Tracking systems requirements
ALICE-3 versus FCC-ee

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Outline

Comparison of current Silicon tracking systems for ALICE-3 and FCC-ee

(configurations, performance, operating conditions)

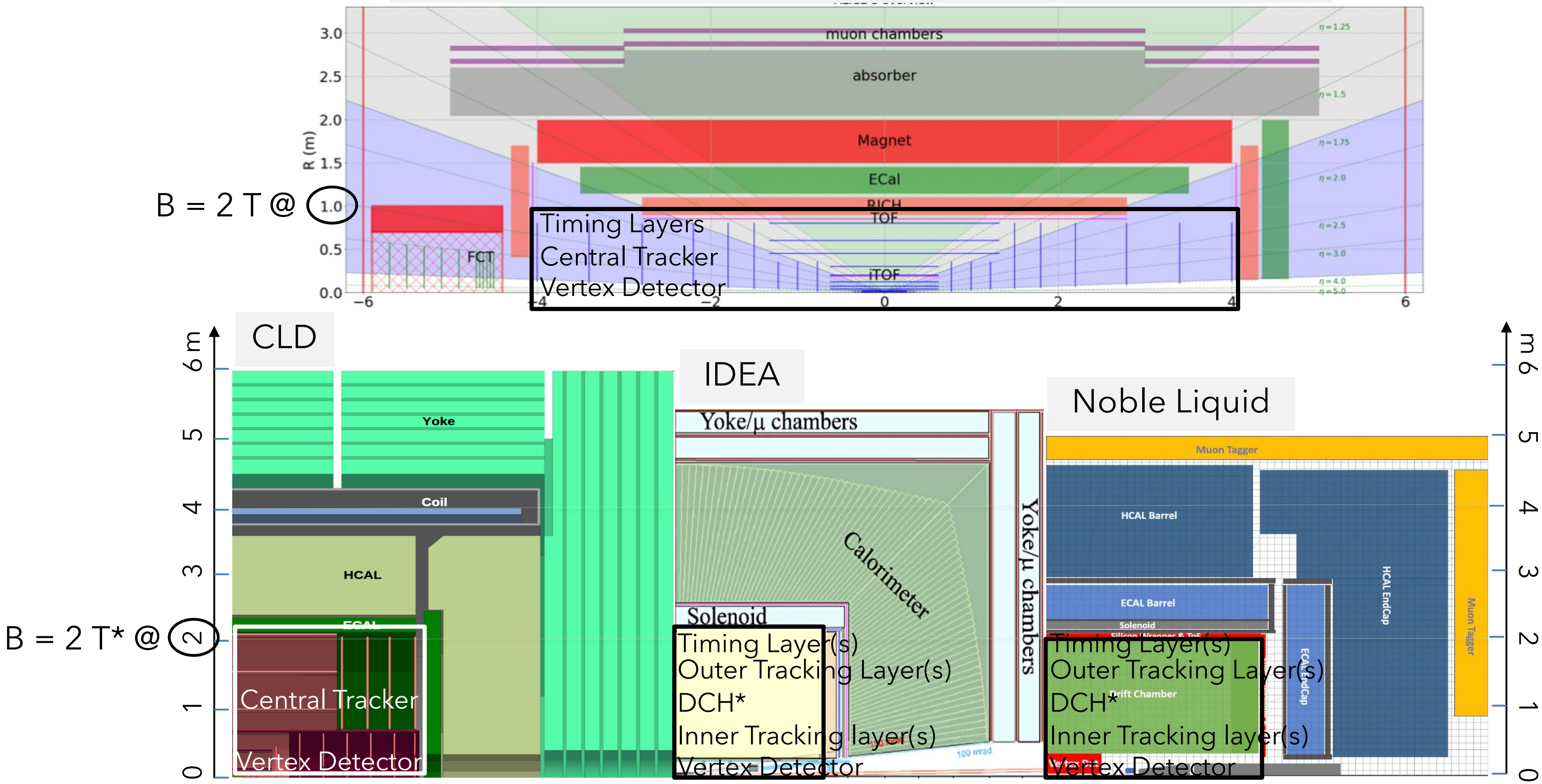
R&D highlights

(see more in D. Bartoletto's and M. Mager's presentations)

Special thanks to A Dainese, A. Di Mauro, M. Mager

ALICE-3 and FCC-ee detector concepts

ALICE-3 new detector, TPC replaced by full Silicon Tracker



** Possibly higher above Z-pole beam energy*

Detector performance requirements

ALICE-3

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, $\sigma_{DCA} \approx 30$ 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	σ_{p_T} / p_T ~1-2 %		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: aerogel, $\sigma_\theta \approx 1.5$ 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: aerogel, $\sigma_\theta \approx 1.5$ mrad possibly preshower detector

Optimization driven toward low p_T signals

- High precision - ultralight VD close to the beam
- High precision light Central Tracker
- ToF precision for PID up to O (3) GeV (+ RICH)

FCC-ee (M. Selvaggi's presentation)

