A next-generation of the heavy-ion experiment for the LHC: ALICE 3

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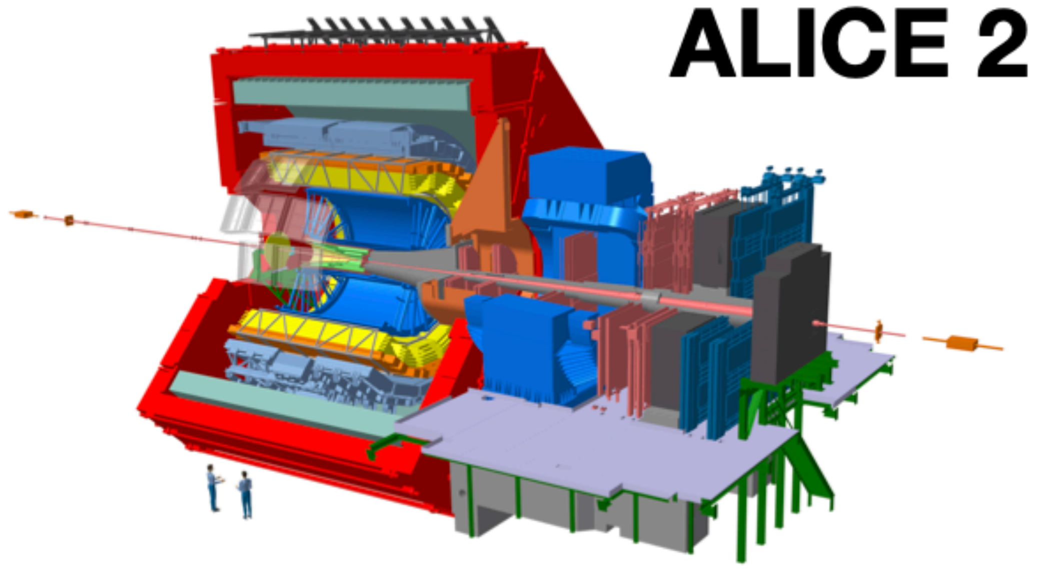
for the ALICE Collaboration
Inha University

APCTP Workshop on the Physics of Electron Ion Collider, Nov. 4. 2022

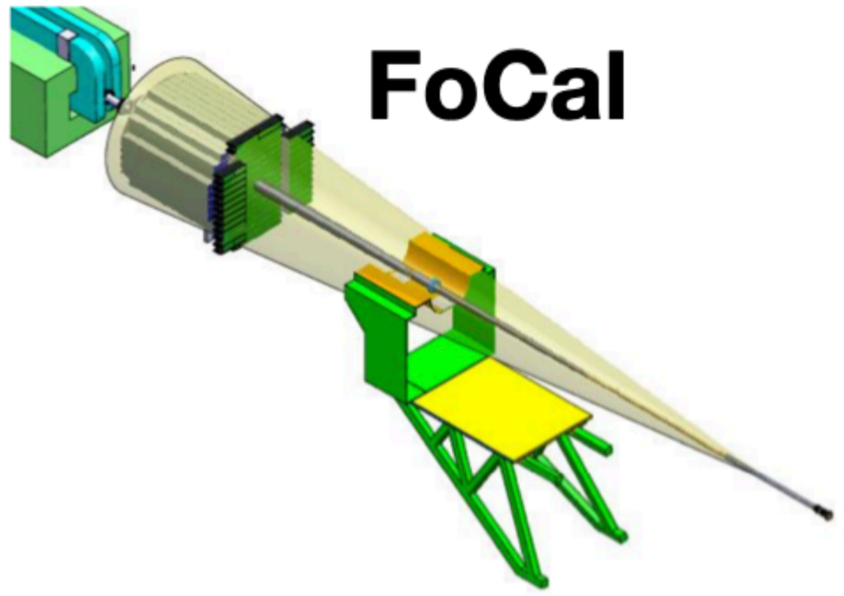
Milestons of the ALICE upgrade

High luminosity for ions | High luminosity LHC | Higher luminosity for ions

ALICE 2

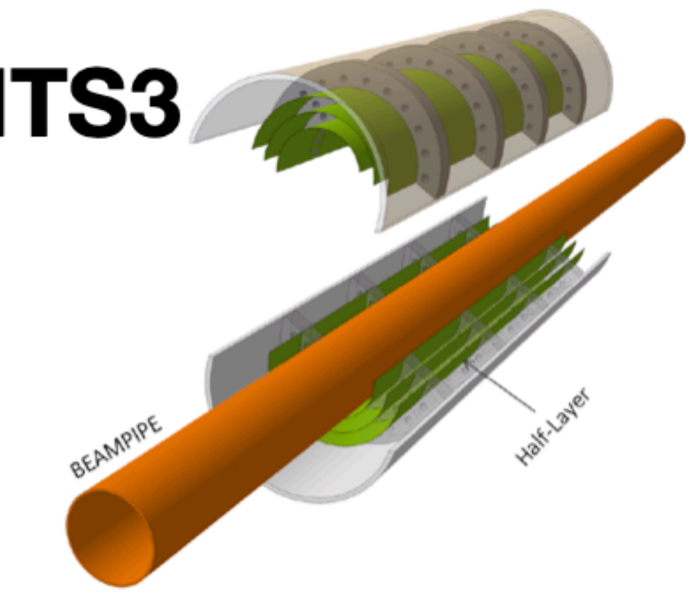


FoCal



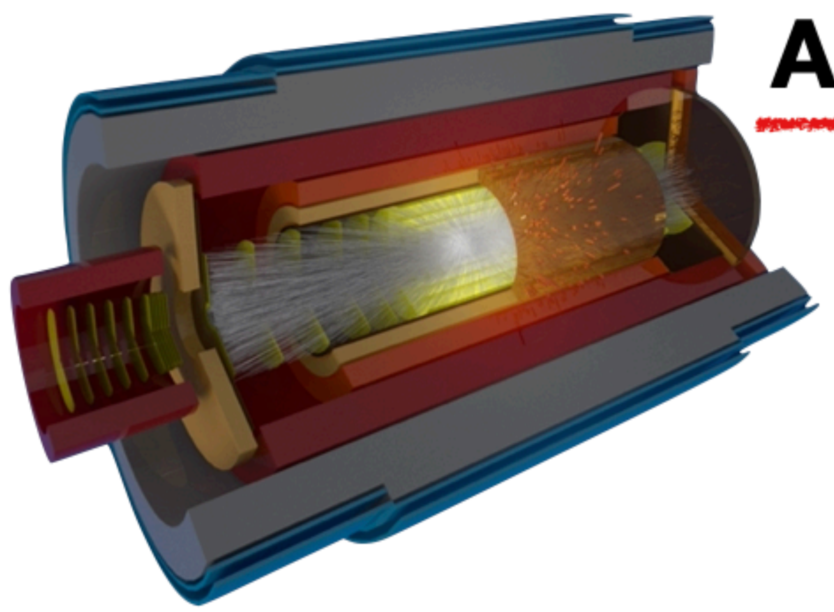
CERN-LHCC-2020-009

ITS3



CERN-LHCC-2019-018

ALICE 3



CERN-LHCC-2022-009

Beyond Run 4

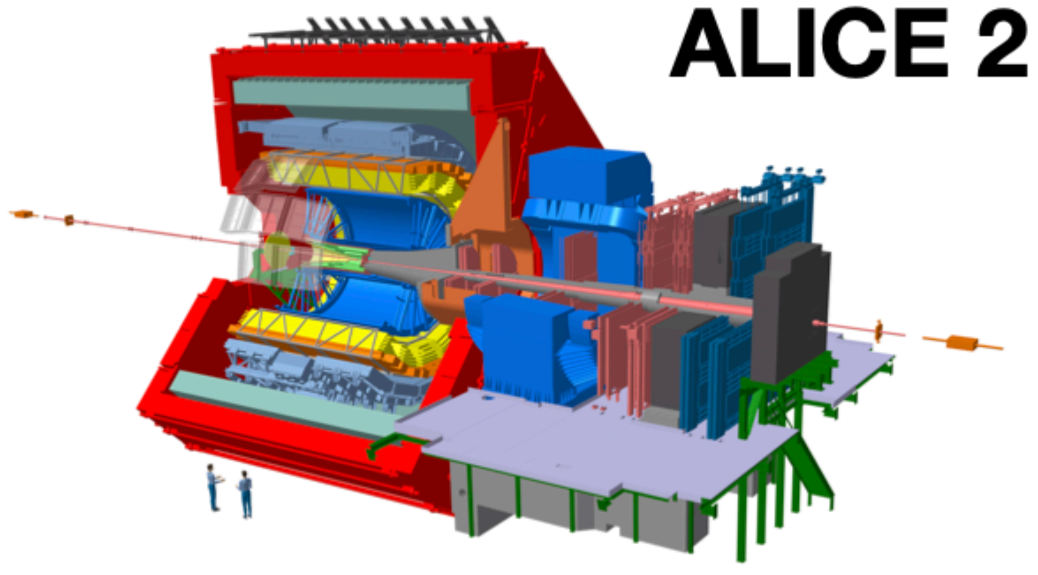
Address fundamental questions will remain still open:

- Fundamental QGP properties driving its constituents to equilibration
- Hadronisation mechanisms of the QGP
- Partonic equation of state and its temperature dependence
- Underlying dynamics of chiral symmetry restoration

Milestons of the ALICE upgrade

High luminosity for ions | High luminosity LHC | Higher luminosity for ions

ALICE 2



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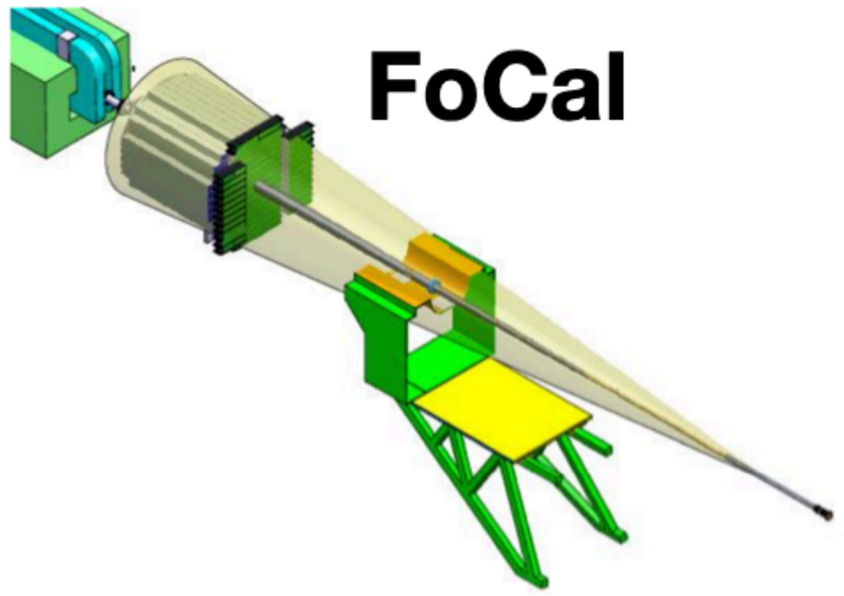

CERN-LHCC-2020-009

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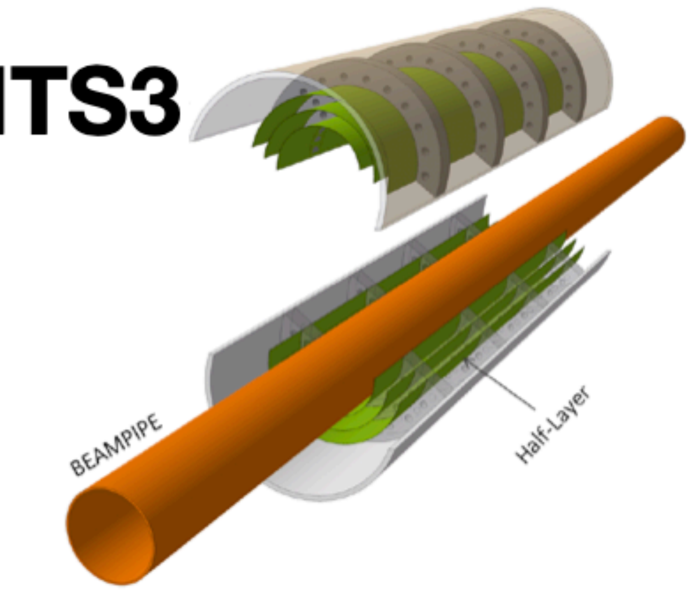

CERN-LHCC-2019-018

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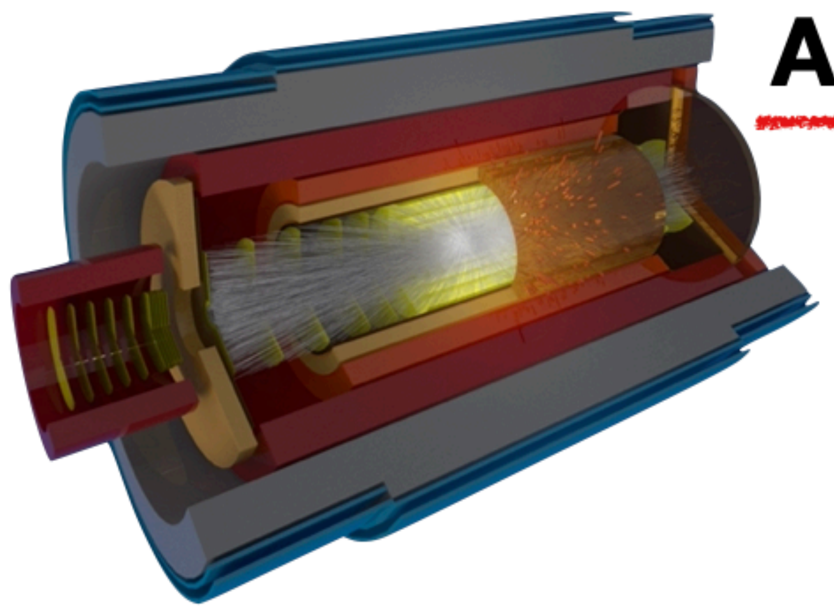


CERN-LHCC-2022-009

Beyond Run 4

Address fundamental questions will remain still open:

ALICE 3!

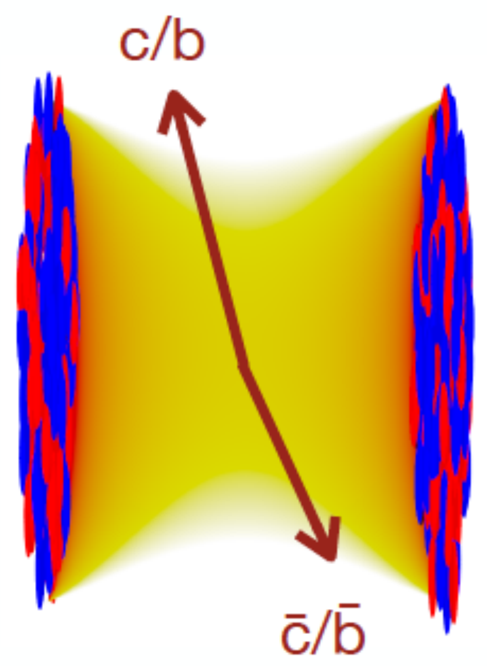
→ Next-generation heavy-ion experiment - First ideas at Heavy-Ion town meeting 2018 (arXiv:1902.01211)

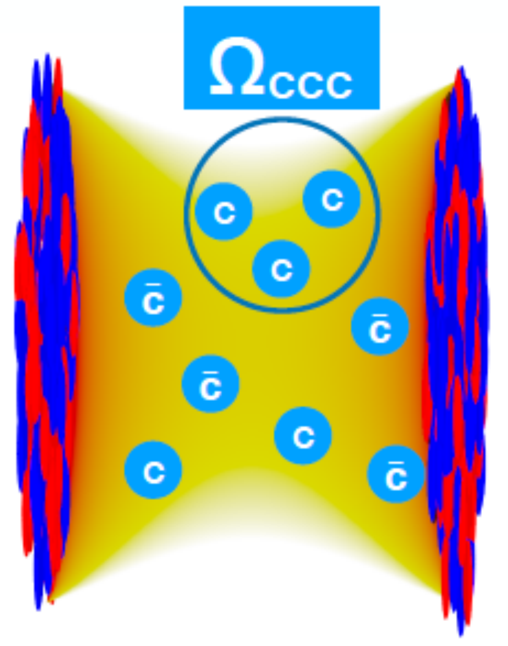
→ Letter of Intent for ALICE 3:
Review concluded with very positive feedback by the LHCC in March 2022, recommendation to proceed with R&D (CERN-LHCC-2022-009)

Physics for ALICE 3

Systematic measurements of (multi-)heavy-flavoured hadrons down to low p_T

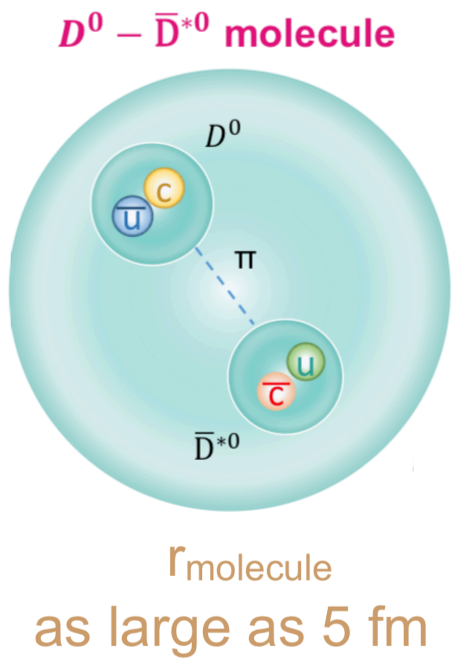
- Transport properties in the QGP down to thermal scale
- Mechanisms of hadronisation from the QGP





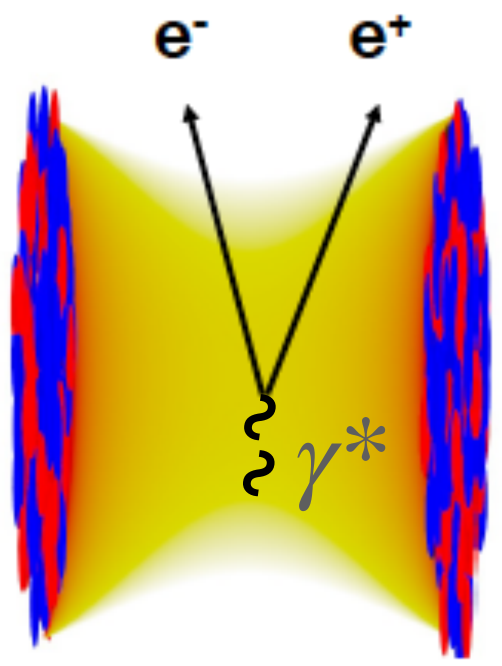
Hadron interaction and fluctuation measurements

- Existence and nature of heavy-quark exotic bound states and interaction potential
- Search for super-nuclei (light nuclei with c)
- Search for critical behaviour in event-by-event fluctuations of conserved charges



Precision differential measurements of dileptons

- Evolution of the quark-gluon plasma
- Mechanisms of chiral symmetry restoration in the QGP



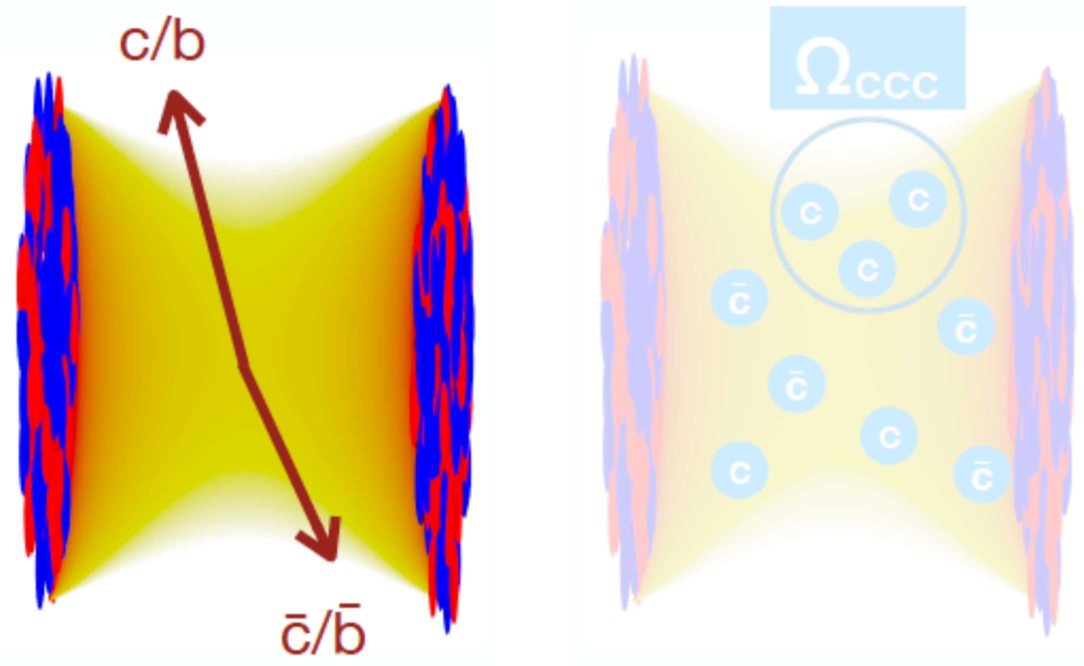
Many more…

Physics for ALICE 3

Systematic measurements of (multi-)heavy-flavoured hadrons down to low p_T

Heavy quark transport

- [illegible] scale
- Mechanisms of hadronisation from the QGP



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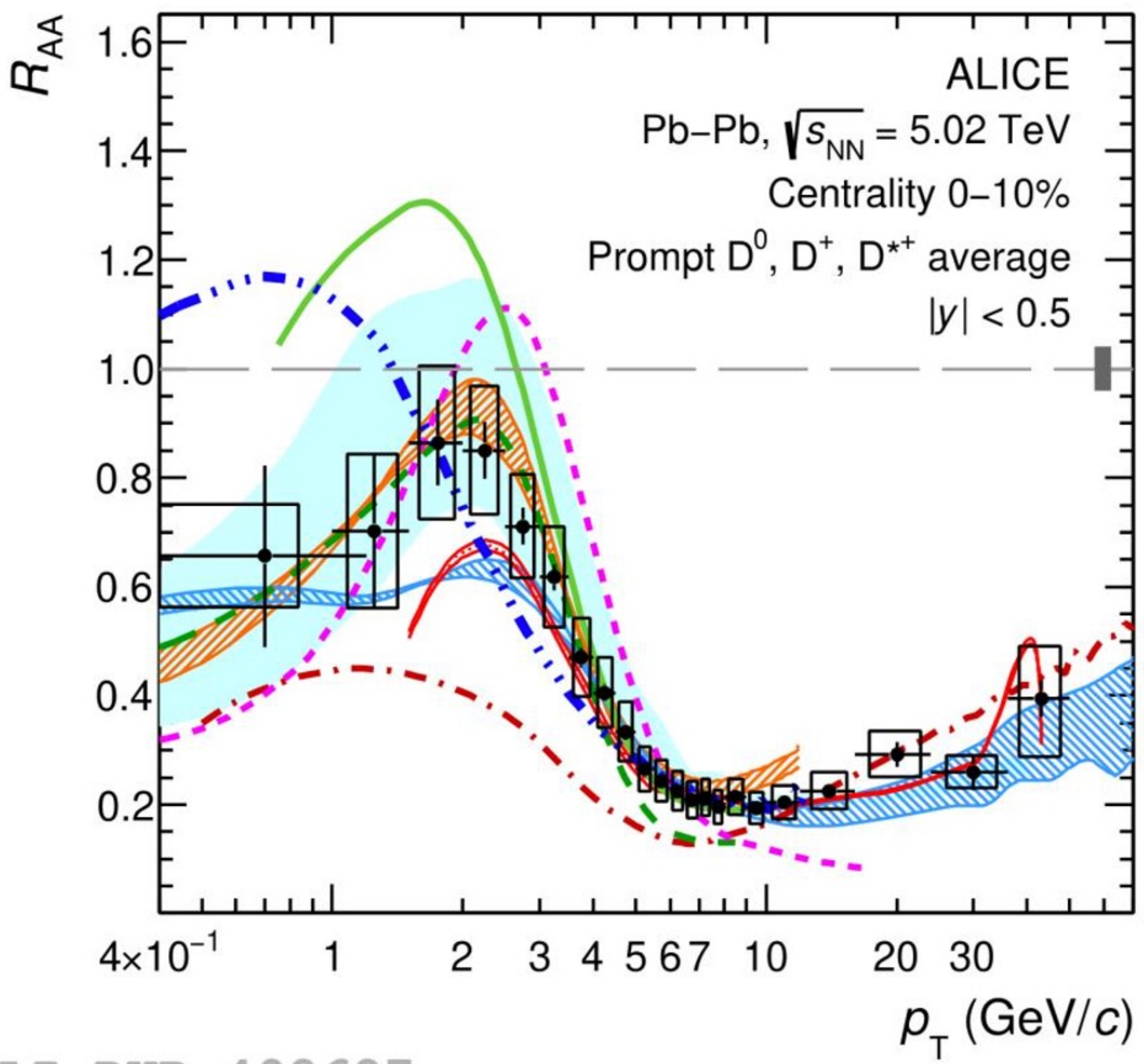
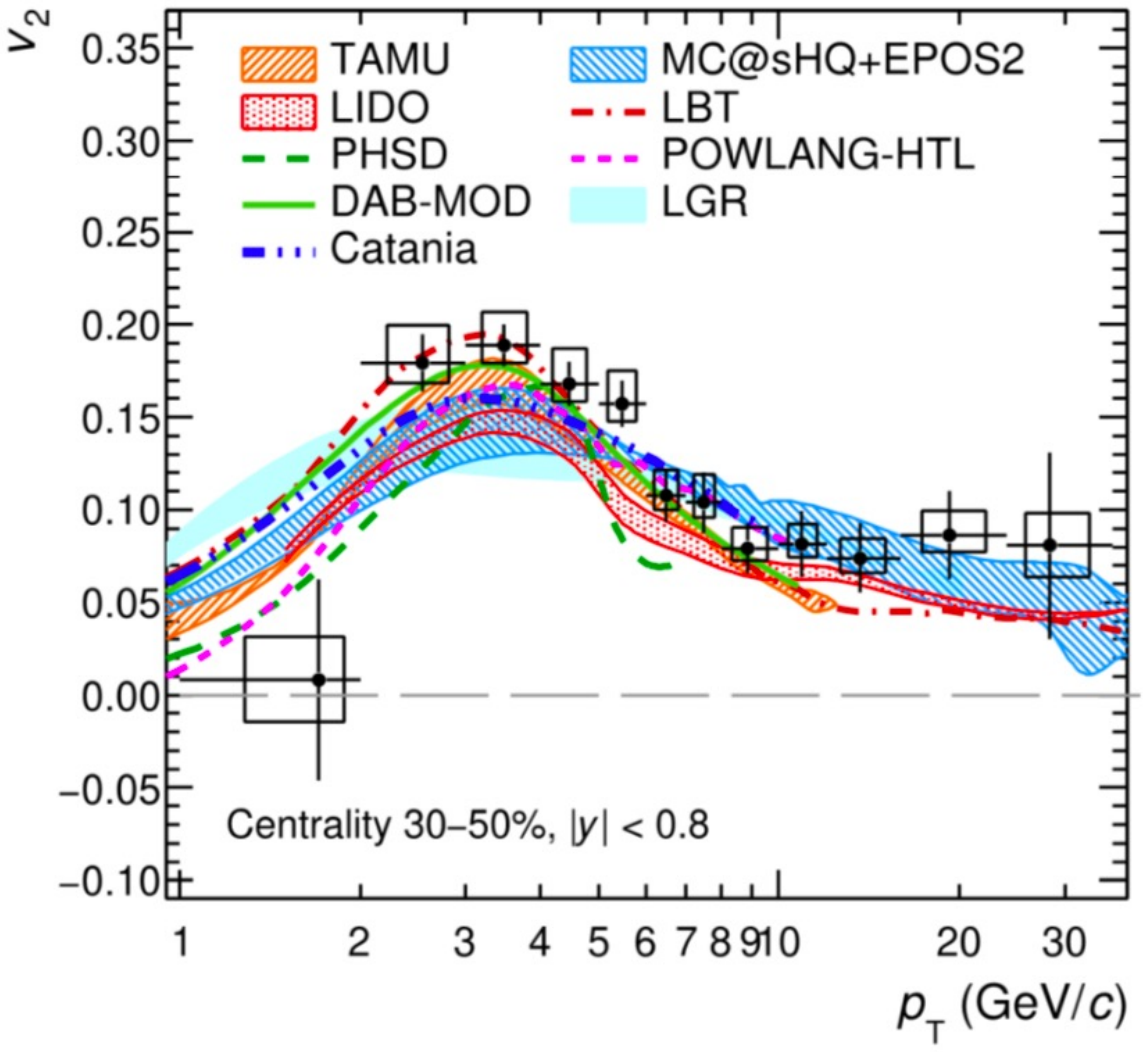
Many more…

Charm quark transport

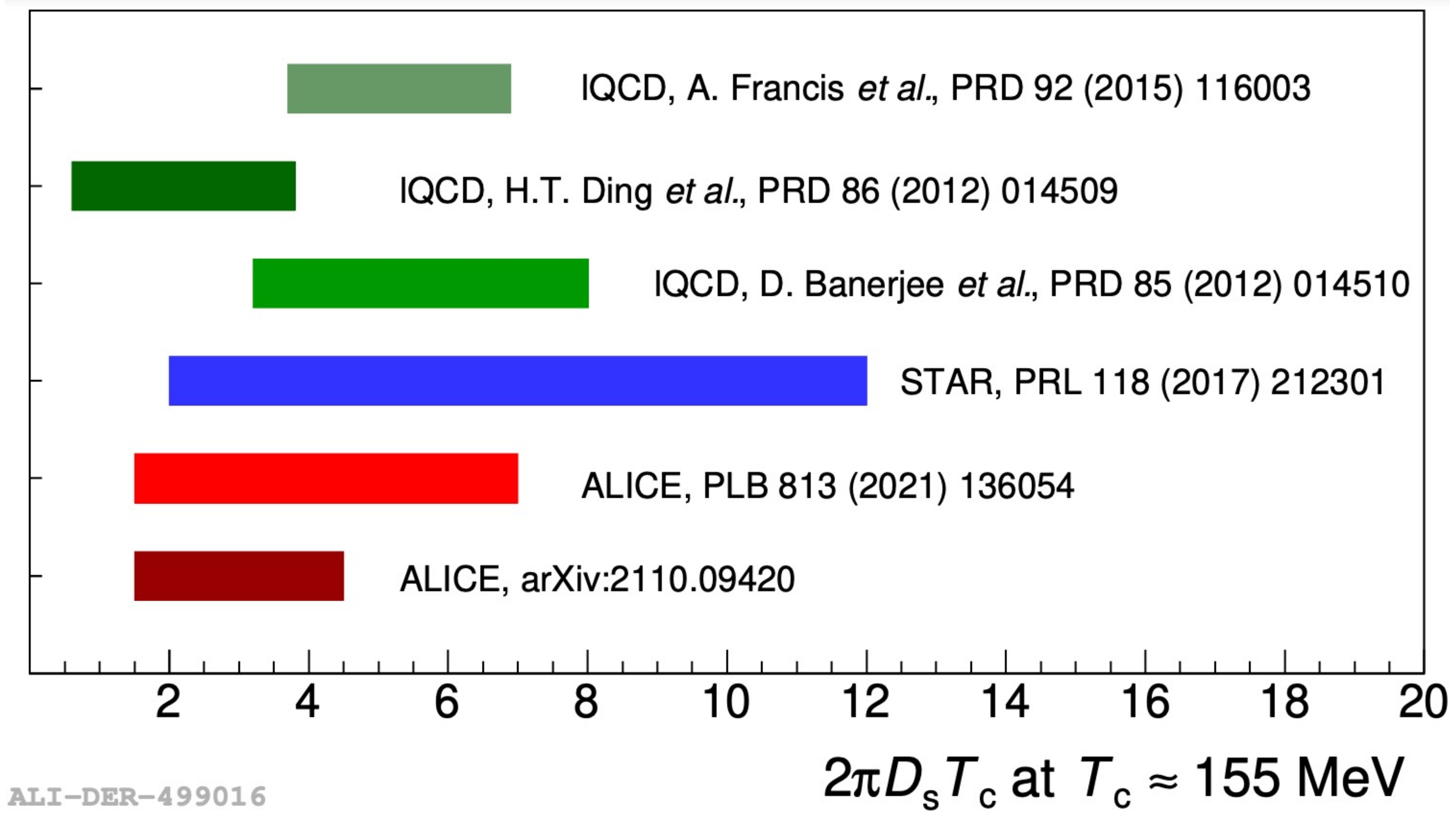
Run 1+2



ALI-PUB-498687



ALICE, JHEP 01 (2022) 174
ALICE, PLB 813 (2021) 136054



Data-to-model agreement: TAMU, MC@sHQ, LIDO, LGR, and Catania "selected"

Heavy quark propagating in the QGP interact with medium constituents

- Lose energy via elastic collisions and radiative processes

Low p_T heavy flavour interaction described by transport models in terms of diffusion coefficient (D_s)

- Multiple elastic scatterings in the QGP → "Brownian motion"

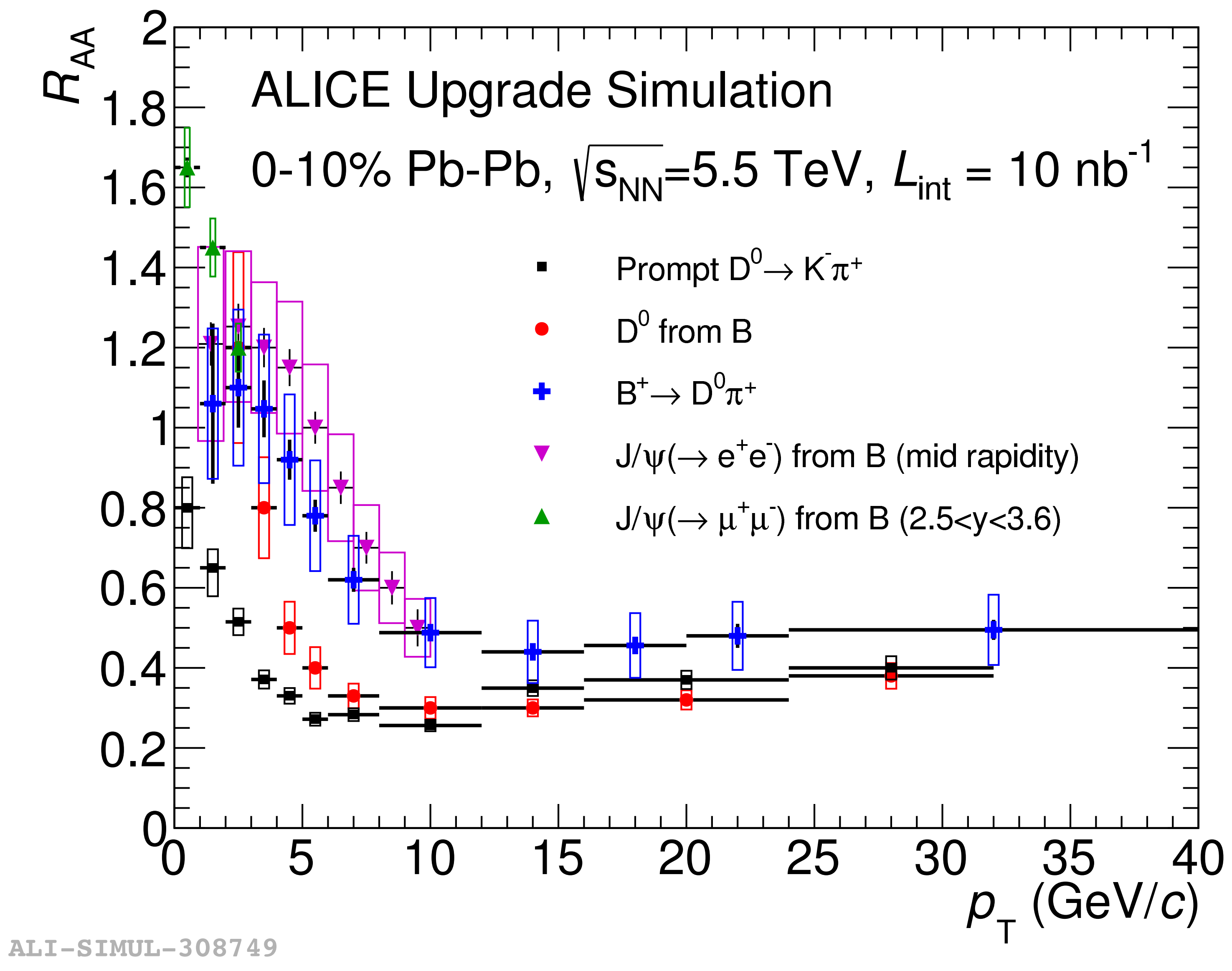
D^0 measured down to zero p_T (first time in Pb-Pb at the LHC)

- R_{AA} and v_2 measurements down to low p_T → **constrain diffusion coefficients D_s**
- **1.5 < $2\pi D_s T_c$ < 4.5 → direct access to heavy flavour relaxation time: τ_{charm} ~ 3-8 fm/c**

