Prototyping and Data Analysis of the 65 nm CMOS Sensor for High Energy Physics

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OUTLINE

Introduction

- Tracking and Vertexing
- Why silicon ?
- ALICE-ITS upgrade

Objectives

- Evaluate the performance of the CE65 sensor

Materials & Methods

- CE65 design and variants
- Experimental setup
- Analysis flow

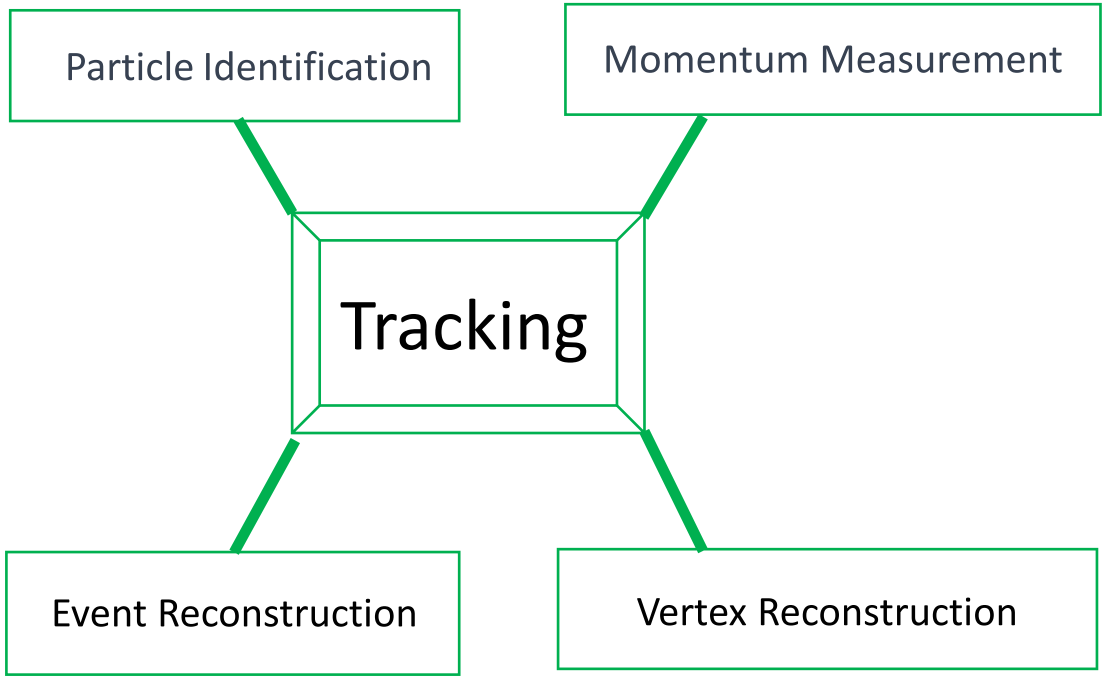
Results & Discussion

- Efficiency
- Residual
- Charge sharing
- Cluster and Seed charge

Conclusions

- Conclusion and Future Work

Tracking and Vertexing

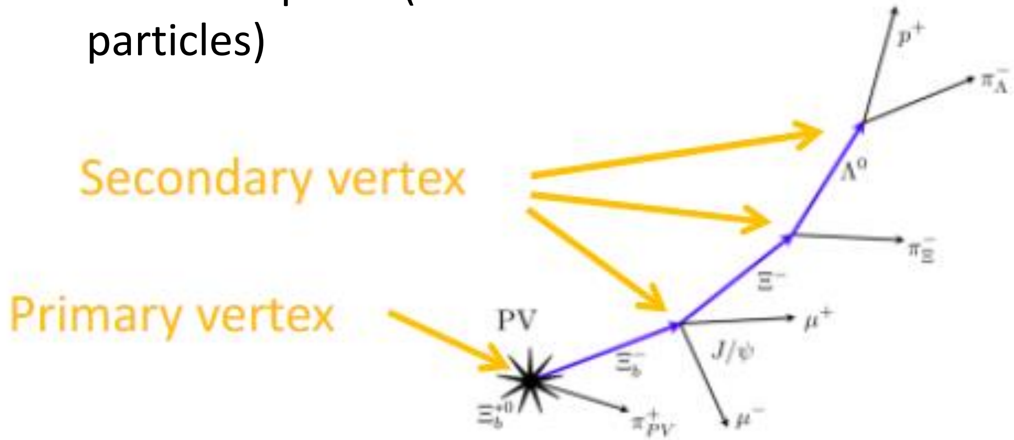


Vertex detector close to the interaction point

→ Reduce multiple scattering

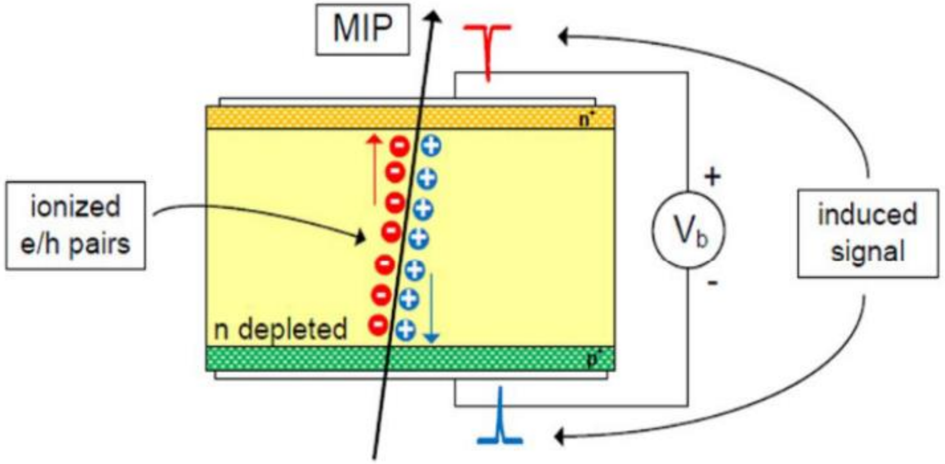
Measurement of secondary vertices

→ Identify heavy flavour particles and tau leptons (short lifetime particles)



Why silicon ?

