ALICE 3:

a next-generation heavy-ion detector for LHC Run 5 and Run 6

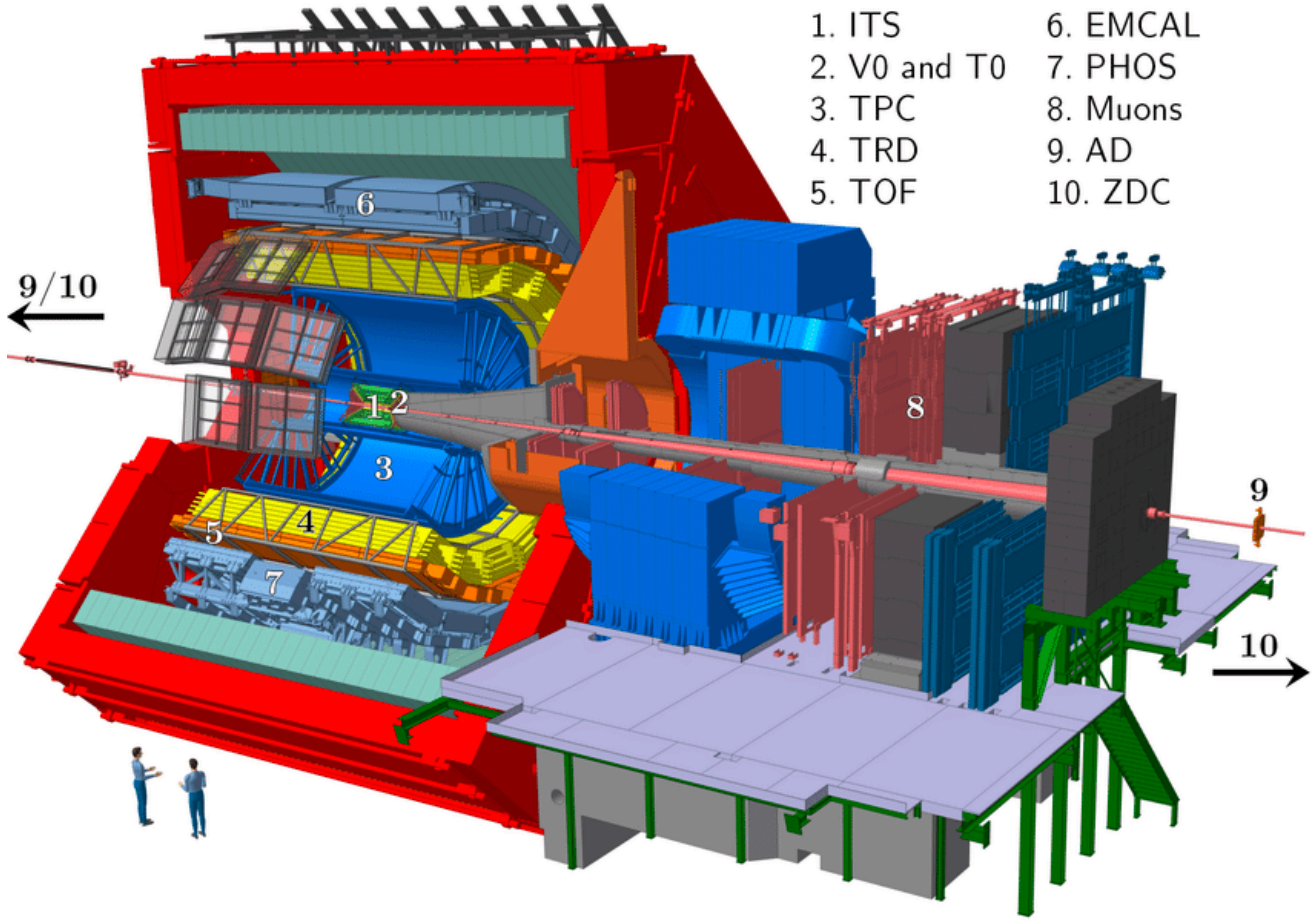
ALICE

Nikhef

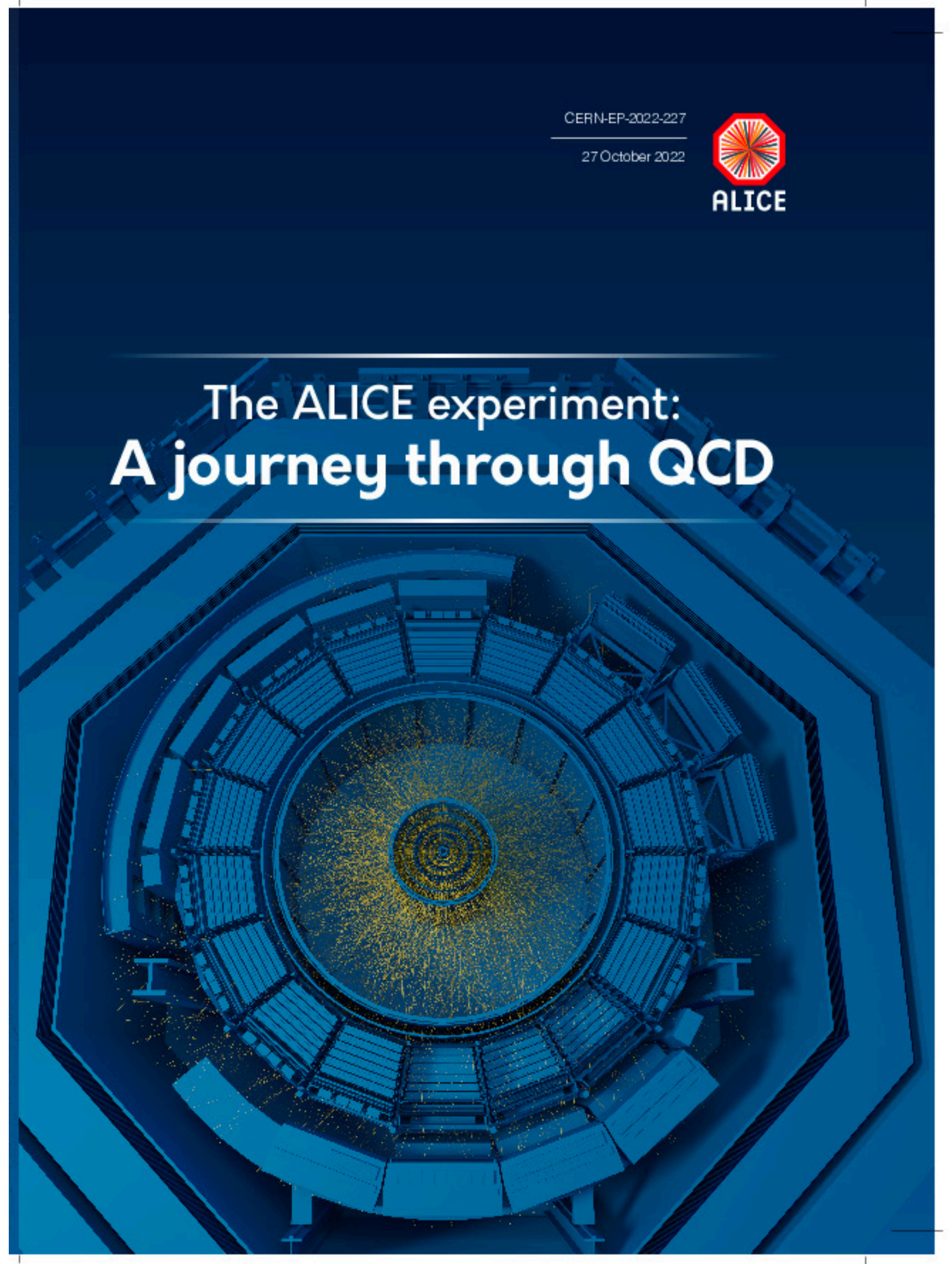
ALESSANDRO GRELLI

For the ALICE Collaboration

Current ALICE detector



ALICE Review paper



arXiv:2211.04384 (submitted to EPJC)

The ALICE detector

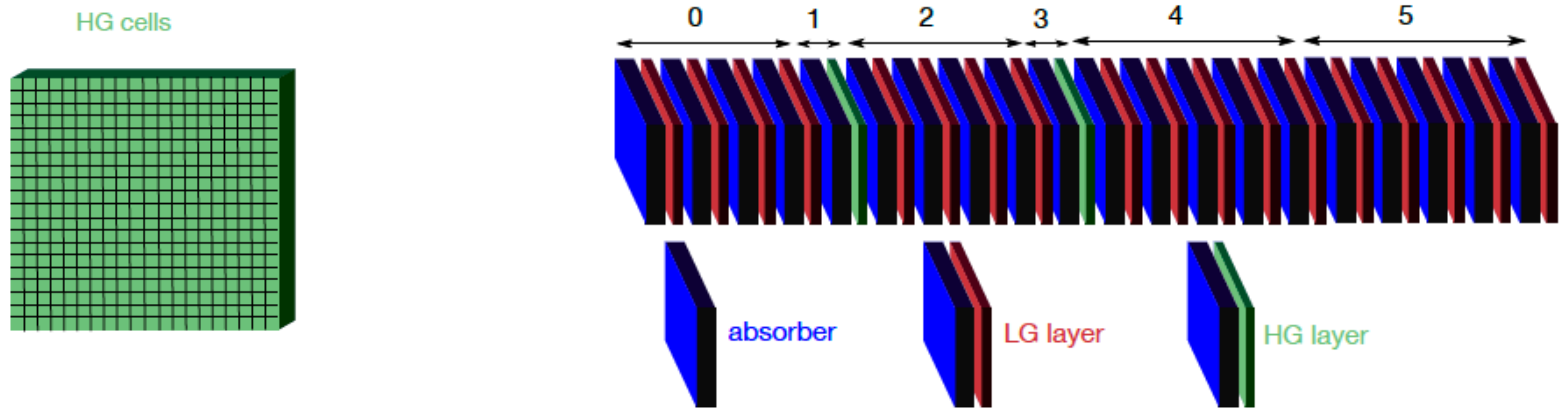
- Central Barrel: tracking, particle ID and calorimetry (**$|\eta|<0.9$**)
- Forward muon arm: **$2.5< \eta < 4.0$**
- Major upgrades in LS2 just completed: *New inner tracking system, forward muon tracker and TPC upgrade*

arXiv:2302.01238 (submitted to JINST)

ALICE @ Run 4: ITS3, FOCAL

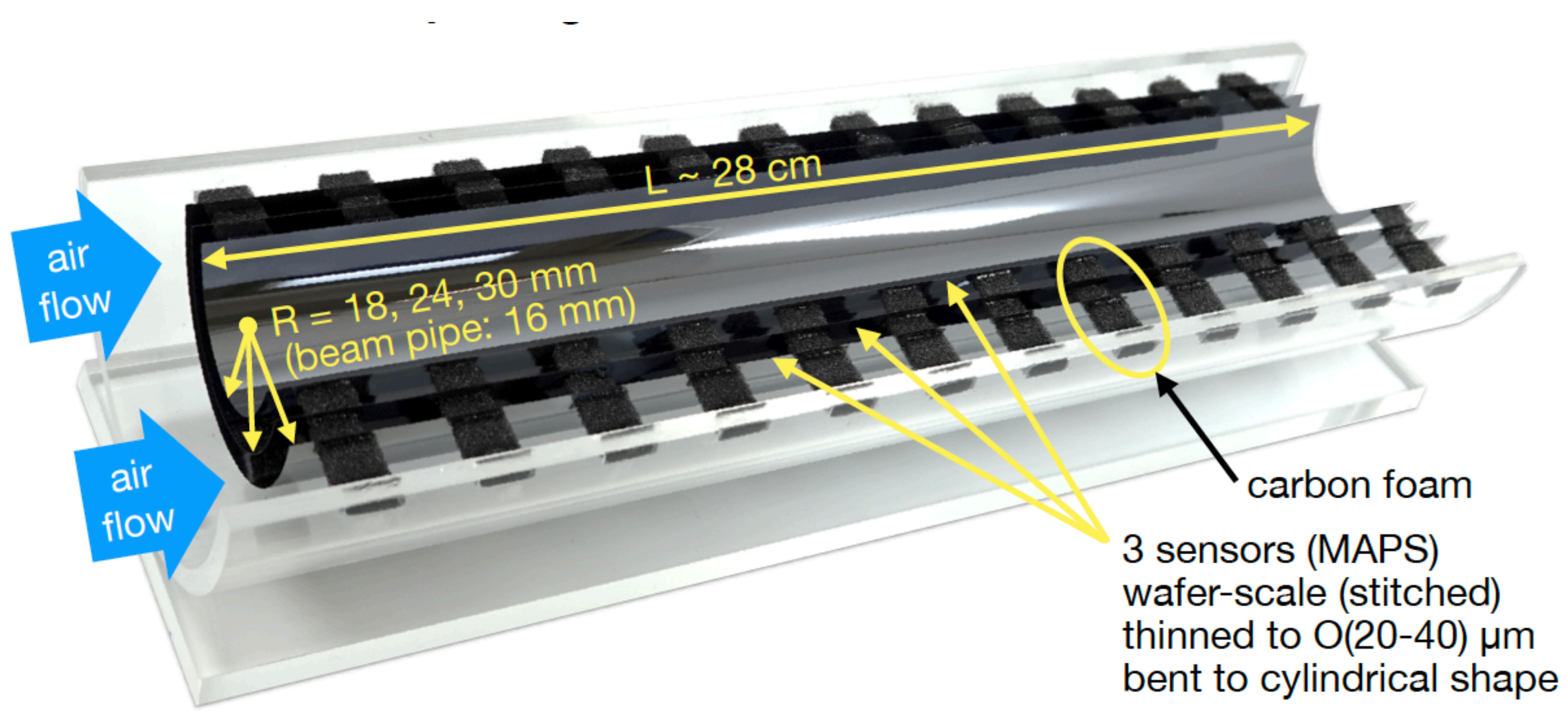
FOCAL – FORWARD CALORIMETER

- Parton distributions in protons and nuclei
- Long range correlations in pp and p-A
- Forward jets and UPCs



See Tatsuya Chujo talk, this session

ITS3 – Vertex tracker



- Replacement of 3 innermost layers of ITS2
- Curved wafer-scale ultra-thin silicon sensors: perfectly cylindrical layers
- Low power → air cooling → low material budget: 0.05% X_0 per layer
- Improved tracking precision and efficiency at low p_T

See Jory Sonneveld talk, this session

Some of the open questions for LHC Runs 5 and 6

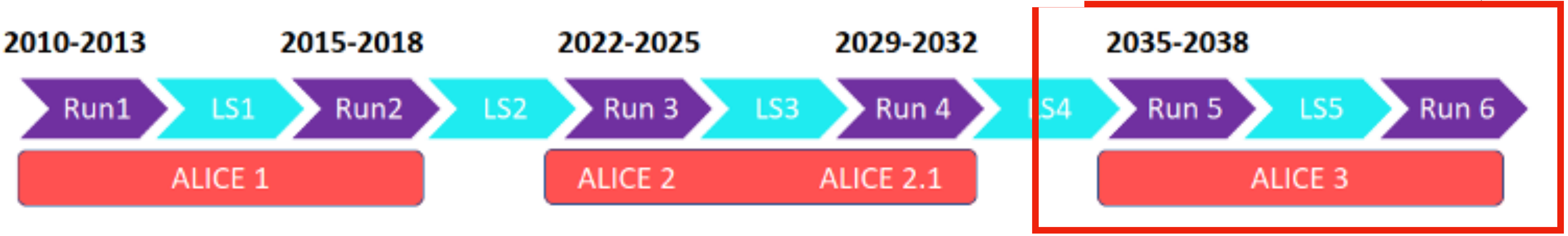
- How to establish a firm connection between parton transport, collective phenomena and hadronisation?
  - Requires extension of the study of parton energy loss down to momenta typical of diffusion phenomena ➜ *Needs precision measurements of beauty hadrons*
- Do we understand hadron formation from deconfined QGP? ➜ *Needs multi charm hadrons, exotic hadrons*
- Complete picture of the temperature dependence of QGP bulk and shear viscosities? ➜ *Needs electromagnetic radiation*
- Chiral symmetry restoration? ➜ *Needs precise measurement in the di-lepton sector*
- Origin of collectivity in small systems? ➜ *Needs large phase space, high data rate*
- High-statistics hadronic physics ➜ *Needs large phase space, high data rate*
- ....

