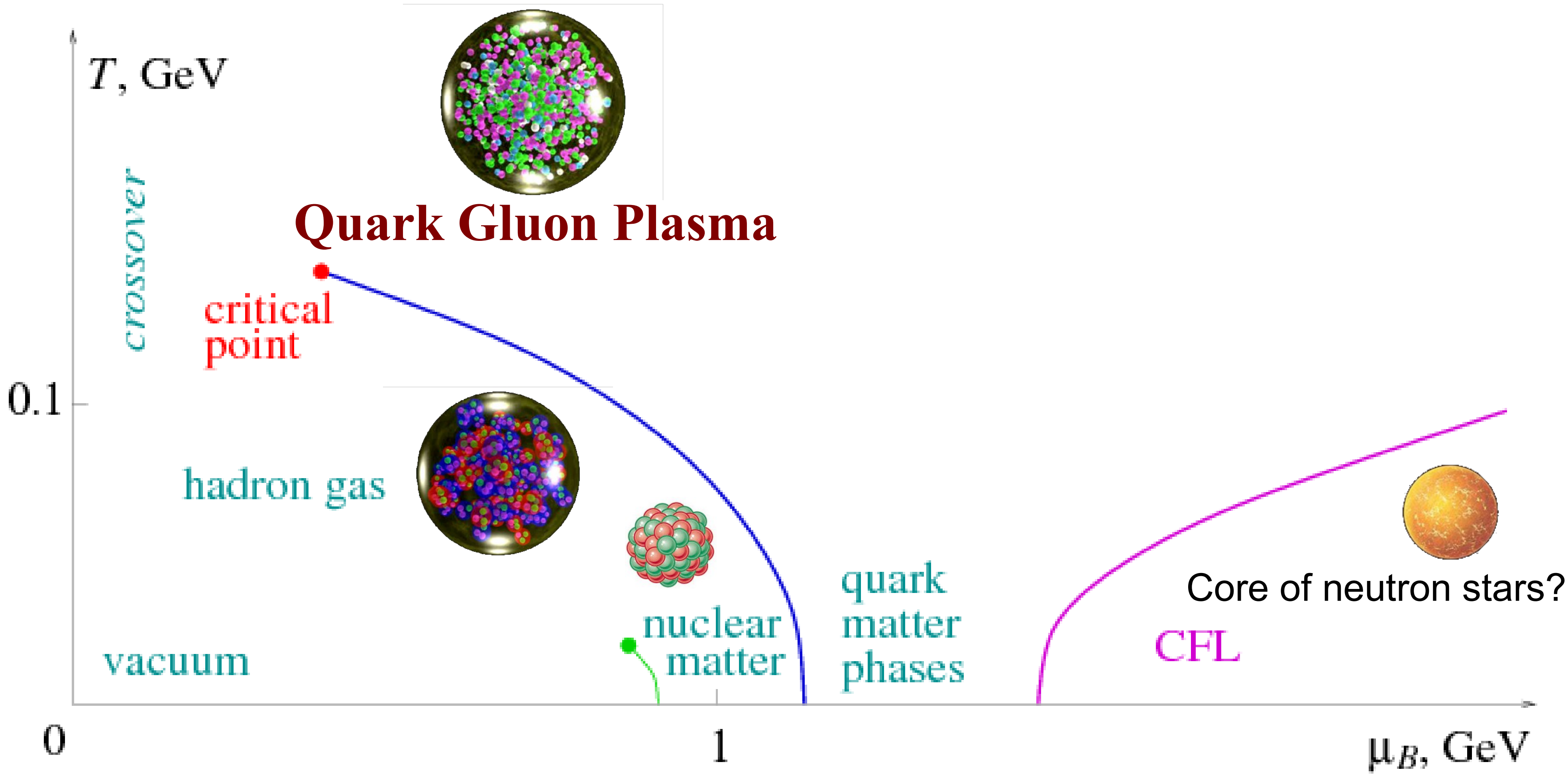
Results from ALICE

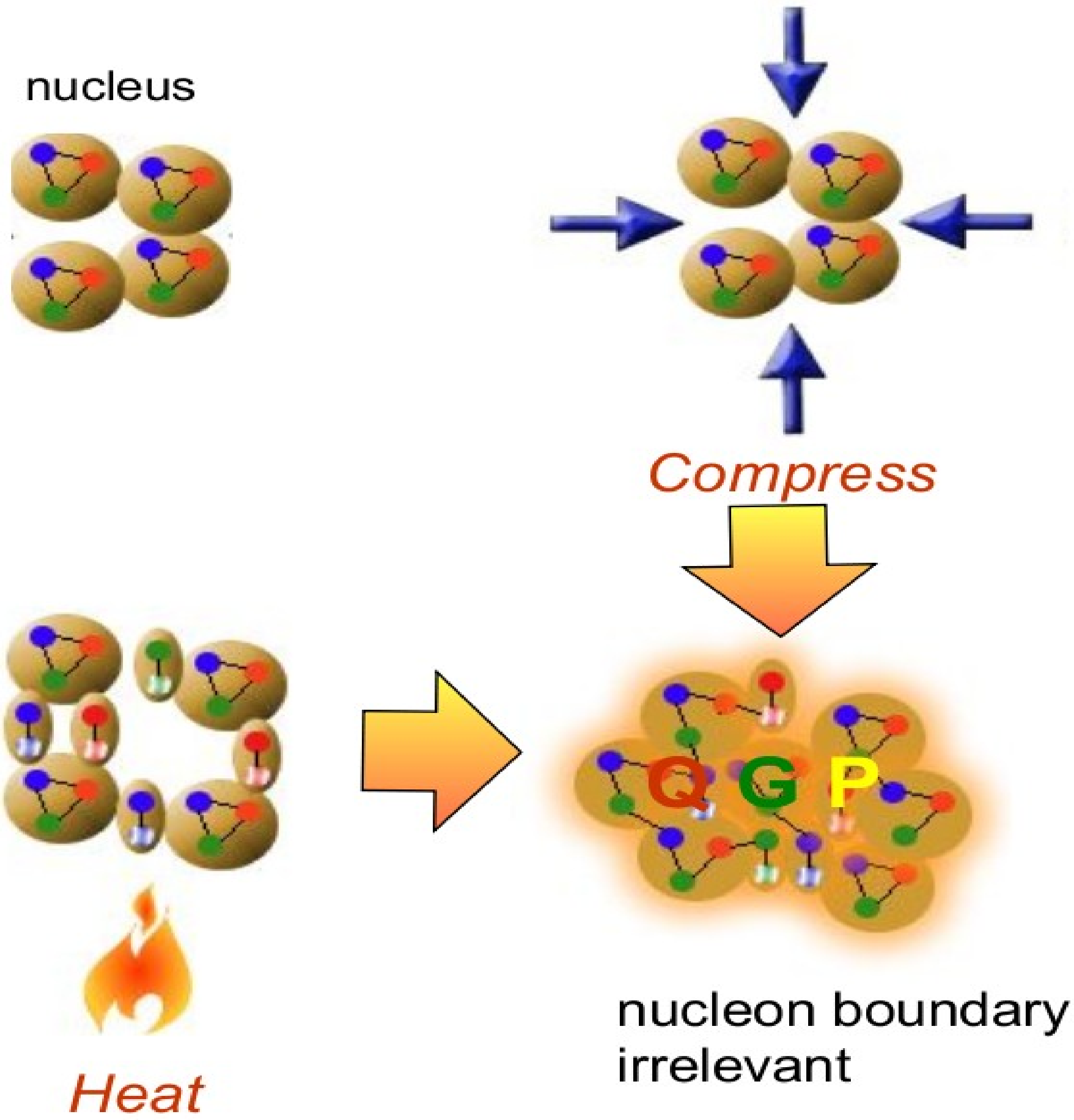
Christine Nattrass
University of Tennessee at Knoxville

