Development and testing of particle detector technology for high-energy experiments

My work as an international visiting graduate student at LNF 2017-2018

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GRENAC Meeting

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LNF-INFN

Figure 1 : Laboratori Nazionali di Frascati - Istituto Nazionale di Fisica Nucleare – Frascati, IT. Ref.: www.lnf.infn.it

LNF-INFN

As an international visiting graduate student at LNF-INFN/Italy from Nov/2017 to Sep/2018, my research activities were divided in two parallel blocks:

- **Assembly tasks:** my goal was to take part on the assembly of the outer-layer super-modules for the new ALICE Inner Track System at LNF and understand the challenging steps of such activity.
- **Analysis tasks:** my goal was take part on the ALICE-LNF Analysis Group, work on selected topics of Heavy-Ion Collision Physics and also get familiarized with the analysis techniques and software development.

ALICE – A Large Ion Collider Experiment

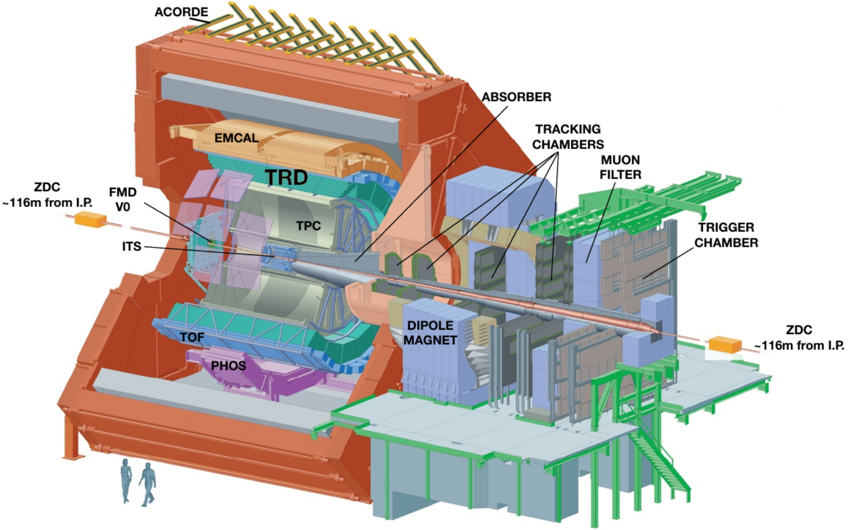


Figure 2 : ALICE (CERN)

ITS – Inner Tracking System

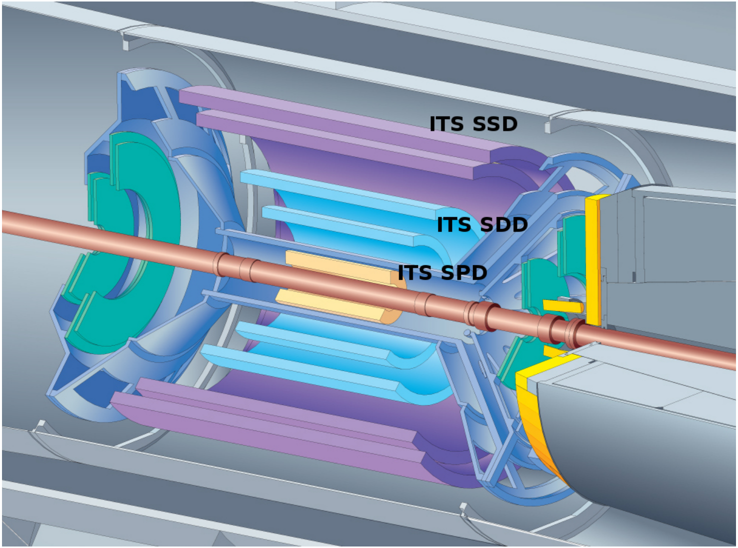


Figure 3 : Current ALICE ITS.

ITS Upgrade

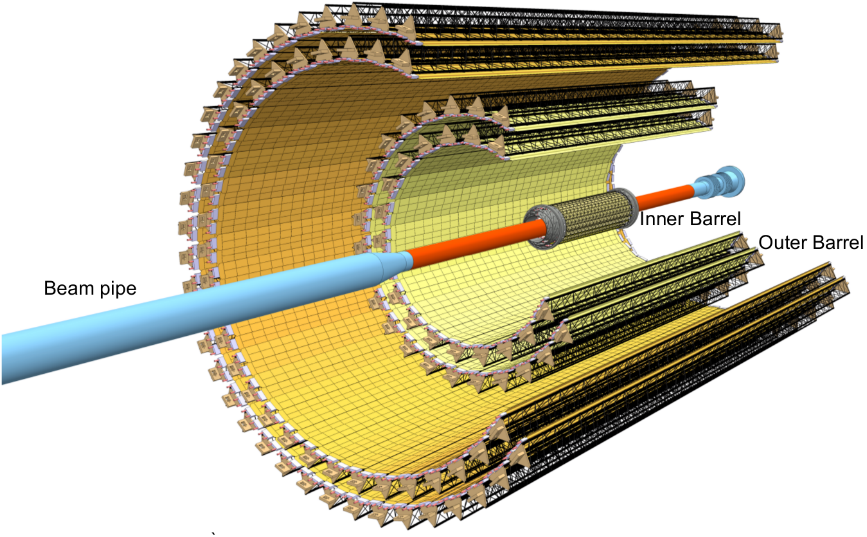


Figure 4 : ALICE ITS upgrade.

