ÖAW AUSTRIAN ACADEMY OF SCIENCES

MARIETTA BLAU INSTITUTE FOR PARTICLE PHYSICS

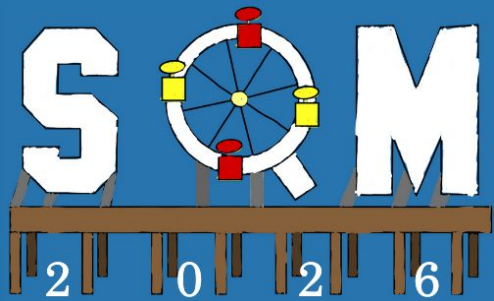
TU WIEN

ALICE

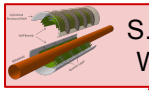
ALICE 3: a next-generation heavy-ion experiment

Jesper Karlsson Gumprecht, Austrian Academy of Sciences
On behalf of the ALICE Collaboration

The 22nd International Conference on
Strangeness in Quark Matter
22-27 March, 2026, Los Angeles, CA

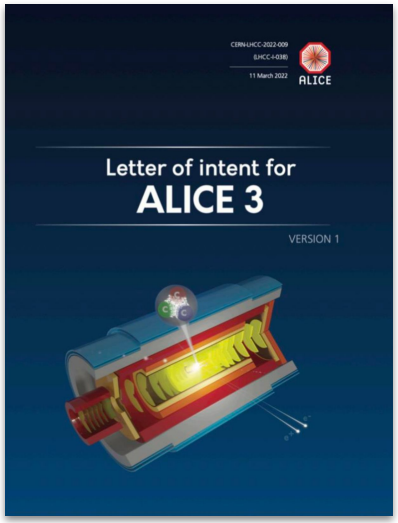


ALICE upgrade overview



S. Siddhanta
Wed., 10:55

LOI: CERN-LHCC-2022-003



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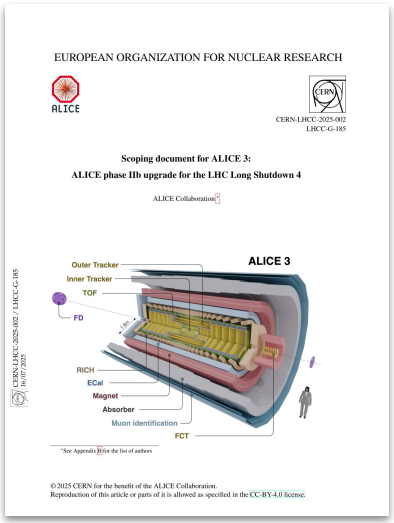
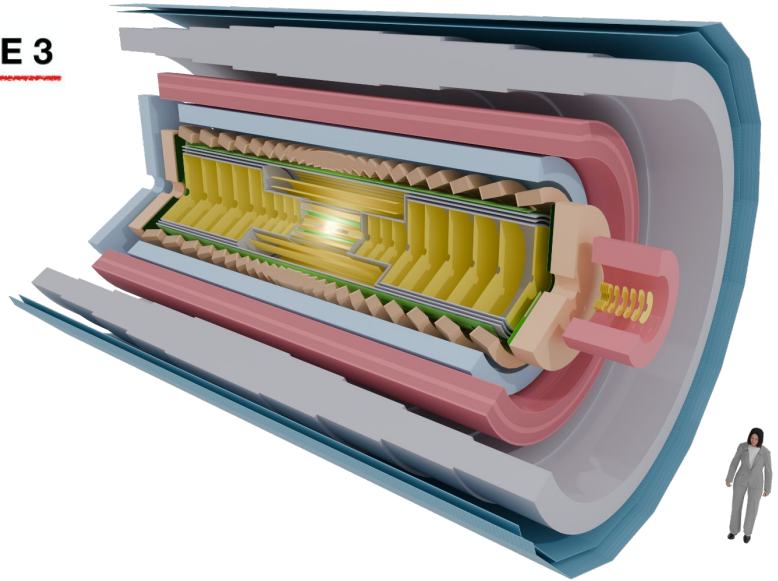


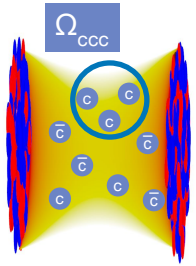
ALICE 3



Heavy-Ion physics at the LHC beyond Run 4

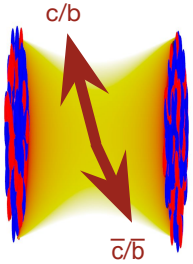
Systematic measurements of (multi-)heavy-flavoured hadrons

- Propagation and hadronisation mechanisms in the QGP
- Study heavy quark equilibrium and diffusion



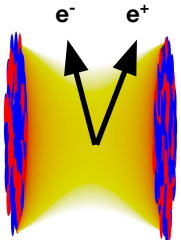
Hadron correlations and fluctuations

- Hadron-hadron interaction potentials
- Net-baryon and net-charm fluctuations



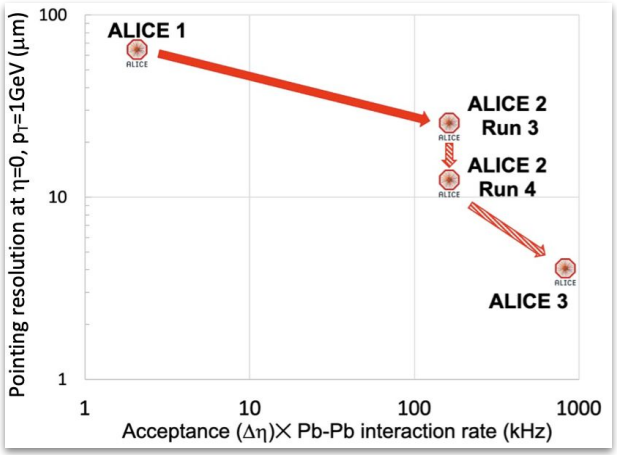
Precise measurements of dileptons

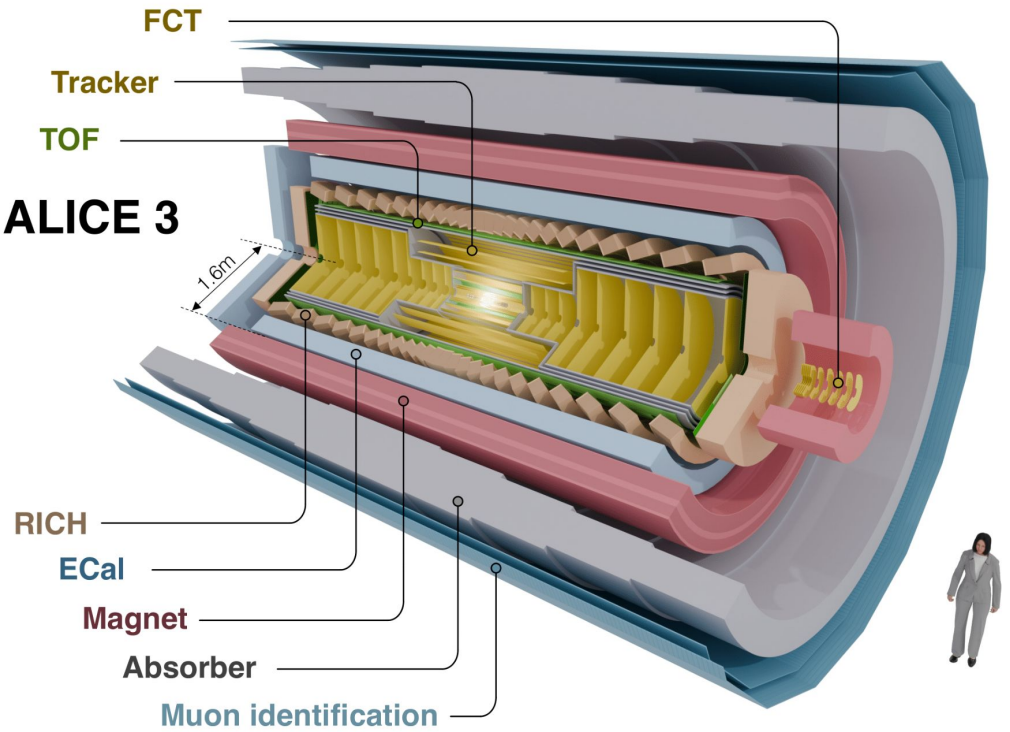
- Evolution of the quark–gluon plasma temperature
- Mechanisms of chiral symmetry restoration in the QGP



ALICE 3 detector concept

- Compact all-silicon tracker with a high-resolution retractable vertex detector
- Large acceptance and extensive particle identification
- Superconducting 2T solenoid
- Continuous readout and online processing





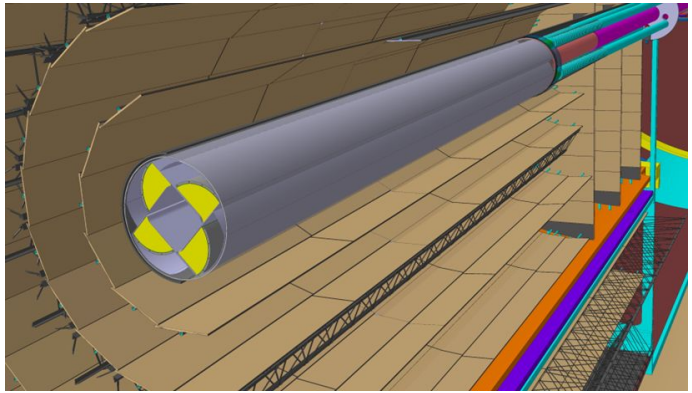
Tracking: Inner tracker

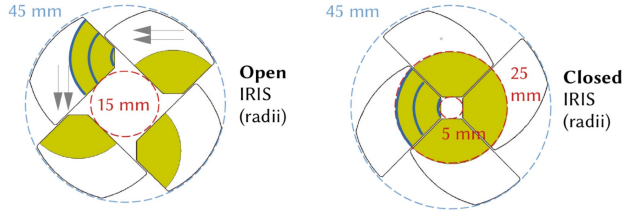
Retractable vertex detector

- Three layers within the beam pipe in secondary vacuum
- Strongly relying on **I**nner **T**racking **S**ystem 3 R&D
  - → Sensor design
  - → Stitching
  - → Wafer-scale bent sensor
- IRIS service system being developed
- Resolution: 10 µm pixel pitch → σ_{pos} ~ 2.5 µm
- Material: ~0.1% X/X_0 per layer

