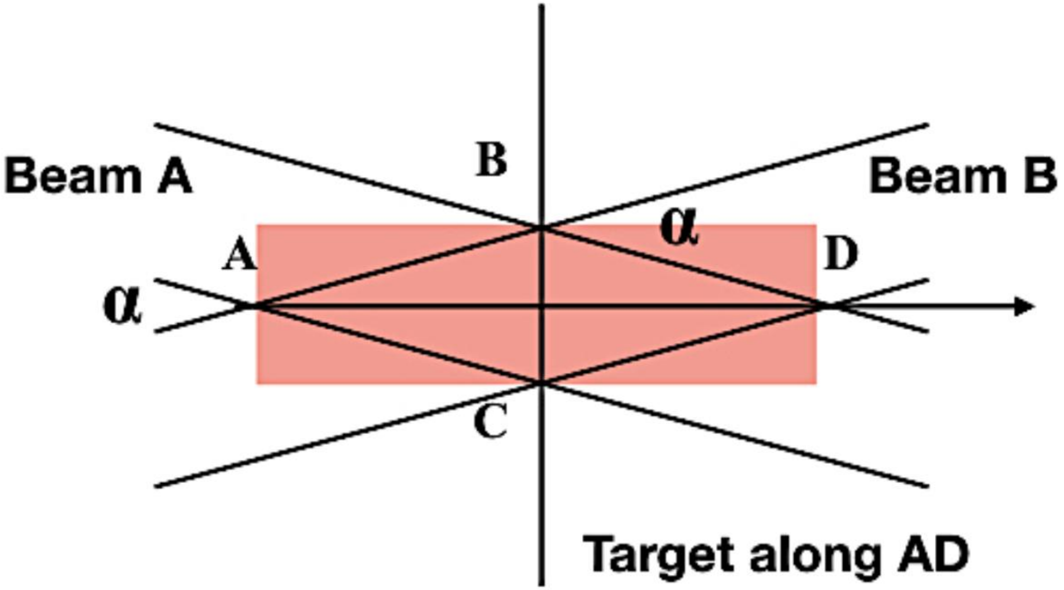


- Comparing to chemical freeze-out ⇒ accuracy of $\mu_B \sim 15$ MeV
- Central cell parameters at LHC are similar to A+A at RHIC, but initial n_B is 2 times higher
- Much higher μ_B can be reached in TNC!

TNC Rates

But what are the TNC rates?
Are the TNC the dreams of theoreticians?





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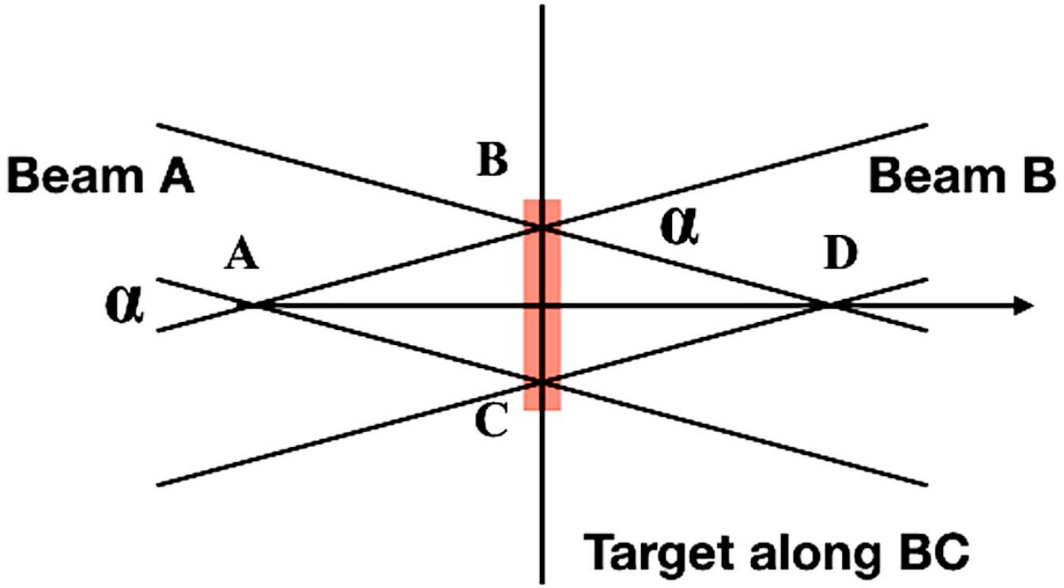
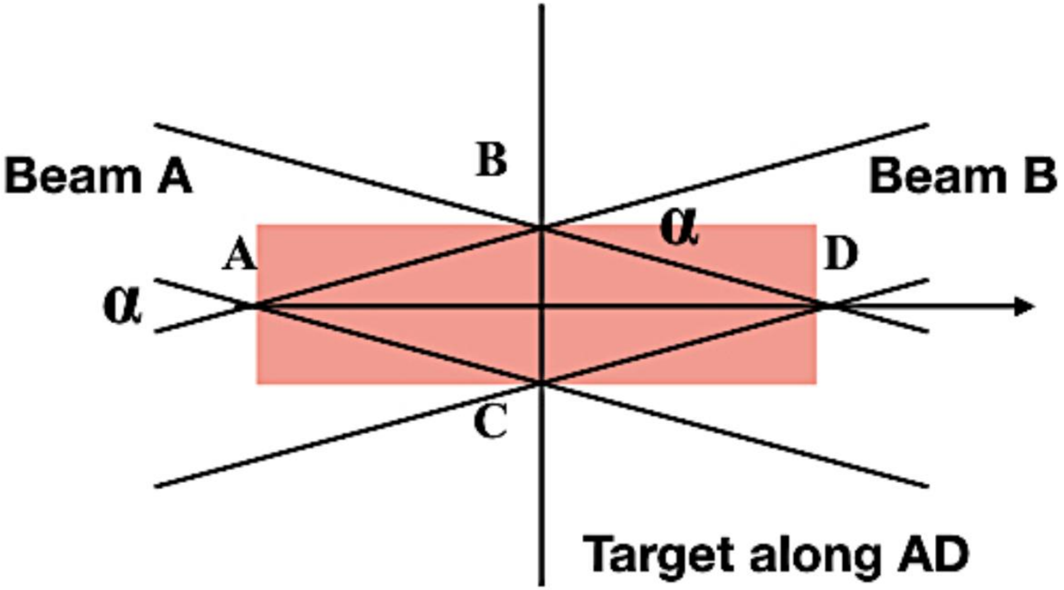
$$\frac{dN_{A+T+B}}{dt} = L\sigma_{A+B}\rho_T V_{A+T+B}^{int}\frac{V_T^{irrad}}{V^{beams}}$$





