The TPCs of ND280 T2K near detector

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SAND Bi-weekly meeting (26 November 2019)

IRFU (CEA)

- **French CEA laboratory** including 6 Departements:
  Particle Physics, Nuclear Physics, Astrophysics,
  Electronics&Detectors, Systems Engeneering, Accelarators Magnet&Cryo Systems

- Large and sophisticated facilities for **development and production of detectors and electronics: IRFU invented the MicroMegas technology** (1996, Y. Giomataris, G. Charpak, Ph. Rebourgeard, J-P Robert)

- Involved in **T2K since the beginning** of the experiment:

  development, building and maintenance of the **Near Detector (ND280) TPCs**

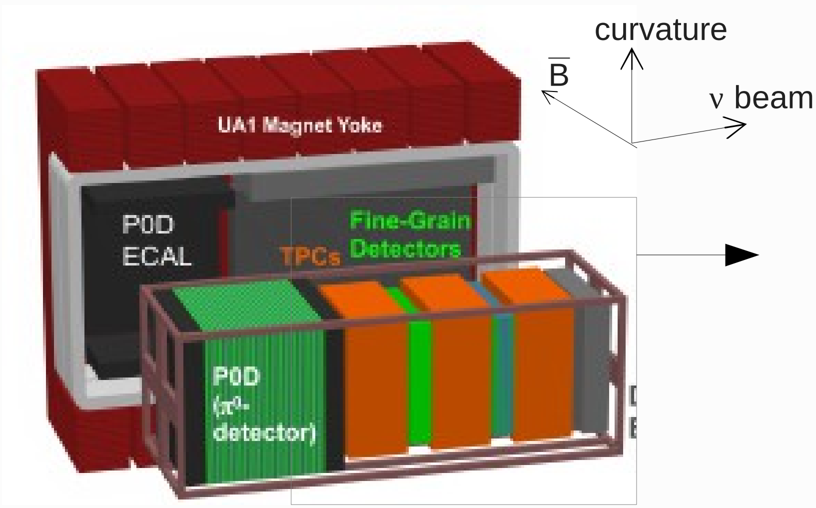
  deep expertise in ND physics

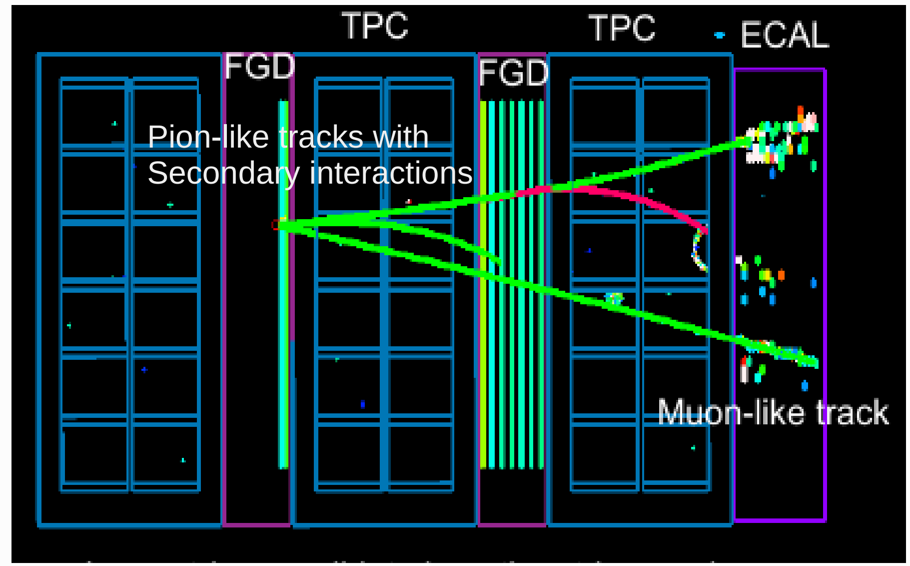
- DUNE:

heavily involved in the **Double Phase technology (WA105)**: charge readout system (LEM)

Interest in participating to **PIP2**

The role of TPCs in ND280





- **Momentum reconstruction:**

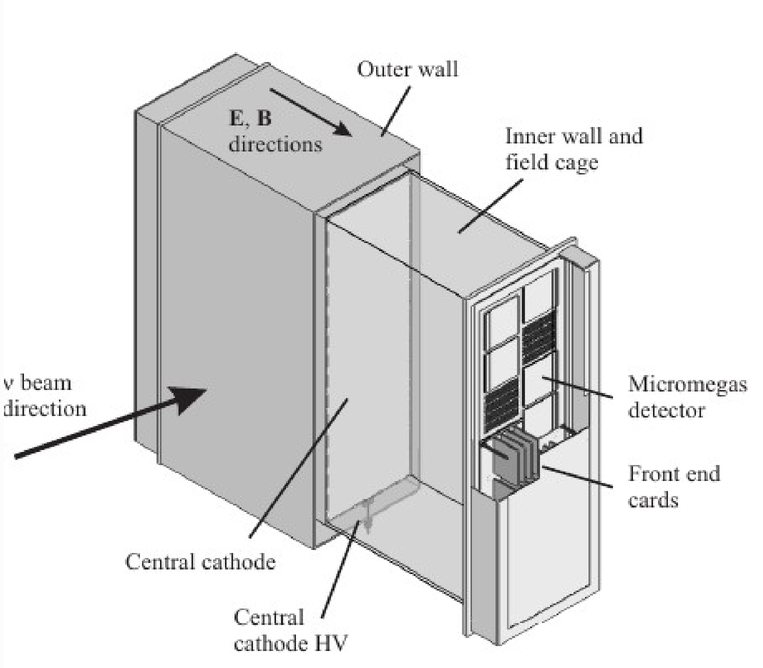
  Spatial Resolution ~10% (→ @0.2T space point resolution ~0.7mm: pads of 7x10 mm2) beyond 10%, limited by Fermi momentum smearing → better resolution achievable with resistive MicroMegas / pad size, depending on the improved understanding of νN cross-section model

  Momentum scale ~2% → direct impact on mean flux energy → Δm^2_{32}

- **Particle identification through dE/dx:**

  Energy resolution ~10% (~45% more ionization for electrons than muon/pions)

The TPC design



Dedicated gas: Ar+2%iC_4H_{10}+3%CF_4

Non-flammable, low transverse diffusion, very large v_{drift} (7.5 cm/us), minimize effect of impurities (30m attenuation lenght)

Dirft E field 200 V/cm

Field cage: electric distorsion <0.2mm and minimal amount of material (G10/rohacell)

Cathode in the middle and 12 **MicroMegas** at each anode ($9m^2$)

2 incapsulated boxes (CO_2) → 3.3% rad lenght

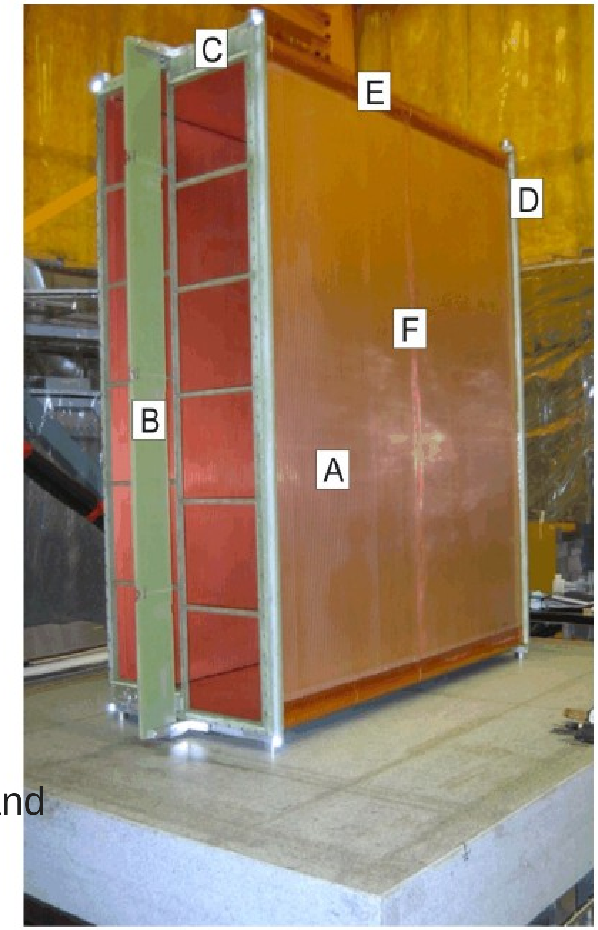


Figure 2: Inner box on the granite table in the TRIUMF clean room. A: one of inner box walls; B: module frame stiffening plate; C: module frame; D: inner box endplate; E: field-reducing corners; F: central cathode location.

