A Large Ion Collider Experiment

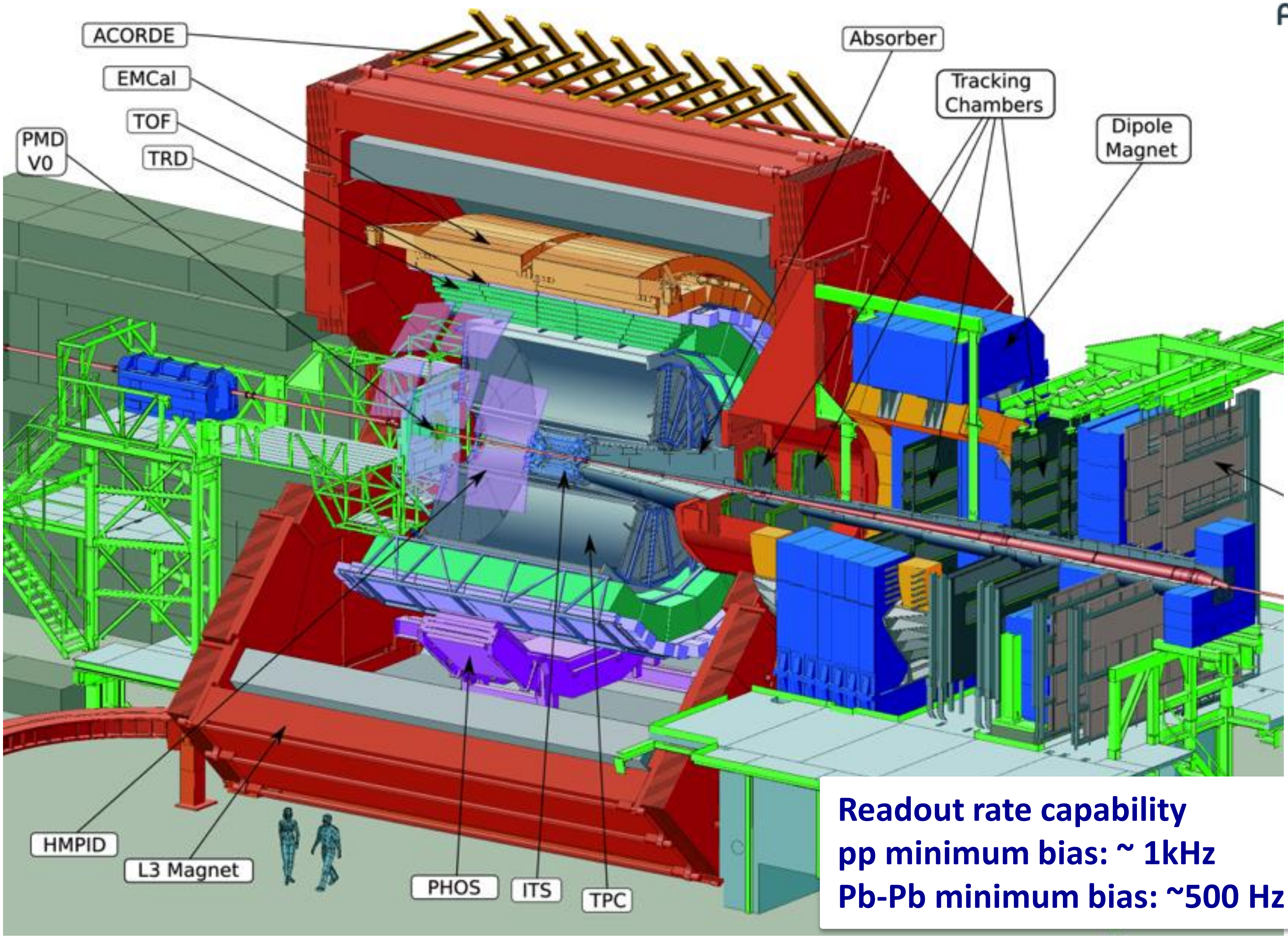
ALICE

The ALICE Upgrade Programme

ECFA High Luminosity LHC Experiments Workshop

W. Riegler, CERN

The Current ALICE Detector



Readout rate capability
pp minimum bias: ~ 1kHz
Pb-Pb minimum bias: ~500 Hz

ALICE Upgrade Strategy

High precision measurements of rare probes at low $p_{T,}$ which cannot be selected with a trigger, require a large sample of events recorded on tape

Target

- Pb-Pb recorded luminosity ≥ 10 nb^{-1} ➡ 8 x 10^{10} events
- pp (@5.5 Tev) recorded luminosity ≥ 6 pb^{-1} ➡ 1.4 x 10^{11} events

Gain a factor **100** in statistics over approved programme

… and significant improvement of vertexing and tracking capabilities

I. Upgrade the ALICE readout systems and online systems to

- read out all Pb-Pb interactions at a maximum rate of 50kHz (i.e. L = 6×10^{27} $cm^{-1}s^{-1}$), with a minimum bias trigger
- Perform online data reduction based on reconstruction of clusters and tracks (tracking used only to filter out clusters not associated to reconstructed tracks)

II. Improve vertexing and tracking at low p_T → NEW ITS

General Considerations on Pb-Pb Luminosity Upgrade

The LHC High Luminosity Heavy Ion program assumes an integrated PbPb Luminosity of >10nb^{-1} achieved during a 6-7 year program after LS2.

The basic assumption is to continue the pattern of one month LHC Heavy Ion operation per year.

This program therefore asks for a PbPb luminosity in excess of 6x10^{27} cm^{-2}s^{-1} starting from LS2.

This can be achieved by

- **Improvements of the Source, RFQ and Linac3**
- **A new SPS injection kicker system with a rise-time of the order of 50ns**
- **Installation of collimators in the dispersion suppressor regions around the experimental points to avoid quenches and excessive radiation load on the magnets from BFPP**

ALICE Upgrade Strategy, cont'd.

- The upgrade plans entails building
  - New, high-resolution, low-material ITS
  - Upgrade of TPC with replacement of MWPCs with GEMs and new pipelined readout electronics
  - Upgrade of readout electronics of: TRD, TOF, Muon Spectrometer, ZDC
  - Upgrade of the forward trigger detectors
  - Upgrade of the online systems
  - Upgrade of the offline reconstruction and analysis framework

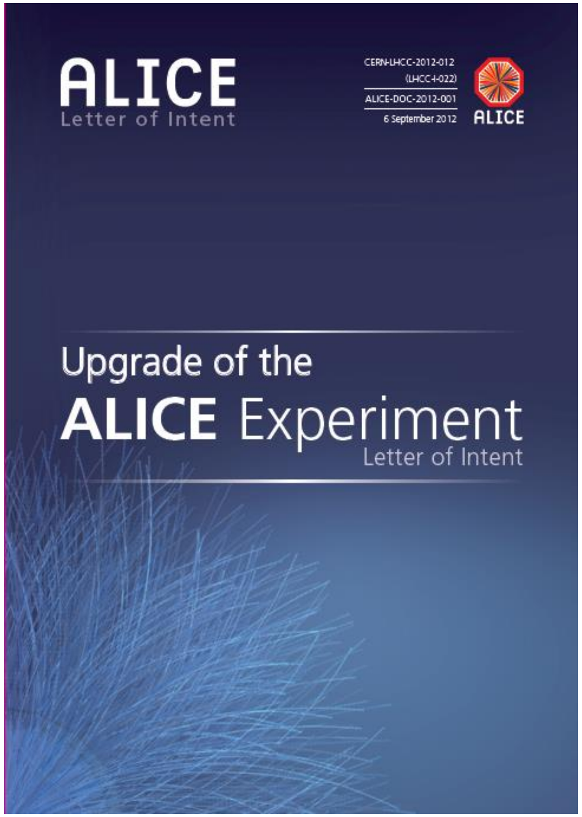
LoI approved in 2012

  - New 5-plane silicon telescope in front of the hadron absorber covering the acceptance of the Muon Spectrometer

Add. LoI Sep 2013

- It targets 2018/19 (LHC 2nd Long Shutdown)

LoI and ITS CDR endorsed by LHCC in Sep 2012
MFT as addendum to LOI endorsed by LHCC in Sep 2013

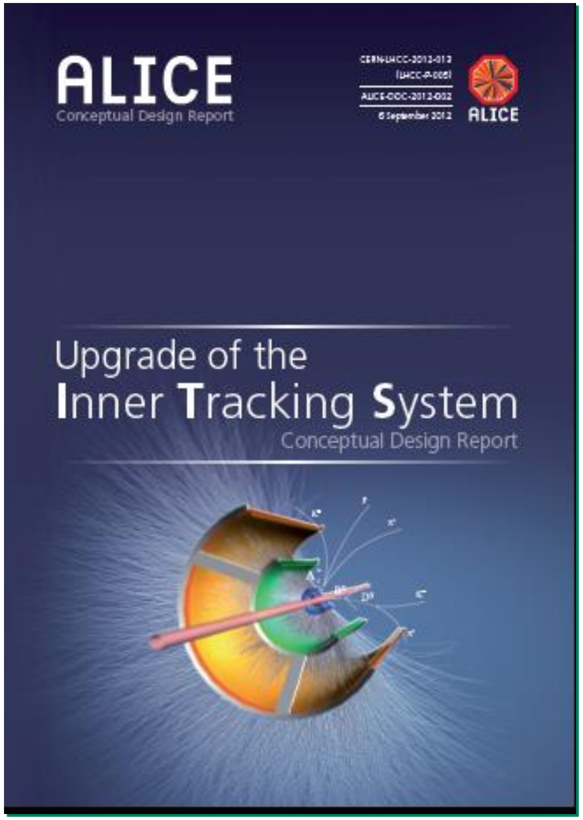


ALICE
Letter of Intent

CERN-LHCC-2012-012
(LHCC-I-022)
ALICE-DOC-2012-001
6 September 2012

ALICE

Upgrade of the
ALICE Experiment
Letter of Intent

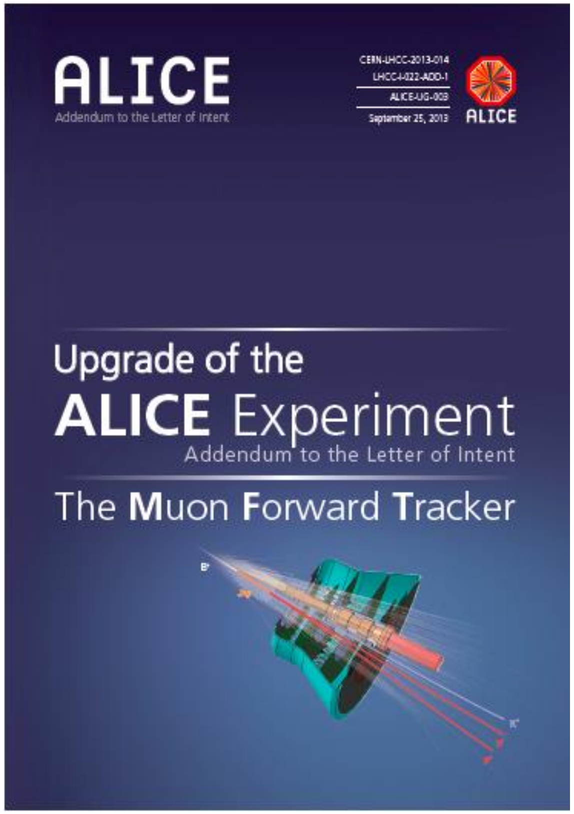


ALICE
Conceptual Design Report

CERN-LHCC-2012-013
(LHCC-P-005)
ALICE-DOC-2012-002
6 September 2012

ALICE

Upgrade of the
Inner **T**racking **S**ystem
Conceptual Design Report



ALICE
Addendum to the Letter of Intent

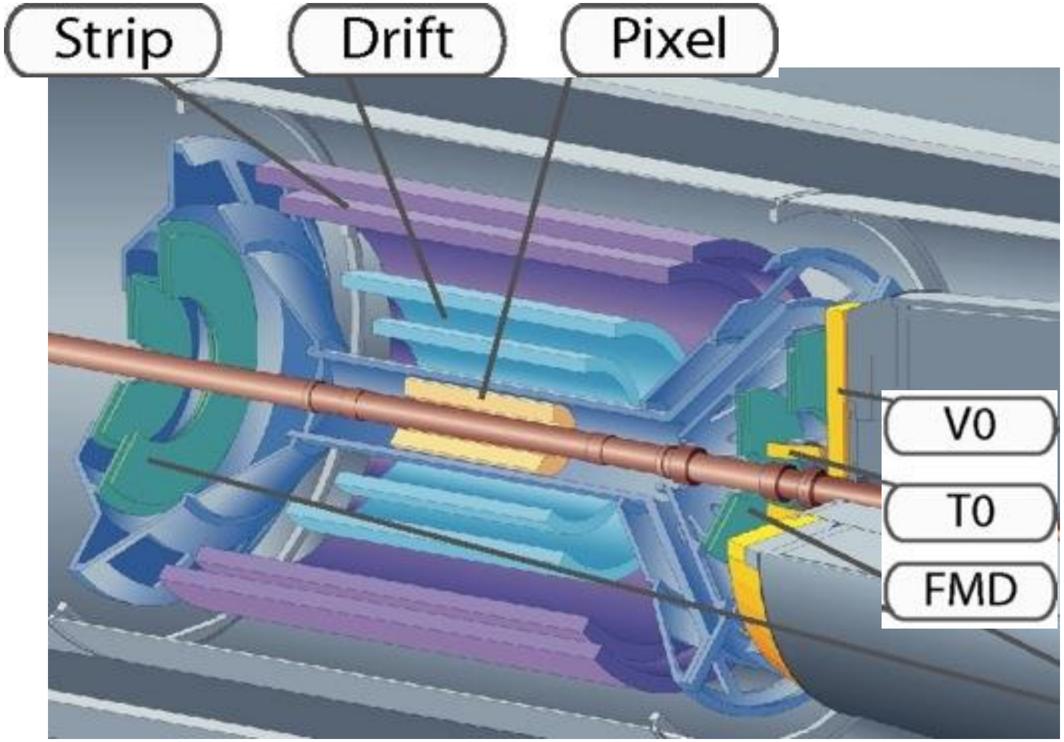
CERN-LHCC-2013-014
LHCC-I-022-ADD-1
ALICE-UG-003
September 25, 2013

