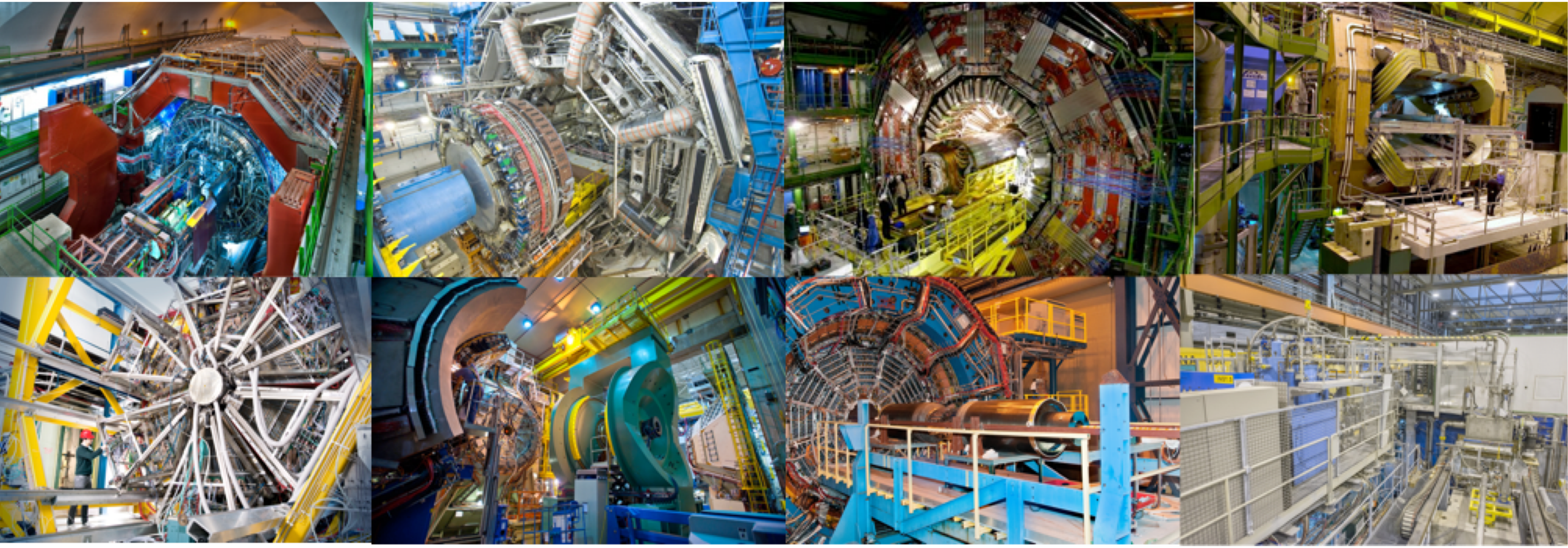
High density QCD with heavy-ion beams



Alexander Kalweit, *CERN*

Overview

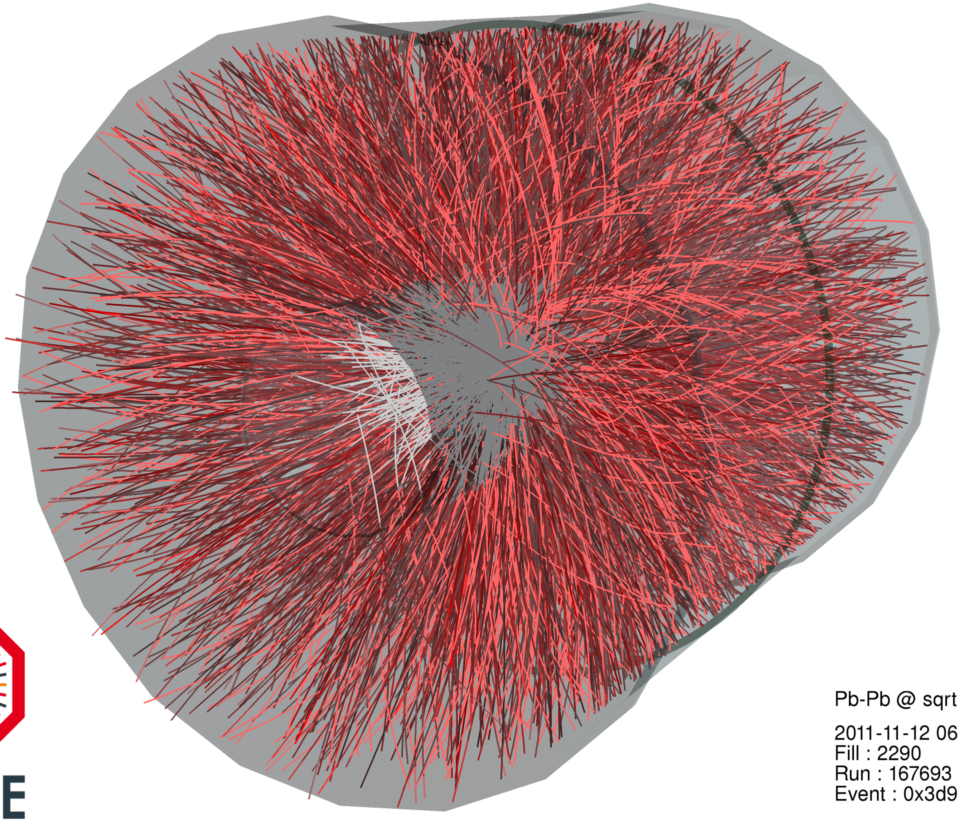
- Four lectures (one hour each):
  - Tuesday, 10:30h-11:30h → AK
  - Wednesday, 10:30h-11:30h → AK
  - Thursday, 09:00h-10:00h → Marco van Leeuwen
  - Friday, 14:15h-15:15h → Marco van Leeuwen

- Specialized discussion sessions with **heavy-ion experts**

- Feel free to contact me for any questions regarding the lecture: Alexander.Philipp.Kalweit@cern.ch

- Many slides, figures, and input taken from:
  Jan Fiete Grosse-Oetringhaus, Constantin Loizides,
  Federico Antinori, Roman Lietava, Francesca Bellini

ALICE
A JOURNEY OF DISCOVERY



Pb-Pb @ sqrt(s) = 2.76 ATeV
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Outline and discussion leaders

→ Heavy-ion physics is a huge field with many observables and experiments: impossible to cover all topics! I will present a personally biased selection of topics.

- Introduction
- The QCD phase transition
- QGP thermodynamics
  - Particle chemistry
  - QCD critical point and onset of de-confinement
  - (anti-)(hyper-)nuclei
  - Radial and elliptic flow
- Hard scatterings Nuclear modification factor
  - Jets
- Heavy flavor in heavy-ions
  - Open charm and beauty
  - Quarkonia
- Di-leptons
- Special focus: High density QCD with **proton** beams (phenomena in small systems)

Soft probes

Eliane
Epple

Gian-Michele
Innocenti

Hard probes

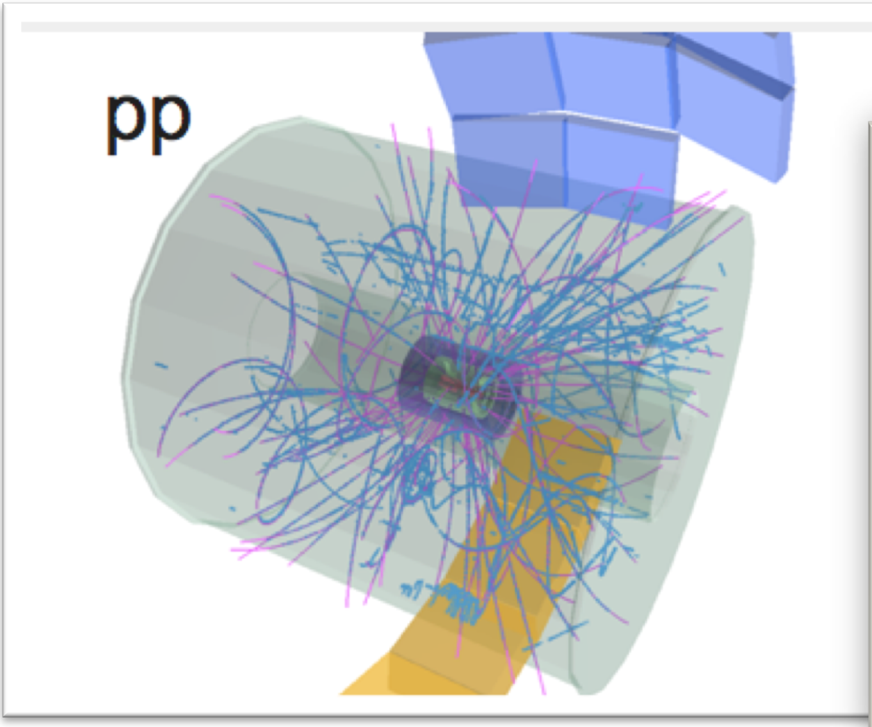
Friederike
Bock

Maximiliano
Puccio

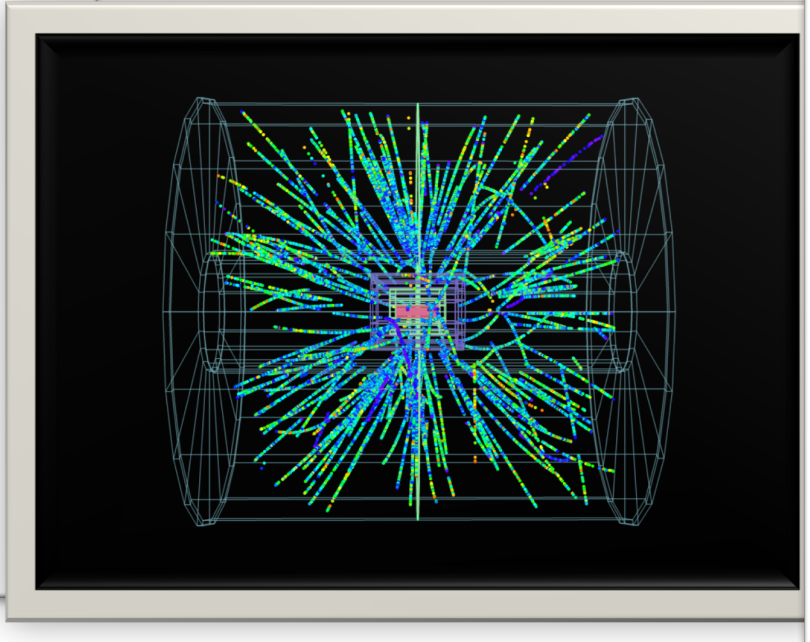
Short summary of lecture 1

pp / p-Pb / Pb-Pb collisions

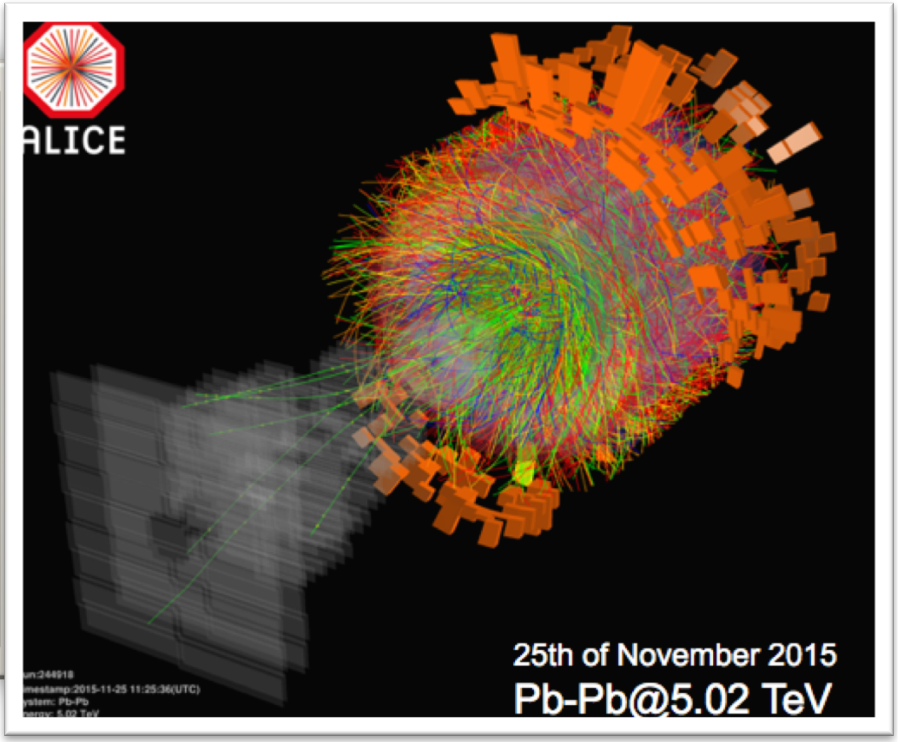
- The LHC can not only collide protons on protons, but also heavier ions.
- Approximately one month of running time is dedicated to heavy-ions each year.



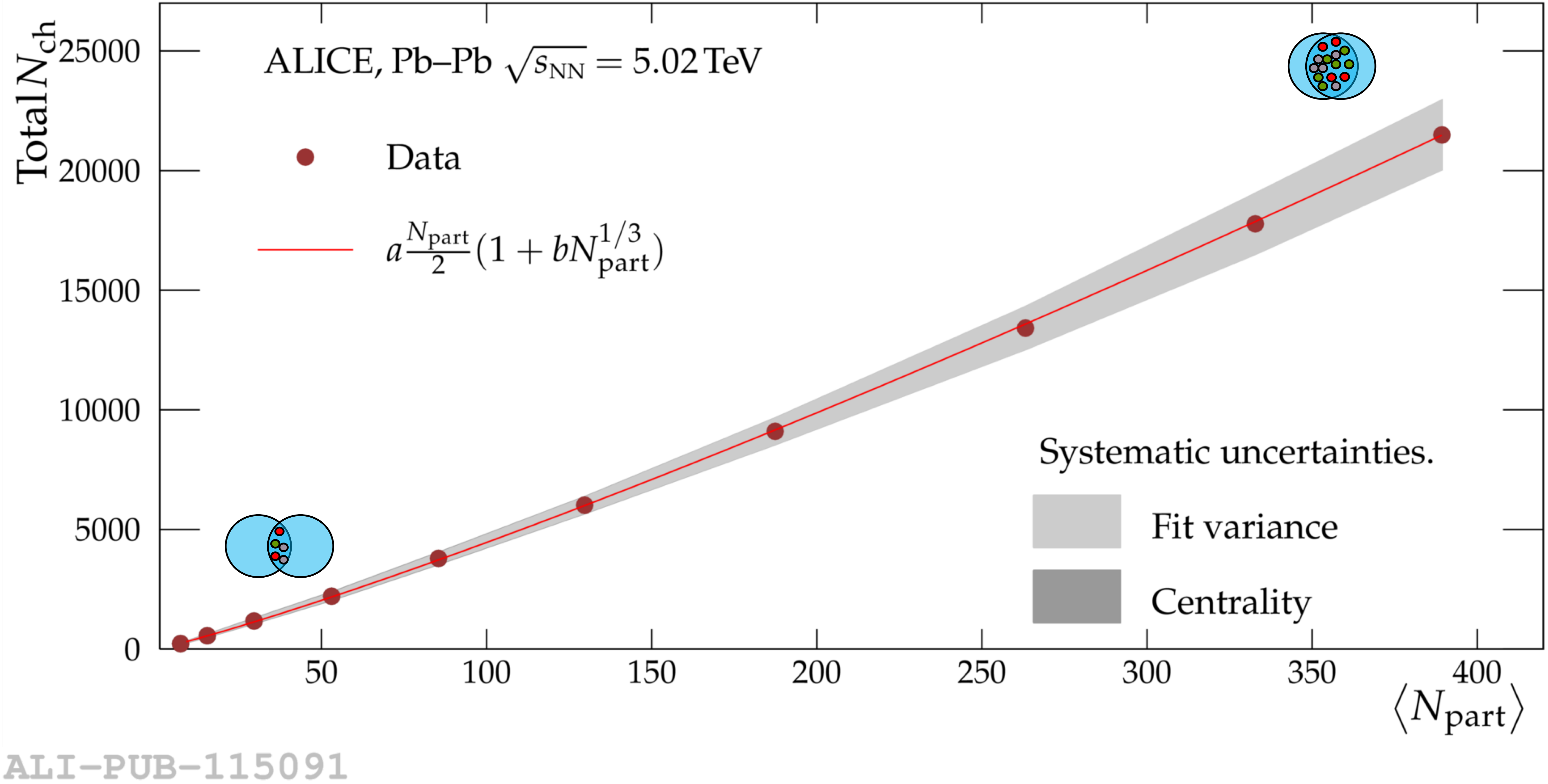
p-Pb



Pb-Pb



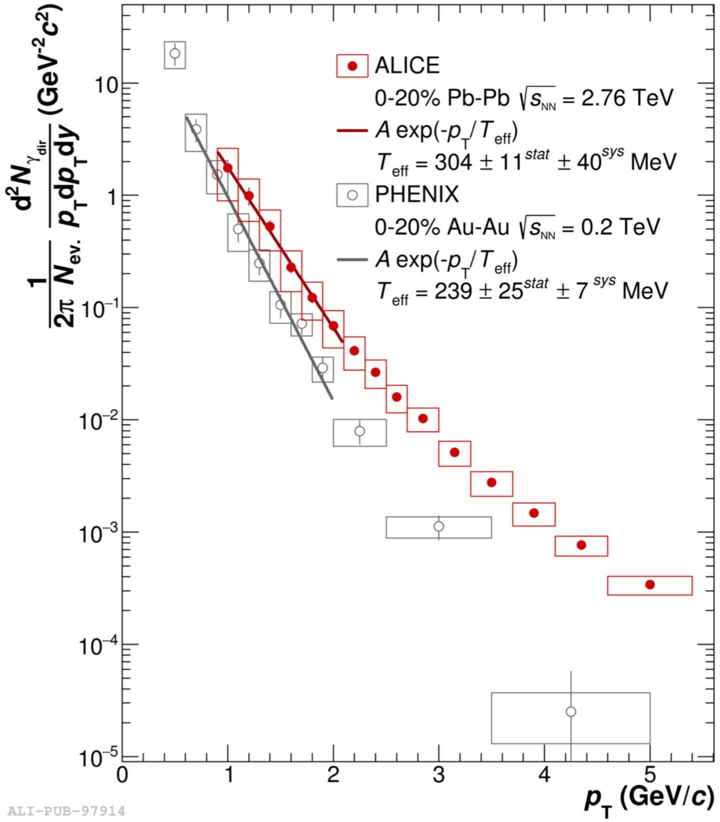
Number of charged particles produced

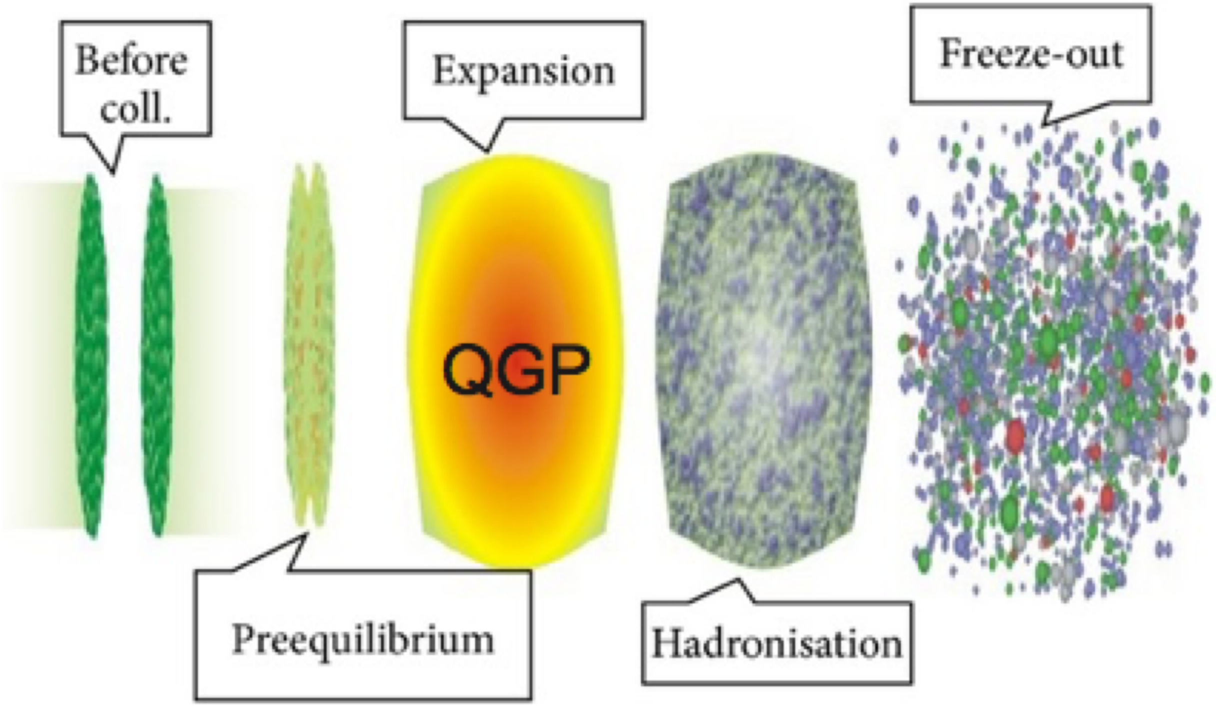


[Phys.Lett. B772 (2017) 567-577]

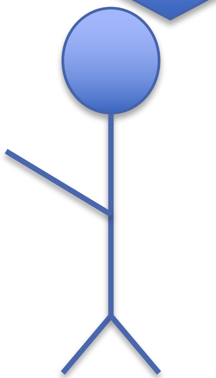
Can we reach such temperatures in the experiment?

→ We would need initial temperatures of more than 200 MeV.
→ Let’s look first at a schematic evolution of a heavy-ion collision:





We reach more than 300 MeV temperature in the initial stages of the collision!



[arXiv:1207.7028]

A short introduction to statistical thermodynamics (3)

- A small example: barometric formula (density of the atmosphere at a fixed temperature as a function of the altitude *h*).

- Probability to find a particle on a given energy level *j*:

$$P_j = \frac{\exp\left(-\frac{E_j}{k_B T}\right)}{Z}$$

Boltzmann factor

Partition function *Z*
(*Zustandssumme = “sum over states”*)

- Energy on a given level is simply the potential energy: $E_{pot} = mgh$. This implies for the density n (pressure p):

$$\frac{p(h_1)}{p(h_0)} = \frac{n(h_1)}{n(h_0)} = \frac{N \cdot P(h_1)}{N \cdot P(h_0)} = \exp\left(-\frac{\Delta E_{pot}}{k_B T}\right) = \exp\left(-\frac{mg}{RT}\Delta h\right)$$

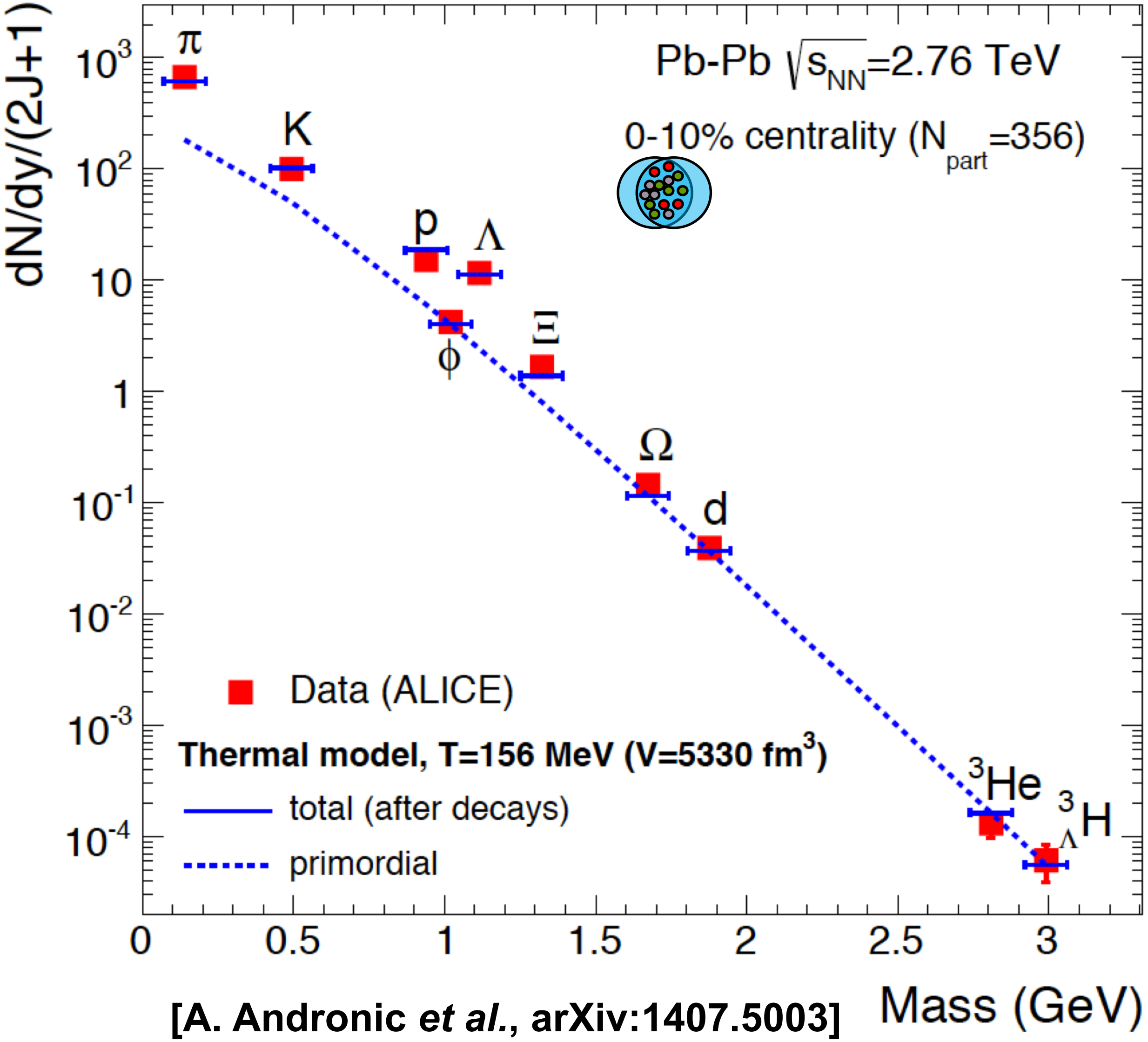
Chemical equilibrium at the LHC (1)

Production yields of light flavour hadrons from a chemically equilibrated fireball can be calculated by statistical-thermal models (roughly $dN/dy \sim \exp\{-m/T_{ch}\}$, in detail derived from partition function)

→ In Pb-Pb collisions, particle yields of light flavor hadrons are described over 7 orders of magnitude with a **common** chemical freeze-out temperature of **$T_{ch} \approx 156$ MeV**.

