The T2K TPCs

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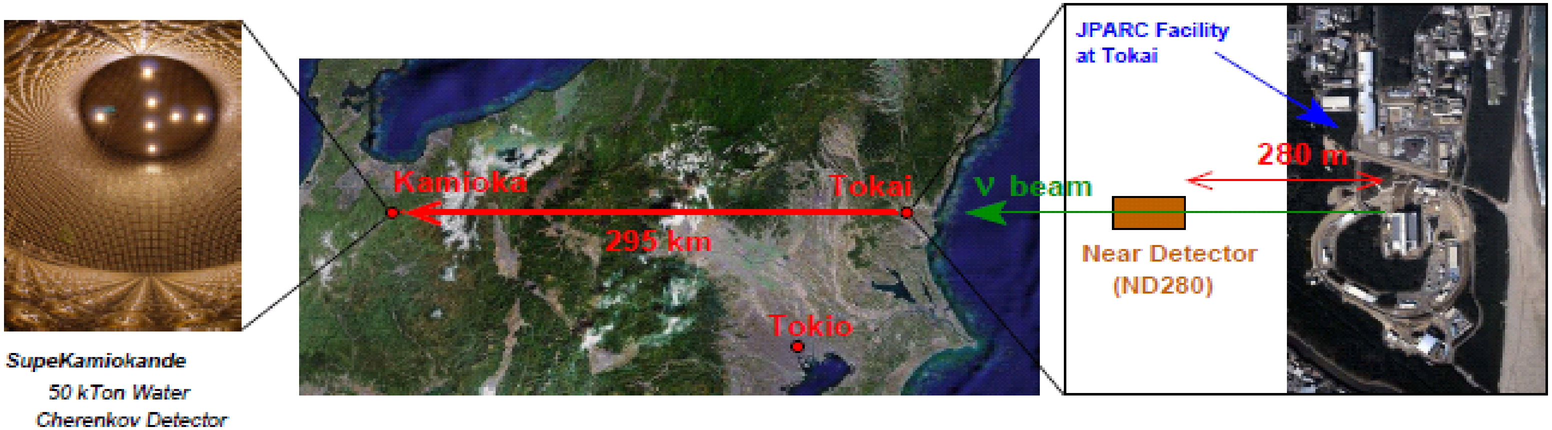
On behalf of the **T2K TPCs working group**:

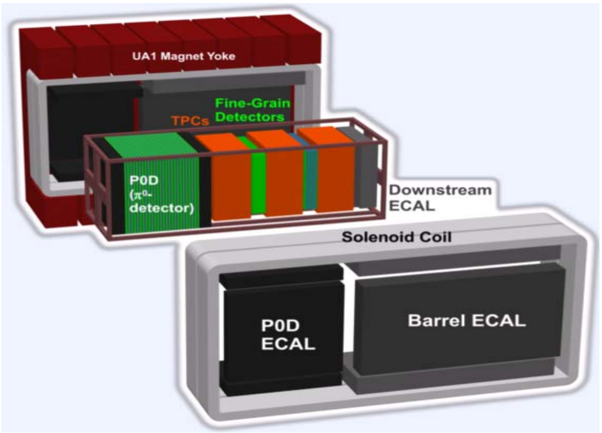
Canada	University of British Columbia University of Victoria TRIUMF
France	IRFU-CEA Saclay LPNHE Paris-VI-VII universities
Germany	RWTH Aachen
Italy	INFN
Spain	UAB/IFAE University of Barcelona University of Valencia
Switzerland	University of Geneva

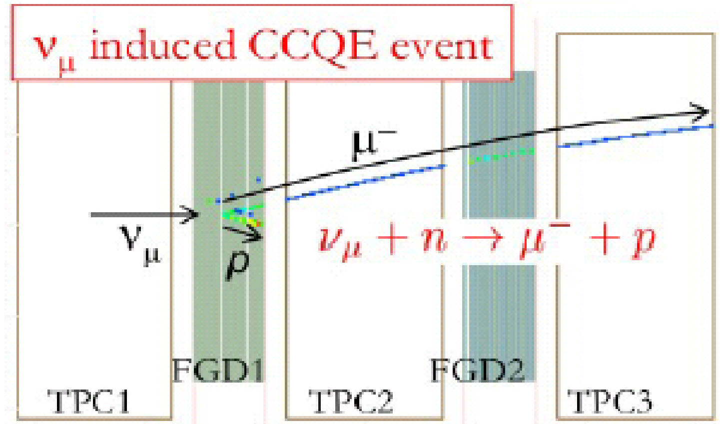
The T2K experiment



- Long Baseline Neutrino oscillation experiment
  - The neutrino beam started in April 2009
  - The data taking with all the ND280 facility installed will start in December 2009
- 30 GeV proton accelerator will be used to produce a ν_μ **beam** that will be sent from Tokai to SuperKamiokande
  - **L = 295 Km**
  - Mean neutrino energy **E_ν = 0.7 GeV** (where the maximum of the oscillation is expected)
- Search for ν_e **appearance** → Improve the actual limit on θ_{13} by 1 order of magnitude
- ν_μ **disappearance** → Precise measurement of θ_{23} and Δm^2_{23}

The Near Detector and the TPC

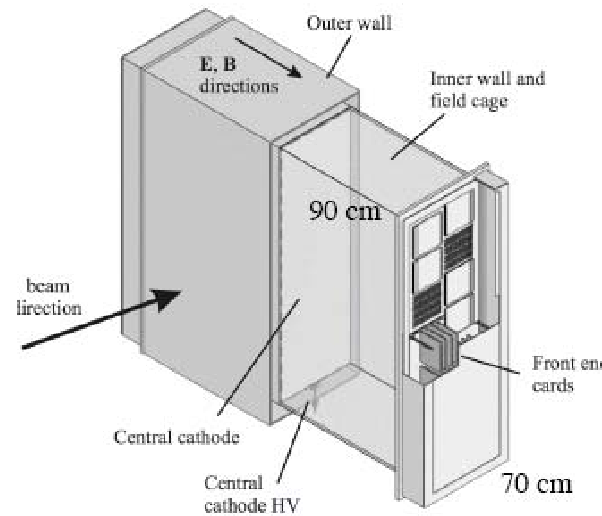




- Near Detector complex at **280 meters** from the proton target
- Several detectors inside the UA1 magnet (with a field of **0.2 T**)
  - **Characterize neutrino beam** (before the oscillations)
  - Measure **ν_e contamination** in the beam
  - Study background process to oscillation signal

- **Tracker system (TPC + FGD):**
  - **ν_μ and ν_e fluxes and spectra**
  - Measure neutrino cross section
- **3 large TPCs**
  - Excellent **pattern recognition** to distinguish the different interactions
  - Measure the **charge** and the **momenta** of the charged particles
  - **Particle Identification**: distinguishing electrons/muons and pions/protons

