Study of the Quark Gluon Plasma in the light-flavor sector at the LHC with ALICE

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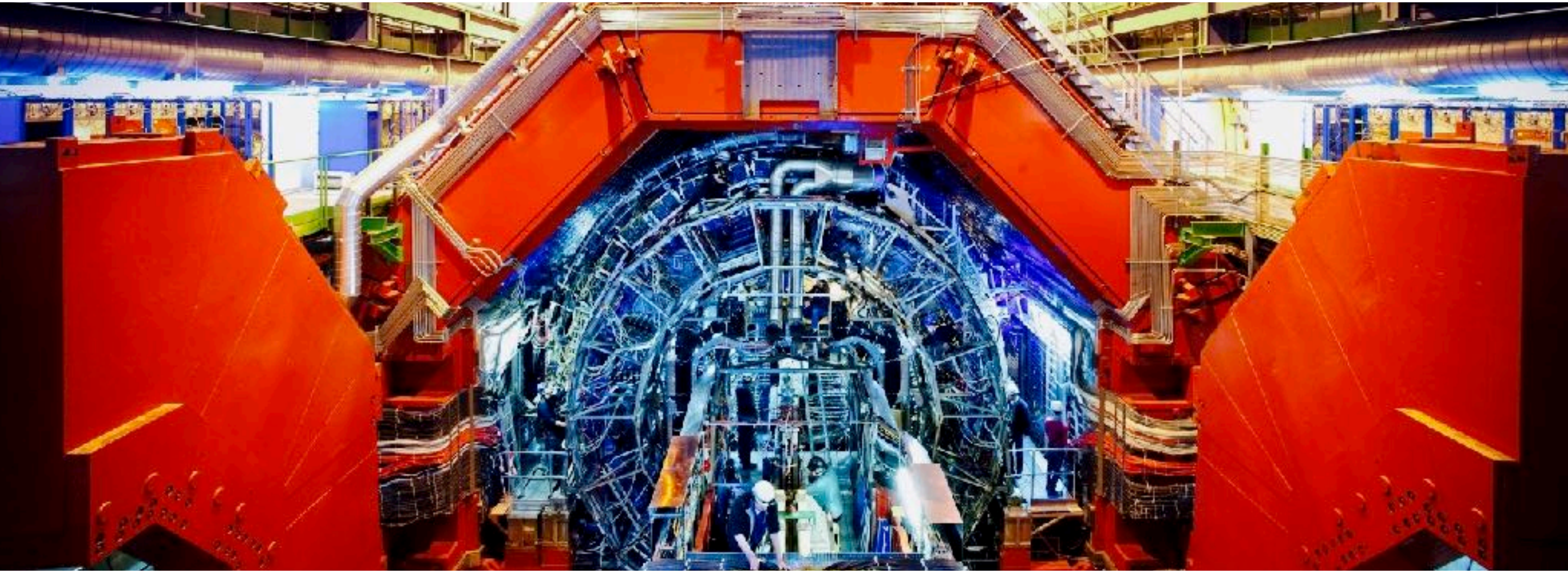
Outline

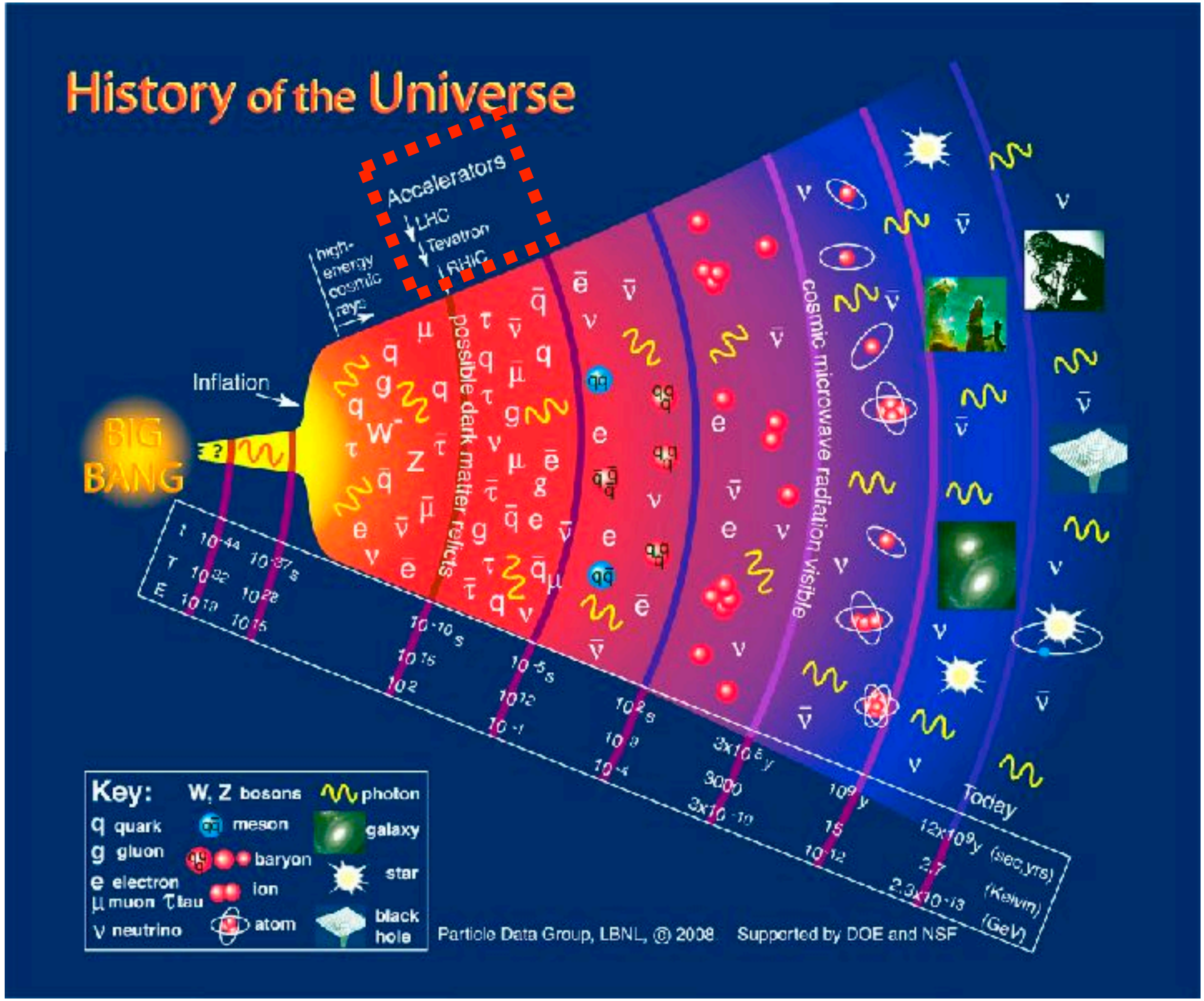
- Introduction
- Experimental details
- Strangeness production
- Hadronic phase
- Conclusion

Introduction



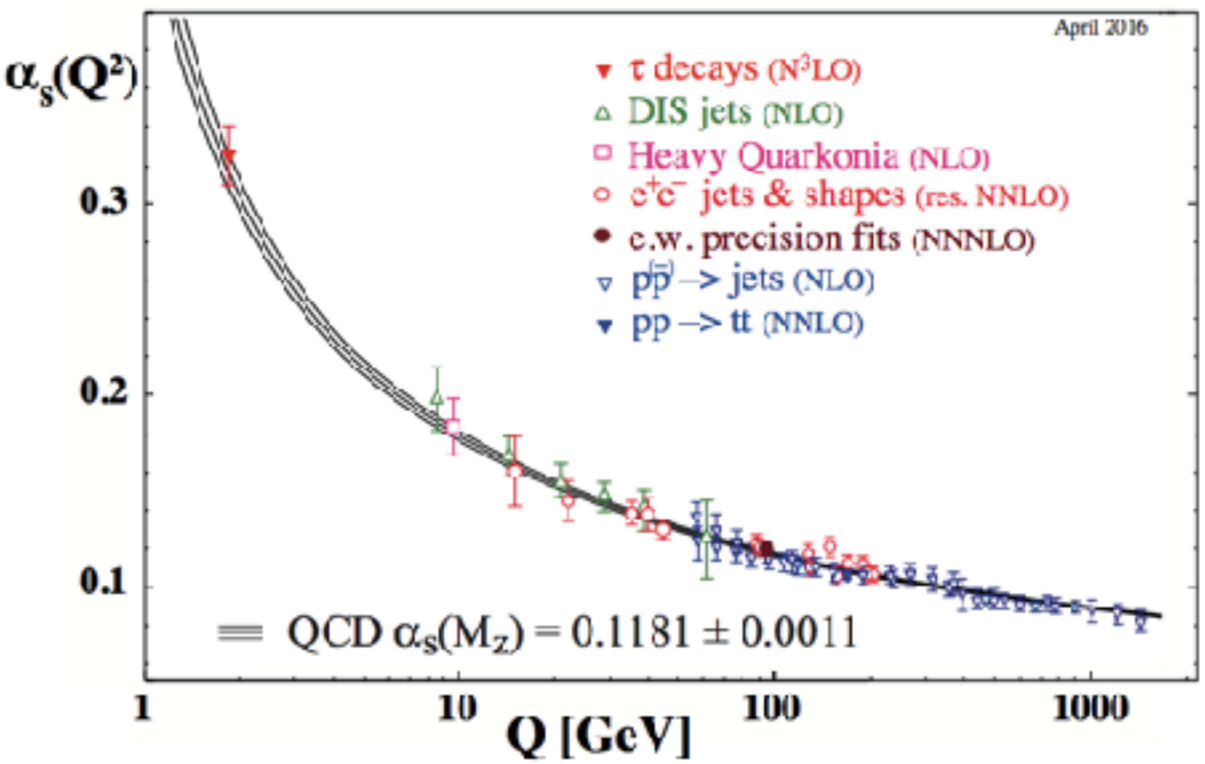
QGP and the early universe

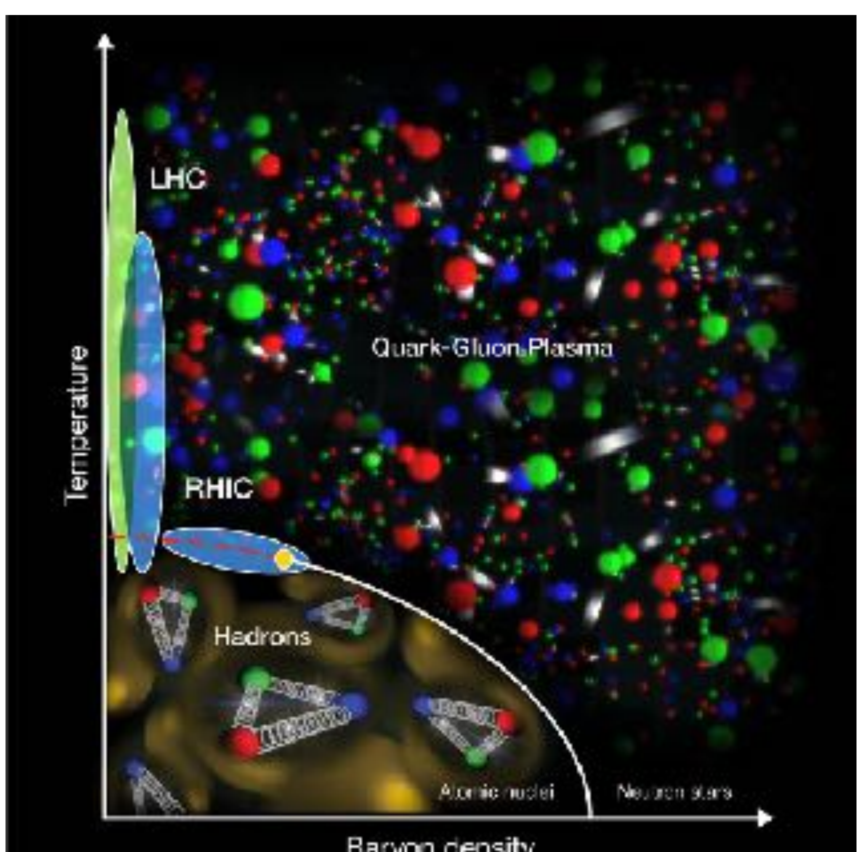
- Big bang in the early universe
- The Universe went through a QGP (Quark Gluon Plasma) phase about 10ps after its creation and froze out into hadrons after about 10μs which later formed nuclei
- Big bang (universe QGP) and little bang (heavy-ion collisions)



QCD and its phase diagram

C. Patrignani et al. (PDG), Chin. Phys. C, 40, 100001 (2016)





- Quarks and gluons exist in nature as **confined in colorless hadrons**
  ➔ confining property of QCD
  - α_s is large

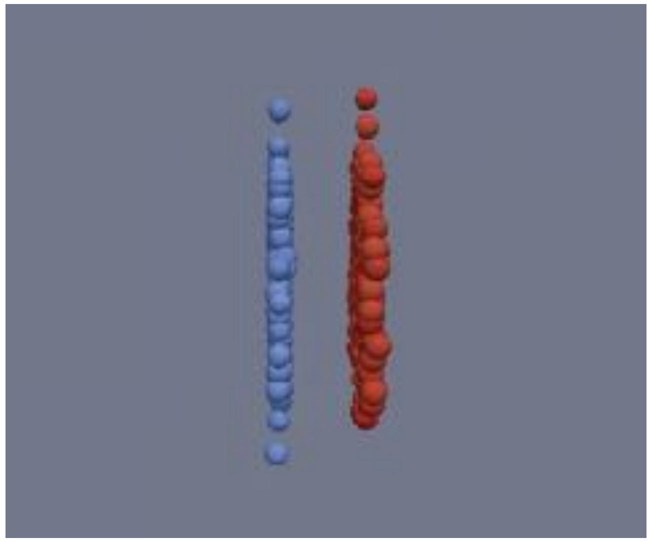
- The strong coupling becomes weak for processes involving large momentum transfers
  ➔ **asymptotic freedom**
  - free quarks and gluons, α_s is small

- A **de-confined state** of matter (QGP) can be reached by compressing the system to a **high-density** and/or heating it up to a **high temperature**