Phase diagram of nuclear matter

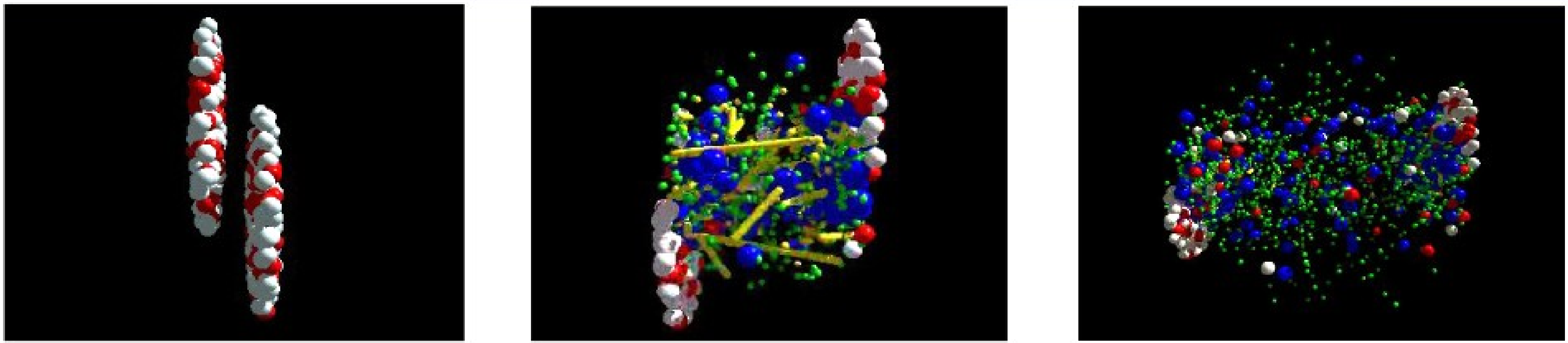


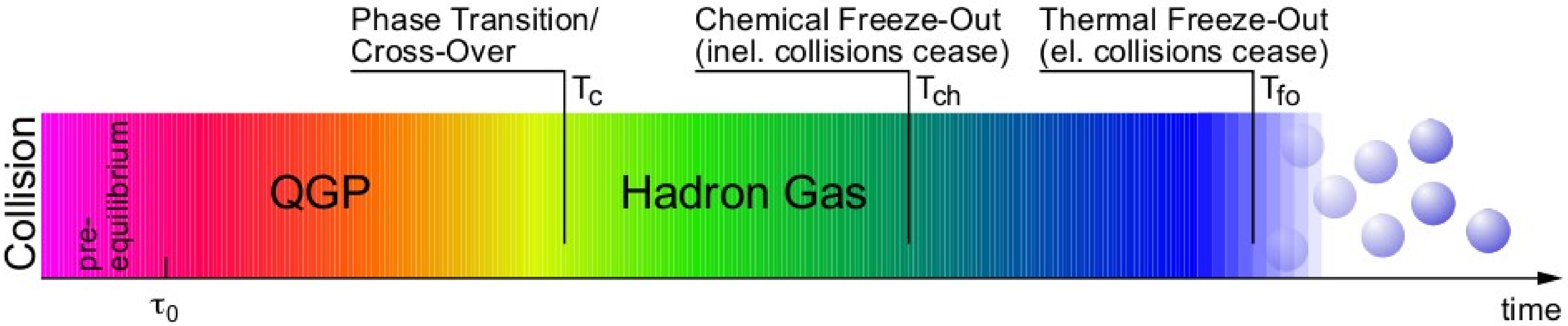
Quark Gluon Plasma – a *liquid* of quarks and gluons created at temperatures above ~170 MeV ($2 \cdot 10^{12}$K) – over a million times hotter than the core of the sun

How to make a Quark Gluon Plasma



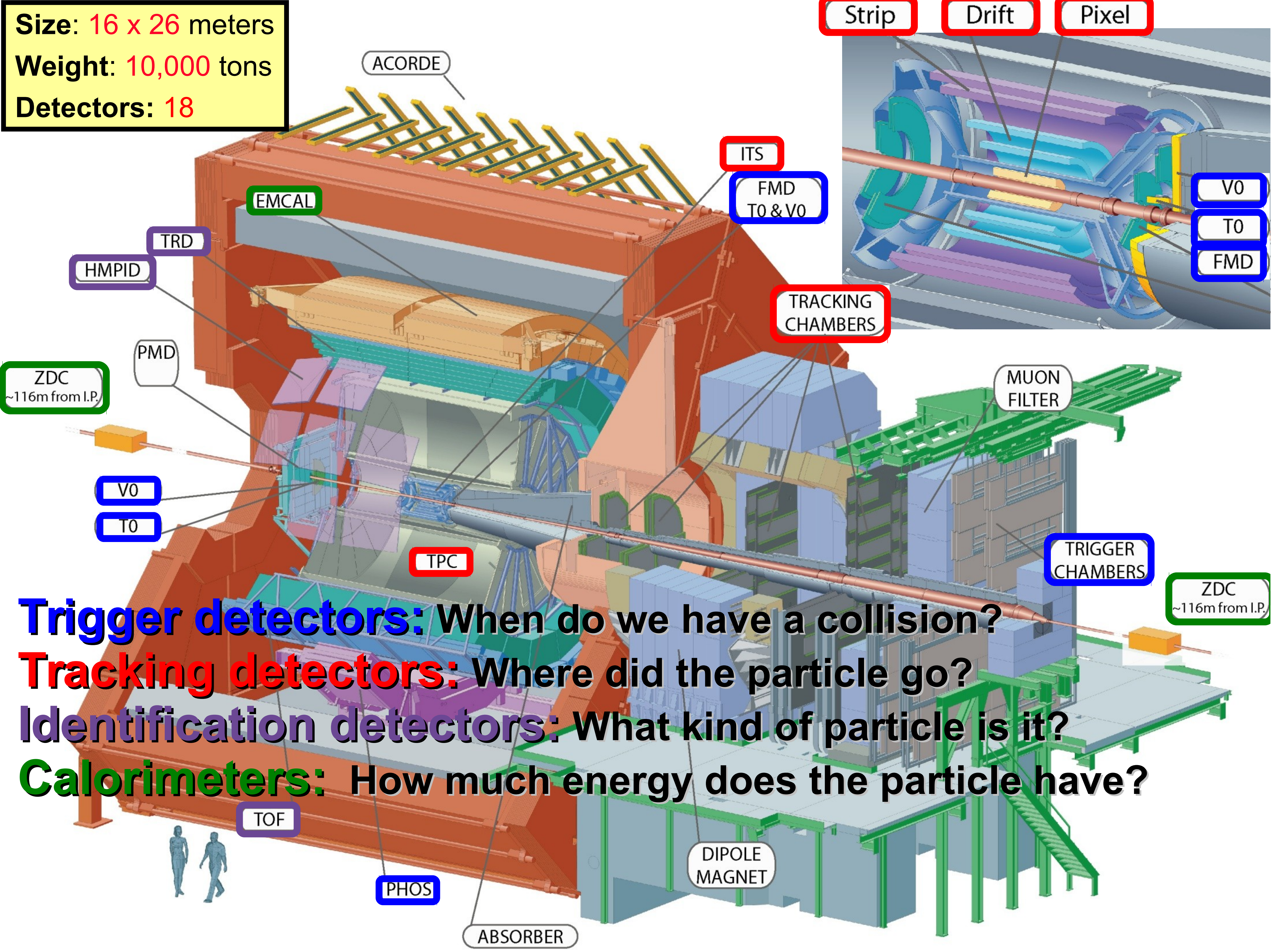
The phase transition in the laboratory





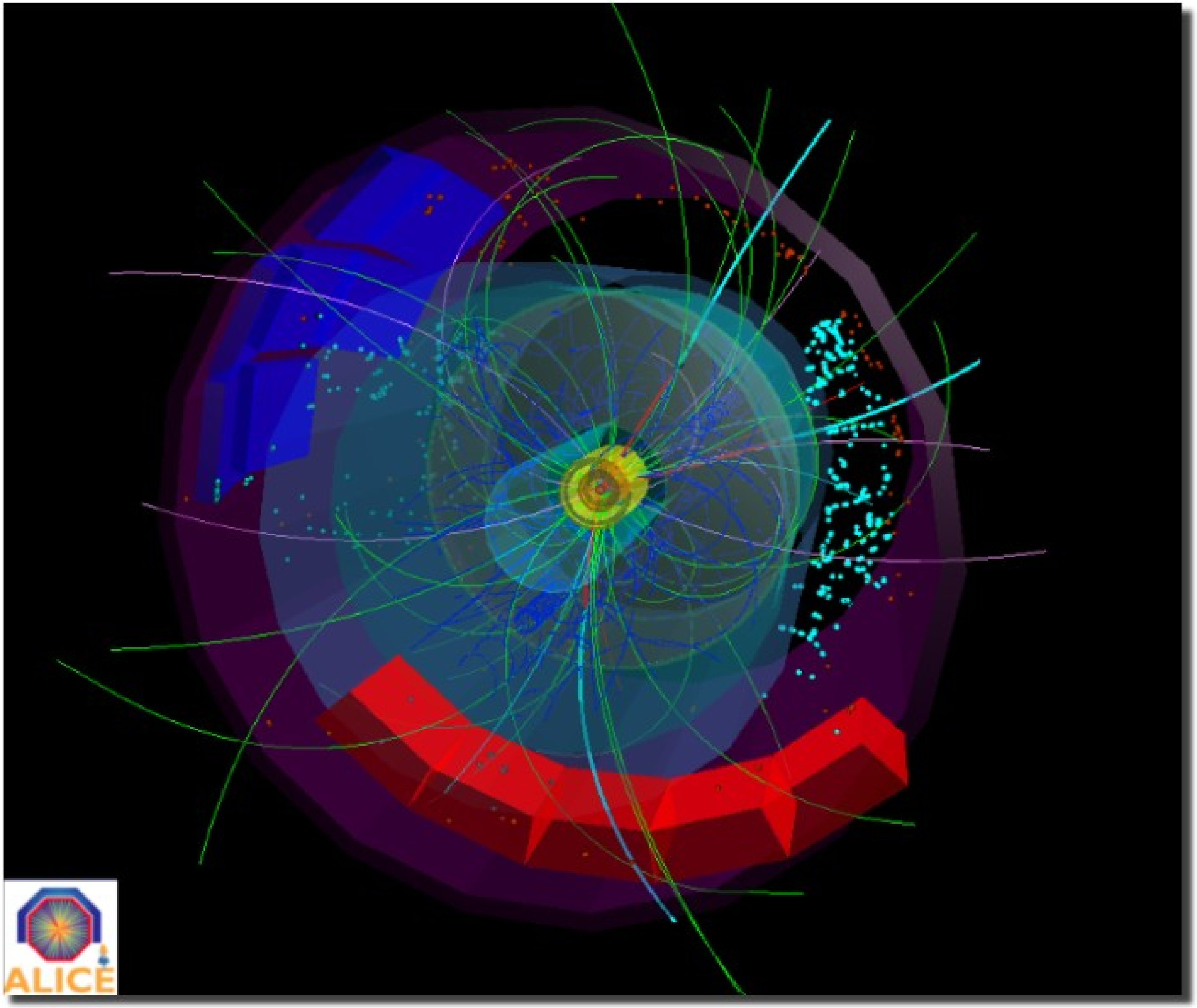
Large Hadron Collider
Geneva, Switzerland
8.6km diameter
p+p, *p+Pb*, Pb+Pb
$\sqrt{s}_{NN}$ = 2.76 GeV, *5.5 TeV*
CMS
LHCb
ALICE
ATLAS
LHCf

Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18



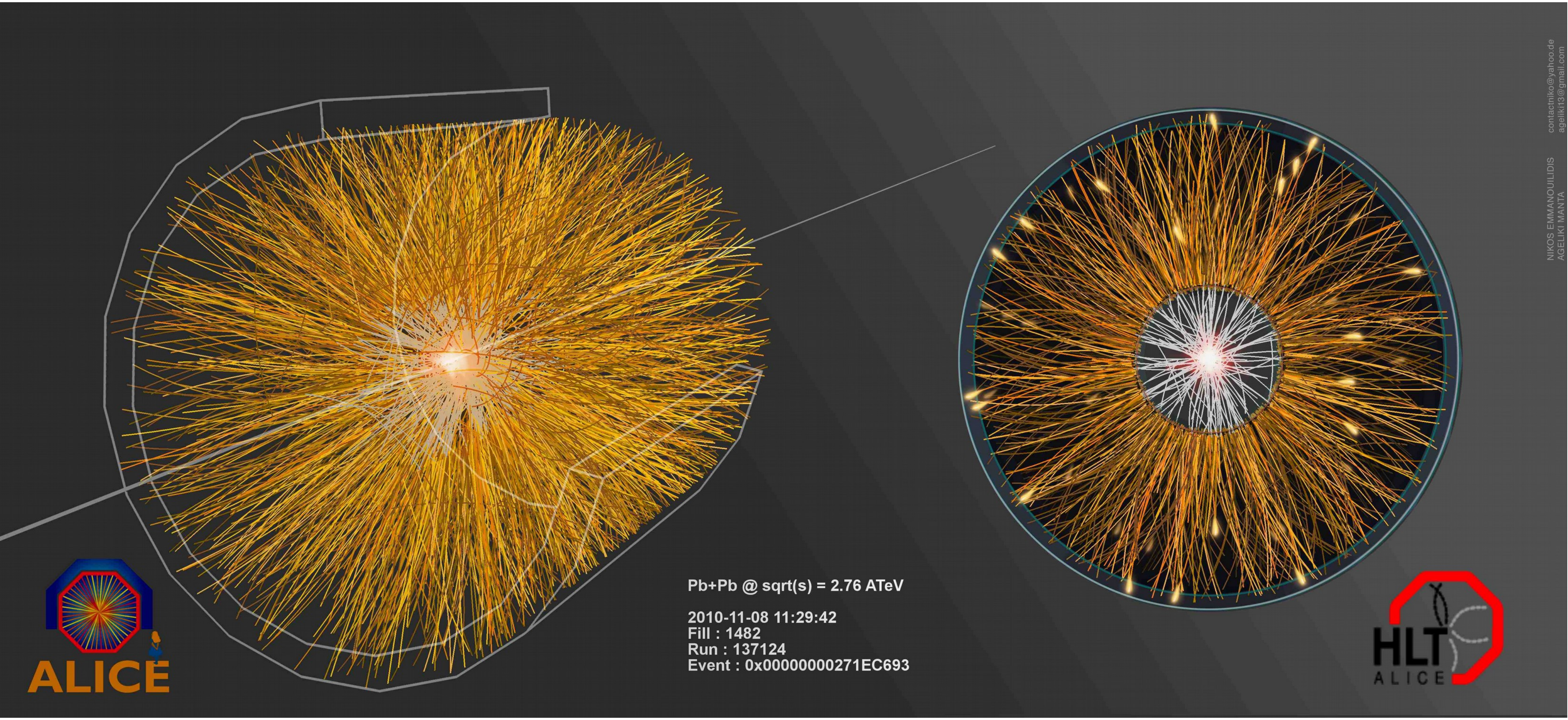
Trigger detectors: When do we have a collision?
Tracking detectors: Where did the particle go?
Identification detectors: What kind of particle is it?
Calorimeters: How much energy does the particle have?

