# Characterization of ITS upgrade prototype chips at Pusan

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ITS-MFT and $O^2$ Asia Workshop @ Pusan
December 15, 2014


PUSAN NATIONAL UNIVERSITY

# Outline

1. Characterization of irradiated Explorer-1 chips with $^{55}$Fe
2. 60 MeV $e^-$ test beam of irradiated Explorer-1 chips at Pohang
3. 60 MeV $e^-$ test beam of pALPIDEfs chips at Pohang

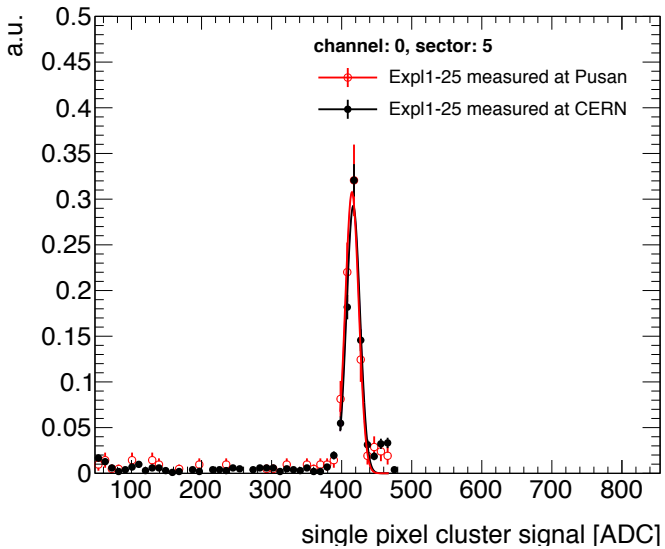
# Reminder of previous workshop on June at Thailand

Milestones:

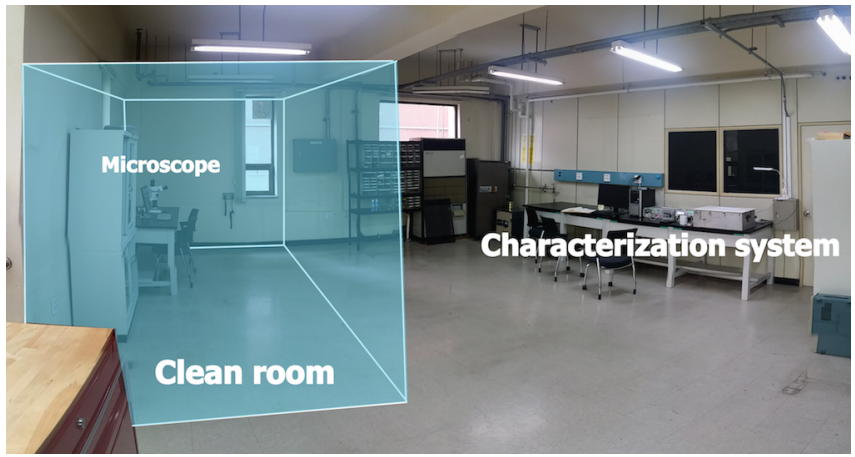
- Characterization system of Explorer-1 was fully commissioned.
- New lab space for mass test of chips and HIC assembly.
  → See Bong-Hwi's talk this afternoon.

Plan (characterization):

- Characterization of irradiated Explorer-1 chips with temperature control.
  → Chips were delievered on October.
- Start to work on pALPIDEfs characterization
  → Jongsik and myself visited CERN last August for a month.




[ Comparison between Pusan and CERN data ]

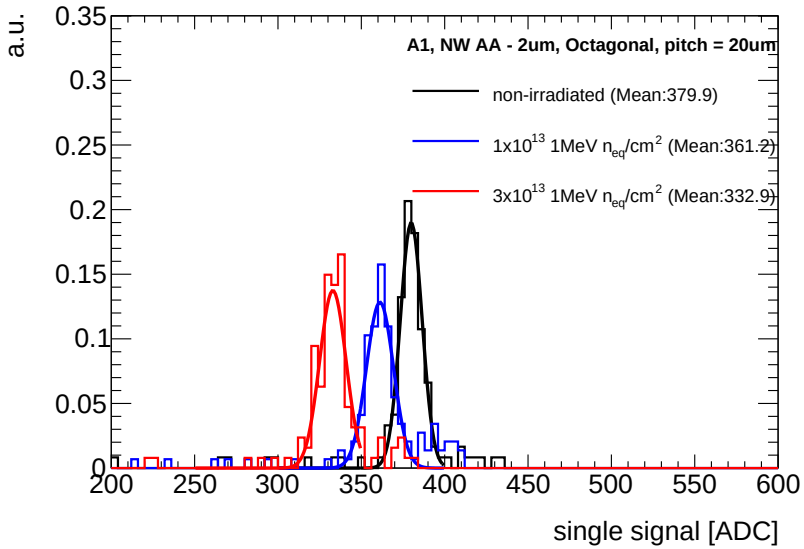


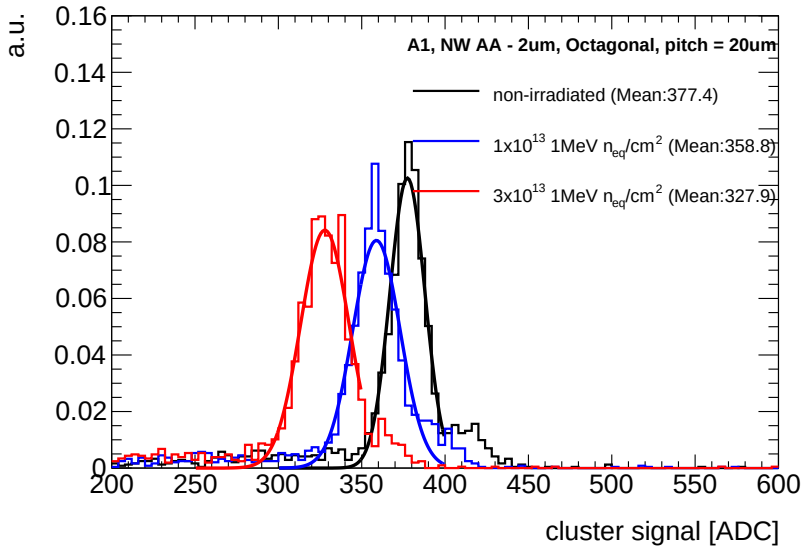

[ New lab space for mass test and assembly ]

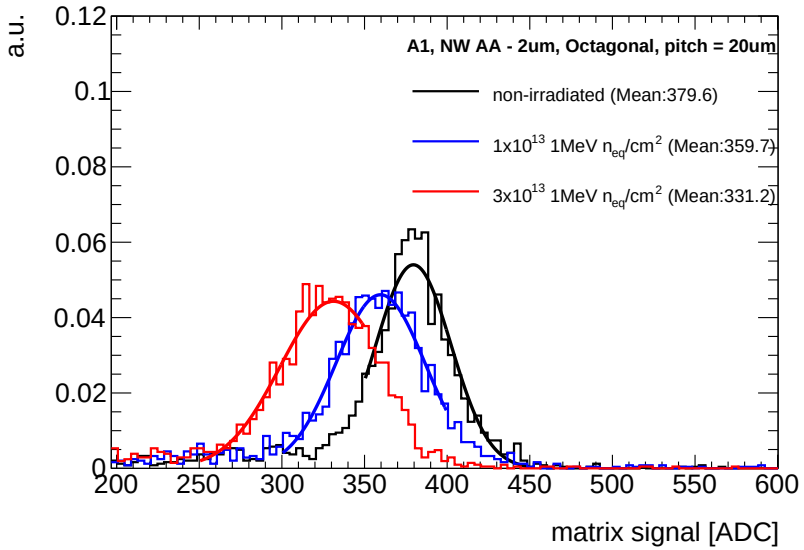
# Outline

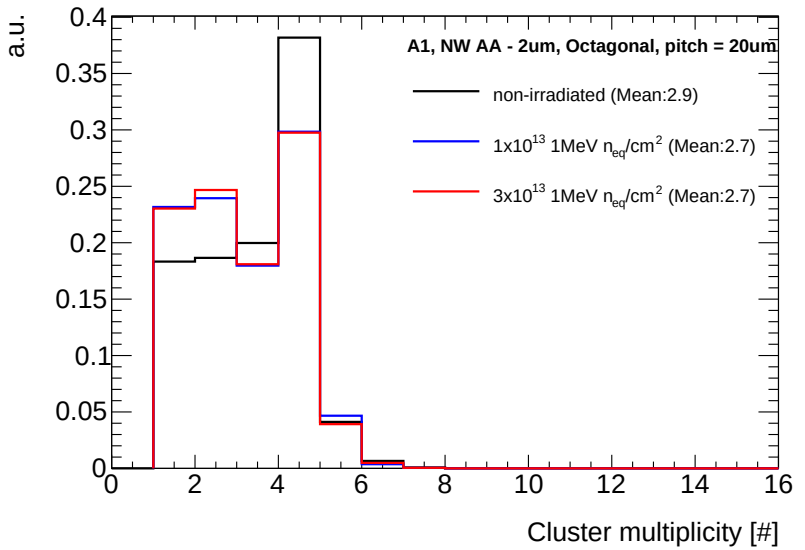
# Characterization of irradiated Explorer-1 chips with $^{55}$Fe

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.



