the T2K TPC, 10 years later

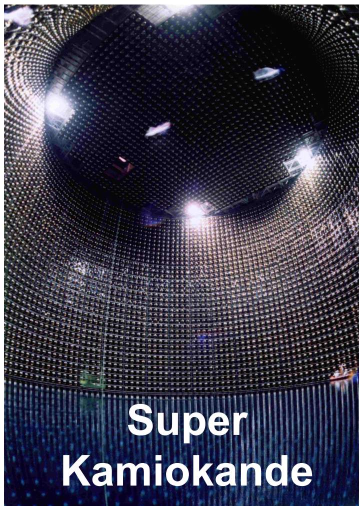
E. Radicioni

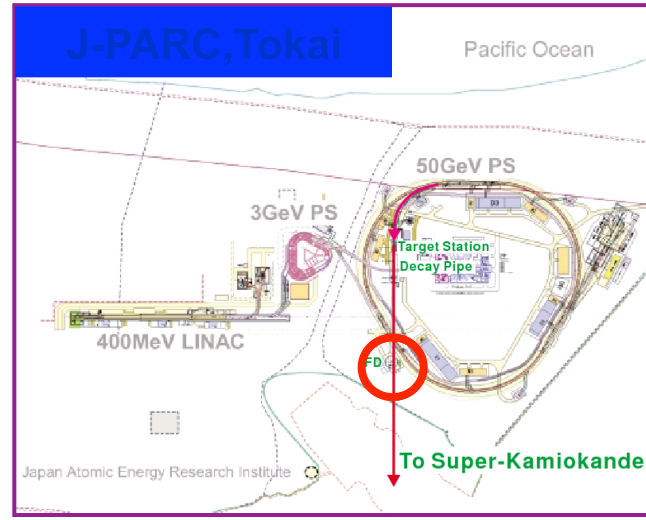
INFN

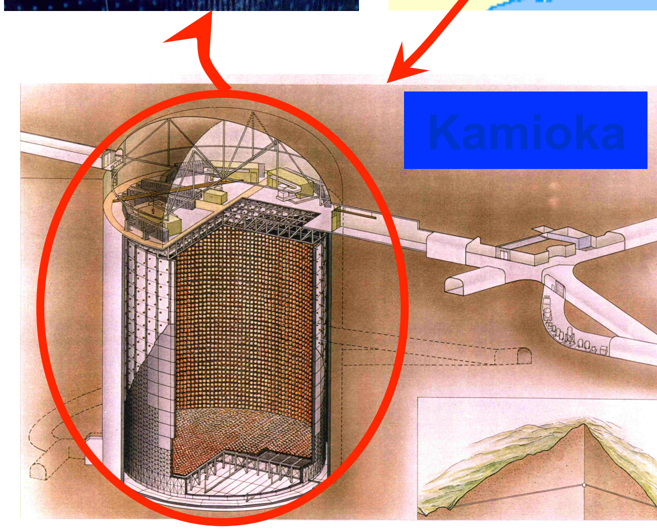
outlook

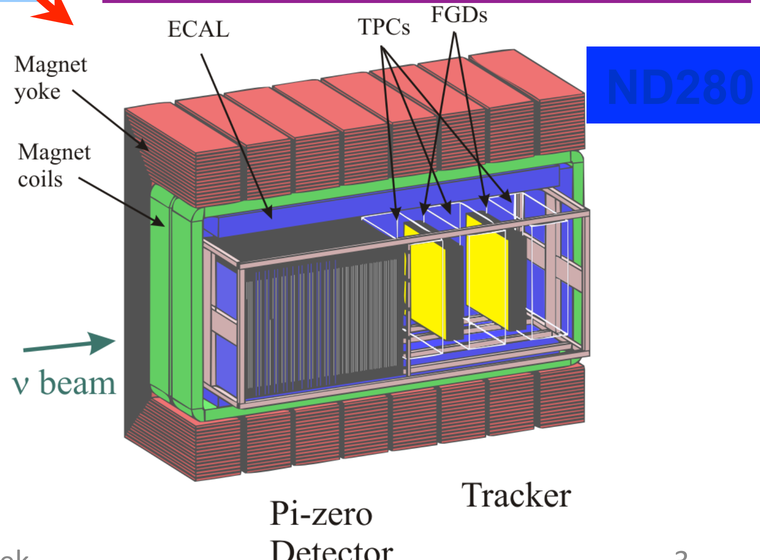
- Detector concept and requirement
- R&D activity
- Description of subsystems
- Performances and faults
- Lessons learned
- Likely future

the T2K experiment

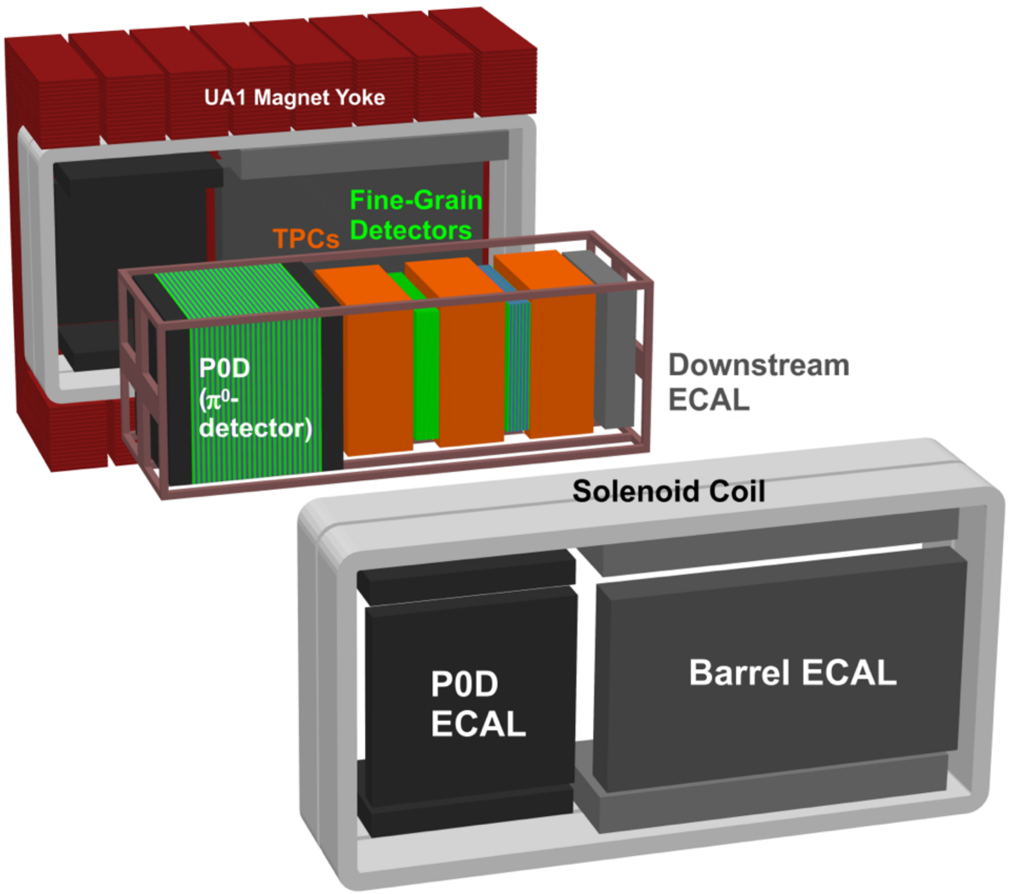








ND280 detector concept



- ND280 goals
  - Measure ratios of CCQE, CCnQE, NC ν interactions
  - ν_e fraction in beam
  - Non-QE misinterpreted as QE
  - ν cross sections
- R&D 2005-2006, construction, operation started in 2009

