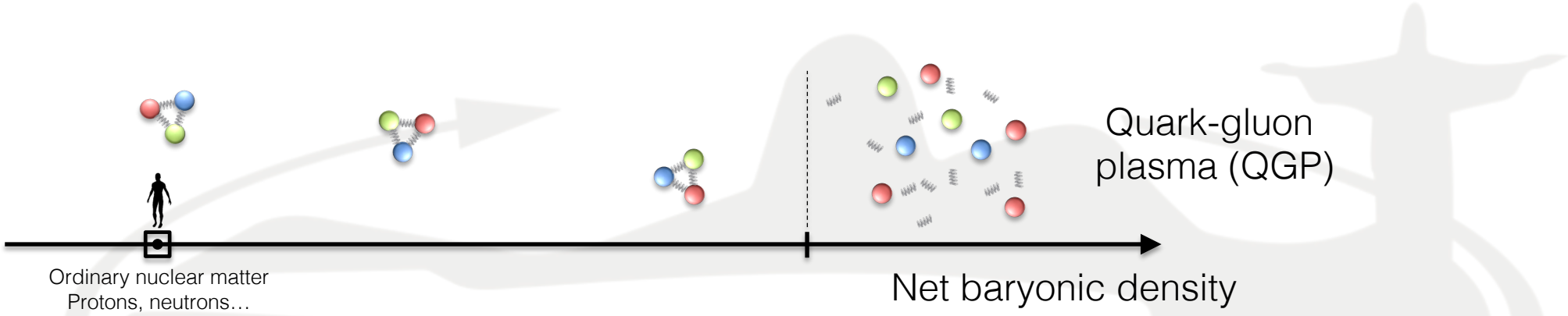
Soft physics highlights

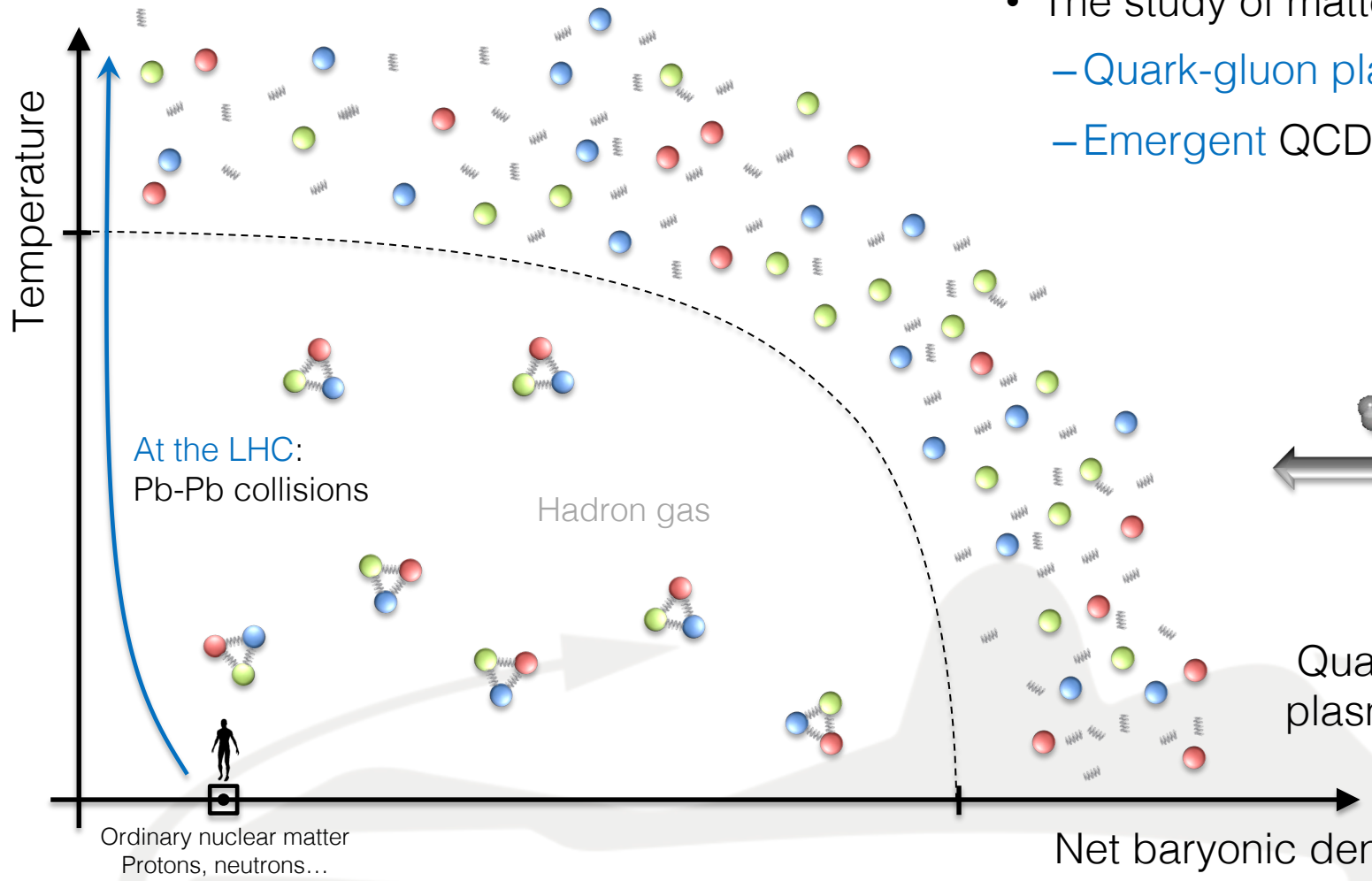
D.D. Chinellato for the ALICE Collaboration

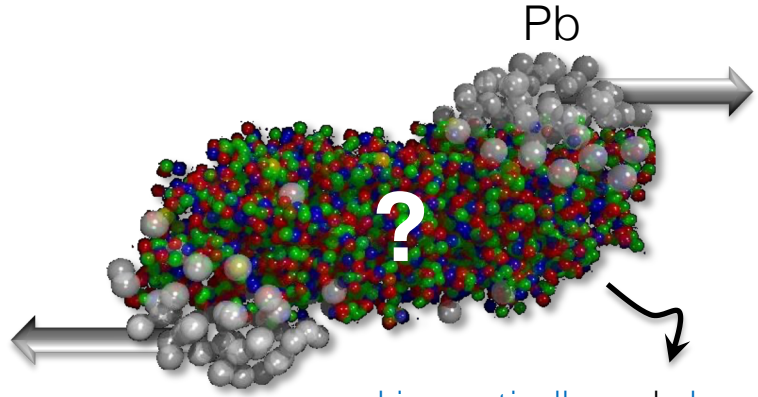
The mandate of the ALICE collaboration



The mandate of the ALICE collaboration

- The study of matter under extreme conditions:
  - Quark-gluon plasma characterization
  - Emergent QCD phenomena

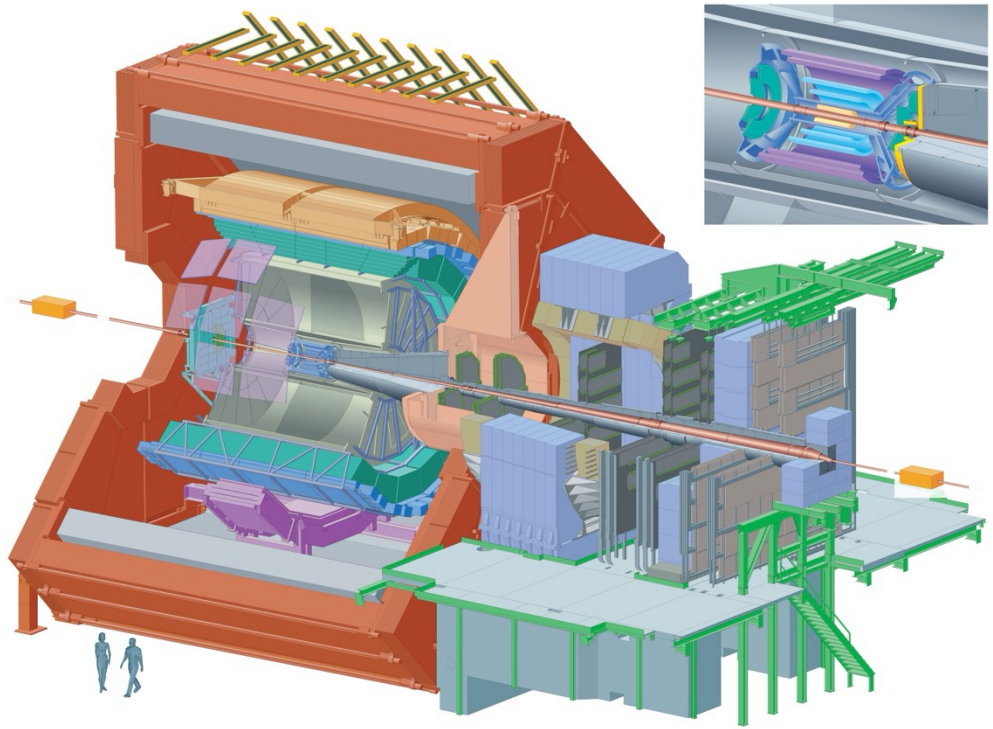




kinematically and chemically equilibrated system: hydrodynamics and statistical principles

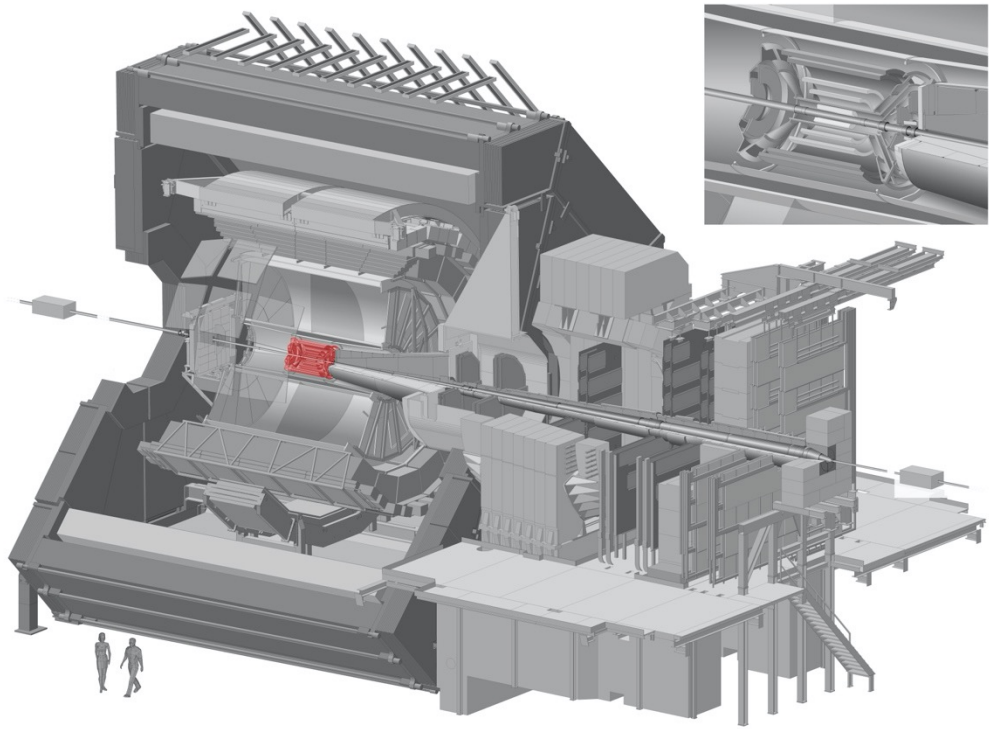
Quark-gluon plasma (QGP)

The ALICE Experiment at the LHC



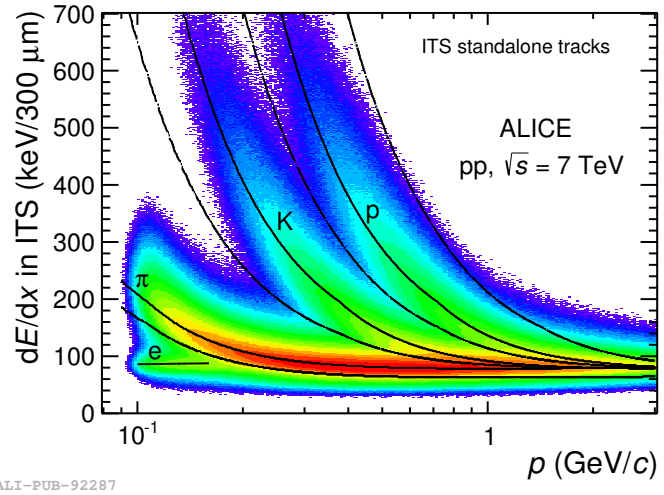
Specificity: low-momentum tracking and particle identification in a high-multiplicity environment

The ALICE Experiment at the LHC



ITS ($|\eta|<0.9$)

- 6 Layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)