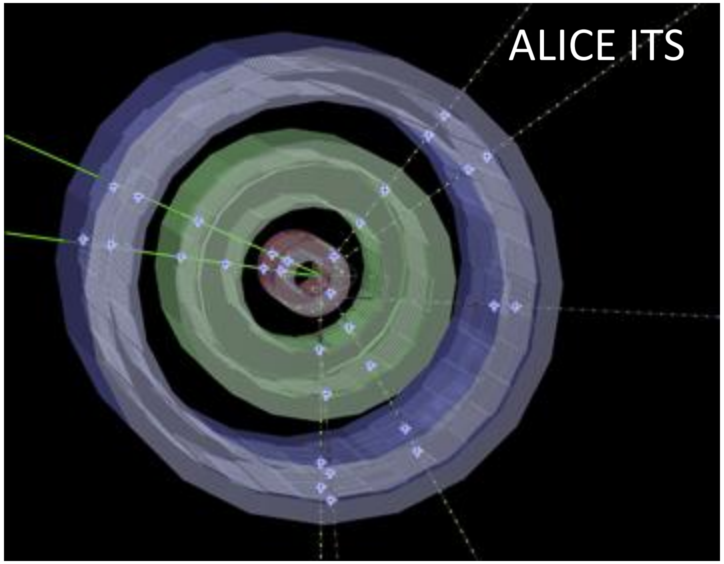
ALICE

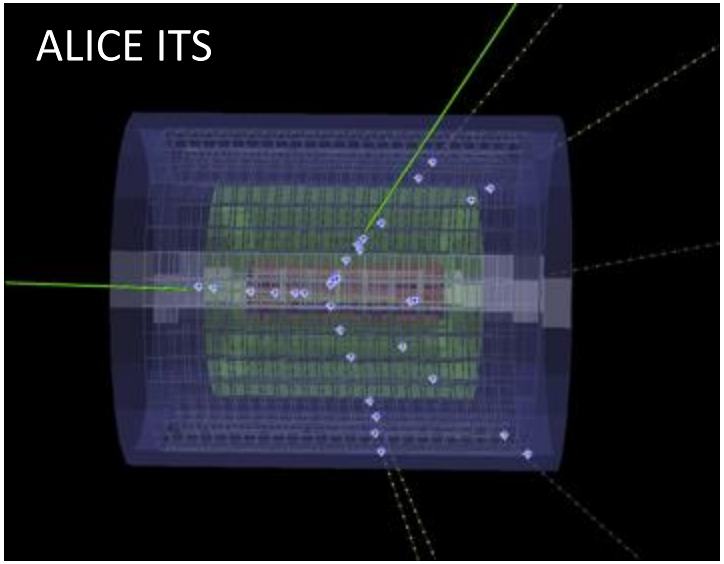
Upgrade of the
ALICE Experiment
Addendum to the Letter of Intent

The **M**uon **F**orward **T**racker

The Current ALICE Inner Tracking System







Current ITS

6 concentric barrels, 3 different technologies

- 2 layers of silicon pixel (SPD)
- 2 layers of silicon drift (SDD)
- 2 layers of silicon strips (SSD)

New ITS Design goals

1. Improve impact parameter resolution by a factor of ~3

- Get closer to IP (position of first layer): 39mm ➡22mm
- Reduce material budget: X/X_0 /layer: ~1.14% ➡ ~ 0.3% (for inner layers)
- Reduce pixel size
    - currently 50µm x 425µm

      monolithic pixels ➡ O(20µm x 20µm),

2. Improve tracking efficiency and p_T resolution at low p_T

- Increase granularity: 6 layers ➡ 7 layers , reduce pixel size

3. Fast readout

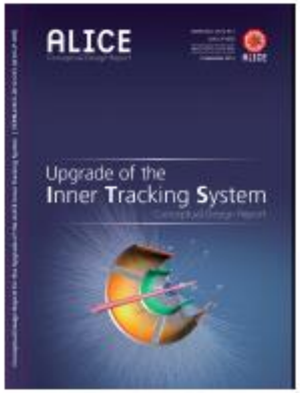
- readout of Pb-Pb interactions at > 50 kHz and pp interactions at ~ 1 MHz

4. Fast insertion/removal for yearly maintenance

- possibility to replace non functioning detector modules during yearly shutdown

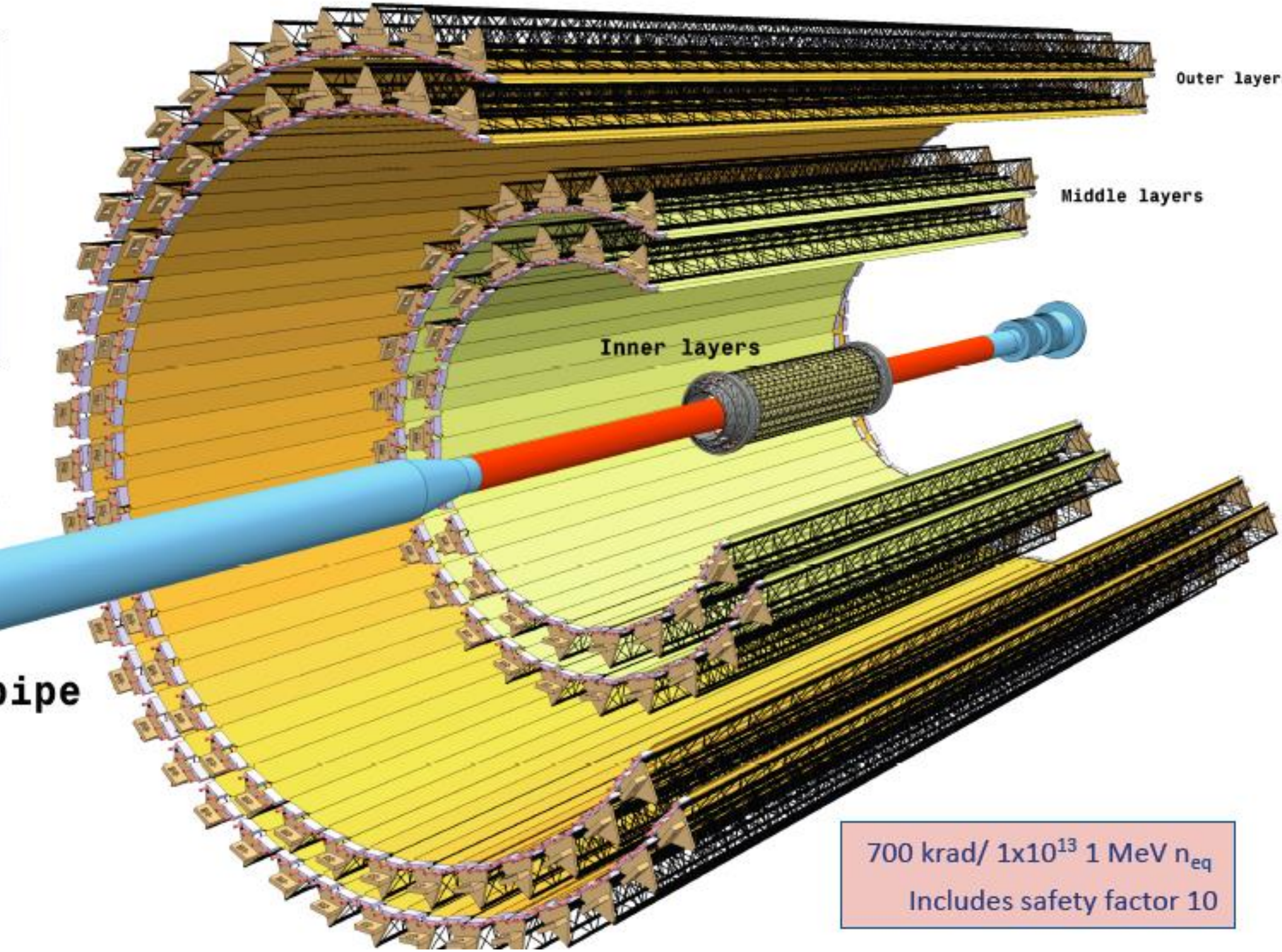
New ITS Layout

25 G-pixel camera
(10.3 m^2)


ALICE

Upgrade of the
Inner Tracking System

CDR – LHCC-2012-013

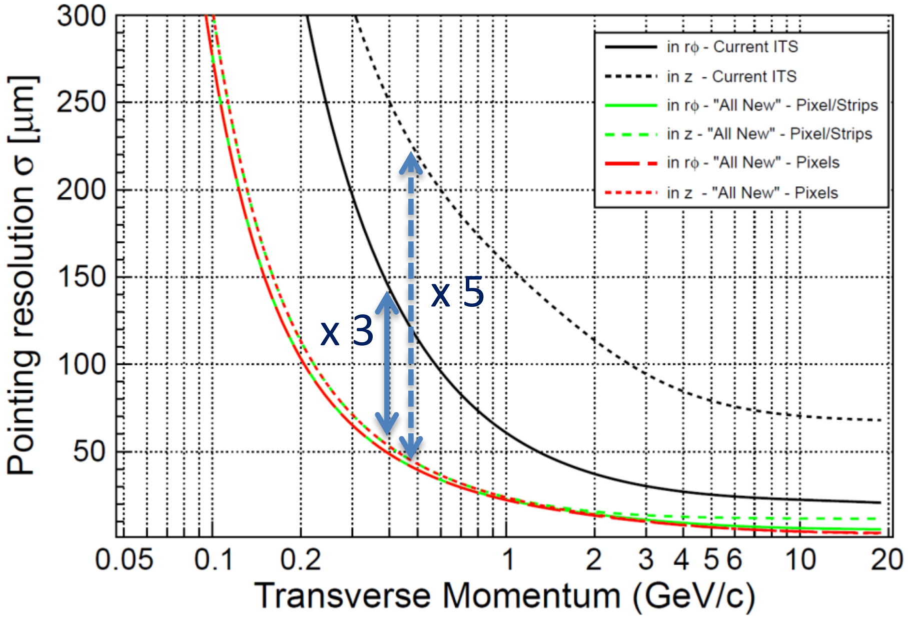


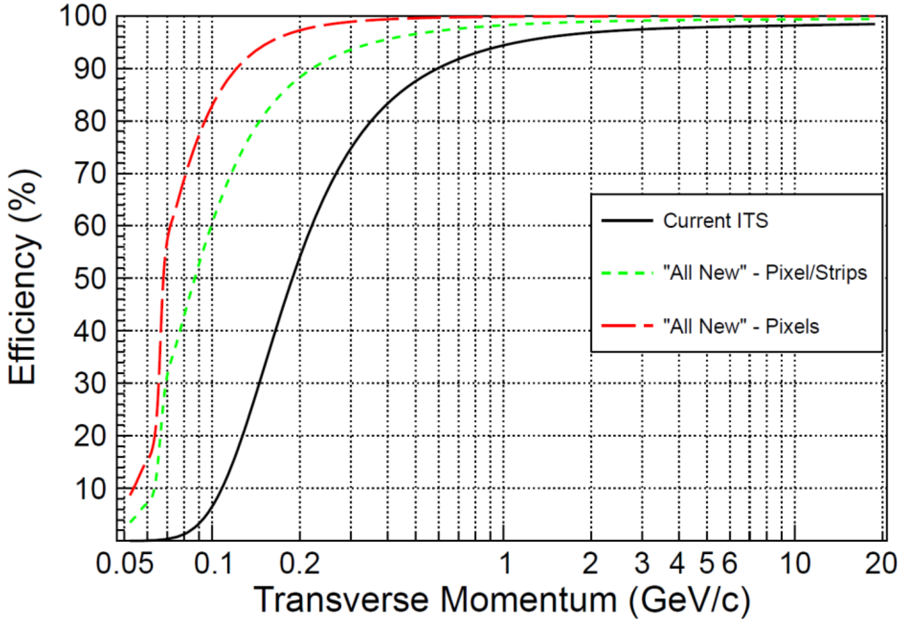
7 layers of MAPS

Radial coverage
22 – 406 mm

700 krad/ $1\text{x}10^{13}$ 1 MeV n_{eq}
Includes safety factor 10

Improvement of impact parameter resolution and tracking efficiency





Simulation layout

7 pixel layers

- Resolutions: $\sigma_{r\phi} = 4\ \mu m$, $\sigma_z = 4\ \mu m$ for all layers
- Material budget: $X/X_0 = 0.3\%$ for all layers

