ALICE upgrades

Giuseppe Bruno
Dipartimento di Fisica and INFN – Bari –Italy

Exploring Quark-Gluon Plasma through soft and hard probes

Belgrade - May the 31st 2023

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Outline:

- Expected timeline
- ALICE in Run 3: current experiment
- ALICE for Run 4: upgrades in LS3
  - ITS3
  - FoCal
- ALICE 3: a new experiment for Run 5 and beyond
- Conclusions

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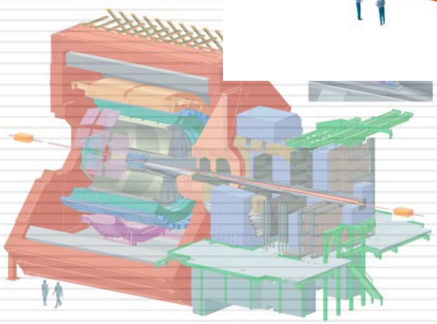
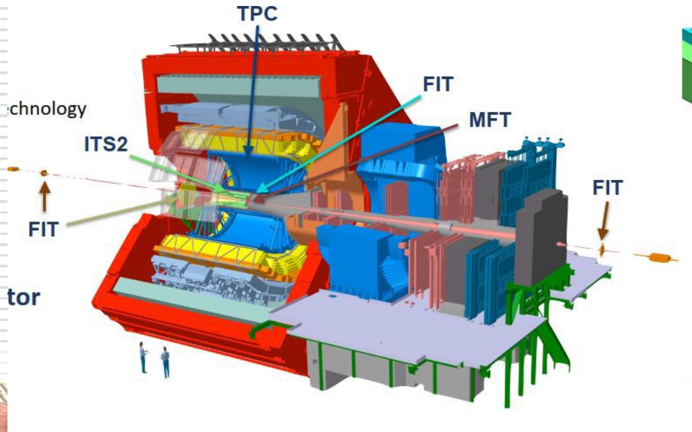
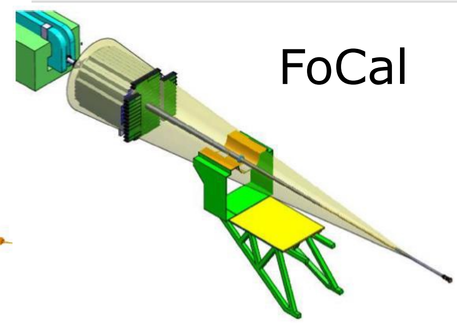
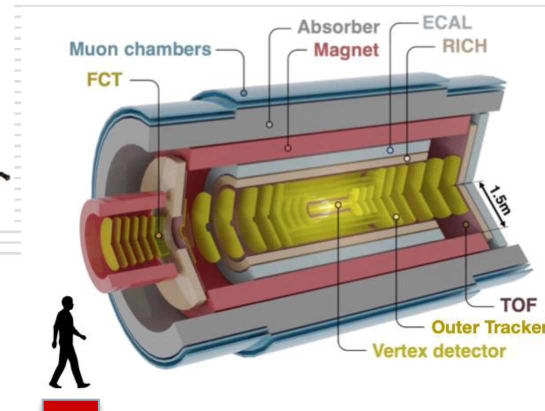
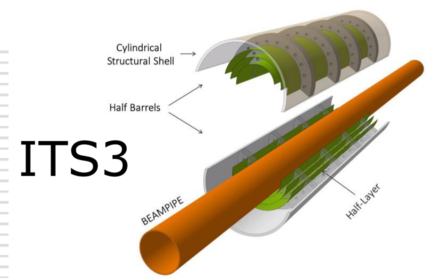
ALICE Timeline











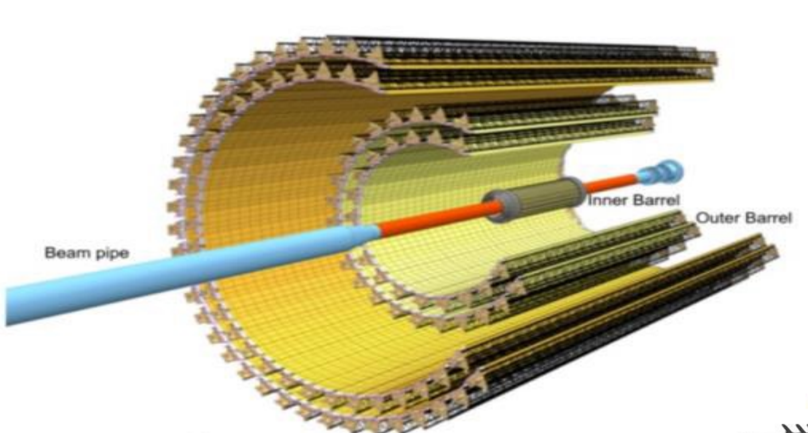
2010-2013		2015-2018		2022-2025		2029-2032		2035-2038		
Run1	LS1	Run2	LS2	Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
ALICE 1				ALICE 2		ALICE 2.1		ALICE 3		

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

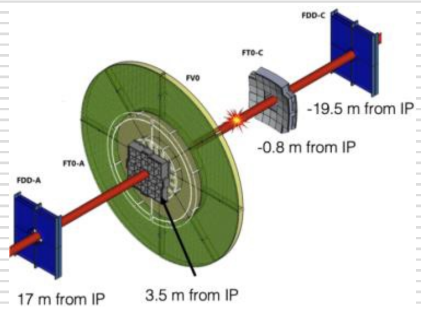
ALICE upgrades for Run 3

ALICE upgrades during the LHC Long Shutdown 2
https://arxiv.org/abs/2302.01238

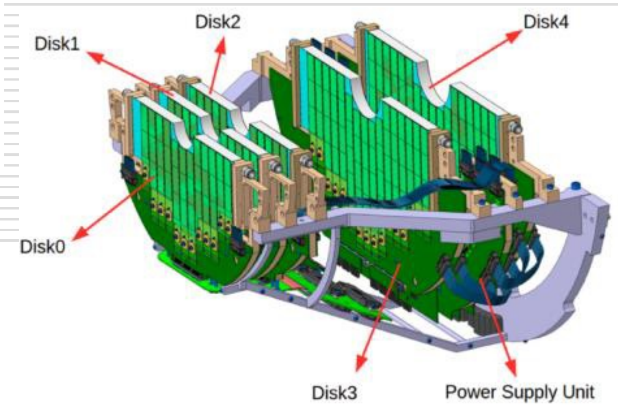
New Inner Tracking system (ITS2)



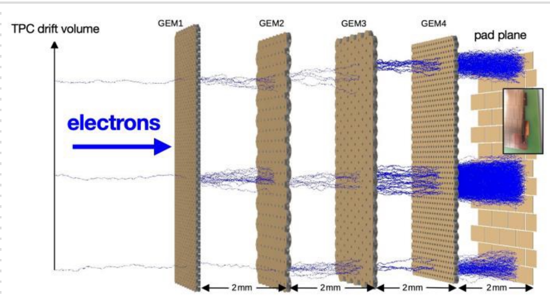
New Fast Interaction Trigger (FIT)

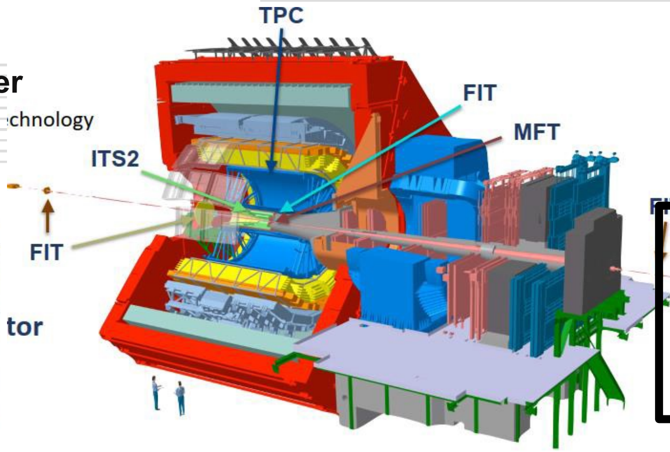


New Muon Forward Tracker (MFT)



Upgrade of Time Projection Chamber (TPC) with GEM amplification





New data acquisition and reconstruction framework –(Online –Offline , O2)

Continuous data taking of min. bias Pb-Pb data at 50 kHz

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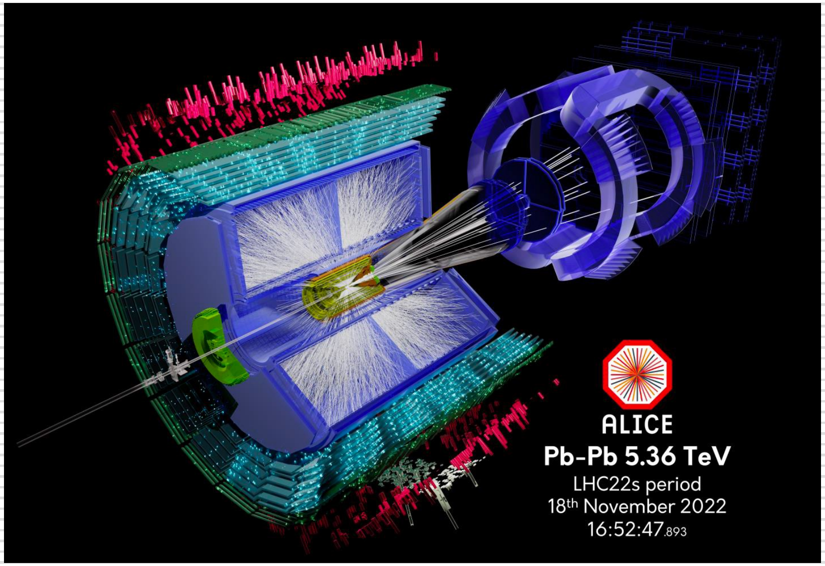
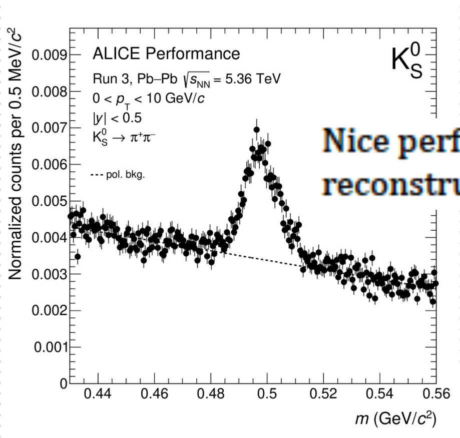
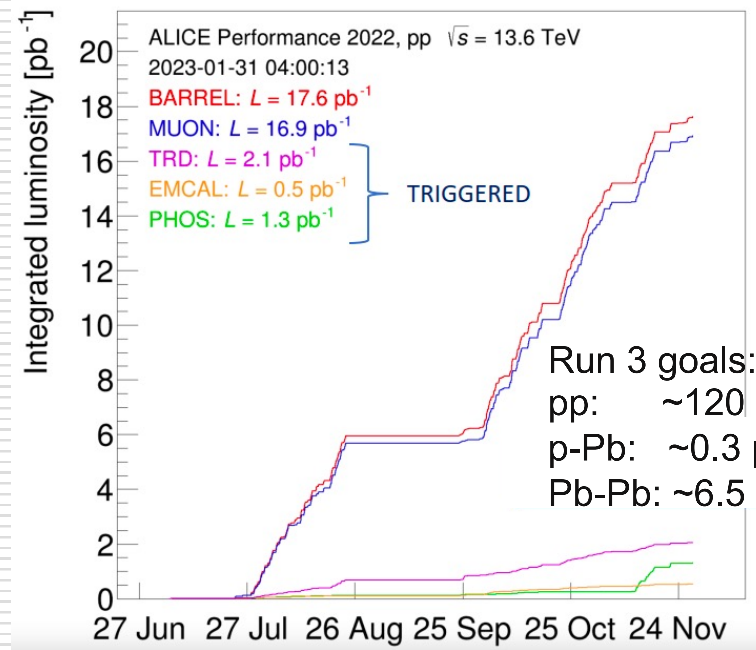




Nice performance for $K^0_s \to \pi^+\pi^-$ signal reconstruction in 2022 Pb-Pb data



Run 3 goals:
pp: ~120 pb-1
p-Pb: ~0.3 pb-1
Pb-Pb: ~6.5 nb-1

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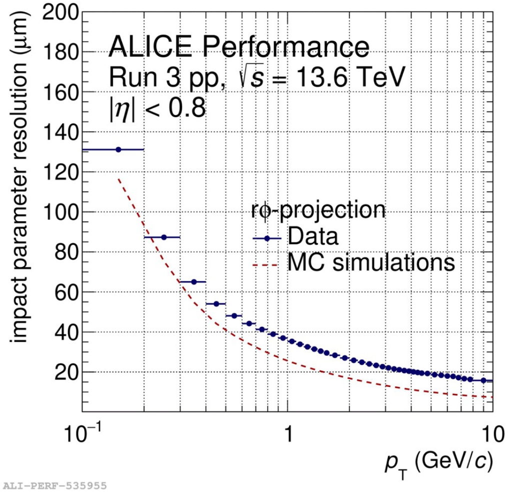

