The particle identification in the T2K TPC

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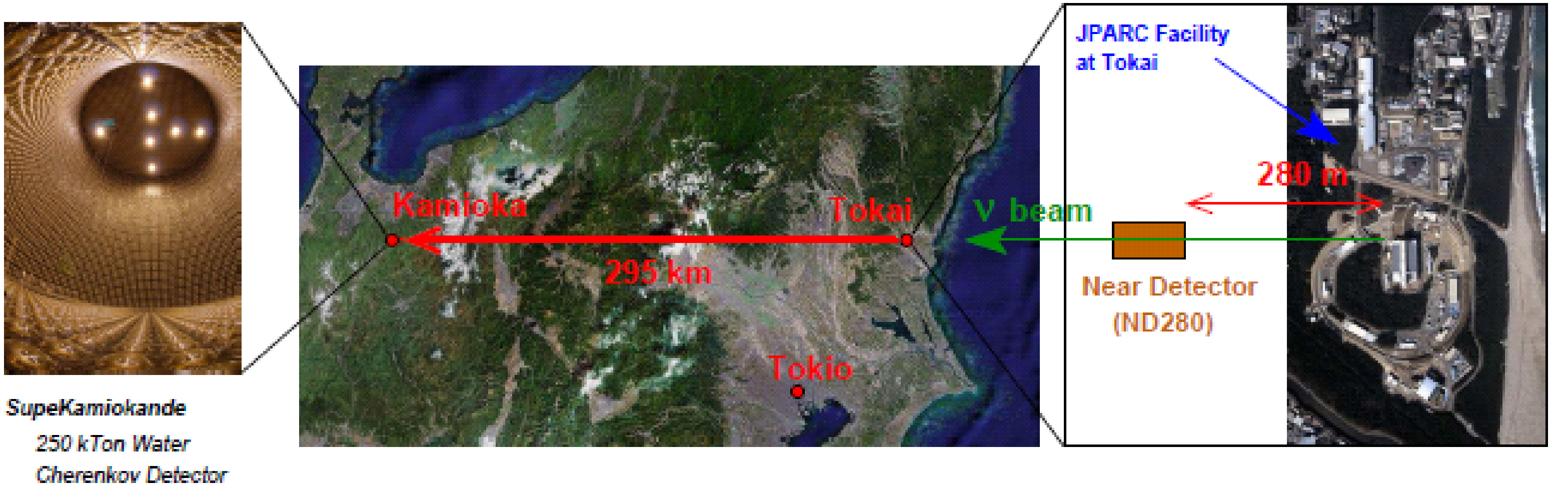
T2K TPC group: CERN/TS-DEM-PMT, *INFN, IRFU-CEA Saclay, LPNHE University of Paris VI-VII, RWTH Aachen University, TRIUMF, University of British Columbia,* UAB/IFAE *Barcelona University, University of Geneva, University of Victoria, and Valencia University*

The T2K experiment



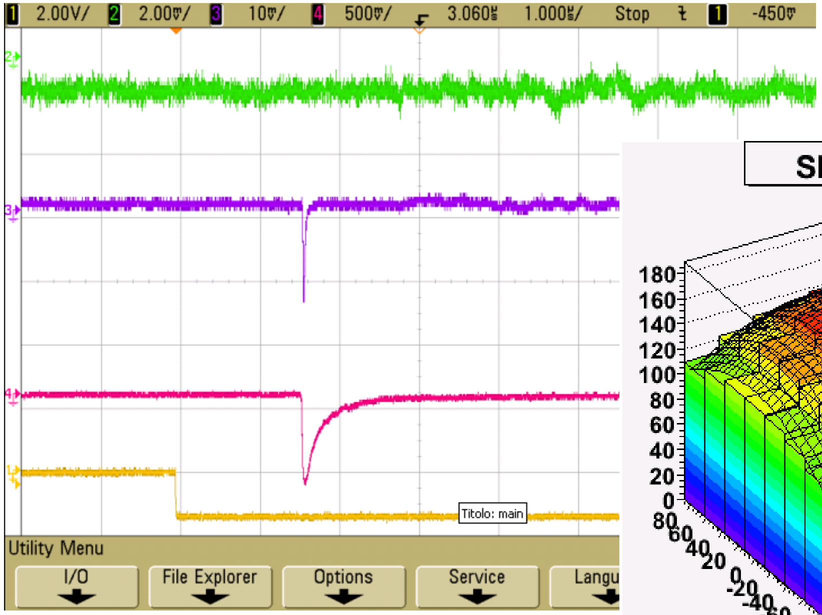
- Long Baseline Neutrino oscillation experiment
  - The neutrino beam started in April 2009
  - The data taking with all the ND280 facility installed will start in December 2009
- 30 GeV proton accelerator will be used to produce a ν_μ beam that will be send from Tokai to SuperKamiokande
  - **L = 295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

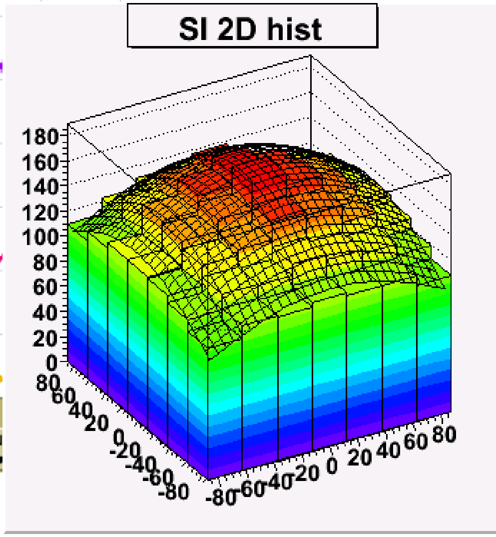
First T2K neutrino beam

- The T2K neutrino beam is in the commissioning phase
- On April 23rd the proton beam has been extracted and sent to the target → The first T2K neutrinos has been produced!

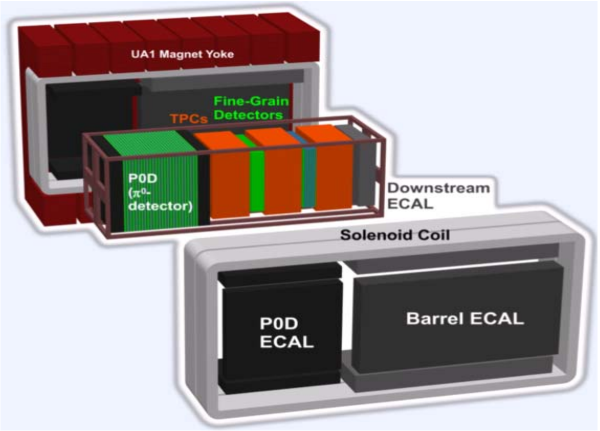
$p + N \rightarrow \pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$

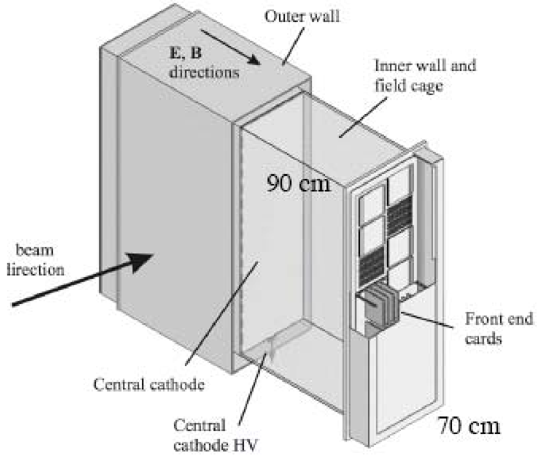
- Muons produced with neutrinos have been detected in the Muon Monitor
- Many neutrinos to detect in the next months/years!
- Many physics to do…





The Near Detector and the TPC



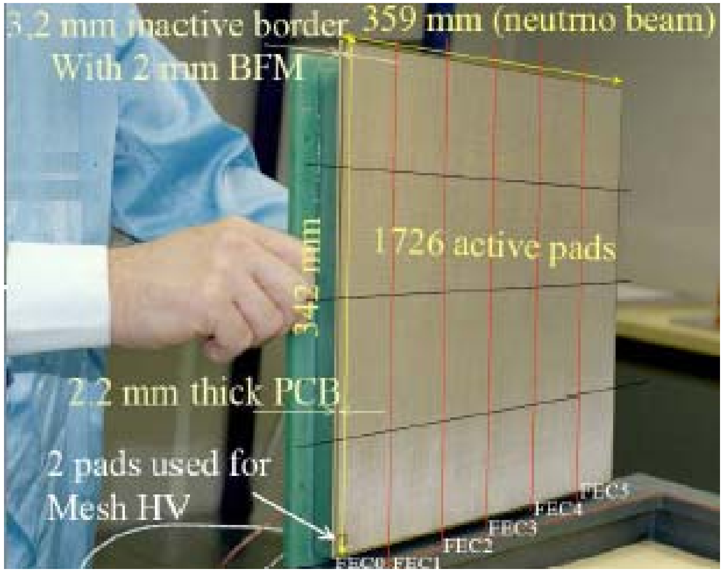


- Near Detector complex at **280 meters** from the neutrino beam production point
- Several detectors inside the UA1 magnet (with a field of **0.2 T**)
  - Characterize neutrino beam (before the oscillations)
  - Measure ν_e contamination in the beam
  - Study background process to oscillation signal