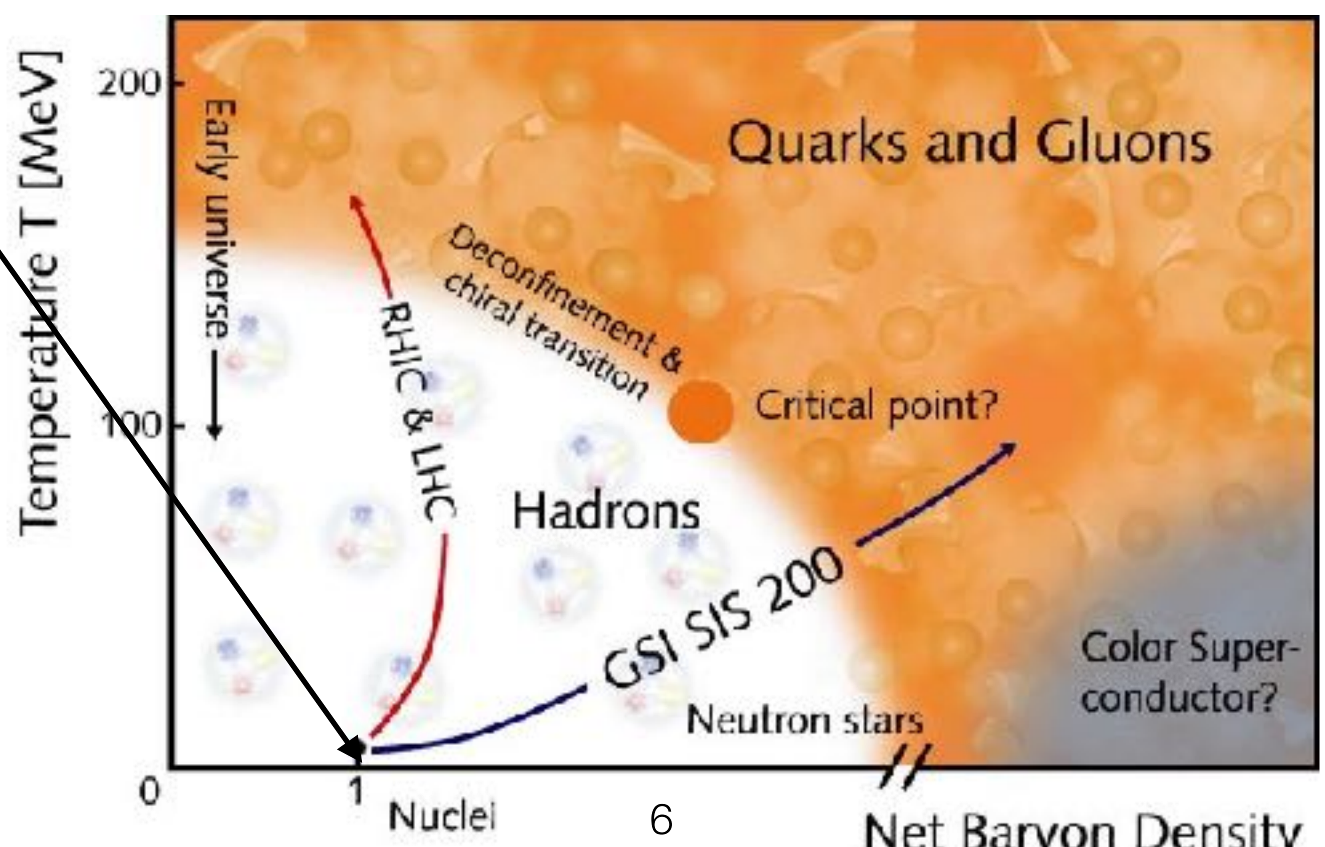
- A **phase transition** is expected to occur around **T_c ~ 145 - 164 MeV** (from lattice QCD, PRD 90 (2014) 094503)

  ➔ Use heavy-ion collisions to investigate region around the phase transition boundary

