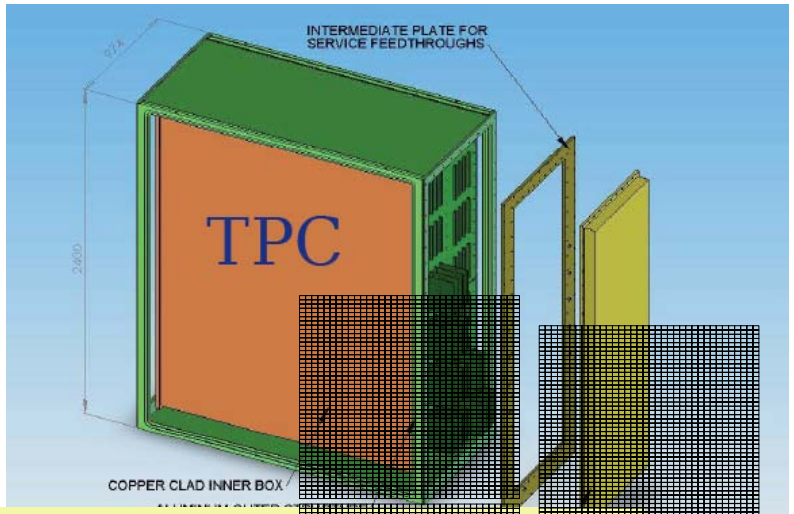
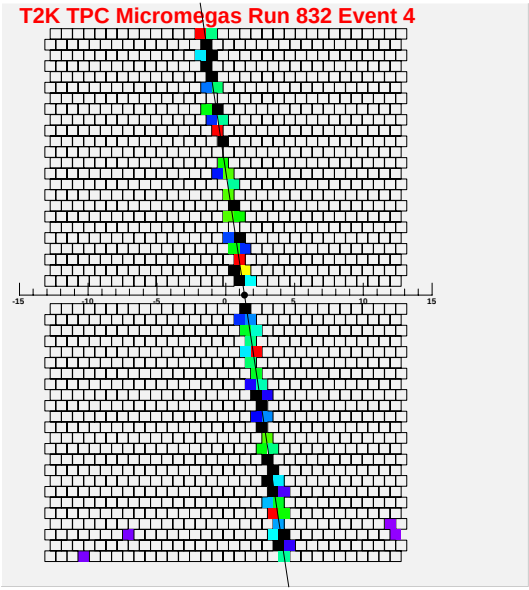


Track reconstruction for a T2K TPC prototype



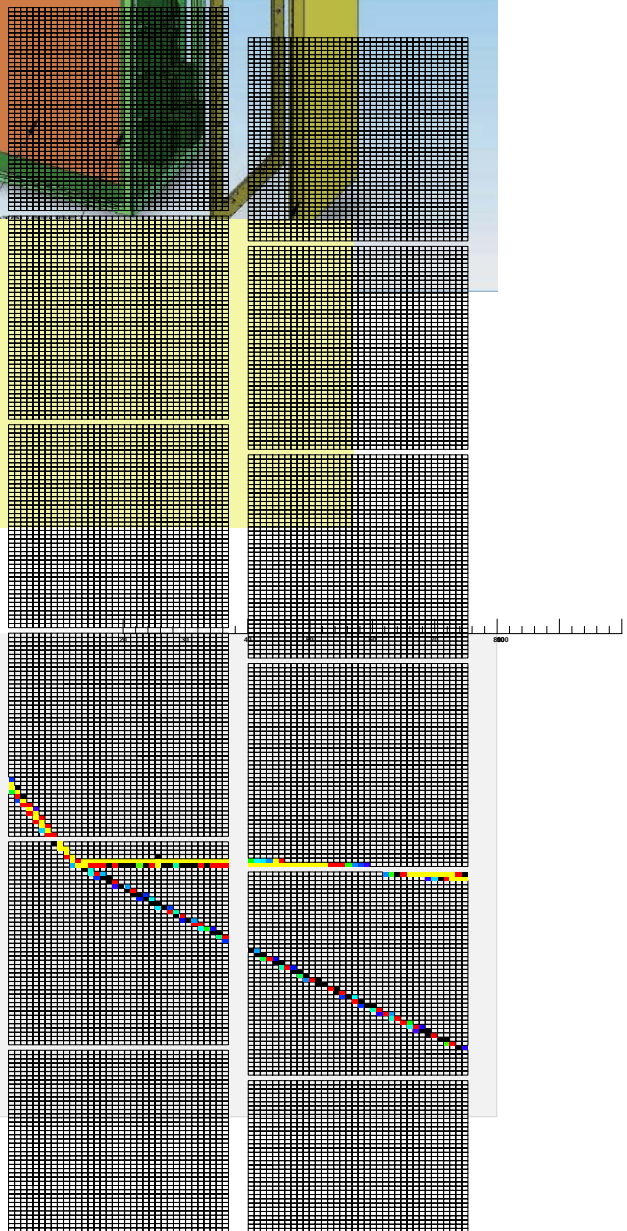
Marco Zito

Dapnia-SPP (>Saclay)