TPCs design

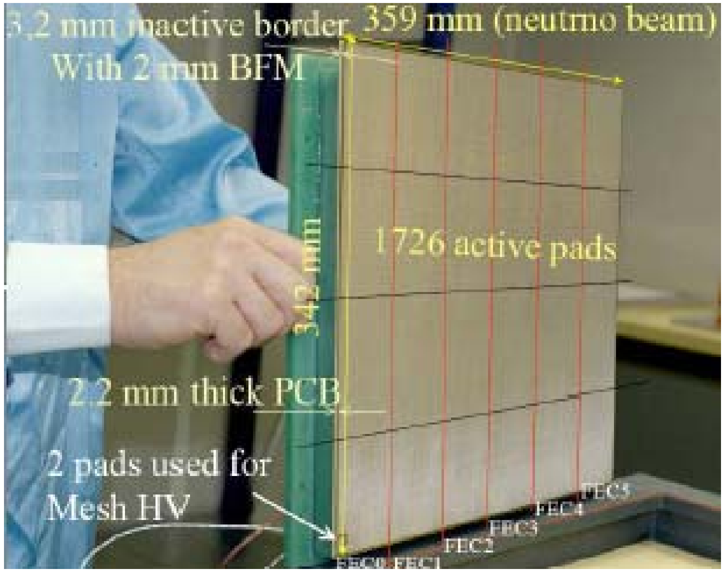


- Double wall structure:
  - Inner volume walls create the drift field
  - Outer volume for gas/HV insulation
  - Sensitive volume: 180 x 200 x 70 cm
  - Total active area of ~9 m^2
- Gas mixture: $Ar/CF_4/iC_4H_{10}$ (95/3/2)
  - Fast gas:
    - $v_d \sim 7.9$ cm/μs @ 280 V/cm
  - Low transverse diffusion:
    - $D_t \sim 270$ μm/√cm @ 280 V/cm → good spatial resolution
- Electron amplification provided by MicroMegas
- A Laser system is installed to provide real time calibration during the operations

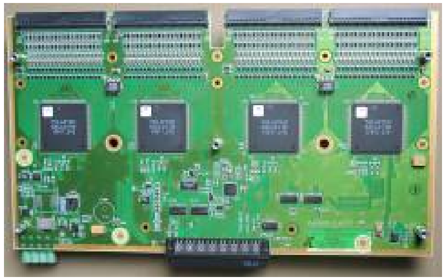
- TPC physics requirements:
  - **δp/p < 10% @ 1GeV** to reconstruct neutrino energy spectrum
  - **dE/dx resolution better than 10%** to perform electron/muon separation
  - **Energy scale** to be controlled at the **2%**

Readout plane: Bulk MicroMegas

- **Signal Amplification**:
  - 12 large (35x36 cm²) **bulk-MicroMegas** on each endplate → **72 modules** in 3 TPCs
  - Each module has 1726 active pads (6.9x9.7 mm)
  - Pads arranged in 36 columns and 48 rows
  - Total of ~**120 000 channels**
  - Produced @ **CERN/TS-DEM-PMT,** tested and validated in a test bench at CERN



- **Readout electronic**:
  - ASIC AFTER (72 channels) with programmable gain, sampling time…
  - 6 FEC + 1 FEM on each module

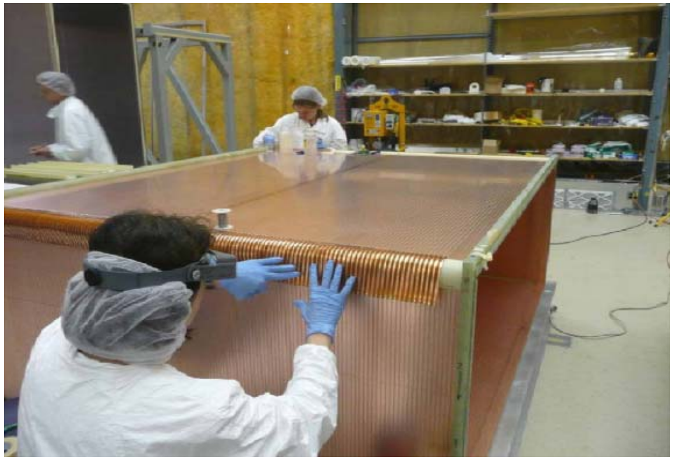


Front-End Card (FEC)

Front-End Mezzanine (FEM)

Construction status

- Assembling and integration undergoing at TRIUMF
- Module 0:
  - Construction completed
  - Fully equipped
  - Beam test completed
  - Shipped to Tokai
- Module 1:
  - Construction completed
  - Fully equipped
  - Beam test currently undergoing
  - Will be shipped to Tokai in August
- Module 2:
  - Under construction
  - Sent to Tokai by the end of the year

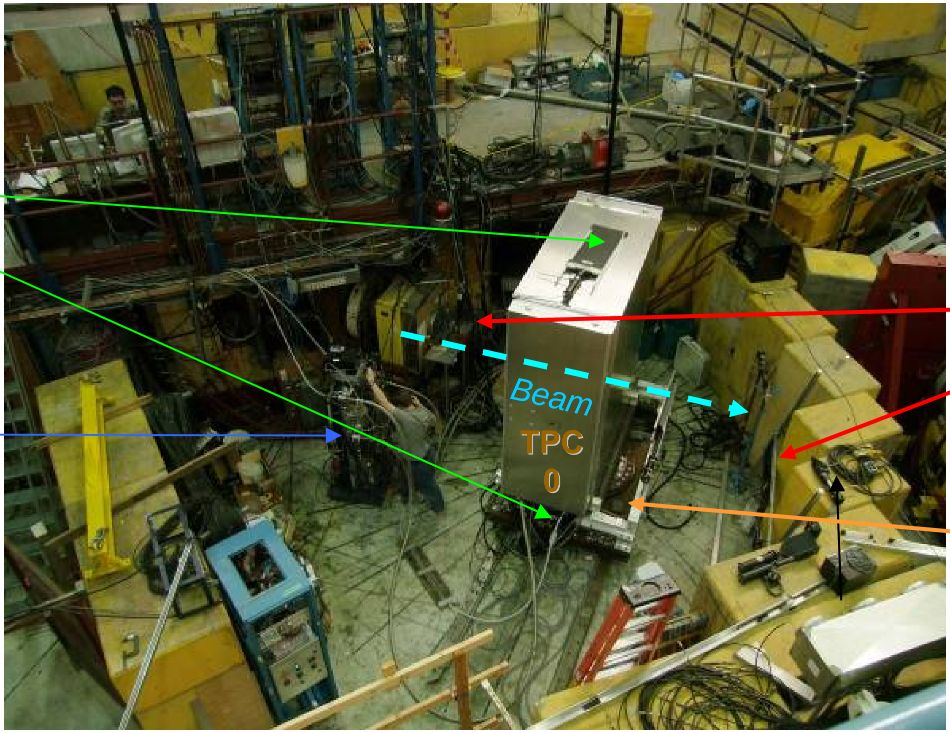


Beam test with TPCs

- The TPC Mod0 and Mod1 underwent beam tests in the M11 area at TRIUMF
- The beam provides e, μ, π with a momentum up to 400 MeV/c
- A Time Of Flight system provides e, μ, π tagging
- Each track crosses 2 MicroMegas modules