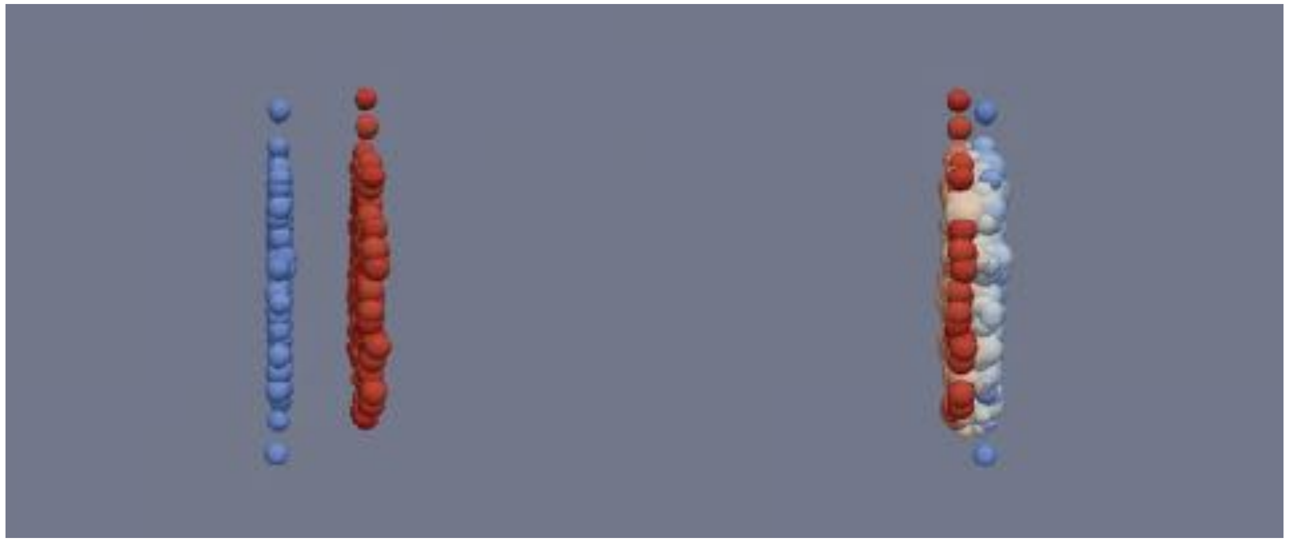
From nuclear matter to QGP



Nuclear initial state



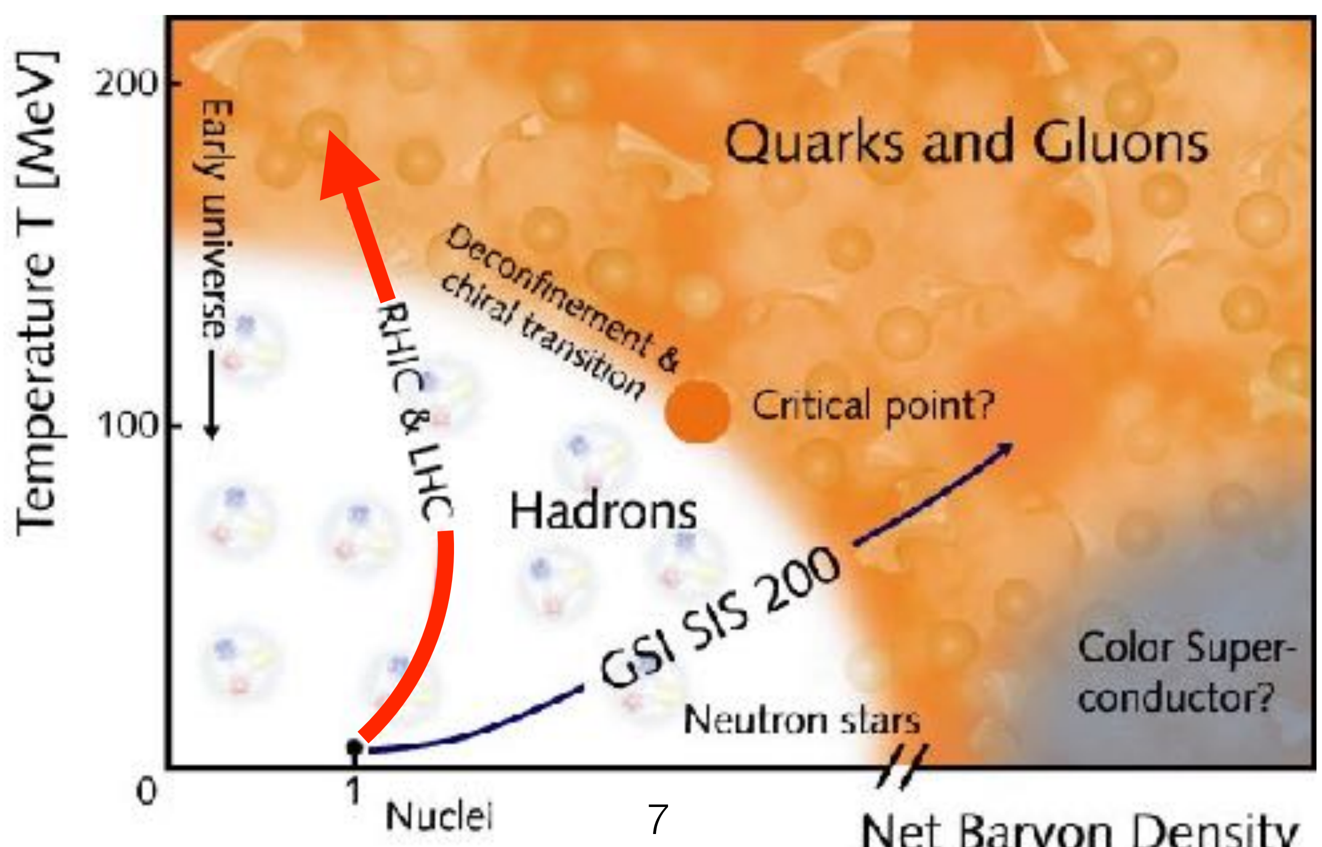
From nuclear matter to QGP



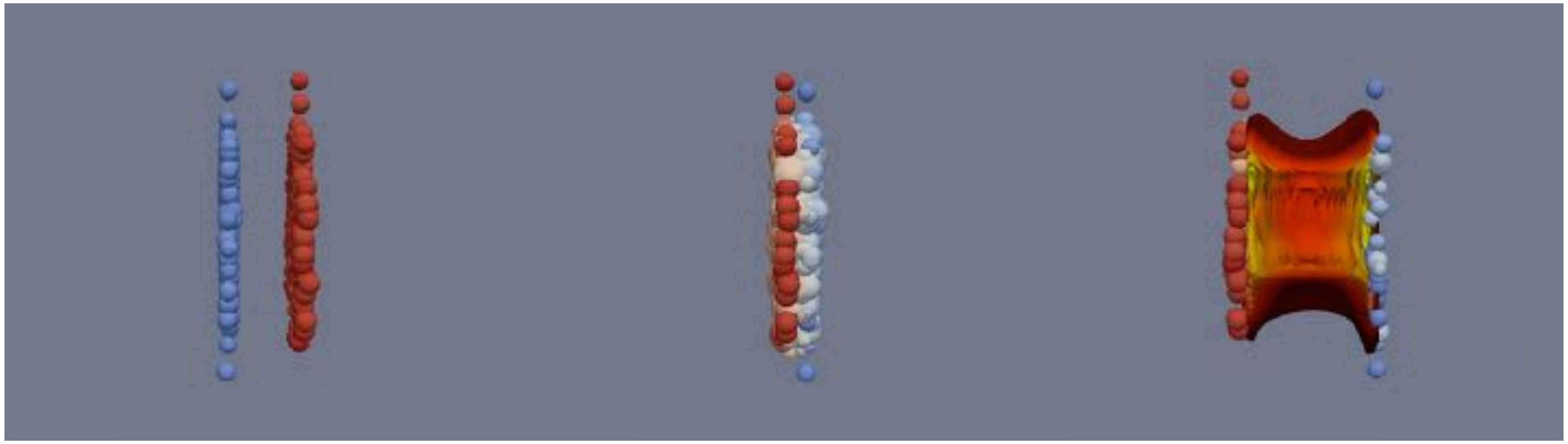
Nuclear initial state

Energy stopping hard collisions

Phase transition: confined → de-confined



From nuclear matter to QGP



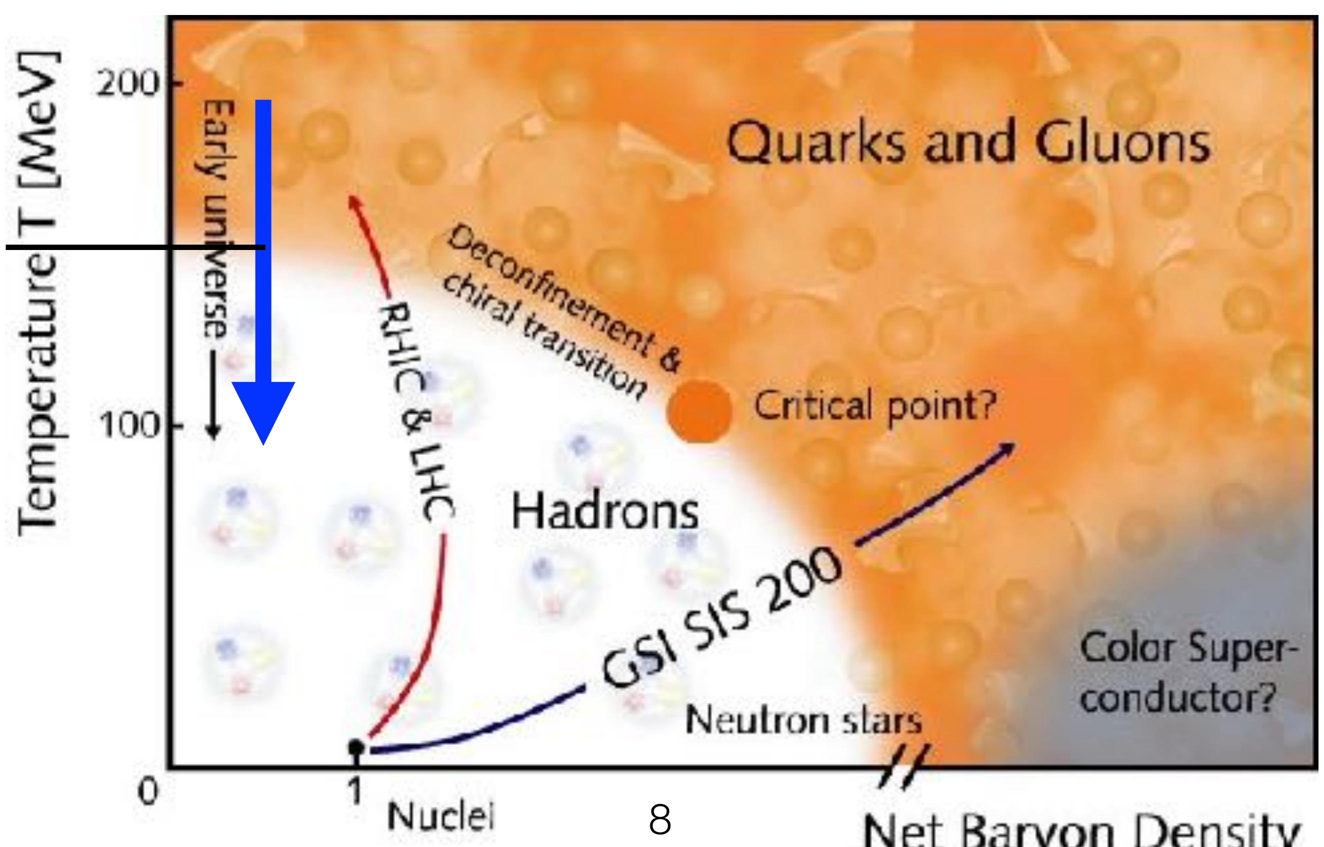
Nuclear initial state

Energy stopping hard collisions

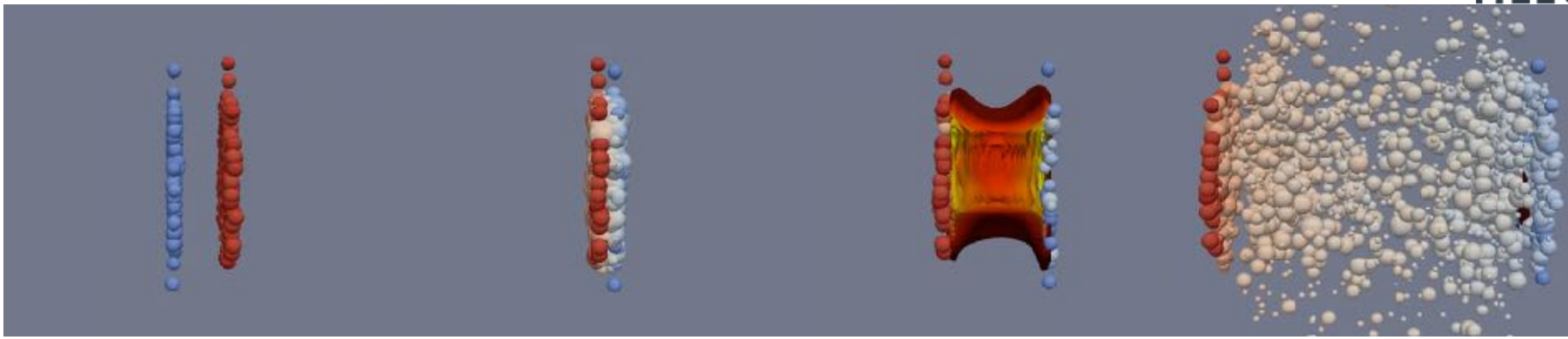
Hydrodynamic evolution

Phase transition: de-confined → confined

T_c = (154 ± 9) MeV



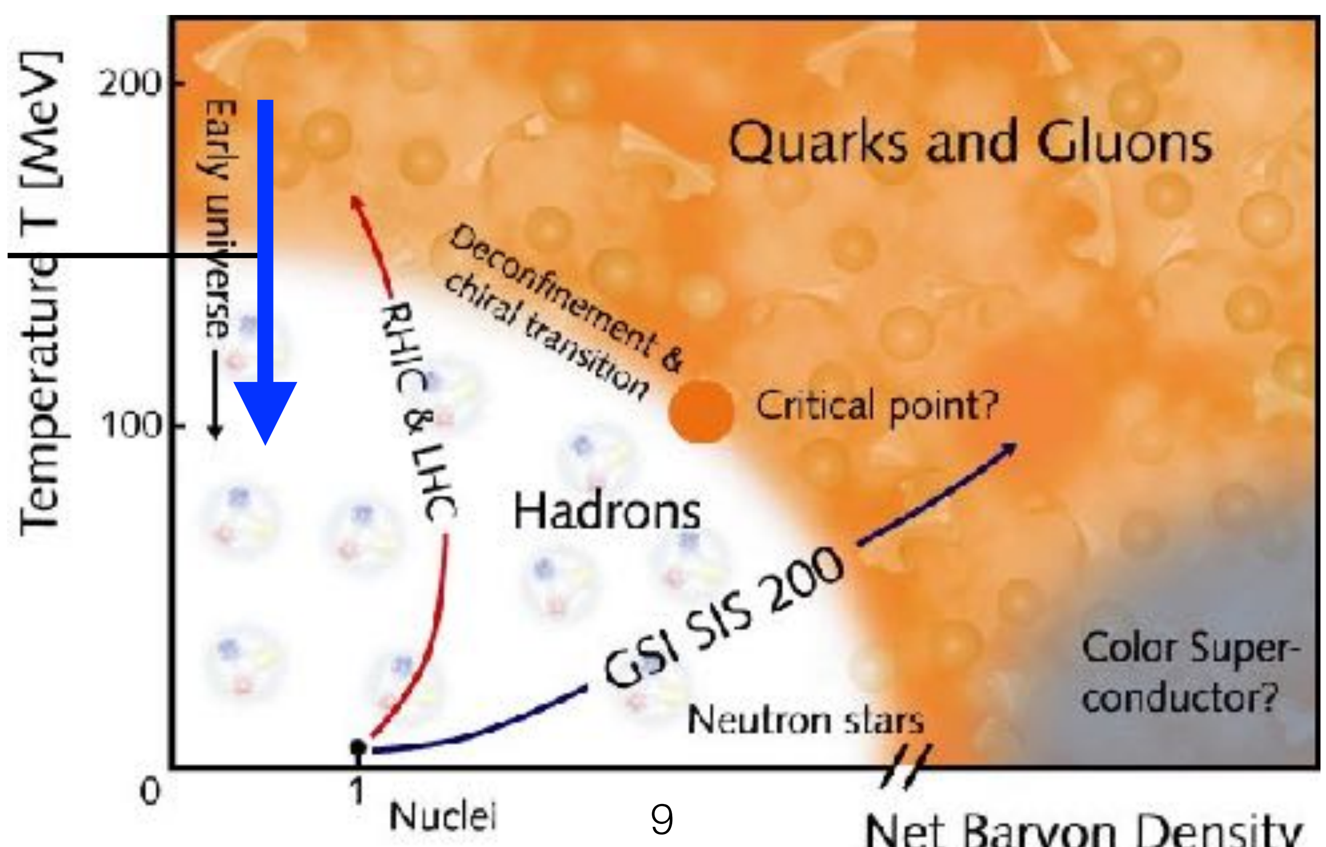
From nuclear matter to QGP



Nuclear initial state | **Energy stopping hard collisions** | **Hydrodynamic evolution** | **Hadron freeze-out**

Chemical freeze-out: inelastic interactions stop

T_{ch} ~ 156 MeV
Abundance of hadron species are fixed



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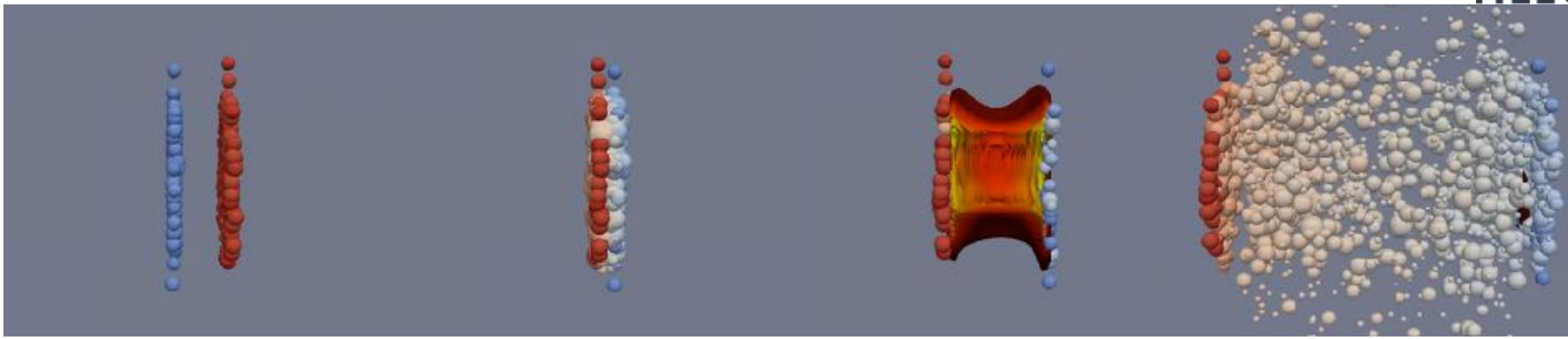
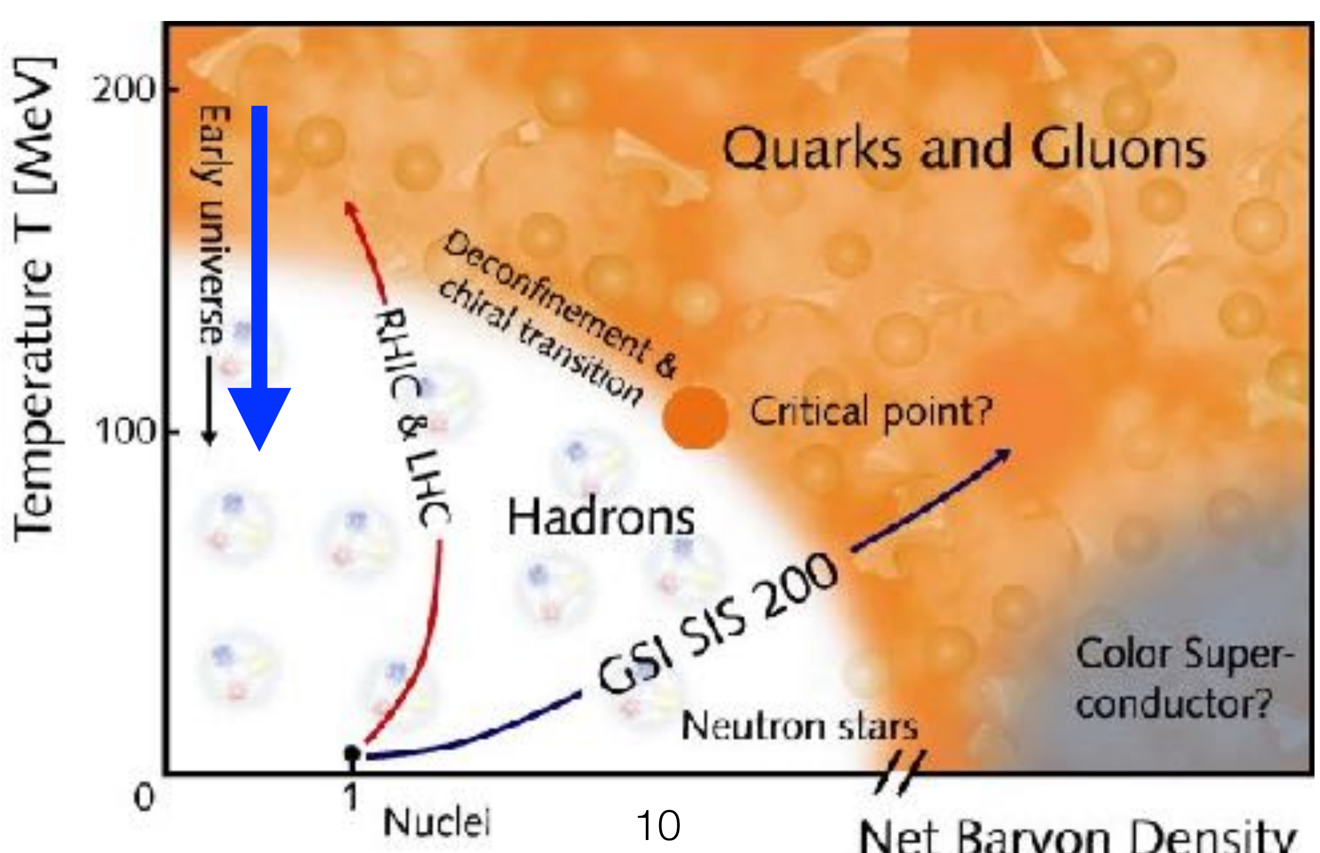
From nuclear matter to QGP



Nuclear initial state | **Energy stopping hard collisions** | **Hydrodynamic evolution** | **Hadron freeze-out**

Hadronic phase: (pseudo-)elastic interactions



τ_{HP} ~ 10-15 fm/c short-lived resonances decay and undergo re-scattering and regeneration -> yield established at T_{ch} can be modified