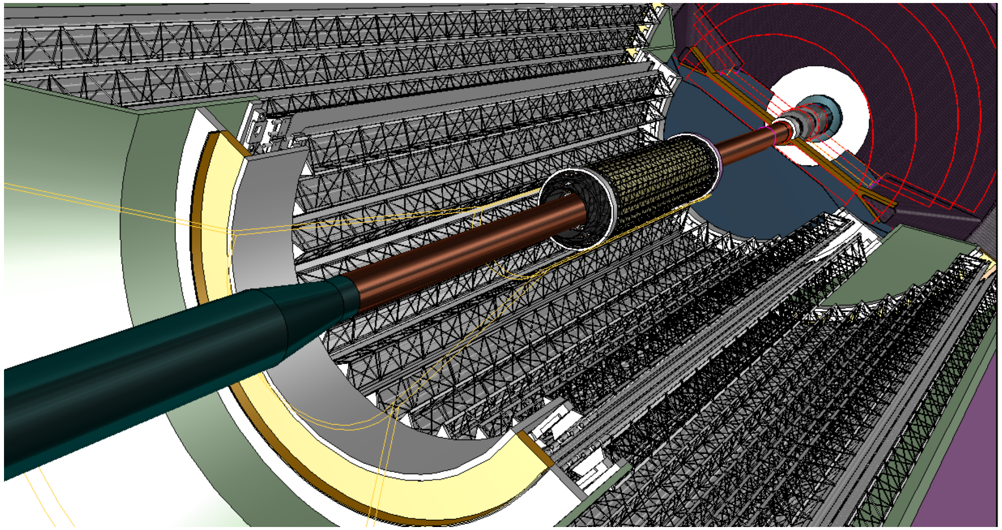
radial positions (cm):

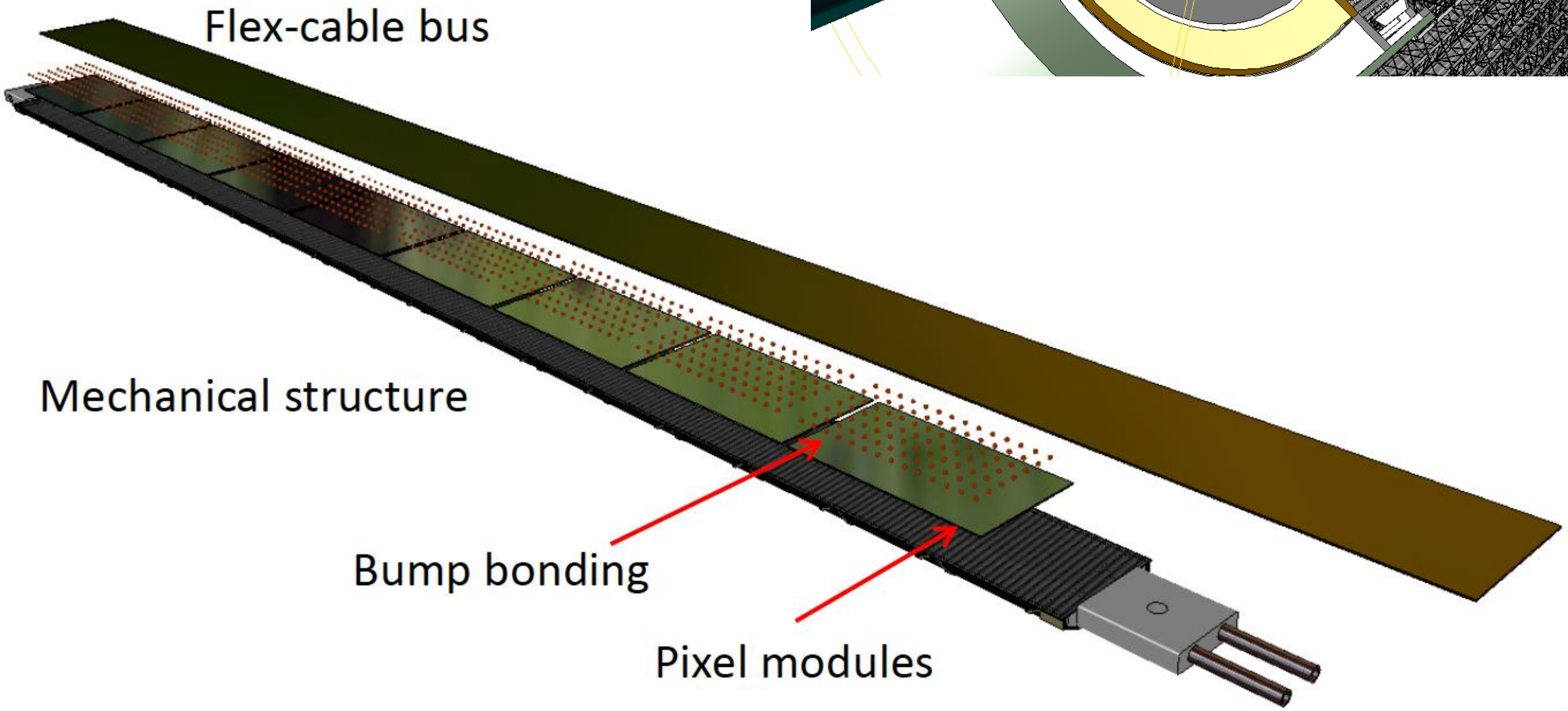
2.2, 2.8, 3.6, 20, 22, 41, 43

New ITS (baseline)

Inner Barrel: 3 layers
Outer Barrel: 4 layers

Detector module (Stave) consists of
- Carbon fiber mechanical support
- Cooling unit
- Polyimide printed circuit board
- Silicon chips (CMOS sensors)





PIXEL Chip - technology

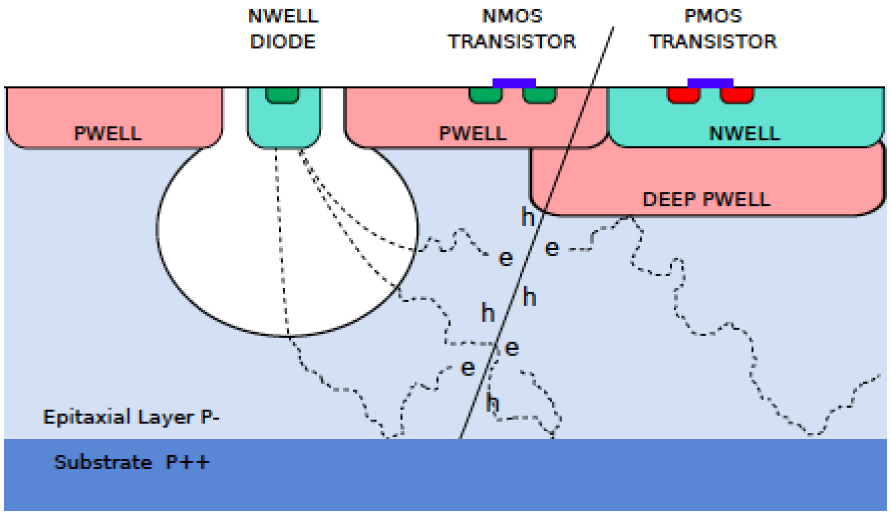
Monolithic PIXEL chip using Tower/Jazz 0.18 µm technology

- feature size 180 nm
- gate oxide < 4nm
- metal layers 6

- high resistivity epi-layer
  - thickness 18-40 µm
  - resistivity 1-6 k Ω×cm

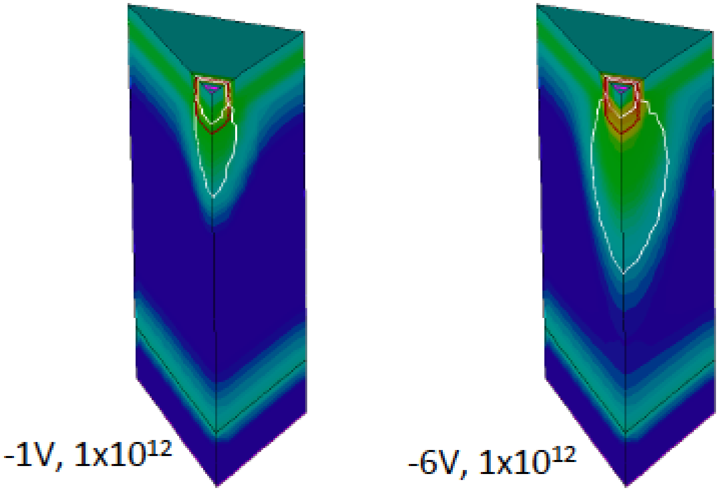
- “special” deep p-well layer to shield PMOS transistors (allows in-pixel truly CMOS circuitry)

- Possibility to build single-die circuit larger than reticle size



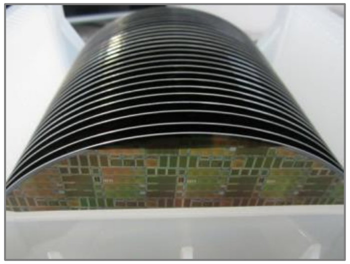
Schematic cross-section of CMOS pixel sensor
(*ALICE ITS Upgrade TDR*)

TCAD simulation of total diode reverse bias
(*ALICE ITS Upgrade TDR*)


-1V, 1x10^{12} -6V, 1x10^{12}

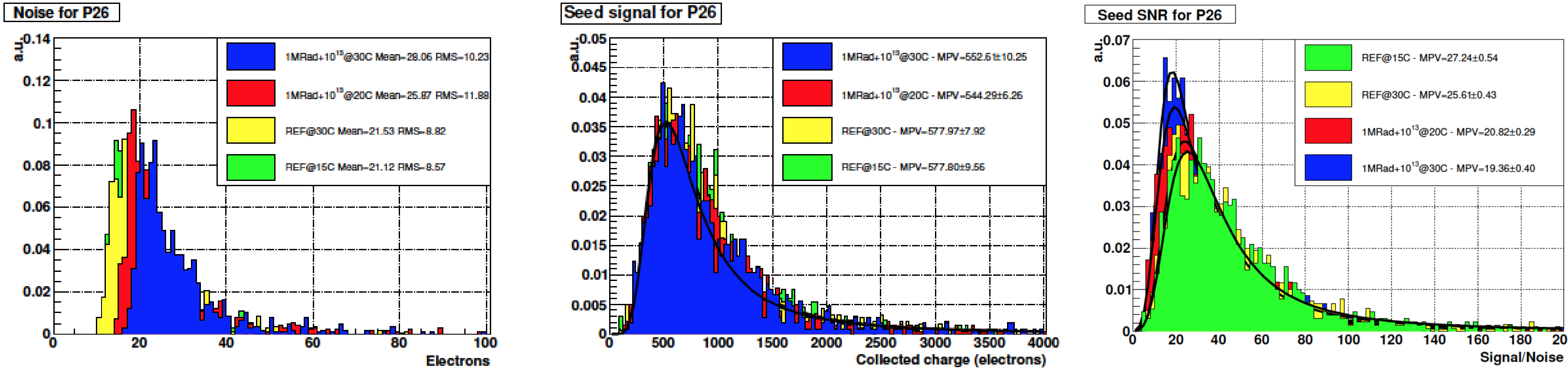
diode 3µm x 3µm square n-well with 0.5µm spacing to p-well white line: boundaries of depletion region

Pixel chip - R&D with TowerJazz technology



- R&D with TowerJazz CIS process in 2011-2013
- What has been established so far
  - Adequate radiation hardness
  - Excellent charge collection efficiency for pixel O(20-30)µm
  - Excellent detection efficiency
  - Prototypes of different readout architectures have being built and fully characterized

Example of experimental results



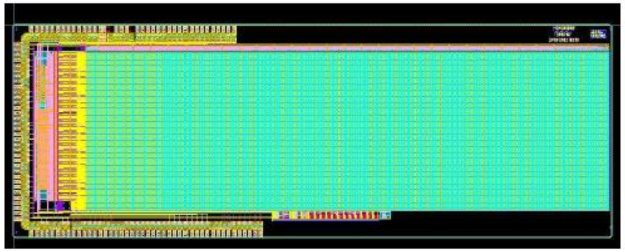
MIMOSA-32ter (IPHC), test-beam results

Towards a full-scale Chip

Prototype circuits

MISTRAL (IPHC-IRFU)

