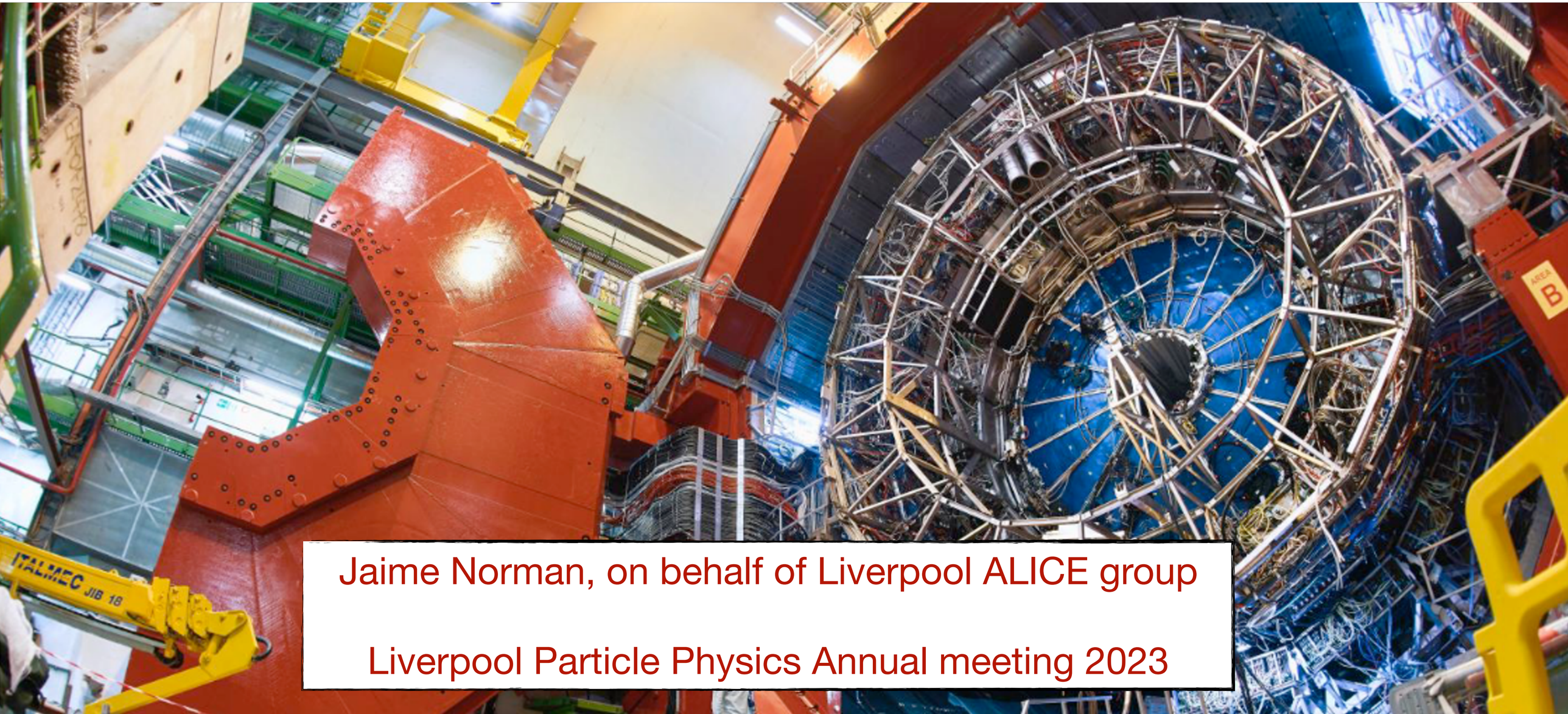
ALICE - A Large Ion Collider Experiment

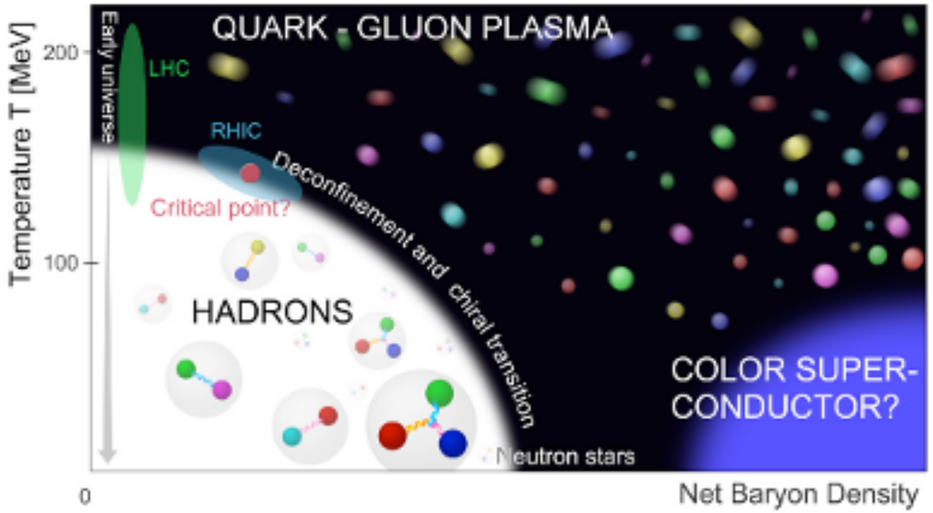


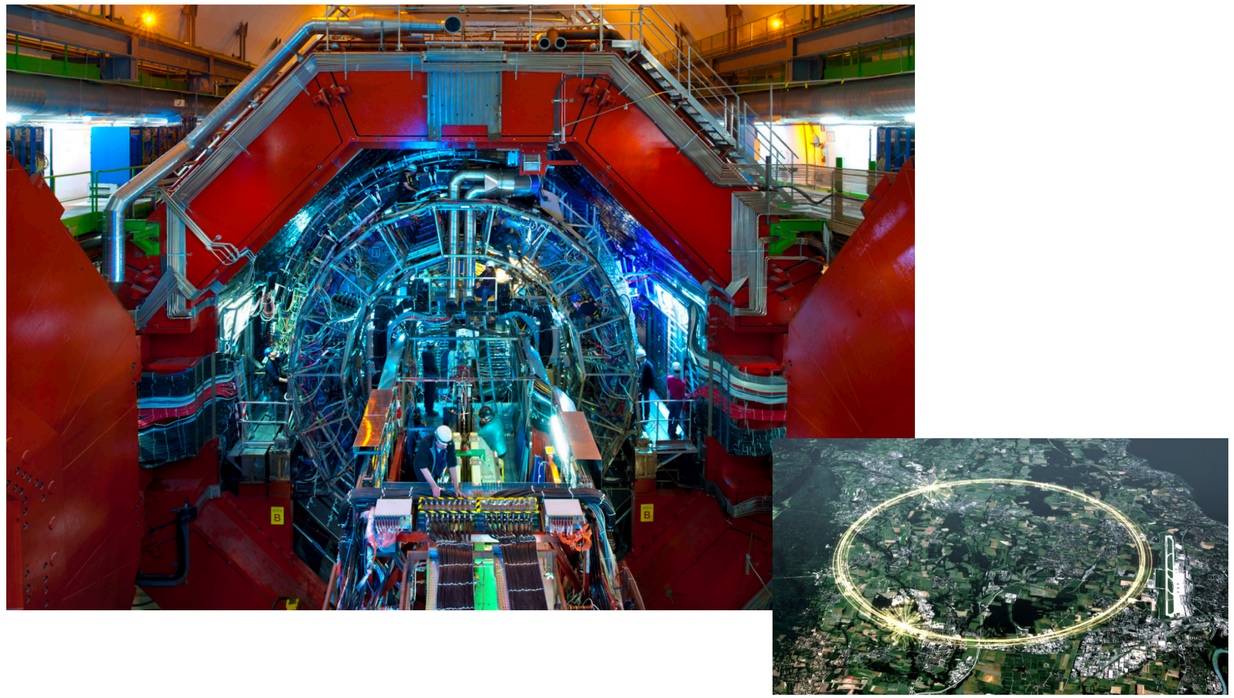
Jaime Norman, on behalf of Liverpool ALICE group

Liverpool Particle Physics Annual meeting 2023

ALICE and the Quark-Gluon Plasma

- Phase transition at high energy density/temperature to deconfined state of quarks and gluons
  - **Quark-Gluon Plasma (QGP)**
- Created in the lab using **ultra-relativistic heavy-ion collisions**
- ALICE is the LHC experiment designed to study heavy-ion collisions and the QGP
  - Physics program cover a broad range of QCD measurements