ITS Upgrade – Dimensions

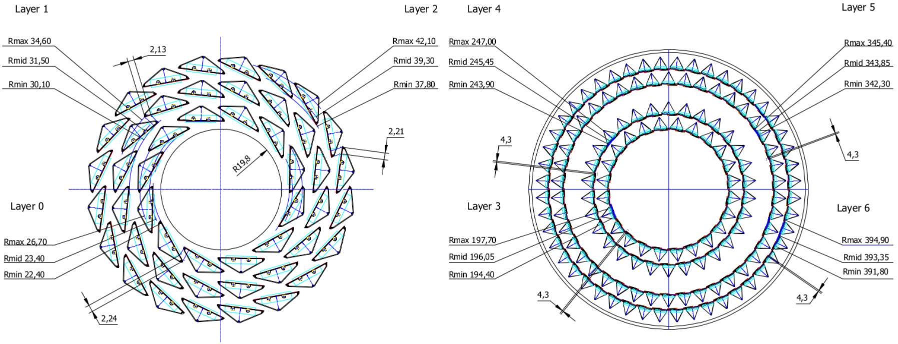


Figure 5 : ITS Upgrade: dimensions of the inner (left), middle and outer (right) layers.

ITS Upgrade – The Stave

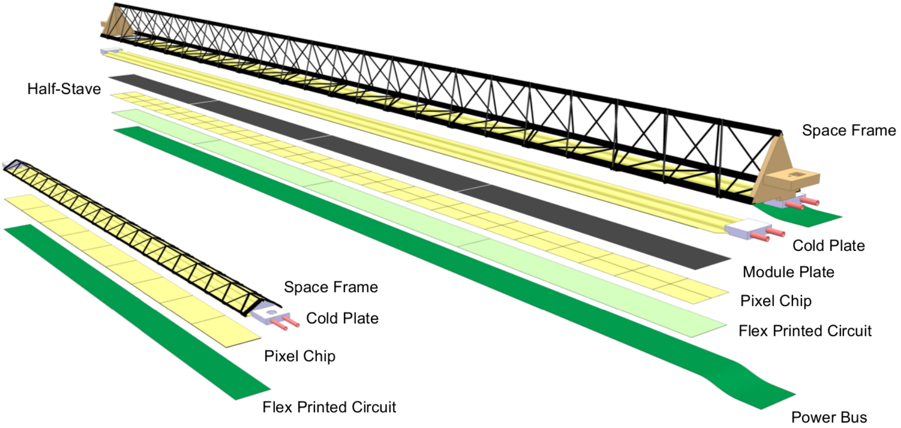


Figure 6 : ITS Stave: details of the inner (left), middle and outer (right) layers.

ALPIDE – ALICE PIxel DEtector

CMOS MAPS – Monolothic Active Pixel Sensor:

- Sensor and read-out electronics integrated.
- Chip dimensions: 15mm X 30mm x 100μm.
- Pixel matrix: 1024 columns x 512 rows.
- Pixel pitch: 29 X 27 μm^2.
- Spatial resolution: 5 μm
- Material budget: 0.3% X_0 (inner layer) and 0.8% X_0 (middle and outer layer).

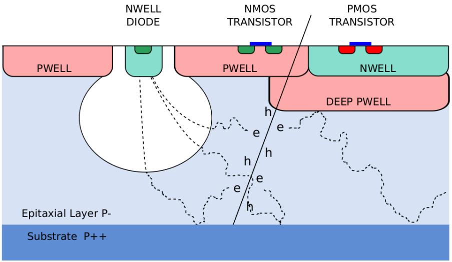


Figure 7 : CMAPS pixel (cross section).

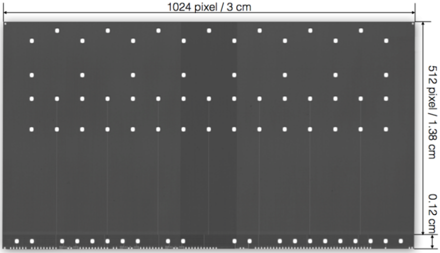


Figure 8 : ALPIDE Pixel Chip.

ALPIDE read-out electronics.