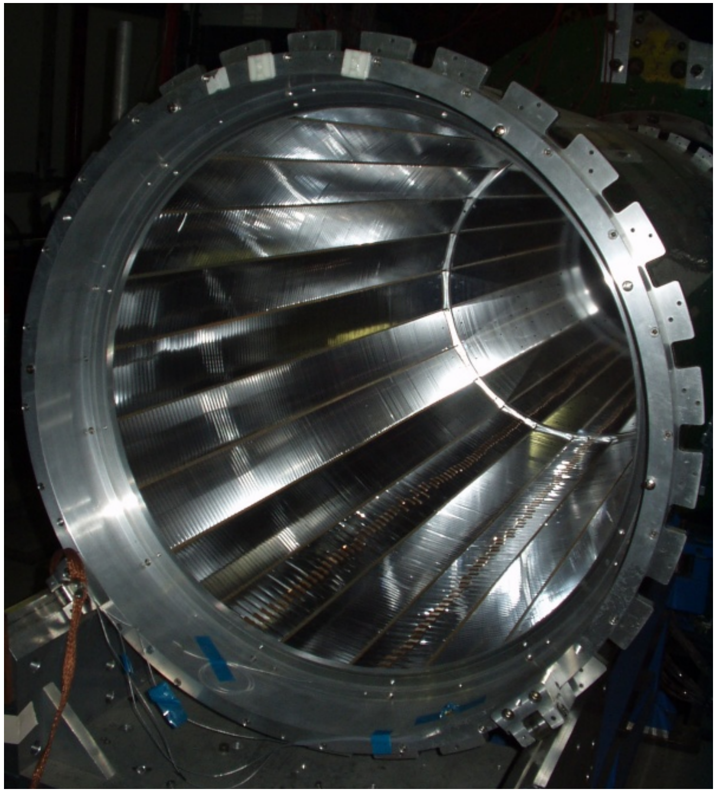
TPC motivations

Resolution: σ ~ 500μm	Any decent tracker could do
Particle ID: e/μ/p	TPC !
Avg. momentum < 1GeV/c	As-light-as-possible: TPC
Mild magnetic field	Low diffusion gas
Low track density	Few tracks per event → no need for small pads
Broad angle range for e and μ, + very large angle p	Dependency of σ from track angle → MPGD amplification → Squared (or almost) pads

R&D

- Optimize pad size & shape to the specific case
- Test gas mixture to find the most appropriate for low-diffusion in mild (0.2T) magnetic field
- Need large (~1.5m^2) pad planes
  - maximum size of GEM and MM ~30cm
  - Study modularity (dead space, mechanical constraints, etc)
- Study performance of prototypes of realistic size

Test-bed

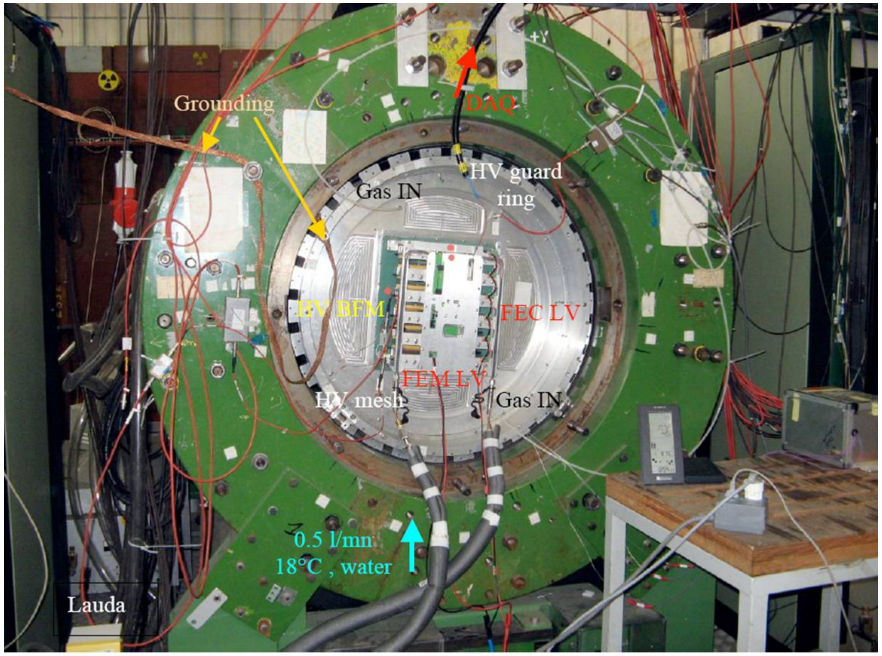


Field cage:

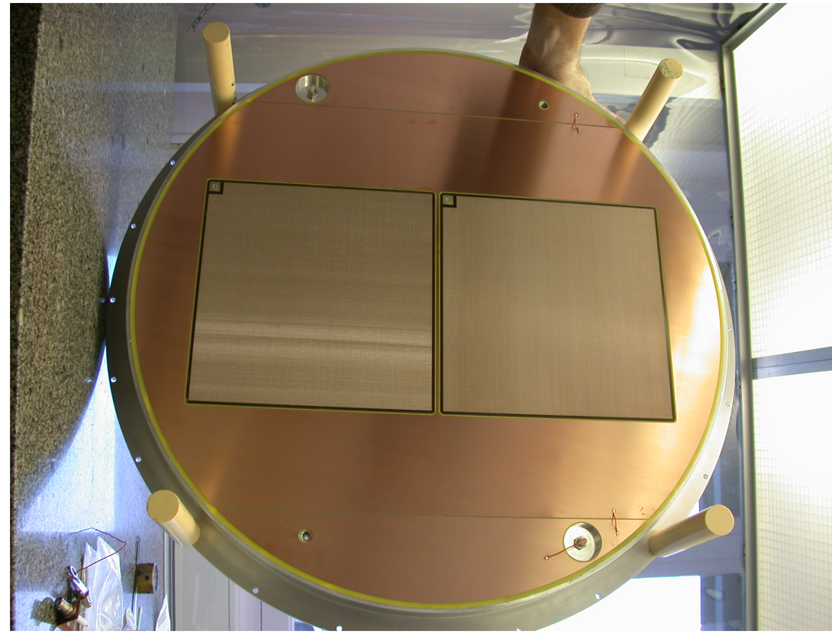
- used in the HARP experiment
- "sweet field" region: ~ 150 cm long, ~ 80 cm diameter
- less than 1% field (E and B) distortion