Middle layers

- Four layers at 7 − 20 cm and six end cap disks
- Baseline requirement: ~1% X/X_0 per layer
  - — Possible lighter option currently being studied with lighter setup → ~0.5% X/X_0
- Benefits on tracking of soft electrons and charged hyperons (e.g. Ξ, Ω)





IRIS engineering model

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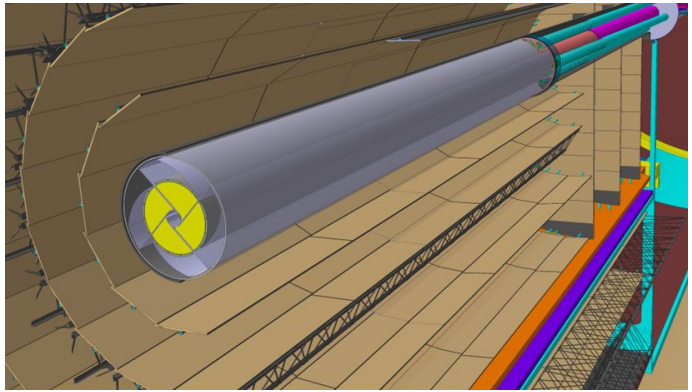

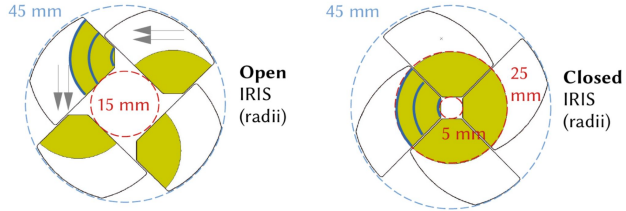

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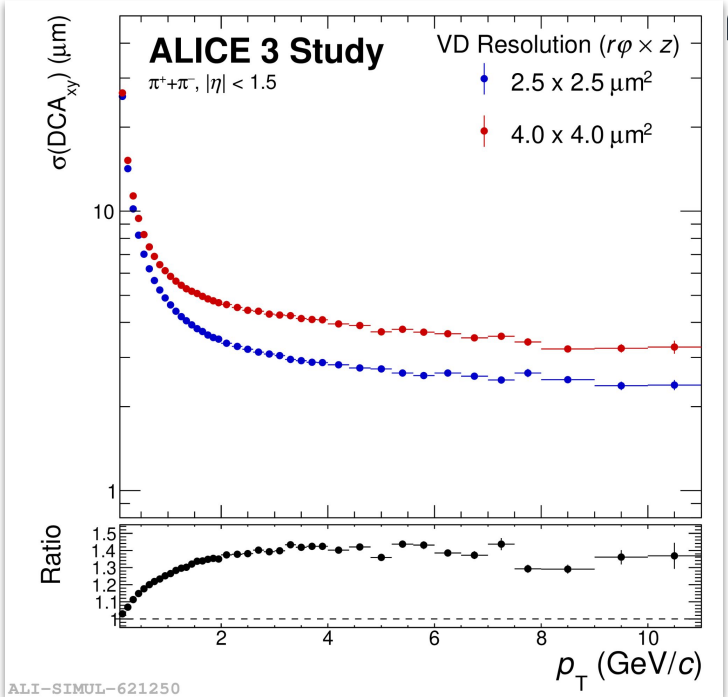
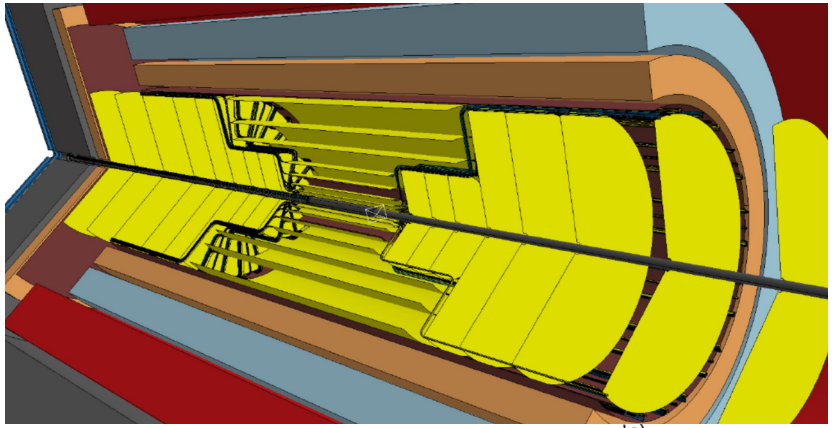
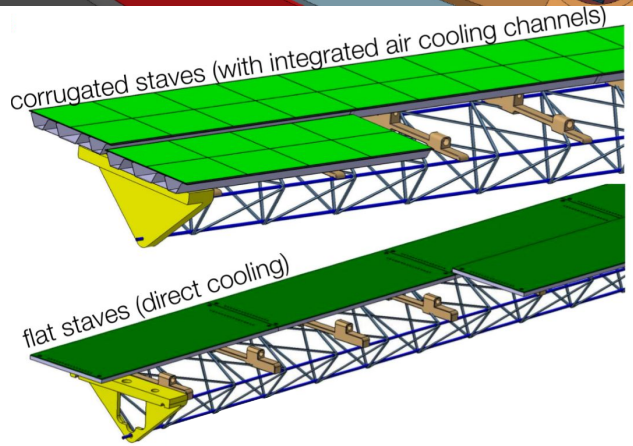


Tracking: Outer tracker

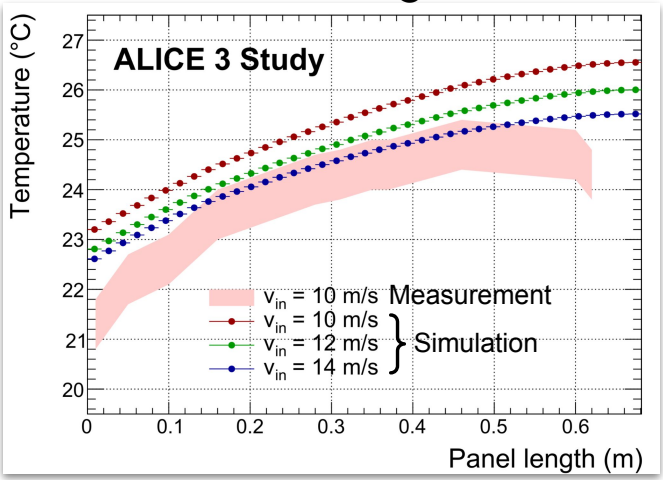


OT barrel design

- Stave mechanics leveraging ITS2 carbon space frames
- 60 m^2 active detection area
- Resolution: σ_{pos} ~ 10 µm, pixel pitch < 50 µm
- Material: ~1% X/X_0 per layer
- Low power density ~ 20 mW/cm^2
- Cooling options under study



Corrugated frame



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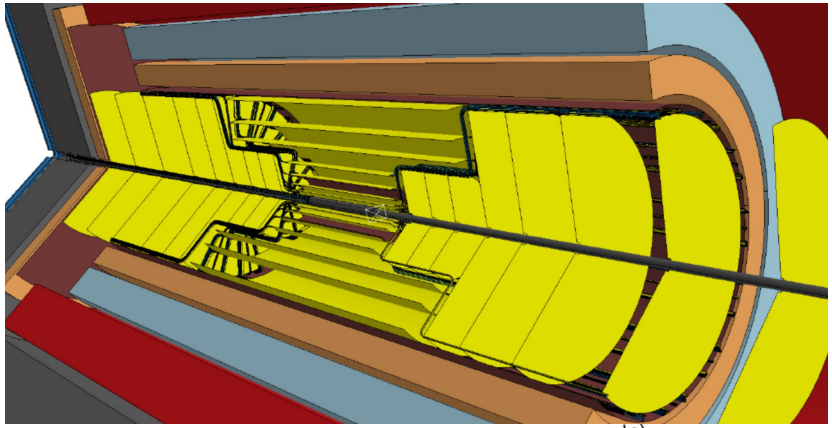

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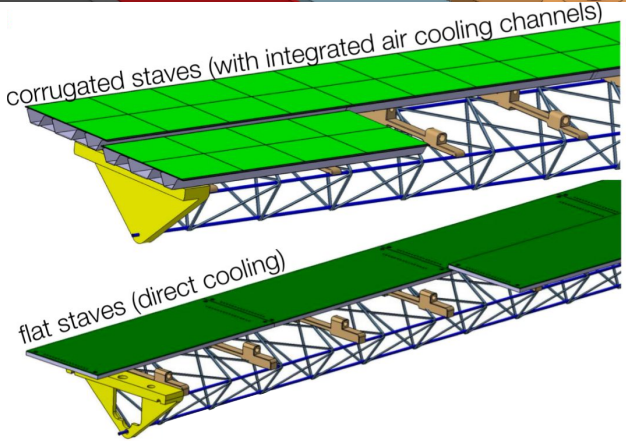
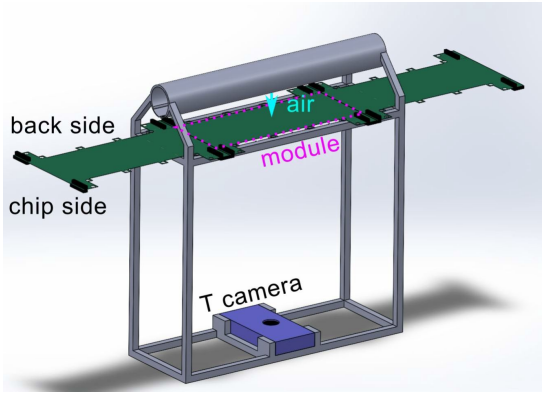
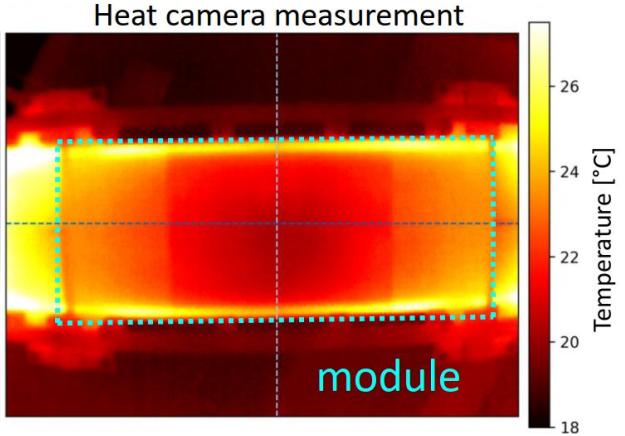
Direct cooling