→ This includes **strange hadrons** which are rarer than u,d quarks. Approx. every fourth to fifth quark (every tenth) is a strange quark in Pb-Pb collisions (in pp collisions).

→ Light (anti-)nuclei are also well described despite their low binding energy ($E_b << T_{ch}$).

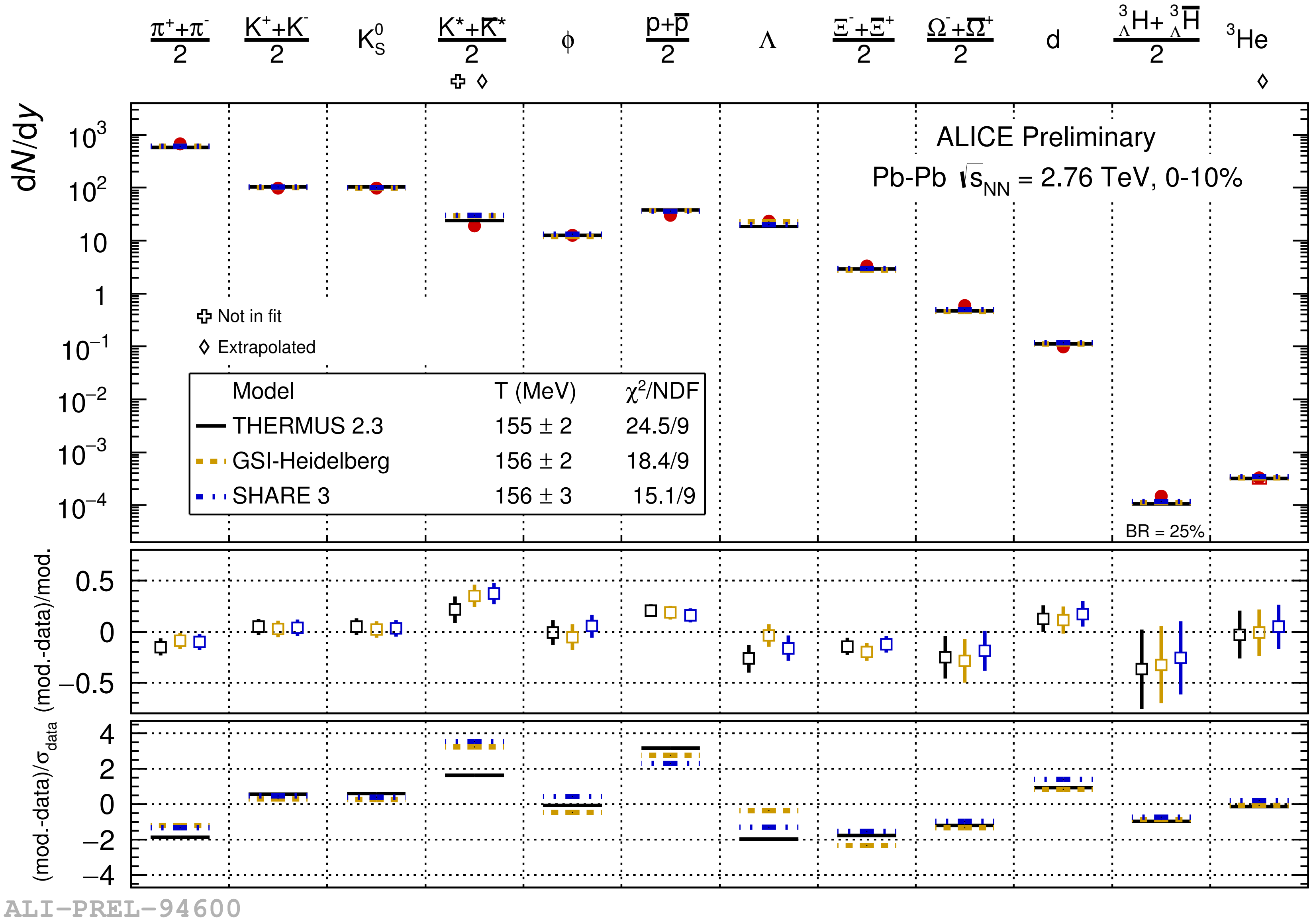


[A. Andronic *et al.*, arXiv:1407.5003]

QGP thermodynamics and soft probes

Particle chemistry
(continued)

Chemical equilibrium at the LHC (2)



Model	T (MeV)	χ^2/NDF
THERMUS 2.3	155 ± 2	24.5/9
GSI-Heidelberg	156 ± 2	18.4/9
SHARE 3	156 ± 3	15.1/9

Particle yields of light flavor hadrons are described over 7 orders of magnitude within 20% (except K*0) with a common chemical freeze-out temperature of Tch ≈ 156 MeV (prediction from RHIC extrapolation was ≈ 164 MeV).

Hadrons are produced in apparent chemical equilibrium in Pb-Pb collisions at LHC energies.

Largest deviations observed for protons (incomplete hadron spectrum, baryon annihilation in hadronic phase,..?) and for K*0.

Three different versions of thermal model implementations give similar results.

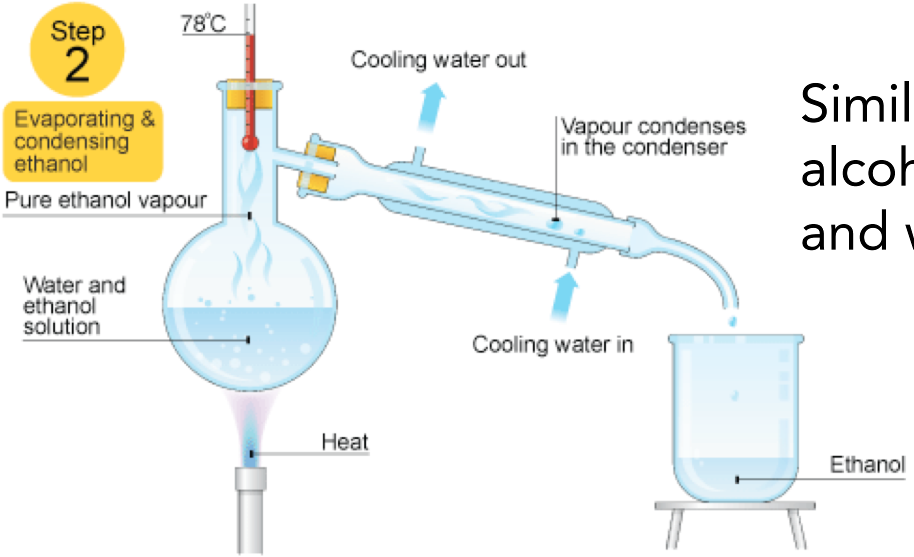
[Wheaton et al, Comput.Phys.Commun, 18084]
[Petran et al, arXiv:1310.5108]
[Andronic et al, PLB 673 142]

Sequential freeze-out?

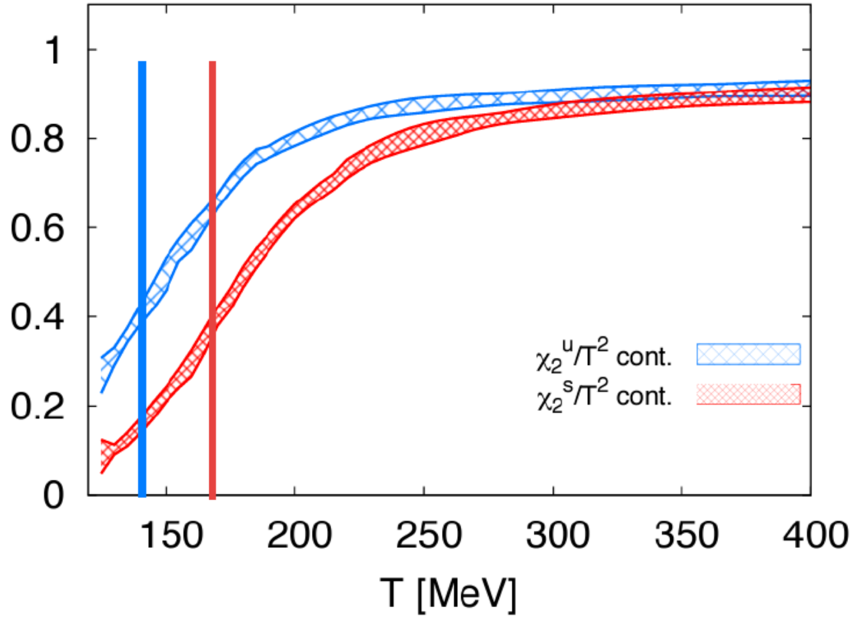
- Are the deviations observed in the thermal model fit for p and Ξ due to physics?

- Two main ideas on the market:

(1.) Different chemical freeze-out temperatures for *s* w.r.t. to *u*,*d* quarks.
→ motivated by LQCD



Similar to heating a mixture of alcohol (boiling point 78,32 °C) and water (boiling point 100 °C).



C. Ratti et al., PRD 85, 014004 (2012)

(2.) Inelastic collisions in the hadronic phase.

→ Was this previously overlooked, because the difference is "only" about 10 MeV?
Interesting research topic for the next years.

Chemical equilibrium vs collision energy (1)

- Hadron yields from SIS up to RHIC and LHC can be described in a hadro-chemical model applying thermal fits.

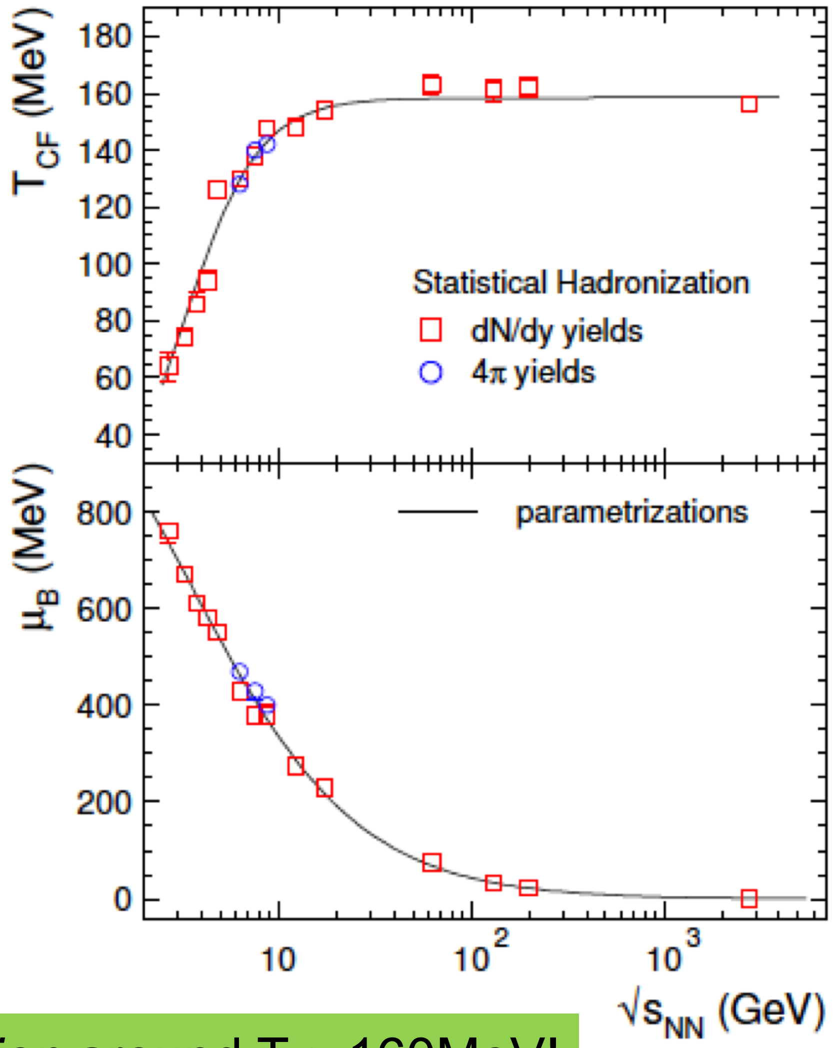
- Effective parameterization of (T, μ_B) as a function of collision energy:

$$T[\mathrm{MeV}] = T_{lim}\left(1 - \frac{1}{0.7 + (\exp(\sqrt{s_{NN}}(\mathrm{GeV})) - 2.9)/1.5}\right)$$

$$\mu_b[\mathrm{MeV}] = \frac{a}{1 + b\sqrt{s_{NN}}(\mathrm{GeV})},$$

- Particle ratios can be calculated (or predicted) at any collision energy….

[A. Andronic et al **Nature 561 (2018) no.7723, 321-330**]



→ One observes a *limiting temperature of hadron production* around T ≈ 160MeV!

Chemical equilibrium vs collision energy (2)

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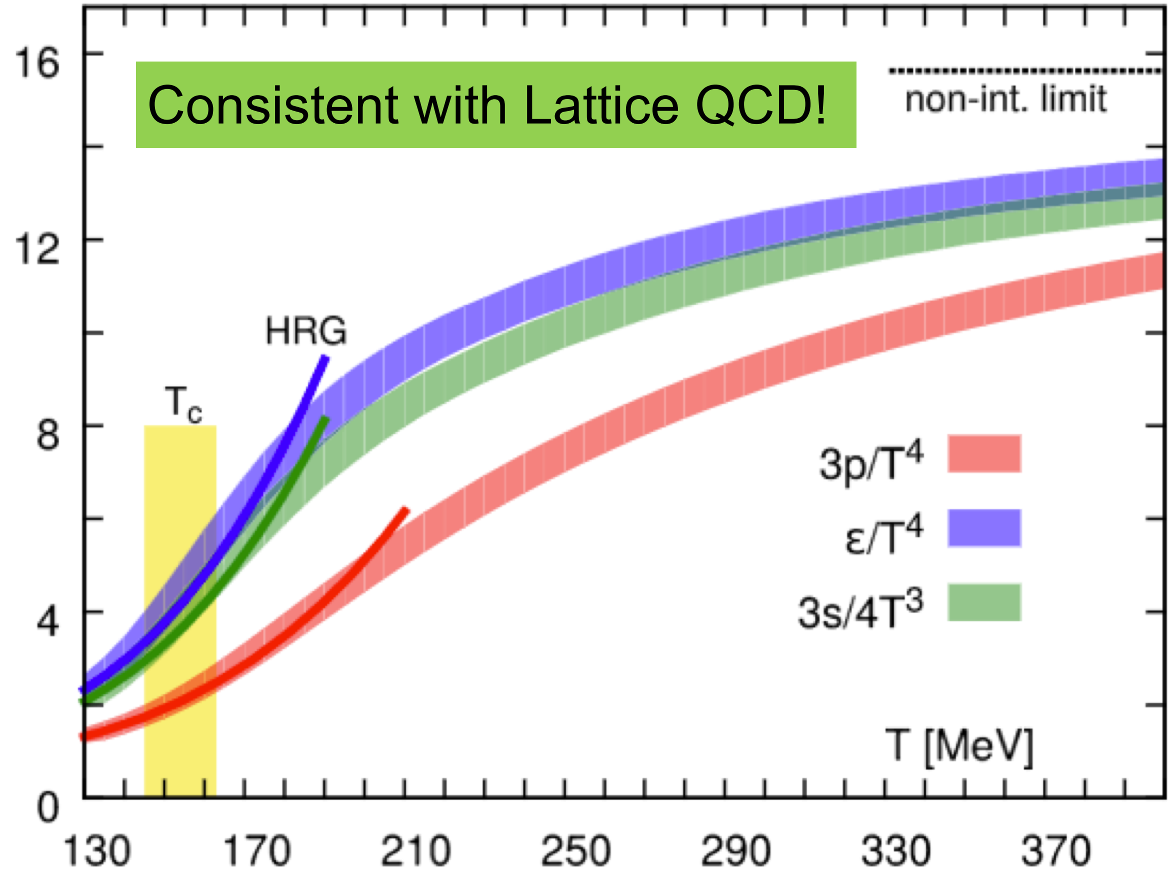
[PRD 90 094503 (2014)]



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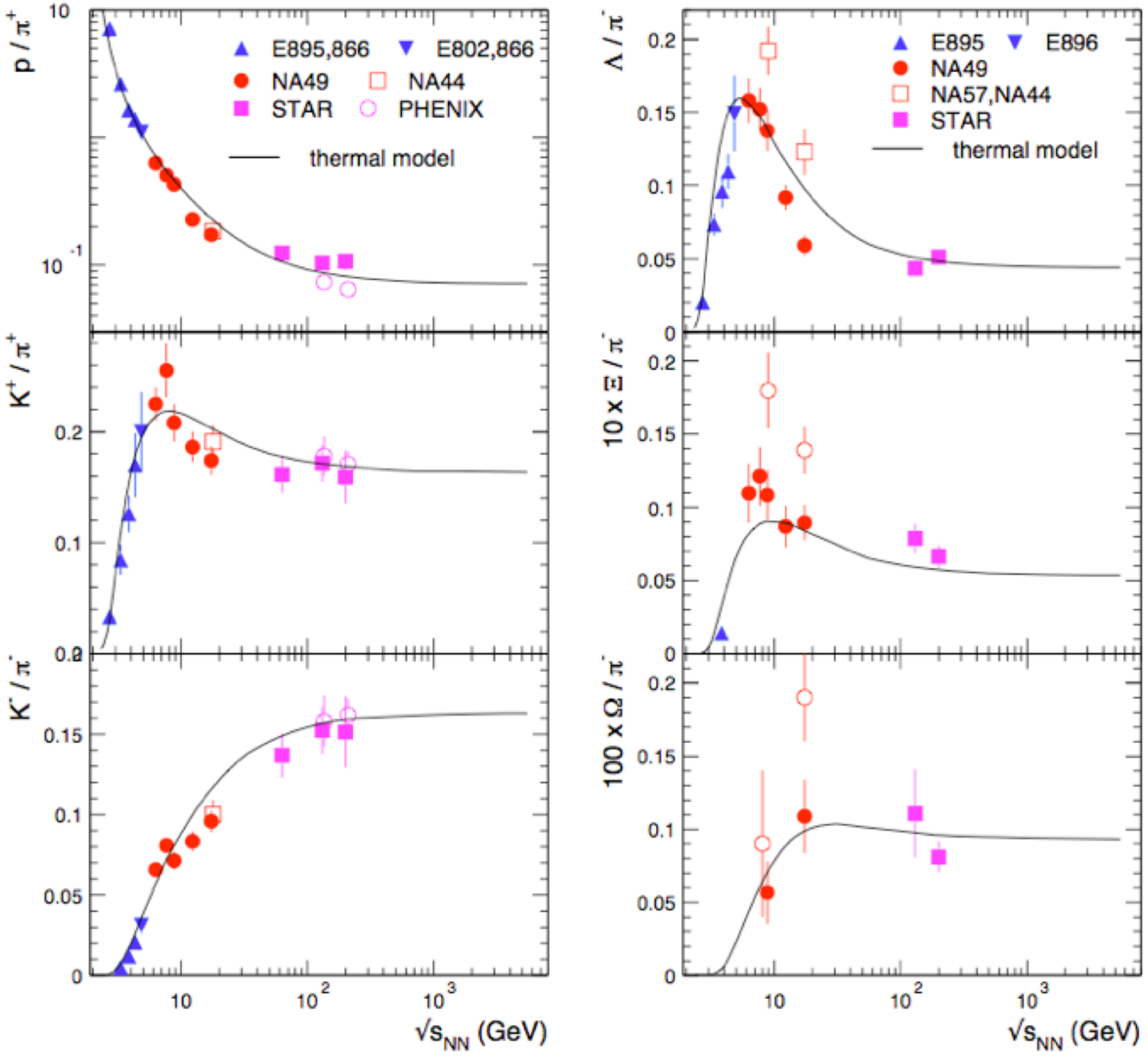
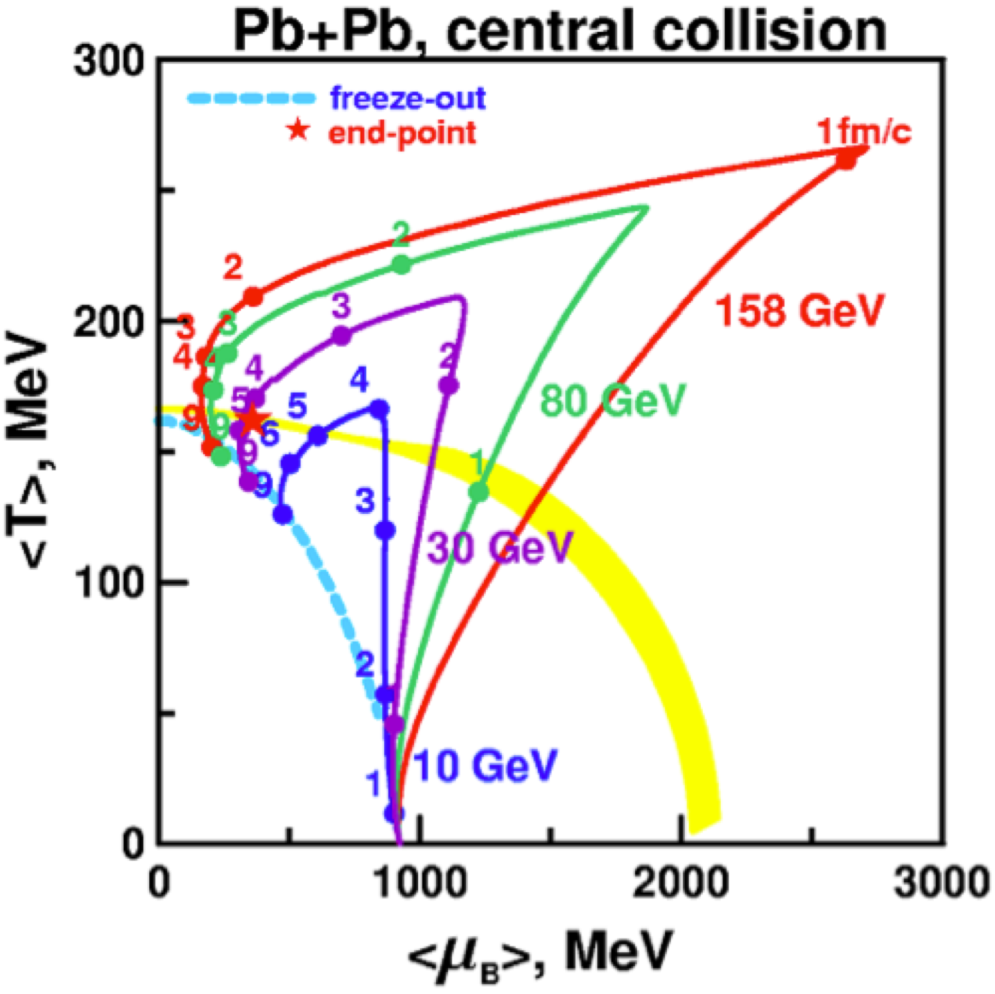


Chemical freeze-out line (1)

- By colliding nuclei with different center of mass energies, different regions of the phase diagram are explored.
- Thermal model fits to the experimental data define the chemical freeze-out line in the QCD phase diagram.
- The previously schematic phase diagram becomes one which is actually measured!



Y.B. Ivanov et al., Phys. Rev. C 73 (2006) 30.

