Review of ALICE Experiments

尹　珍　姬　(Jin-Hee Yoon)

Dept. of Physics

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Outline

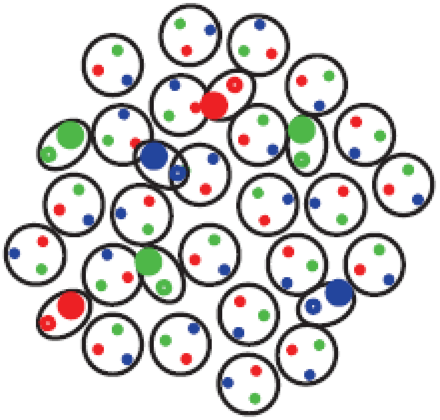
- ✓ Introduction
- ✓ Review of Alice Results
- ✓ ITS upgrade
- ✓ Conclusion

Objects

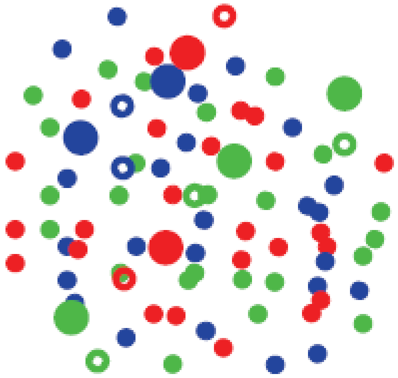
- ✓ Searching for the initial stage of Universe

- ✓ From QCD calculation,

  Confining at normal temperature

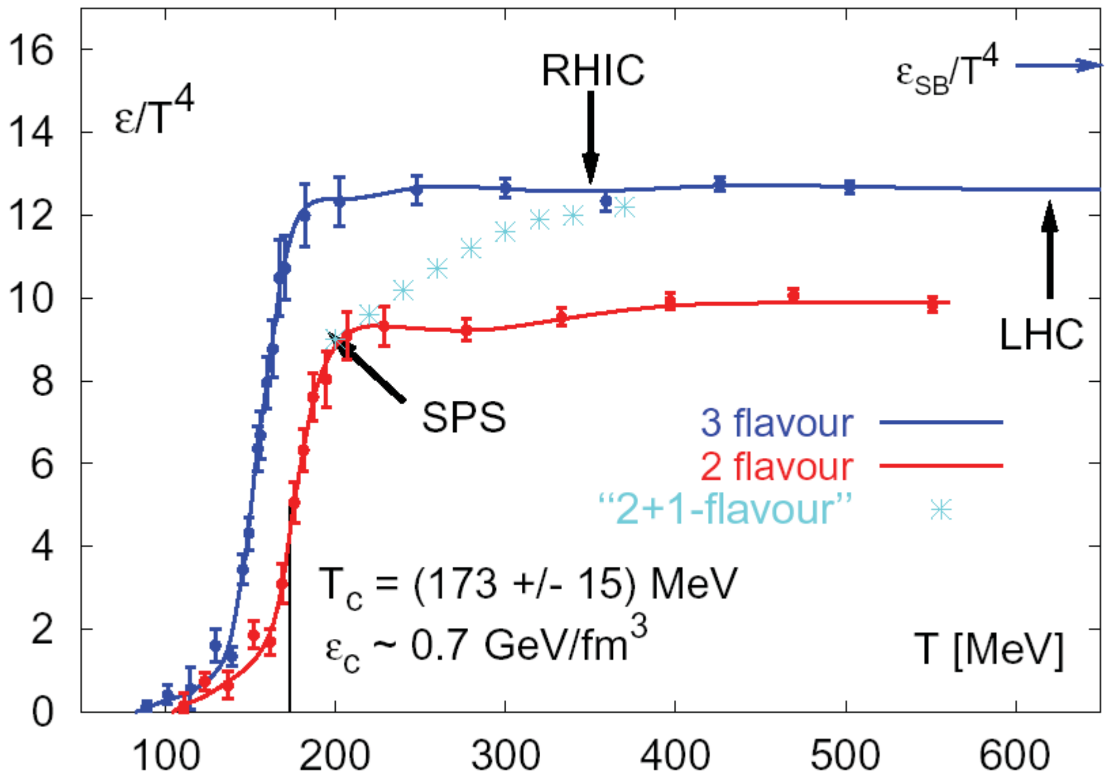


- ✓ At high momentum transfer
  - → α_s becomes weak
  - → asymptotic freedom
  - → **Quark-Gluon Plasma(QGP)**

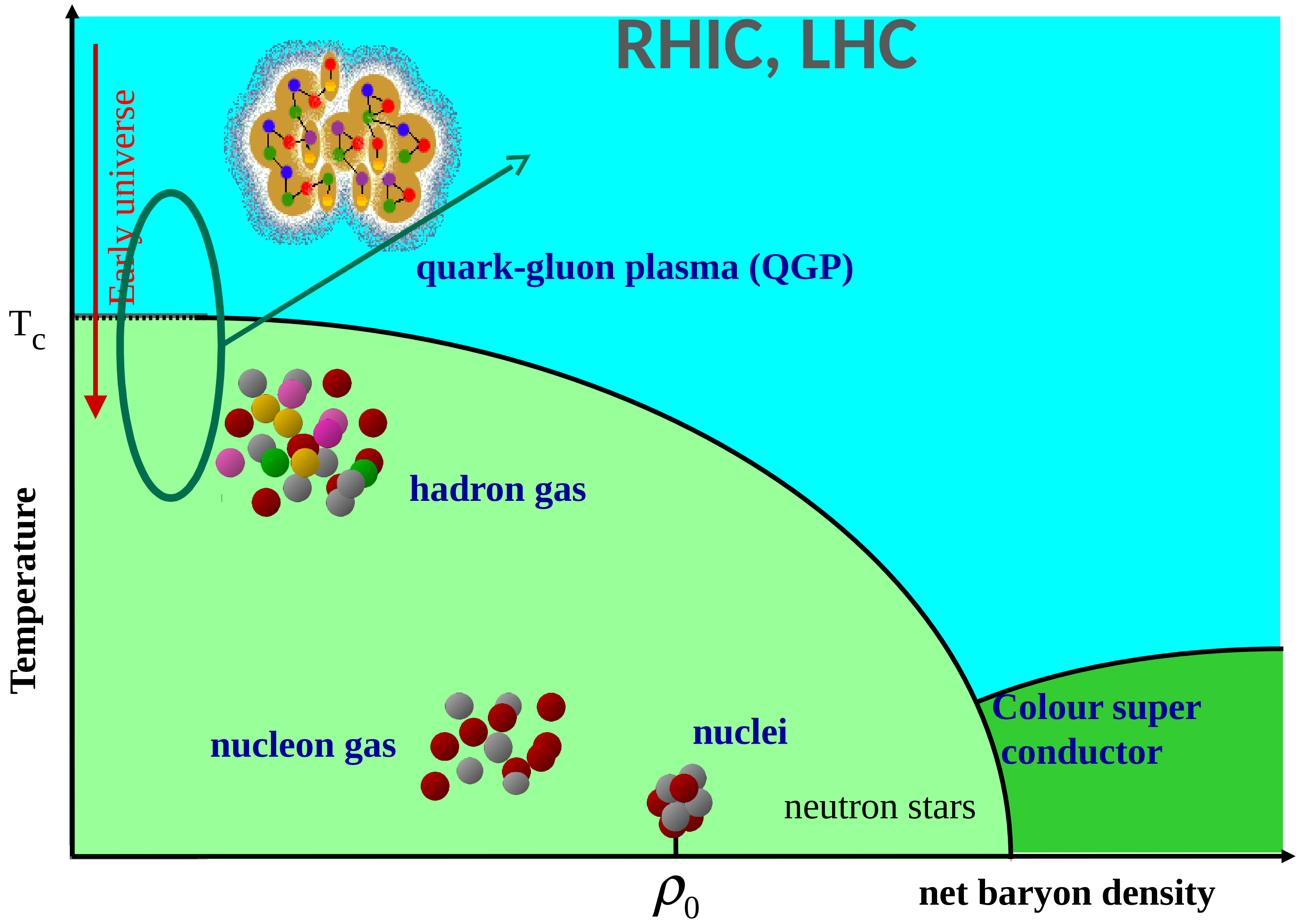


Lattice QCD Calculation

- ✓ $T_C = 173 \pm 15$ MeV $\varepsilon_C = 0.7 \pm 0.2$ GeV/fm^3

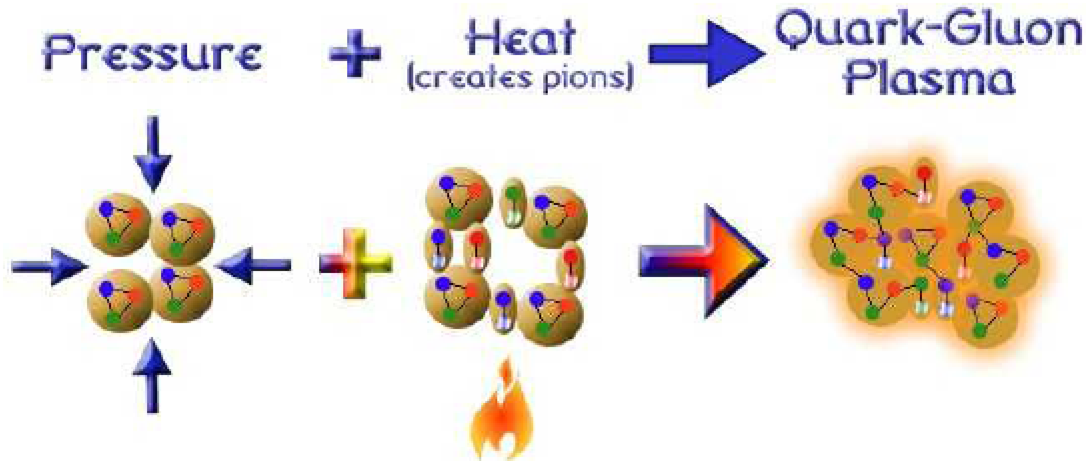


Phase Diagram

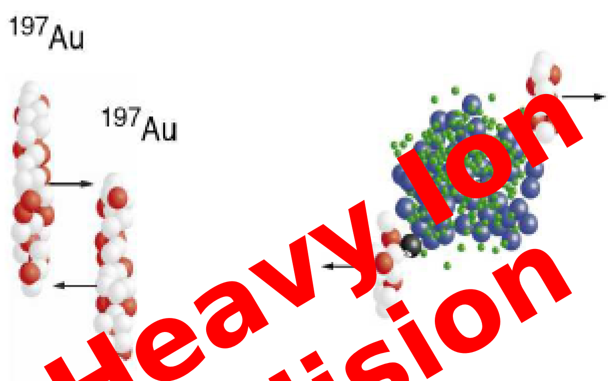


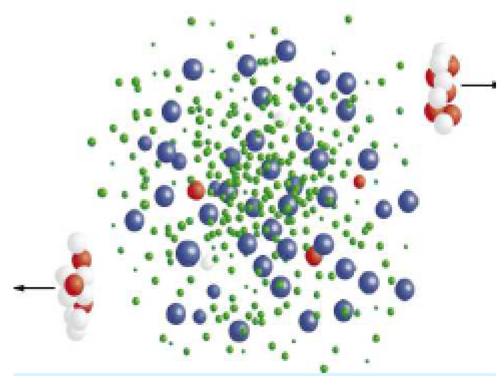
How to produce?