- Low ionization energy: 3.6 ev compared to 30 ev for gas detectors
- High density: 80 electron-hole pairs (MIP case)



Charged particles undergo ionization

Reverse bias is applied to a PN junction

Electrical charge carriers are separated by an electric field

collected on electrodes

Currents generated

q: charge carrier
D:diffusion coefficient
n: number density of charge carriers
μ: mobility
E: electric field

Drift Current:

$$J_{\text{diffusion}} = -q \cdot D_{\text{e/h}} \cdot \frac{dn}{dx}$$

Diffusion Current:

$$J_{q_{\text{n/p}}} = q_{\text{n/p}} \cdot \mu(E) \cdot E$$

ALICE ITS upgrade

180 nm CMOS imaging technology

- 7 layers of MAPS
- Pixel size 27 x 29 μm^2
- Thickness 50 μm
- **0.3 % X0 /inner layer**

CMOS sensor

combination of an active sensor and readout on a single silicon wafer

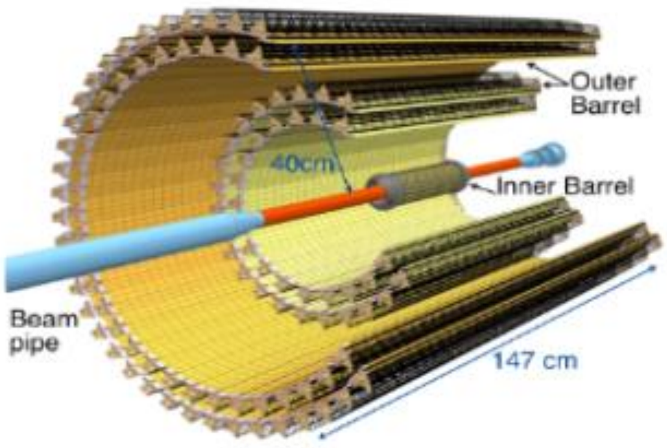
↓

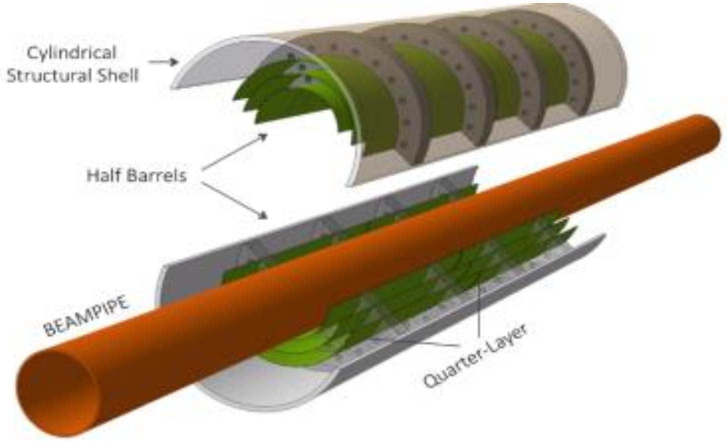
Reduce cost and scattering material

65 nm CMOS imaging technology

- 4 outer layers of ITS2
- 3 new fully cylindrical inner layers
- Pixel size ~ 20×20 μm^2
- Thickness 30-40 μm
- **0.05 % X0 /inner layer**
- **Bent sensors works well**