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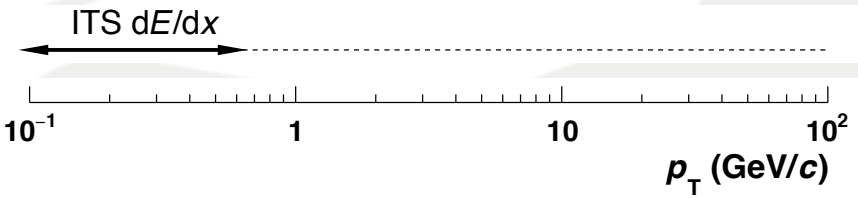
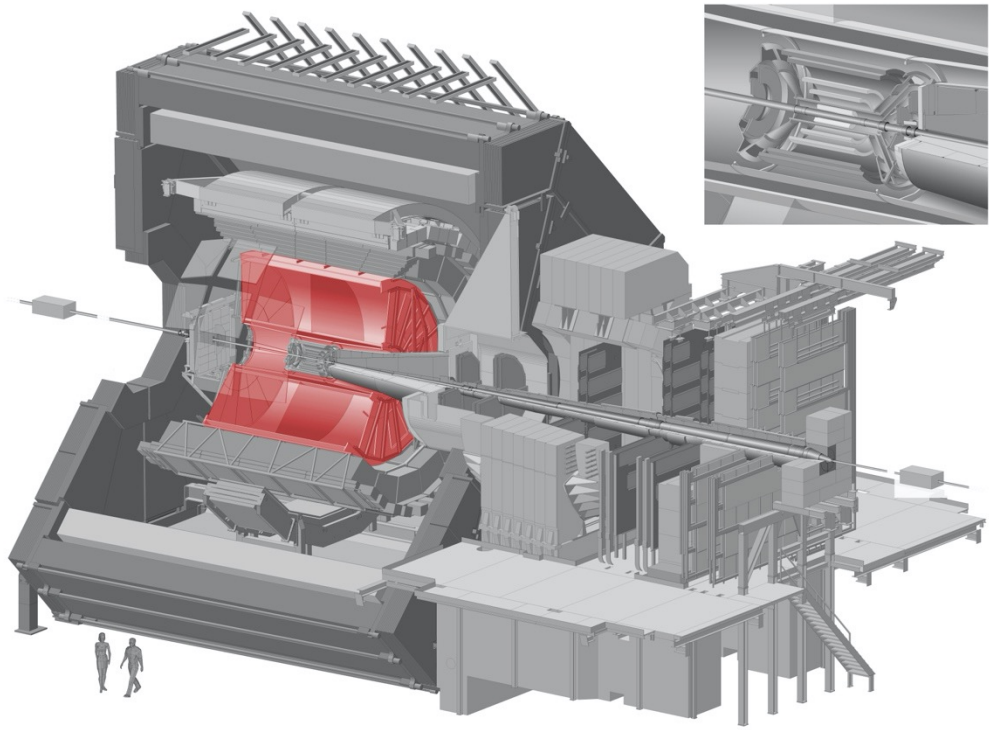


The ALICE Experiment at the LHC



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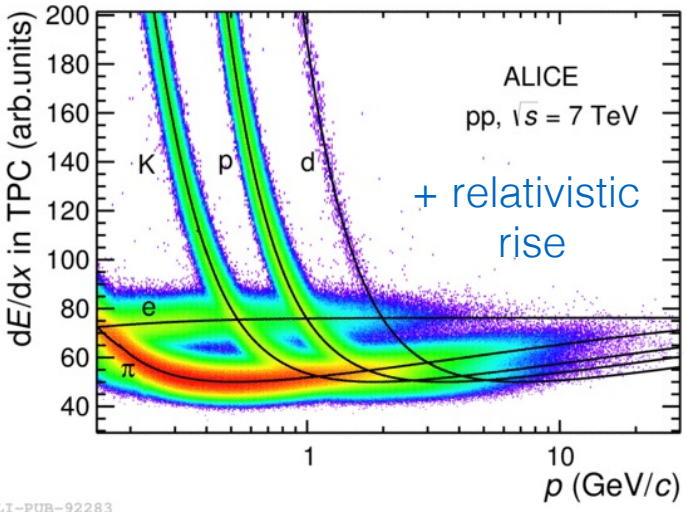
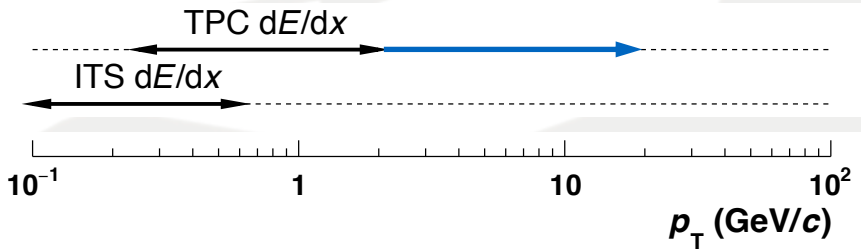
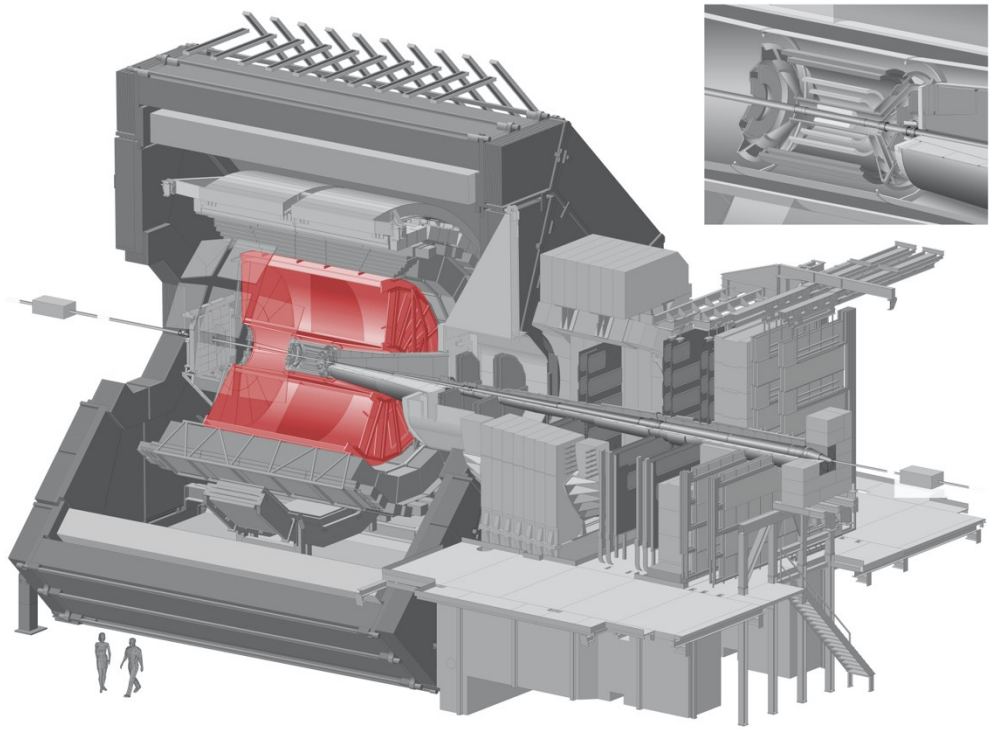
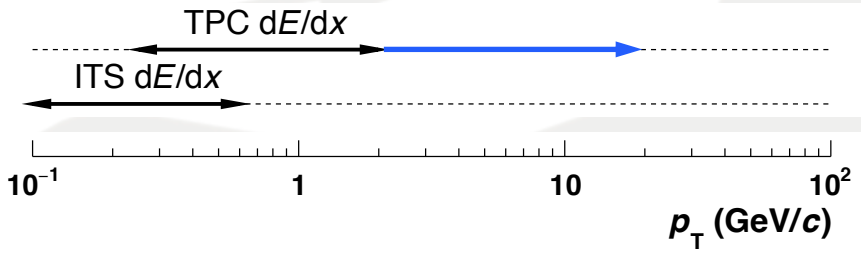
TPC ($|\eta|<0.9$)
- Gas-filled ionization detection volume
- Tracking, vertex, PID (dE/dx)





The ALICE Experiment at the LHC





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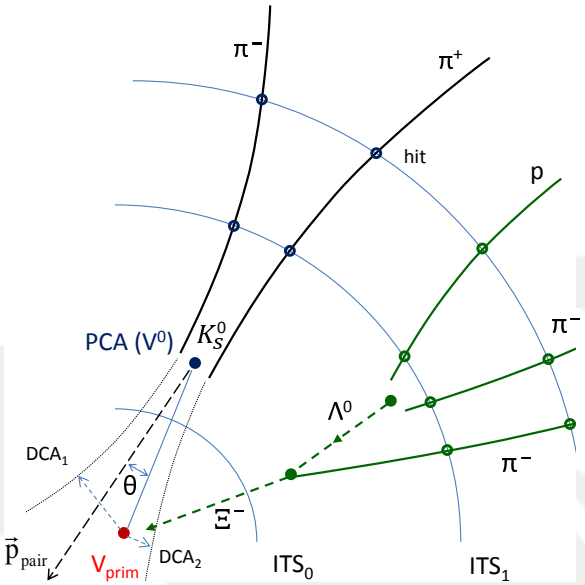
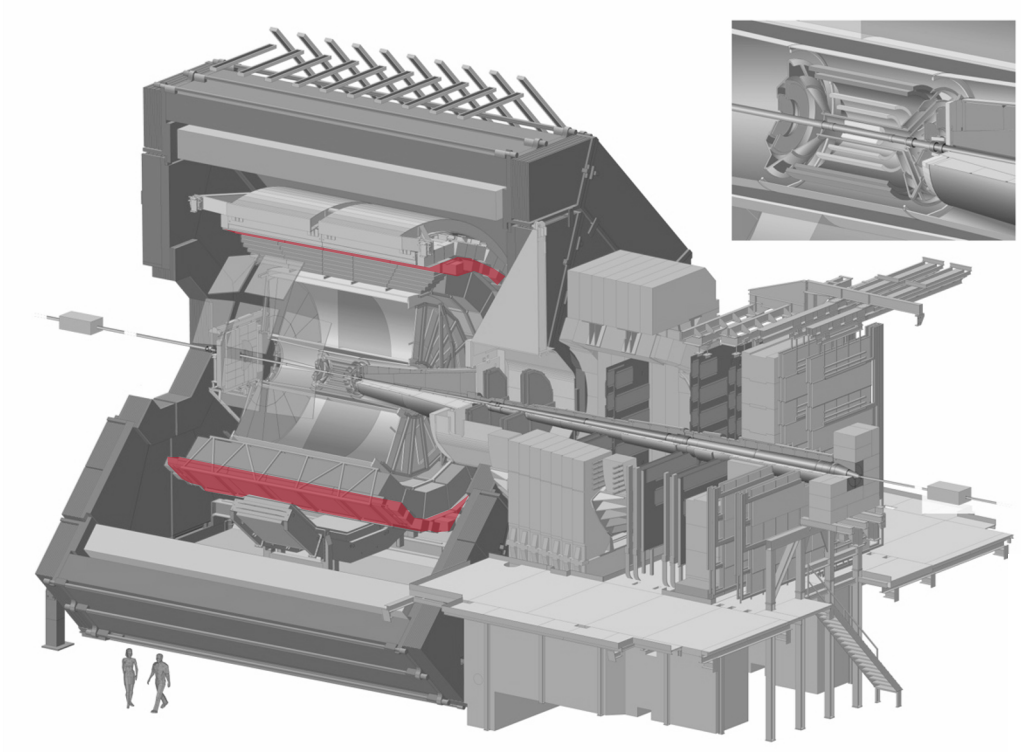
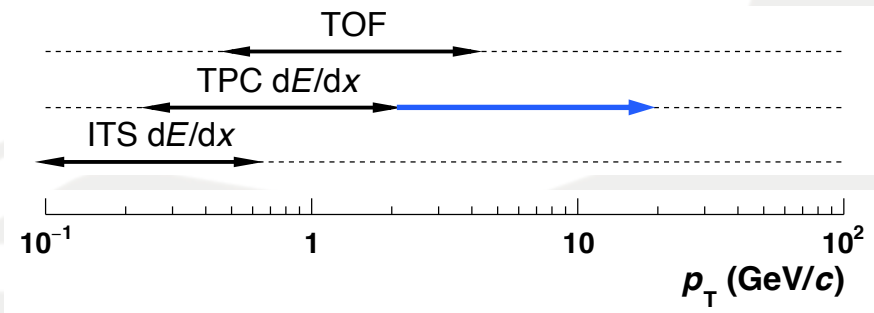
- Tracking, vertex, PID (dE/dx)
- Weak decay reconstruction (topological)

$$\Xi^- \rightarrow \Lambda + \pi^-$$



The ALICE Experiment at the LHC





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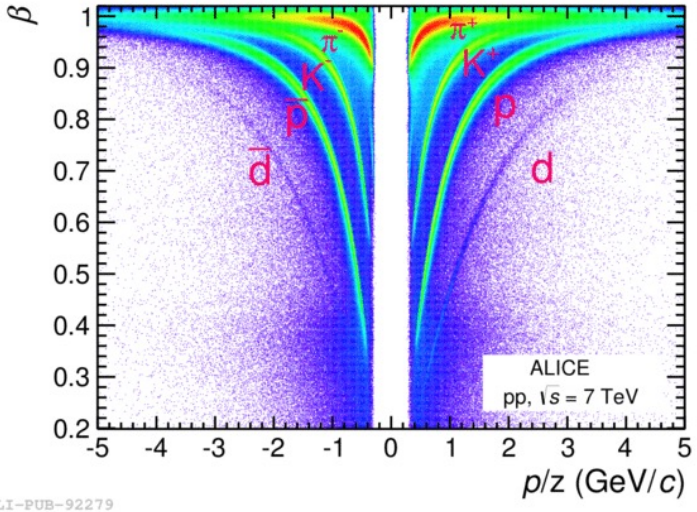
TOF ($|\eta|<0.9$)
- Multi-gap resistive plate chambers
- PID via velocity determination



