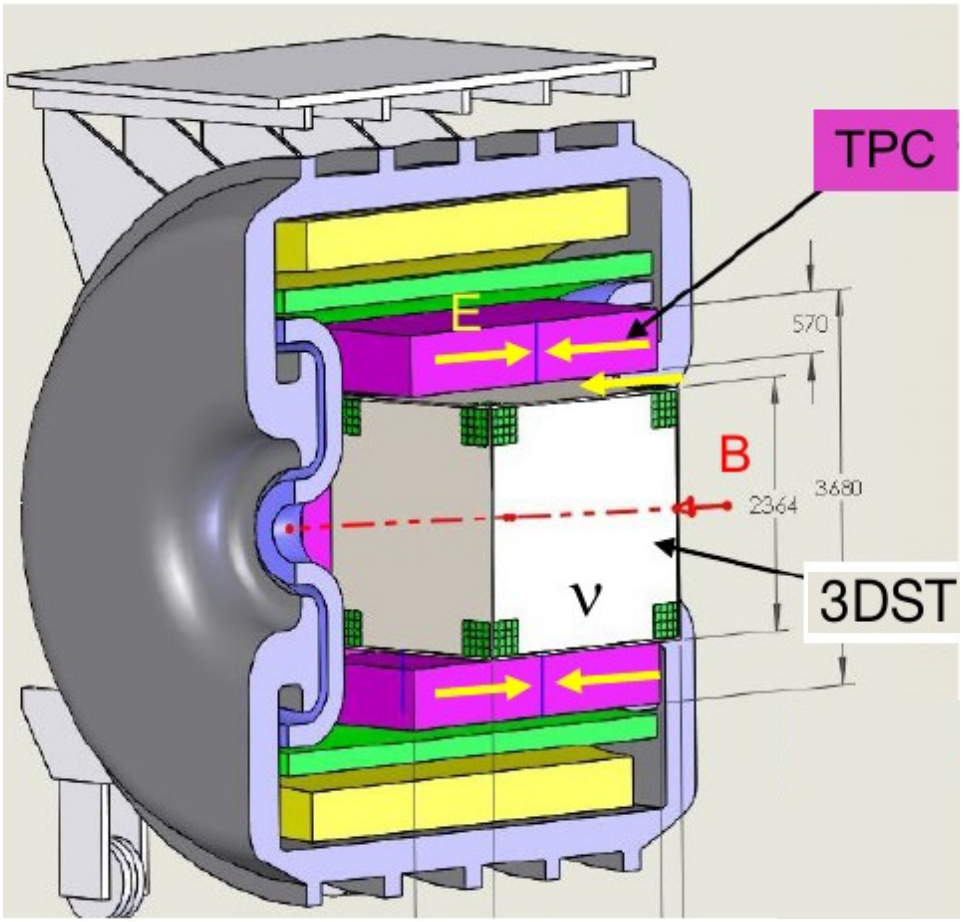
Time Projection Chambers with MPGDs for SAND

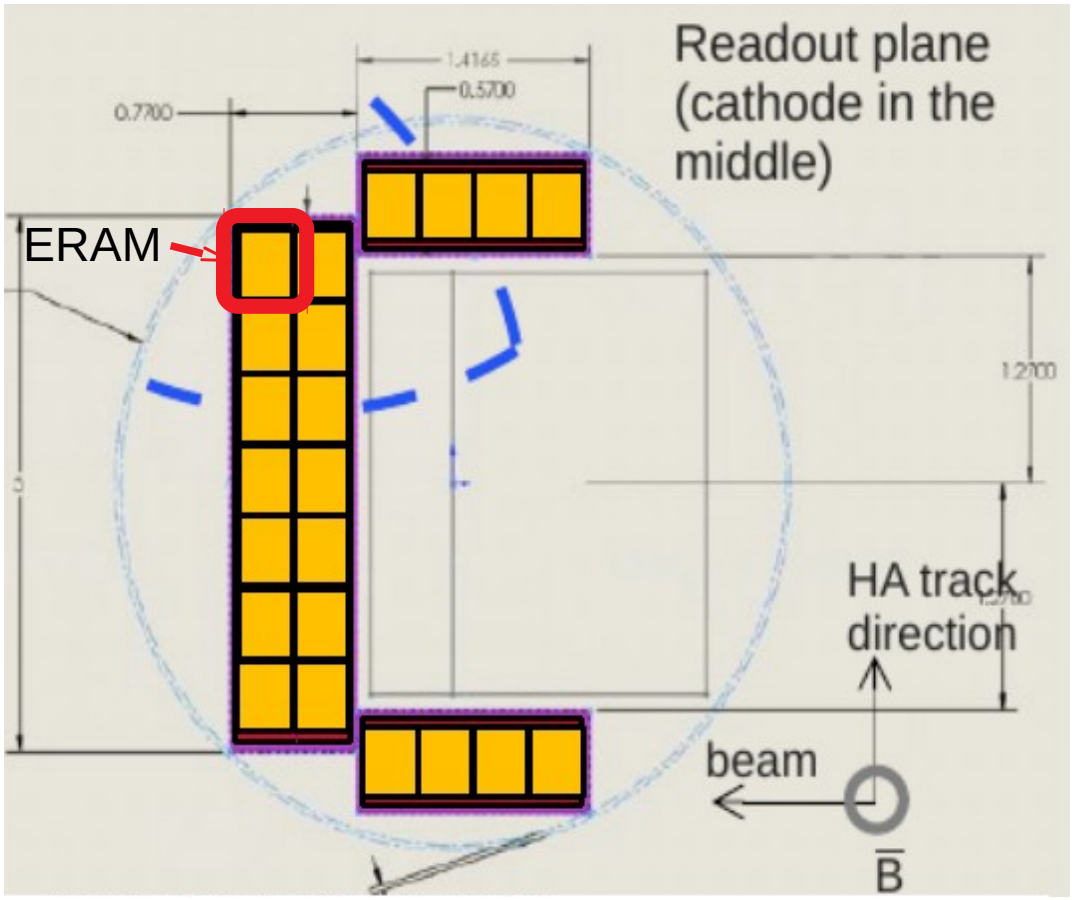
S. Bolognesi, A. Delbart, **G. Eurin**, P. Granger, S. Hassani (IRFU, CEA)

for the DUNE SAND group

DUNE CDR: Near Detector Review – 09 July 2020

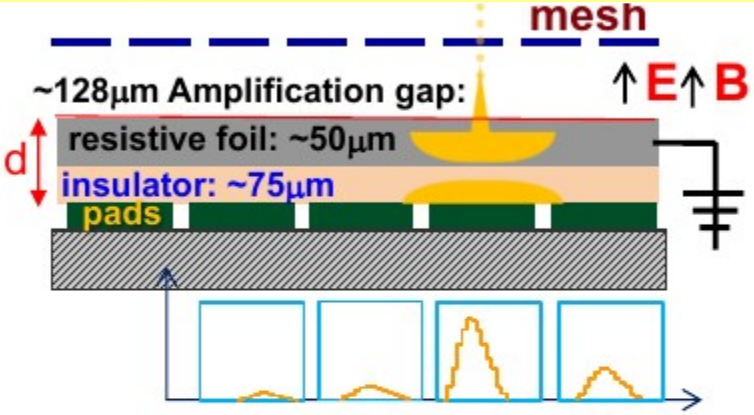
SAND TPCs from ND280-Upgrade



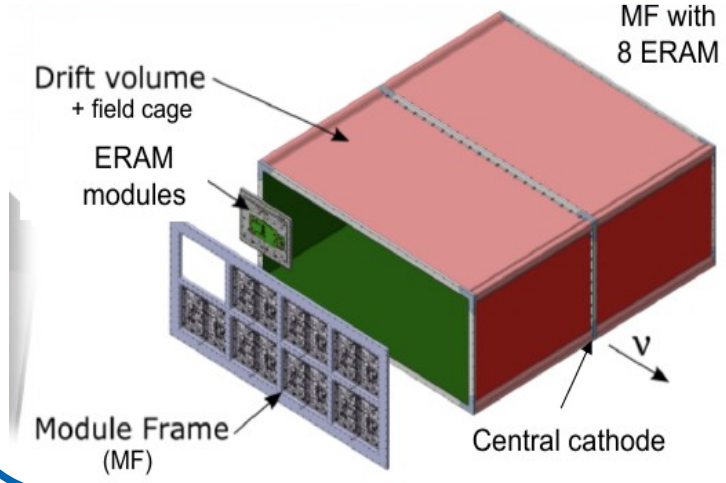


- **Momentum reconstruction:**
  Momentum resolution: ~3 % depends on magnetic field, pads numbers and size
  Momentum scale: ~2 % depends on uniformity of Bfield, Efield, alignment → can be calibrated
- **Particle identification through dE/dx:**
  Energy resolution: ~10 % (~45 % more ionization for electrons than muon/pions)
- **Detectors which we know how to build and which proved stable over time**

The detectors: ERAM (Encapsulated Resistive Anode bulk Micromegas)