Cosmic trigger

Gas system

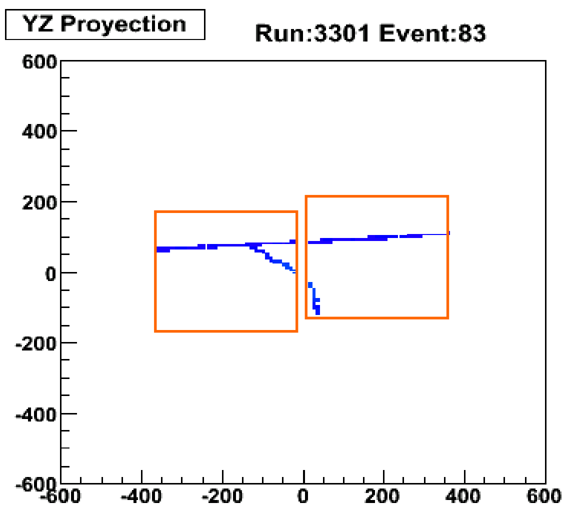


Beam trigger

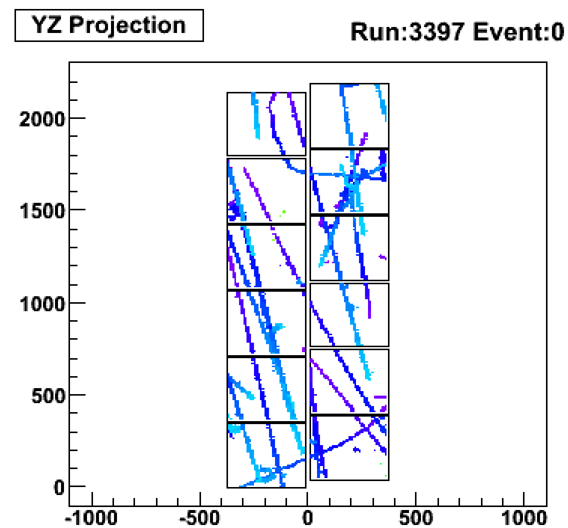
Movable platform to rotate and translate the TPC

Tracks in the TPC Module 0

- Beam track on 2 MM modules (with a δ ray)



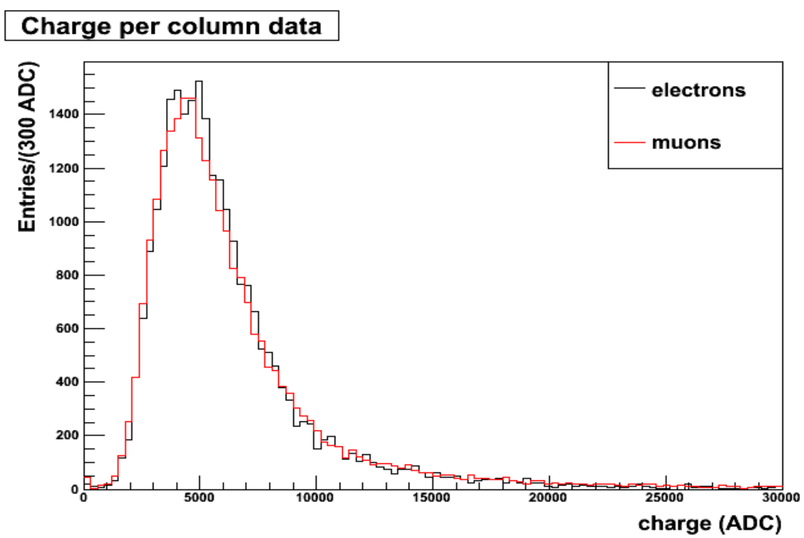
- Cosmic on the full endplate



- We used these data to study the TPC performances in terms of:
  - Energy resolution → Particle Identification
  - Spatial resolution → Momentum resolution

M11 results: Energy loss

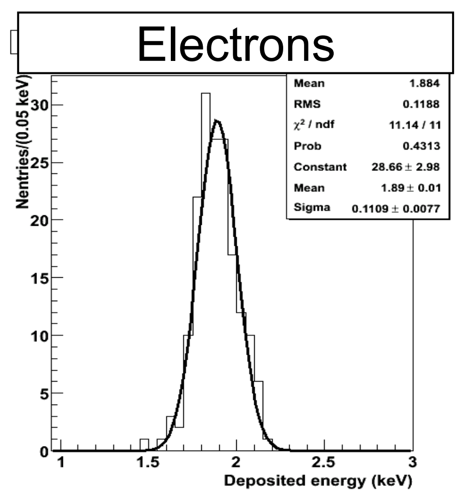
- One of the main purposes of the TPCs is the Particle Identification
- The **PID** is based on the **deposited energy** by the charged particles
- This distribution is broad due to the Landau tails

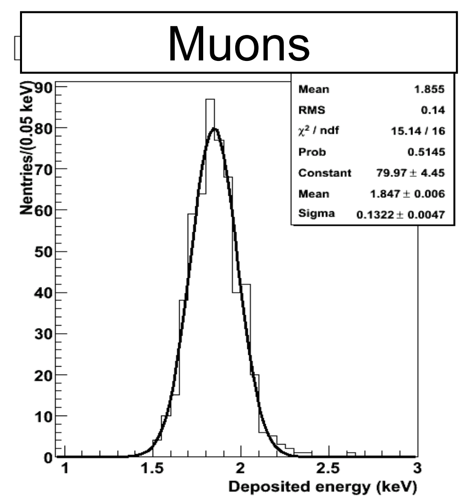


- A **truncated mean method** is used to exclude the tails:
  - Order the charge per column C_C as a function of increasing charge