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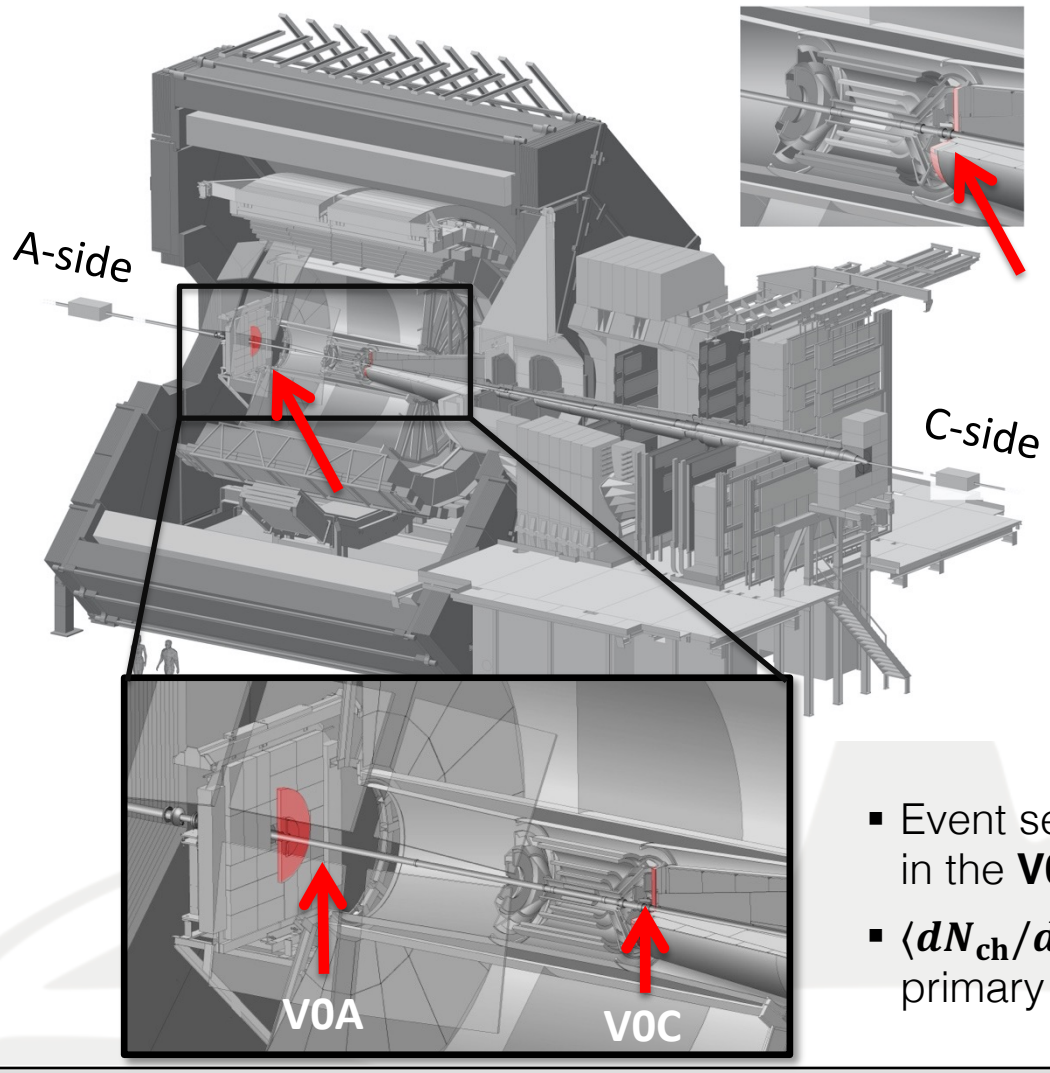
The ALICE Experiment at the LHC



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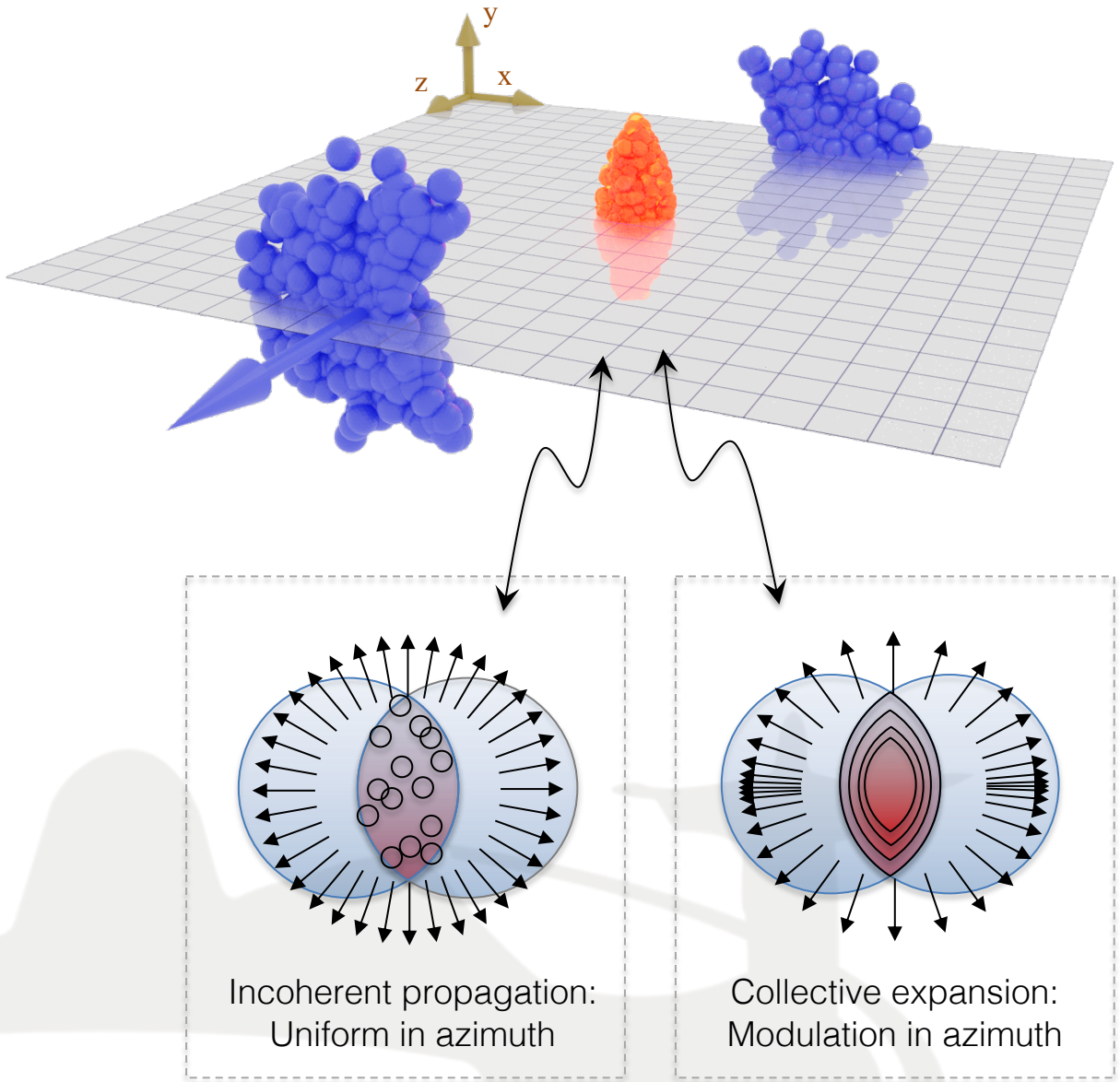
TOF ($|\eta|<0.9$)
- Multi-gap resistive plate chambers
- PID via velocity determination

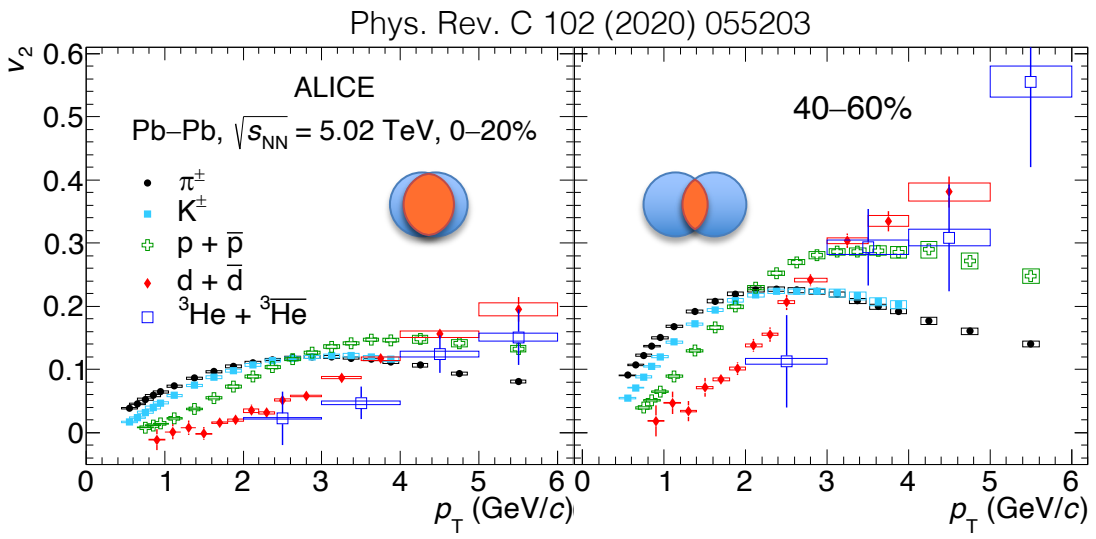
V0 [V0A ($2.8<\eta<5.1$) & V0C ($-3.7<\eta<-1.7$)]
- Forward arrays of scintillators
- Trigger, beam gas rejection
- Multiplicity estimator:

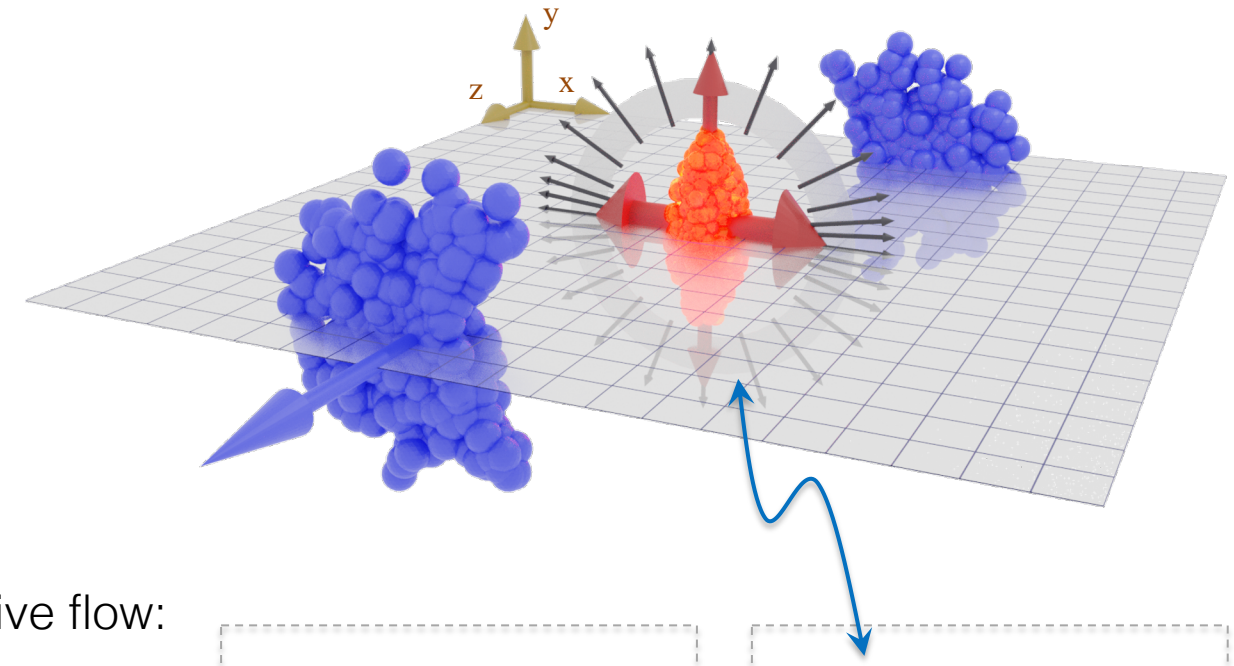
- Event selection based on total charge deposited in the **V0A** and **V0C** detectors ("V0M")
- $\langle dN_{\mathrm{ch}}/d\eta \rangle$ estimated as the average number of primary charged tracks in $|\eta| < 0.5$

Kinematic equilibration: the development of flow

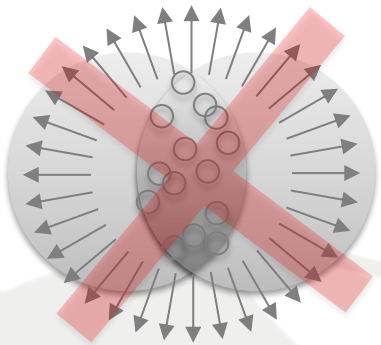


Kinematic equilibration: the development of flow

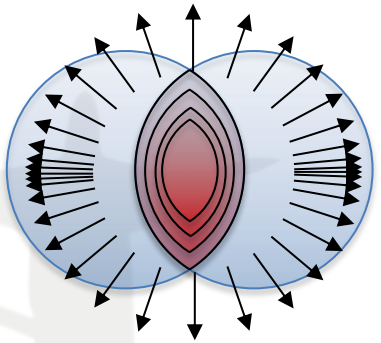




- Nearly all particle species participate in collective flow: quantified via a Fourier decomposition [1]
- Light flavor: mass ordering (π, K, p, d, ^{3}He)