Relaxation time

$$\tau_Q = (m_Q/T) D_s$$

Determining transport properties with precision

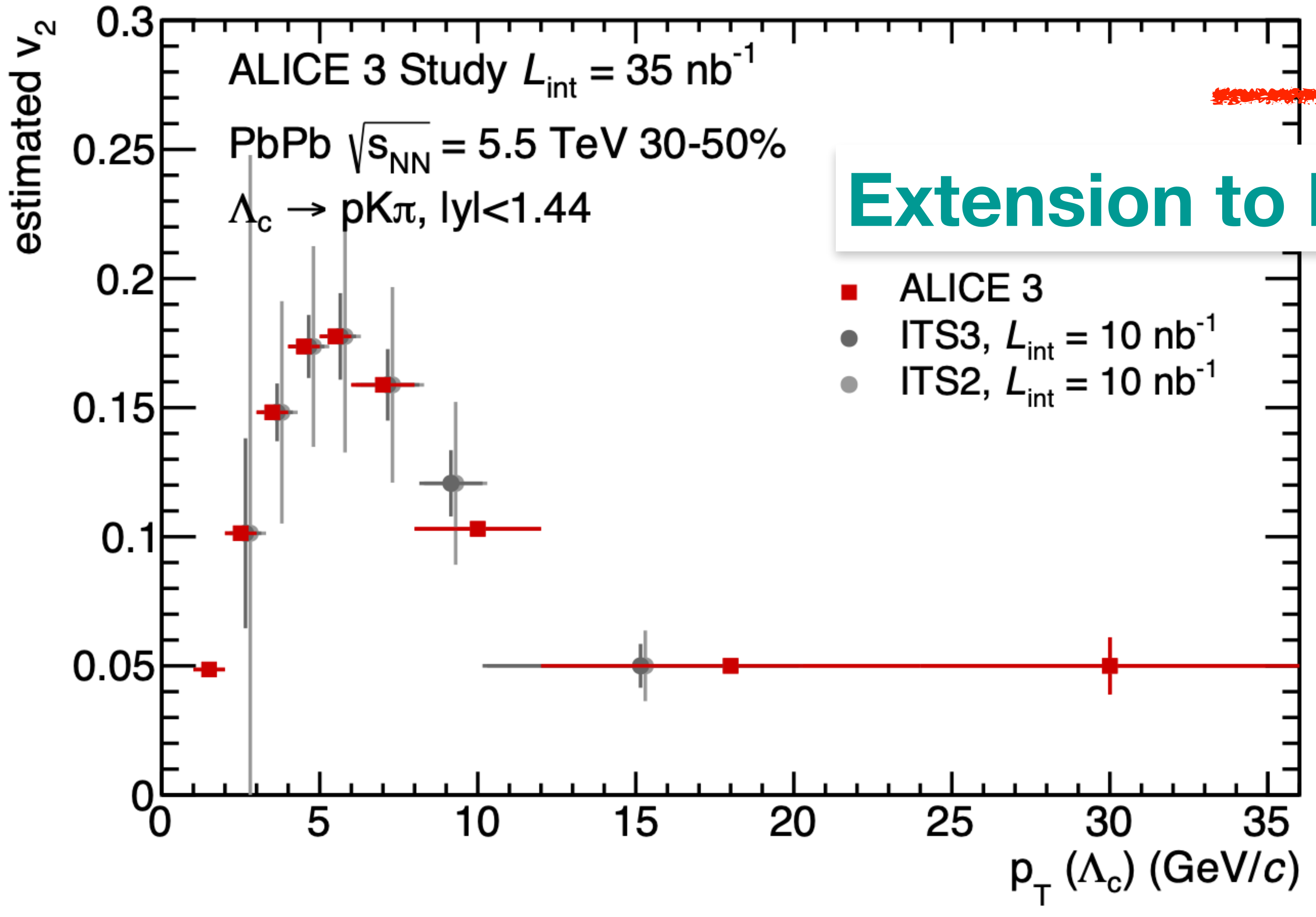


Run 3+4 & Run 5

Run 3+4 (w/ ITS2, 3): beauty measurements down to low p_T including heavy flavor baryons

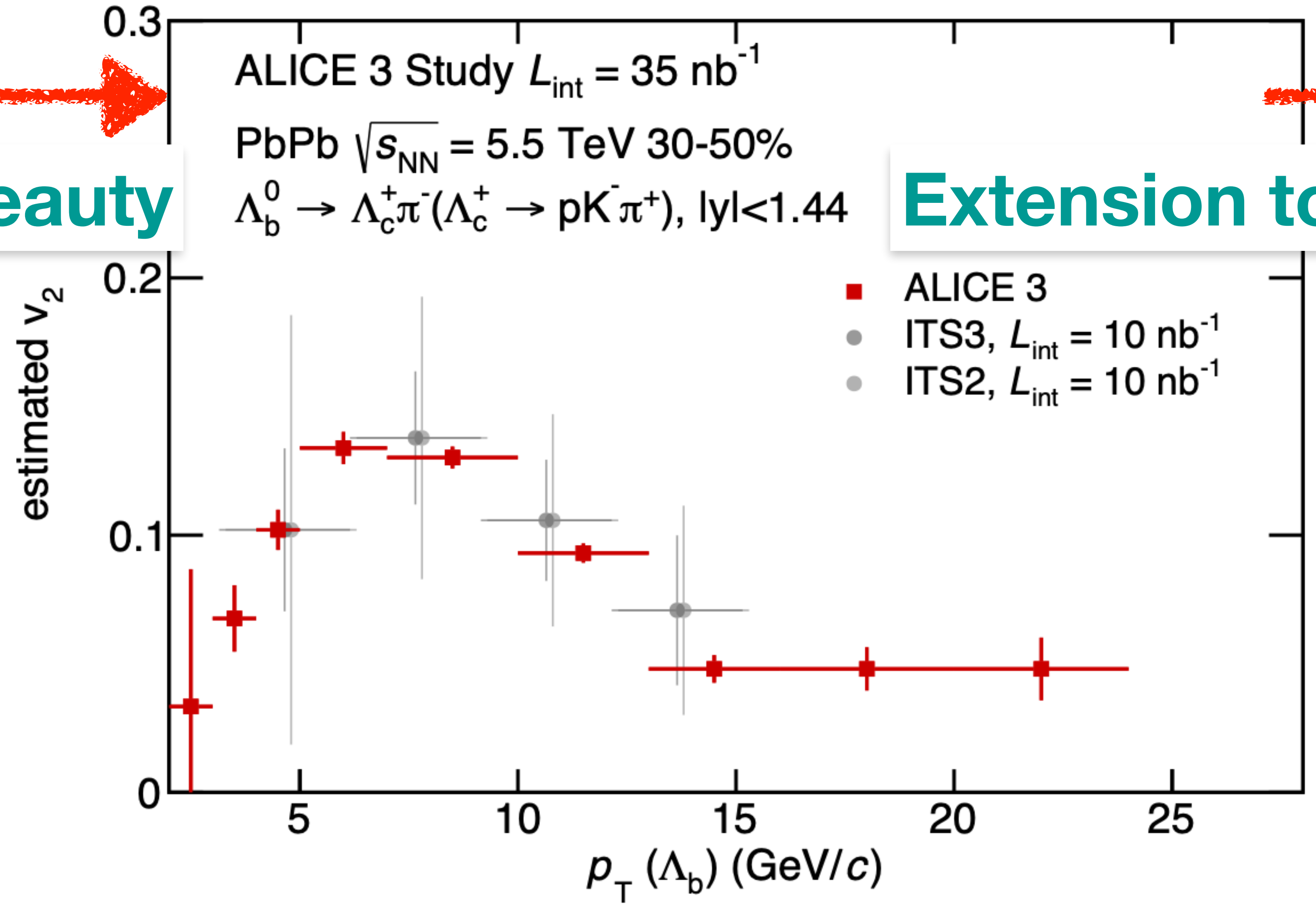
Need ALICE 3 performance (pointing resolution, acceptance) for precision measurement of e.g. Λ_c, Λ_b , and multi-charm v_2

Λ_c v_2 performance



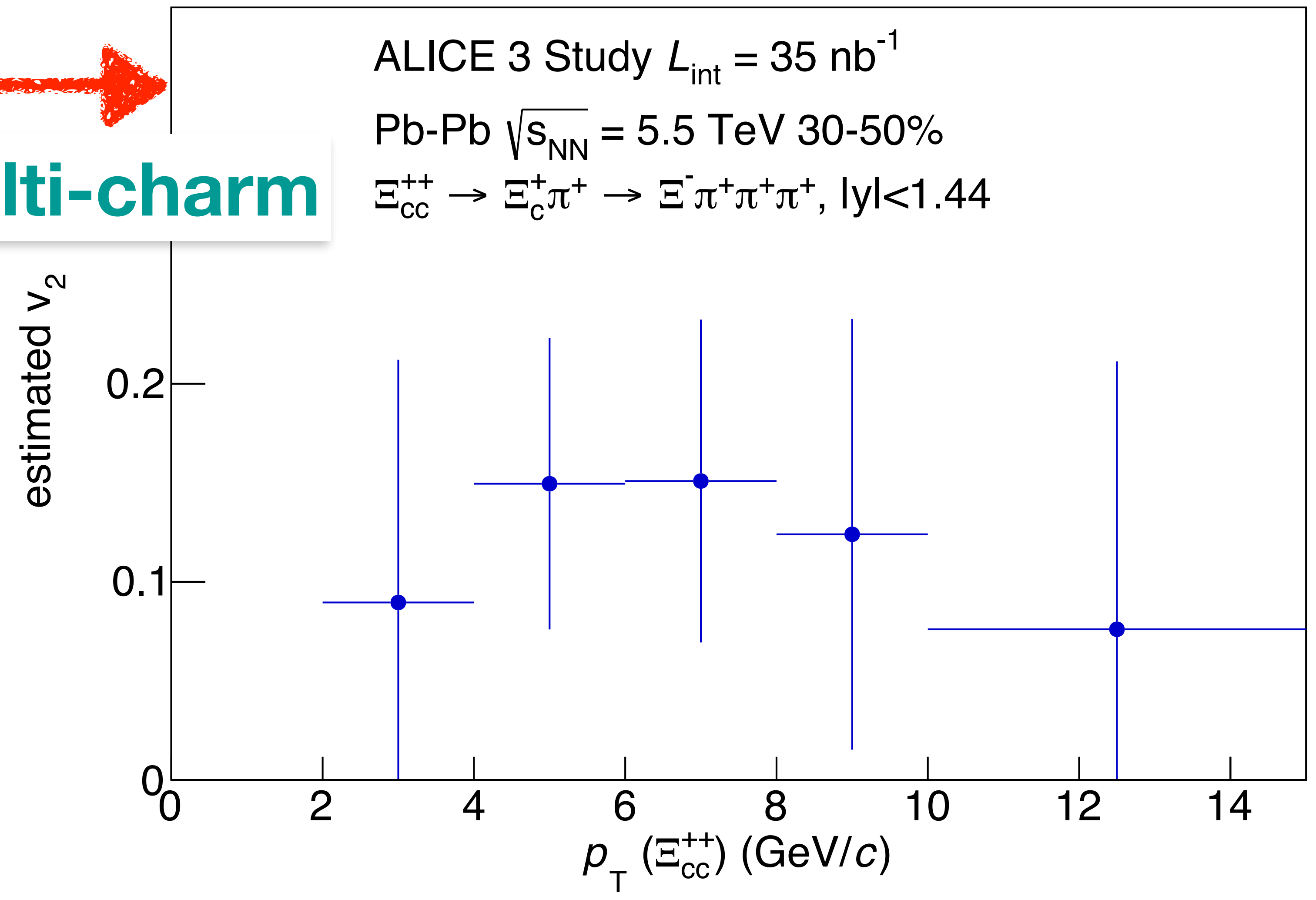
Extension to beauty

Λ_b v_2 performance



Extension to multi-charm

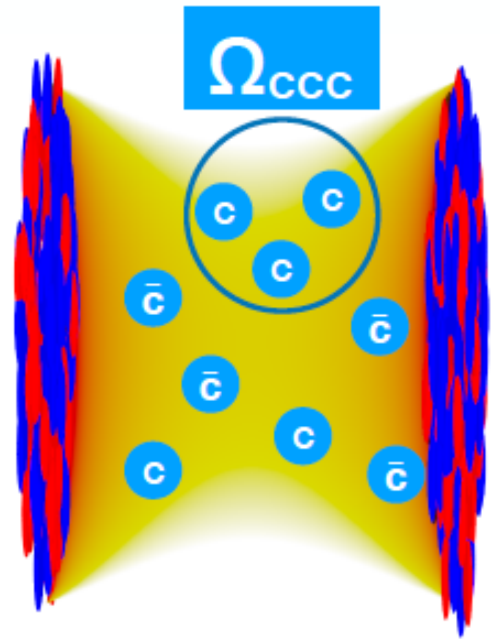
Ξ_{cc}^{++} v_2 performance



Physics for ALICE 3

Systematic measurements of (multi-)heavy-flavoured hadrons down to low p_T

- Transport properties in the QGP down to thermal scale
- **Charm hadronization**



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Precision differential measurements of dileptons

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- Mechanisms of chiral symmetry restoration in the QGP

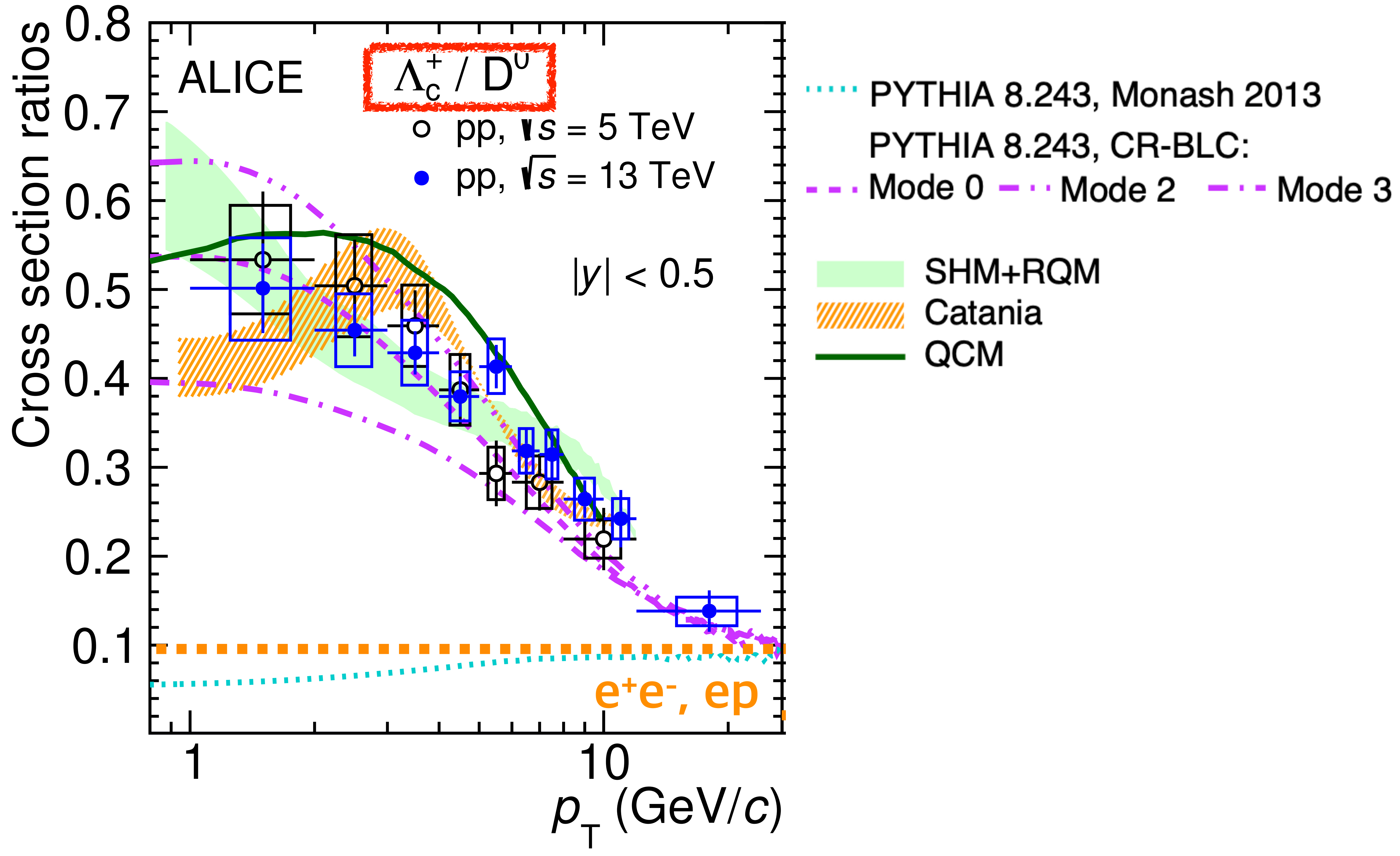
Many more…

Charm hadronization

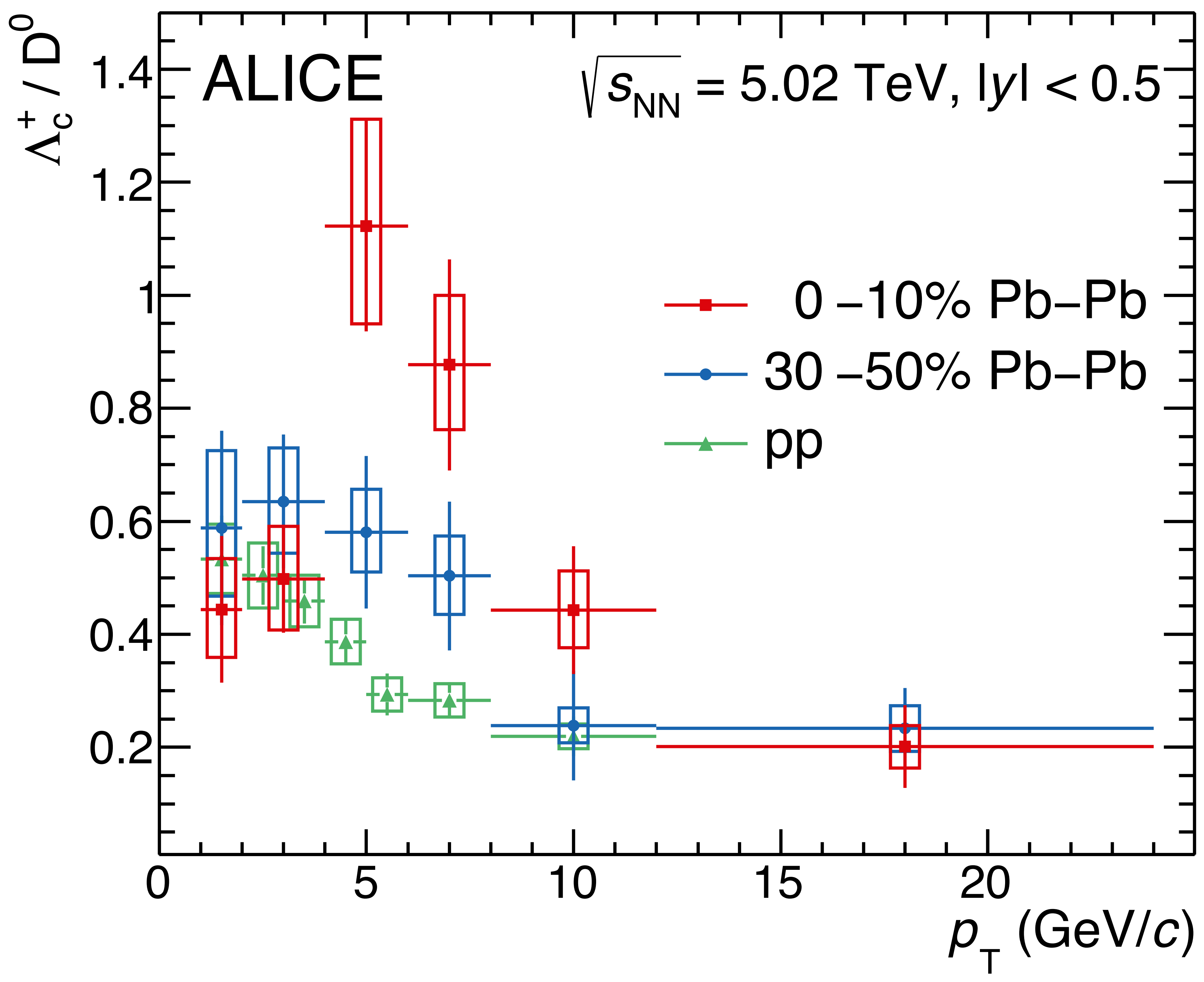
Run 1+2

ALICE

PRL 128 (2022) 012001



arXiv:2112.08156



Enhancement at low p_T w.r.t to e^+e^-, ep collisions

- Universality of charm fragmentation among different collision system broken?

Well described by SHM+RQM, Catania and QCM

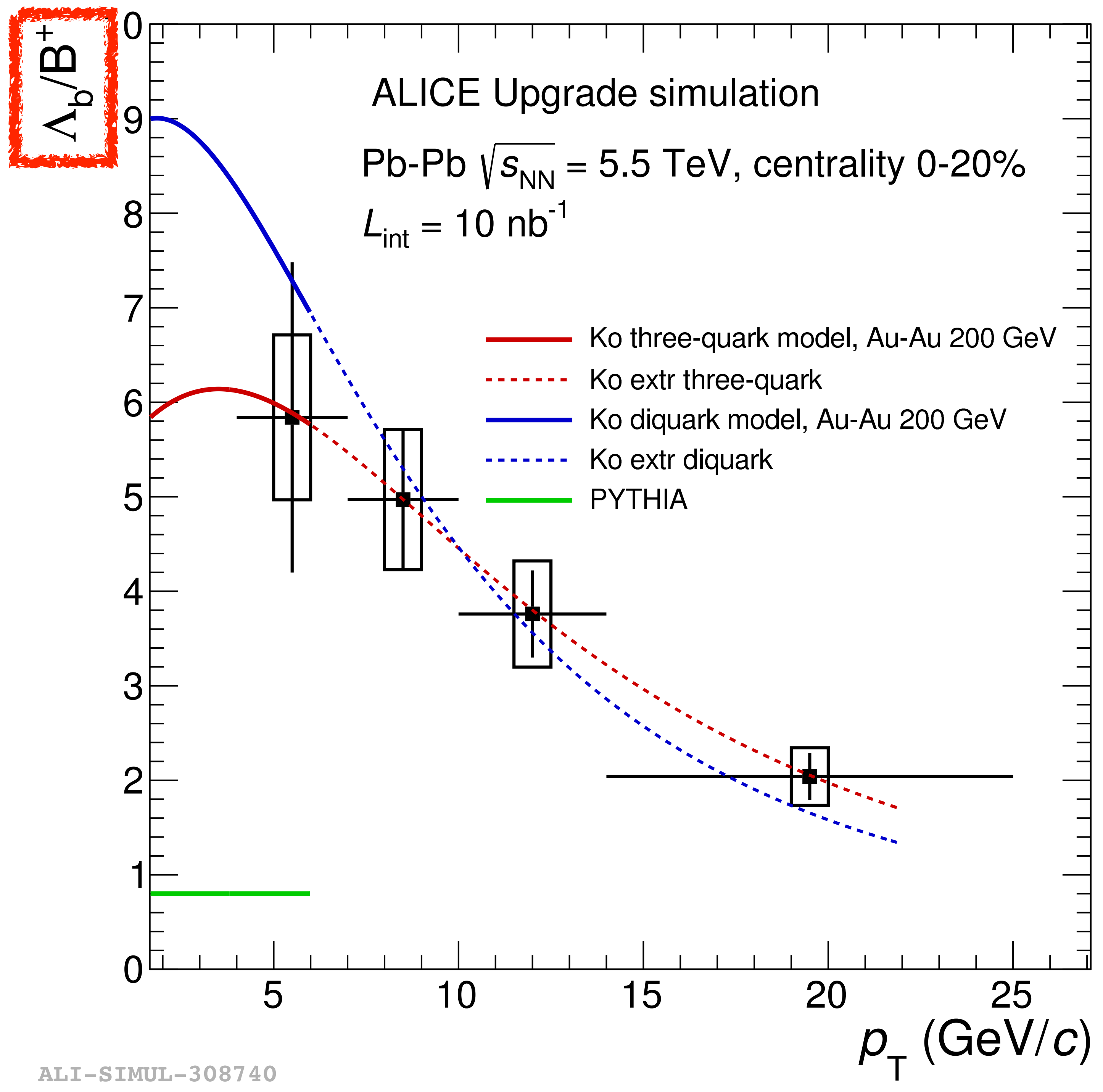
Additional dynamics in central Pb-Pb collisions: Λ_c/D_0 enhancement at intermediate p_T

Suggests hadronization by recombination + mass-dependent p_T shift from collective expansion

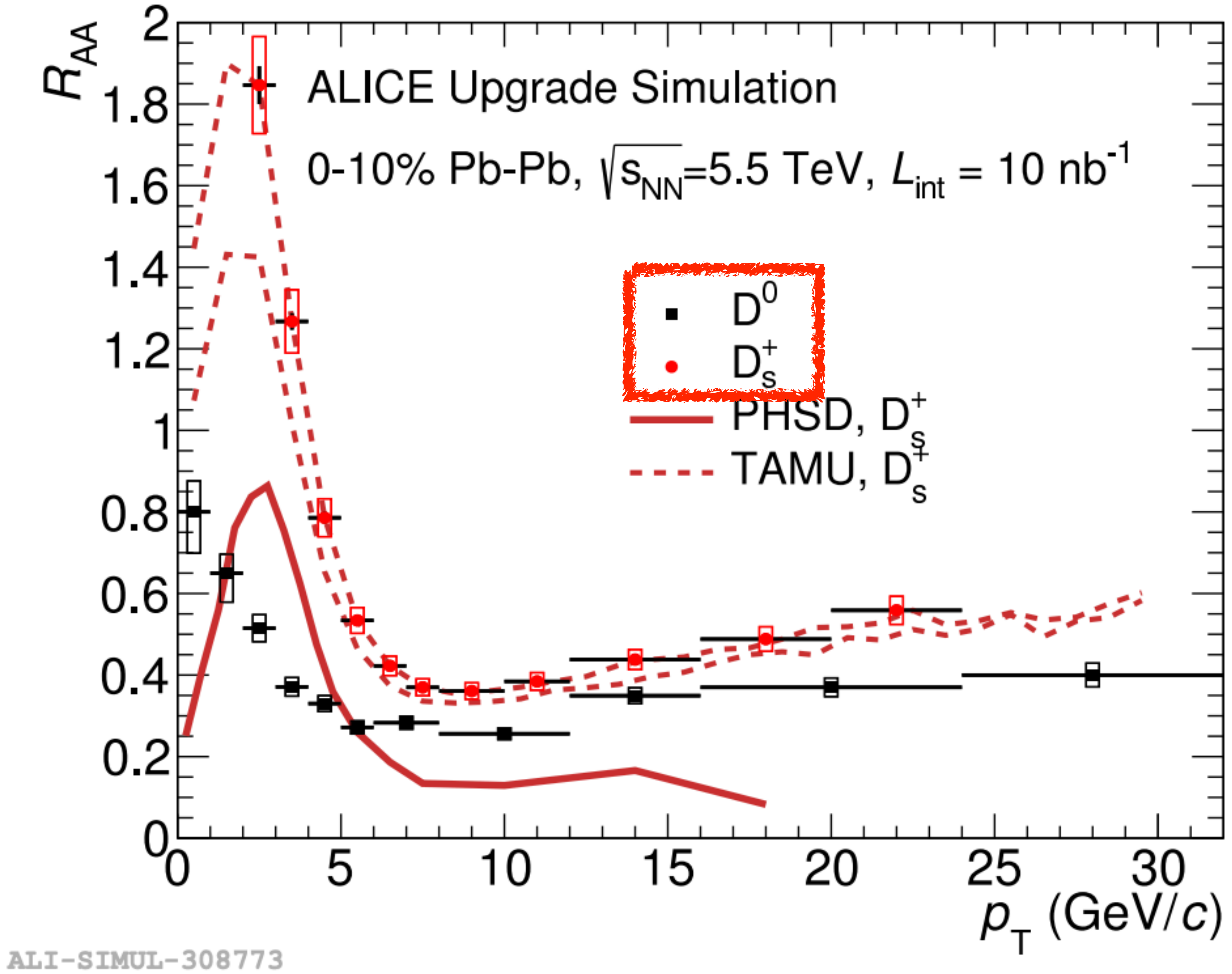
Heavy flavor hadronization

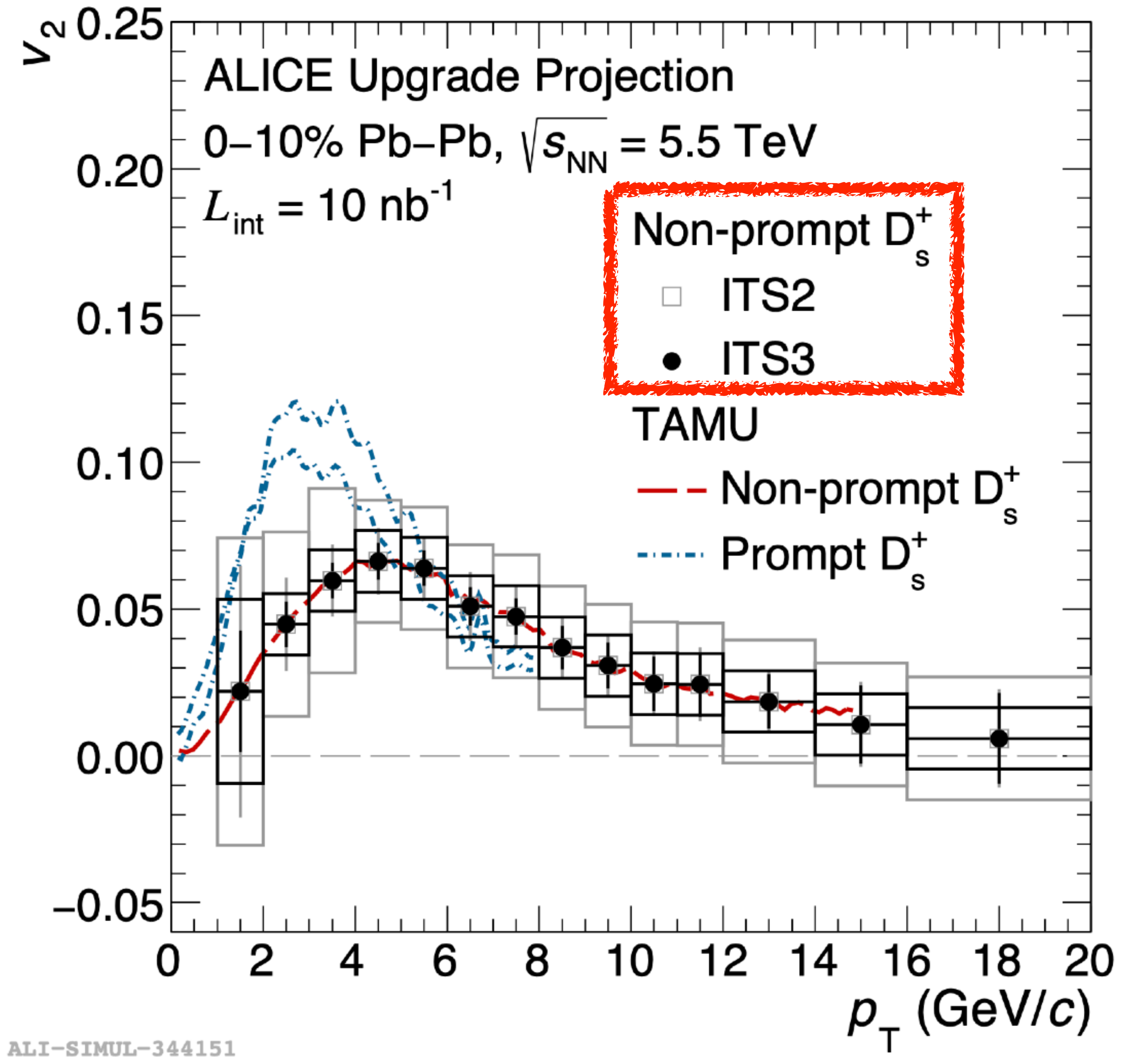
Run 3+4

Baryon/meson ratios: beauty



Heavy-strange hadrons: D_s, non-prompt D_s





Extend heavy flavor measurements to beauty sector, D_s, and baryons

Important input for

- Total heavy-flavor cross sections
- Interplay strangeness enhancement and heavy flavors
- Baryon formation - coalescence

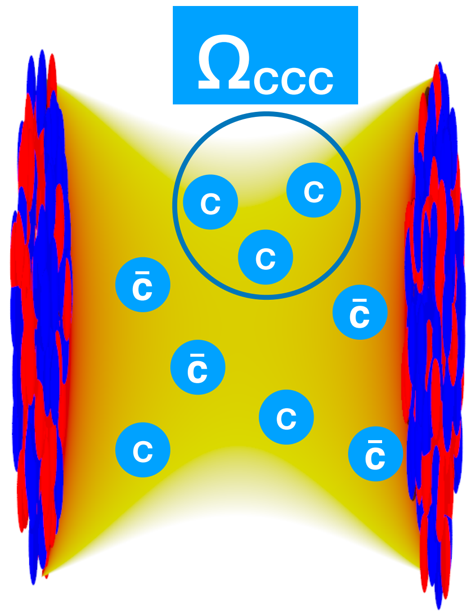
Extend to multi-charm hadrons

Run 5

Test how independently produced quarks form hadrons

→ Measurement of multi-charm hadrons

- Contribution from single parton scattering is very small
- Very large **enhancement** predicted by Statistical hadronization model in Pb-Pb collisions

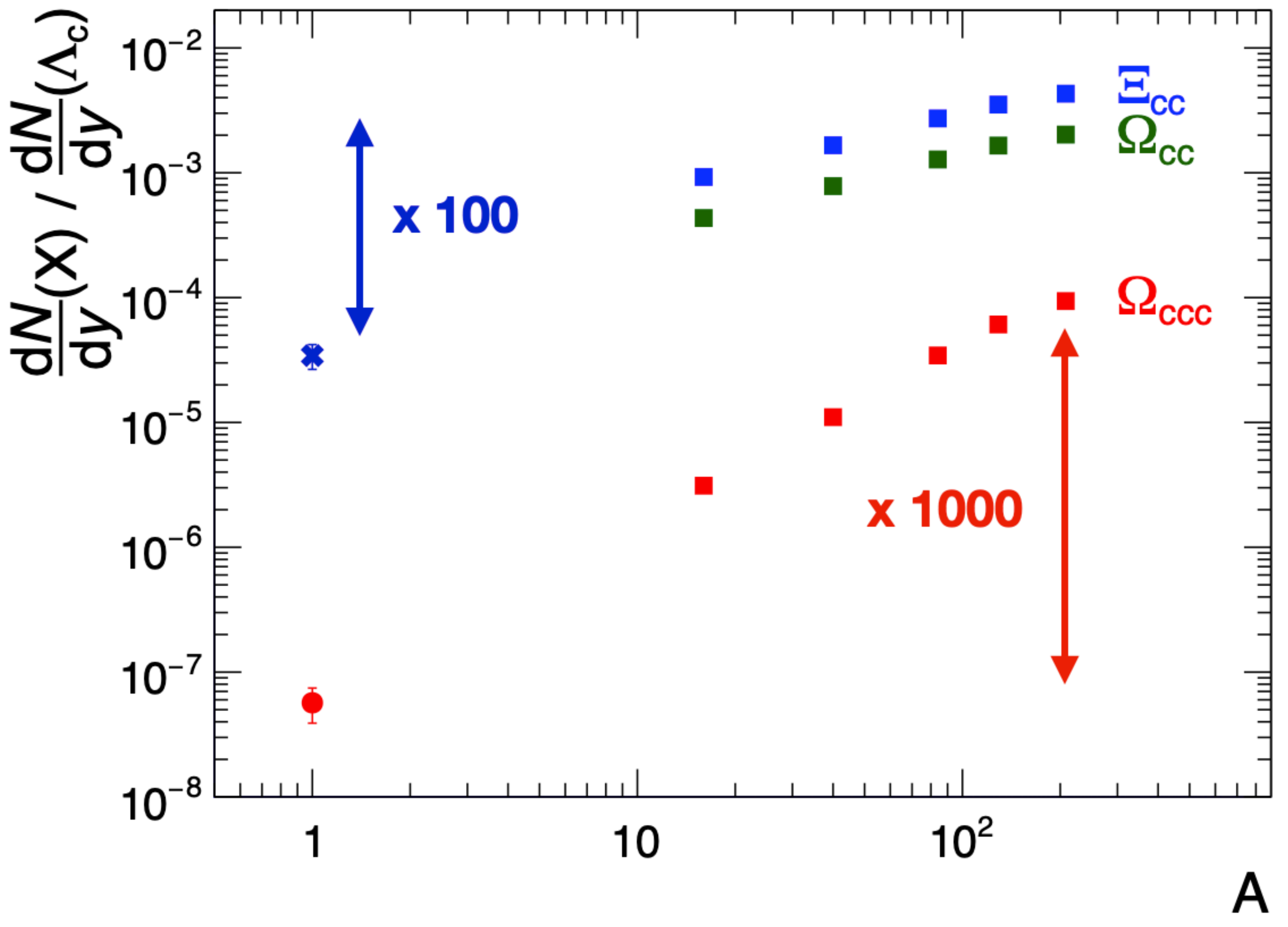


- Progress relies on the **reconstruction** of complex decay chains

Ex) $\Omega^{++}_{ccc} \rightarrow \Xi^{+}_{c} + D^{+}$

$\Xi^{+}_{c} \rightarrow p + K^{-} + \pi^{+}$

$D^{+} \rightarrow K^{-} + \pi^{+} + \pi^{+}$



⇒ With ALICE 3, measure additional states to test physical picture

These measurements are very sensitive to the approach to chemical equilibrium!