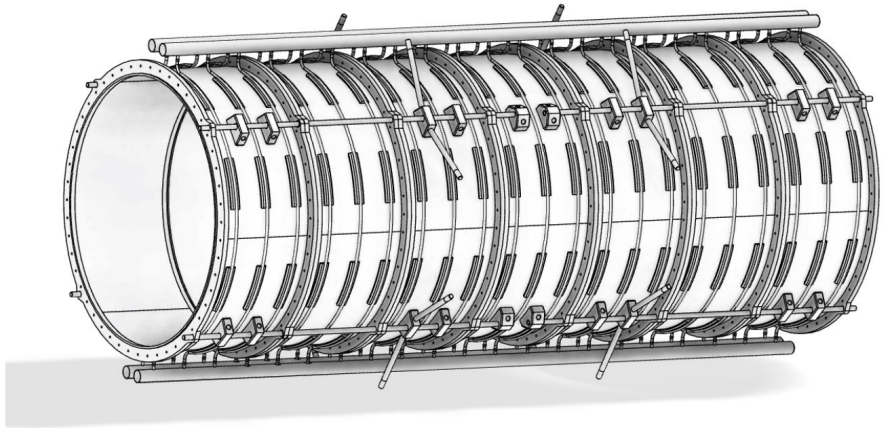




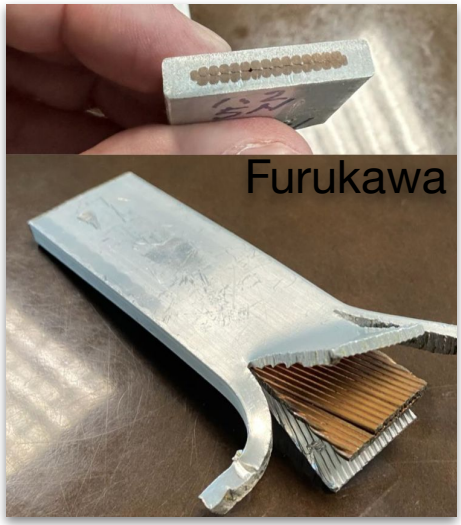


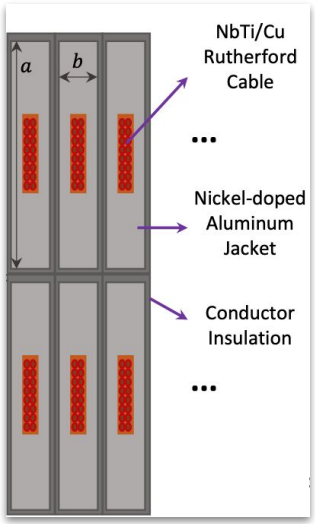
Superconducting 2T solenoid

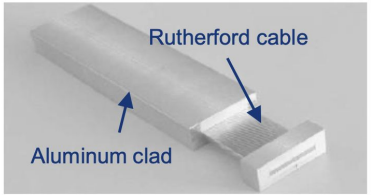
- Long superconducting solenoid (~7 m, with R_{in} 1.4m)
- Al-cladded Nb-Ti Rutherford cable (similar design as the existing detector solenoids)
  → Possible alternative: Cu-cladded
- Project pursued by Brazilian Centre for Research in Energy and Materials (CNPEM)



From 5 to 7 modules of 1071,5mm







Aluminum co-extruded cable

EMuS conductor sample

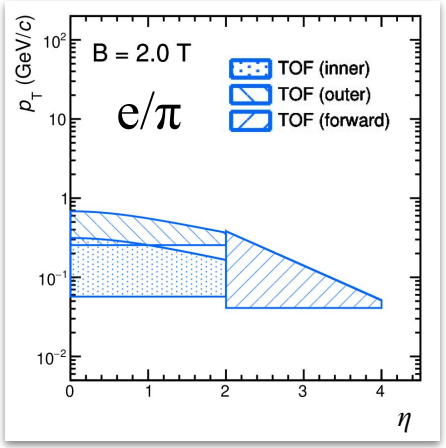
Particle identification: Time of flight

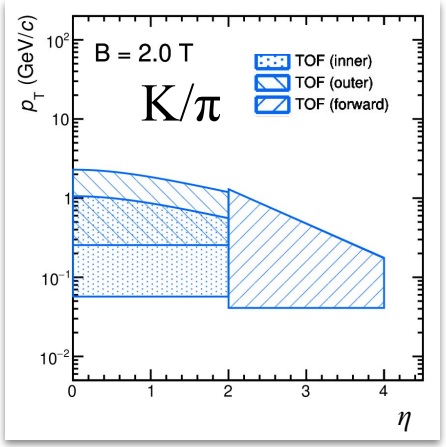
Requirements for particle identification

- Separation for e/π, π/K, and K/p at low p_T (up to 0.5, 2, and 4 GeV/c)
- σ_{TOF} ~ 20 ps

Sensor options

- CMOS–LGAD (baseline)
- **L**ow **G**ain **A**valanche **D**iodes
- **Si**licon **P**hoto**M**ultipliers





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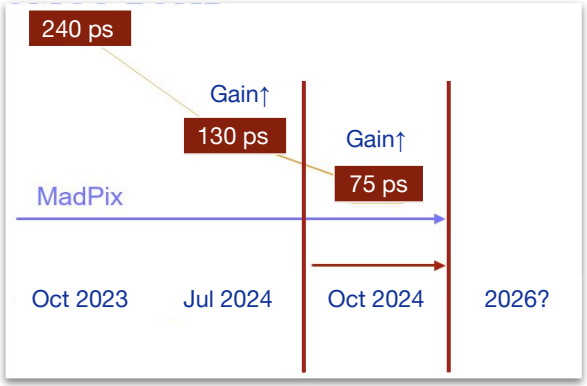
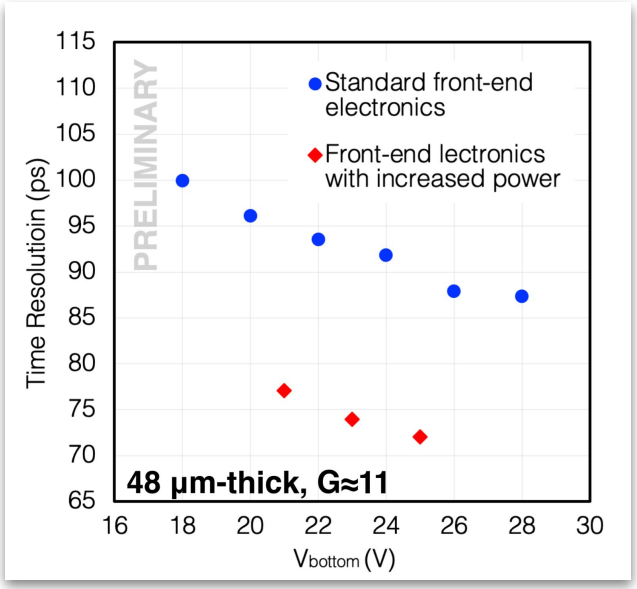
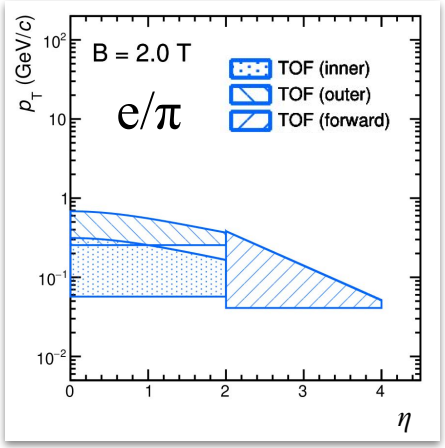
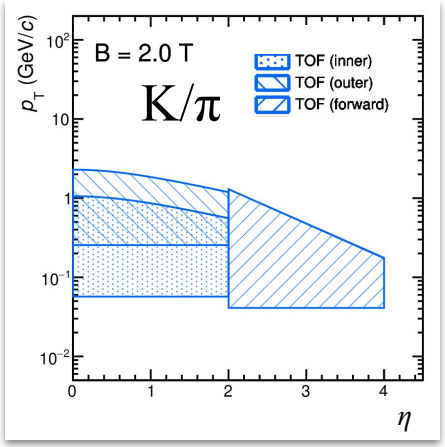