- Liverpool involvement in heavy-flavour and jet measurements, silicon tracker R&D and construction, silicon tracker run coordination, data QA…

Who are we?

Marielle Chartier

Danny Jones
1st year PhD

Clara Bartels
4th year PhD

Jaime Norman
PDRA

John Dainton
(Liverpool + Daresbury)

Jonathan Witte
BSc student (DE)

Roy Lemmon
(Daresbury Lab, visiting professor)

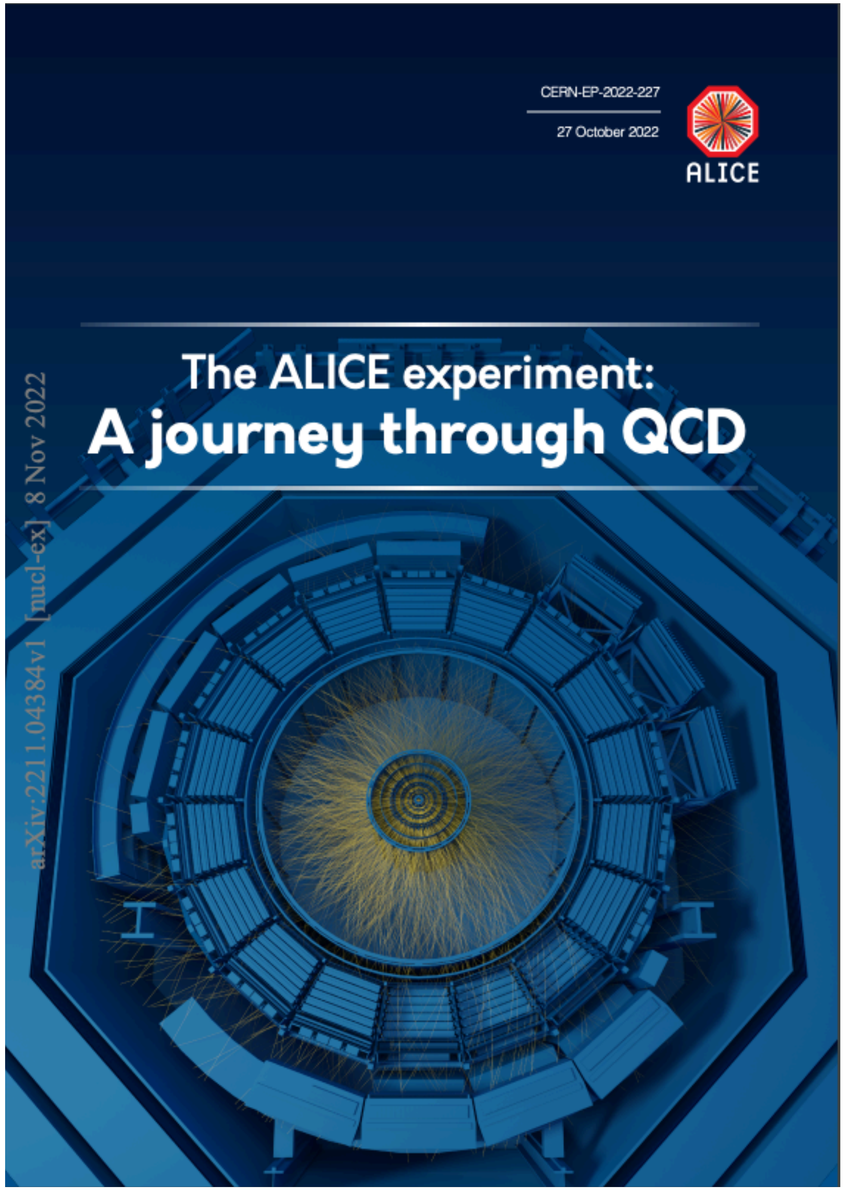
Jian Liu
PDRA

- **Leadership roles within the collaboration**
  - Marielle:
    → Collaboration board chair, 2022-2025
  - Jian:
    → ITS system run coordinator, July 2021 - June 2022
    → Data preparation group Quality Control coordinator from Jan 2023
  - Jaime
    → physics convenor - jet and hard photon analyses, Nov. 2021 - 2023

