Results from ALICE

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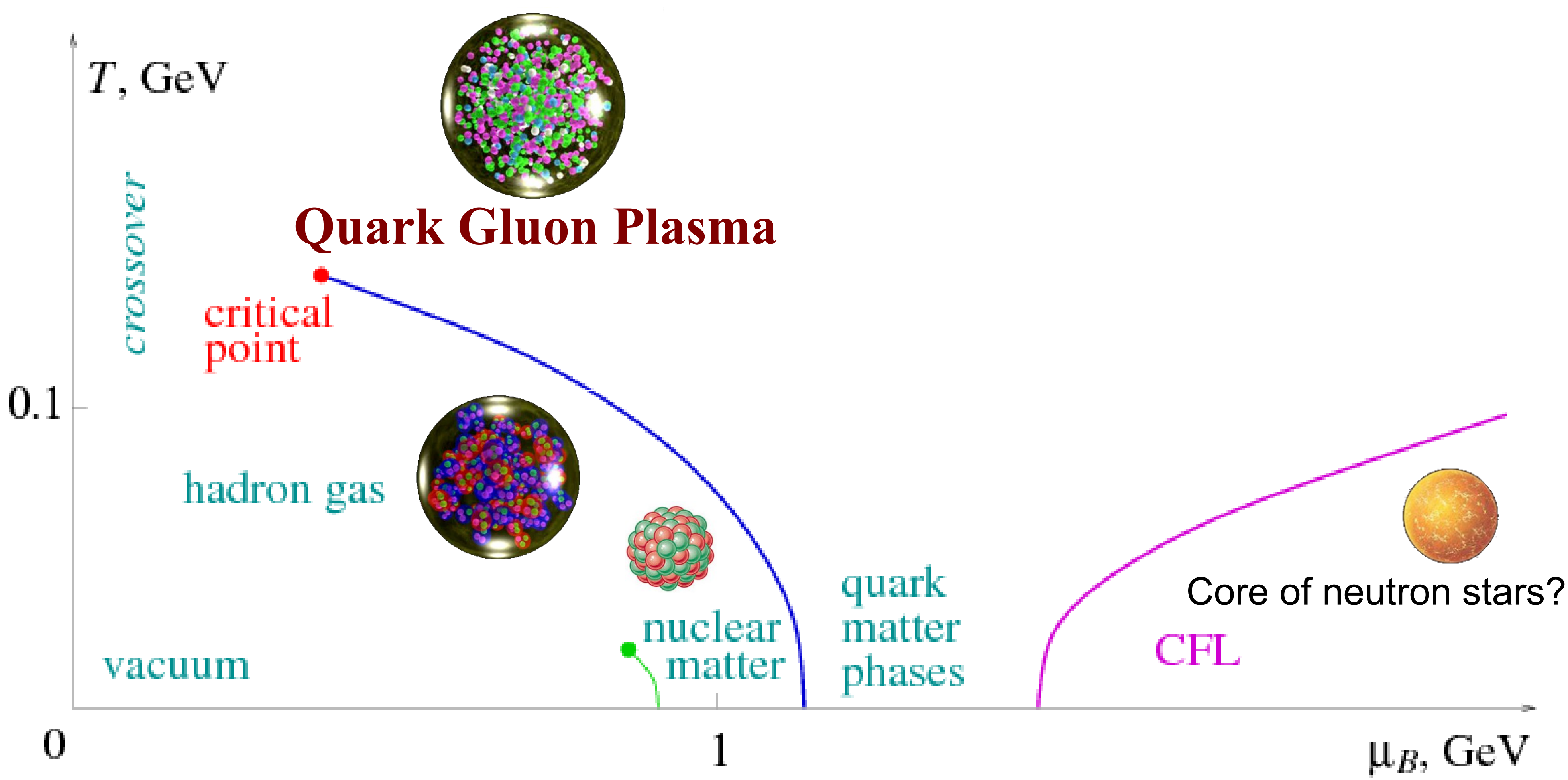
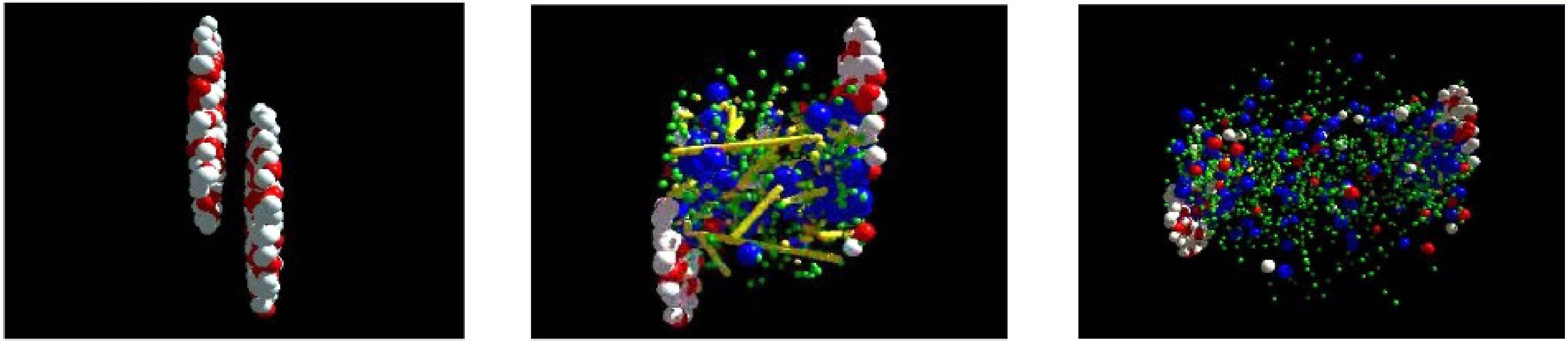
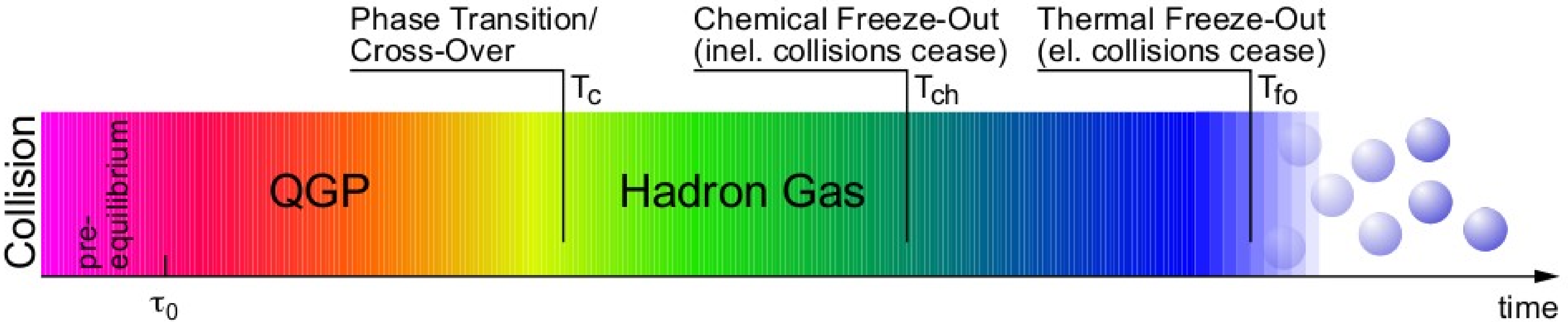
Phase diagram of nuclear matter



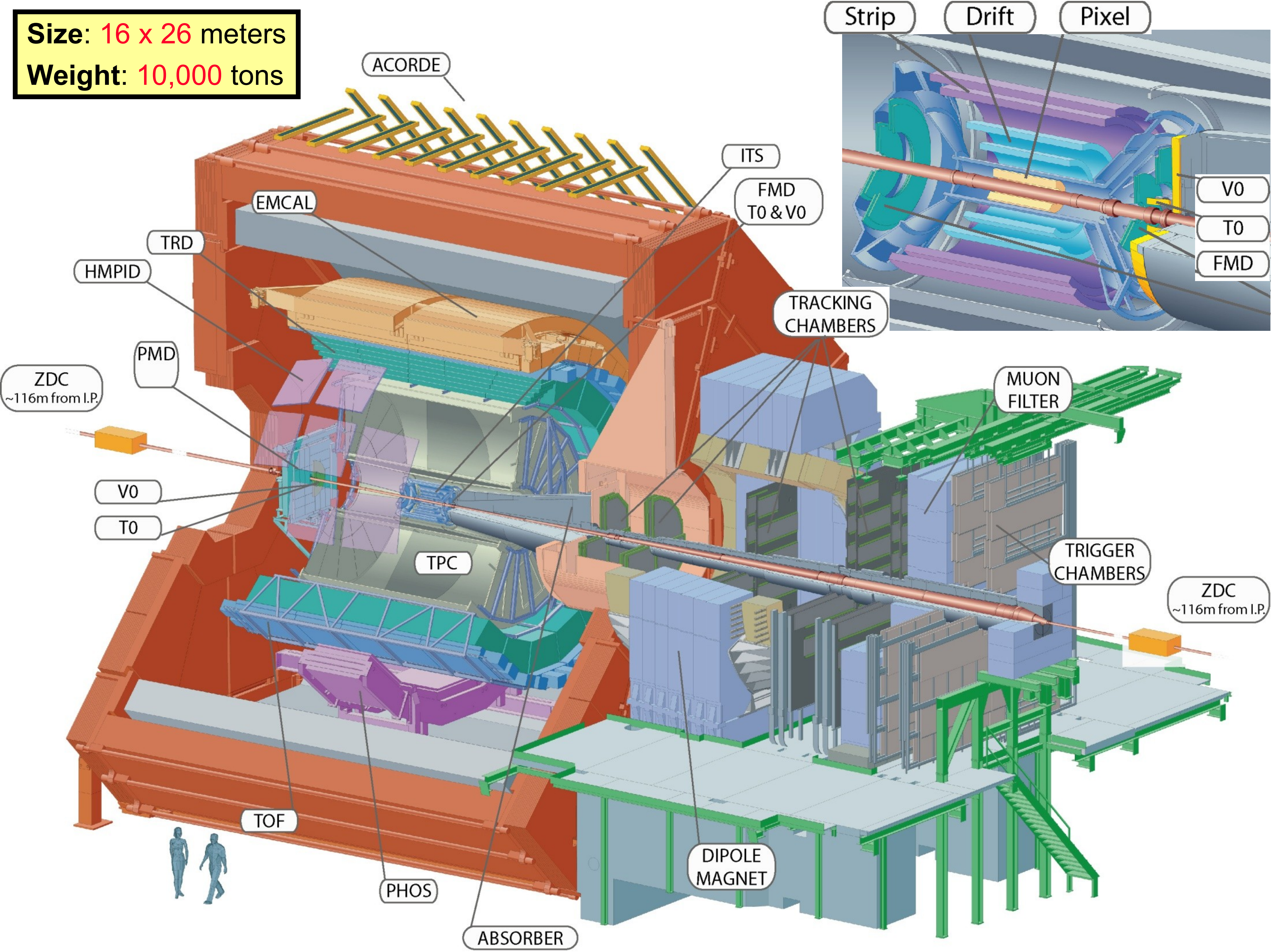
Quark Gluon Plasma – a *liquid* of quarks and gluons created at temperatures above ~170 MeV ($2 \cdot 10^{12}$K) – over a million times hotter than the core of the sun