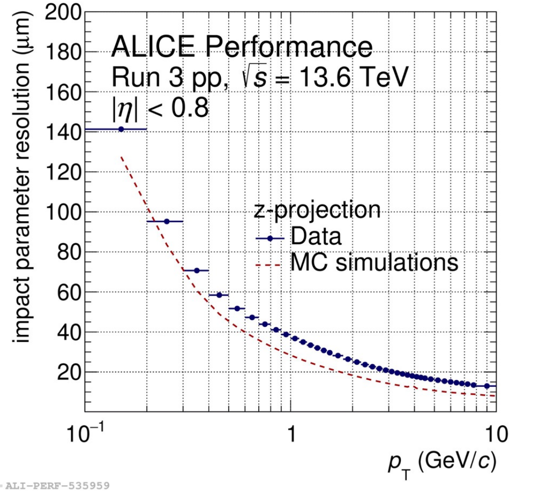

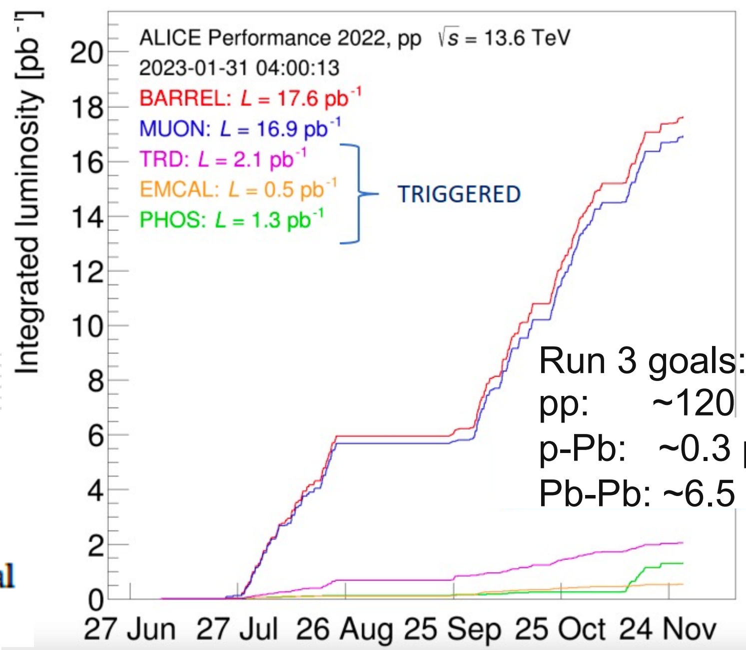

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pp: ~120 pb-1
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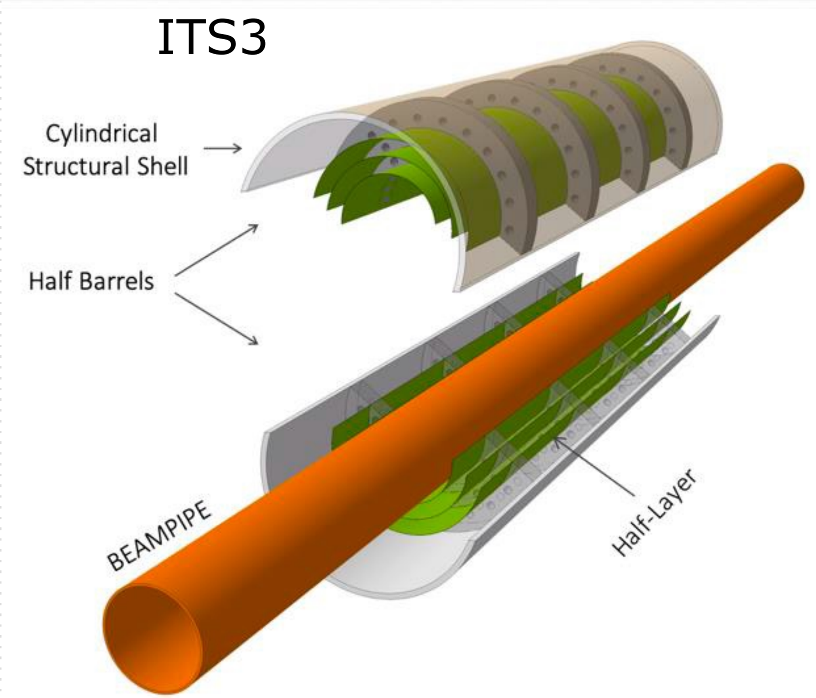
Pointing resolution to the PV of **~35-40 μm @ p_T = 1 GeV/*c***

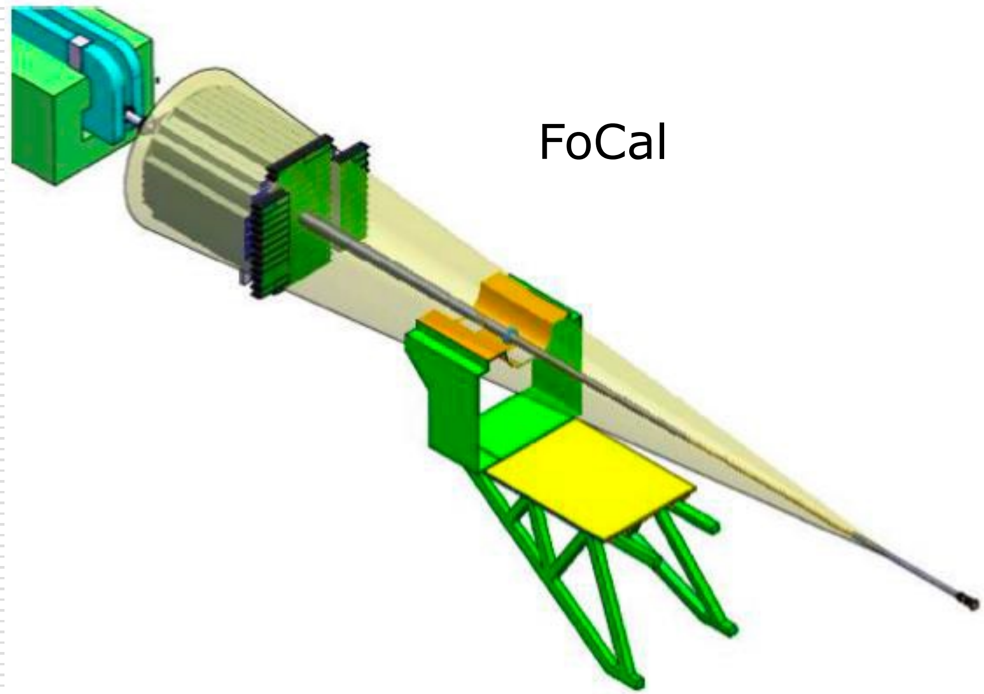
2x (4-5x) better performance in ***rφ* (*z*)** compared to Run 2

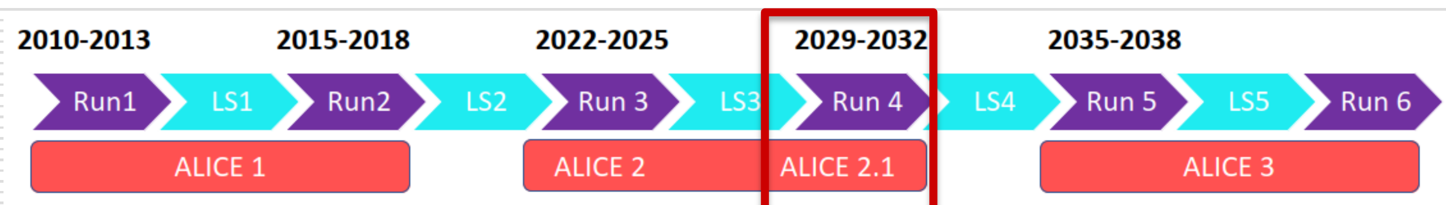
Fine-tuning on TPC calibrations/ITS alignment ongoing to fix residual mismatch with MC

This project has received funding

ALICE upgrades for Run 4







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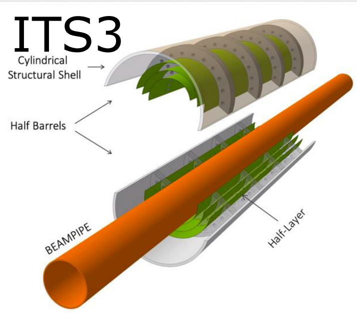
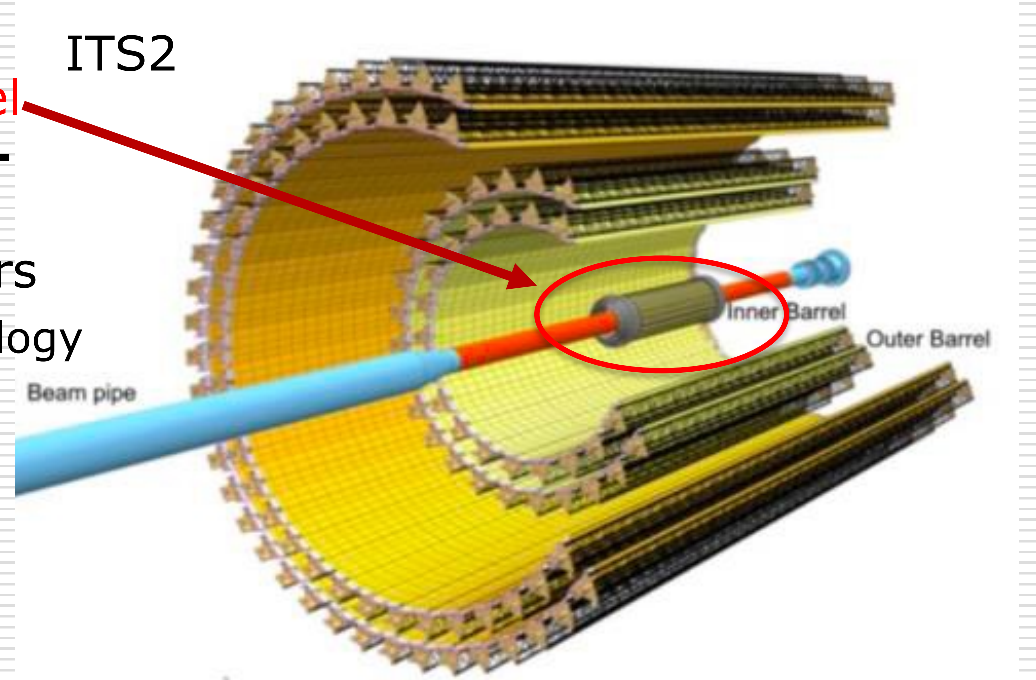
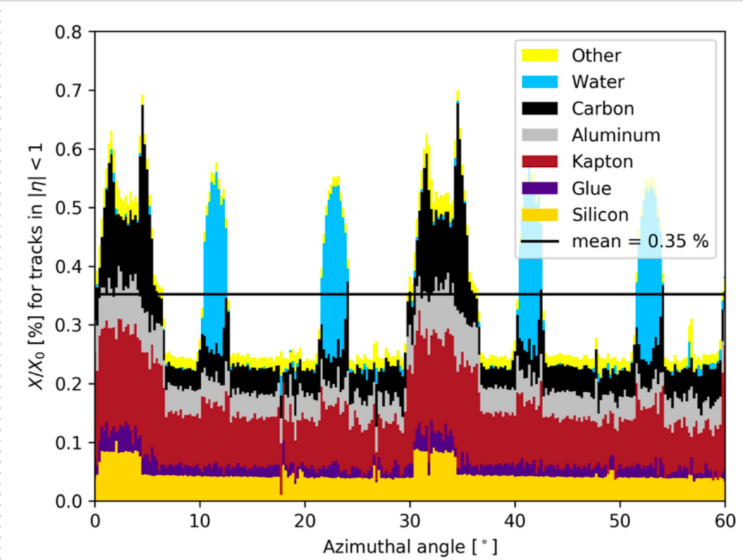
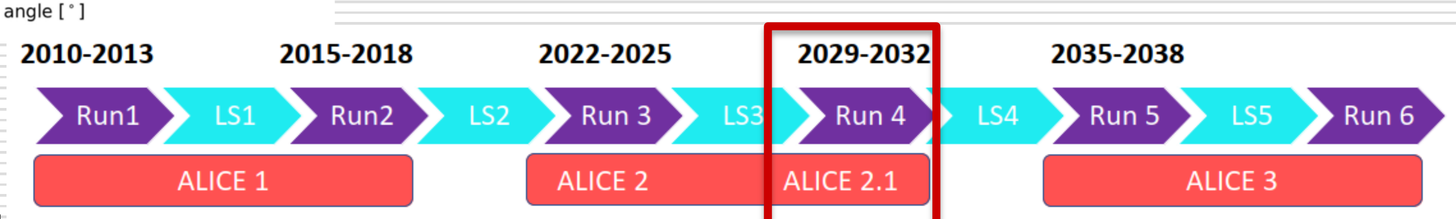


goal of ITS3 project: replacing inner barrel of ITS2 with **silicon-only** wafer-scale truly-cylindrical layers in 65 nm CMOS technology







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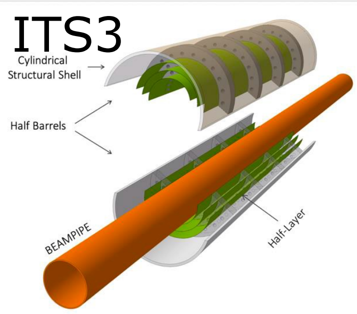