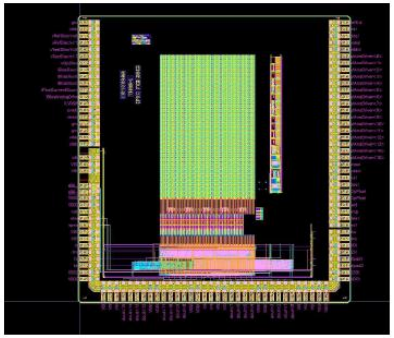
- Built on the experience from the STAR-PXL detector
- 350 rows x 1300 columns (pixel size: 22μm x 33μm)
- Frame integration/readout time ~30 μs
- Power consumption ~300mW / cm^2



MIMOSA-22 THRa

ASTRAL (IPHC-IRFU)

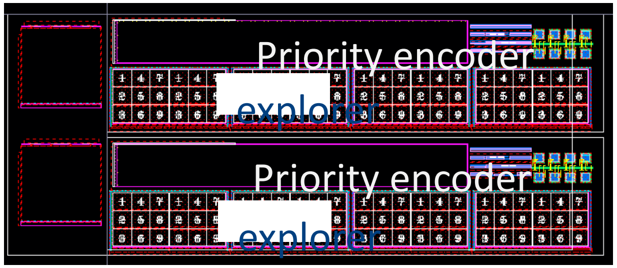
- Signal discrimination embedded in each pixel
- Integration time 15 (10) μs
- Power consumption 150 (200) mW



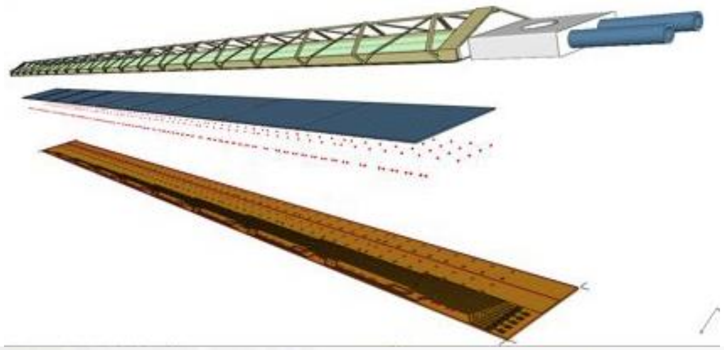
MIMOSA-22 THRb

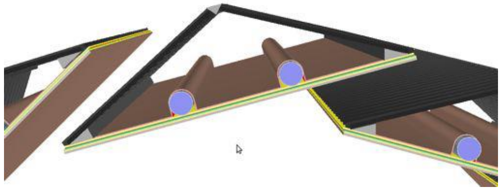
ALPIDE Chip (CERN – INFN – CCNU)

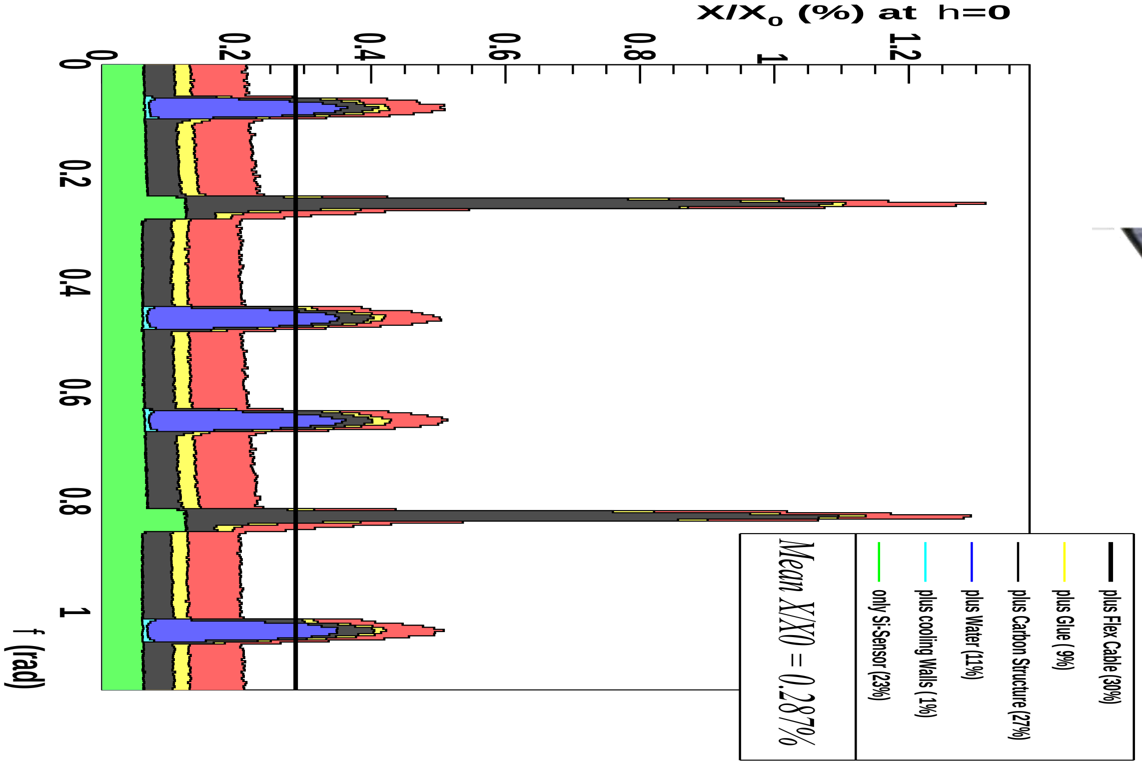
- Signal discriminator inside the pixel
- Integration (~readout time) ~ 4 μs
- pixel size: 28μm x 28μm
- Power consumption < 100mW/ cm^2



Inner Barrel Detector Stave







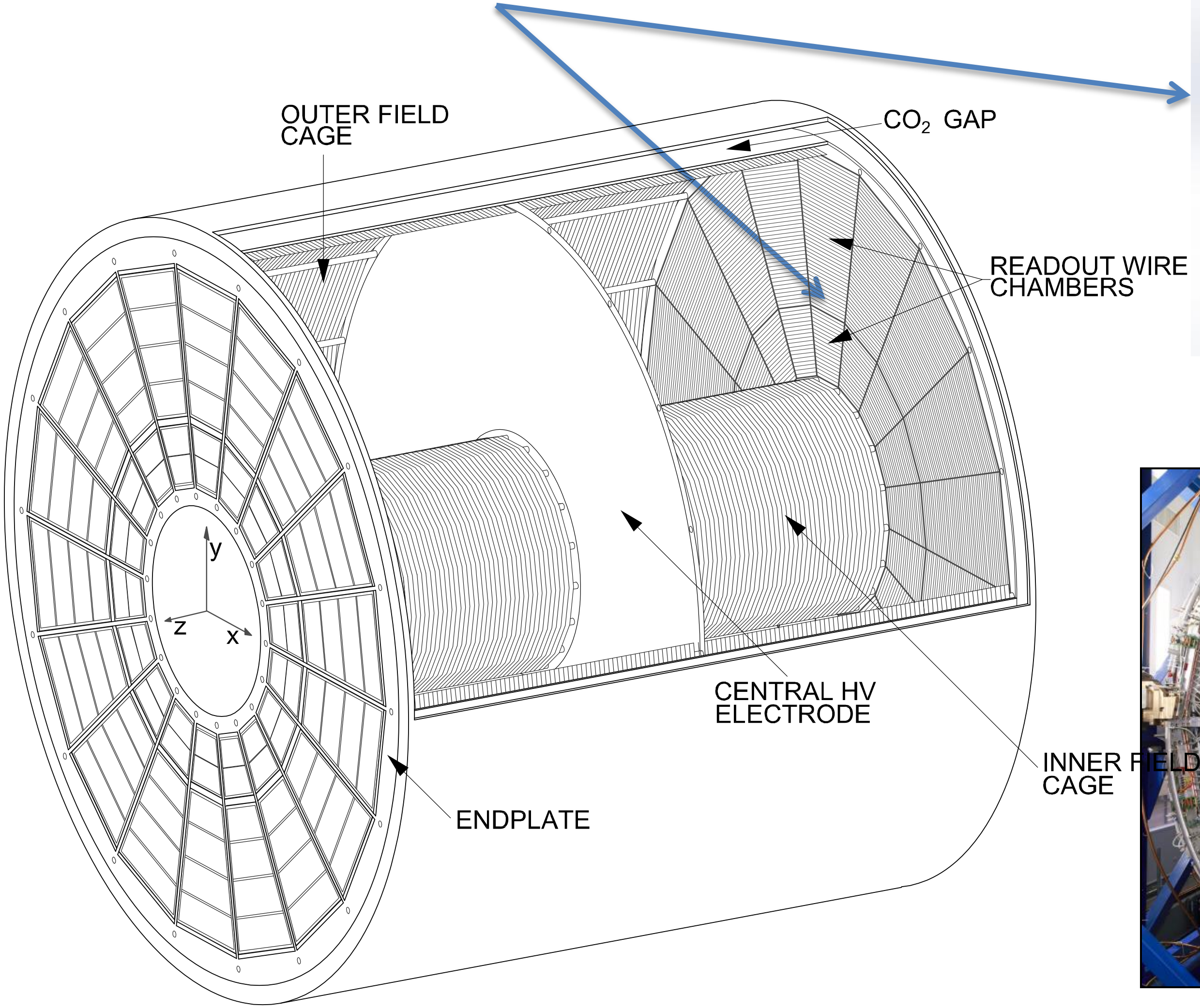
MECHANICS &COOLING

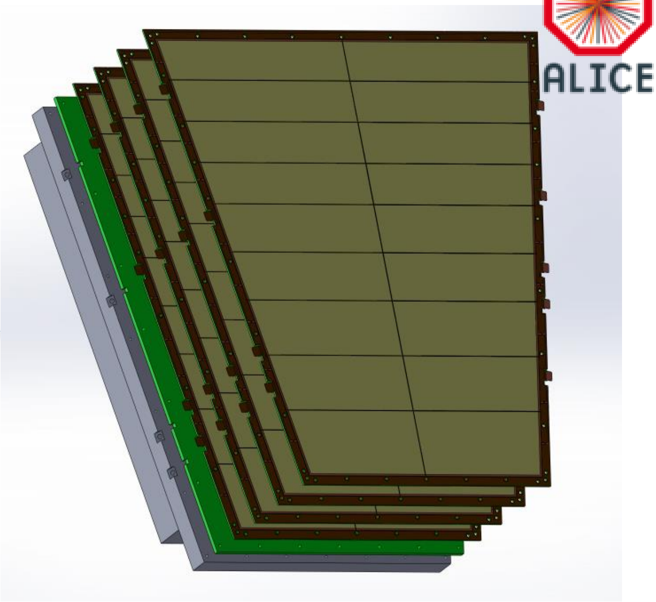
- ✓ Design optimization for material budget reduction

Total weight
1.4 grams

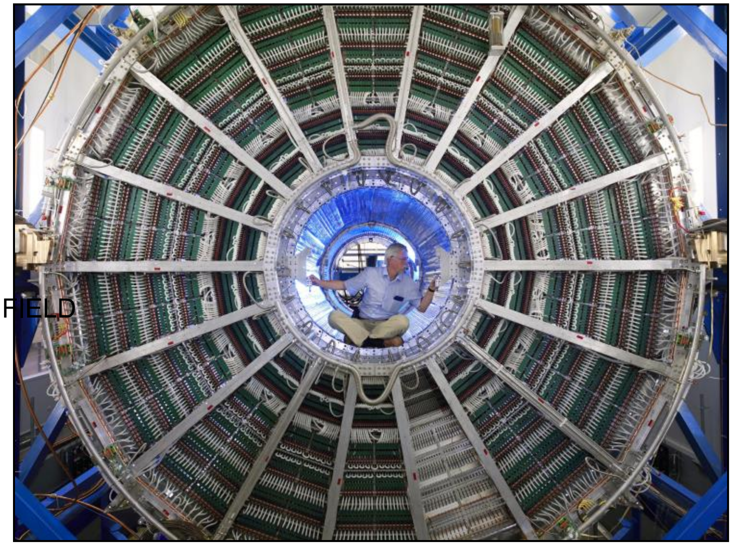
TPC Upgrade with GEMs

Replace wire chambers
With quadruple-GEM chambers



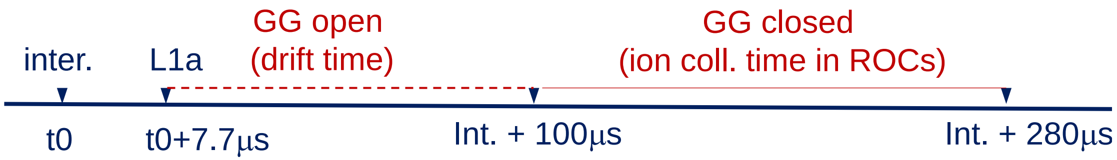


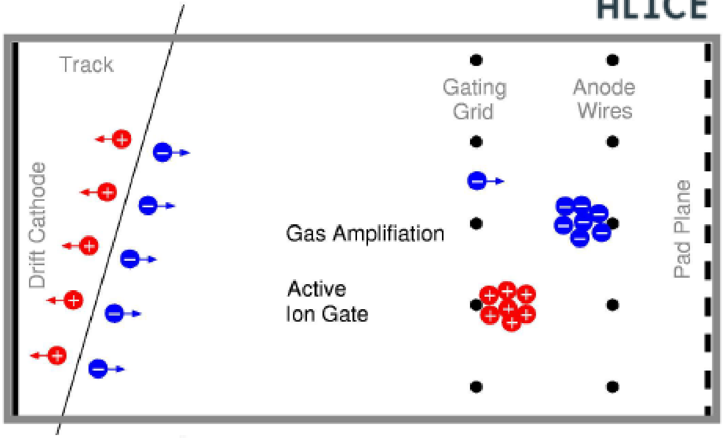
Exploded view of a GEM IROC



TPC upgrade – Why?