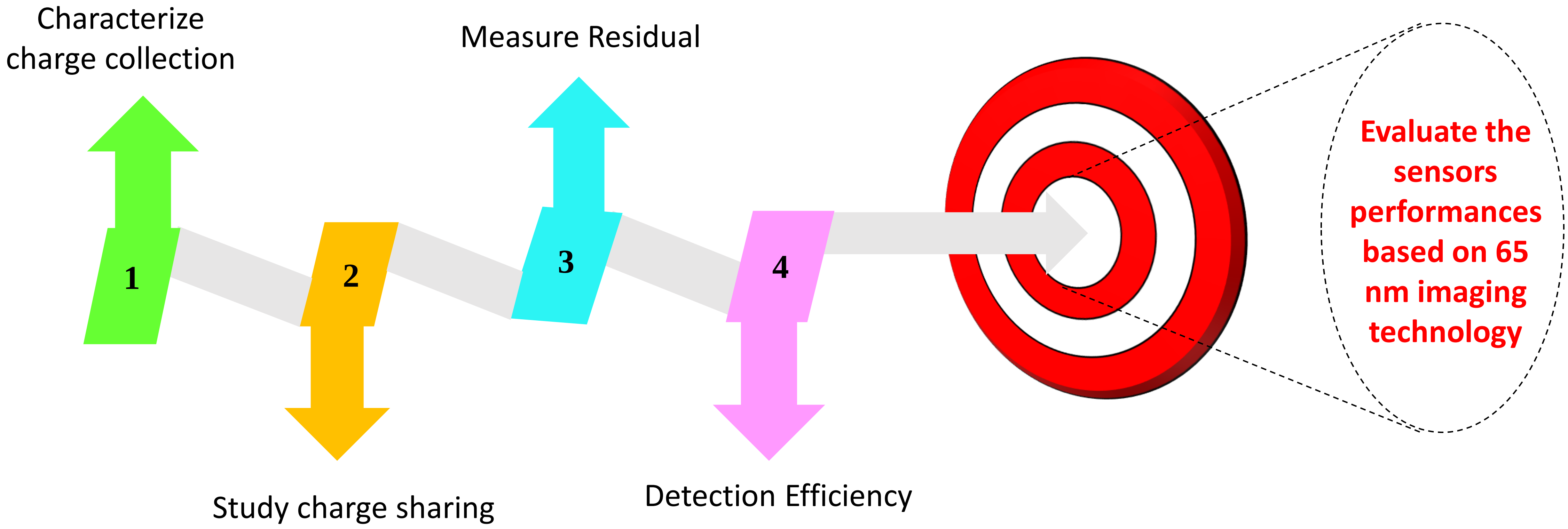
ITS2



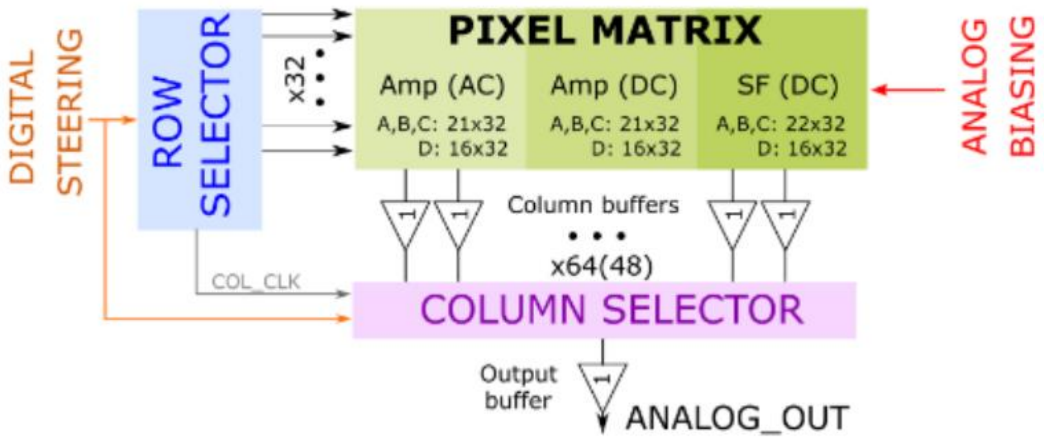


ITS3
Inner barrel

Objectives

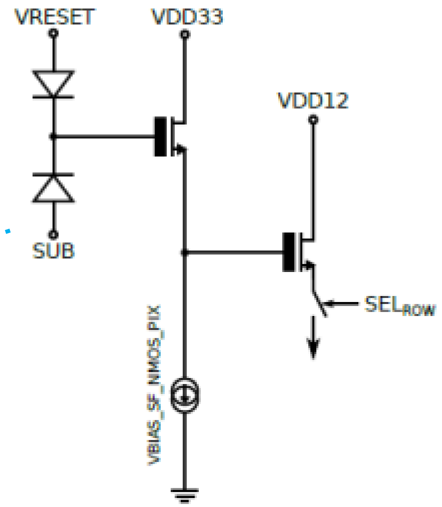

Characterize charge collection
Measure Residual
1
2
3
4
Evaluate the sensors performances based on 65 nm imaging technology
Study charge sharing
Detection Efficiency

CE65 design



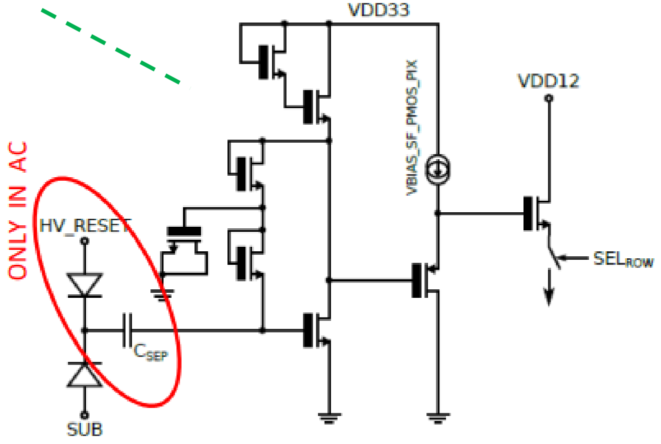
Thickness: 50 µm
Rolling shutter readout
Integration time: 200 µs (@10 MHz clock)
Signal digitized outside the chip
Three sub-matrices:
AC coupled amplifier [Amp (AC)]
DC coupled amplifier [Amp (DC)]
SF source-follower [SF]

SF pixel
- Simplest approach
- Direct estimation of the input node voltage



DC AMP
- Input voltage determined by the supply voltage
- Signal gain: 5 times

AC AMP
- Sensing node depletion voltage can be applied independently and go over the supply voltage
- Slightly reduced gain compared to DC



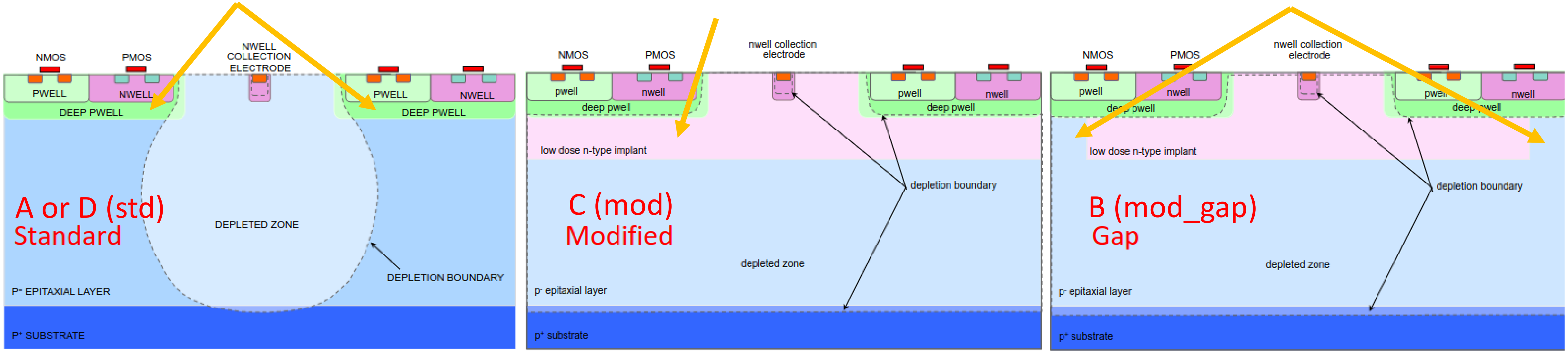
CE65 variants

Variant	Process	Pitch	Matrix	Sub-matrix
CE65-A	std	15μm	64×32	AC/21, DC/21, SF/22
CE65-B	mod_gap	15μm	64×32	AC/21, DC/21, SF/22
CE65-C	mod	15μm	64×32	AC/21, DC/21, SF/22
CE65-D	std	25μm	48×32	AC/16, DC/16, SF/16