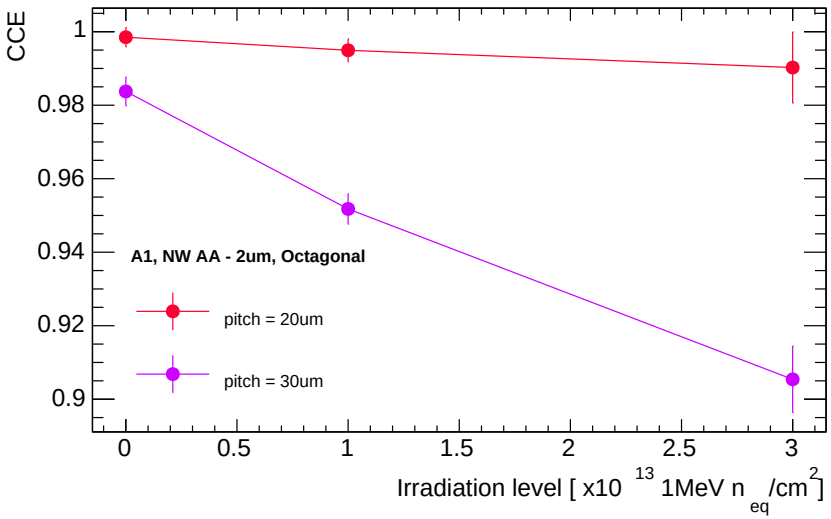




(** gain and cmc correction applied. Temperature = 30 $^o$C)

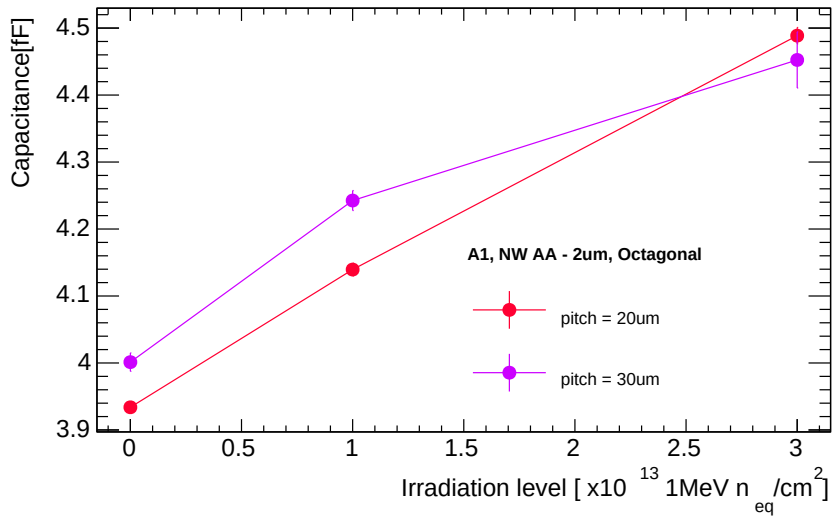
# Comparsion of 20 $\mu$m and 30 $\mu$m pixel pitch

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.

[ CCE vs. irradiation level ]




[ Capacitance vs. irradiation level ]



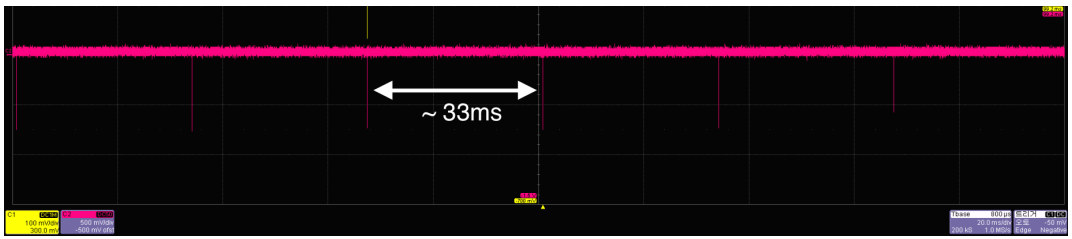

- Charge collection efficiency of 20 $\mu$m pitch stay almost 100% while 30 $\mu$m pitch decreases with irradiation level.
- Capacitace increases for both pixel pitches.

(** gain and cmc correction applied)

# Outline

# Introduction of Pohang Accelerator Lab

- Pohang Accelerator Laboratory (PAL) at Pohang ($\sim$ 2 hour drive from Pusan)
- Facilities
  - Light Source: 3 GeV electron Main LINAC + Strorage ring
  - **Test LINAC**
    - 60 MeV e$^-$ beam
    - $\sim$ $\mu$s bunch, 33 ms bunch space
    - Designed current $\sim$ mA, but can be tuned!



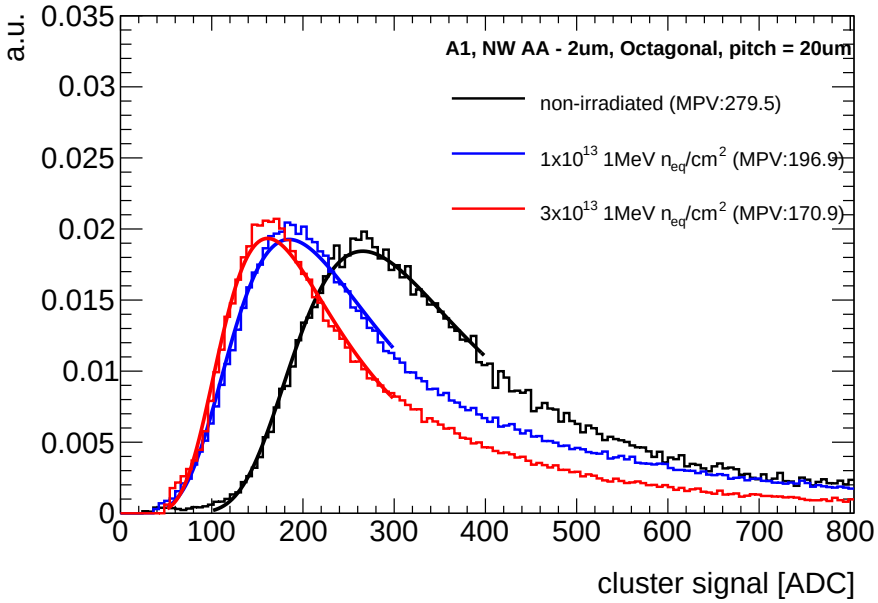

[ Trigger signal ]

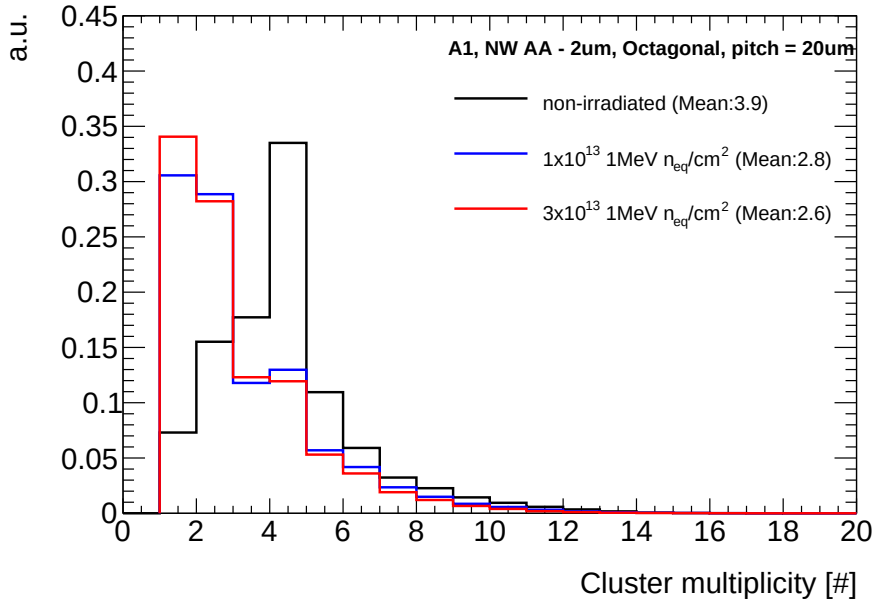

[ PAL bird's-eye view ]

[ Test LINAC ]

# 60 MeV e$^-$ test beam of irradiated Explorer-1 chips

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.



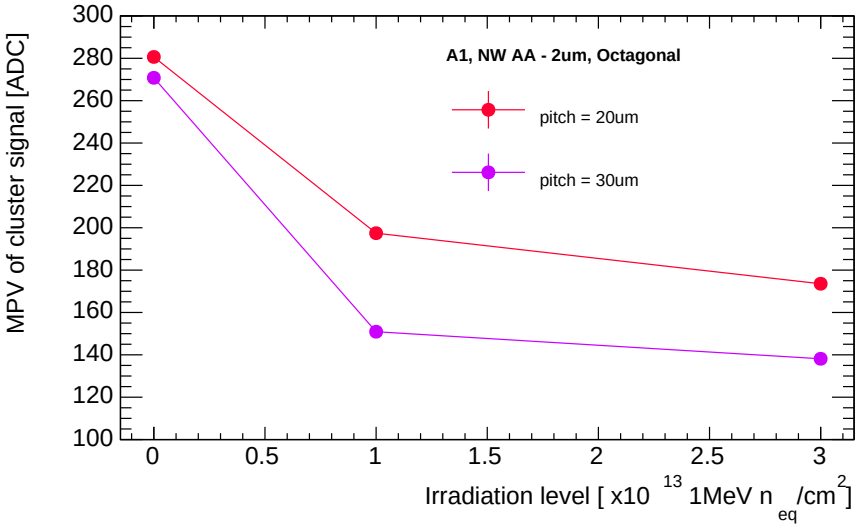



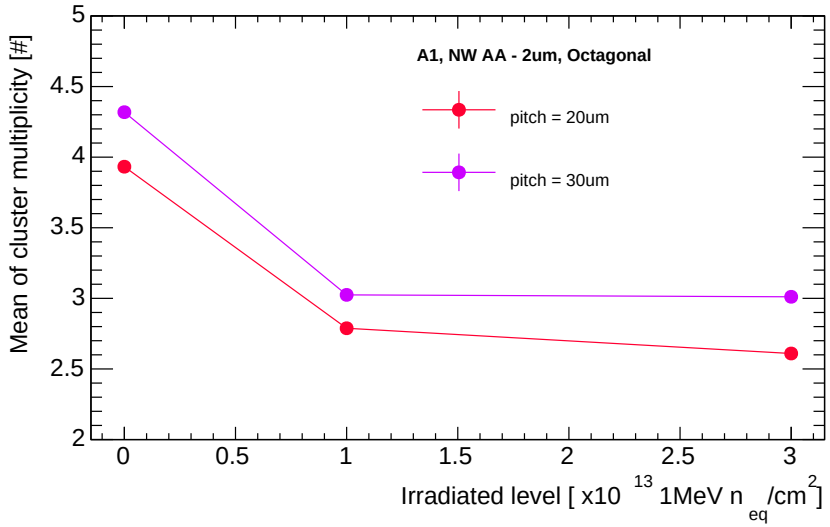

- Cluster signal (MPV) decreases about 30% after $1\times10^{13}$ irradiation and about 40% after $3\times10^{13}$ irradiation.
- Cluster multiplicity also decrease substantially and dominant multiplicity is changed from 4 to 1 or 2.
- Difference between 1 and 3 $\times$ $10^{13}$ irradiation is relatively small (needs further study, see backup).

