Experience with the Time Projection Chambers for the T2K Near Detector

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for the T2K ND280 TPC collaboration

TIPP 2011
Chicago
June 11, 2011

Tokai To Kamioka Experiment: T2K

Plan for Talk:

- Introduction to T2K and the near detector
- Design of the TPCs
- Calibration of the TPCs
- Performance of TPCs
- Conclusion

Tokai 2 Kamioka experiment

Main physics program

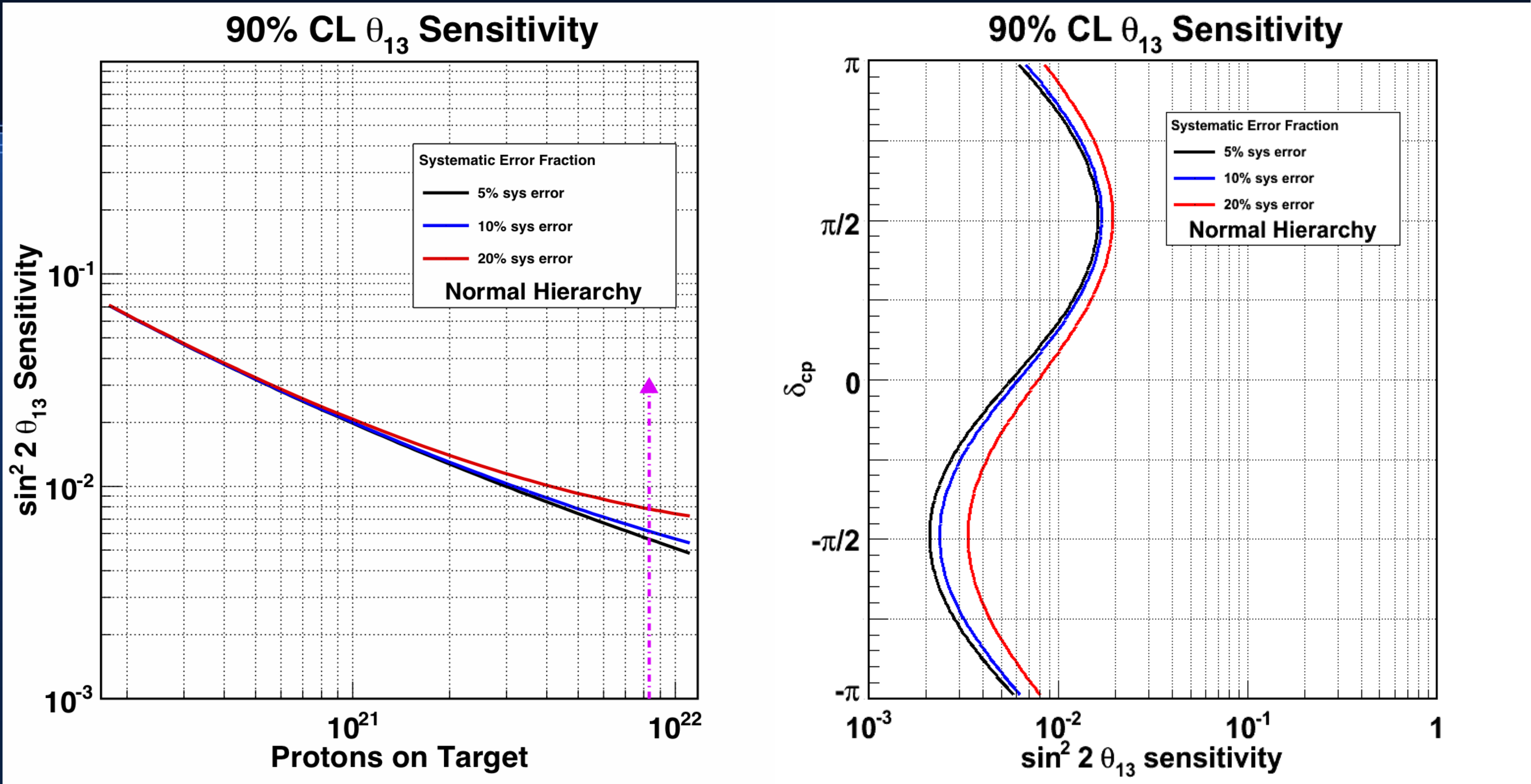
- Precise measurement of ν_μ disappearance

  $(\Delta m^2_{23}, \theta_{23})$

- Search for $\nu_\mu \rightarrow \nu_e$ appearance

  θ_{13}

Core T2K Measurement : ν_e appearance



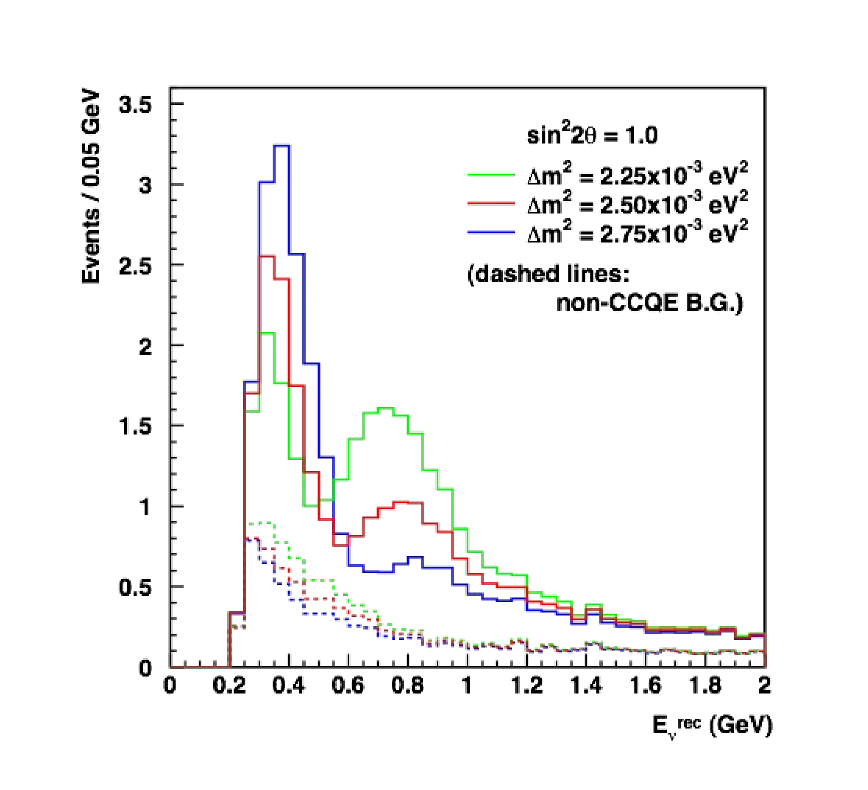
Run 1 + Run 2 have enough statistics to surpass the CHOOZ limit

T2K will also do precision measurements of ν_μ disappearance

Core T2K Measurements : ν_μ Disappearence

Plan:

- Measure the unoscillated ν_μ energy spectrum at ND280
- Measure the oscillated ν_μ energy spectrum at Super-K
  - Using CCQE interaction mode in both cases
- Comparisons of near/far spectrum spectrum allows for precise extraction of ν_μ disappearance

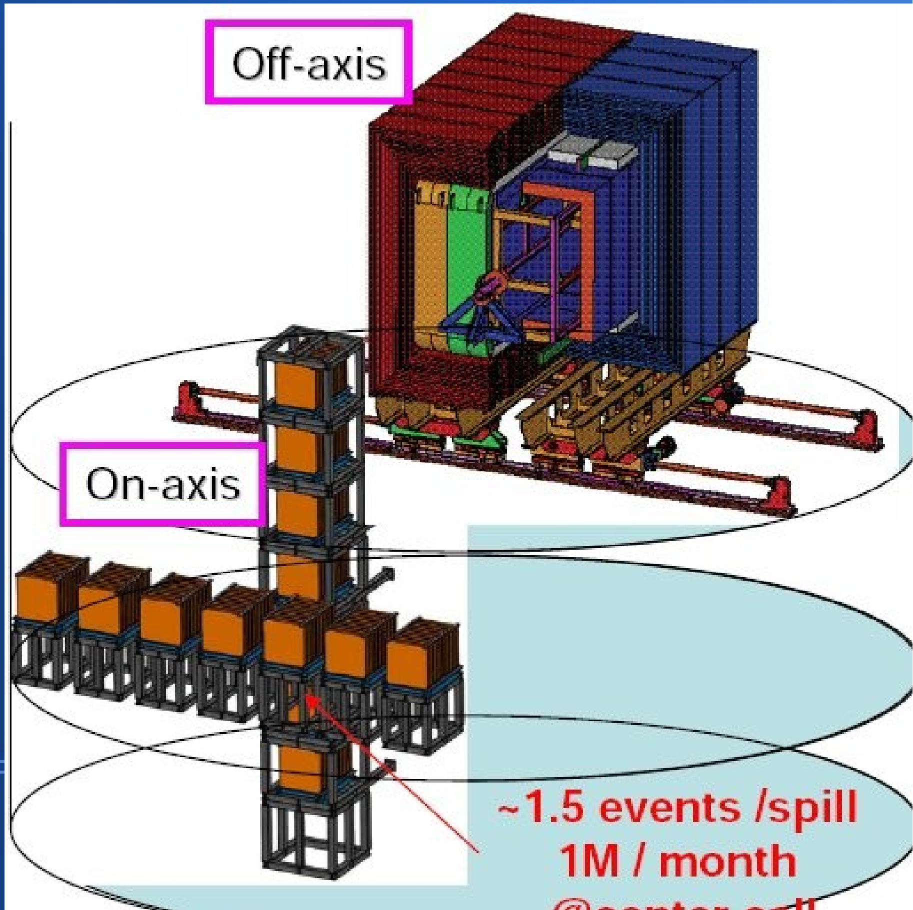


Plots of predicted CCQE energy spectra at Super-K, for different values of Δm^2_{23}. @0.75kW x 5 years

T2K Near Detectors – Physics Role

To achieve T2K sensitivity, we require accurate/precise measurements of unoscillated ν beam. This will be provided by a pair of neutrino detectors at 280m:

- INGRID : on-axis
  - ν beam profile monitoring
- ND280 : off-axis
  - ν_μ energy spectum (flux x cross section)
  - Intrinsic beam ν_e
  - NC π_0



ND280 Detector - Off-Axis

Tracker Section:
2 FGDs (Fine Grained Detectors):
- Thin, wide scintillator planes.
- Provides active target mass.

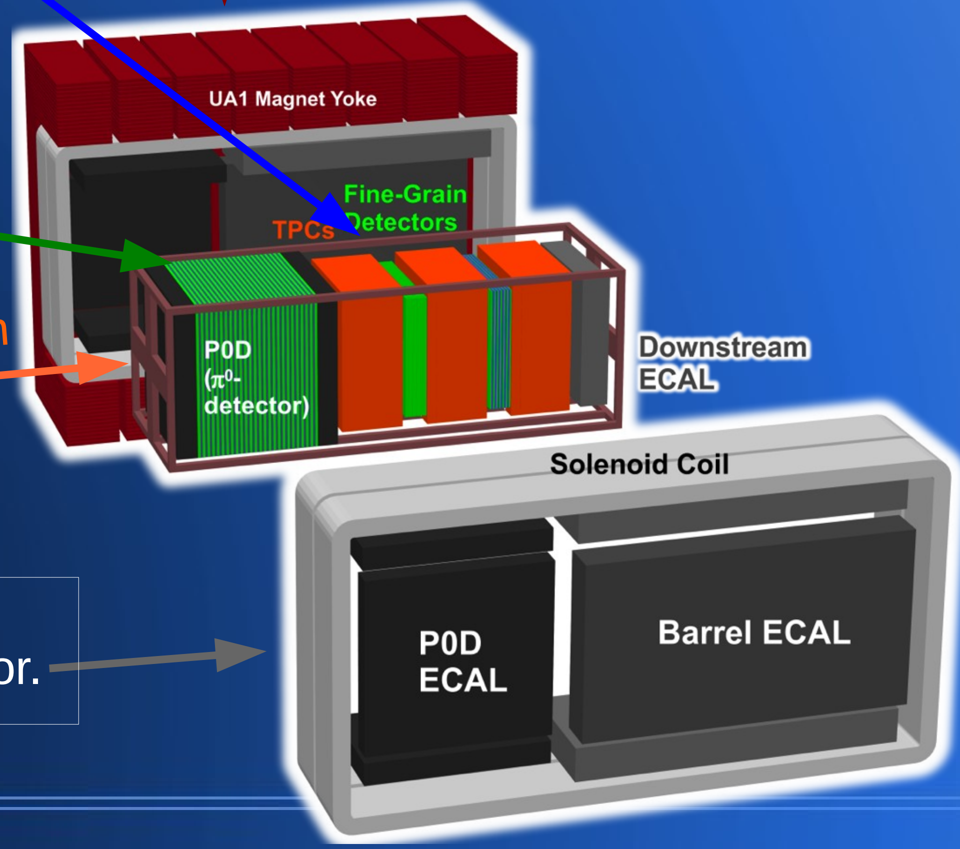
3 TPCs (Time Projection Chambers):
- Excellent measurements of charged particles from FGD and P0D.

