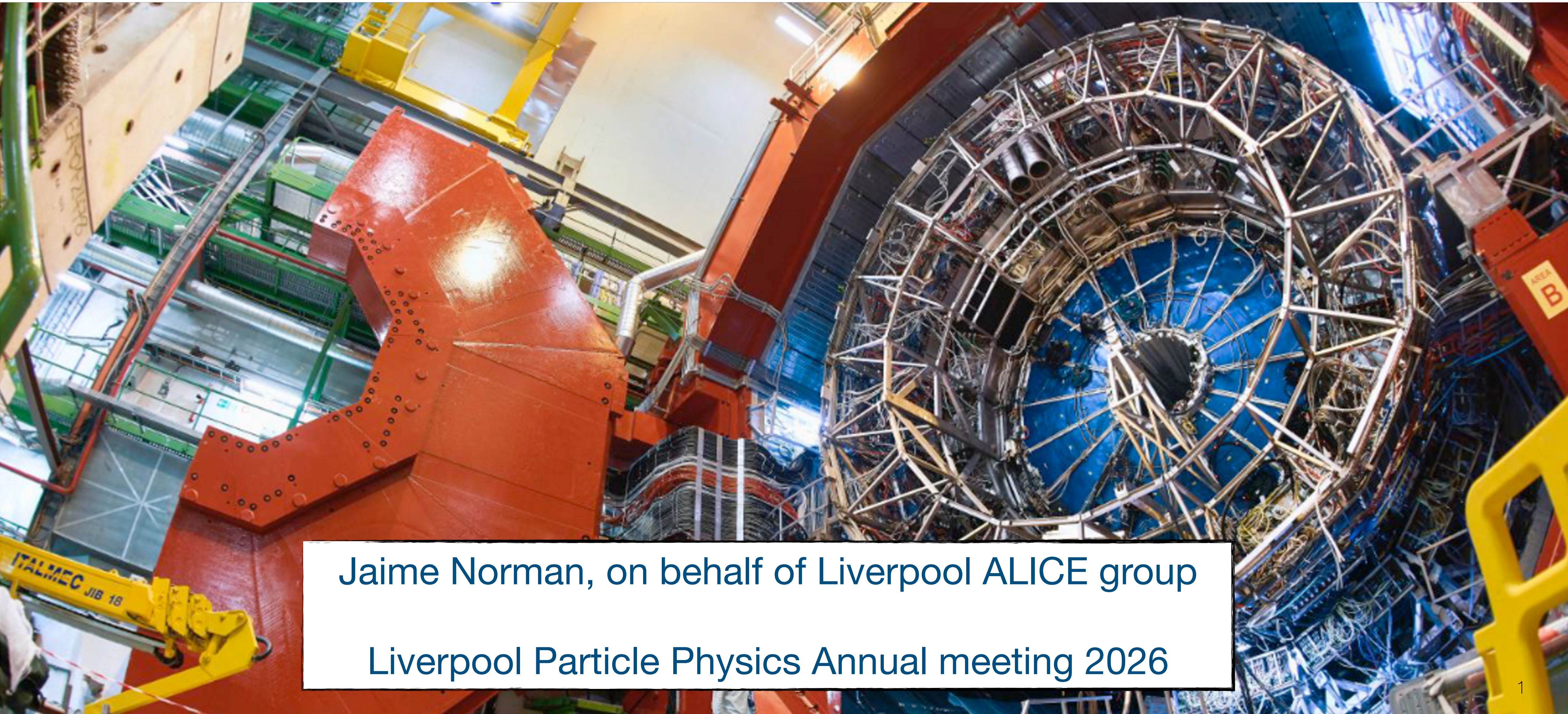


# ALICE - A Large Ion Collider Experiment

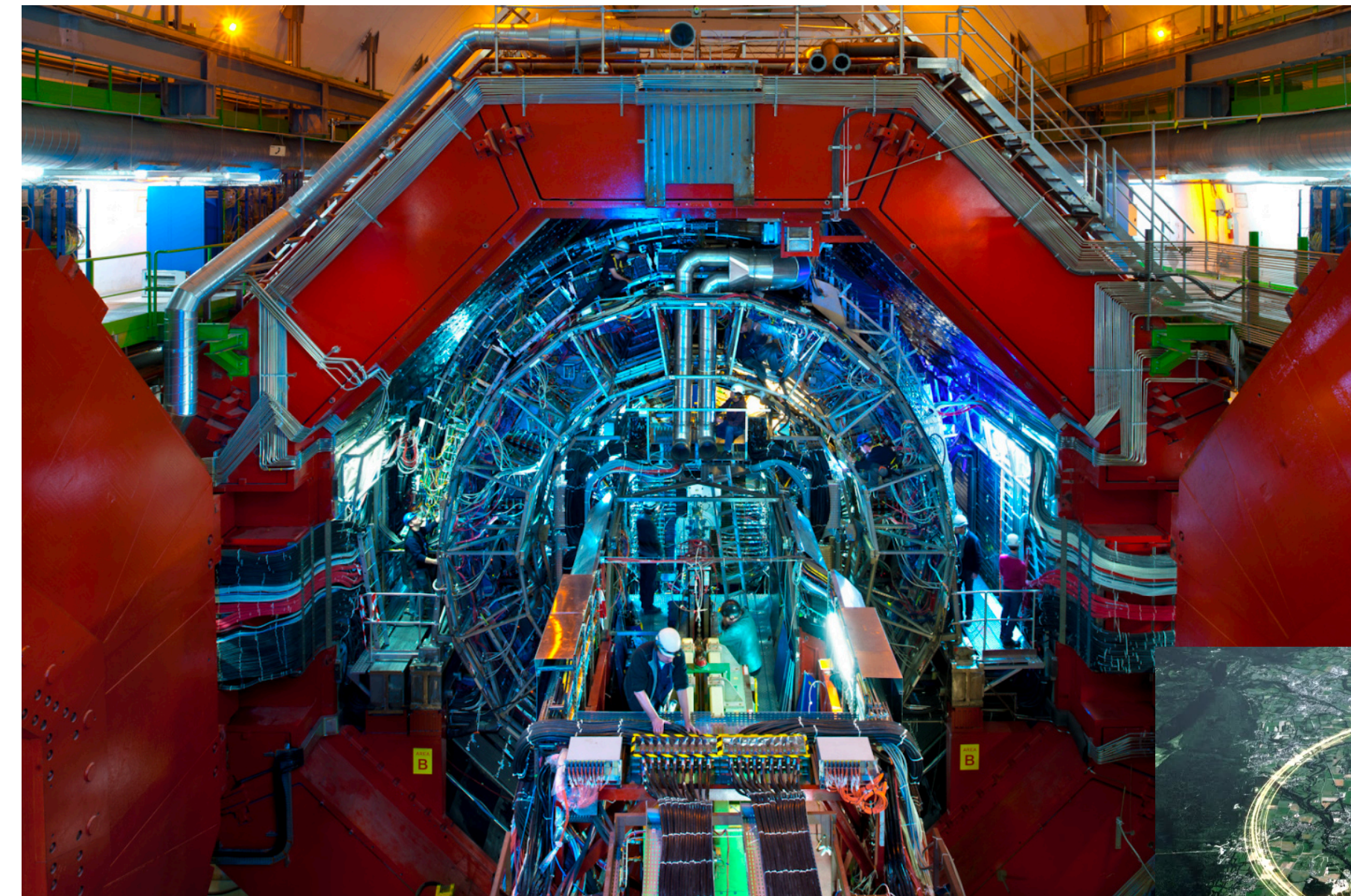
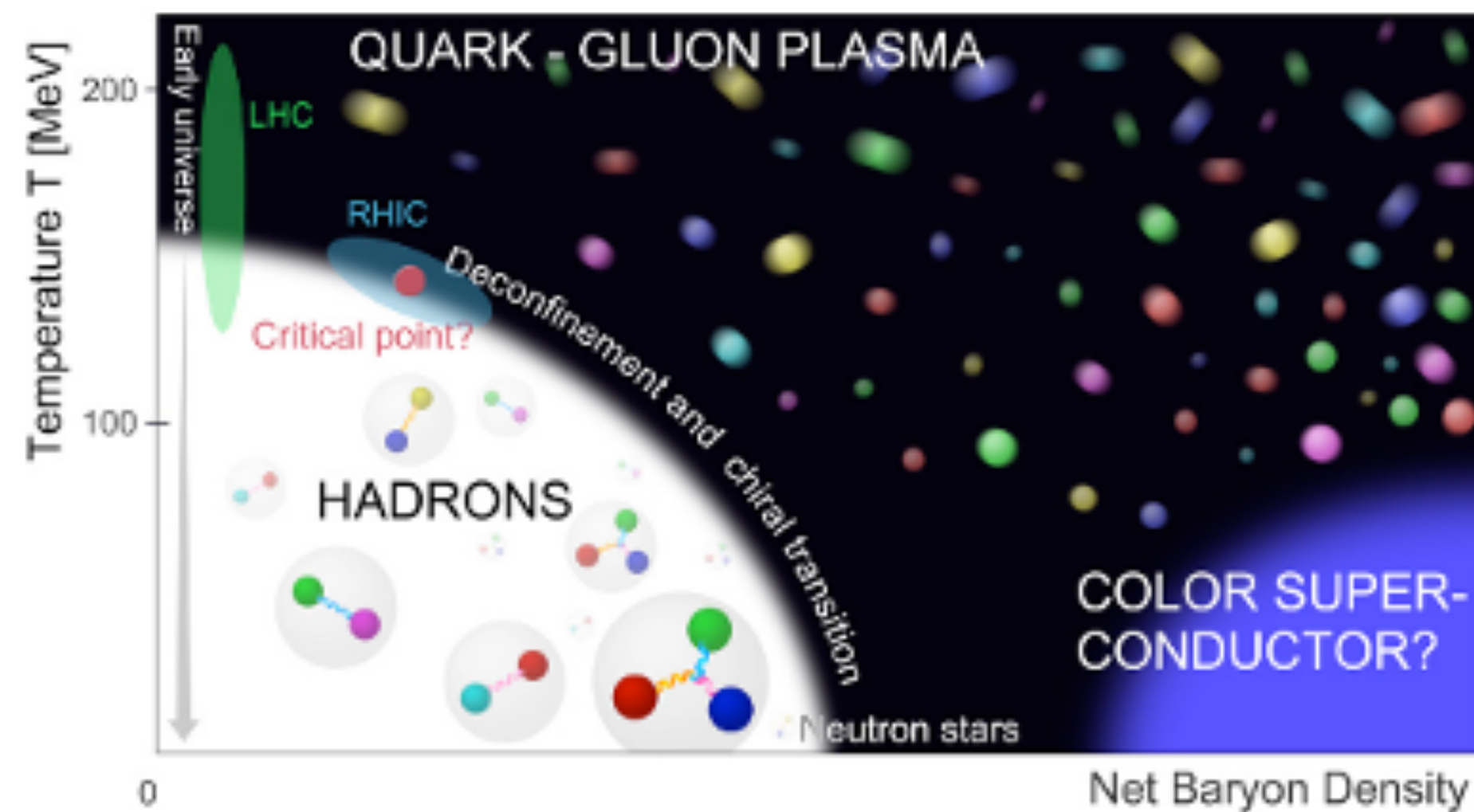


Jaime Norman, on behalf of Liverpool ALICE group

Liverpool Particle Physics Annual meeting 2026

# 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?

May 2025...



Marielle Chartier



Jaime Norman  
PDRA



Danny Jones  
PhD



John Dainton  
(Liverpool + Daresbury)



Jian Liu  
PDRA



Matt Ockleton  
PhD

# Who are we?

May 2026...

→ rapid collective expansion of our group



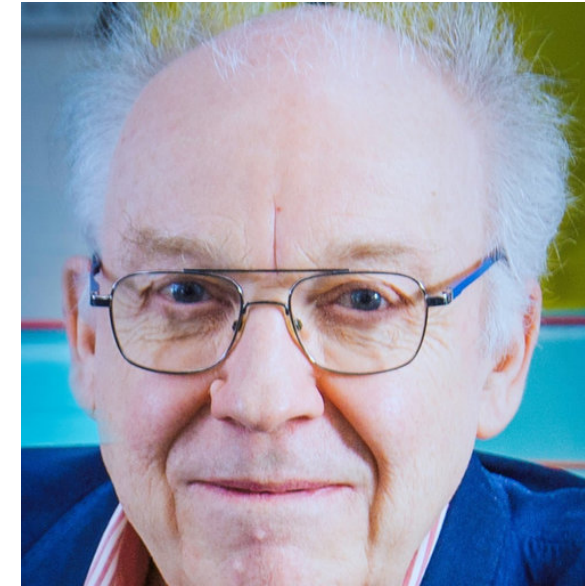
Marielle Chartier



Jaime Norman  
Rutherford Fellowship



Danny Jones  
PhD  
(viva tomorrow!)