Magnet: 0-0.7 T

R&D prototypes

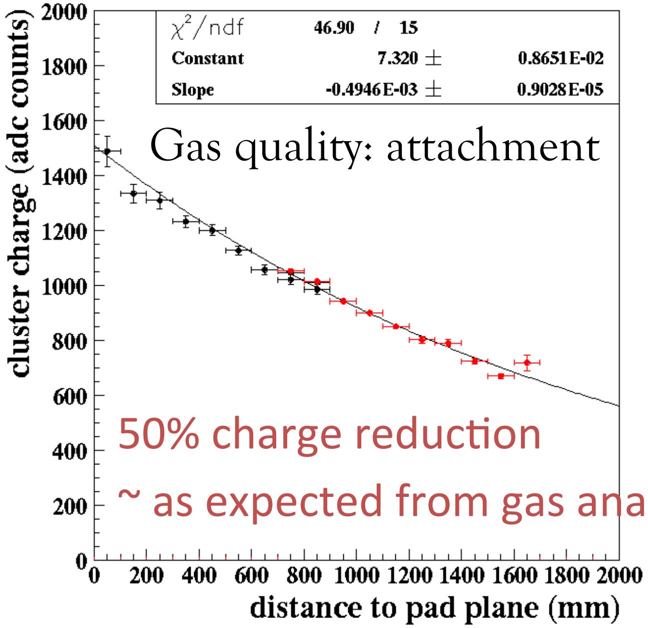


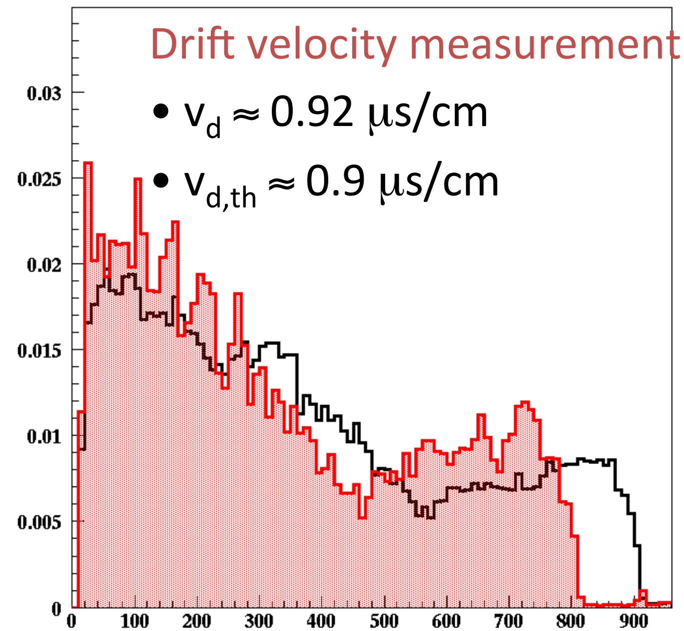
Hardware setup in T9A experimental zone (09/19/2007)

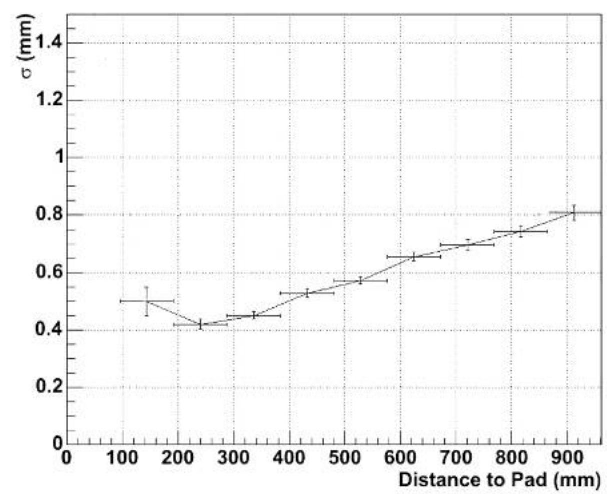


- GEM and MM end-plates developed by late 2005 and tested early 2006
- Several gas mixtures (Ar + CO2, CH_4 and iCH_4)

R&D: initial performances



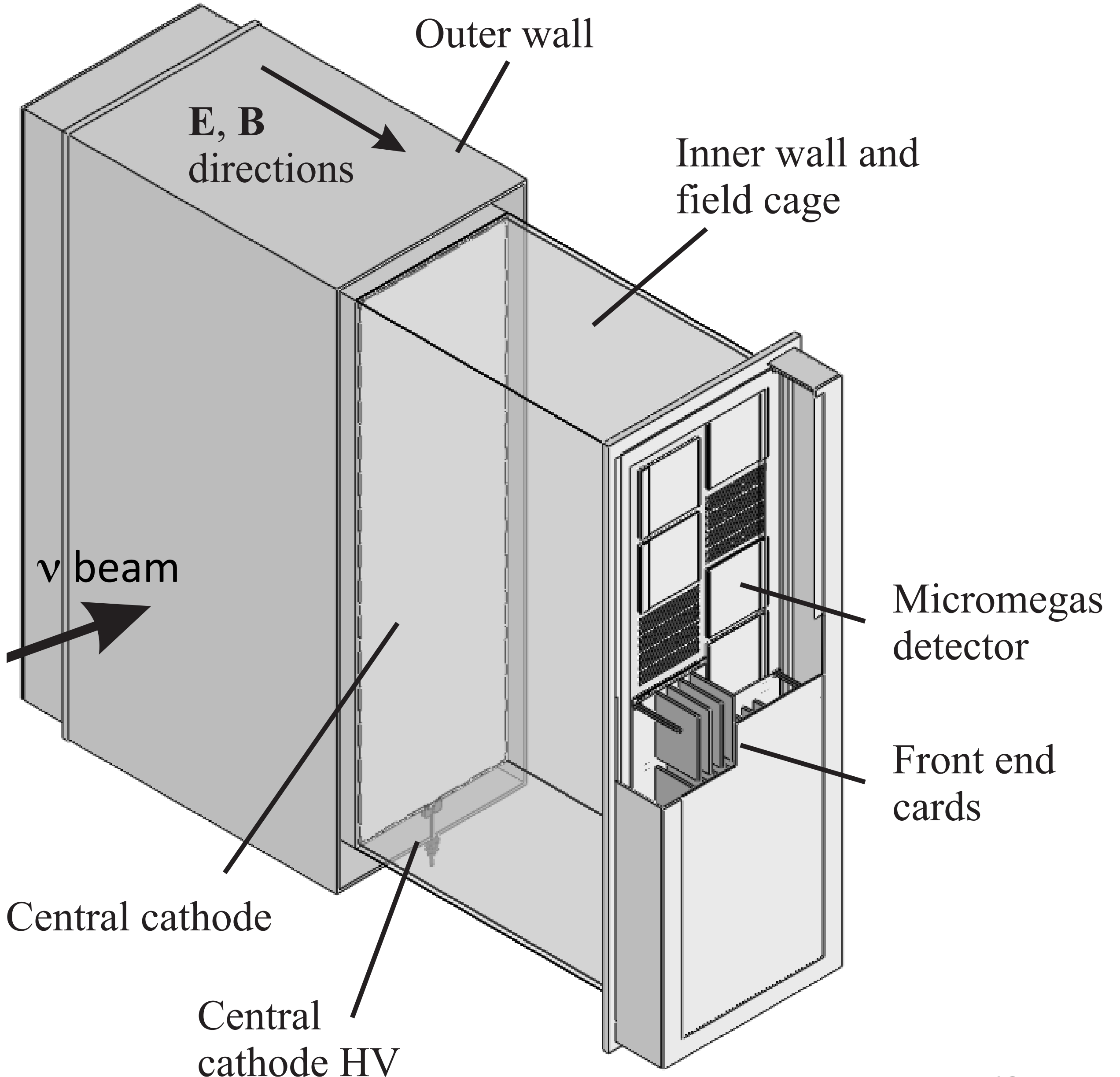




- first indications from the test beam
  - resolution within specs
  - ability to measure typical working parameters

ND280 TPC module

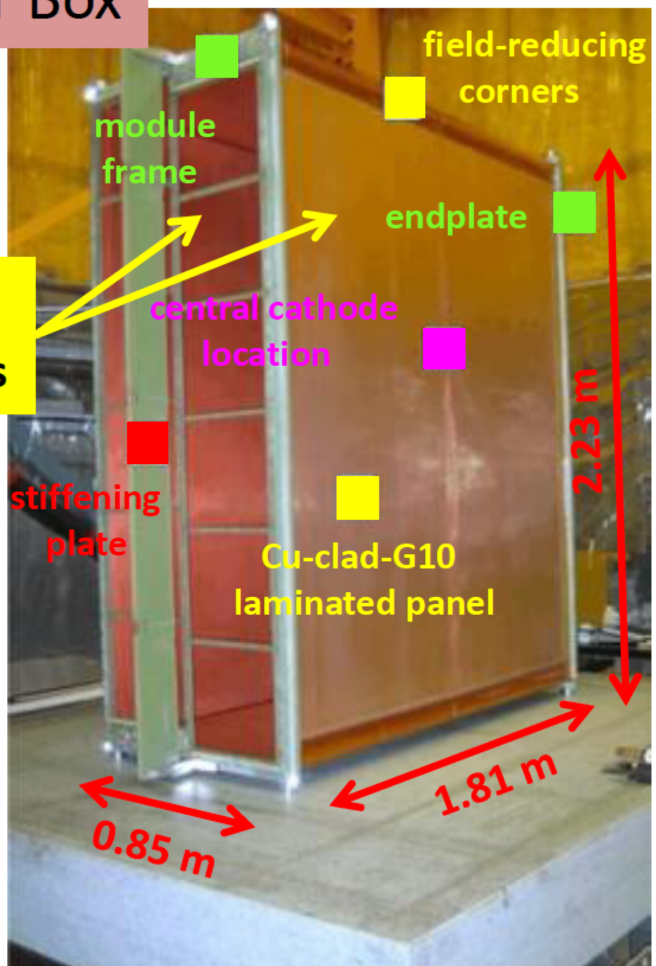
- Outer volume (2*.5 x 2.5 m2 in the plane perpendicular to the neutrino beam direction, and 0.9*m along the beam direction
- Active volume 1*.8 x 2.2 x0.7 m3*
- Gas mixture of (*Ar,iC4H10,CF4 (95/2/3)*
- The central cathode is set at moderately high potential (close to 25 kV).
- The outer box is separated from the inner box by a gap of 6.8 cm on the sides and top and 11.8 cm on the bottom.
- Pad plane made by tiles of MM readout modules



