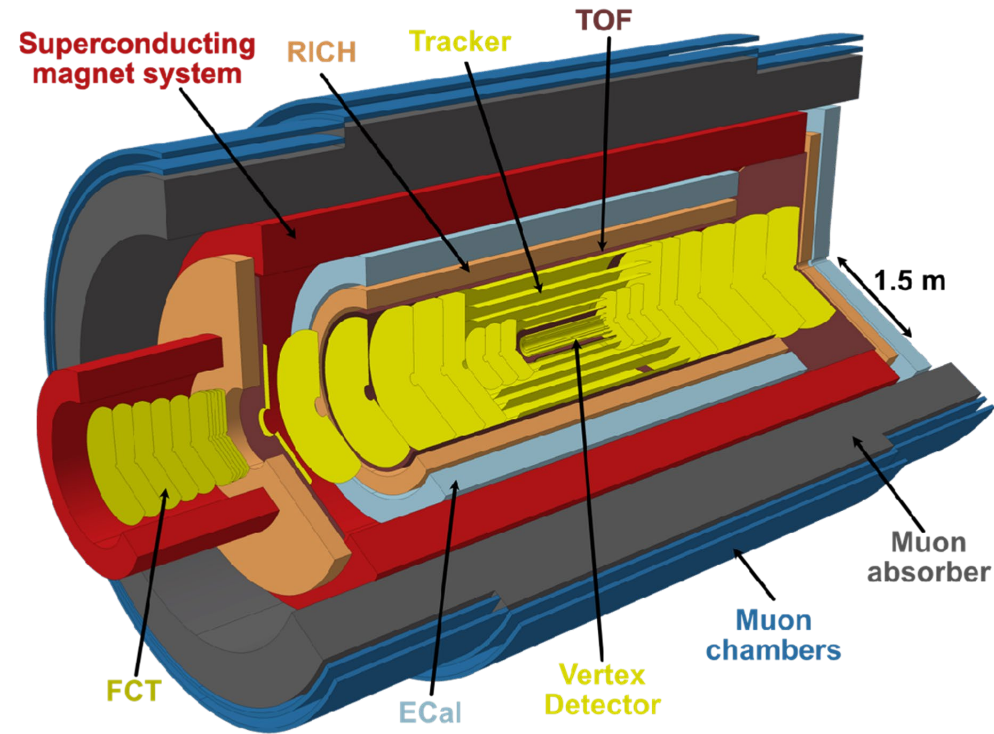


ALICE

R&D for ALICE 3 Inner Tracker

BA, BS/PV, CA, CT/ME, PD, LNF, TO, TS

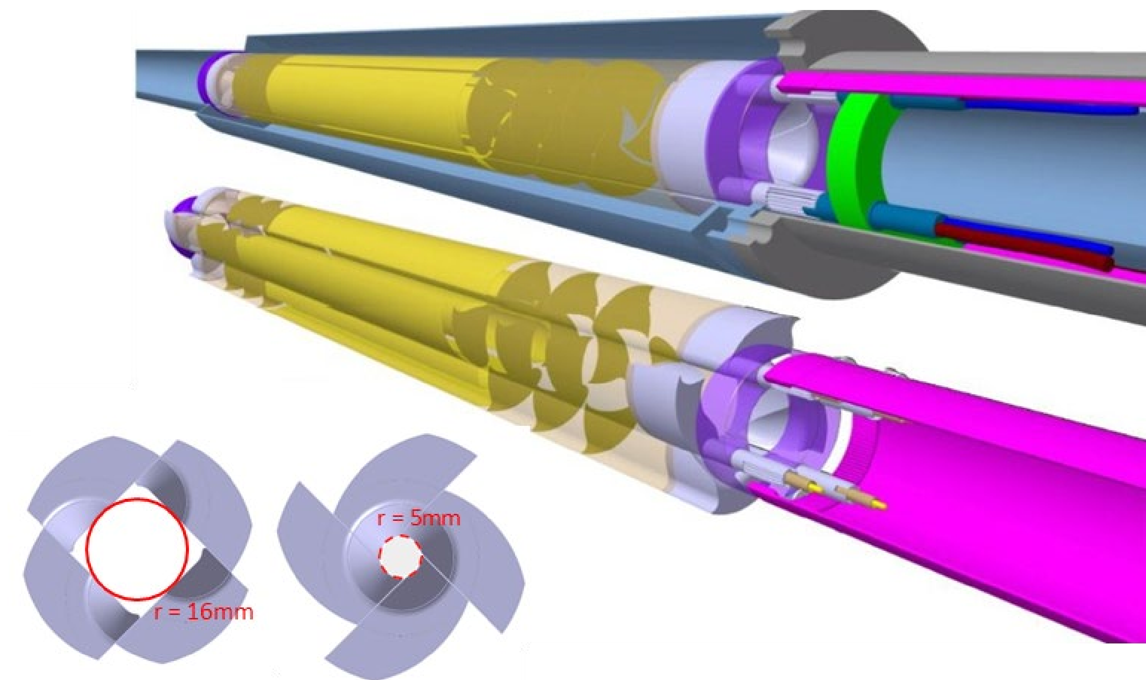
ALICE 3 Inner Tracker: Vertex Detector (Iris)

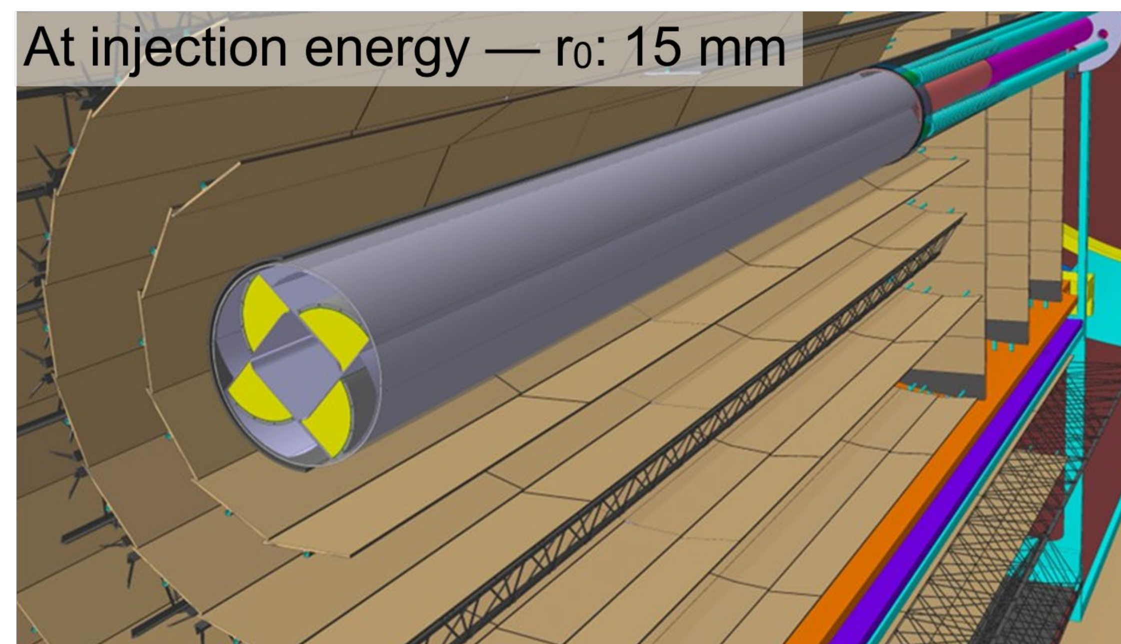
ALICE

3 barrel layers of ultra-thin, curved, wafer-scale MAPS

- **Unprecedented pointing resolution:** radius and material of first layer crucial
- Retractable structure inside the beam pipe **secondary vacuum**
- First detection layer at **5 mm from the interaction point**

INFN R&D on
Vertex Detector (= Iris)