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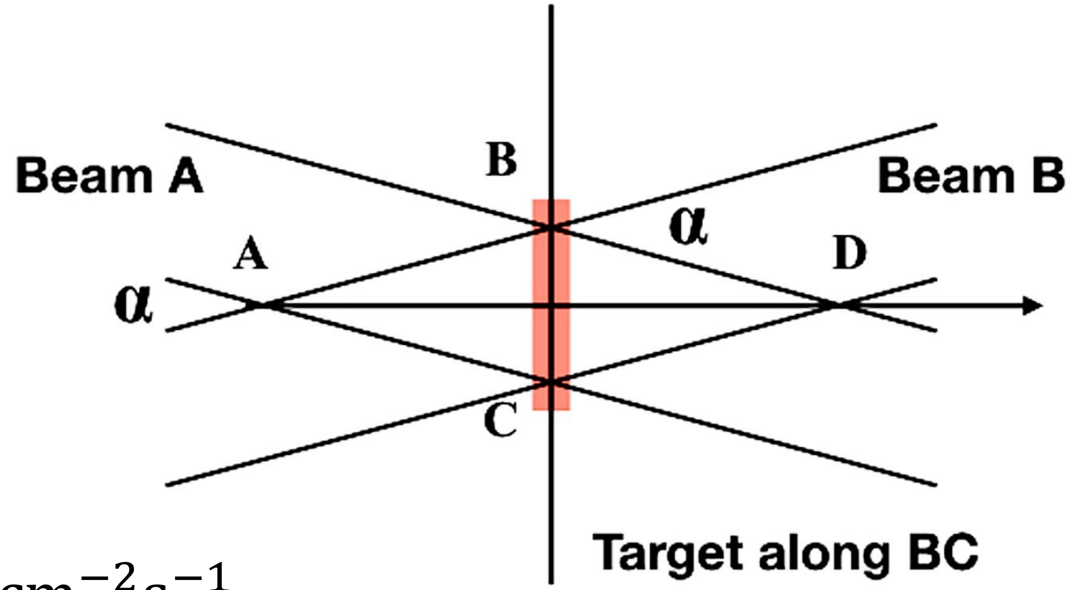
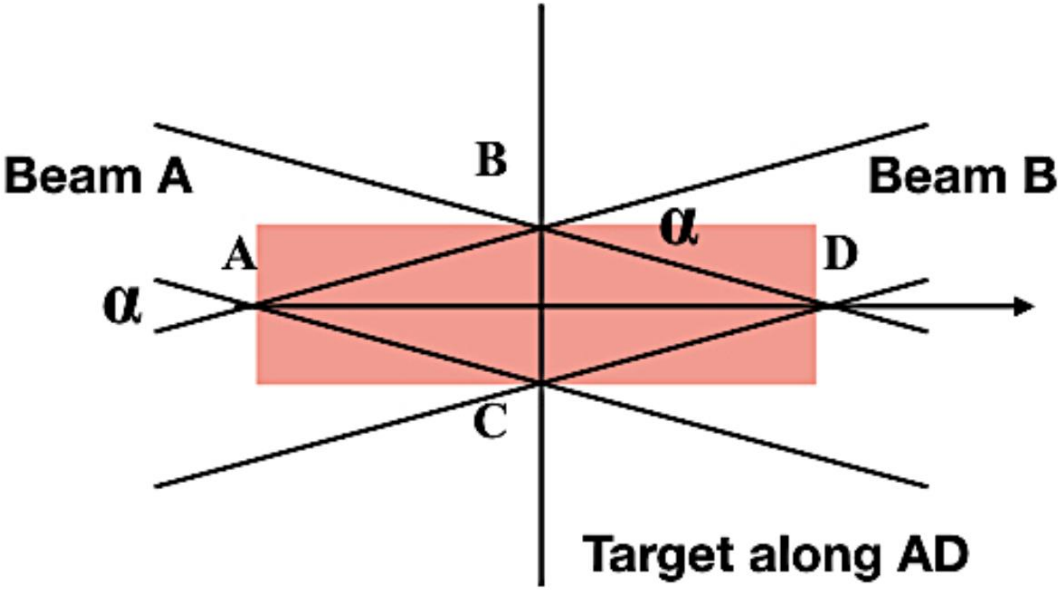