(** gain and cmc correction applied)

# Comparsion of 20 $\mu$m and 30 $\mu$m pixel pitch

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.



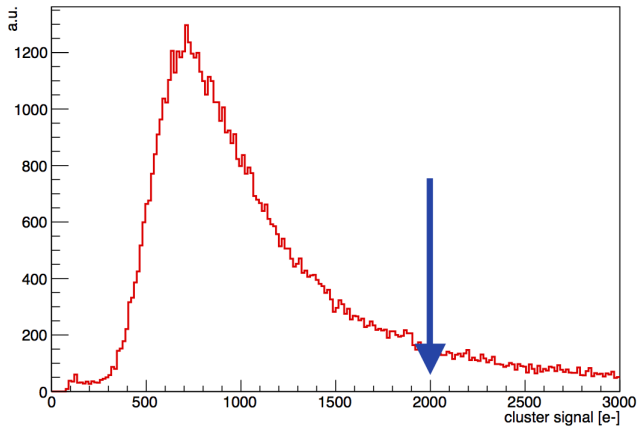

- Irradiation effect on cluster signal size is more evident for 30 $\mu$m pixel pitch: $\sim$ 30% drop for 20 $\mu$m and $\sim$ 45% drop for 30 $\mu$m in case of 1 $\times$ $10^{13}$ irradiation level.

(** gain and cmc correction applied)

# Outline

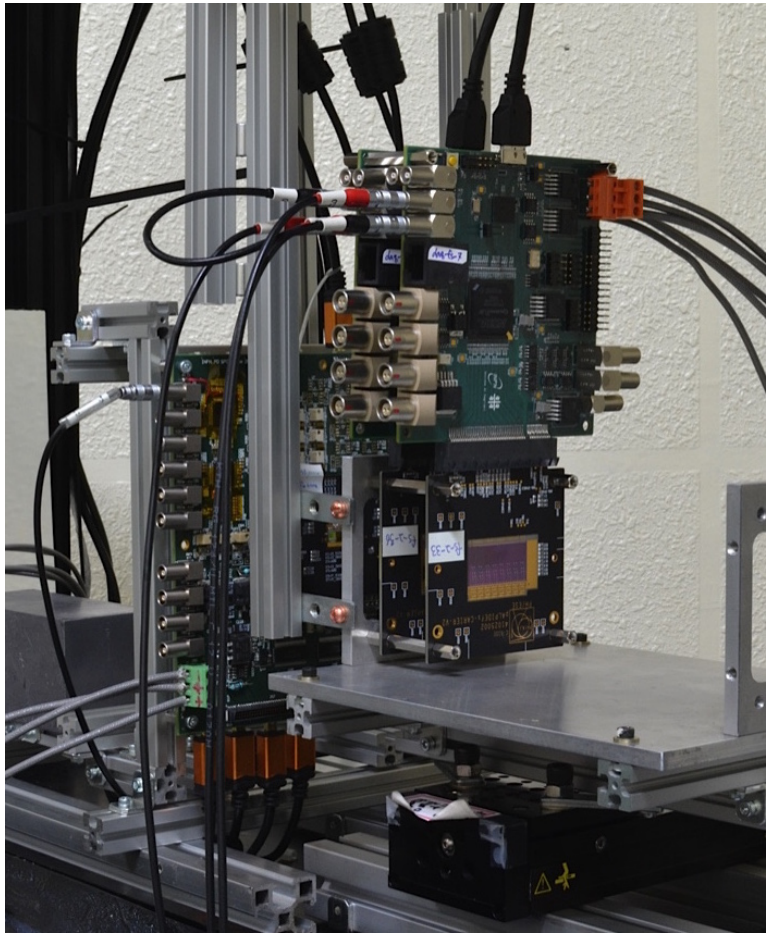
# Threshold catastrophe of pALPIDEfs on October

- Detector setup: **2 pALPIDEfs layers**
- Maximum occupancy of each chip was limited to 400 hits per event.
- Due to very high beam intensity, possible threshold range for the measurement: **2000 $\sim$ 2800 electrons**
  $\rightarrow$ Very high threshold!




[ cluster signal on Explorer-1 ]

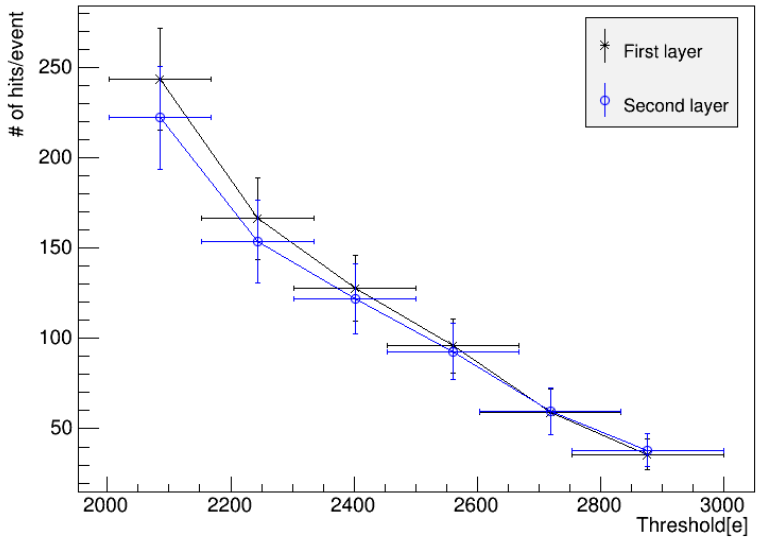
- No hit from noise for these thresholds.
- **Therefore, very hard to see X and Y position correlation between two pALPIDEfs planes, but we still can see electrons who deposit large energy.**



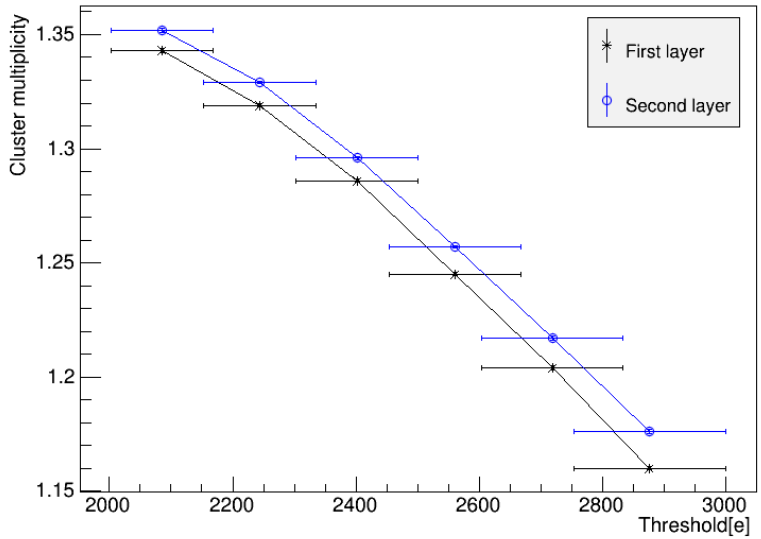
[ Detector layout at beamline ]

# Basic plots

[ Number of hits per event vs. threshold ]




[ Cluster multiplicity vs. threshold ]

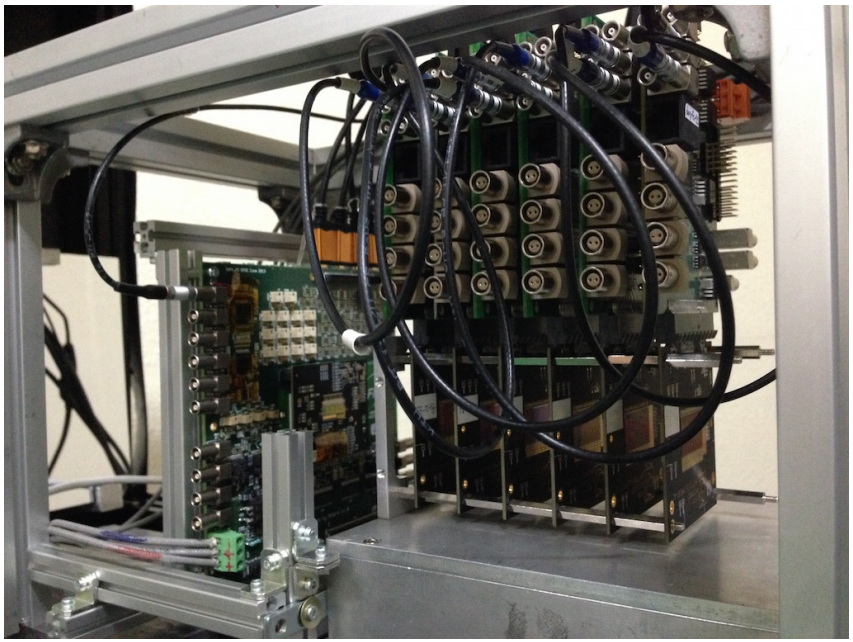



- Number of hits (or pixels) per event and cluster multiplicity decreases as a function of threshold.
- More than 200 hits with lowest threshold and we could expect more than 400 hits with one step lower threshold.
- Although we weren't able to measure with nominal threshold range to see correlations, pALPIDEfs chips behaved functionally under harsh condition.

