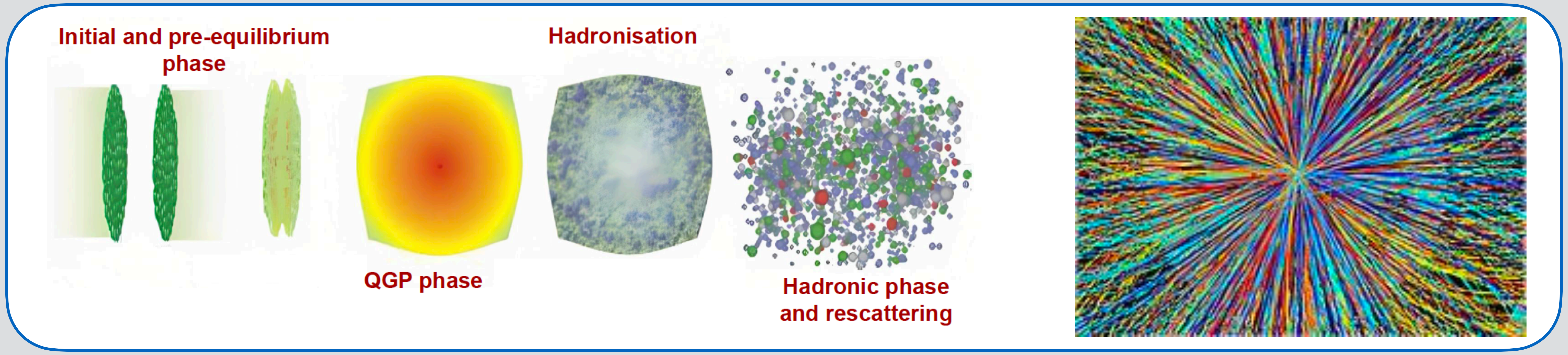
# ALICE

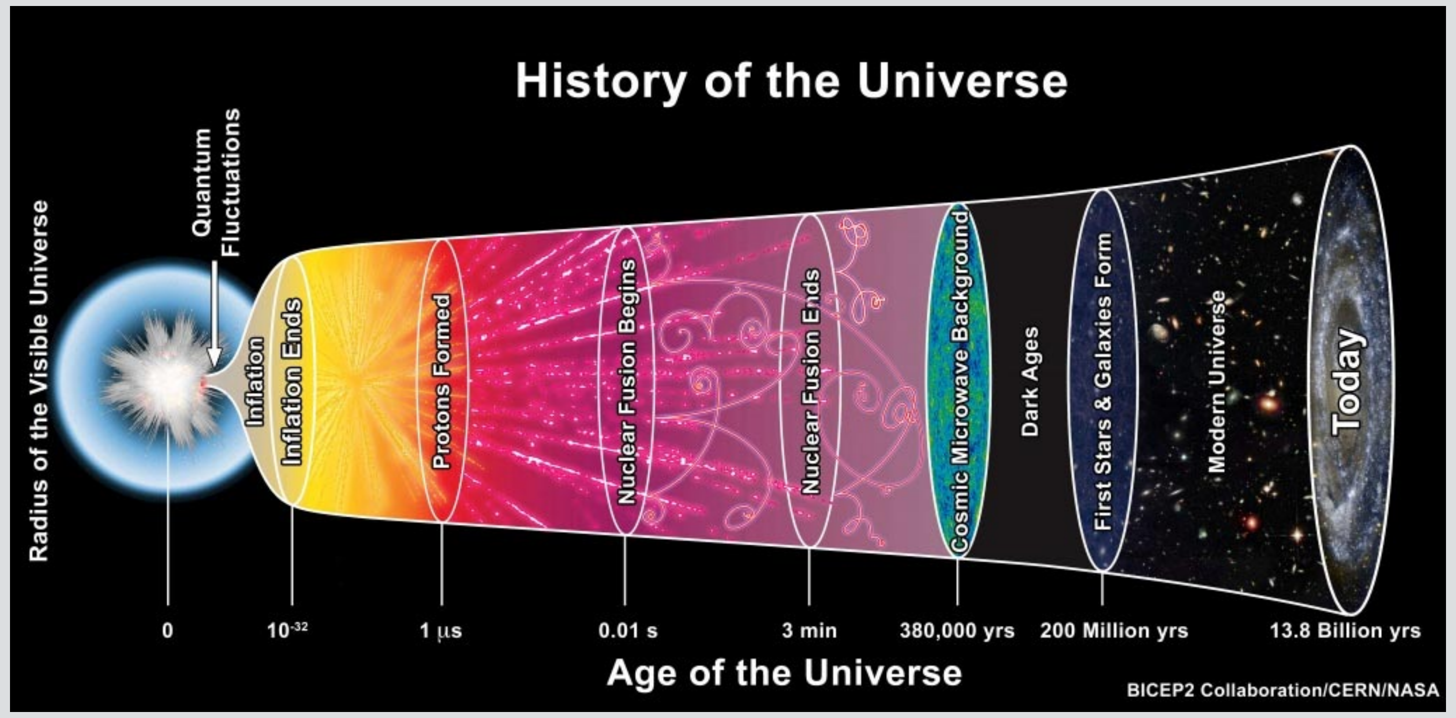
## in The Netherlands


ALICE

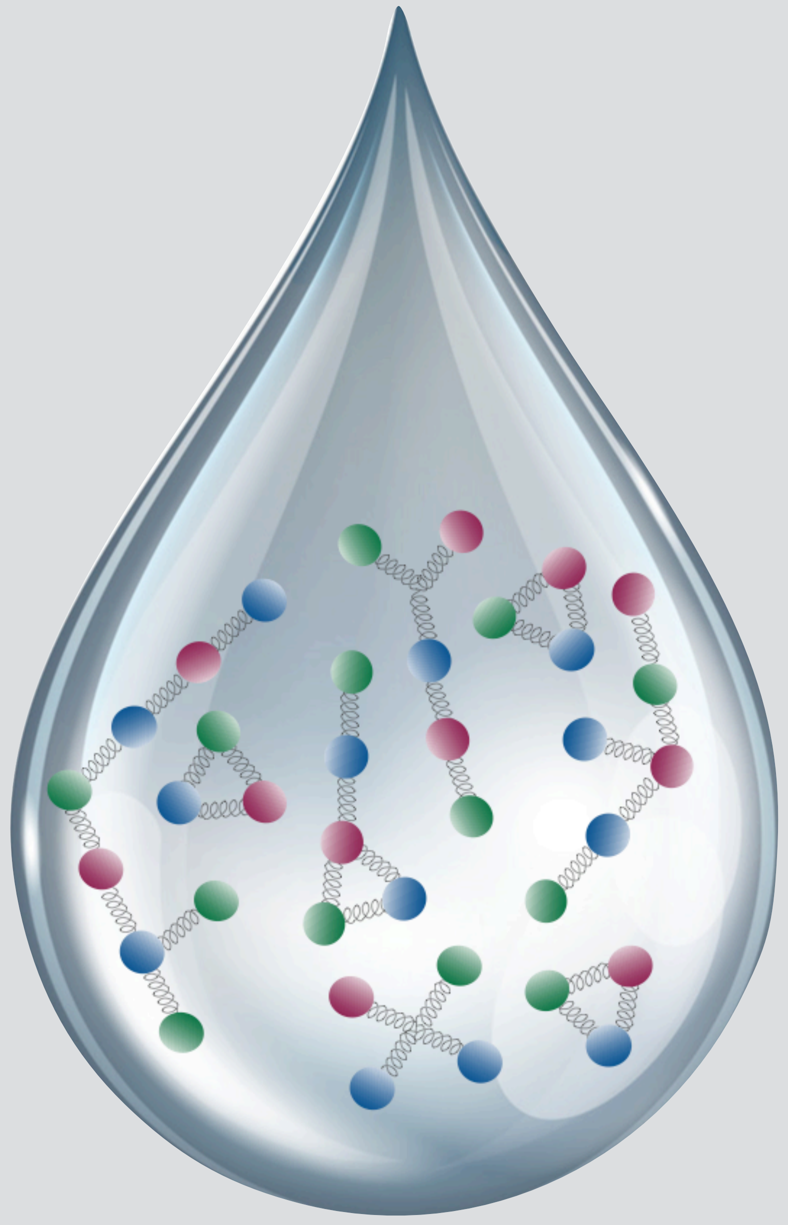
Nikhef

# The ALICE Program



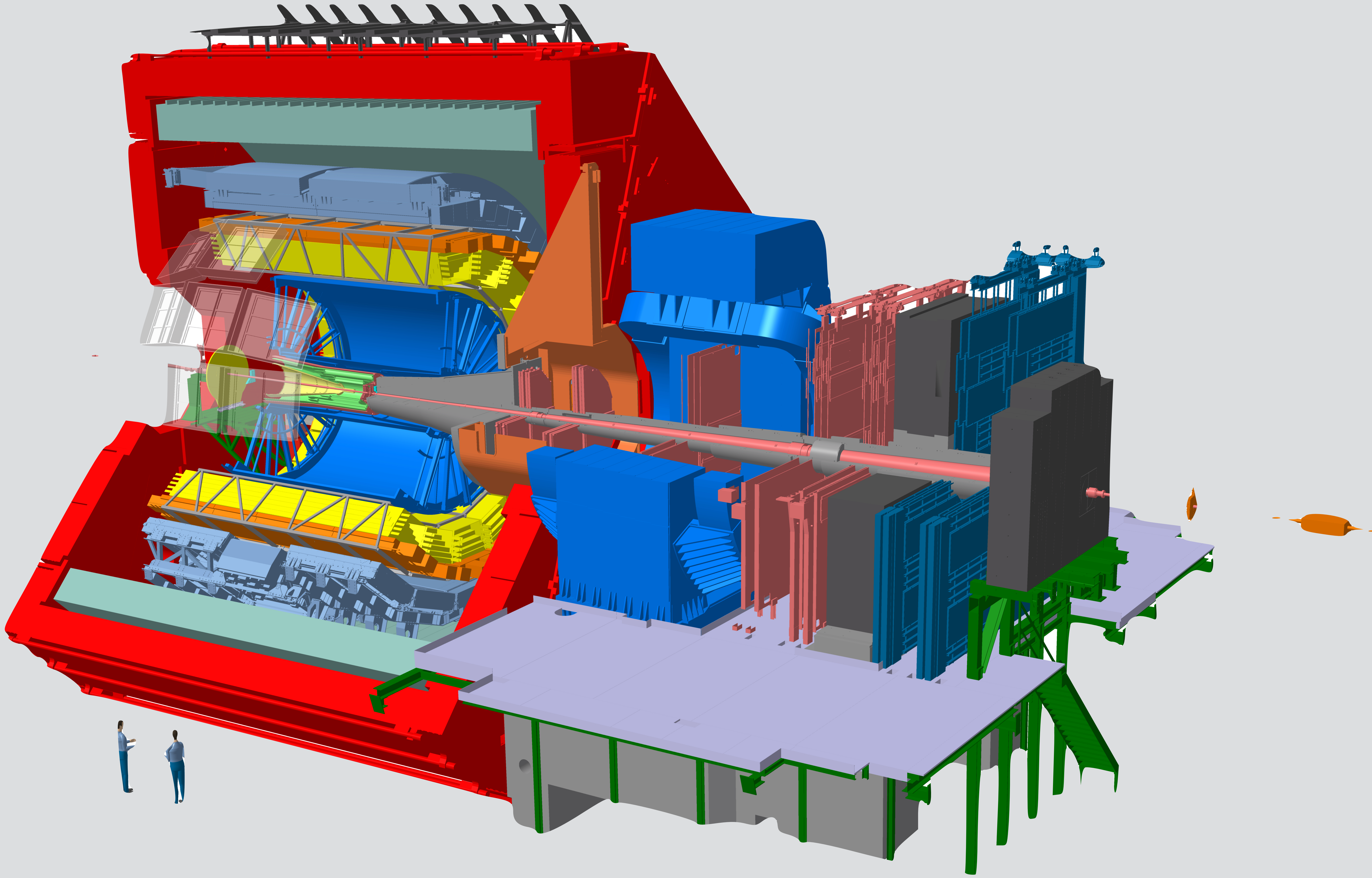

- **What happens to matter when you heat and compress matter to extreme magnitudes which existed in the primordial universe?**
  - Phase transition to a **quark-gluon-plasma**
    - **QCD in the regime of extreme matter with emergent phenomena**
    - ➡ Unique conditions to study QCD
      - Temperature ≈ $10^{12}$ K – $10^{5}$ times larger than the core of the sun
      - Magnetic fields ≈ $10^{18}$ G – $10^{10}$ times larger than in the lab
      - Initial angular momentum of order J = $10^{7}$, of which a fraction is transferred to the interaction region
  - Properties of the quark-gluon-plasma are still not well understood
    - ➡ Theoretically challenging (lQCD, AdS/CFT, pQCD, Hydro, ..)
  - Experimentally studied with high-energy nuclear collisions at the LHC: **the ALICE experiment**



Picture: Umut Gursoy

# The ALICE Program

- **Dutch ALICE group (Nikhef+UU) is participating in the ALICE experiment at the LHC as a leading group**
  - ➡ Leading positions in ALICE
    - ➡ Very productive in data analysis using different probes of the quark-gluon plasma:
      - our group produced the most cited publications
    - ➡ Significant and visible contribution to the detector hardware



The ALICE Collaboration: 40 countries, 163 institutes, ~1900 members

# The Dutch ALICE Group

ALICE spokesperson

Scientific Staff

Support Staff

PhD and Postdocs

- **External funding (PI and/or co-PI)**
  - ➡ NWO VENI & VICI grant
  - ➡ NWO M1 grant
  - ➡ NWO-ENW XL grant: FASTER (co-PI)
  - ➡ NWO-ENW XL grant: Probing the phase diagram of QCD (co-PI)
  - ➡ NWA-ORC grant: Emergence at all scales

# 2025 Breakthrough Prize

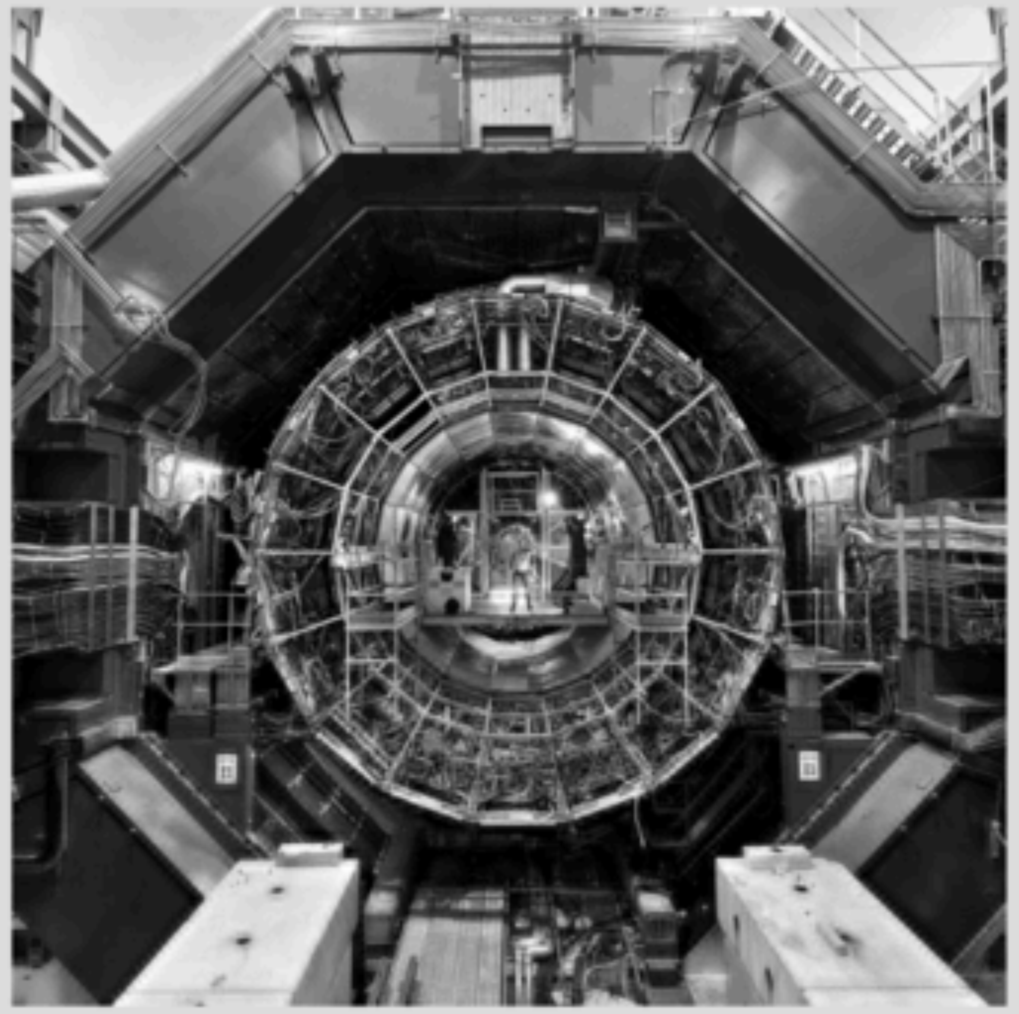
## ALICE Collaboration

2025 Breakthrough Prize in Fundamental Physics

For detailed measurements of Higgs boson properties confirming the symmetry-breaking mechanism of mass generation, the discovery of new strongly interacting particles, the study of rare processes and matter-antimatter asymmetry, and the exploration of nature at the shortest distances and most extreme conditions at CERN's Large Hadron Collider.