Reused the UA1 Magnet.
Operate with 0.188T field.
Inner volume ~ 3.5m x 3.6m x 7m.

SMRD (Side Muon Range Detector):
Scintillator planes in magnet yoke. Detect muons from inner detector.

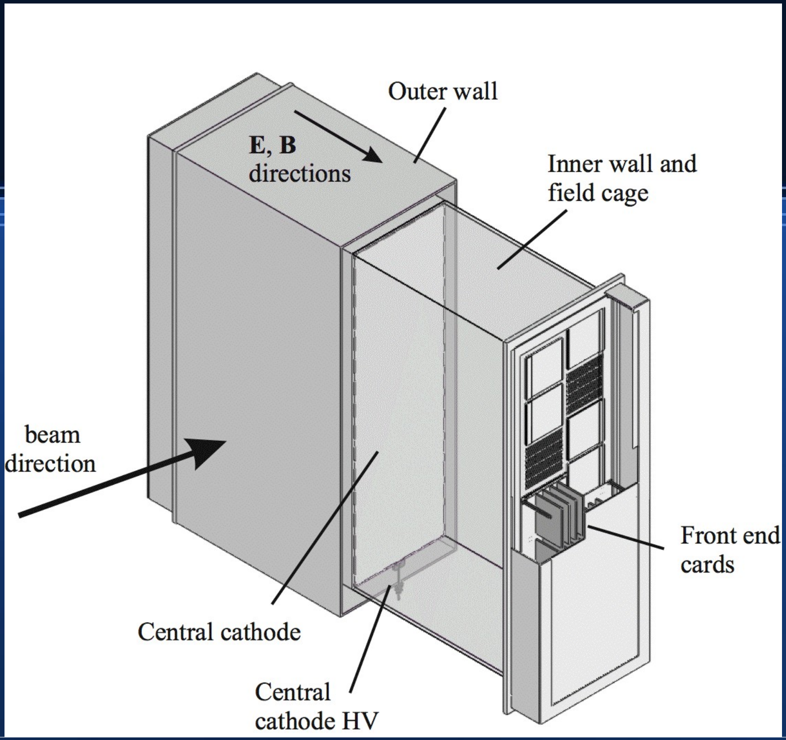
P0D (π^0 Detector):
Scintillators planes interleaved with lead/brass and water layers; optimized for gamma detection.

ν direction



ECAL: Scintillator planes with radiator.
Measure EM showers from inner detector.

Detector Details: TPC

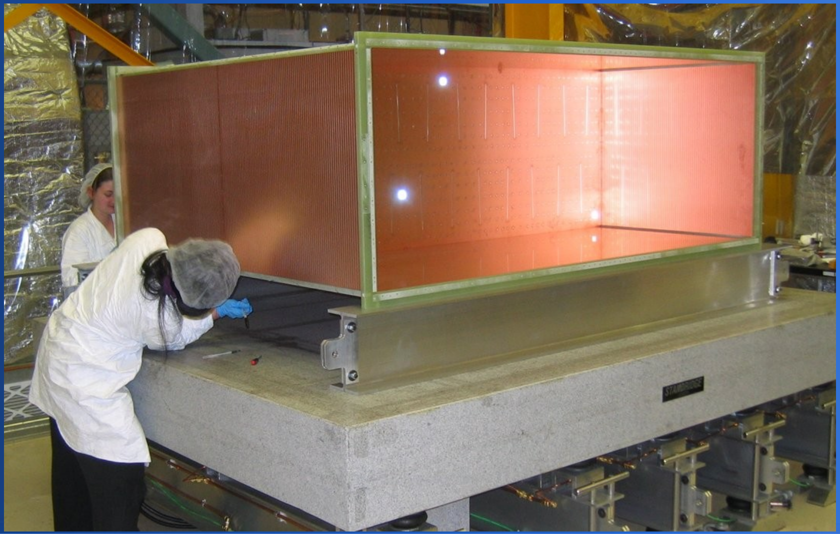


TPC overview:

- Excellent tracking and particle identification for charged tracks.
- Momentum resolution ~7% @ 1GeV/c
- Point resolution ~700μm at full drift

Mechanical construction:

- Inner box constructed from copper-clad G10; outer box from aluminum/rohacell.
- Designed, fabricated and assembled at TRIUMF

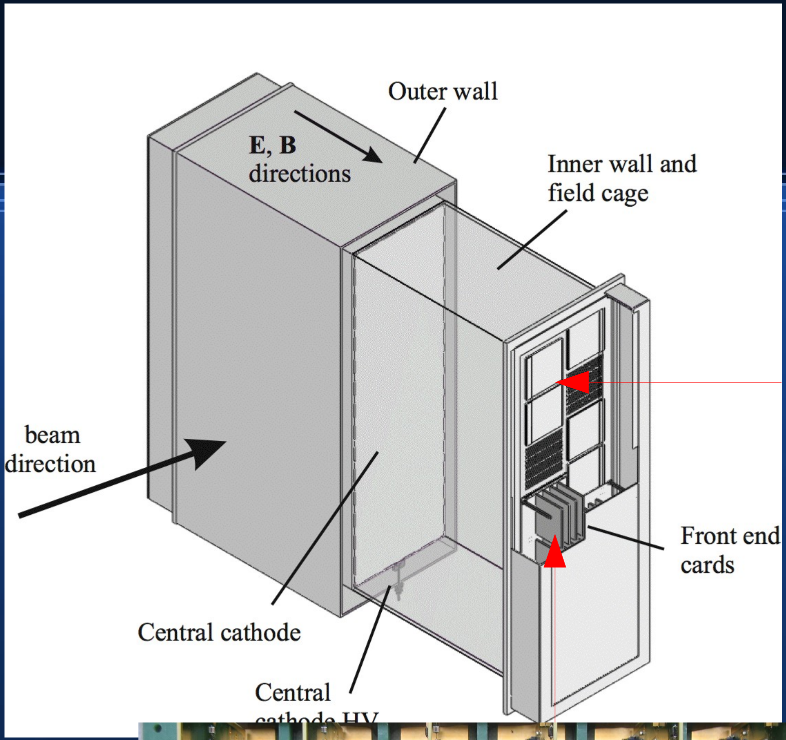


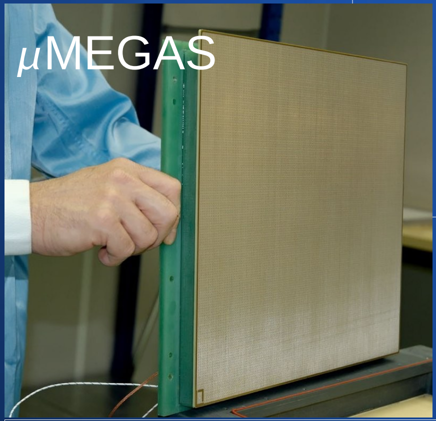
TPC inner box

TPC

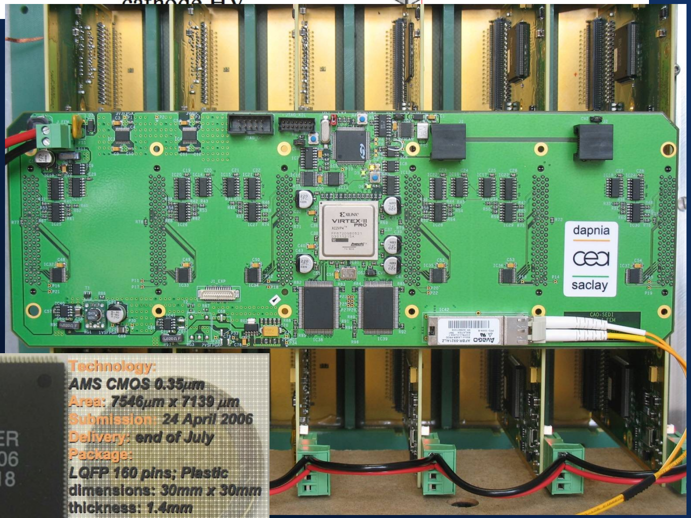
µMEGAS:

- First production of "bulk" µMEGAS:
  - Pad pitch: 7.0 x 9.8 mm^2.
  - Number of pads: 1726.





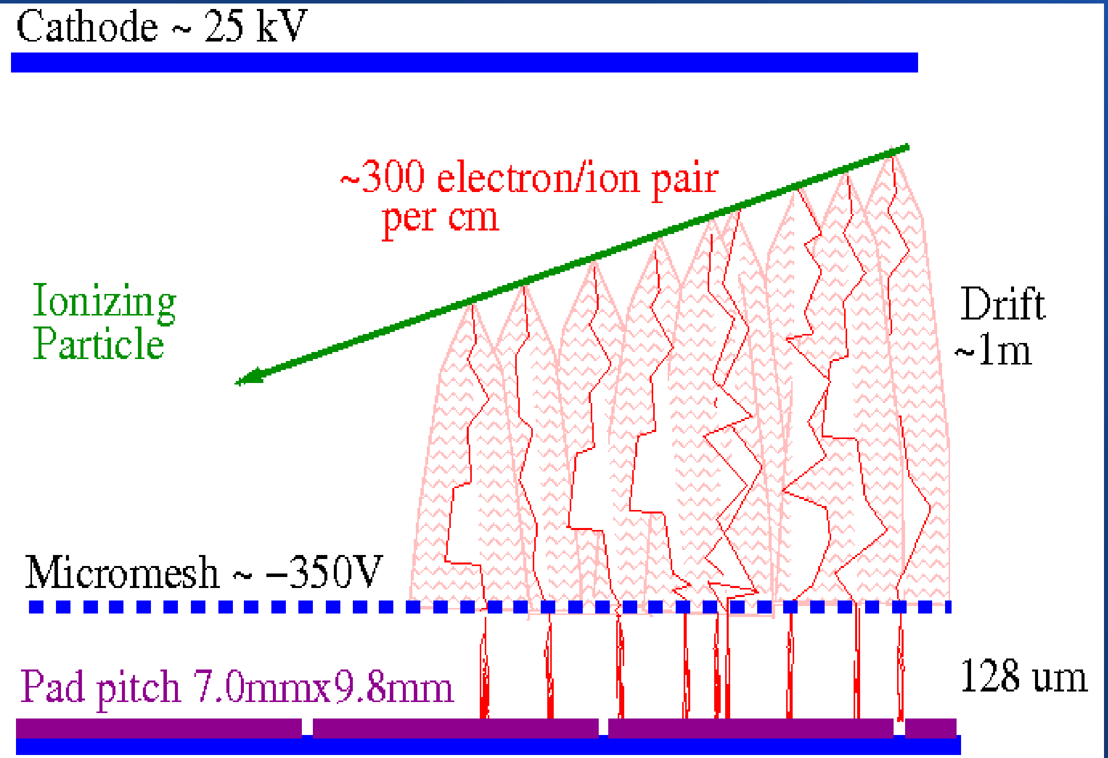
12 µMEGAS per end: 72 total



TPC Electronics:

- ~100,000 TPC readout channels.
- Signal readout using AFTER chip; based on a 511-deep switched capacitor array (FGD uses same).
- Data transfer by fibre optics.