The phase transition in the laboratory

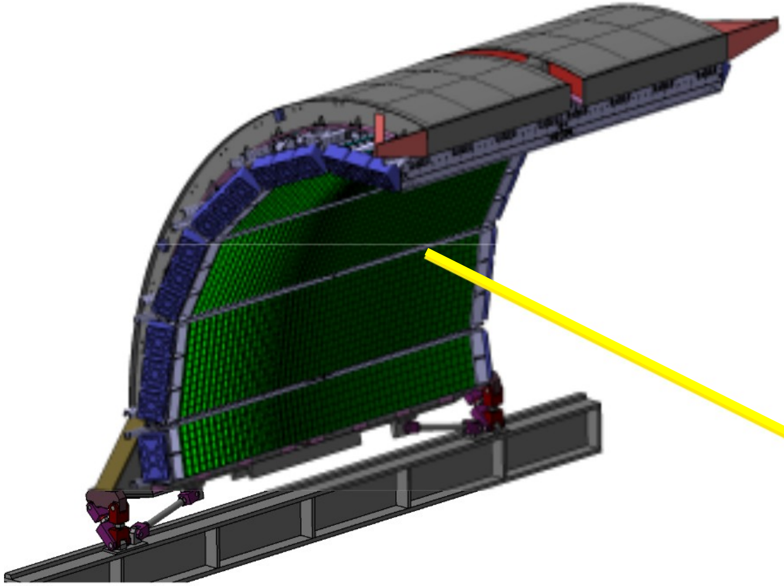




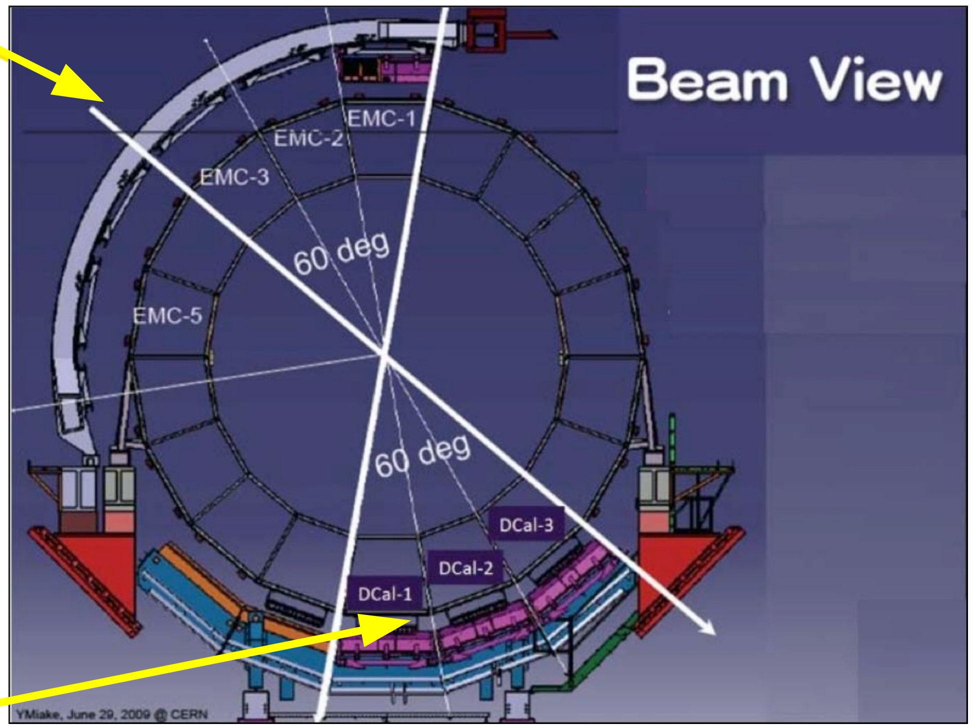
Size: 16 x 26 meters
Weight: 10,000 tons



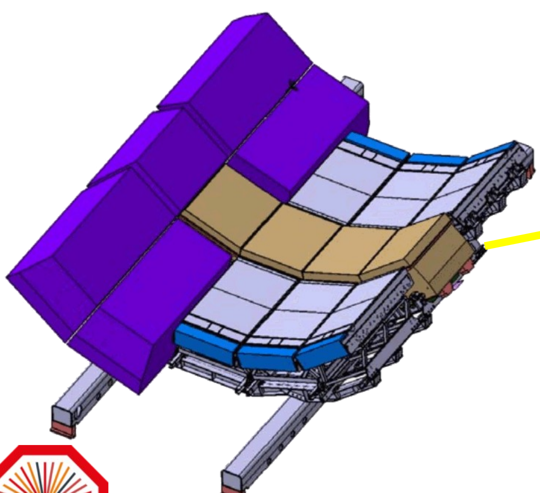
EMCal & DCal



$\Delta\eta$=1.4,$\Delta\varphi$=107°

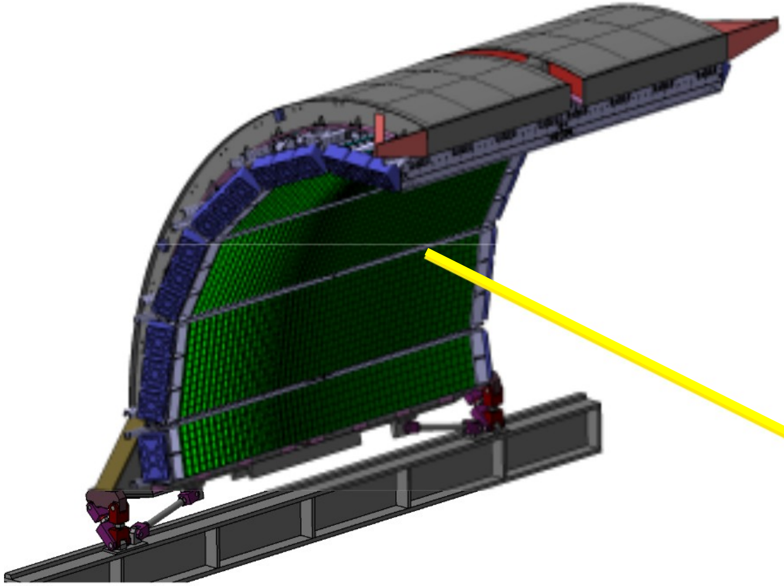


Installed in Fall 2014
$\Delta\eta$=1.4,$\Delta\varphi$=60°



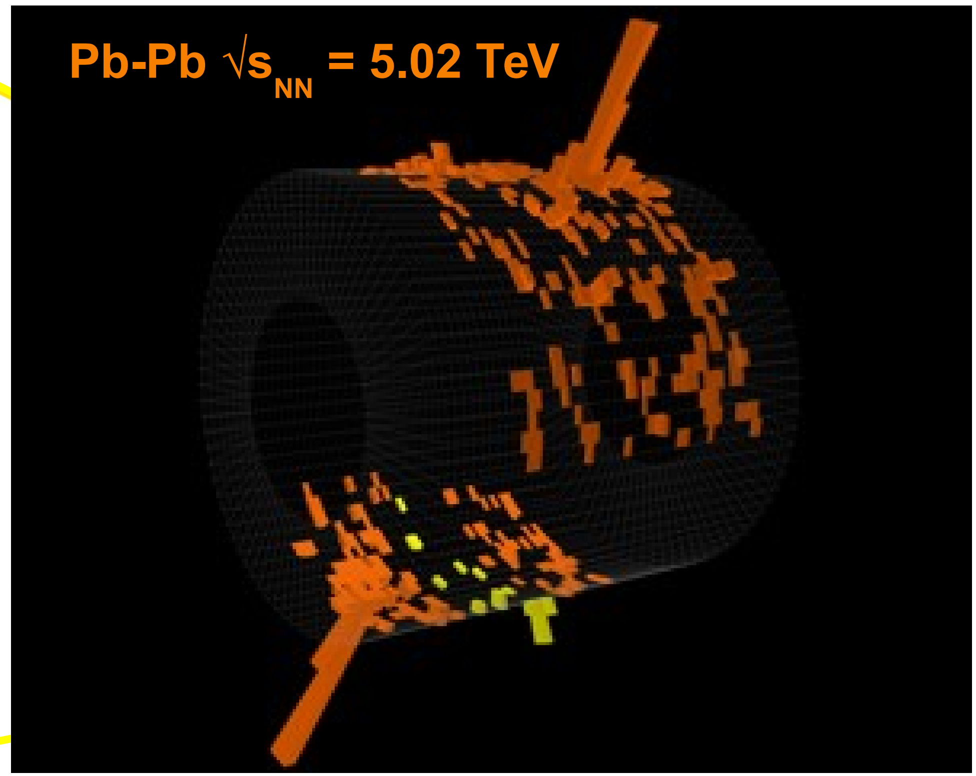
- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta\eta$ x $\Delta\varphi$= 0.014 x 0.014
- $\sigma(E)/E=0.12/\sqrt{E} + 0.02$

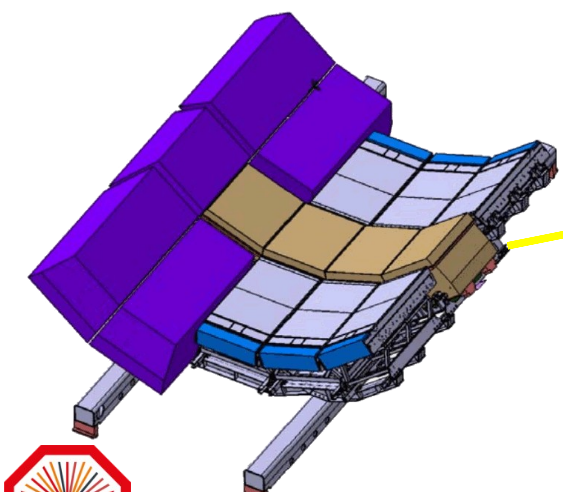
EMCal & DCal



$\Delta\eta=1.4, \Delta\varphi=107^{o}$

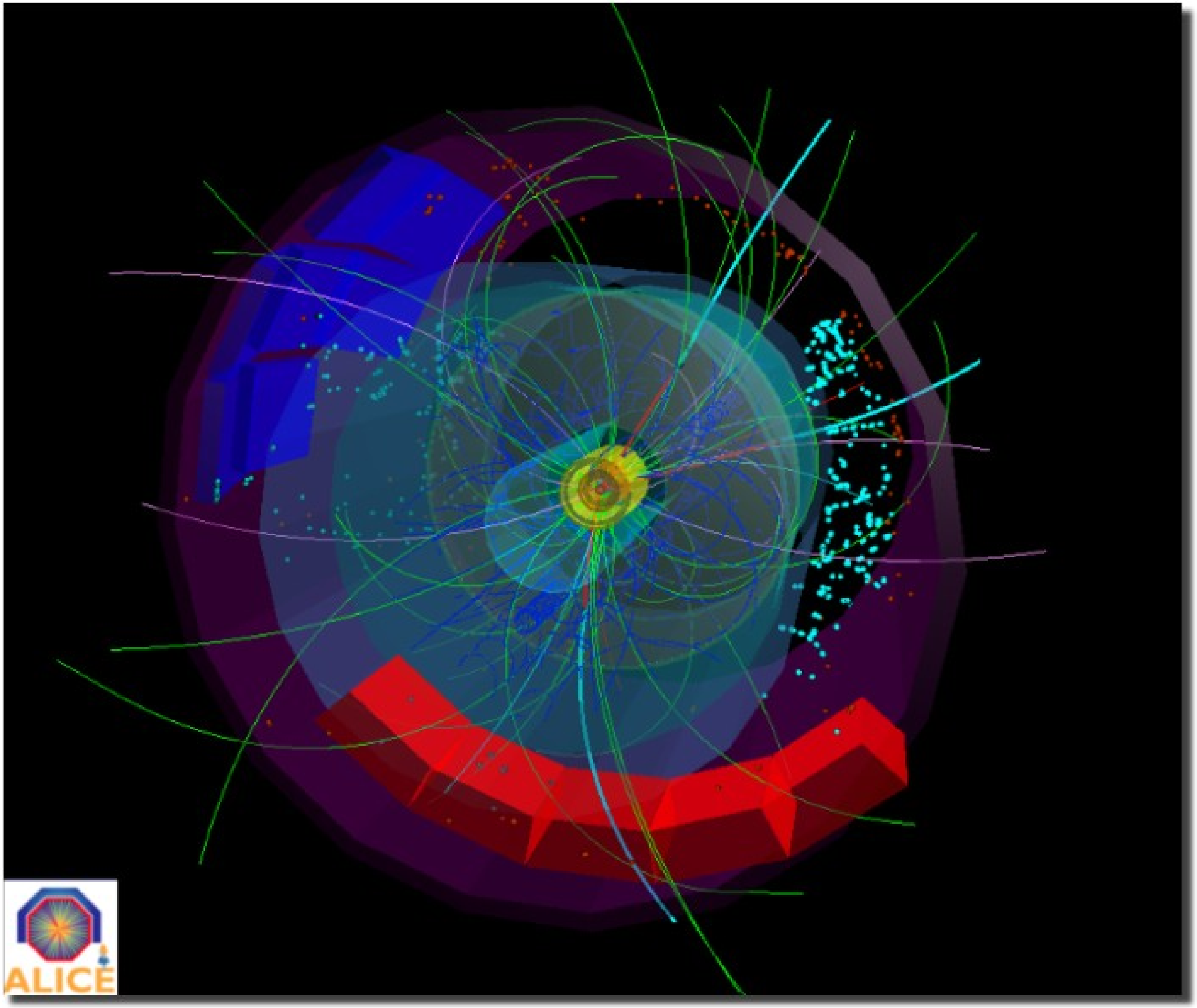
Installed in Fall 2014
$\Delta\eta=1.4, \Delta\varphi=60^{o}$





