ALICE Upgrades: introduction

Riunione INFN ALICE-Referees, 19 July 2024

Andrea Dainese (INFN Padova)

Timeline of future upgrade projects

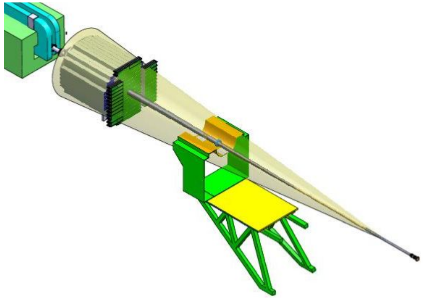
FoCal & ITS3

- Specific upgrade in LS3 (2026-2028)
- TDR preparation & submission this year

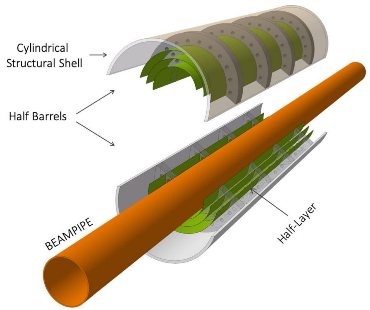
ALICE 3

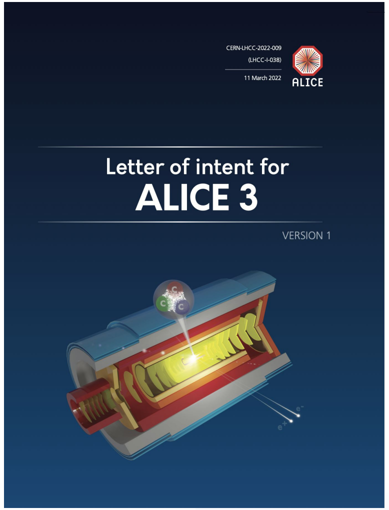
- New detector in LS4 (2033-2034)
- LoI reviewed in 2022

FoCal LoI: CERN-LHCC-2020-009



ITS3 LoI: CERN-LHCC-2019-018

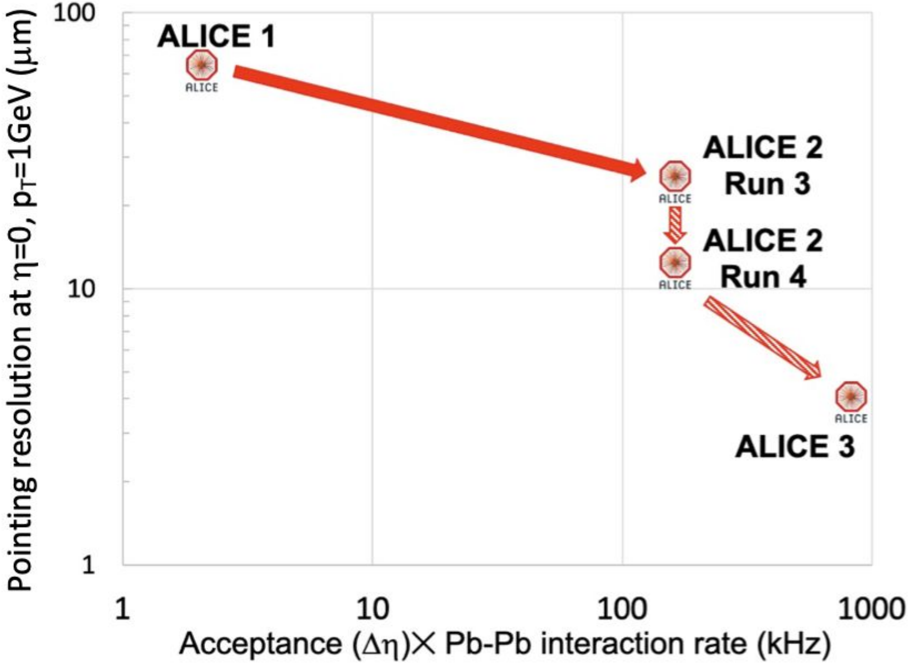




CERN-LHCC-2022-009

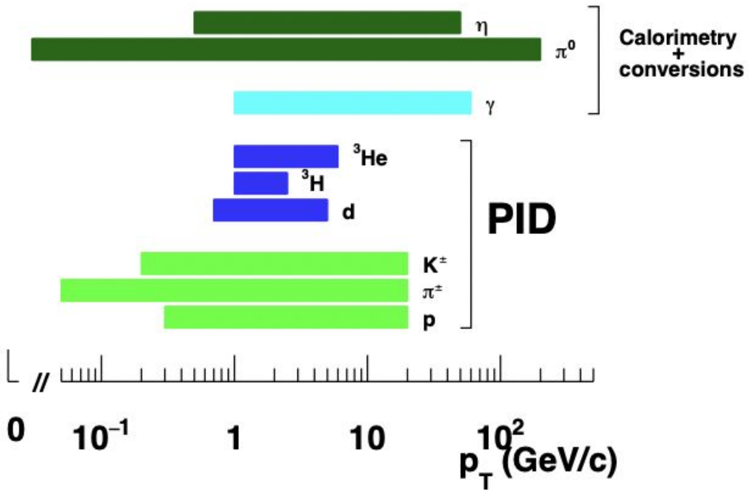
ALICE upgrades strategy

Large steps in pointing precision and "effective acceptance"

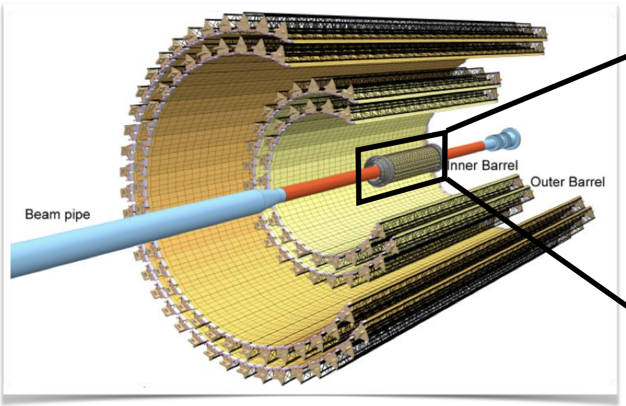


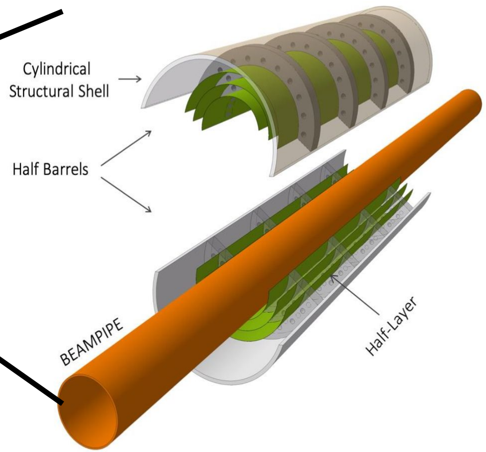
+

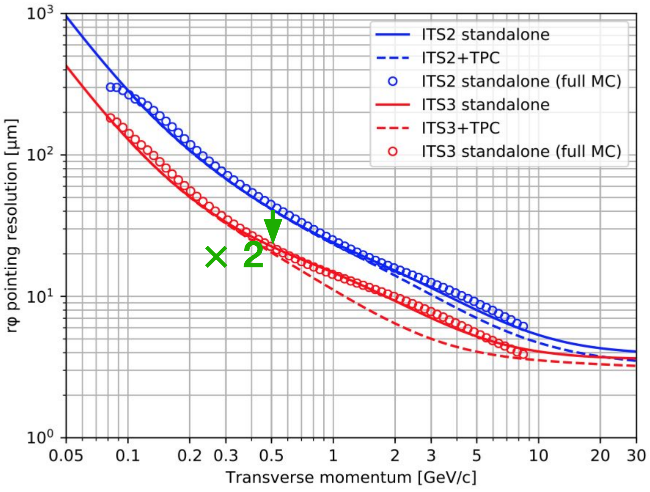
Keep/strengthen ALICE unique reach in particle identification



ITS3: a new inner barrel for the ITS2







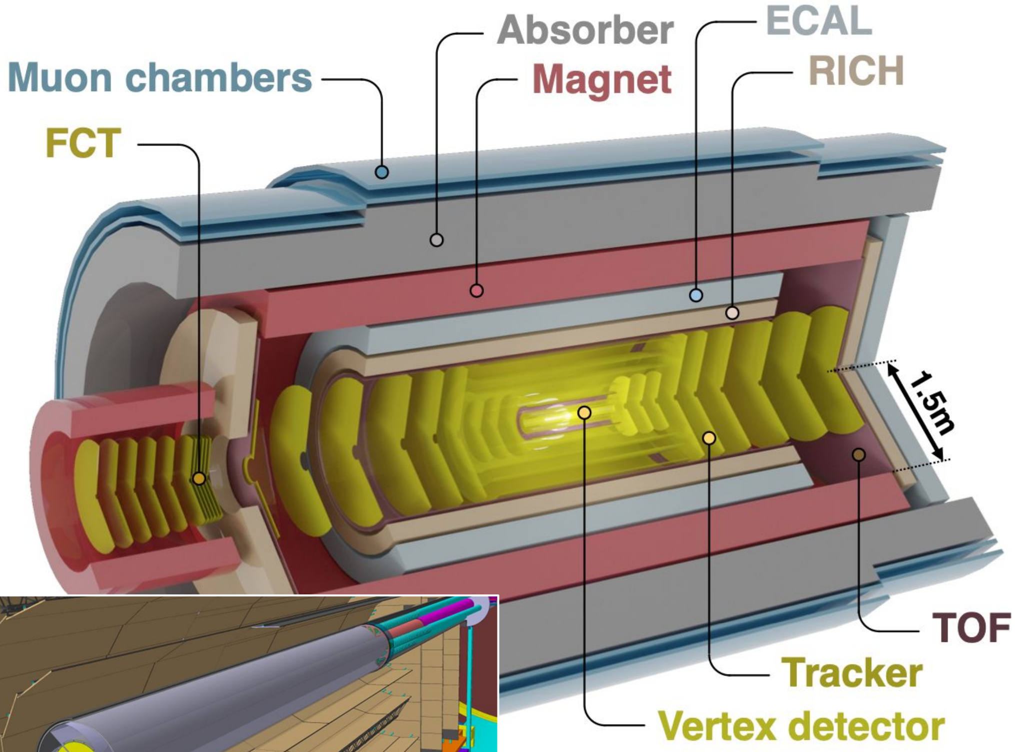
- Detection layers closer to the interaction point, reduced beam pipe diameter, reduce material thickness (no supporting and cooling materials)