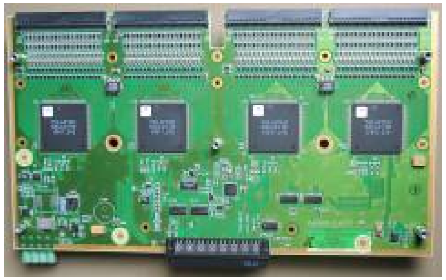
- **3 large TPCs**
- Long drift distance (**90 cm**)
- Total active area ~9m^2
- Requirements:
  - **$\delta p/p$ < 10% @ 1GeV** to reconstruct neutrino energy spectrum
  - **dE/dx resolution better than 10%** to perform electron/muon separation

Readout plane

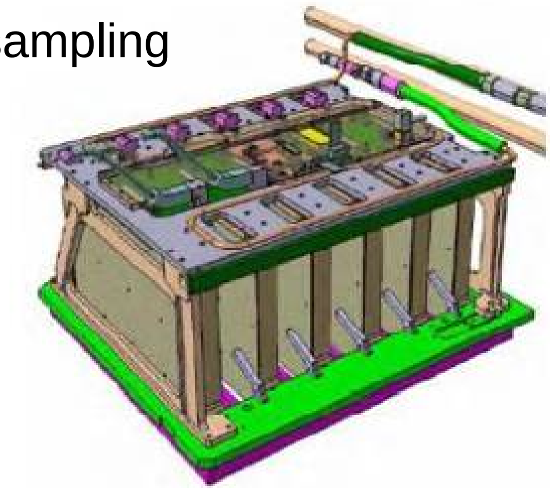
Signal Amplification:
•12 large (35x36 cm²) bulk-MICROMEGAS on each endplate → 72 modules in 3 TPCs
•Each module has 1726 active pads (6.9x9.7 mm)
•Pads are arranged in 36 columns and 48 rows
•Total of ~120 000 channels
•MM are produced **CERN/TS-DEM-PMT** and are tested and validated in a test bench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



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

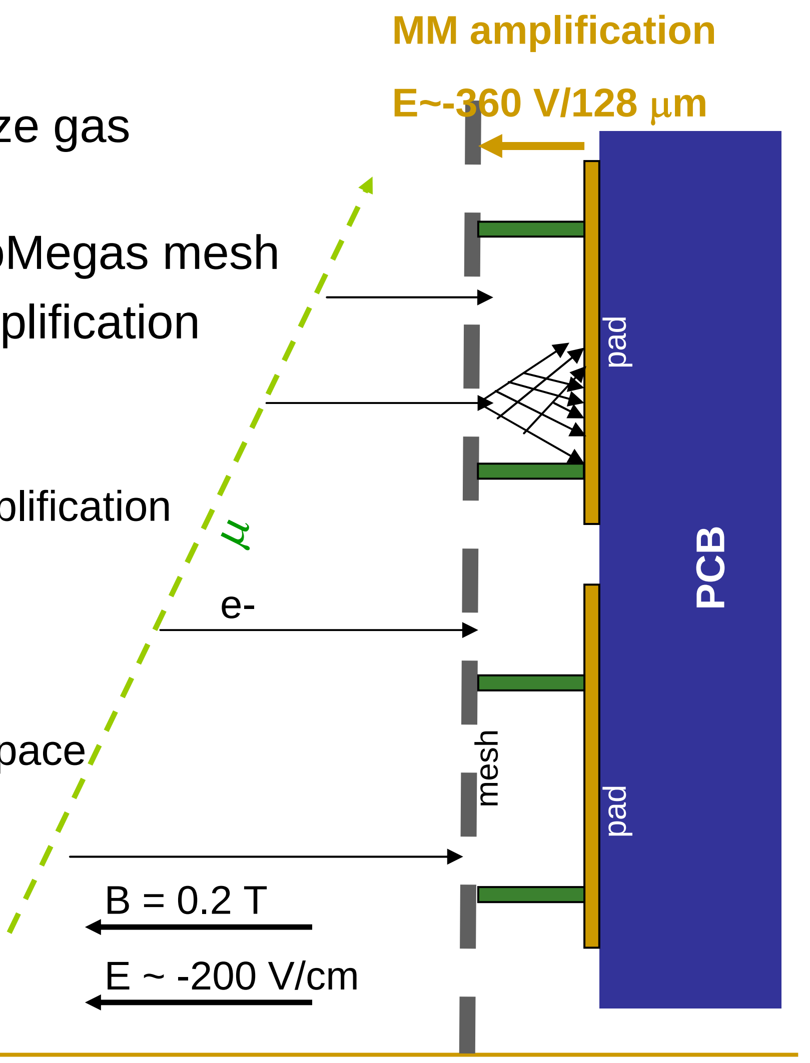

Front-End Card (FEC)


Front-End Mezzanine (FEM)



The MicroMegas principles

- Charged particles crossing the TPC ionize gas molecules
- The produced electrons drift to the MicroMegas mesh
- Once on the mesh the e^- enter in the amplification region where avalanches are generated
  - **Gain ~ 10^3 - 10^4**
  - **~ 100% collection efficiency** (if drift/amplification field is high enough)
  - Small gap → short rise time
- Ions flow back to the mesh
  - Only few ions permil go back to the drift space
  - Avoids space charge effects

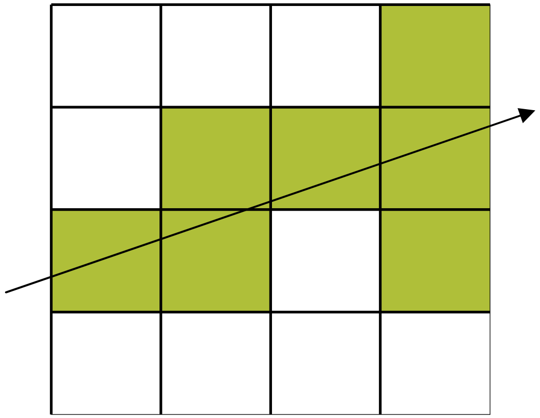


Particle Identification in the TPC

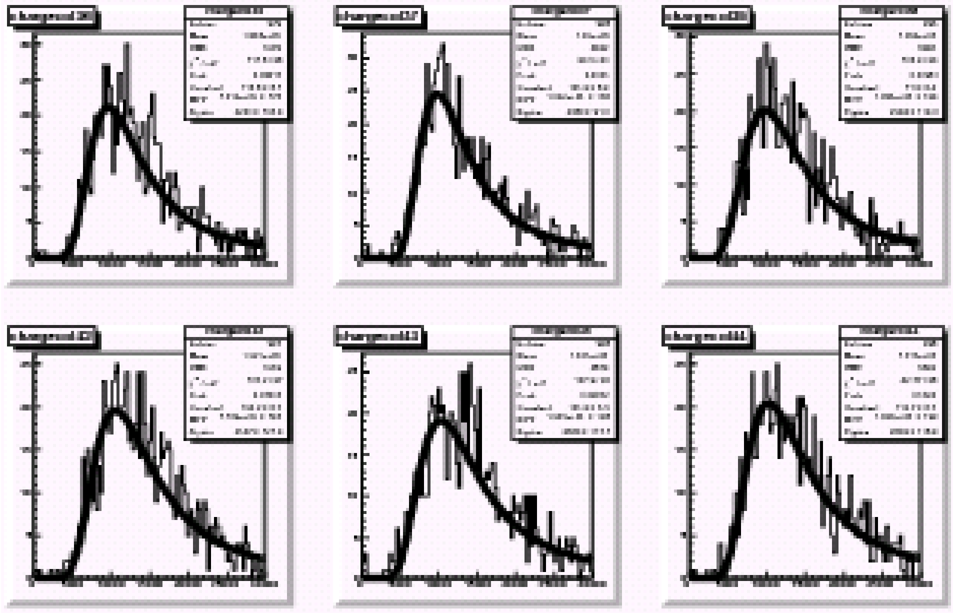
The Particle Identification in the TPC

- The TPCs are able to recognize different particles using measurements of the energy loss in the gas
  - The main purpose of this measurement is to distinguish electrons from muons → Measure the ν_e contamination in the beam, one of the main backgrounds to the measurement of θ_{13} via ν_e appearance
- We developed a method to perform the PID using MC simulation
- We tested this method using the beam test of the TPC Module 0
- The PID is based on the measurement of the truncated mean of the track crossing the TPC

