The silicon tracking system of the future **ALICE 3** experiment at the LHC

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[1]CERN

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Outline

- **ALICE 3**: from observables to requirements

- ALICE 3 tracking system
  ➪ Vertex detector
  ➪ Outer tracker

- R&D activities and challenges

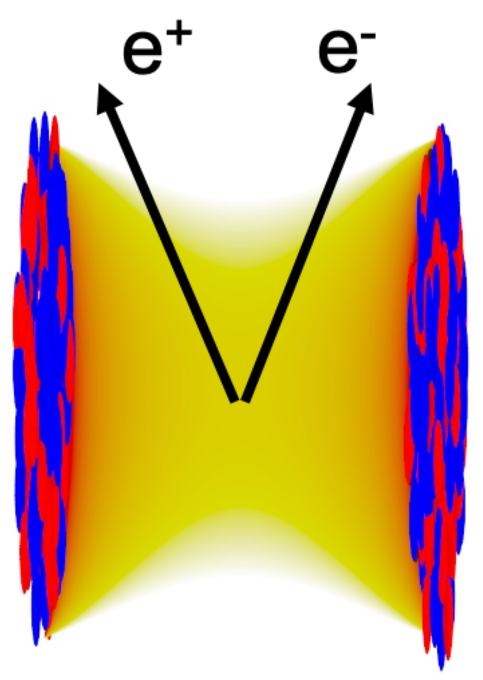
- Expected performance

- Summary

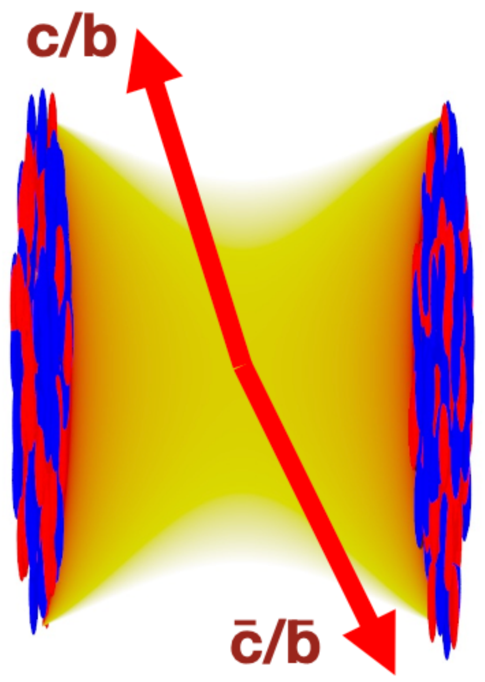
LHC heavy-ion physics beyond Runs 3-4

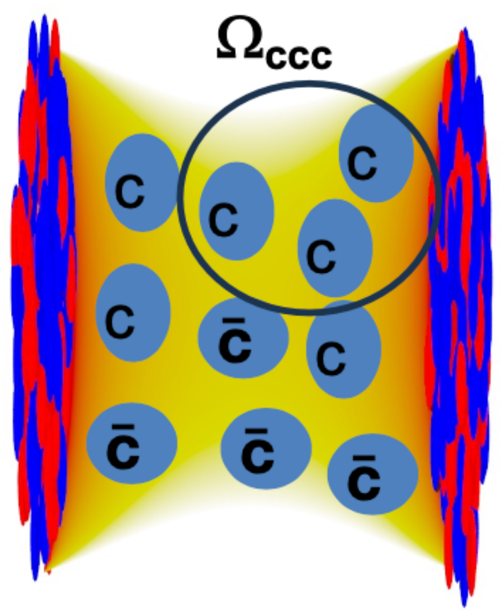
Main questions that will remain open (ALICE perspective)

- **Precision measurements of dileptons**
  - ➪ Evolution of the quark-gluon plasma (QGP) temperature
  - ➪ Mechanisms of chiral symmetry restoration in the QGP



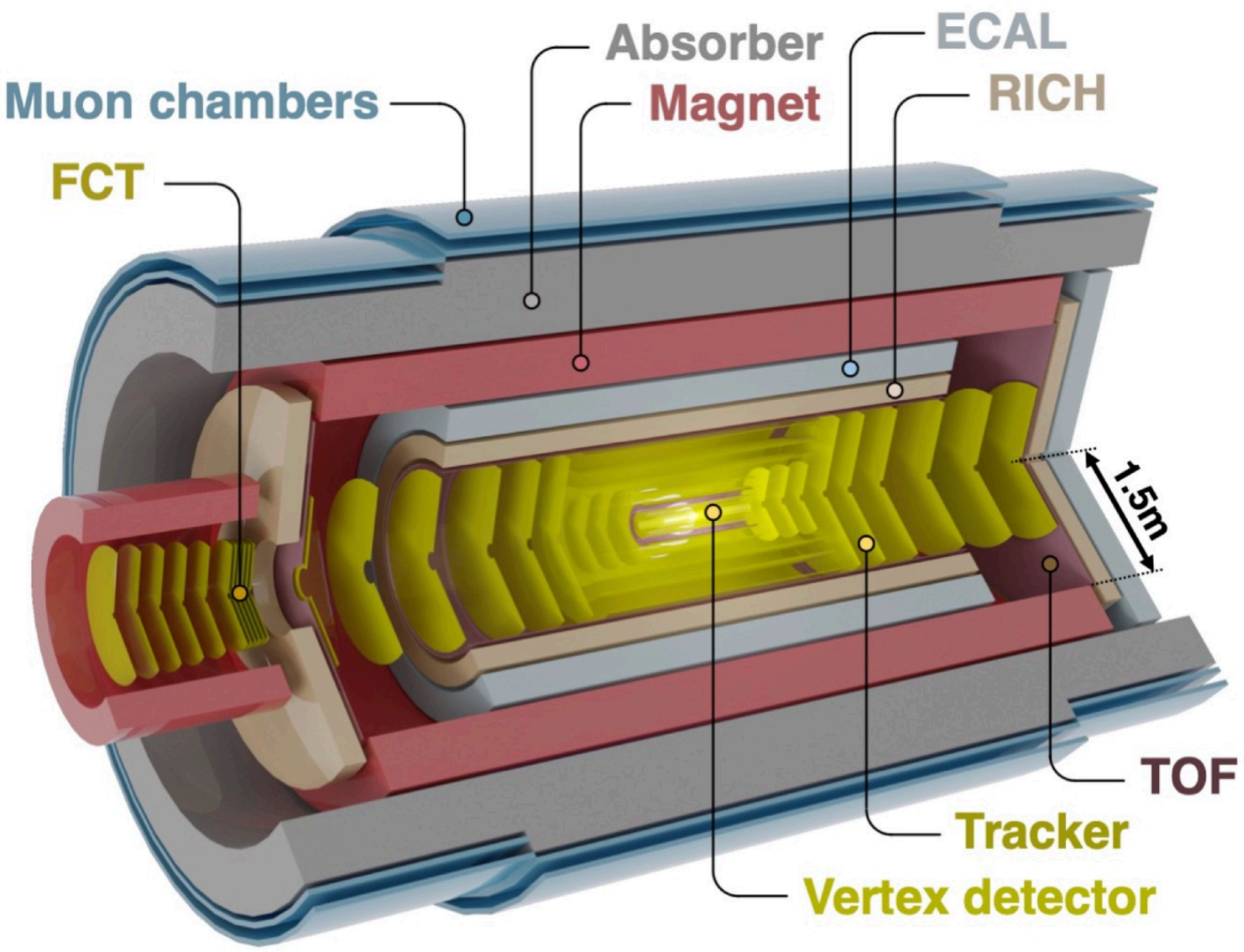
- **Systematic measurements of (multi-) heavy-flavoured hadrons**
  - ➪ Transport properties in the quark-gluon plasma
  - ➪ Mechanisms of hadronisation from the QGP

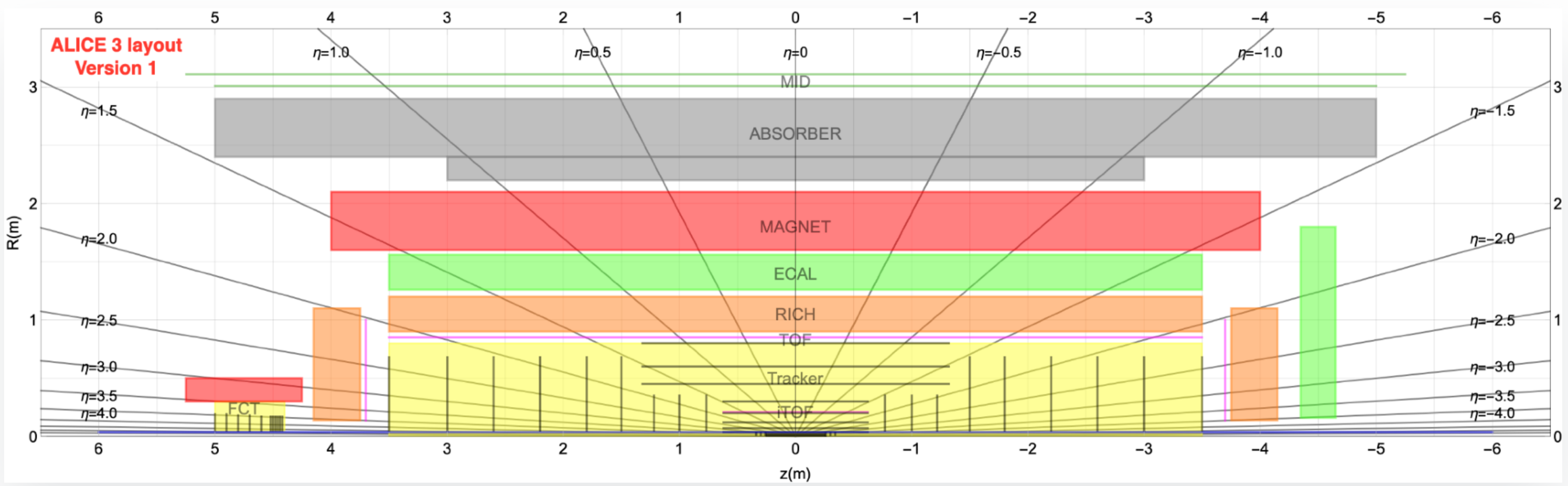




- **Hadron correlations**
  - ➪ Hadron-hadron interaction potentials
  - ➪ Net-baryon and net-charm fluctuations

ALICE 3 detector concept





➠ Novel and innovative detector concept

Tracking system

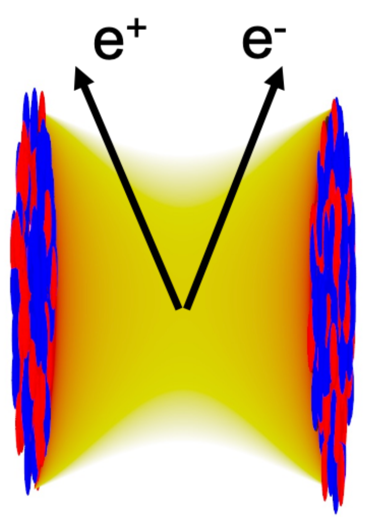
- Compact and lightweight all-silicon MAPS **tracker of ≈ 70 m²**
- **Retractable** vertex detector
- Large acceptance **$|\eta| < 4$**

+

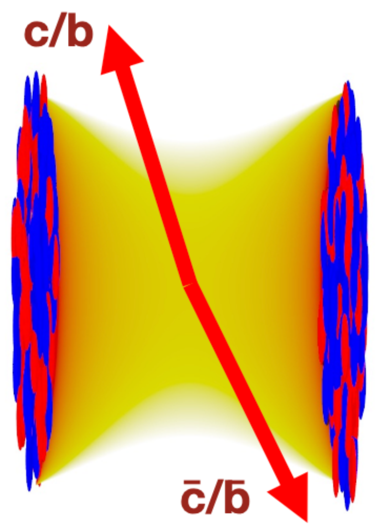
Forward conversion tracker (FCT)

- Extensive particle identification
  ➪ Details in previous talk by G. Volpe
- Letter of intent
  ➪ CERN-LHCC-2022-009

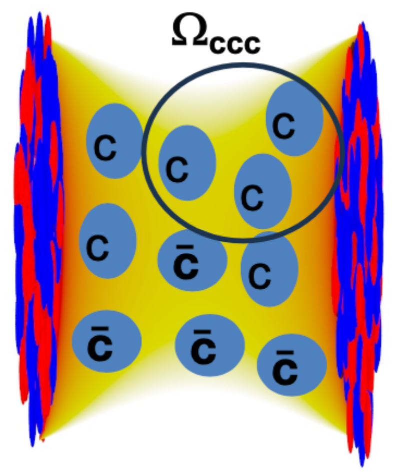
Main requirements from the physics program



Dileptons



Heavy flavour correlations



Multi-charm baryons

Component	$\|\eta\| < 1.75$ (barrel)	$1.75 < \|\eta\| < 4$ (forward)
Vertexing	Best possible DCA resolution, $\boldsymbol{\sigma_{DCA} \approx 10\ \mu m}$ at $p_T = 200$ MeV/c	Best possible DCA resolution, $\boldsymbol{\sigma_{DCA} \approx 30\ \mu m}$ at $p_T = 200$ MeV/c
Tracking	$\boldsymbol{\Delta p_T/p_T \sim 1 - 2\%}$	

Main requirements from the physics program

How do we meet these requirements? 🤔

Component	$\lvert\eta\rvert < 1.75$ (barrel)	$1.75 < \lvert\eta\rvert < 4$ (forward)
Vertexing	Best possible DCA resolution, $\sigma_{DCA} \approx$ **10 µm** at p_T = 200 MeV/c	Best possible DCA resolution, $\sigma_{DCA} \approx$ **30 µm** at p_T = 200 MeV/c
Tracking	$\Delta p_T/p_T \sim$ **1 - 2%**	

Vertex detector requirements

- First layer (r_0) as close as possible to the interaction point
- Unprecedent spatial resolution
  σ_{pos} ~ 2.5 µm
- Extremely low material budget
  0.1% X_0 per layer
- Radiation tolerance
  300 Mrad TID[1] +
  10^{16} 1 MeV n_{eq}/cm^2 NIEL[2]

Pointing resolution $\propto r_0 \cdot \sqrt{x/X_0}$
(multiple scattering limit)

➪ **Many challenges**

[1] Total ionising dose
[2] Non ionising energy loss

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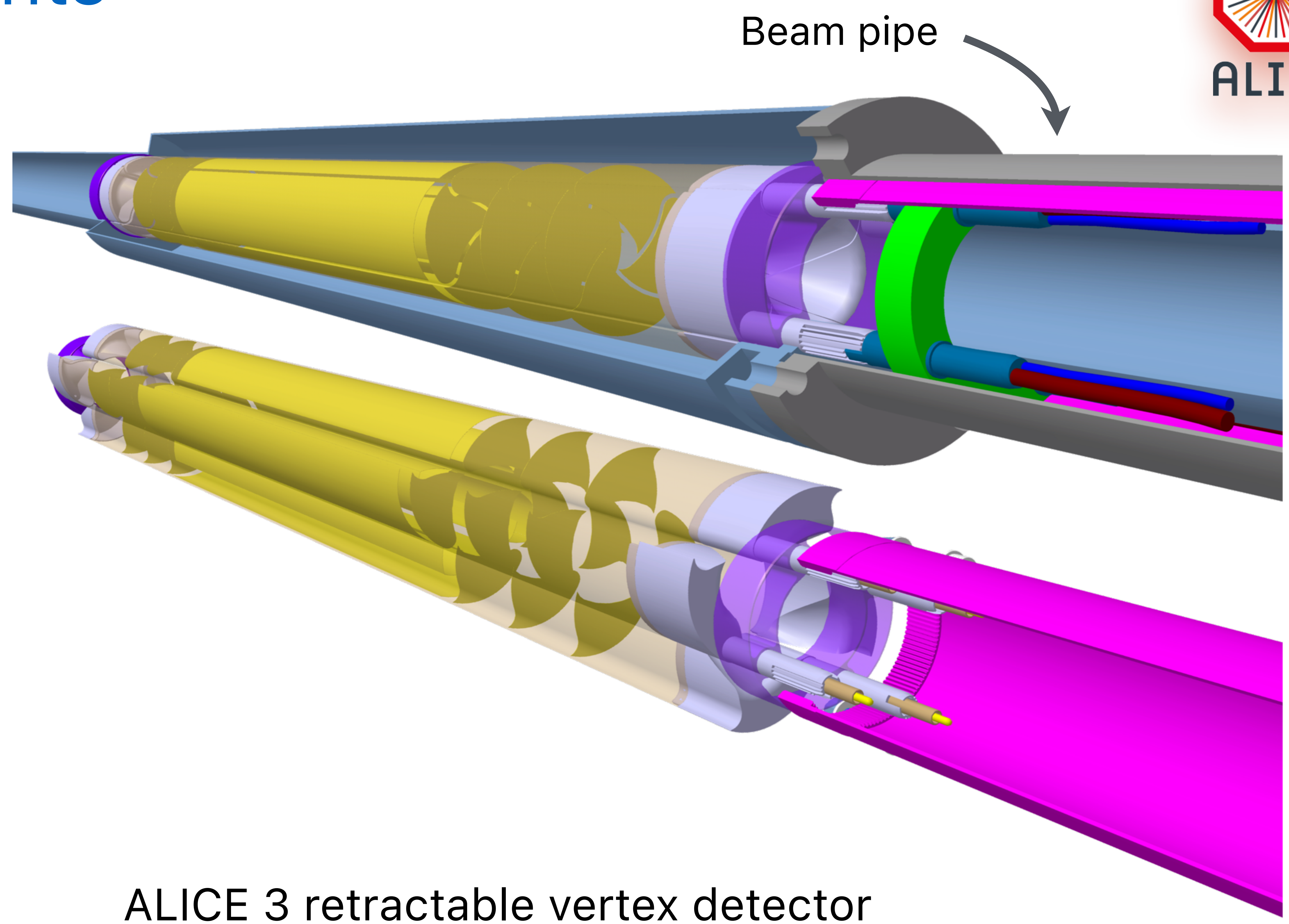