Field cage

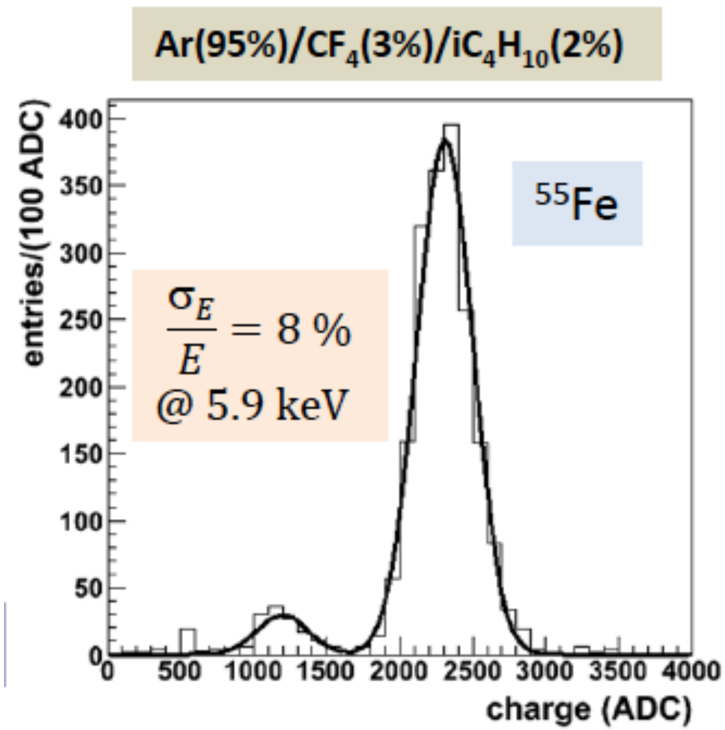
Inner Box

E-field shaping strips



Outer Box

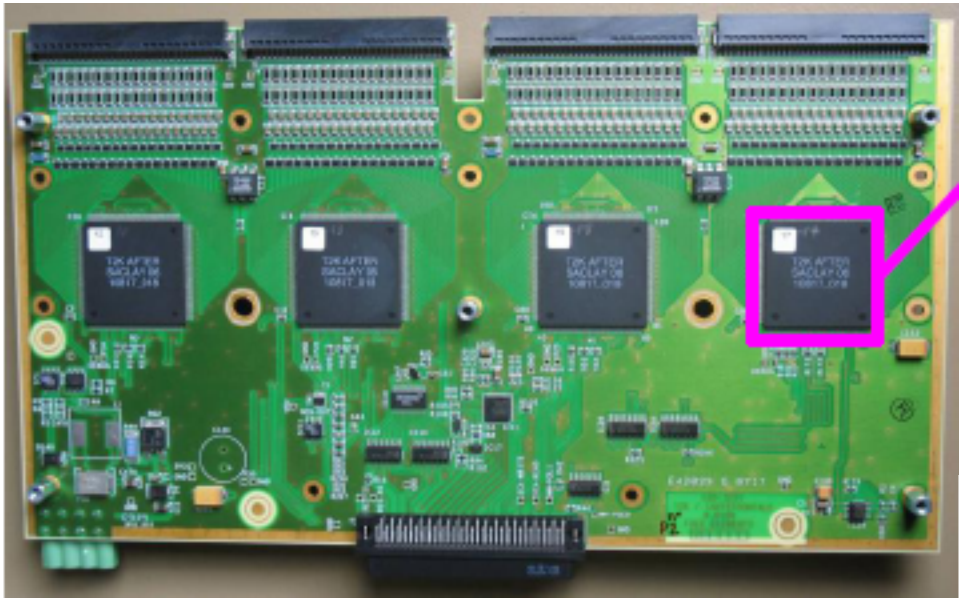
Amplification



- 359.1 x 349.3 mm2
- 1726 active pads.
- 9.8 x 7.0 mm2
- 128 μm amplification gap.
- 72 modules for 3 TPC´s.

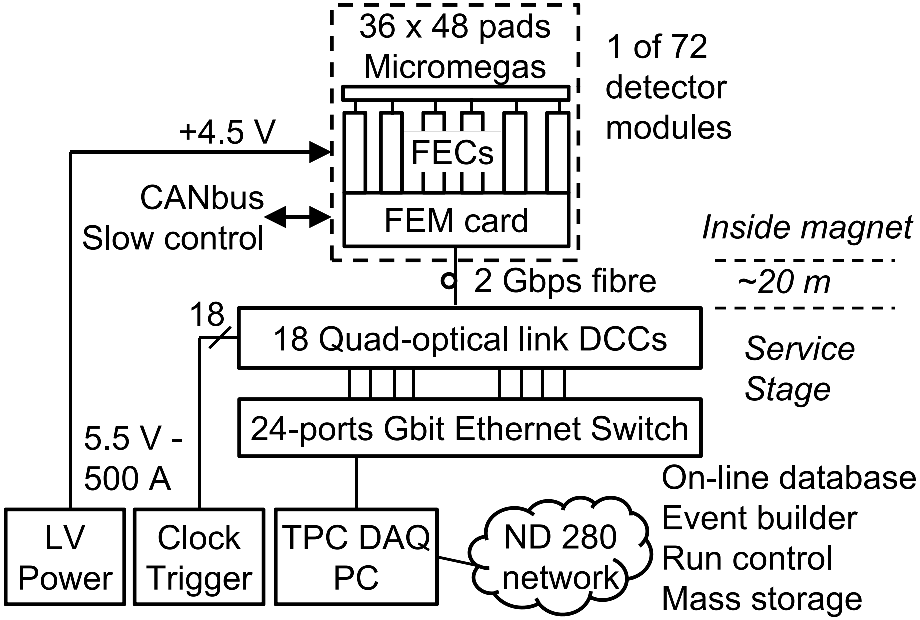
- TPC Gas: Ar(95%) CF4(3%) iC4H10 (2%)
- Gain: 1500 @ 27.4 kV/cm
- Drift Velocity : 7.8 cm/μs
- Drift field: 279 V/m

