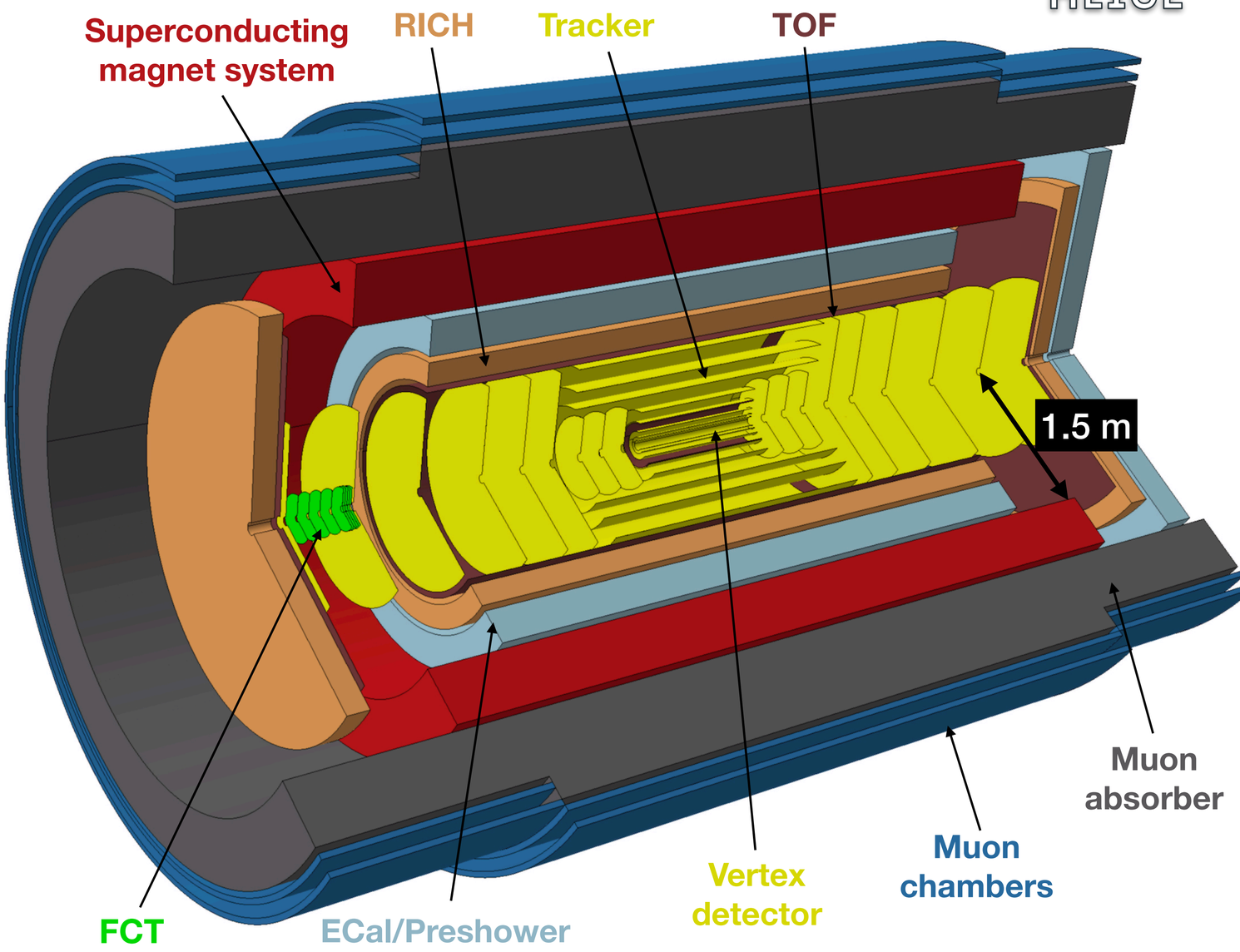
ALICE 3

Detector Concept

ALICE 3 workshop
October 18-19, 2021

Jochen Klein (CERN)



Observables

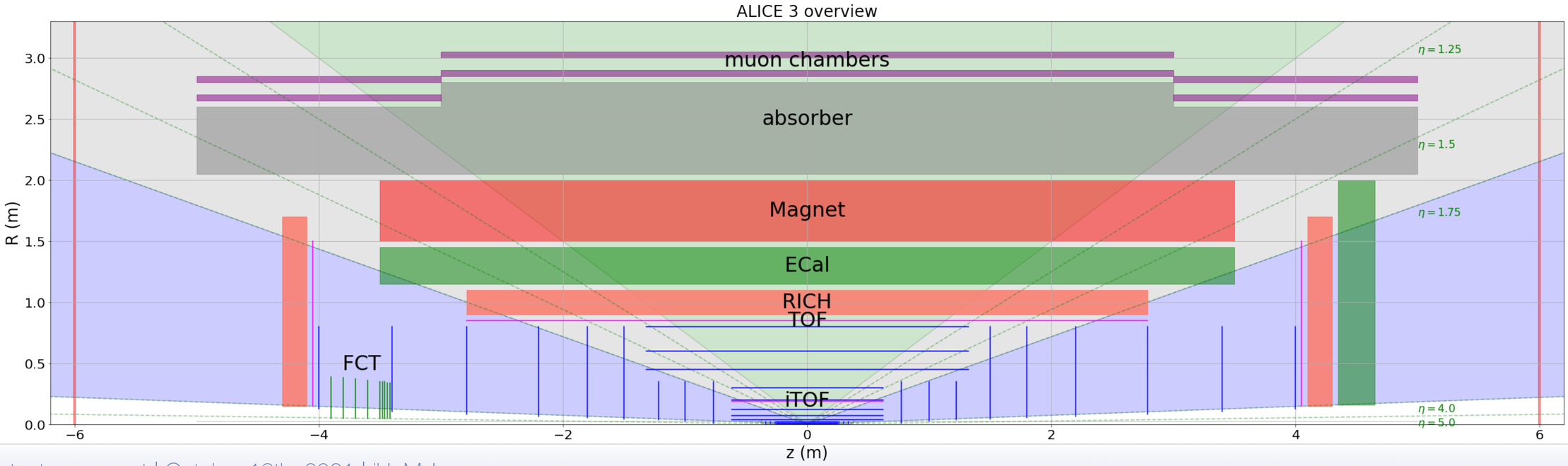
- **Heavy-flavour hadrons** ($p_T \rightarrow 0$, $|\eta| < 4$)
  - vertexing (decay chain)
  - tracking (inv. mass resolution)
  - hadron ID (background suppression)
- **Dielectrons** (p_T ~0.1 - 3 GeV/c, M_{ee} ~0.1 - 4 GeV/c^2)
  - vertexing (HF background suppression)
  - tracking (inv. mass resolution)
  - electron ID
- **Photons** (100 MeV/c - 50 GeV/c, wide η range)
  - electromagnetic calorimetry
- **Quarkonia and Exotica** ($p_T \rightarrow 0$)
  - muon ID
- **Ultrasoft photons** (p_T = 1 - 50 MeV/c)
  - dedicated forward detector
- **Nuclei**
  - identification of $z > 1$ particles