- ✓ *Theoretically*



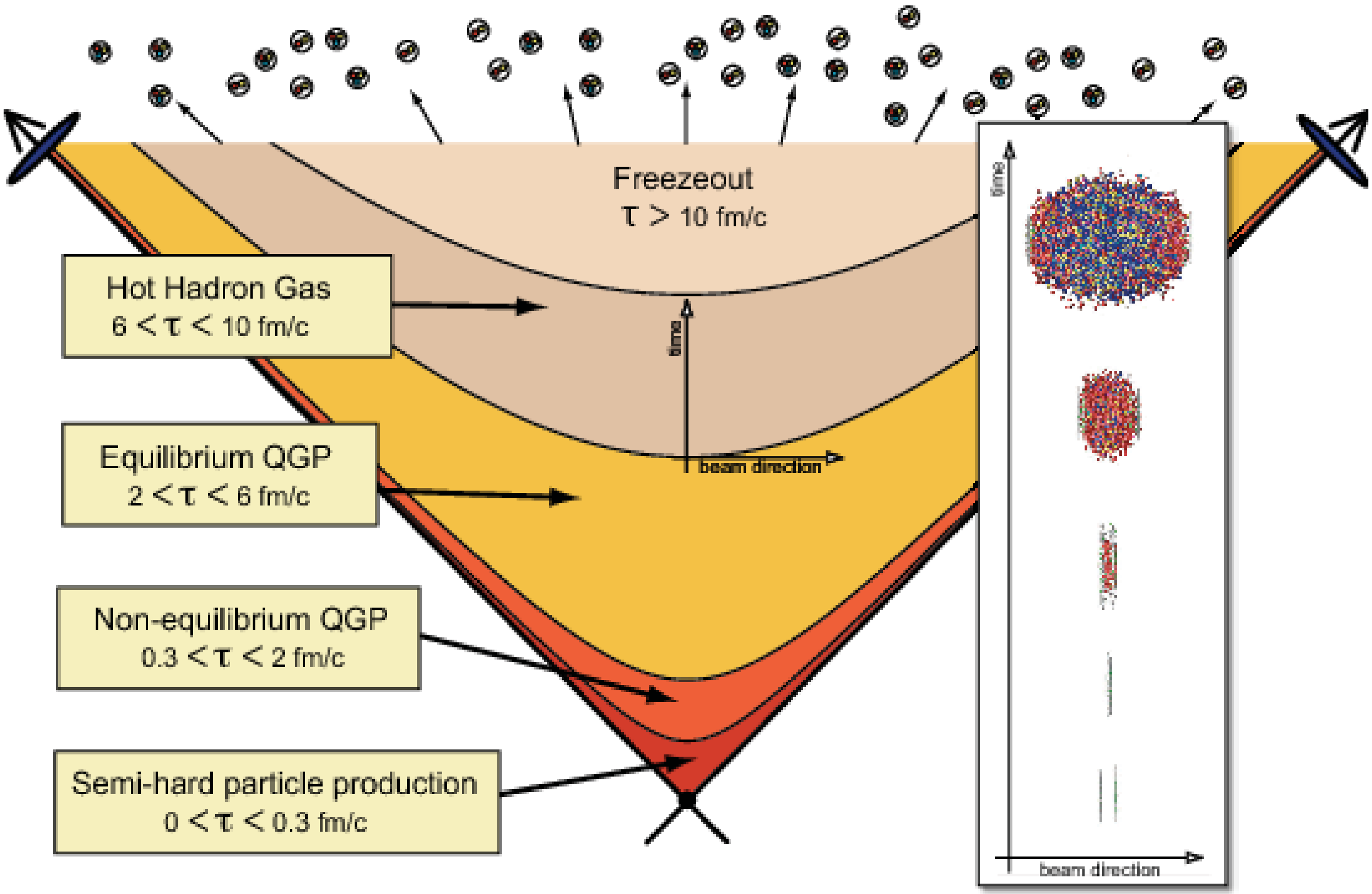
- ✓ *Experimentally*





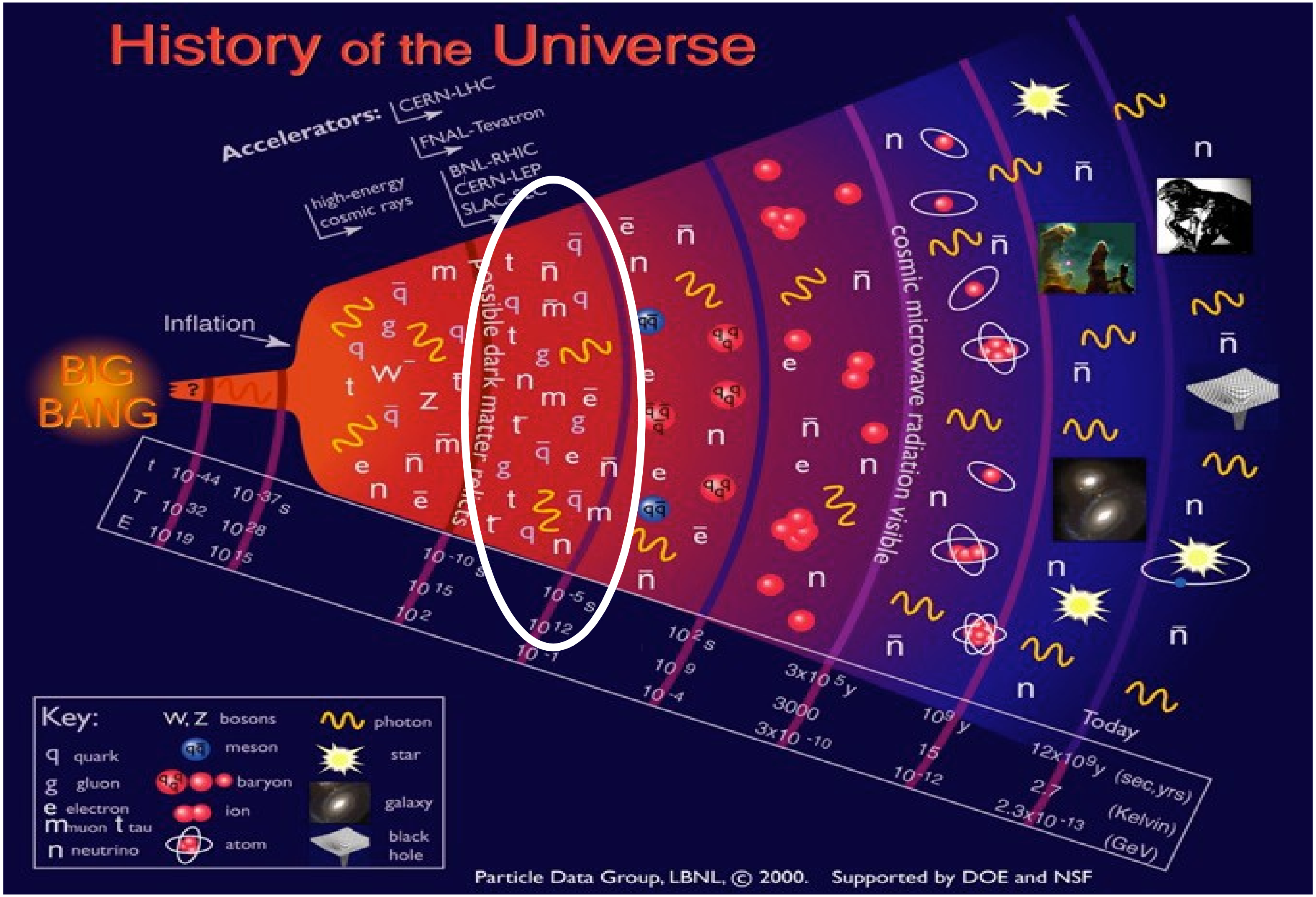
Heavy Ion Collision

Evolutions

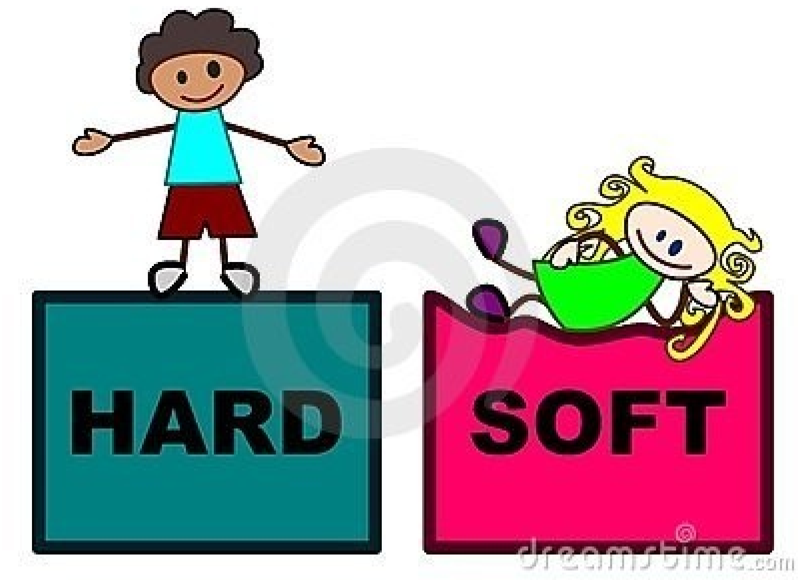


Freezeout
τ > 10 fm/c
Hot Hadron Gas
6 < τ < 10 fm/c
Equilibrium QGP
2 < τ < 6 fm/c
Non-equilibrium QGP
0.3 < τ < 2 fm/c
Semi-hard particle production
0 < τ < 0.3 fm/c
time
beam direction
time
beam direction

QGP in the Universe

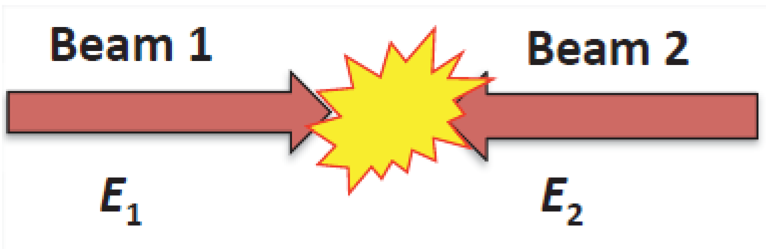


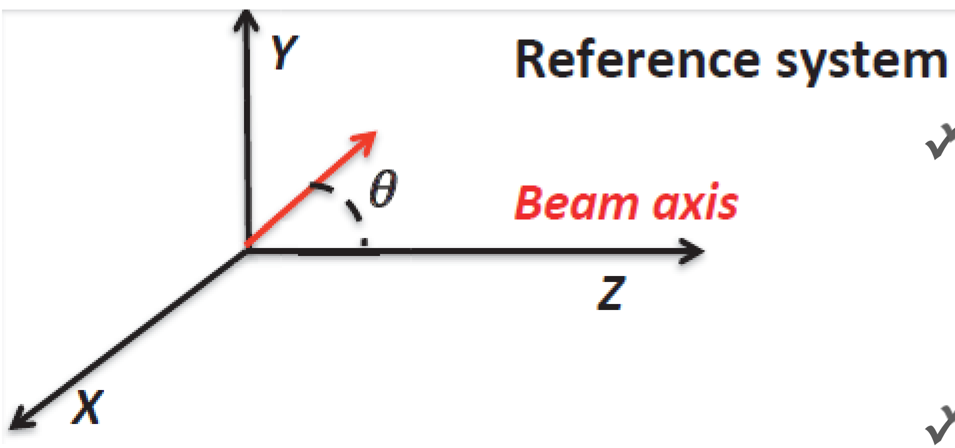
Observables?



