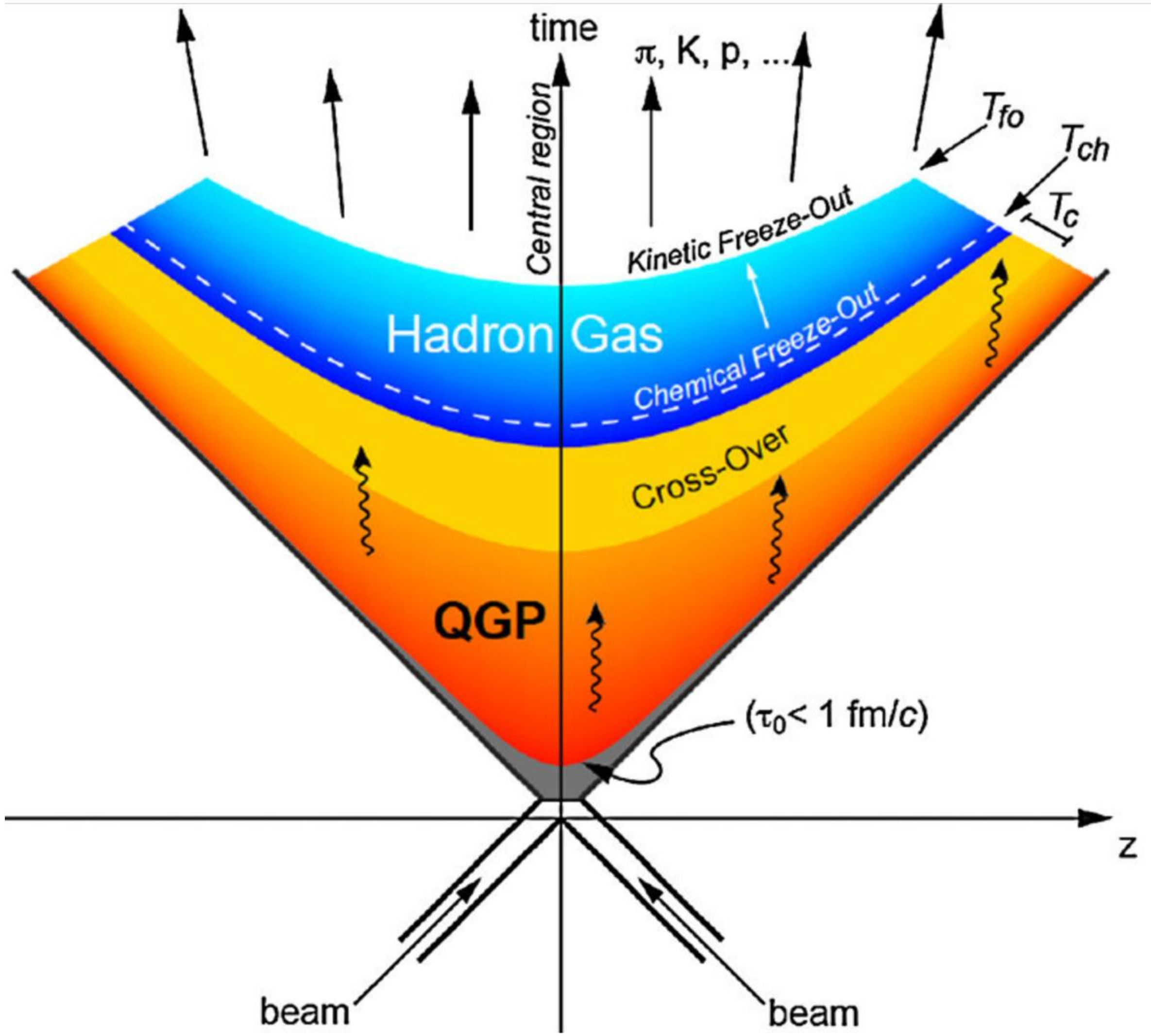
Future heavy ion experiment ALICE3

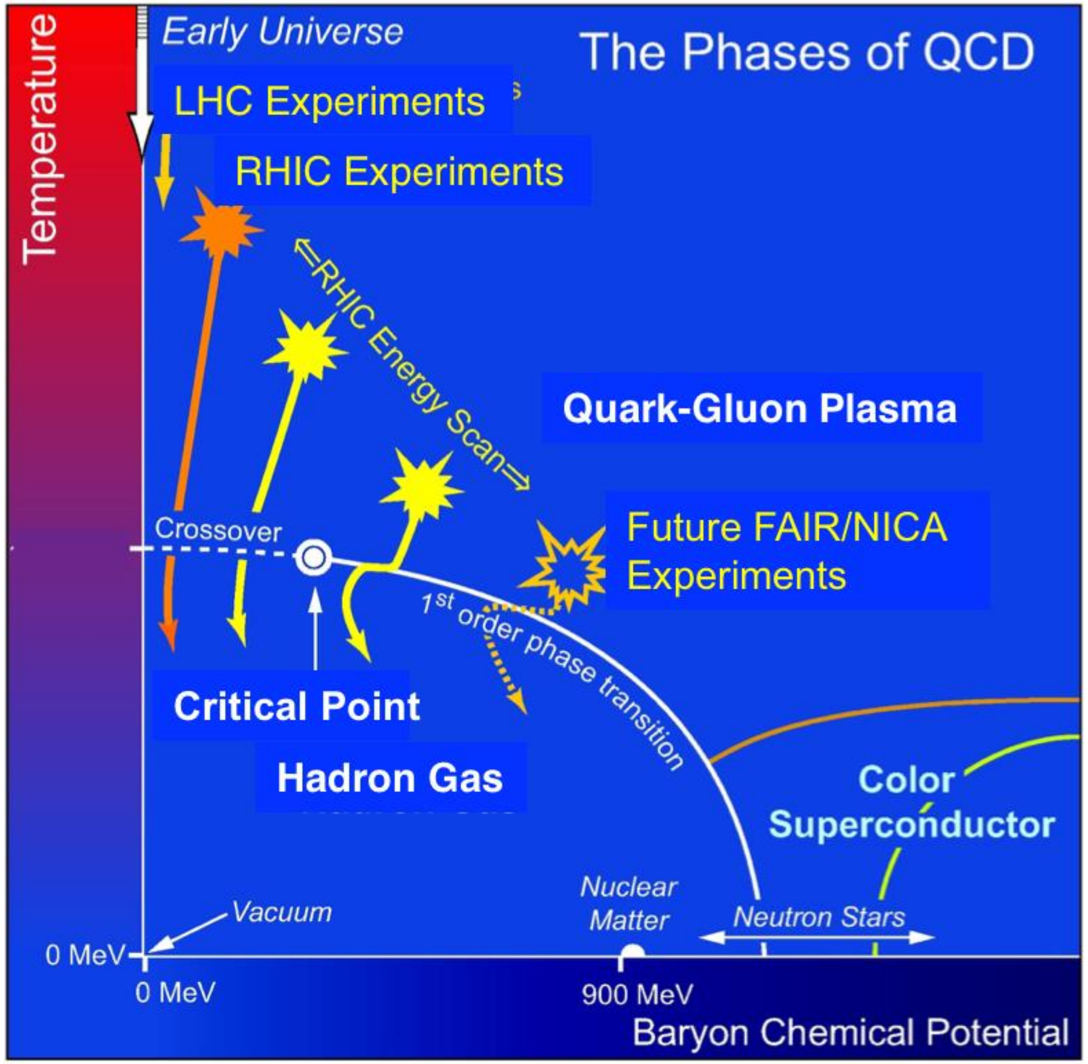
Sami Räsänen

Particle Physics Days in Lammi

28th November 2024

Relativistic heavy ion collisions – QGP in laboratory





ALICE – A Large Ion Collider Experiment

- Letter of Intent submitted 1993
- Finland joined ALICE 1998

Physics program as presented in 1993:

1) Initial conditions of heavy ion collisions
   - global event features, N_{part}
   - produced energy density

2) Quark-gluon plasma (QGP)
   -direct photons and thermal electromagnetic radiation
   - energy loss of partons at QGP
   - J/ψ probing the deconfinement

3) Phase transition to QGP
   - strangeness production
   - multiplicity fluctuations
   - particle interferometry (to probe the expansion time of the mixed phase)

4) Hadronic matter
   - particle ratios (chemical composition), p_T –distributions
   - freeze-out radius of the hadronic fireball

CERN/LHCC/93-16
LHCC/I 4
1 March 1993

Letter of Intent
for
A **L**arge **I**on **C**ollider **E**xperiment

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   - energy loss of partons at QGP !
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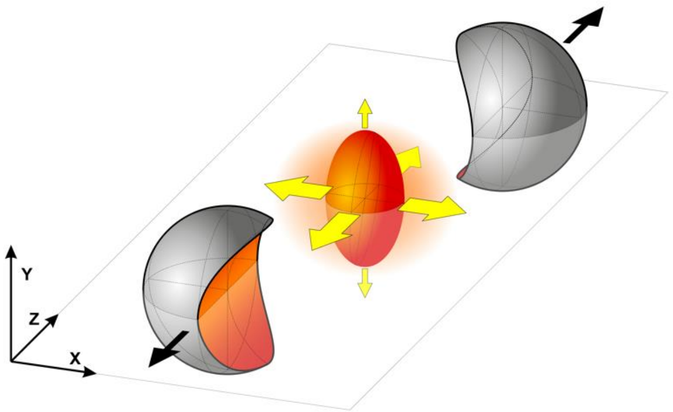
Letter of Intent
for
A Large Ion Collider Experiment

“ [...] , reflect the energy loss of partons (before fragmentation) and this results in striking differences in the shape of the spectra predicted for nucleus-nucleus and pp collisions.”