p+p collisions

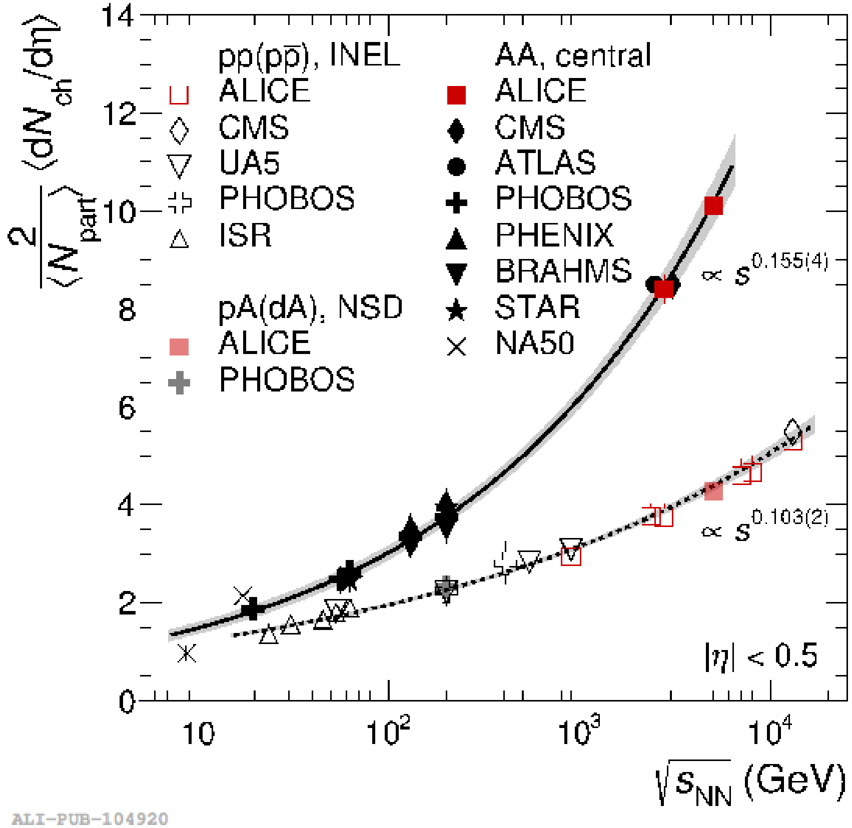


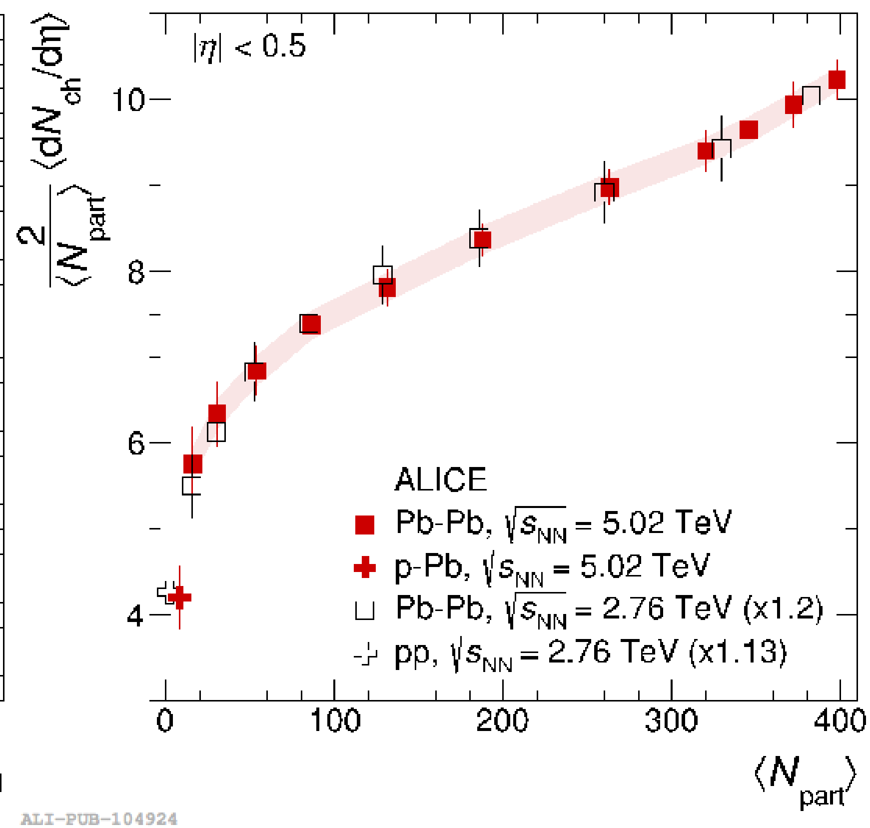
3D image of each collision

Pb+Pb collisions



Charged particle multiplicity

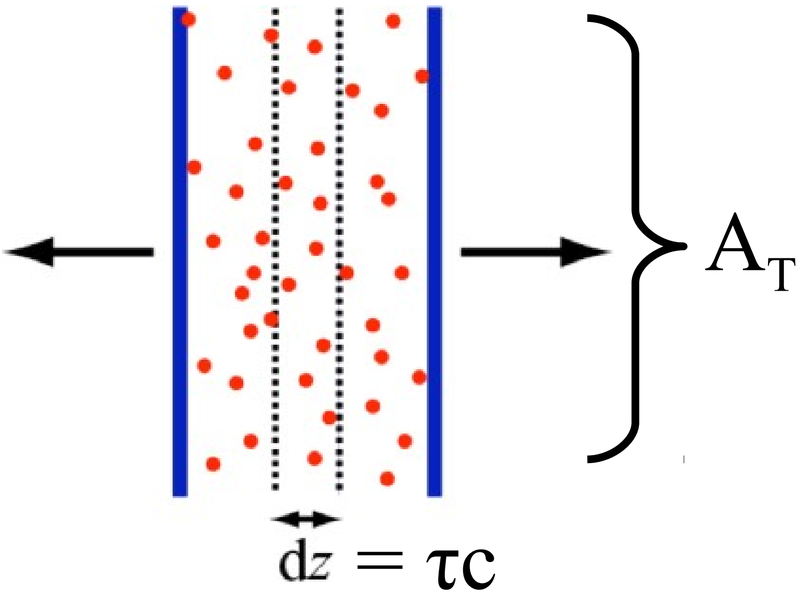




- ALICE: Pb–Pb at 5.02 TeV — highest energy so far
  - For 0–5% most central collisions, confirms trend from lower energies
- $\langle dN_{ch}/d\eta \rangle$ vs. $\langle N_{part} \rangle$: similar evolution with centrality between 5.02 and 2.76 TeV
  - ~20% increase going from 2.76 to 5.02 TeV
  - Provides further constraints for models

How can we estimate the energy density?

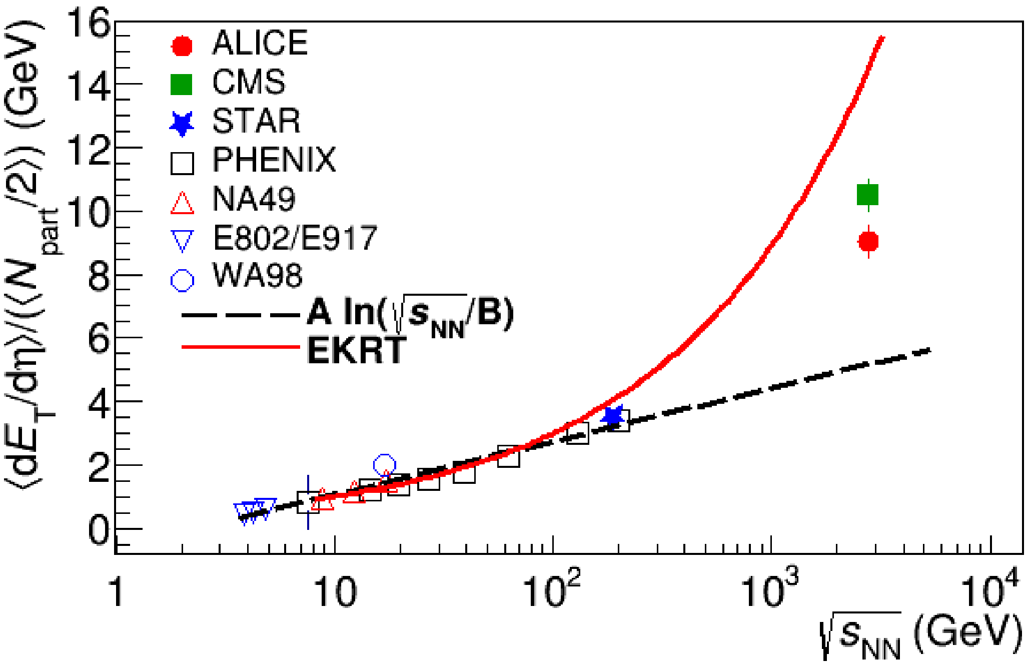
- Transverse energy (E_T)
  - sum of particle energies in transverse direction
- Volume $V = A_T \tau c$
- τ = formation time
- Energy density ε

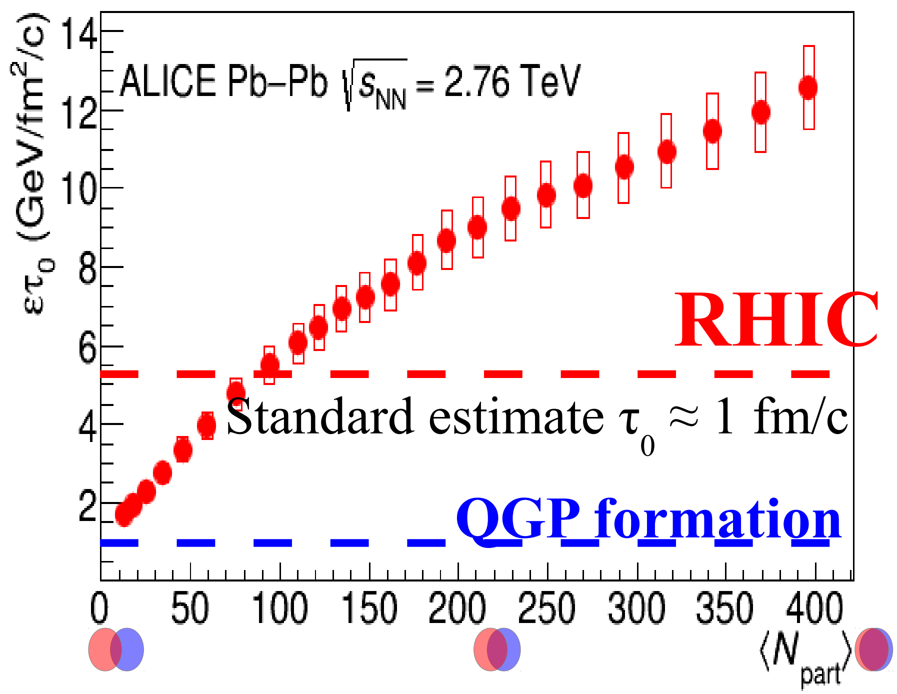


$$\epsilon = \frac{1}{V}\frac{dE_T}{dy} = \frac{J}{A_T \tau c}\frac{dE_T}{d\eta}$$