- ✓ High energy process
  - Energy loss by quarks, gluons and other particles
  - Quarkonia and heavy flavour
- ✓ Low energy process
  - Radiation of hadrons and photons (multiplicity, pT spectra, PDF..)
  - Azimuthal asymmetry, expansion

Variables





- ✓ Center of Mass Energy
Center of Mass Energy

$$\sqrt{s} \approx 2*(E_1*E_2)^{1/2}$$

- ✓ Rapidity
Rapidity

$$y = \frac{1}{2}\ln\frac{E + p_Z}{E - p_Z}$$

- ✓ Pseudo Rapidity
Pseudo Rapidity

$$\eta = -\ln(tg(\theta / 2))$$

- ✓ At high energy, $\boldsymbol{y \approx \eta}$
At high energy,

A Large Ion Collider Experiment

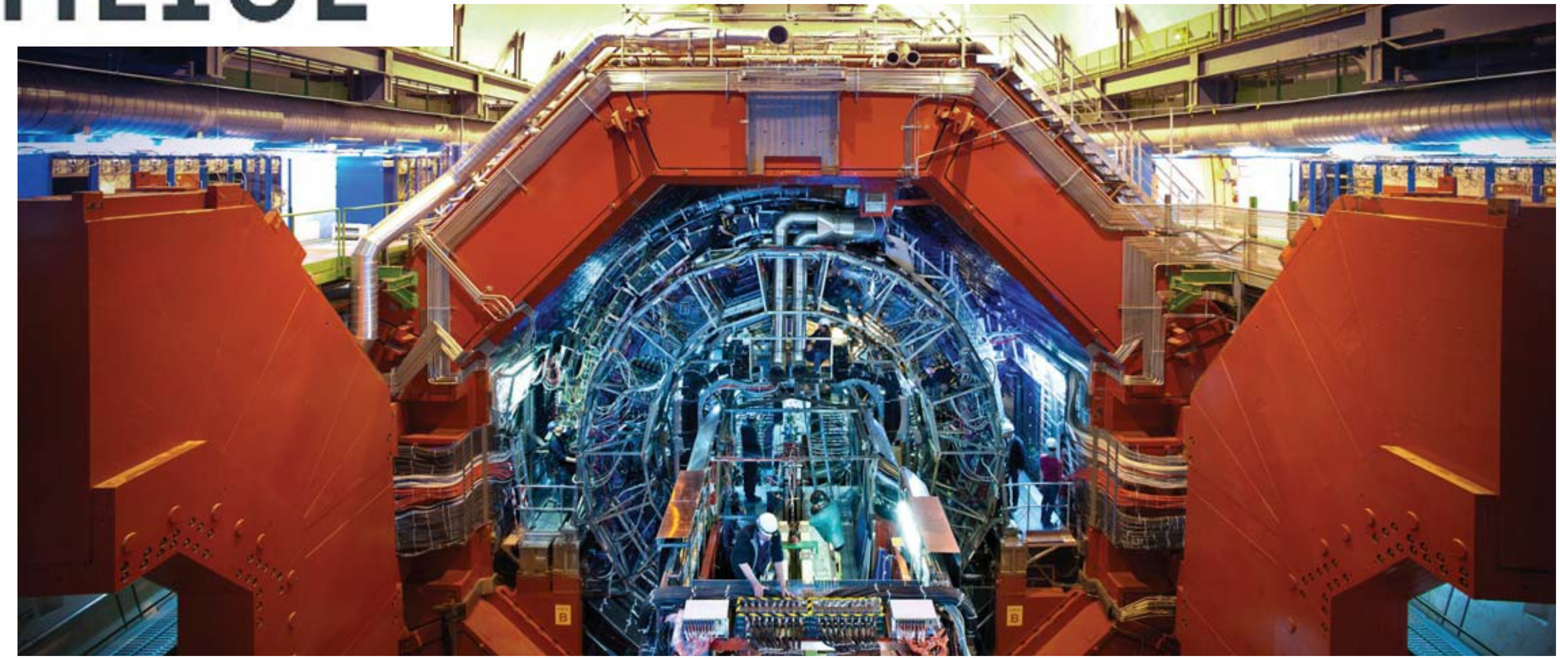
ALICE

Detector : 16X26 m 10000 tons

Collaborations : 1500 members,

154 institute,

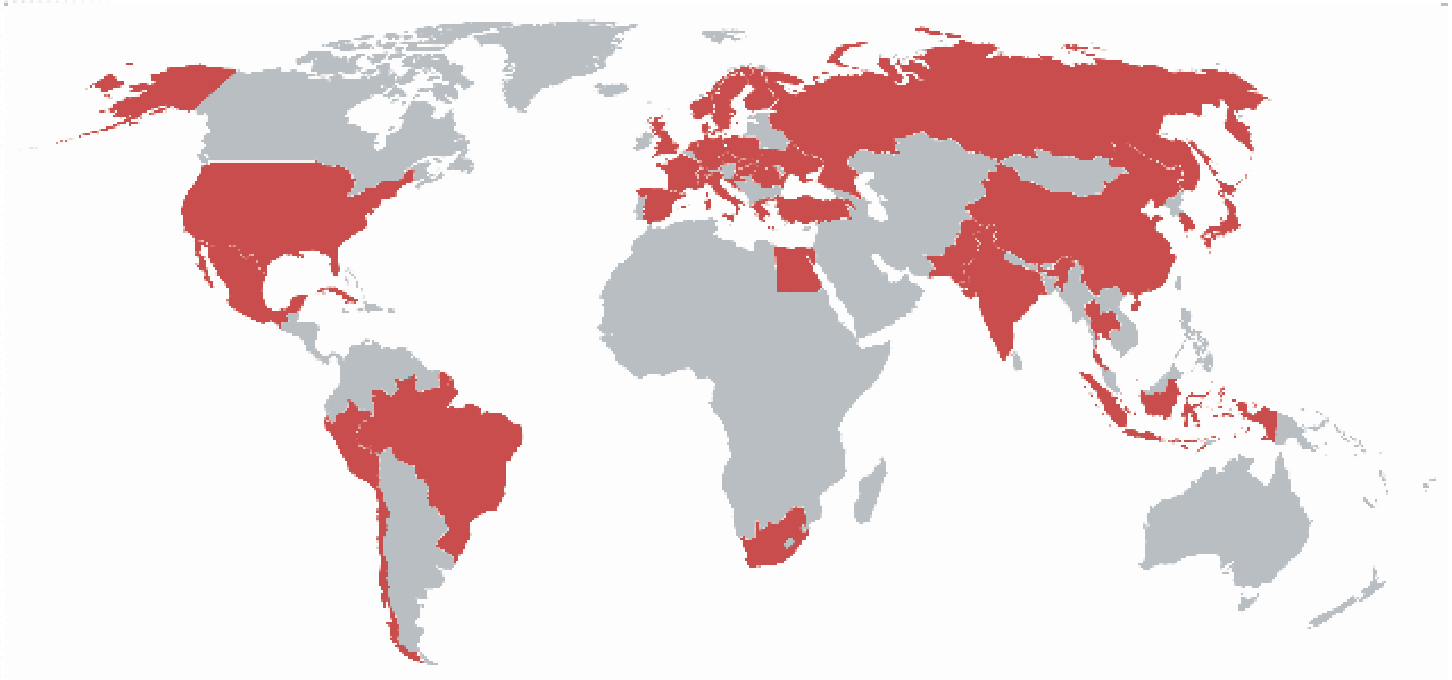
37 countries



ALICE COLLABORATION

International Collaboration

The ALICE Collaboration :
37 Countries, 154 Institutes and over 1500 members



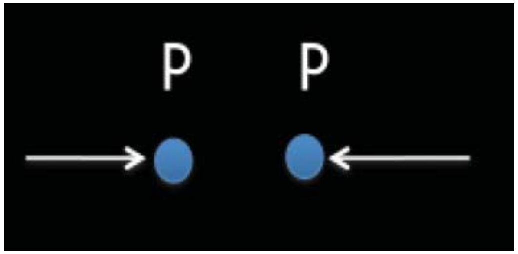
Participating Institutes

Participants (39)

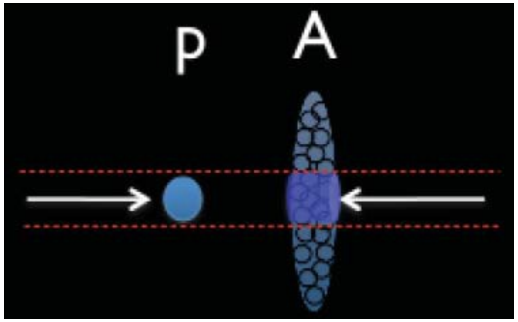
- **6 Univs. + 1 Institute**
- **Prof : 10**
- **PhD : 5**
- **Graduates : 24**

Collisions

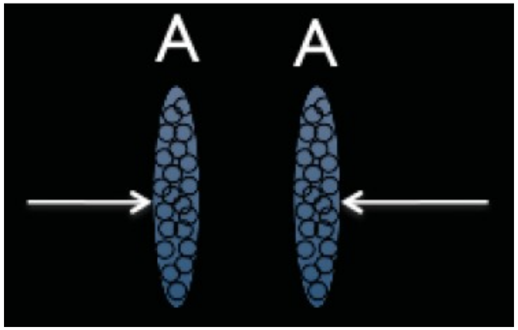
- proton-proton collisions:
  - **high energy QCD reference.**
  - collected pp data at $\sqrt{s}$ = 0.9, 2.76, 7, 8, 13 TeV (2009-2012, 2015, 2016)



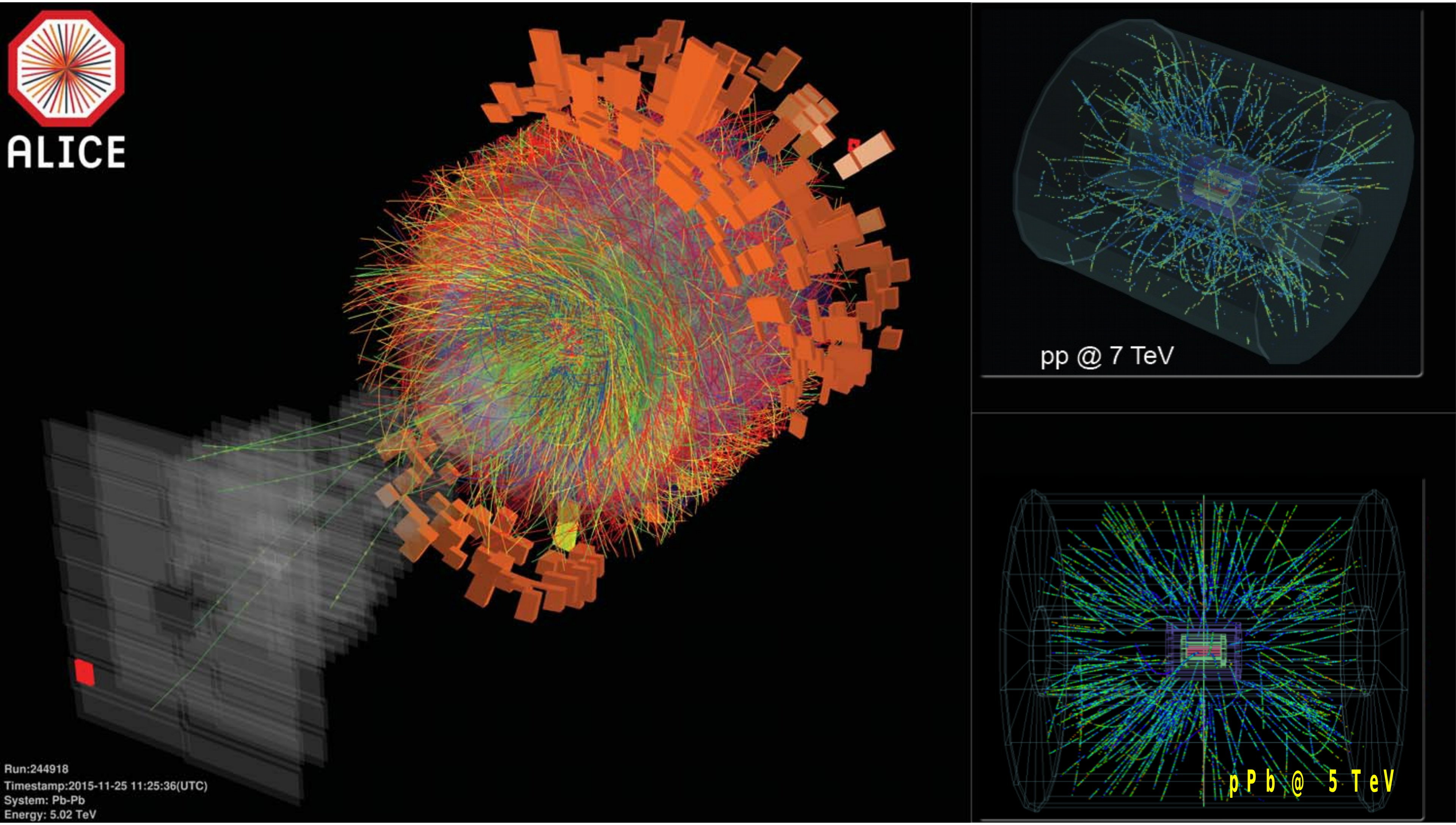
- proton-nucleus collisions:
  - **initial state/cold nuclear matter.**
  - collected p-Pb data at $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV (2012, 2013, 2016)