Multi-charm baryon reconstruction in ALICE 3 Run 5

$$\Xi_{cc}^{++} \rightarrow \Xi_c^{+} + \pi^{+} \rightarrow \Xi^{-} + 3\pi^{+}$$

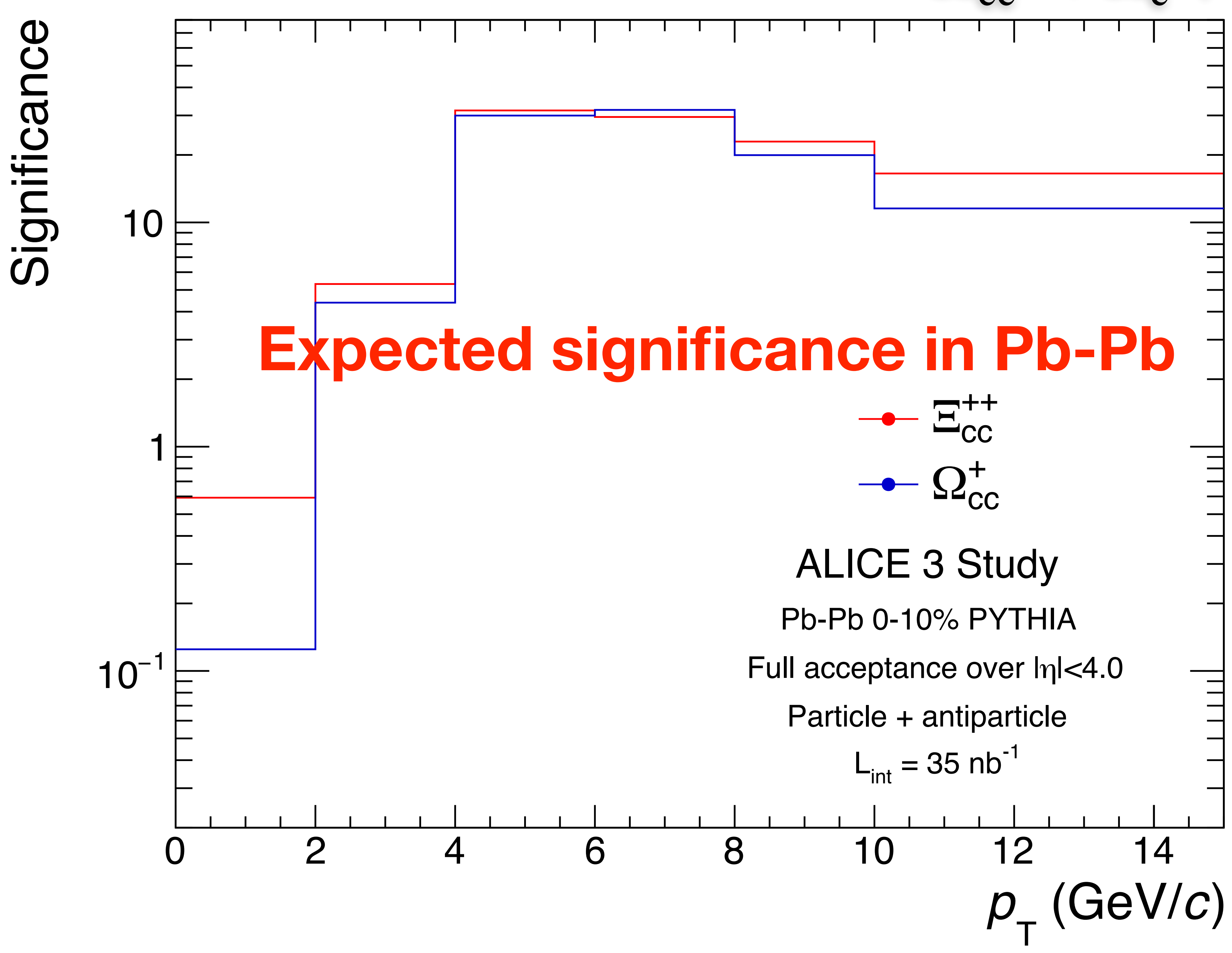
First ALICE 3 tracking layer at 5 mm

- **Track (non-prompt) strange baryon (Ξ^-) before it decays**
- High selectivity thanks to pointing resolution of Ξ^- baryon

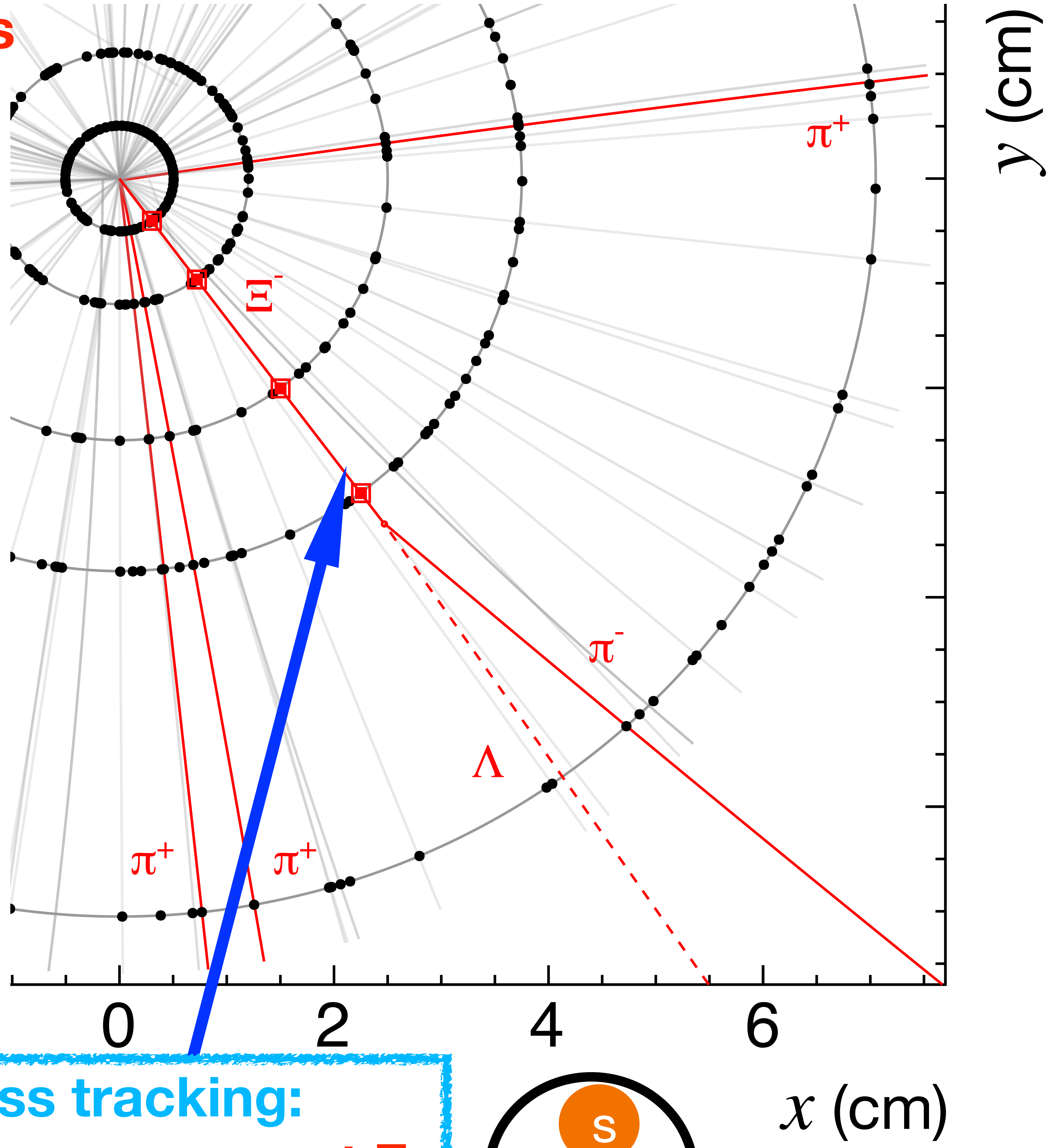
⇒ **Unique access with ALICE 3 in Pb-Pb collisions**

- Same for Ω_{cc}^+ using non-prompt Ω^- !

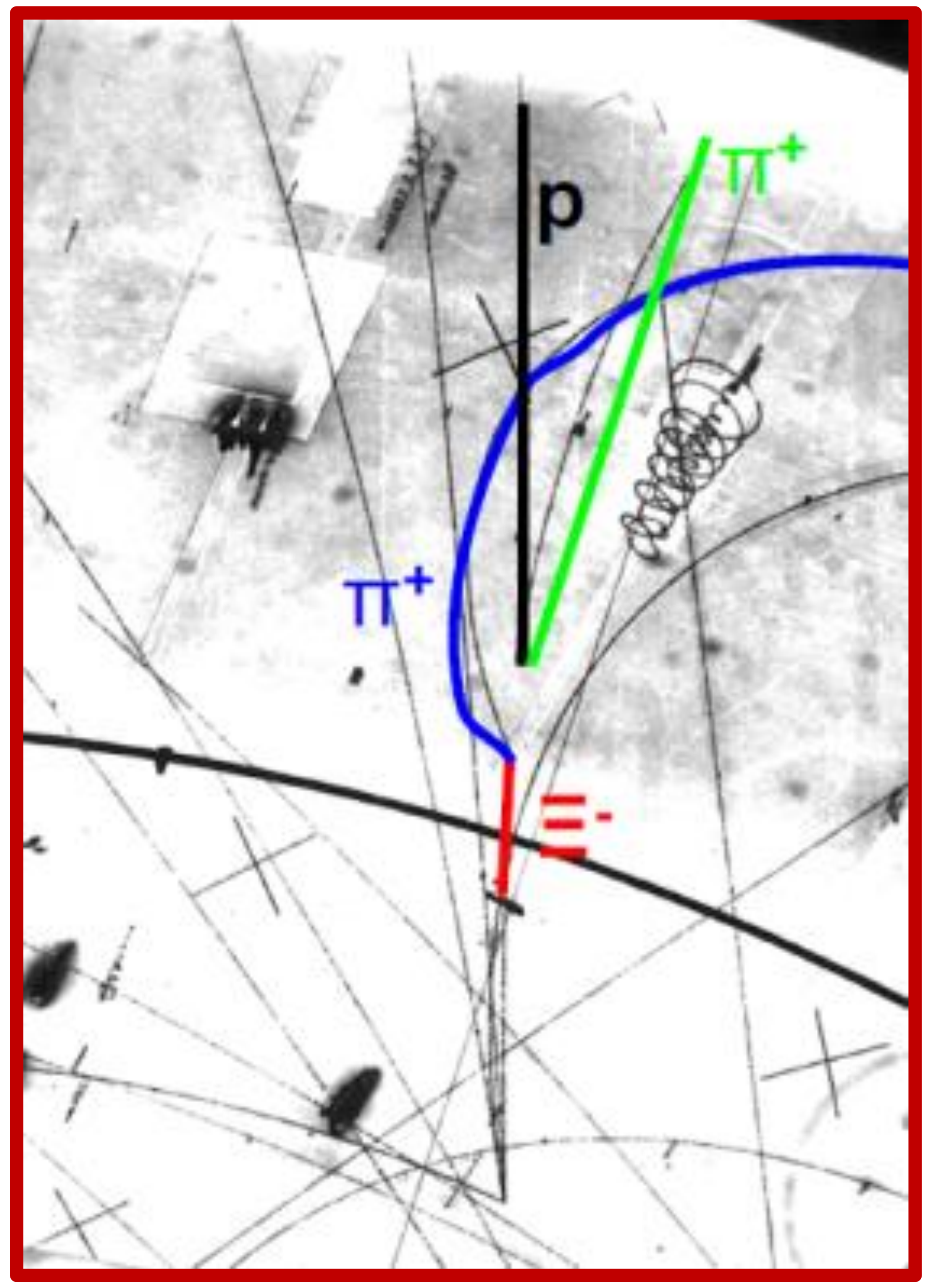
$$\Omega_{cc}^{+} \rightarrow \Omega_c^{0} + \pi^{+} \rightarrow \Omega^{-} + 2\pi^{+}$$



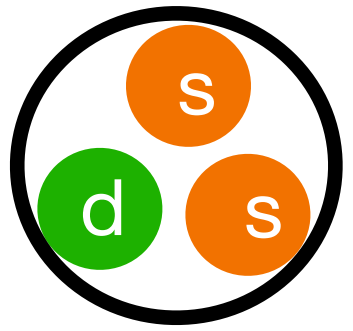
Reconstruction of
Ξ_{cc}^{++} decay in the ALICE 3 tracker



Strangeness tracking,
Like a bubble chamber



Strangeness tracking:
tracking directly non-prompt Ξ^- decaying from Ξ_{cc}^+



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Hadron interaction and fluctuation measurements

Hadron-hadron interaction

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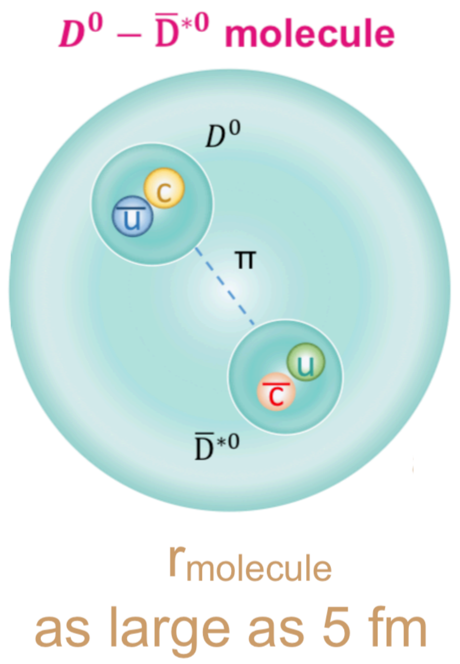

Precision differential measurements of dileptons

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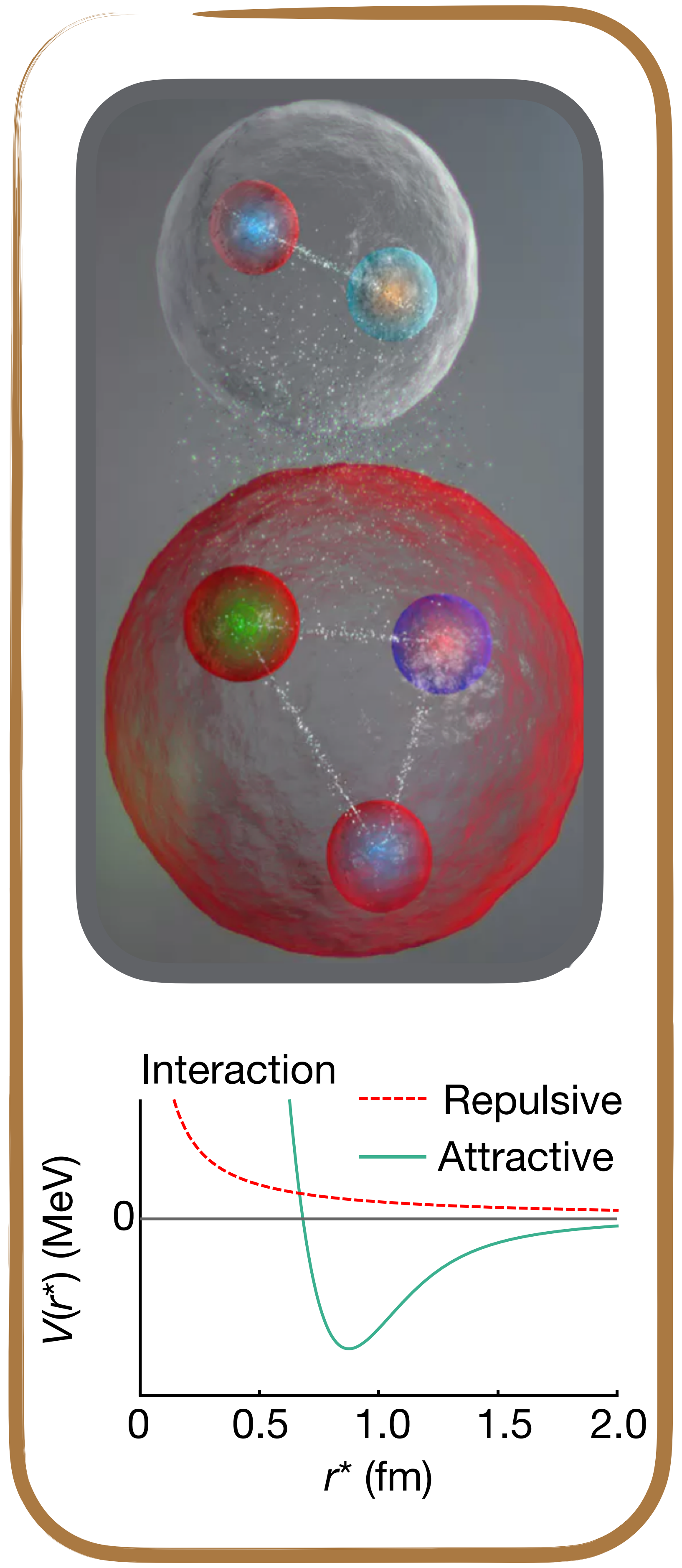
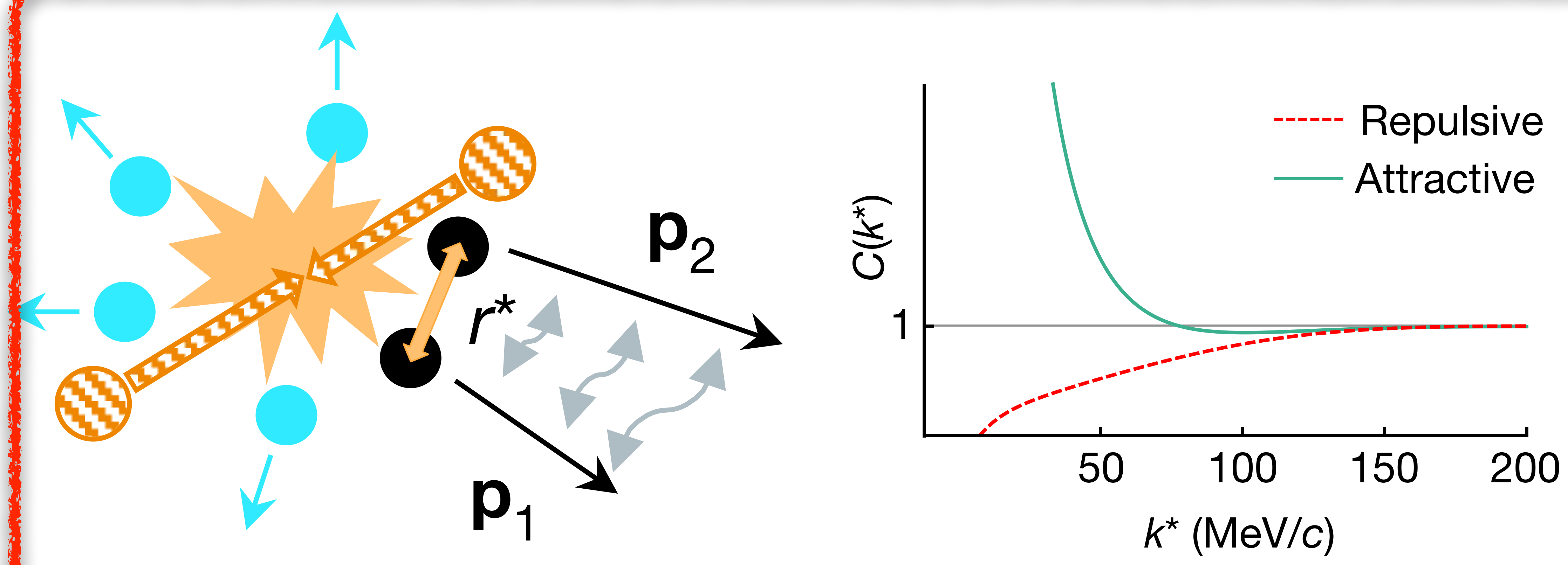
- Mechanisms of chiral symmetry restoration in the QGP

Many more…

Final state interaction

Run 1+2



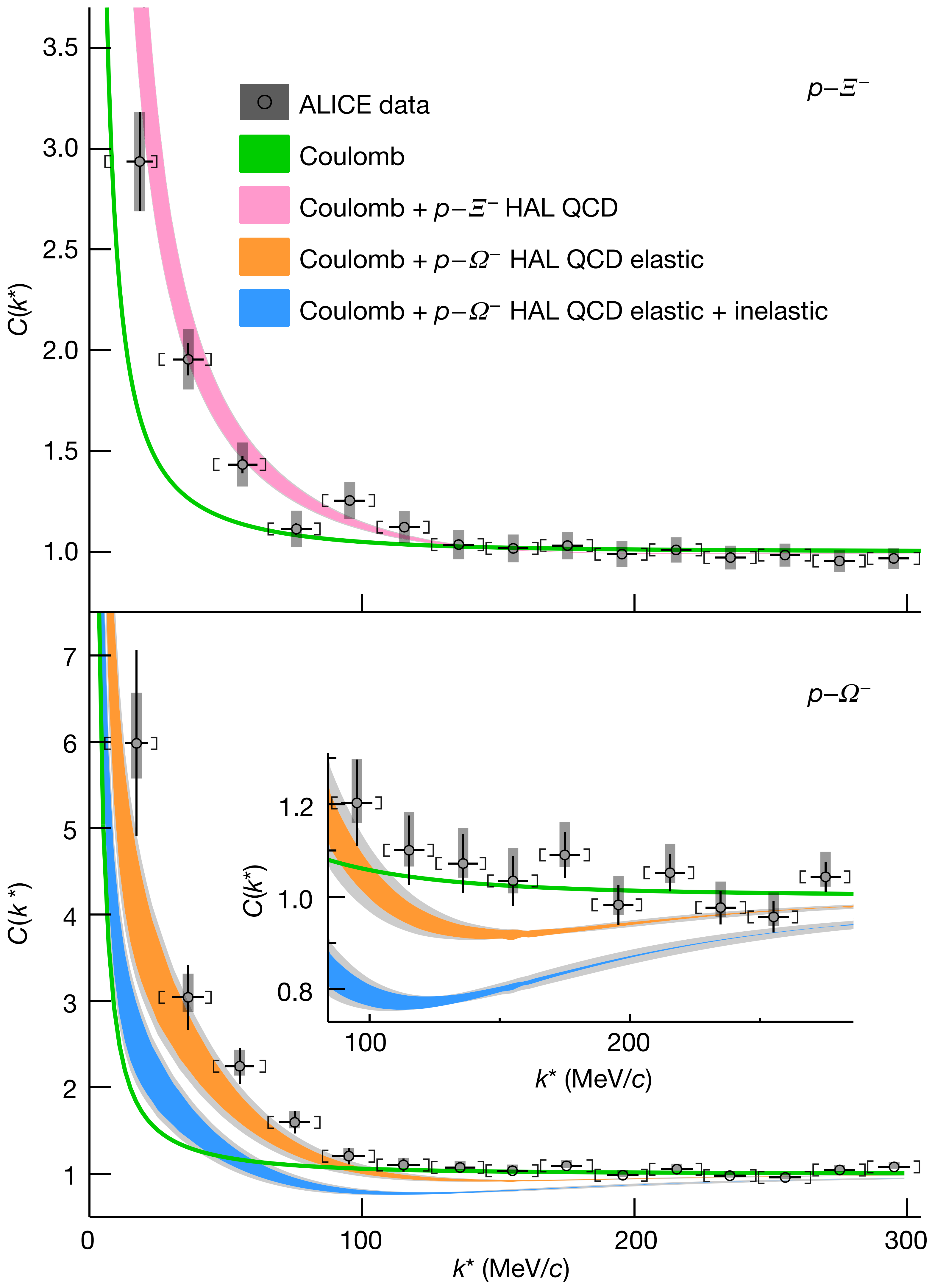


Correlation function

$$C(k^*) = \int S(r^*)|\psi(\mathbf{k}^*, \mathbf{r}^*)|^2 d^3r^*$$

k*: reduced relative momentum of the pair ($k^* = 1/2\,|\,\mathbf{p}^*_{\mathrm{D}^0} - \mathbf{p}^*_{\mathrm{D}^{*+}}|$)

Nature 588 (2020)



p-Ξ⁻: predicted attractive interaction

- Consequences for the possible appearance in neutron stars

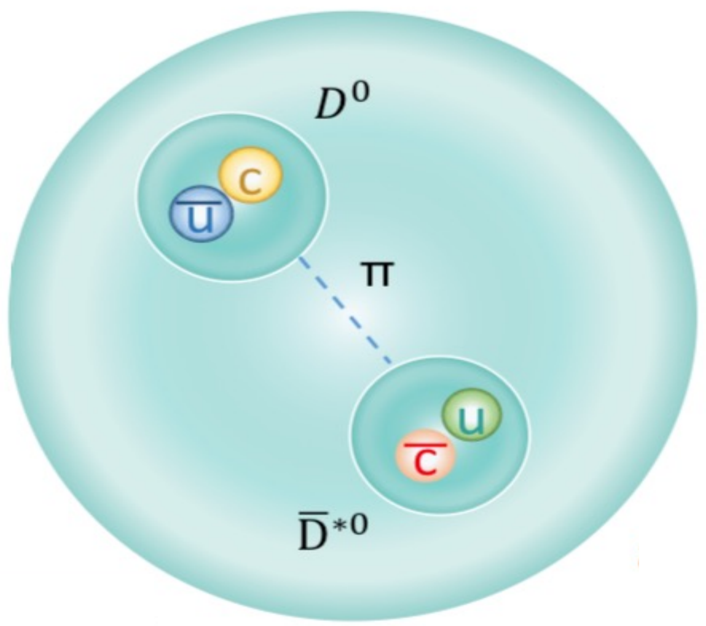
p-Ω⁻: predicted very attractive interaction

- Opens the door for a NΩ di-baryon (bound state)

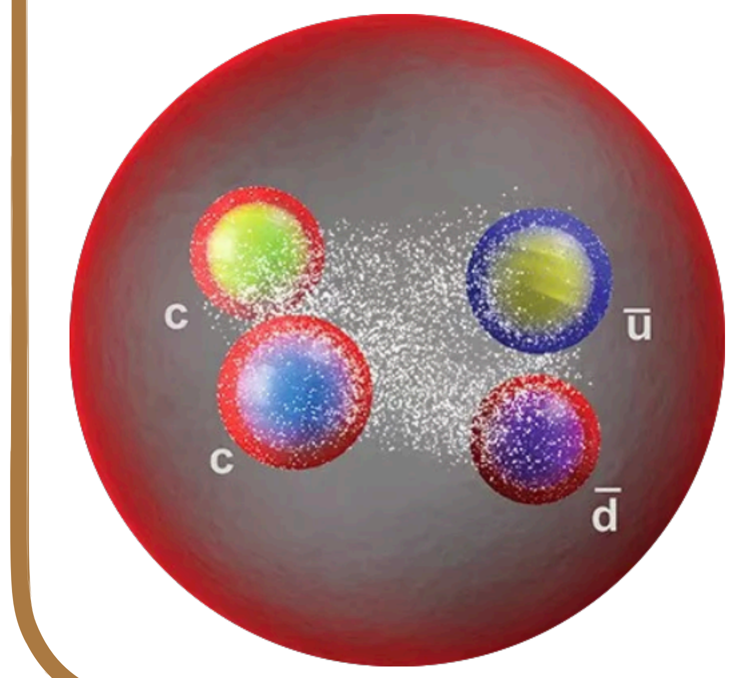
Nature of Exotic bound states

Run 5

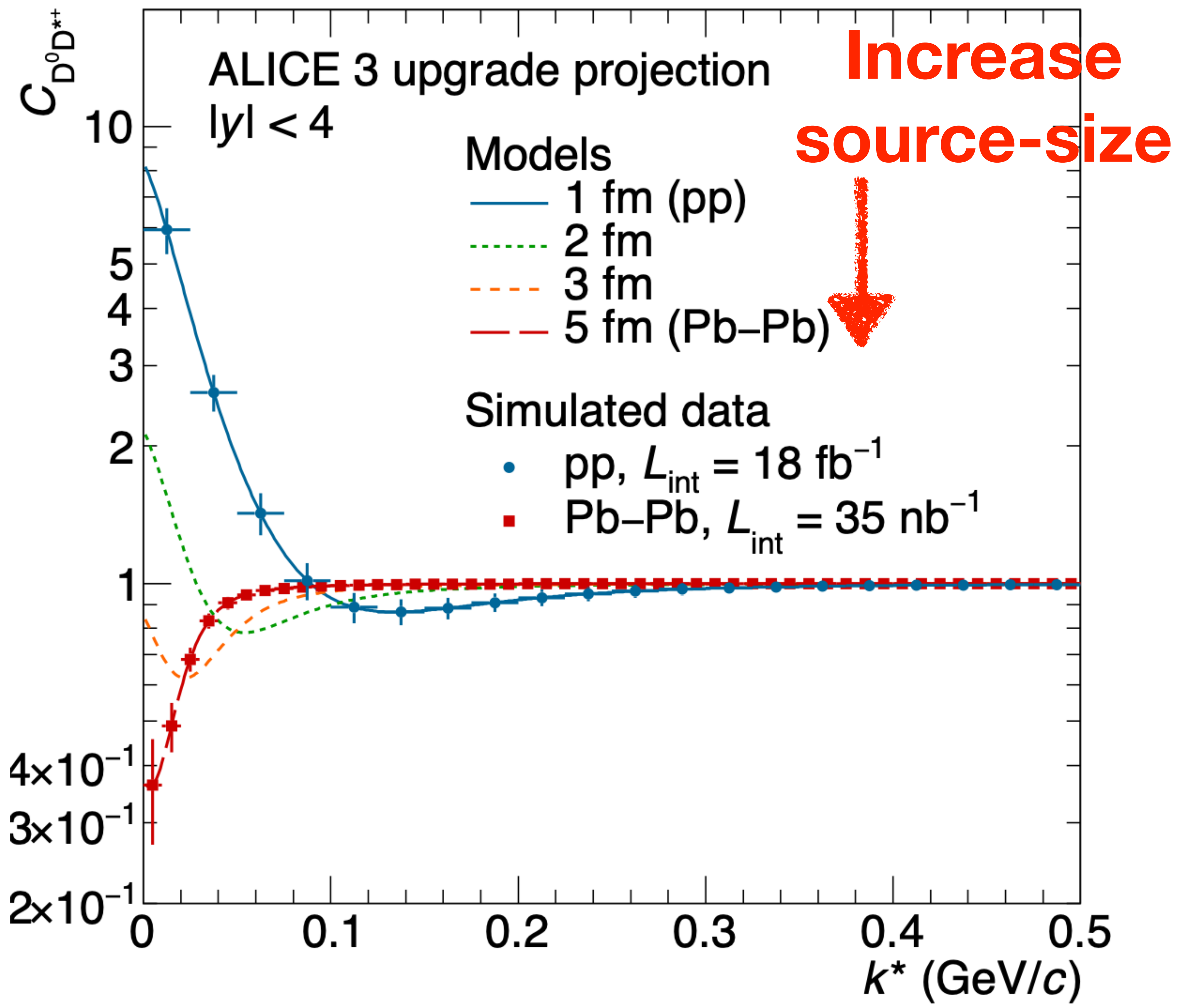
$D^0 - \bar{D}^{*0}$ molecule



$r_{molecule}$
as large as 5 fm
Or



$D^0 D^{*+}$: nature of T_{cc}^{+}



ALICE CERN-LHCC-2022-009

Exotic states: T_{cc}^{+}, χ_{c1}(3872)…

- Include double charm states, potentially weakly-bound states
- **Investigate structure** with two particle momentum correlations and yields arXiv:2203.13814
- Understand dissociation and regeneration in QGP → unique access to low p_T χ_{c1}(3872)

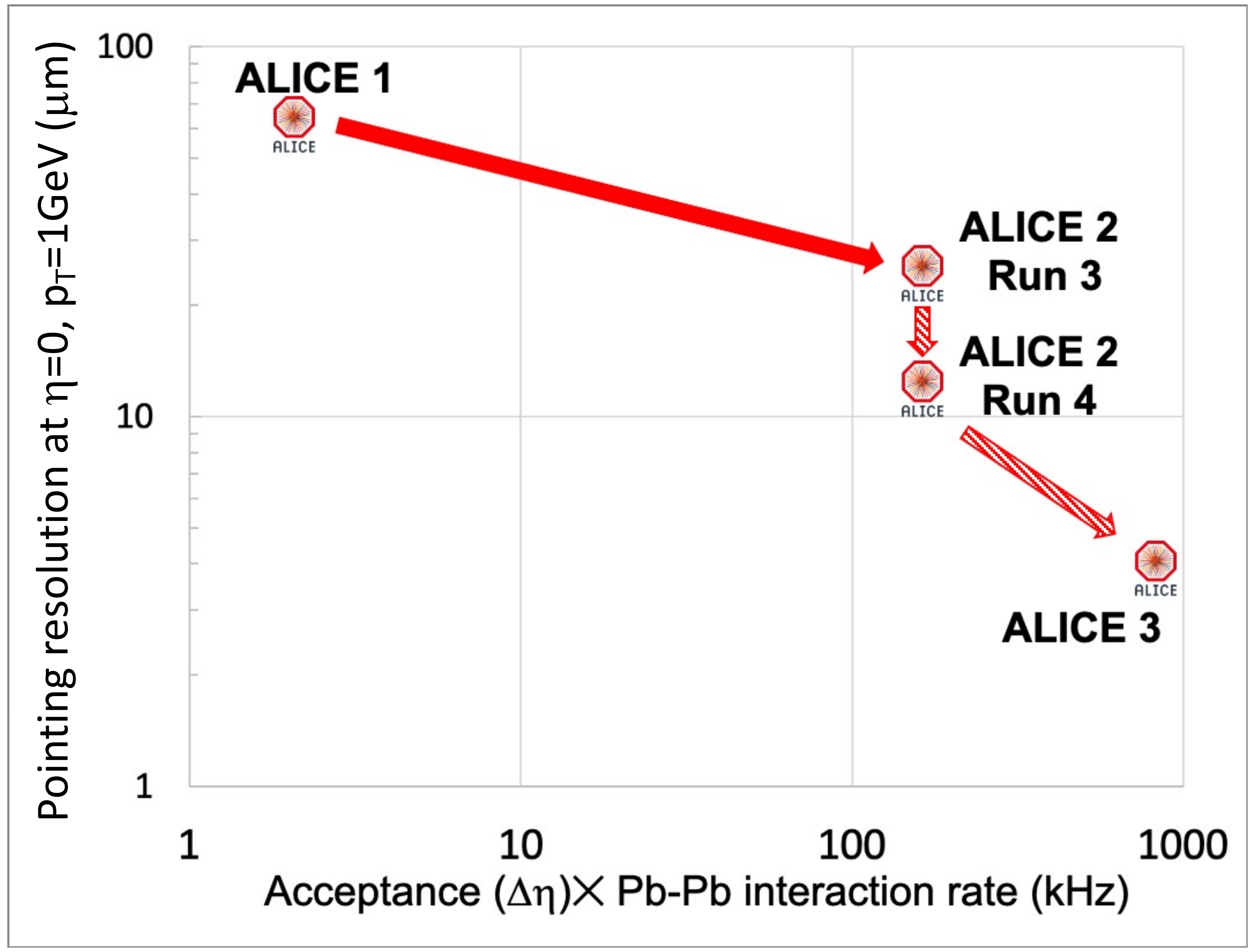
Possible with ALICE 3 thanks to excellent pointing resolution + large acceptance