Prevent circuitry's nwells from collecting charge

To obtain a full depletion

To overcome the weak electric field near the edges



Experimental setup

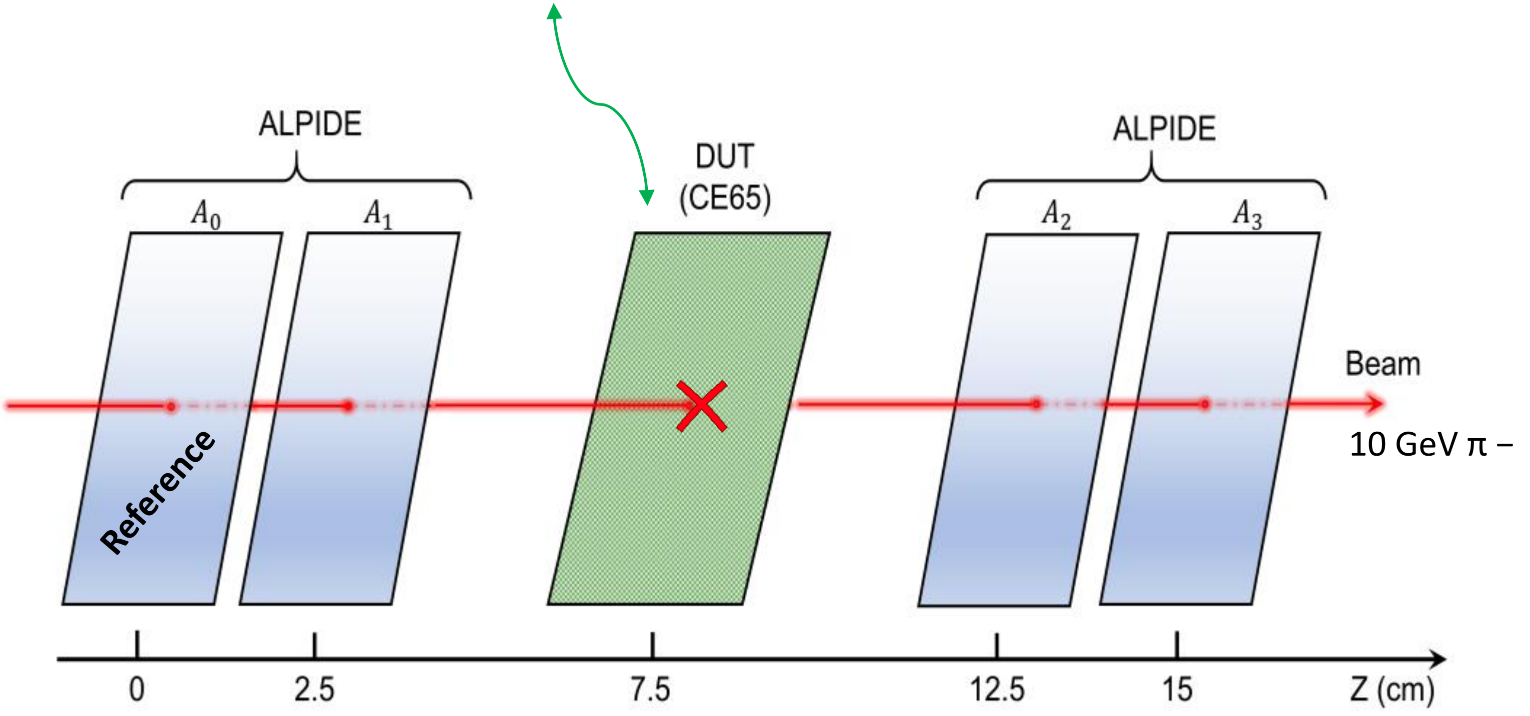
Telescope:

Reference Arms : 4 ALPIDE planes for track reconstruction
DUT : CE65
TRG : DPTS

Test beam:

May 2022 at CERN-PS

Data acquisition:
EUDAQ2
Event reconstruction algorithm and data analysis framework:
Corryvreckan
Noise run-**Beam** run:
correlated double sampling method (**CDS**)



Analysis flow

Preparation Files
- Main configuration file
- Geometry configuration file
- Calibration file

Masking
- Frequency cut to mask noisy pixels (>0.005)

Pre-alignment
- Aligns the translational telescope planes
- Generates spatial correlation plots

Alignment
- Multiple times iteration
- Residuals centered around zero
- Translational and rotational alignment
- Straight line fit

Analysis DUT
- (SF-AC-DC) analyzed independently

$$\sigma^2_{\mathrm{Res}} = \sigma^2_{\mathrm{Tel}} + \sigma^2_{\mathrm{DUT}} + \sigma^2_{\mathrm{M.S}}$$

- Detection Efficiency

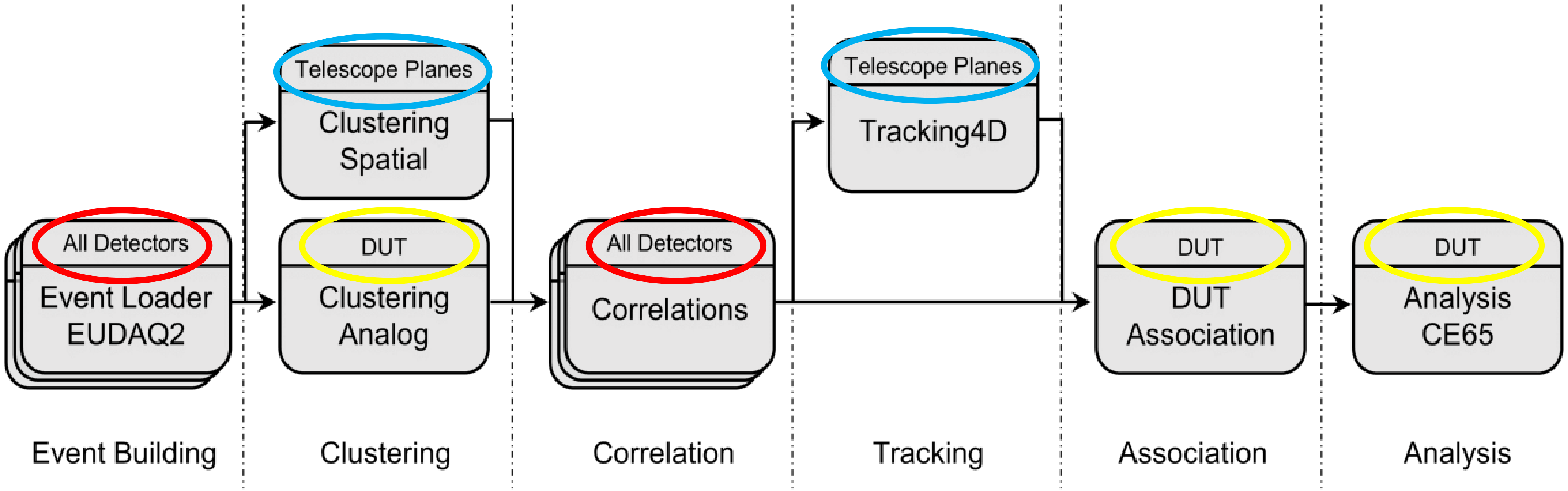
Reconstruction chain

Main Configuration file

Tracking: spatial cut at 100 µm,100 µm for reference, 50 µm,50 µm and $\chi 2/ndf$ <1 for DUT association
Clustering: Set 2 Thresholds and calculate position by center of gravity for 3x3 window
SF: seeding charge > 150 ADCu , SNR>3
AC/DC: seeding charge > 500 ADCu, SNR>3
Edge: drop track with interception at **2 pixels** to DUT edge.
Seeding method: **multi** (probability of having more then one cluster per track)

Geometry file

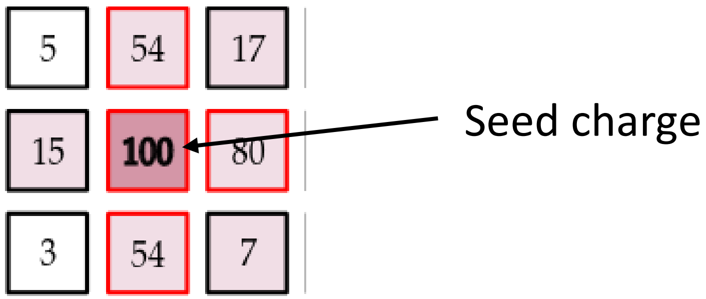
position, number of pixels, spatial and time resolution for each detector
Region of interest
Calibration file