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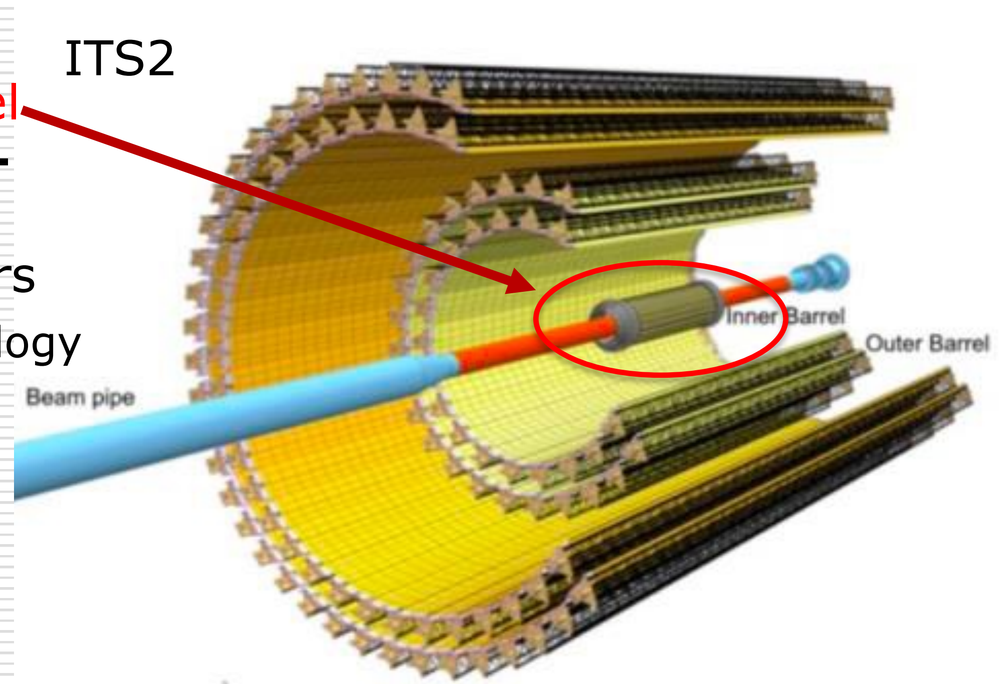

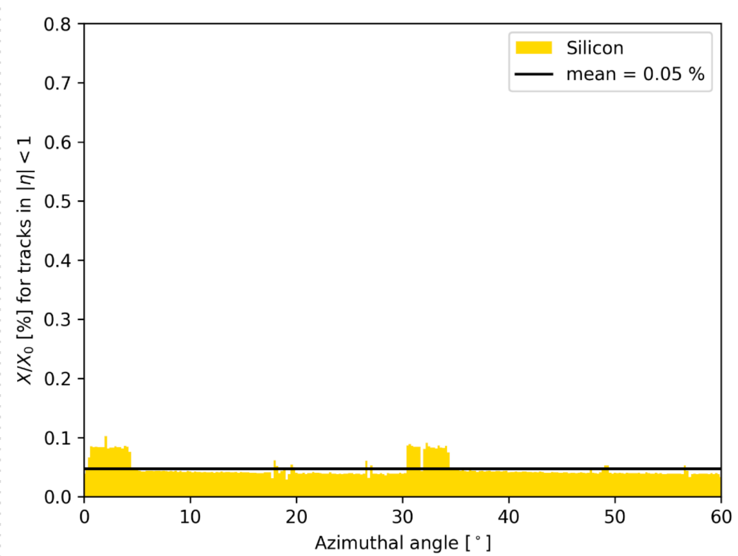

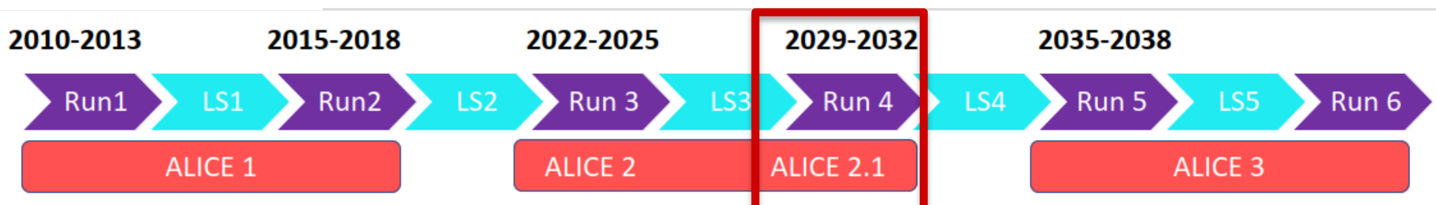

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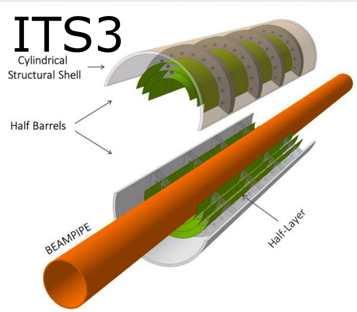
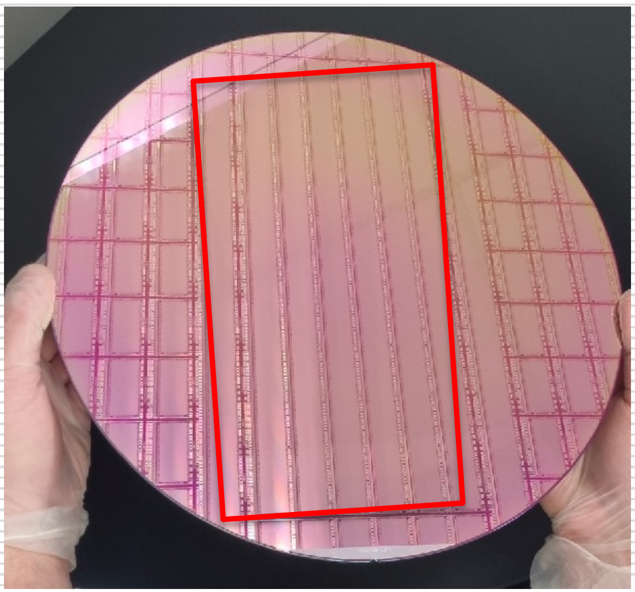
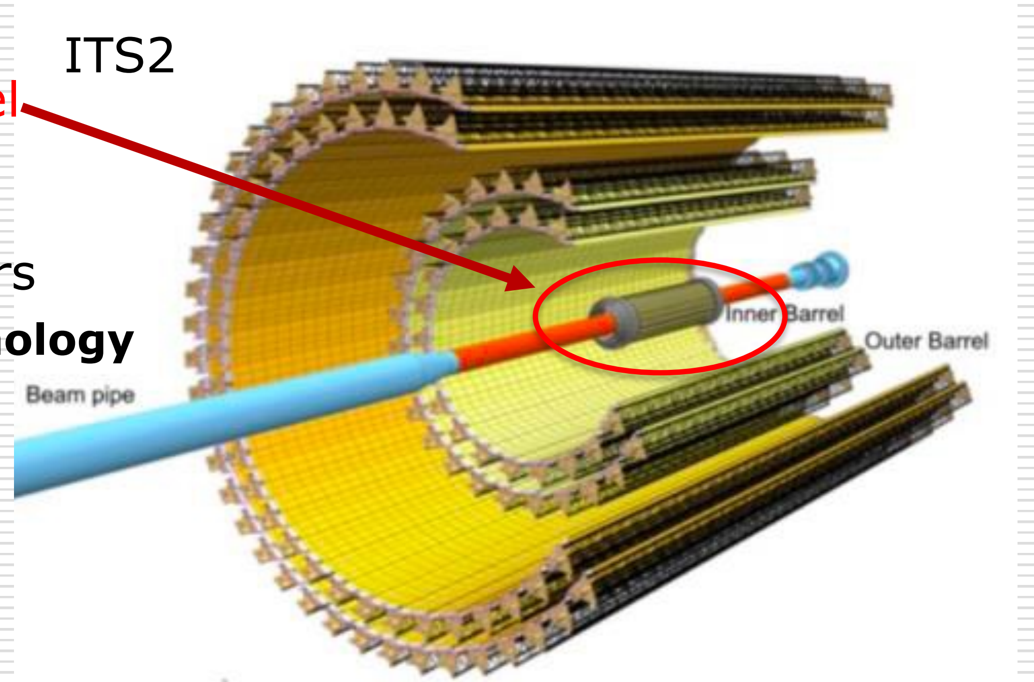
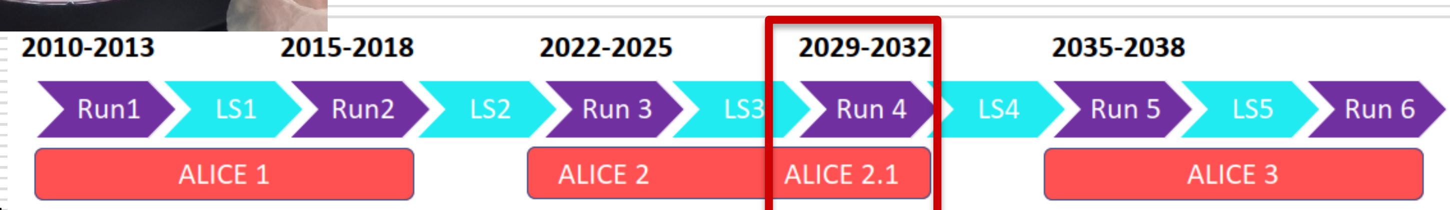


goal of ITS3 project: replacing inner barrel of ITS2 with silicon-only **wafer-scale** truly-cylindrical layers

in **65 nm CMOS technology**







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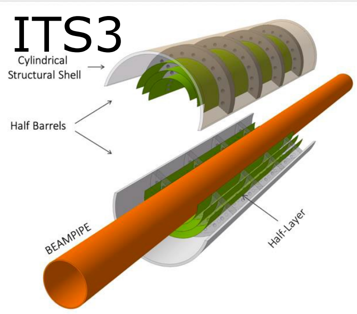

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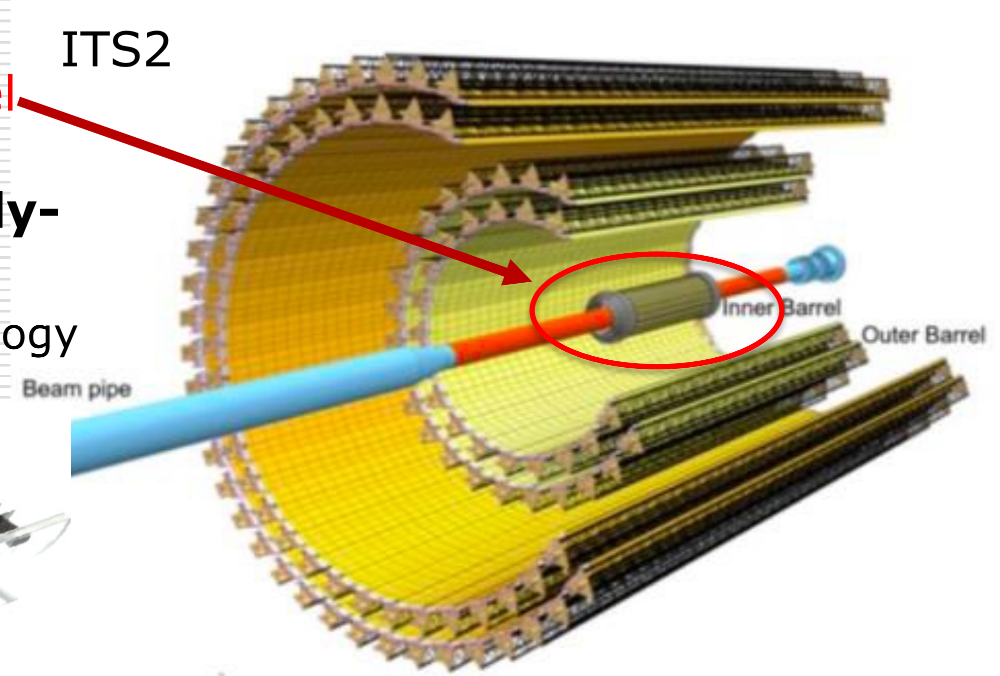

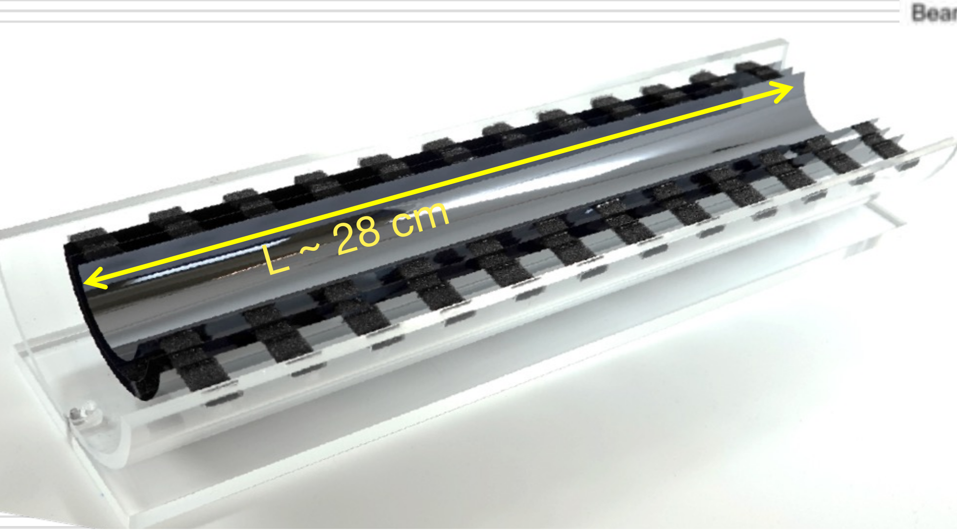

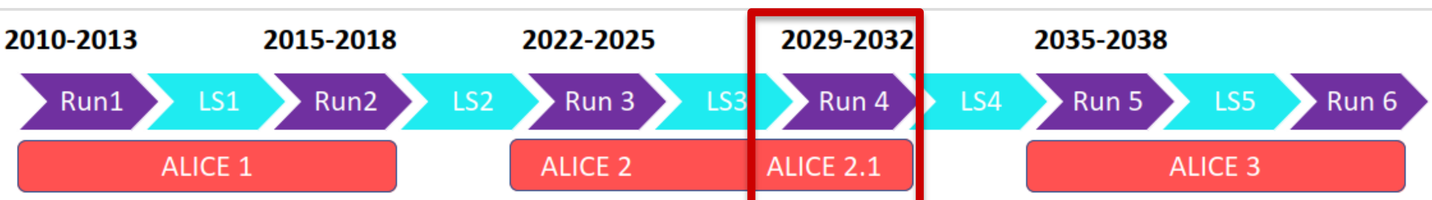

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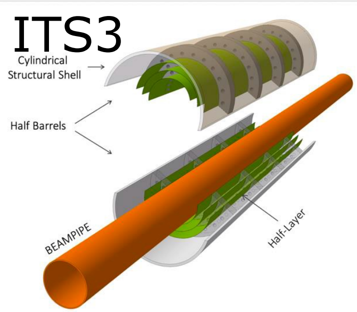

