

IFAE 2023

Incontri di Fisica
delle Alte Energie

Catania
13/04/2023

Studio di rivelatori al silicio avanzati per l'esperimento **ALICE 3** nel Run 5 e 6 di LHC

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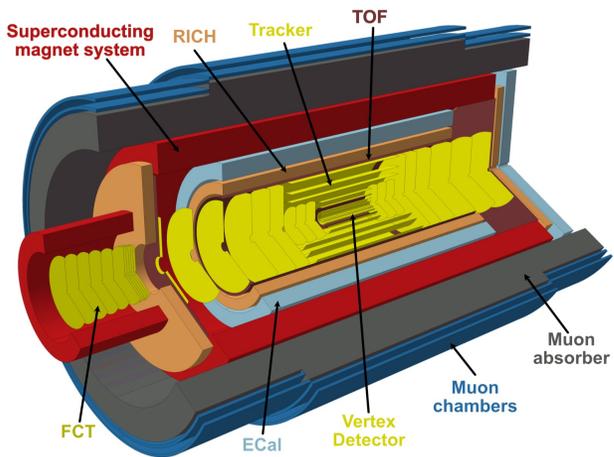
ALICE

L'esperimento ALICE ha raggiunto in questi anni un ambizioso programma nel campo della caratterizzazione del Quark Gluon Plasma e molti progressi sono previsti per i Run 3 e 4.

Il detector concept attuale lascerà però **diverse domande fondamentali aperte**

- Meccanismi di adronizzazione e termalizzazione di quark pesanti
- Precisa descrizione microscopica delle interazioni dei quark heavy-flavour
- Produzione di barioni multi-charmati
- ρ - a_1 mixing

<https://arxiv.org/abs/2211.02491>



Nuovo apparato sperimentale realizzato interamente da tecnologie al silicio di ultima generazione

➔ **Ricco programma e nuove opportunità di studio**

◆ Rivelazione di **adroni multi-charm a basso impulso** → test critico per modelli di coalescenza

◆ Radiazione EM prodotta dal QGP nelle **prime fasi di evoluzione**

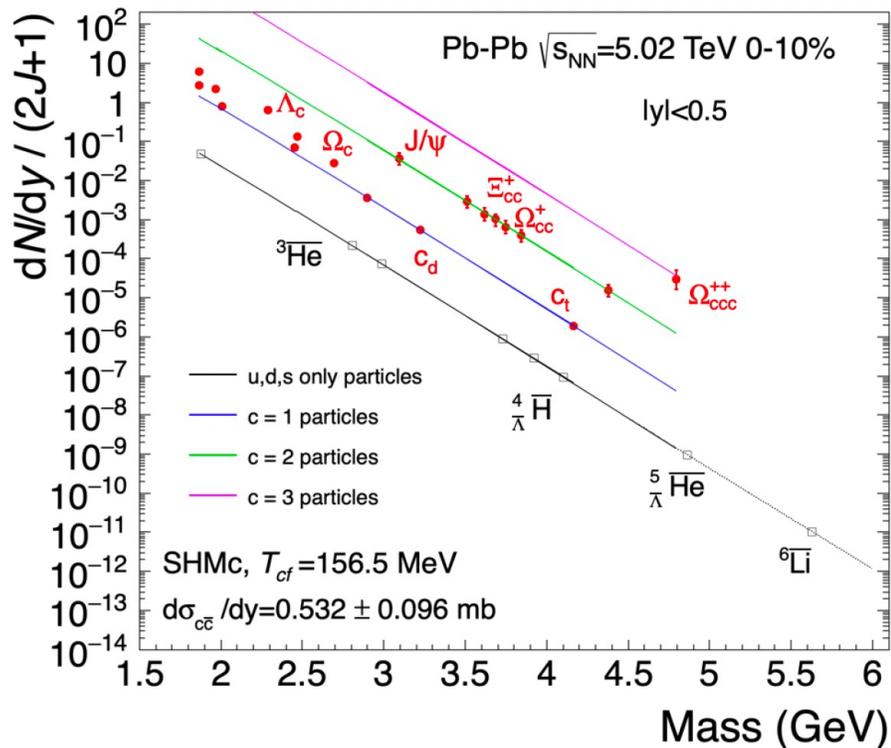
ALICE 3 a next generation heavy-ion experiment



L'esperimento ALICE ha raggiunto in questi anni un ambizioso programma nel campo della caratterizzazione. Molti progressi sono previsti per i Run 3 e 4.

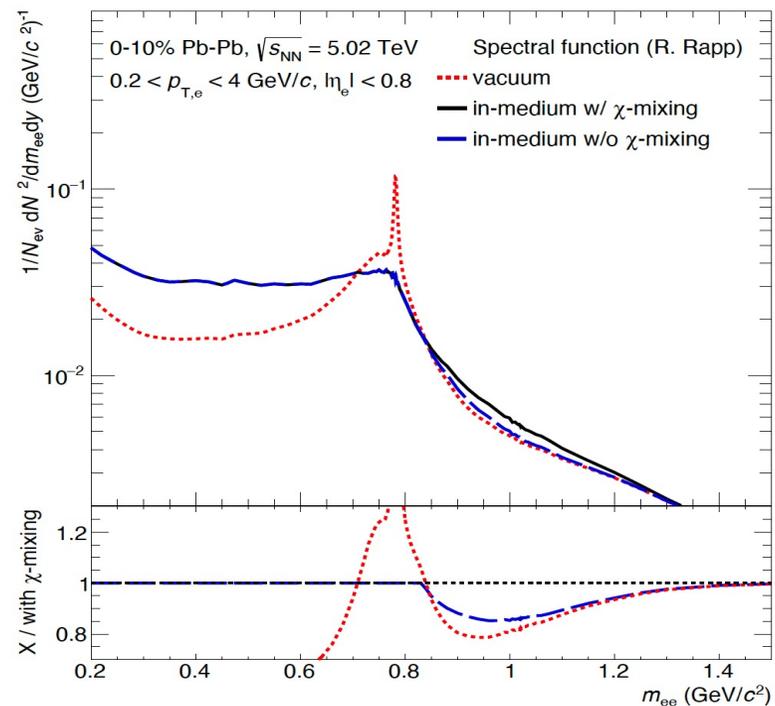
Esempi di nuove opportunità di studio

Tutti gli stati qua riportati sono potenzialmente misurabili da ALICE3



Statistical-thermal model predictions

Test cruciali riguardo alla ristorazione della simmetria chirale



Thermal dilepton mass spectra for three different scenarios

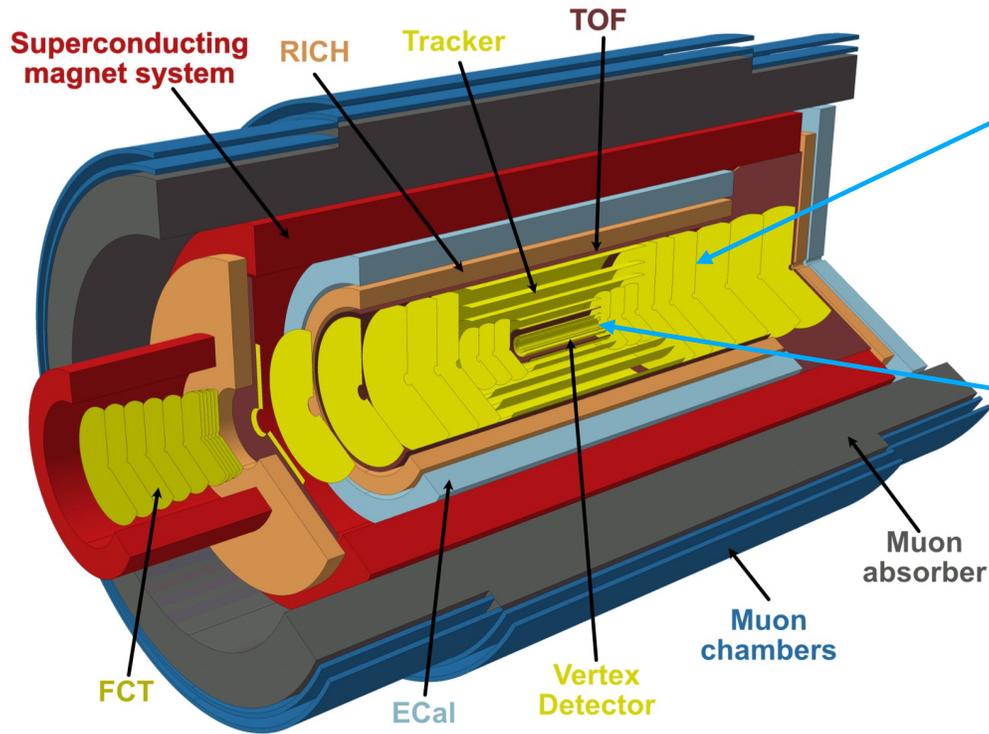
<https://>

Superconducting magnet system

FCT

2025

Esperimento **compatto**, totalmente basato su **rivelatori al silicio** innovativi e progettato per raccogliere **luminosità elevate** ($L_{PbPb} \sim 1.2 \times 10^{28} \text{ cm}^{-2}\text{s}^{-1}$)

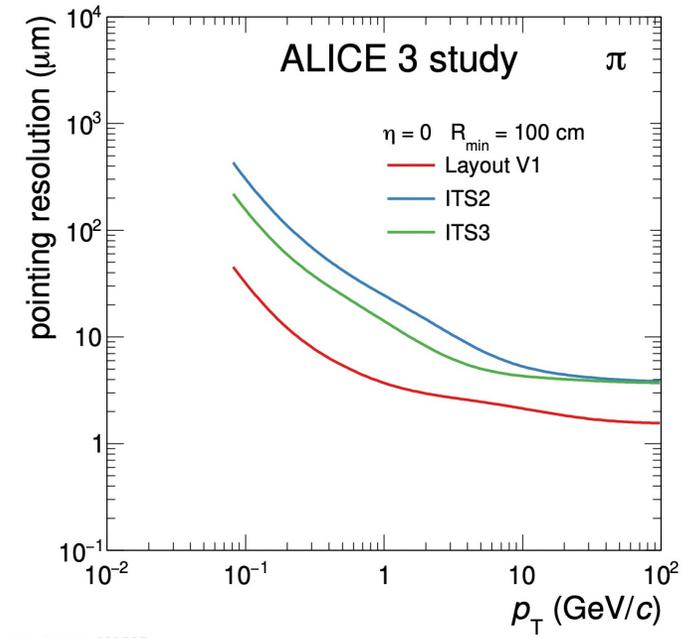


Tracking:

- **Eccellente risoluzione sul p_T** $\sim 1-2 \%$
- **Larga regione di pseudorapidità** ($|\eta| < 4$)

Vertexing:

- **Primi piani all'interno della beam pipe**
- **Eccellente risoluzione di pointing**



ALICE 3

a next generation heavy-ion experiment

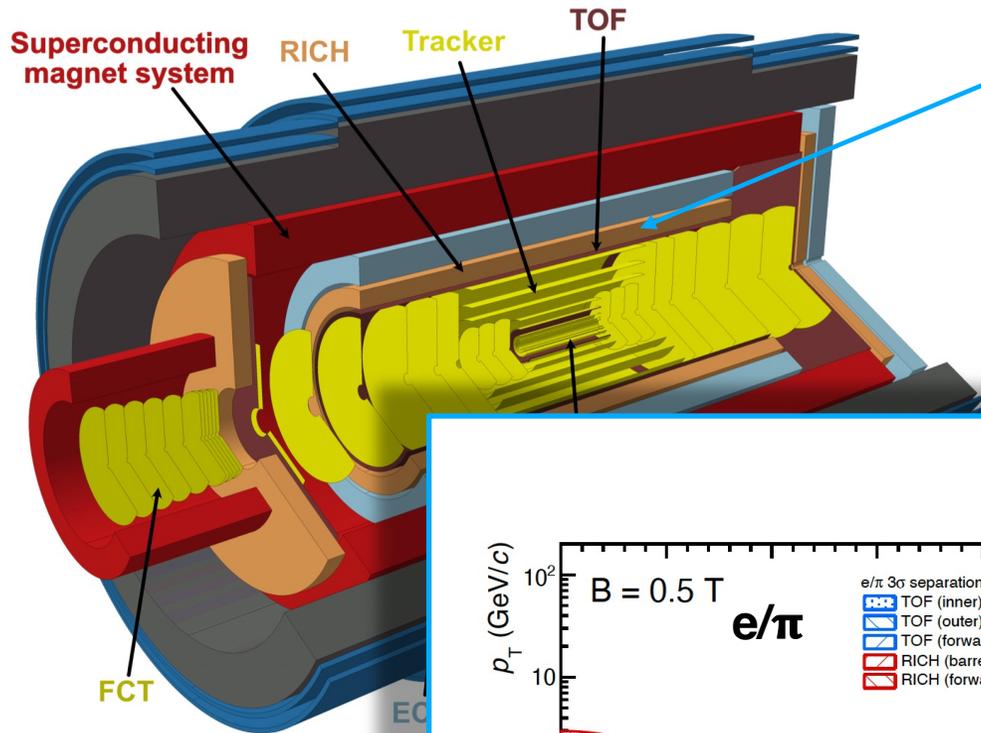


Esperimento **compatto**, totalmente basato su **rivelatori al silicio** innovativi e progettato per raccogliere **luminosità elevate** ($L_{PbPb} \sim 1.2 \times 10^{28} \text{ cm}^{-2}\text{s}^{-1}$)

Identification:

- **Identificazione delle particelle in un range di p_T molto vasto**

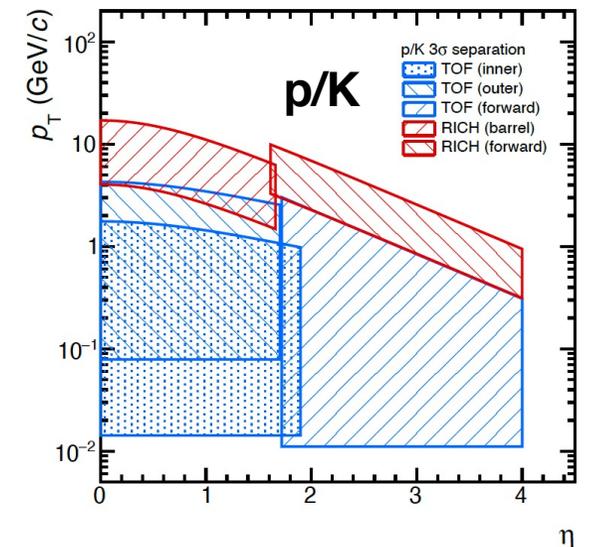
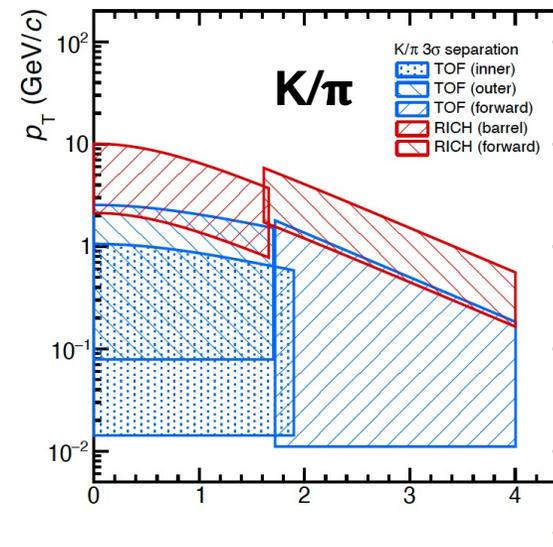
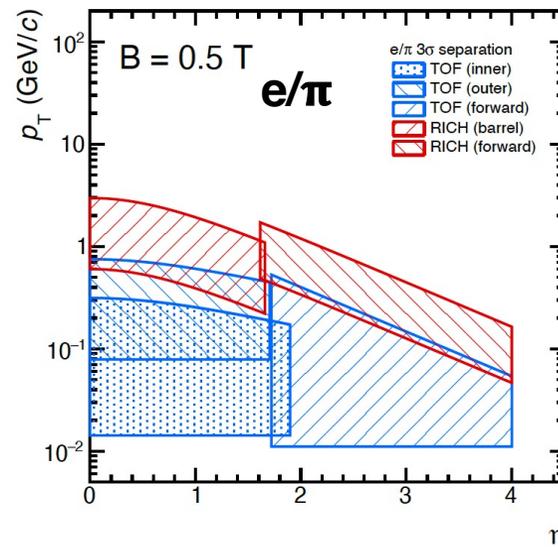
- adroni fino a 2-3 GeV/c
- elettroni tra $0.05 < p_T < 2 \text{ GeV/c}$
- fotoni fino a bassissimi $p_T (\geq 1 \text{ MeV/c})$



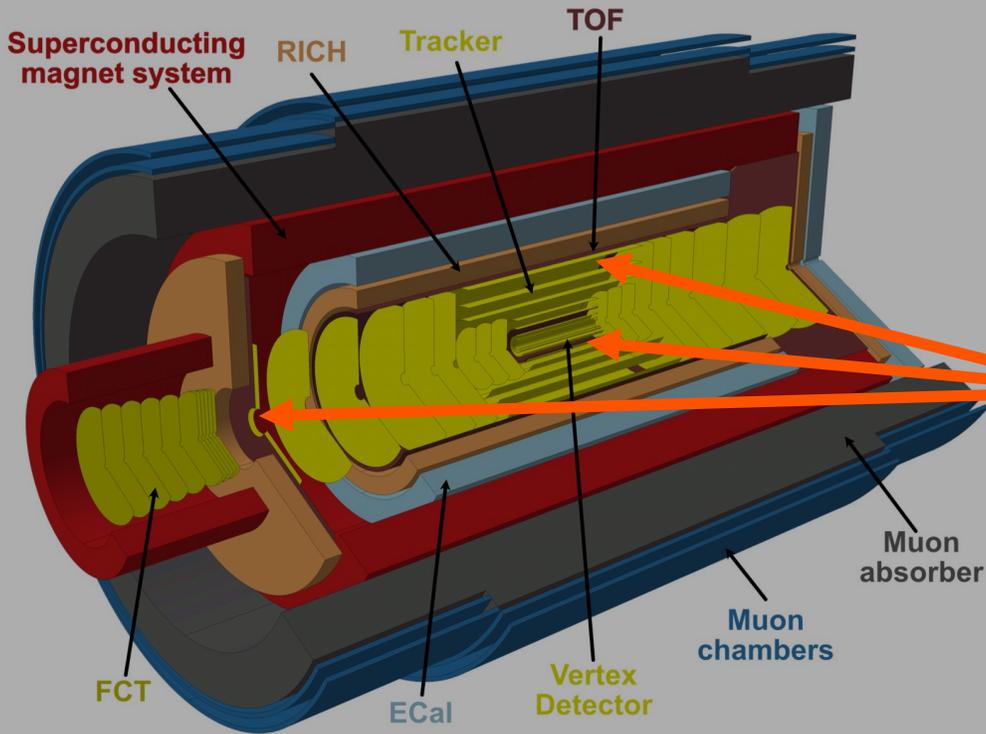
ALICE



TOF + RICH Separation (B = 0.5T)



Esperimento **compatto**, totalmente basato su **rivelatori al silicio** innovativi e progettato per raccogliere **luminosità elevata**



ALICE 3

a next generation heavy-ion experiment

Sistema a Tempo di Volo (TOF)

$$\text{Separation Power} \propto \frac{L}{\sigma_{\text{TOF}}}$$

- outer TOF $R \approx 85 \text{ cm}$
- inner TOF $R \approx 19 \text{ cm}$
- forward TOF $z \approx 405 \text{ cm}$

Requisiti:

- Buona rad. hardness (inner TOF: $\text{NIEL} \sim 10^{13} \text{ 1MeVn}_{\text{eq}} / \text{cm}^2$)

Risoluzione temporale

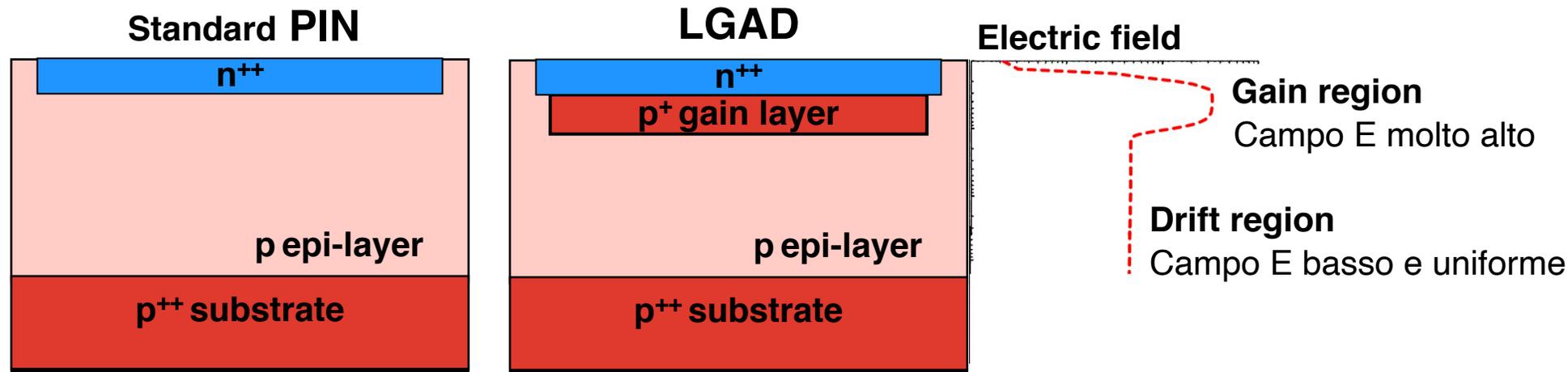
20ps

Diverse **tecnologie al silicio innovative** sono sotto studio

- *LGAD*
- *SiPM*
- *MAPS*



LOW GAIN AVALANCHE DETECTOR (LGAD)



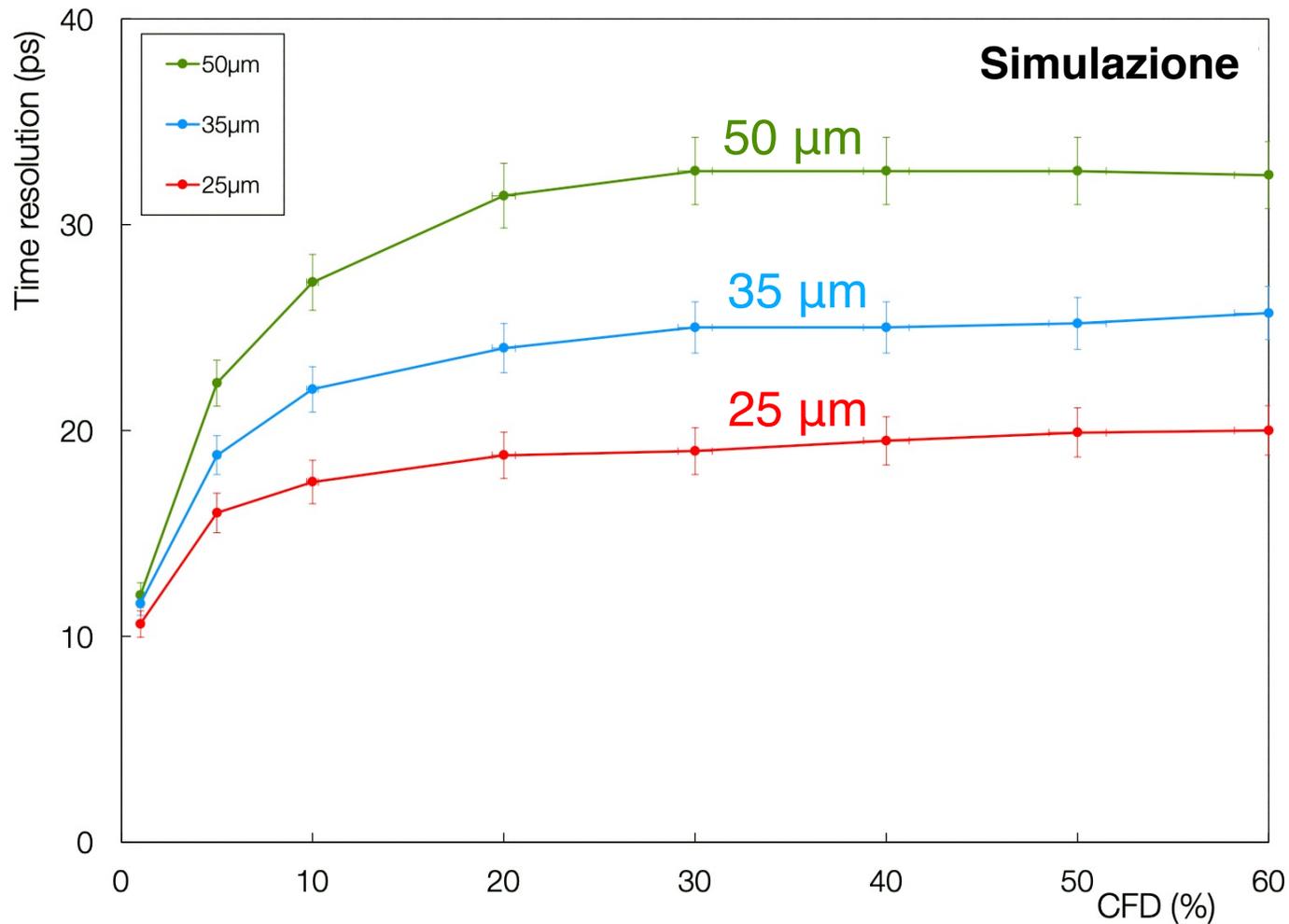
Basato su un meccanismo di moltiplicazione a basso guadagno (10-70)

Rapporto tra segnale e rumore più alto

→ **Risoluzione temp. eccellente**

Sensore allo stato dell'arte (50 μm) → **~30 ps**

Già utilizzati nei principali esperimenti di LHC e previsti per diversi upgrades a HL-LHC (ATLAS & CMS)



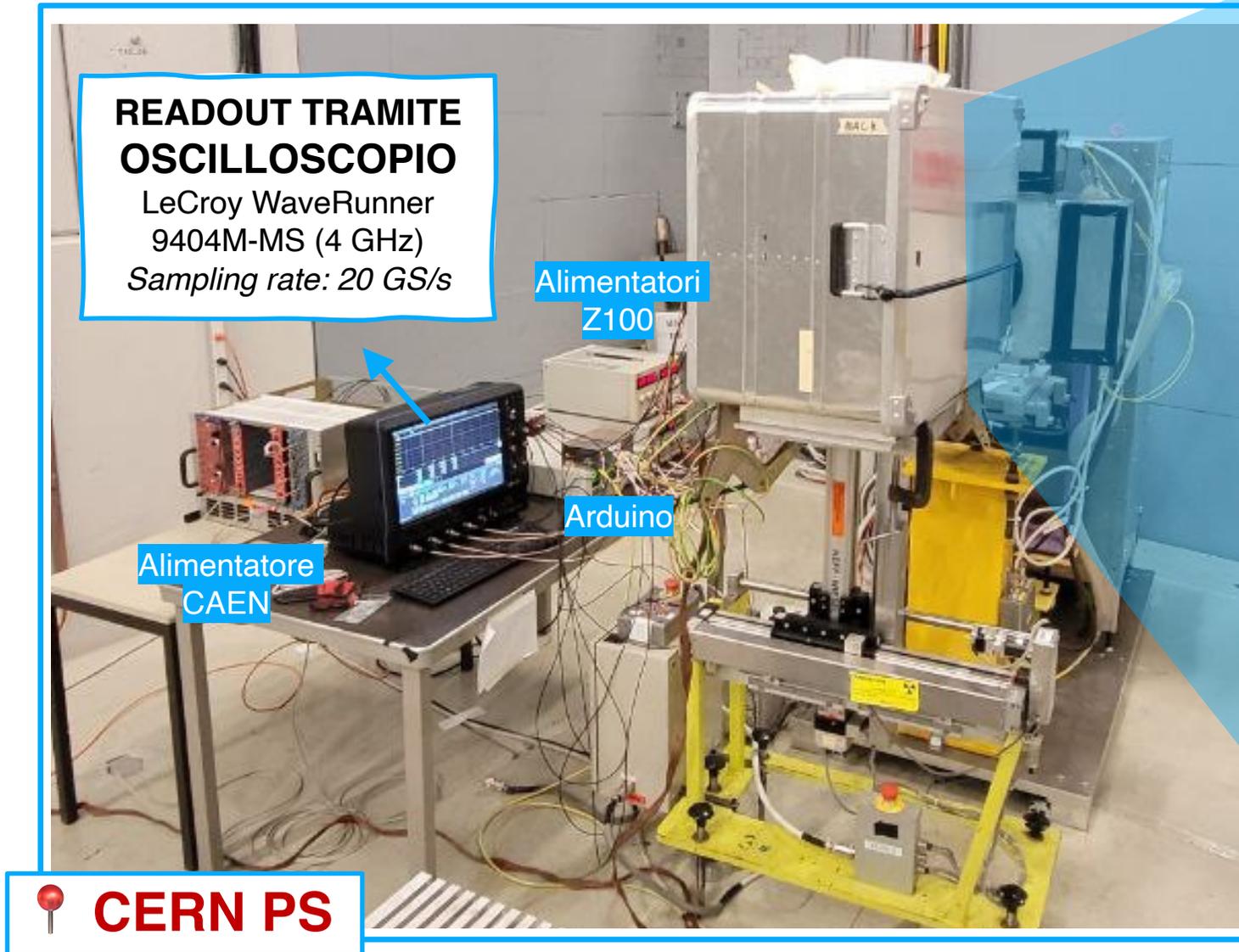
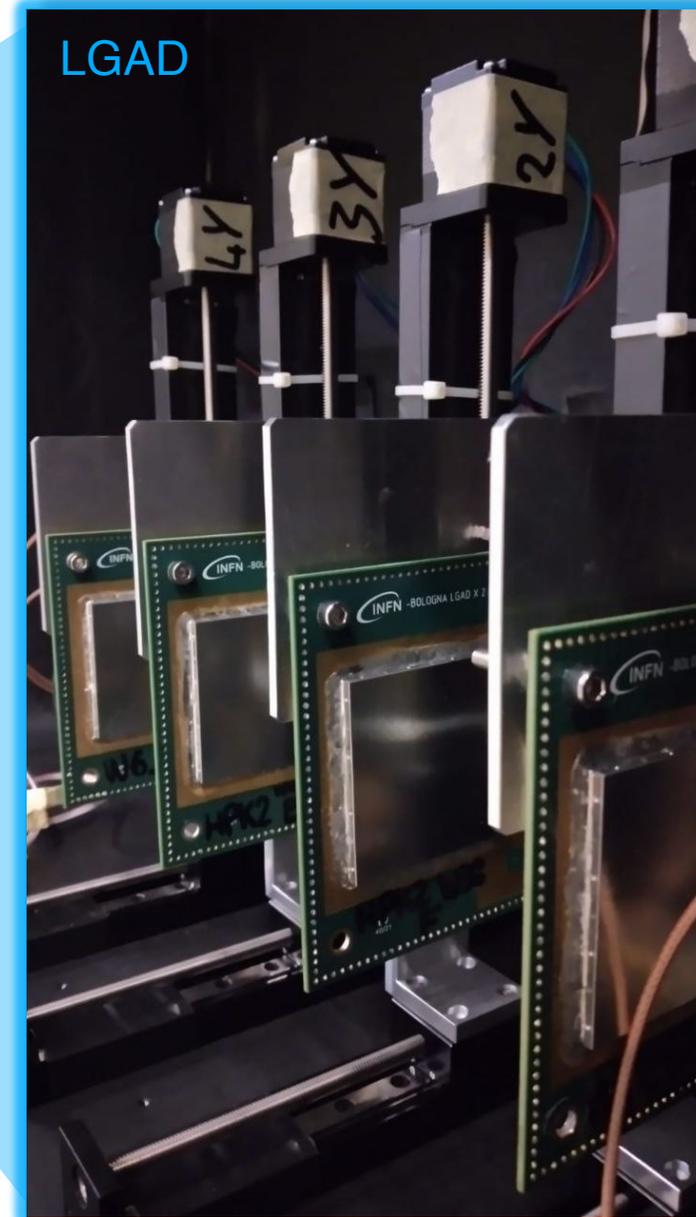
→ Potenziale di design di **LGAD** più sottile

