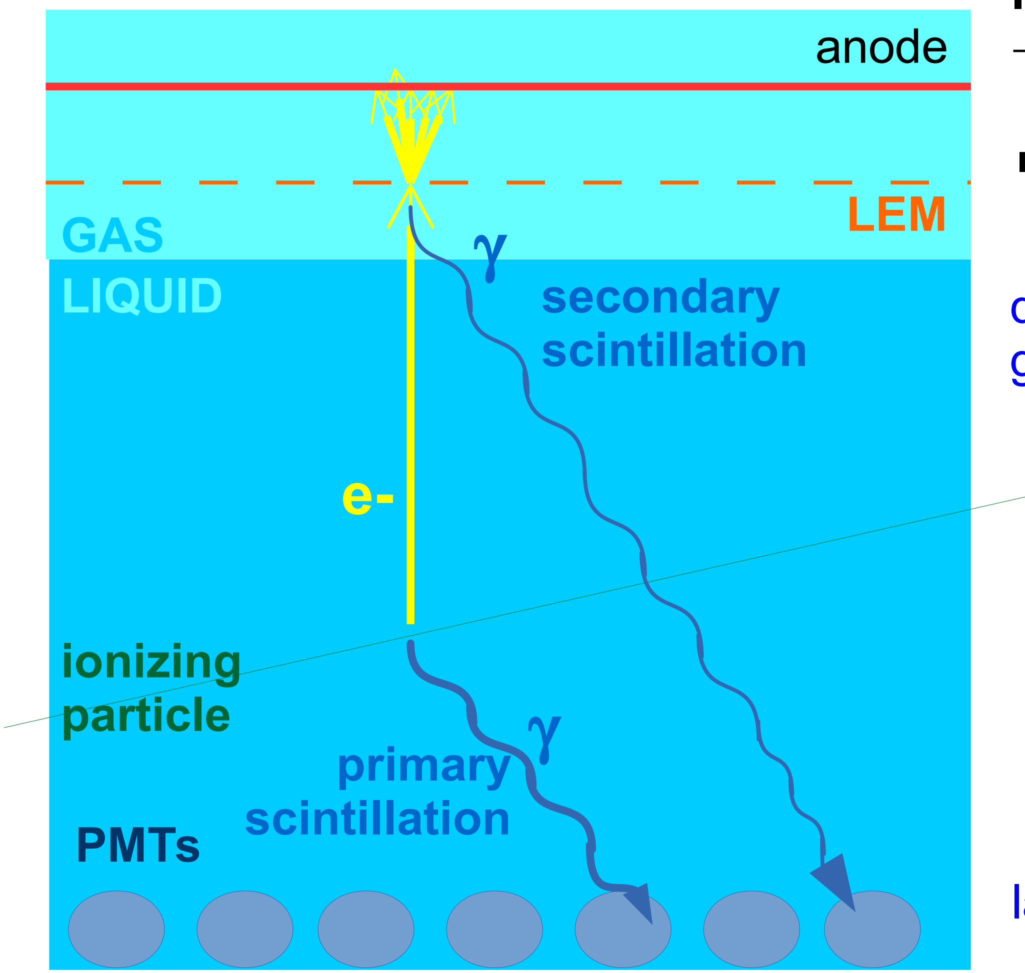
International Workshop for the Next generation Nucleon Decay and Neutrino Detector (NNN15)

Stony Brook, New York – October 2015

Status & plans of the **WA105** 6x6x6 m^3 Double Phase Liquid Argon TPC at CERN neutrino platform

Sara Bolognesi (CEA Saclay)
on behalf of WA105 collaboration

Double-phase Liquid Argon detector concept



Ionizing particle in LAr (2.12 MeV/cm for mip) → two measurements :

- **charge from ionization**
  → tracking and calorimetry

double phase : multiplication in gas to increase gain and allow for long drift distances (>5 meters)

- **scintillation light**
  - primary scintillation
    → trigger and t0 (charge drift time → vertical coordinate)
  - secondary scintillation in gas

large surface instrumented with PMTs in LAr

WA105

CERN-SPSC-2014-013; SPSC-TDR-004 (2014)

10 countries
22 institutes
120 physicists

- LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux
- OMEGA Ecole Polytechnique/CNRS-IN2P3
- UPMC, Université Paris Diderot, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE)
- APC, AstroParticule et Cosmologie, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Observatoire de Paris, Sorbonne Paris Cité
- IRFU, CEA Saclay, Gif-sur-Yvette
- Université Claude Bernard Lyon 1, IPN Lyon

- Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona)
- CIEMAT

- University of Glasgow
- University College London

- University of Jyväskylä
- University of Oulu
- Rockplan Ltd

- Horia Hulubei National Institute (IFIN-HH)
- University of Bucharest

- University of Geneva, Section de Physique,
- ETH Zürich

- INFN-Sezione di Pisa

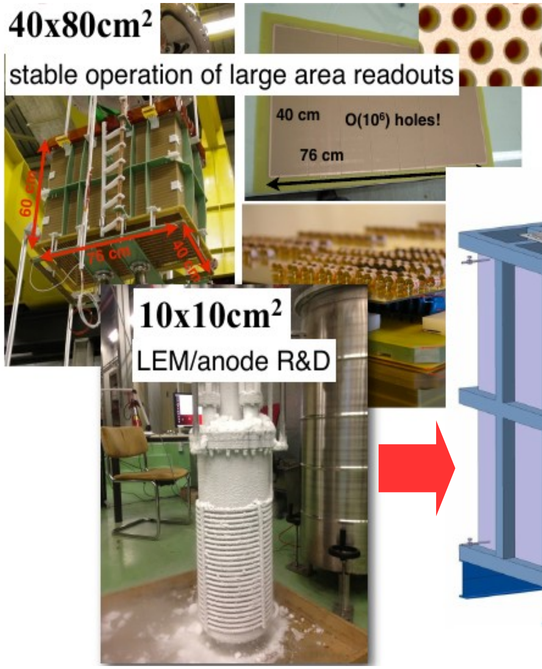
- CERN

- High Energy Accelerator Research Organization (KEK)

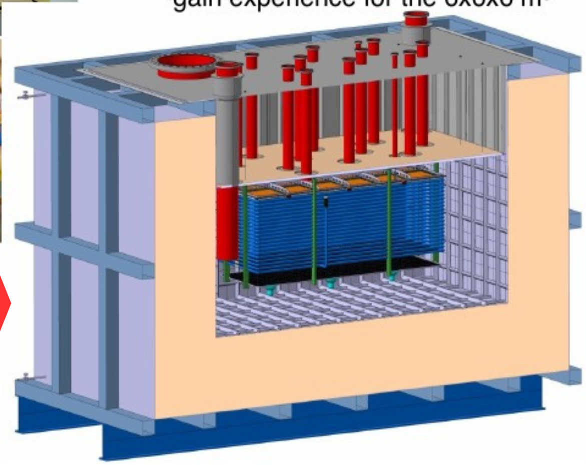
- Faculty of Physics, St.Kliment Ohridski University of Sofia

- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow

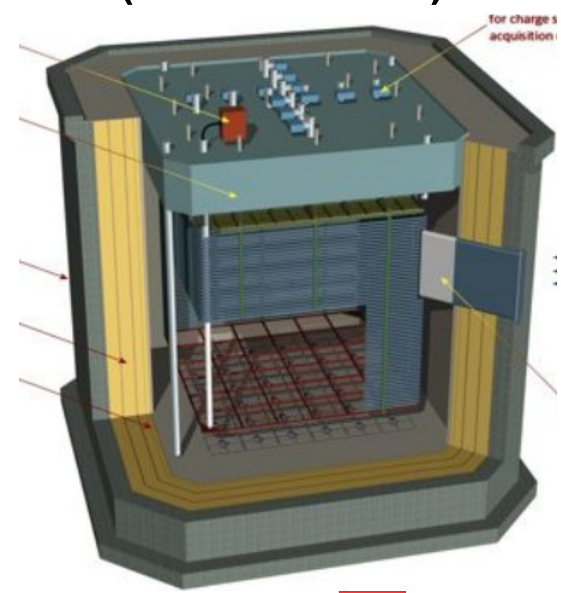
Years of R&D



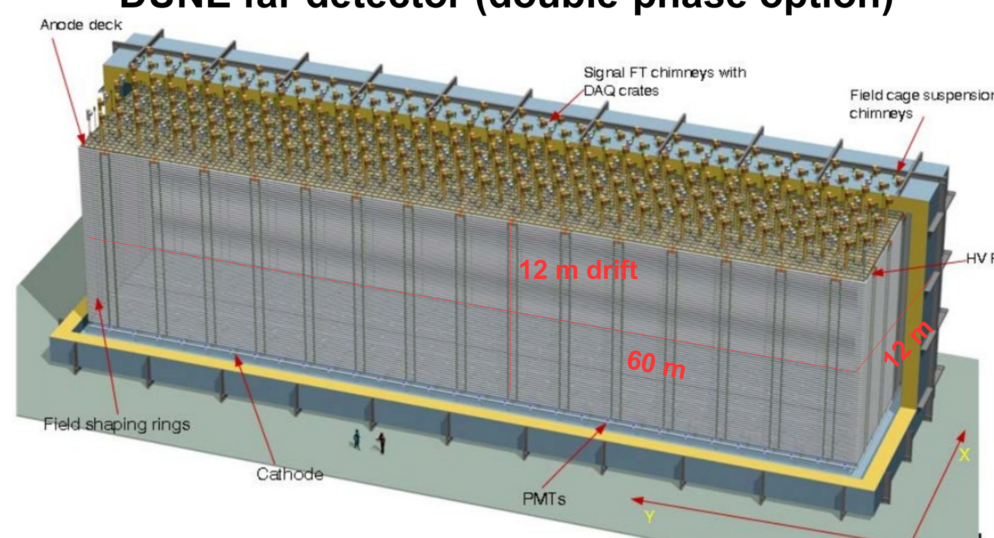
1x1x3 m³
-membrane tank technology
-gain experience for the 6x6x6 m³



WA105 (LBNO-DEMO) 6x6x6m³



DUNE far detector (double-phase option)

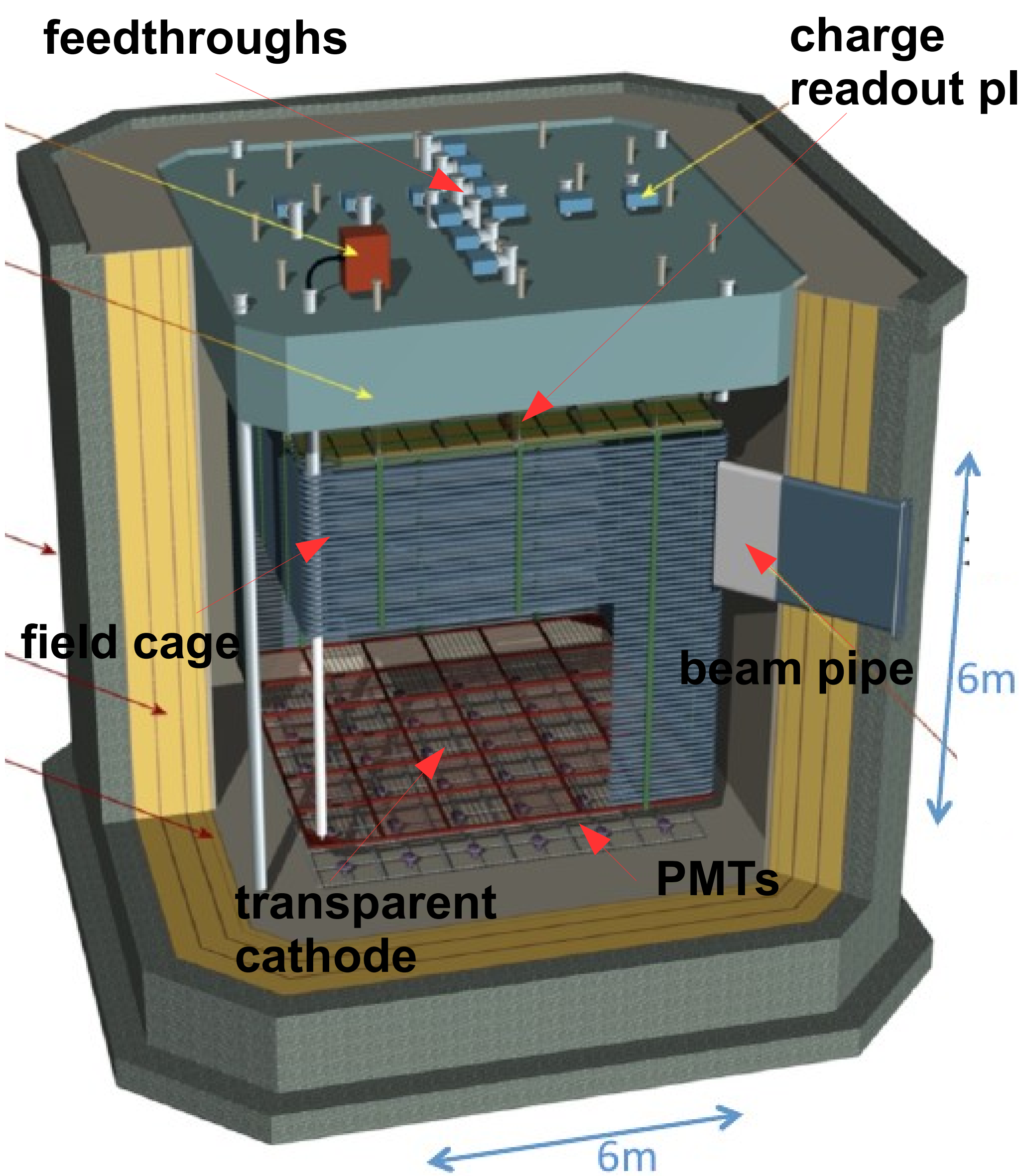


WA105 is fully engineering prototype for

- long drift, very large charge readout plane, LAr purification, very high voltage, ...
- industrialization of mechanical and electronical solutions, assembling procedures, cryogenic operation, ...
- tracking and calorimetry in liquid argon to assess performances and to develop automatic software reconstruction
- measurement of charged pions and proton cross sections on Ar nuclei (input to model FSI in nuclear environment)

WA105

LBNO-DEMO TDR arXiv:1409.4405

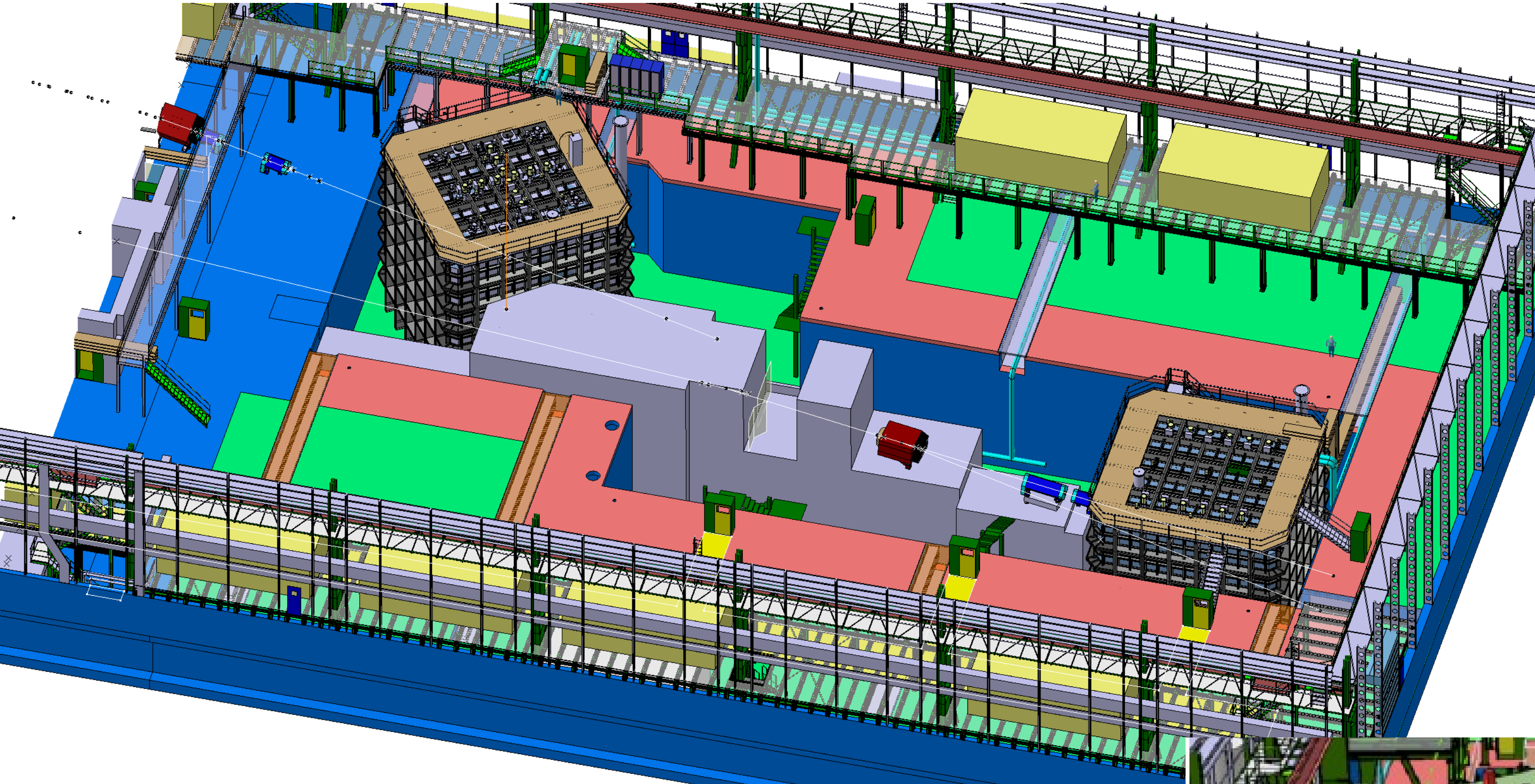


Fiducial volume 6x6x6m^3
(4 DUNE CRP modules 3x3m^2)