Marco van Leeuwen (Nikhef, spokesperson 2023 to 2025) accepted the prize on behalf of the collaboration. The $500,000 (of the $3 million prize) allocated to ALICE was donated to the CERN & Society Foundation for grants to doctoral students from member institutes to spend research time at CERN.

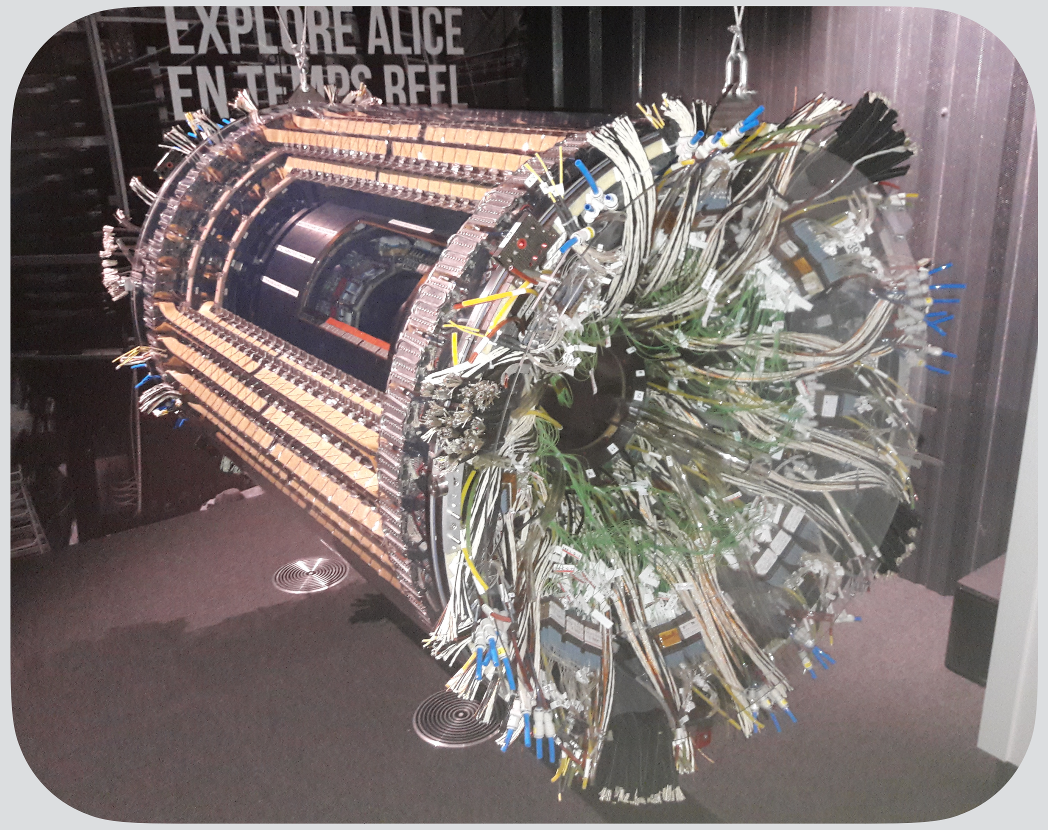
Names of the ALICE prizewinners are listed below.



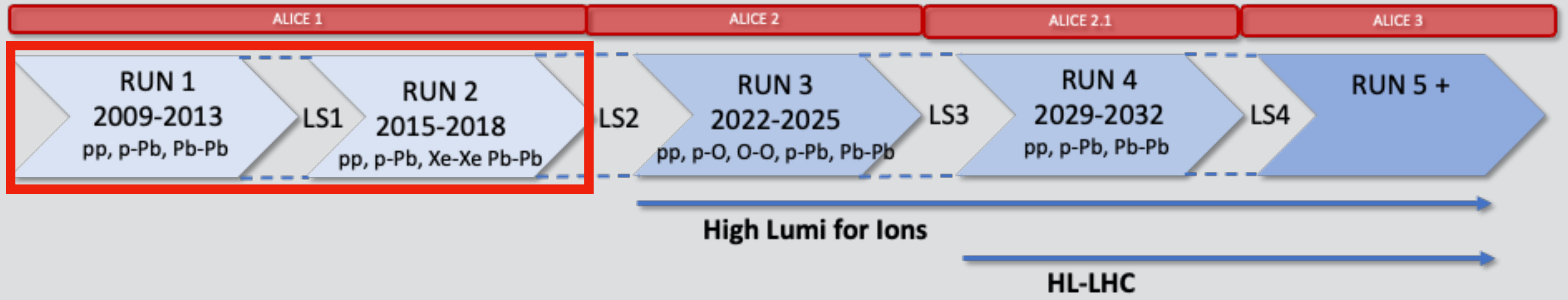
Prize for LHC experiments; the ALICE Collaboration: 40 countries, 163 institutes, ~1900 members

# ITS 1 (2010-2018)

- The ITS 1 consisted of 6 layer of silicon detectors
  - ➡ Key for almost every physics analysis in ALICE
  - ➡ Nikhef led the construction of the outer two layers of the ITS (silicon strip detectors) and assembled half of the ITS
  - ➡ This detector worked almost perfectly for the last decade, due to Nikhef's continuous support for its operation




Now a museum piece

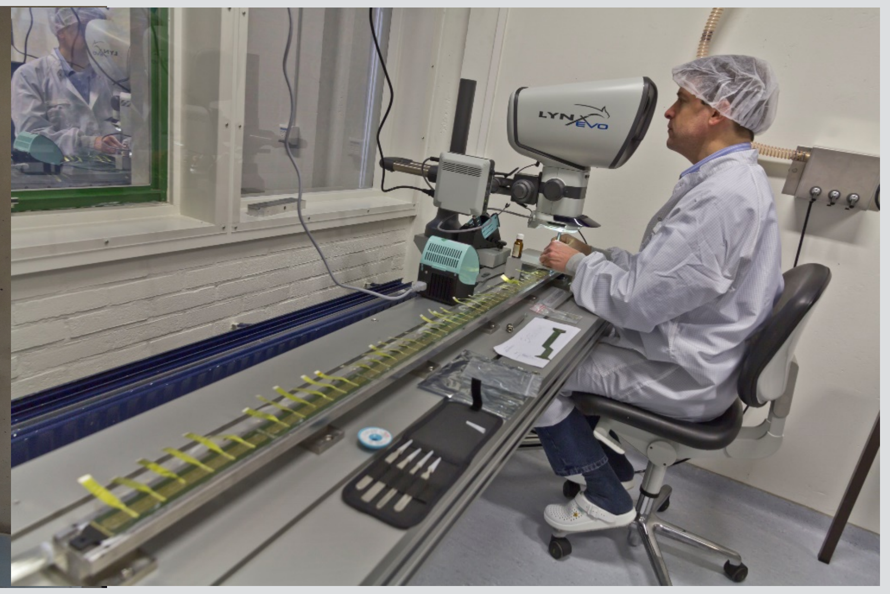


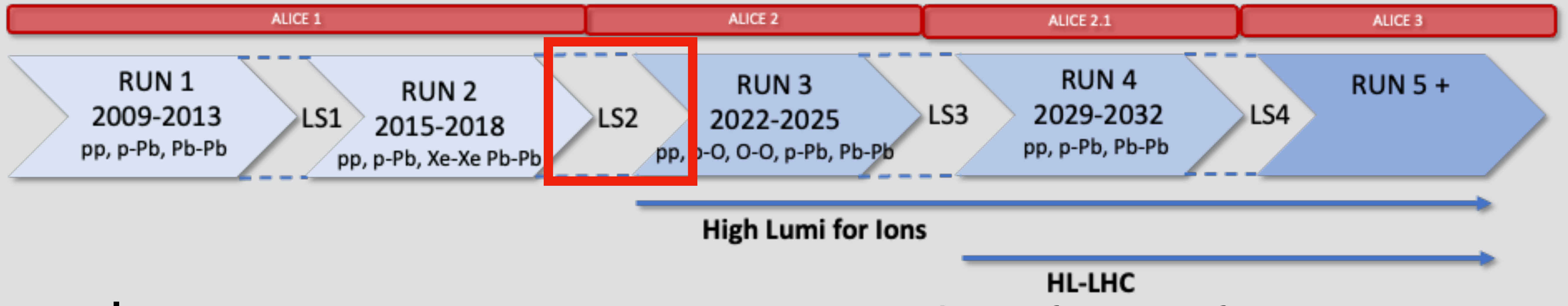

# ITS 2 (MAPS ALPIDE, 2021-2032)

Change of technology: new tracker based on monolithic CMOS sensors!

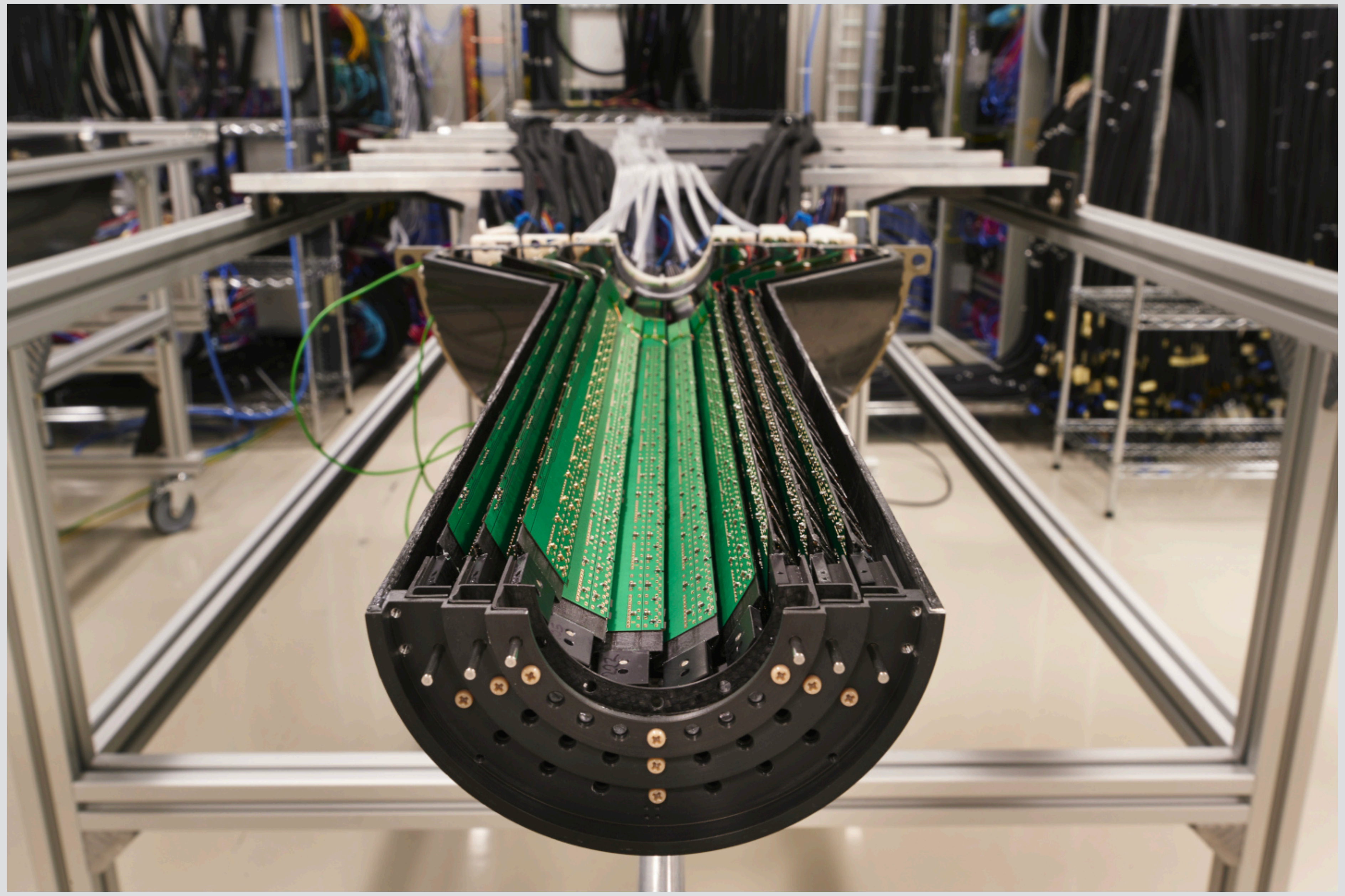
- Thin sensor with on-chip digital readout (~10m²)