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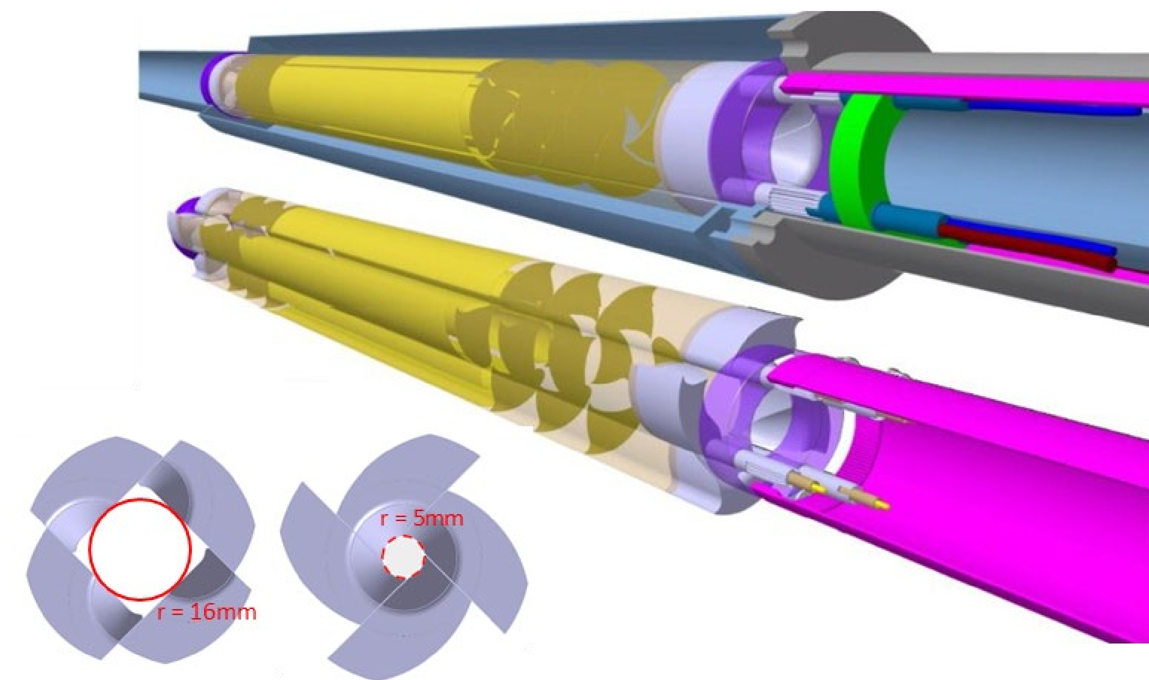
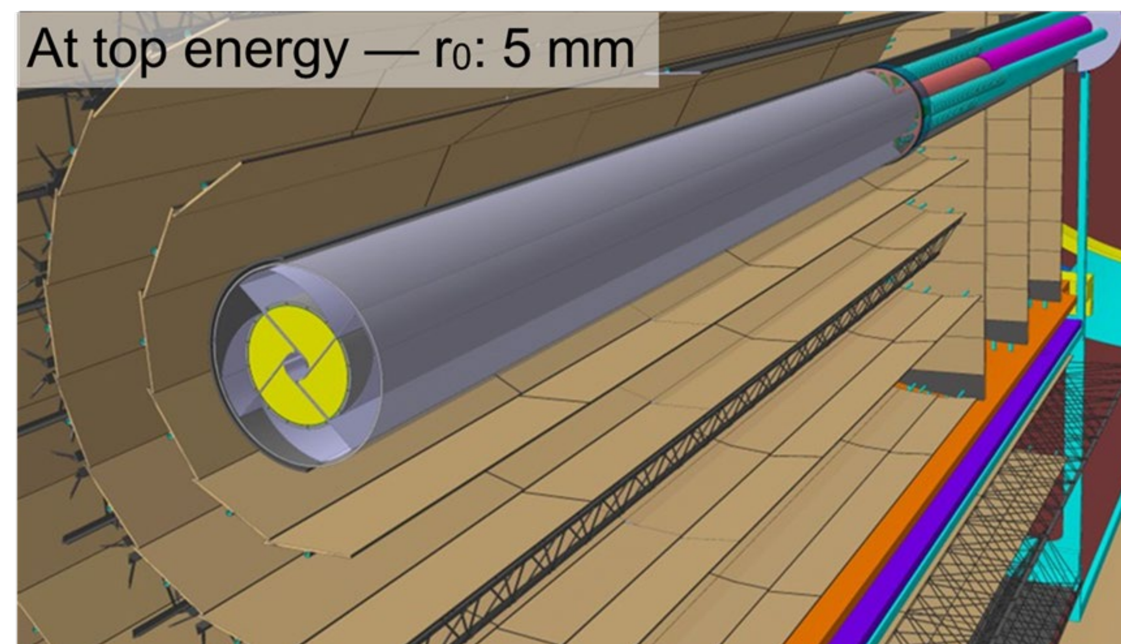
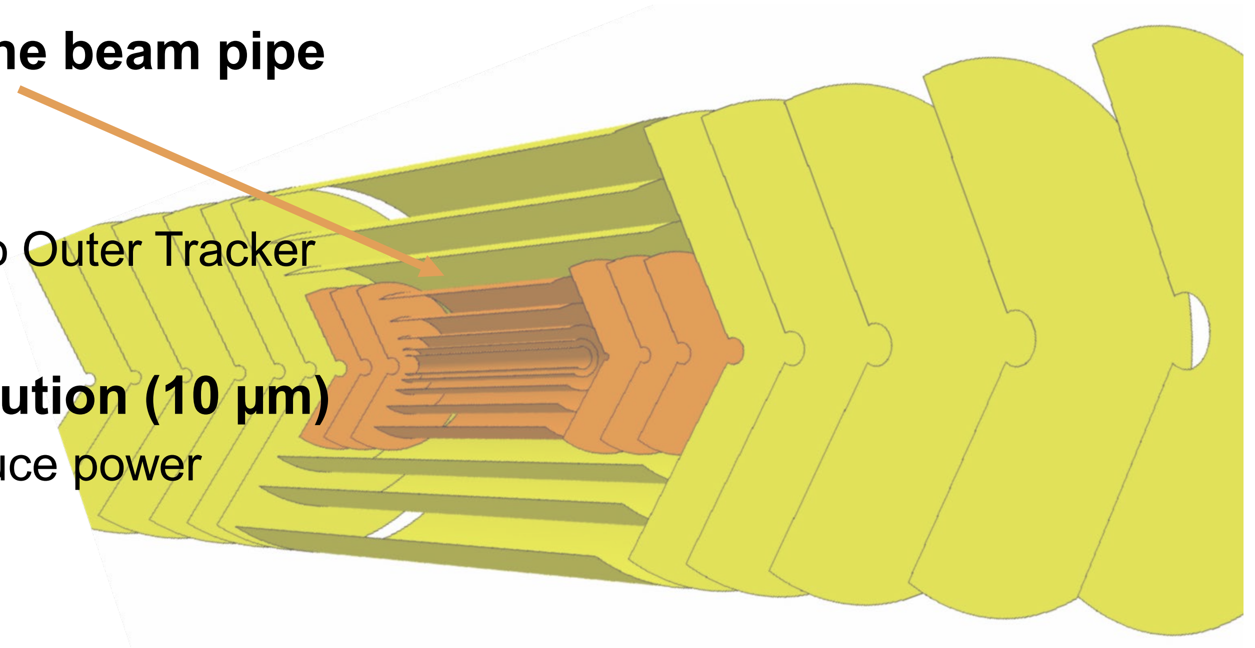




ALICE 3 Inner Tracker: Middle Layers

- **Middle Layers: first (up to 4) layers outside the beam pipe**
  - 6.5 cm < r < 20 cm
  - Surrounded by Inner TOF layer
  - LOI option: standard module/stave layout, similar to Outer Tracker



- **Less stringent requirement on position resolution (10 µm)**
  - Will allow for larger pixels/grouping of pixels to reduce power
  - Reducing the noise contribution to the bandwidth

- **A specific design for the Middle Layers:**
  - **Minimal material** (→ 0.1% X0) and optimized sensor
  - **Improved tracking** of secondaries and pT resolution at very low pT
  - **Reducing power** consumption will be key
  - Challenging power distribution and **services routing**

INFN R&D on Middle Layers

R&D INFN su Inner Tracker = Vertex + Middle Layers

- Sviluppo del **sensore ALICE 3 Inner Tracker**
  - Sensore ITS3 e' il primo passo dello sviluppo del sensore per ALICE 3 Inner Tracker
  - Per 2025 non c'e' richiesta dedicata per ALICE 3 chip
- Indispensabile **anticipare alcune attivita'** per preparare il terreno per il chip per ALICE 3
  - **Porting del readout** da ITS3 a sistema ALICE 3 per essere pronti a testare il futuro chip
  - **Risk mitigation**: Strato di ridistribuzione con manifattura additiva per portare la tensione su grandi distanze

			2023 (Q1 Q2 Q3 Q4)	2024 (Q1 Q2 Q3 Q4)	2025 (Q1 Q2 Q3 Q4)	Q1
			Run 3	Run 3	Run 3	
TPSCo 65m Engineering Runs				ER2 (ITS3)	ER3 (ITS3)	
Inner Tracker	Vertex Detector	Chip	Study of ITS3 prototypes wrt. use in ALICE3 VD			
		Petals		Design	Prototyping	
		Beam pipe		Design	Prototyping	
		Mechanics		Design	Prototyping	
		Cooling Plant			Design	
		Services			Design	
	Middle Layers	Chip	Study of ITS3 prototypes wrt. use in ALICE3 ML			
		Module		Design	Prototyping	
		Mechanics		Design	Prototyping	
		Services		Design		Prot
		Detector				

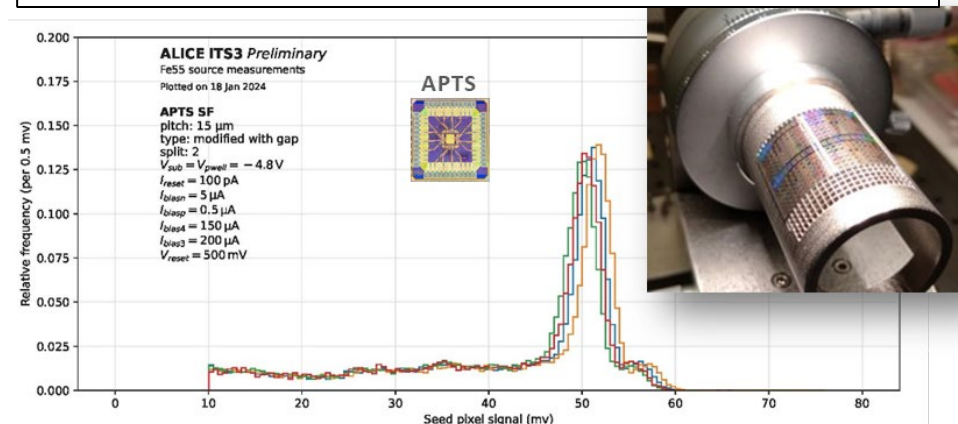
from ALICE 3 schedule

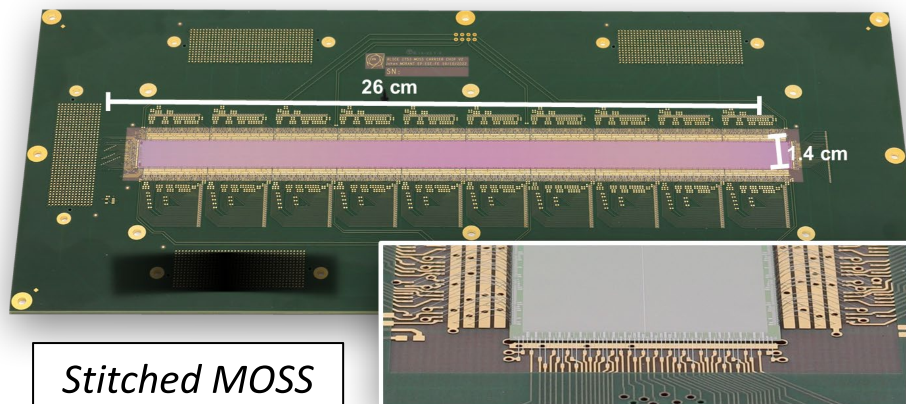
- Sviluppo **tecnologie compatibili col vuoto** per Iris
  - Meccaniche, sistema di raffreddamento, interconnessioni, materiali e colle
- Esplorazione comparata di **diversi layout dei Middle Layers e sviluppo delle meccaniche globali**