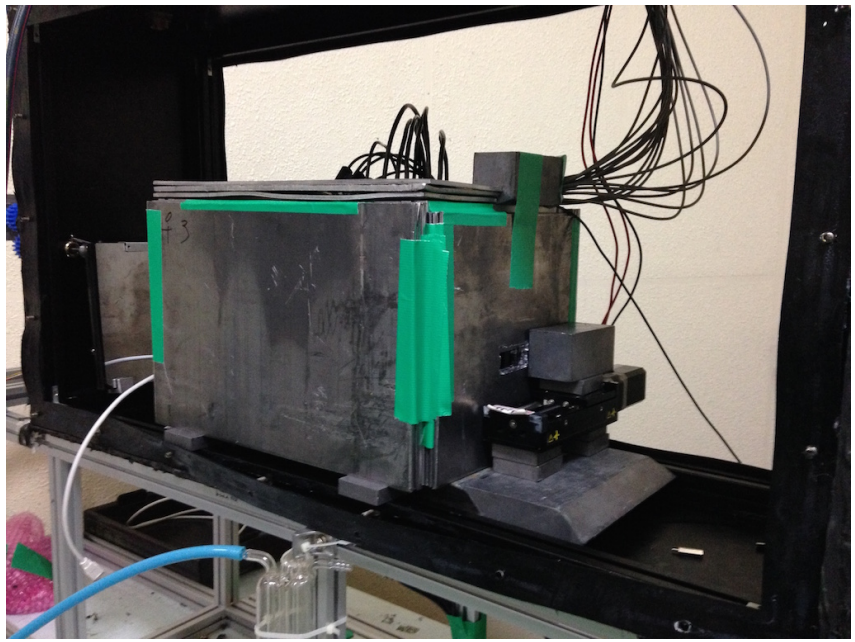
# Test beam on December

Main updates from October test beam:

1. Reduction of beam intensity dramatically $\sim$ factor 50
2. 6 pALPIDEfs layers (4 pALPIDEfs layers are added) to reconstruct tracks.



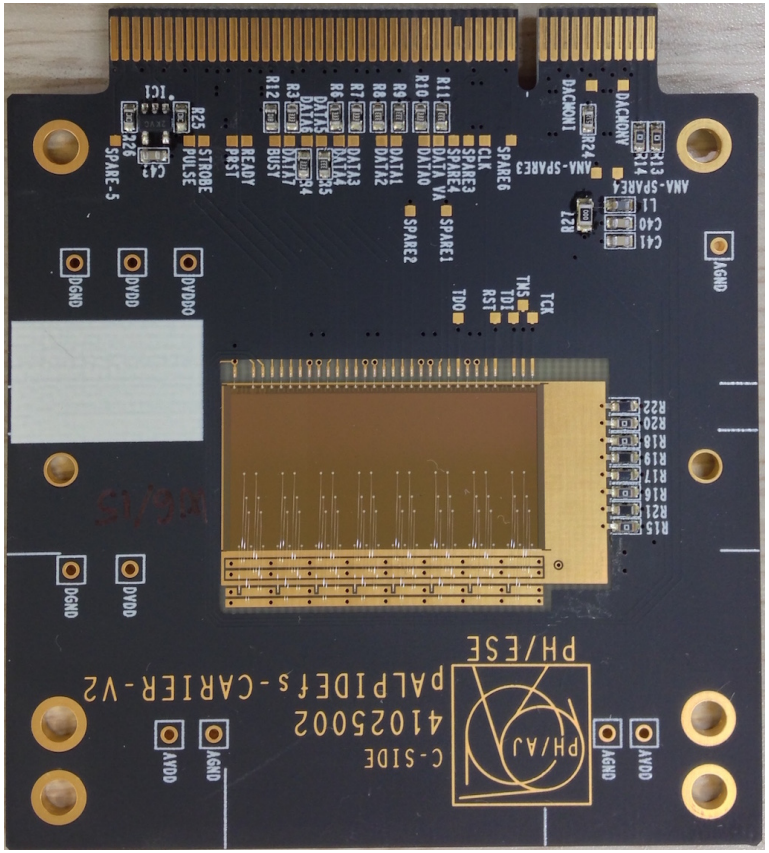
[ Detector layout at beamline ]



[ Before turn beam on ]

# Before plots from pALPIDEfs chips

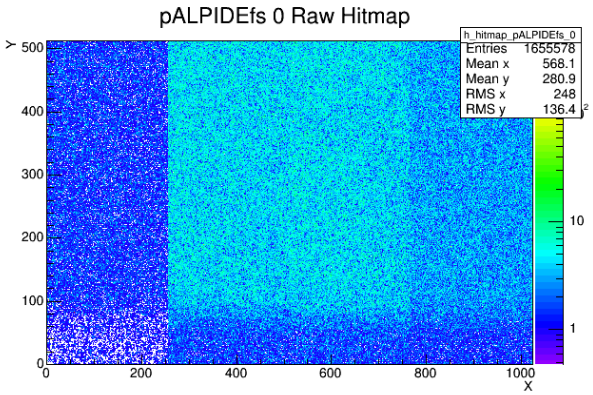
[ Front ]

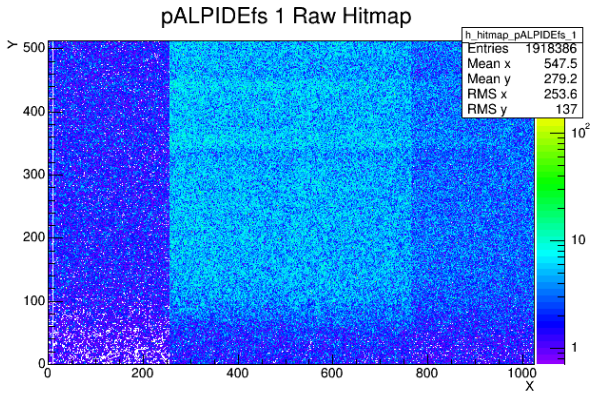


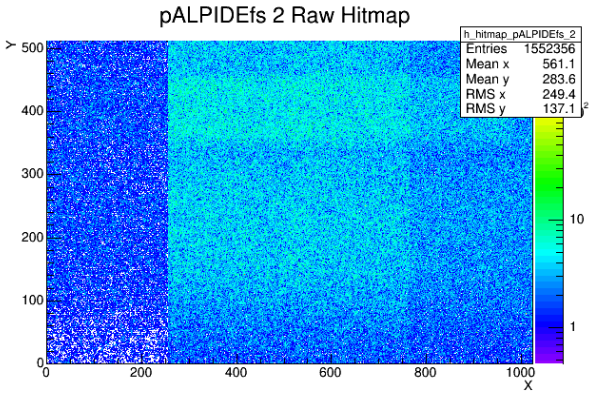

[ Back ]

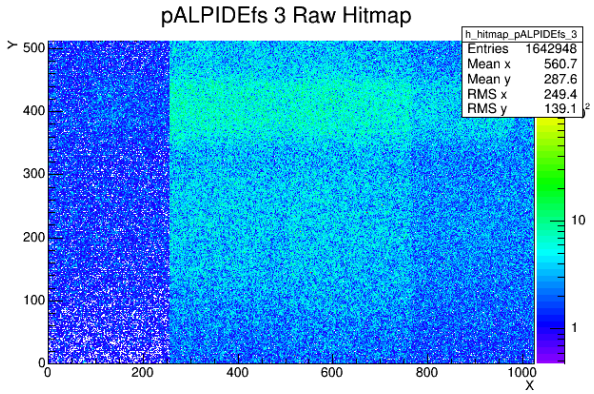

- pALPIDEfs chip is mounted on the carrier board (PCB $\sim$ 2mm thick)
- Large fraction of chip is overlaped with the carrier board (PCB) except long window.
  $\rightarrow$ **No material after 50 $\mu$m thick chip itself**

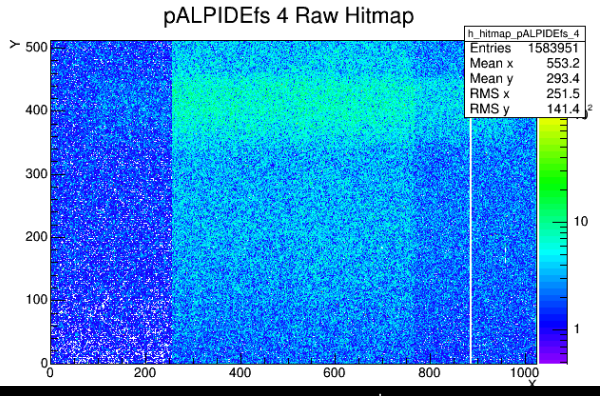
# Hit map of 6 pALPIDEfs planes

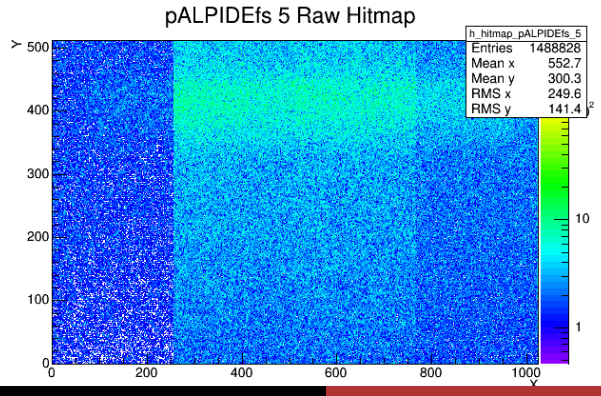


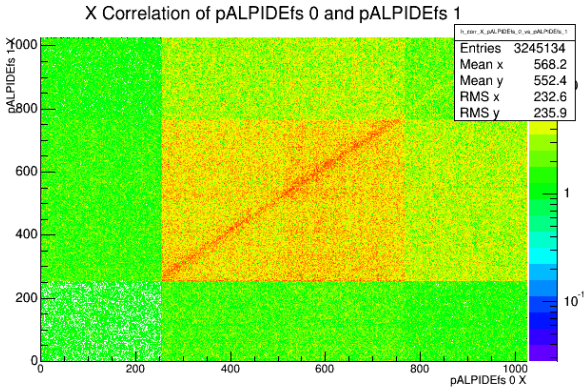



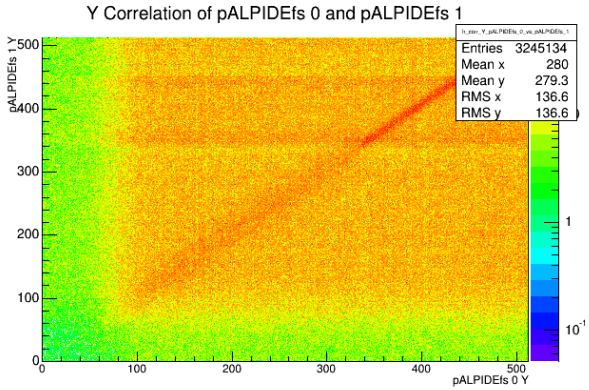

[ Layout ]