Higgs factory	**Flavor** "boosted" B/D/τ factory	**QCD – EWK** most precise SM test	**BSM** feebly interacting particles
m_H, σ, Γ_H self-coupling H→ bb, cc, ss, gg H→inv ee→H H→bs, … **Top** m_{top}, Γ_{top}, ttZ, FCNCs	CKM matrix CP measurements Charged LFV Lepton Universality τ properties (lifetime, BRs..) $B_c \to \tau \nu$ $B_s \to D_s K$ $B_s \to K^* \tau \tau$ $B \to K^* \nu \nu$ $B_s \to \varphi \nu \nu$ …	m_Z , Γ_Z , Γ_{inv} $\sin^2\theta_W$, R^Z_ℓ , R_b, R_c $A_{FB}^{b,c}$, τ pol. α_S m_W, Γ_W	Heavy Neutral Leptons (HNL) Dark Photons Z_D Axion Like Particles (ALPs) Exotic Higgs decays
Higgs factory track momentum resolution (low X_0) IP/vertex resolution for flavor tagging PID capabilities for flavor tagging Hadron energy resolution (stochastic and noise) and PF	**Flavor** "boosted" B/D/τ factory track momentum resolution (low X_0) IP/vertex resolution PID capabilities Photon resolution, pi0 reconstruction	**QCD – EWK** most precise SM test acceptance/alignment knowledge to 10 μm magnetic field uniformity lumiCal coverage down to 60 mrad	**BSM** feebly interacting particles Large decay volume High radial segmentation - tracker - calorimetry - muon impact parameter resolution for large displacement triggerless

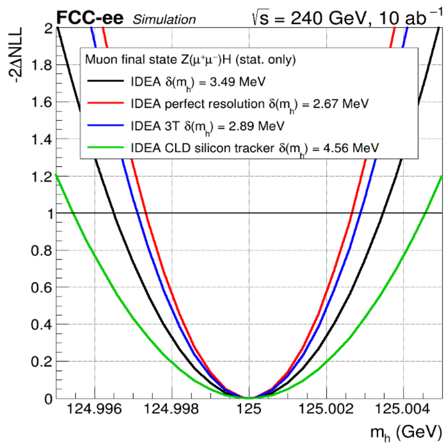
Large p_T range, new precision constraints for flavor tagging (including Higgs sector), and detached vertices

Unprecedented precision in beam energy, luminosity, acceptance and B-field knowledge

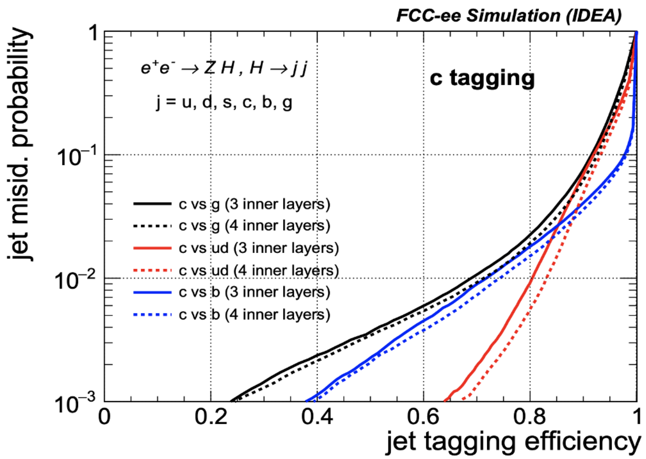
FCC-ee detector performance requirements

Ongoing PED work* to establish configurations and identify detector features that matter most
(including benefits of recent progress in reconstruction and analyses techniques)

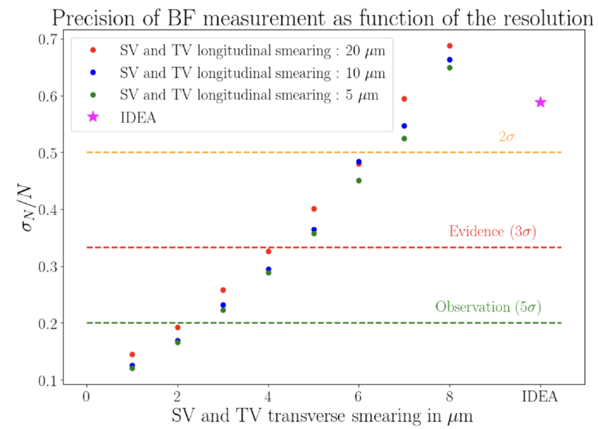
FCC-ee (M. Selvaggi presentation's)