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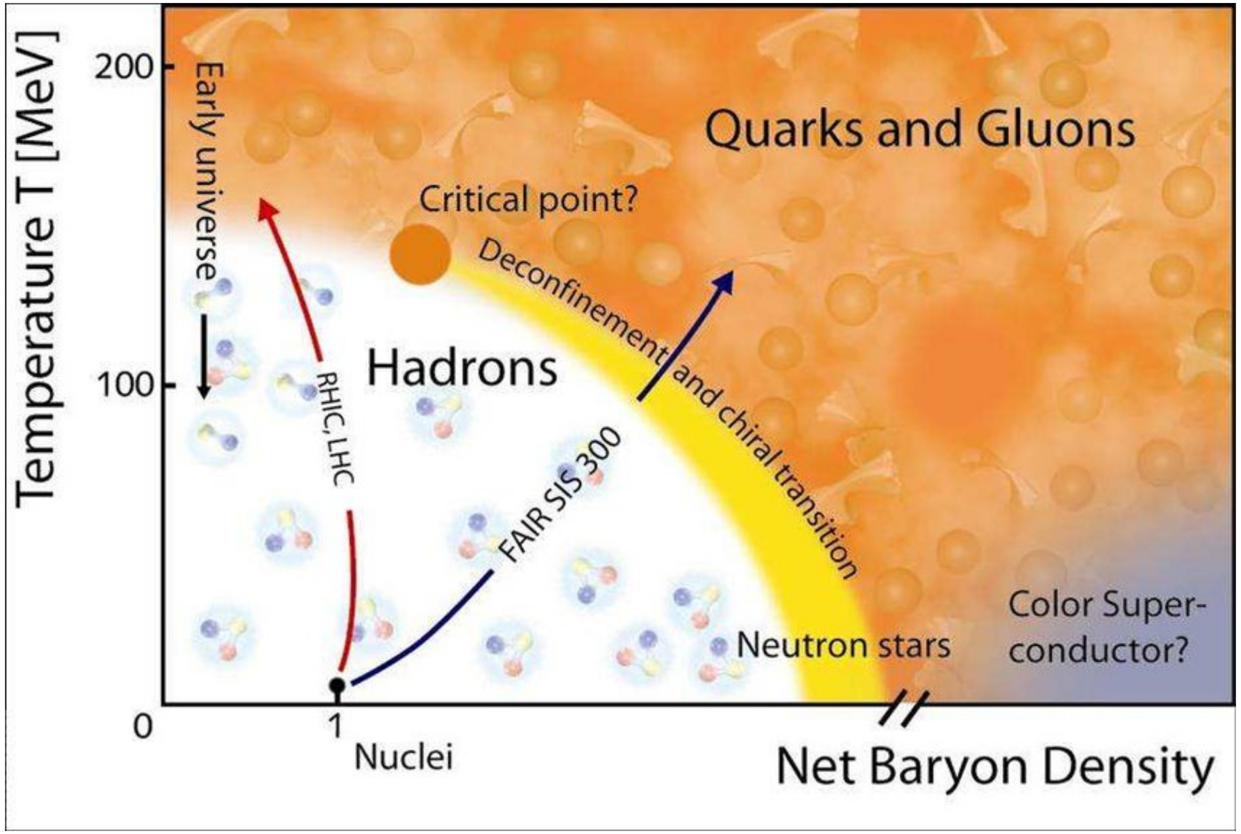

Chemical freeze-out line (3)

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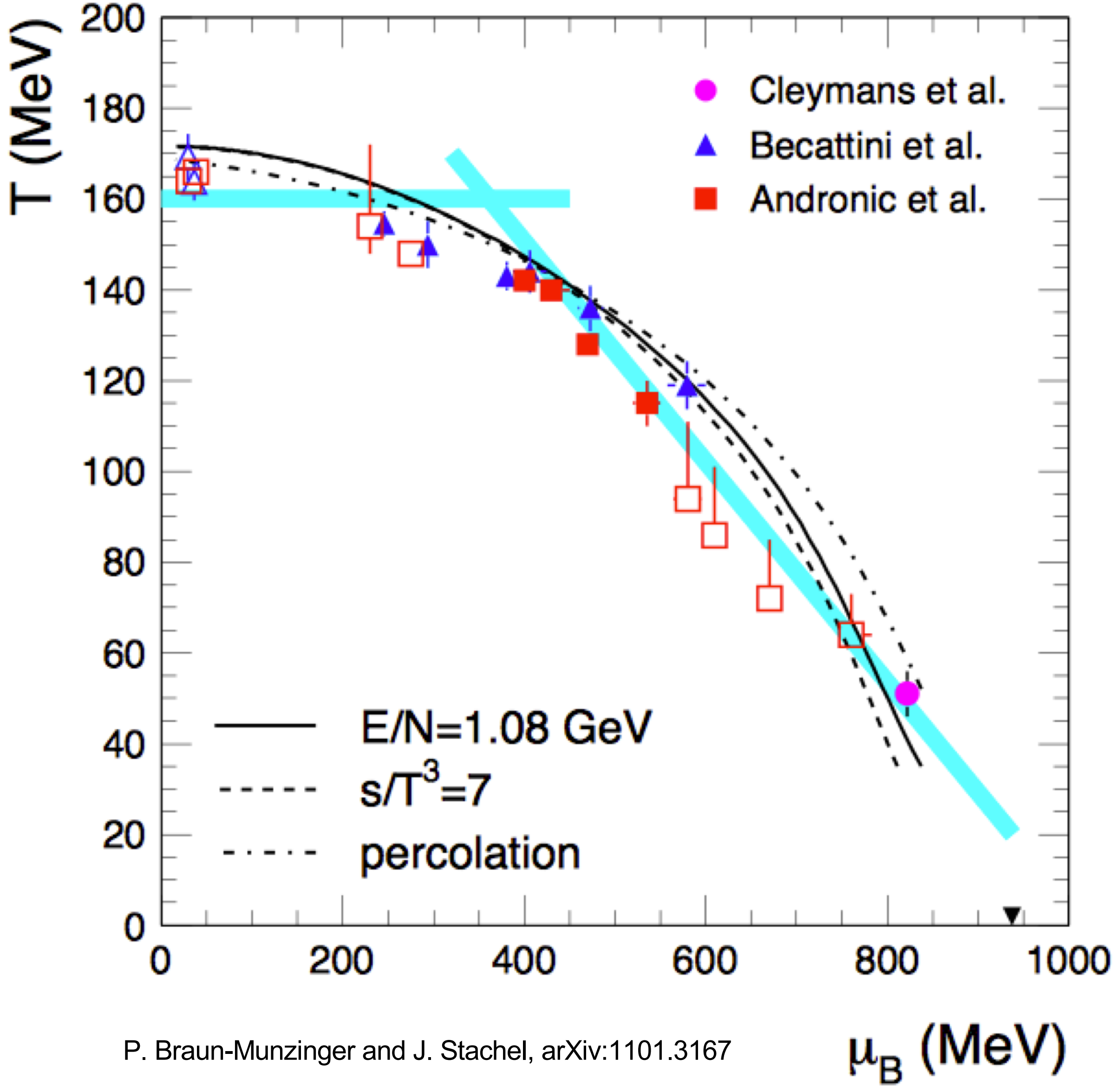

P. Braun-Munzinger and J. Stachel, arXiv:1101.3167

Chemical freeze-out line (4)

- By colliding nuclei with different center of mass energies, different regions of the phase diagram are explored.
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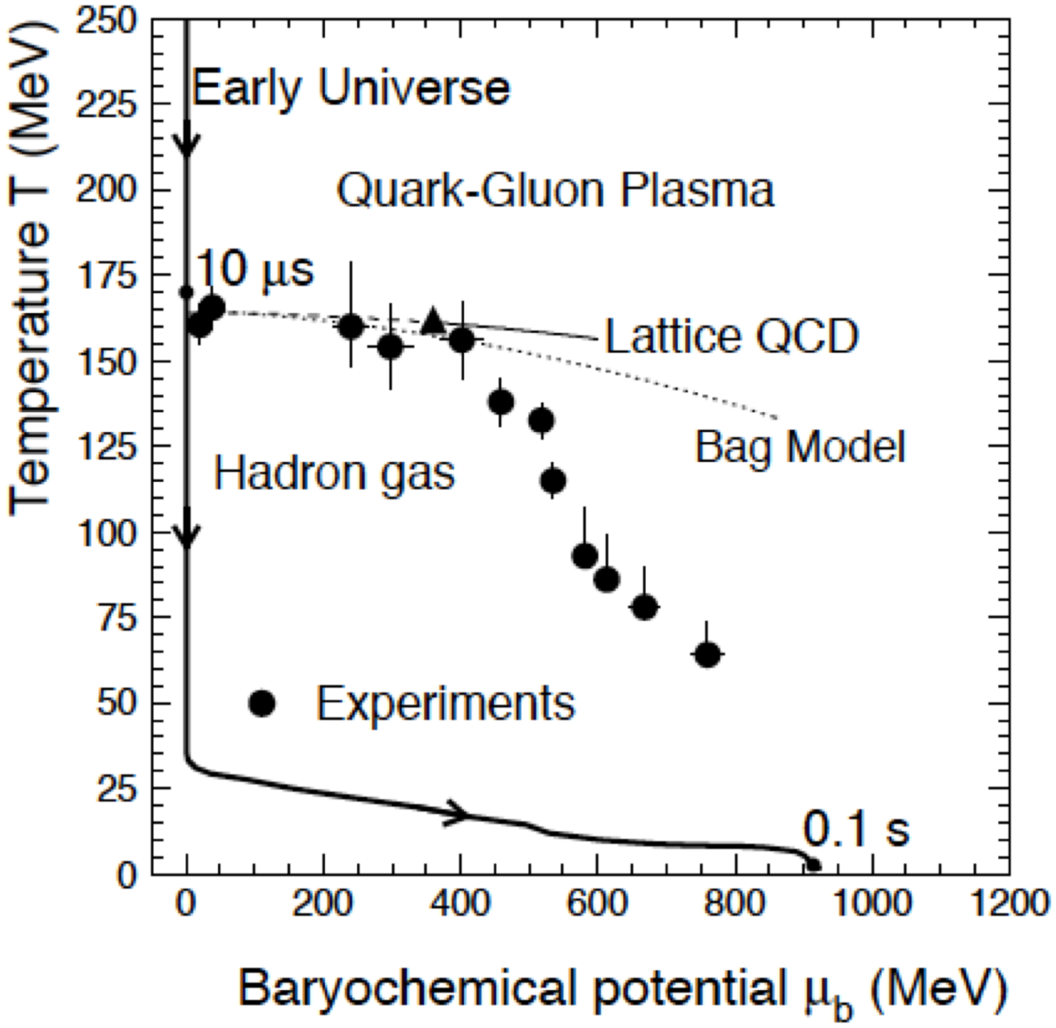
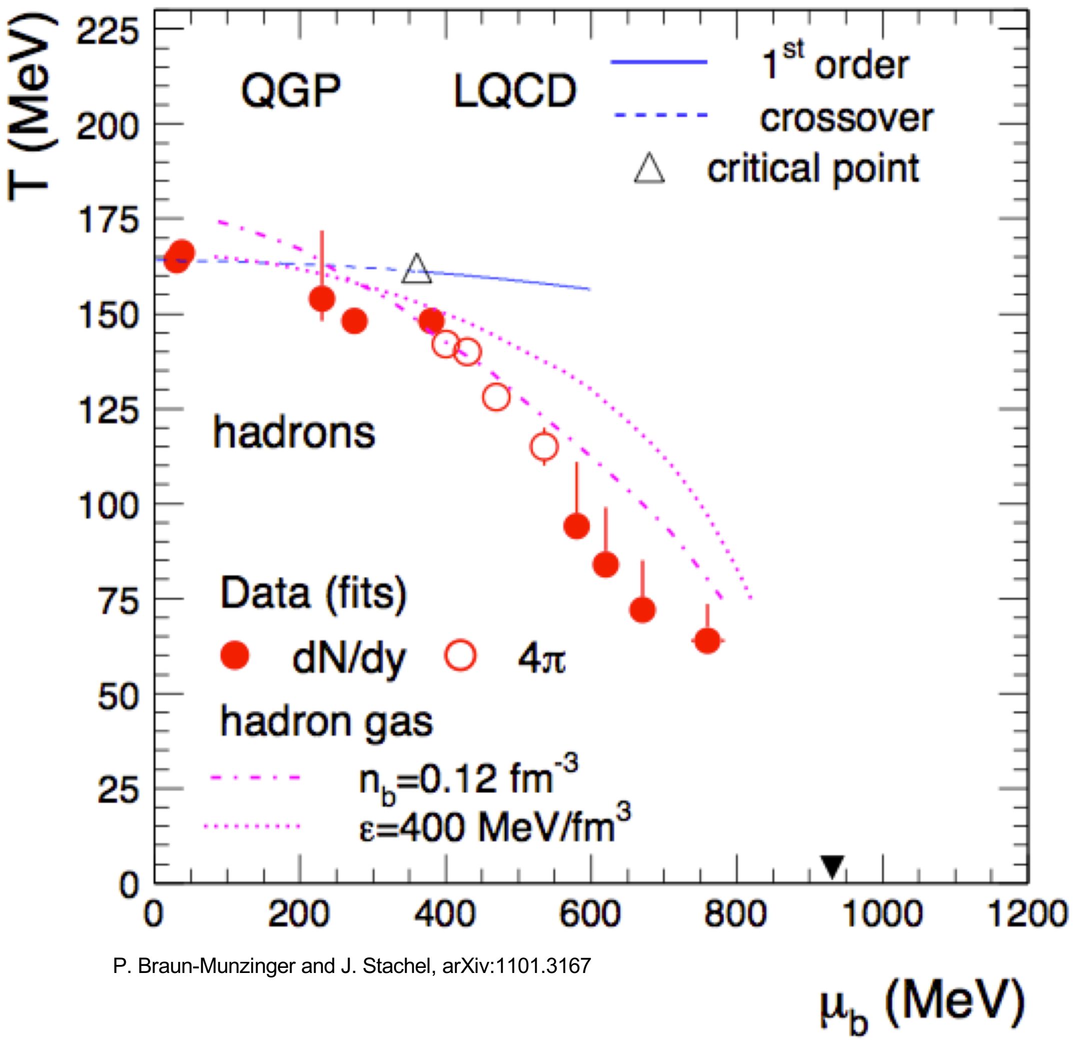


[Rev.Mod.Phys. 81 (2009) 1031-1050]

Chemical freeze-out as a proof of QGP existence?



P. Braun-Munzinger and J. Stachel, arXiv:1101.3167

A priori, a thermal model description is not related to the QGP itself. It describes a *hadron gas and not a parton gas*.

However, the *chemical freeze-out line* determined by thermal fits coincides with the phase boundary calculated by lattice QCD above top SPS energies!

However, a detailed study of collision rates and timescales of fireball expansion imply that equilibrium cannot be reached in the hadronic phase…

Do multi-particle collisions near TC equilibrate the system? A rapid change in density near the **phase transition** can explain this [1].

Alternatively, the system is 'born into equilibrium' by the filling of phase space during hadronization [2].

[1] Braun-Munzinger, P., Stachel, J. & Wetterich, C., Phys. Lett. B. 596, 61–69 (2004).

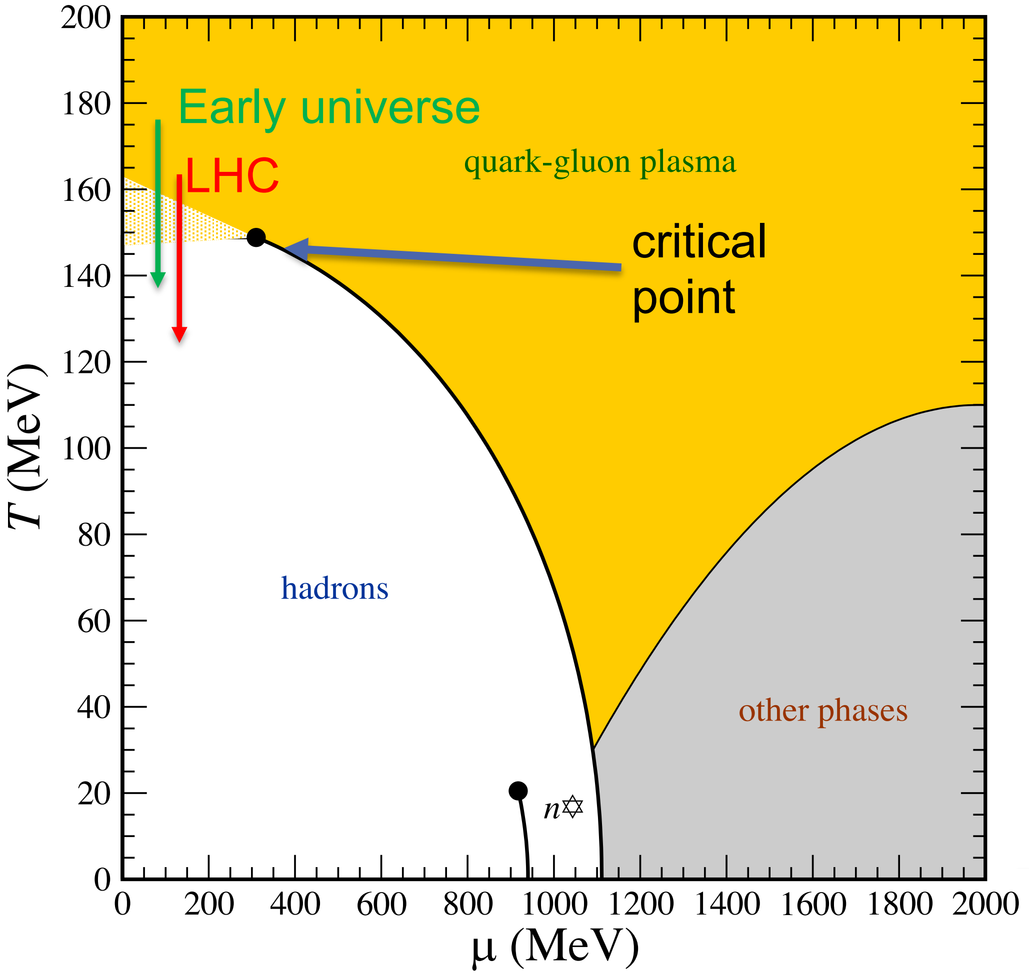
[2] Stock, R. Phys. Lett. B 456, 277–282 (1999).

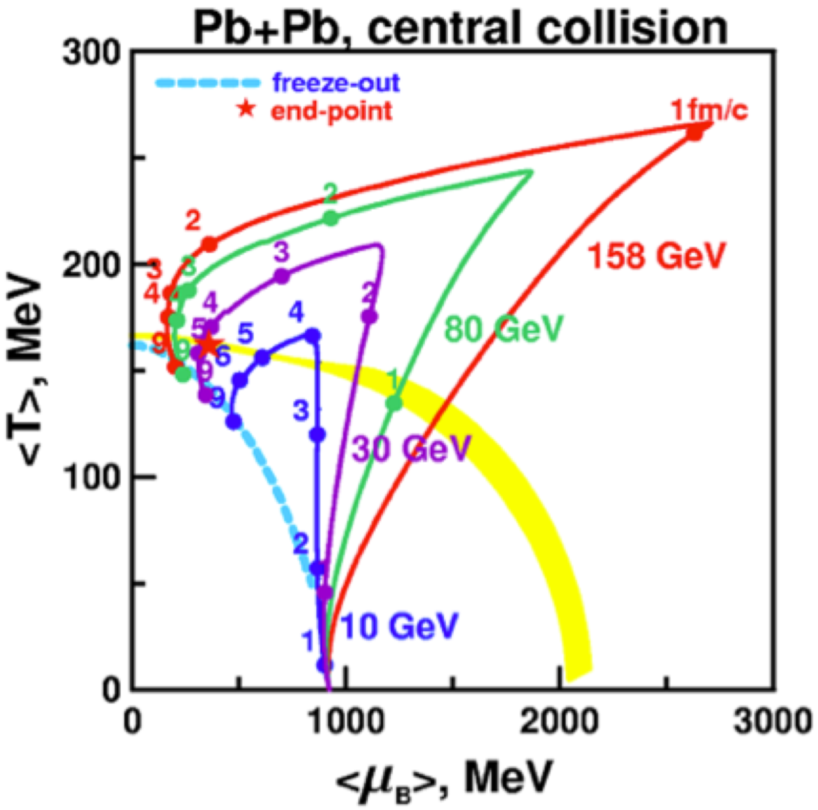
QGP thermodynamics and soft probes

Search for QCD critical point and onset of de-confinement

The QCD critical point

By a variation of beam energies, one might hit the critical point in the QCD phase diagram => ***critical chiral dynamics***.





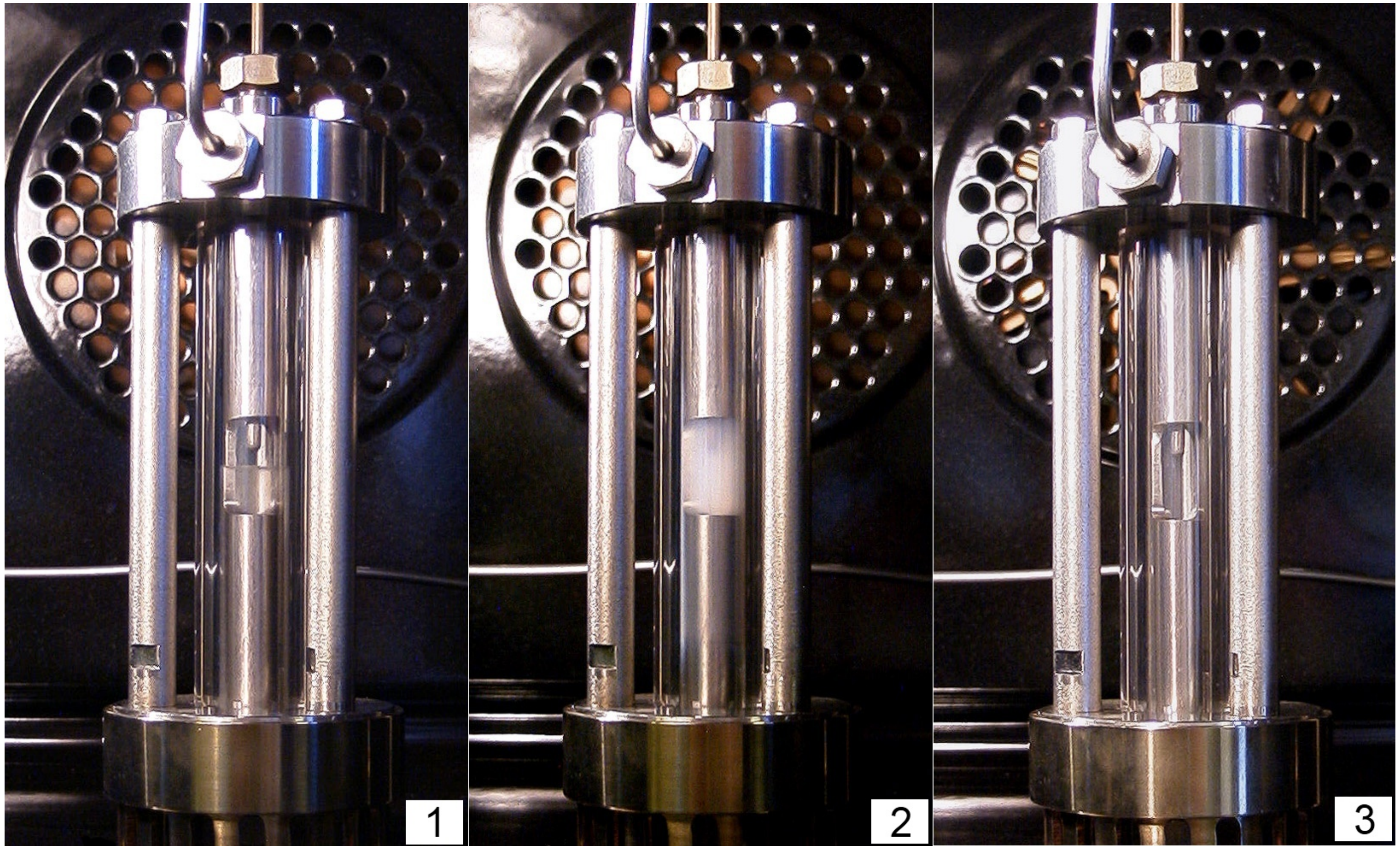
Y.B. Ivanov et al., Phys. Rev. C 73 (2006) 30.

→ Different regions of the phase diagram are probed with different $\sqrt{s_{NN}}$.

=> Beam energy scan (BES) at RHIC.

Critical fluctuations – in ordinary matter

- Phase transitions are often connected to critical phenomena.
- Example: Opalescence of Ethene at the critical point (divergence of correlation lengths).