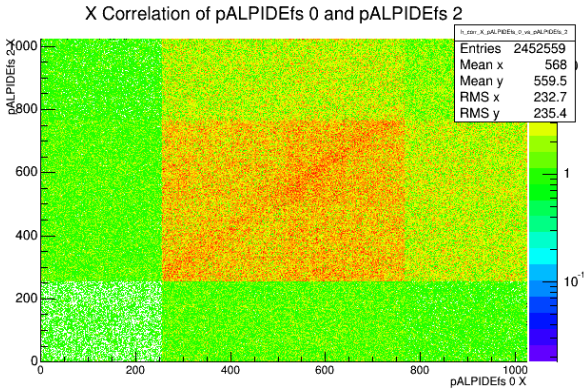
| | |
|---|---|
| **Layer 1** | **Layer 2** |
| **Layer 3** | **Layer 4** |
| **Layer 5** | **Layer 6** |

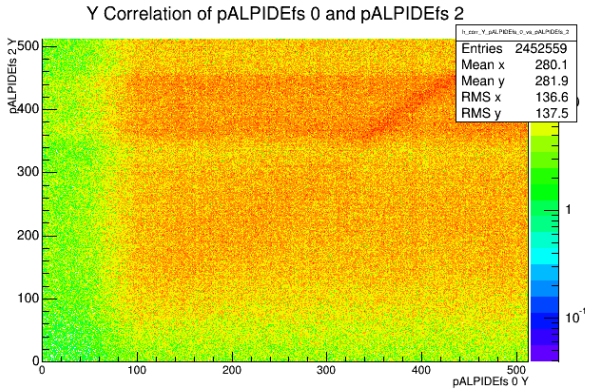
- Threshold settings $\sim$ 150 electrons.
- Hit map of 1st layer is very uniform within each sector (4 sectors can be distinguished via vertical lines). Less hits at bottom caused by collimator.
- Electrons experience multiple-scattering or are absorbed by PCBs underneath pALPIDEfs chips.

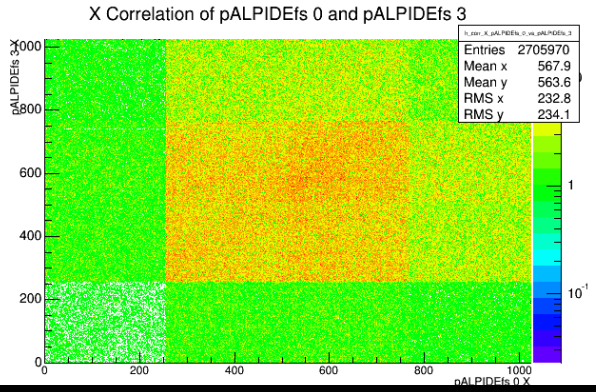
# X and Y correlations btw 1st and other pALPIDEfs planes

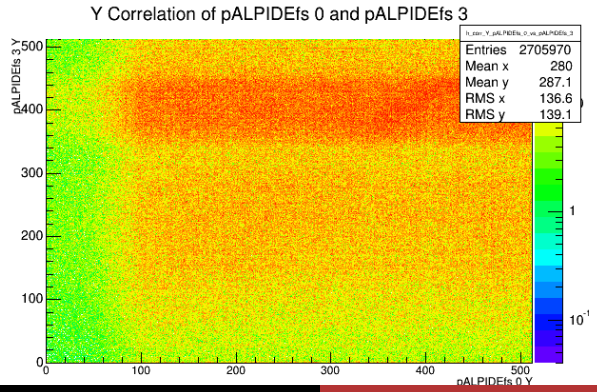


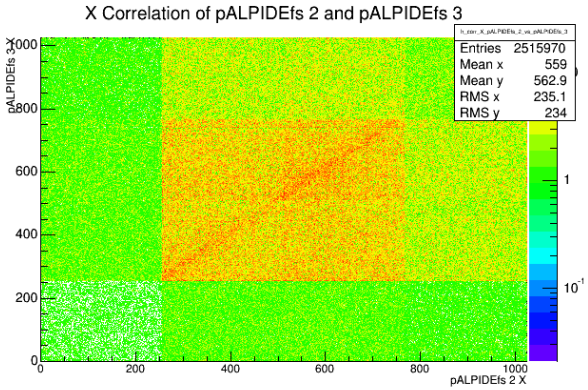



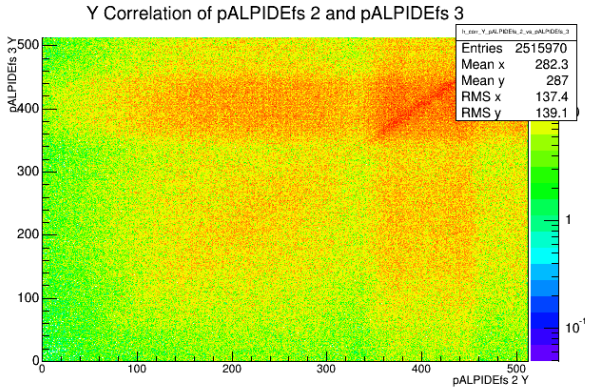

[ Layout ]

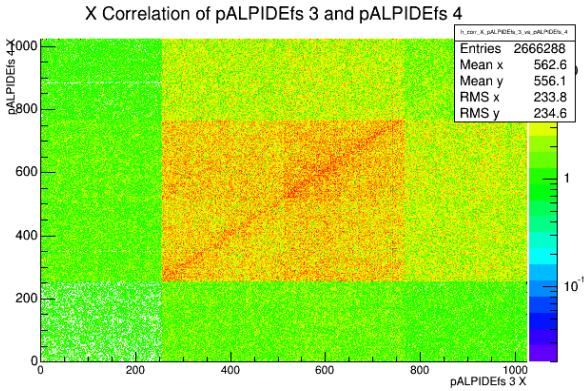
| |
|---|
| **Correlation btw 1 and 2 layer** |
| **Correlation btw 1 and 3 layer** |
| **Correlation btw 1 and 4 layer** |

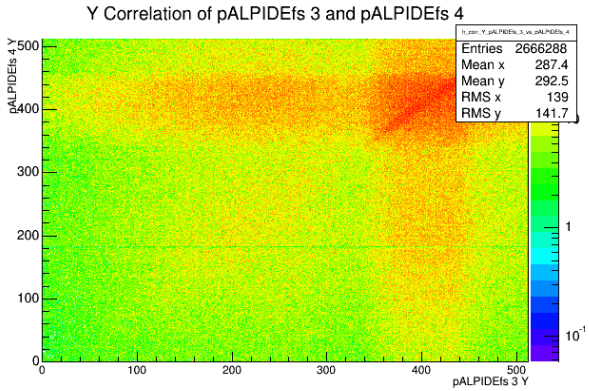
- Clear X position correlation between 1st and 2nd layers especially efficient middle 2 sectors.
- Y position correlation is basically visible and clear only hole area of carrier board.
- Correlations are getting faint as we correlate farther layers.

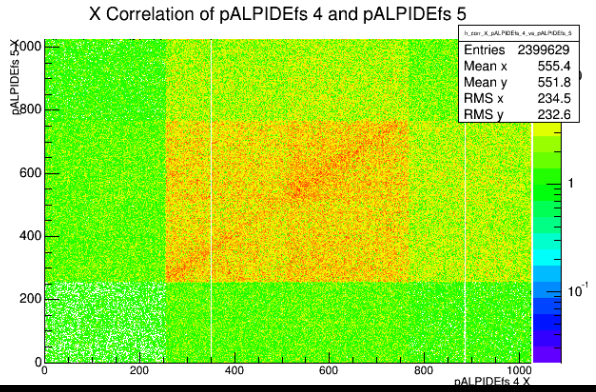
# X and Y correlations btw pALPIDEfs planes

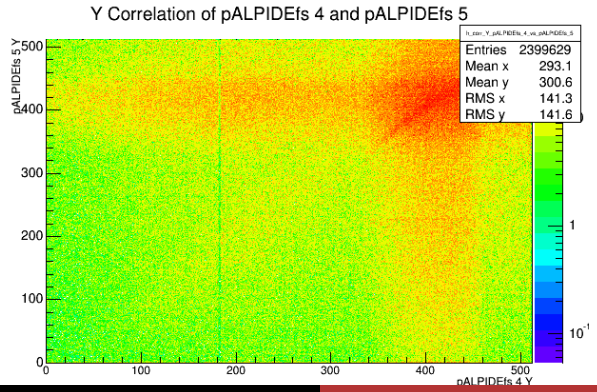



[ Layout ]

| |
|---|
| **Correlation btw 3 and 4 layer** |
| **Correlation btw 4 and 5 layer** |
| **Correlation btw 5 and 6 layer** |

- It's always possible to see correlations between two neighboring pALPIDEfs planes though it gets more backgroud from scattered electrons.

# Summary & Outlook

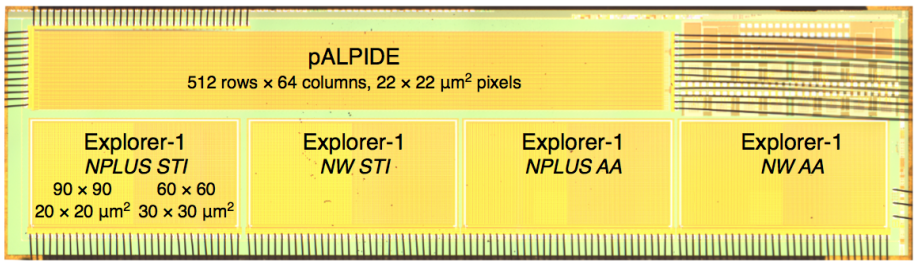
- There are many ongoing activities at Pusan for pixel chip characterization.
- Explorer-1:
  - Measurement of irradiated chips with $^{55}$Fe is ongoing and many more analyses can be done.
  - Test beam data of irradiated chips will be further analyzed then write a documentation together with $^{55}$Fe data.
- pALPIDEfs characterization:
  - We were able to tune the beam to reach enough low intensity for pALPIDEfs measurements.
  - Low energy electrons (60 MeV) scatter a lot at carrier boards (PCB).
  - Electrons pass through the holes in the carrier board look promising.
- Jongsik will be at CERN from January 19th to February 13th, 2015 for the detail analysis of pALPIDEfs data based on Eutelescope.

# Backup

# ALPIDE prototypes (CERN)

1. **Explorer**: analog output, pixel sensor optimization - diode geometry, epitaxial layer thickness, back bias, etc.
2. pALPIDEss: binary output, circuit optimization
3. **pALPIDEfs**: binary output, full scale prototype for system studies
4. Investigator: analog output, pixel sensor optimization - pixel size, input transistor location, etc.