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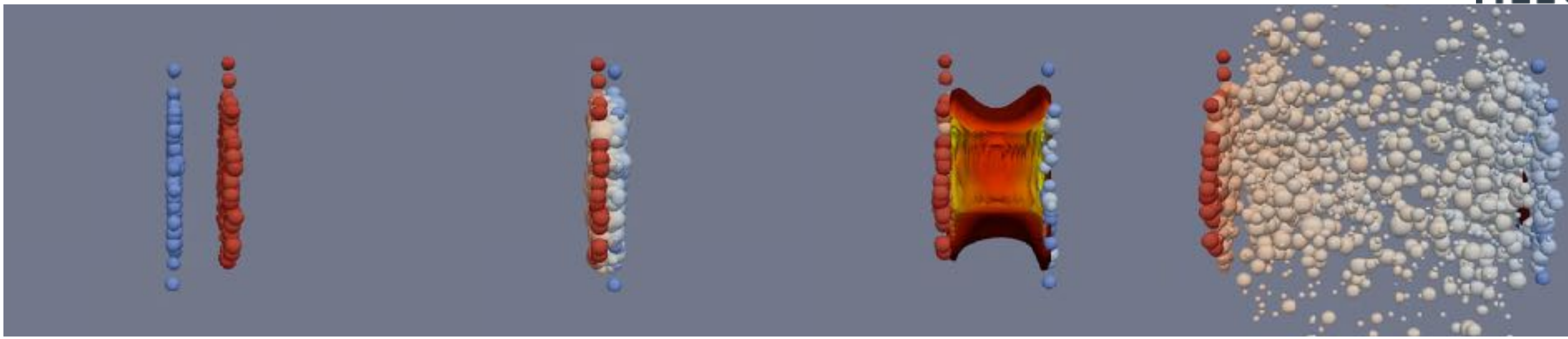
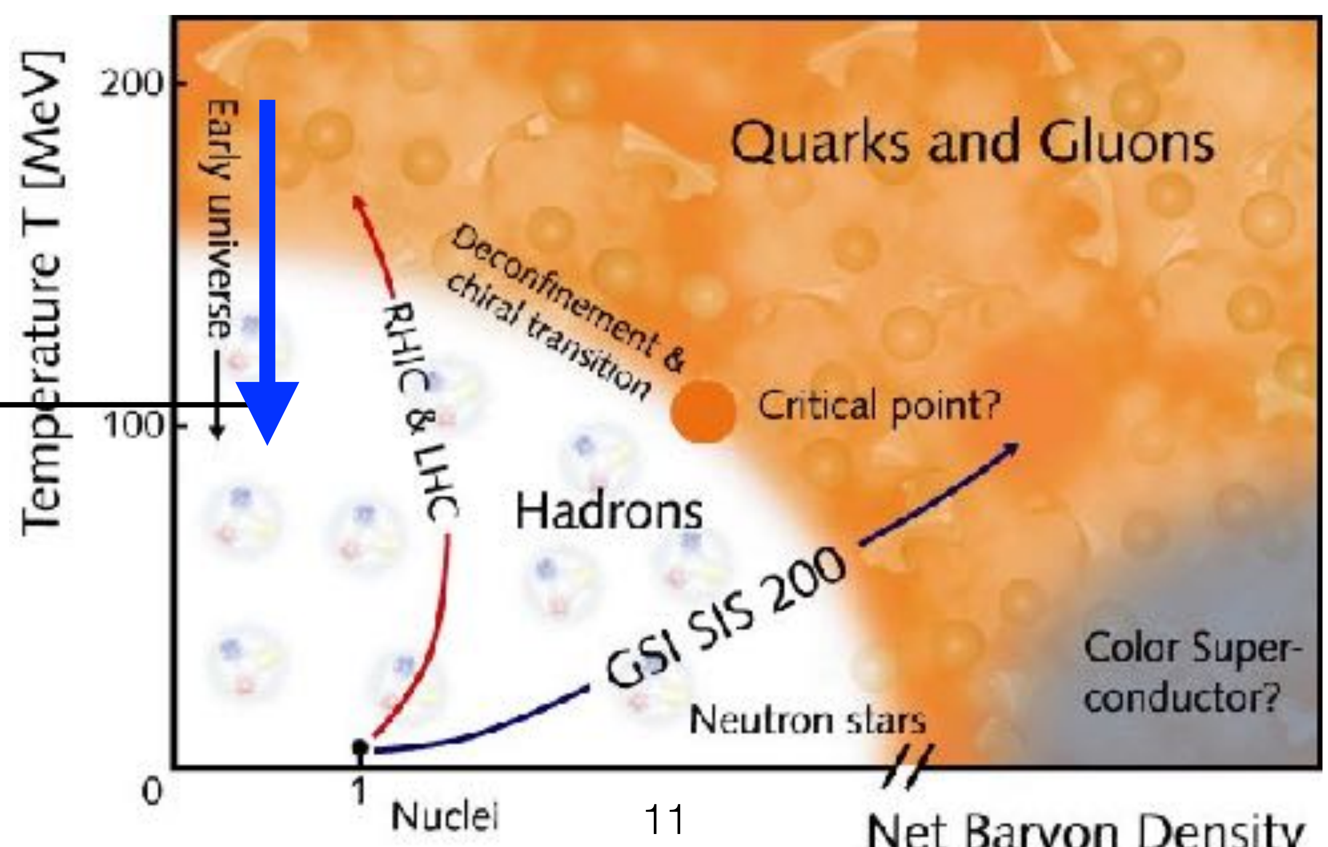


Nuclear initial state | **Energy stopping hard collisions** | **Hydrodynamic evolution** | **Hadron freeze-out**

Kinetic freeze-out: elastic interactions stop

T_{kin} ~ 90-110 MeV kinematical distribution of hadron are fixed



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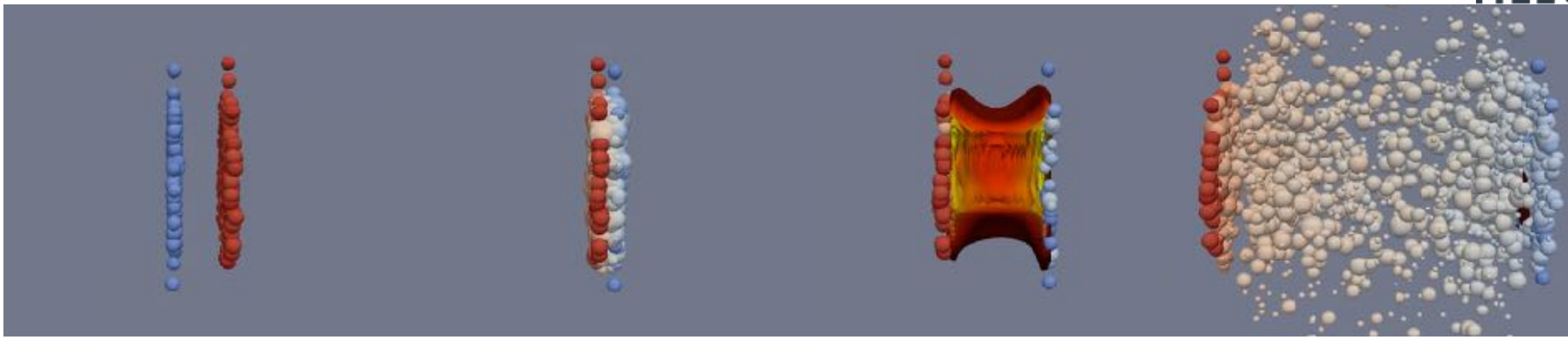
From nuclear matter to QGP



Nuclear initial state

Energy stopping hard collisions

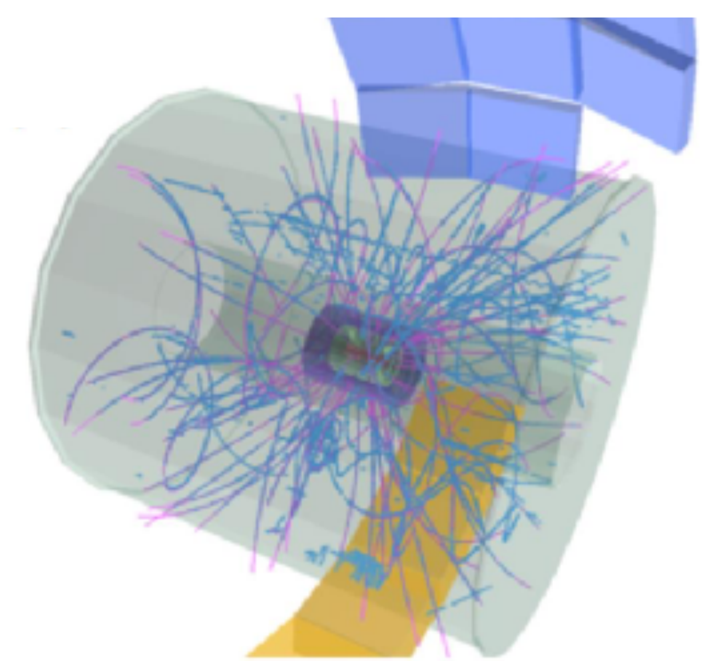
Hydrodynamic evolution

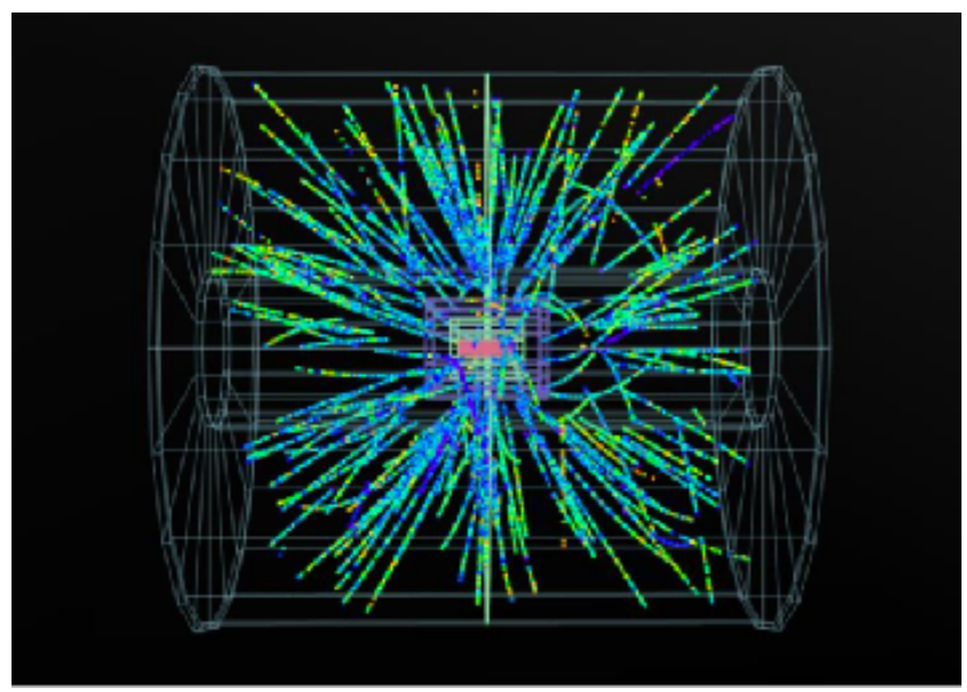
Hadron freeze-out

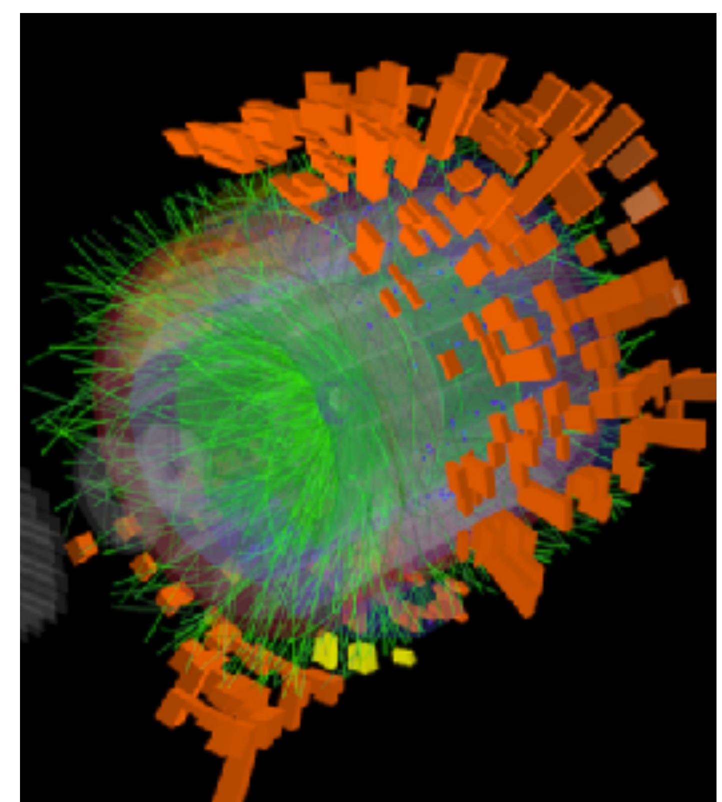
pp

p-Pb

Pb-Pb

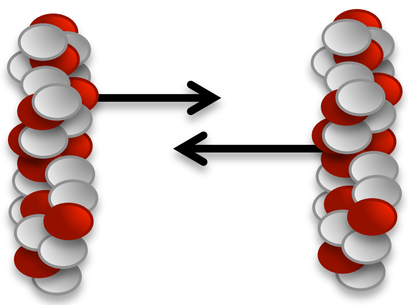






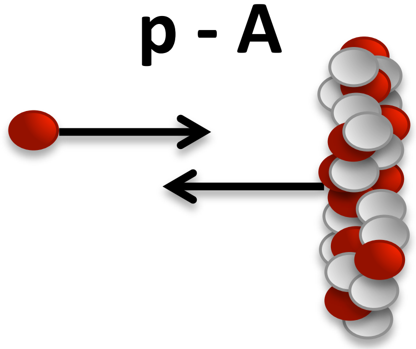
Collision systems

A - A



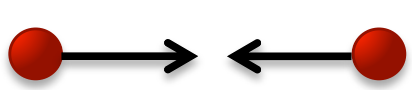
Nuclear initial state
Hot matter in final state

p - A



Nuclear initial state
Cold matter in the final state

p - p



Hadronic initial state
Hadronic final state

- **Pb-Pb collisions**
  - Particle production mechanisms
  - Strangeness enhancement
  - In-medium energy loss
  - Properties of the hadronic phase
- **p-Pb collisions**
  - Disentangle final from initial state effects
- **pp collisions**
  - No de-confinement expected
  - Reference for “larger” system

Recent measurement have revealed **striking similarities across different collision systems**
- Smooth evolution of particle production
- Enhancement of strangeness production from pp to p-Pb

Light flavor hadrons

- Light flavor hadrons are composed by u,d and s quarks
  m_u = 2.2 MeV
  m_d = 4.7 MeV **<<< m_c ~ 1.3 GeV**
  m_s = 96 MeV