ALICE physics

arxiv:2211.04384

- **> 400 papers from Run 1 and 2 of the LHC**
- Recent review paper summarises the wealth of physics from this period



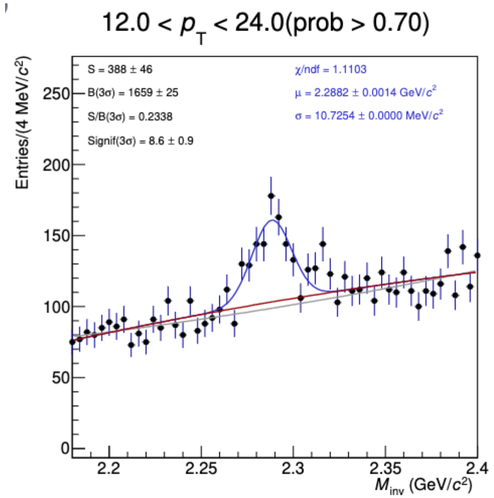
Charmed baryon production in Pb-Pb collisions

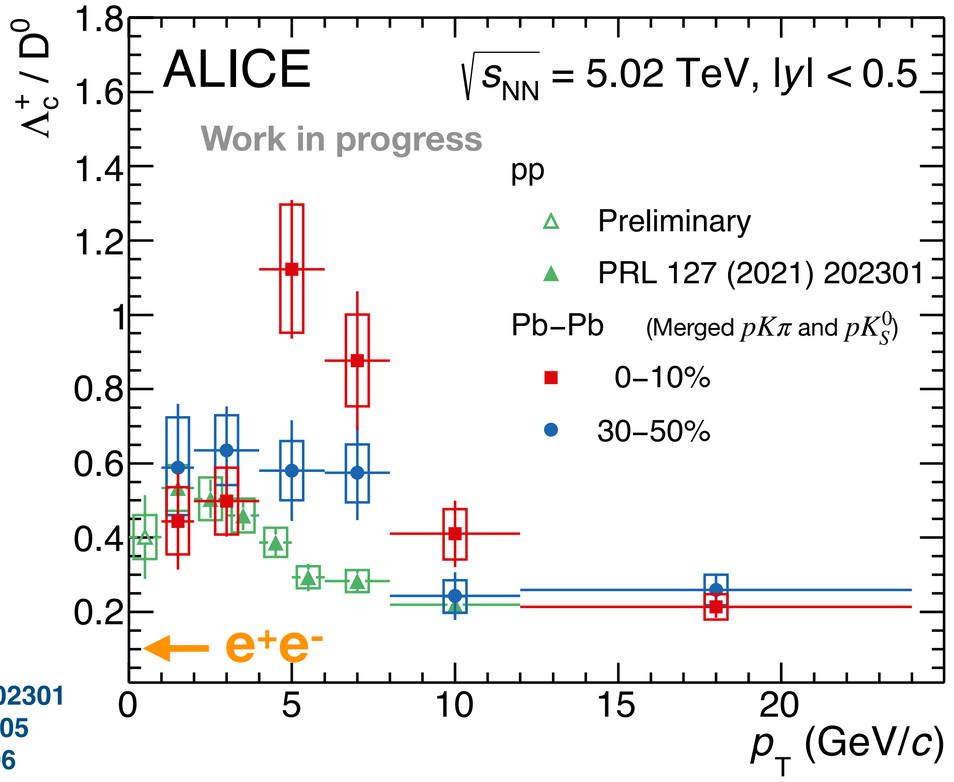
Clara, Jaime

Probe hadronisation in the QGP through charm hadron / baryon-to-meson production ratios

- Λ_c^+ production yield measured in Pb-Pb collisions via $\Lambda_c^+ \rightarrow pK^-\pi^+$ decay channel
- Challenging analysis! 3-body decay, huge combinatorial background in Pb-Pb collisions…
  - Optimised selection of Λ_c^+ signal using ML (BDT / XGBoost)
- Combine with $\Lambda_c^+ \rightarrow pK_S^0$ decay channel for significant stat. unc. improvement
- **Concludes the Λ_c^+ production 'story' from Run 1 and 2**

See Clara's poster for more information!



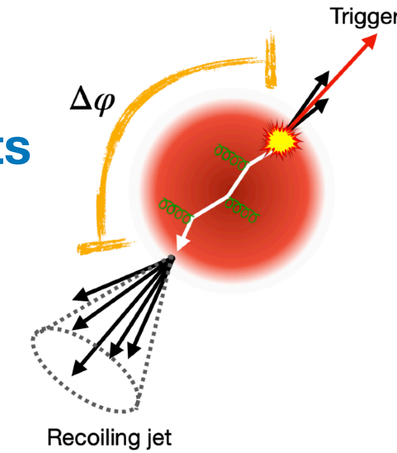


Phys. Rev. Lett. 127 (2021) 202301
Phys. Rev. C 104 (2021) 054905
Phys.Lett.B 839 (2023) 137796