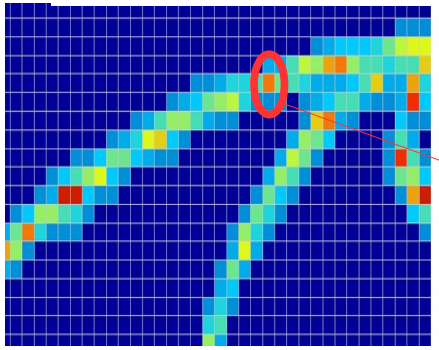
- **TPC for ND280-Upgrade**

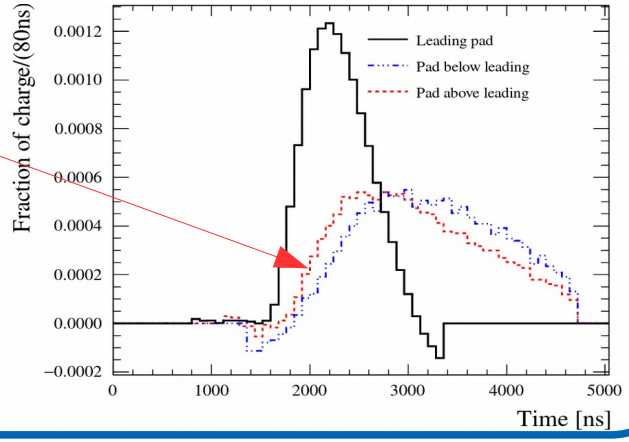


- **Charge spreading over multiple pads with DLC (adjustable via RC)**

$$\sigma_r = \sqrt{\frac{2t}{RC}} \qquad \begin{cases} t \approx shaping\ time\ (few\ 100\ ns) \\ RC_{[ns/mm^2]} = \dfrac{180\ R_{[M\Omega/\blacksquare]}}{d_{[\mu m]}/175} \end{cases}$$

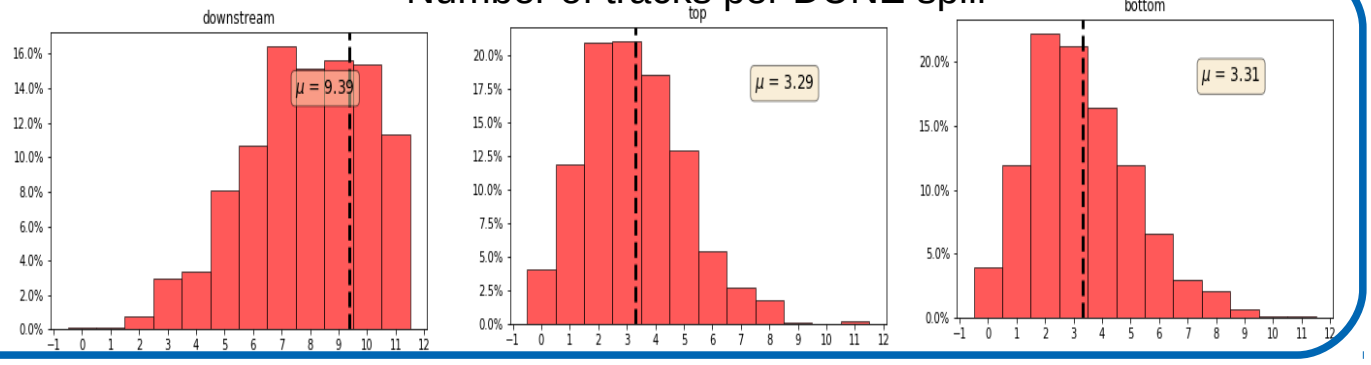
- **Test beam signal and event display**





- Study on-going for SAND: **optimization of pad granularity / resistivity**
  → optimization of resolution with SAND occupancy

Number of tracks per DUNE spill



Electronics

- **Main TPC characteristics**

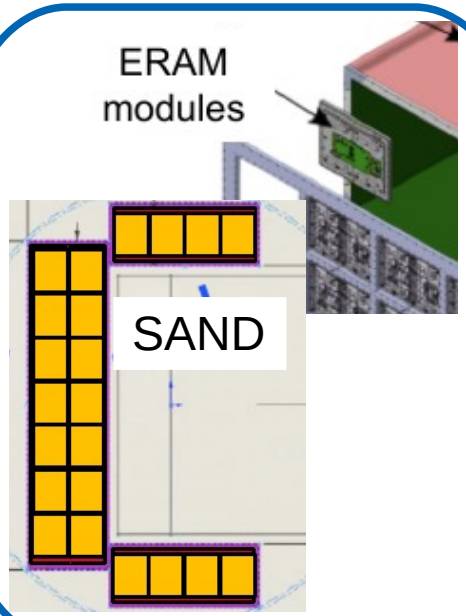
Parameter	Value	2x T2K/ HA-TPC	2+1 DUNE SAND
Overall x × y × z (m)	2.0 × 0.8 × 1.8		1,41 x 0,57 x 2,3 0,77 x 3 x 2,3
Drift distance (cm)	90		
Magnetic Field (T)	0.2		
Electric field (V/cm)	275		
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2		
Drift Velocity $cm/\mu s$	7.8		
Transverse diffusion ($\mu m/\sqrt{cm}$)	265		
Micromegas gain	1000		
Micromegas dim. z×y (mm)	340x420 (32)		340x420 (44)
Pad z × y (mm)	10 × 11		10x11
N pads	36864		50688
el. noise (ENC)	800		
S/N	100		
Sampling frequency (MHz)	25		
N time samples	511		

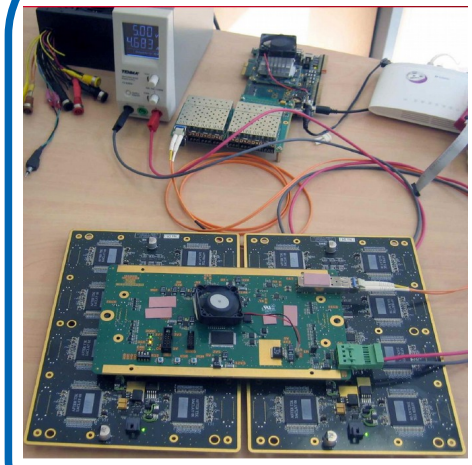
- **First estimates for SAND:**

Downstream TPC: 300x77 cm^2
→ 28 (2x14) ERAM (42x34 cm^2)

Top/bottom TPCs: 2 x 57x141 cm^2
→ 16 (2 x 2x4) ERAM (42x34 cm^2)

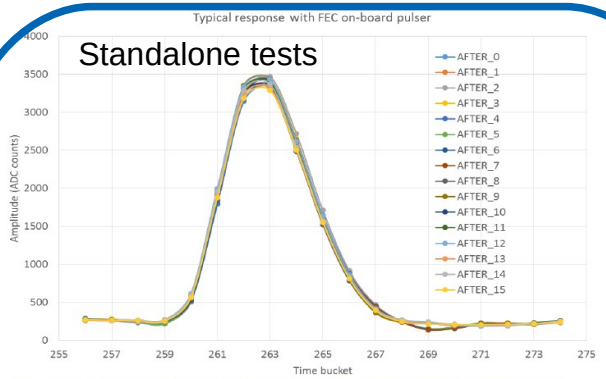
Total:
1152 pads/ERAM
→ 50688 channels
→ ~1000 ASICs

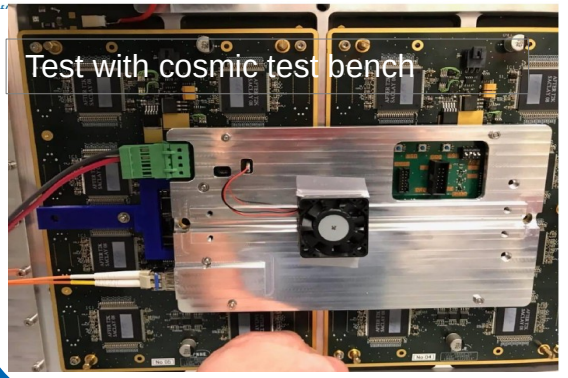




1 ERAM from ND280-Upgrade:

2x8 ASICs
2 Front-End Card
1 Front-End Mezzanine Card





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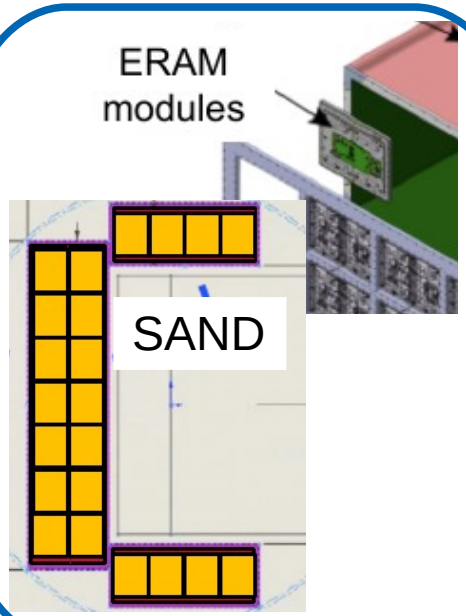