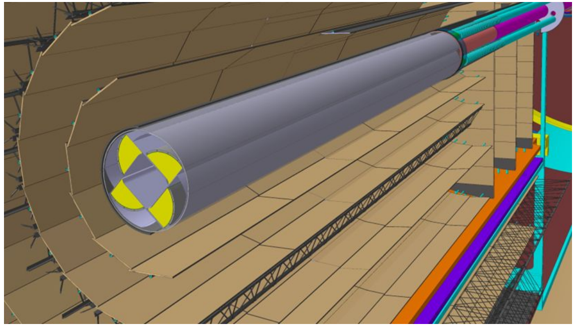
  → **next talk: S. Beolè**

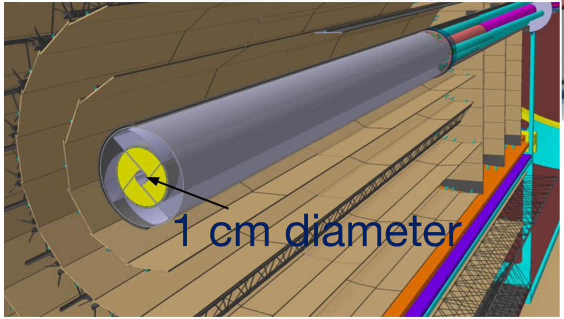
ALICE 3 concept

➡ Novel and innovative detector concept

- Compact and lightweight all-silicon tracker
- Retractable vertex detector
- Extensive particle identification
- Large acceptance
- Superconducting magnet system
- Continuous read-out and online processing

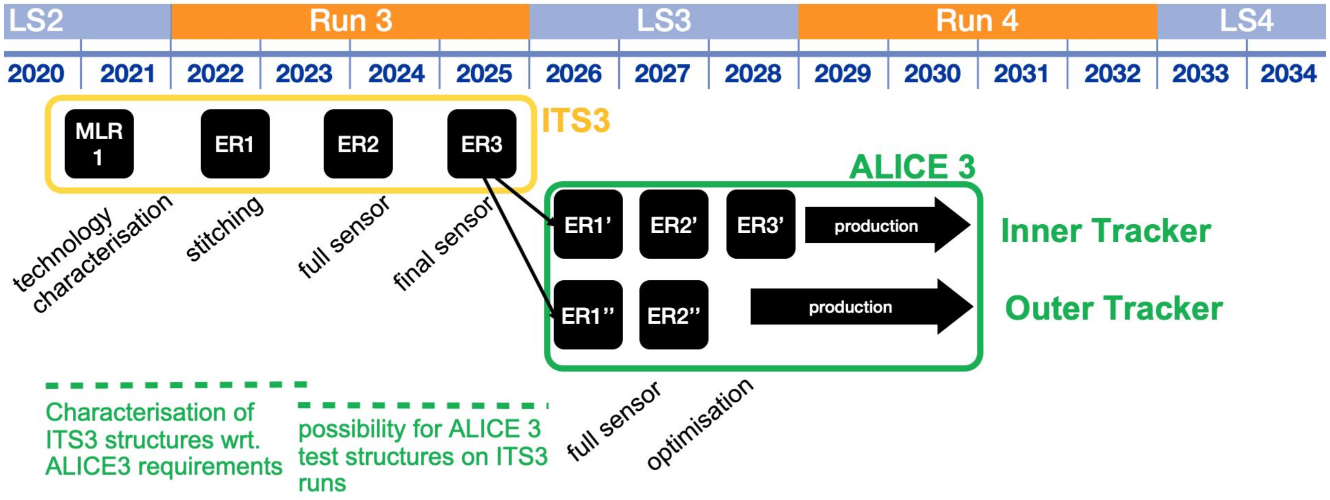






Frontier MAPS R&D: ITS3 → ALICE 3

ALICE 3 Inner and Outer Trackers will use Monolithic Active Pixel Sensors (MAPS) - evolution of ITS3 sensors



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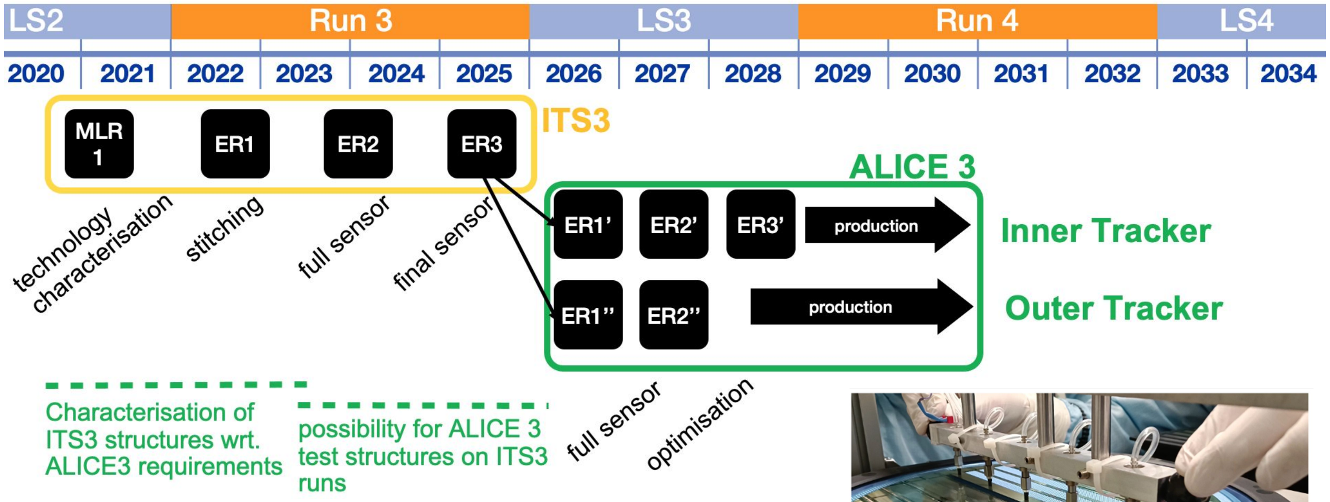
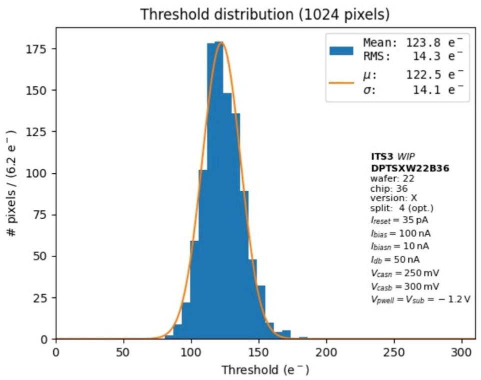
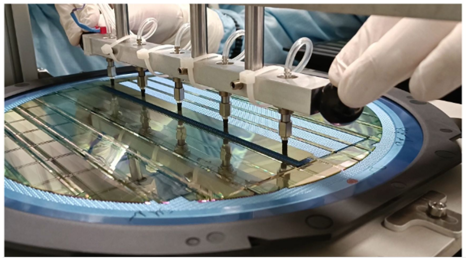
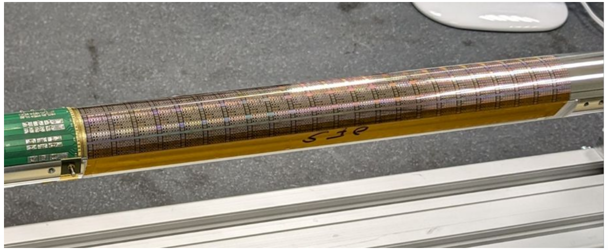


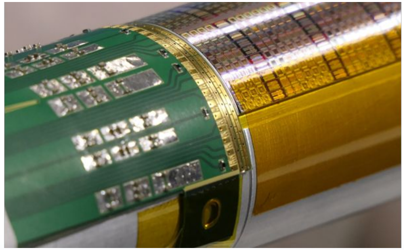
Radiation hardness studies at 2×10^{15} 1 MeV n_{eq} cm^{-2}
~ 1/5 of total Inner Tracker req.





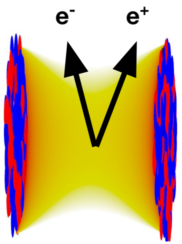
Wafer-scale bent MAPS

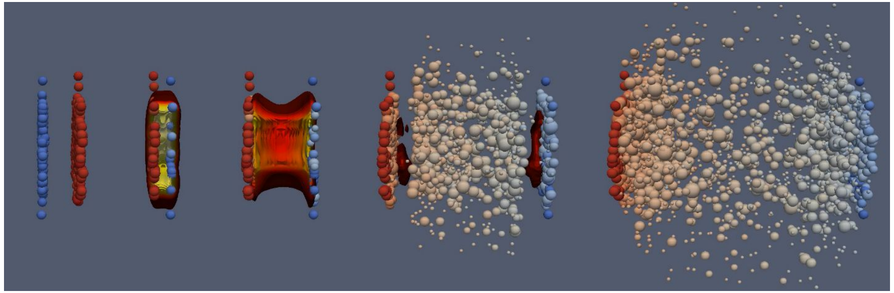




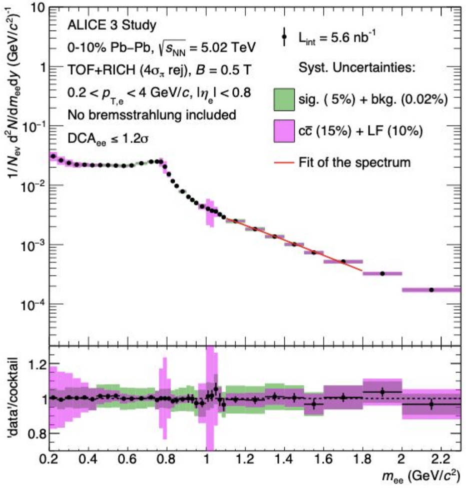
Unique ALICE 3 physics goals

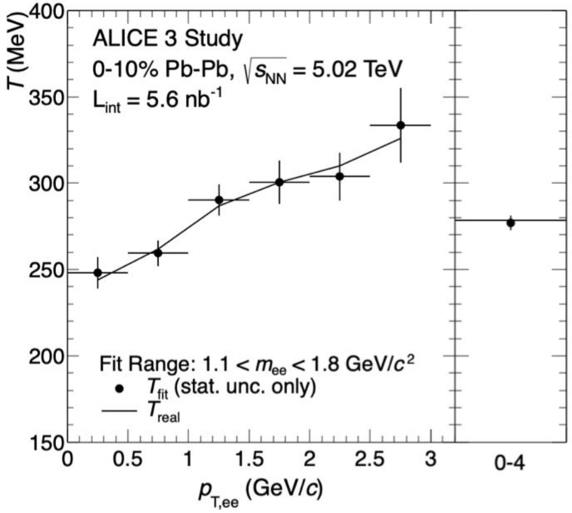
- **Precision measurements of dileptons**
  - ➡ evolution of the quark gluon plasma temperature
  - ➡ mechanisms of chiral symmetry restoration in the quark-gluon plasma