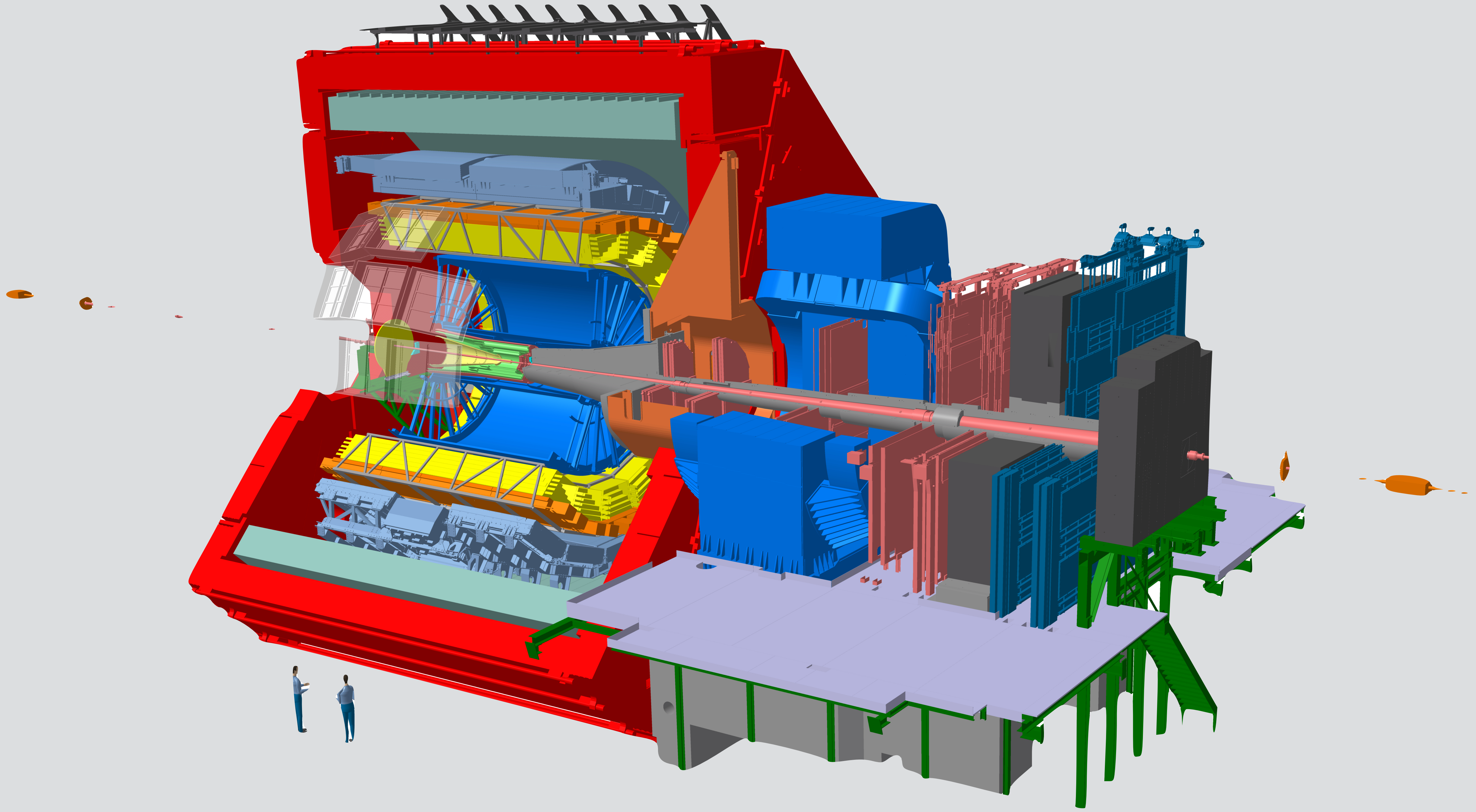


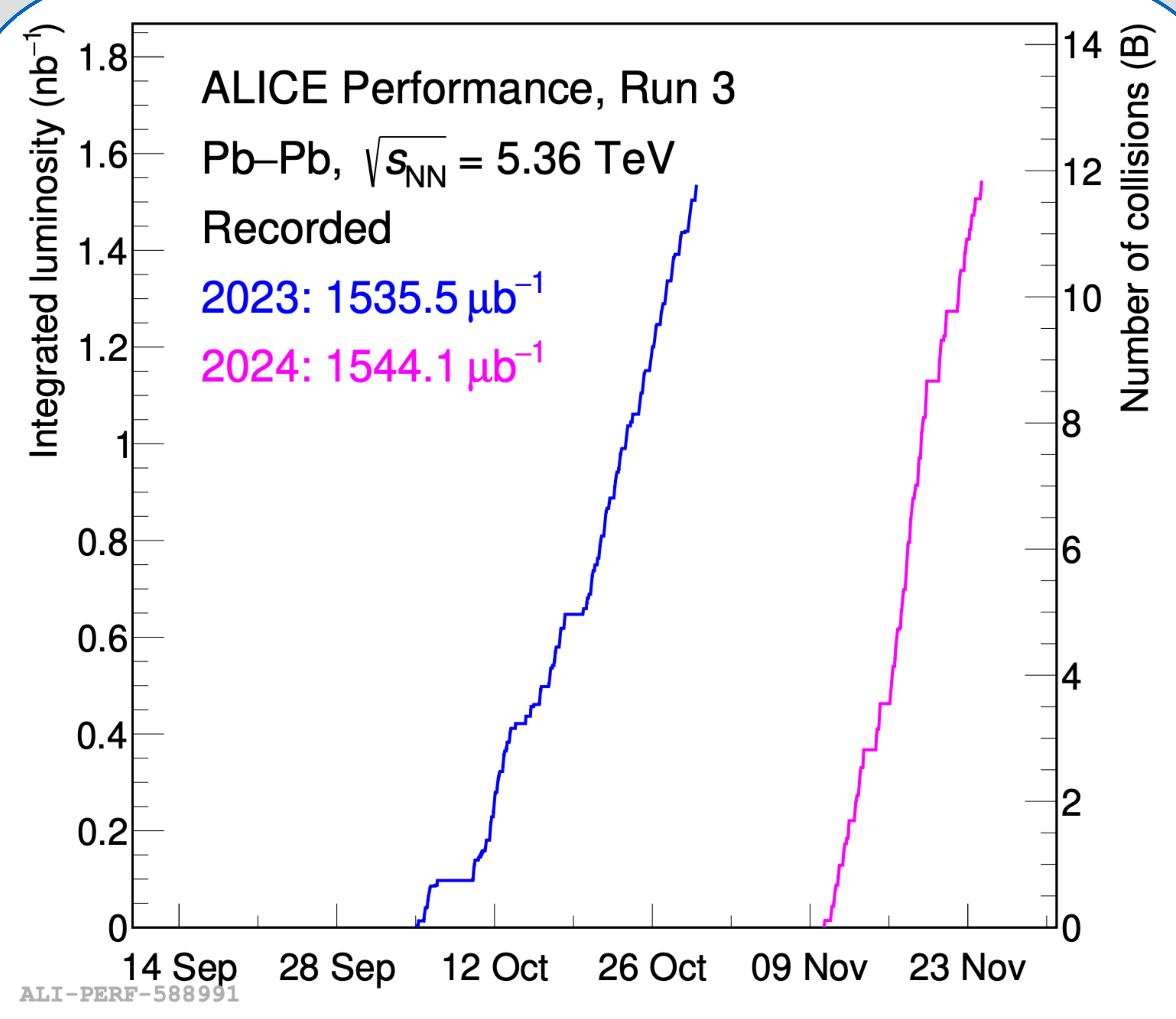

- Improve impact parameter resolution by a factor of 3
  - ➡ Get closer to the IP: first layer 39 -> 22 mm
  - ➡ Reduce material budget: 1.14% -> 0.3% $X_0$ inner layers
  - ➡ Increase pixel density 50 x 425 µm -> 20 x 20 µm
- High standalone tracking efficiency and $p_T$ resolution
  - ➡ Increase granularity 6 -> 7 layers with reduced pixel size
- Fast PbPb (and pp) readout
  - ➡ Instantaneous luminosity: $6 \times 10^{27}$ cm$^{-2}$s$^{-1}$ gives hadronic interaction rate of 50kHz

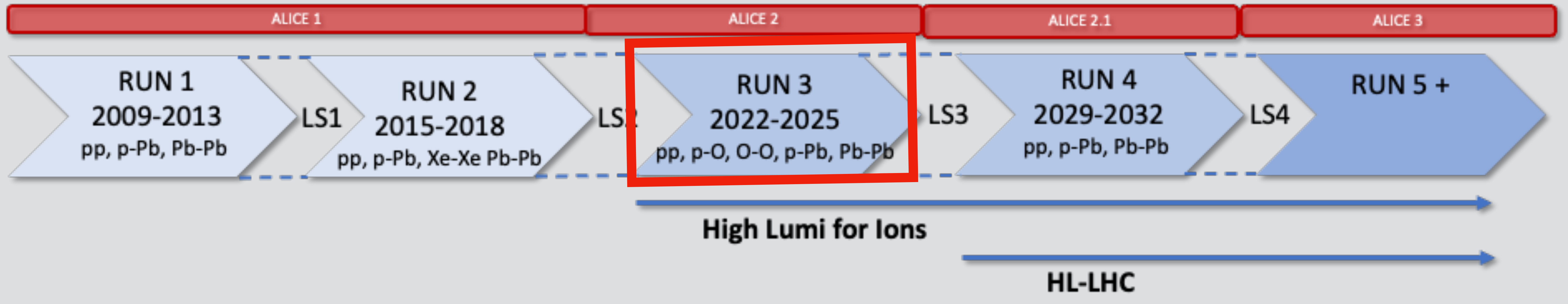


*J. Phys. G: Nucl. Part. Phys.* **41** 087002 (2014)

# ALICE Run 3



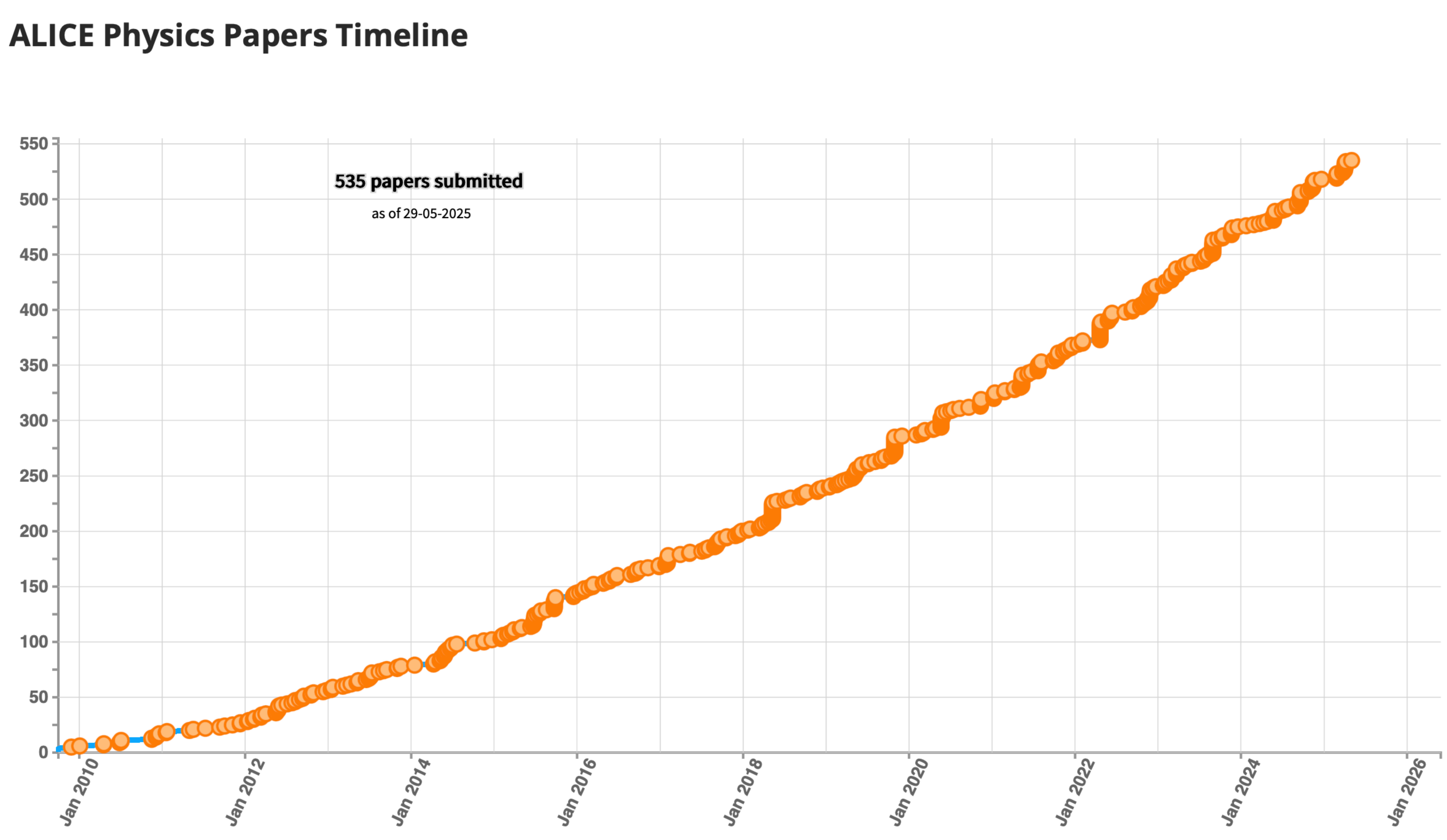


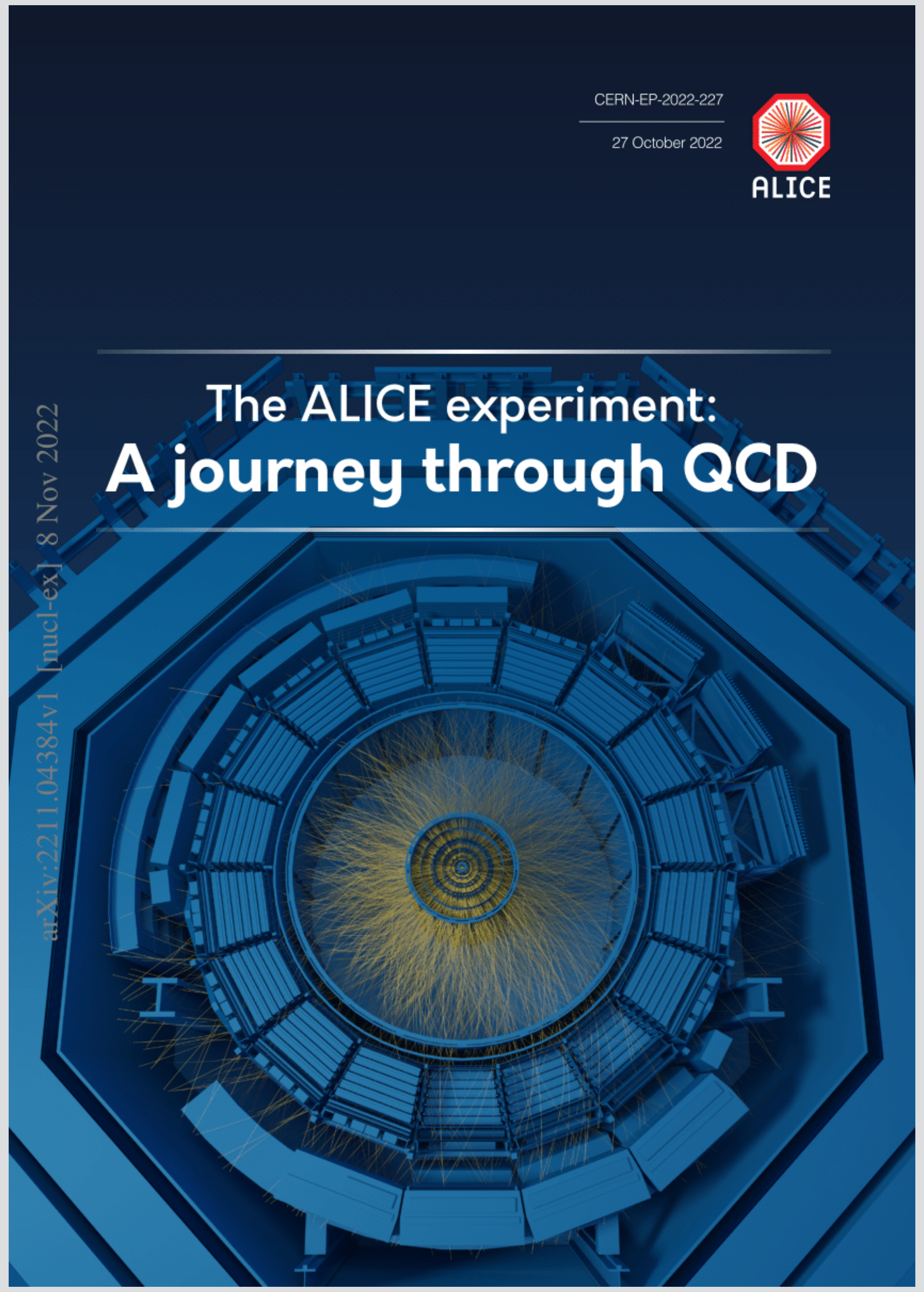




## Data collection very successful!

- Already collected about ~30 times more collisions than in Run 1+2. End of run run 3 projected a factor 50 increase in recorded collisions