ROC ion feedback (λ_{int} and $\lambda_{readout}$ dependent)

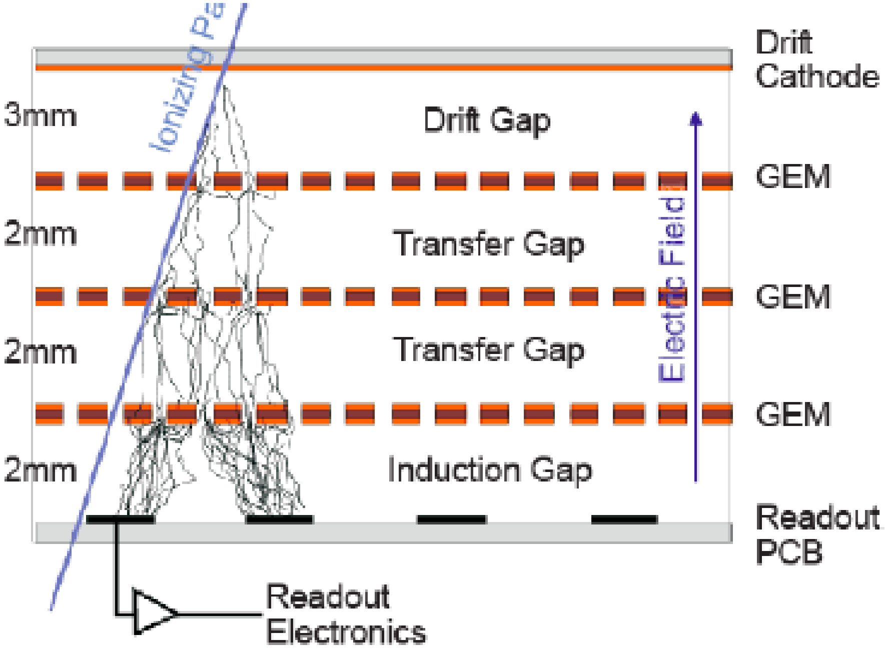




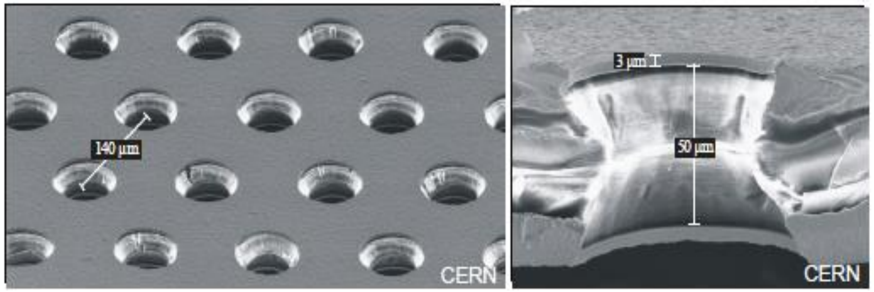
- Space charge (no ion feedback from triggering interaction)
  - GG open [t0, t0+100us], t0 ≡ interaction that triggers TPC
  - GG closed [t0+100us, t0+280us]
  - Effective dead time ~ 280us ➡ max readout rate ~3.5 kHz
  - Maximum distortions for λ_{int} =50kHz and L1=3.5kHz: Δr ~1.2mm (STAR TPC distorsions ~1cm)
- Space charge for continuous readout (GG always open)
  - gain ~6x10^3
  - 20% ion feedback if GG always open ➡ ion feedback ~10^3 x ions generated in drift volume
  - Max distortions for 50kHz ~100cm

MWPC not compatible with 50 kHZ operation

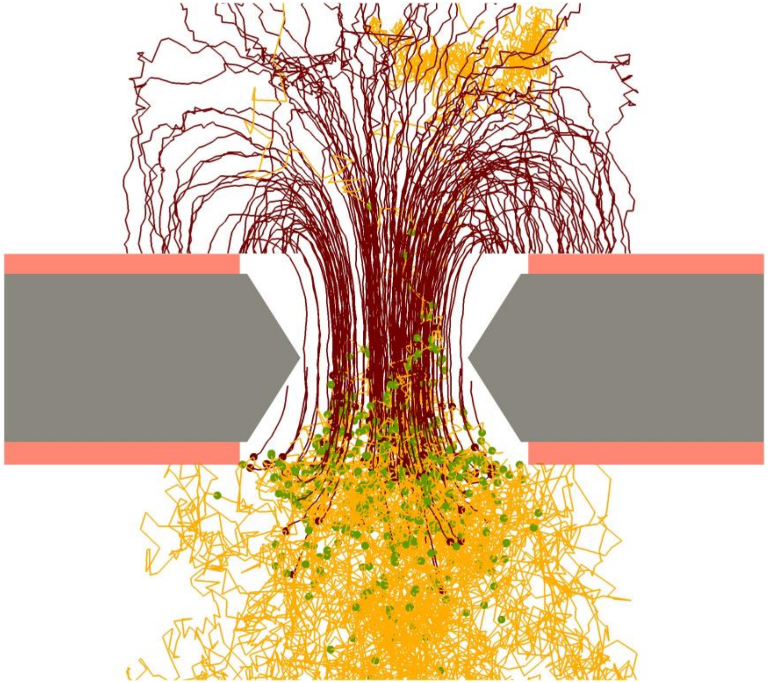
Triple-GEM principle of operation



GEMs are made of a copper-kapton-copper sandwich, with holes etched into it



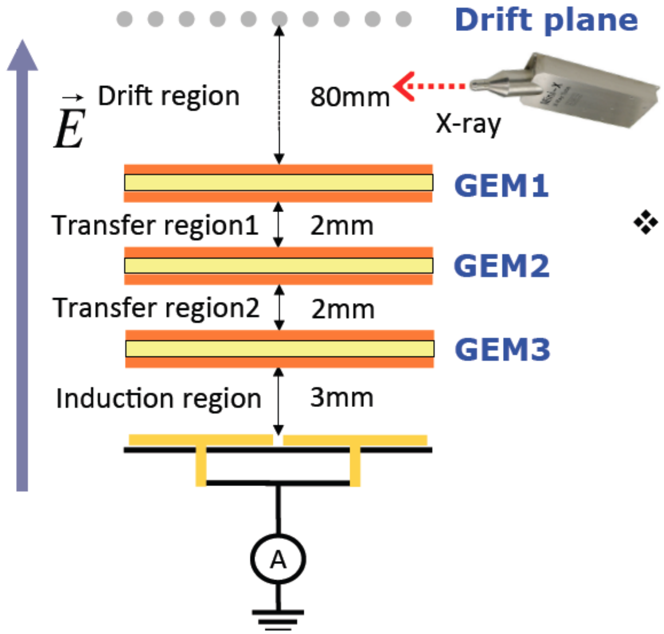
Electron microscope photograph of a GEM foil



- Fast electron signal (polarity!)
- no “ion tail”
- No “coupling to other electrods”

➔ Gas gain about a factor 3 lower than in MWPC

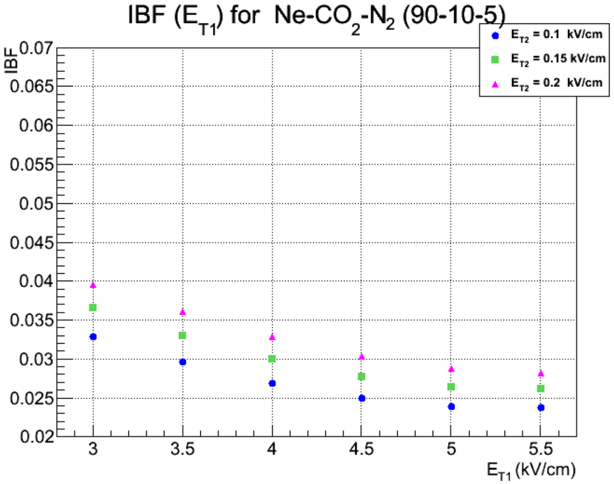
Ongoing R&D – Ion Backflow

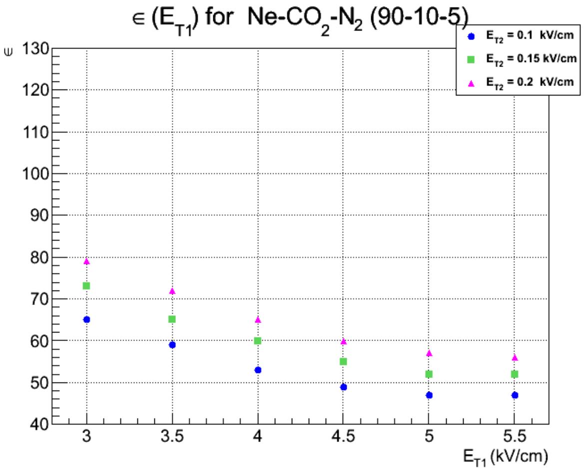


❖ ε : number “back-drifting” ions per electron reaching the GEM stack

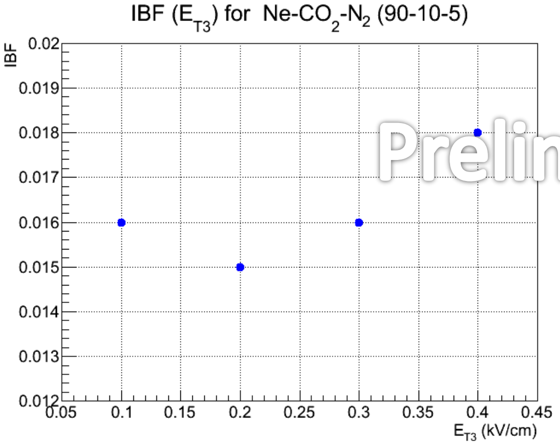
❖ Results for 3-GEM

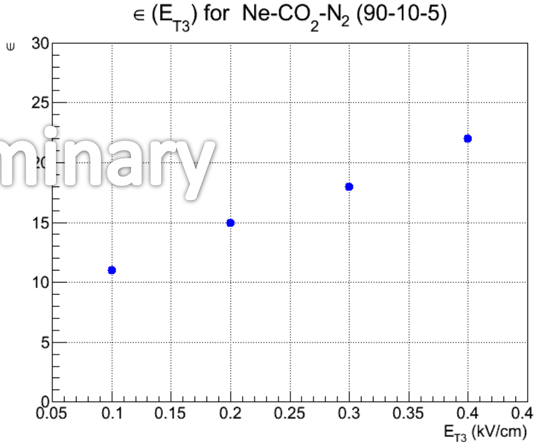
Ion back-flow (IBF) and ε do not fulfill ALICE requirements (IBF ≤ 1%, ε ≤ 10 at gain 1000-2000 in Ne-based mixture)





Results for 4-GEM stack-up with GEM-3 with x2 pitch





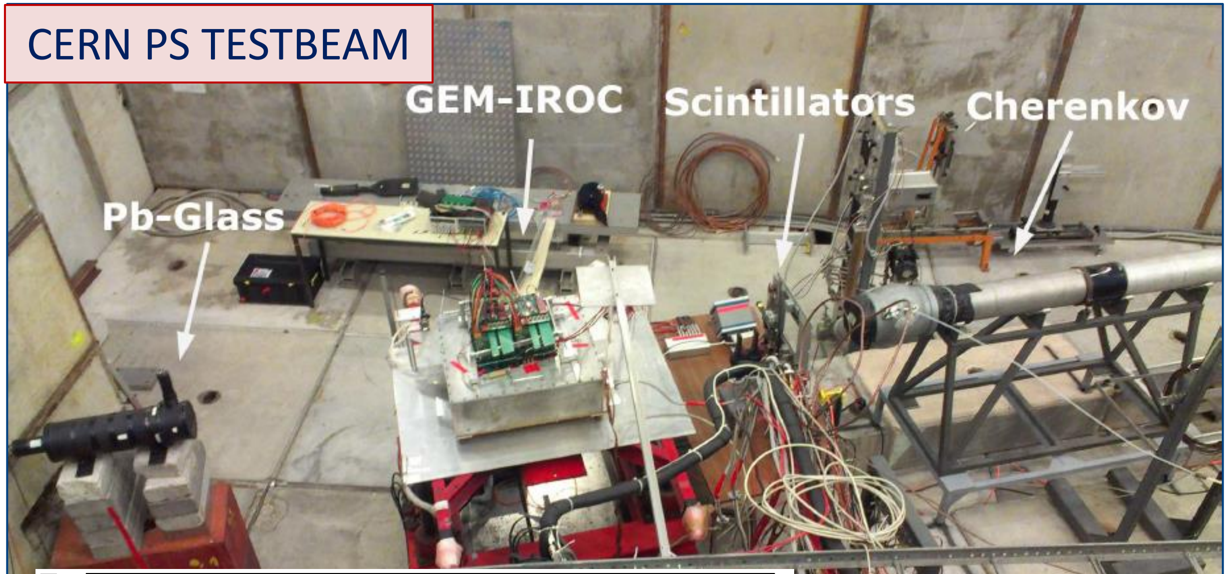
Preliminary results with 4-GEM chambers are very promising (in the ballpark of the target value)