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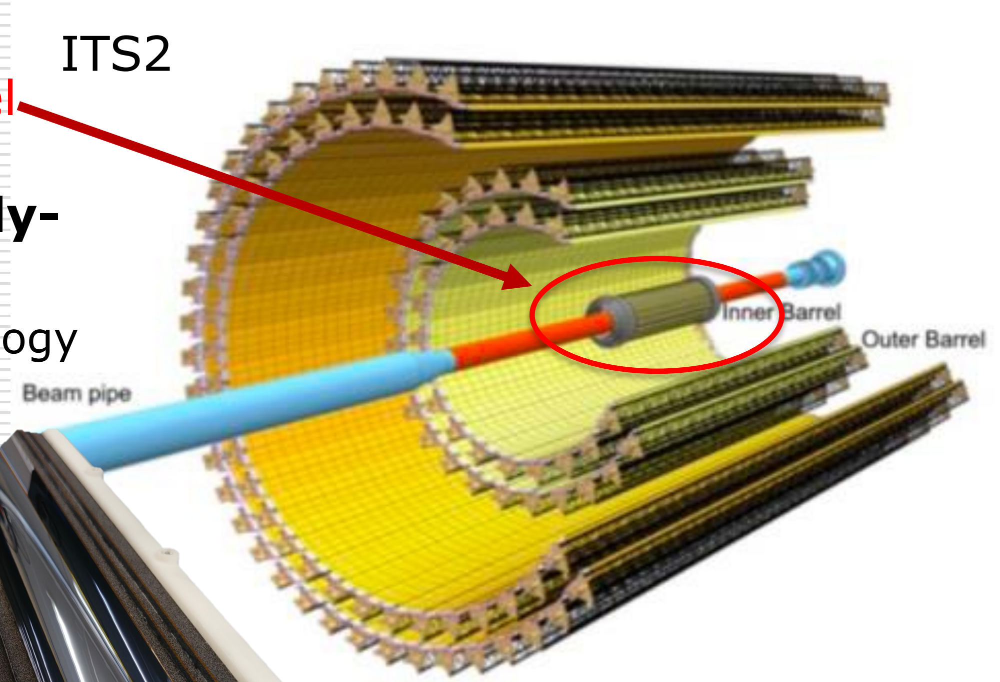

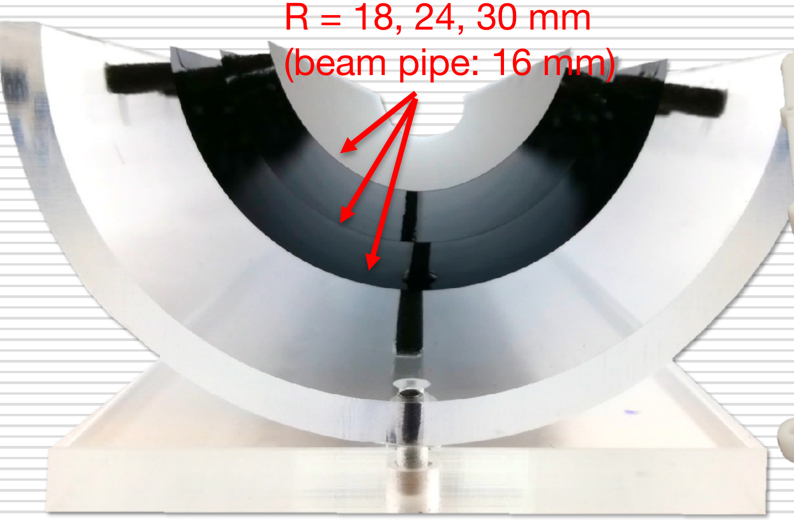

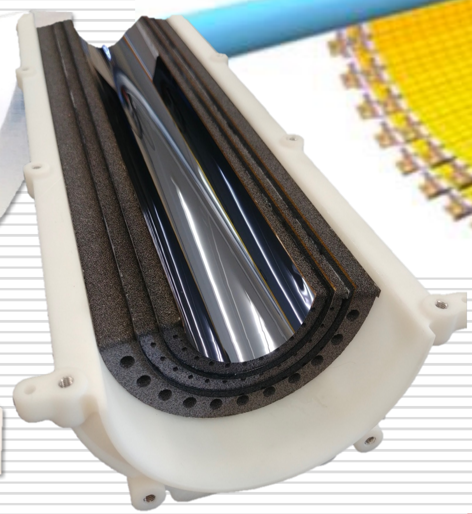

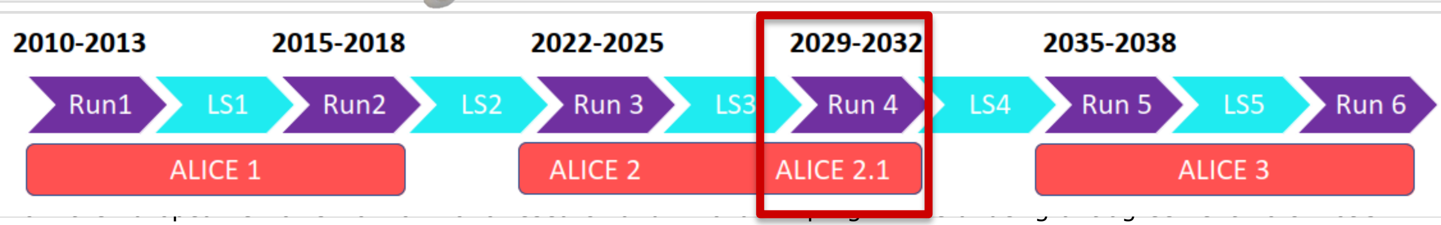

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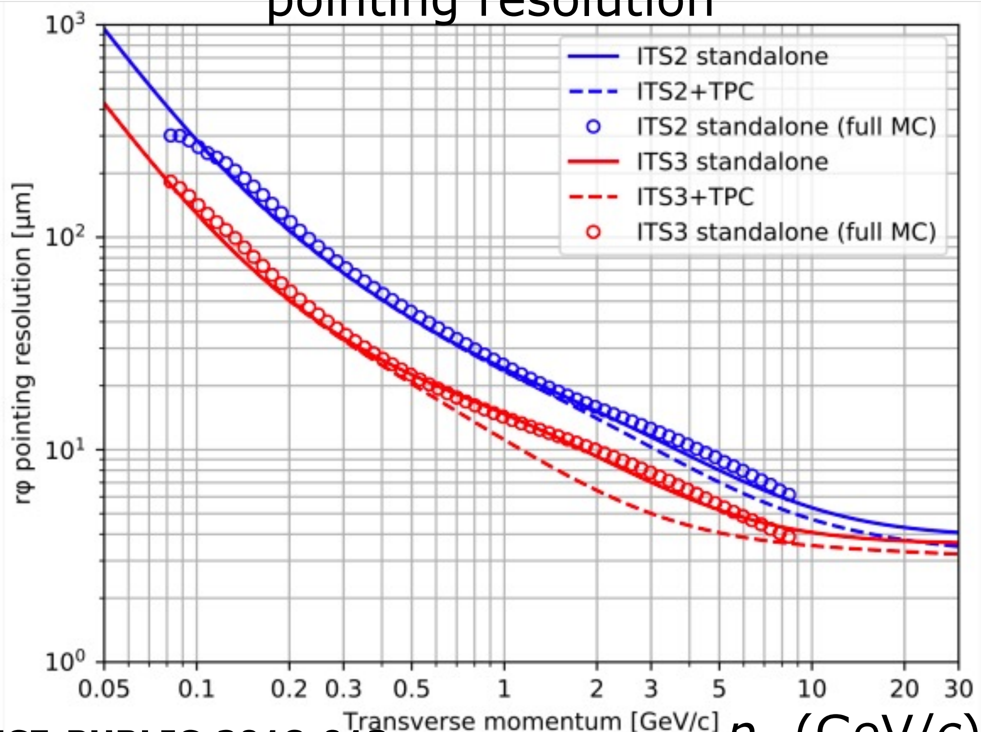
ALICE upgrades for Run 4

pointing resolution



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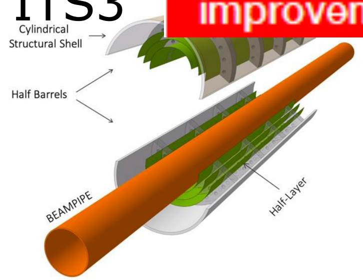
ITS3

improvement of factor 2 over all momenta



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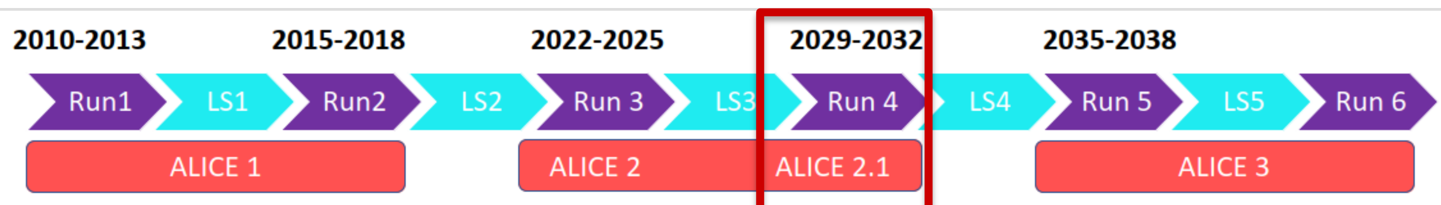
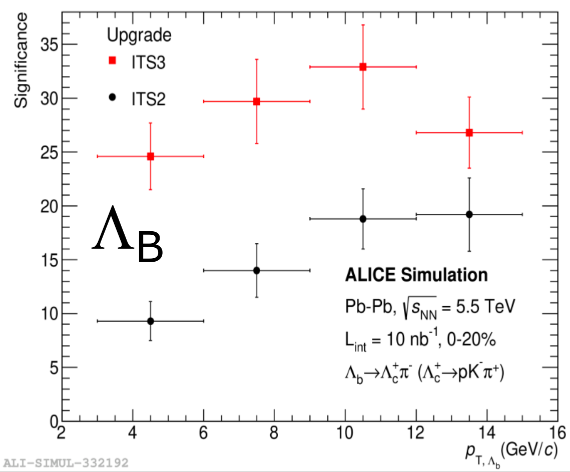
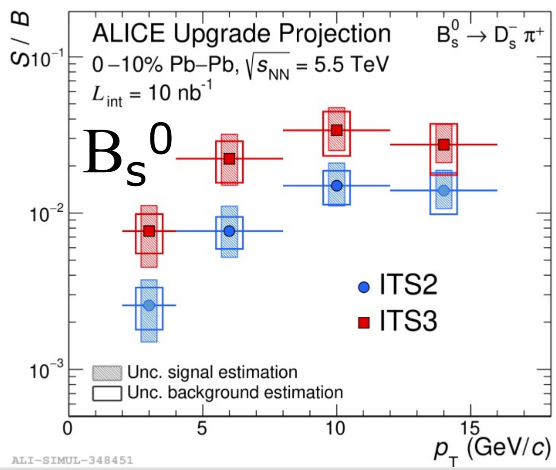
- Improvement of pointing resolution by:
  - drastic reduction of **material budget** (0.3 → 0.05% X0/layer)
  - being **closer** to the interaction point (24 → 18 mm)
  - thinner and smaller **beam pipe** (700 → 500 μm; 18 → 16 mm)
- Directly boosts the ALICE core physics program that is largely based on:
  - low momenta
  - secondary vertex reconstruction
- E.g. Λ_c S/B improves by factor 10, significance by factor 4



