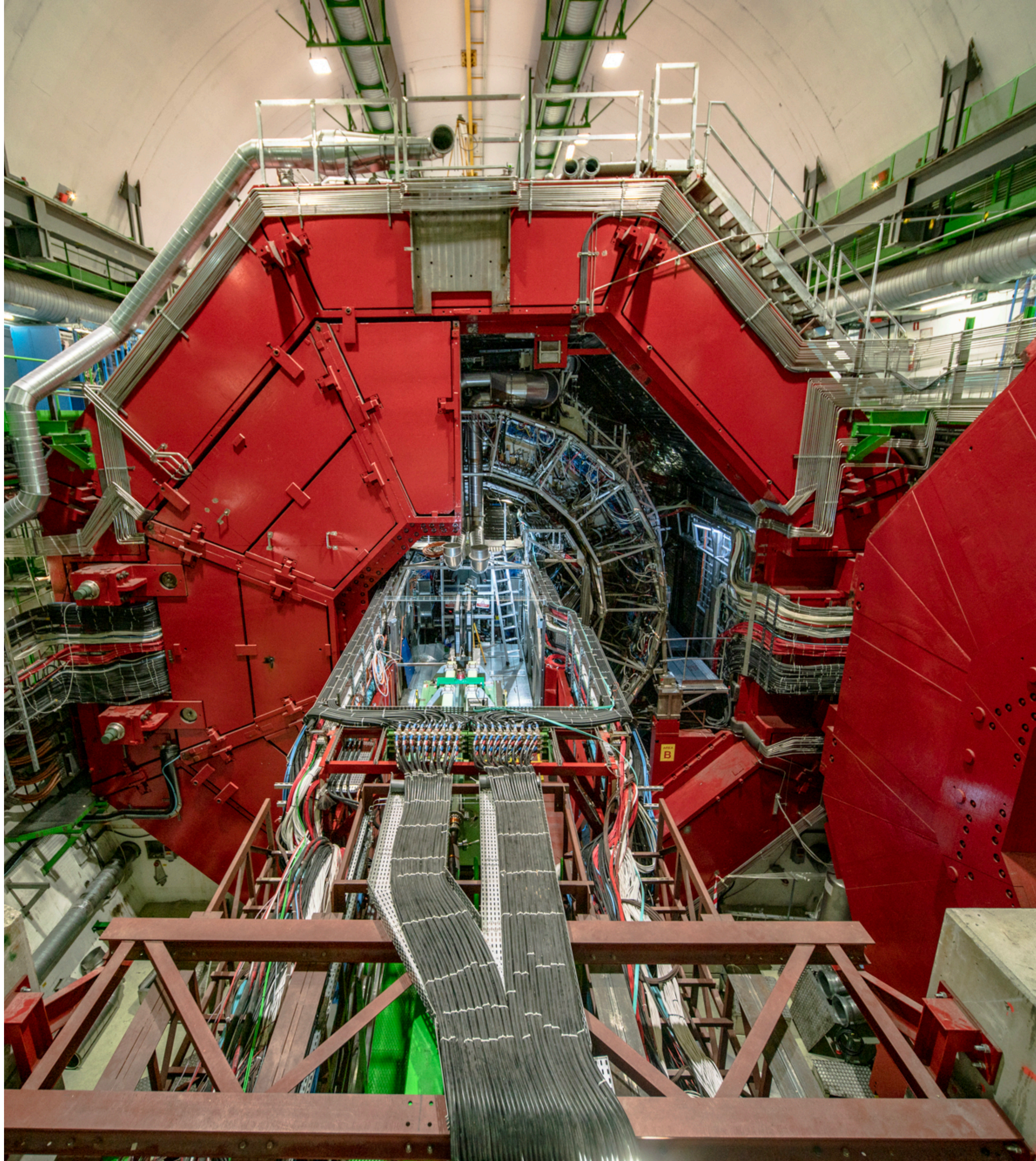
Perspektiven mit ALICE 2 & 3 am LHC

KHuK Jahrestagung

9. - 10. Dezember 2021

Jochen Klein (CERN)



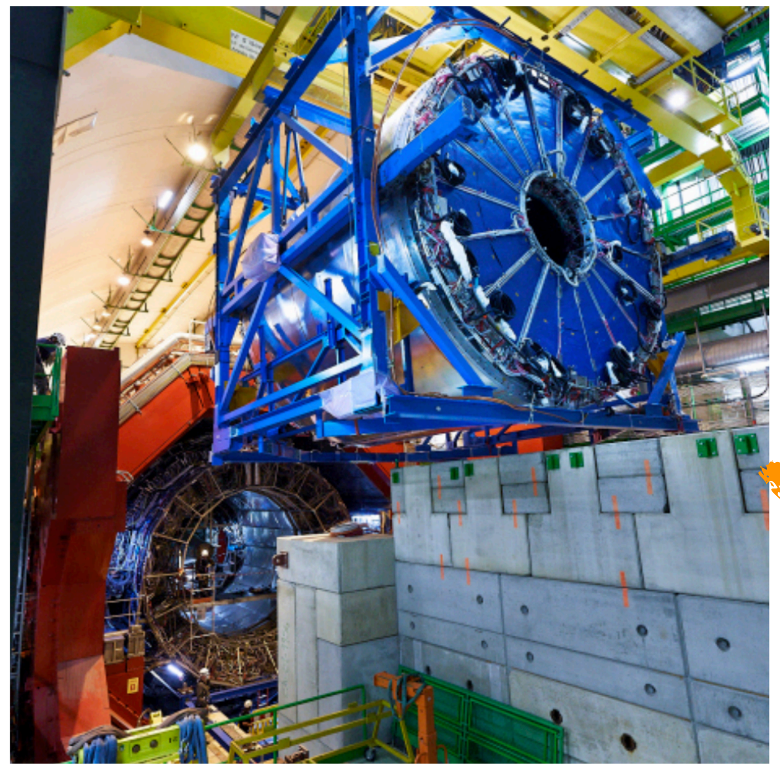
ALICE timeline

NB: LHC schedule under discussion

LS2 upgrades → ALICE 2

New and upgraded central detectors
continuous readout of Pb-Pb @ 50 kHz
→ 13 nb^{-1} in Run 3 & 4