$$C_T = \frac{1}{\alpha N} \sum_{i}^{\alpha N} C_C(i) \qquad \alpha = 0.7$$

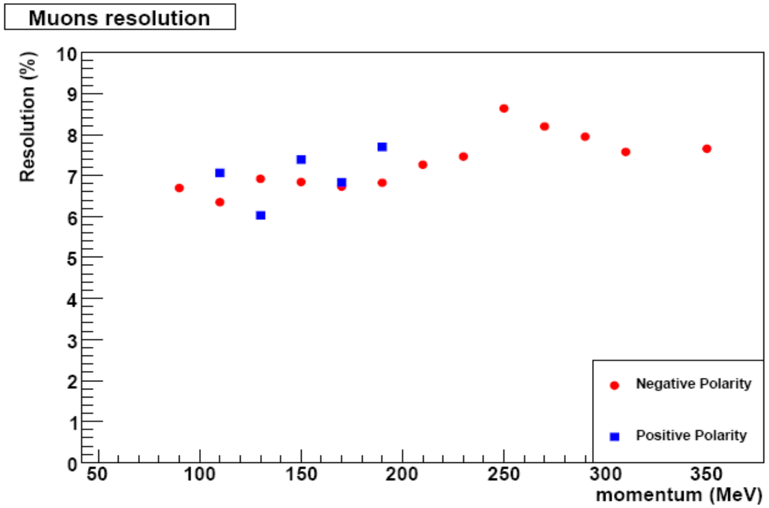
- C_T has a **Gaussian distribution** with a resolution < 8%

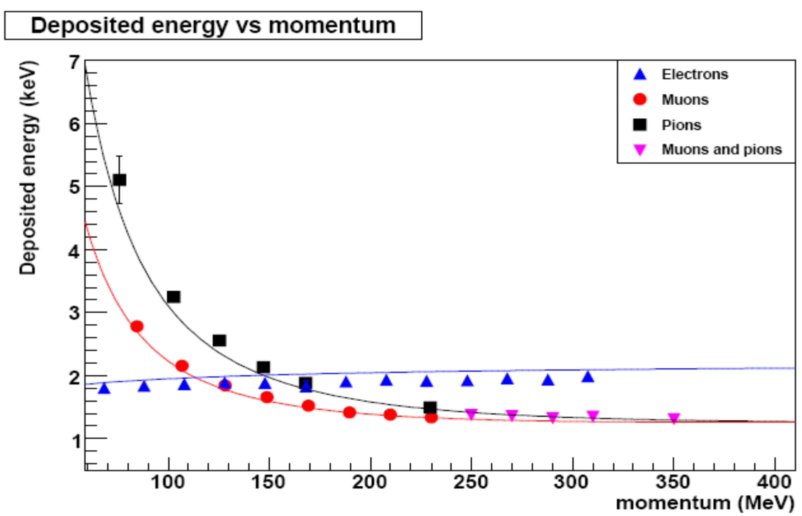


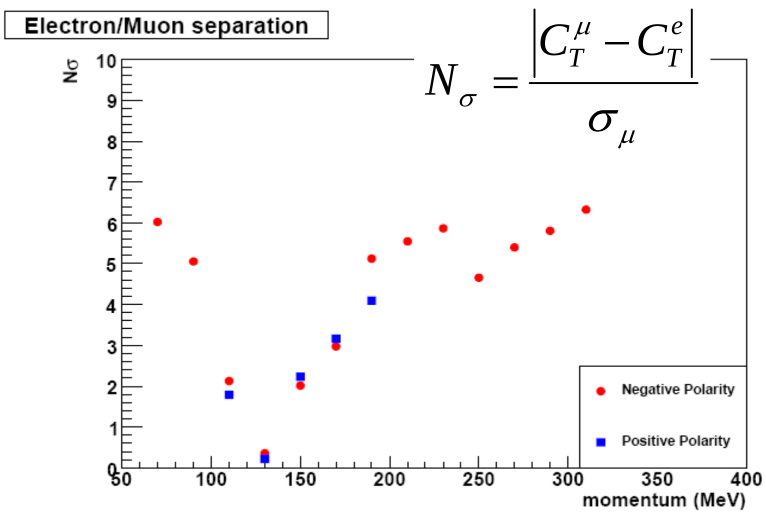


Energy resolution

- Good agreement between data and MC
- **~40% separation** between electrons and muons → We need a resolution better than 10% to distinguish them
- Energy **resolution better than 9%** for all the momenta
- Electron/Muon **separation better than 5σ** if the momentum is larger than 200 MeV



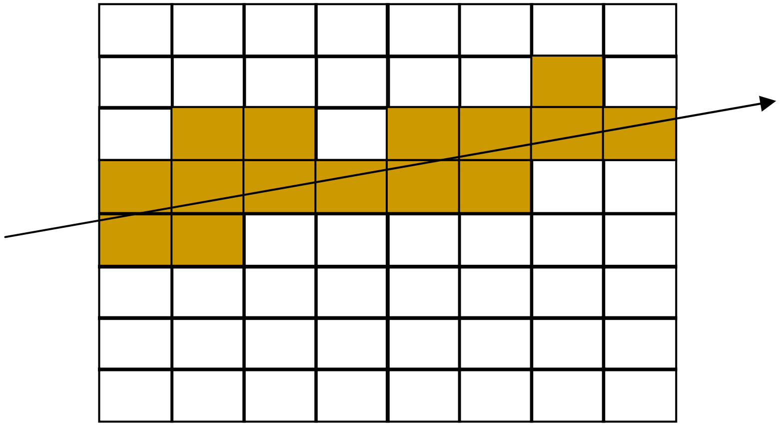


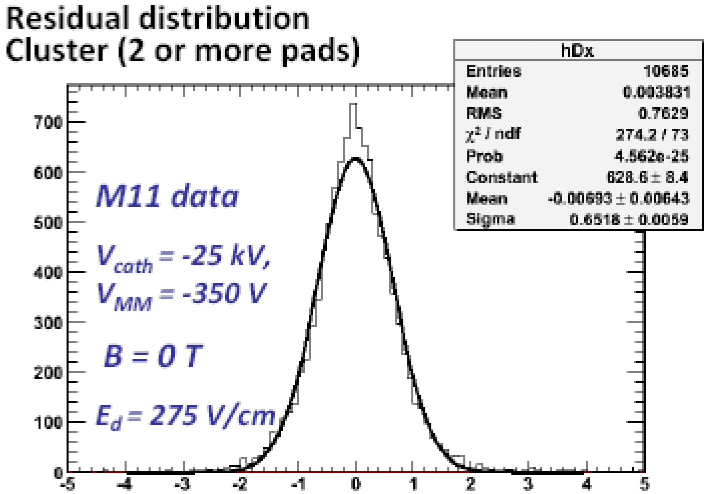


$$N_\sigma = \frac{\left|C_T^\mu - C_T^e\right|}{\sigma_\mu}$$

Spatial resolution

- The spatial resolution is defined by the residual distribution:
  - Distance column by column between the center of mass of the charge and the track's fit position
  - The resolution is better if more than one pad are illuminated