[S. Horstmann, Ph.D. Thesis University Oldenburg]

Fluctuations in QCD

- QCD phase transitions: the thermodynamic susceptibilities χ of the conserved quantities of QCD (**electric charge *Q*, baryon number *B*, Strangeness *S***) correspond to (event-by-event) fluctuations in the particle production.

$$\chi_{lmn}^{BSQ} = \frac{\partial^{l+m+n}(P/T^4)}{\partial(\mu_B/T)^l\,\partial(\mu_S/T)^m\,\partial(\mu_S/T)^n}$$

- Fluctuations are quantified as moments (mean, variance, skewness, kurtosis) or cumulants ***K*** of the event-by-event distributions:

$$\begin{array}{ccccccccc}
M & = & K_1 & = & \mu & = & \langle N \rangle & = & VT^3 \cdot \chi_1 \\
\sigma^2 & = & K_2 & = & \mu_2 & = & \langle (\delta N)^2 \rangle & = & VT^3 \cdot \chi_2 \\
S & = & K_3/\sigma^3 & = & \mu_3/\sigma^3 & = & \langle (\delta N)^3 \rangle/\sigma^3 & = & VT^3 \cdot \chi_3/(VT^3 \cdot \chi_2)^{3/2} \\
\kappa & = & K_4/\sigma^4 & = & (\mu_4 - 3\mu_2^2)/\mu_2^2 & = & \langle (\delta N)^4 \rangle/\sigma^4 - 3 & = & (VT^3 \cdot \chi_4)/(VT^3 \cdot \chi_2)^2
\end{array}$$

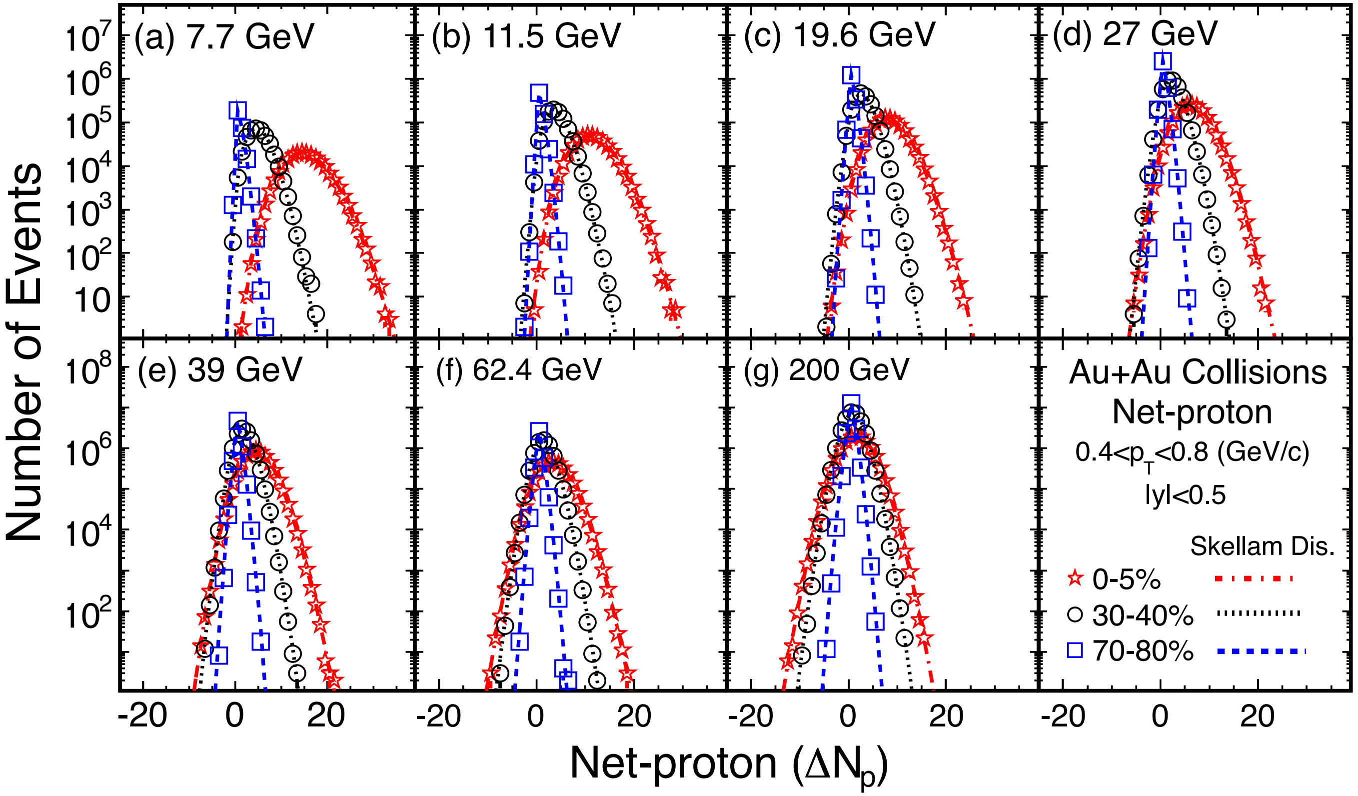
$$\mu_i = \langle (\delta N)^i \rangle$$

$$\delta N = N - \langle N \rangle$$

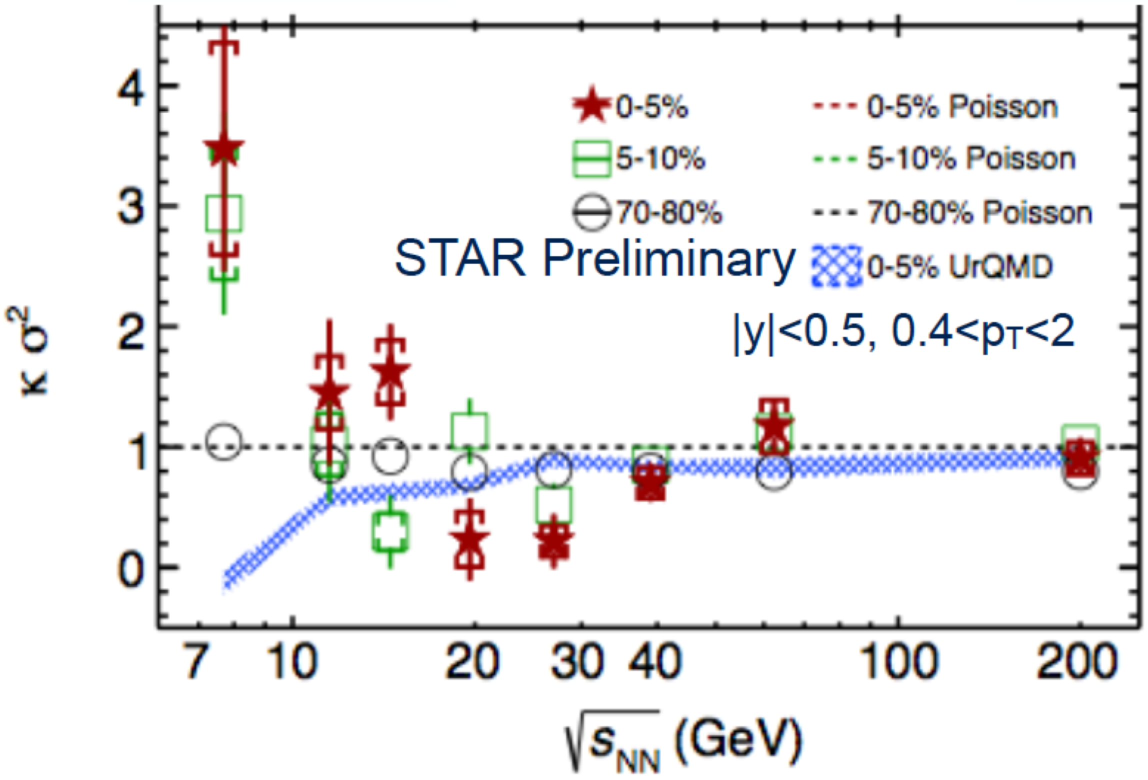
Critical fluctuations – in quark matter

- In the QCD case, **event-by-event fluctuations** in the conserved charges of QCD (Baryon number *B*, Strangeness *S*, electric charge *Q*).
- Key observable: baryon number fluctuations quantified as the higher moments χ_B of the net-proton (N_p-$N_{anti\text{-}p}$) distribution => fixed at chemical freeze-out

→ Hint for deviation from Poisson baseline in kurtosis around $\sqrt{s_{NN}} \approx 20$ GeV?



[PRL 112 (2014) 032302]

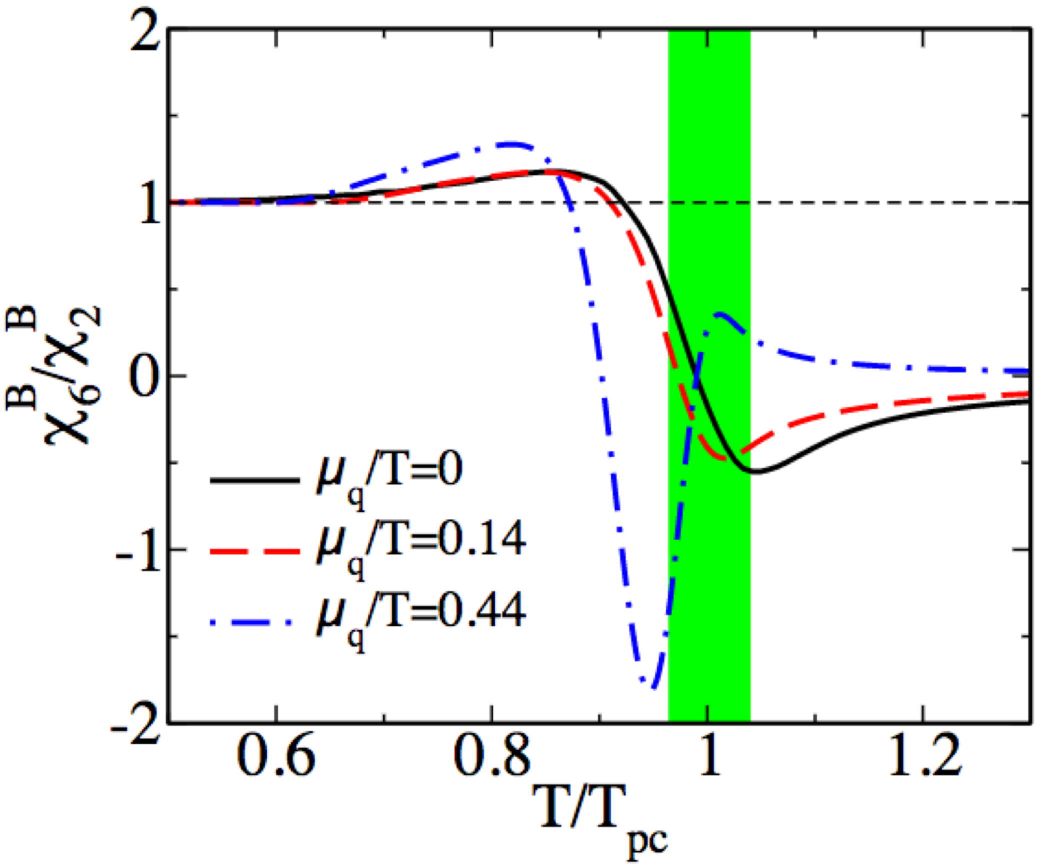


Chiral critical dynamics at LHC energies

Even though LHC energies are far away from the critical point, remnants of the critical chiral dynamics might still be measurable in higher order net-charge fluctuations at the LHC.

→ Test of a Lattice QCD prediction.

→ Experimental proof that chiral and de-confinement phase transition occur indeed at the same temperature.

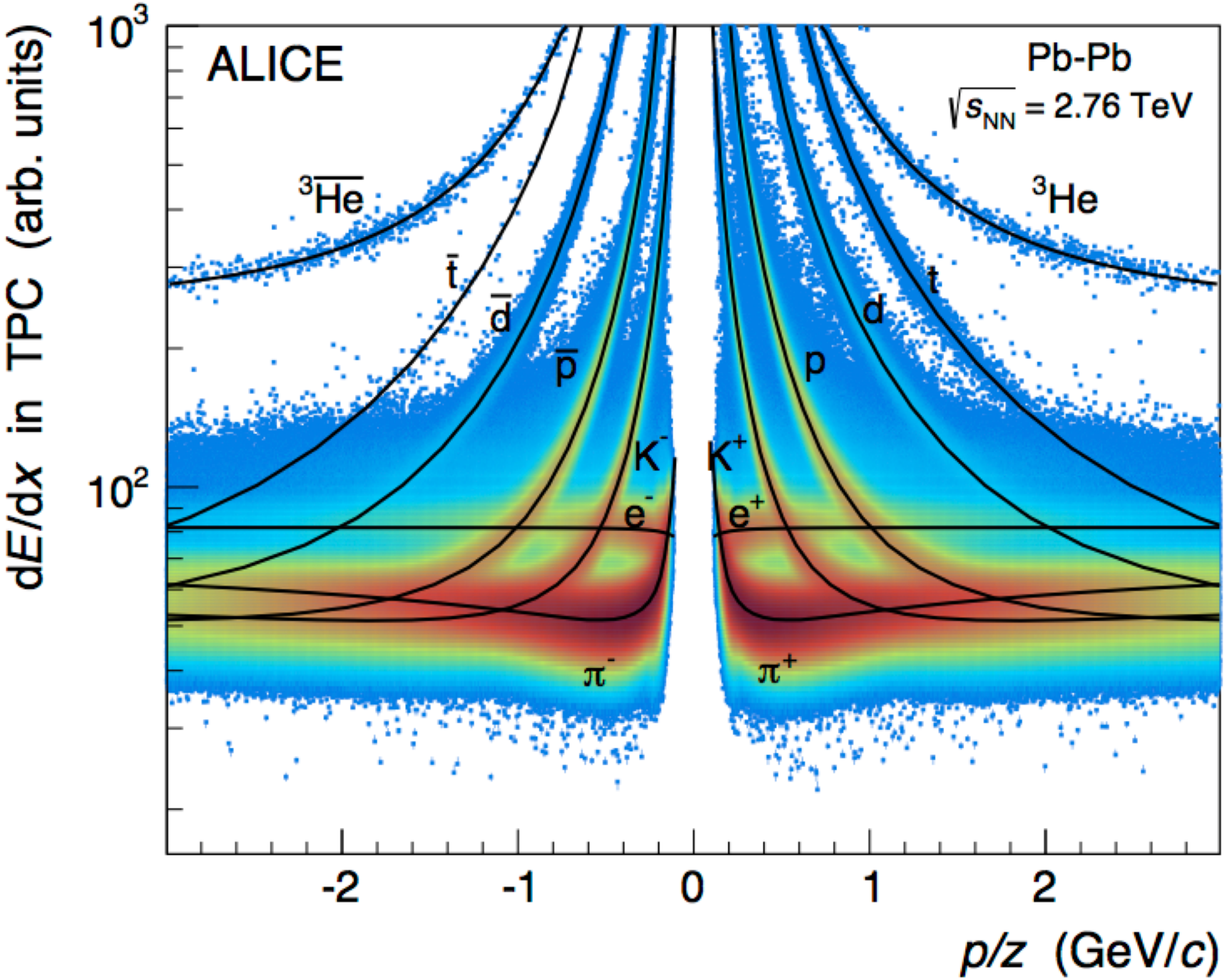


[Eur. Phys. J. C 71 (2011) 1694]

QGP thermodynamics and soft probes

(anti-)(hyper-)nuclei

Particle identification via d*E*/dx



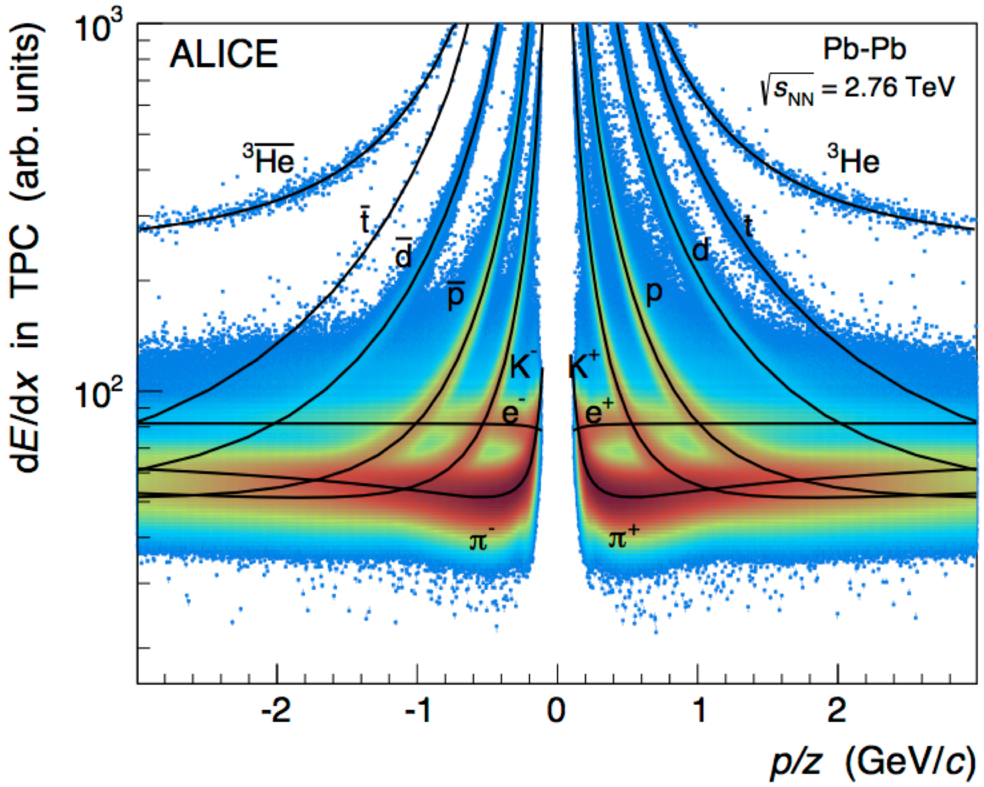
$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Separation of z = 1 and z = 2 via dE/dx is also very important for the correct determination of the momentum via the track curvature: $p_T \sim 0.3\, B \cdot r \cdot z$

Measurements of (anti-)(hyper-)nuclei

Collisions at the LHC produce a large amount of (anti-)(hyper-)nuclei.

- Matter and anti-matter are produced in equal abundance at LHC energies.
- Open puzzle: production yields are in agreement with thermal model prediction even though light (anti-)nuclei should be dissolved in such a hot medium.



[PRC 93 (2016) 024917]

[ALICE-PUBLIC-2017-006]

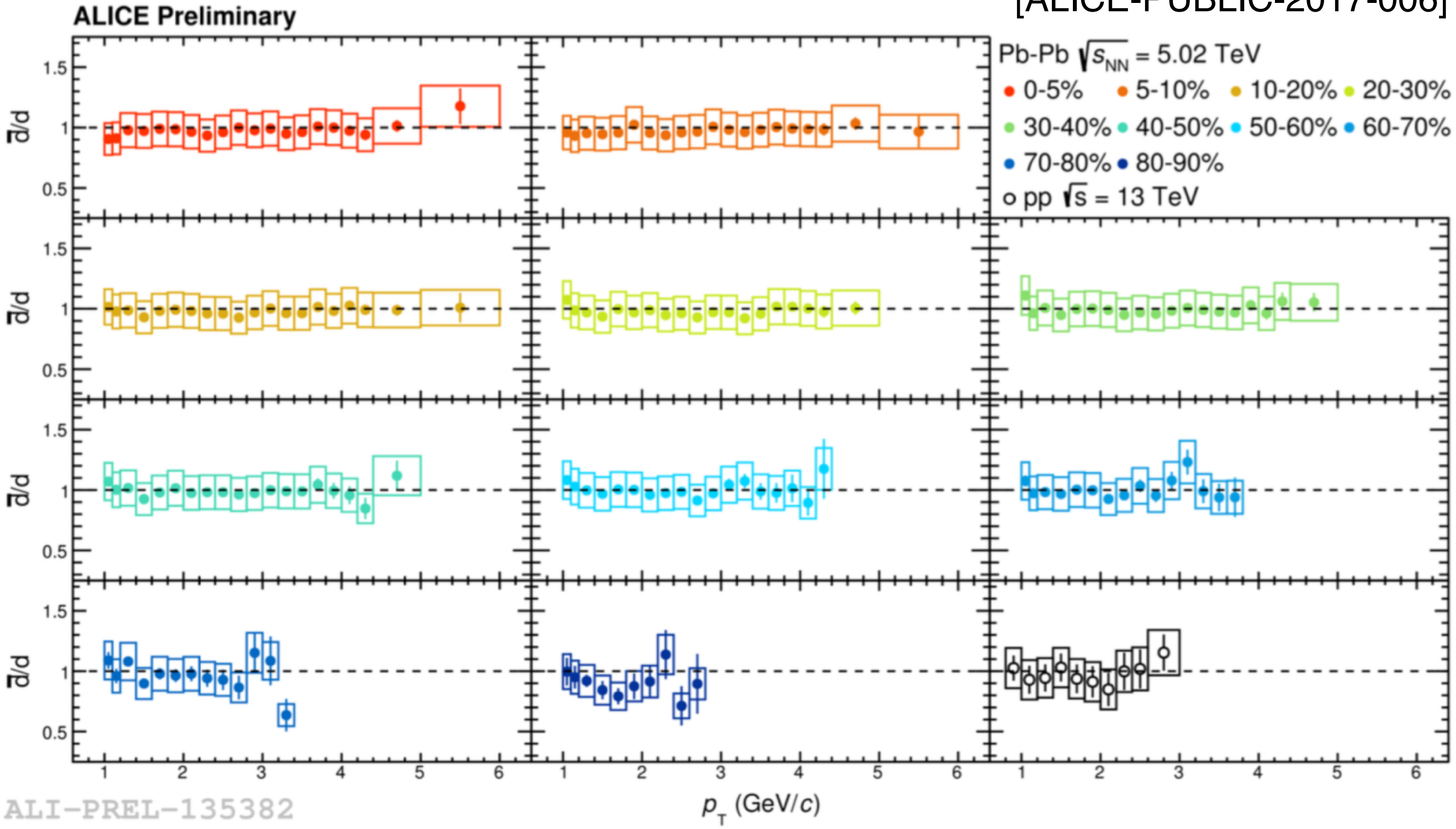
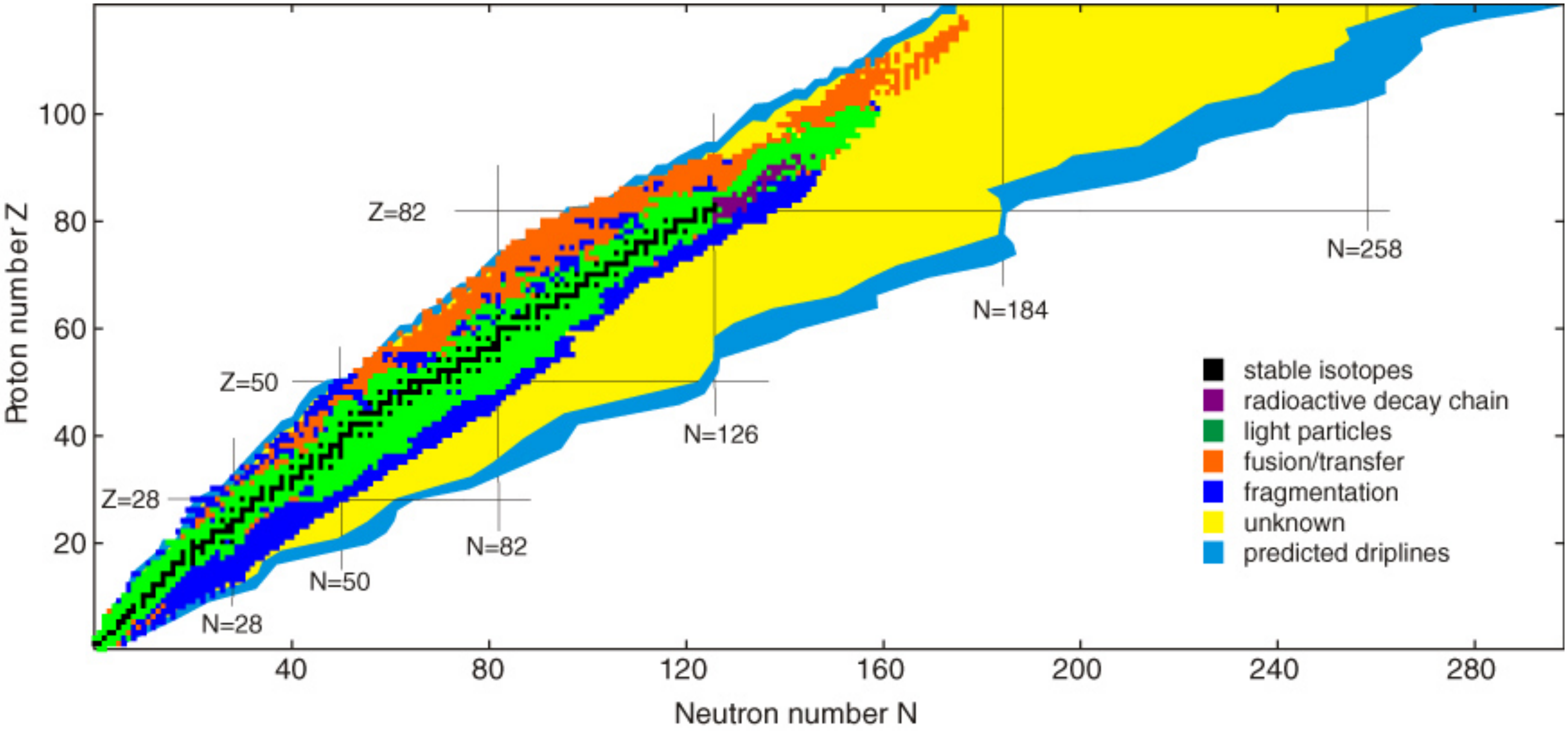