Assuming the Pb beams luminosity value $L = 10^{28}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

$$\frac{dN_{3Pb}}{dt} = \begin{cases} 2.4 \times 10^{-11}\mathrm{s}^{-1}, \text{for } 3.3\ \mu\mathrm{m} \text{ target} \\ 3.4 \times 10^{-7}\mathrm{s}^{-1}, \text{for large target} \end{cases}$$



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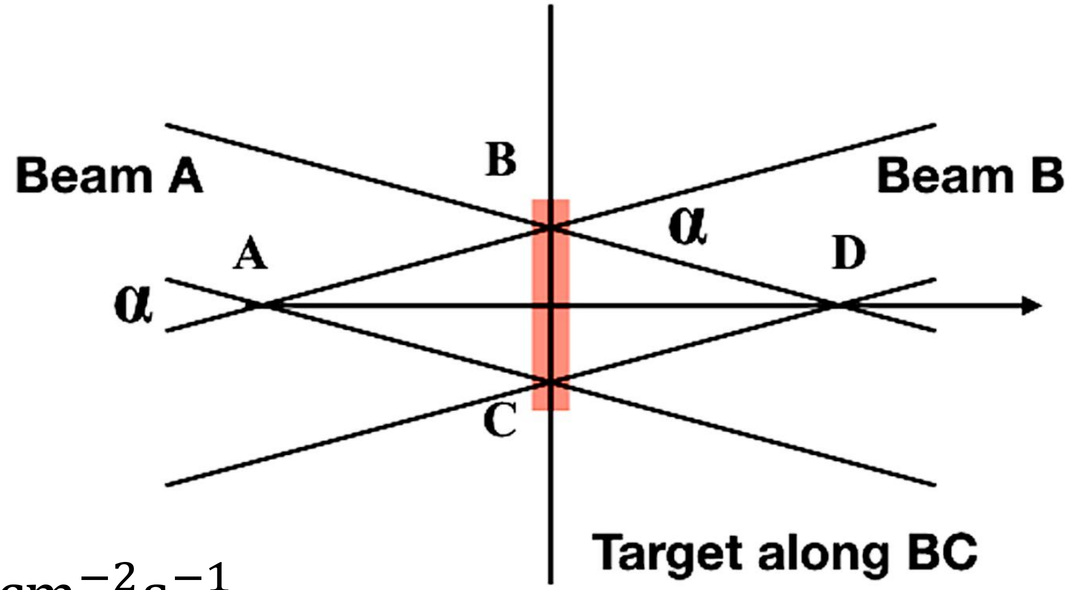
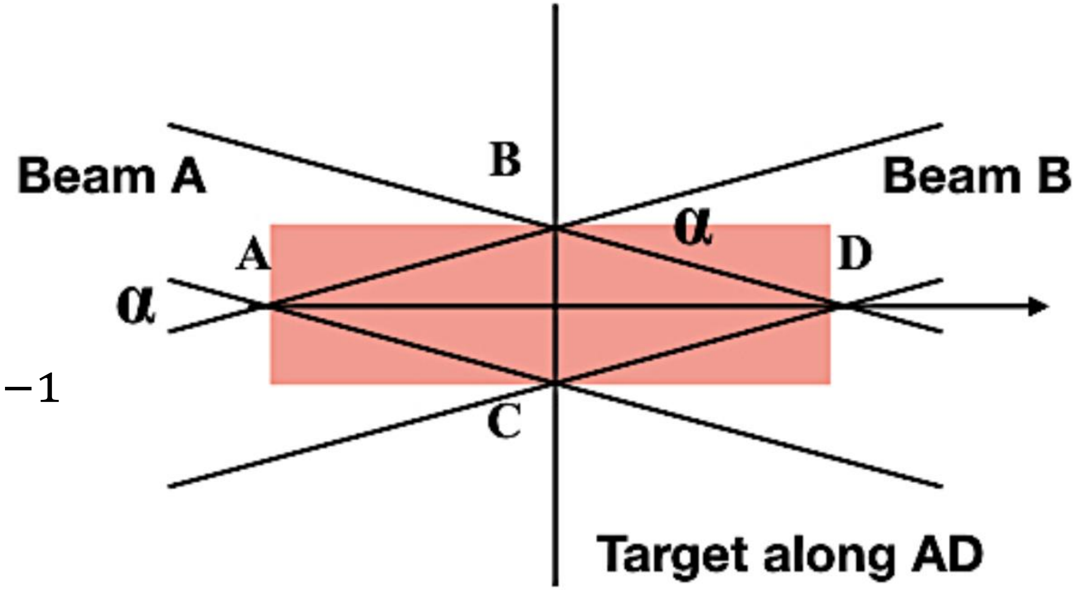
$$\frac{dE}{dt} \simeq 10^6 \mathrm{J} \cdot \mathrm{s}^{-1} \Rightarrow \text{explosion of 0.5 kg of TNT s}^{-1}$$