Uni Frankfurt
Uni Heidelberg
TU München
Uni Bonn
GSI



Time Projection Chamber
- GEM-based chambers
- New front-end electronics

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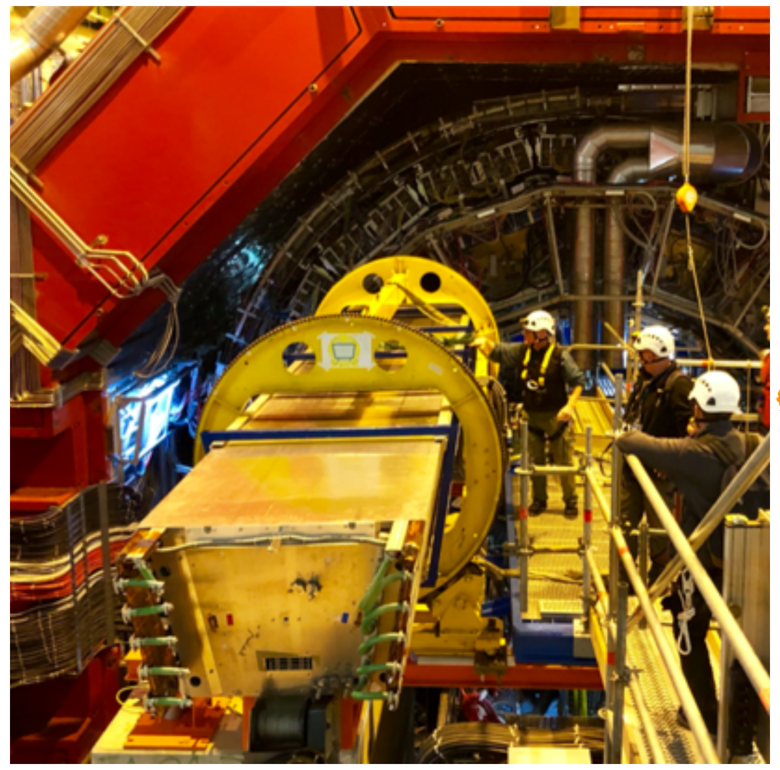
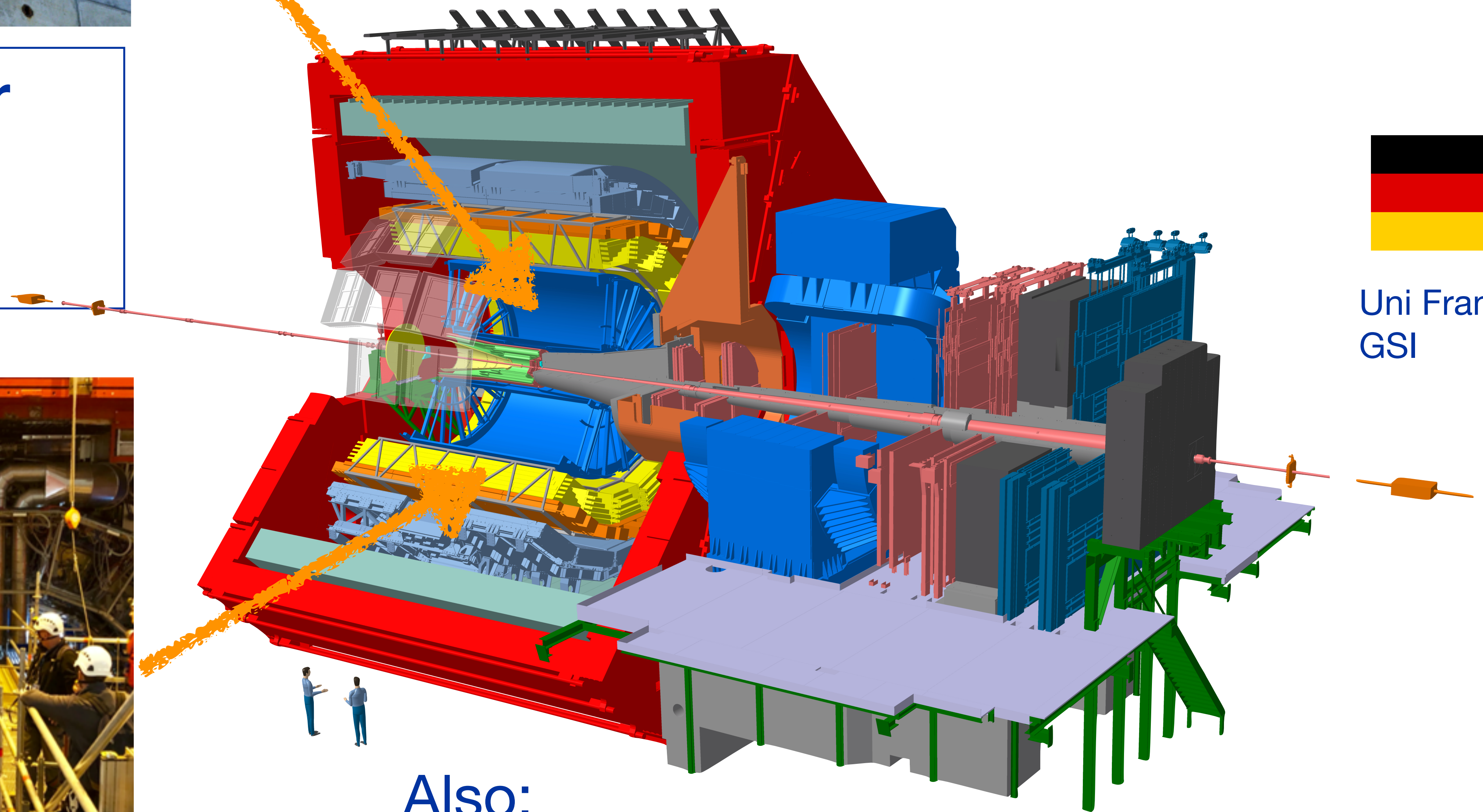
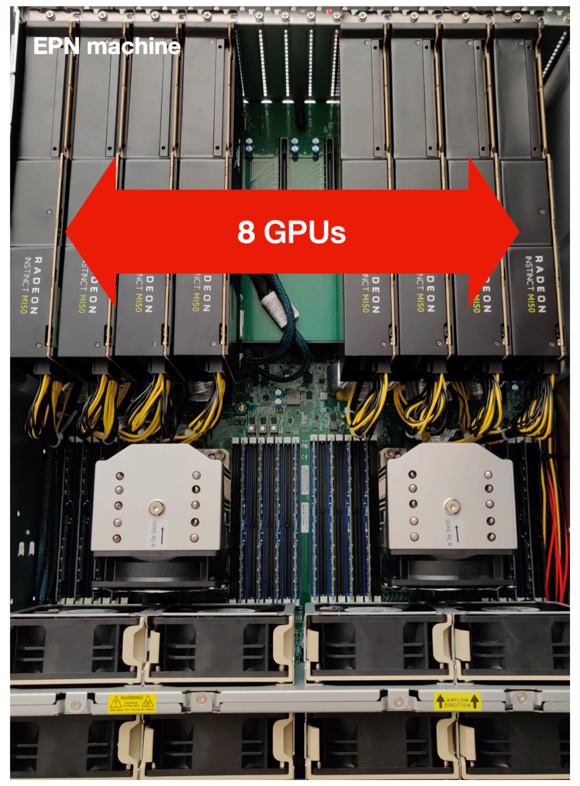


Transition Radiation Detector
- Repair of supermodules
- New readout scheme



Also:
- new Inner Tracking System
- new forward interaction trigger
- new muon forward tracker
- further detectors upgraded
- readout and trigger upgrade for all detectors



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Event Processing Nodes
- **Online processing of all events**
- ALICE **pioneering usage of GPUs** at LHC
- relevant for experiments at LHC, FAIR, …
- excellent collaboration with AMD

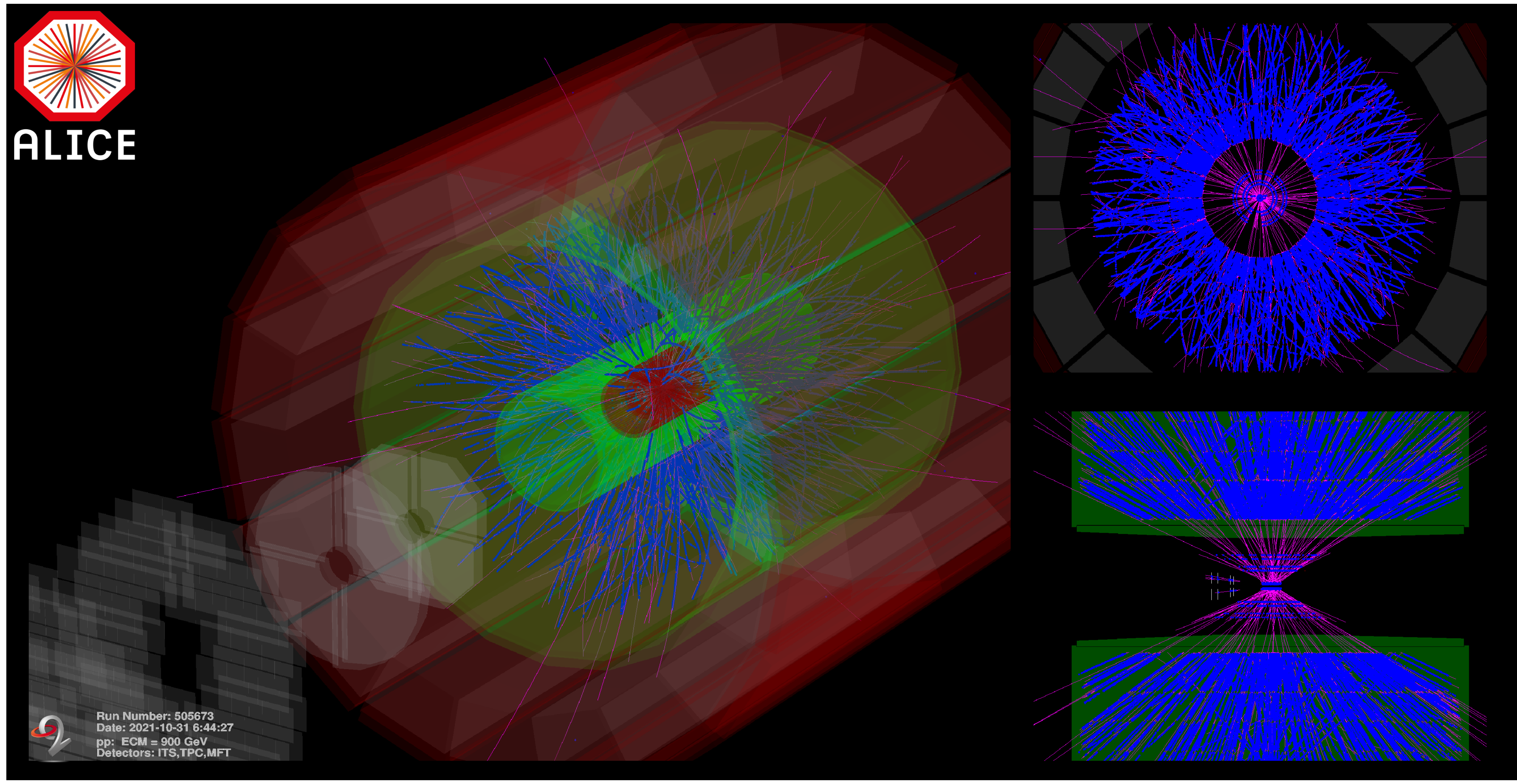
Industry Award for AMD
(Dec 2nd, 2021)