- Spatial resolution in M11 data:
  - 650 μm @ 75 cm of drift dist
- Good agreement with previous results with MicroMegas prototypes (NIM 602(2): 415- 420)
- Will allow to meet the requirements for the momentum resolution
  - ($\delta p/p < 10\%$ @ 1 GeV)

Conclusions

- The 3 TPCs are one of the key elements of the T2K Near Detector
  - The Module 0 is ready, fully equipped and has already been received in Japan
  - The Module1 is ready, fully equipped and is under beam test at TRIUMF
  - The Module 2 is under construction and will be sent to Tokai by the end of the 2009
  - T2K will start the data taking in December 2009
- The beam tests performed at TRIUMF showed that the TPCs meet the requirements:
  - Energy resolution better than 8% for a MIP
  - Electron/Muon separation better than 5σ @ p>200 MeV
  - Spatial resolution of 650 μm @ 75 cm → $\delta p/p < 10\%$ @ 1 GeV

Back up slides

Neutrino mixing

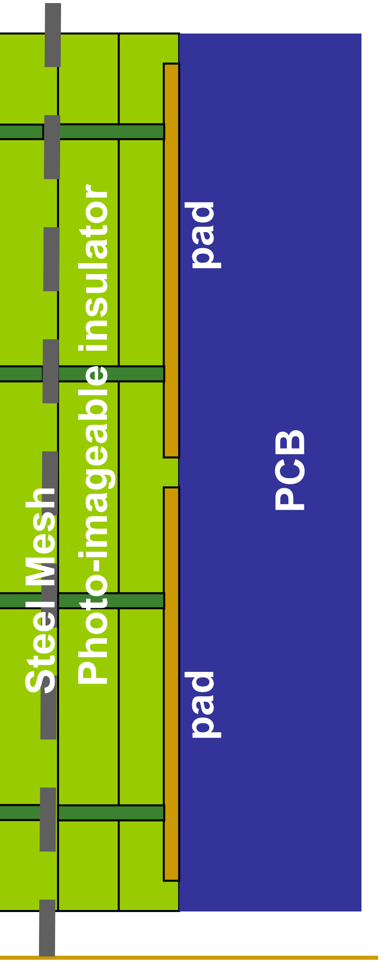
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{-i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.27\ \Delta m^2_{23}\ L/E_\nu)$$

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2(1.27\ \Delta m^2_{13}\ L/E_\nu)$$

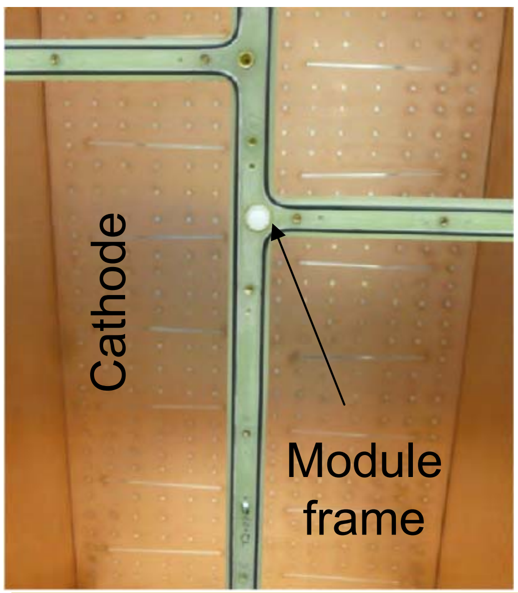
The Bulk MicroMegas

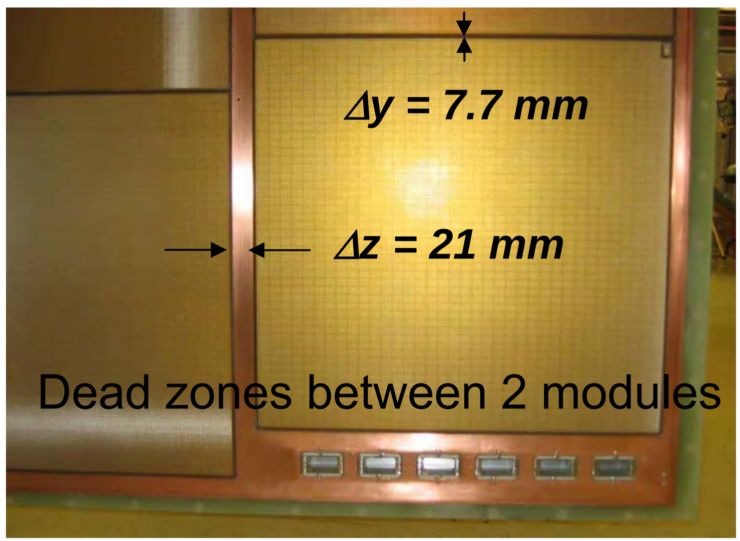
- The Bulk MicroMegas is a technology developed at CERN/Saclay
- Sandwich of:
  - 3 photo-imageable insulator layer (Pyralux) of 64 μm each
  - 1 steel mesh with a width of 2.4 mm and 2 layers (x,y) of 19 μm wires
- The sandwich is laminated on the PCB, exposed to UV, cleaned-heat-dried 2-3 times and then after a global QC test it's cut to the final dimensions
- Total thickness 19.5 mm
- Advantages:
  - Steel mesh → **Robustness**
  - **Large area** can be produced
  - **Less dead zones** on the edge
  - Better **gain uniformity** in the corners