# ALICE Physics Papers




## Summary paper Run 1&2

- Review of key ALICE physics results from run 1&2 with big involvement and contribution from Nikhef ALICE group

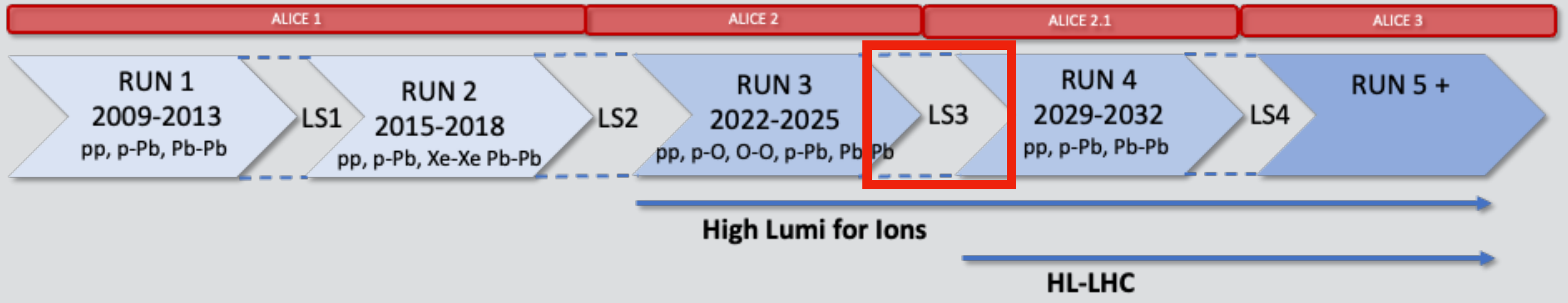
# ITS 3 (MAPS, 2025-2032)

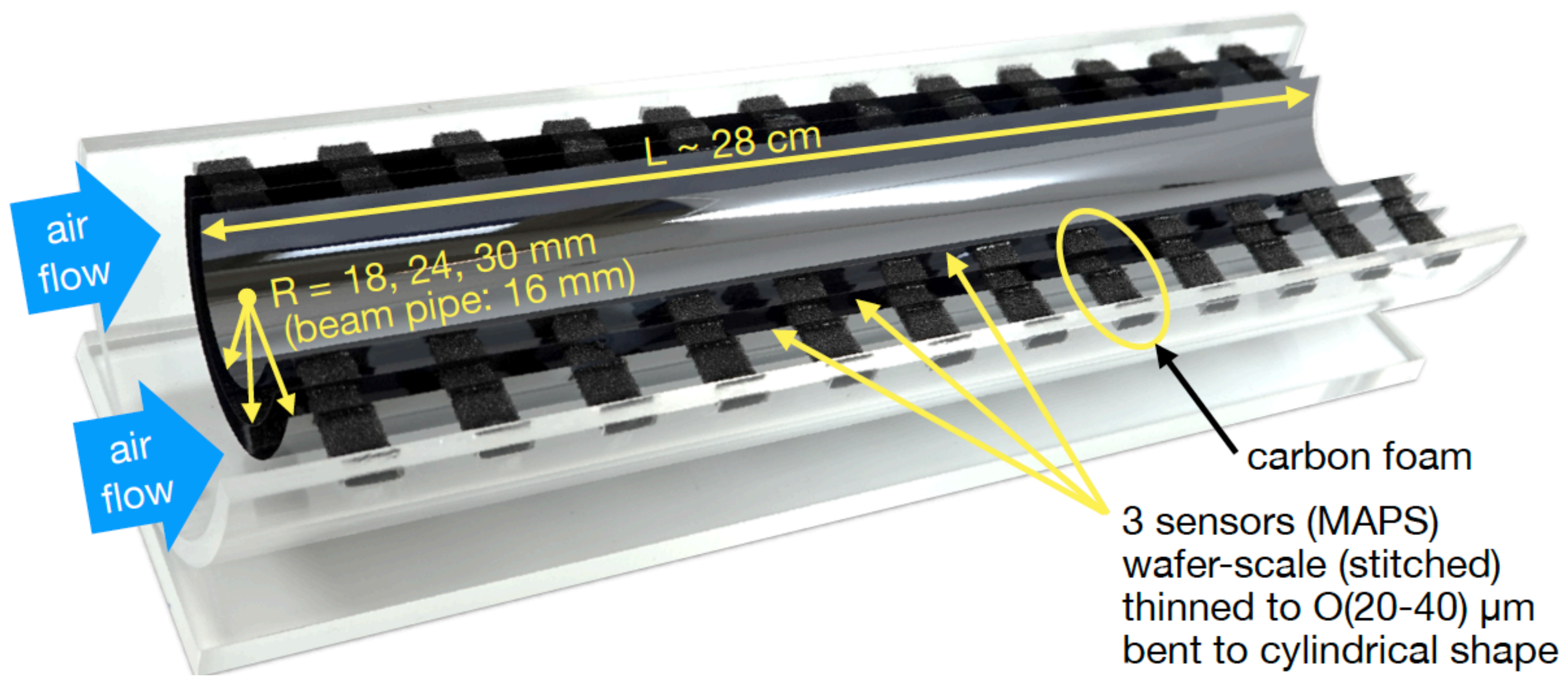
Chip size is traditionally limited by CMOS manufacturing

- New option: stitching and bending

- Can we get thinner?
  - ➡ Reduce material budget:
  - ➡ Can we get closer?
    - ➡ Improved tracking precision and efficiency at low $p_T$

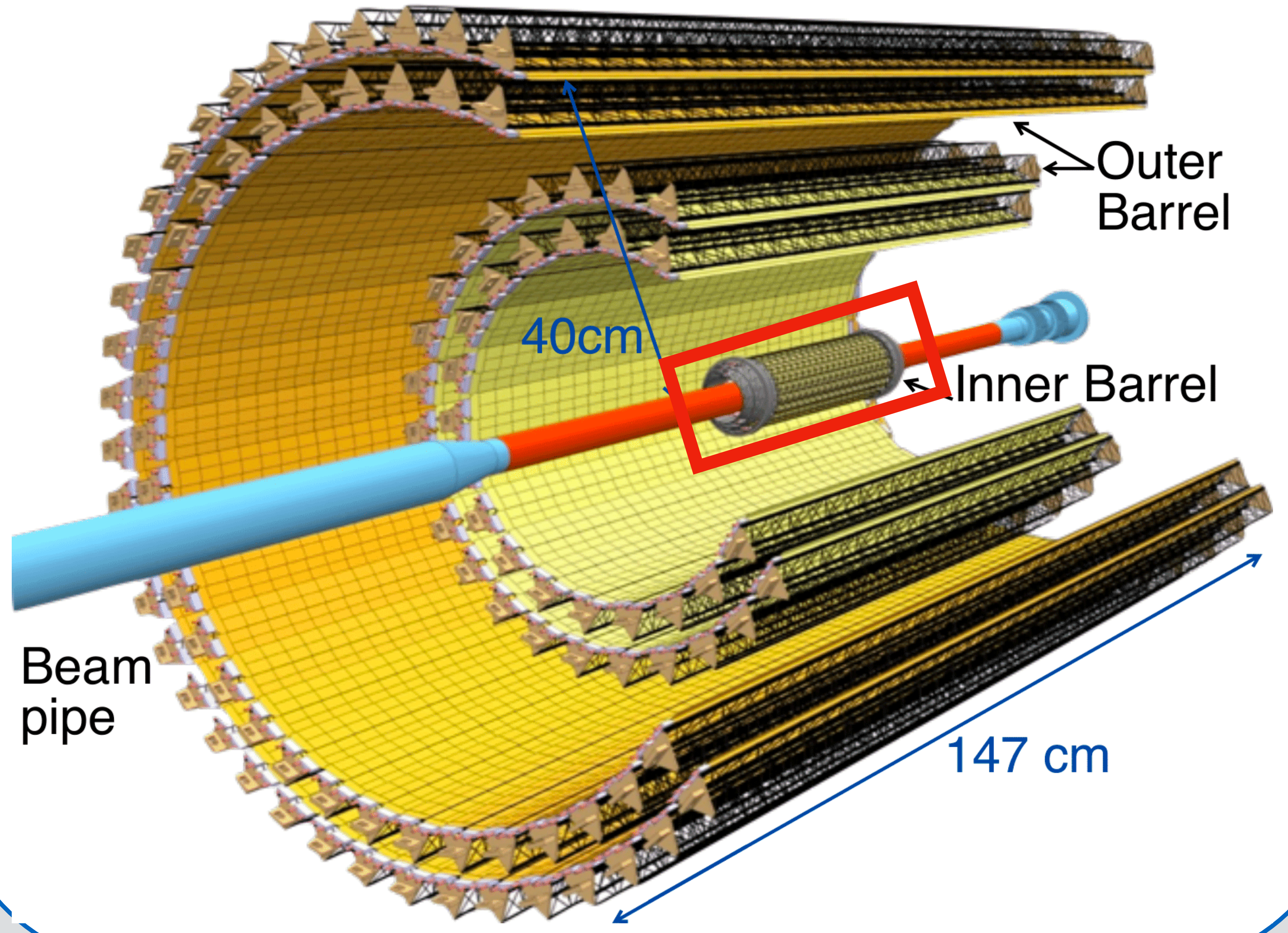
- Contribute to analog and digital design Nikhef
- Contribute to data transmission Nikhef
- Contribute to mechanical design Nikhef