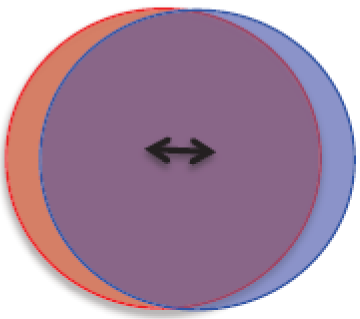
- nucleus-nucleus collisions:
  - **quark-gluon plasma formation!**
  - collected Pb-Pb data at $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV (2010, 2011, 2015)

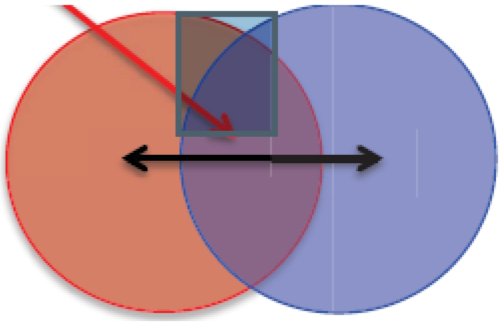


2015 Pb-Pb Event Display



Centrality



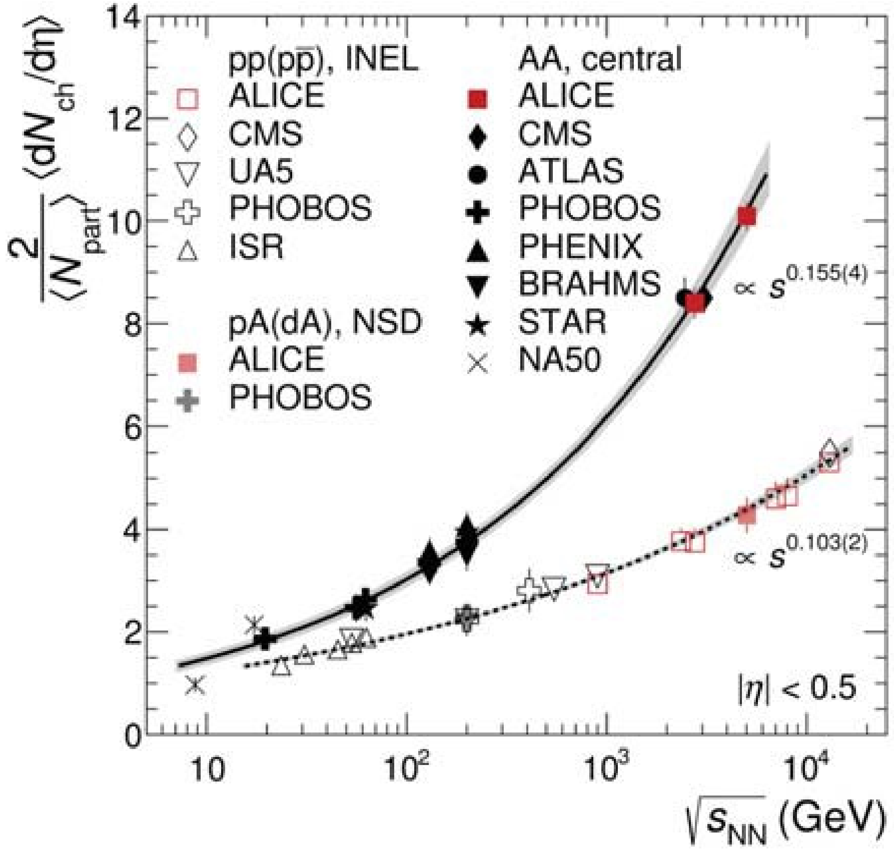


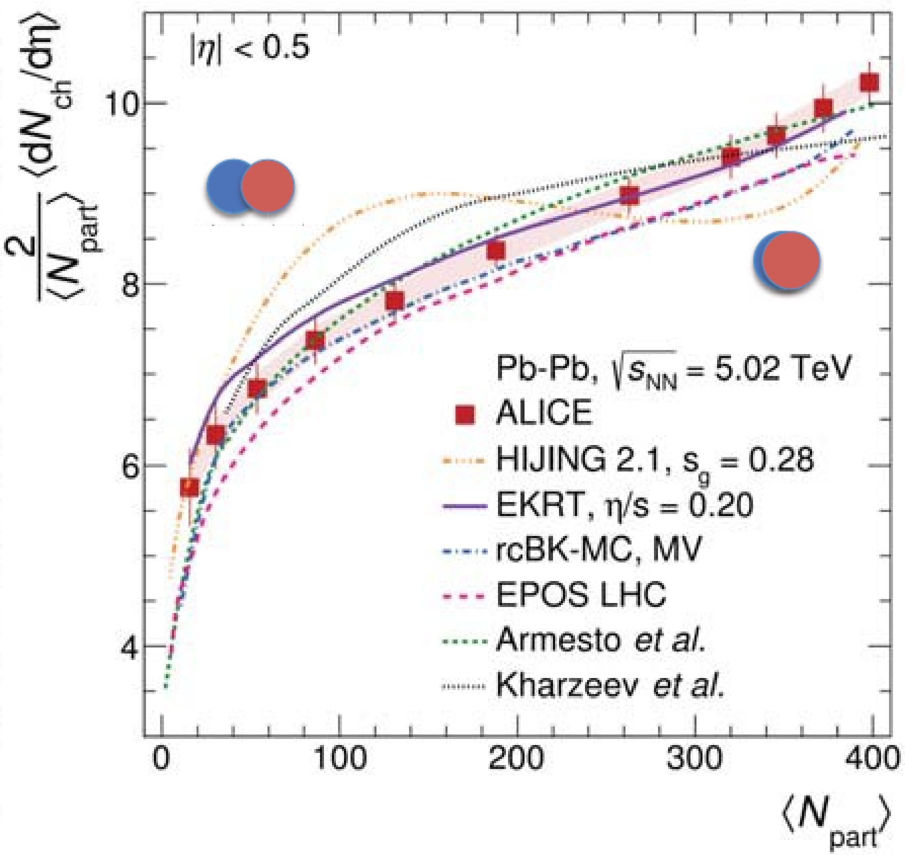
"Central"
Small impact parameter
Large system volume
Large particle multiplicity

"Peripheral"
Large impact parameter
Small system volume
Small particle multiplicity

Map these measurements into IP using Models!

Charged particle multiplicity



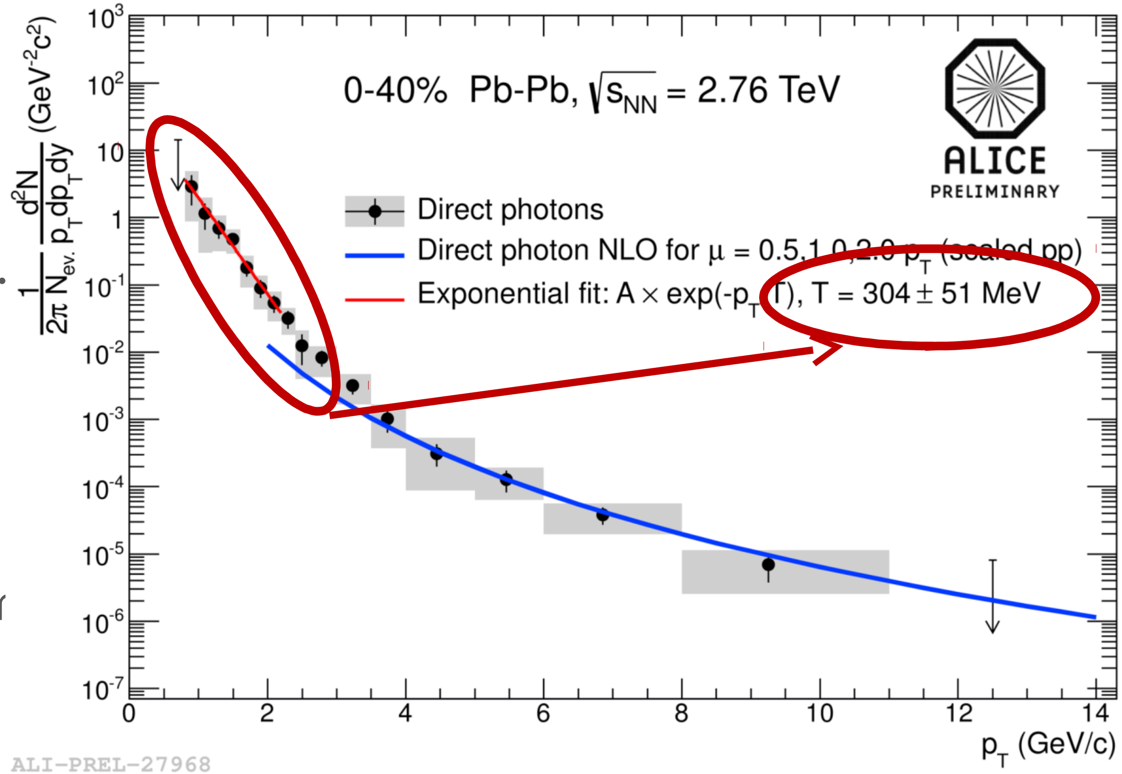


Soft Probes – Direct photons

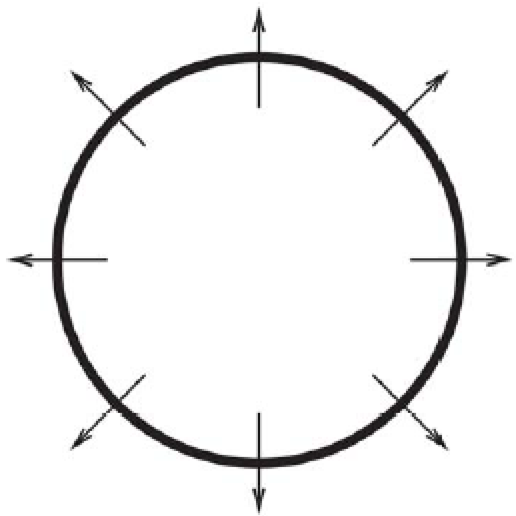
- ✓ Inclusive – Decay = Direct

- ✓ Prompt
  - Hard scattering
  - High pT
  - Information on PDF, QCD…

- ✓ Thermal
  - Thermal production
  - Low/medium pT
  - Information on early therm