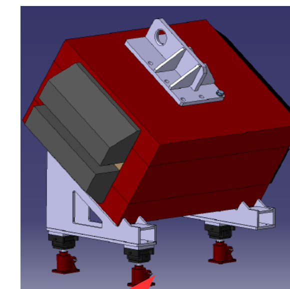
Liquid argon density	T/m^3	1.38
Liquid argon volume height	m	7.6
Active liquid argon height	m	5.99
Hydrostatic pressure at the bottom	bar	1.03
Inner vessel size (WxLxH)	m^3	$8.3 \times 8.3 \times 8.1$
Inner vessel base surface	m^2	67.6
Total liquid argon volume	m^3	509.6
Total liquid argon mass	t	705
Active LAr area	m^2	36
Charge readout module (0.5 x0.5 m^2)		36
N of signal feedthrough		12
N of readout channels		7680
N of PMT		36

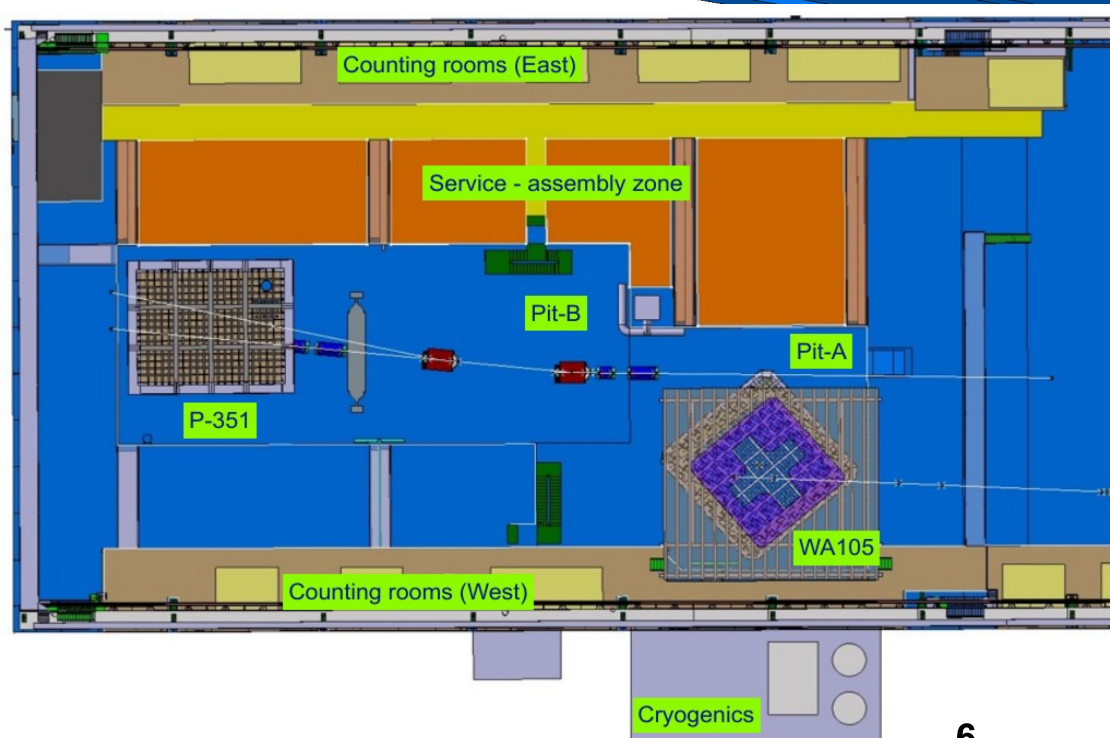
On CERN dedicated test-beam line in extension of North Experimental Hall

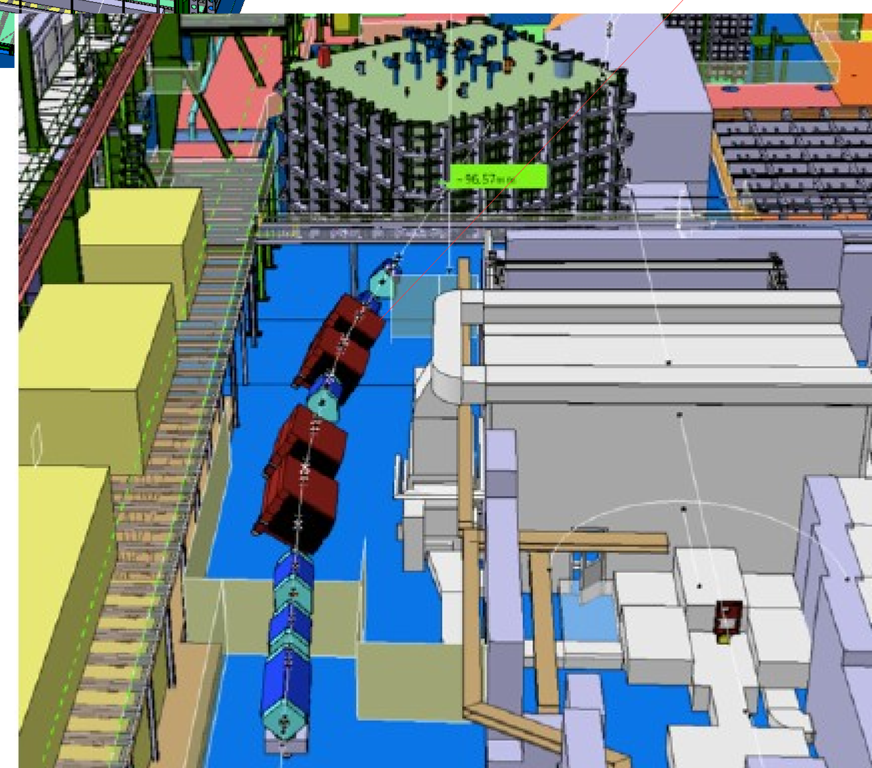
Extension of CERN North Experimental Hall for new beam line



tilted magnets

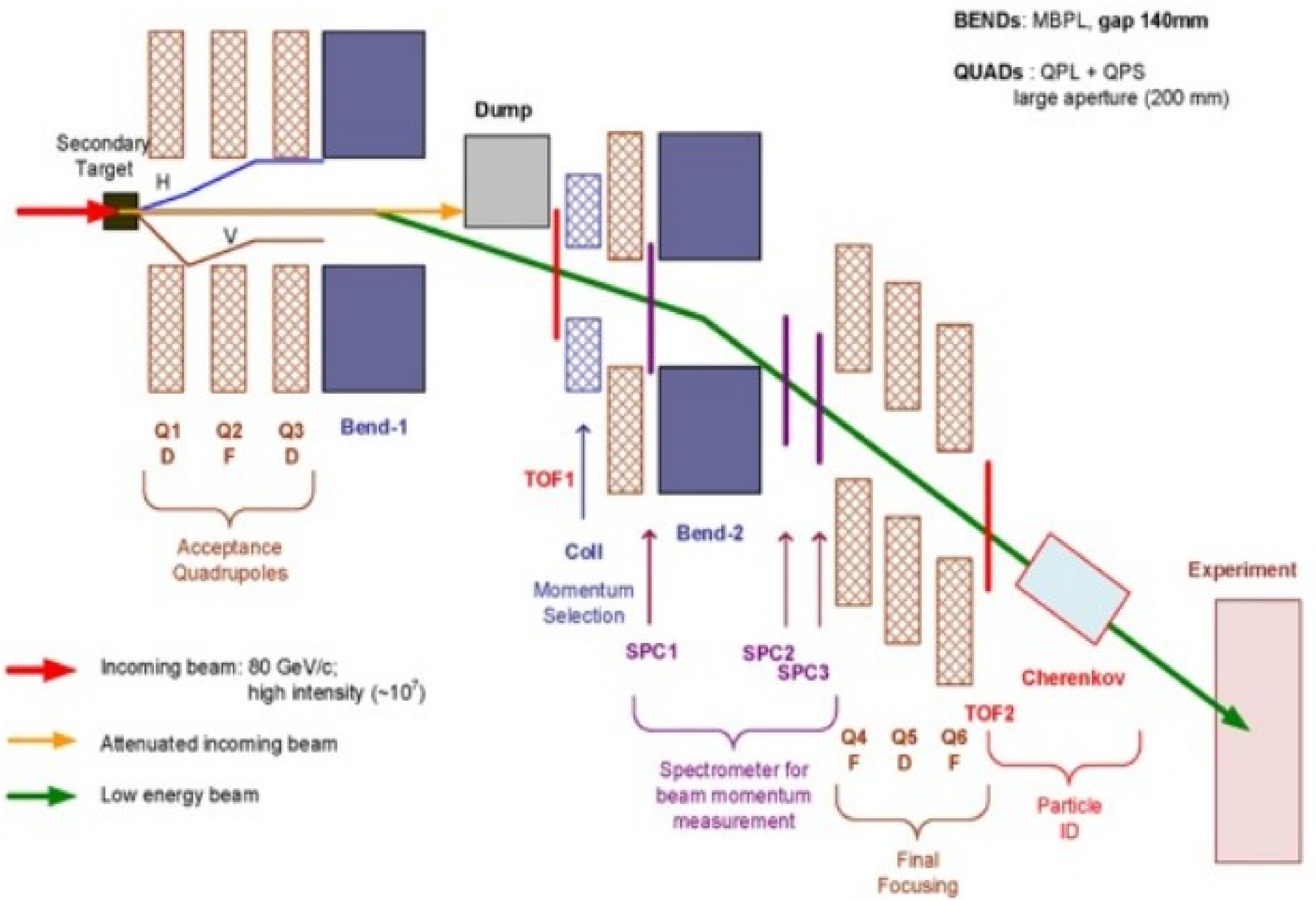






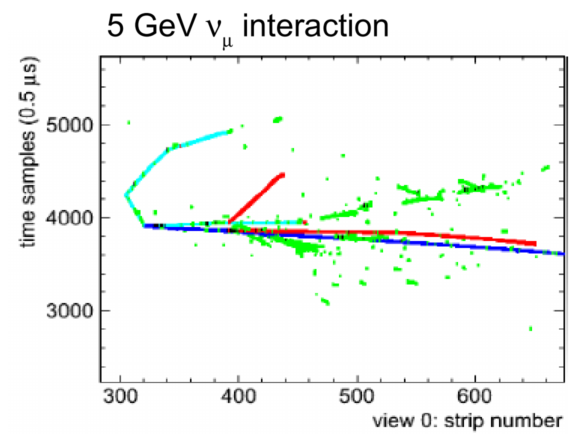
New building under construction, to be delivered in July 2016

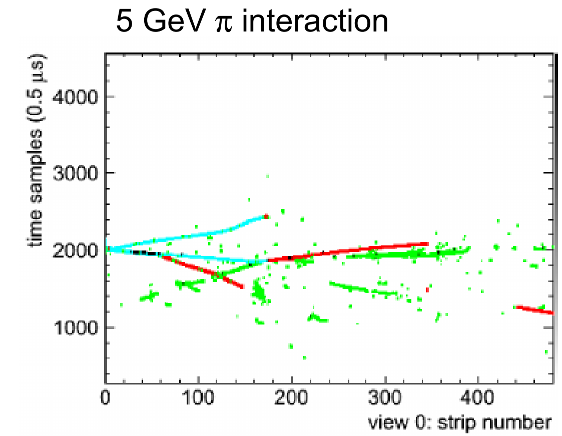
Instrumentation on the beam line



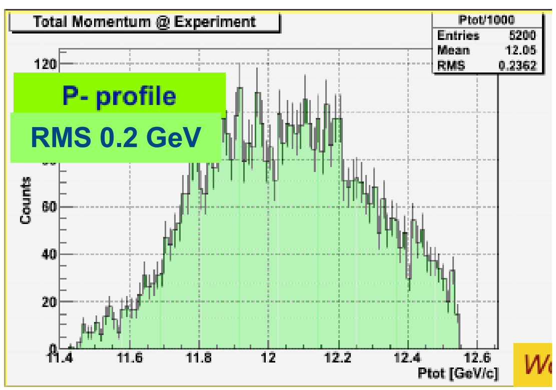
Beam characteristics

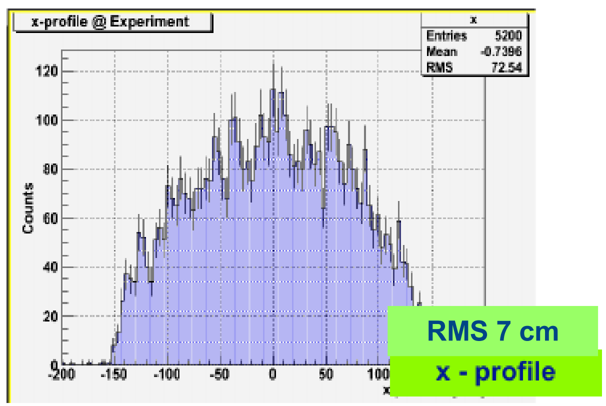
- Energy range **0.4 -12 GeV**
  (going below 0.4 GeV is challenging for power-supplies)

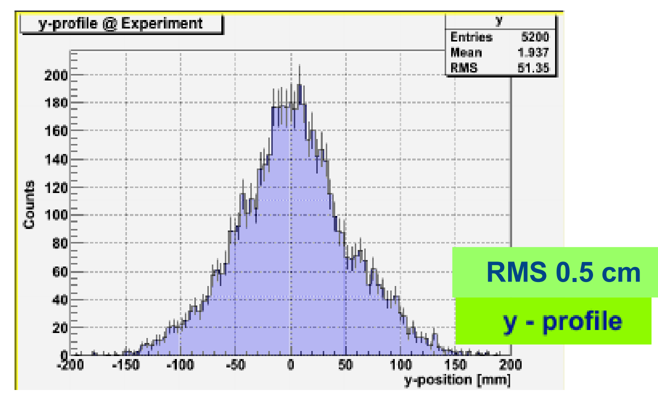




- **Beam profile** at 12 GeV



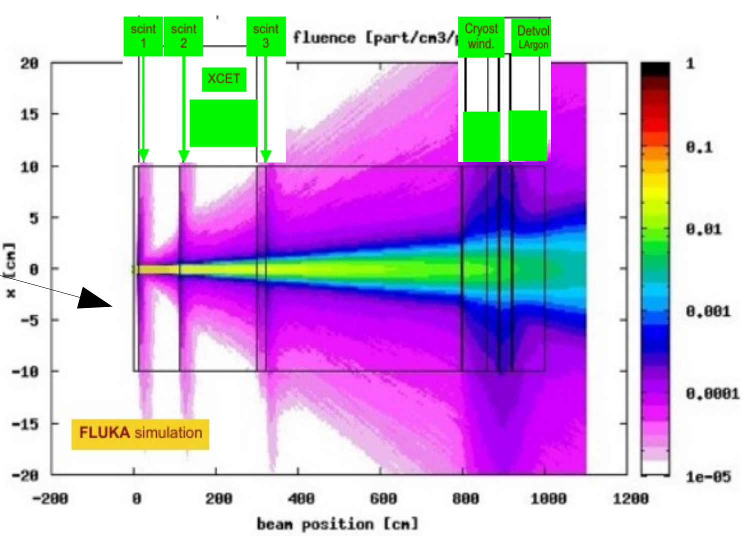


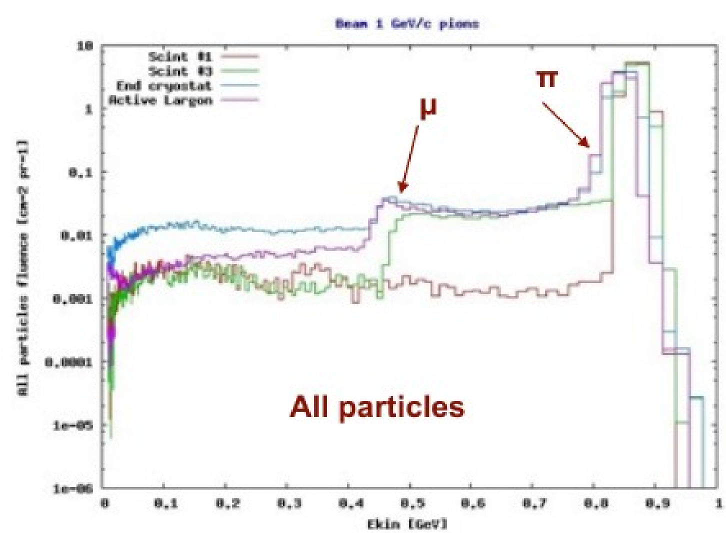


- μ, π, e at **100 Hz**

particle fluence
(including secondaries)
for 1GeV π beam

75% π survive
(45% at 0.4 GeV)