Richieste sempre più esigenti da parte della futura generazione di esperimenti → **20 ps**

Sensore allo stato dell'arte (50 µm) → **~30 ps**

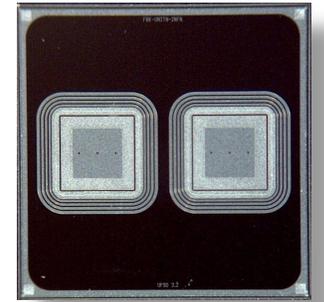
Già utilizzati nei principali esperimenti di LHC e previsti per diversi upgrades a HL-LHC (ATLAS & CMS)

SETUP AL BEAM TEST



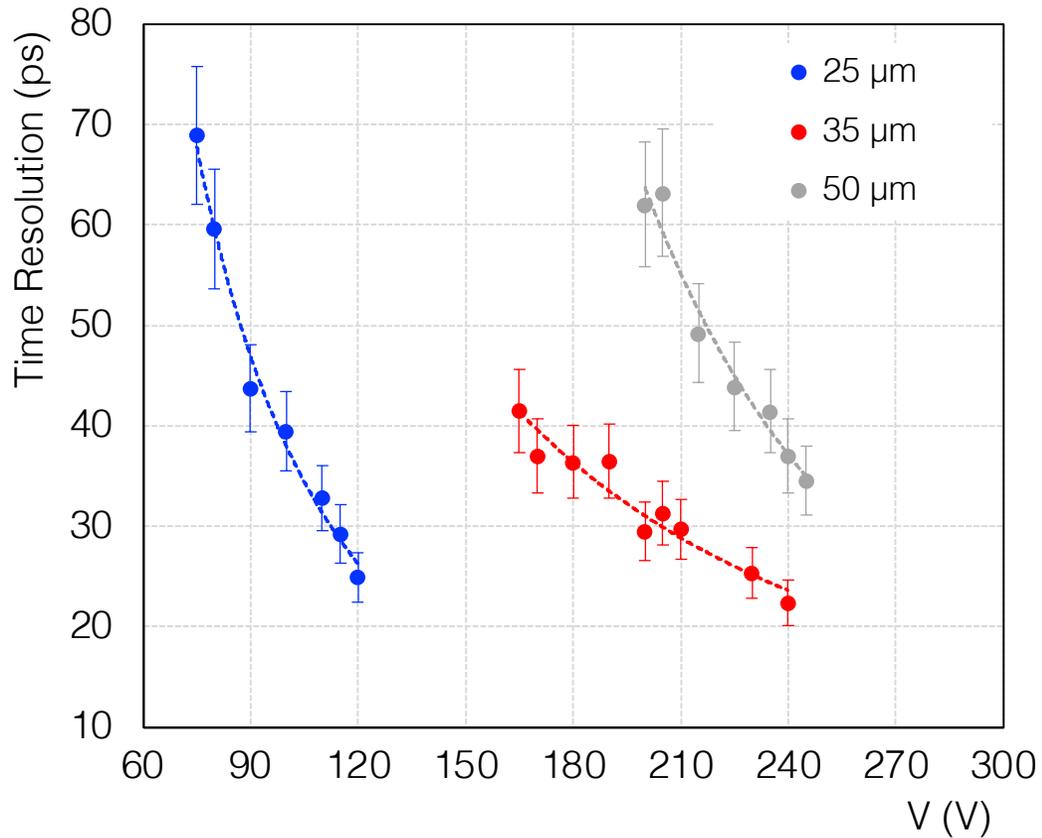
 **CERN PS**

BEAM TEST OF NOVEMBER 2021



I primi LGAD sottili di spessore 25 e 35 μm prodotti da FBK sono stati testati per la prima volta con un fascio di Pioni di 12 GeV/c

<https://link.springer.com/article/10.1140/epjp/s13360-022-03619-1>



LGAD standard (50 μm) in linea con le aspettative

- Validazione del setup e della procedura di analisi

**25
 μm**

25 ps : Leggermente peggiore di quanto previsto dalle simulazioni (basso S/N)

**35
 μm**

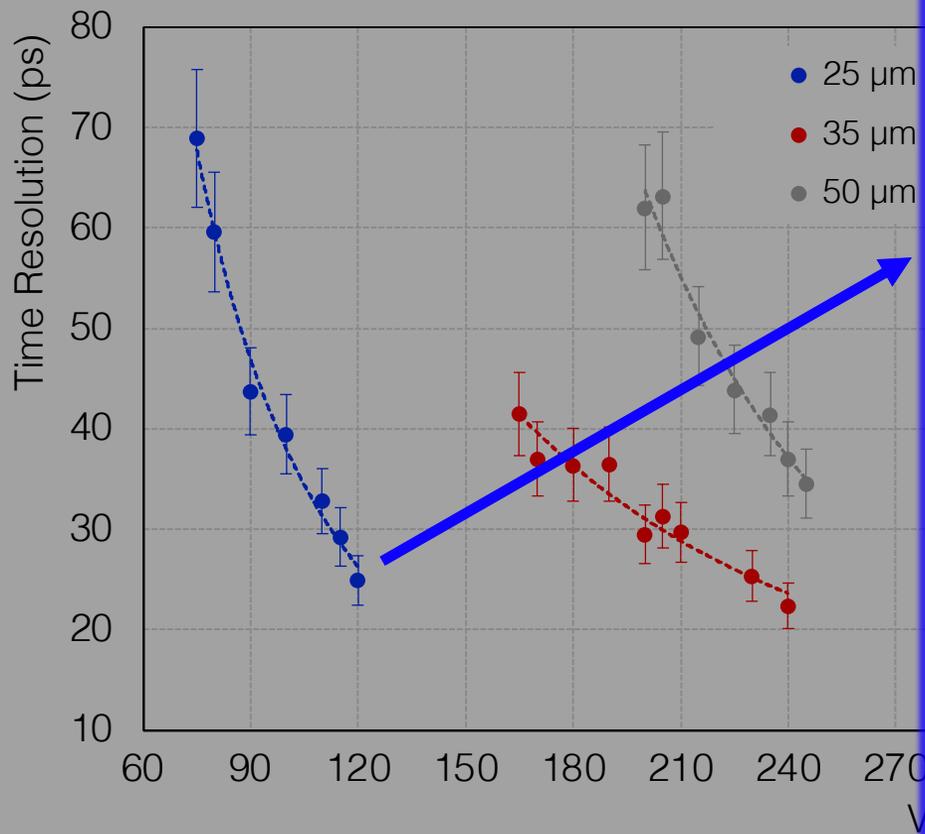
22 ps : totalmente in accordo con le simulazioni MC

LGAD più sottili permettono di arrivare ad una risoluzione temporale migliore

BEAM TEST C

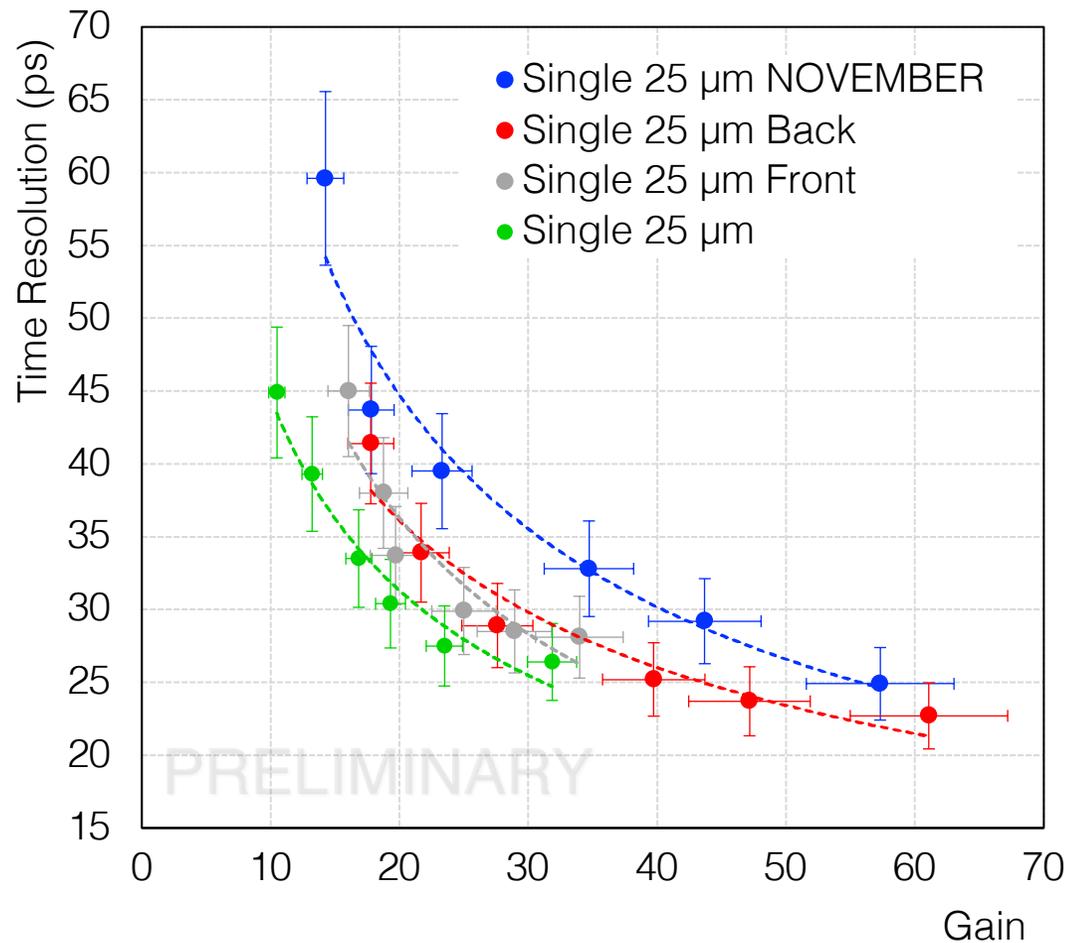
I primi LGAD sottili di spessore
testati per la

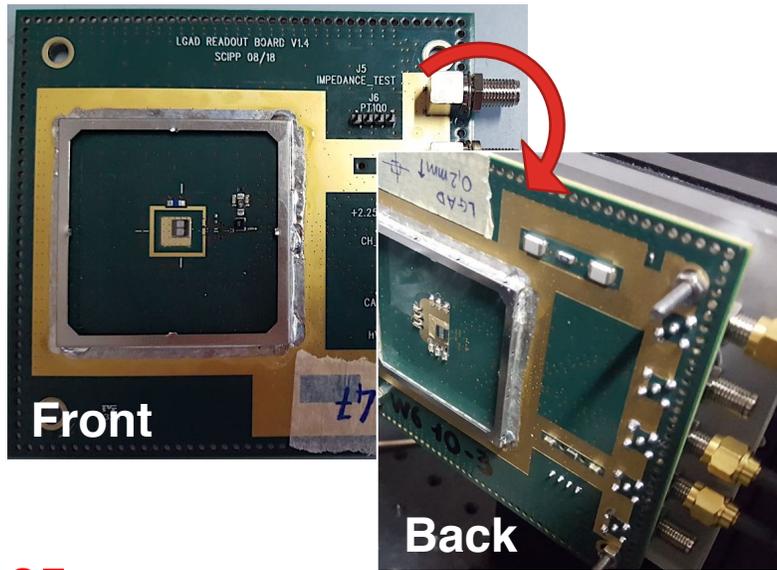
<https://>



July BT
10 GeV/c pion beam

Miglioramento dei risultati
Dovuto a un più alto rapporto S/N
(migliore schermatura dal rumore) e gain