Charge per cluster distribution



- The track is reconstructed fitting along the TPC the charge contained in each MM column
- This charge is usually distributed on 1, 2 or 3 pads
- The charge distribution in each column is large and not gaussian



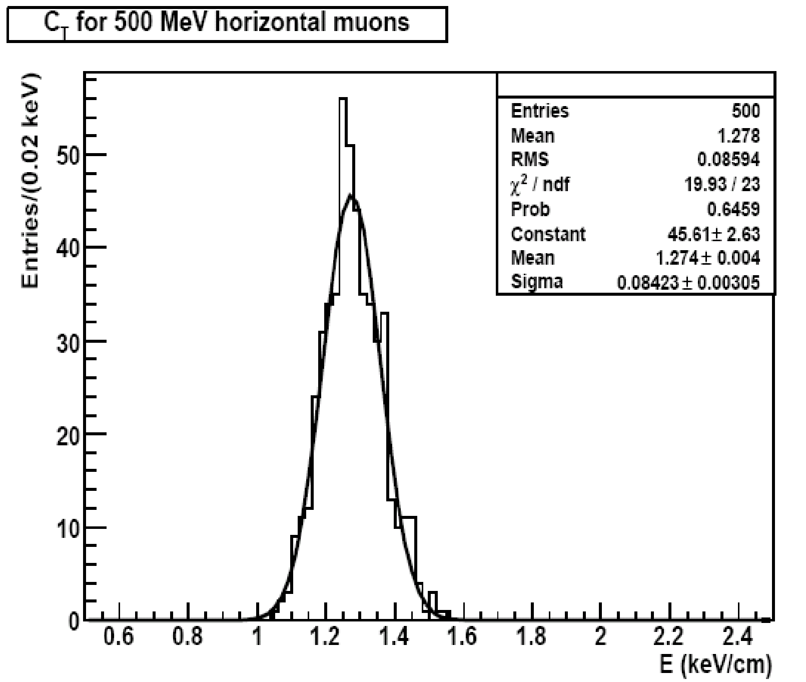
PID with MC simulation

- For each reconstructed track that crosses all the TPC we have 72 measurements of energy (36 in each MM module)
- We measure the truncated mean of the charge for each track, selecting the 70% of the clusters with less charge (to reject Landau tails)

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

- We also need to parameterize corrections for the track angle and for the number of samples

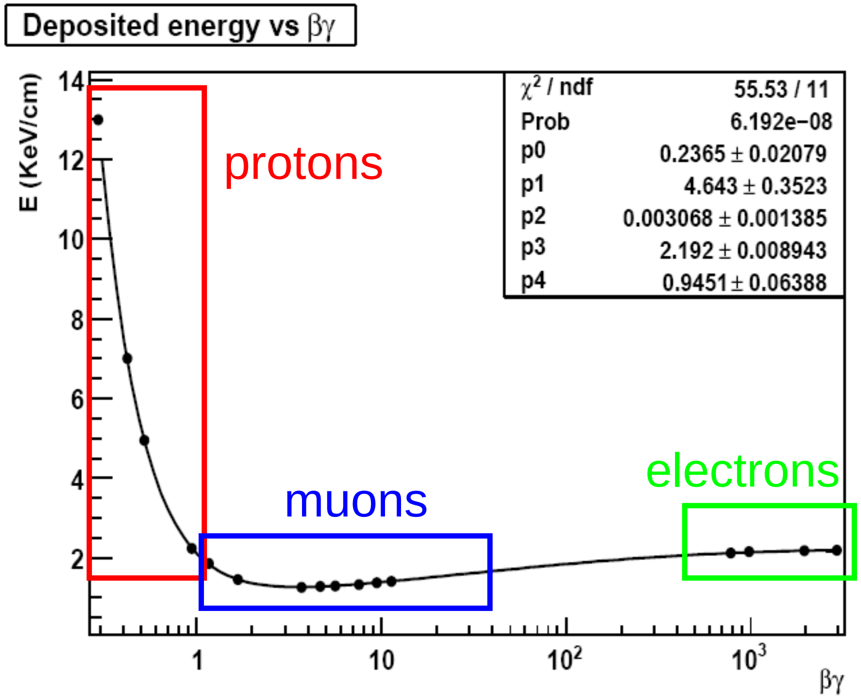
MC simulation



- Gaussian distribution
- Resolution (σ/Mean) ~6.6%

Parameterization of the expected energy loss curve

- The energy loss in the gas is a function of only $\beta\gamma$
- Producing samples of different particles (electrons, muons, protons) we parameterized the expected curve of the energy loss



- Knowing the parameterization for each track:
  - Measure the momentum P
  - Measure the trun mean C_T
  - Compare C_T with C_E for a particle of momentum P and mass M_i (i= e, μ, π, p, K)

Corrections for number of samples and gap

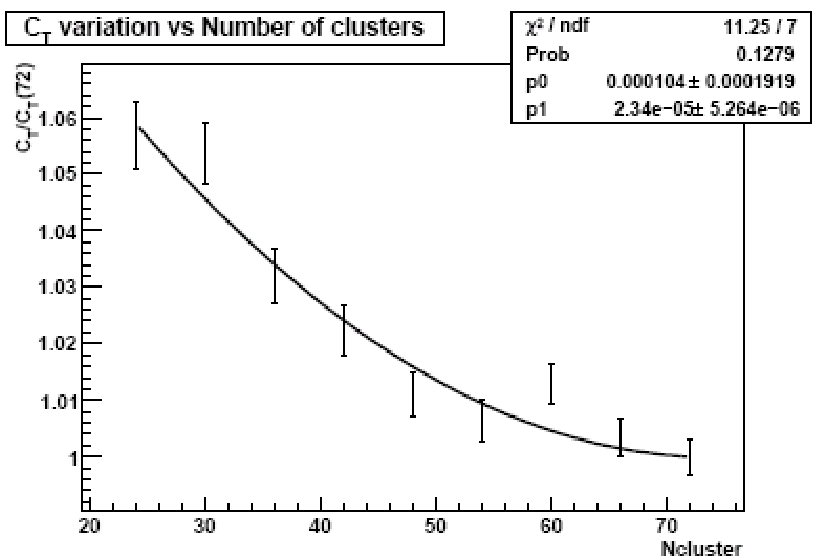
- The energy loss depends also from the number of samples that we used to perform the measurement and from the path of the particle into each pad
- To check the effect of the sample number we used the same horizontal muons and we computed the energy loss using only different numbers of columns (from 24 to 72)
- To check the effect of the different sample length we produced muons with different angles into the TPC and we analyzed their energy loss

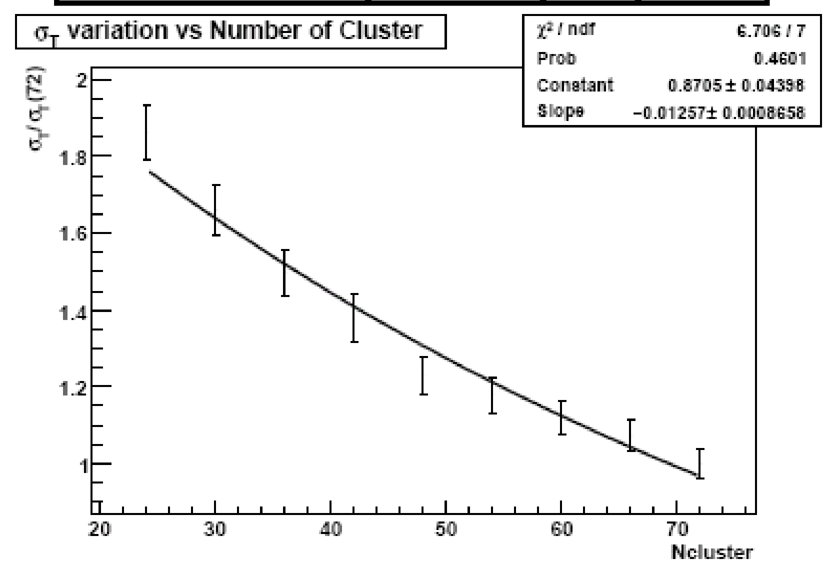
Sample number correction

- Important correction for tracks that exit from the TPC

Truncated mean
→ ~6 % effect from 72 to 24 samples

Sigma
→From ~6% (72 samples) to ~11% (24 samples)