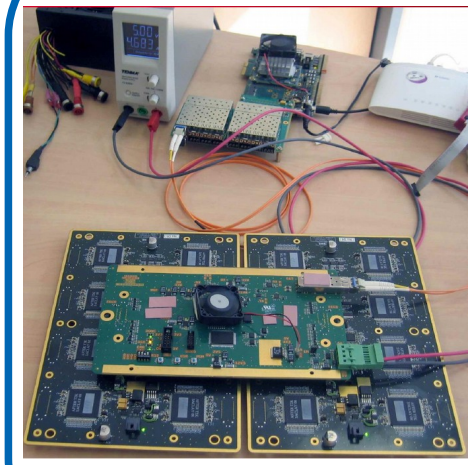

1 ERAM from ND280-Upgrade:

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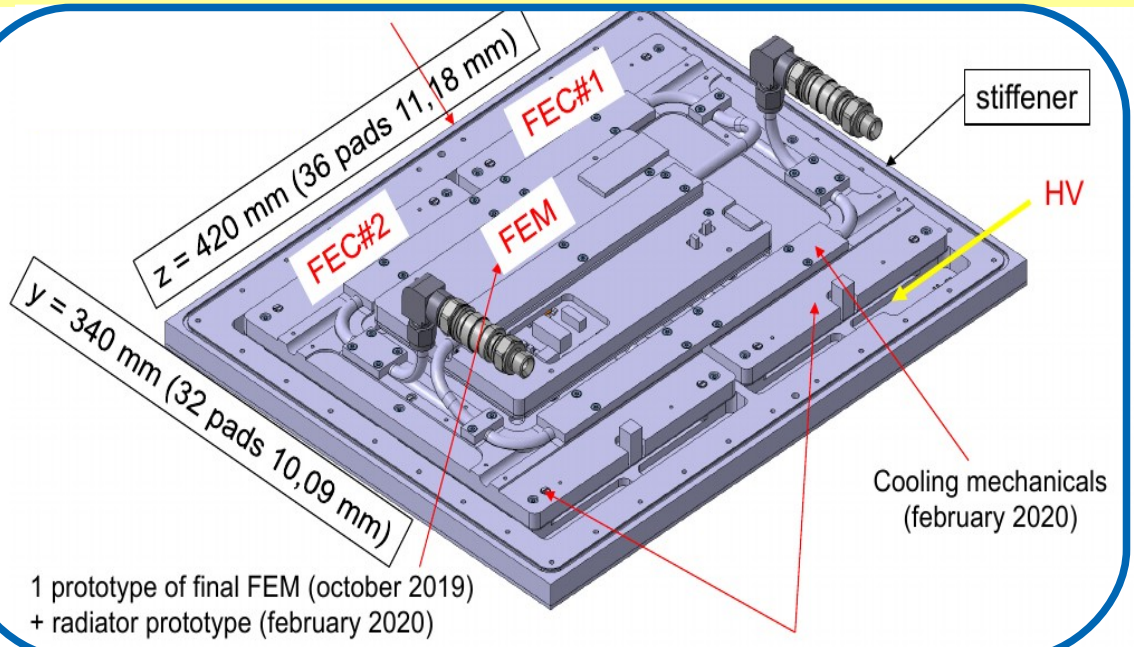
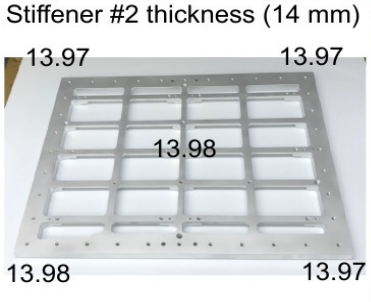
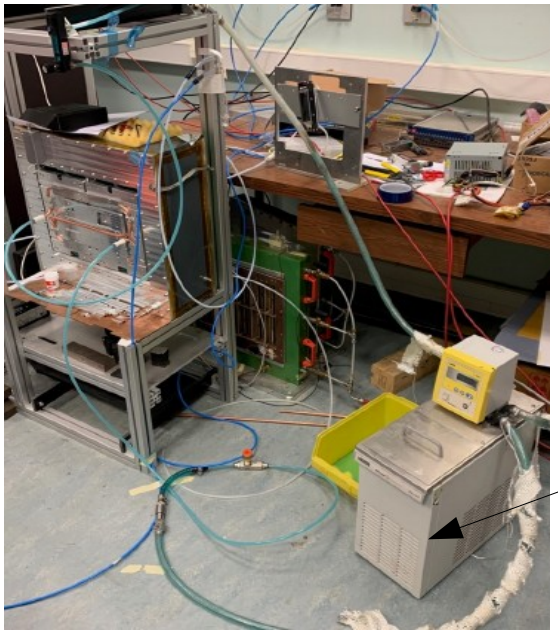
Back-End: 1 TDCM per ND280-Upgrade TPC

ND280-Upgrade design and prototyping
Mechanics / electronics cooling



- Full test of assembly procedures

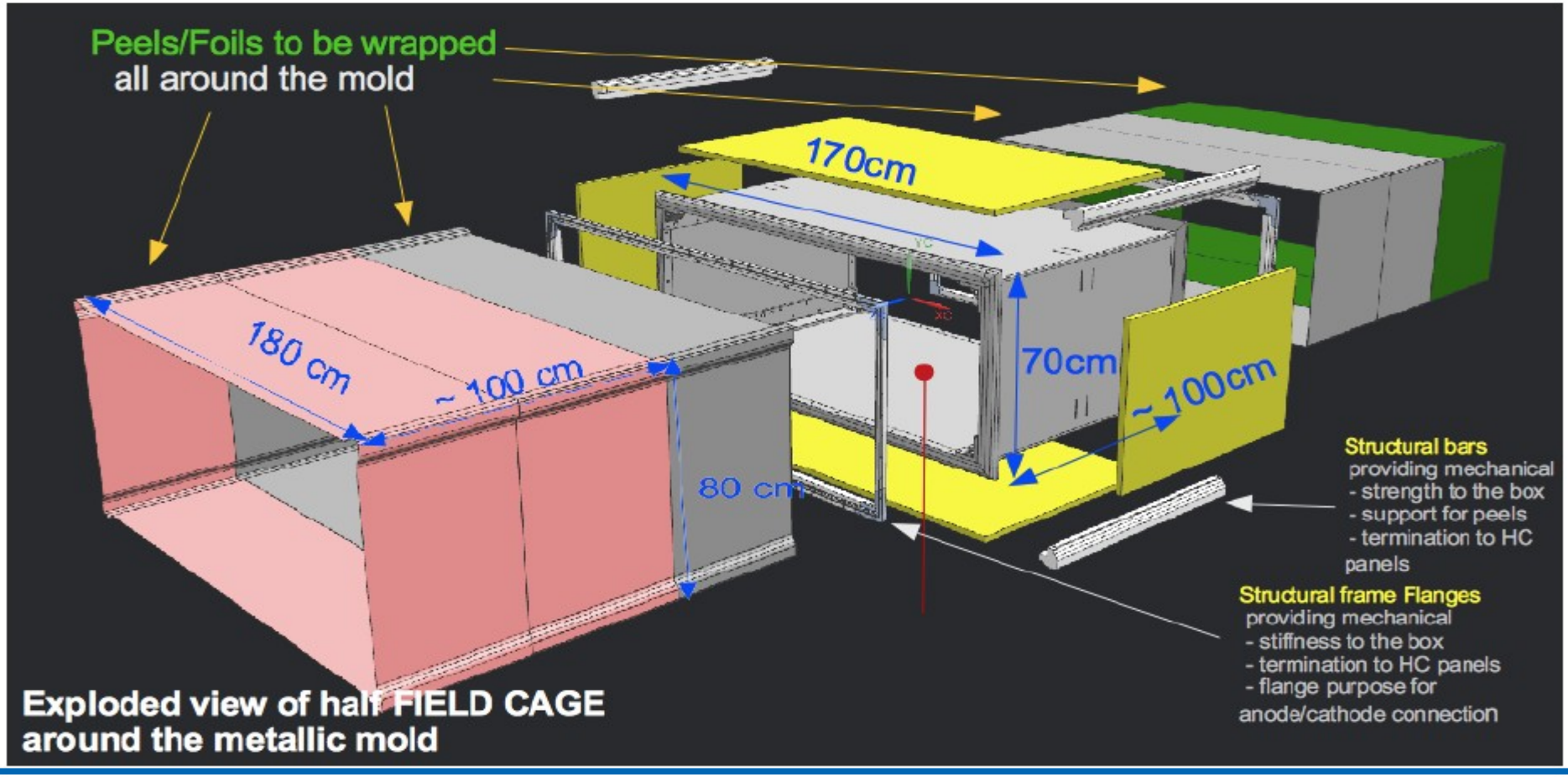




- Cooling tests with new chiller at Saclay
- **Re-usable for SAND tests**

ND280-Upgrade field cage (INFN Padova-Bari)