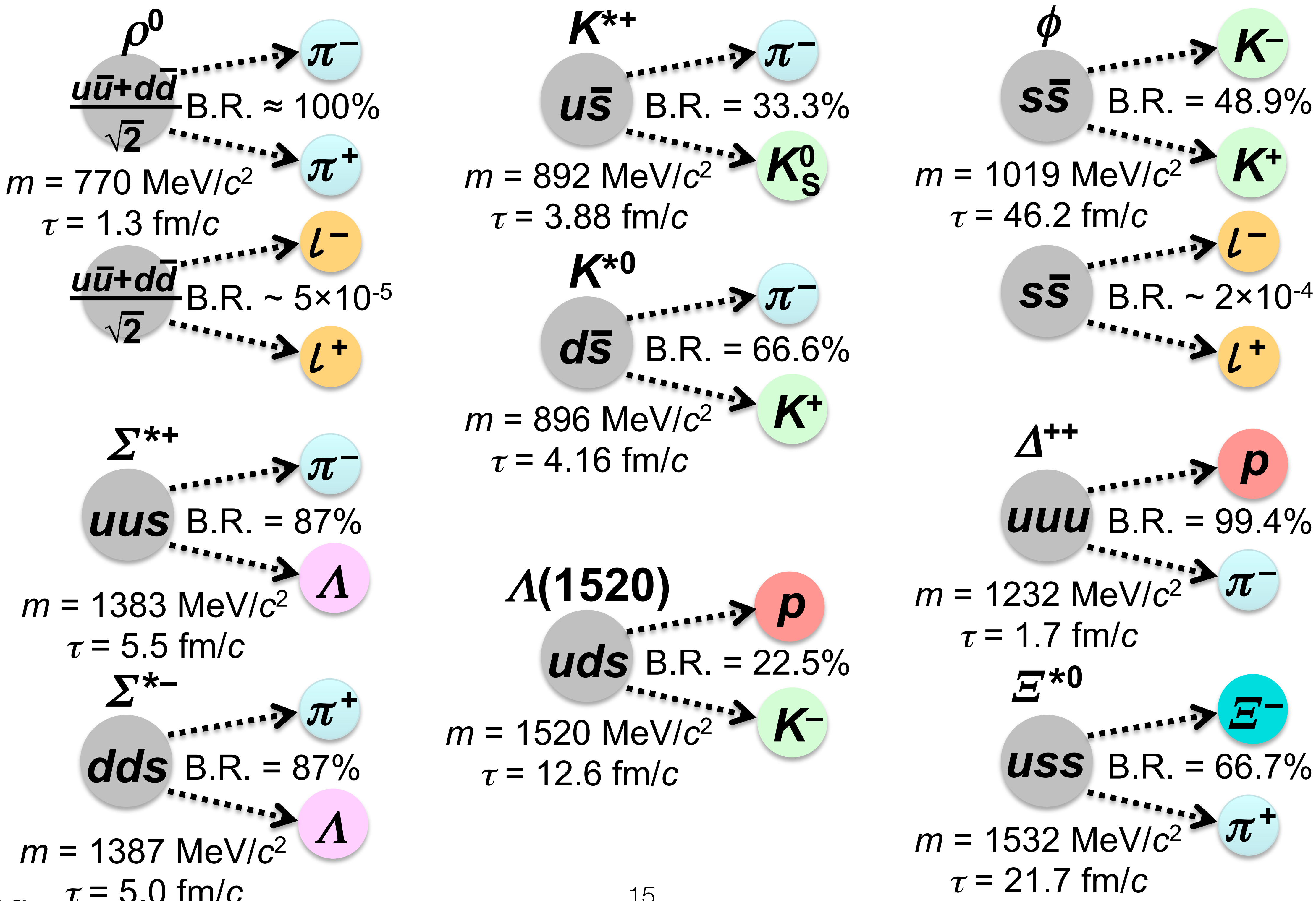
- u,d and s quarks thermally produced in QGP, as $m_{u,d,s} < T_c$
  → study of light-flavor hadron production

A comprehensive set of measurement of identified particle production in all collision systems:

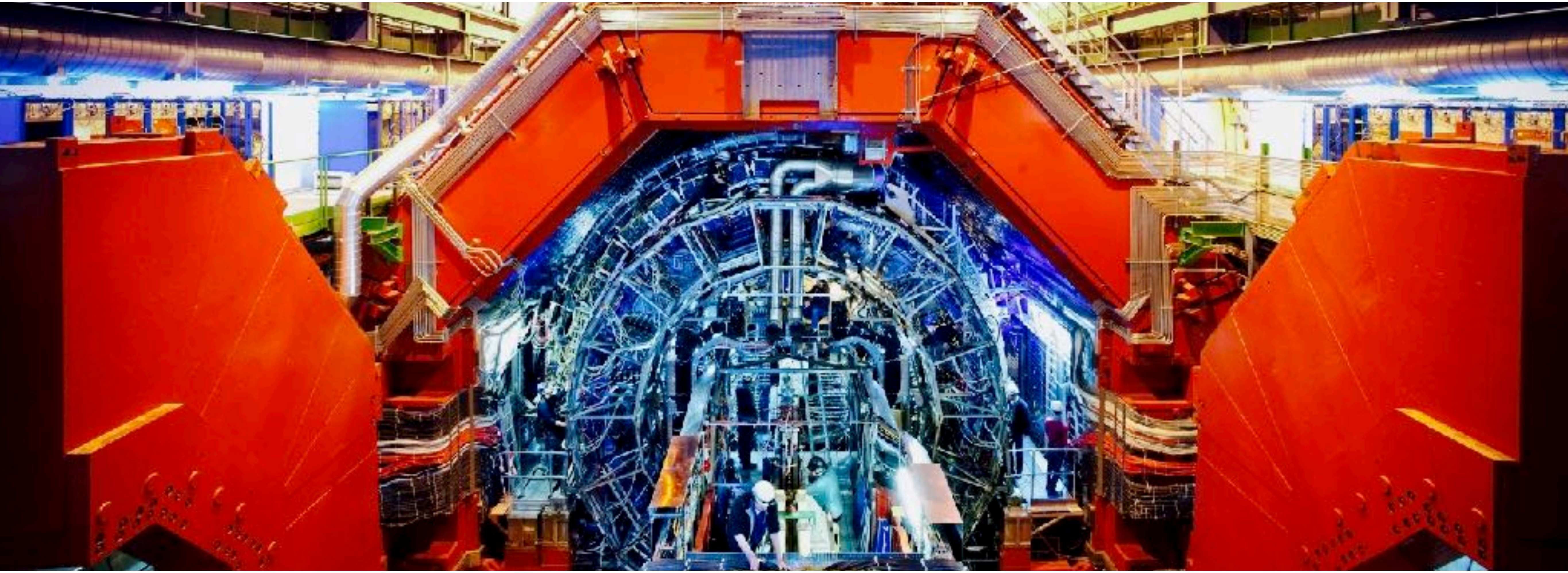
$\pi^{\pm}$, $K^{\pm}$, K^0_s, p, Λ, Ξ, Ω,