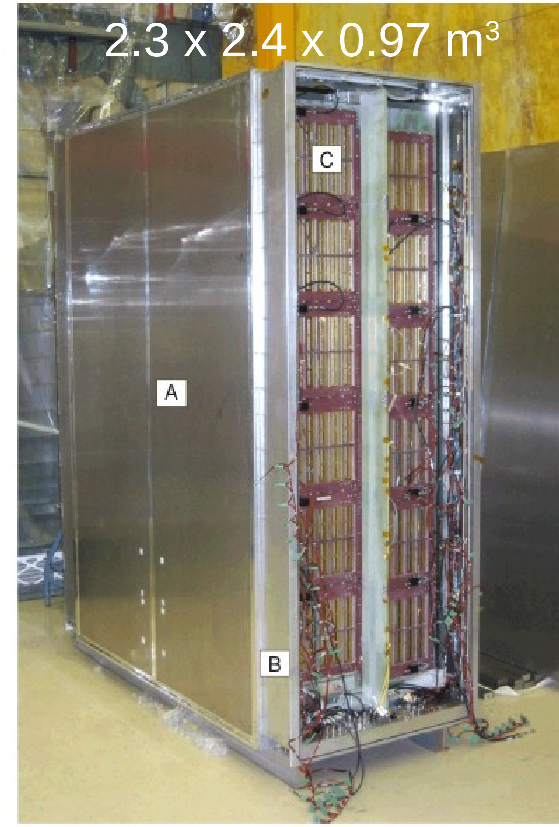
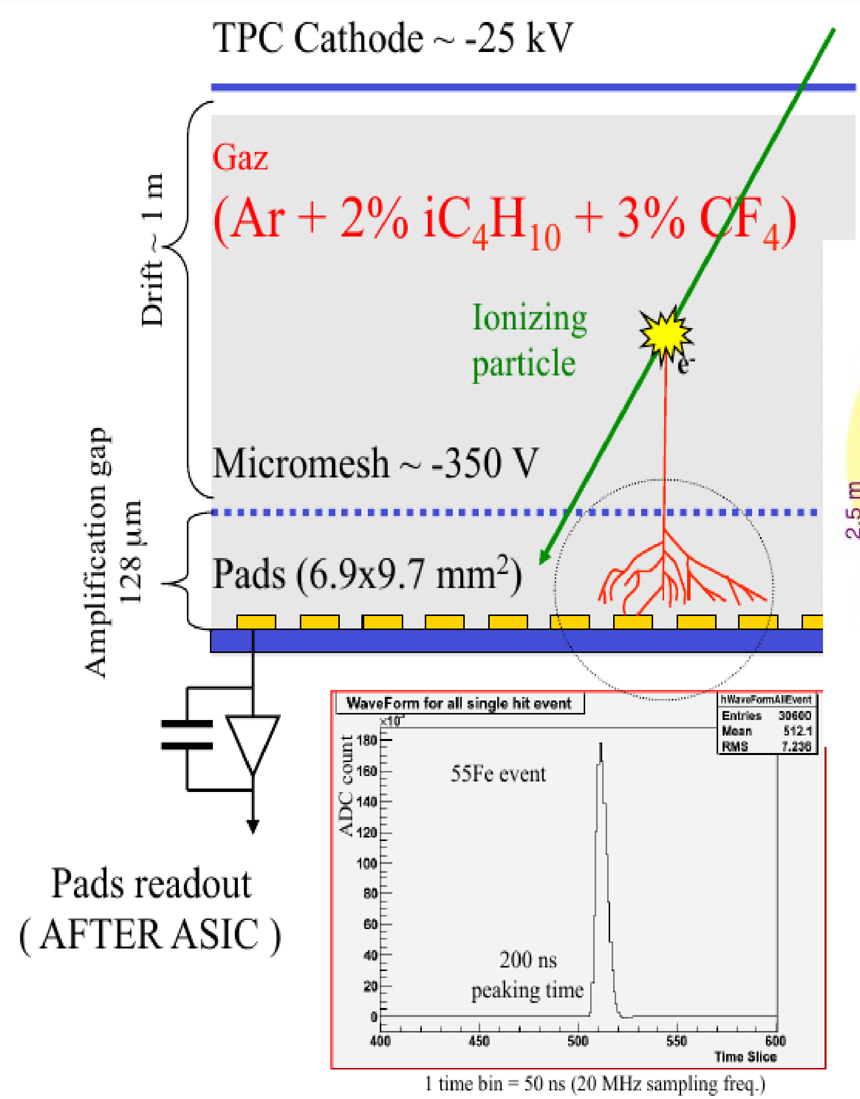


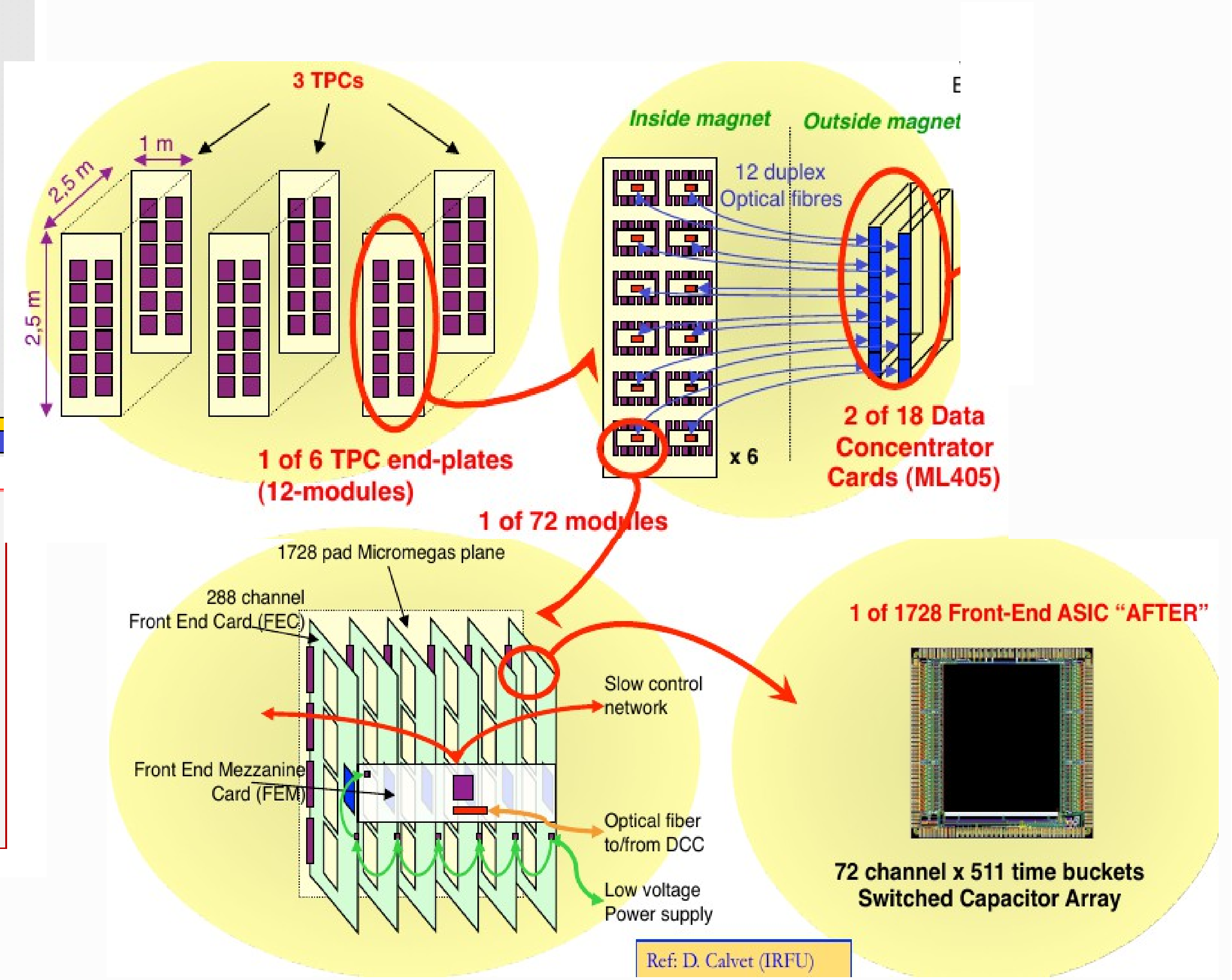
Figure 3: Outer box with the different components labeled. A: one of the outer box walls; B: service spacer; C: one of the micromegas modules inserted into the module frame.

Calibration systems:
- gas monitoring chambers (O_2<10ppm, H_2O<100ppm, CO_2<100ppm)
- photo-electron calibration with laser

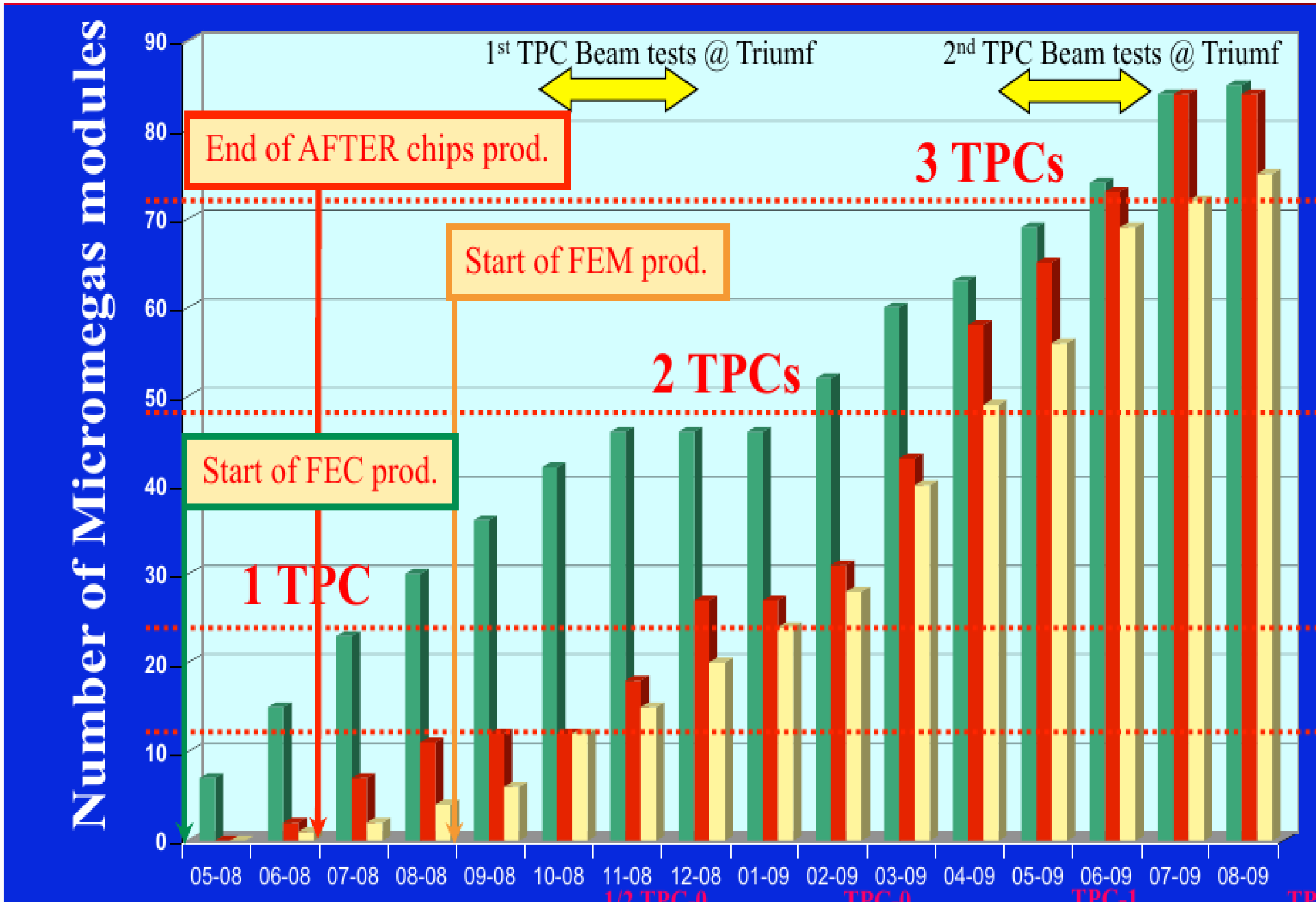
Micromegas & electronics



Dedicated electronics developed for TPC purpose
(adapted for Micromegas or wire chambers):
chips AFTER (→ AGET) + FEC + FEM