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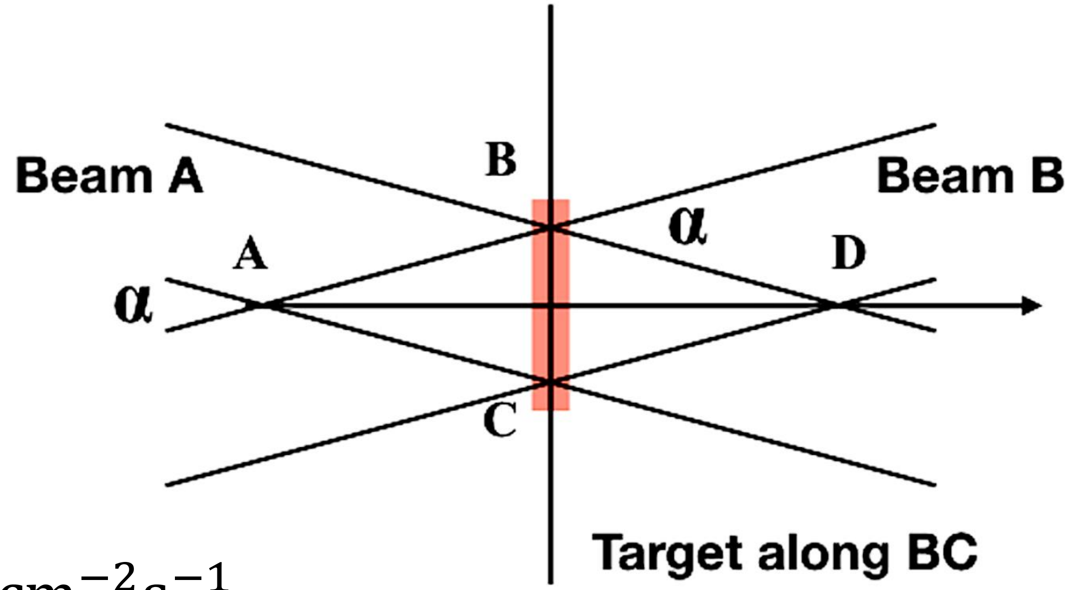