ρ^0, K^{*0}, φ, Σ^0, $\Sigma^{*\pm}$, Λ*, Ξ^{*0}

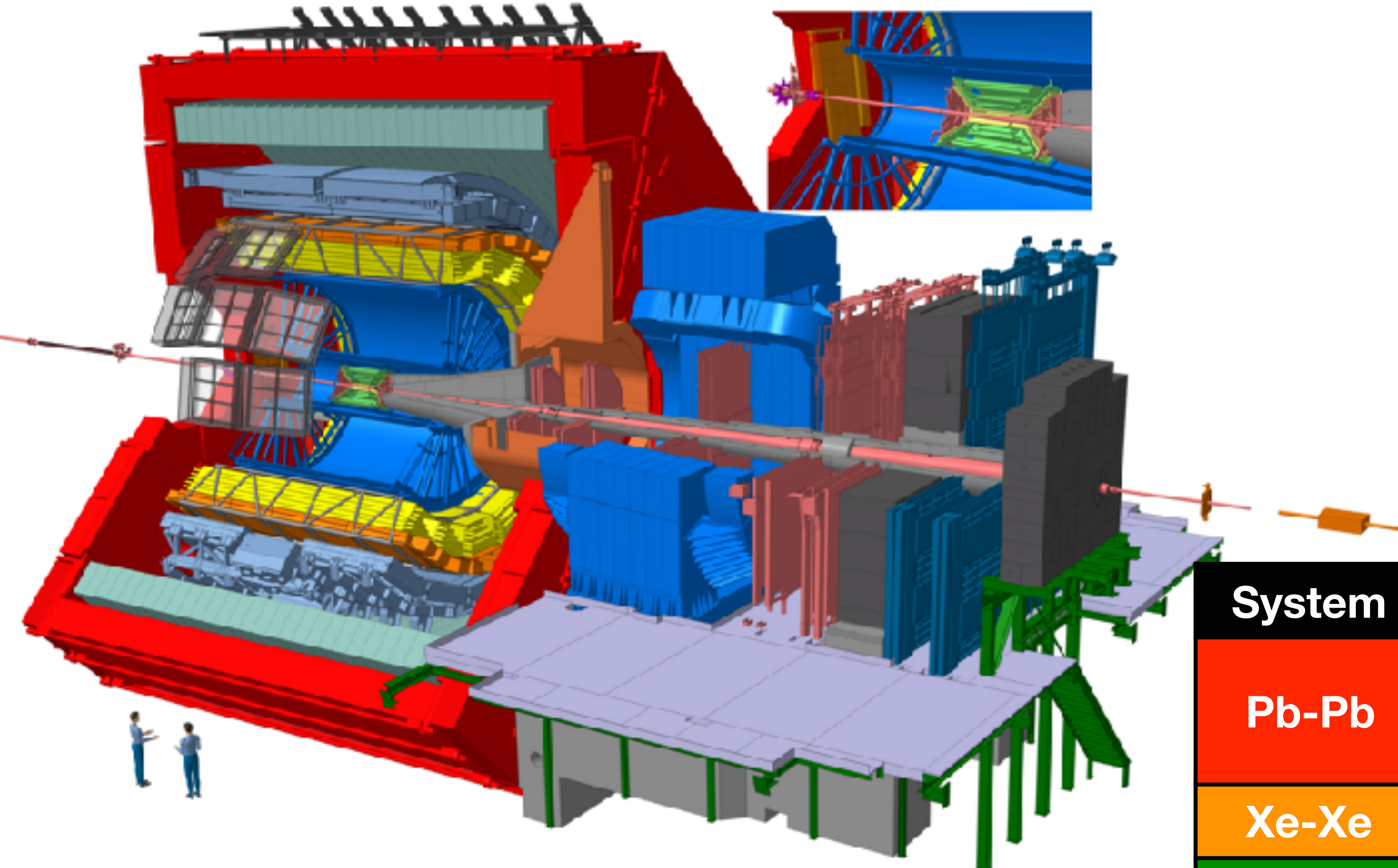
Resonances
- Particles and decay-



Experiment

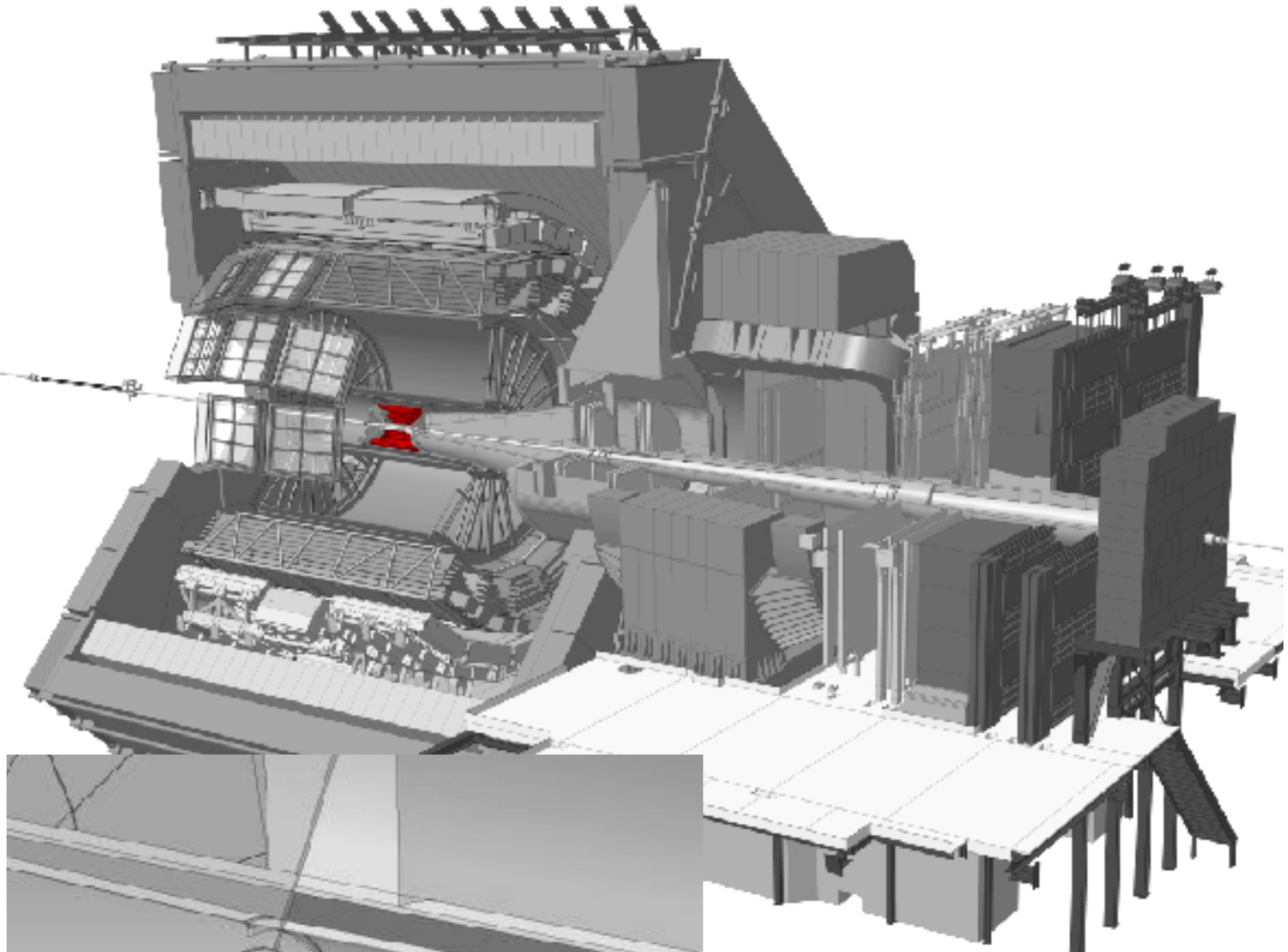


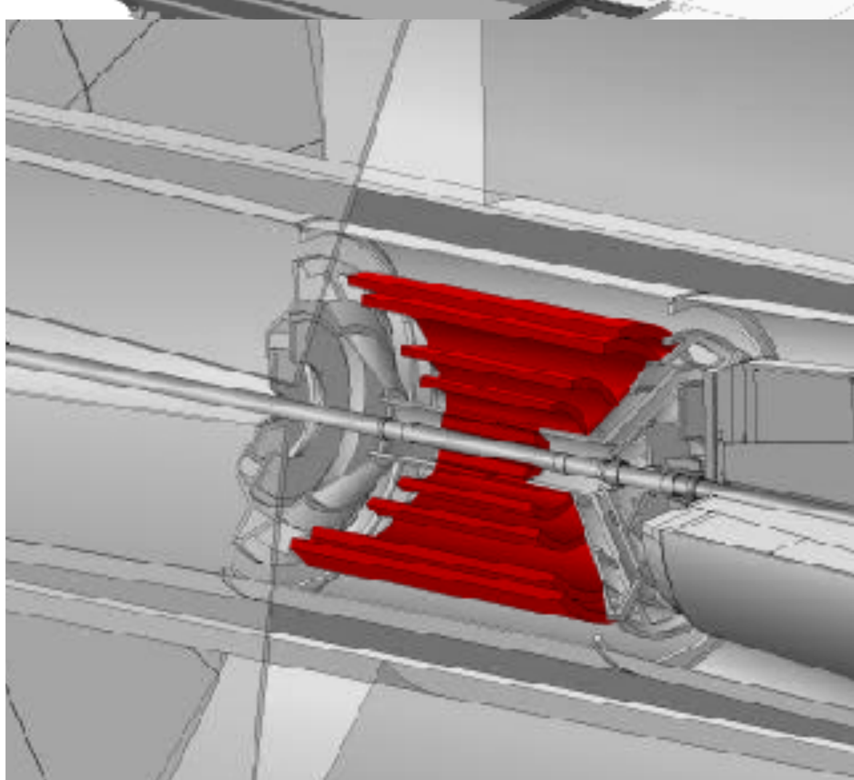
The ALICE detector



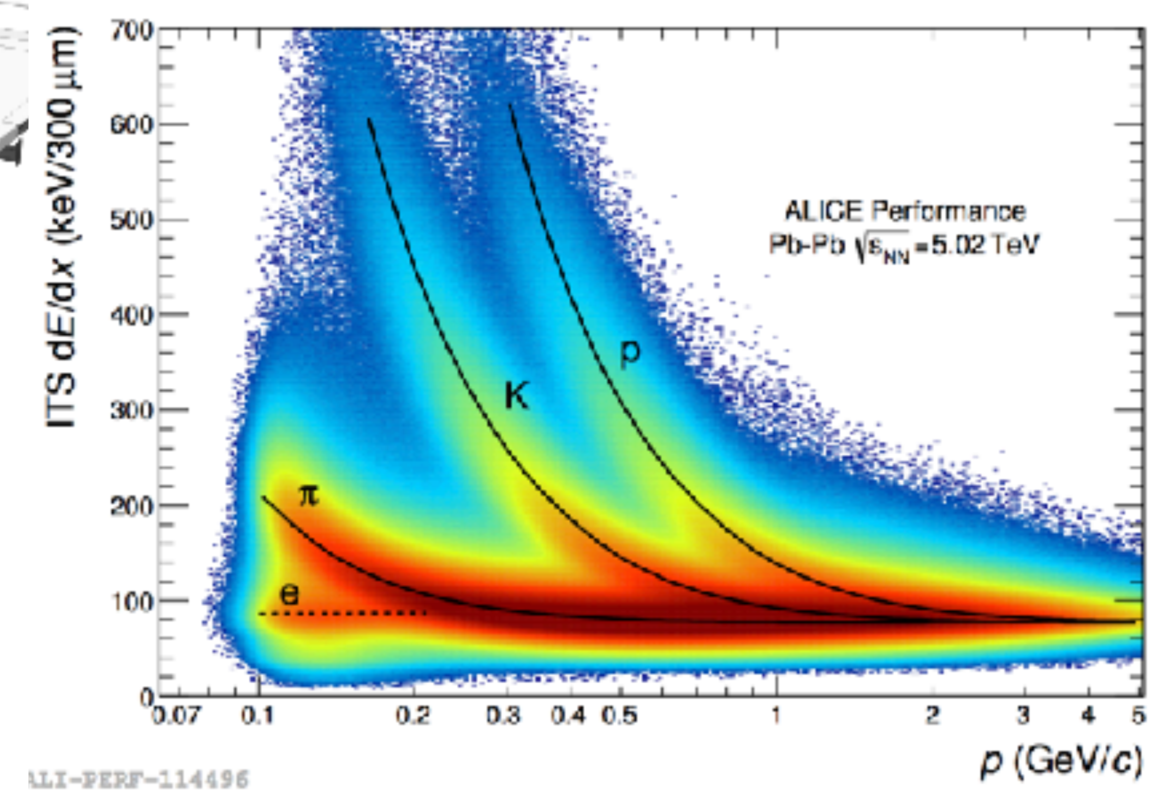
System	Year(s)	$\sqrt{s_{NN}}$ [TeV]
Pb-Pb	2010-2011	2.76
	2015	5.02
Xe-Xe	2017	5.44
p-Pb	2013	5.02
	2016	5.02, 8.16
pp	2009-2013	0.9, 2.76, 7, 8
	2015, 2017	5.02, 13

The ALICE detector

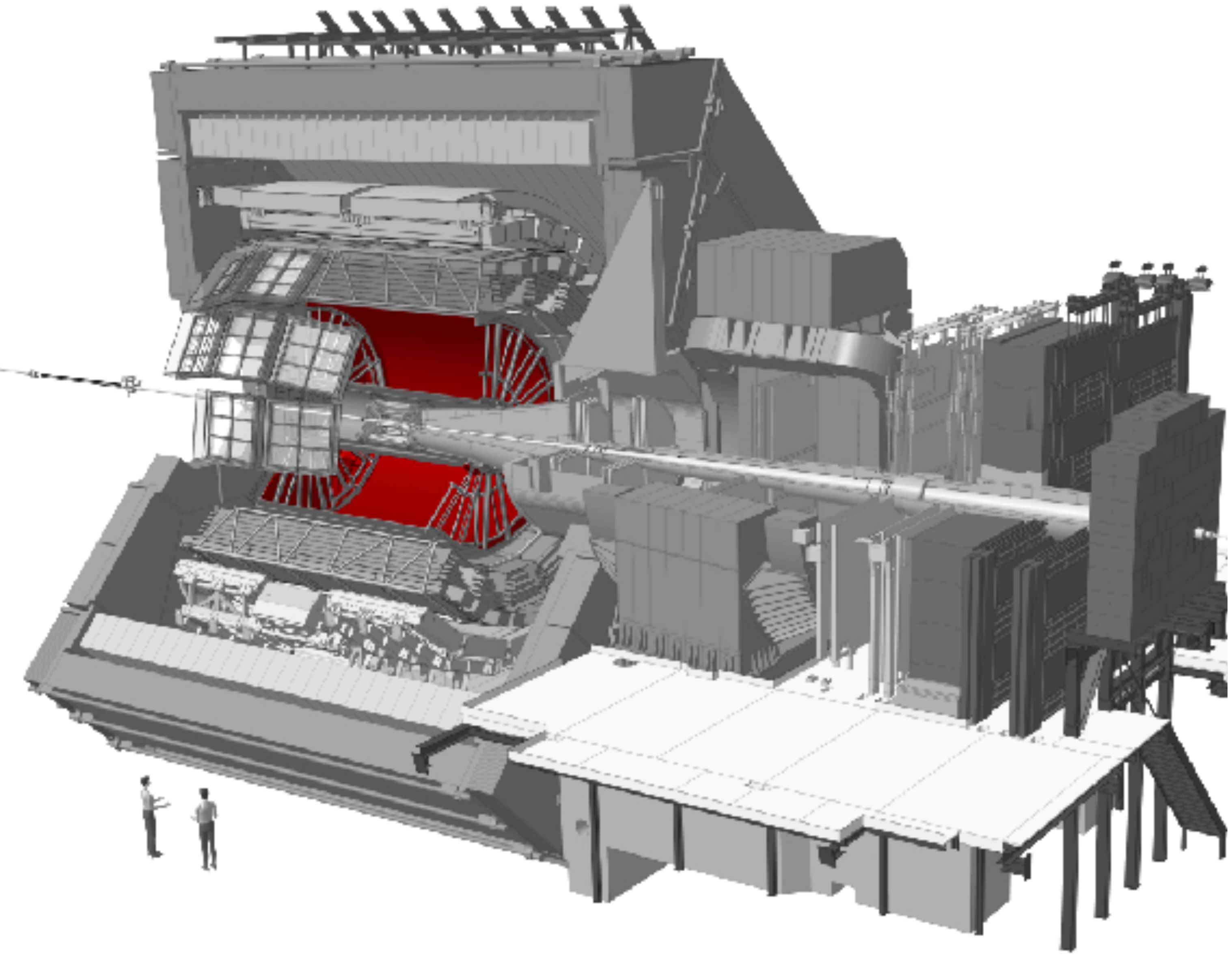




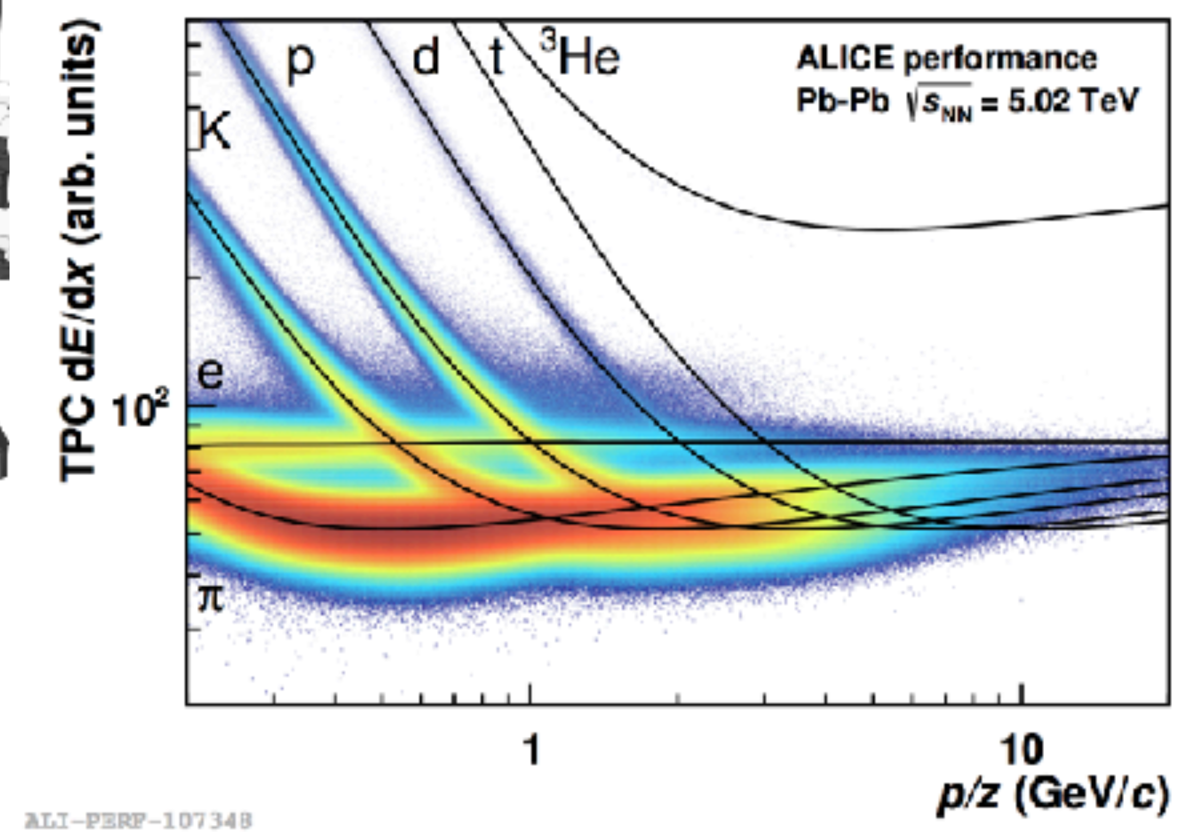
- **Inner Tracking System (ITS)**
  - SPD, SDD, SSD
  - Trigger, tracking, vertex, PID (d*E*/d*x*)



