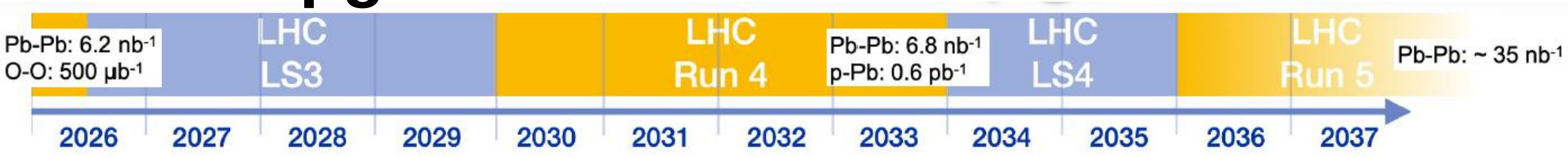
PID detectors for a next generation heavy-ion experiment (ALICE 3)

Manuel Colocci[1] on behalf of *ALICE Collaboration*

[1]University and INFN, Bologna (mcolocci@bo.infn.it)

ALICE upgrades



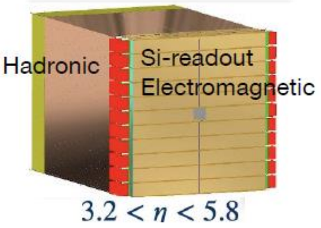
ITS3, FoCal

- Specific upgrades in **LS3** (2026-29)
- TDRs approved in March 2024
- Moving towards “production” phase

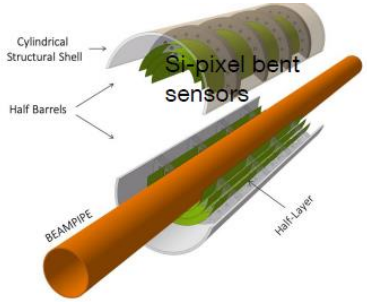
ALICE 3

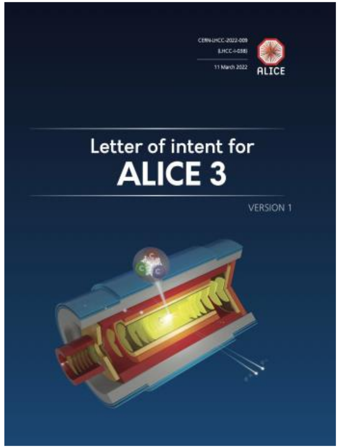
- **New detector** in **LS4** (2034-35)
- LoI reviewed in 2022 (CERN-LHCC-2022-009)
  Scoping Document review just completed

FoCal TDR: CERN-LHCC-2024-004



ITS3 TDR: CERN-LHCC-2024-003

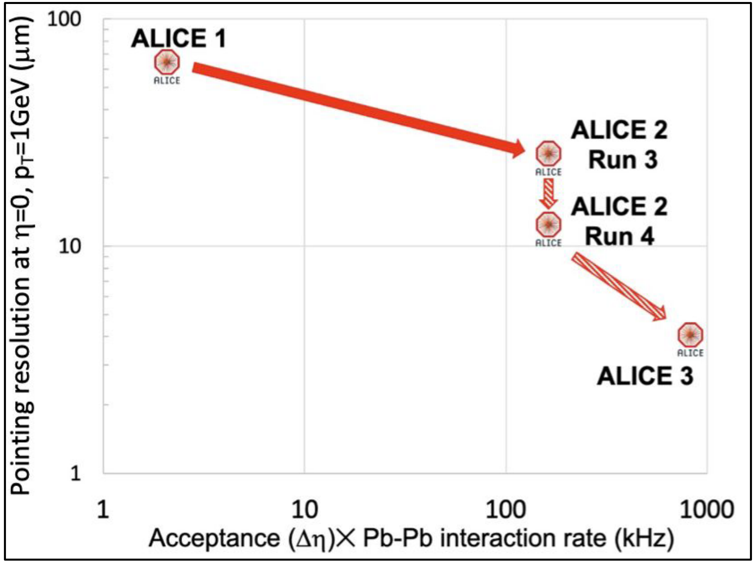


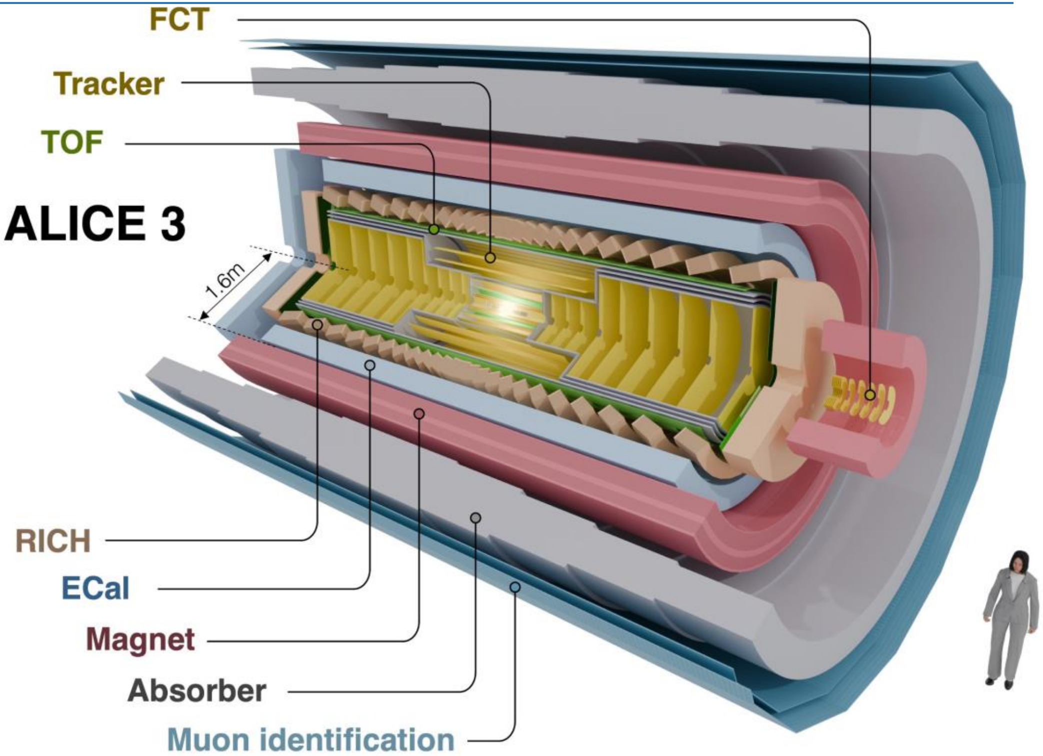


ALICE 3 concept

Novel and innovative detector concept

- Compact and lightweight all-pixel tracker
- Retractable vertex detector
- ***Extensive particle identification***
- Large acceptance $|\eta|<4$
- Superconducting solenoid magnet (2 T)
- Continuous read-out and online processing





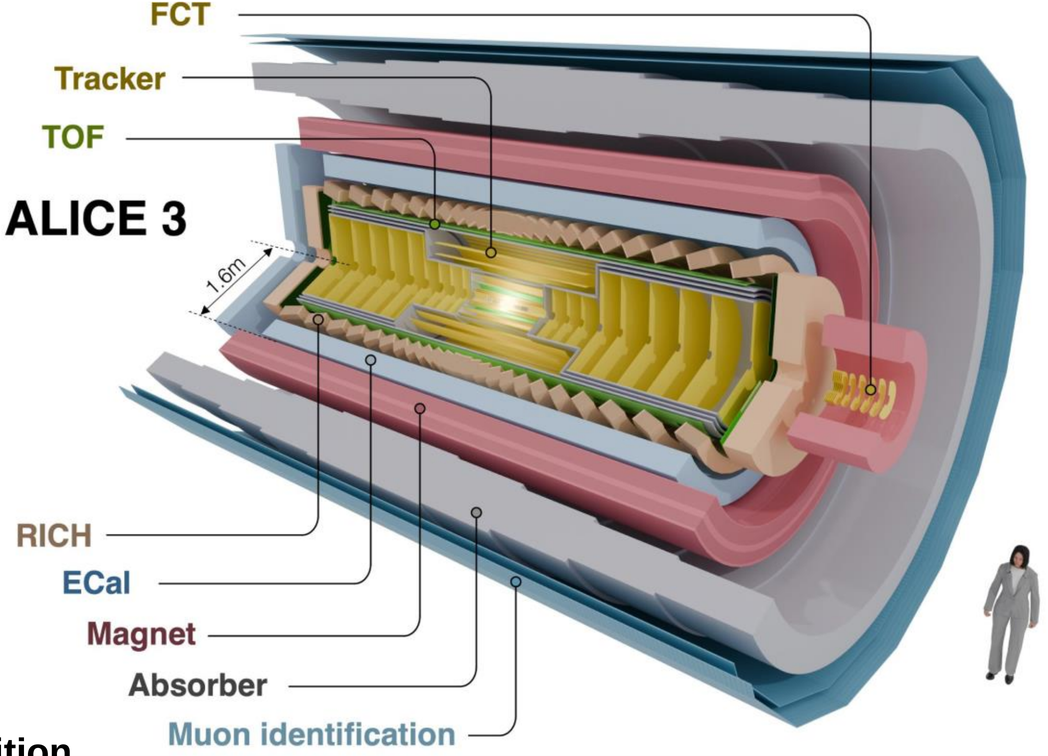
Interaction rates	ALICE*	ALICE 3
pp	500 kHz-1 MHz	**24 MHz**
Pb-Pb	50 kHz	**100 kHz****

* from LHC Run3
** limited by LHC projections (not detector)

ALICE 3 concept

Novel and innovative detector concept

- Compact and lightweight all-pixel tracker
- Retractable vertex detector
- ***Extensive particle identification***
- Large acceptance $|\eta|<4$
- Superconducting solenoid magnet (2 T)
- Continuous read-out and online processing



Key objectives:

- **Access to QGP temperature vs. time**
  → Precision measurement of dileptons
- **Understanding thermalization in QGP**
  → beauty and (multi-)charm hadrons
- **Fundamental aspects of QCD phase transition**
  → chiral symmetry restoration: di-elector mass spectrum
- **Laboratory for hadron physics**
  → hadron-hadron interaction potential, exotic hadrons

Interaction rates	ALICE*	ALICE 3
pp	500 kHz-1 MHz	**24 MHz**
Pb-Pb	50 kHz	**100 kHz****

* from LHC Run3
** limited by LHC projections (not detector)

ALICE 3 detector requirements

Component	Observables	Barrel ($\lvert\eta\rvert < 1.75$)	Forward ($1.75 < \lvert\eta\rvert < 4$)	Detectors
Vertexing	(Multi-)charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{DCA} \approx 10\,\mu m$ at $p_T = 200\,MeV/c$, $\eta = 0$	Best possible DCA resolution, $\sigma_{DCA} \approx 30\,\mu m$ at $p_T = 200\,MeV/c$, $\eta = 3$	retractable Si-pixel tracker: $\sigma_{pos} \approx 2.5\,\mu m$, $R_{in} \approx 5\,mm$, $X/X_0 \approx 0.1\,\%$ for first layer
Tracking	(Multi-)charm baryons, dielectrons, photons ...	$\sigma_{p_T}/p_T \approx 1--2\,\%$		Silicon pixel tracker: $\sigma_{pos} \approx 10\,\mu m$, $R_{out} \approx 80\,cm$, $L \approx \pm 4\,m$ $X/X_0 \approx 1\,\%$ per layer
Hadron ID	(Multi-)charm baryons	$\pi/K/p$ separation up to a few GeV/c		Time of flight: $\sigma_{tof} \approx 20\,ps$ RICH: $n \approx 1.006 - 1.03$, $\sigma_\theta \approx 1.5\,mrad$
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: $n \approx 1.006 - 1.03$, $\sigma_\theta \approx 1.5\,mrad$
Muon ID	Quarkonia, $\chi_{c1}(3872)$	reconstruction of J/ψ at rest, i.e. muons from $p_T \sim 1.5\,GeV/c$ at $\eta = 0$		steel absorber: $L \approx 70\,cm$ muon detectors
ECal	Photons, jets	large acceptance		Pb-Sci sampling calorimeter
ECal	χ_c	high-resolution segment		$PbWO_4$ calorimeter
Soft photon detection	Ultra-soft photons		measurement of photons in p_T range 1–50 MeV/c	Forward conversion tracker based on silicon pixel tracker