John Dainton  
(Liverpool + Daresbury)



Anju Bhasin  
(University of Jammu,  
Visiting RS Fellow)



Peter Jacobs  
(LBNL,  
Visiting RS Fellow)



Mia Mylne  
PhD (from October)



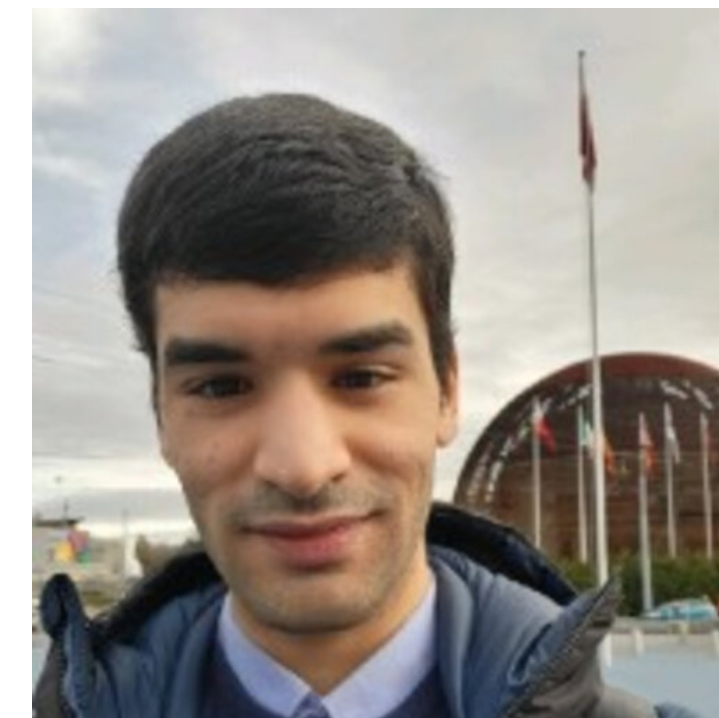
Jian Liu  
PDRA



Matt Ockleton  
PhD



Aimeric Landou  
PDRA



Alessandro Sturniolo  
PDRA



Jetnipit Kaewjai  
PDRA

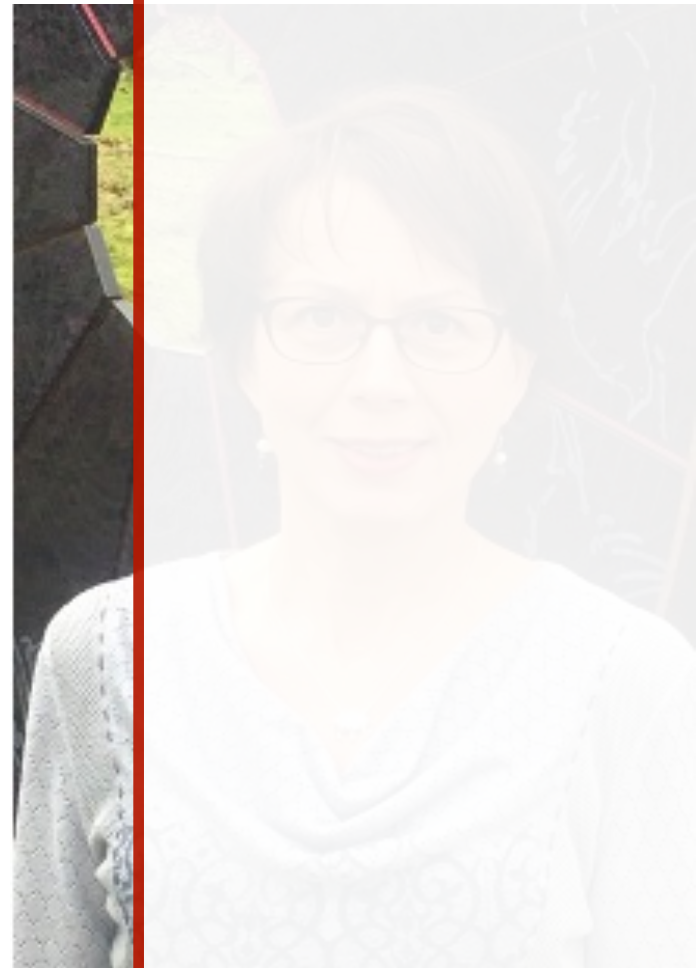


Nicola Wilson  
PhD (joint Liverpool-  
GSI funding)

# Who are we?

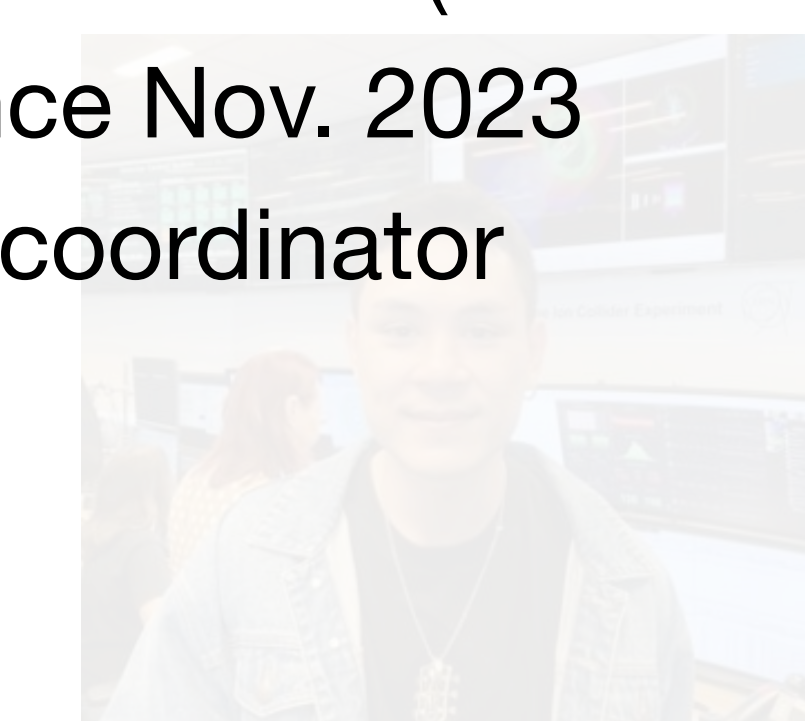
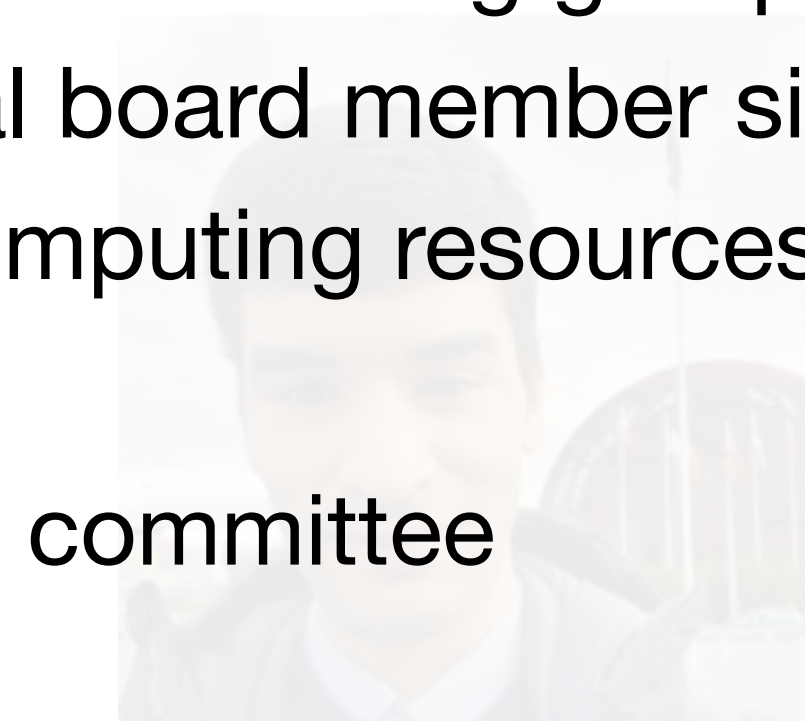
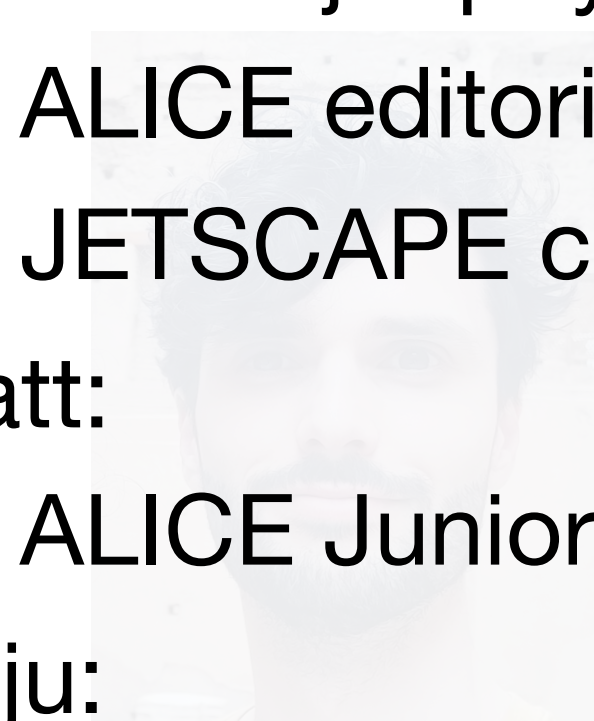
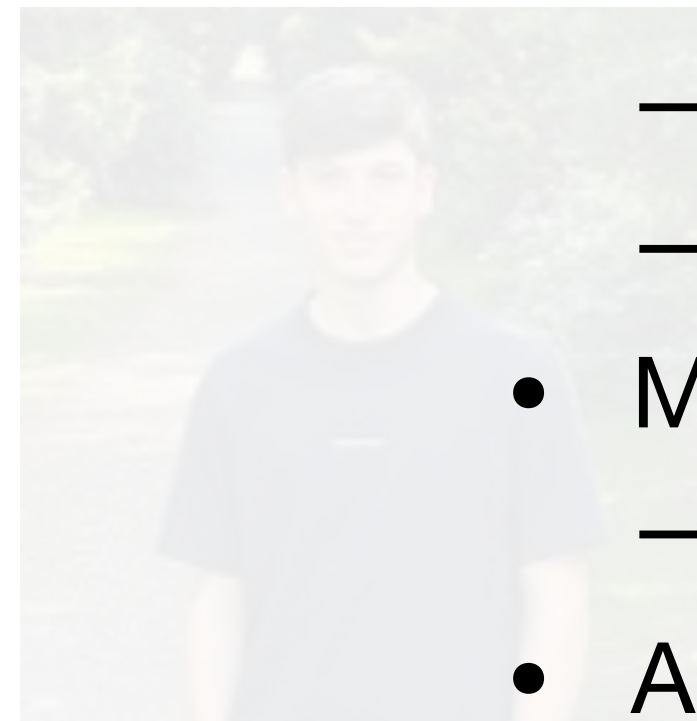


ALICE

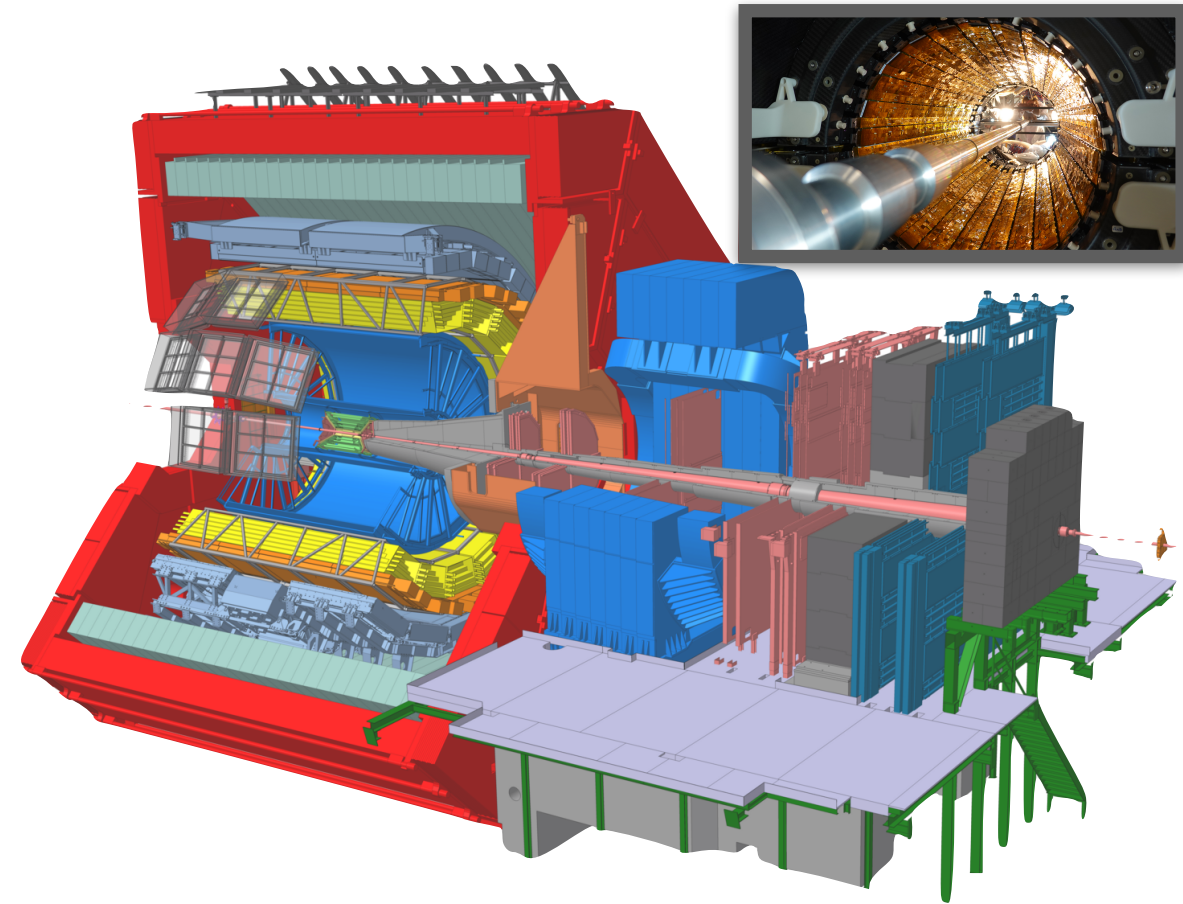


- Marielle:
  - Collaboration board chair, 2022-2025
- Jian:
  - Deputy technical Coordinator of ITS, since Jan. 2024
  - Data preparation group Quality Control coordinator since Jan. 2023
- Alessandro:
  - ITS Data Quality Control coordinator
- Jaime:
  - ALICE jet physics working group convenor (PWG-JE) since April 2026
  - ALICE editorial board member since Nov. 2023
  - JETSCAPE computing resources coordinator
- Matt:
  - ALICE Juniors committee
- Anju:
  - ALICE thesis prize committee
- Peter:
  - JETSCAPE STAT working group convenor