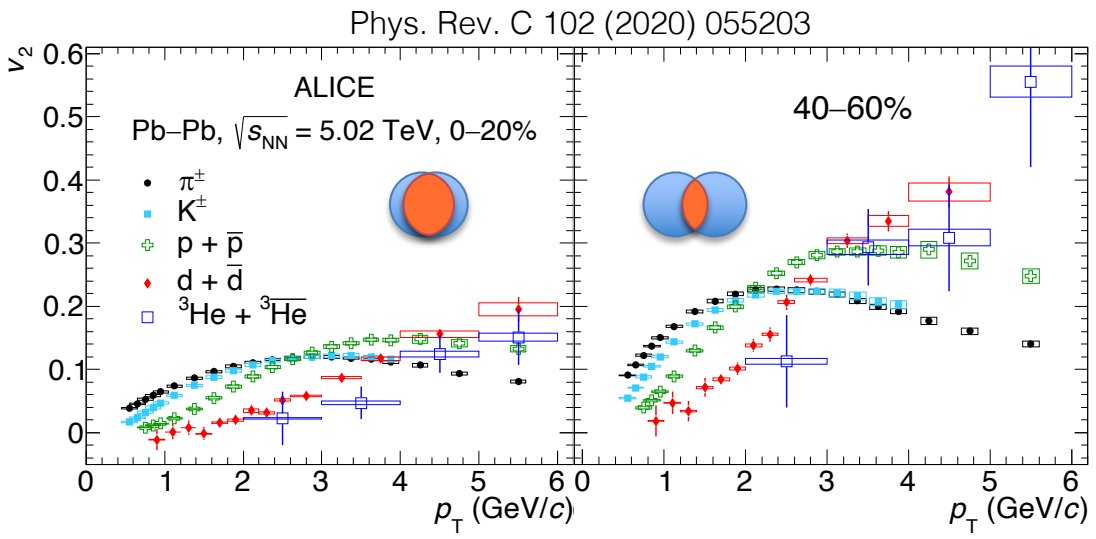


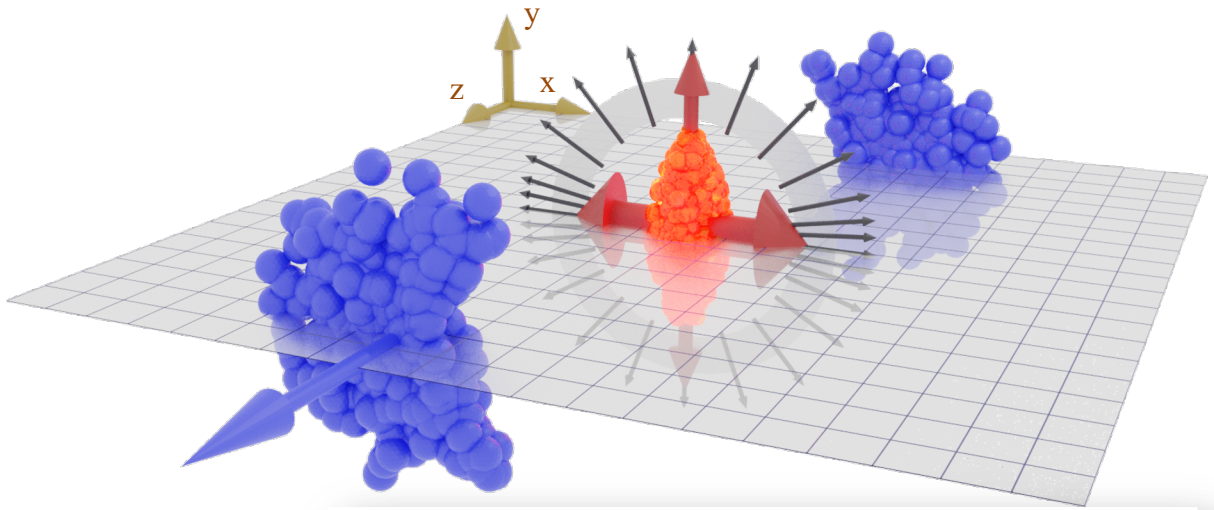
Incoherent propagation:
Uniform in azimuth



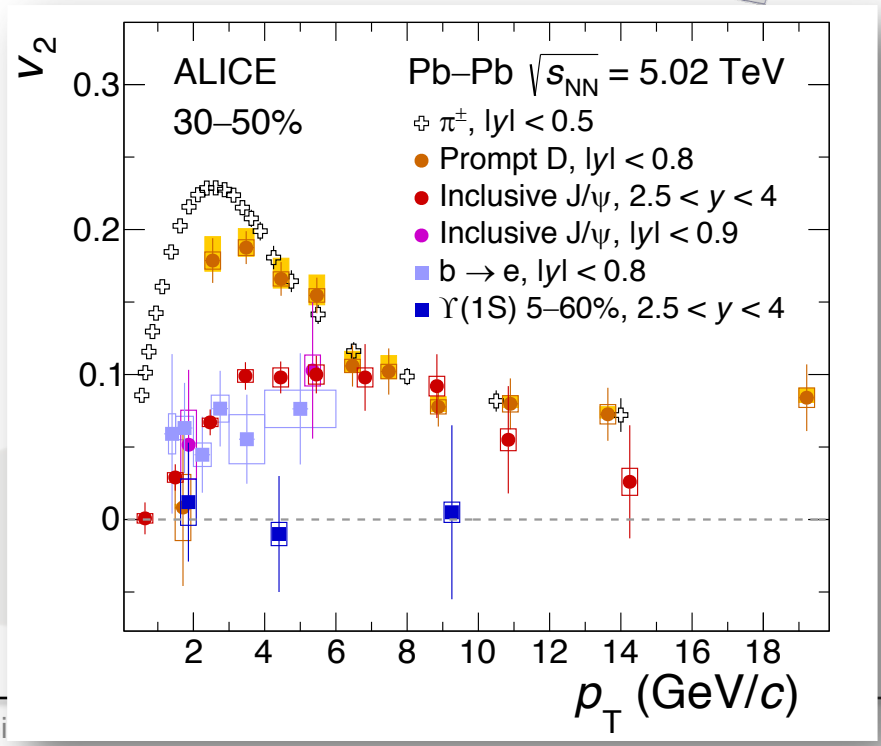
Collective expansion:
Modulation in azimuth

Kinematic equilibration: the development of flow



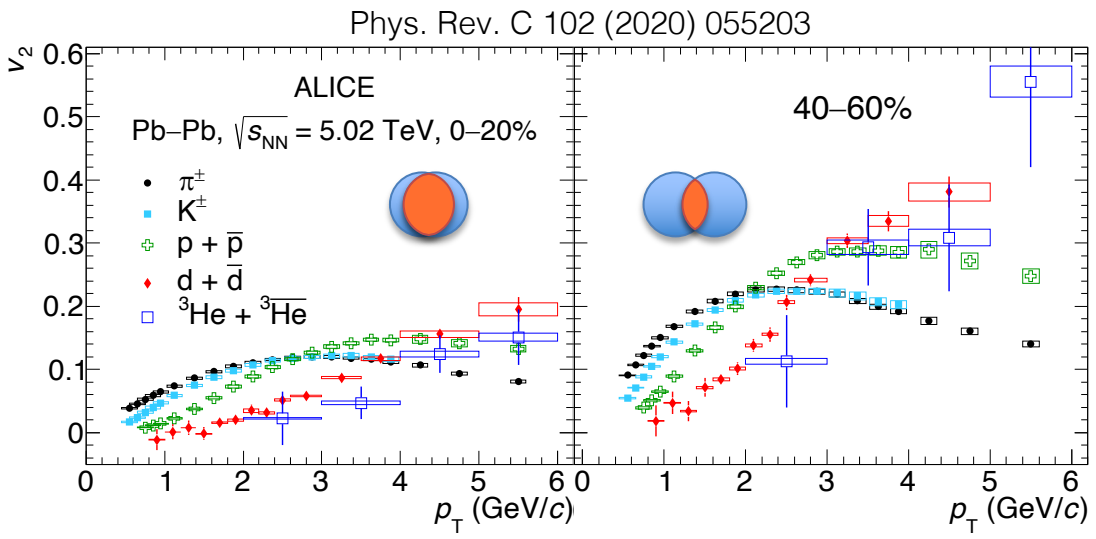


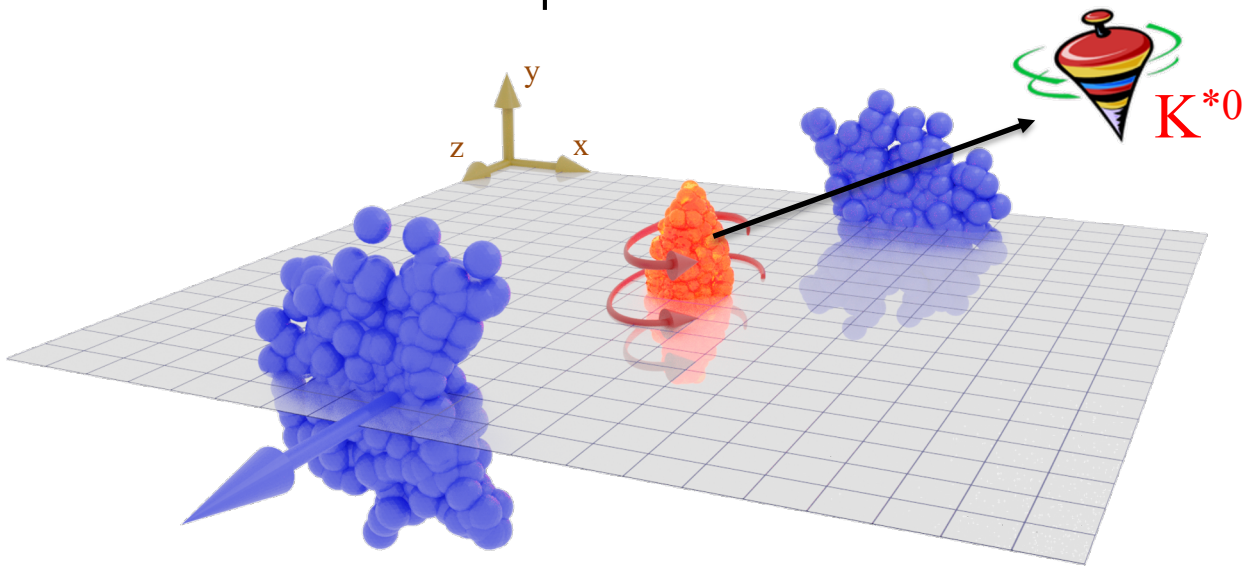
- Nearly all particle species participate in collective flow: quantified via a Fourier decomposition [1]
- Light flavor: mass ordering (π, K, p, d, ^{3}He)
- Heavy flavor: progressively lower flow for D^0, J/ψ, b → e
  - No flow for ϒ(1S)



Phys. Rev. Lett. 126, 162001 (2021)
JHEP 10 (2020) 141
Phys. Lett. B 806 (2020) 135486

Kinematic equilibration: the development of flow





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- Light flavor: mass ordering (π, K, p, d, ^{3}He)
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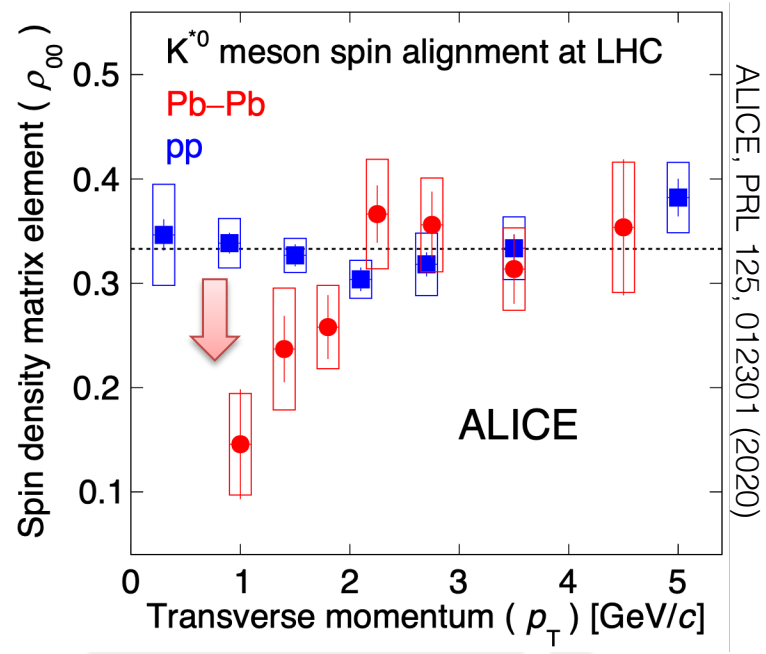
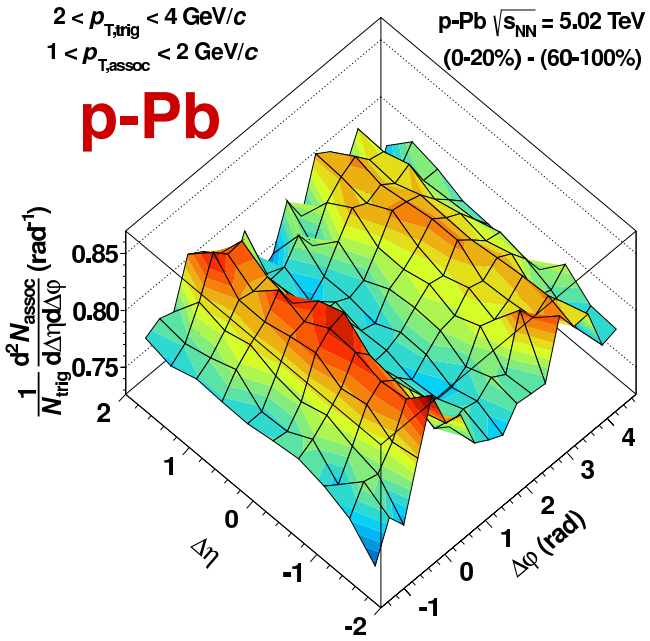
Rotating QGP aligns vector-meson spin