ALICE 3 detector requirements

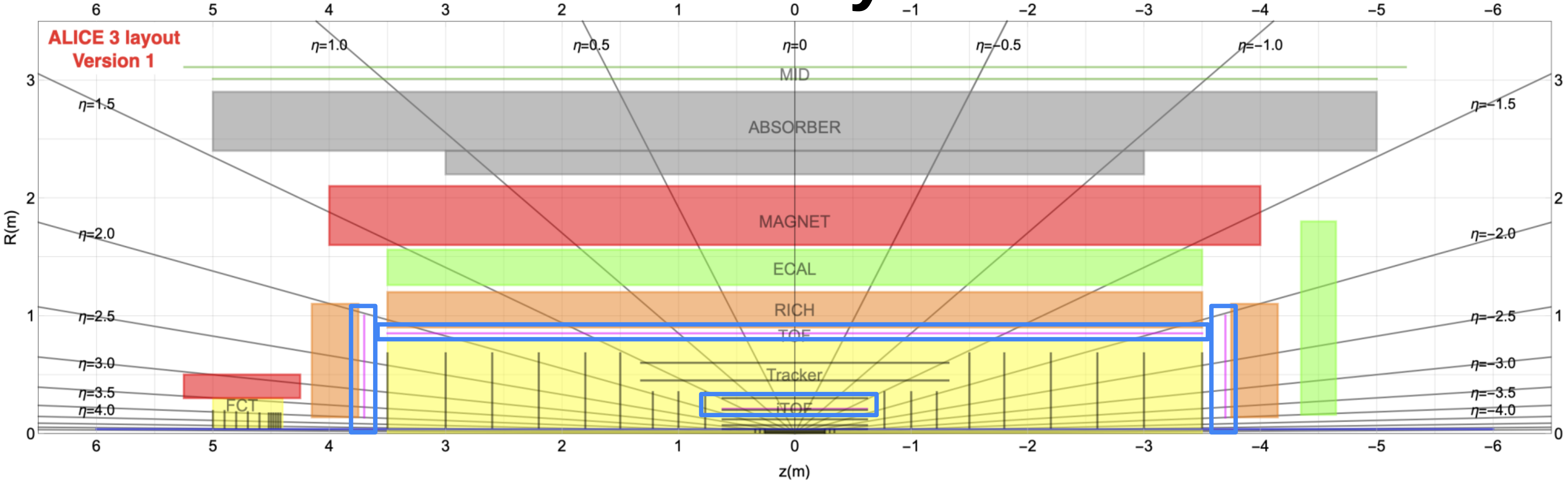
Component	Observables	Barrel ($\lvert\eta\rvert < 1.75$)	Forward ($1.75 < \lvert\eta\rvert < 4$)	Detectors
Vertexing	(Multi-)charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{DCA} \approx 10\,\mu m$ at $p_T = 200\,MeV/c$, $\eta = 0$	Best possible DCA resolution, $\sigma_{DCA} \approx 30\,\mu m$ at $p_T = 200\,MeV/c$, $\eta = 3$	retractable Si-pixel tracker: $\sigma_{pos} \approx 2.5\,\mu m$, $R_{in} \approx 5\,mm$, $X/X_0 \approx 0.1\,\%$ for first layer
Tracking	(Multi-)charm baryons, dielectrons, photons ...	$\sigma_{p_T}/p_T \approx 1--2\,\%$		Silicon pixel tracker: $\sigma_{pos} \approx 10\,\mu m$, $R_{out} \approx 80\,cm$, $L \approx \pm 4\,m$, $X/X_0 \approx 1\,\%$ per layer
Hadron ID	(Multi-)charm baryons	$\pi/K/p$ separation up to a few GeV/c		Time of flight: $\sigma_{tof} \approx 20\,ps$ RICH: $n \approx 1.006 - 1.03$, $\sigma_\theta \approx 1.5\,mrad$
Electron ID	Dielectrons, quarkonia, $\chi_{c1}(3872)$	up to 2–3 GeV/c		Time of flight: $\sigma_{tof} \approx 20\,ps$ RICH: $n \approx 1.006 - 1.03$, $\sigma_\theta \approx 1.5\,mrad$
Muon ID	Quarkonia, $\chi_{c1}(3872)$	reconstruction of J/ψ at rest, i.e. muons from $p_T \sim 1.5\,GeV/c$ at $\eta = 0$		steel absorber: $L \approx 70\,cm$ muon detectors
ECal	Photons, jets	large acceptance		Pb-Sci sampling calorimeter
ECal	χ_c	high-resolution segment		[illegible]
Soft photon detection	Ultra-soft photons		measurement of photons in p_T range 1–50 MeV/c	Forward conversion tracker based on silicon pixel tracker

Timing is needed

→ Strategic R&D on timing silicon sensors

This talk is focused more on the ALICE3 timing detector

ALICE 3 TOF detector: layout



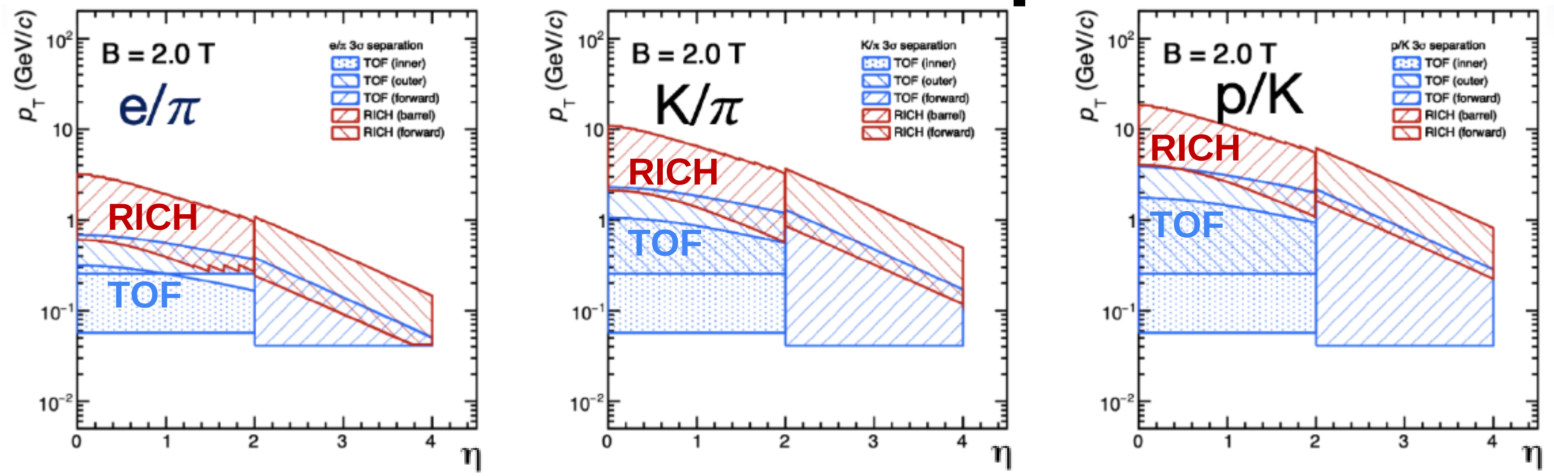
The ALICE3-TOF detector will provide PID over the full acceptance ($|\eta|<4$)

Two barrel layers ($|\eta|<2$) → inner-TOF: R ≈ 19 cm, |z| < 62 cm, 1x1 mm^2 pixels
outer-TOF: R ≈ 85 cm, |z| < 350 cm, 5x5 mm^2 pixels

Two forward disks ($2<|\eta|<4$) → forward-TOF: z ≈ ±370 cm, R ≈ 15-100 cm, 1x1 mm^2 pixels

Total surface (TOF) ~ **45 m^2**

ALICE 3 TOF detector requirements



3σ TOF PID separations

$e/\pi \lesssim$ 500 MeV/c
$K/\pi \lesssim$ 2.5 GeV/c
$p/K \lesssim$ 4 GeV/c

Separation power $\propto L/\sigma_{TOF}$
→ required **time resolution: $\sigma_{TOF} \approx 20$ ps**

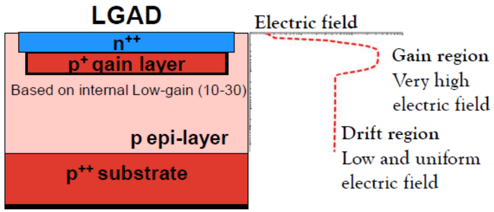
Rad. hardness:
outer-TOF: NIEL ~ $9 \cdot 10^{11}$ [1 MeV n_{eq} /cm^2]
inner-TOF: NIEL ~ $6.1 \cdot 10^{12}$ [1 MeV n_{eq} /cm^2]
forward-TOF: **NIEL ~ $8.5 \cdot 10^{12}$** [1 MeV n_{eq} /cm^2]

Low material budget 1-3% X_0

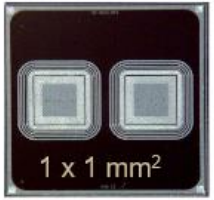
	Ch. part. fluence
iTOF	200 kHz/cm^2
oTOF	15 kHz/cm^2
fTOF	28 kHz/cm^2

R&D on advanced silicon technologies
LGADs, CMOS-LGADs and SiPMs

LGADs

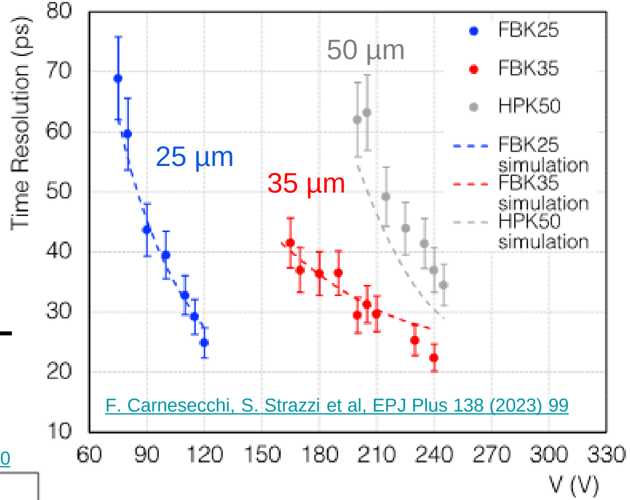


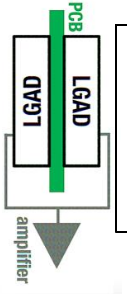
Structures under test (1 x 1 mm^2) ←
FBK prototypes



[25 μm] **25 ps**: slightly worse time resolution than what expected

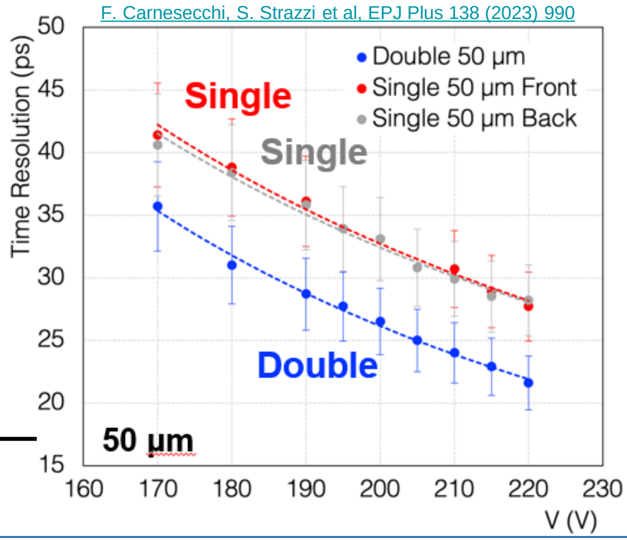
[35 μm] **22 ps**: in agreement with MC simulations





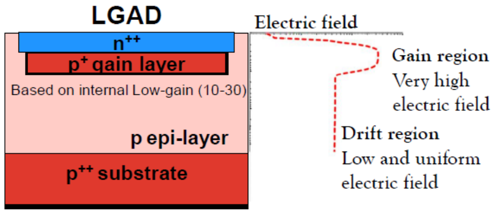
double-LGAD introduced and tested *for the first time*

→ signals of both layers sum up using a *single* front-end amplifier

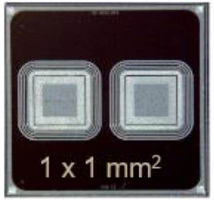


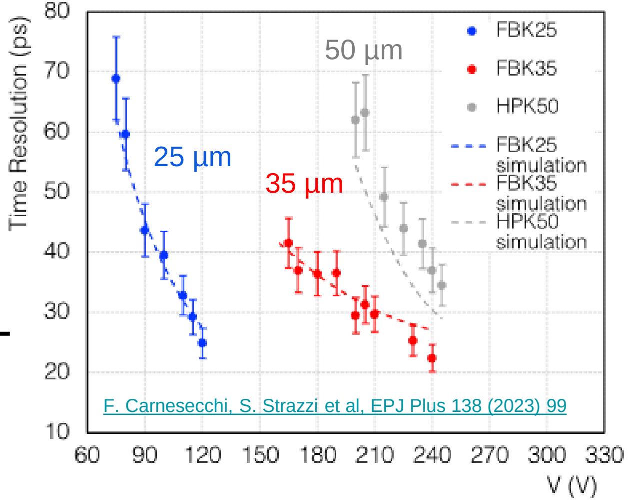
consistent improvement of the time resolution for double-LGAD w.r.t. single LGAD