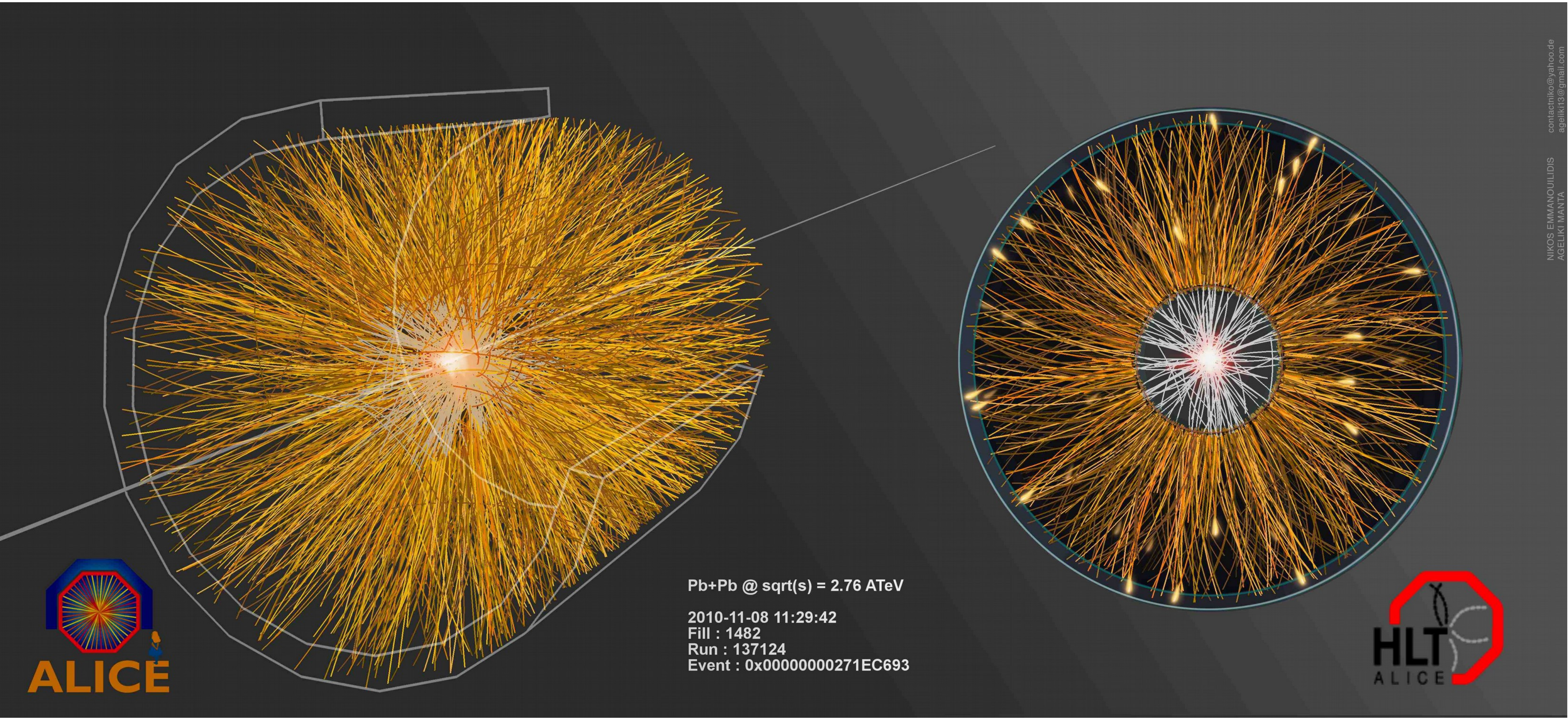
- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta\eta \times \Delta\varphi = 0.014 \times 0.014$
- $\sigma(E)/E=0.12/\sqrt{E} + 0.02$

p+p collisions

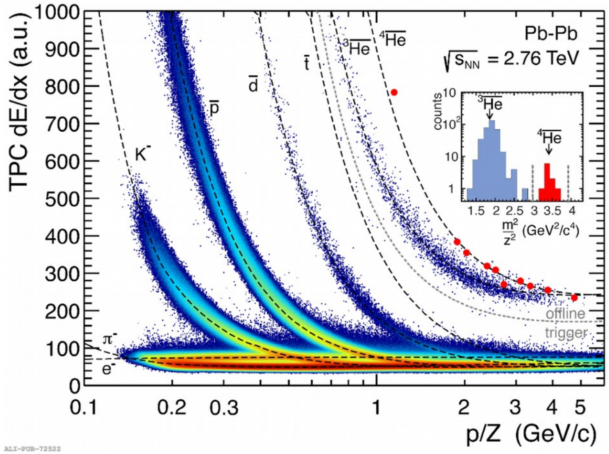


3D image of each collision

Pb+Pb collisions



ALICE Performance



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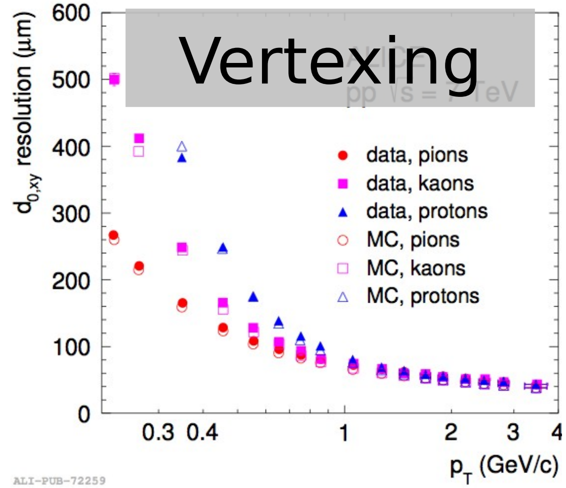
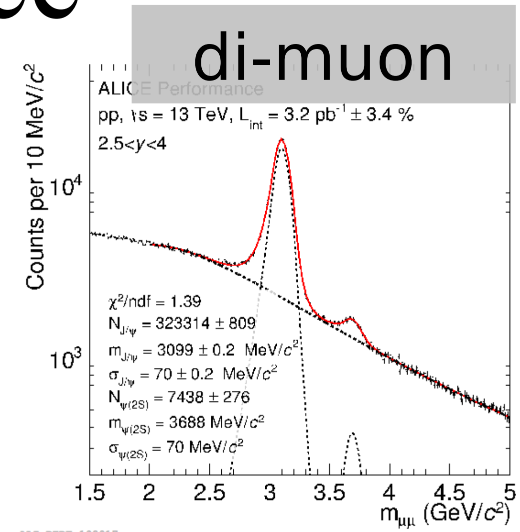
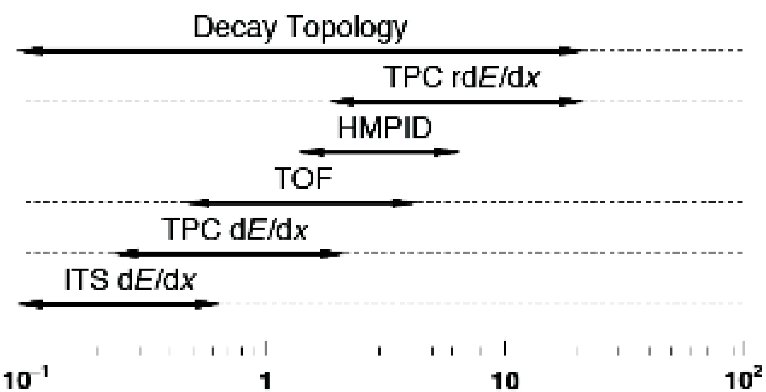
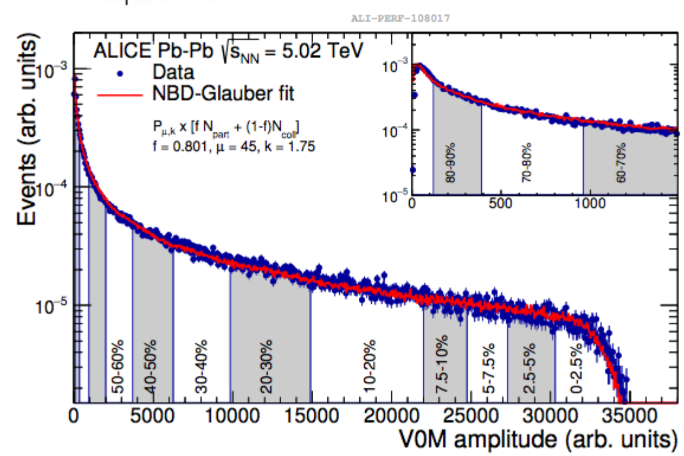






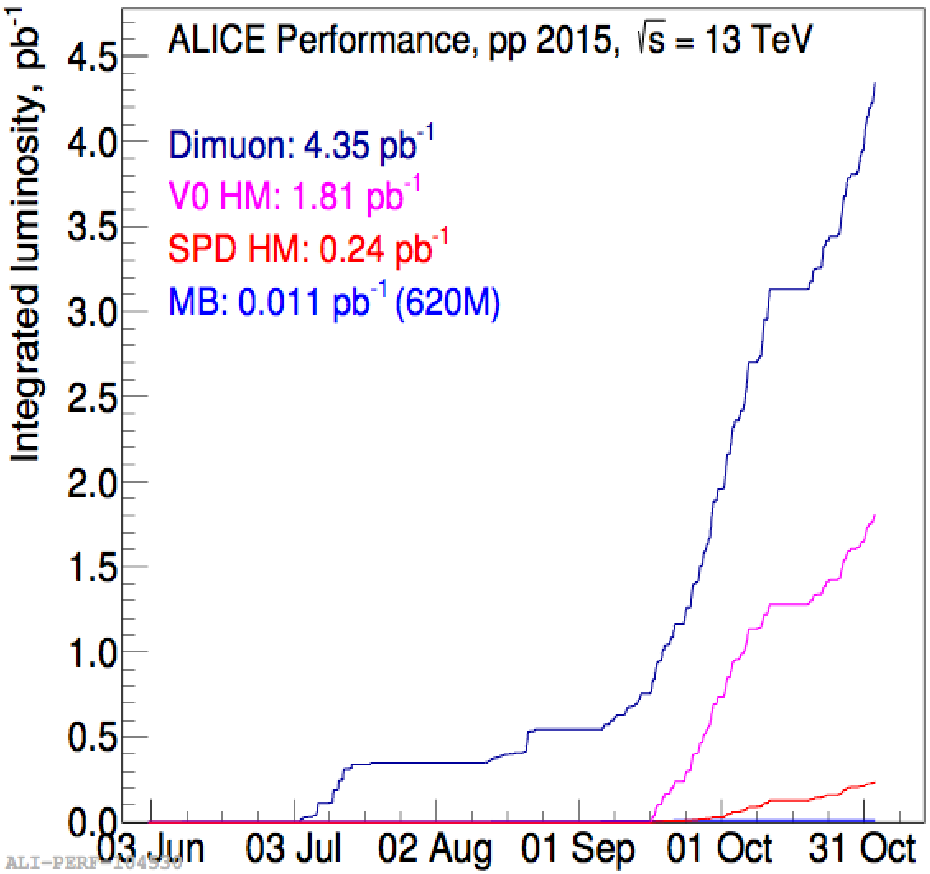
p_T (GeV/c)