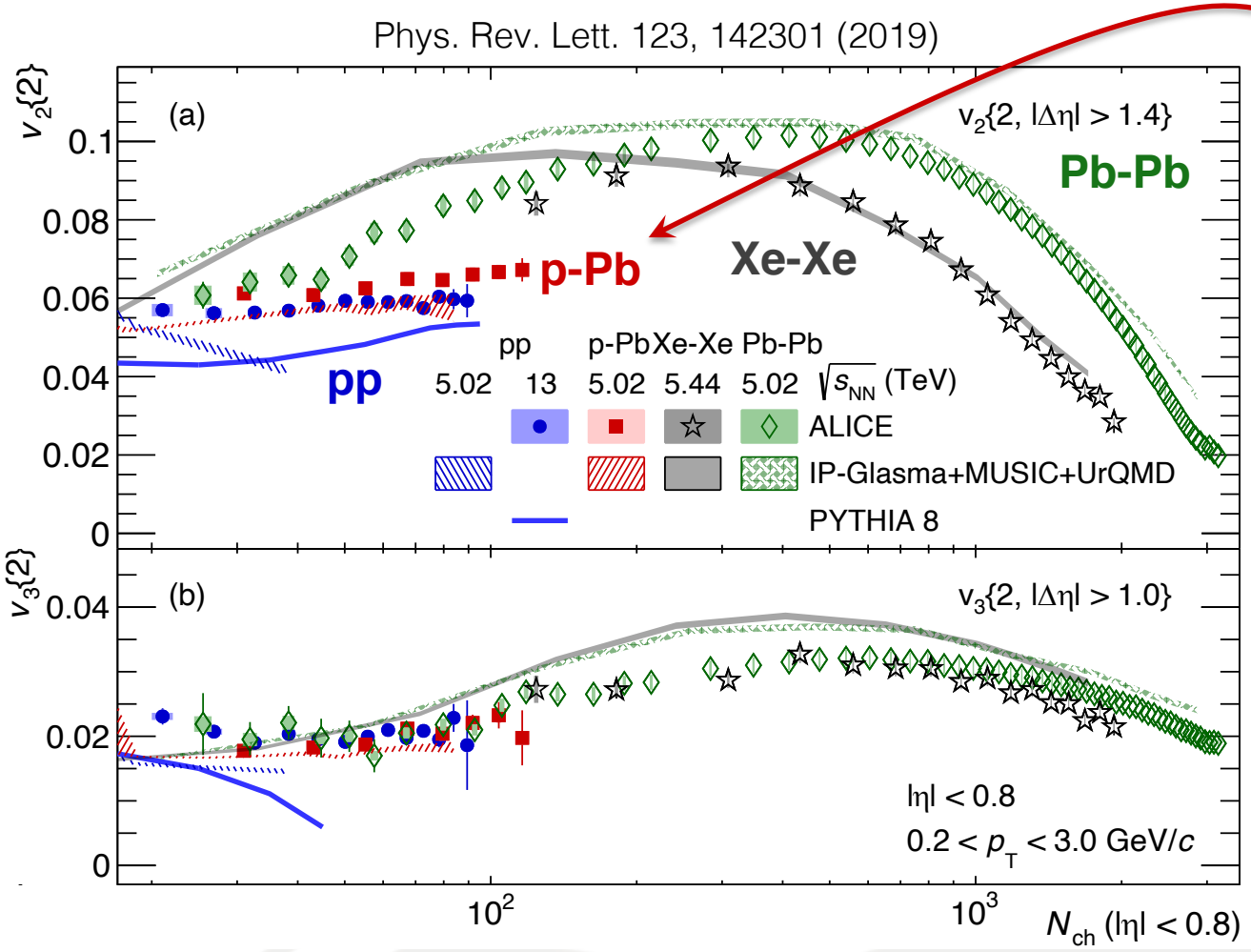
The onset of kinematic equilibration: small systems

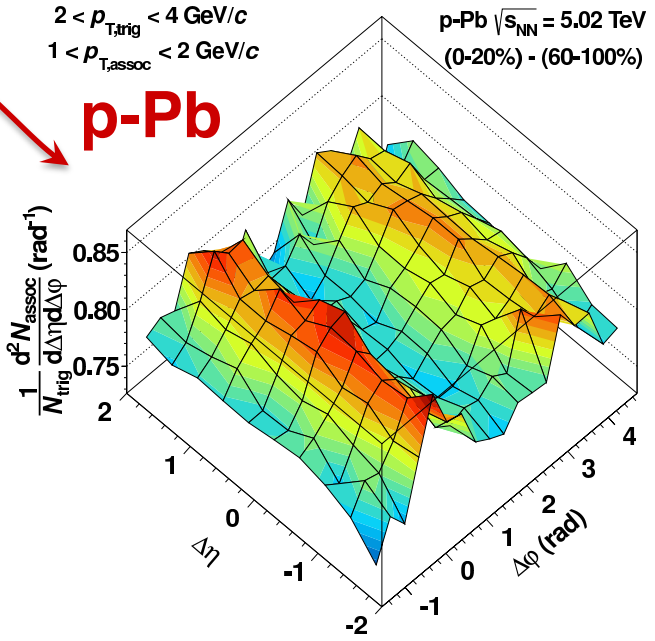


Phys. Lett. B 719 (2013) 29-41

- Pb-Pb → Xe-Xe → p-Pb → pp:
  - Flow-like features in smaller systems too

The onset of kinematic equilibration: small systems

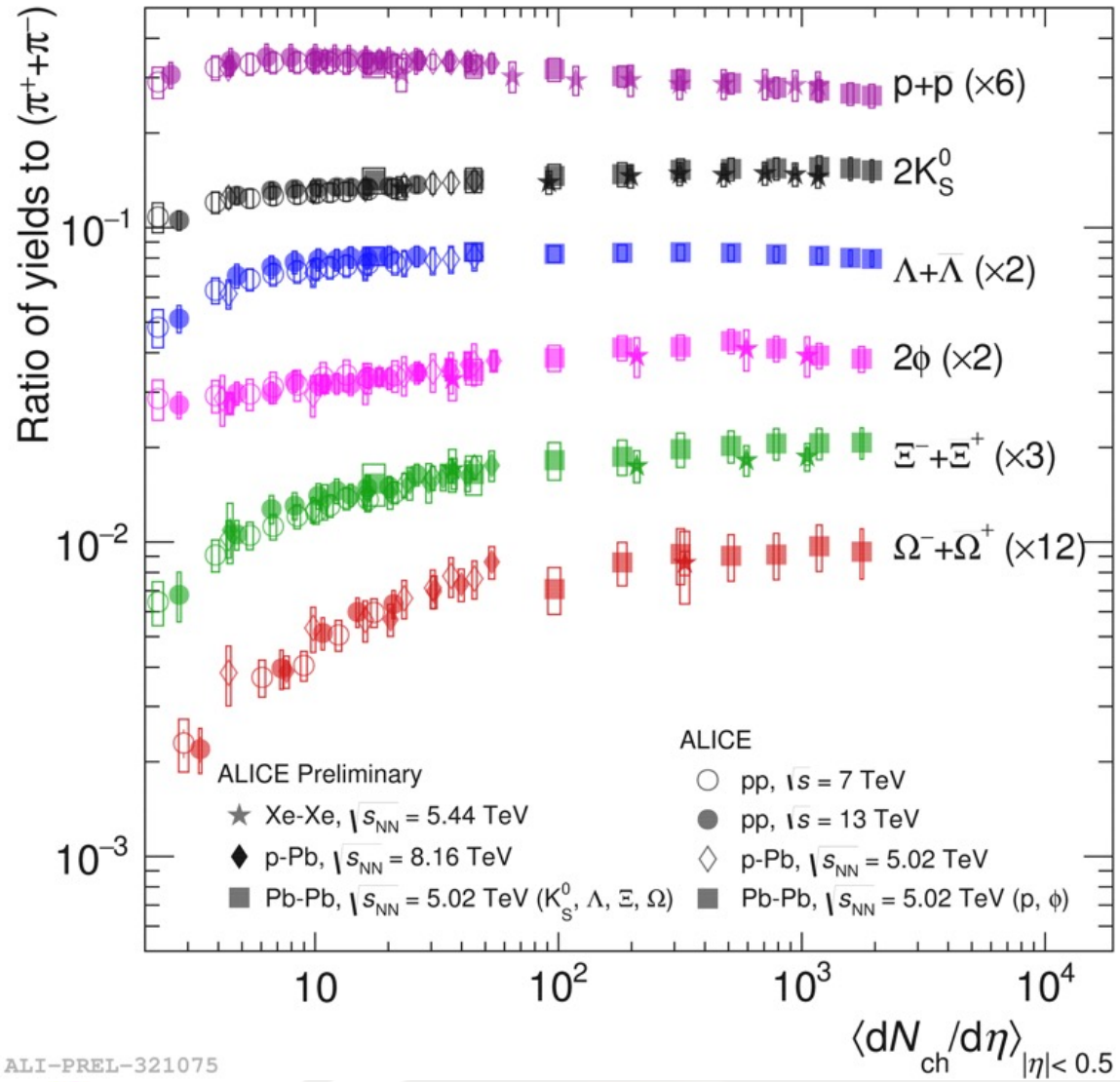




Phys. Lett. B 719 (2013) 29-41

- Pb-Pb → Xe-Xe → p-Pb → pp:
  - Flow-like features in smaller systems too
  - Due to hydrodynamics in heavy-ion paradigm
  - Due to string shoving: PYTHIA, etc
  - Complementarity remains theoretical challenge

Reaching chemical equilibration: from pp to Pb-Pb



s = 0

s = 1

s = 1

s = 0

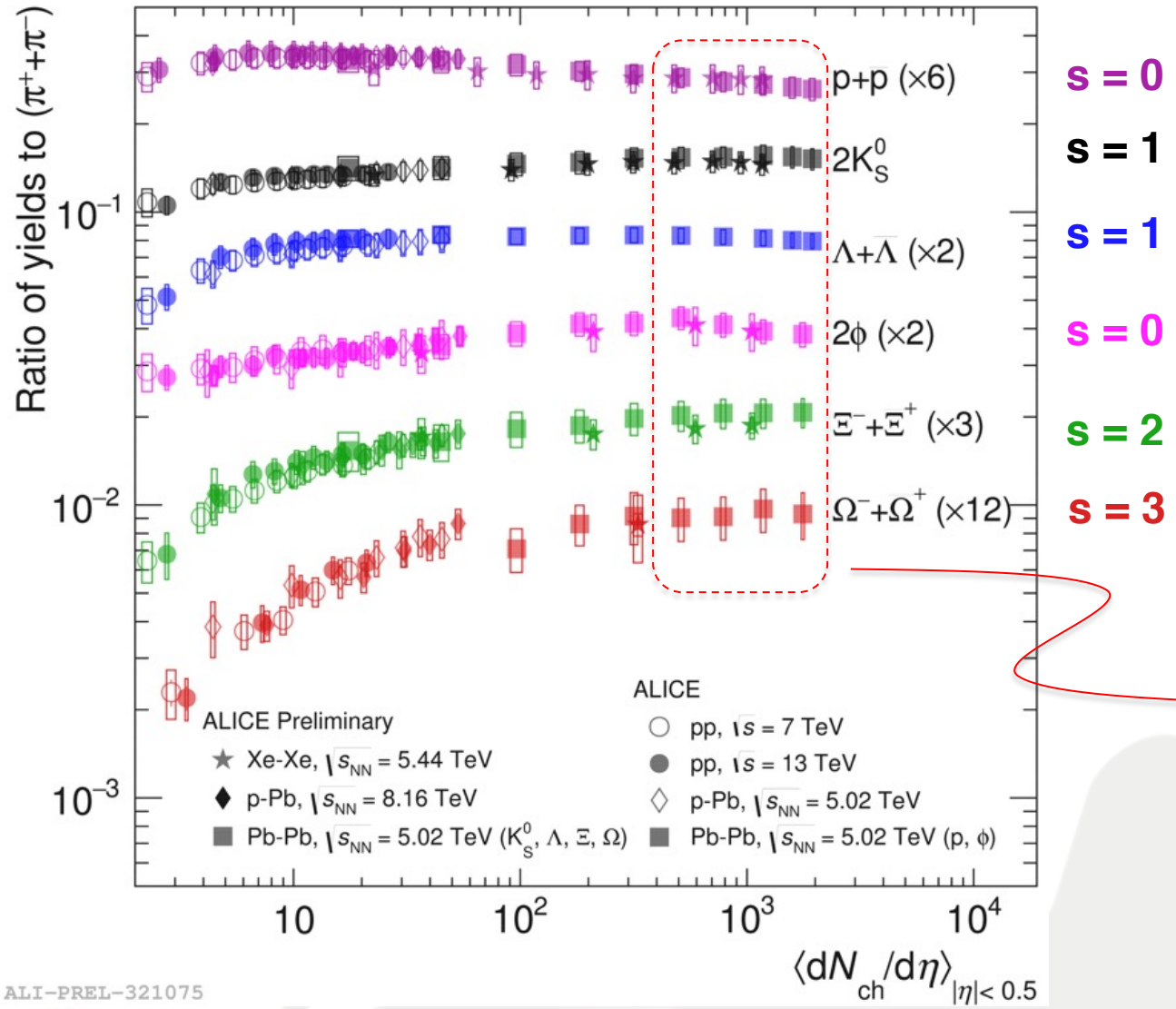
s = 2

s = 3

- From proton-proton to Pb-Pb: identified particle ratios asymptotically converge on values consistent with statistical hadronization models