ALICE 3 Tracker sensor

- **ITS3 MAPS sensor** development as **stepping stone towards ALICE 3**
- All **Inner Tracker INFN groups** are working on ITS3 sensor:
  - 65 nm **CMOS sensor design**
  - **Stitched large-area sensor characterization**
  - **Bending techniques** and curvature effects measurements
  - Test and **readout system development**
  - Running MAPS **detector operations and maintenance**

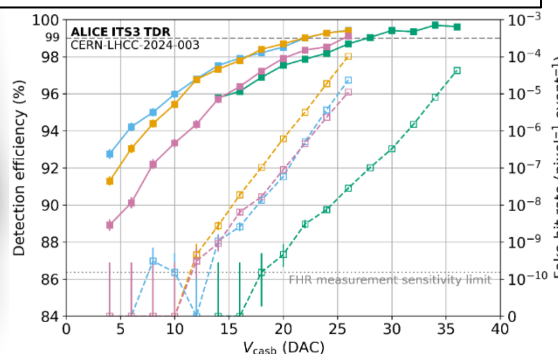
Unchanged collection properties of bent sensors



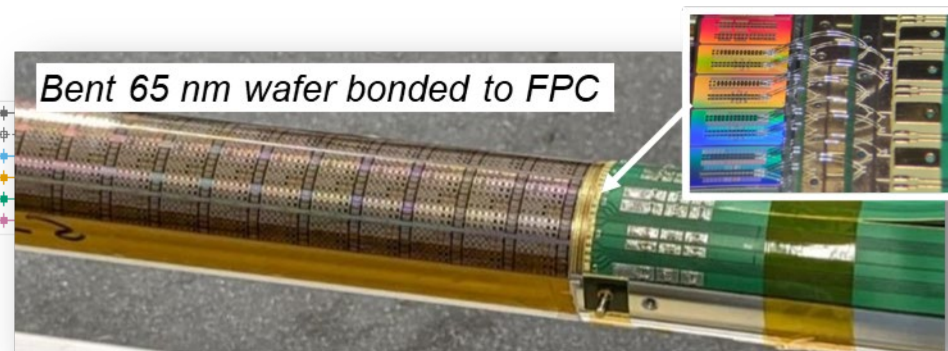


Stitched MOSS & babyMOSS

Stitched MOSS detection efficiency and fake-hit rate



Bent 65 nm wafer bonded to FPC



INFN BA, BS/PV, CA, CT/ME, PD, LNF, TO, TS

R&D for ALICE 3 Inner Tracker readout in 2025

- Nessuna richiesta specifica per il sensore, ma necessita' di cominciare nel 2025 lo **sviluppo del sistema di readout e test** compatibile con infrastrutture di ALICE 3
- ALICE 3 Inner Tracker readout system basato su **FELIX board**
  - Implementa protocollo lpGBT per trasferimento dati e controllo
- Nuova attivita': *porting* del firmware readout da CRU (ITS3) a FELIX system (ALICE 3)

INFN CA

- Cagliari - Acquisto FELIX board e server per sviluppo firmware **12 k**

ALICE 3 Vertex Layers (Iris): Vacuum technology

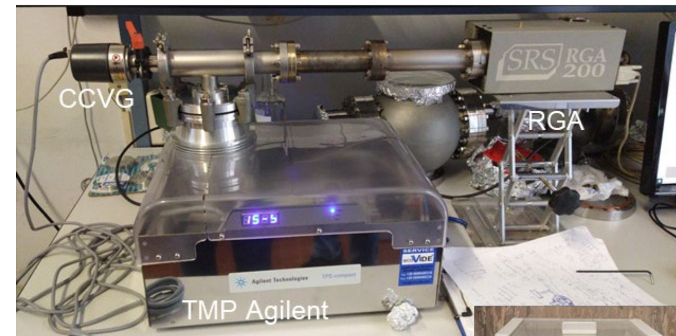
Iris will operate in **10^{-11} mbar** secondary vacuum

- All the materials and components have to be vacuum-compatible

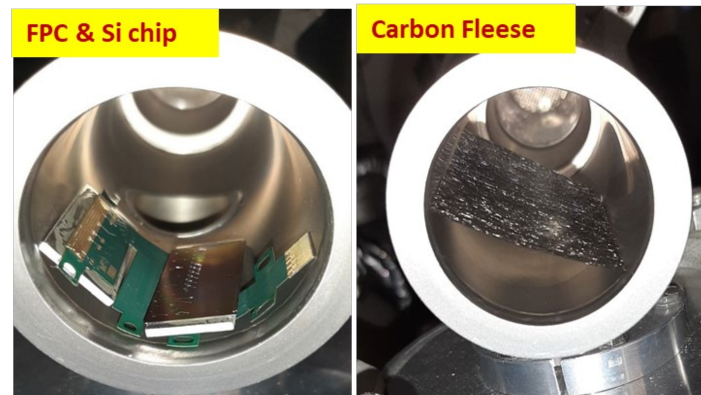
Existing facility for vacuum studies being upgraded **(INFN BA)**

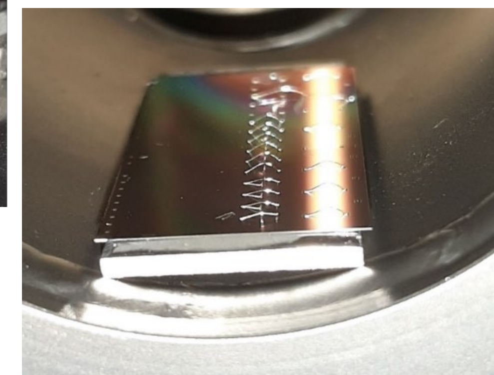
Vacuum studies in 2023/2024 (**~10^{-6} mbar**):

- Outgassing measurements down to 10^{-6} mbar
  - vacuum level comparison
  - a.m.u. behaviour of residual gasses
  - sample weight comparison (*after outgassing*)
- Stress measurements on mechanical assembly
  - gluing
  - wire-bonding



Existing equipment





Wire-bonding samples

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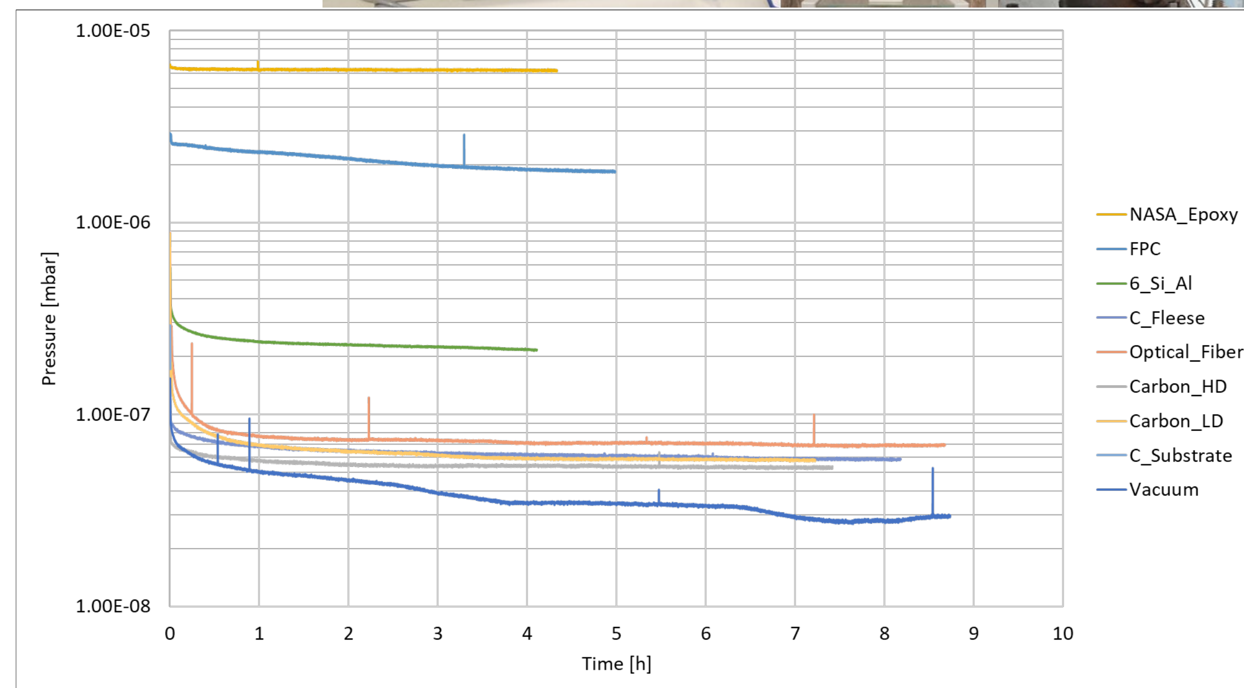