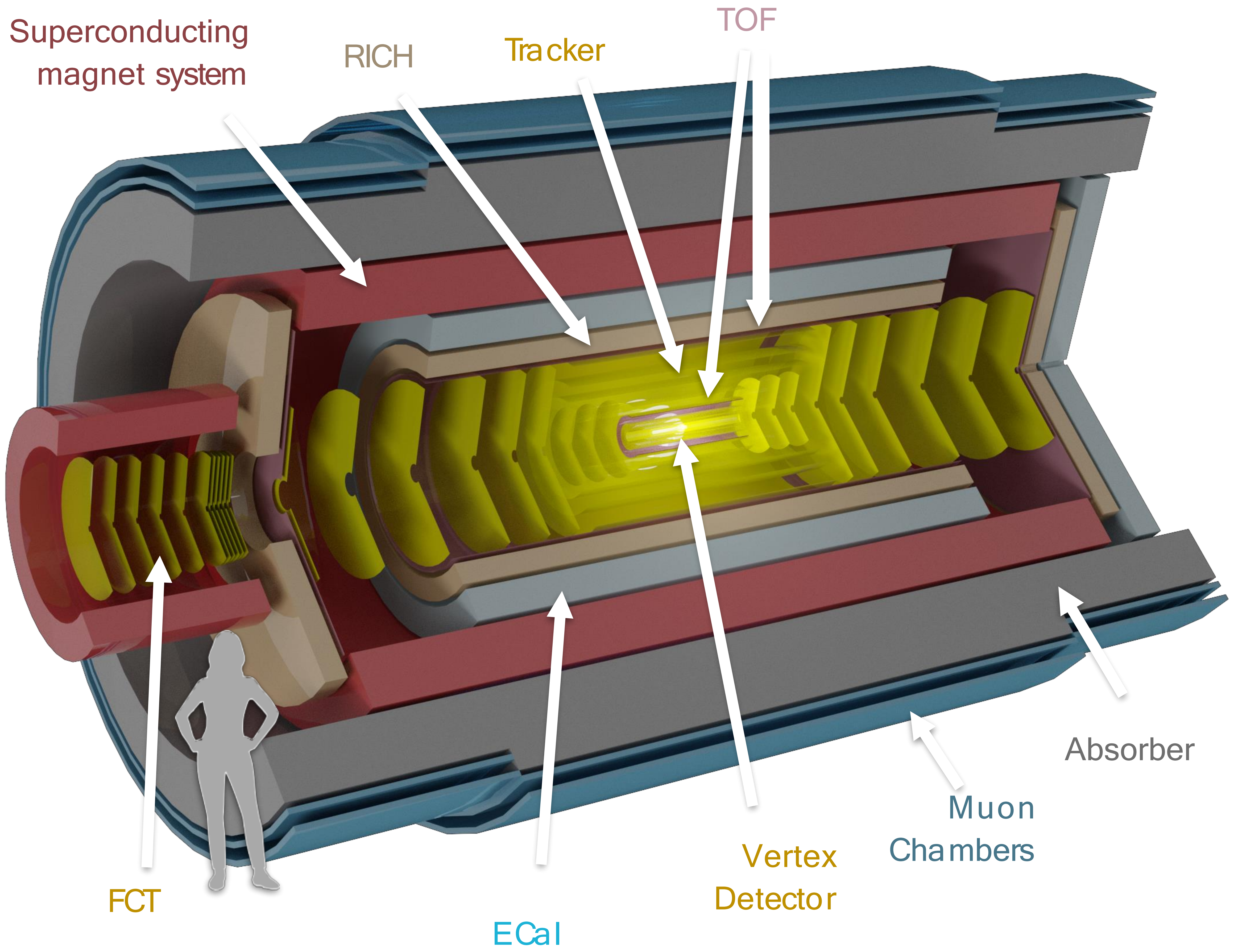
ALICE 3 detector

Experimental challenges

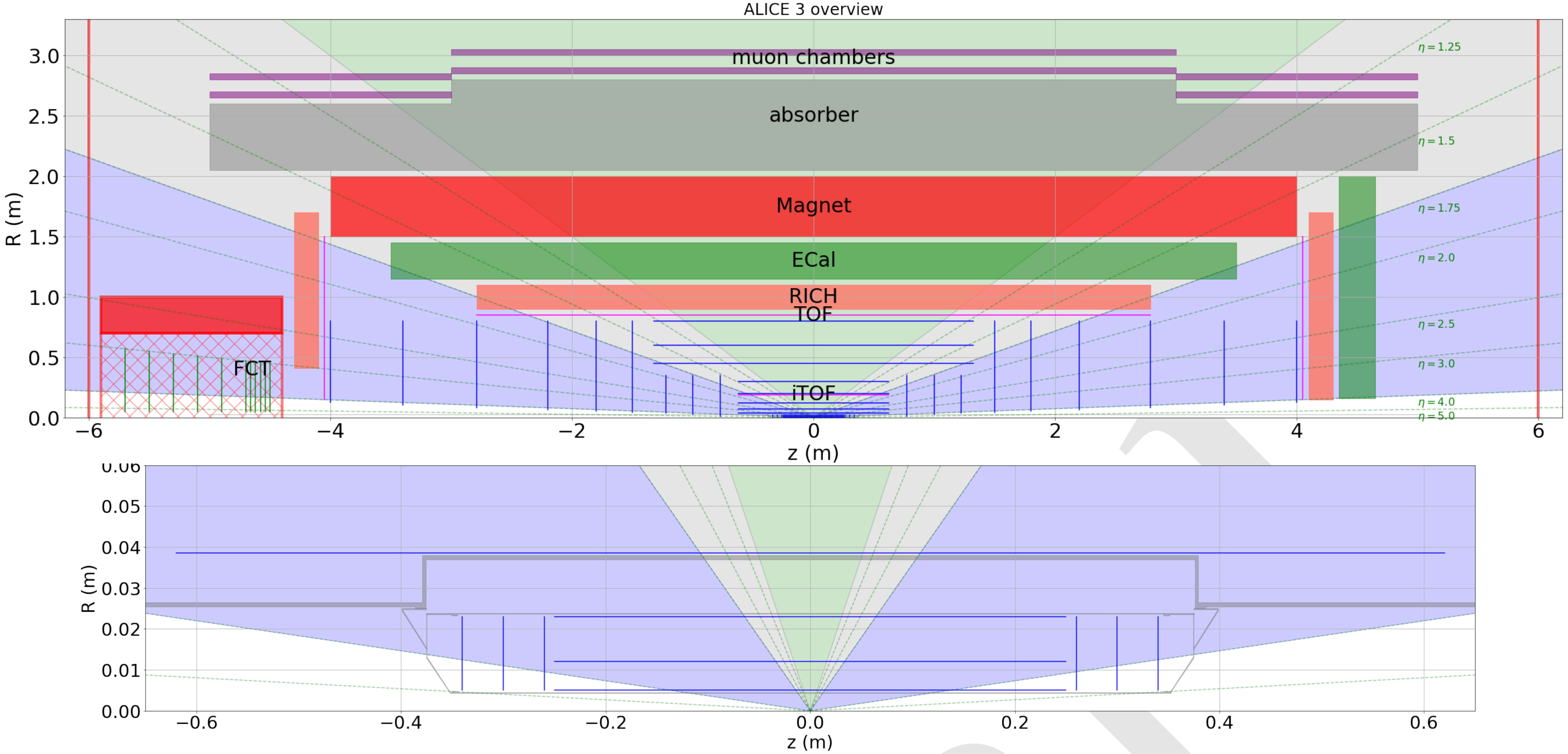
- Compact, ultra-lightweight **all-silicon tracker** → $\sigma_{p_T}/p_T \approx$ 1-2%
- **Vertex detector** with unprecedented pointing resolution → $\sigma_{DCA} \approx$ 10 μm (p_T = 200 MeV)
- Particle Identification over large acceptance ($-4 < \eta < 4$) → γ, $e^{\pm}$, $\mu^{\pm}$, $K^{\pm}$, $\pi^{\pm}$
- Continuous read-out and online processing

⇒ **Detector with unique and unprecedented features at the LHC**



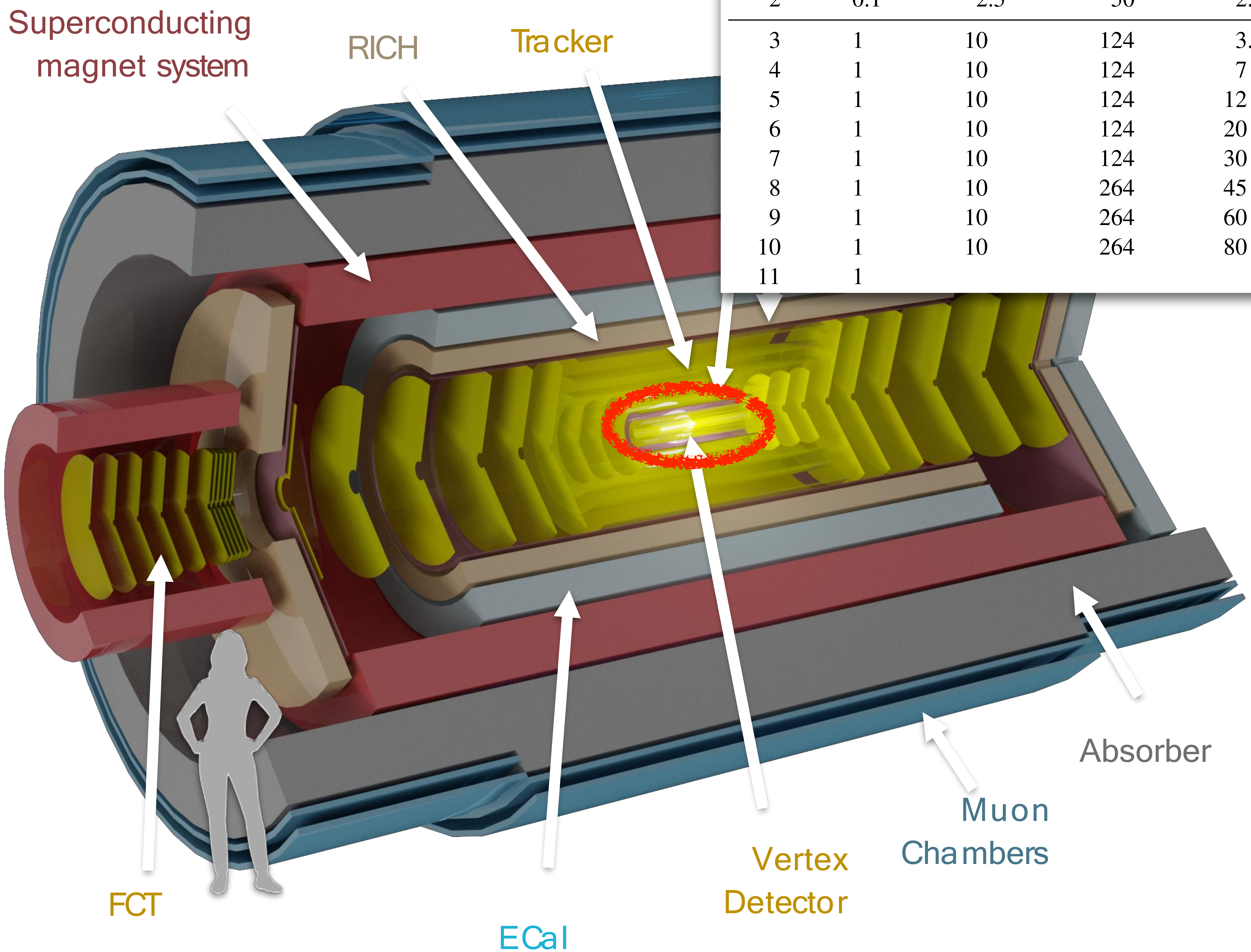


ALICE 3 schematic R–z view



Vertex detector

Layer	Material thickness ($\%X_0$)	Intrinsic resolution (μm)	Barrel layers Length ($\pm z$) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position ($\|z\|$) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.005	3
1	0.1	2.5	50	1.20	30	0.005	3
2	0.1	2.5	50	2.50	34	0.005	3
3	1	10	124	3.75	77	0.05	35
4	1	10	124	7	100	0.05	35
5	1	10	124	12	122	0.05	35
6	1	10	124	20	150	0.05	80
7	1	10	124	30	180	0.05	80
8	1	10	264	45	220	0.05	80
9	1	10	264	60	279	0.05	80
10	1	10	264	80	340	0.05	80
11	1				400	0.05	80



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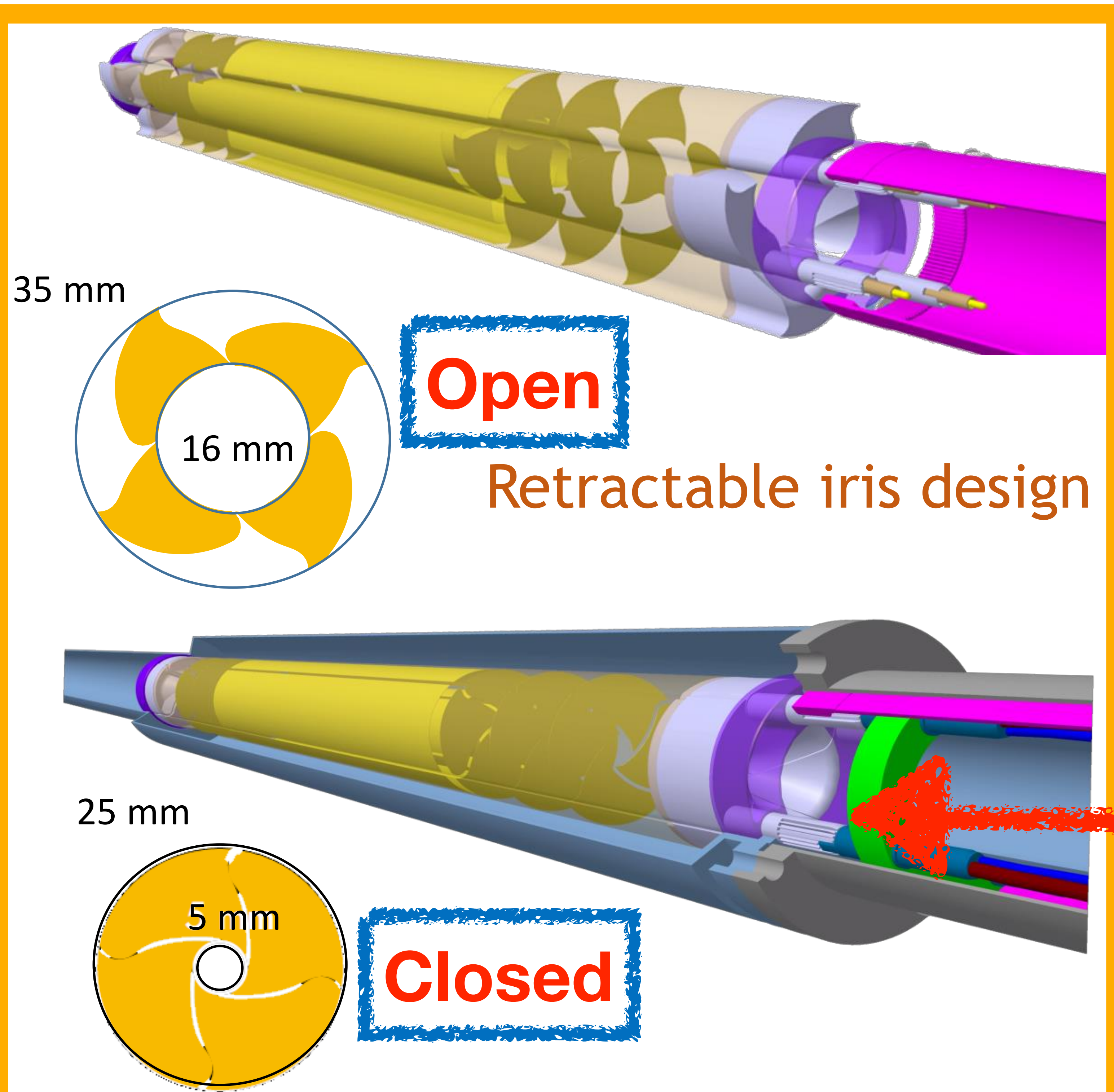
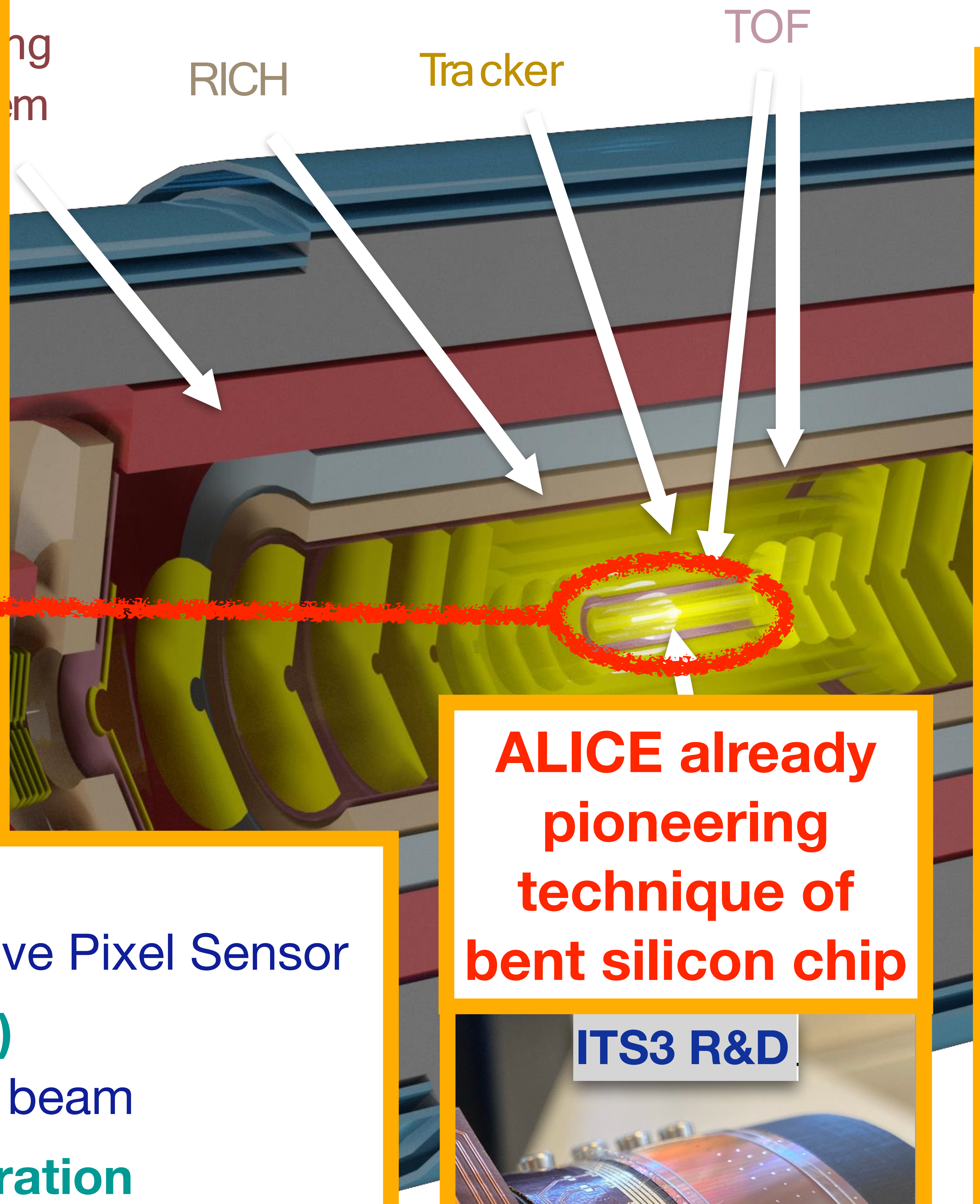




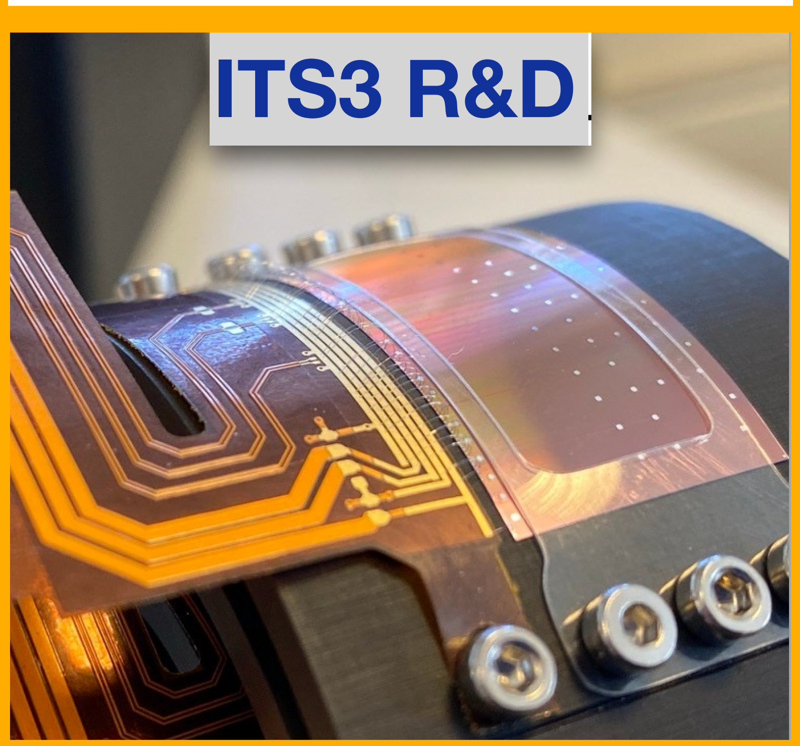
Conceptual study of iris tracker

- Wafer-size, ultra-thin, curved, CMOS Active Pixel Sensor

  ⇒ **Ultimate performance (same for ITS 3)**
- First layer at mid-rapidity: 5 mm from the beam

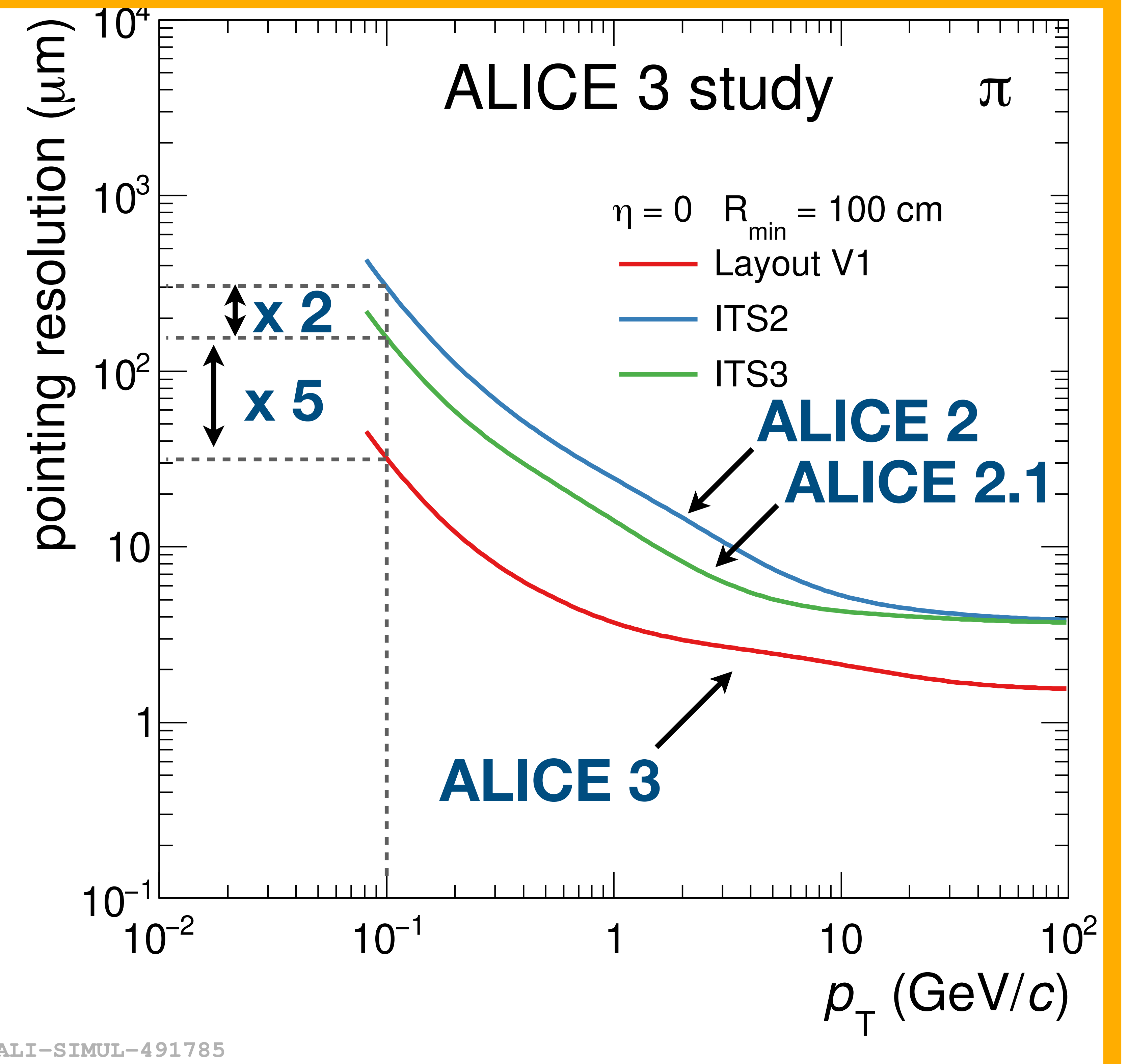
  ⇒ **Inside beam pipe, retractable configuration**
- Unprecedented spatial resolution: $\sigma_{pos} \approx 2.5$ μm
- Extremely low material budget
  - 1‰ X_0 per layer

ALICE already pioneering technique of bent silicon chip



Pointing resolution $\propto r_0 \cdot \sqrt{x/X_0}$

- ~10 μm at p_T = 200 MeV/c
- ~2 μm at high p_T



Large acceptance tracker

Layer	Material thickness ($\%X_0$)	Intrinsic resolution (μm)	Barrel layers: Length ($\pm z$) (cm)	Barrel layers: Radius (r) (cm)	Forward discs: Position ($\|z\|$) (cm)	Forward discs: R_{in} (cm)	Forward discs: R_{out} (cm)
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2	0.1	2.5	50	2.50	34	0.005	3
3	1	10	124	3.75	77	0.05	35
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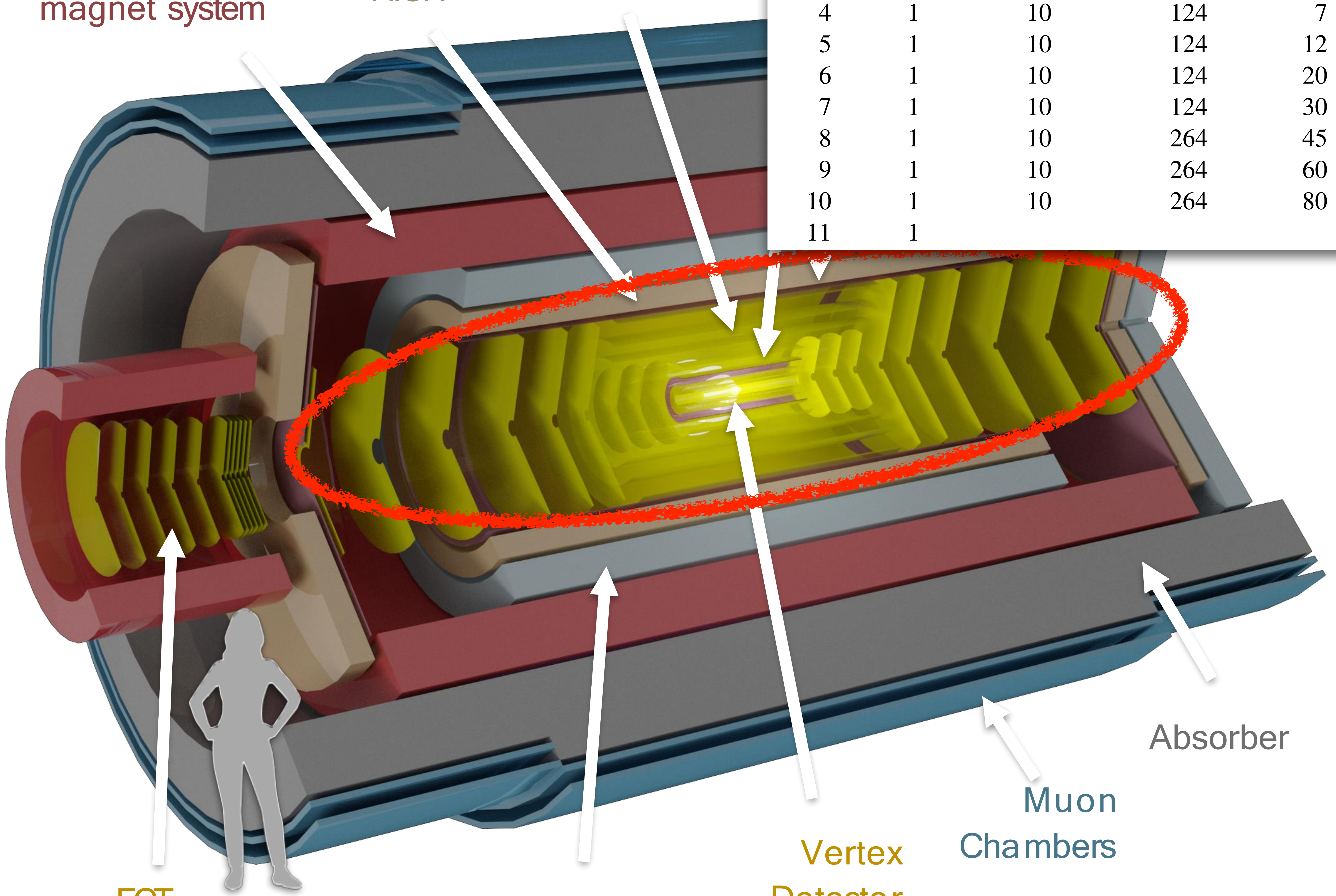
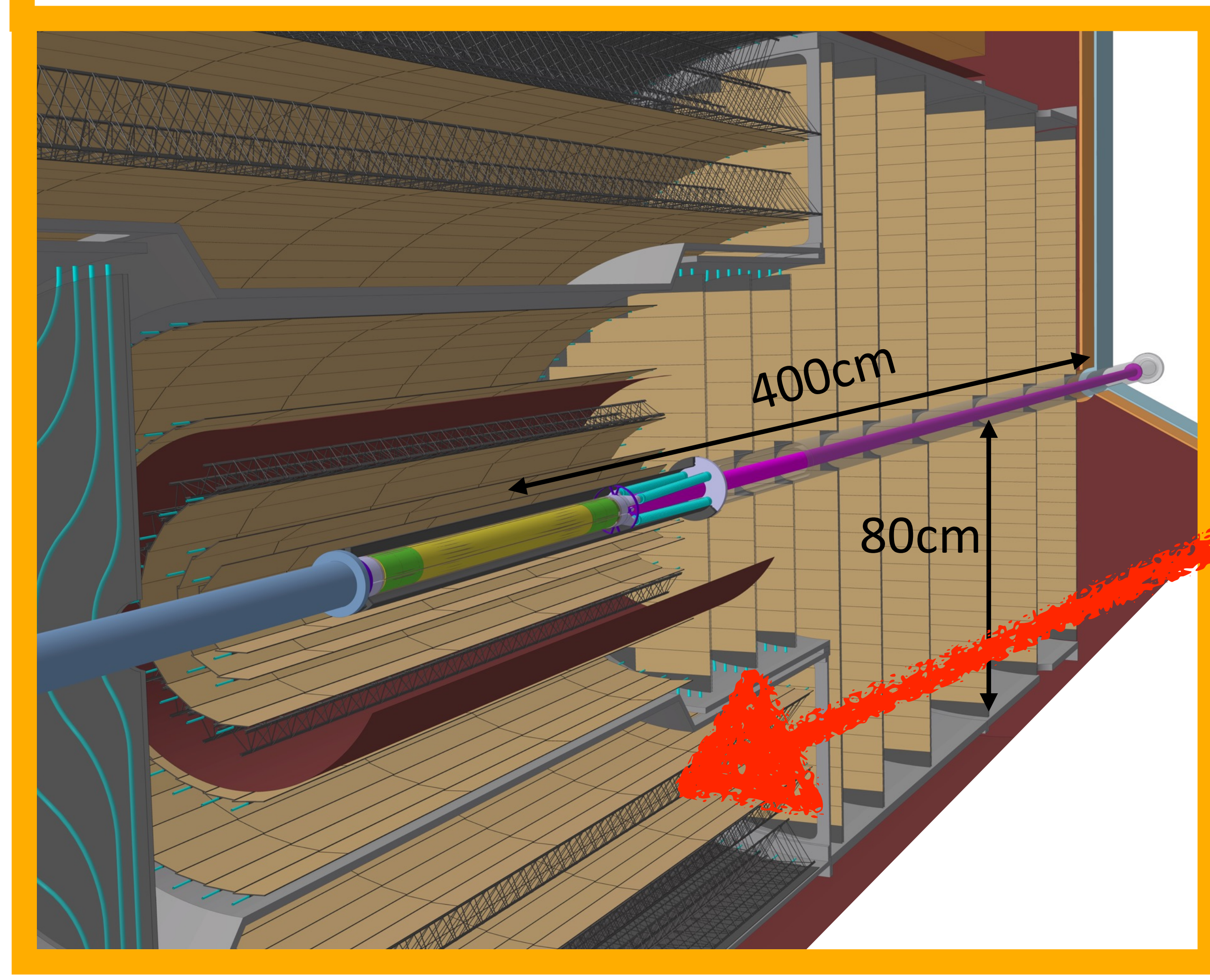
7	1	10	124	30	180	0.05	80
8	1	10	264	45	220	0.05	80
9	1	10	264	60	279	0.05	80
10	1	10	264	80	340	0.05	80
11	1				400	0.05	80

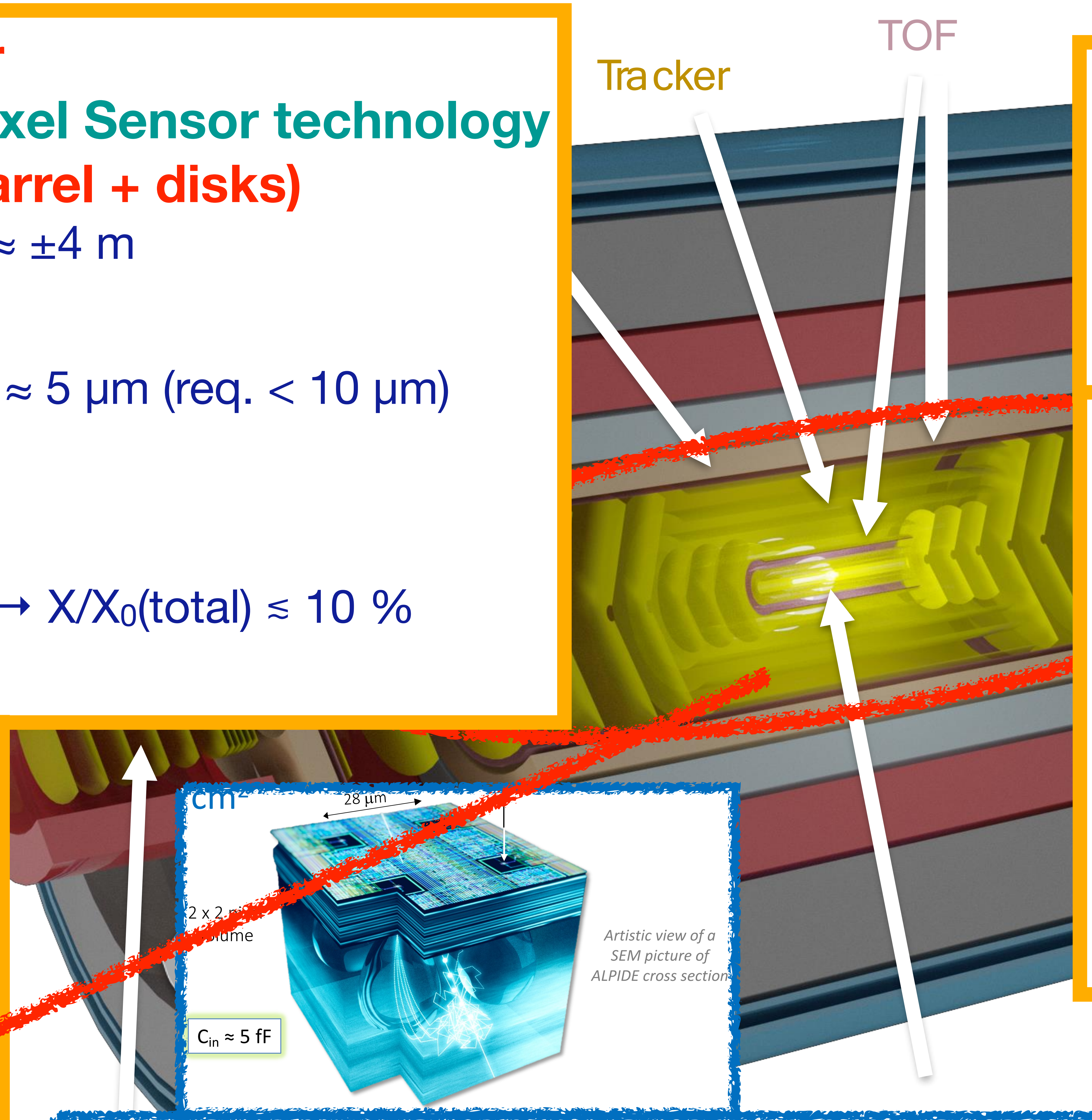


Large acceptance tracker

60 m² silicon pixel detector
based on CMOS Active Pixel Sensor technology
8 + 2 x 9 tracking layers (barrel + disks)