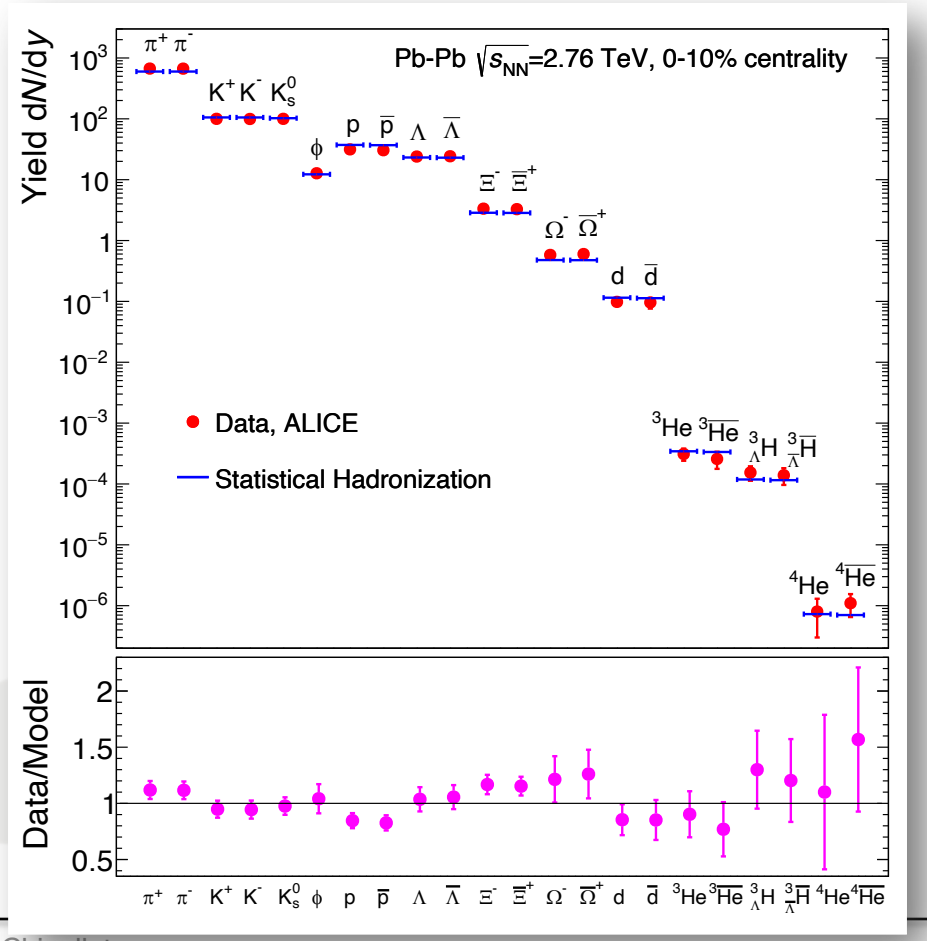
ALI-PREL-321075

Reaching chemical equilibration: from pp to Pb-Pb



ALI-PREL-321075

- From proton-proton to Pb-Pb: identified particle ratios asymptotically converge on values consistent with statistical hadronization models



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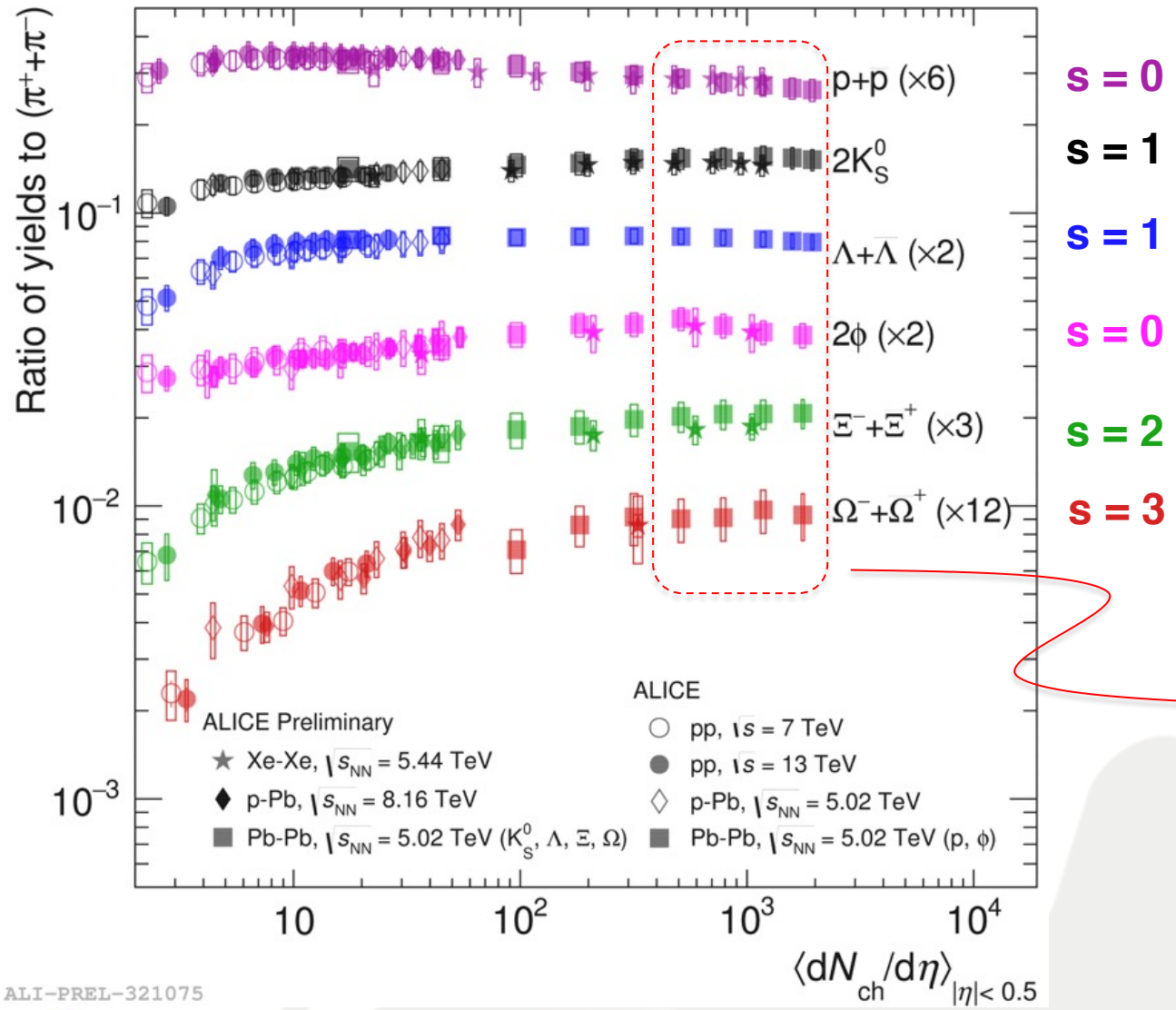

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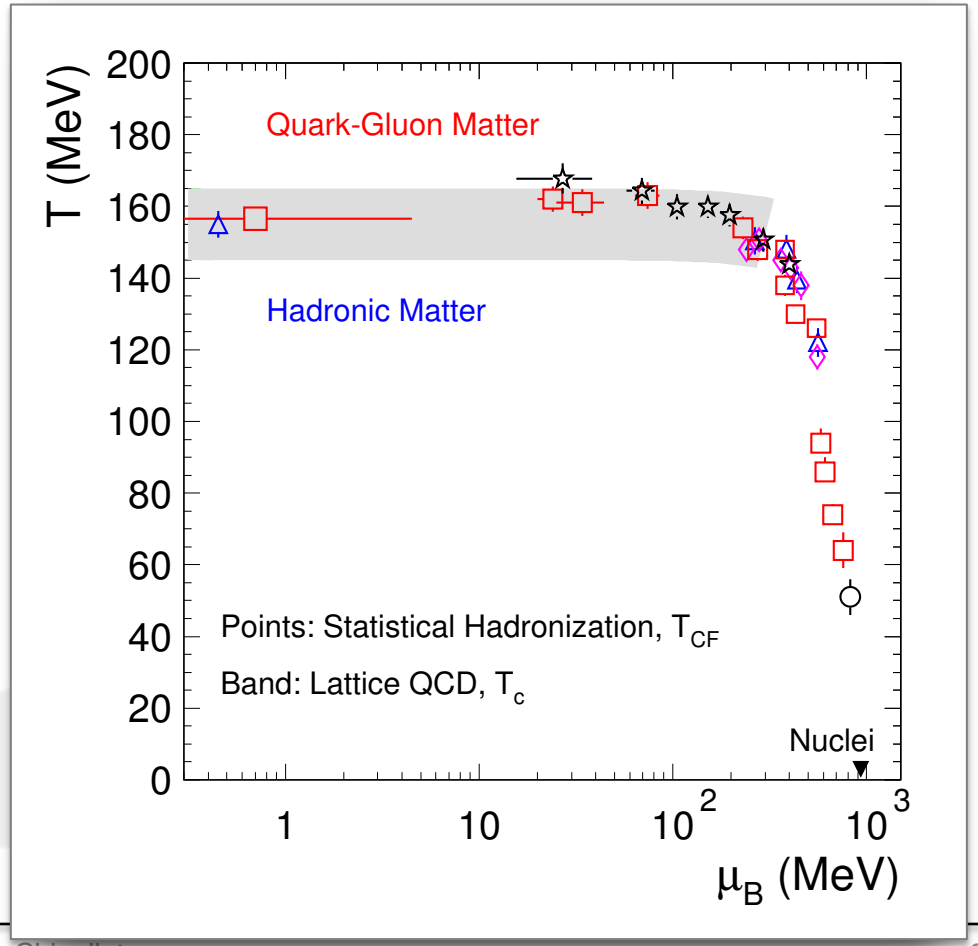
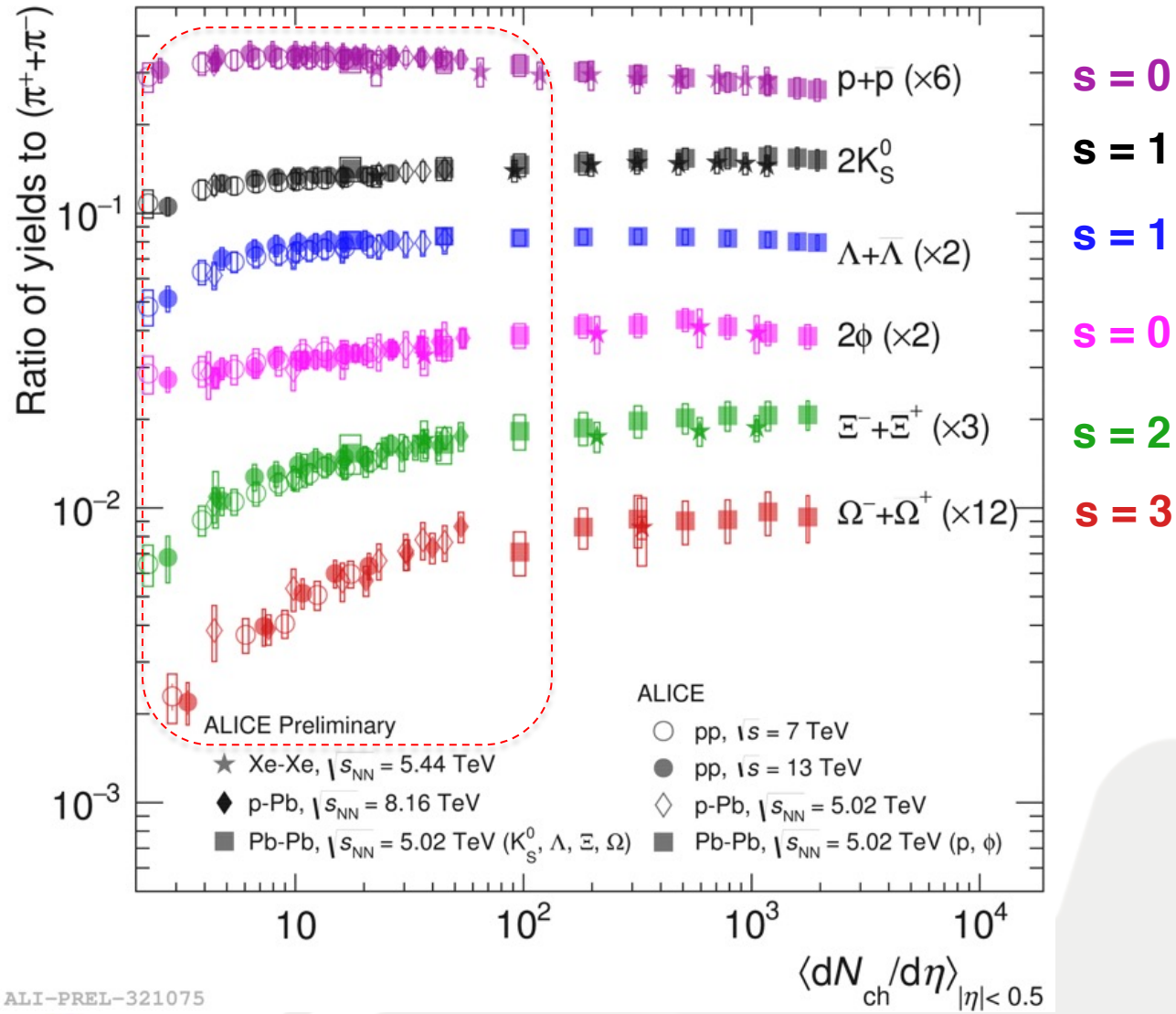


Nature 561, 321–330 (2018)

Reaching chemical equilibration: from pp to Pb-Pb

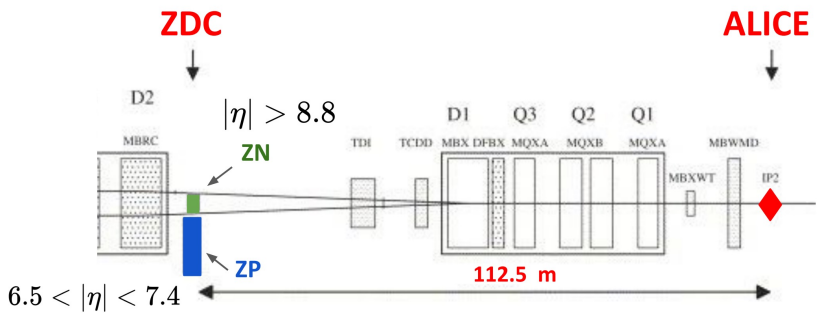


ALI-PREL-321075

- From proton-proton to Pb-Pb: identified particle ratios asymptotically converge on values consistent with statistical hadronization models
  - The onset: prompted new theoretical, experimental work!