LGADs



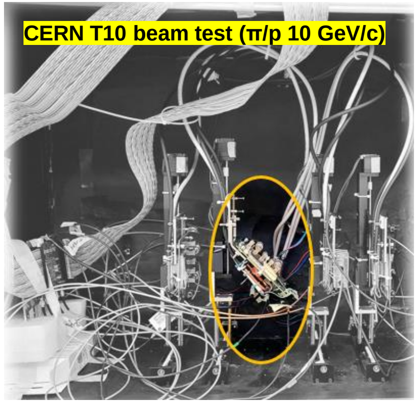
Structures under test (1 x 1 mm^2) ←
FBK prototypes

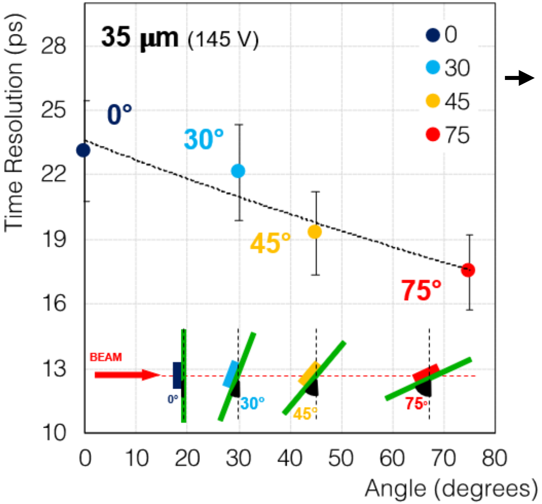




[25 µm] **25 ps**: slightly worse time resolution than what expected

[35 µm] **22 ps**: in agreement with MC simulations





LGAD inclined with respect to the beam direction to probe the sensor response at the edges of the outer barrel ($\eta \simeq 2$)

Intense beam-test campaigns at CERN-T10 **demonstrated the possibility of achieving a time resolution of 20 ps with thin LGAD design**

Next slides: monolithic approach (CMOS-LGAD)

Less material and costs, simpler and cheaper assembly

CMOS-LGAD starting point

INFN-ARCADIA project

Fully depleted MAPS in 110 nm LFoundry CMOS

Available **thicknesses**:

- **48 um**, 100 um, 200 um (full depletion demonstrate up to 400um)

Target applications:

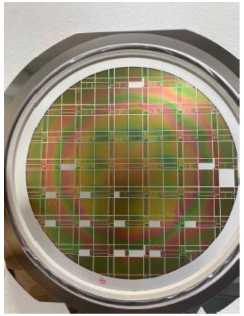
- Medical Imaging (PCT)
- Space applications
- **HEP experiments**
- X-ray imaging

3 engineering runs:

- 1st – mid 2021
- 2nd – beginning 2022
- **3rd – beginning 2023**

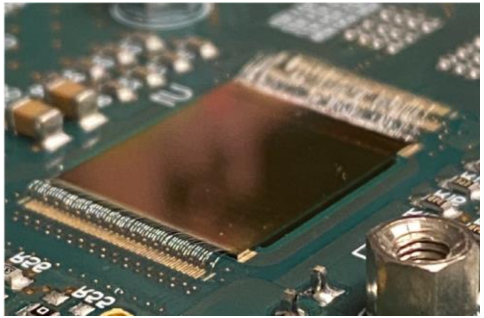
Main demonstrator (MD):

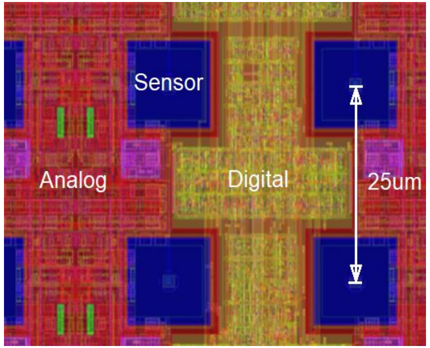
- Sensor array of 512x512 pixels
- Pixel pitch: 25um
- Binary pixel with event-driven readout



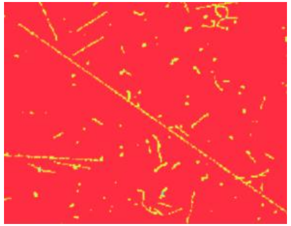
A. Patternò, Vertex 2021

ARCADIA Main Demonstrator

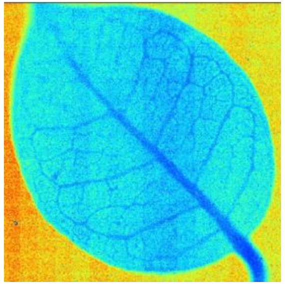




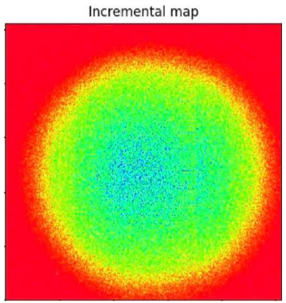
M. Rolo, **Pixel layout**



Cosmic Rays

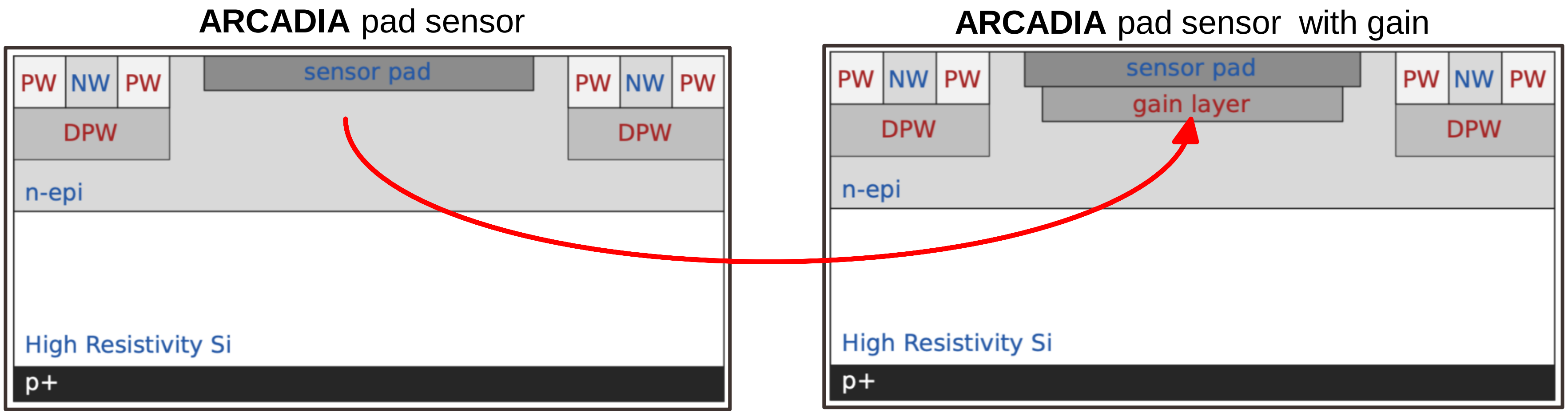


X-ray image -photon counting



^{90}Sr source

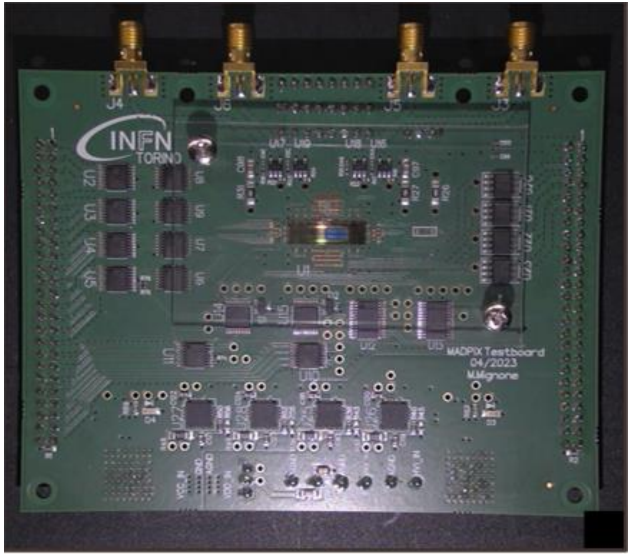
ARCADIA MAPS: gain add-on option



- Add-on **p-gain** below the collecting electrode ("LGAD layout") starting from 3rd engineering run
- **48um** active thickness
- ARCADIA production:
  ↳ **passive structures** and **monolithic structures**
- Requires **negative bias** of the backside, **positive bias** at the sensor pad and AC coupling of readout electronics

MadPix

***M**onolithic CMOS **A**valanche **D**etector **PIX**elated Prototype*

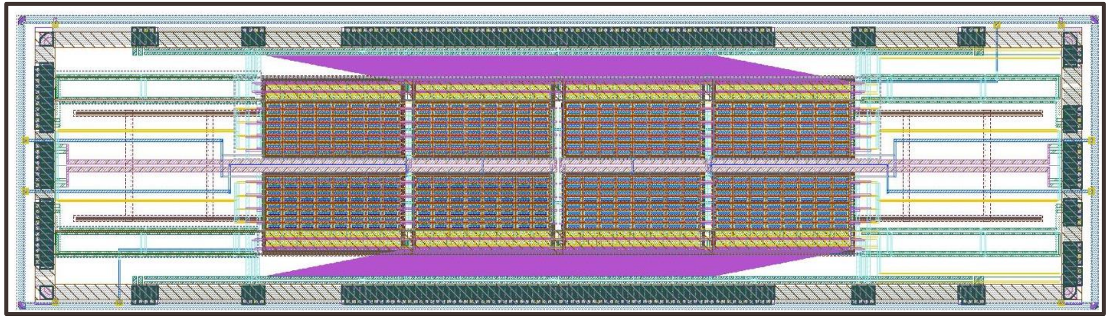


First CMOS-LGAD prototype with integrated electronics and gain layer

Active thickness: 48 µm

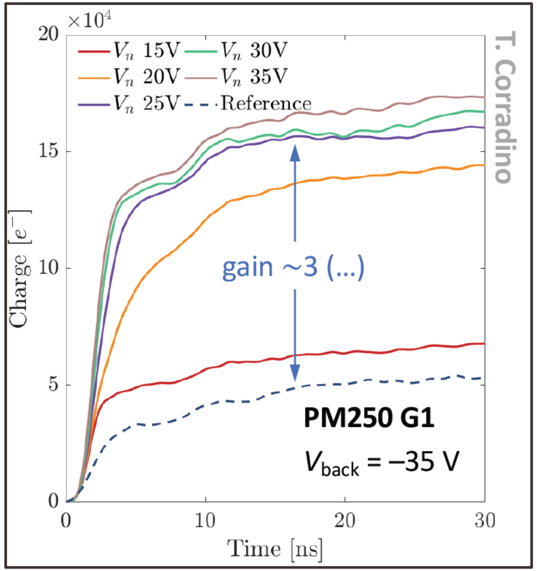
- **Backside HV**: allow full depletion → -20 V to -40 V
- **Topside HV**: manage the gain → 35 V to 65 V

- 8 matrices of 64 pixels each
- 64 x 2 analogue outputs
- 4 flavours
- Pixels of 250 µm x 100 µm

