Sensor characterisation

Report on ALICE ITS Upgrade work package 5 activities

Magnus Mager

CERN

4th ALICE ITS upgrade, MFT and O^2 Asian Workshop 2014 at Pusan

15–16th December 2014

Haeundae Grand Hotel, Pusan, South Korea

Outline

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Sensor characterisation: overview

Prototypes (still) being characterised

- Prototypes to study basic properties of technology: Explorer-X, Investigator, MIMOSA32/34
- Building blocks of final sensor: pALPIDEss-X (aka "pALPIDE-X"), MIMOSA22thrX, memory chip (aka "SEU chip")
- Full-scale chips: **pALPIDE-1**⋆ (aka "pAPLPIDEfs"), MISTRAL FSBB

Test being carried out

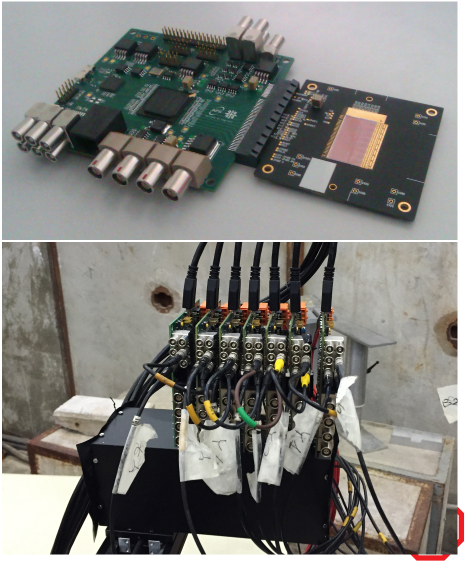
- Basic functionality
- Radioactive source (X-ray, beta)
- Test beams

⋆ Today, focus mainly on ALPIDE developments

pALPIDE set-ups around the world

- Bari
- Cagliari
- Catania
- CERN
- Frascati
- **Inha**
- **Pusan**
- St. Petersburg
- Strasbourg
- Trieste
- **Yonsei**

Analyses carried out at even more places



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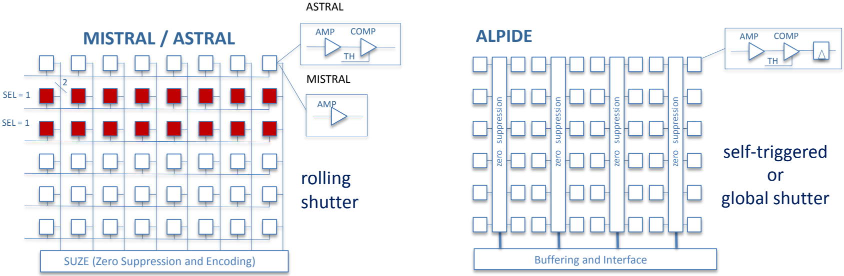
MISTRAL FSBB: overview

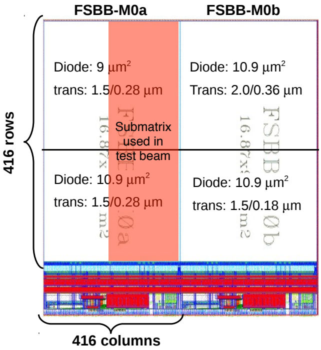
- The ALICE ITS upgrade is following two design streams: ALPIDE (more later) and MISTRAL-O (next few slides)
- MISTRAL is based on the rolling shutter architecture

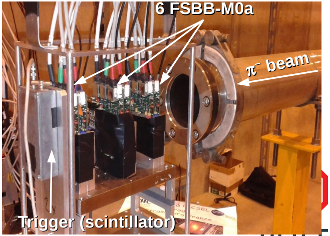


- The MISTRAL FSBB is 1/3rd of the full sensor
- Its purpose is to study integration related aspects
- MISTRAL-O will be an optimised version (essentially using larger pixels) of this technology for the outer layers