Key requirements

- Tracking over large rapidity range
- Excellent vertexing
- Excellent particle identification
- High rate

Detector concept

- Compact all-silicon tracker
  with high-resolution vertex detector
- Superconducting magnet system
- Particle identification over large acceptance
- Fast readout and online processing



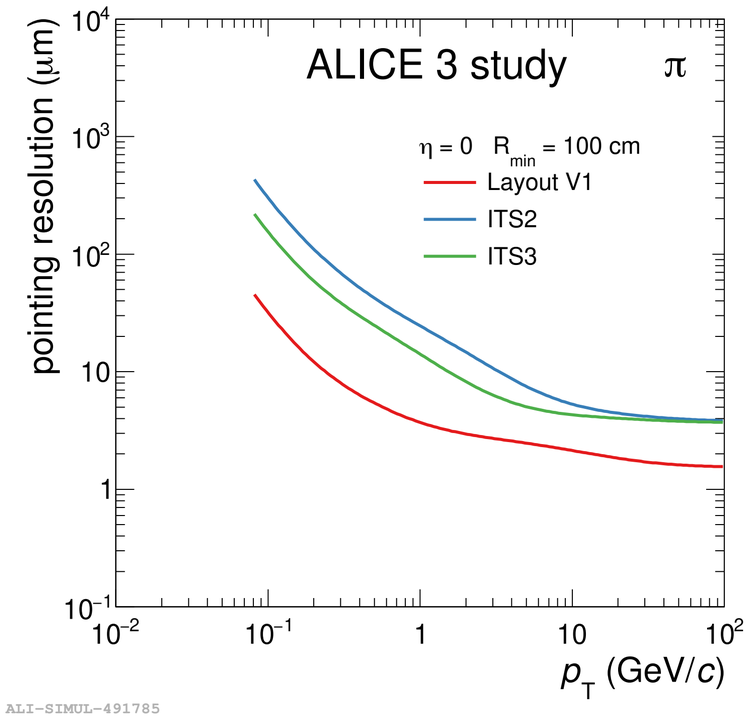
Detector requirements

Component	Observables	$\|\eta\| < 1.75$ (barrel)	$1.75 < \|\eta\| < 4$ (forward)	Detectors
Vertexing	Multi-charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{DCA} \approx 10$ µm at 200 MeV/*c*	Best possible DCA resolution, $\sigma_{DCA} \approx$??? µm at 200 MeV/*c*	Retractable silicon pixel tracker: $\sigma_{pos} \approx 2.5$ µm, $R_{in} \approx 5$ mm, $X/X_0 \approx 0.1$ % for first layer
Tracking	Multi-charm baryons, dielectrons	$\sigma_{pT} / p_T \sim 1$ %		Silicon pixel tracker: $\sigma_{pos} \approx 10$ µm, $R_{out} \approx 80$ cm, $X/X_0 \approx 1$ % / layer
Hadron ID	Multi-charm baryons	π/K/p separation up to a few GeV/*c*		Time of flight: $\sigma_{tof} \approx 20$ ps RICH: n = 1.03, $\sigma_\theta \approx 1.5$ mrad
Electron ID	Dielectrons, quarkonia, $\chi_{c1}(3872)$	pion rejection by 1000x up to ~2 - 3 GeV/*c*		Time of flight: $\sigma_{tof} \approx 20$ ps RICH: n = 1.03, $\sigma_\theta \approx 1.5$ mrad possibly preshower detector
Muon ID	Quarkonia, $\chi_{c1}(3872)$	reconstruction of J/Ψ at rest, i.e. muons from 1.5 GeV/c		steel absorber: L ≈ 70 cm muon detectors
Electromagnetic calorimetry	Photons, jets	large acceptance		Pb-Sci calorimeter
	χ_c	high-resolution segment		$PbWO_4$ calorimeter
Ultrasoft photon detection	Ultra-soft photons		measurement of photons in p_T range 1 - 50 MeV/c	Forward Conversion Tracker based on silicon pixel sensors

Vertexing

- **Pointing resolution** $\propto r_0 \cdot \sqrt{x/X_0}$
  (multiple scattering regime)
  ➟ 10 μm @ p_T = 200 MeV/*c*
  - radius and material of first layer crucial
  - minimal radius given by required aperture:
    R ≈ 5 mm at top energy,
    R ≈ 15 mm at injection energy
    → **retractable vertex detector**

- **3 layers within beam pipe** (in secondary vacuum) at radii of 5 - 25 mm
  - wafer-sized, bent Monolithic Active Pixel Sensors
  - σ_{pos} ~2.5 μm → 10 μm pixel pitch
  - 1 ‰ X_0 per layer