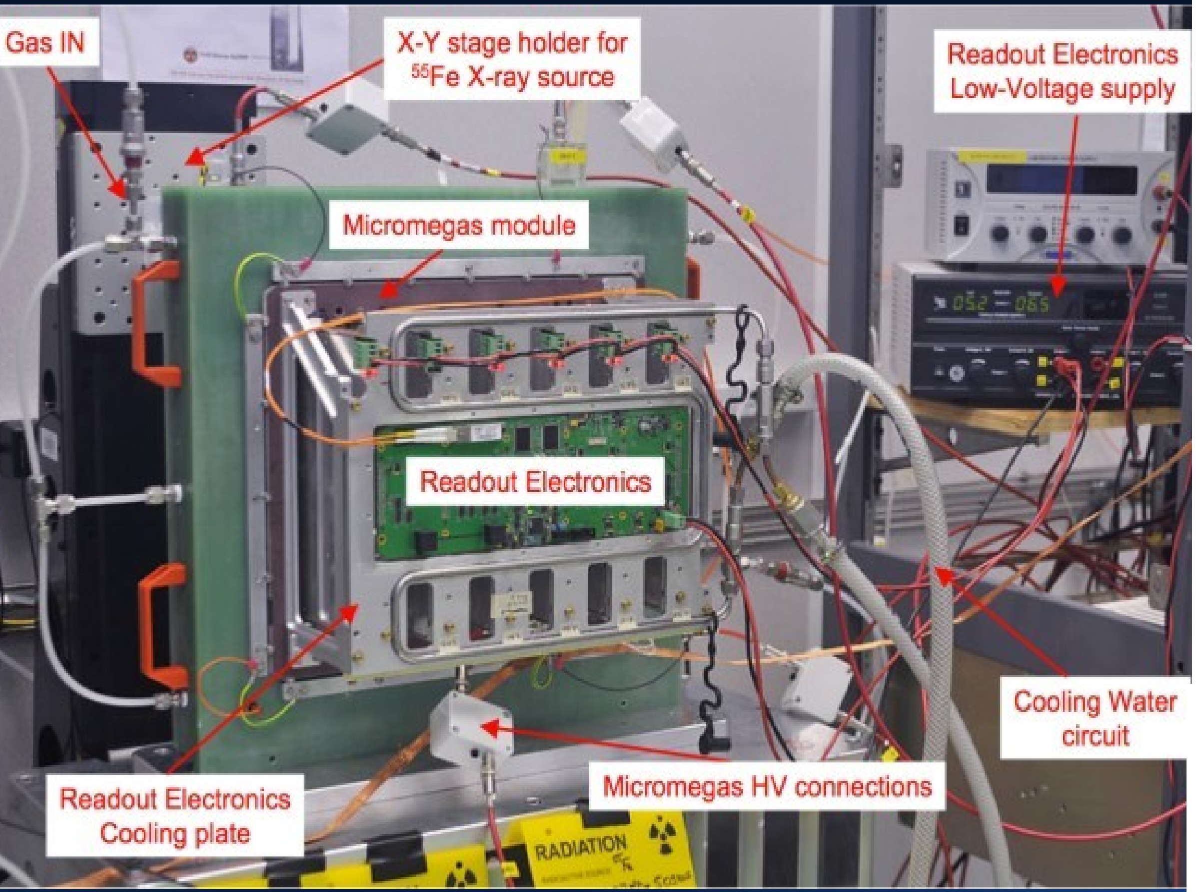
Micromegas

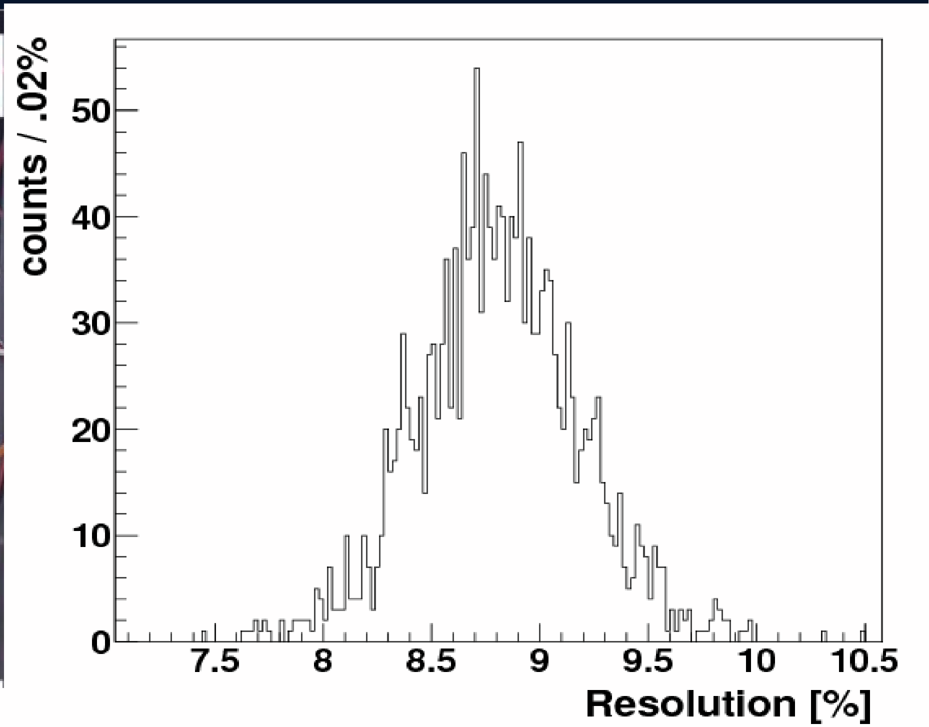


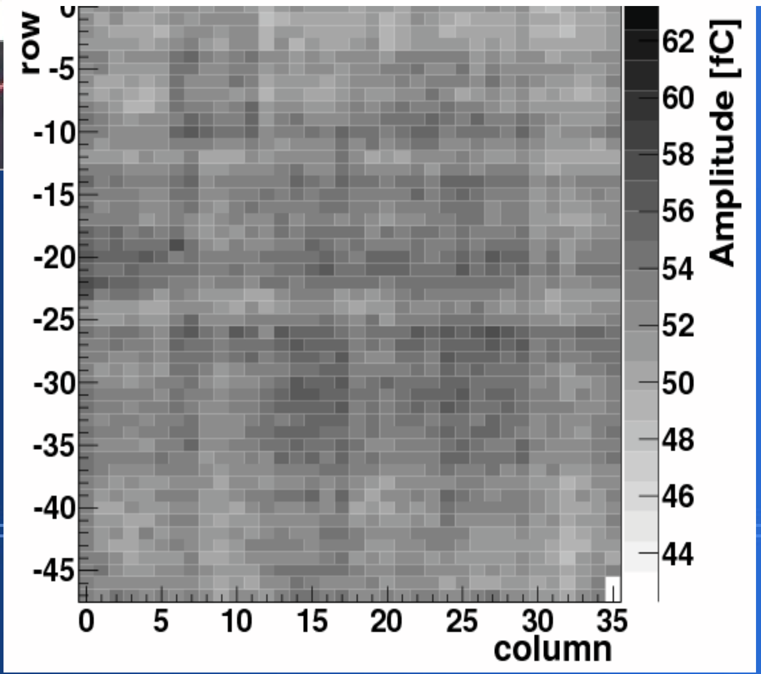
- Gain 1500 (mesh at -350V)
- Gain Uniformity 2.8% / module
  - 7.3% over all 72 modules
- σE/E = 9.0% (5.9keV 55Fe x-ray)
  - similar with cosmic rays
- σE/E uniform to 6%
- ~9m^2 of active area
  - ~10^5 channels
  - 10 dead random dead channels
  - Sparking in one MM required disabling 1/12 of one MM
- 0.1 sparks / hour at -350V

Bulk MM cost (PCB+mesh+integration+connectors) ~ 10k€ / m^2

Micromegas tests at CERN







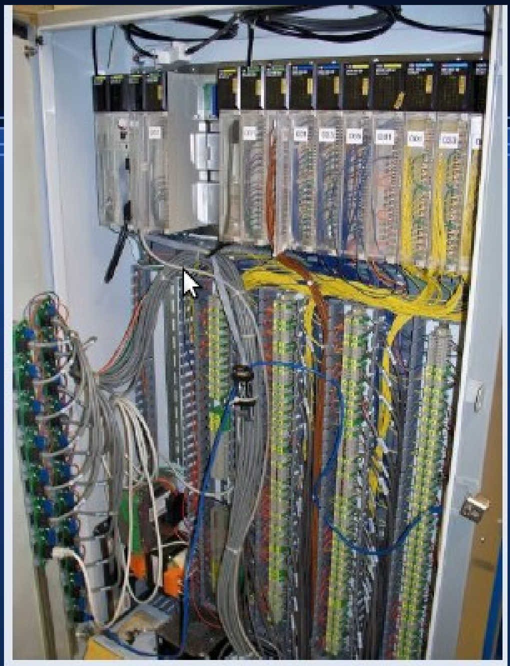
55Fe Source to measure response of each pad.

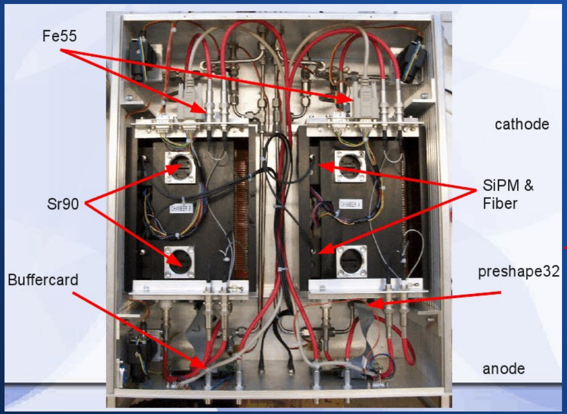
Typical energy resolution for the 5.9keV xray for the 1728 pads shown at top right.