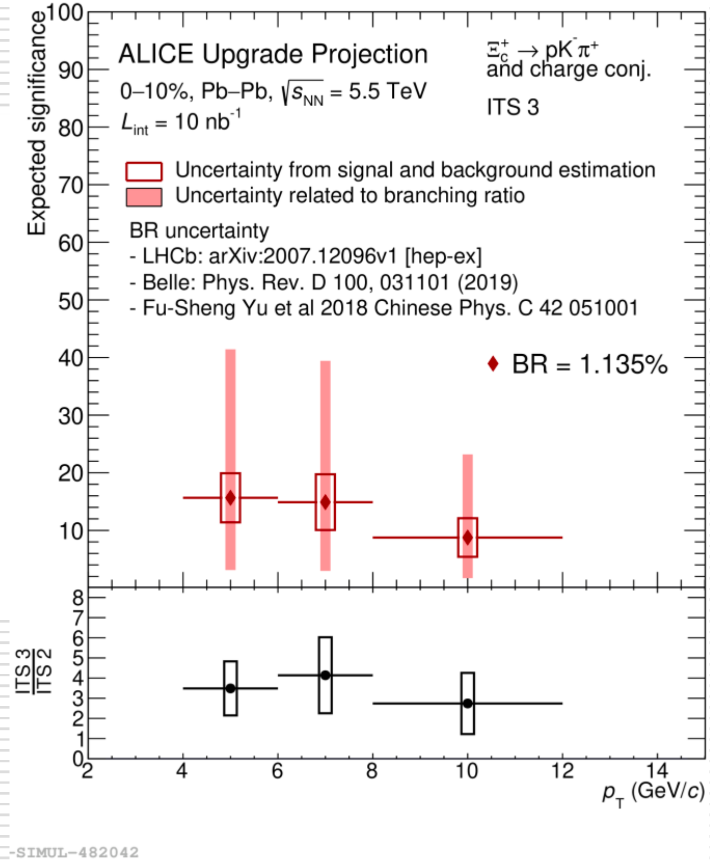
ALICE upgrades for Run 4

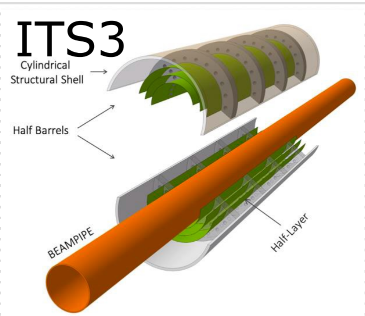
Physics performances

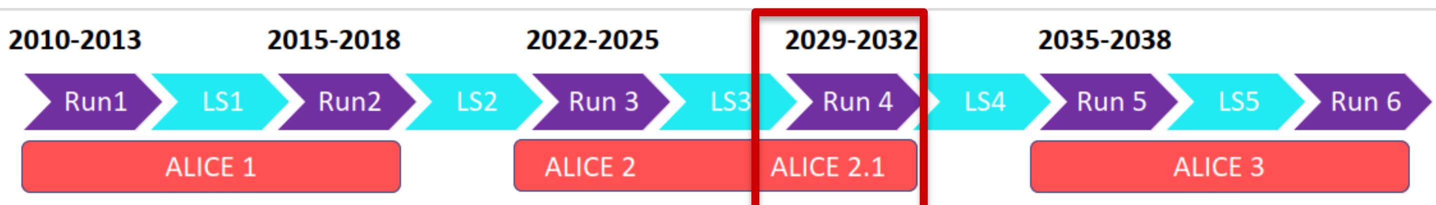




$\Xi_c^+ \to pK^-\pi^+$







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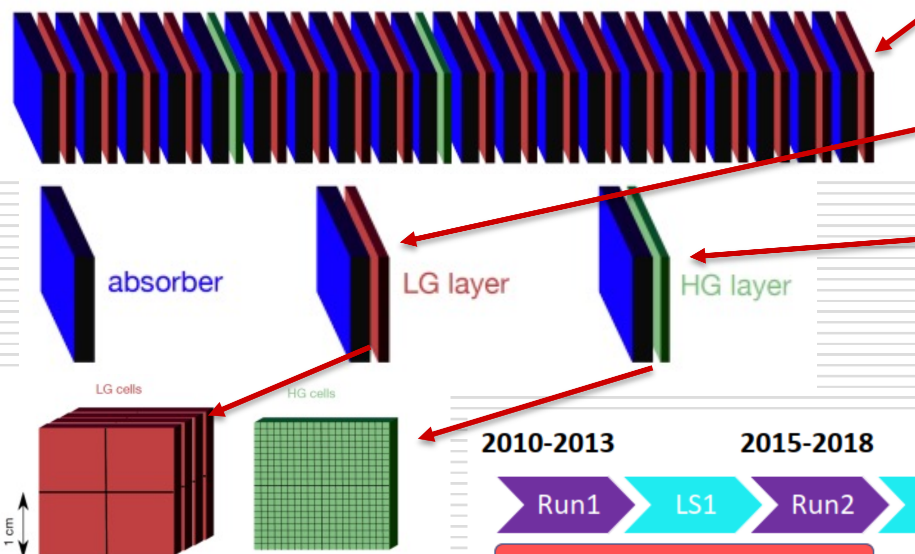
ALICE upgrades for Run 4

FoCal Letter of Intent: CERN-LHCC-2020-009
https://inspirehep.net/literature/1805025



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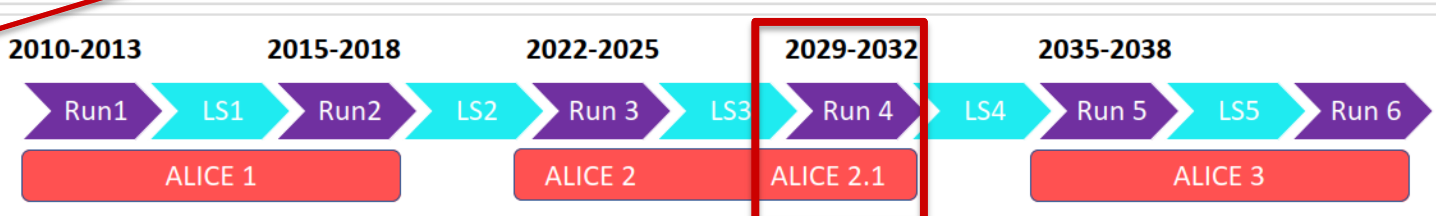
FoCal-H

- Cu-scintillator: direct γ isolation and jets
- Metal/scintillating calorimeter with high granularity of up to 2.5 x 2.5 cm^2

FoCal-E

- Optimized for γ and π^0 reconstruction
- Segmented in 18 layers of tungsten and silicon pads with low granularity (~ 1 cm)
- **Two layers of tungsten and silicon pixels with high granularity (~ 30 x 30 μm^2)**



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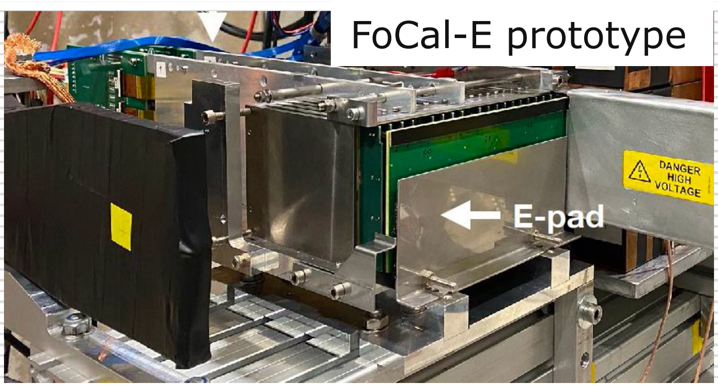

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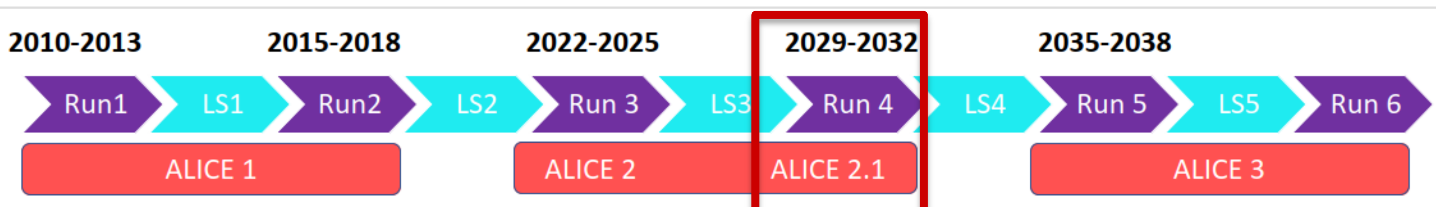

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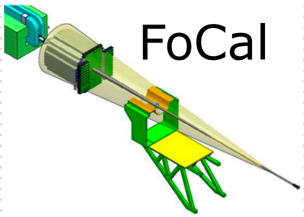
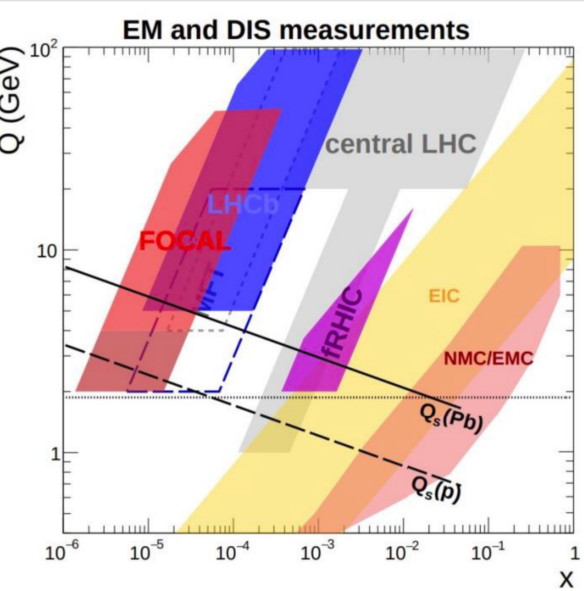
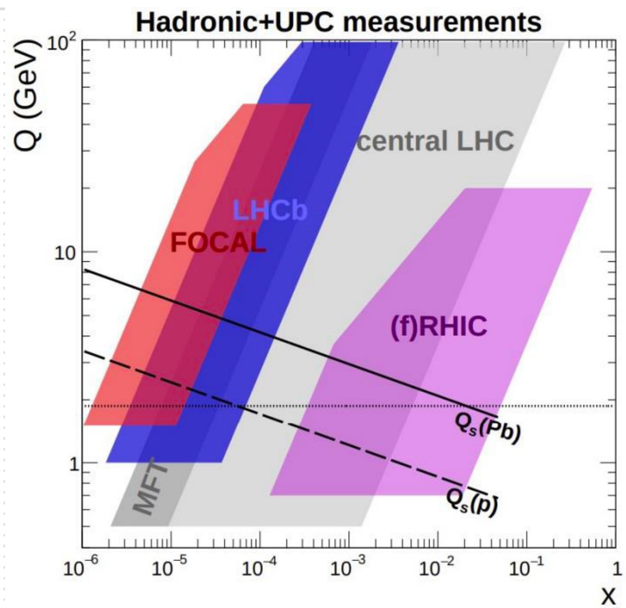
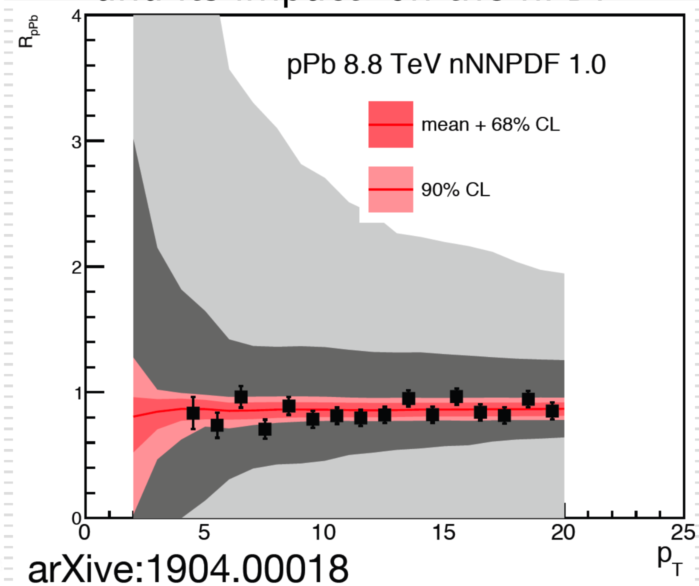


- Energy resolution: ~ <5% (EM) ~12% (hadron)
- Position resolution: ~ 5 mm (EM shower)
  - Required for two shower separation
- S/B ratio > 0.1 for p_T> 4 GeV/c





Expected uncertainties and its impact on the nPDF



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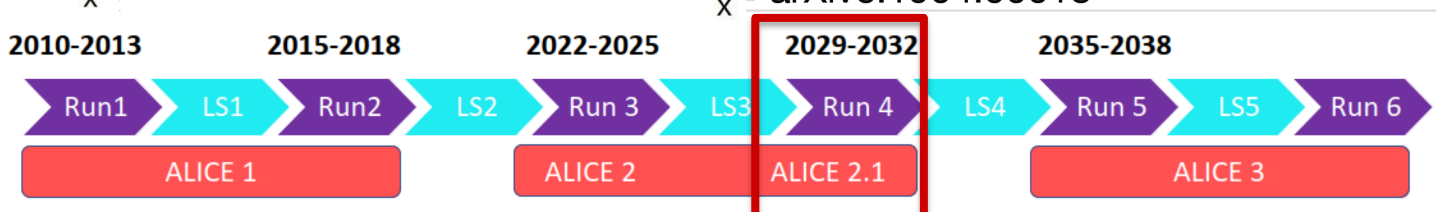
ALICE-PUBLIC-2023-001