The ALICE 3 experiment

arXiv:2211.02491 ; CERN-LHCC-2022-009 ; LHCC-I-038 ; LHCC-I-038

ALICE 3 integrated luminosities:

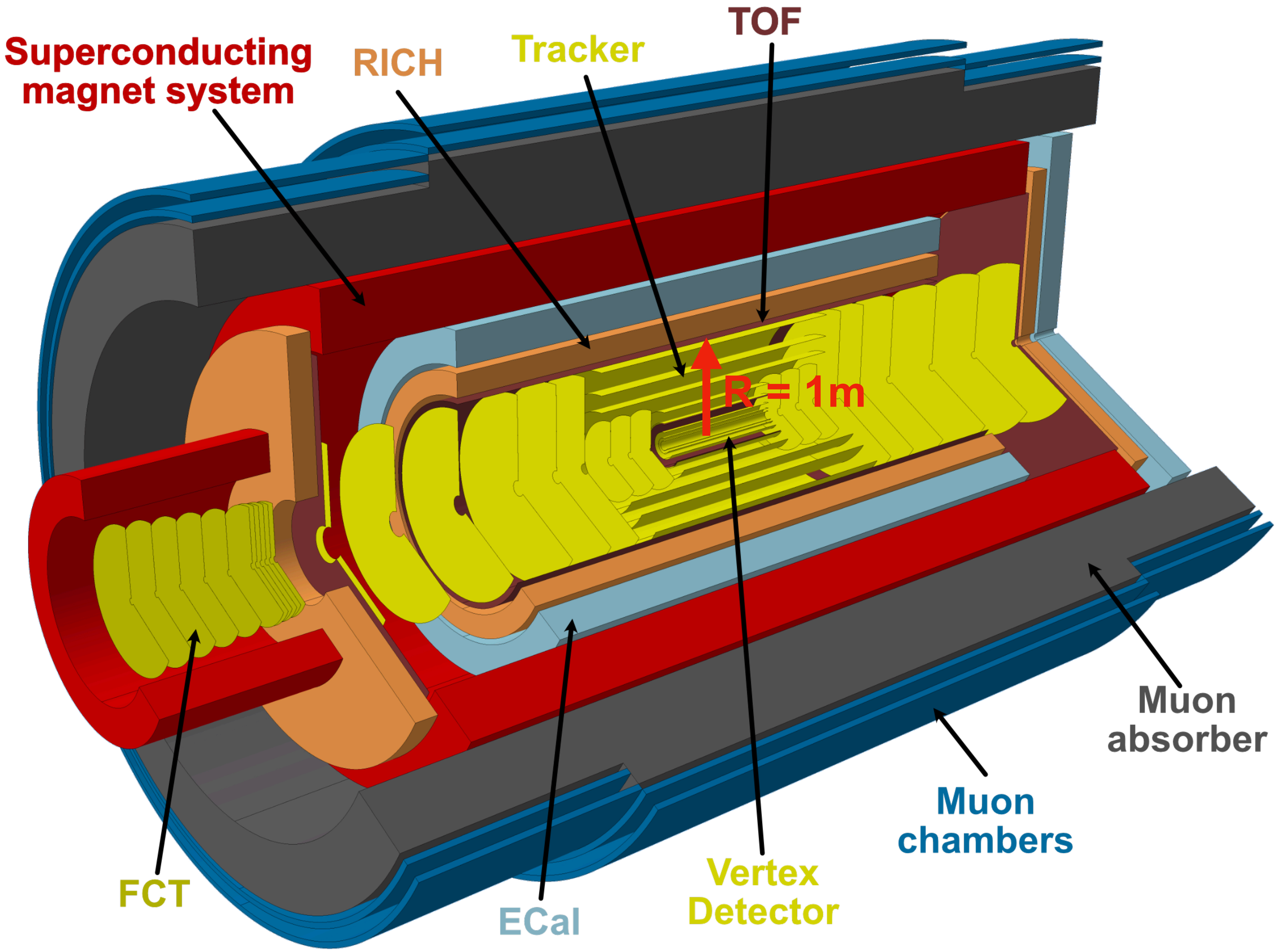
- $\mathcal{L}_{pp}^{month} \sim 0.5\ \mathrm{fb}^{-1}$ and $\mathcal{L}_{pp}^{Run5+6} \sim 18\ \mathrm{fb}^{-1}$
- $\mathcal{L}_{Pb\text{-}Pb}^{month} \sim 5.6\ \mathrm{nb}^{-1}$ and $\mathcal{L}_{Pb\text{-}Pb}^{Run5+6} \sim 33.6\ \mathrm{nb}^{-1}$
- Options for pA collisions and lighter AA system with higher $\mathcal{L}_{NN}$ under study



ALICE 3: Envisioned detector

ALICE 3 in a nutshell:

- Compact *(r ≃2m, z ≃ 8m)*
- Large acceptance, **|η|<4, p_T >0.02 GeV/*c***
- Superconducting magnet system
- Max field: B = 2 T (*0.5 T runs foreseen*)
- Continuous readout and online processing
- Pointing resolution ~3-4 µm and p_T resolution better than 1% @1 GeV/*c*
- Particle Identification (PID) in a wide range of momenta and |η|<4

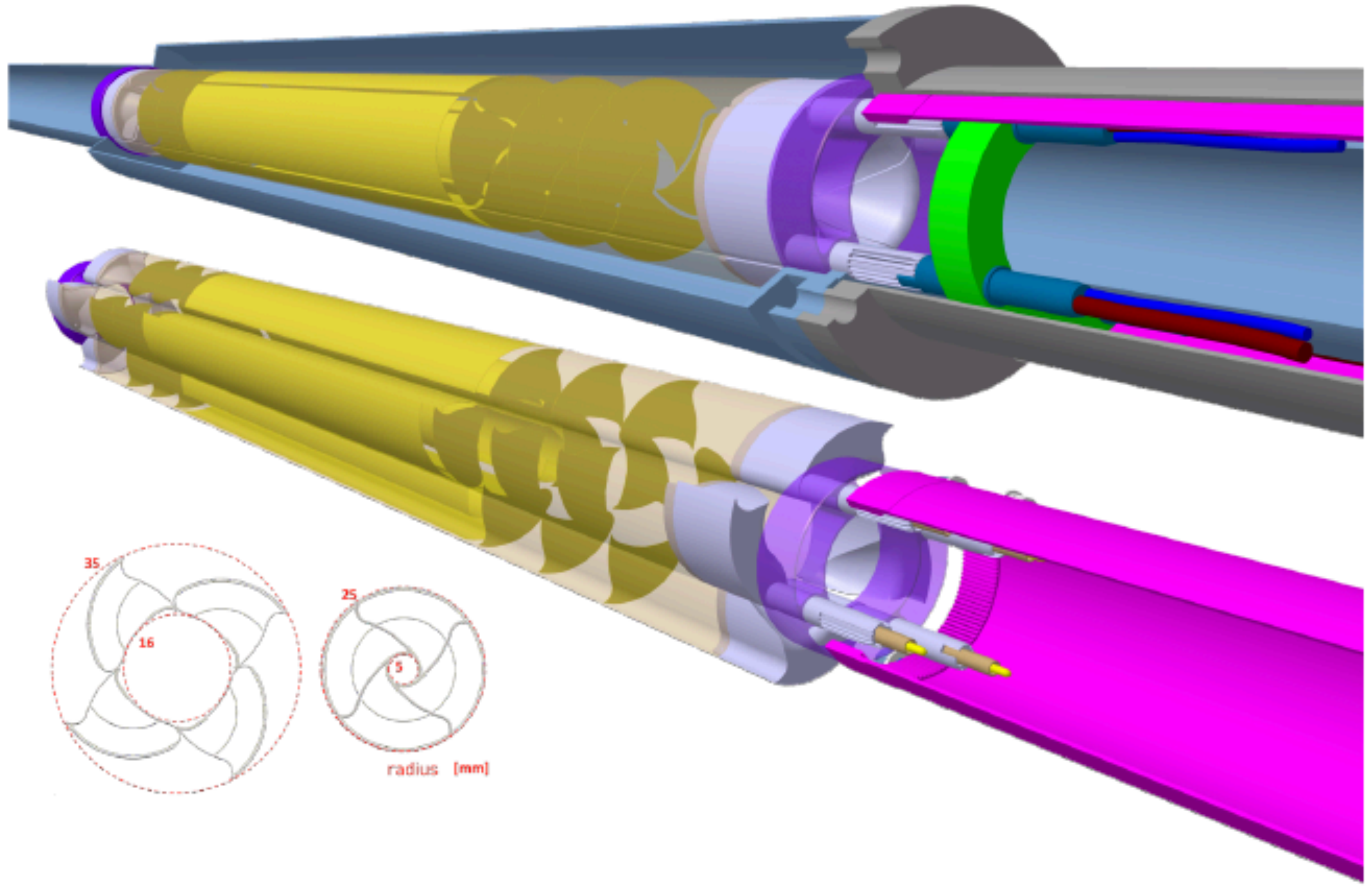


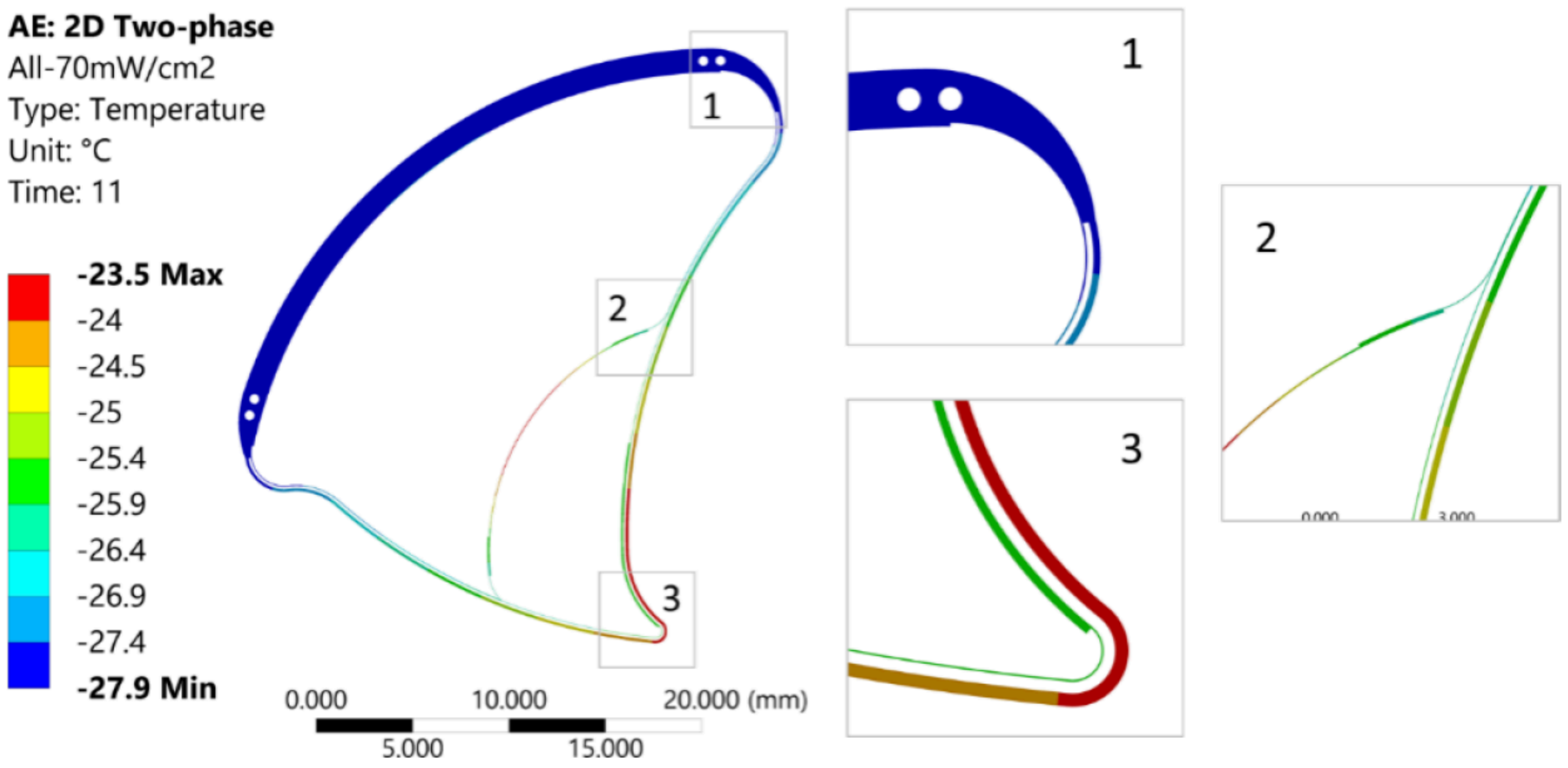
Vertex tracker

☑ Iris concept:

- In vacuum, *retractable,* tracker (**3 layers + 3 disks**): In closed position the first layer will be at **5 mm** from the beam
- Wafer-size sensors based on CMOS Monolithic Active Pixel Sensors (MAPS) technology
- Pixel pitch of about 10 µm and **~0.1% X_0/layer** for **2.5 µm** intrinsic resolution
- The maximum radiation load per operational year will be about **1.5 10^{15} 1 MeV n_{eq}/cm^2**
- Cooling on the outer surface of the 3rd layer (micro-channel) while the layer 0 and 1 cooled via conduction on the petals

R&D challenges: radiation hardness, technology feature size, cooling and services





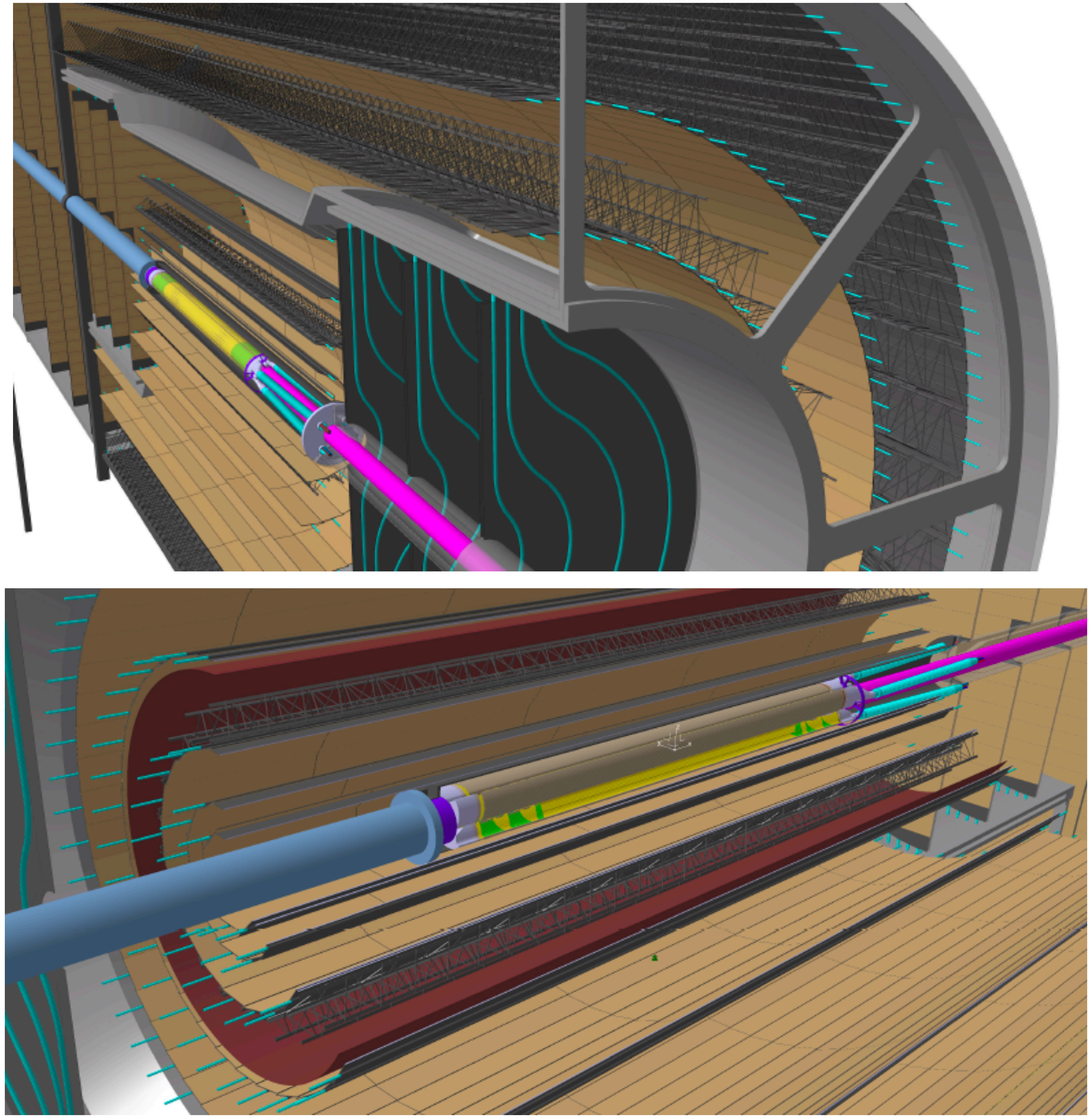
ALICE Coll. arXiv:2211.02491

Outer tracker

Concept:

- **8 layers** and **9 disks** based on MAPS for a total of ~67m² of silicon
- Sensor pixel pitch of ~40 µm for $\sigma_{POS}^{intrinsic} = 10\mu m$.
- Compact design with outer layer at 80 cm
- Material budget: about **1% X_0/layer** (<10% of the whole detector)
- Low power: ~**20mW/cm²**
- Industrialised sensor module production process: modular structure with modules mounted on a developed in-house space frame

R&D challenges: module integration, time performance and material budget



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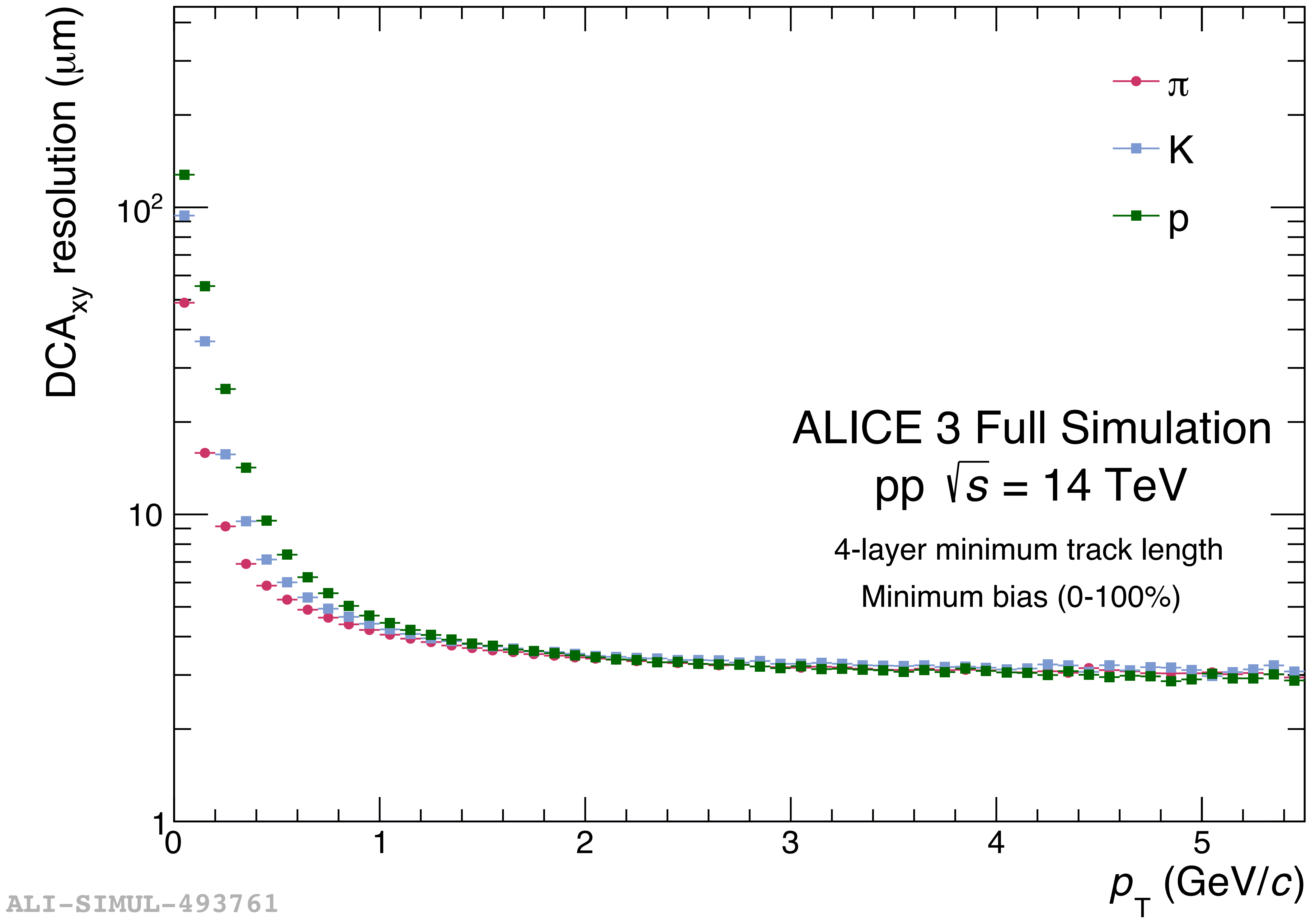
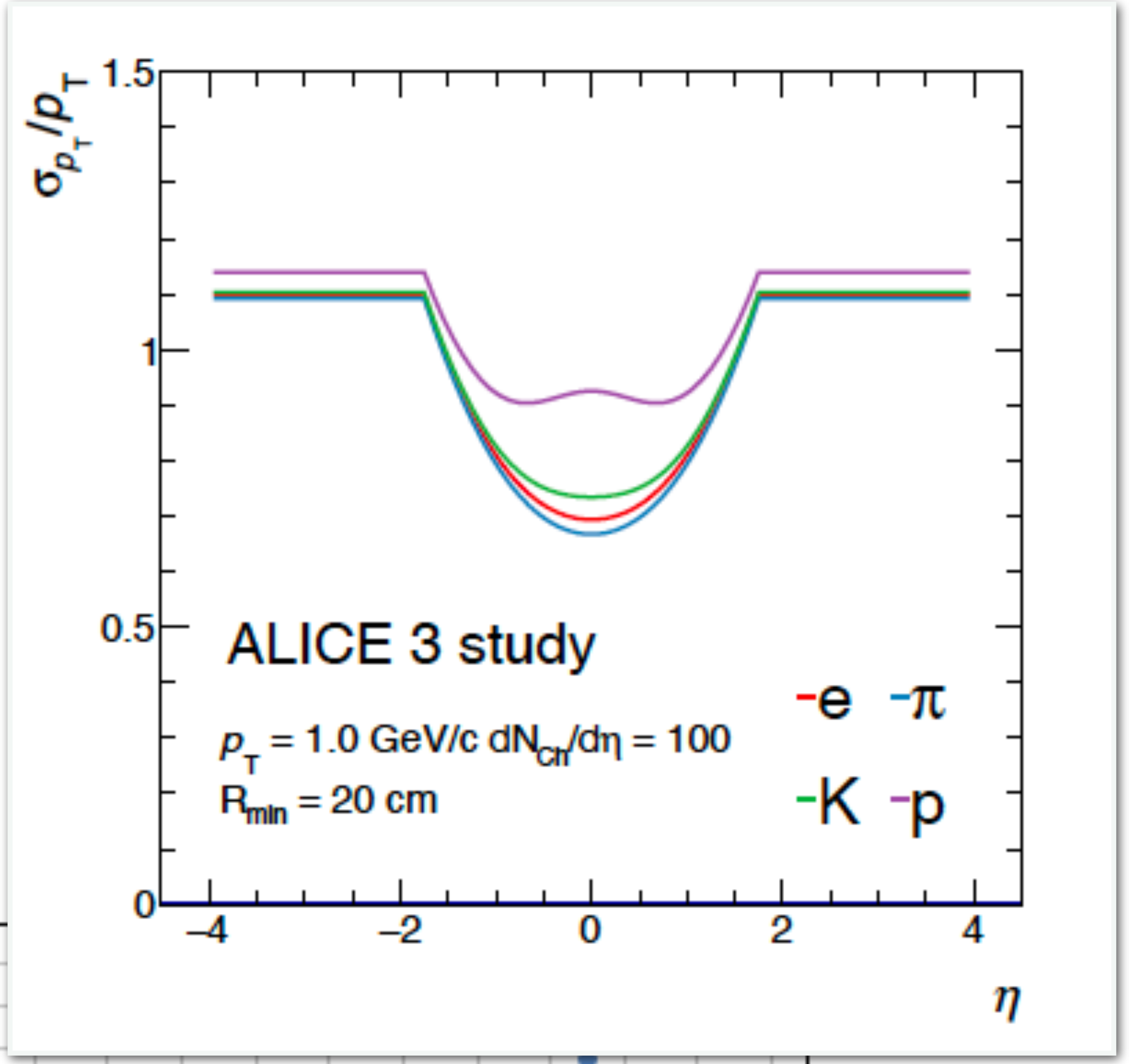
XY pointing and p_T resolutions

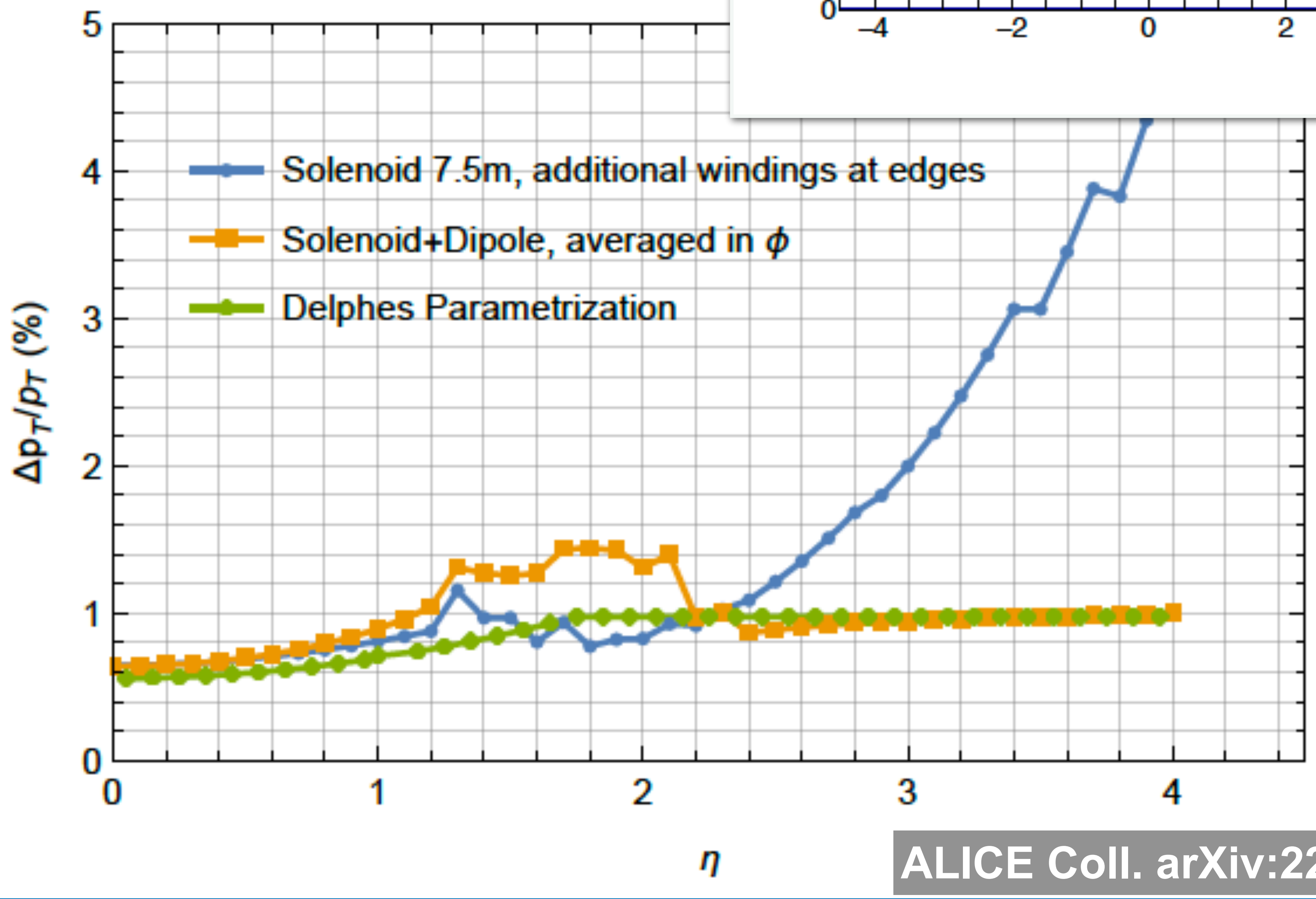
XY pointing



σ_{p_T}/p_T @ B =2 T

- Resolution better than 1% at central rapidity
- Resolution for 1 GeV muon with solenoid+ dipole magnet better than 1% up to η = 4.



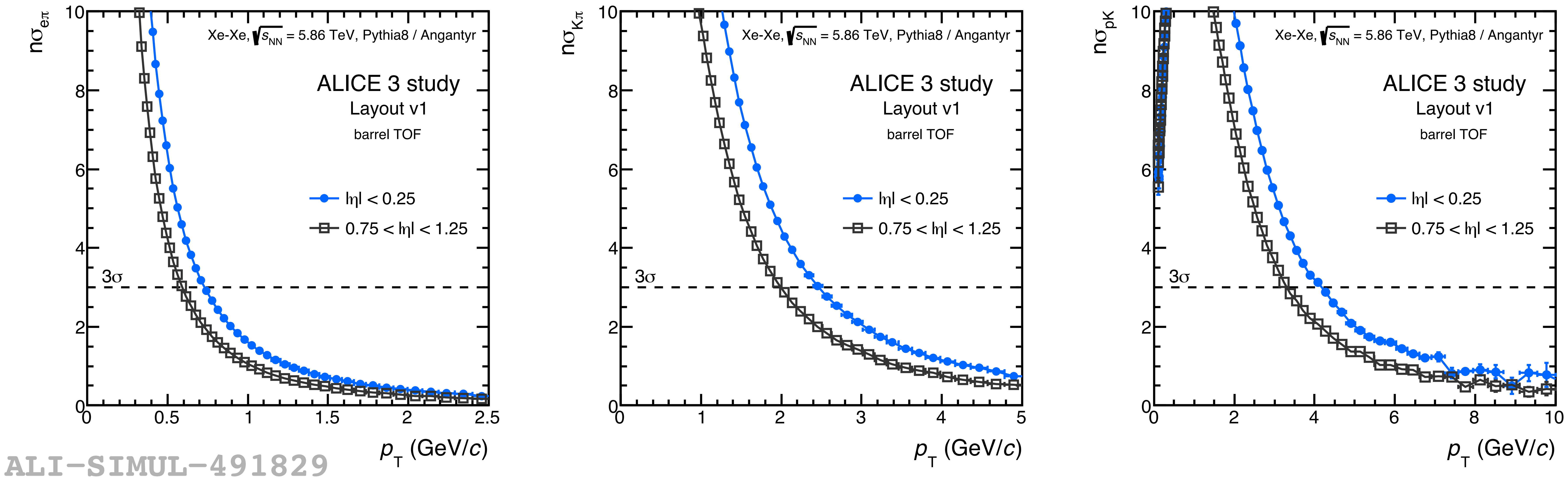


Particle identification systems

Time-of-Flight:

- **Barrel Time-of-flight**: two layers with inner TOF at 19 cm and outer TOF at 85 cm. Time resolution at **20 ps**, $|\eta|<1.75$. Total surface ~ 31.5 m^2 (1.5 inner + 30 outer)
- **Two forward disks:** $1.75<|\eta|<4$ with r_{IN} = 15 cm, r_{out} =50 cm and z = 405 cm for a total surface of 14 m^2

Outer TOF: separation power in Xe-Xe



R&D challenges: depends on the technology of choice, if MAPS: uniform and fast charge collection together with fast readout electronics and high signal-to-noise ratio