- New efforts to understand mechanisms at play:
  - Transverse activity analysis
  - Spherocity-differential analysis
  - Effective energy analysis

Effective energy analysis in proton-proton collisions



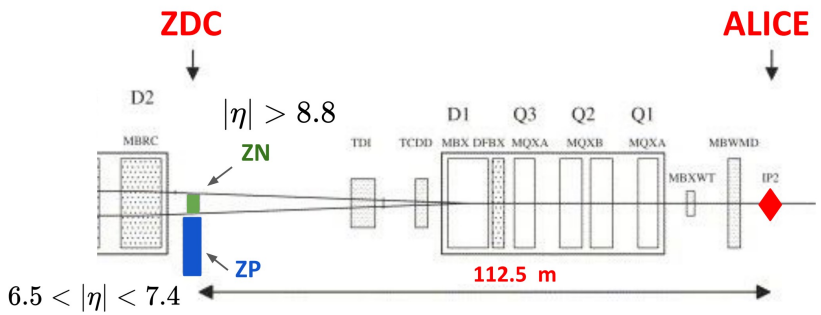
- measure energy available for initial state particle production E_{EFF} as:

$$E_{EFF} = \sqrt{s} - E_{forward}$$

with E_{EFF} measured with the Zero Degree Calorimeter (at $|\eta| > 8.0$)

- Determine if relative Ξ production depends on E_{EFF} in addition to depending on multiplicity
- Is strangeness production associated to the initial state or to the final state (multiplicity)?

Effective energy analysis in proton-proton collisions



- measure energy available for initial state particle production E_{EFF} as:

$$E_{EFF} = \sqrt{s} - E_{forward}$$

with E_{EFF} measured with the Zero Degree Calorimeter (at $|\eta| > 8.8$)

- Determine if relative Ξ production depends on E_{EFF} in addition to depending on multiplicity
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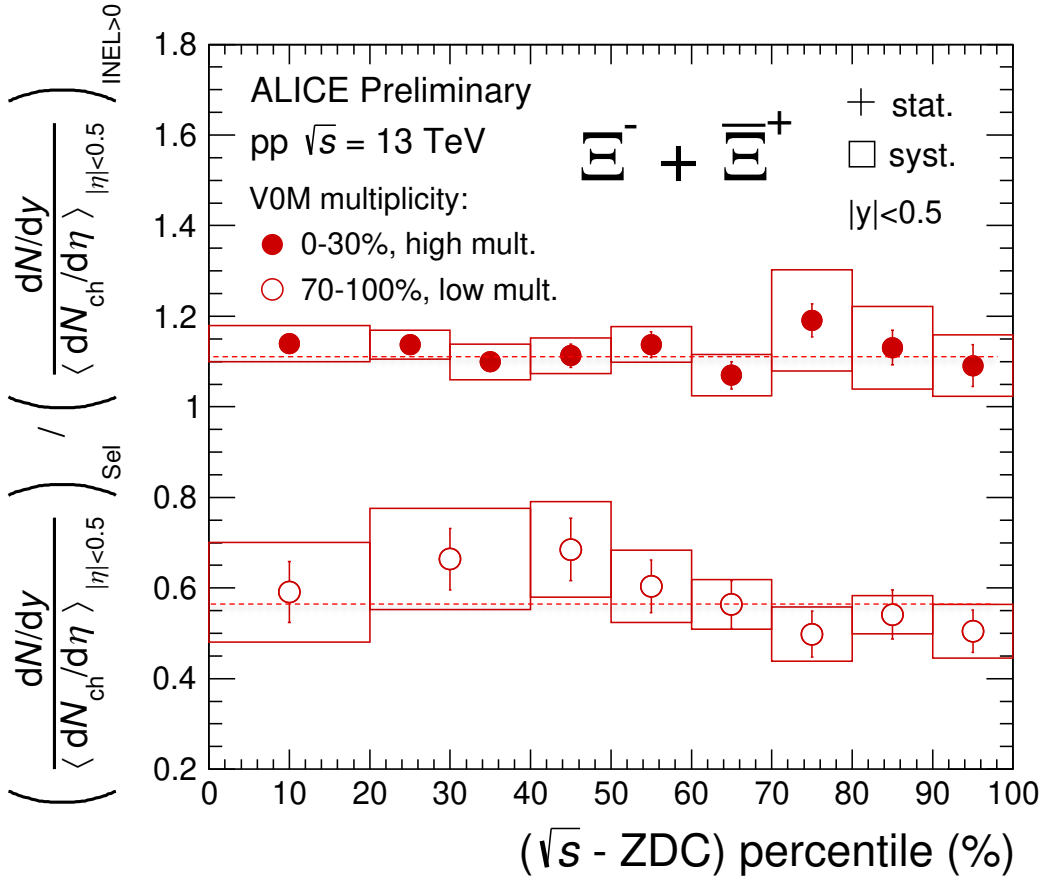
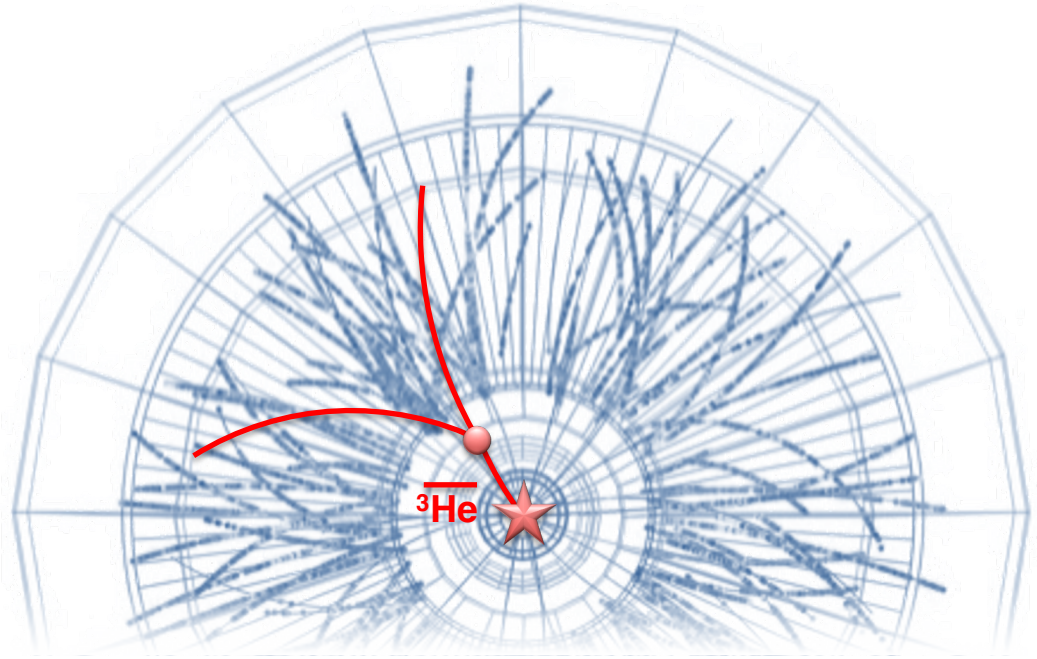
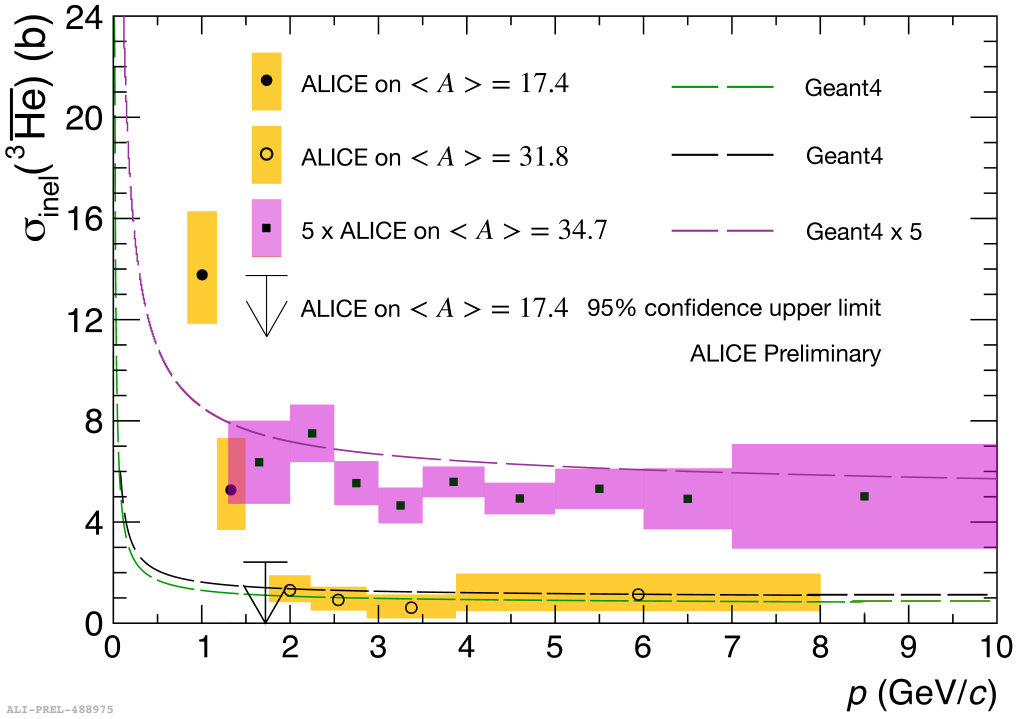


ALI-PREL-486025

Initial state is unimportant, strangeness production solely dependent on final-state charged-particle density!

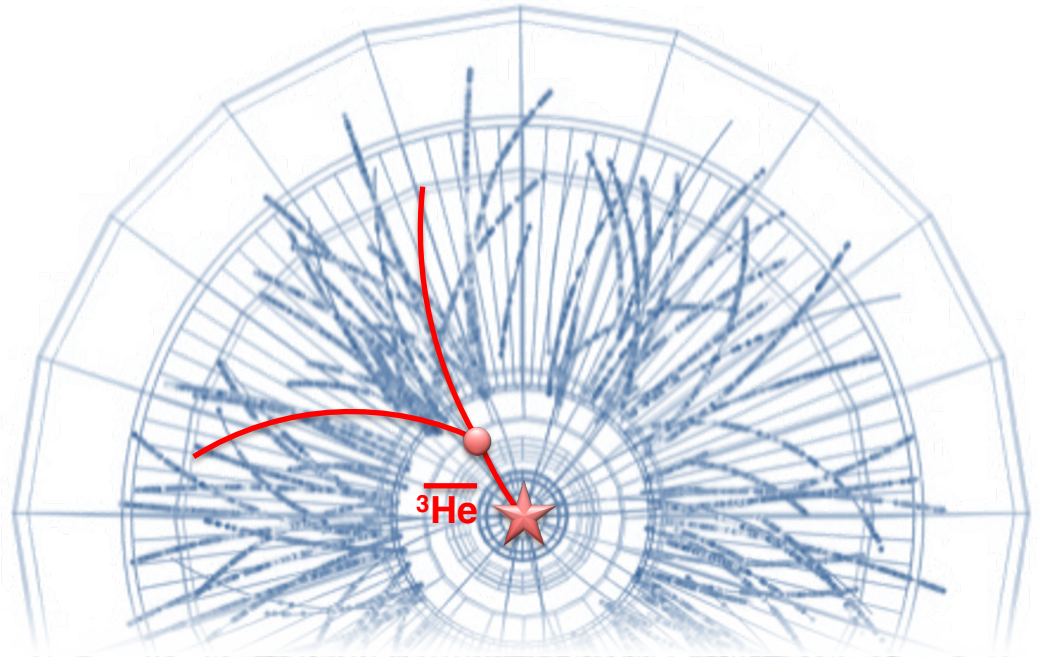
Antinuclei measurements with impact for astrophysics