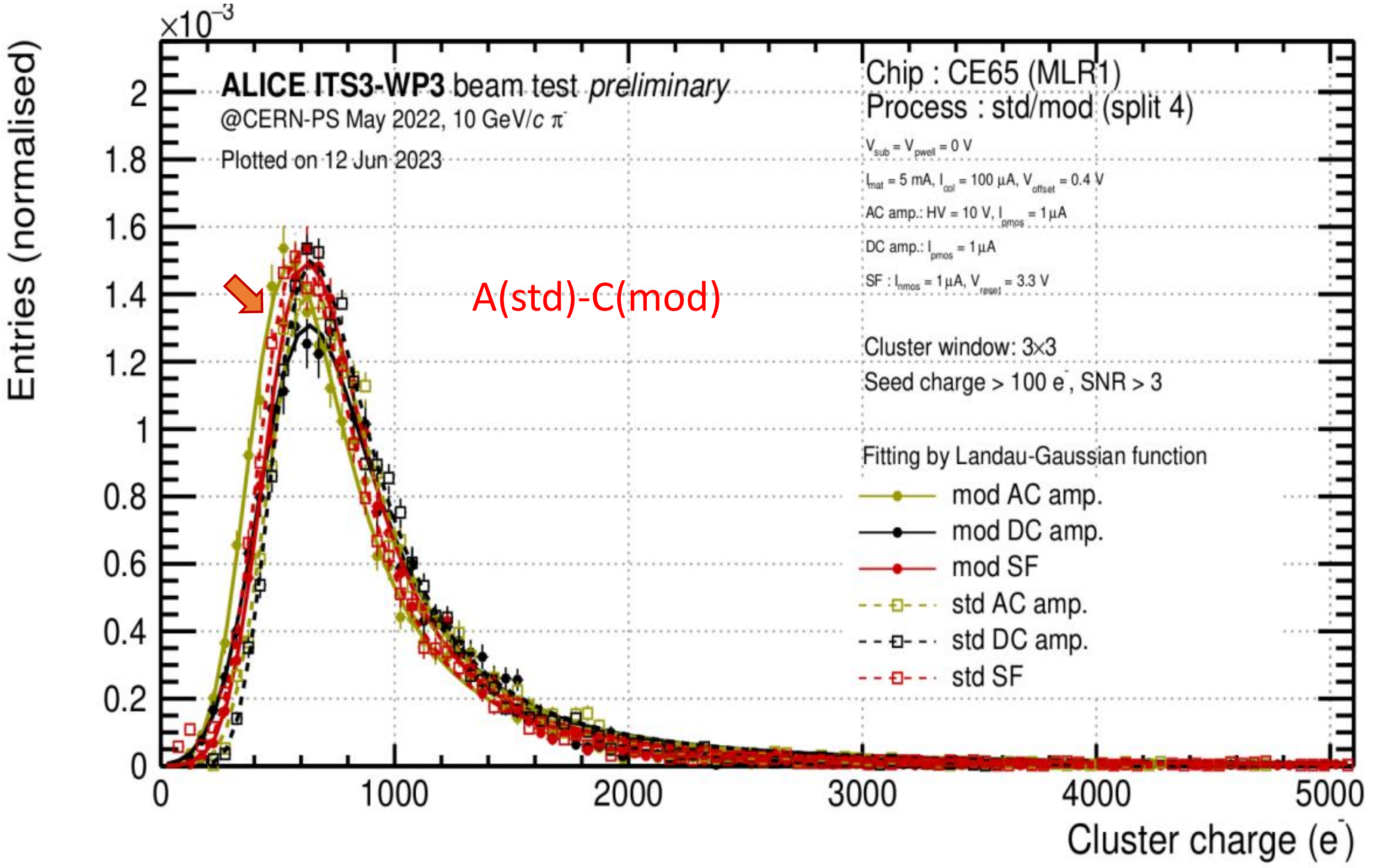


Cluster charge

Expected: cluster charge is almost the same

Landau distribution
MPV range 550-600 electron





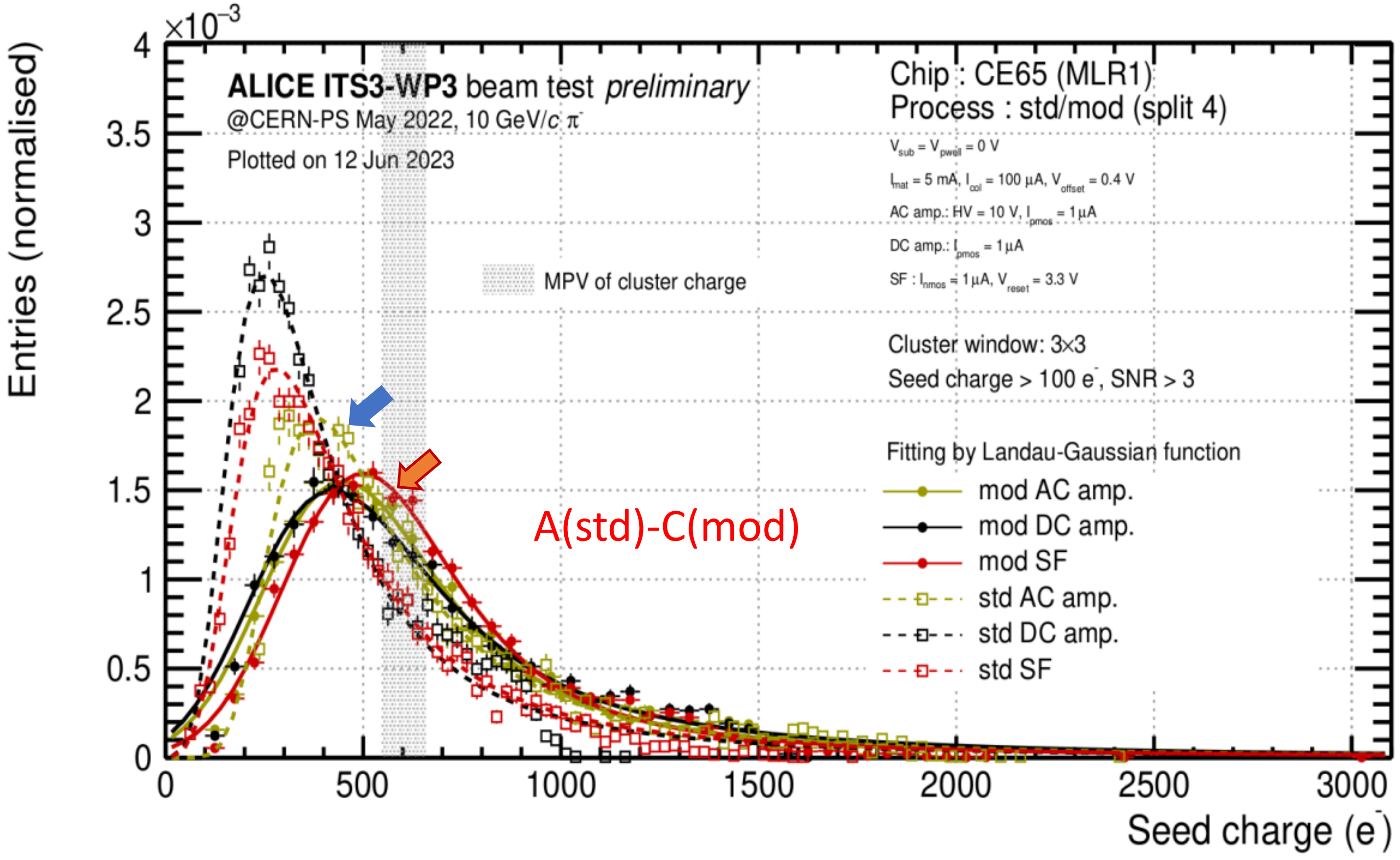
Seed charge

Expected : **C(mod)** a little bit closer to the **MPV**