p_T resolution B-field effect on Higgs mass resolution



inner layer radius effect on Higgs jet tagging



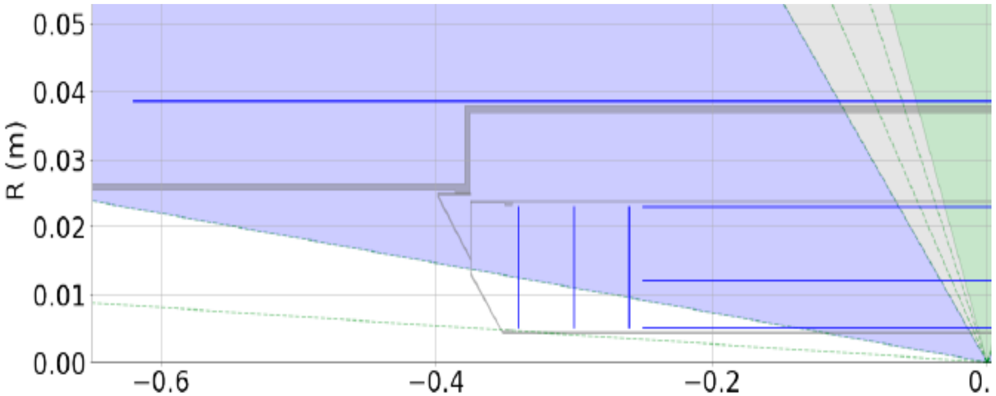
effect of Secondary and Tertiary Vertex transverse precision on S/N of Bs → K***ττ**

Initial requirements are not in asymptote of physics performance (also in M. Selvaggi's presentation)

* *complementary work in <u>ECFA Working Groups</u> with communities of other future lepton collider projects*

Vertex Detector configurations

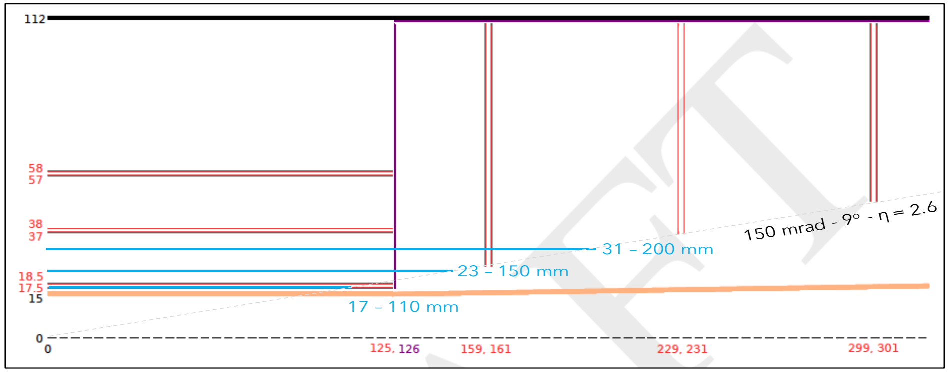
ALICE-3
VD within beam pipe



Layer	Material thickness ($\%X_0$)	Intrinsic resolution (µm)	Barrel layers Length ($\pm z$) (cm)	Radius (r) (cm)	Forward discs Position ($\|z\|$) (cm)	R_{in} (cm)	R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.50	3
1	0.1	2.5	50	1.20	30	0.50	3
2	0.1	2.5	50	2.50	34	0.50	3

Resolution balanced with expected X/X_0

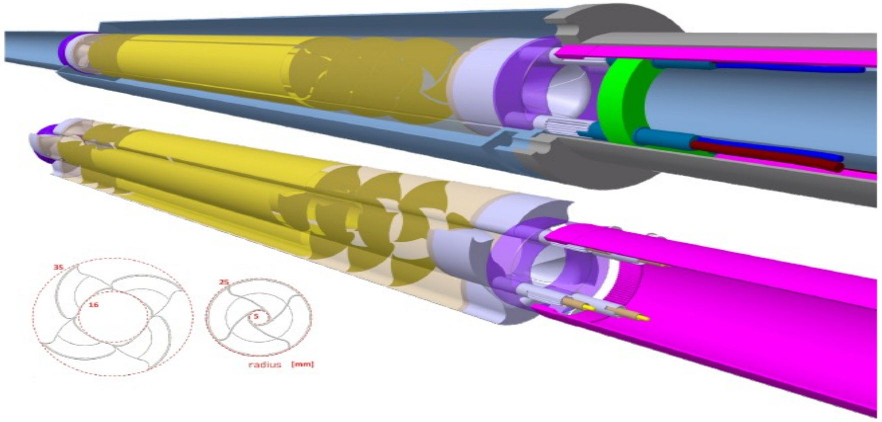
CLD / IDEA inner VD
to be scaled to new BP radius of 10 mm



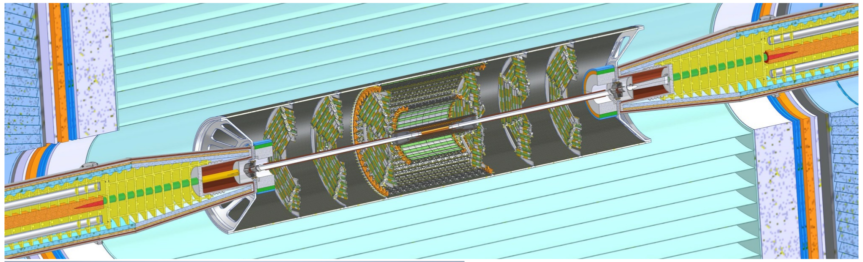
- CLD : 3 double layers/disks in Barrel/Endcaps
- IDEA : 3 single closer layers in Long Barrel
  - resolution 3 µm - $X/X_0 \simeq$ (2 x) 0.3 - 0.25 % / layer
  - $r_{BeamPipe}$ = 1 cm - X/X_0 = 0.3%