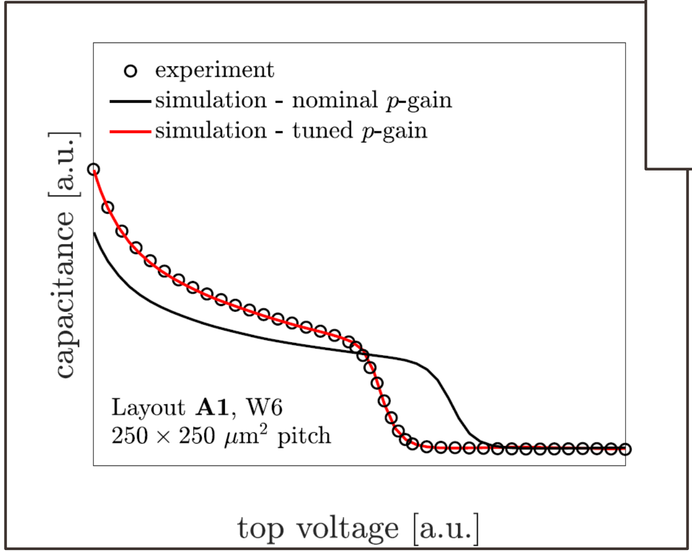


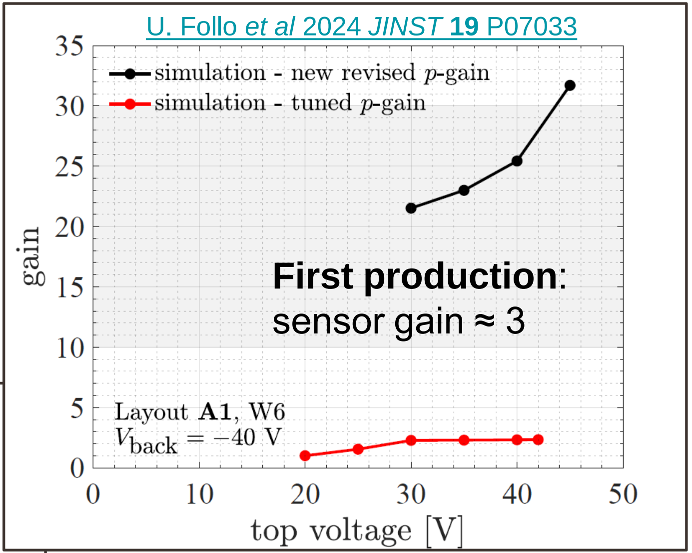
- Not optimal for timing (distortion term), bigger pixels can be implemented in dedicated runs
- Four adjacent px's can be acquired simultaneously (4 SMA 50 Ω to scope)

First characterization



- Lateral **CV**
- P-gain **implantation energy is lower than expected** (TCAD simulations)
- **Gain target** with nominal profile: **10-20**





- Passive structures under focused **IR laser**
- Backside Illumination
- Integrated charge in time
- We have **gain**…

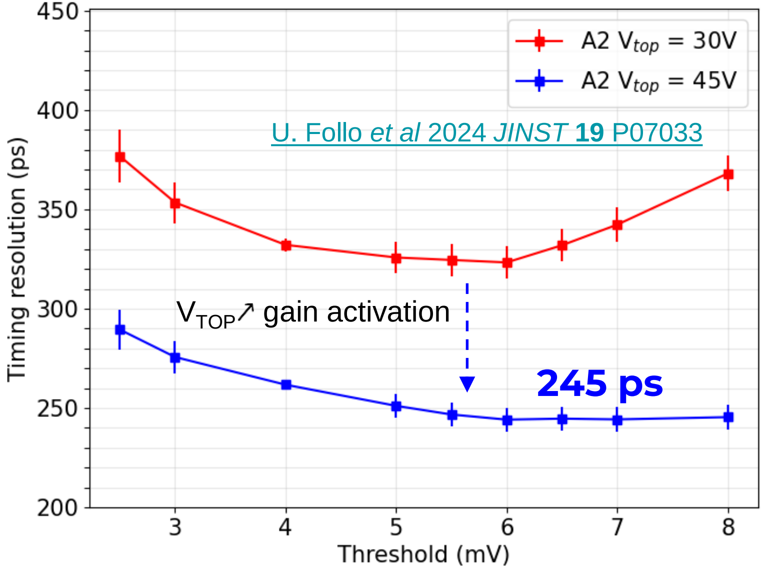
  … but lower than expected

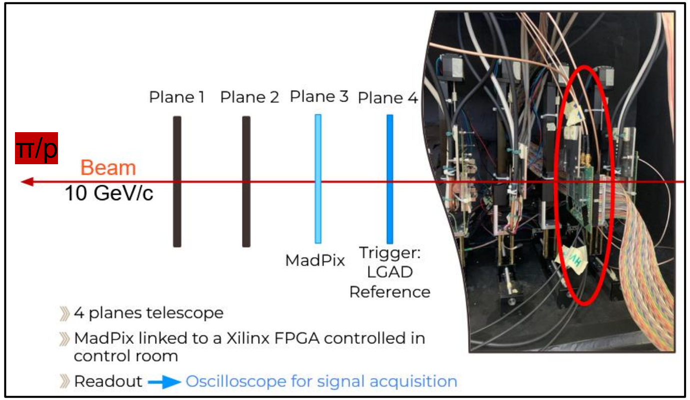
- Gain extraction using TCAD simulations with tuned p-gain profiles (TCAD simulations)
- **Gain simulated ≈ 3**
- **Good agreement** between data and simulation

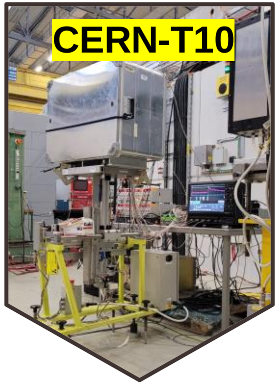
MadPix: first beam-test

October 2023

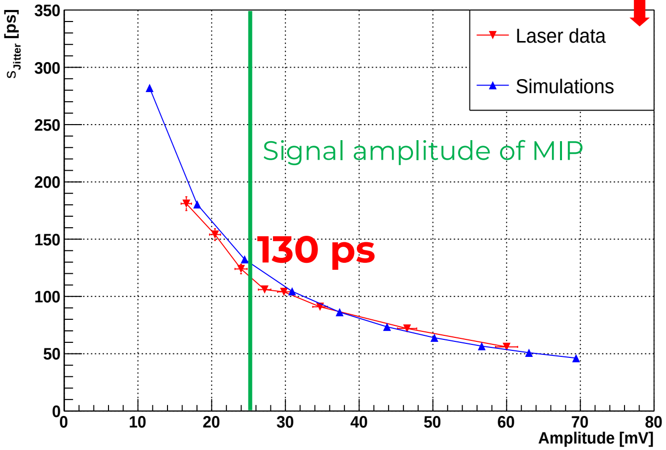
Time resolution measured in a beam test







Jitter: RMS of the time difference between laser trigger out (TTL) and analogue output of MadPix (@ 50% signal amplitude)



$$\sigma_t^2 = \sigma^2_{\text{Time Walk}} + \sigma^2_{\text{Landau Noise}} + \sigma^2_{\text{Distortion}} + \sigma^2_{\text{Jitter}} + \sigma^2_{\text{TDC}}$$

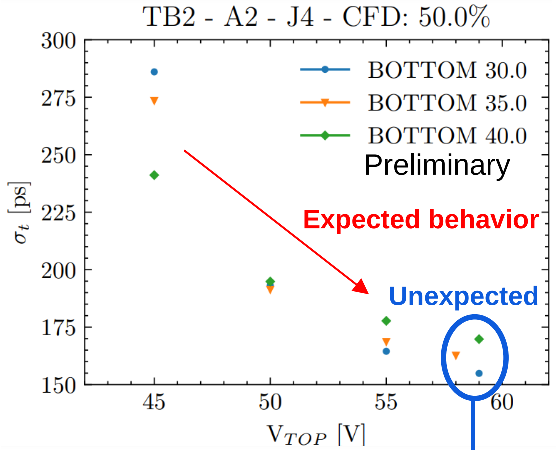
Time resolution of **245 ps** can **not** be explained with **jitter**

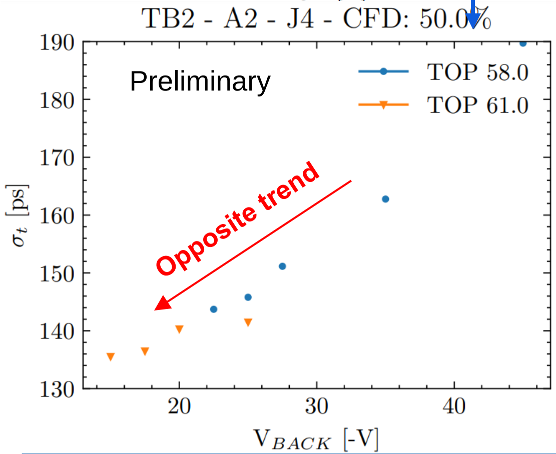
→ **Main contributor: Sensor**

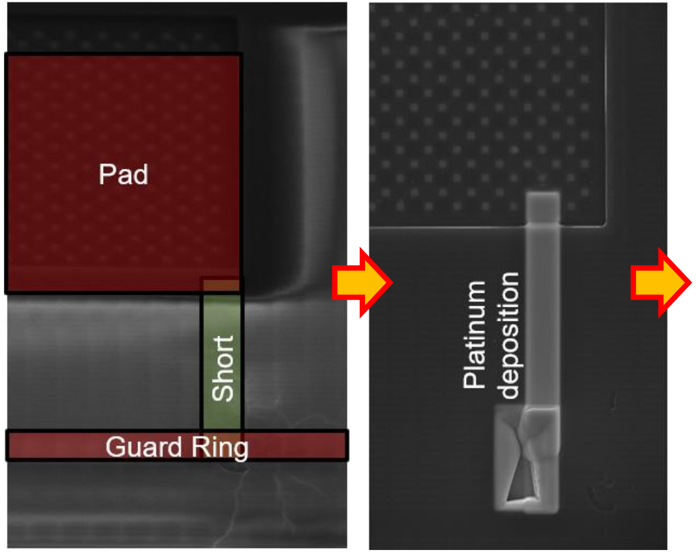
In next short-loop run the gain increased (MPV > 60 mV) → jitter contribution will decrease (< 50 ps)

MadPix: Focused Ion Beam

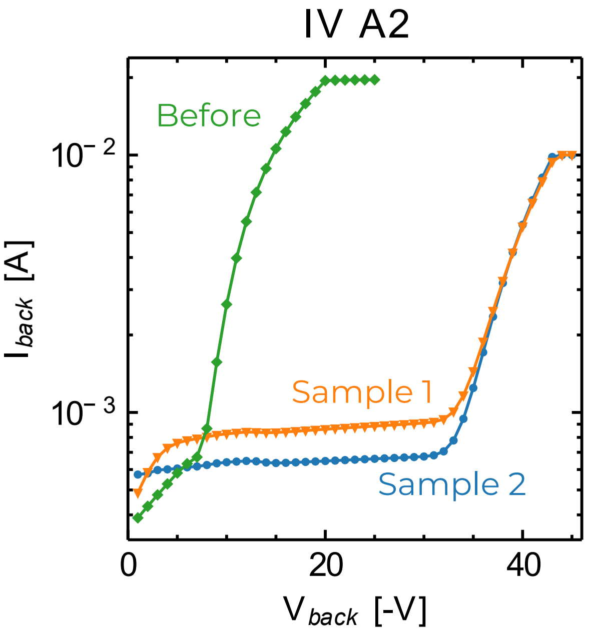
CERN T10 - July 2024







FIB surgery done at INRIM (Torino - Italy)

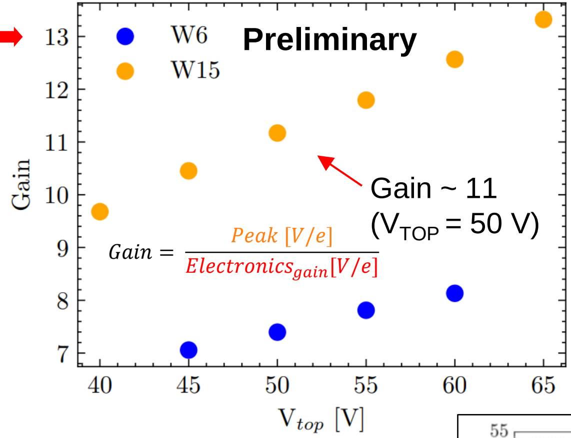


Too high substrate current (guard ring was floating)
→ **guard ring shortened with a Focused Ion Beam**

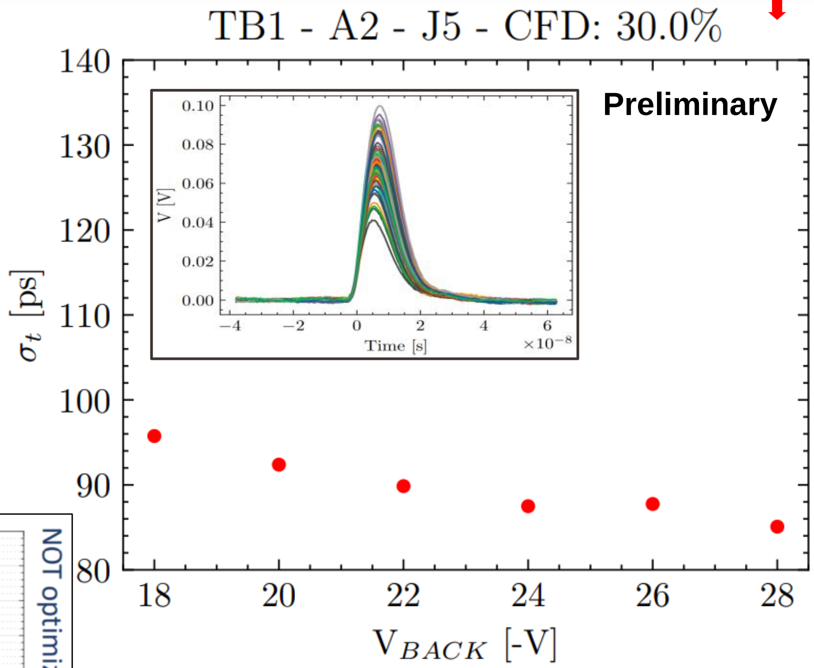
→ Backside current lowered of 2 order of magnitude