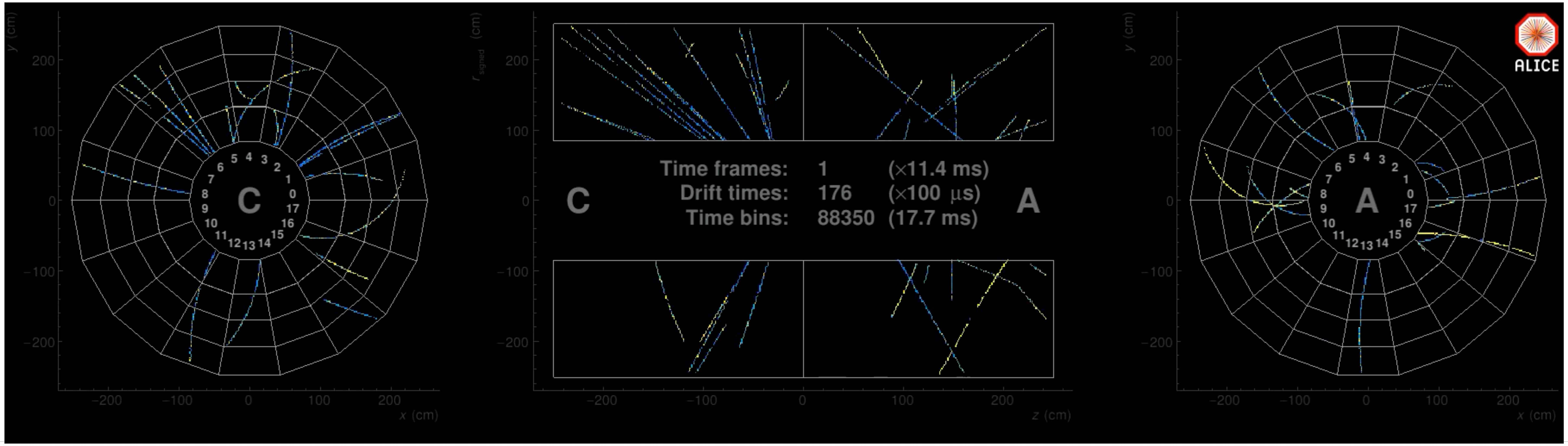
LHC pilot beam

pp collisions:
$\sqrt{s} = 900$ GeV
Oct 2021

Upgrades completed on schedule, in budget, and it works!

- Detector performance confirmed
- Continuous readout and synchronous reconstruction verified





Ready for 10 years of physics with ALICE 2

Physics prospects

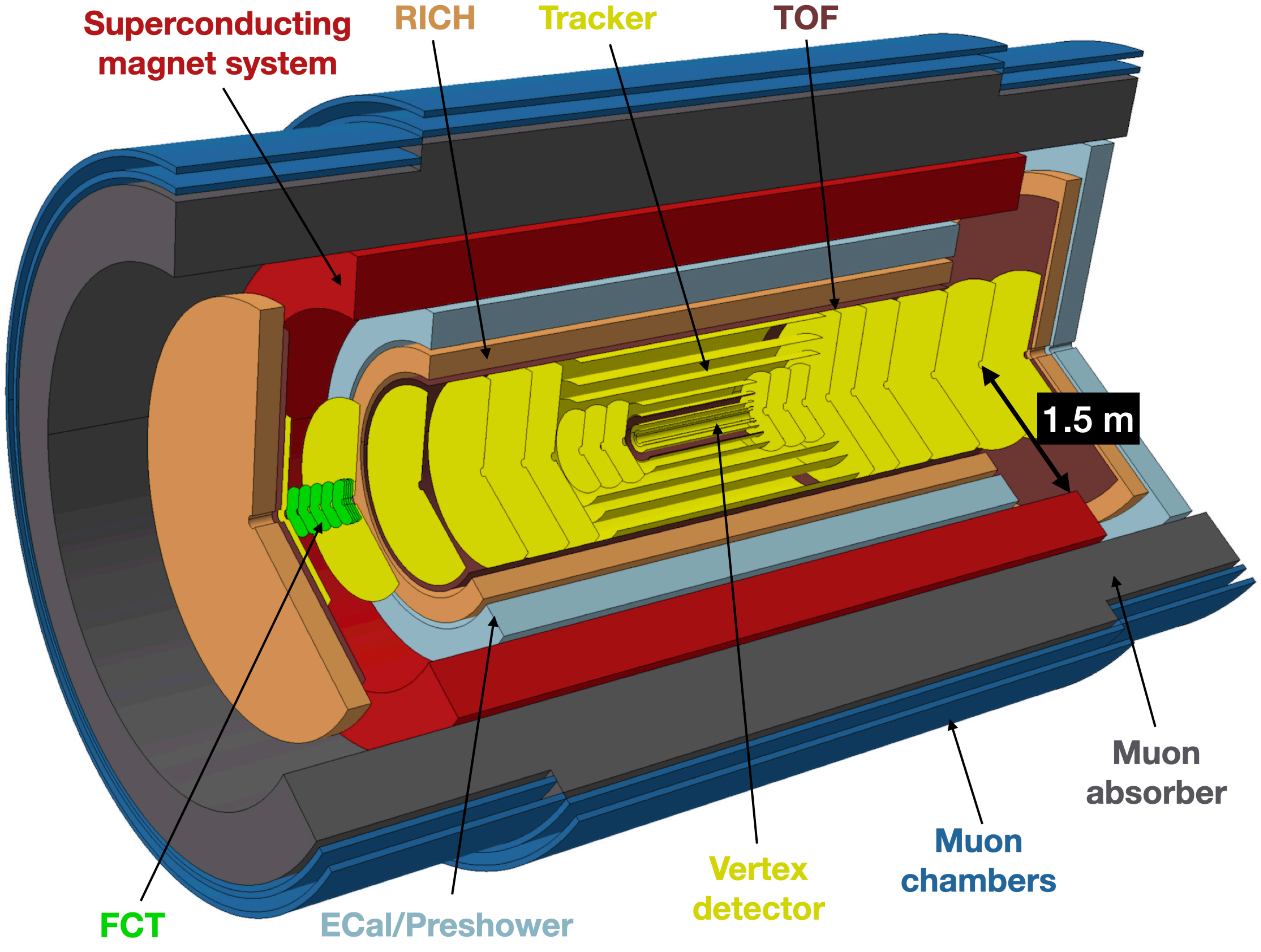
- **ALICE 2 will allow comprehensive measurements** of
  - medium effects and hadrochemistry of single charm
  - time-averaged thermal QGP radiation
  - patterns that are indicative of chiral symmetry restoration
- **Fundamental questions will remain open → ALICE 3**
  - fundamental QGP properties driving its constituents to equilibration
  - microscopic mechanisms leading to strong partonic collectivity
  - partonic equation of state and its temperature dependence
  - underlying dynamics of chiral symmetry restoration

Progress requires qualitative steps
in detector performance and statistics
→ next-generation heavy-ion experiment

ALICE 3

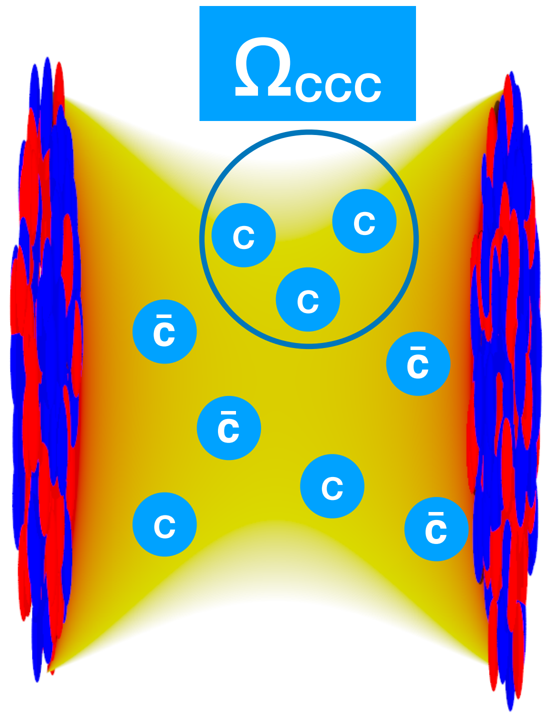
Novel and innovative detector concept

- **Compact and lightweight all-silicon tracker**
  → good efficiency and p_T resolution down to low p_T
- **Retractable vertex detector**
  → excellent pointing resolution
- **Particle identification** over large acceptance
  → clean reconstruction of multi-prong decays
- **Large acceptance** ($\Delta\eta = 8$)
  → correlations, η dependence
- **Superconducting magnet system**
  → optimised magnetic field over full volume
- **Continuous read-out and online processing**
  → large data sample to access rare signals