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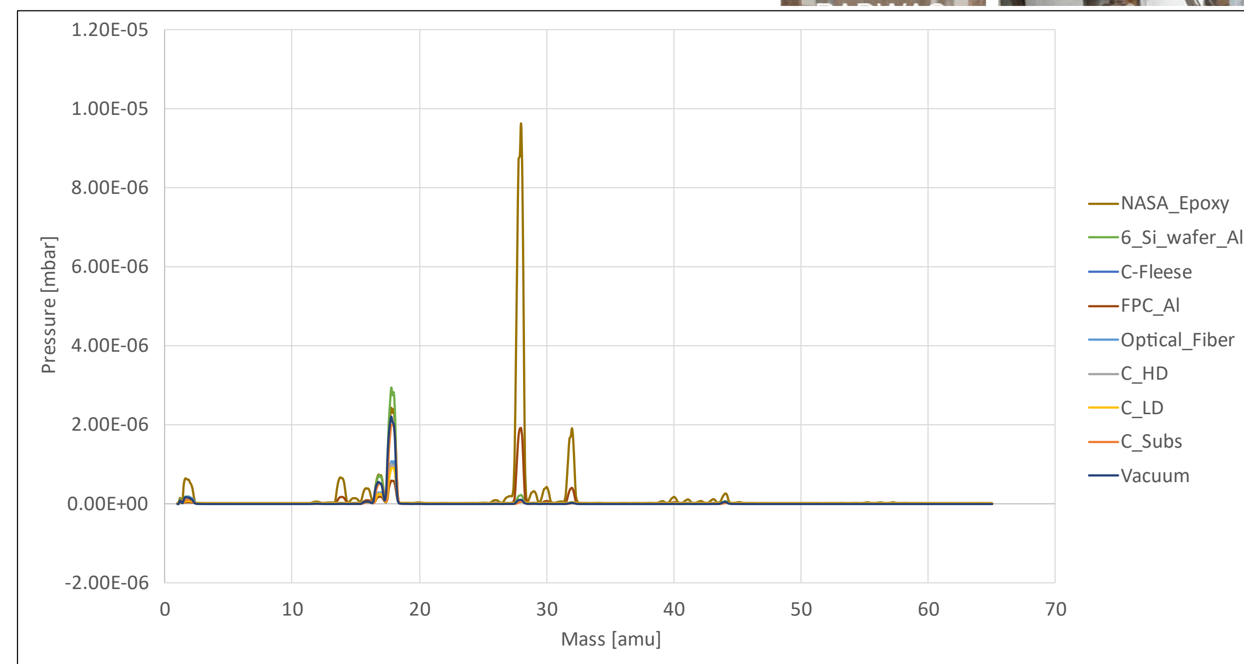
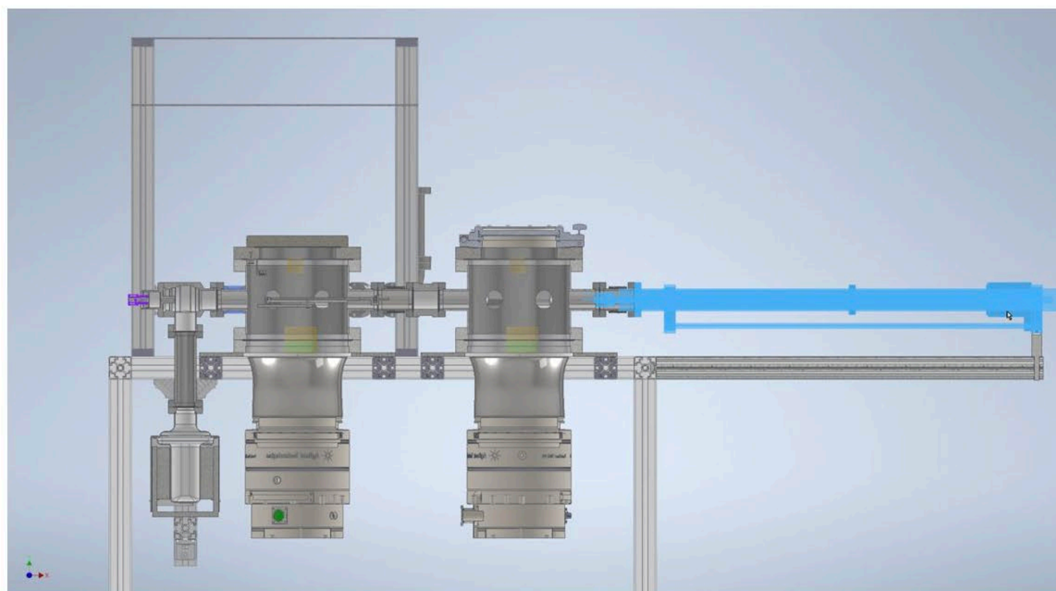


R&D for vacuum technology in 2025

- Bari – nuovo setup per studio outgassing fino a **10^{-11} mbar** con camera piu' grande per ospitare interi 'moduli' Vertex Detector
  - Acquisto sistema per vacuum bakeout delle camere **~5 k**
  - Valvole, connessioni feed-through e gasket in rame per nuova camera **~12k**

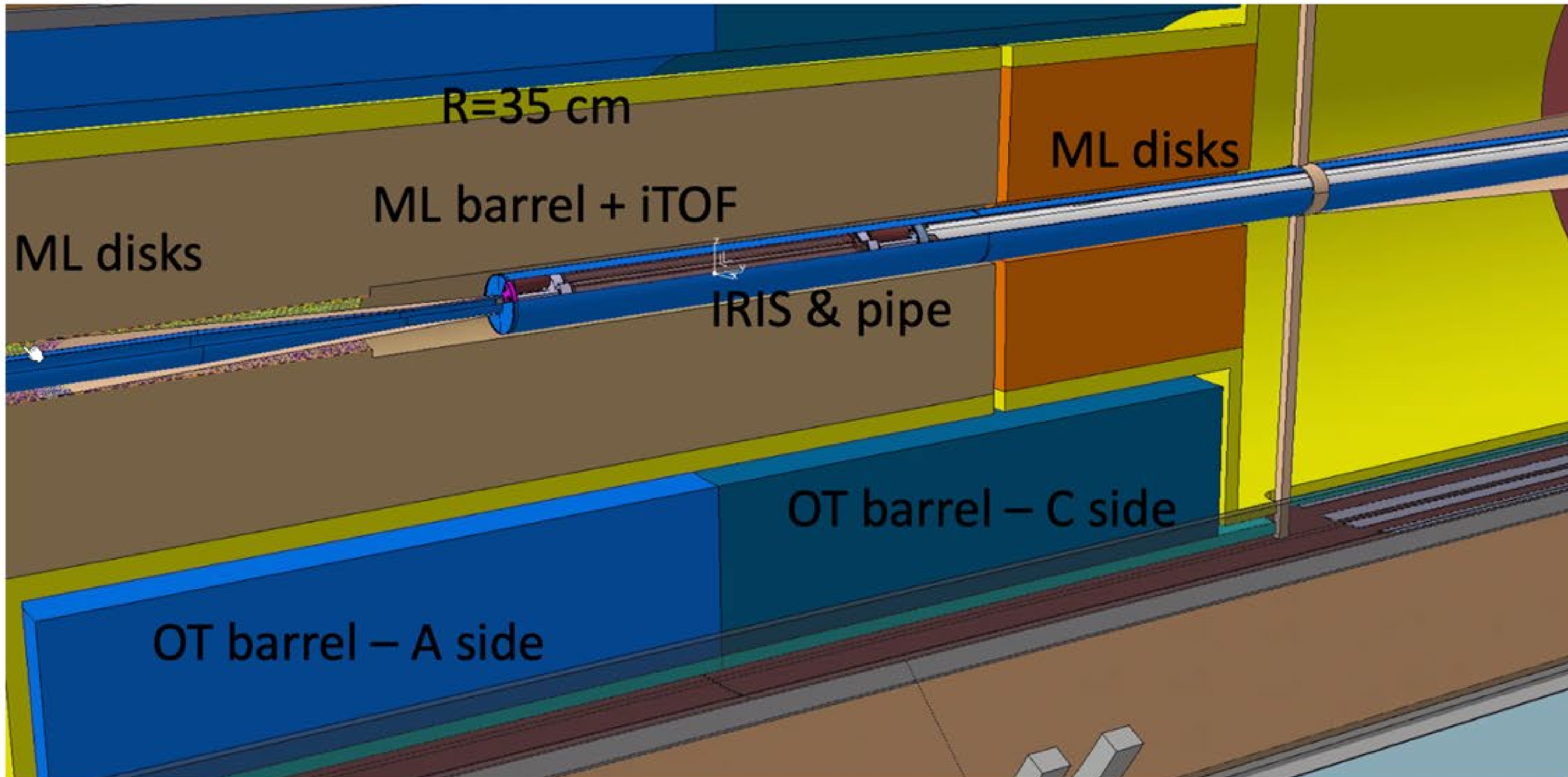
Old Setup

New Setup (CAD) : 10^{-10} - 10^{-11} mbar -> IRIS vacuum level



INFN BA

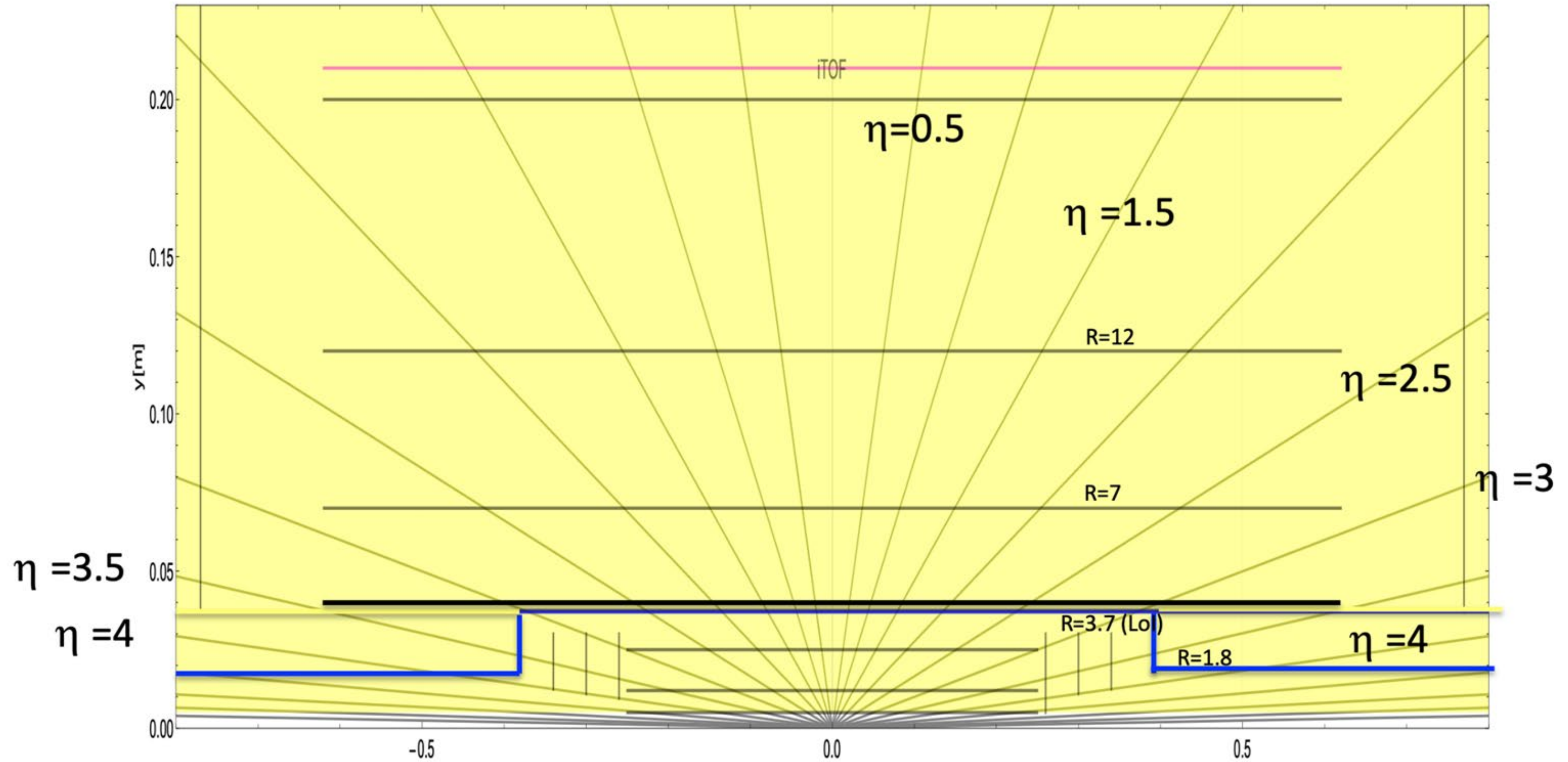
Updated envelope for Middle Layers (Feb 2024)