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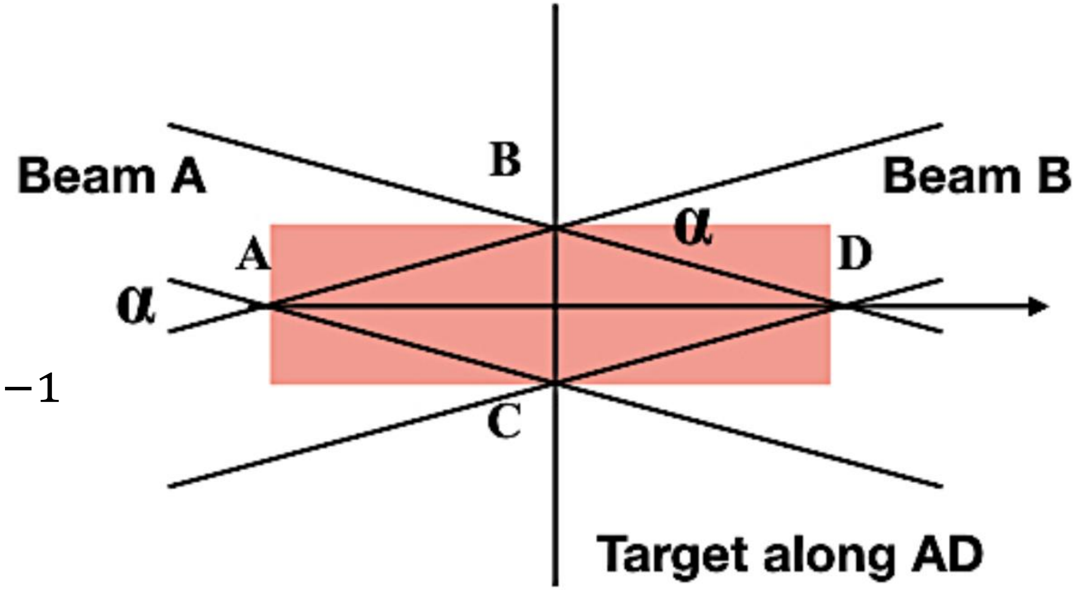
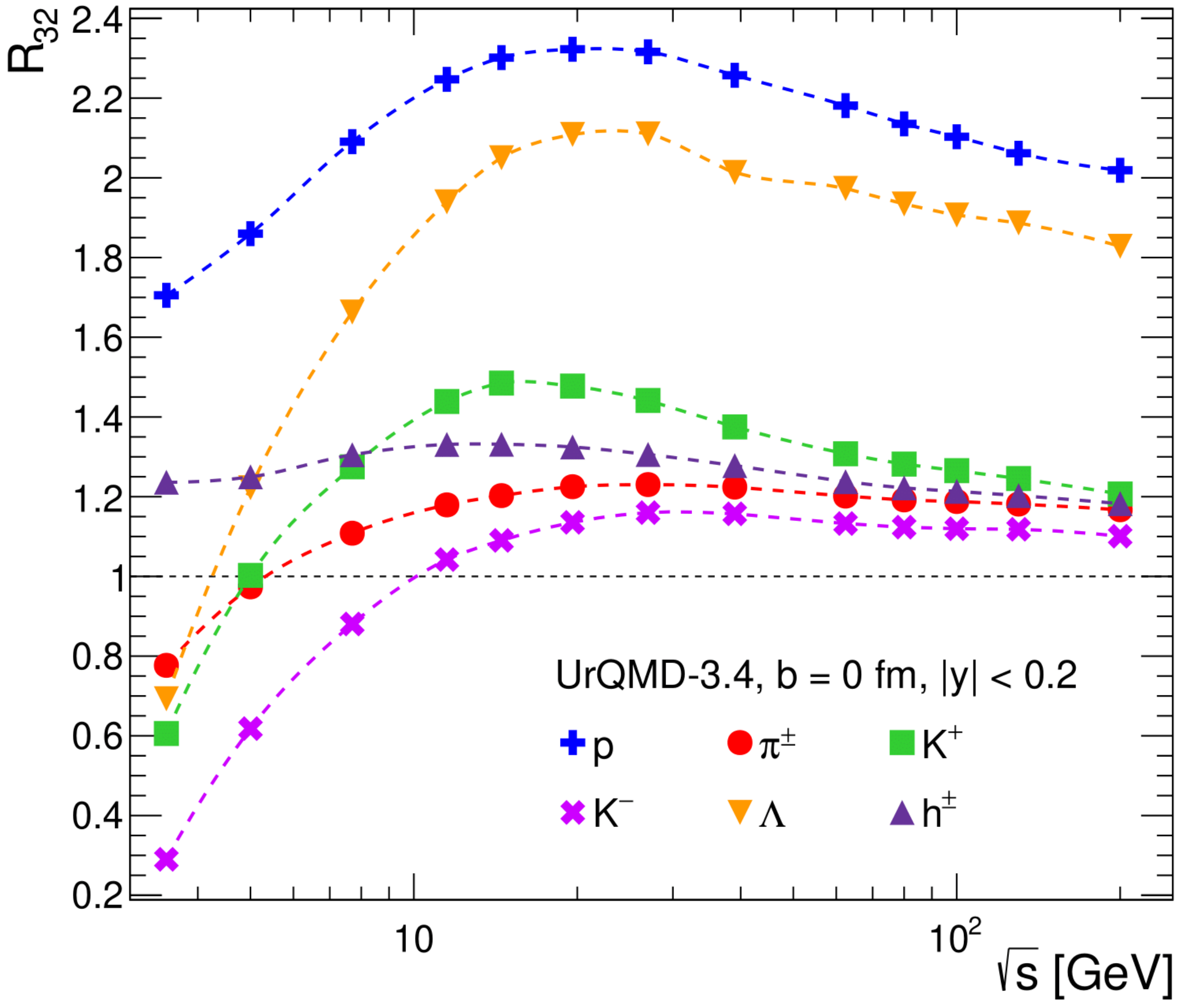