Jet measurements in Pb-Pb collisions

Jaime, Roy, Danny

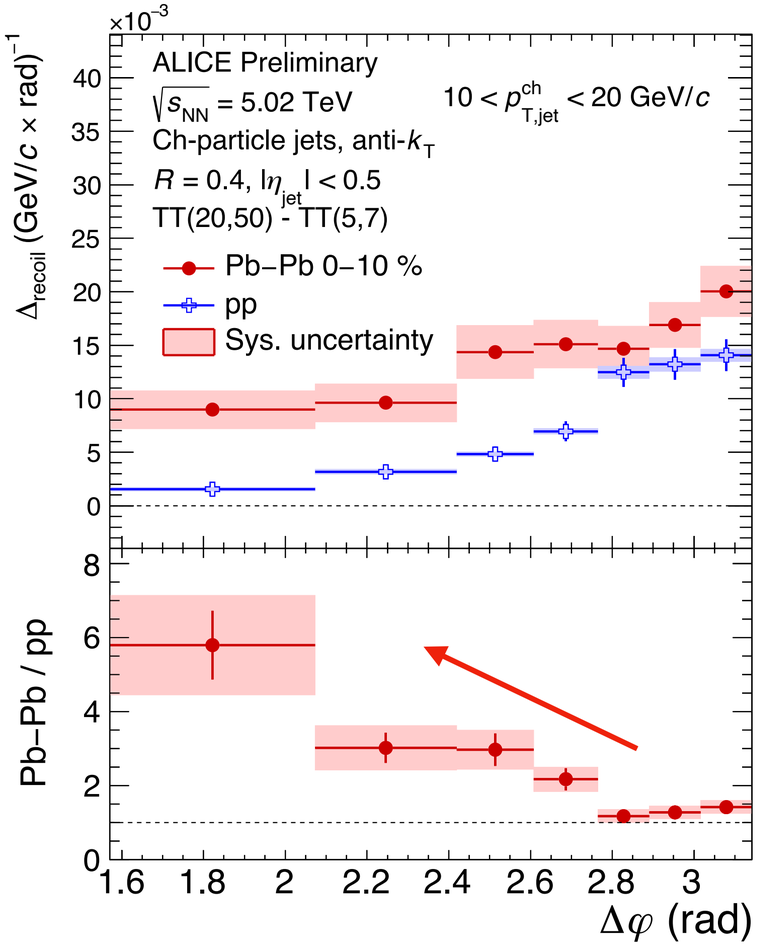
Probe the short-distance structure of the QGP using jets



- Dijet acoplanarity through hadron+jet measurement
- Novel techniques developed to subtract huge combinatorial background in heavy-ion collisions, to access low-p_{T} jets:

$$\Delta_{\mathrm{recoil}} = \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^3 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\Delta\varphi \mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}_{\mathrm{Sig}}} - c_{\mathrm{ref}} \cdot \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^3 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\Delta\varphi \mathrm{d}\eta_{\mathrm{jet}}}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}_{\mathrm{Ref}}}$$

- **(first) significant medium-induced azimuthal broadening observed in Pb-Pb collisions**
  - In-medium ‘scattering’? Medium response? Discussion ongoing…



ALI-PREL-540382

- **Finalising Run 2 jet analyses + Run 3 activities starting:**
  - Coordinating Run 3 MC QA
  - Starting ‘Lund Plane’ analysis - jet substructure modification in QGP

Papers expected this year
(including model studies from Danny!)

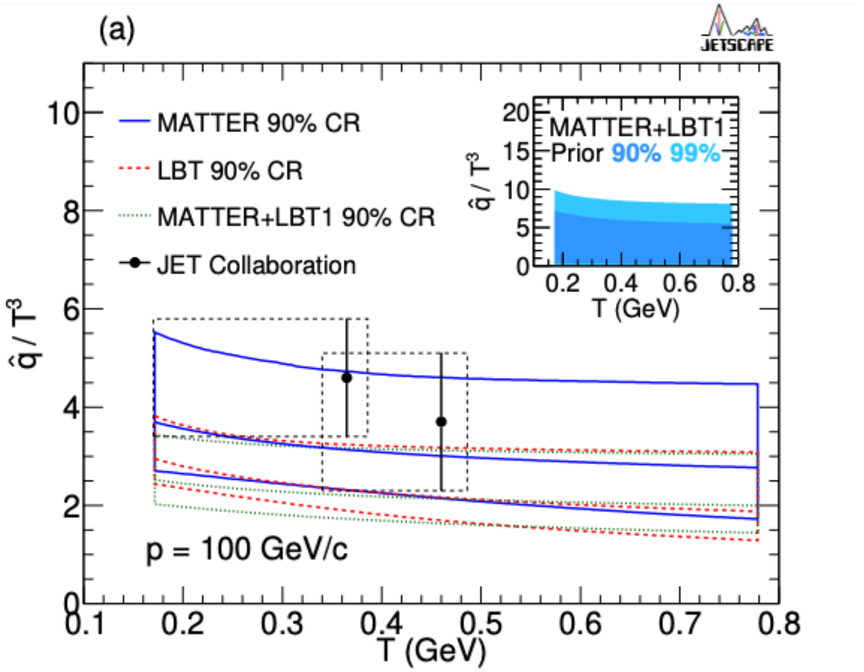
Connecting measurement to theory with JETSCAPE

Roy, Jaime

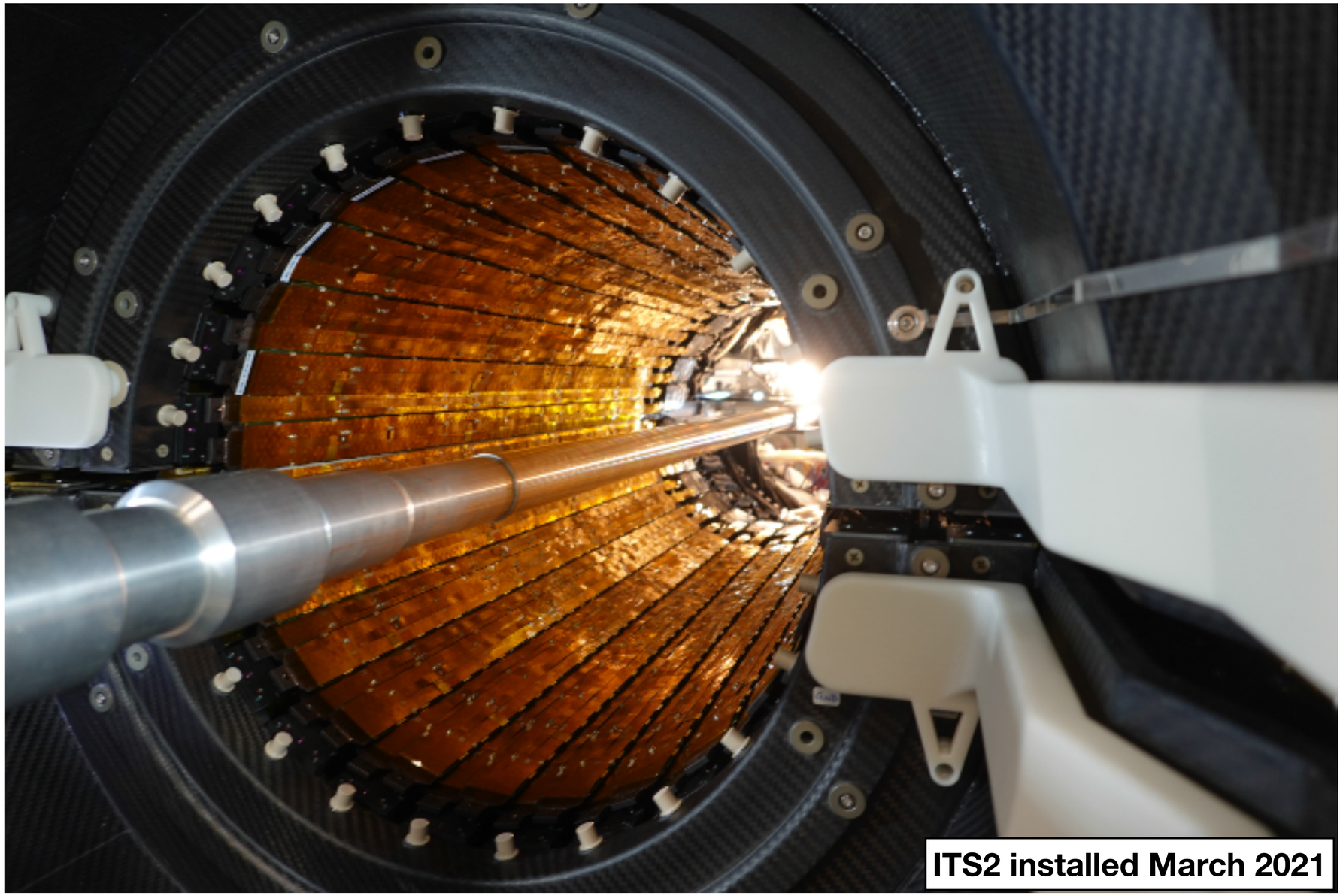
Interdisciplinary collaboration developing state-of-the art, modular event generator framework simulating heavy-ion collisions