A success story



	05-08	06-08	07-08	08-08	09-08	10-08	11-08	12-08	01-09	02-09	03-09	04-09	05-09	06-09	07-09	08-09
Bulk MMs	7	15	23	30	36	42	46	46	46	52	60	63	69	74	84	85
MM Modules	0	2	7	11	12	12	18	27	27	31	43	58	65	73	84	84
Validated MM Modules	0	1	2	4	6	12	15	20	24	28	40	49	56	69	72	75

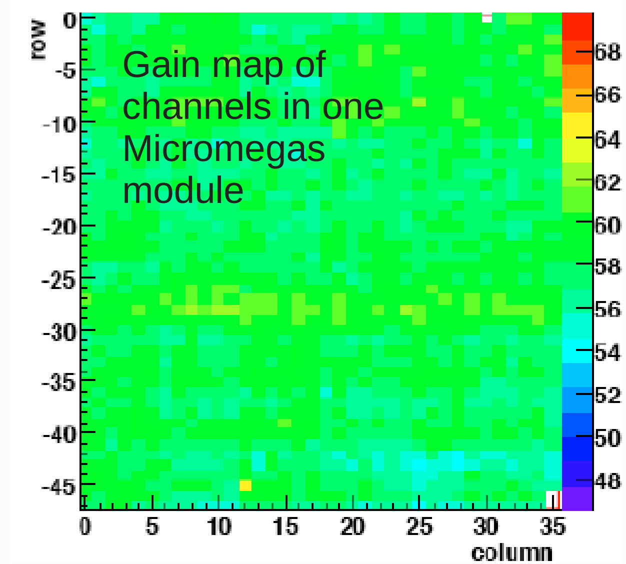
Final percentage of good modules/produced:
Micromegas (82/89) 92%
FEC (499/514) 97%
FEM (84/93) 90%

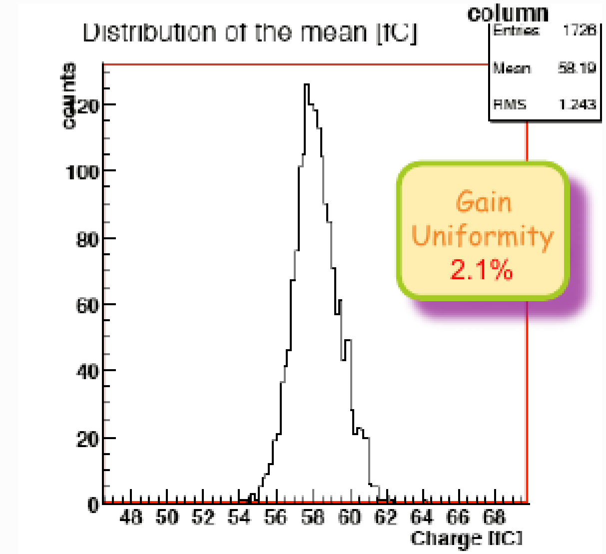
12 **dead MM channels** over 124272 channels (0.01%)

10 years of operation with only 1 FEM failure and 2HV filters to repair

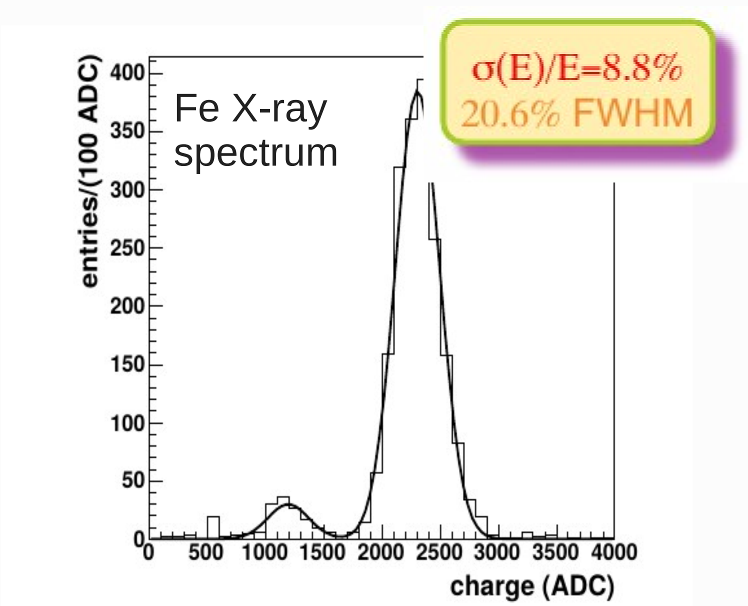
The Micromegas performances

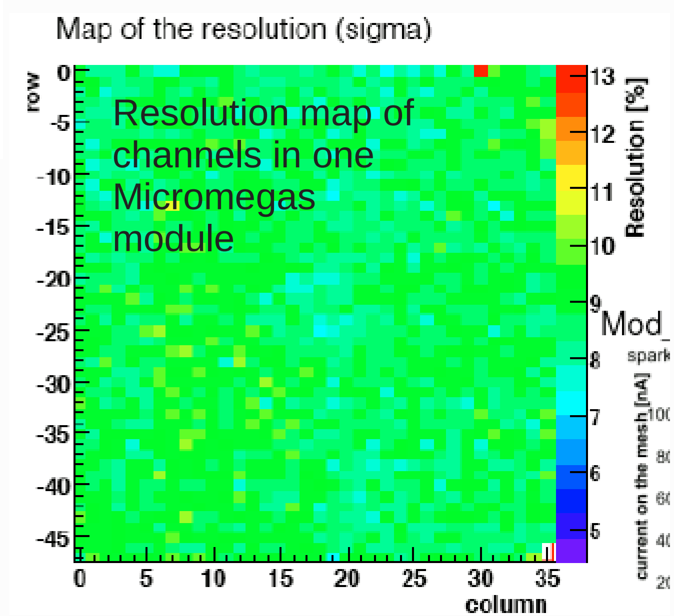
- Micromegas gain~1500 with spark rate <0.1/h and 2% uniformity

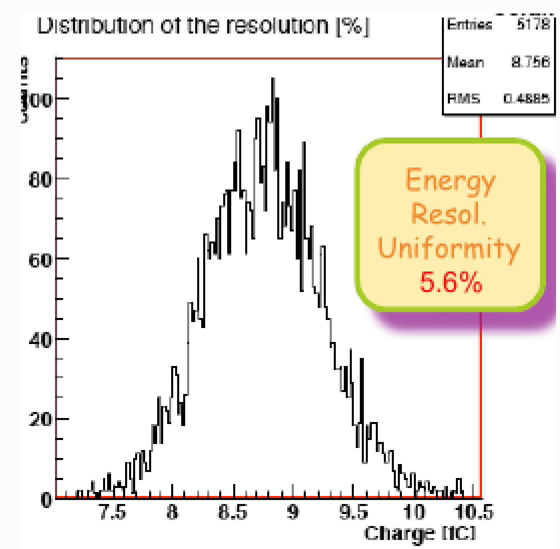




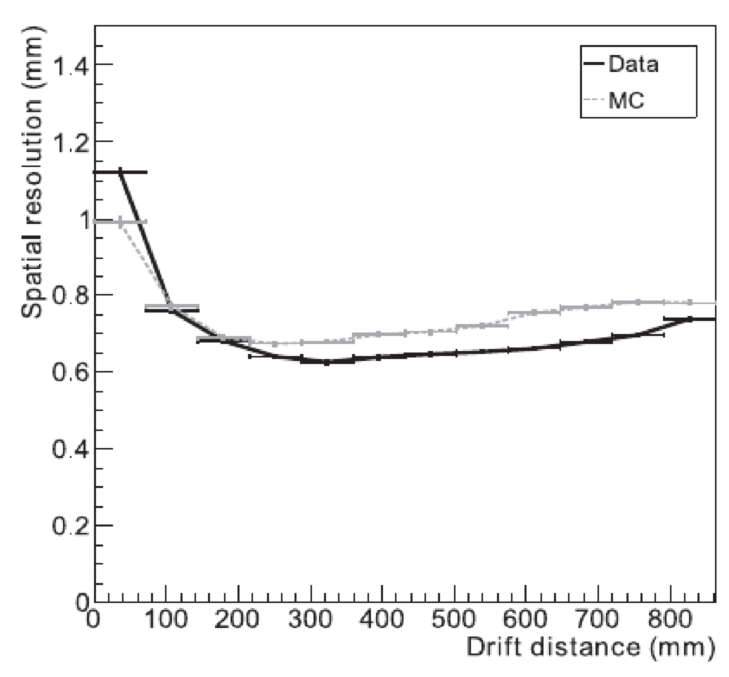
- Energy resolution 8-9% with uniformity better than 8% (3% between detectors)