FE electronics



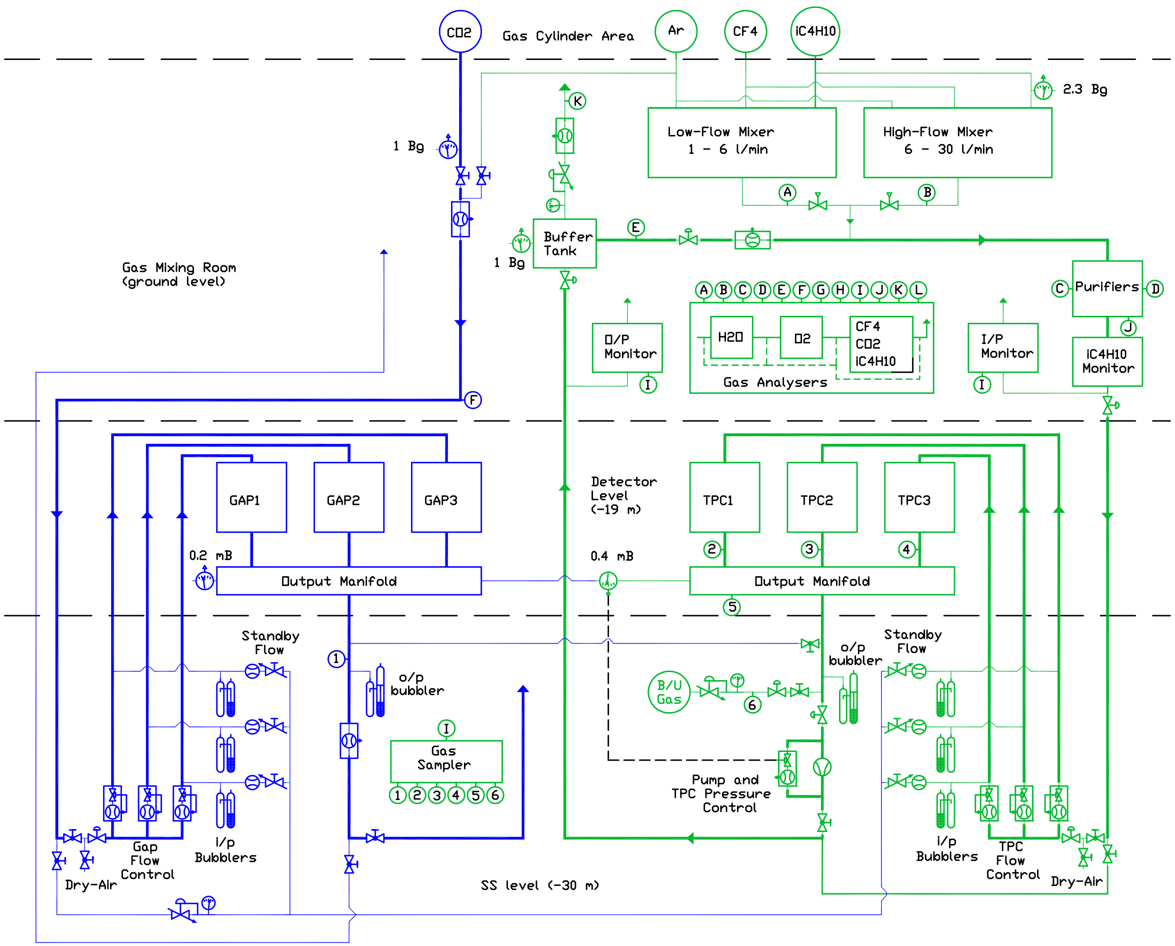
- 1 MM = 1 FEM + 6 FECs = (24 AFTERS)
- FEM : data collector, 0 suppression, slowcontrol…
- Data Concentrator Card (DCC) reads 4 FEM´s.

18 DCC´s based on xlink demonstrator card.



- 124416 channels / 3 TPC
- Front End Electronics based on ASIC chip:
- 72 channels x 511 analog memory cells.
- programable gain: 18. - 4.1 mV/fC
- peaking time : 0.1- 2 μs (0.2 μs).
- sampling frequency up to 100 MHz (25Mhz)

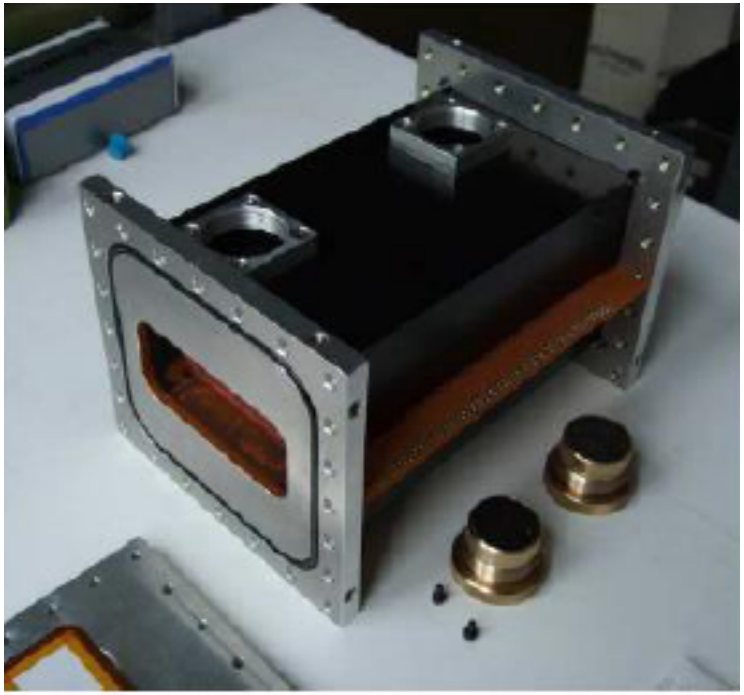
Gas system

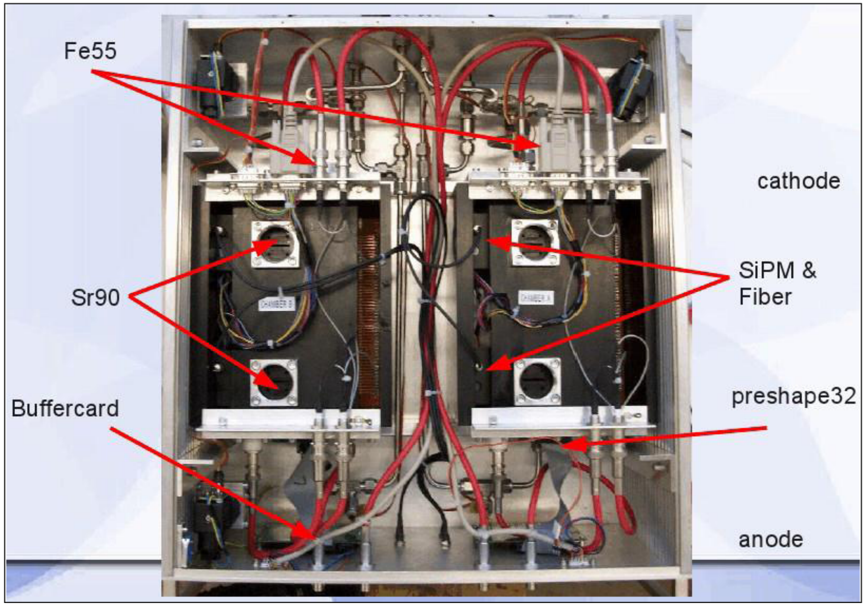


- Very stable operation:
- H20 (<5ppm) 02 (<2ppm) and C02 (20ppm-120ppm) at the exhaust pipe.
- Ar (95.001±0.001%), CF4 (2.9999±0.0008%) and iC4H10. (2.0000±0.0007%)
- Gap differential pressure 0.4+-0.03 mbar
- 22.2 L/min for the 3 gaps. (~5 volume exchanges every 1.5 days).
- 30.0 L/min for the 3 volumes (~5 volume exchanges every day).

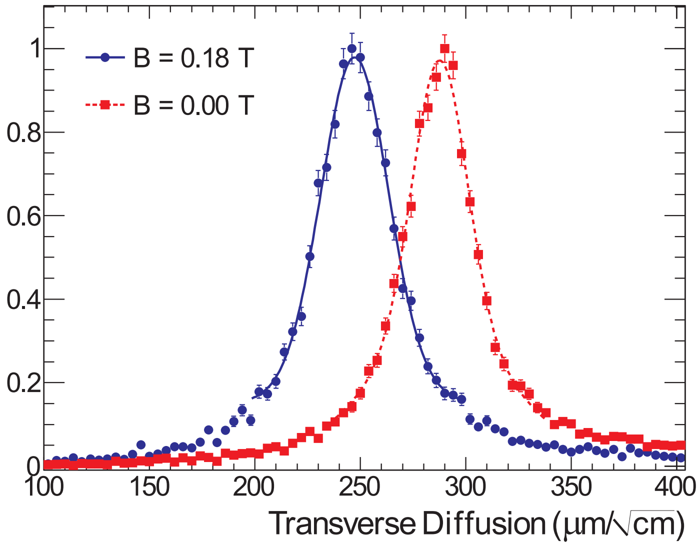
Gas monitoring chambers

- Two chambers inserted in the gas system (sample input and output gas from the big TPC volumes).
- Use 2 90Sr sources at different distances to monitor drift velocity. T0 from scintillator fibers. Online monitor every 30 minutes.
- Use 1 55Fe source to monitor gas amplification variations.