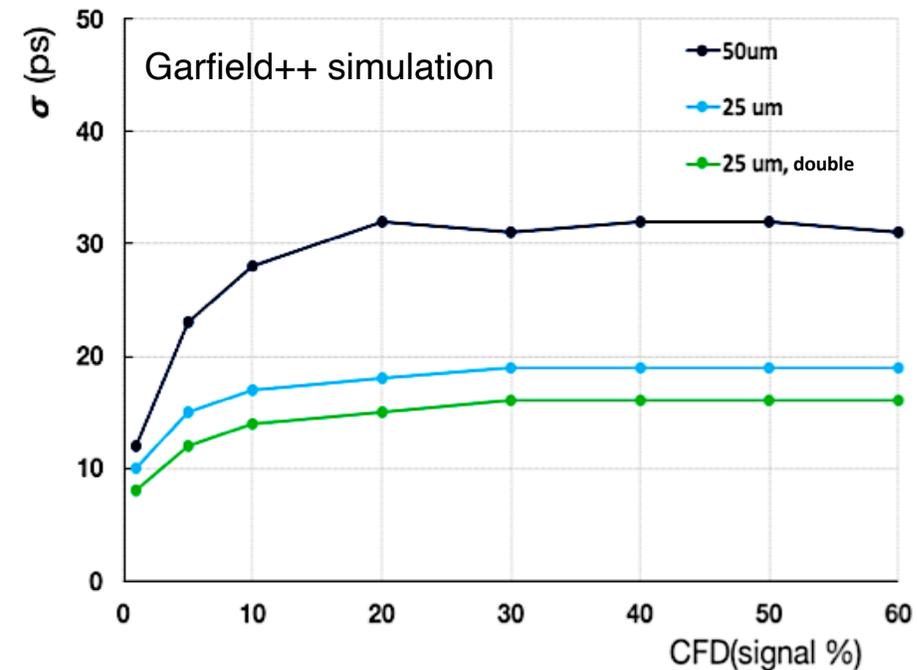


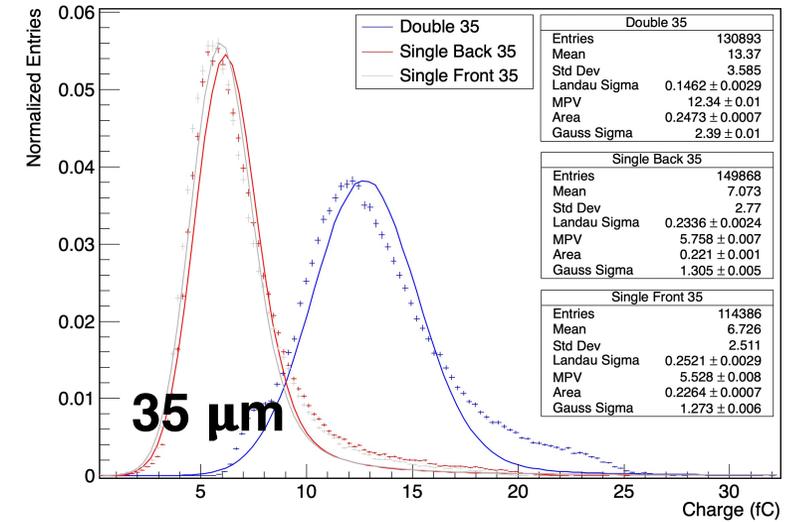
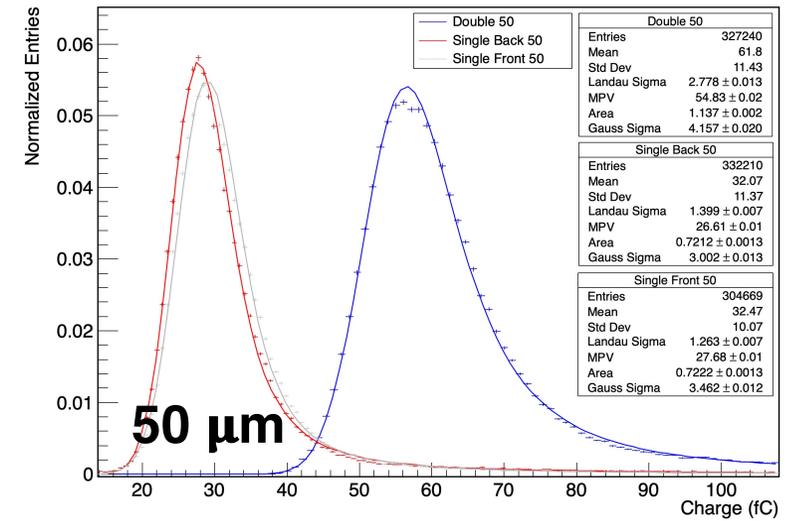
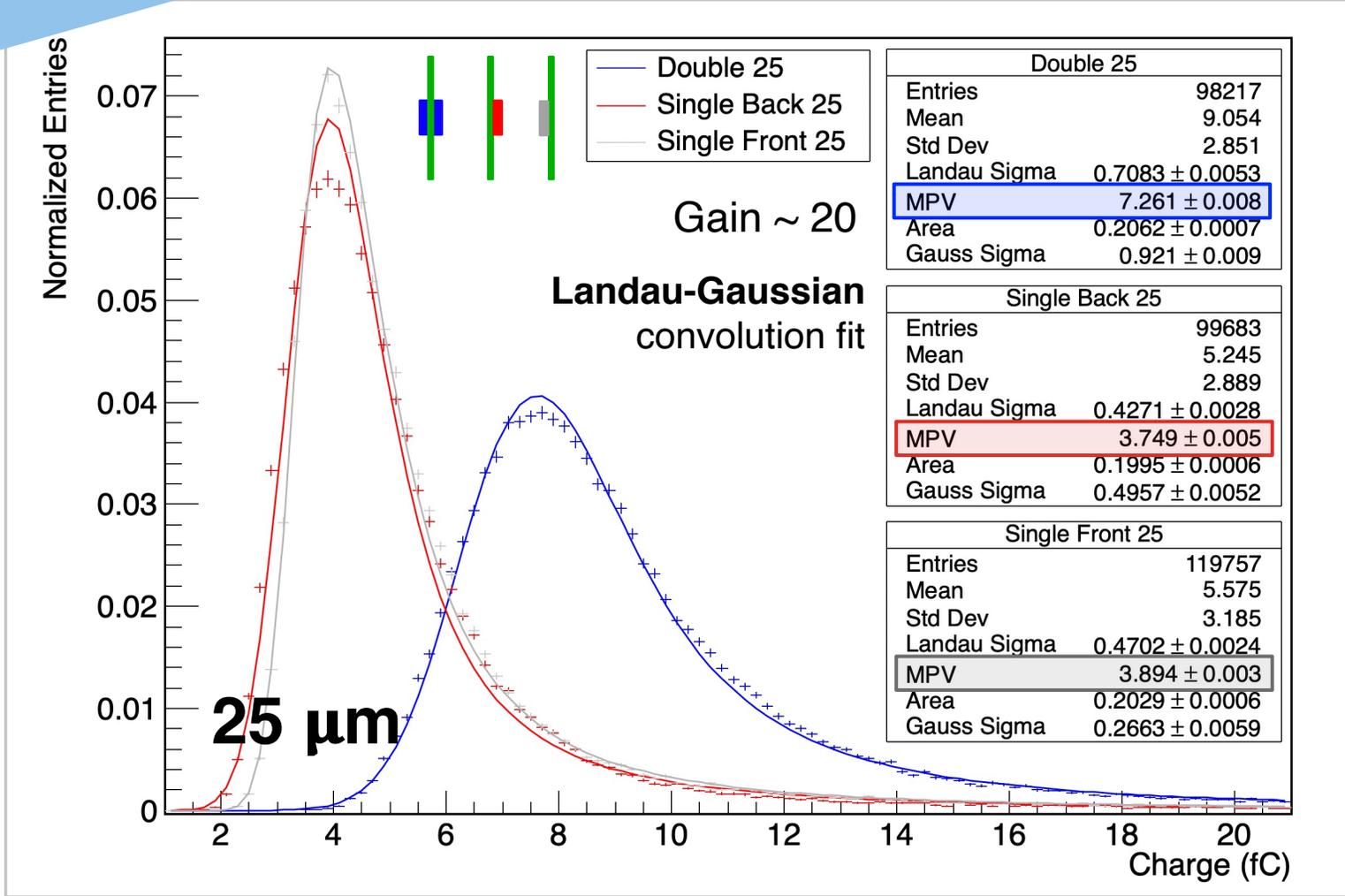
25+25 μm

Due LGAD uniformi attaccati sui due lati della scheda ed **entrambi connessi allo stesso amplificatore**

(unico canale di front-end e readout)

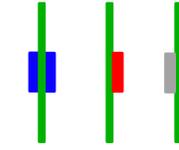
- **Segnale più alto**
 - Elettronica di front-end meno power-consuming
 - Elettronica simile a quella utilizzata per gli LGAD standard (50 μm)
- **Risoluzione temporale migliore**



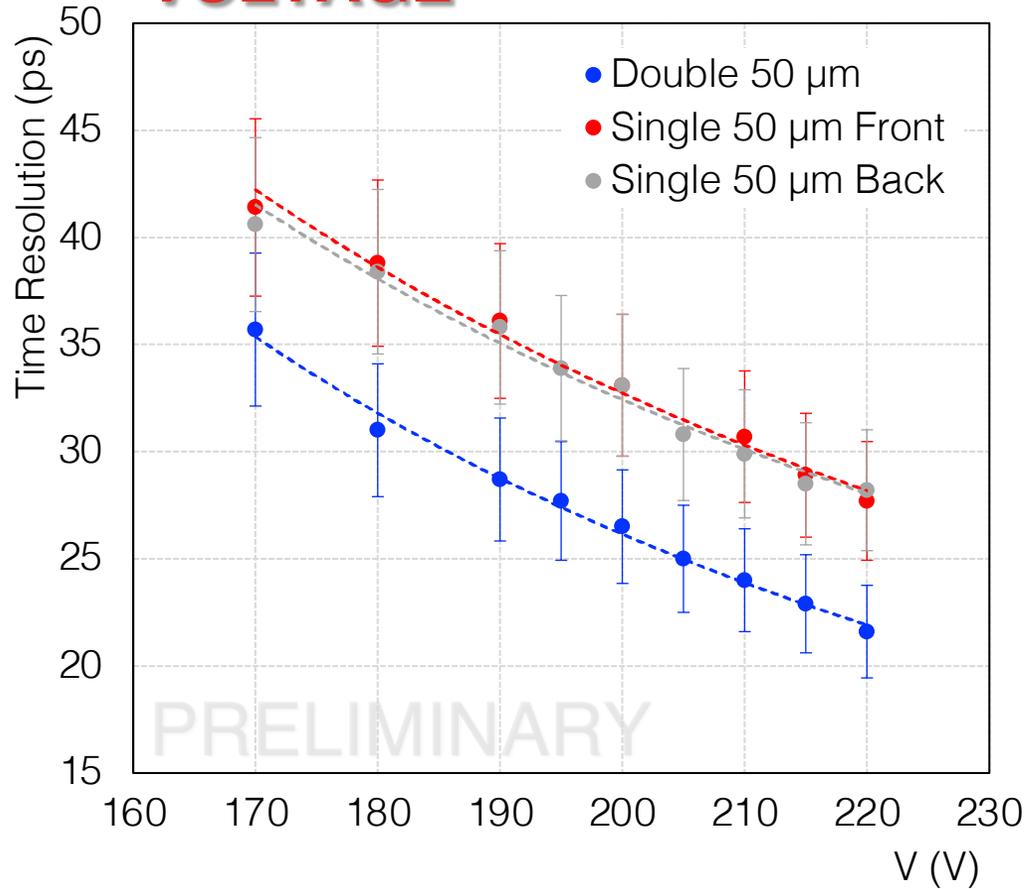


MPV della carica **doppio** per il doppio-LGAD, come aspettato → **Vantaggio per l'elettronica**

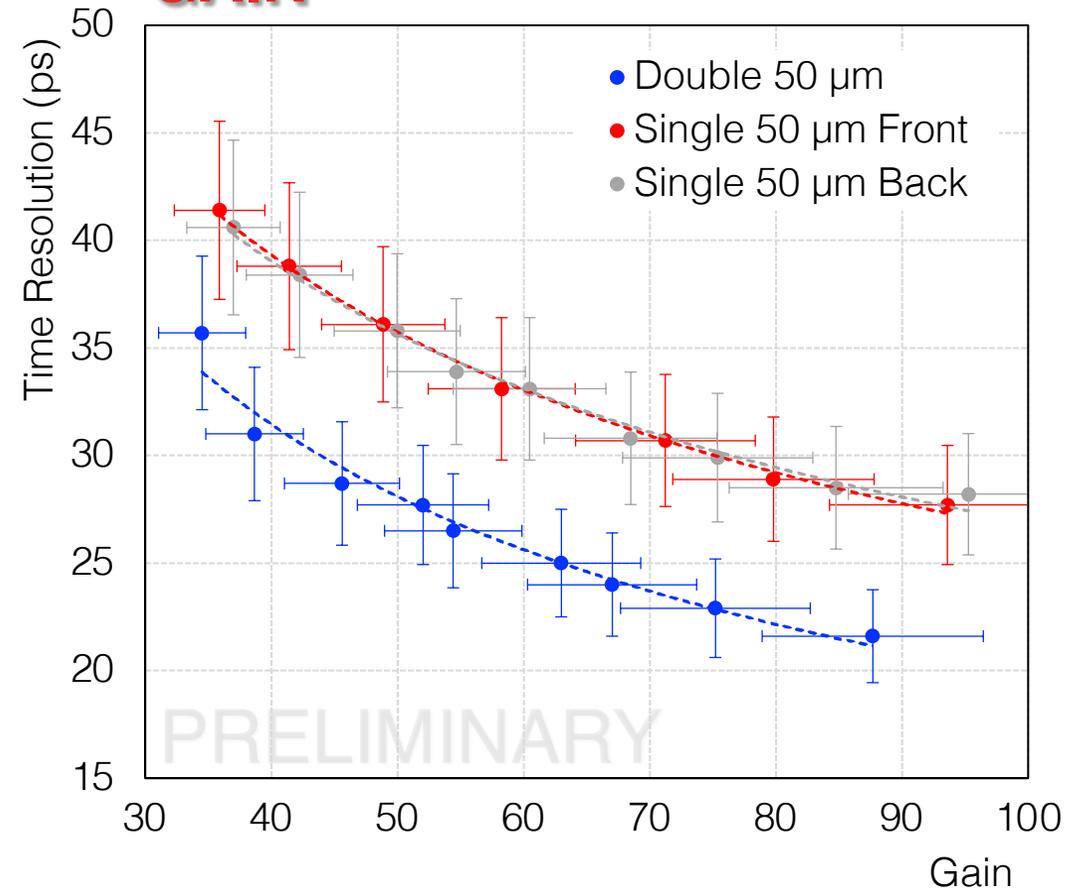
Risoluzioni temporali: Singolo VS doppio-LGAD 50 μm