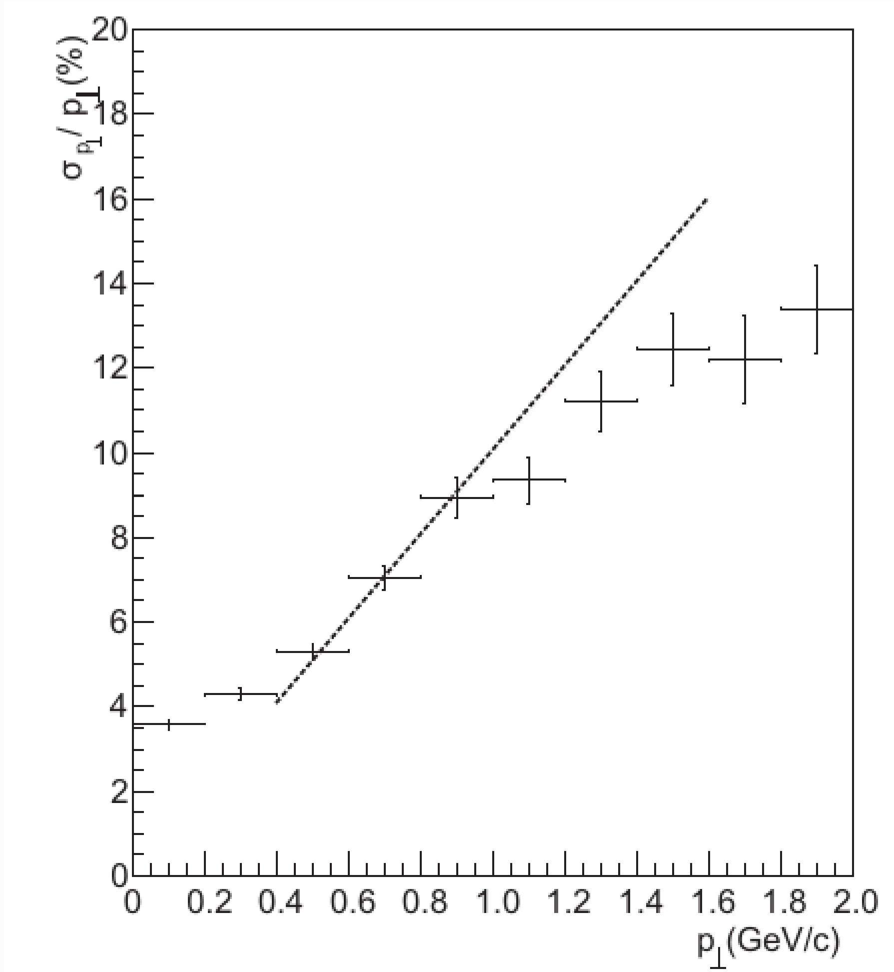


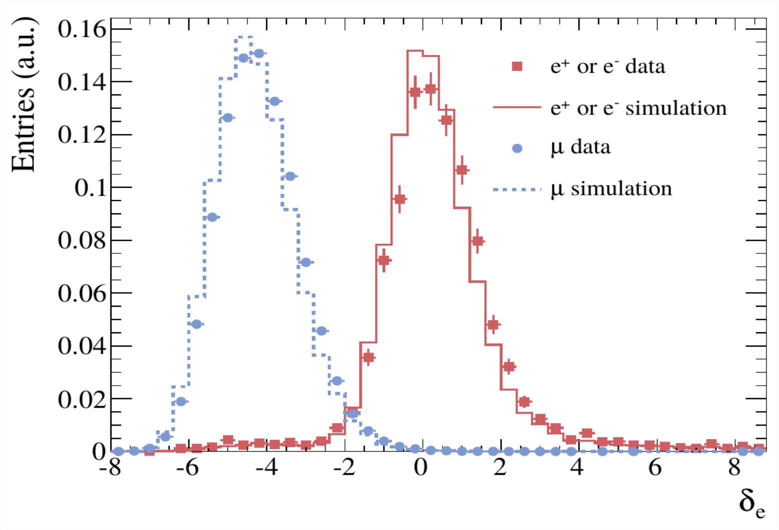


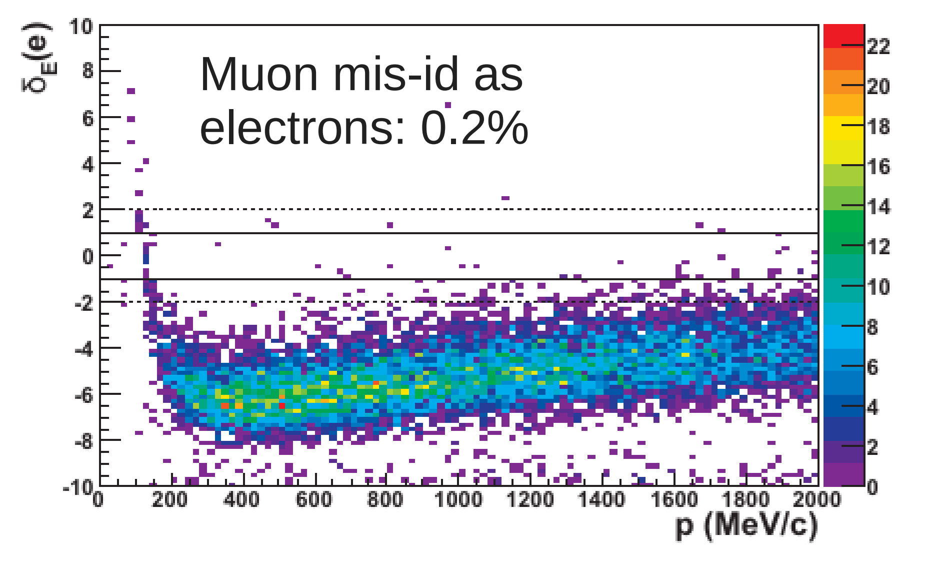


The TPC performances



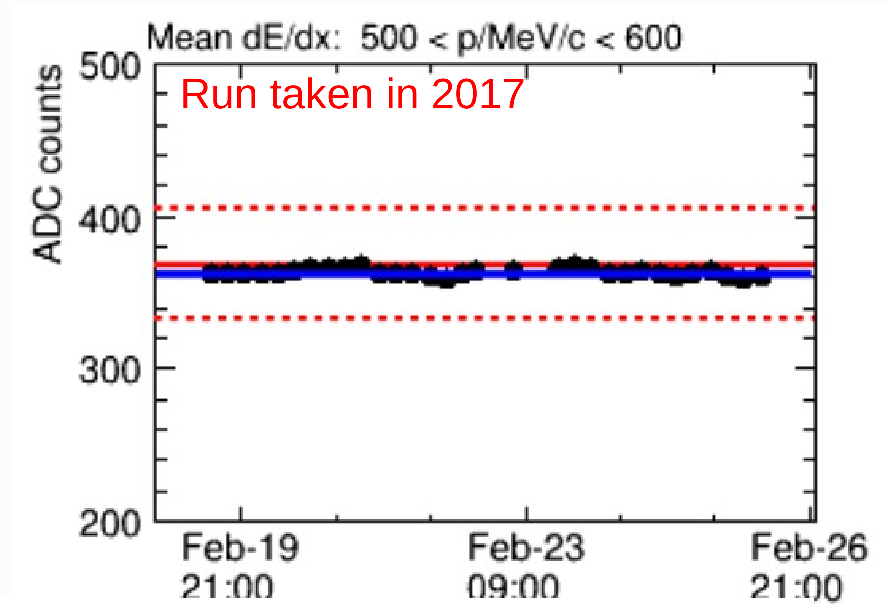




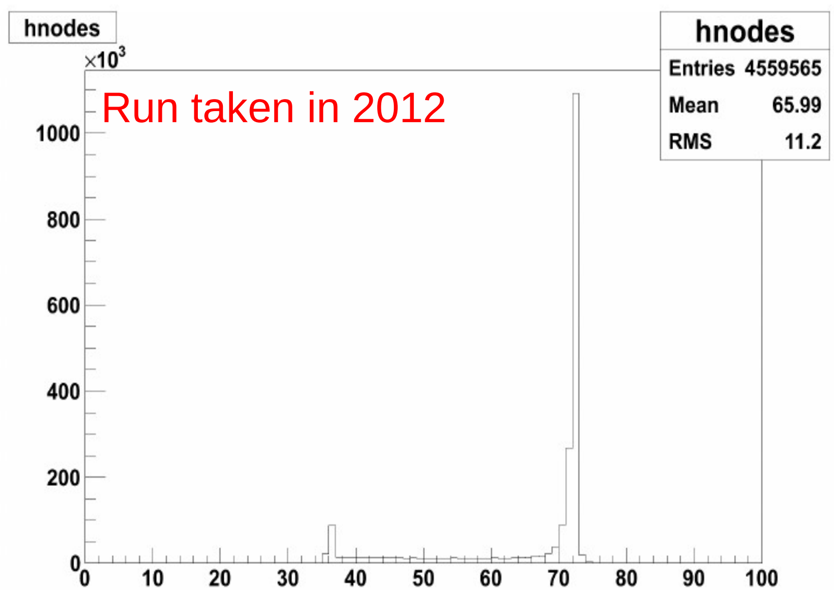


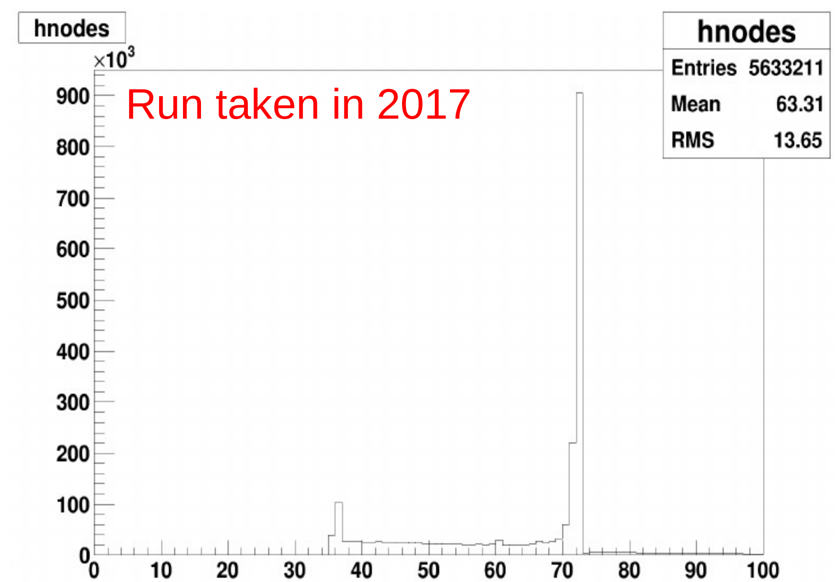
Astonishing stability/reliability in 10 years