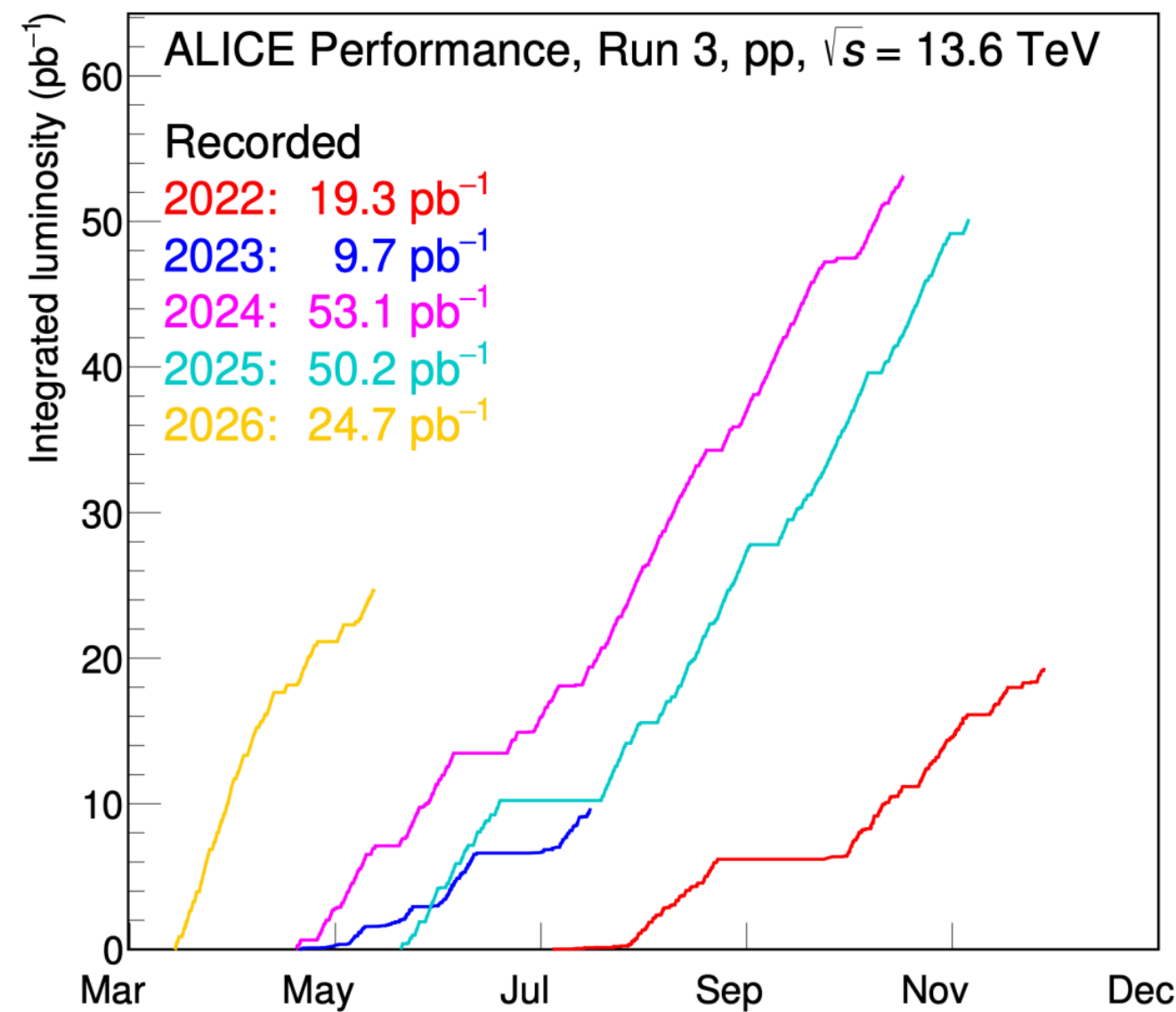
## Leadership roles:



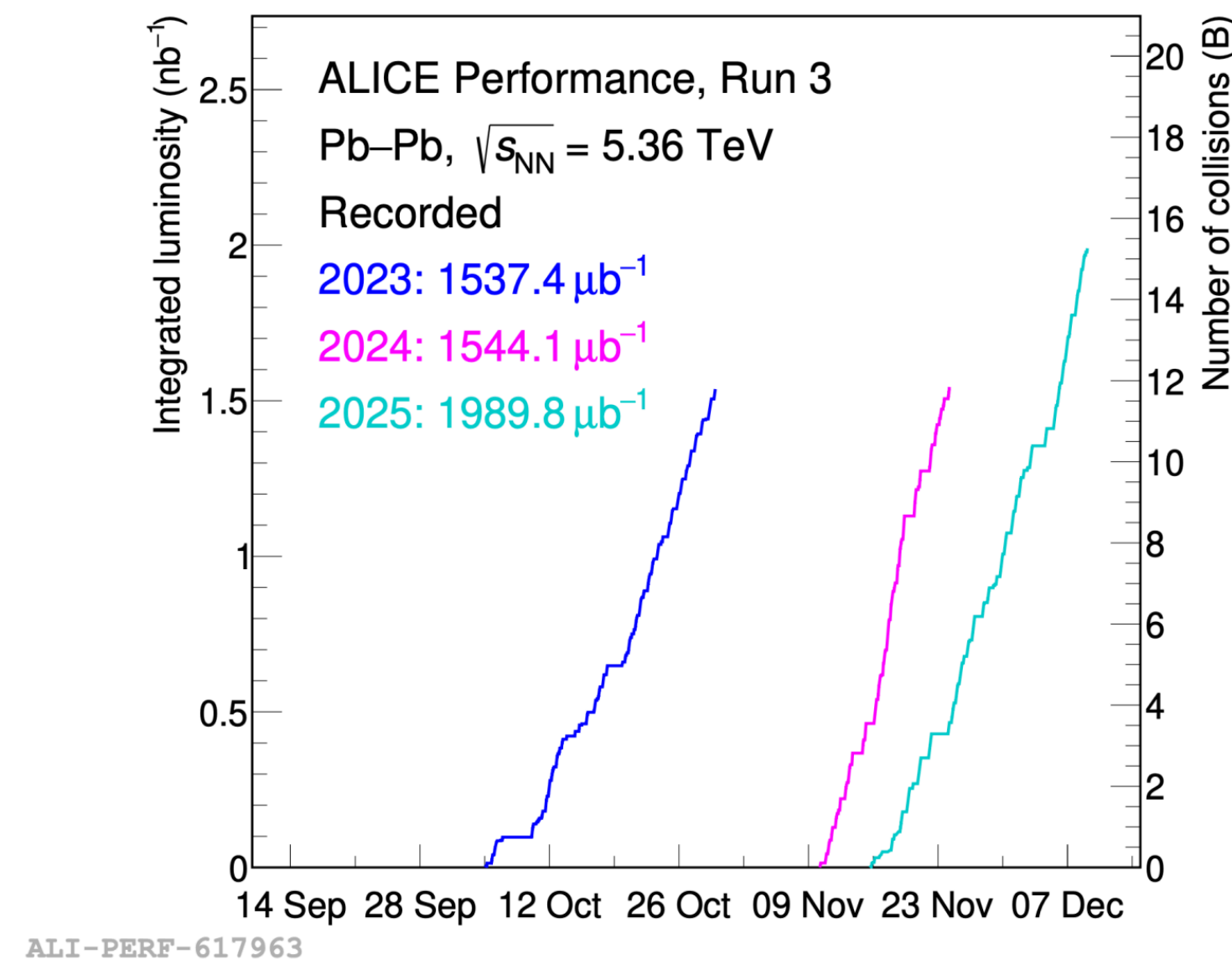
# The ALICE detector in Run 3 (2022-2026)



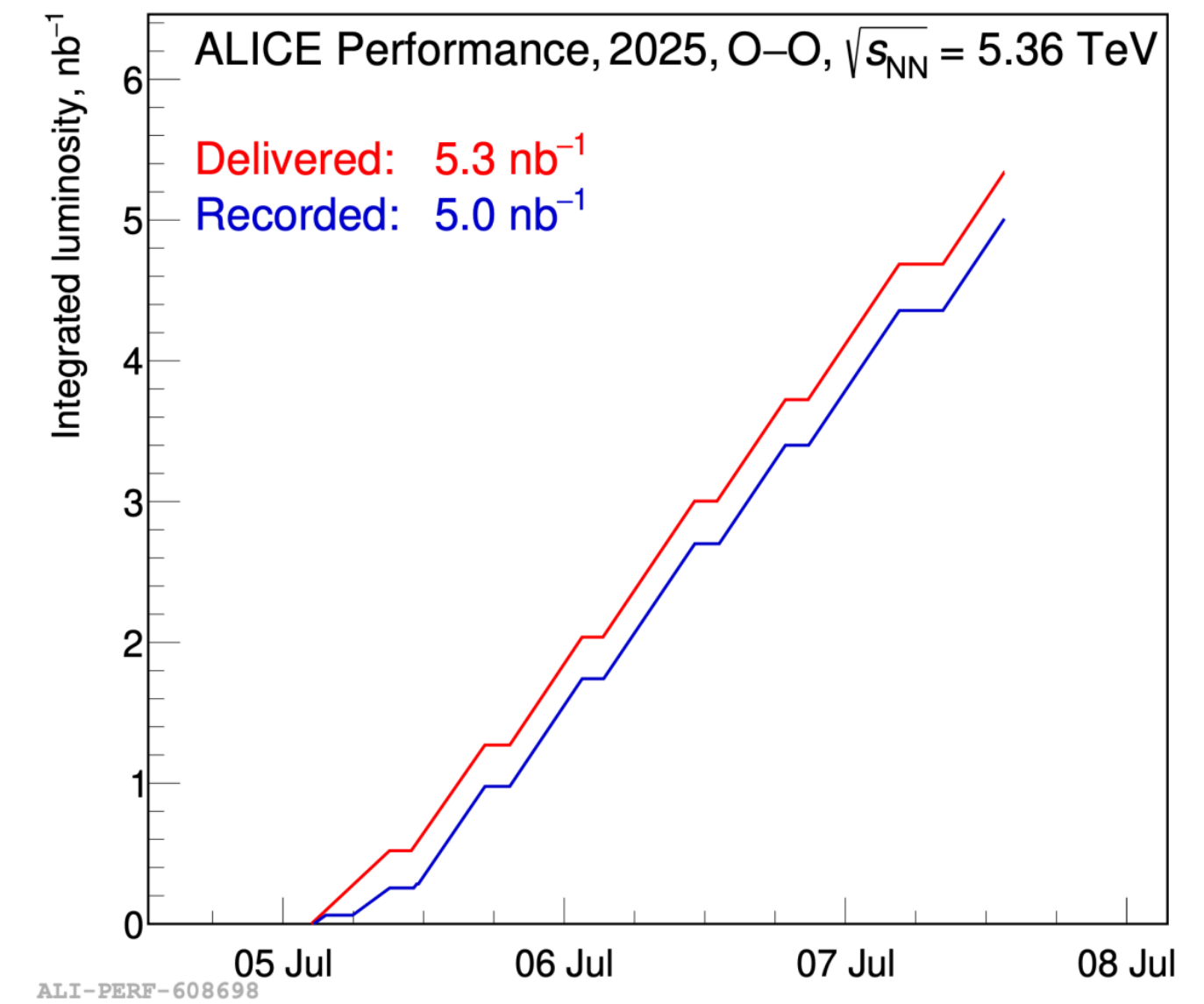
- Significant upgrades to the detector for Run 3
- Inner Tracking System upgrade with **Liverpool leading role in construction, commissioning and operation**
- +TPC GEM readout, forward integration time scintillators, Muon forward tracker, GPU farm for data processing....



