ICHEP 2022
BOLOGNA

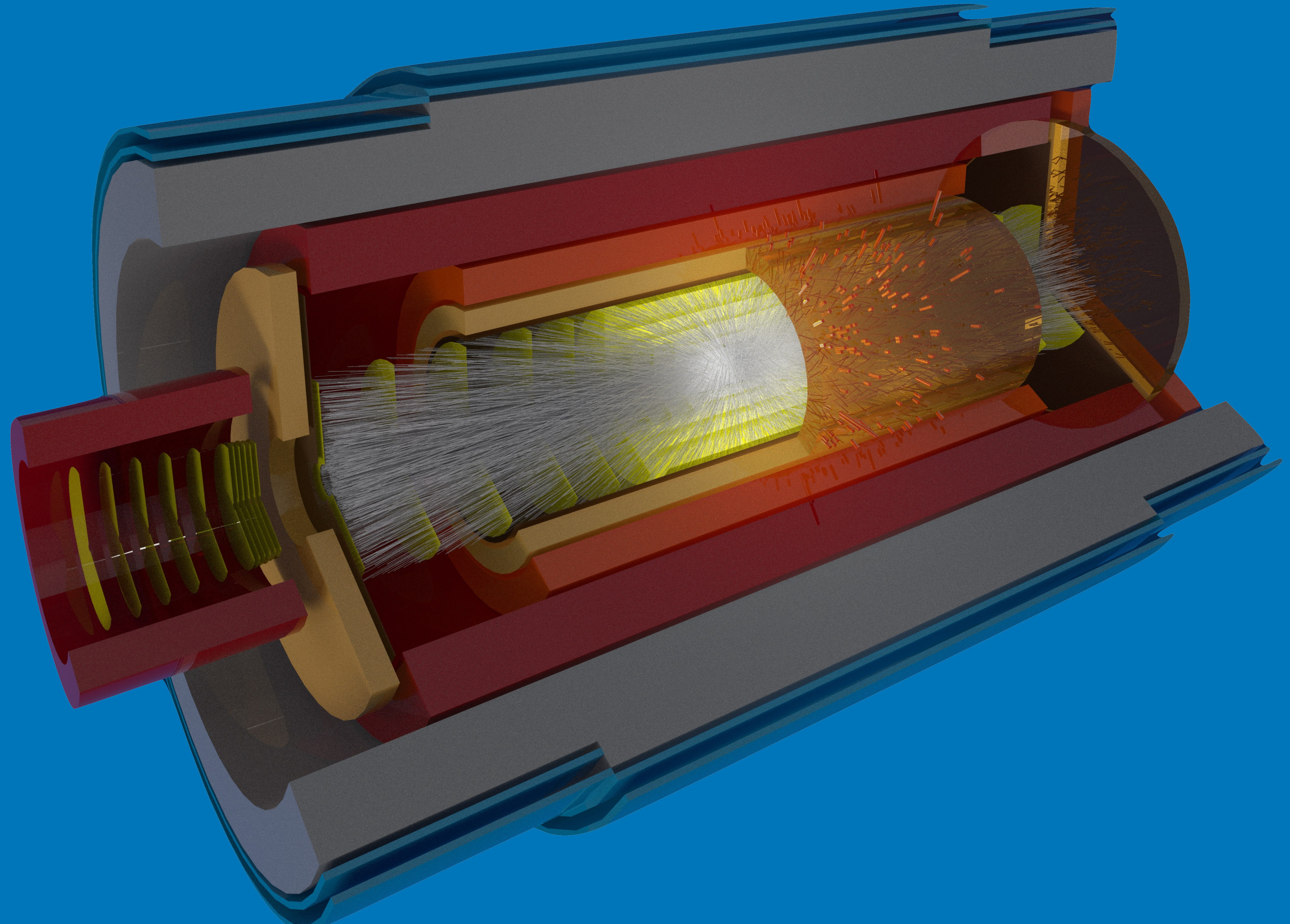
ICHEP 2022
XLI
International Conference
on High Energy Physics
Bologna (Italy)

6
13 07 2022

ALICE 3

Nicolò Jacazio (Bologna University)
on behalf of the ALICE Collaboration

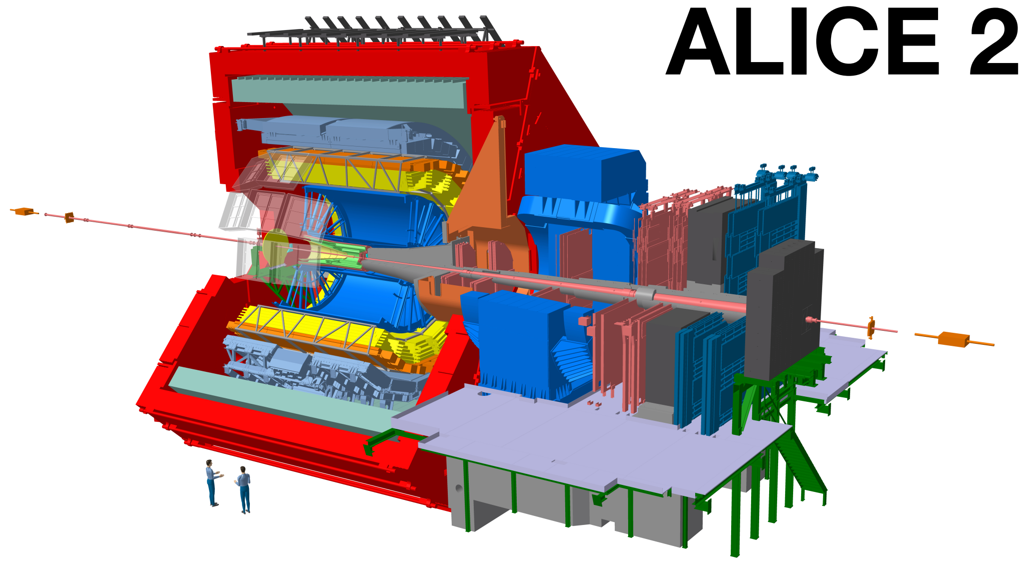
ALICE



ICHEP 2022 in Bologna - 07/07/2022

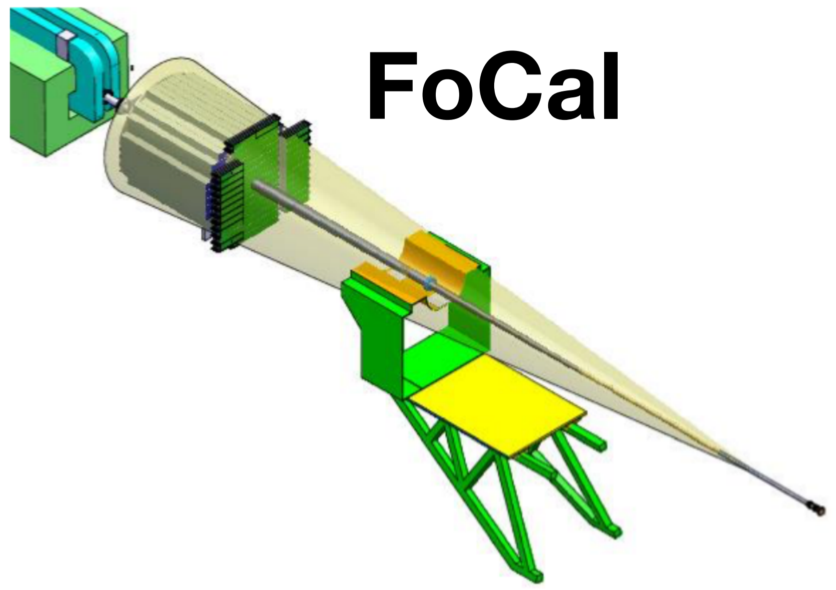
Milestones of the ALICE upgrade

ALICE 2



08 July 2022 09:00 R. Münzer

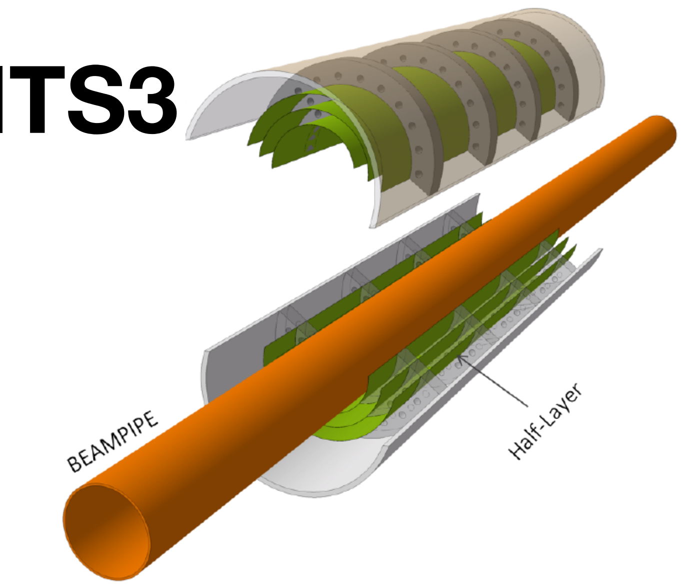
FoCal



CERN-LHCC-2020-009

07 July 2022 15:30 M. Rauch

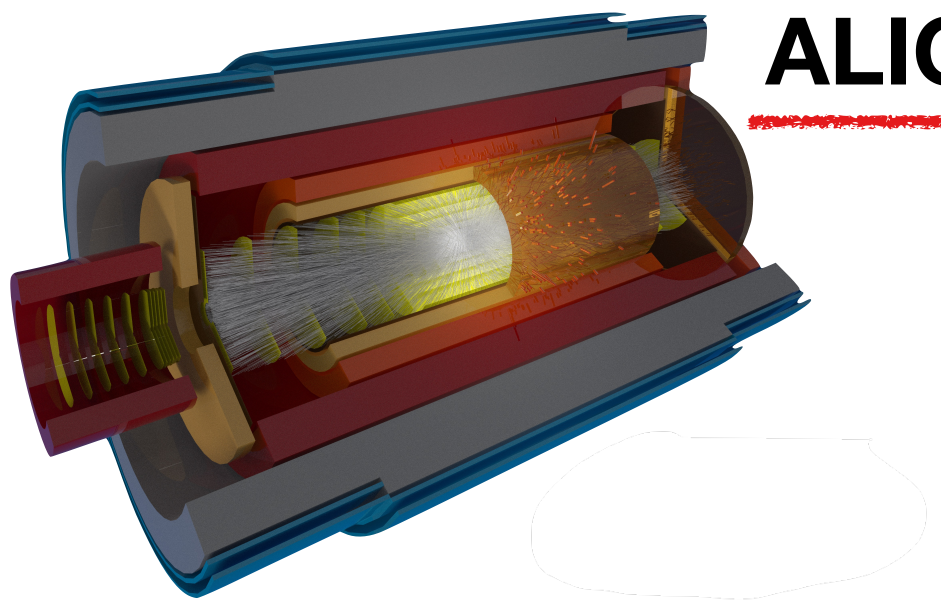
ITS3



CERN-LHCC-2019-018

07 July 2022 15:50 M. Mager

ALICE 3



CERN-LHCC-2022-009

Proposal for heavy-ion program in Run 5 and 6 with a next-generation experiment

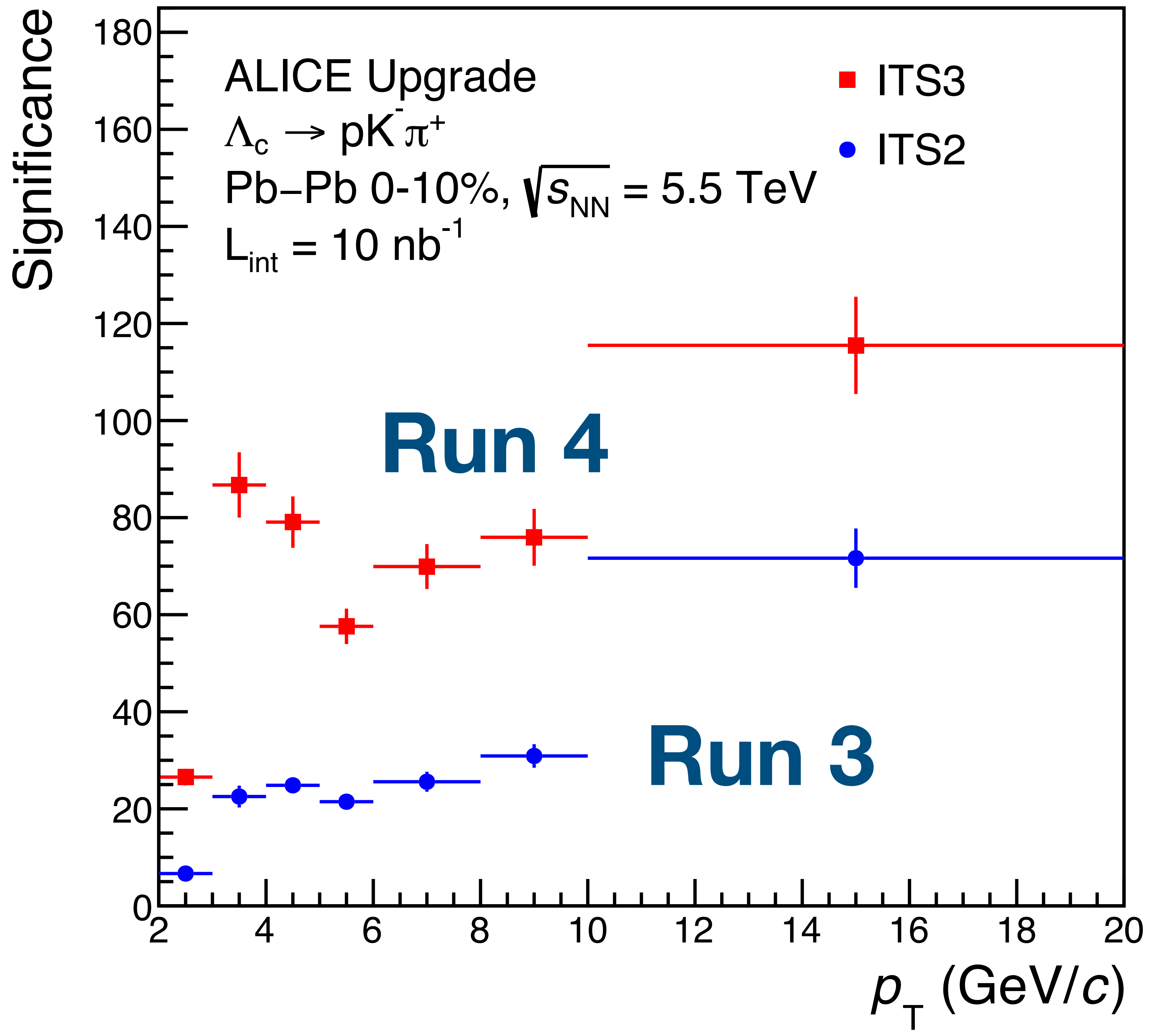
- Concept developed in **2018** and submitted to Strategy Update meeting in **2019**
- Three ALICE 3 **workshops** in 2020 and 2021
- **Letter of Intent submitted to LHCC** and reviewed late 2021/ early 2022
  - **Very positive review** and recommendation to **proceed with R&D**

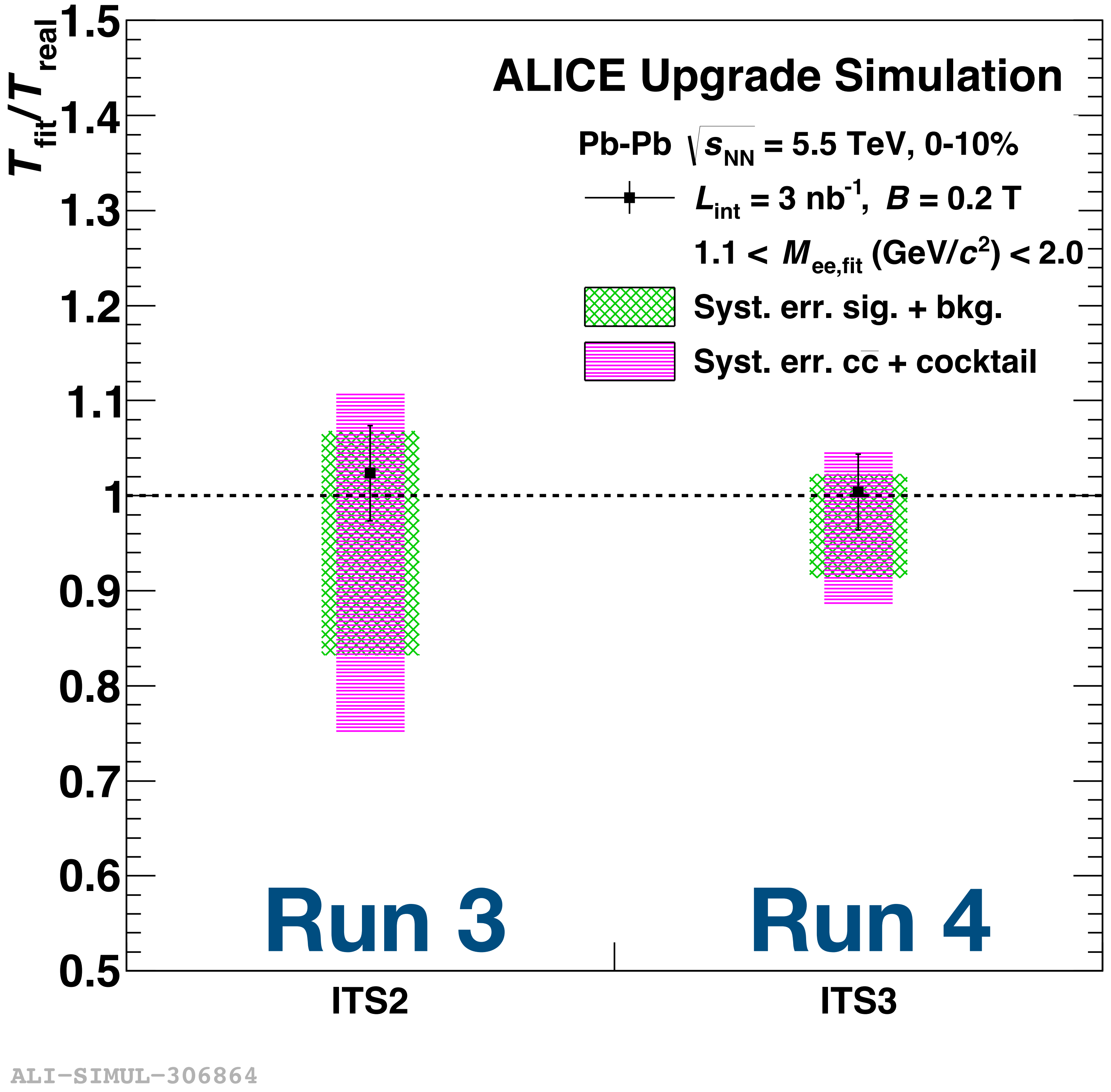
ALICE beyond Run 4

significant improvement achieved after Run 4

New insights with Runs 3+4

- medium effects and **hadrochemistry** of single charm
- time-averaged **thermal radiation** from the quark-gluon plasma
- patterns indicative of **chiral symmetry** restoration
- **collectivity** from small to large systems



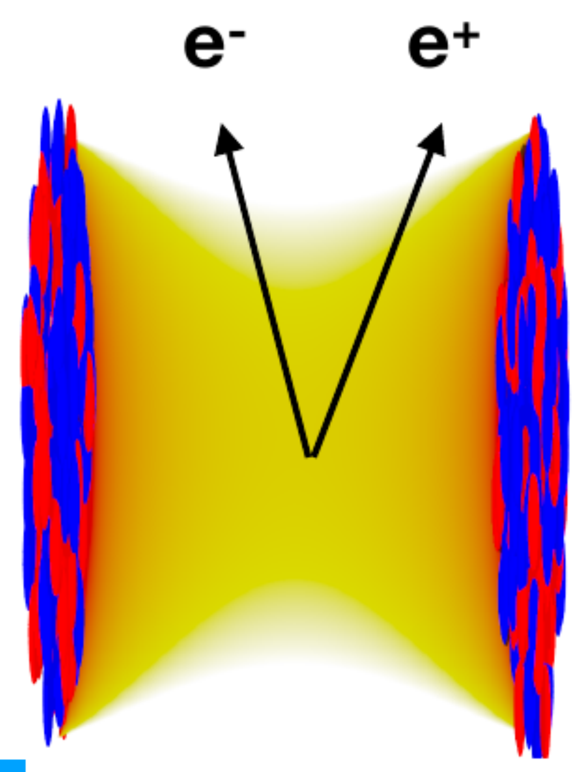


Precision measurements with Run 3 and 4 will help us understanding the QGP

More fundamental questions ahead!