Mean dE/dx from cosmics

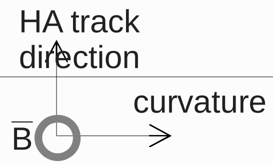


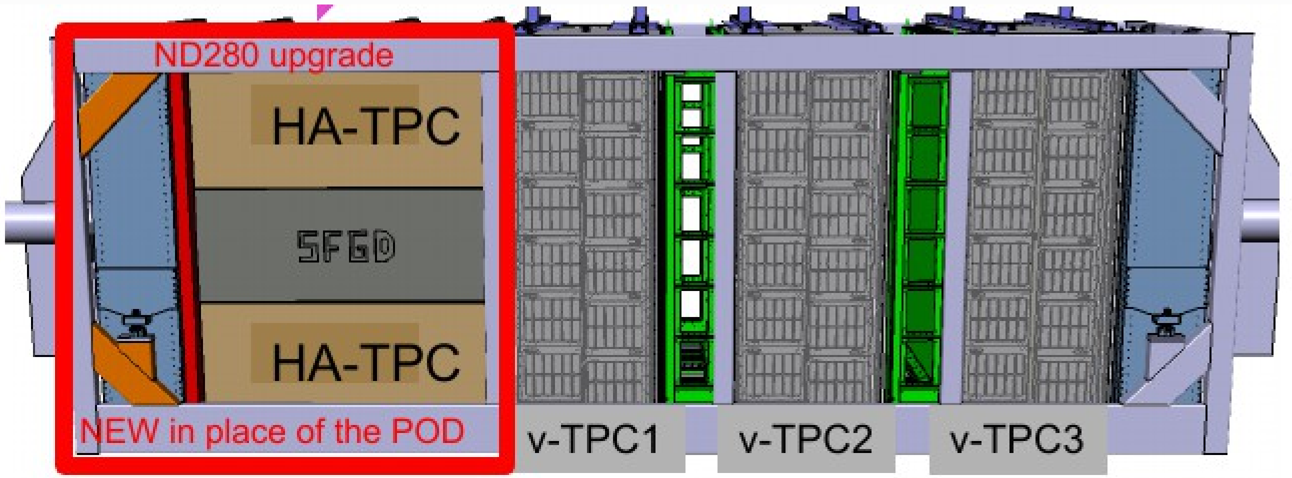
Number of hits per track





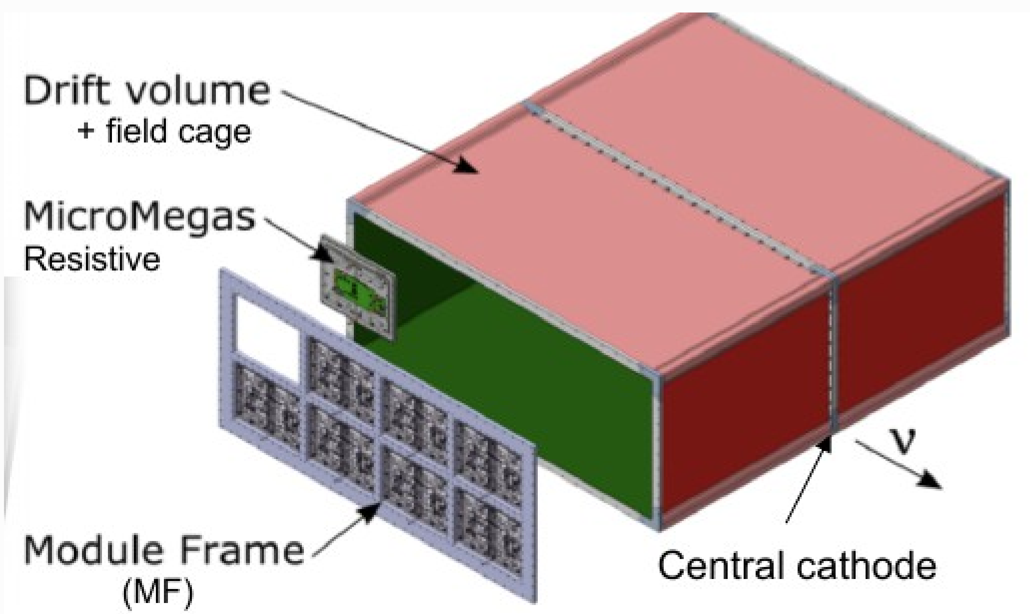
ND280 upgrade





+ 6 TOF planes surrounding the new tracker

High Angle TPCs to recover same acceptance as at SK

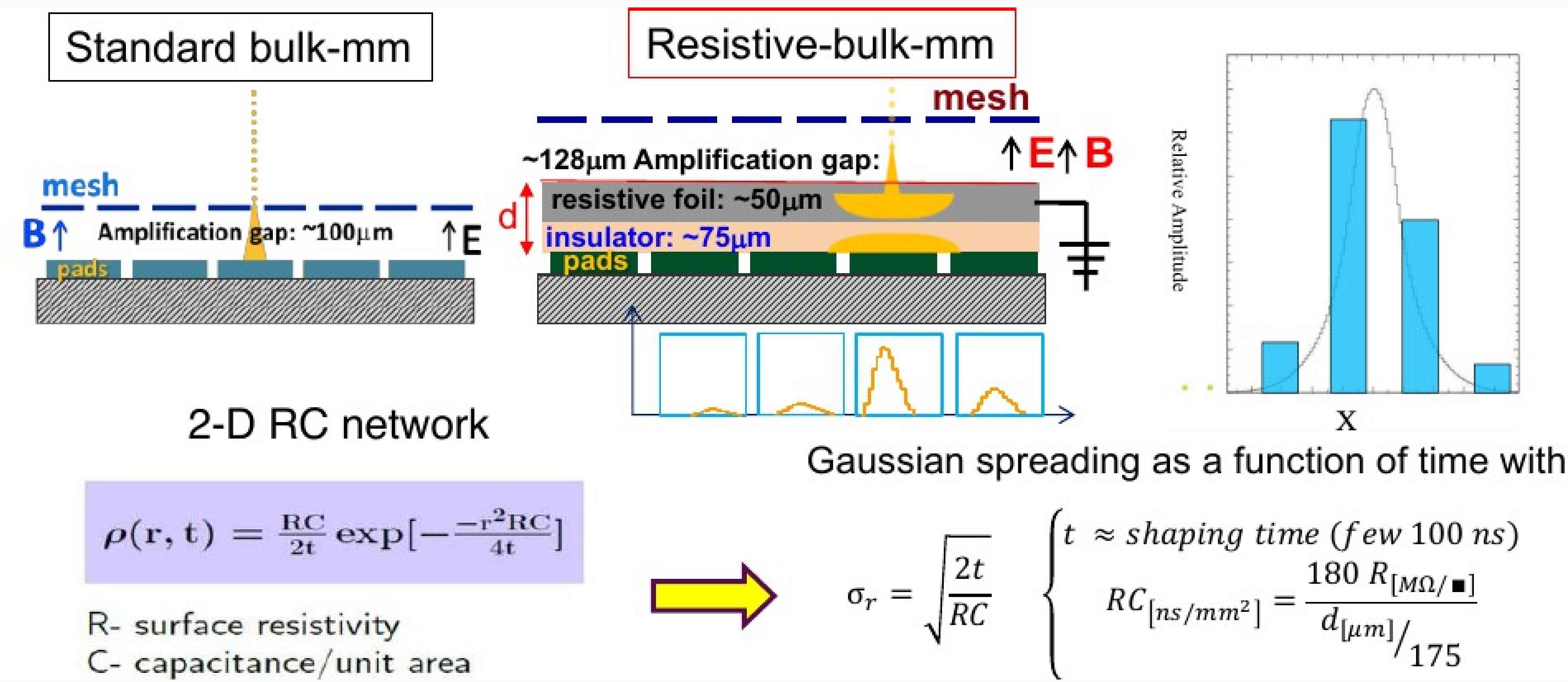


Parameter	HA-TPC Value	V-TPC
Overall x × y × z (m)	2.0 × 0.8 × 1.8	0.85 x 2.2 x 1.8
Drift distance (cm)	90	
Magnetic Field (T)	0.2	
Electric field (V/cm)	275	
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2	
Drift Velocity $cm/\mu s$	7.8	
Transverse diffusion ($\mu m/\sqrt{cm}$)	265	
Micromegas gain	1000	
Micromegas dim. z×y (mm)	340x420	340x360
Pad z × y (mm)	10 × 11	7x10
N pads	36864	124272
el. noise (ENC)	800	
S/N	100	
Sampling frequency (MHz)	25	
N time samples	511	

Resistive Micromegas

Spread the charge from the avalanche over multiple pads → compute the charge 'barycenter' → get good resolution with larger pads (less number of channels)