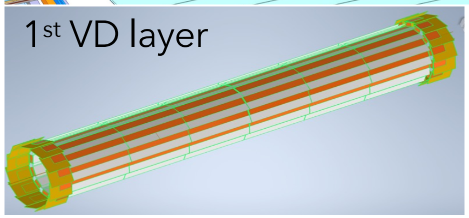
Vertex Detector designs

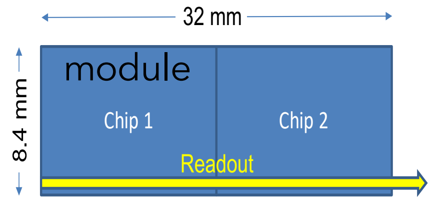
ALICE-3
iris mechanical concept



IDEA stave concept
(see F. Palla's presentation)



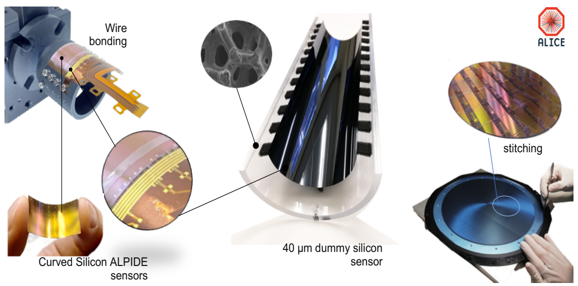




CO_2 colling at -35° micro-channel plate attached to Berylium case (250 μm) & 3rd layer
Monotlithic CMOS TPSCo 65 nm stitched - thin - bent sensors as for ITS3 (M. Mager's presentation)

Monolithic CMOS LFoundry 110 nm (ARCADIA) reticule size chips abutted in z, airflow cooling

Component	Material	Thickness (μm)	Radiation length (cm)	Radiation length ($\%X_0$)
Sensor	Si	30	9.37	0.032
Support	Be	250	35.28	0.071
Glue		50	35	0.014
Total				0.117



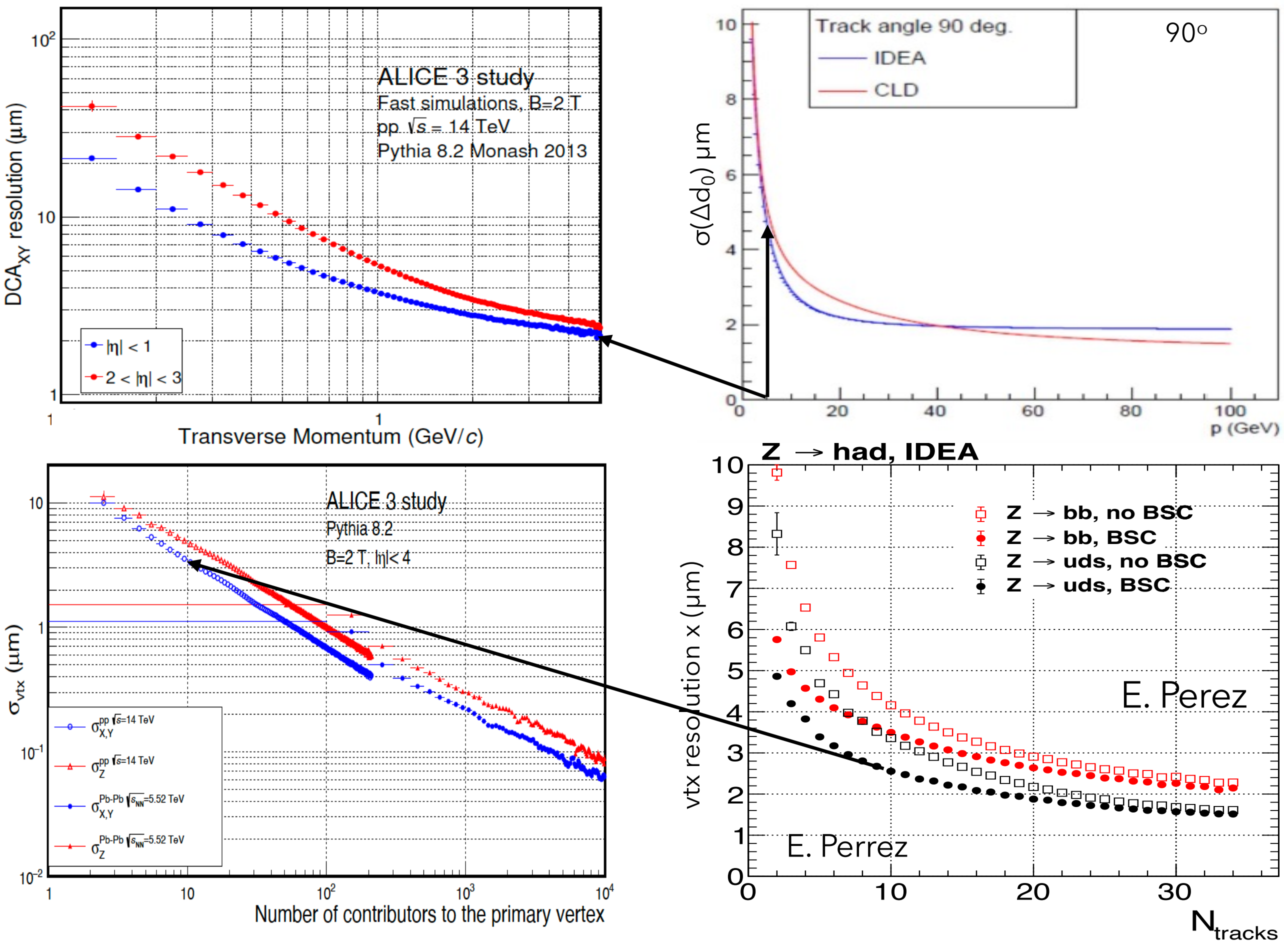
- an anlternative to stave design
- risks from SR is one possible show stopper to consider layers inside the beam pipe