Radial Flow



Thermal + Collective expansion velocity

Thermal + Collective expansion velocity

MeV

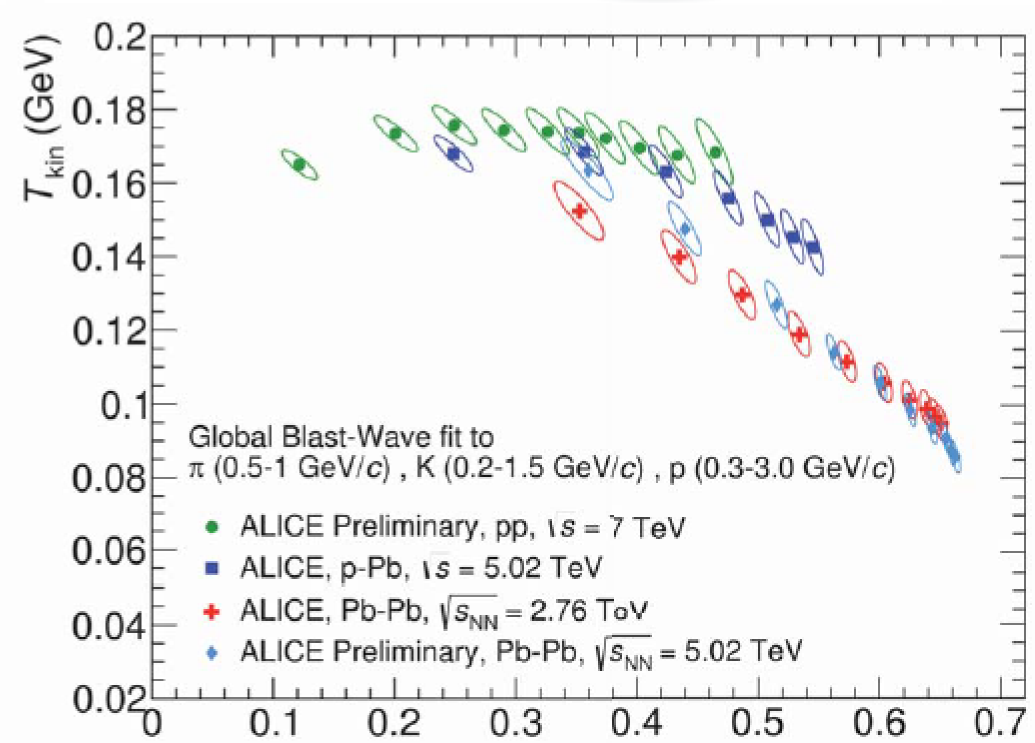
$T_{kin} \approx 100$ MeV

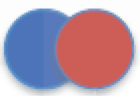
$\beta \approx 0.67$

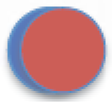
$$m_T = \sqrt{m^2 + p_T^2}$$

$$\frac{d^2 N_j}{m_T dy dm_T} = \int_0^{R_G} A_j m_T \cdot K_1\left(\frac{m_T \cosh\rho}{T}\right) \cdot I_0\left(\frac{p_T \sinh\rho}{T}\right) r dr$$

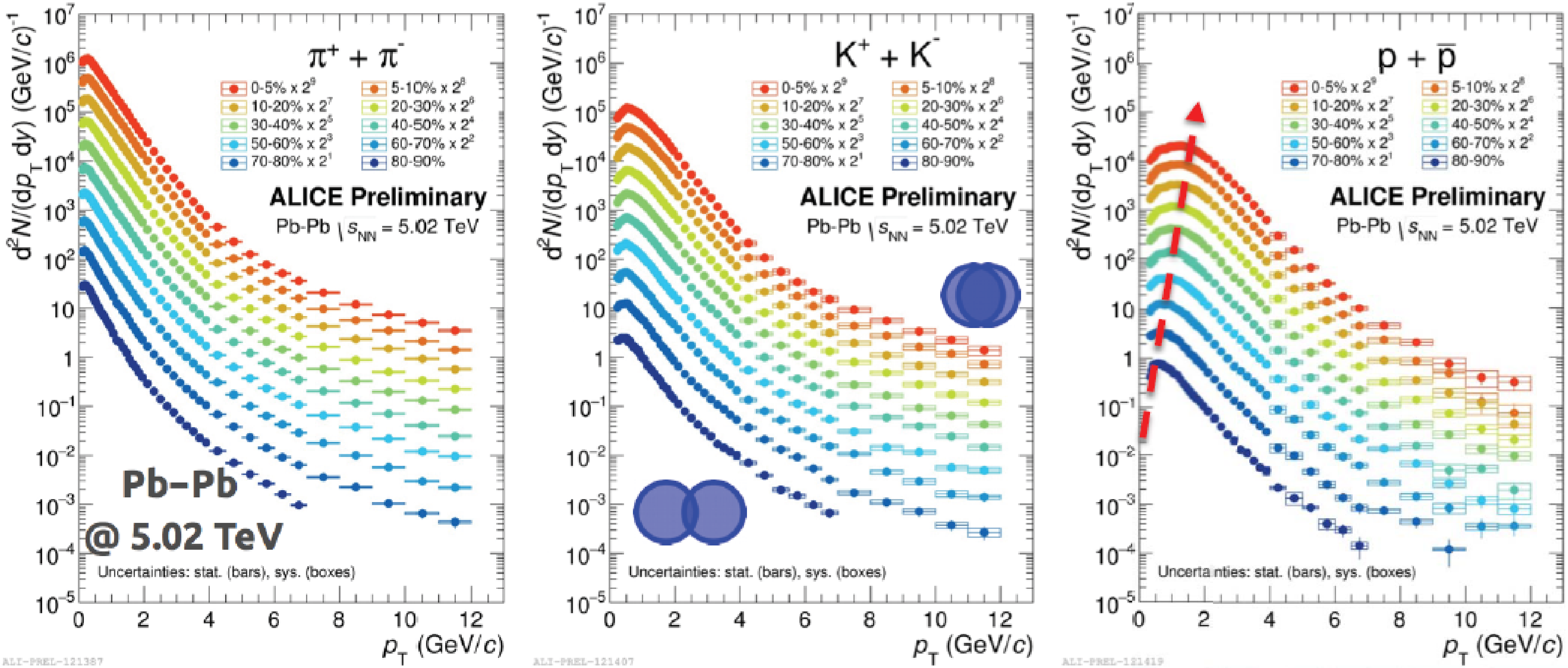
$$\rho(r) = \tanh^{-1} \beta_\perp(r) \qquad \beta_\perp(r) = \beta_S \left[\frac{r}{R_G}\right]^{n(=1)} \qquad r \leq R_G$$







PT spectra of charged particles



- ✓ Get flatten for more central
- ✓ Stronger effect for heavier particles
- ✓ Heavier particles have larger momentum with same velocity

Elliptic Flow

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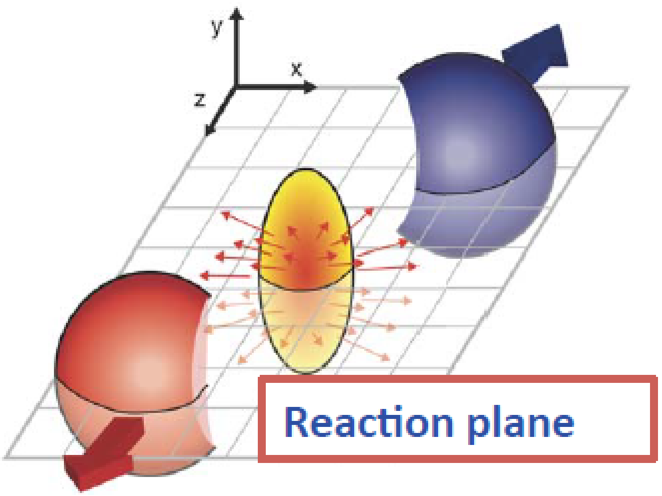
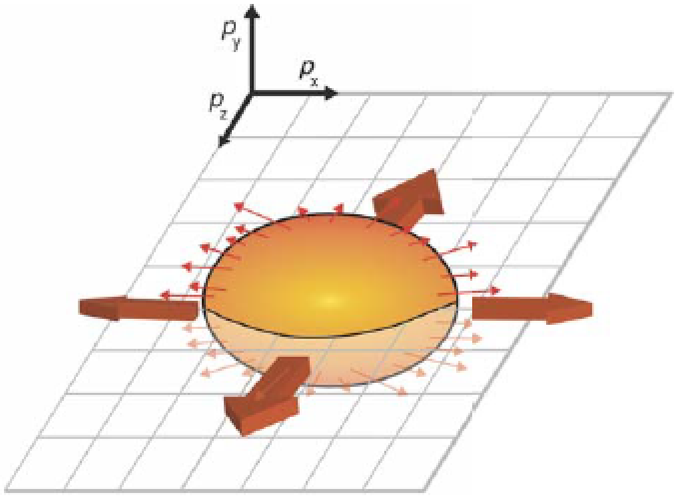
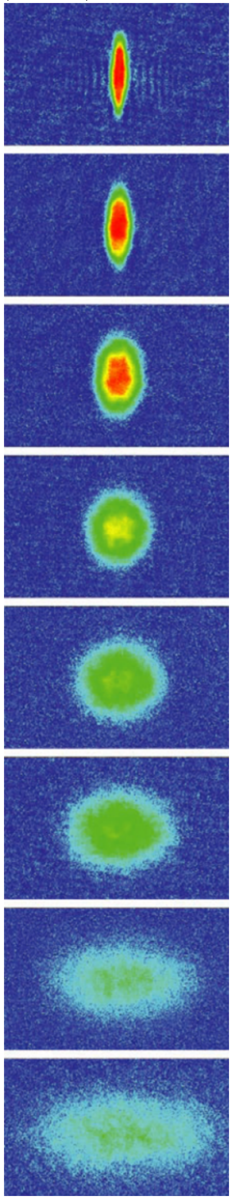




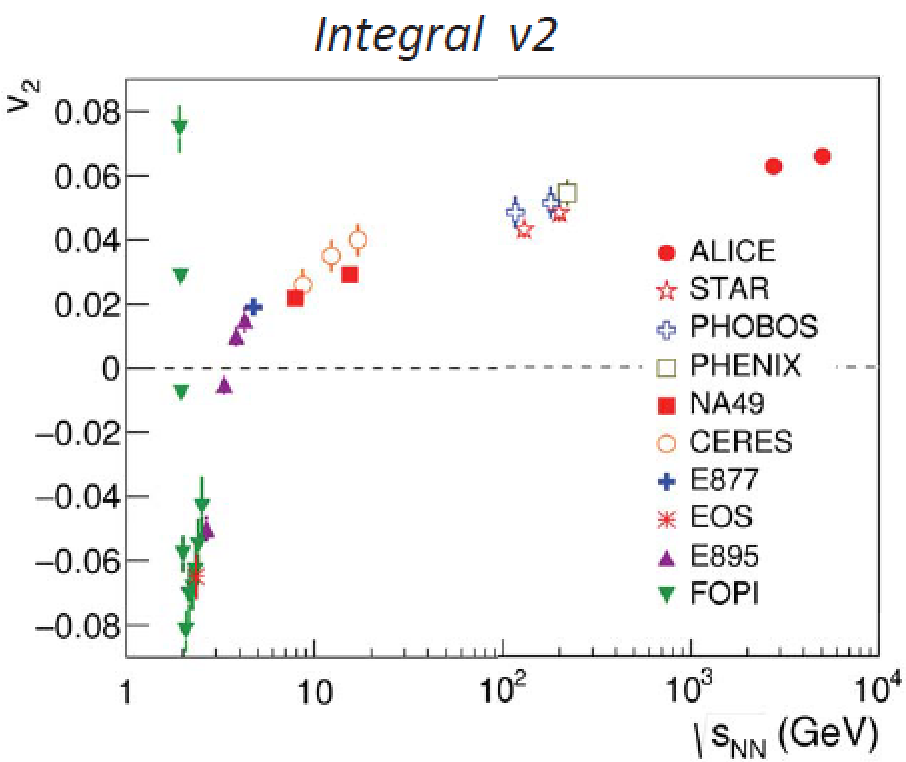


Spatial anisotropy → Anisotropy in momentum space

$$\frac{dN}{d(\varphi - \psi_{RP})} \propto 1 + 2\sum_{n=1} v_n \cos\left(n[\varphi - \psi_{RP}]\right)$$

$$v_2 = \left\langle \cos\left[2(\varphi - \psi_{RP})\right]\right\rangle$$

Elliptic Flow



- ✓ v_2@LHC is 30% larger than @RHIC.
- ✓ Transfer of the anisotropy from in space to in momentum space ⇒ viscosity info.
- ✓ η/s=0.2 (perfect fluid)