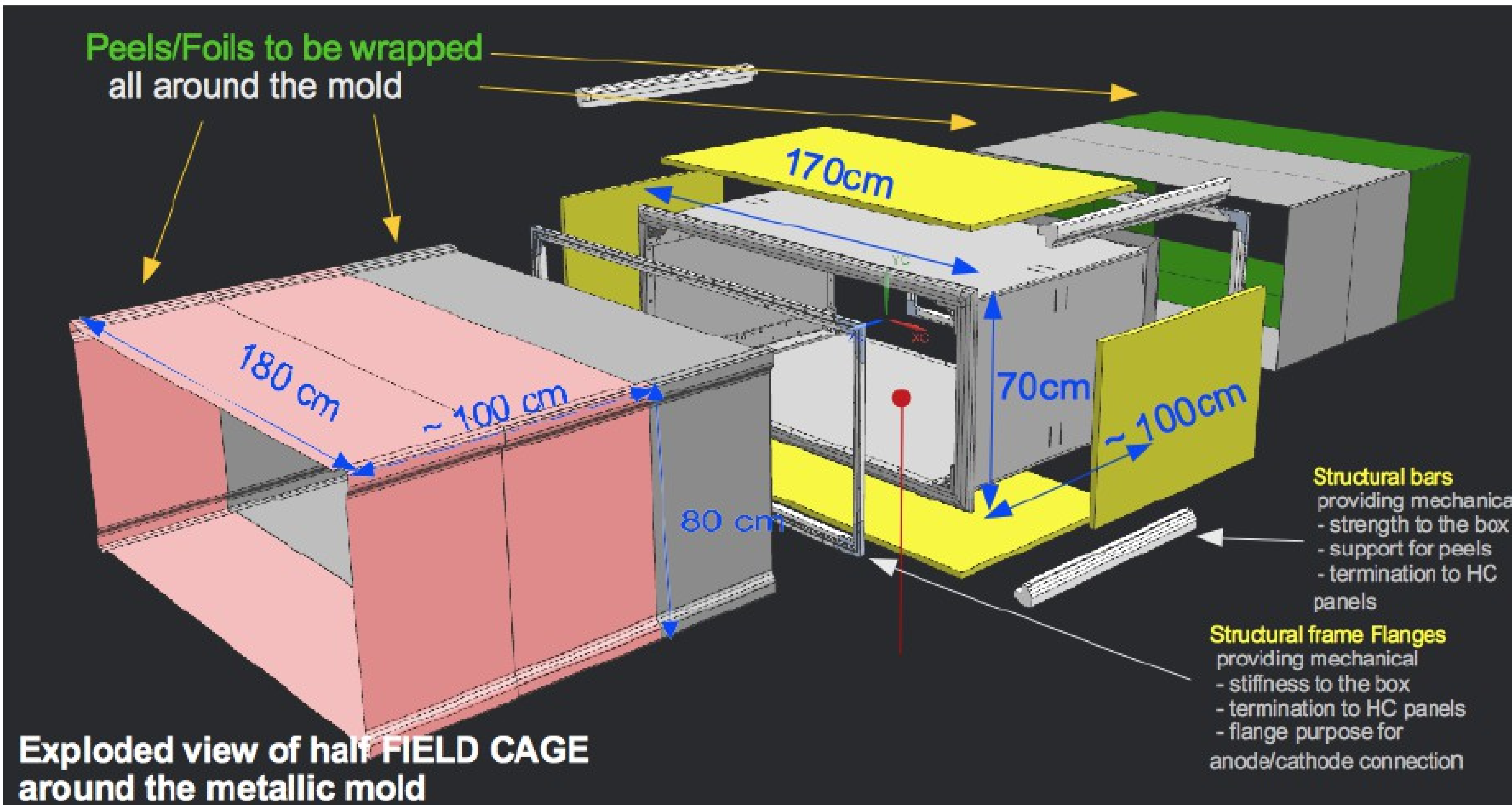
Heavily based on ILD R&D



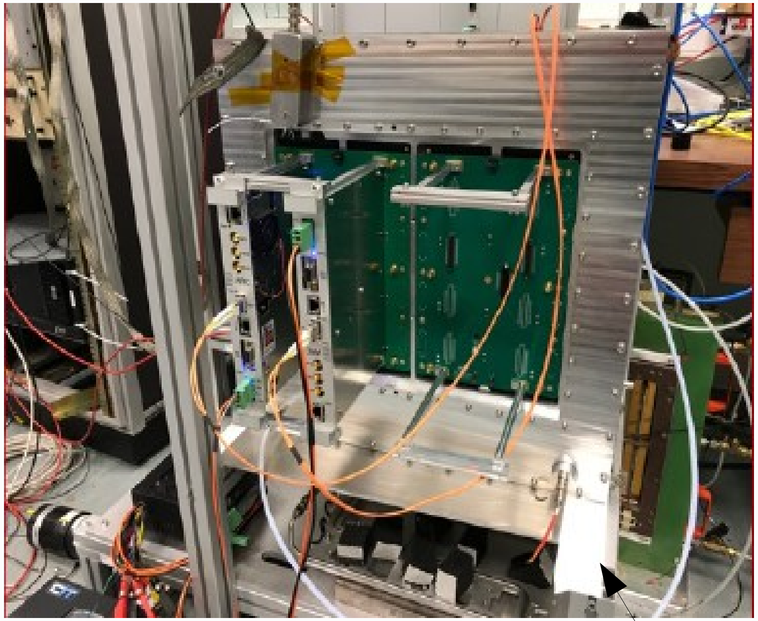
Field cage

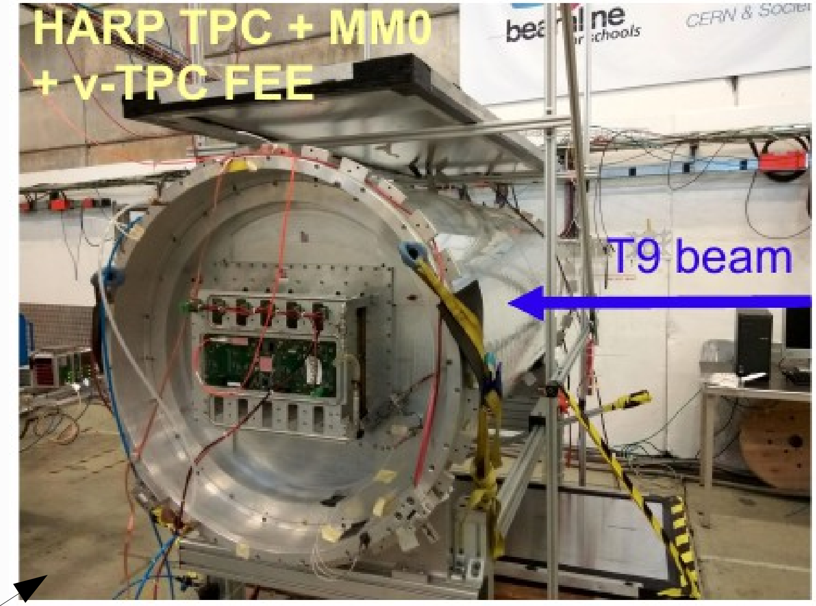
INFN
Padova-Bari

To keep $^{\Delta E}/_{E} \leq 10^{-4}$ confined at <1cm from FC walls, the TPC cage requirements are :
Cathode flatness better than 0.1mm, Micromegas plane flatness better than 0.2 mm,
Cathode/Anode planes parallel to within 0.2mm, Field Cage walls flatness better tham 0.3mm
Voltage divider resistors matched within rms ~ 0.1%

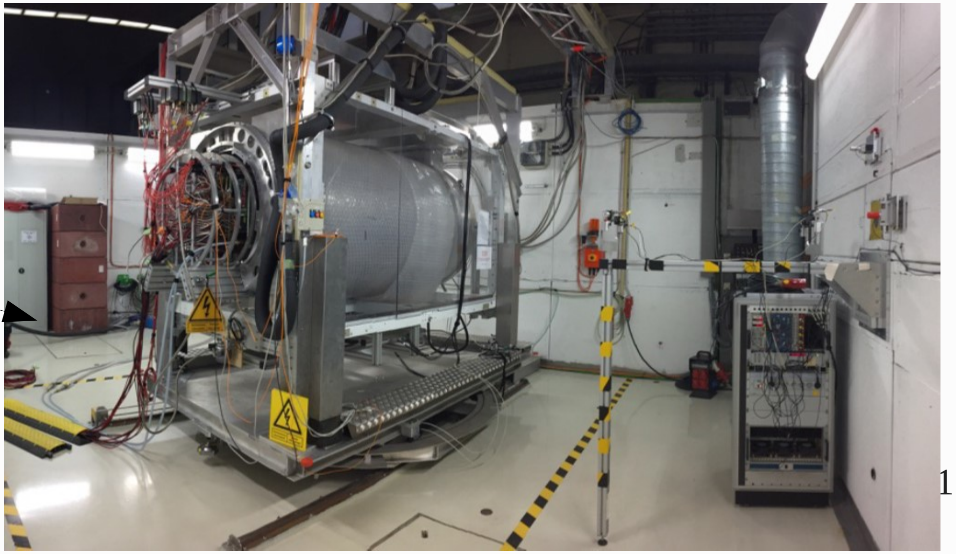


Extensive tests on-going



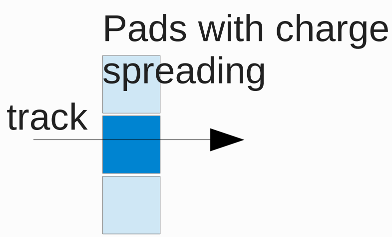


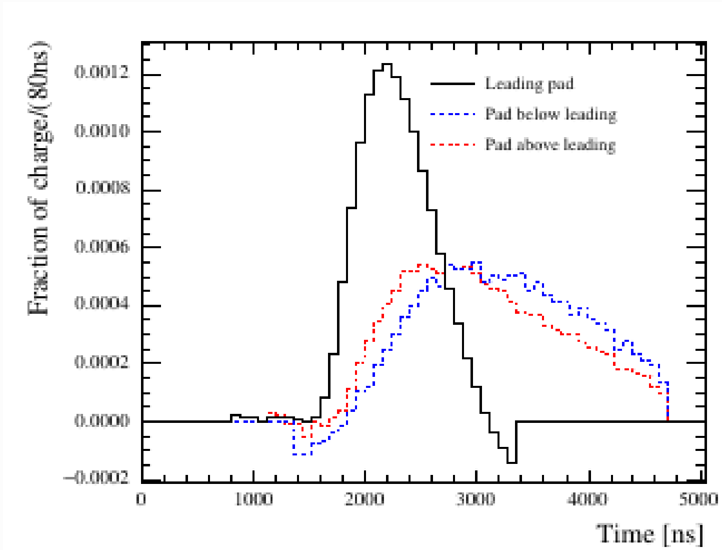
- Cosmic test bench @ IRFU Saclay
- Test beam at CERN in 2018
- Test beam at DESY, with magnetic field, in 2019
- Test beam at DESY with field cage prototype planned in 2020
- Installation at ND280 in summer 2021

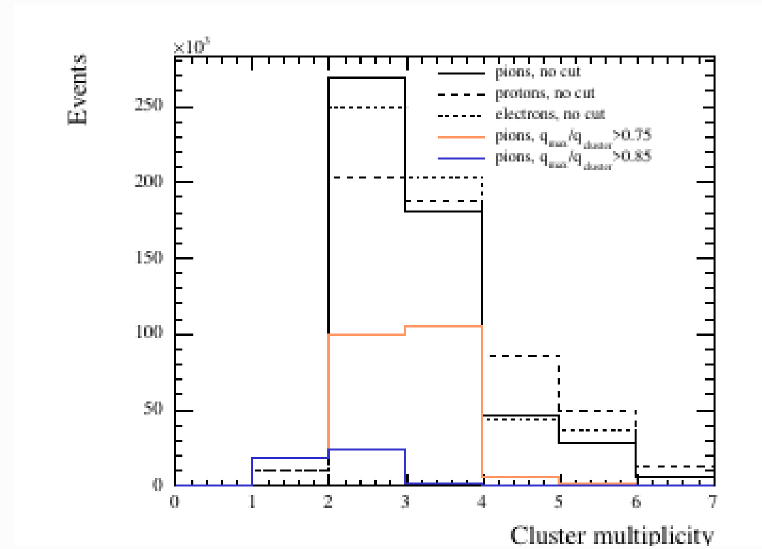


(arXiv:1907.07060):

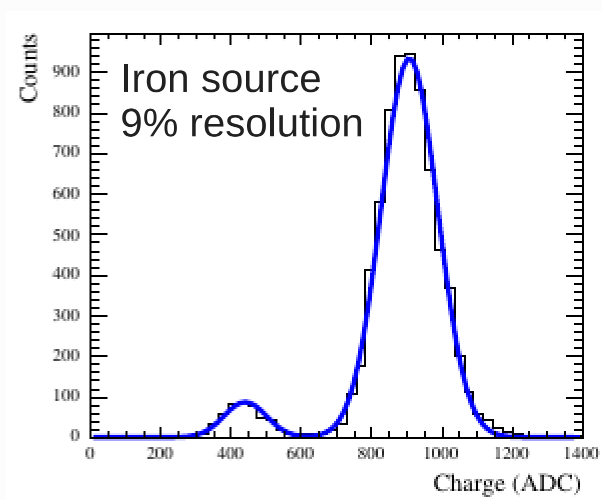
CERN prototype performances (1)