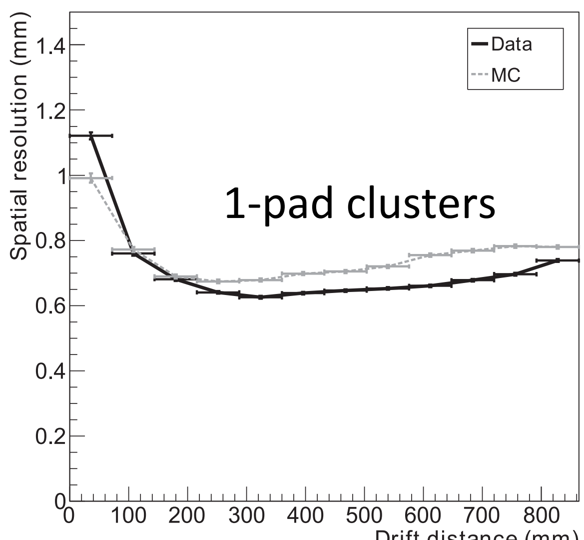


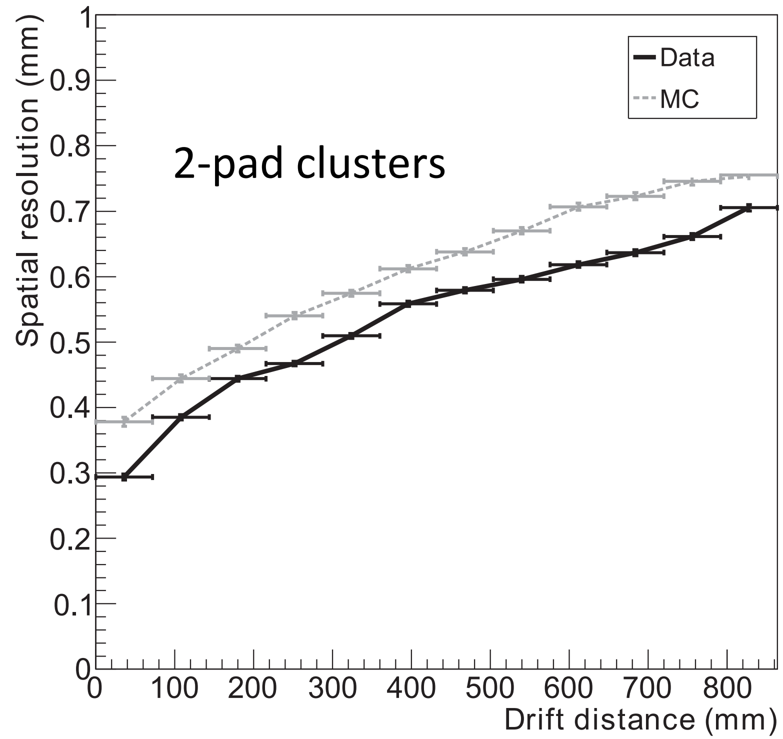


Performance

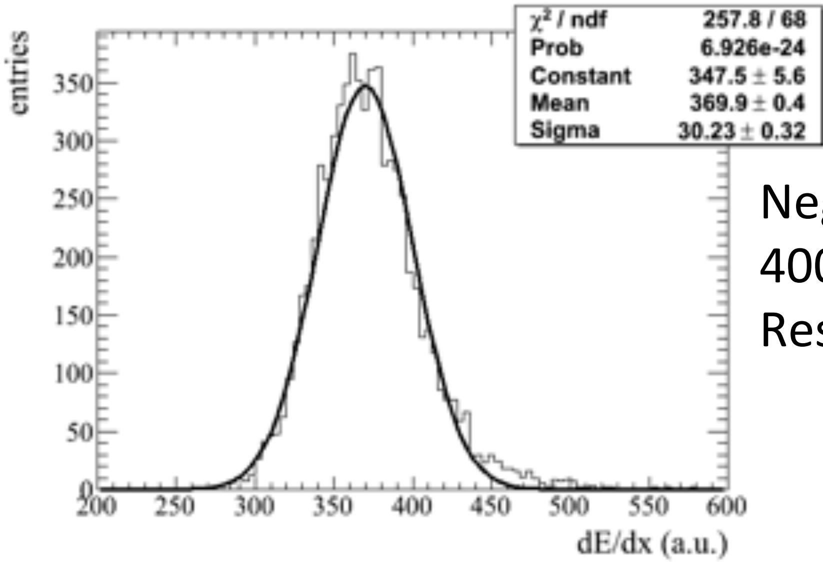


Likelihood fit: take into account (and fits) transverse diffusion



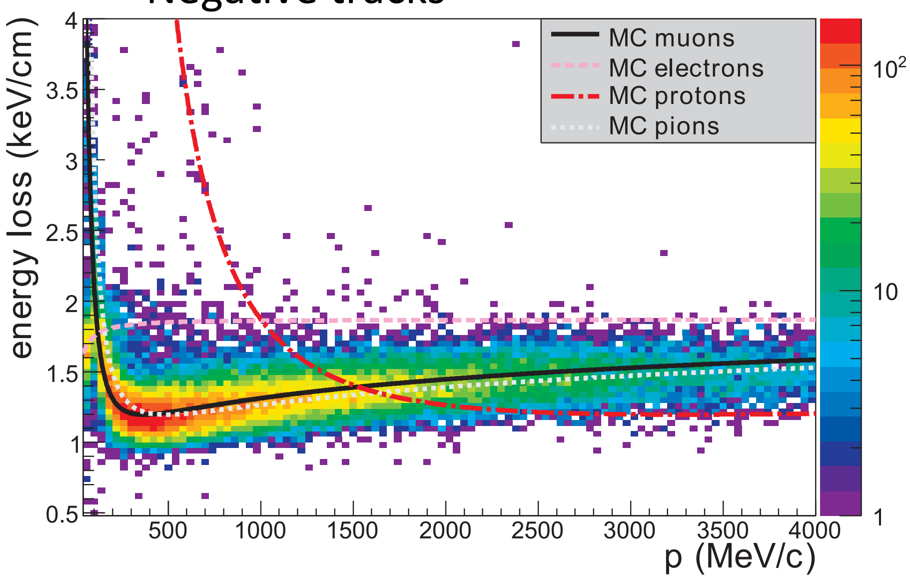


Performance

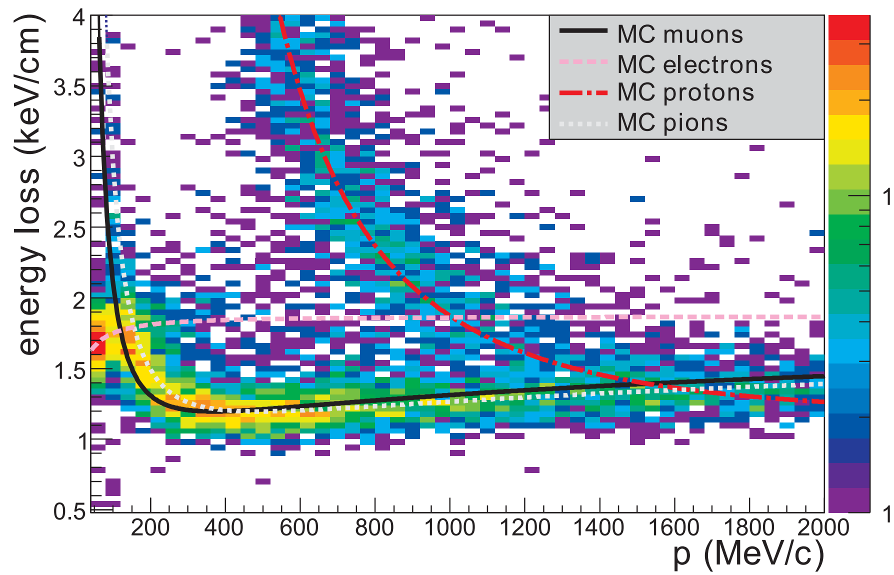


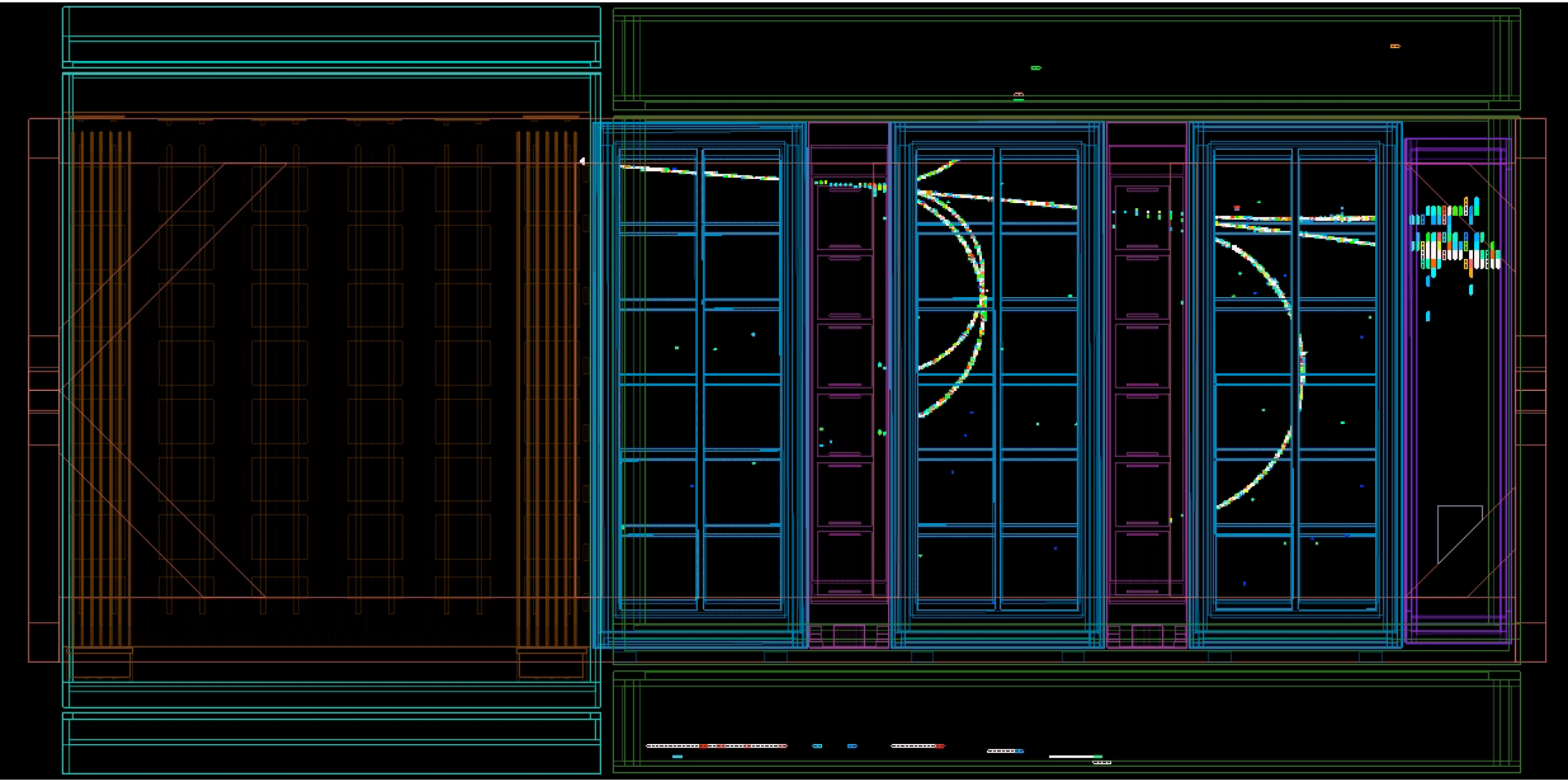
Negative tracks
400 MeV/c < p < 500 MeV/c
Resolution: 8%