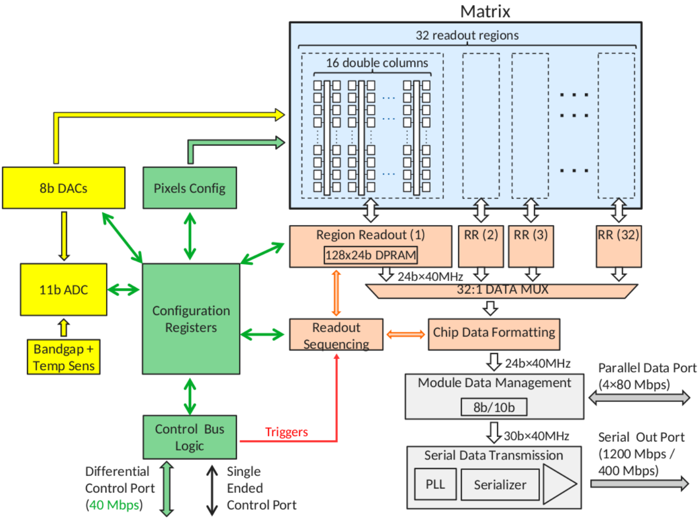


Figure 9 : Read-out electronics.

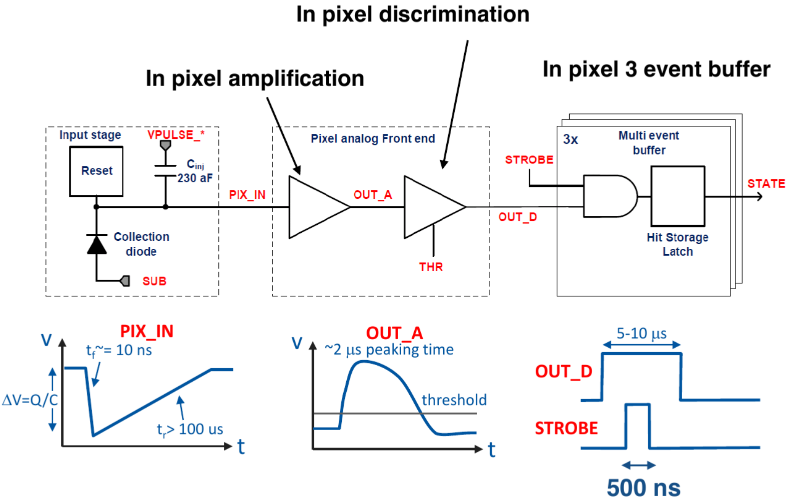


Figure 10 : ALPIDE pixel cell.

ALPIDE interface signals.

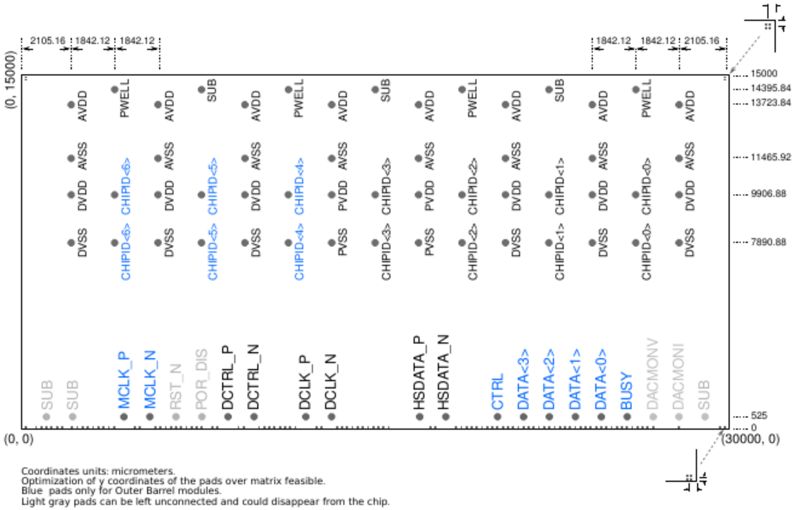
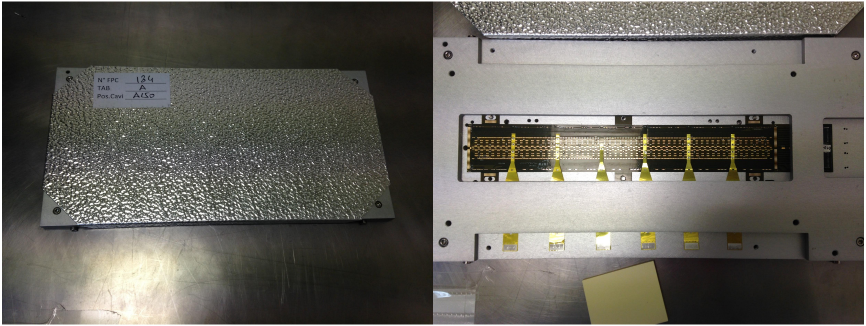


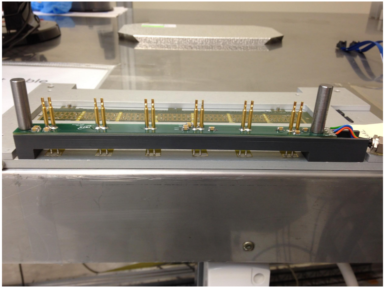
Figure 11 : Flex-Printed Circuit map (interface signals).