CMOS–LGAD







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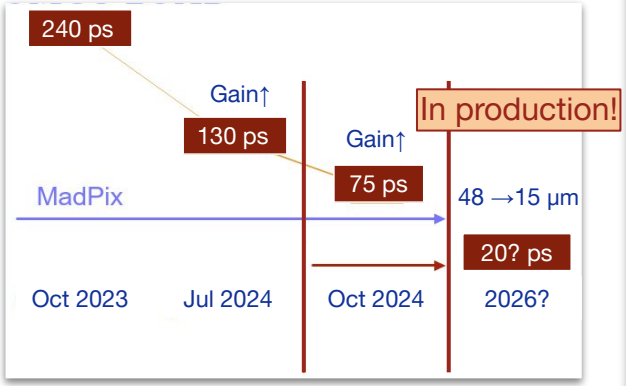
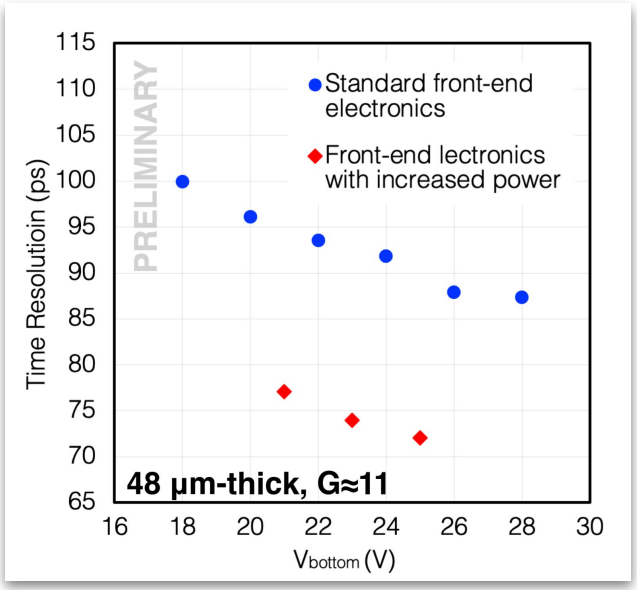
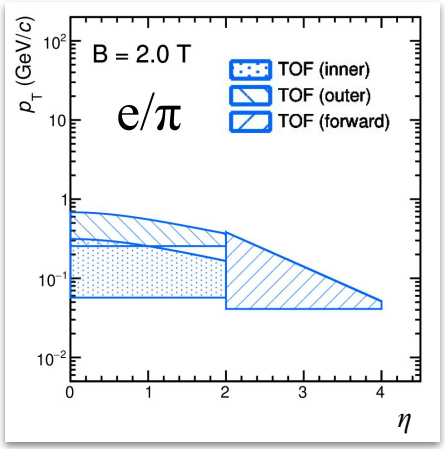
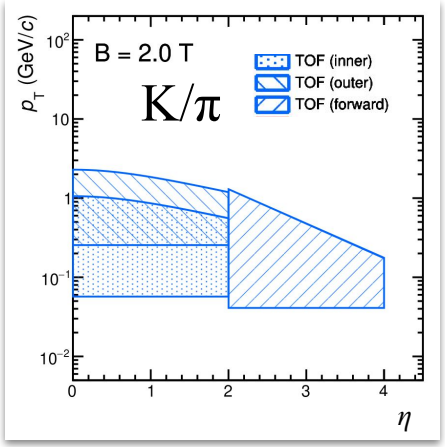








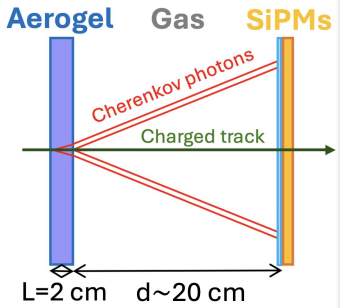
Particle identification: Cherenkov light

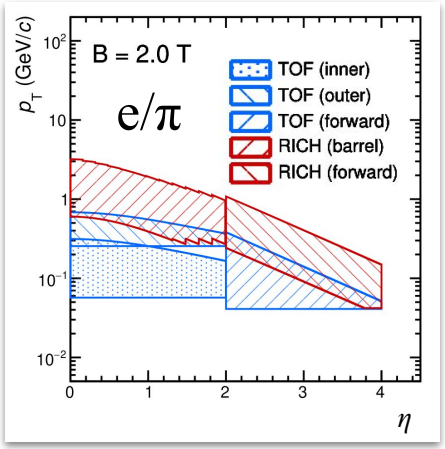
Requirements for particle identification

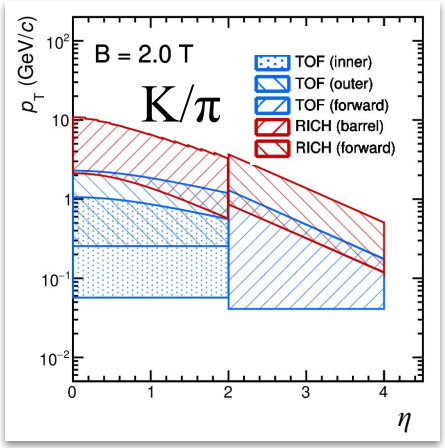
- Complement TOF PID for e/π, π/K, and K/p separation for higher p_T (up to 2, 10, and 16 GeV/c)
- σ_{RICH} ~ 1.5 mrad at saturation

Detector concept: Ring–imaging Cherenkov detector

- Aerogel with refractive index n = 1.03
- Detection area ~30 m^2 of SiPMs







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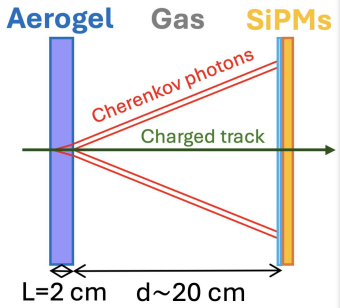

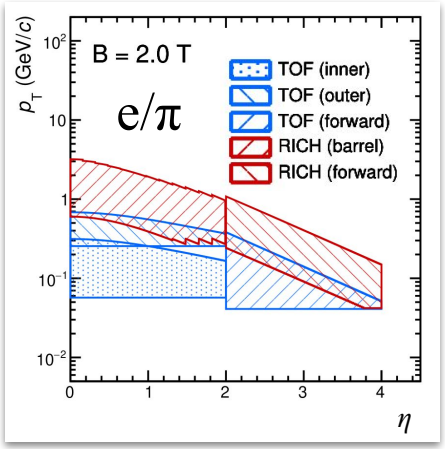

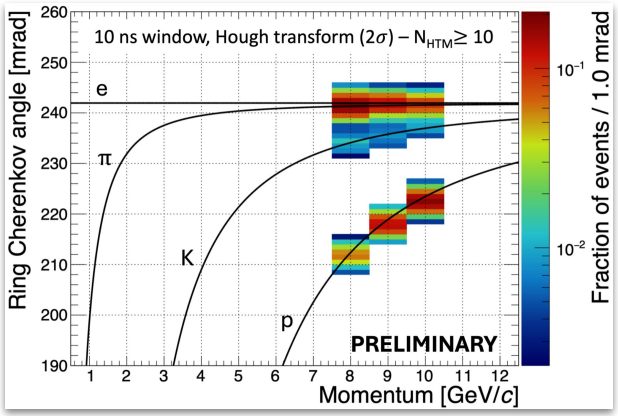

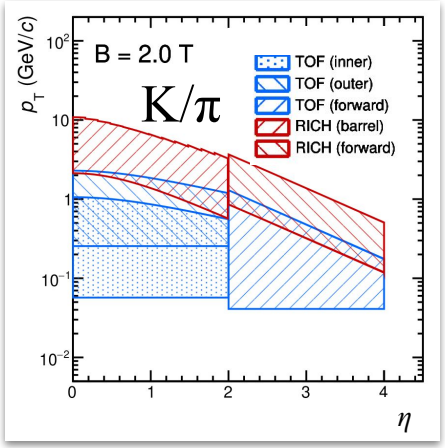

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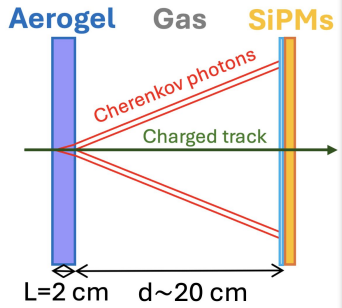
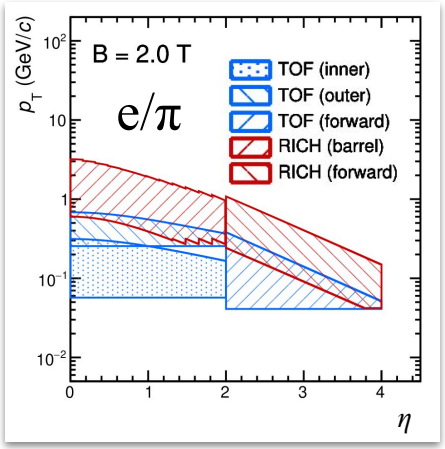
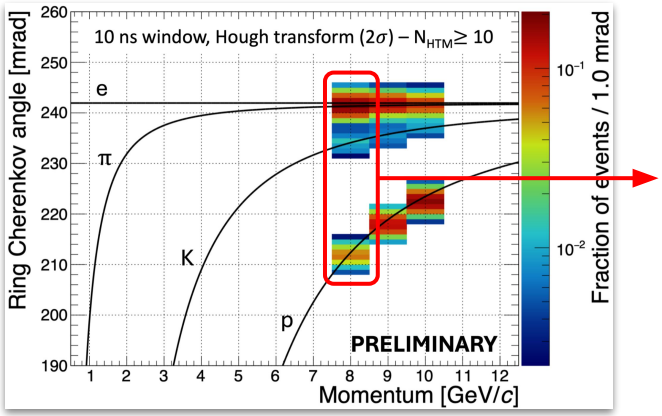
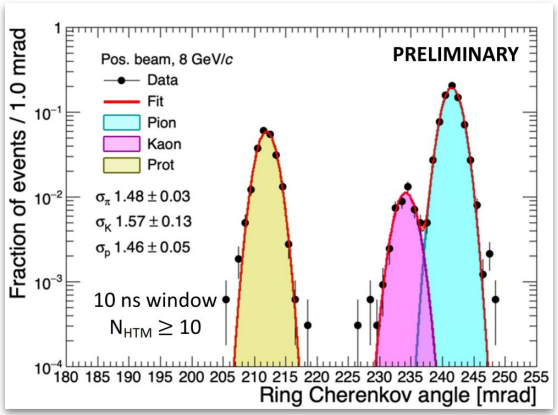
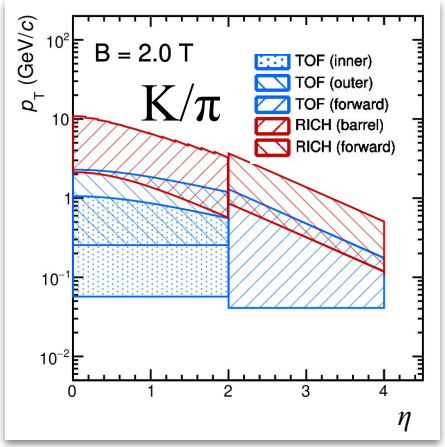