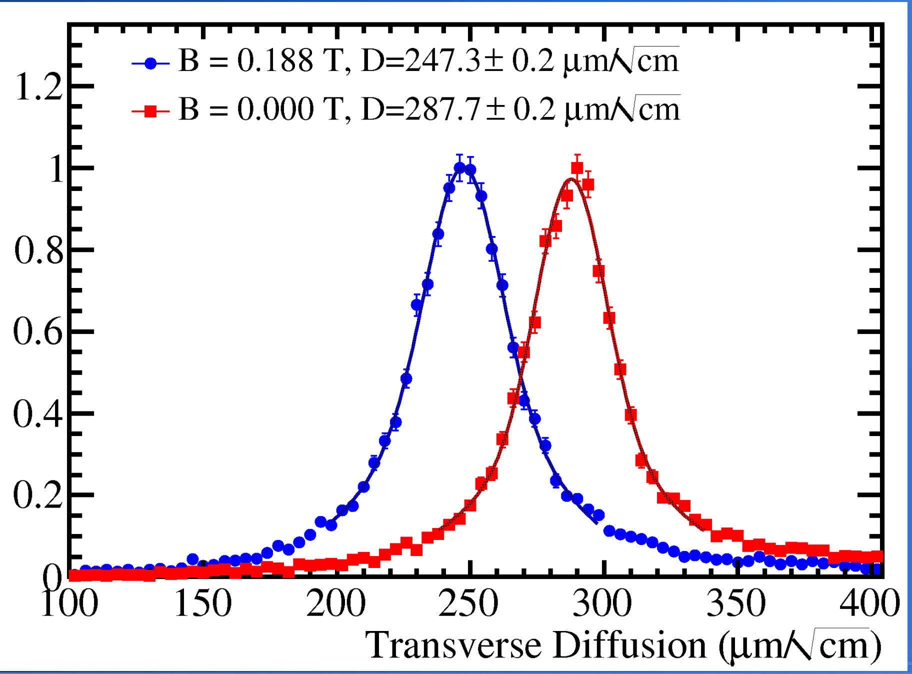
TPC Gas

Gas System:

- Inner (drift) volume gas: 95:3:2 Ar:CF_4:isobutane
- Outer (buffer) volume of CO_2
- PLC for safe gas delivery, control and data acquisition
- Two small TPCs ^{55}Fe, ^{90}Sr src monitor gain, drift velocity



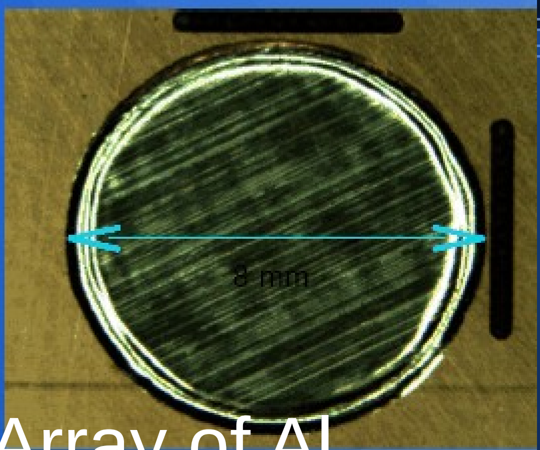




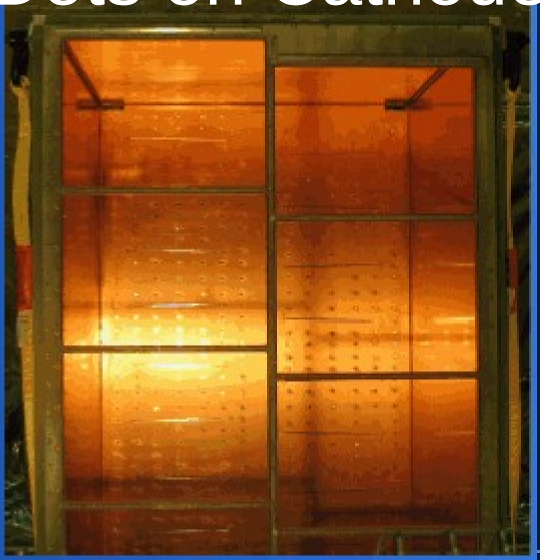
- Non-flammable gas mixture
- Low transverse diffusion (~250 μm/√cm)
- Close to max drift velocity (~7.5cm/μs)
- Minimized gas impurities (mainly O2)

>30m attenuation length

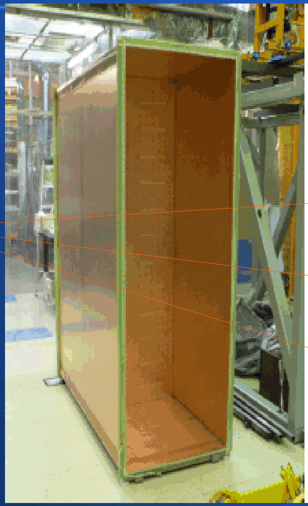
TPC laser targets for p.e. calibration

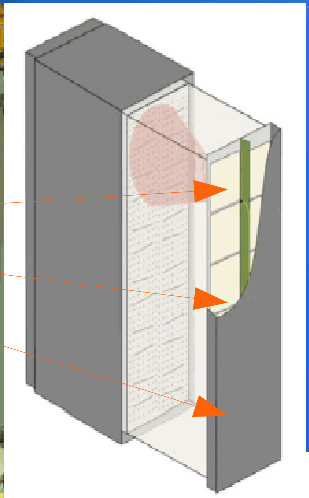


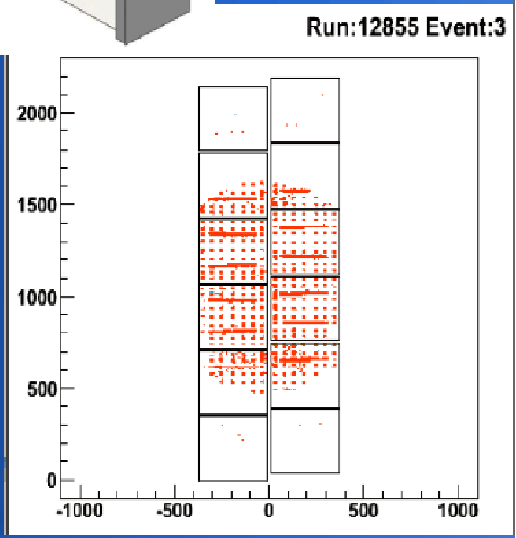
Array of Al Dots on Cathode



UV laser
Multiplexed
To 18 locations
To cover cathode



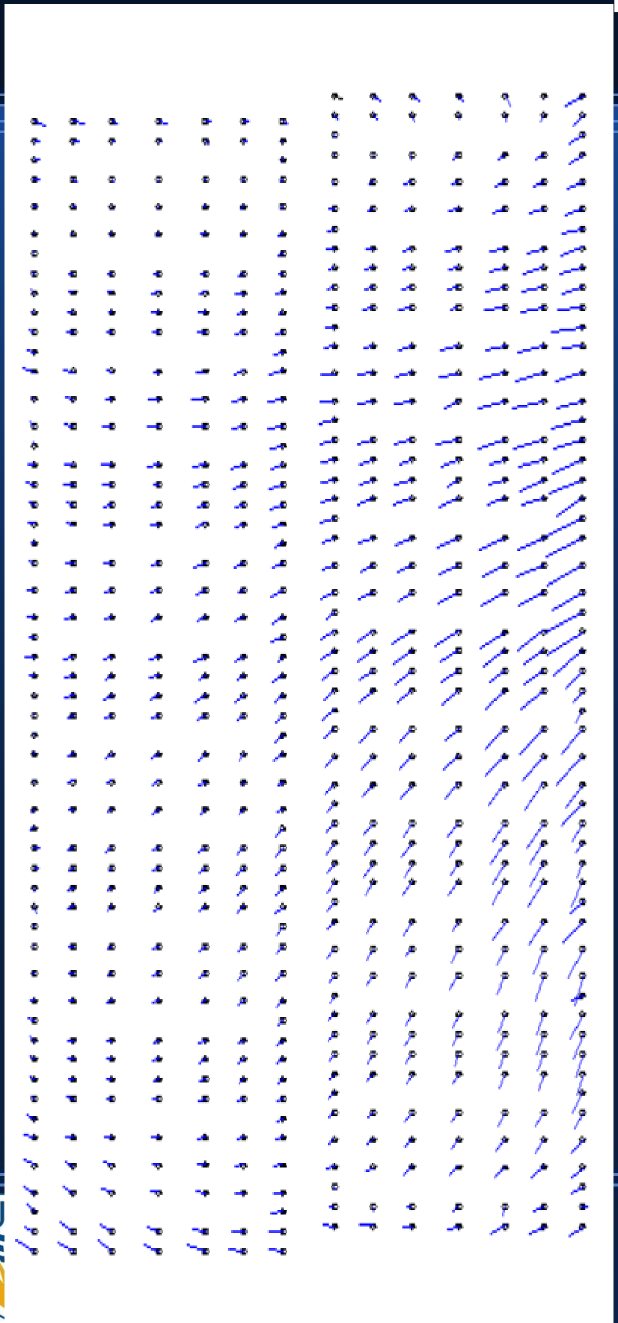




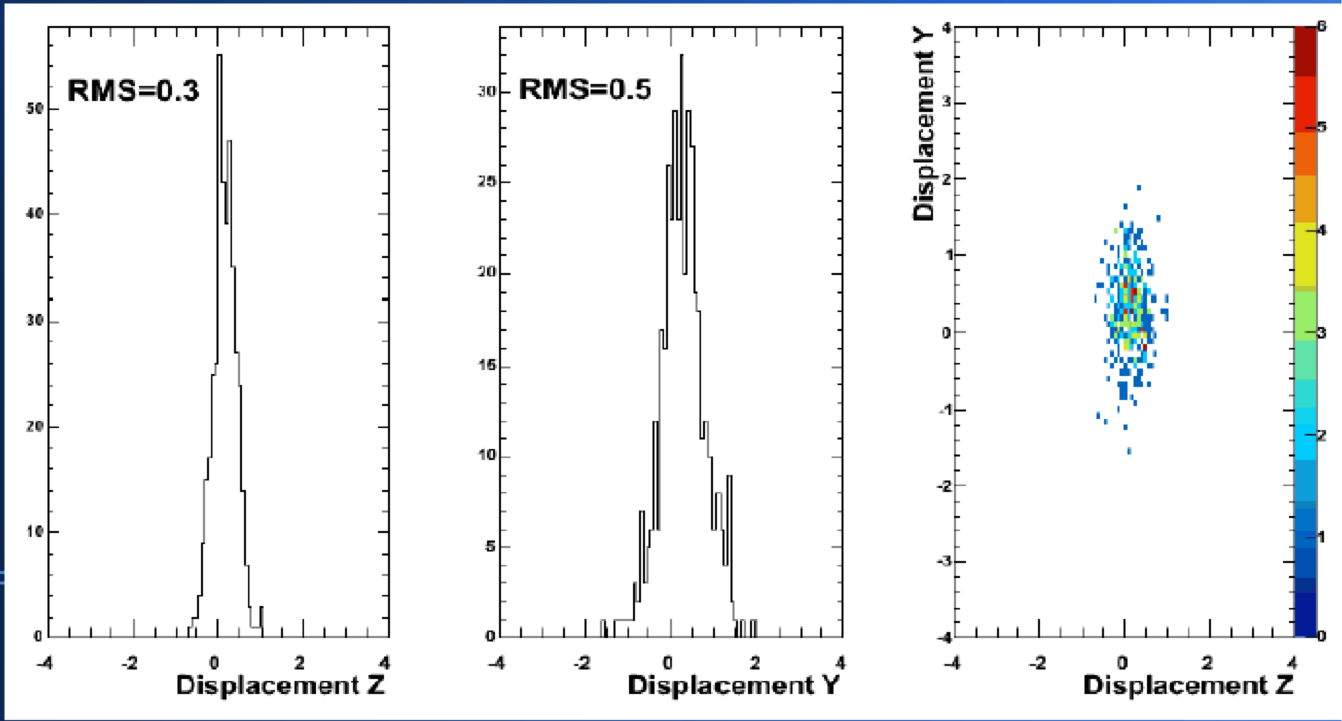
- Al targets emit p.e. when flashed with UV light
- Center of target measured from survey and with charge collected at readout
- Distortions of track shape for pe full drift can be measured