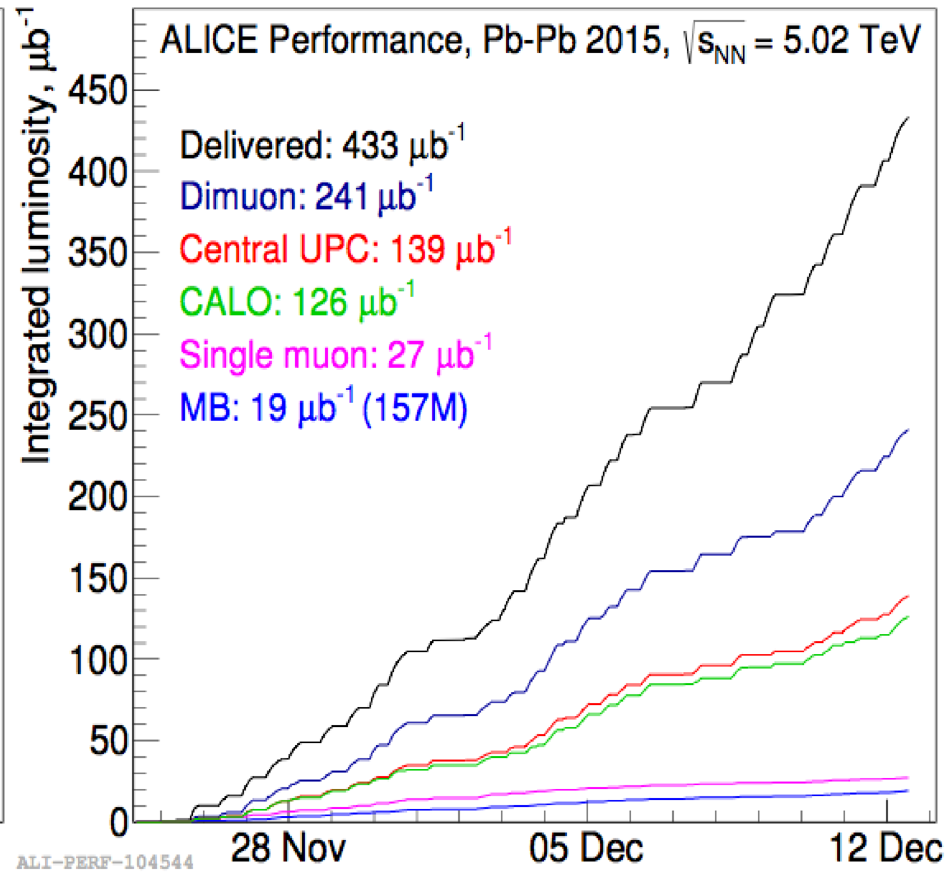


ALICE-PUBLIC-2015-008

- Low-p_T tracking: down to 150 MeV/c
- PID: anti-^{3}He observed directly
- Vertexing capabilities: heavy flavors, V^0, cascades, conversions

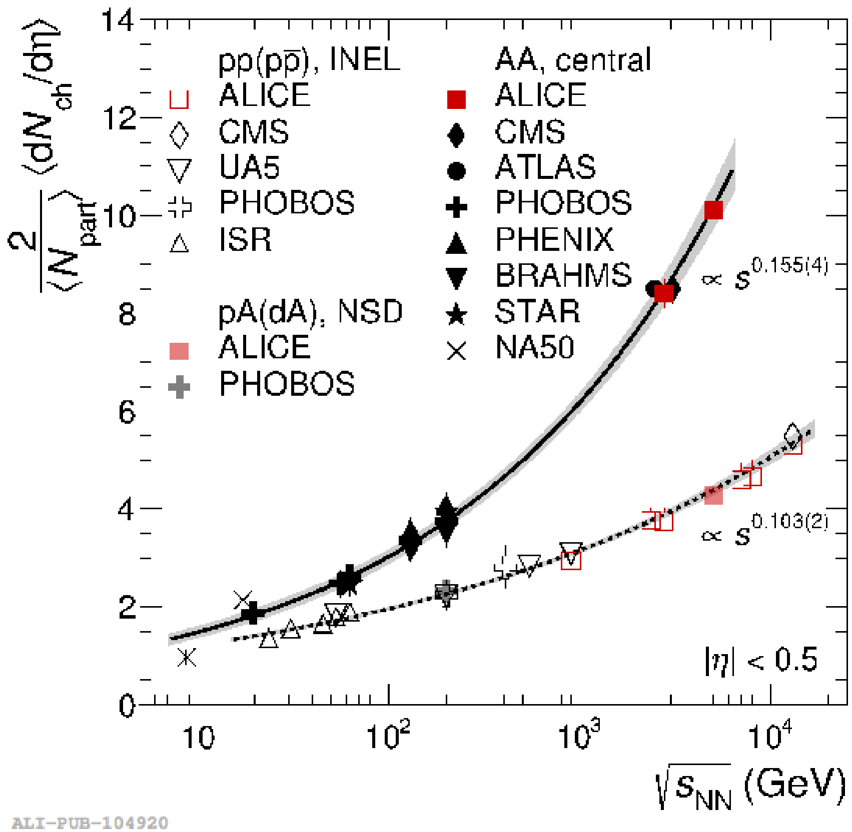
Data collection

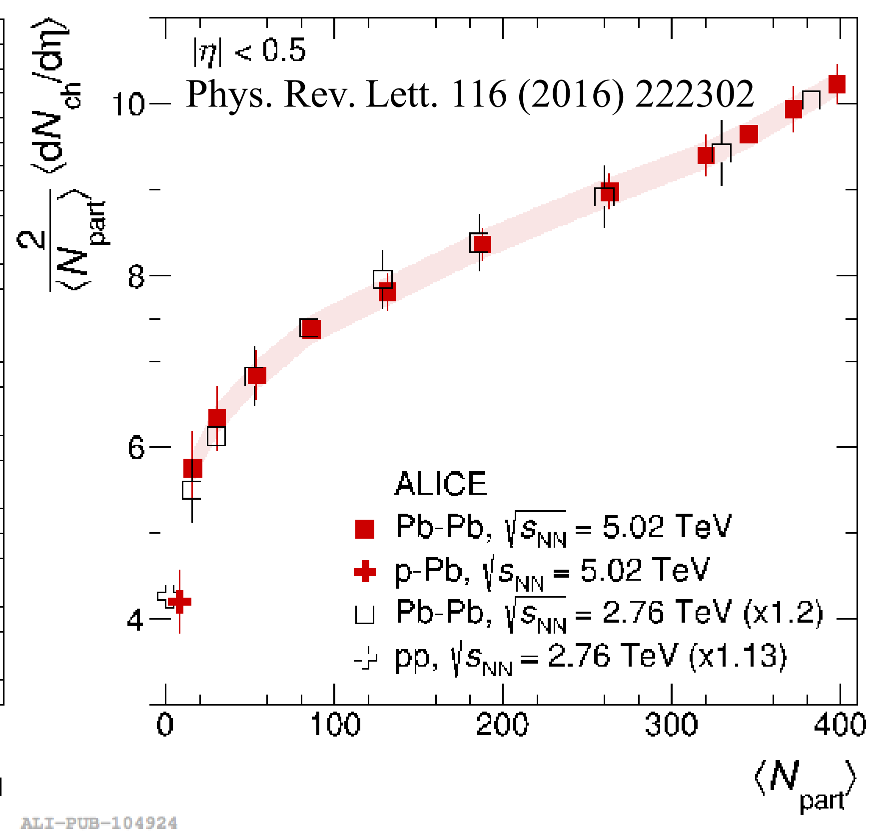




- Pb–Pb at 5.02 TeV: up to 0.5 nb^{-1}
- pp at 13 TeV and 4 days at 5.02 TeV (~100 nb^{-1})
- Upcoming p–Pb at 5.02 and 8 TeV: 10 times more statistics than in RUN-I

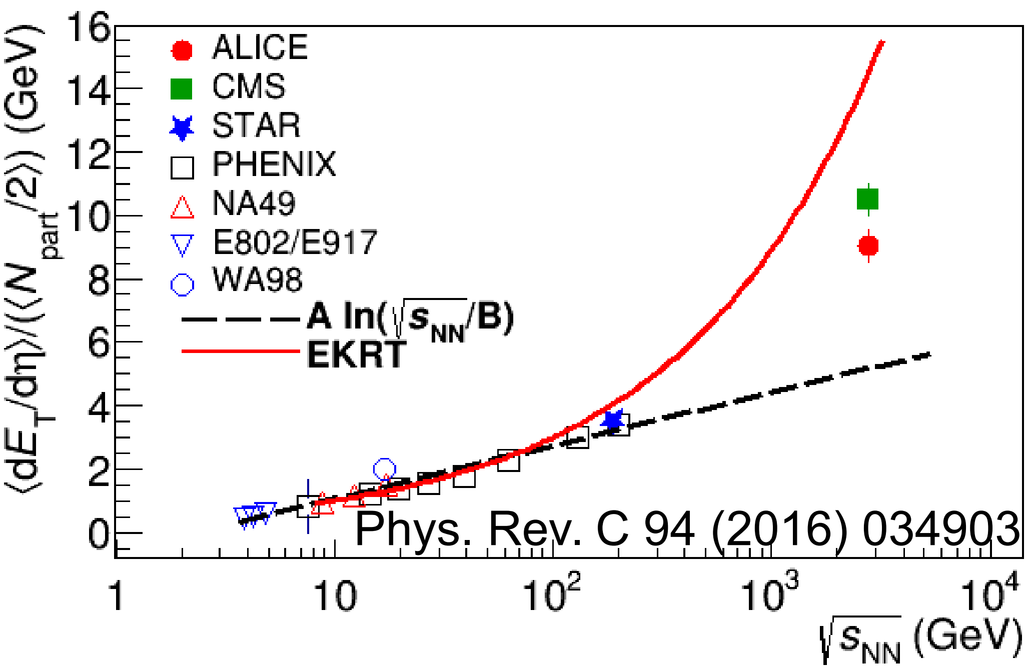
Charged particle multiplicity

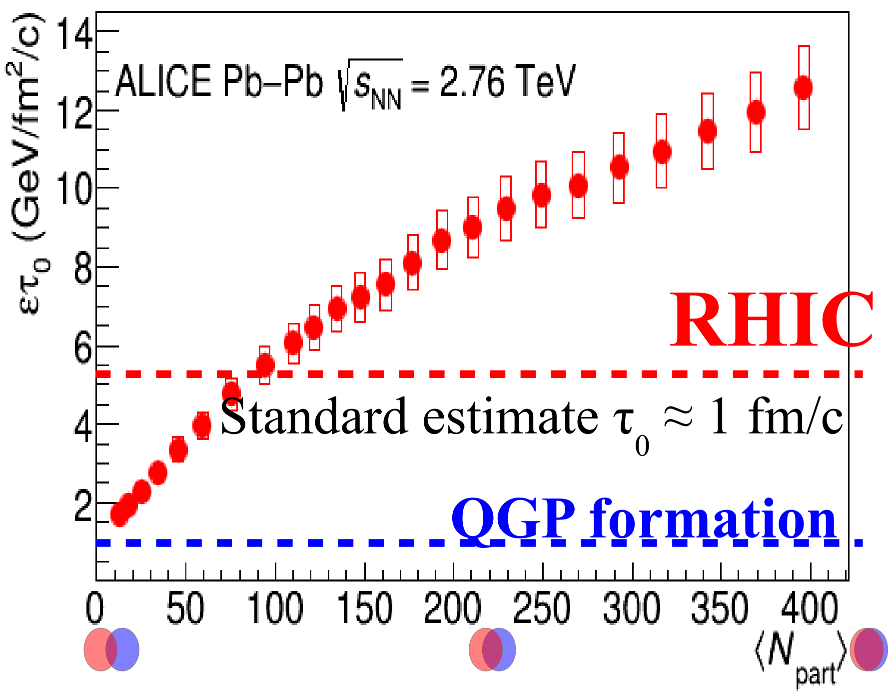




- ALICE: Pb–Pb at 5.02 TeV — highest energy so far
  - For 0–5% most central collisions, confirms trend from lower energies
- $\langle dN_{ch}/d\eta \rangle$ vs. $\langle N_{part} \rangle$: similar evolution with centrality between 5.02 and 2.76 TeV
  - Provides further constraints for models
  - ~20%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