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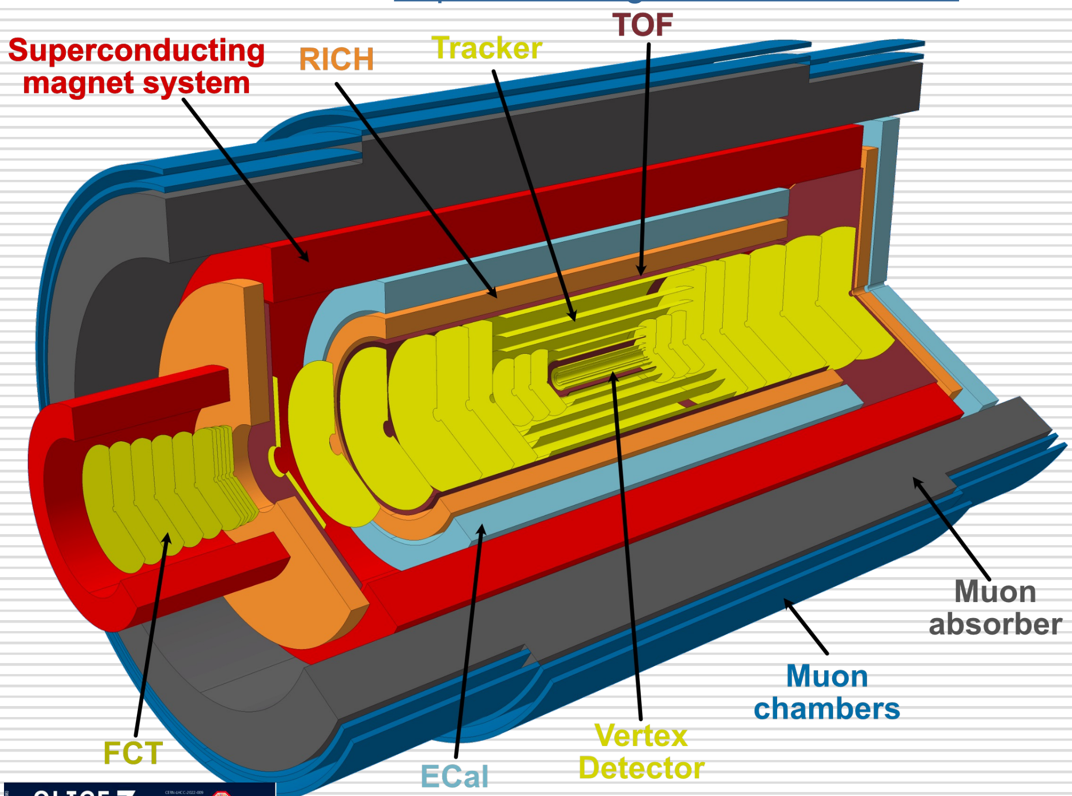
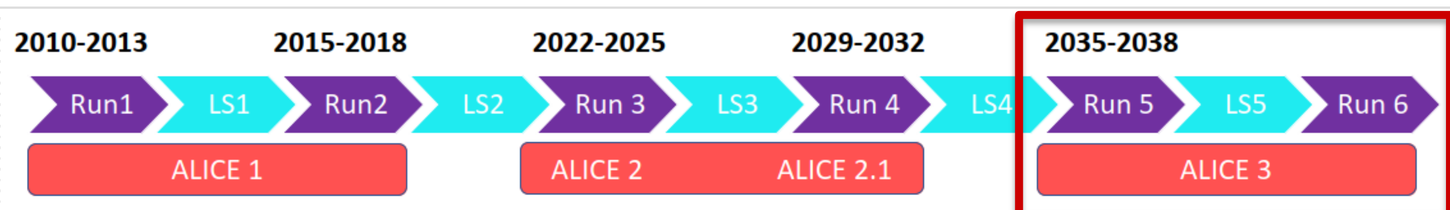
ALICE 3: Run 5 and beyond

CERN-LHCC-2022-009 https://arxiv.org/abs/2211.02491v1



ceived funding

- Compact **all-silicon** tracker
  - Pointing resolution ~3-4 μm and p_T resolution < 1% @1 GeV/*c*
- Large acceptance, **$|\eta|<4$, p_T >0.02 GeV/*c***
- Superconducting magnet system
  - Max field: B = 2 T (*0.5 T runs foreseen*)
- Continuous readout and online processing
- Particle Identification (PID) in a wide range of p_T and $|\eta|<4$



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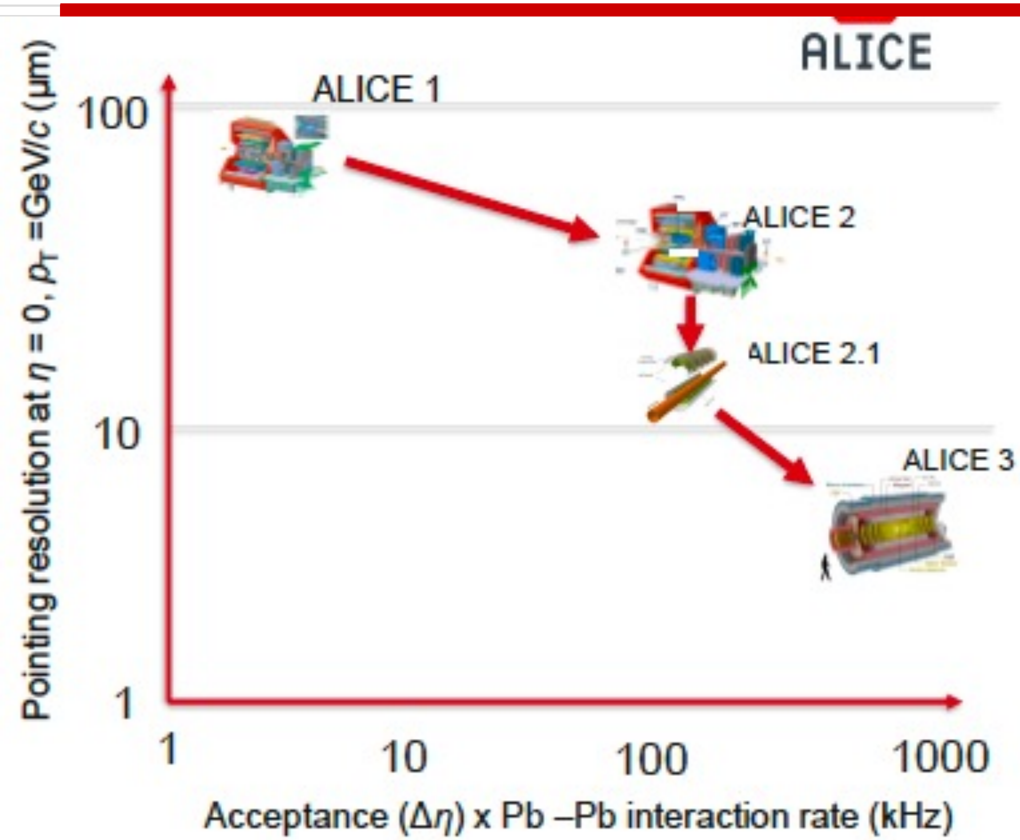

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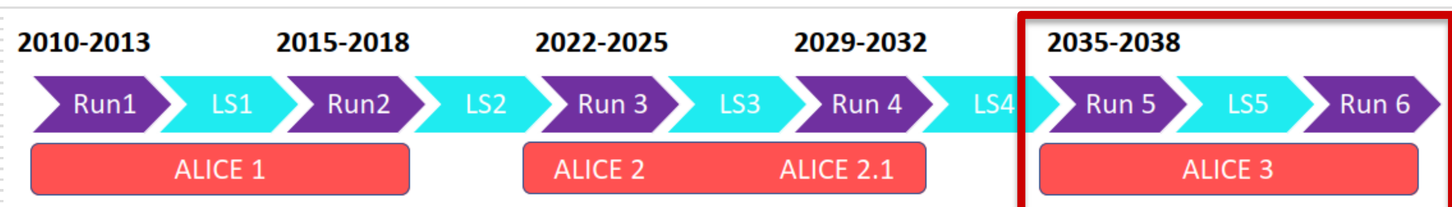
- Particle Identification (PID) in a wide range of p_T and $|\eta|<4$

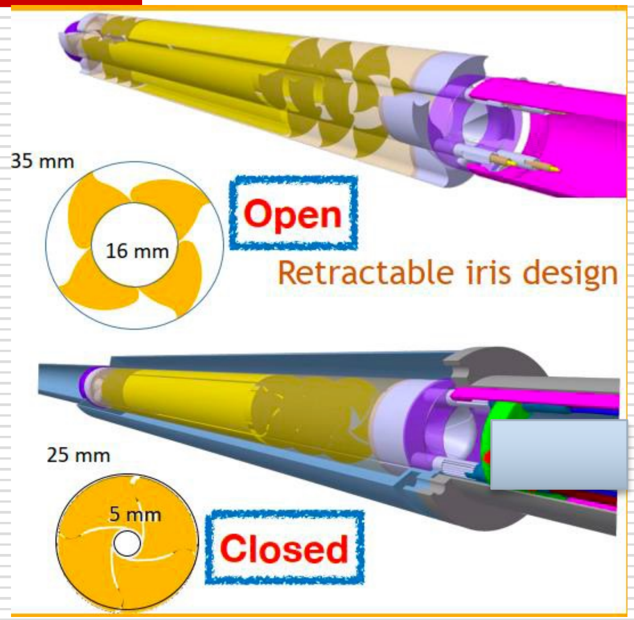
ceived funding



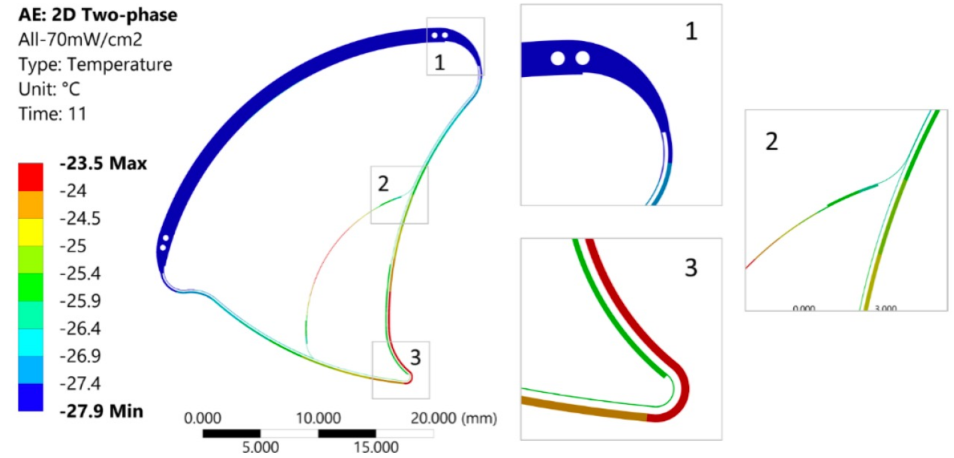
ALICE 3: vertex detector

"Iris" vertex detector

- In vacuum, *retractable,* tracker (**3 layers + 3 disks**): in closed position first layer at **5 mm** from the beam
- Wafer-size sensors based on CMOS MAPS technology (synergy with ITS3 R&D)
- Pixel pitch of about 10 μm (**2.5 μm** intrinsic resolution) and **~0.1% X0/layer**
- Max. radiation load per operational year ~ **1.5 10^{15} 1 MeV neq/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



mockup



R&D challenges: rad. hardeness, mechanics, cooling & services

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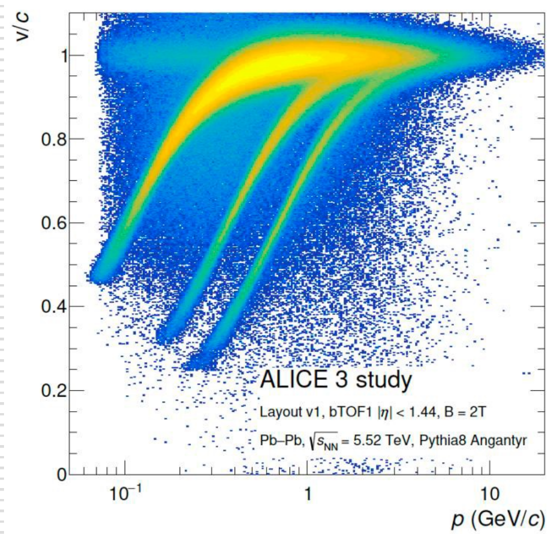
ALICE 3: PID systems

CERN-LHCC-2022-009

Time-of-flight

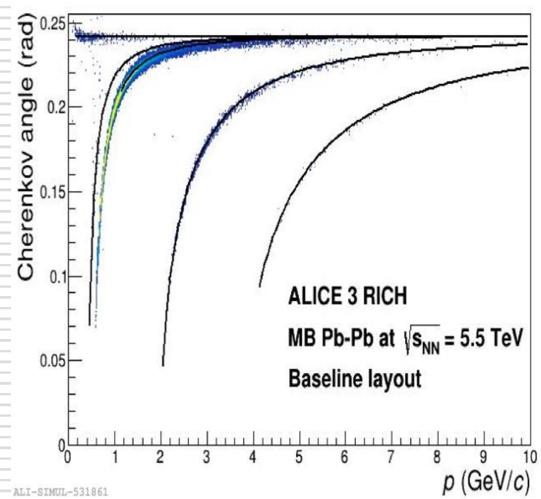
- **Barrel TOF**: two layers at 19 cm and at 85 cm. Time resolution **20 ps**, $|\eta|<1.75$. Total surface ~ 31.5 m^2
- **Two forward disks:** $1.75<|\eta|<4$ with r_{in} = 15 cm, r_{out} =50 cm at z = $\pm$405 cm Tot. surface ~ 14 m^2



R&D challenges: depends on technology If MAPS uniform and fast charge collection + fast readout electronics and high S/N ratio

RICH 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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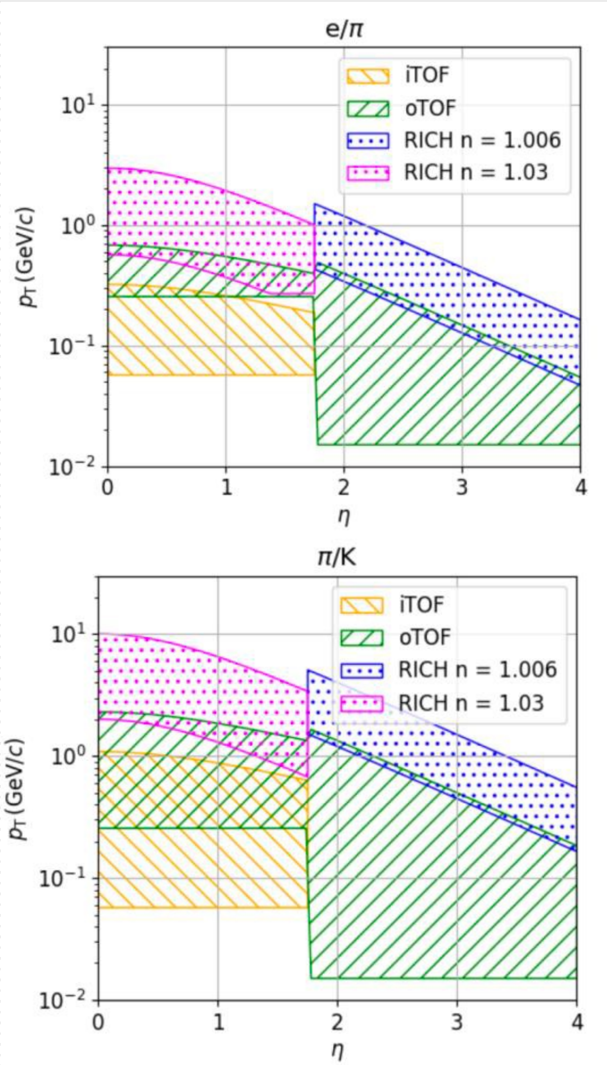