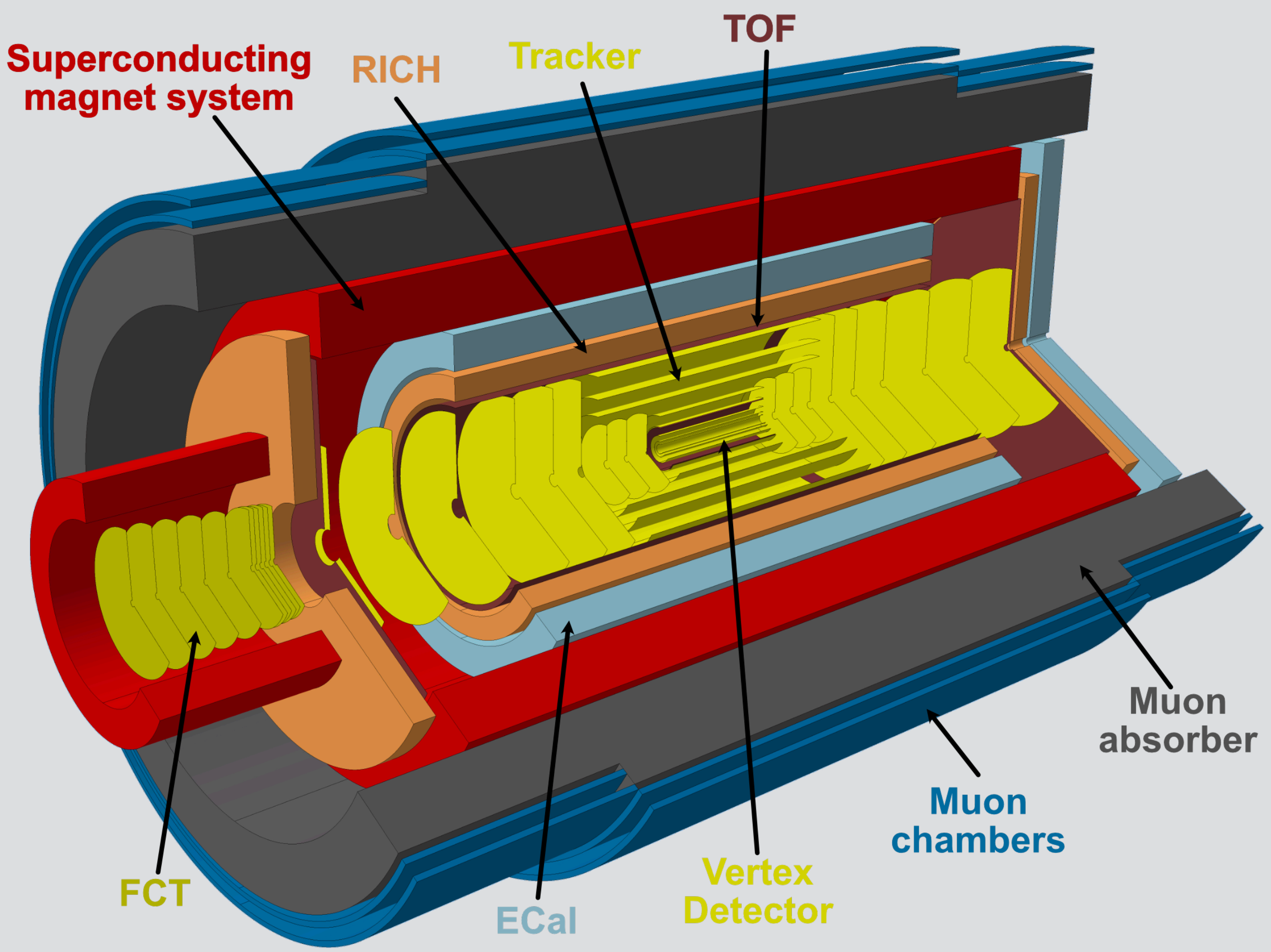

CERN-LHCC-2024-003 ; ALICE-TDR-021

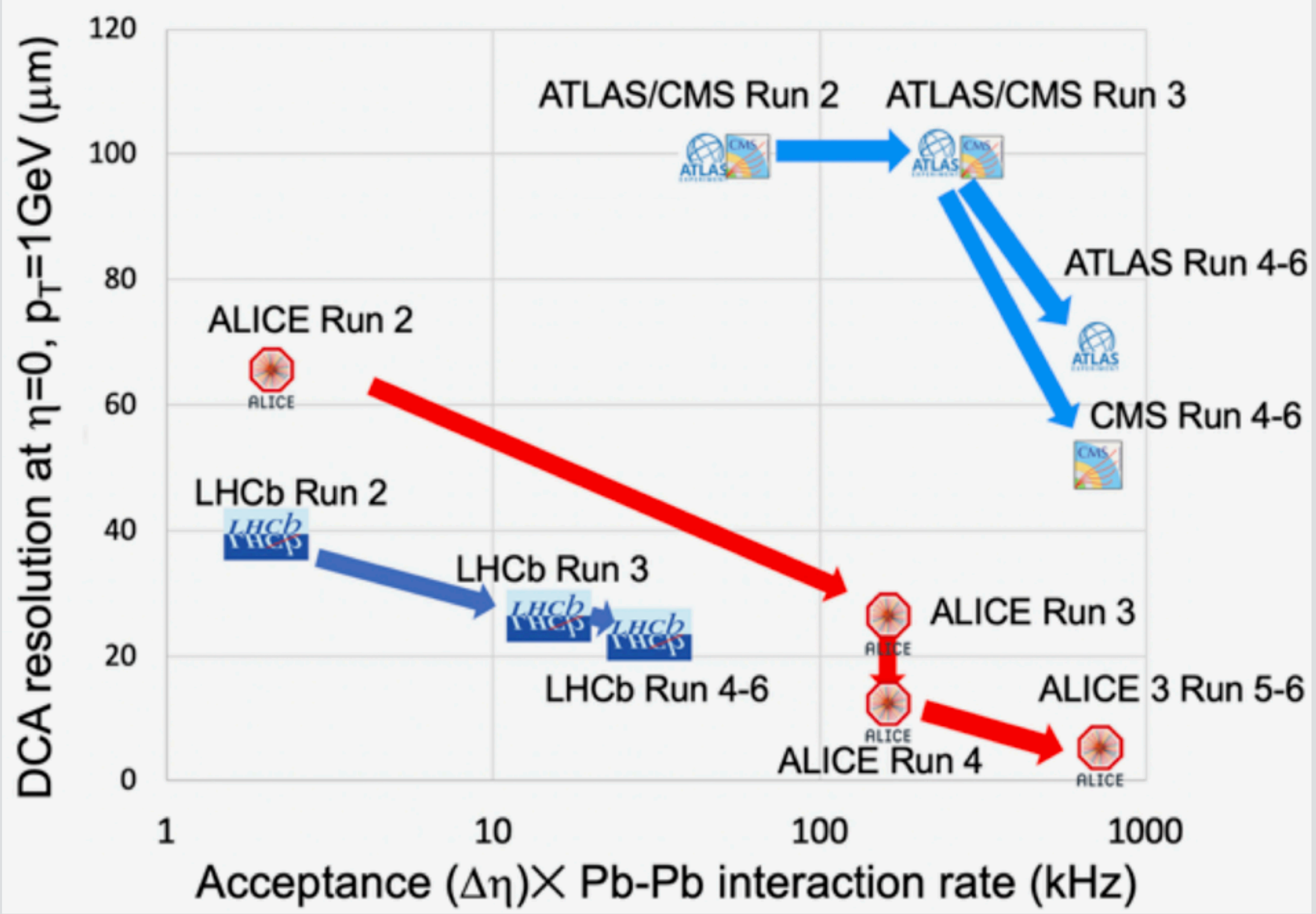
replace innermost 3 layers ITS 2

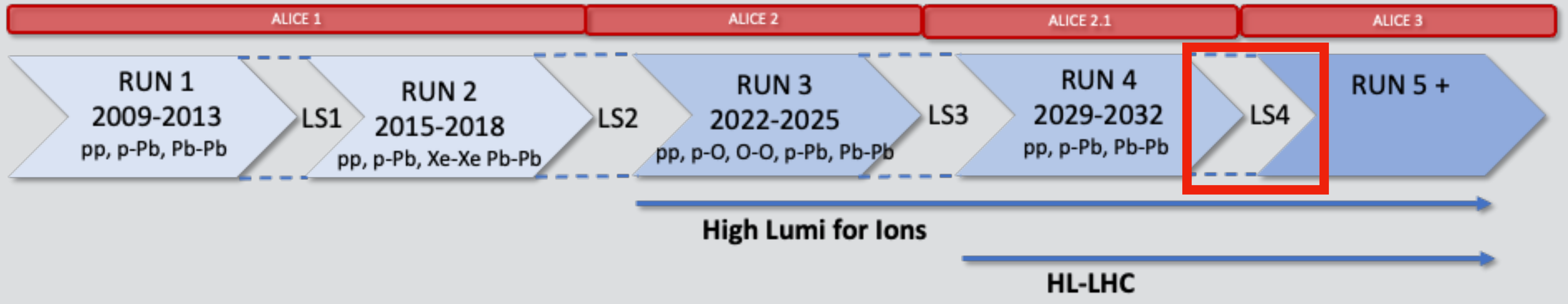


# ALICE 3 (2032-   )

- Completely new experiment
  - Material budget: 0.1% $X_0$ iris layer (other layers < 1% $X_0$)
  - Magnetic Field: 0.2 and 0.5 T
  - Rapidity coverage: up to 8 rapidity units
  - Trying to get as close to the beam as possible
    - Improved Velo like solutions
  - Time measurements: outer layer ~ 20 ps
    - More timing layers and different silicon pixel technologies considered



# European Strategy


**Properties of Strongly Interacting Matter at Extreme Conditions of Temperature and Baryon Number Density**

**Coordinators:**
Laura Fabbietti (TU München, Germany)
Urs Achim Wiedemann (CERN Geneva, Switzerland)

**NuPECC Liaisons:**
Gert Aarts (Swansea, UK and ECT* Trento, Italy)
Raimond Snellings (Utrecht University, The Netherlands)

**WG Members:**
- Roberta Arnaldi (INFN Torino, Italy)
- Andrea Dainese (INFN Padova, Italy)
- Stefan Flörchinger (Jena University, Germany)
- Tetyana Galatyuk (GSI and TU Darmstadt, Germany)
- Tuomas Lappi, (JYFL-ACCLAB, Jyväskylä, Finland)
- Yen-Jie Lee (MIT, Cambridge, USA)
- Giulia Manca, (Cagliari University, Italy)
- Alexander Milov (Weizmann Institute, Israel)
- Luciano Musa (CERN Geneva, Switzerland)
- Piotr Salabura (Jagiellonian University, Krakow, Poland)
- Carlos Salgado (University of Santiago de Compostela, Spain)

Conclusions of the Town Meeting:
Heavy Ion and QGP Physics at CERN
http://indico.cern.ch/event/1483832/

On Monday, February 17, 2025, a town meeting was held at CERN to gather input on heavy ion and quark gluon plasma (QGP) physics for the European Strategy for Particle Physics 2026. The meeting included brief presentations on current and upcoming heavy ion experiments at CERN's LHC and SPS, along with future projects at the FAIR facility in Darmstadt and Brookhaven RHIC. It also highlighted CERN's injector and accelerator complex capabilities for providing ion beams to the HL-LHC (with a view to FCC-hh) and future fixed-target experiments. Additionally, the meeting offered a platform for scientists and groups to share comments and statements, including a panel on theory.

The meeting had 279 registered participants representing all experimental and theoretical activities in the field. It concluded with an open discussion on the priorities within the field. The following text, while not officially endorsed by any of the mentioned experimental collaborations or facilities, summarizes the **consensus** of the scientific community on the field's priorities, as expressed by the town meeting participants. It is submitted to the Open Symposium of the European Strategy Group in Venice by the convenors of the meeting.

R. Arnaldi, Y.-J. Lee, A. Milov, R. Snellings, U.A. Wiedemann and M. Winn

Heavy Ion and QGP physics aims at understanding the properties of strongly interacting matter at extreme temperature and density directly from the fundamental interactions of quarks and gluons. At the highest energies available at the Large Hadron Collider, the QGP is created and diagnosed at nearly vanishing baryon density, i.e., under conditions prevailing in the very early Universe. Lower beam energies, currently available at the CERN-SPS and at future facilities such as FAIR in Darmstadt, probe the baryon-rich quark matter under conditions encountered in various astrophysical settings.

1. Physics opportunities at HL-LHC

Over the past decade, the LHC heavy-ion program has yielded groundbreaking results, including: a comprehensive characterization of the nearly perfect fluidity of the quark-gluon plasma through light-flavored hadron spectra, momentum anisotropies, and various correlation measurements; evidence of a novel in-medium hadronization mechanism via hadrochemical abundances and soft charmonium production; detailed insights into quarkonium dissociation and heavy-quark energy loss in the QGP; and an unprecedented study of jet quenching phenomena, which remains the only significant high-pT effect not fully understood theoretically at the LHC. Additionally, the program has led to unexpected discoveries, such as the observation of collectivity across all system sizes, including those in proton-proton collisions.

Despite significant recent progress, important questions remain unanswered, and the scientific opportunities at HL-LHC for studying the quark-gluon plasma (QGP) are not yet explored. For example, the transport of heavy flavor in a nearly perfect non-abelian fluid can be calculated from first principles in quantum field theory, yet the corresponding QGP transport properties remain to be experimentally constrained. Additionally, the expectation that the QGP radiates electromagnetically still needs testing with Lorentz-invariant observables, such as dilepton spectra, where temperature measurements are unaffected by blueshift. This is also a crucial step toward experimentally detecting direct signatures of chiral symmetry restoration in the QCD high-temperature phase through


Open Symposium on the European Strategy for Particle Physics

Jun 23 – 27, 2025
Venice Lido
Europe/Rome timezone



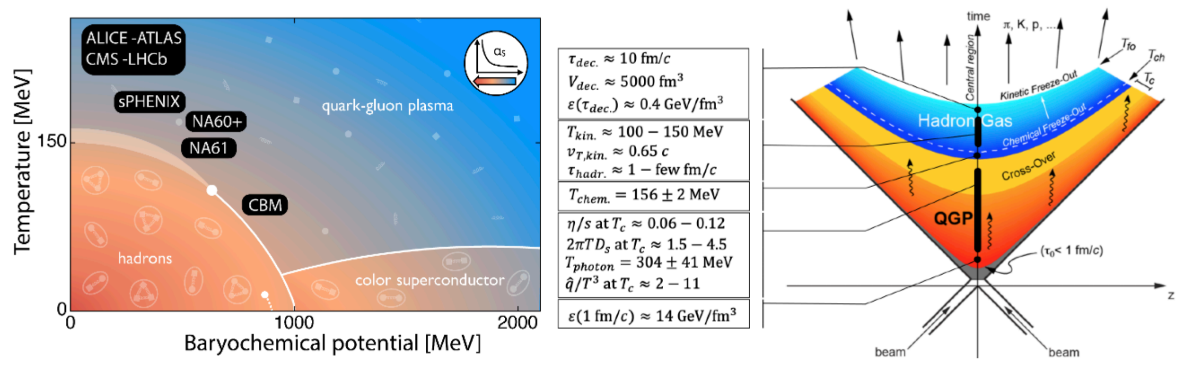
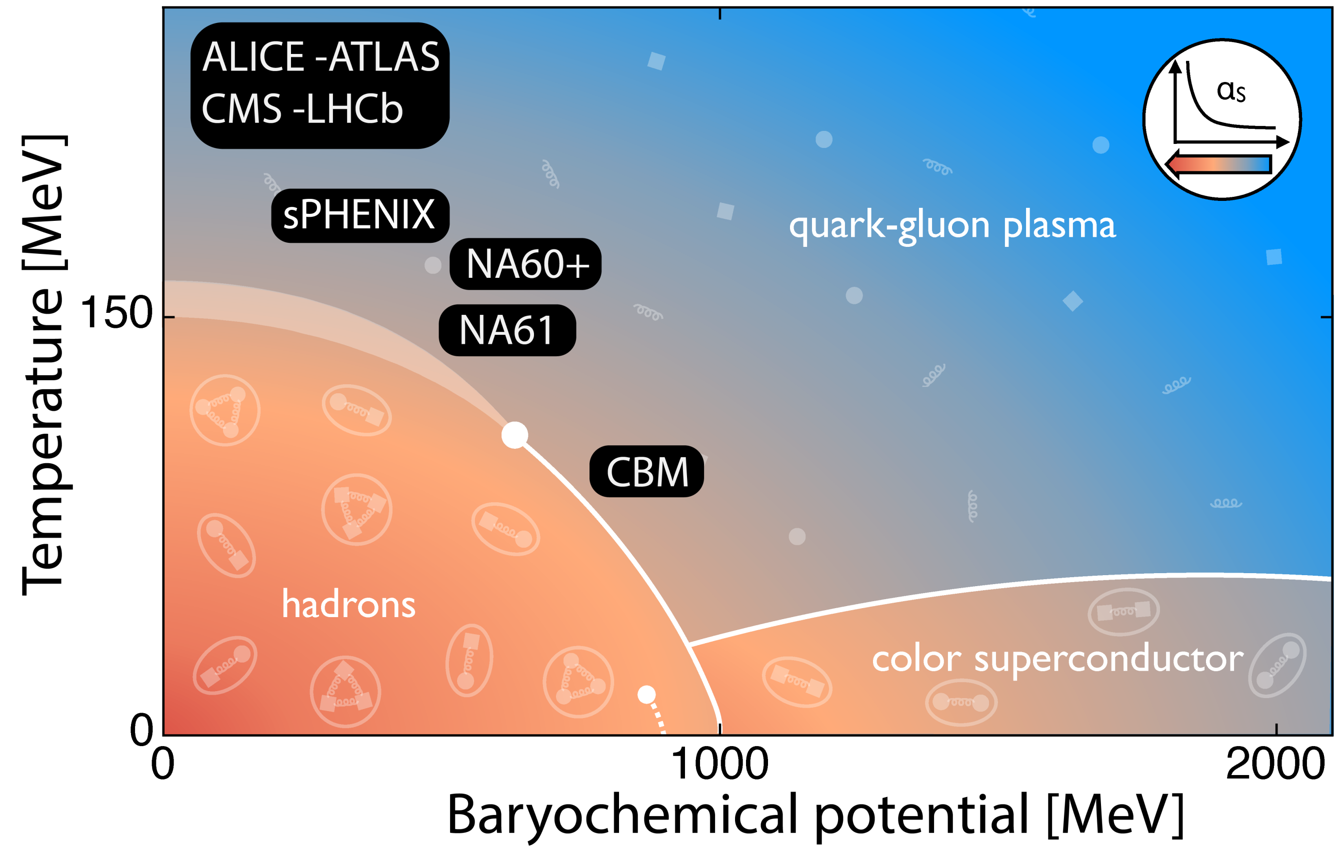