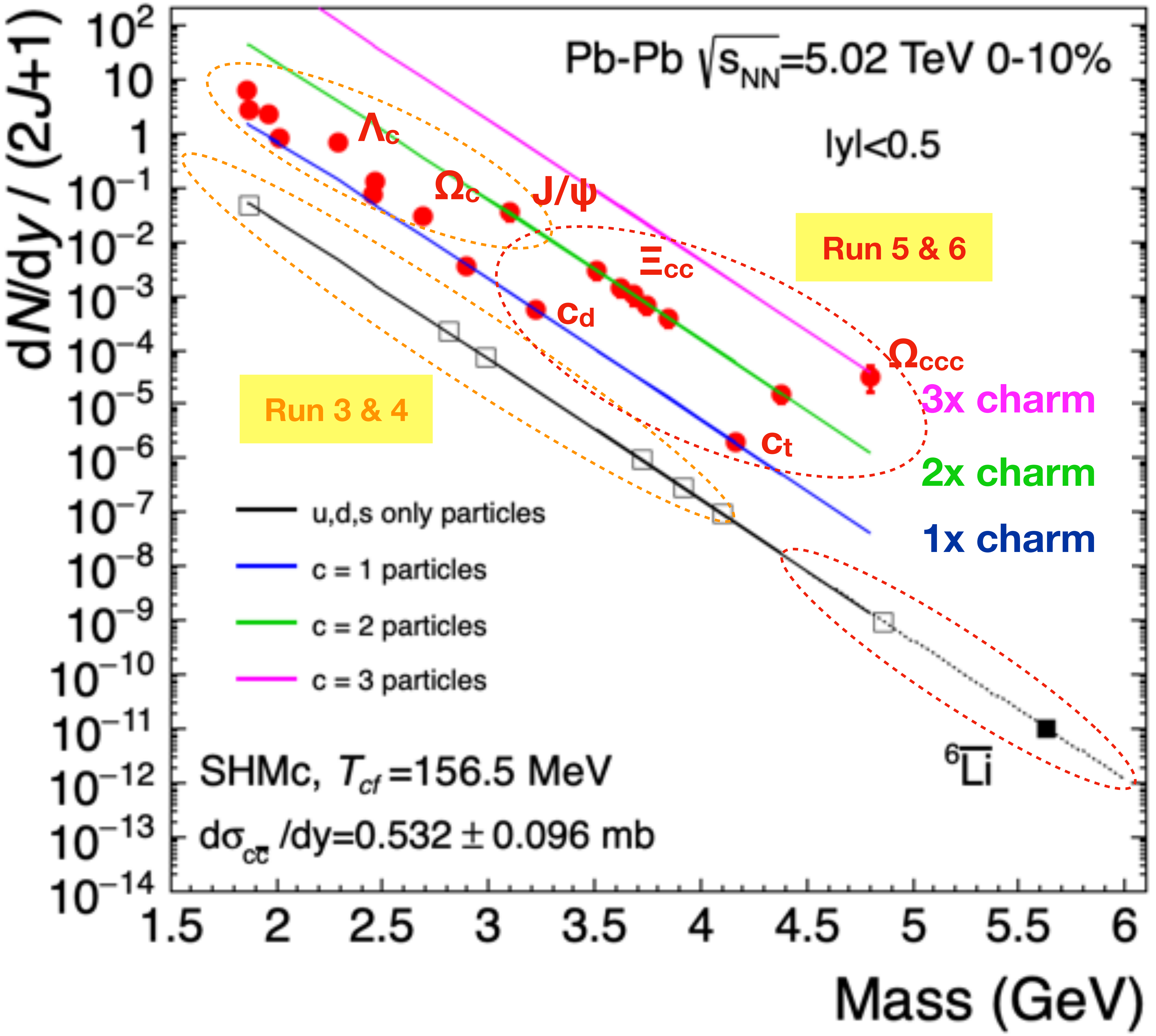


Hadronisation

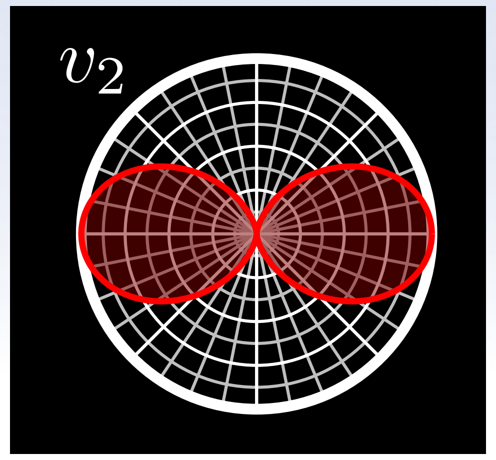
- Hadronic states populated according to **statistical hadronisation** model (T ≈ 156 MeV, μ ≈ 0)
  - (anti-)hypernuclei up to A = 4, single-charm states (c = 1) → **ALICE 2**
  - (hyper-)nuclei with A > 4, multi-charm states (c > 1) → **ALICE 3**
- **Open questions**
  - degree of thermalisation? (charm and beauty)
  - how is thermalisation approached? → dynamics?