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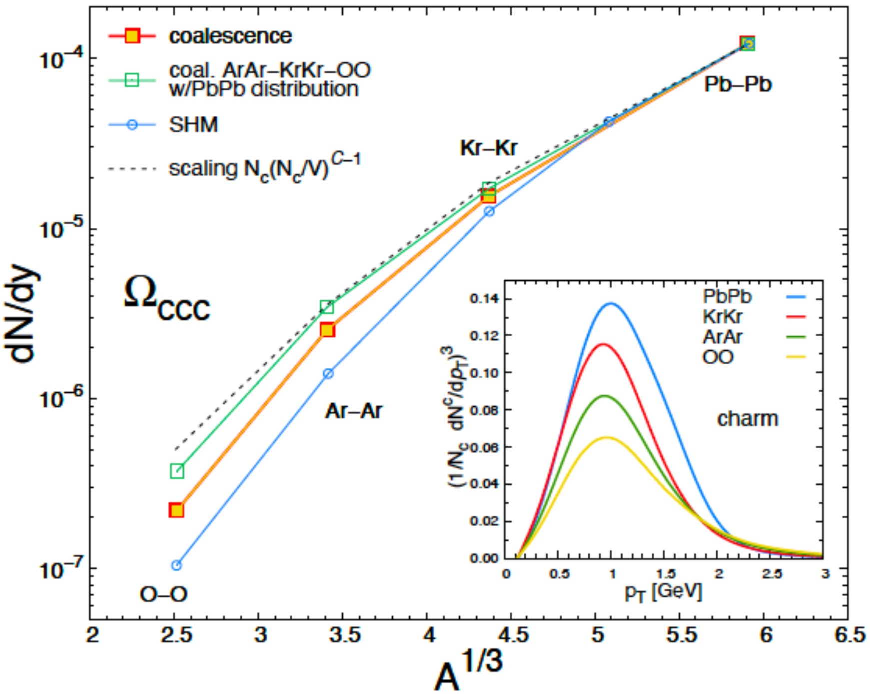
ALICE 3: physics performance

Multi-charm baryons: why?

V. Minnisale et al. arXiv:2305.03687

- different models to describe charm equilibration and hadronisation:
  - H. He et al. PLB 746 (2015) 59
  - A. Andronic et al. JHEP 07 (2021) 035
  - J. Zhao et al. PLB 771 (2017) 349
  - X. Yao et al. PRD 97 (2018) 074003
  - S. Cho et al. PRC 101 (2020) 024902
  - etc…
- study of multi-charm baryons over different collisions systems (e.g. from O-O to Pb-Pb) very sensitive to the non-equilibrium features of charm quarks



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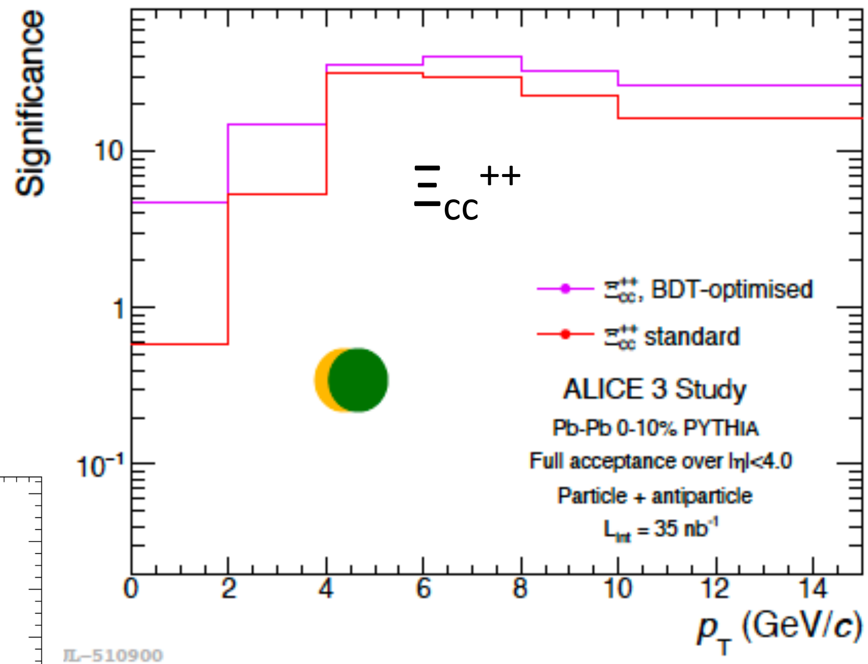
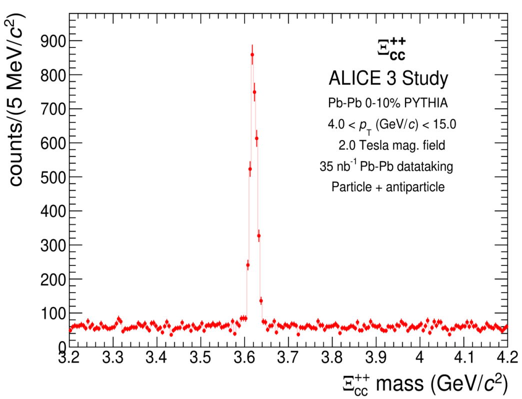
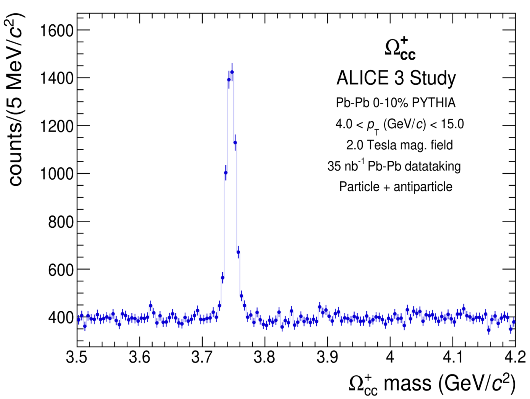
ALICE 3: physics performance

Multi-charm baryons

- 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







ALICE Coll. arXiv:2211.02491

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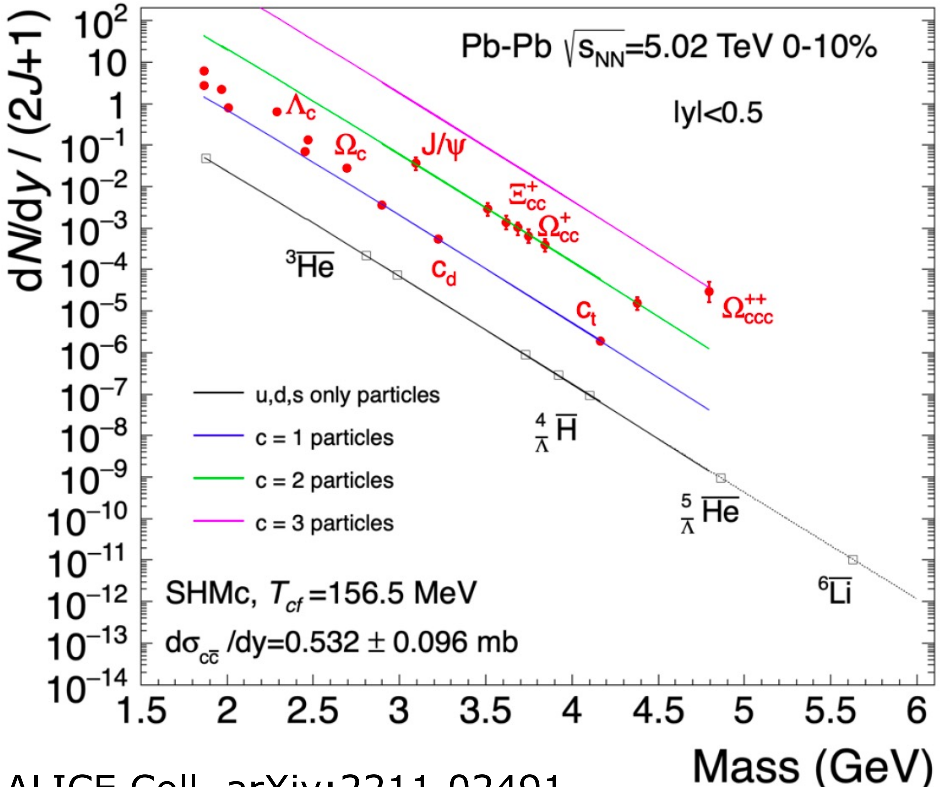
ALICE 3: physics performance

Also **exotic nuclei** are abundantly produced

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



ALICE Coll. arXiv:2211.02491

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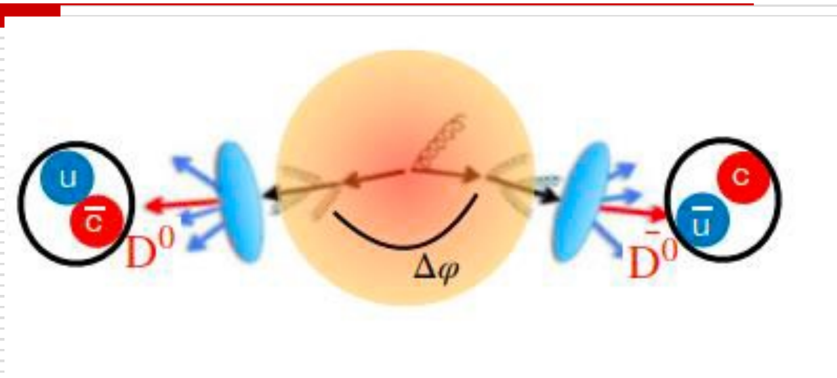
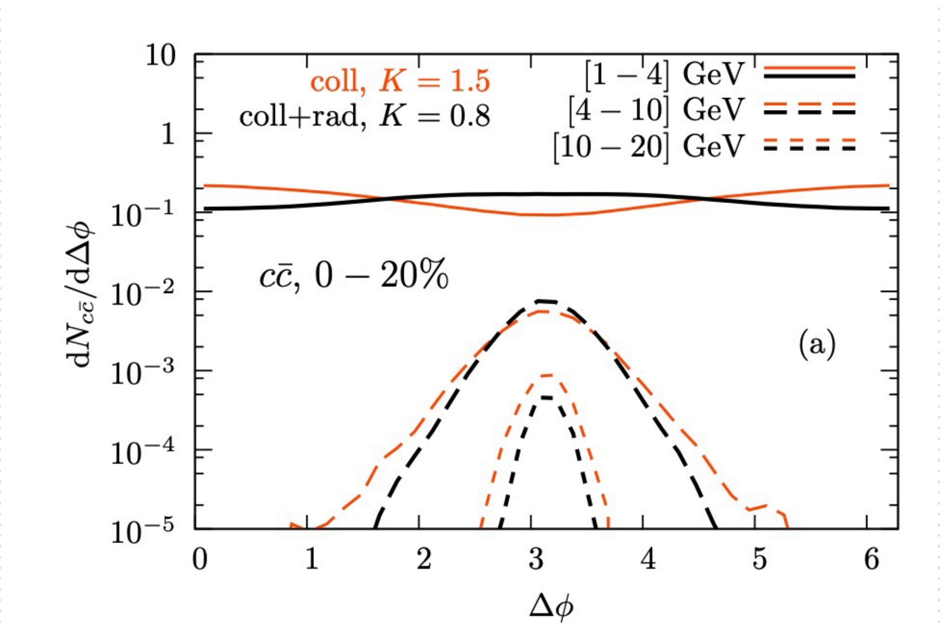
ALICE 3: physics performance

$D^0 - \overline{D}^0$ azimuthal correlation

- measure angular (de)correlation
  - direct probe of HF interaction with the QGP
- Strongest signal at low p_T
- Very challenging measurement:
  - good purity, efficiency and η coverage

In heavy-ion collisions doable only with ALICE 3





M Nahrgang et al, PRC 90, 024907

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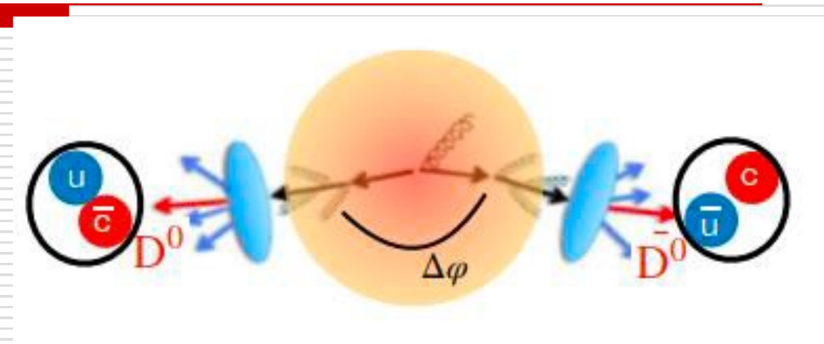