$$\Delta C_T = 1 + p0 \cdot (72 - N) + p1 \cdot (72 - N)^2$$

$$\sigma = e^{(C + A \cdot N_{row})}$$

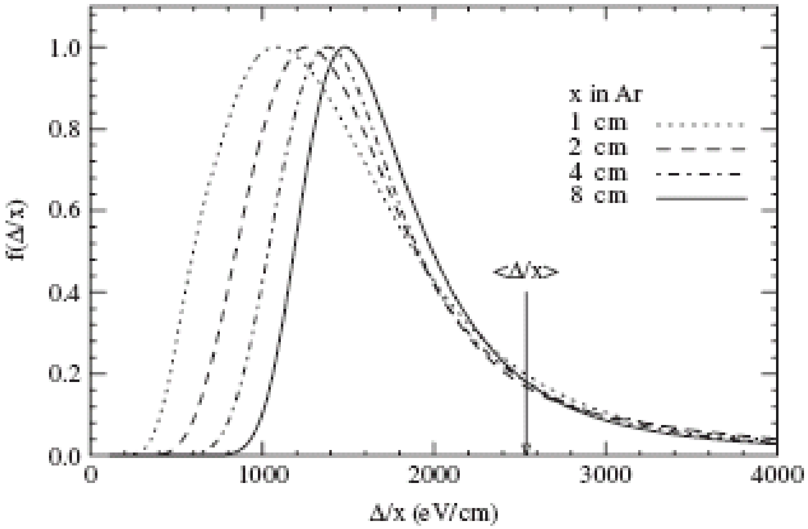
Sample length

Gap definition:
Length of the track segment producing the ionisation detected in one column

- In the case of bented tracks is not sufficient to simply correct for the angle of the track

$$dE/dx_{true} = dE/dx_{meas} \cdot \sqrt{\frac{1}{1 + tg^2(\vartheta_{xz}) + tg^2(\vartheta_{yz})}}$$

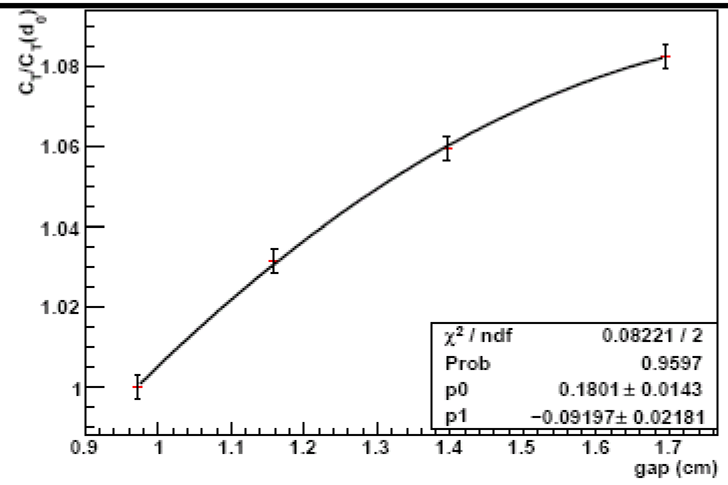
- With the truncated mean method we basically perform a measurement of the peak of the distribution of the energy lose that doesn't scale linearly with the angle
- To study this effect we produced some samples of muons with different gap and we studied the energy release

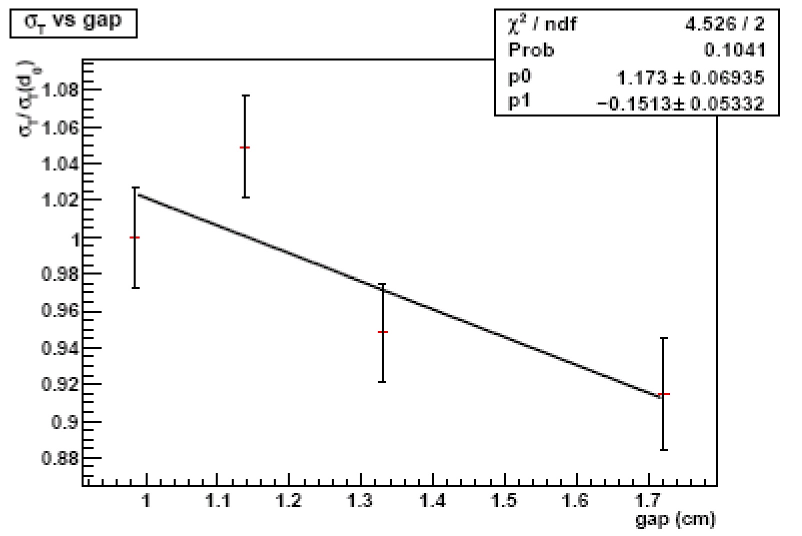


Sample length corrections

- With these bent muons we confirmed that the truncated means and the sigma depends by the gap and we parameterized this dependence

Truncated mean
→~8 % effect if the sample length is doubled





$$\Delta C_T = 1 + p0\cdot(d-d_0) + p1\cdot(d-d_0)^2$$

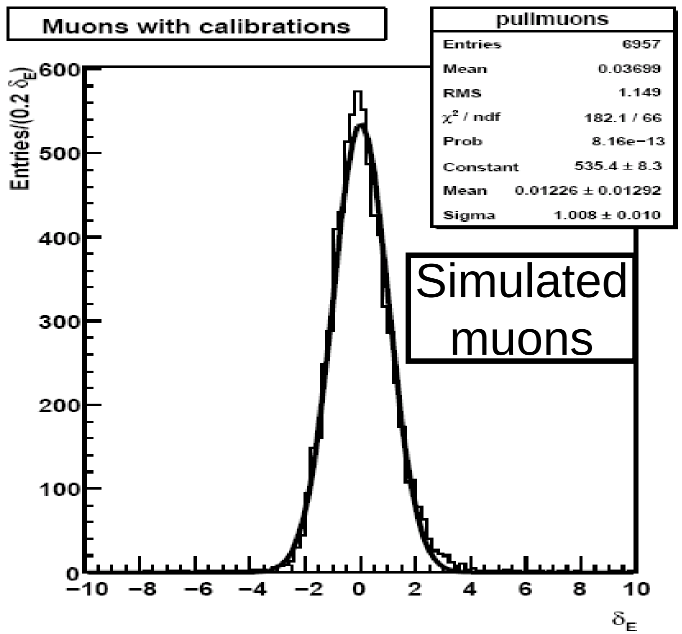
$$\sigma = p0 + p1\cdot d$$

Simulation of neutrino interactions

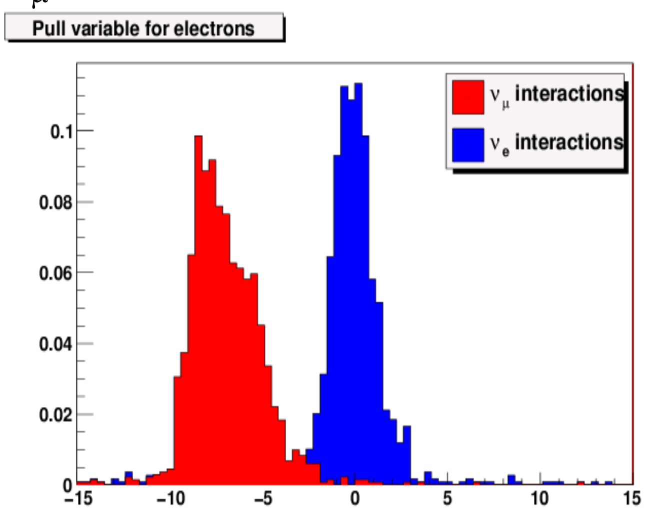
- To quantify the PID we define a pull variable

$$P^j(i) = \frac{C_T(i) - C_E^j(i)}{\sigma_E^j(i)} \qquad j = e, \mu, \pi, p, K$$

- The distribution of the pull for a given particle in the right hypothesis is a gaussian centered in 0 with width 1