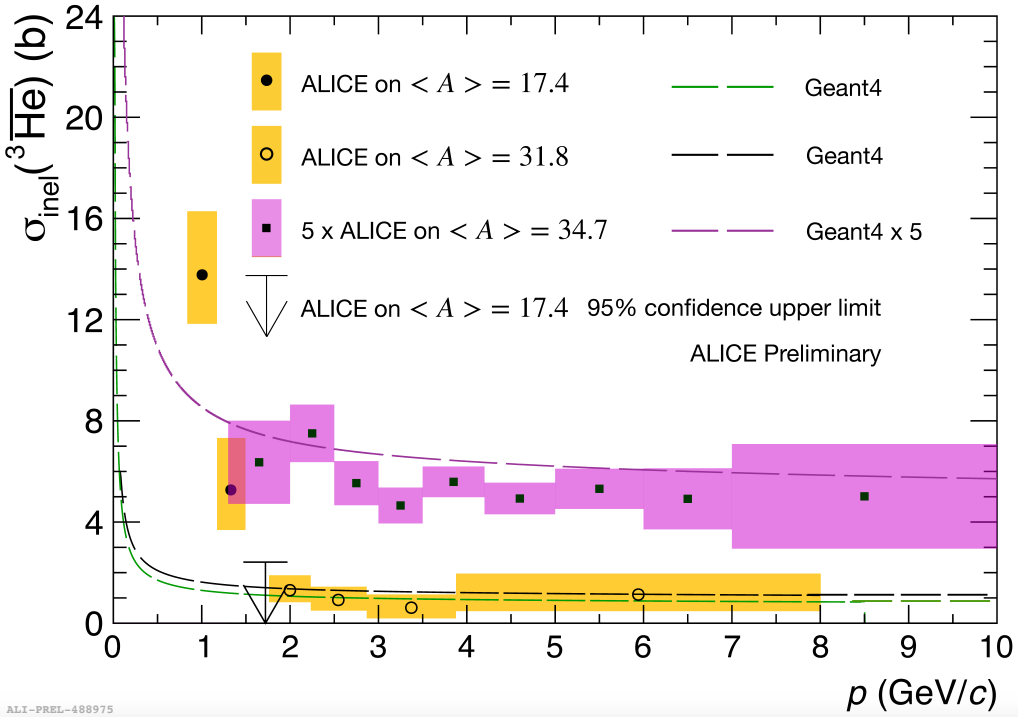




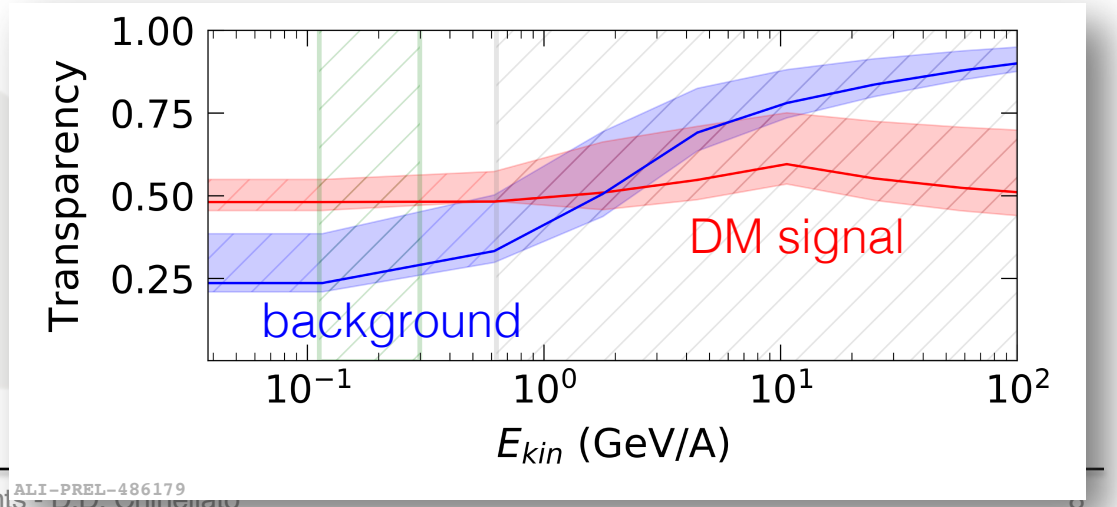
- Antihelium absorption cross sections measured as a function of momentum when interacting with the ALICE detector

Antinuclei measurements with impact for astrophysics

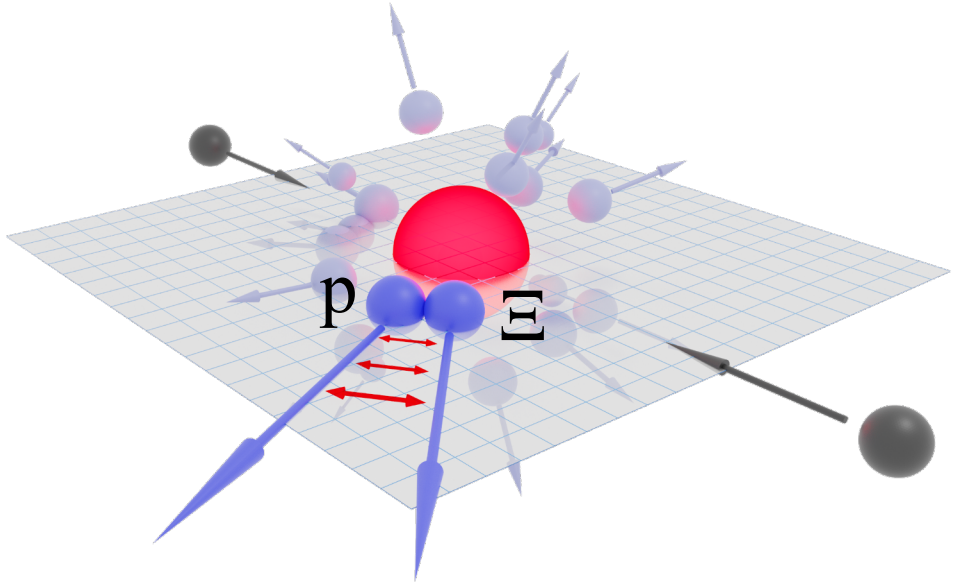




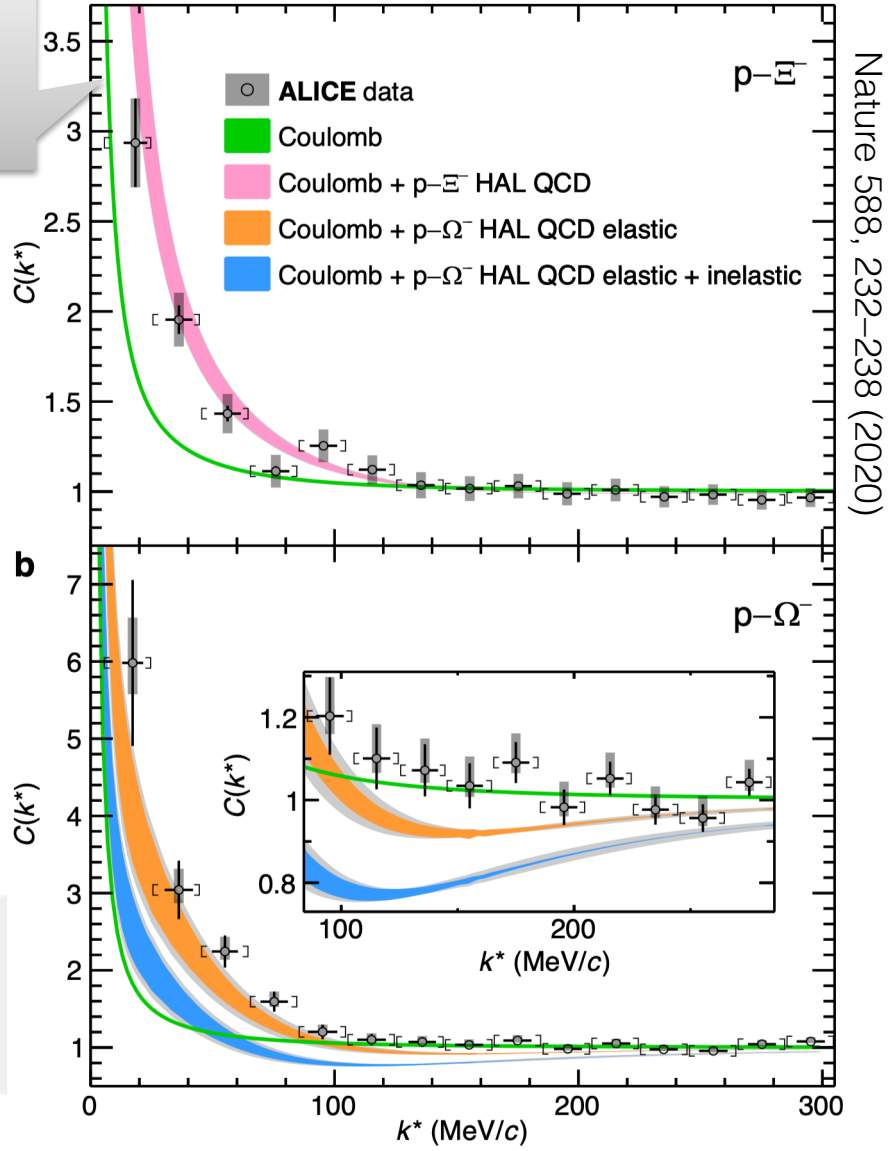
- Antihelium absorption cross sections measured as a function of momentum when interacting with the ALICE detector
- Important input for dark matter searches
  - Constrains the transparency of the galaxy to DM signal, background



Unprecedented precision in proton-hyperon interactions



Correlation peak at small momentum differences: signature of interaction

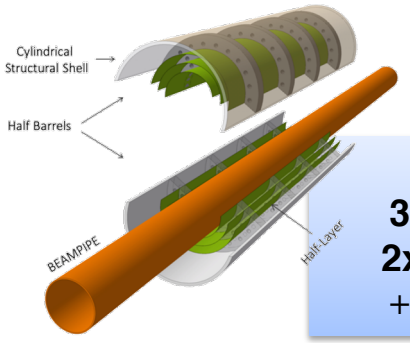


Nature 588, 232–238 (2020)

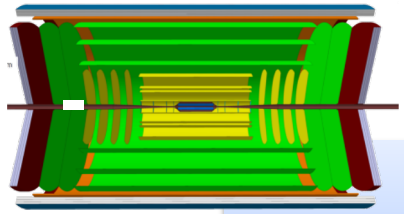
- Proton-hyperon strong interaction poorly known
- Measured in ALICE: momentum correlation of proton-hyperon pairs from a source of known size [1]
- Latest result [2]: precise measurement of attractive strong interaction for p-Ξ, p-Ω
  - Direct comparison to lattice QCD
  - p-Ξ important for neutron star EoS
- More to come in Run 3: d-Λ, p-Σ, Ω-Ω

ALICE in wonderland: the future

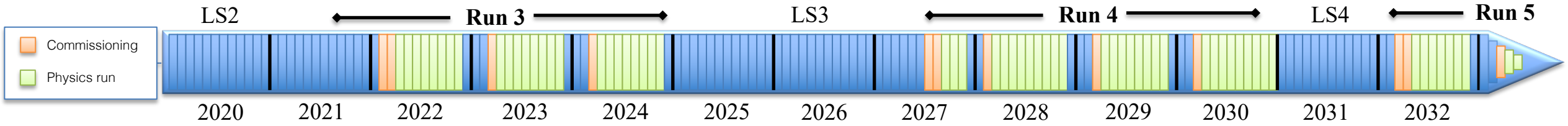
GEM-based TPC, ITS2, MFT
50x readout capability
3x tracking precision



ITS3, FoCal
3x tracking precision
2x efficiency at low p_T
+ forward γ detection



ALICE 3
Ultra-thin, entirely Si-based
50x readout capability



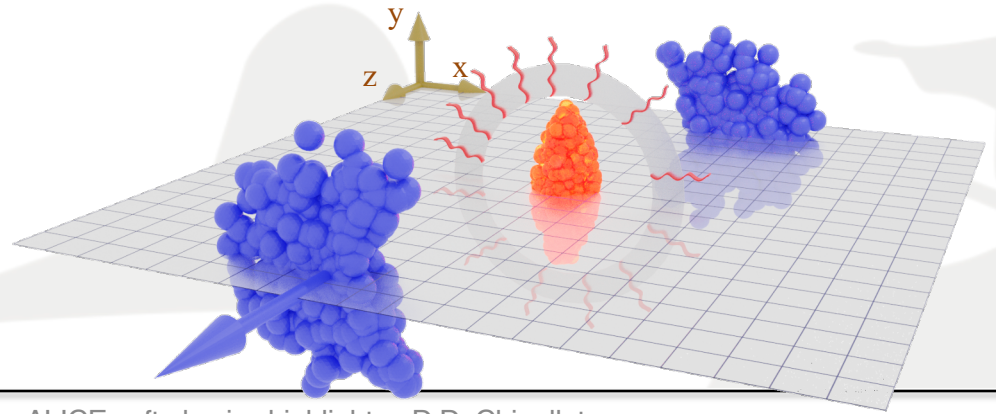
Hypernuclei production

High-multiplicity pp, p-Pb

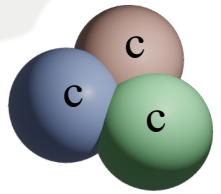
Low-p_T quarkonia

Hadronic interactions up to **Ω-Ω**

The 'glow' from the QGP:
Thermal radiation from the plasma via soft dileptons



Multi-charm baryons:
Key to understanding hadronization



Conclusions

Soft physics results from Run 1+2 show:

- A **kinematically** and **chemically** equilibrated state is formed in AA
- Fundamental advances in **QCD at high density** from pp, pA
- Further contributions to astrophysics, hadron structure, …

Underway and coming up:

- Major LS2 upgrade well on track
- Coming up: ITS3, FoCal in LS3
- Ambitious plans for Run 5+: the next generation

Questions? Please ask: daviddc@ifi.unicamp.br

Thank you!