TPC laser dot position measurements

Largest line is 5mm movement

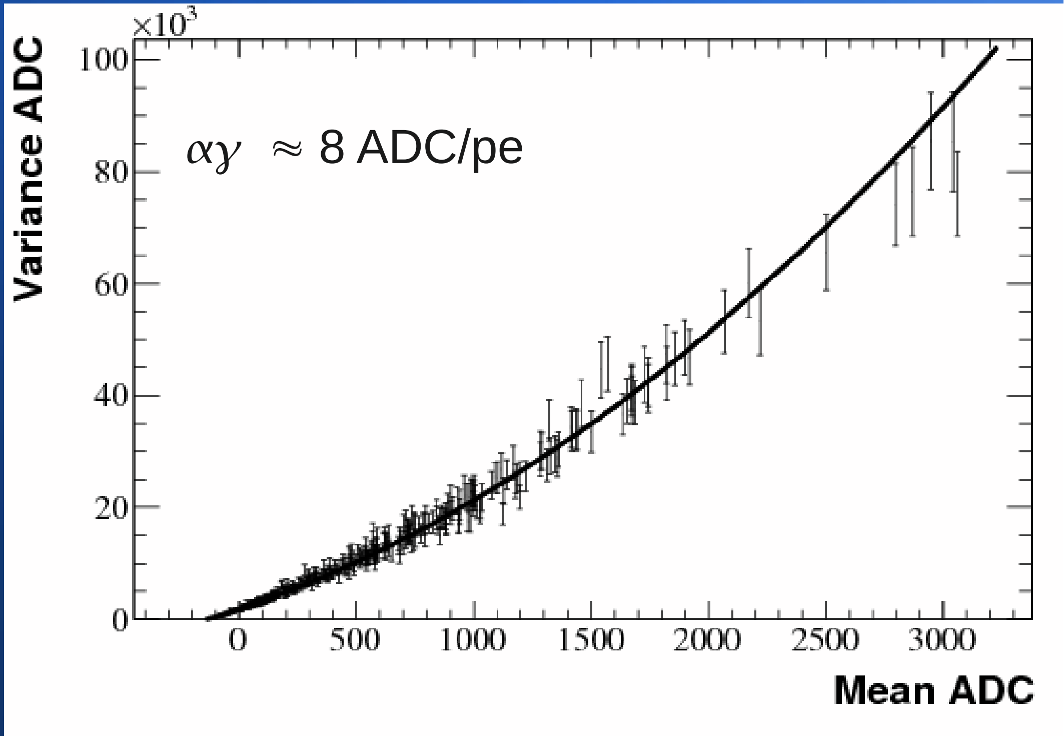


- Left shows apparent movement of dots from B-field off to on for the downstream-most TPC
- Below shows reconstructed dot position minus survey position
- Adequate resolution for understanding E,B distortions



Micromegas gain measured by laser

- Number of p.e. on given pad Poisson random number N, mean ν
- Number produced in avalanch at mesh exponential random number G, mean γ
- Laser energy gaussian random with std. dev. β

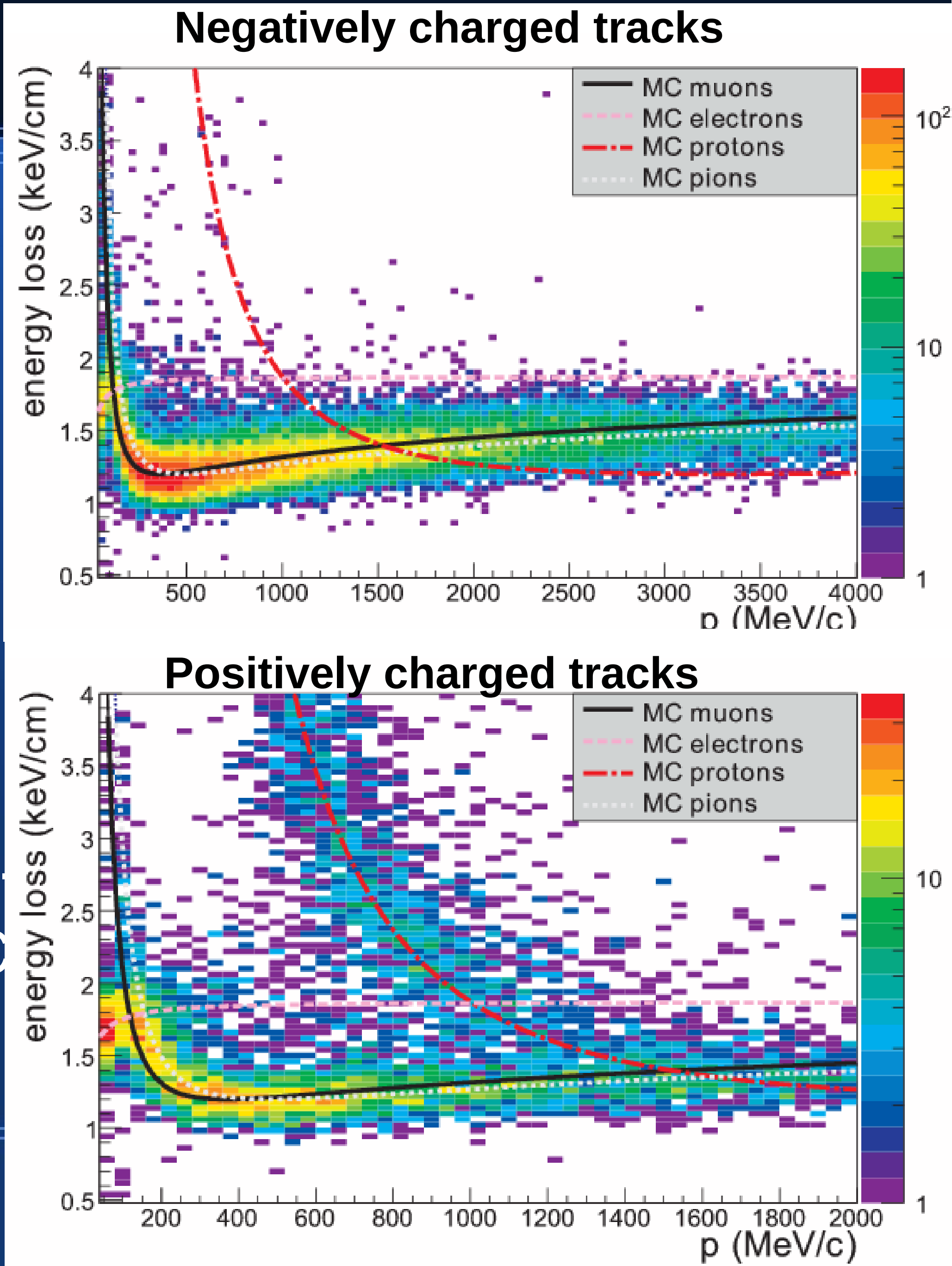


$$E[A]=\alpha\gamma\nu$$

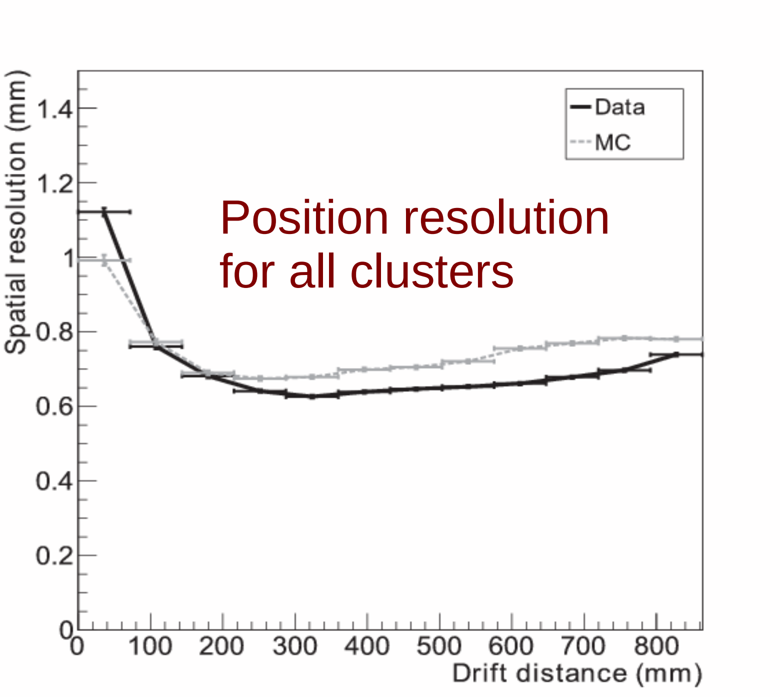
$$V[A]=(\alpha\gamma)^2 V[N]+\alpha^2\nu V[G]+(\beta\alpha\gamma\nu)^2=2\alpha\gamma E[A]+\beta E[A]^2$$

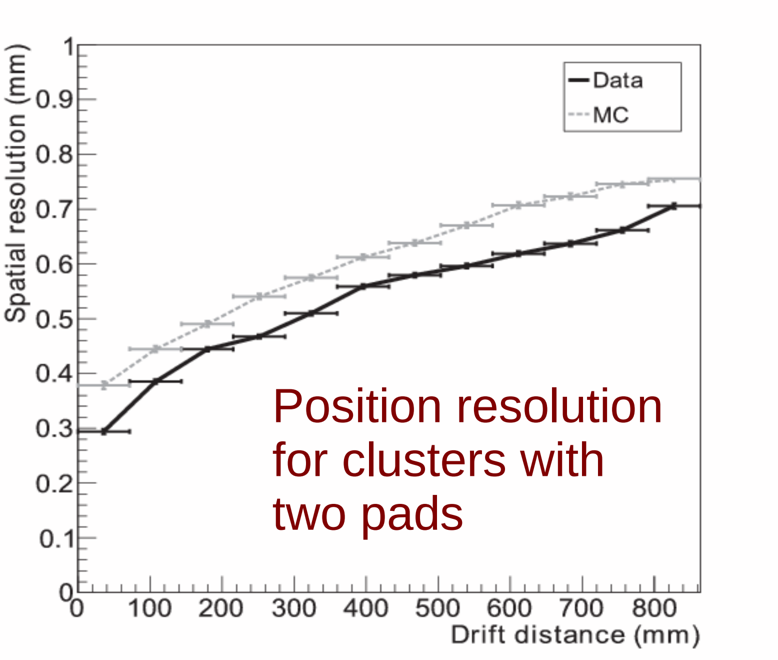
TPC PID Performance

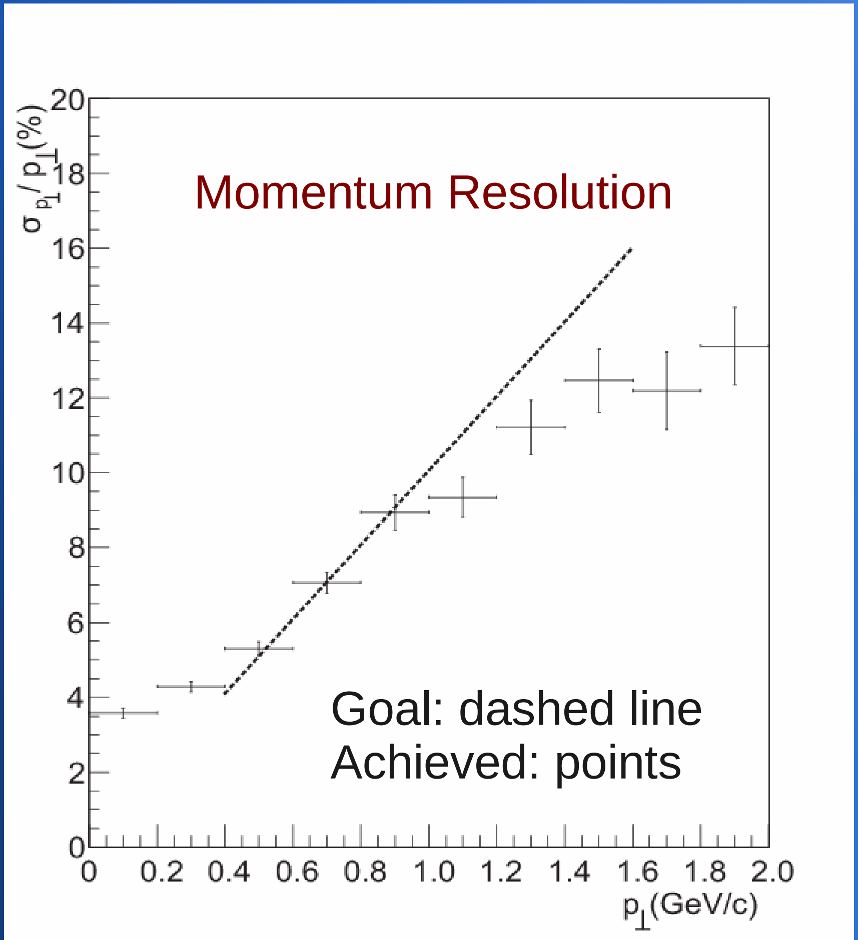
- Plots show the TPC dE/dx as a function of momentum
  - 2D Histogram shows results for tracks from real neutrino events.
  - Lines are predicted values.
  - Upper plot is negatively charged particles; lower plot is positively charged.
- Plots demonstrate impressive TPC particle identification capabilities.