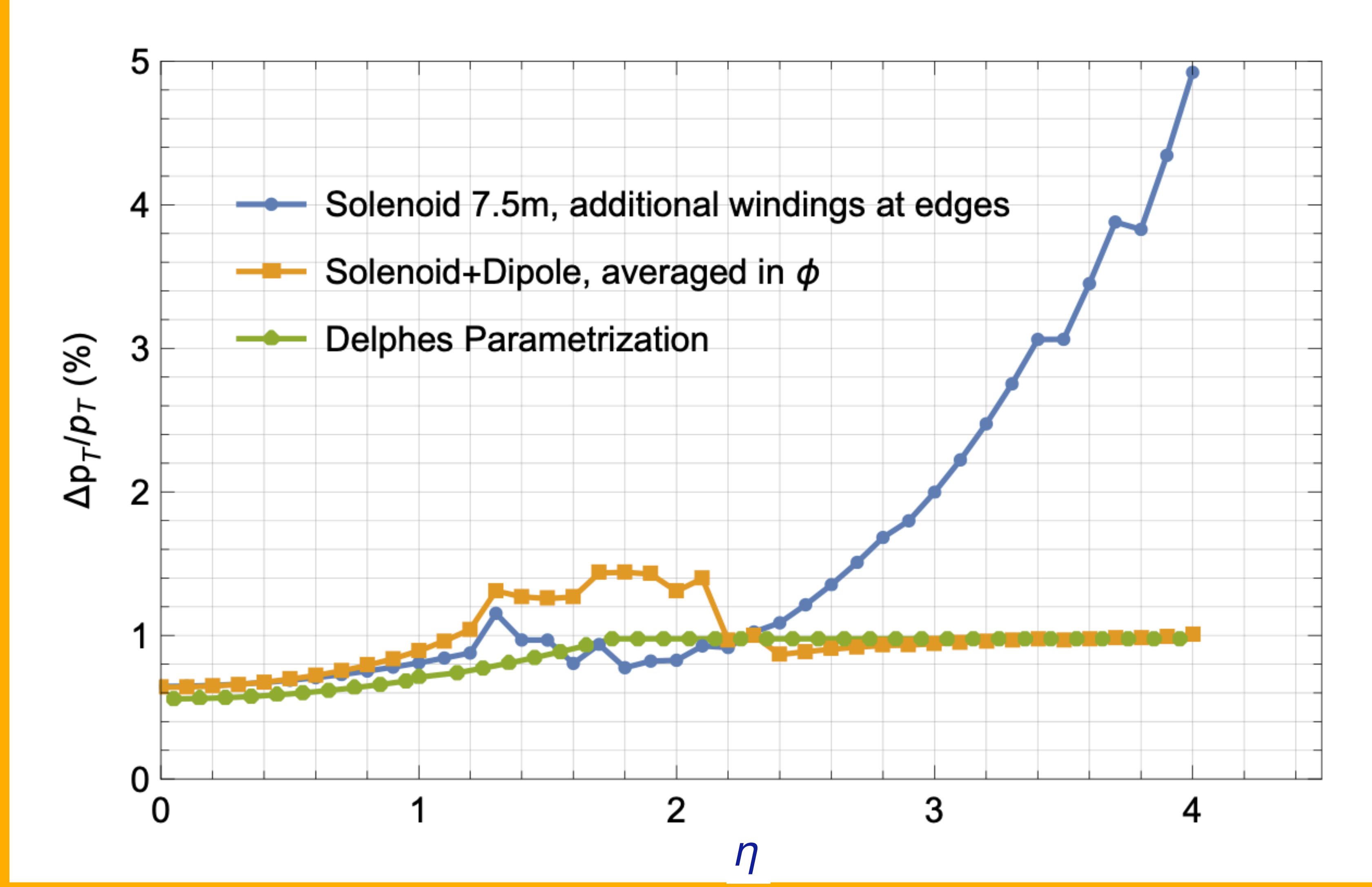
- Compact: $r_{out} \approx 80$ cm, $z_{out} \approx \pm 4$ m
- Large coverage: ±4η
- High-spatial resolution: $\sigma_{pos} \approx 5$ μm (req. < 10 μm)
- Timing resolution ~ 100 ns
- Very low material budget
  - 1% X_0 per layer overall → X/X_0(total) ≲ 10 %
- Low power: ≈ 20 mW/cm²





Relative p_T resolution $\propto \frac{\sqrt{x/X_0}}{B \cdot L}$

- ~1% over large acceptance
  - integrated magnetic field crucial (2T)
  - overall material budget critical



Build on experience with ITS 2 and ITS 3 (same CMOS process)
10 m² → 60 m²: challenges on industrialisation

Tracker sensor requirement

The ALICE 3 tracker has two sets of requirements

- Vertex detector: high hit rate, high radiation load
- Outer tracker: low power, large surface (yield, fill factor)

A common sensor might be possible, but is not needed

- Main benefit would be synergies, possibly cost savings

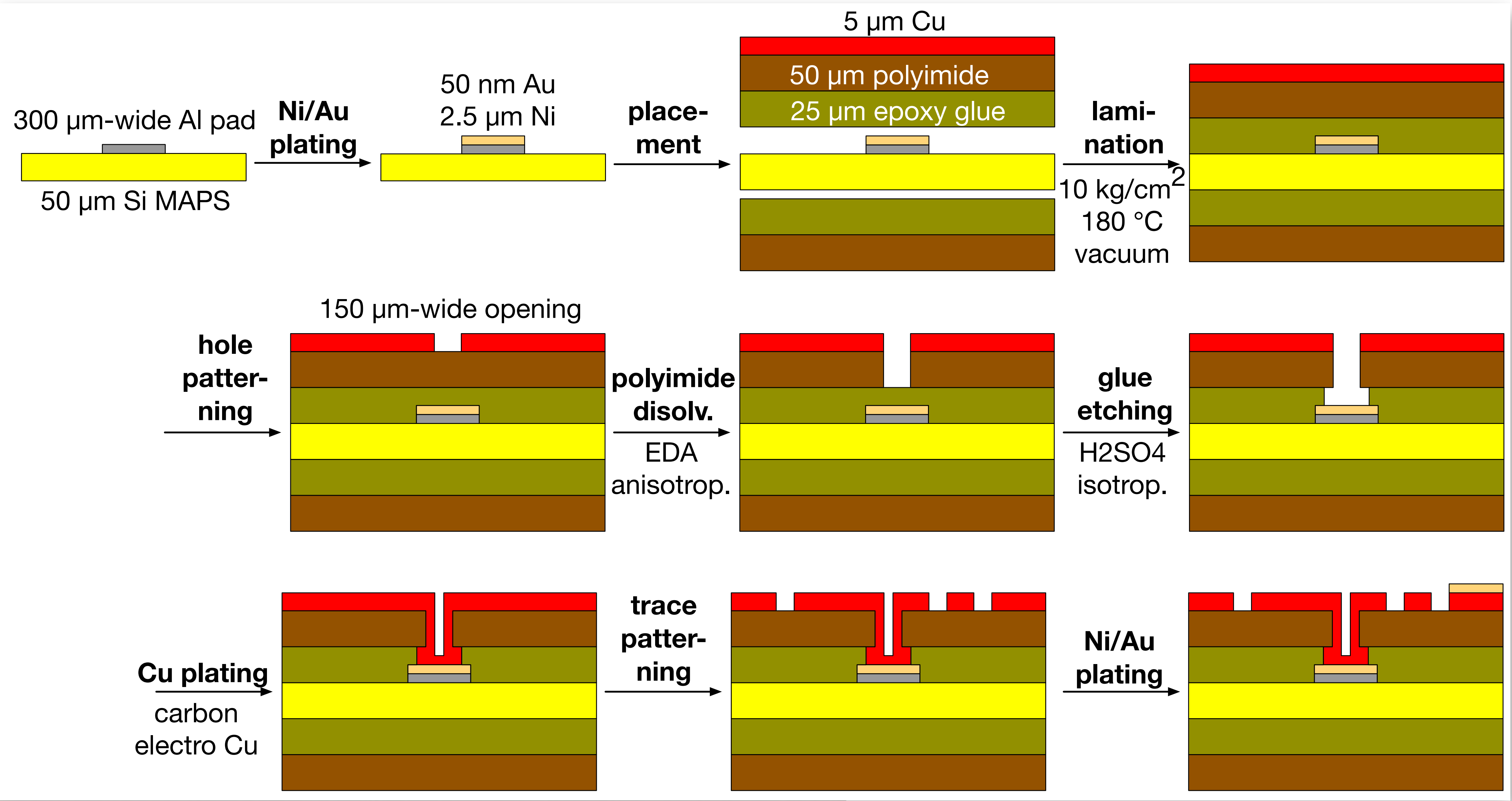
→ Naturally follows the ITS 3 developments

Parameter	Vertex detector	Outer tracker
Spatial resolution	2.5 μm	10 μm
Time resolution	100 ns (RMS)	100 ns (RMS)
Hit rate capability	35×10^6 / (s cm^2)	5×10^3 / (s cm^2)
Power consumption	70 mW / cm^2	20 mW / cm^2
Radiation hardness	1.5 10^{15} 1 MeV n_{eq} / cm^2 / year	

Key R&D topics

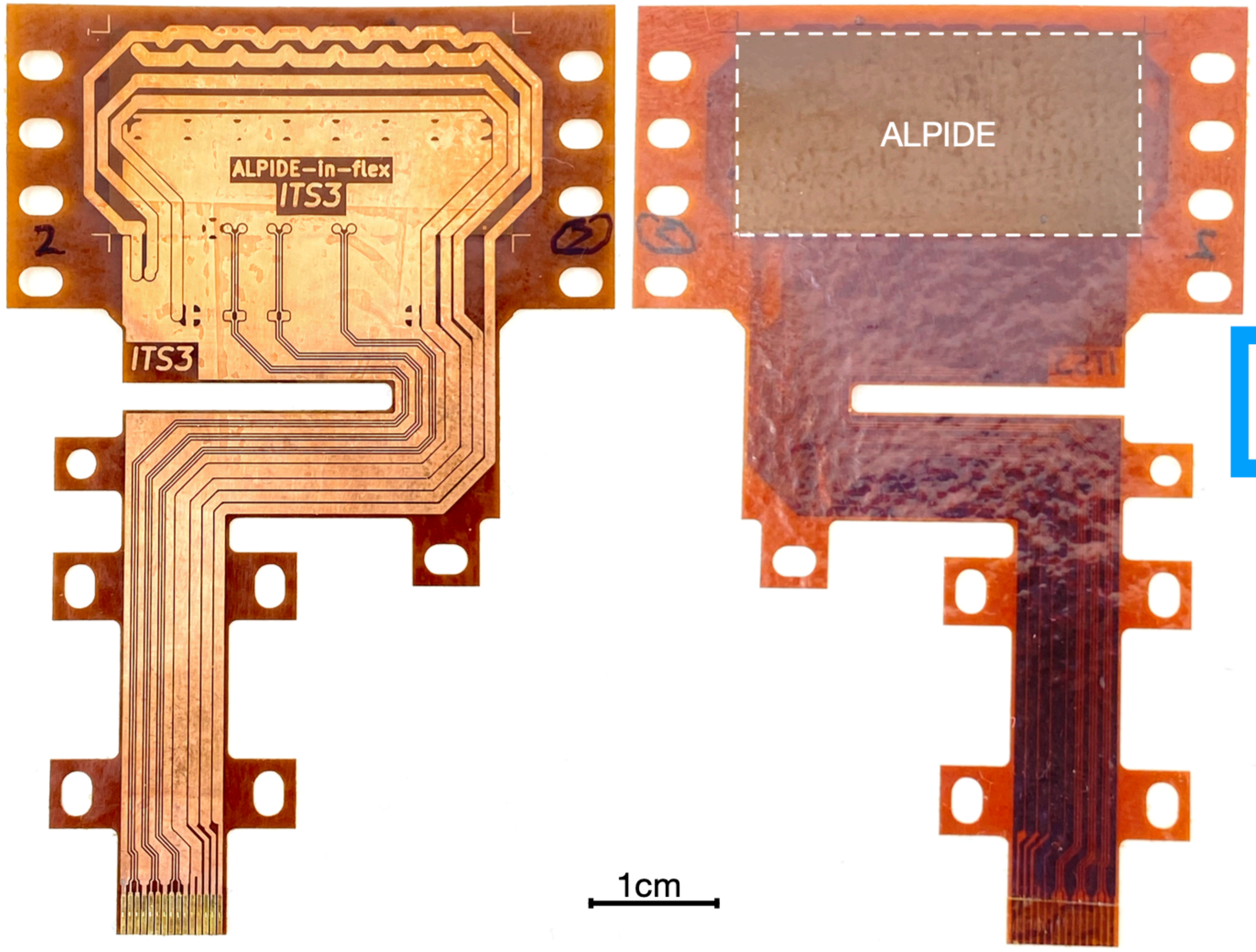
- **Radiation hardness**
  - 5×10^{15} 1 MeV n_{eq}/cm^2 is demonstrated for HVMAPS at -25°C
  - At least 5×10^{15} 1 MeV n_{eq}/cm^2 seem feasible in 65 nm at room temperature (preliminary results)
- **Power consumption**
  - Several contributors: in-pixel front ends, on-chip data aggregation, high-speed links
  - Scales with time resolution and pixel pitch
  - Optimisation process to be carried through
- **Integration**
  - The modularization for the other tracker needs to be co-developed with the chip design (e.g. chip dimensions)

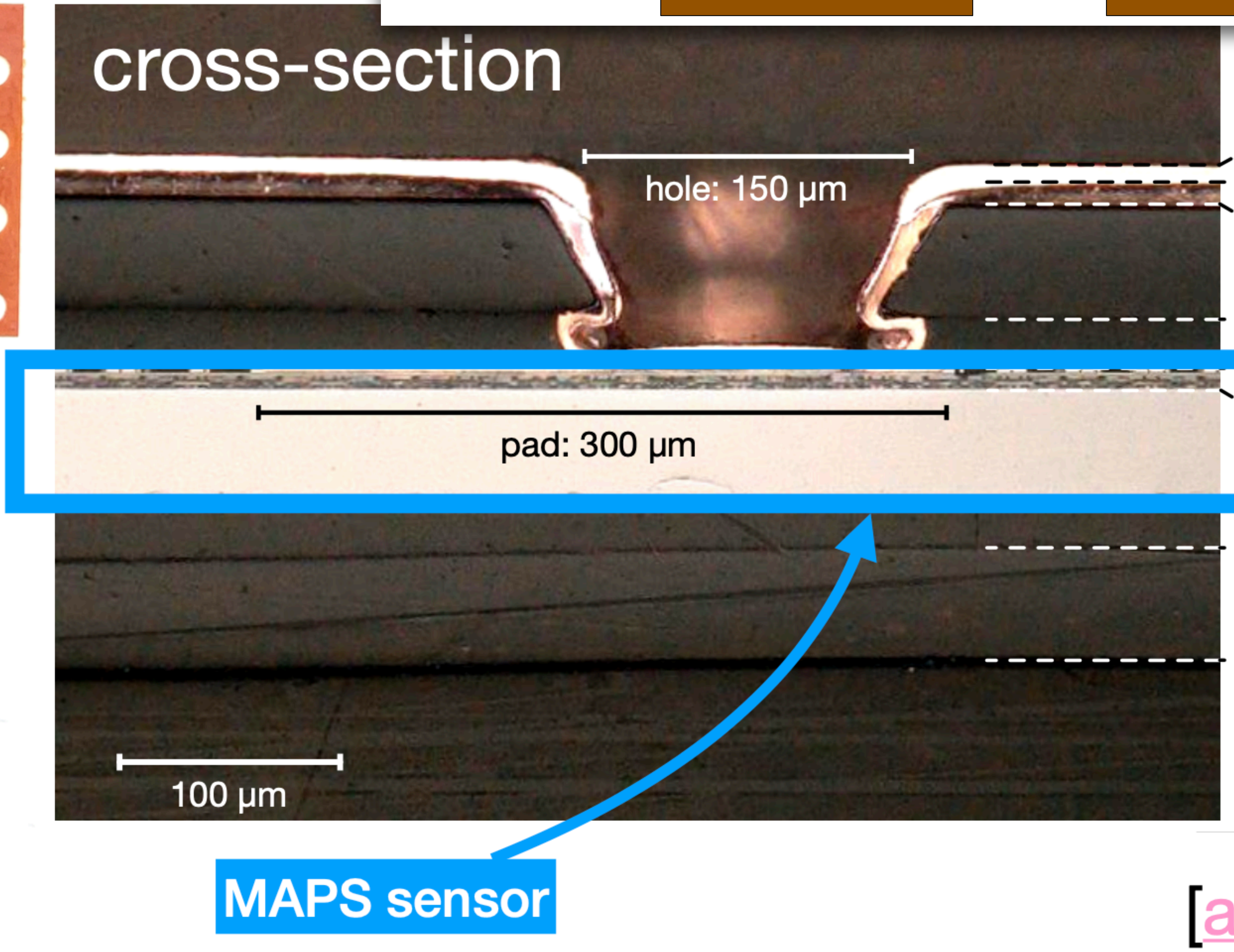
Tracker example "MAPS foils"



MAPS foils - chips within printed circuit boards

- "Novel" concept (revised and updated from 2012)
- Will be studied further as an option





part	thickness
Cu plating	13 µm
Cu gladding	5 µm
Polyimide	45 µm
glue	25 µm
metal stack	10 µm
silicon	45 µm
glue	25 µm
Polyimide	45 µm
total:	**213 µm**

[arXiv:2205.12669]

Particle identification with Time Of Flight

Separation power ∝ L/σ_{TOF}
→ Distance and time resolution crucial
→ Larger radius results in lower p_T bound

2 barrel TOF layers (|η| < 1.75)
- Outer TOF at $r \approx 85$ cm, surface: 30 m², pitch: 5 mm
- Inner TOF at $r \approx 19$ cm, surface: 1.5 m², pitch: 1 mm

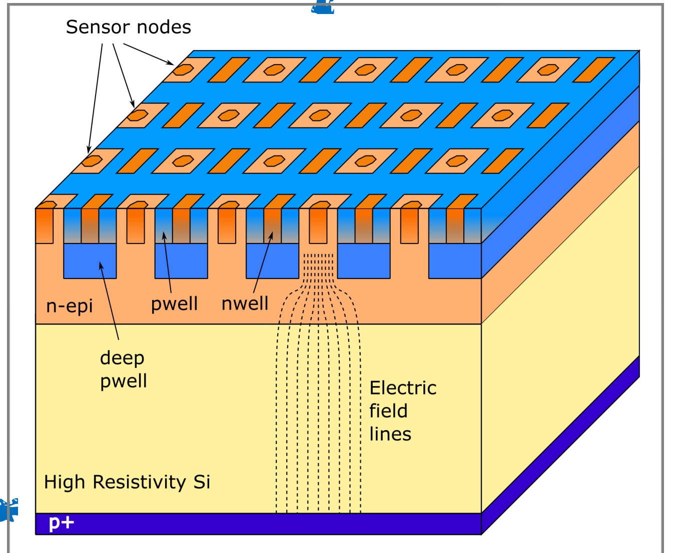
1 forward TOF layers (1.75 < |η| < 4)
- Inner radius = 15 cm, outer radius = 150 cm, $z \approx 405$ cm, surface: 14 m², pitch: 1mm to 5 mm

$\sigma_{TOF} \lesssim 20$ps

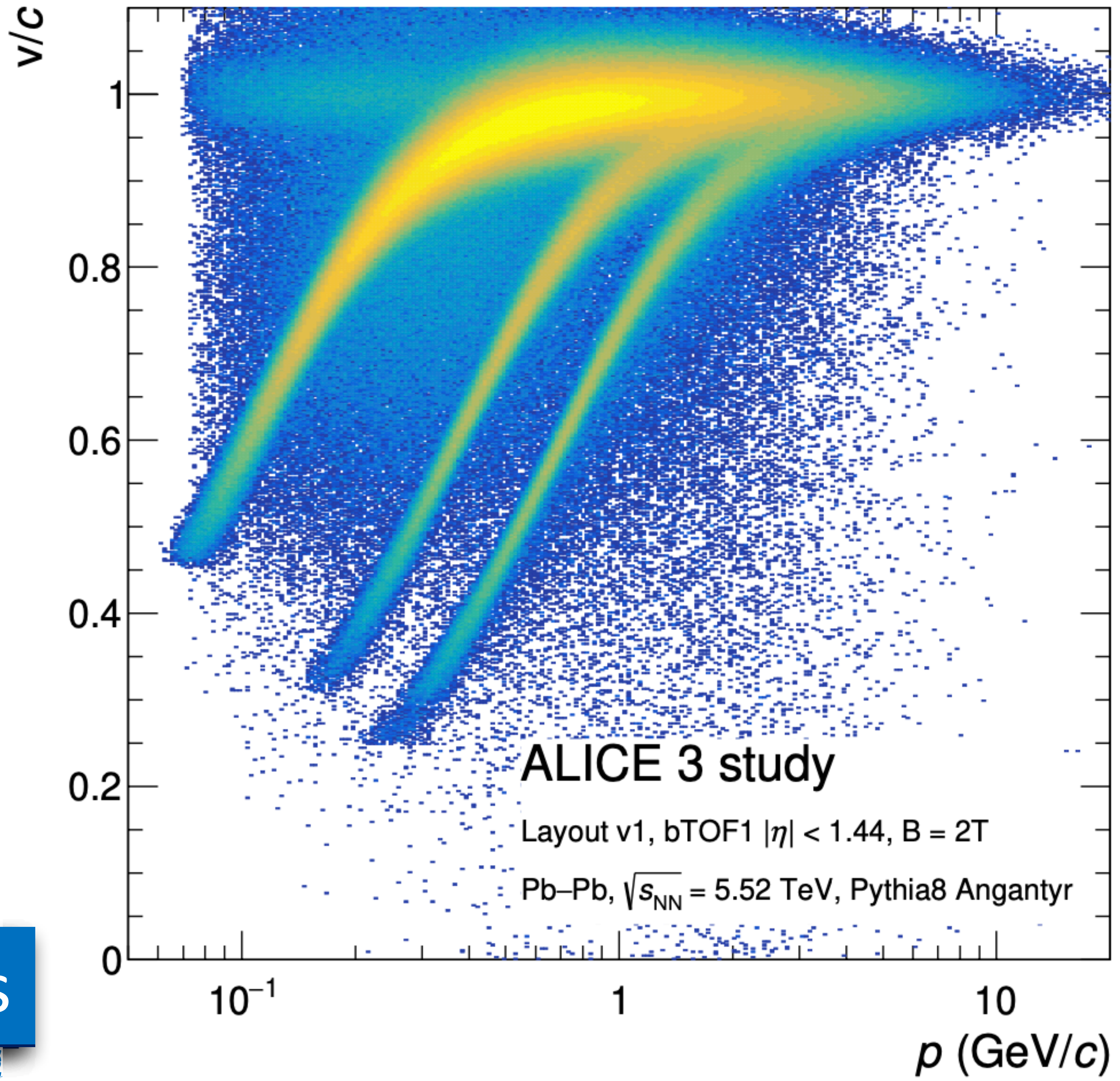
Silicon timing sensors

CMOS sensor with gain (baseline)
- R&D on monolithic CMOS sensors with integrated gain layers

Conventional LGADs (fallback)
- R&D with very thin sensors

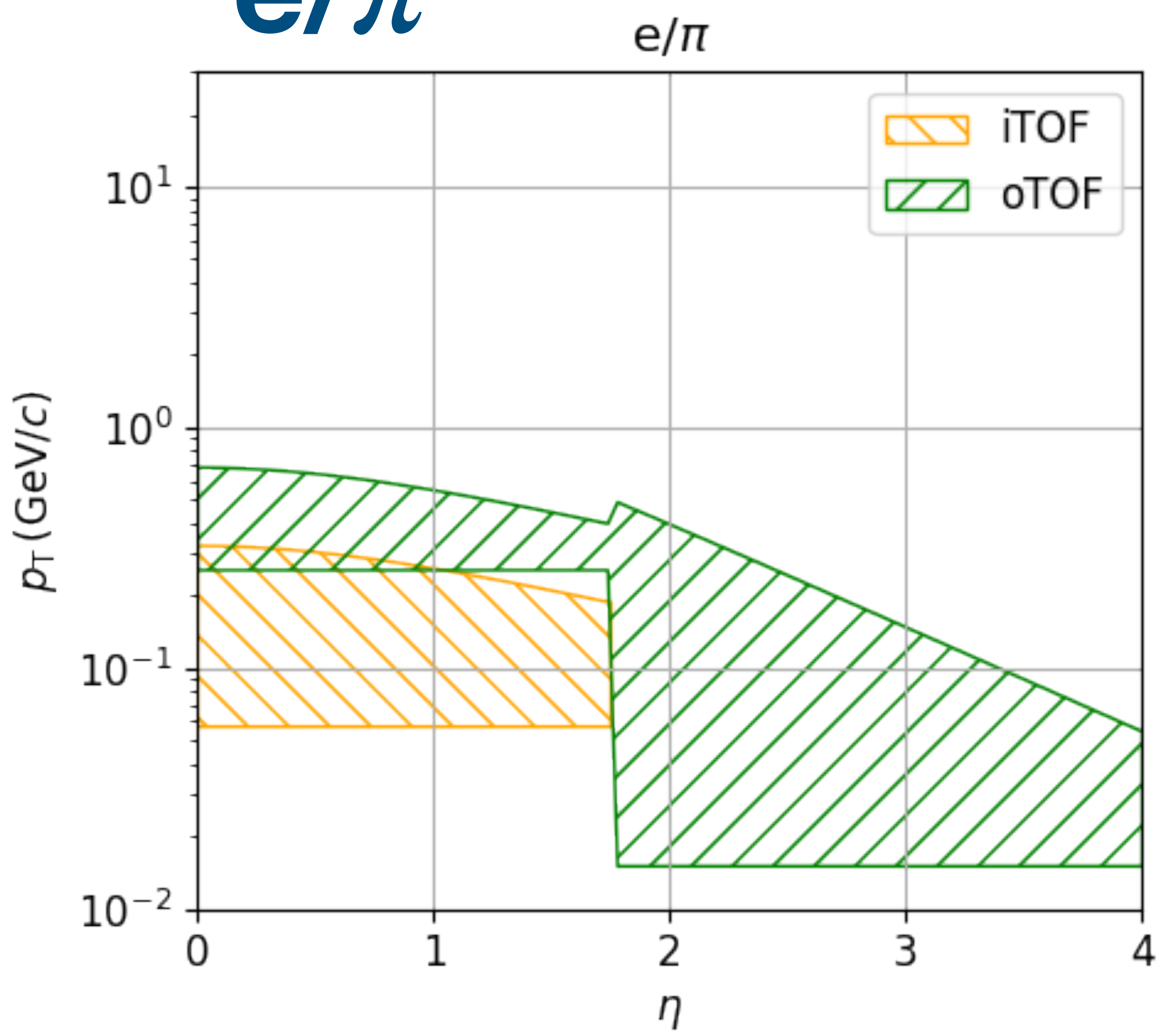


ARCADIA

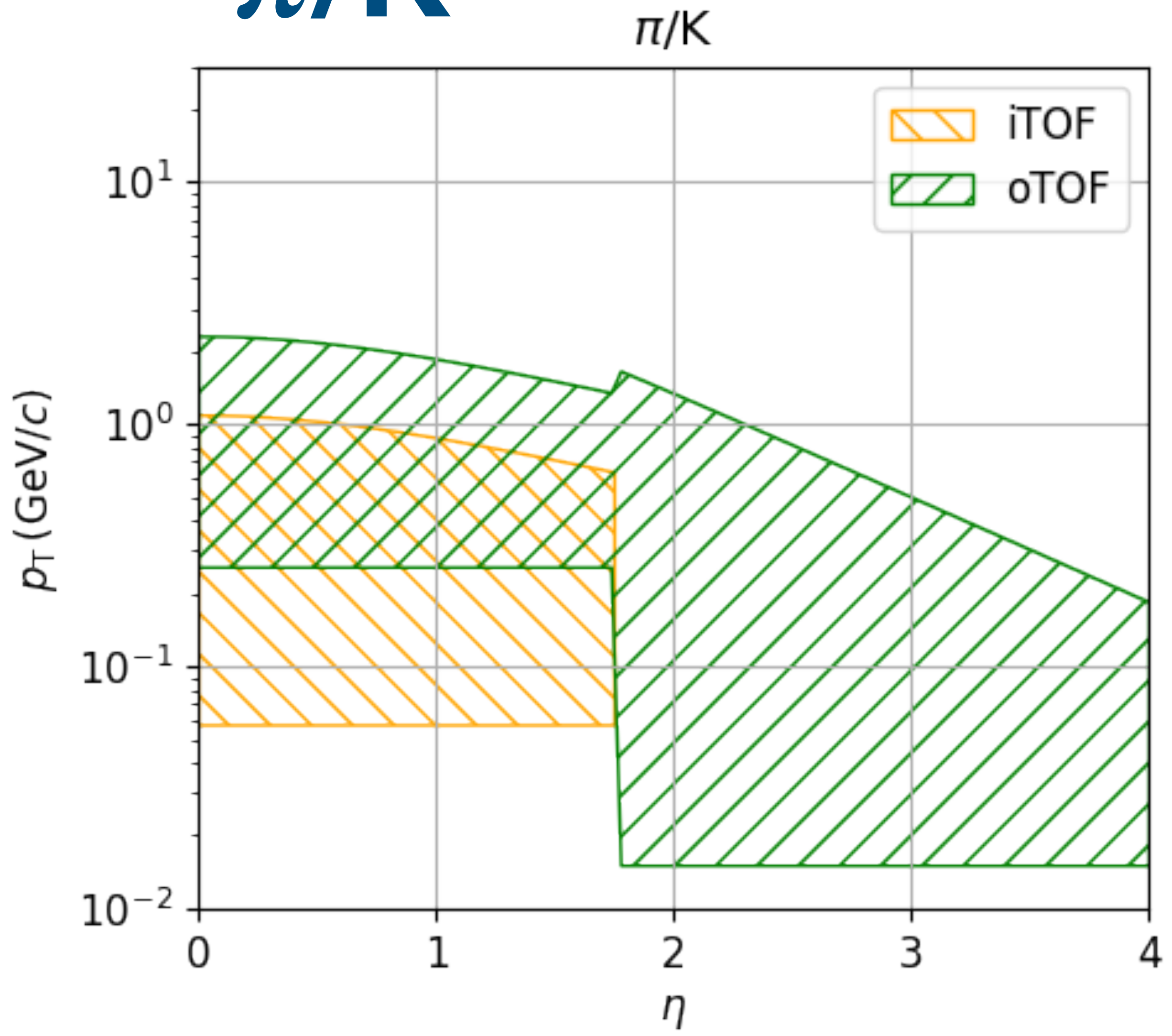


Total silicon area ~ 45 m²

e/π



π/K

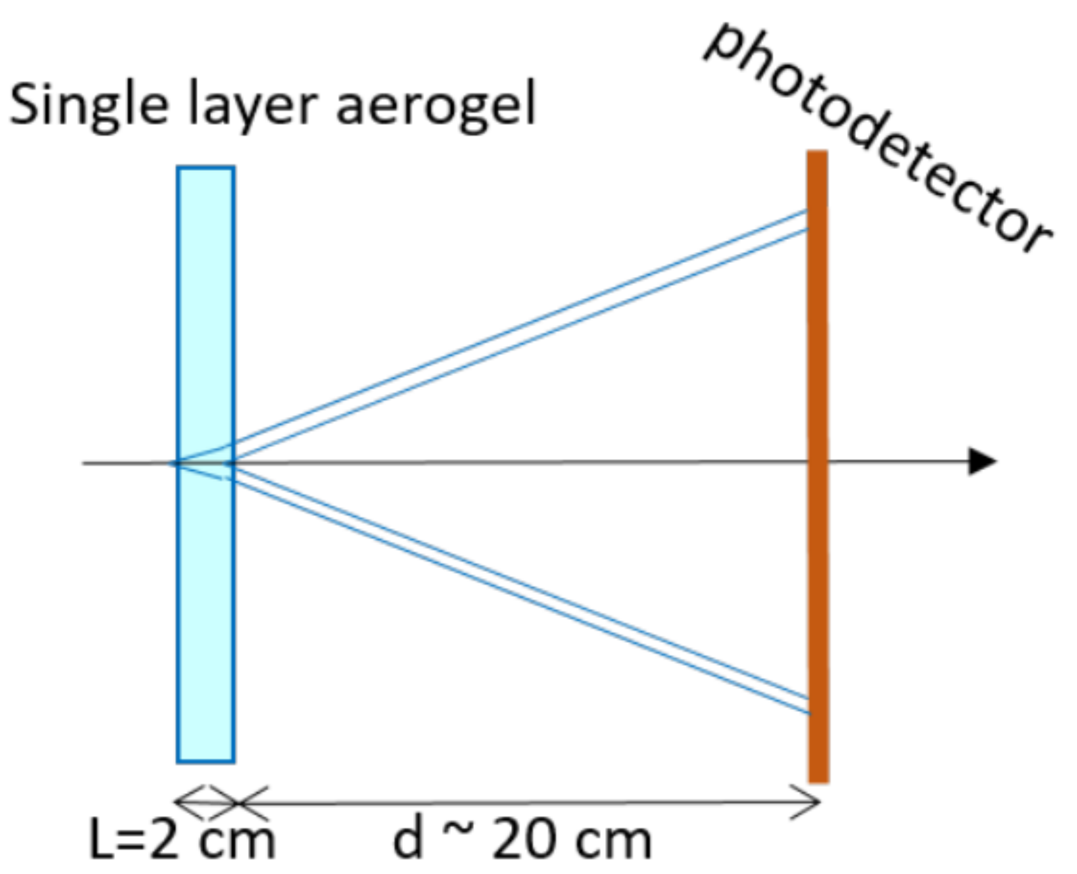


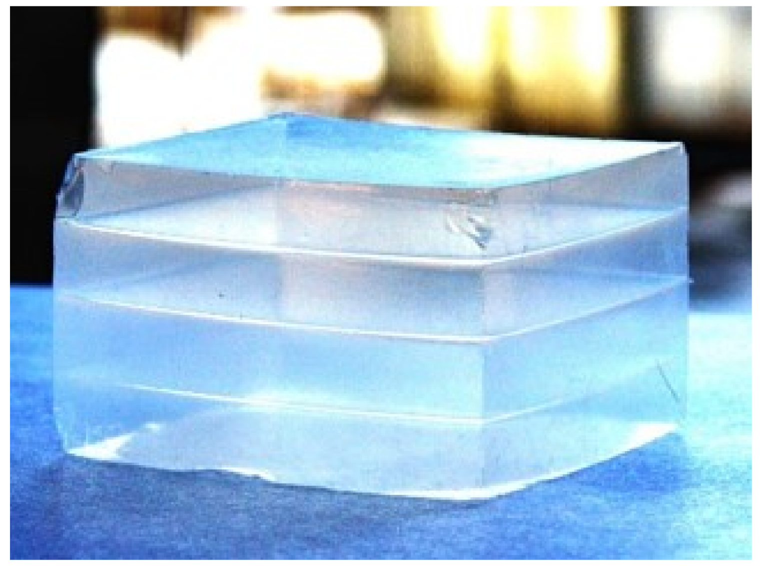
Particle identification with Cherenkov light

Complement PID reach of outer TOF to higher p_T with Cherenkov detector
→ Ensure continuous coverage with the TOF

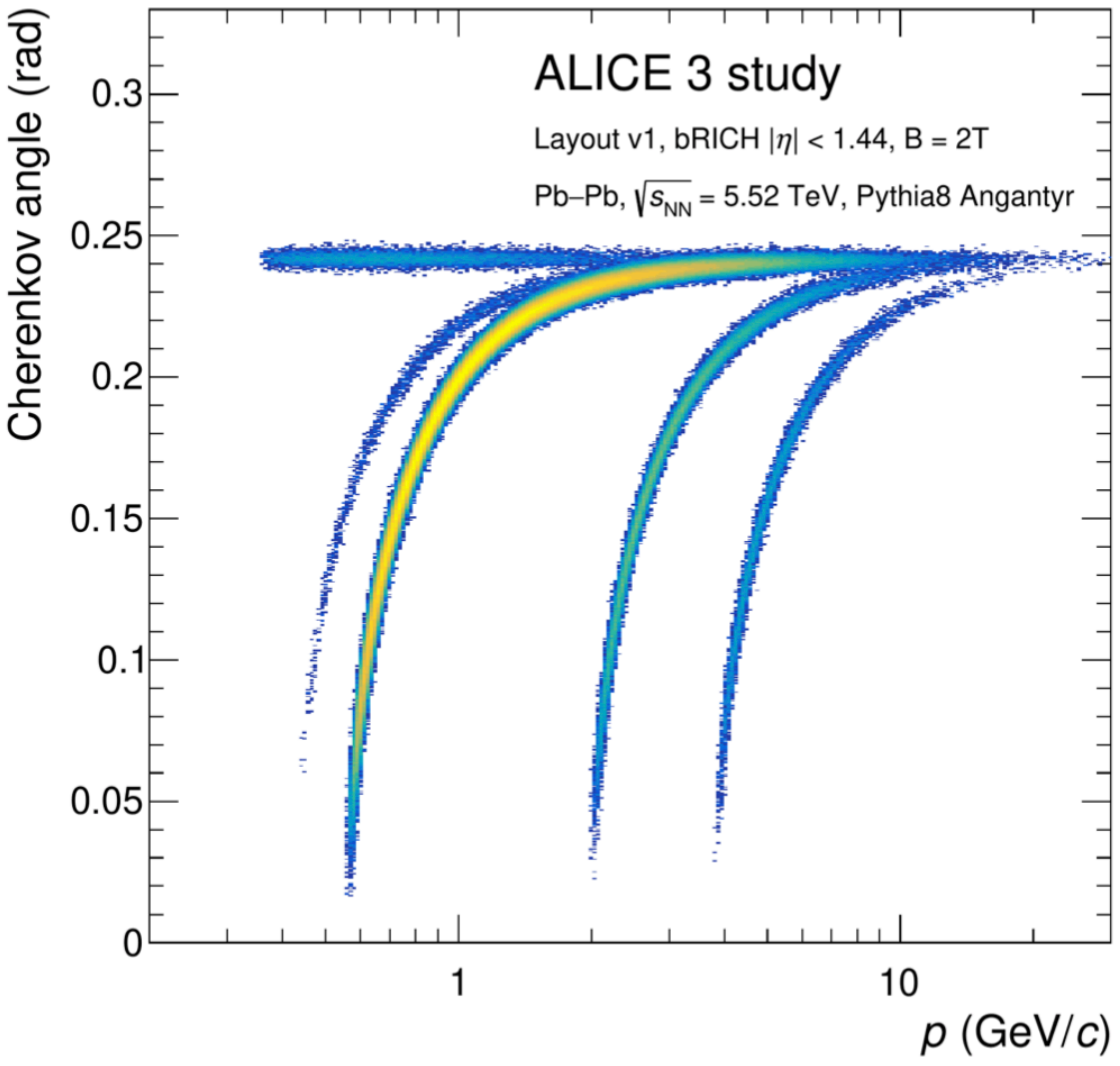
Aerogel radiator
- Refractive index n = 1.03 (barrel)
- Refractive index n = 1.006 (forward)