Vertex Detector performance

ALICE-3 | CLD / IDEA (15 mm BP)

Impact parameter

Primary vertex

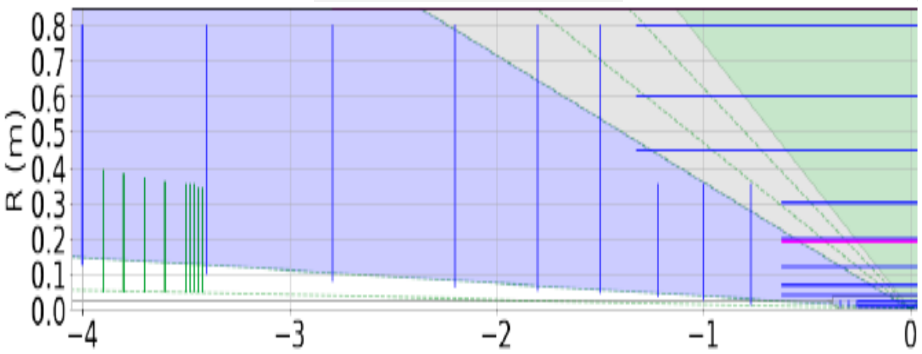


ALICE-3 x 2 better
with lower inner radius & X/X_0
IDEA detailed simulation in progress A. Ilg's presentation

FCC-ee benefits from the beam spot constraint

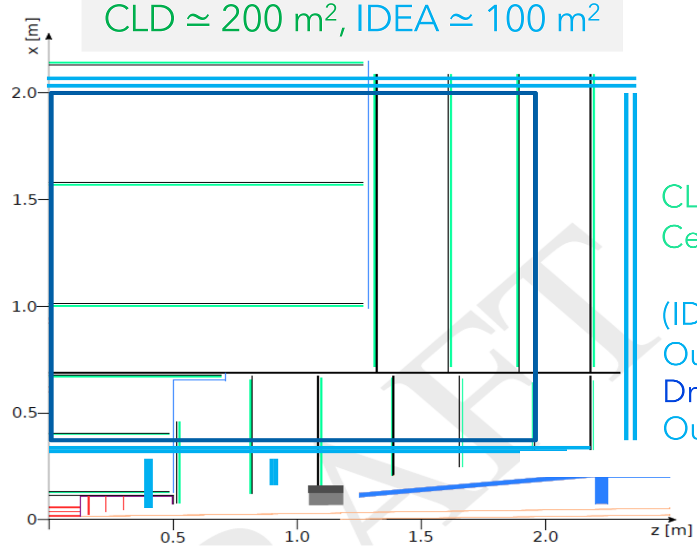
Central Tracking Detector configurations

ALICE-3 ≃ 60 m²



Layer	Material thickness ($\%X_0$)	Intrinsic resolution (µm)	Barrel layers Length (±z) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position (|z|) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
3	1	10	124	3.75	77	5	35
4	1	10	124	7	100	5	35
5	1	10	124	12	122	5	35
6	1	10	124	20	150	5	80
7	1	10	124	30	180	5	80
8	1	10	264	45	220	5	80
9	1	10	264	60	279	5	80
10	1	10	264	80	340	5	80
11	1				400	5	80