Less charge sharing than **A(std)**

Unexpected : **SF** in C(mod) shifted more toward MPV

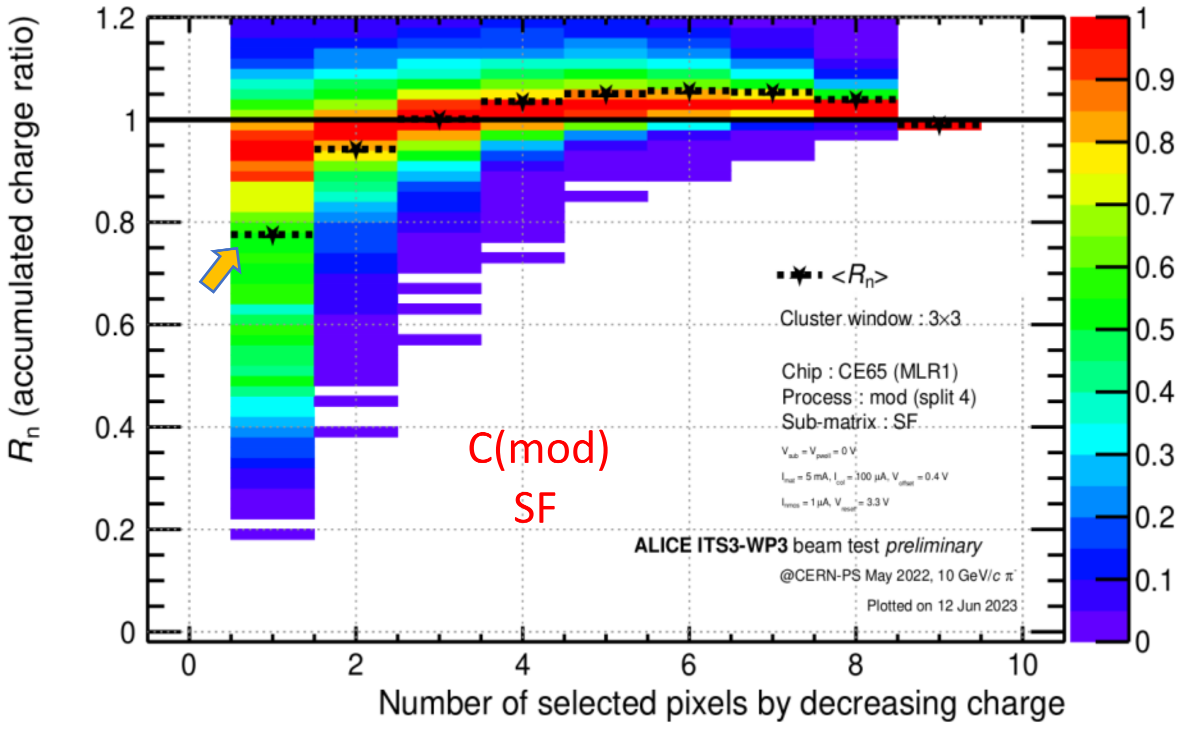
Different calibration factor



Charge sharing

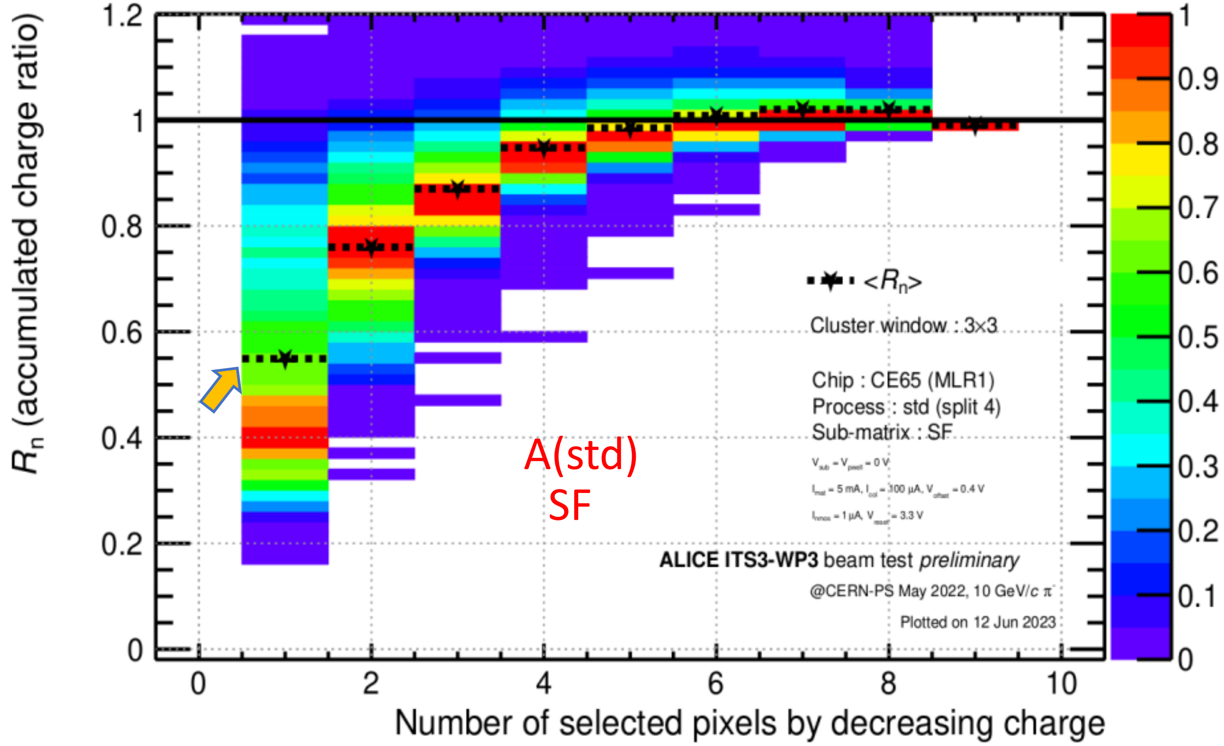
3 pixels contain all cluster charge