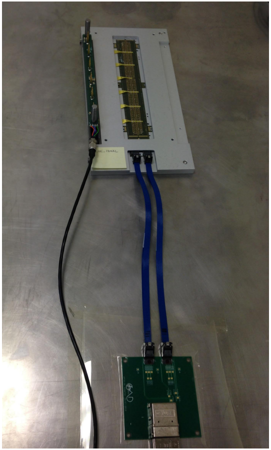
ITS Upgrade at LNF-INFN

Assembly of the new ITS outer-layer super-modules (2017-2018)

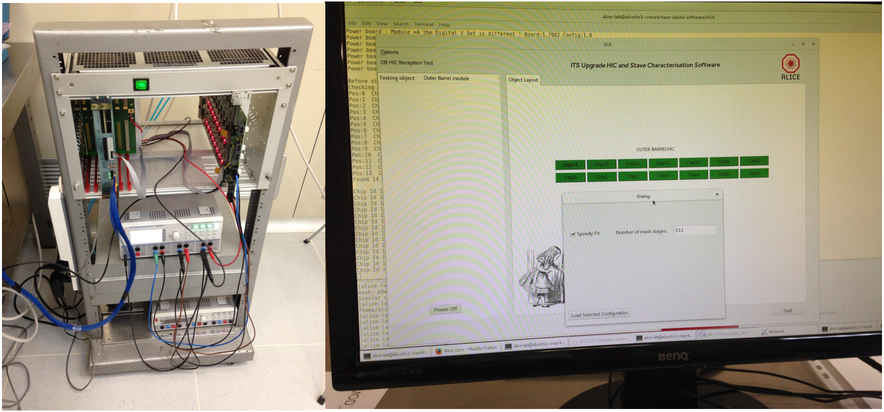


OBHIC: carrier plate.



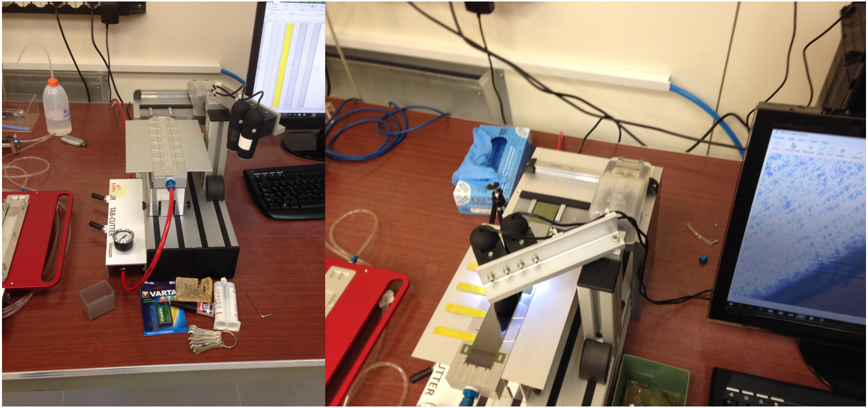


OBHIC: Reception Test

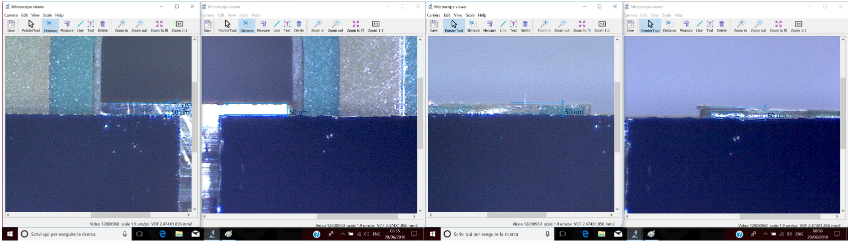


OBHIC: Reception Test Setup and GUI.

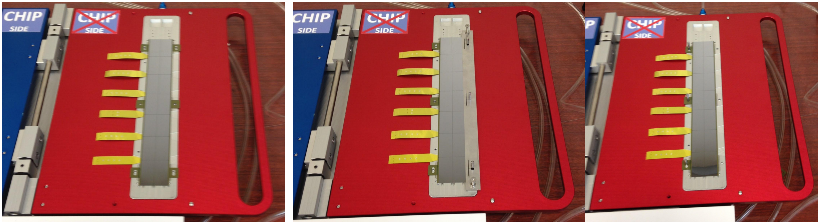
OBHIC: flipping table.



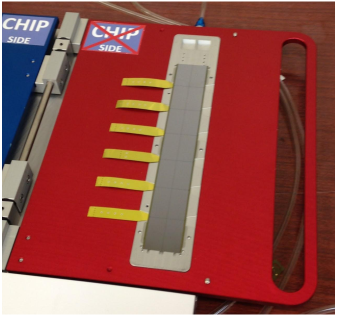
OBHIC: Tab-cutter.

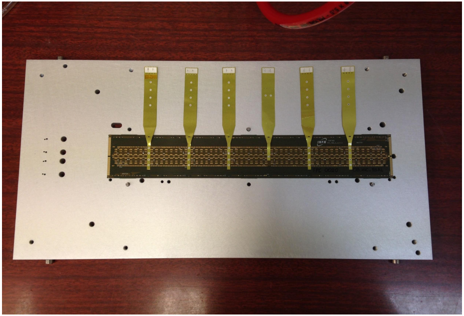


OBHIC: Tab Cutting - before and after the cut.