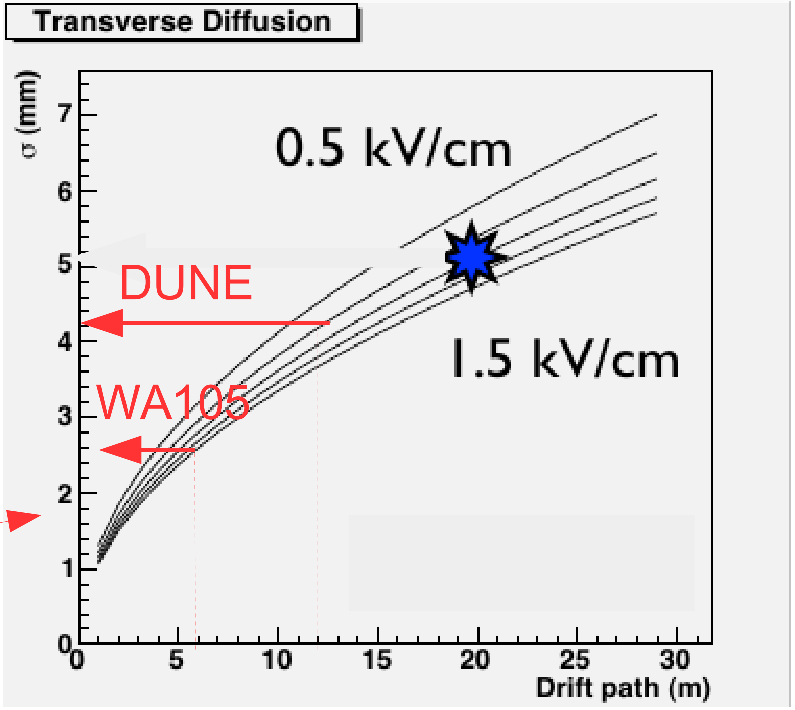


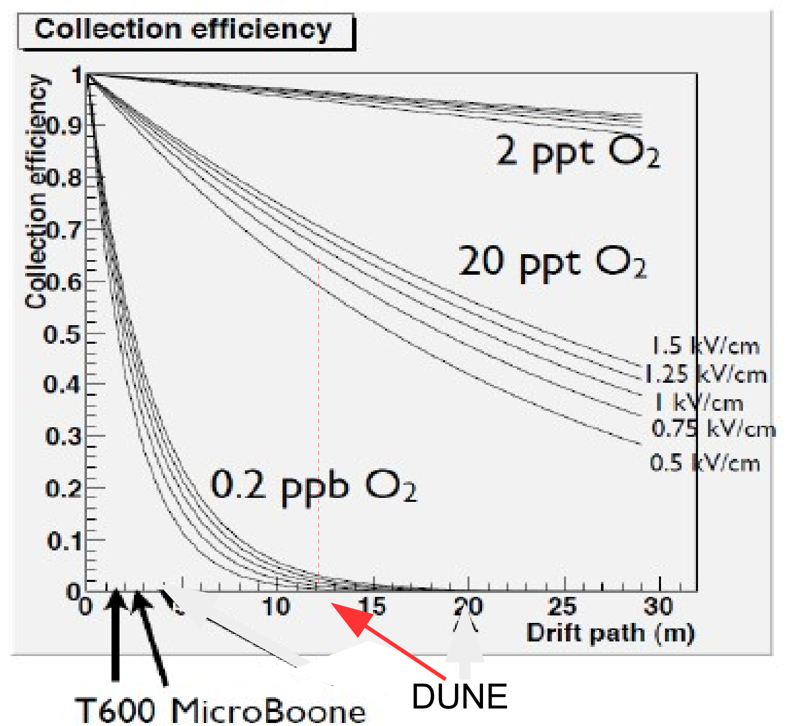
Charge signal

- W_e = 23.6 eV → mip produces ~ 100k e- per cm
  → 60k e- after recomb.
- dirft velocity ~mm/µs (→ total drift time ~few ms)

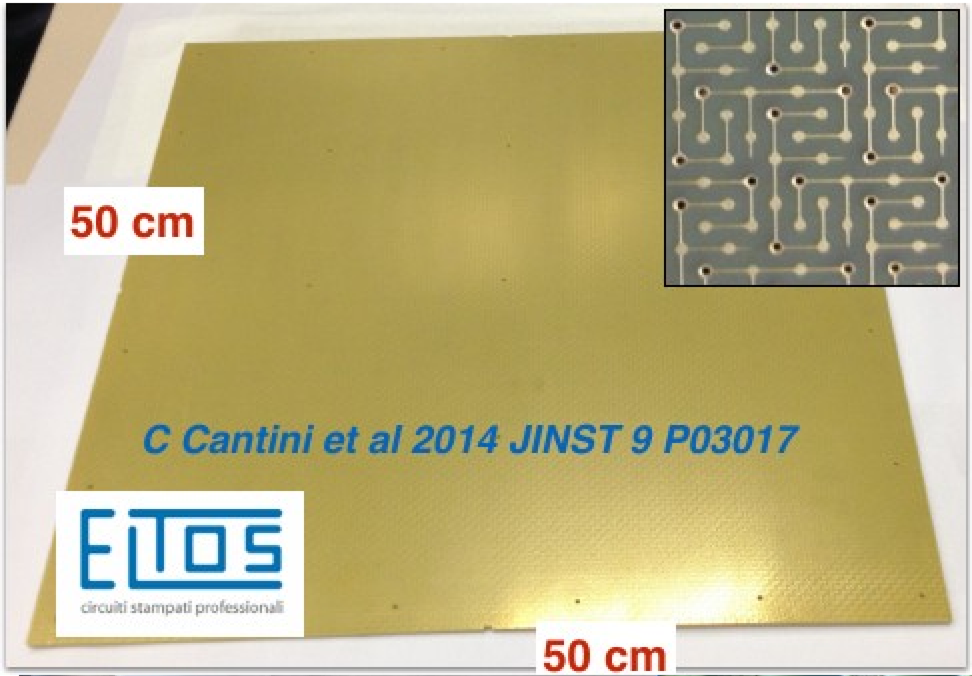
- **Very long drift path → diffusion and attachment**
  - diffusion ~few mm with 1-0.5 kV/cm
    (→ pitch readout few mm)
  - O_2 pollution captures ionization electrons
    → charge attenuation
    (→ impurity ~20 ppt O_2 needed)

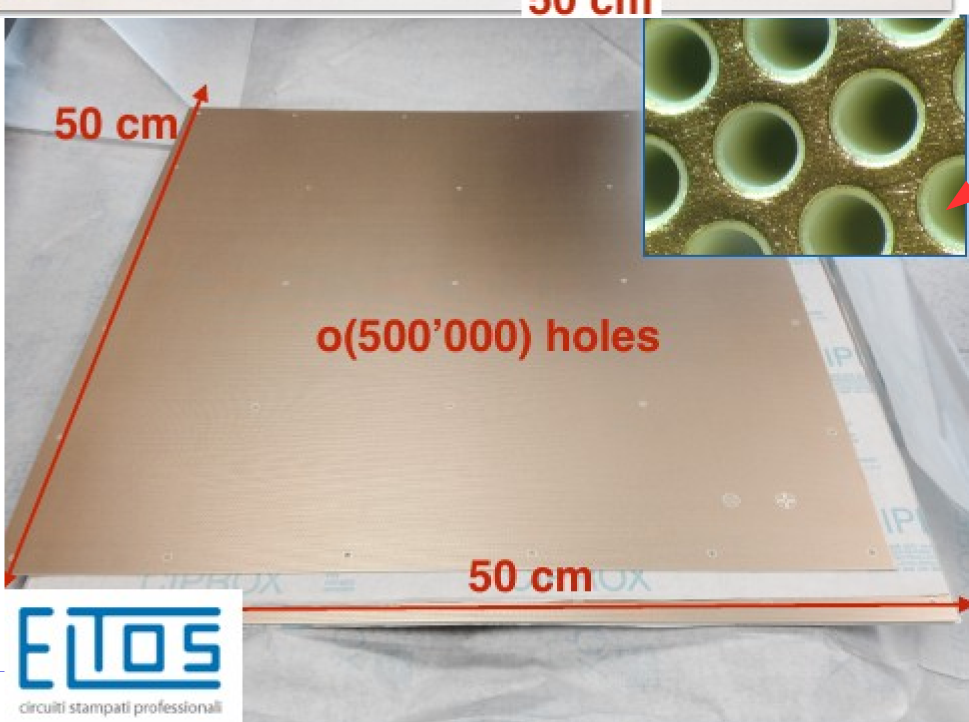
- **Double phase charge readout**
  - high signal/noise thanks to avalanche multiplication in gas
  - 2 view (X,Y) of equal quality