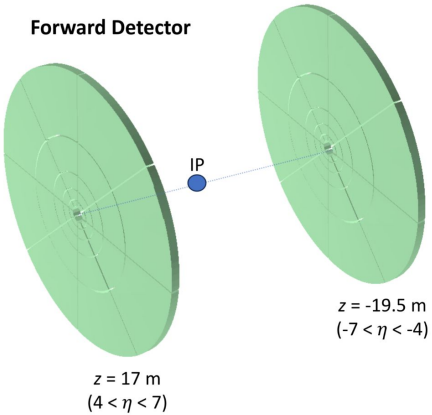


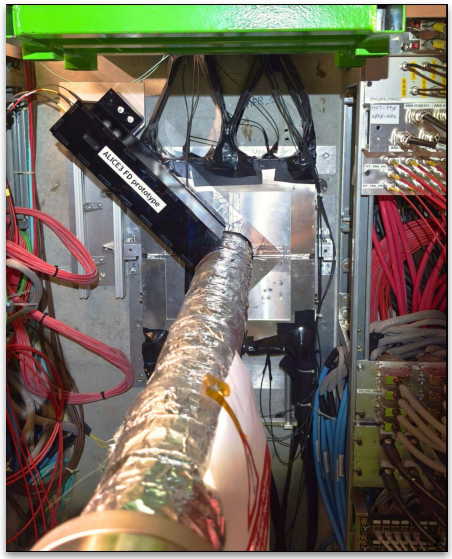


Event characterisation and muon identification

Forward detector (FD):

- Luminometer and interaction trigger
- Vertex position and collision time
- Forward multiplicity and centrality
- FD prototype (one channel) already installed at LHC for testing





Muon identifier (MID):

- Muon identification down to p_T ~ 1.5 GeV/c
- Strong pion rejection (> 96 %) for $|\eta| < 1.25$
- Plastic scintillators + SiPM
- Scintillator chamber installed in the ALICE cavern on top of the L3 magnet

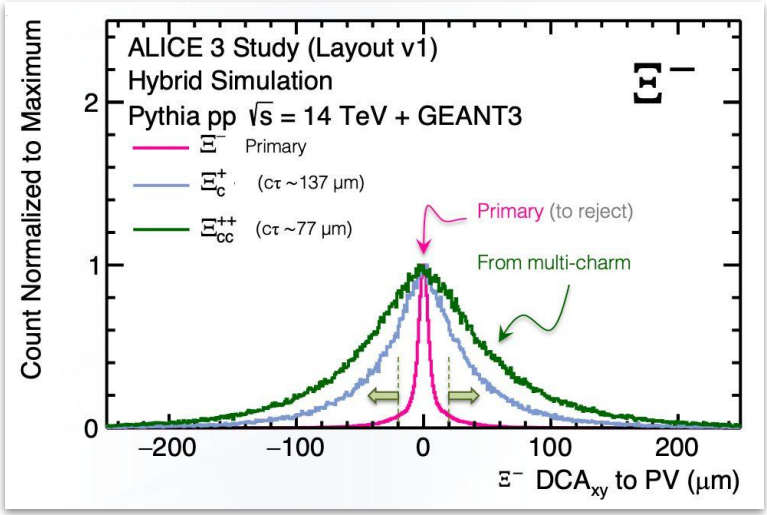
Unique access to multi-charm hadrons

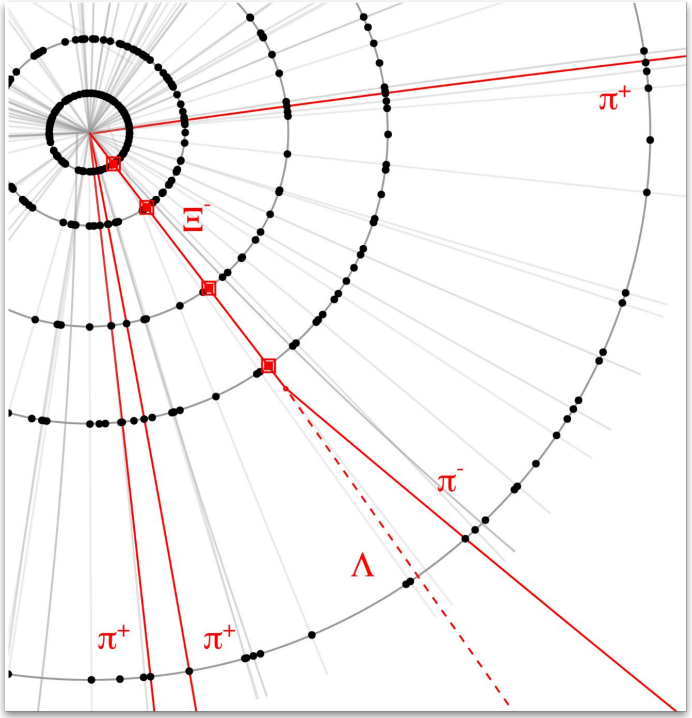
Direct detection of weakly decaying particles

- Charged hyperons can leave hits in tracking layers before decay
- Match corresponding hits to topologically reconstructed candidate to greatly improve precision

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

$$\Xi^- \rightarrow \Lambda + \pi^- \rightarrow p + 2\pi^-$$





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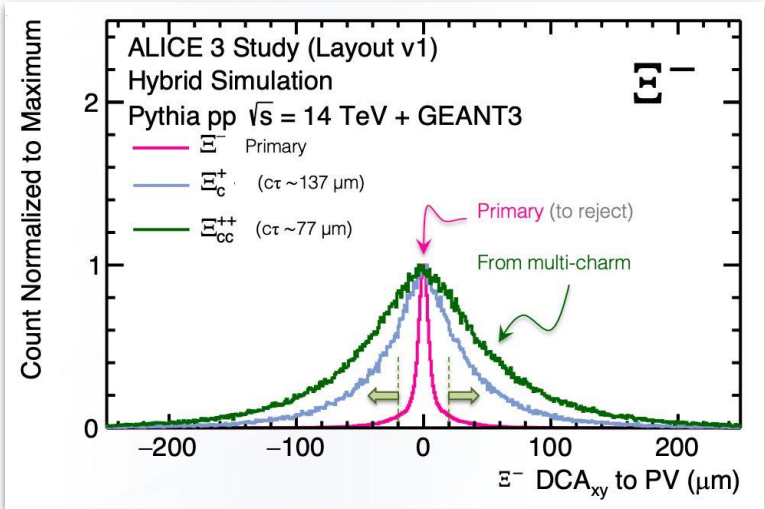
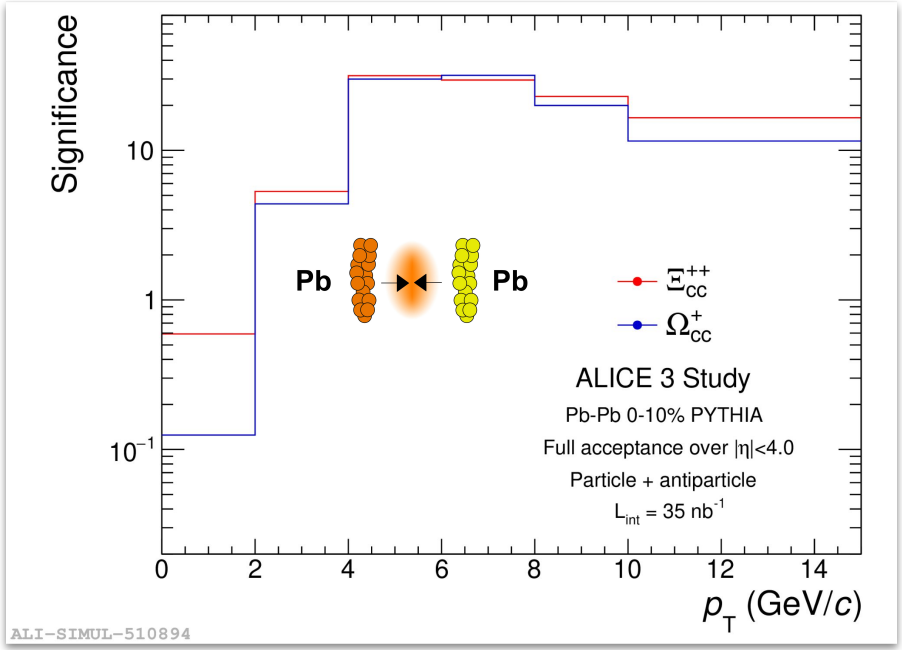
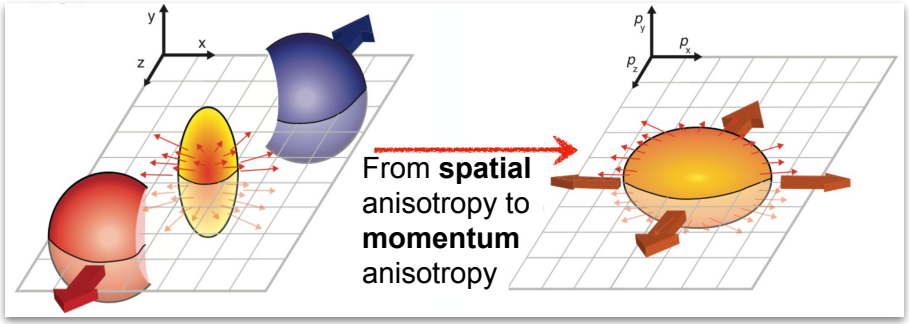
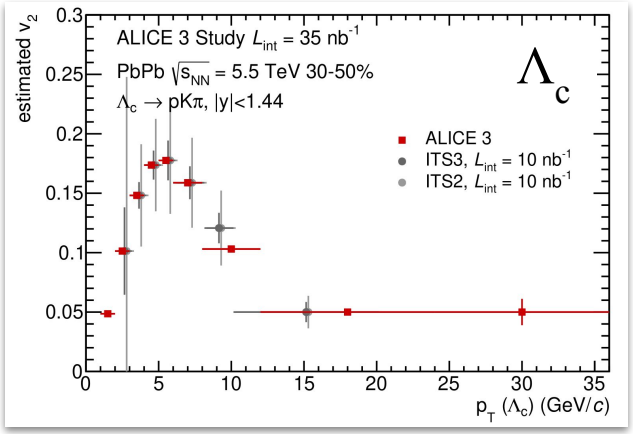
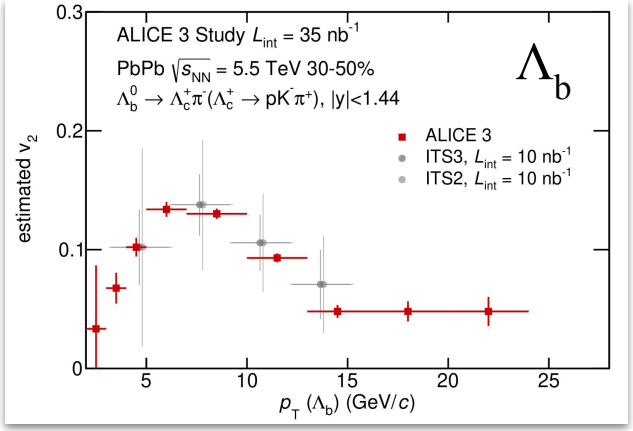