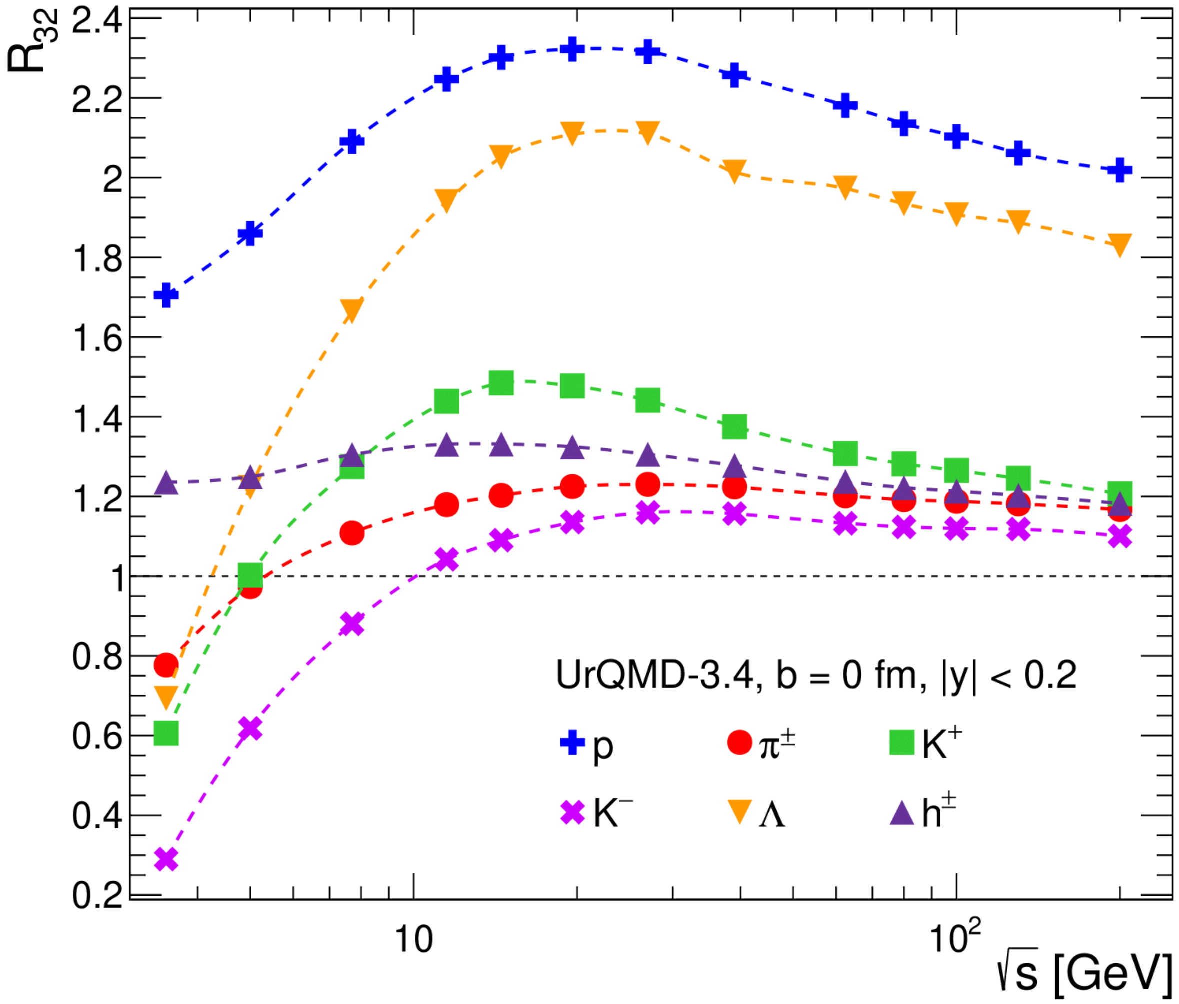
New ideas are needed!