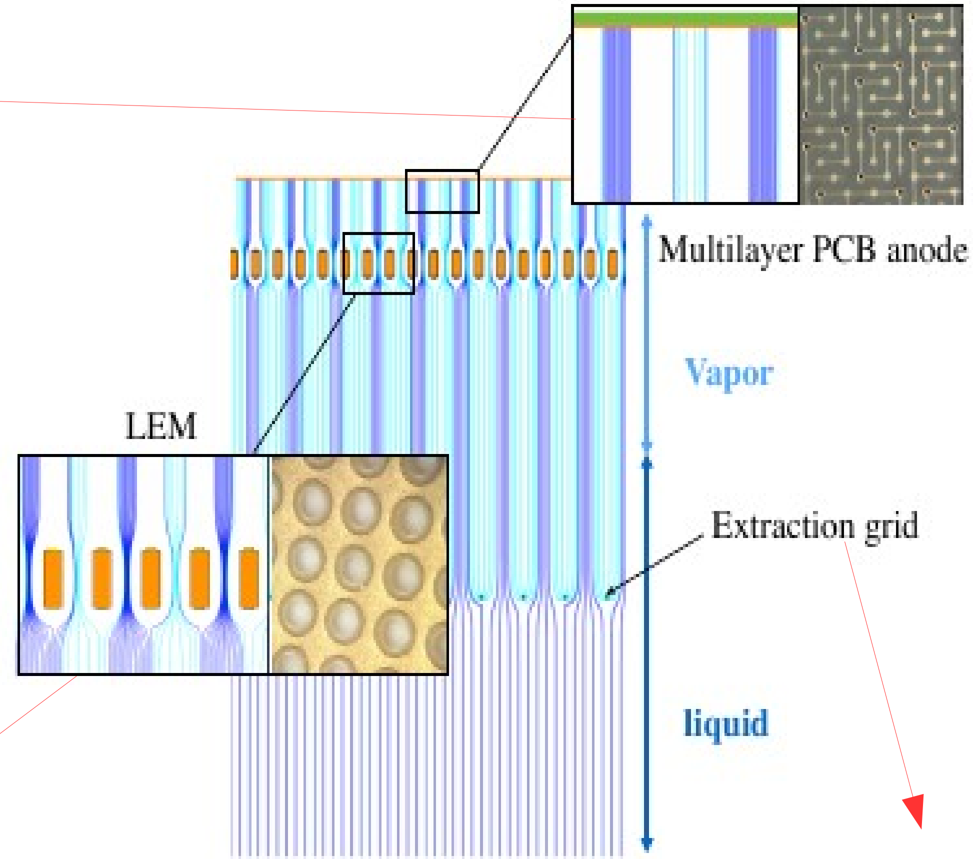




Double phase charge collection

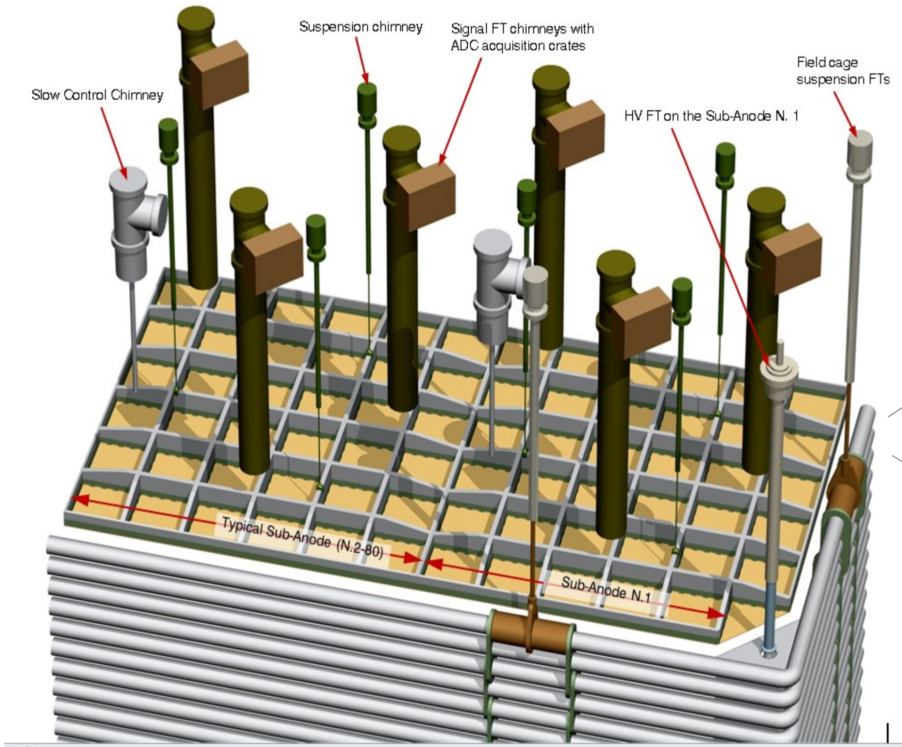


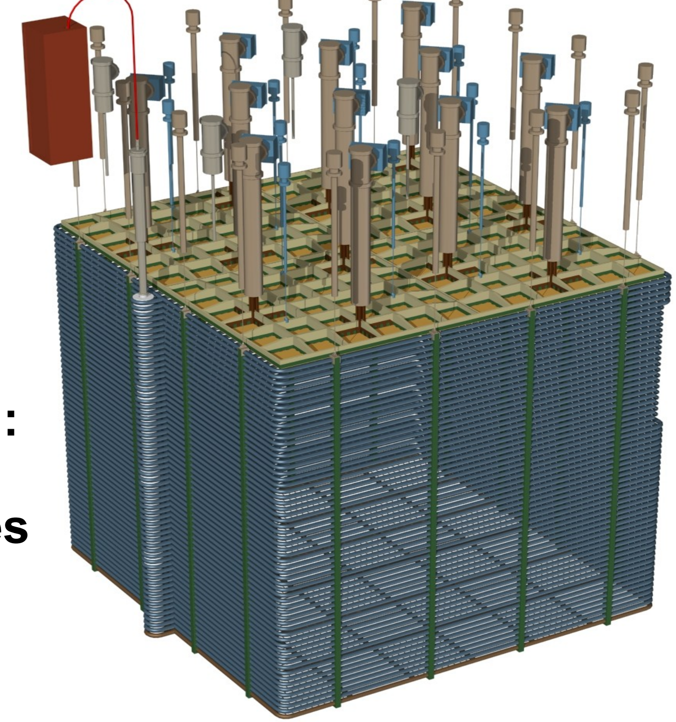




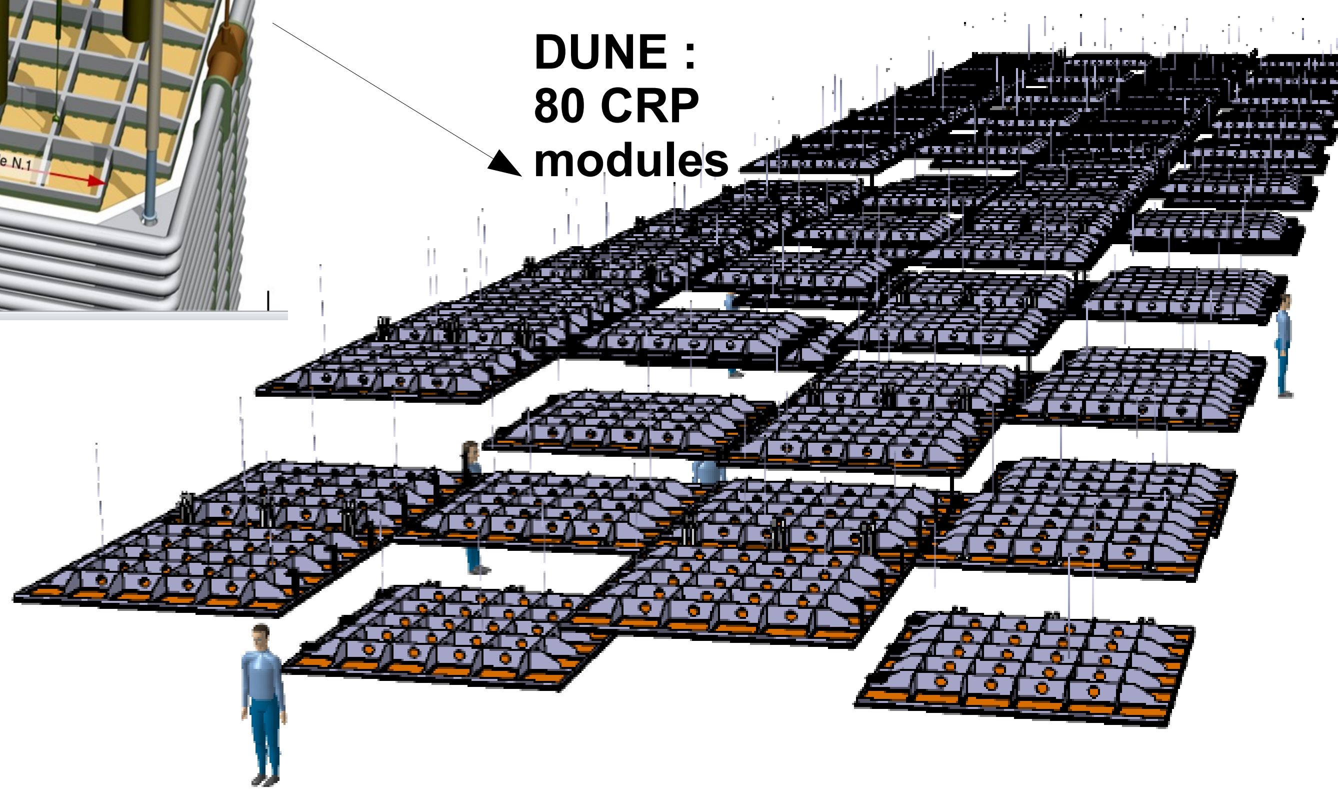
Charge Readout Plane

Zoom on 2 CRPs





WA105 : 4 CRP modules



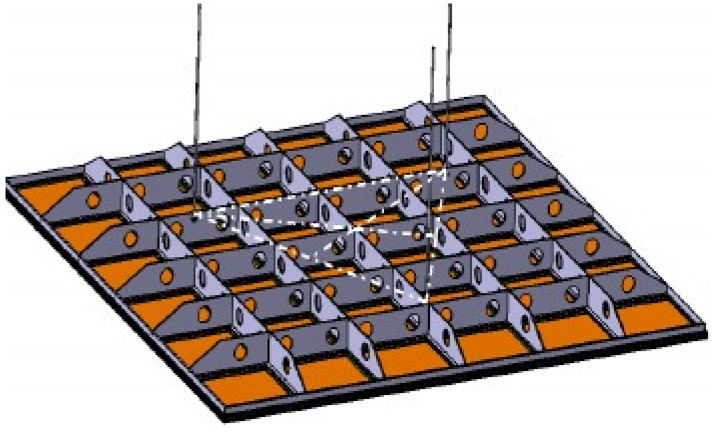
DUNE : 80 CRP modules

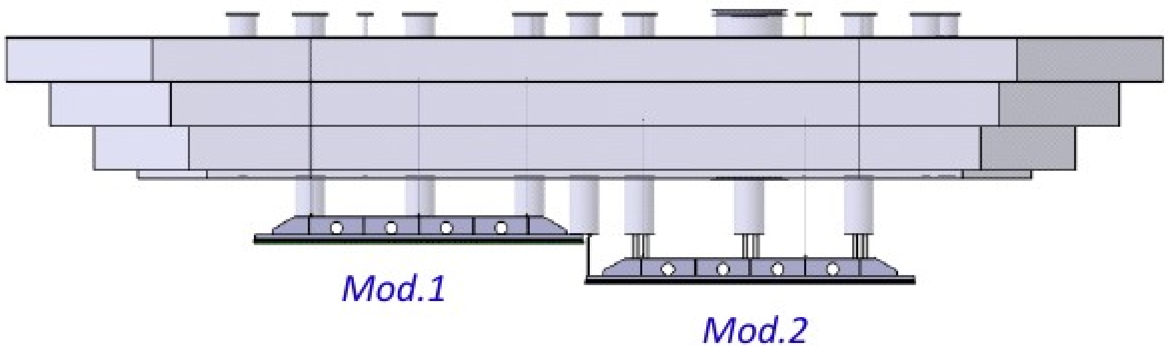
6x6 LEM assembled in a single, independent, rigid Charge Readout Plane units (CRPs) 3x3m

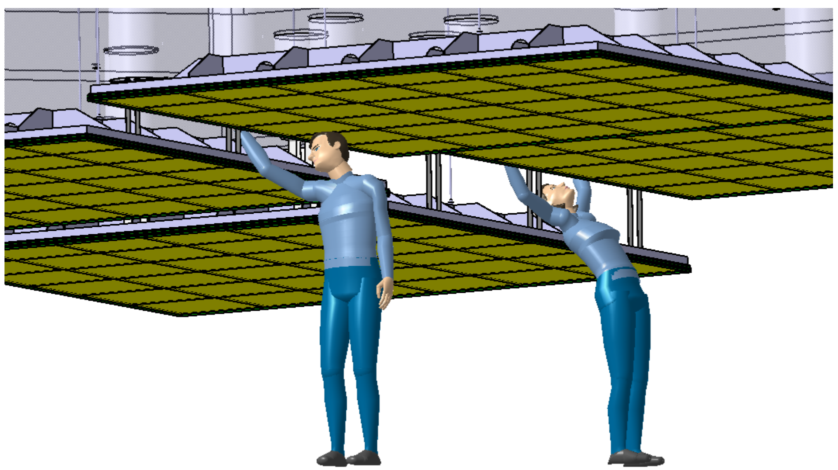
→ modularity ←

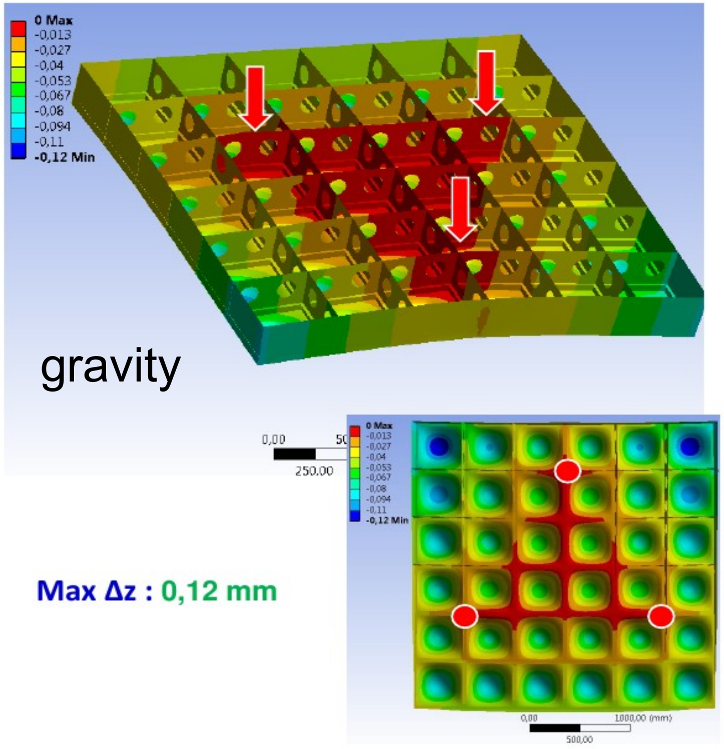
CRP assembling and structure

- 3 points suspension system to minimize gravitational deformation → optimal design, built and tested
- Assembly and connection from inside the tank by lifting up-down the modules





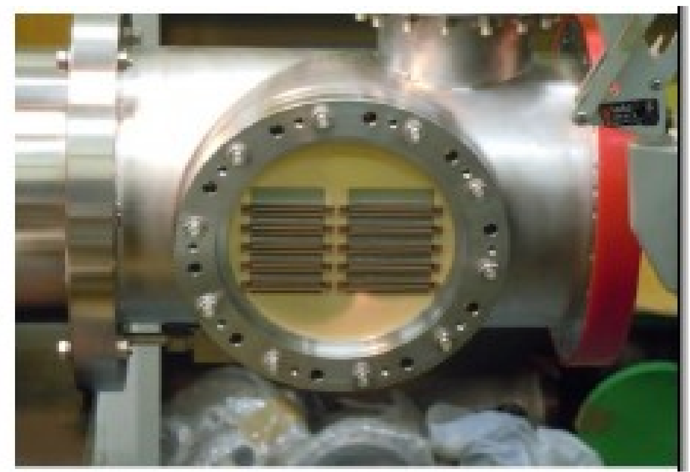




Charge FE electronics

WA105 (7680 channels) test for DUNE (few 100k channels)
→ large scale readout system : need high-integration and low cost

(Signal chimneys for 3x1x1 prototype)

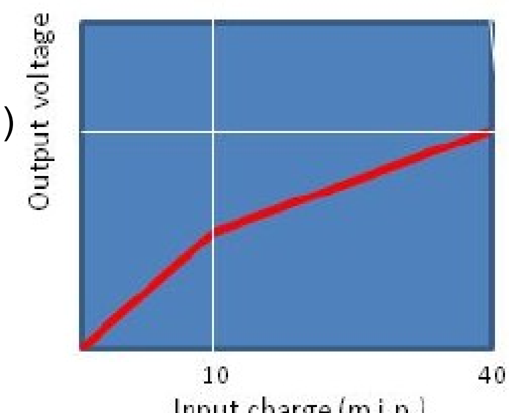


- FE analog electronics at cryogenic temperature inside chimneys in the tank roof
  - → guarantee accessibility of electronics
  - → minimize noise (minimum at 100K)
  - → minimize cabling

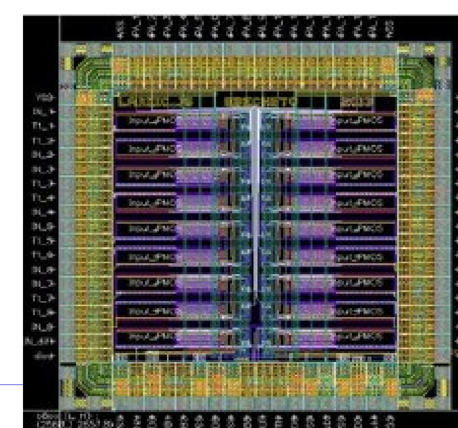
- **Since 2006 : 7 generations of ASIC protoypes**

• double slope regime: high gain up to 10 mip (best resolution) → lower gain to match dynamic range up to 40 mip

• heat dissipation (in cryostat)
<18 mW per channel → <11.5 W per chimney

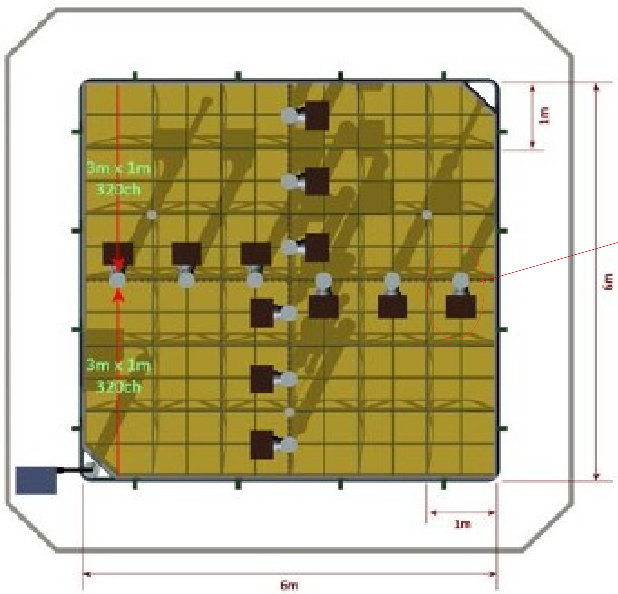


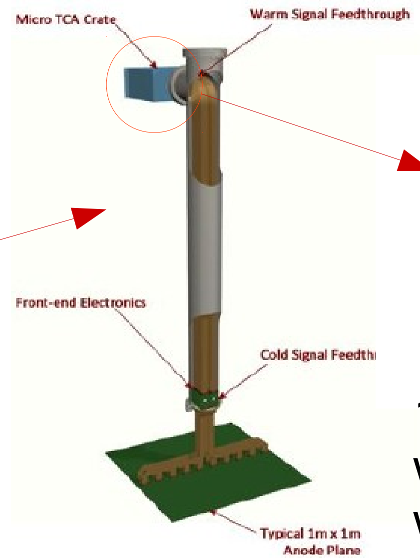
ASIC (16ch)



Charge DAQ

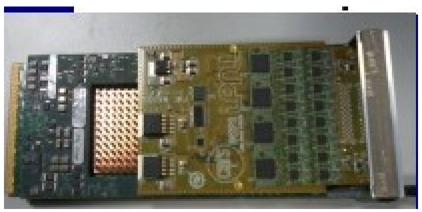
- Micro-TCA standards → very compact and easily scalable architecture to manage large number of channels at low cost





crate and card prototype ready

1 crate per chimney with 10 DAQ cards with 64 channel each



16 bits, 400ns sampling rate

- Special time distribution system → synchronization between nodes at 1ns (White Rabbit time and trigger system)

- Gigabit Ethernet connection to a farm for event building merging with light readout

(**w/o zero-suppression at 100 Hz ~15 Gb/s → 1 PB/day data storage**
w zero-suppression up to 10kHz : read beam data and cosmics)

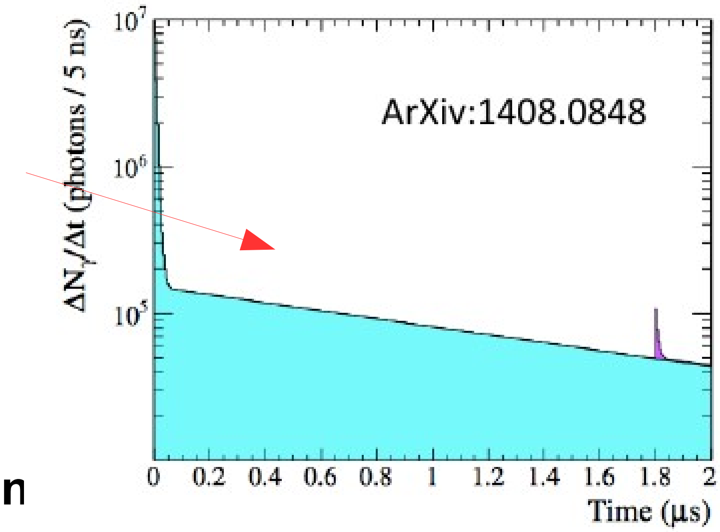
FPGA card for online processing under test