Pipe Radius:
- 57 mm (central and C side)
- ~18 mm (A side)

Disks Inner Radius:
- 65 mm (C side) → eta~3.2
- 50 mm (A side) → eta~3.5

Updated envelope for Middle Layers (Feb 2024)



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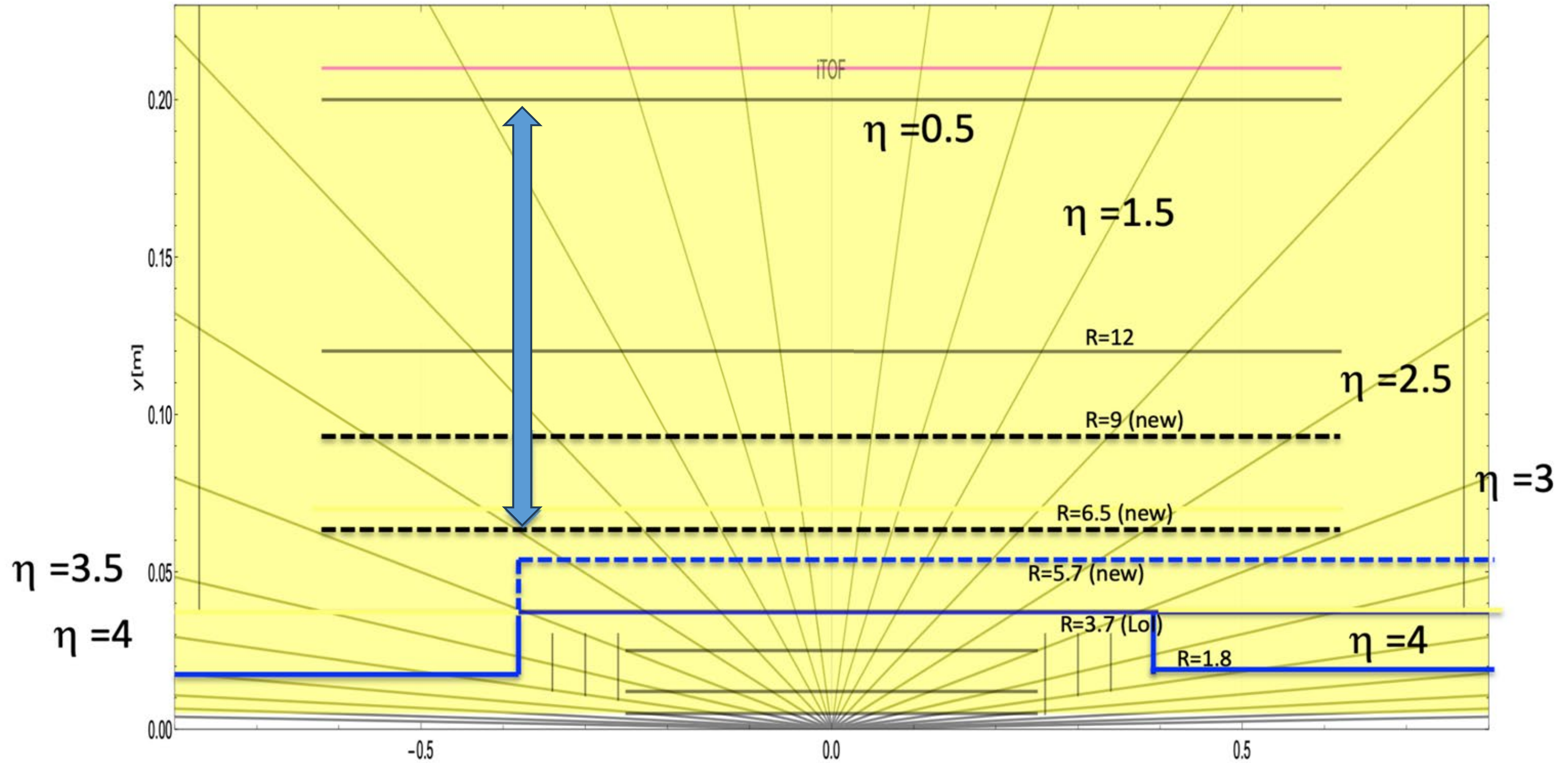
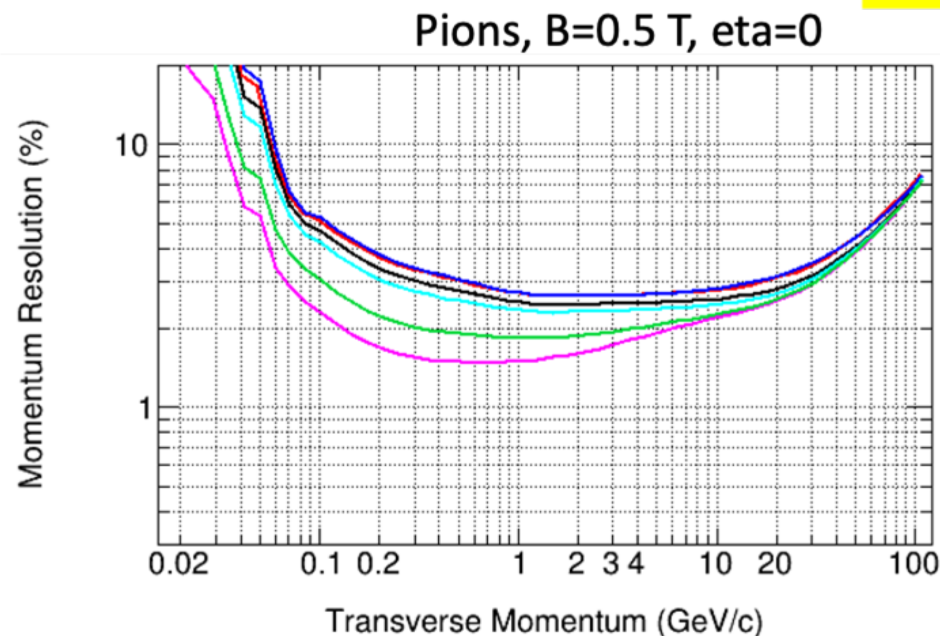
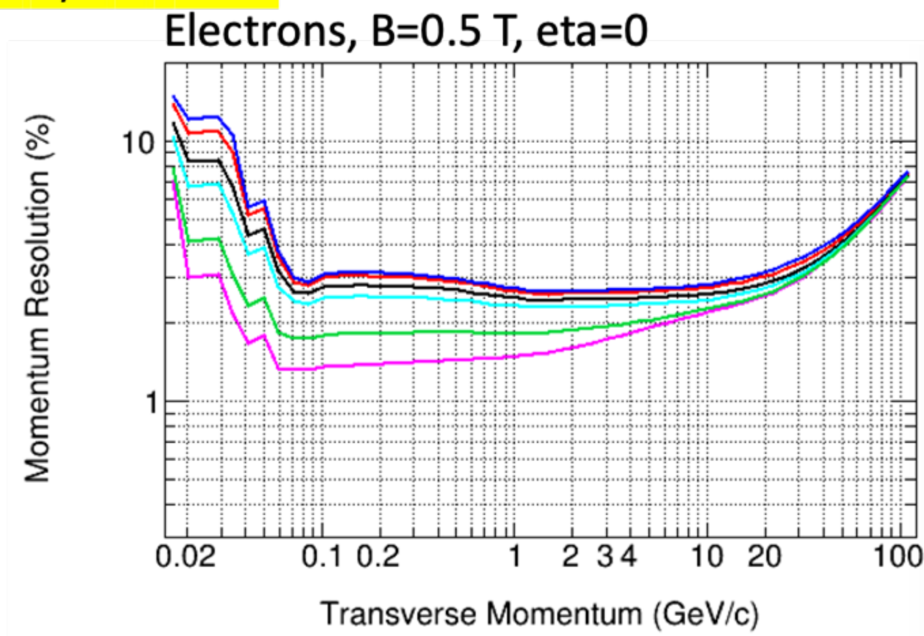