8 x 10<sup>12</sup> MB pp events  
x1000 more than Runs 1+2



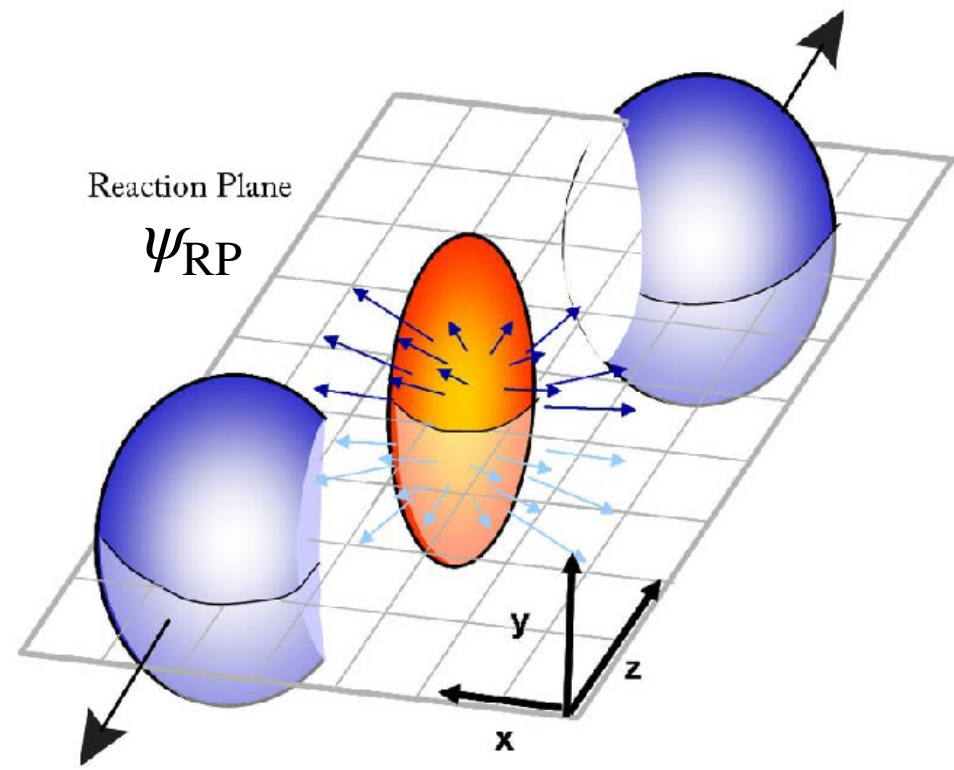
40 x 10<sup>9</sup> MB Pb-Pb events  
x120 more MB than Runs 1+2  
x20 more central than Runs 1+2



8 x 10<sup>12</sup> MB OO events

# Highlight from Run 3 - charm baryon flow in Pb-Pb collisions

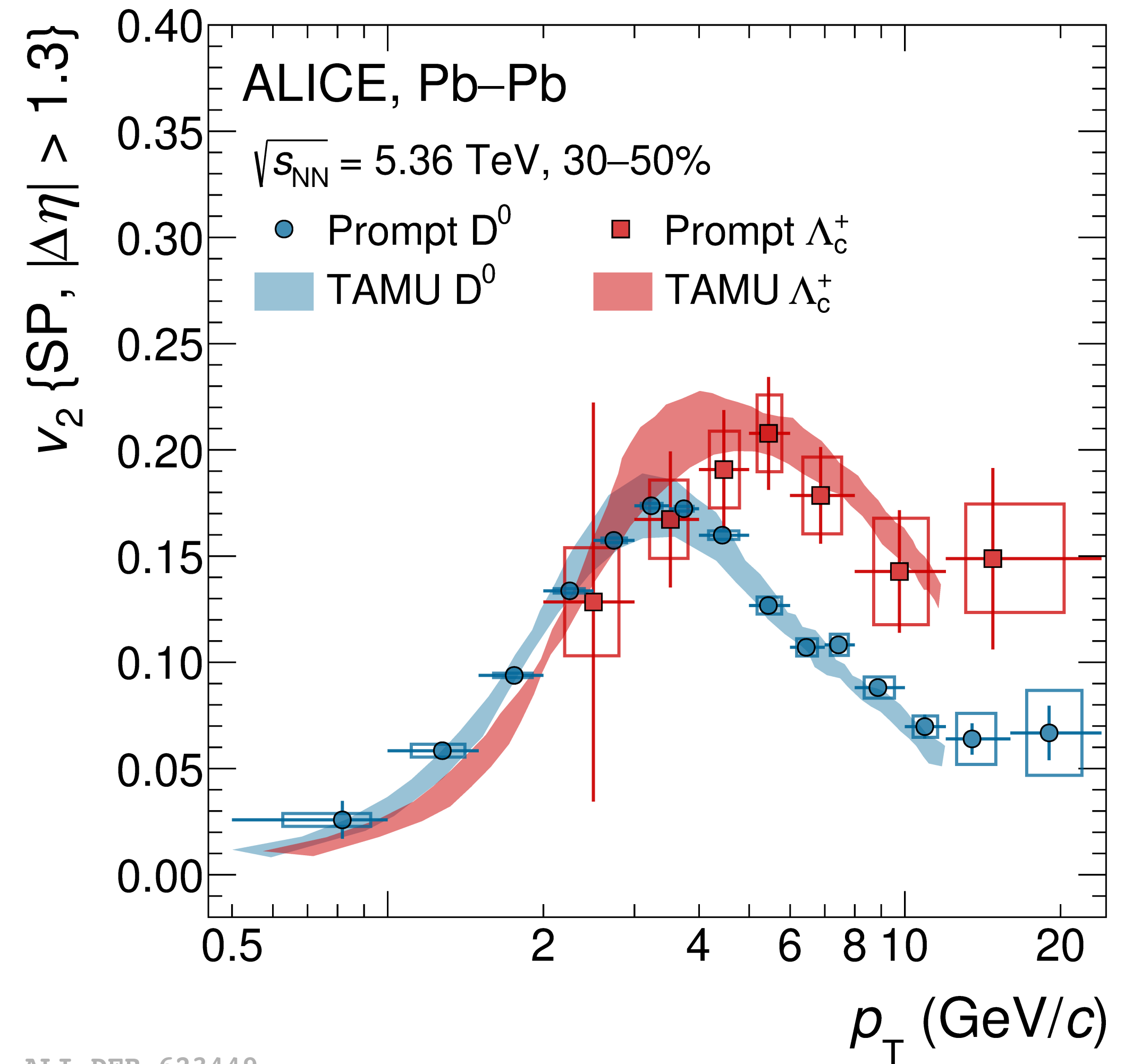
ALICE, [arxiv:2603.18966](https://arxiv.org/abs/2603.18966)



$$\frac{dN}{d\phi} = \frac{N_0}{2\pi} (1 + 2v_2 \cos[2(\phi - \psi_{RP})] + \dots)$$

$$v_2 = \langle \cos[2(\phi - \psi_{RP})] \rangle$$

- The ‘elliptic flow’  $v_2$  of  $\Lambda_c^+$  baryons has been measured for the first time
- anisotropy of particle emissions  
→ key signature of QGP coupling and thermalisation
- Measurement consistent with partial thermalisation of charm quarks followed by hadronisation via coalescence
- Challenging measurement ( $c\tau_{\Lambda_c^+} \sim 60\mu m$ )  
→ Made possible by ITS2 Inner Tracker



ALI-DER-623449

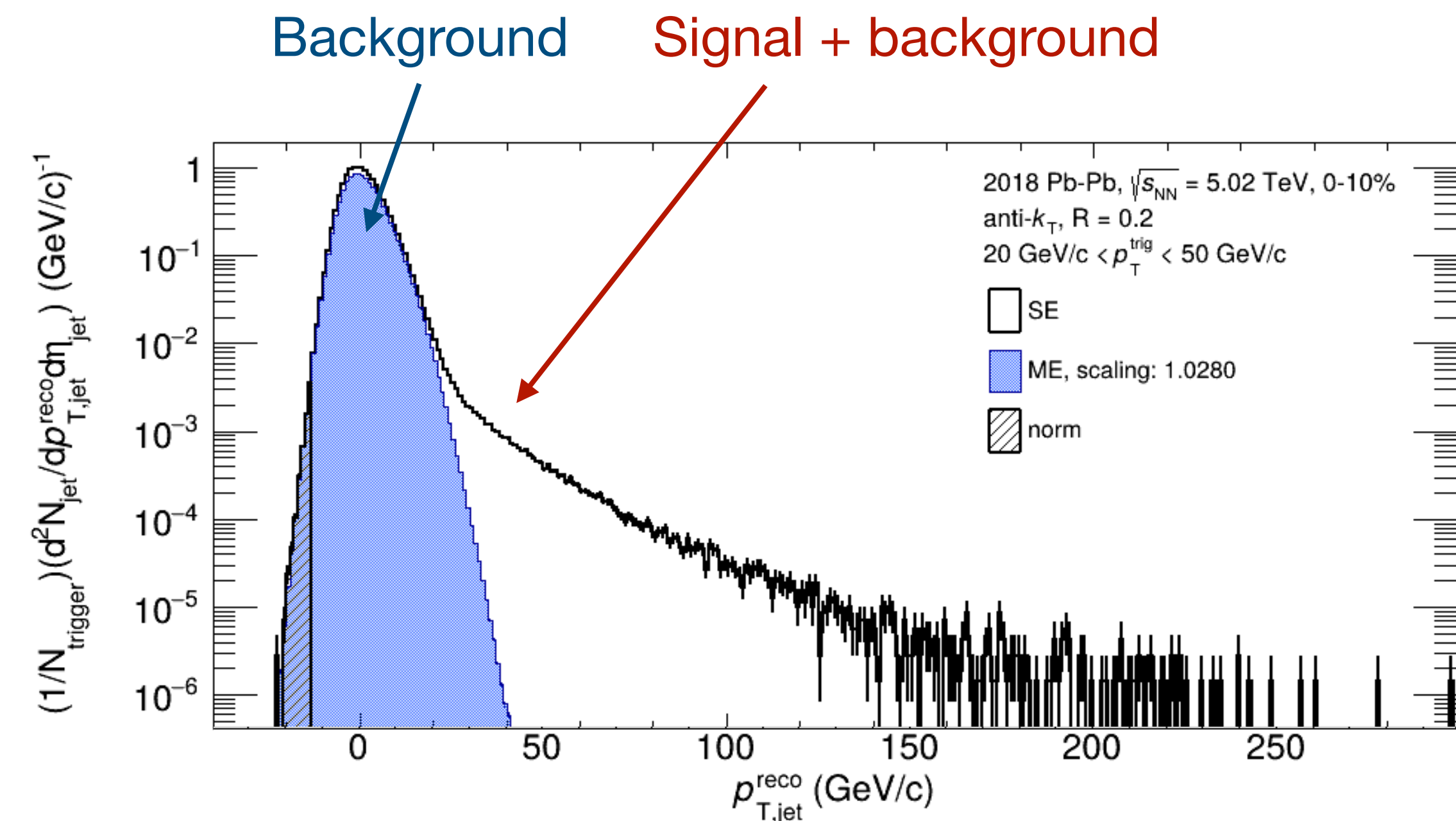
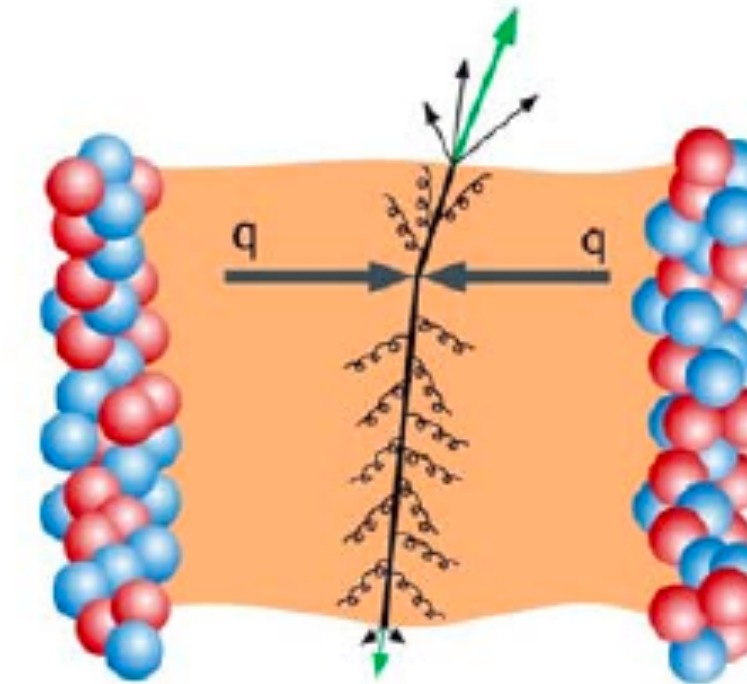
# Jet quenching measurements in Pb-Pb collisions

Aimeric, Jaime, Marielle, Peter, Nicola



Jets (high-energy quarks/gluons) act as unique probes of the QGP

- We are leading **first jet measurements in heavy-ion collisions using Run 3 data**
  - expected in June (Hard probes conference)
  - leading ALICE jet programme as PWG-JE convenor
- Multi-hadron ‘correlated’ objects among a huge ‘uncorrelated’ background
- Pioneering **novel techniques to subtract the large uncorrelated background** in heavy-ion collisions
  - low momentum jet measurements crucial to fully characterise jet energy redistribution