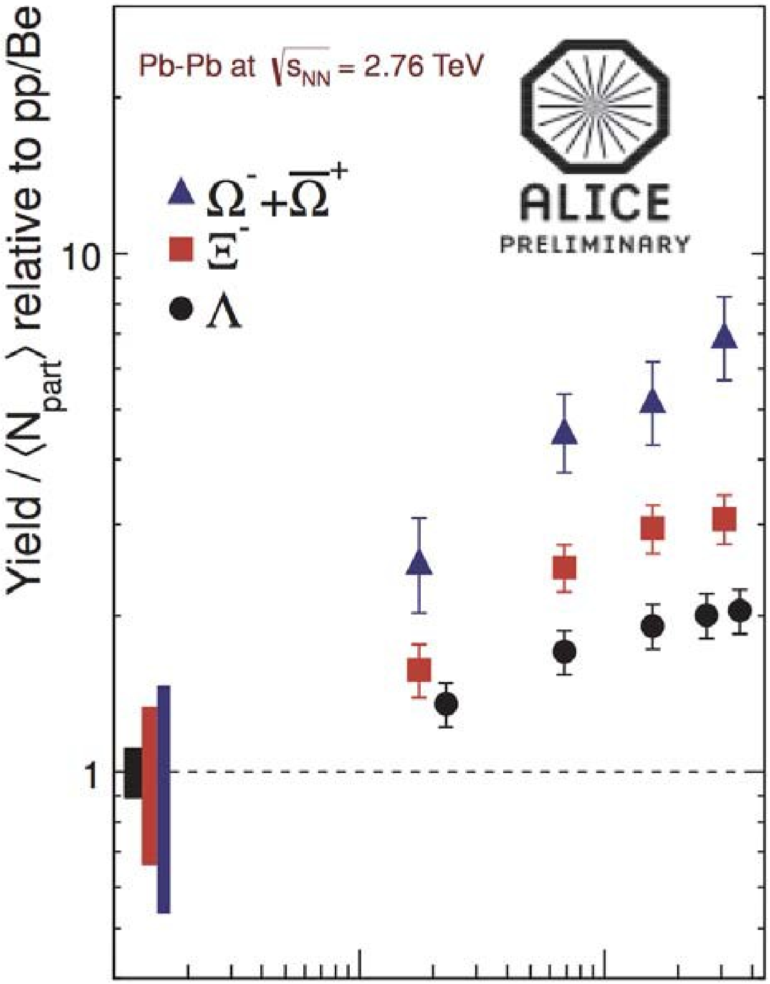
Strangeness Enhancement

- ✓ In elementary pp collisions,
- ✓ Strangeness products are suppressed relative to the production of light flavors
- ✓ For a large system, strangeness is enhanced.
- ✓ How to confirm?

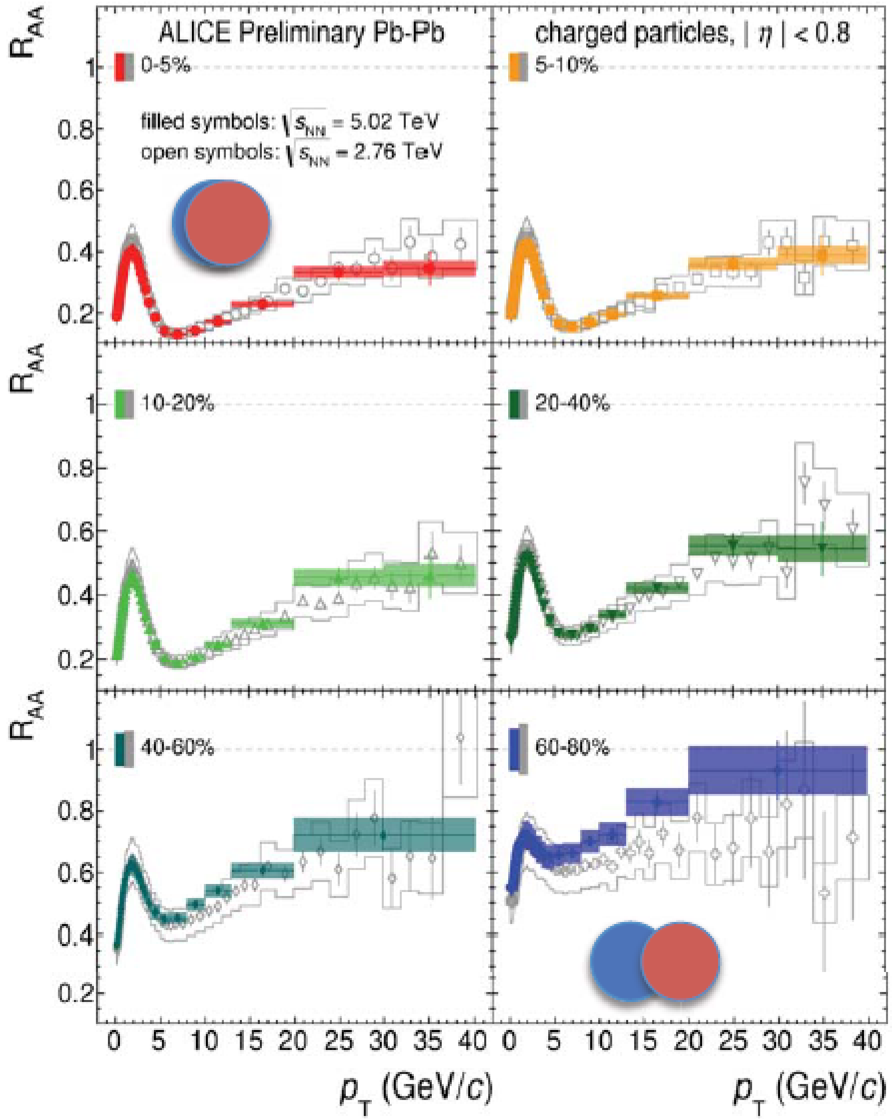
Nuclear Modification Factor

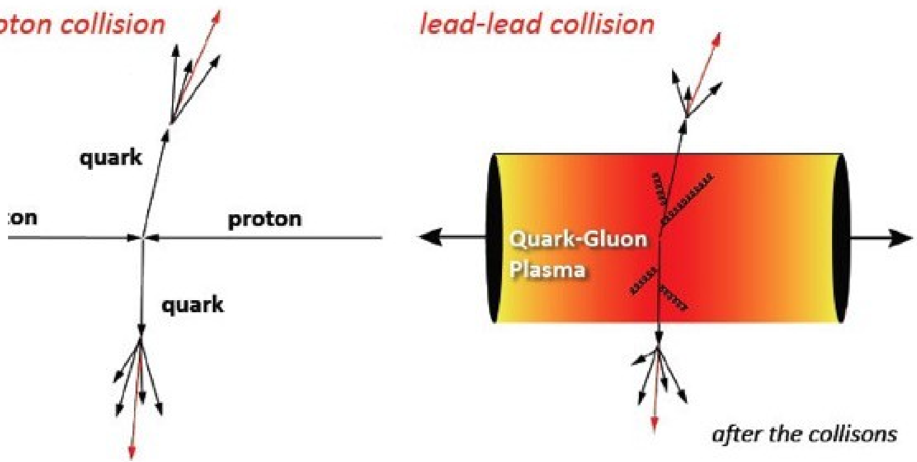
$$R_{AA} = \frac{Y(A\text{–}A)}{Y(pp) \times \langle N_{coll} \rangle}$$

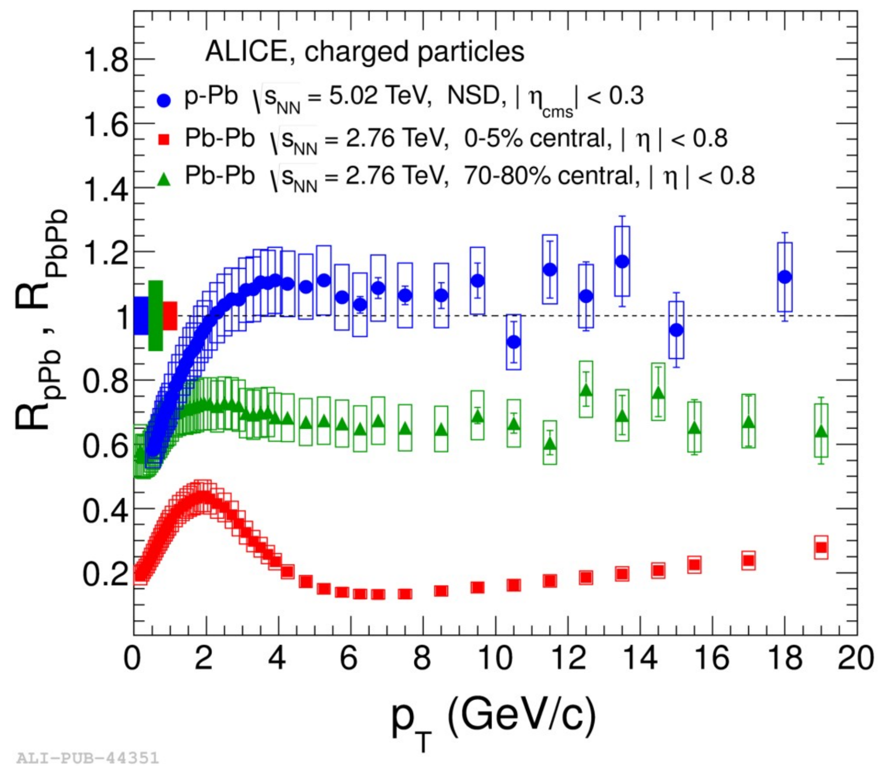
- ✓ $R_{AA} > 1$: enhancement
- ✓ $R_{AA} = 1$
- ✓ $R_{AA} < 1$: suppression



Hard Probes – Jet Quenching







QUARKONIA

✓ J/ψ : pair of c & anti-c

- Inside the QGP, quarks are color-screened → suppression
- Debye length depends on Temp. → thermometer