Flow of heavy quarks



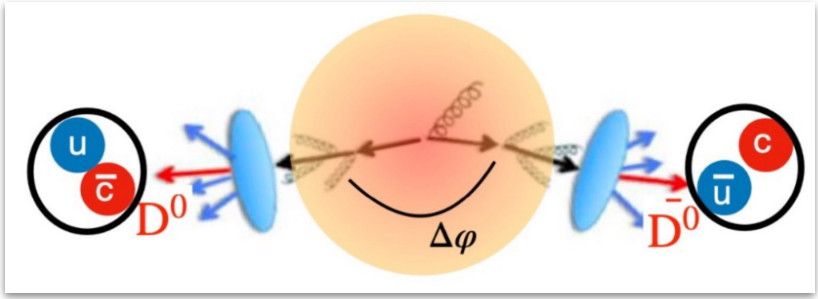


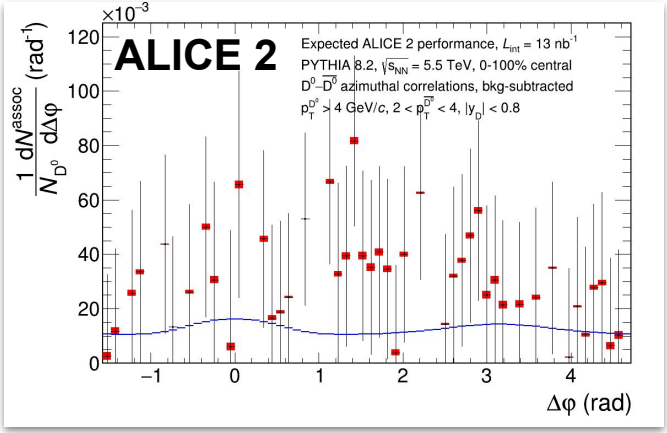


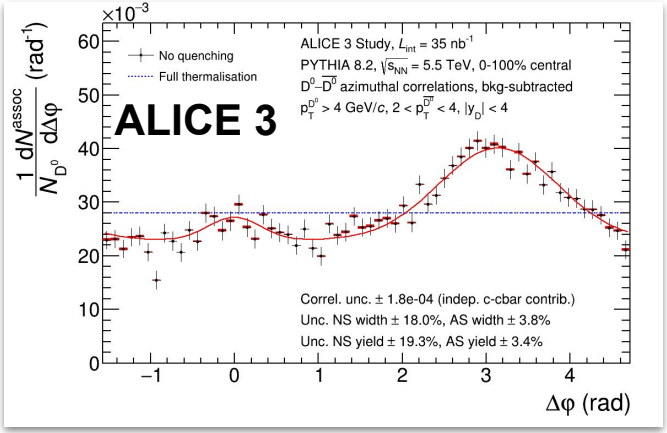
Access to heavy quark transport properties in the QGP

- Precise R_{AA} and v_2 measurements of charm and beauty
  → Constrain diffusion coefficients D_s
- Assess charm and beauty degree of thermalisation

Heavy quark correlations



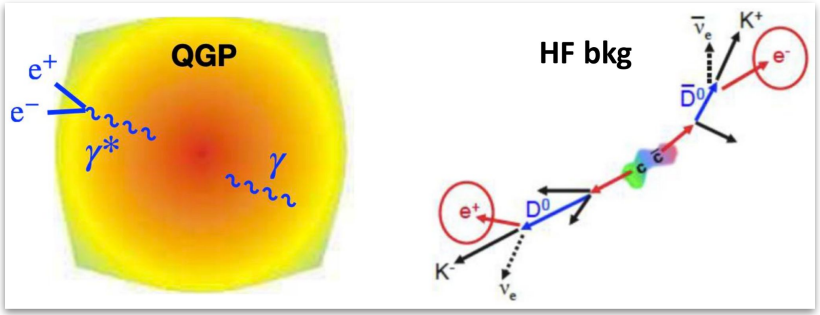




Angular decorrelation of heavy-flavour hadrons

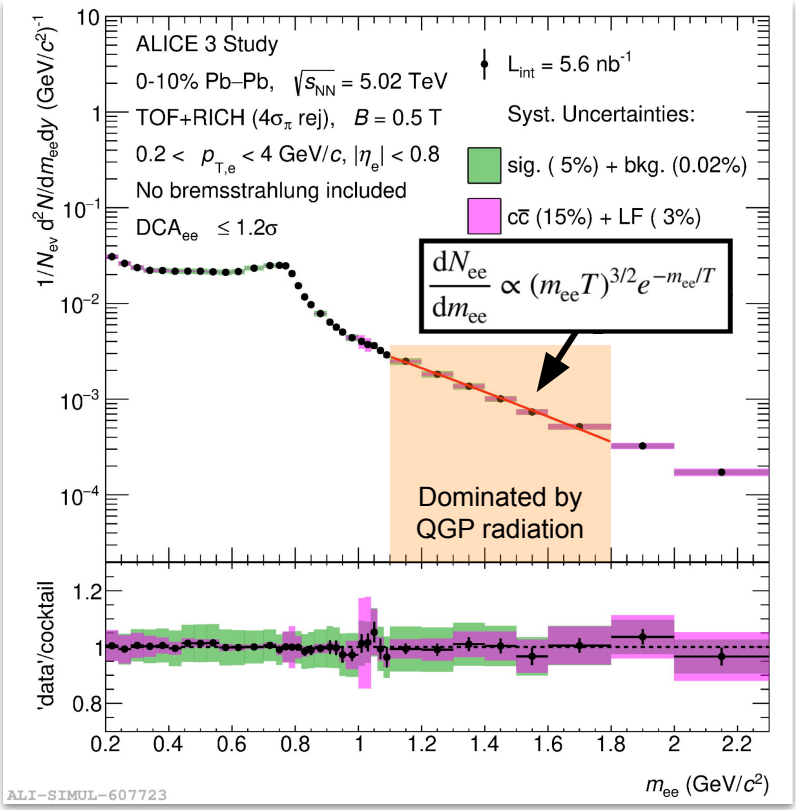
- Sensitive to energy loss and degree of thermalisation
- Requires high purity, efficiency and large η coverage
- Strongest signal at low p_T

QGP temperature and time evolution with dileptons

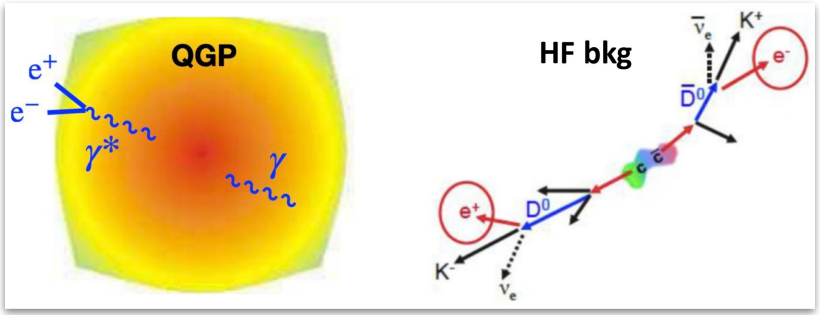


Accessing the QGP temperature

- Excellent pointing resolution for HF rejection
- Exceptionally low material budget
  → Little background from γ-conversion
- Very good electron identification down to low p_T



QGP temperature and time evolution with dileptons



Accessing the QGP temperature

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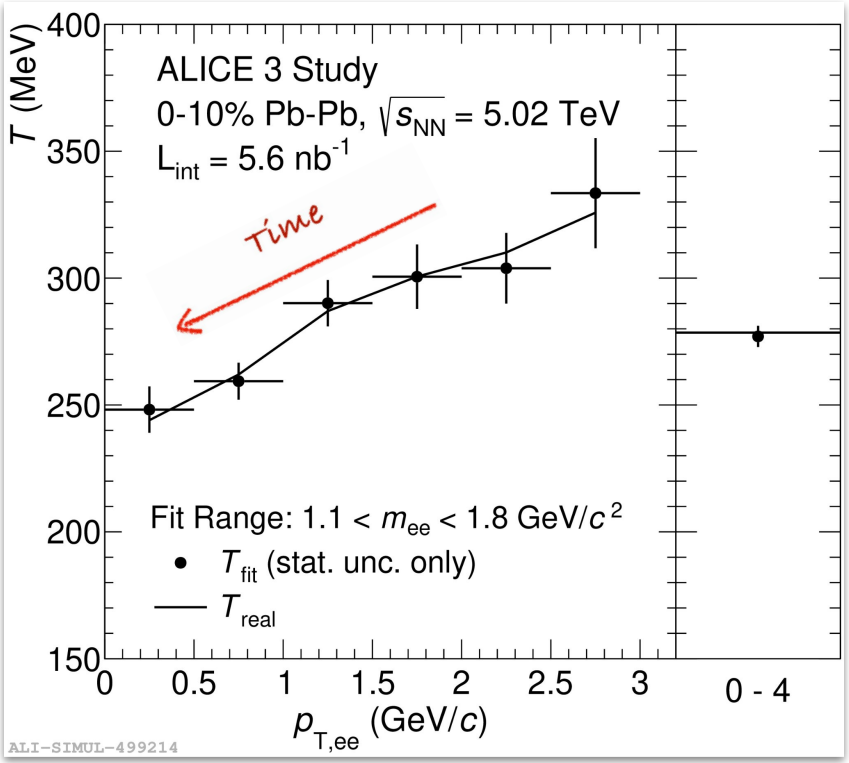
  → Little background from γ-conversion
- Very good electron identification down to low p_T

Probe time dependence of temperature

- With ALICE 3 precision: differential in p_T



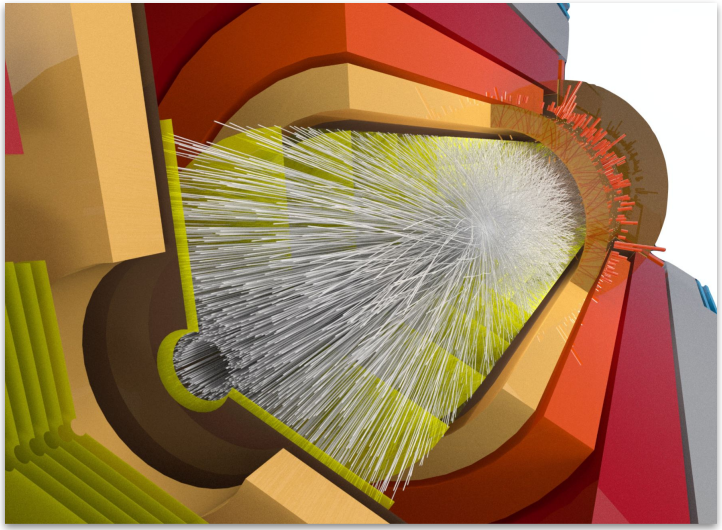
Conclusion

Thank you!