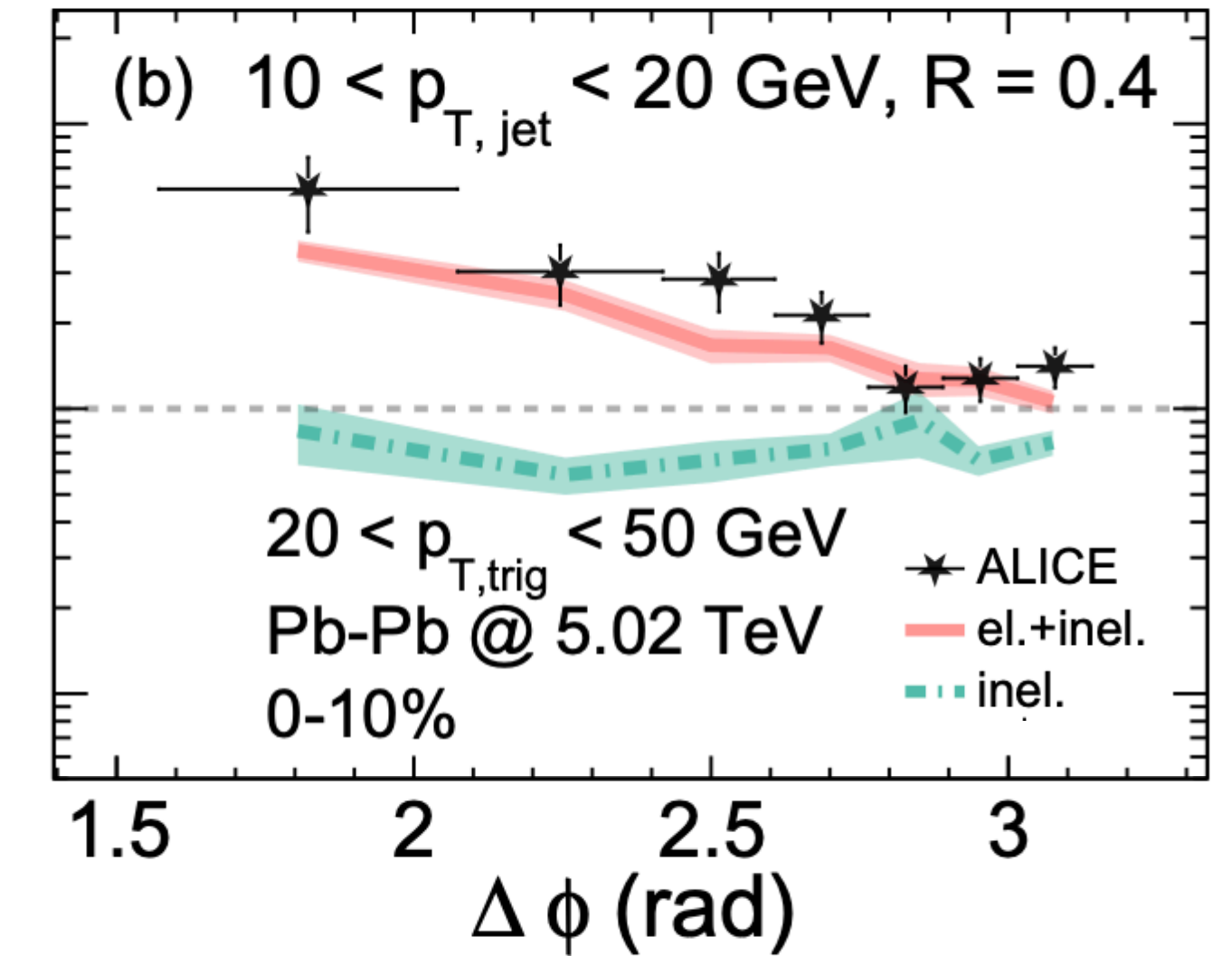
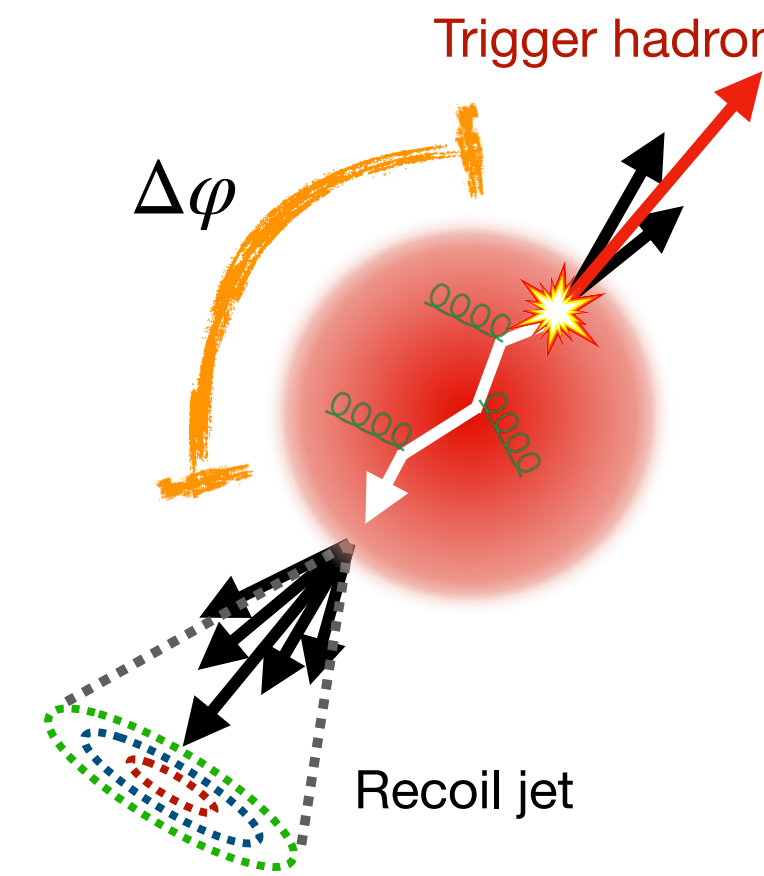
See Nicola's talk!

# Characterising the origin of low- $p_T$ jet broadening

Anju, Danny, Jaime, Marielle, Matt, Peter

ALICE: Phys.Rev.Lett. 133 (2024) 2, 022301, Phys.Rev.C 110 (2024) 1, 014906

- Run 2 measurement we led revealed low  $p_T$  jet azimuthal broadening through hadron+jet correlations
- Recent interpretation by theorists points to new phenomena:
  - emergence of ‘thermal jets’
  - new way to measure QGP transport properties



P. Jing, W. Dang, Y. He, S. Cao, L. Yi, X.N. Wang: arxiv:2512.12715

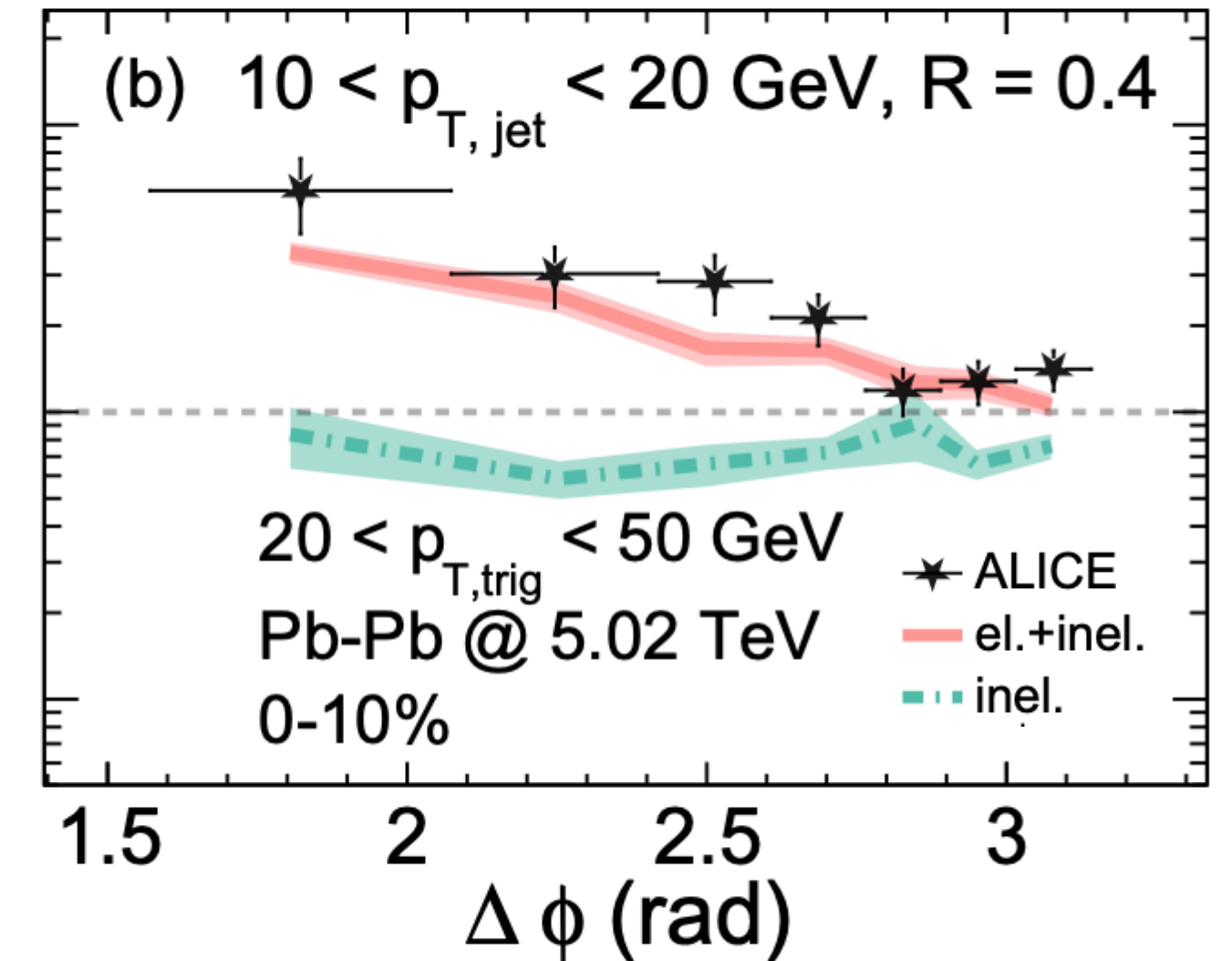
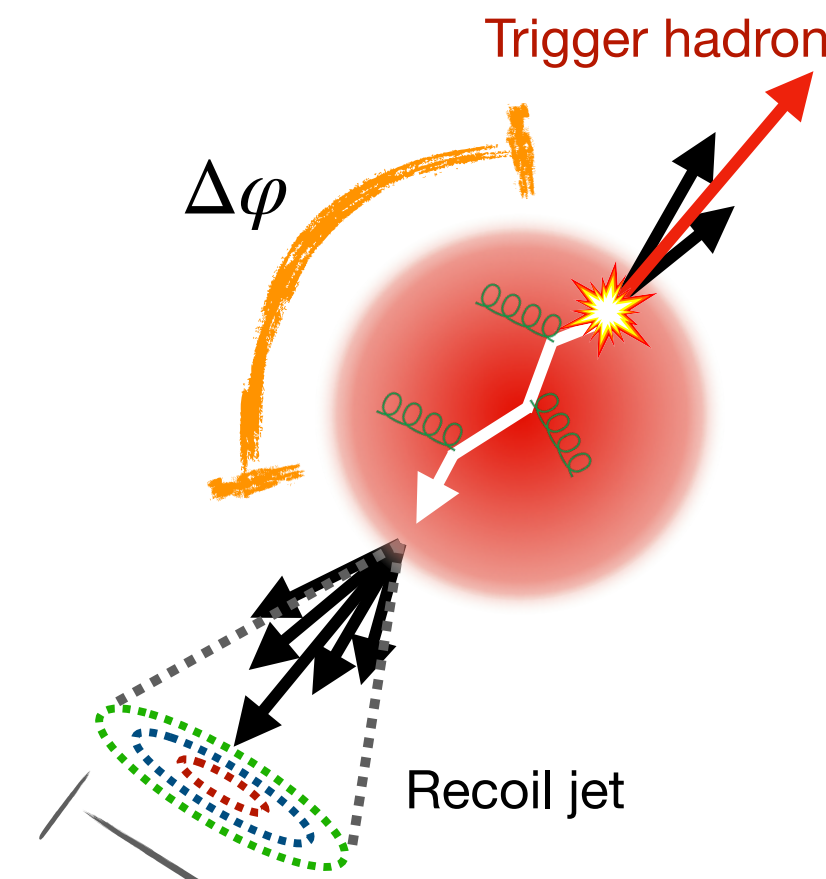
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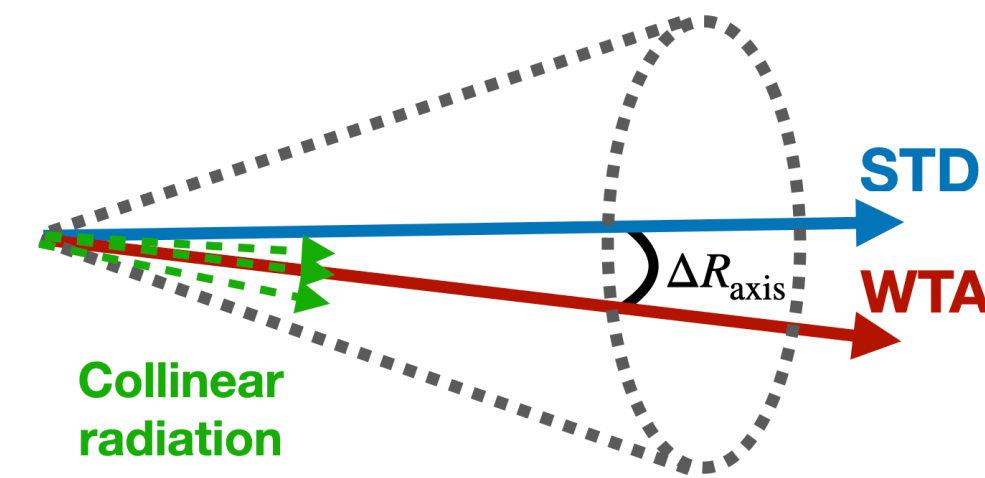
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- Run 2 measurement we led revealed low  $p_T$  jet azimuthal broadening through hadron+jet correlations
- Recent interpretation by theorists points to new phenomena:
  - emergence of ‘thermal jets’
  - new way to measure QGP transport properties
- Follow up with measurement of low- $p_T$  jet substructure via axes differences in pp collisions with Run 3 data
- Sensitive to soft, large-angle radiation
  - steps towards characterising thermal jets in Pb-Pb collisions
- Work also ongoing to study charm quark (de)correlation via  $D^0$ -jet correlations with Run 3 data