ALICE 3 retractable vertex detector

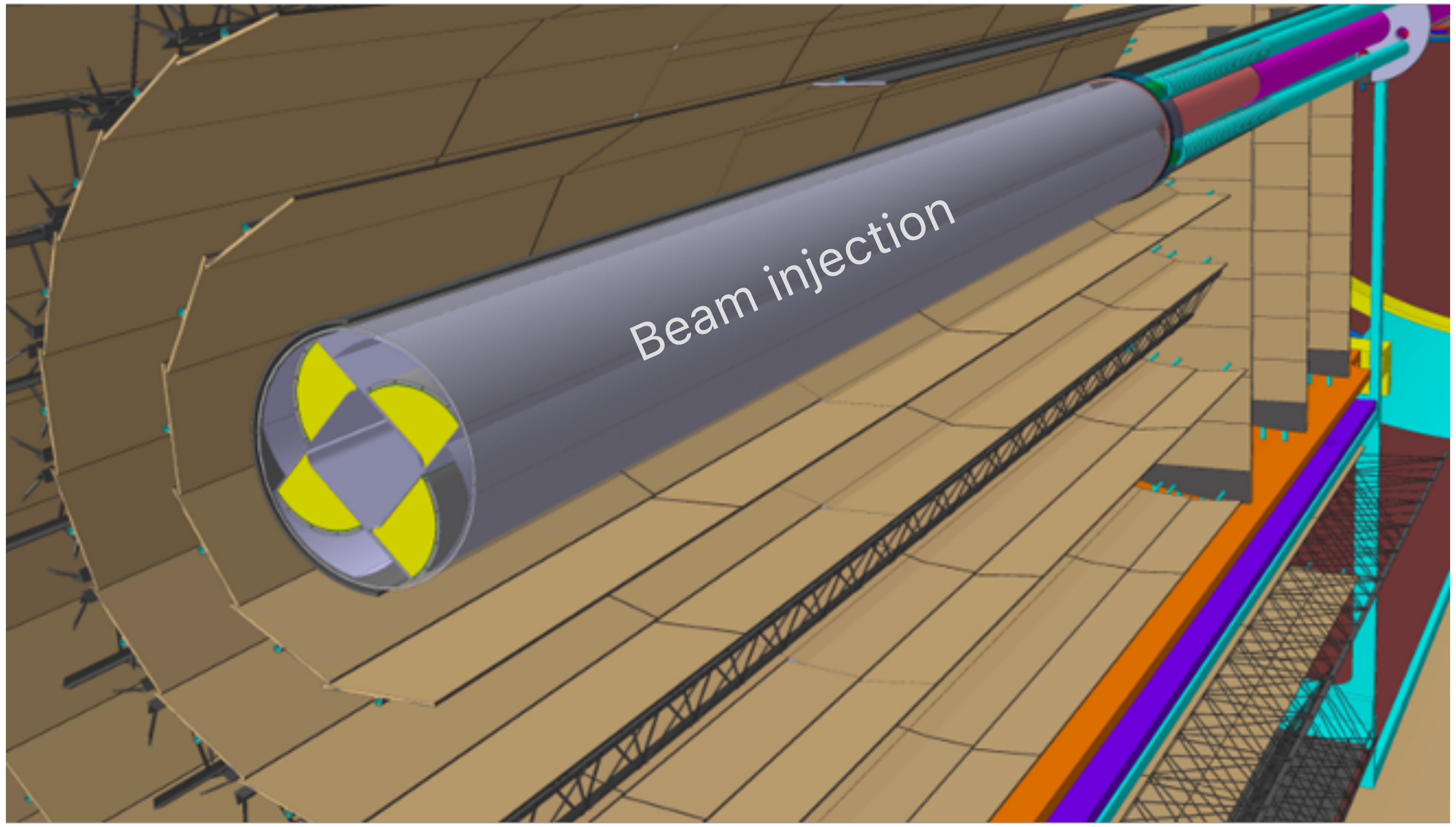
😎

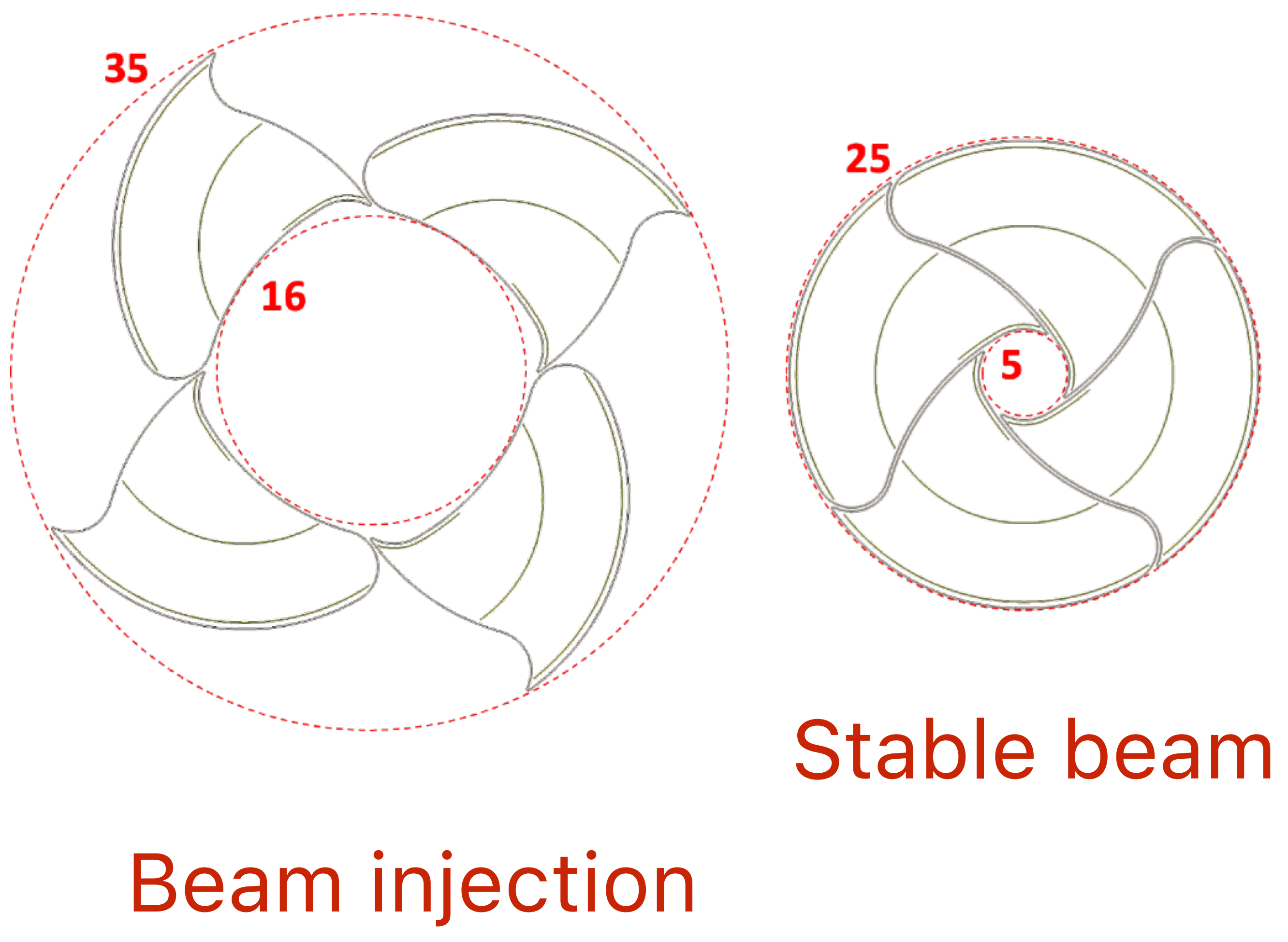
[1] Total ionising dose

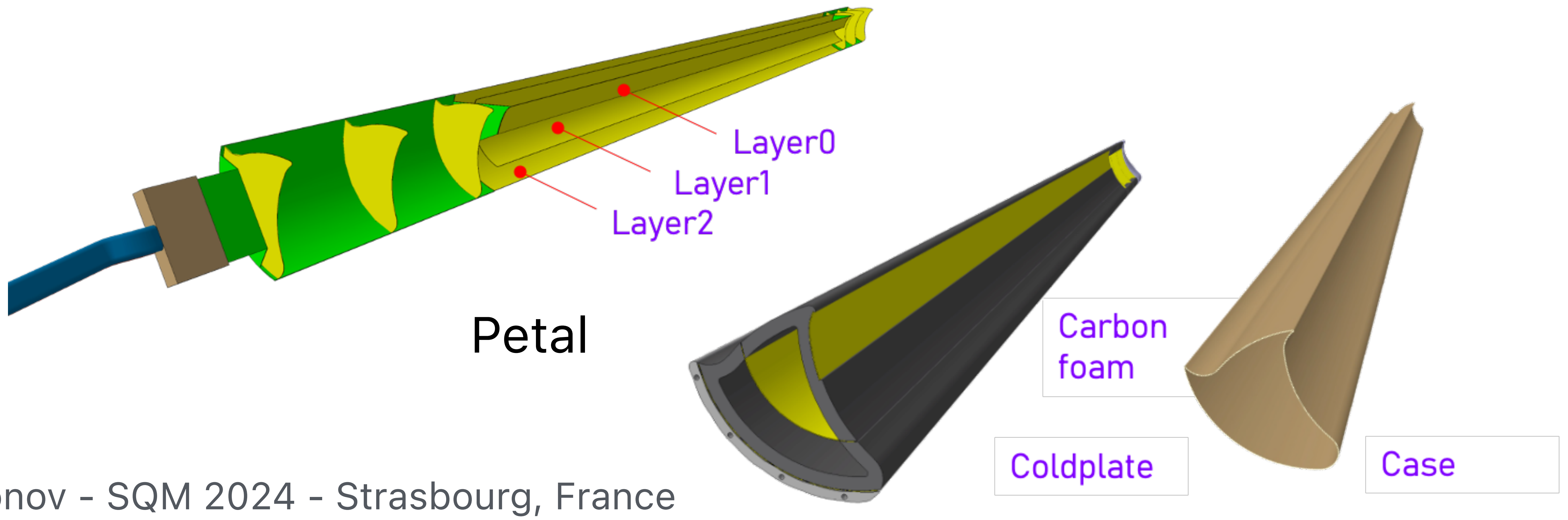
[2] Non ionising energy loss

Vertex detector

- **Curved** wafer-size MAPS **inside the beam pipe**
- Retractable configuration
- ***4 petals*** in secondary vacuum form cylinder and disk layers
- First tracking layer at **5 mm** from beam axis → limit by LHC beam aperture







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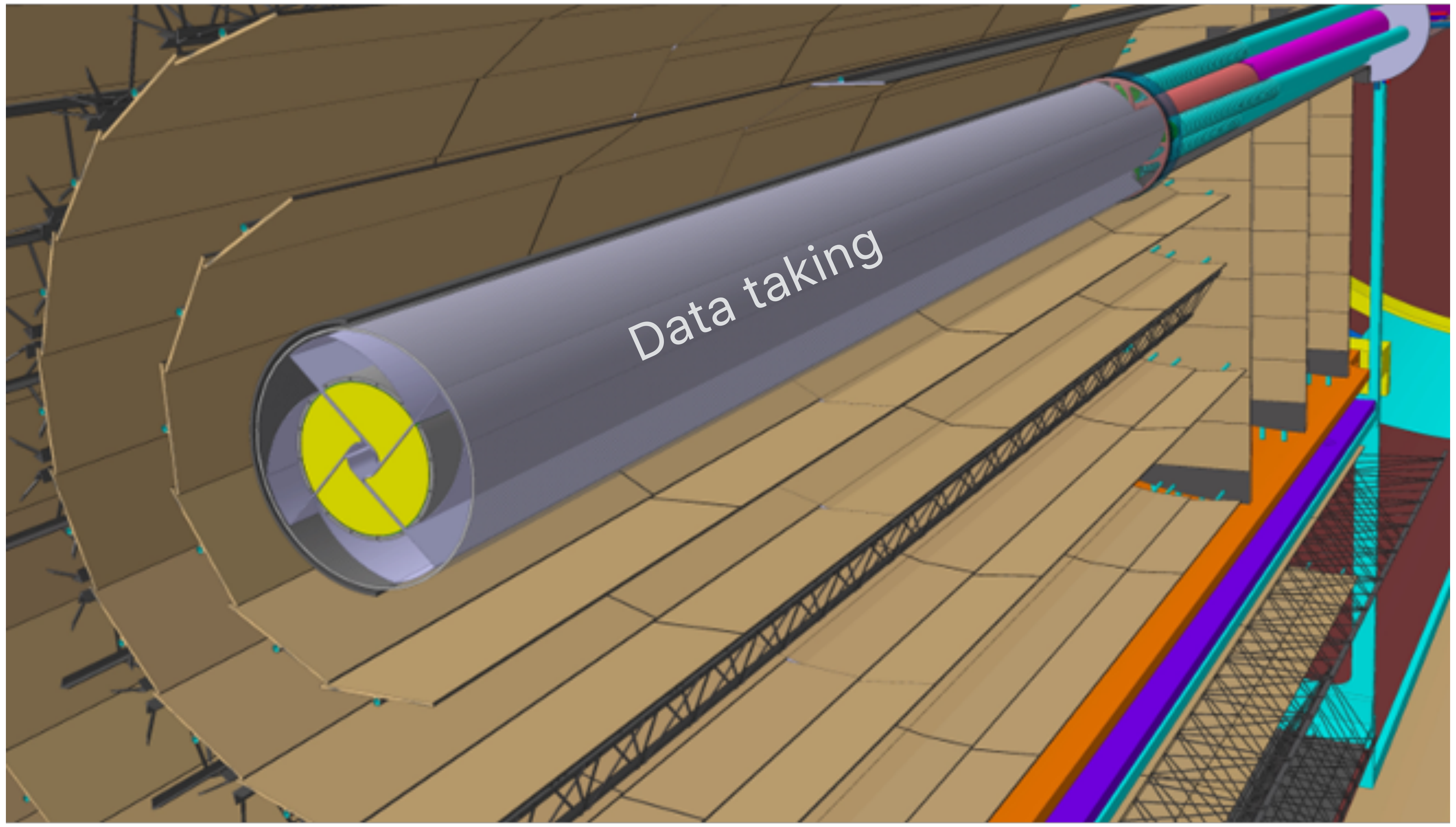
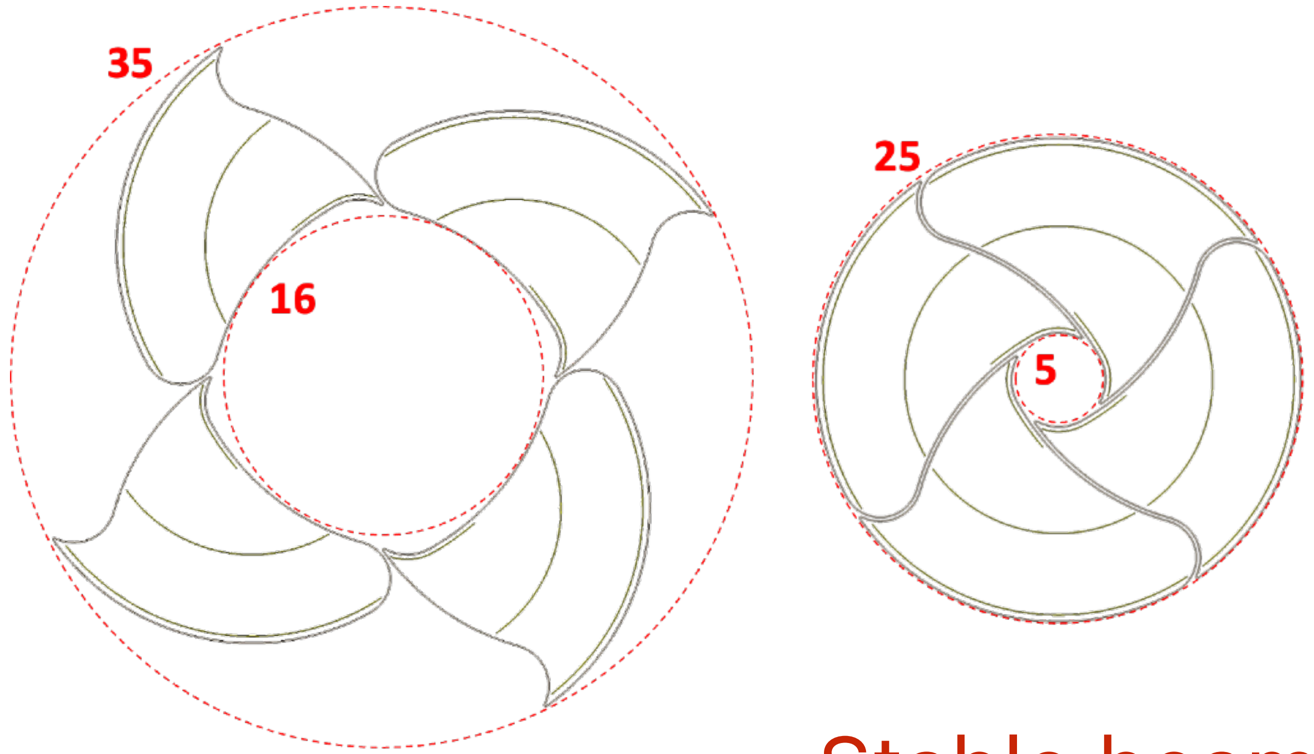
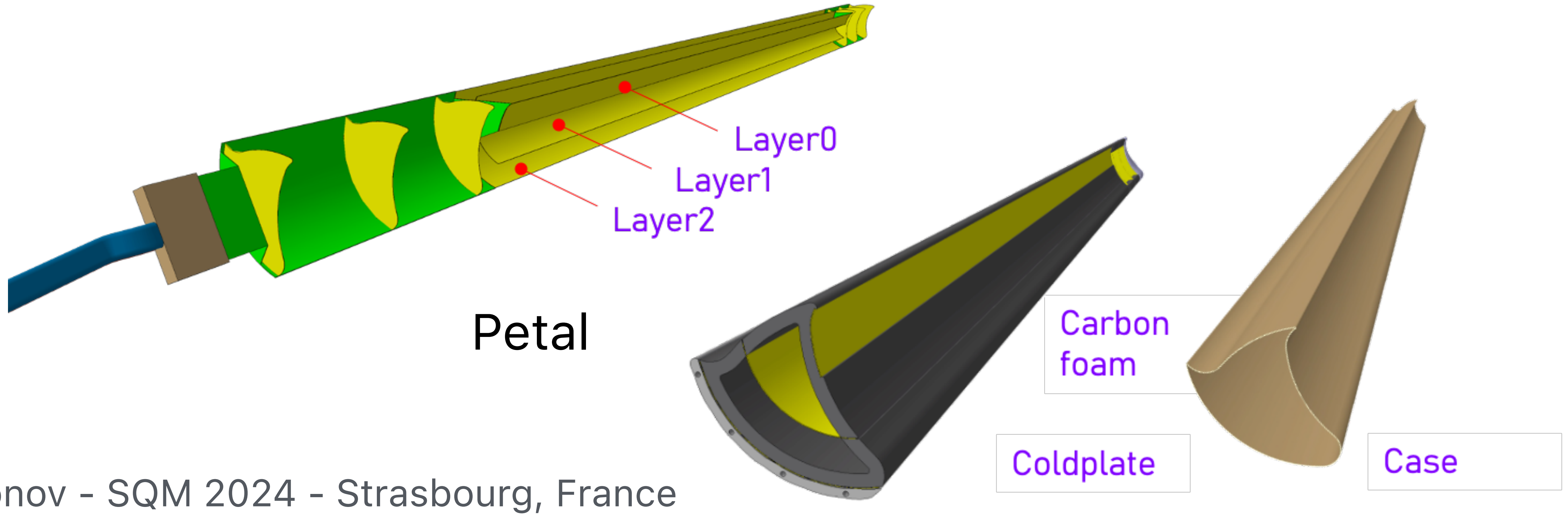




Stable beam

Beam injection



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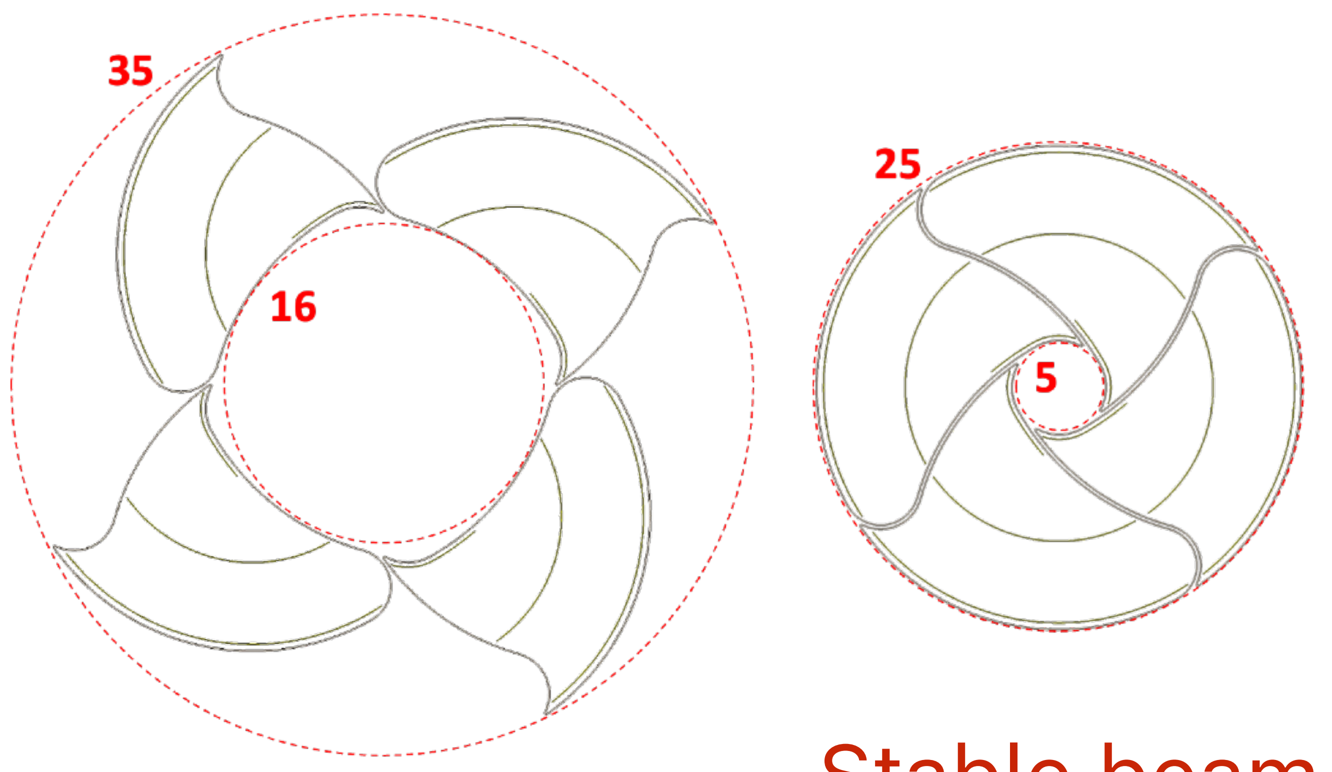

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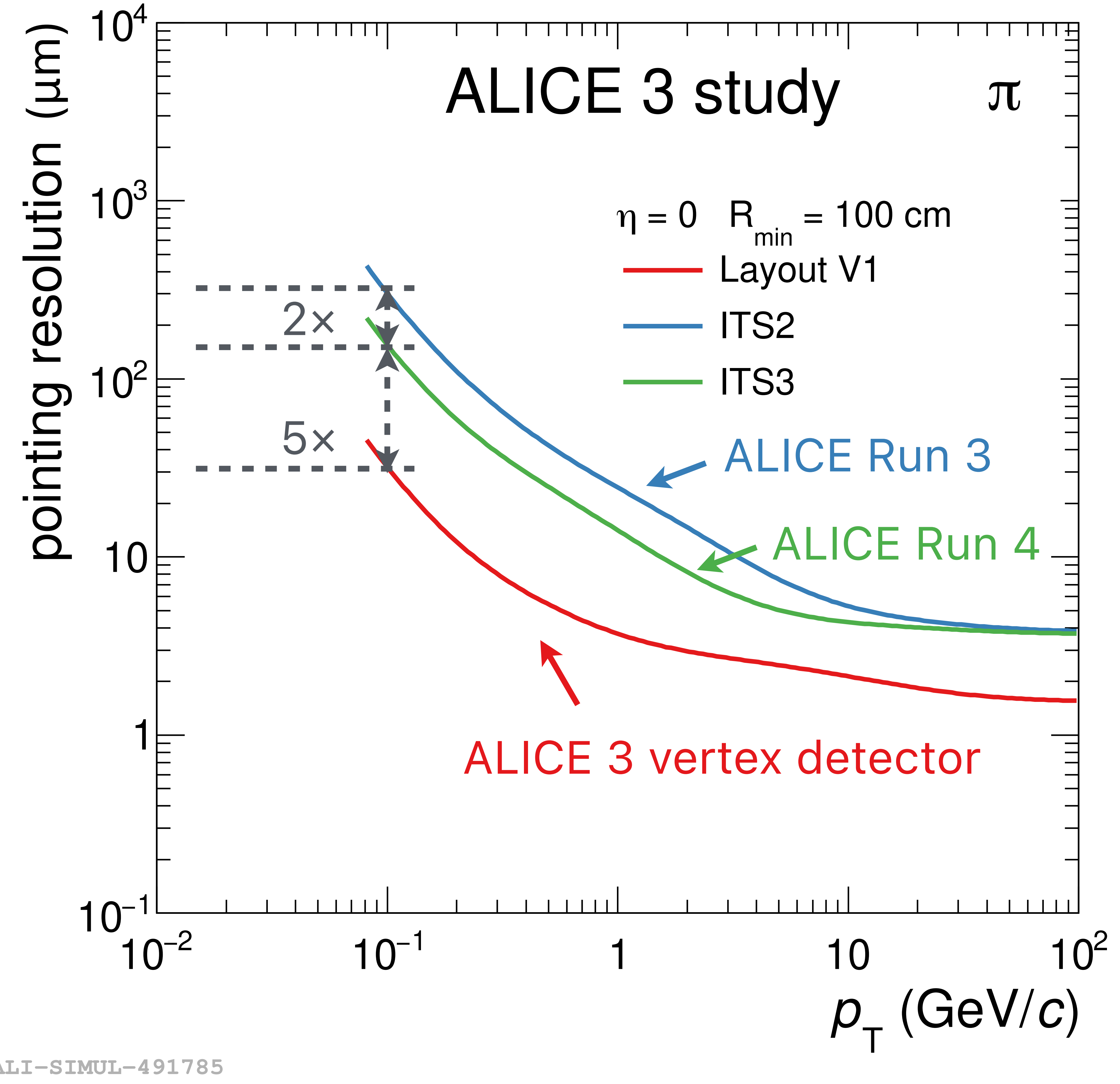