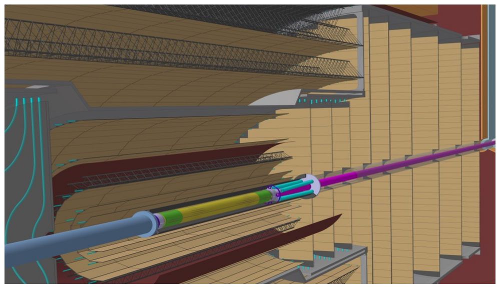
CLD ≃ 200 m², IDEA ≃ 100 m²



CLD : 6 layers and 9 disks

IDEA : 1-2 layers surrounding DCH

- ball park 5-7 µm resolution & 1 – 2 % X/X_0 inside-out

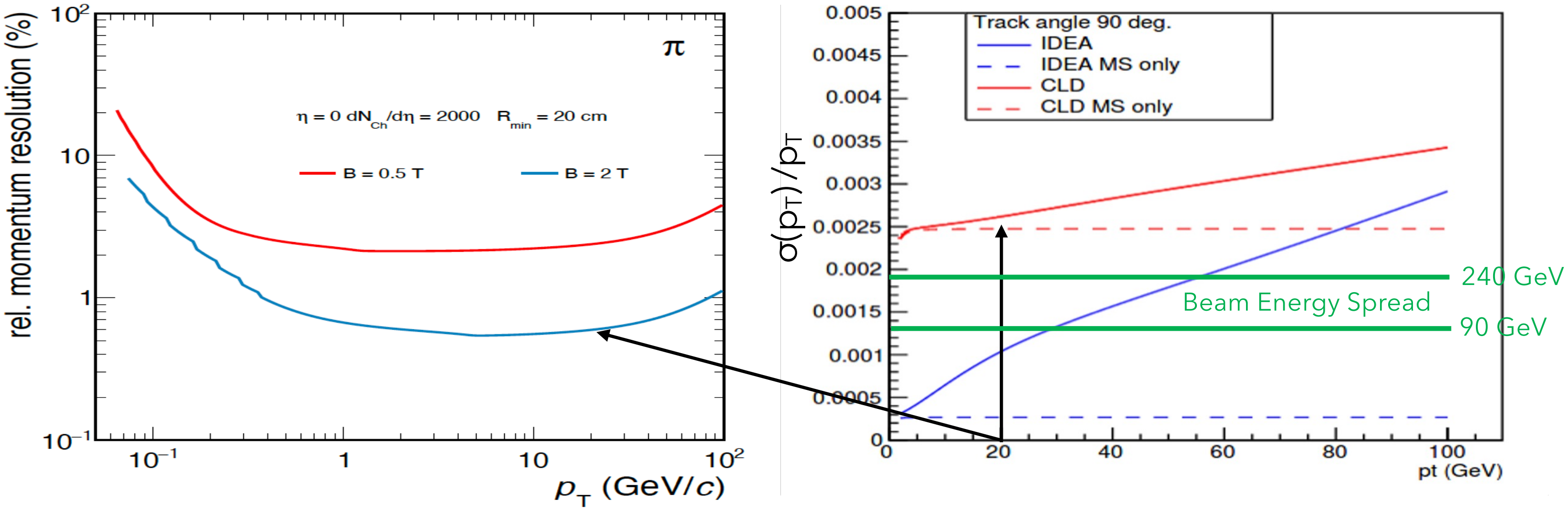


ALICE-3 stave concept inspired from ITS2

- 10 x 10 cm² modules of Monolithic CMOS reticle size sensors (≃ 8 cm²)
- commercial module production
- water cooling at room temperature
- ➢ Stitched sensors are considered, pending full characterization

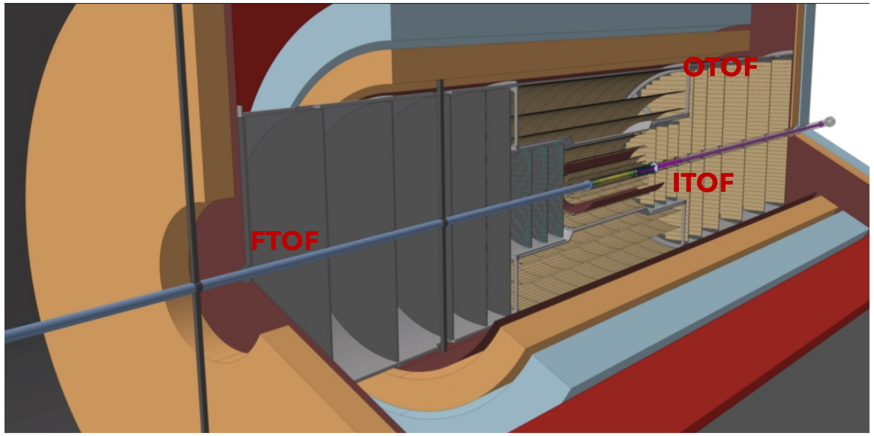
Central Tracking performance

ALICE-3 CLD / IDEA



FCC-ee CLD better with x 2 larger outer radius however need to improve X/X_0

ALICE-3 Particle ID configuration and technology



	Inner TOF	Outer TOF	Forward TOF
Radius (m)	0.19	0.85	0.15–1.5
z range (m)	−0.62–0.62	−2.79–2.79	4.05
Surface (m^2)	1.5	30	14
Granularity (mm^2)	1×1	5×5	1×1 to 5×5
Hit rate (kHz/cm^2)	74	4	122
NIEL (1 MeV n_{eq}/cm^2) / month	1.3×10^{11}	6.2×10^{9}	2.1×10^{11}
TID (rad) / month	4×10^{3}	2×10^{2}	6.6×10^{3}
Material budget ($\%X_0$)	1–3	1–3	1–3
Power density (mW/cm^2)	50	50	50
Time resolution (ps)	20	20	20