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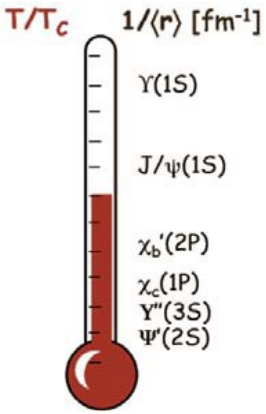
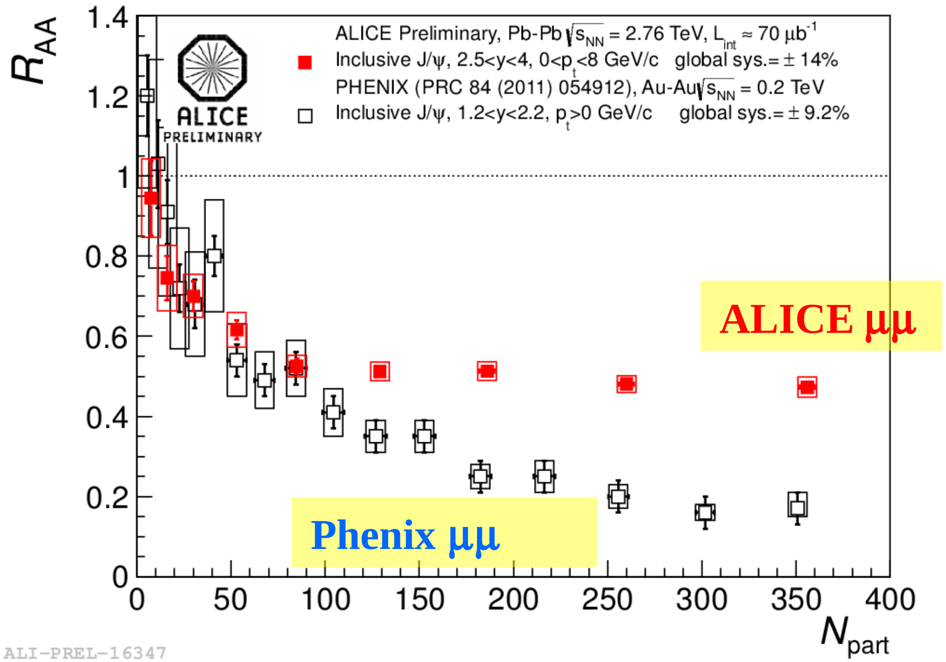
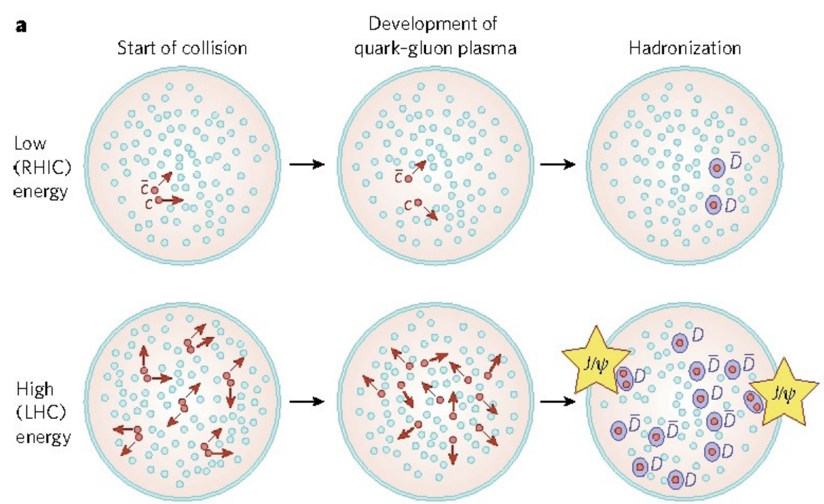


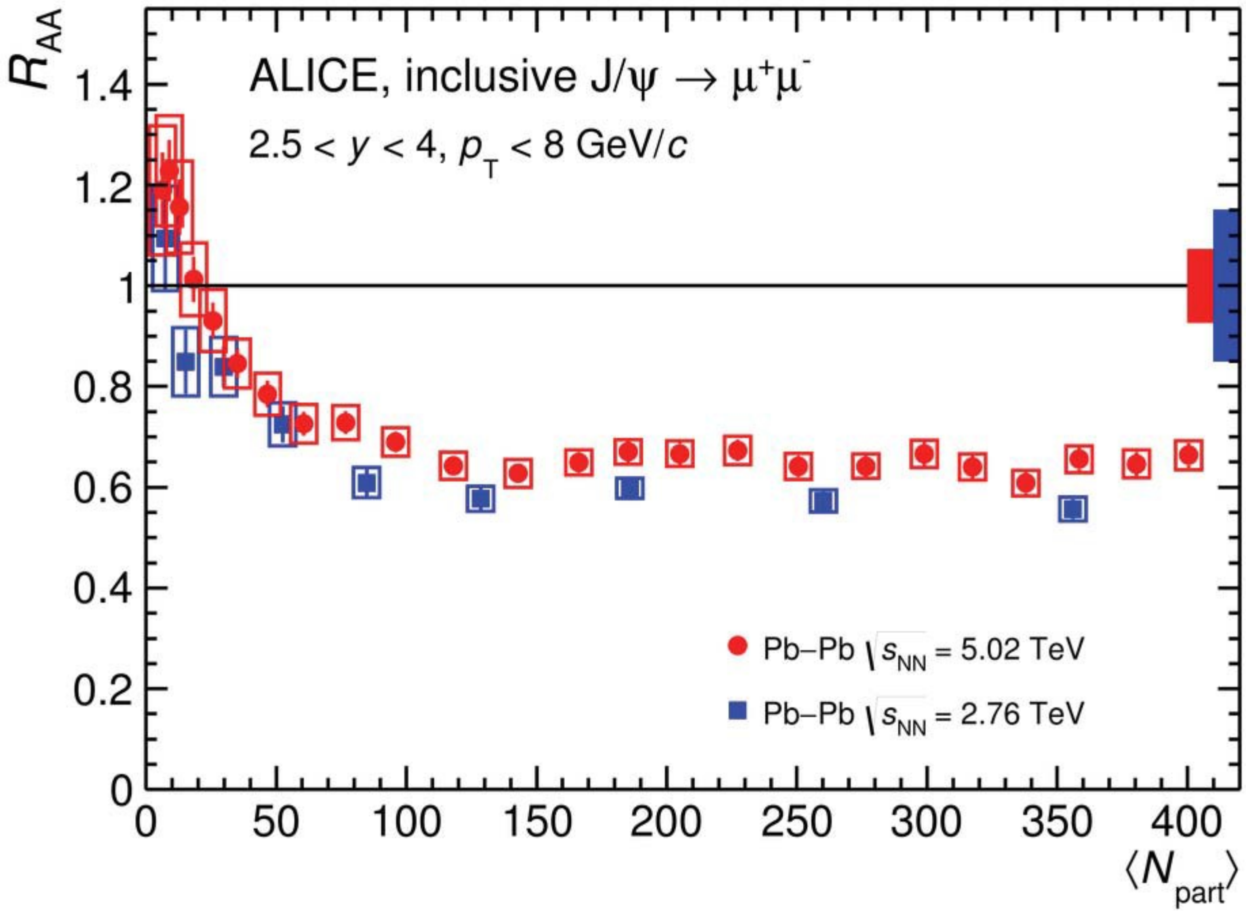


Less suppression than RHIC

due to recombination

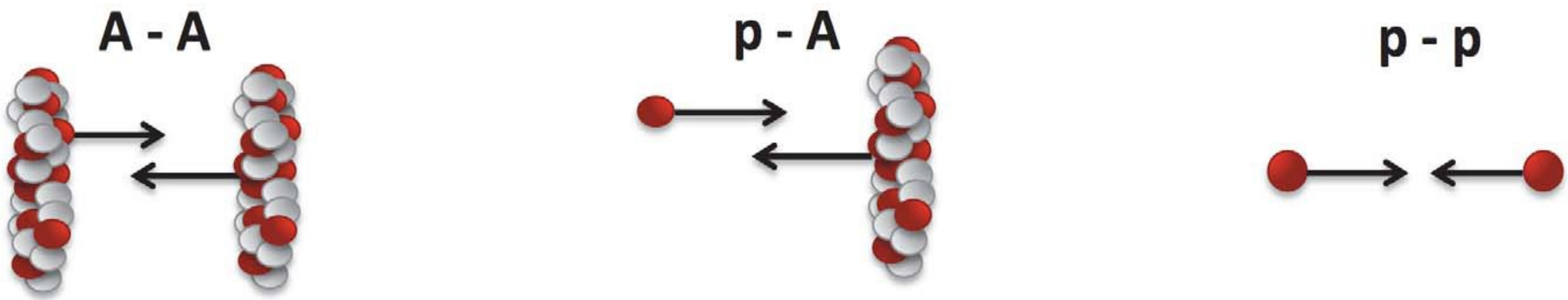


QUARKONIA



- ✓ Suppression is independent of centrality.
- ✓ Need to measure total charm production around pT~0 GeV.

Small systems as reference?



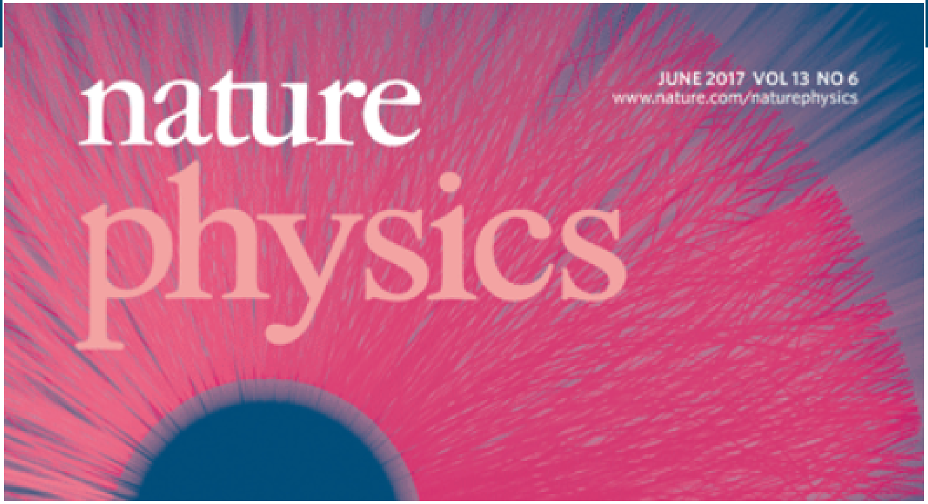
Nuclear initial state
Hot matter in the final state