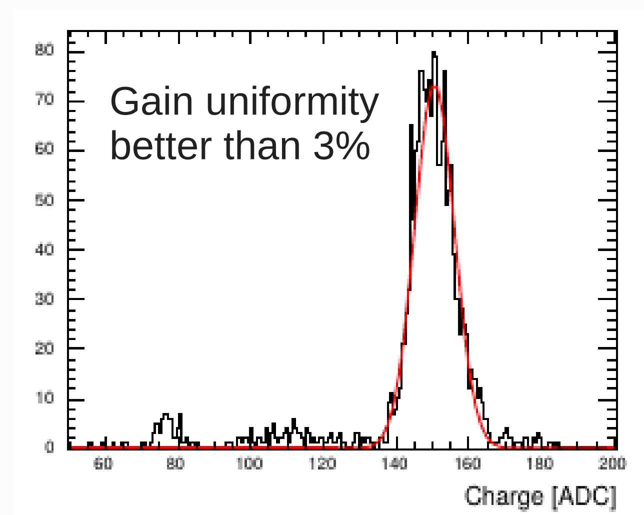






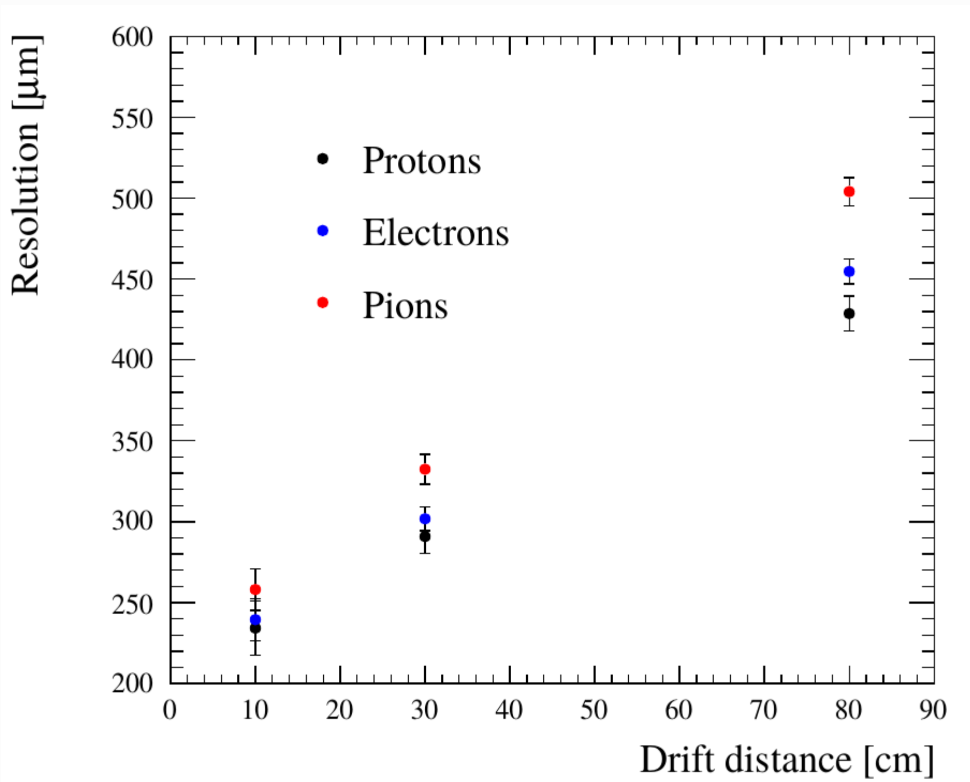
Results from preliminary prototype at CERN
(pad 9.8x7mm^2 and not optimal RC 2.5 MΩ/square)

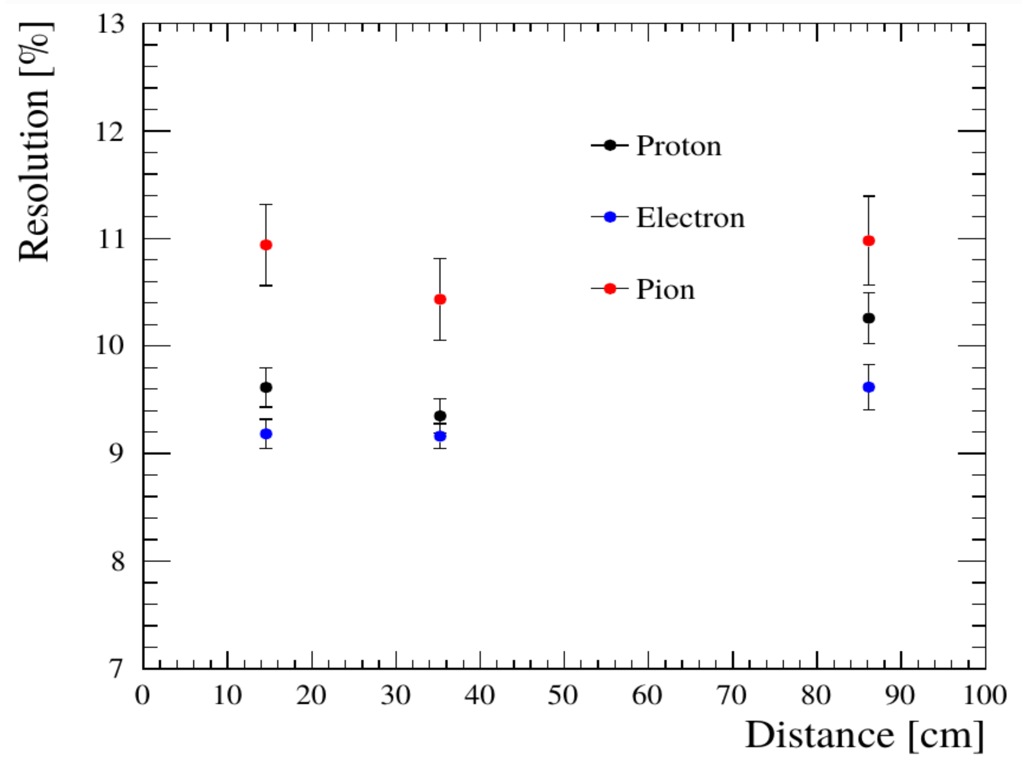




(arXiv:1907.07060):

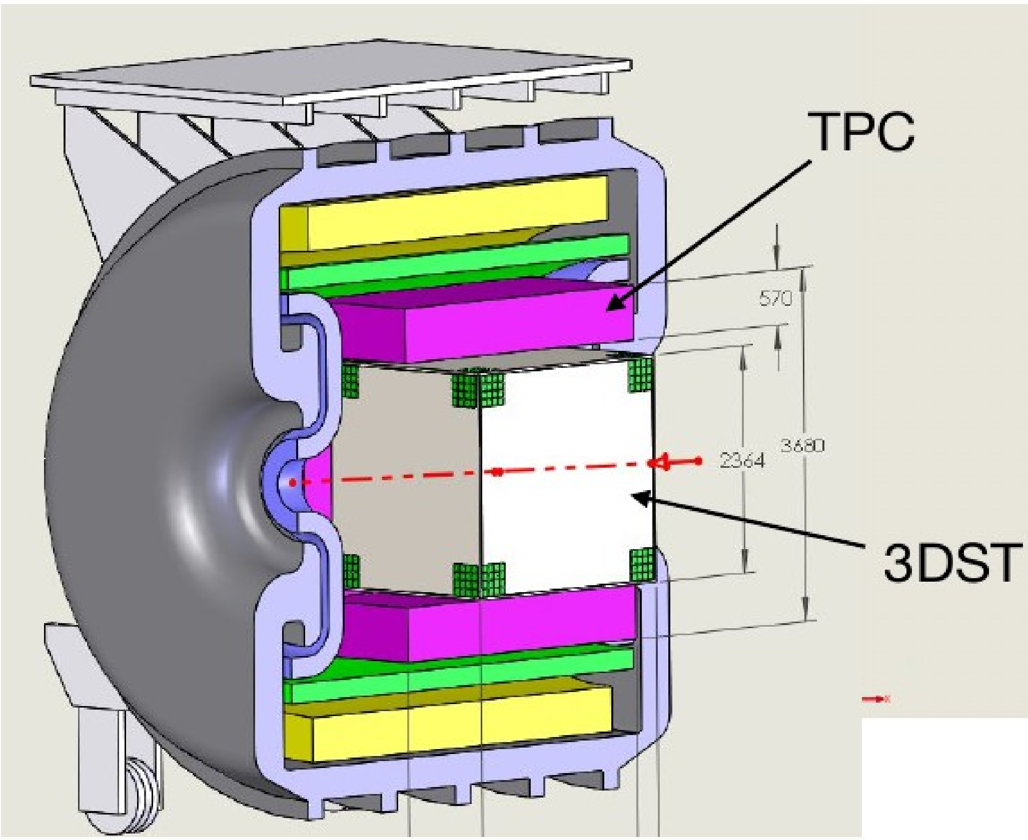
CERN prototype performances (2)





Even better results at DESY with final pad design (10x11mm^2) and improved RC (500 kΩ/square)
(preliminary spatial resolution ~200um → factor 3-4 better than present TPCs)

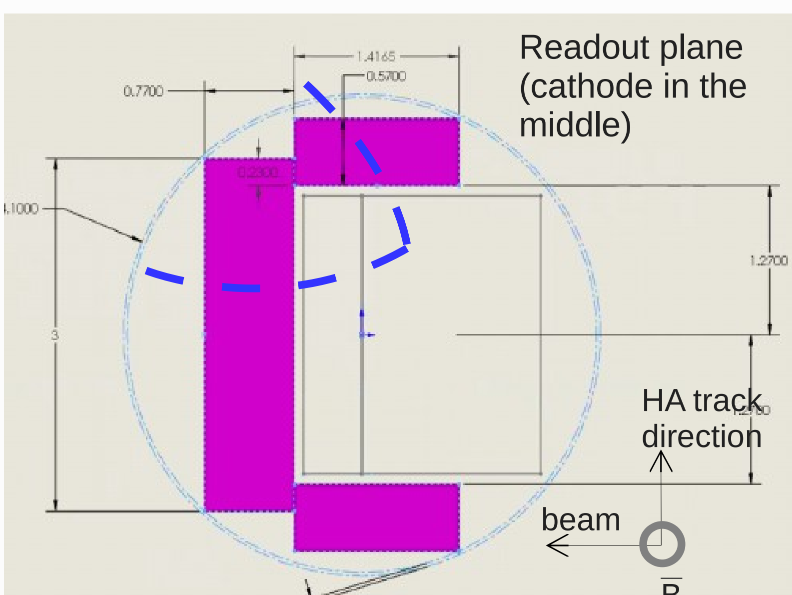
SAND TPCs



Resistivity and pad size can be adjusted to match the SAND needs, given the E_{ν}, magnetic field and space available

- Important to have small B non-uniformities and small $B_{r\phi}$ component, (in general less harsh requirements for TPC equipped with MPGD than drift chambers)
- Geometry:

  3 rectangular TPCs with readout planes: 2 x 2 x (57 x 141)cm^2 ; 2 x(300 x 77)cm^2 ~ 8m^2