- QGP formation for $\varepsilon > 0.5$ GeV/fm^3

Energy dependence from dE_T/dy

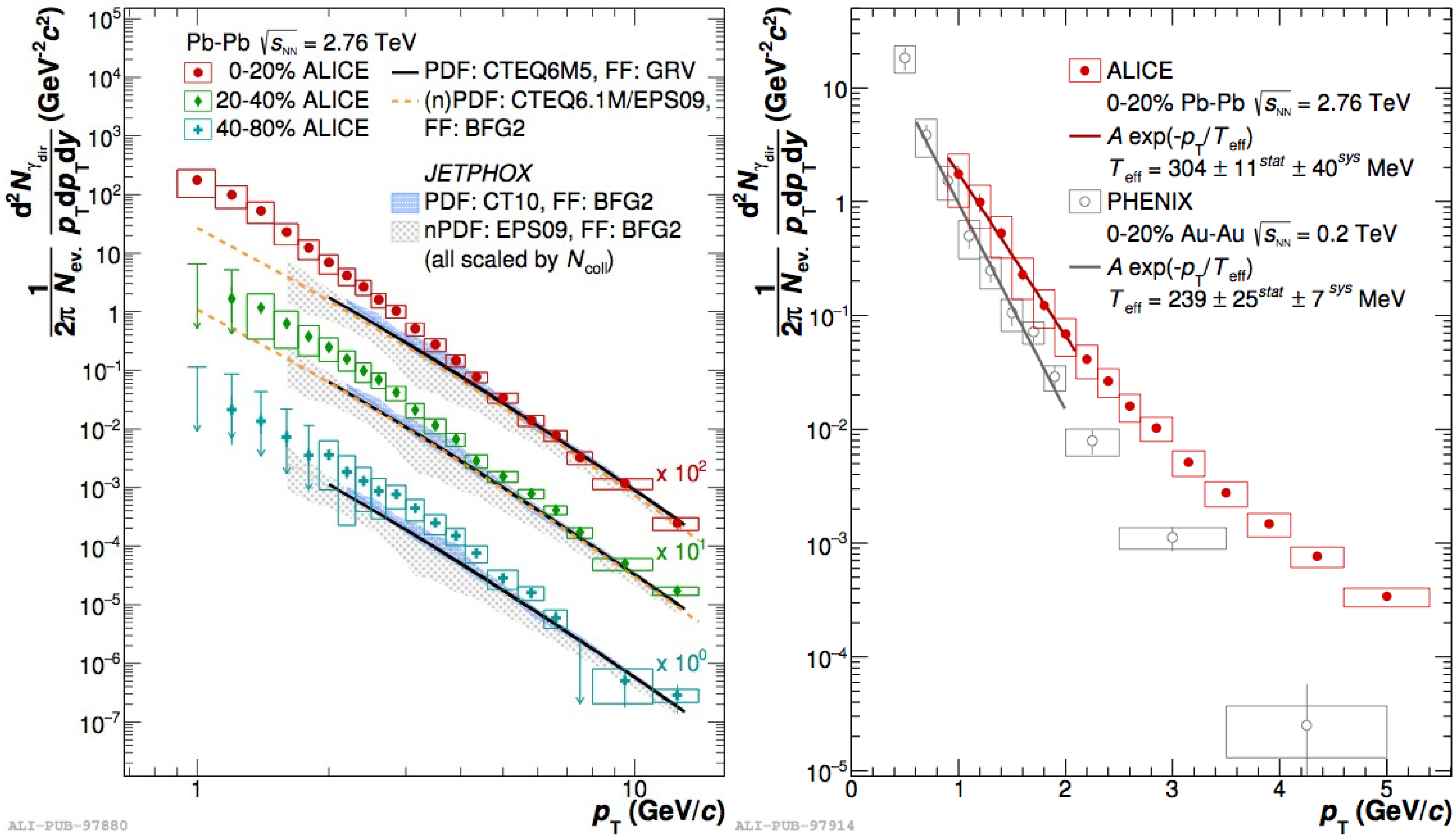




$$\epsilon = \frac{1}{A c \tau_0} \frac{dE_T}{dy}$$

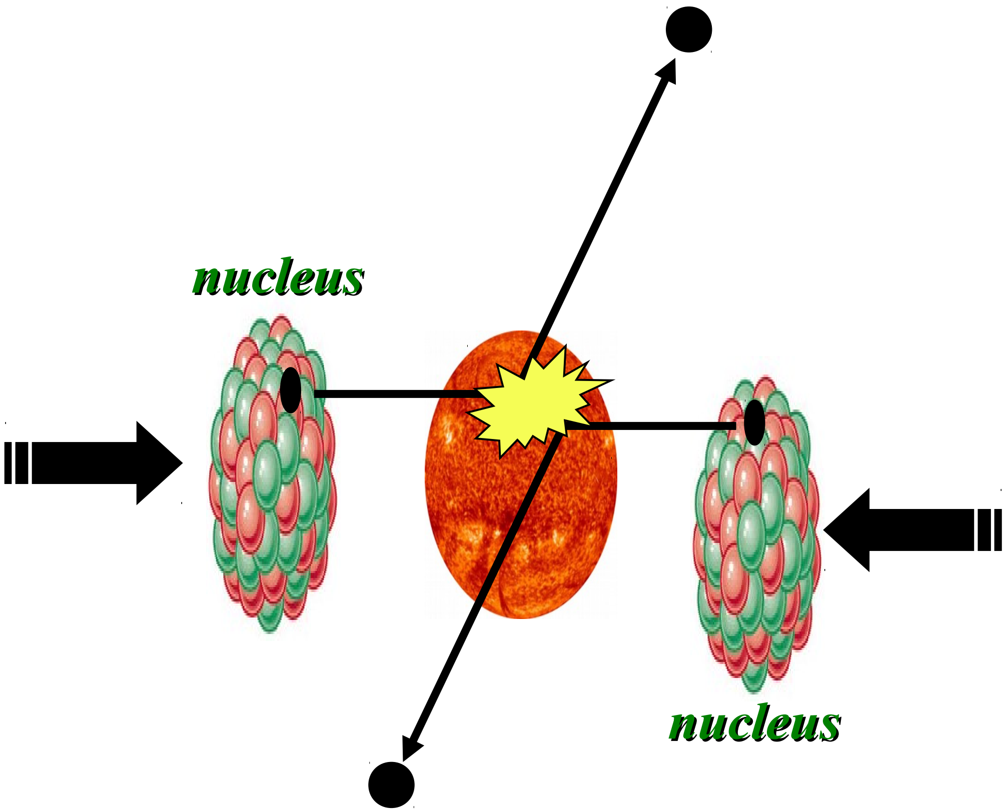
➔ Higher than extrapolations of RHIC data

Direct photons in Pb-Pb collisions



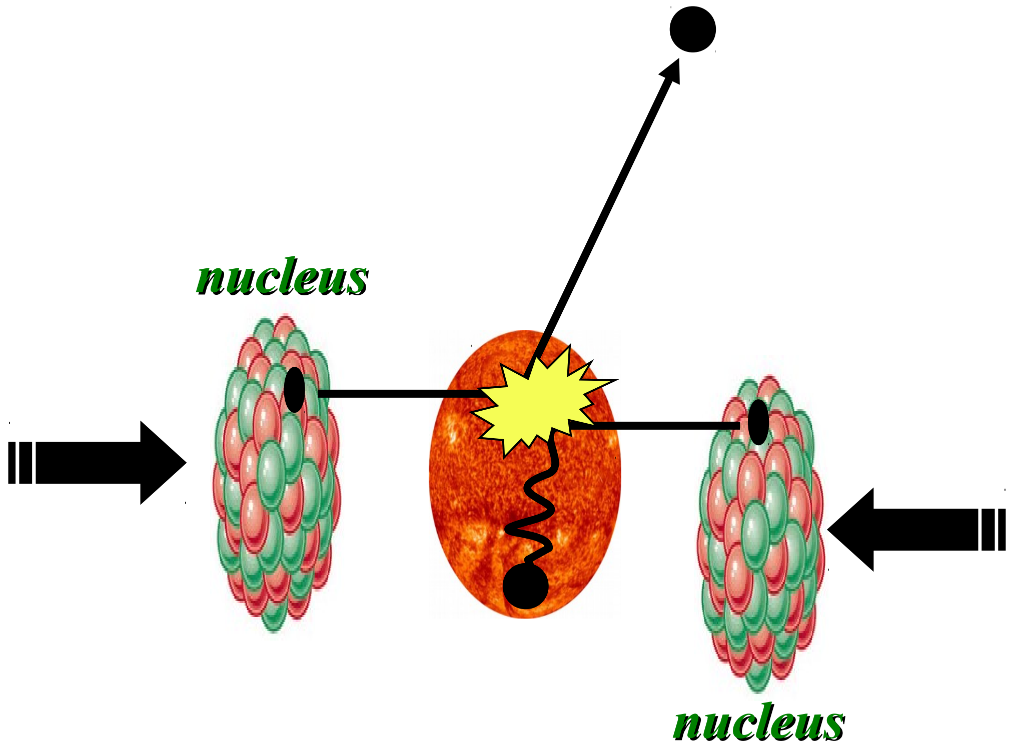
- Low-p_T: 2.6σ excess w. r. t. models in 0–20% central — thermal contribution
- T_{eff} = 304 ± 11(stat.) ± 40 (syst.) MeV in central Pb–Pb collisions at 2.76 TeV
- 30% higher than at RHIC (Au–Au at $\sqrt{s_{NN}}$=200 GeV)