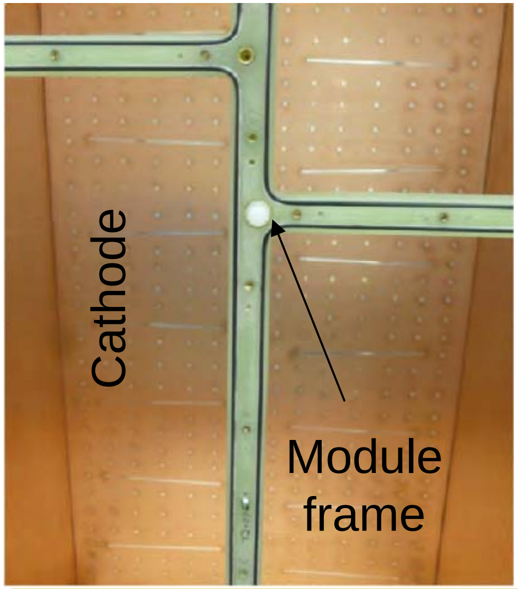
Looking at the pull in the electron hypothesis we can distinguish ν_e/ν_μ interactions

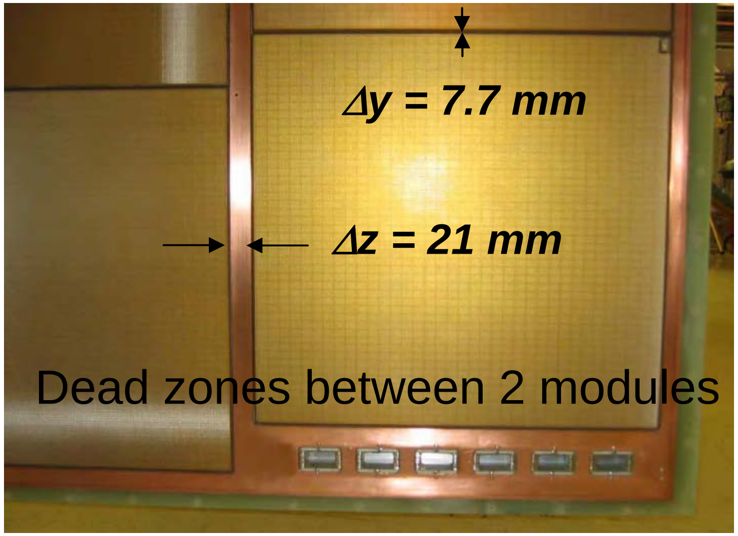


Results of the Beam Test

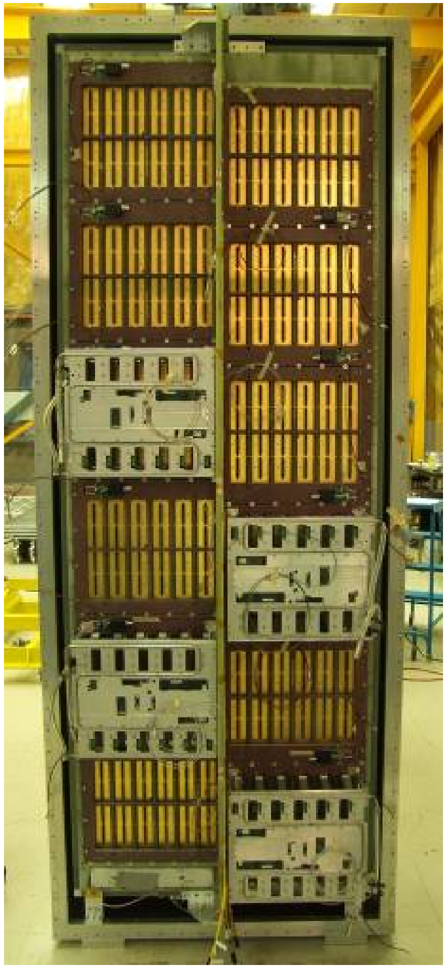
TPC Module 0 @ TRIUMF

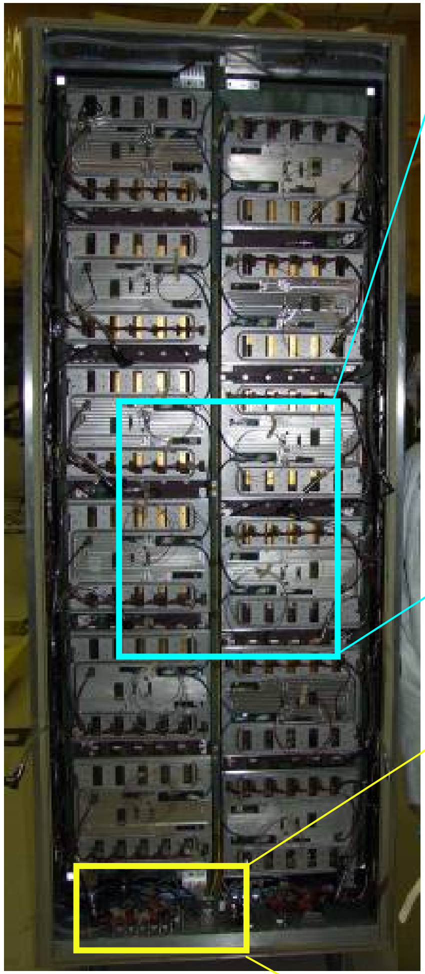
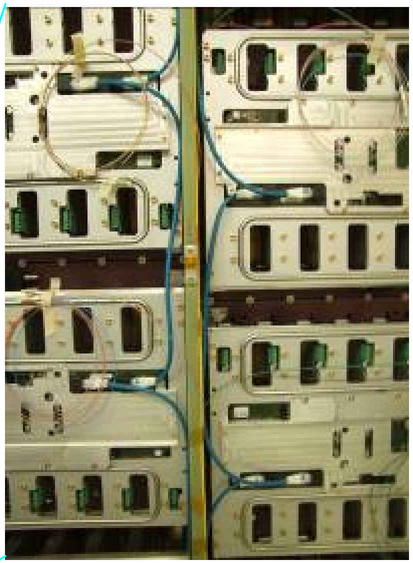
Internal face





Installation of the electronic on the TPC

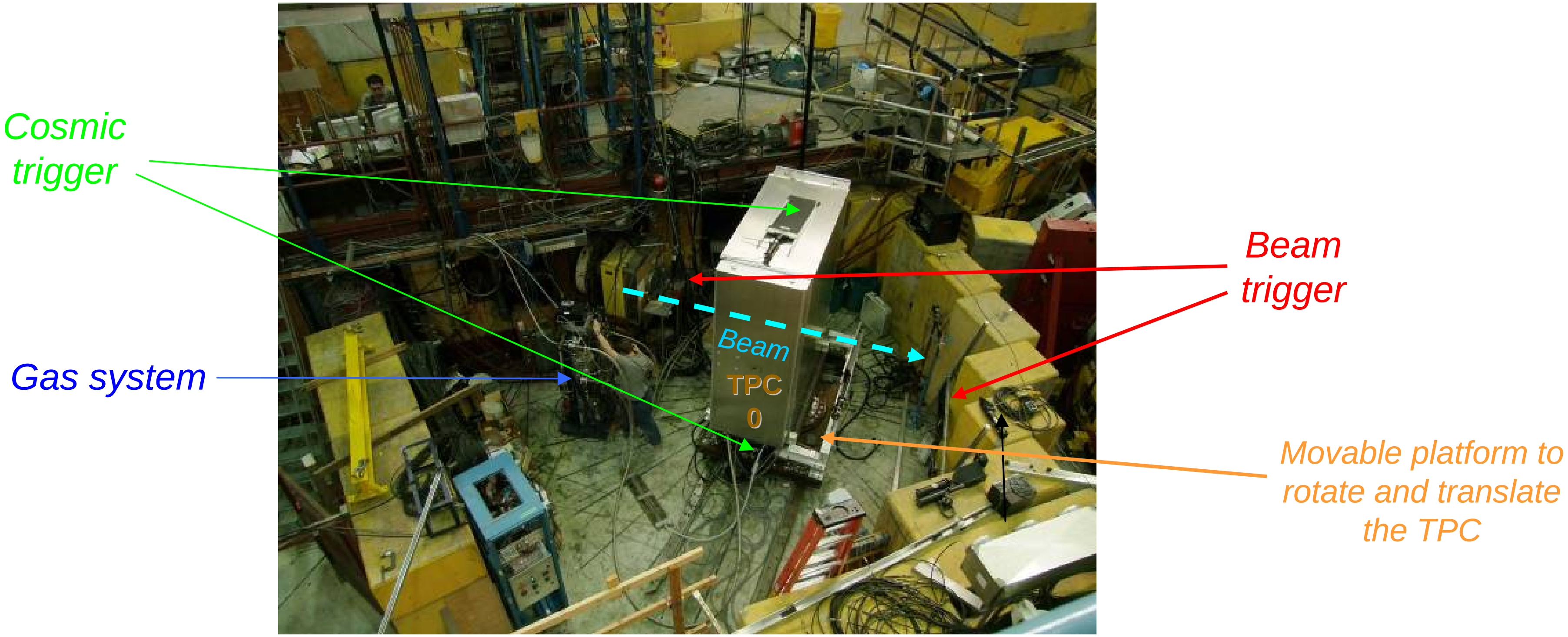



Module 0 is now fully equipped with 24 MicroMegas
and all the Front-End electronic