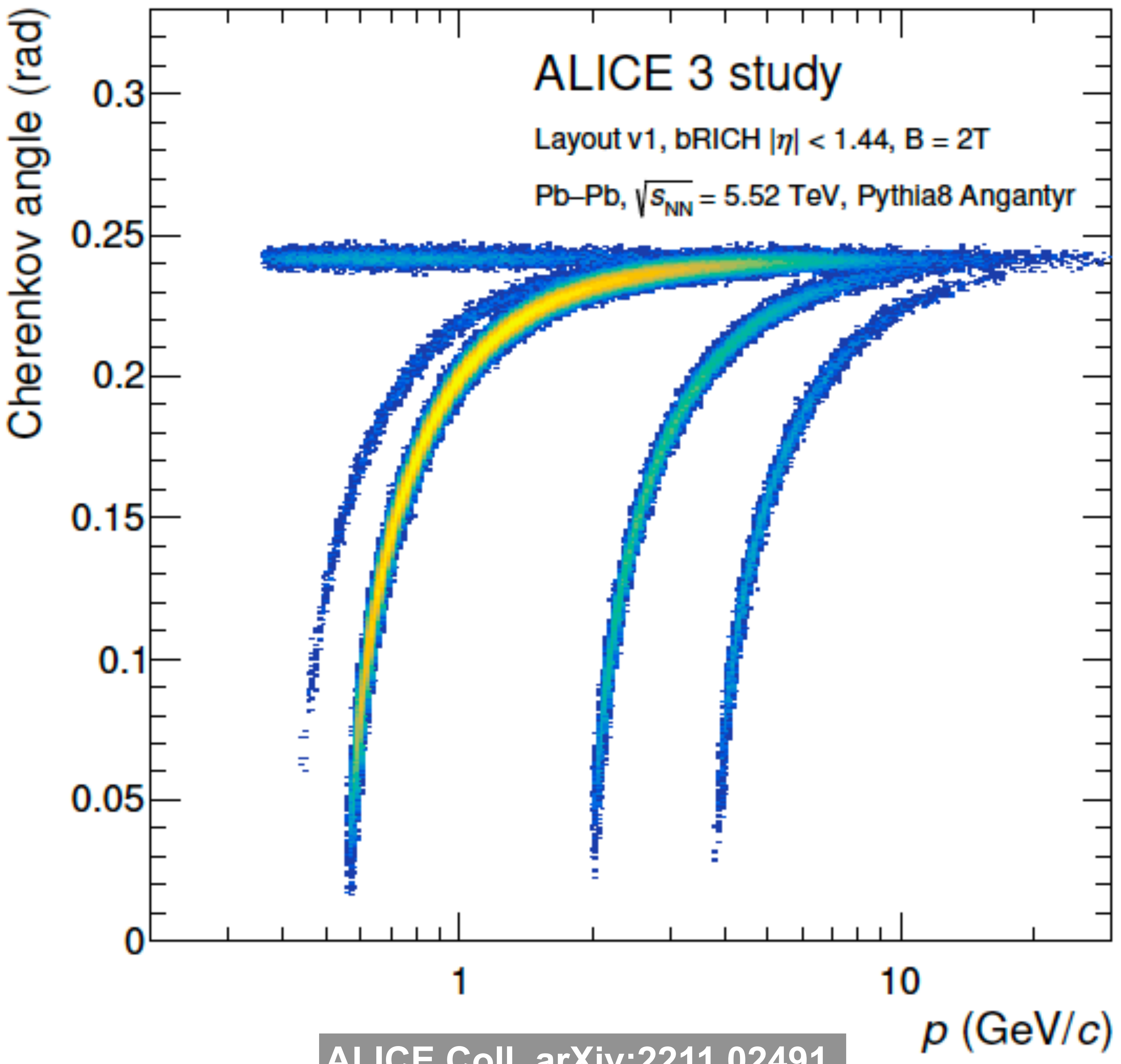
Particle identification systems

☑ RICH:

- Cherenkov detector to complement the TOF system for higher p_T reach
- 2 cm thick aerogel tile and photo-detection layer (SiPMs) at 20 cm from the radiator
- Aerogel radiator refraction index **n = 1.03 (barrel)** and **n= 1.006 (forward)** → determine the p_T reach

R&D challenges:

Quality of the aerogel over production cycle, digital SiPMs radiation resistant



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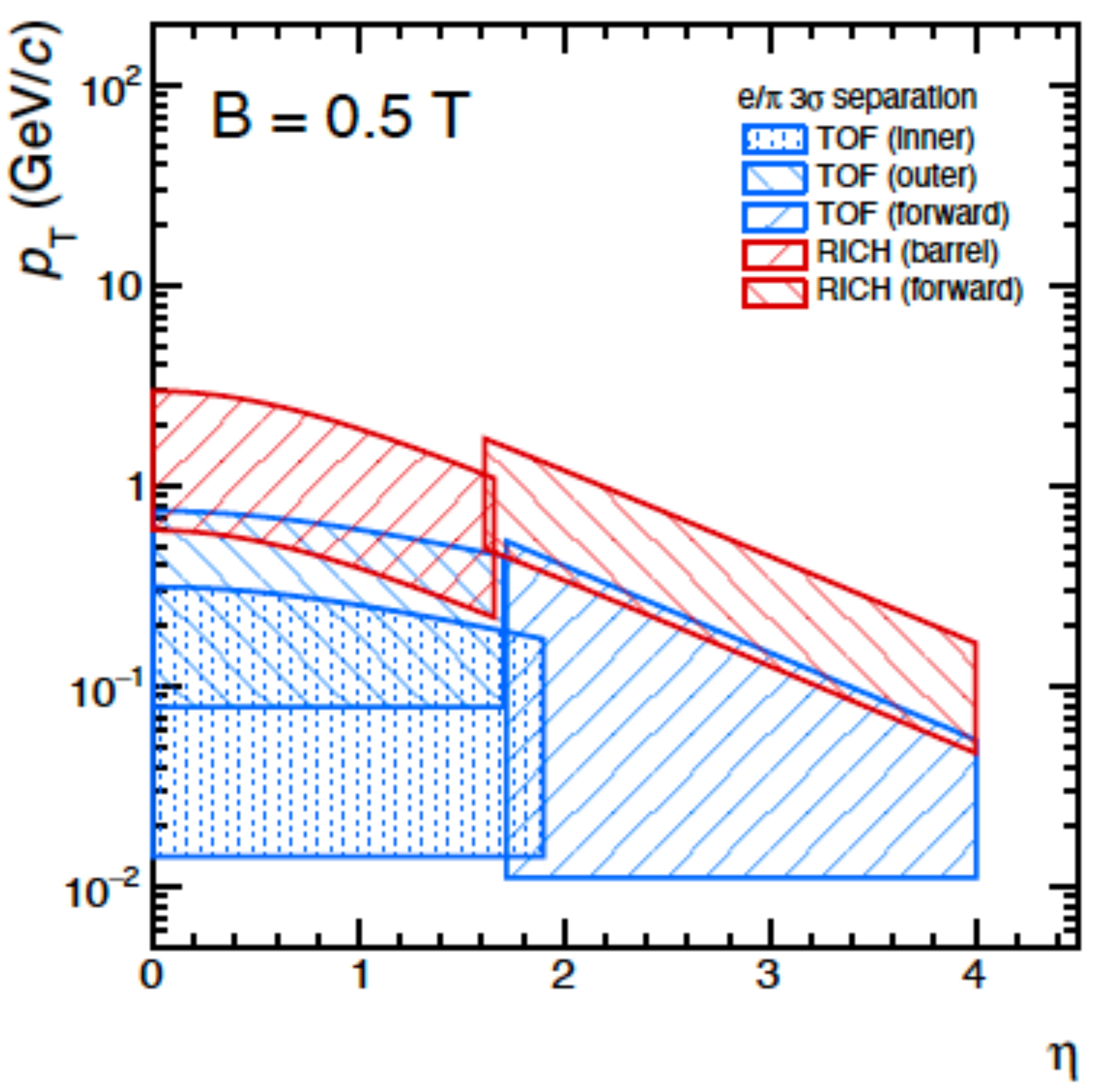
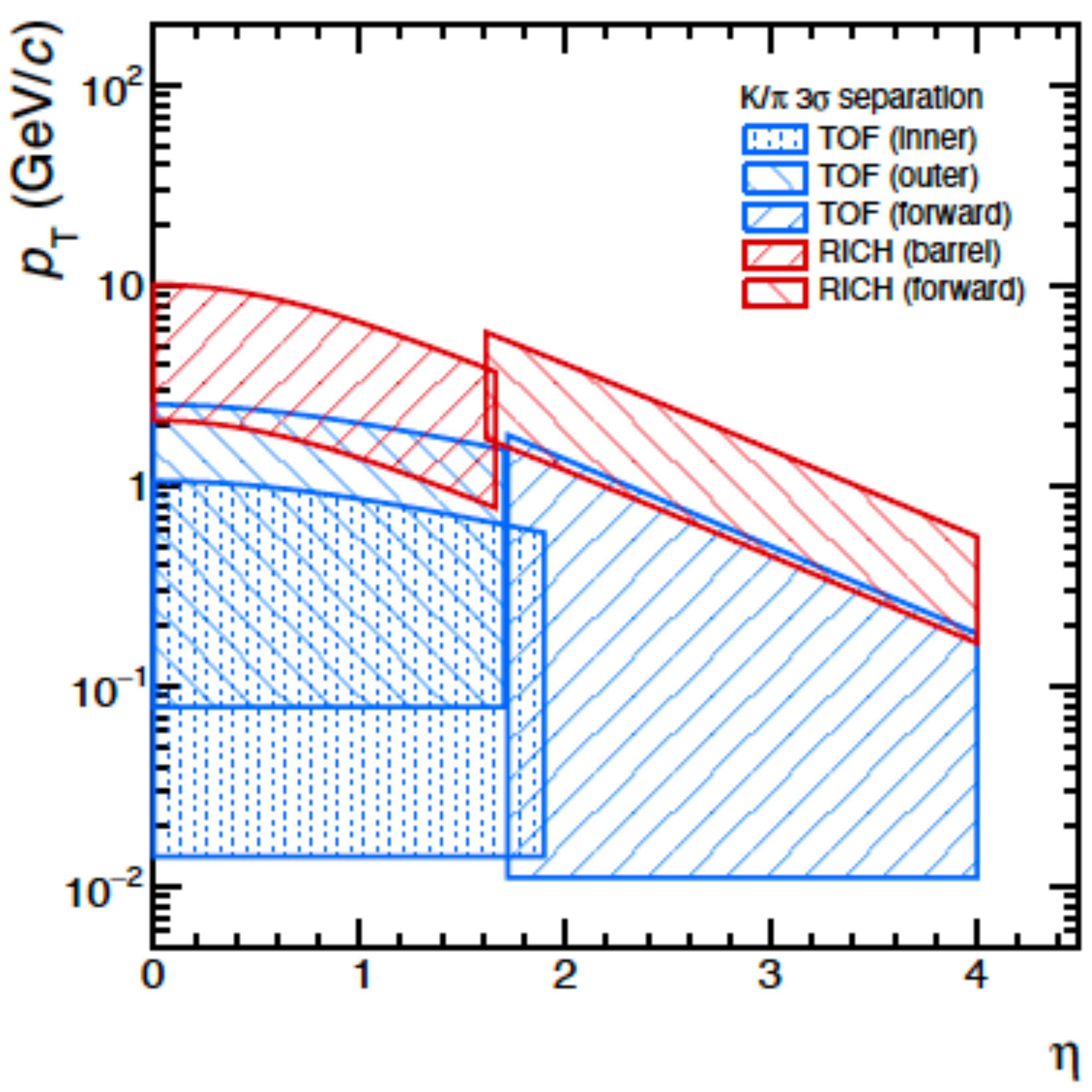
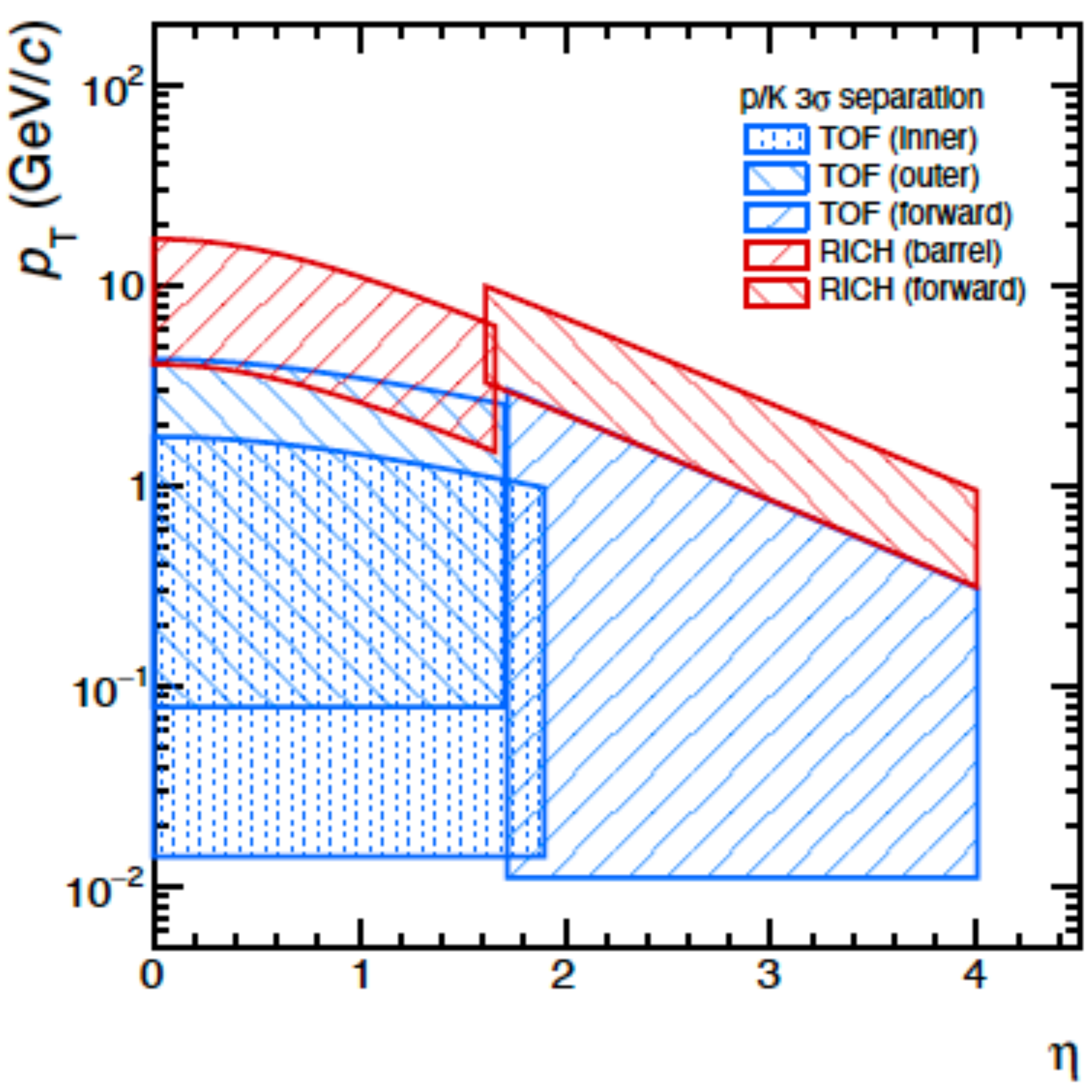
PID performances @ B =0.5 T

3σ separation TOF+ RICH e/π	3σ separation TOF+ RICH K/π	3σ separation TOF+ RICH p/K







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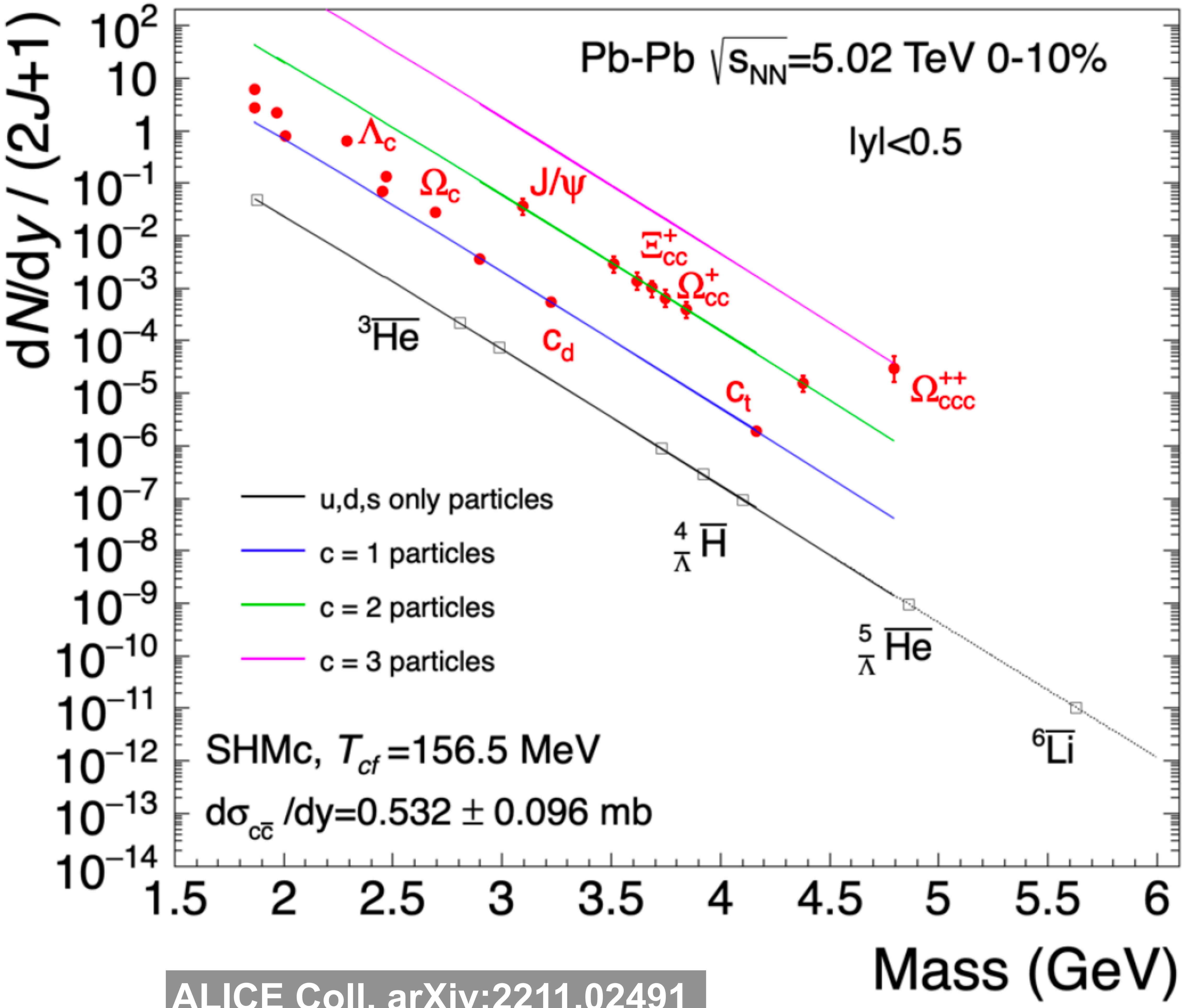
Physics performances: a selection of

Multi-charm baryons

→ *Needs multi charm hadrons, exotica*

- ALICE 3 can shed light on the sector of hyperon-nucleon and charmed-baryon nucleon interactions.
- Anti-hyper nuclei with A>5 as $^{5}_{\bar{\Lambda}}\overline{\mathrm{He}}$ or $^{6}\overline{\mathrm{Li}}$ yet to be discovered
- ALICE 3 apparatus well suited for the study of $^{4}_{\Lambda}$He or $^{5}_{\Lambda}$He of interest as baseline for the study of multi-charm baryon production in QGP
- Discovery potential for super-nulei (?) like c-deuteron, c-triton and c-^{3}He.