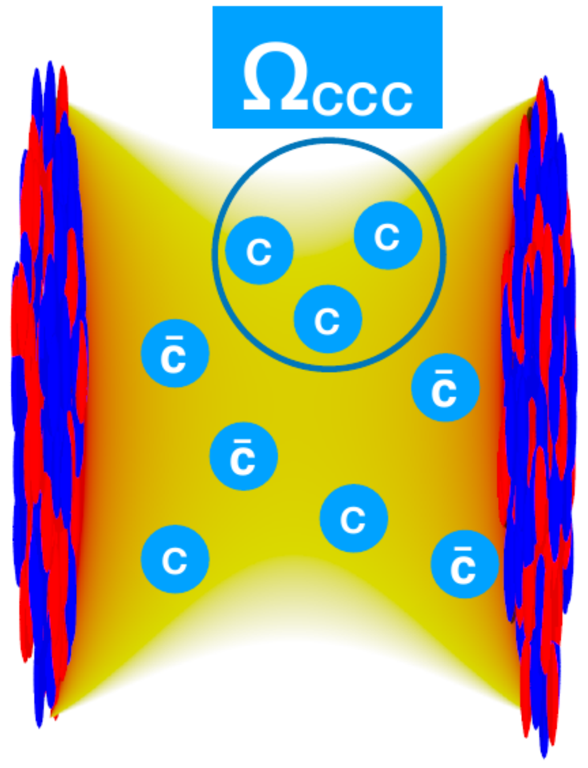
- QGP properties driving its constituents to equilibration
- microscopic mechanisms leading to strong partonic collectivity
- mechanisms for hadronisation from the quark-gluon plasma
- partonic equation of state and its temperature dependence
- underlying dynamics of chiral symmetry restoration

QGP physics beyond Run 4



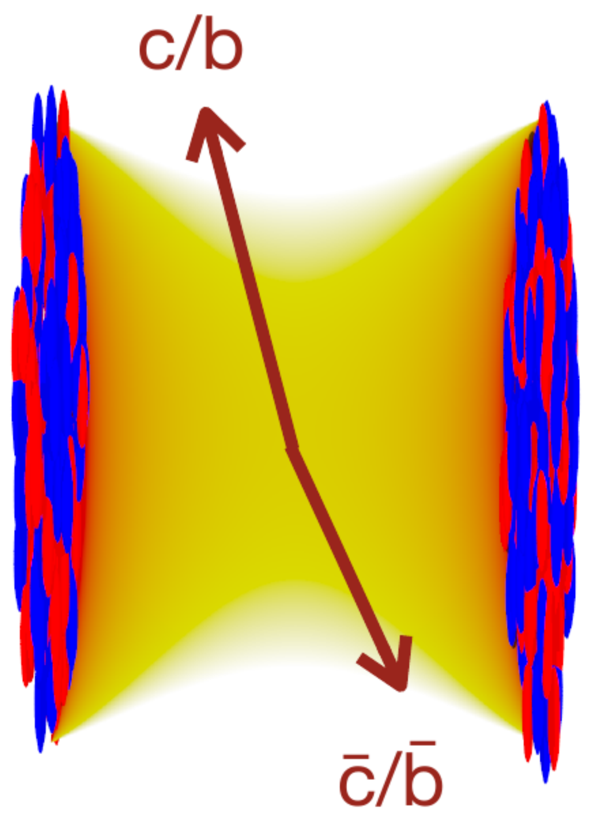
Precision measurements of dileptons

- accessing the evolution of the quark-gluon plasma
- mechanisms of chiral symmetry restoration in the quark-gluon plasma



Systematic measurements of (multi-)heavy-flavoured hadrons

- accessing parton propagation mechanisms in QGP
- study equilibration of heavy quark equilibration and diffusion in QGP
- mechanisms of hadronisation from the quark-gluon plasma



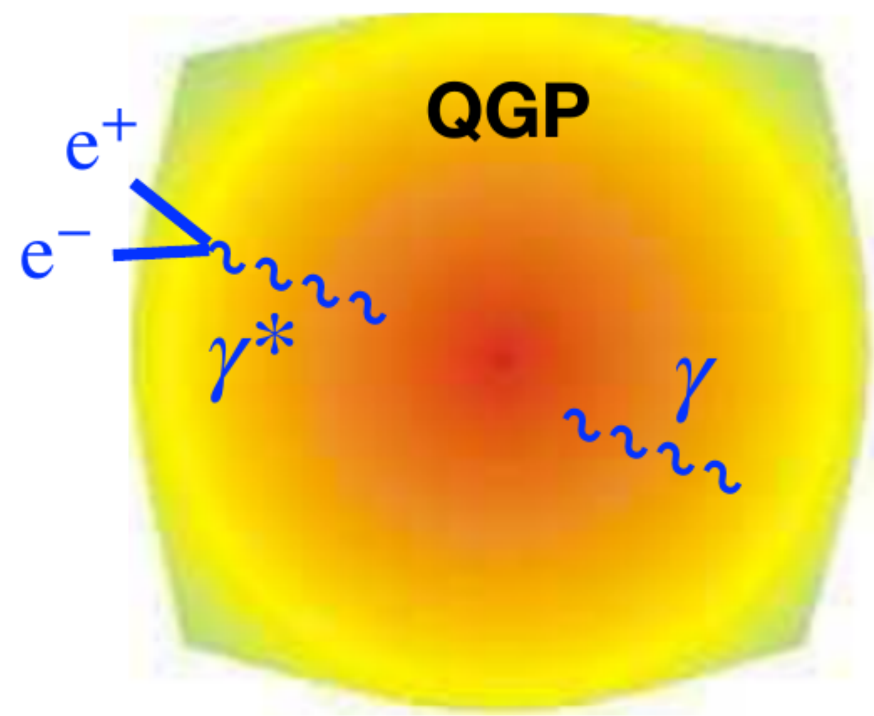
Hadron correlations and fluctuations

- interaction potentials and charmed-nuclei
- susceptibility to conserved charges

To achieve all this, the next leap is needed in detector performance and statistics

→ **next-generation heavy-ion experiment!** ←

Electromagnetic radiation



Accessing the QGP temperature

In Run 3 and 4:

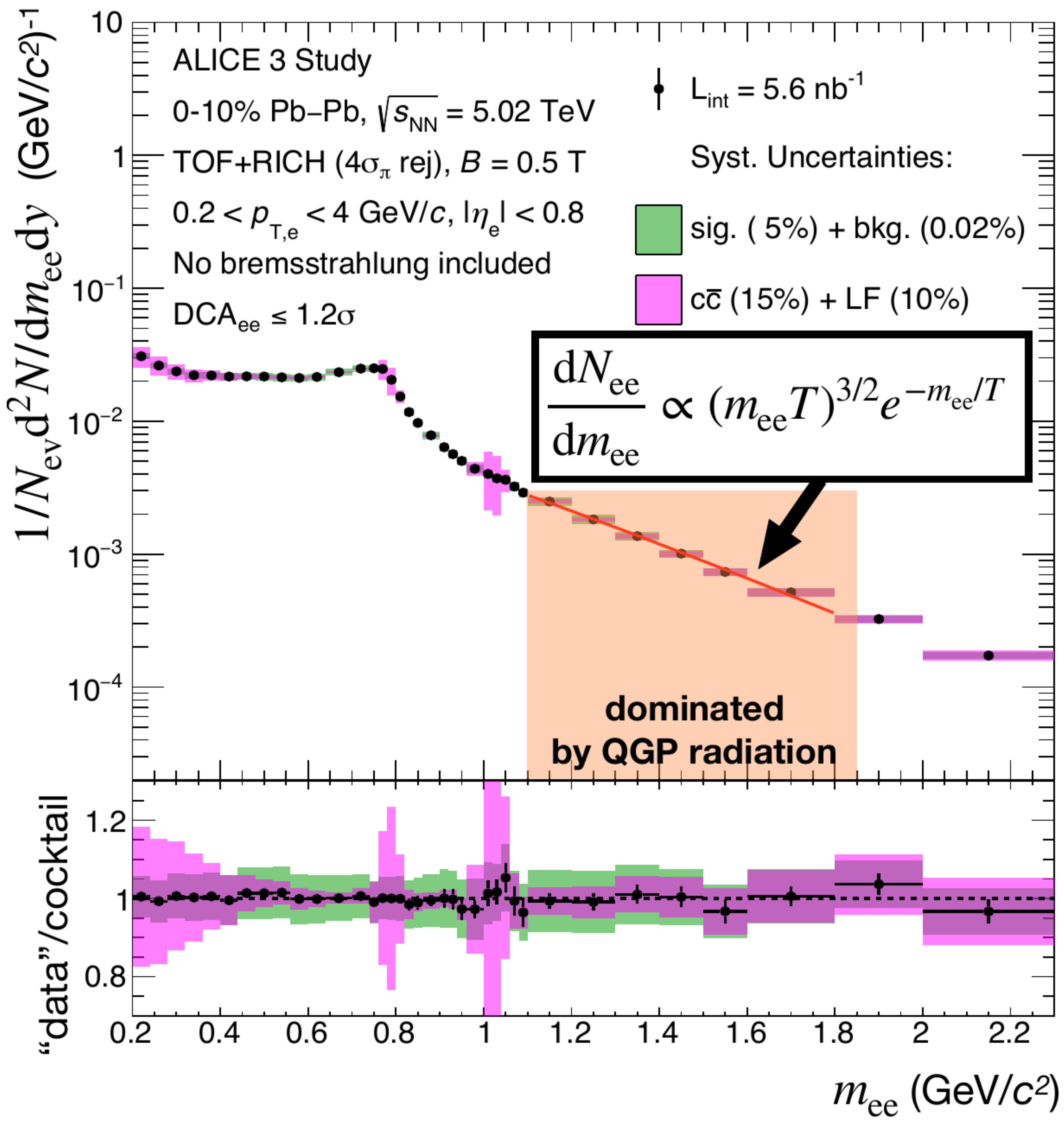
- First measurement of average QGP temperature using thermal dielectron spectrum at $M_{ee} > 1.1$ GeV/c²

In Run 5 with ALICE 3:

- probe **time dependence** of the QGP temperature
- double-differential spectra: T vs mass, p_T

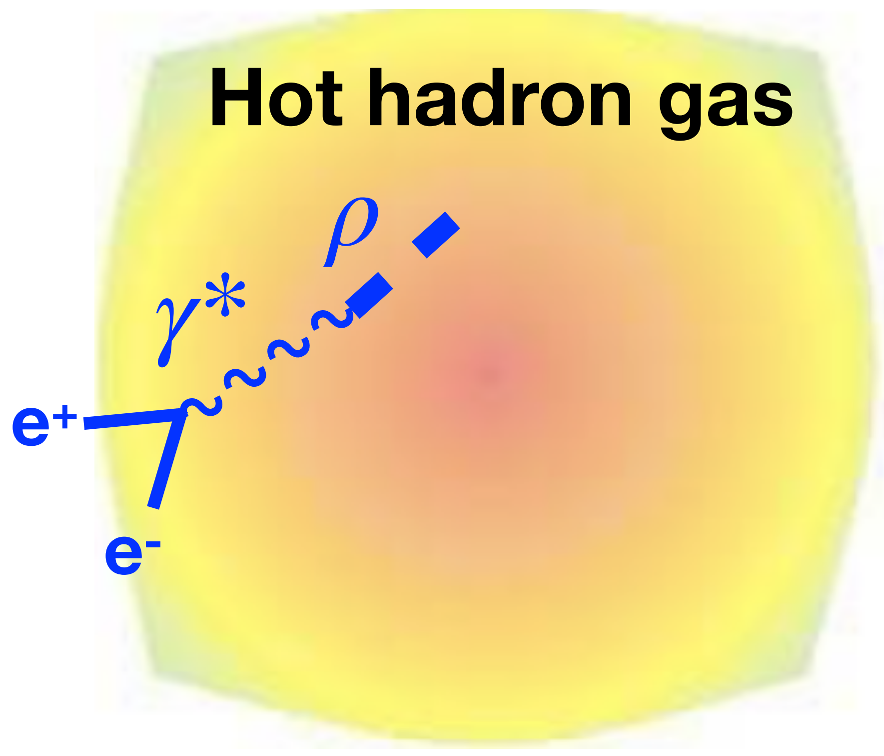
- Excellent pointing resolution
  - Large background for $M_{ee} \gtrsim 1$ GeV/c² due to heavy-flavour decays can be effectively suppressed with ALICE 3
- Complementary to measurements with real photons

Projection for one month Pb—Pb with ALICE 3



R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103

Chiral symmetry restoration



Chiral symmetry restoration mechanisms

- using thermal dielectron spectrum at $M_{ee} < 1.2$ GeV/c^2

Thermal production of ρ

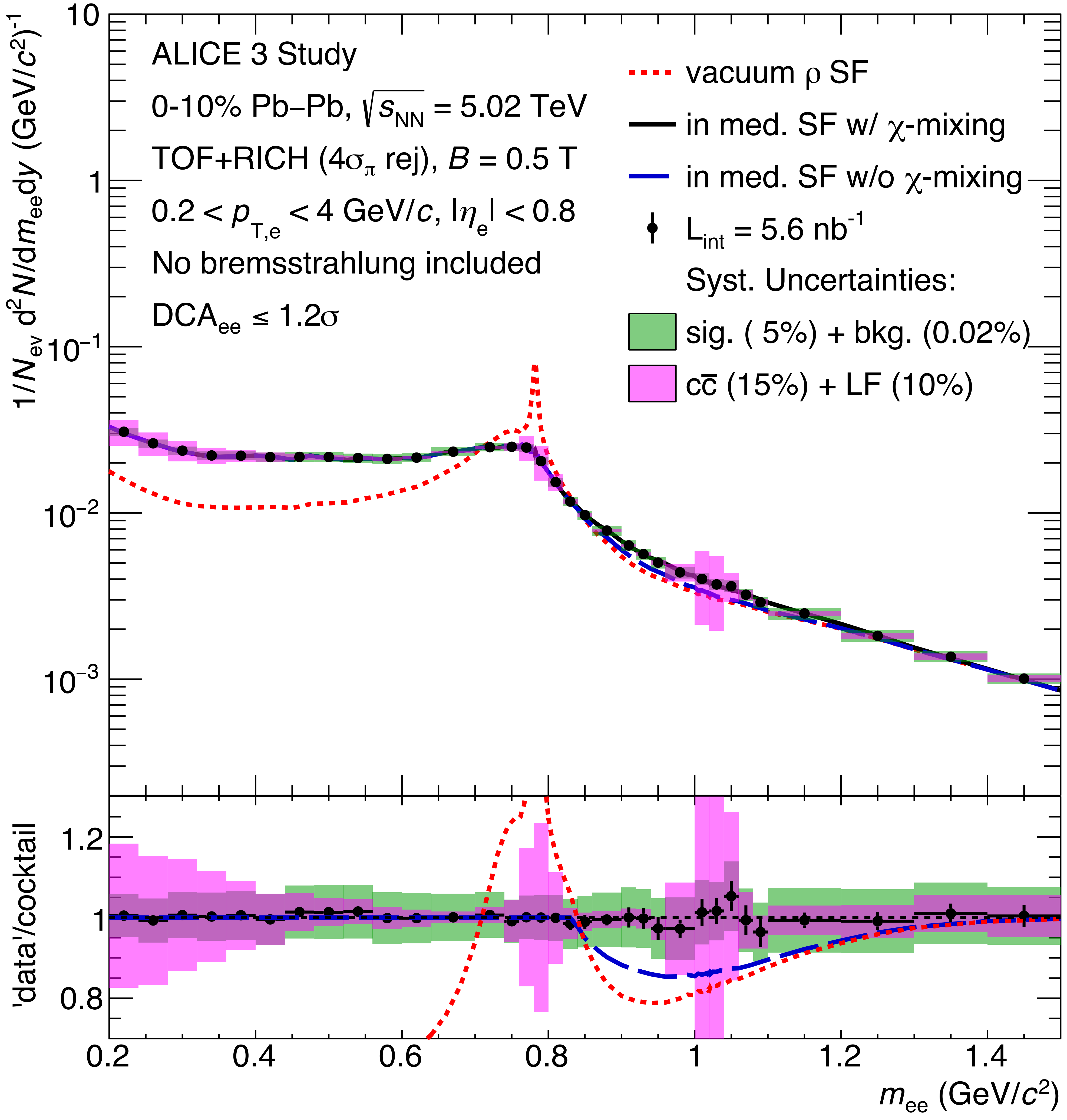
- ρ sensitive to surrounding medium (τ_ρ = 1.3 fm < $\tau_{fireball}$)