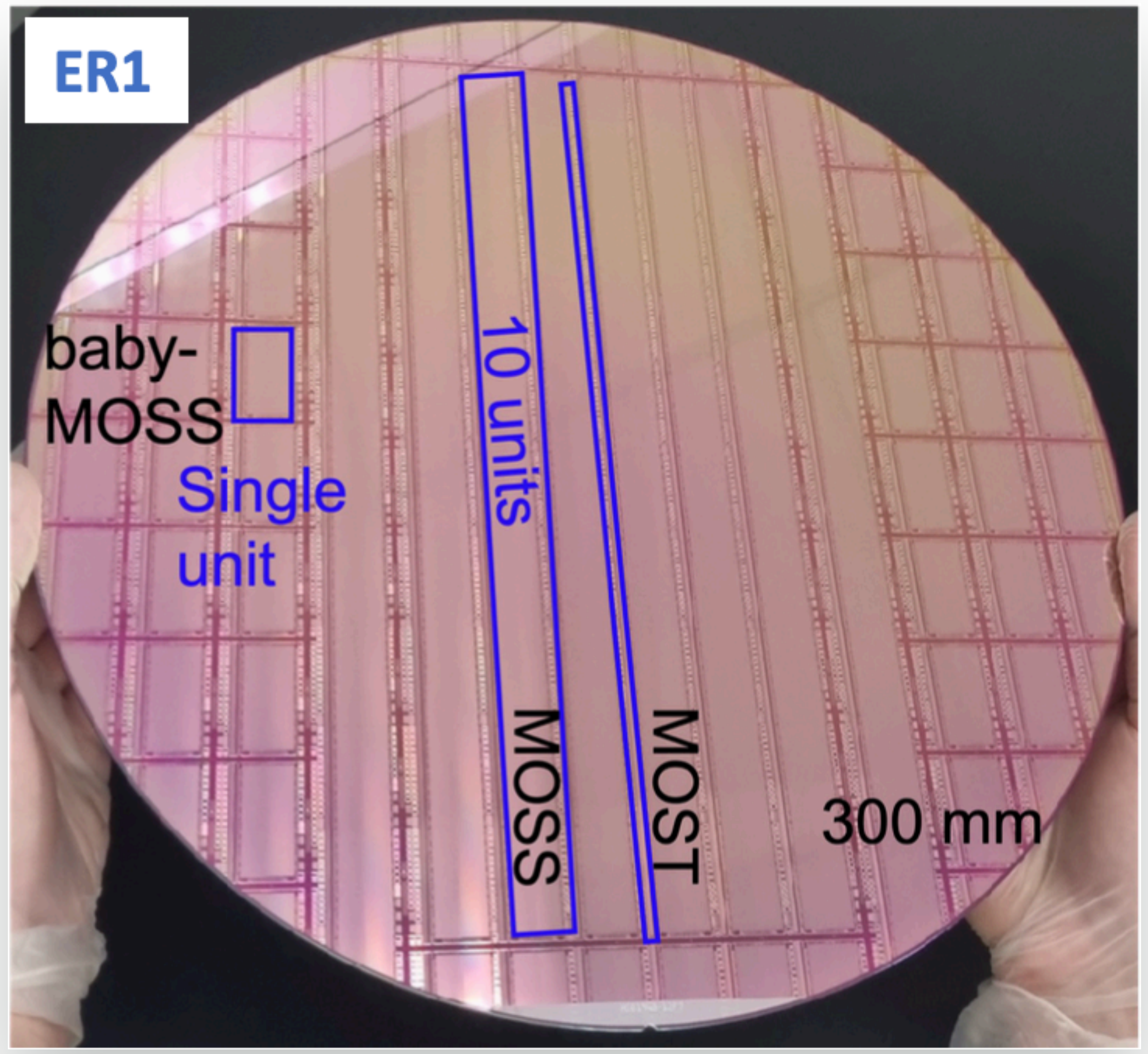
R&D of the vertex detector

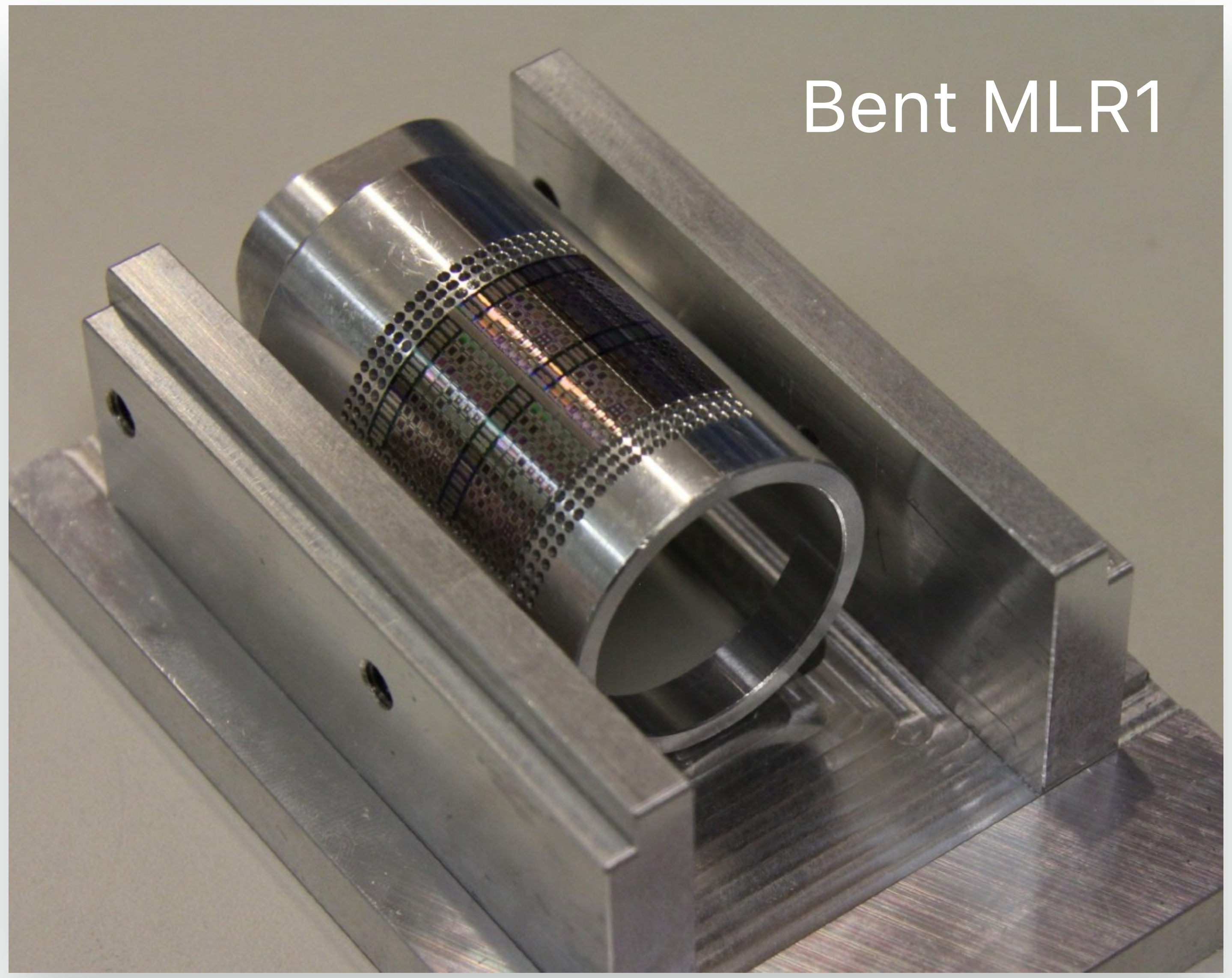
➪ **Sensors**

- Strongly relying on ALICE ITS3* R&D (sensor design, stitching, wafer-scale bent sensor)
- Tests successful
  - Bent sensors ✅
  - Wafer-sized stitched sensors ✅

ITS3 engineering model v2

Wafer-sized sensors





*ALICE Inner Tracking System (Upgrade for Run 4)

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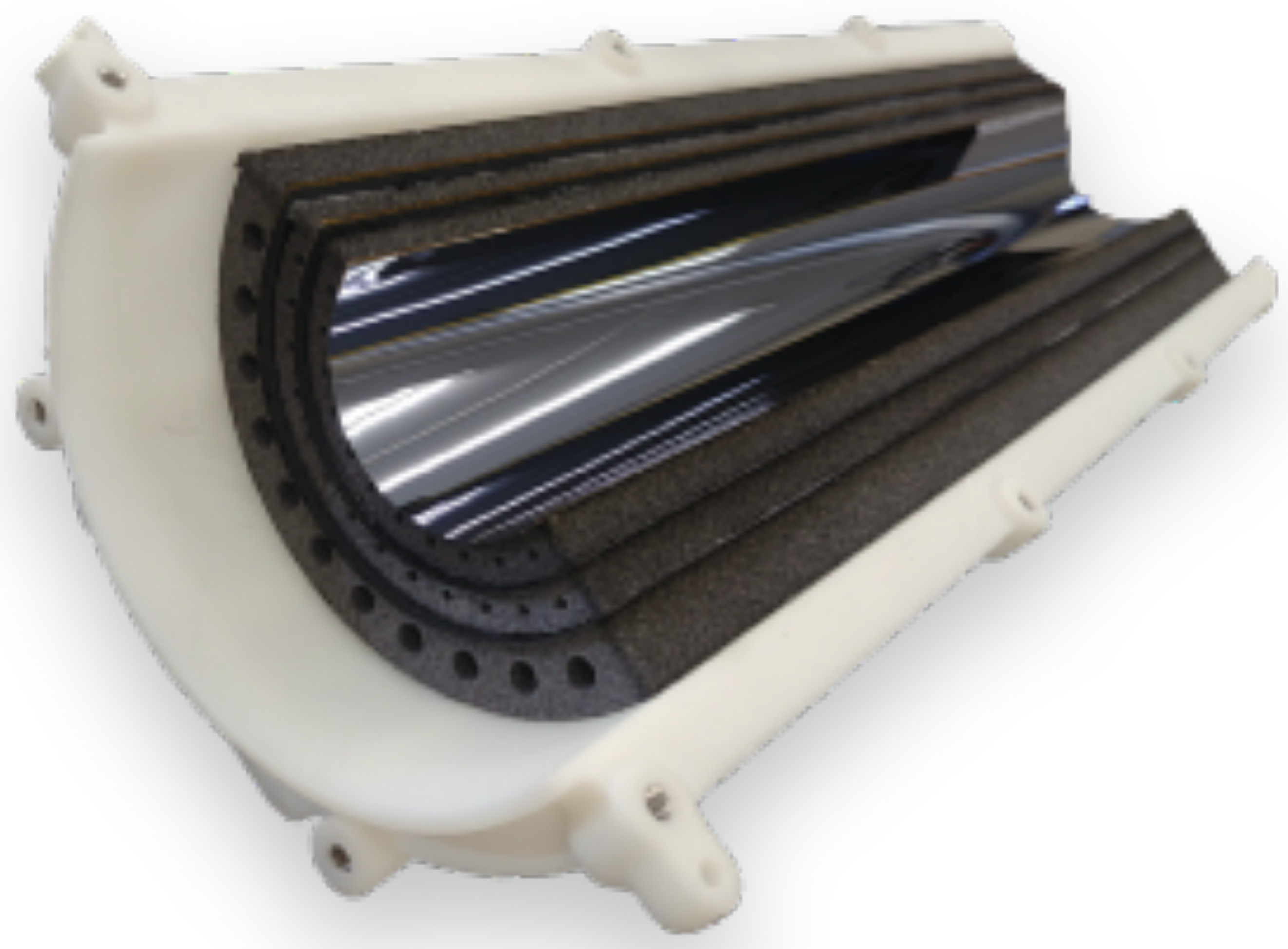
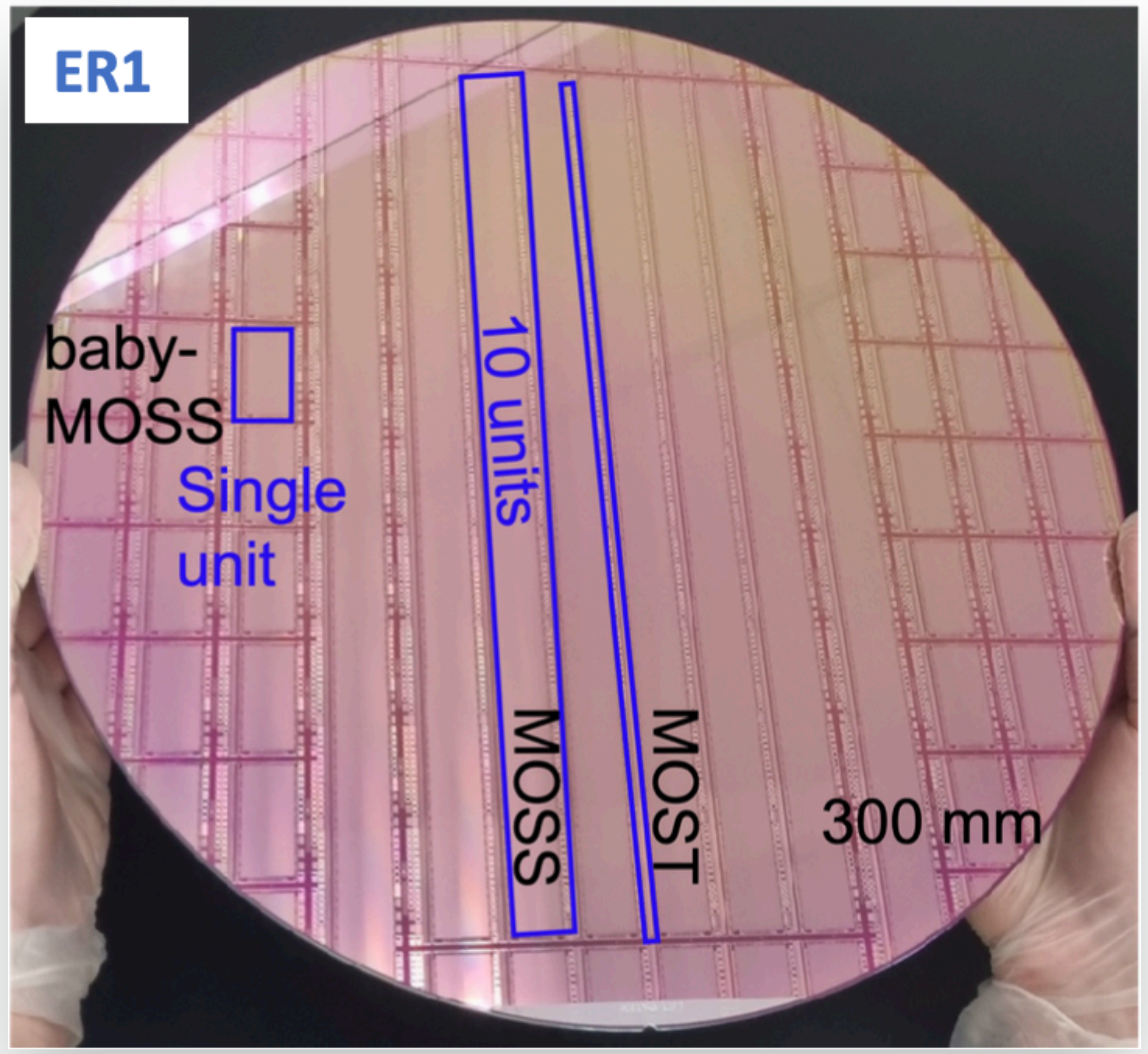
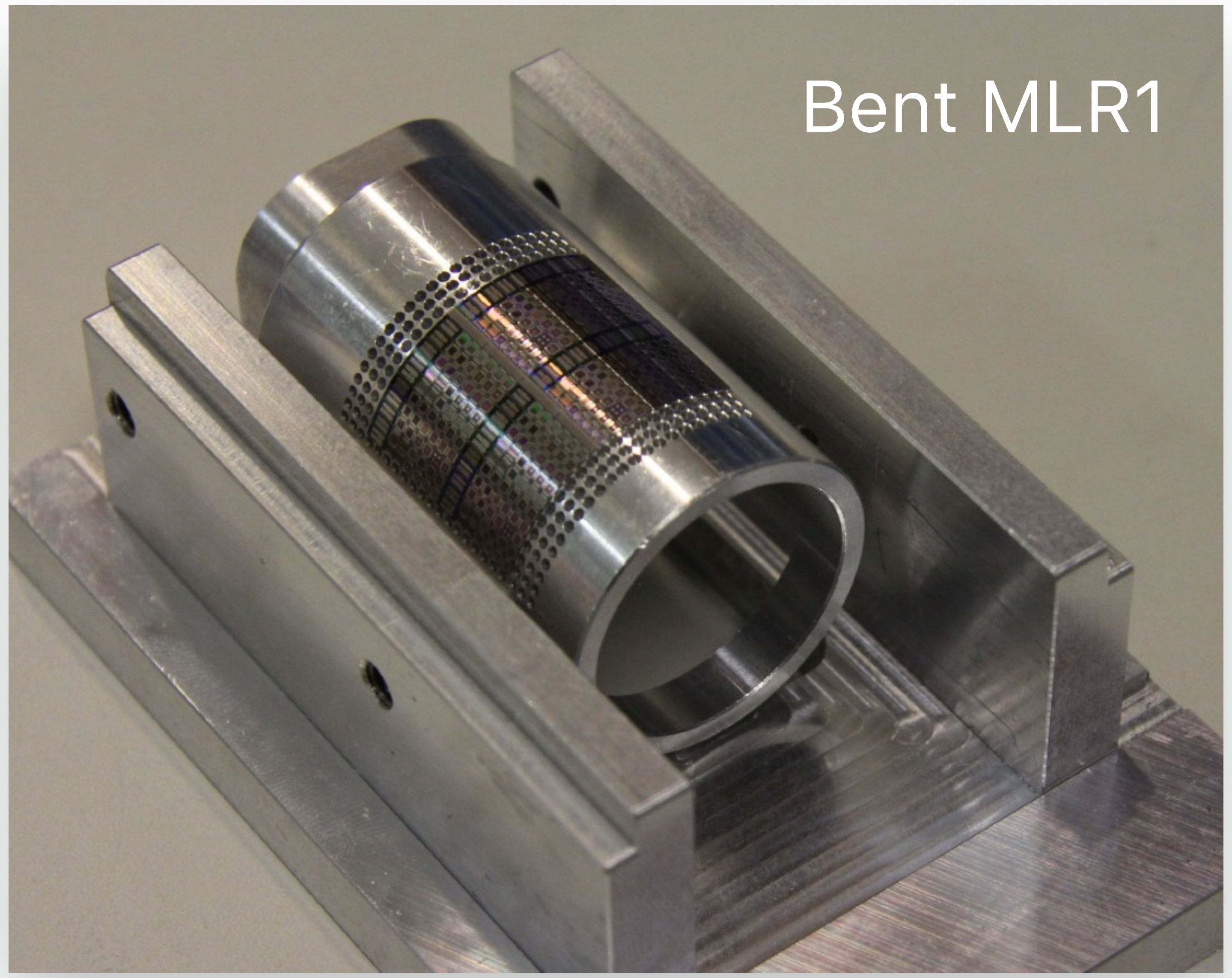
Cutting edge technologies pioneered by ALICE

ITS3 engineering model v2



Wafer-sized sensors





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☞ The ITS3 detector and physics reach of the LS3 ALICE Upgrade by Chunzheng Wang, Tue 14:20