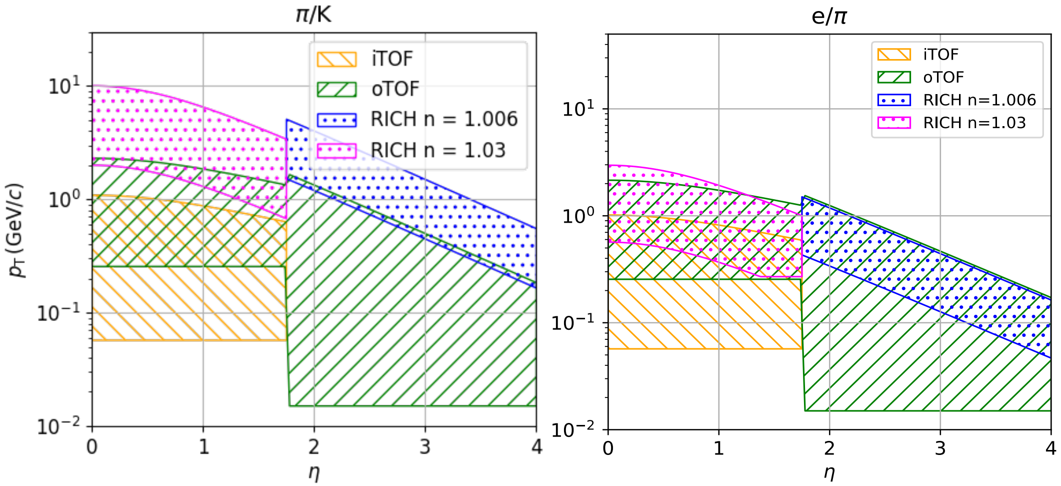
Technology options

- Monolithic CMOS with amplification layer (ex. ARCADIA) - baseline
  - channel grouping after front-end toward TDC at the matrix periphery
- Thin LGADs with pads
- Alternative/complementary option with ToF from RICH readout with SPADS
- ➢ R&D on power consumption to allow higher channel density (integrate ToF in tracking layer)

ALICE-3 Particle ID performance

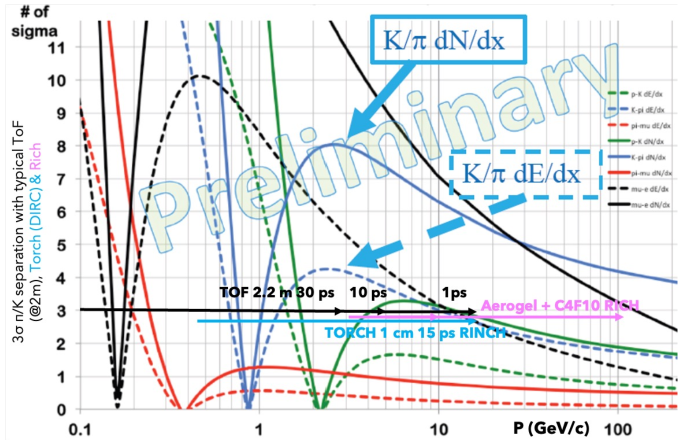
ALICE-3 PID

p_T range vs η with 3σ separation versus η
complementarity of ToF layers and aerogel RICH



IDEA

3σ separation momentum
complementarity of ToF layer at 2 m and DCH



Beyond PID, interest for precision O(≲ 10) ps for correction of BES within bunches
4D tracking would also allow to reduce beam background (if it does not affect X/X_0)

Summary comparison of today's requirements including operation conditions

			ALICE 3	FCC-ee
Vertex Detector[3]	MAPS Planar/3D/Passive CMOS LGADs	Position precision (µm)	2.5	3
		X/X_0 (%/layer)	0.1	0.1
		Power (mW/cm^2)	70	tbd
		Rates (MHz/cm^2)	100	50
		Wafer are (cm^2)	25 x 10	tbd
		Time bin/precision (µs)	0.5/0.1	1
		NIEL (1 eV neq/cm^2)	1×10^{16}	?
		TID (rad)	300×10^{6}	?
Tracker[6]	MAPS Planar/3D/Passive CMOS LGADs	Position precision (µm)	10	7
		X/X_0 (%/layer)	1	1
		Power (mW/cm^2)	20	tbd
		Rates (kHz/cm^2)	1 - 5	
		Wafer are (cm^2)	2.6 x 3.2	tbd
		Time bin/precision (µs)	0.5/0.1	1
		NIEL (1 MeV neq/cm^2)	5×10^{9}	
		TID (rad)	1.5×10^{2}	
Time of Flight[8]	MAPS Planar/3D/Passive CMOS LGADs	Timing precision (ps)	20	tbd
		Granularity (mm)	1 x 1 5 x 5	
		Power (mW/cm^2)	50	tbd
		Rates (kHz/cm^2)	74/4/120	
		NIEL (x 10^{11} neq/cm^2)	2×10^{11}	
		TID (rad)	7×10^{3}	