Impact of ultra-light ML on tracking

ML (Layers 7, 10, 13, 16 cm): Thickness: x/X0: 0.05, 0.1, 0.3, 0.5, 1, 1.5%

without layer at R=20cm



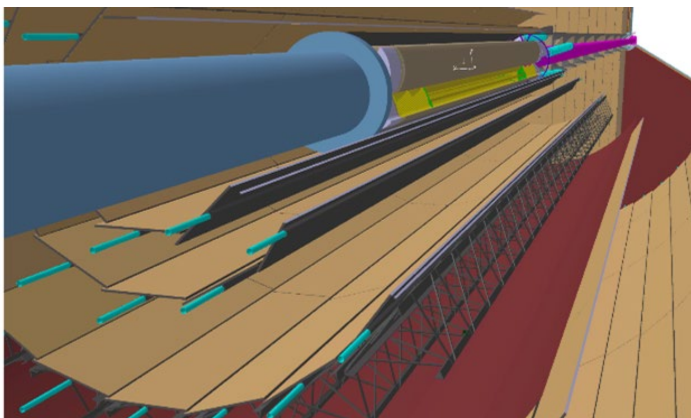


- **2x improvement of resolution at p_T = 50 MeV with x/X_0 < 0.1%**
- Improved secondary vertex reconstruction
- Increase of Xi_{cc} acceptance

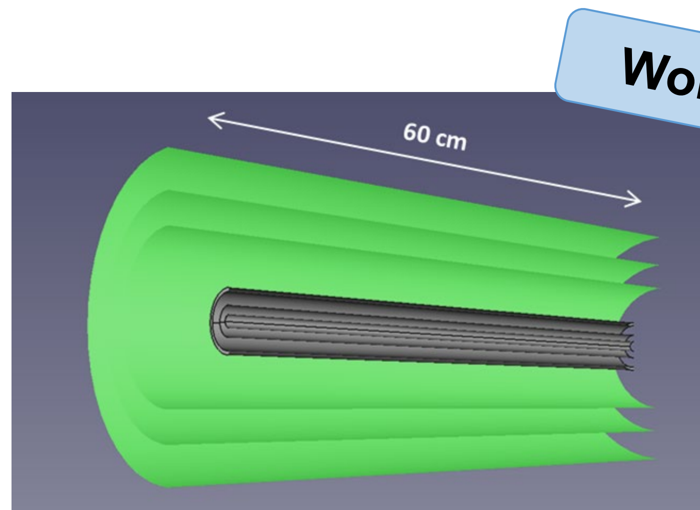
Milestone 2024 (31/12/2024): Studio comparativo per la progettazione dei Middle Layers dell'Inner Tracker

ALICE 3 Middle Layers (ML)

- Specific layouts being proposed for **Middle Layers**
  - 3-4 layers outside the beam pipe (r < 20 cm)
  - **Material budget reduction from 1% to 0.1%** beneficial for secondary particles and soft e^-

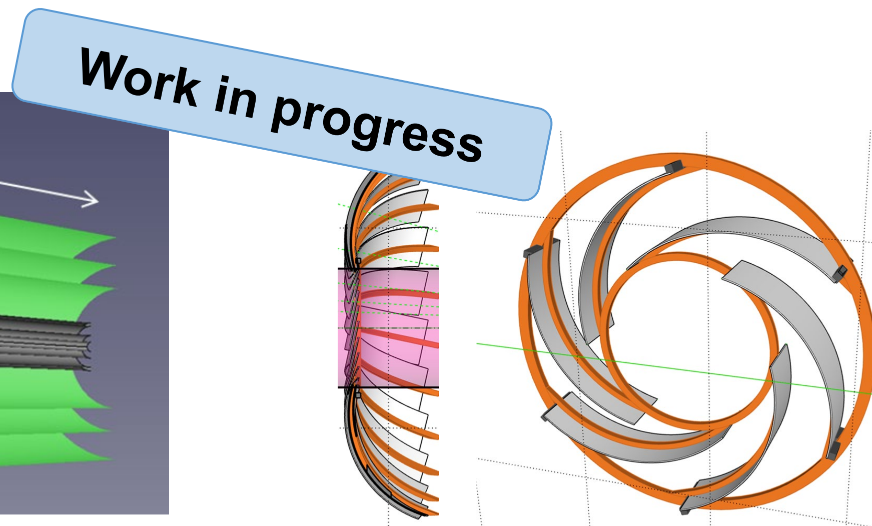


Standard staves/module layout (LOI)



ITS3-like bent large-area sensors

Work in progress



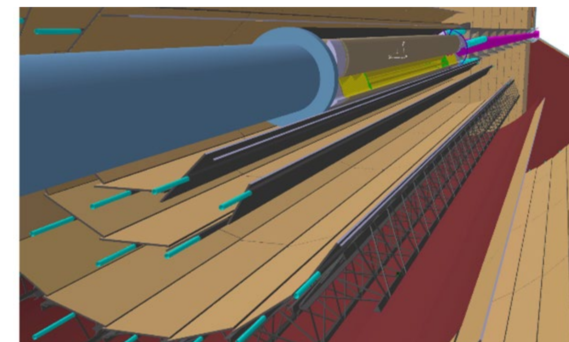
Novel wheel/blade layout

- Each options needs to be verified in **simulation** and with **prototypes**
  - **Routing of services** is crucial to minimize the material budget
- **Global mechanics** will be developed, also in synergy with TOF layer
  - Mechanical structure prototype for Middle Layers and interface to TOF

INFN PD - TO - TS

ML: ITS3-like truly-cylindrical layout

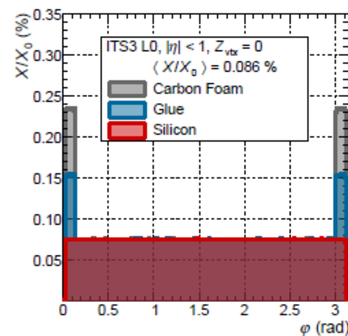
- Evaluating how to minimize material in the standard module/stave layout
  - 1% (LoI) - low uniformity [based on ITS2 OB]
    - Mechanics: sheet carbon layers with embedded polyimide water cooling pipes
    - FPC: Cu → Al: -0.1% → 0.9%
    - remove water cooling: -0.2% → 0.7% - air cooling to be demonstrated

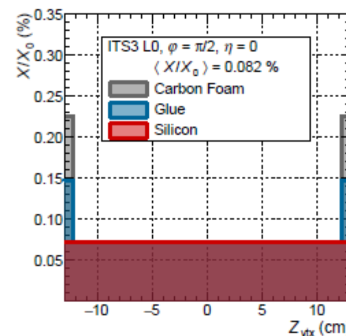


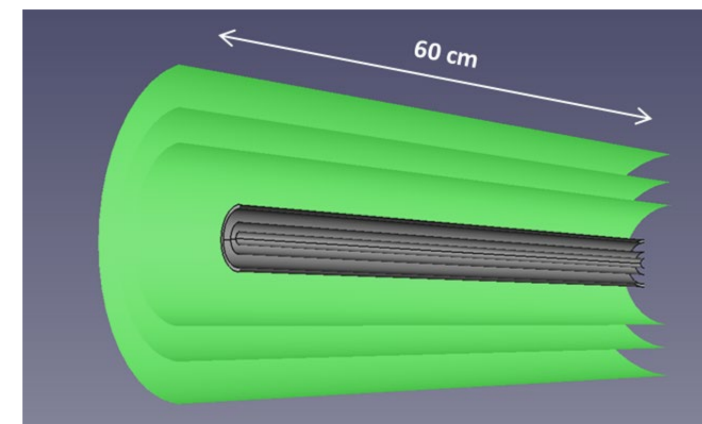
- Alternative layout based on bent silicon cylinders, as for ITS3
  - 0.1 - 0.2 %
    - ITS3: 0.09% average - 0.07% on most of phi [based on ITS3 TDR]
    - Route aluminum FPC or alternative power distribution nets minimizing impact on tracks
    - Add longerons along phi, add rings along z for increased segmentation