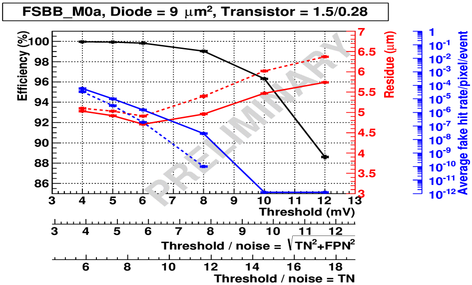
MISTRAL FSBB: SPS beam test set-up

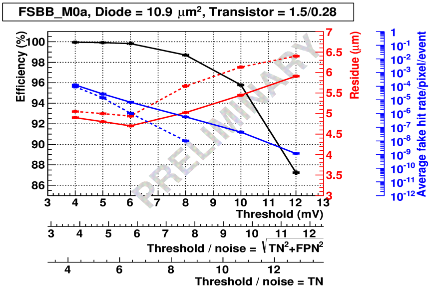
- π^- with 120 GeV/c
- Particle flux: trigger rate: 2.5 kHz to 100 kHz per 5 mm × 10 mm
- Sensor arrangement: 6 FSBB-M0a, thinned to 50 µm





MISTRAL FSBB: SPS beam test results





- Requirements of $\epsilon_{\text{det}} > 99\,\%$ and $\lambda_{\text{fake}} < 10^{-5}$ achievable
- Expected resolution (removing telescope tracking error): 4.5 μm
- NB: the FSBB is not optimised in some respects (pixel dimensions, power consumption, speed, . . .)

⇝ Currently MISTRAL-O is being optimised for use in the outer layers (less need for spatial resolution, but more stringent power consumption limit)

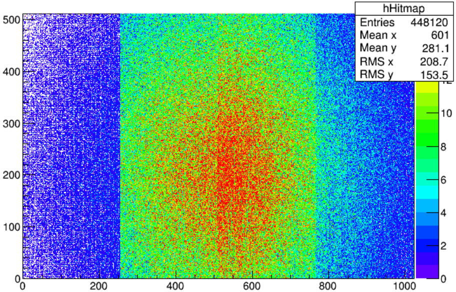
pALPIDE: overview

- pALPIDE-1 is the first full-scale (1.5 cm × 3 cm) prototype
- Electrically, it is fully functional (though its functionality is not yet final)
- Full characterisation (laboratory and test beam) is being carried out on a small number of chips
- Current focus lies on extending the parameter space:
  - Different irradiation levels
  - Different operating environments (particle energies/multiplicities)
  - Testing of more chips

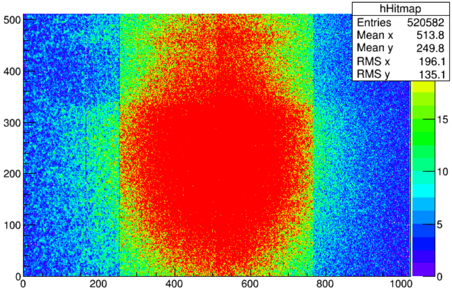
. . . pALPIDE-2 is on the way (expected in Q1/2014)

pALPIDE: tests with radioactive sources

Fe-55



Sr-90

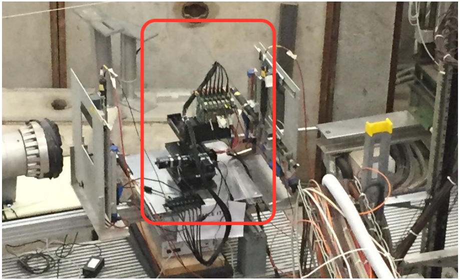


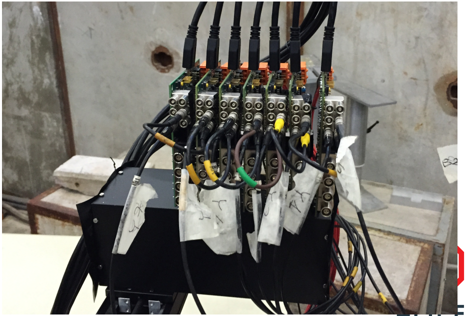
- Hit maps show different response of pALPIDE sectors
- Difference caused by two effects: detection efficiency and cluster size
- Sr-90 reveals a structure cased by a hole in the PCB
- Very important check of sensor response uniformity