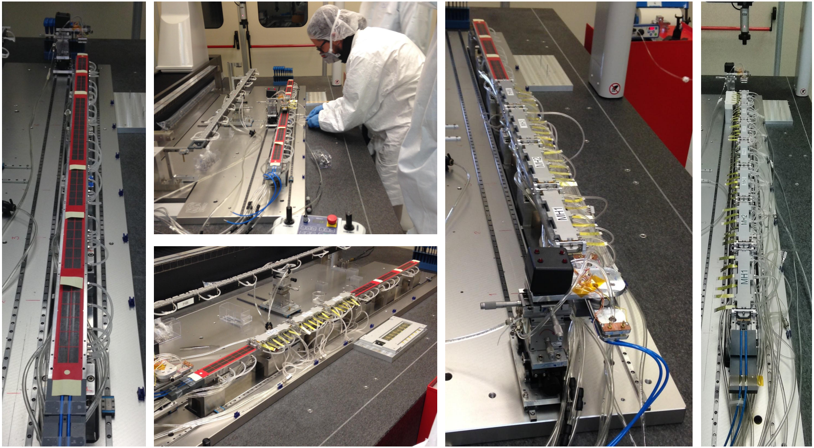


OBHIC: Cutting the wings.

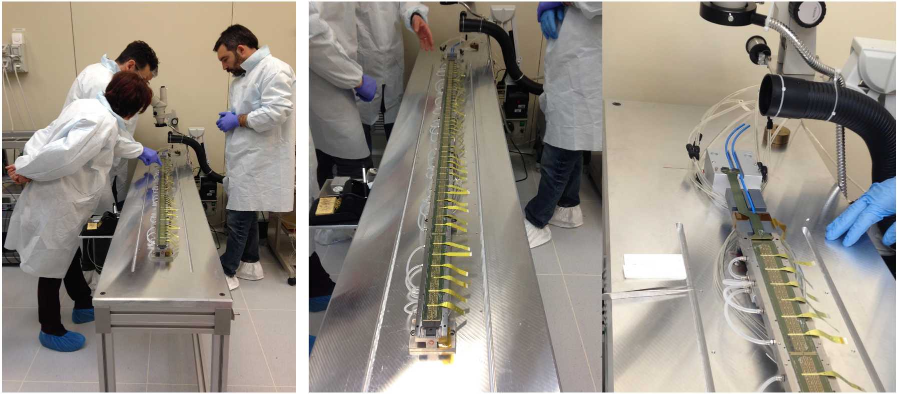




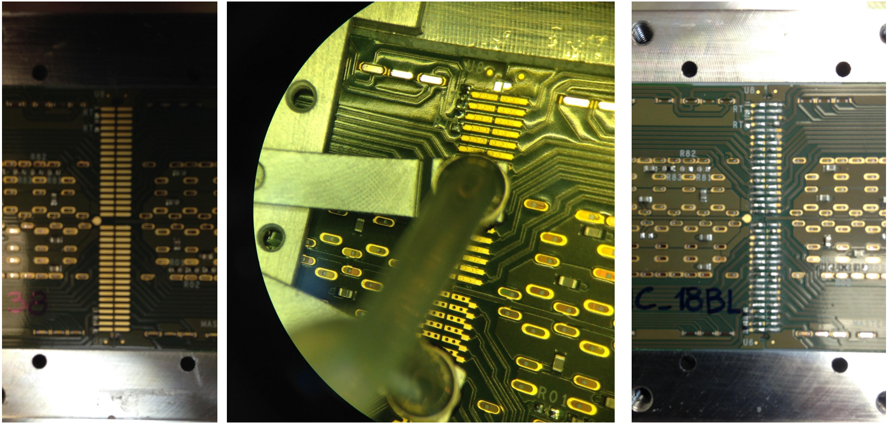
OBHIC ready



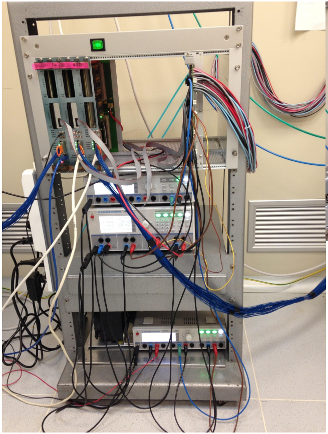
Half-Stave: gluing of the modules on the cold plate.

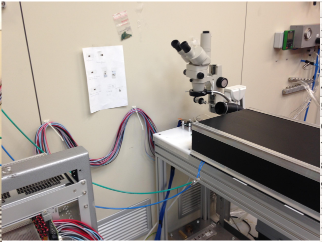


Half-Stave: soldering table.