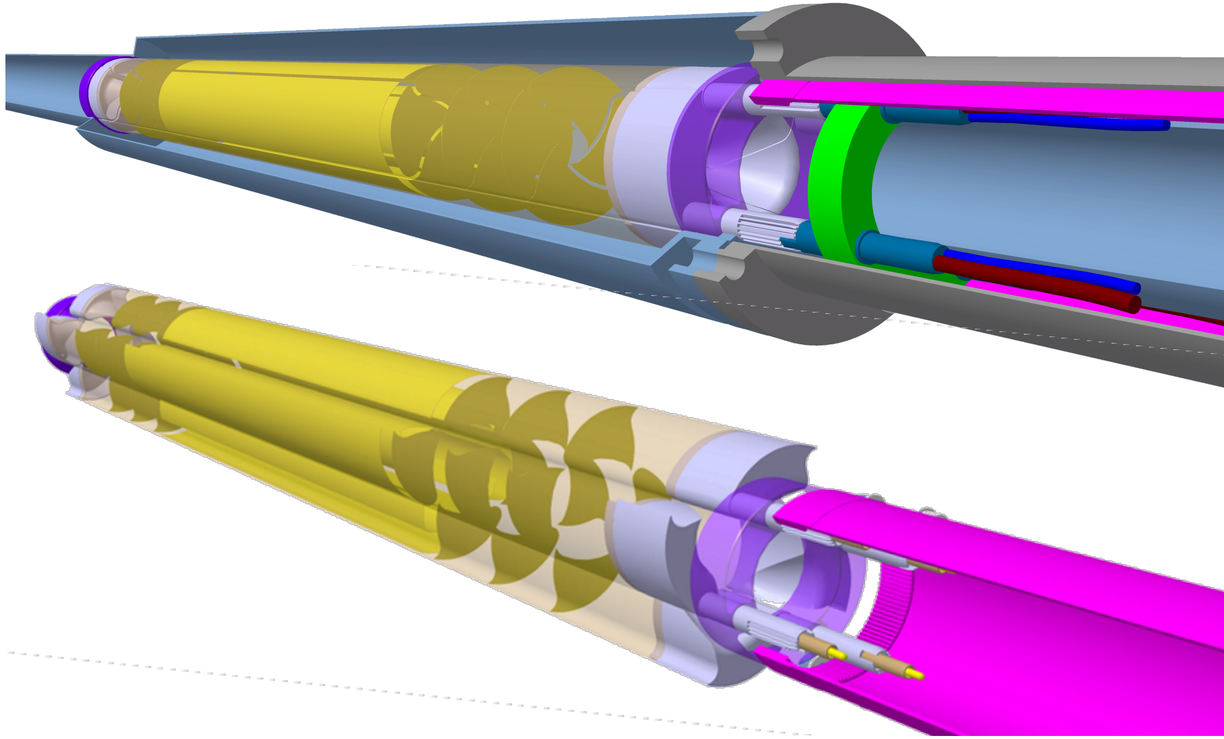


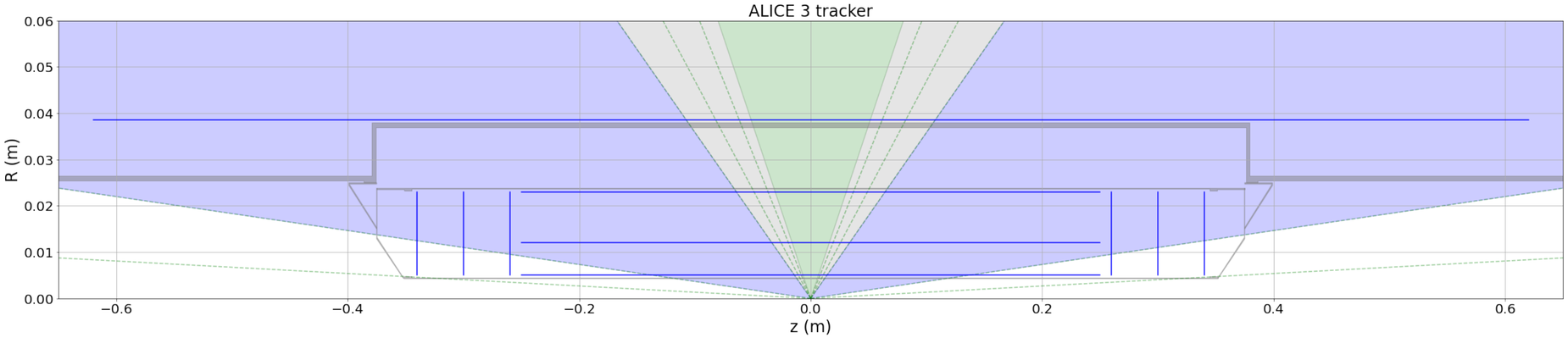
5x better than ALICE 2.1 (ITS3 + TPC)

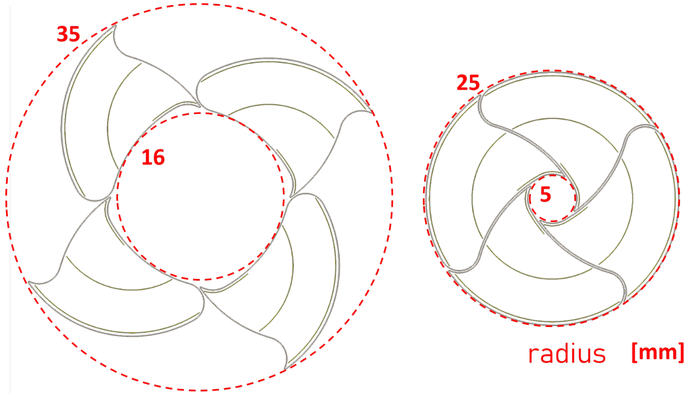
Vertex Detector

→ M. Mager, Tuesday

- **Conceptual study**
  - wafer-sized, bent MAPS (leveraging on ITS3 activities)
  - rotary petals for secondary vacuum (thin walls to minimise material)
  - matching to beampipe parameters (impedance, aperture, …)
  - feed-throughs for power, cooling, data
- **R&D challenges** on mechanics, cooling, radiation tolerance