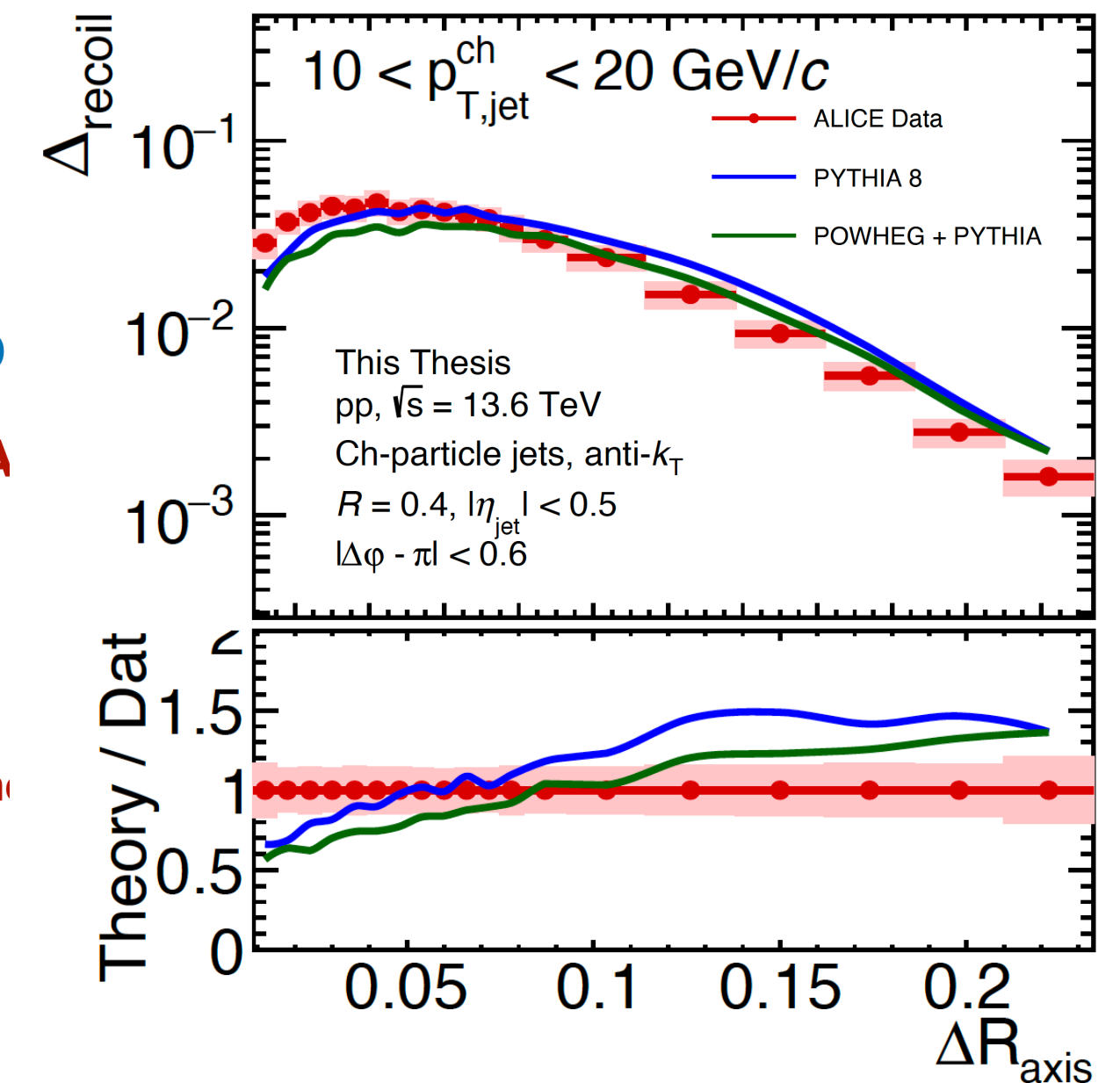
See Matt’s talk!



P. Jing, W. Dang, Y. He, S. Cao, L. Yi, X.N. Wang: arxiv:2512.12715



STD ~ 4-momentum sum of constituents  
WTA ~ hardest constituent of hardest branch



# Connecting measurement to theory

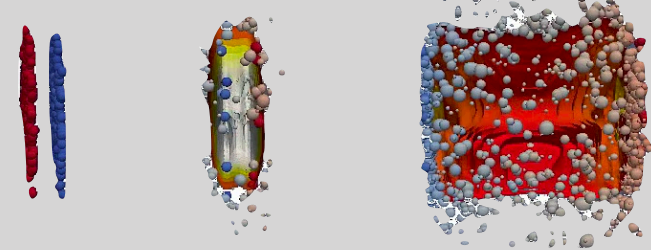
## The JETSCAPE collaboration

Tool for **comprehensive validation** of cutting-edge models with multi-messenger data

→ **constrain properties of the QGP** (e.g. opacity, viscosity, microscopic structure...)

### Heavy-ion event generator

Framework for modelling all aspects of heavy-ion collisions

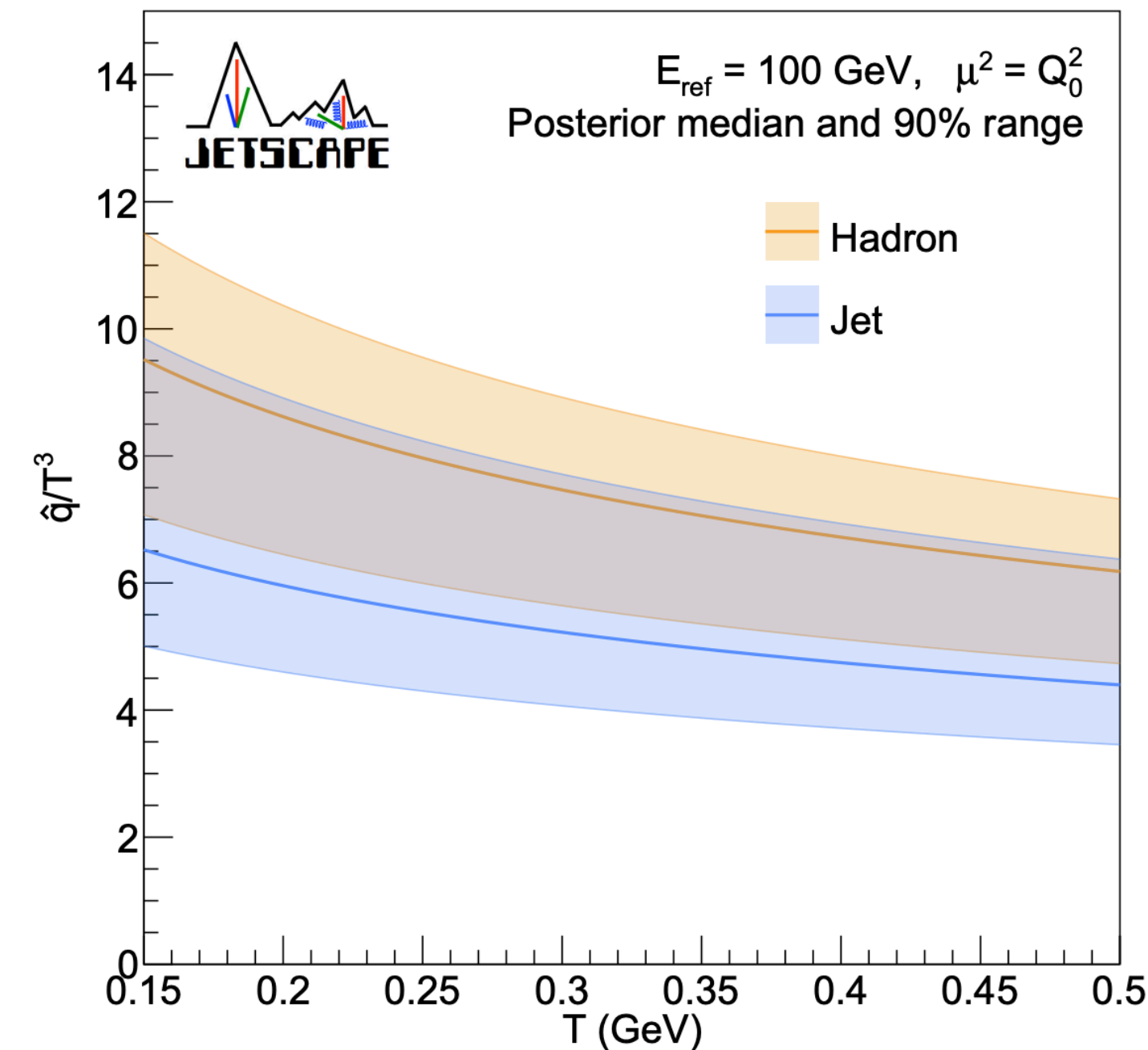
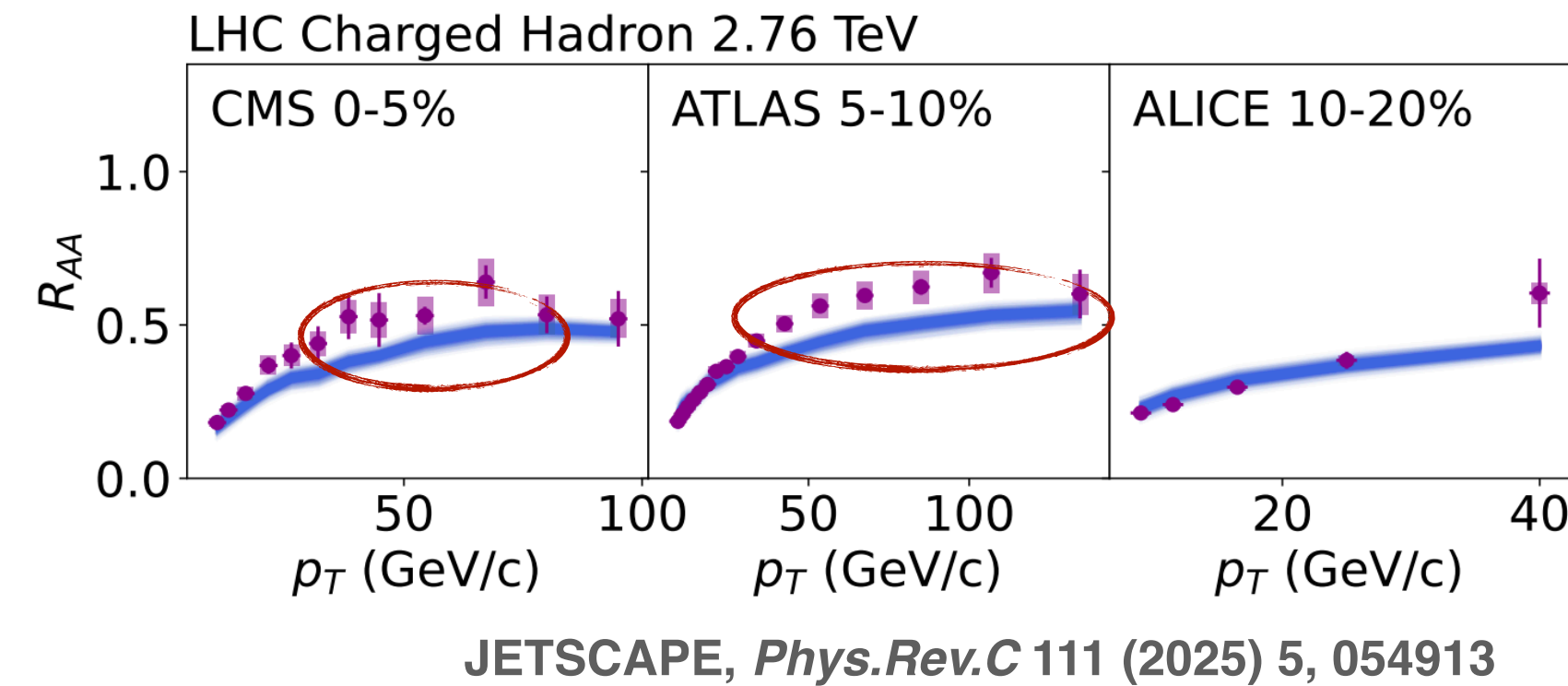


### Statistical toolkit

Bayesian inference for data-theory comparison

$$P(\theta | \text{data}) = \frac{P(\text{data} | \theta)P(\theta)}{P(\text{data})}$$

**Interdisciplinary** collaboration of ~50 (experimentalists, theorists, statisticians)  
US-based, NSF-funded



Complete set of measurements

Parameter constraints

jet transport coefficient

$$\hat{q} \sim \frac{\langle k_T \rangle}{L}$$

See also JETSCAPE, *Phys.Rev.C* 103 (2021) 5, 054904  
*Phys.Rev.C* 104 (2021) 2, 024905  
*Phys.Rev.Lett.* 126 (2021) 24, 242301

# Connecting measurement to theory

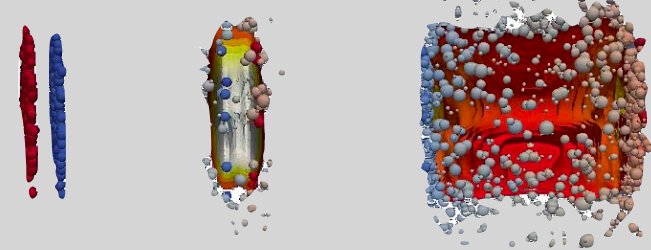
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**Interdisciplinary** collaboration of ~50 (experimentalists, theorists, statisticians)  
US-based, NSF-funded