Energy dependence from dE_T/dy

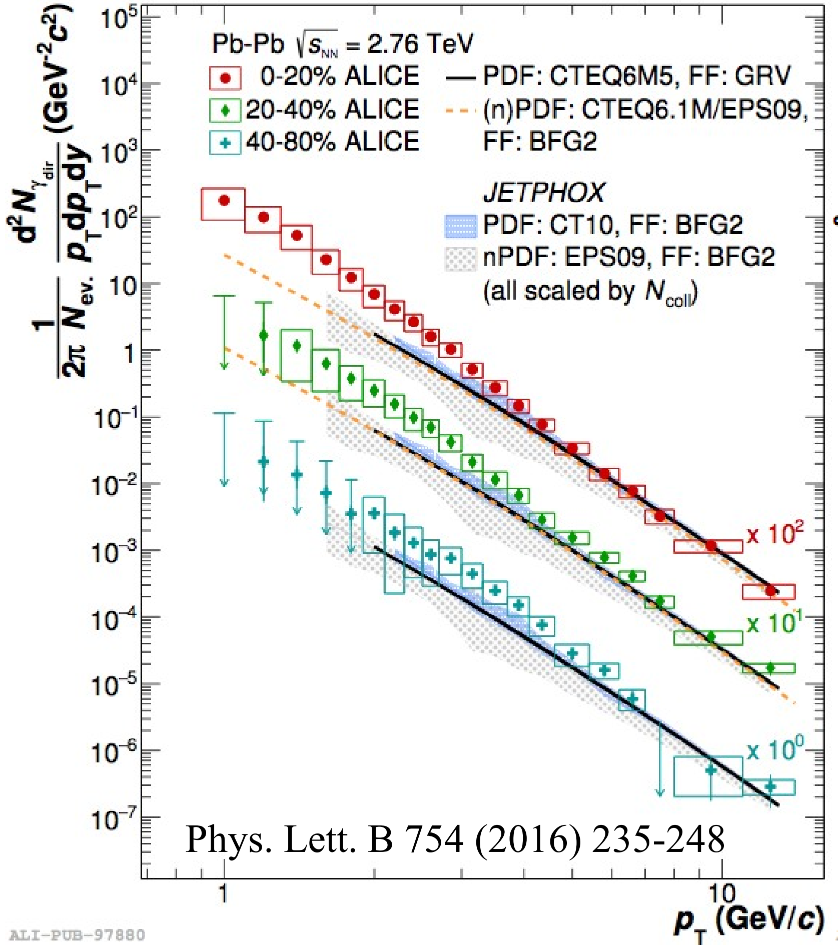


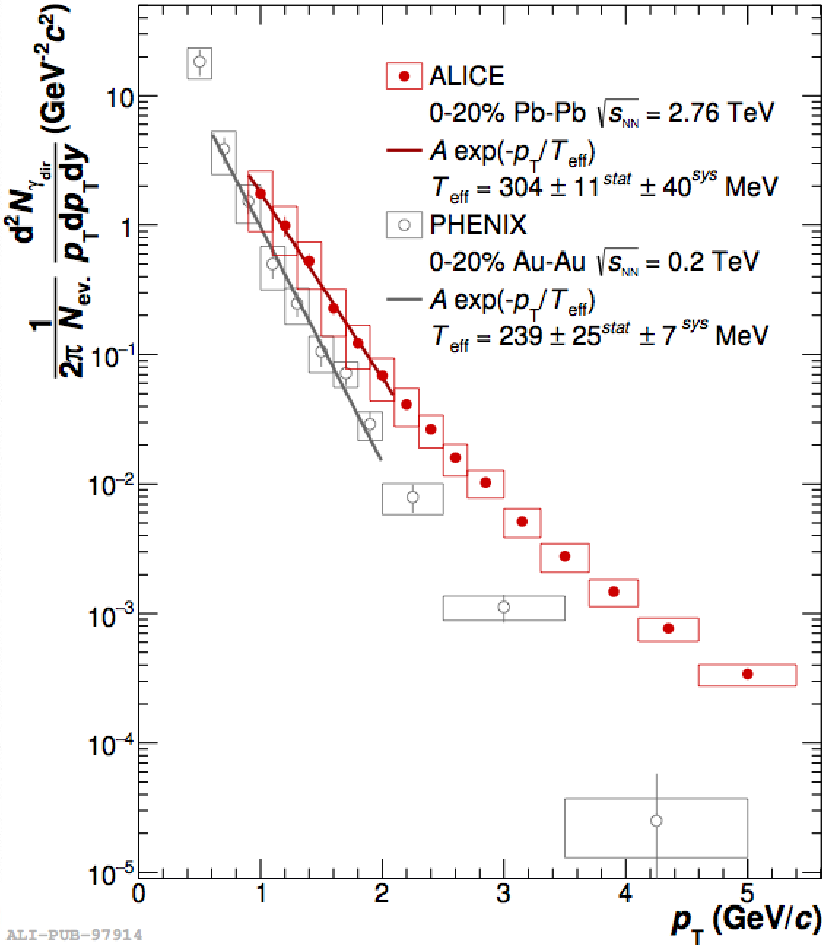


$$\epsilon = \frac{1}{A c \tau_0} \frac{dE_T}{dy}$$

➔ Higher than extrapolations of RHIC data

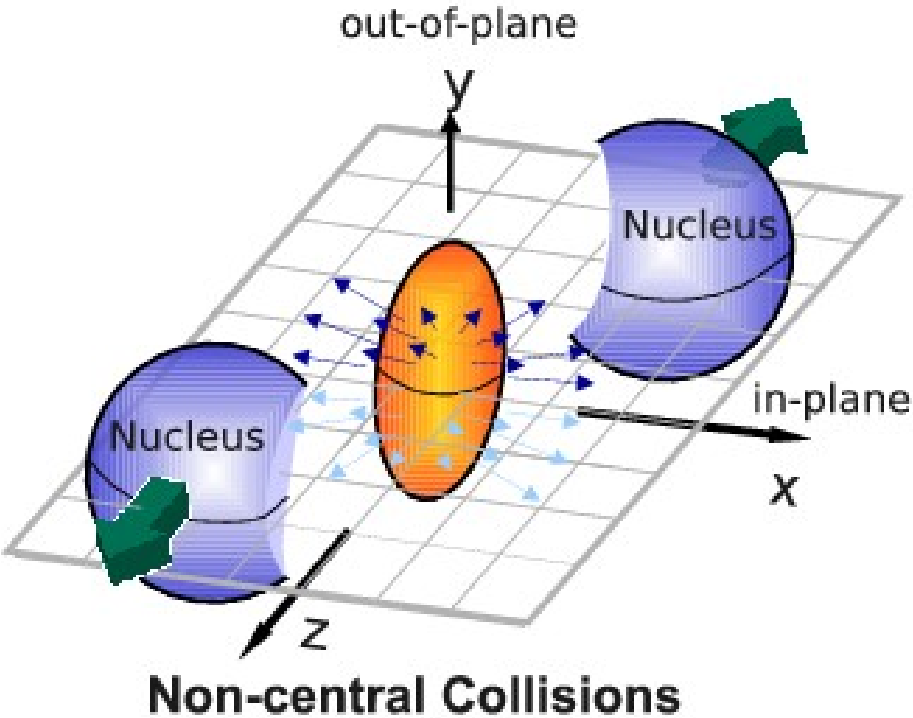
Direct photons in Pb-Pb collisions

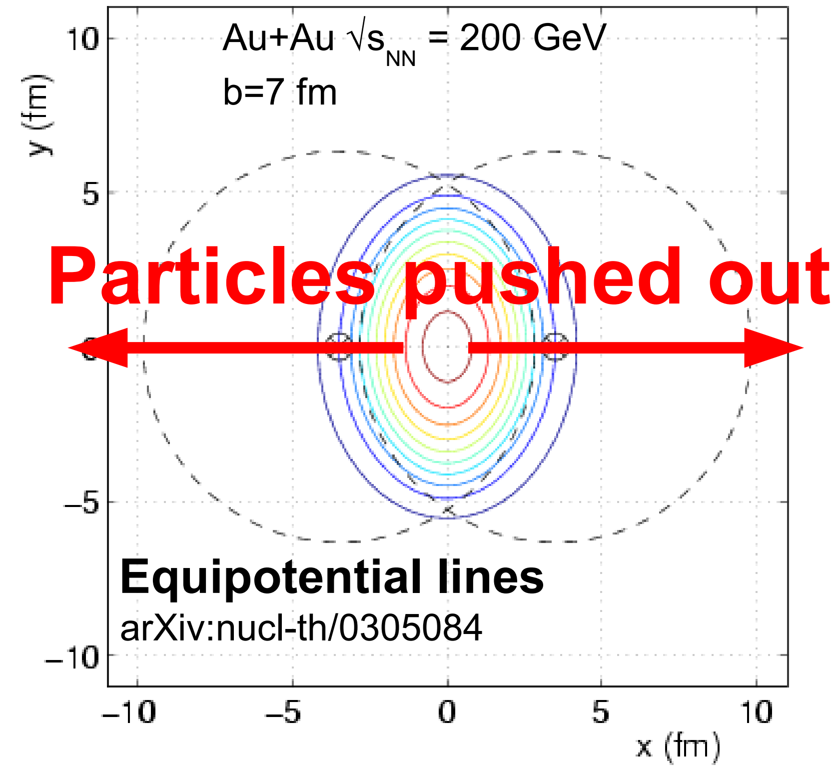




- Low-p_T: 2.6σ excess w. r. t. models in 0–20% central — thermal contribution
- T_{eff} = 304 ± 11(stat.) ± 40 (syst.) MeV in central Pb–Pb collisions at 2.76 TeV
- 30% higher than at RHIC (Au–Au at $\sqrt{s_{NN}}$=200 GeV)