Nuclear initial state
Cold matter in the final

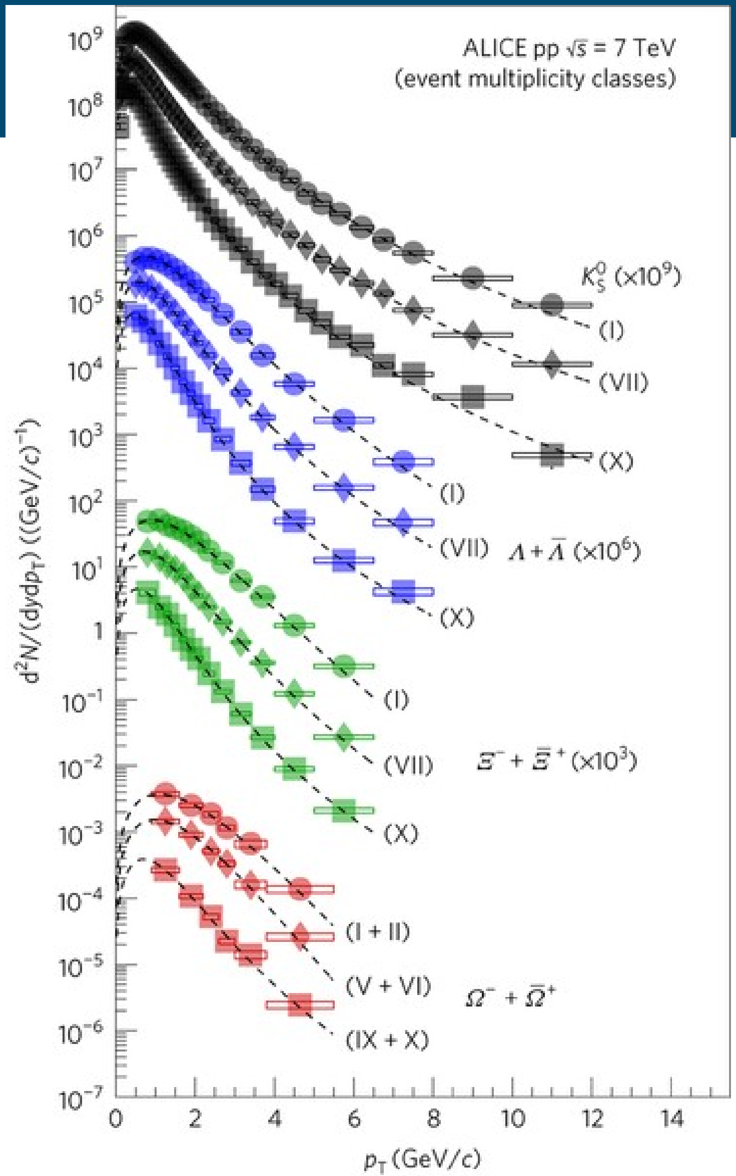
Hadronic initial
& final state

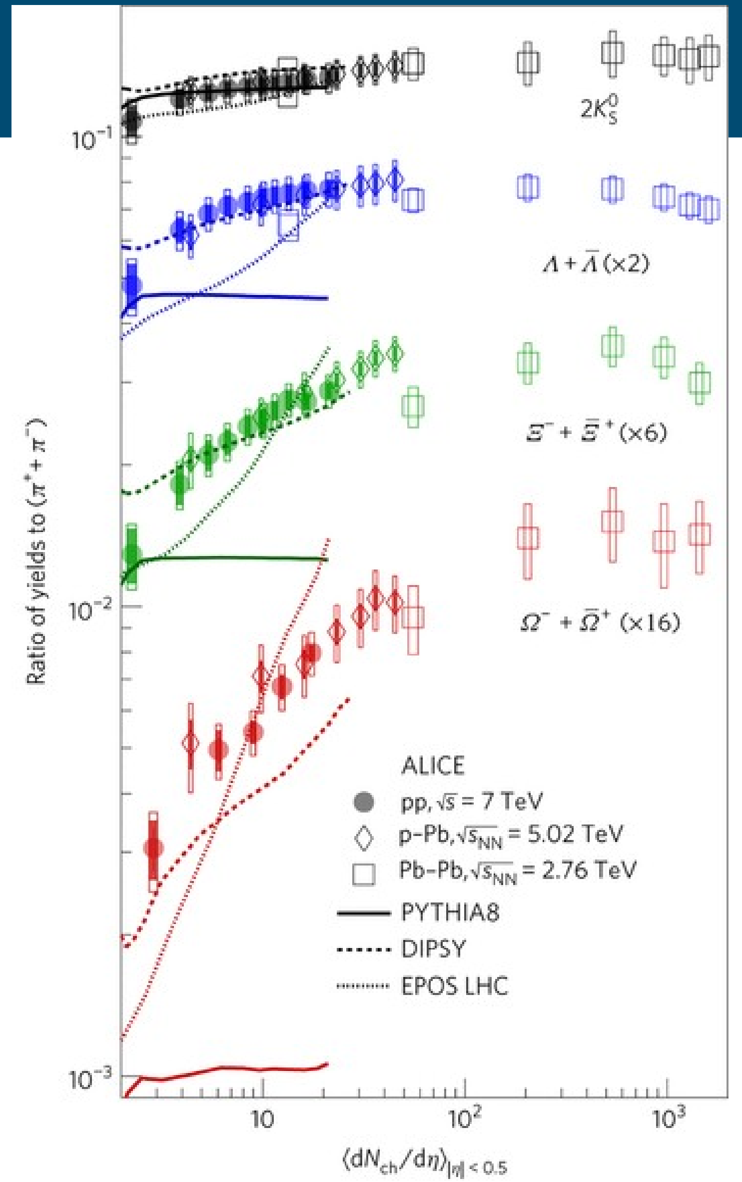
- ✓ No phase transition in pp or pA collisions is expected.
- ✓ But striking **similarity across different systems**!

Strangeness

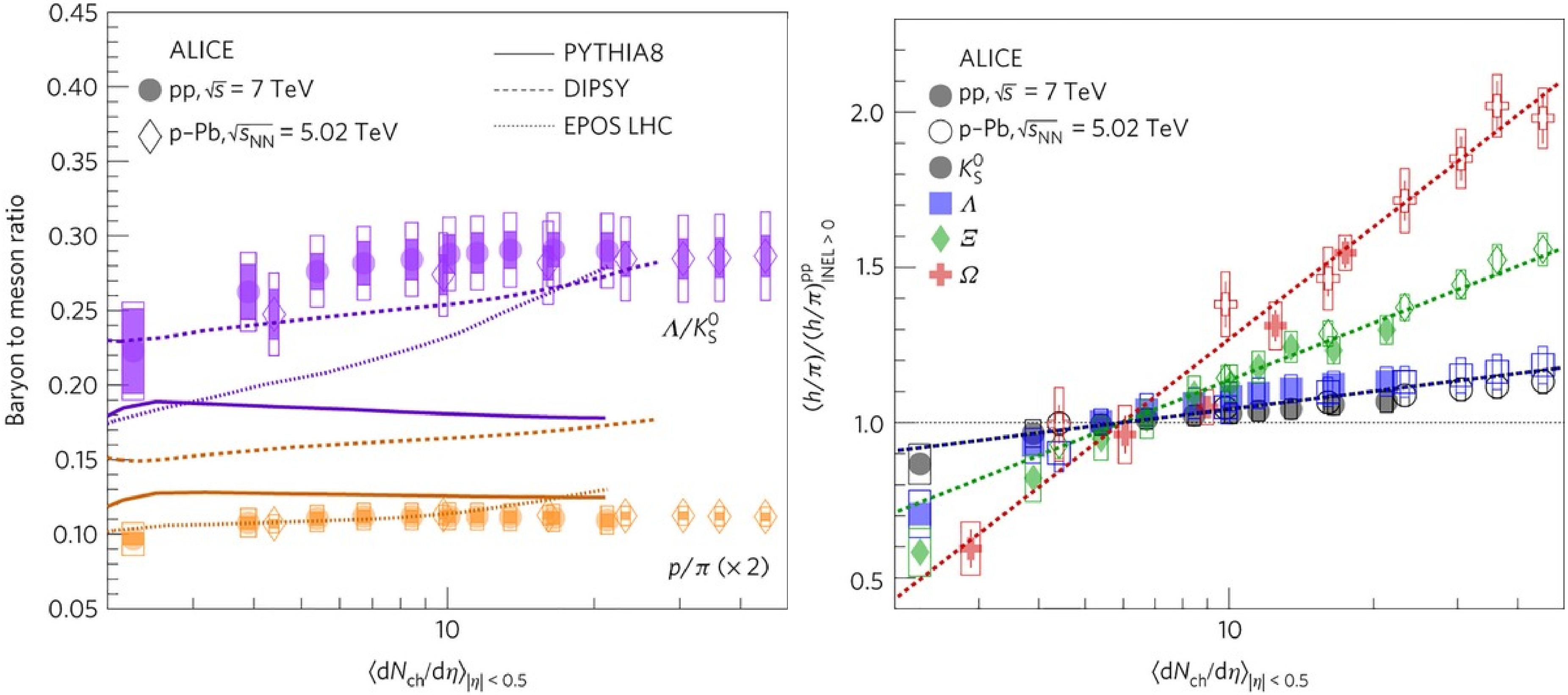


strange hadrons is observed[2, 3, 4, 5, 6]. Strangeness enhancement, originally proposed as a signature of QGP formation in nuclear collisions[7], is more pronounced for multi-strange baryons. Several effects typical of heavy-ion phenomenology have been observed in high-multiplicity proton–proton (pp) collisions[8, 9], but the enhanced production of multi-strange particles has not been reported so far. Here we present the first observation of strangeness enhancement in high-multiplicity proton–proton collisions. We find that the integrated yields of strange and multi-strange particles, relative to pions, increases significantly with the event charged-particle multiplicity. The measurements are in remarkable agreement with the p–Pb collision results[10, 11], indicating that the phenomenon is related to the final system created in the collision. In high-multiplicity events strangeness production reaches values similar to those observed in Pb–Pb collisions, where a QGP is formed.



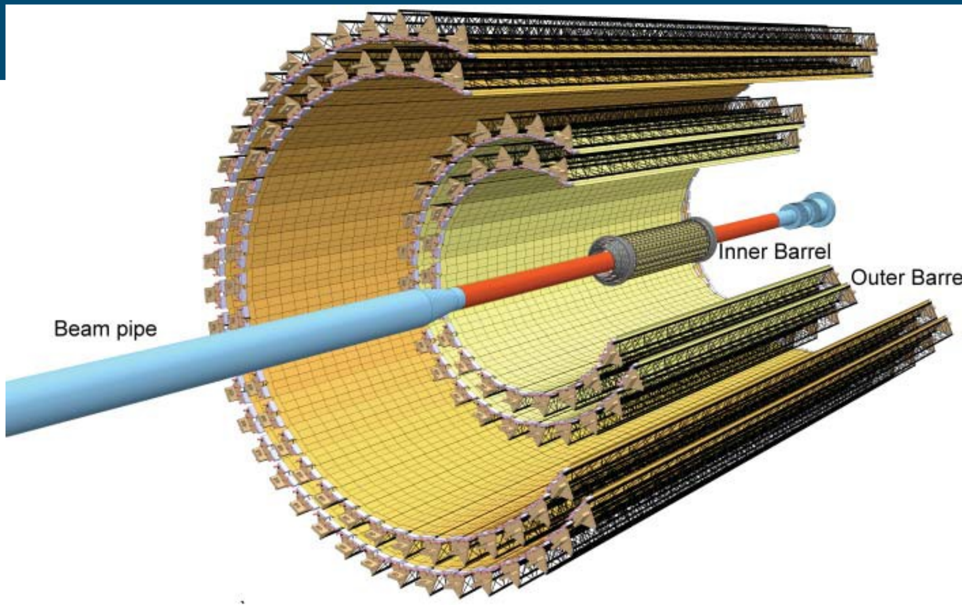


The p_T spectra become harder as the multiplicity increases.



- No baryon number dependency.
- No mass dependency.
- No MC models cannot reproduce this result.

ITS Upgrade



- ✓ Improve IP resolution by 3~5 times
  - Closer to IP : 39 mm → 23 mm
  - Reduce the material budget : 1.14% → 0.3 %
  - Spatial resolution : 12mmX100mm → 5mmX5mm

- ✓ Improve tracking efficiency and pT resolution at low pT

Conclusion

✓ Heavy-ion collisions during RUN1 and RUN2 periods.

- Energy density ~ 15 GeV/fm^3 >> ε_c
- T=300 MeV
- Elliptic flow from hydro-dynamics → QGP as a perfect fluid
- J/ψ suppression smaller than at RHIC → dissociation + recombination

✓ Similarities among different systems (pp,p-Pb, Pb-Pb)

- Collectivity in small systems?
- Strangeness enhancement from low to high multiplicity pp collisions

✓ Need high precision measurements of the production of heavy quarks, quarkonia, jet and di-leptons over a large momentum range. → Looking forward to Upgrades

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