- Liverpool Joined JETSCAPE as associate members in 2023 (upgraded to full members last year)
  - **October 2025:** Obtained significant HPC allocation via IRIS on Cambridge HPC (CSD3)  
*(12M CPU hours, 100 TB storage)*
  - **April 2026:** Allocation request approved for next year  
*(12M CPU hours, 100 TB storage)*
  - **Playing leading role in next generation of calculations:**
    - Significant dimensionality increase
    - Sequential inference
- **ML/AI crucial** to optimise analyses and resource use

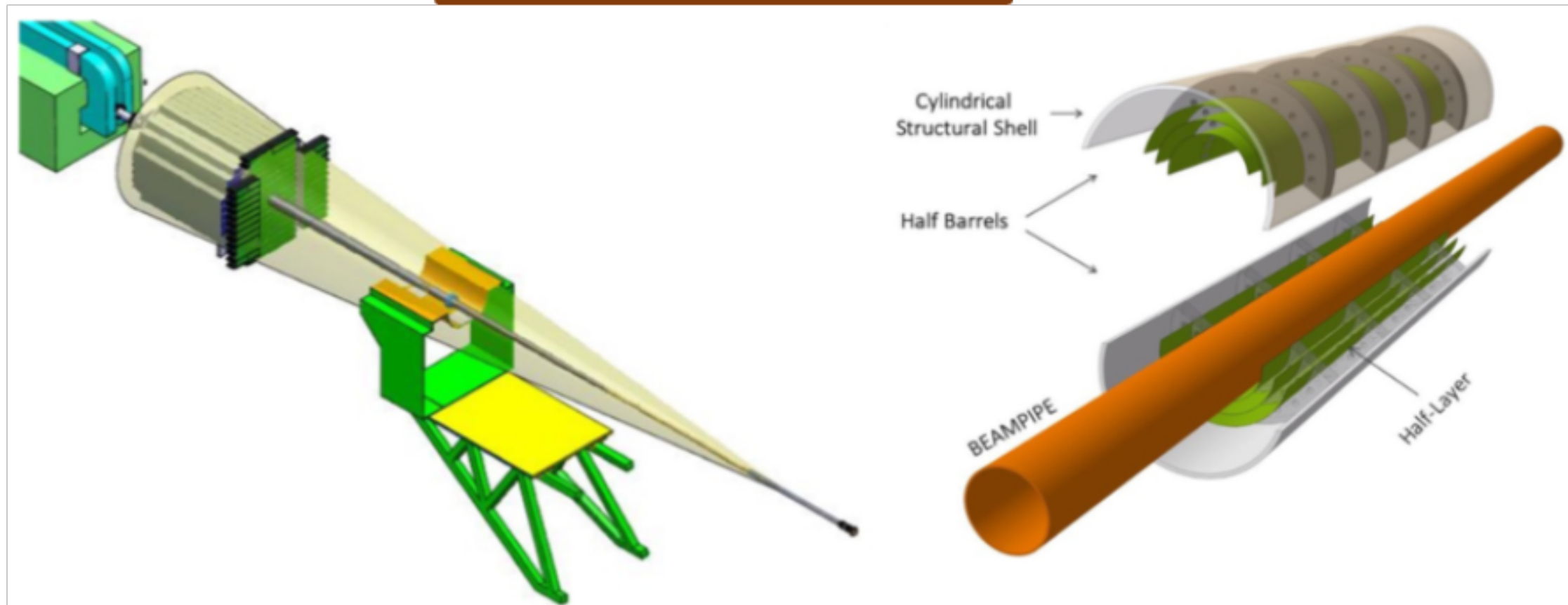
**The way forward for precision era of heavy-ion physics**

# Future projects timeline



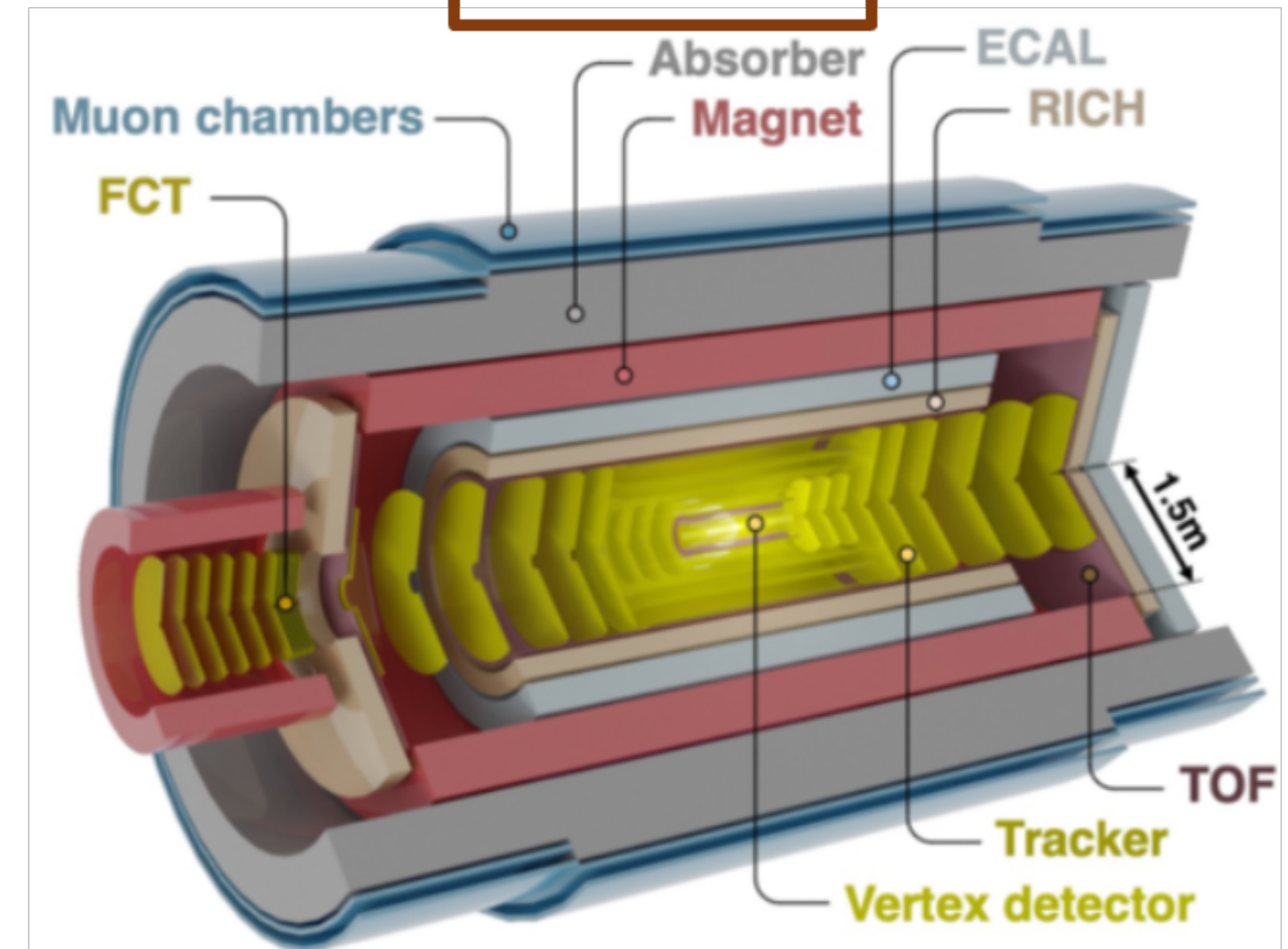
LS3: FoCal and ITS3

LS4: ALICE 3



FoCal Lol: [CERN-LHCC-2020-009](https://cds.cern.ch/record/2781000)  
FoCal TDR: [ALICE-TDR-022](https://cds.cern.ch/record/2781000)

ITS3 Lol: [CERN-LHCC-2019-018](https://cds.cern.ch/record/2781000)  
ITS3 TDR: [ALICE-TDR-021](https://cds.cern.ch/record/2781000)



ALICE 3 Lol: [CERN-LHCC-2022-009](https://cds.cern.ch/record/2781000)

# ITS3 and EIC silicon detector R&D

Aimeric, Alessandro, Jetnipit, Jian, Matt



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

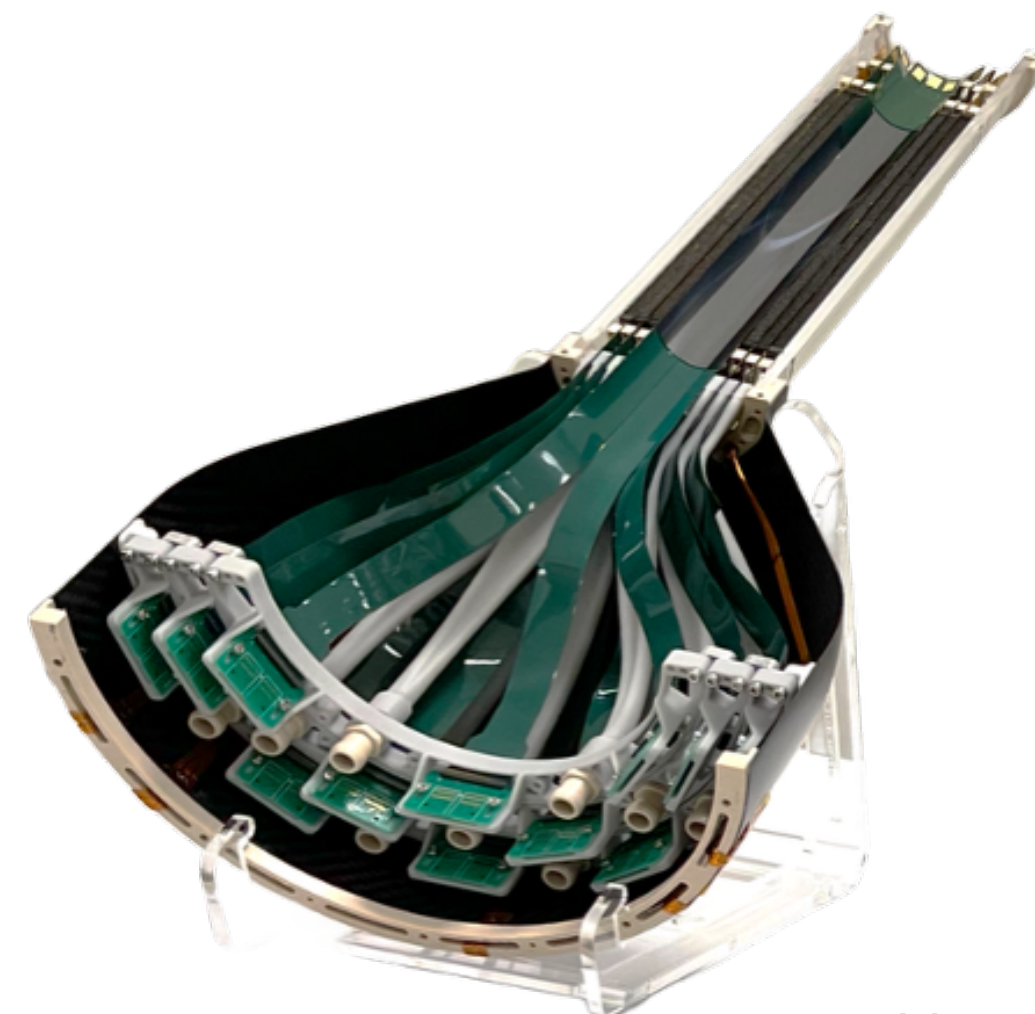
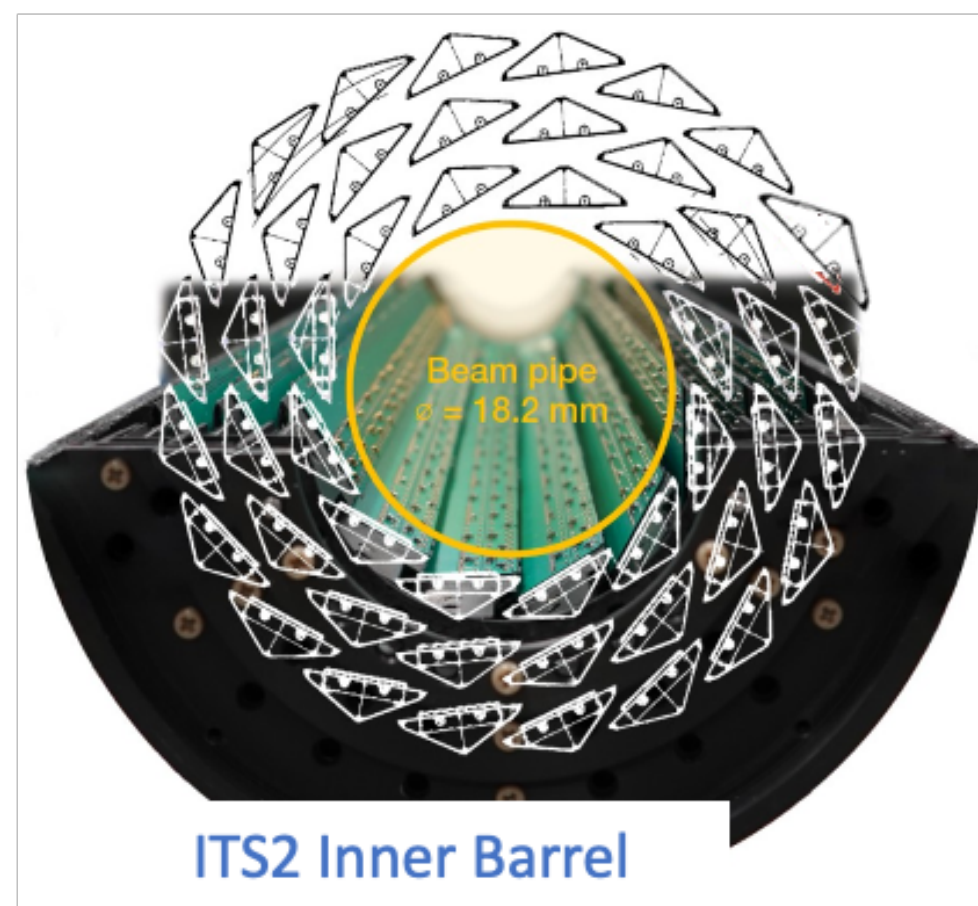
- **bent, wafer-scale CMOS (MAPS) sensors**
  - Extremely low material budget 0.07%  $X_0$
  - Homogeneous material distribution
- x2 improvement in pointing resolution, large improvement in tracking efficiency at low  $p_T$
- Electron-Ion Collider (EIC) Silicon Vertex Tracker (SVT) will have similar sensor architecture - overlapping characterisation effort