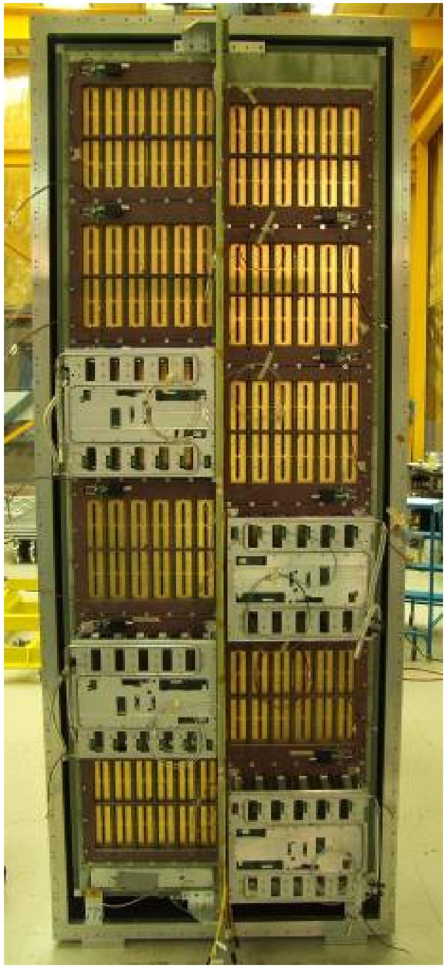
TPC Module 0 @ TRIUMF

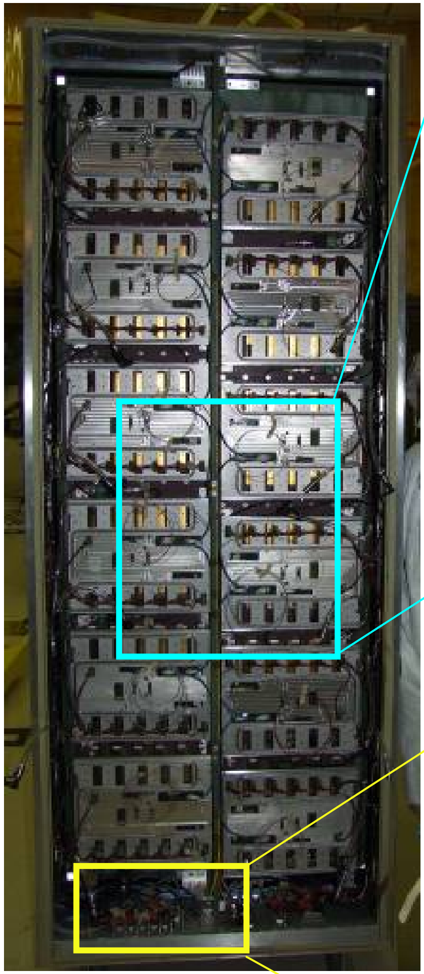
Internal face

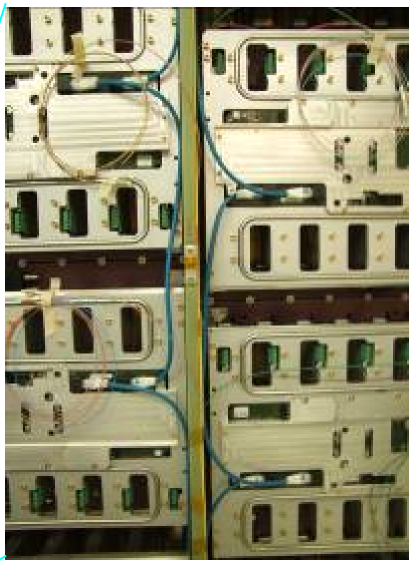




Installation of the electronic on the TPC





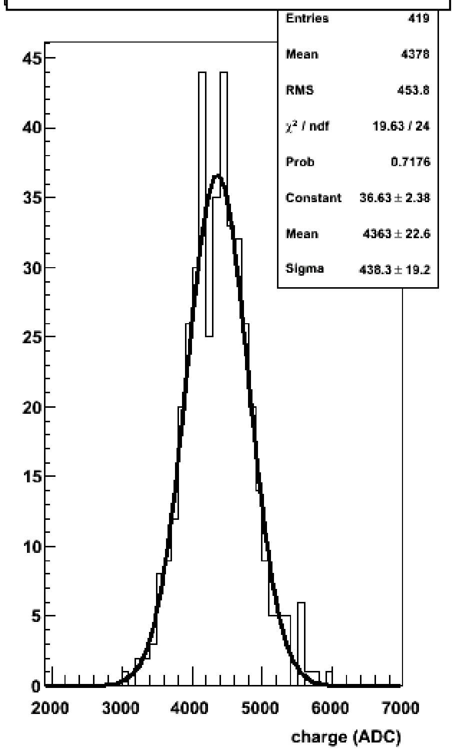


Module 0 is now fully equipped with 24 MicroMegas
and all the Front-End electronic