Table of nuclides

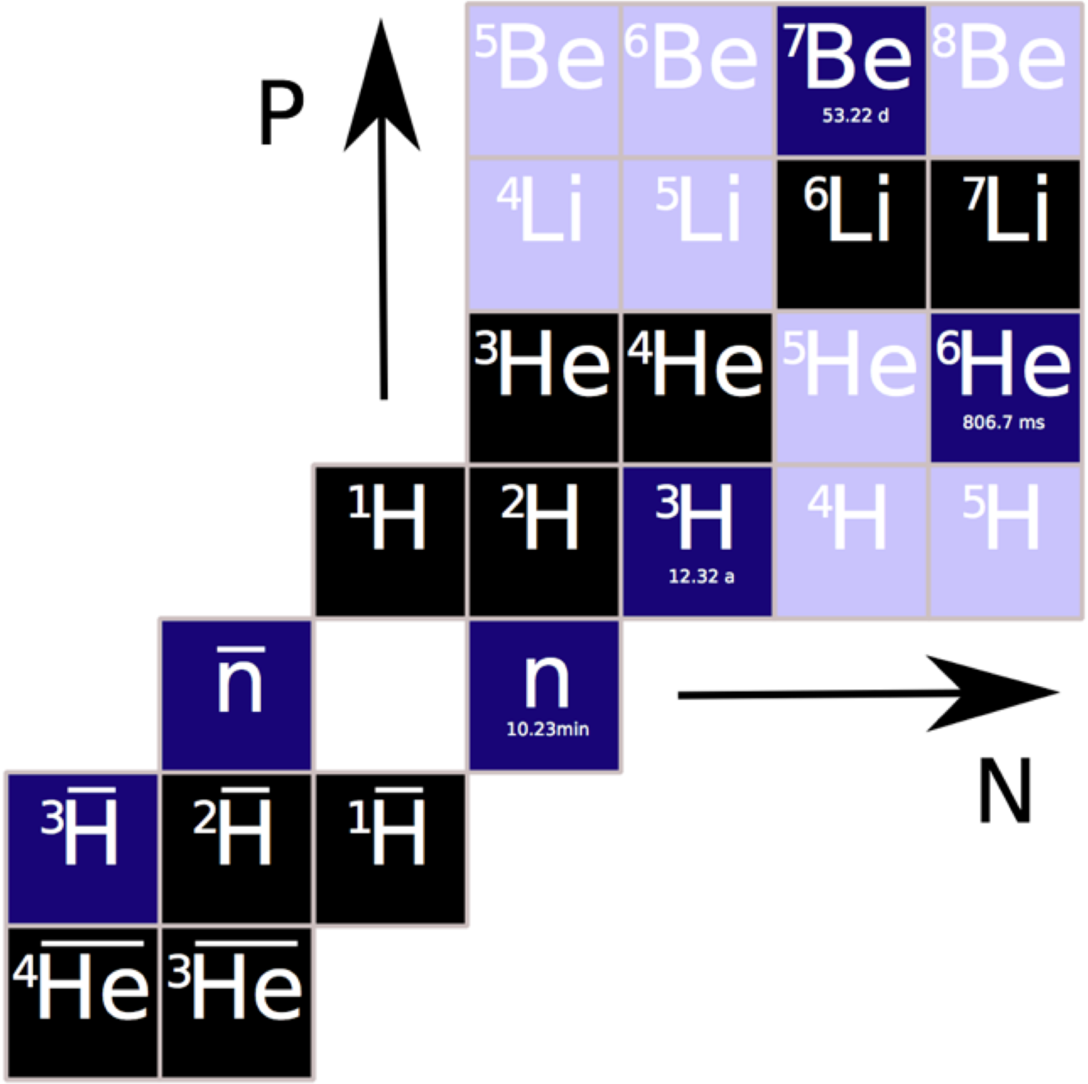


Light (anti-)nuclei

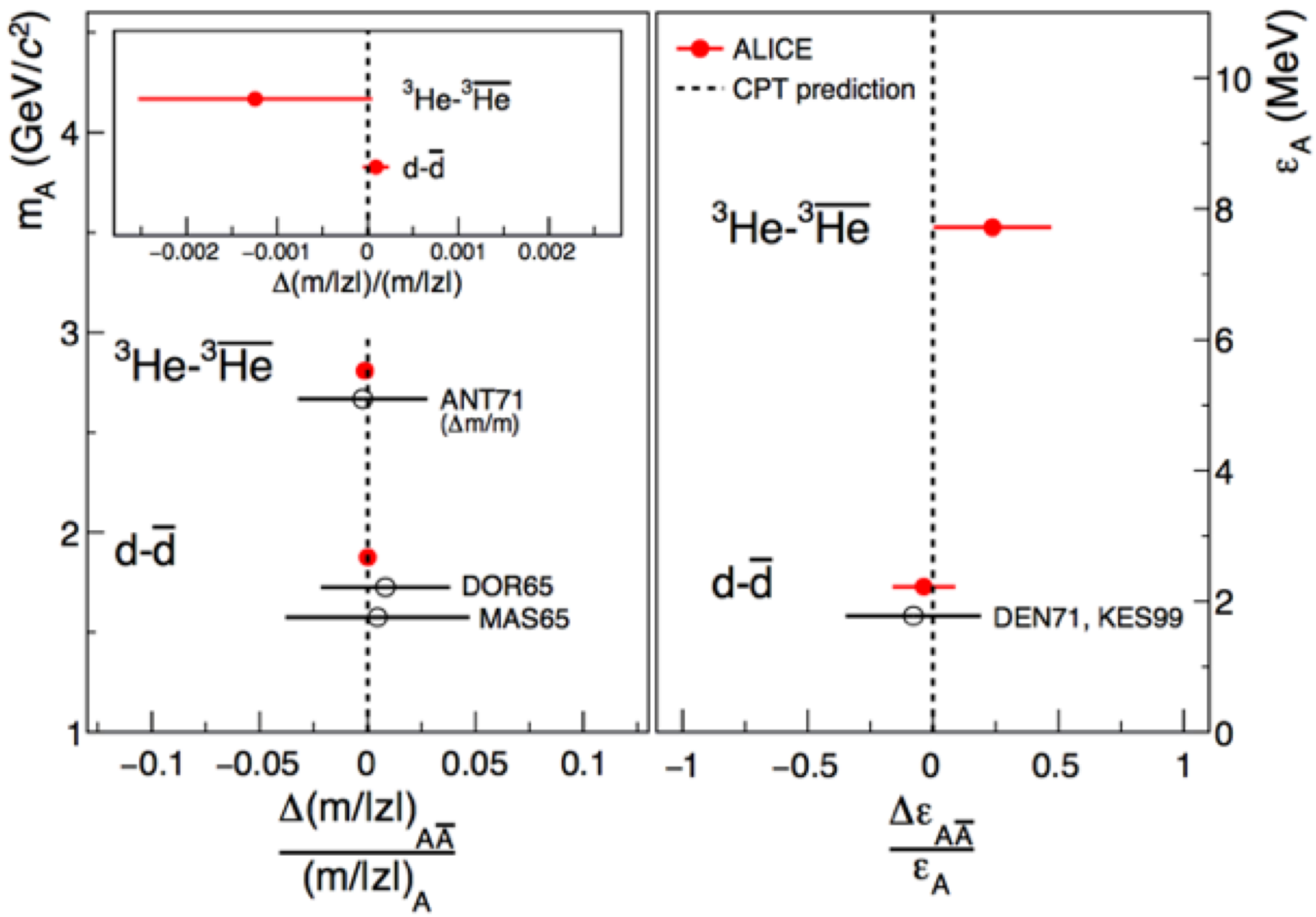
- Even in Pb-Pb collisions at LHC energies, light anti-nuclei are rarely produced.

- (Anti-)nuclei up to the (anti-)alpha are in reach (1st observation of the anti-alpha by the STAR experiment at RHIC in 2011).

→ A very good and very stable particle identification is needed to separate these rare particles from the background.



Testing CPT with anti-nuclei



[Nature Physics 11 (2015) 811-814]

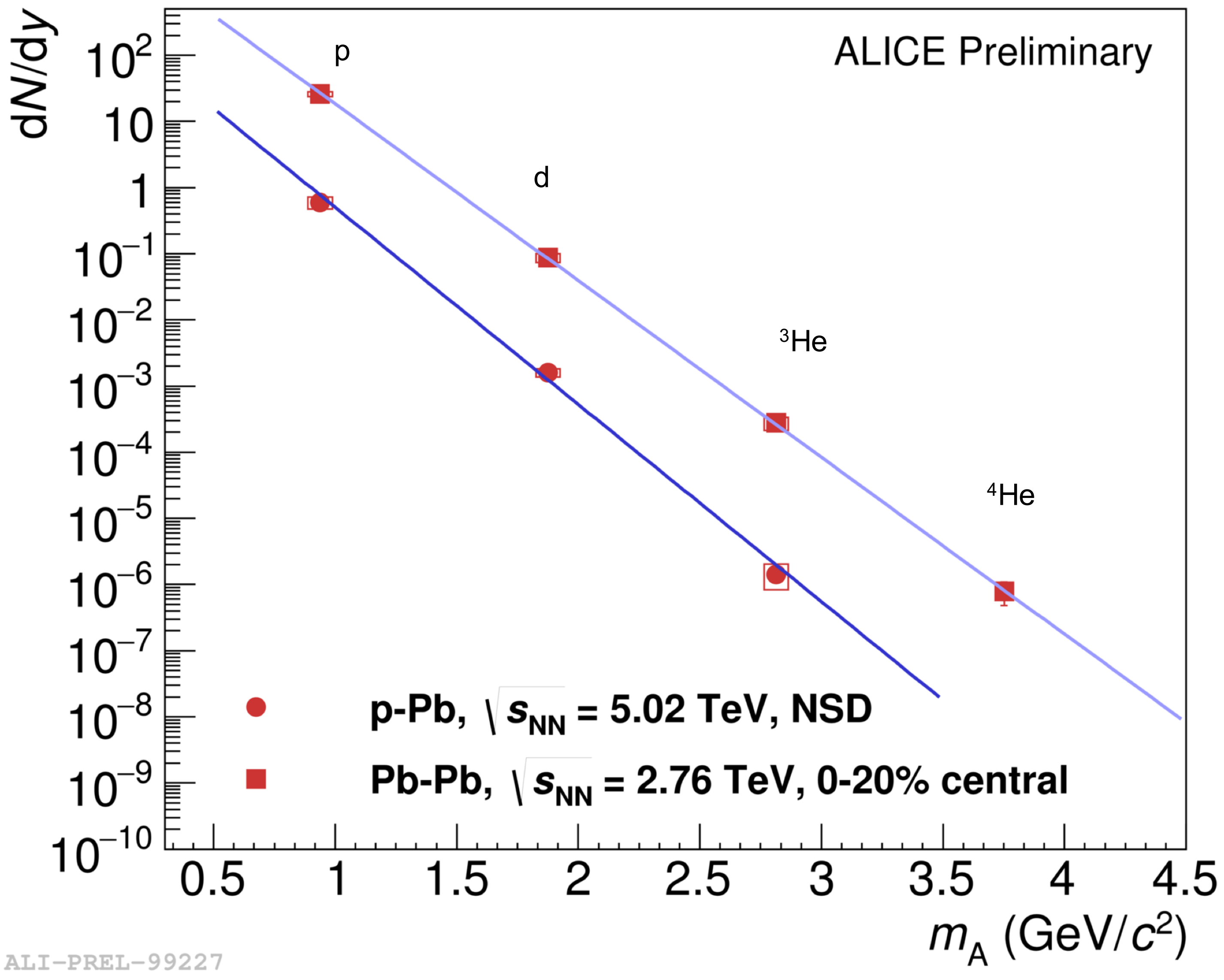
The ALICE collaboration performed a test of the CPT invariance looking at the mass difference between nuclei and anti-nuclei.

This test shows that the masses of nuclei and anti-nuclei are compatible within the uncertainties. The binding energies are compatible in nuclei and anti-nuclei as well.

Mass ordering

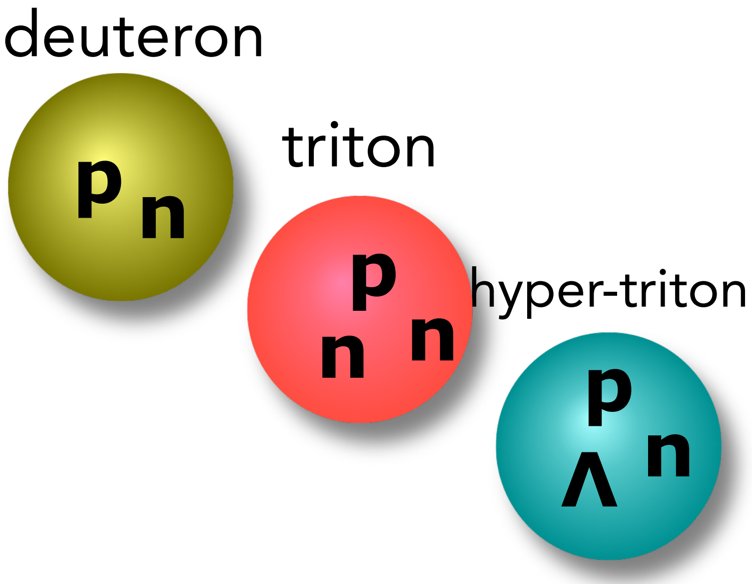
→ For each additional nucleon the production yield decreases by a factor of about 300!

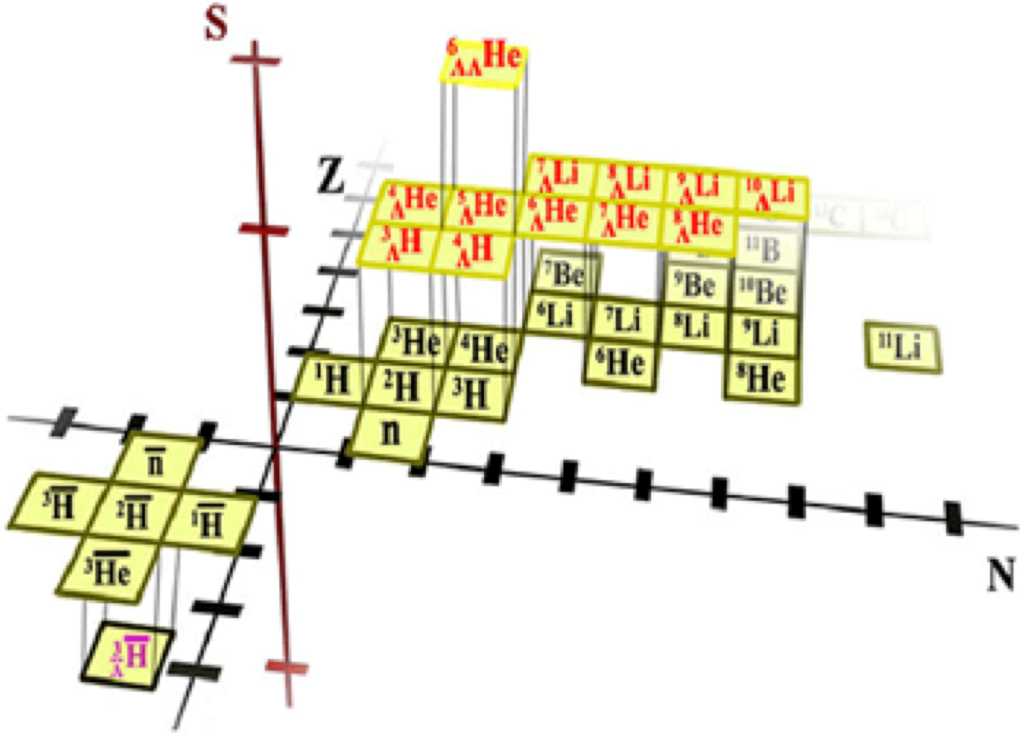
→ Such a behaviour can be directly derived from the thermal model which predicts in first order d*N*/dy ~ exp(-*m*/*T*)



Hyper-nuclei (1)

- By ‘replacing’ one nucleon by one hyperon, the table of nuclides can be extended in a third dimension.
- Hyper-nuclei have a long tradition in nuclear physics: discovery in the 1950s by M. Danysz and J. Pniewski in a nuclear emulsion exposed to cosmic rays.





The STAR Collaboration, **Science 328, 58 (2010)**

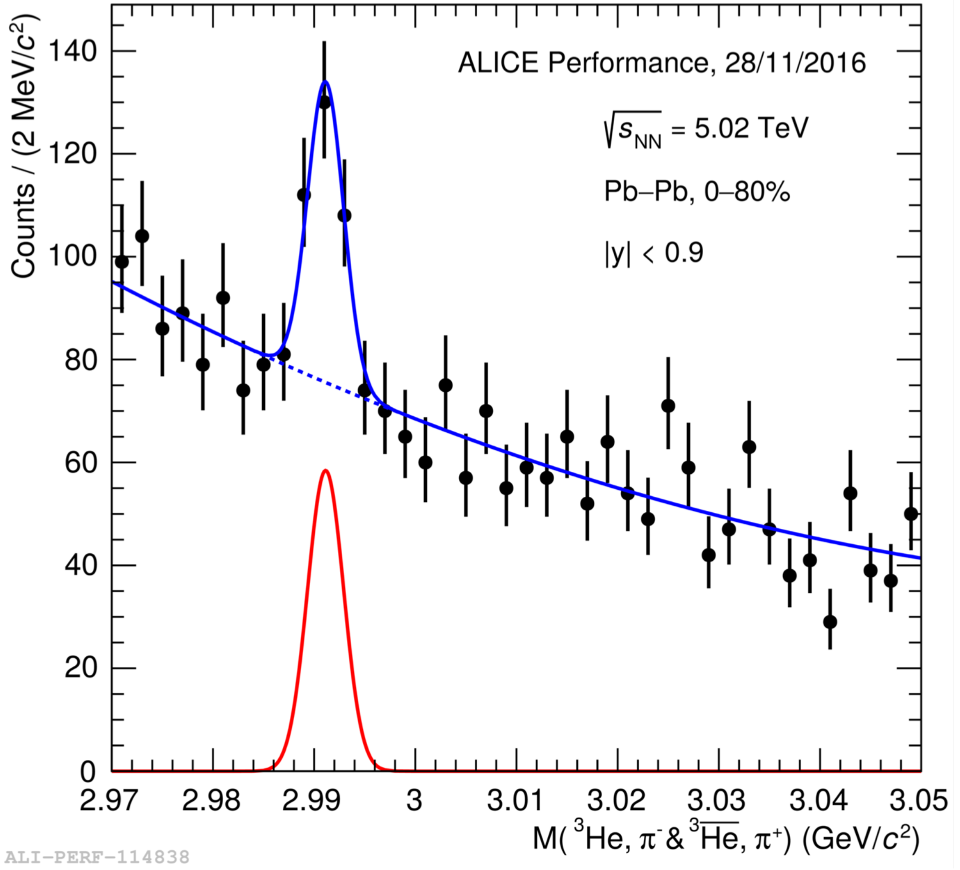
Hyper-nuclei (2)

- Reconstruction of hyper-nuclei can be based on well established techniques for Λ and other weakly decaying light flavor hadrons as lifetimes and decay topologies are similar.

$$\Lambda \longrightarrow p + \pi^- \quad (63.9\%)$$

- Experimentally one searches for (anti-)nuclei from displaced vertices:

$$\begin{aligned}
{}^{3}_{\Lambda}\mathrm{H} &\longrightarrow {}^{3}\mathrm{He} + \pi^- \\
{}^{3}_{\Lambda}\mathrm{H} &\longrightarrow \mathrm{d} + \mathrm{p} + \pi^- \\
{}^{4}_{\Lambda}\mathrm{H} &\longrightarrow {}^{4}\mathrm{He} + \pi^- \\
{}^{4}_{\Lambda}\mathrm{He} &\longrightarrow {}^{3}\mathrm{He} + p + \pi^- \\
{}^{5}_{\Lambda}\mathrm{He} &\longrightarrow {}^{4}\mathrm{He} + p + \pi^-
\end{aligned}$$

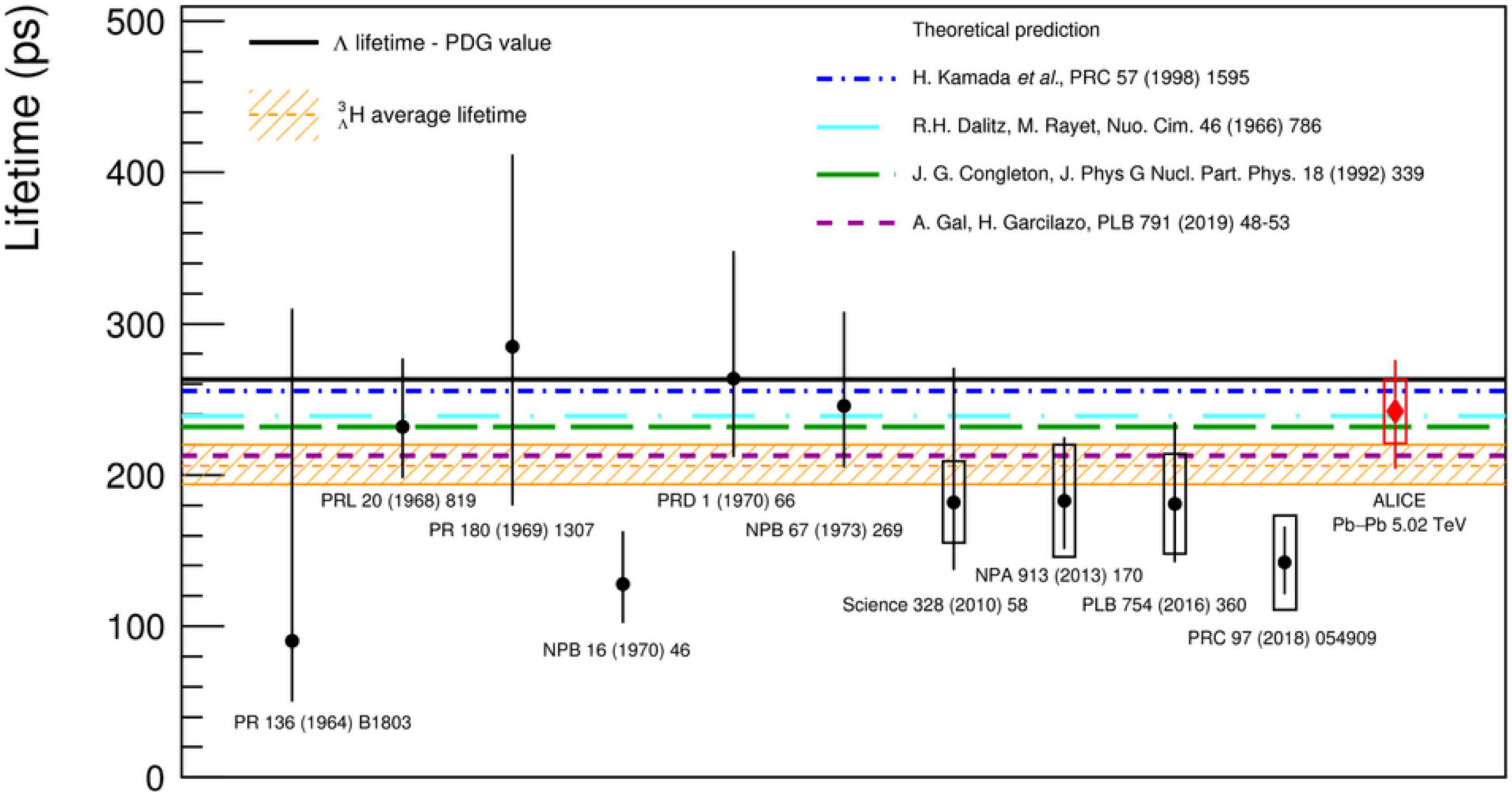


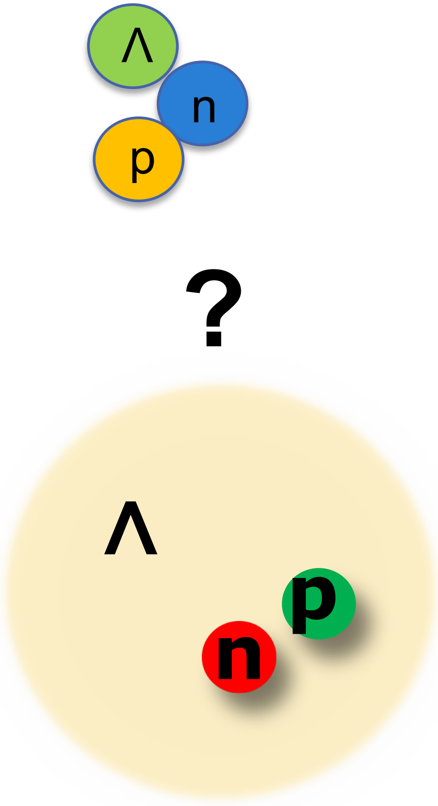
- Branching ratios are only partially constrained by measurements.

(anti-)(hyper-)nuclei – impact beyond heavy-ion physics

A. Heavy-ion measurements may help in constraining the not well known lifetime of the hyper-triton (sensitive to the hyperon-nucleon interaction potential in nuclear physics).