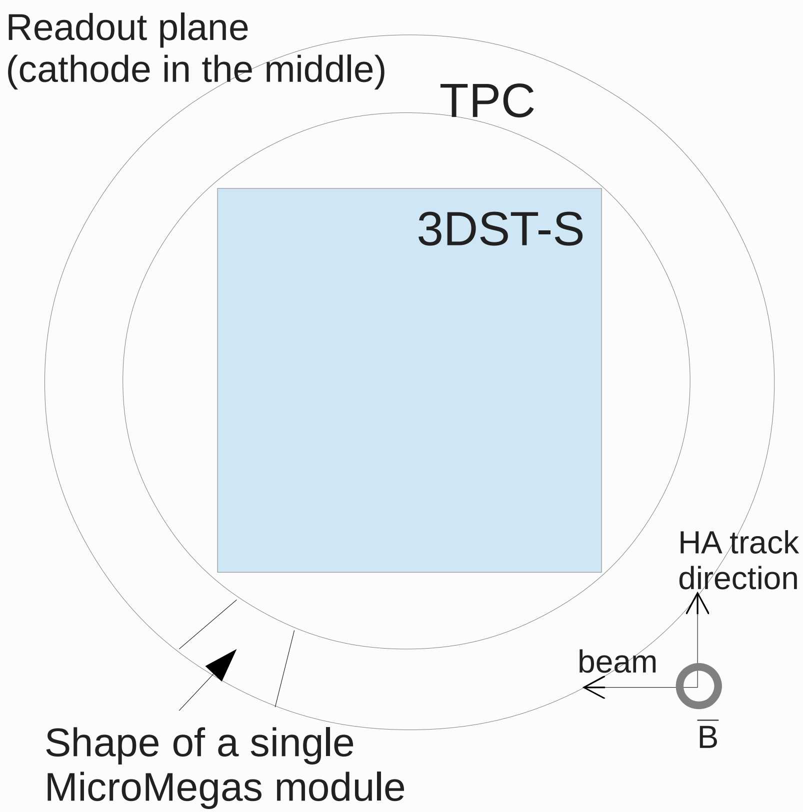


- Using ~1*1.1 cm^2 pads and RC as ND280 upgrade (200 um point spacial resolution):

  71K channels→ few % resolution @ 3 GeV

Pad size and RC can be optimized to improve resolution vs # electronics channel for fwd/HA TPCs:
eg for 10% resolution ~20-30k channels should be enough

Cylindrical geometry



Keeping the same geometry/mass for 3DST-S
Keeping the same overall envelope
→ cylindrical TPC

- field cage: easier to have uniform electric field
- ~40 cm thick (readout planes ~ 8m^2): resolution~8% at 3 GeV
  with 1x1.1cm2 pads and same RC (~200um resolution)
- Full angular coverage: backward tracks with lower momentum and lower occupancy: can use larger pads → less channels

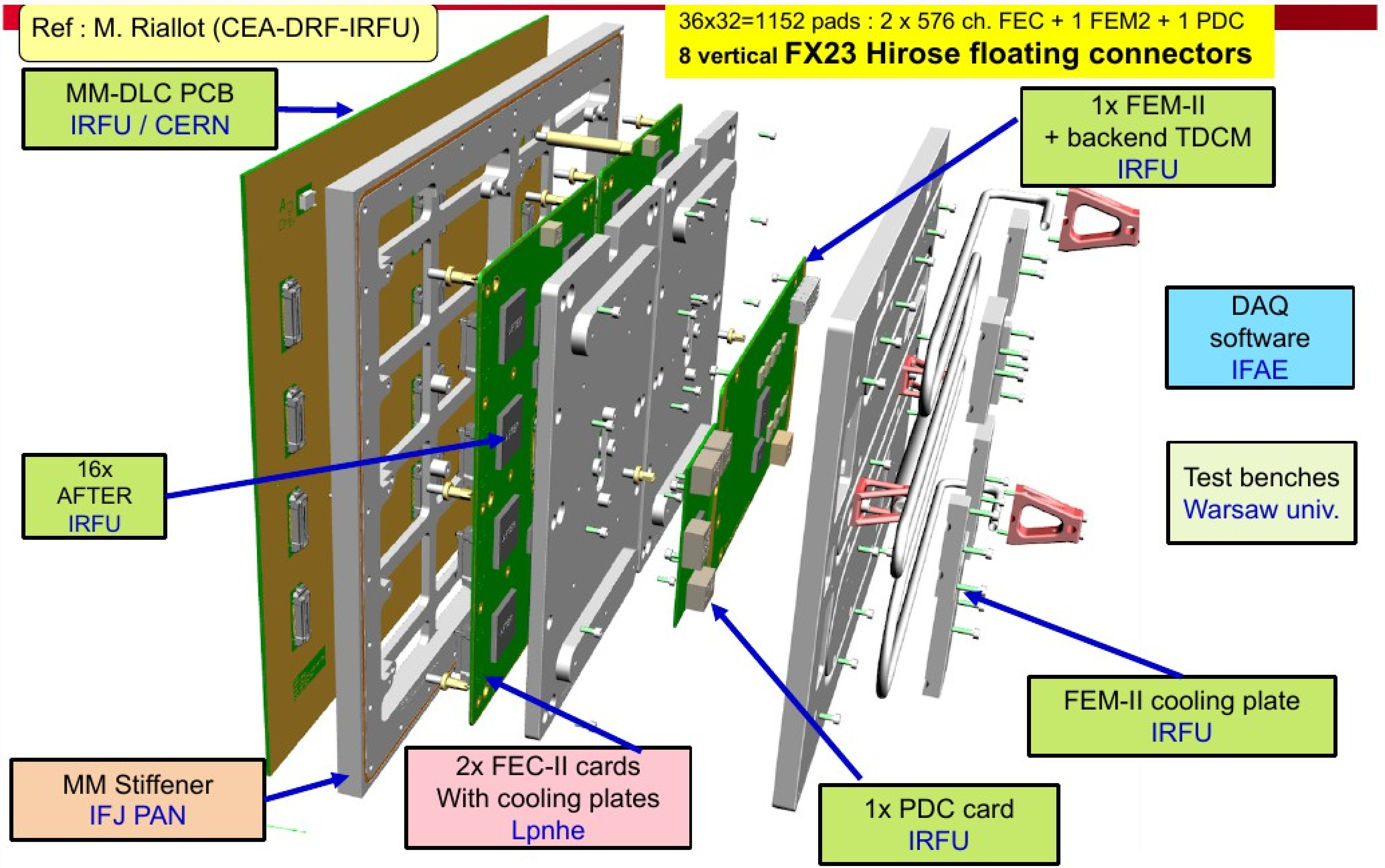
Empty spaces between TPCs and 3DST-S: can be filled with additional cubes or other materials
→ gain in target mass

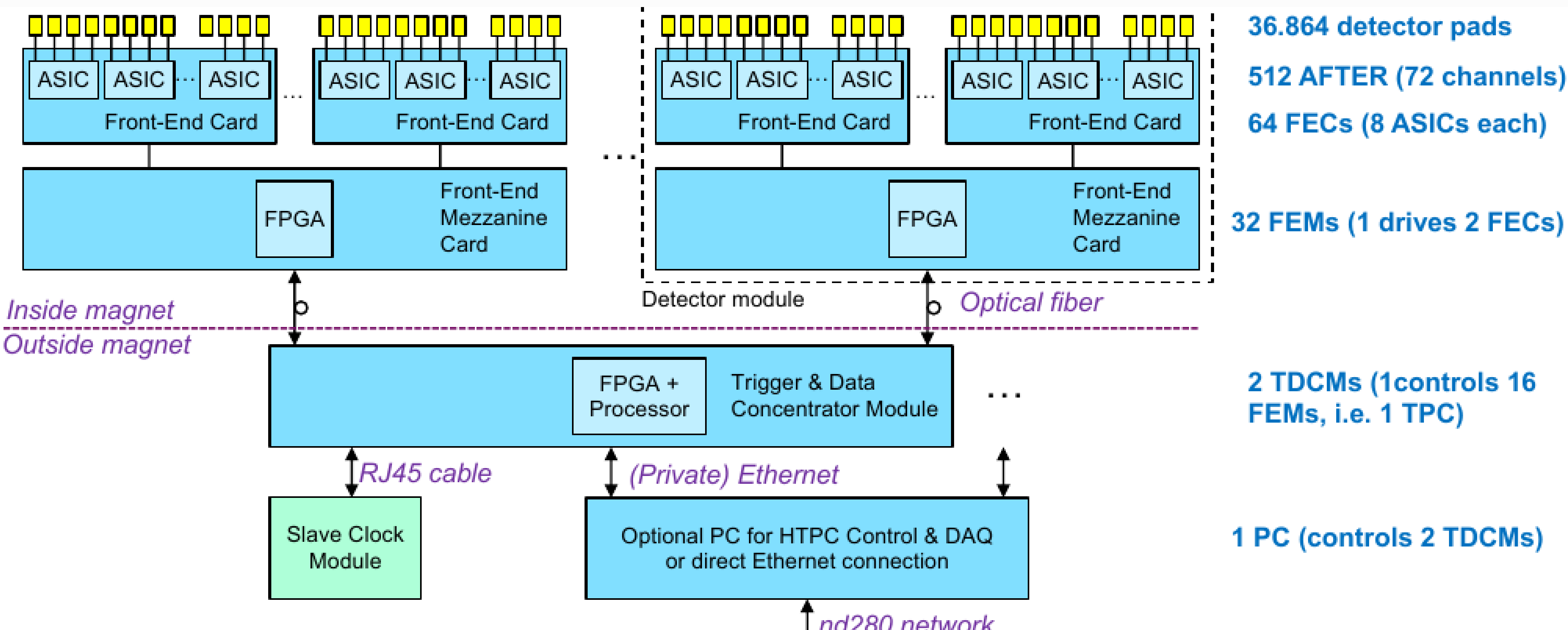
Simulation studies to optimize the design and tests of dedicated MM modules with different pads sizes and different values of RC

Conclusions

- TPCs are a robust detector with good performances which have proven to be a **crucial ingredient in T2K physics**
  - **Great experience** on building/installing/maintining it at IRFU (and in ND280 community in general)
  - **Very smooth production and 10 years of running** have shown the astonishing stability and reliability of such detector
  - On-shelf **TPC dedicated electronics** already developed
- The resistive Micromegas allows to tune the resolution vs number of channels by playing on RC and pad size to adapt the design to DUNE/SAND needs
- A cylindrical geometry may be more adapted to KLOE magnet: more easy to build/operate, larger acceptance, may allow to increase the 3DST-S mass

Back-up


Ref : M. Riallot (CEA-DRF-IRFU)
36x32=1152 pads : 2 x 576 ch. FEC + 1 FEM2 + 1 PDC
8 vertical FX23 Hirose floating connectors
MM-DLC PCB
IRFU / CERN
1x FEM-II
+ backend TDCM
IRFU
DAQ
software
IFAE
16x
AFTER
IRFU
Test benches
Warsaw univ.
FEM-II cooling plate
IRFU
MM Stiffener
IFJ PAN
2x FEC-II cards
With cooling plates
Lpnhe
1x PDC card
IRFU



Ref : D. Calvet (CEA-DRF-IRFU)
IEEE, Real Time 2018
arXiv 1806.07618

Main concepts

- AFTER chip designed for T2K (511 bucket SCA sampling@25 MHz, 120fC-600 fC, 100ns-2μs peaking time)
- New FEC with 8 AFTER chips which digitizes pad signal with an 8 ch. ADC (minimum dead time of 3.3 ms)
- FEM provides control (&trigger), synchronization, data aggregation, data buffering & data zero suppression
- The TDCM is a generic clock and trigger distributor and data aggregator (FPGA+2 xilinx CPU+1 GB DDR3)