→ ρ spectral function modification related to chiral symmetry restoration

- High precision measurement with ALICE 3

→ Access to chiral symmetry restoration mechanisms like ρ – a1

Projection for one month Pb—Pb with ALICE 3



R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
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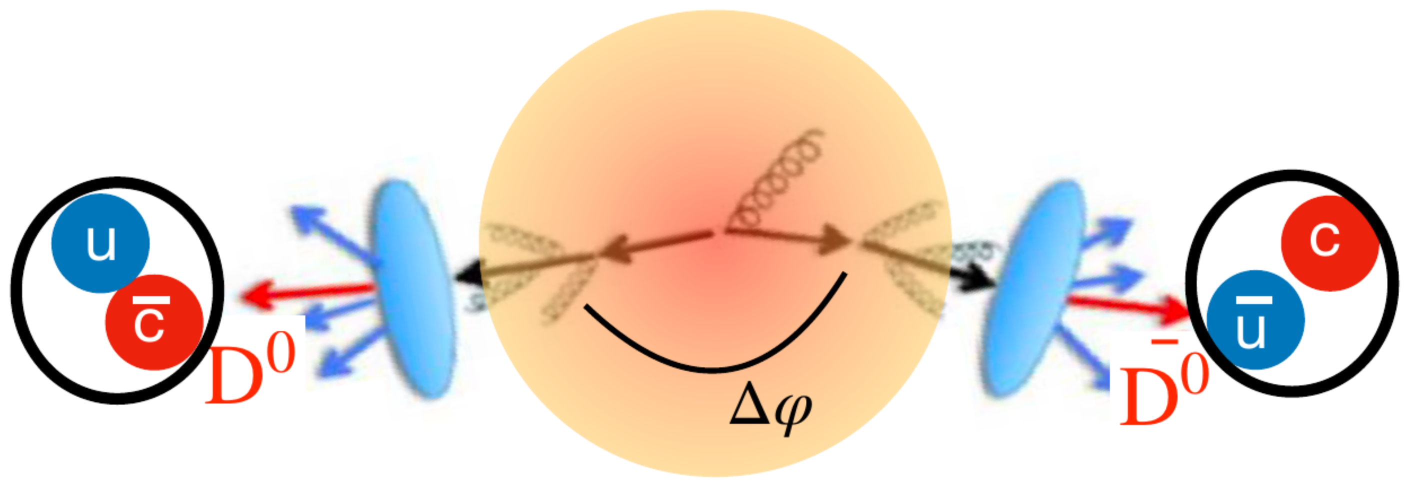
Heavy quark correlations



Charm quark energy loss in QGP

Angular decorrelation of $D^0\overline{D^0}$ mesons

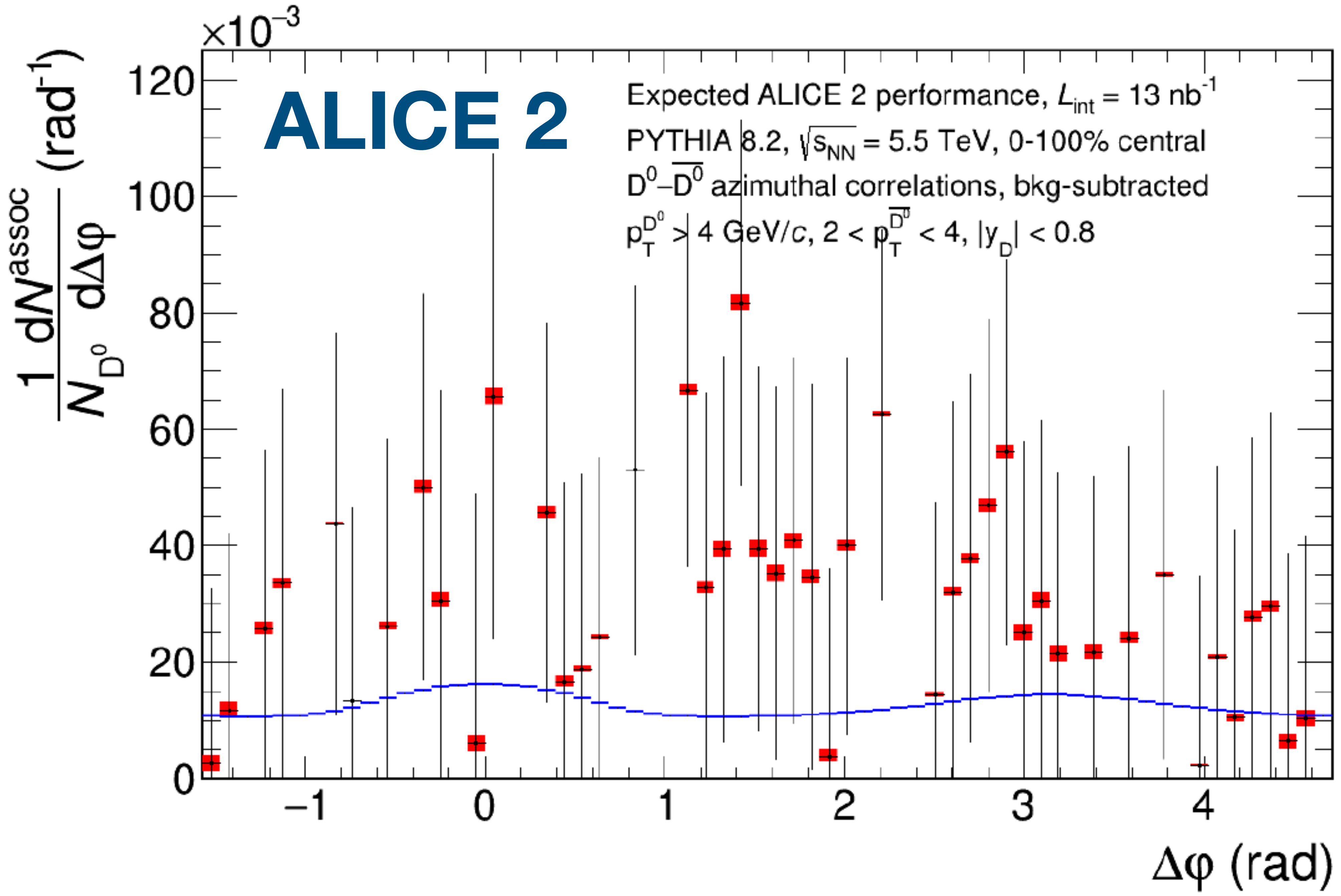
→ probe heavy quark rescattering in QGP

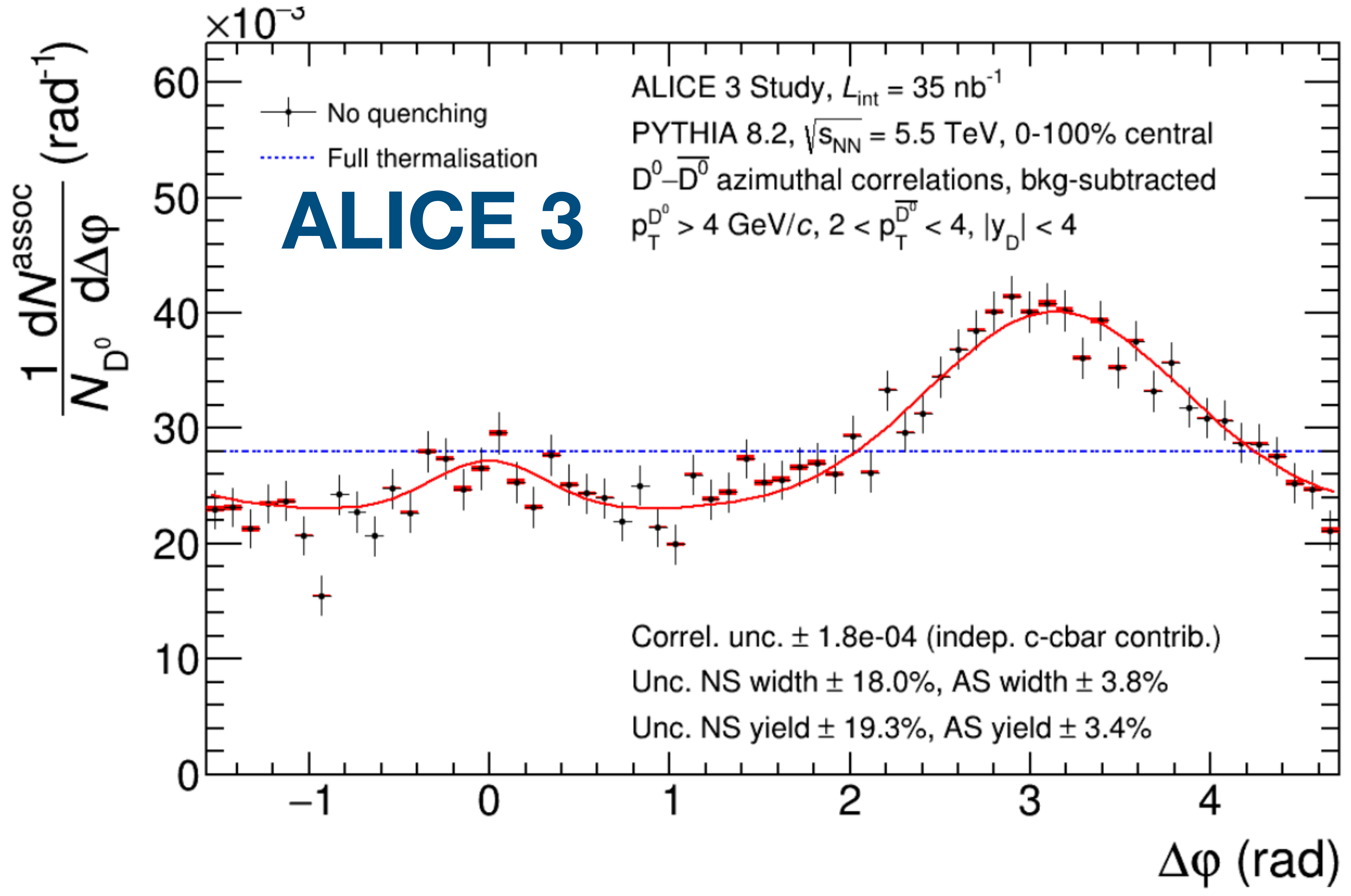
Sensitive to:

- Energy loss mechanisms
- Heavy quark thermalisation

Strongest signal at low p_T → very challenging measurement

- Requires: high purity, efficiency and large η coverage
- **Heavy-ion measurement possible only with ALICE 3**

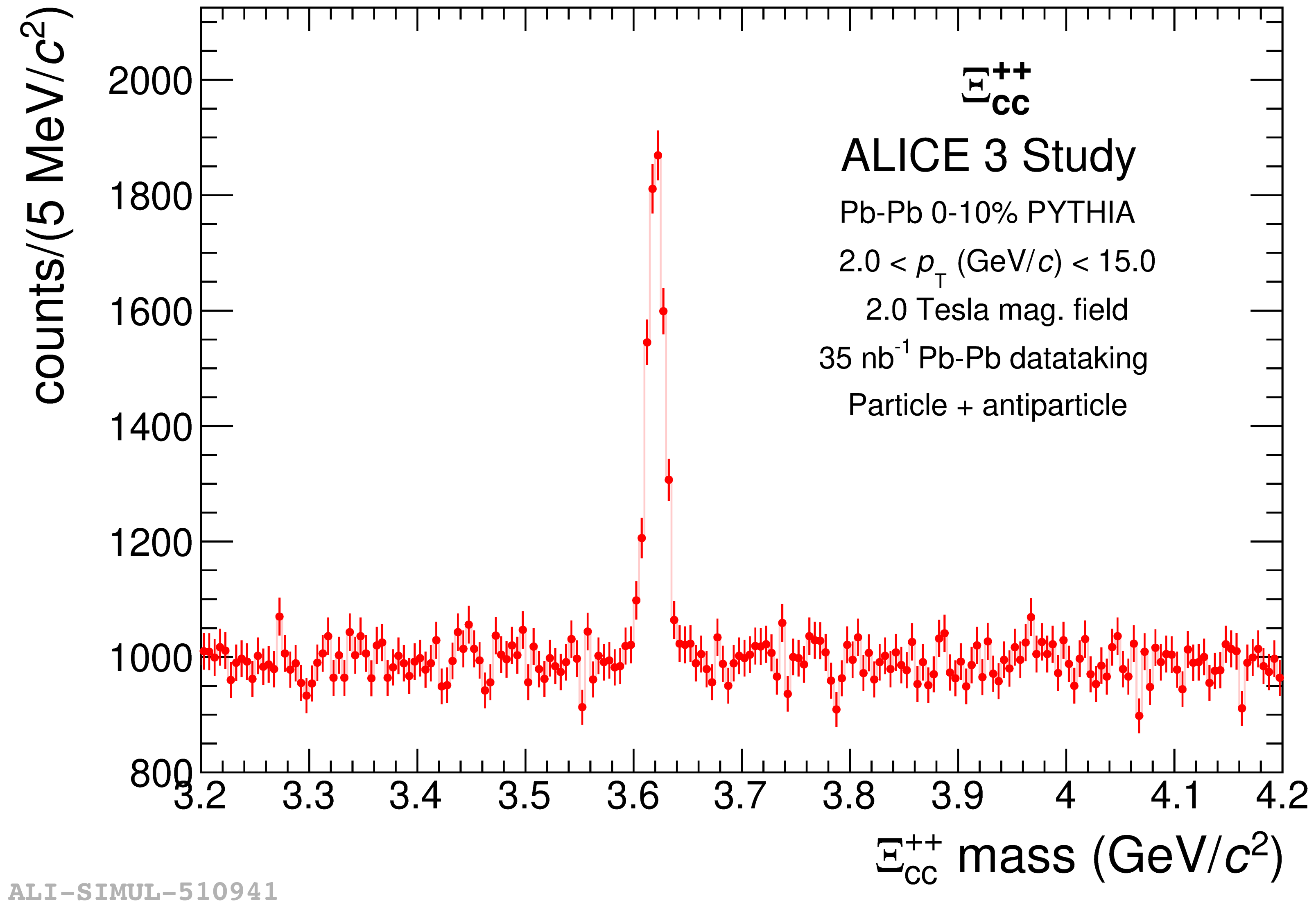




A few more examples

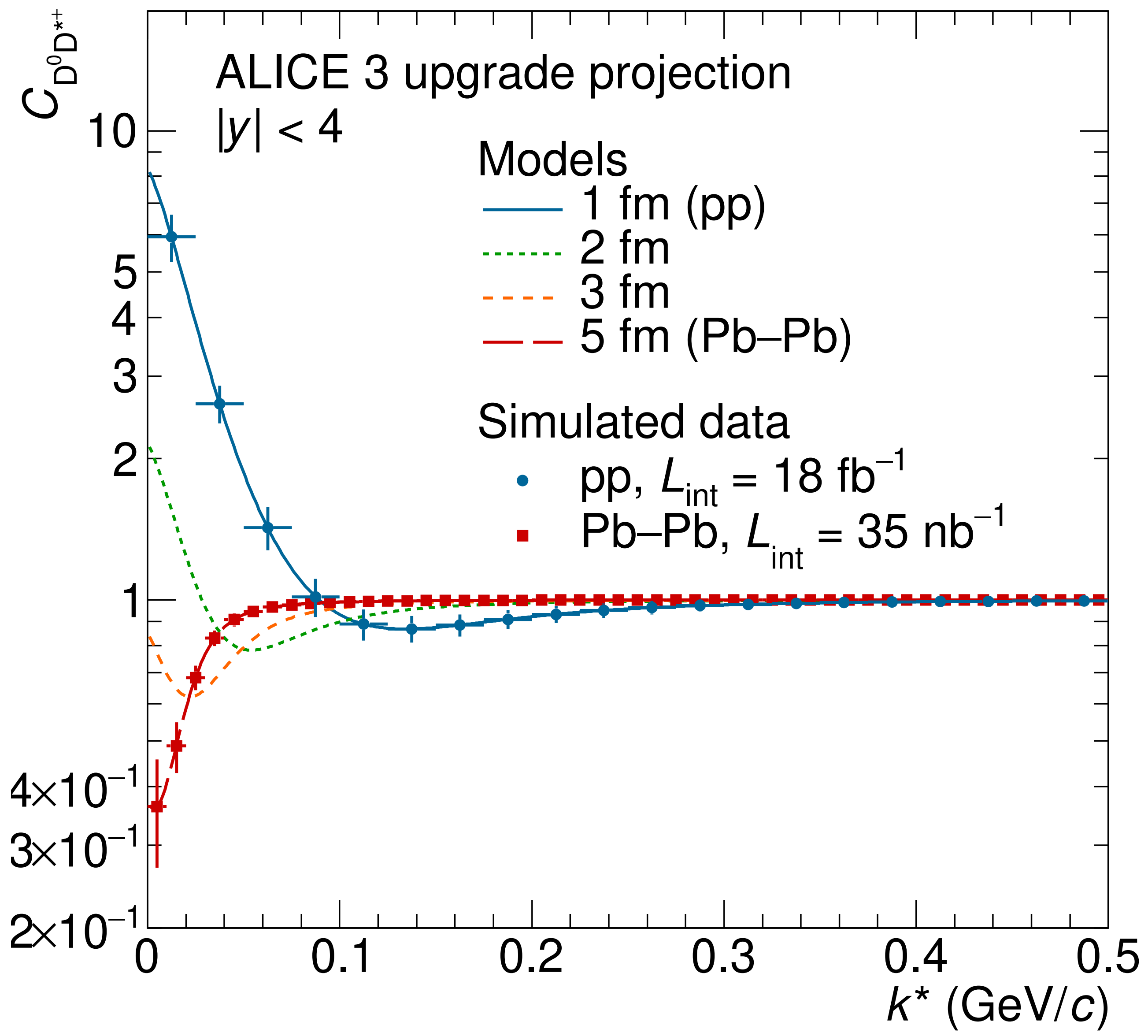
Extensive details in CERN-LHCC-2022-009

Multi-charm hadrons



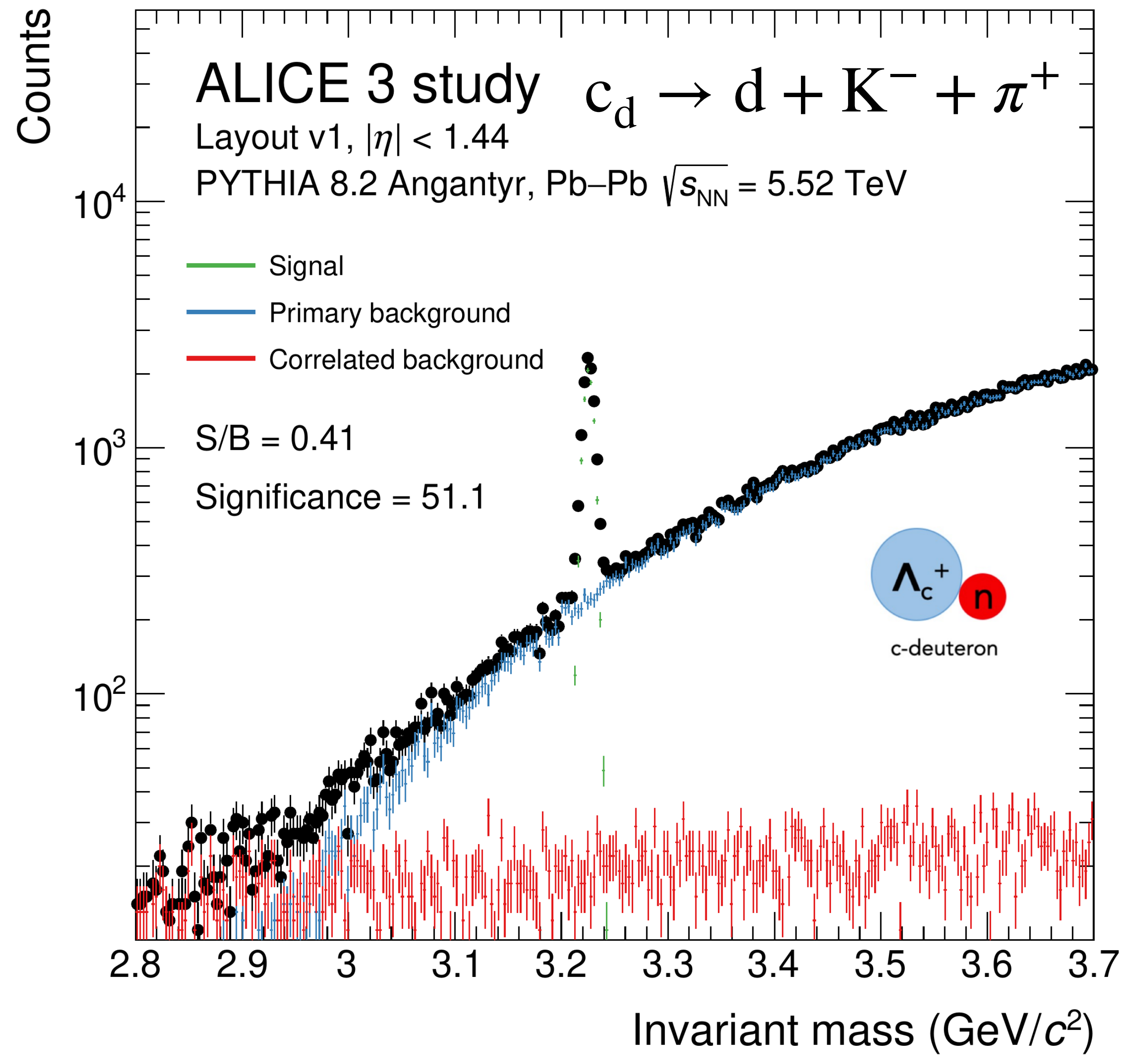
Unique experimental access to multicharm hadrons with ALICE 3 in Pb-Pb collisions