Summary & Conclusions



Summary & Conclusions

☺ With TNC we can probe very high densities of baryonic and electric charges



Summary & Conclusions

- With TNC we can probe very high densities of baryonic and electric charges
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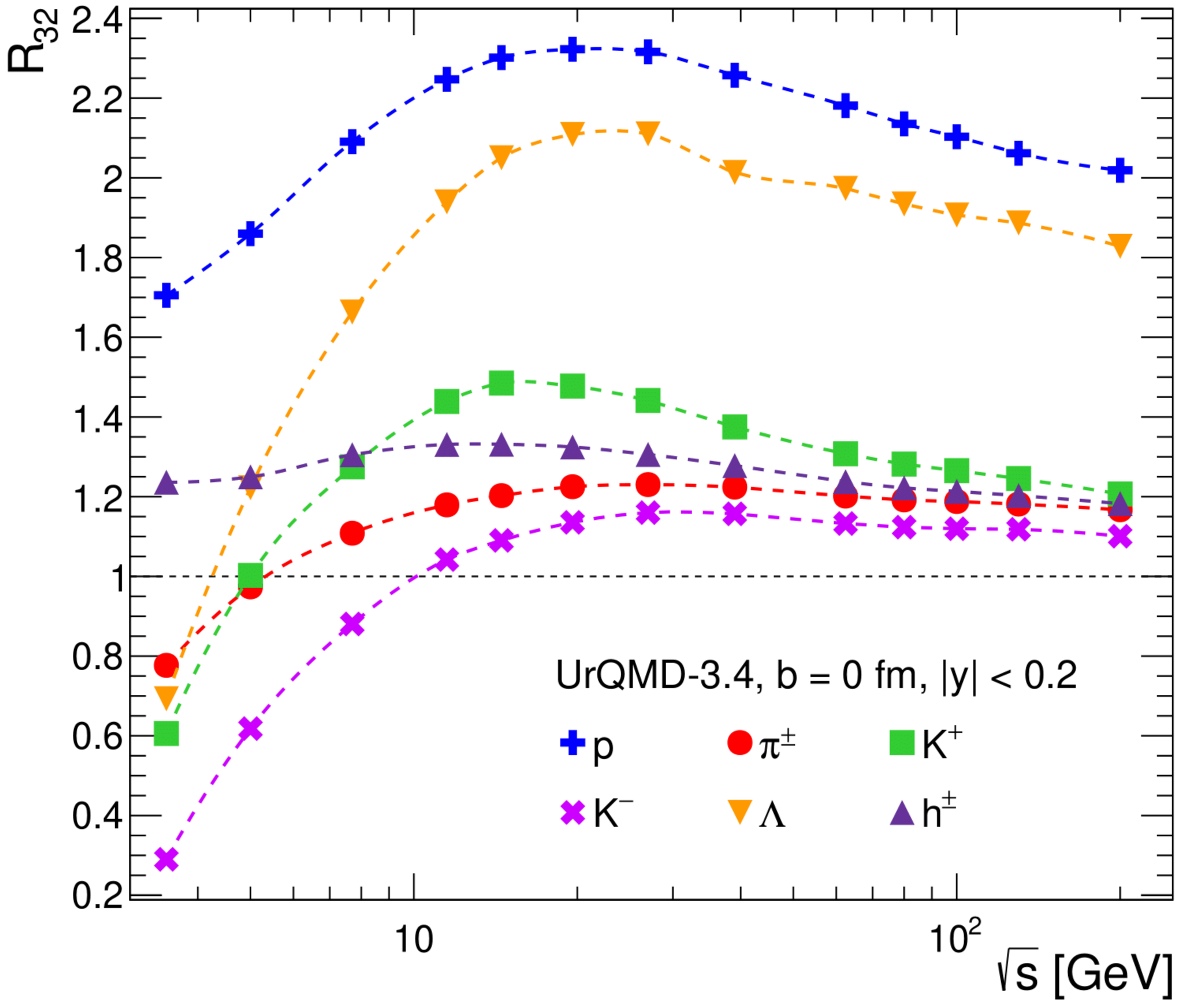

Summary & Conclusions

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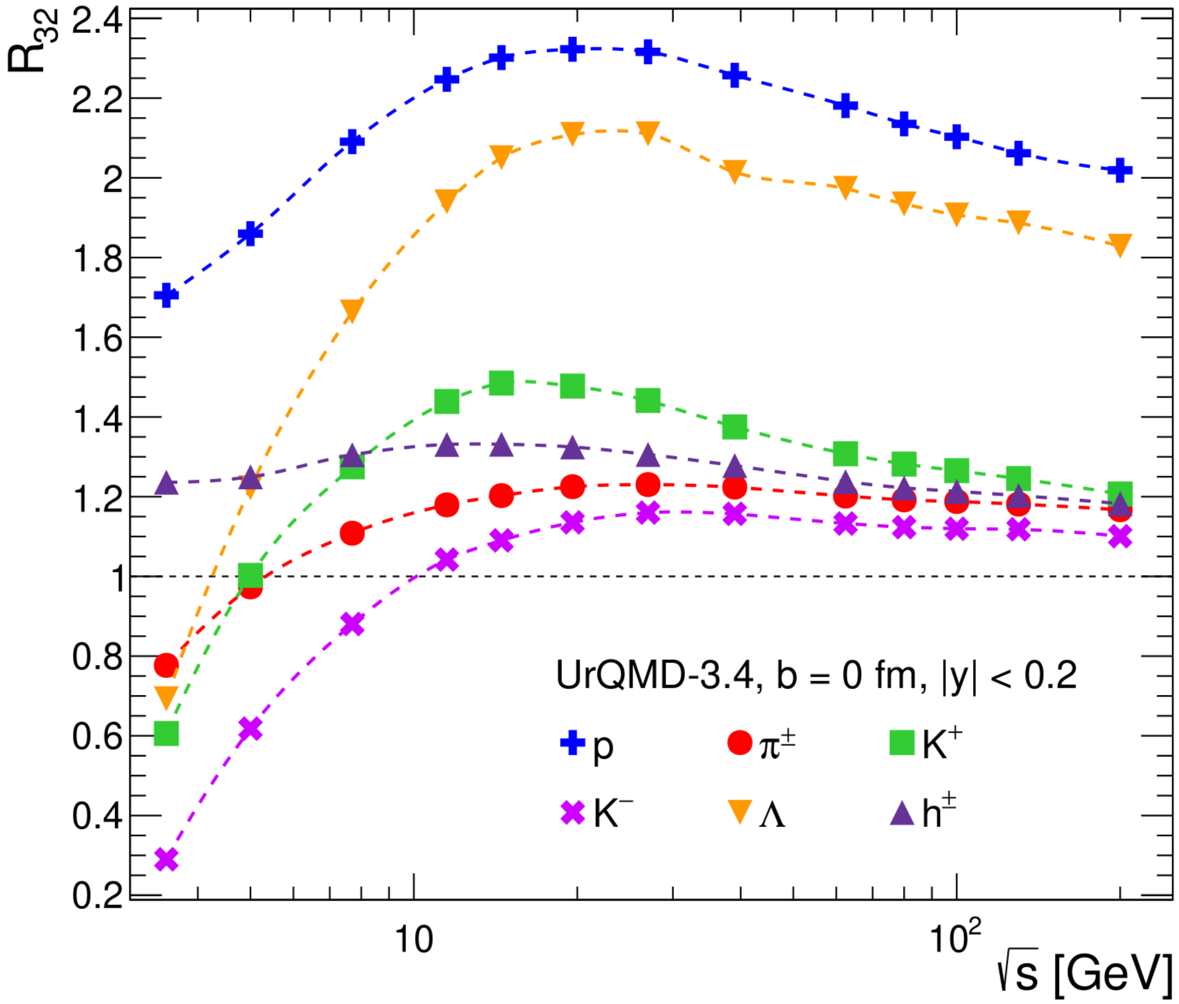