Relativistic fluids



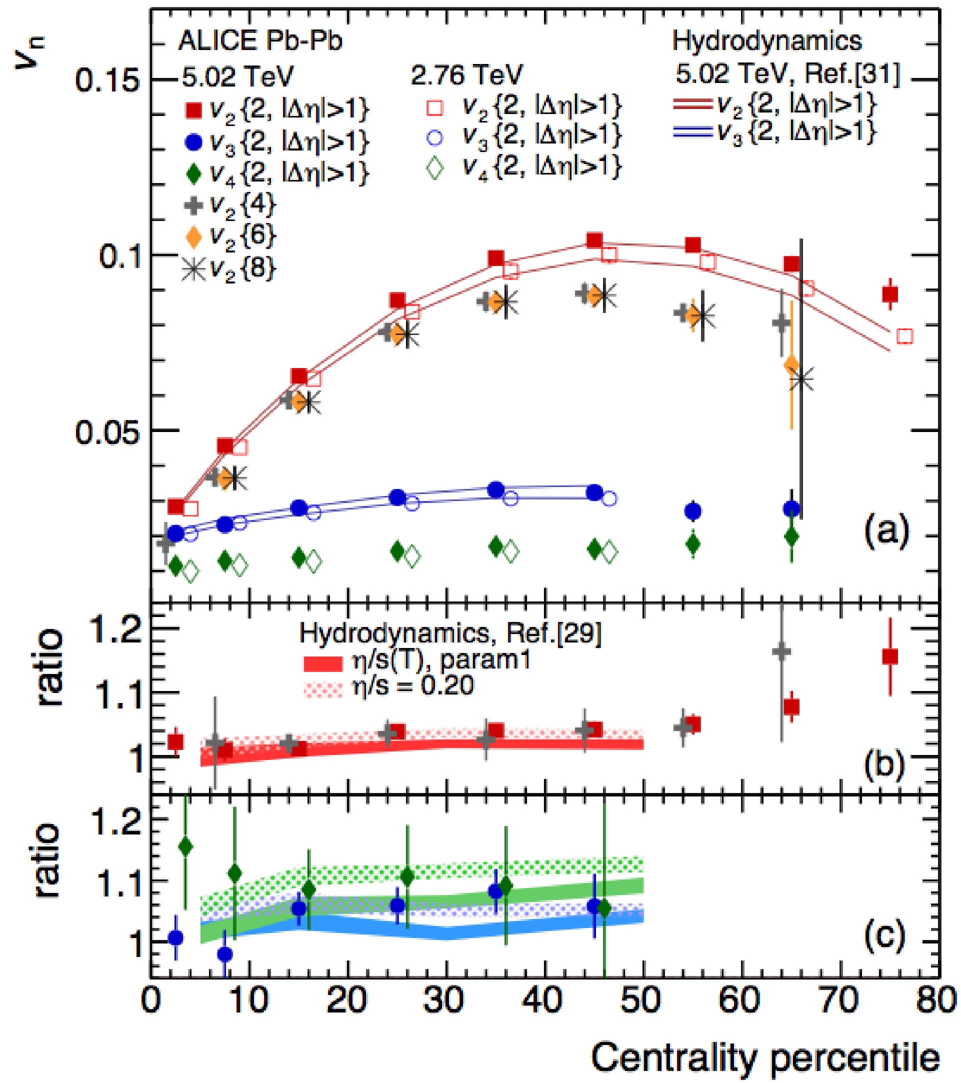


- Initial overlap asymmetric → pressure gradients
- Momentum anisotropy → Fourier decomposition:

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

Ratio of v_n at different energies

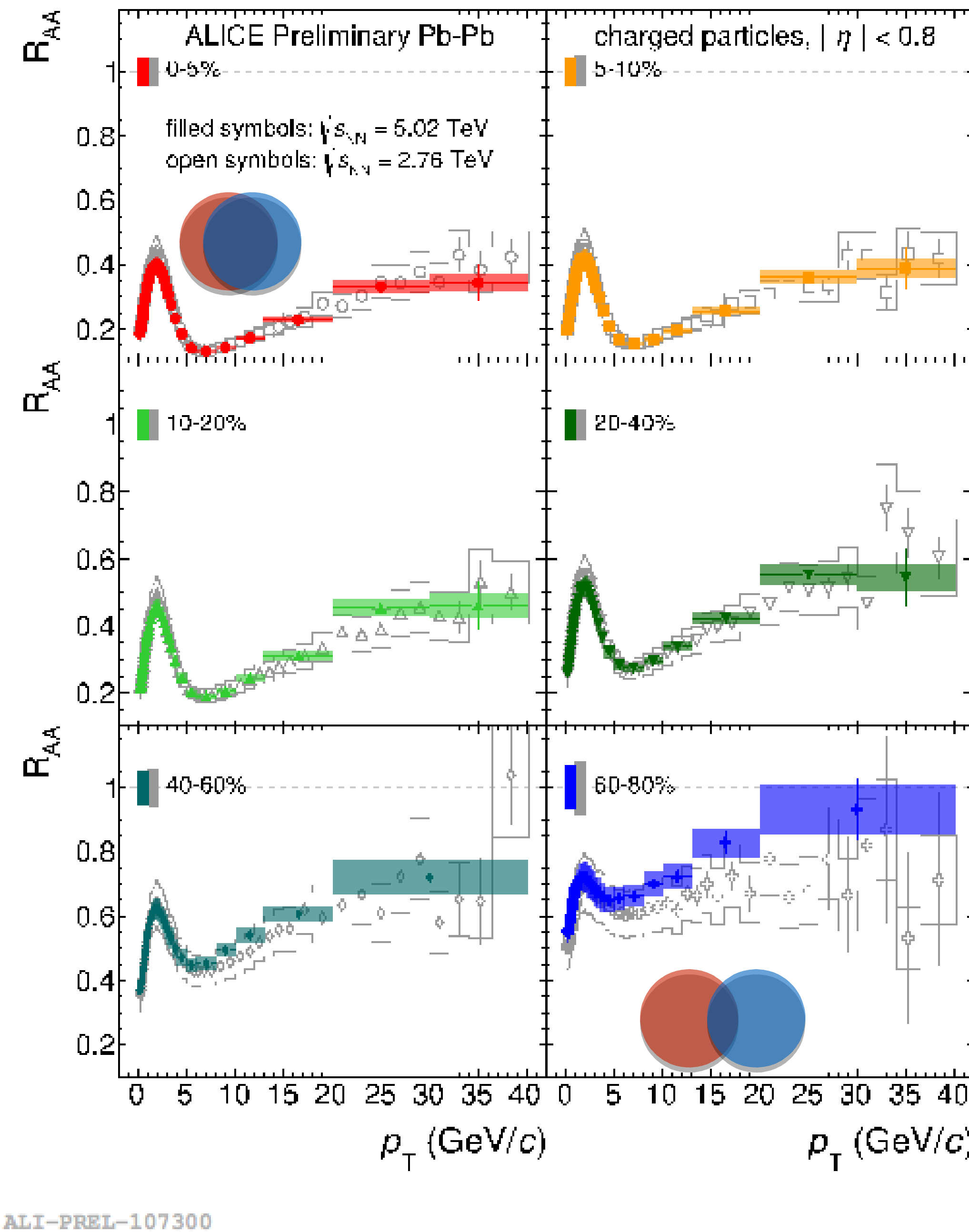
Phys. Rev. Lett. 116 (2016) 132302



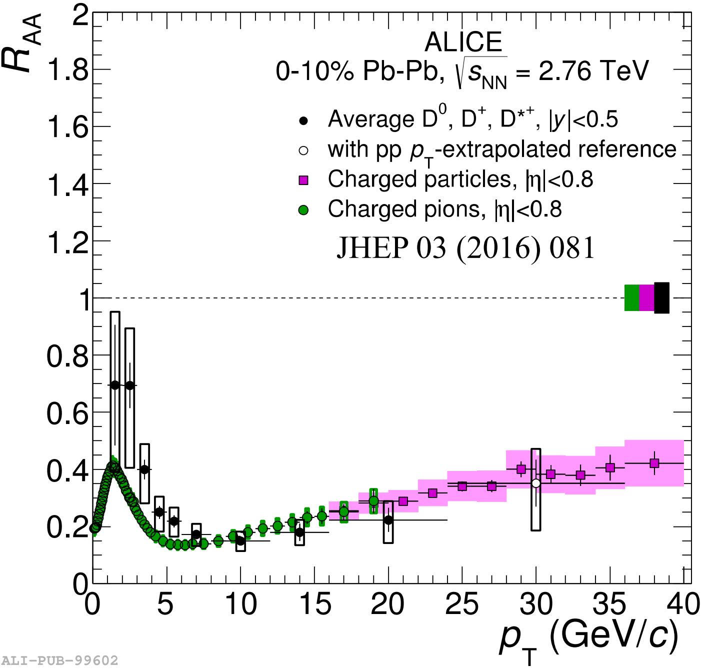
Charged particle R_{AA}

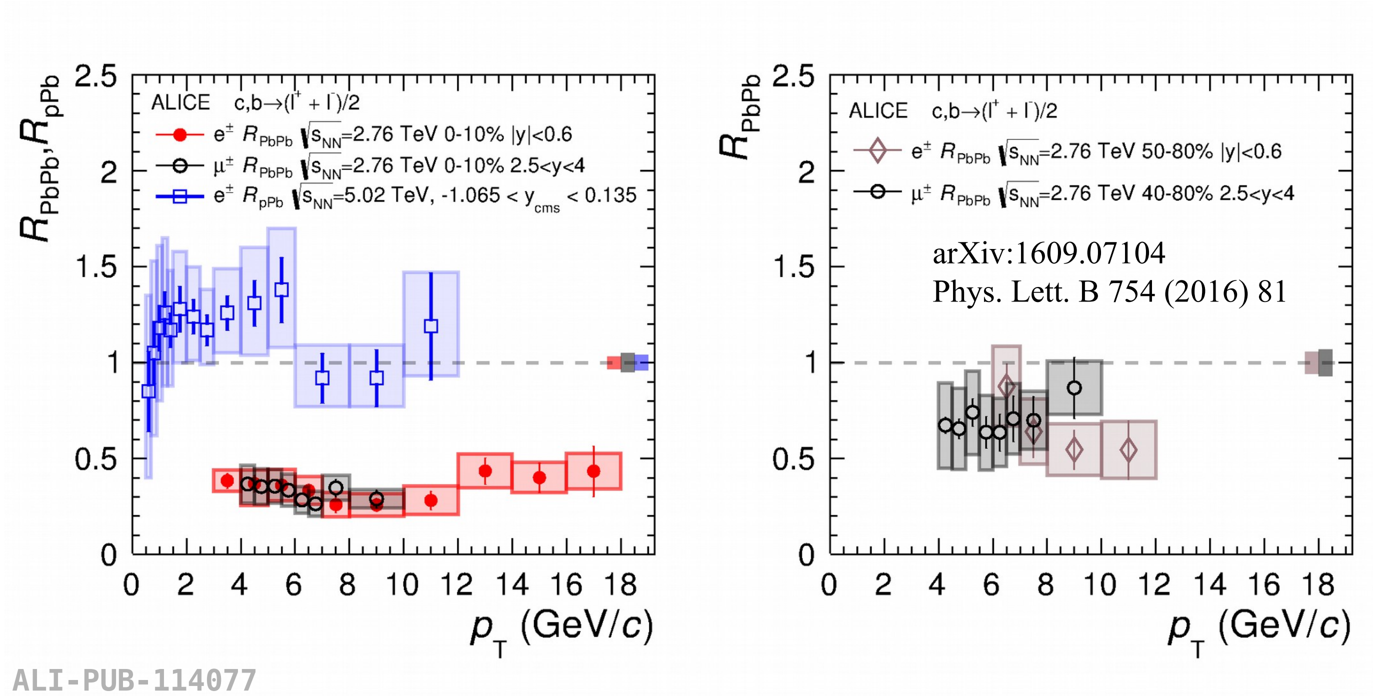
$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