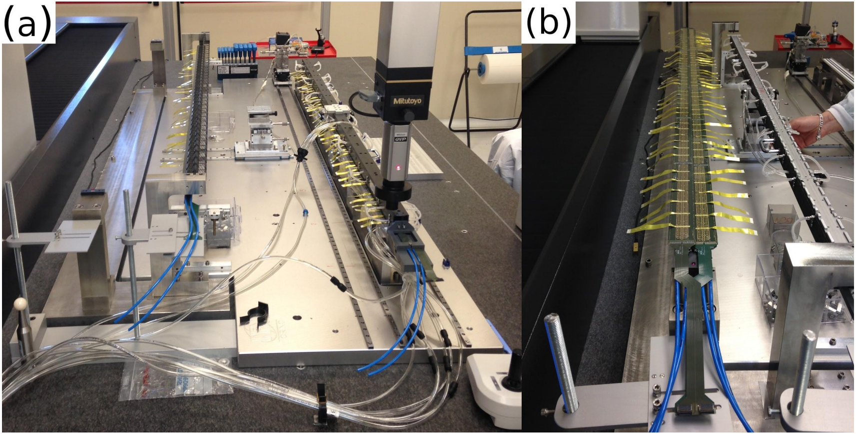
Half-Stave: soldering / Interconnections.



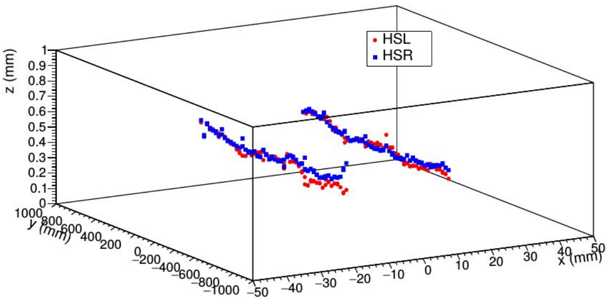


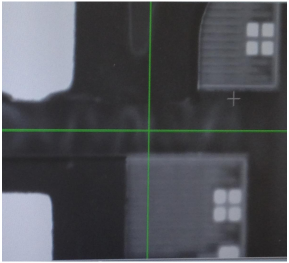
	scan	status
1	Power Test	Done (in 11 min)
2	Dctrl Measurement	Done (in 30 min)
3	Fifo Scan	Done (in 10 min)
4	Fifo Scan, V +10%	Done (in 10 min)
5	Fifo Scan, V -10%	Done (in 10 min)
6	Digital Scan BB 0	Done (in 7 min)
7	Digital Scan BB 0, V +10%	Done (in 7 min)
8	Digital Scan BB 0, V -10%	Done (in 7 min)
9	Digital White Frame BB 0	Done (in 5 min)
10	Tune VCASN Scan 0.0 V	Done (in 2 min)
11	Tune ITHR Scan 0.0 V	Done (in 2 min)
12	Threshold Scan 0.0 V	Done (in 46 min)
13	Noise Occupancy 0.0 V	Done (in 3 min)
14	Noise Occupancy 0.0 V	Done (in 3 min)
15	Digital Scan BB 3	Done (in 7 min)
16	Digital White Frame BB 3	Done (in 5 min)
17	Tune VCASN Scan 3.0 V	Done (in 2 min)
18	Tune ITHR Scan 3.0 V	Done (in 2 min)
19	Threshold Scan 3.0 V	Done (in 49 min)
20	Noise Occupancy 3.0 V	Done (in 3 min)
21	Noise Occupancy 3.0 V	Done (in 3 min)

Half-Stave: qualification test.

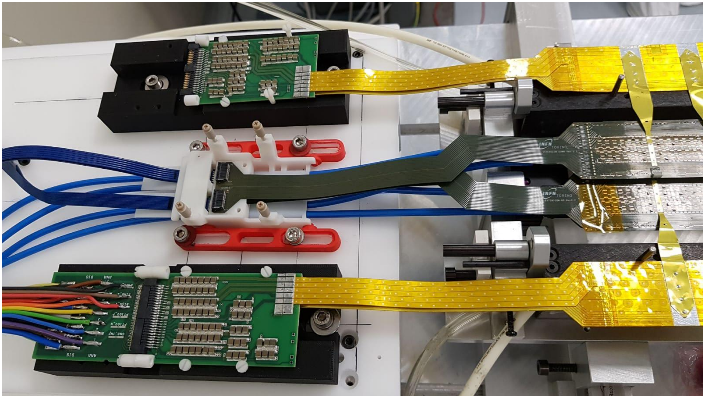


Stave: gluing the Half-Staves to the Space-Frame.