Most constraining conditions in VD

- Maximum rates have same scale in ALICE-3 and FCC-ee
- Integration time have same scale in ALICE-3 and FCC-ee
- NIEL and TID likely more constraining in ALICE3

➢ Work in progress in MDI to reassess FCC-ee conditions with more realistic simulations (A. Ciarma's presentations)

Power consumptions*

- VD ≃ 70 mW/cm^2, CT ≃ 20 mW/cm^2 ALICE-3
- TL ≃ 50 mW/cm^2 (ARCADIA)

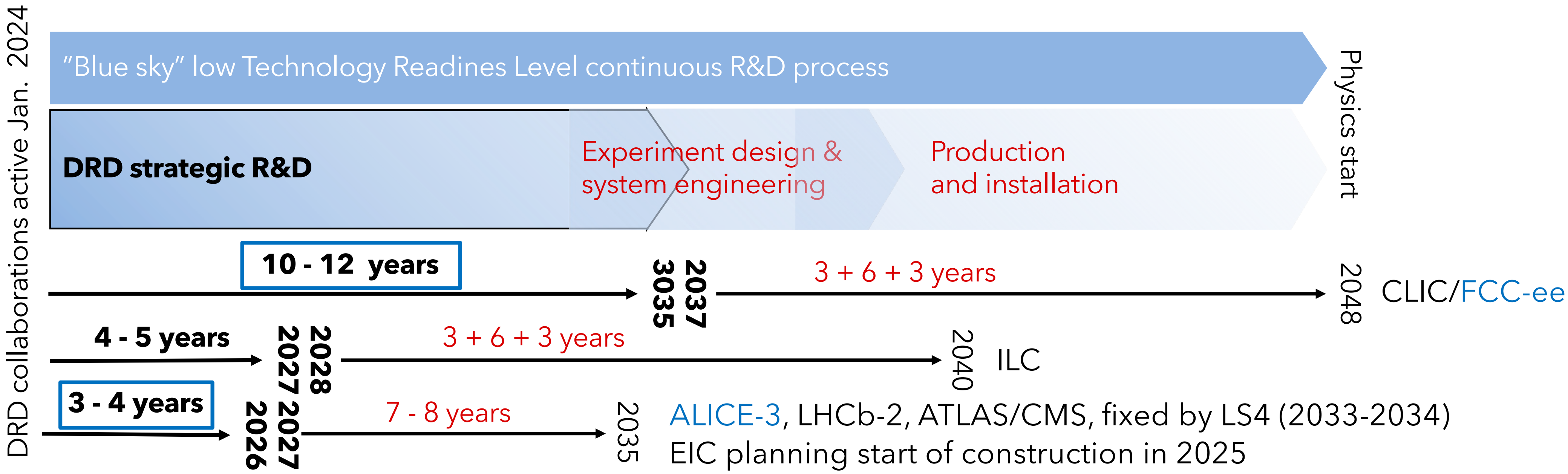
➢ Slightly less constraining conditions at FCC-ee may help, a priori similar model for architecture ?

Radiation tolerance

- should be within SoA MCMOS technology limit assuming operation at -25° temperature

** Depending on channel density, timing precision, rates, technology, RO architecture, sensor size through power distribution*

Broad brush timeline of ECFA roadmap strategic programs*



** Not exhaustive, now BELLE considering 3rd upgrade at high luminosity, Muon Collider new timeline from Snowmass, and also CEPC*

Summary

ALICE-3 and current FCC-ee detector performance targets are in the same ballpark
smaller radius for inner layer improves IP resolution in ALICE-3
larger outer radius in FCC-ee improves momentum resolution

R&D topics
main challenge to lower X/X_0 (VD, but also CT to reach FCC-ee BES limit)
needs optimization of resolution versus X/X_0 (realistic description), drives channel density/power
needs realistic rates to design readout architecture
yield and fill factor need to be assessed for stitched sensors
low power RO is a major challenge, determines channel density achievable vs timing precision and rates
system integration and cooling are crucial elements (including approach to beam line)
track timing precision < 20 ps is another challenge for sensors …
radiation tolerance seems within current state of the art performance

Main R&D goals are common to several other projects
CERN DRD3 collaborations are being formed to organize R&D
ALICE-3 is a stepping stone with a relatively short timescale
new steps in technology are likely needed and possible to improve performance by FCC-ee