TPC Resolution Goals Met

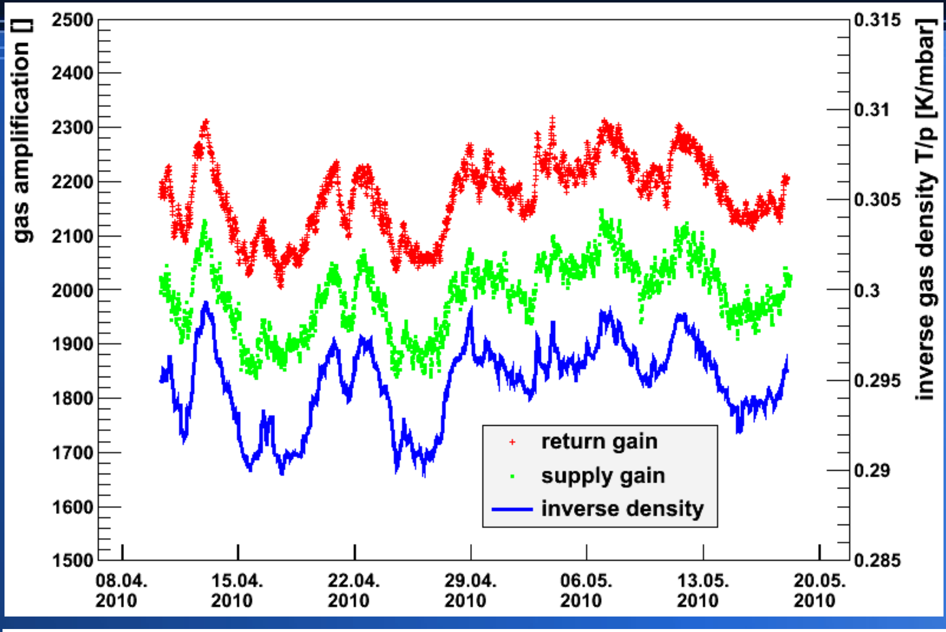


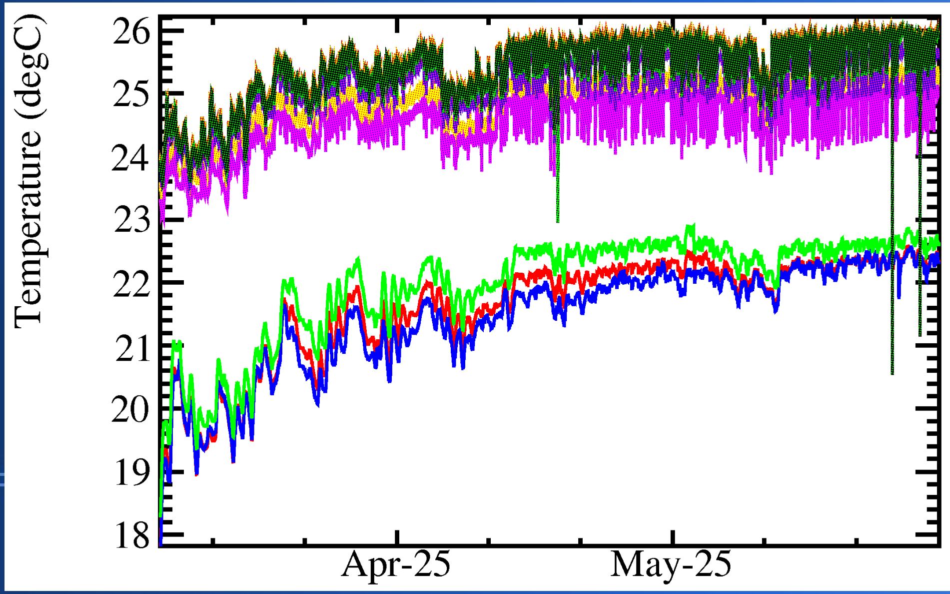




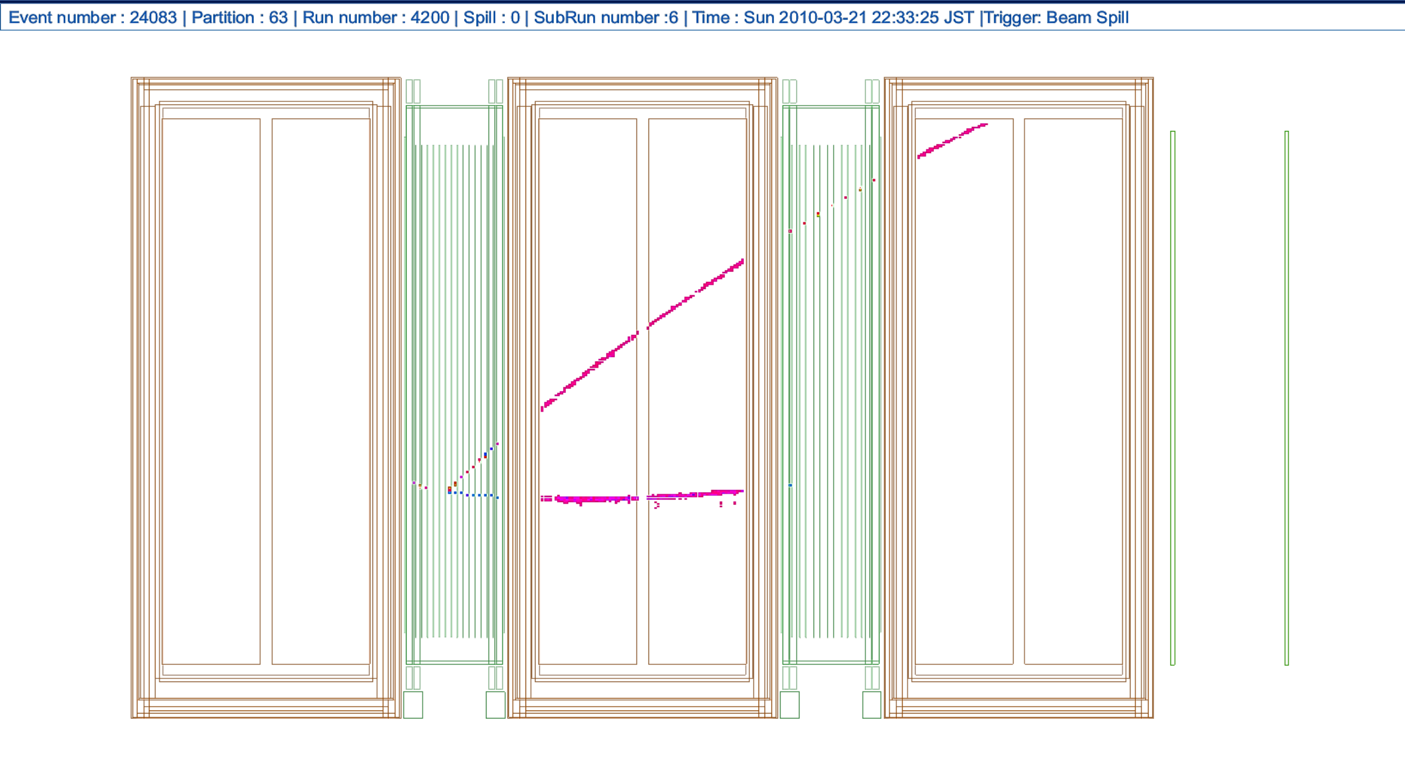
TPC Operation

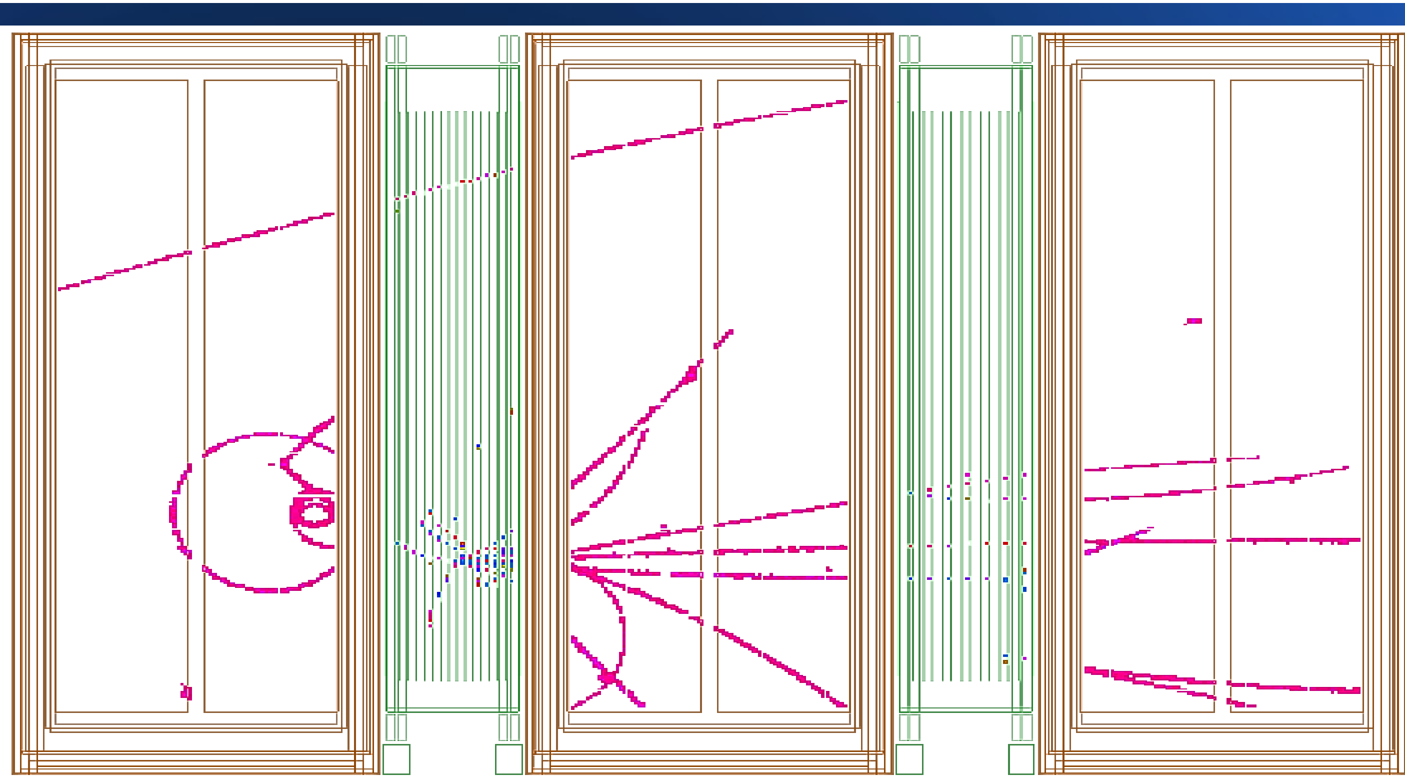
- Nearly 100% live fraction during beam time; off time due to:
  - low voltage or MM HV trip -- quickly recovered
  - Failure of 1 MM HV channel
  - Failure of one electronics optical coupler
- Monitored gain, gas density, gas quality, drift velocity, electroincs temperatures, many voltages and currents