ITS3 engineering model v2

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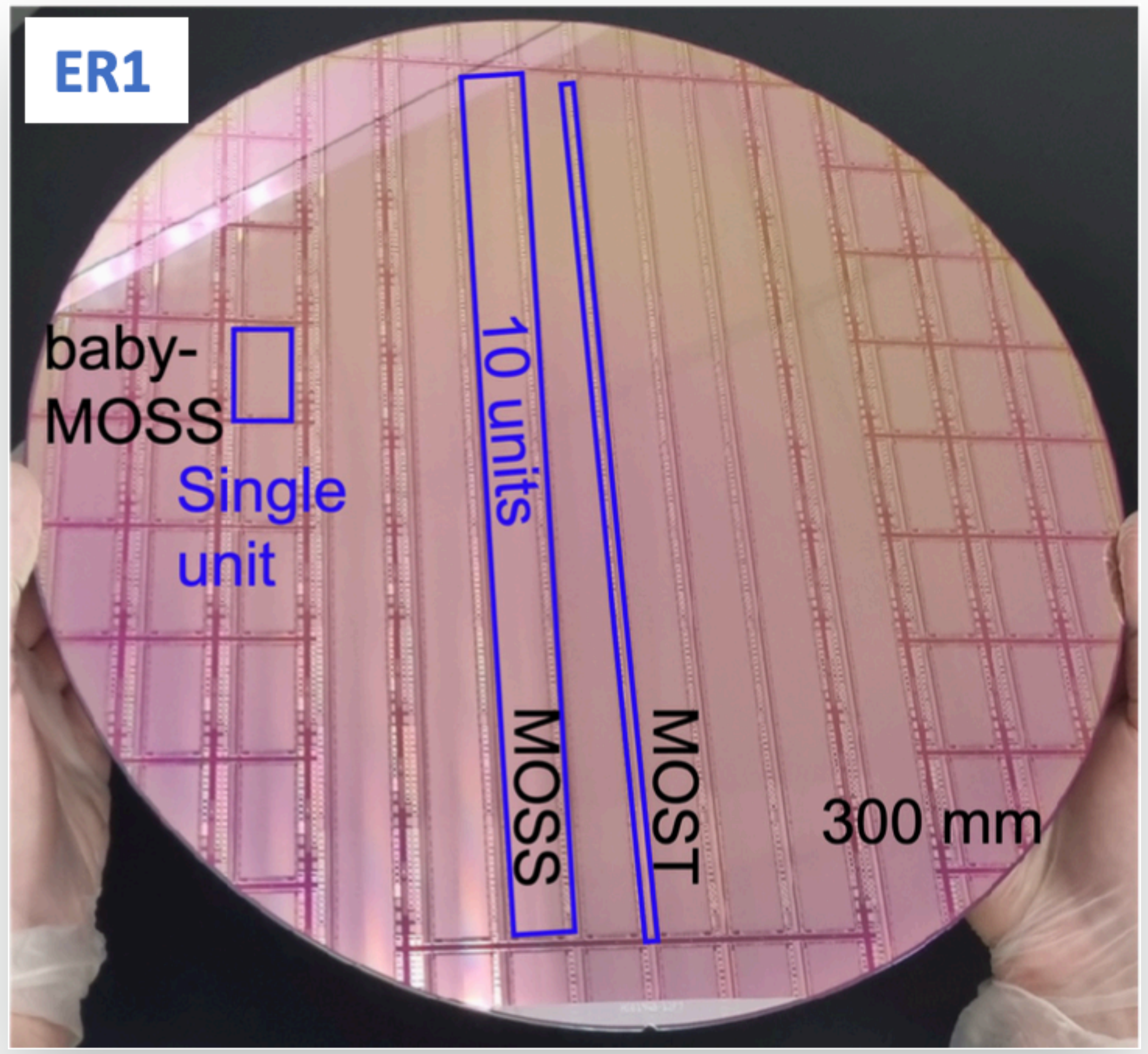
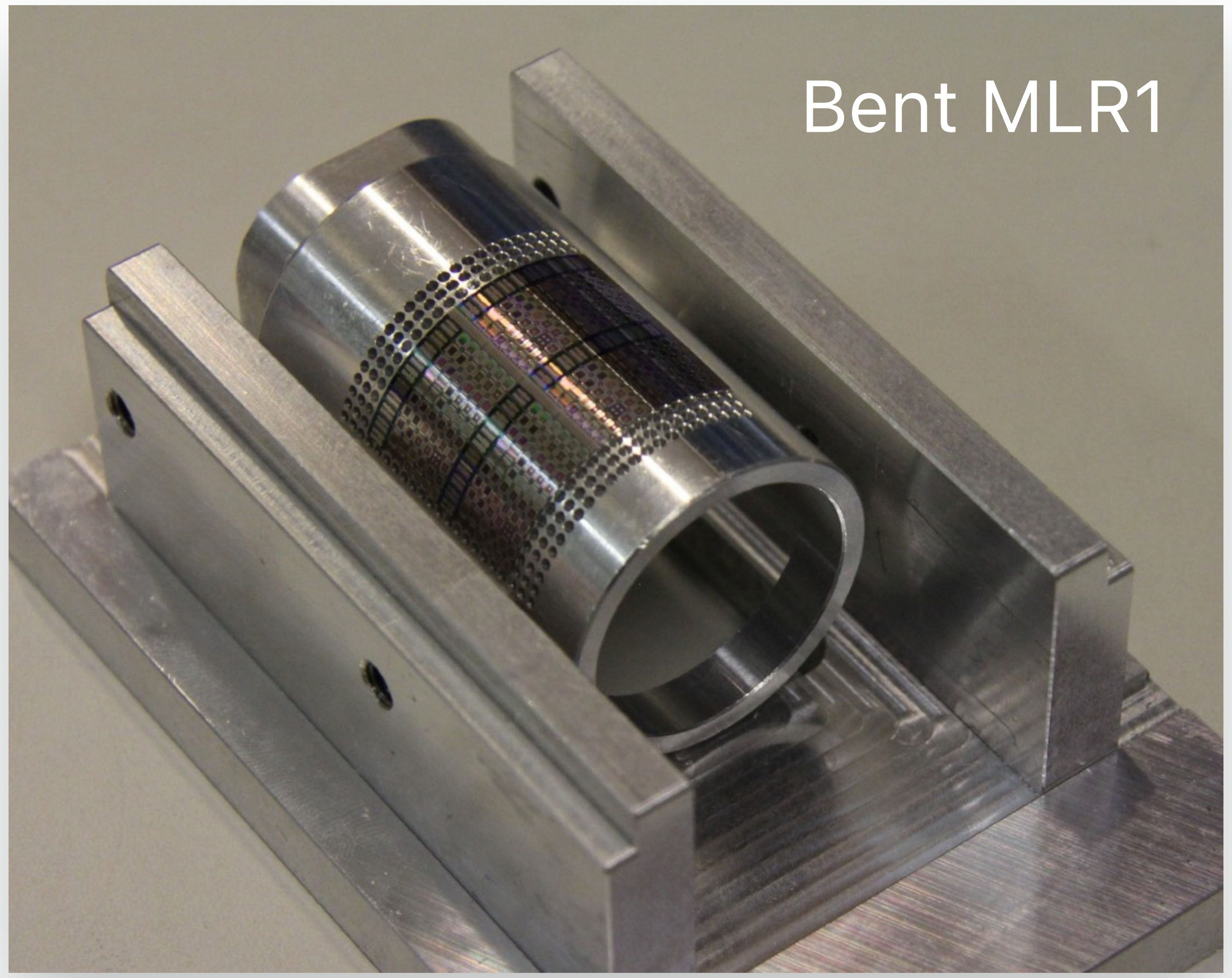
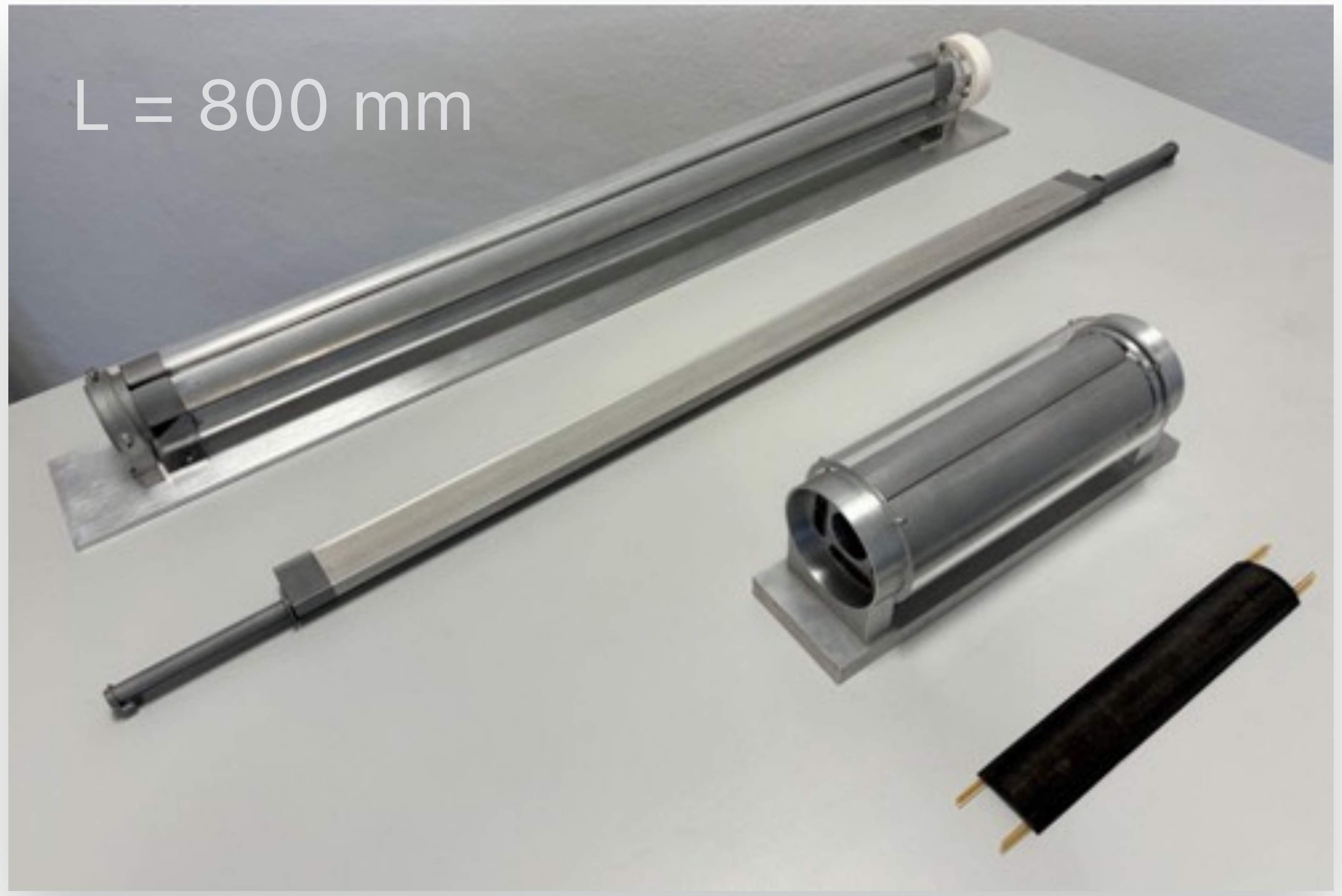




R&D of the vertex detector

IRIS breadboard model v3

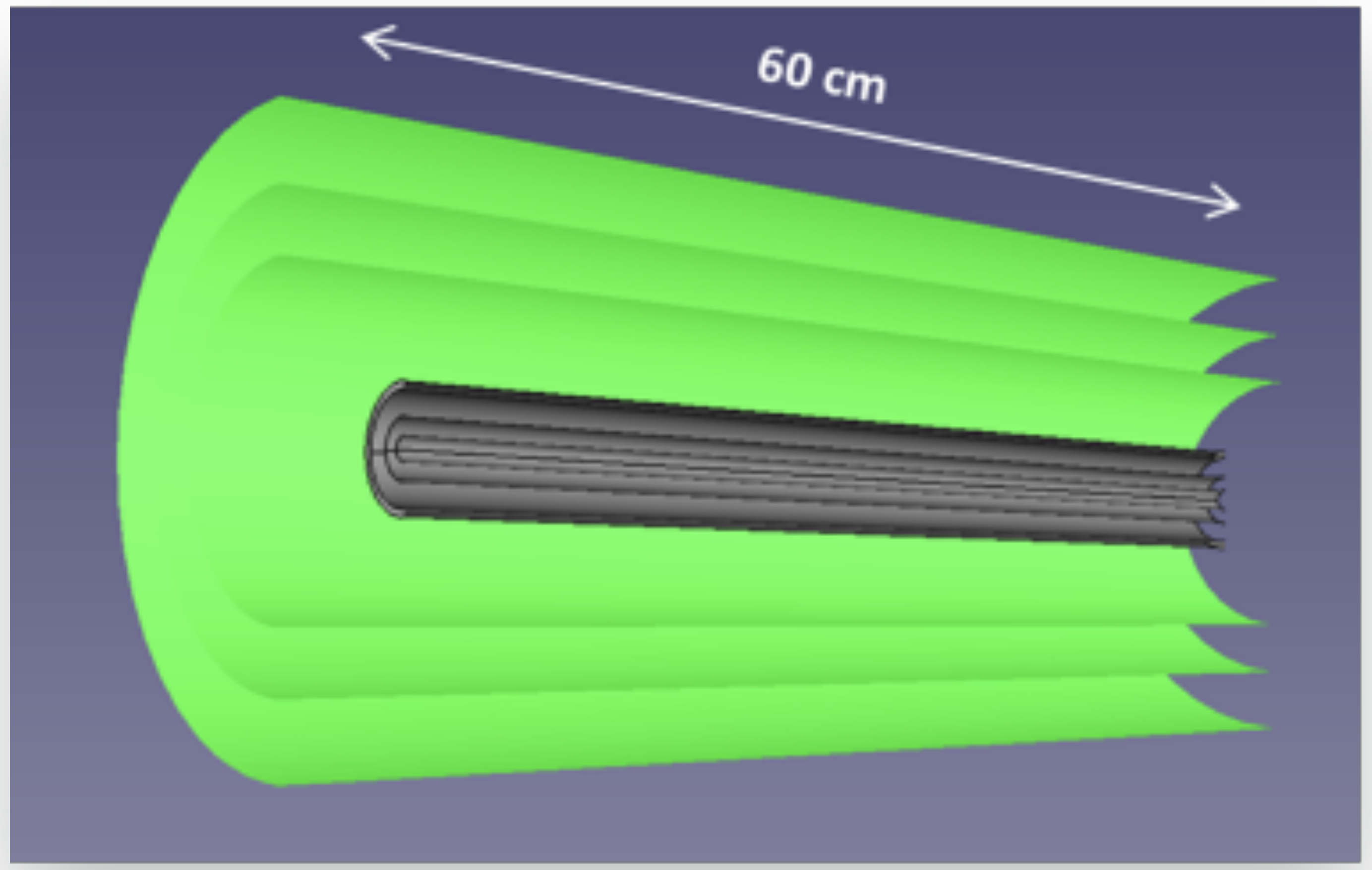


IRIS system

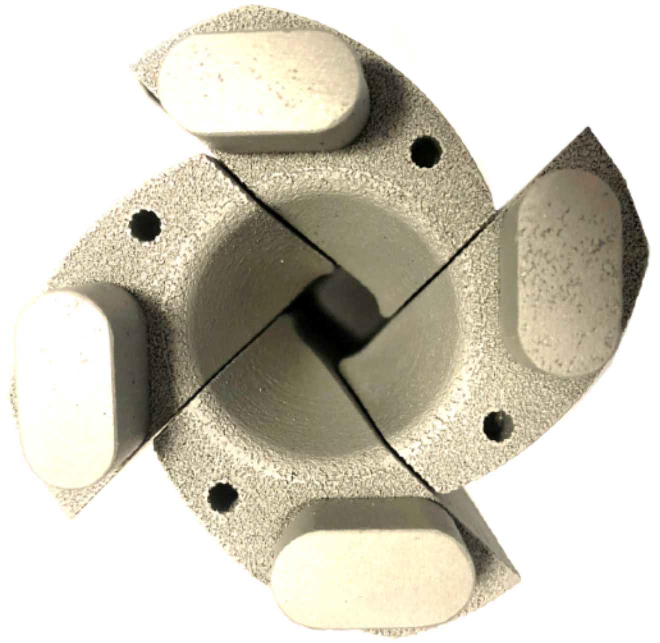
- Services integration being detailed
- Study of protection between primary and secondary vacuum
- Impact of vacuum on components, wire bonding, glued parts

Middle Layers

- studying various options for ultra-light layers, leveraging on ITS3 technology
- benefits on tracking of soft electrons and of charged hyperons (Ξ^-, Ω^-)



Option with ultra-light curved sensor layers



3D printed Al petals
0.5 mm* thick wall

*Our target thickness ≈ 0.15 mm

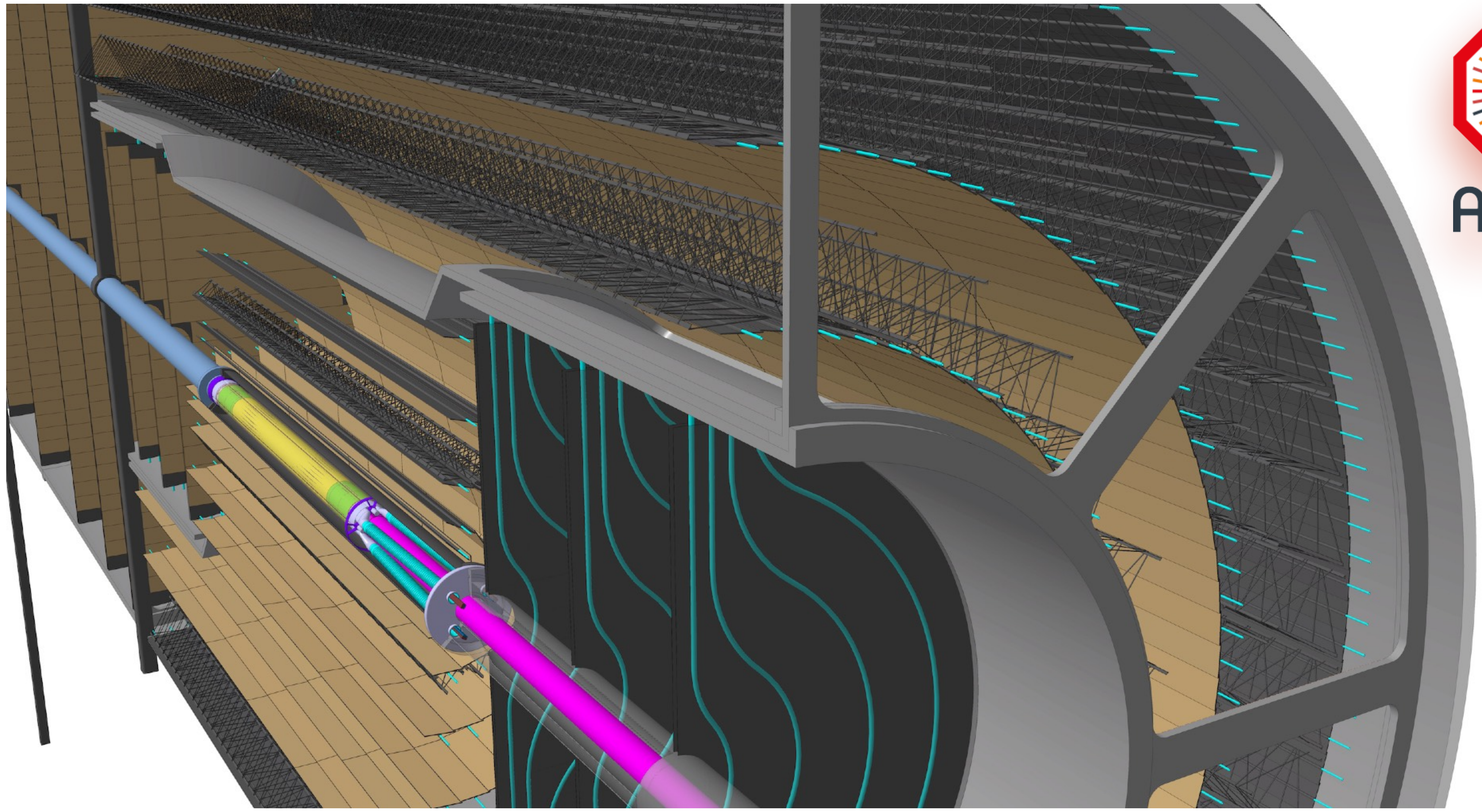
Outer Tracker

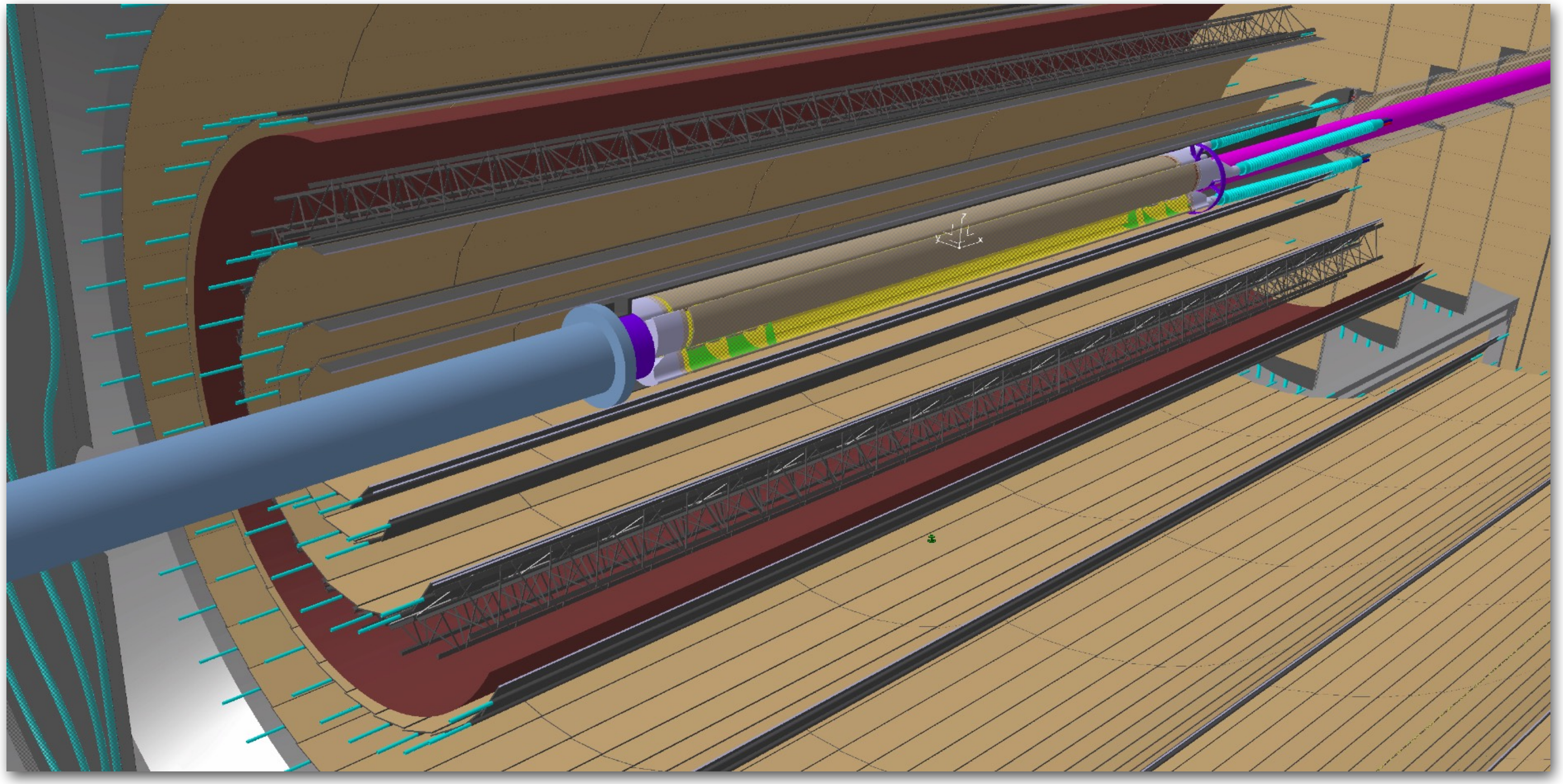
70 m² silicon pixels, CMOS MAPS technology, larger pixel size