- **Systematic measurements of (multi-)heavy-flavoured hadrons**
  - ➡ transport properties in the quark-gluon plasma
  - ➡ mechanisms of hadronisation from the quark-gluon plasma
- **Hadron correlations**
  - ➡ hadron-hadron interaction potentials
  - ➡ net-baryon and net-charm fluctuations
- …





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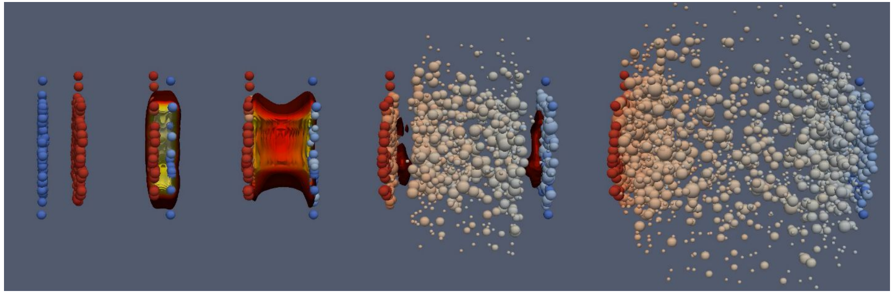

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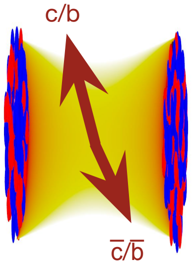

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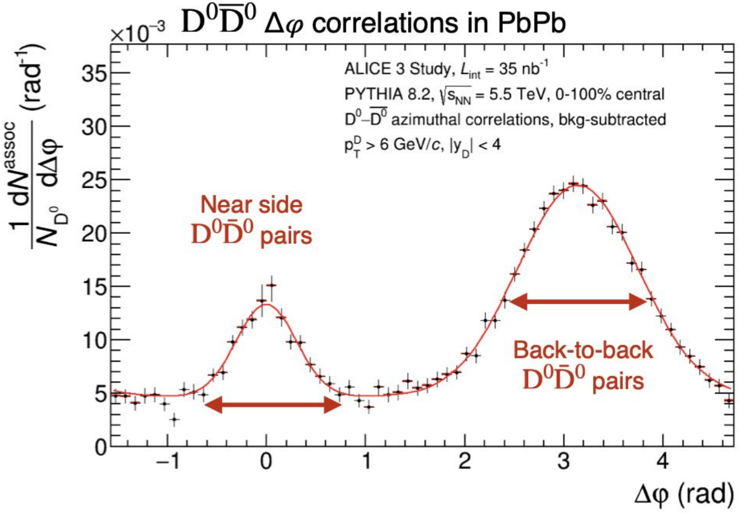

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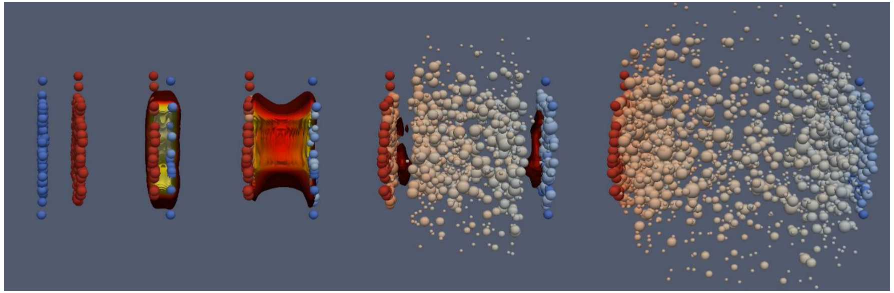

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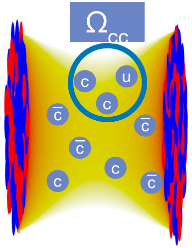

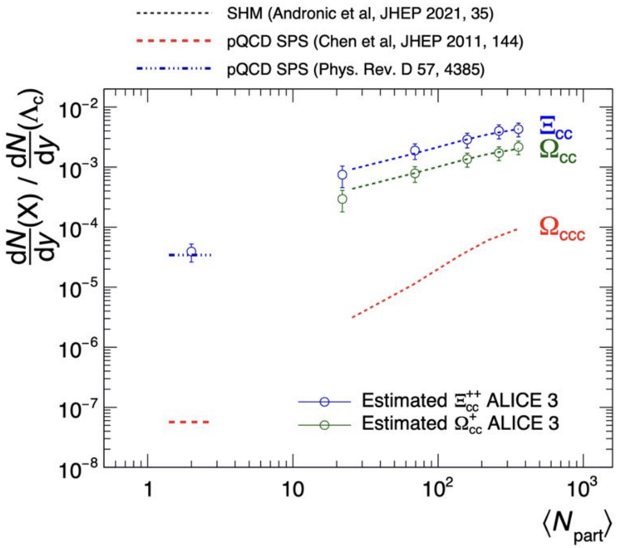

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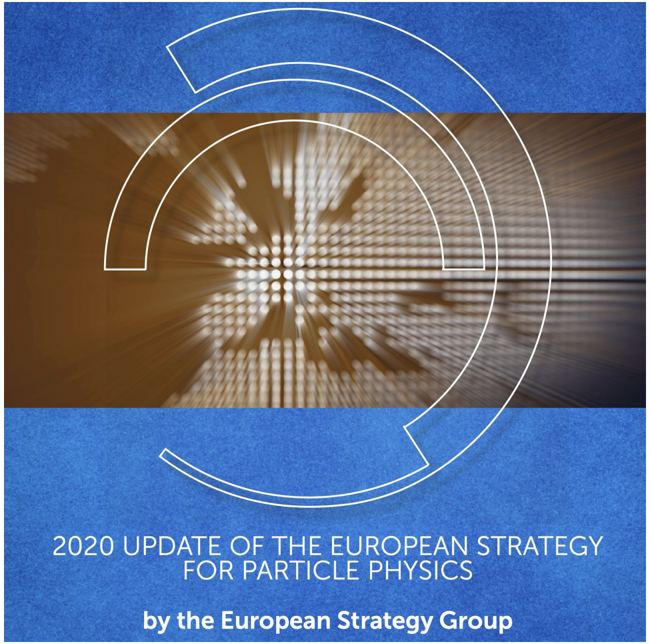
ESPP Update 2020: full exploitation of LHC as a heavy-ion collider



been developed. ***The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.***

Inputs on HI at HL-LHC and ALICE 3 will be prepared for the 2026 Strategy Update

ESPP Update 2020

ALICE 3 in the NuPECC LRP

NuPECC Long Range Plan 2024 Town Meeting:

ALICE 3 is the first priority recommendation by the Topical Working Group on *Strongly-interacting matter in extreme conditions*:

- ALICE 3 regarded as essential for **continuing after 2035 a scientifically leading role of Europe in high-energy nuclear physics**
- Stressed that the **innovative R&D for ALICE 3 (large-area ultralight Si pixels, Si sensors for timing, Si sensors for RICH, …) will benefit neighbouring fields of nuclear and particle physics** (EIC, FCC-ee, …)

ALICE 3 coordination team

Subsystem WGs:

- Inner Tracker: **G. Contin** (Trieste), **F. Reidt** (CERN)
- Outer Tracker: **H. Büsching** (Frankfurt), **L. Fabbietti** (Munich), **A. Maire** (Strasbourg)
- Forward Conversion Tracker: **K. Reygers** (Heidelberg)
- TOF Detector: **S. Bufalino** (Torino), **M. Colocci** (Bologna), **A. Rivetti** (Torino)
- RICH Detector: **G. Volpe** (Bari)
- MID: **A. Ortiz** (Mexico City)
- Data flow and online processing: **V. Barroso** (CERN), **P. Hristov** (CERN), **T. Kollegger** (Frankfurt)

Contacts for general items and other activities:

- General infrastructure, integration: **TC - W. Riegler, A. Tauro, C. Gargiulo, E. Laudi** (CERN)
- Detector readout, links: **EC - A. Kluge** (CERN)
- Forward Detectors: **J. Otwinowski** (Krakow)

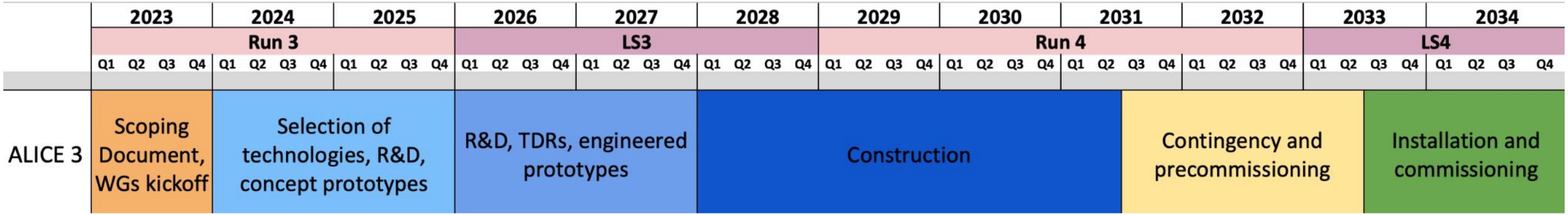
Simulation and Physics Studies WGs:

- Simulation and Performance: **M. Concas** (CERN)
- Heavy Flavour and Quarkonia: **D. Chinellato** (Campinas), **A. Uras** (Lyon)
- Dileptons and Photons: **T. Gunji** (Tokyo), **K. Reygers** (Heidelberg)