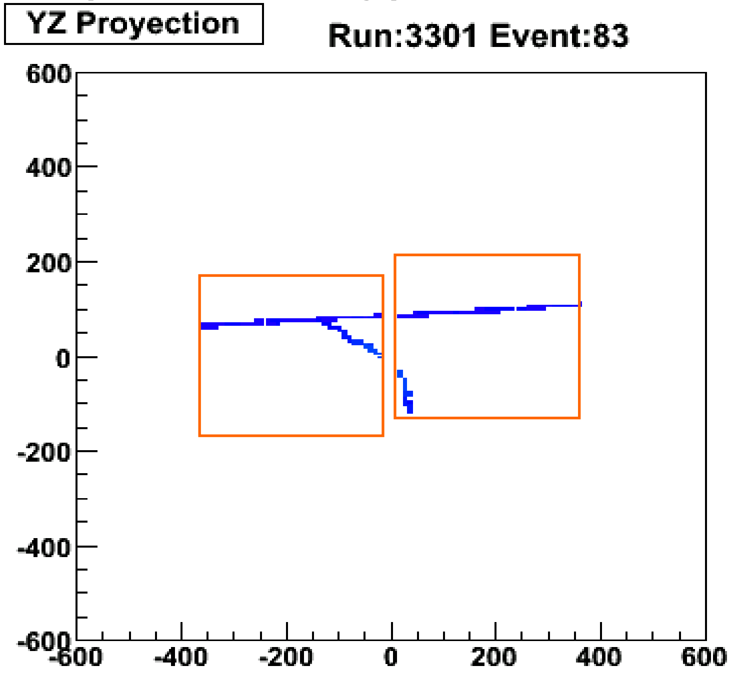
Beam test with Module 0

- Starting from September the Mod 0 has been installed in the M11 beam line 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 module

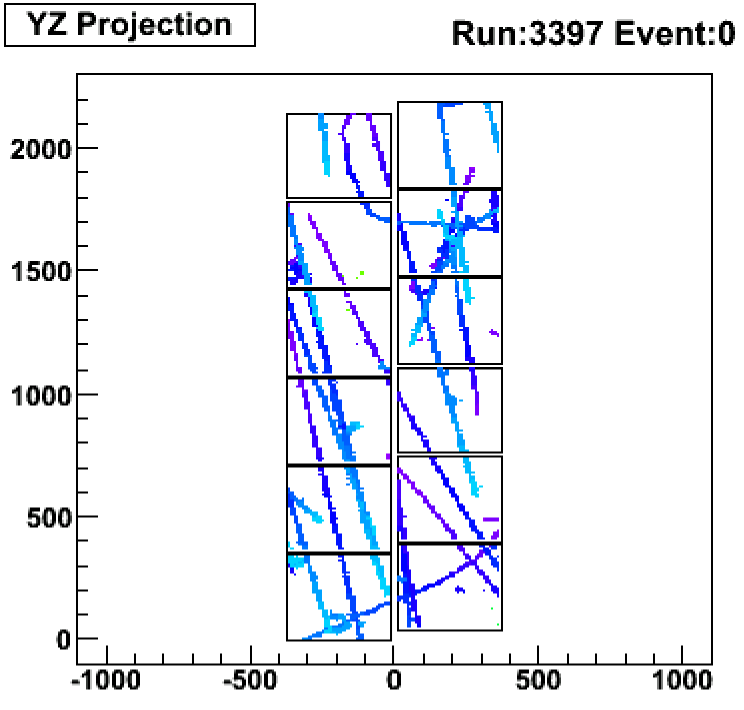


Some tracks from module 0 tests

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



- Cosmic on the full endplate



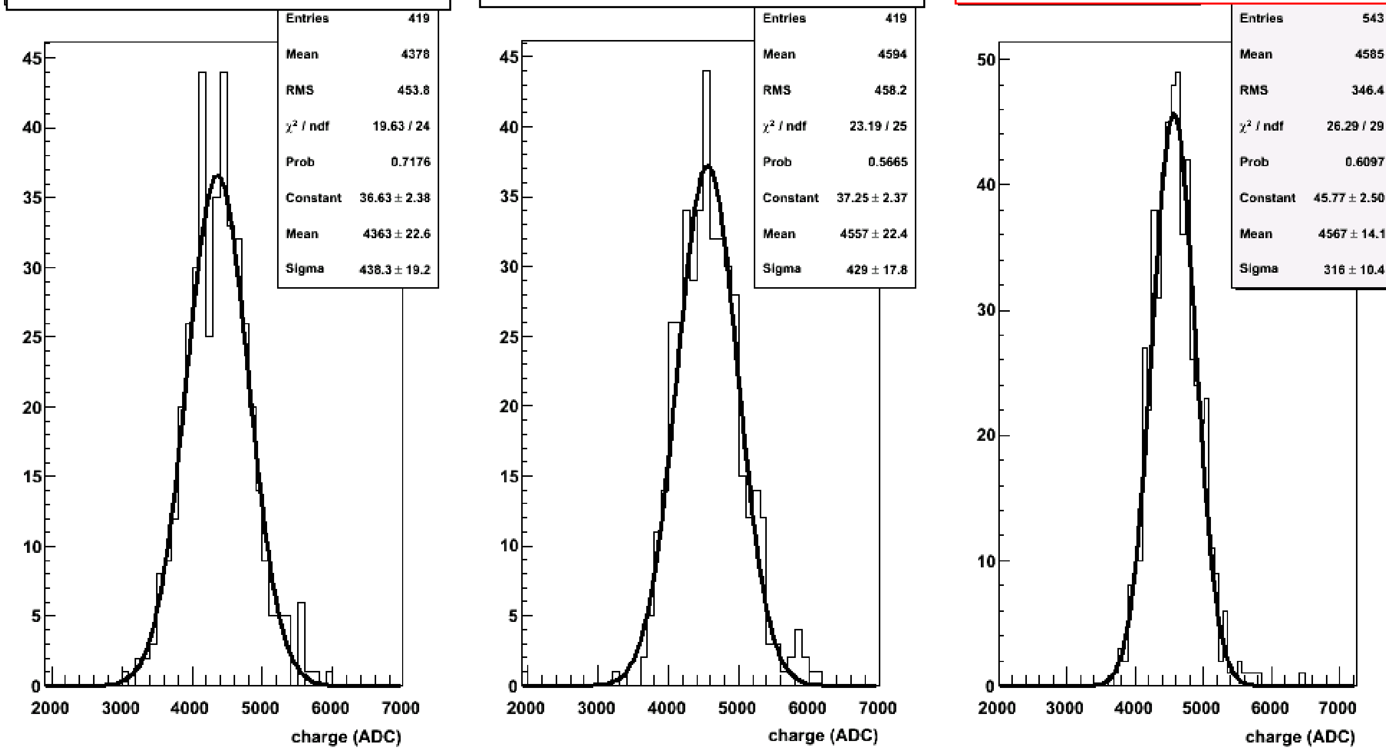
Purpose of these studies

- The beam test have been used to check the capabilities of the T2K TPC
- In particular we used the beam test data to:
  - Study the energy resolution of the TPC
  - Test the PID method
- We took data with different momenta (from 100 MeV/c to 350 MeV/c)
- For each reconstructed track we measured the truncated mean
- The TOF allowed to select samples of different particles independently from the TPC response

Energy resolution in the MicroMegas

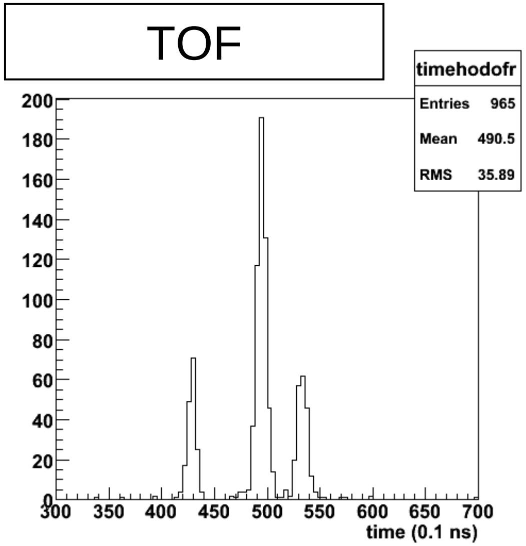
- Muons, p = 150 MeV/c, energy resolution in the 2 MM modules