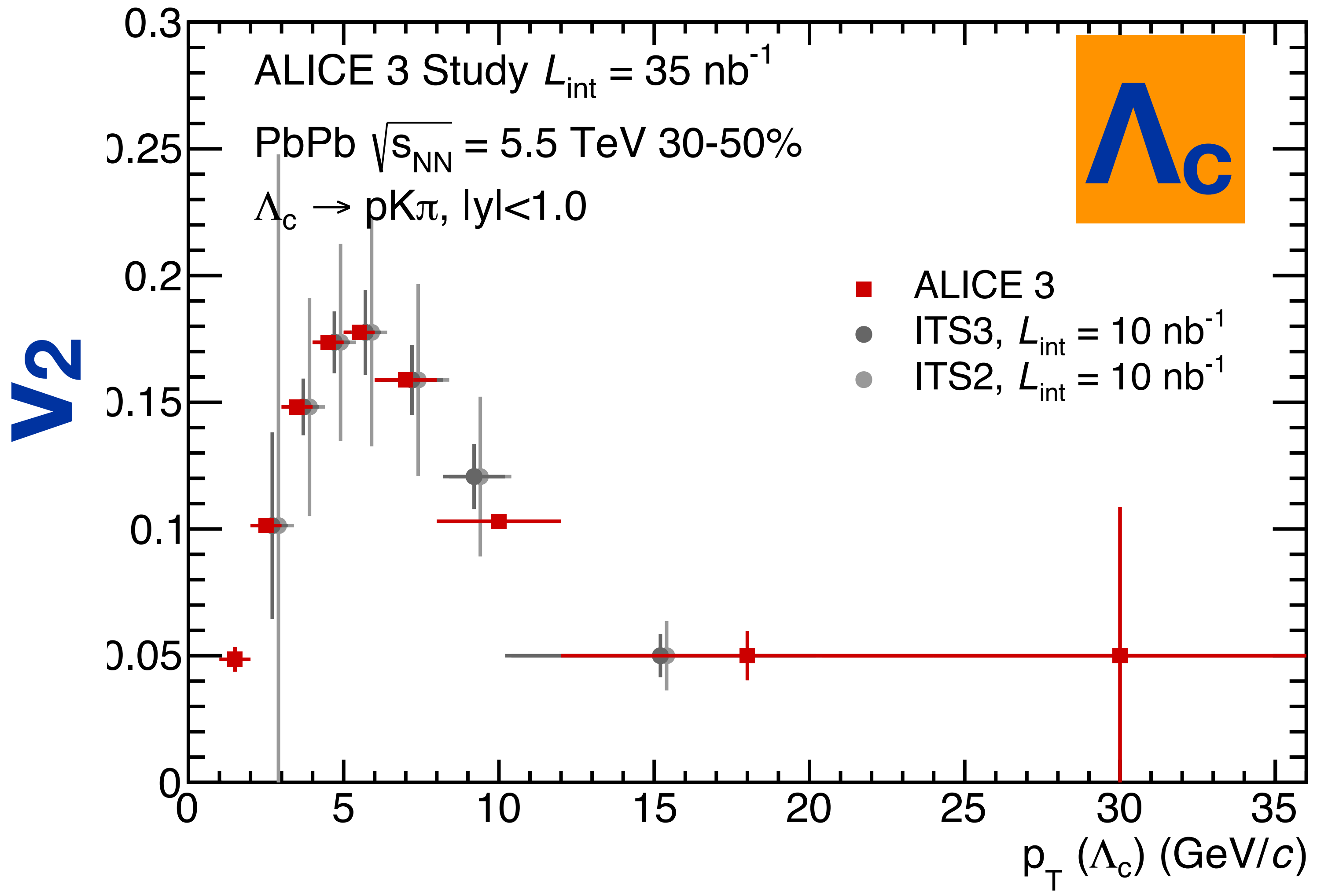
potential for discovery

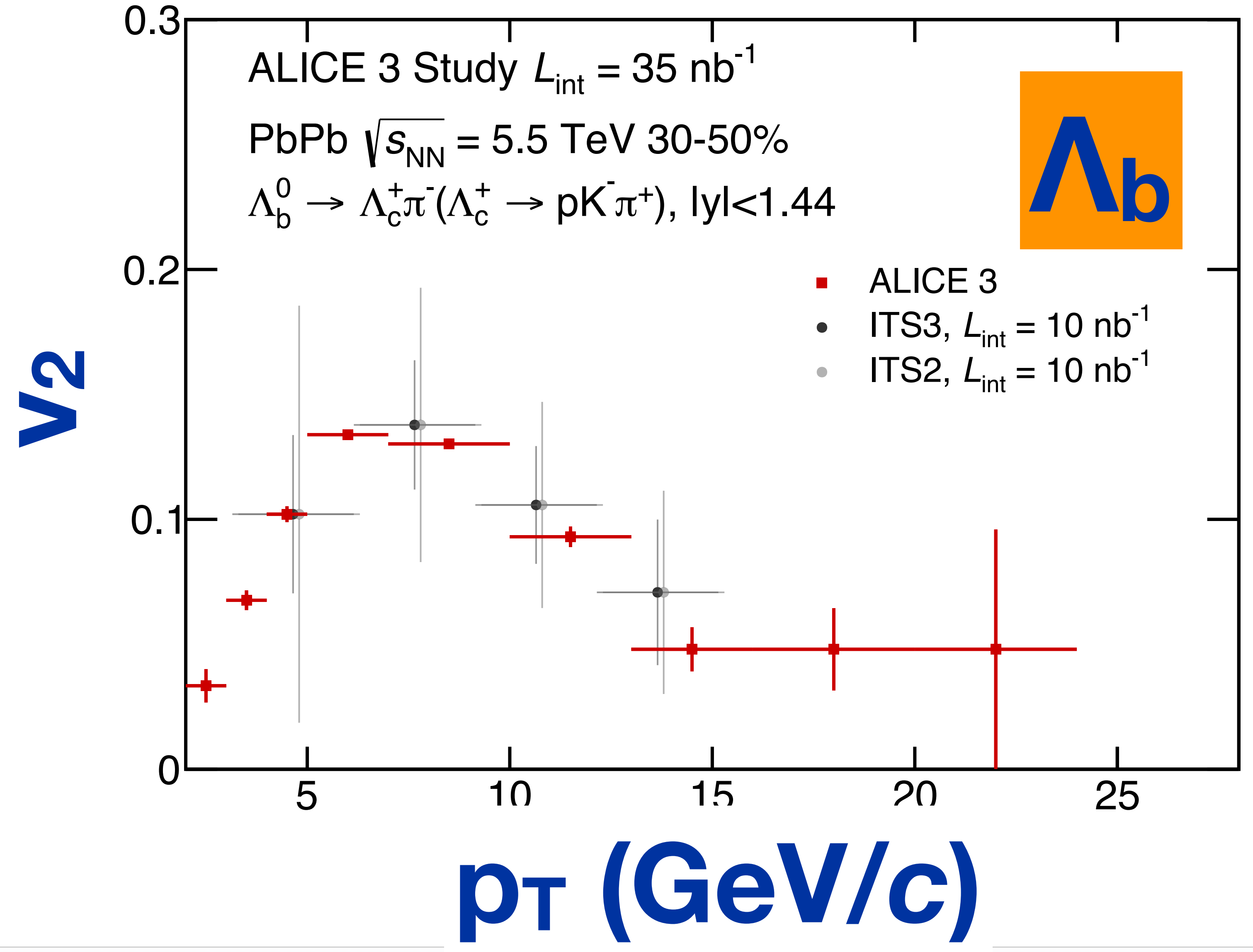


Heavy-quark transport



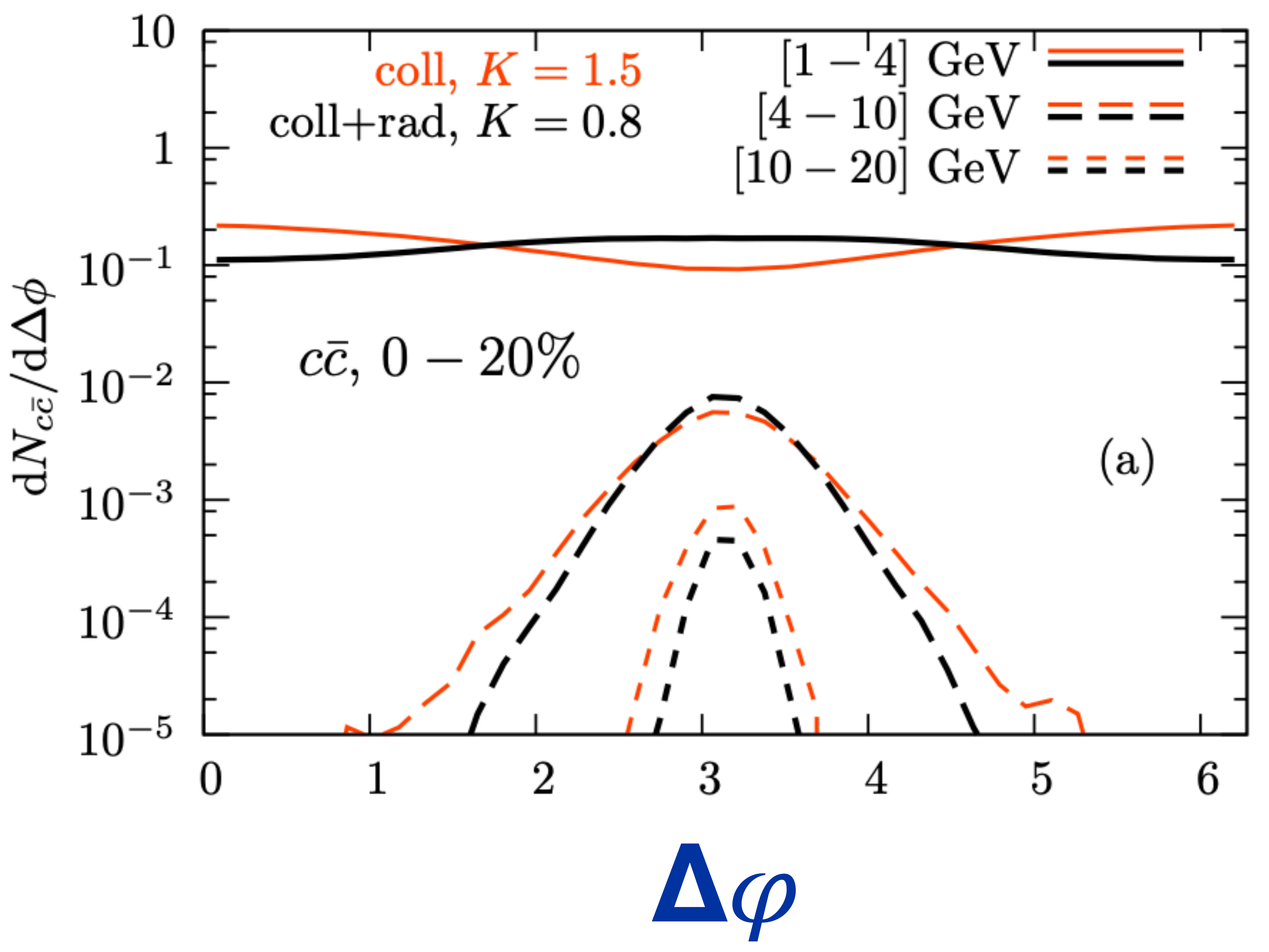
- **Heavy-flavour quarks** produced in initial scatterings then traceable throughout the evolution
- Simultaneous measurement of **R_{AA} and v_2** → diffusion coefficient D_s
- Precise measurements needed for **charm and beauty hadrons**
  - First measurements with charm baryons → ALICE 2
  - Precision measurements for charm and beauty → **require ALICE 3**