Negative tracks



Positive tracks





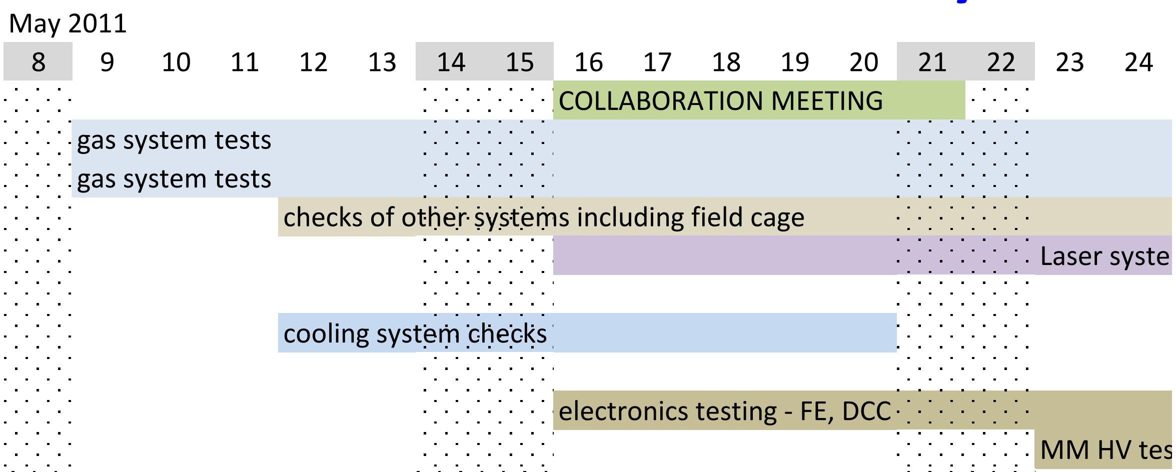
Operation record

- Very stable operation during 7 years
  - expected operational lifetime > 10 years
- Hardware faults
  - no failures of MM (72 of them) or FEC
  - replaced a few FEMs
  - few ASICs off (<0.2% dead channels)
  - disconnected 1 PhotoMOS (1/12 MM)
- DCCs upgraded
  - with more recent model of Virtex demonstration boards