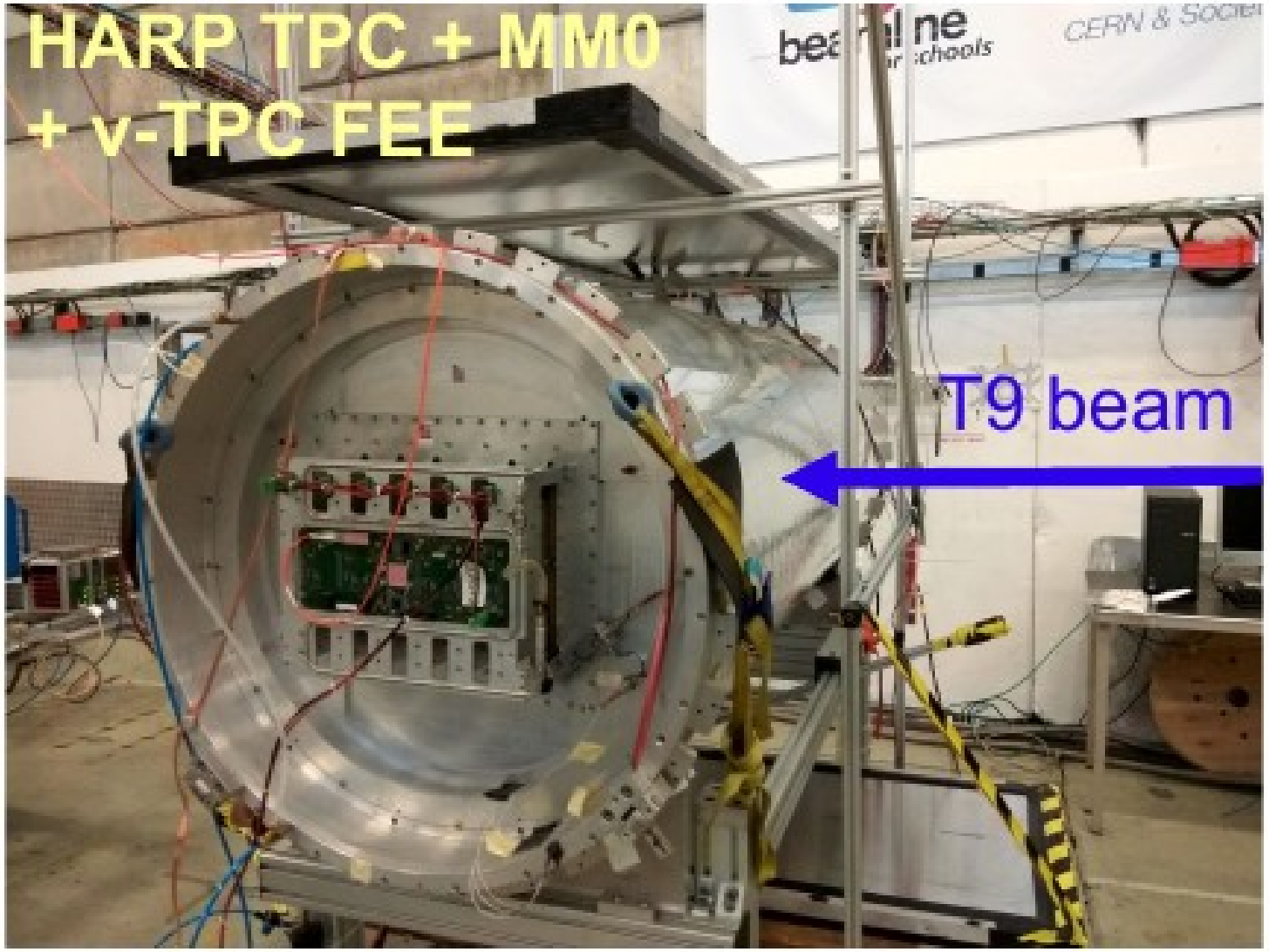
To keep $^{\Delta E}/_{E} \leq 10^{-4}$ confined at <1cm from FC walls, the TPC cage requirements are :
Cathode flatness better than 0.1mm, Micromegas plane flatness better than 0.2 mm,
Cathode/Anode planes parallel to within 0.2mm, Field Cage walls flatness better tham 0.3mm
Voltage divider resistors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



- 2nd prototype being developed for testing at DESY by end of 2020
- Installation scheduled for 2022 at ND280

Prototyping for ND280-Upgrade

- Test beam at CERN (2018): first prototype with large pads and resistive micromegas



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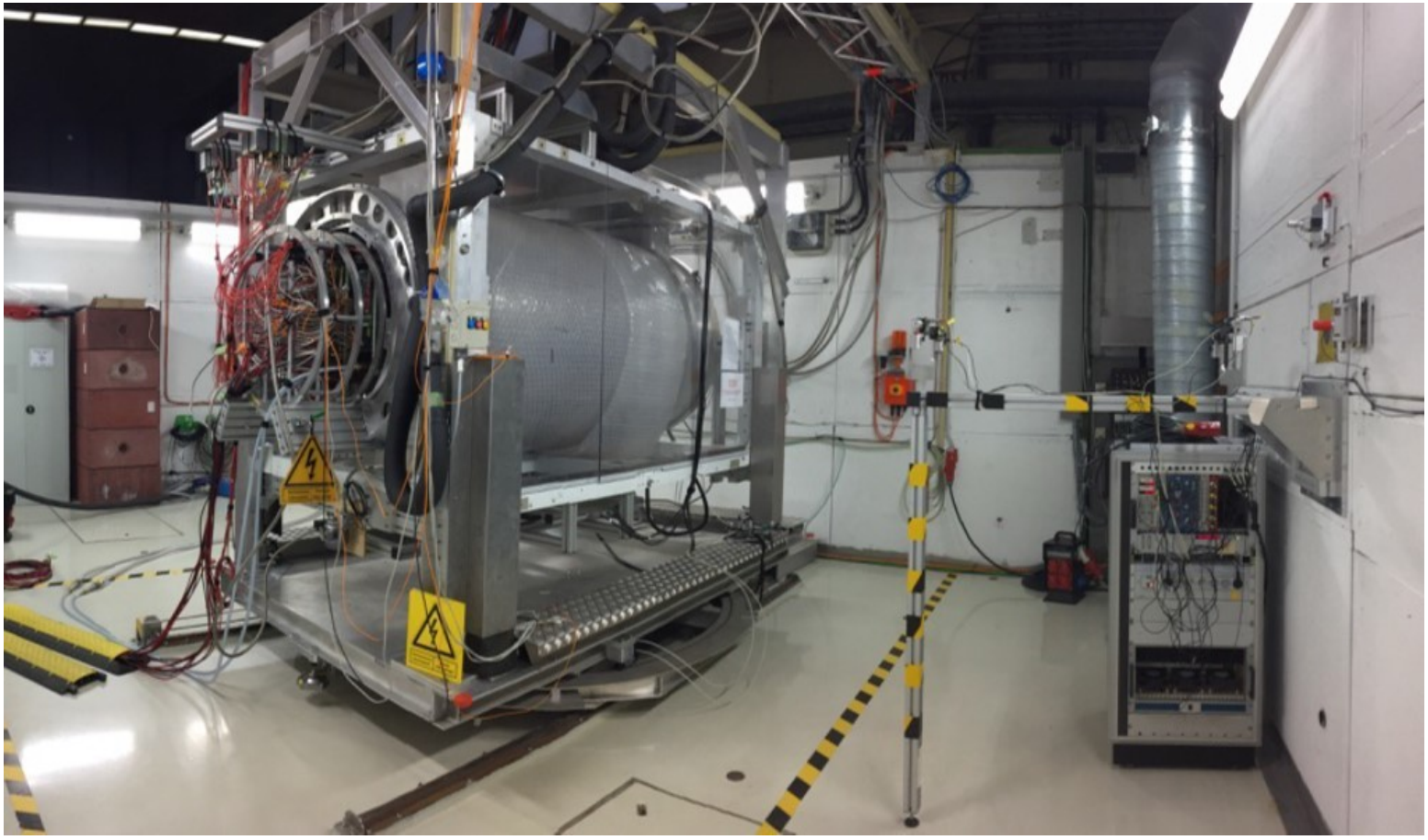