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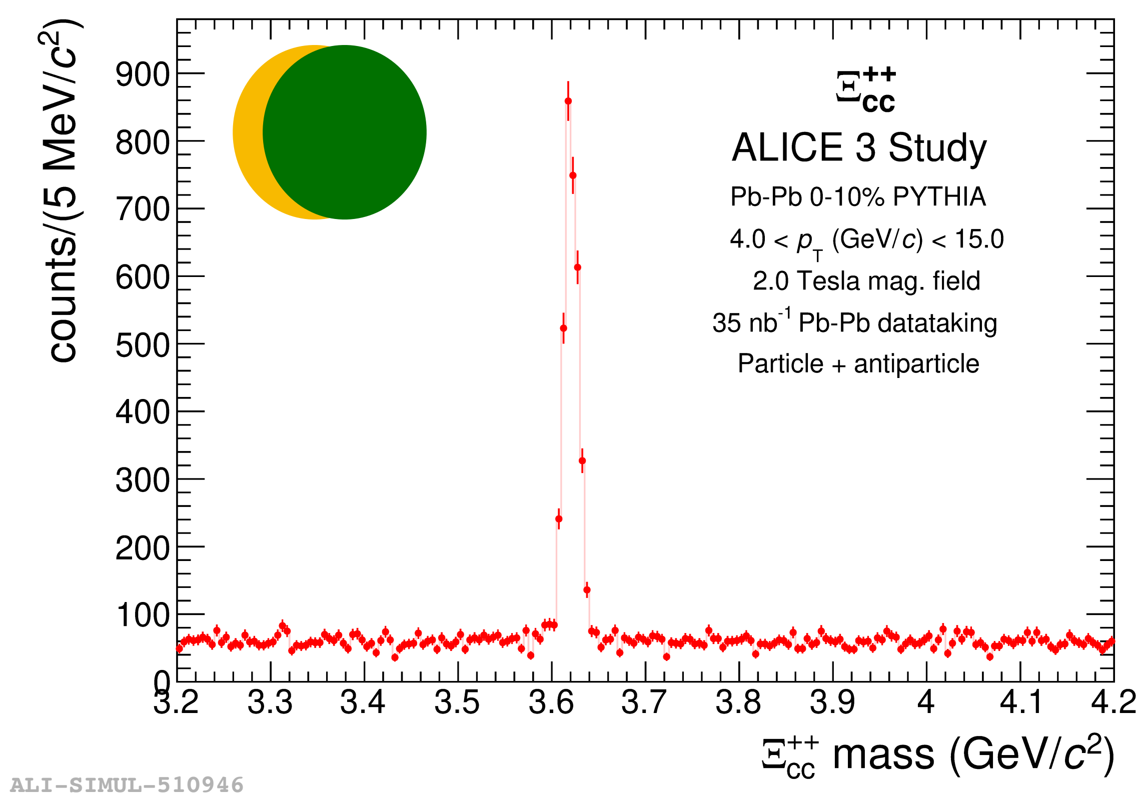
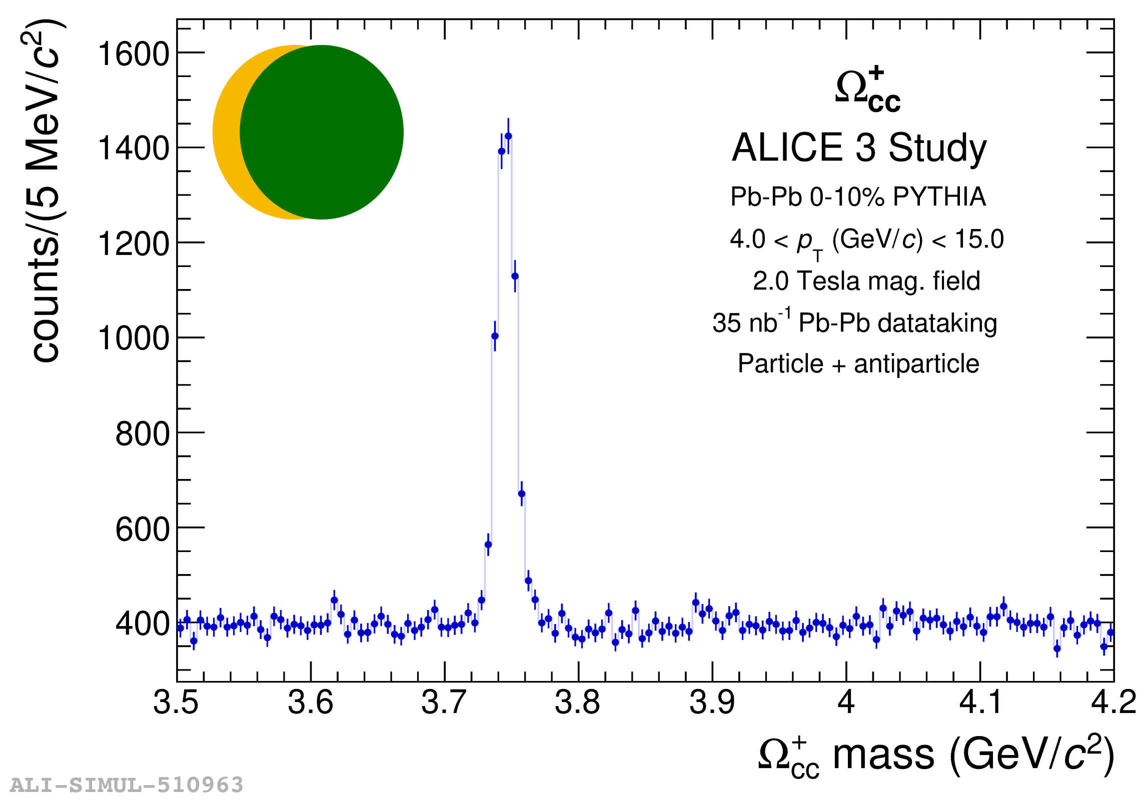
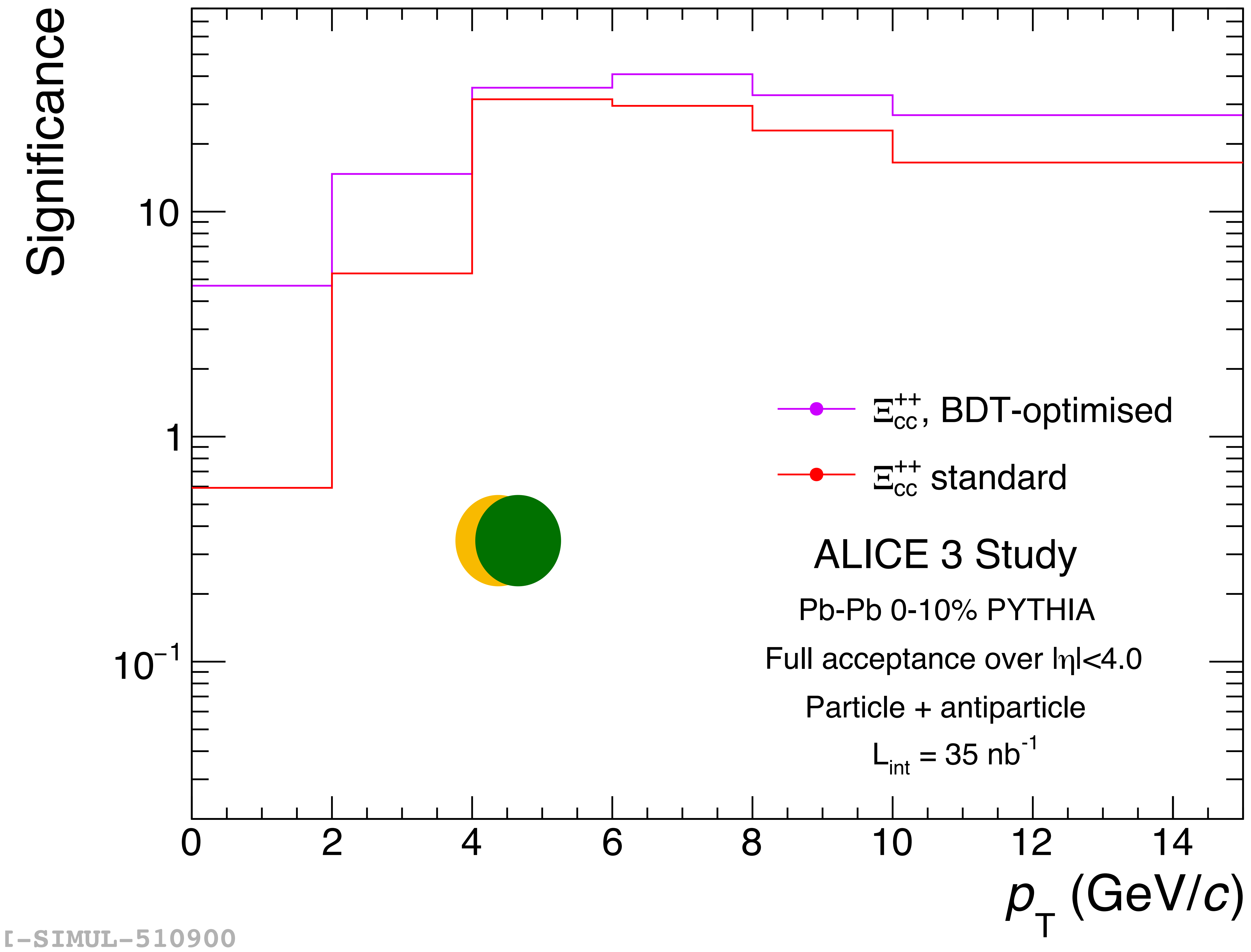
Multi-charm baryons

- → *Needs multi charm hadrons, exotica*
  - Ξ_{cc}^{++} reconstructed in the channel: $\Xi_{cc}^{++} \rightarrow \Xi_c^+\pi^+ \rightarrow \Xi^-\pi^+\pi^+\pi^+$
  - Ω_{cc}^{+} reconstructed in the channel: $\Omega_{cc}^{+} \rightarrow \Omega_c^0\pi^+ \rightarrow \Omega^-\pi^+\pi^+$
  - Performance for Ω_{ccc} studies ongoing



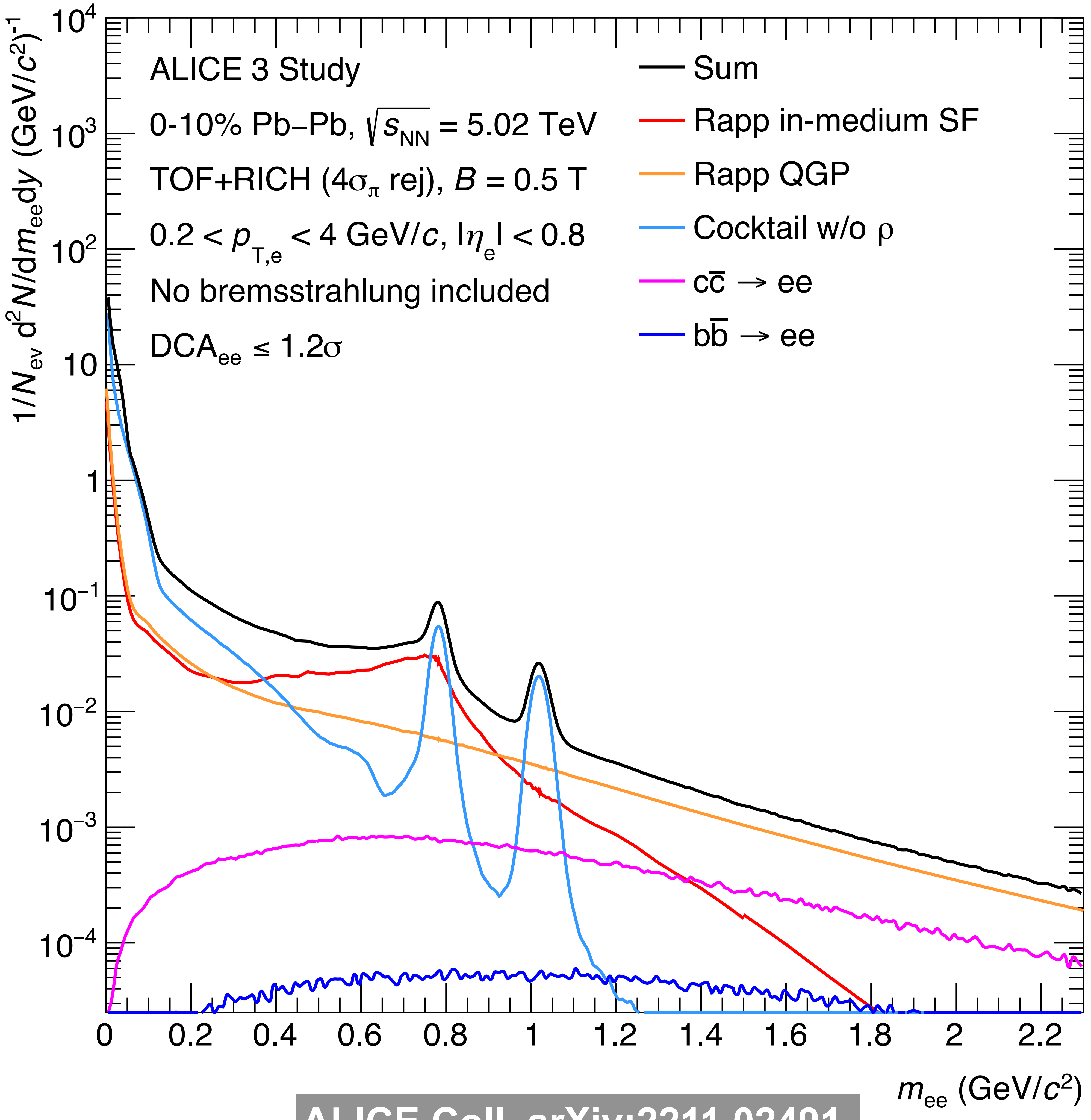




Thermal radiation and chiral symmetry

→ *Needs precise measurement in the di-lepton sector*

- Spectral function of low mass dielectrons determined with 6-8% unc. in the region $0.4 \leq m_{ee} \leq 1.3$ GeV/c^2
- Chiral mixing produces a 20-25% change versus vacuum spectral functions ($0.8 \leq m_{ee} \leq 1.2$ GeV/c^2)
- ALICE 3 can observe chiral mixing effect and together with more differential measurements (dielectrons v_2) constraint the modification of a_1 spectral function