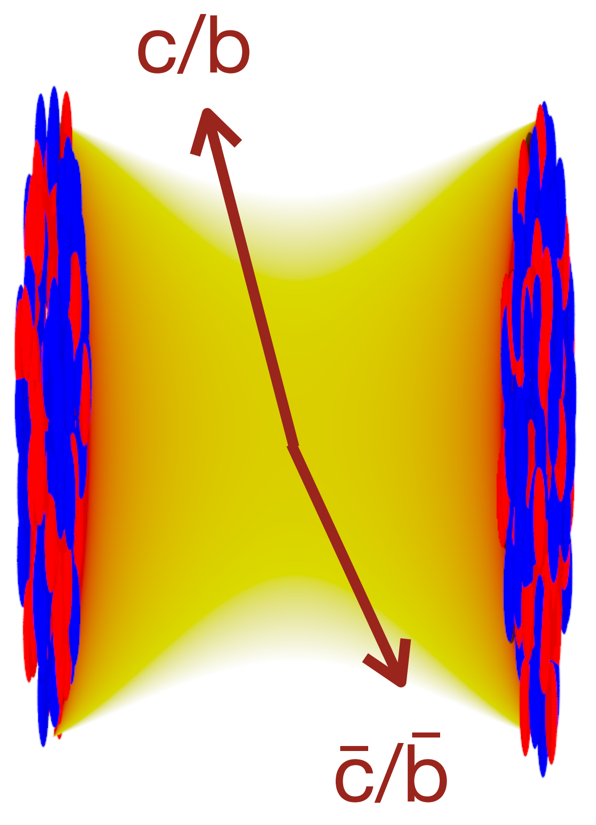
Heavy-quark correlations

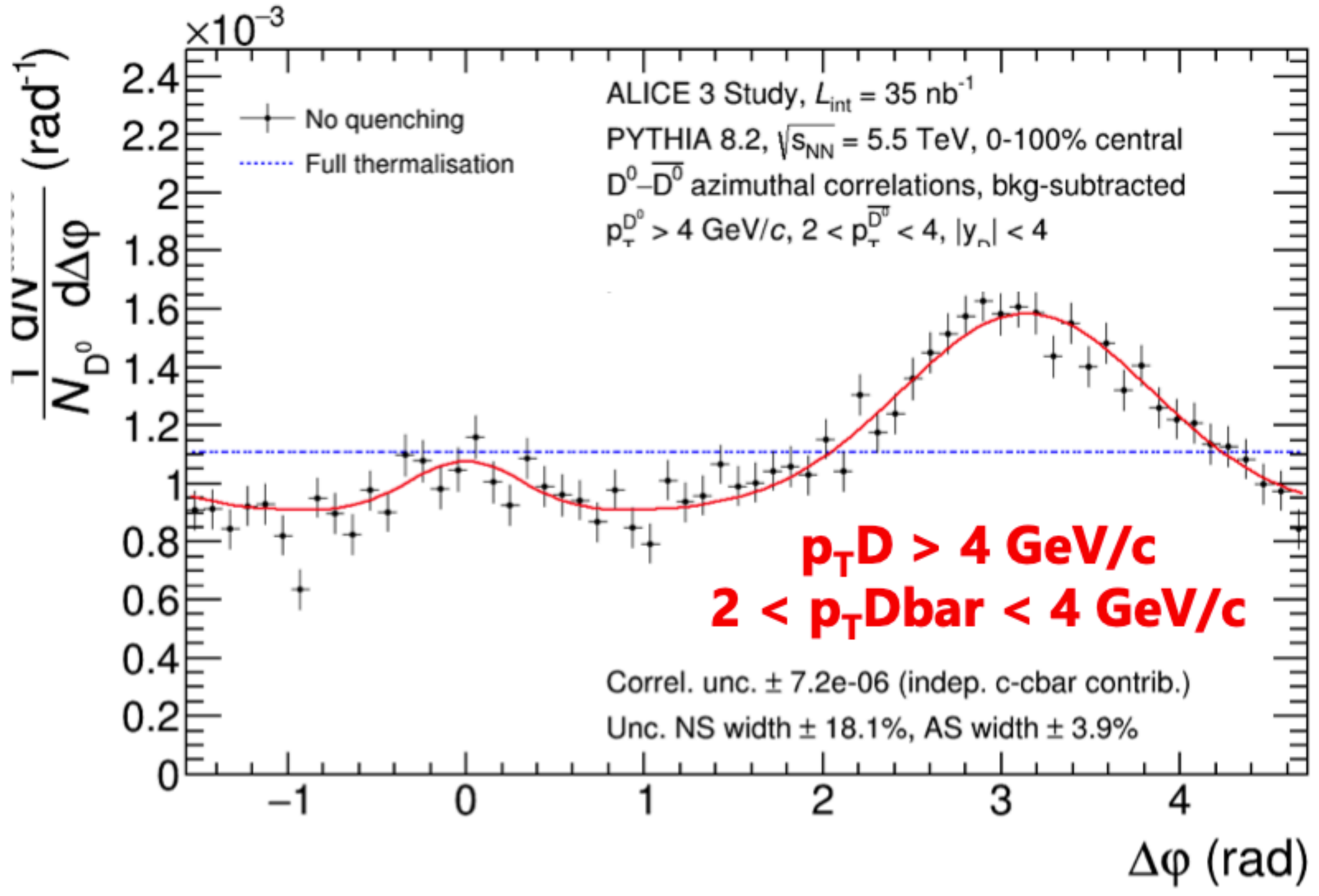
- Azimuthal correlations between $D\bar{D}$, $B\bar{B}$ pairs
  - **Direct access** to interactions with QGP, momentum diffusion, in particular at low p_T
- **Complementary to heavy-flavour flow**
  - Sensitive to **interaction mechanism**, nature of scattering centres



M Nahrgang et al, PRC 90, 024907

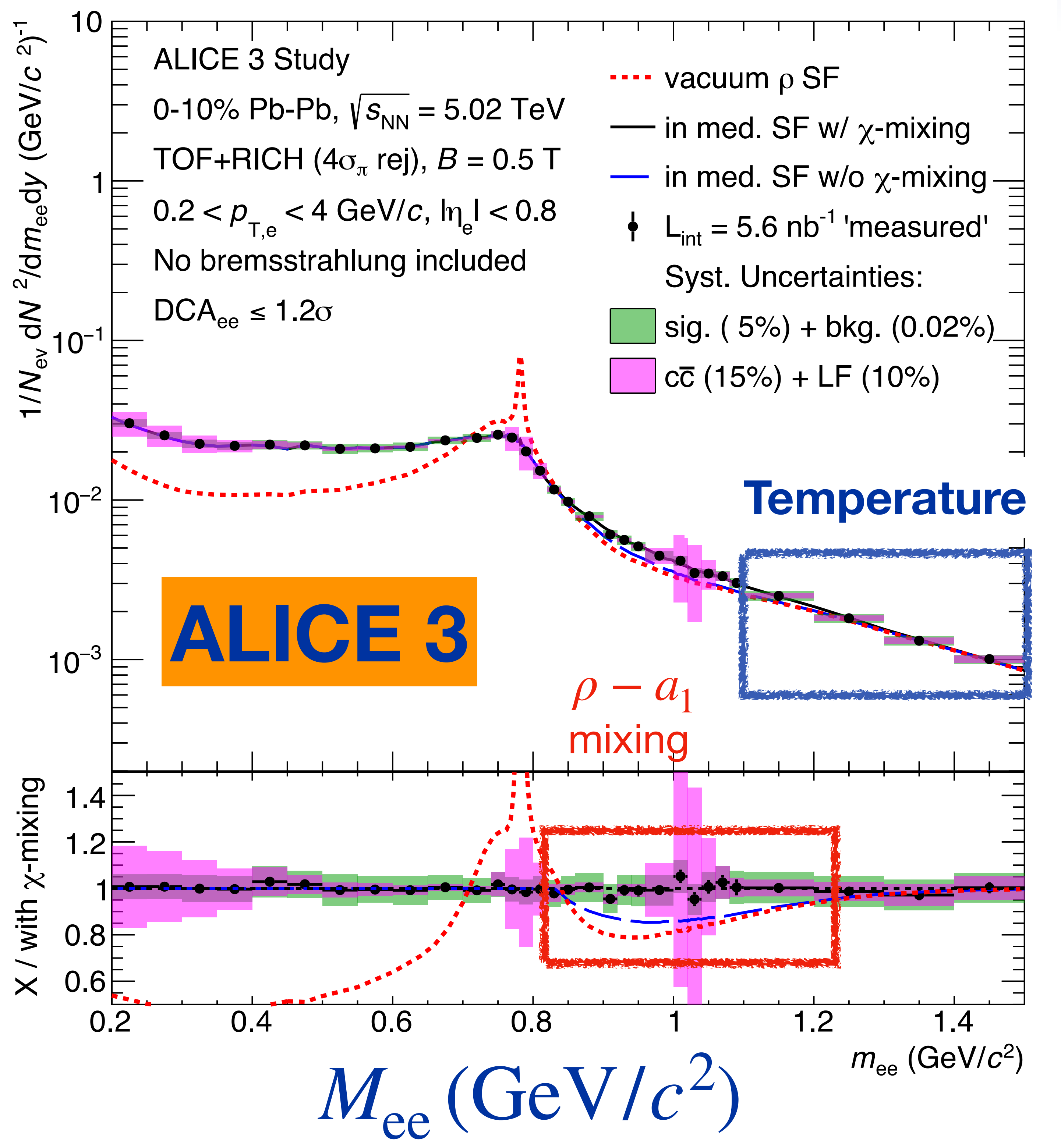
Need large statistics, large purity for D (B) mesons, large η coverage
→ requires ALICE 3

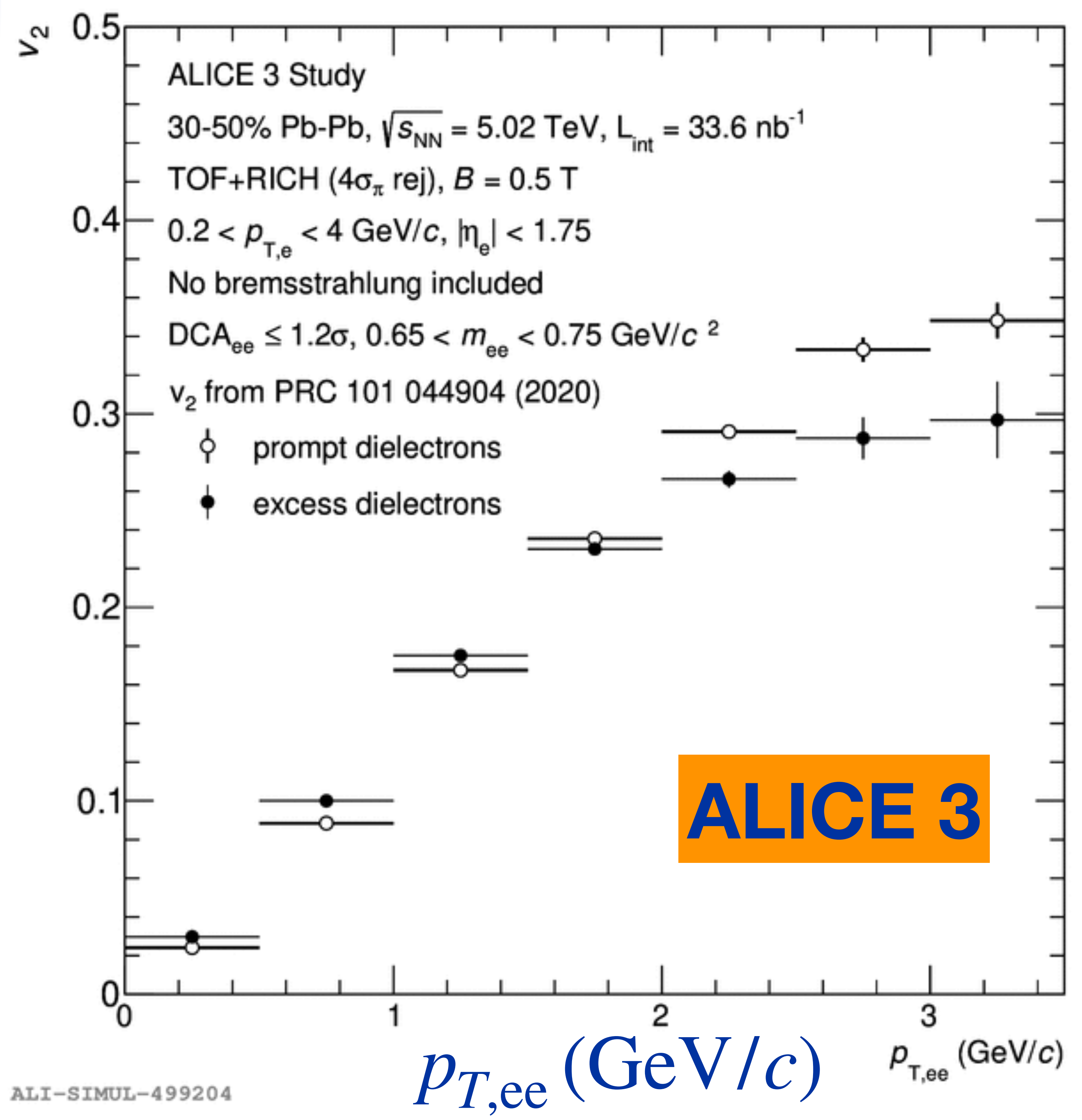




Thermal radiation

- Study early phases, e.g. plasma temperature before hadronisation → dielectrons
- **ALICE 2**: first measurement of **average plasma temperature** ($T_{QGP} \gg T_{fo}$)