R&D on monolithic silicon photon sensors



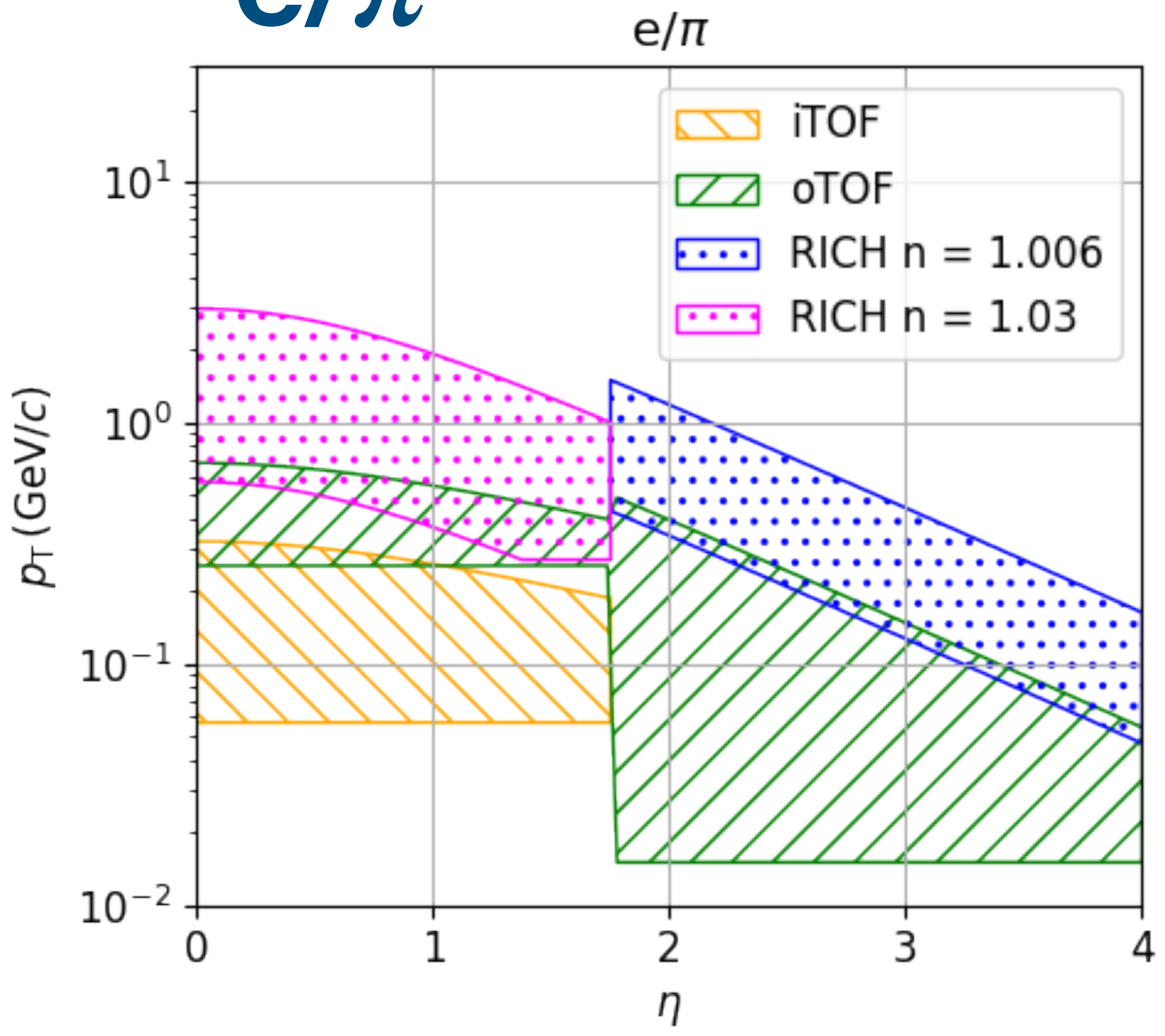


aerogel radiator

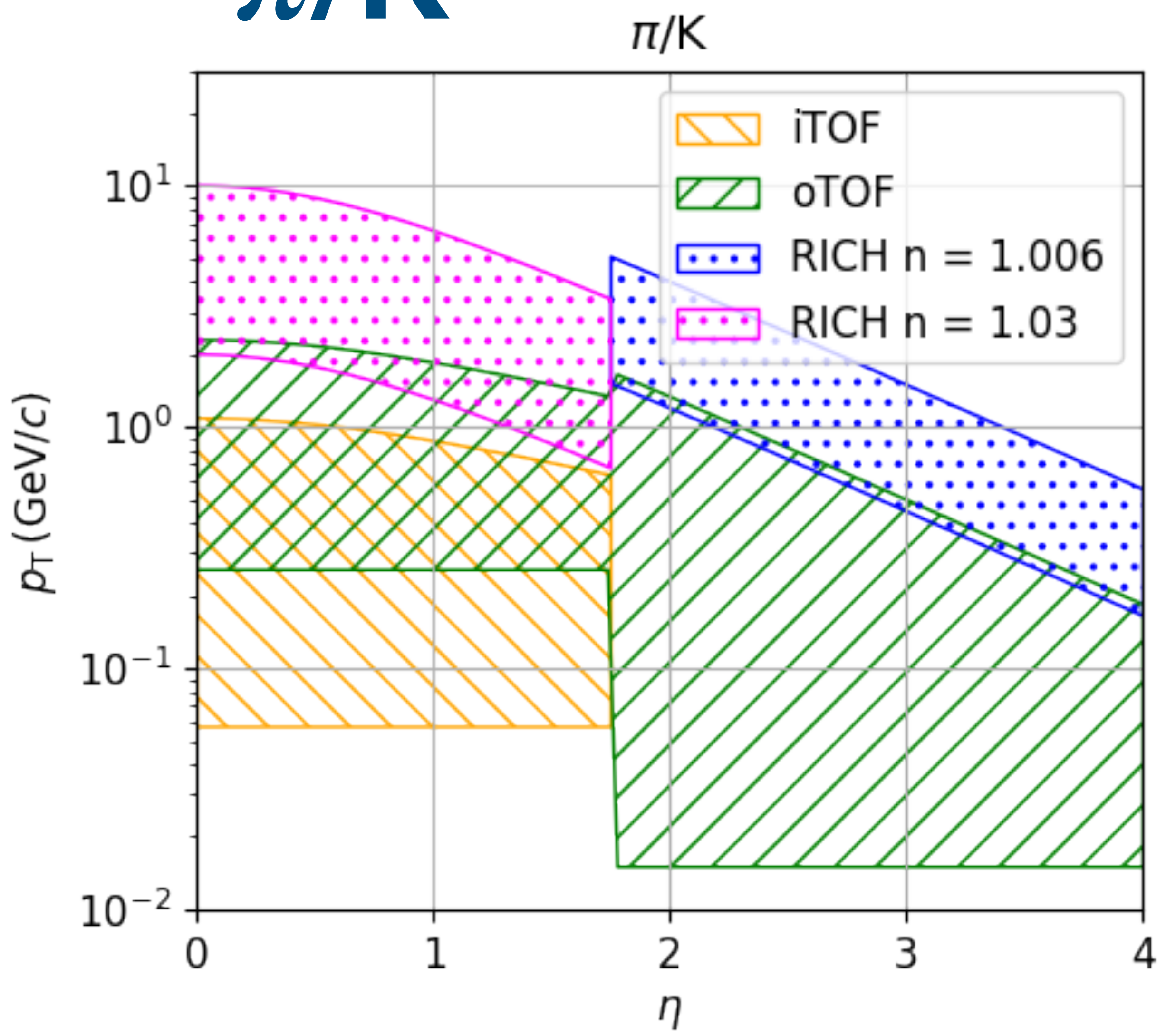


Total SiPM area ~ 60 m²

e/π



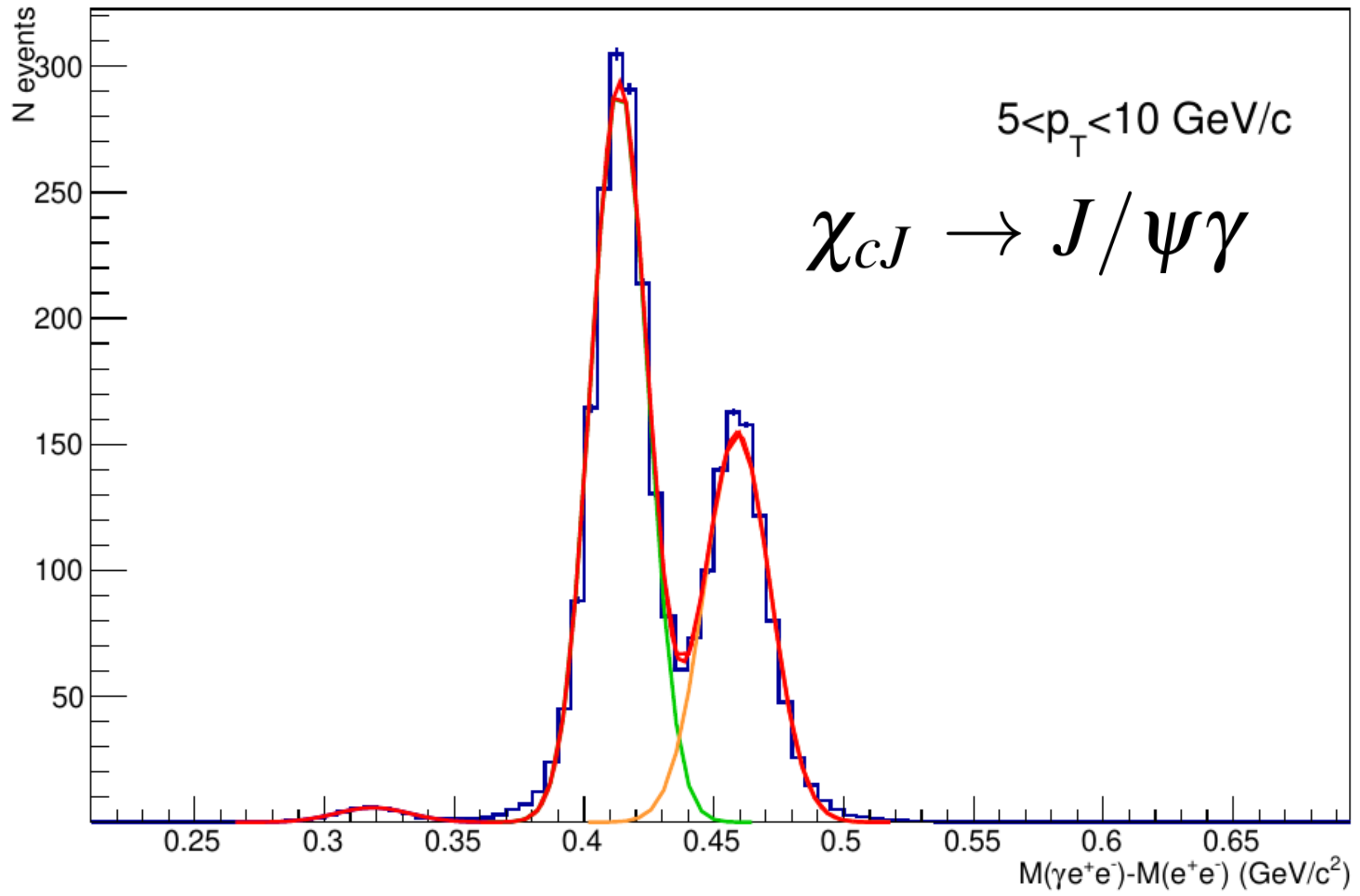
π/K



More on particle identification

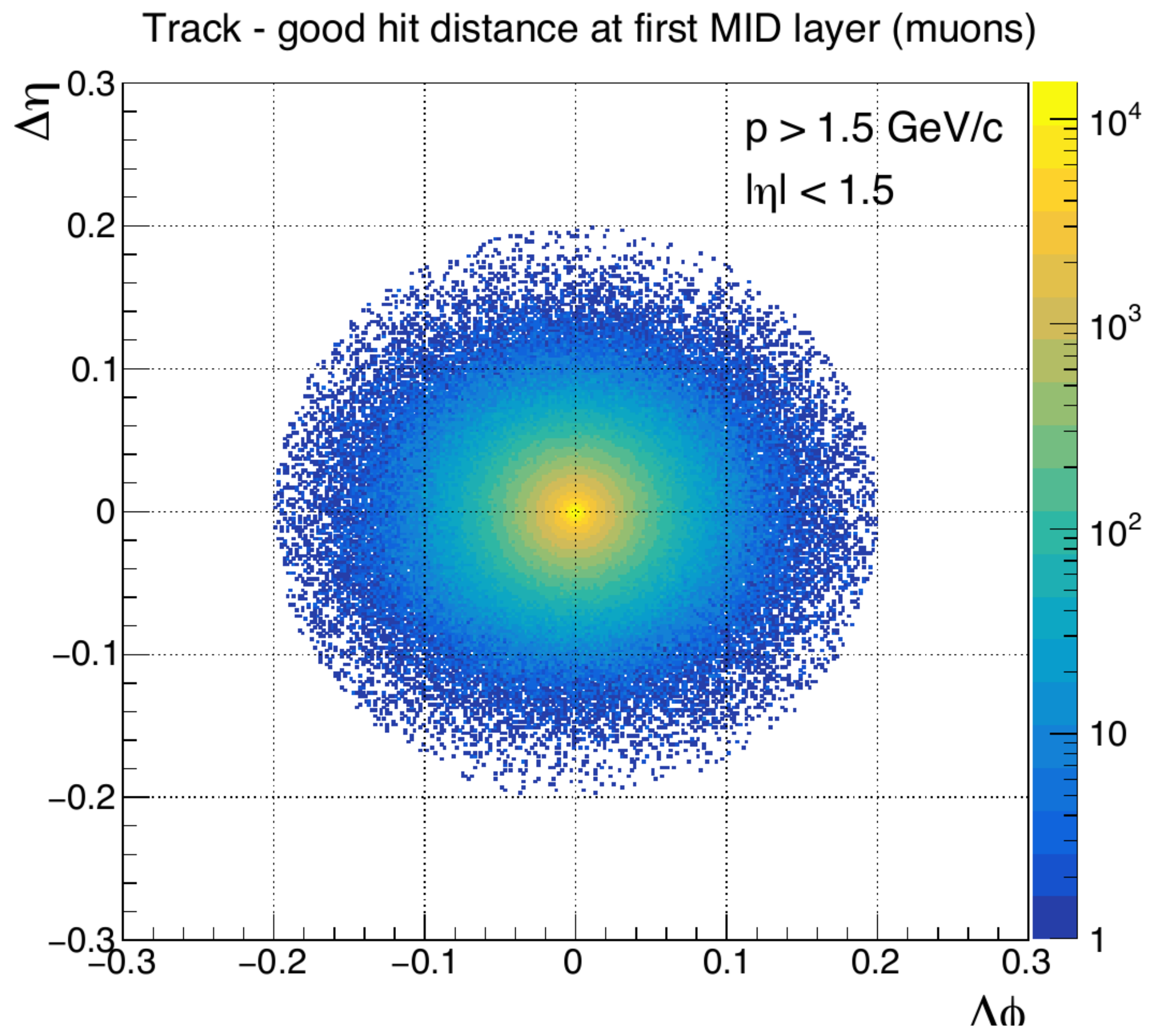
Large acceptance Electromagnetic calorimeter (2π coverage)

- Pb-scintillator sampling calorimeter + at $\eta \approx 0$ crystal calorimeter
- Photons + high p electrons identification
- Critical for measuring P-wave quarkonia and thermal radiation via real photons



Muon Identifier

- Absorber + 2 layers of muon detectors
- Muons down to $p_T \geq 1.5$ GeV/c
- Scintillator bars with SiPM read-out
- Possibility to use RPCs as muon chambers



Search spot for muons ~0.1 x 0.1 ($\eta \times \varphi$)

Forward conversion tracker

- Thin tracking disks in $3 < \eta < 5$ in its own dipole field
- Very low p_T photons ($\lesssim 10$ MeV/c)

R&D activities

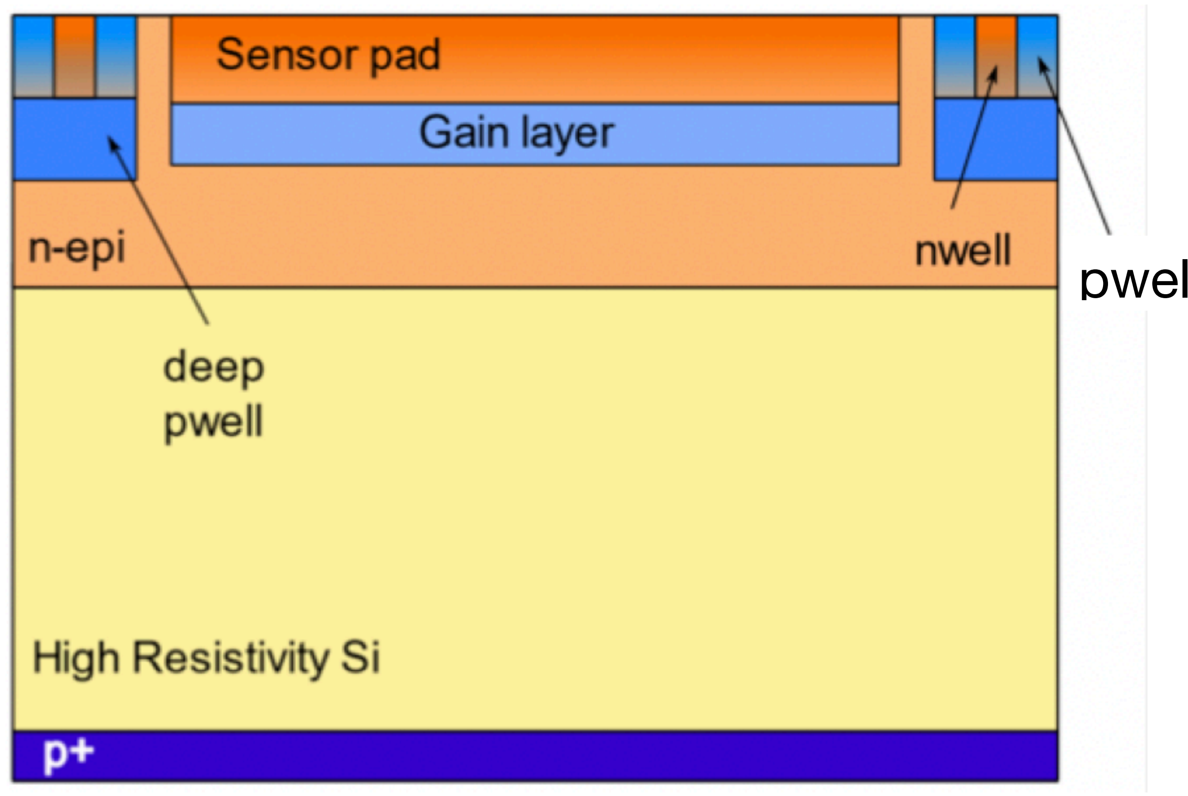
Silicon pixel sensors
- Thinning and bending of silicon sensors
  - Expand on experience with ITS3
- Exploration of new CMOS processes
  - First in-beam test with 65 nm process
- Modularization and industrialization

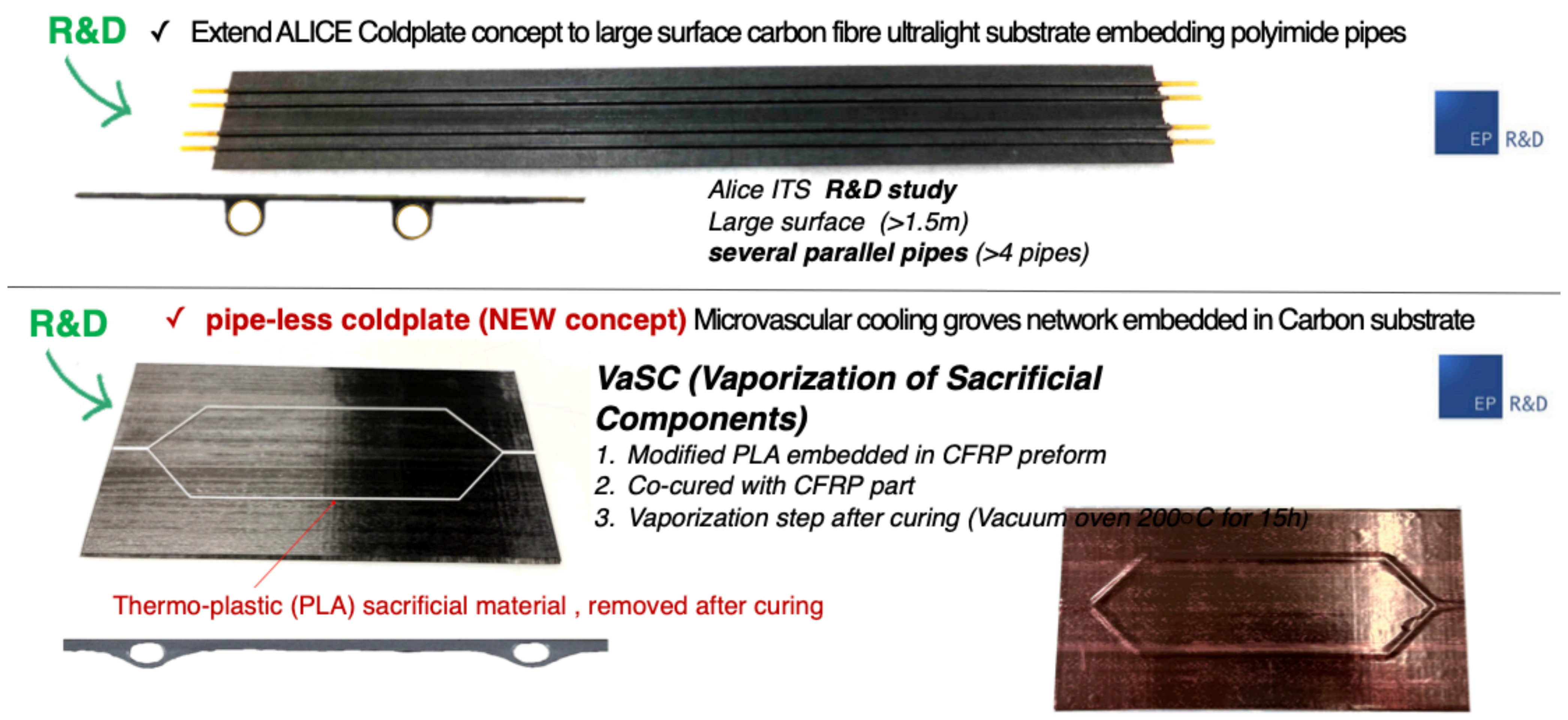
Silicon timing sensors
- Characterization of SPADs/SiPMs
  - First test in beam
- Monolithic timing sensors
  - Implement gain layers

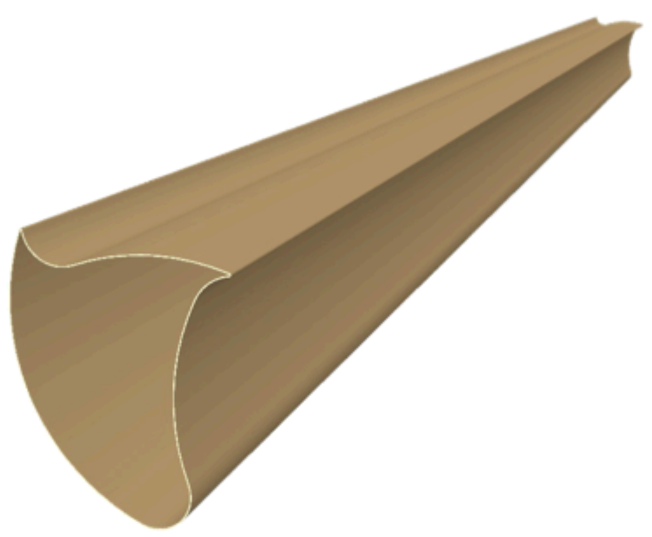
Photon sensors
- Monolithic SiPMs
  - Integrated read-out

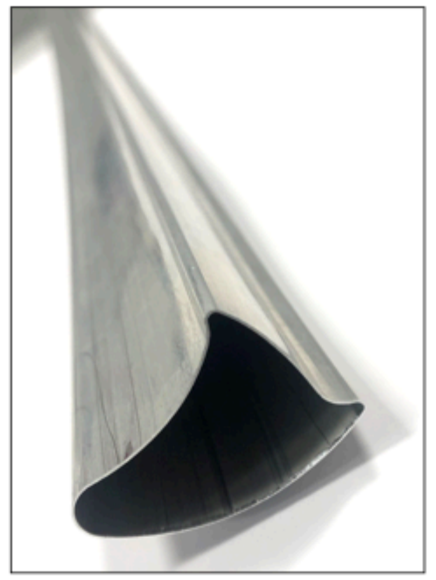
Detector mechanics and cooling
- Mechanics for operation in beam pipe
  - Establish compatible with LHC beam
- Minimization of material in the active volume
  - Micro-channel cooling

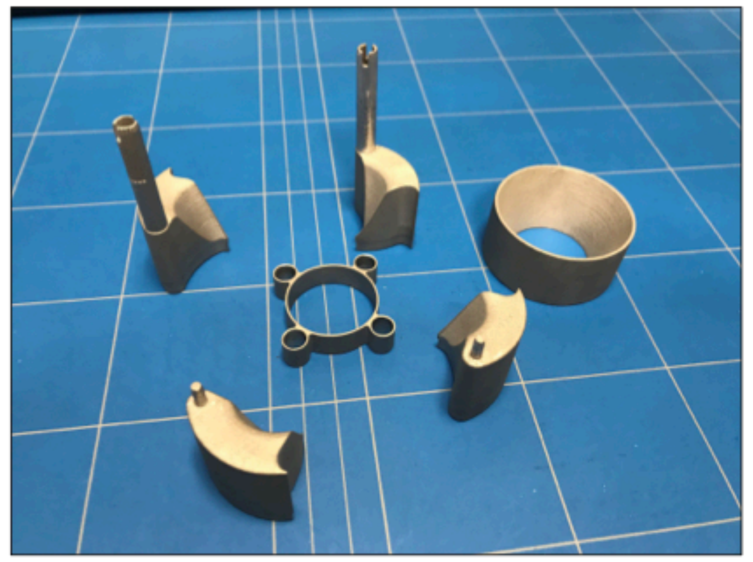
R&D has already started!











Summary and outlook

ALICE

ALICE 3 will provide access to fundamental properties of QCD matter at extreme energy density

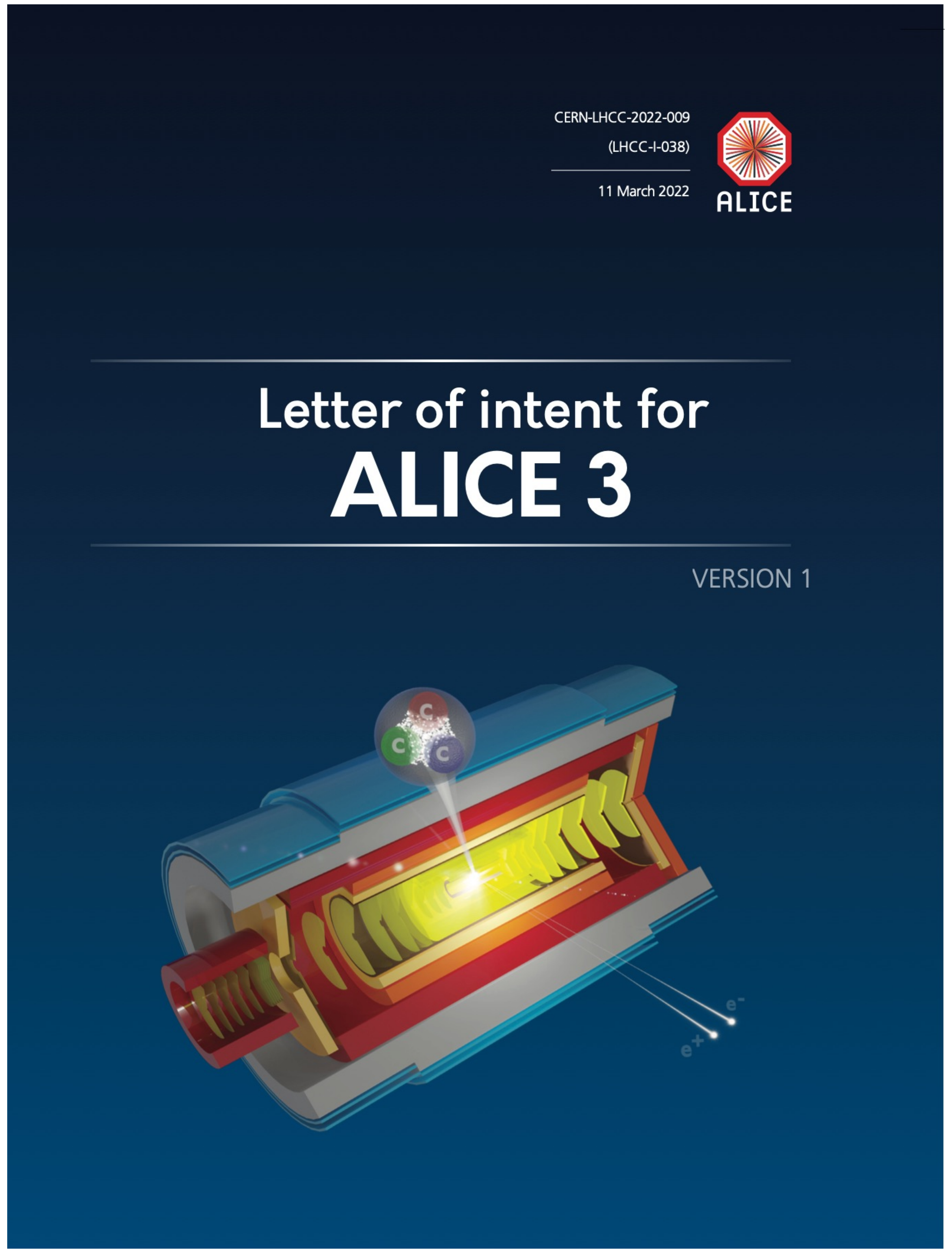
- Thermalization of heavy quarks
- Hadronisation and nature of hadronic states
- Partonic equation of state and its temperature dependence
- Deconfinement and chiral symmetry restorations, …

Novel detector concept based on innovative technologies

- Building on experience with cutting-edge technologies pioneered in ALICE
- Requiring R&D activities in several strategic areas

Planning

- **2023-25**: selection of technologies, small-scale proof of concept prototypes
- **2026-27**: large-scale engineered prototypes → Technical Design Reports
- **2028-31**: construction and testing
- **2032**: contingency
- **2033-34**: installation and commissioning



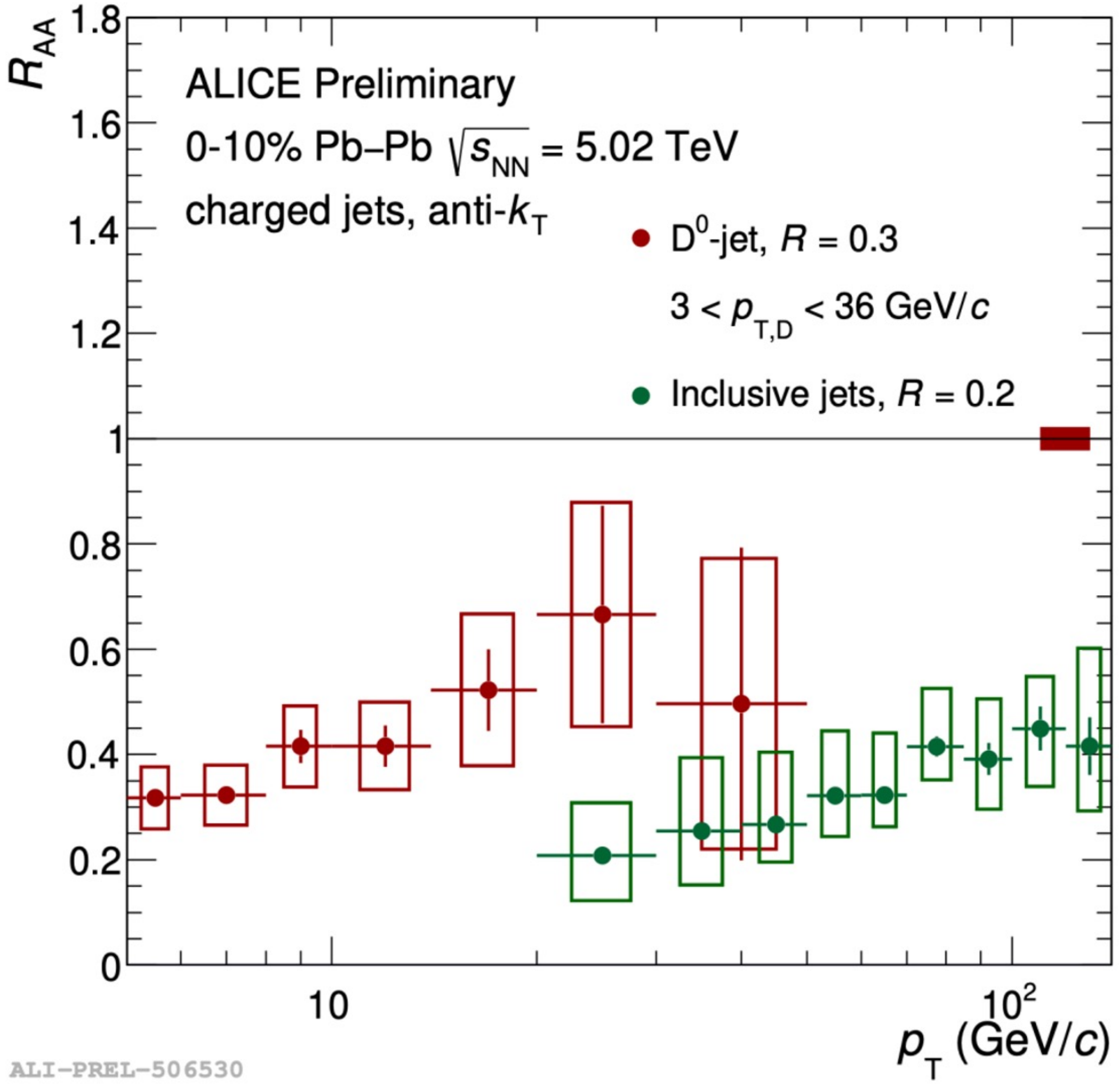
CERN-LHCC-2022-009

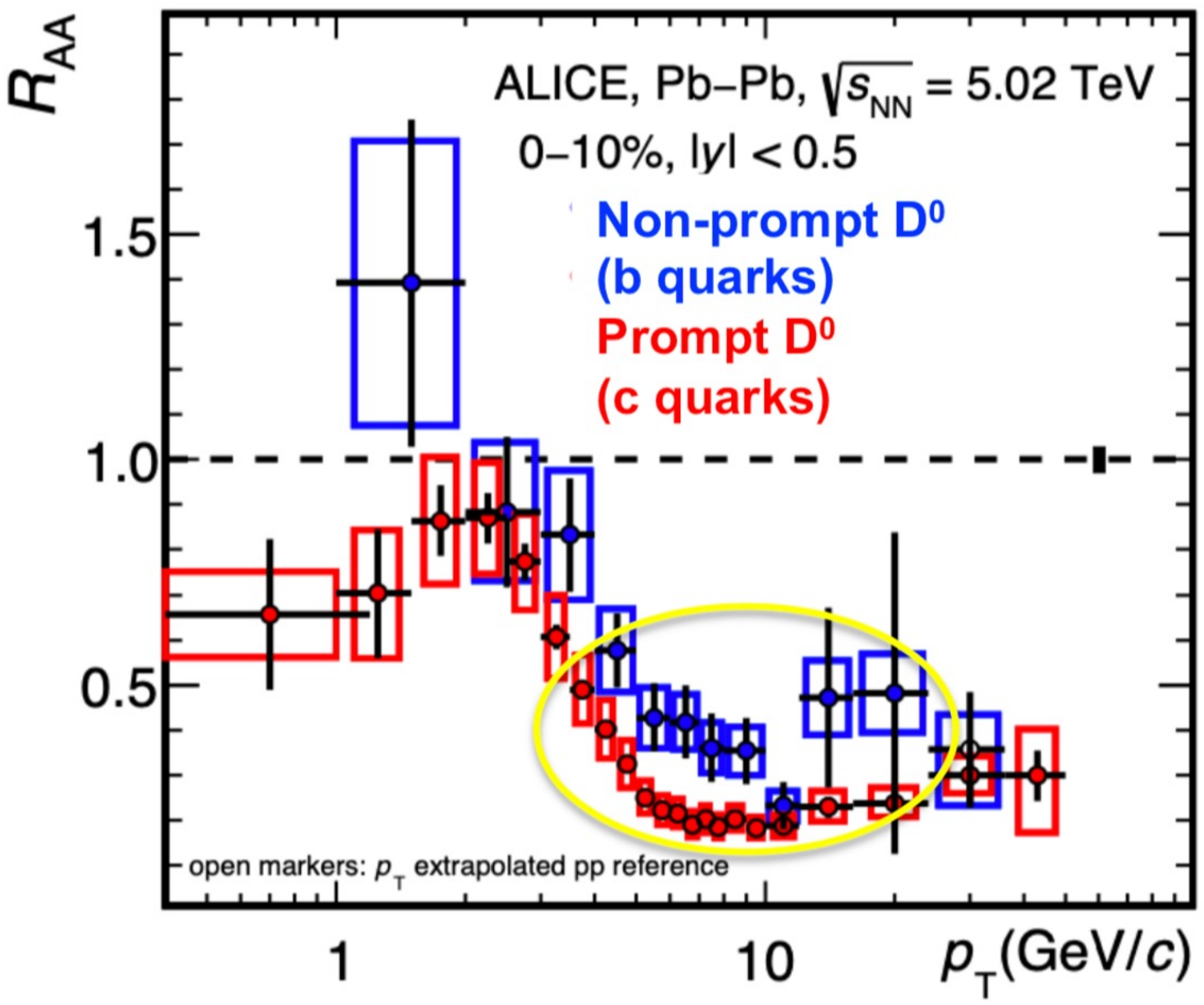
Letter of Intent submitted in 2021
LHCC review → Recommendation to proceed with **R&D program**

Thank you for your attention!