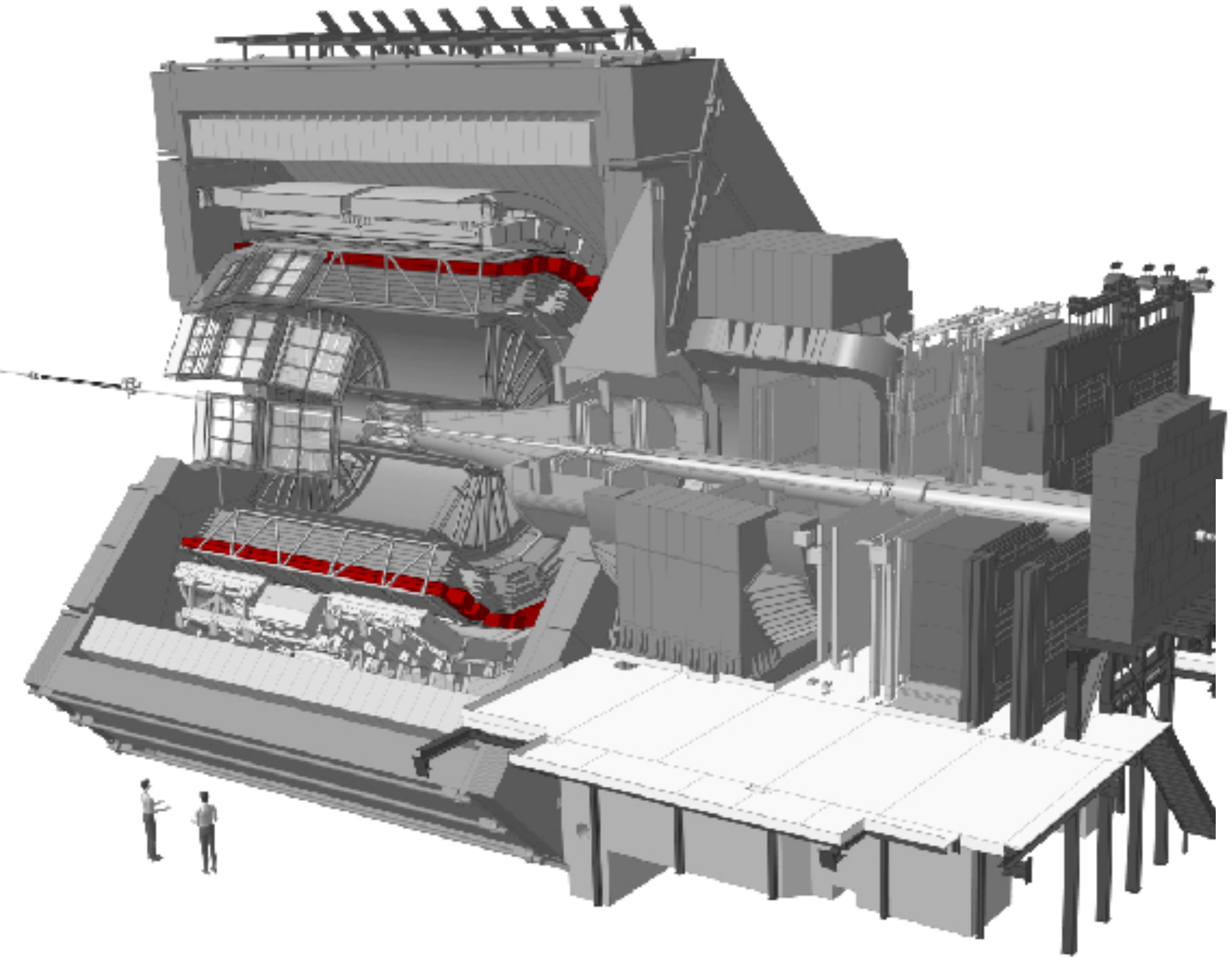
The ALICE detector



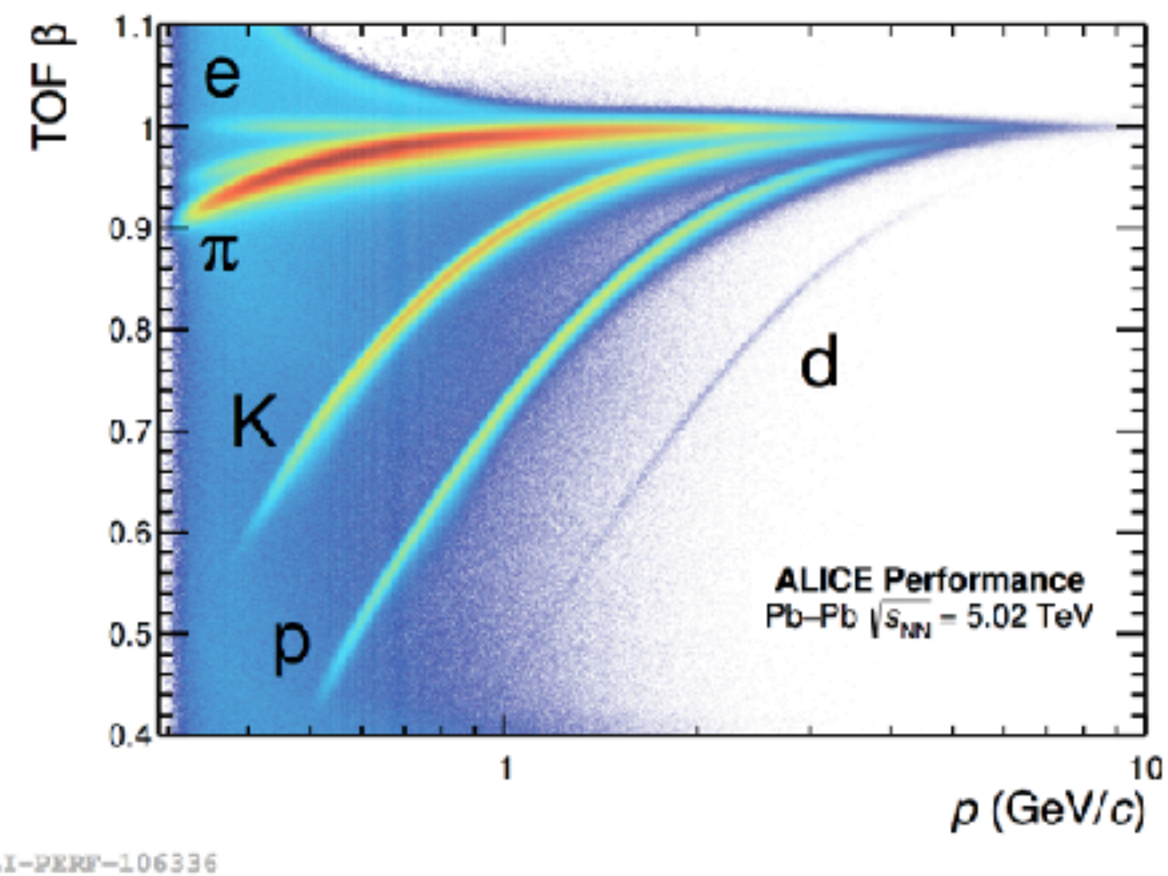
- **Time Projection Chamber (TPC)**
  - Gas-filled ionization detector
  - Tracking, vertex, PID, (d*E*/d*x*)



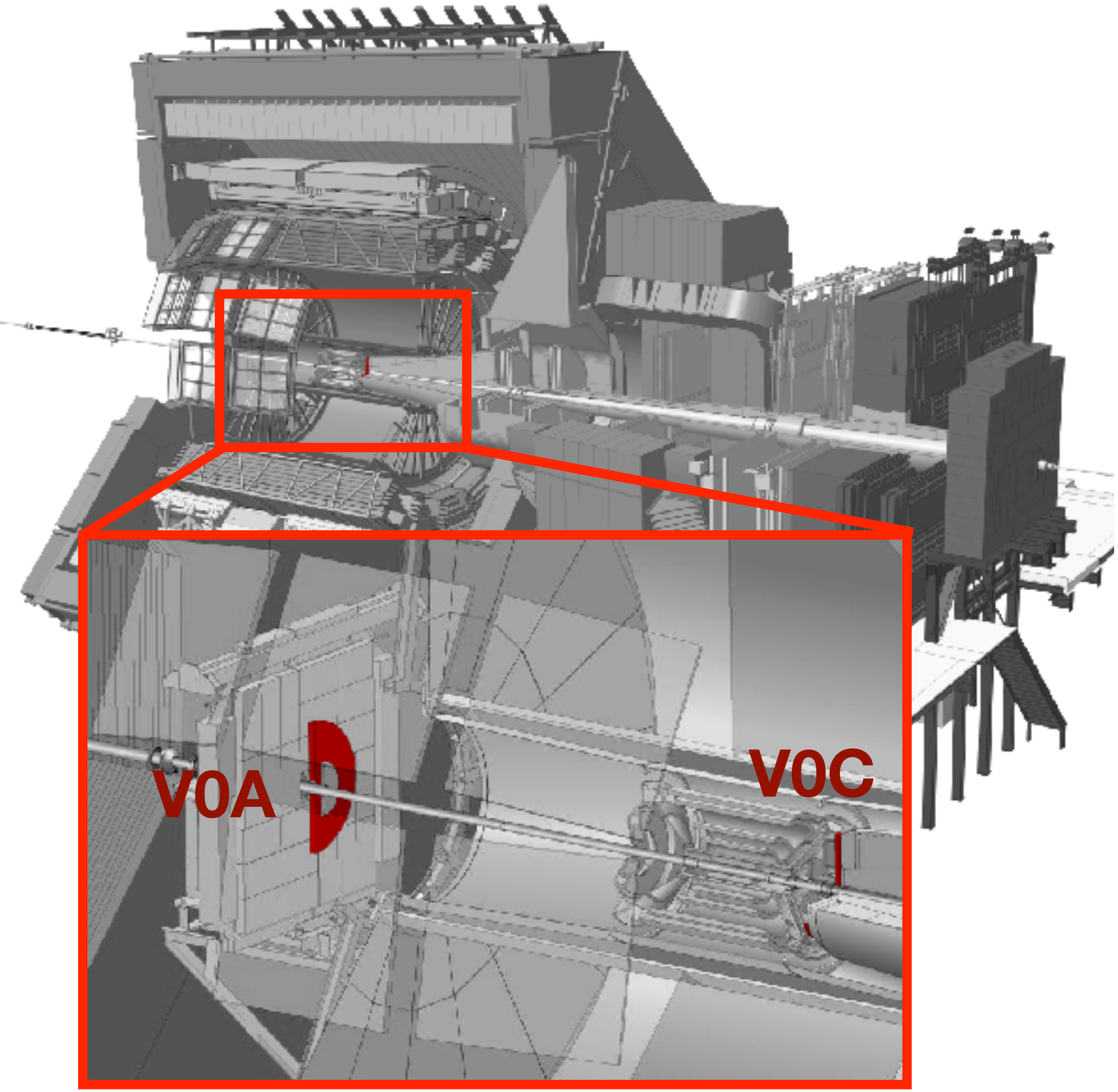
The ALICE detector



- **Time Of Flight (TOF)**
  - PID through particle time of flight



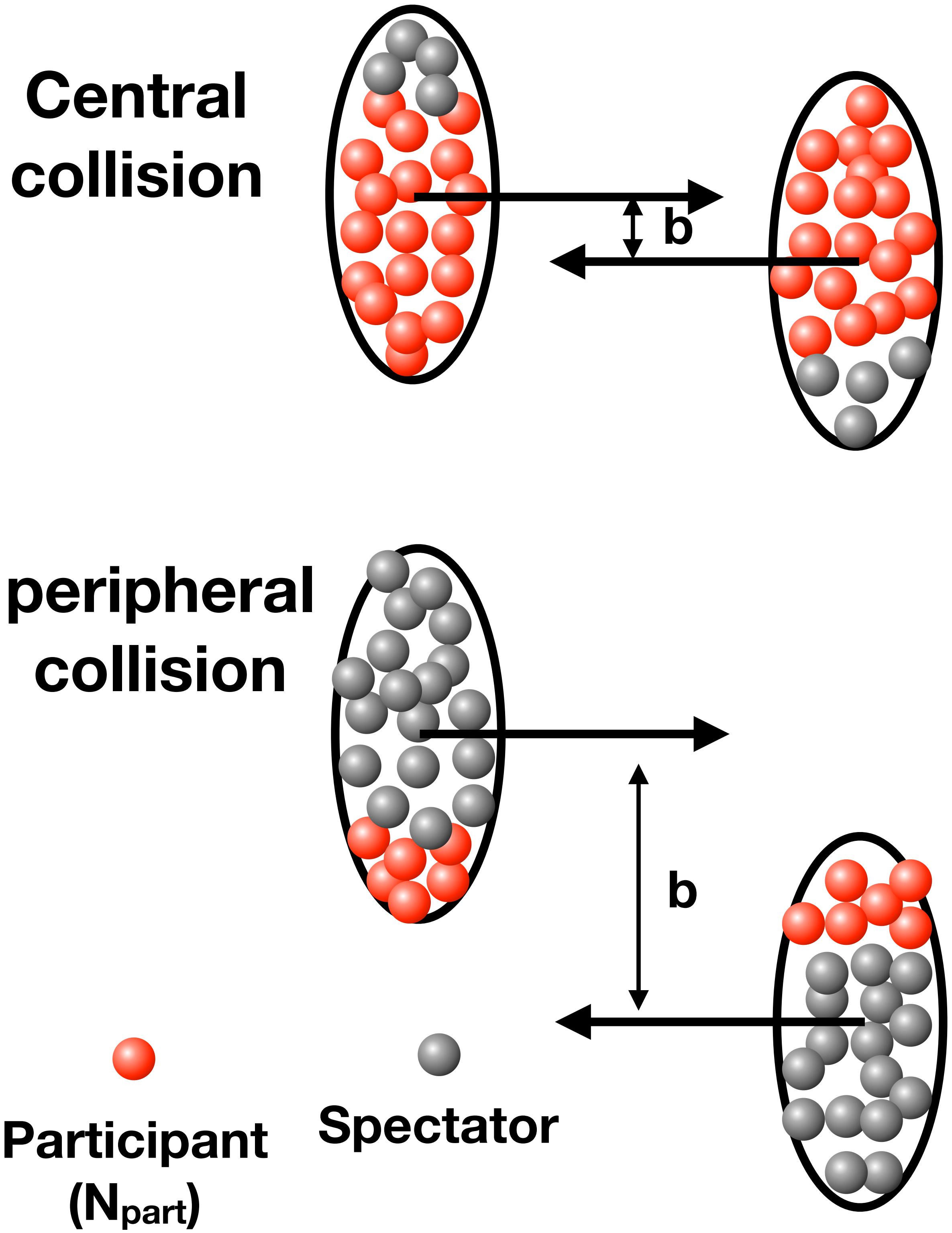
The ALICE detector



- **V0A and V0C**
  - Trigger, centrality/multiplicity estimator

Collision geometry

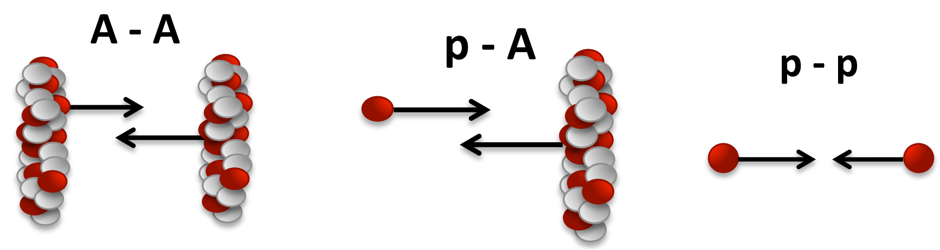
N_{coll}: Binary nucleon- nucleon collisions