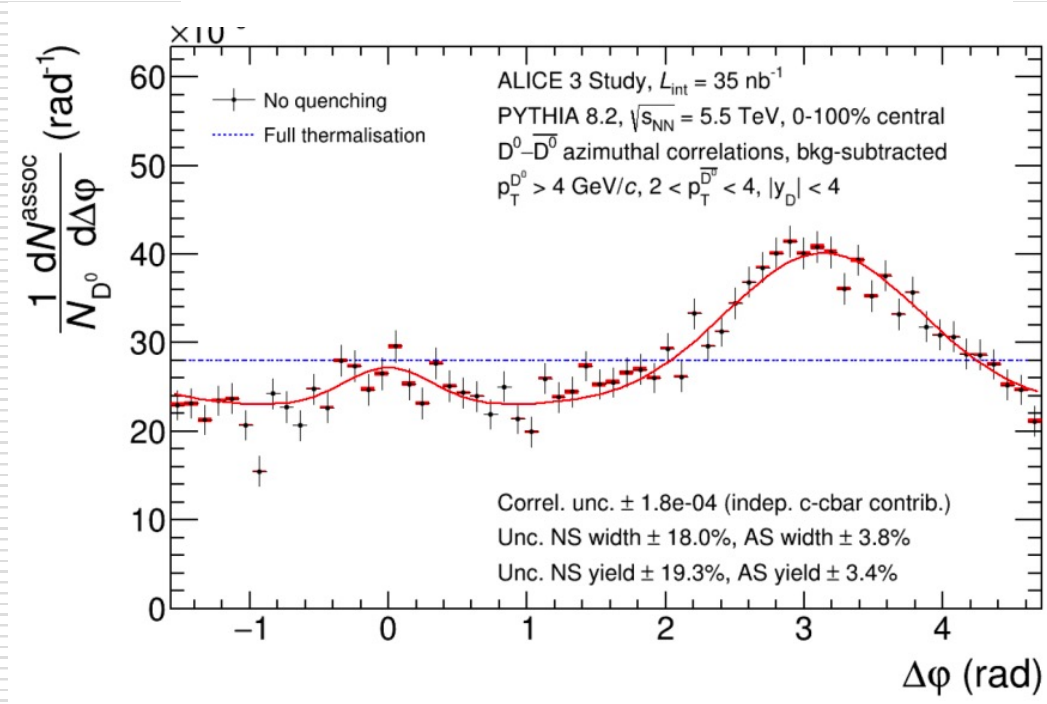

ALICE Coll. arXiv:2211.02491

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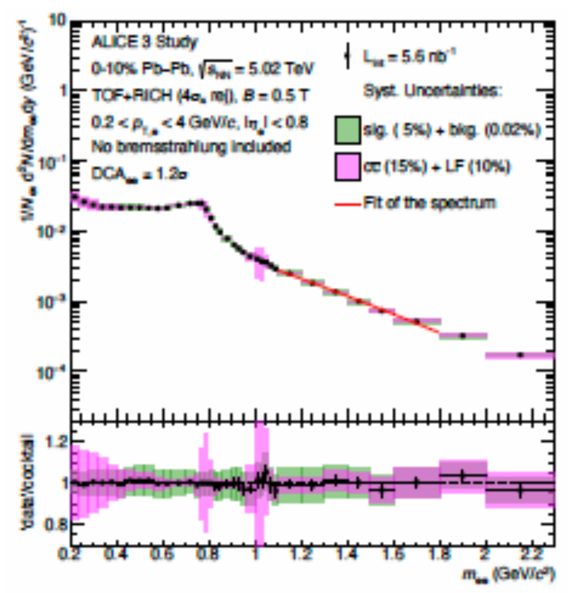
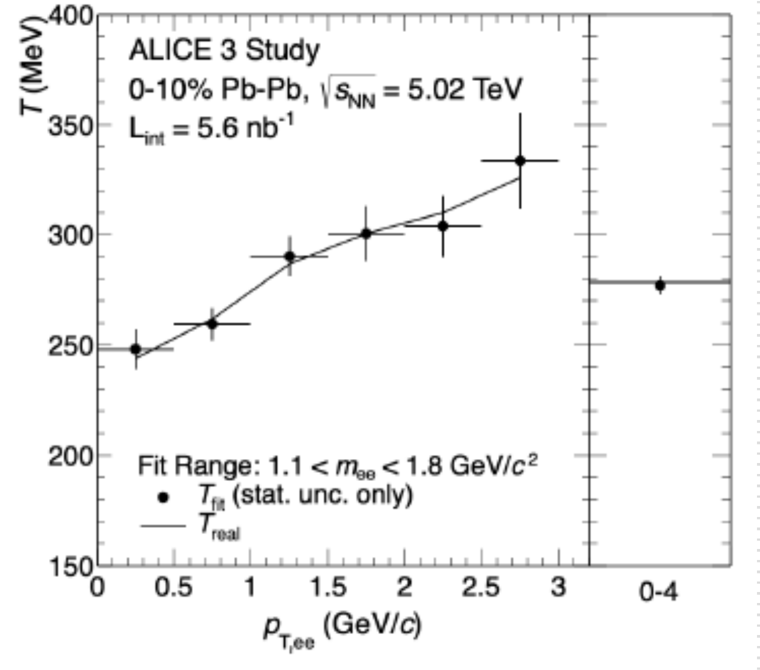
ALICE 3: physics performance

Thermal radiation and chiral symmetry restoration

- access to time evolution of the QGP temperature





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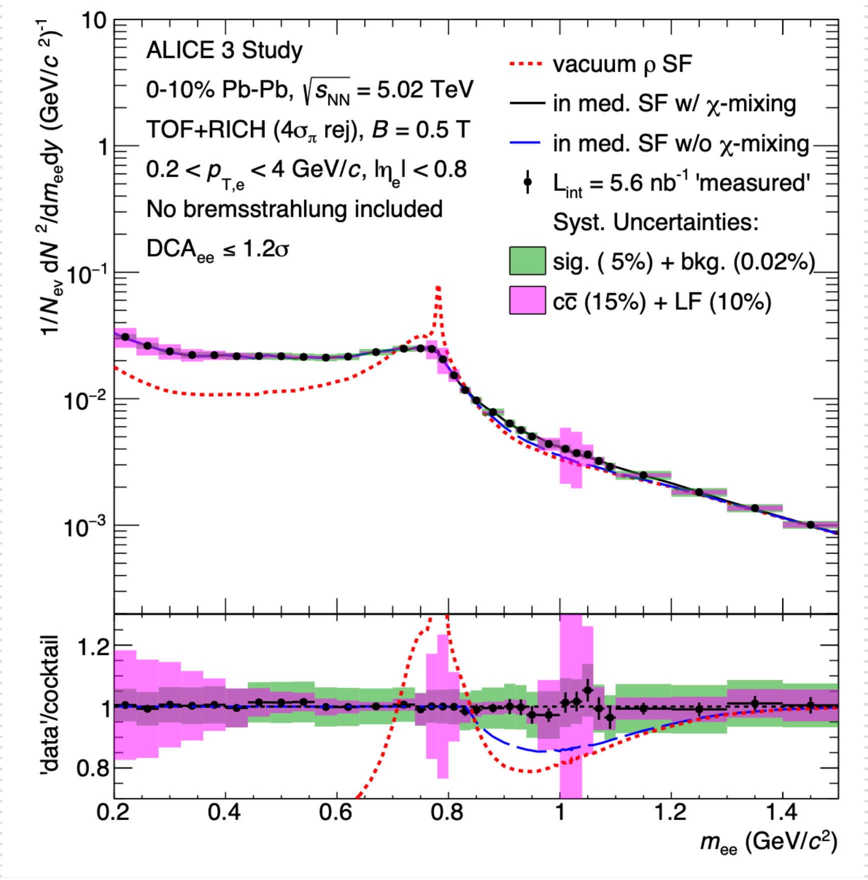
ALICE 3: physics performance

Thermal radiation and chiral symmetry restoration

- access to time evolution of the QGP temperature
- 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 would produce a 20-25% change versus vacuum spectral functions ($0.8 \leq m_{ee} \leq 1.2$ GeV/c2)



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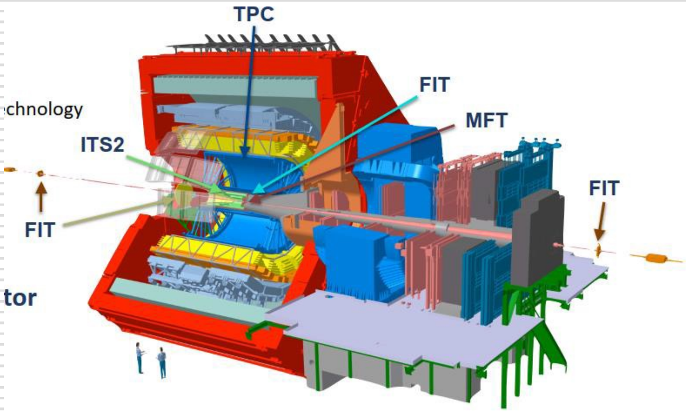
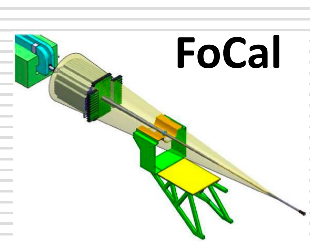
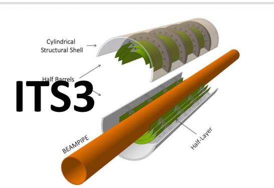
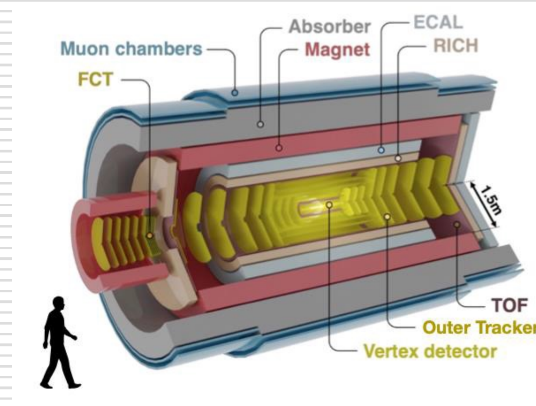
Conclusions and outlook

- ALICE came a long way in the investigation of QCD in extreme conditions
- much more is to come with LHC Run 3 and later on with **ITS3** and **FoCal** in Run 4.
- obtained results pose additional fundamental questions that call for a new detector @ LHC ready for Run 5: ALICE 3 letter of intent published in 2022. Next steps are :
  - Scoping Document (2024)
  - Technical Design Reports (2027)





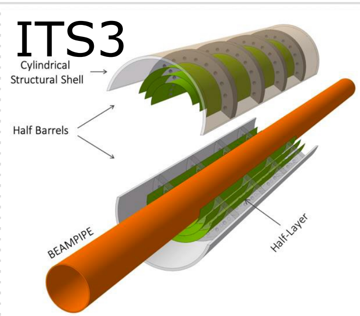




EXTRA

ALICE upgrades for Run 4

- Assembly procedure developed
- Gluing optimised
- Detailed characterization ongoing
  - including wind tunnel tests

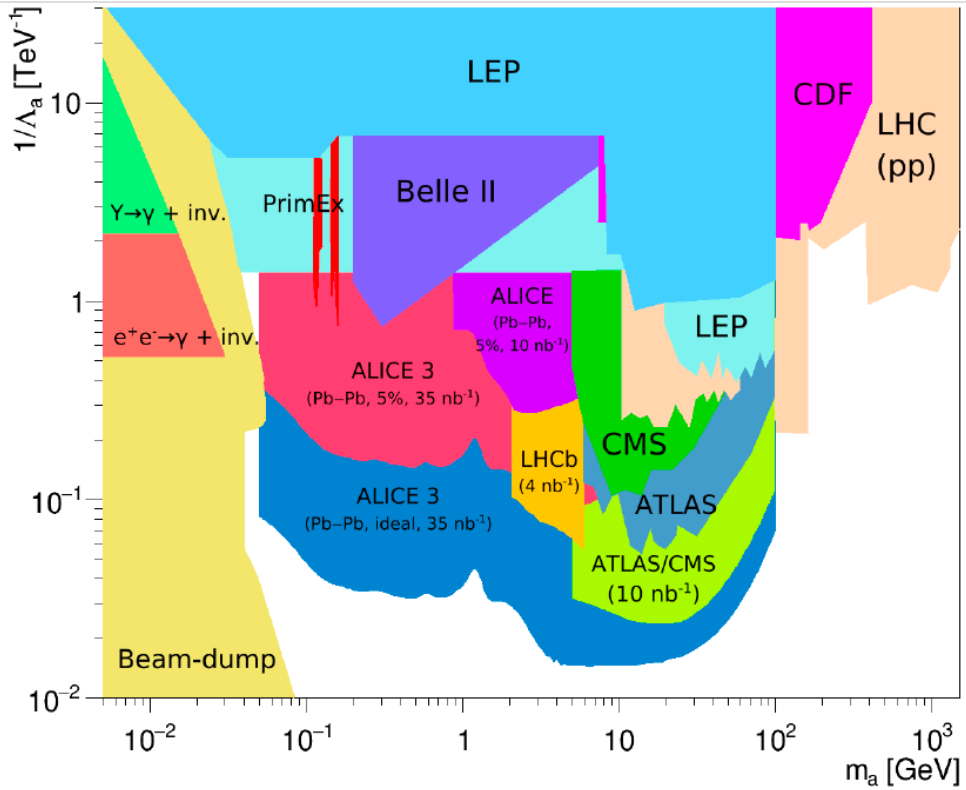


This project has received funding

ALICE 3: physics performance

BSM searches in UPCs

- 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 distribu1on
- Performance on the estimated production cross-sec1on given as mass and recast limit in the plane (m_a ,$1/\Lambda_a$)



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