Latest production

- Prototypes of the latest short-loop run arrived in **Sep. 2024**
- First estimation of **gain** using ^{55}Fe

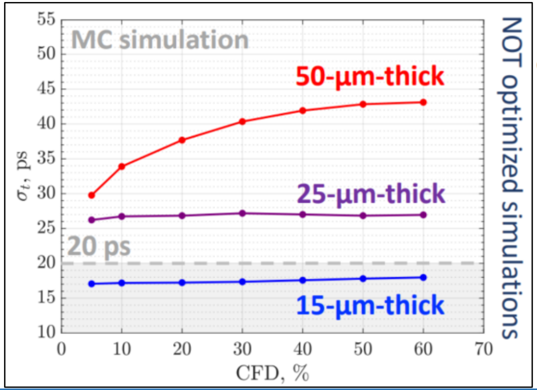


- Beam-test results (Oct. 2024 at CERN-T10)



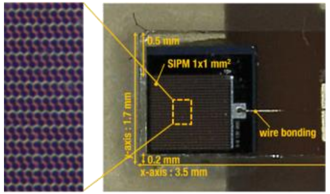
Time res. sensor + front-end (@0.18mW/ch): 88 ps
Time resolution sensor: ≈ 75 ps

Next:
- Position-time correlation
- Radiation hardness studies
- **Short-loop run with lower active thicknesses in the 2nd part of this year**



SiPMs for timing

- SiPM as array of O(10^4) **SPAD**s (Single Photon Avalanche Detectors) in Geiger mode (gain 10^6) above breakdown
- Direct response of SiPMs to the passage of **charged particles** was studied for the first time

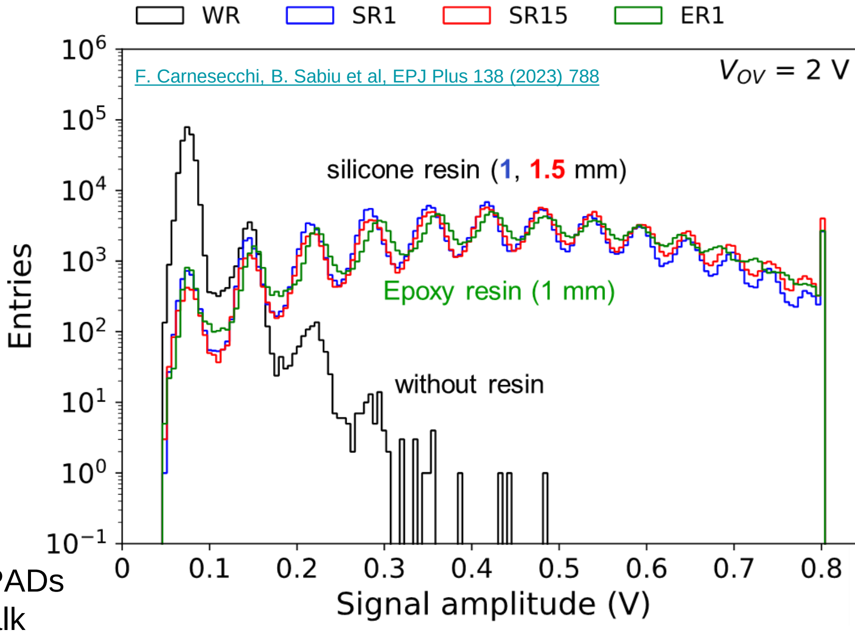


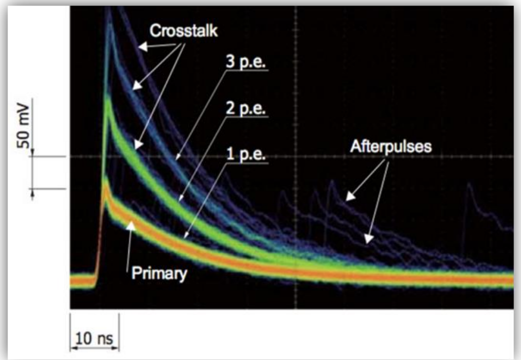
FBK NUV-HD-RH technology
20 µm pixel pitch, 72% FF
(2444 SPADs in 1 x 1 mm^2)

high crosstalk with the protection resin ←

→ large contribution of the **Cherenkov light** produced in the resin
(acting as Cherenkov radiator)

$V_{OV} = V_{bias} - V_{breakdown}$





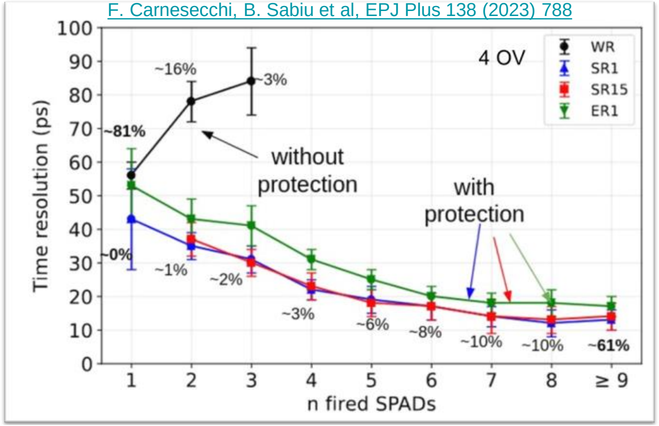
← without protection layer →
mainly 1 SPAD firing, up to 4-5 SPADs compatible with intrinsic crosstalk

SiPMs for timing

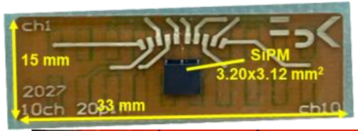
The increased number of firing SPADs improves significantly the time resolution (below 20 ps) ←

Large fraction of multi SPADs events
→ huge noise rejection w.r.t. standard SiPMs

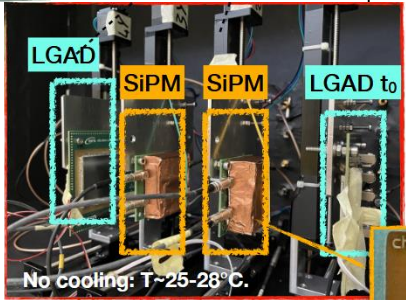
[%] percentage of events with 1, 2, 3, etc firing SPADs

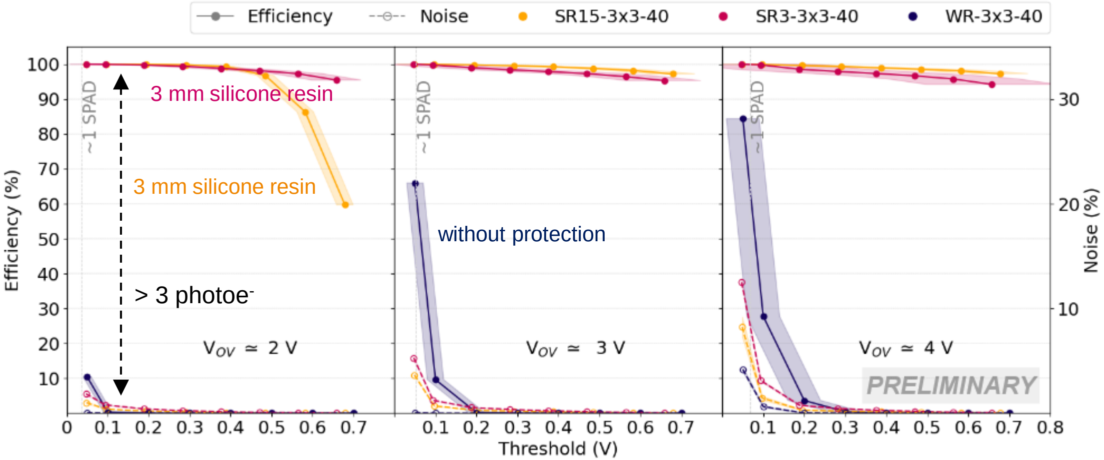


- **Larger area SiPMs** (3.2 x 3.12 mm^2)
  – enough to collect all produced Cherenkov photons –
  tested in October 2023 (CERN T10)



- NUV-HD SiPMs produced by **FBK**
40 µm pixel pitch, 83% FF
(6200 SPADs in 3.2 x 3.12 mm^2)
- Customized front-end XLEE amplifiers of ~40d dB gain





→ SiPMs can be operated at large n.p.e. threshold i.e. above the dark count

Rad hardness studies ongoing (lower T needed)

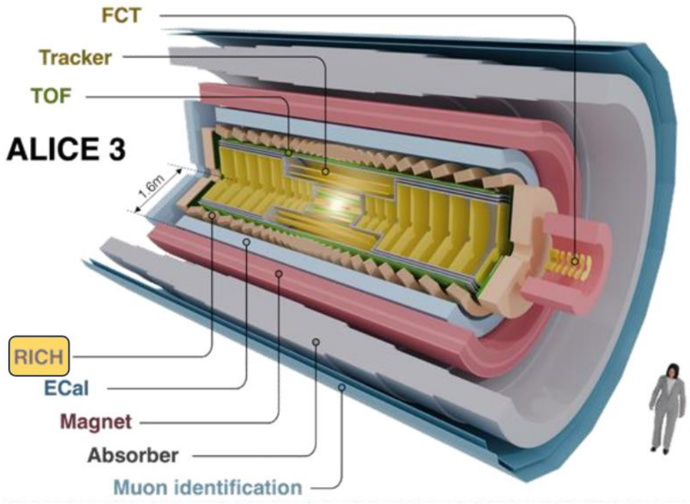
***Large variety of applications* from space experiments to colliders**

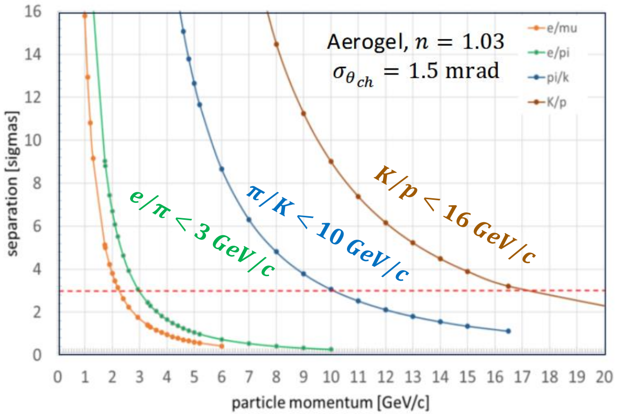
RICH

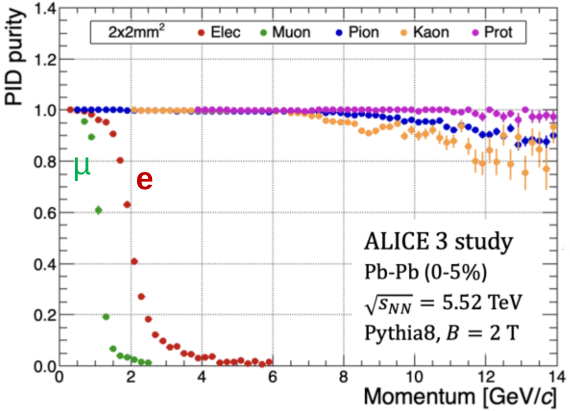
Detector requirements

- **Extend charged PID beyond TOF limits**

	Surface [m²]	NIEL [1 MeV neq/cm²]
bRICH	28	$8.3 \cdot 10^{11}$
fRICH	9	$8.5 \cdot 10^{12}$