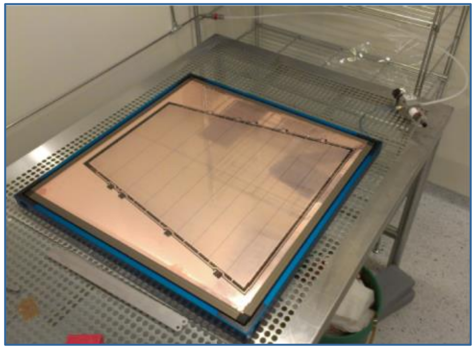
Further optimization:

- Field configuration
- Second large pitch foil

TPC upgrade – GEM-IROC prototype at test-beam

CERN PS TESTBEAM

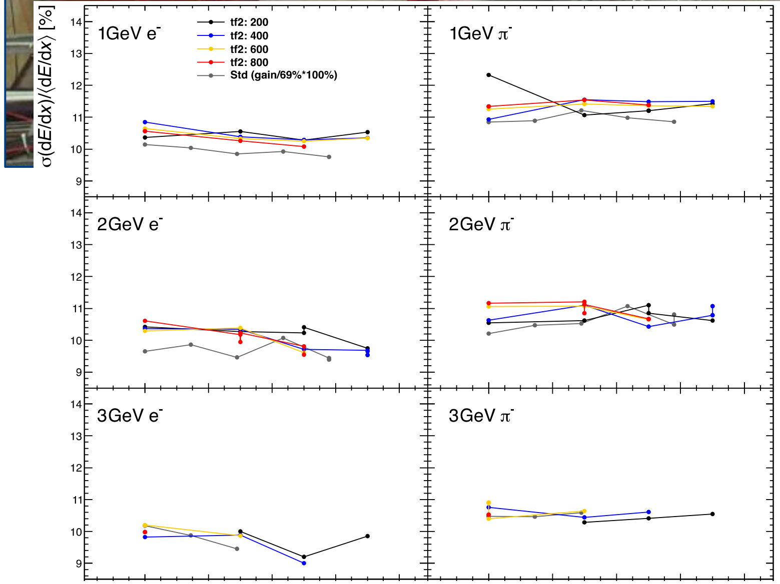




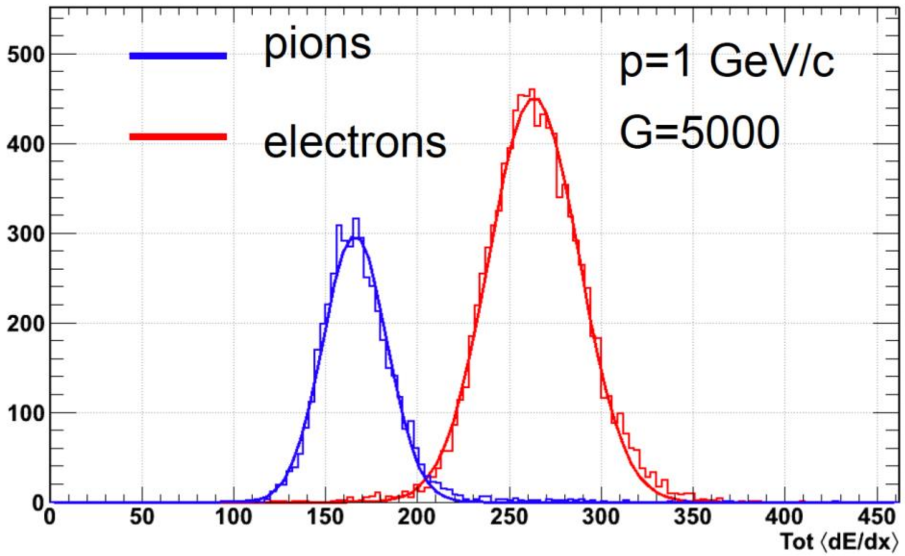
GEM-IROC only tracks

dE/dx: ~10%

same as in current TPC

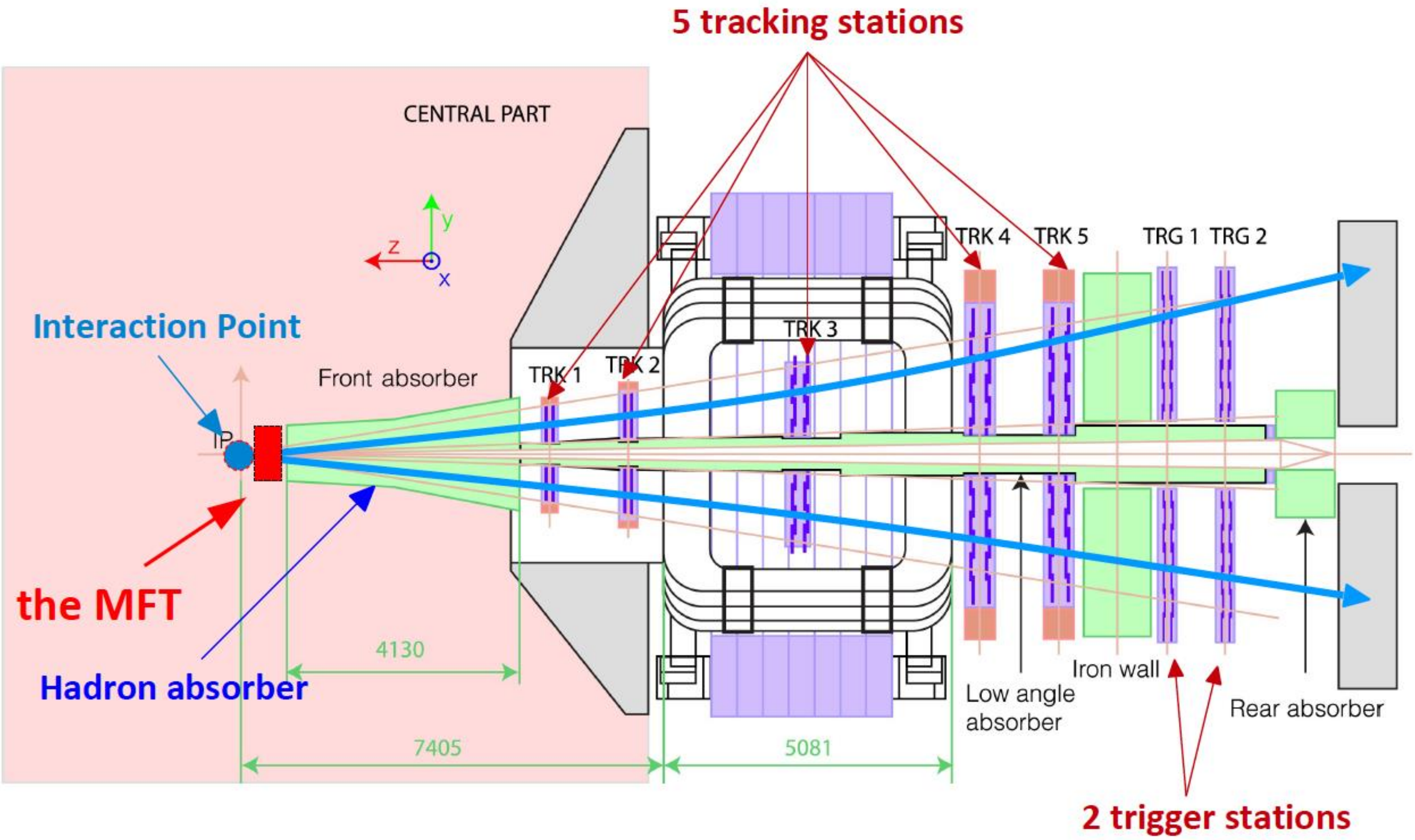


Relative dE/dx measurements for different HV settings for *e* and *p*
With momentum from 1 to 3 Gev/c. 46 pad rows used for this analysis



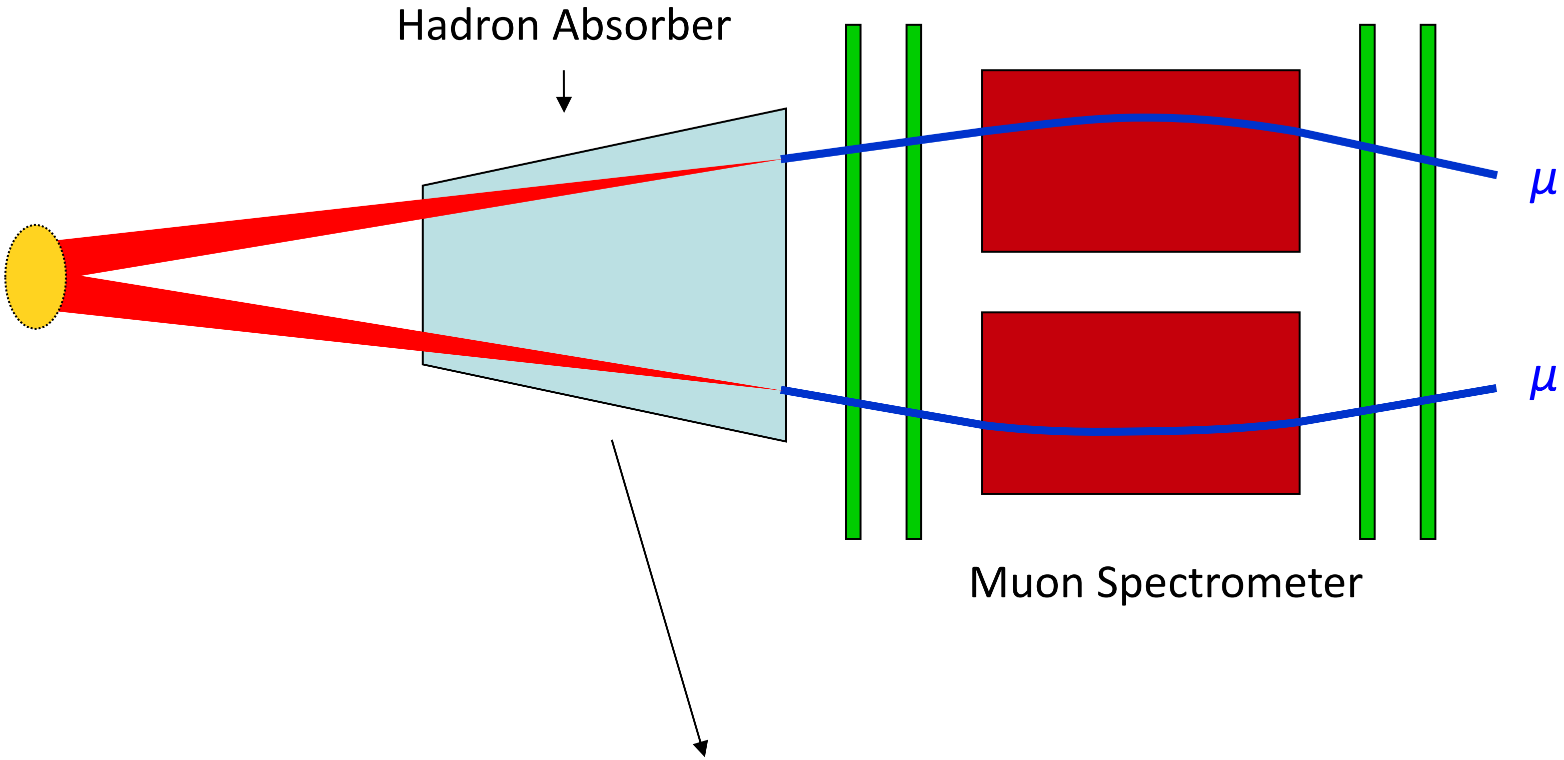
dE/dx spectrum of 1GeV/c electrons and pions

The MFT and the Muon-Spectrometer



Silicon pixel tracker in the acceptance of the Muon Spectrometer placed between the Interaction Point and the Hadron Absorber