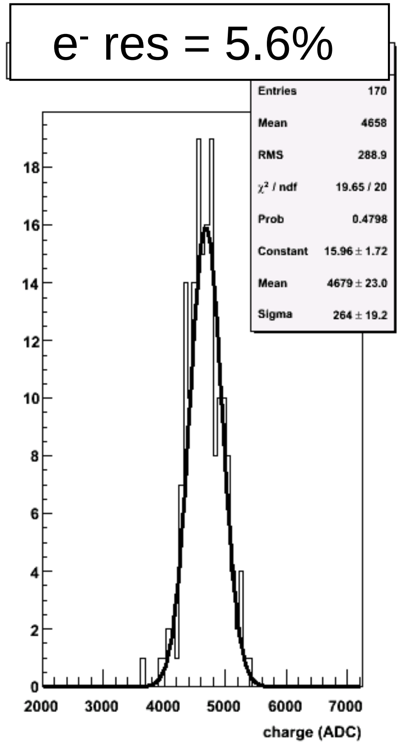
Res 1st MM = 10.0% | Res 2nd MM = 9.4% | Res all TPC = 6.9%

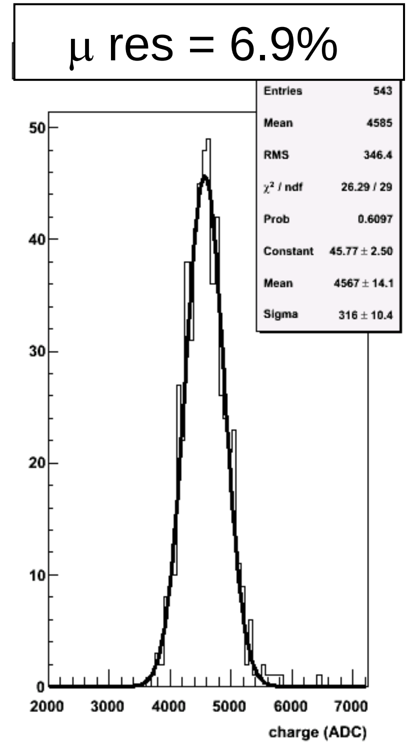


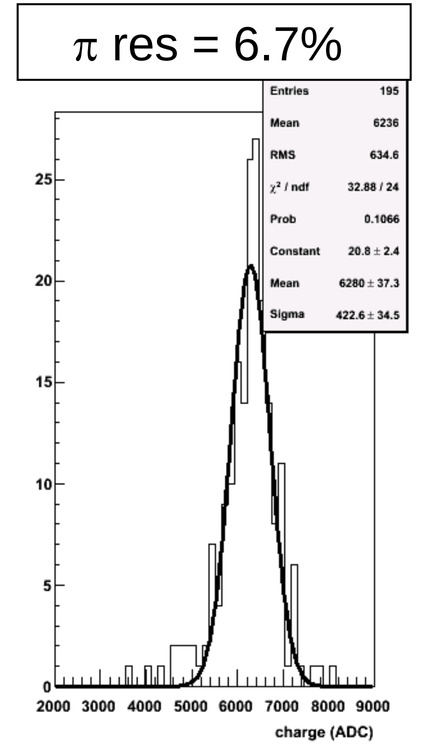
Resolution for different particles

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





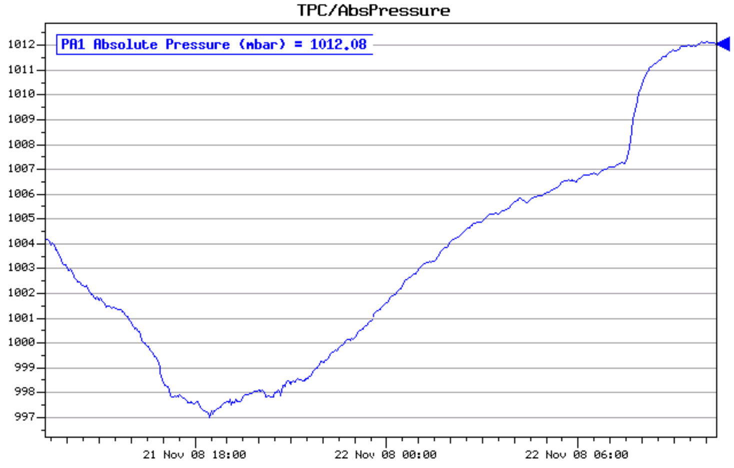


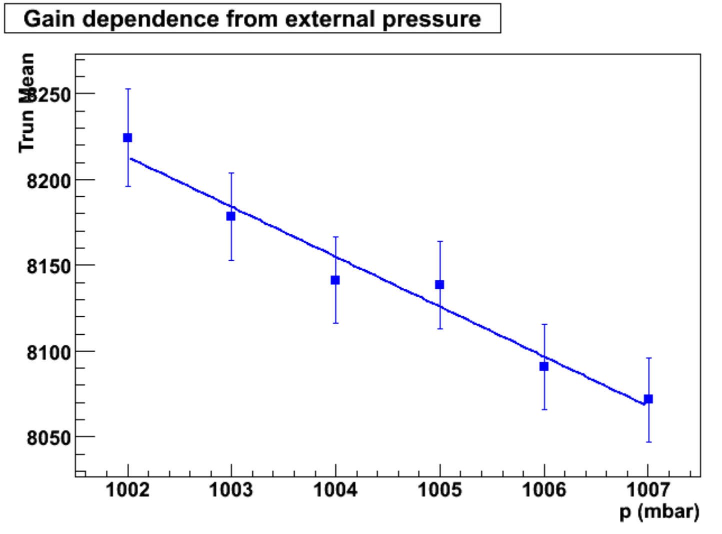


- At 150 MeV/c we can clearly see 3 different peaks

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

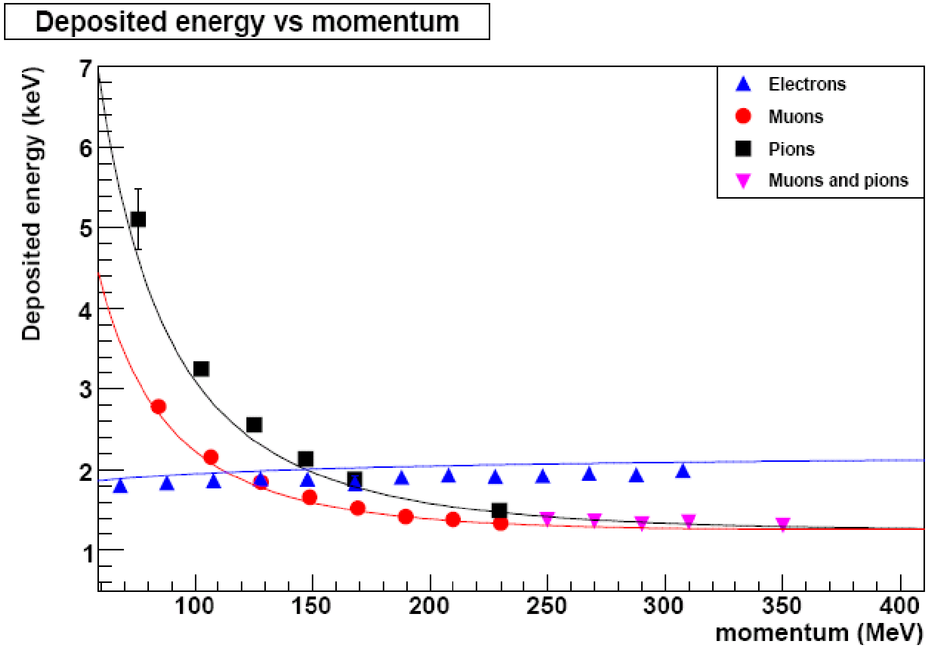




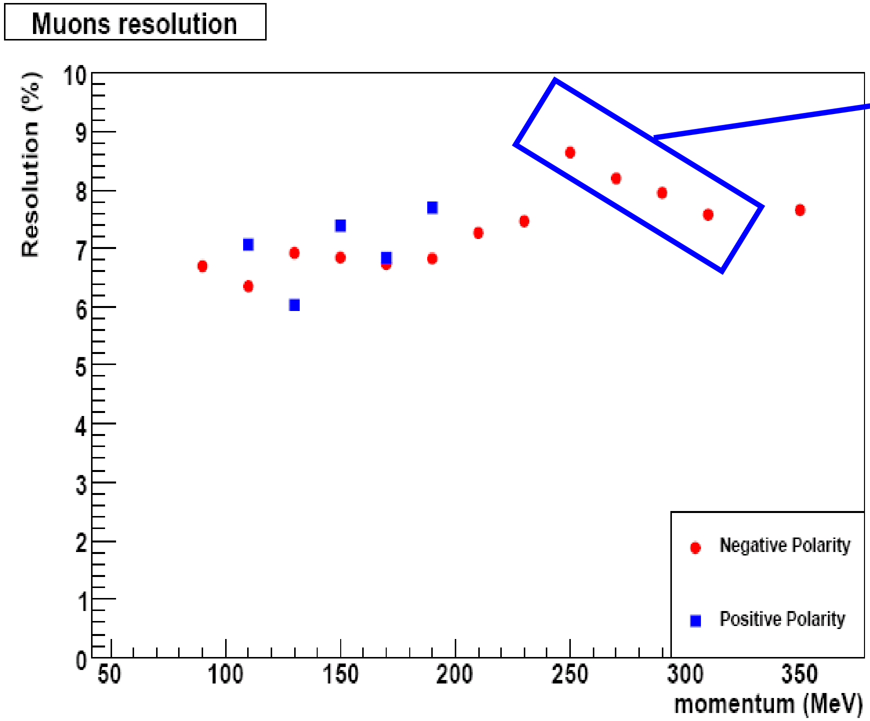
- $\Delta g = 3.3 \pm 0.6$ % for $\Delta p = 1\%$
- During previous MicroMegas test, with a ^{55}Fe source, we found $\Delta g = 3.1 \pm 0.3$ % for $\Delta p = 1\%$

Energy loss vs momentum

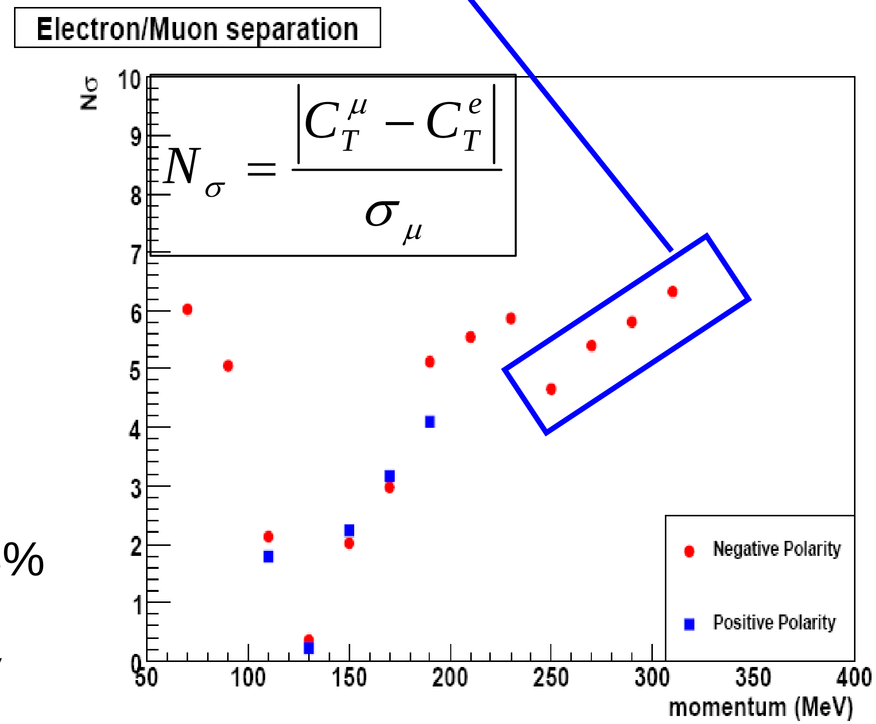
- Selecting particle with the TOF we computed the C_T
- Compared the obtained curve for μ, π and e with the expected one from the MC studies →good agreement



e/μ separation



The TOF cannot distinguish muons from pions



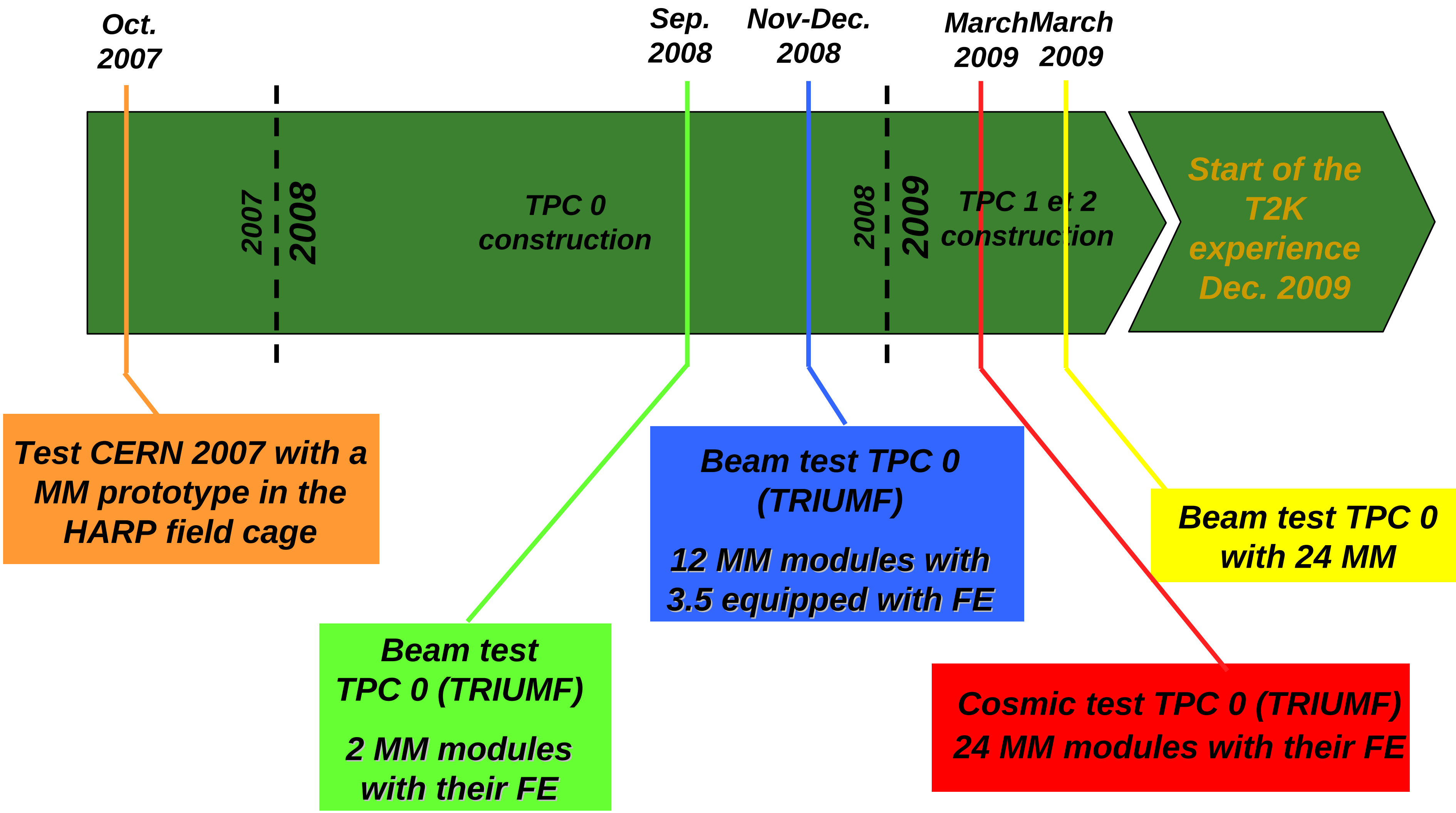
- Resolution for muons better than 8%
- Separation larger than 5σ if the momentum is larger than 200 MeV

Conclusions

- We developed methods to perform the PID in the TPC and we tested them with the data taken in the beam test
  - The method is based on measuring the truncated mean for each track
  - It allows to recognize different particles according to their energy loss
  - Energy resolution for muons better than 8% in both, data and MC
  - e/μ separation better than 5σ if the momentum is larger than 200 MeV
  - This will allow to measure the ν_e contamination in the T2K beam
- The T2K TPCs are under construction at TRIUMF
  - The Module 0 is ready, fully equipped and is taking data in a beam test, the others 2 modules will come soon
  - With the data taken in the Module 0 beam test we successfully tested the PID method
  - The TPCs will be installed in the summer/fall 2009T2K will start the data taking in December 2009

Back up slides

History of tests



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