ALICE

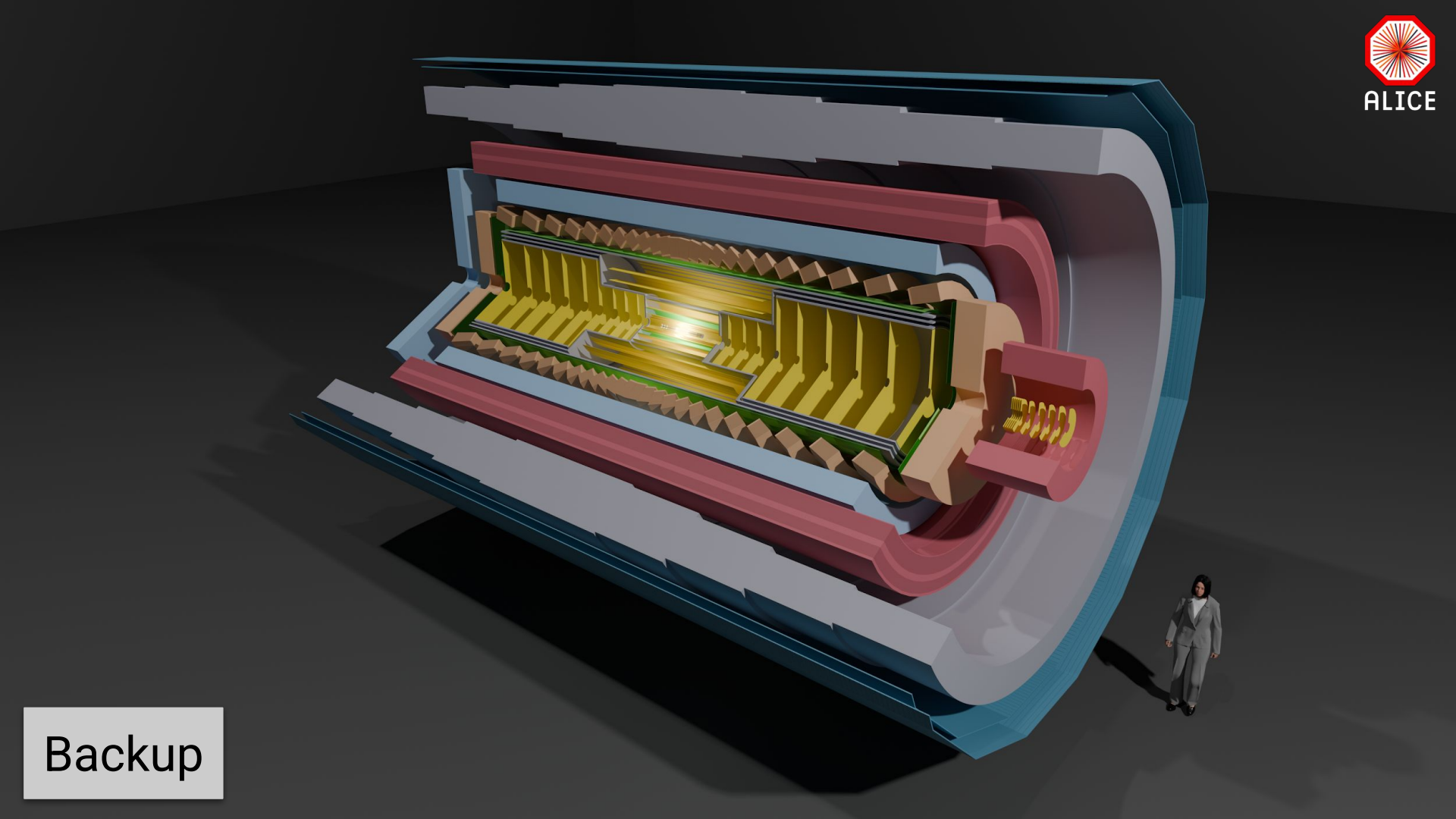
Summary

- Novel detector technology and extremely low material budget
- Sensitive down to very low p_T
  → Designed to study and address open questions in QCD physics left to be studied at the LHC



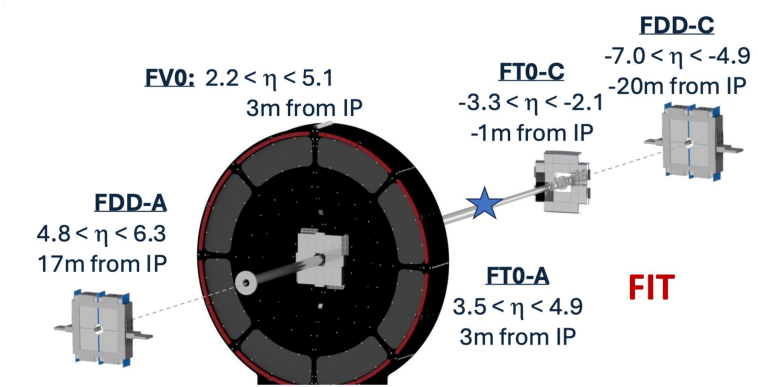
Outlook

- ALICE 3 is entering a critical phase: converging on selection of technologies
- Innovative R&D that future HEP experiments can exploit



Backup

Luminosity and event characterisation: FD

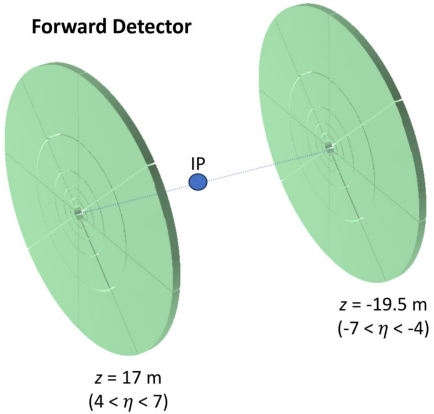


Current Fast Interaction Trigger:

- Luminometer and interaction trigger
- LHC background monitoring
- Vertex position and collision time
- Forward multiplicity and centrality
- Determination of reaction plane

ALICE 3 Forward Detector:

- Combining functionality from FIT
- Two segmented organic Eljen scintillator disks
- FD prototype (one channel) already installed at LHC for testing



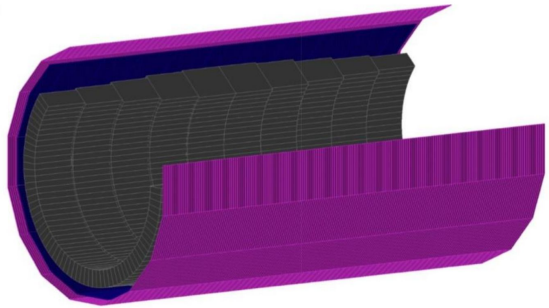
Particle identification: MID

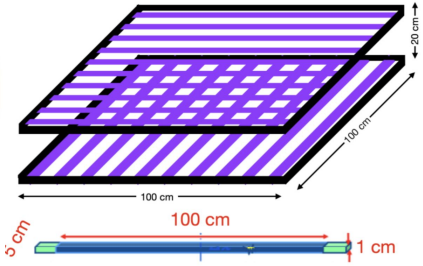
Requirements for particle identification

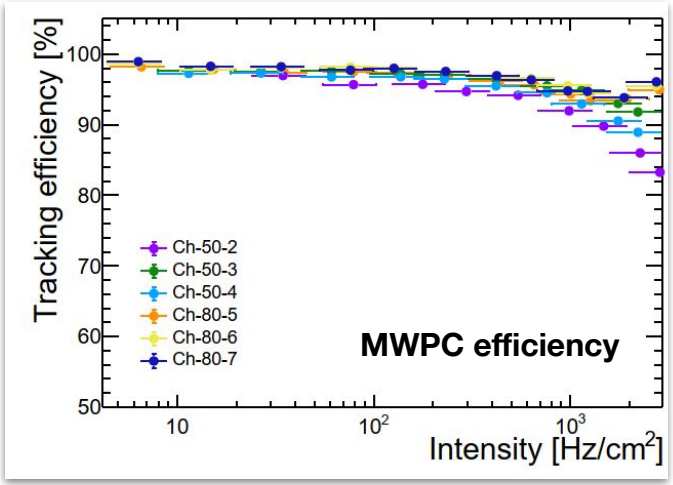
- Muon identification down to p_T ~ 1.5 GeV/c
- Strong pion rejection (> 96 %) for $|\eta| < 1.25$