Scintillation in LAr

- Peak of emitted light in Ar at **128 nm** → need coating to shift into PMT wavelength
- W_γ = 19.5 eV → **few 10^7 γ per GeV**
  one 8" PMT per sq. meter inside LAr
  (QE~10 % → collection efficiency few 10^{-4})

  ➡ few 1000 PE/PMT dynamic range

- Scintillation signal shape :
  - **fast component** (singlet): τ_1 ~10 ns (~23% for mip)
  - **slow component** (triplet): τ_2 ~1 μs (~77% for mip)



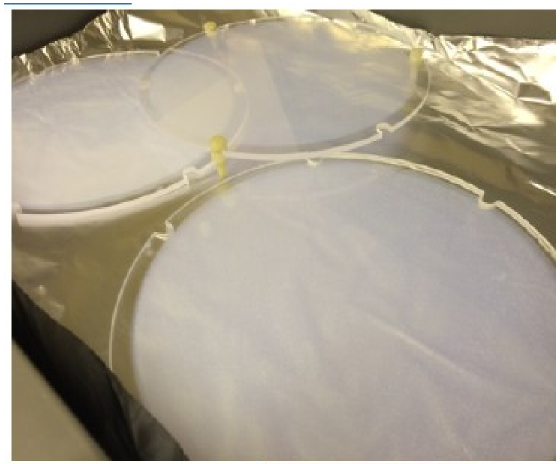
- Background from 7kHz cosmics
  - **primary scintillation** → deadtime < 100μs
  - continuous background of **secondary scintillation (from avalanche in gas)**

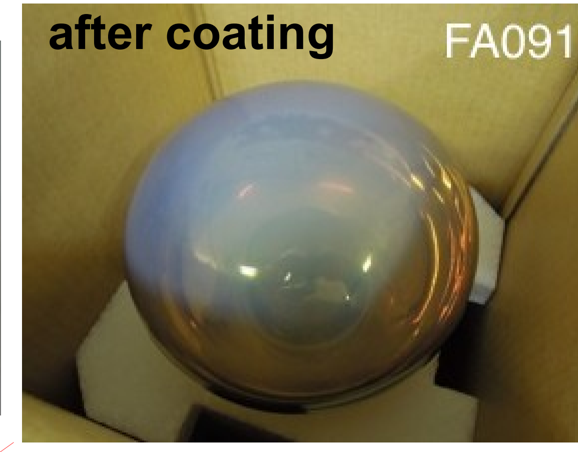
➡ (S+B)/B ~ 50 (20 ns) → 1 (1 μs) use signal shape to isolate signal over background

PMTs under test

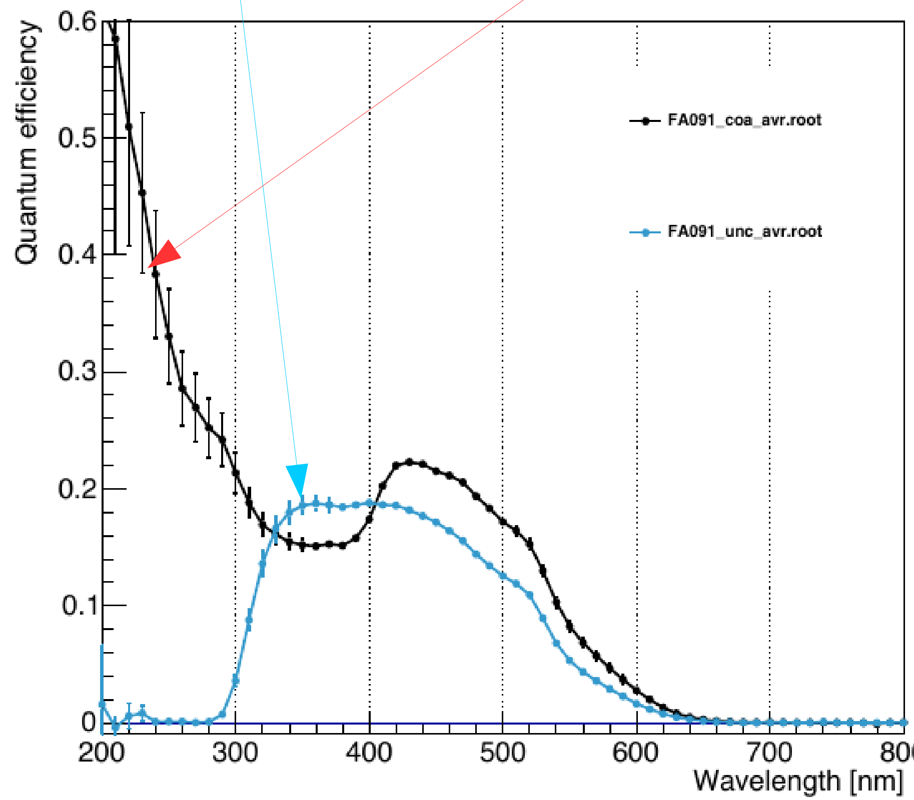
PMTs under test at CERN

Coating with TPB(*) by evaporation on PMT or on plexiglas plates





(* Tetraphenyl-butadiene)

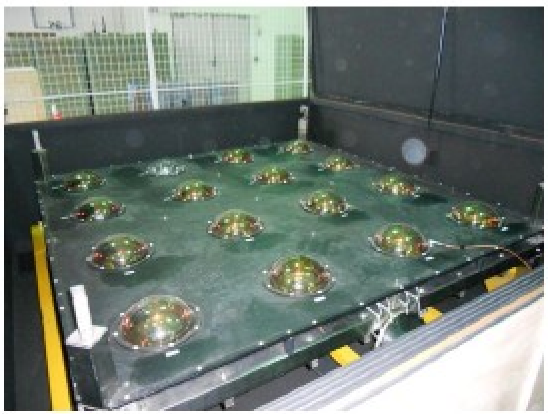
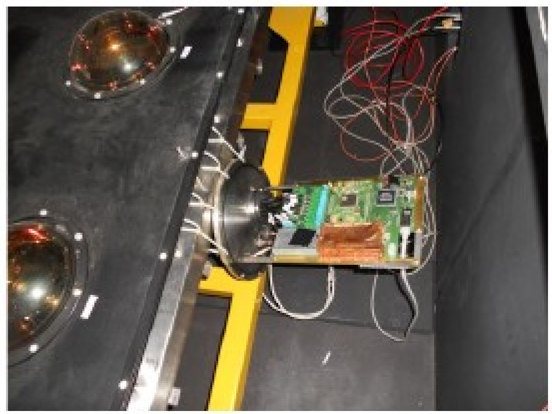


Light readout electronics

FE card with « PARISROC » ASIC

- grouping 16 PMTs with single HV → minimize cabling connections and feedthroughs

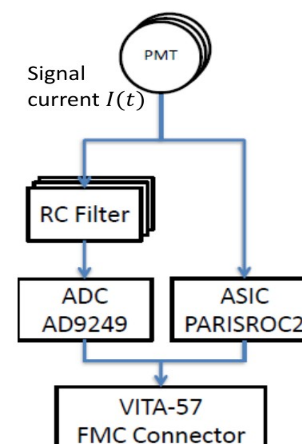
  (in view of DUNE detector, low-cost and high-integration solutions for signal digitization of large equipped surfaces)


(inheriting from experience of Memphys large water-cherenkov for Laguna/LBNO)

- fast channel for trigger and t_0 of electrons drift
  (down to 10 fC with a fast shaper of 15 ns)

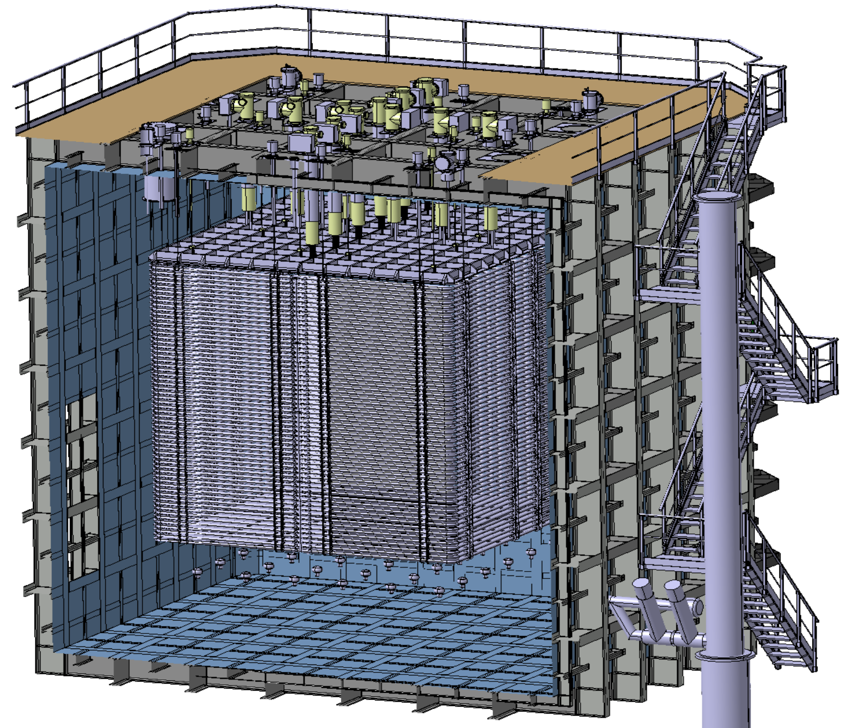
  \+ slow channel with analogue memory for signal shape to improve calorimetry and distinguish primary scintillation from continuous secondary scintillation from cosmics (up to 50 pC with slow shaper 50-200ns)



- 50% chance of missing cosmics because of self-trigger dead-time
  → second mode of acquisition : continuous acquisition +/- 4ms

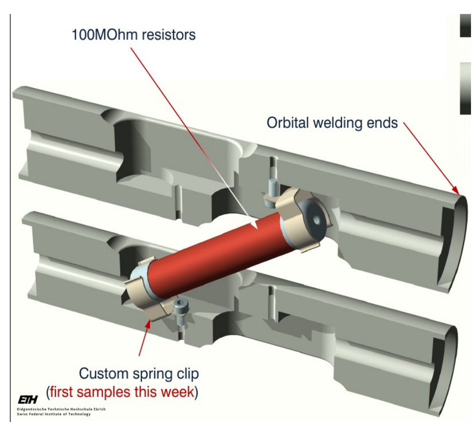
Cryostat and field cage

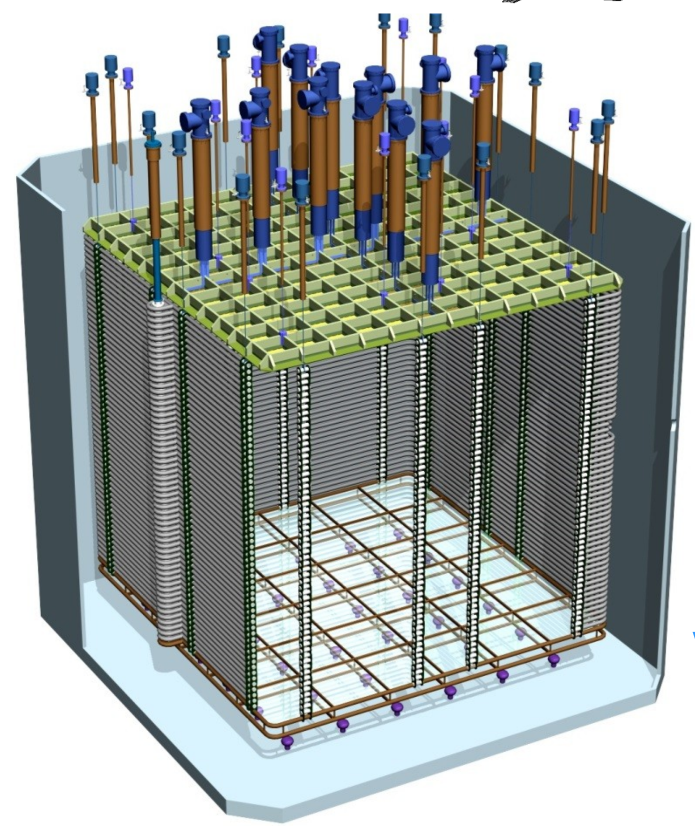
- Cryostat design :
  - inner size : 8x8x8 m^3
  - average heat flow < 5W/m^2



- Large drift cage sustaining a large potential difference (~500 kV)

  (very low noise and stable power supply up to 600 kV)





E = 0.5-1 kV/cm

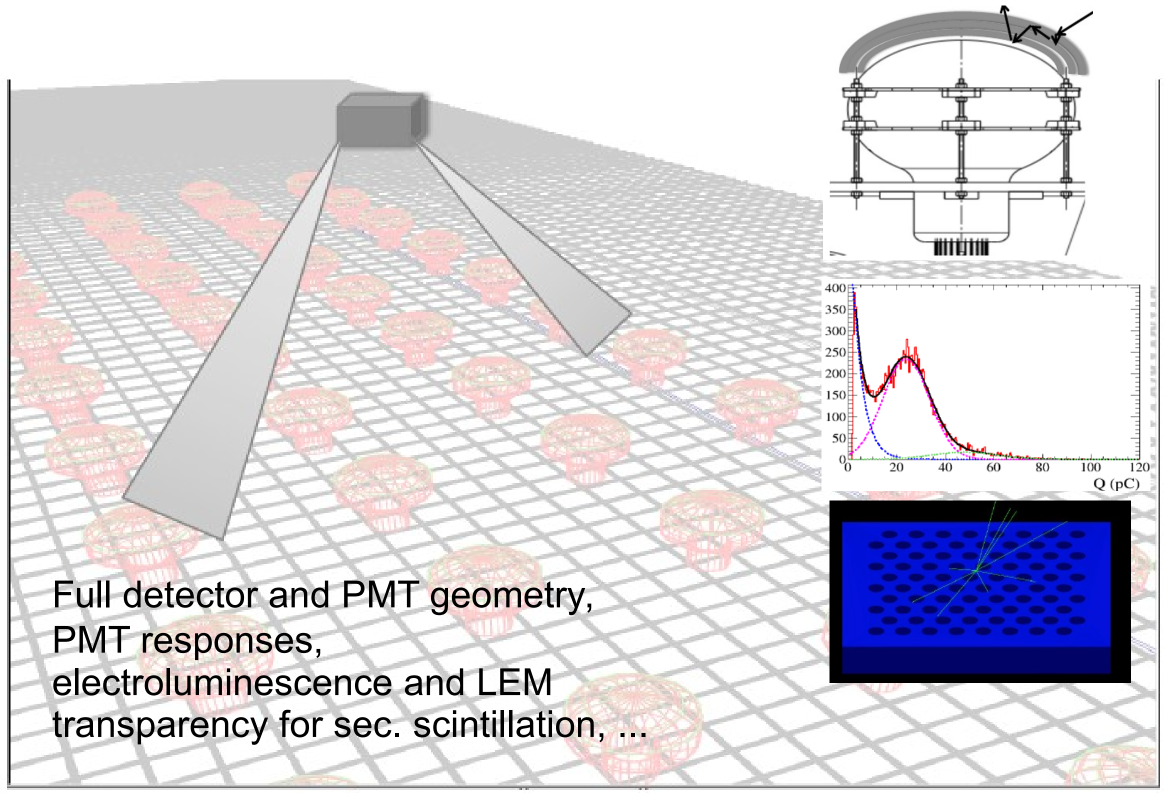
ΔV = 300-600 kV

Simulation, reconstruction and some physics measurements

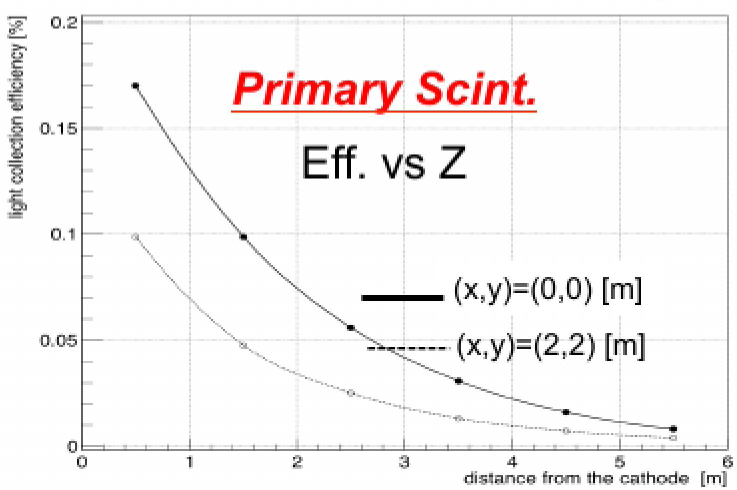
- light and charge simulation
- track reconstruction (cosmics)
- calorimetry
- pion cross-section