Probes of the Quark Gluon Plasma



Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision

Probes of the Quark Gluon Plasma

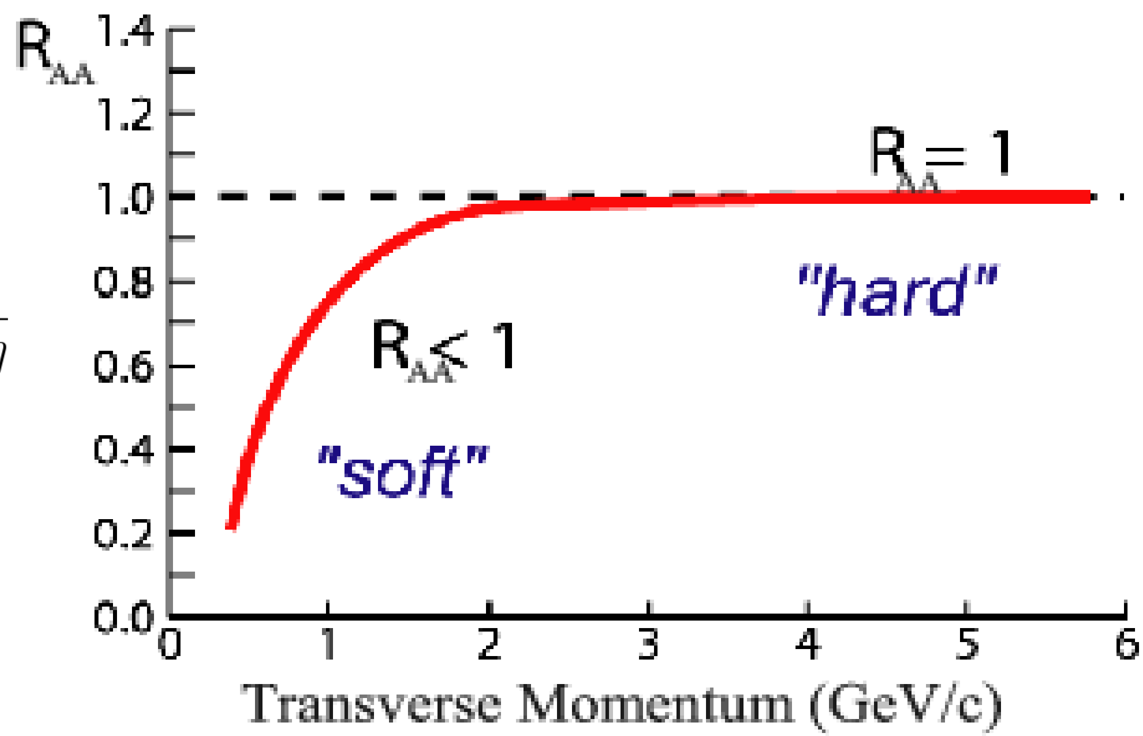


Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision
We expect the medium to be dense → absorb/modify probe

Nuclear modification factor

- Measure spectra of probe (jets) and compare to those in p+p collisions or peripheral A+A collisions
- If high-p_T probes (jets) are suppressed, this is evidence of jet quenching

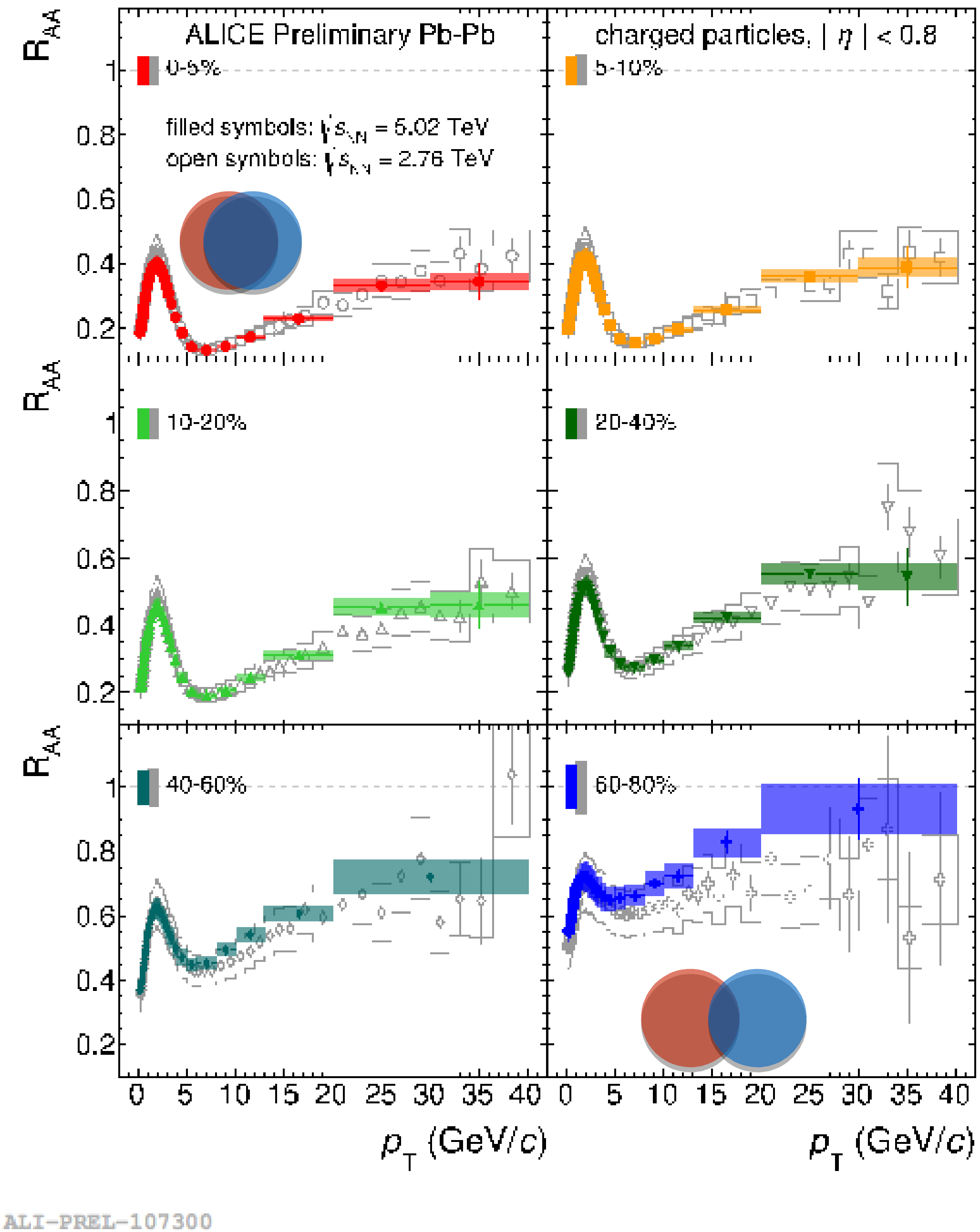
$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$