The MFT Concept

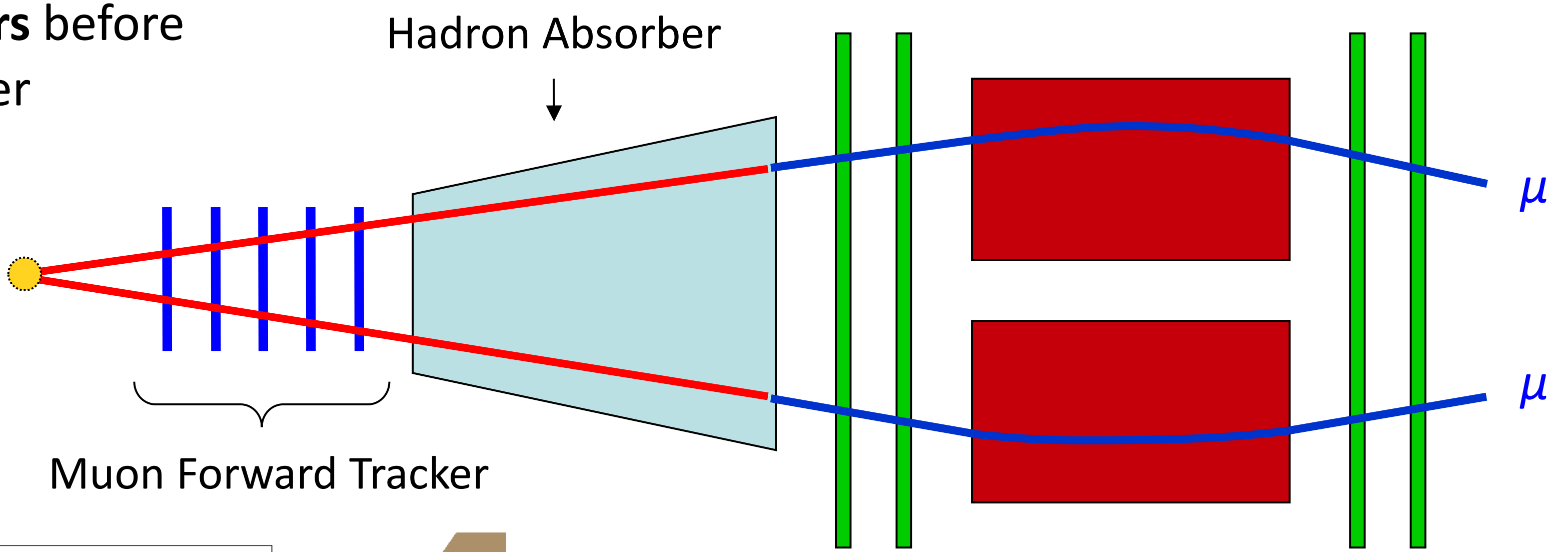


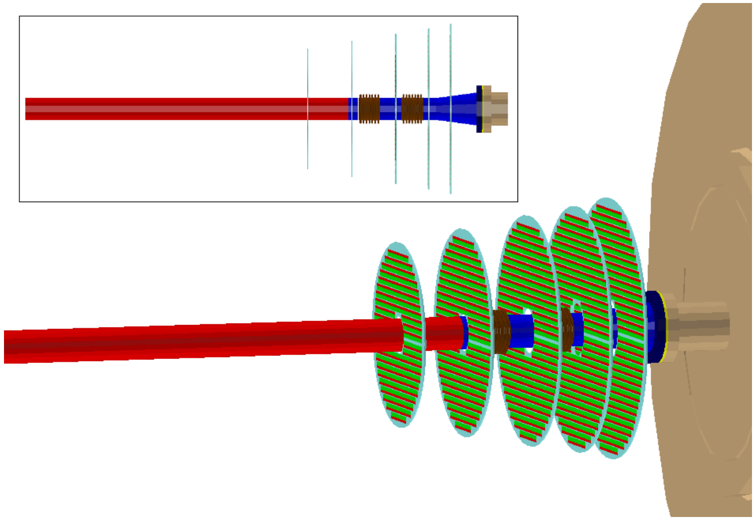
Extrapolating back to the vertex region **degrades the information** on the kinematics

The MFT Concept

Muon tracks are extrapolated and **“matched” to the MFT clusters** before the absorber

High pointing accuracy gained by the muon tracks after matching with the MFT clusters





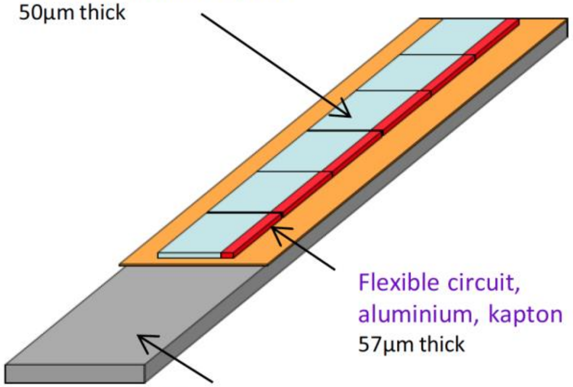
MFT baseline simulation set-up

Plane	Int. radius (cm)	Ext. radius (cm)	Z location (cm)	Pixel pitch (μm)	Thickness (% of X_0)
0	2.5	11.0	-50	25	0.4
1	2.5	12.3	-58		
2	3.0	13.7	-66		
3	3.5	14.6	-72		
4	3.5	15.5	-76		

MFT Layout

Pixel chip: common development with ITS

Ladder: basic detector element

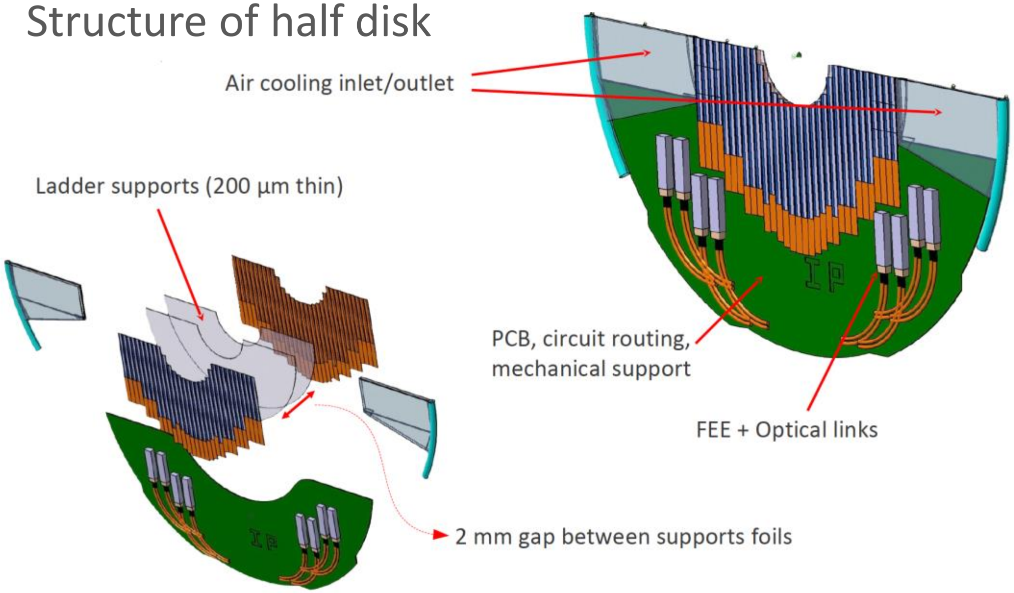


Sensors, silicium, kapton
50µm thick

Flexible circuit, aluminium, kapton
57µm thick

Ladder support
(different material, thickness, conductivity)

Structure of half disk



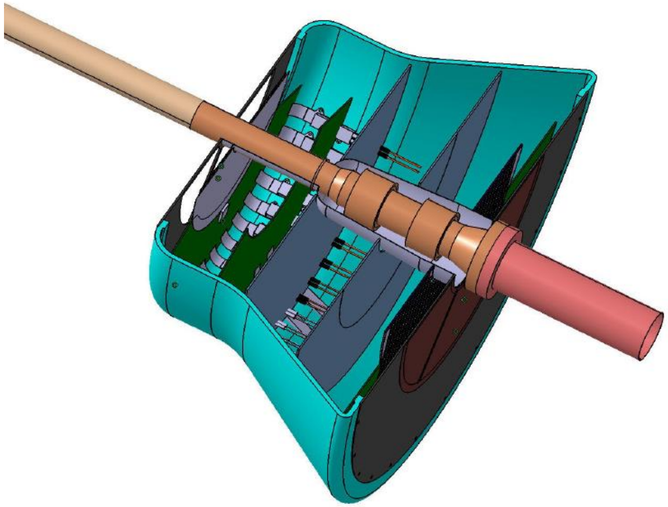
Air cooling inlet/outlet

Ladder supports (200 µm thin)

PCB, circuit routing, mechanical support

FEE + Optical links

2 mm gap between supports foils

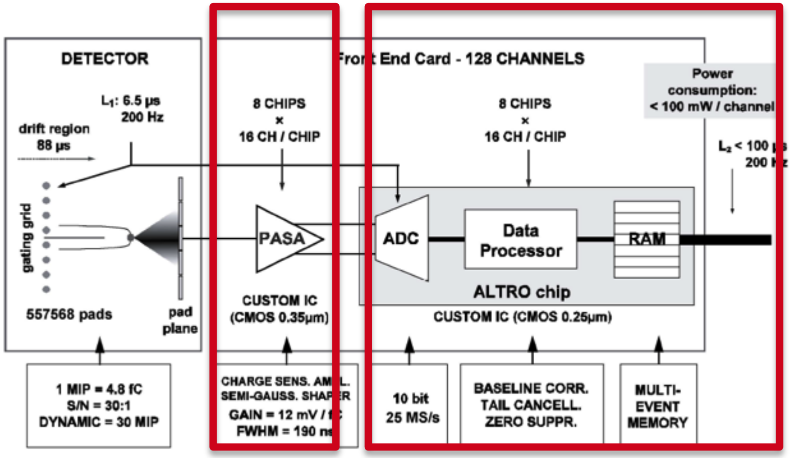


- MFT planes are ladder assemblies of active and (dead) readout zones
- Pixel sensors are mounted on both sides of the plane to guarantee hermeticity