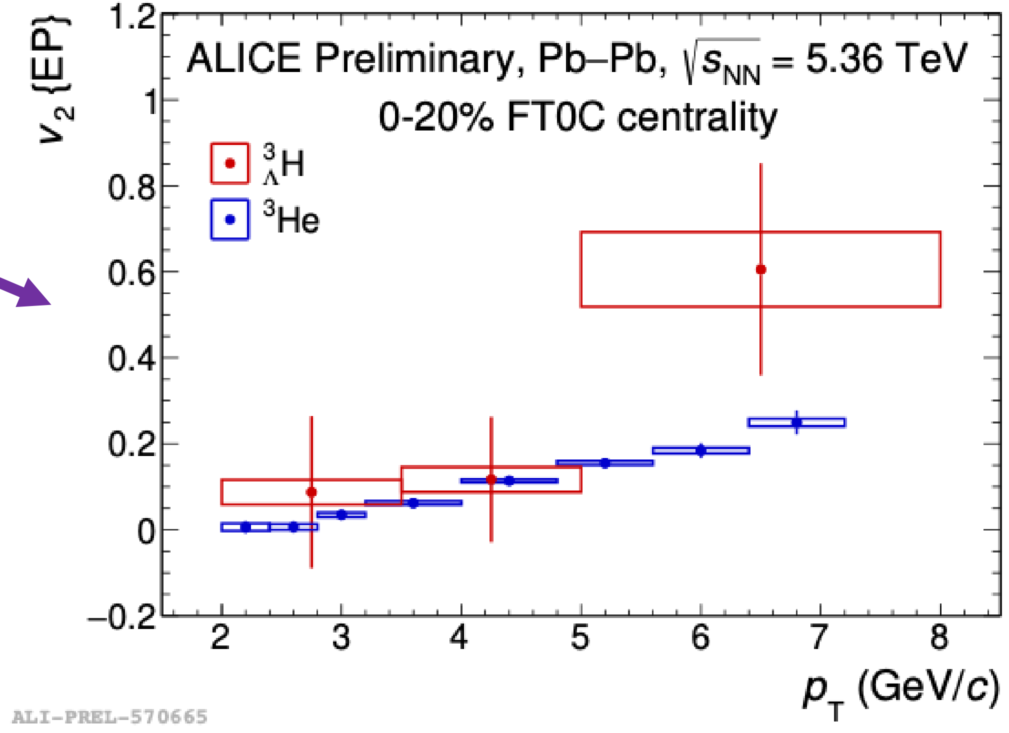
--- no citation given

Long Shutdown 2 (LS2) upgrades:



ALICE specialty – non-triggerable observables:

- Quark-medium interactions via measurements on heavy flavoured hadrons down to low momenta
- Disassociation and regeneration via measurements of charmonium states
- Medium evolution via thermal photons and dileptons
- Production and degree of thermalization of light and hyper nuclei



Based on physics targets:

Keep old:

- Tracking down to low momenta
- Particle identification over large momentum range

Bring something new:

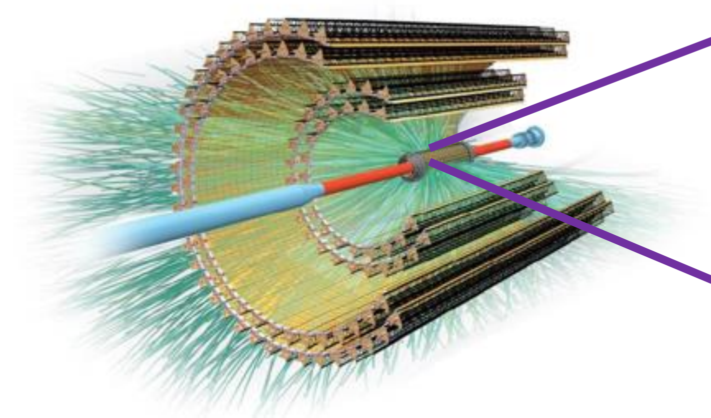
- Continuous readout of detectors
- Large minimum bias (MB) data set with low pileup

LS3 Upgrades – FoCal and ITS3

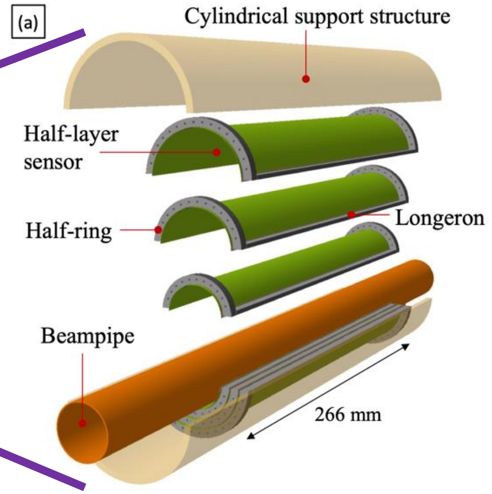
New vertex detector ITS3
- improve secondary vertexing and pointing resolution

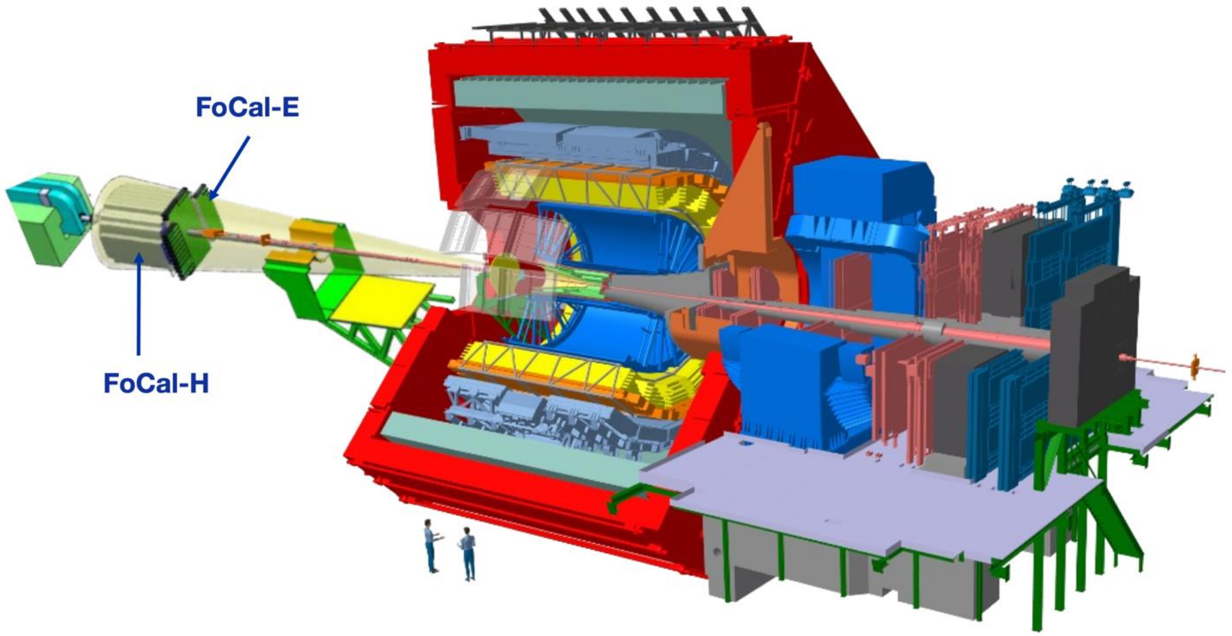
New forward calorimeter (FoCal)
- physics of gluon saturation

ITS NOW

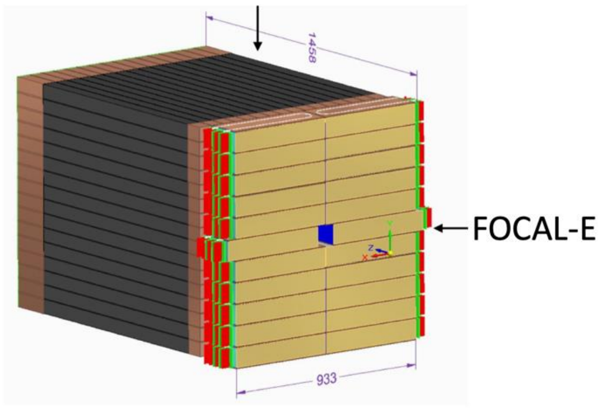


In Run4 !

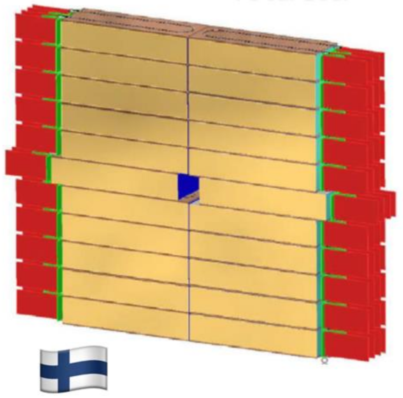




FOCAL-H



FOCAL-E – 22 modules



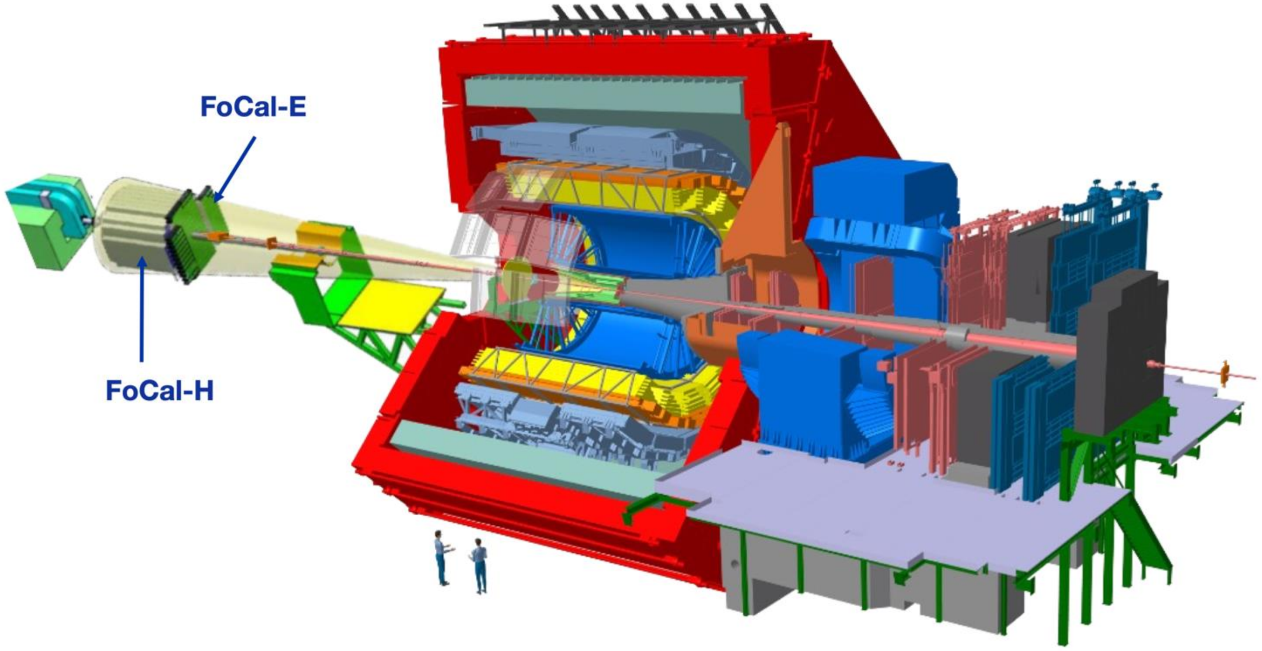
Future upgrades of ALICE:

- ALICE1
  - what we had in Run1+2

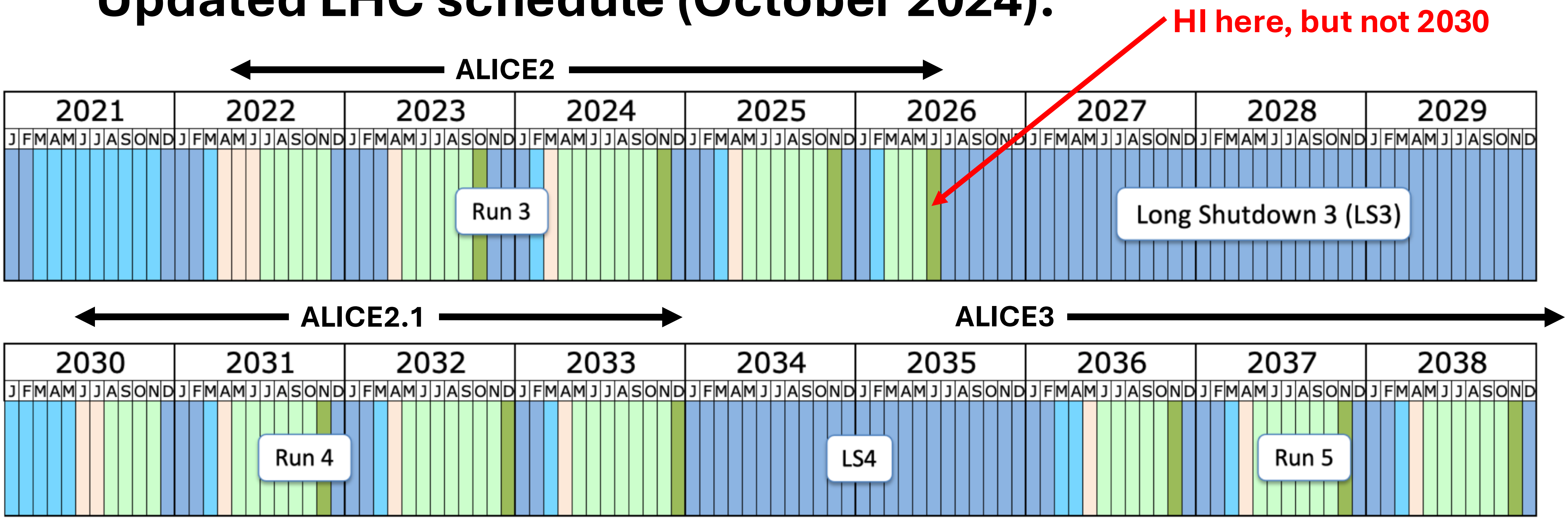
- ALICE2
  - present setup
  - Run3, years 2022-2026
  - refurbish subsystems in LS3

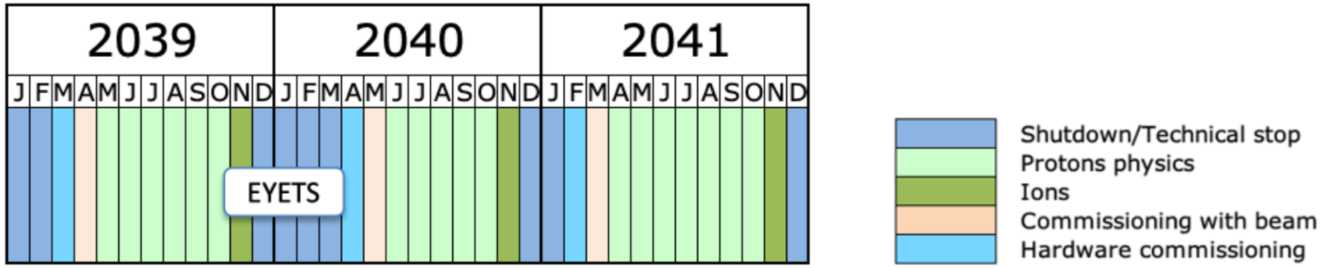
- ALICE2.1
  - Run4, years 2030-2033
  - add forward calorimeter FoCal
    and new vertex detector ITS3

- ALICE3
  - Run5, years 2036-2041
  - new experiment!



Updated LHC schedule (October 2024):





LS3 start 7/2026 → +7 months
Run4 starts 1/2030 → +12 months
Run 5 & Run 6 combined
→ LS5 cancelled, replaced by extended year-end technical stop (EYETS)

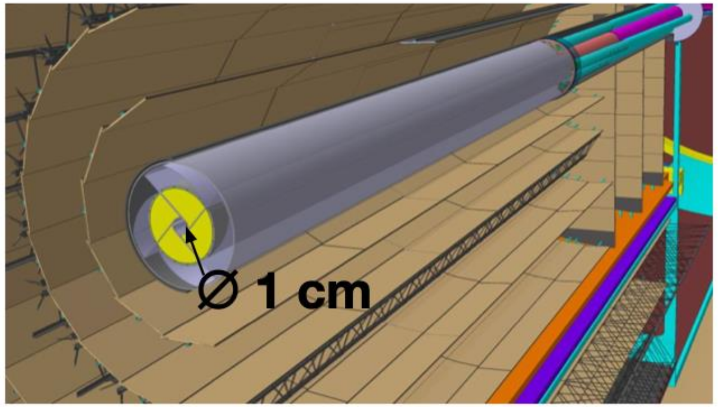
12/2041 = end of the HL-LHC

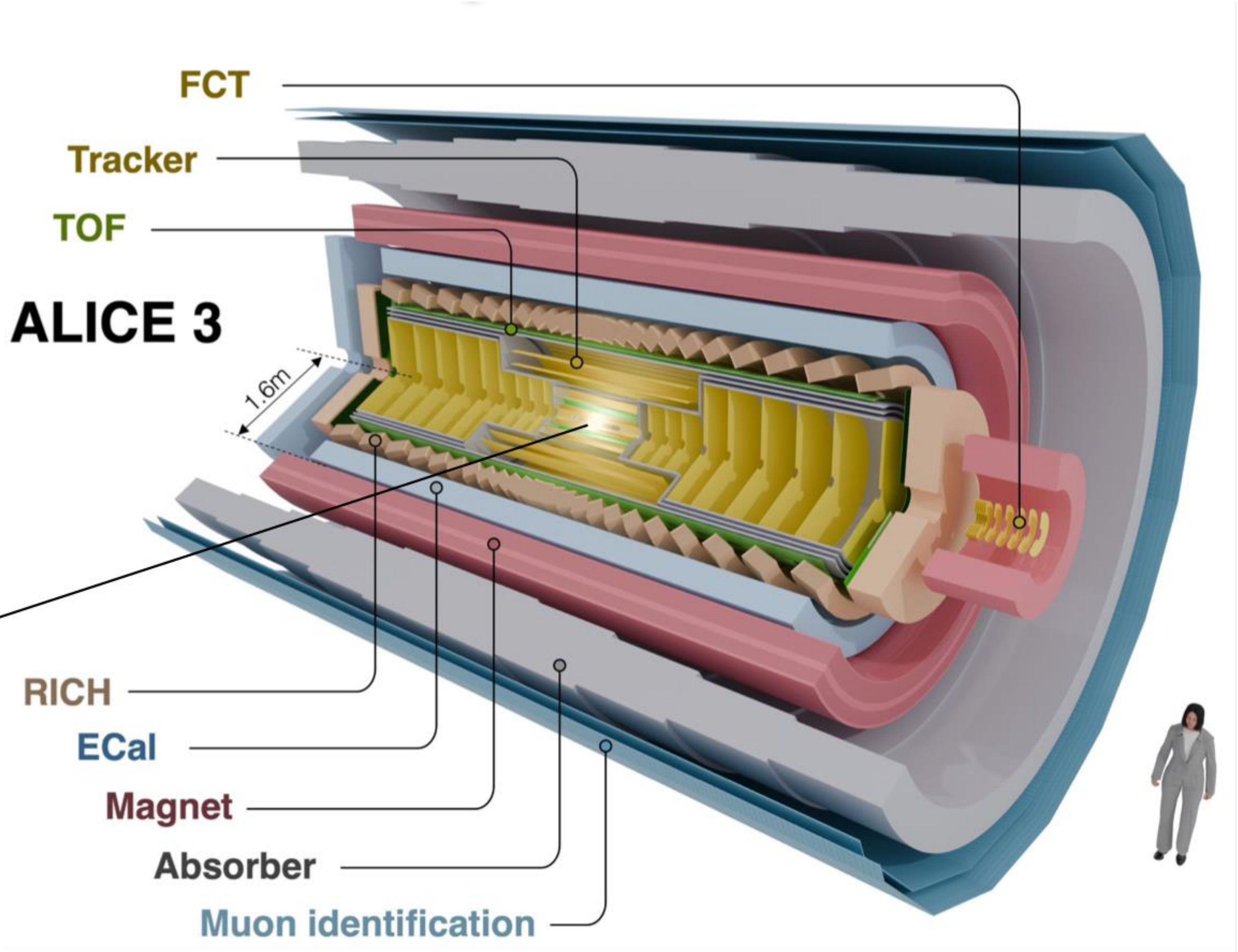
→ FCC-ee 2045-2048, FCC-pp ~2070-2075 (?)

ALICE3 – Letter of Intent

➡ 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





What is drives the design?

EM radiation – thermal photons:

ALICE, Physics Letters B 754 (2016) 235

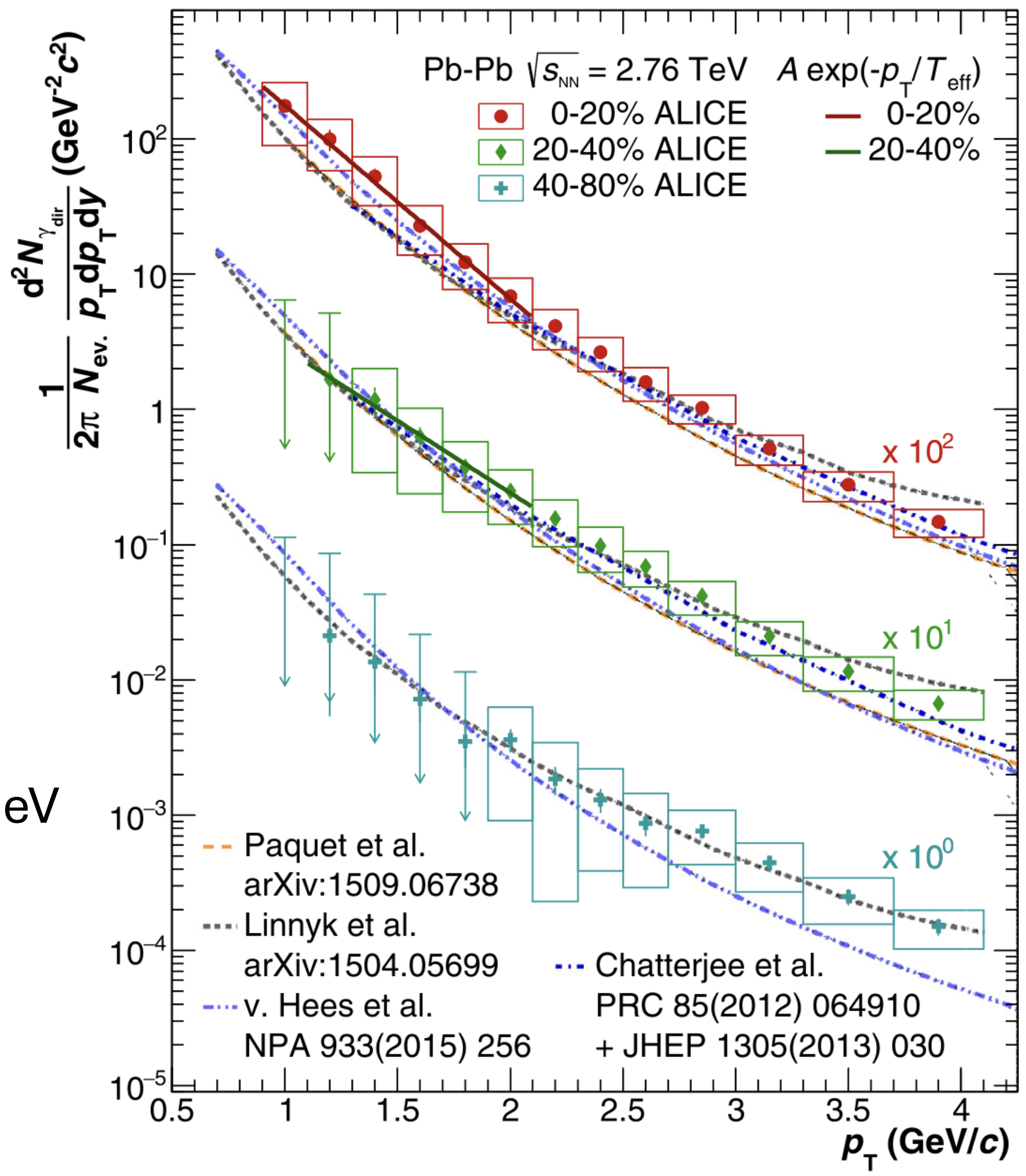
Mean free path of photons and electrons ~100 fm
→ leave interaction region without further interactions