- $R_{AA}>1$: 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



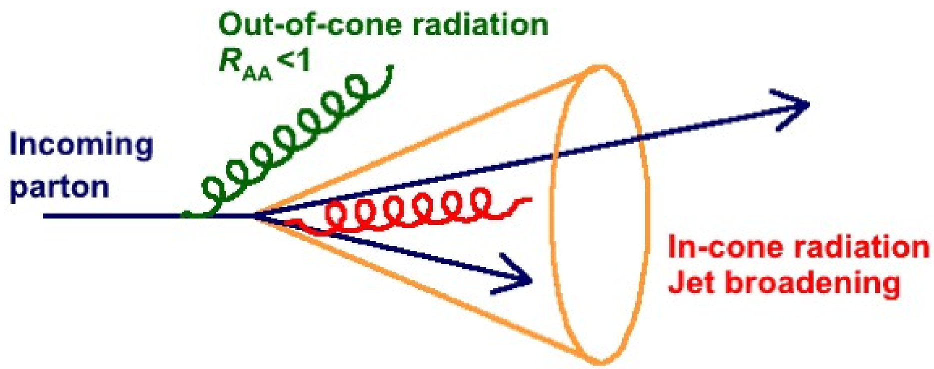
Heavy-Flavor R_{AA}



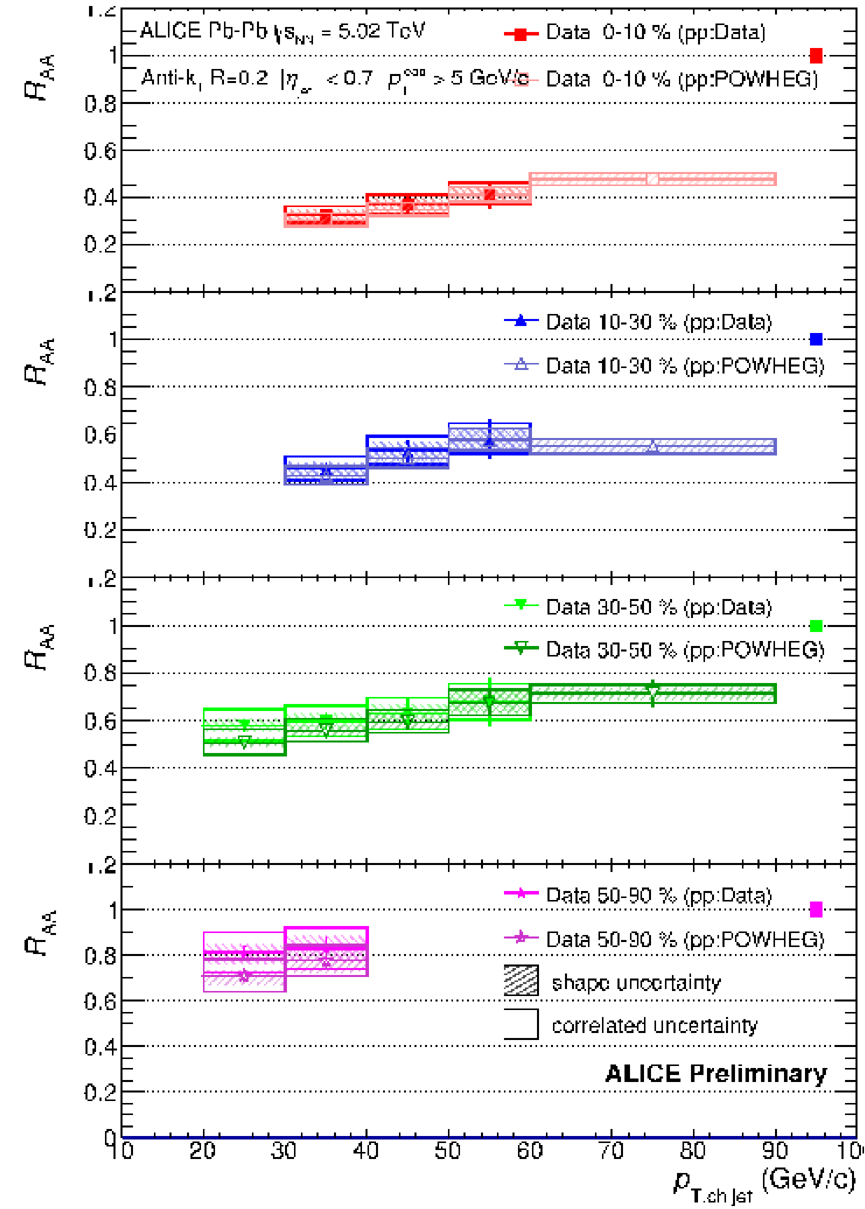


- Heavy flavor electron R_{pPb} consistent with unity for $p_T > 2$ GeV/c
- Large suppression at high p_T heavy quark in-medium energy loss
- $R_{AA}(D)$ and $R_{AA}(\pi)$ compatible with uncertainty at high p_T

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

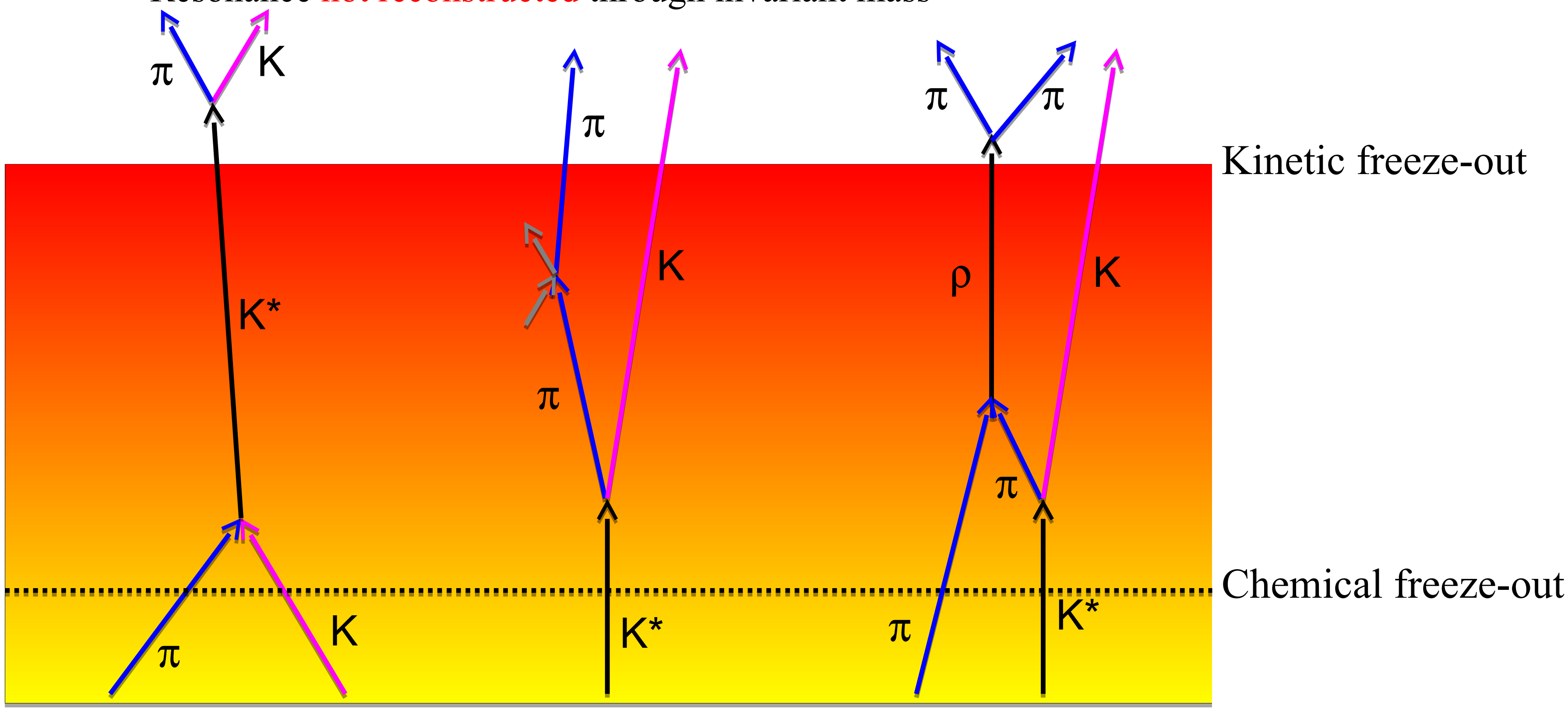


ALI-PREL-113513

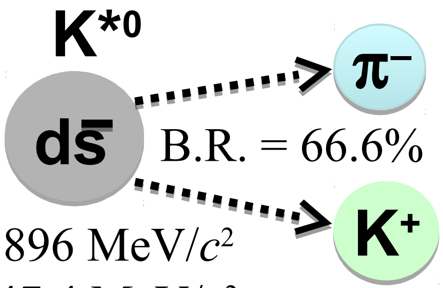
$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$

Hadronic Phase

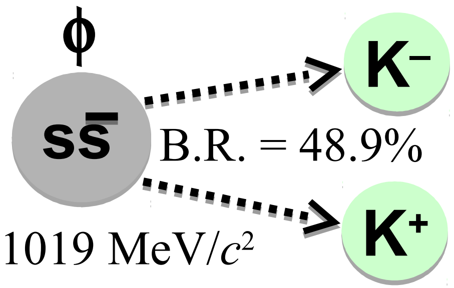
- Reconstructible resonance yields may be changed by hadronic scattering processes after chemical freeze-out:
  - **Regeneration:** pseudo-elastic scattering of decay products
  - **Re-scattering:**
    - Resonance decay products undergo elastic scattering
    - Or pseudo-elastic scattering through a different resonance (e.g. r)
    - Resonance not reconstructed through invariant mass



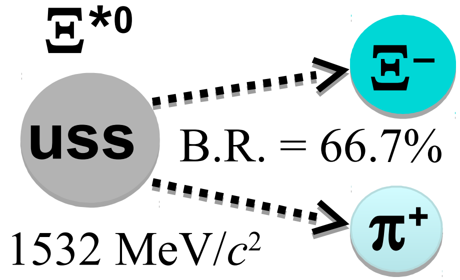
Other Resonances



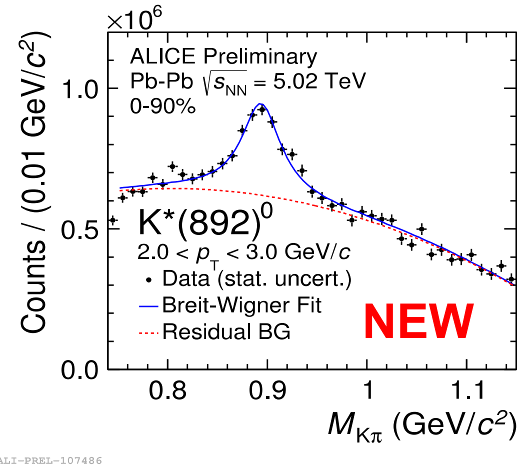
$m = 896$ MeV/c^2
$\Gamma = 47.4$ MeV/c^2

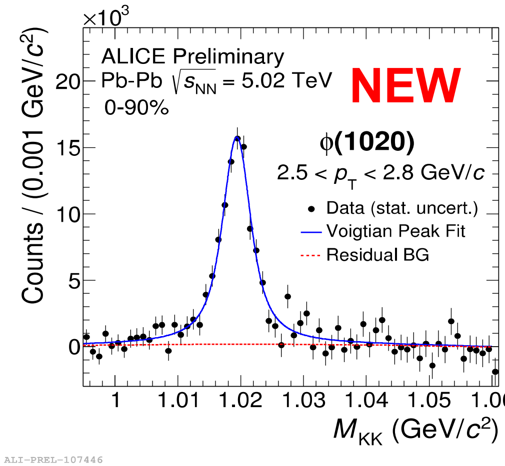


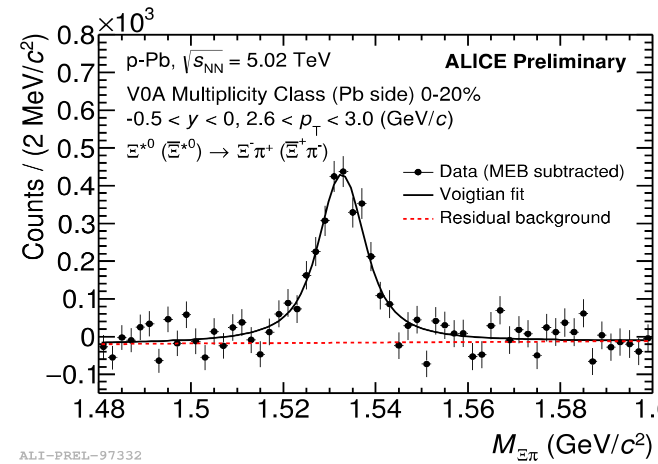
$m = 1019$ MeV/c^2
$\Gamma = 4.266$ MeV/c^2