pALPIDE: test beam set-up at CERN PS

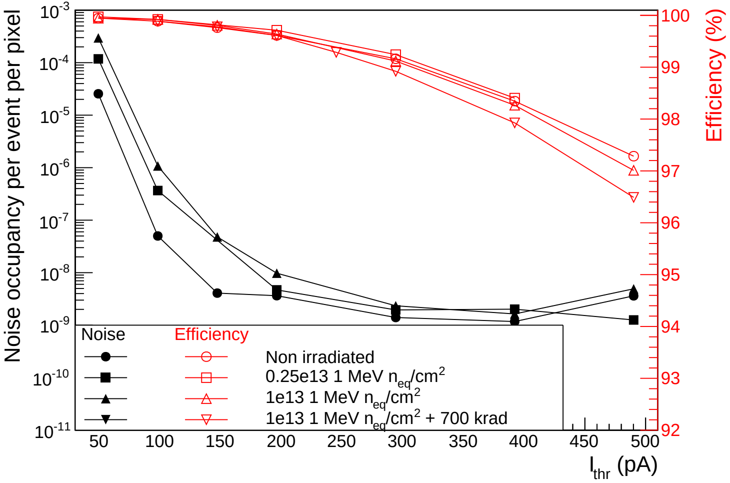
- Beam: π^- with 6 GeV/c (nom.)
- Intensity: 400 ms spills of 10 000 particles (typ.) focussed on sensor
- Sensor arrangement (logical):
  - 3 tracking planes
  - 1 device under test (DUT)
  - 3 tracking planes
- Plane spacing: around 2 cm

⇝ Tracking precision at DUT: 3 µm





pAELPIDE: detection efficiency and fake rates



⇝ Requirements of $\epsilon_{det} > 99\,\%$ and $\lambda_{fake} < 10^{-5}$ can be fulfilled

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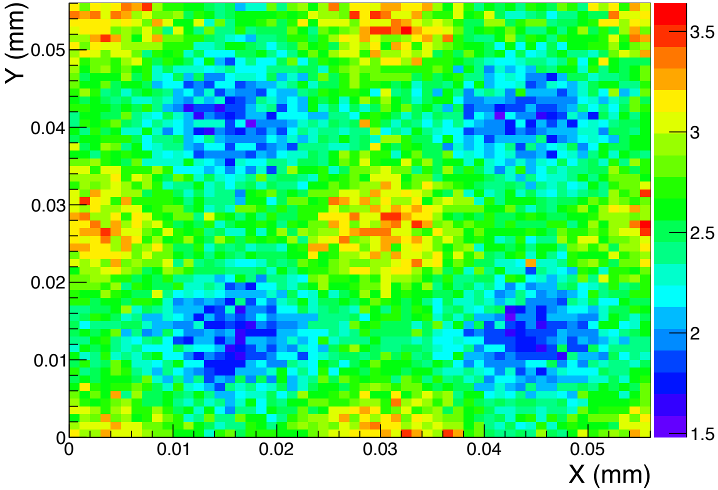
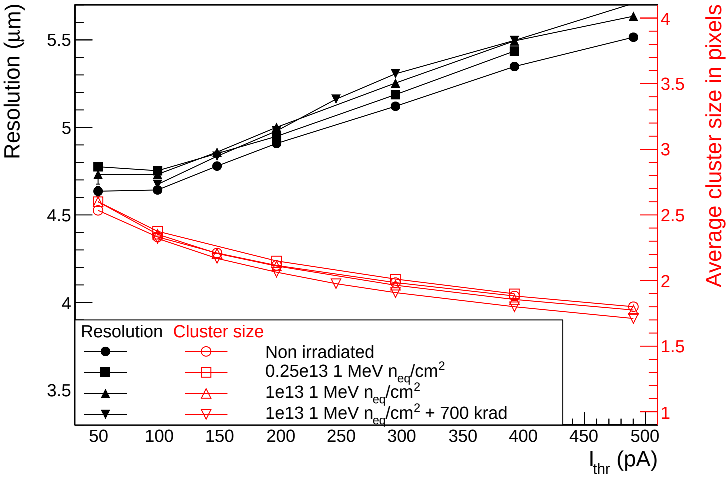
pALPIDE: cluster size vs. position within pixel



⇝ Small clusters, but large enough to gain resolution

pALPIDE: resolution

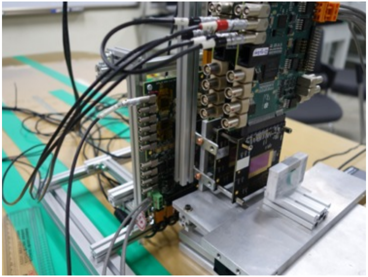


⇝ Requirement of $\lesssim 5\,\mu m$ can be fulfilled

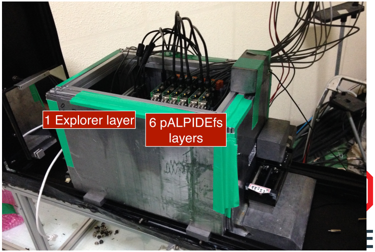
pALPIDE: test beam set-up at Pohang

- Beam: e^- with 60 MeV/c (nom.)
  - Large multiple scattering/absorption in PCB
  - But, particles, that make it through can be used for efficiency calculations
  - Also, cutout in PCB underneath the sensor results in localised very small material budget (only ≈50 μm of Si)
- Sensor arrangement: 6 pALPIDE-1, 1 Explorer-1
- Plane spacing: around 2 cm
- (Primary) beam largely attenuated to about 10 particles per spill on the sensor