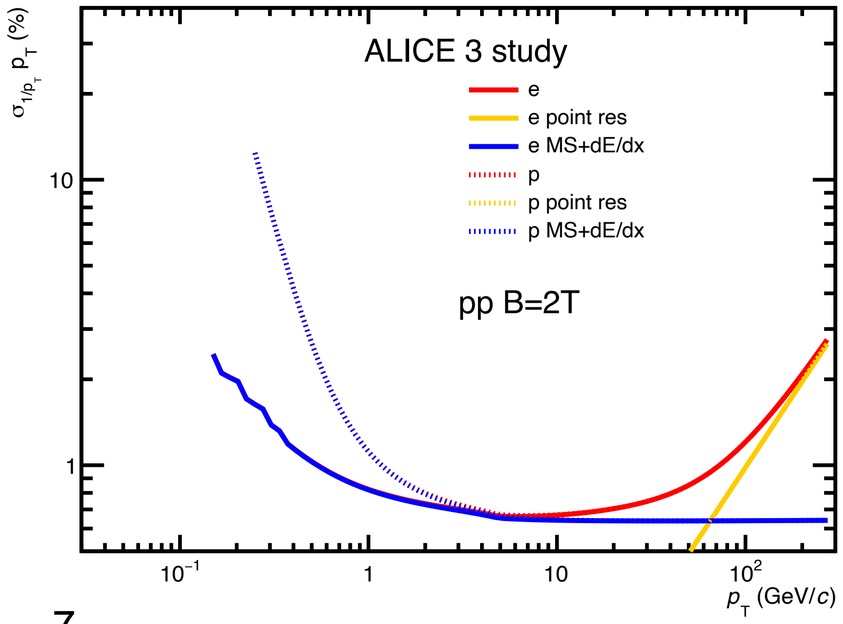


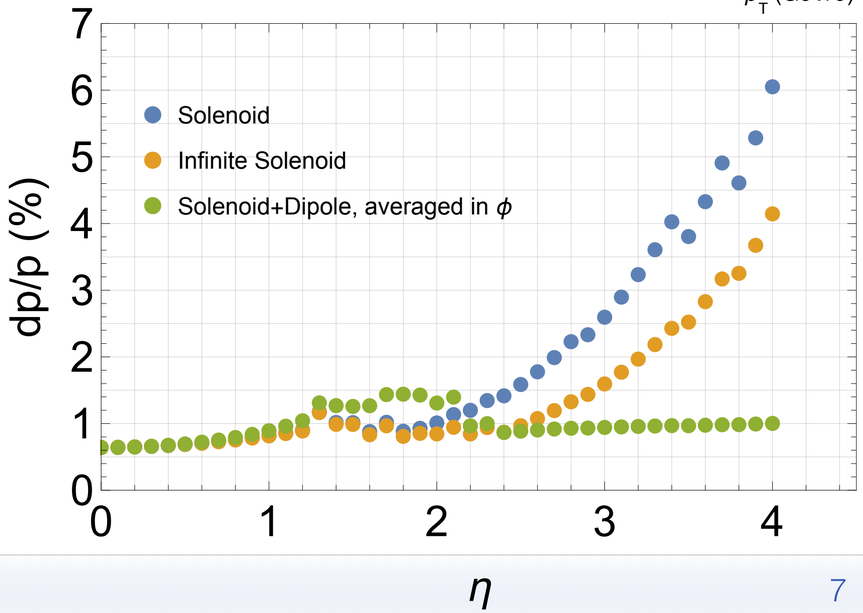


Tracking

- **Relative p_T resolution** $\propto \frac{\sqrt{x/X_0}}{B \cdot L}$
  (limited by multiple scattering)
  ➟ ~1 % up to η = 4
  - integrated magnetic field crucial
  - overall material budget critical

- **~11 tracking layers (barrel + disks)**
  - MAPS
  - σ_{pos} ~10 μm → 50 μm pixel pitch
  - R_{out} ≈ 80 cm and L ≈ 4 m (→ magnetic field integral ~1 Tm)
  - timing resolution ~100 ns (→ reduce mismatch probability)
  - material ~1 % X_0 / layer → overall X/X_0 = ~10 %

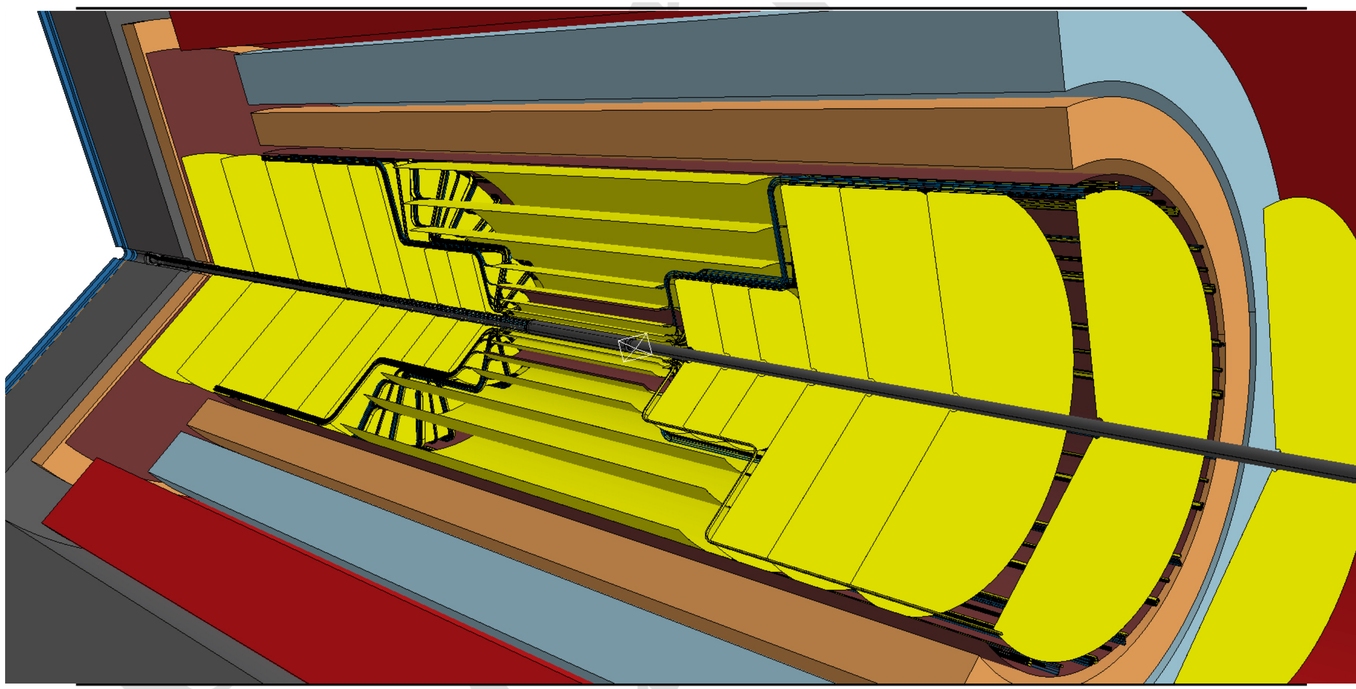


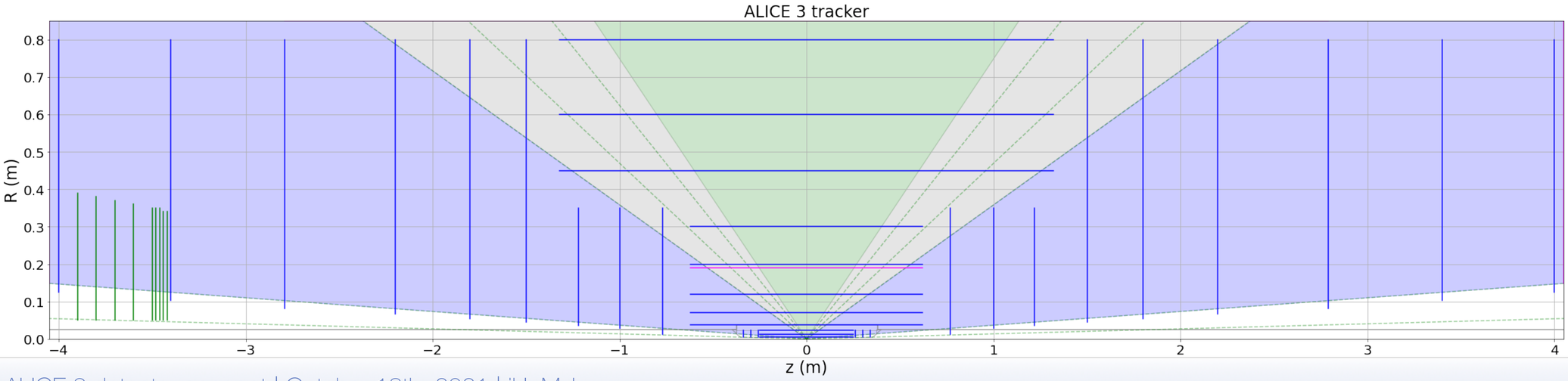


Outer Tracker

→ M. Mager, Tuesday

- MAPS on modules on water-cooled carbon-fibre cold plate
- carbon-fibre space frame for mechanical support
- **R&D challenges** on
  - powering scheme (→ material)
  - industrialisation