Exotic bound state



Search for possible DD bound states using momentum correlations

High mass (charm-)nuclei



Unique sensitivity to undiscovered charm-nuclei: c-deuteron, c-triton

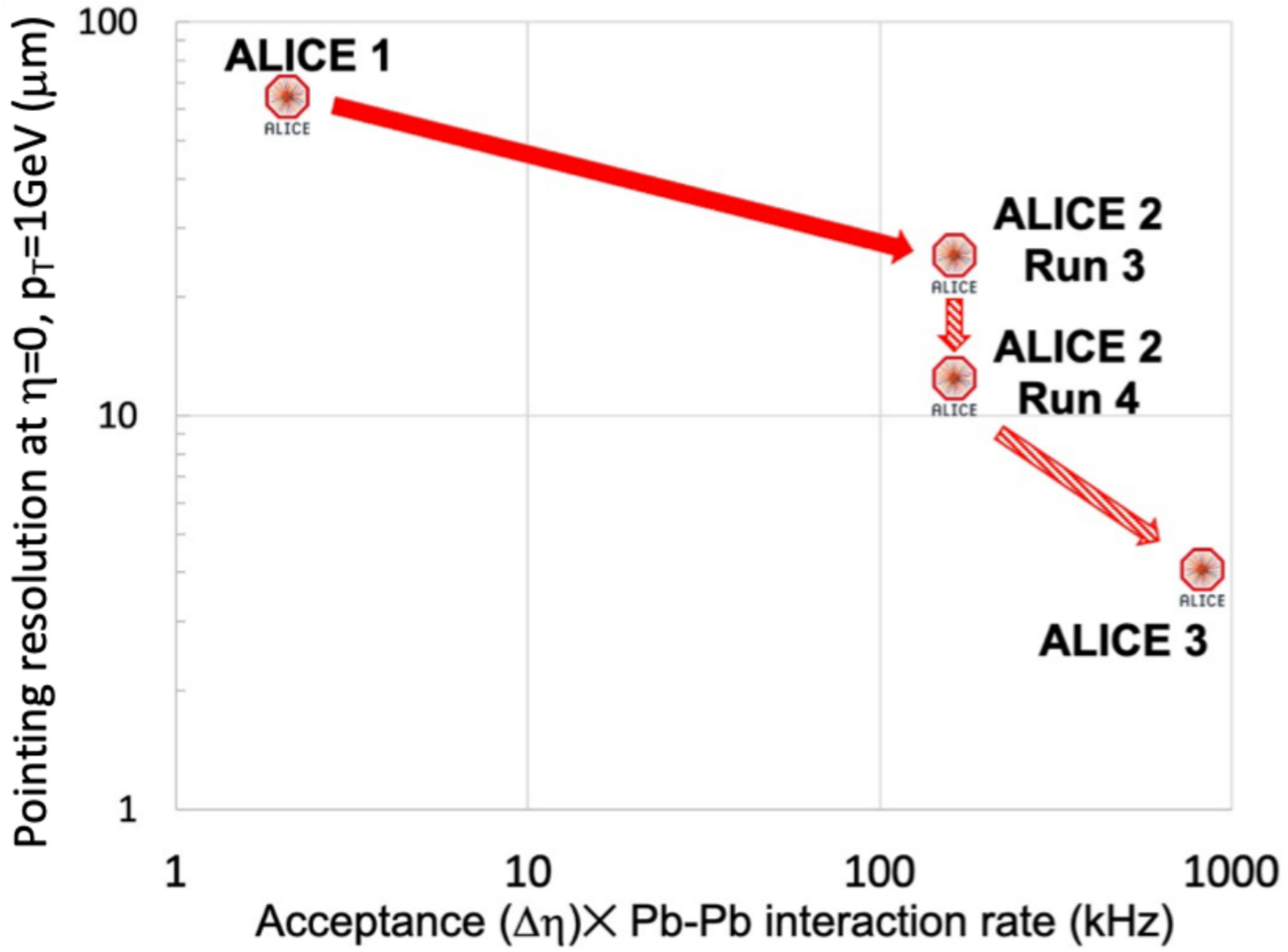
Key detector requirements

- Good tracking down to $p_T = 0$
- Low-mass detector
- Excellent pointing resolution
- Excellent particle identification
- Large acceptance
- High rates, large data samples

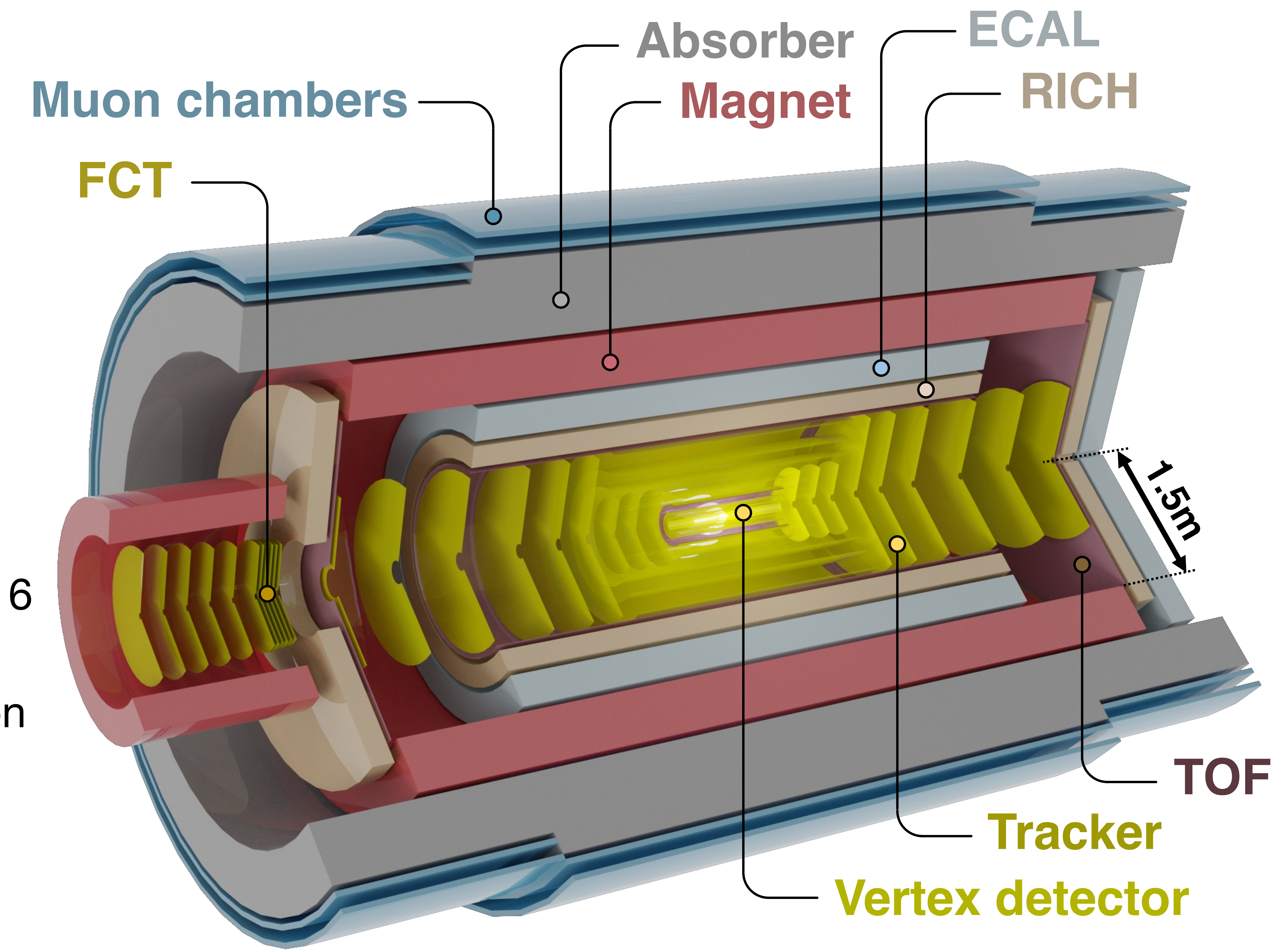
ALICE 3 detector concept

In few words:

Compact **all-silicon tracker**
with **high-resolution** vertex detector
Superconducting magnet system
Particle Identification over large acceptance:
muons, electrons, hadrons, photons
Fast read-out and online processing



For LHC Run 5 & 6
Improvement of pointing resolution and effective statistics



Requirements for vertexing

Pointing resolution crucial for:

- dileptons
- heavy flavour

Target pointing resolution

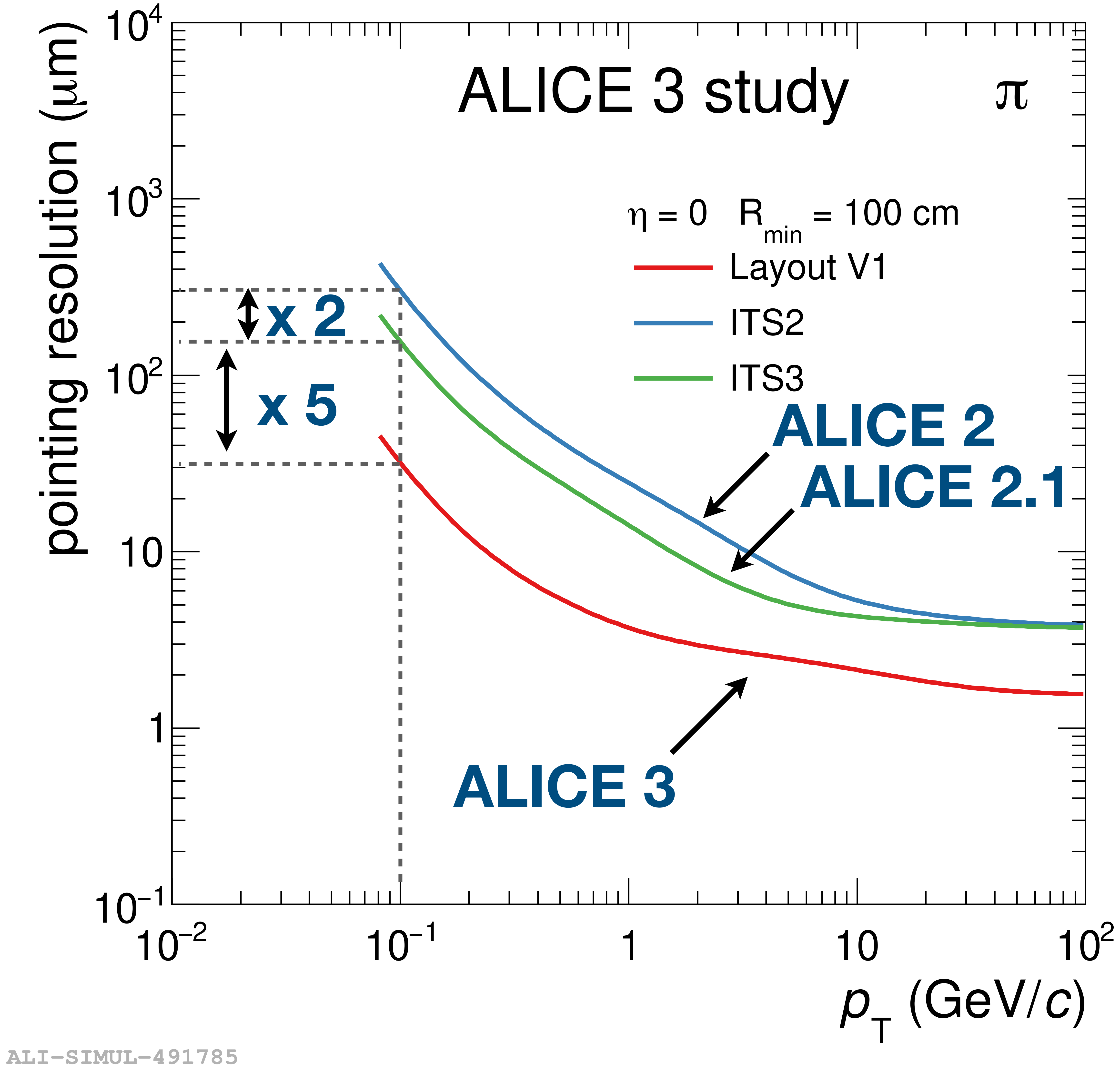
Pointing resolution $\propto r_0 \cdot \sqrt{x/X_0}$ (multiple scattering regime)

~10 μm @ p_T = 200 MeV/*c* → 5x better than ALICE 2.1

Unique pointing resolution at mid-rapidity at the LHC!

Critical for this step:

- radius and material thickness of first layers
- minimum radius limited by LHC



Vertex detector concept

Retractable vertex detector

3 layers within the beam pipe in secondary vacuum

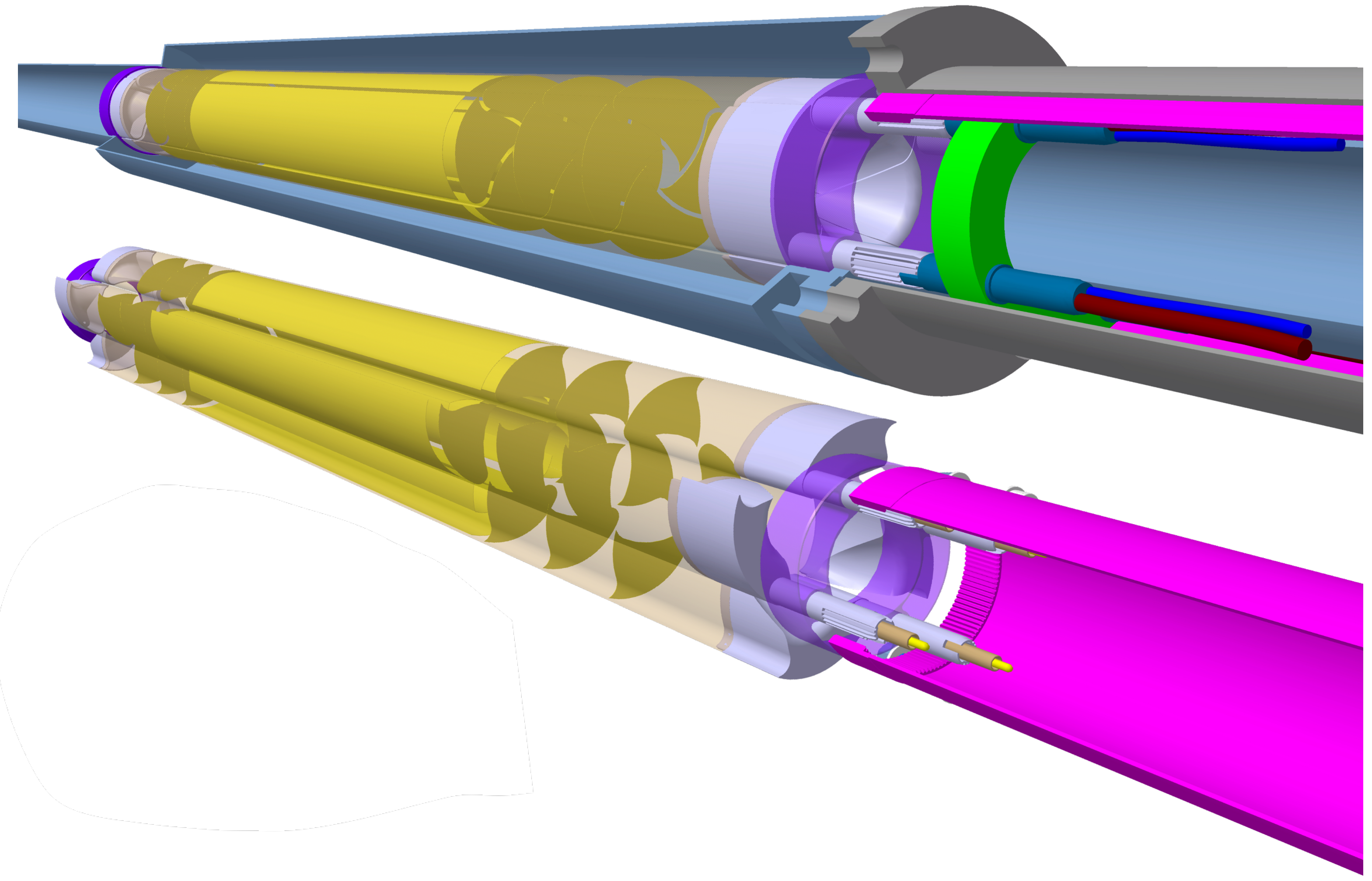
- wafer-sized, bent Monolithic Active Pixel Sensors
- σ_{pos} ~2.5 μm → 10 μm pixel pitch
- 1 ‰ X_0 per layer