ER1 (Engineering run 1): MOSS first stitched MAPS in LSDC



ER2: MOSAIX first ITS3 sensor prototype in LSDC

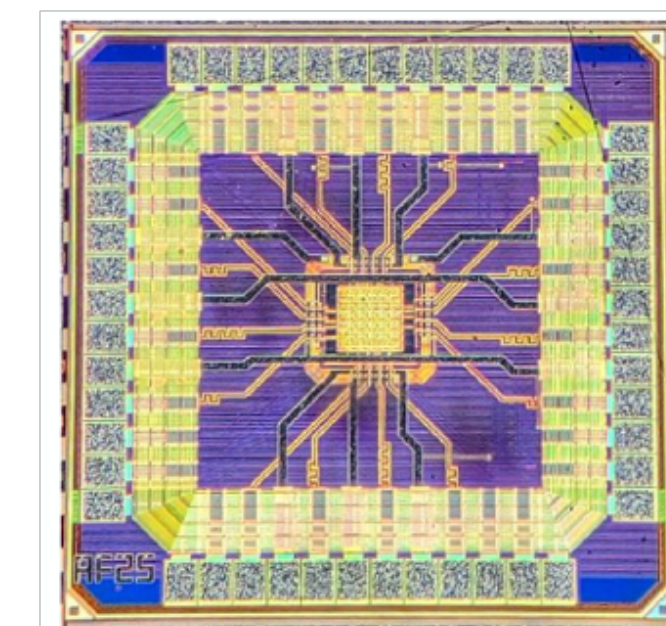
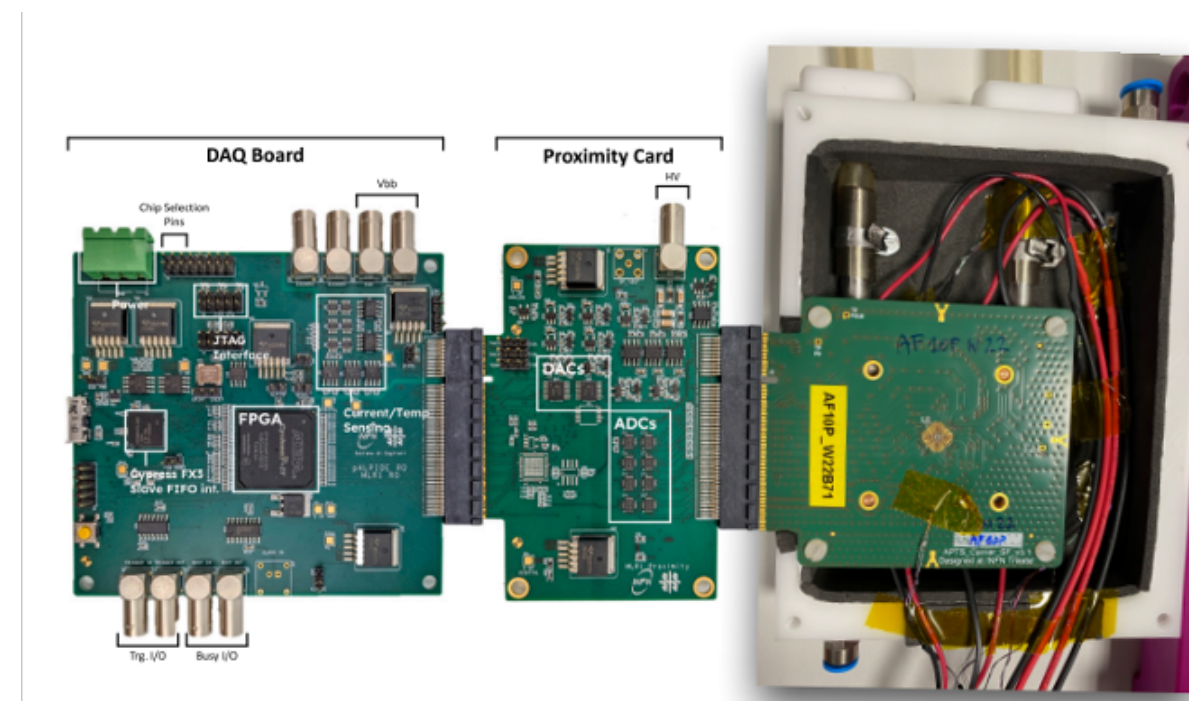
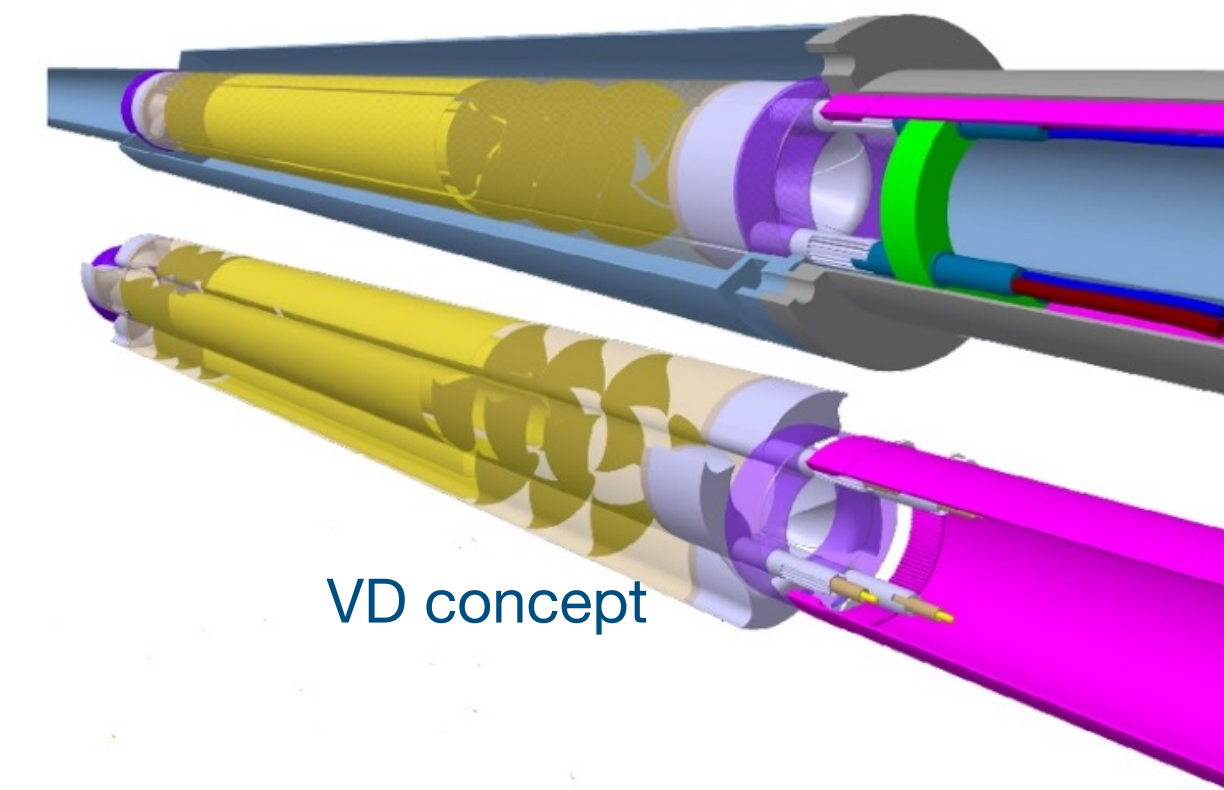
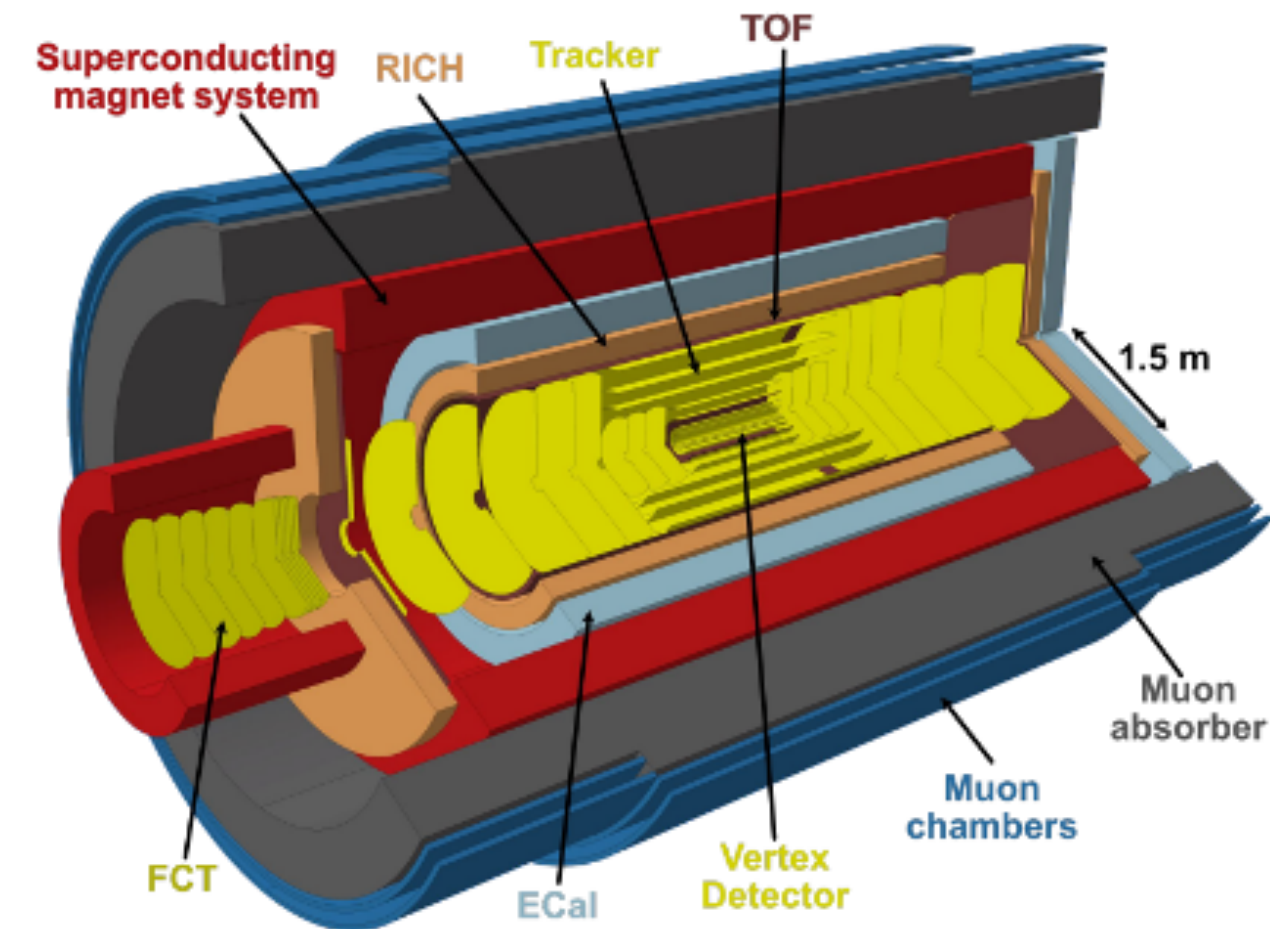


MOSAIX test beam campaign at CERN PS



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

- Liverpool contributions to Inner Tracker R&D
- **Vertex Detector (VD)**
  - 3 layers of wafer-size, ultra-thin, curved, CMOS MAPS inside the beam pipe in secondary vacuum
  - Retractable configuration thanks to movable petals
    - Similar concept to LHCb VELO, but in barrel configuration
  - Unprecedented spatial resolution:  $\sigma_{\text{pos}} \sim 2.5 \mu\text{m}$
- **Outer Tracker (OT)**
  - 3 + 2 x 6 tracking layers (barrel + disks) based on CMOS MAPS technology
    - Largely leverages ITS2 and ITS3 experience
  - Compact:  $r_{\text{out}} \sim 80 \text{ cm}$ ,  $z_{\text{out}} \pm 3.5 \text{ m}$ , Large coverage:  $\pm 4 \eta$



Innovative technologies relevant for future particle physics experiments

Analogue Pixel test structures (APTS) to be constructed in Liverpool  
6x6 pixel matrix varying pitch + readout

*Thank you!*