$$(\text{yield}) \sim \int_{4-\text{volume}} (\text{emission rate})$$

ALICE: inverse slope $\sim e^{-p_T/T}$, $T \approx 297 \pm 12^{stat} \pm 41^{sys}$ MeV,
An effective temperature reflecting evolution over the whole fireball.

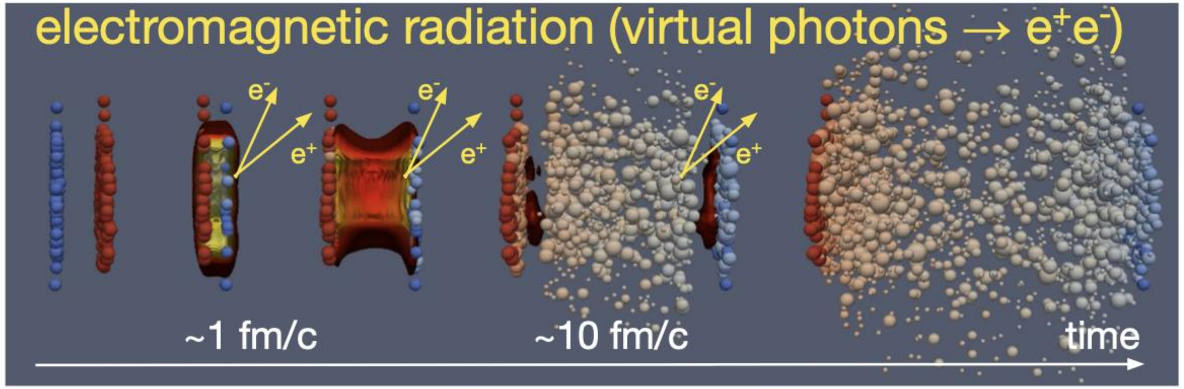
Detailed hydrodynamical simulations:

- Initial temperature at center of the fireball T_{max} = 345-740 MeV (large spread due to assumption of initial time)
- Average temperature theoretically a bit "cumbersome", depends on choices
- Photons are blue shifted by flow → affects interpretation



This result from ALICE1

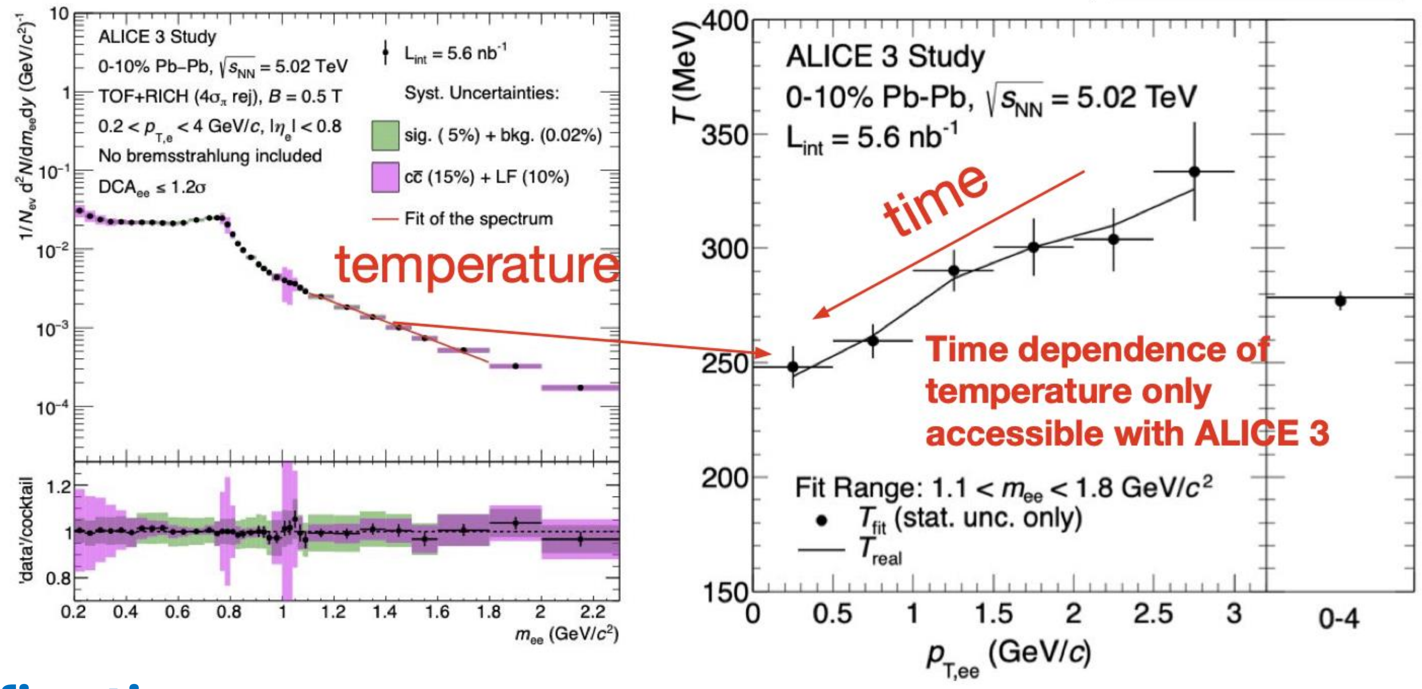
ALICE3 – Temperature evolution of QGP



Dilepton mass spectrum:

- mass window dominated by the thermal dileptons
- slope of the mass spectrum
  ⇔ temperature
- <u>invariant</u> mass
  → better access to T
- binning in dilepton pair p_T
  ⇔ access to time