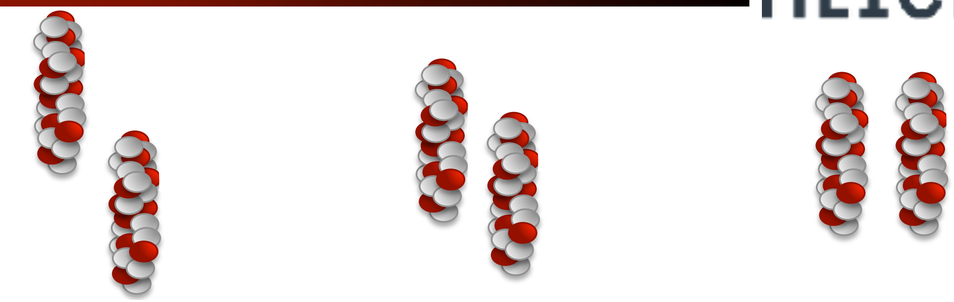


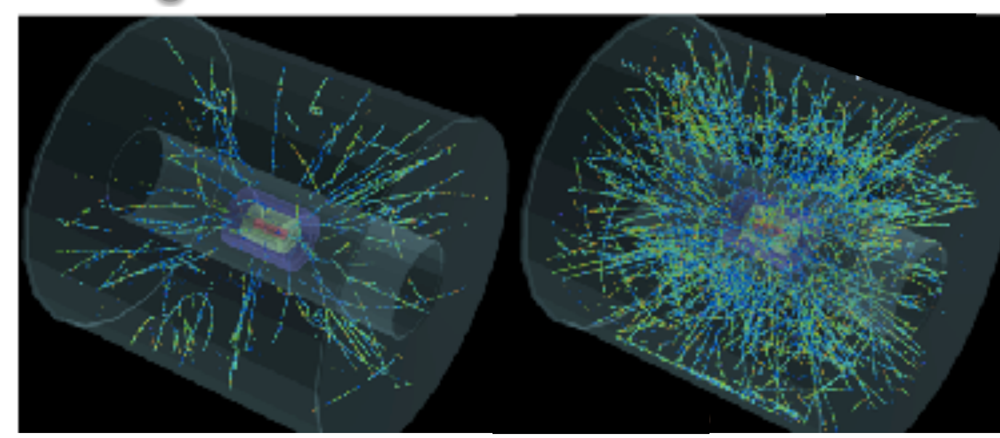
- Each event has different collision geometry
  - central (small “b”)
  - peripheral (large “b”)
- Volume of initial overlapped is expressed via number of participant nucleons, N_{part}
- centrality is not directly measured
  → deduced from combination of <u>experimentally measured quantities</u> and Monte-Carlo simulation

b: impact parameter
(2D vector connecting center of 2 nuclei)

Collision systems and geometry







- Event from different collision
  - system: pp, p-Pb, Pb-Pb
  - geometry: multiplicity/centrality [%]

- A global observable is required to compare results

➔Charged particle multiplicity density, $\langle dN_{ch}/d\eta \rangle$

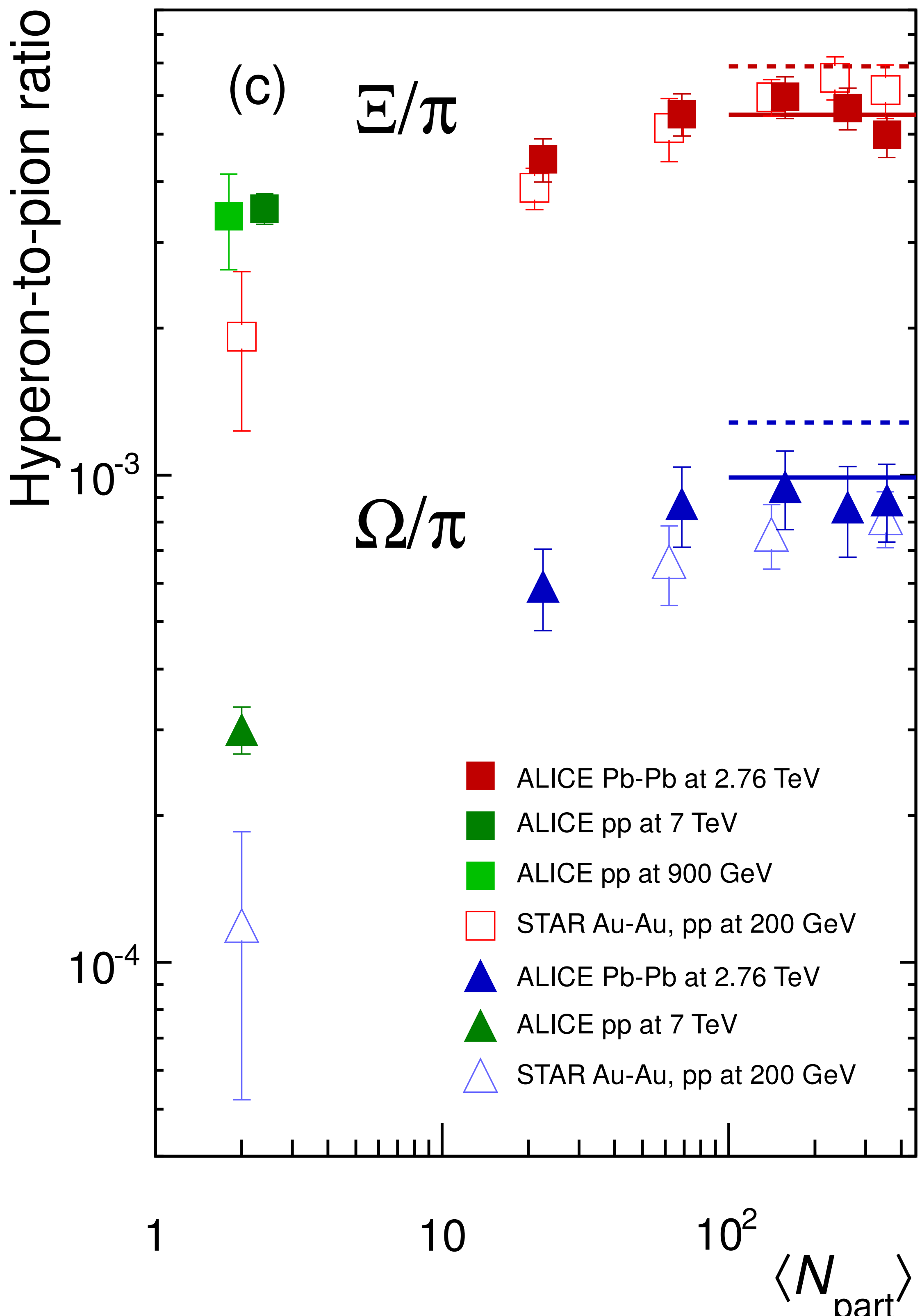
In **Pb-Pb** collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
0-5%: $\langle dN_{ch}/d\eta \rangle$ = 1601 ± 60
$\langle N_{part} \rangle$ = 328.8 ± 3.1
70-80%: $\langle dN_{ch}/d\eta \rangle$ = 35 ± 2
$\langle N_{part} \rangle$ = 15.8 ± 0.6

In **p-Pb** collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
0-5%: $\langle dN_{ch}/d\eta \rangle$ = 45 ± 1
60-80%: $\langle dN_{ch}/d\eta \rangle$ = 9.8 ± 0.2

In **pp** collisions at $\sqrt{s}$ = 7 TeV
0-0.95%: $\langle dN_{ch}/d\eta \rangle$ = 21.3 ± 0.6
48-68%: $\langle dN_{ch}/d\eta \rangle$ = 3.9 ± 0.14

Strangeness production

Strangeness enhancement



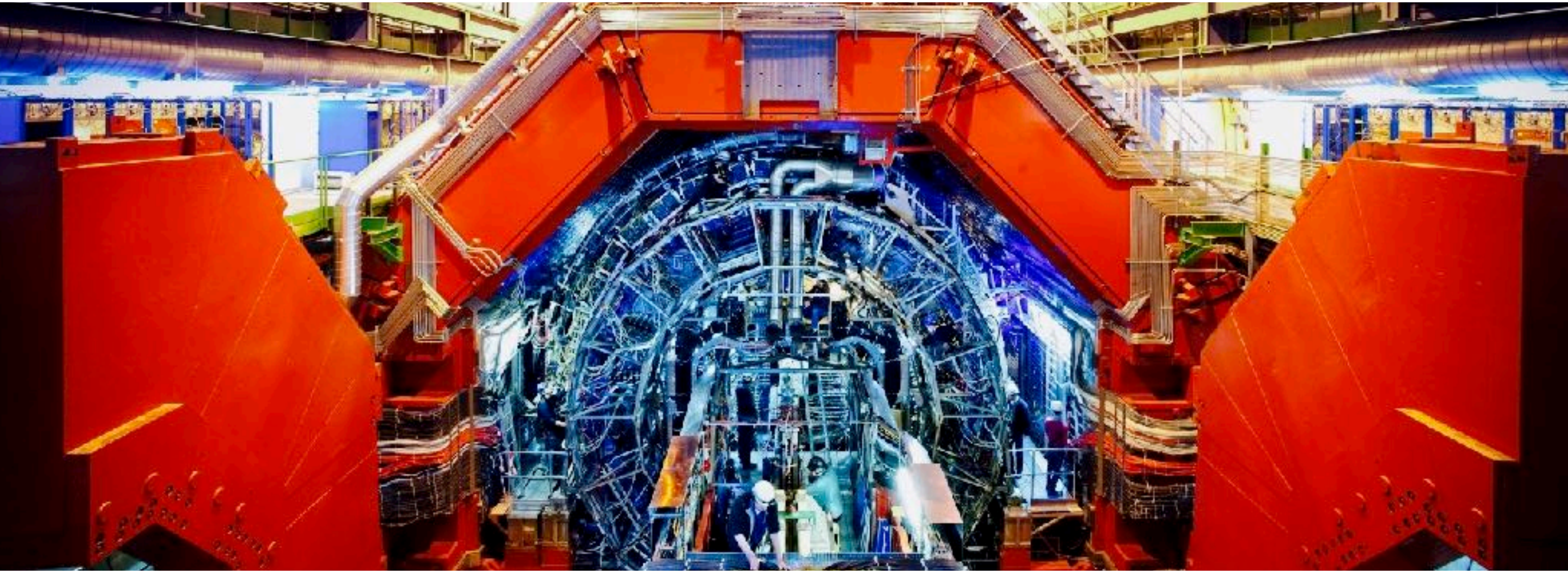
- Enhanced production of strangeness particles in AA w.r.t. pp

	Mass[GeV/c²]	quark contents
Ξ	1.321	dss
Ω	1.672	sss

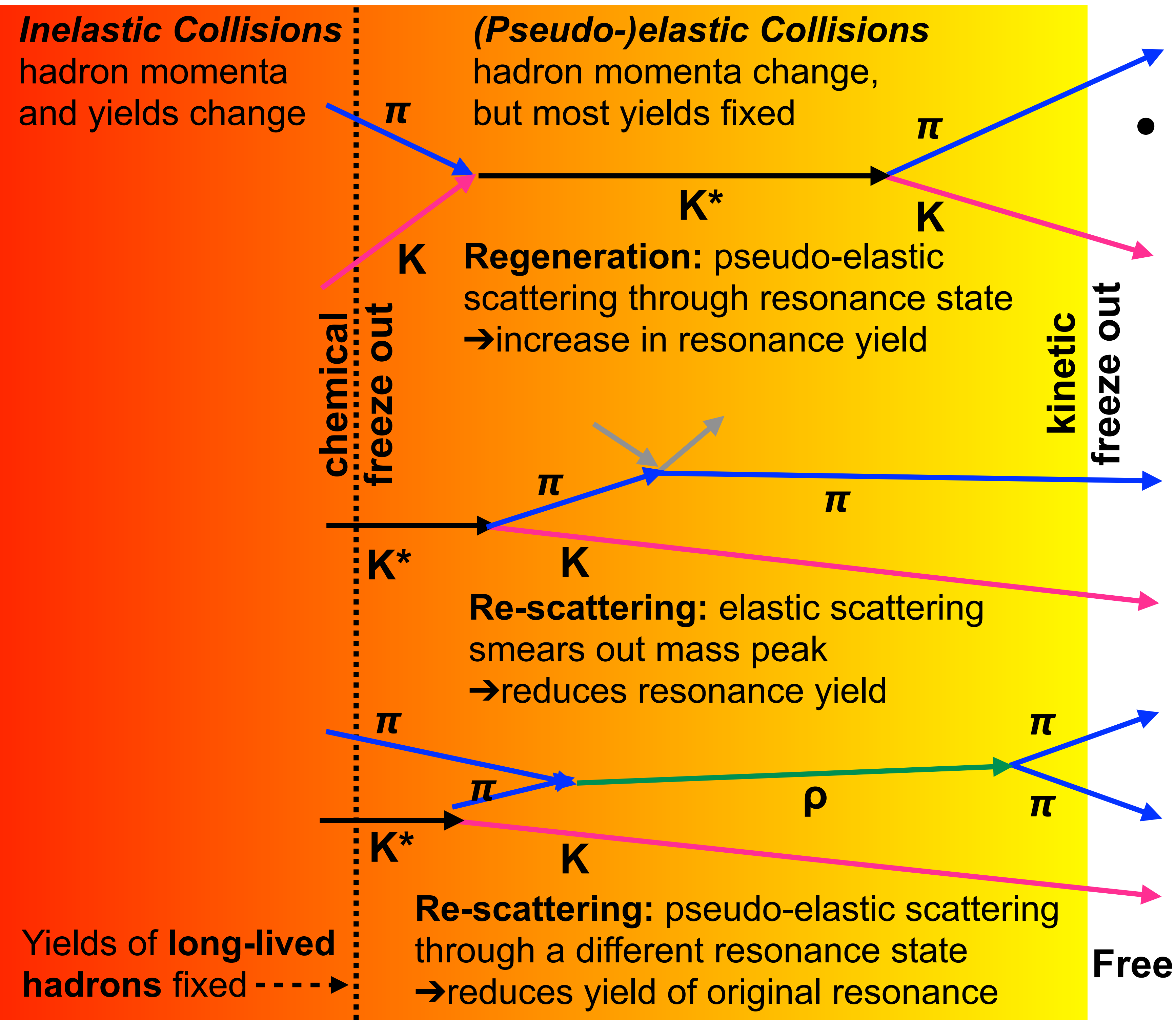
What are the latest results on strangeness production in different colliding systems at the top LHC energy?

What causes the enhancement?

Hadronic phase



Probing the hadronic phase



Resonances have

- Different short lifetimes
  - allow to study properties of hadronic phase in terms of **re-scattering and regeneration** effects

	Lifetime [fm/c]
ρ	1.3
K^{*0}	4.2
Λ*	12.6
Ξ^{*0}	21.7
ϕ	46.2

Summary

- **ALICE** has measured comprehensive set of identified particles

- We presented latest results on **multiplicity-dependent strangeness** production in all the available colliding systems at the top LHC energy
  - **smooth enhancement** has been observed with multiplicity
  - the enhancement increases with **strangeness content**
  - at similar multiplicity, no dependence with system nor energy is observed
  - ϕ has **effective strangeness of 1-2 units**

- Measurements of mesonic and baryonic **resonances** were presented
  - **suppression of short-lived resonances**, ρ^0, K^{*0}, Λ^{*0} ,has been observed in most central collisions w.r.t. small collision systems
  - **re-scattering is dominant over regeneration**
  - there is **no suppression of long-lived resonances**, ϕ