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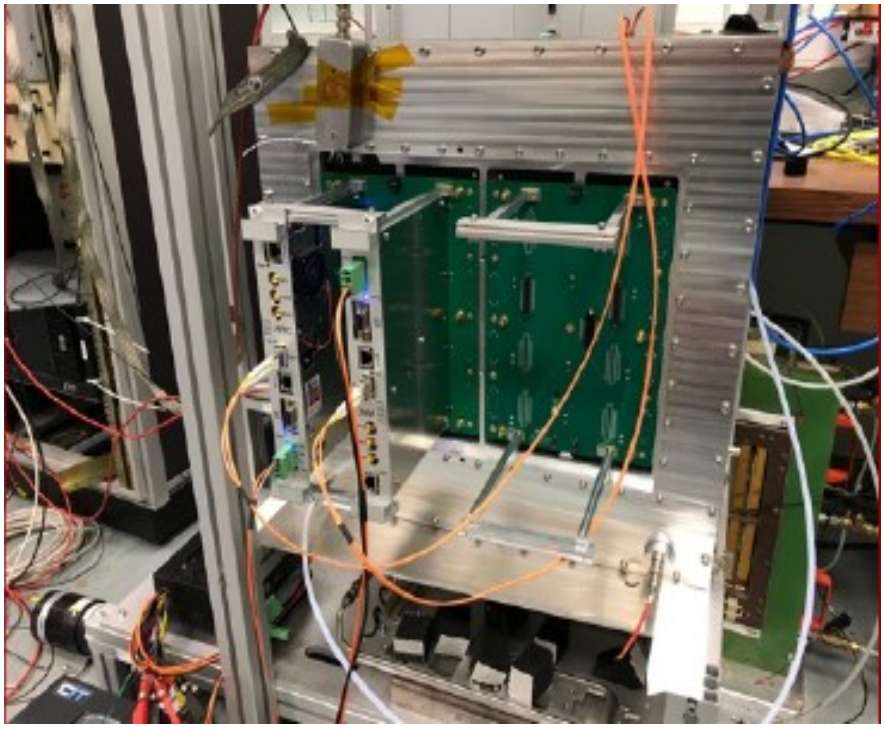

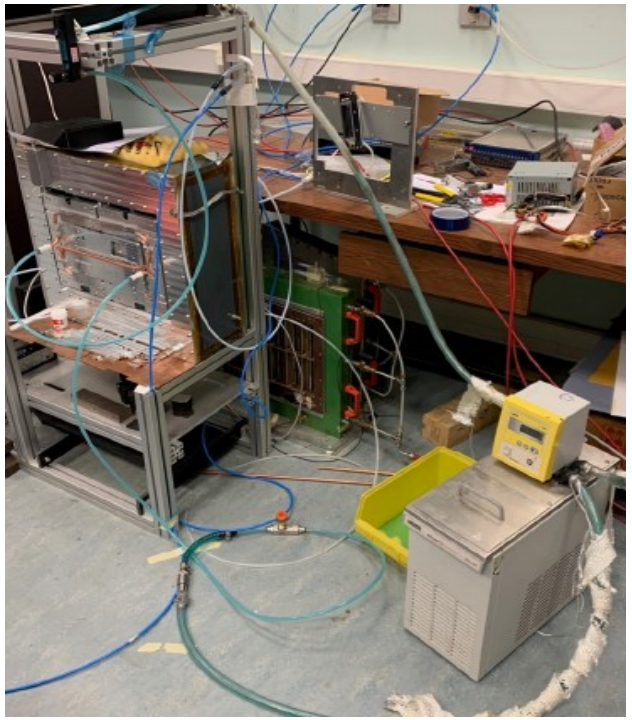

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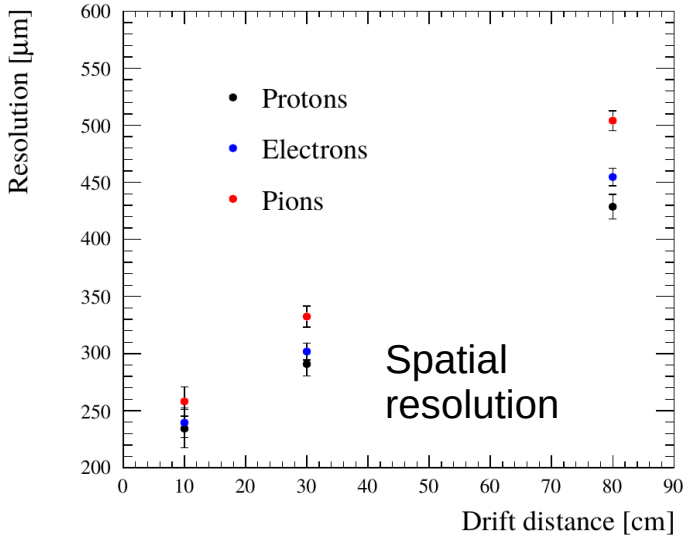
A lot of expertise developed and an infrastructure already built

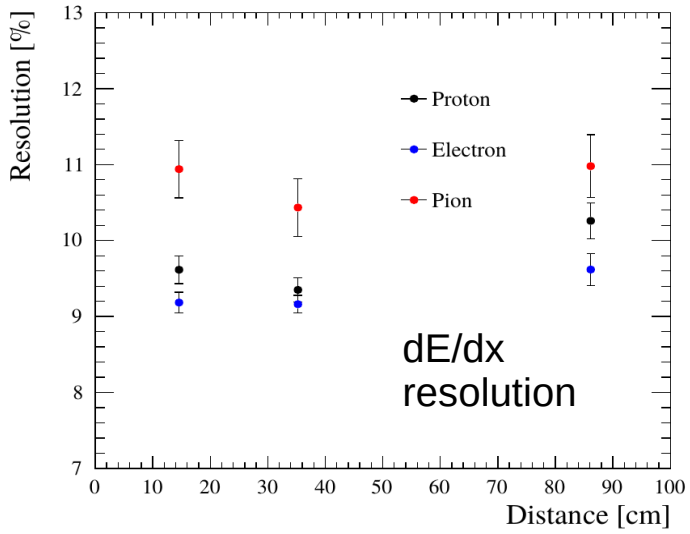
SAND dedicated prototyping:

- new pad size and RC values: resistivity of DLC foil + glue thickness
- can be installed in Saclay cosmic bench (PMTs for trigger, gas, cooling, electronics, DAQ, … and even analysis code!)

Performances

- Results from **prototype at CERN in 2018**: without pad size and resistivity optimization

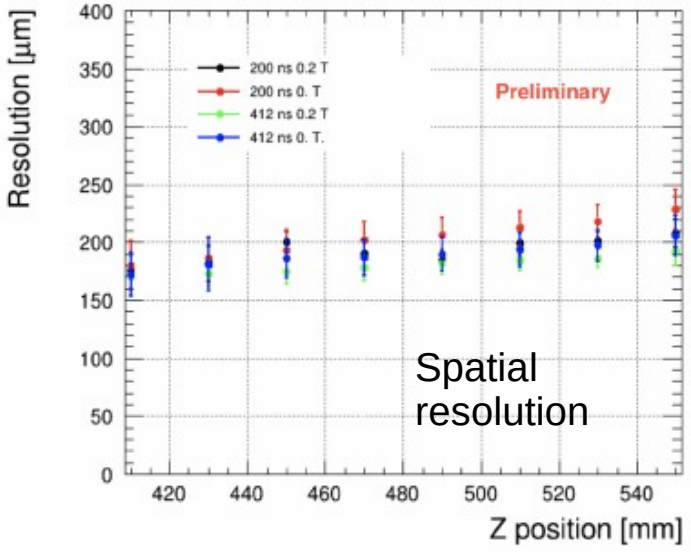


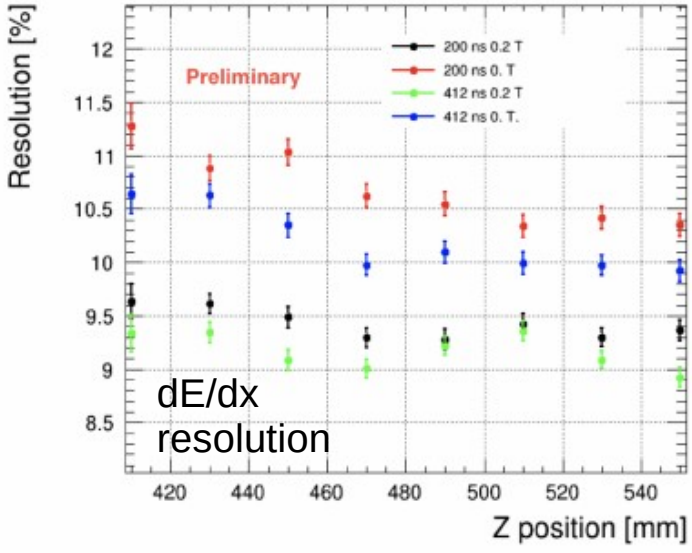


Nucl.Instrum.Meth.A 957 (2020) 163286

- Improved results at **DESY in 2019 with final pad design and improved RC**

=> preliminary spatial resolution 3-4 times better than present T2K TPCs





arXiv:2005.05695

Production prospects

- Micromegas and electronics production for T2K (not resistive) TPC from 2005 to 2009 was very successfull

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: amazing stability with only 1 FEM failure and 2HV filters to repair