- Large coverage: **$|\eta| < 4$**
- Time resolution: ~ 100 ns
- Sensor pixel pitch ~ 50 µm for $\sigma_{POS} \approx 10$ µm
- Very low material: **~1% X_0** per layer

Challenges:

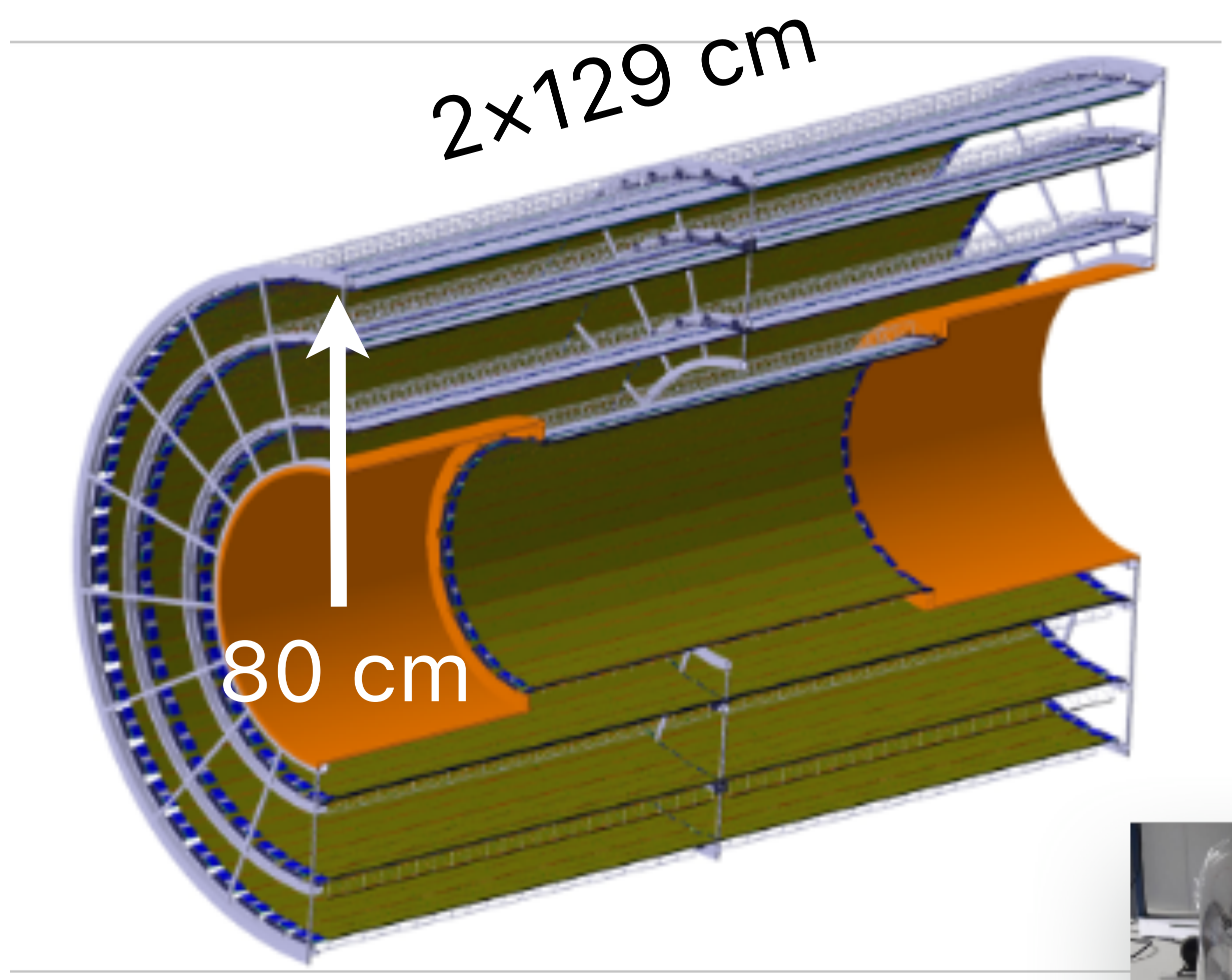
☞ Industrialization of the **module assembly**
☞ Optimization of powering scheme to **minimize material**

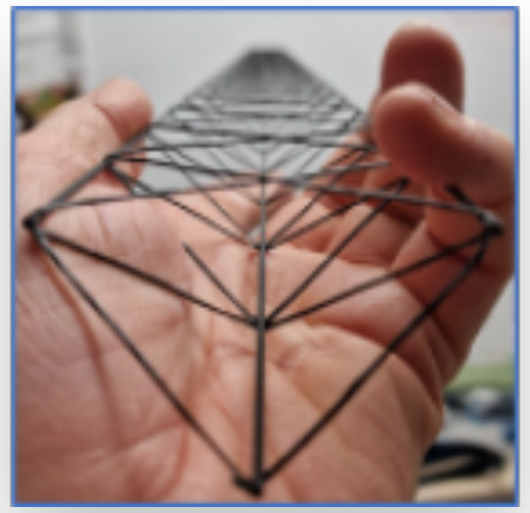




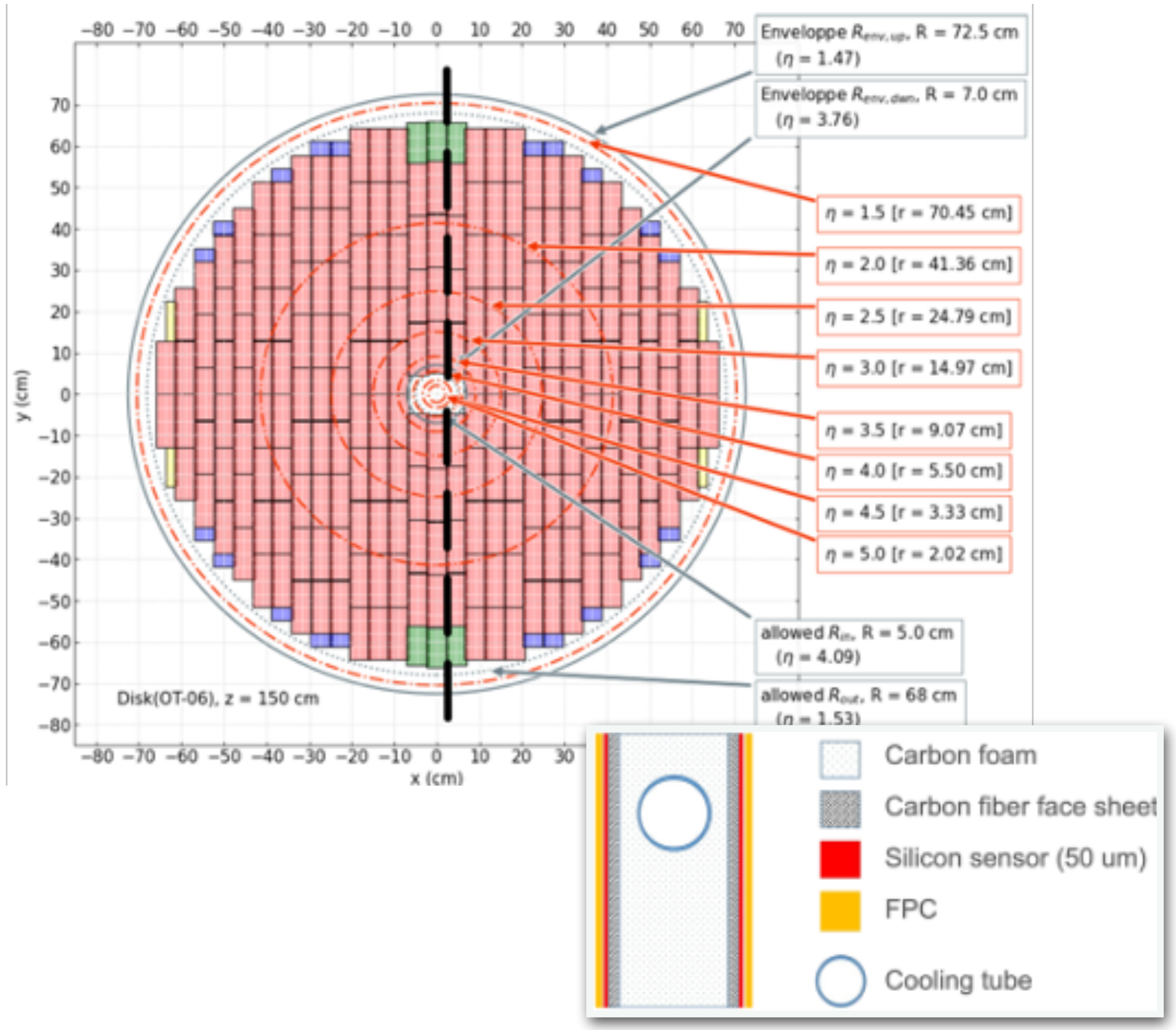
R&D for Outer Tracker

OT barrel design
- Full-scale stave model
- Air and water cooling studies
- Mechanical support studies

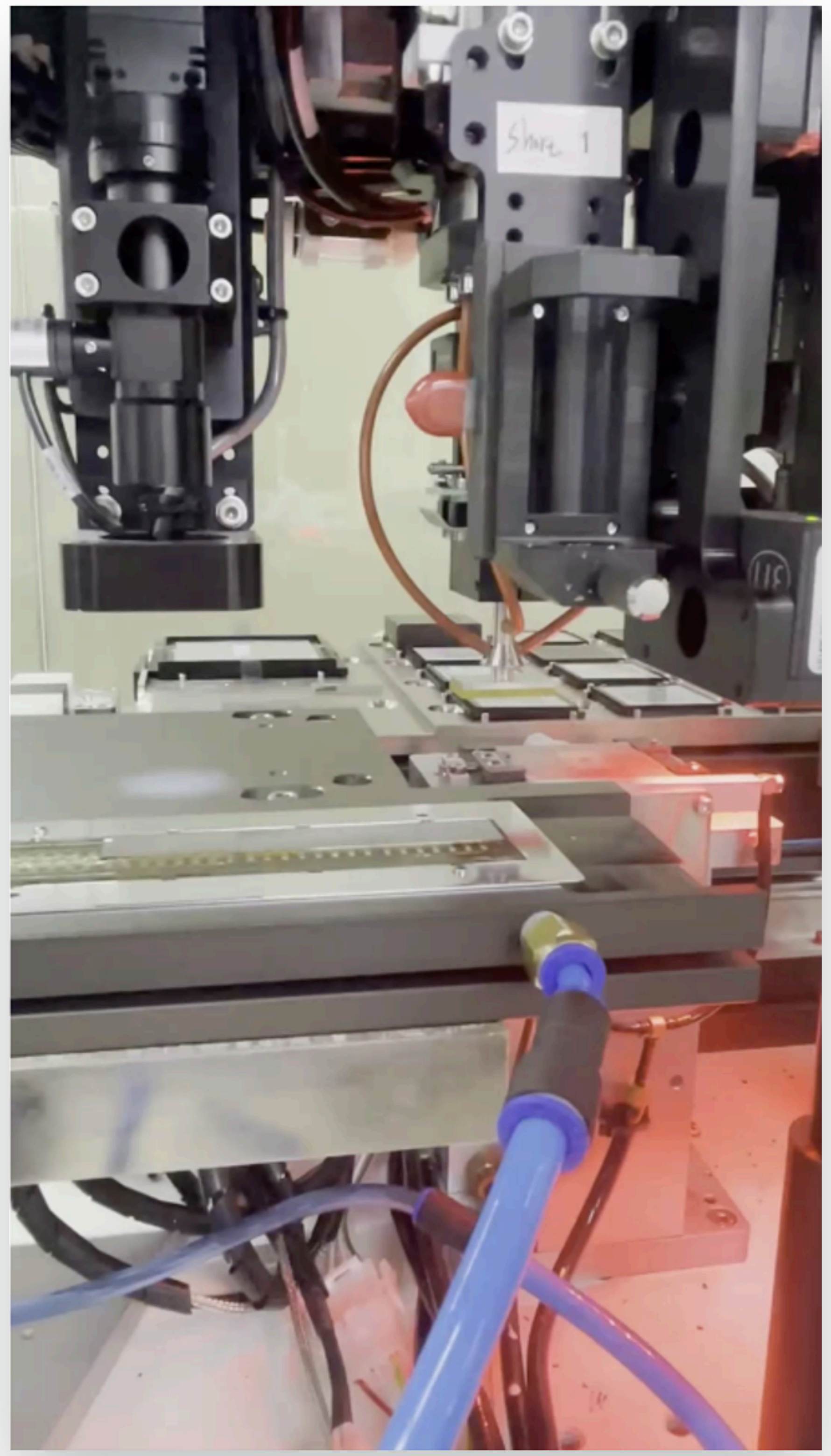




OT endcaps with disks
- "Paving" with modules
- Mechanical layout (double-sided disks?), carbon-fibre support



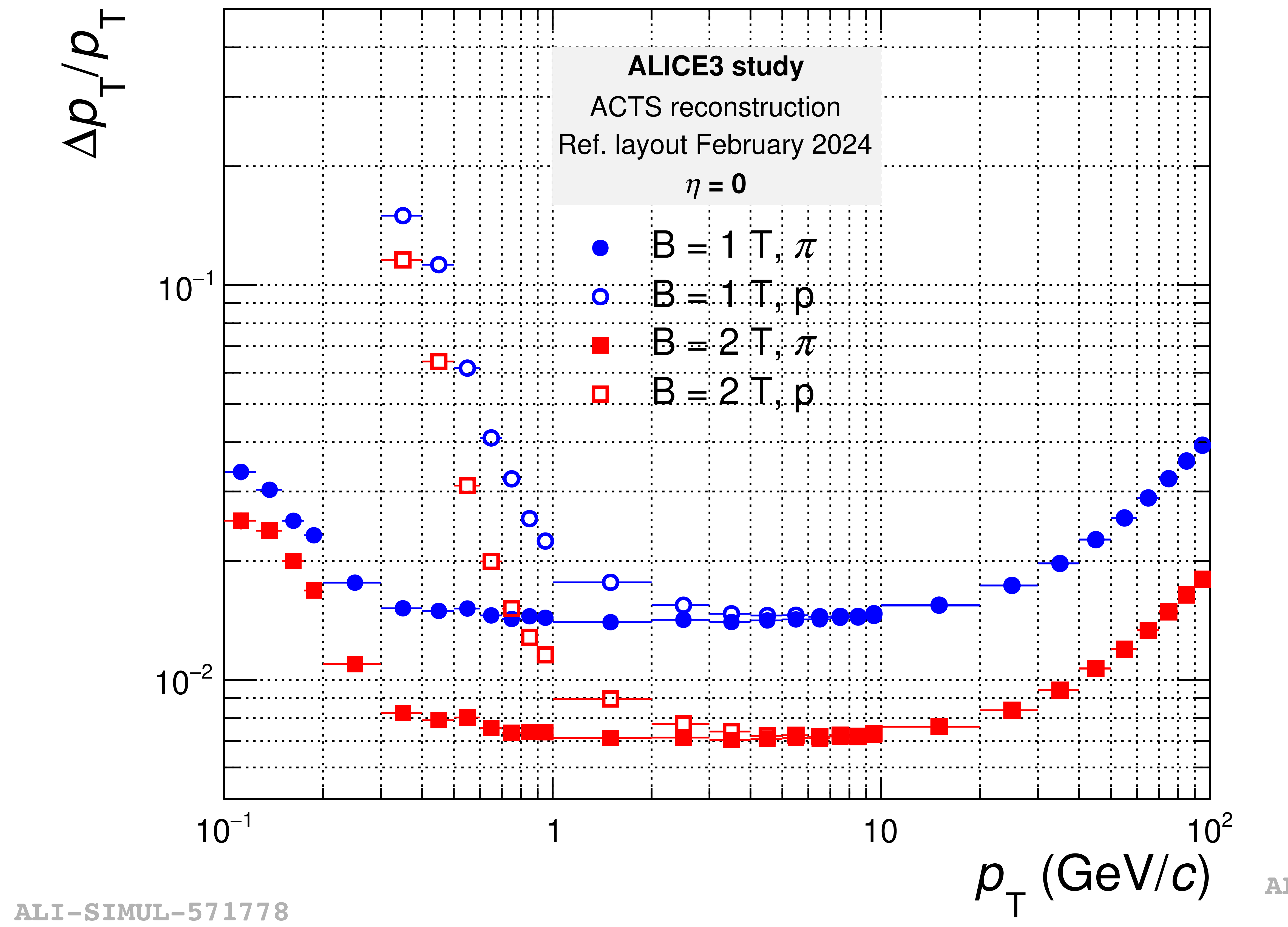
Automated module assembly
- General-purpose die-bonder machine
- Flexible printed circuit, sensor gluing and interconnections

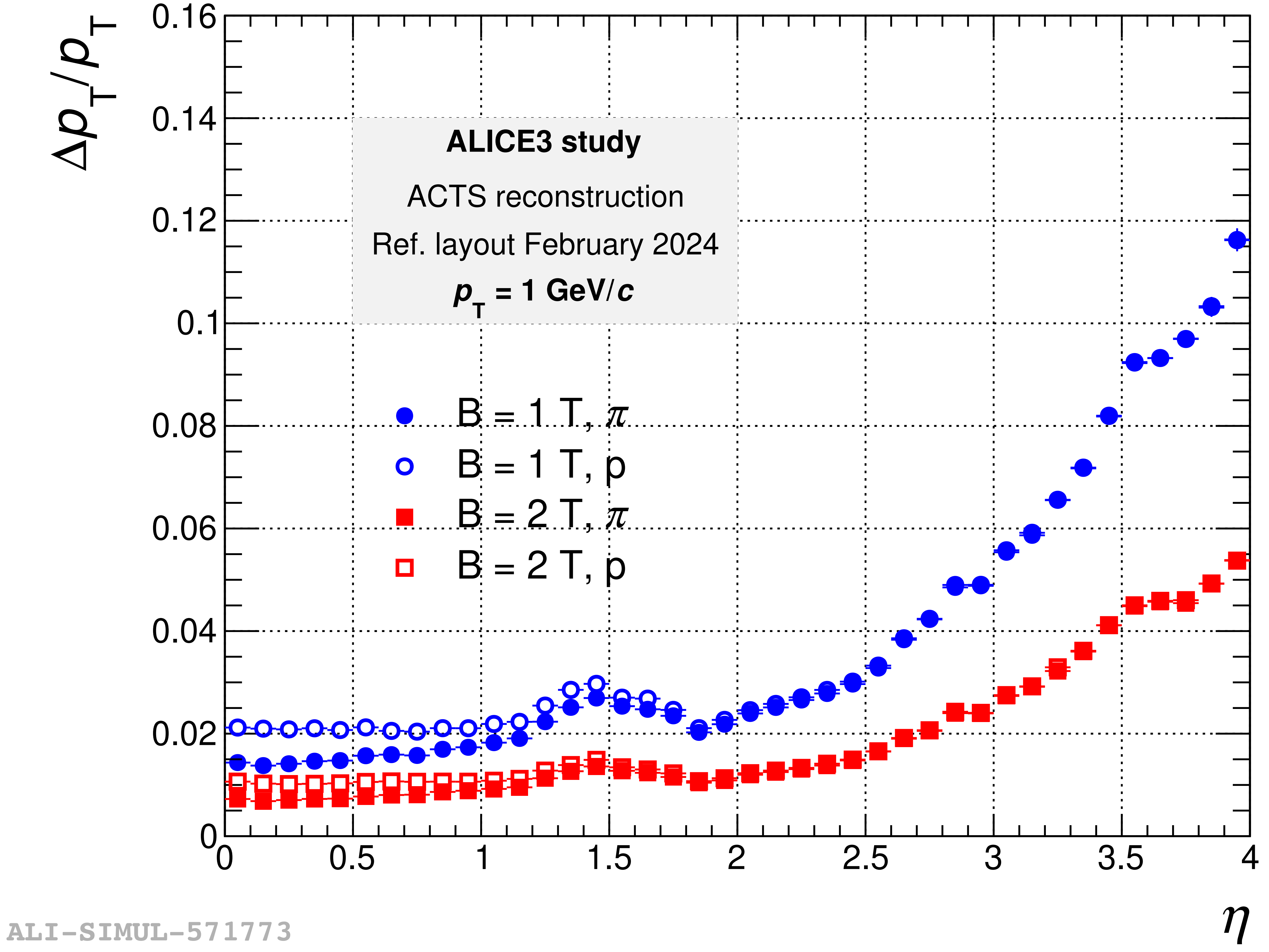


ALICE 3 tracker performance

Tracking performance validation

- ACTS reconstruction software [1]





p_T resolution < 2% for $p_T \geq$ 200 MeV/c (π, B = 2 T)