Enhancement

Suppression

Charged particle R_{AA}

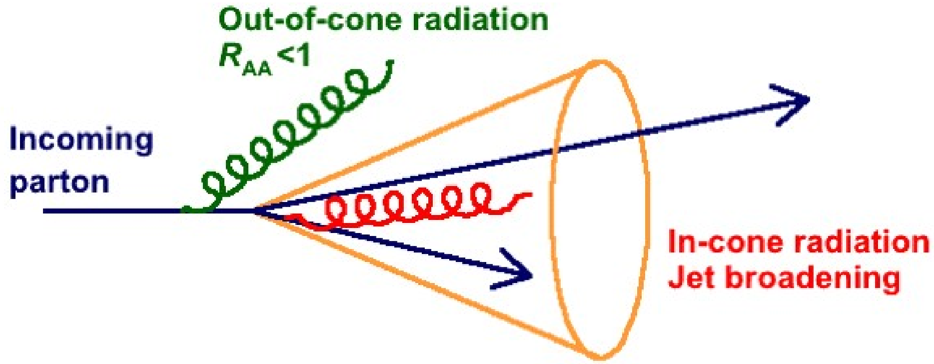


$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

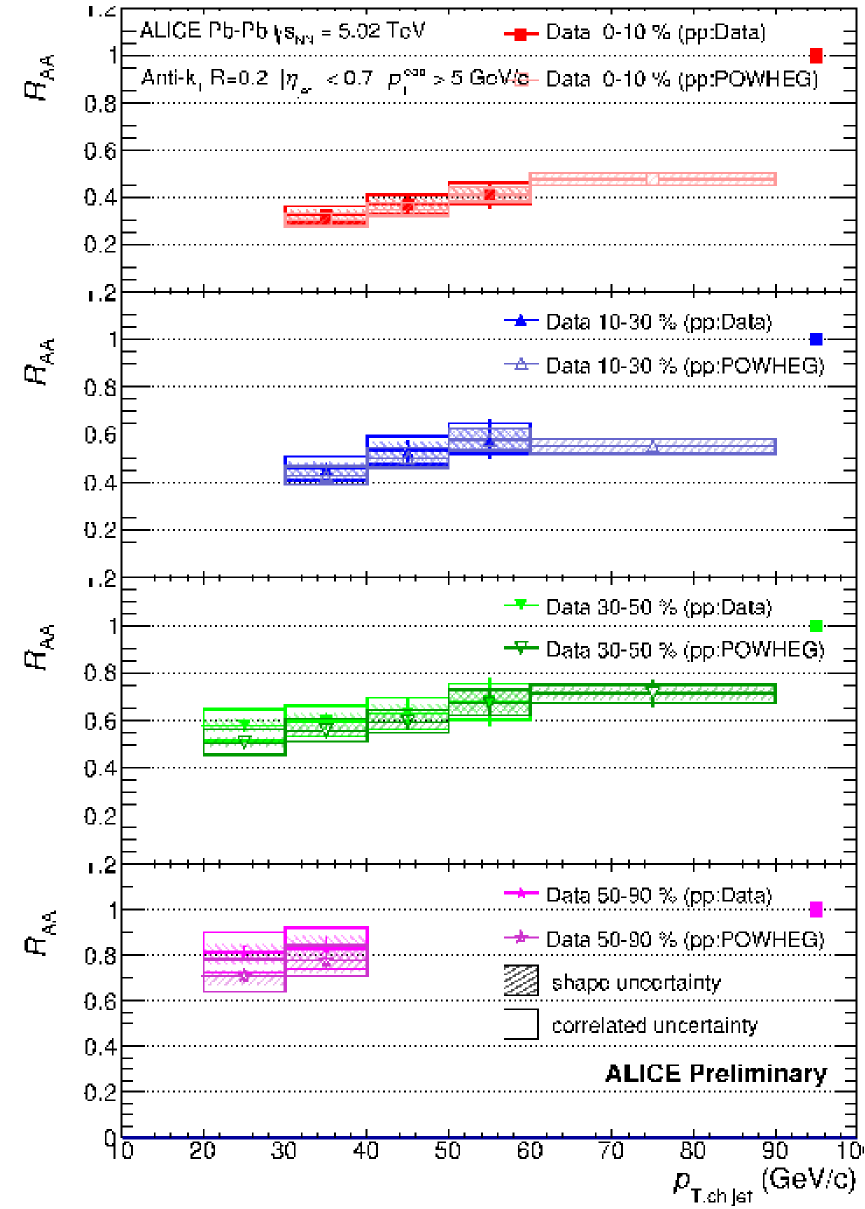
- $R_{AA}>1$: enhancement

  $R_{AA}<1$: suppression
- Strong modification of the spectrum shape in most central collisions
- Strong centrality dependence
- R_{AA} at 5.02 TeV similar to 2.76 TeV

Jet R_{AA}



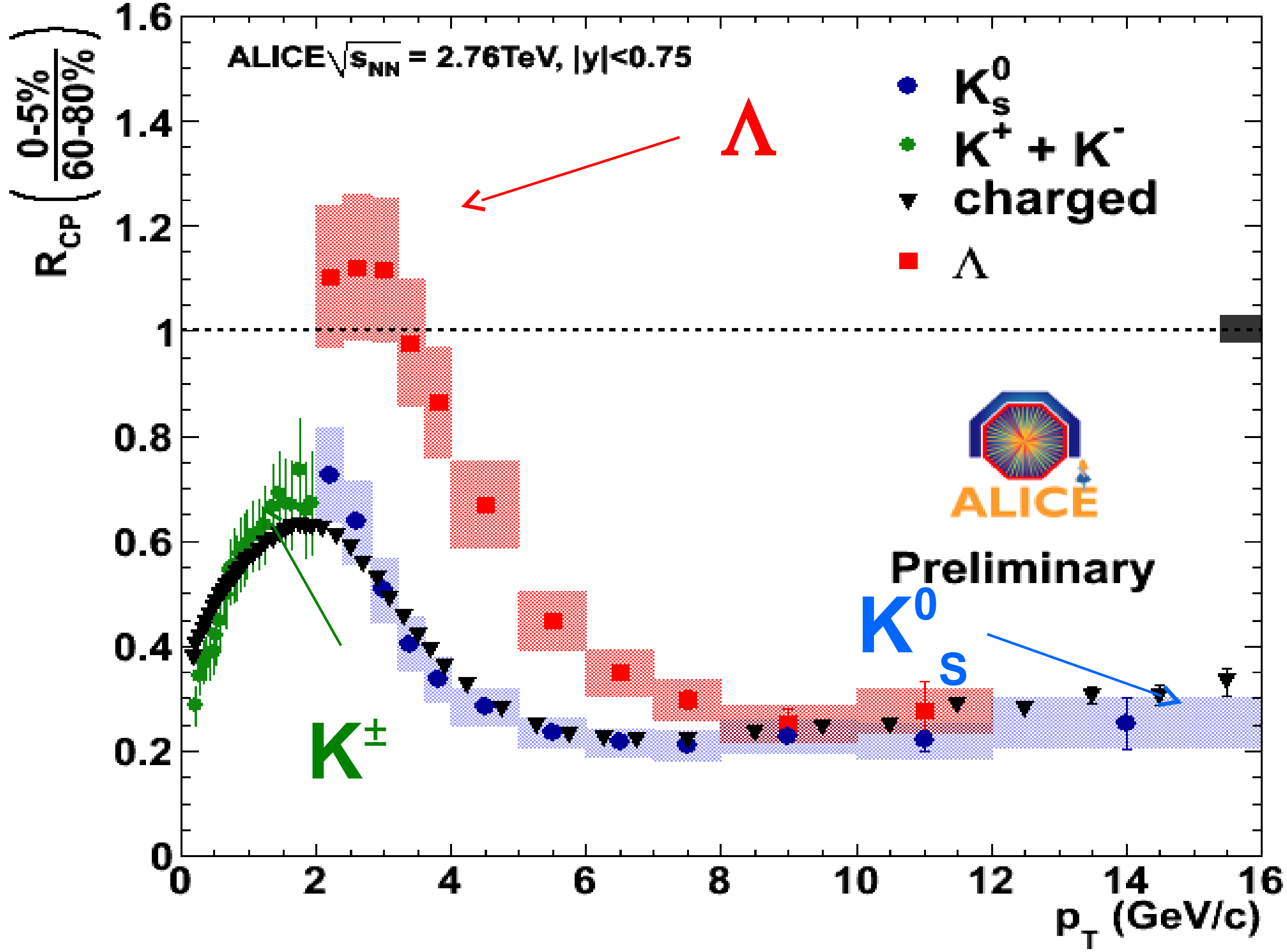
- Out-of-cone radiation: energy loss in jet cone
  - Jet yield suppression, di-jet energy imbalance, jet-jet/hadron-jet acoplanarity…
- In-cone radiation: medium modified fragmentation
  - Jet shape broadening, modification of transverse energy profile…
- Consistent with R_{AA} of charged particles and charged-jet R_{AA} at 2.76 TeV



ALI-PREL-113513

$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

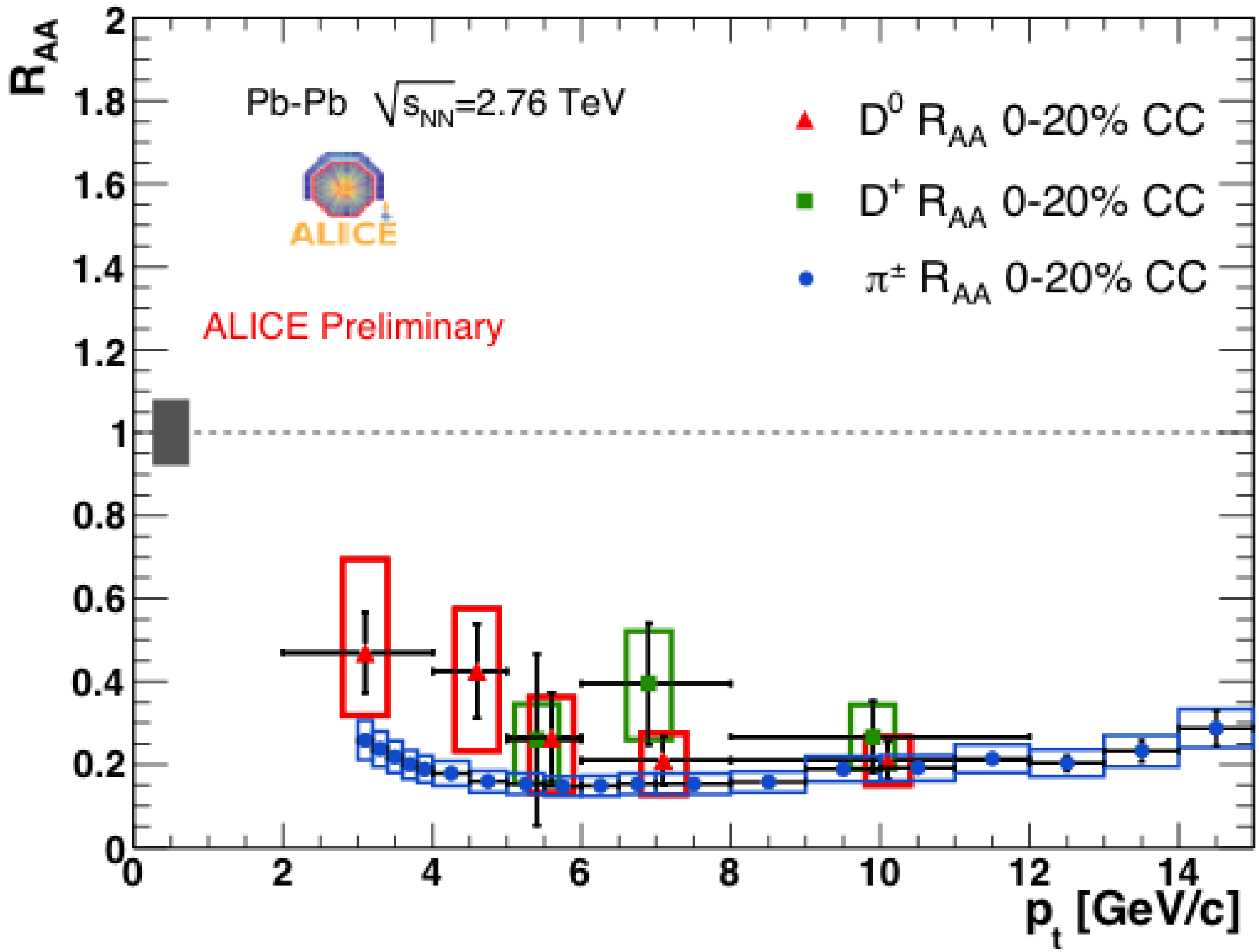
Nuclear modification factor (R_{AA})