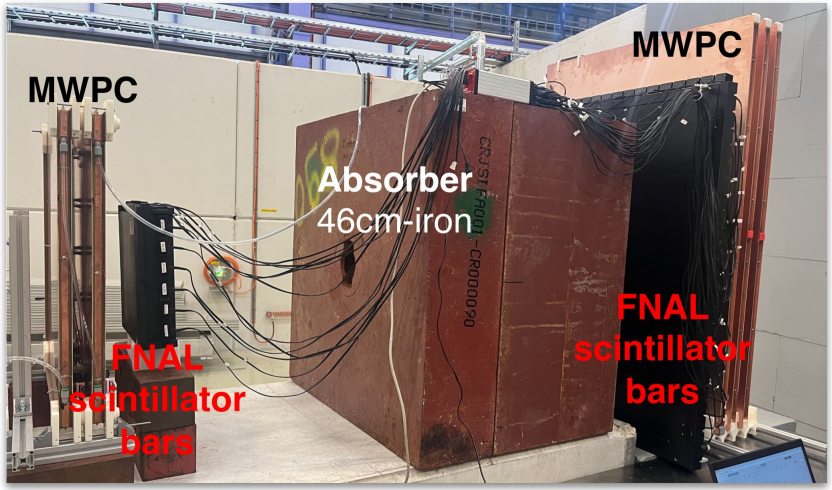
Considered technologies:

- Plastic scintillators + SiPM
- Multiwire proportional chambers









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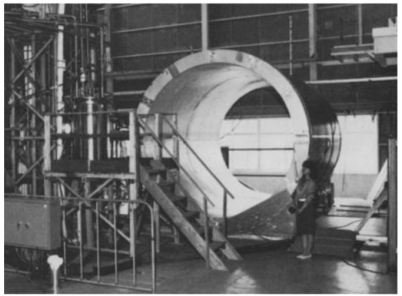
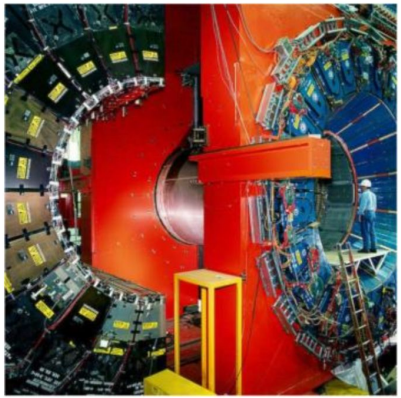
Magnet backup options

CDF magnet (Hitachi, 1984)

B=1.4 T, r_in=1.4 m, l=5 m

Located at Fermilab

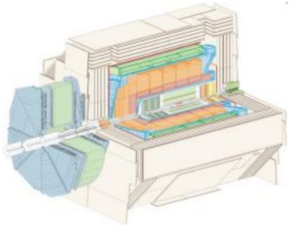


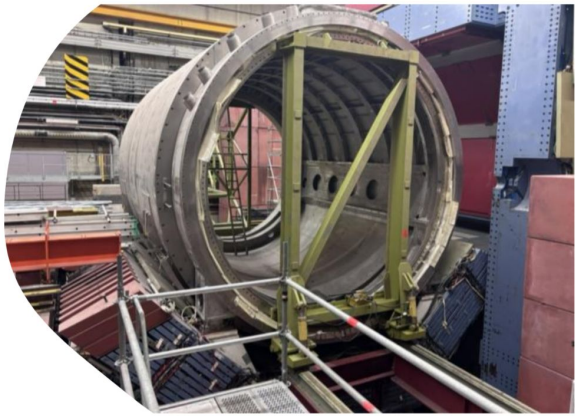


H1 magnet (RAL, 1992)

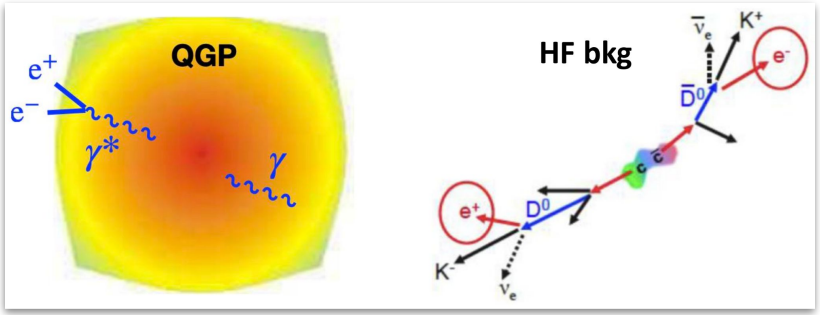
B=1.15 T, r_in=2.6 m, l=5.75 m

Located at Desy





Chiral symmetry restoration

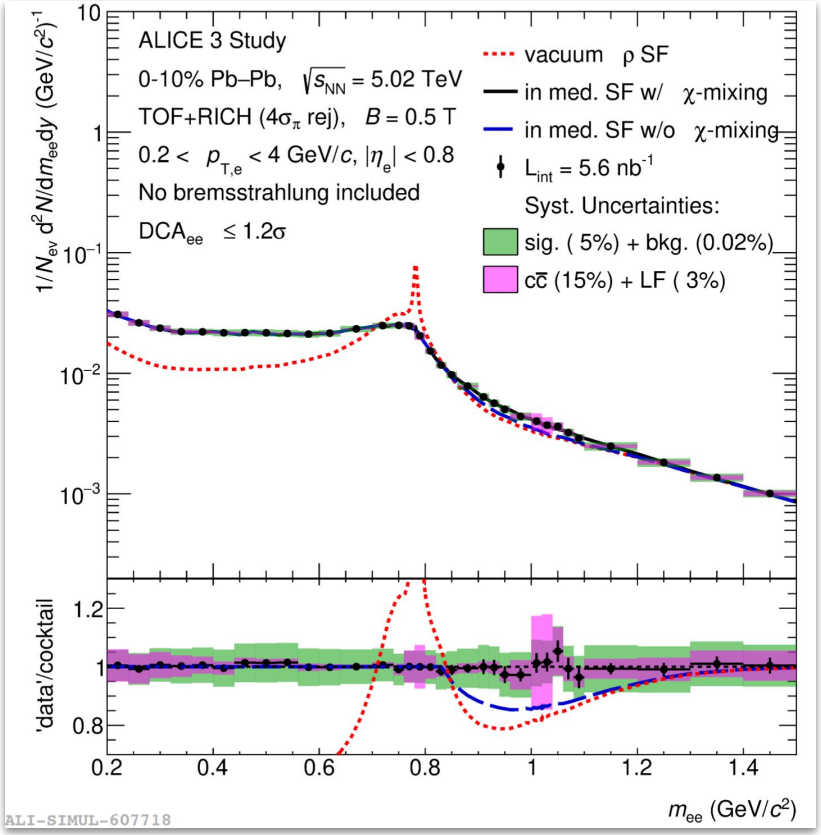


Accessing the QGP temperature

- Excellent pointing resolution for HF rejection
- Exceptionally low material budget for ɣ-conversion
- Very good electron identification down to low p_T

Thermal production of ρ mesons

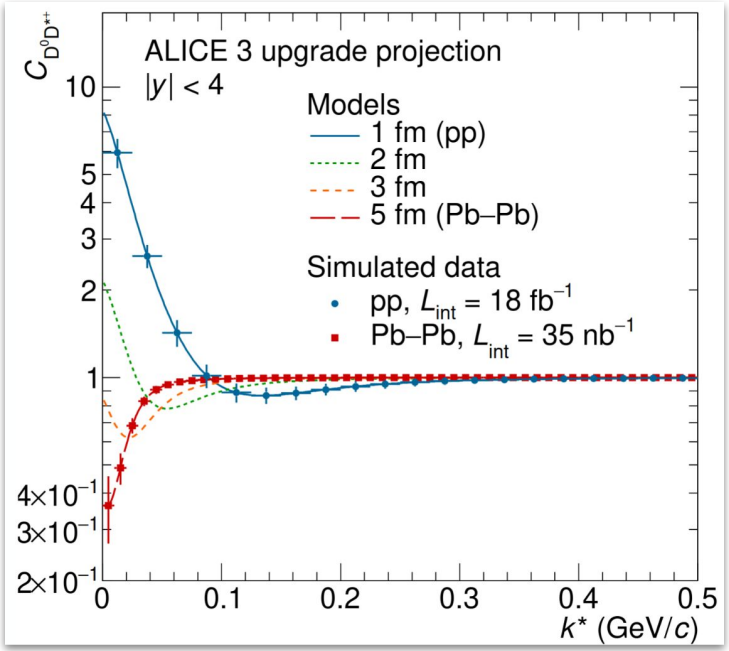
- Sensitive to surrounding medium (τ_ρ = 1.3 fm < τ_{QGP})
- Precision of data sufficient to measure 15% effect in ρ−a1 mixing region

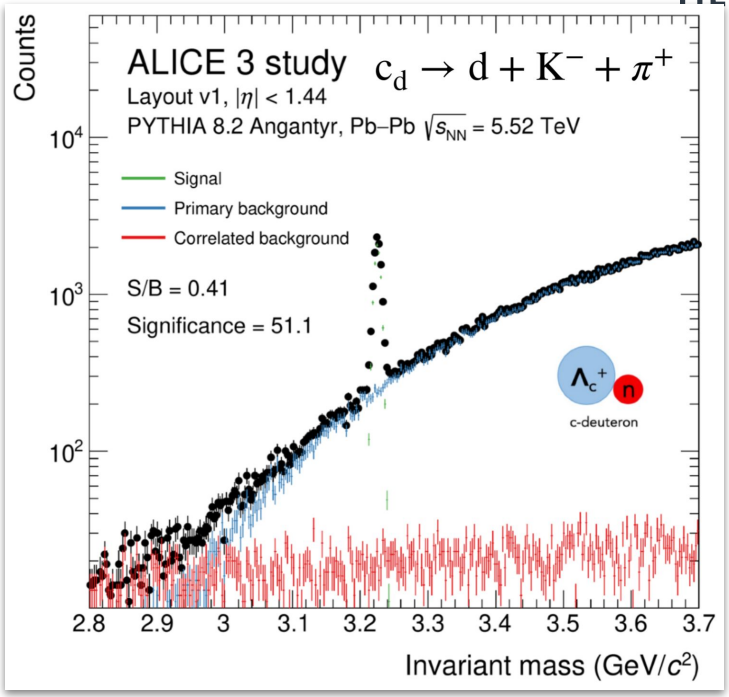


Exotic bound states

Charm hadron molecules

- D^0–D^{*+} momentum correlations accessible via two-particle femtoscopy measurements
- Search for possible D^0–D^{*+} bound states





Unique sensitivity to undiscovered charm-nuclei

- Super-nuclei: c-deuteron (c_d) and c-triton (c_t)
- Search for anti-(hyper)nuclei with A>5