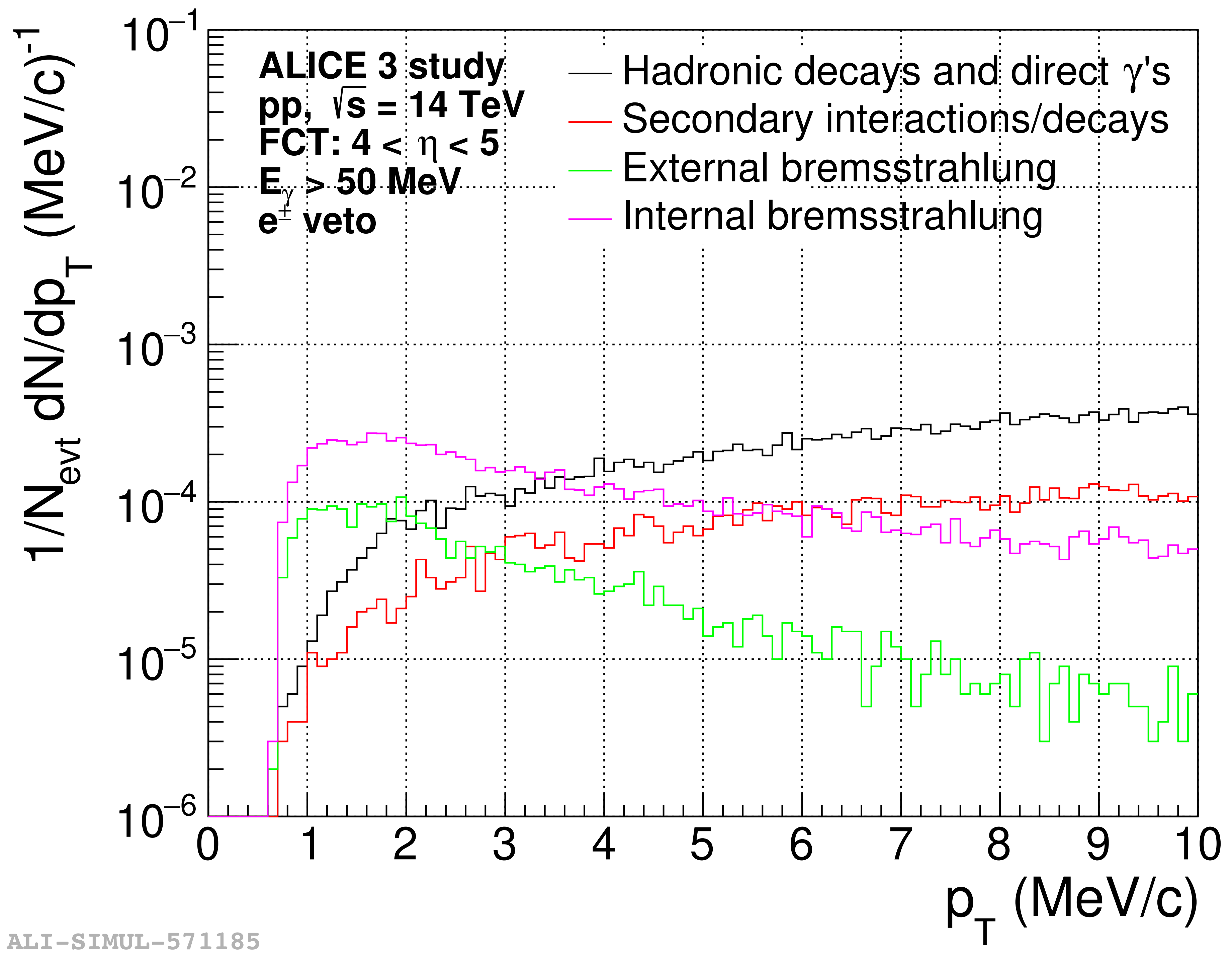
p_T resolution < 2% up to $\eta \approx 3$ (π, B = 2 T)

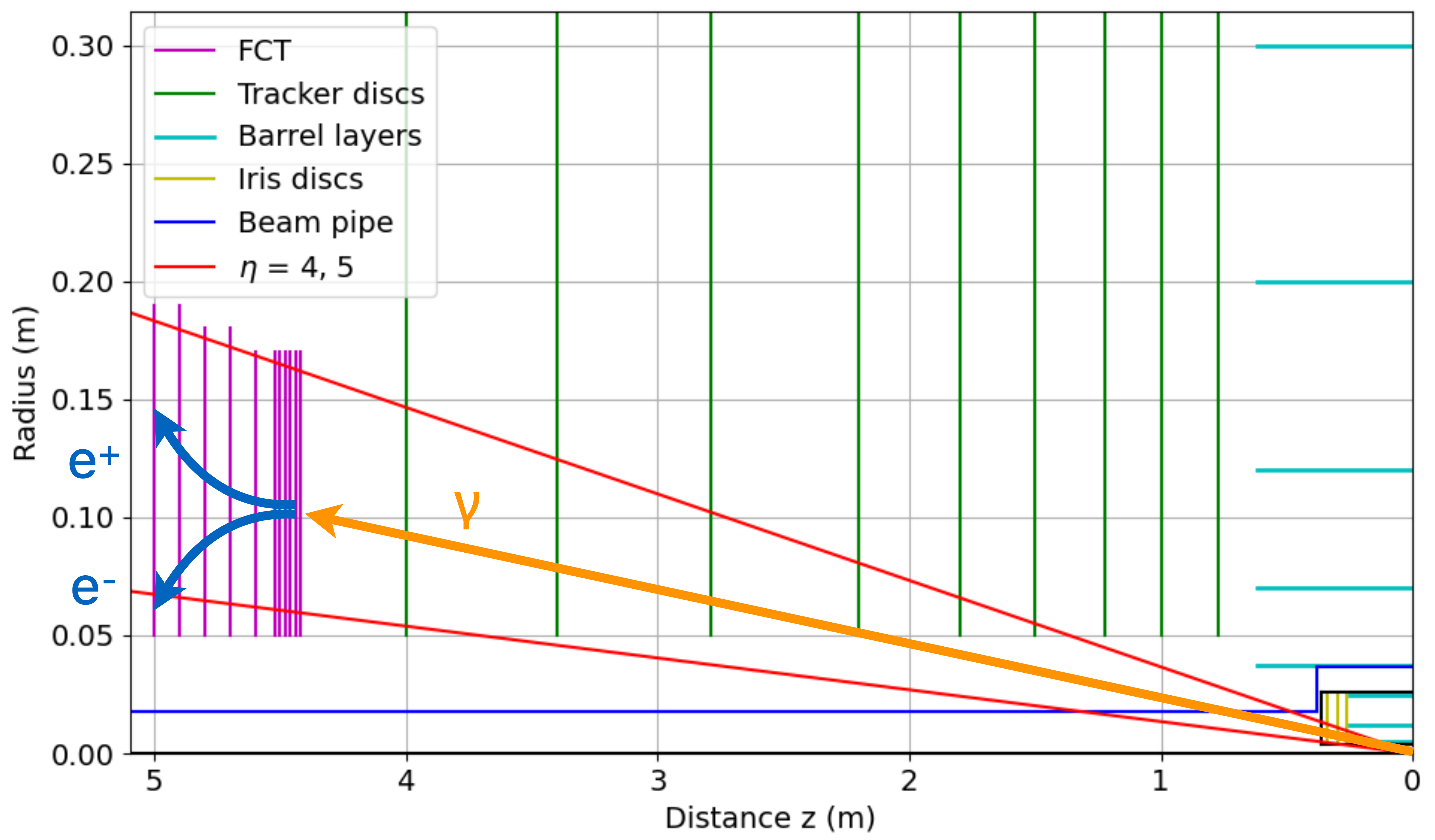
[1] A. Salzburger et. al., A Common Tracking Software Project, Comput Softw Big Sci 6, 8 (2022), arXiv, GitHub

Forward conversion tracker

Resolve the soft photon puzzle

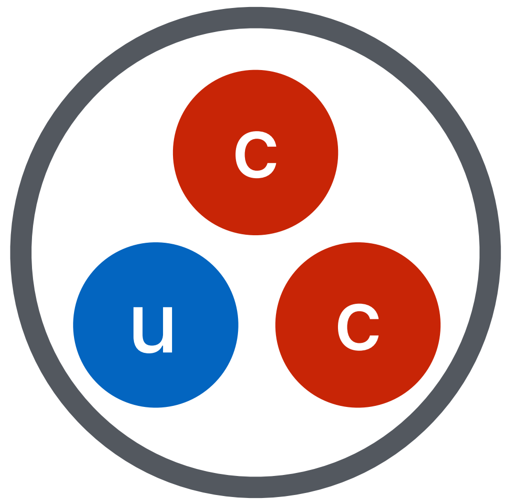
- Soft photon reconstruction, p_T ~ 1-10 MeV/c
- Pseudorapidity coverage **5 < η < 4**
- Technology: MAPS, $X/X_0 \approx 1\%$ per layer
- Dedicated dipole magnet





Performance: multi charm measurements

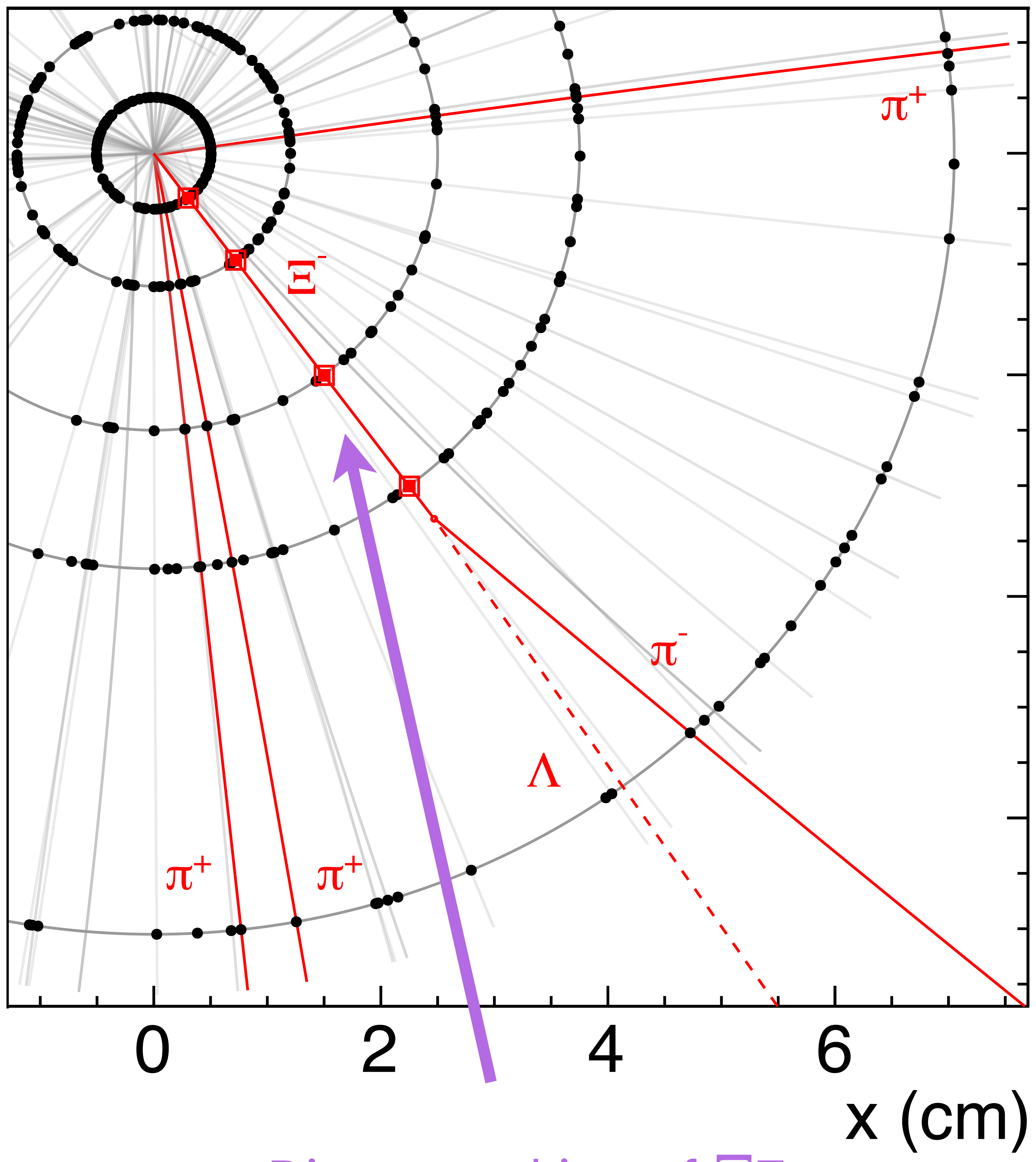
- **Multi-charm baryons** at low p_T: unique probe of hadron formation
- First ALICE 3 tracking layer at 5 mm
- Direct tracking of Ξ/Ω baryons (**strangeness tracking**)



$$\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+$$

$$\Xi_c^+ \rightarrow \Xi^- + 2\pi^+$$

Reconstruction of Ξ_{cc}^{++} decay



Direct tracking of Ξ^- with ALICE 3

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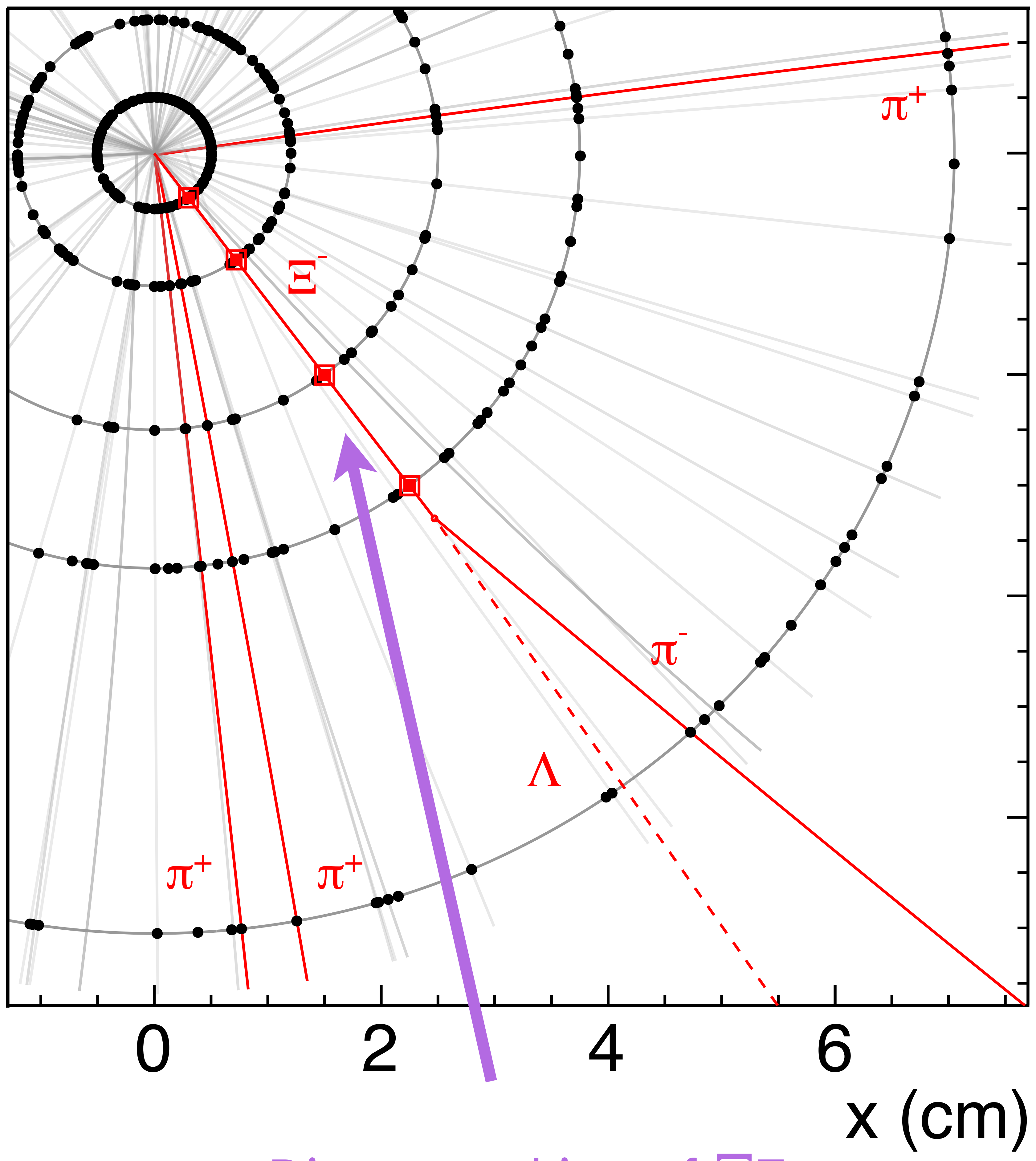
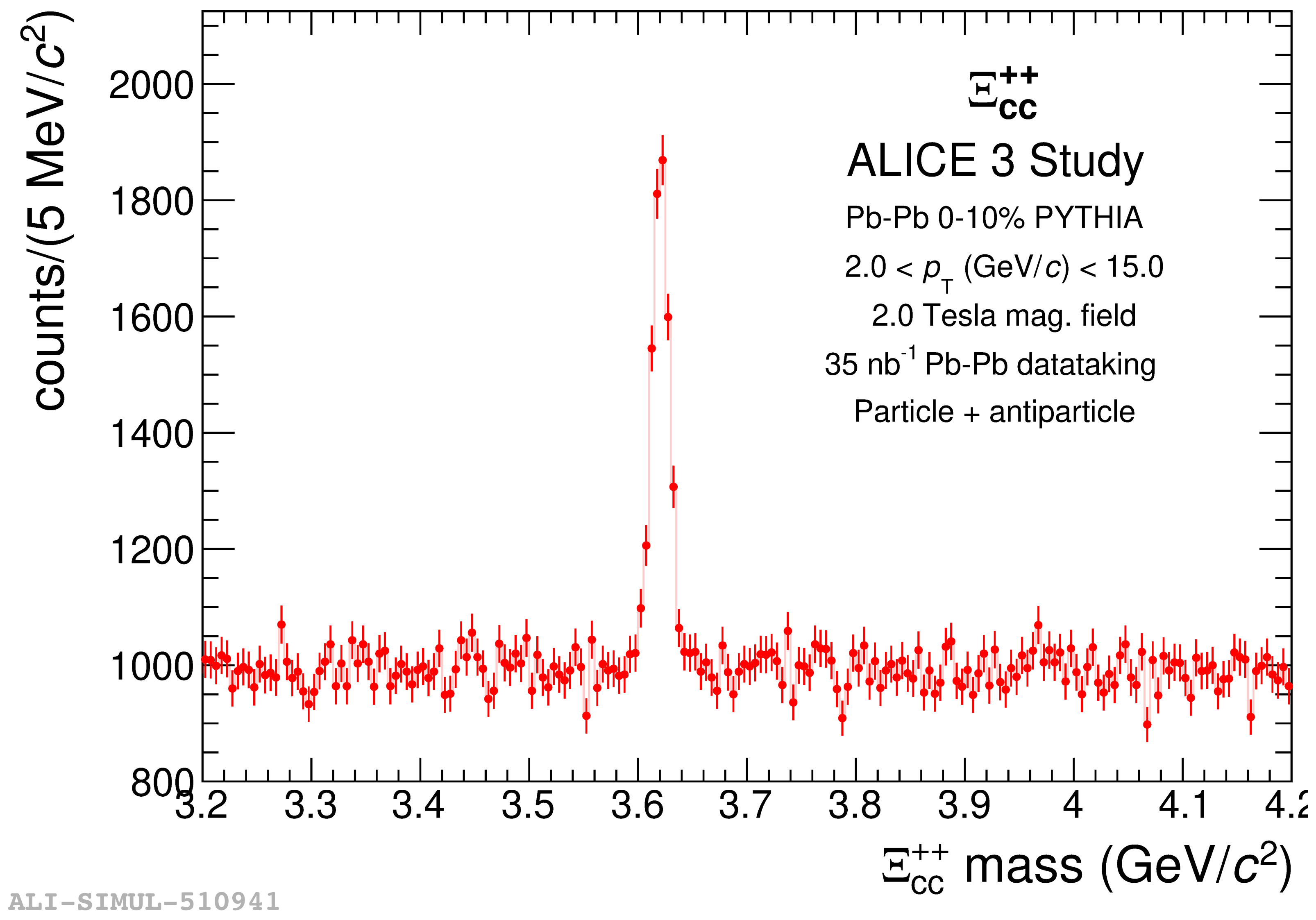
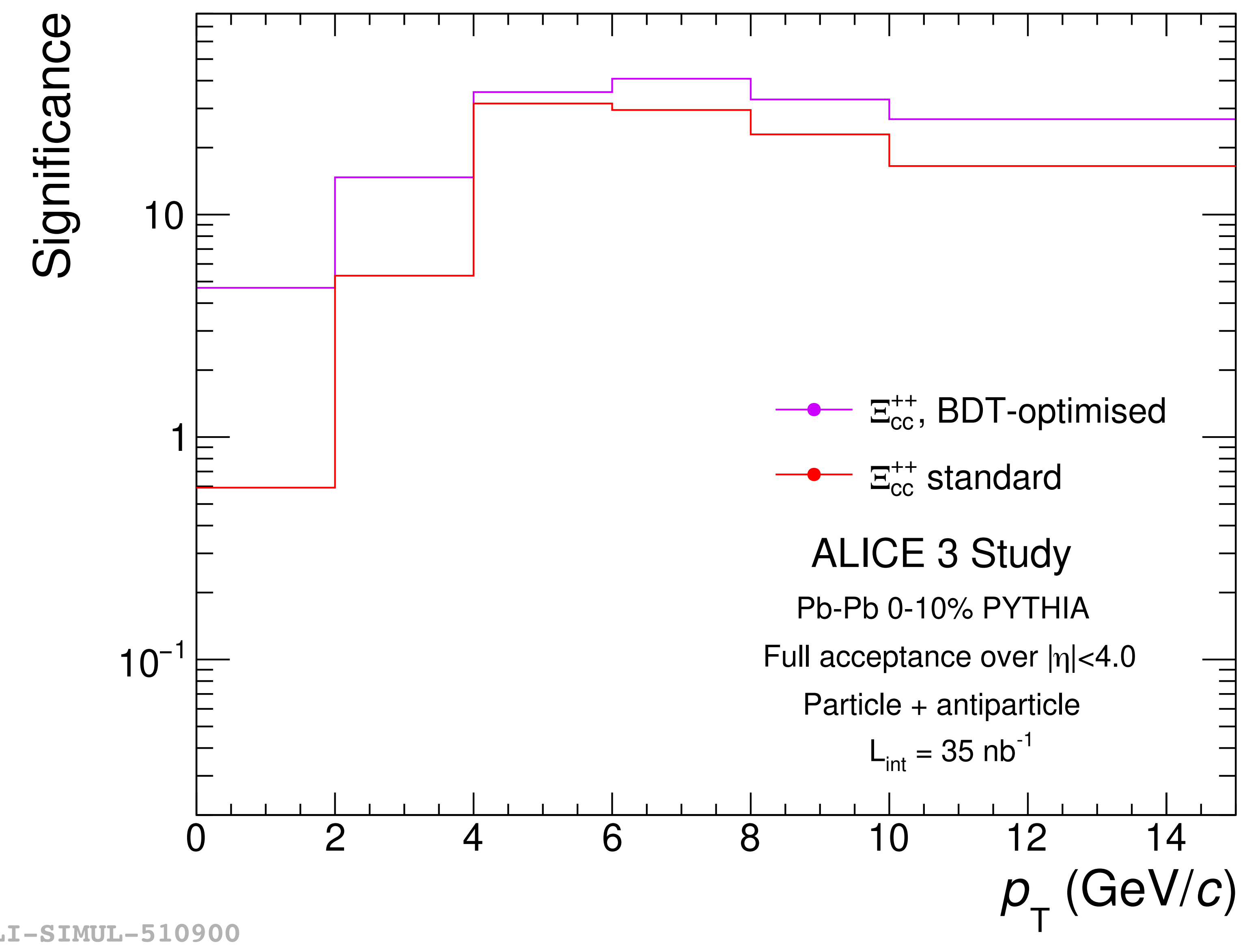