VOLTAGE

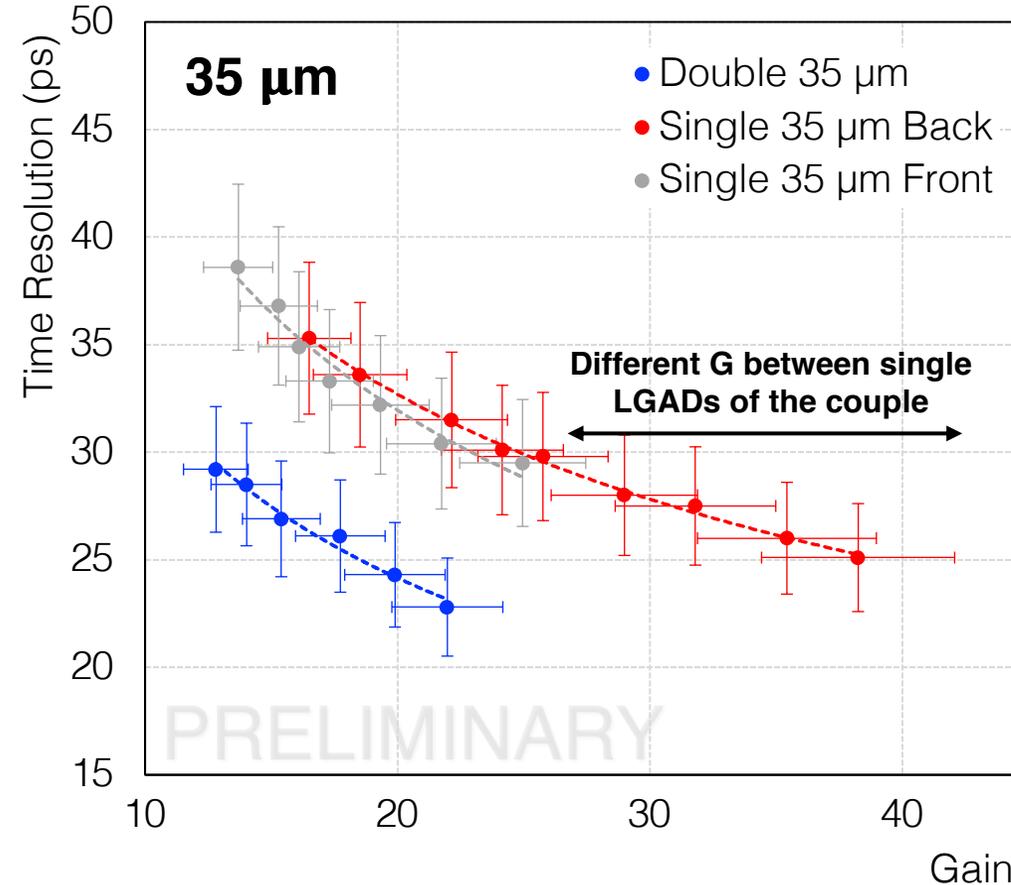
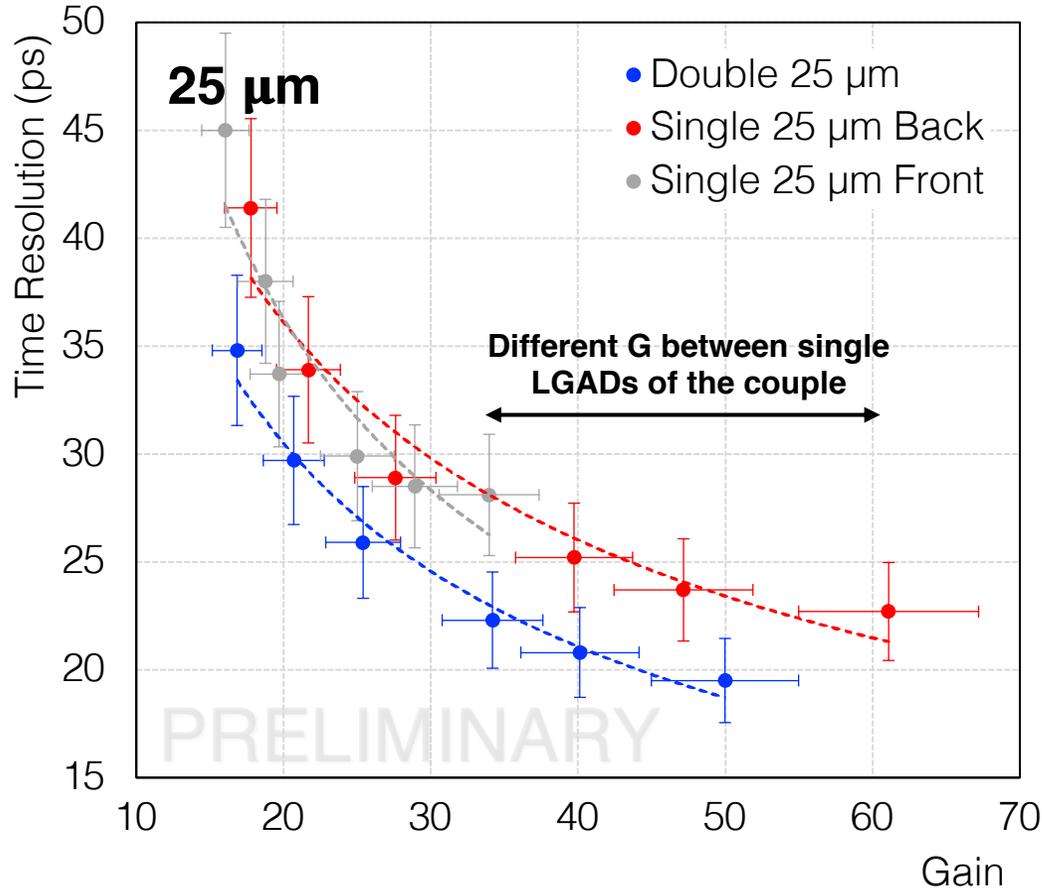
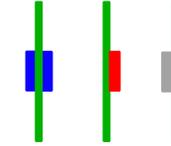


GAIN



- Risultati uniformi per i sensori singoli con spessore standard di 50 μm
- **Risoluzioni temporali migliori per il doppio-LGAD rispetto al singolo (~23%)**

Risoluzioni temporali: Singolo VS doppio-LGAD 25-35 μm



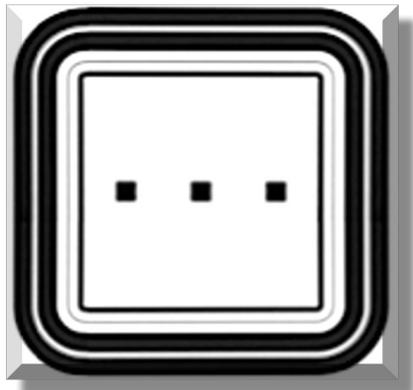
- LGAD singoli: risoluzione temporale **comparabile a parità di gain**
- **Risoluzioni temporali migliori per il doppio-LGAD** rispetto al singolo (~15 & 24%)

CONCLUSIONI

I risultati mostrano che con LGAD sottili (25, 35 μm) e con il concetto di doppio-LGAD si raggiungono risoluzioni molto vicine alla richiesta di 20 ps

FUTURE PLANS: Beam Test in Luglio

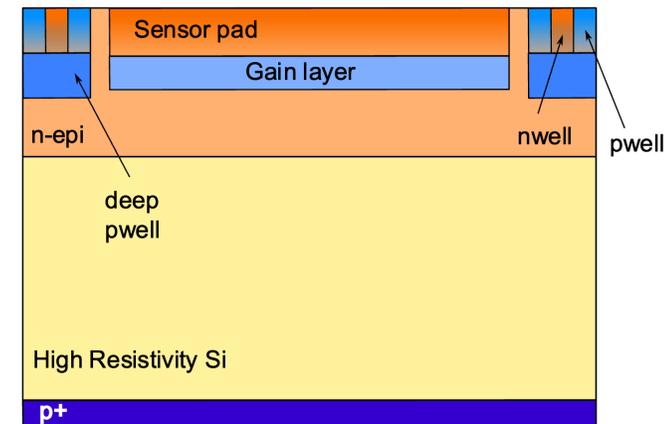
LGAD più sottili (10-15 μm)



Singoli e doppi

Test di caratterizzazione in laboratorio già iniziati

CMOS LGADs





BACKUP SLIDES

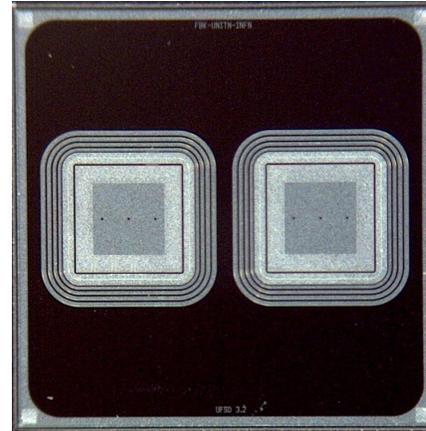
BACKUP SLIDES

TESTED LGADs & ELECTRONICS

First very thin LGAD prototypes produced by FBK

25 μm and **35 μm** -thick
FBK single channel

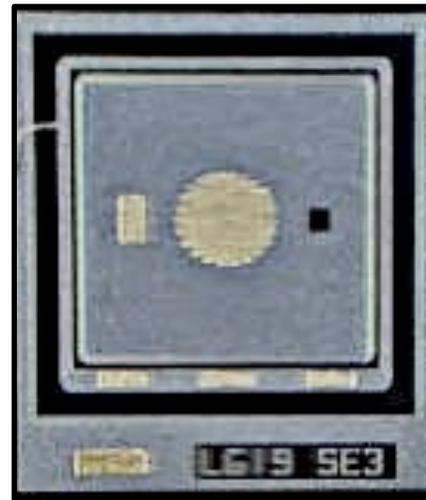
Area = **1x1 mm²**



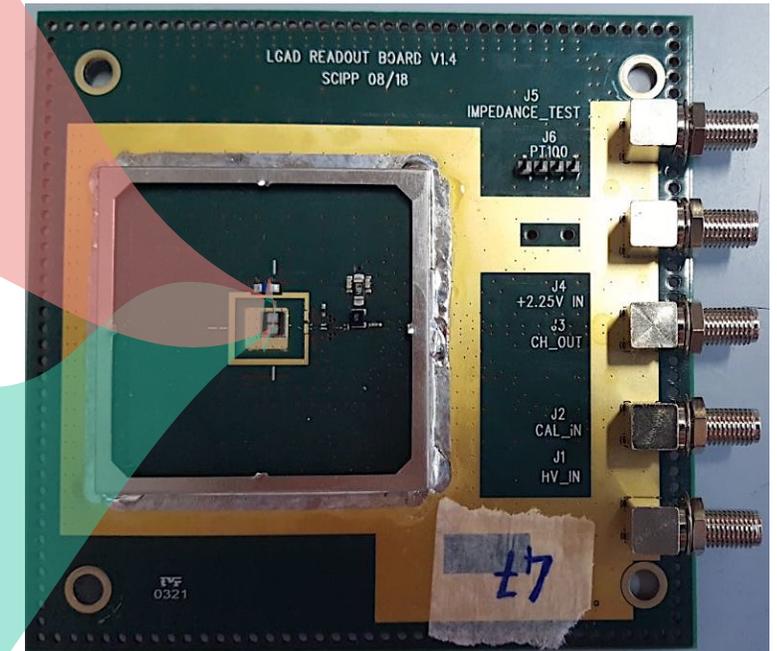
Standard sensors produced by HPK

50 μm -thick HPK
single channel
(W42 & W36 with different
doping concentrations)