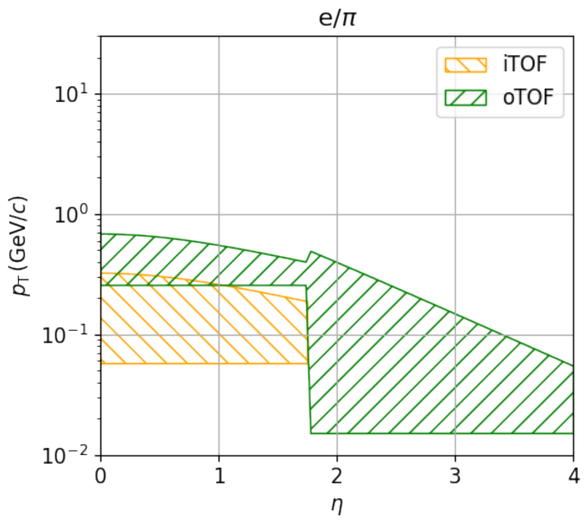


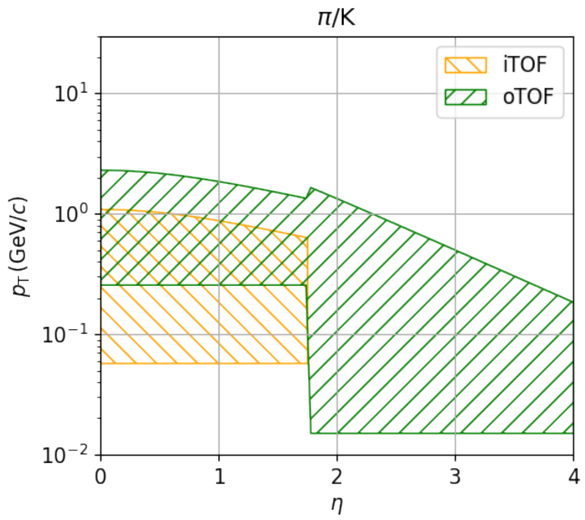


Total silicon surface ~60 m²

Time of Flight

- **Separation power** $\propto \frac{L}{\sigma_{\mathrm{tof}}}$
  - distance and time resolution crucial
  - larger radius results in lower p_T bound
- **2 barrel + 1 forward TOF layers**
  - TOF resolution $\sigma_{TOF} \approx 20$ ps based on silicon timing sensors
  - outer TOF at R ≈ 85 cm
  - inner TOF at R ≈ 19 cm
  - forward TOF at z ≈ 405 cm

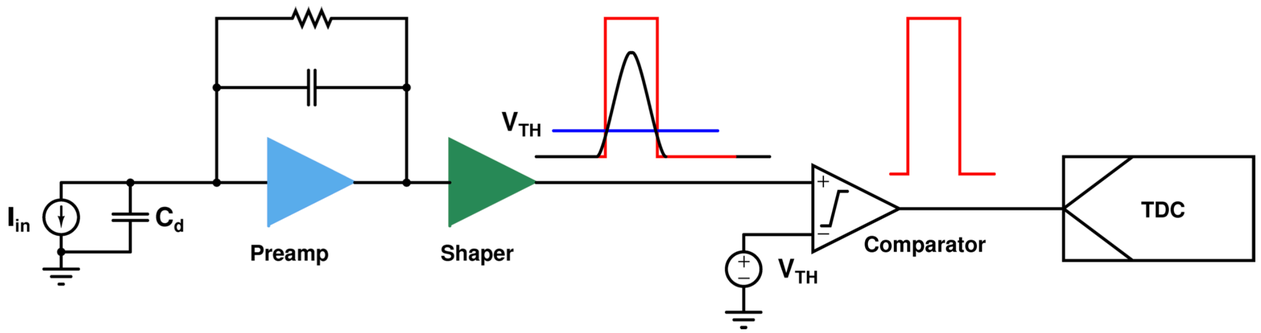




TOF detector

→ A. Rivetti, Tuesday

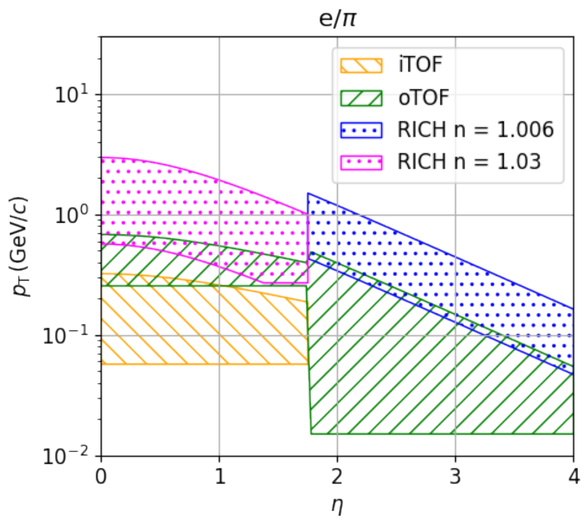
- **Sensor**
  - Low Gain Avalanche Diodes (LGAD)
    → established technology
    - requires separate read-out chip
  - **Monolithic timing sensors**
    → attractive solution
    - time resolution achievable with additional gain layer
  - Single Photon Avalanche Diodes (SPAD)
    → interesting in combination with photon detection for RICH
- **Front-end electronics and Time to Digital Converter (leading edge and time over threshold)**
  - needs good engineering but no substantial R&D