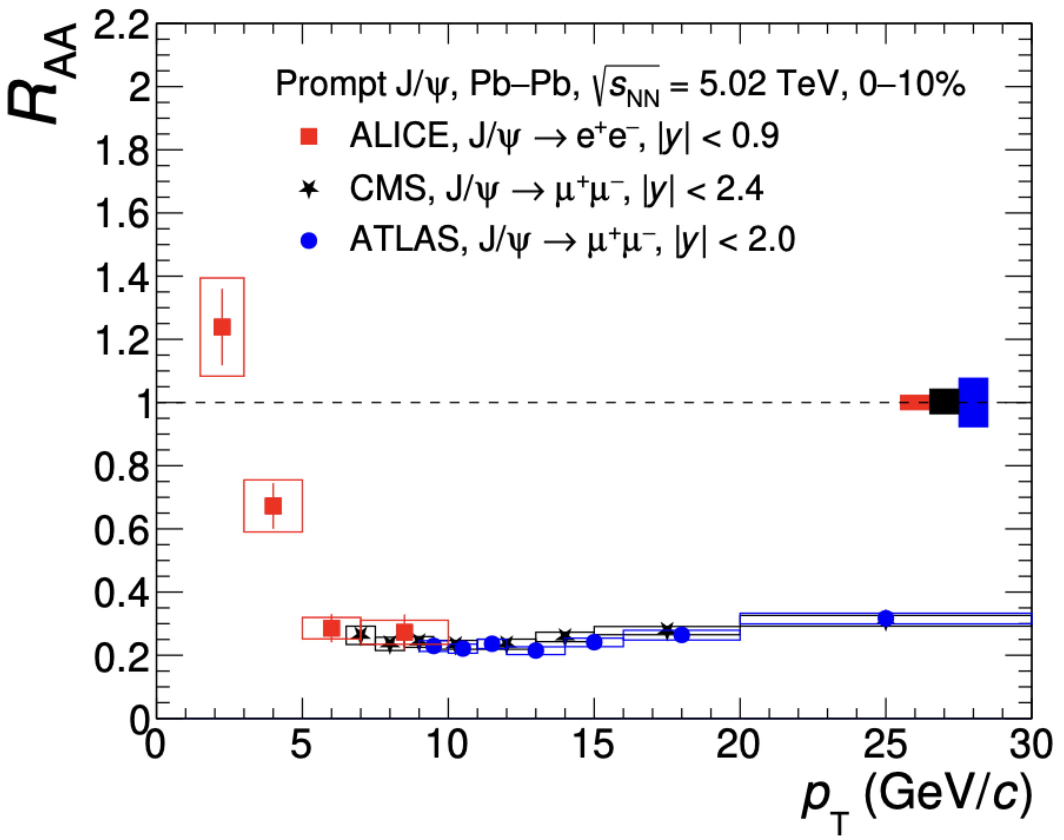
ALICE 3 LoI, CERN-LHCC-2022-009

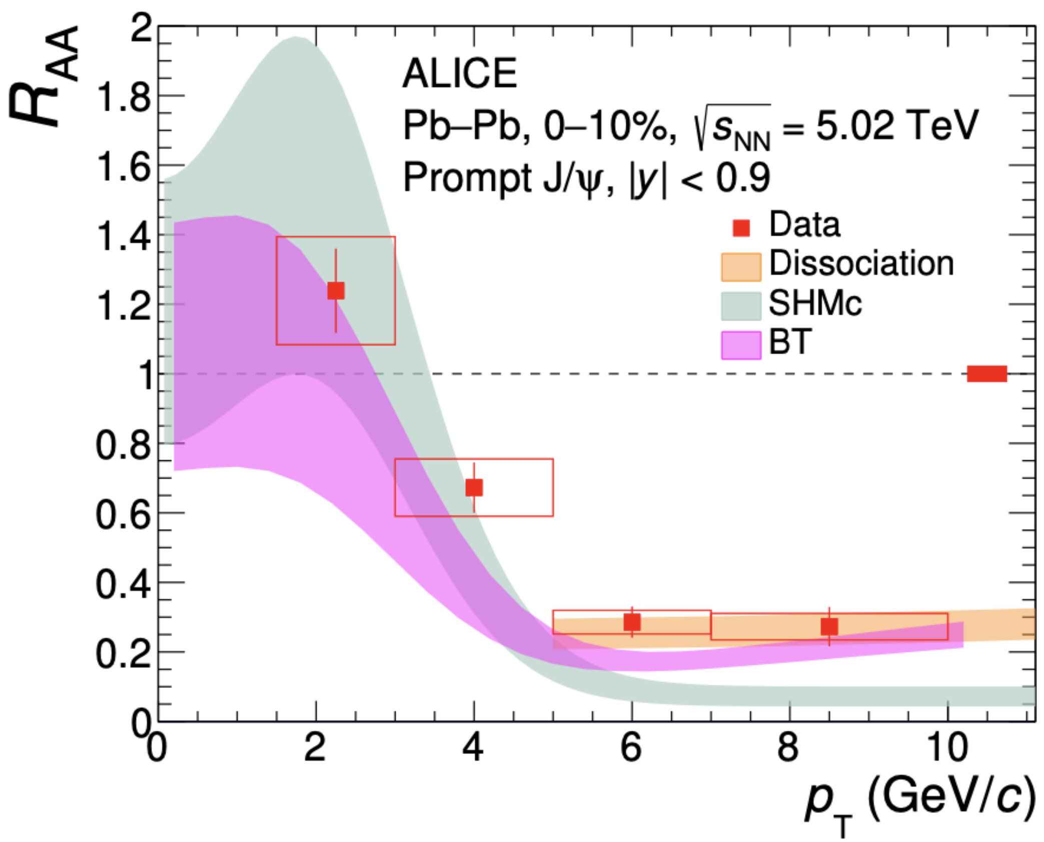


Gimmick: Precision electron identification

Heavy quarks at the QGP medium:

ALICE, JHEP02 (2024) 066





Dissociation = melting of bound charm states due to Debye colour screening
SHMc = statistical hadronization model with charm
BT = Boltzmann transport model, includes dissociation and regeneration in medium

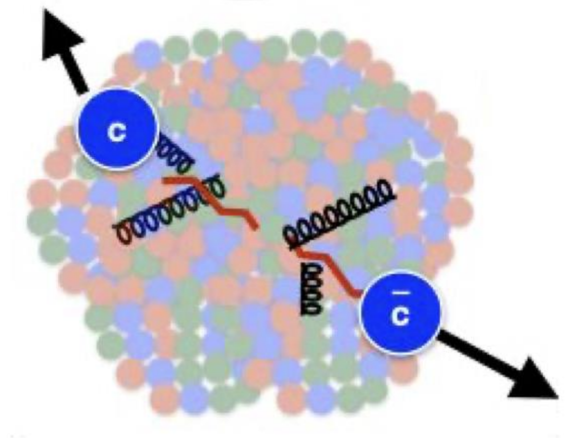
These results ALICE1 → ALICE2 much better statistics

ALICE3 – two-particle correlations with charm

- Charm diffusion in QGP with DD-correlations
- Degree of thermalization of charm

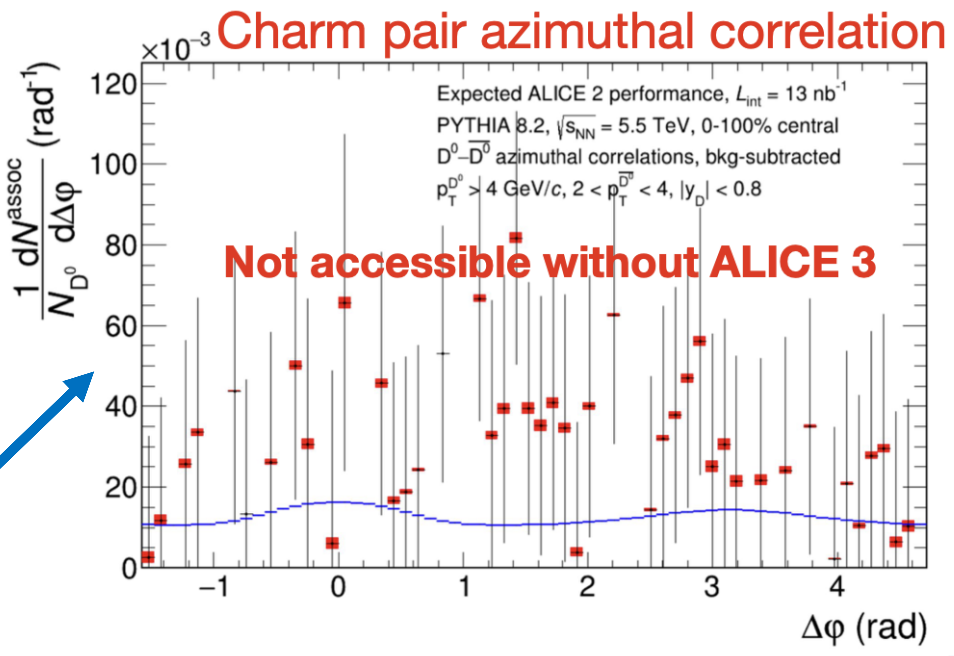
→ **Gimmick: Large acceptance, PID, high-rate**

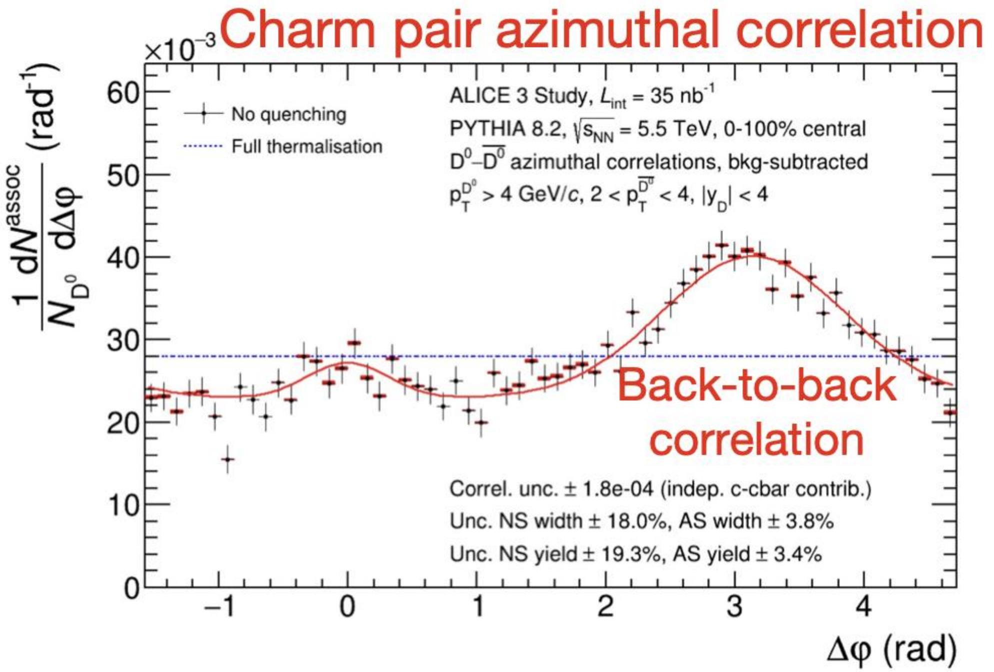
example: $D^+ \rightarrow K\pi\pi$, $D_s \rightarrow KKp$



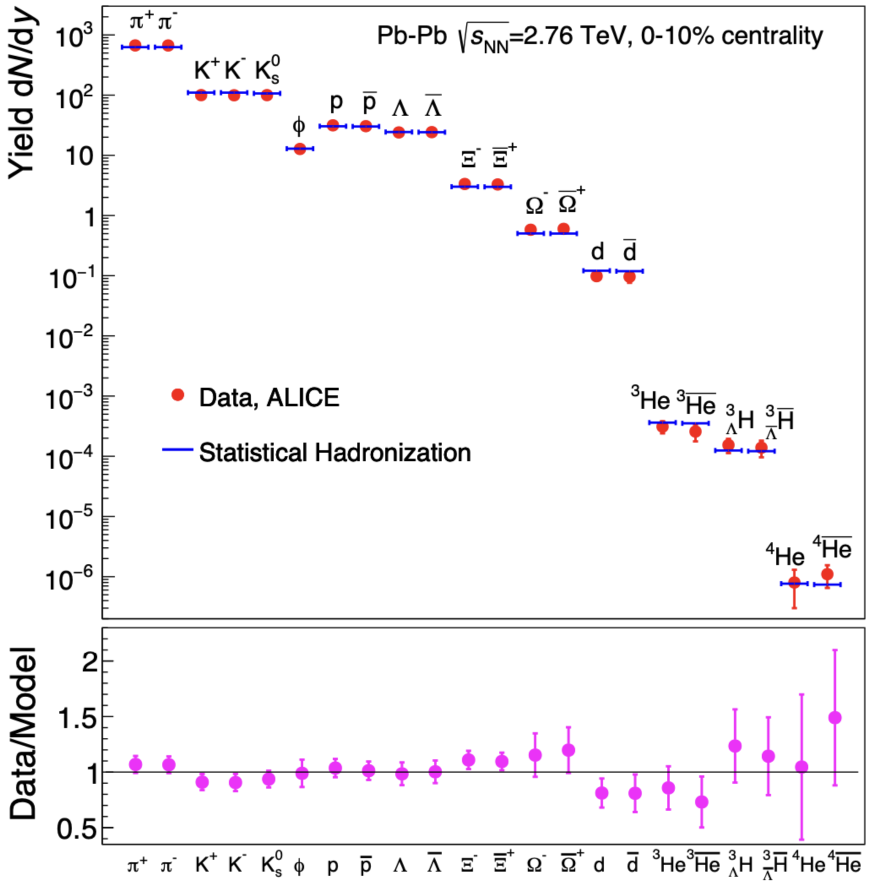
ALICE 3 LoI, CERN-LHCC-2022-009

ALICE Run 3 + 4 statistics

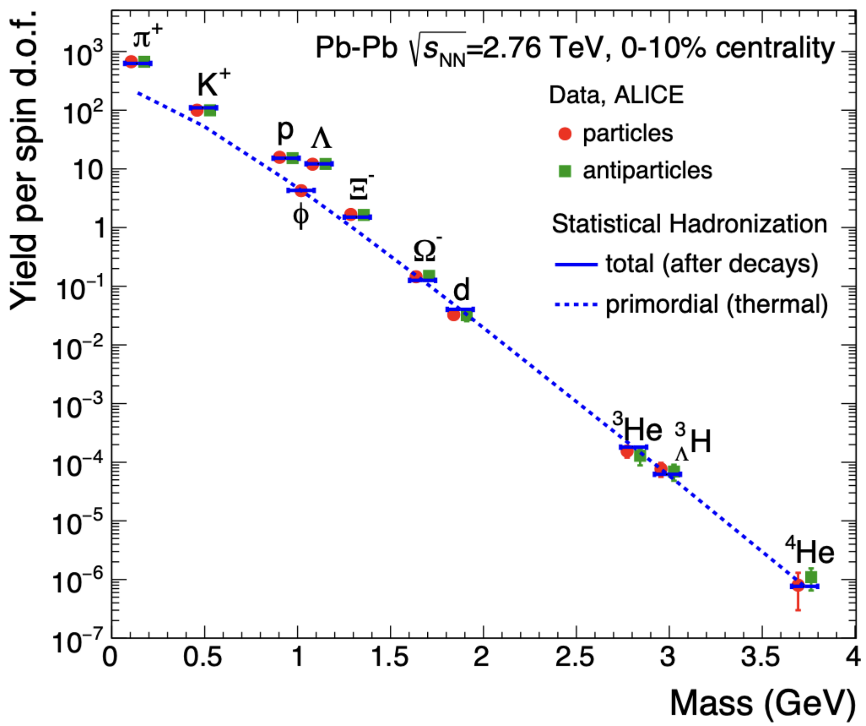




Thermal models – enhancement of heavy states:



A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Workshop proceedings, arXiv:2101.05747 [nucl-th]

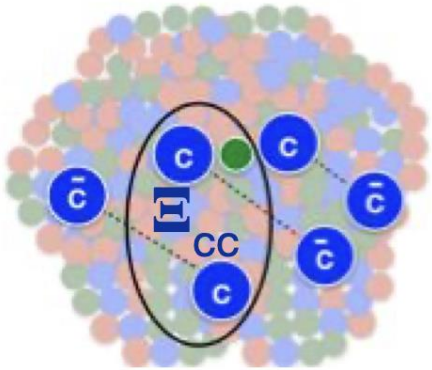


- Statistical hadronization model (SHM) describes observed yields well
- IF charm quarks are thermalized, SHM predicts very large enhancement of multiply charmed states compared to fragmentation based hadronization

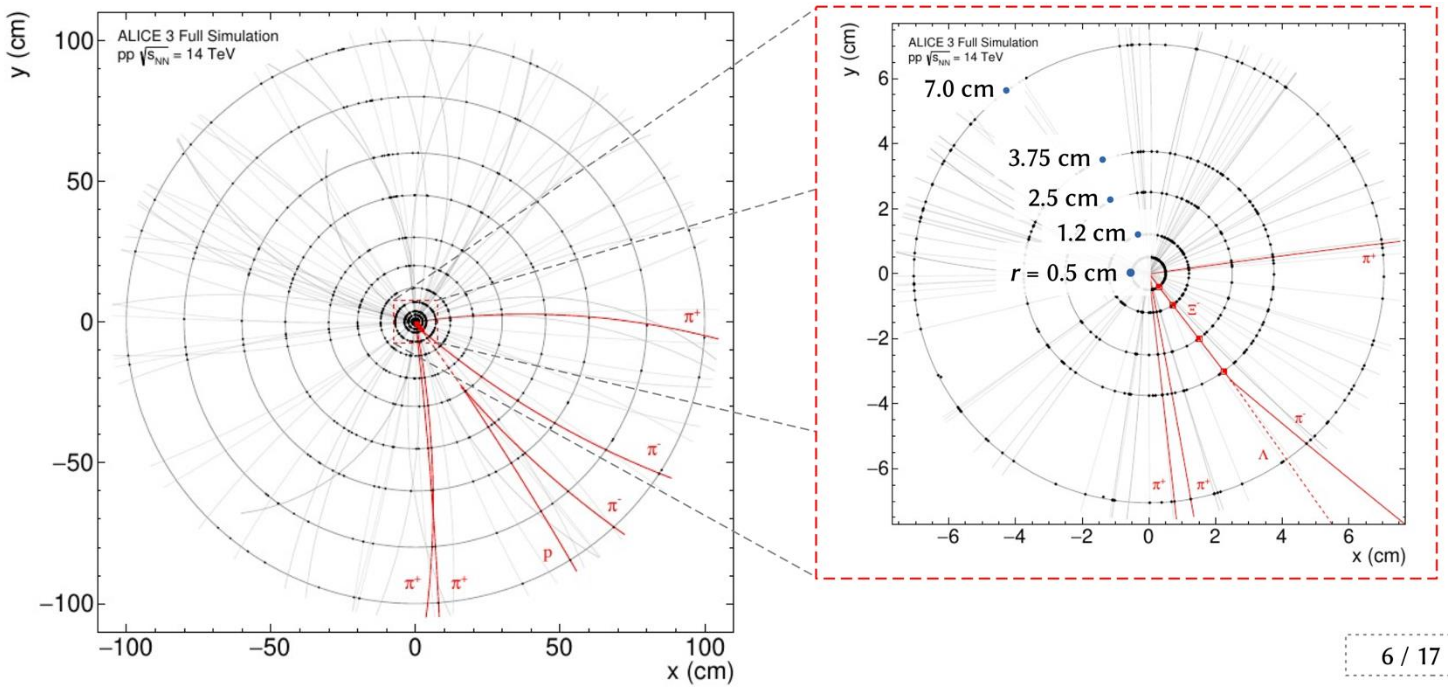
ALICE3 – studies on hadronization

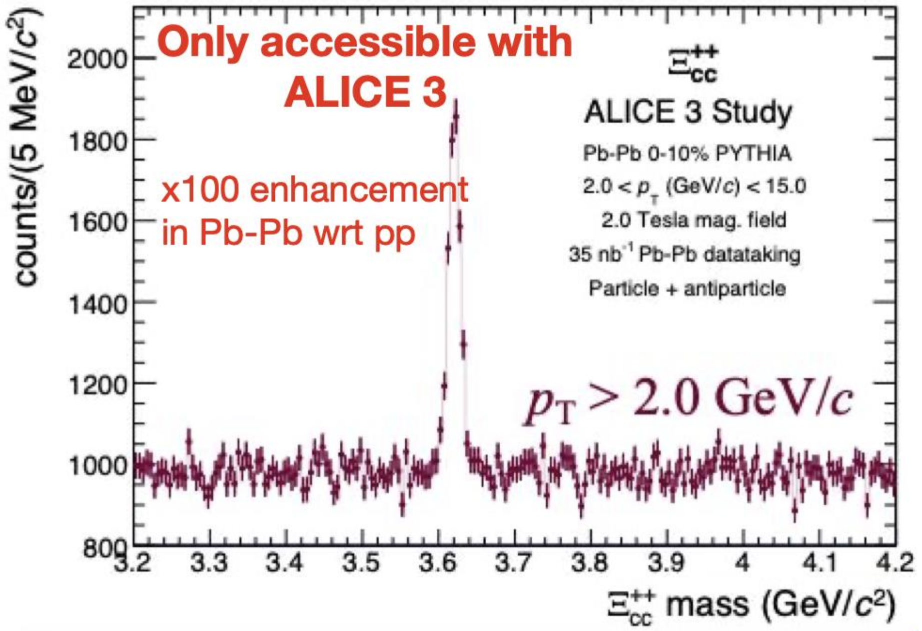
Thermal models predict very large enhancements for yields of the multi-charmed hadrons

→ **Gimmick: all above + "strangeness tracking"**

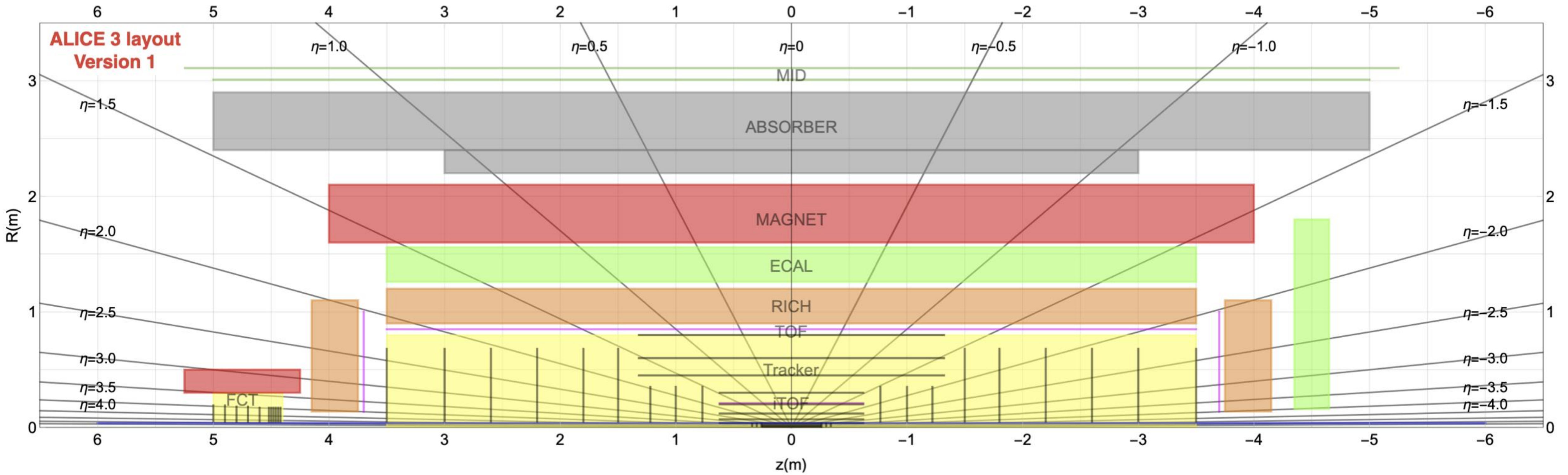


ALICE 3 LoI, CERN-LHCC-2022-00





ALICE3 – a reference detector that can do it all



- A large acceptance |η| < 4 and compact radius detector (length |*z*| < 5 m, *R* = 3 m)
- New superconducting 2 T magnet, vertex detector inside the beam pipe
- Particle identification = time of flight (TOF) + ring-imaging Cherenkov detector (RHIC)
  + electromagnetic calorimeter (ECAL) + muon identification (MID)
- Fast, silicon only technology, similar readout scheme as in ALICE2
  → pp collision rate 24 MHz (up to 50x more) and Pb-Pb rate ~100 kHz (x2 up)