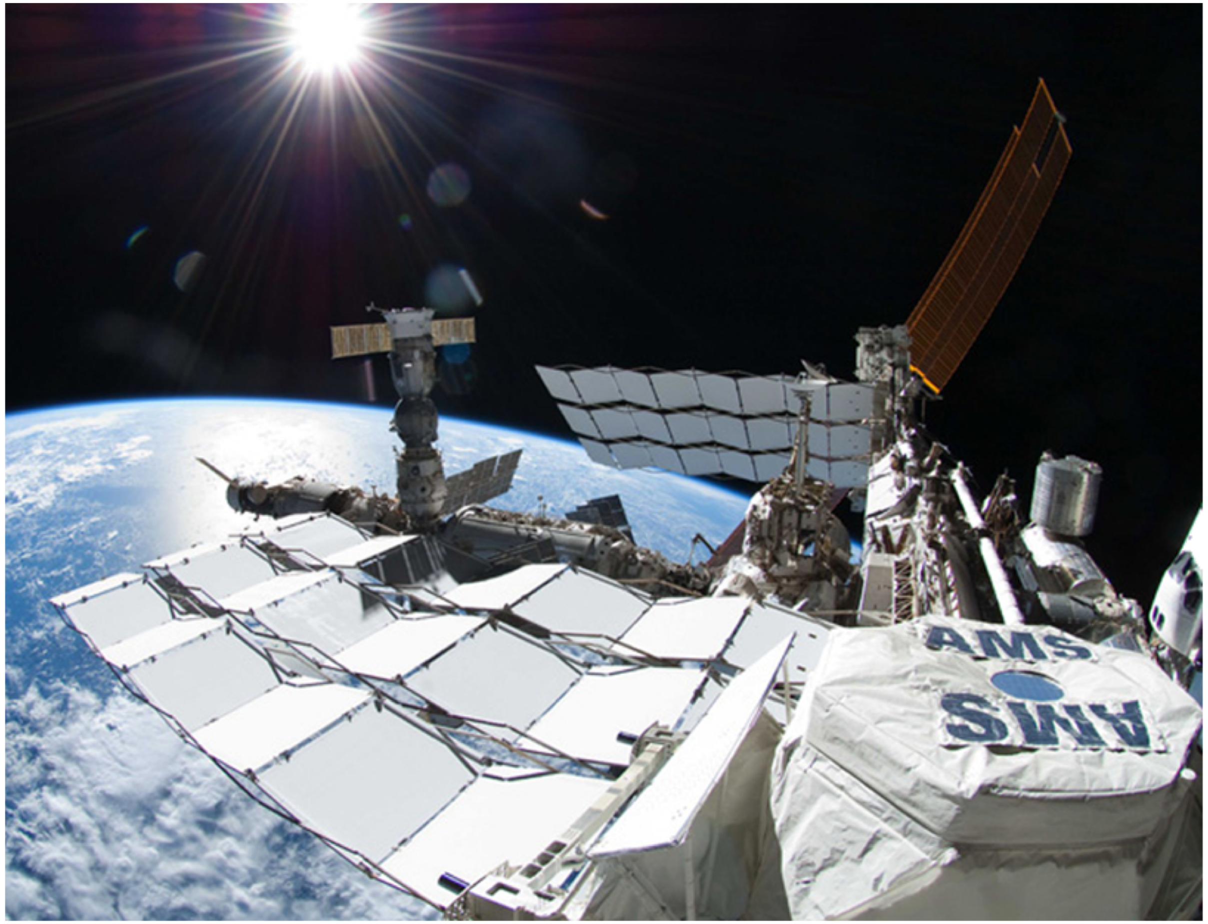
B. Collider measurements are used for background estimations in the searches for (anti-) nuclei of galactic/dark matter origin (such as in AMS).

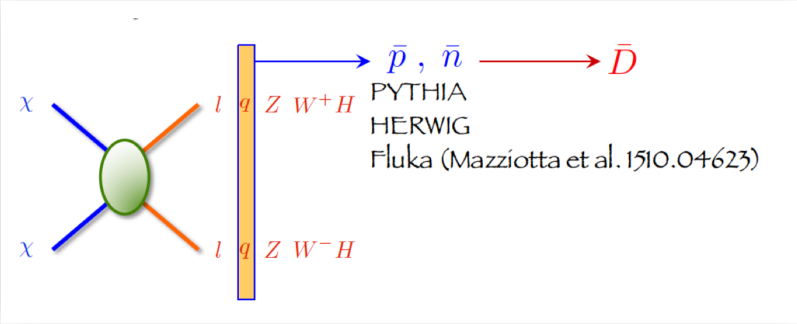




Impact on AMS searches

→AMS (and other experiments) search for anti-nuclei in space which are either of primordial origin or from annihilations of dark matter particles.





(see for instance talk by F. Donato linked here)

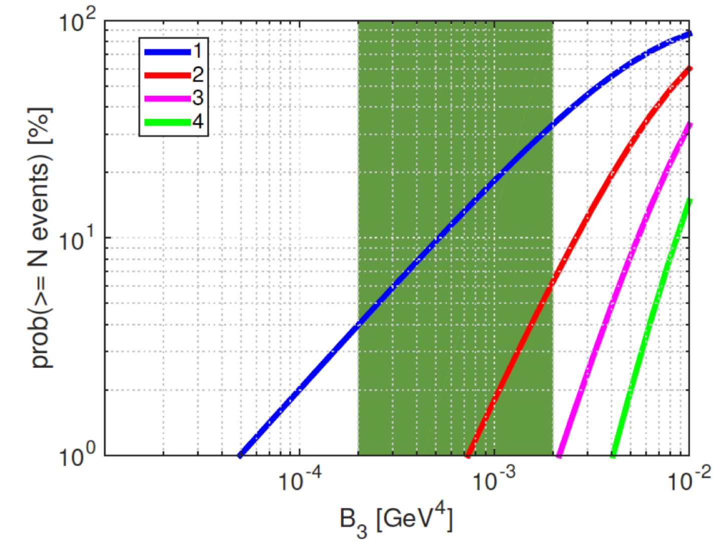


FIG. 5: Poisson probability for detecting $N \geq 1, 2, 3, 4$ $\overline{^3\text{He}}$ events in a 5-yr analysis of AMS02, assuming the same exposure as in the $\bar{p}$ analysis [28]. Eq. (14) shown as green band.

[K. Blum *et al.*, Phys.Rev. D96 (2017) no.10, 103021]

QGP thermodynamics and soft probes

Radial and elliptic flow

Bulk particle production and collectivity

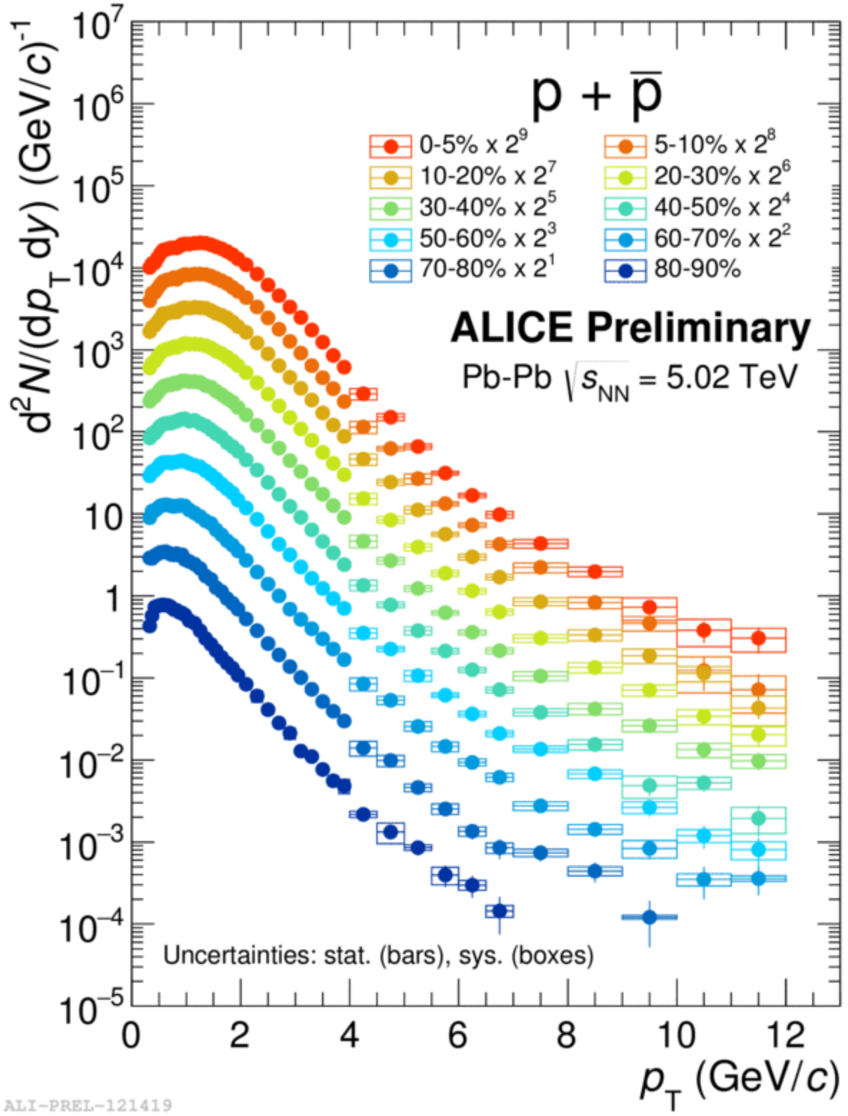
- Low p_T hadrons composed of (u,d,s) valence quarks define the collective behaviour of the fireball.

- "Baseline model of ultra-relativistic heavy-ion physics"

A fireball in *local thermodynamic equilibrium*:

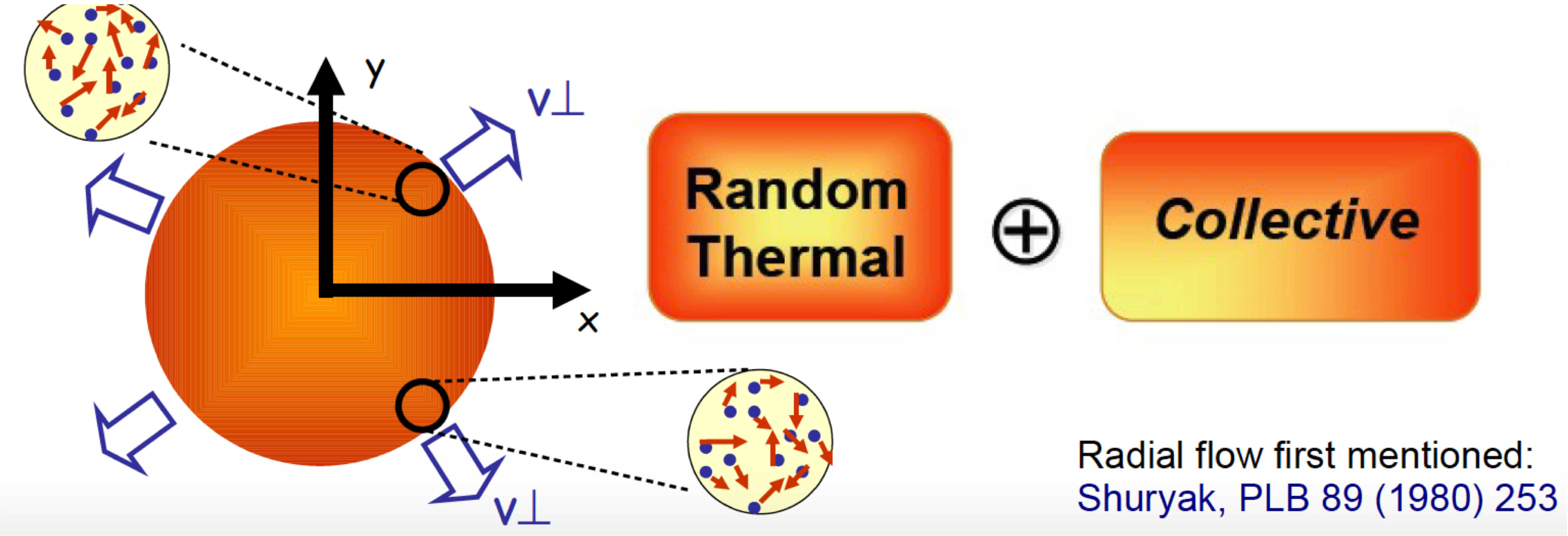
- particle chemistry in agreement with thermal model predictions
- *p_T*-spectra and *v_2* measurements show patterns of radial and elliptic hydrodynamic flow.

N.B.: Collective flow has nothing to do with the particle flow method to reconstruct tracks and jets in ATLAS/CMS



Flow in AA collisions

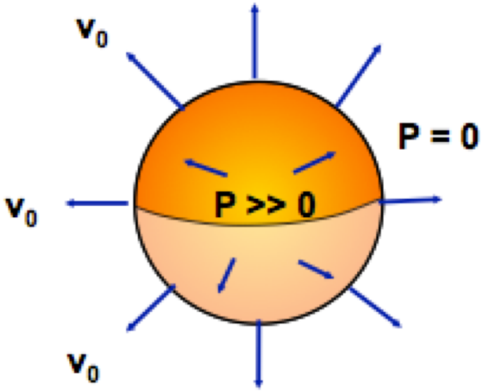
- Flow picture: Collective motion of particles superimposed to the thermal motion.
- Radial flow is a natural consequence of any interacting system expanding into the vacuum.

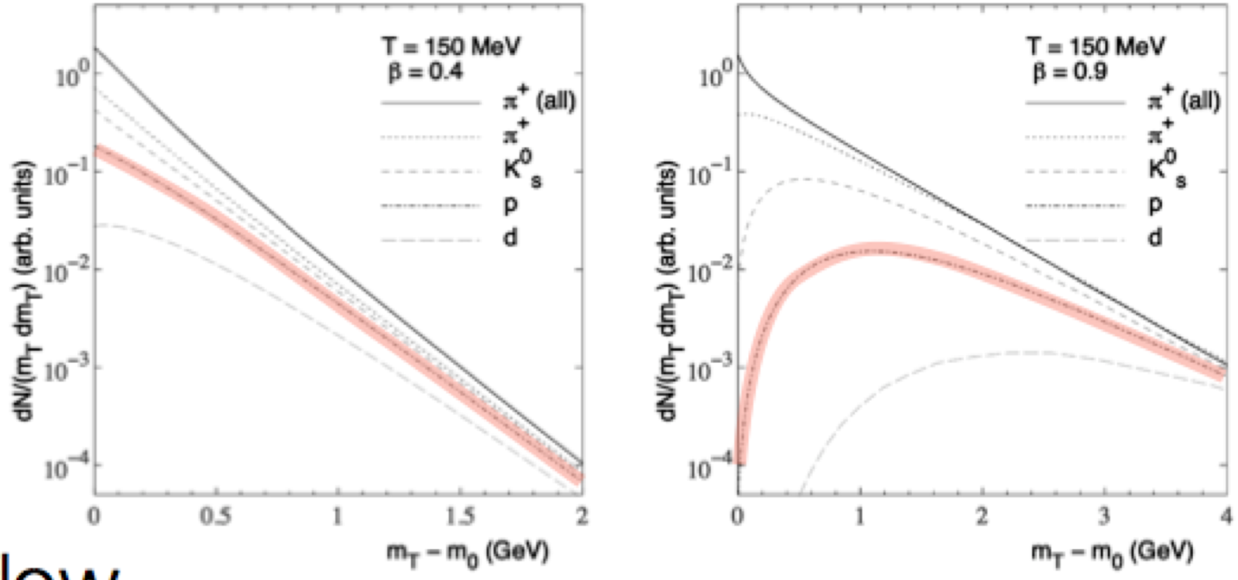


Radial flow first mentioned:
Shuryak, PLB 89 (1980) 253

From: C. Loizides

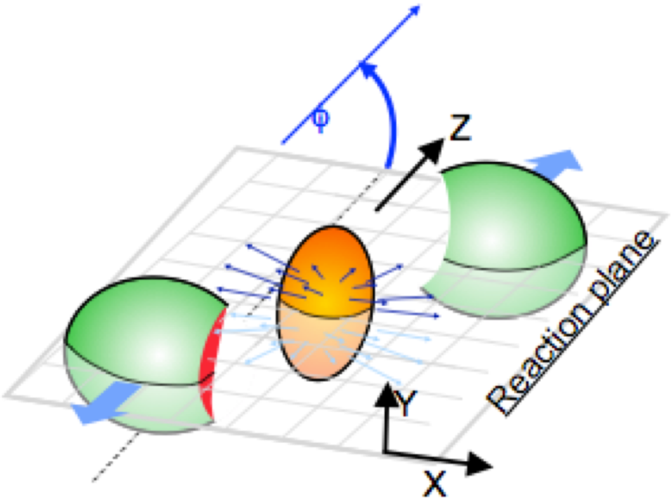
Isotropic radial flow



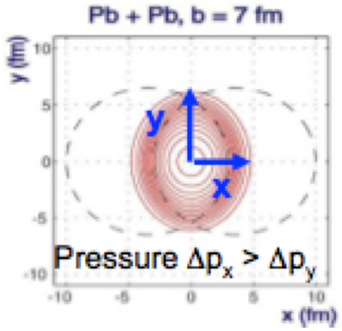


Anisotropic (elliptic) flow

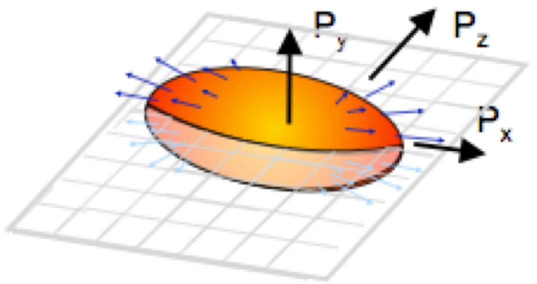
Spatial deformation



Azimuthal (φ) pressure gradients

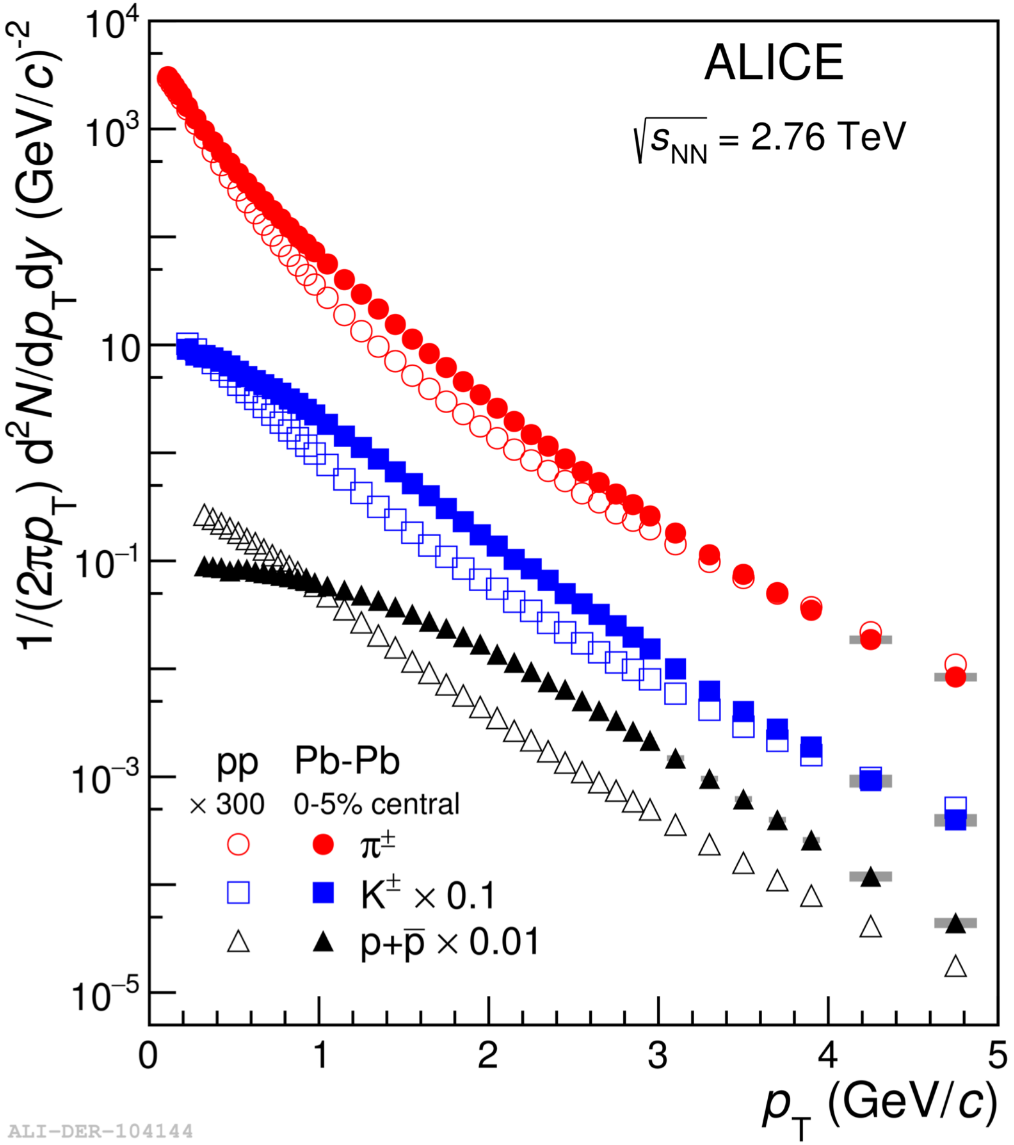


Anisotropic particle density



$$\frac{dN}{d\varphi} \propto 1 + 2v_1\cos[\varphi - \Psi_1] + 2v_2\cos[2(\varphi - \Psi_2)] + 2v_3\cos[3(\varphi - \Psi_3)] + ..$$

Radial flow



Common radial hydrodynamic expansion leads to a modification of the spectral shape: mass dependent *boost.*

→ p_T-spectra harden with centrality.

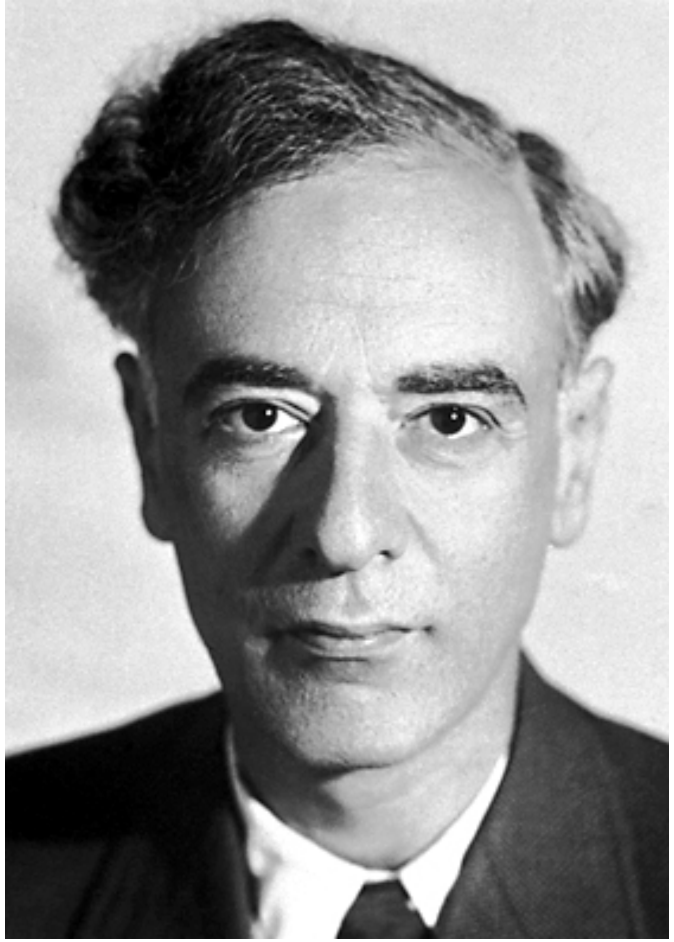
→ More pronounced for heavier particles(e.g.: $p > K > \pi$) as *velocities* become equalized in the flow field (p = **βγ**·m).

→ Hydrodynamic models show a good agreement with the data.

→ Kinetic freeze-out temperature from Blast-Wave model: ~90 MeV

Relativistic Hydrodynamics

- General framework of relativistic hydrodynamics was first developed by Landau and is textbook knowledge since then.
- Only requirement for applicability: *local thermodynamic equilibrium*.
- **Perfect fluid: no dissipation**
  - Conservation of energy and momentum: $\partial_\mu T^{\mu\nu} = 0$
  - Conservation of baryon number current: $\partial_\mu j_B^\mu(x) = 0$
    → gives five independent equations
- Six thermodynamic variables: the energy density $\varepsilon(x)$, the momentum density $P(x)$, the baryon number density $n_B(x)$, and the fluid velocity $v(x)$.
- Equation-of-state: functional relation of ε, P, and n_B (taken from Lattice QCD).
- In reality: dissipative corrections play an important role:
  → **shear viscosity η** and bulk viscosity ζ (so called *transport coefficiencts*) enter in correction terms on the right hand side of the equations above.