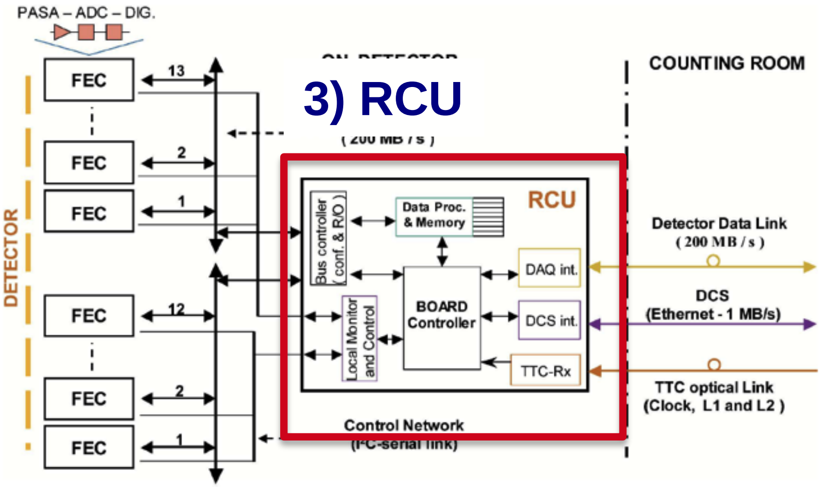
Common FE Chip for TPC/Muon Tracker

1) PASA

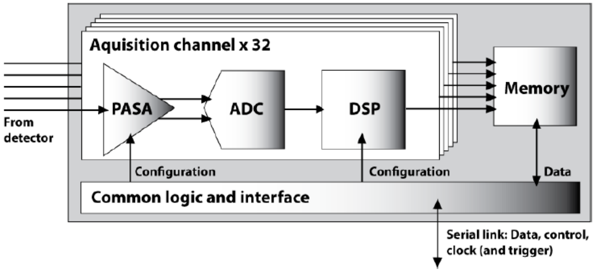
2) ALTRO



3) RCU

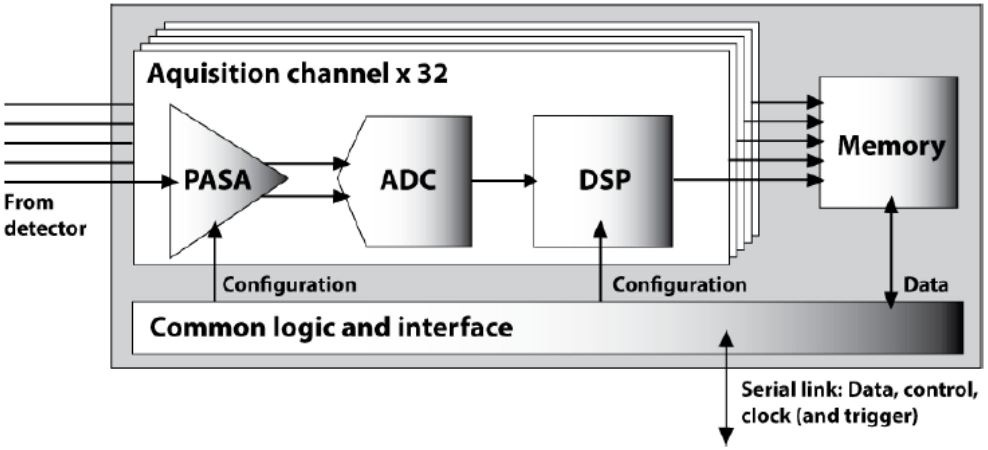


SAMPA Chip



32 Channels
Including the
PASA,
ALTRO,
RCU functionalities

SAMPA Chip



PASA: Low Noise Shaping Amplifier

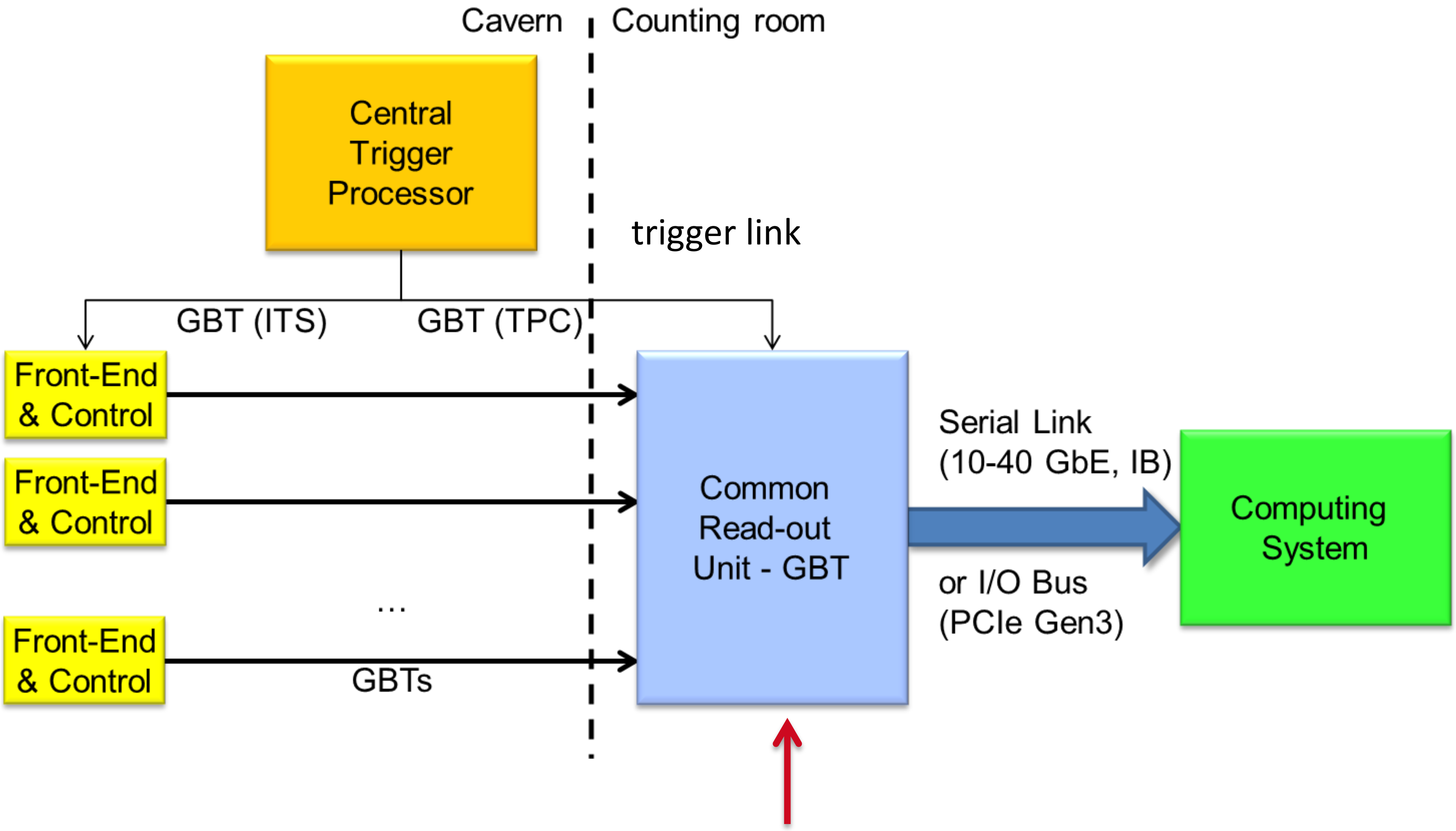
ADC: 10MHz, 10bit low power SAR ADC

DSP: Digital Signal Processing i.e. signal shaping, zero suppression …

Memory, Serial link: High Speed links to Data Acquisition

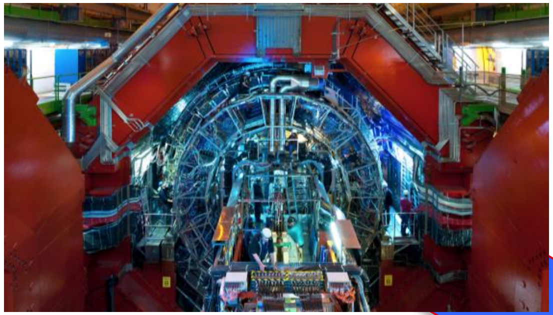
→ University of Sao Paulo, University of Campinas / Brazil

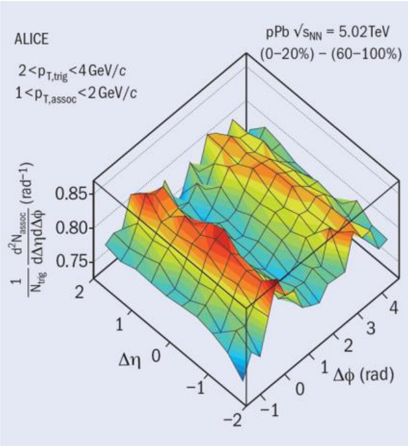
Common Readout Unit



possible common solution with LHCb

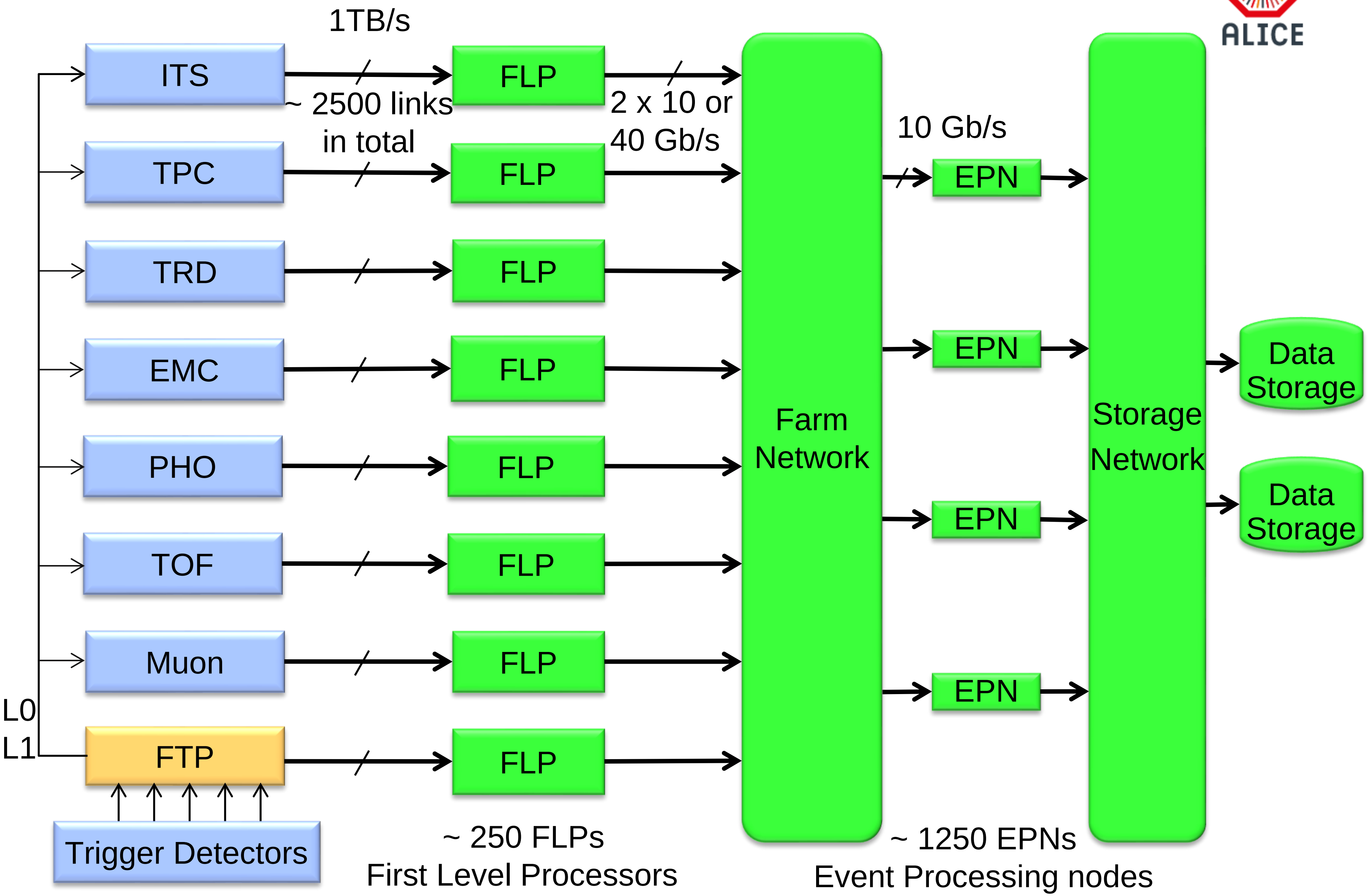
O² Project





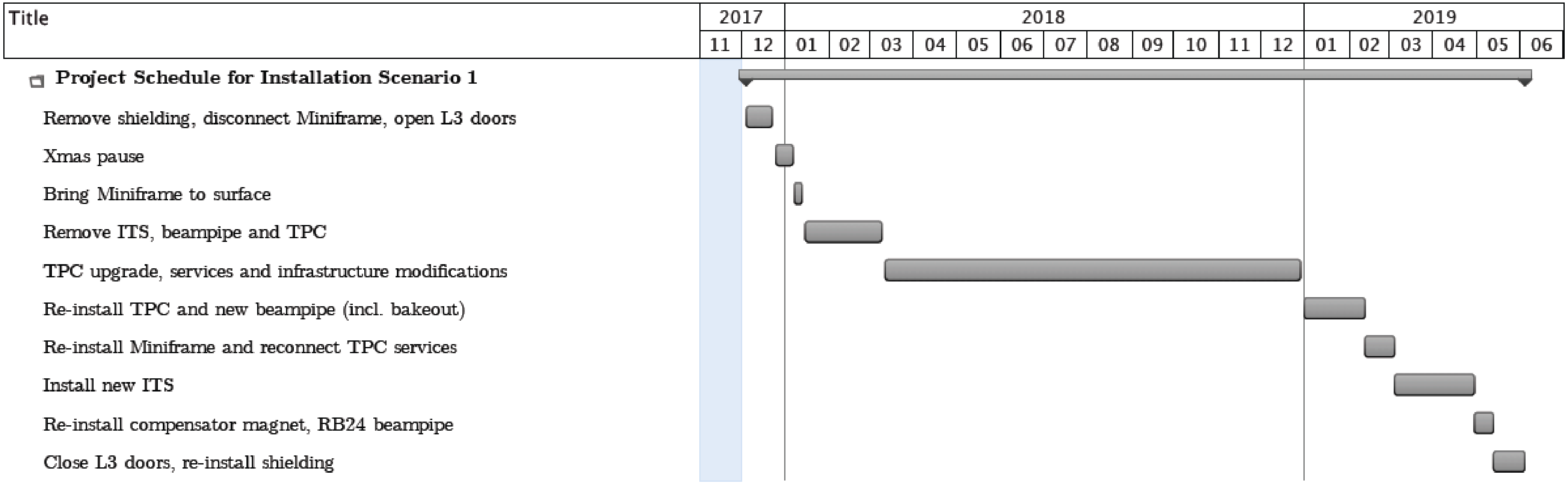
From Detector Readout to Analysis:
What is the “optimal” computing architecture?

O^2 Hardware System from LoI



Upgrade Installation

ALICE plans installation of the upgrade in an LS2 of 18 months



TPC on the surface: 10 months

ITS installation and commissioning: 3 months

Summary

- Major upgrade of ALICE detector, for installation in 2018/19, to cope with Pb-Pb collisions at high rates and improve vertexing capabilities at low p_T
- The detectors will be modified to inspect up to 50 kHz Pb-Pb collisions shipping all data to the online systems either continuously or upon a minimum-bias trigger
- Key detector items of this upgrade programme are:
  - New ITS (the largest HEP pixel detector ever, 7 layers, ~11m^2)
    - Built on the experience from STAR PXL
    - Very low material thickness: 0.3% per layer
  - Replacement of TPC endplates with new readout based on quadruple-GEM detectors and new electronics for continuous readout
  - New 5-plane muon silicon telescope, based on MAPS, in front of hadron absorber in the acceptance of the Muon Spectrometer
  - Readout rate upgrade, of all other ALICE subdetectors
- Next Steps
  - Technical Design Reports