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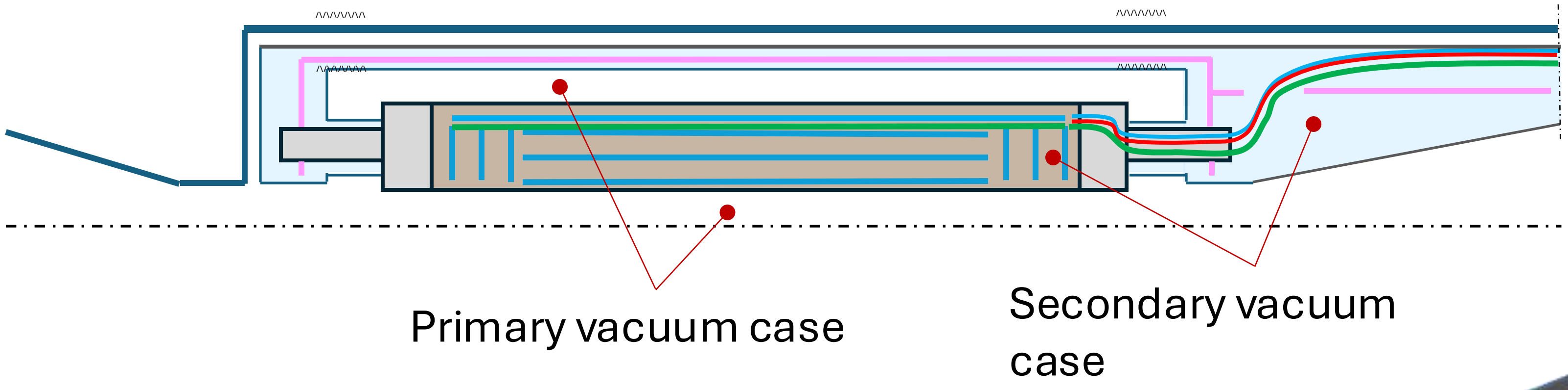
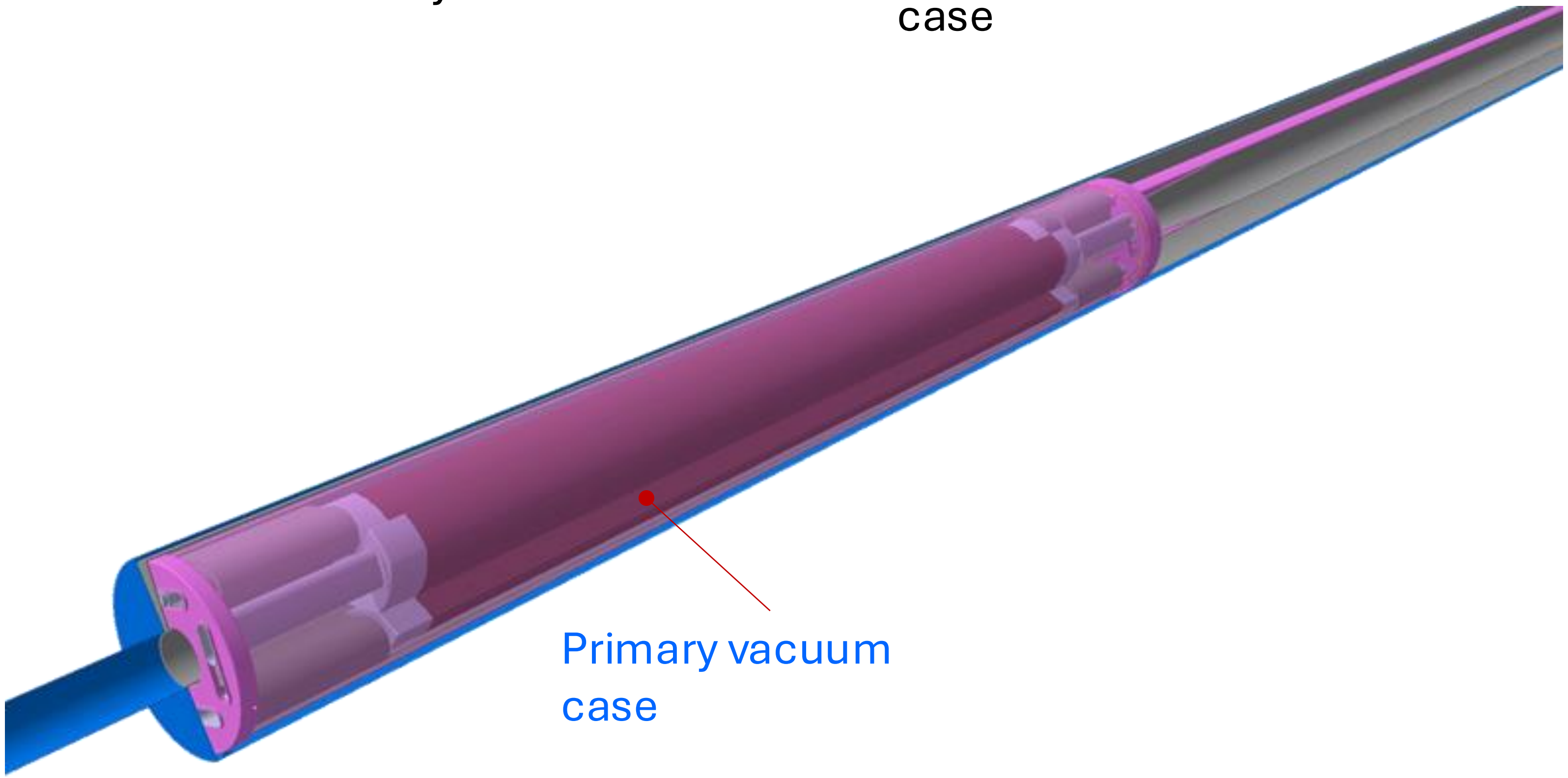
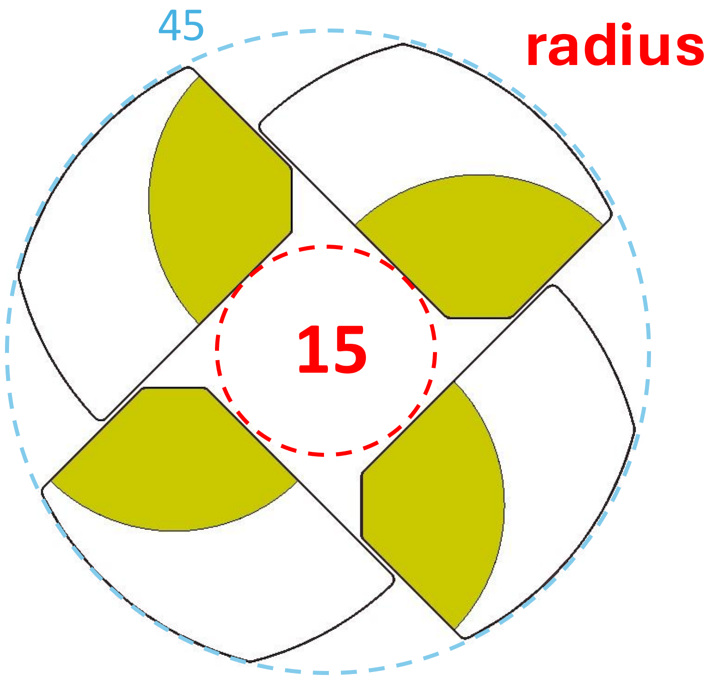
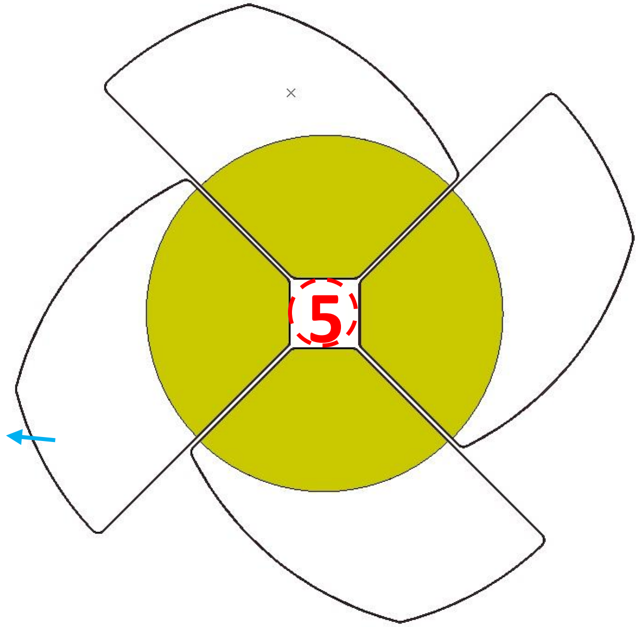
ALICE3 – retractable vertex detector