Participation and interests of national groups

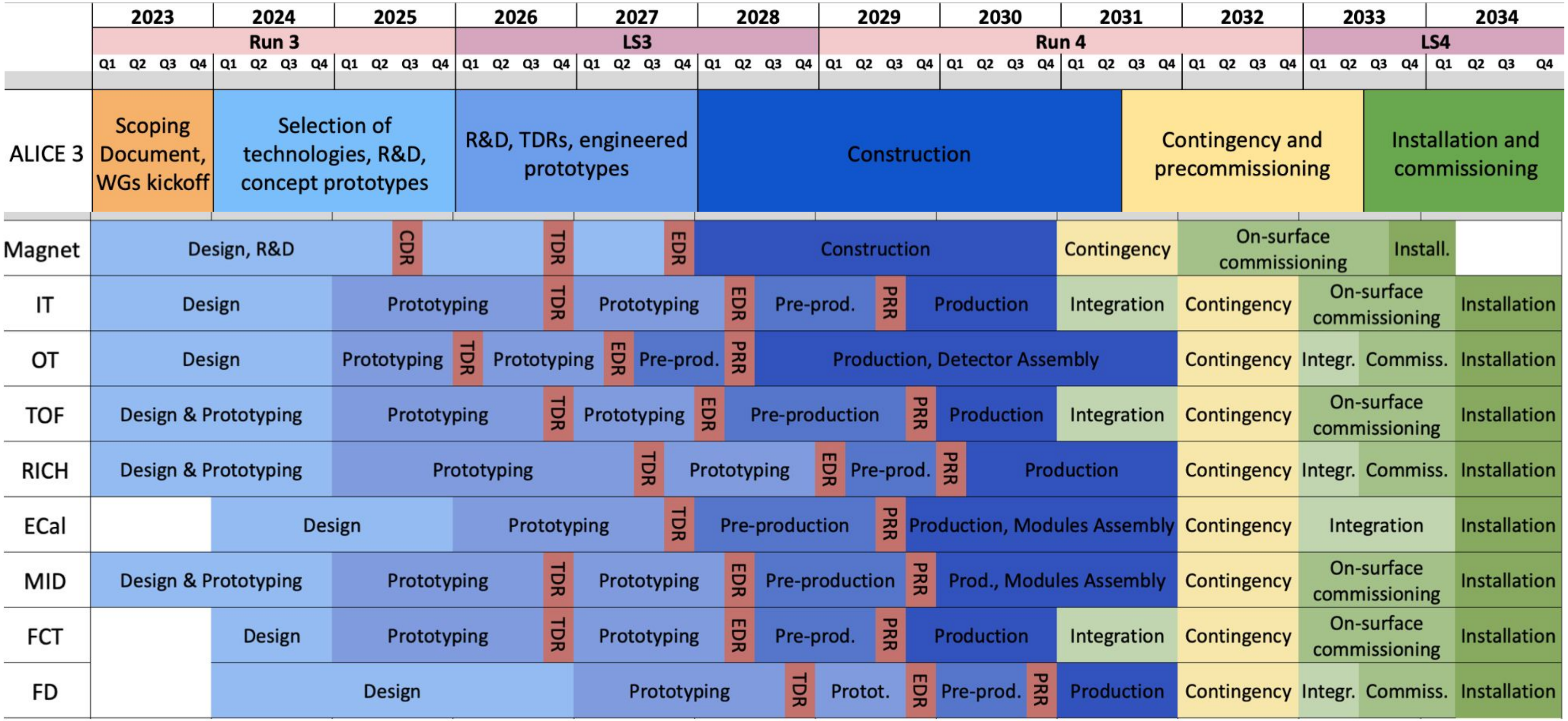
Experiment subsystems	National groups
Inner Tracker	CERN, China, Czech Republic, Italy, Netherlands, Norway, Ukraine
Outer Tracker	Finland, France, Germany, Japan, South Korea, Sweden, UK, US
Forward Conversion Tracker	Germany
TOF Detector	Brazil, China, Italy, India, Netherlands, South Africa, Romania?
RICH Detector	Hungary, India, Italy, Malta?, Mexico, Poland, US?
Muon Identification Detector	Czech Republic, Hungary, India, Mexico, US
Data flow and online processing	CERN, Germany, Romania
Detector readout, links, clock distribution	CERN, Hungary, Slovakia, UK
Forward Detectors	Denmark, Mexico, Poland
Superconducting magnet design	Brazil, CERN, Italy

ALICE 3 timeline



- **2023-25**: Scoping Document, selection of technologies, small-scale prototypes (~25% of R&D funds)
- **2026-27**: large-scale engineered prototypes (~75% of R&D funds) → TDRs and MoUs
- **2028-30**: construction and testing
- **2031-32**: contingency and pre-commissioning
- **2033-34**: preparation of cavern, installation

Compact schedules and milestones



Subsystem schedules with main milestones (Technical Design Reports, Engineering Design Reviews, Production Readiness Reviews)

Updated cost table

Preliminary SD table

Table 2: Summary of CORE cost estimates of the ALICE 3 detector layout version 1.

System	Technology	Cost (MCHF)
Inner Tracker	MAPS	13.7
Outer Tracker	MAPS	27.8
TOF	Monolithic LGADs	17.6
	Hybrid LGADs	+11.6
RICH	Aerogel, SiPMs	24.2
ECal	Pb-scintillator + $PbWO_4$	18.1
MID	Iron absorber, scintillator bars, SiPMs	4.0
FD	Scintillators, PMTs	1.1
Magnet system	Superconducting solenoid $B = 2$ T	31.0
Online Computing	CPU and GPU nodes, disk buffer	10.3
Total		147.8
Common items	Beampipe, infrastructure, services	+11.1
	TC design and engineering	+10.9
FCT	MAPS, dedicated dipole magnet	+3.45

LoI table

System	Technology	Cost (MCHF)
Tracker	MAPS	30.5
TOF	Monolithic LGADs	14.8
	Hybrid LGADs[6]	26.4
RICH	Aerogel and monolithic SiPMs	20.9
	Aerogel, analogue SiPMs + readout[6]	34.0
ECal	Pb-scintillator + $PbWO_4$	17.0
MID	Steel absorber, scintillator bars, SiPMs	7.0
FCT	MAPS (solenoid + separate magnet)	5.3
	MAPS (solenoid + dipoles)	2.3
Magnet system	Superconducting solenoid + FCT magnet	25.0
	Superconducting solenoid and dipoles	40.0
Computing	Data acquisition and processing	6.0
Common items	Beampipe, infrastructure, engineering	15.0
Total		141.5

LoI baseline: 141.5 MCHF
with fallback options: 178.2 MCHF

Cost estimate within LoI range, about 20% above minimal scenario:

- More detailed cost estimates:
  - Information from vendors
  - Change of RICH baseline (analogue SiPM + readout)
  - Common infrastructure, engineering
- Inclusion of ~5-10% spare components

Updated cost: example (IT and OT)

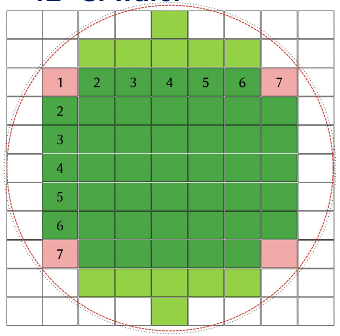
Table 5: Cost breakdown for the IT.

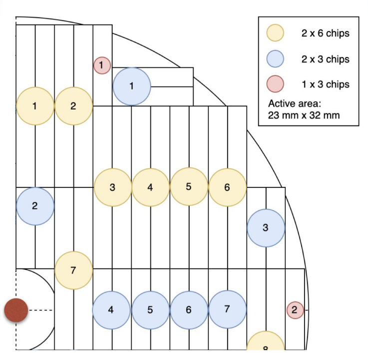
Component	Description	Cost (MCHF) VD	ML	Total IT
Sensors	CMOS production	1.00	1.83	2.83
Module assembly	Industrialisation, fabrication, chip testing, thinning and dicing	–	1.90	1.90
Module integration	Tooling and materials to mount modules on detector	0.50	1.36	1.86
Mechanics	Support structures including tooling	3.00	1.10	4.10
Cooling	CO_2 and water cooling including piping	1.00	0.30	1.30
Readout	VTRx+, lpGBT, PCIe cards, fibers	0.12	0.47	0.59
Power	Power supplies, regulators, cables	0.05	0.17	0.22
Services	Ventilation, DCS, DSS, VD movement	0.35	0.50	0.85
Total		6.02	7.63	13.65

Table 7: Cost breakdown for OT.

Component	Description	Cost (MCHF)
Sensors	CMOS production of 3.2×2.5 cm^2, including thinning and dicing of wafers	8.24
Module assembly	Industrialisation, fabrication, chip testing, module testing	7.06
Module integration	Tooling and materials to mount modules on detector	3.22
Mechanics	Support structures including tooling	3.40
Cooling	Water or air cooling	2.00
Readout	Readout cards and cabling	0.62
Power	Power supplies, regulators, cables	2.60
Services	Ventilation, DCS, DSS	0.70
Total		27.84

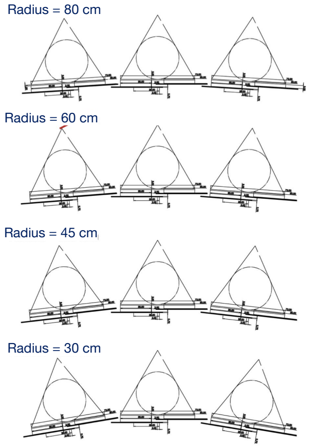
12” Si wafer



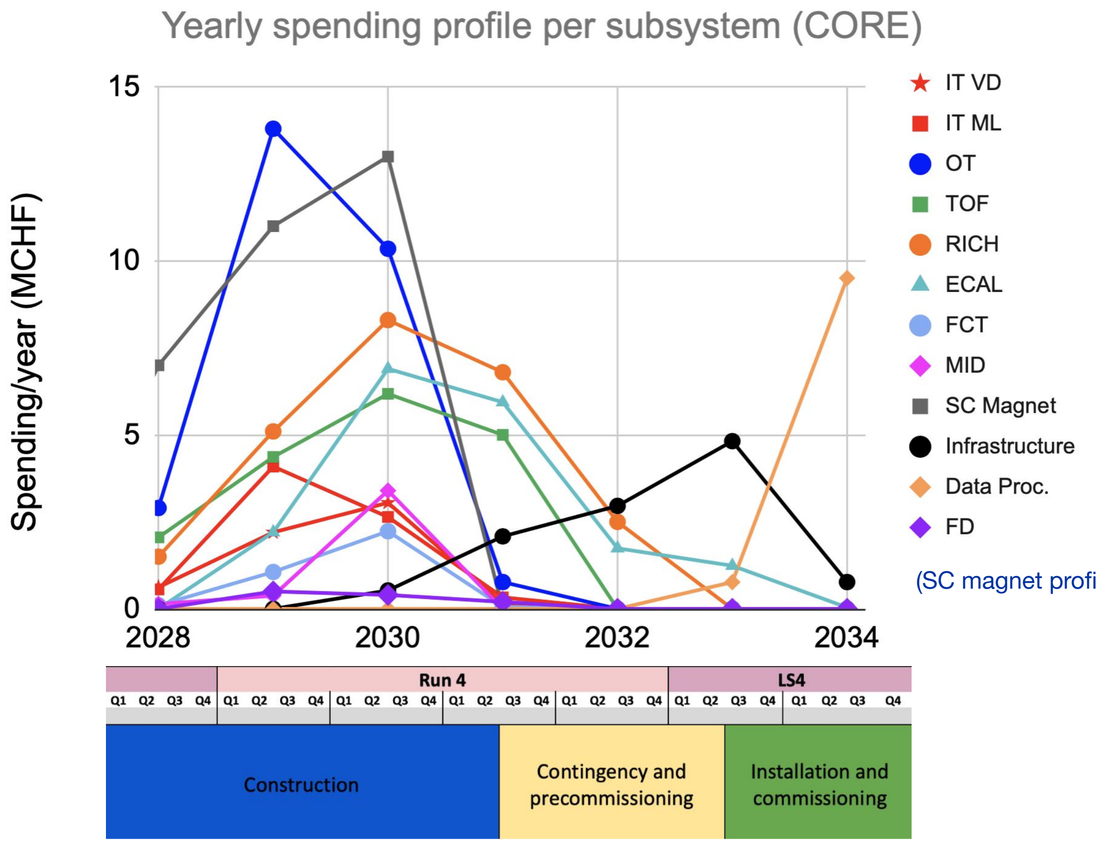


Quarter of Middle Layer disk

OT barrel “paving”