Light simulation

- **Fully detailed light response simulation parametrized with Lookup Tables**

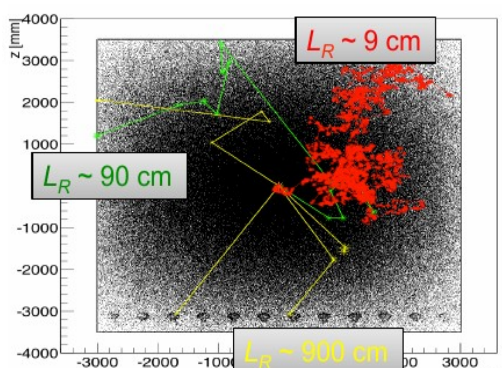


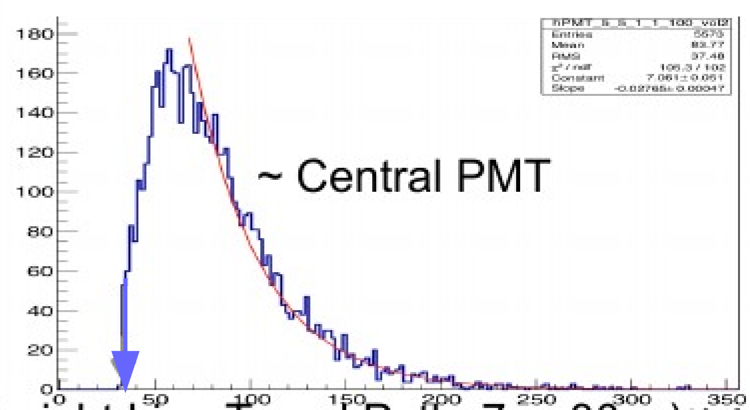
- Primary scintillation in LAr ~ 10^{-3} – 10^{-4} collection efficiency



- Secondary scintillation in GAr ~30% efficiency w.r.t LAr primary scinitllation

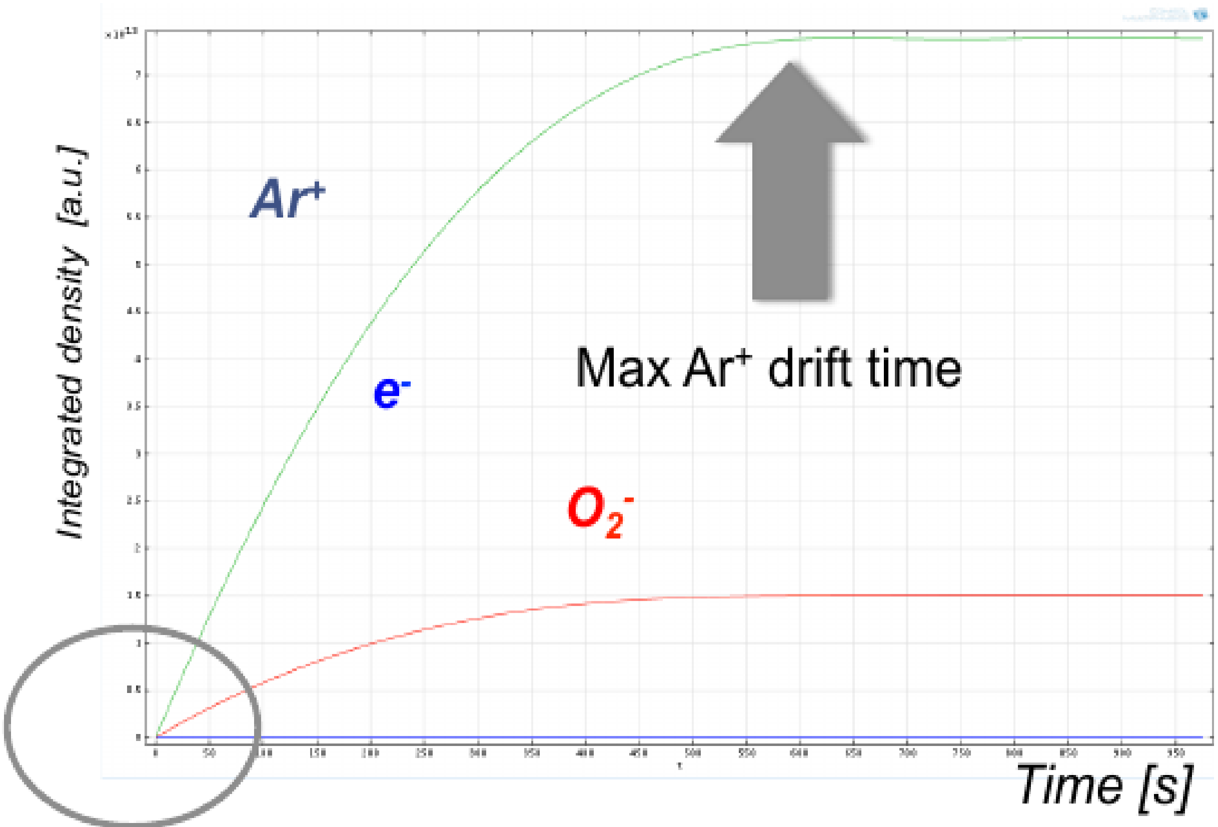
- Time signal spread due to Rayleigh scattering





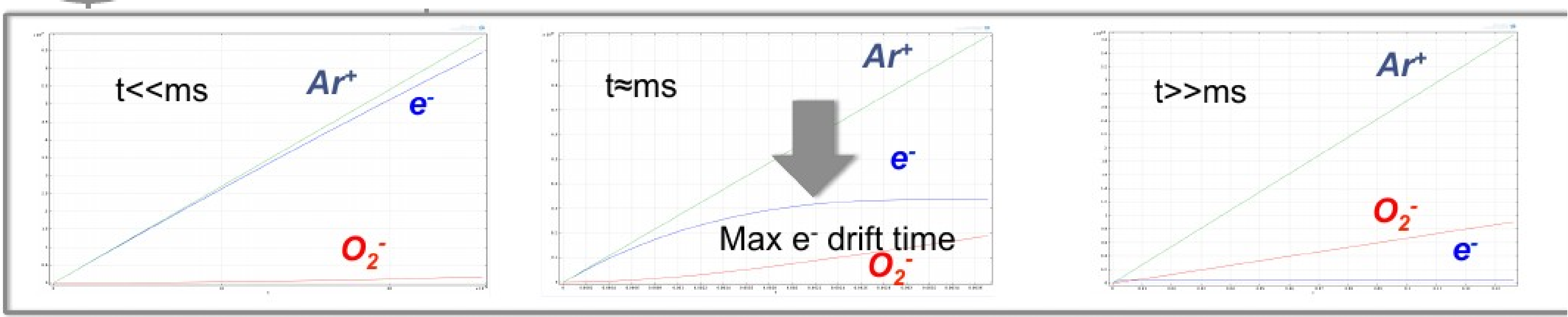
(Straight Line Travel Path: 7m, 30ns)

Space-charge effects (cosmics)



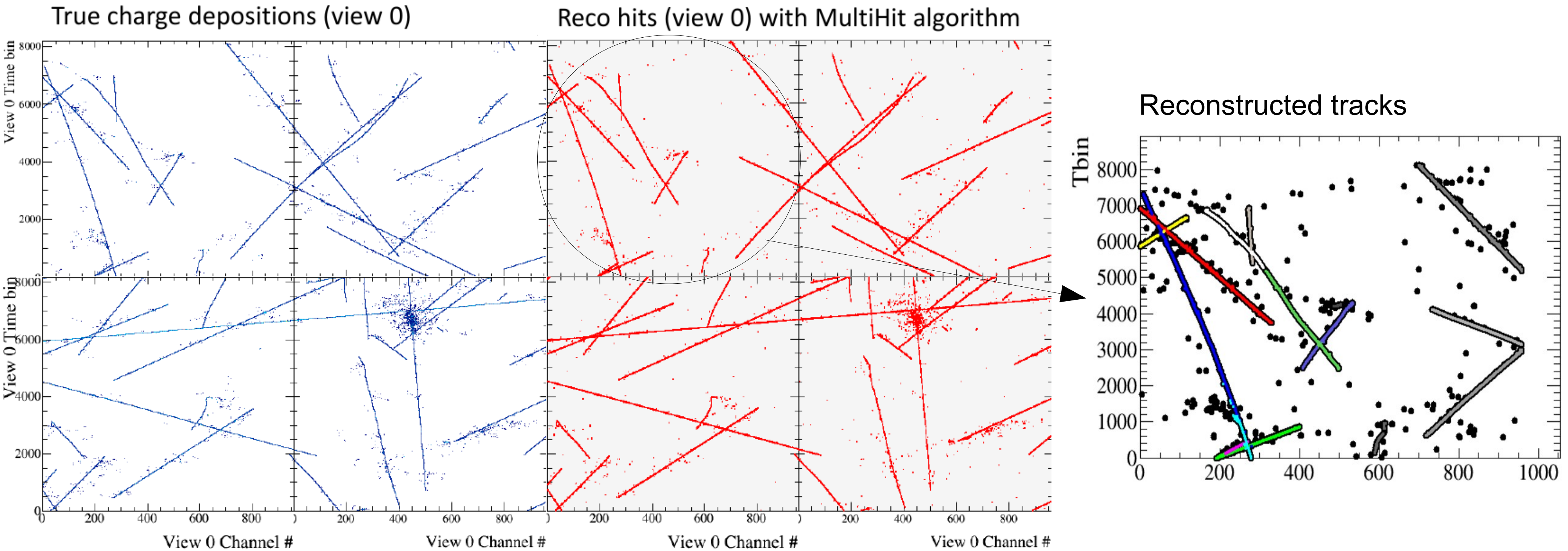
Field distortion due to continuous charge deposition from cosmics :

- **full simulation of effect → modified field map**
- **need experimental data to quantify** (liquid convection, charge neutralization at surface, ...)



Track reconstruction (cosmics)

Up to ~70 cosmics overlaped in the triggered drift window (from +/-4ms → chopped tracks)



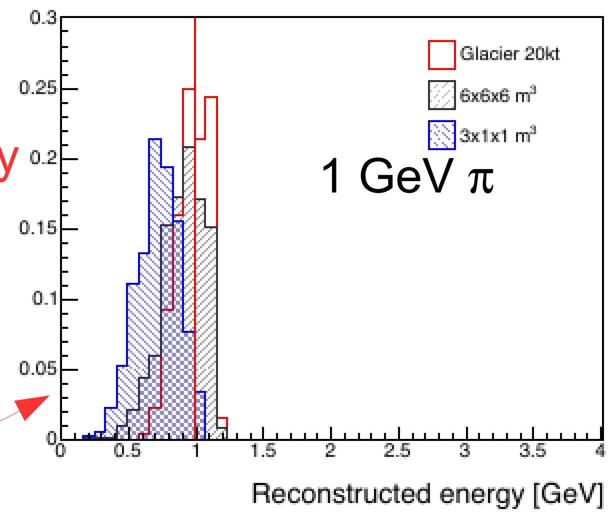
PRELIMINARY

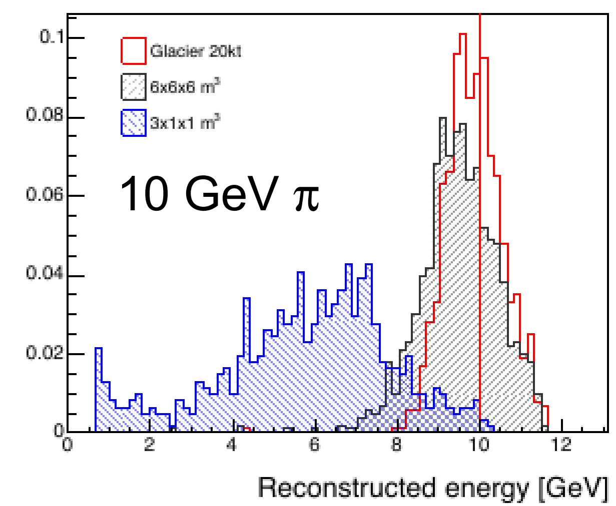
Calorimetry

- **Total charge (+ light) = energy of incoming particle :**

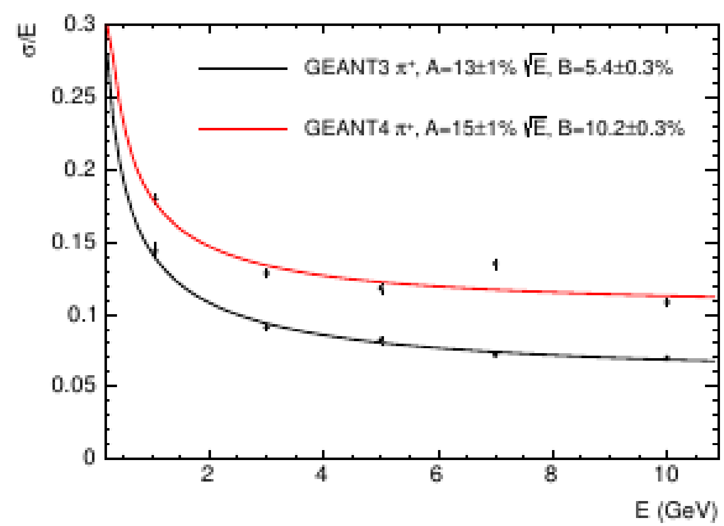
  completely omogeneous calorimetry with 3mm x 3mm granularity

  - reco of muon, charged pion and π0/electron separation
  - very limited leakage out of the detector





- need to keep under control calibration/uniformity and noise (cosmics)
- need detailed understanding of charge recombination, quenching/saturation for high density ionization



→ **improvement in shower modeling**

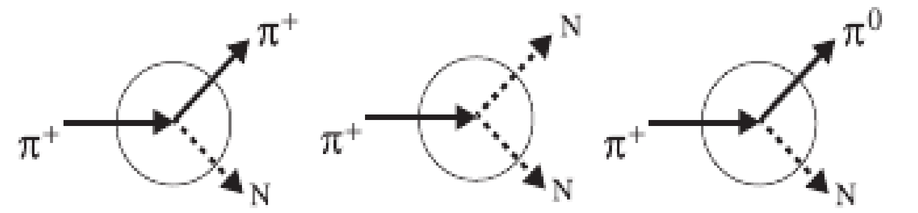
- dE/dx → identification of secondaries in shower
- p_T balance in secondary vertices → understanding of 'invisible' energy : neutrinos, binding energies

Pion cross-section measurement

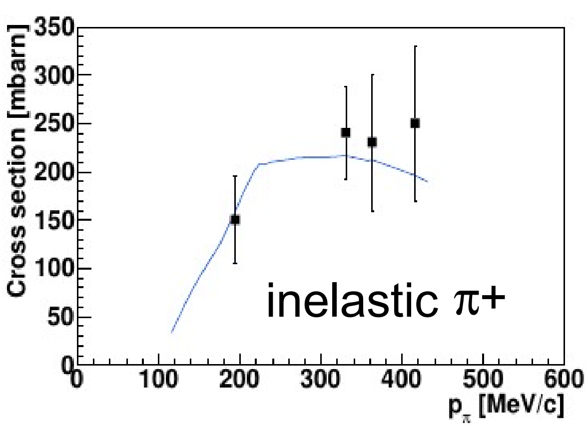
Pion final state interactions and secondary interactions in the detector: large systematics for oscillation analysis

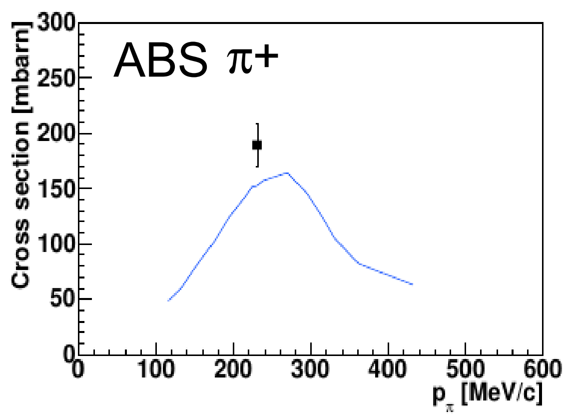
(ν_μ T2K systematics~3% (for 8% total syst.) → more important for higher energy ν beams)