rotary petals matching to beampipe parameters

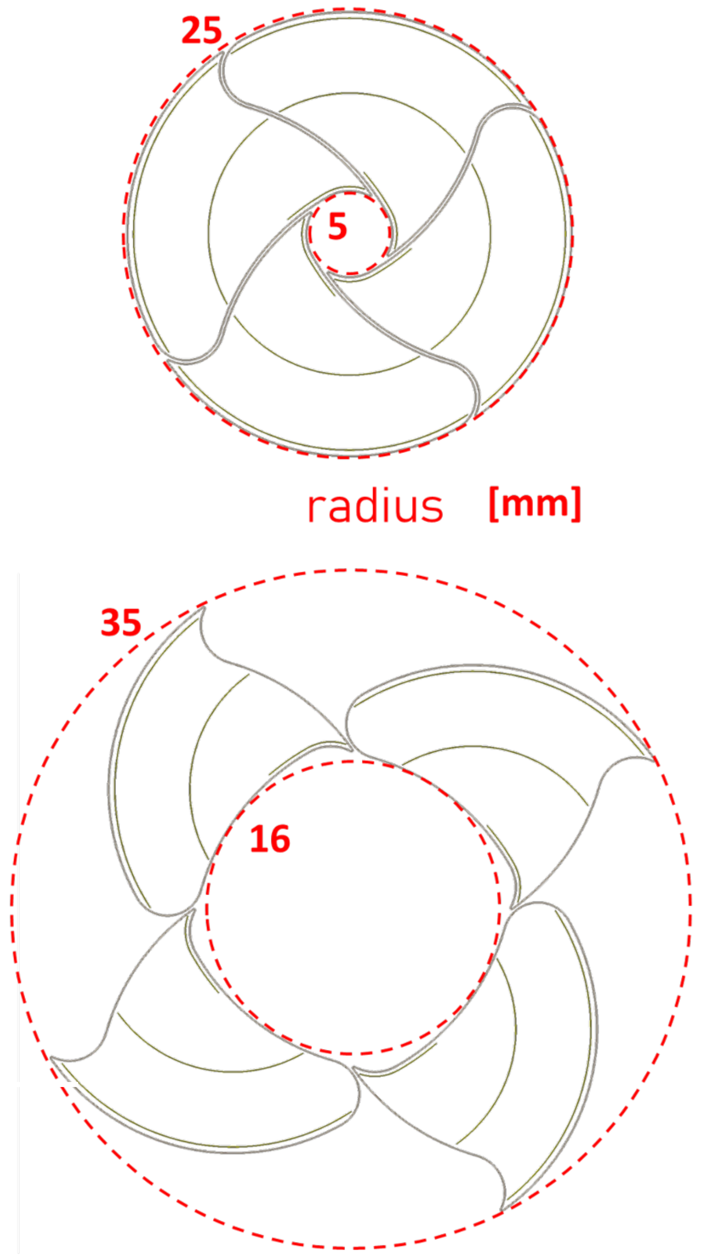
- R_{min} ≈ 5 mm at top energy
- R_{min} ≈ 15 mm at injection energy

• feed-throughs for power, cooling, data

R&D ongoing: challenges on mechanics, cooling, radiation tolerance

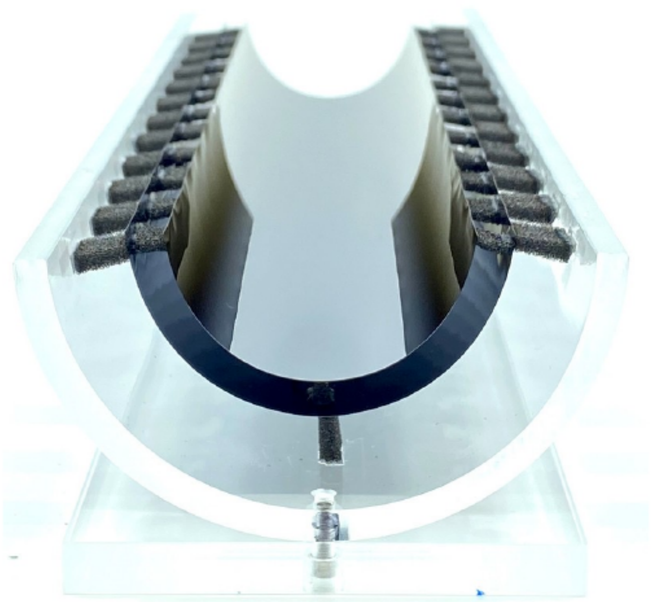


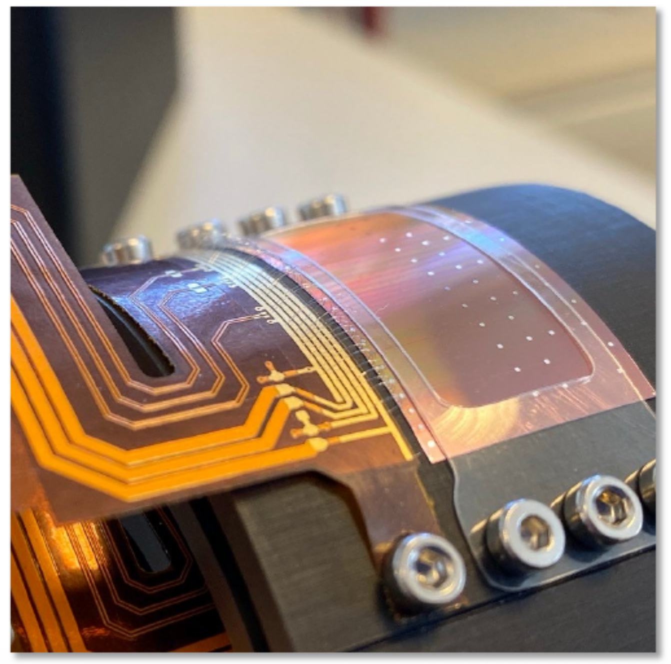
closed



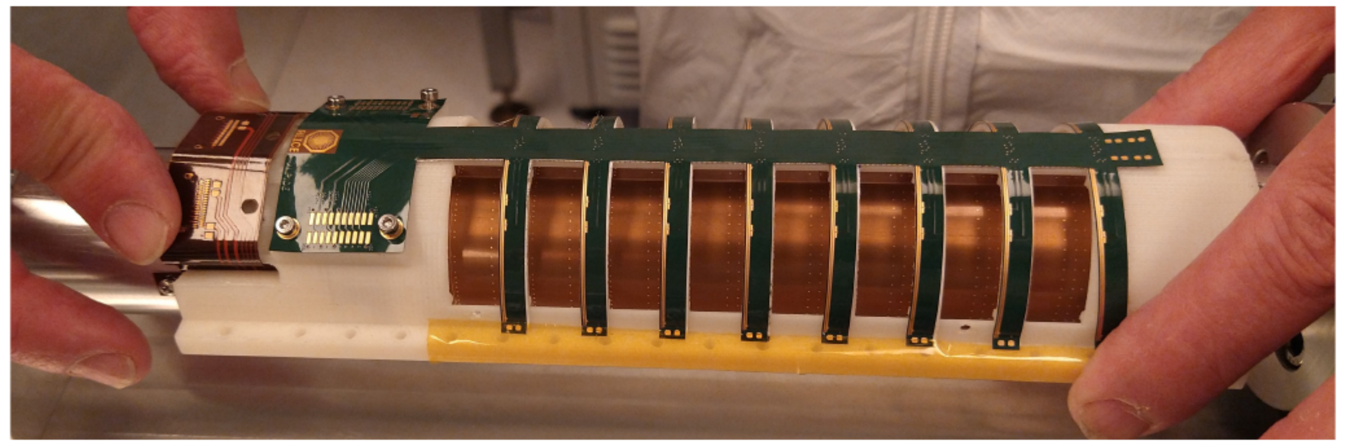
retracted

Pioneering with ITS3 R&D experience





Discussed in previous talk by M. Mager



Requirements for tracking

Momentum resolution crucial for:

- dileptons
- heavy flavour
- jets

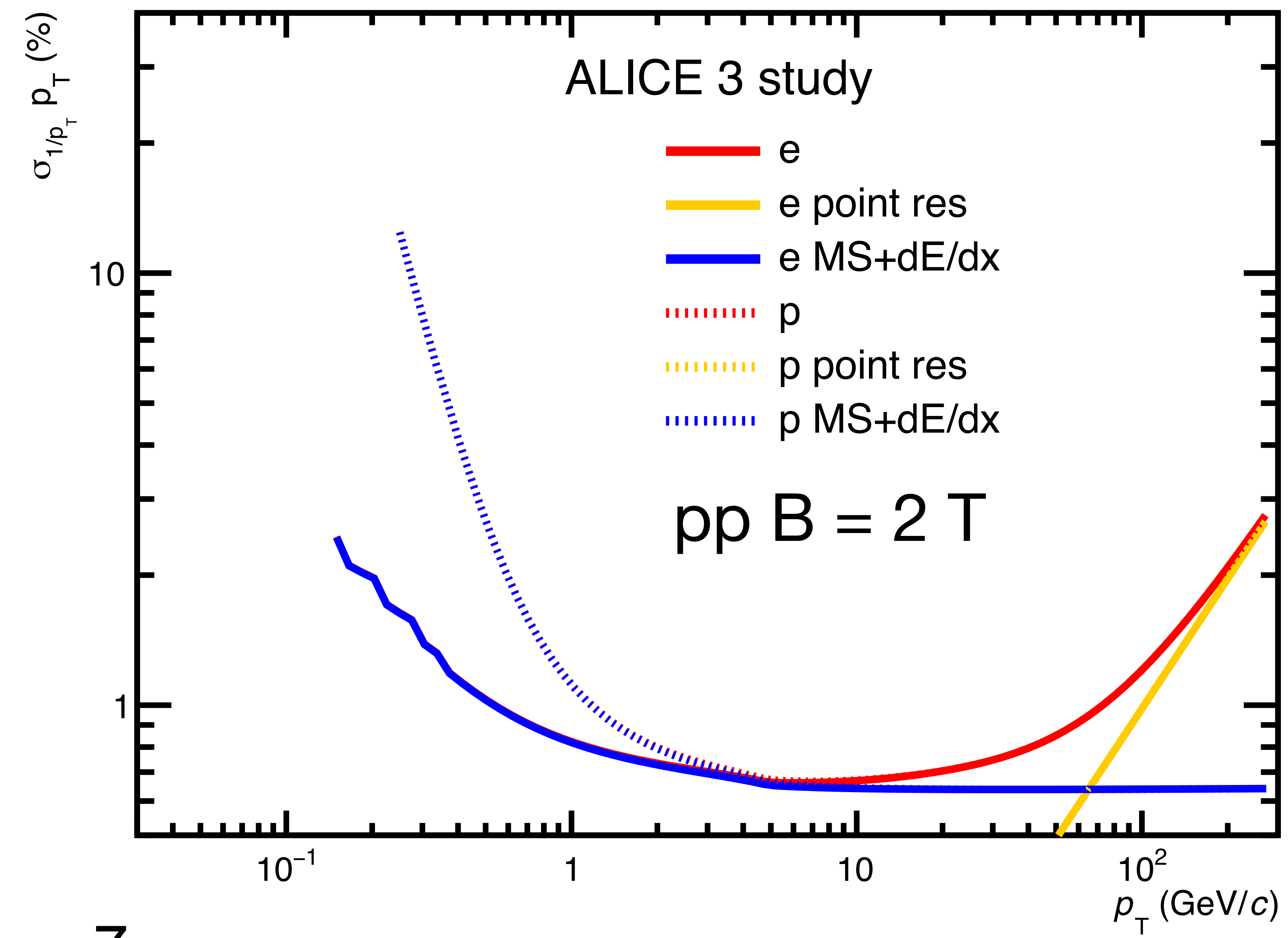
Target momentum resolution

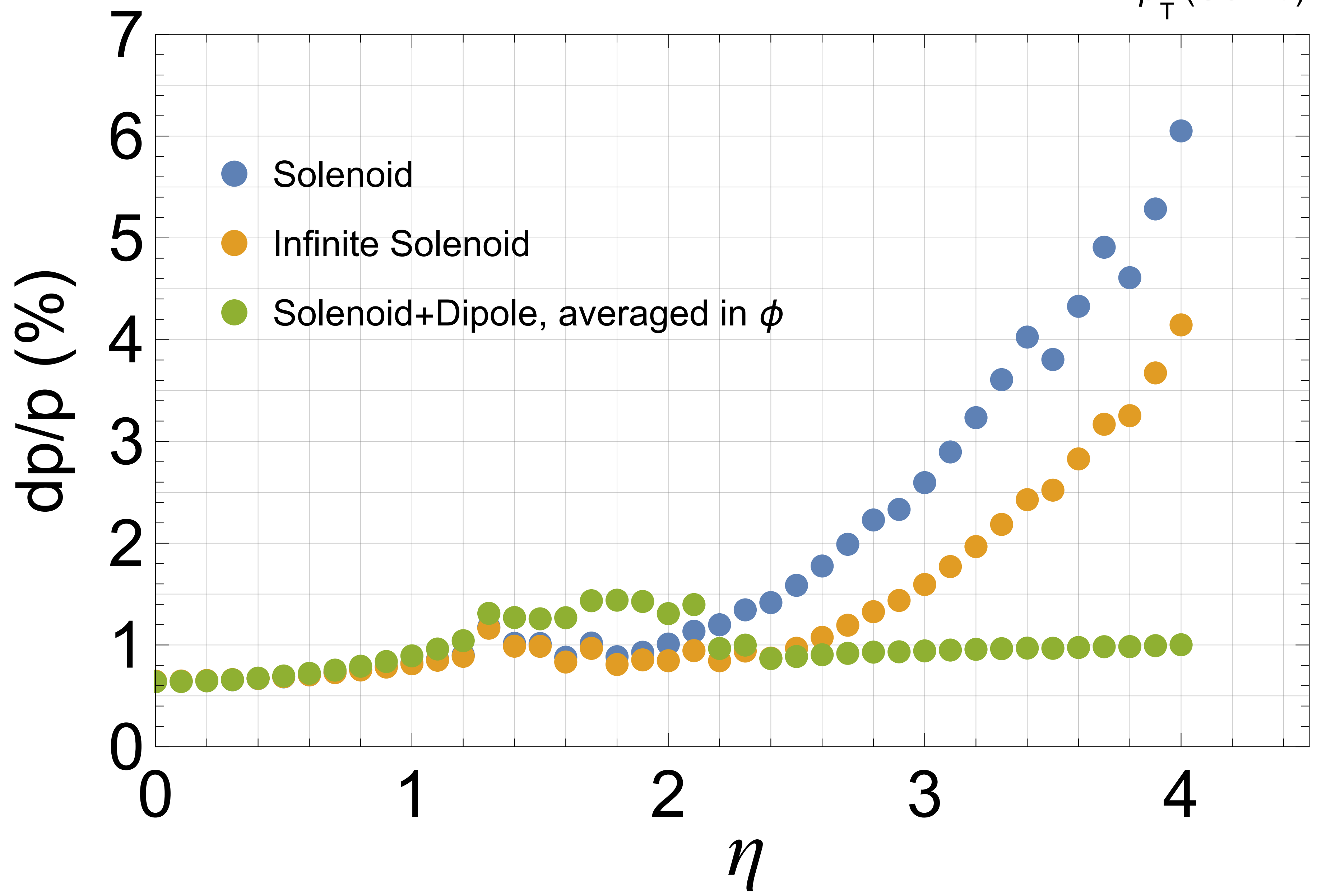
Relative p_{T} resolution $\propto \dfrac{\sqrt{x/X_0}}{B \cdot L}$ (limited by multiple scattering)

~1 % up to η = 4 → large coverage

Critical for this step:

- integrated magnetic field
- overall material budget

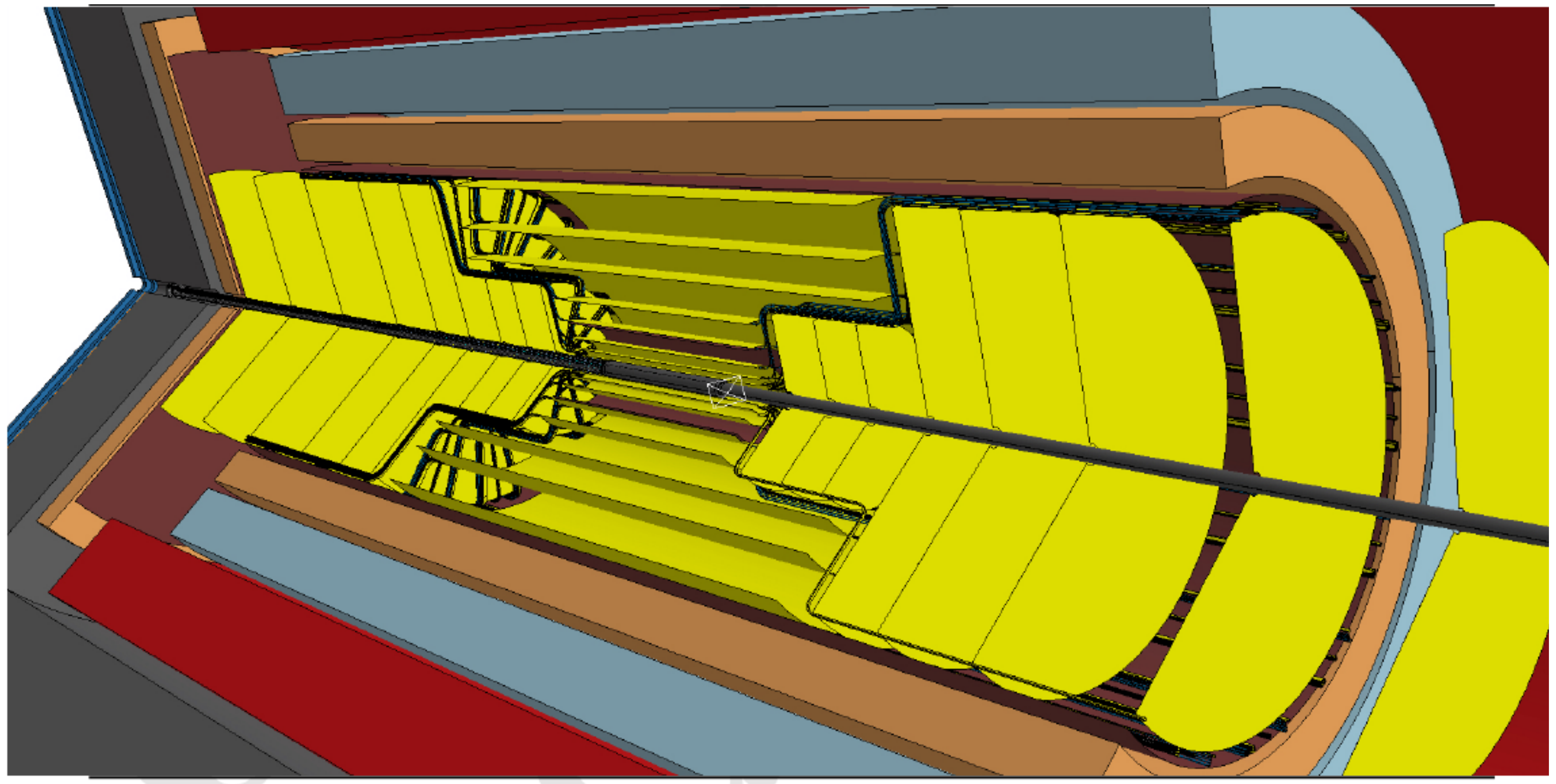




The outer tracker

Concept:

- ~11 tracking layers (barrel + disks) MAPS
- σ_{pos} ~10 μm → 50 μm pixel pitch
- $R_{out} \approx$ 80 cm and L ≈ 4 m (→ magnetic field B = 2 T)
- timing resolution ~100 ns (→ reduce mismatch probability)
- carbon-fibre space frame for mechanical support
- material ~1 % X_0 / layer → overall x/X_0 = ~10 %



R&D: build on the expertise of ITS2

Total silicon area ~ 60 m²

Particle identification with Time Of Flight

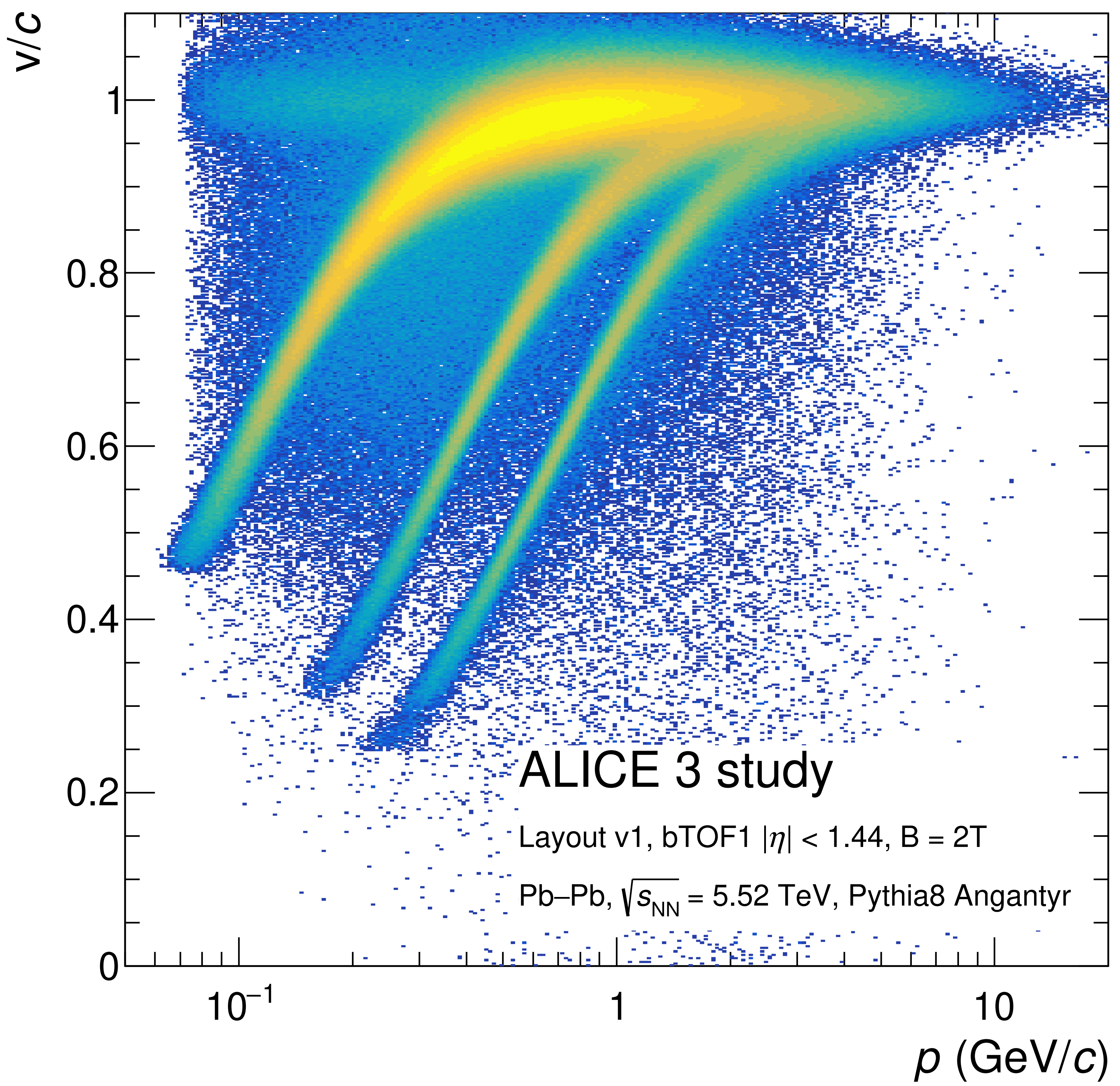
Separation power $\propto L/\sigma_{\mathrm{TOF}}$

Critical for this step:

- distance and time resolution crucial
- larger radius results in lower p_T bound

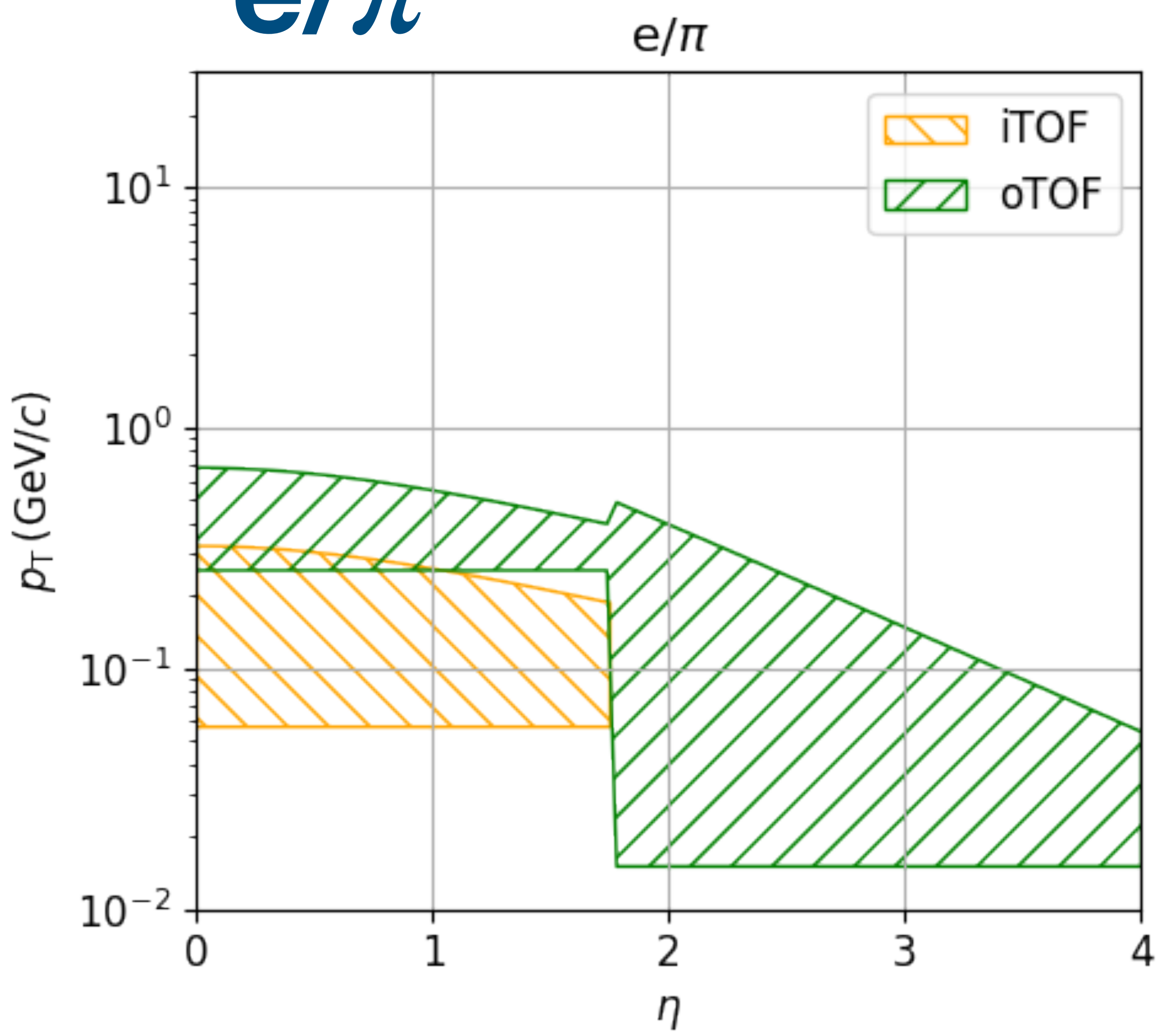
Concept:

- 2 barrel + 1 forward TOF layers
  - outer TOF at R ≈ 85 cm
  - inner TOF at R ≈ 19 cm
  - forward TOF at z ≈ 405 cm
- Silicon timing sensors ($\sigma_{\mathrm{TOF}} \approx 20$ ps)
  - R&D on monolithic CMOS sensors with integrated gain layer

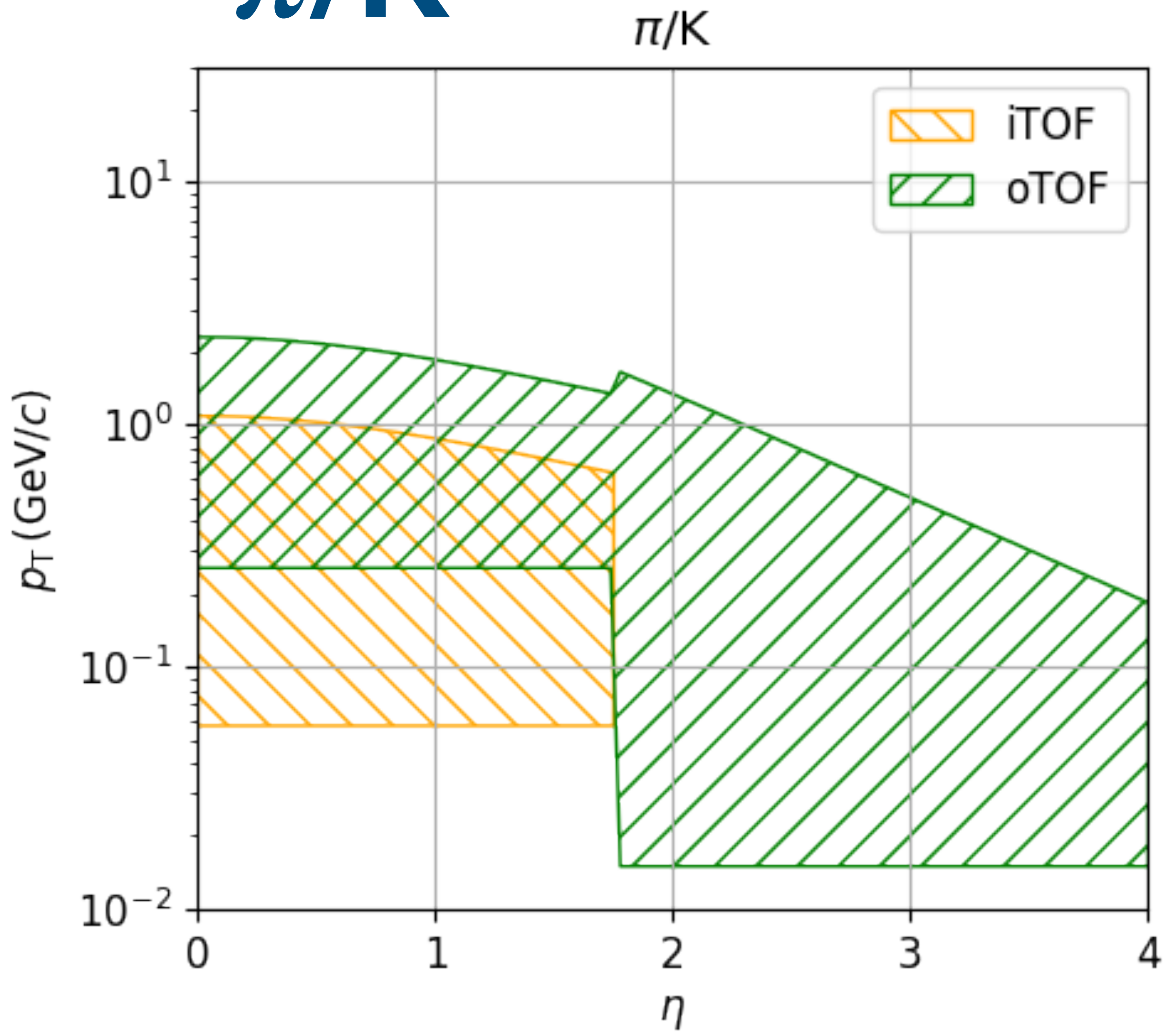


Total silicon area ~ 45 m²

e/π



π/K



Particle identification with Cherenkov light

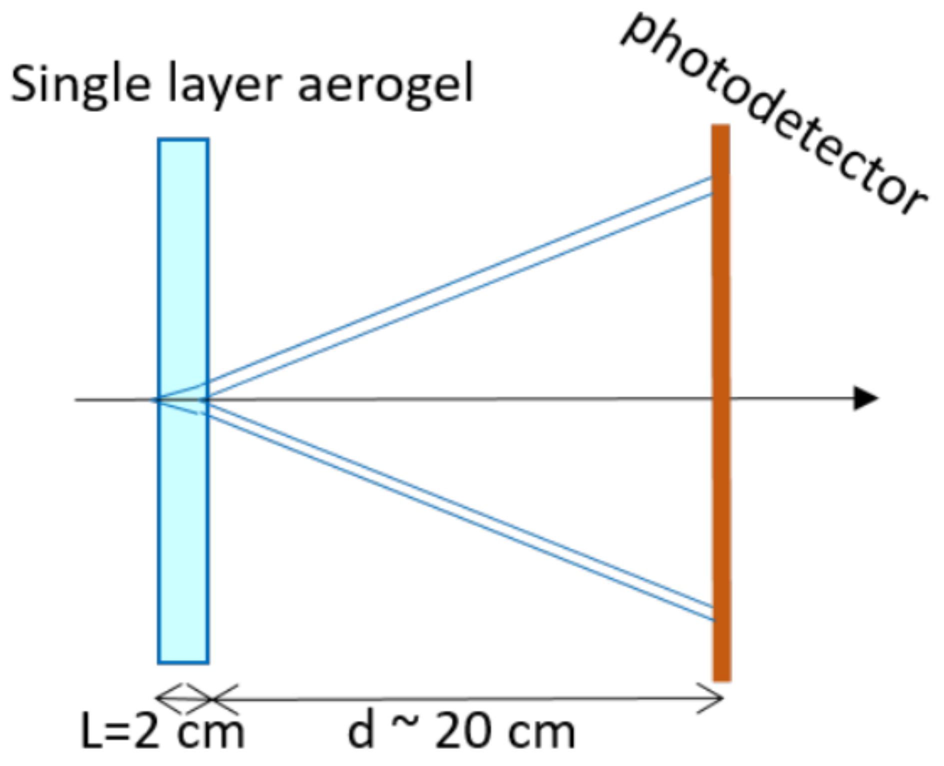
Complement PID reach of outer TOF to higher p_T with Cherenkov detector

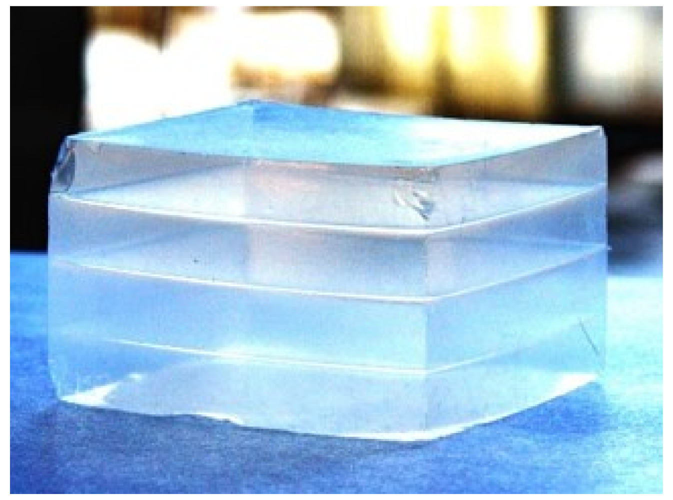
Critical for this step:

- ensure continuous coverage with the TOF system

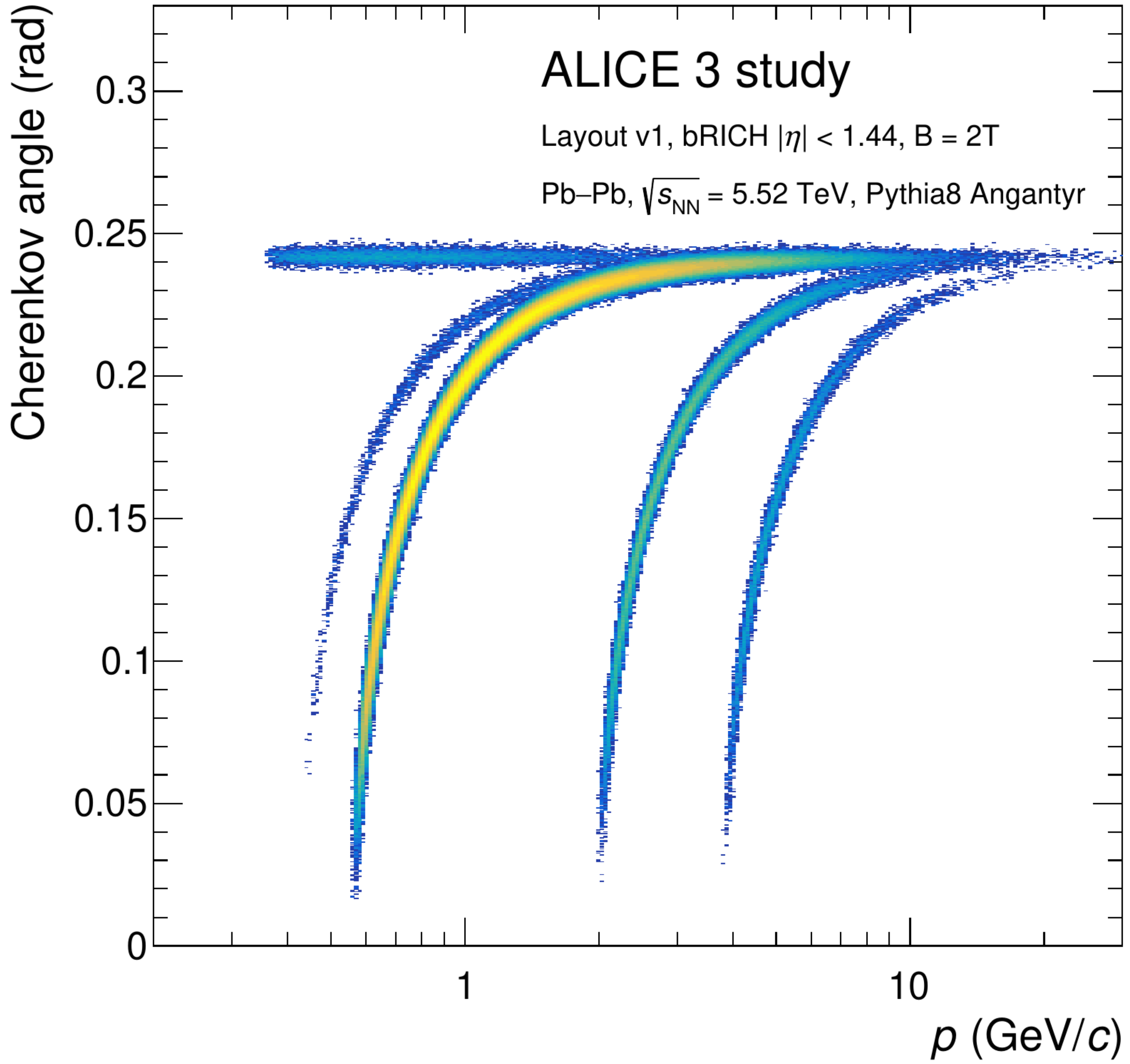
Concept:

- aerogel radiator
  - refractive index n = 1.03 (barrel)
  - refractive index n = 1.006 (forward)
- R&D on monolithic silicon photon sensors





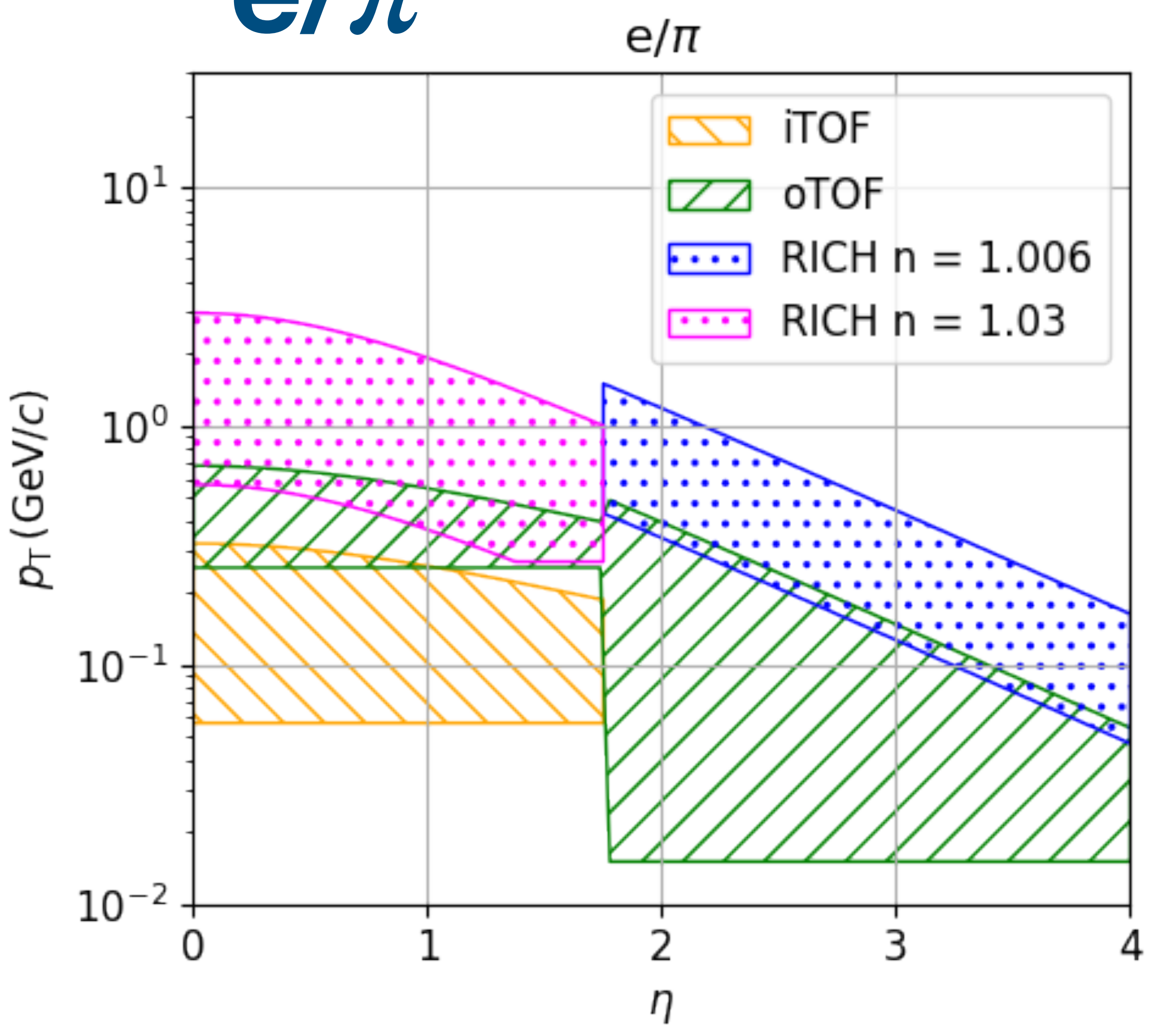
aerogel radiator



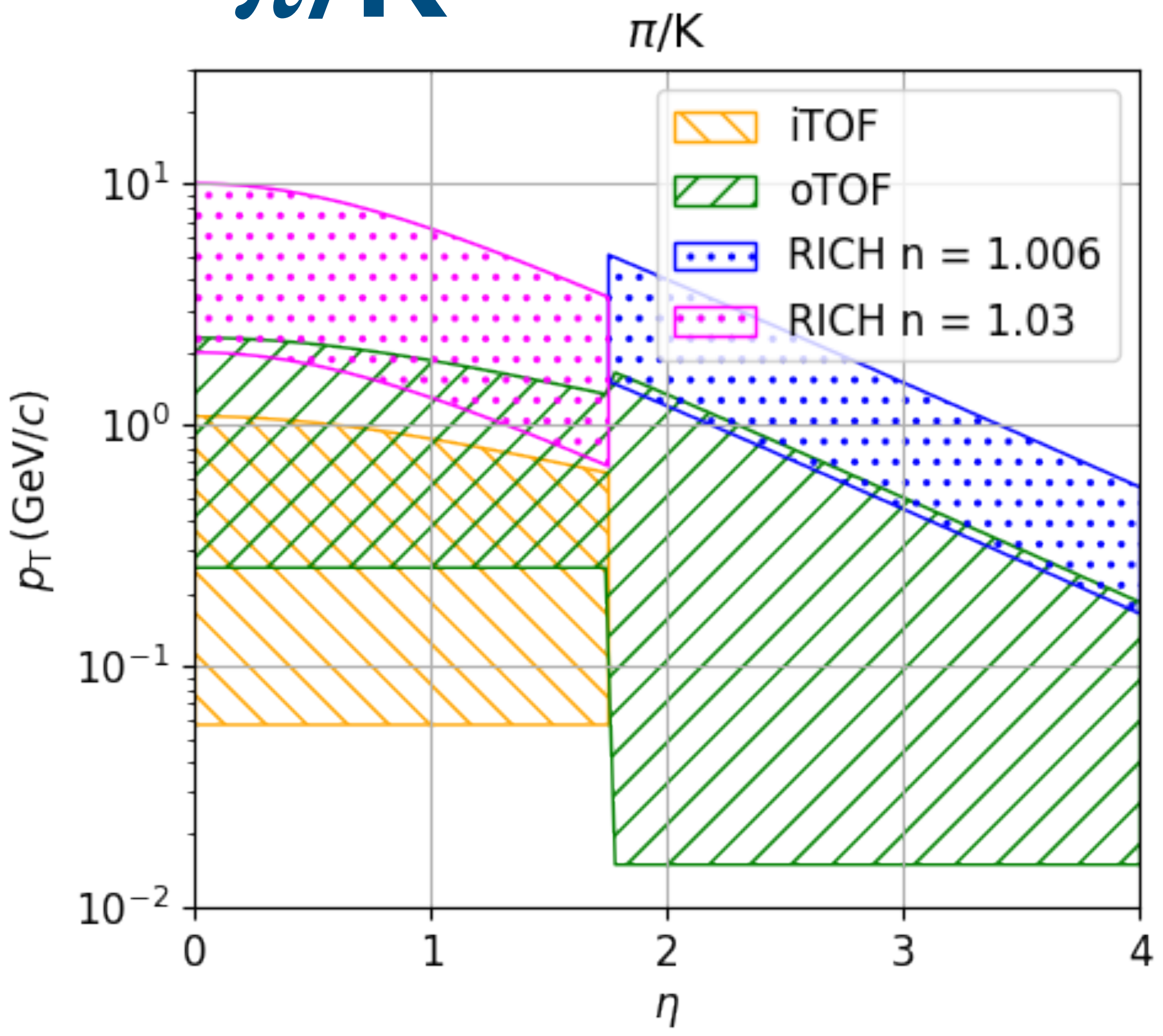
Total SiPM area ~ 60 m²

Continuous separation from 100 MeV/c to 10 GeV/c

e/π



π/K

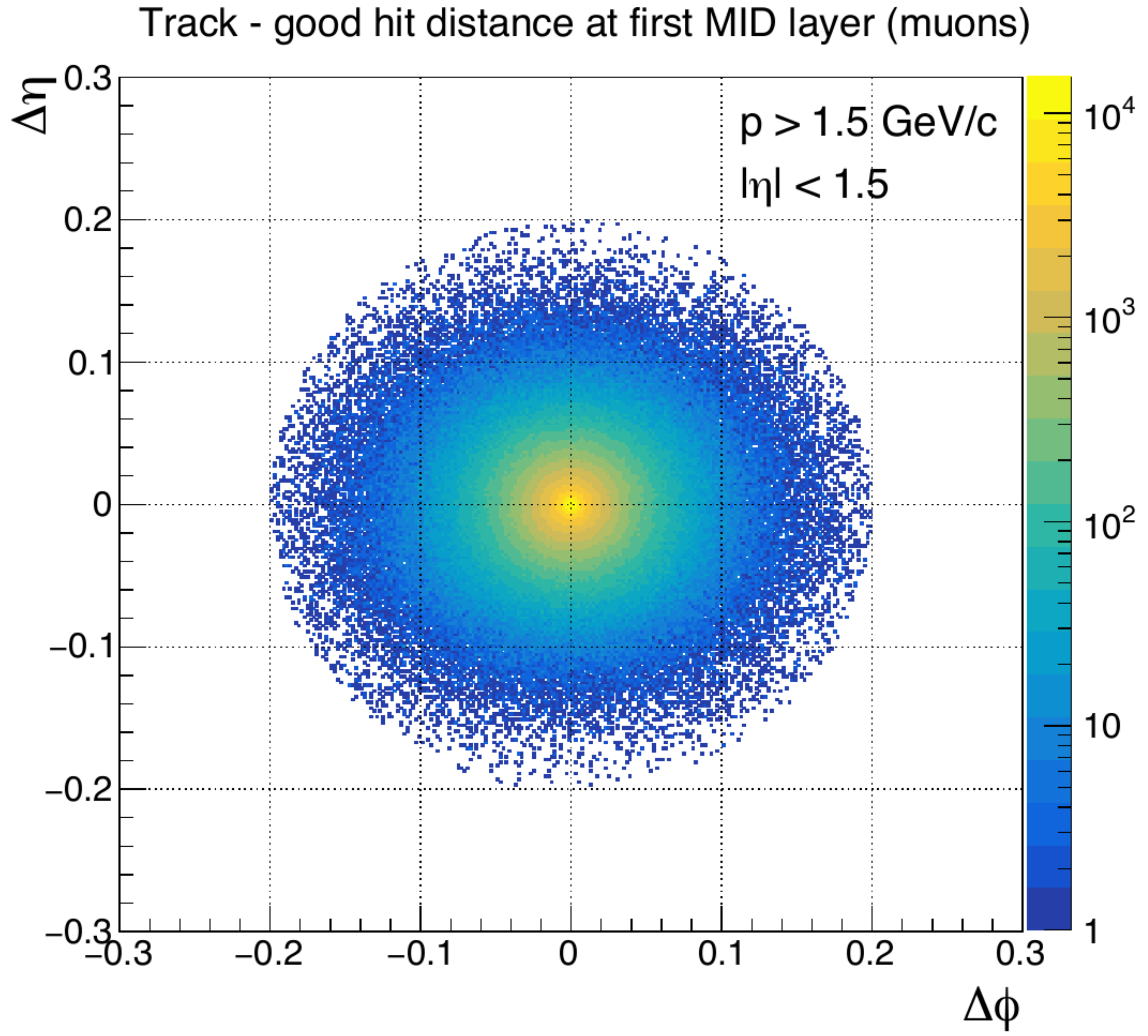


Muon and photon identification

Muon chambers at central rapidity

- ~70 cm non-magnetic steel hadron absorber
- search spot for muons ~0.1 x 0.1 ($\eta \times \varphi$)
- ~5 x 5 cm^2 cell size
- matching demonstrated with 2 layers of muon chambers
  - scintillator bars
  - wave-length shifting fibers
  - SiPM read-out
  - possibility to use using RPCs as muon chambers

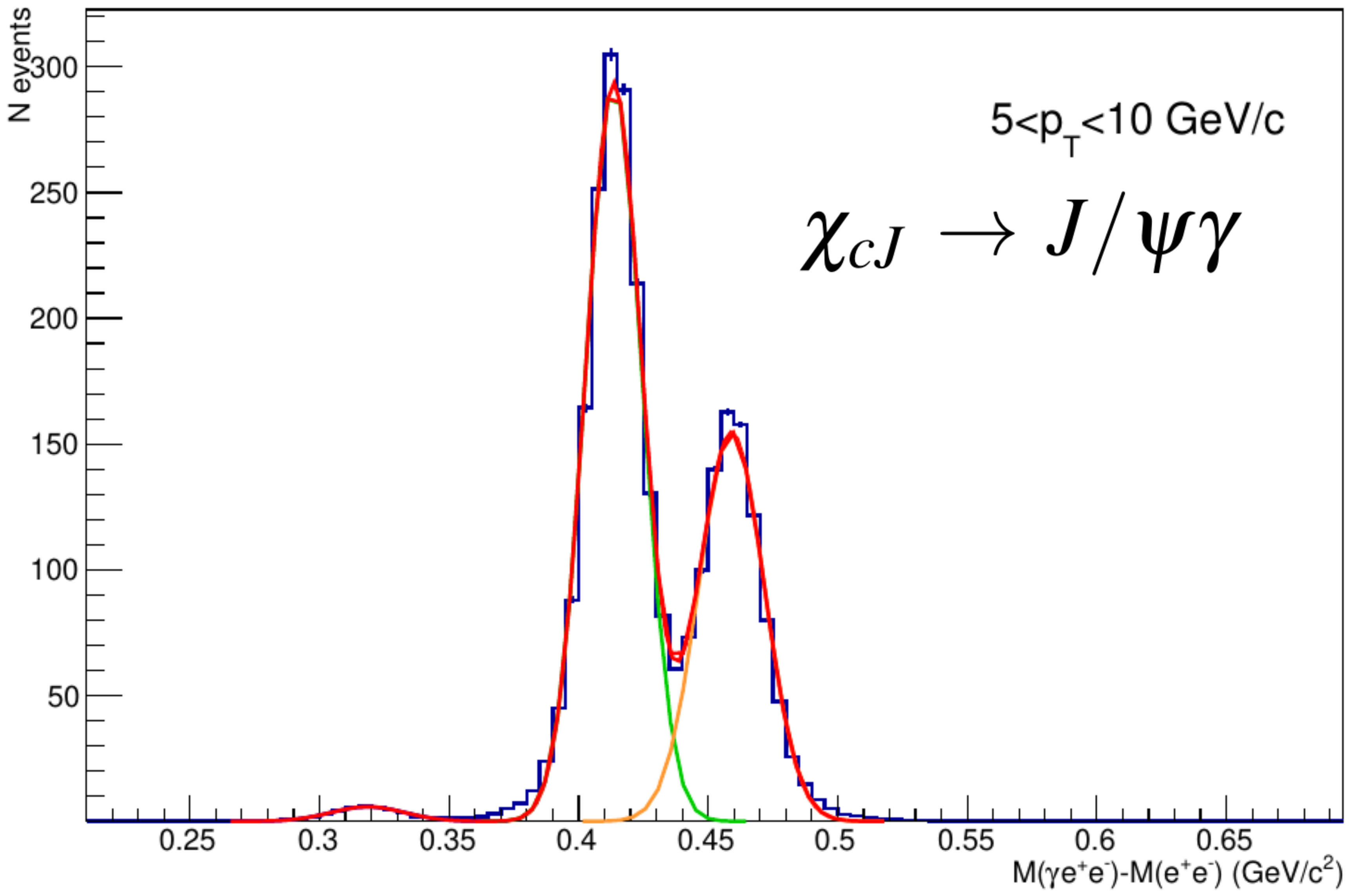
optimized for J/ψ reconstruction down to p_T 0 GeV/*c*



Large acceptance ECal (2π coverage)