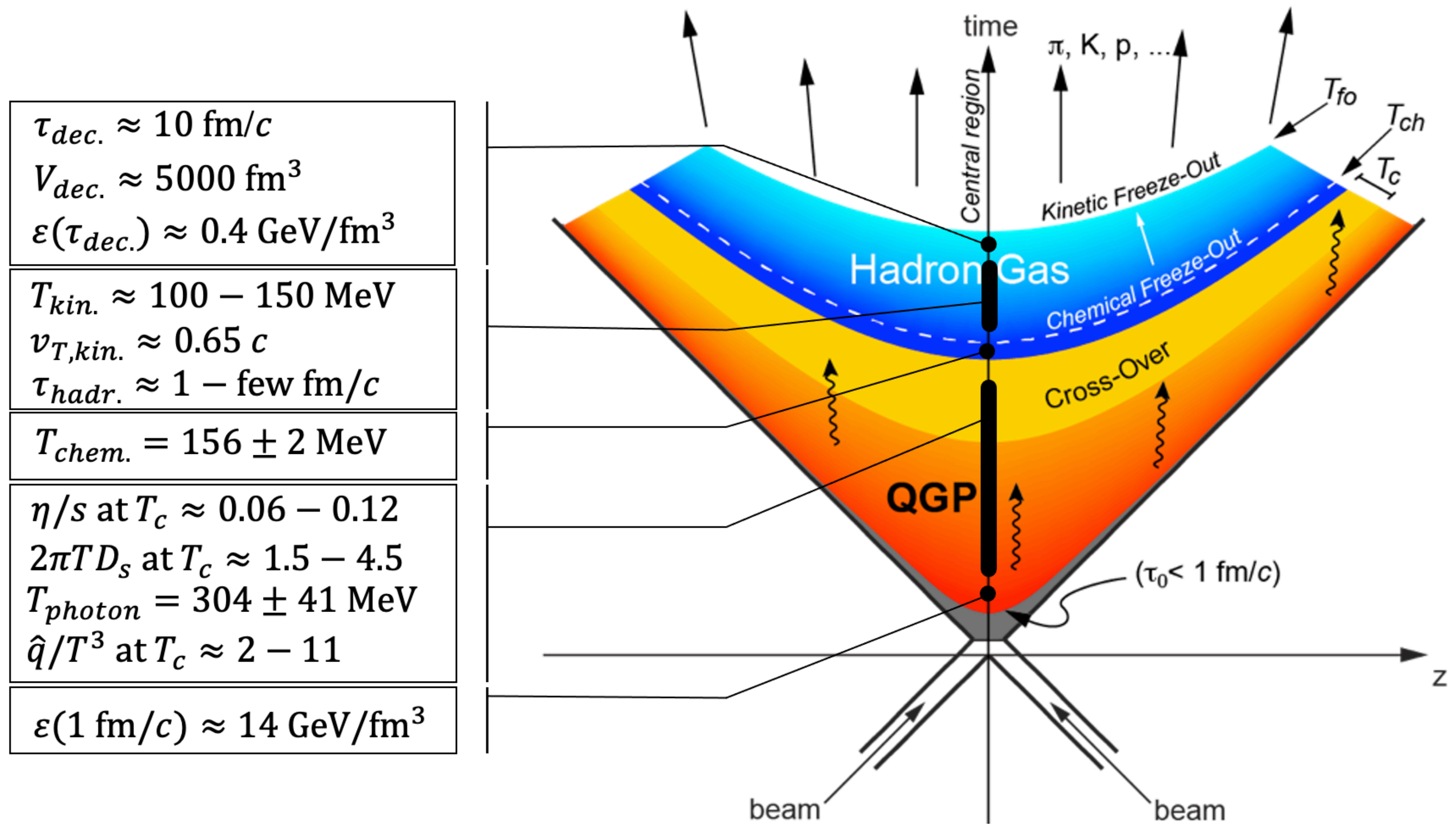

Fig. 1.6: a) placeholder figure for QCD phase diagram and experiments. b) placeholder figure for time evolution with numbers obtained from Bayesian analysis of data.

LHC. Additionally, the program has led to unexpected discoveries, such as the observation of collectivity across all system sizes, including those in proton-proton collisions. Despite significant recent progress, important questions remain unanswered, and the scientific opportunities at HL-LHC for studying the quark-gluon plasma (QGP) are not yet explored. For example, the transport of heavy flavor in a nearly perfect non-abelian fluid can be calculated from first principles in quantum field theory, yet the corresponding QGP transport properties remain to be experimentally constrained. Additionally, the expectation that the QGP radiates electromagnetically still needs testing with Lorentz- invariant observables, such as dilepton spectra, where temperature measurements are unaffected by blueshift. This is also a crucial step toward experimentally detecting direct signatures of chiral symmetry restoration in the QCD high-temperature phase through $\rho$ and $a_1$ spectral function measurements. Characterizing the QGP through medium modifications of rare hard probes, like Z-boson and high transverse momentum photon tagged jets, will require the integrated luminosity from HL-LHC run 4 and 5.

ALICE high priority in European strategy; Nikhef strongly involved in strategy proces

# ALICE Physics



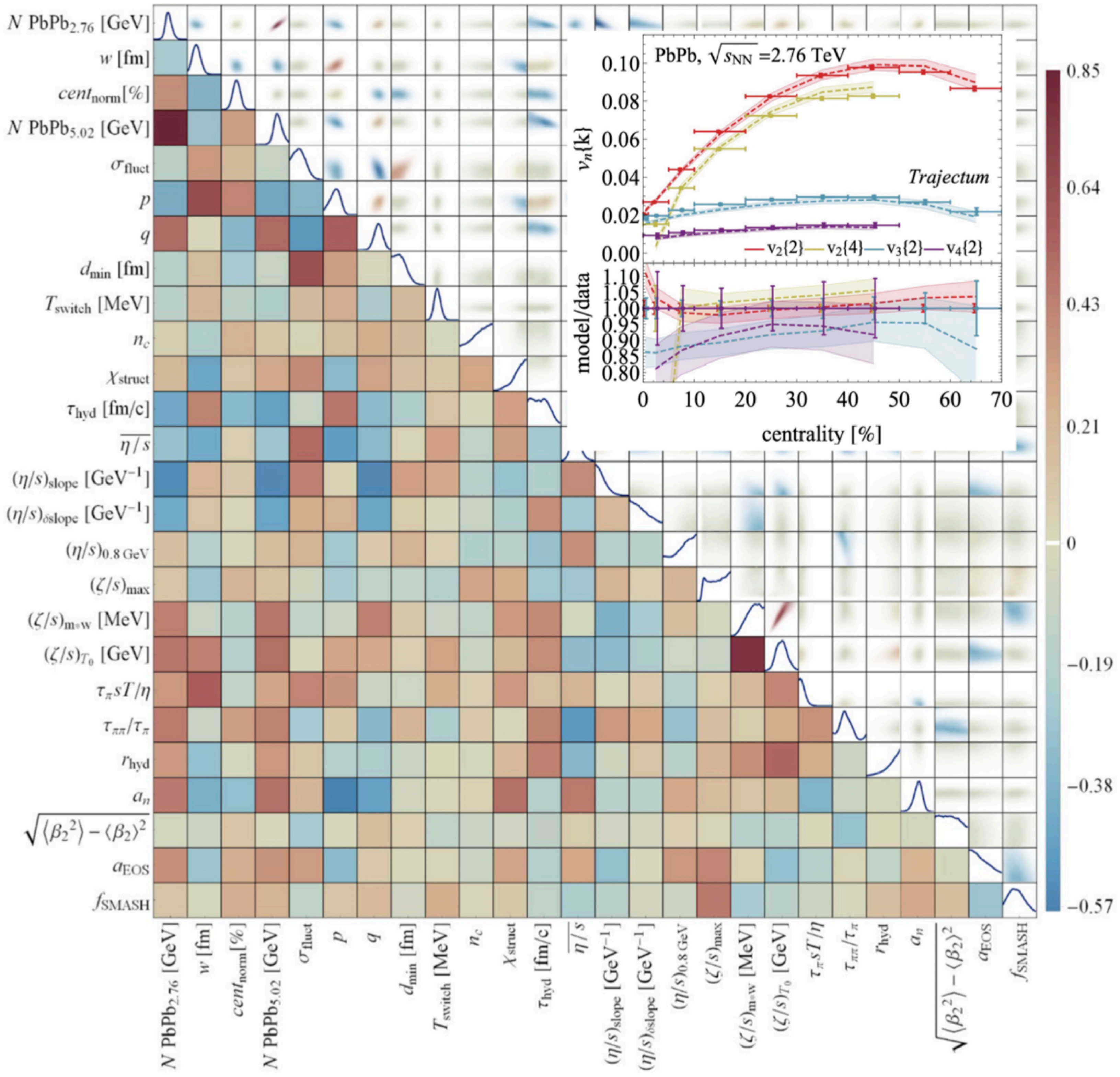
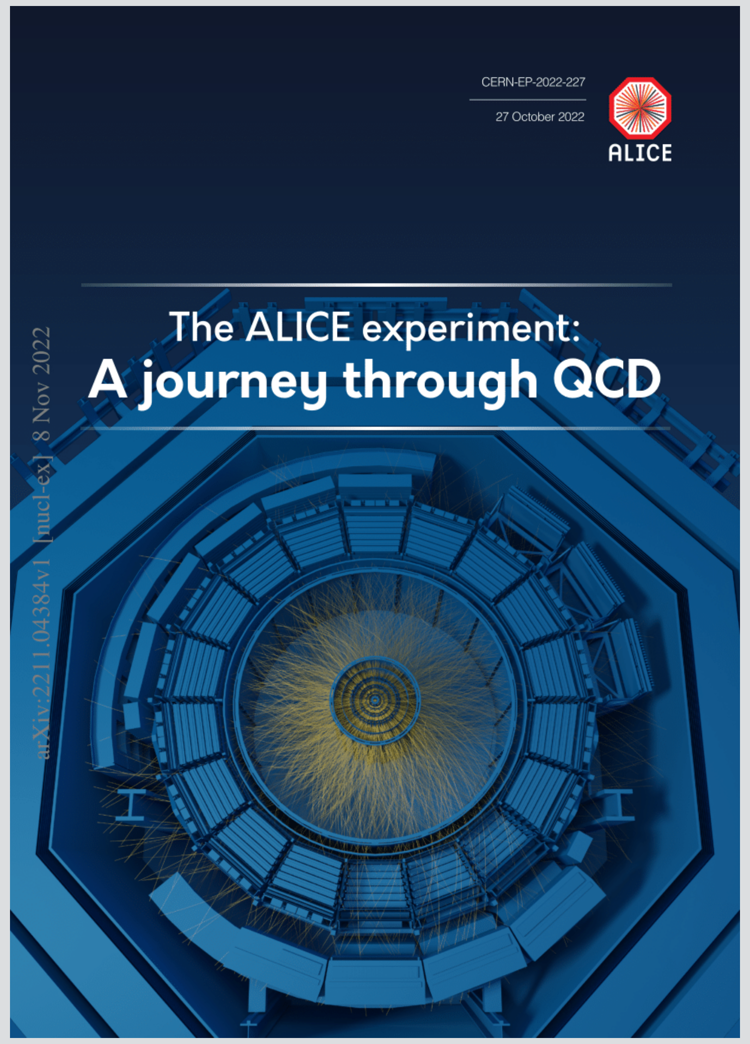




Fig. 3.3: Results of a Bayesian inference analysis using 670 individual data points to constrain the space-time evolution and material properties of the QGP produced in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [Giacalone, Nijs, v.d.Schee, Phys.Rev.Lett. 131 (2023) 02]. The correlation matrix displays all 26 model parameters. The inset shows, as an example, the comparison of the model with data on the centrality dependence of the flow anisotropies $v_n$.