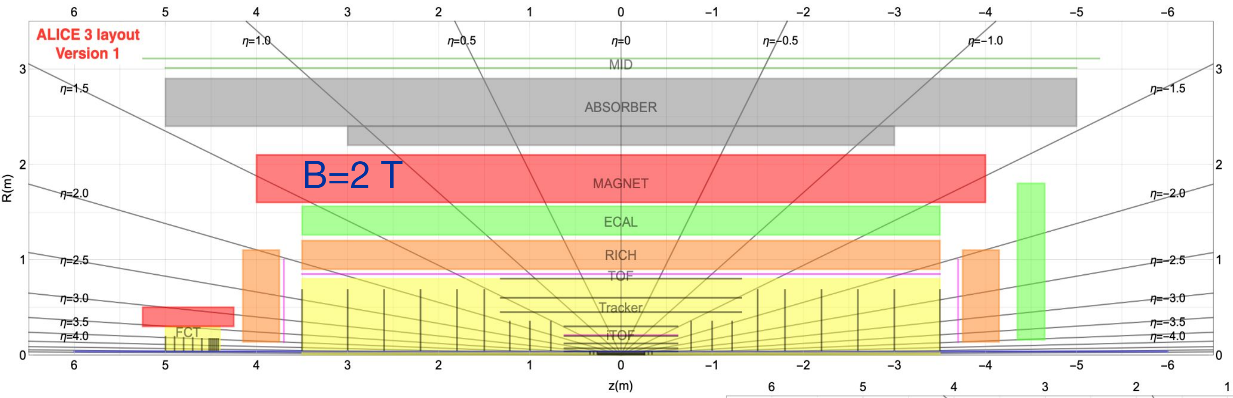
Spending profiles



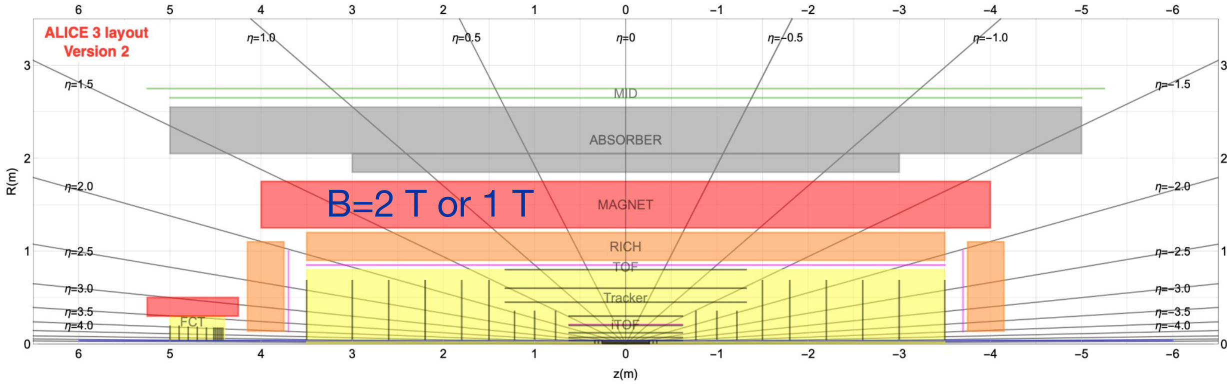
(SC magnet profile still tentative)

Spending starts in 2028, after TDRs approval, and peaks in 2029-31 depending on the total construction time

Detector scoping options



Reference Detector Configuration



- Version without ECal and smaller magnet radius
- Possibility to reduce B field value to 1 T

→ Impact on physics programme studied in view of Scoping Document

Ongoing R&D

Detectors	Activities	Plans for 2024
SC Magnet	Conceptual design of SC magnet	Initial design, investigation of cable options (Nb-Ti/Cu, Nb-Ti/Al, MgB_2) INFN
Inner Tracker	Sensor rad. hard. (ITS3 MLR1), mechanics (IRIS), components outgassing	New irradiation tests (NIEL, TID), sensor specs, lab tests (mechanics, vacuum,...) INFN
Outer Tracker	Module concept, mechanics, cooling	Sector mechanical prototype, sensor specs, lab tests
TOF	LGAD and SiPM time resolution, CMOS-LGAD design and characterization	New FEE with picoTDC, new CMOS-LGAD, PS testbeam in Apr, July, Oct INFN
RICH	Angle resolution, time resolution for TOF (SiPM+window)	Focusing aerogel, new FEE with picoTDC, PS testbeam in Oct INFN
ECal	SiPM timing, test new FEC32 with HPTDC	PbWO4 crystal +dual chan. photodet. +FEC32, energy and time resolution, SPS testbeam in May
MID	Scintillator selection, SiPM response, MWPC, RPC	Scintillator prototype module, new FEE, PS testbeam in Sept of all options

Broad participation to discussions and R&D

Upcoming event:
5th ALICE Upgrade Week, Krakow, 7-11 October

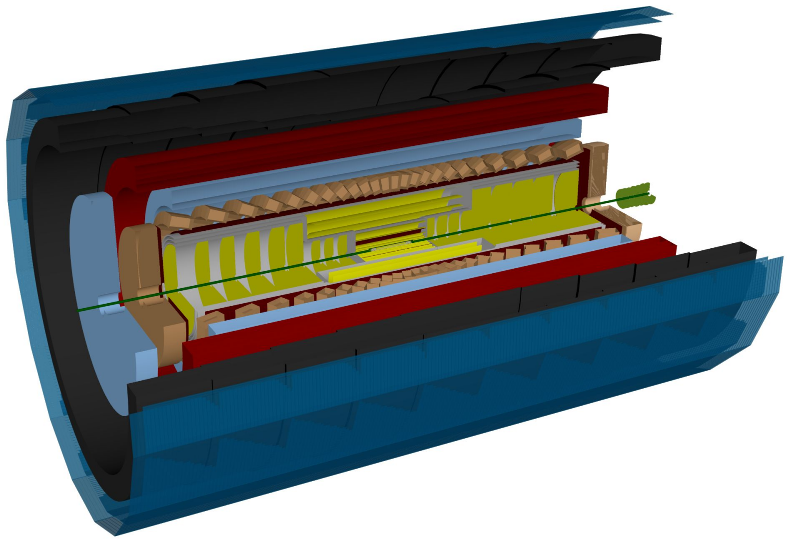
Summary

- ALICE 3 detector needed to access fundamental properties of QGP and the dynamic of its constituents
- Targets large increase x3-5 in: track precision, acceptance (with PID), rate capabilities
- Novel R&D on MAPS (continuation of ITS3 development), as well as on Si-based TOF and RICH sensors

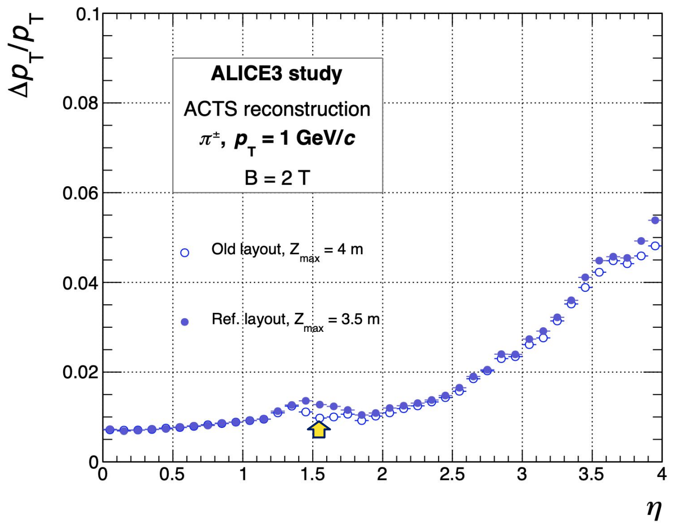
- Scoping scenarios explored and impact physics programme assessed
- Scoping Document being finalised: internal review completed
- Ongoing R&D:
    - Several prototypes and test beams this year
    - Important to continue supporting R&D in this phase

Thanks for your attention!

Software geometry and tracking

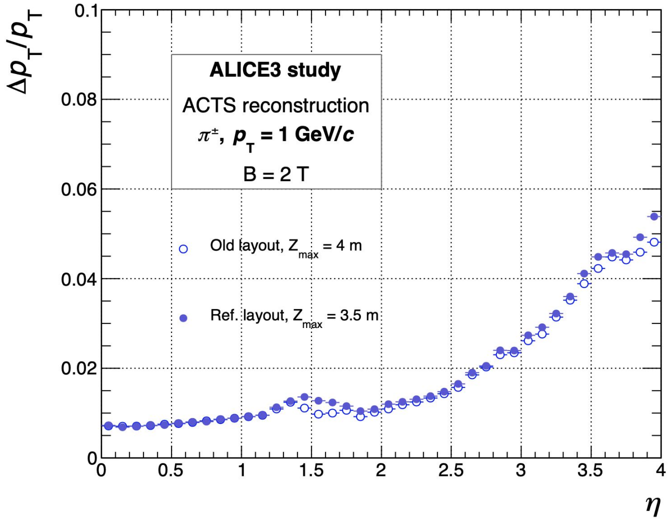


All subsystems implemented in ALICE O^2 software geometry

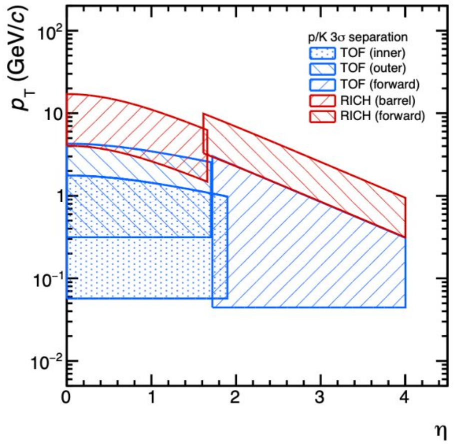


Minor effect of layout changes on tracking performance (momentum resolution)

Layout update: p_T resolution ~unaffected



LoI:



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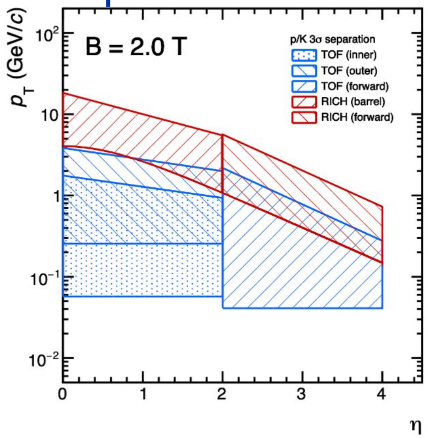
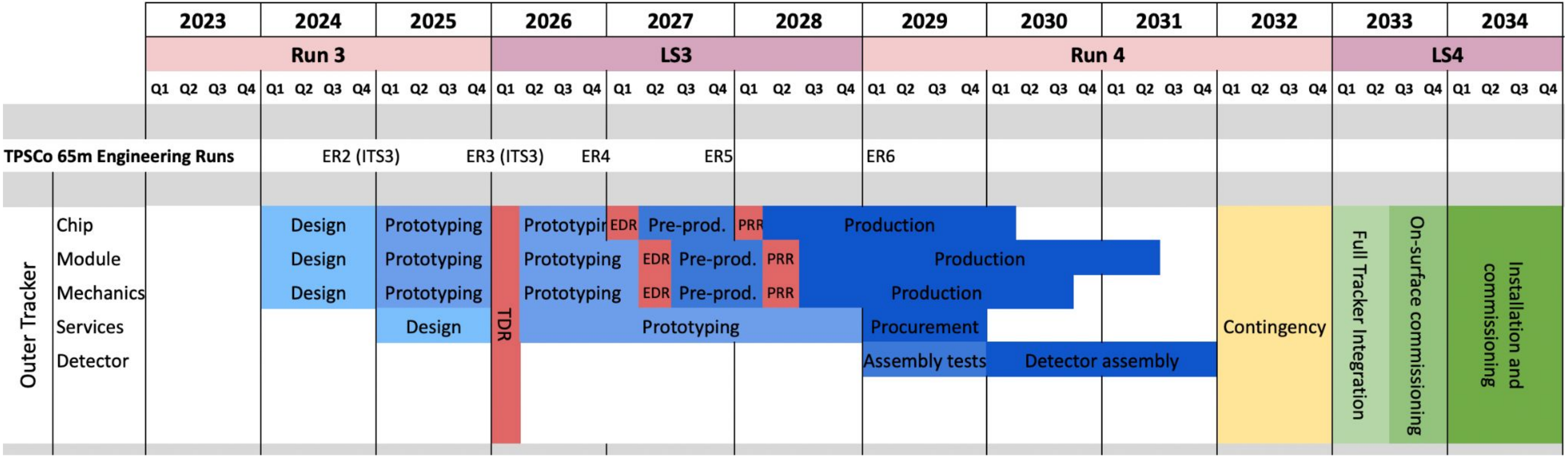


- Smaller and shorter OT endcaps don't worsen p_T resolution at $|\eta|>2.5$
- 10-20% worsening at $1.4<|\eta|<1.6$

- PID coverage is preserved

Detailed schedules example (OT)



Summary of impact of scoping options

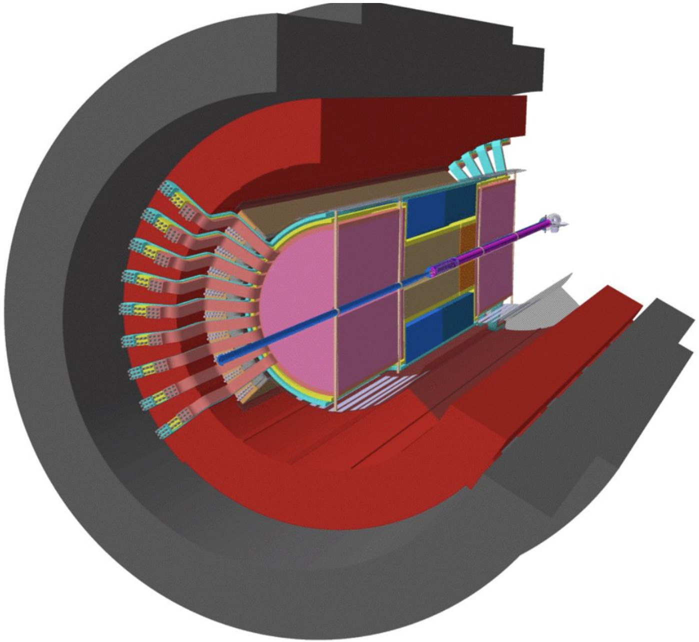
Measurement	Layout v2-2T	Layout v2-1T
ALPs searches in $\gamma\gamma \to \gamma\gamma$	strongly limited ($m_a < 2$ GeV/c^2, $1/\Lambda_a > 0.2$ TeV^{-1})	
$\chi_{c1,2} \to J\psi\gamma$	measurement limited to $p_T > 4$ GeV/c	
		minor additional impact
γ–jet correlations	limited improvement w.r.t. ALICE 2	
$\chi_{c1}(3872) \to J\psi\pi\pi$	not affected	minor impact
Ξ_{cc} yield	not affected	minor impact
Ξ_{cc} rapidity dependence	not affected	large impact
B^+ yield and flow	not affected	moderate impact at low and high p_T
Λ_c and Λ_b flow	not affected	large impact at $2 < \lvert y \rvert < 4$
D^0–$\overline{D^0}$ vs. $\Delta\varphi$	not affected	minor impact
D–D* vs. k^*	not affected	significant impact
Dielectrons	not affected	can exploit full integrated luminosity

→ **B = 2 T is the preferred field strength**

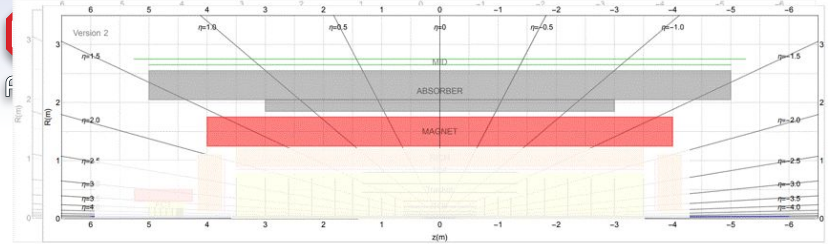
→ **B = 1 T not the ideal option, but still enables a strong programme**

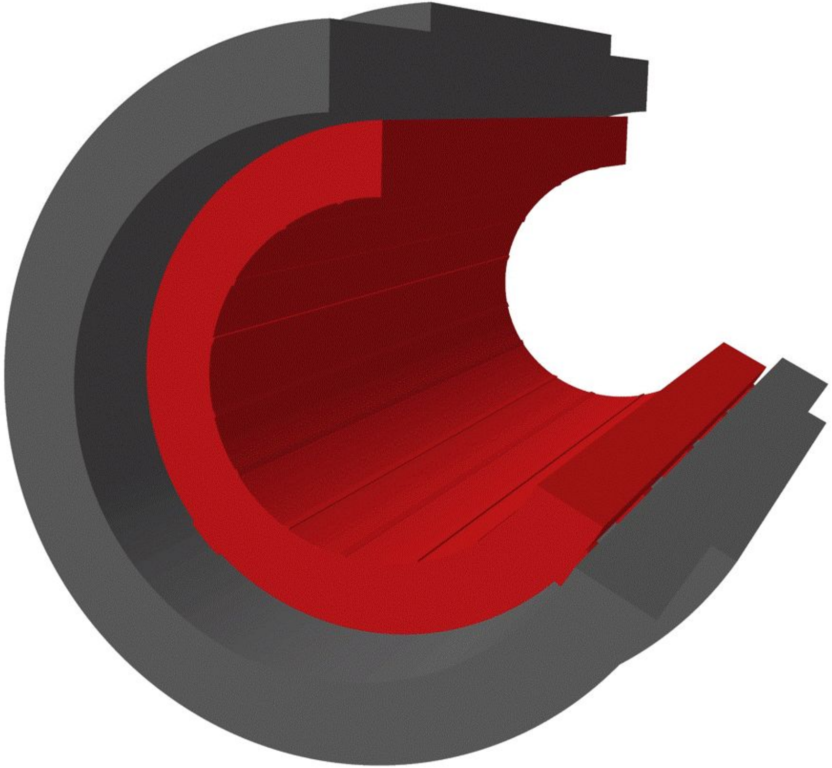
→ an intermediate value of magnetic field (e.g. 1.5T), can be considered as well

Services and installation



- Main guideline: **optimise installation sequence and add flexibility to the LS4 schedule**
- Integration scheme with alternating services on the two sides
- **Enables modular and independent installation** of: Outer Tracker endcaps, RICH and TOF barrels, forward RICH and forward TOF endcaps
- In case of delay, any of these **components can be installed during a YETS, without affecting the LHC schedule**



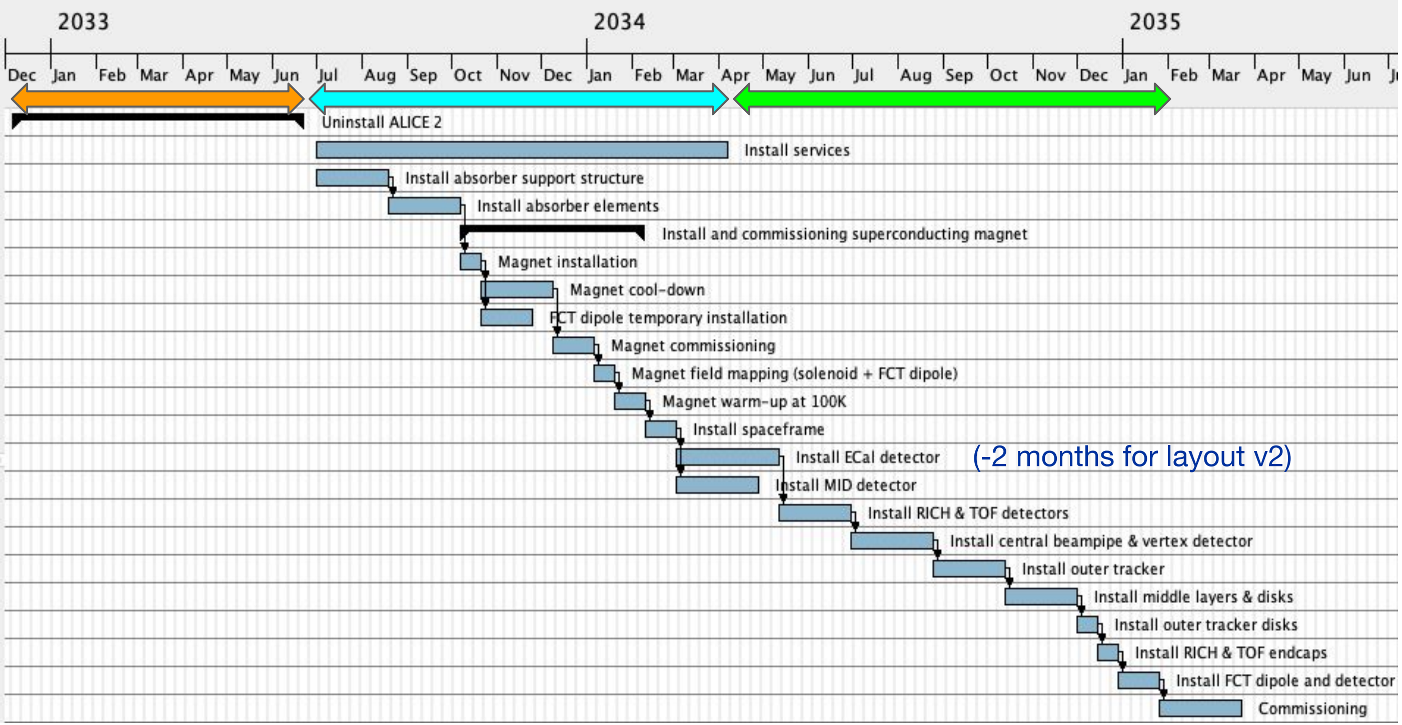


Magnet

LS4 schedule

Dismantling of ALICE 2, installation of magnet and services, and of ALICE 3 fit in LS4