Earthquake

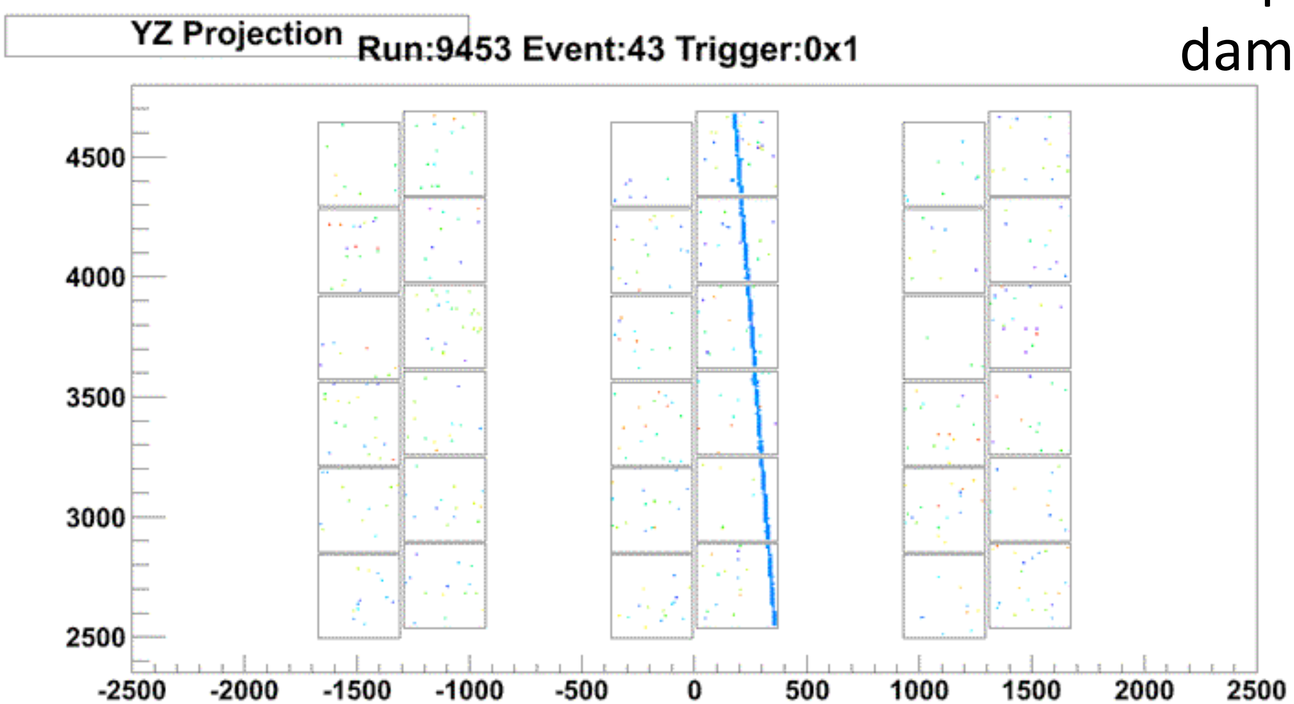
- 11/03/2011 Tohoku earthquake. M9 at epicenter, M7.5 in Tokai
- Electrical power to ND280 goes off immediately (TPC has no backup). Safety Ar supply remains active in the inner volumes, outer volume flow stops.
- Air conditioning in the pit stops → very high humidity (beyond dew point)
- No access allowed to the lab during several weeks

Recovery



~ 2 months later the TPC was switched back on

Assessment (to our surprise): no damage!



Initial motivations and requirements

- All elements proved very stable and robust
- The T2K TPC has been fully successful w.r.t. the main requirements:
  - The momentum resolution better than 10% for 1 GeV muons. Good point resolution to balance the very low magnetic field.
  - The energy scale known at the 2% level. Achieved by an excellent control of magnetic and electric field distortions
  - The dE/dx resolution better than 10% to allow a 3 sigma separation of electrons and muons for momenta > 200MeV/c

Lessons learned

- Resolution: pad charge sharing limitations
  - resistive readout planes not realistic 10 years ago
- Complexity of the gas system for dual-layer field-cage
  - involved manpower and issues with long-term maintenance
- Acceptance (dead space and material in walls)
  - 200 MeV/c cutoff for muons
  - large-angle protons undetected most of the time
- Track length
  - 3 σ separation of e/μ is OK, but μ/π in lower-momentum region is not
- dynamic range with heavily ionizing tracks
- relative alignment of the MM modules
  - → larger modules now possible

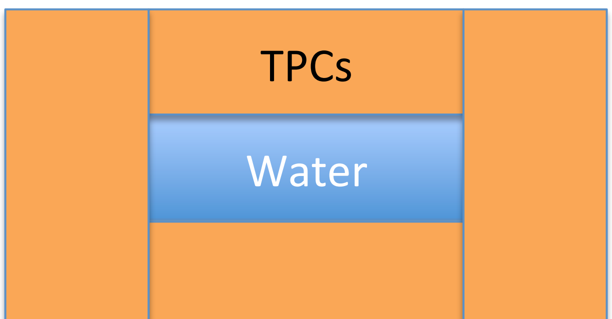
Personal point of view

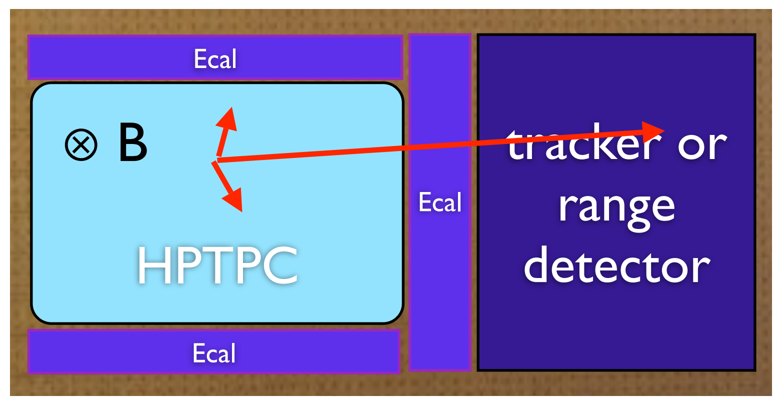
Motivation for upgrades

- the observation of the $\nu_\mu \rightarrow \nu_e$ appearance, the observation of CP violation becomes possible
  - given adequate increase of flux AND reduction of systematic errors
- The role of ND280 becomes more and more linked to reduction of systematics
- Specifically for the tracker system (TPC included):
  - very precise measurement of cross-sections
  - need full solid angle acceptance, including low-momentum and very short tracks (< 200 MeV)
  - possibly measure a fraction of the interactions in a light active medium (i.e. gas) to fully measure all tracks down to very low momenta
- Several options under discussion

Options under discussion

- active water target surrounded by TPCs
  - re-using the old ones and adding more
- single large gas volume as a target
  - possibly high-pressure





gas as a target

	He	Ne	Ar
Density [kg/m3]	0.17	0.9	1.7
Volume [m3] (100 kg @ 10 bar)	56	12	6
Price	↙	↓	↑
HV insulation	↓	–	↑
Stopping power	Small	Medium	Large
High gain @ high pressure	↑	↑	–↙

	MIP	proton (100 MeV/c)	
	e– per cm	CSDA range [cm]	dE/dx [MeV/cm]
He	80	~19.5	~0.25
Ne	430	~5.3	~0.95
Ar	940	~3.5	~1.4

NIST DB

multi-gas HP TPC

- concept: record interaction in gas
- scan different gases (pure?): He, Ne, Ar
- low stopping power to provide precise data for cross-section models
  - e.g. distinguish CCQE from CC1π / detect hadrons with low momentum (100 MeV/c)
- general-purpose detector (T2K, HK, DUNE, ...)

- challenges (and potential R&D items)
  - light pressurized field-cage
  - gas amplification and readout in (almost) pure noble gasses
  - large dynamic range (gasses with very different specific ionizations)
  - diffusion, drift velocity and attachment issues → very large cathode HV
  - complexity of gas system and vessel

future R&D

- foreseeable R&D activity in the future includes
  - better charge sharing in the pad plane (resistive vs smaller size)
  - field-cage technology, with different goals
    - lighter, to lower the momentum and angle cut-off
    - vessel for HPTPC
  - gas mixtures
    - Possibility to scan different target gasses (He/Ne/Ar) to study cross sections
    - behavior at high pressure (~10 Atm)
  - pad plane construction with larger MPGD modules

conclusions

- more than 10 years have passed since the original idea of a TPC tracker for ν-oscillation in 2004
- The detector has been in stable operation since 2009
- Overall a very positive experience
- Changing needs of the experiment shows shortcomings in the present TPC configuration
- The concept of a TPC in the near detector of a ν-oscillation experiment is there to stay
- Future evolution will provide new occasions for R&D