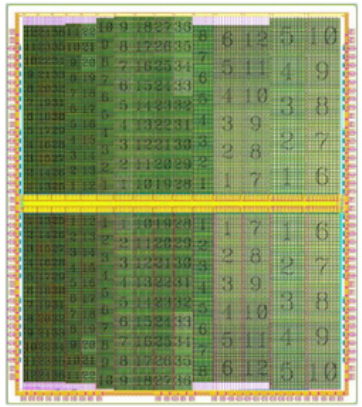
[ Explorer and pALPIDE ]




dimension: 3.6 × 1.8 mm (per Explorer-1)

#pixels: 2k (per Explorer-1)

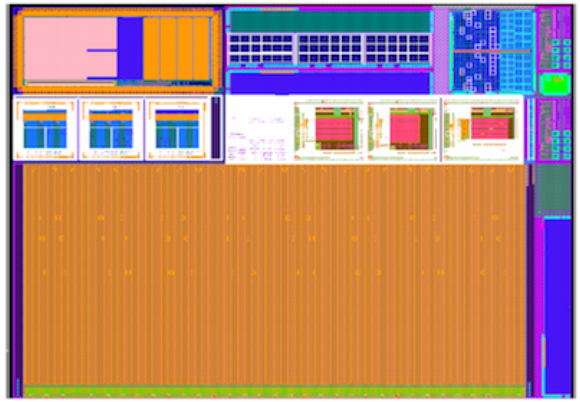
[ Investigator ]



5.0 × 5.8 mm

#pixels: 8k

[ pALPIDEfs ]

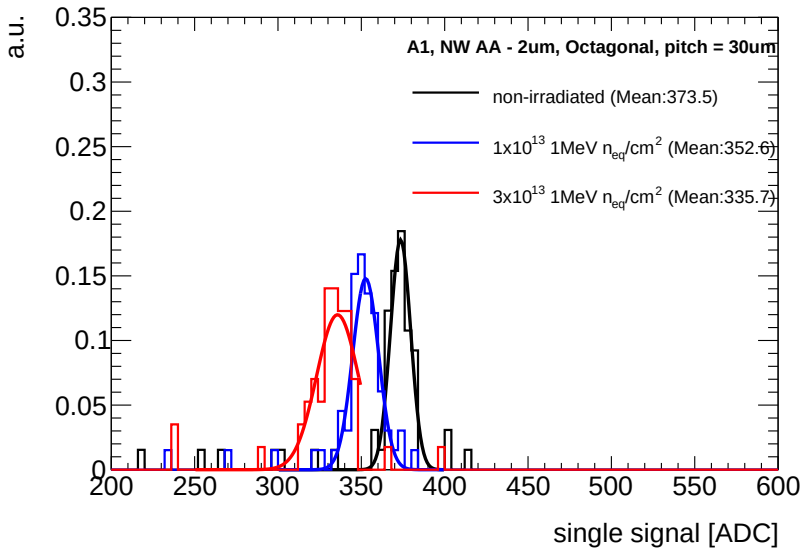


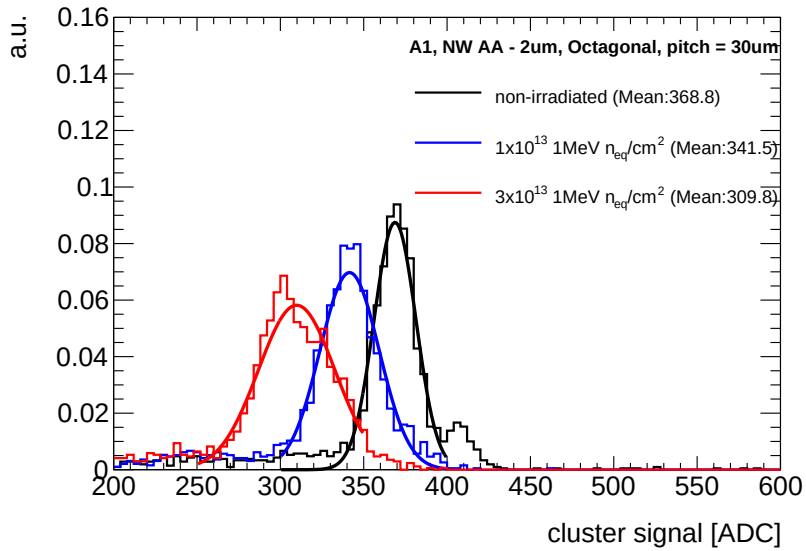
15 × 30 mm

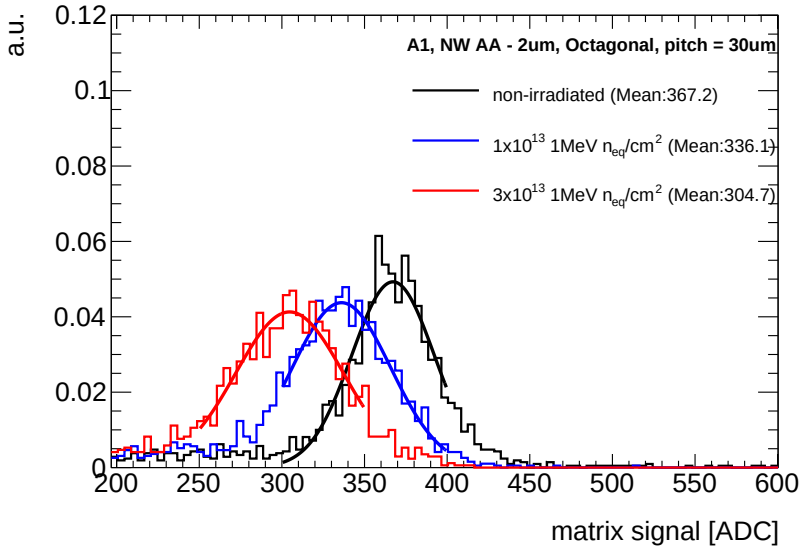
#pixels: 524k

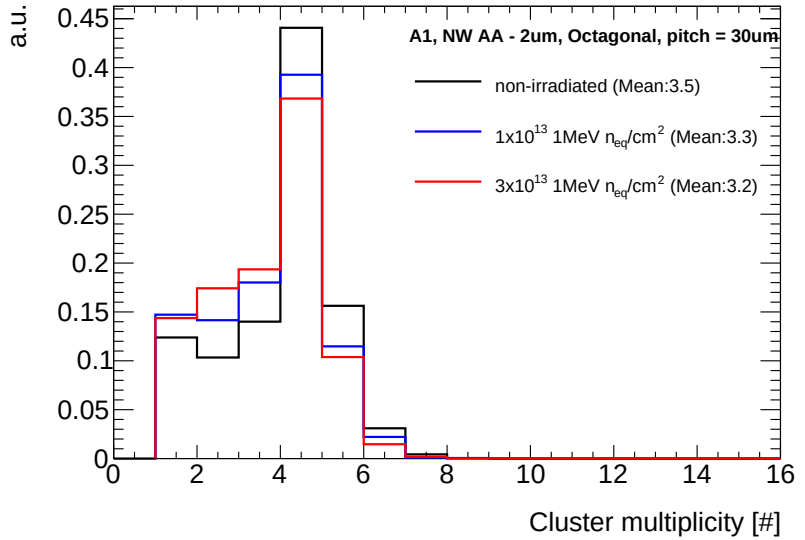
# Characterization of irradiated Explorer-1 chips with $^{55}$Fe

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.