Heavy quark energy loss

Run 1+2





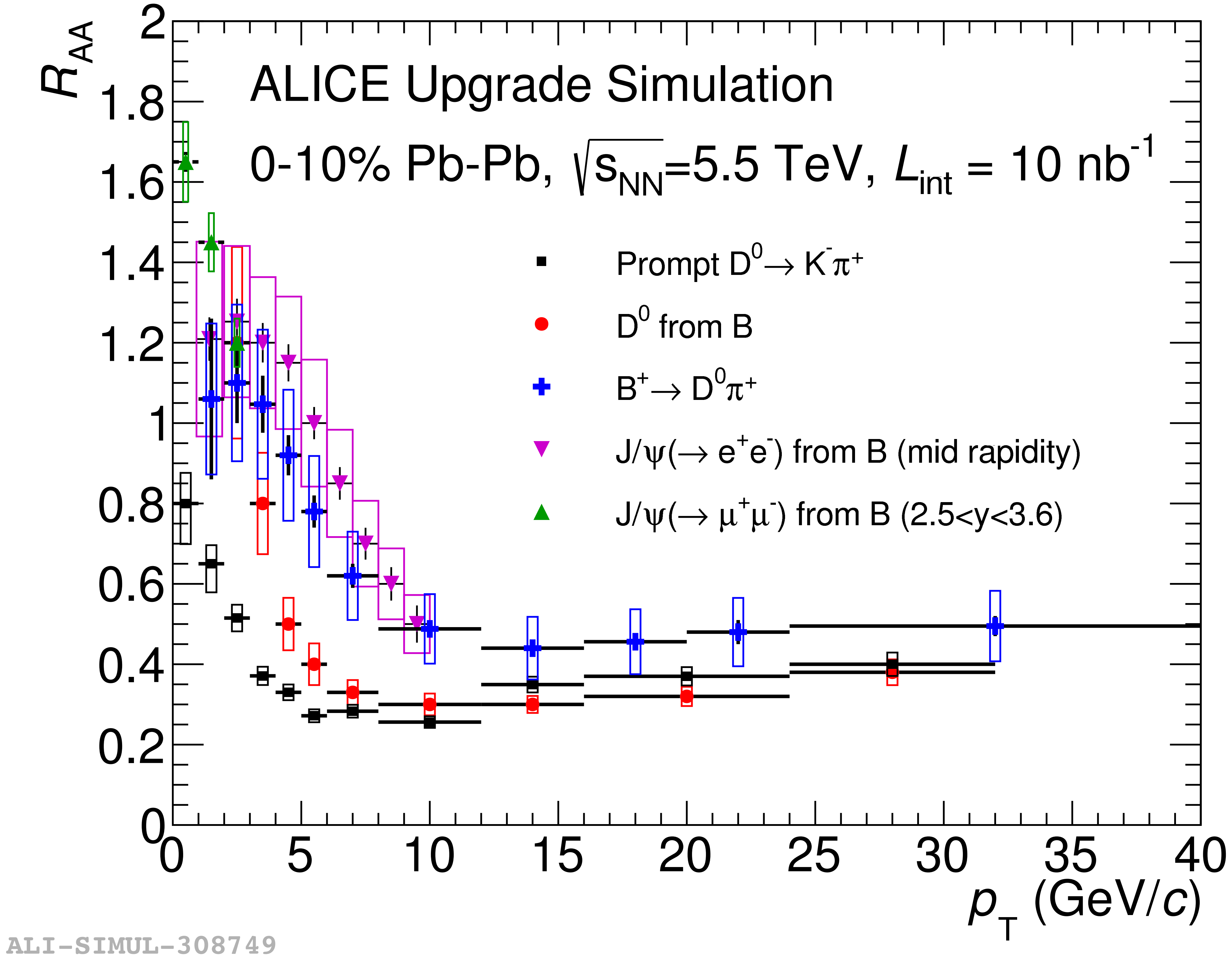
Hint of a higher R_{AA} of D^0-jets compared to inclusive jets in Pb-Pb

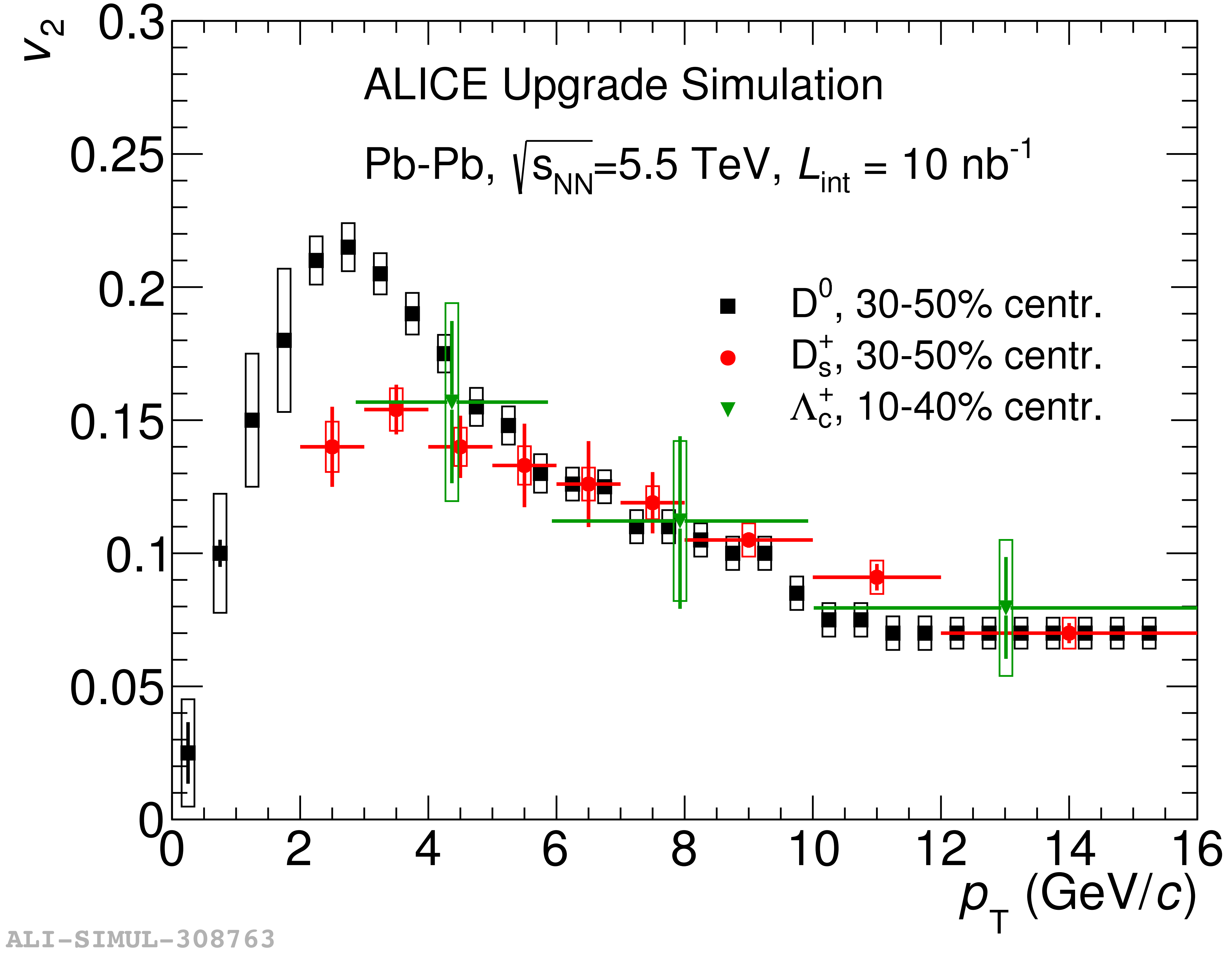
- Quark vs. gluon energy loss
- Mass effects (dead cone)

Less suppression for non-prompt D mesons from B decay than prompt D mesons

Determining transport coefficients: heavy flavour

Run 3+4

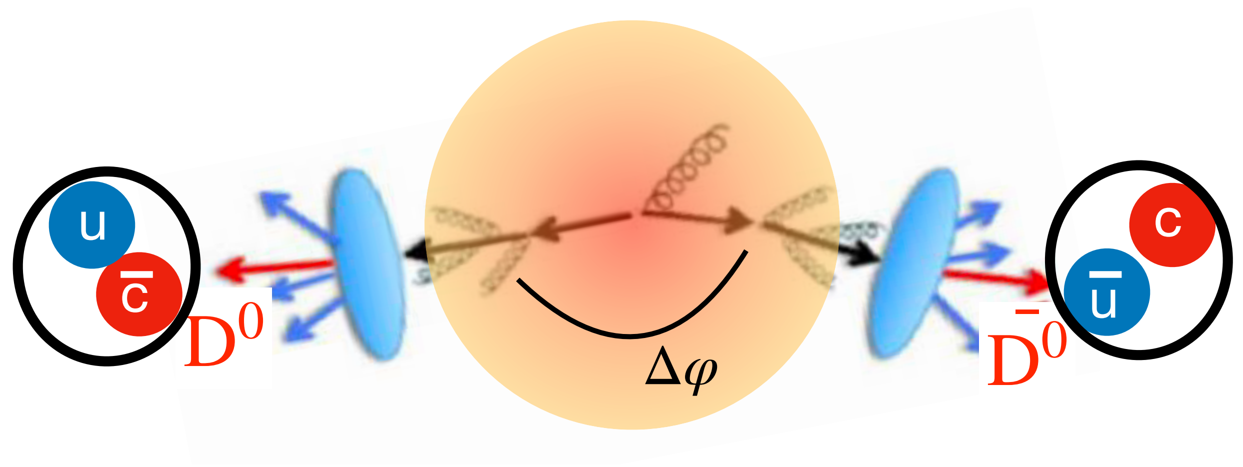




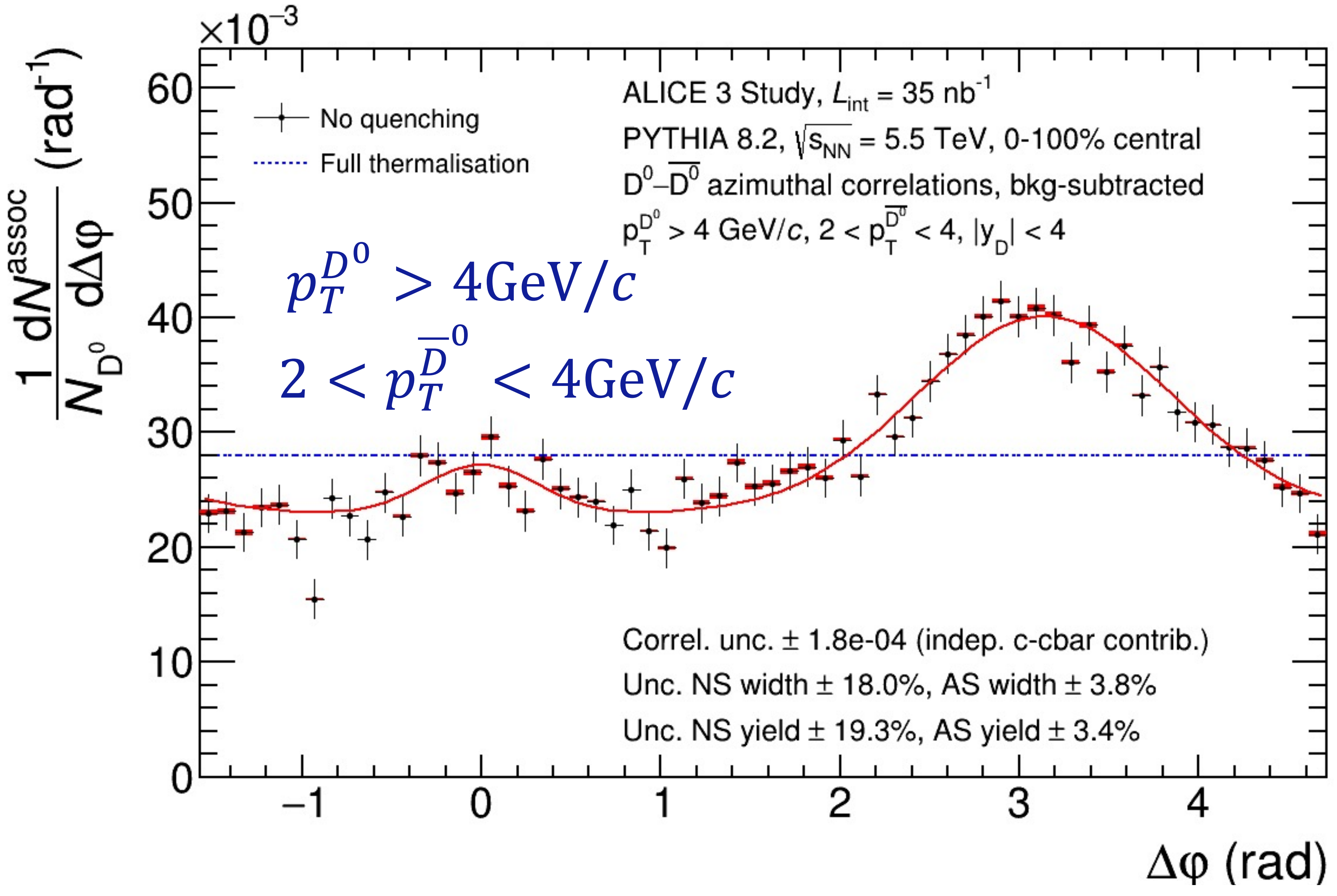
Run 3+4: high-precision beauty measurements; heavy flavor baryons

$D\bar{D}$ azimuthal correlations

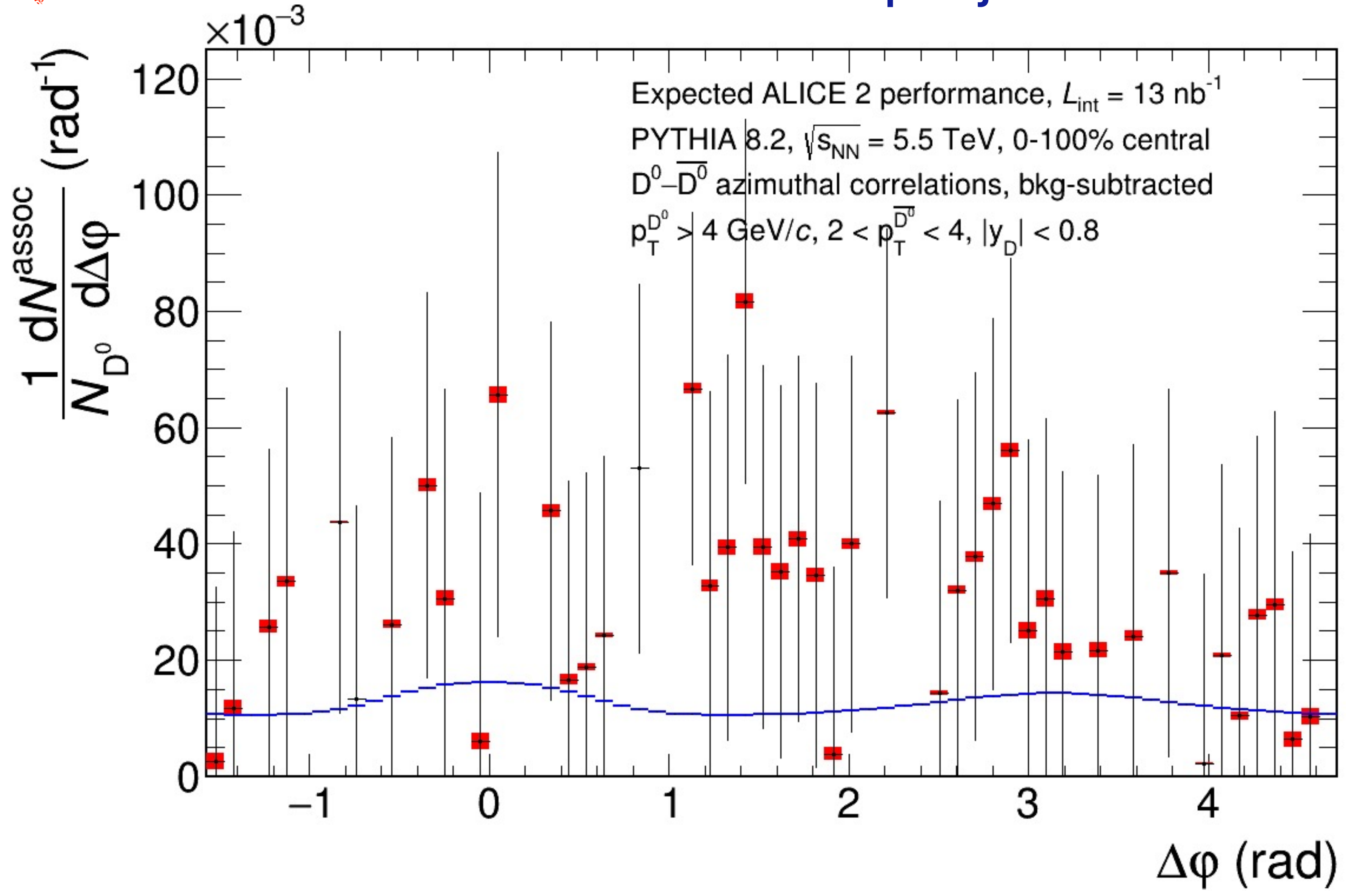
Run 5

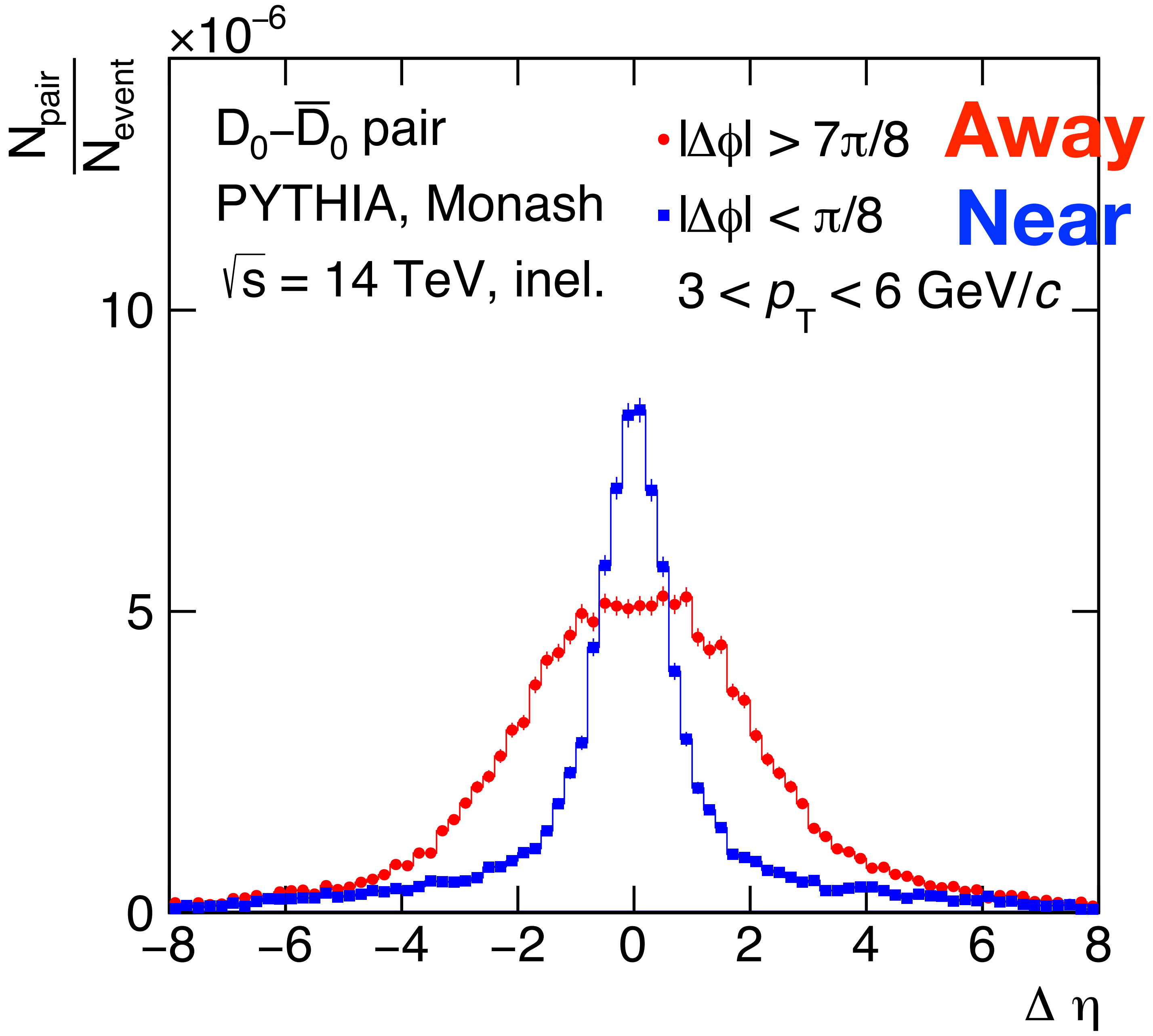


ALICE 3 projection: $D\bar{D}$ correlations



ALICE Run 3 + 4 projection





Angular decorrelation directly probes QGP scattering

- Sensitive to energy loss mechanisms, degree of thermalisation
- Strongest signal at low p_T

Very challenging measurement: need good purity, efficiency and η coverage

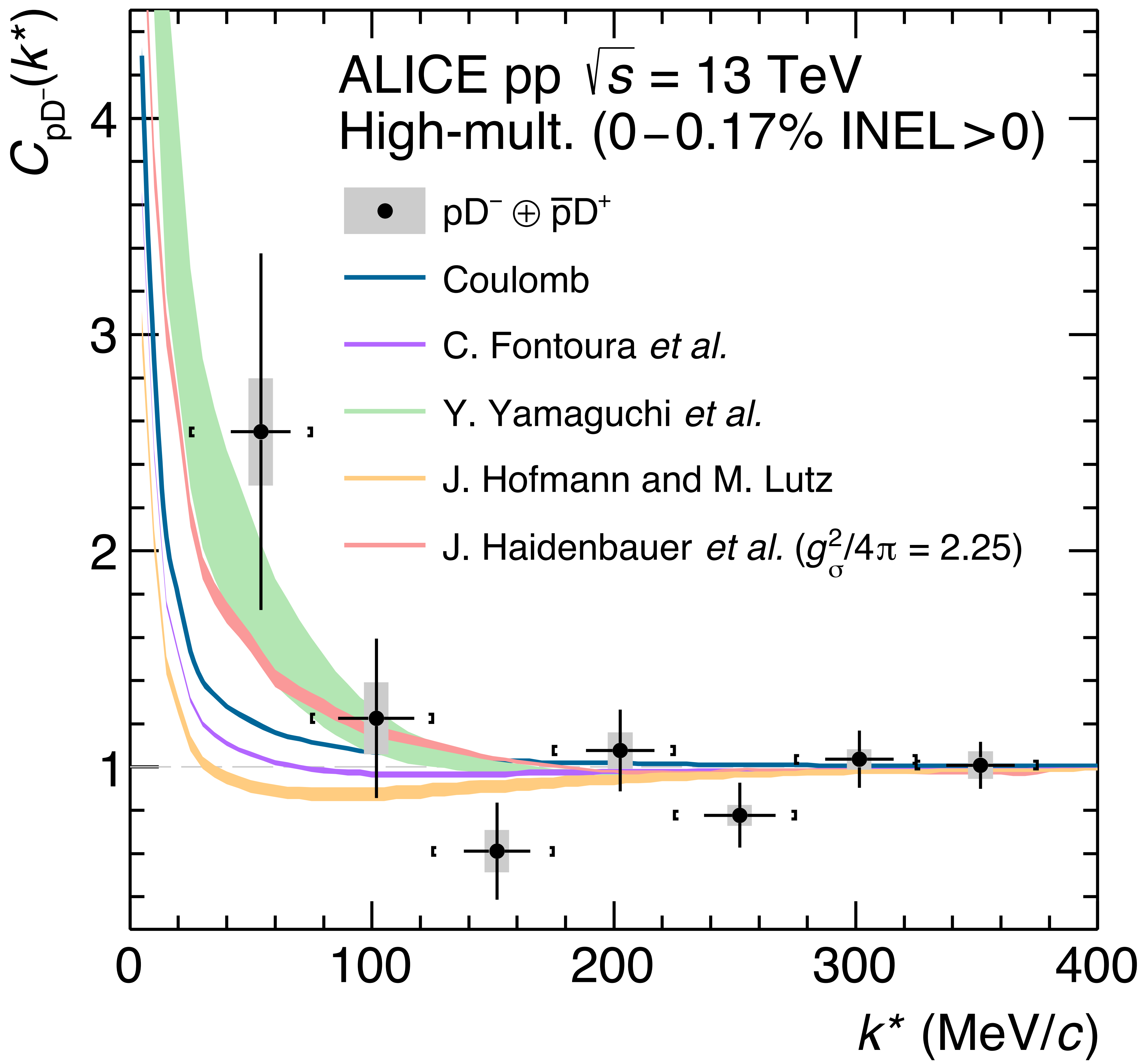
Heavy-ion measurement only possible with ALICE 3!

Final state interaction

Run 1+2

ALICE

arXiv:2201.05352



First measurement of correlation functions involving charm hadrons

- allows access to the strong interaction between a proton and a charm meson

p-D⁻: genuine pD⁻ correlation function reflects the pattern of an overall attractive interaction

- degree of consistency improves when considering, in addition, state-of-the-art models that predict an attractive strong ND interaction with or without a bound state

Paves the way for precision studies of the strong interactions involving charm hadrons!

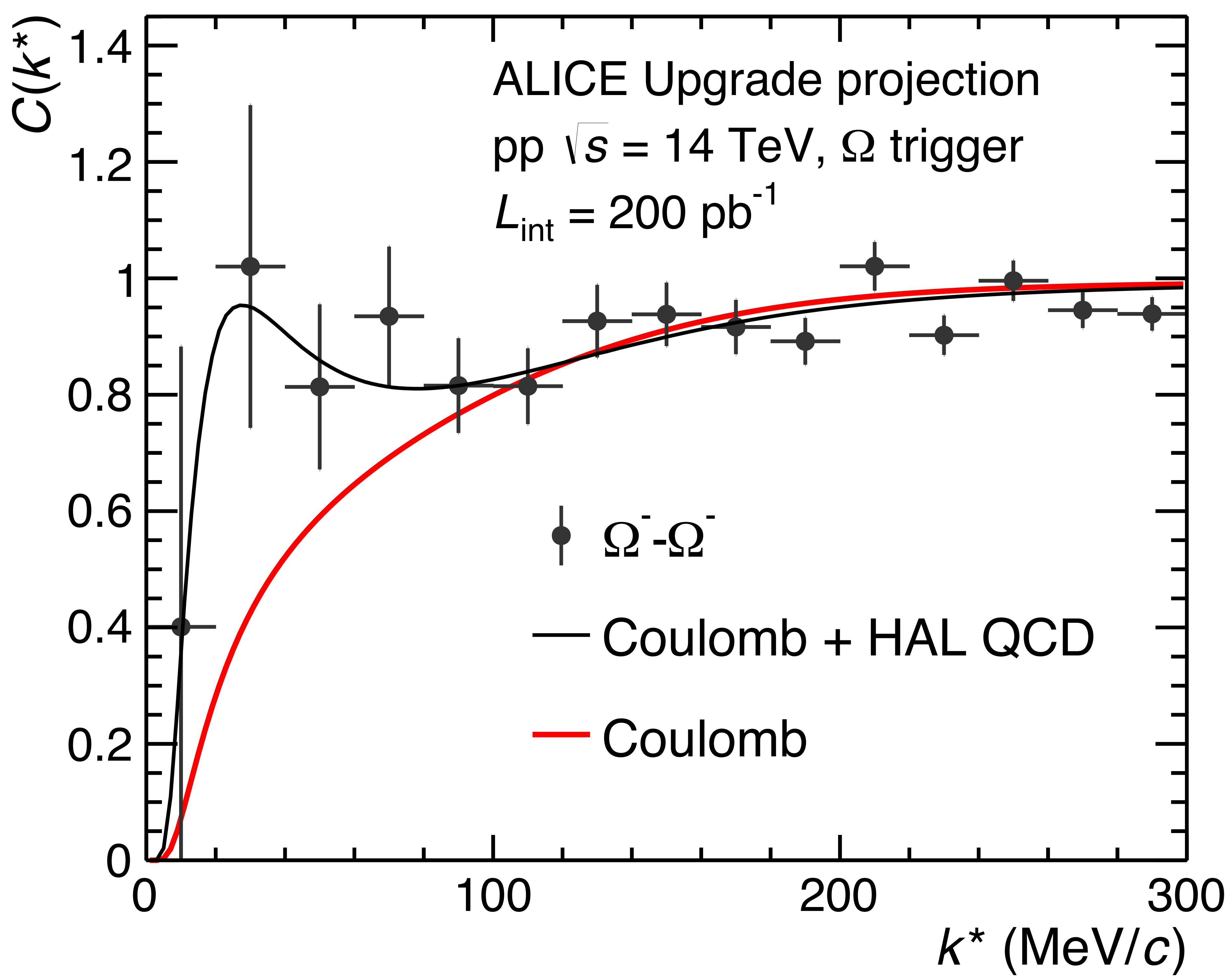
Model	f_0 (I = 0)	f_0 (I = 1)	n_σ
Coulomb			(1.1–1.5)
Haidenbauer et al. [21]			
– $g^2_\sigma/4\pi = 1$	0.14	−0.28	(1.2–1.5)
– $g^2_\sigma/4\pi = 2.25$	0.67	0.04	(0.8–1.3)
Hofmann and Lutz [22]	−0.16	−0.26	(1.3–1.6)
Yamaguchi et al. [24]	−4.38	−0.07	(0.6–1.1)
Fontoura et al. [23]	0.16	−0.25	(1.1–1.5)

Final state interaction

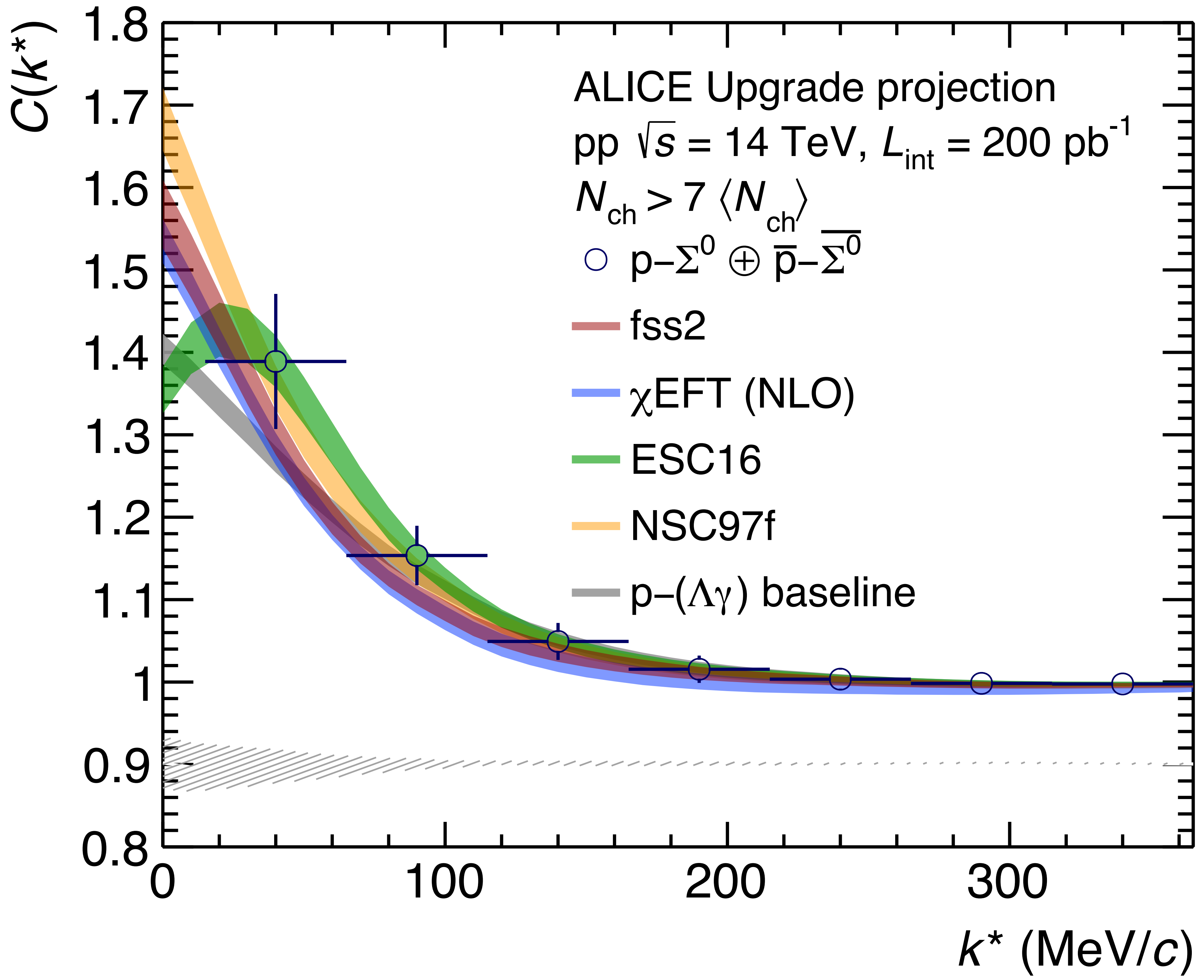
Run 3+4

ALICE

Ω-Ω correlations



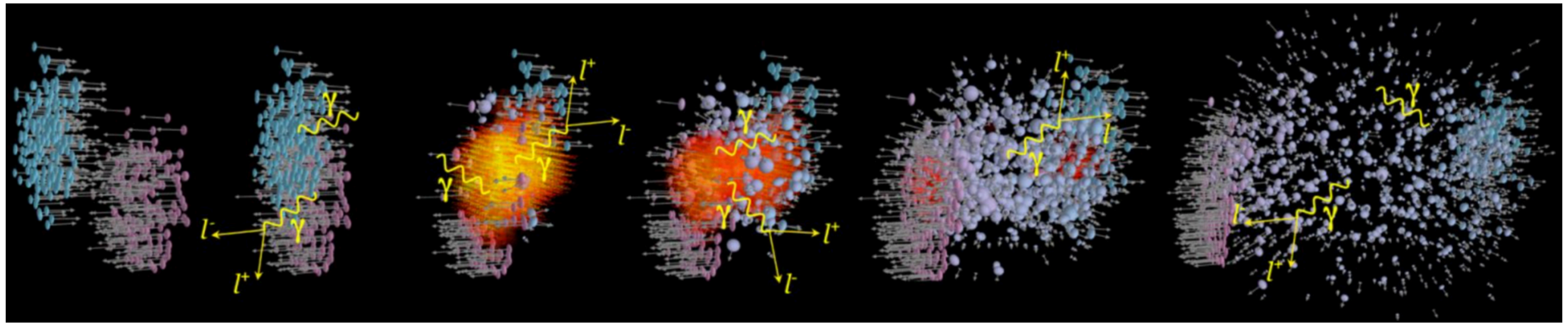
p-Σ correlations



ALICE pp program document

Probe interaction potential a the fm scale!