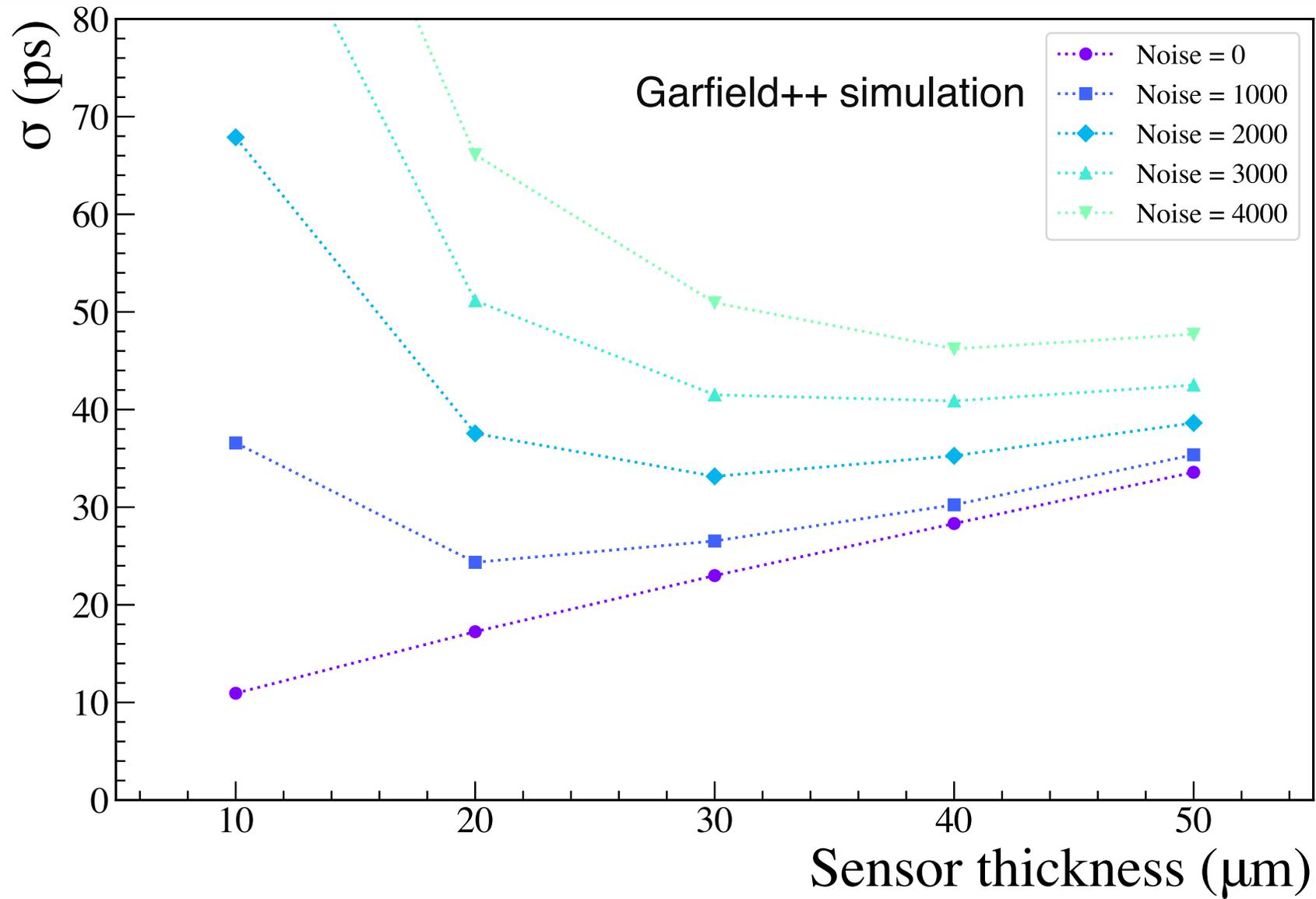
Area = **1.3x1.3 mm²**

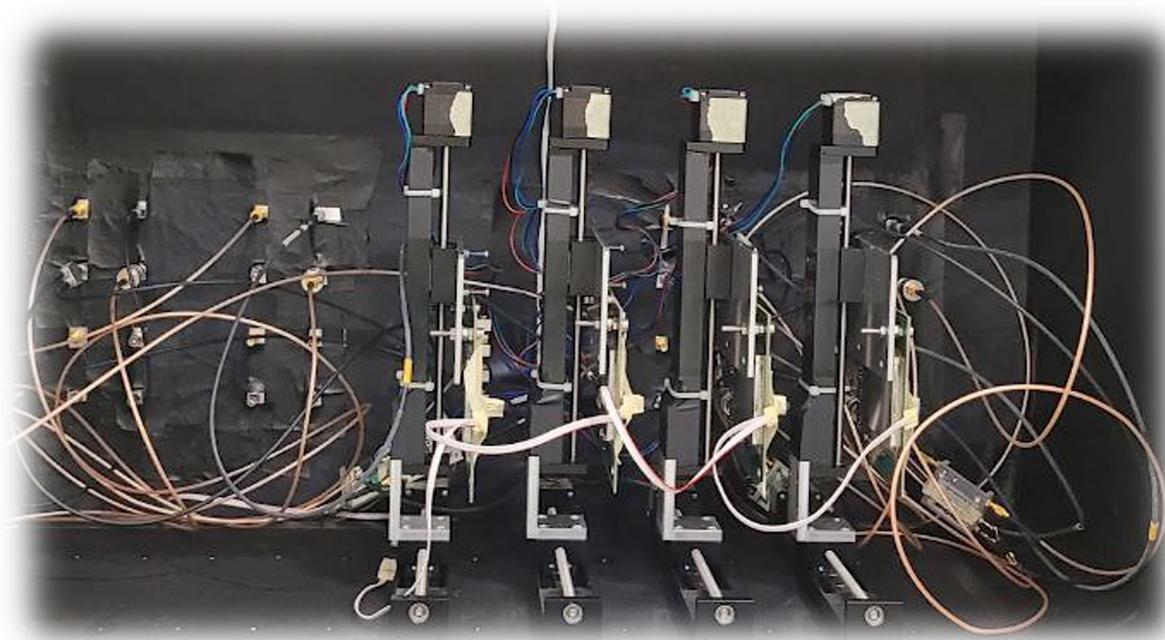


SantaCruz single-channel LGAD
read-out board V1.4 SCIPP
08/18 ($G_{\text{amplifier}} \sim 6$)



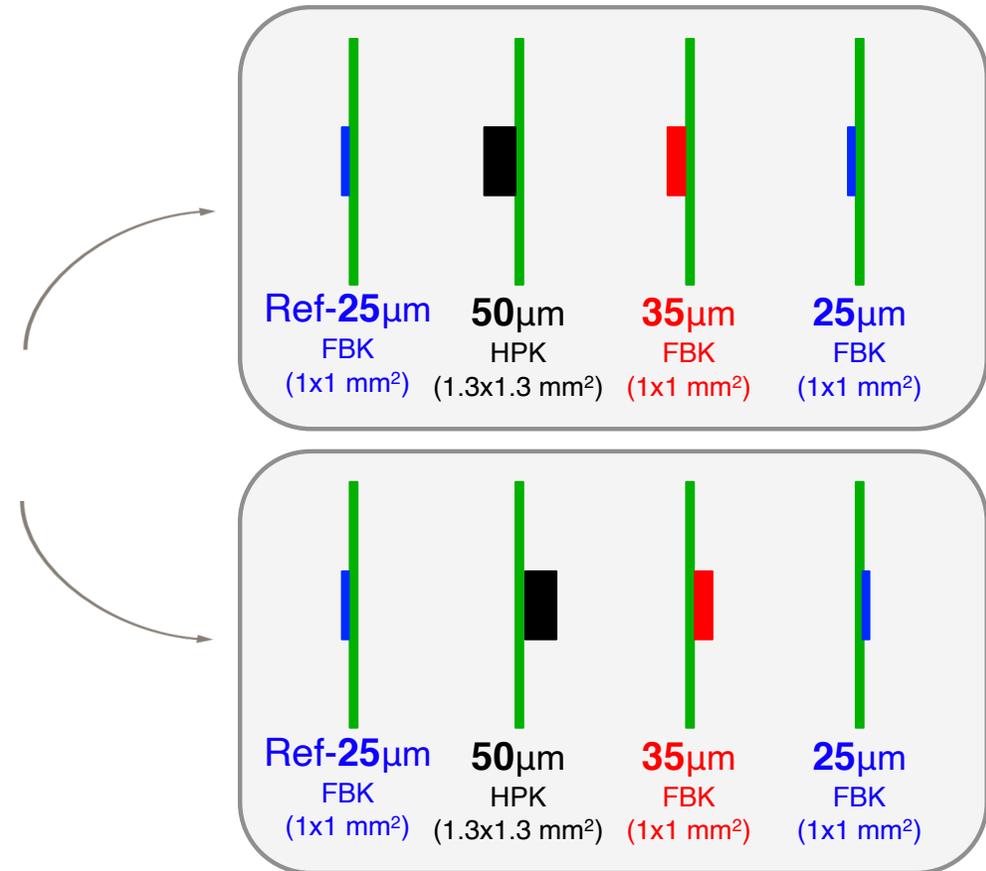
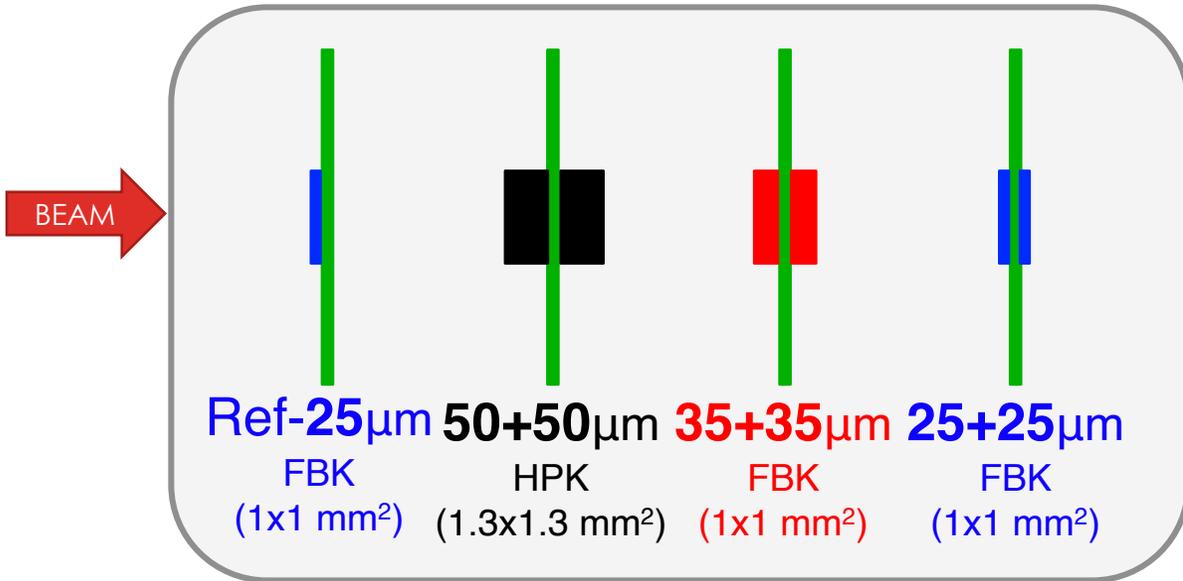
+ Second stage external amplifier
($G_{\text{amplifier}} \sim 11-14$)





Configuration example

All the runs were repeated with both the single sensors of each couple using the same electronics



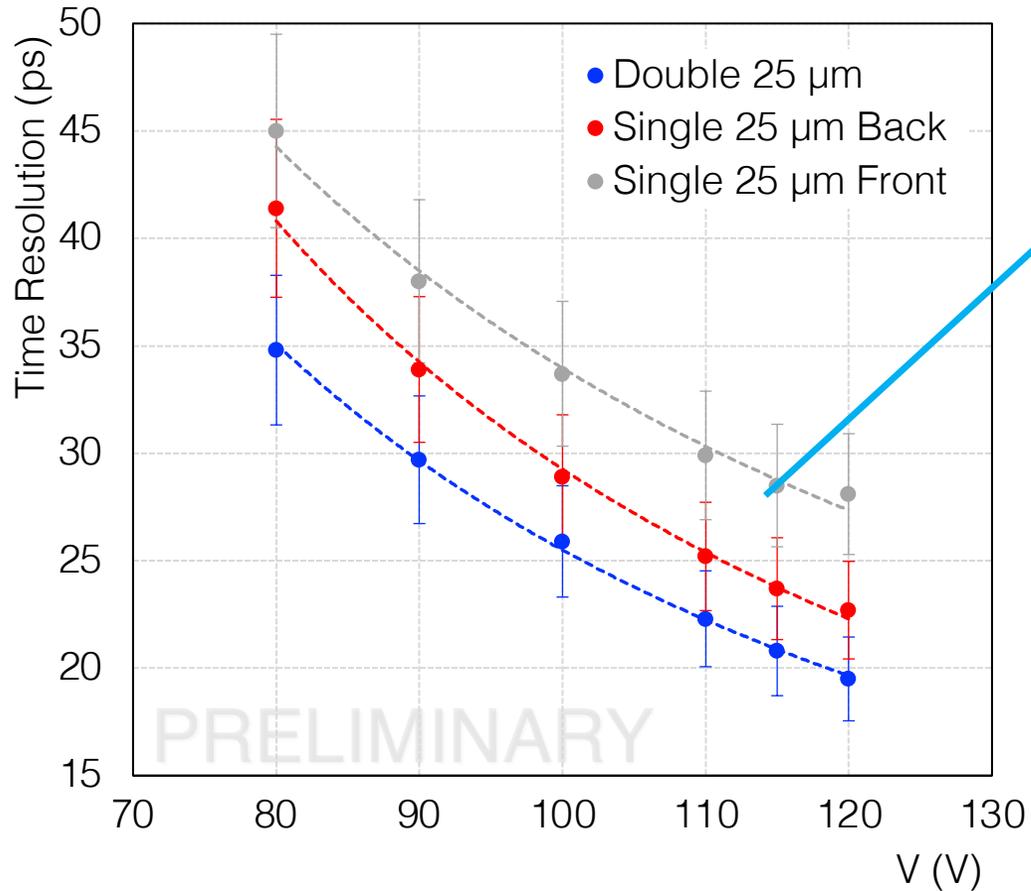


DATA ANALYSIS

DATA ANALYSIS

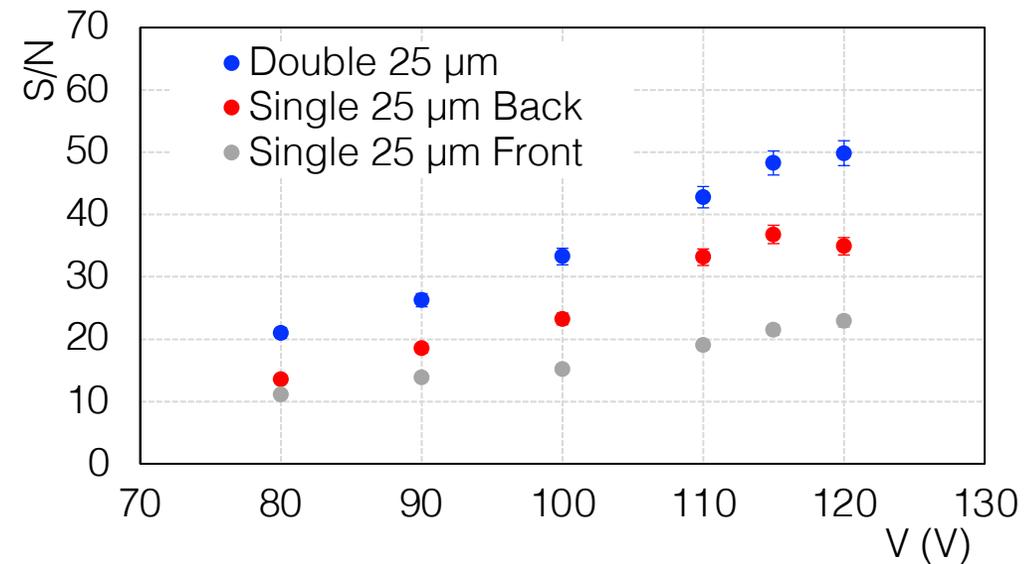
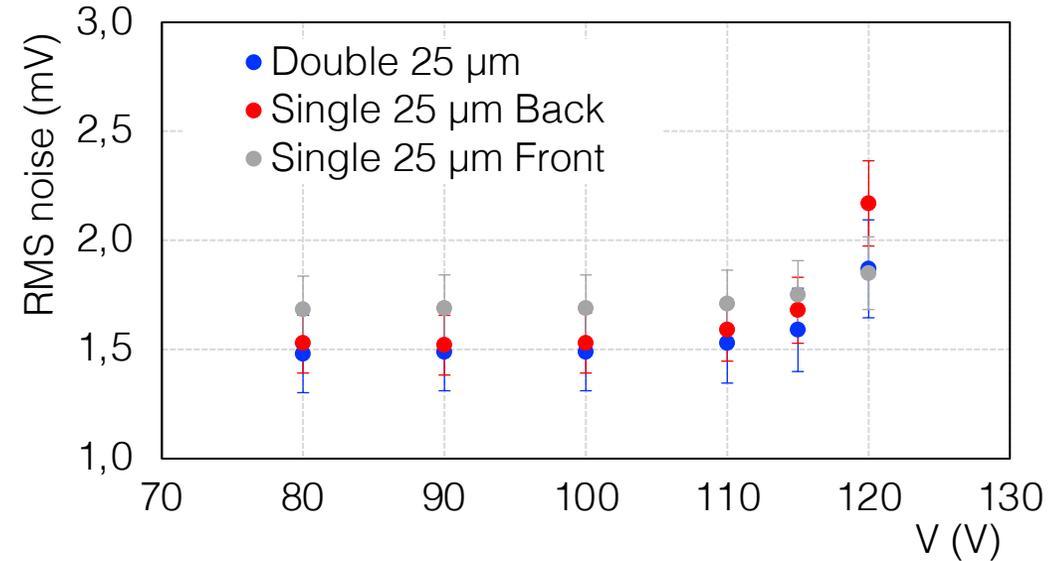
TIMING PERFORMANCE: S