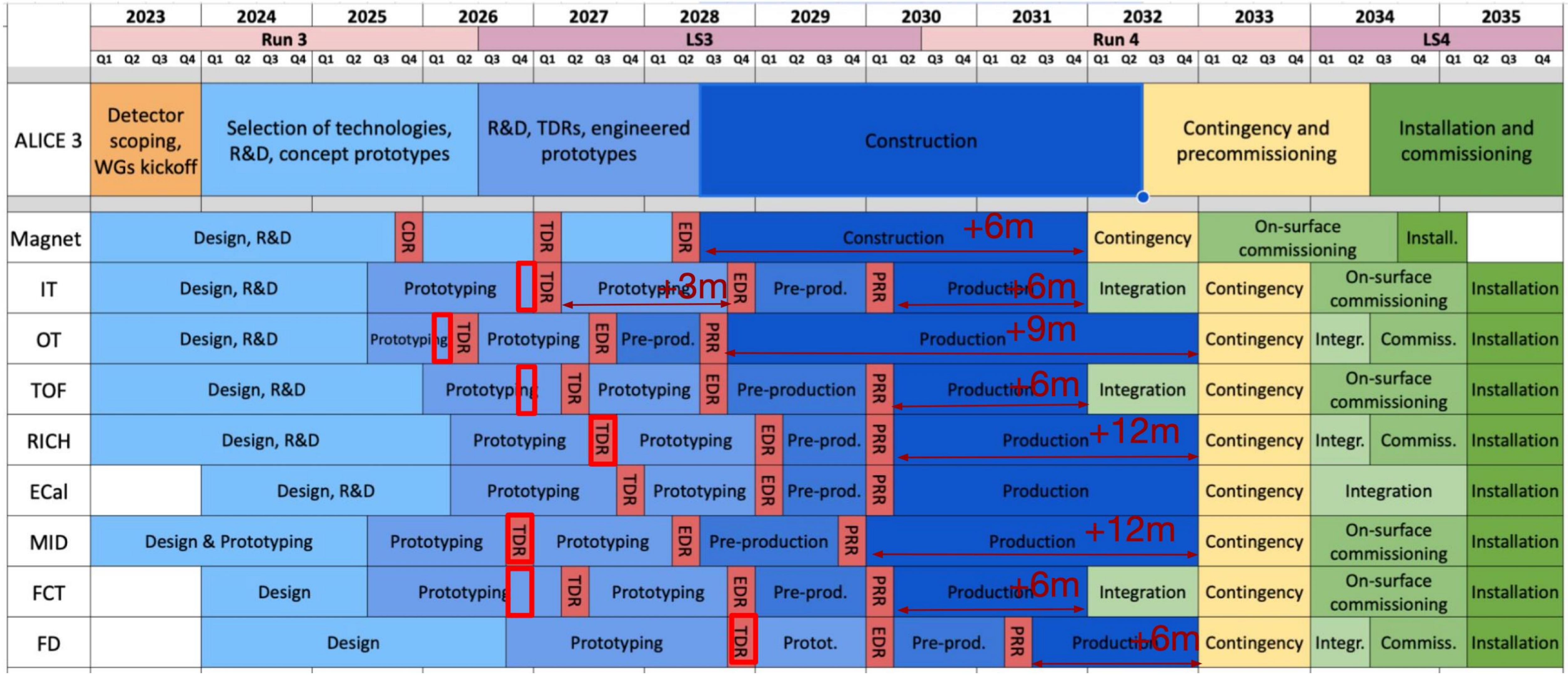








ALICE3 – current timetable of the projects

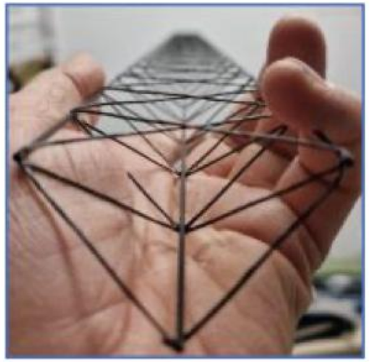


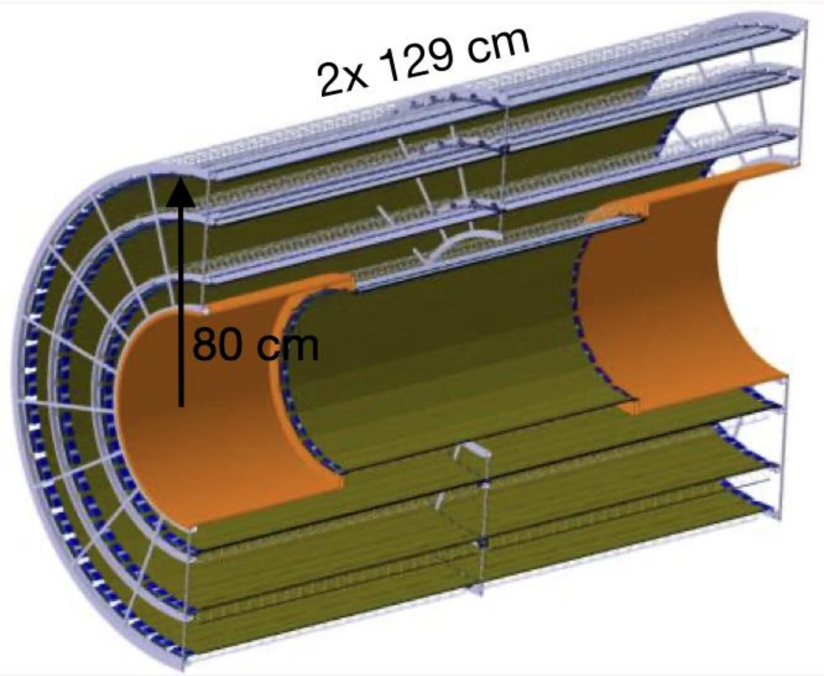
Finnish contribution to ALICE3

Outer Tracker of the new ALICE3 experiment:

- ALICE3 tracking will have total of 11 layers (12 for end caps), $|\eta| < 4$
  - vertex detector: 3 innermost layers inside the beam pipe
  - 4 middle layers
  - 4 outer tracking layers

- ALICE3 Outer Tracker (OT)
  - large area of ~50 m^2 : barrel 33 m^2 and disks 18 m^2
  - total of 10 000 OT modules, each containing 8 chips, and each chip 60 wire bonds → 4.8 M bonds
  - with an automated bonder, 3 s per wire → 4000 net hours
  - 5 hour curing time for the radiation hard glue (Araldite 2011)
    → several years, if modules manufactured one-by-one

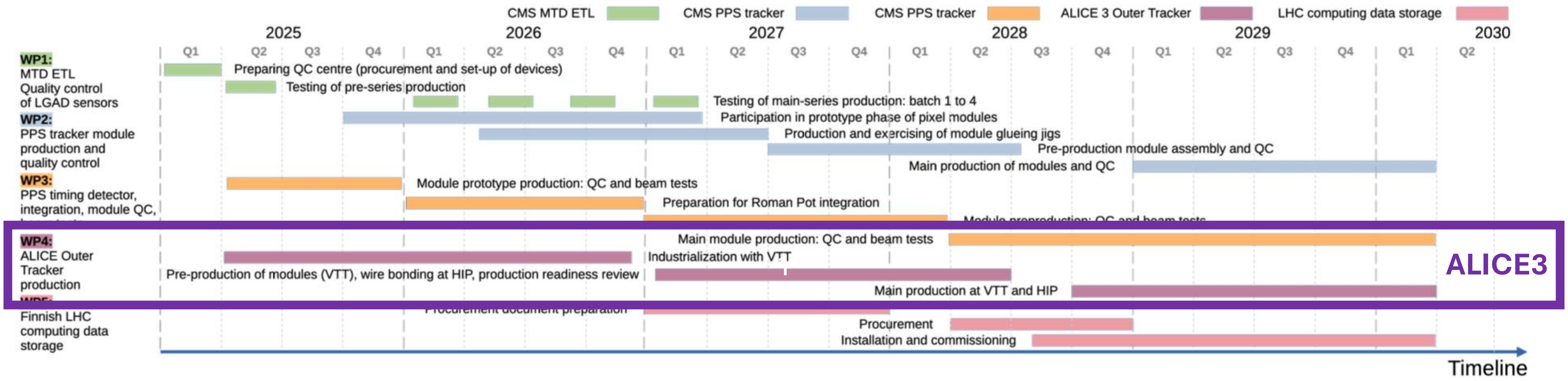




OT module production needs to be industrialized

- Plan: contribute to R&D of the OT module production

Finnish contribution to ALICE3 – where we are today?



- Joint CMS-ALICE proposal to select CERN to Roadmap for Finnish research infrastructures 2025
  → decision by end of January 2025
- For ALICE3, Roadmap application covers 2/3 of Finnish core contributions + our plans for the R&D
- Industrialization of the Outer Tracker module production:
  - Collaboration with VTT Technical Research Centre of Finland Ltd
  - VTT: mass production of module production using industrial pick-and-place robots
  - HIP lab: wire bonding of the tracker elements with our new automated bonder
  - Inside ALICE, also Korean group works with industrialization

Summary:

Will we see the next generation heavy ion experiment?

We shall find out in ~2026 – hopefully even earlier:

- first parts ordered soon! – not available later
- technical design reports (TDRs) 2026-2027
- engineering design runs (EDRs) 2027-2028
- production readiness reviews (PPRs):

  Outer tracker 2028

  Majority of other systems 2029-2030

  Forward disks 2031

ALICE3 – what would it cost?

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	18.0
	Hybrid LGADs	+13.4
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		148.2
Common items	Beampipe, infrastructure, services	+11.1
	TC design and engineering	+10.9
FCT	MAPS, dedicated dipole magnet	+3.45

Default version:

- Detector 149 MCHF
- Common items +22 MCHF

Total > 170 MCHF

(core only)

+14 MCHF, if future R&D is not successful and fallback needed.

+3.5 MCHF, if Forward conversion tracker (FCT) included

+ (???) MCHF, if FoCal included

Total of 6 running years.

→ **no major exp. comes cheap!**

ALICE3 – descoping of the experiment

Standard procedure: prepare scenarios that are 10-30% cheaper to the LHCC.
LHCC review gives recommendations to funding agencies.

ALICE3 scoping document – public part in this link.

Version	Cost (MCHF)	Difference to v1
Reference detector layout v1	148.2	
Without ECal	−18.1	−12%
Smaller radius of magnet	−6.3	
Smaller radius of absorber and MID	−0.4	
Detector layout v2-2T	123.4	−17%
Magnetic field of 1 T	−5.1	
Detector layout v2-1T	118.3	−20%
Without TOF and RICH disks	−3.0 −4.3	
OT disk surface reduction	−5.0	
IT disk surface reduction	−2.0	
Shorter magnet (1 T)	−3.0	
Detector layout v3-a	101.0	−32%
Smaller RICH acceptance	−6.5	
Detector layout v3-b	94.5	−36%
Common items	+22.0	
Additional cost with FCT	+3.45	

Reduce performance, save money:

- Letter of Intent version, 149 MCHF
- No electromagnetic calorimeter, 124 MCHF
- Previous, and lower B-field, 119 MCHF
- Even smaller B and reduce $|\eta|$, 95 MCHF
- In all scenarios, +22 MCHF common items

Save money 12-36% with more and more painful reductions on performance.

(No time to discuss details today.)

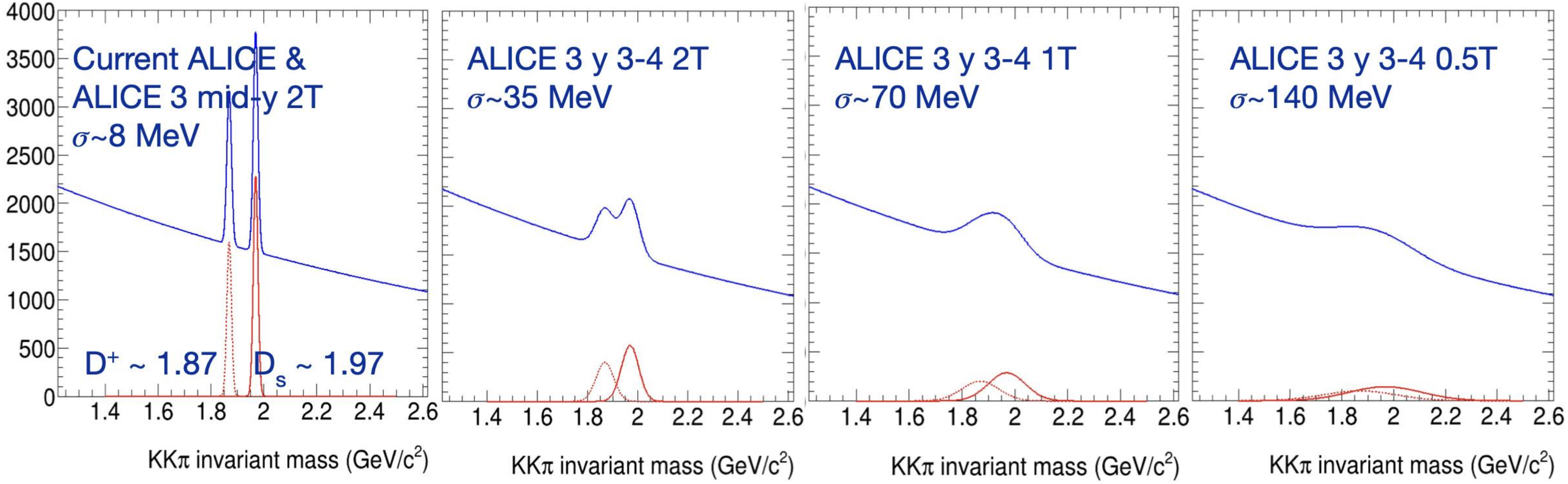
ALICE3 – descoping of the experiment

LHC experiments committee

<u>Standard procedure</u>: prepare scenarios that are 10-30% cheaper to the LHCC.
LHCC review gives recommendations to funding agencies.

ALICE3 scoping document – public part in this link.

Example: what if we save money by building a weaker magnet?



Mid rapidity, large field

Forward rapidity, reduce field from B = 2 T down to 0.5 T

ALICE3 – what does weaker field mean for the PID?

B=2T
3 sigma separation
coverage: p_T vs η

B=1T
3 sigma separation
coverage: p_T vs η

B=0.5T
2.5 sigma separation
coverage: p_T vs η