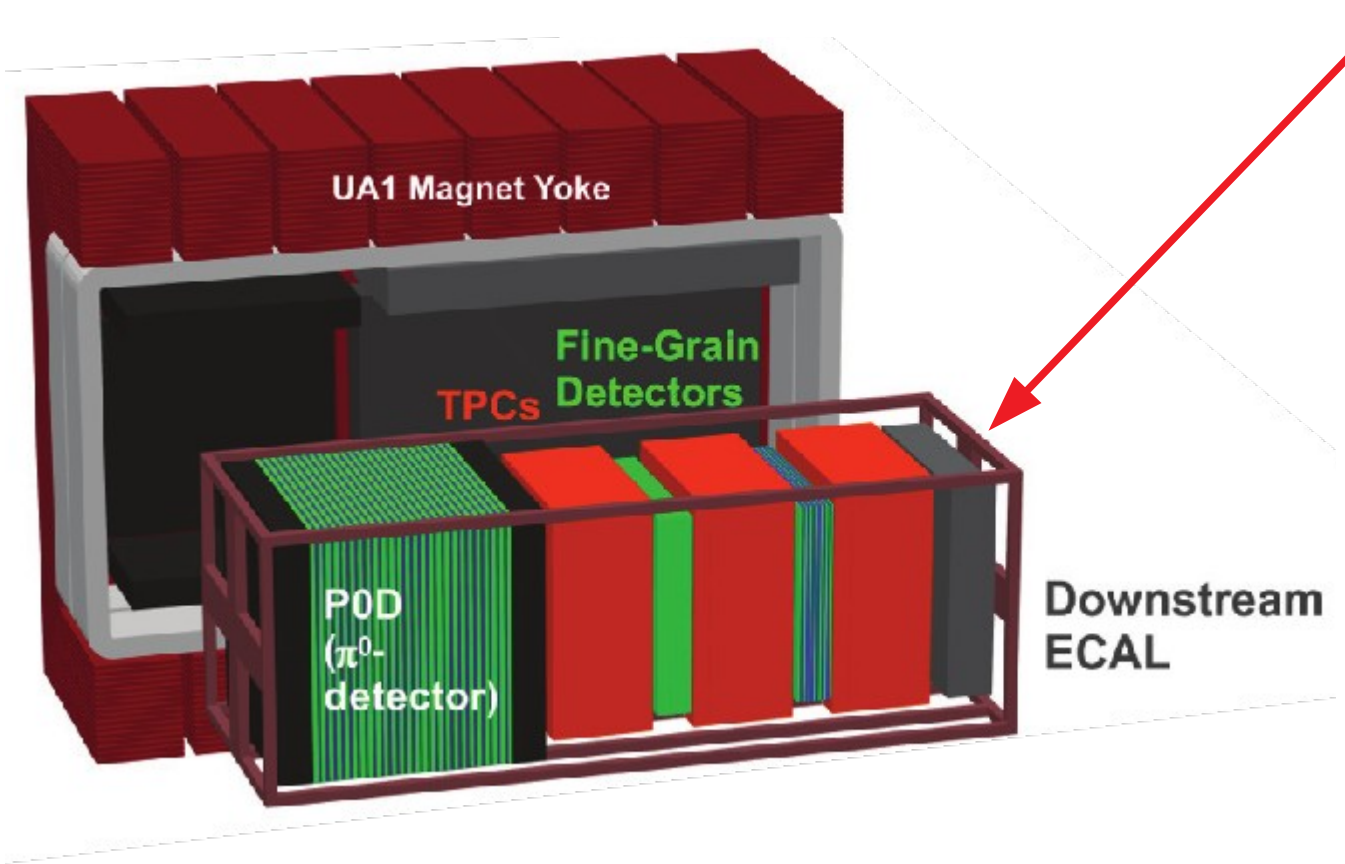
- The Resistive Micromegas (ERAM) is a **bulk-micromegas: mature technology, mastered by CERN, IRFU & some PCB industrials**

→ **series production of ERAM detector & its Front-End Electronics (FEC & FEM)** planned to start at the end of the year for ND280-Upgrade

→ will **secure the path for production for SAND (DLC procurement, production yield, ...)**

Installation and interface

- One possibility: stainless steel 316Ti frame container a la T2K, the so-called “basket”



- Would provide a global structure inside KLOE for the ERAM detectors, the TPCs, etc.
- 3DST could be installed inside such a metal frame
- Cooling of the electronics designed to operate in KLOE along with other SAND components

Schedule

- Current development plan for SAND based on ND280-Upgrade experience:

	2021	2022	2023	2024	2025	2026	2027
ND SAND	R&D for TDR & techno choice	Prototype desing & tests for techno. Choice		Pre-Production / Production / assembly / tests			ND installation
SAND simulations	Conceptual design	Physics simulations					
IRFU SAND ASIC	generic ASIC 130 nm design	SAND TPC ASIC 1st proto	2nd prototype	Mask production	Chip production & QA/QC		
TPC vessel (incl. Cage & R&D)	Conceptual design	R&D / prototypes	Detailed design	Full scale prototype 1/2	TPC production		Installation
ERAM	Conceptual design	R&D prototype	Detailed design Full scale proto	pre-production for 1/2 TPC#1 &	ERAM production		
FEE	CDR global architecture based on T2K upgrade	pre-design	Detailed design	FEE V1	1/2 TPC#2 Pre-production & Final FEE production		
Backend		pre-design	Detailed design	Backend V1	1/2 TPC#2 Pre-production & Final backend production		DAQ integration
Services (HV, LV, FO, cables, ...)					Specifications	Procurements	Installation
FEE cooling (incl. Global system)			conceptual design	conceptual design proto for 1/2 TPC	Final FEE cooling production		Installation

- Major steps taken into account, will be updated as design and installation progress

Summary

- **The expertise and infrastructures developed** for ND280 vertical TPCs and ND280-Upgrade horizontal TPCs are a phenomenal advantage in the path to build SAND TPCs

- **On-going studies to adapt the design to produce prototypes to be installed on Saclay cosmics test-bench**

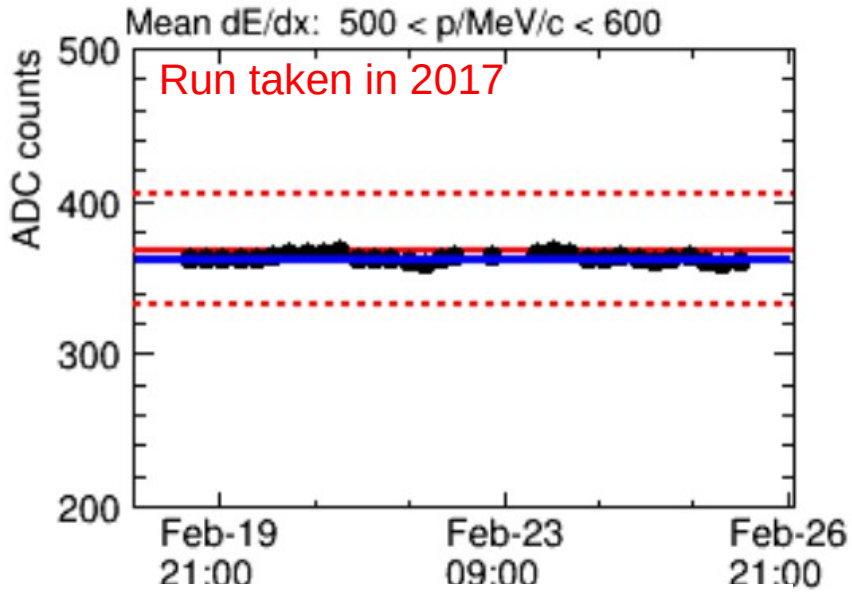
- Clear path to design and build ERAM, electronics, mechanics, infrastructures (gas, cooling, ..)

- Preliminary cost estimates (very detailed thanks to ND280-Upgrade expertise → rescaled to SAND size) is of the order of **2M€**

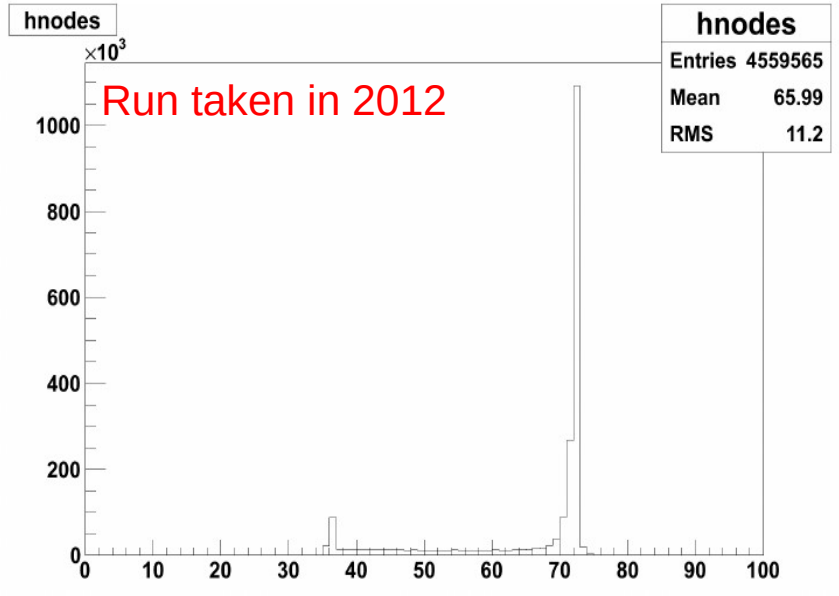
- For additional information: sara.bolognesi@cea.fr & alain.delbart@cea.fr