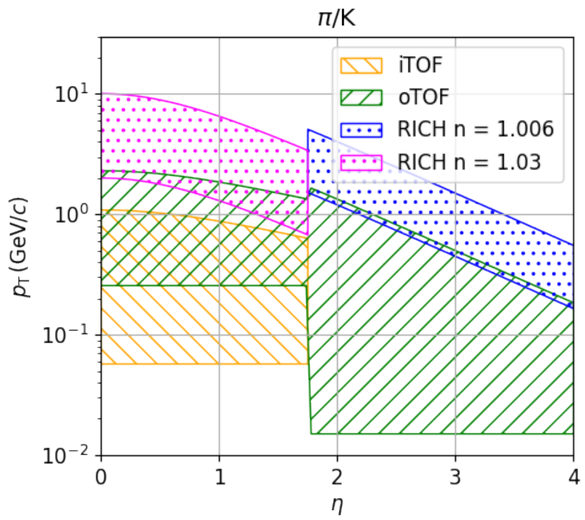


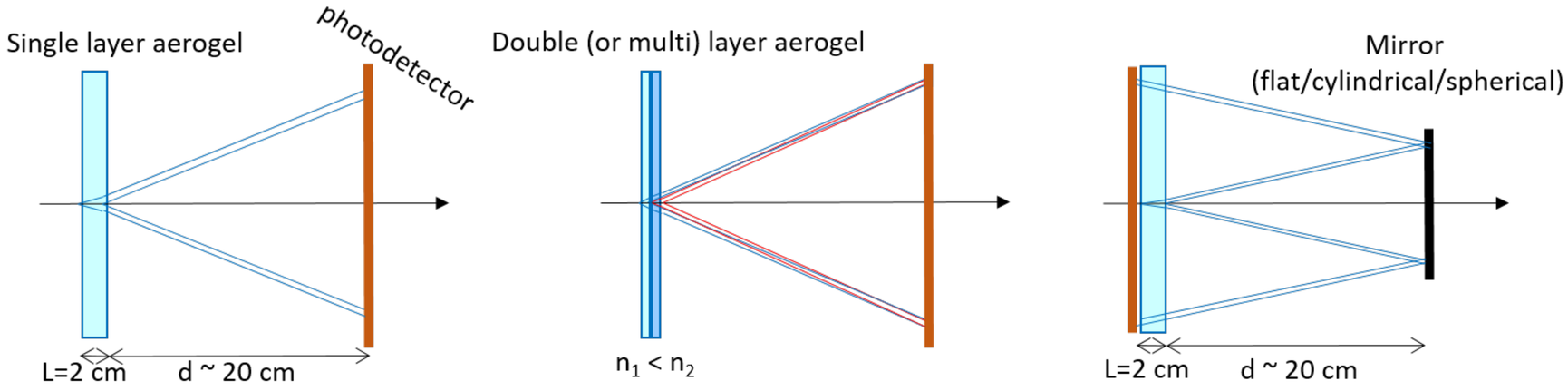
Total silicon surface ~45 m²

RICH

- **Extend PID reach of outer TOF to higher p_T**
  ➟ Cherenkov
  - ensure continuous coverage from TOF
    → refractive index n = 1.03 (barrel)
    → refractive index n = 1.006 (forward)
  - aerogel radiator + photon detection layer







Technologies and R&D

- **Silicon Photomultipliers (SiPM)**
  → established technology, commercially available
  - limited area per device
  - requires separate front-end
  - high dark count rates
- **Monolithic sensors**
  → interesting in combination with charged particle timing measurement
  - requires significant R&D
- **MCP-based solutions** (e.g. LAPPD)
  to be followed, suffer from magnetic field

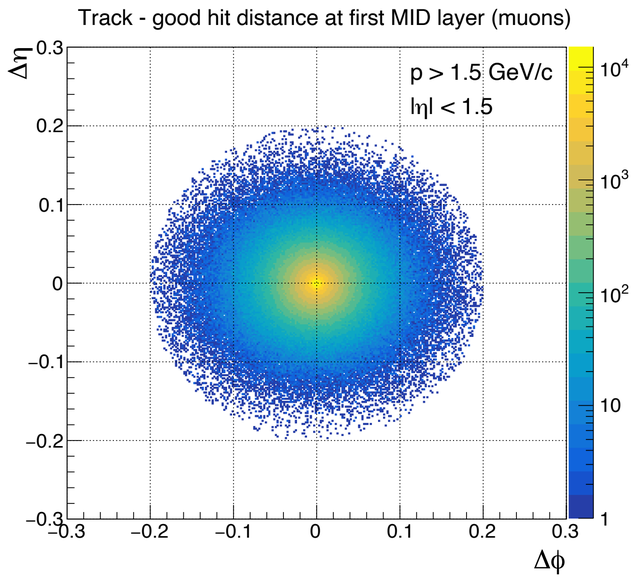
Total SiPM surface ~60 m²

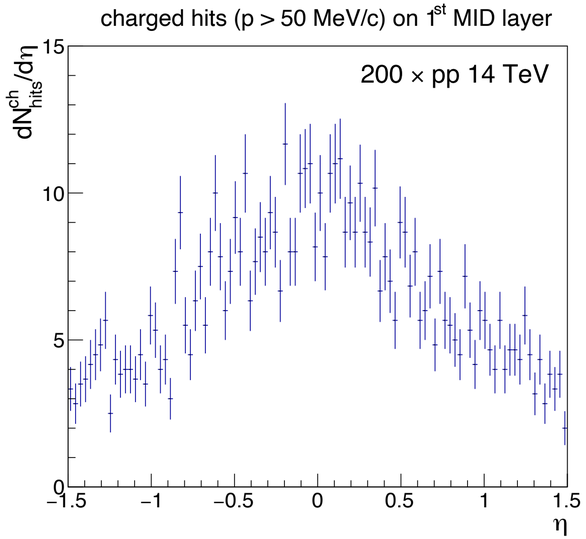
Requirements

- PDE (visible light) > 40 - 50 %
- fill factor > 90 %
- time jitter < 100 ps
- total area O(50) m²
- operation in magnetic field (up to 2 T)
- radiation load < 10^{12} 1 MeV n_{eq} / cm²

Muon ID

- **Hadron absorber**
  - ~70 cm non-magnetic steel
- **Muon chambers**
  - search spot for muons ~0.1 x 0.1 (eta x phi) → ~5 x 5 cm^2 cell size
  - matching demonstrated with 2 layers, 1 layer might be enough
  - RPCs as baseline, other options can be considered





ECal

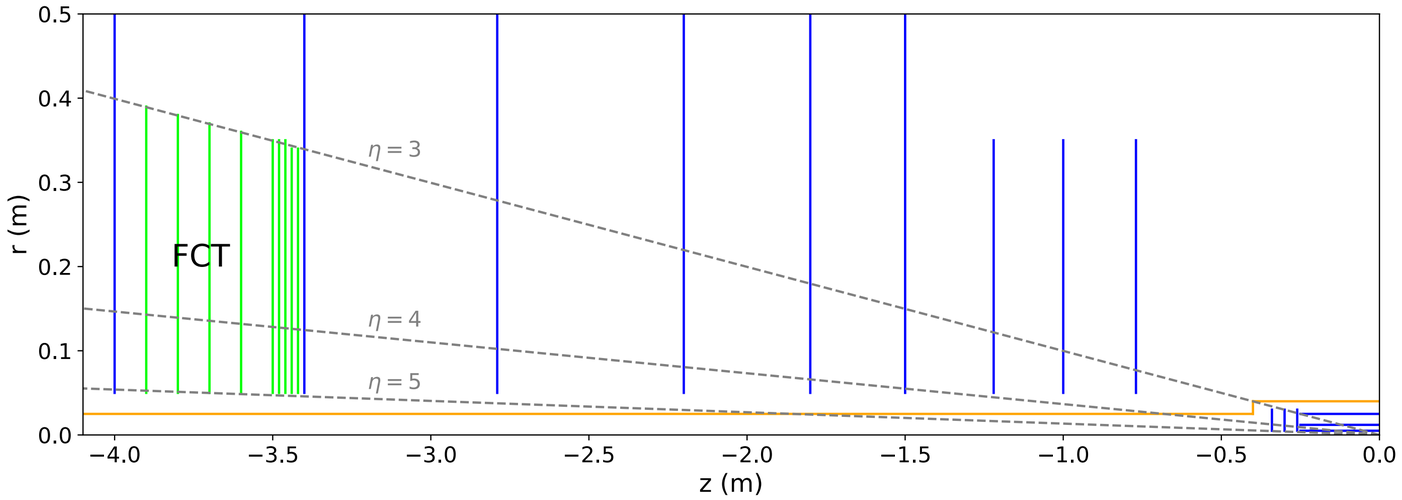
- **large acceptance ECal**
  → sampling calorimeter (à la EMCal/DCal):
  e.g. O(100) layers (1 mm Pb + 1.5 mm plastic scintillator)