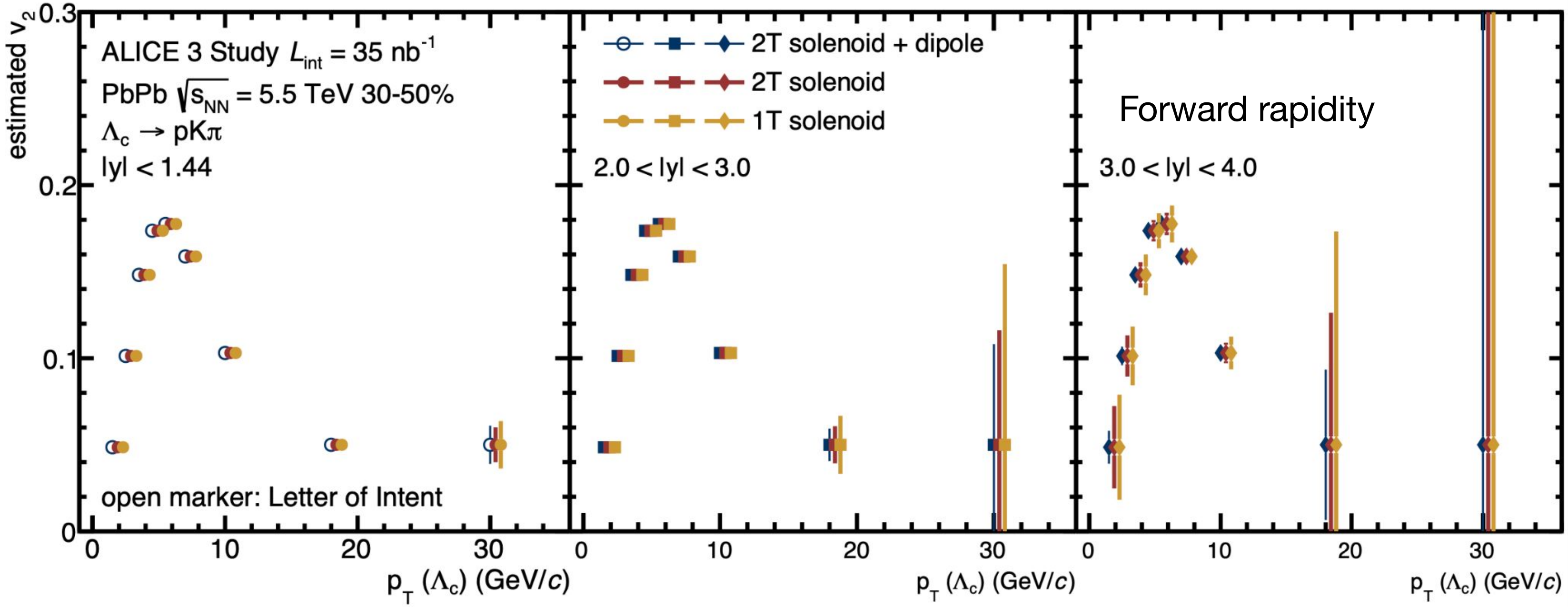
Begin date	End date	Dura...	Task
12/6/32	6/22/33	143	Uninstall ALICE 2
7/1/33	4/6/34	200	Install services
7/1/33	8/18/33	35	Install absorber support structure
8/19/33	10/6/33	35	Install absorber elements
10/7/33	2/9/34	90	Install and commissioning superconducting magnet
10/7/33	10/20/33	10	Magnet installation
10/21/33	12/8/33	35	Magnet cool-down
10/21/33	11/24/33	25	FCT dipole temporary installation
12/9/33	1/5/34	20	Magnet commissioning
1/6/34	1/19/34	10	Magnet field mapping (solenoid + FCT dipole)
1/20/34	2/9/34	15	Magnet warm-up at 100K
2/10/34	3/2/34	15	Install spaceframe
3/3/34	5/11/34	50	Install ECal detector
3/3/34	4/27/34	40	Install MID detector
5/12/34	6/29/34	35	Install RICH & TOF detectors
6/30/34	8/24/34	40	Install central beampipe & vertex detector
8/25/34	10/12/34	35	Install outer tracker
10/13/34	11/30/34	35	Install middle layers & disks
12/1/34	12/14/34	10	Install outer tracker disks
12/15/34	12/28/34	10	Install RICH & TOF endcaps
12/29/34	1/25/35	20	Install FCT dipole and detector
1/26/35	3/22/35	40	Commissioning



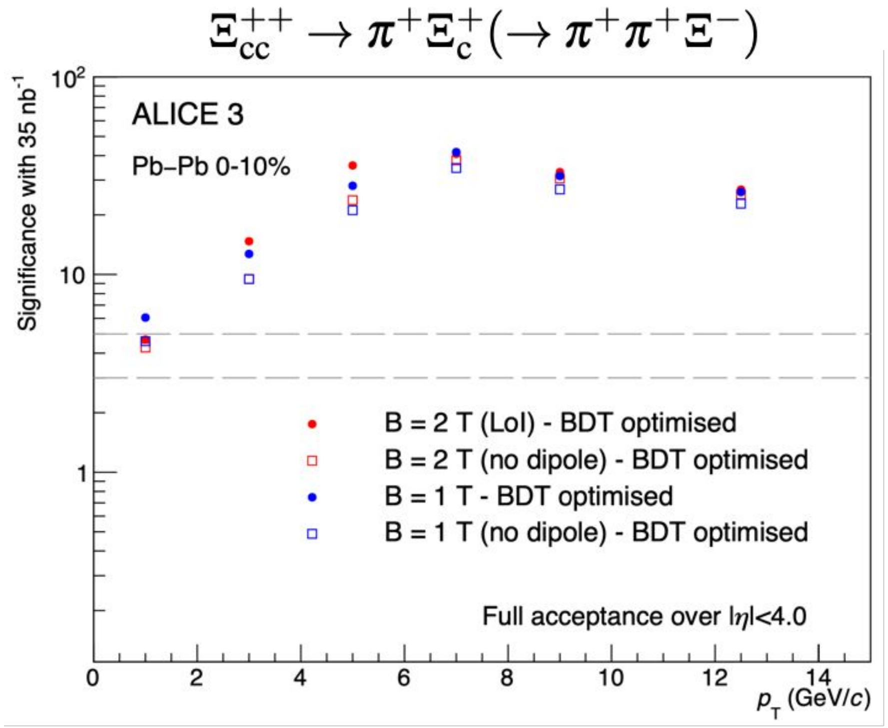
(-2 months for layout v2)

Layout v2-1T: Λ_c elliptic flow

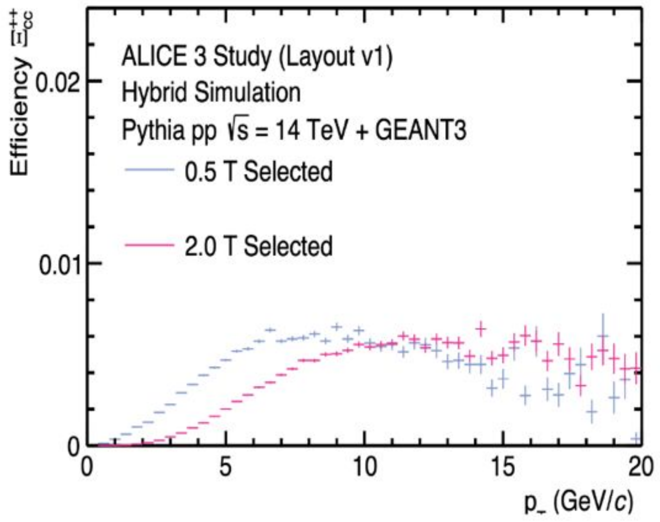
- **Measurement at central rapidity |*y*|<3 remains precise** also with solenoid 1 T
- **Measurement at forward rapidity 3<|*y*|<4 is degraded**, especially with 1T



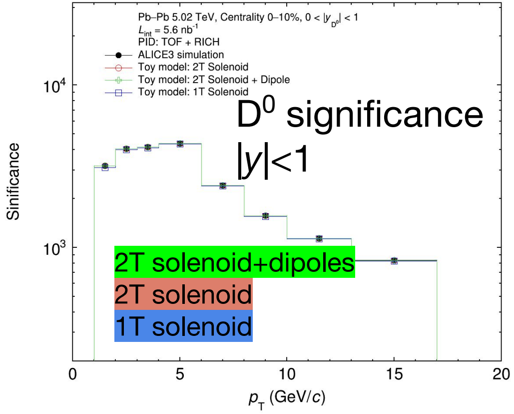
Layout v2-1T: multicharm baryon Ξ_{cc}

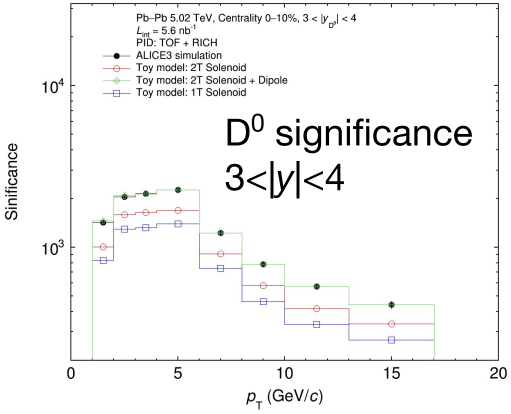


- **Significance ~30% lower without dipoles, at 2-6 GeV/c**
- 1T quite similar to 2T: a bit higher at low p_T, a bit lower at intermediate p_T
- Larger background due to lower p_T resolution partly compensated by larger acceptance for soft pions