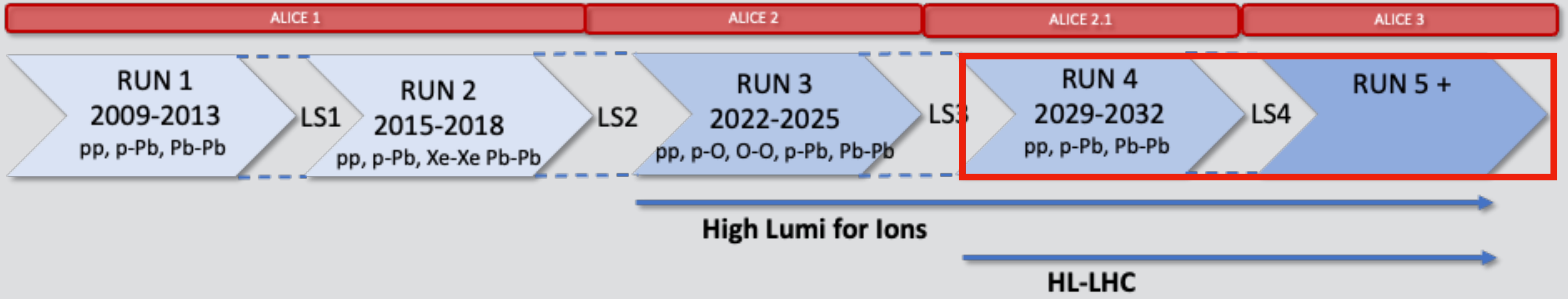


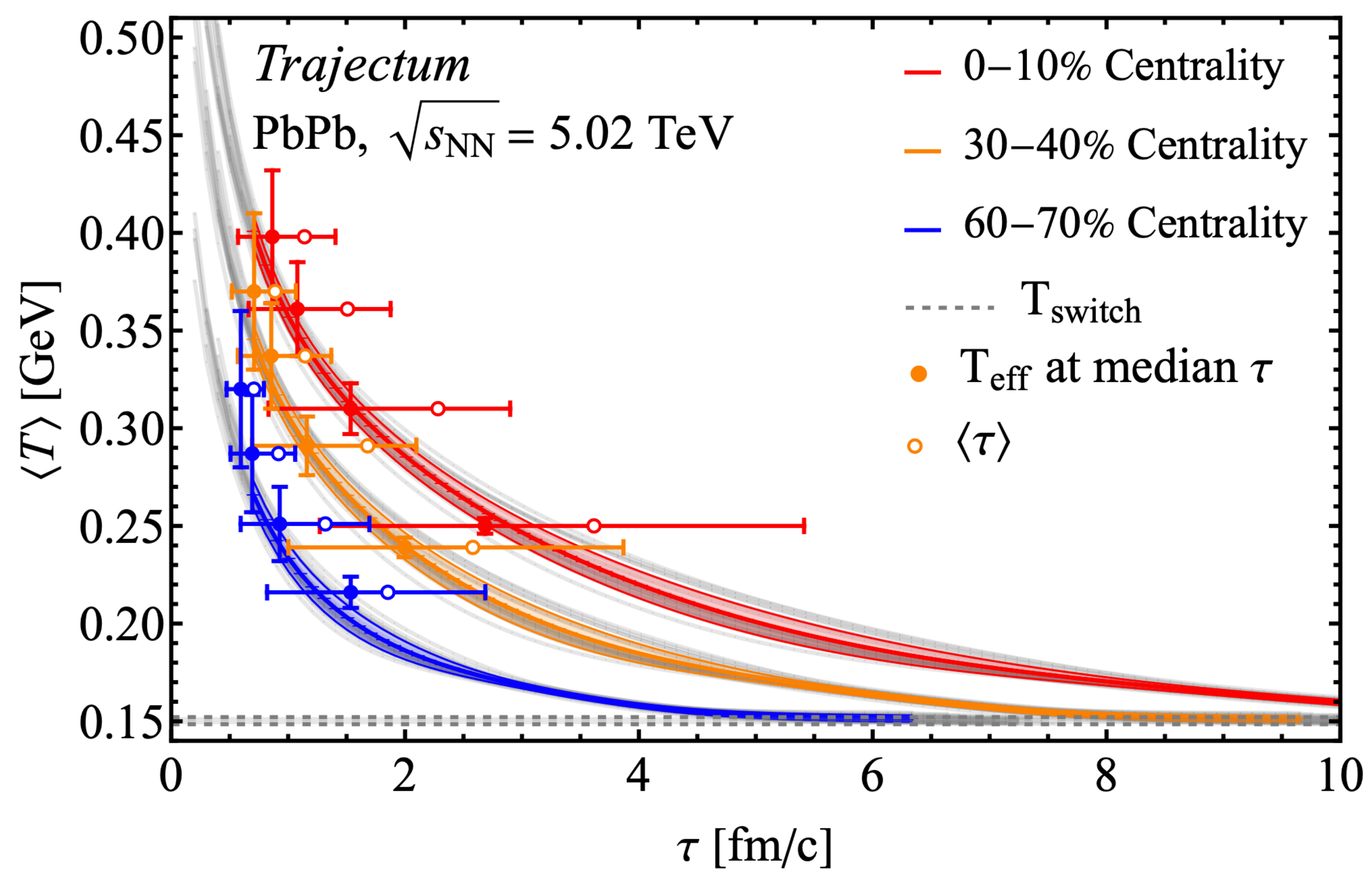

Summary paper Run 1&2

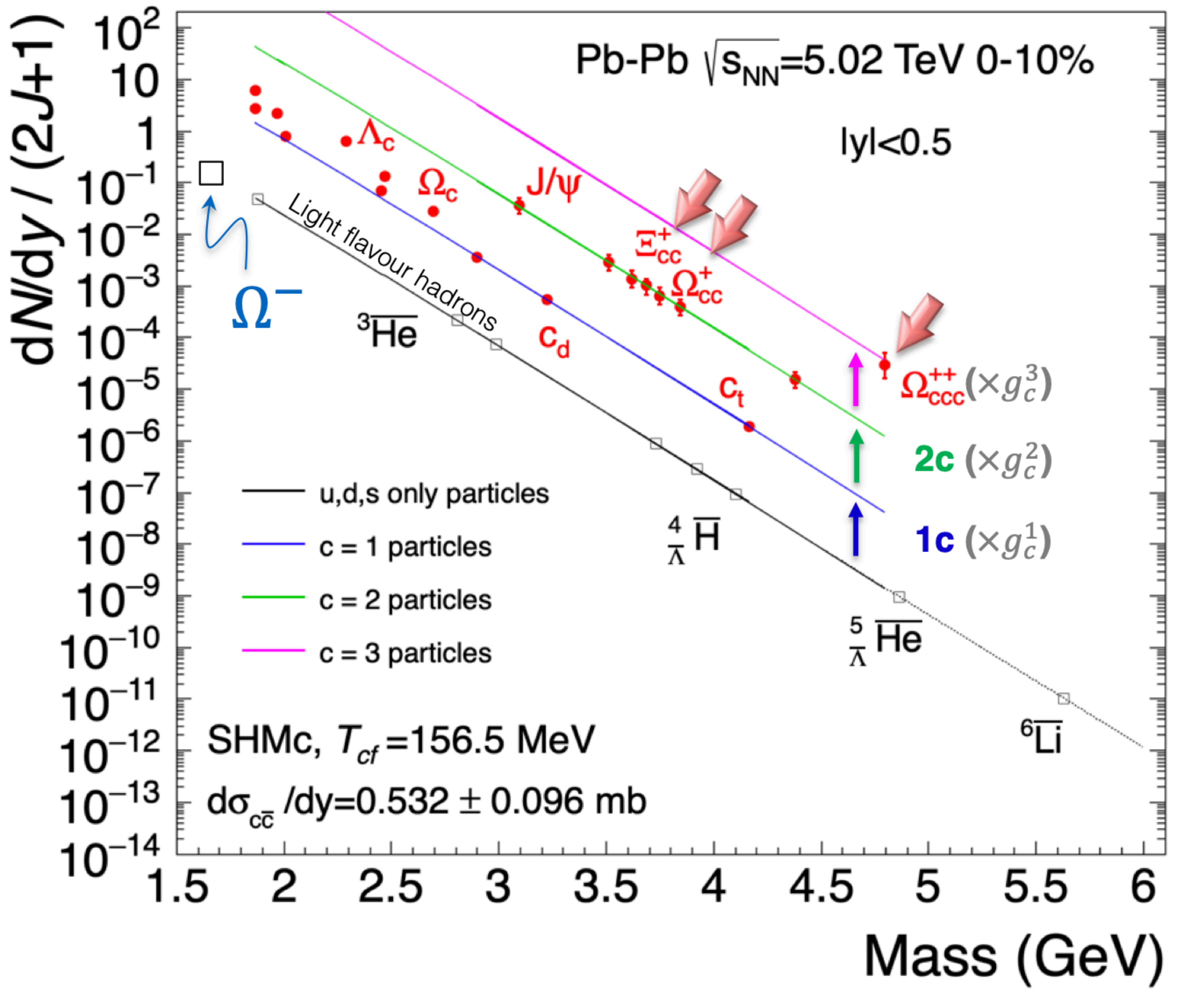
- Review of key ALICE physics results from run 1&2 with big involvement and contribution from Nikhef ALICE group

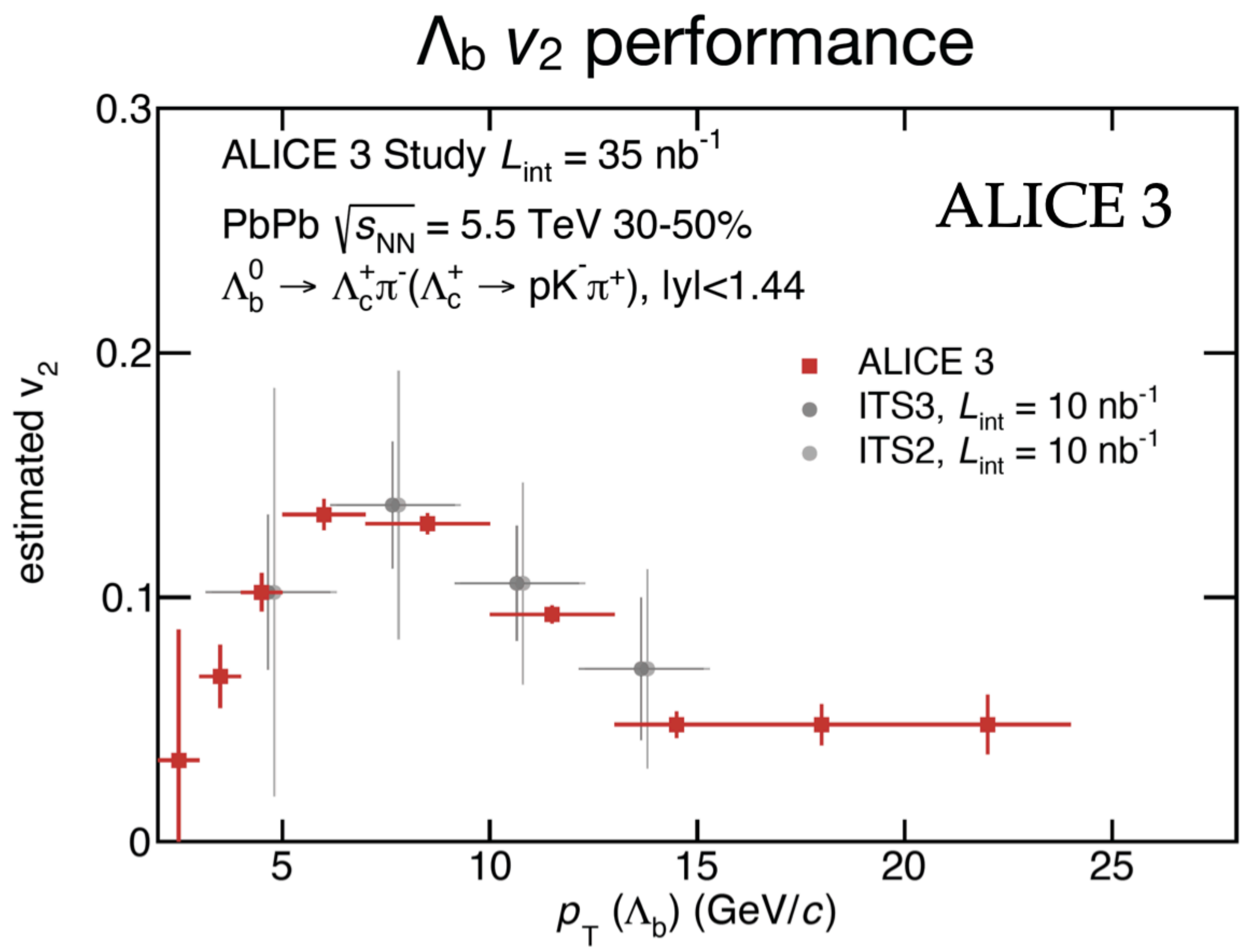
Comprehensive characterization of Quark Gluon Plasma properties through light-flavored hadron spectra, momentum anisotropies, and various correlation measurements; based on properties at chemical and kinetic freeze-out

# ALICE 2025- 20..; key physics goals



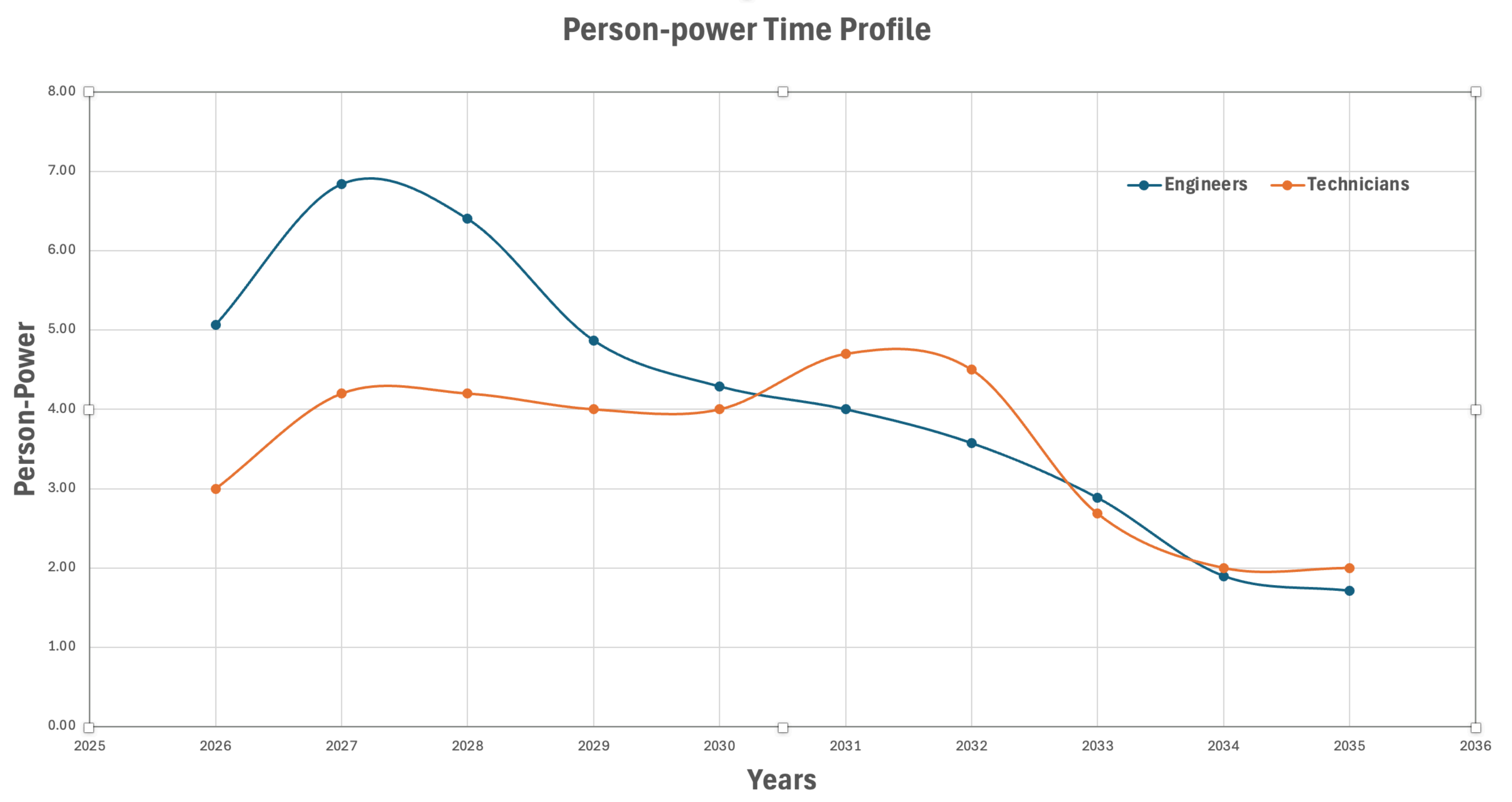




Characterization of Quark Gluon Plasma properties through rare probes (heavy-flavor, electromagnetic probes, hard probes) will allow us to study the space-time evolution of the QGP, which will require the integrated luminosities from HL-LHC run 4 &5