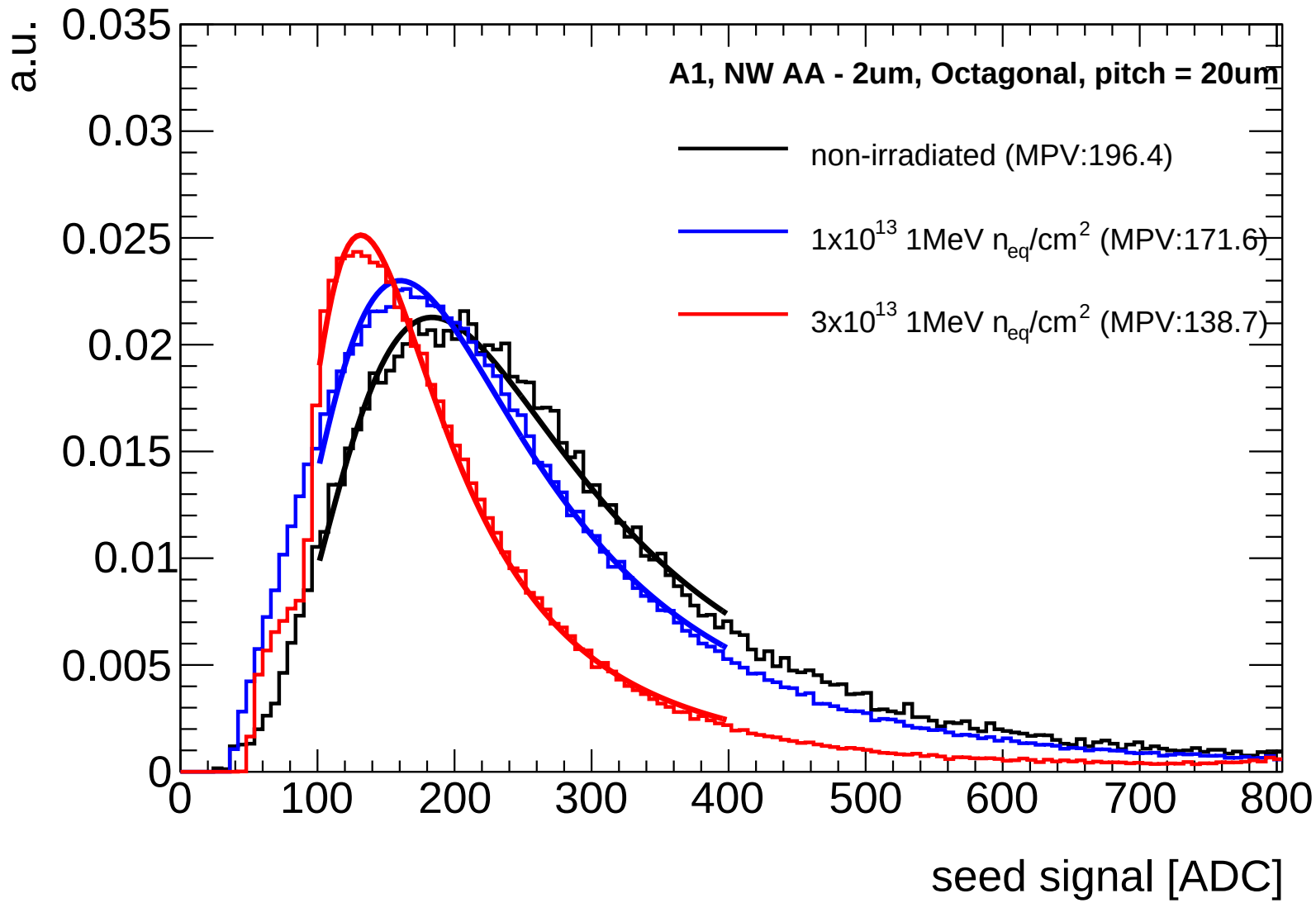


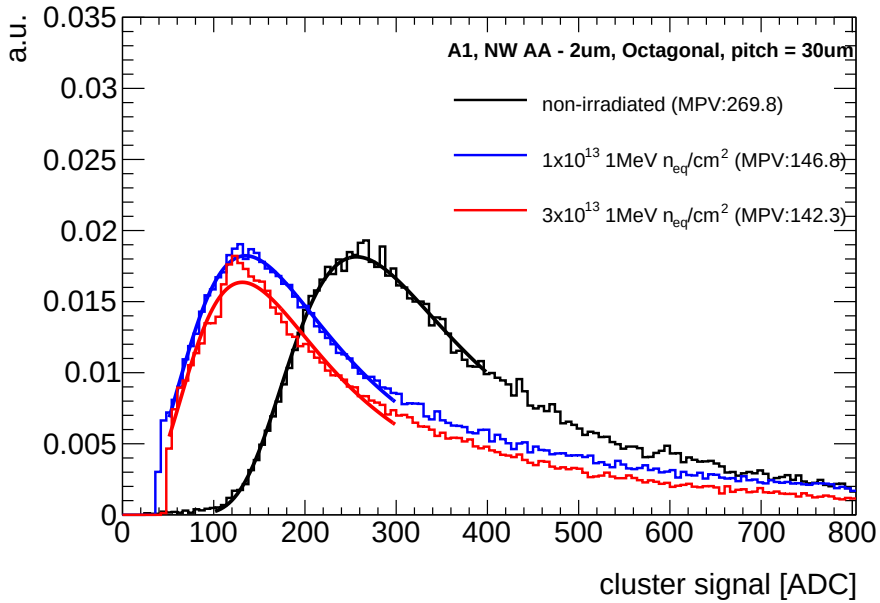



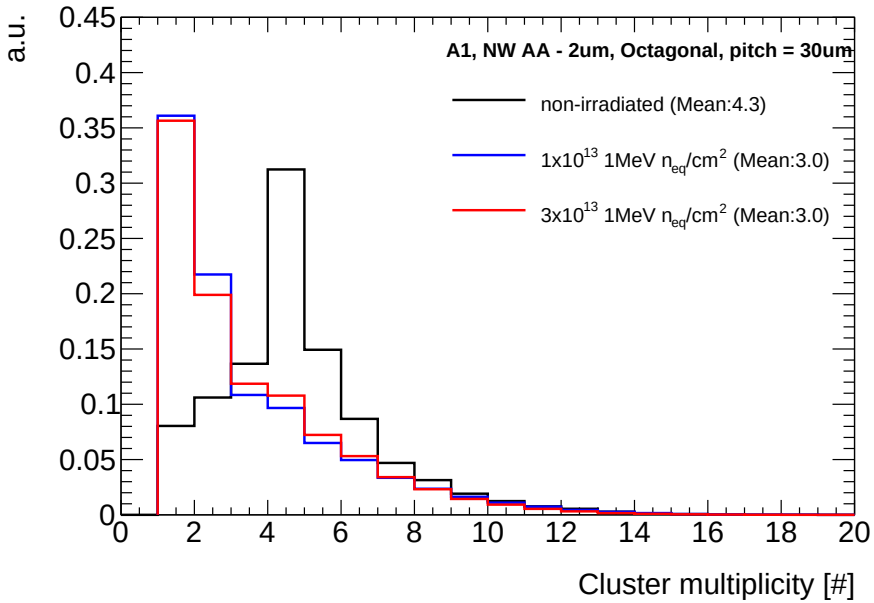
# Deformation of seed distribution after irradiation



# 60 MeV e$^-$ test beam of irradiated Explorer-1 chips

- 18 $\mu$m epitaxial layer thickness, 1k$\Omega$cm resistivity, -6 V reverse bias voltage.

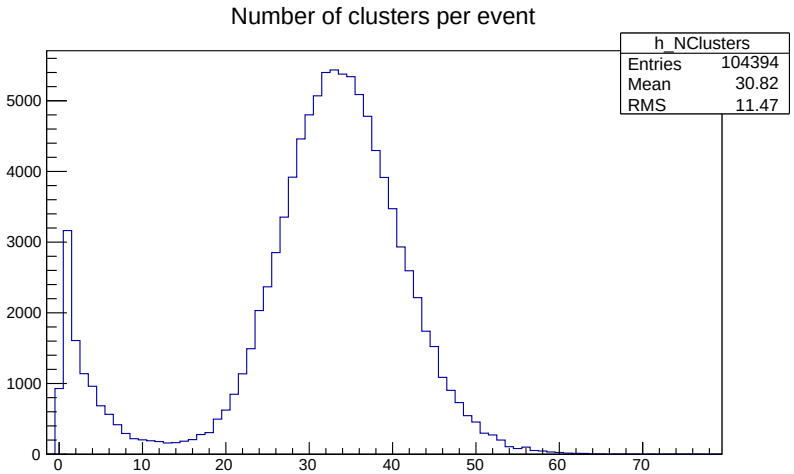


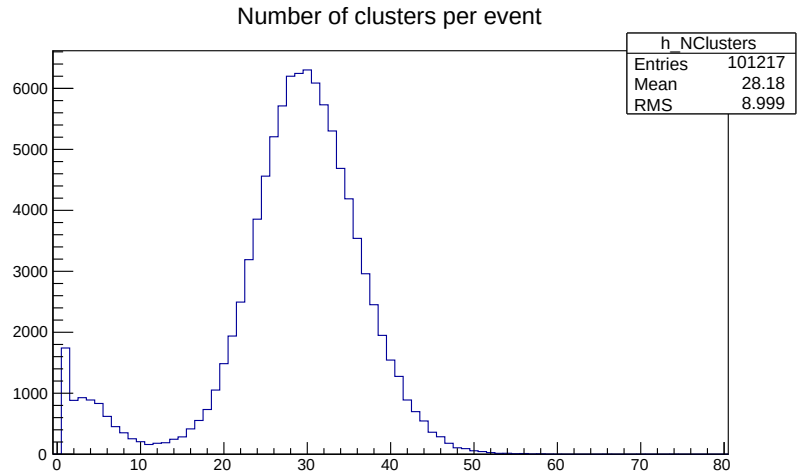

(** gain and cmc correction applied)

# Naive estimation of beam intensity via Explorer-1

- Assume Explorer-1 is fully efficient at back bias = -6V.
- Average number of clusters in Explorer-1 $\sim$ 60 clusters (or electrons).
- Active area of pALPIDEfs/Explorer-1 $\sim$ 20.
- $\sim$ **1800** electrons on pALPIDEfs if beam is uniform.
- $\sim$ 2700 hits (or pixels) on pALPIDEfs (if, cluster multiplicity = 1.5)
- pALPIDEfs cannot measure all these particles, moreover we cannot have clean reconstructed tracks from 2700 hits.

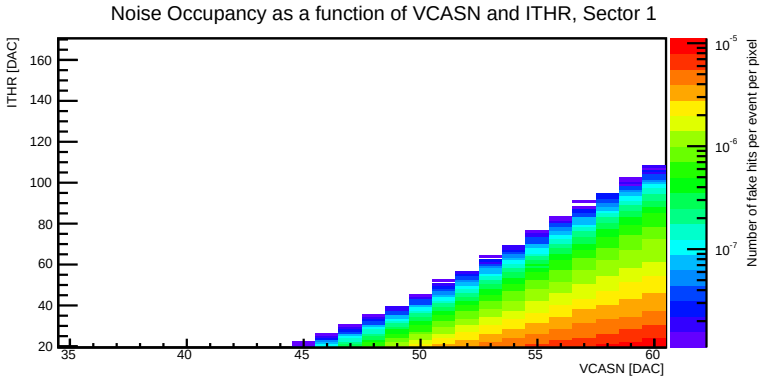


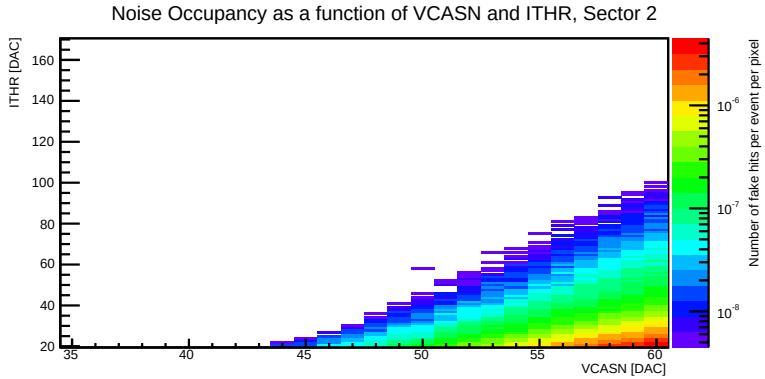

[ 20x20 $\mu$m$^2$ ]