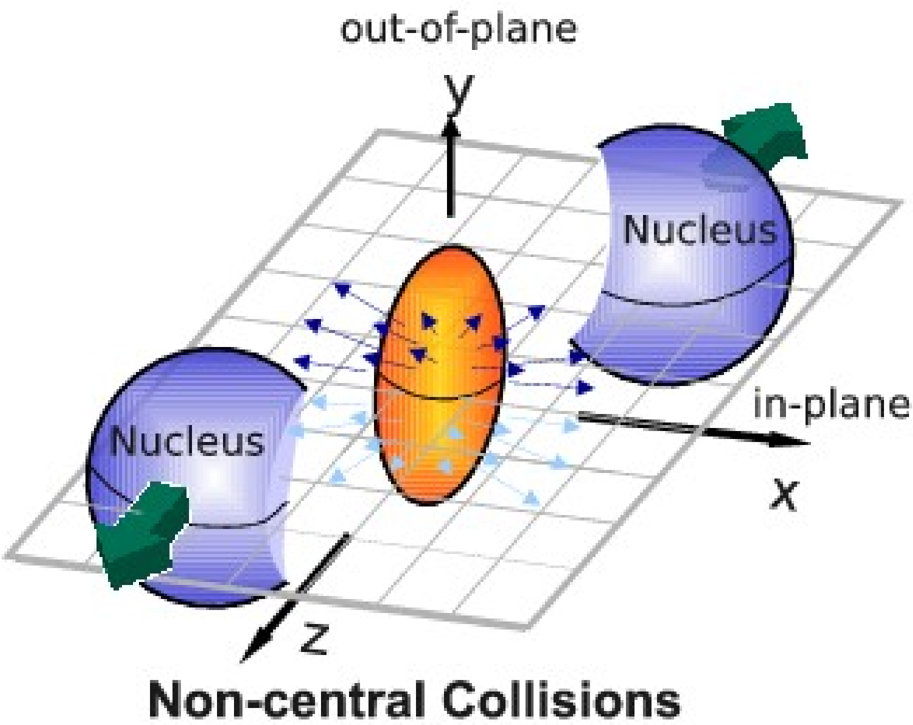
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$

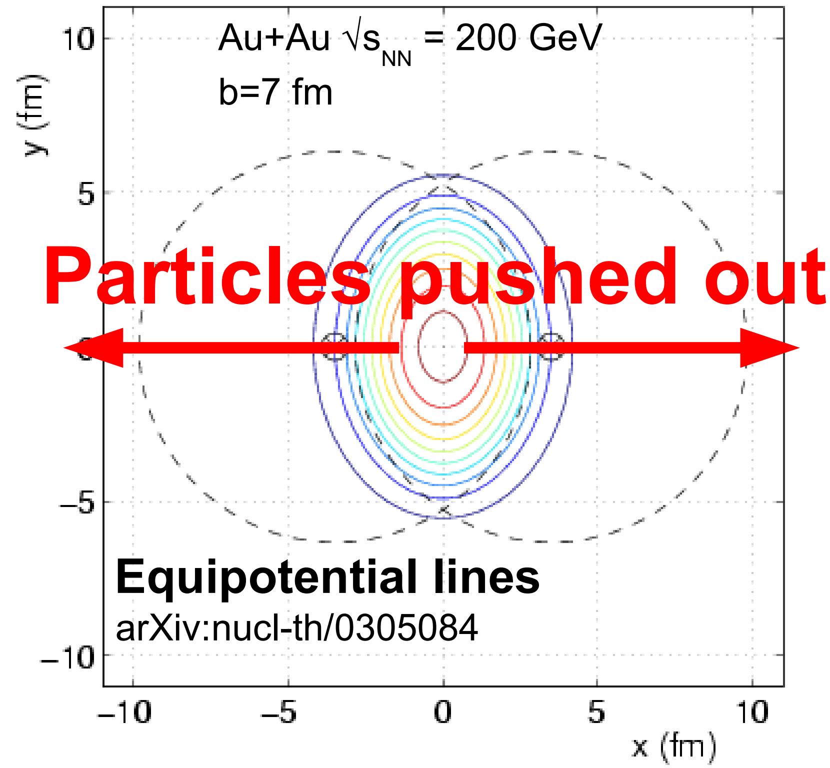
Pb+Pb

Charm nuclear modification factor



Relativistic fluids

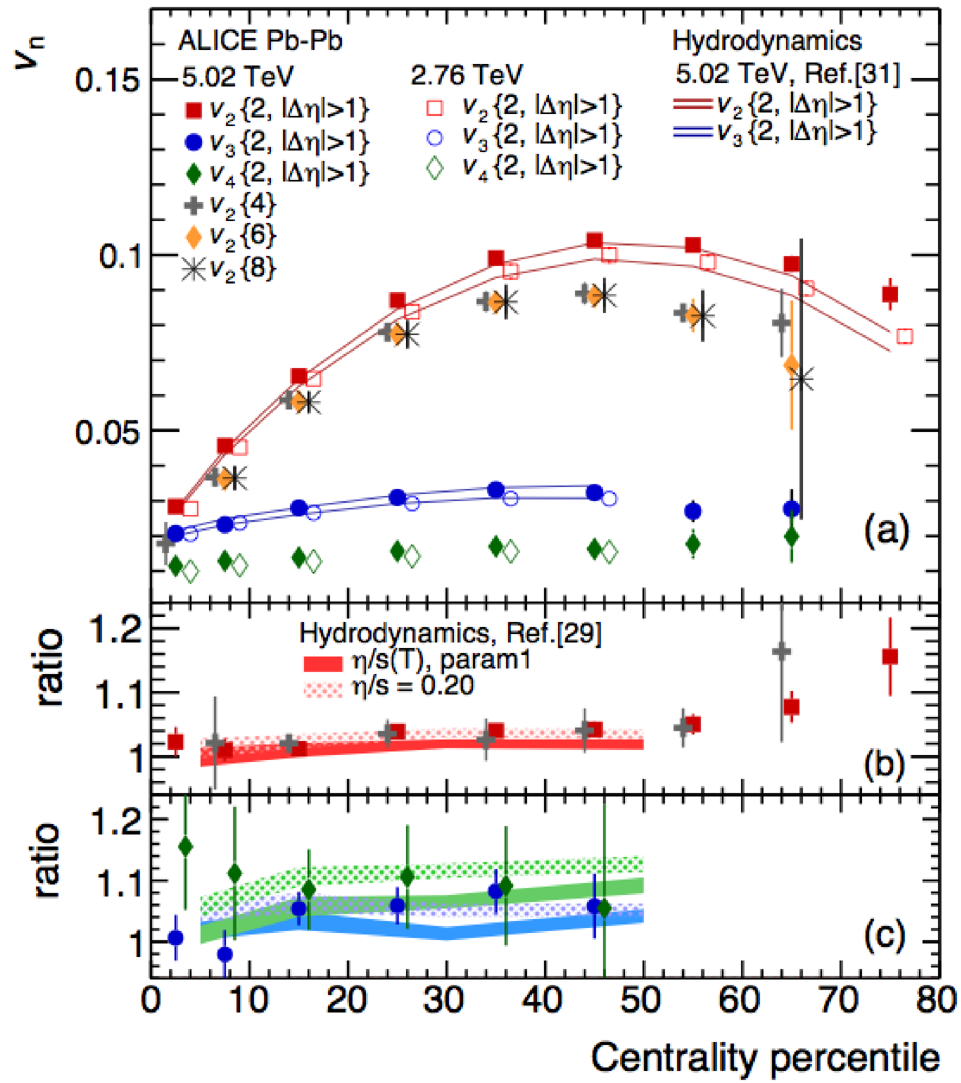




- Initial overlap asymmetric → pressure gradients
- Momentum anisotropy → Fourier decomposition:

$$\frac{d^2N}{dp_T\,d\phi} \approx 1 + 2v_1\cos(d\phi) + 2v_2\cos(2d\phi) + 2v_3\cos(3d\phi) + 2v_4\cos(4d\phi) + 2v_5\cos(5d\phi) + \ldots$$

v_n at different energies



Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter, which we produce in high energy heavy ion collisions.
- This medium is transparent to colored probes and translucent to electromagnetic probes...
- ...and an extremely hot and dense...
- ...perfect liquid.