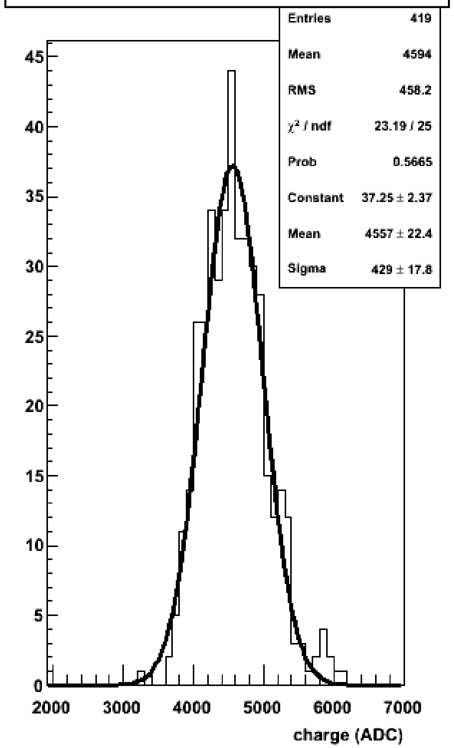
Energy resolution in the MicroMegas

- Muons, p = 150 MeV/c, energy resolution in the 2 MM modules

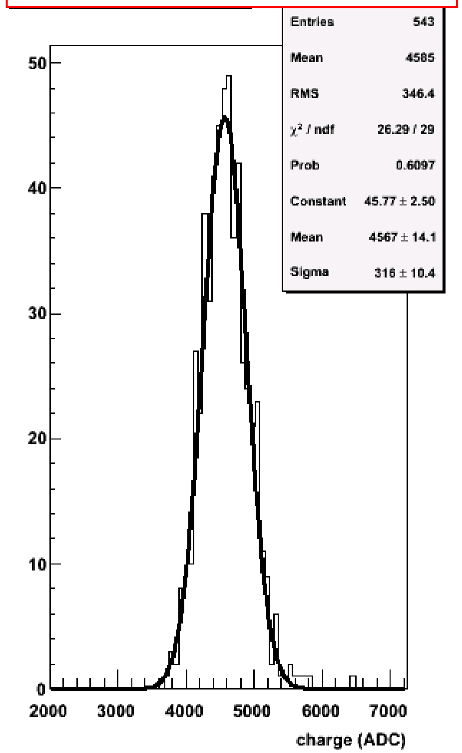
Res 1st MM = 10.0%



Res 2nd MM = 9.4%



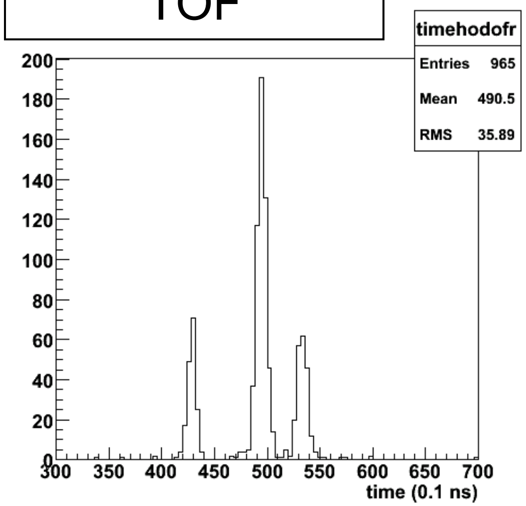
Res all TPC = 6.9%



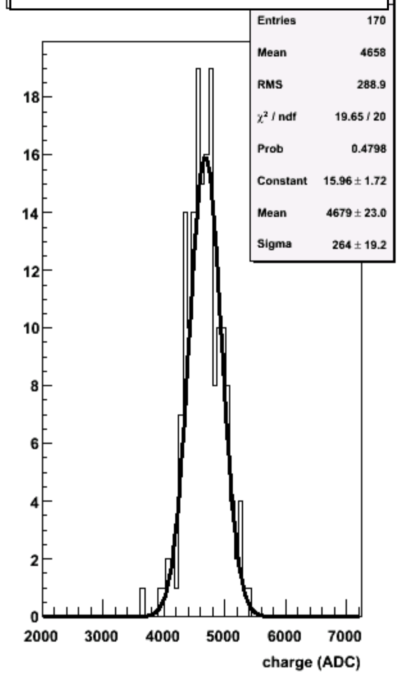
Resolution for different particles

- With the TOF system we selected samples of electrons, muons and pions for a given momentum
- TPC horizontal, p = 150 MeV/c

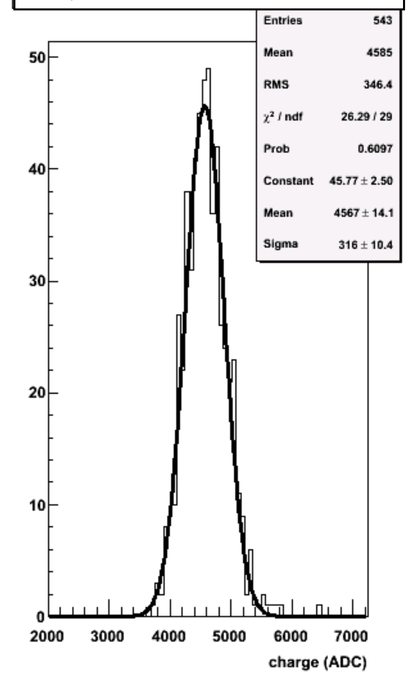
TOF



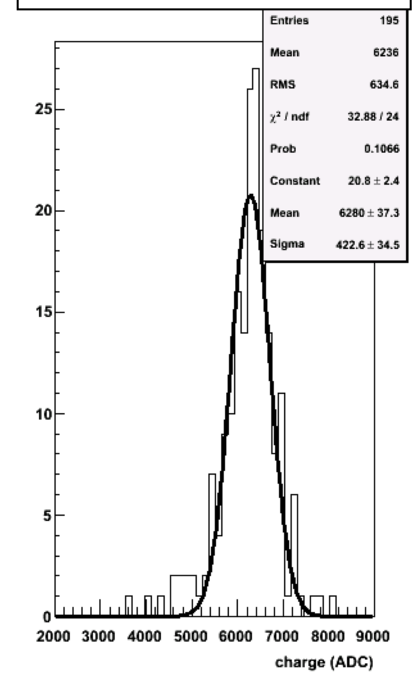
e^- res = 5.6%



μ res = 6.9%



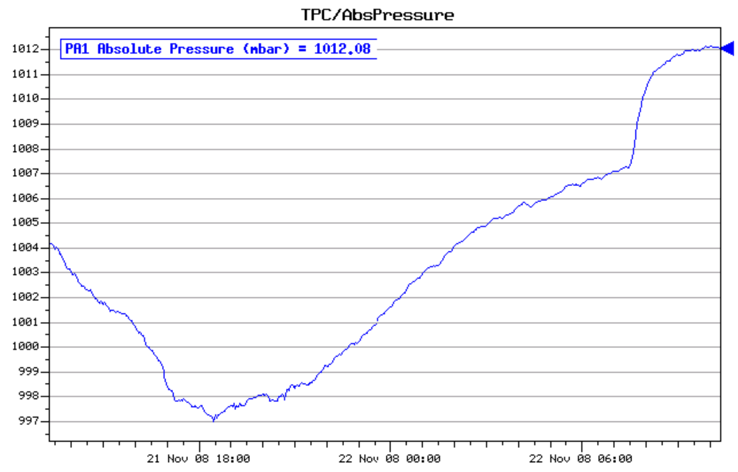
π res = 6.7%

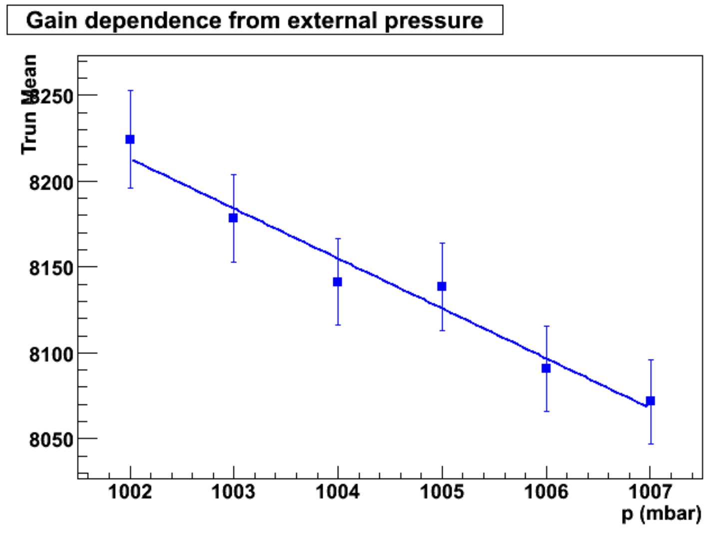


- At 150 MeV/c we can clearly see 3 different peaks

M11 data pressure dependence

- The gain of the MicroMegas depends on the external pressure
- This dependence can be seen analyzing runs taken at the same conditions and with different external pressure
- Useful runs in the night of 22nd November, P = 300 MeV/c
  - Pressure variation from ~ 1001 mbar to ~ 1007 mbar