VOLTAGE



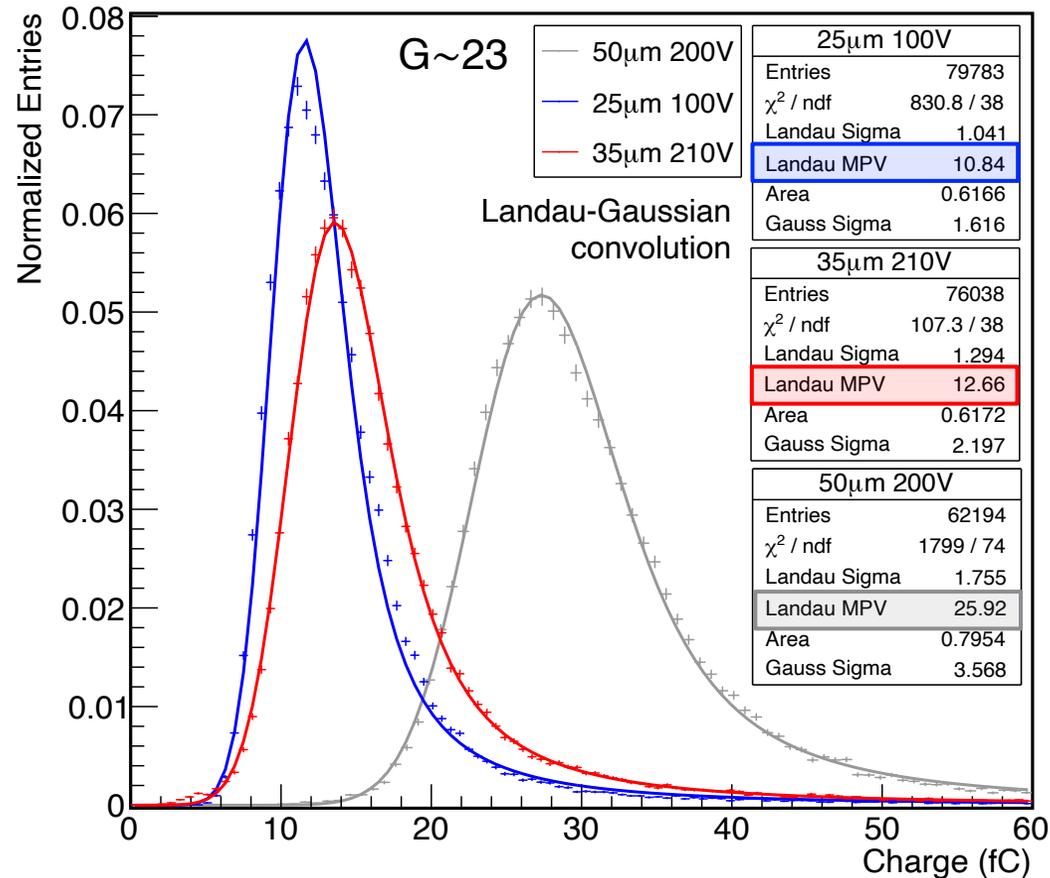
- Same trend
- The 'double LGAD' shows a slightly better ti

Noise RMS & S/N

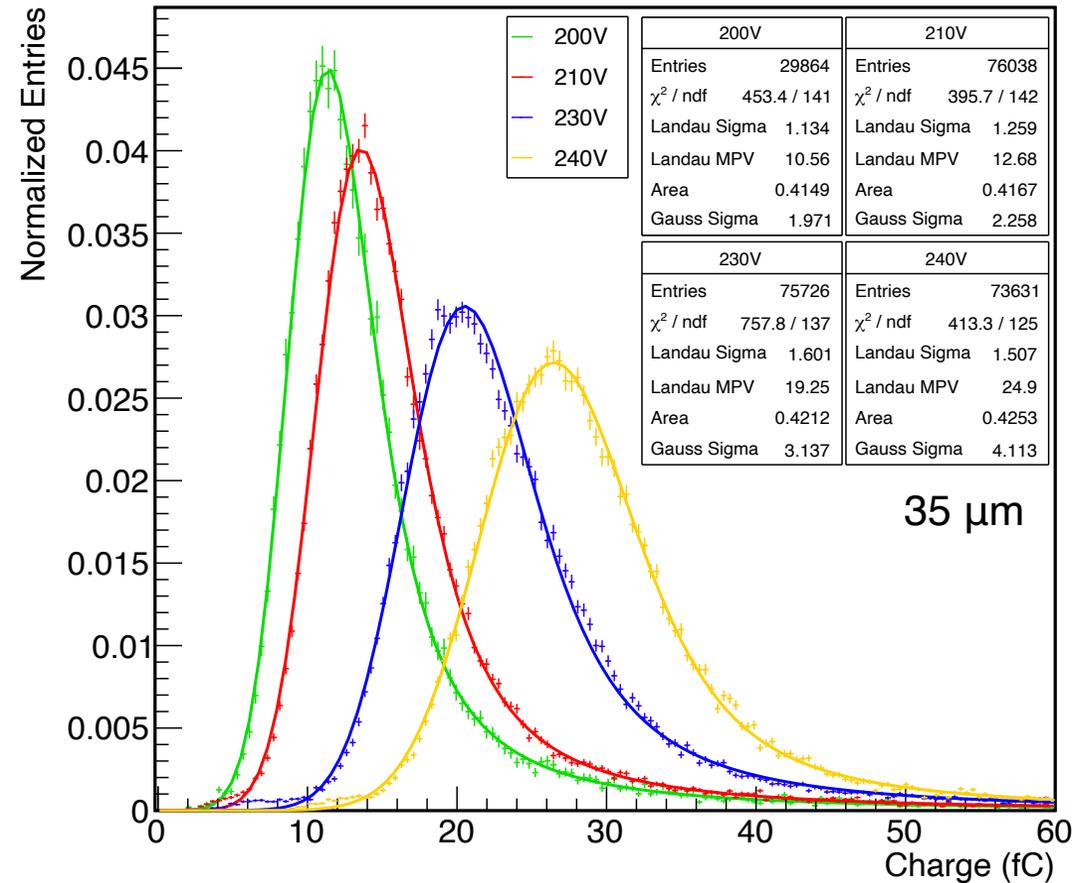


CHARGE DISTRIBUTIONS

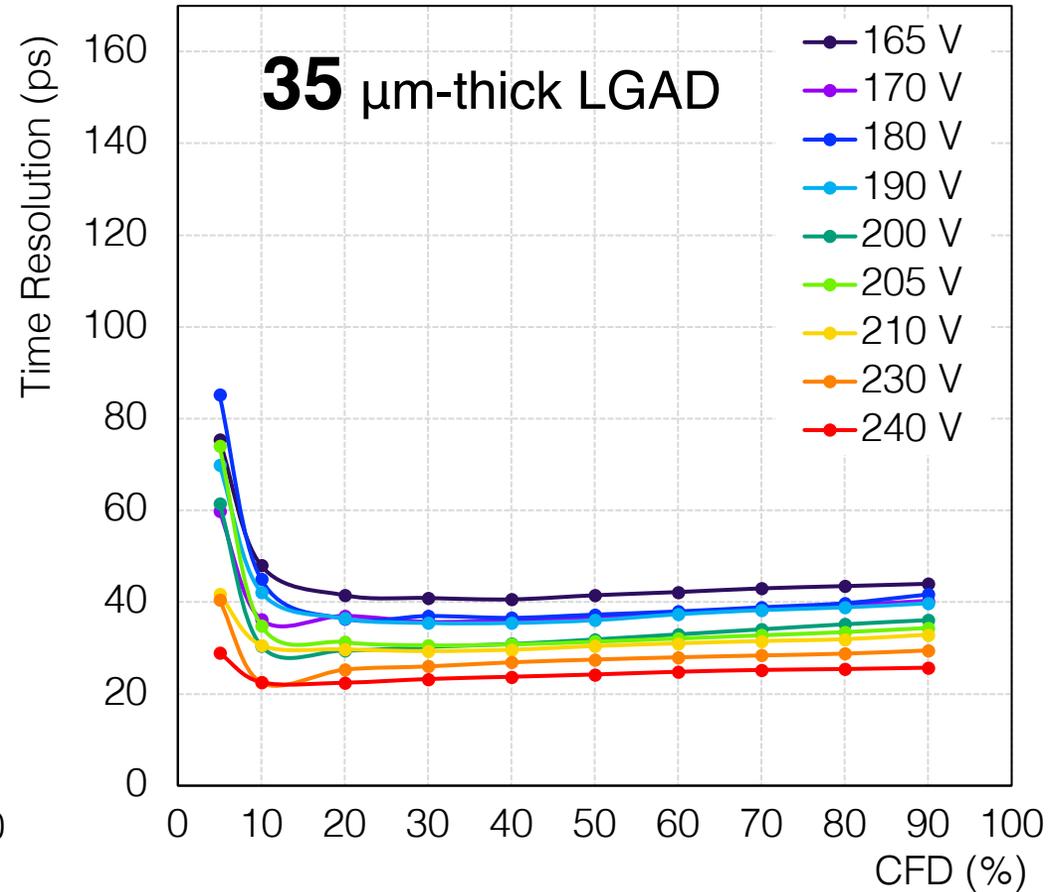
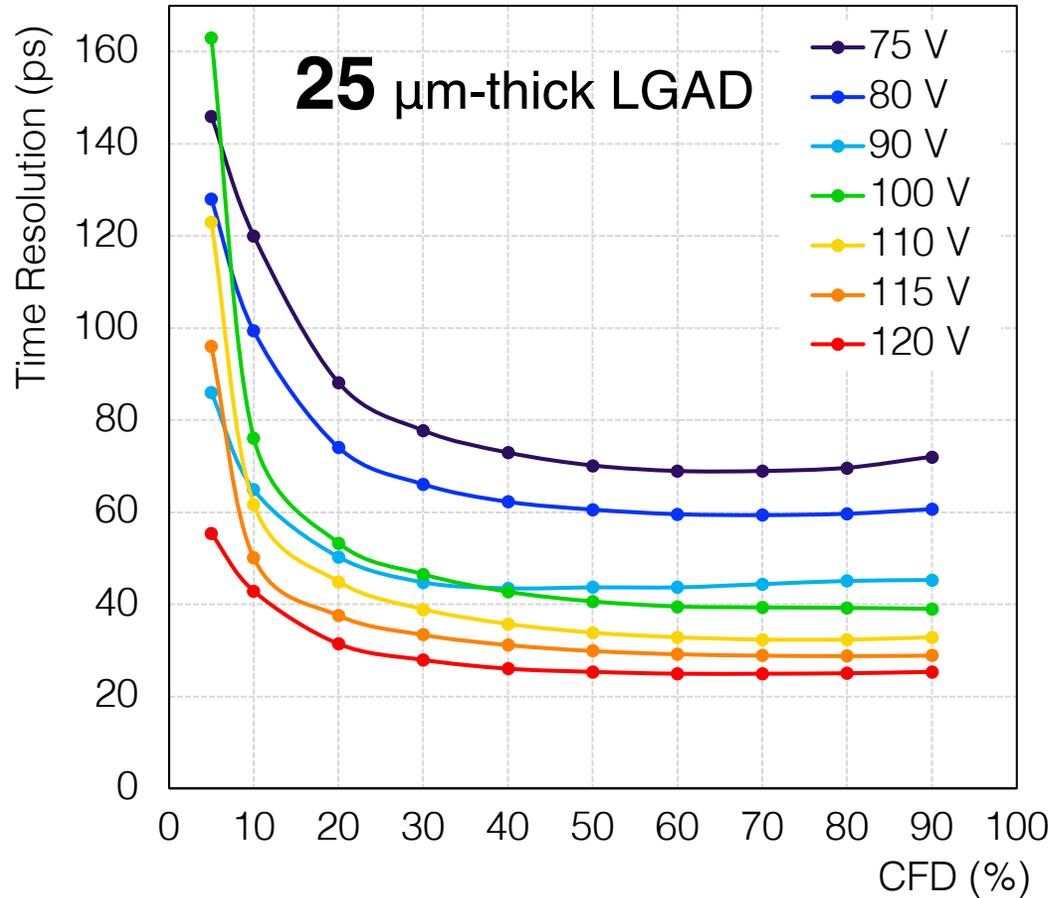
Charge MPV increases →