Seed pixel: contain around **80%** in average



6 pixels contain all cluster charge

Seed pixel: contain around **50%** in average



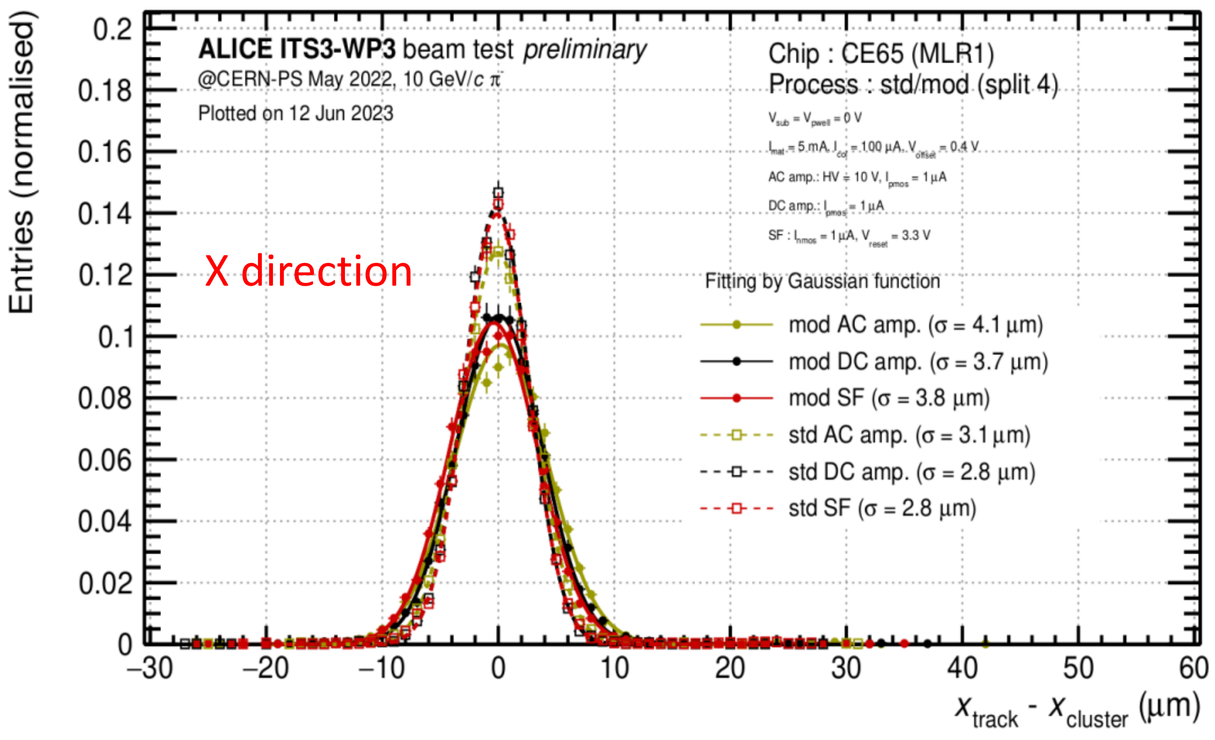
Residual

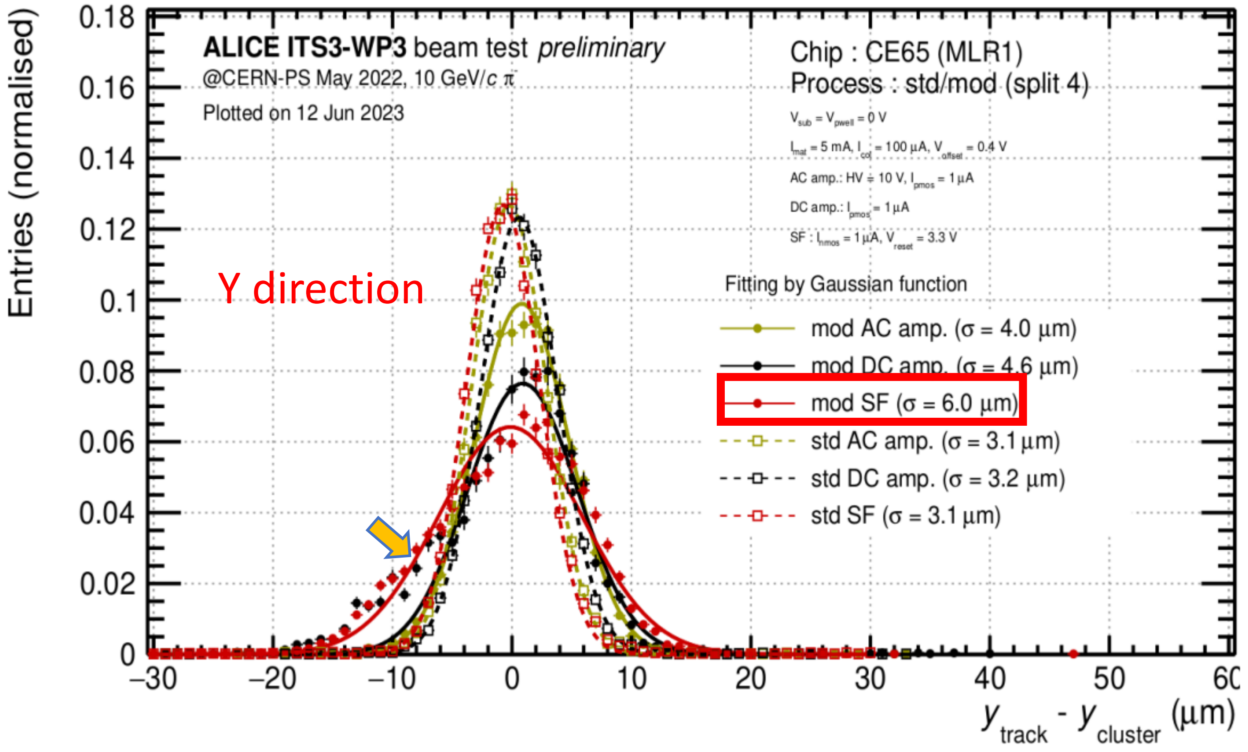
Better resolution for A(std)