Neutrino Event Displays





- Top display is a clean CC interaction
- Bottom display is more complicated thru going track and shower interaction

Conclusions

- The T2K near detector TPCs have been operating successfully since installation at J-Parc in 2010
- The TPCs and near detector will play an important role in studying neutrino interactions before oscillation
- For more information see:
  - NIM A637 (2011) 25-46

The T2K Collaboration

~500 members, 59 Institutes, 12 countries

Canada
TRIUMF
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.
U. Tokyo

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroclaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin
N. U. Seoul

Spain
IFIC, Valencia
IFAE Barcelona

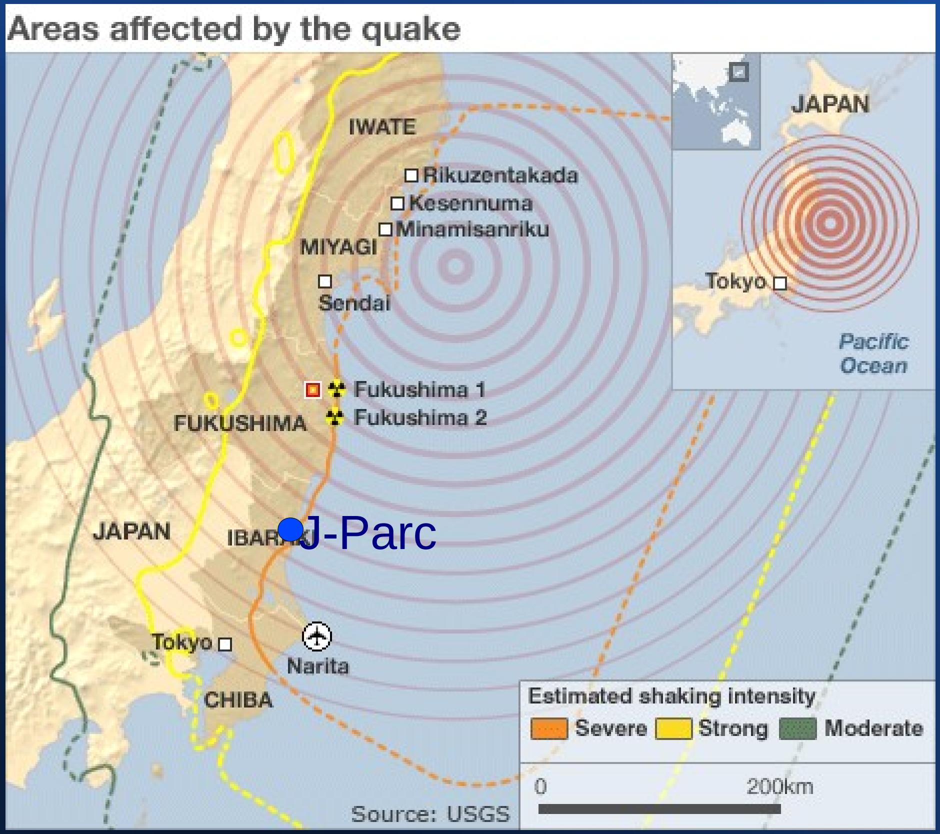
Switzerland
U. Bern
U. Geneva
ETH Zurich

United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

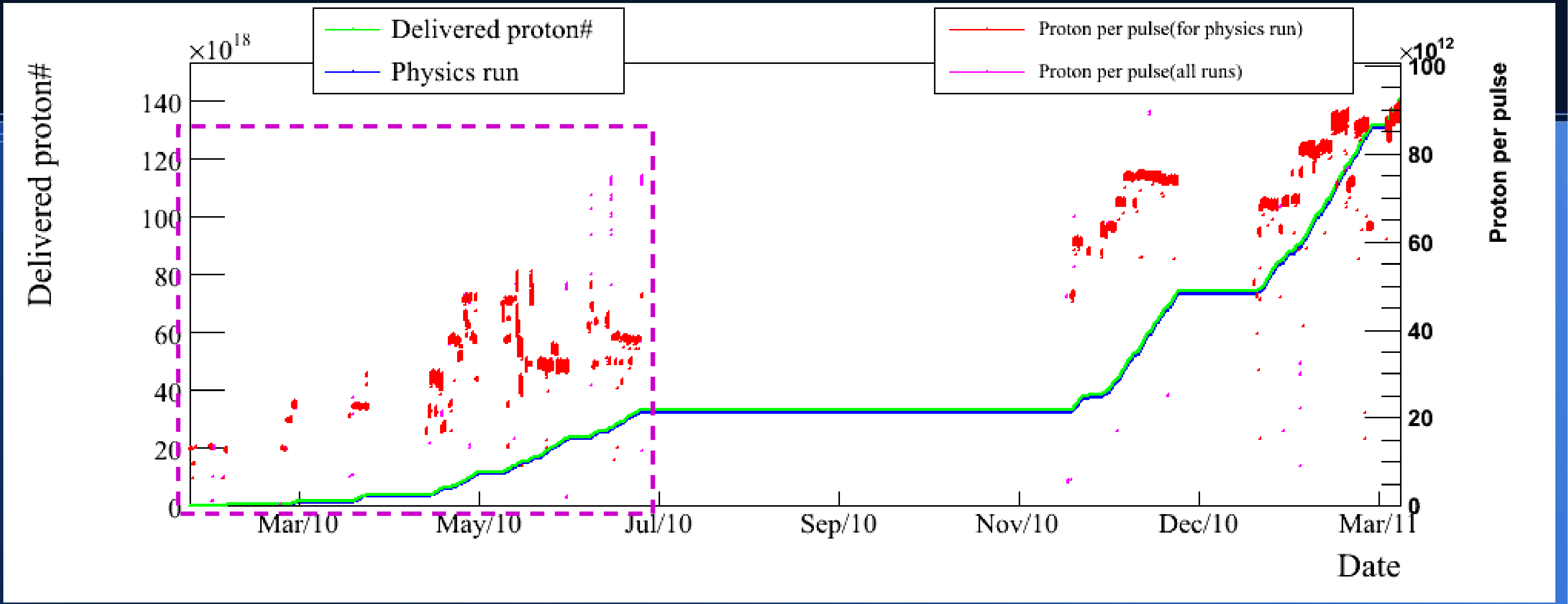
Backup

Japan Earthquake



- All T2K members safe
- Tsunami missed J-Parc lab
- Tokai reactor okay
- Minor damage to buildings and roads
- Plan in place to begin recovering detectors and beamline before Jan 2012
- TPCs have been restored to full operation

Run 2



Achieved 145kW stable run in March prior to earthquake

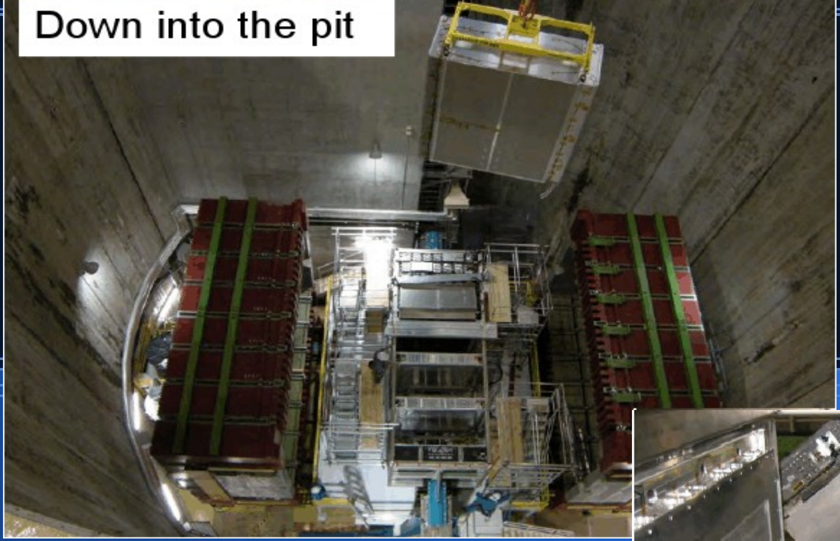
Entire run at 8 bunches / spill / 3.04s

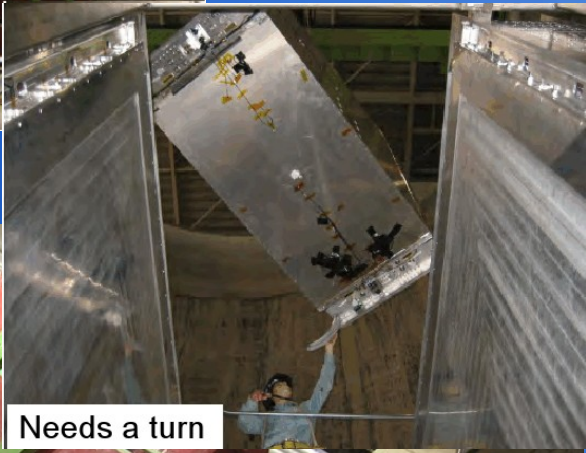
1.45×10^{20} POT collected total

Extra POT is ~4x dataset presented today

Installation of ND280

- Involved installing and removing scaffolding to connect all services
- Detectors “dropped” into place by crane
- Survey of detector locations