- **Quantitative constraints of QGP properties** combining measurements of different observables from different experiments a **big goal in the field**
  - **Bayesian parameter estimation** pioneered by **JETSCAPE collaboration**
- Joined JETSCAPE as associate members and currently exploring options to acquire significant HPC allocation in UK (DiRAC/IRIS)
  - Used DiRAC seedcorn allocation to successfully demonstrate feasibility to run large-scale simulations on UK facilities

Phys. Rev. C 104, 024905 (2021)



ALICE Inner tracker - current and future status



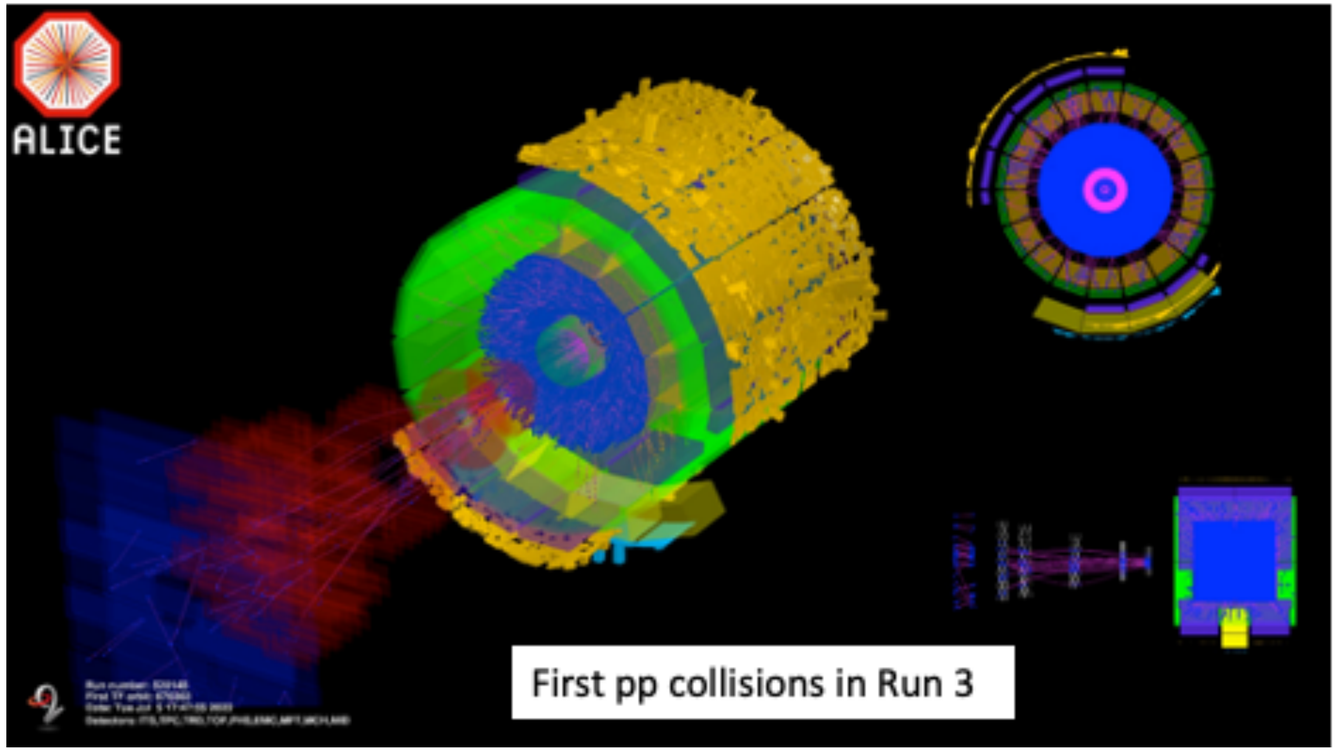
ITS2 operation and Run 3 data preparation

Jian

Successful data taking in the first phase of the LHC Run 3 after significant upgrade campaign!