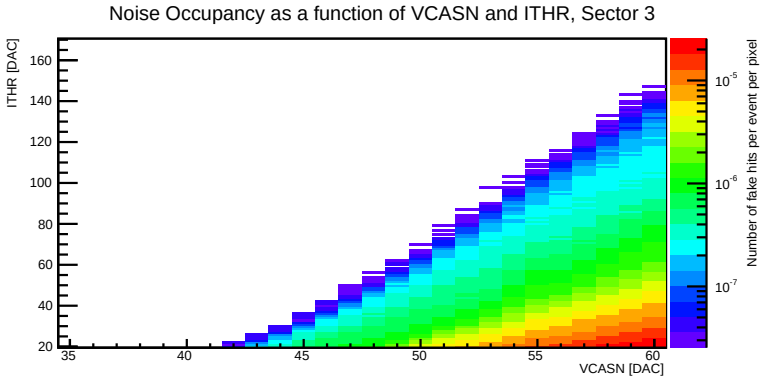


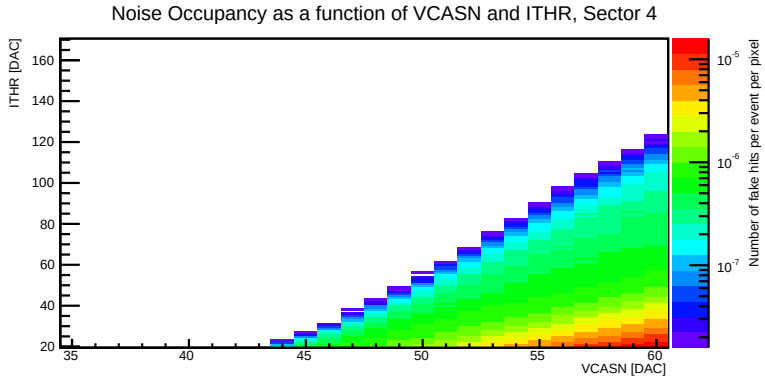

[ 30x30 $\mu$m$^2$ ]

# Noise occupancy

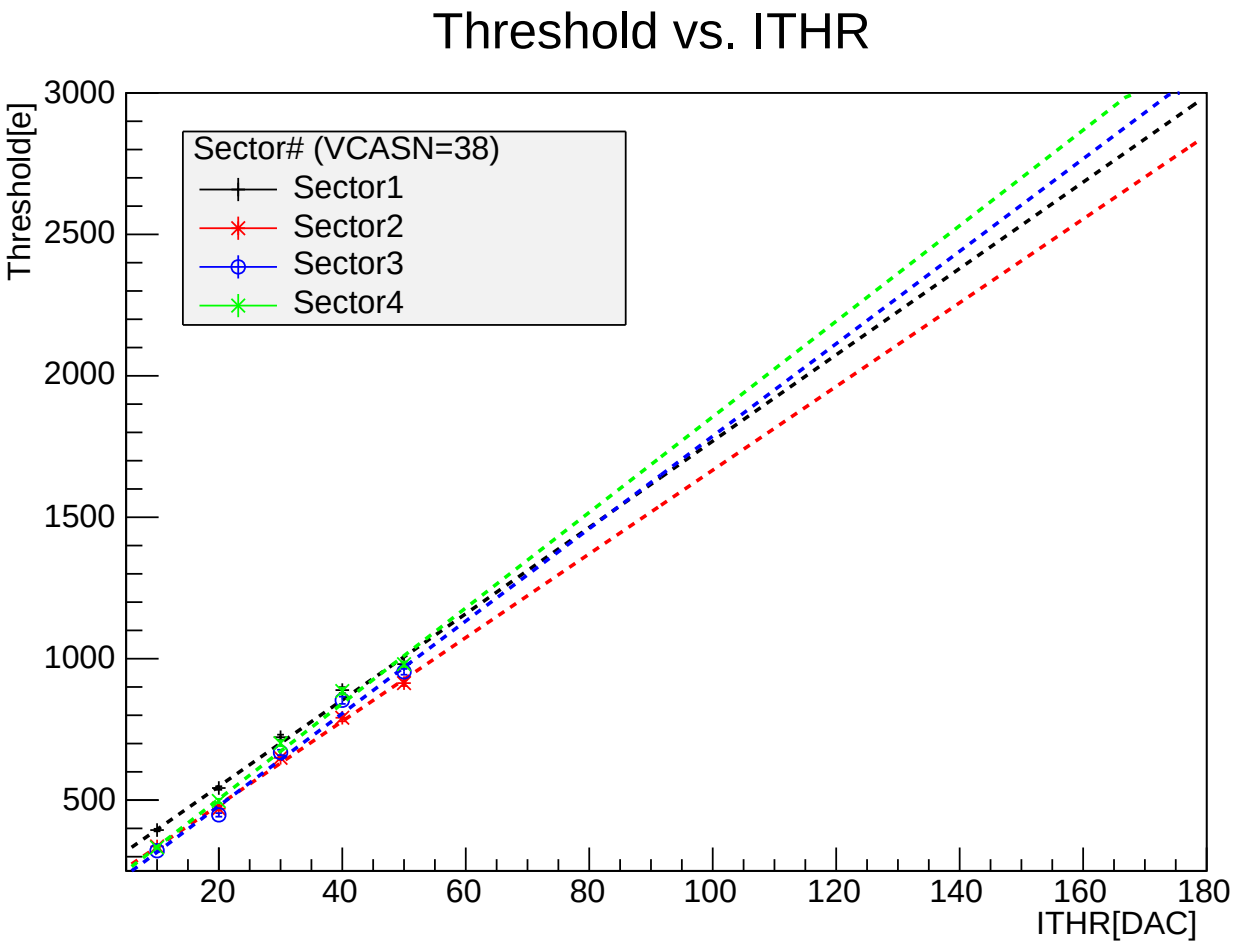


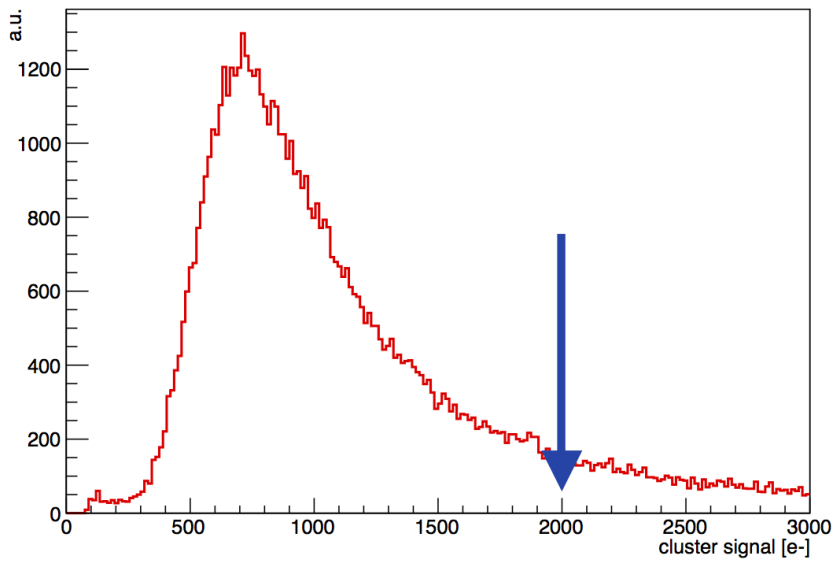



# Threshold extraction



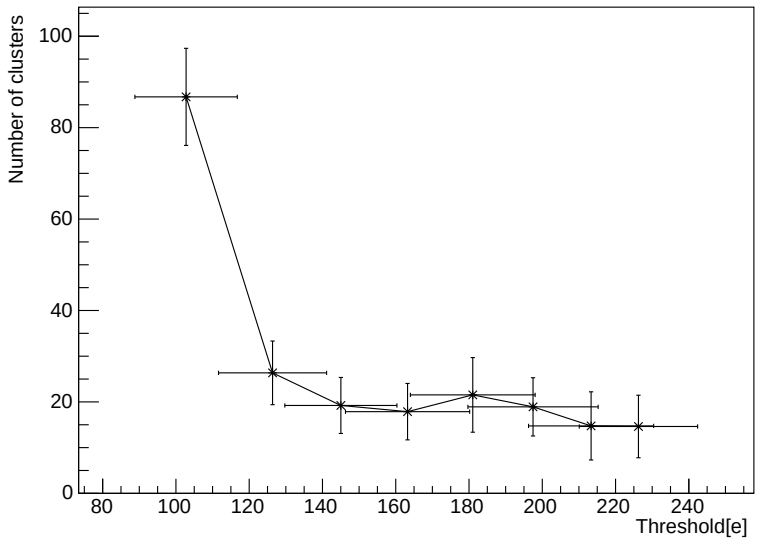
# Some useful information from Explorer-1



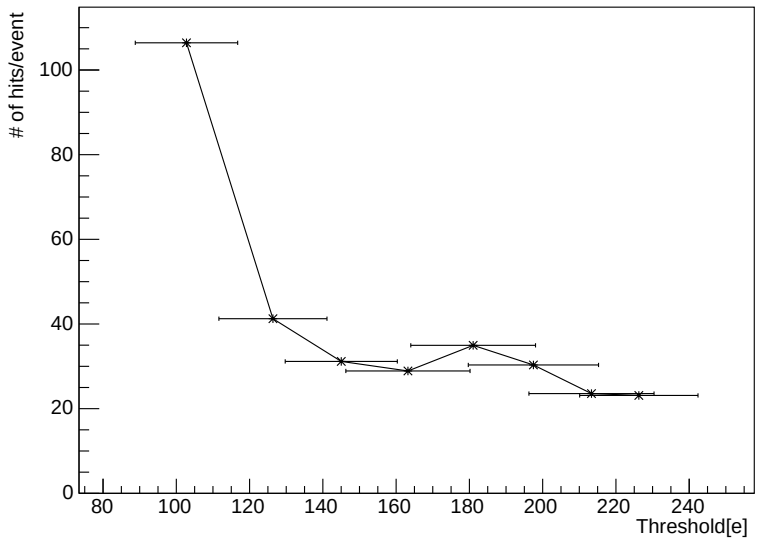

- Cluster signal of Explorer-1 (20x20 $\mu$m$^2$ pixel, 2 $\mu$m octogonal n-well and STI) at back bias voltage = -6V from 60 MeV electron.
- Calibrated with $^{55}$Fe source $\rightarrow$ x-axis in electrons.
- Small fraction ($\sim$ 9 %) of electrons deposit enough energy to generate more than 2000 electrons.
- **Therefore, very hard to see X and Y position correlation between two pALPIDEfs planes, but we still can see electrons with large energy deposit.**
- **No X and Y position correlation between two planes means we cannot reconstruct track!**

# Basic plot of DUT on December

[ Cluster multiplicity vs. threshold ]




[ Number of hits per event vs. threshold ]



# Hits vs. Plane