- sampling calorimeter (à la EMCal/DCal): e.g. O(100) layers (1 mm Pb + 1.5 mm plastic scintillator)
- $PbWO_4$-based high energy resolution segment

critical for measuring P-wave quarkonia and thermal radiation via real photons



R&D activities

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

Photon sensors

- monolithic SiPMs
  - integrate read-out

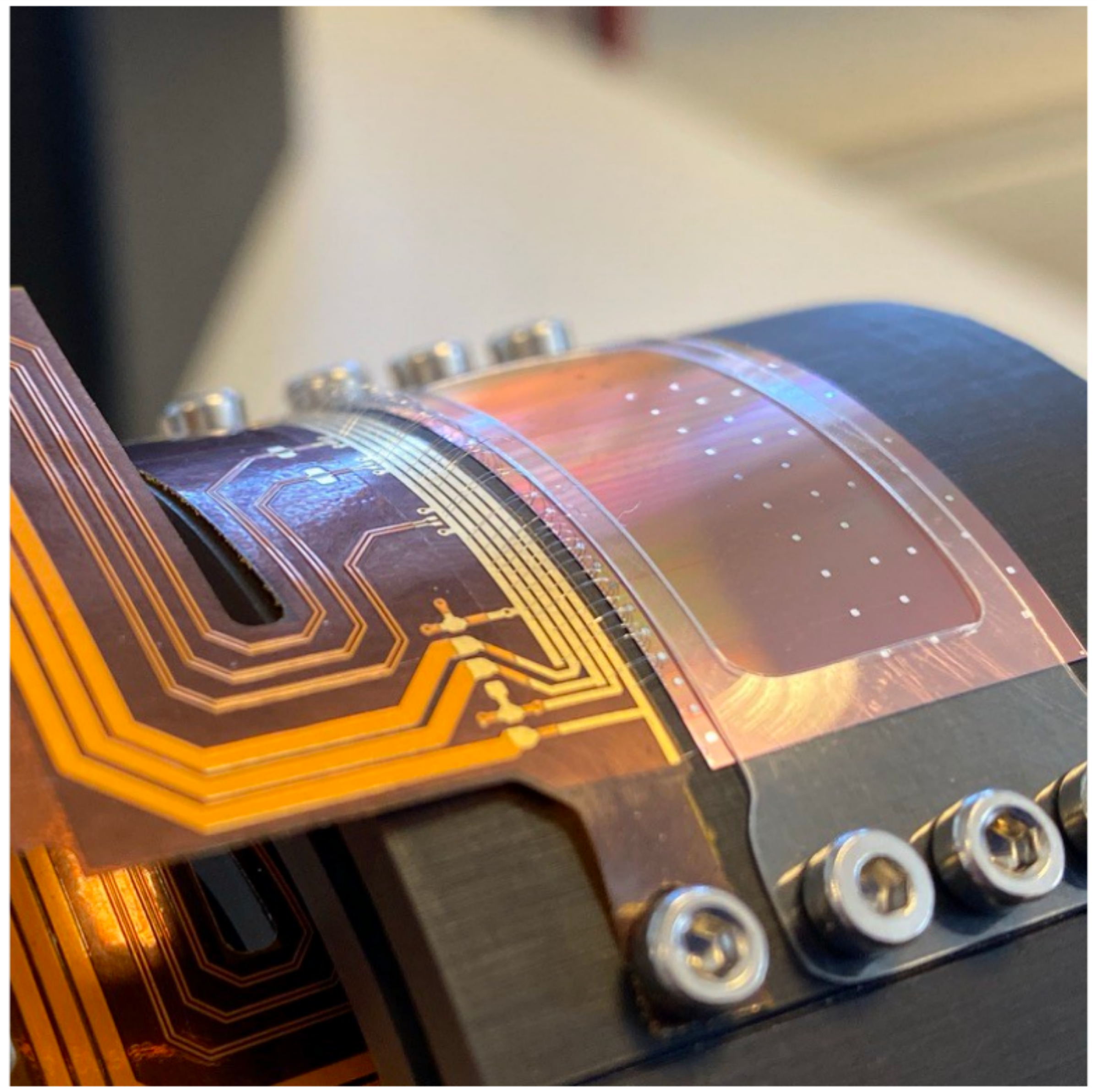
Detector mechanics and cooling

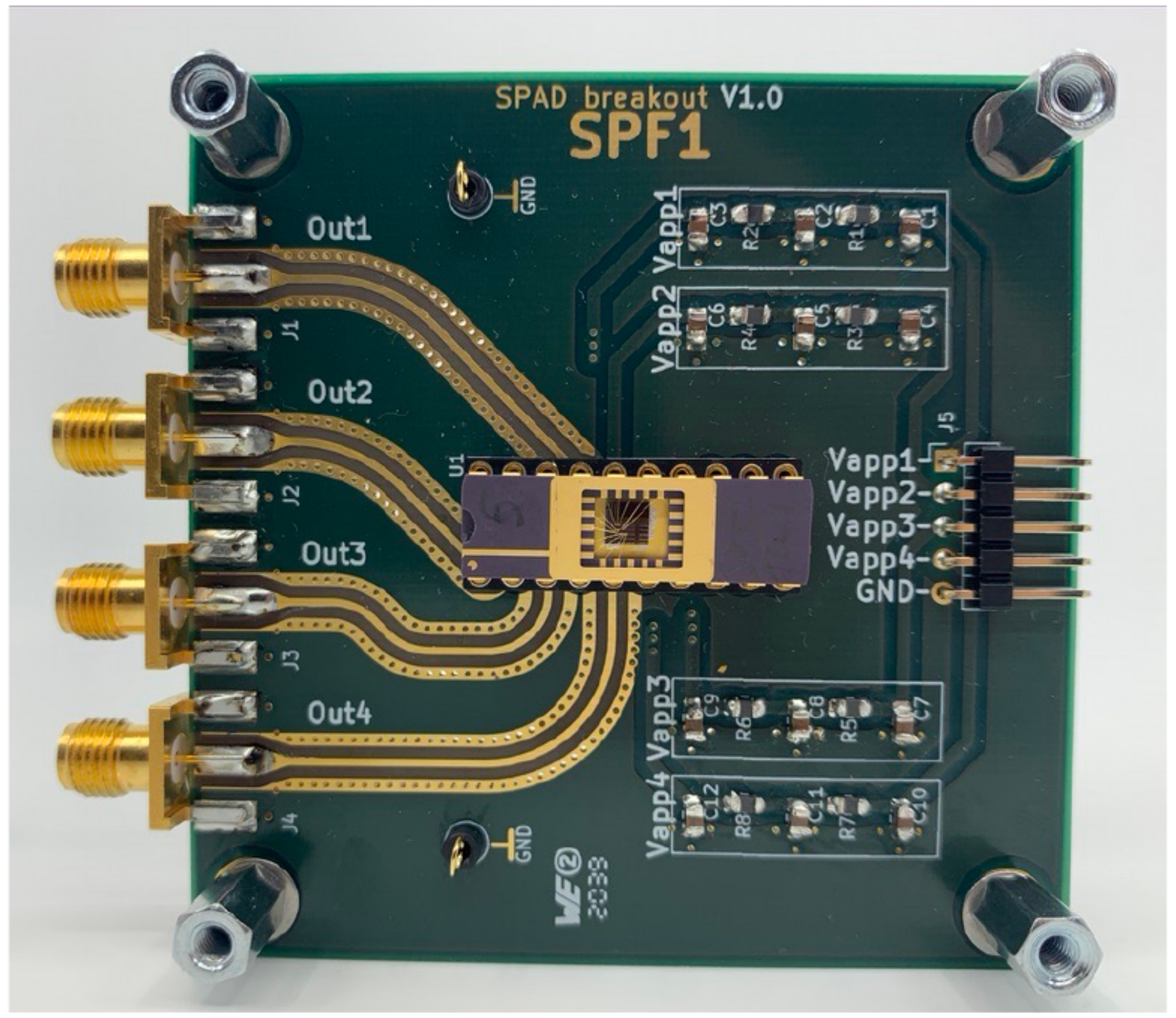
- mechanics for operation in beam pipe
  - establish compatible with LHC beam
- minimisation of material in the active volume
  - micro-channel cooling

Unique and relevant technologies

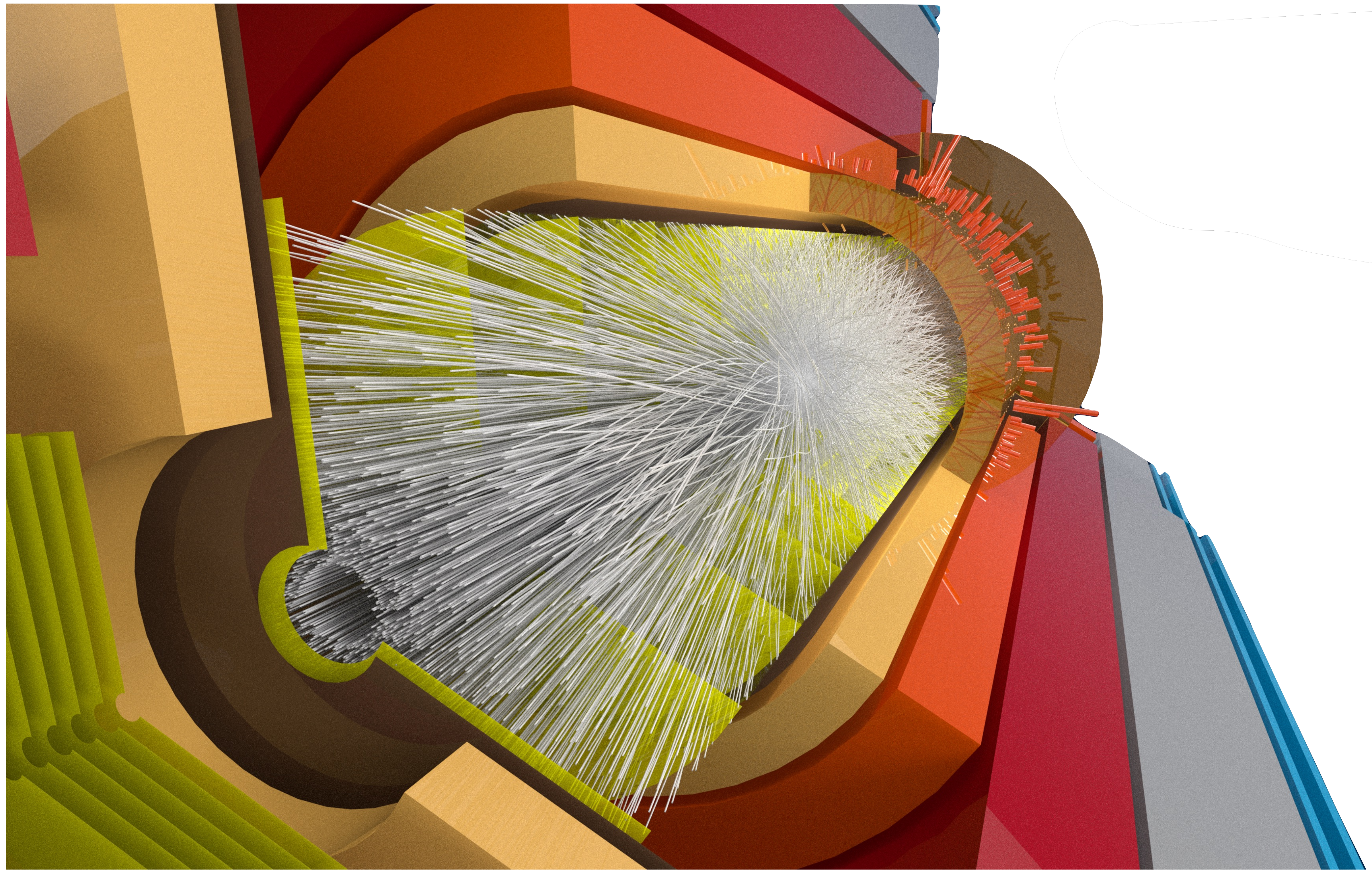
→ Synergies with LHC, FAIR, EIC, ...

R&D has already started!





Summary and conclusions



ALICE 3 will unravel the QGP dynamics

- Evolution of thermal properties of the QGP
- Chiral symmetry restoration
- Hadronisation and nature of hadronic states
- Exotic states and charmed nuclei

Innovative detector concept

- focusing on **silicon technology**
- building on experience pioneered in ALICE upgrades
- requiring R&D activities in several strategic areas
- **R&D already started!**

6 years of running with ALICE 3

Heavy ions: 1 month/year

35 nb^{-1} for Pb-Pb

Under study:

$\rightarrow$ lighter species for higher luminosity

pp at $\sqrt{s}$ = 14 TeV:

3 fb^{-1} / year $\rightarrow \times 100$ compared to Run 3+4

Thank you

Observables and requirements

Goal observables

Dileptons (p_T~0.1- 3 GeV/c, M_{ee} ~0.1-4 GeV/c^2)
- vertexing, tracking, lepton ID

Photons (100 MeV/c - 50 GeV/c, wide η range)
- electromagnetic calorimetry

Heavy-flavour hadrons ($p_T \rightarrow 0$, wide η range)
- vertexing, tracking, hadron ID

Quarkonia and Exotica ($p_T \rightarrow 0$)
- muon ID

Jets
- tracking and calorimetry, hadron ID

Ultrasoft photons (p_T = 1 - 50 MeV/c)
- dedicated forward detector

Nuclei and exotica
- identification of z > 1 particles

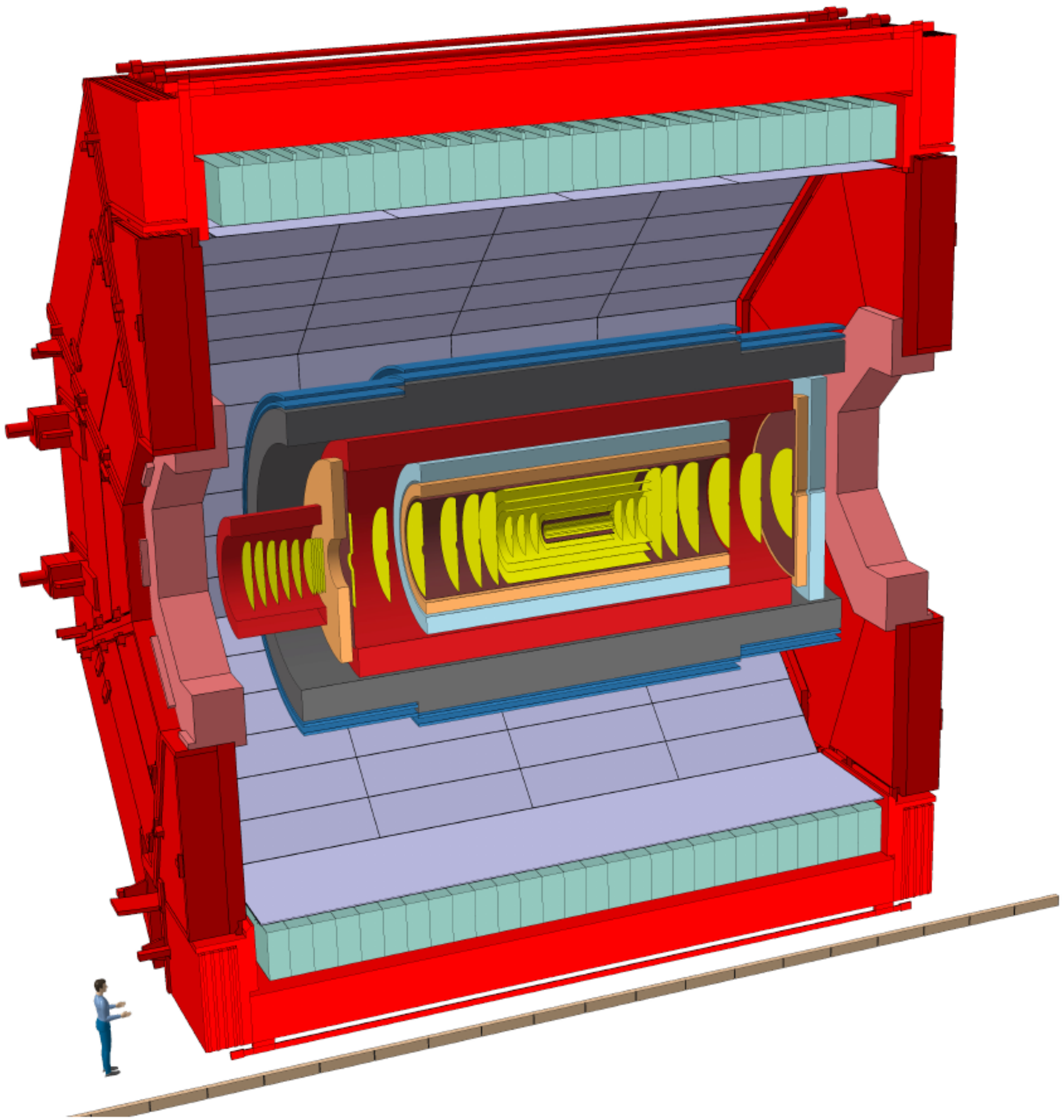
Key requirements

- Good tracking down to p_T = 0
- Low-mass detector
- Excellent pointing resolution
- Excellent particle identication
- Large acceptance
- High rates, large data samples

Performance summary

Component	Observables	$\lvert\eta\rvert$ < 1.75 (barrel)	1.75 < $\lvert\eta\rvert$ < 4 (forward)	Detectors
Vertexing	Multi-charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{DCA} \approx$ 10 μm at 200 MeV/c	Best possible DCA resolution, $\sigma_{DCA} \approx$ 30 μm at 200 MeV/c	Retractable silicon pixel tracker: $\sigma_{pos} \approx$ 2.5 μm, $R_{in} \approx$ 5 mm, $X/X_0 \approx$ 0.1 % for first layer
Tracking	Multi-charm baryons, dielectrons	σ_{p_T} / p_T ~1-2 %		Silicon pixel tracker: $\sigma_{pos} \approx$ 10 μm, $R_{out} \approx$ 80 cm, $X/X_0 \approx$ 1 % / layer
Hadron ID	Multi-charm baryons	π/K/p separation up to a few GeV/c		Time of flight: $\sigma_{tof} \approx$ 20 ps RICH: aerogel, $\sigma_\theta \approx$ 1.5 mrad
Electron ID	Dielectrons, quarkonia, χ_{c1}(3872)	pion rejection by 1000x up to ~2 - 3 GeV/c		Time of flight: $\sigma_{tof} \approx$ 20 ps RICH: aerogel, $\sigma_\theta \approx$ 1.5 mrad possibly preshower detector
Muon ID	Quarkonia, χ_{c1}(3872)	reconstruction of J/Ψ at rest, i.e. muons from 1.5 GeV/c		steel absorber: L ≈ 70 cm muon detectors
Electromagnetic calorimetry	Photons, jets	large acceptance		Pb-Sci calorimeter
	χ_c	high-resolution segment		$PbWO_4$ calorimeter
Ultrasoft photon detection	Ultra-soft photons		measurement of photons in p_T range 1 - 50 MeV/c	Forward Conversion Tracker based on silicon pixel sensors

Installation at LHC



Installation of ALICE 3 around nominal IP2

L3 magnet can remain, ALICE 3 to be installed inside

Cryostat of ~8 m length, free bore radius 1.5 m, magnetic field configuration to be optimized

Running scenario:

6 running years with 1 month / year with heavy-ions

- 35 nb^{-1} for Pb—Pb x 2.5 compared to Run 3 + 4
- Lighter species for higher luminosity under study

pp at s = 14 TeV:

- 3 fb^{-1} / year x 100 compared to Run 3 + 4