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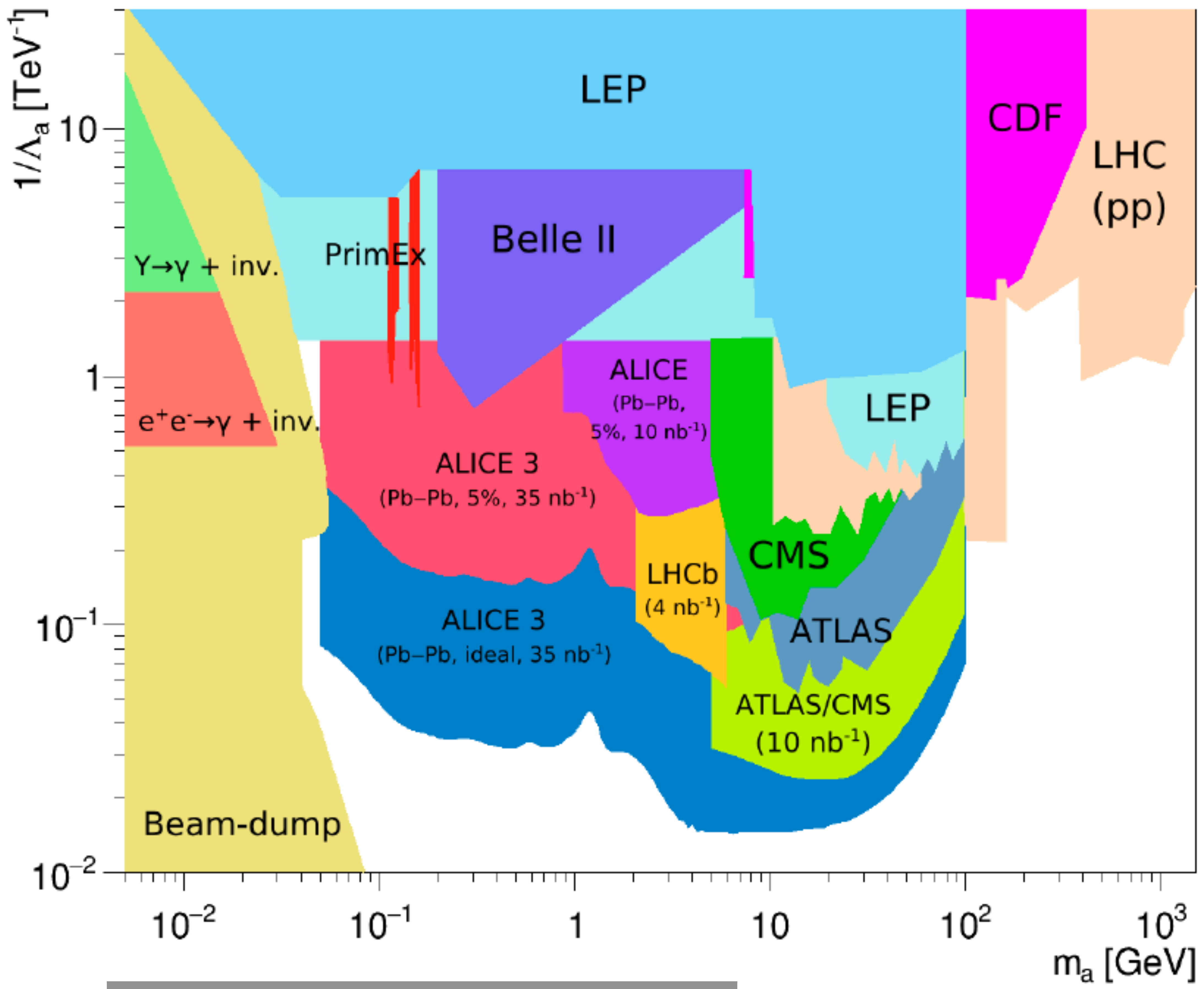
BSM searches in UPCs



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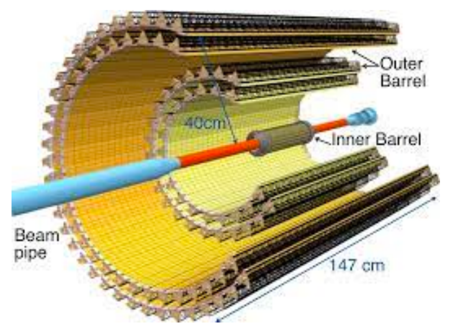
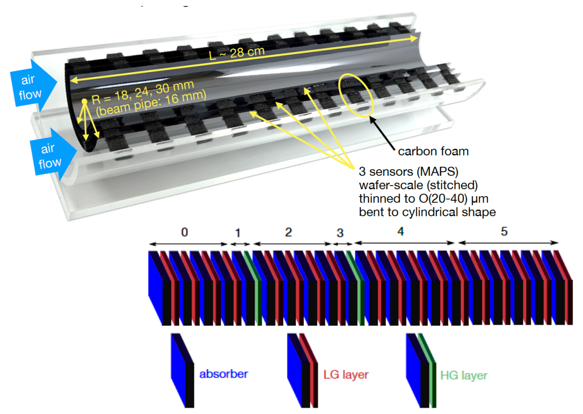
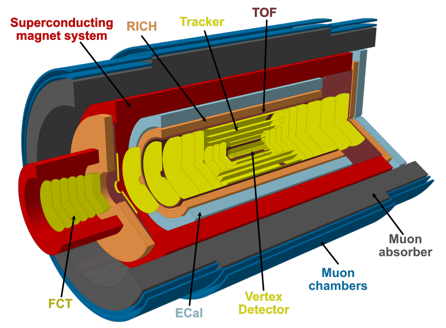
- Ultra-peripheral collisions (UPCs) are dominated by photon-photon and photon-nucleus interactions. Provide for a clean environment for axion-like particles (ALP) studies
- Searches via $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$ process. Signal would be visible as a peak in the diphoton mass distribution
- Performance on the estimated production cross-section given as mass and recast limit in the plane $(m_a, 1/\Lambda_a)$

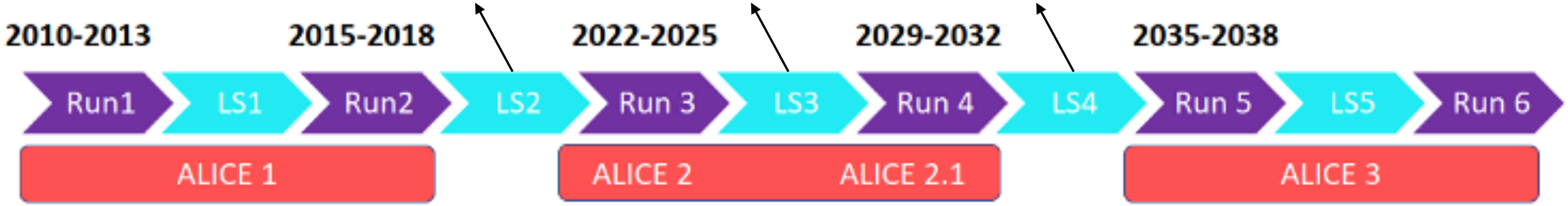
Concluding

- ALICE came a long way in the investigation of QCD in extreme conditions and more is to come during LHC run 3 and 4.
- Results obtained poses additional fundamental questions that require a new heavy-ion program at LHC.
- The physics questions call for a new heavy-ion detector @ LHC ready for Run 5 and 6: ALICE Collaboration has published the ALICE 3 letter of intent in 2022.
- Several R&D challenges have been highlighted with clear plans for addressing them in the coming years

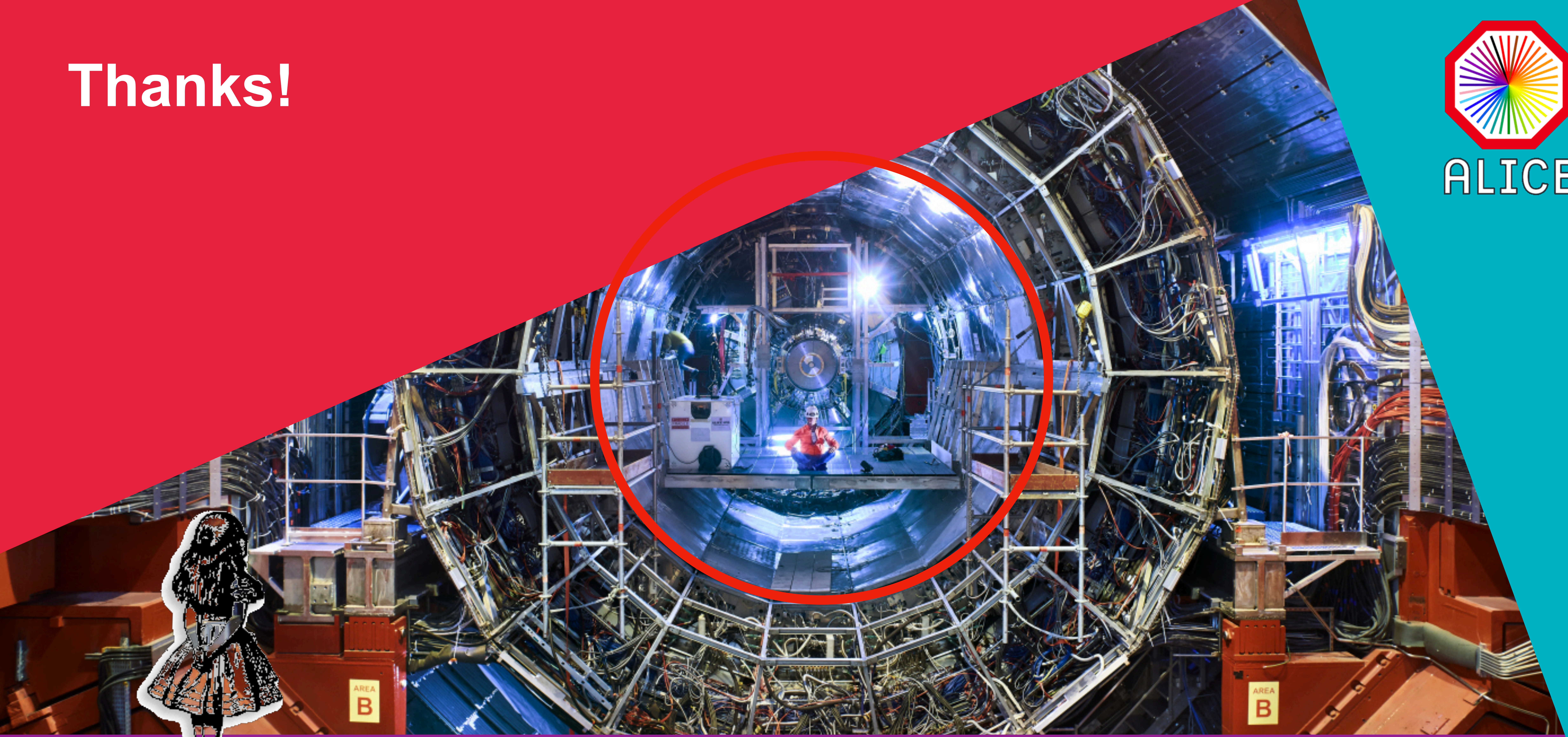








Thanks!



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Collision systems @ LHC

Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{NN}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} (cm^{-2}s^{-1})	3.0×10^{32}	1.5×10^{30}	3.2×10^{29}	2.8×10^{29}	8.5×10^{28}	5.0×10^{28}	3.3×10^{28}	1.2×10^{28}
$\langle L_{AA}\rangle$ (cm^{-2}s^{-1})	3.0×10^{32}	9.5×10^{29}	2.0×10^{29}	1.9×10^{29}	5.0×10^{28}	2.3×10^{28}	1.6×10^{28}	3.3×10^{27}
$\mathcal{L}_{AA}^{month}$ (nb^{-1})	5.1×10^{5}	1.6×10^{3}	3.4×10^{2}	3.1×10^{2}	8.4×10^{1}	3.9×10^{1}	2.6×10^{1}	5.6
$\mathcal{L}_{NN}^{month}$ (pb^{-1})	505	409	550	500	510	512	434	242
R_{max} (kHz)	24 000	2169	821	734	344	260	187	93
μ	1.2	0.21	0.08	0.07	0.03	0.03	0.02	0.01
$dN_{ch}/d\eta$ (MB)	7	70	151	152	275	400	434	682
	at $R = 0.5$ cm							
R_{hit} (MHz/cm^2)	94	85	69	62	53	58	46	35
NIEL (1 MeV n_{eq}/cm^2)	1.8×10^{14}	1.0×10^{14}	8.6×10^{13}	7.9×10^{13}	6.0×10^{13}	3.3×10^{13}	4.1×10^{13}	1.9×10^{13}
TID (Rad)	5.8×10^{6}	3.2×10^{6}	2.8×10^{6}	2.5×10^{6}	1.9×10^{6}	1.1×10^{6}	1.3×10^{6}	6.1×10^{5}
	at $R = 100$ cm							
R_{hit} (kHz/cm^2)	2.4	2.1	1.7	1.6	1.3	1.0	1.1	0.9
NIEL (1 MeV n_{eq}/cm^2)	4.9×10^{9}	2.5×10^{9}	2.1×10^{9}	2.0×10^{9}	1.5×10^{9}	8.3×10^{8}	1.0×10^{9}	4.7×10^{8}
TID (Rad)	1.4×10^{2}	8.0×10^{1}	6.9×10^{1}	6.3×10^{1}	4.8×10^{1}	2.7×10^{1}	3.3×10^{1}	1.5×10^{1}