- **Complete picture requires precision measurements** (differential in $p_{T,ee}$, v_2)
  - Time evolution and pre-hydrodynamic phase
  - Chiral symmetry restoration
  - Electrical conductivity

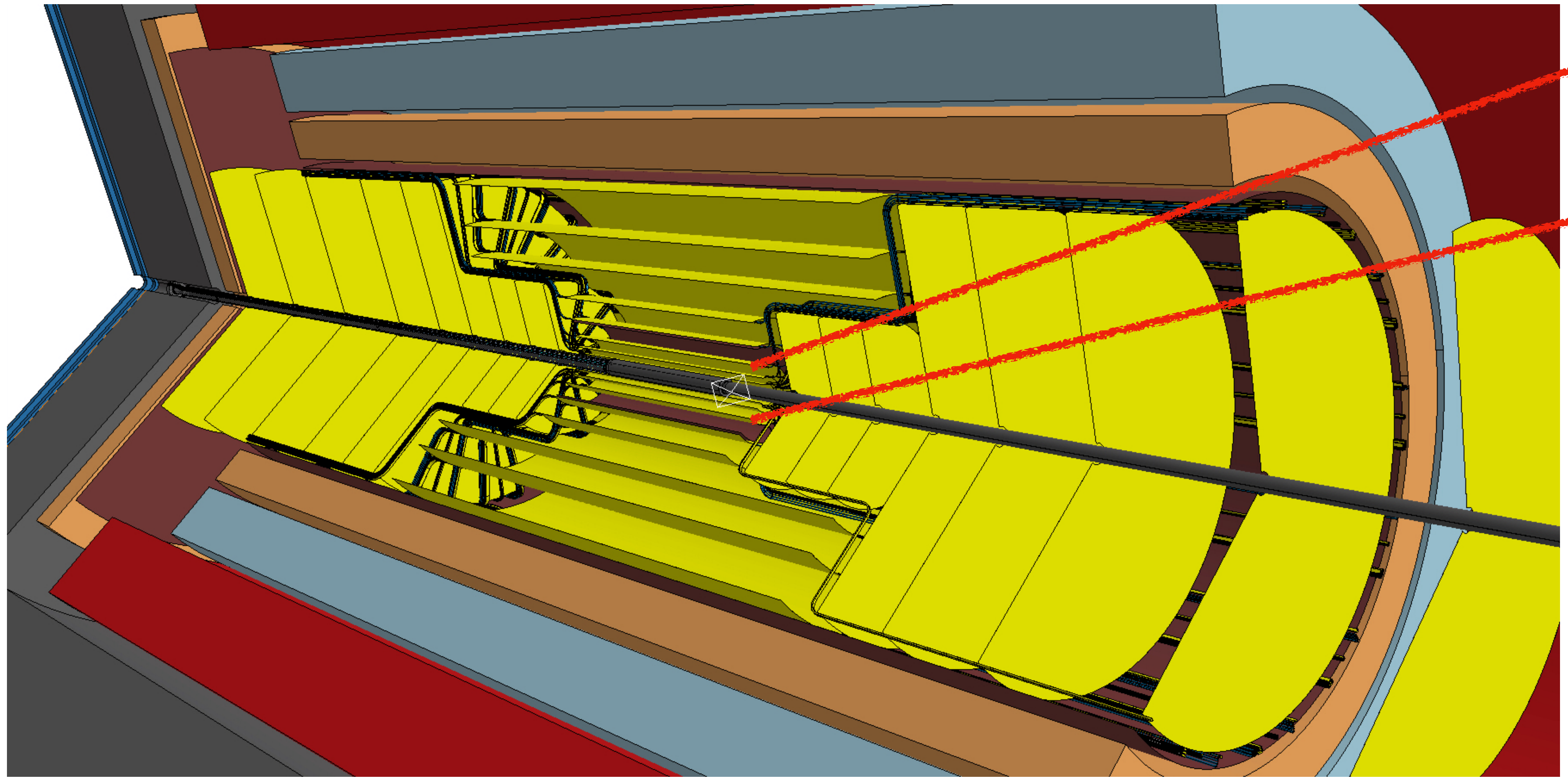
requires ALICE 3

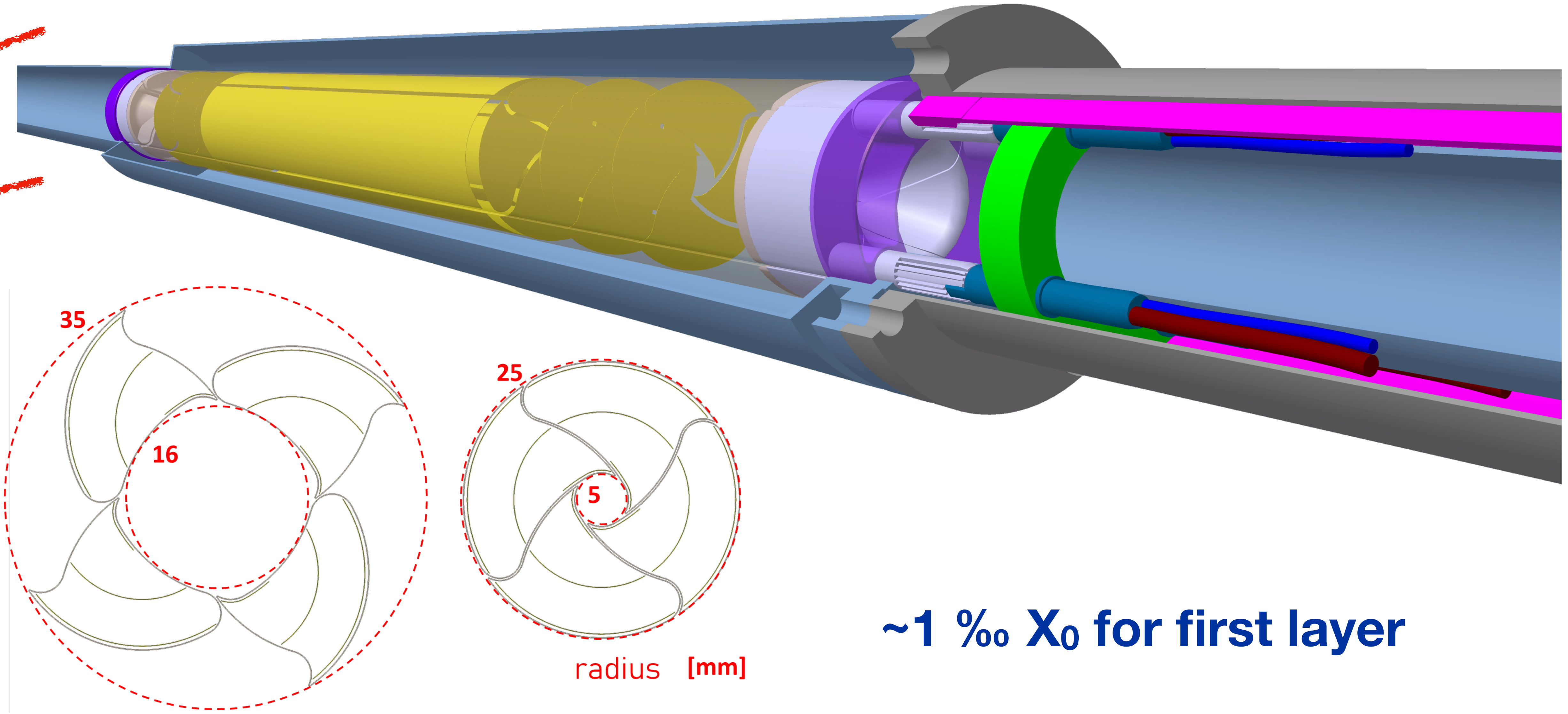
Further ALICE 3 topics

- Higher-order event-by-event fluctuations (incl. charm)
- Charmonium and bottomonium P-wave states
- Nature and production of exotic hadronic states
- Interaction potentials between strange and charmed hadrons
- QGP-like phenomena in small systems
- Ultra-soft photons: experimental test of Low's theorem (infrared limits of gauge theories)
- BSM searches: axion-like particles, dark photons

Broad physics programme for ALICE 3 → Letter of Intent

Tracking and vertexing





Large-area MAPS-based tracker

- ~60 m^2 of CMOS pixel sensors
- next-level detector (w.r.t. ITS2)
  - modularisation
  - powering scheme