Lew Landau (1908-1986)

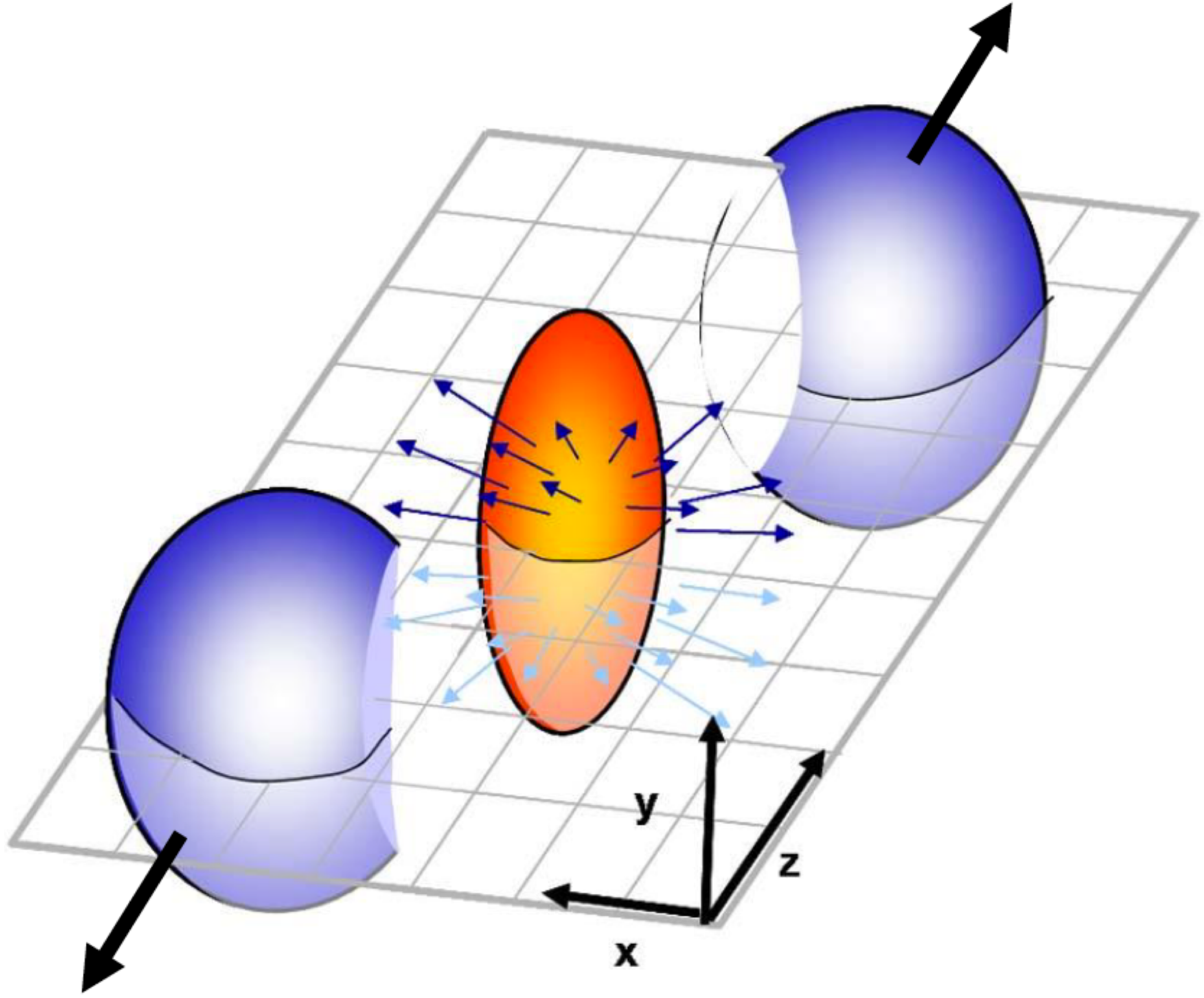
Elliptic flow v_2

- Not only the observed particle spectrum in p_T, but also in φ is the result of the fireball expansion.
- If the system is asymmetric in spatial coordinates, scattering converts it to **anisotropy in momentum space:**

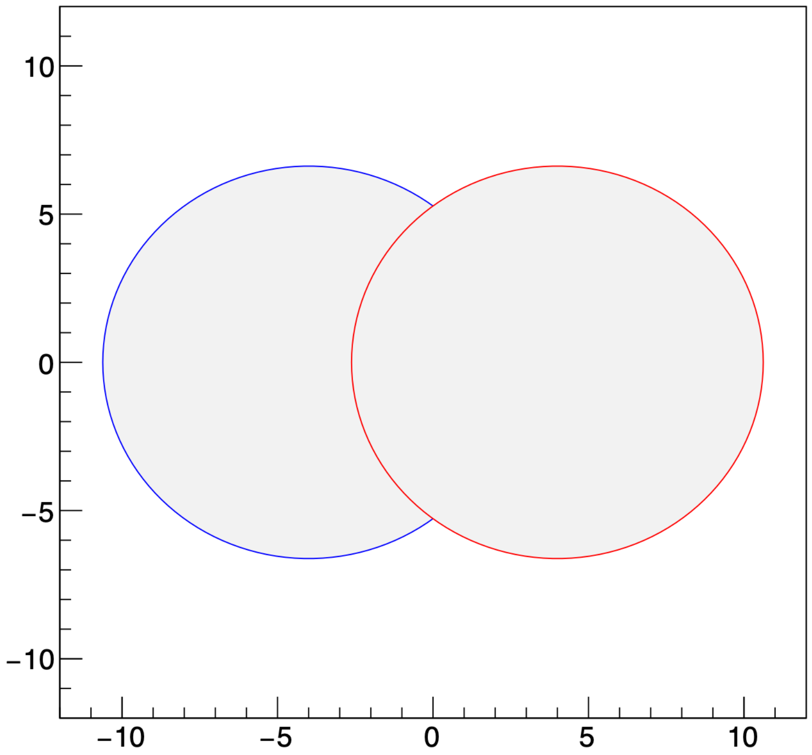
$$E\frac{d^3N}{d^3p} = \frac{d^2N}{2\pi p_T dp_T dy}\left\{1 + 2\sum_{n=1}^{\infty} v_n(p_T)\cos[n(\varphi-\psi_n)]\right\}$$

Radial flow v_1 – direct flow, **v_2- elliptic flow**

- If nuclei overlap was a smooth almond shape, odd harmonics (v_3,..) would be zero.



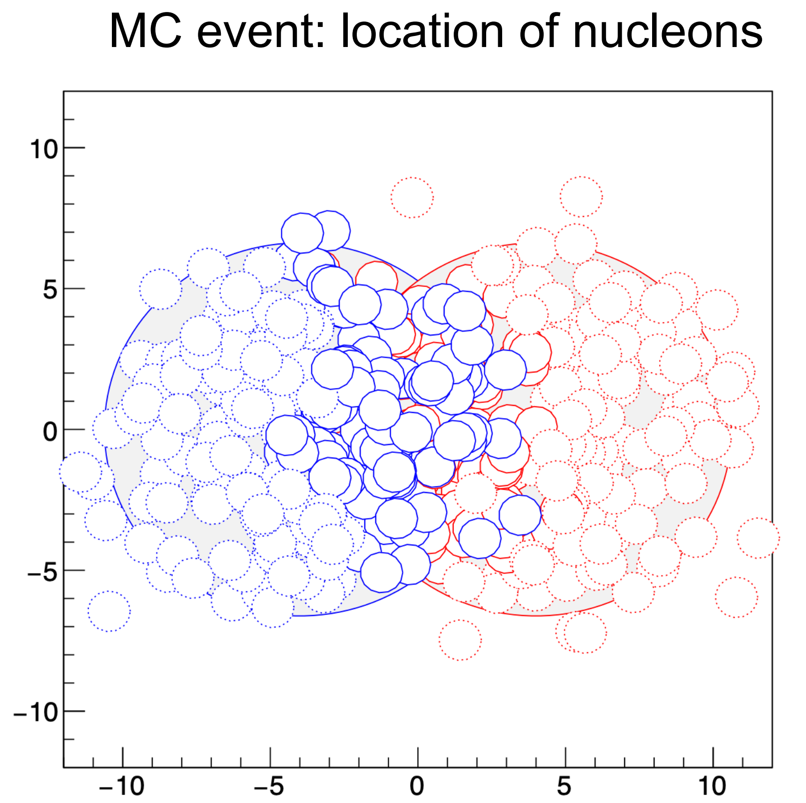
Azimuthal anisotropy (1)



Characterise shape by angular moments:

$$\varepsilon_n = \frac{\sum r^2(\cos^2 n\varphi + \sin^2 n\varphi)}{\sum r^2}$$

Azimuthal anisotropy (2)

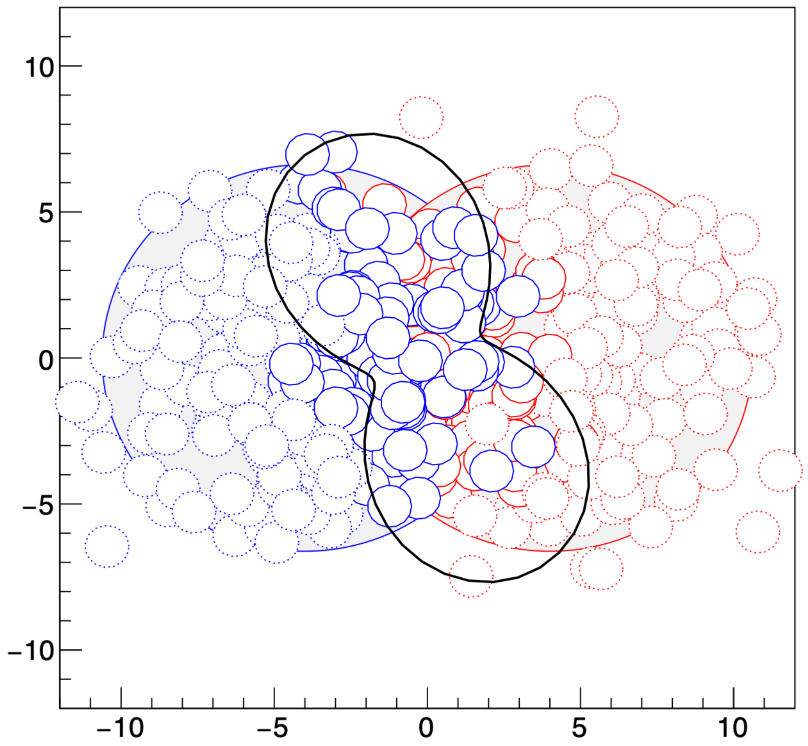


Characterise shape by angular moments:

$$\varepsilon_n = \frac{\sum r^2(\cos^2 n\varphi \;+\; \sin^2 n\varphi)}{\sum r^2}$$

Azimuthal anisotropy (3)

MC event: location of nucleons

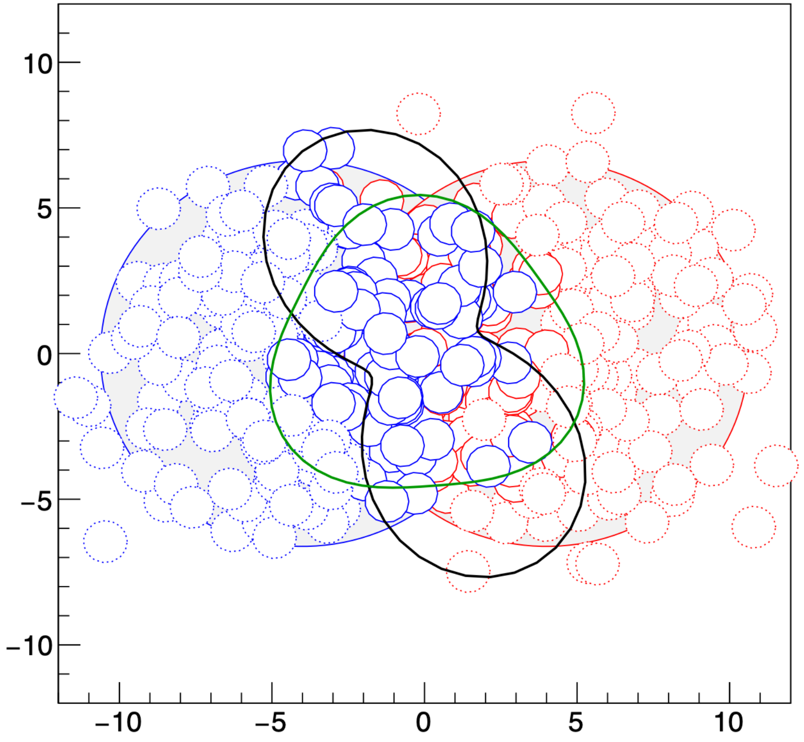


Characterise shape by angular moments:

$$\varepsilon_n = \frac{\sum r^2(\cos^2 n\varphi \; + \; \sin^2 n\varphi)}{\sum r^2}$$

Azimuthal anisotropy (4)

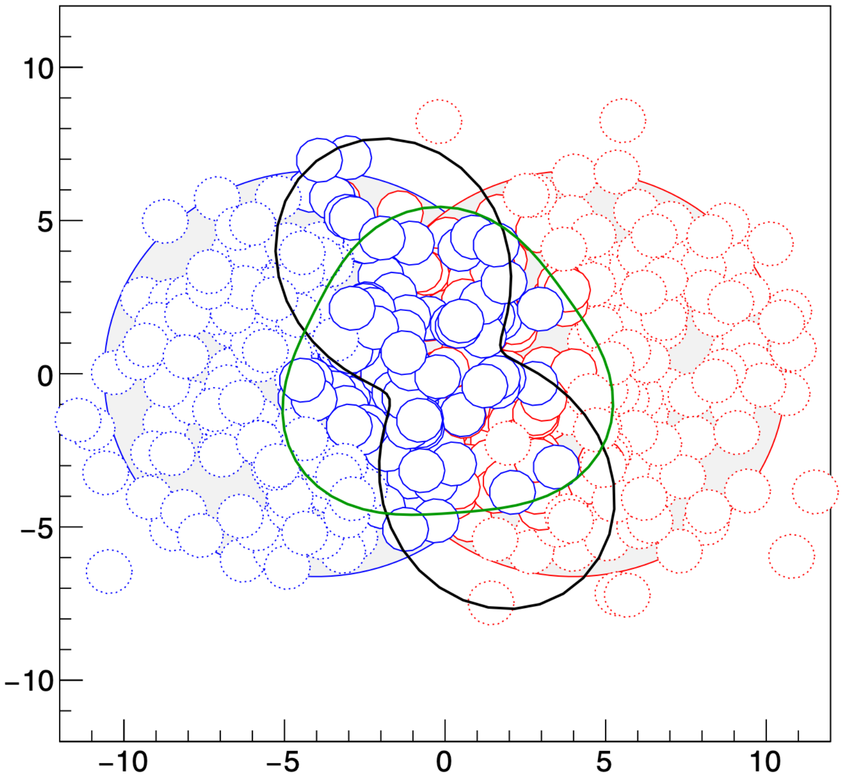
MC event: location of nucleons



Characterise shape by angular moments:

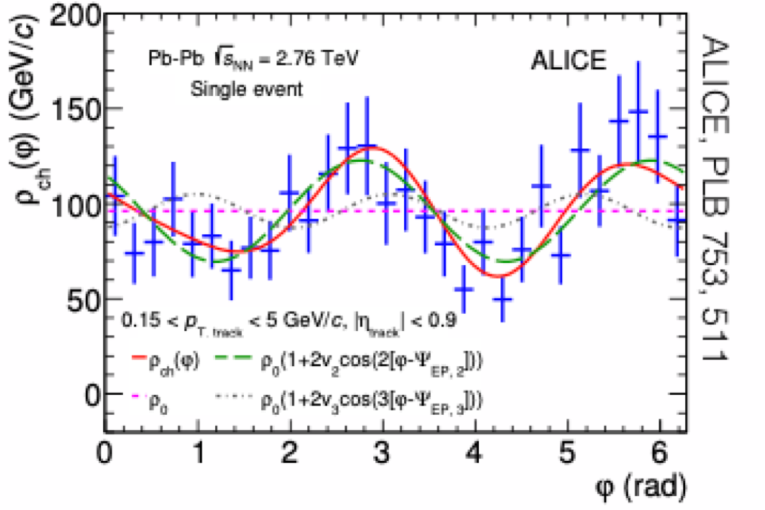
$$\varepsilon_n = \frac{\sum r^2 (\cos^2 n\varphi + \sin^2 n\varphi)}{\sum r^2}$$

Azimuthal anisotropy (5)

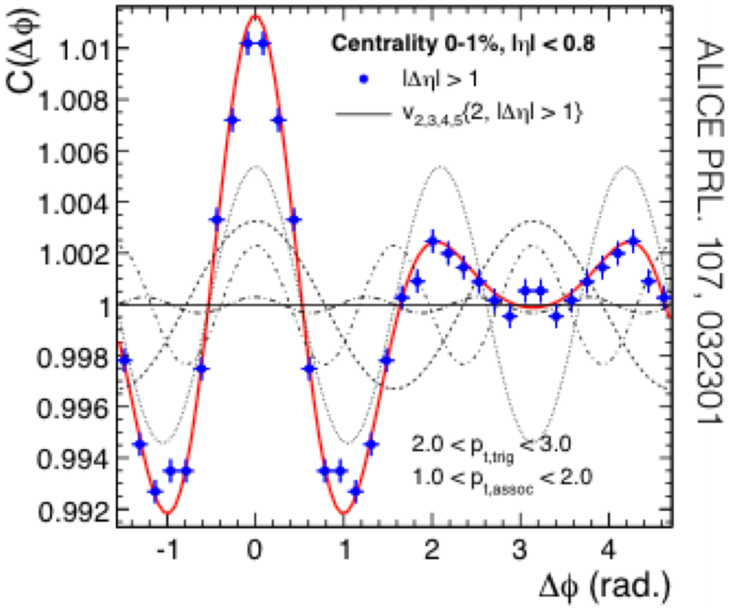


$$\nabla p = \rho \frac{d\vec{v}}{dt}$$

Azimuthal distribution single event



Sum over many events



Initial state spatial anisotropies $\boldsymbol{\varepsilon}_n$ are transferred into final state momentum anisotropies v_n by pressure gradients, flow of the Quark Gluon Plasma

Centrality dependence of v_2

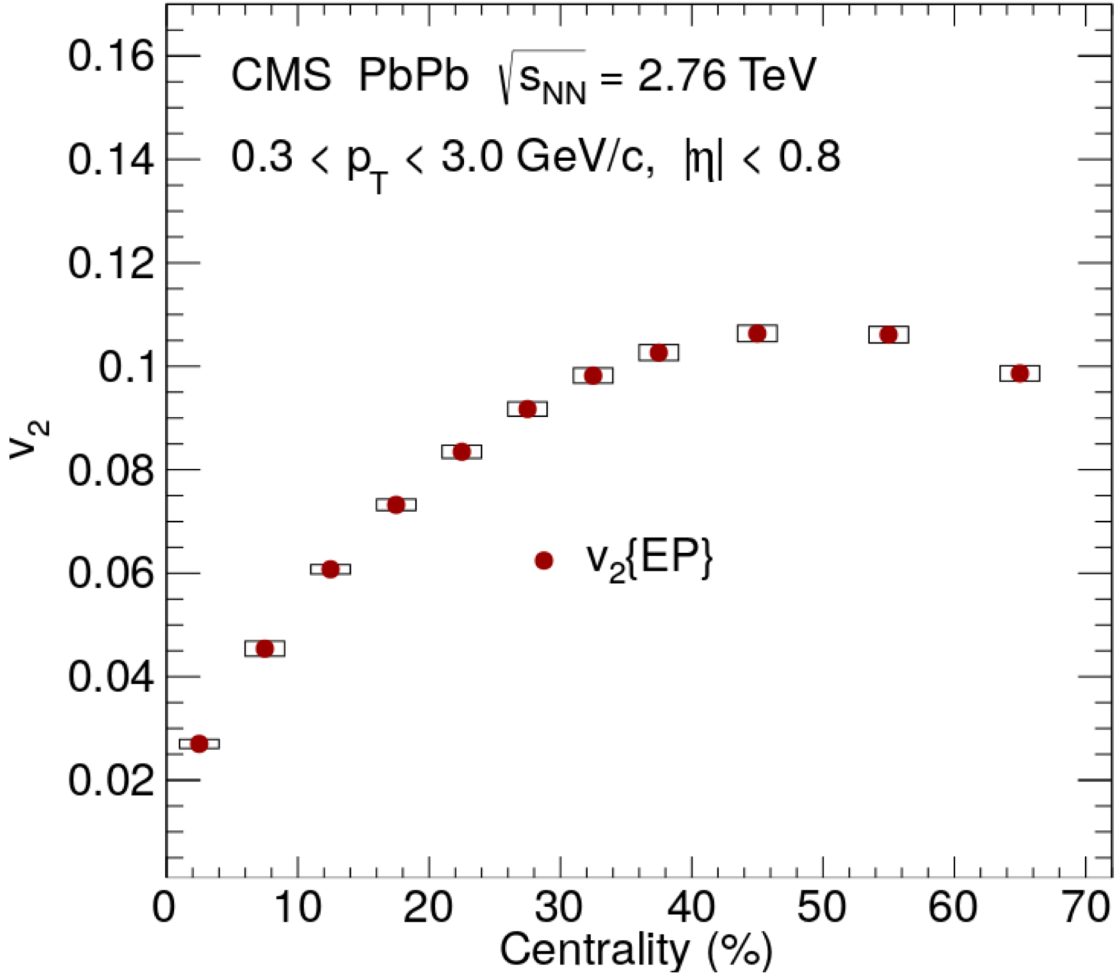
- v_2 exhibits a strong centrality dependence

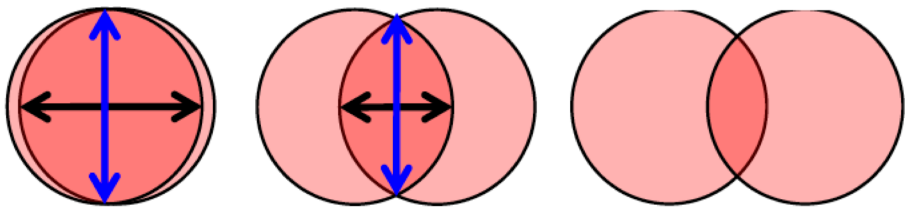
- v_2 largest for 40-50%

- Spatial anisotropy very small in central collisions

- Largest anisotropy in mid-central collisions

- Small overlap region in peripheral collisions

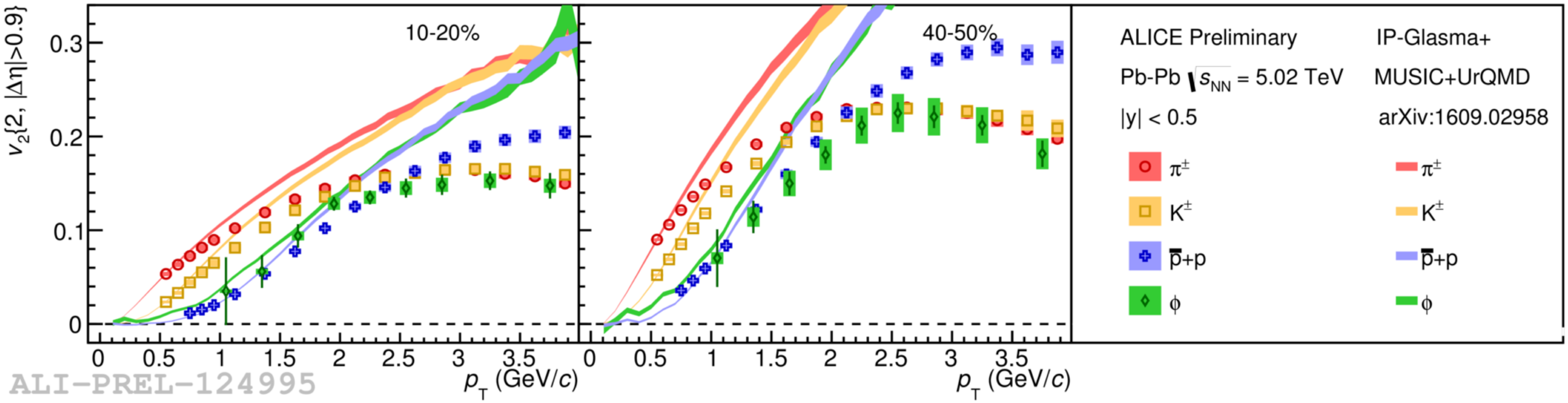




CMS, PRC 87(2013) 014902

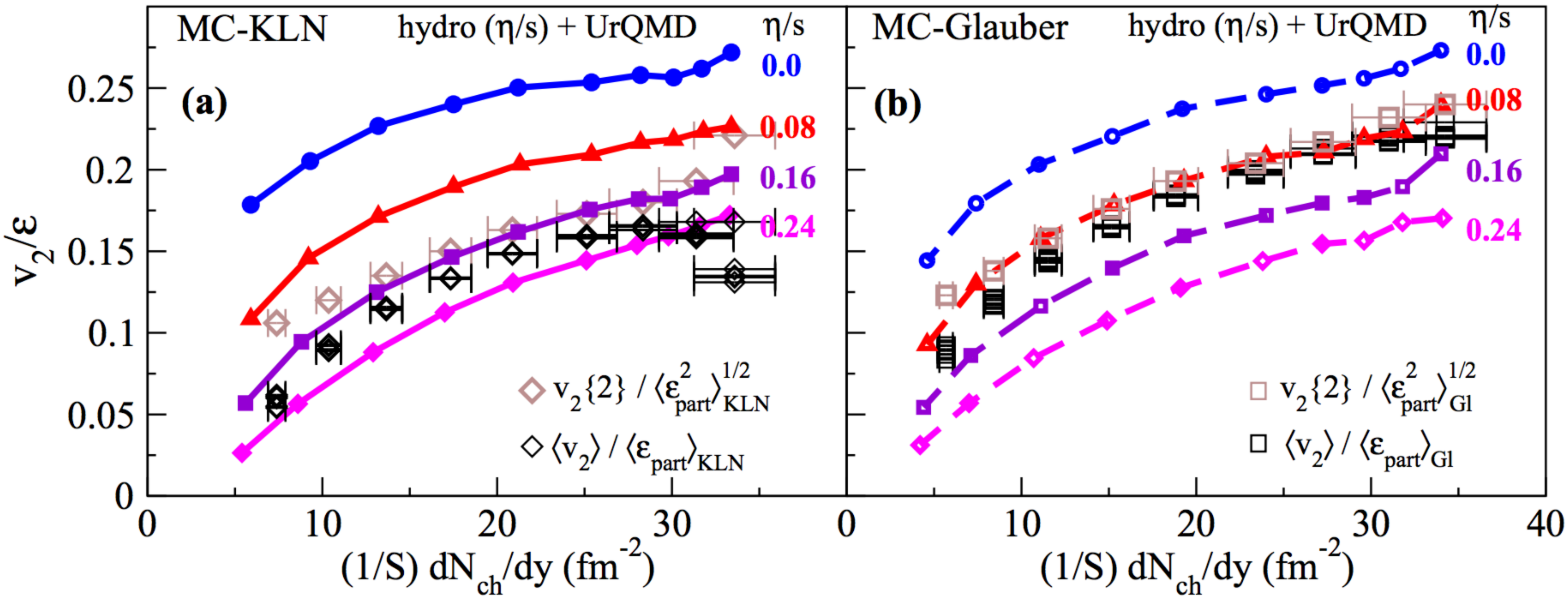
Mass ordering of v_2 vs. transverse momentum

Transverse momentum dependence of elliptic flow shows the same mass ordering (p = **β**γ·m) as radial flow and as expected from hydrodynamics.
→ interplay of radial and elliptic flow.