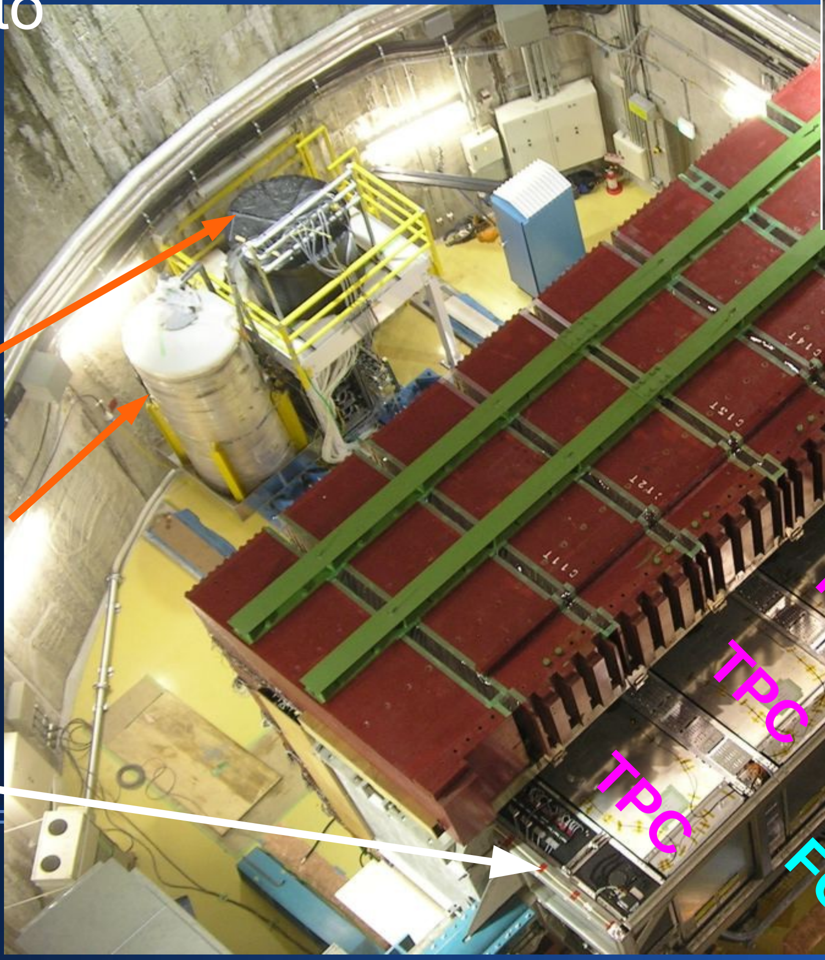




FGD Water supply

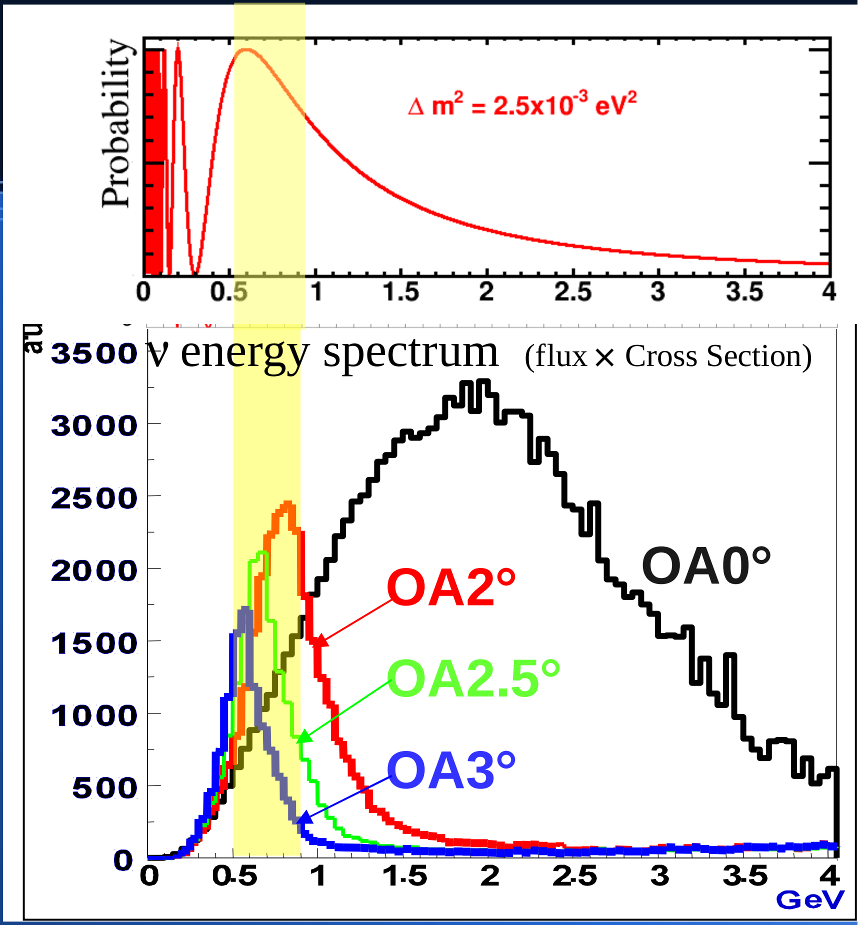
P0D Water supply

DSECAL



T2K Off-axis Beam

- T2K uses a novel off-axis neutrino beam (idea developed at TRIUMF).
  - Super-K and ND280 are located 2.5° off-axis from direction of proton beamline.
- The off-axis beam results in a quasi-monochromatic ν beam in the energy range of our oscillation maximum.
  - Also means less backgrounds from higher energy neutrinos.



$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \sin^2 \left[1.27 \Delta m^2 \frac{L(km)}{E(GeV)} \right]$$

Off-axis beam technique
(Ref: BNL-E889 proposal)

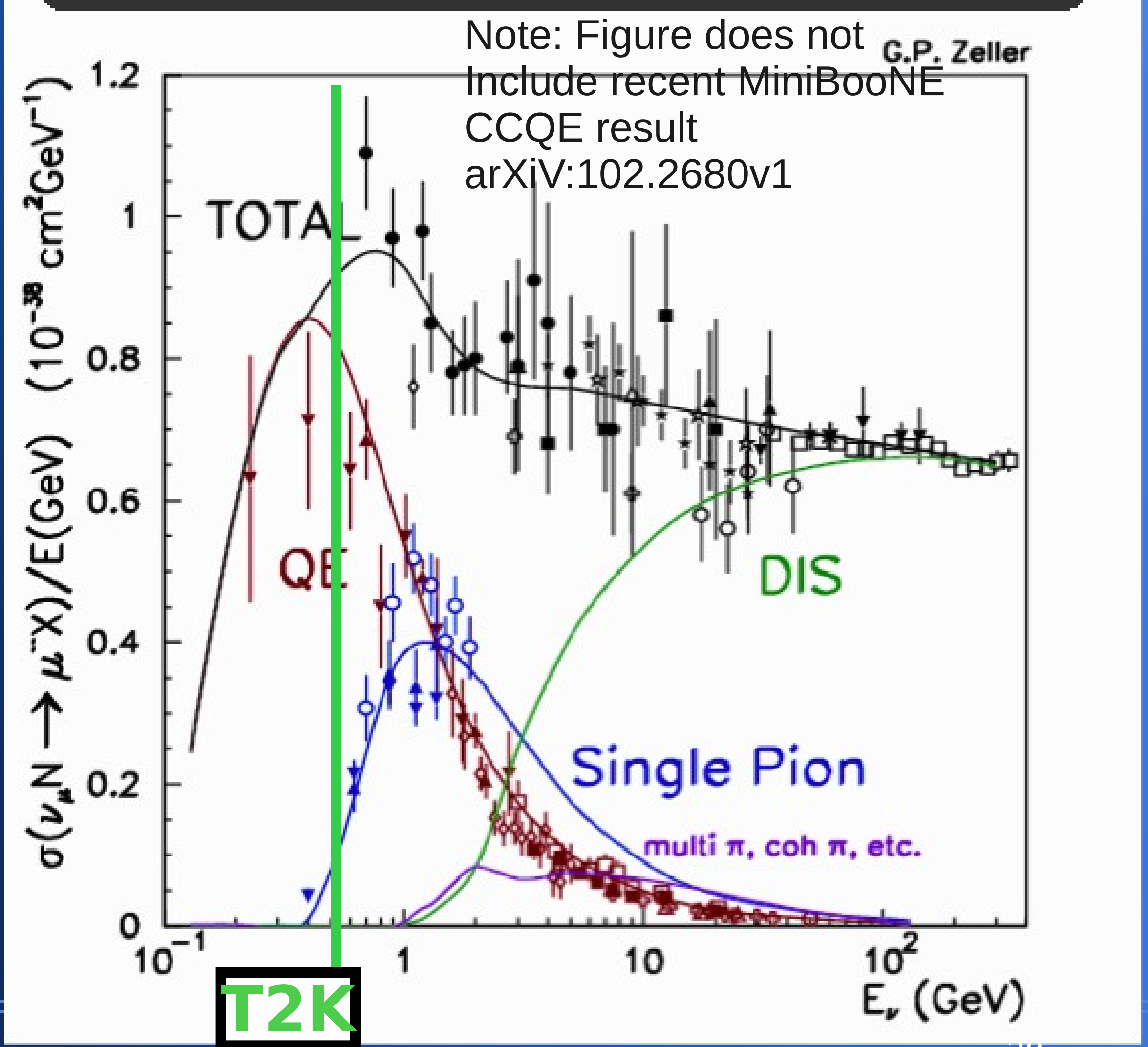
Japan Proton Accelerator Research Complex (JPARC)

Bird's eye photo in January of

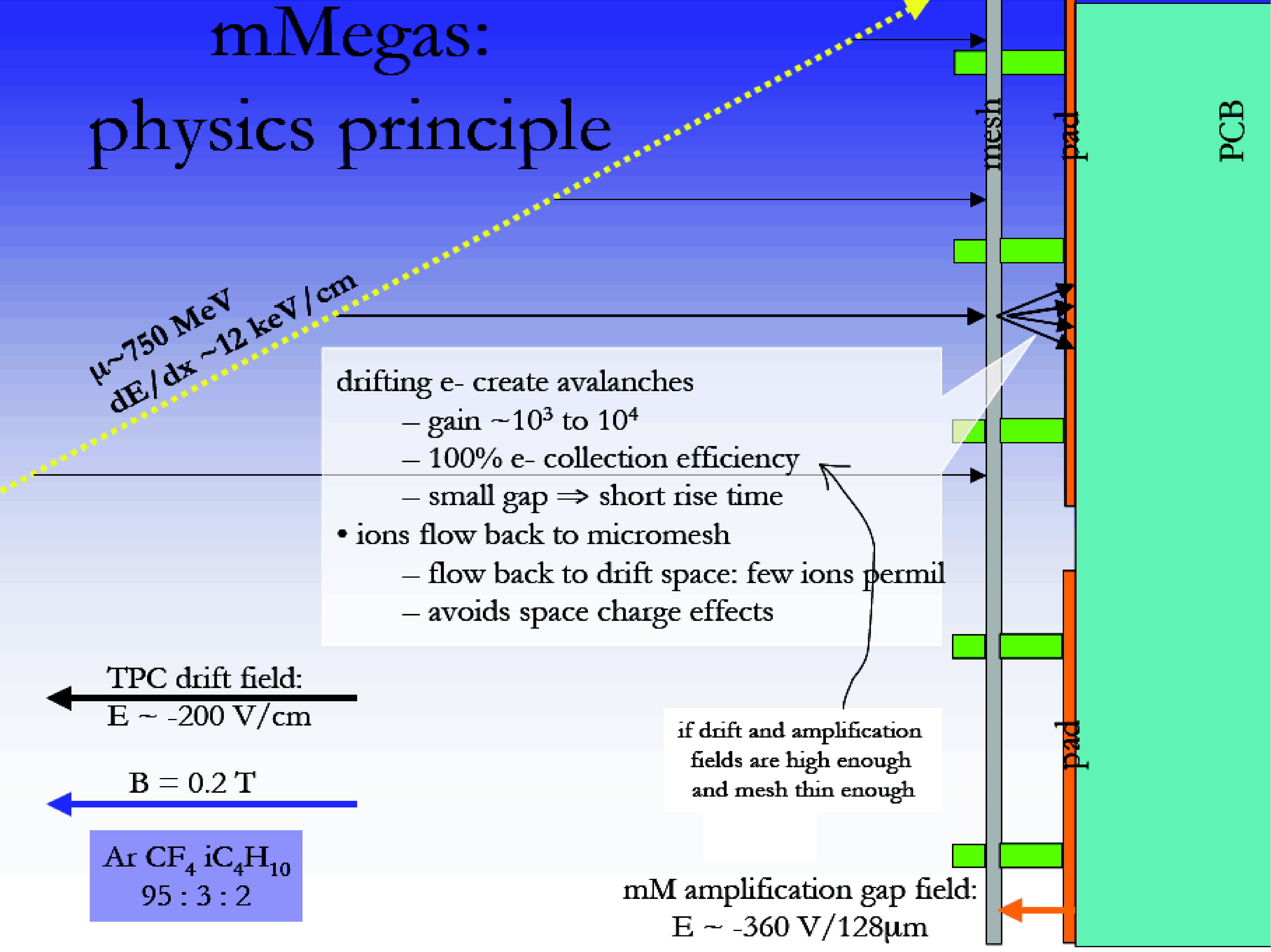
GeV Neutrino Interactions

- GeV Neutrinos are detected through a variety of processes.
- Signal mode for our measurement is Charged Current Quasi-Elastic (CCQE):
  - $\nu_{\mu/e} + n \rightarrow \mu^-/e^- + p$
  - Allows flavor tagging of the neutrino via the charged lepton.
  - Dominant process at T2K oscillation maximum.

Charged Current Cross Sections



mMegas: physics principle



drifting e- create avalanches

- gain ~10^3 to 10^4
- 100% e- collection efficiency
- small gap ⇒ short rise time

• ions flow back to micromesh

- flow back to drift space: few ions permil
- avoids space charge effects

TRIUMF M11 Beamtest

- After assembly, the TPC and FGD detectors were tested in the M11 beamline at TRIUMF (in 2008 and 2009).
  - Similar tests were done for the DsECAL at CERN in 2009.
- The M11 tests were an important part of the final integration of the many components of the detectors;
  in particular, was critical for developing and validating our electronics and DAQ.

M11-specific G4 simulation, as well as default Tracker simulation.