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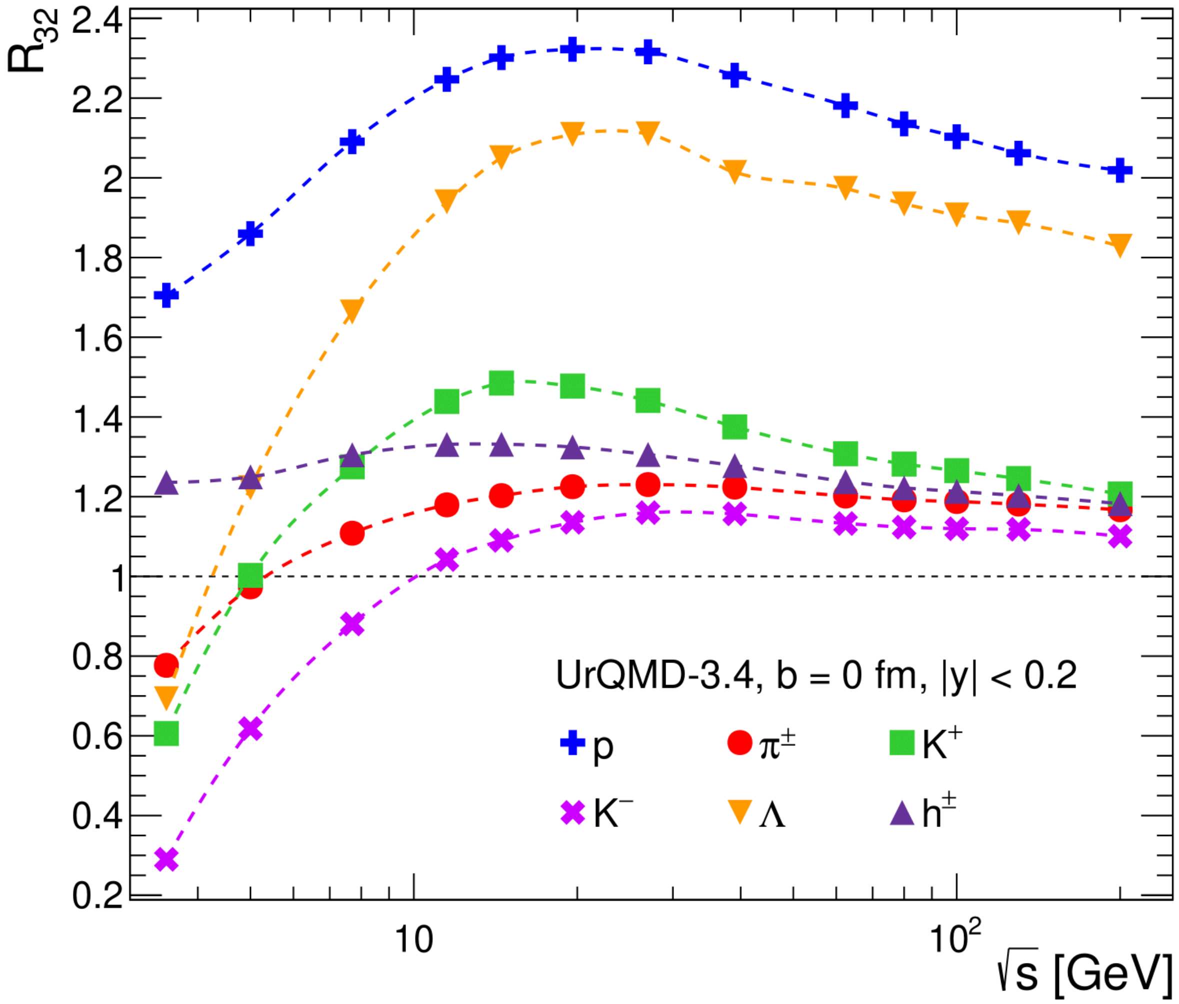
Very interesting Physics of TNC Awaits for us!



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