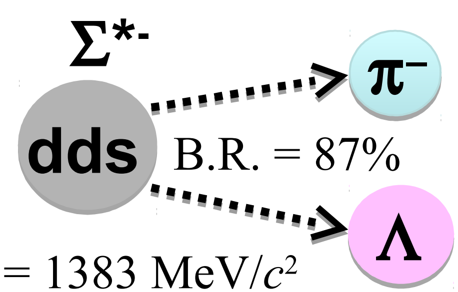


$m = 1532$ MeV/c^2
$\Gamma = 9.1$ MeV/c^2

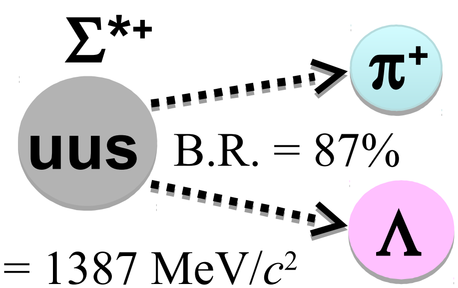




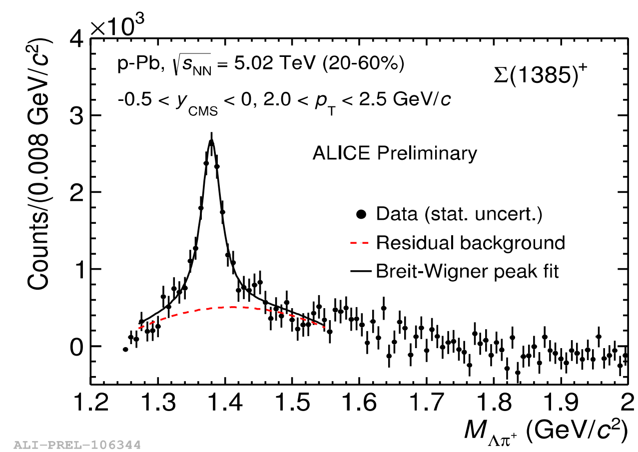




$m = 1383$ MeV/c^2
$\Gamma = 36.0$ MeV/c^2

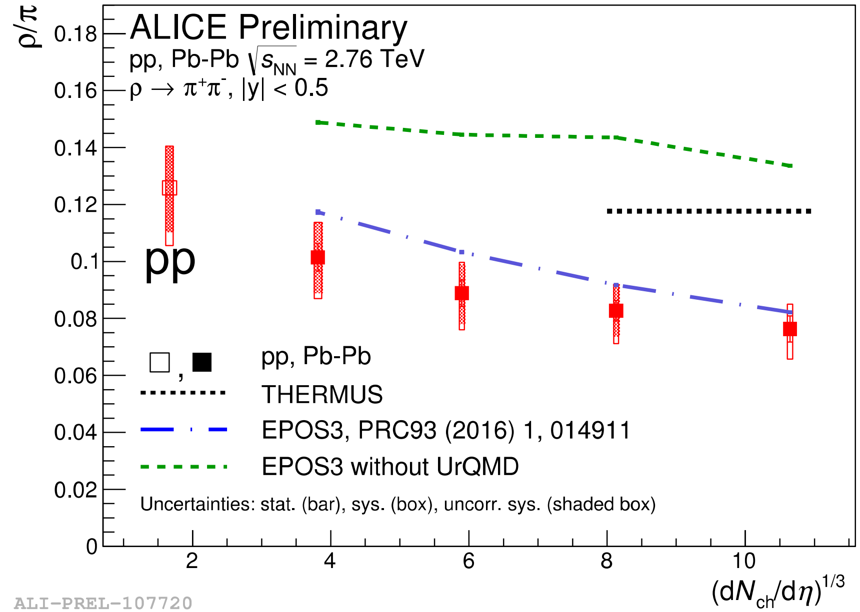


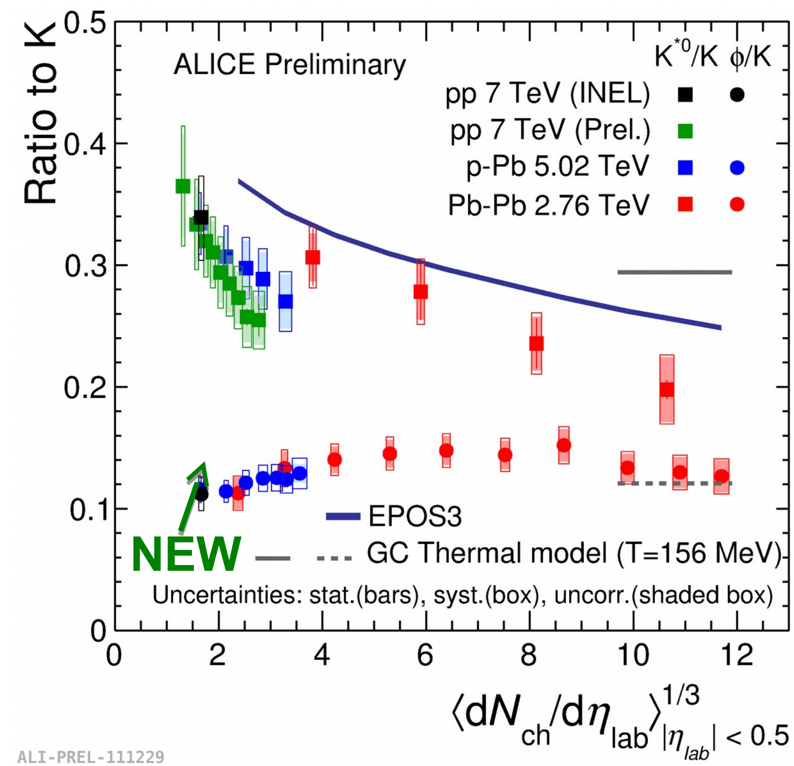
$m = 1387$ MeV/c^2
$\Gamma = 39.4$ MeV/c^2



Ratios to Stable Hadrons

- Suppression of ρ^0/p and K^{*0}/K in central Pb–Pb w.r.t. peripheral, pp, p–Pb, thermal model
  - Suggests that re-scattering is dominant over regeneration
  - Well described by EPOS+UrQMD
- K^{*0}/K in small systems:
  - decreasing trend observed in p–Pb (slope not consistent with 0)
  - Multiplicity-dependent suppression in pp
- No suppression of ϕ/K, no strong centrality dependence
  - Central Pb–Pb consistent w/ thermal model
    - Lifetime of ϕ ~10× longer than K^{*0}, ~35× longer than ρ^0, re-scattering effects not significant
  - Ratio in p–Pb consistent with trend from pp to peripheral Pb–Pb





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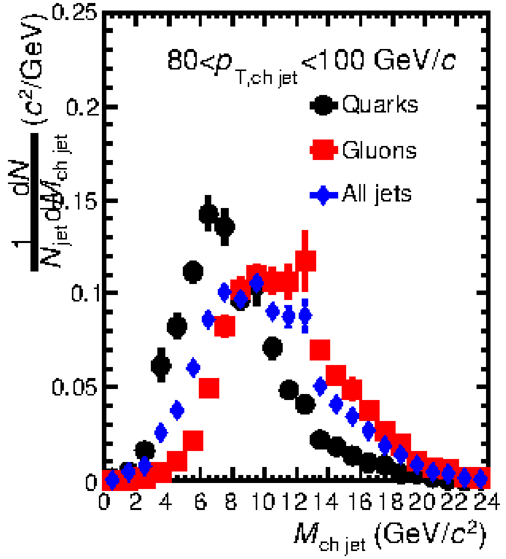
Eur. Phys. J. C **76** 245 (2016)

Jet mass and virtuality

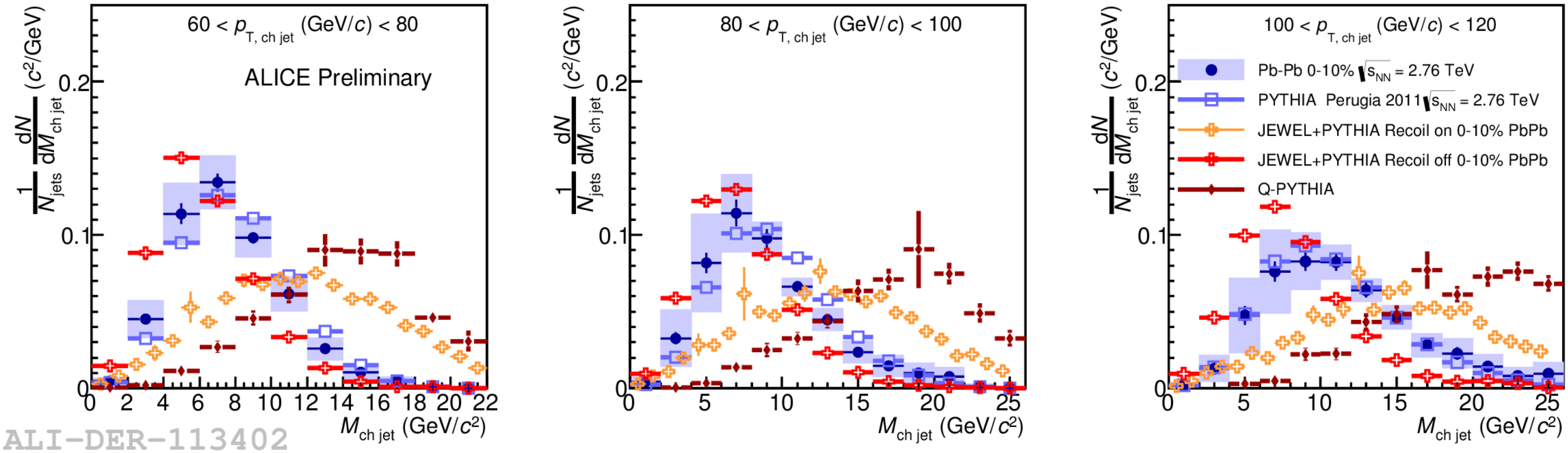
$$M = \sqrt{p^2 - p_T^2 - p_z^2} \qquad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i \qquad p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i$$

- Jet mass increases with the radial distance of the constituents from the jet axis
  - Soft constituents, away from the jet axis within the cone → larger mass
  - Few hard constituents → smaller mass

→ E.g. gluon vs quark jets jet mass difference



Comparison to models



- Quenching models (JEWEL, Q-PYTHIA) show a larger mass than pp-like PYTHIA jets
  - JEWEL: 2→2 pQCD matrix elements with parton shower taking into account radiation. For charged jets the background subtraction is implemented by shifting the distribution considering the background estimated for full jets and the difference between full and charged jets in pp
  - Q-PYTHIA: PYTHIA with medium effects in the final state branching through an additive term in the splitting functions computed in the multiple-soft scattering approximation
- JEWEL with "recoil off" (removing recoil centres before hadronization) shows a depletion of the jet mass wrt pp due to less low-p_T fragments wrt recoil on
- Pb-Pb measurement can discriminate among these predictions

Conclusions

- Precision tracking and PID enable precision measurements of
  - Global observables (N_{ch}, E_T)
  - Direct photons
  - Hydrodynamical flow
  - Jets
  - Resonances
- More to come!
  - Results from DCal
  - Upgrades for run 3