Direct tracking of Ξ^- with ALICE 3

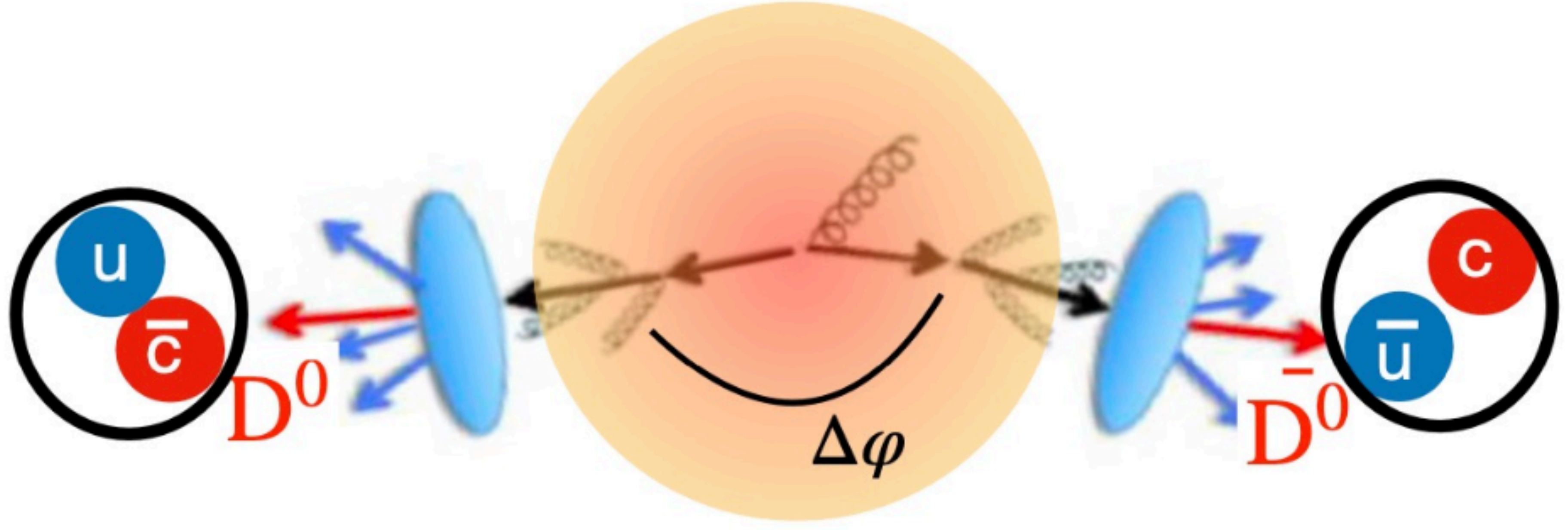
Mass peak of Ξ_{cc}^{++} in Pb-Pb



Significance for Ξ_{cc}^{++} in Pb-Pb



Heavy-flavour correlations

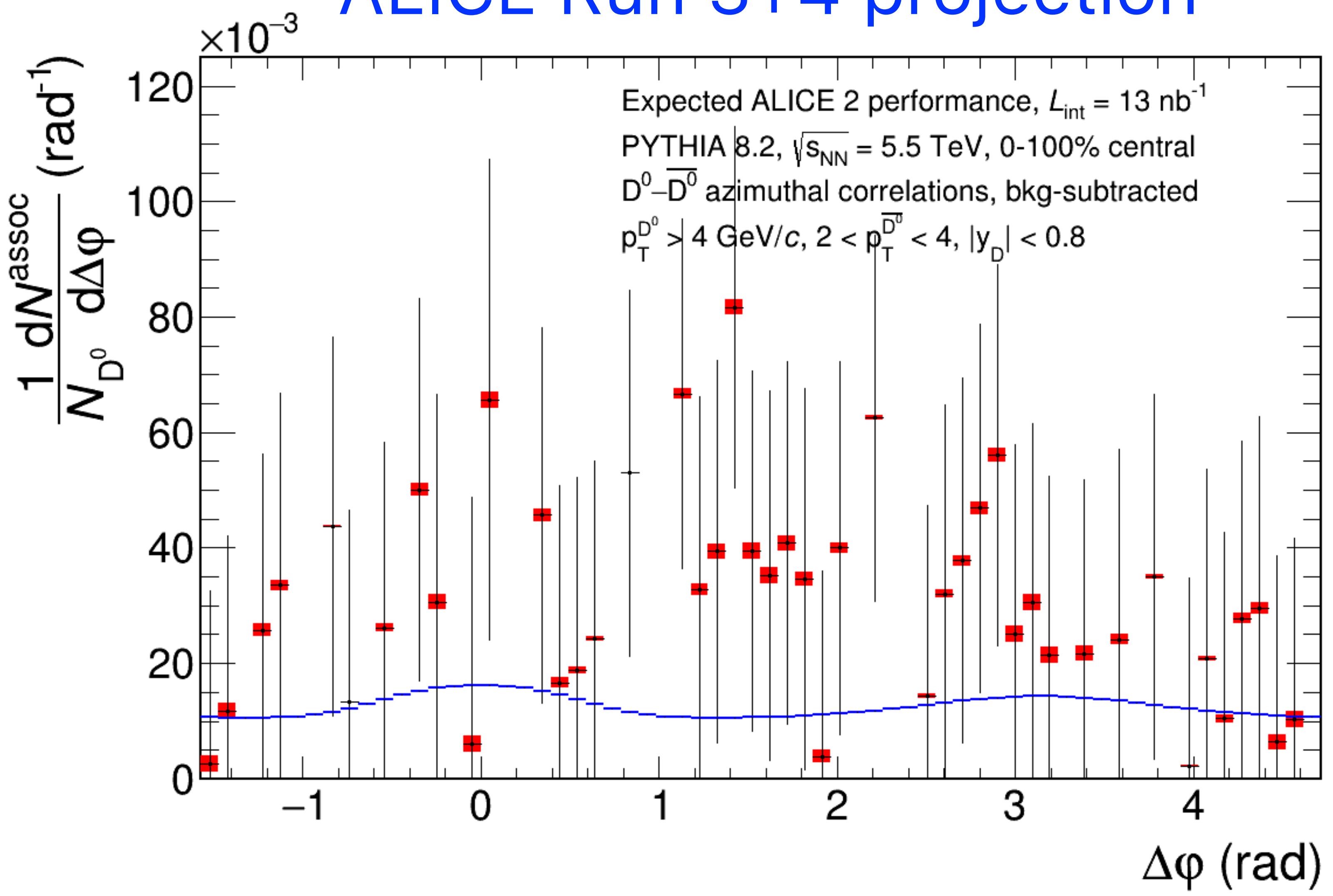


Angular decorrelation of HF hadrons

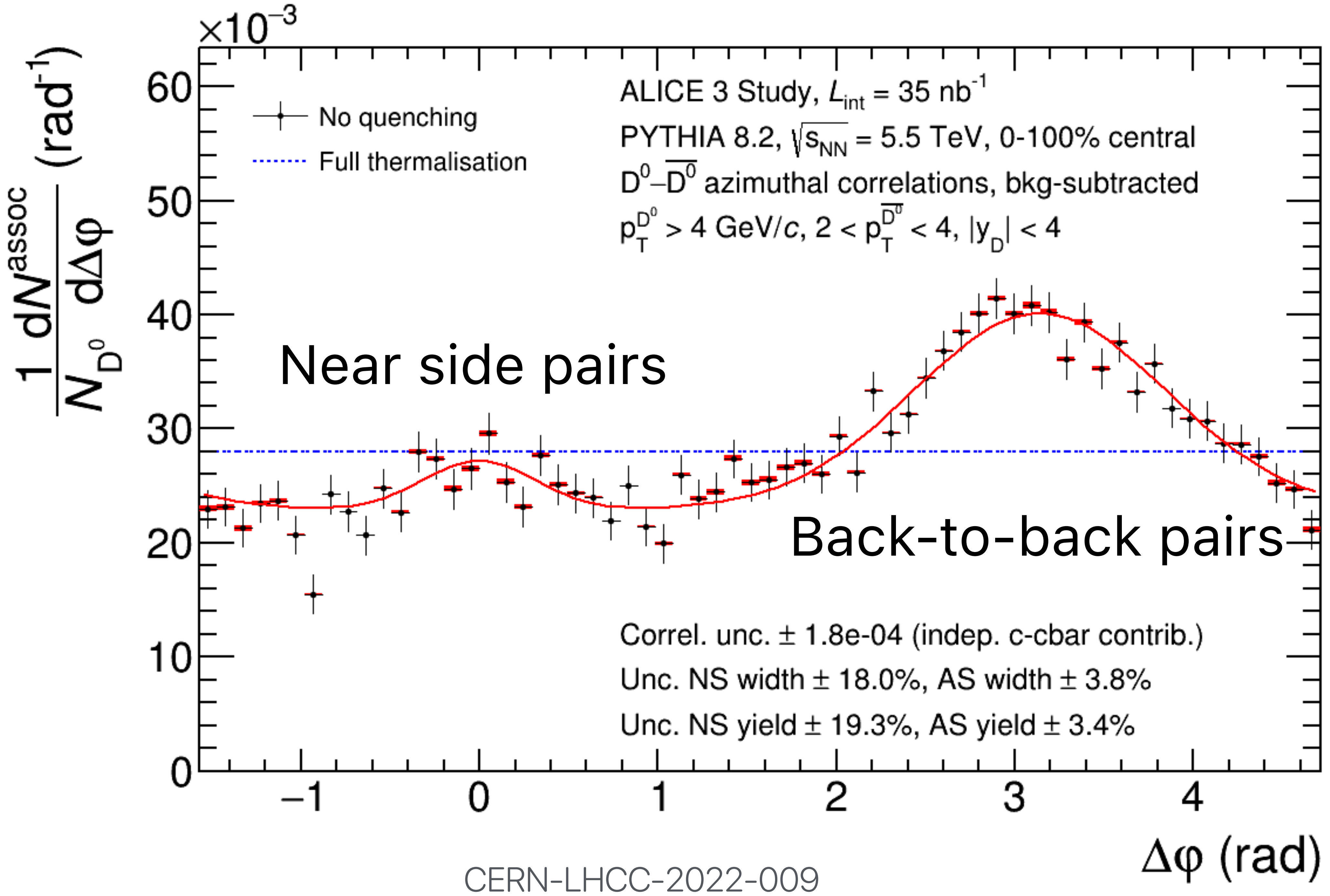
Directly probe QGP scattering

- Sensitive to energy loss and thermalization degree
- Strongest signal at low p_T
- Requires high purity, efficiency and η coverage

ALICE Run 3+4 projection



ALICE 3 projection for $D^0\overline{D^0}$ correlation



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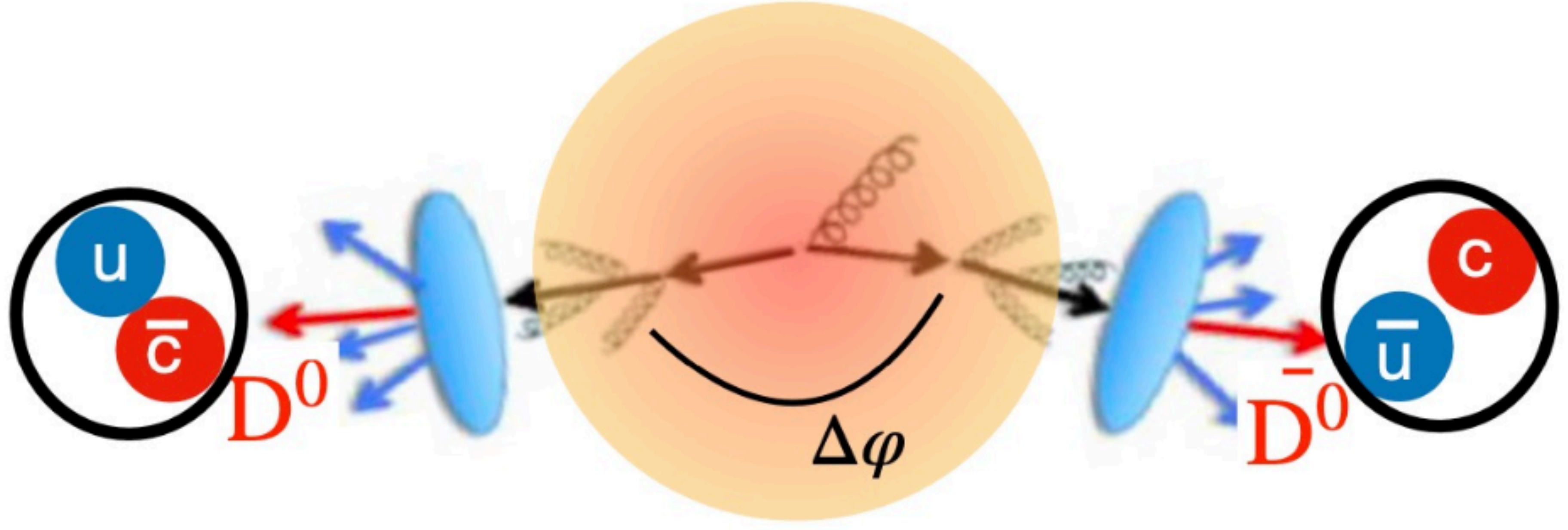
Heavy-flavour correlations

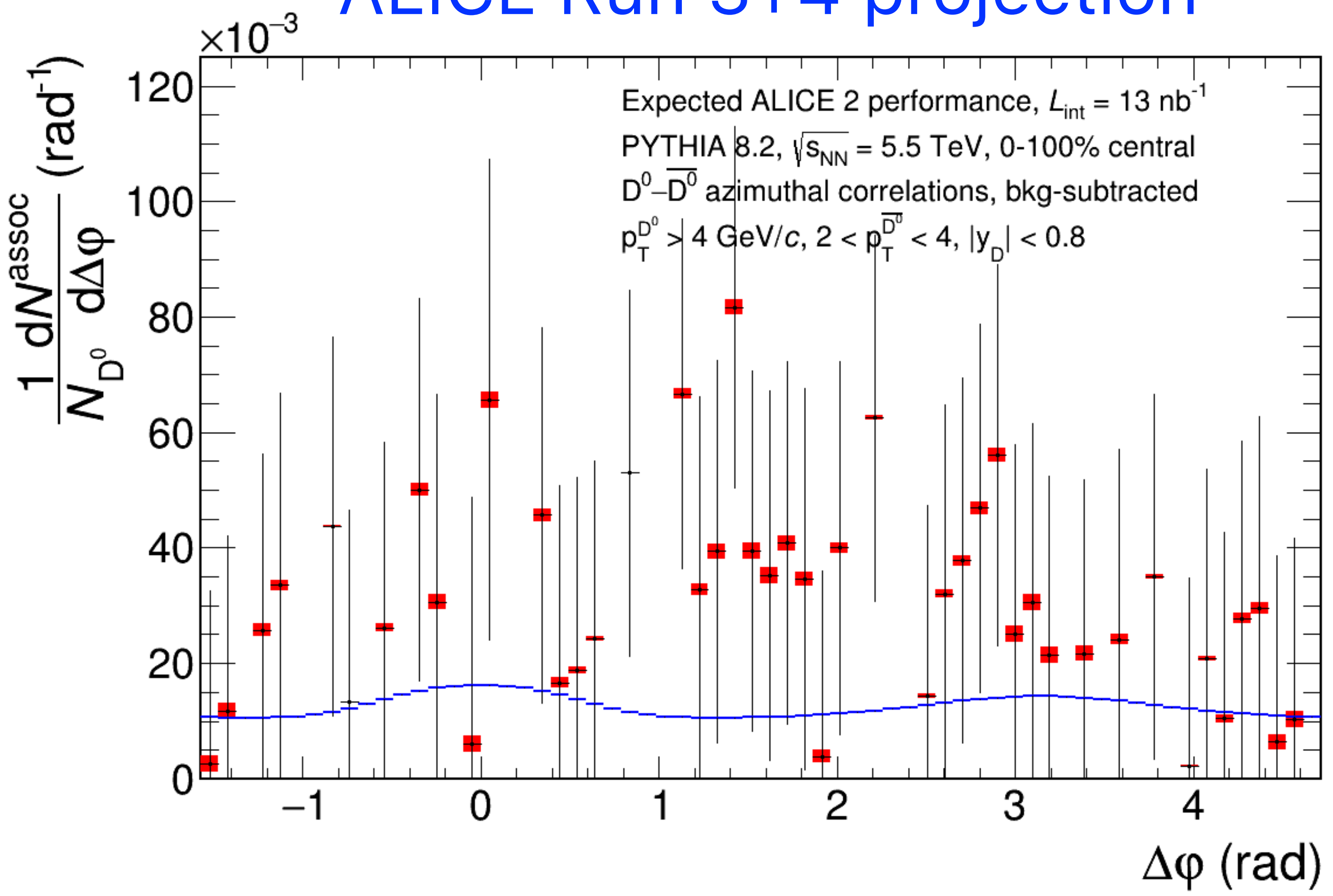


Angular decorrelation of HF hadrons

Directly probe QGP scattering

Only possible with ALICE 3

ALICE Run 3+4 projection



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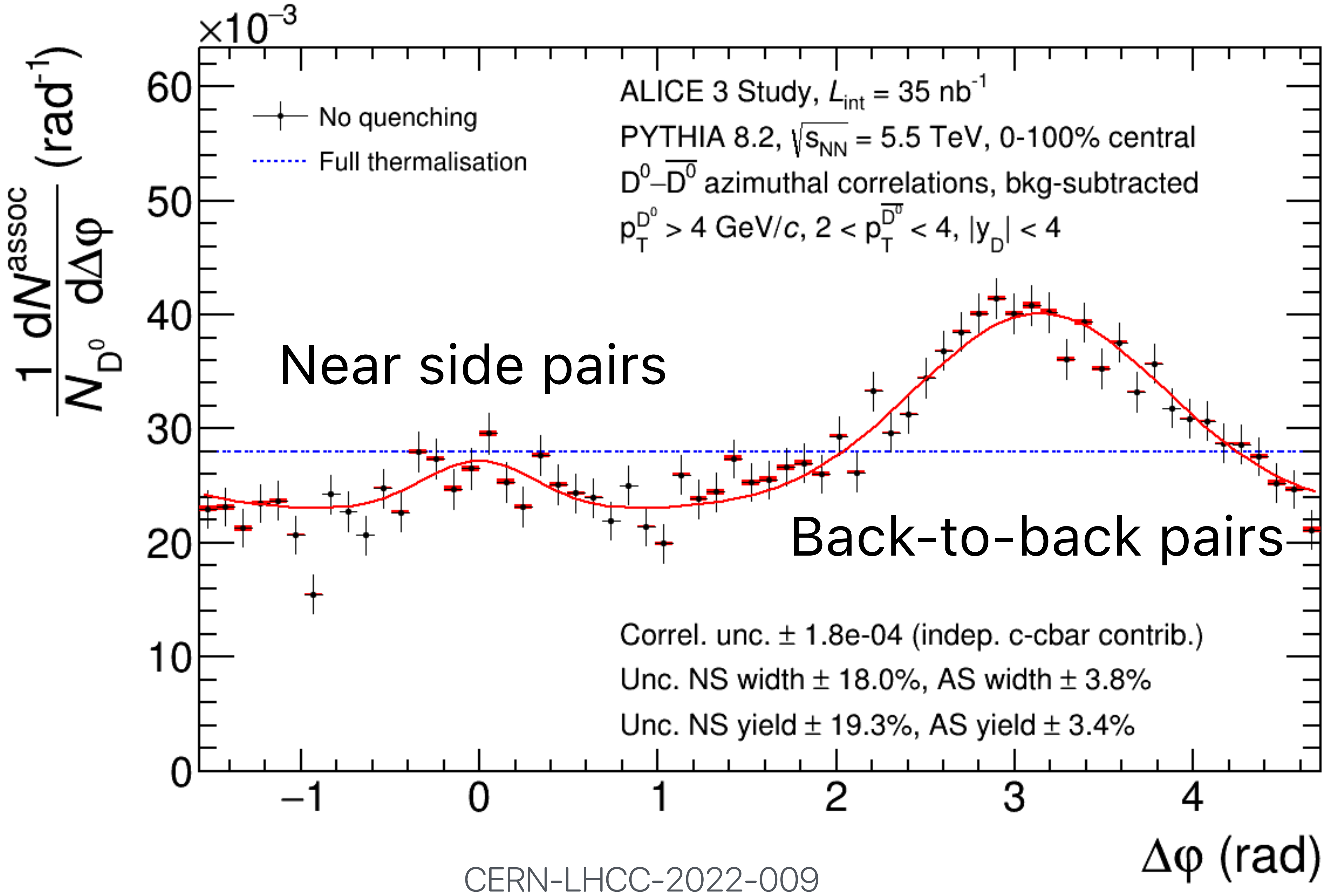