INFN PD - TS

ITS3-like approach with increased segmentation in z and phi





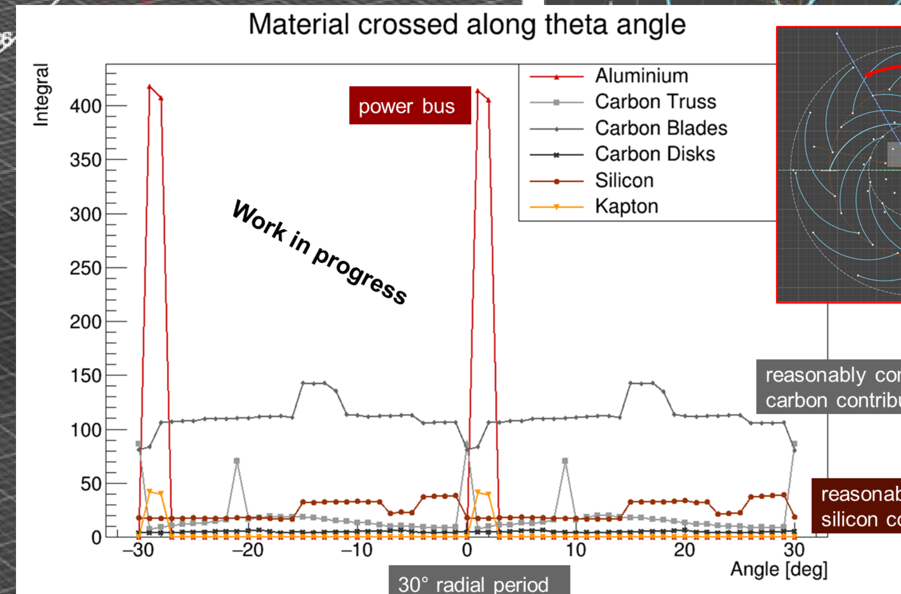


ML: Blade/wheel layout – 100 μm C + 50 μm Si

INFN PD

ALICE

Work in progress



ALICE 3 IT sensor post-processing for module

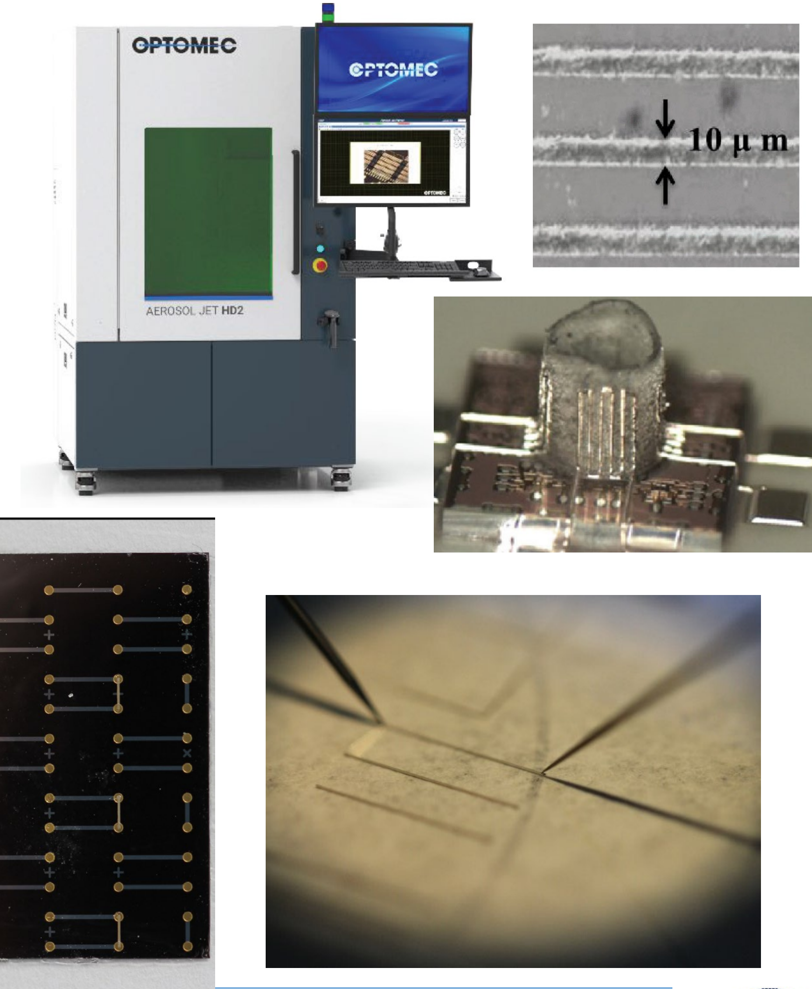
- Development of alternative way to distribute power and data over long distances for risk mitigation

- Application of a **Re-Distribution Layer** (RDL) with additive manufacturing
  - Additional copper and polyamide layer(s) added to the wafer where needed
  - ***Aerosol Jet Printing (AJP)*** machine available at INFN TS – UniTS:
    - 10 μm spatial resolution, on planar and bent substrate

INFN TS

- **2024**: first test runs with **conductive traces on silicon**
  - Achieved resistance:
    < 1 Ohm/cm with Henkel ECI 1011 conductive silver ink
    < 2 Ohm/cm with 426 Novacentrix conductive silver ink
  - Good adhesion to plated bonding pads

- **Plans for end 2024 and 2025**:
  - Try different inks and curing methods
  - Optimize trace pattern and deposition process
  - Characterize trace profile and ohmic behavior with higher current
  - Attempt application to working CMOS structure



Conductive trace deposition and measurements

R&D per Middle Layers in 2025

ALICE

- Sulla base degli studi sull'impatto dei vari layout per i Middle Layers:
  - **Costruzione prototipo meccanico** di modulo
  - Accoppiamento **sensori con bus di distribuzione** alimentazione e dati
  - **Interconnessione** meccanica ed elettrica

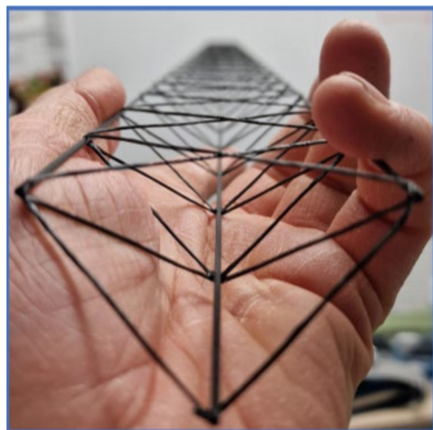
INFN PD - TS

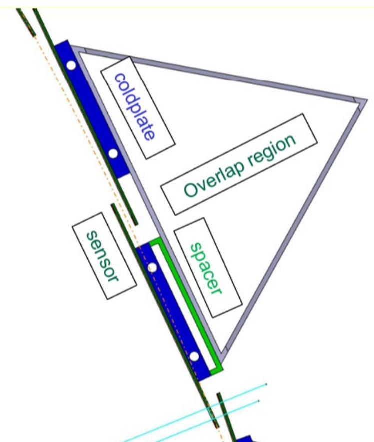
- Trieste – prototipi sensori curvi autosupportanti
  - Produzione mandrino con raggio ML piu' interno **6k**
  - Prototipazione layer e bus (FPC) di redistribuzione **6k**

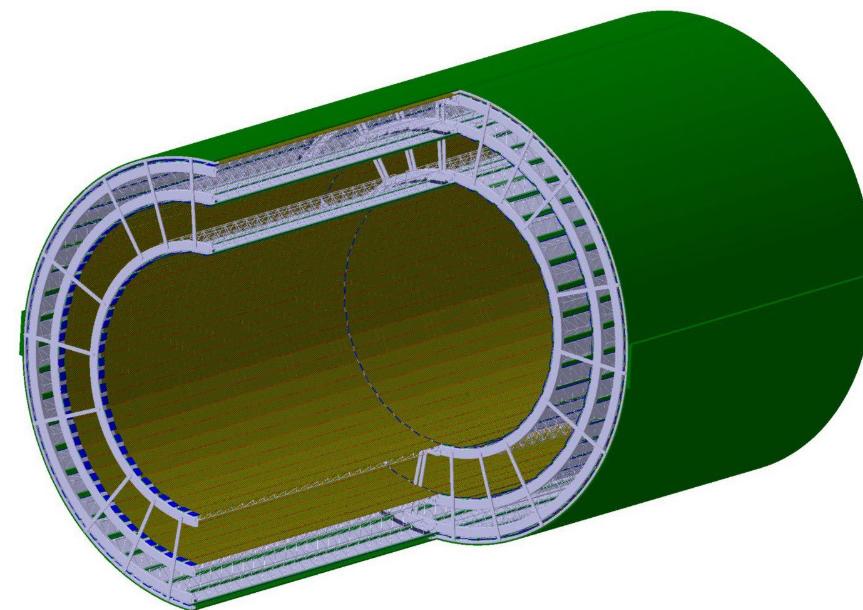
- Padova – prototipi sensori curvi su fibra di carbonio
  - Produzione struttura meccaniche per versioni low-mass **10k**
  - Produzione dummy-FPC per compatibilita' meccanica **2k**

Middle Layers – mechanical supports

- Development of support structures for modules and staves







- High synergy with inner TOF layer, Outer Tracker
- Start from baseline design (LOI)
- Move then to global structure for low-mass version

INFN TO

- Torino – supporto meccanico globale
  - Sviluppo di mock-up di supporti meccanici per moduli e stave **12k**

Tabella riassuntiva ALICE 3 Inner Tracker

Sezione	k€	Descrizione attivita’
BA	17	Studio outgassing per IRIS in vuoto secondario
CA	12	Sviluppo firmware per sistema readout ALICE 3 basato su FELIX board
PD	12	Prototipazione Middle Layers e routing bus elettrico
TO	12	Studio meccaniche Middle Layers e interfaccia TOF
TS	12	Prototipazione Middle Layers e sviluppo strati ridistribuzione rete alimentazione
Totale	**65**	
Missioni	5	Prove cooling prototipi ML (TS) + verifica componenti studio vuoto in altri laboratori (BA)

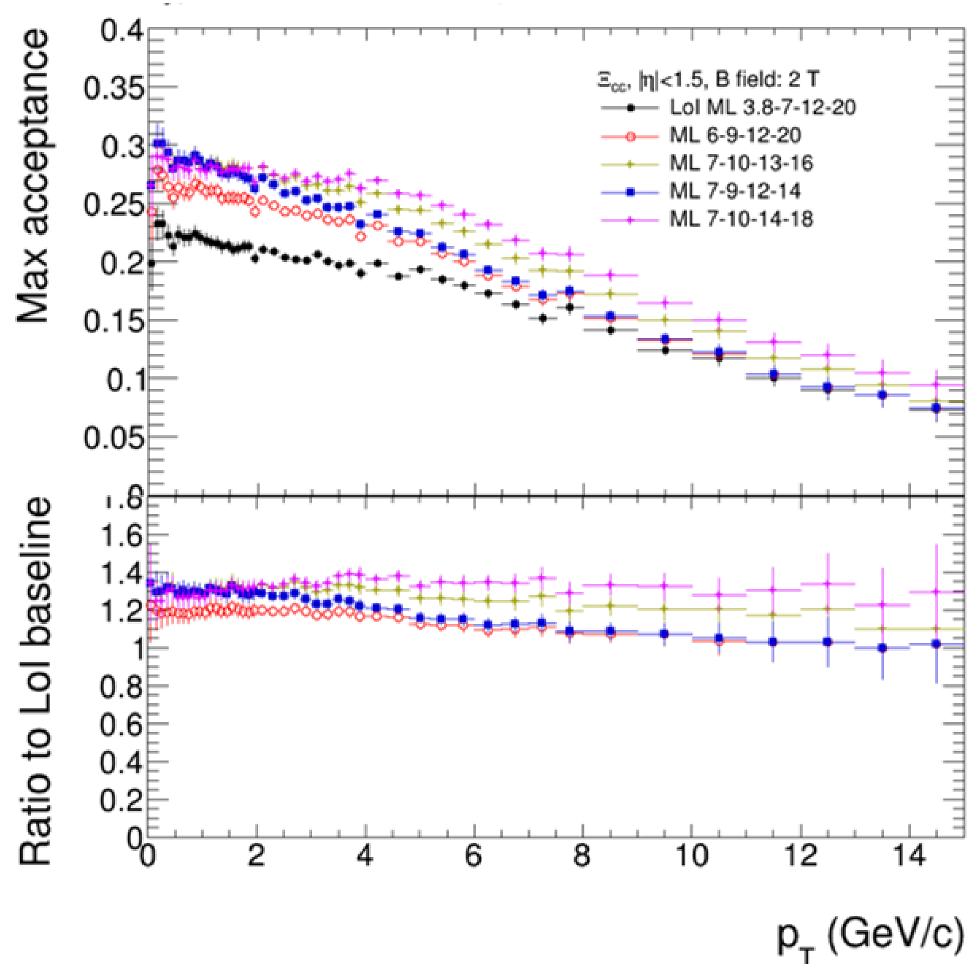
Milestones 2025 per ALICE 3 Inner Tracker:

- Completamento campagna misure di outgassing su set di primi campioni di materiali 30/06/2025
- Costruzione prototipo meccanico di modulo Middle Layers 31/12/2025

Backup

Xi_cc acceptance: 6 cm ≤ radii ≤20 cm

Based on generator-level decay chain, no efficiency, minimum hits / track = 6



4 layers in updated envelope:

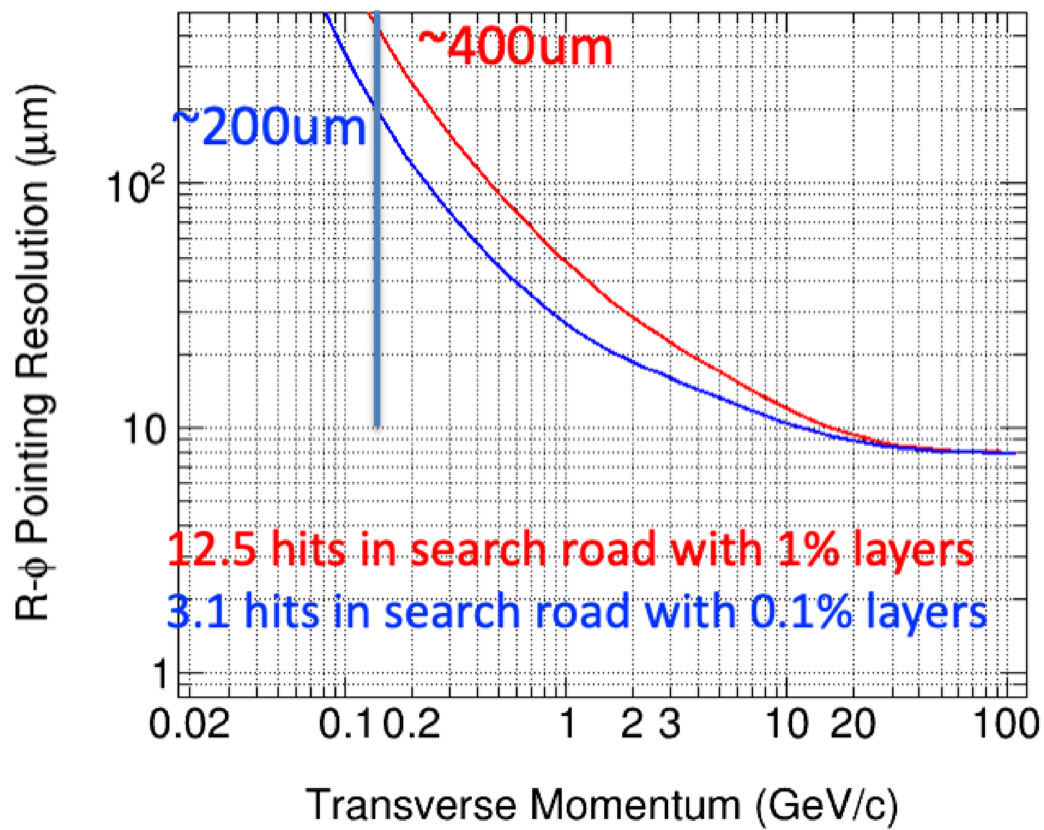
- between 6 cm and 20 cm
- the acceptance for Ξ_{cc} increases with larger radii

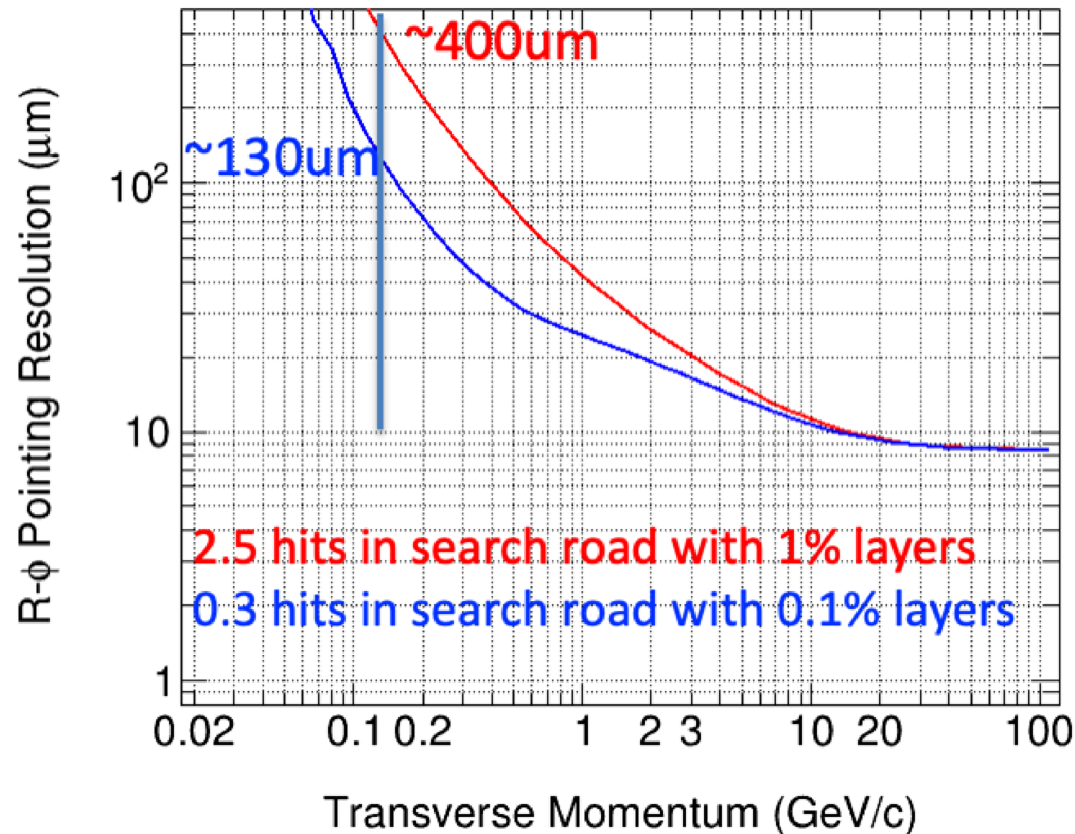
Milestone 2024 (31/12/2024):
Studio comparativo per la progettazione dei Middle Layers dell'Inner Tracker

Effect of material budget outside the barrel

R3 = 6.5, R4=9, R5=12 x/X0=1%, σ=10 um;

R3=6.5, R4=9, R5=12 x/X0=0.1%, σ=10 um





Backup: ALICE 3 tracker – specifications

	Layer ID	Radius [cm]	Length [cm]	< |η|	Area [m^2]	Tot Area [m^2] up to this Layer	Pixel pitch [um]	Tot Pixels (10^6)	Power density [mW/cm^2]	Tot Power (+20%) [W]	Max Hit Rate [10^6/cm^2/s]	Required BW for Hits [Gbit/s]	Required BW for Noise [Gbit/s]	Total Installed BW [Gbit/s]
Inside the beam pipe	0	0.5	50	4.6	0.016	0.016	10	157	70	13	94	236	1.0	237
	1	1.2	50	3.7	0.038	0.053	10	377	70	32	16	97	2.4	99
	2	2.5	50	3.0	0.079	0.132	10	785	70	66	3.8	48	5.0	53
Middle Layers	3	3.8	100	3.3	0.239	0.371	10	2388	70	201	1.7	65	15.3	80
	4	7.0	100	2.7	0.440	0.811	10	4398	70	369	0.48	34	28.1	62
	5	12.0	124	2.3	0.935	1.745	50	374	20	224	0.16	24	2.4	26
	6	18.0	124	1.9	1.402	3.148	50	561	20	337	0.058	13	3.6	17
	7	30.0	124	1.4	2.337	41.972	50	935	20	561	0.026	10	6.0	16
	8	45.0	264	1.8	7.464	49.437	50	2986	20	1791	0.012	14	19.1	33
	9	60.0	264	1.5	9.953	59.389	50	3981	20	2389	6.50E-03	10	25.5	36
	10	80.0	264	1.2	13.270	72.659	50	5308	20	3185	3.70E-03	8	34.0	42

- Hit density decreases by $O(10^4)$ from layer 0 to layer 10
- Bandwidth dominated by the vertex detector
- Noise performance critical for the outer most layers

- Bandwidth:16 bit / hit, single pixel clusters
- Radiation load: 50 months of 24 MHz pp interactions
- Fake-hit rate: 10-8 / pixel / event at 40 MHz readout rate

ALICE 3 Inner Tracker **Sensor** development

ALICE

	Vertex Detector		Outer Tracker		ITS3	ITS2
Pixel size (μm²)	÷ 9	O(10 x 10)	✖2.8	O(50 x 50)	O(20 x 20)	O(30 x 30)
Position resolution (μm)	÷ 2	2.5	✖2	10	5	5
Time resolution (ns RMS)	÷ 10	100	÷ 10	100	O(1000)	O(1000)
Shaping time (ns RMS)	÷ 25	200	÷ 25	200	O(5000)	O(5000)
Fake-hit rate (/ pixel / event)	≈	$< 10^{-8}$	≈	$< 10^{-8}$	$<10^{-7}$	$<< 10^{-6}$
Power consumption (mW / cm²)	+ 75%	70	67%	20	20 (pixel matrix)	40 / 30**
Particle hit density (MHz / cm²)	✖20	94	÷ 100	0.06	8.5	5
Non-Ionising Energy Loss (1 MeV n_{eq} / cm²)	✖3000	1×10^{16}	✖100	2×10^{14}	3×10^{12}	3×10^{12}
Total Ionising Dose (Mrad)	✖1000	300	✖20	5	0.3	0.3

** Innermost layers / outer layers

- Improving ITS2/ITS3 performance in all aspects
- Current goals extremely challenging, will be revised based on simulations, results from ITS3 development, and available resources

Different optimisations at different radii