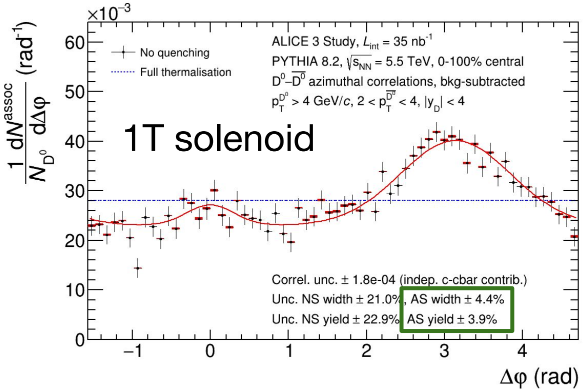


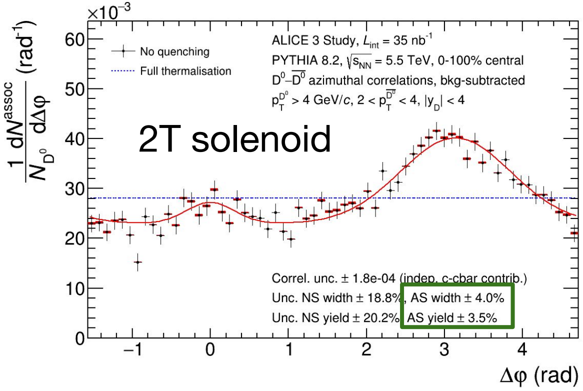
Layout v2-1T: D^0 and D-$\bar{D}$ correlations



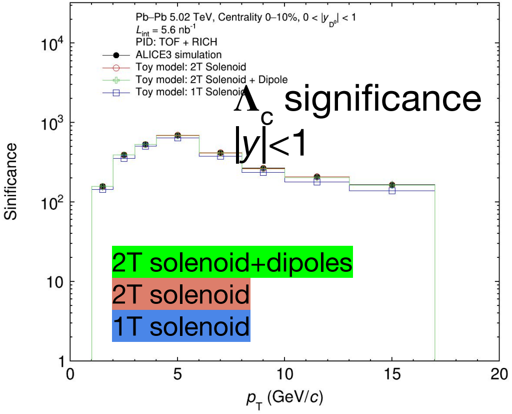


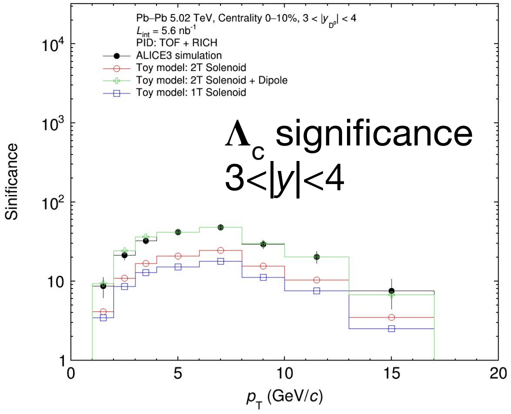
- D^0 meson significance:
  - no impact of field value/configuration at $|y|<3$, because S/B >>1
  - large reduction of S/B and significance in $3<|y|<4$
- Effect propagated to D-Dbar azimuthal correlations:
  - minor impact on precision of near-side and away-side peak yields and widths
  - e.g.: away-side width precision is 4.4% with 1T solenoid-only, 4.0% with 2T solenoid-only and 3.8% with 2T solenoid+dipoles



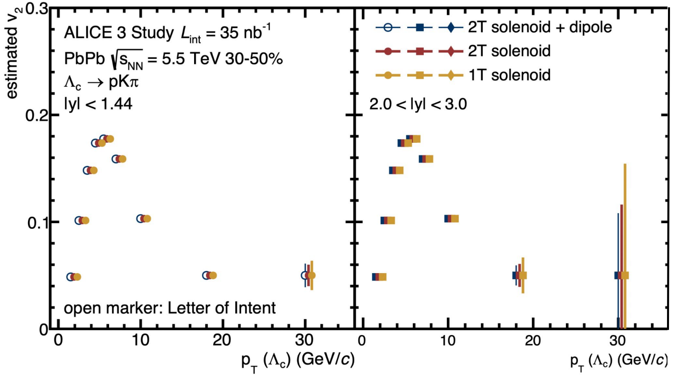


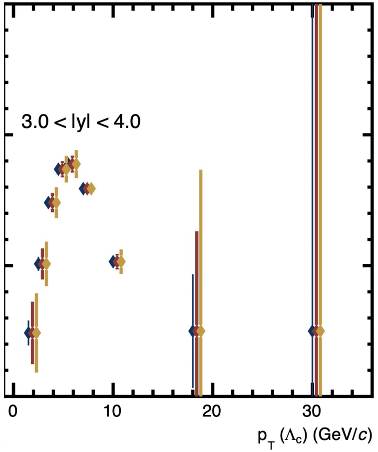
Layout v2-1T: Λ_c significance and flow





- Λ_c meson significance:
  - no impact of field value/configuration at $|y|<2$, because S/B >>1
  - large reduction of S/B and significance in $3<|y|<4$ without dipoles, but small difference between 2T and 1T
- Λ_c Elliptic flow:
  - measurement at $|y|<3$ remains very precise also with solenoid only and with 1 T
  - measurement at $3<|y|<4$ degraded without dipoles, especially with 1T





ECal descoping

Physics loss without ECal:

- Strong limitation in performance for BSM searches in $\gamma\gamma \rightarrow \gamma\gamma$
- $\chi_{c1,2}$ measurement starts at p_T 4-5 GeV/c instead of 1-2 GeV/c
- No possibility of full-jet and gamma-jet measurements

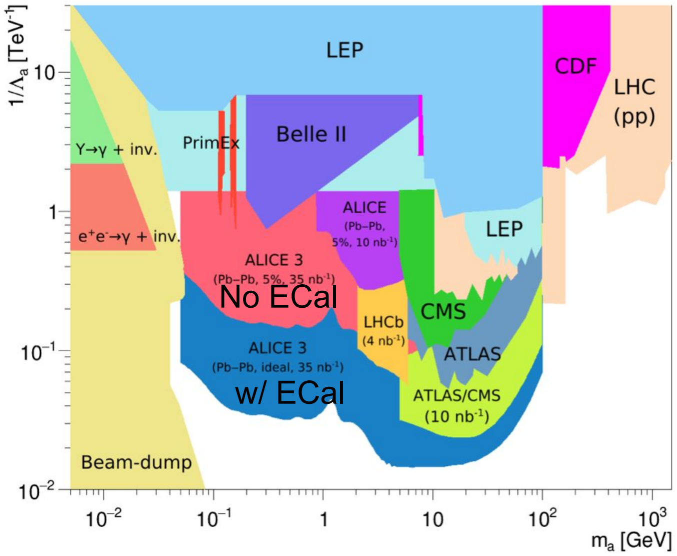
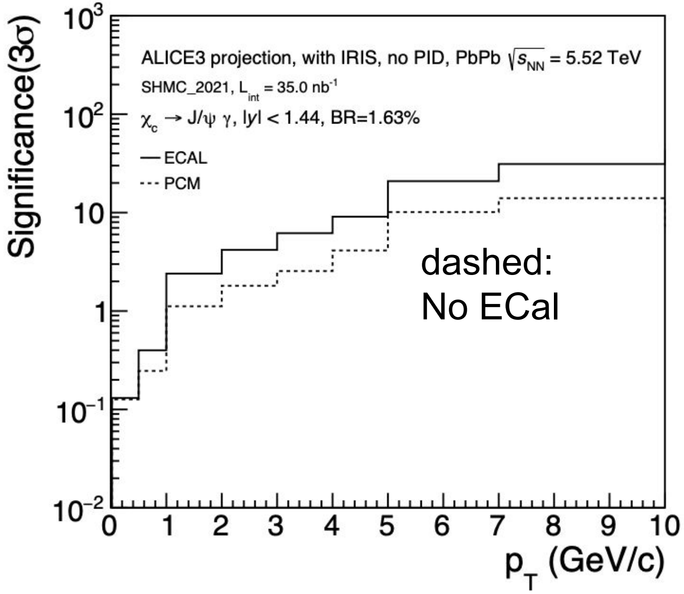
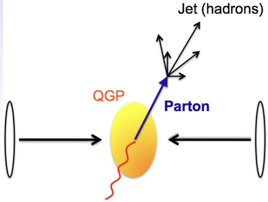


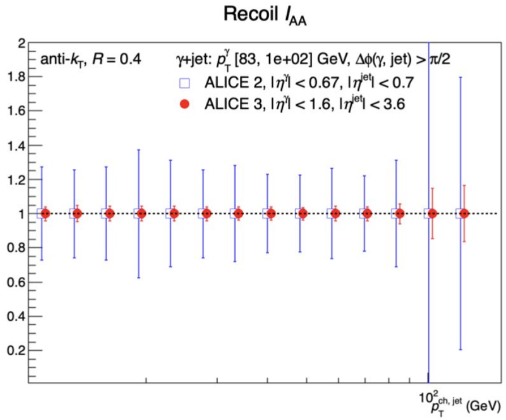
Figure 76: Bounds in the $(m_a, 1/\Lambda_a)$ plane from existing and future ALP searches.

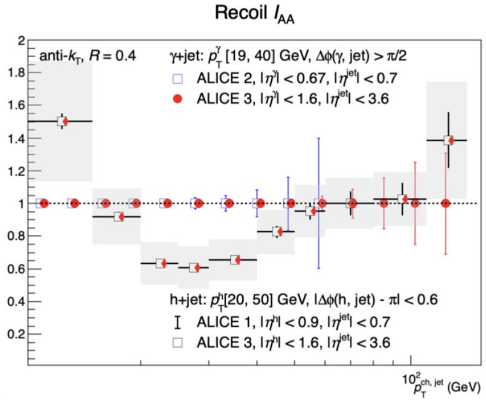


ECal: gamma-jet



- ECal can measure photons with x10 larger acceptance than ALICE 2 (EMCal)
- Photon can be correlated with charged-jets in |eta|<4 (exploiting ALICE 3 tracker acceptance)
- Uniqueness:
  - wrt ATLAS/CMS: low p_T
    - p_{Tjet}>10 GeV in ALICE 3 (same ALICE), vs 50 in ATLAS/CMS
    - p_{Tgamma}>10-20 GeV in ALICE 3, vs 50 in ATLAS/CMS
  - wrt ALICE 2: x10 larger acceptance for the photon (EMCal vs ECal), x2 larger L_{int}, ch. jets in |eta|<3.6 vs |eta|<0.5
- Projections for recoil jet R_{AA} and I_{AA}





2T vs 1T: multicharm baryon Ξ_{cc}

$$\Xi_{cc}^{++} \rightarrow \pi^{+}\Xi_{c}^{+}(\rightarrow \pi^{+}\pi^{+}\Xi^{-})$$

- **Significance at forward rapidity is reduced by ~25% with 1 T compared with 2 T**