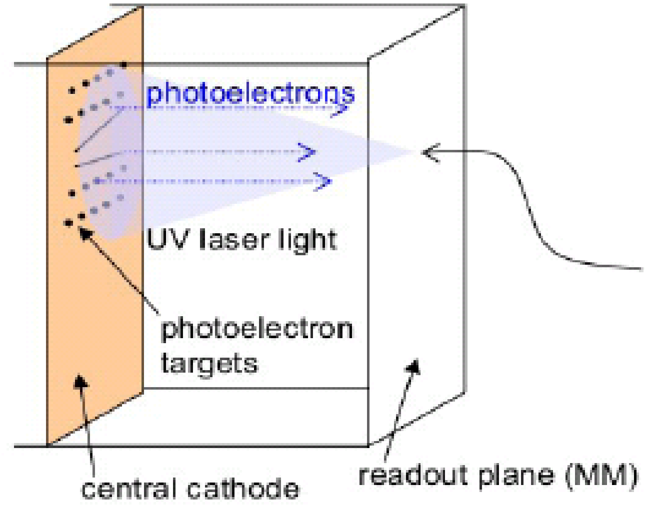


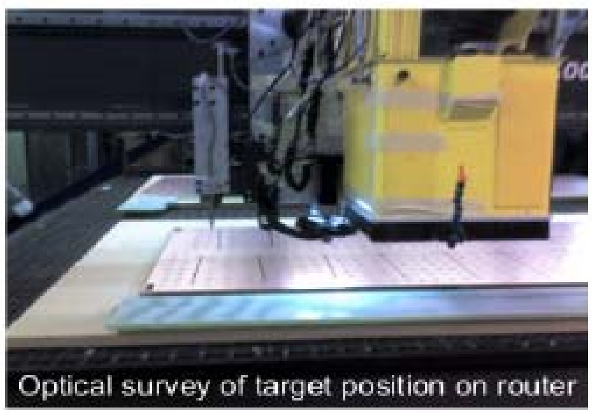


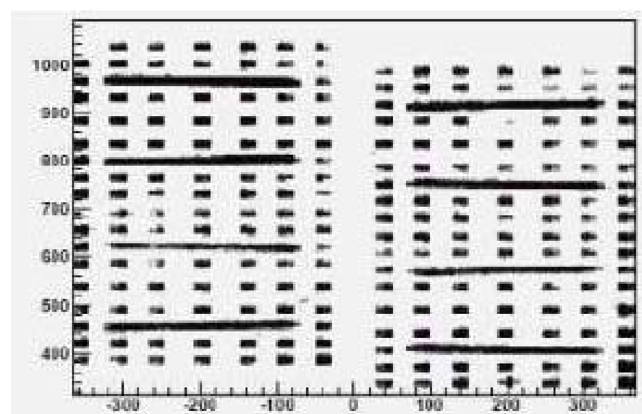
- Δg = 3.3 ± 0.6 % for Δp = 1%
- During previous MicroMegas test, with a ^{55}Fe source, we found Δg =3.1 ± 0.3 % for Δp = 1%

Laser calibration system

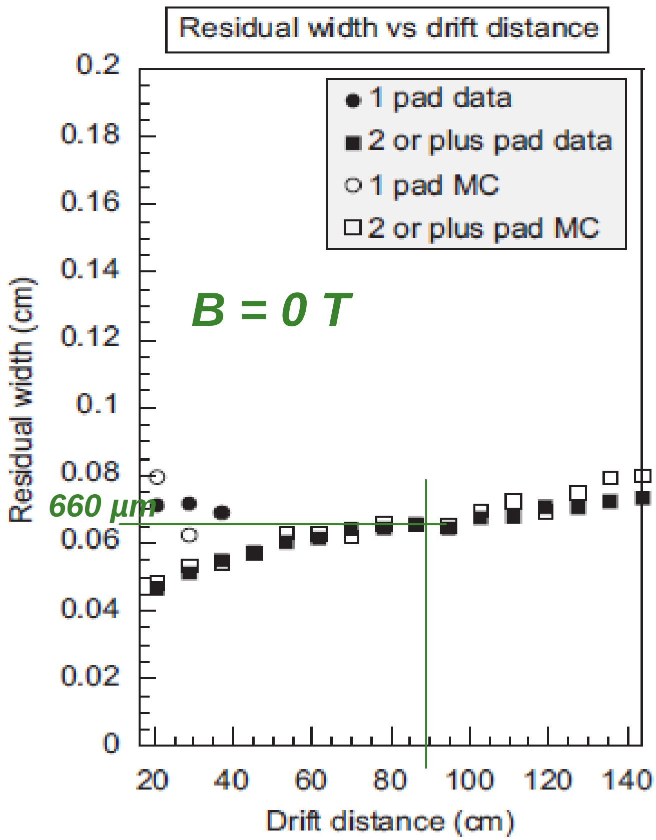
- In situ field distortion calibration
- Targets placed on the central cathode, positions surveyed by router (accuracy better than 100 μm
- The targets, illuminated with UV laser light, emit photoelectrons that are then collected on the MicroMegas plane

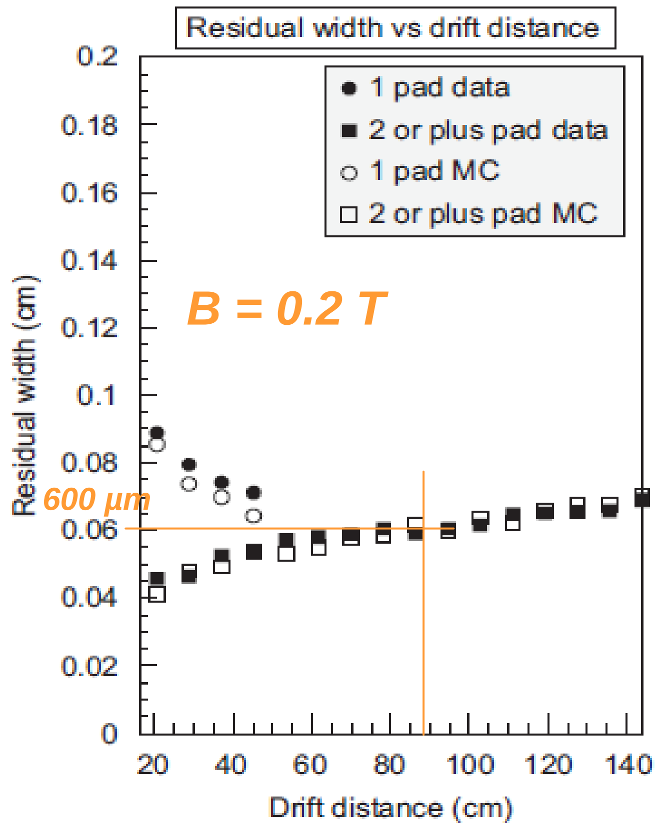






MicroMegas tests in the HARP field cage





History of tests