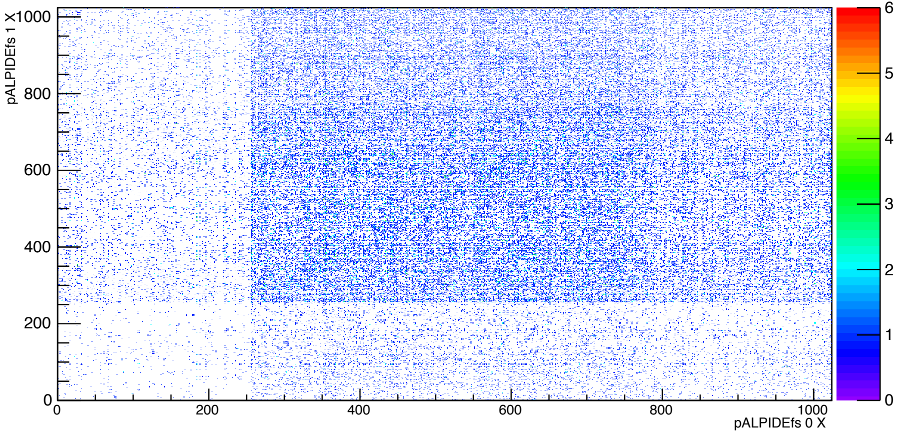
October 2014:



December 2014:



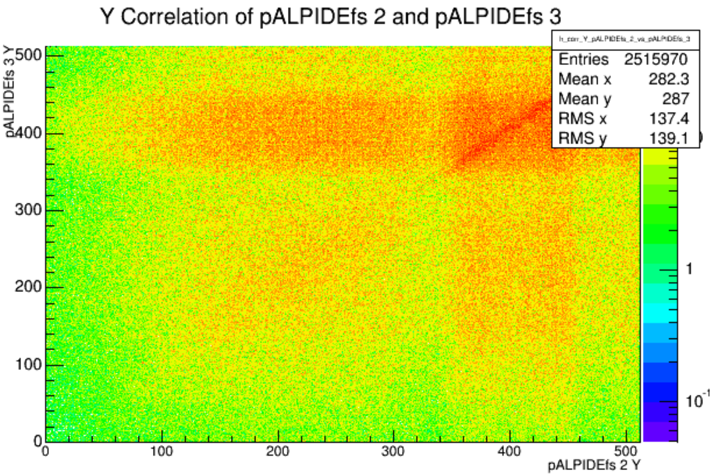
pALPIDE: tracks at Pohang



- Clear pattern visible

⇝ Data contains tracks

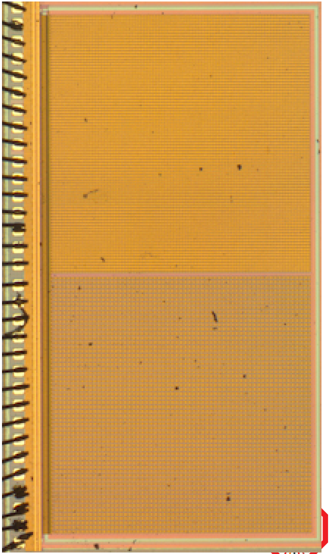
pALPIDE: tracks at Pohang II



- Very interesting to study sensor performance under different operating conditions (particle rate & energy)

Explorer: overview

- First prototypes in the ALPIDE development
- Main goal was to qualify the TowerJazz technology (this has been achieved)
- Still of interest to:
  - optimise sensor layout
  - study radiation effects
- Main advantage: analogue read-out