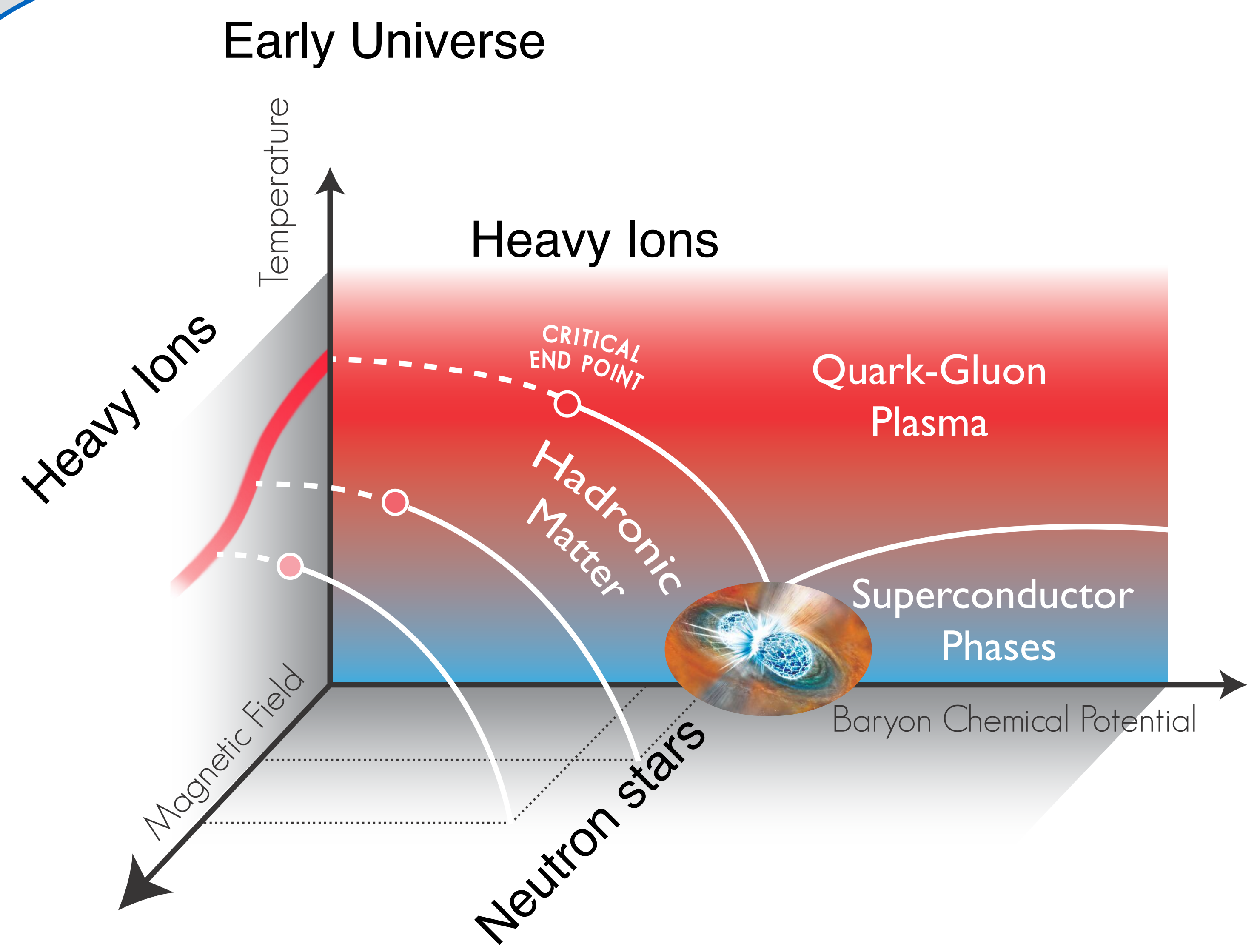
# FASTTRACK

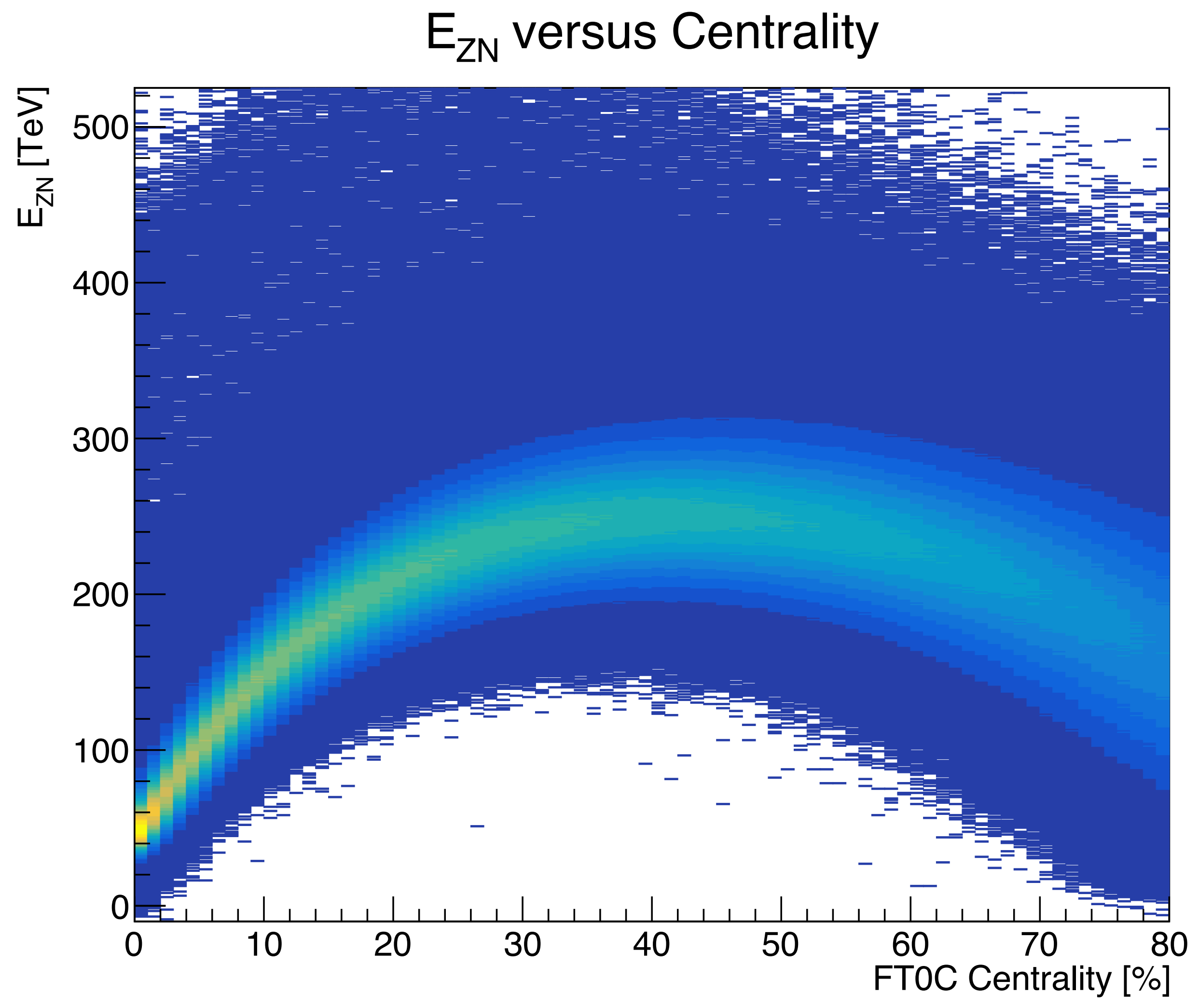
| | | | WP1 Sensors | | | | | | WP2 ASICs | | | | WP3 Readout | | | | WP3 Mechanics & Cooling | | | | | | WP5 IT Infrastructure, Data & Software | | | | Partial Totals Material | Partial Totals Personnel | Total Material | Total Personnel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | WP1.1 3D Hybrids Material | WP1.1 3D Hybrids Personnel | WP1.3 LGAD Hybrids Material | WP1.3 LGAD Hybrids Personnel | WP1.2 Monolithic Material | WP1.2 Monolithic Personnel | WP2.2 Monolithic Material | WP2.2 Monolithic Personnel | WP2.1 Hybrid ASICs Material | WP2.1 Hybrid ASICs Personnel | WP3.1 High-Speed Transmission Material | WP3.1 High-Speed Transmission Personnel | WP3.2 Data Acquisition Material | WP3.2 Data Acquisition Personnel | WP4.1 Module Construction Material | WP4.1 Module Construction Personnel | WP4.2 Cooling Material | WP4.2 Cooling Personnel | WP4.3 Mechanics & Infrastructure Material | WP4.3 Mechanics & Infrastructure Personnel | WP5.1 Accelerators Material | WP5.1 Accelerators Personnel | WP5.2 Algorithms Material | WP5.2 Algorithms Personnel | | | | |
| ALICE | Detector | Sensor | | | | | 0.3 | | | | | | | | | | | | | | | | | | | | | | | |
| | | Mechanics | | | | | | | | | | | 0.2 | 1 | | | 0.3 | 1 | 0.3 | 1 | 1.2 | 3 | | | | | | | | |
| | | Module Assembly | | | | | | | | | | | | | | | 0 | 0 | | 0 | 0.2 | | | | | | 3.8 | 8 | | |
| | | Cooling | | | | | | | | | | | | | | | | | 0.3 | | | | | | | | | | | |
| | | Readout | | | | | | | | | | | 0.3 | 1 | 0.7 | 1 | | | | | | | | | | | | | | |
| | | Power | | | | | | | | | | | | | | | | | | | 0 | | | | | | | | 8.1 | 9 |
| | Common Funds | Common Funds | | | | | 0.5 | | | | | | | | 0.5 | | | | | | 0.25 | | | | 0.25 | | 1.5 | 0 | | |
| | R&D | Sensor Submission Costs | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| | | Characterisation | | | | | 0.4 | | 0.4 | | | | | | | | | | | | | | | | | | 2.3 | 0 | | |
| | | R&D | | | | | | | | | | | | | 0.1 | | 0.2 | | | | 0.2 | | | | | | | | | |
| | Computing | Computing | | | | | | | | | | | | | | | | | | | | | 0.25 | | 0.25 | 1 | 0.5 | 1 | | |
| | | | | 0 | | 0 | | 0 | | 0 | | 0 | | 2 | | 1 | | 1 | | 1 | | 3 | | 0 | | 1 | | | | |

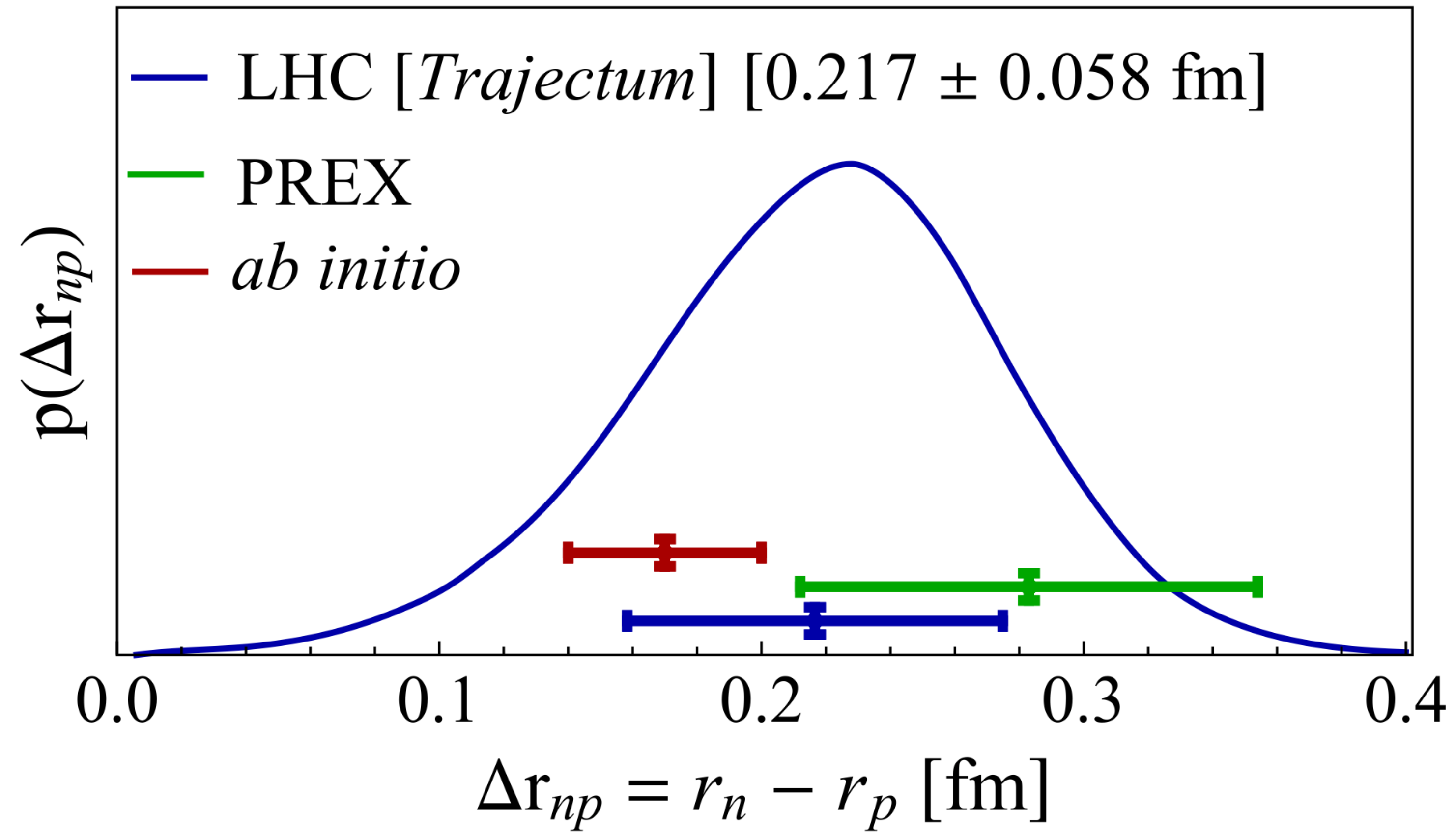



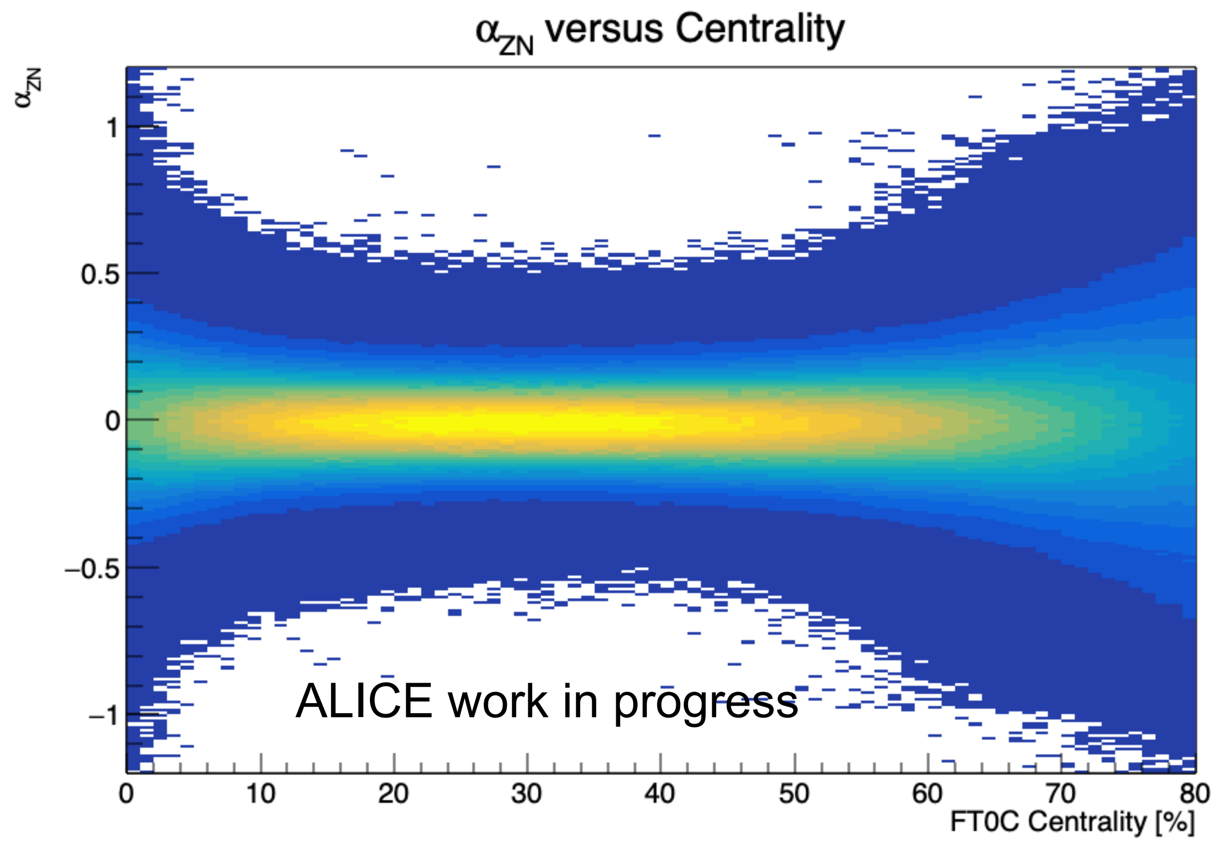

To contribute our share to building this detector requires a significant investment which relies heavily on the NWO roadmap proposal

# Nikhef ALICE connections




Probe nuclear (neutron star) EoS with heavy ion collisions: e.g. neutron skin

- ➡ Nikhef ATLAS, LHCb, R&D & PDP program
  - ➡ Via e.g. ENW-XL: FASTER
    - ➡ MAPS & 4D tracking
- ➡ Nikhef/UU Gravitational Waves program
  - ➡ Via e.g. ENW-XL: Probing the QCD phase diagram
    - ➡ Neutron Star properties
- ➡ Nikhef/UU theory program
  - ➡ Via e.g. NWA-ORC: Emergence at all scales
    - ➡ Dutch theoretical contributions (AdS/CFT, pQCD, relativistic viscous hydrodynamics, spin transport theory,…)

# ALICE in the LHC Wonderland

- The Nikhef ALICE group is very productive and has a large impact on the ALICE program
  - Connected to the Nikhef and Utrecht Theory department, joint effort on heavy-ions and gravitational waves
  - Connected to other Nikhef programs via 4D tracking
- Current ALICE data taking well on track

- Strong future program and ambitions!
  - ➡ Started with R&D for ALICE 3
  - ➡ Joint Nikhef R&D program for 4D-tracking with the detector R&D and other LHC groups
  - ➡ Funding required for 4D tracking R&D, Physics analysis and building ALICE 3