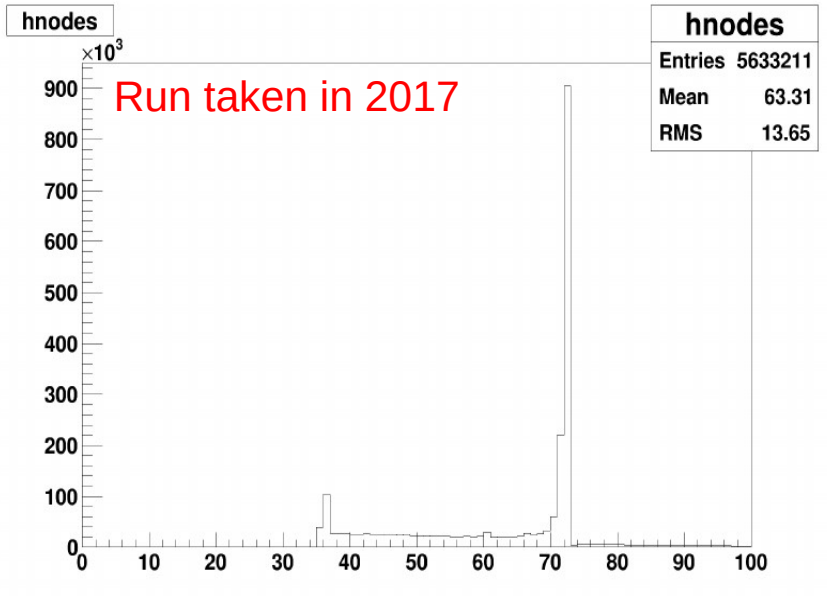
Astonishing stability/reliability in 10 years for T2K