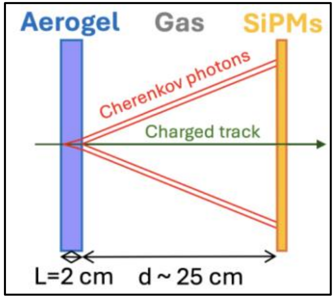


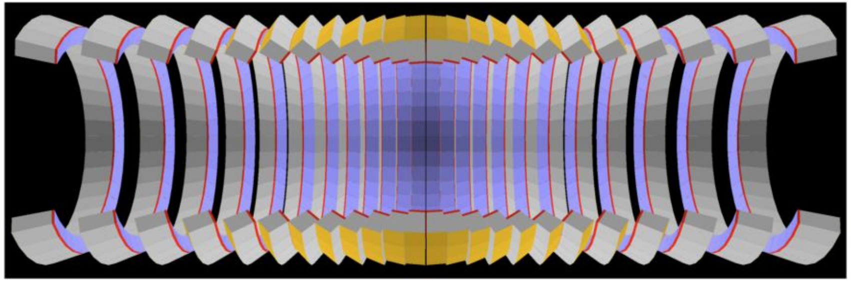


Projective bRICH to improve coverage at large $|\eta|$ while saving on overall photosensitive area

- Cherenkov threshold:
  - n = 1.03 (barrel), n = 1.006 (forward)
  - **Aerogel** radiator
  - **SiPMs** for photon detection (2x2 mm² pixel size)

- **Angular resolution**: $\sigma_{\text{ring}} \approx 1.5$ mrad



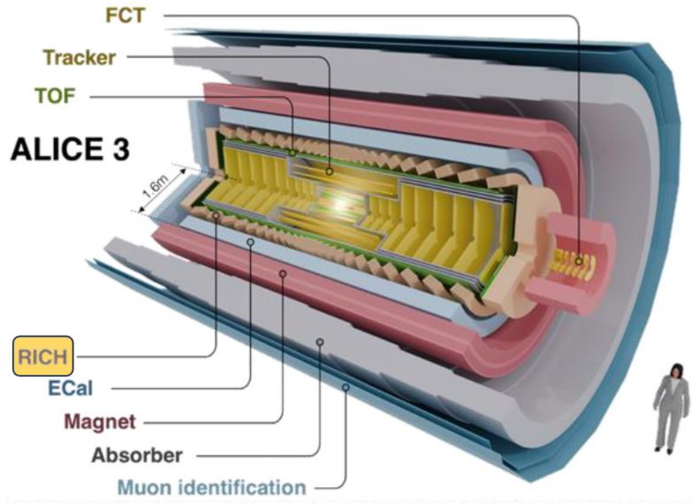


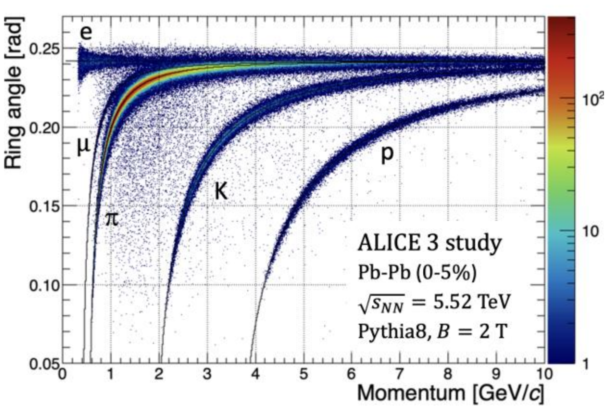
RICH

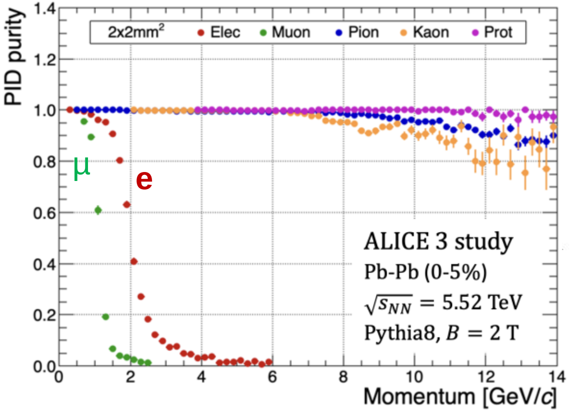
Detector requirements

- **Extend charged PID beyond TOF limits**

	Surface [m^2]	**NIEL** [1 MeV neq/cm^2]
bRICH	28	$8.3\cdot10^{11}$
fRICH	9	$8.5\cdot10^{12}$



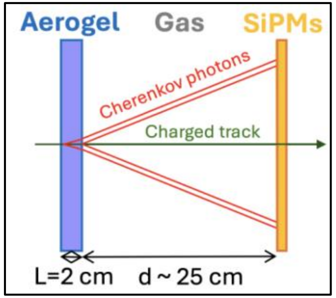


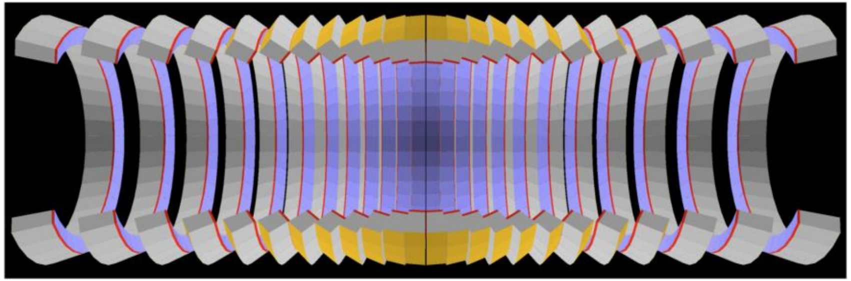


Projective bRICH to improve coverage at large $|\eta|$ while saving on overall photosensitive area

- Cherenkov threshold:
  - n = 1.03 (barrel), n = 1.006 (forward)
  - **Aerogel** radiator
  - **SiPMs** for photon detection (2x2 mm^2 pixel size)

- **Angular resolution**: $\sigma_{\text{ring}} \approx 1.5$ mrad

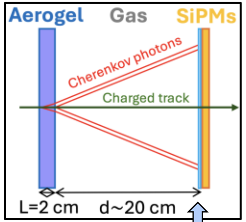


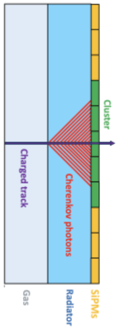


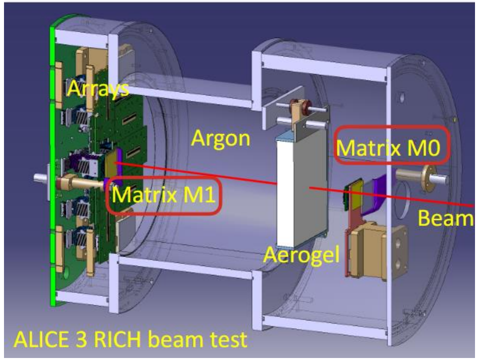
RICH

R&D directions

- High radiation load expected in the barrel ($8.4 \cdot 10^{11}$ 1 MeV neq/cm^2)
  → SiPM DCR increase to not tolerable values (> 4 MHz/mm^2)
  - **Improve SiPM radiation hardness**
  - **Development of cooling (-40 C)/annealing (+50 C?) systems**
- "Merged" oTOF+bRICH using a common SiPM layer coupled to a **thin radiator**
- Extend electron PID up to ≈ 4 GeV/c by introducing Cherenkov radiator gas ($C_5F_{10}O/N_2$ (20/80%), n ≈ 1.0006) into the proximity focusing gap

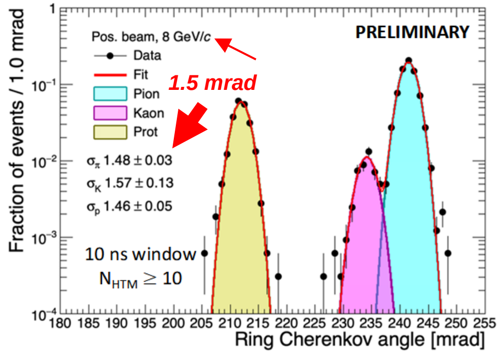




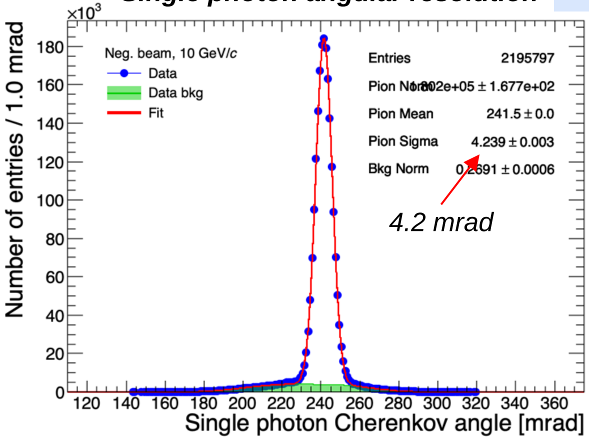


Central array: 1 HPK S13361-3050AE-08 (64 3x3 mm^2 SiPMs)
Ring arrays: 7 HPK S13361-2050AE-08 (64 2x2 mm^2 SiPMs)
Additional vessel equipped with 2 extra HPK S13361-2050AE-08 for timing
Front-end: custom based on Radioroc 2 FE ASIC and picoTDC

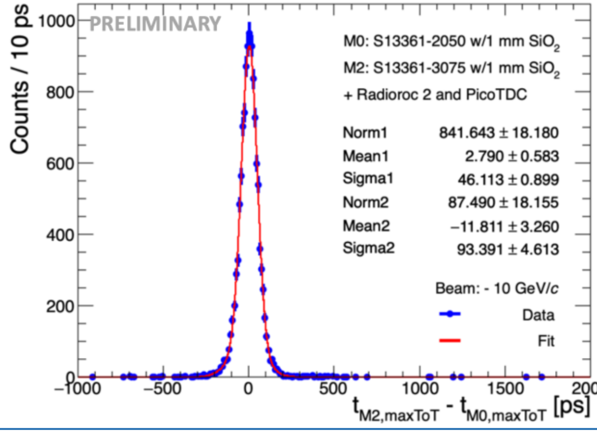
CERN T10 beam test highlights (October 2024)



Single photon angular resolution



Correcting for time walk and ch. by ch. offset,
Δt_{max} res. down to ≈ 50 ps ⇒ ≈ **35 ps at single SiPM level**



MID detector

Requirements

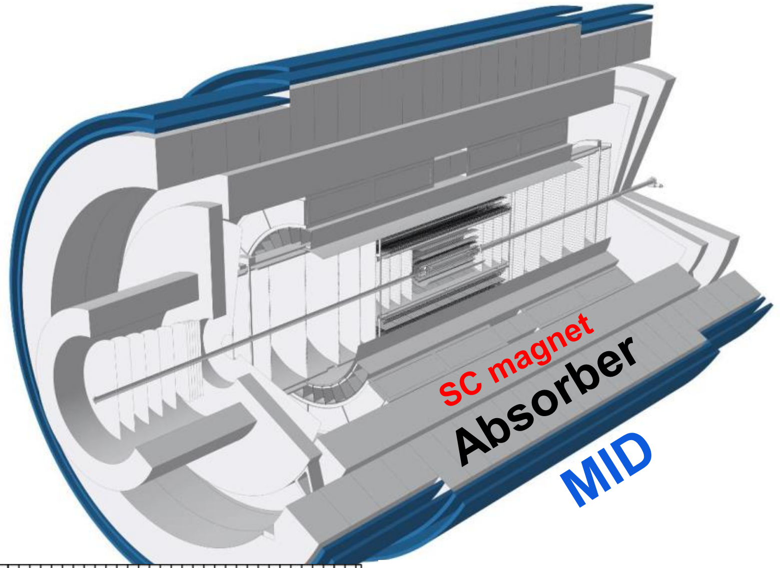
- Muon ID down to $p_T \approx 1.5$ GeV/c
- $|\eta|<1.3$

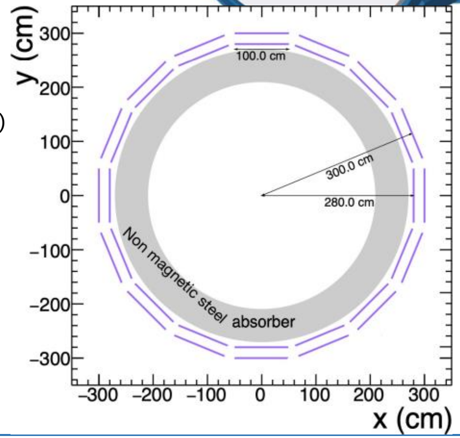
Absorber outside SC magnet

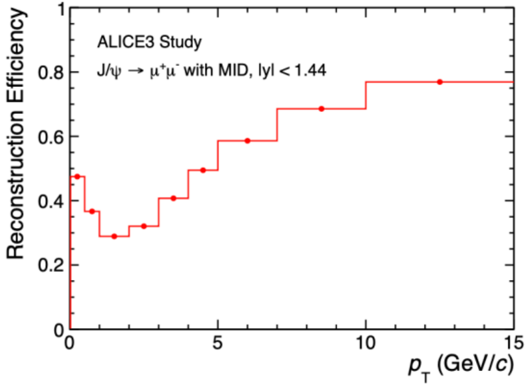
- Standard magnetic steel absorber
- Thickness of ≈ 70 cm at $\eta = 0$