Less charge sharing affects the resolution

Poor resolution for SF in C(mod)

Bad alignment at Y

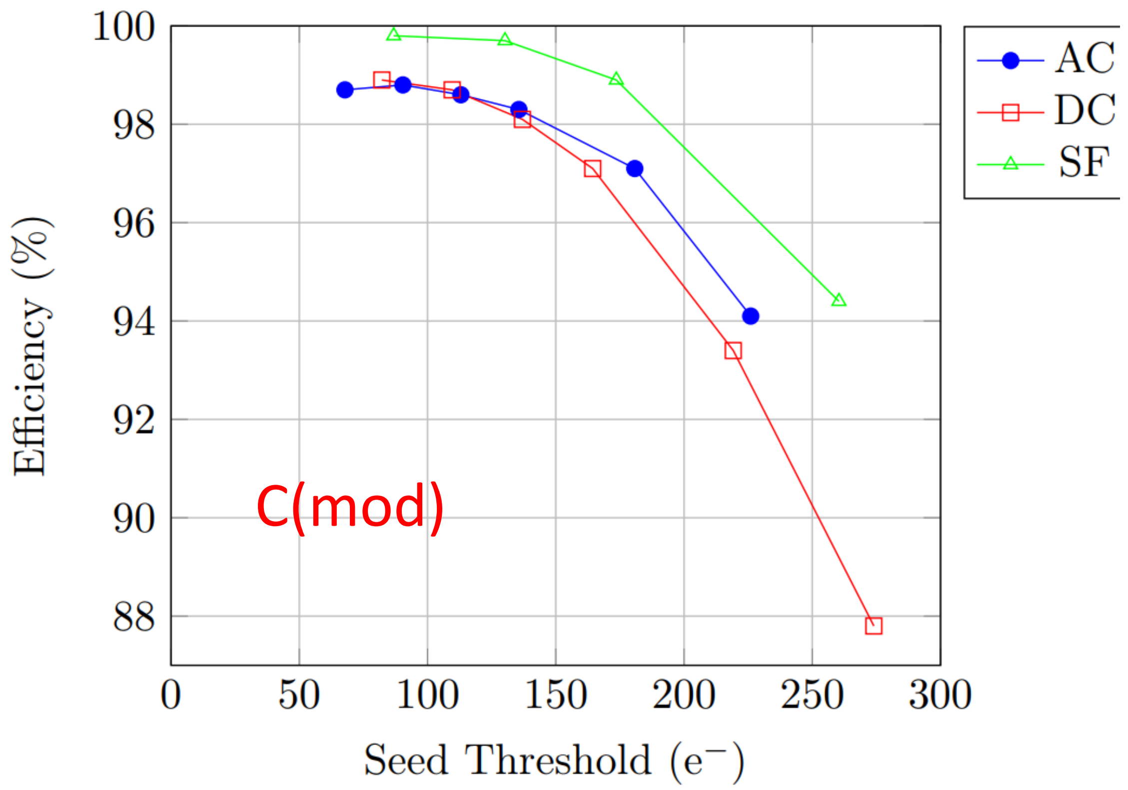




Efficiency

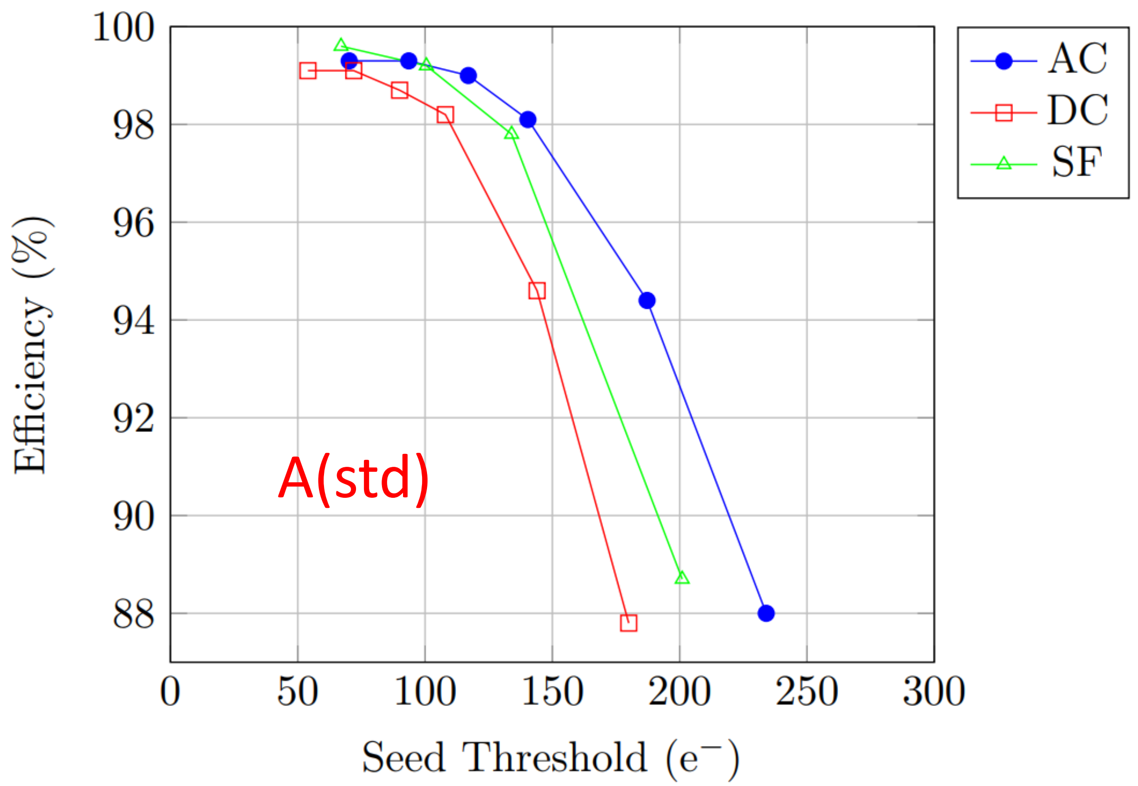
A(std) drop **faster** then that of chip C(mod)

charge sharing **reduce** efficiency



AC in A(std) has the higher efficiency

Least charge sharing as observed in the shift toward MPV



Conclusions & Perspectives

Take Home Messages

- ✓ Cluster charge is not affected by the pixel doping process or the electronics architecture
- ✓ charge sharing reduce efficiency
- ✓ All cluster charge is mostly collected by a single pixel in the modified process

Future Work

1. Implementing η corrections to cluster positions. These corrections can help compensate for non-linear charge sharing effects
2. Analyze larger pixel sizes, like the D chip (25 μm)
3. Investigate more on the efficiency observed for C chip

Thank You For Your Attention

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