- **Excellent detector performance**
- Data processing and calibration workflows fully functional
- Detector/reconstruction validated with Pb-Pb pilot run at end of 2022
  -> preparation for full Pb-Pb run starting at the end of 2023

- Coordination of the detector commissioning, operation, and data taking
  - Also coordinating asynchronous Quality Control (A-QC) in ALICE data preparation group
    - Review reconstruction quality from sub-detectors/PWGs, workflow maintenance + run condition table development



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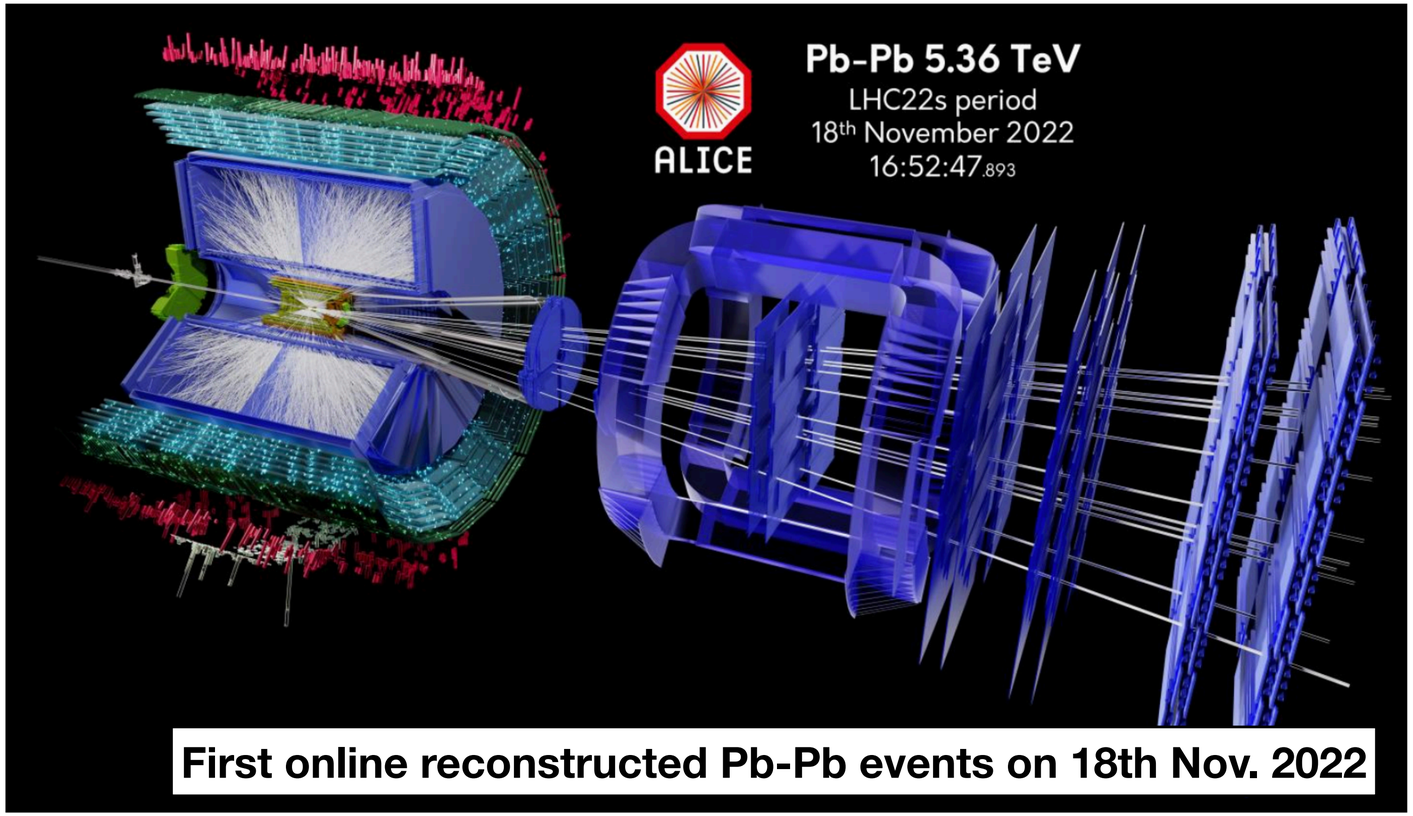


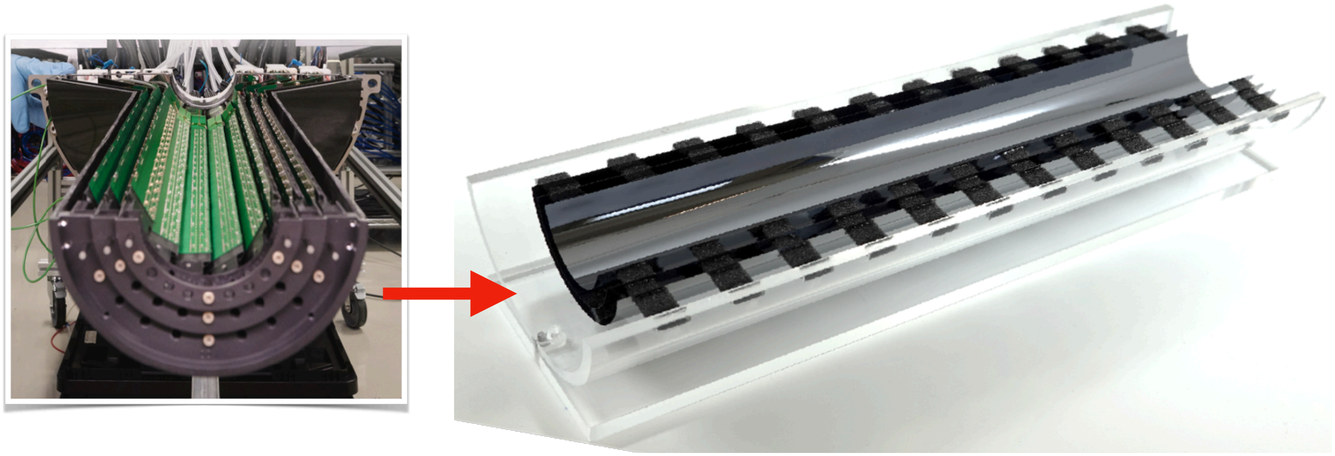
ITS3 concept and R&D

Jian, Danny, Jonathan

Replacing the ITS2 inner barrel for Run 4 (2029-2032)

- **bent, wafer-scale CMOS (MAPS) sensors**
  - Extremely low material budget 0.02-0.04% X_0
  - Homogeneous material distribution
- x2 improvement in pointing resolution,
  large improvement in tracking efficiency at low p_T

APTS test system



- Liverpool involvement with sensor characterisation
  - APTS laboratory tests in LSDC with ^{55}Fe and ^{90}Sr
  - Beam tests at CERN PS and SPS
  - Software development and test beam data analysis