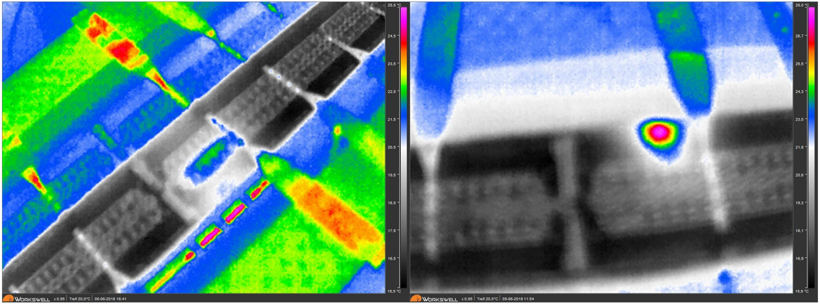




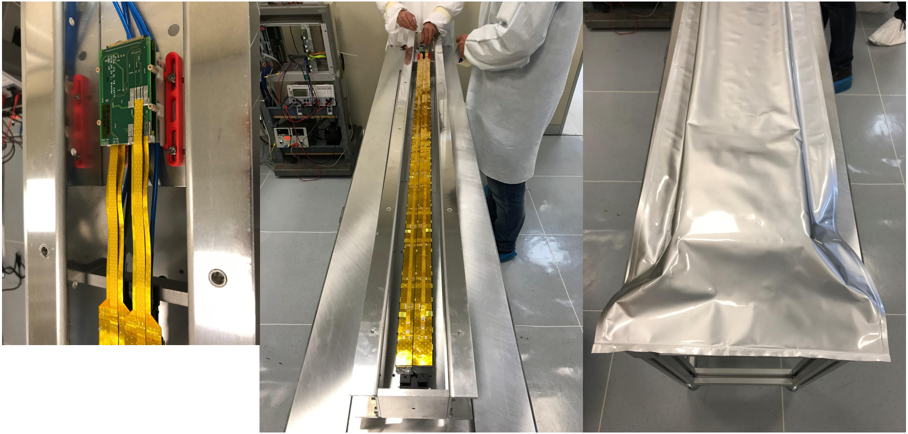
Stave: Metrology.



Stave: electrical components.



Stave: visual inspection with thermal camera (looking for broken chips).



Stave: transport box.

Analysis

Production spectra of κ, π and p for the p-Pb data at $\sqrt{s_{NN}} = 8.16$ TeV (NEW).

- ONGOING.
- PWG-LF: Physics Working Group - Ligh-Flavor Spectra.
- AliPhysics framework, ROOT/C++.
- Status: each member of the group is responsible for one of the ALICE subdetectors.
- My analysis: Relative Rise using TPC data (complementary).

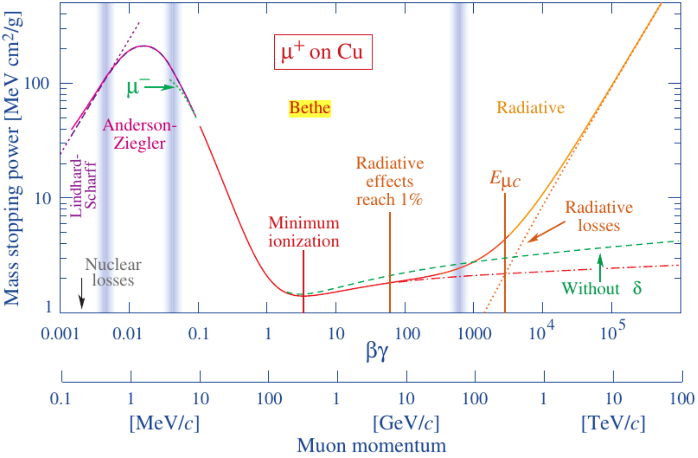


Figure 12 : Bethe-Bloch curve [1].

[1] Ref.: http://pdg.lbl.gov/2017/reviews/rpp2017-rev-passage-particles-matter.pdf

Analysis

Bethe-Bloch formula [2]:

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi N e^4}{mc^2} \frac{z^2}{\beta^2} \left(\ln \frac{2mc^2\beta^2\gamma^2}{I^2} - \beta^2 - \frac{\delta(\beta)}{2} \right) \tag{1}$$

Modified Bethe-Bloch formula with E_{max} cut-off due to δ-electrons:

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi N e^4}{mc^2} \frac{z^2}{\beta^2} \left(\frac{1}{2} \ln \frac{2mc^2 E_{max}\beta^2\gamma^2}{I^2} - \frac{\beta^2}{2} - \frac{\delta(\beta)}{2} \right) \tag{2}$$

As $\beta\gamma$ increases:

- Low momenta: curve falls $\propto 1/\beta^2$.
- $\beta\gamma \approx 3.6$: minimum (MIP).
- Relativistic rise – logarythmic behavior.
- Very high momenta: Fermi plateau (constant).

[2] Ref.: tuprints.ulb.tu-darmstadt.de/3063/1/PhDThesis.pdf

Analysis – Relativistic Rise

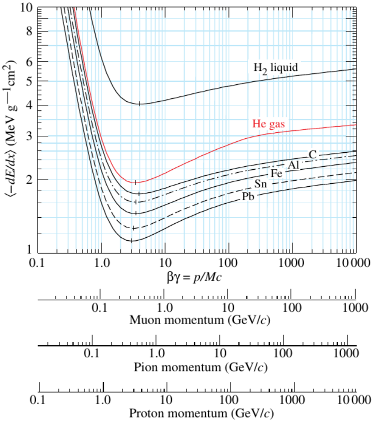


Figure 13 : Bethe-Bloch curve[3].

Why?

- E_{max} rises.
- Cross section for excitation and ionization rises due to the relativistic contraction of the EM field in longitudinal direction.