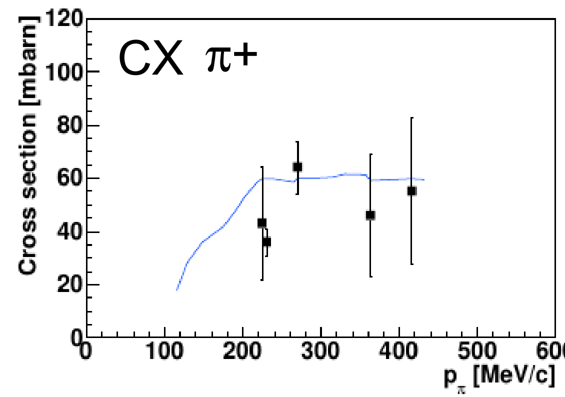
- Very sparse data available for single reactions: need reconstruction of low energy nucleons and π0



1. Hadronic scattering (SCAT) 2. Absorption (ABS) 3. Charge exchange (CX)

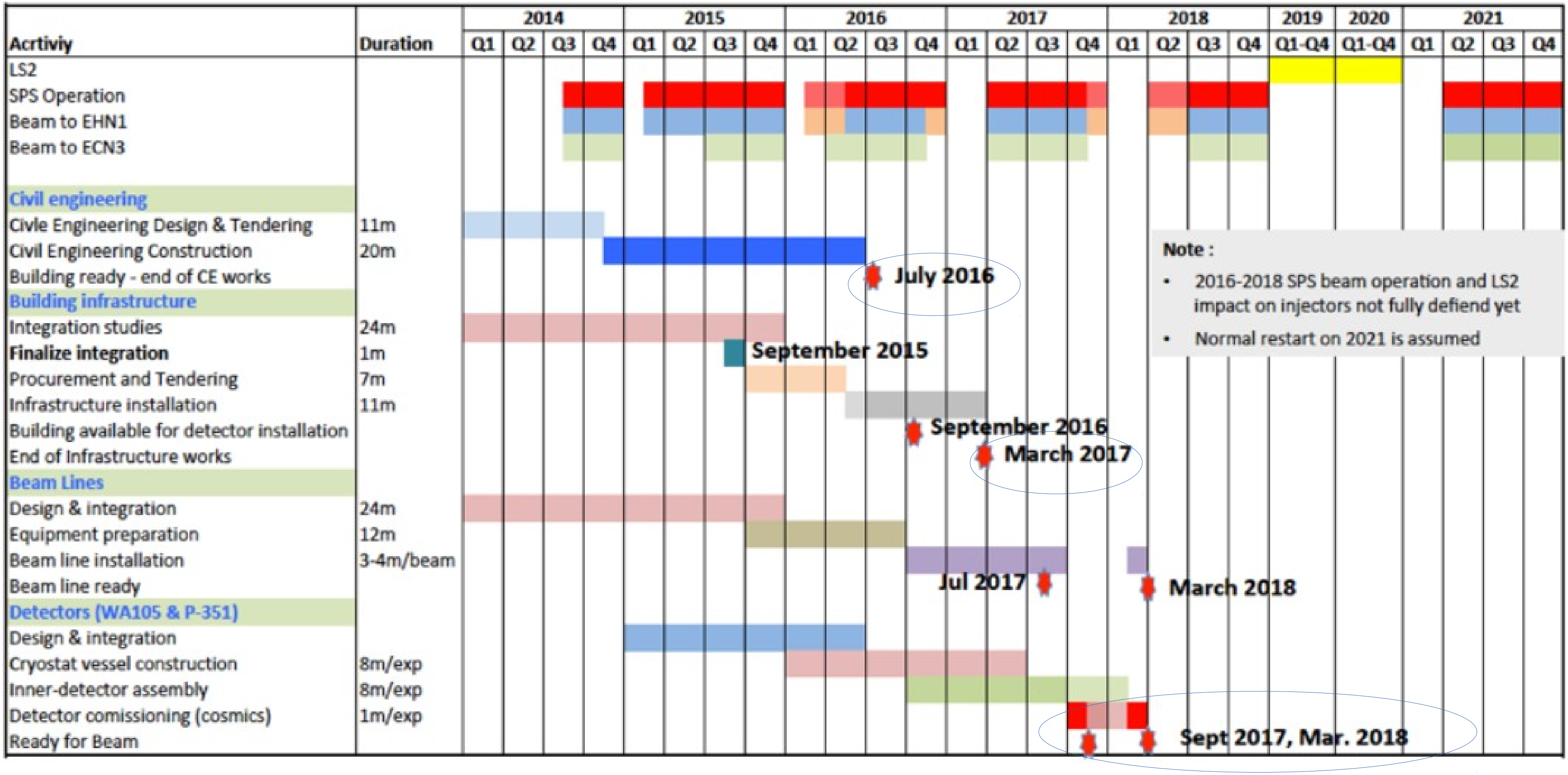




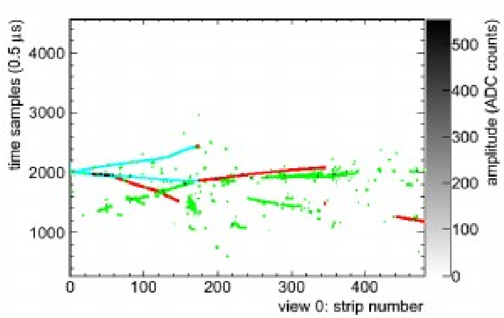


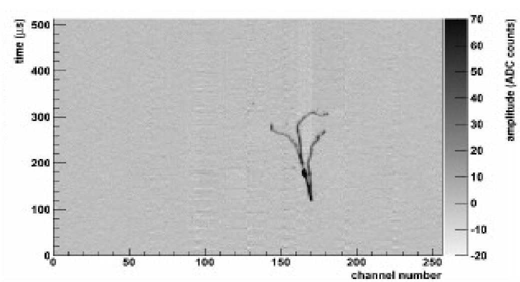
- Can use primary and secondaries pions from CERN beam (primary rate up to 20 GeV ~100 Hz)

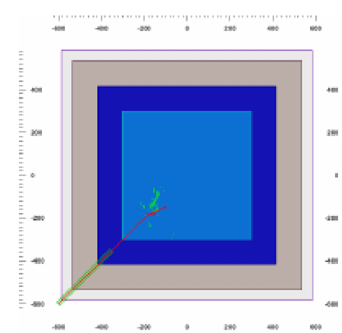
Planning timeline



See you in few years with beam events !







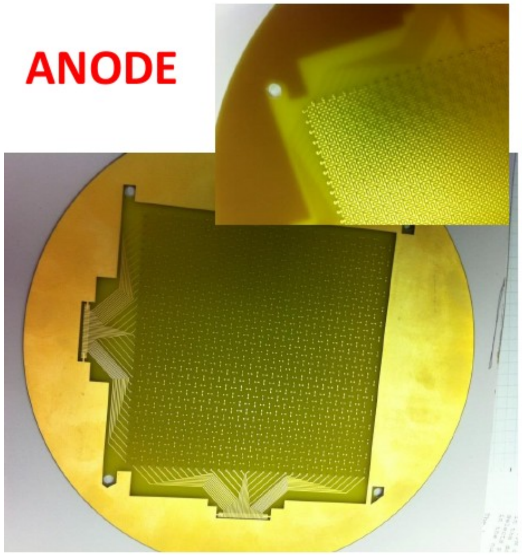
BACKUP

Status & plans
of the **WA105** 6x6x6 m3
Double Phase Liquid Argon TPC
at CERN neutrino platform

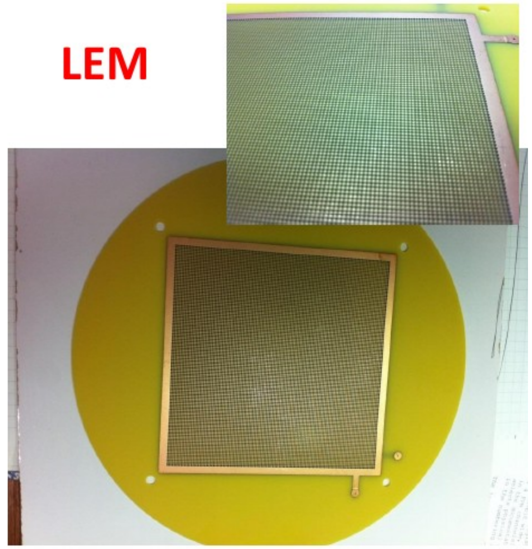
Sara Bolognesi (CEA Saclay)
on behalf of WA105 collaboration

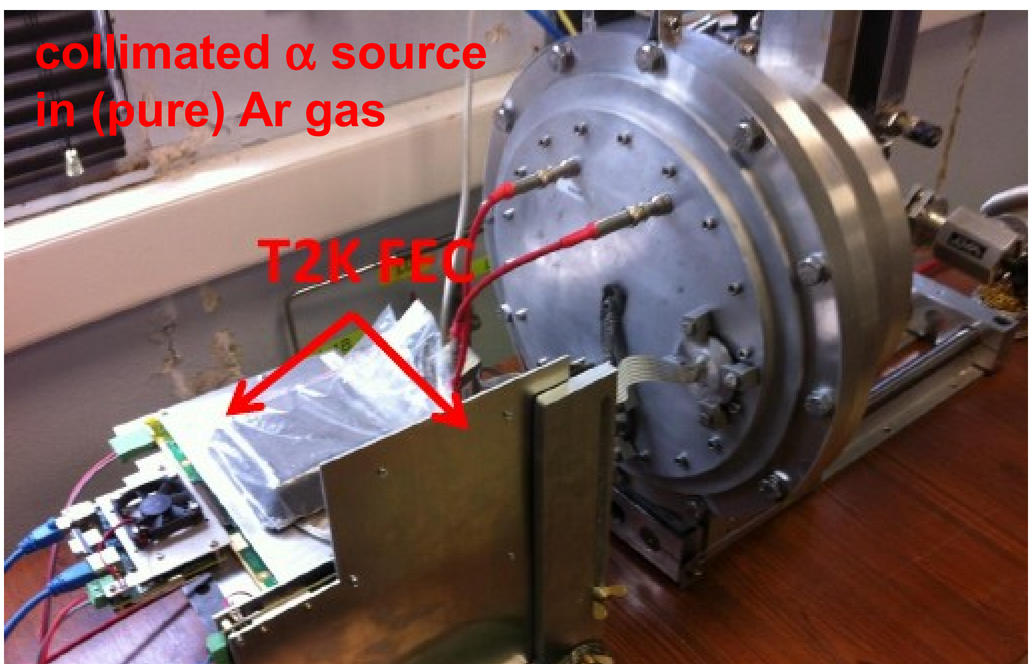
LEM 10x10cm^2 test @ Saclay

ANODE

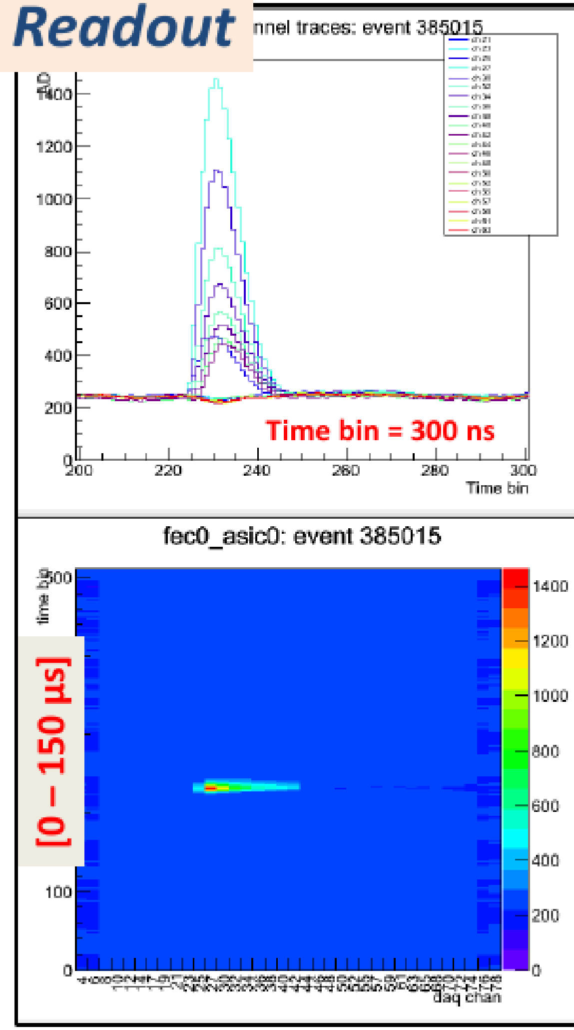


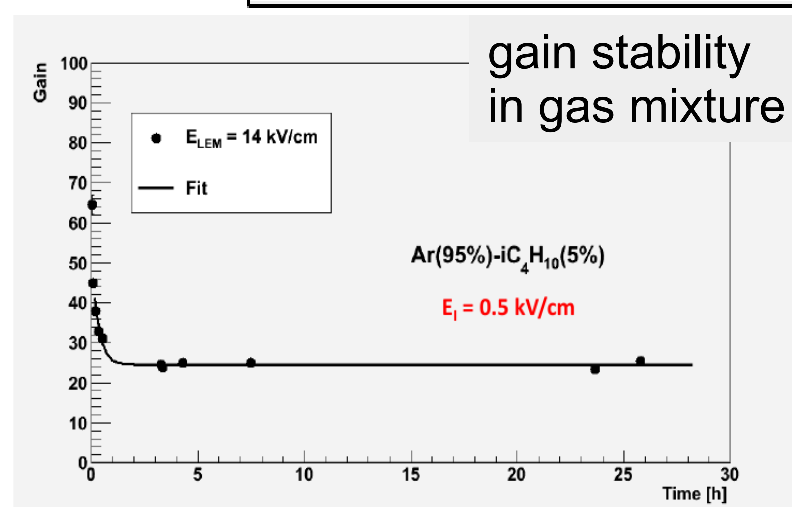
LEM





1D Readout

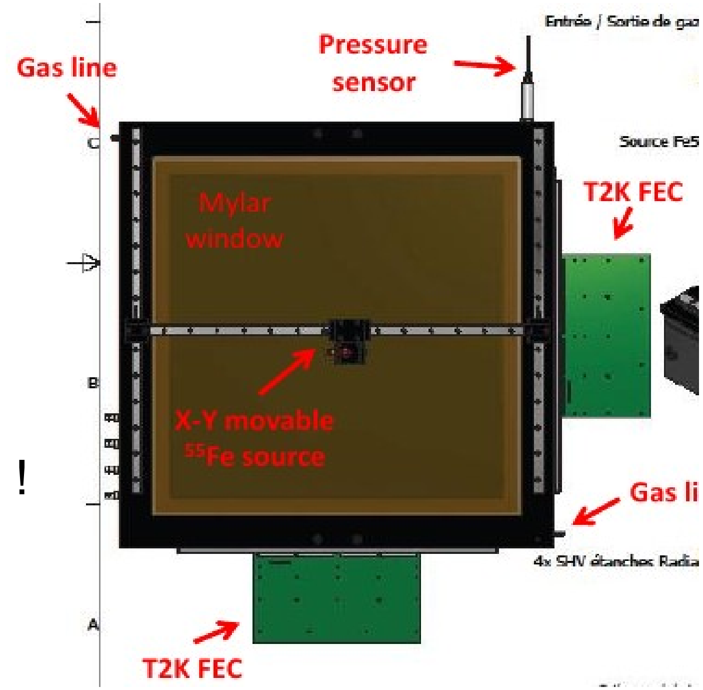




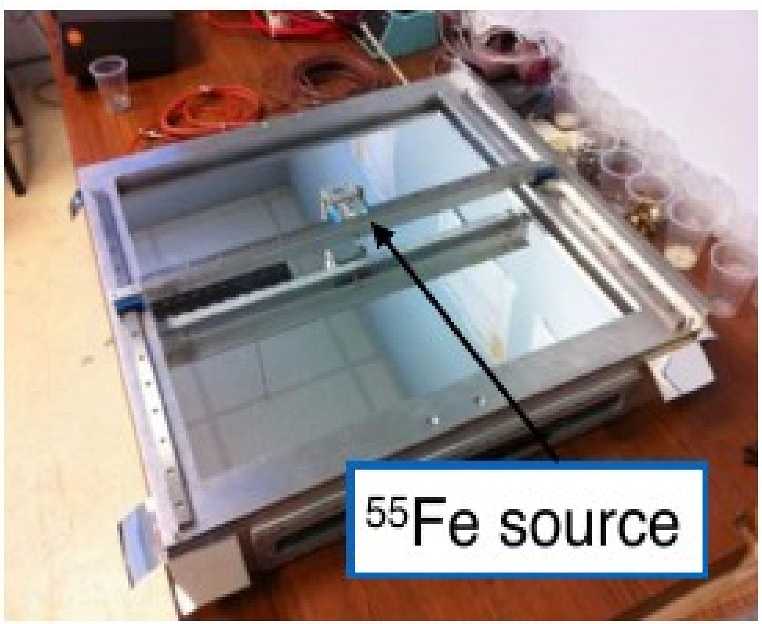
gain stability
in gas mixture

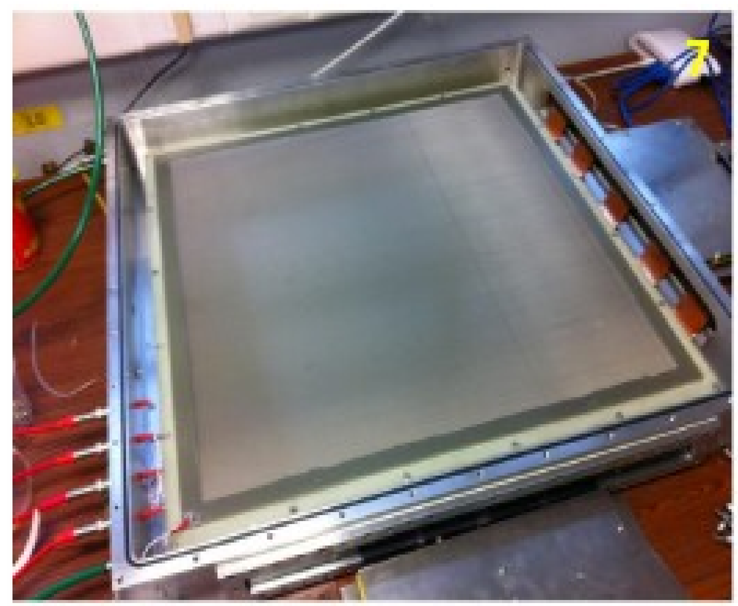
LEM characterization

Very large LEM never used in previous experiments: construction, operation and calibration are challenging !