- **additional high energy resolution segment** at midrapidity or forward
  → $PbWO_4$-based

ECal module	Barrel sampling	Endcap sampling	Barrel high-precision
acceptance	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 1.5$	$\Delta\varphi = 2\pi$, $1.5 < \eta < 4$	$\Delta\varphi = \pi$, $\lvert\eta\rvert < 0.67$
geometry	$R_{in} = 1.15$ m, $\lvert z\rvert < 2.7$ m	$0.16 < R < 1.8$ m, $z = 4.35$ m	$R_{in} = 1.15$ m, $\lvert z\rvert < 1.27$ m
technology	sampling Pb + scint.	sampling Pb + scint.	$PbWO_4$ crystals
cell size	30×30 mm^2	40×40 mm^2	22×22 mm^2
no. of channels	30 000	6 000	20 000
energy range	$0.02 < E < 100$ GeV	$0.1 < E < 250$ GeV	$0.01 < E < 100$ GeV

Forward conversion tracker

- **Thin tracking disks** to cover 3 < η < 5
  - few ‰ of a radiation length per layer
  - position resolution < 10 μm
- **Research & Development**
  - Large area, thin disks
  - Minimisation of material in front of FCT
  - Operational conditions



Layer	z (m)	r_{min} (m)	r_{max} (m)
0	−3.42	0.05	0.34
1	−3.44	0.05	0.34
2	−3.46	0.05	0.35
3	−3.48	0.05	0.35
4	−3.50	0.05	0.35
5	−3.60	0.05	0.36
6	−3.70	0.05	0.37
7	−3.80	0.05	0.38
8	−3.90	0.05	0.39

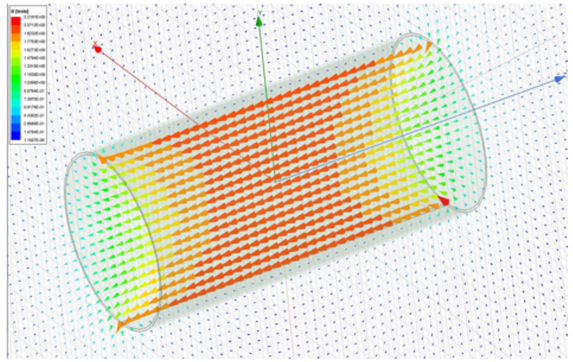
Rates and radiation

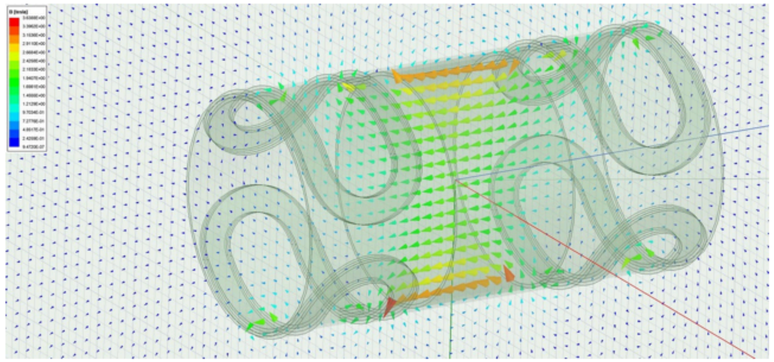
- Design to handle available heavy-ion luminosities,
  with current estimates hit rates similar across collision systems
- **First layer at 5 mm** → challenging hit rates and radiation load:
  ~1.5 10^{15} 1 MeV n_{eq} / cm² per operational year (comparable to first layer in ATLAS/CMS)
- Moderate hit rates and radiation load in other layers,
  already at R = 20 cm (inner TOF) down to ~10^{12} 1 MeV n_{eq} / cm² per operational year