Sensitivity of v_2 to shear viscosity

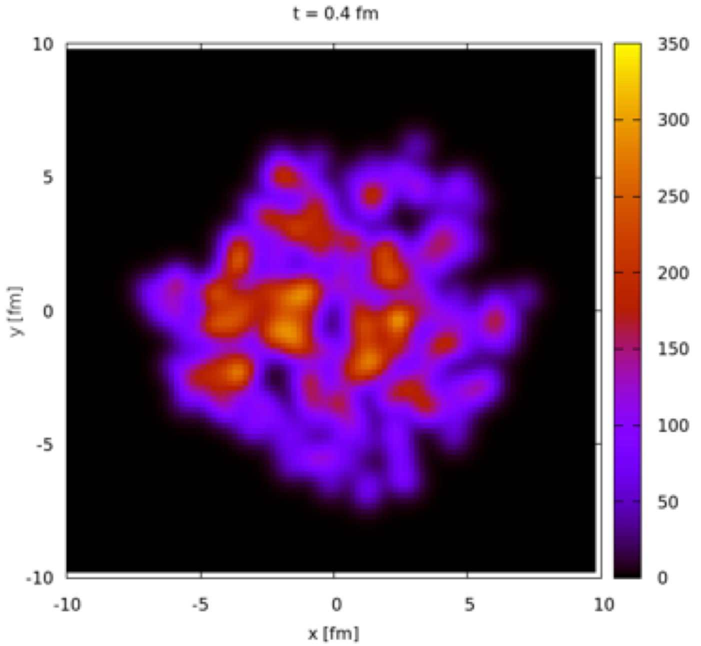
[Phys.Rev.Lett. 106 (2011) 192301]



- The larger the shear viscosity per entropy density ratio *η/s* of the QGP, the more v_2 is reduced.
- Dissipative losses hamper the buildup of flow => measuring the magnitude of v_2 and comparing it to models, we can determine how *ideal* the QGP liquid is.

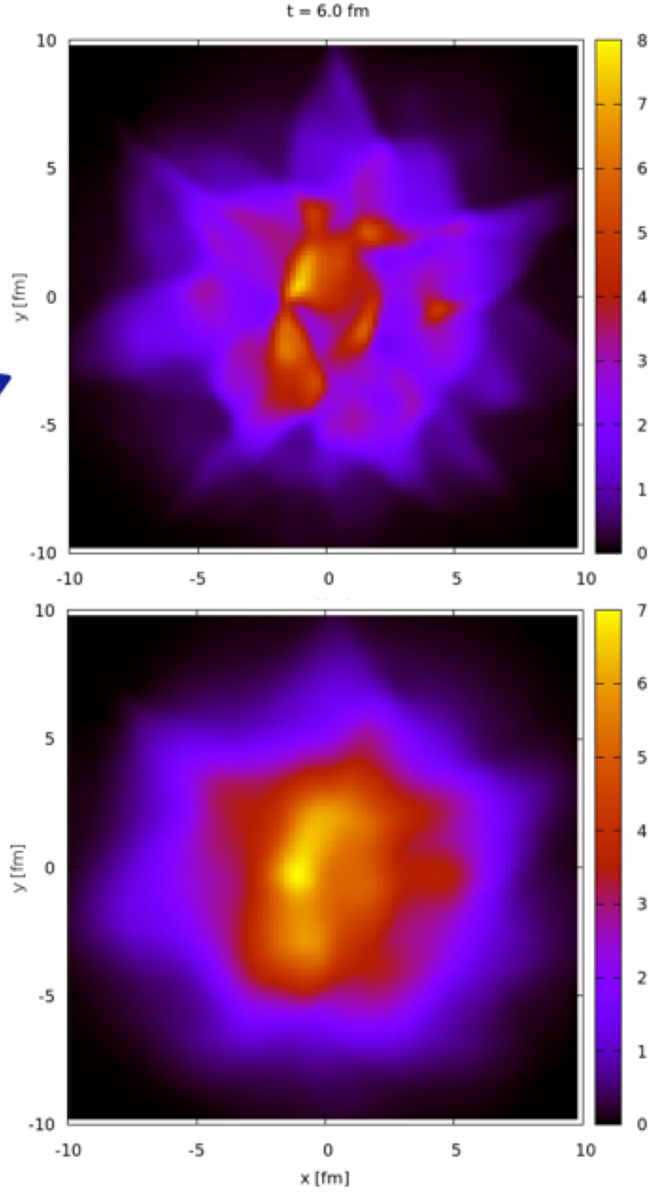
Higher harmonics and viscosity

In general: initial state is lumpy



$\eta/s = 0$

$\eta/s = 0.16$



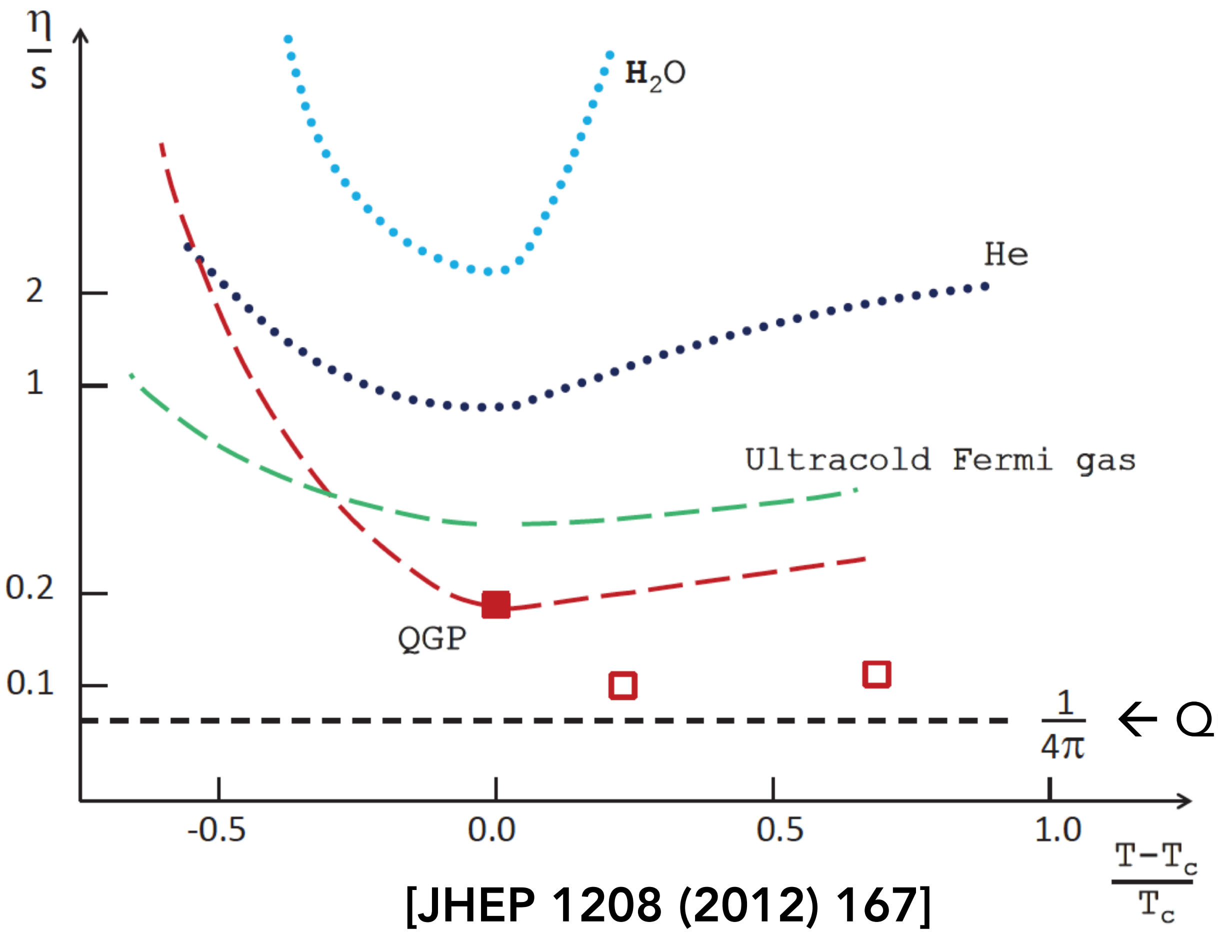
How much of this is visible in the final state, depends on shear viscosity η

and a number of other model parameters

[Schenke and Jeon, Phys.Rev.Lett.106:042301]

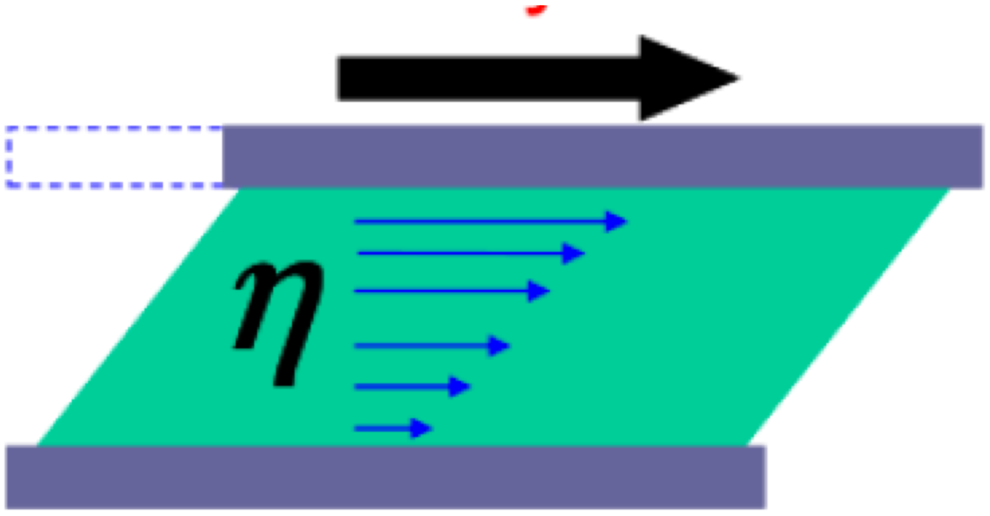
Ideal fluids (1)

→ Why are ideal fluids (η/s very small) fascinating? Look at superfluid Helium as an example: https://www.youtube.com/watch?v=2Z6UJbwxBZI



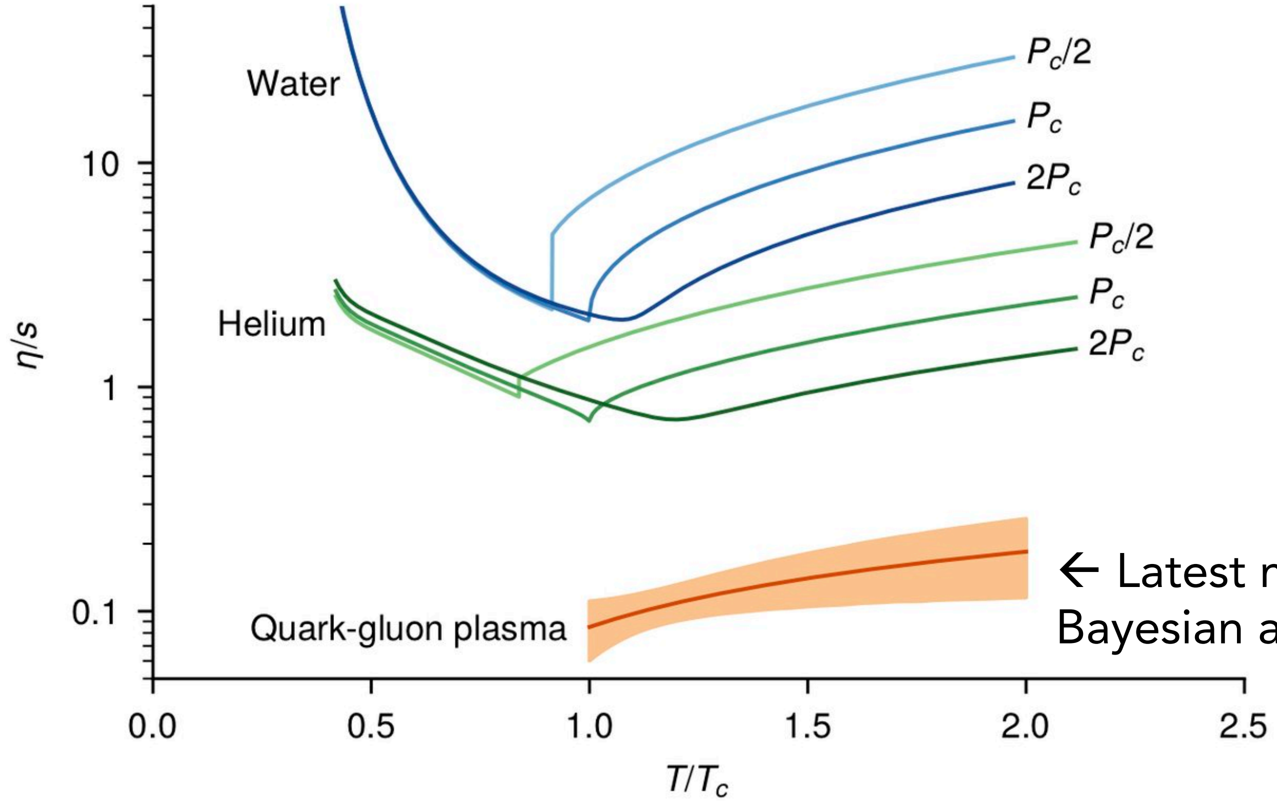
← Quantum limit derived from string theory via AdS-CFT

[JHEP 1208 (2012) 167]



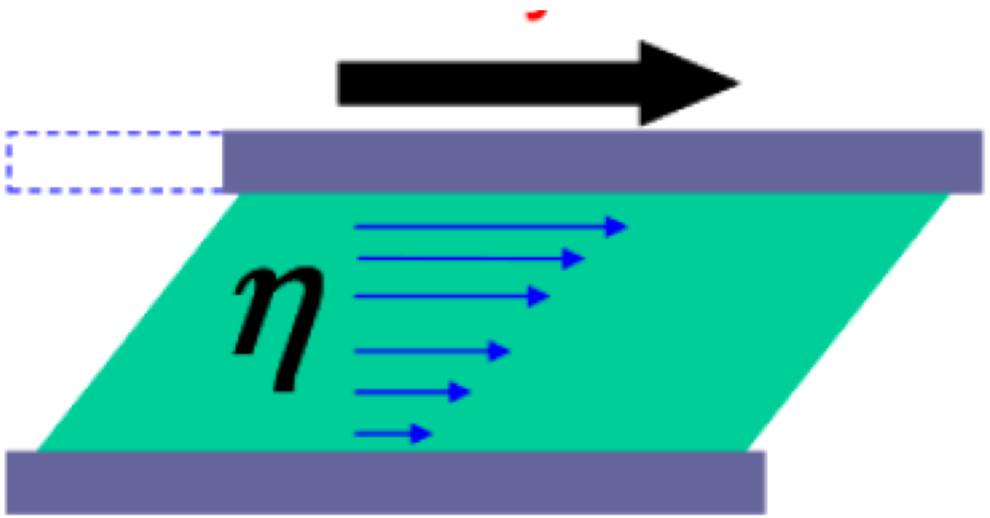
Ideal fluids (2)

→ Why are ideal fluids (η/s very small) fascinating? Look at superfluid Helium as an example: https://www.youtube.com/watch?v=2Z6UJbwxBZI



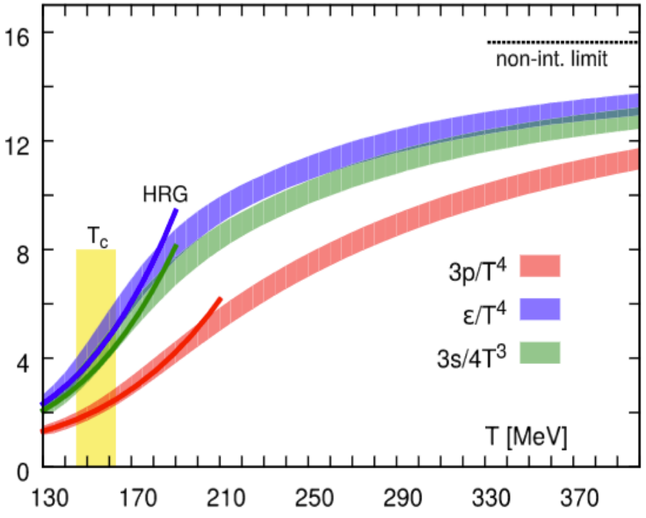
← Latest measurement based on Bayesian analysis of LHC data

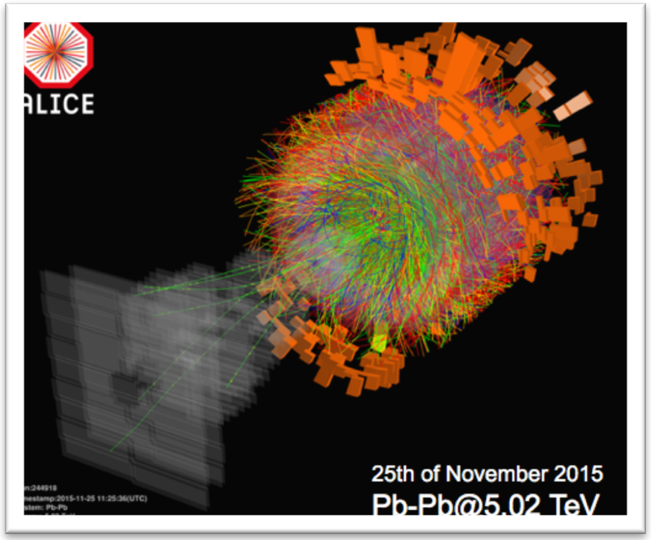
[J. Bernhard et al, *Nature Physics* (2019)]

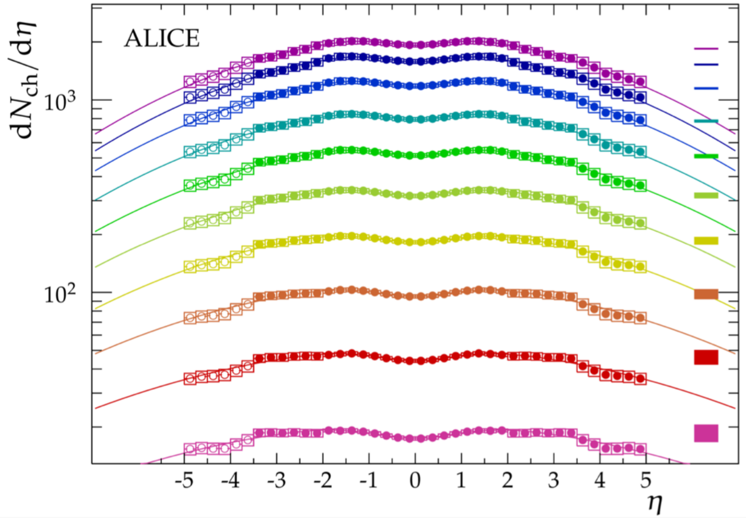


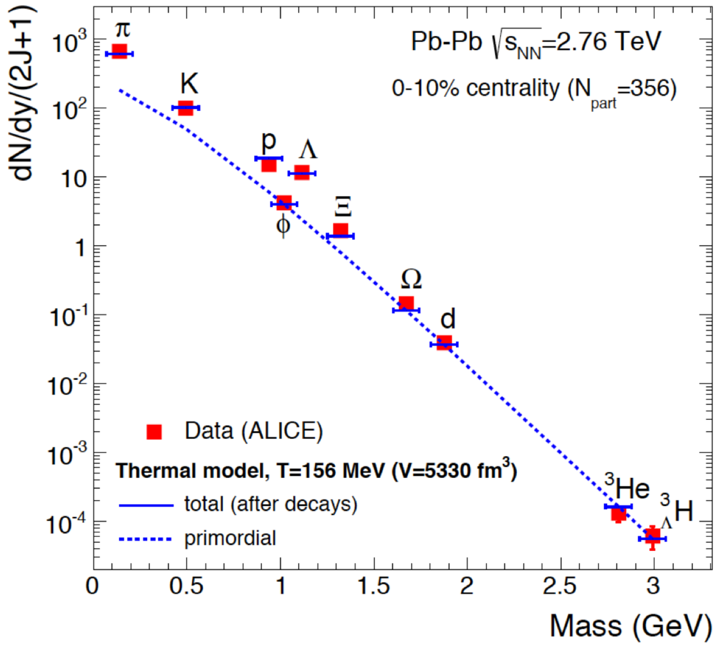
Summary

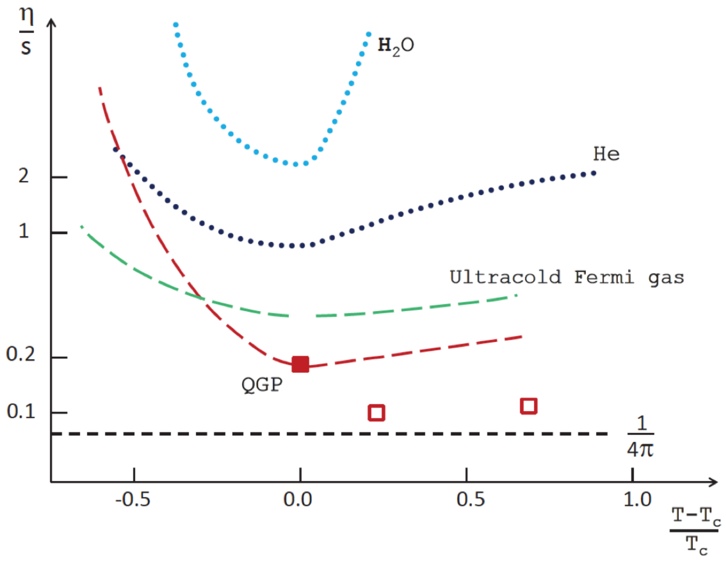
[PRD 90 094503 (2014)]











Further reading

- Lectures
  - J. Stachel, K. Reygers (2011)
    http://www.physi.uni-heidelberg.de/~reygers/lectures/2011/qgp/qgp_lecture_ss2011.html
  - P. Braun-Munzinger, A. Andronic, T. Galatyuk (2012)
    http://web-docs.gsi.de/~andronic/intro_rhic2012/
  - Quark Matter Student Day (2014)
    https://indico.cern.ch/event/219436/timetable/#20140518.detailed
- Books
  - C.Y. Wong, Introduction to High-Energy Heavy-Ion Collisions, World Scientific, 1994
    http://books.google.de/books?id=Fnxvrdj2NOQC&printsec=frontcover
  - L. P. Csernai, Introduction to Relativistic Heavy-Ion Collisions, 1994 (**free as pdf**)
    http://www.csernai.no/Csernai-textbook.pdf
  - E. Shuryak, The QCD vacuum, hadrons, and superdensematter, World Scientific, 2004
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  - W. Florkowski, Phenomenology of Ultra-Relativistic Heavy-Ion Collisions, World Scientific, 2010
    http://books.google.de/books?id=4gIp05n9lz4C&printsec=frontcover