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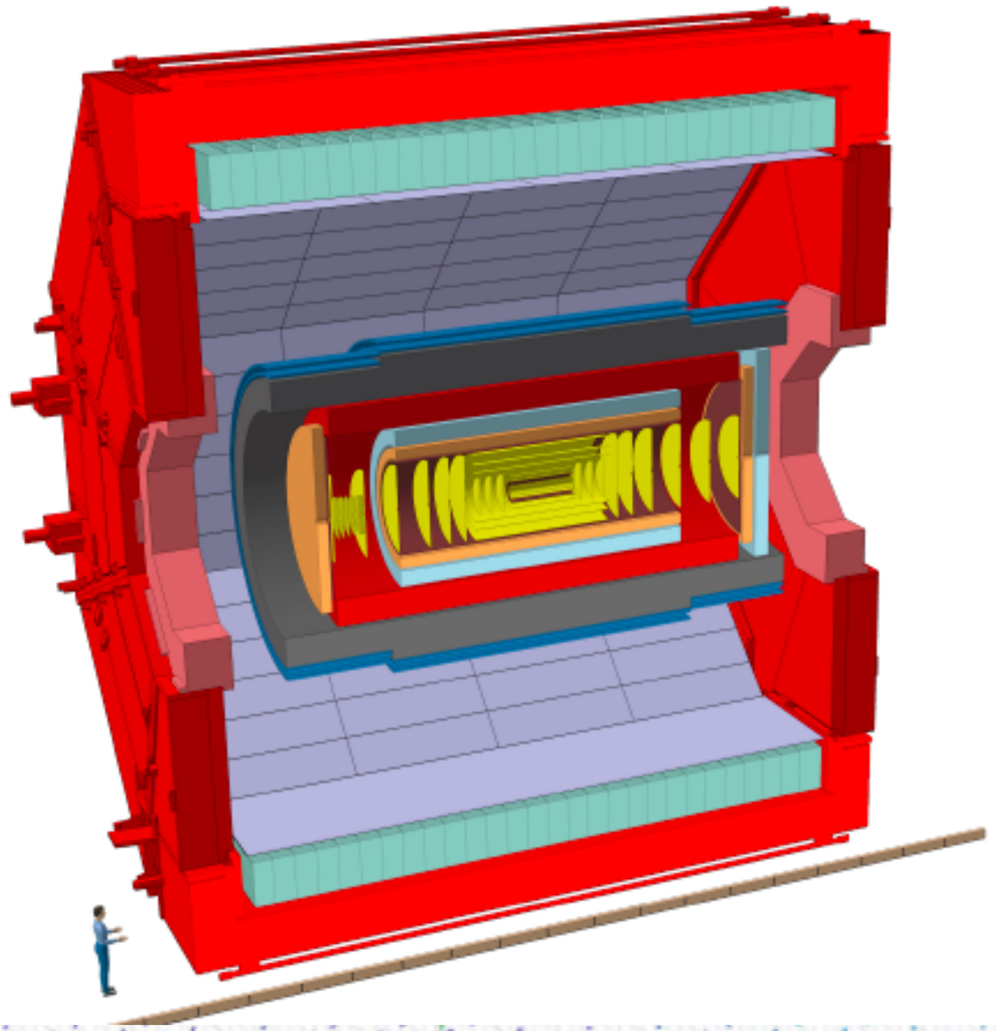
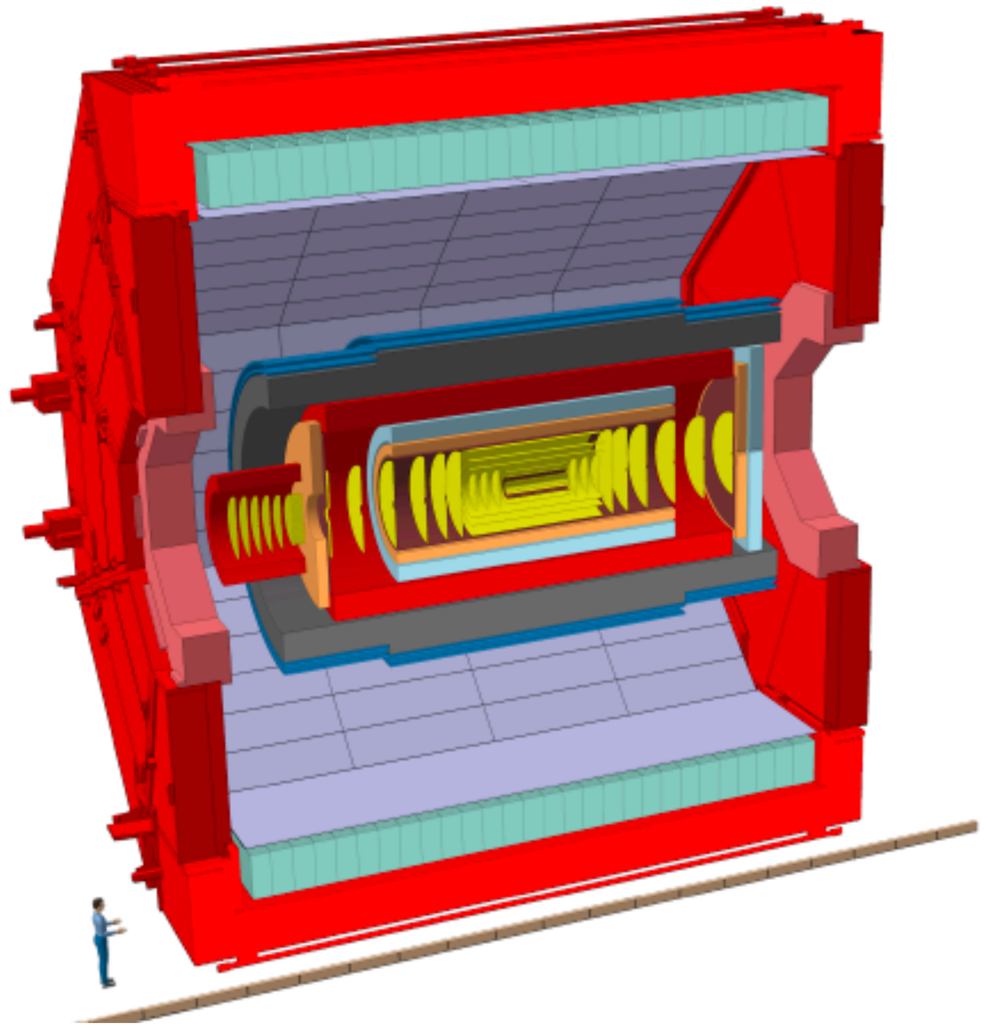
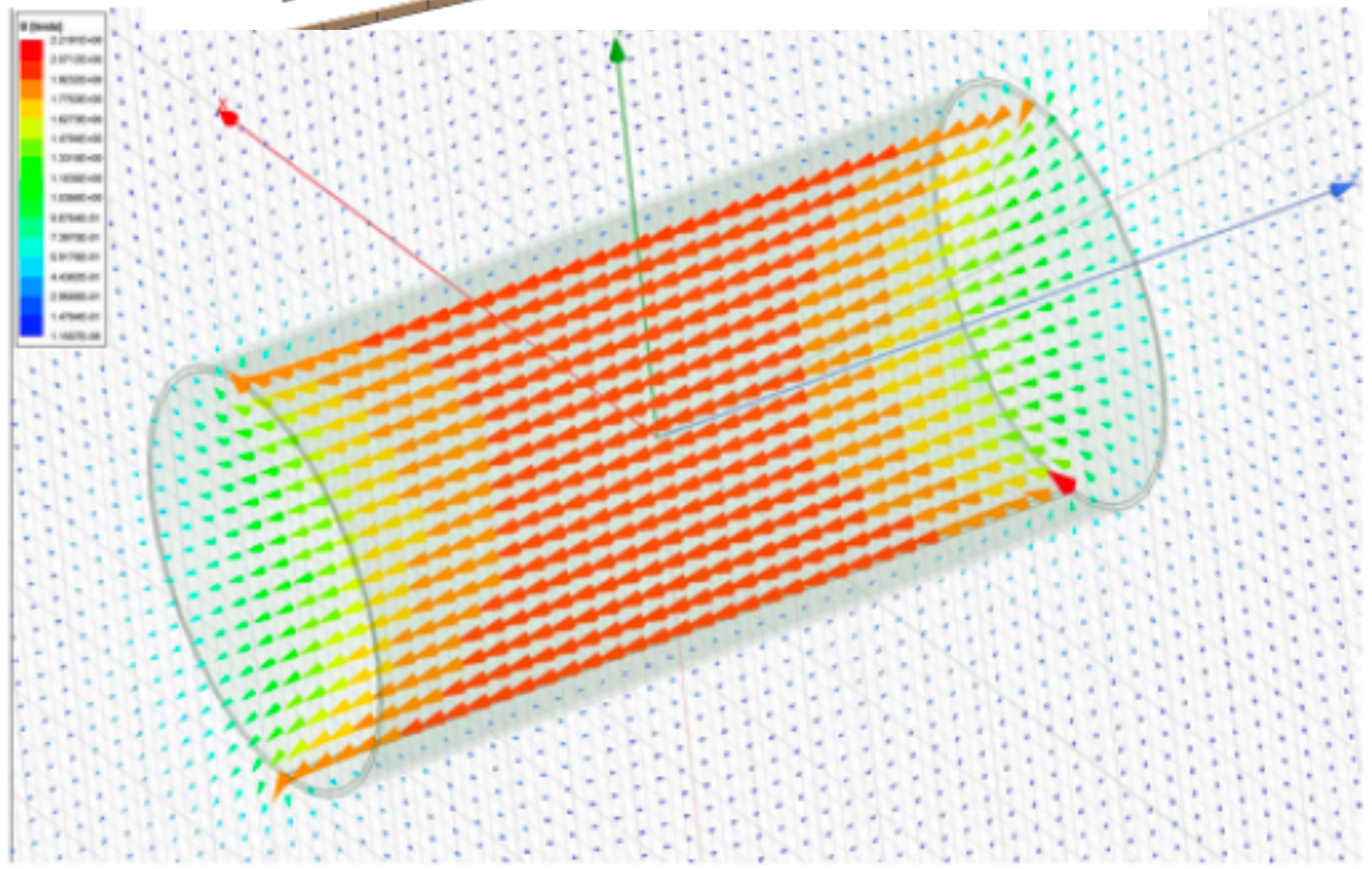
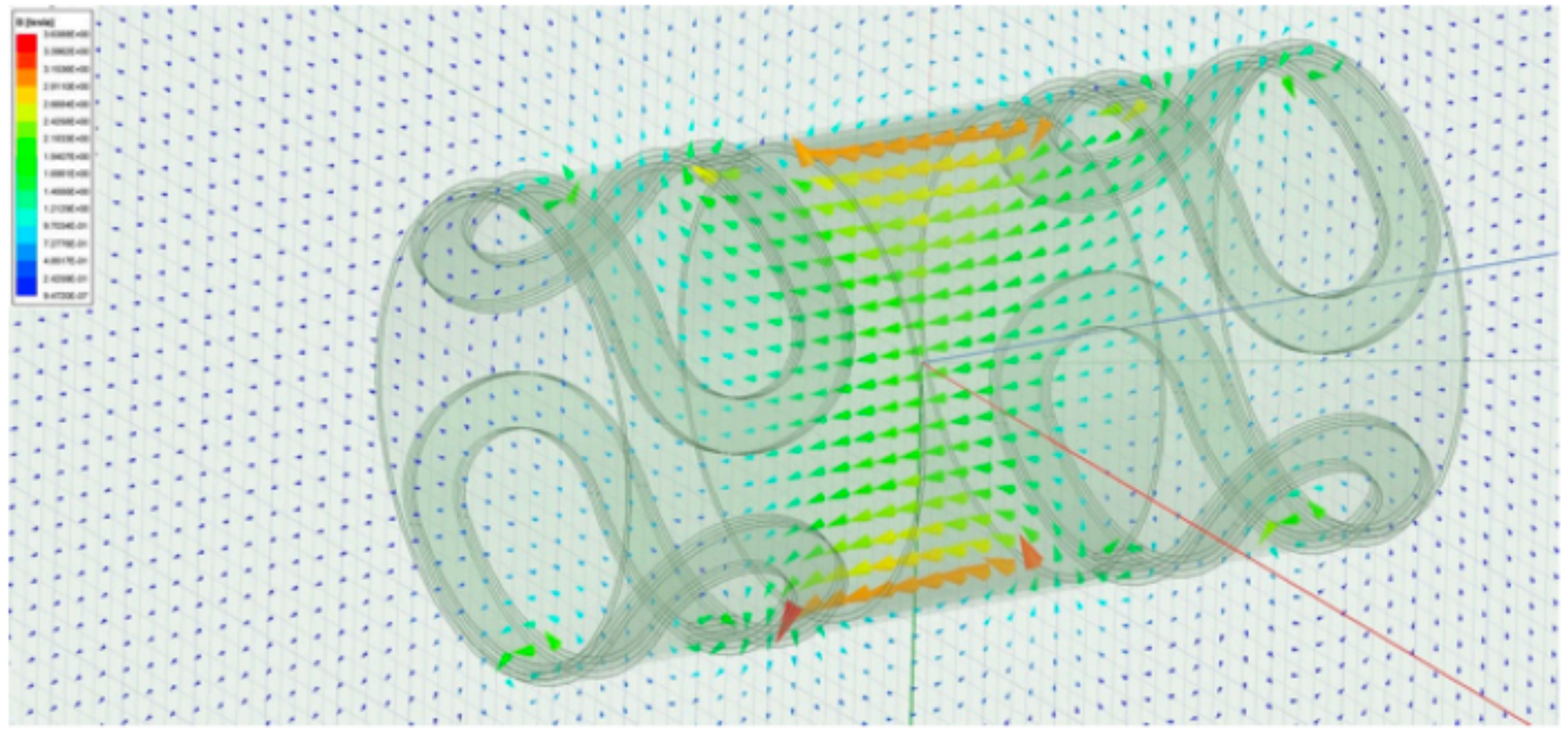
Magnet: *solenoid* vs *solenoid + dipole*









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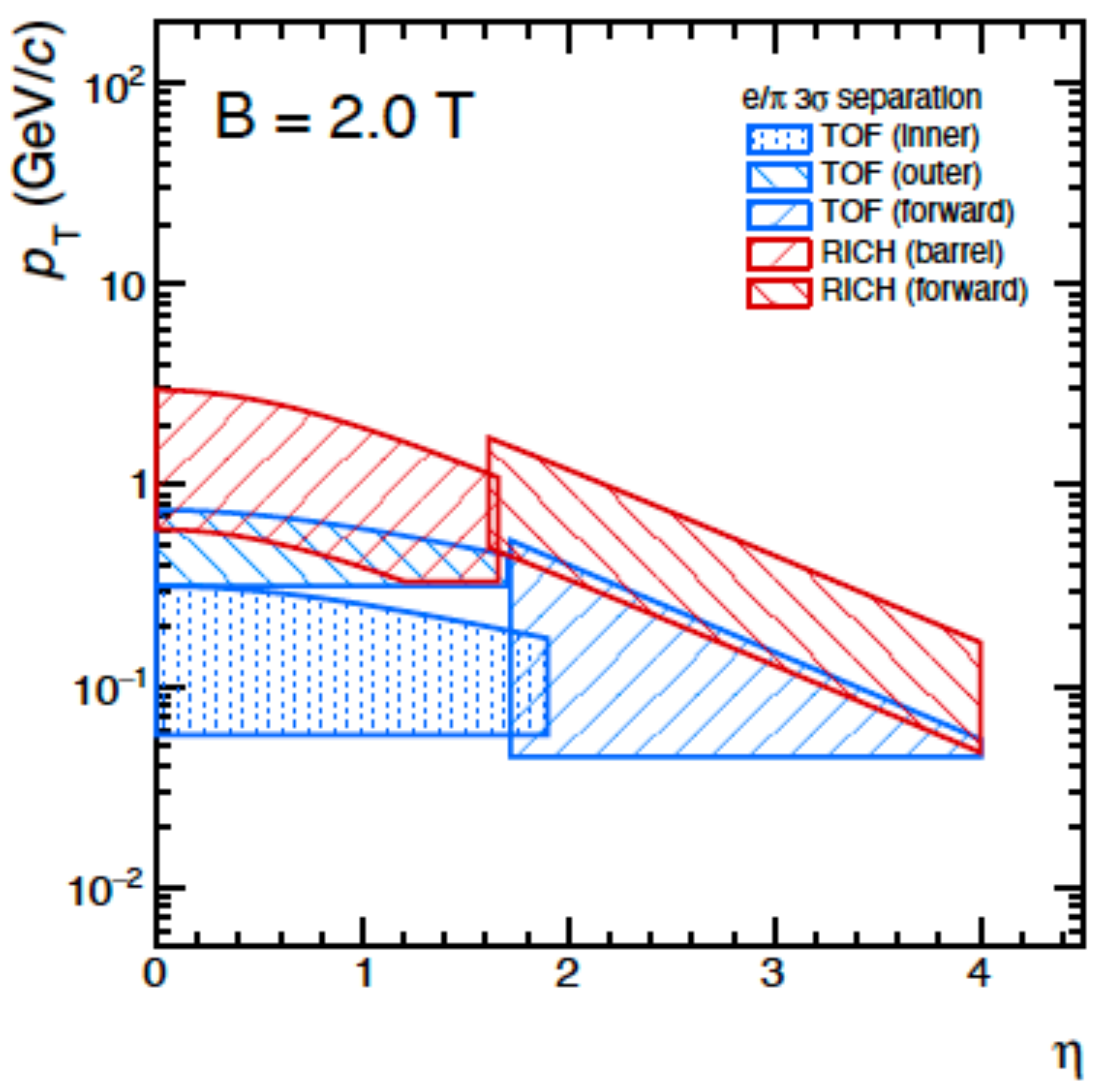
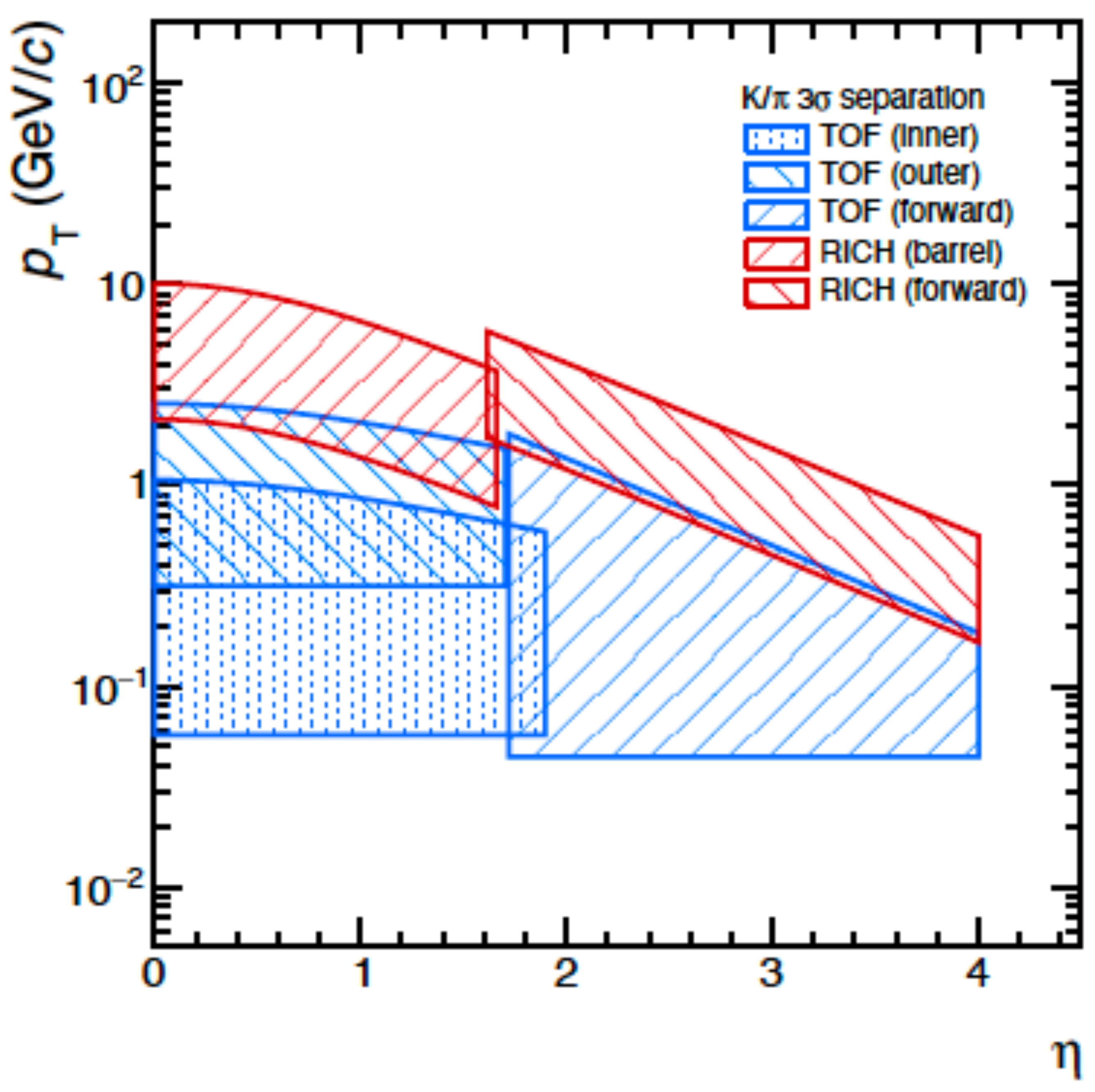
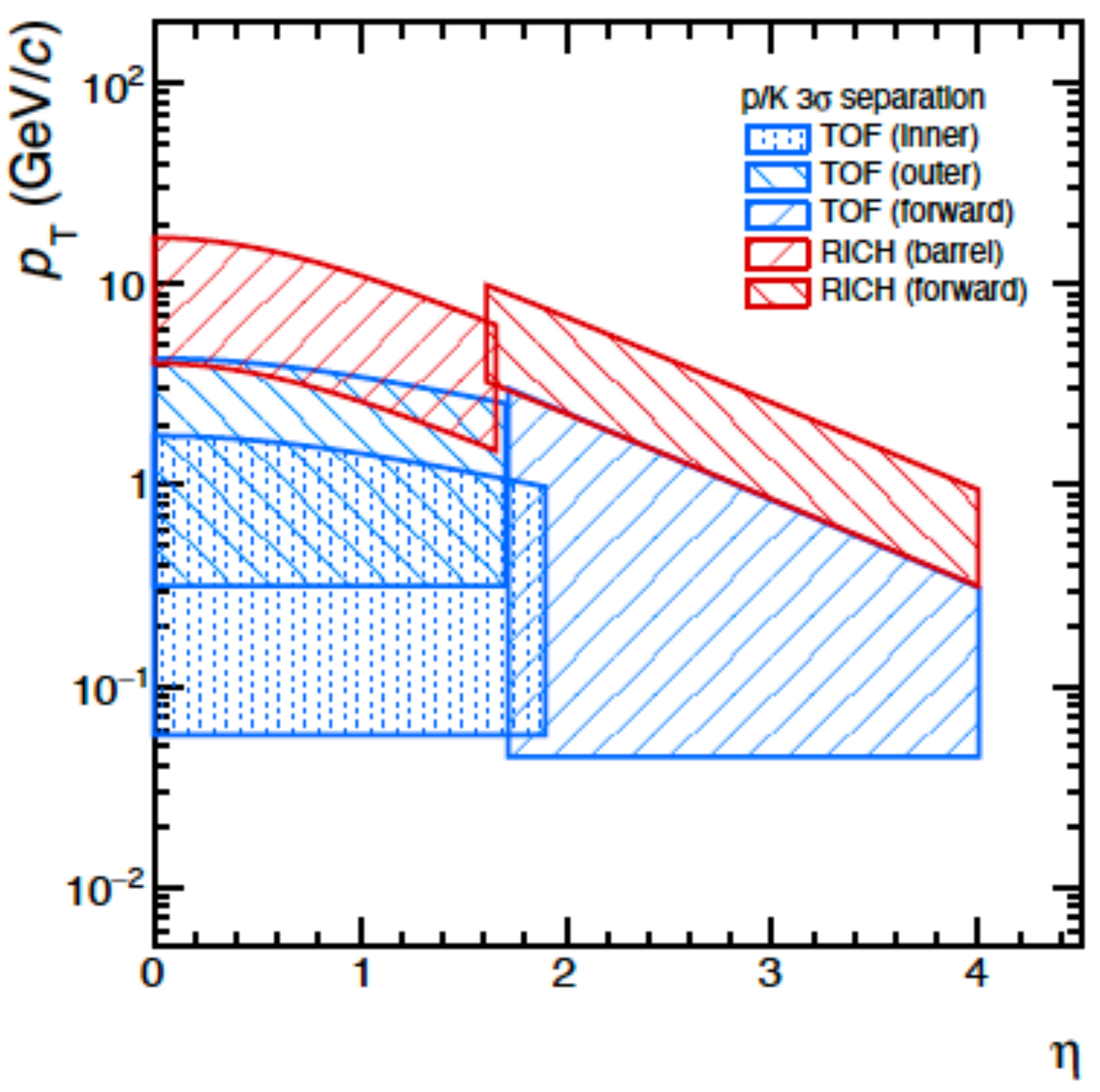
PID performances @ B = 2 T