Muon chambers

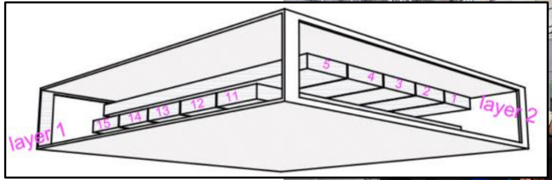
- 160 chambers
- $\Delta\eta$ x $\Delta\phi$ granularity → 5x5 cm^2 cells
- 2 layers of plastic scintillator bars
  (good performance on light-yield output (40 phe), good time resolution (< 2 ns)
- Coupling to WLS fibers is considered
- SiPMs readout
- **Alternative options** to scintillator bars**:**
  - MWPCs: 160 chambers (pos. resolution of a few mm)
  - RPCs: 320 chambers (time, granularity 5x5 cm^2)

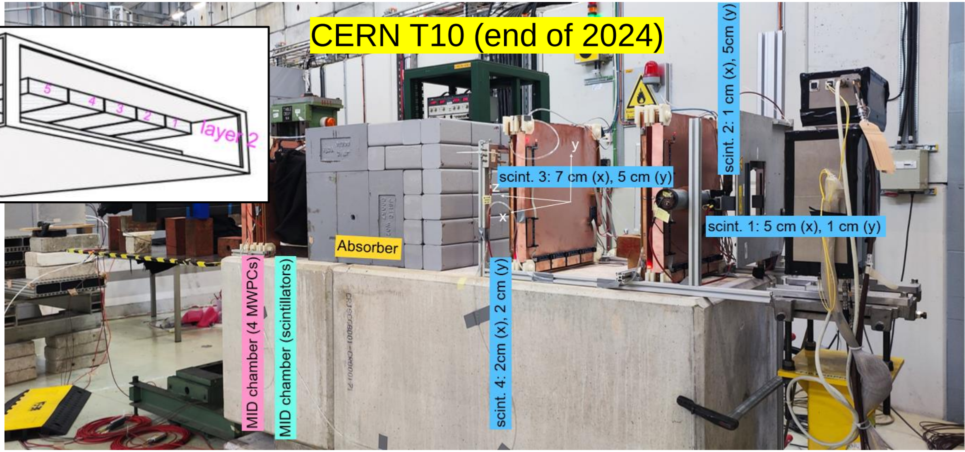




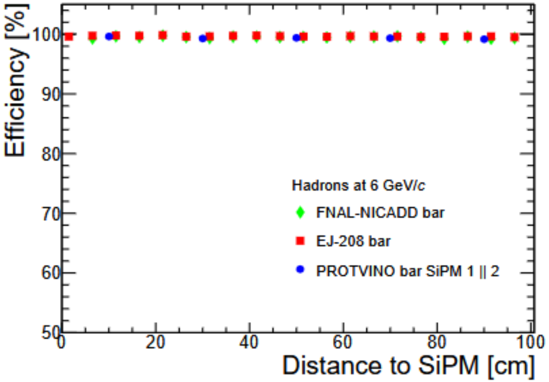


MID detector

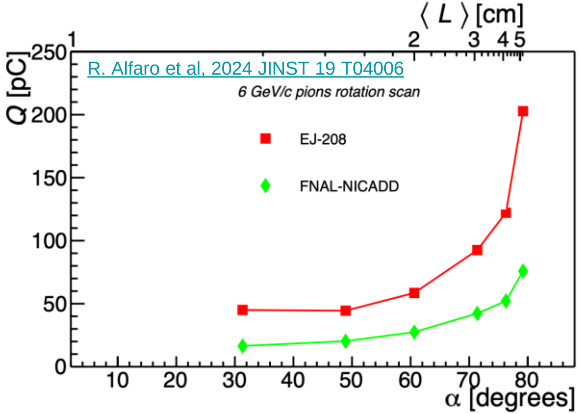




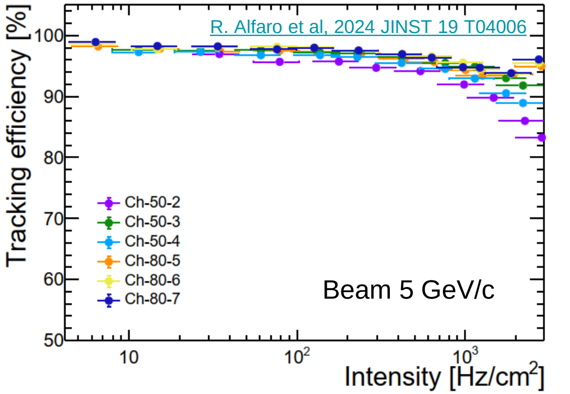
- Considered technologies being tested
- Plastic scintillators:
  - **Small size prototype tested at end of 2024** (**FNAL scintillator bars**, WLS fiber and SiPMs)
  - Hadron suppression **measured with pion beam**



- Uniform efficiency both along the horizontal (and vertical) position



- Charge vs. incident angle in scintillator bars
- 30°-60° covered by particles from the I.P



- **MWPC** efficiency >95% up to 100 Hz/cm^2, well above ALICE 3 MID
- Good spatial res. of 2-5 mm

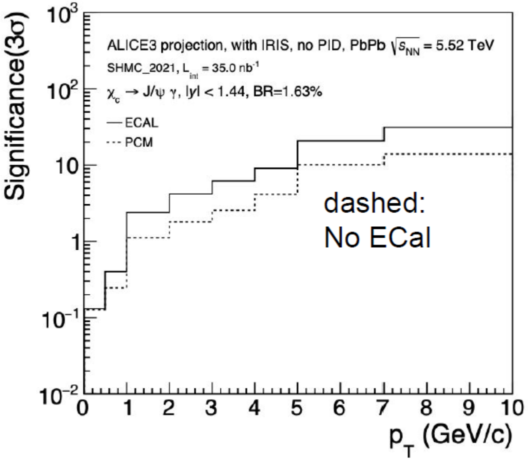
Summary

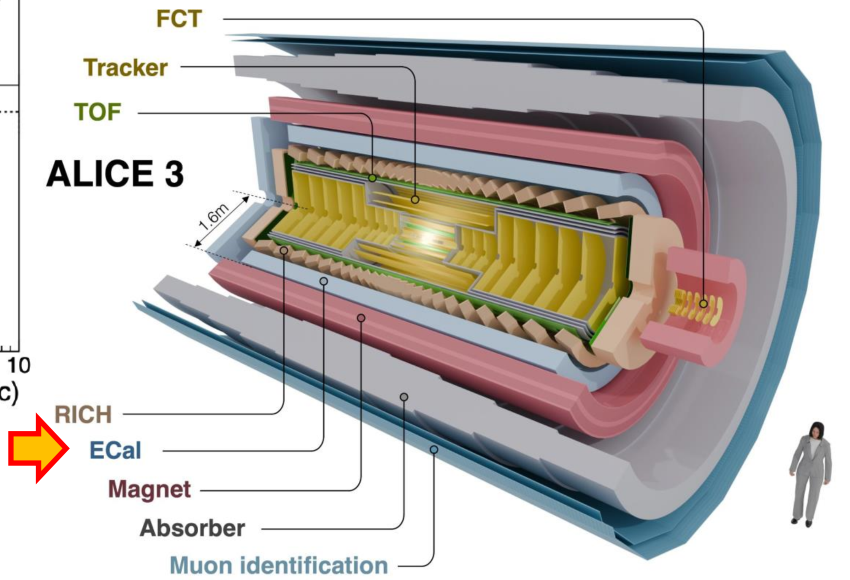
- The **ALICE** collaboration actively pursues future upgrades: **this is crucial to fully exploit LHC as HI collider in the next LHC runs**
- To fulfill the rich physics program, **ALICE 3 is being designed with fast and light PID detectors based on frontier Si-based sensors**
- Extensive R&D in several strategic areas (e.g. MAPS for timing, Rad-hard SiPMs) that **will have a broad and strong impact for future HEP experiments**
  - **New collaborators interested in physics and sensor R&D are welcome**!
- **TDR submission expected in 2027**, installation in 2034-35

Back-up slides

ECal

- Physics channels
  - BSM searches (axions) in $\gamma\gamma + \gamma\gamma$
  - $\chi_{c1,2} \rightarrow J/\psi + \gamma$
  - Direct photon γ_{dir} + jet measurements



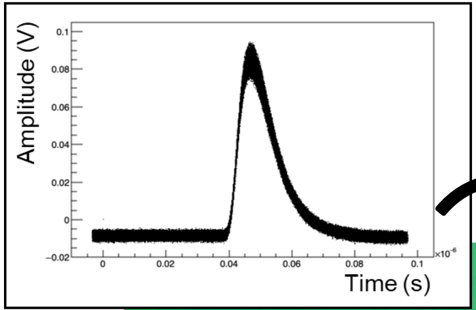


- Specs
  - Cells:
    - Lead tungstate crystals ($PbWO_4$) (inner barrel)
    - Sampling Pb-scintillator cells (both for outer barrel and endcap)
  - Scintillation light emitted by the ECal cells is measured by silicon photomultipliers (multi-pixel photon counters, MPPC)
  - ECal central barrel built from $PbWO_4$ cells needs to be cooled down to -25 °C with temperature stabilization ($\pm$0.1 °C)
  - Sampling cells of the outer barrel and the endcap will be produced from alternating layers of lead absorber and plastic scintillator tiles

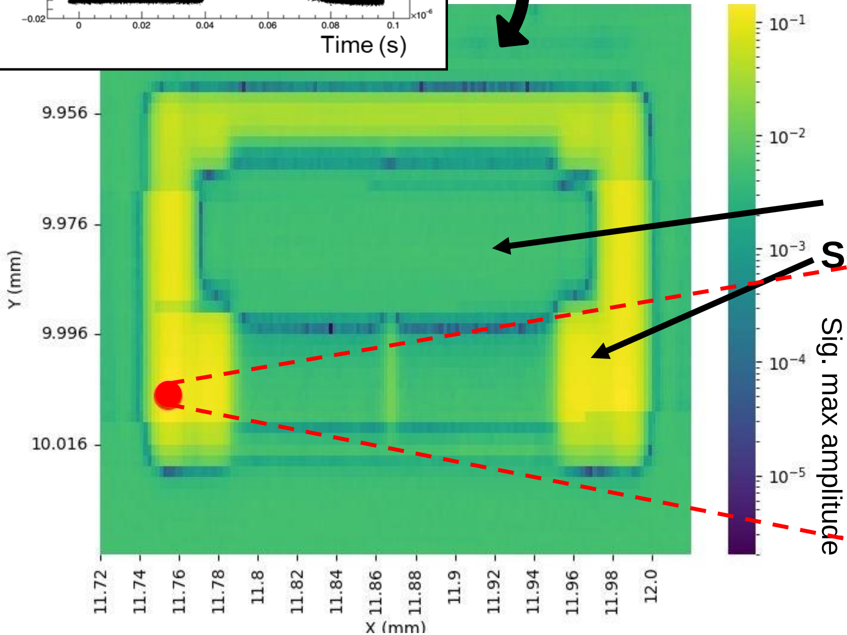
Table 14: ECal geometry specifications for the baseline option.