Mean dE/dx from cosmics



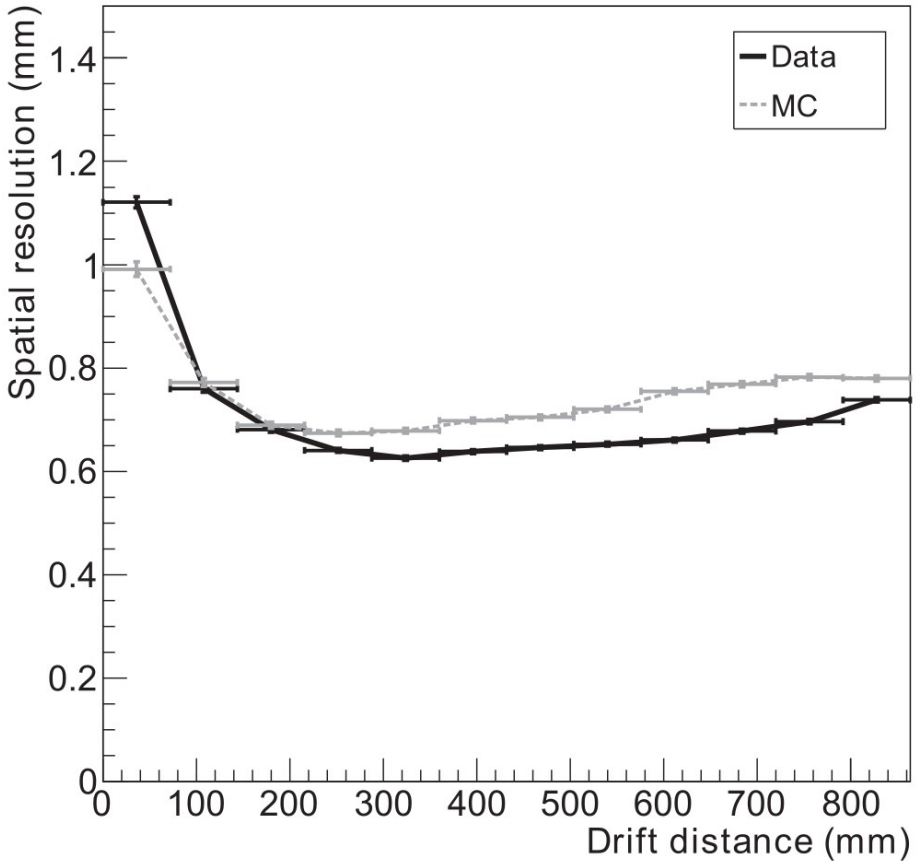
Number of hits per track



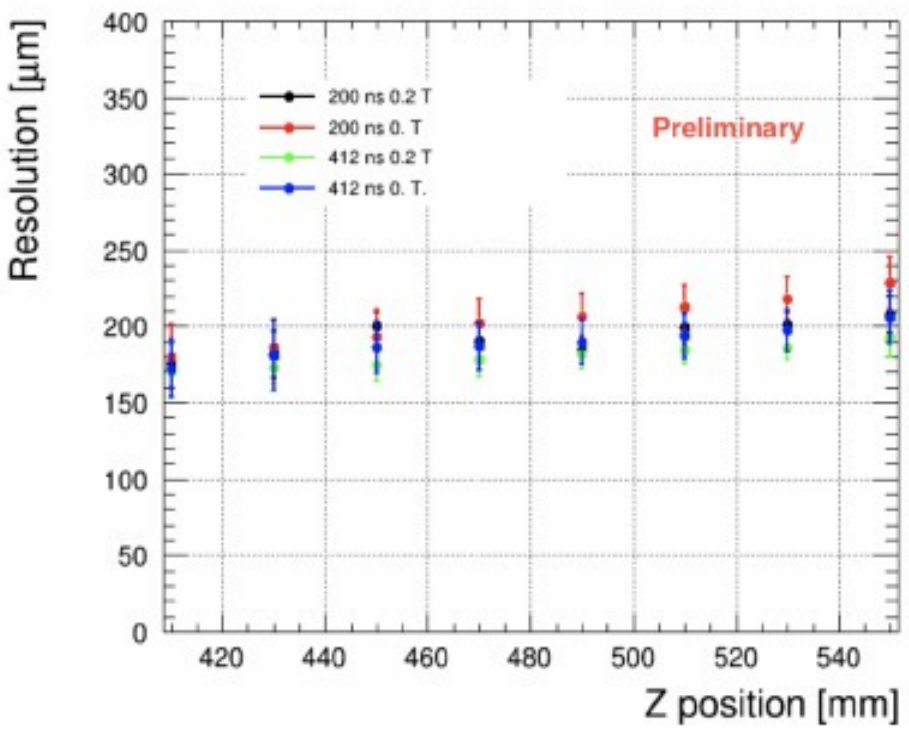


Improvements from T2K-ND280 to SAND

- **Spatial resolution for T2K TPCs**



- **Spatial resolution for ND280-Upgrade MM1 design**

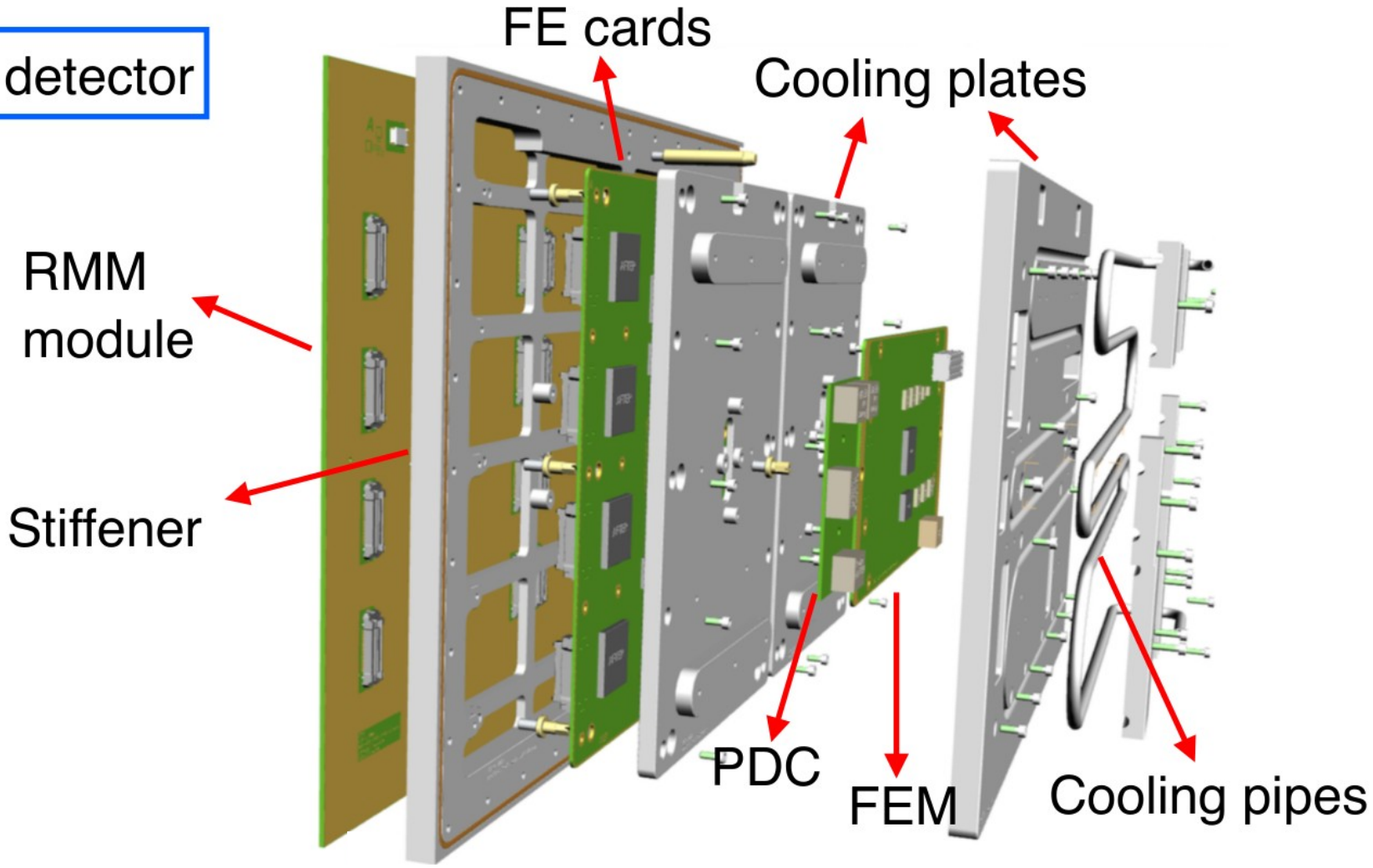


- **For SAND, magnetic field 3 times larger than for ND280 (0.2 → 0.6 T)**

- **Better spatial resolution and larger magnetic field**
  => Momentum resolution 10 % → 2-3 %

Electronics for the ERAM detector

FE on back of detector



Sensitivity to beam changes

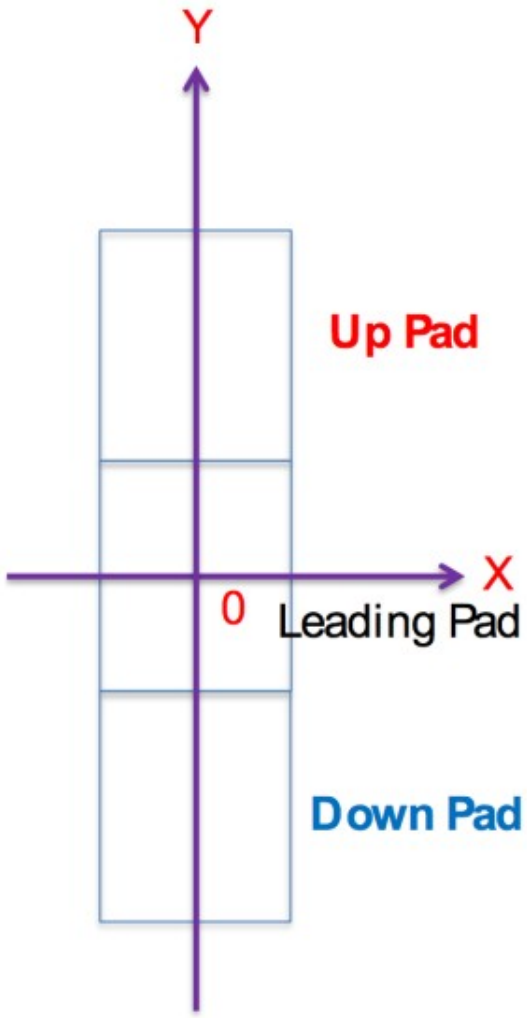
- Assuming an ECAL + 3DST + TPC configuration
- Rate-only monitor: four non-magnetized 7-ton modules for beam rate and profile at 0, 1, 2 and 3 meters from the beam axis position at the ND site
- Significance to the observation of a change in the beamline with 7 days data taking:

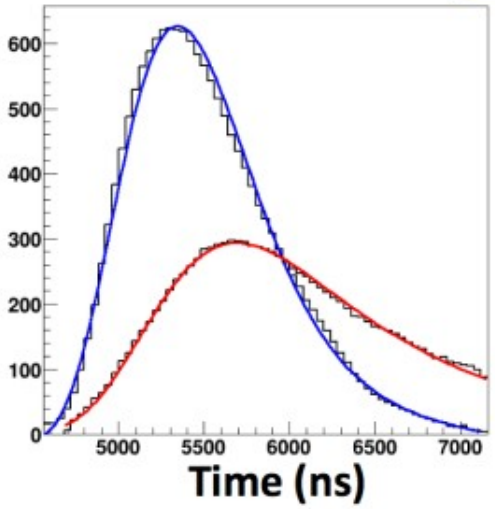
	Parameter description		Significance, $\sqrt{\chi^2}$	
Beam parameter	Nominal	Changed	Rate-only monitor	SAND
proton target density	1.71 g/cm^3	1.74 g/cm^3	0.02	5.6
proton beam width	2.7 mm	2.8 mm	0.02	3.6
proton beam offset x	N/A	+0.45 mm	0.09	4.3
proton beam *theta*	N/A	0.07 mrad	0.03	0.5
proton beam $\theta\phi$	N/A	0.07 mrad θ and 1.5707 ϕ	0.00	1.0
horn current	293 kA	296 kA	0.2	11.9
water layer thickness	1 mm	1.5 mm	0.5	4.2
decay pipe radius	2 m	2.1 m	0.5	7.0
horn 1 along x	N/A	0.5 mm	0.5	4.6
horn 1 along y	N/A	0.5 mm	0.1	3.6
horn 2 along x	N/A	0.5 mm	0.02	0.9
horn 2 along y	N/A	0.5 mm	0.00	0.8

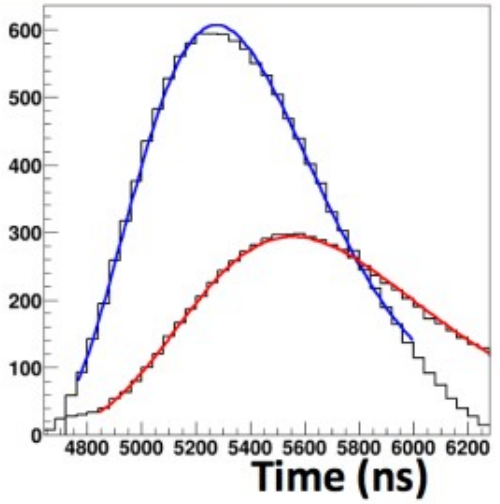
Pad signal waveform modelization

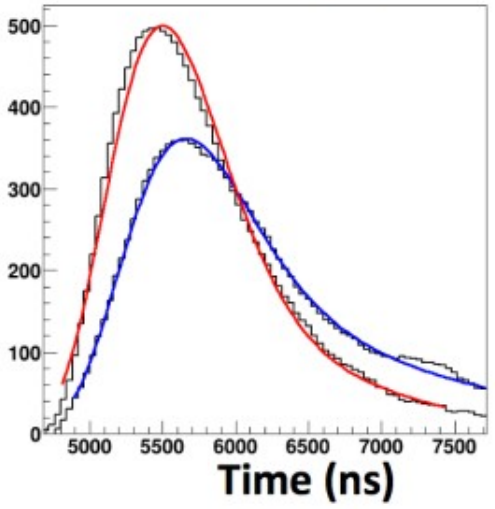
Down resistive pad ; Up resistive pad

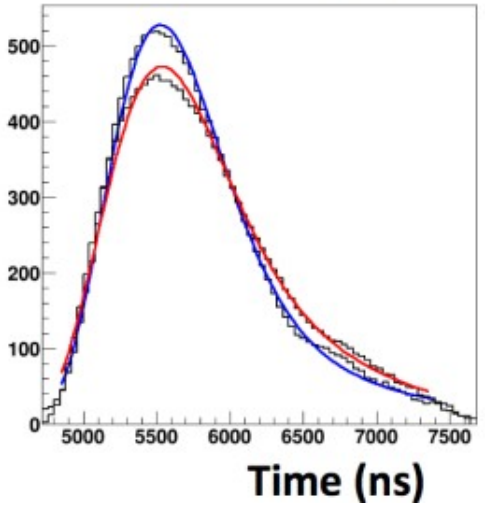
Ref : S. Hassani / S. Emery (Saclay Irfu)











SAND TPC cost estimate

- Including only hardware (no manpower, travel, common funds, technical coordination, …)
- Except for the cage, pretty accurate estimates (excluding only shipping and integration of TPC in KLOE)

Chips	230 k**€**
Front-End + Back-End	215 k**€**
Field cage	1 000 k**€**
Services (HV, LV, gas system)	350 k**€**
Cooling	165 k**€**
Detectors ERAM	300 k**€**
Total	**2260 k€**