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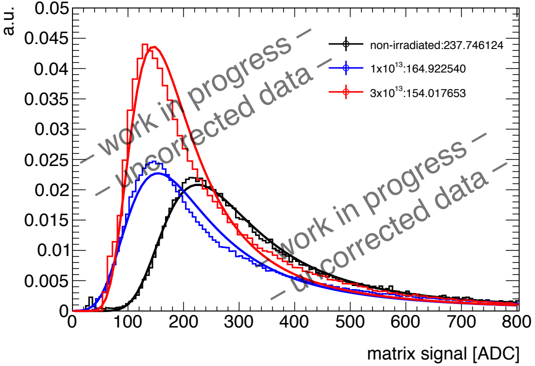
Explorer: Pohang test beam results



- Systematic study of different radiation effects for different sensor geometries (first data shown here)
- Very challenging, as many irradiation-independent effects have to be corrected for first

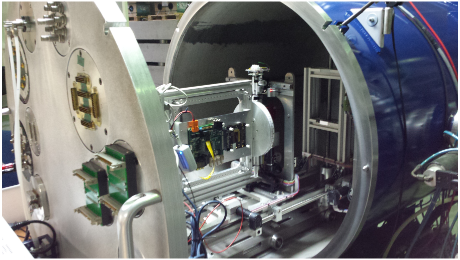
Single-event latch-up (SEL)

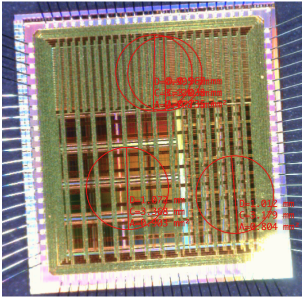
- Refers to the activation of parasitic transistor structures, resulting in a short circuit
- Caused by highly ionising particles (characterised by large linear energy transfers, LETs), originating from recoil fragments of nuclear reaction within the silicon
- Occurs above a technology-dependent LET threshold
- No transient effect, can only be recovered by power-cycling the device
- Potentially destroys the device
- Issue for STAR:
  - happens every few minutes
  - needs careful monitoring of currents
  - detector got damaged (meanwhile protection circuits are adjusted and no further damages are observed)

⇝ Needs careful evaluation/treatment
  - test beams with heavy ions
  - two test vehicles: memory chip and pALPIDEfs

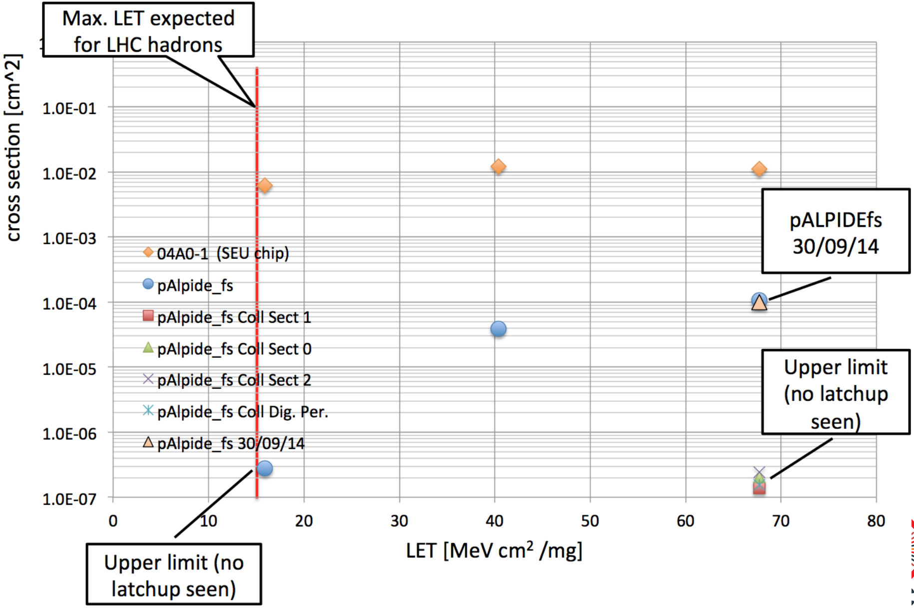
SEL test programme (Louvain-La-Neuve)

- Determination of LET thresholds (using different particles)
- Identification of sensitive regions (using collimators)
- Measurement of (over-)current amplitude and time profiles
- Characterisation of dependencies on:
  - Sensor thickness
  - Direction of particle crossing
  - Supply voltage (including reverse substrate bias)