ECal segment	η range	Cell technology	Cell size	N_φ	N_η	N_{tot}
Central barrel	$\lvert\eta\rvert < 0.45$	$PbWO_4$	2.2×2.2 cm^2	348	57	19836
Outer barrel	$0.45 < \lvert\eta\rvert < 1.6$	Pb-Sci sampling	3×3 cm^2	256	120	30720
End cap	$1.6 < \eta < 4$	Pb-Sci sampling	4×4 cm^2			6000

Laser on MadPix (CMOS-LGAD)

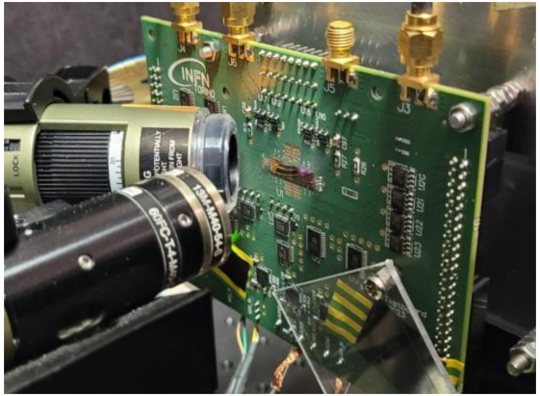


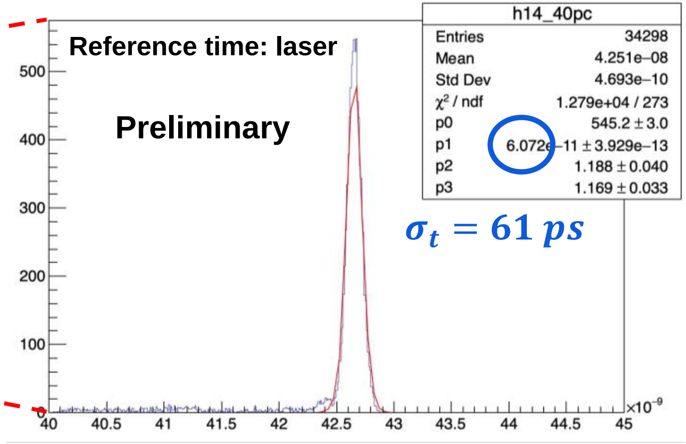
Scan of sensor area



Metallization

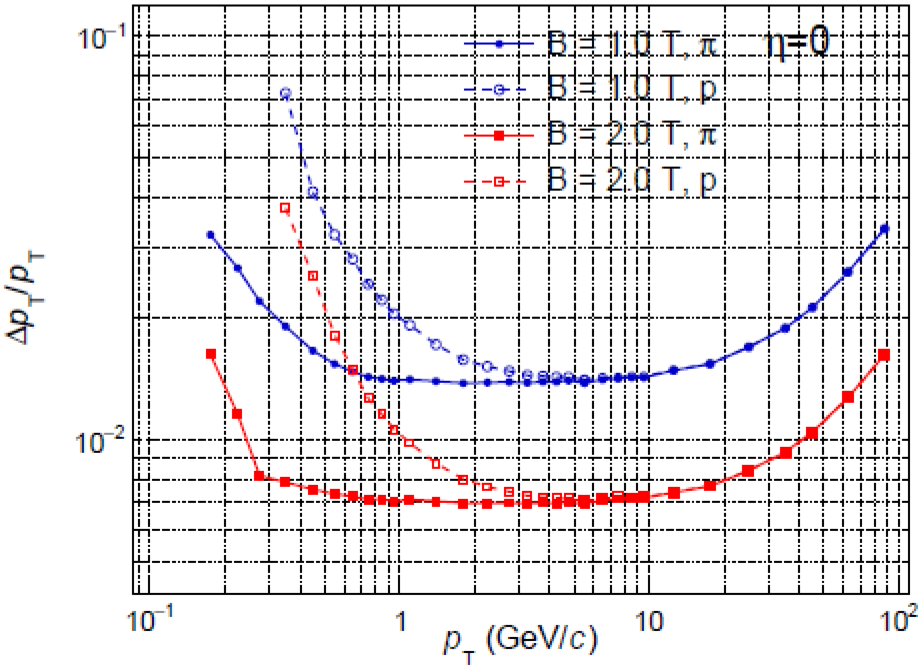
Sensitive area



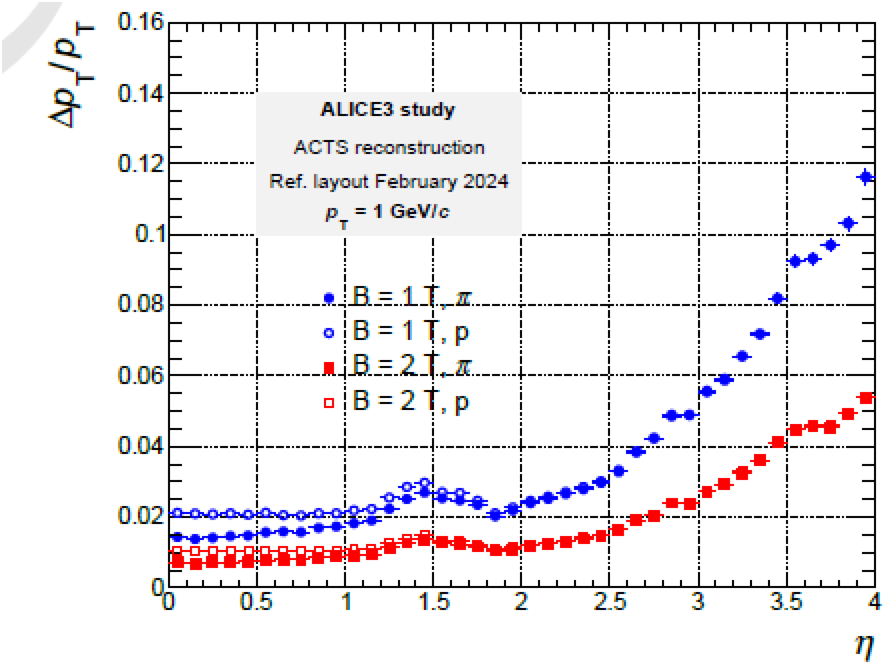


$\sigma_t = 61\ ps$

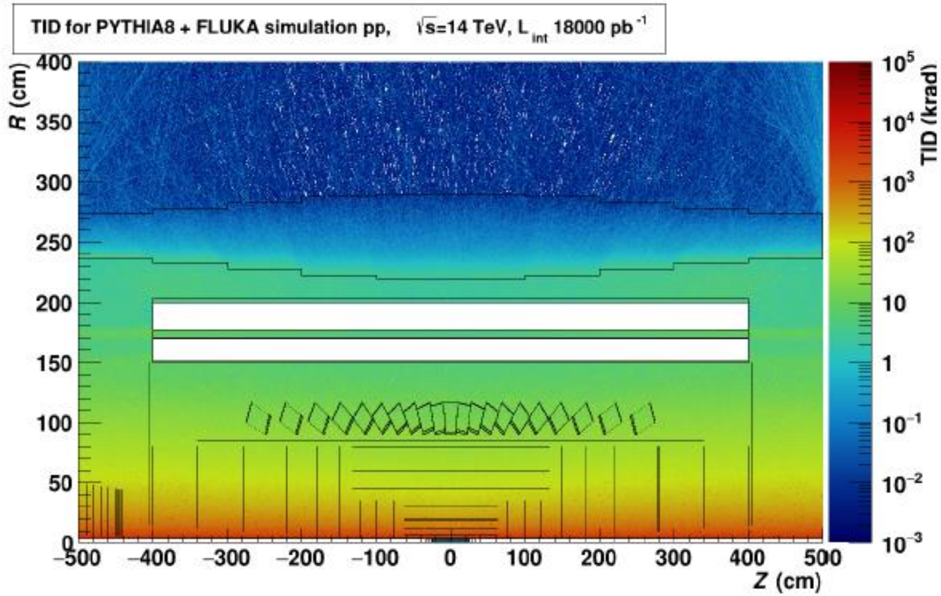
Physics goals		*Subsystems and specifications*							
Observable	***Uniqueness***	**Magnet**	**IT**	**OT**	**TOF**	**RICH**	**ECAL**	**MID**	**FCT**
Multi-charm baryons	Observation of multi-charm baryons in AA collisions	**B = 1-2 T**	**σ ~2.5 µm R_{in}= 5 mm x/X_0~0.1% $\lvert\eta\rvert$<4**	**σ ~10 µm R_{out} > 65 cm x/X_0~1% $\lvert\eta\rvert$<4**	**Outer/Forward σ ~ 20 ps**	Barrel **Forward**			
D-Dbar correlations	Angular de-correlation of soft charm	**B = 1-2 T**	"	"	**Outer/Forward σ ~ 20 ps**	Barrel **Forward**			
Beauty mesons and baryons	Precision of 0.01 on elliptic flow	**B = 1-2 T**	"	"	**Outer σ ~ 20 ps**	Barrel **Forward**		$\lvert\eta\rvert$<1.3	
Quarkonia, χ_{c1}(3872)	Measurement at low p_T and central rap.	**B = 1-2 T**	**$\lvert\eta\rvert$<1.3**	**$\lvert\eta\rvert$<1.3**			Pb/Scintillator	**$\lvert\eta\rvert$<1.3**	
$\chi_{c1,2}$	Excited charmonia in AA collisions	**B = 1-2 T**	**$\lvert\eta\rvert$<1.3**	**$\lvert\eta\rvert$<1.3**	Outer σ ~ 20 ps	Barrel	Crystals segment	**$\lvert\eta\rvert$<1.3**	
Di-leptons (T, flow, χ-symm)	Time-evolution of thermal radiation; chiral symm. at μ_B=0	**B = 0.5-1 T**	**σ ~2.5 µm R_{in}= 5 mm x/X_0~0.1% $\lvert\eta\rvert$<2**	**$\lvert\eta\rvert$<2**	**Inner/Outer σ ~ 20 ps**	**Barrel**		$\lvert\eta\rvert$<1.3	
Net-baryon fluctuations	6th order net-proton cumulants	**B = 1-2 T**	**$\lvert\eta\rvert$<4**	**$\lvert\eta\rvert$ < 4**	**Outer/Forward σ ~ 20 ps**	**Forward**			
Photon-jet, full jets	High-precision low-p_T, large-R jet modification						**Pb/Scintillator barrel/endcap**		
Hadronic physics (femtoscopy, nuclei)	Charm-charm hadronic inter.; observation of charm-nuclei; (hyper)nuclei with A = 5 and 6	**B = 1-2 T**	**σ ~2.5 µm R_{in}= 5 mm x/X_0~0.1% $\lvert\eta\rvert$<4**	**σ ~10 µm R_{out} > 65 cm x/X_0~1% $\lvert\eta\rvert$<4**	**Outer/Forward σ ~ 20 ps**	Barrel **Forward**			
Searches in $\gamma\gamma$ in UPCs	ALPs m>0.1GeV and low coupling	**B = 1-2 T**	$\lvert\eta\rvert$<4	$\lvert\eta\rvert$<4	Inner/Outer/ Forward σ ~ 20 ps	Barrel/Forward	**Pb/Scintillator barrel/endcap**		
Ultrasoft photons	Validity and limits of Low theorem	**Small dipole B ~ 0.25 T**							**4 < η < 5 x/X_0~1%**

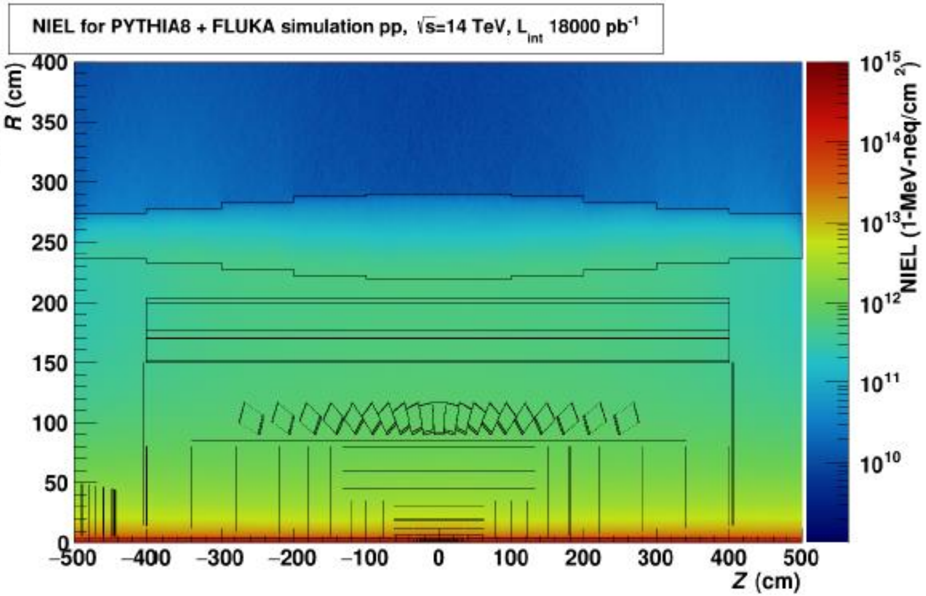


$B = 1.0$ T, π
$B = 1.0$ T, p
$B = 2.0$ T, π
$B = 2.0$ T, p
$\eta=0$
$\Delta p_T / p_T$
p_T (GeV/c)



ALICE3 study
ACTS reconstruction
Ref. layout February 2024
p_T = 1 GeV/c
$B = 1$ T, π
$B = 1$ T, p
$B = 2$ T, π
$B = 2$ T, p
$\Delta p_T / p_T$
η


TID for PYTHIA8 + FLUKA simulation pp, √s=14 TeV, L int 18000 pb -1
R (cm)
Z (cm)
TID (krad)


NIEL for PYTHIA8 + FLUKA simulation pp, √s=14 TeV, L int 18000 pb -1
R (cm)
Z (cm)
NIEL (1-MeV-neq/cm 2)