ITS3 LOI: CERN-LHCC-2019-018

ITS3 physics projection studies

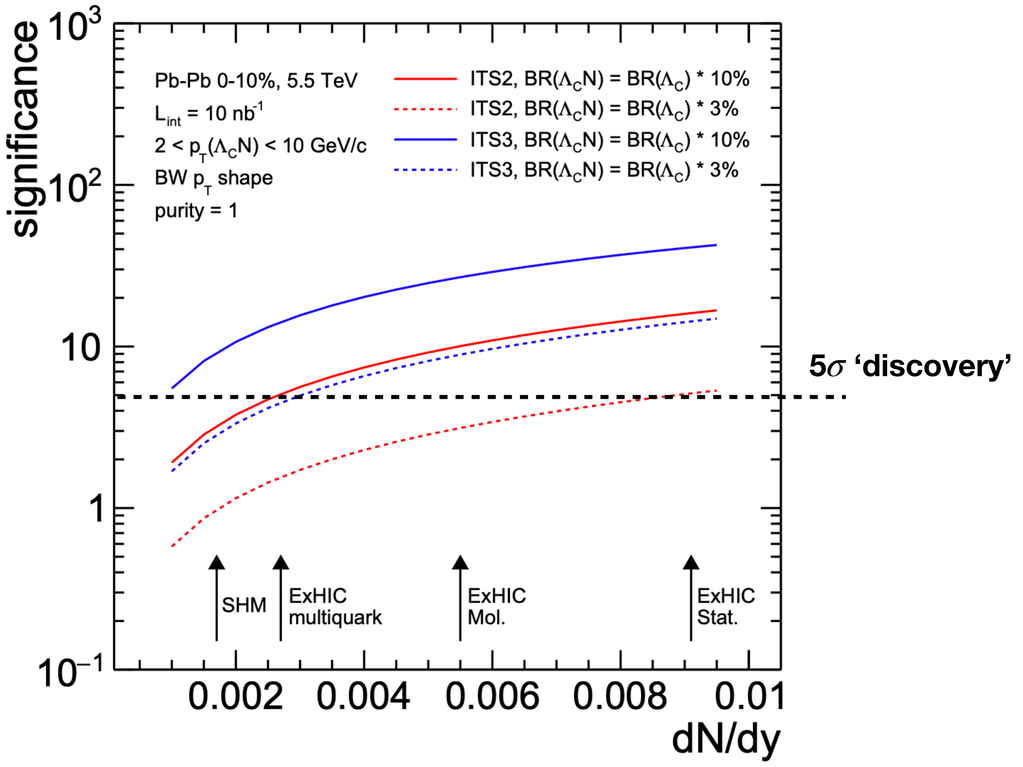
Matt, Jaime

Can nuclei containing charm quarks exist?

- Heavy-ion collisions provide excellent way to produce exotic hadrons + composite particles
- Lightest possible charmed hyper-nucleus - ‘C-deuteron’ - bound state of neutron + Λ_c^+ baryon

→ **Factor 2 improvement in decay length resolution**

→ **Factor ~3 improvement in statistical significance of c-deuteron**



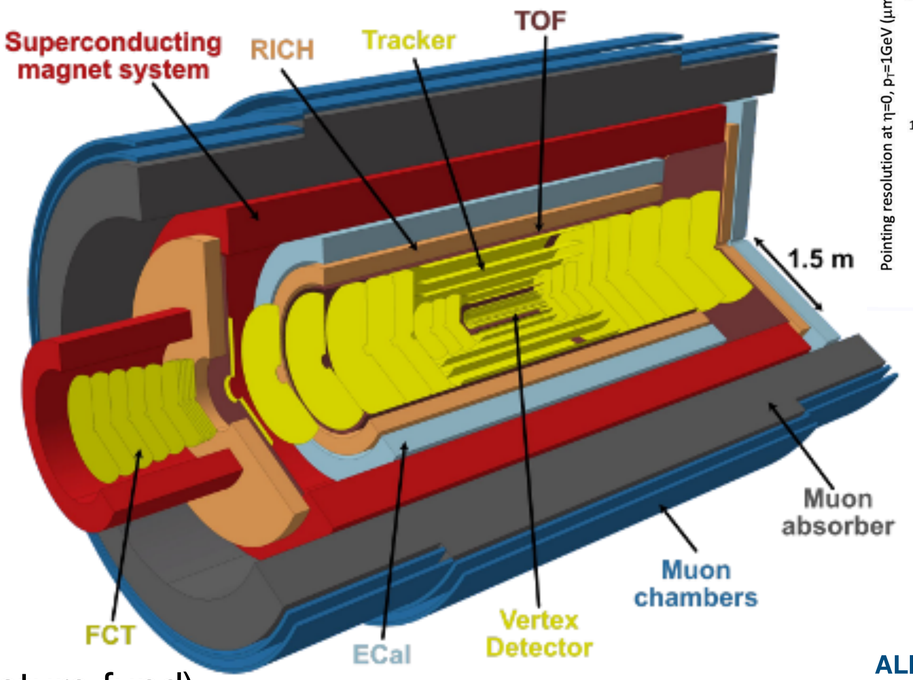
Public note presenting studies of ITS3 physics performance out soon

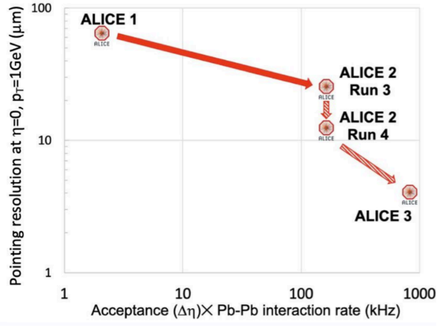
- significant improvement to measurement of low-momenta beauty + charm hadrons, exotica and hypernuclei, low-mass di-electrons, and more

ALICE3

The next-generation heavy-ion experiment for LHC Run 5 and 6 (2035 onwards)

- Novel and innovative detector concept
  - Compact and lightweight all-silicon tracker
  - Retractable vertex detector
  - Extensive particle identification
  - Large acceptance
  - Superconducting magnet system
  - Continuous read-out and online processing