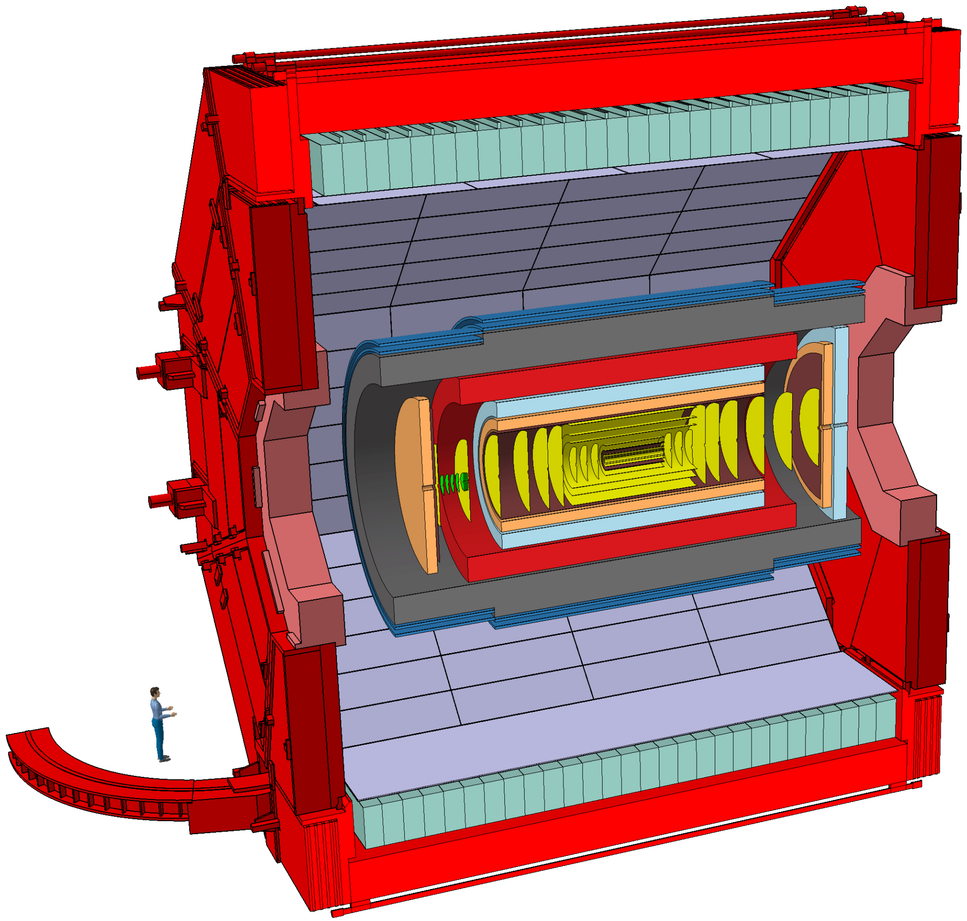
		pp	Ar-Ar	Kr-Kr	Xe-Xe	Pb-Pb
	L_{AA} (cm^{-2} s^{-1})	$3.0 \cdot 10^{32}$	$3.2 \cdot 10^{29}$	$8.5 \cdot 10^{28}$	$3.3 \cdot 10^{28}$	$1.2 \cdot 10^{28}$
	$\langle L_{AA} \rangle$ (cm^{-2} s^{-1})	$3.0 \cdot 10^{32}$	$2.0 \cdot 10^{29}$	$5.0 \cdot 10^{28}$	$1.6 \cdot 10^{28}$	$3.3 \cdot 10^{27}$
R = 0.5 cm	R_{hit} (cm^{-2} s^{-1})	$9.4 \cdot 10^{7}$	$6.9 \cdot 10^{7}$	$5.3 \cdot 10^{7}$	$4.6 \cdot 10^{7}$	$3.5 \cdot 10^{7}$
	NIEL (1 MeV n_{eq} / cm² / month)	$1.8 \cdot 10^{14}$	$8.6 \cdot 10^{13}$	$6.0 \cdot 10^{13}$	$4.1 \cdot 10^{13}$	$1.9 \cdot 10^{13}$
	TID (Rad / m)	$5.8 \cdot 10^{6}$	$2.8 \cdot 10^{6}$	$1.9 \cdot 10^{6}$	$1.3 \cdot 10^{6}$	$6.1 \cdot 10^{5}$
R = 20 cm	R_{hit} (cm^{-2} s^{-1})	$5.9 \cdot 10^{4}$	$4.3 \cdot 10^{4}$	$3.3 \cdot 10^{4}$	$2.8 \cdot 10^{4}$	$2.2 \cdot 10^{4}$
	NIEL (1 MeV n_{eq} / cm² / month)	$1.1 \cdot 10^{11}$	$5.4 \cdot 10^{10}$	$3.7 \cdot 10^{10}$	$2.6 \cdot 10^{10}$	$1.2 \cdot 10^{10}$
	TID (Rad / m)	$3.6 \cdot 10^{3}$	$1.7 \cdot 10^{3}$	$1.2 \cdot 10^{3}$	$8.2 \cdot 10^{2}$	$3.8 \cdot 10^{2}$
R = 100 cm	R_{hit} (cm^{-2} s^{-1})	$2.4 \cdot 10^{3}$	$1.7 \cdot 10^{3}$	$1.3 \cdot 10^{3}$	$1.1 \cdot 10^{3}$	$8.8 \cdot 10^{2}$
	NIEL (1 MeV n_{eq} / cm² / month)	$4.5 \cdot 10^{9}$	$2.1 \cdot 10^{9}$	$1.5 \cdot 10^{9}$	$1.0 \cdot 10^{9}$	$4.7 \cdot 10^{8}$
	TID (Rad / m)	$1.4 \cdot 10^{2}$	$6.9 \cdot 10^{1}$	$4.8 \cdot 10^{1}$	$3.3 \cdot 10^{1}$	$1.5 \cdot 10^{1}$

Integration

- **Cryostat of 7 m length, free bore radius 1.5 m**, magnetic field configuration to be optimised
- **Installation of ALICE 3 around nominal IP2**
  - L3 magnet can remain, ALICE 3 to be installed inside
  - pp luminosities of a few 10^{32} cm^{-2} s^{-1} feasible without additional shielding







Summary

- Detector concept developed
  to meet the requirements for the ALICE 3 physics programme

- Based on established technologies
  with R&D activities required in several areas

- Detector design to be optimised
  based on physics needs and technological progress

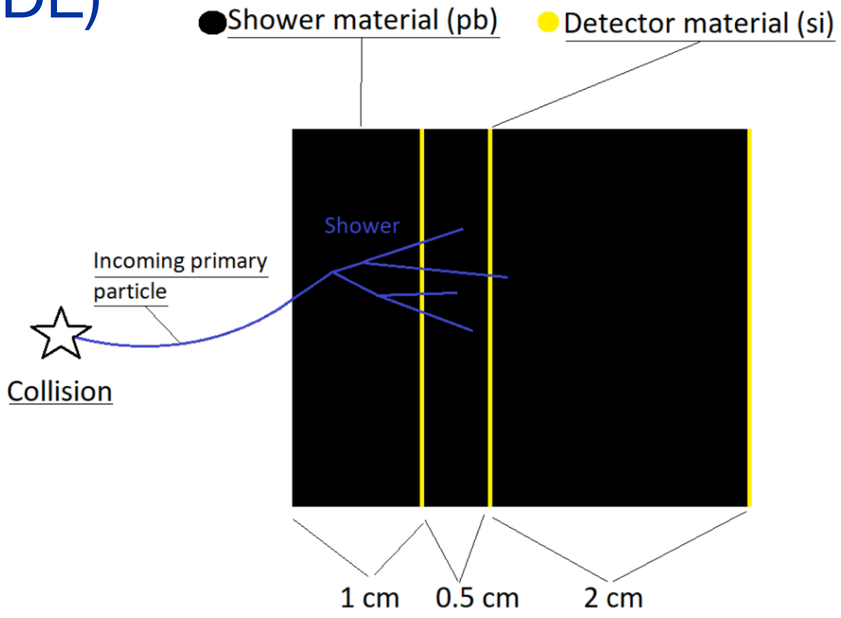
ALICE 3 is taking shape!

Backup

Preshower detector

- Identify electrons
  through measurement of preshower with high granularity
  - 1000x pion rejection
- Consider stack of Pb absorbers and MAPS (here ALPIDE)
  - 3 - 4 sensor layers required for good performance
- Further studies needed on
  - required granularity
  - optimisation of geometry

Si surface
3-4 x 25 m² (barrel)
3-4 x 25 m² (forward)



Data processing

- **Computing time**
  - extrapolation from GPU-based ITS tracking with highest Run 3 occupancy: scaled by acceptance, no. of layers, projected GPU performance (3x)
- **Memory**
  - flexible (no drift time, bucketing can be optimised for computing)
- **Storage**
  - check storage of AODs or raw data

compute farm similar EPN farm for Run 3

	pp	O-O	Ar-Ar	Ca-Ca	Kr-Kr	Xe-Xe	Pb-Pb
No. of GPUs	942	851	695	625	530	455	356
Raw data (GB/s)	361	237	267	240	203	174	136
Compressed data rate (GB/s)	64	58	47	42	36	31	24
Compressed raw data (PB / month)	90	50	43	39	30	21	10
AOD size (PB / month)	181	96	82	75	56	39	18