Charge MPV increases →

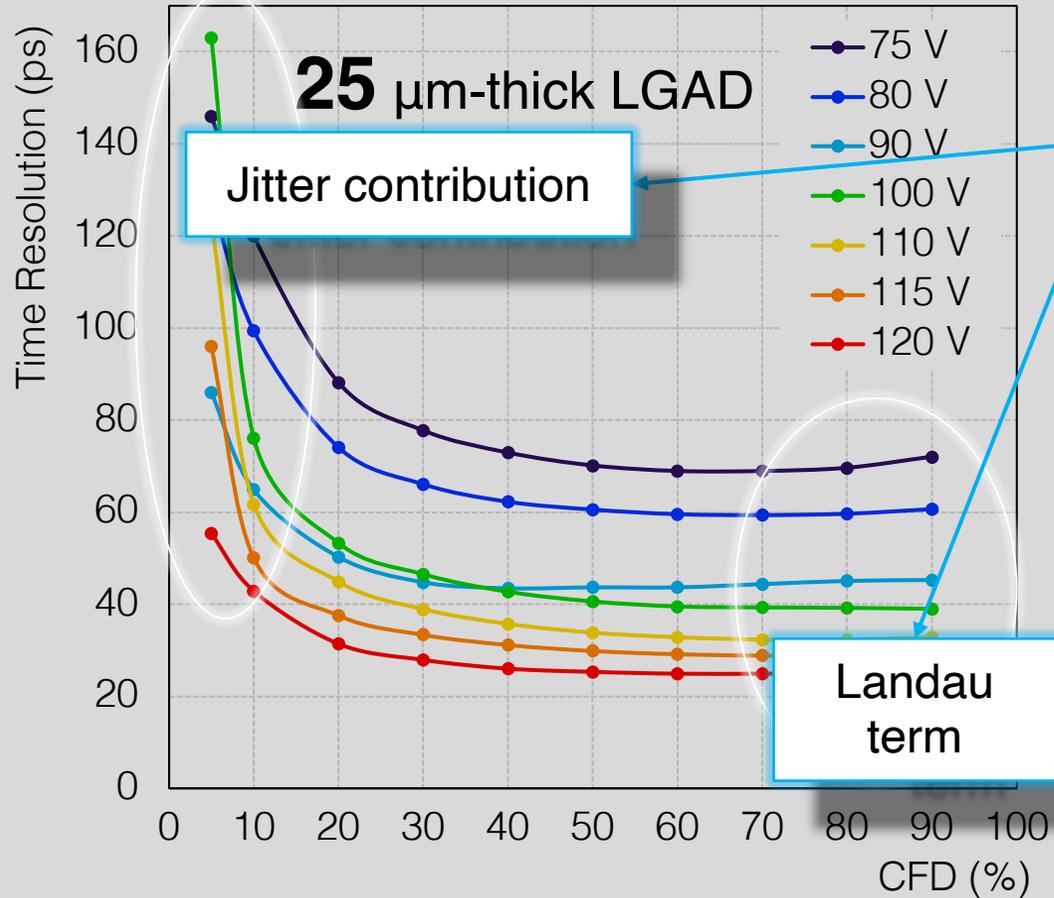


TIMING PERFORMANCES



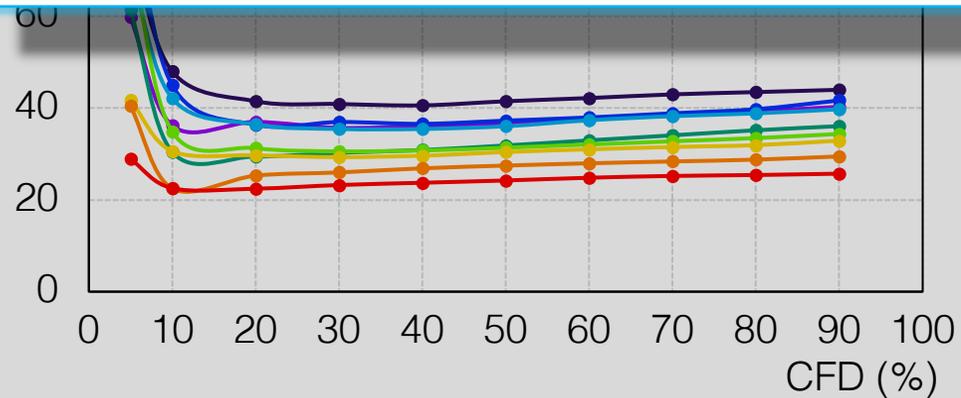
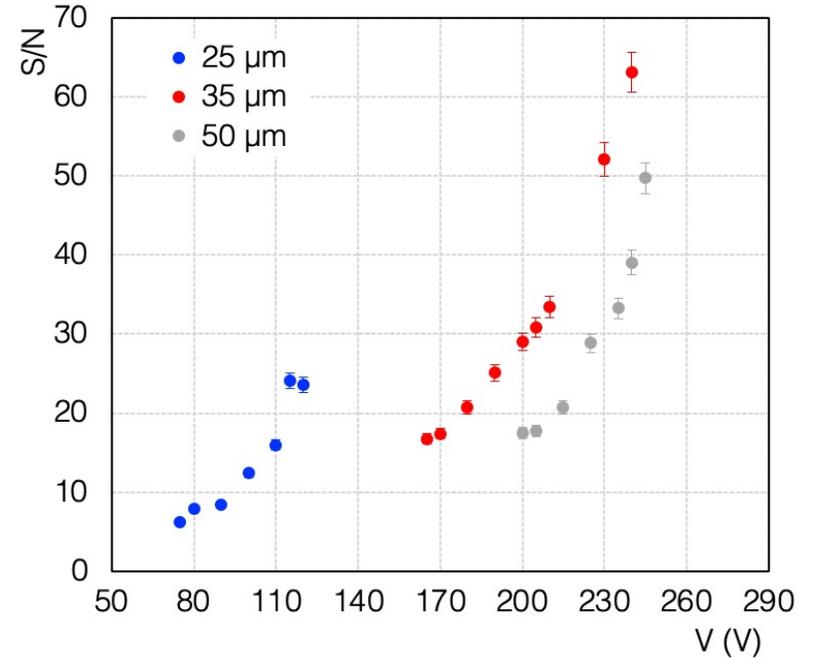
Trend and values of **50 μm LGAD** totally in agreement with previous results

TIMING PERFORMANCE



- Thickness
- S/N
 - Electronics
 - Detectors
 - Shielding

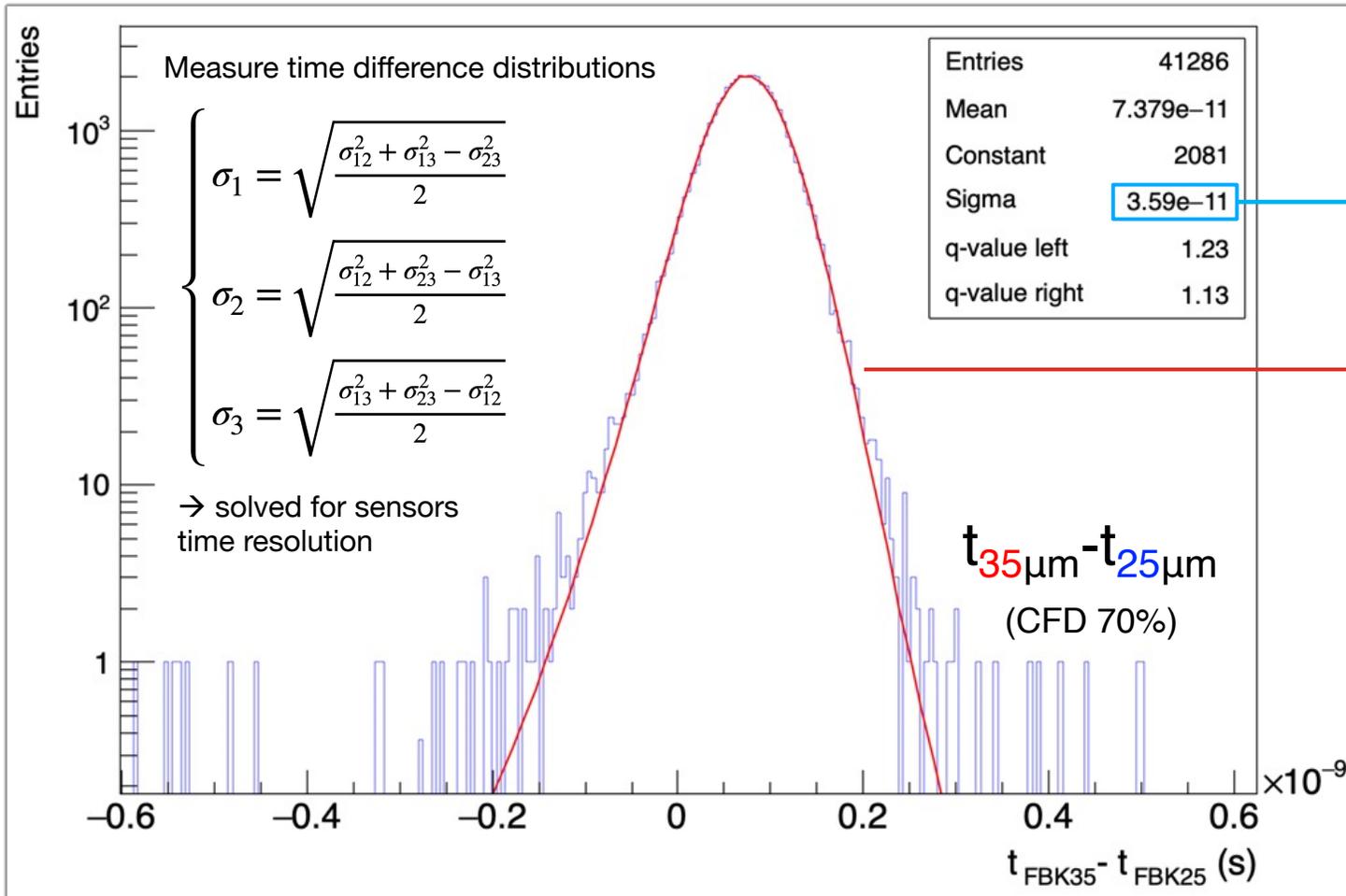
25 μm: 6-24
35 μm: 16-63



Trend and values of 50 μm LGAD totally in agreement with previous results

DATA ANALYSIS FOR THE TIMING PERFORMANCE

Constant fraction discrimination (CFD) technique



Measurements in full bandwidth (4 GHz) $\xrightarrow{\text{Smoothing to remove high frequency noise}}$ 1 GHz

Self-trigger from the DUTs:

Difference between the threshold crossing time of each couple

Asymmetric q-Gaussian fit

- Gaussian shape of the arrival times
- small tails (2.5% of the measures)



ALICE 3 EXPERIMENT

ALICE 3 EXPERIMENT

TOF SPECIFICATIONS

	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

TOF SEPARATION

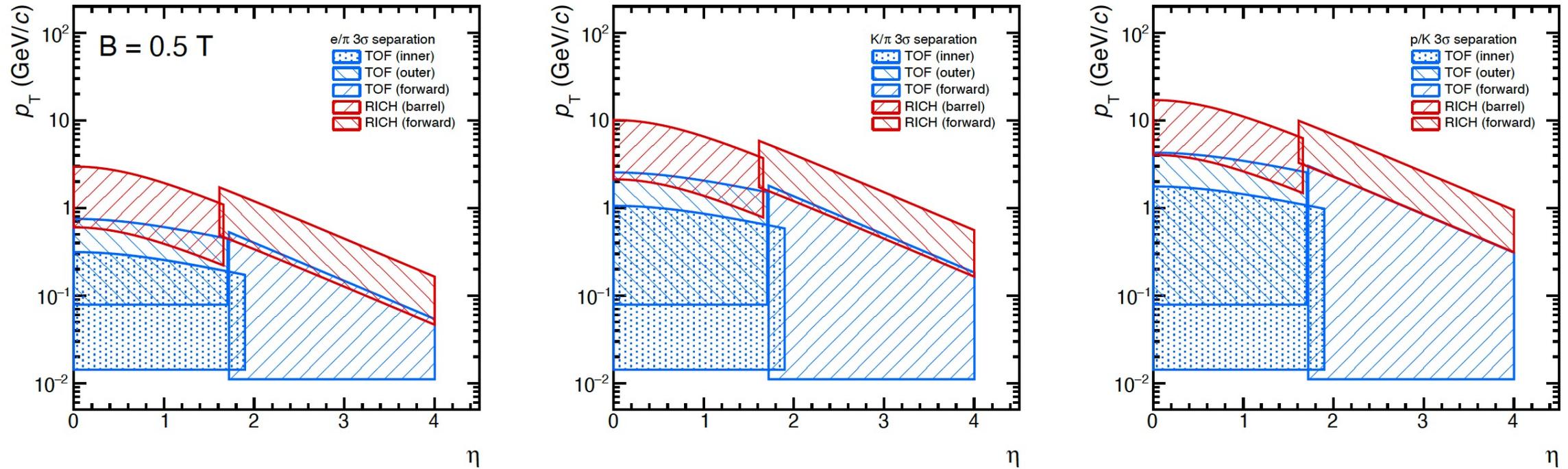


Figure 19: Analytical calculations of the $\eta - p_T$ regions in which particles can be separated by at least 3σ for the ALICE 3 particle-identification subsystems embedded in a 0.5 T magnetic field. Electron/pion, pion/kaon and kaon/proton separation plots are shown from left to right.

ALICE 3 key physics objects

Observables	Kinematic range
Heavy-flavour hadrons	$p_T \rightarrow 0,$ $ \eta < 4$
Dielectrons	$p_T \approx 0.05$ to $3 \text{ GeV}/c,$ $M_{ee} \approx 0.05$ to $4 \text{ GeV}/c^2$
Photons	$p_T \approx 0.1$ to $50 \text{ GeV}/c,$ $-2 < \eta < 4$
Quarkonia and exotica	$p_T \rightarrow 0,$ $ \eta < 1.75$
Ultrasoft photons	$p_T \approx 1$ to $50 \text{ MeV}/c,$ $3 < \eta < 5$
Nuclei	$p_T \rightarrow 0,$ $ \eta < 4$

Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{NN}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} ($\text{cm}^{-2}\text{s}^{-1}$)	3.0×10^{32}	1.5×10^{30}	3.2×10^{29}	2.8×10^{29}	8.5×10^{28}	5.0×10^{28}	3.3×10^{28}	1.2×10^{28}
$\langle L_{AA} \rangle$ ($\text{cm}^{-2}\text{s}^{-1}$)	3.0×10^{32}	9.5×10^{29}	2.0×10^{29}	1.9×10^{29}	5.0×10^{28}	2.3×10^{28}	1.6×10^{28}	3.3×10^{27}
$\mathcal{L}_{AA}^{\text{month}}$ (nb^{-1})	5.1×10^5	1.6×10^3	3.4×10^2	3.1×10^2	8.4×10^1	3.9×10^1	2.6×10^1	5.6
$\mathcal{L}_{NN}^{\text{month}}$ (pb^{-1})	505	409	550	500	510	512	434	242
R_{max} (kHz)	24 000	2169	821	734	344	260	187	93
μ	1.2	0.21	0.08	0.07	0.03	0.03	0.02	0.01
$dN_{\text{ch}}/d\eta$ (MB)	7	70	151	152	275	400	434	682
at $R = 0.5 \text{ cm}$								
R_{hit} (MHz/ cm^2)	94	85	69	62	53	58	46	35
NIEL (1 MeV $n_{\text{eq}}/\text{cm}^2$)	1.8×10^{14}	1.0×10^{14}	8.6×10^{13}	7.9×10^{13}	6.0×10^{13}	3.3×10^{13}	4.1×10^{13}	1.9×10^{13}
TID (Rad)	5.8×10^6	3.2×10^6	2.8×10^6	2.5×10^6	1.9×10^6	1.1×10^6	1.3×10^6	6.1×10^5
at $R = 100 \text{ cm}$								
R_{hit} (kHz/ cm^2)	2.4	2.1	1.7	1.6	1.3	1.0	1.1	0.9
NIEL (1 MeV $n_{\text{eq}}/\text{cm}^2$)	4.9×10^9	2.5×10^9	2.1×10^9	2.0×10^9	1.5×10^9	8.3×10^8	1.0×10^9	4.7×10^8
TID (Rad)	1.4×10^2	8.0×10^1	6.9×10^1	6.3×10^1	4.8×10^1	2.7×10^1	3.3×10^1	1.5×10^1

Vertex detector inside the beam pipe and secondary vacuum