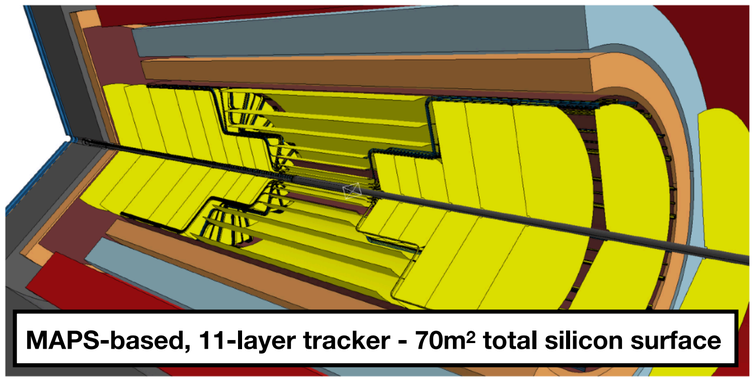




ALICE3 LOI: CERN-LHCC-2022-009

Innovative technologies relevant for future particle physics experiments

- Synergies with EIC (R&D funded through UKRI large infrastructure fund)
- Larger UK collaboration shown interest in the silicon tracker
  - Birmingham, Derby, Lancaster, Liverpool, Queen Mary UK, STFC (PPD, TD@DL & RAL). Also approaching Glasgow, Oxford, Edinburgh
  - All have technical interest in contributing to SVT project
- Extensive Liverpool experience in ATLAS, LHCb and ALICE SVTs



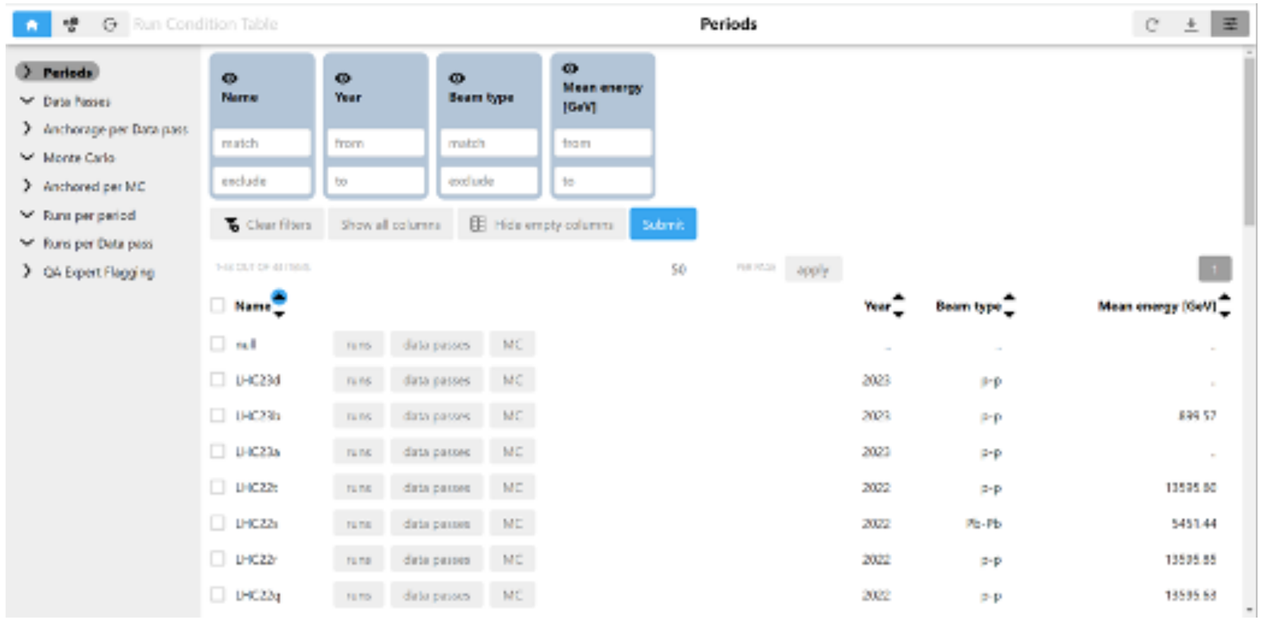
30 years since ALICE LOI!

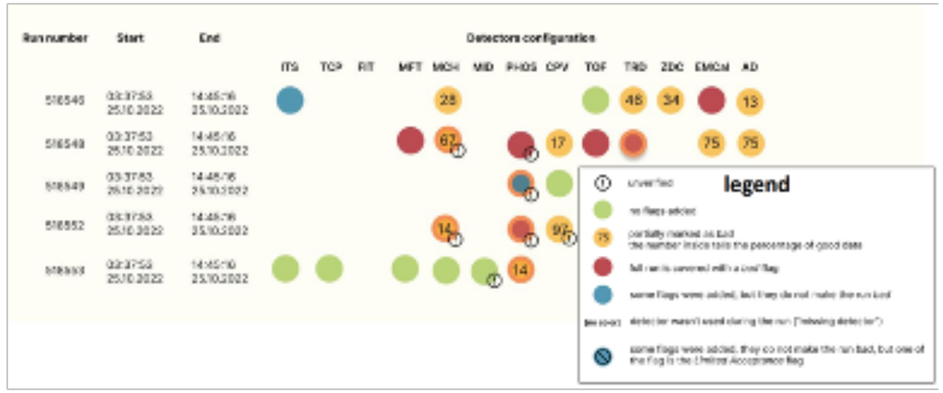
Here’s to the next 20(ish) years!

Backup

ALICE data preparation

- Coordination of asynchronous Quality Control (A-QC) in data preparation group (DPG)
  - Review of data reconstruction quality from sub-detectors and PWGs
  - A-QC workflow maintenance
  - Coordination of ALICE Run Condition Table (RCT) development
    - Javascript based framework for automatic run quality aggregation





ALICE3 silicon vertex tracker

MAPS-based, 11-layer tracker - 70m^2 total silicon surface

- Larger UK collaboration shown interest in the tracker
  - Birmingham, Derby, Lancaster, Liverpool, Queen Mary UK, STFC (PPD, TD@DL & RAL). Also approaching Glasgow, Oxford, Edinburgh
  - All have technical interest in contributing to SVT project
- Sensor design: RAL Microelectronics already involved in design of ITS3 sensor
- Sensor characterisation
- Module and stave design and fabrication
- Module testing and integration
- Construction and industrialisation
- Powering and cooling schemes
- Extensive Liverpool experience in ATLAS, LHCb and ALICE SVTs