Retractable vertex detector

- Bent, wafer-sized CMOS pixel sensors
- new concept
  - cylindrical layers inside the beampipe
    → radiation, beam-induced heating, part of active detector volume

Strategic R&D

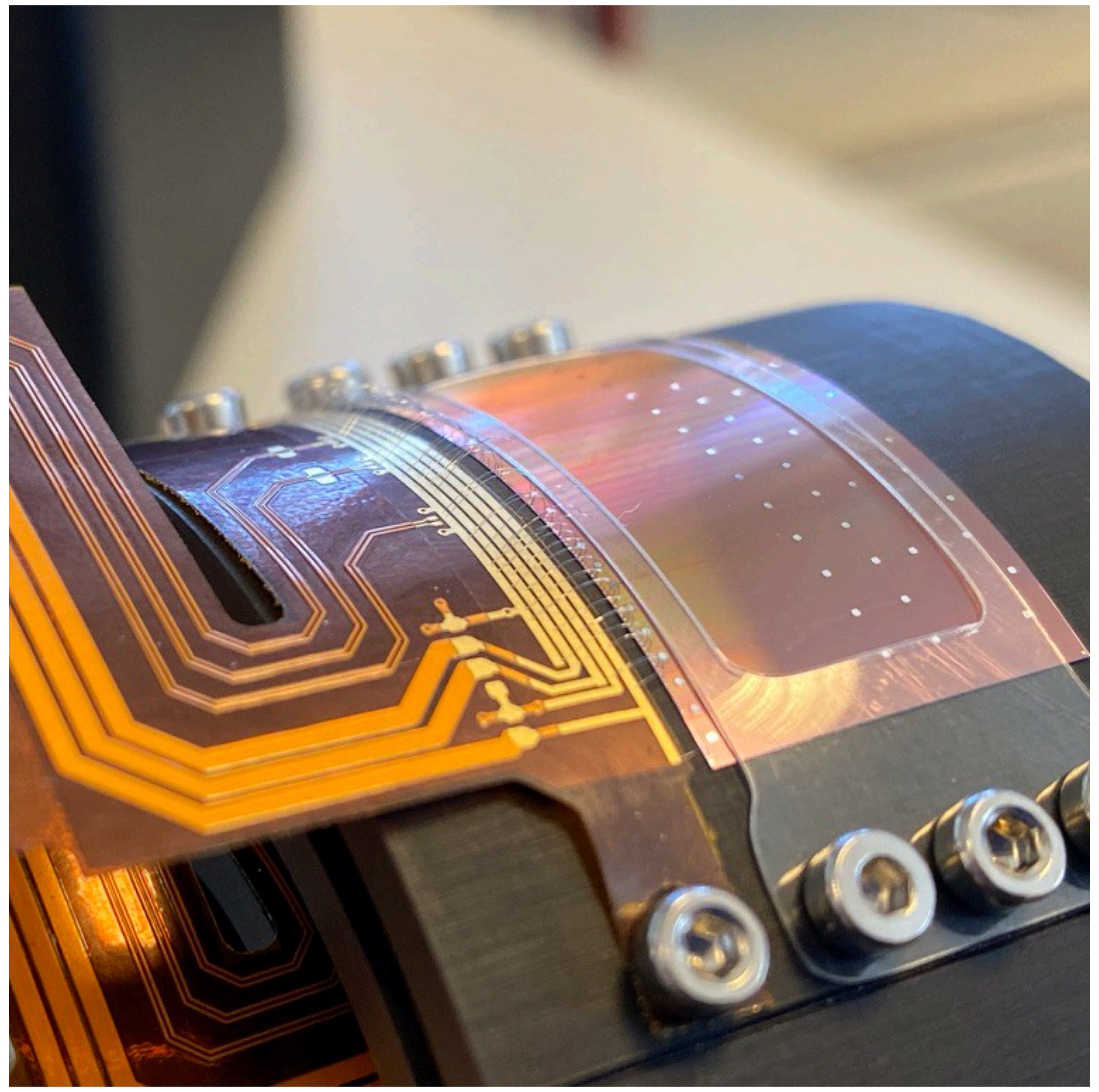
- **Silicon pixel sensors**
  - thinning and bending of silicon sensors
    → expand on experience with ITS3
  - exploration of new CMOS processes
    → first in-beam tests with 65 nm process
  - modularisation and industrialisation

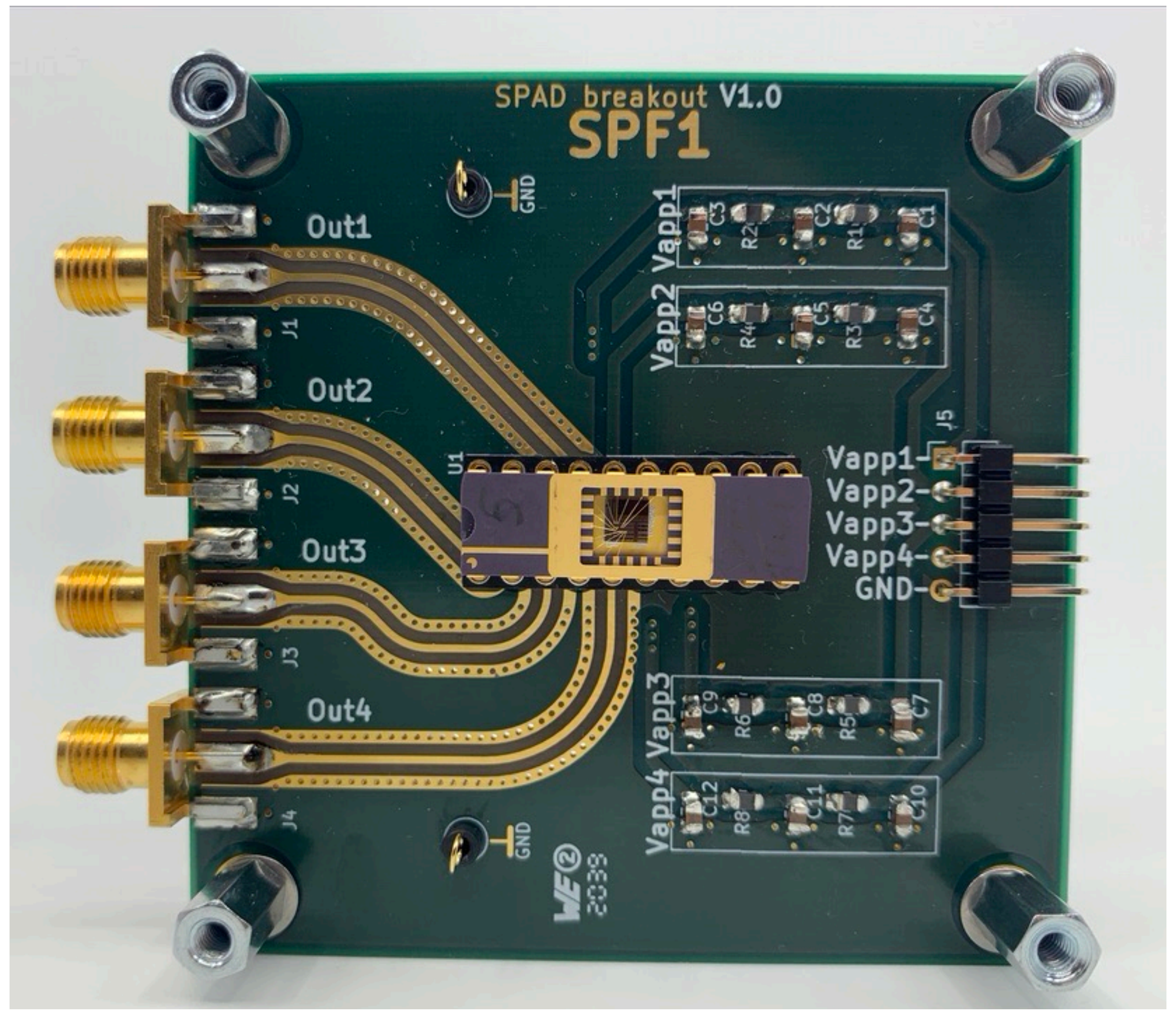
- **Silicon timing sensors**
  - characterisation of SPADs/SiPMs
    → first tests in beam
  - monolithic timing sensors
    → implement gain layer

- **Detector mechanics and cooling**
  - mechanics for operation in beam pipe
    → establish compatible with LHC beam
  - minimisation of material in the active volume
    → micro-channel cooling

Unique and relevant technologies

→ Synergies with LHC, FAIR, EIC, …





Conclusions

- **ALICE 2 (Run 3 & 4)**
  - major upgrades installed, commissioned, tested with pilot beam (on schedule, in budget)
  - ready for rich physics programme (Pb-Pb & pp)
- **ALICE 3 (Run 5 & 6)**
  - **required to** unravel microscopic dynamics of the QGP, e.g.
    - mechanisms of hadronisation
    - QGP evolution and transport properties
    - mechanisms of chiral symmetry restoration
  - **innovative detector concept** to meet the requirements for the ALICE 3 physics programme
  - **Letter of Intent** under LHCC review, expected to converge early 2022

- **Germany plays a key role** in the heavy-ion programme at the LHC
- **Full exploitation of the LHC** crucial to address fundamental questions of QCD
- Access and know-how on **unique and relevant technologies**
- **LHC and FAIR programmes** complement each other → unique role for Germany

Thank you for your attention!