3σ separation TOF+ RICH e/π	3σ separation TOF+ RICH K/π	3σ separation TOF+ RICH p/K







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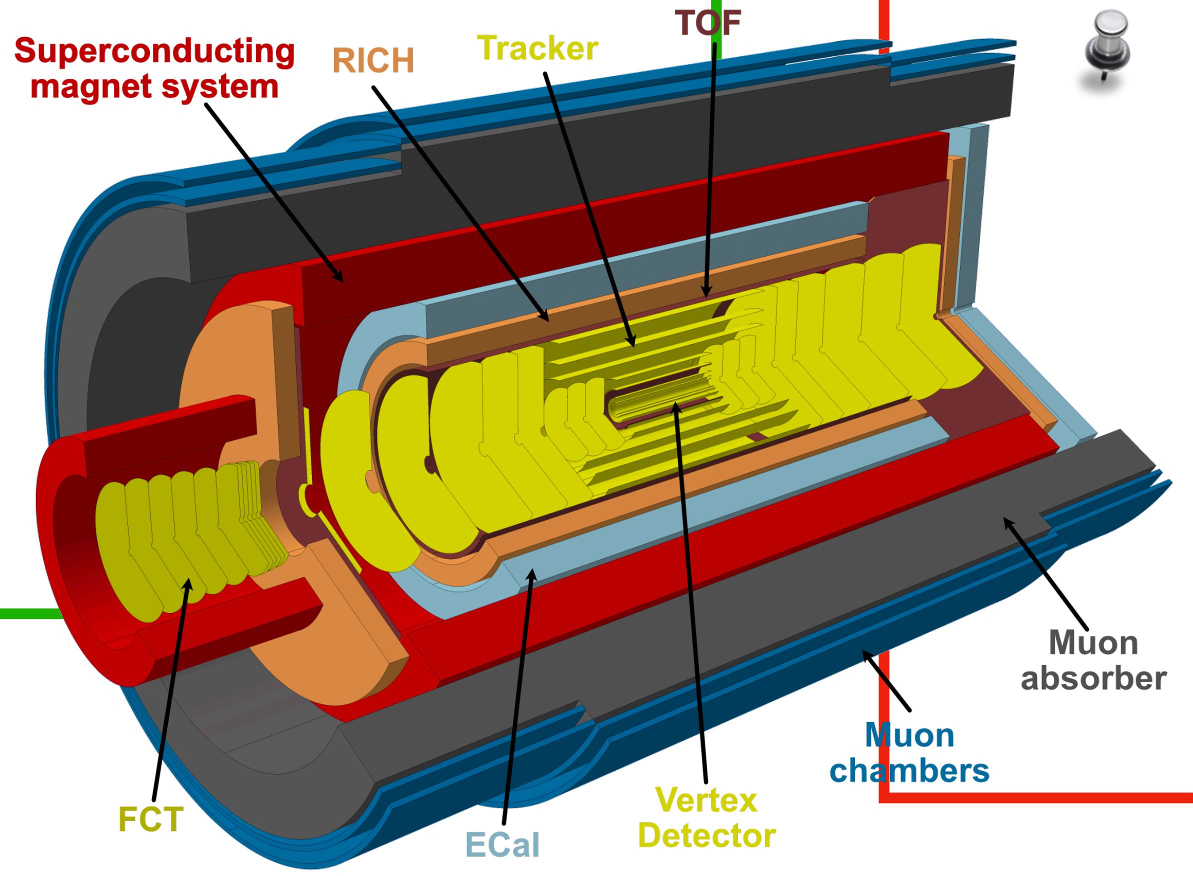
eCAL detector and muon ID

eCAL concept:

- Sampling calorimeter (barrel + endcap) with cell size 2 cm x 2 cm, covering $-1.6 < \eta < 4$
- Barrel inner radius 1.15 m and outer radius 1.45 m for a length of 7 m ($|\eta|<1.6$)
- Endcap disk inner radius 16 cm, outer radius 1.8 m at z = 4.35 m ($1.6 < \eta < 4$)
- $PbWO_4$ crystals with SiPM readout

Muon identifier concept:

- Muon chambers outside the magnet system. Identify particle passing 1kt hadron absorber
- Chambers granularity: $\Delta\eta\Delta\phi = 0.02 \times 0.02 \rightarrow$ RPCs with 50-60 mm granularity
- Endcap disk inner radius 16 cm, outer radius 1.8 m at z = 4.35 m ($1.6 < \eta < 4$)
- $PbWO_4$ crystals with SiPM readout



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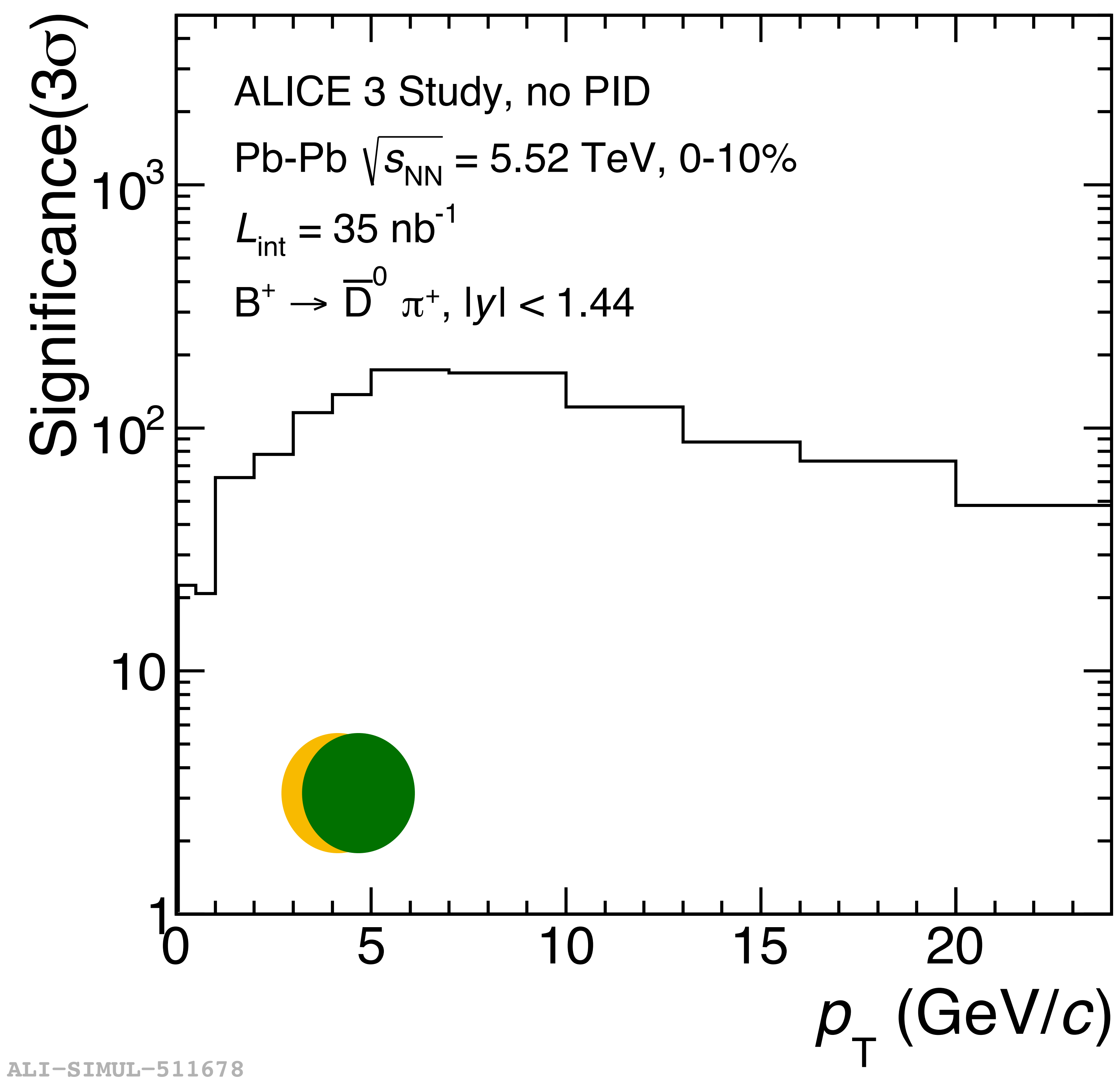
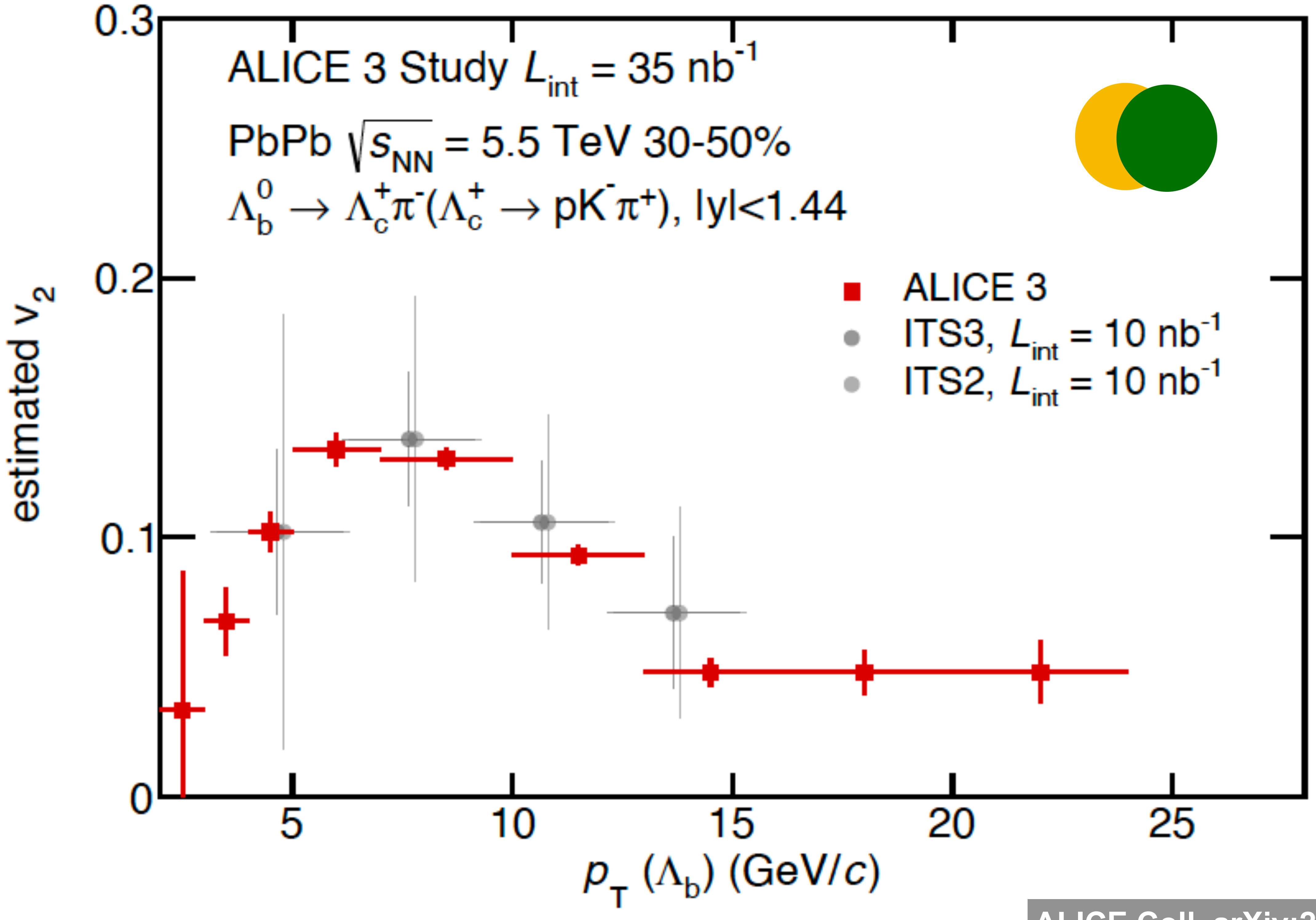
Beauty measurements

→ *Needs precision measurements of beauty quark*

B^+ reconstruction



Λ_b elliptic flow, v_2



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