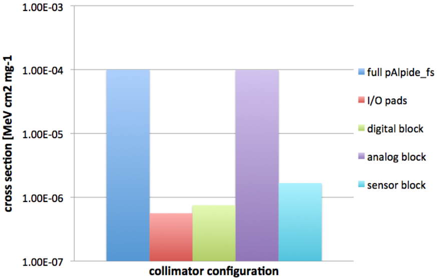


SEL cross-sections



SEL sensitive areas

- **Memories:**
  - Single-port memories have much higher cross-sections/lower LET thresholds than dual-port memories or flip-flops
  - We (luckily) do not use them in our sensor designs
- **pALPIEfs:**
  - Under nominal conditions, most effects happen in the analogue periphery; next submission will have an improved design
  - BUT, unclear what happens at different operating scenarios, e.g. at different angles, supply voltages, substrate biases



Summary & Outlook

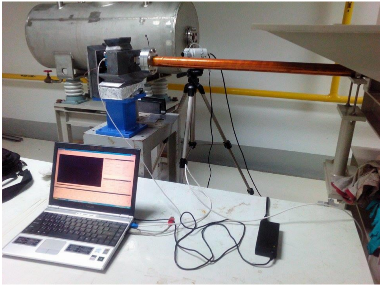
Summary

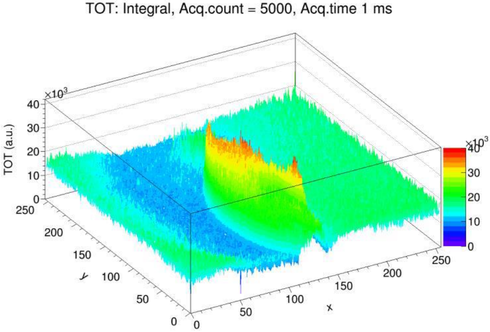
- Two design streams: ALPIDE and MISTRAL-O are being validated
- Various ALPIDE prototypes are being characterised in various conditions
- Several test setups around the world are used to carry out this immense program
- Few measurements still to be done (e.g. SEL with reverse bias)

Outlook

- Need to finalise measurements of all pALPIDE sensors
  - irradiated samples
  - analyses of recent test beams
- pALPIDE-2 is coming very soon

Outlook: SLRI





- Study to use the 1.2 GeV/c electron beam

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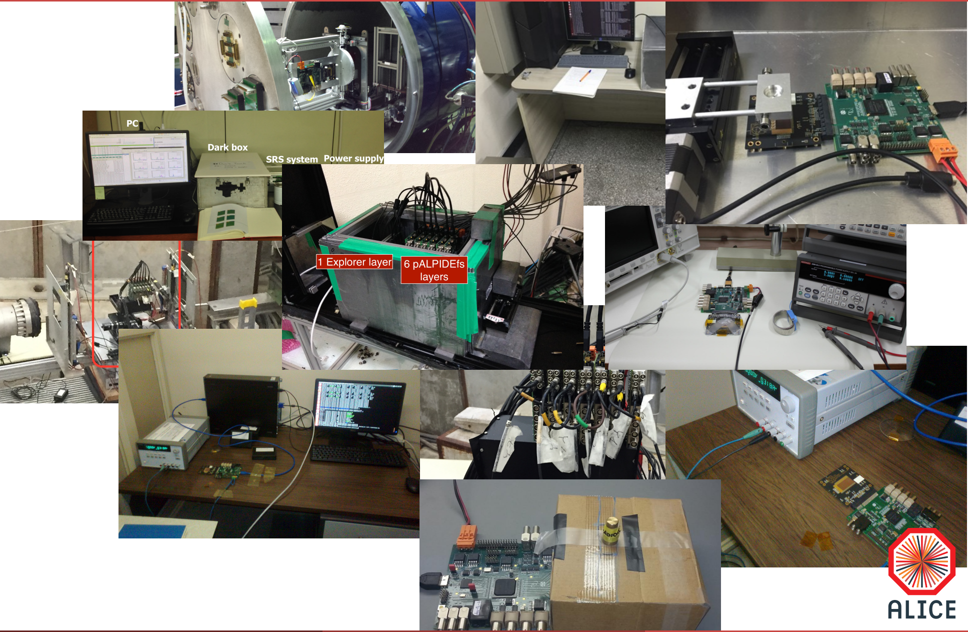
Epilog


PC
Dark box
SRS system
Power supply
1 Explorer layer
6 pALPIDEfs layers

Epilog

Thanks

Such a detailed and diversified characterisation would not be possible without you!