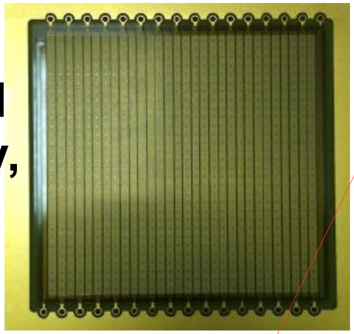
50x50 box built at Saclay for **LEM calibration by scanning with ^{55}Fe source**

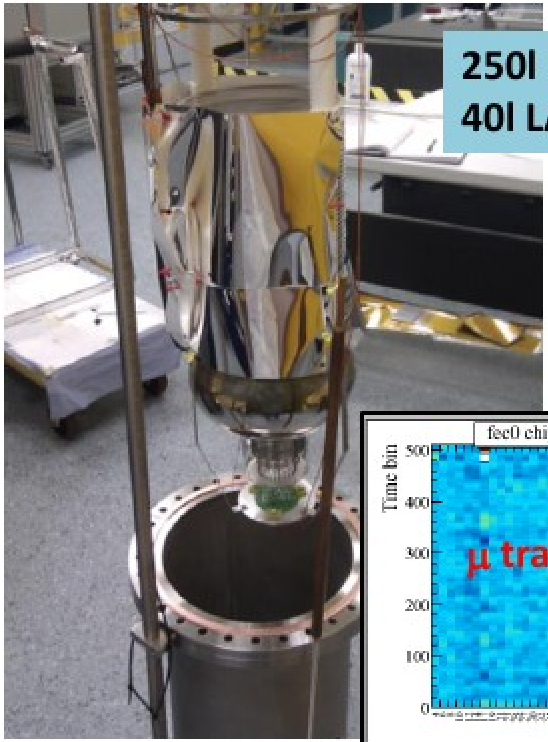


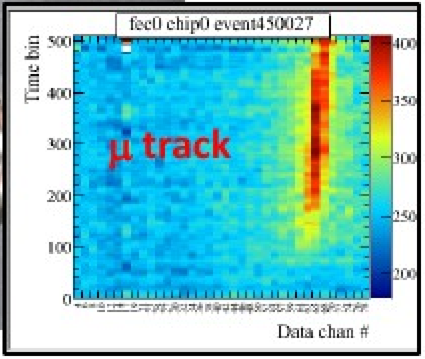


R&D Micromegas

Amplification through micro-grid (invented in Saclay, large experience eg : T2K)

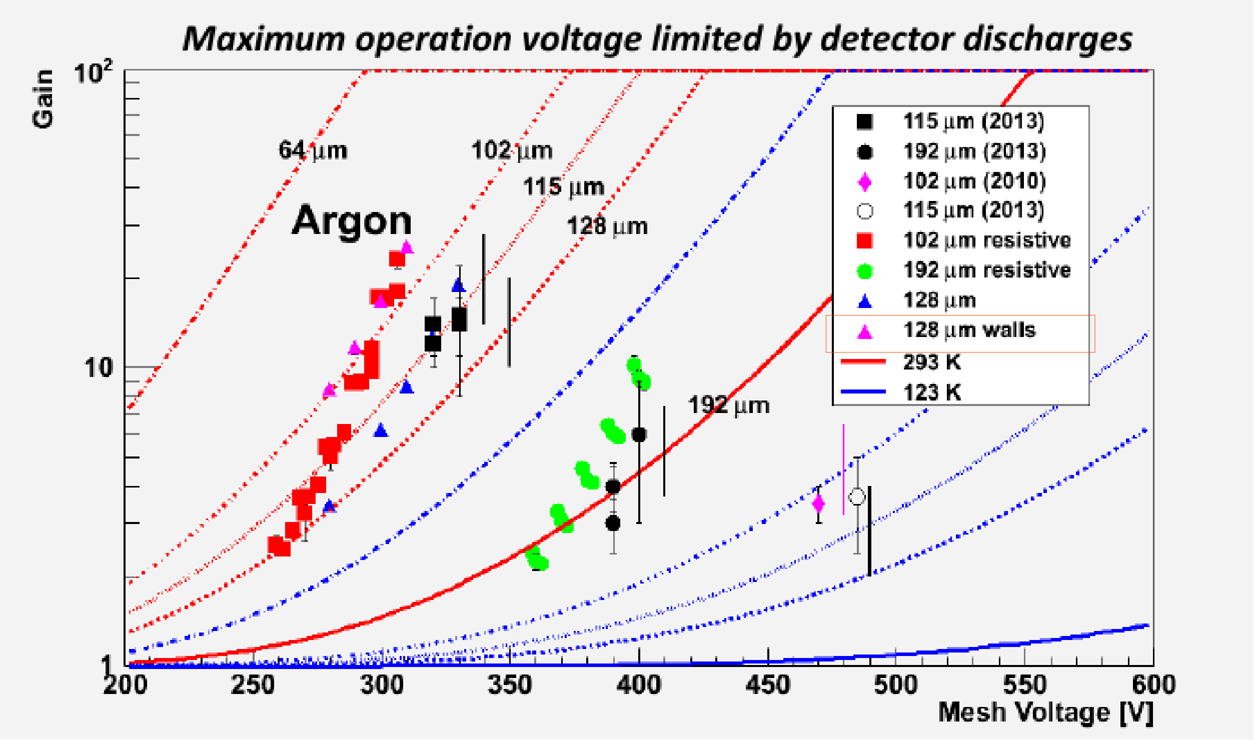






Micromegas proven to work in LAr up to a gain of ~4

→ try to improve by putting walls (instead of pillars) in amplification gap to absorb UV (limit electric discharge)

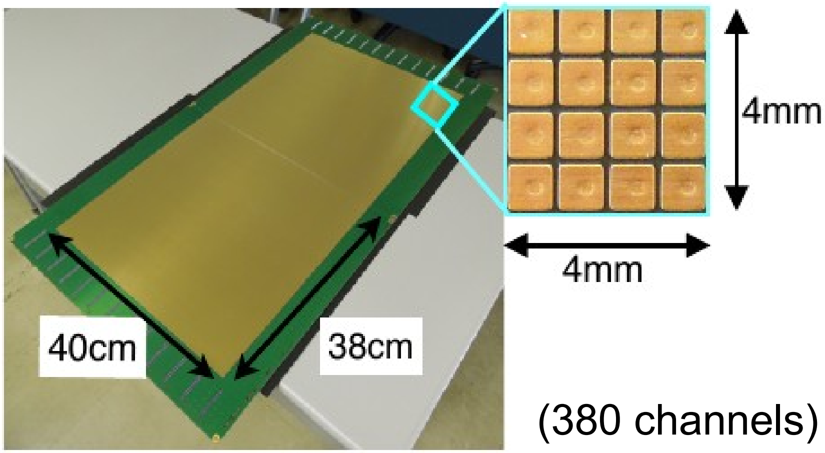


→ up to 20-30 gain in pure Ar gas

R&D Anode

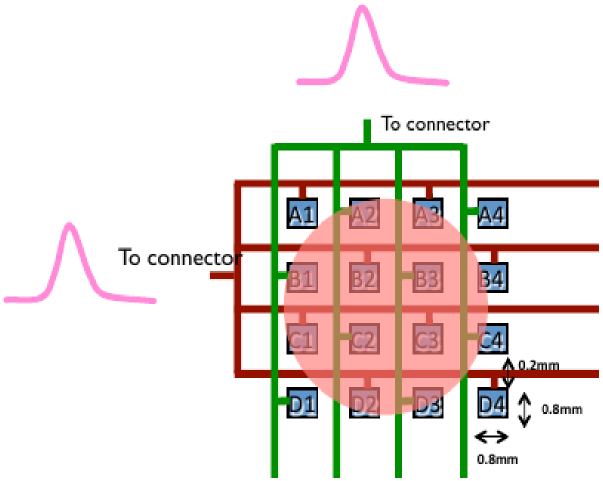
Anode with 'pixels' : 4x4 groups of 0.8 mm² electrodes

→ possibility of large area readout : 50x50cm PCB

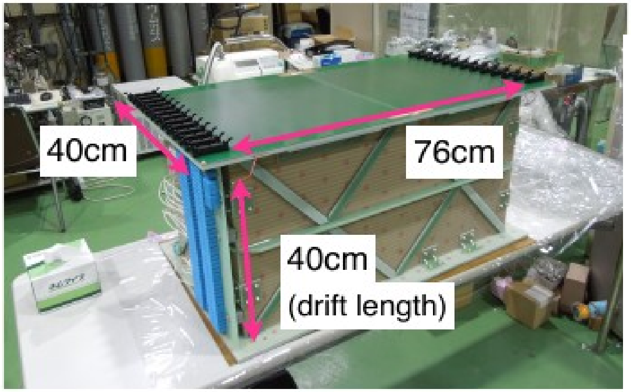


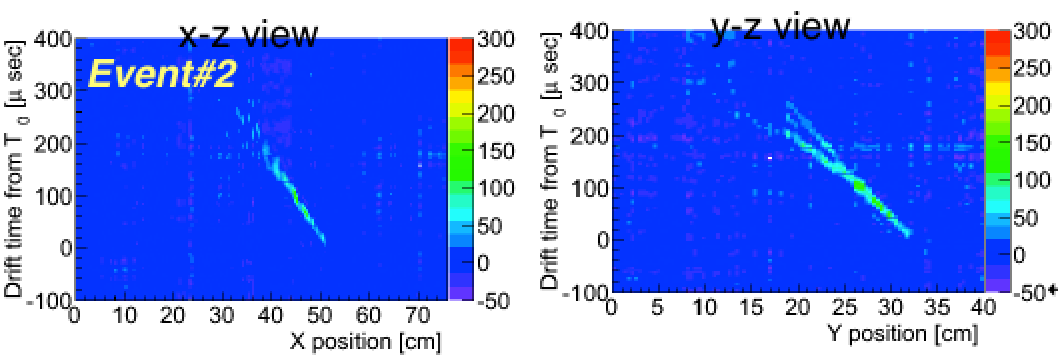
(380 channels)

→ charge equally shared on the 2 readout views with same signal shape

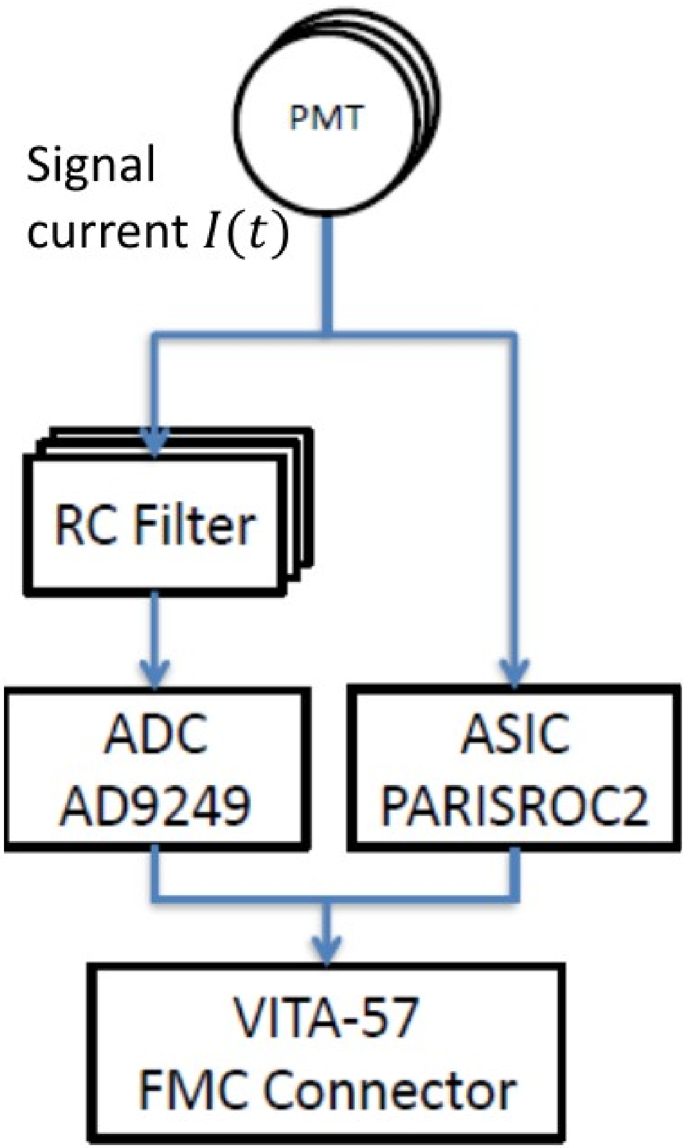


Tested on **250L LAr detector** with cosmics





Considerations for PMT readout (reminder)



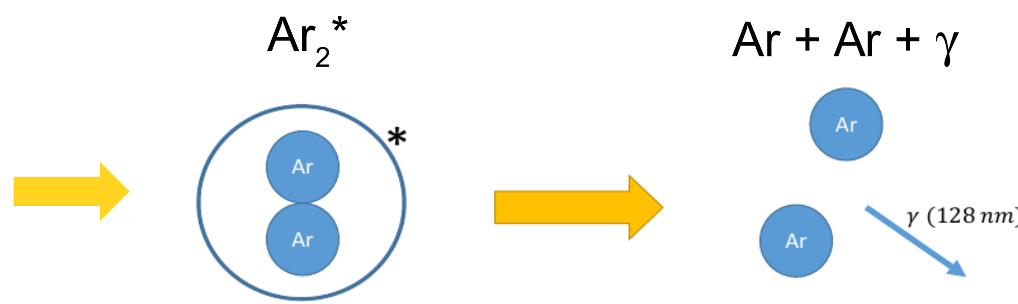
- Two paths:
  - PARISROC for self-trigger
  - AD9249 → digital data output
- ~50% chance of missing cosmics due to dead-time in self-trigger mode

Solution: two modes of acquisition
  - Continuous acquisition of ± 4 ms on beam trigger
  - Special studies using self-trigger mode (short O(us) time segments)
- Nominal digitizer is sampling at 40 MHz
  - Data volume for 36 ch reading 8ms : 15 Gbits/s ← too high for 10 Gbit link
  - Reduce outgoing volume rate by averaging multiple samples in FPGA on the frontend card
    - The optimal number to be averaged has to be cross-checked with simulation

Scintillation in LAr (1)

Scintillation light produced via formation of Ar excimer state :

- self-trapping Ar* + Ar
- recombination $Ar^+ + Ar + e^-$



- WA105 will allow also to test installation and operation of PMTs in LAr (heat dissipation, pressure on PMTs, LAr pollution, electric field distortion...)