RR for PID purposes [4]:

- Steady increase provides a difference in dE/dx for particles with same momentum, but different masses over a large momentum range.
- Requires high precision measurements.
- Resolution does not separare clearly signals from pions, kaons and protons → **Gaussian unfolding fit**.

[3] Ref.: http://pdg.lbl.gov/2017/reviews/rpp2017-rev-passage-particles-matter.pdf
[4] Ref.: http://www.hep.lu.se/staff/gros/thesis.pdf

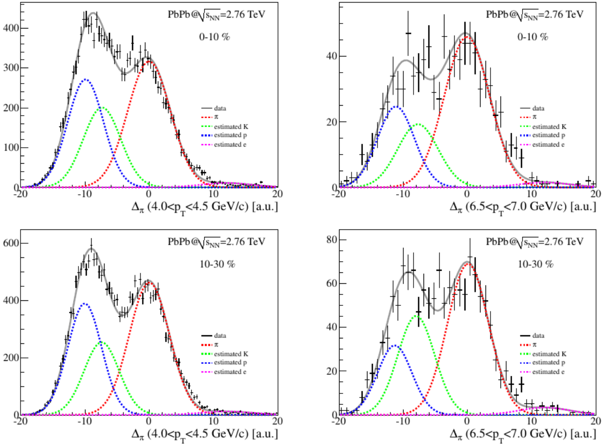


Figure 14 : Example of Gauss unfolding fit [5].

Statistical PID is recommended for high p_T ($> 3GeV/c$).

Gaussian curve parameters:

- Mean: $< dE/dx >$ from BB formula.
- Width: resolution.
- Amplitude: given by the fit; area gives the yield.

[5] Ref.: http://www.hep.lu.se/staff/gros/thesis.pdf

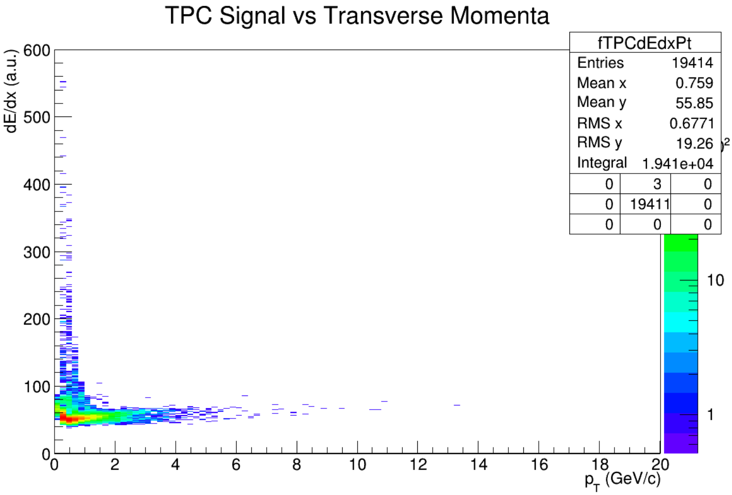


Figure 15 : TPC signal vs p_T.

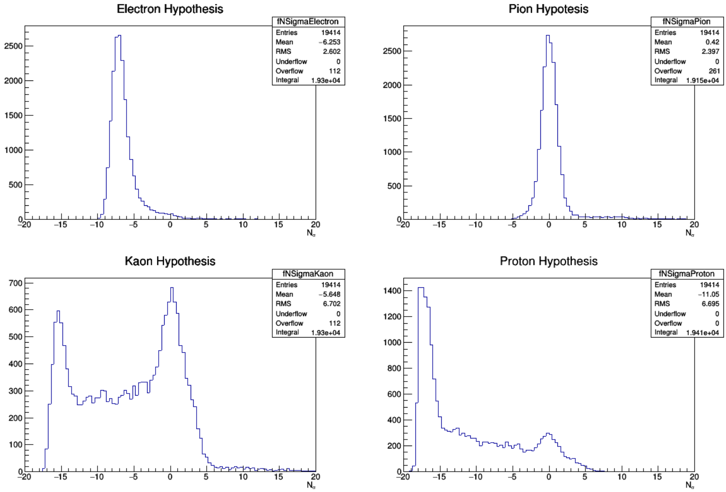


Figure 16 : PID hypotheses for each particle type as functions of number of standard deviation for TPC.

Analysis Roadmap

- Get TPC signal and plot agains p.
- Total number of events: comparison with others.
- Number of clusters $N_{cl} \rightarrow$ resolution.
- Particle hypotheses: identify π, estimate k and p.
- Cuts.
- Check if there's enough statistics for high p_t.
- Efficiency (Monte Carlo simulation).
- Combined spectra.

Conclusion

One of the challenges is to keep track of the super-modules' reproducibility and quality by means of regular tests and measurements throughout the production chain, by identifying possible sources of damage and by finding viable solutions.

TPC relative rise regime is a relevant approach to access the high transverse momenta particle identification. Measurement of multiplicities in extended p_T spectra for different light flavors on p-p, p-Pb and Pb-Pb data provides a comparison of how the hadronization mechanism takes place in the different QCD environment.

Thank you!