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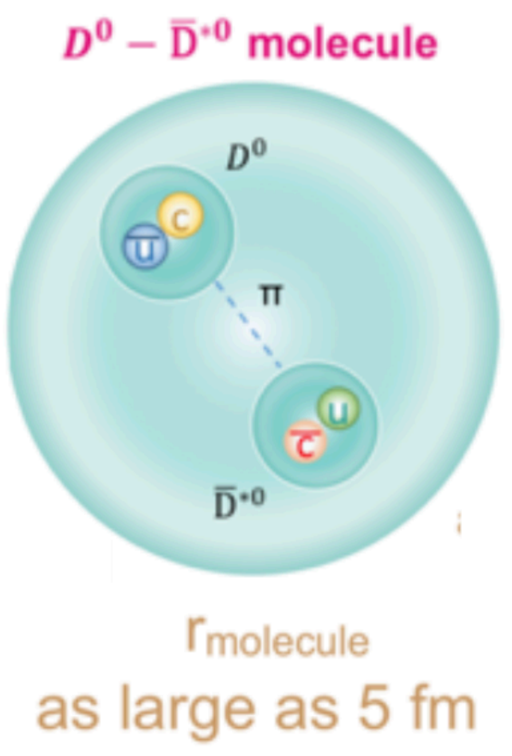
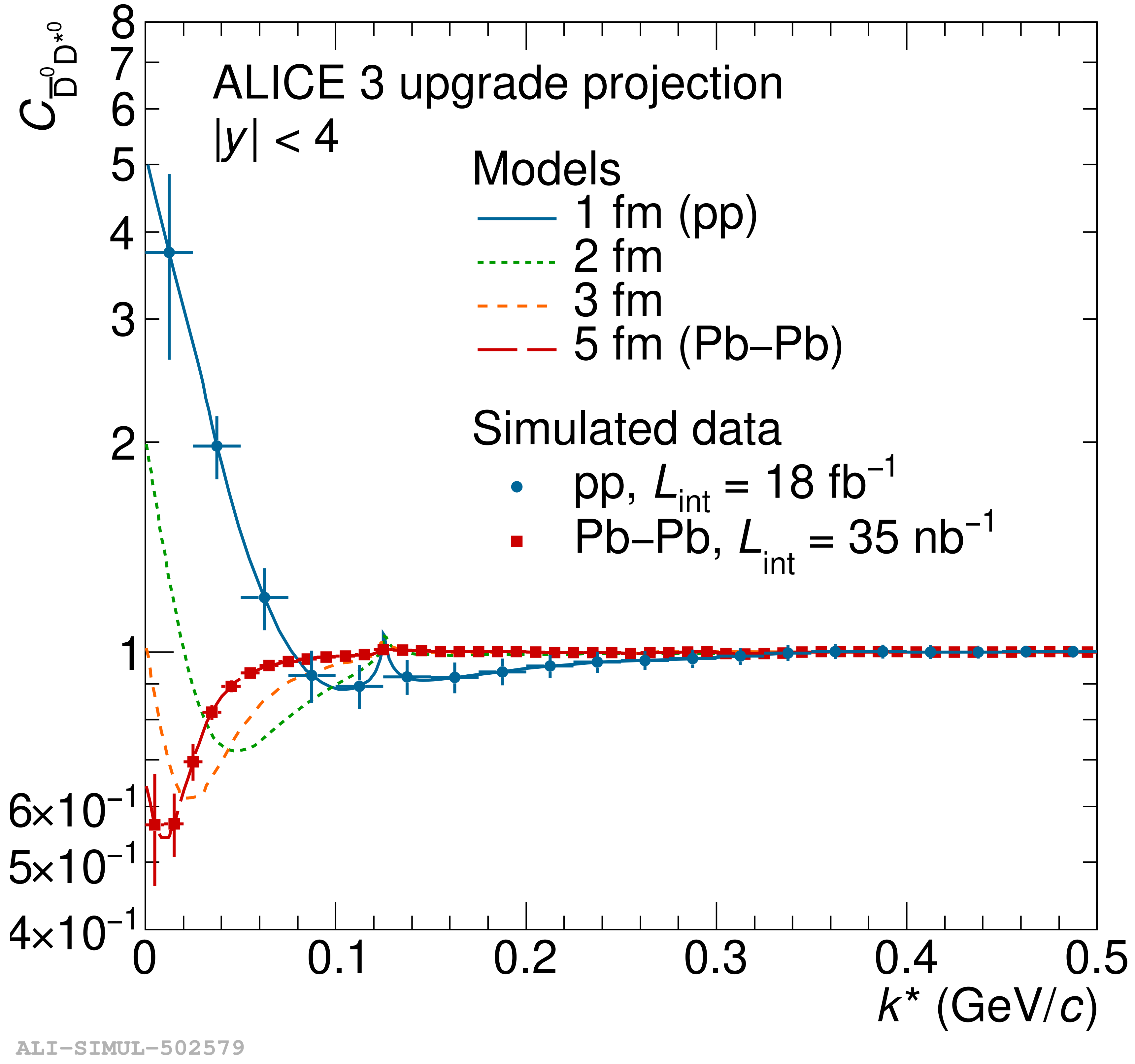
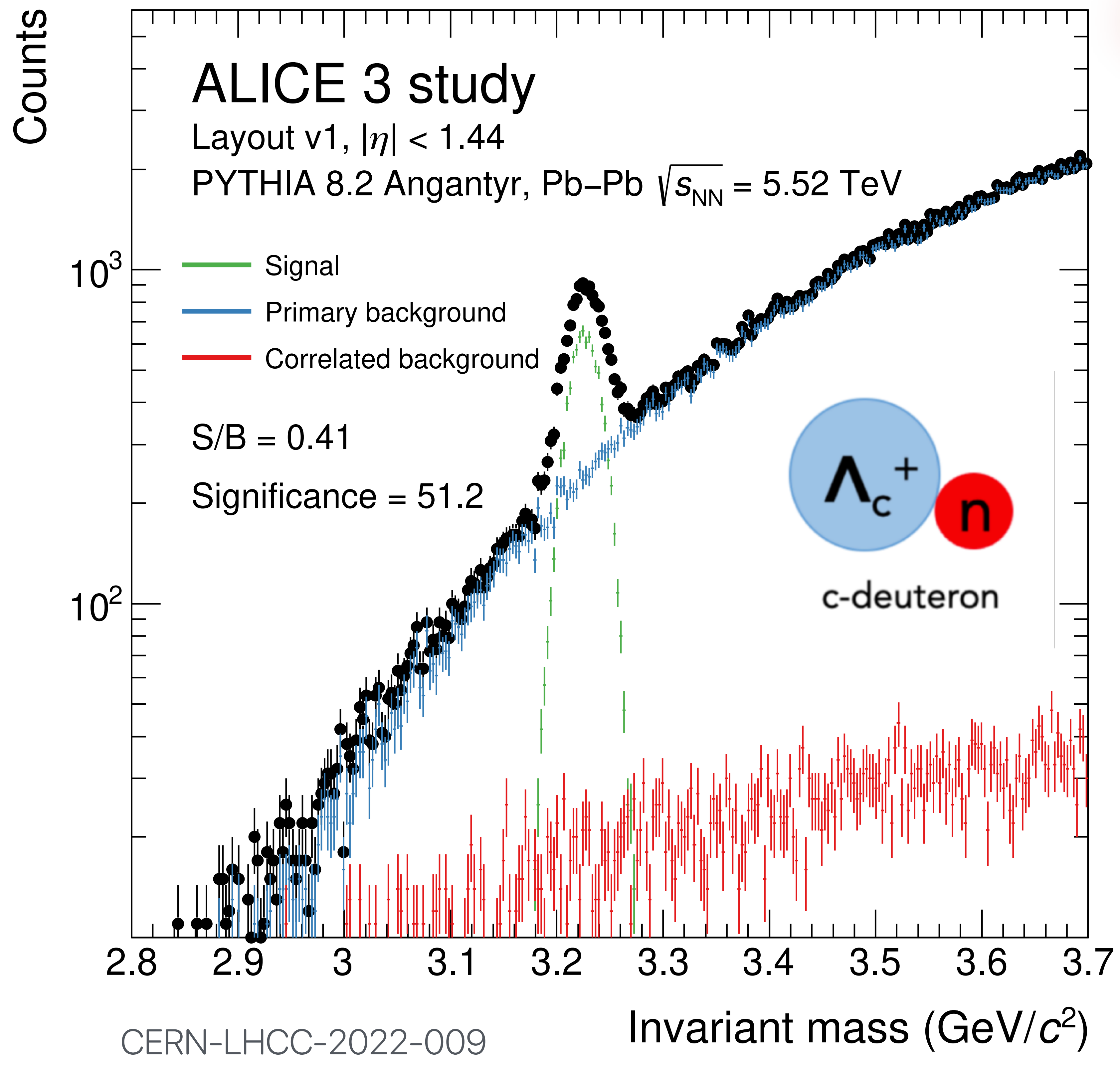
Hadronic interactions and exotic nuclei



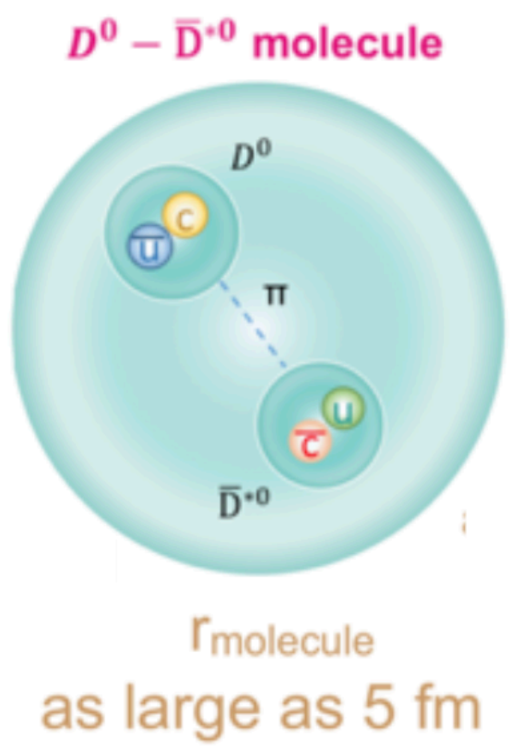


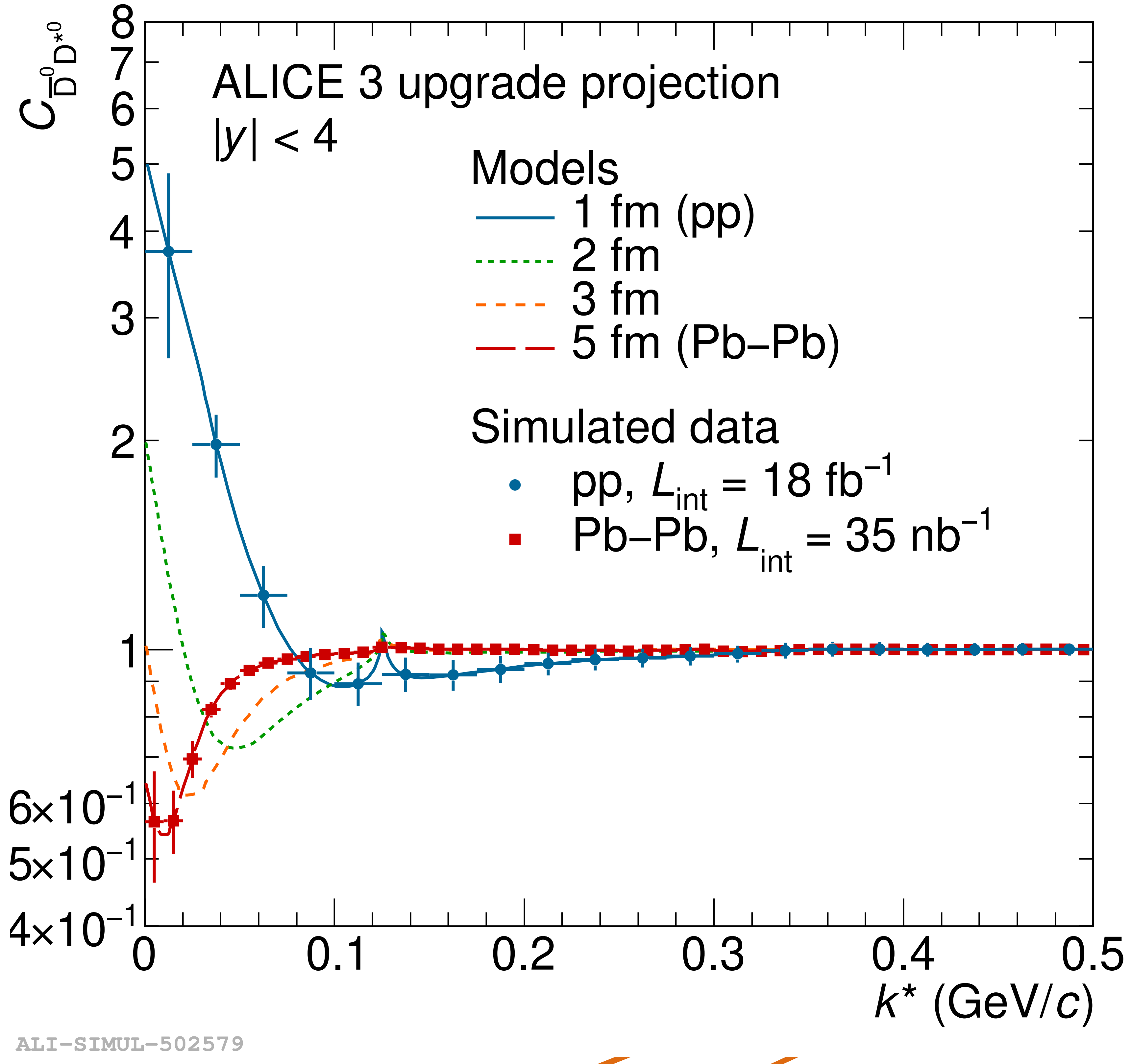
1 month of data taking



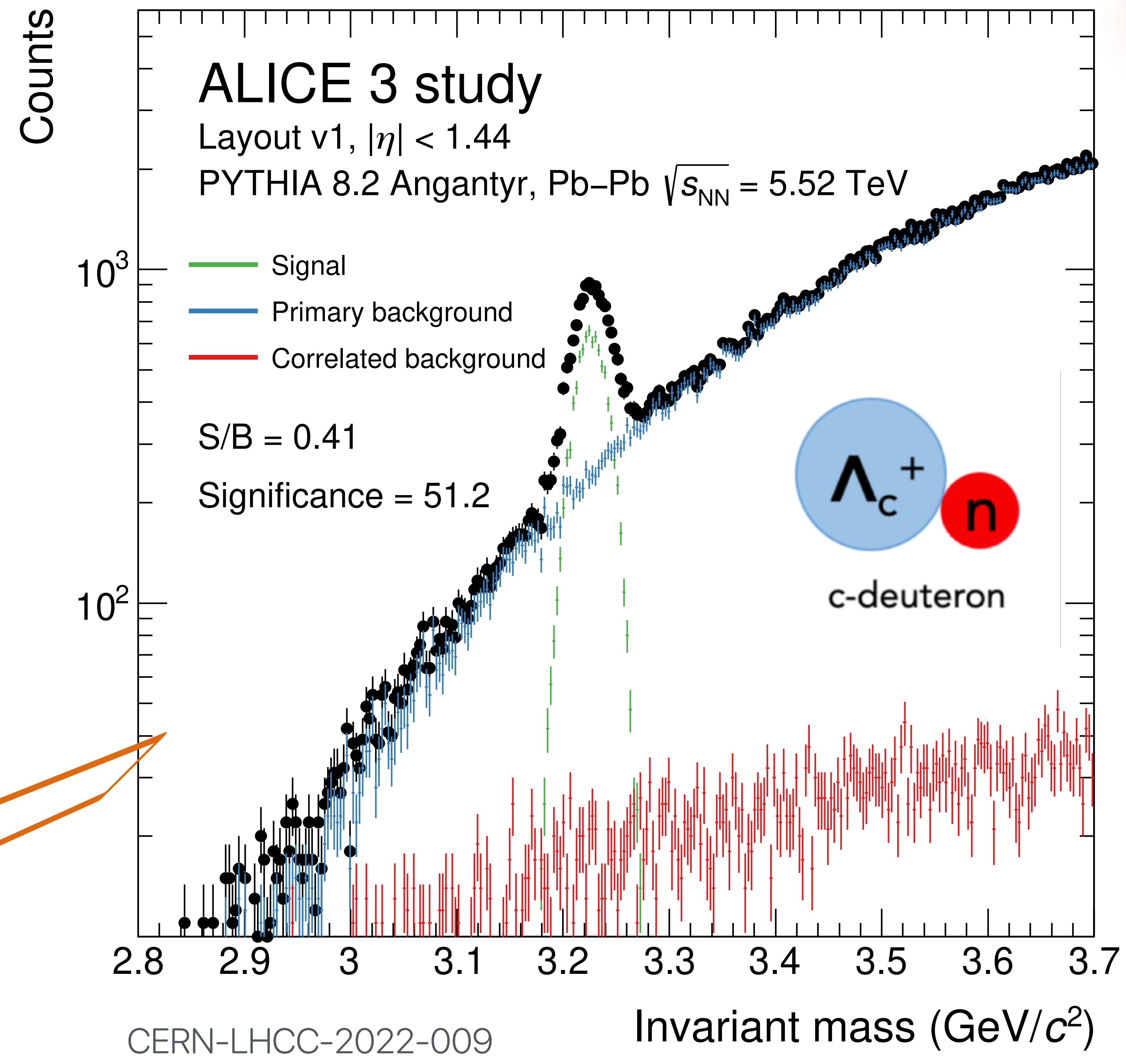
- Two particle D-D* momentum correlations can be used to explore formation of D-D* bound states
- Study c-deuteron: reach significance of 50 for 1 month Pb-Pb fully integrated (centrality, p_T, η)

Hadronic interactions and exotic nuclei





1 month of data taking



- Two particle $\mathrm{D}\text{-}\mathrm{D}^*$ momentum correlations can be used to explore formation of $\mathrm{D}\text{-}\mathrm{D}^*$ bound states
- Study c-deuteron: reach significance of 50 for 1 month Pb-Pb fully integrated (centrality, p_T, η)

Possible with ALICE 3 thanks to pointing resolution + large acceptance

Summary

- **ALICE 3 needed** to unravel the microscopic dynamics of the QGP
- ALICE 3 tracking system **enables new key measurements** in heavy-flavour and low mass dilepton sectors
- **Innovative, very challenging** detector concept focusing on silicon technology
- ALICE 3 **pioneers R&D directions** that have a broad impact on future HEP experiments
- R&D activities started on several strategic areas

Thank you for your attention

ALICE upgrade talks to check out

☞ ALICE 3 particle identification detectors by Giacomo Volpe, Tue 15:20

☞ The ITS3 detector and physics reach of the LS3 ALICE Upgrade by Chunzheng Wang, Tue 14:20

Backup