Electromagnetic radiation

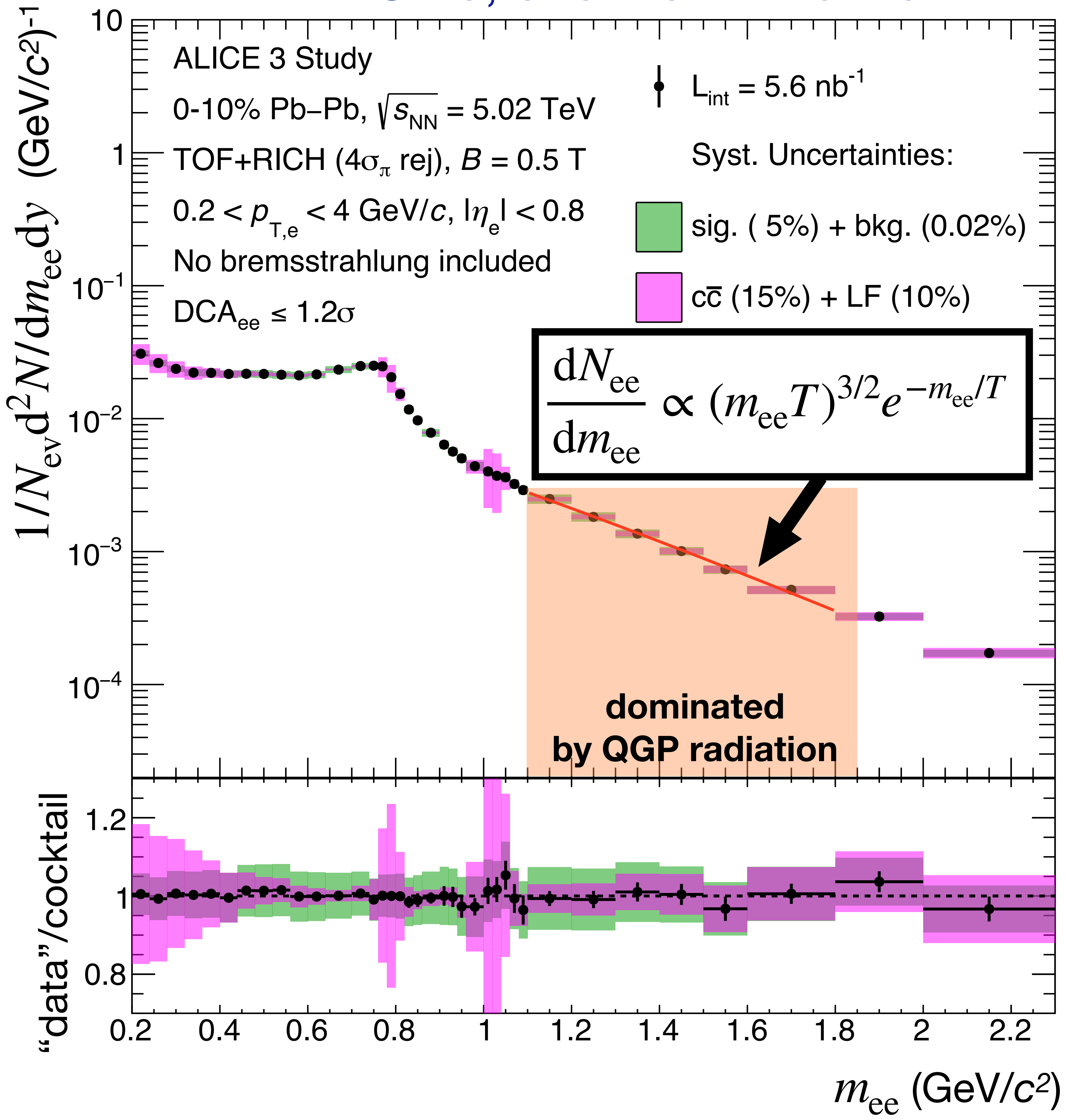


Determination of QGP temperature throughout the evolution requires precision measurement of dielectrons

- Average temperature T of the QGP using thermal dielectron m_{ee} spectrum at $m_{ee} > 1.1$ GeV/c^2 (QGP radiation dominated)
- **Extremely challenging** because of backgrounds → need small detector material budget to minimize γ conversion background & excellent pointing resolution to suppress heavy-flavor decay electrons

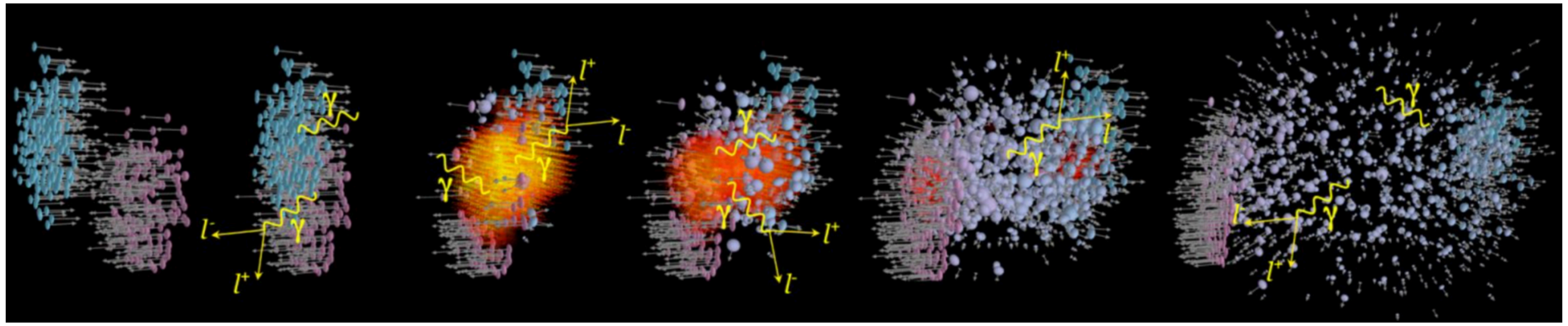
Possible with ALICE 3 thanks to excellent pointing resolution + small material budget

Projection for thermal dielectron m_{ee}
ALICE 3, one month Pb-Pb

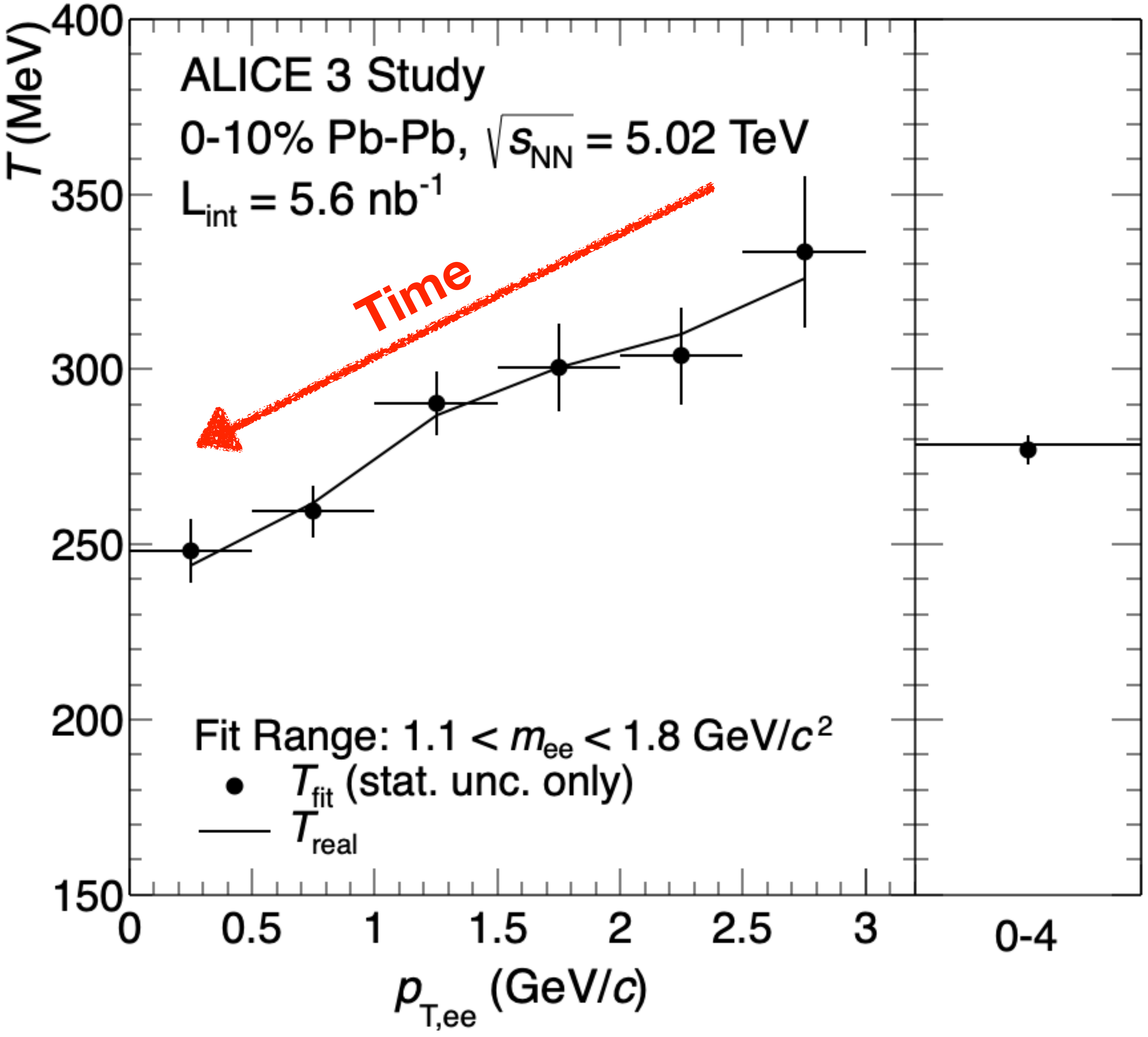


R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103
ALICE CERN-LHCC-2022-009

Electromagnetic radiation



Expected statistical errors of T as a function of $p_{T,ee}$
ALICE 3, one month Pb-Pb



First T measurements in Run 3 and 4

ALICE 3: probe time dependence of T

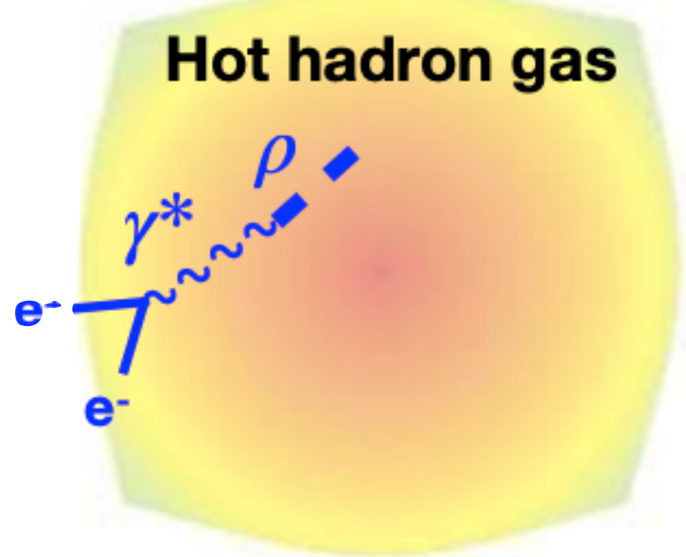
- Double differential spectra: T vs mass, $p_{T,ee}$

Complementary measurements with real photons

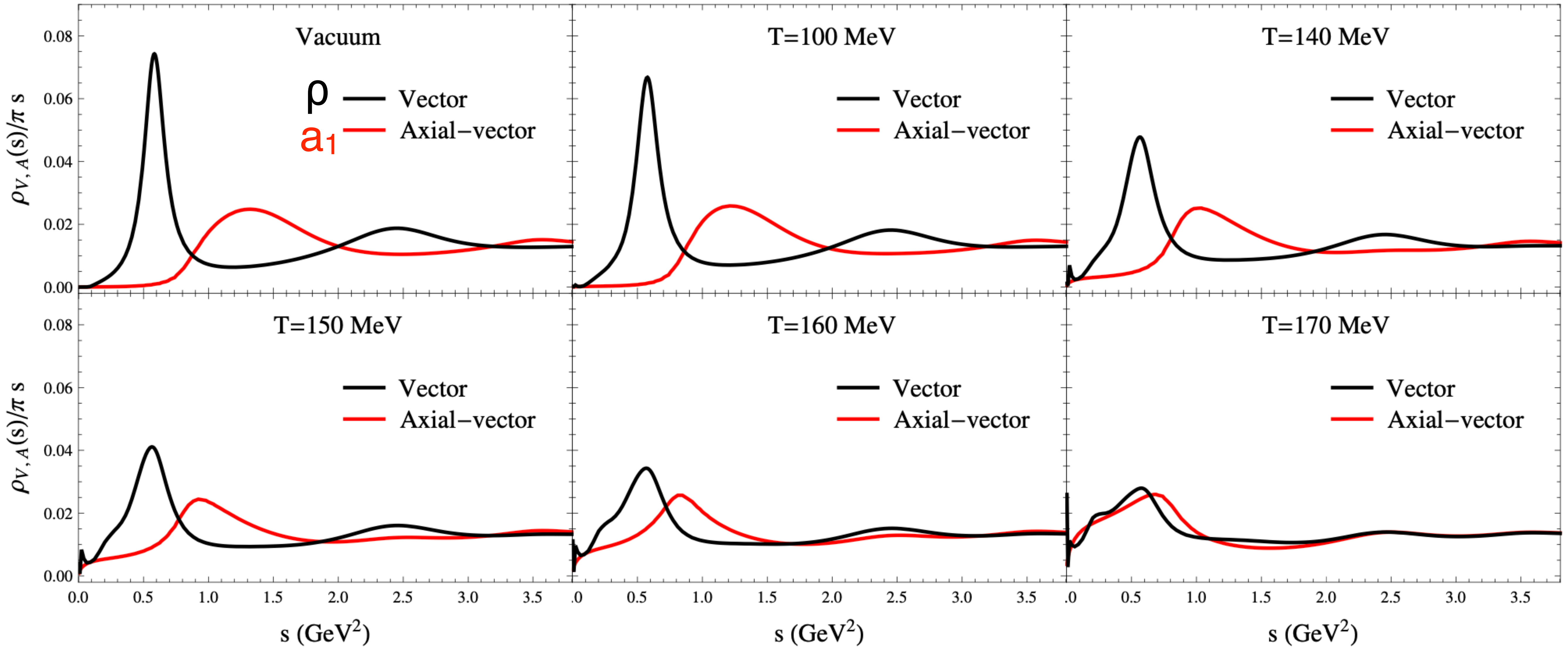
Chiral symmetry restoration

Study chiral symmetry restoration (CSR) mechanisms using thermal dielectron spectrum m_{ee} at m_{ee} < 1.2 GeV/c^2

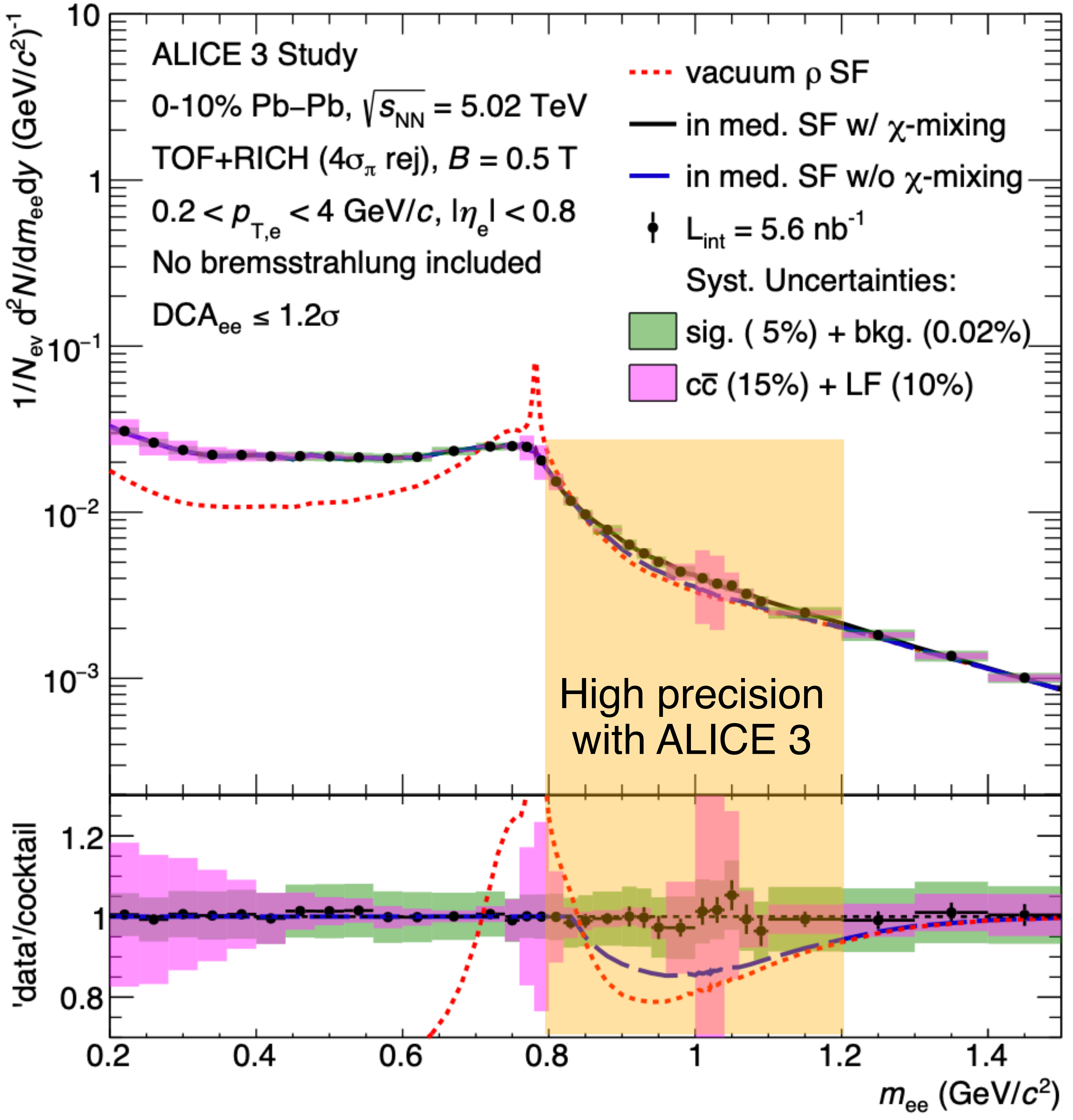
- Thermal production of ρ
- ρ sensitive to surrounding medium
- Modification of ρ spectral function related to CSR

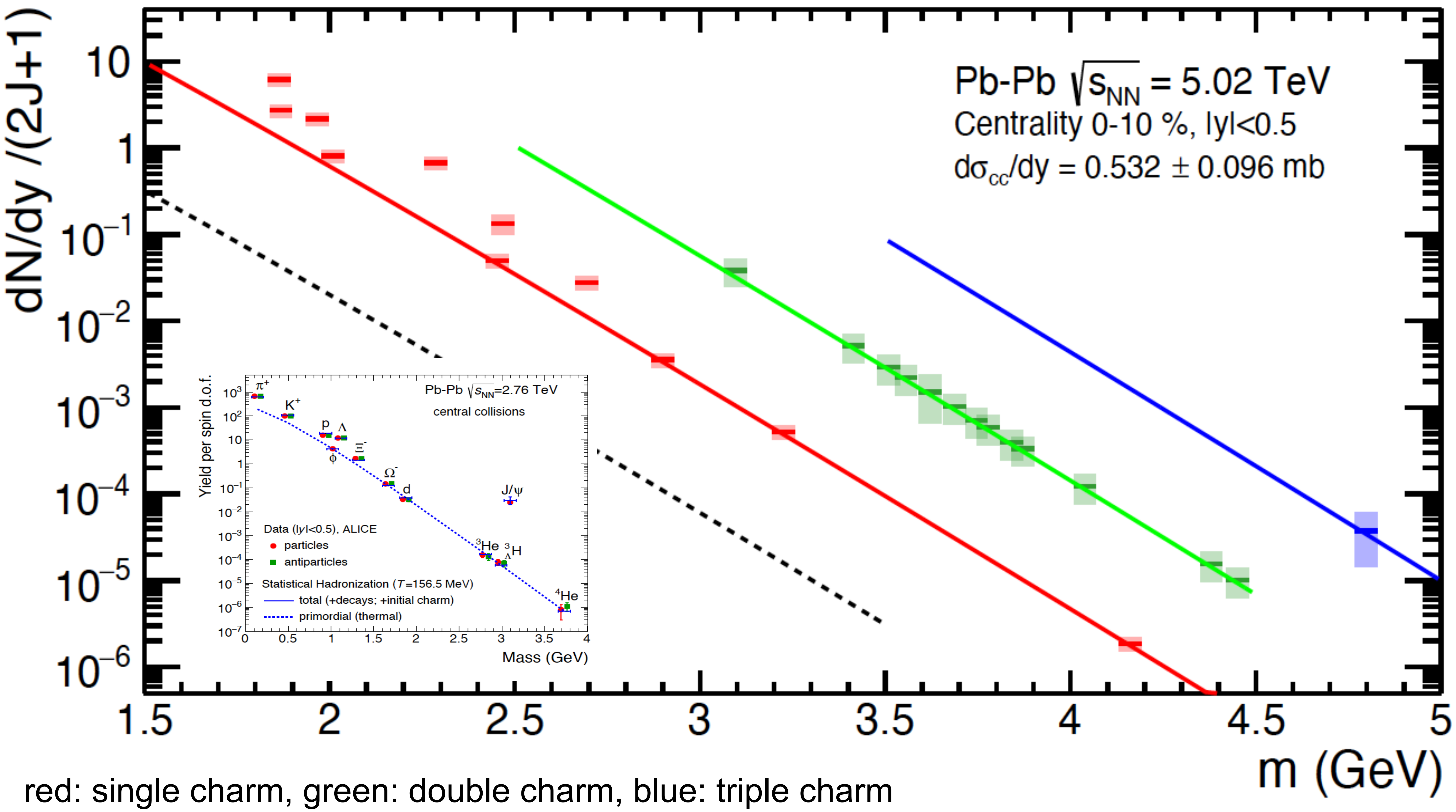


⇒ ALICE 3 access to CSR mechanisms like ρ-a1 mixing



ALICE 3 mass spectrum





red: single charm, green: double charm, blue: triple charm

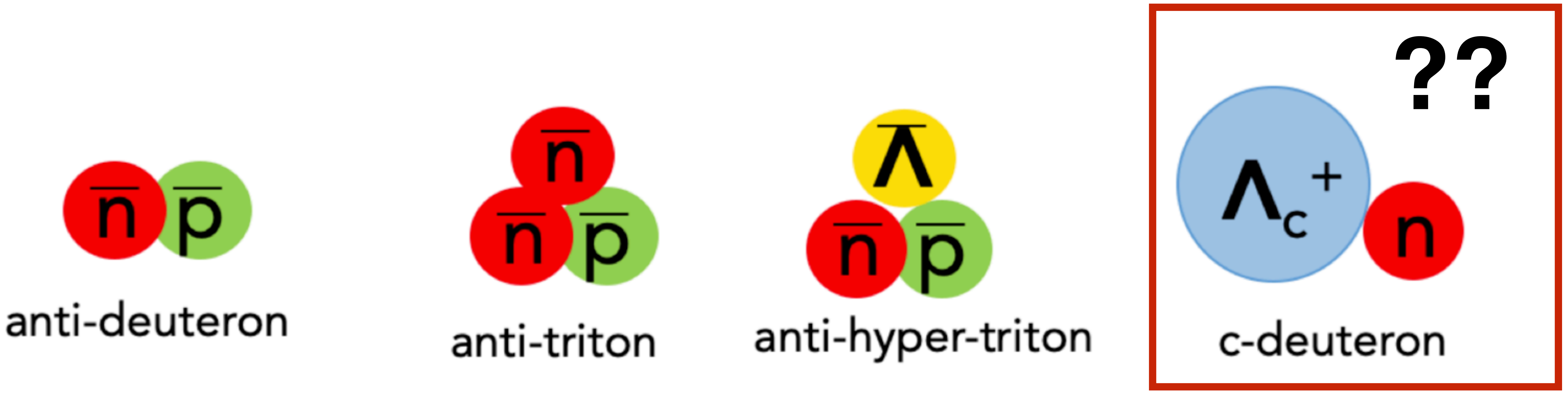
lines: primordial SHM predictions

22

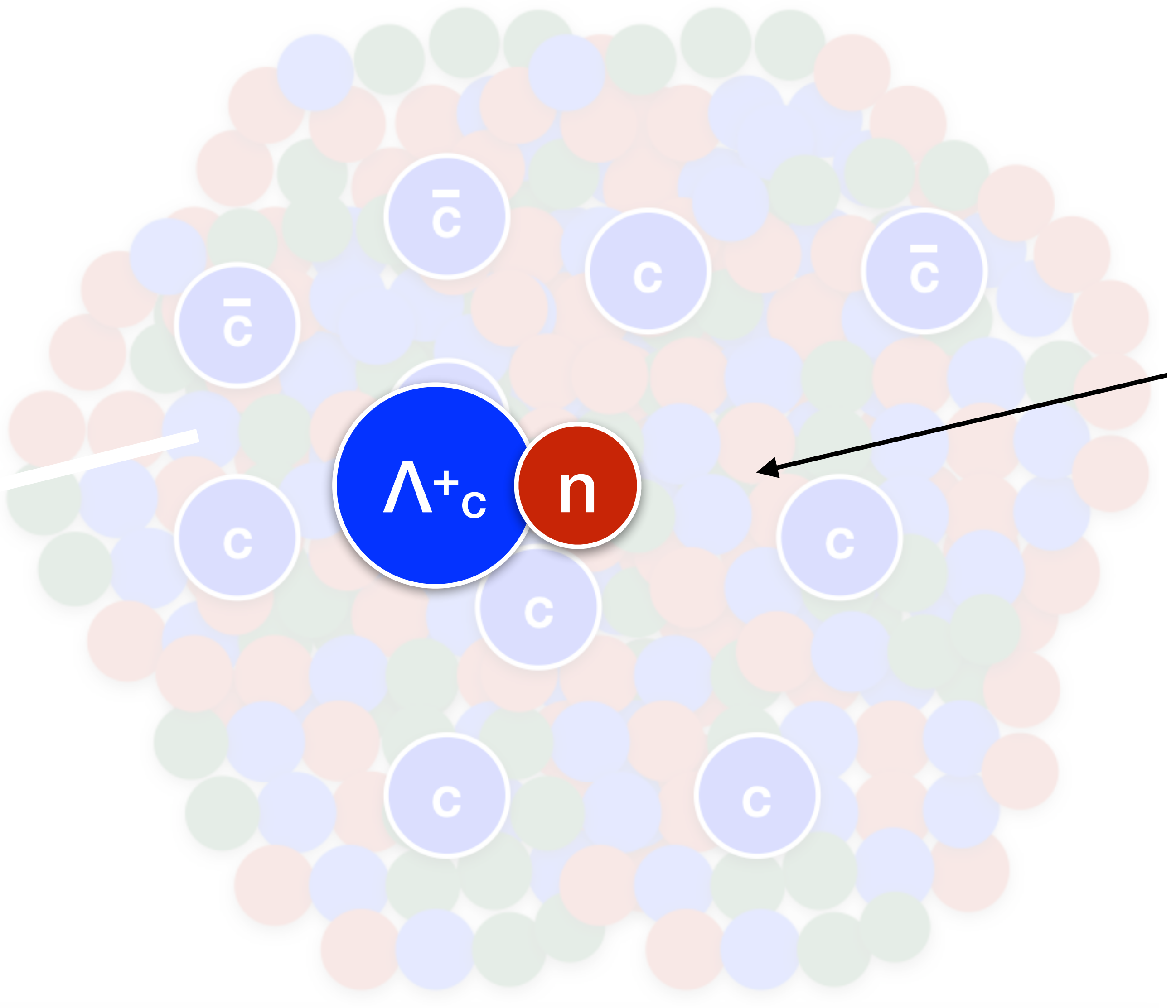
dashed line: SHM (u,d,s), red line: SHMC (1c), green line: SHMC (2c), blue line: SHMC (3c)

Search for charmed hyper nuclei “c-deuteron”

ALICE



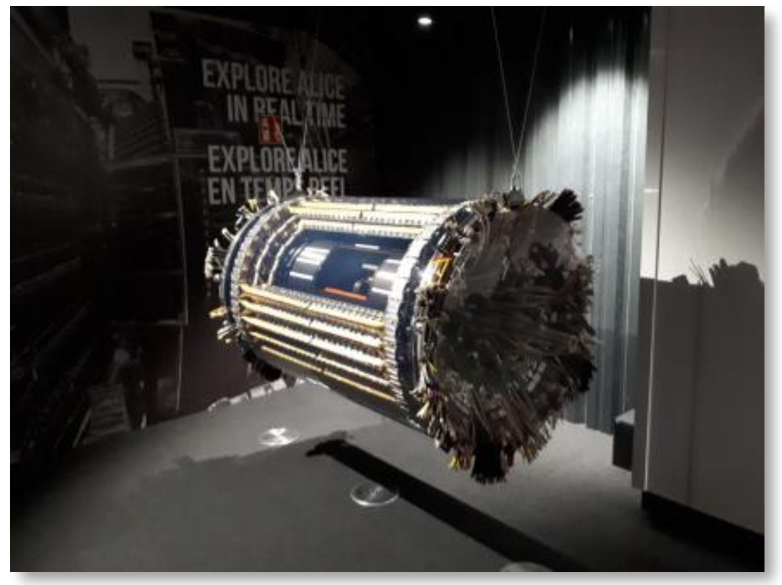
- c-deuteron $d_{\Lambda c}$
  - bound state of neutron-Λ_c
  - lightest possible hyper-nucleus with charm
  - $c\tau \sim c\tau(\Lambda_c) \sim 60$ μm
  - Large uncertainty from branching ratio (0.18~0.6 %) and also from production model
  - mass = 3.226 GeV/c^2
  - decay channel: d + K^- + π^+



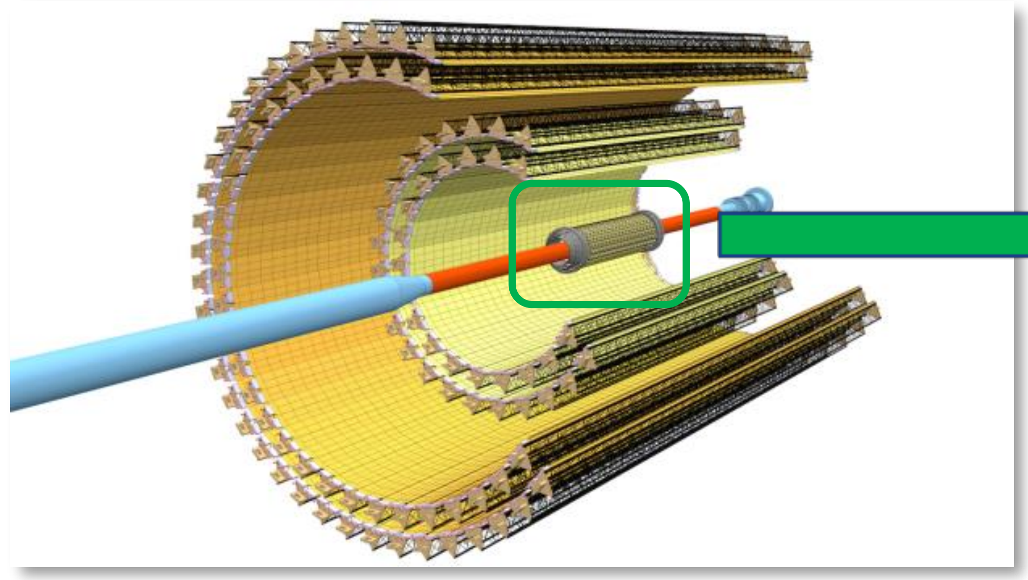
Weakly bound object: strong insights into the QGP and the hadronization phase
→constraint for in-medium and molecular coalescence

ALICE ITS upgrades in Run 3 and 4

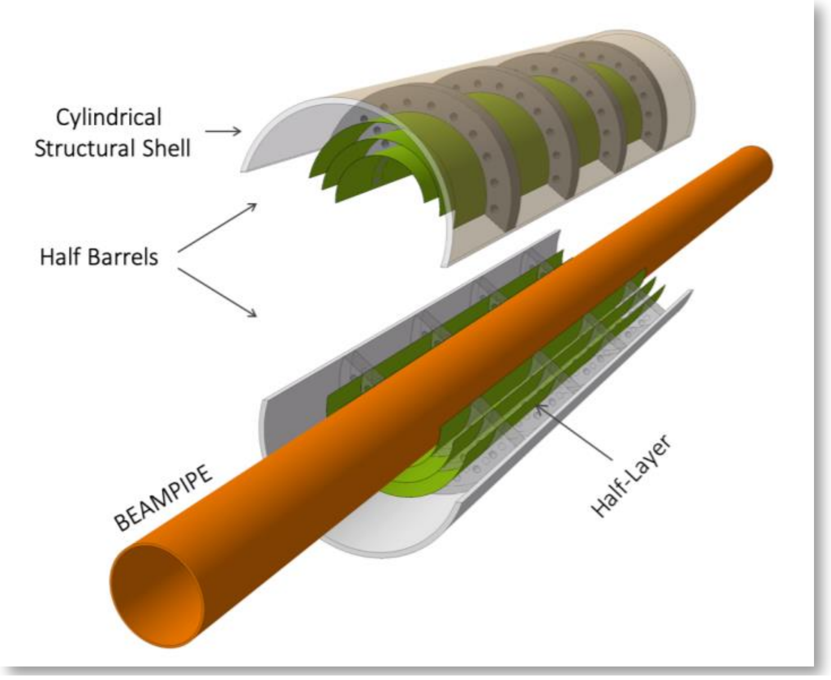
ITS 1 (ALICE exhibition)



ITS 2



ITS 3



6 layers:
- 2 layers of Silicon Pixel Detector (SPD)
- 2 layers of Silicon Drift Detector (SDD)
- 2 layers of Silicon Strip Detector (SSD)

7 layers of ALPIDE Monolitic Active Pixel Sensors
- 10 m² active silicon area
- 12.6 x 10^9 pixels

3 truly cylindrical Si pixel layers
- ultra-thin wafer-sized curved sensors
- no external connections air-flow cooling

	ITS 1	ITS 2	ITS3
Distance to interaction point (mm)	39	22	18
X_0 (innermost layer) (%)	~1.14	~0.35	0.05
Pixel pitch (μm^2)	50×425	27×29	O(15× 15)
Readout rate (kHz)	1	100	
Spatial resolution ($r\varphi \times z$) (μm^2)	11×100	5×5	

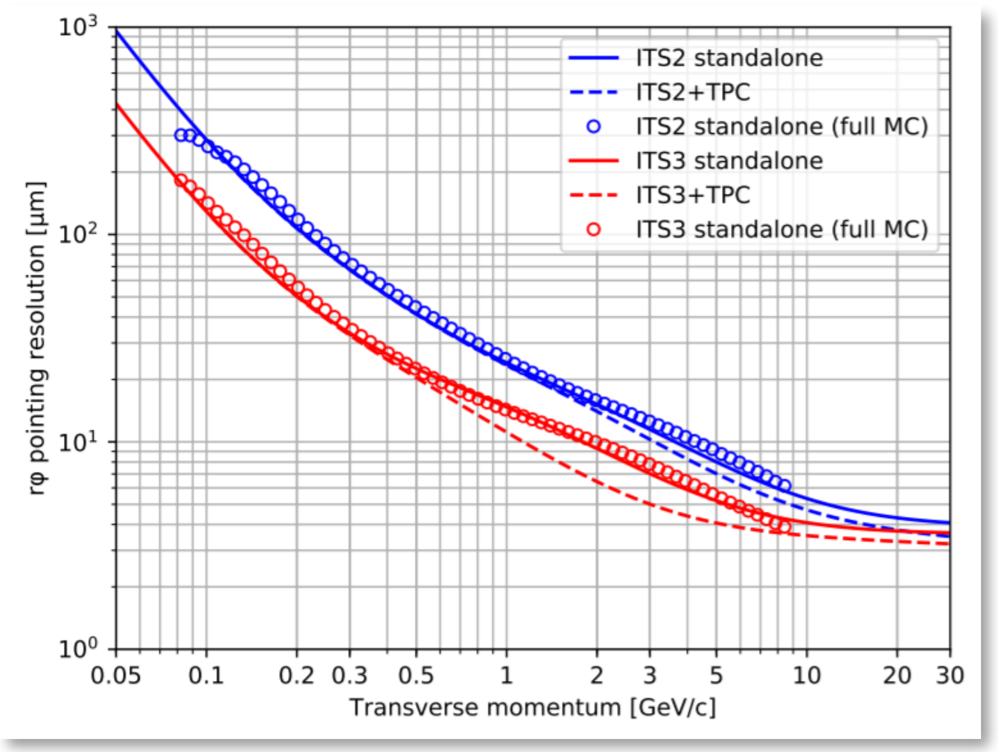
→ Closer to interaction point

→ Lower material budget

→ Improved granularity

→ Faster readout

→ Improved resolution



x ~2 improved in pointing resolution (ITS2 →ITS3)