TPC Jamboree

Aachen, March 15 2007

- The T2K projet and the 280m detector
- The TPC
  - Physics requirements
  - Detector
  - Track reconstruction
  - dE/dx



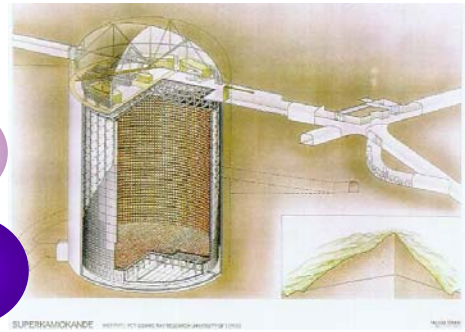
Next Step (2009 -)

ν_e ν_μ ν_τ

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{MNS}\, V_M^{CP} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij}$$
$$s_{ij} = \sin\theta_{ij}$$

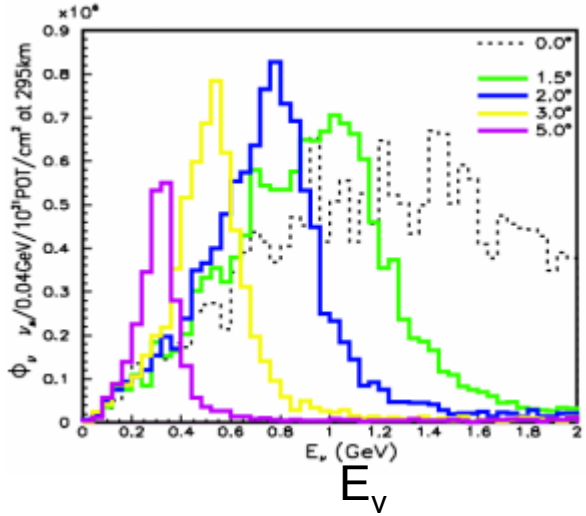
ν_1 ν_2 ν_3



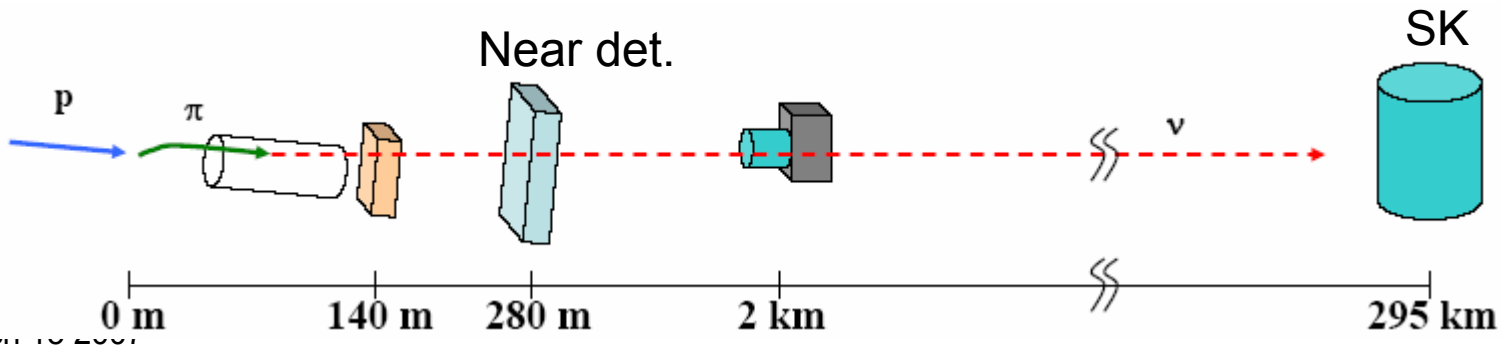
$$U_{MNS} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{atmospheric}} \times \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix}}_{\text{Cross Mixing}} \times \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{solar}}$$

- Discover the last oscillation channel
  - θ_{13}
- CP violation in the lepton sector (ν, $\bar{\nu}$) $\longrightarrow$ Leptogenèse
  - δ (or a new source of CPV)
- Mass hierarchy
  - The sign of Δm_{23}^2 ($m_3 > m_1$ or $m_3 < m_1$)
- Test of the standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations ($\pm\Delta m_{23}^2$, θ_{23})

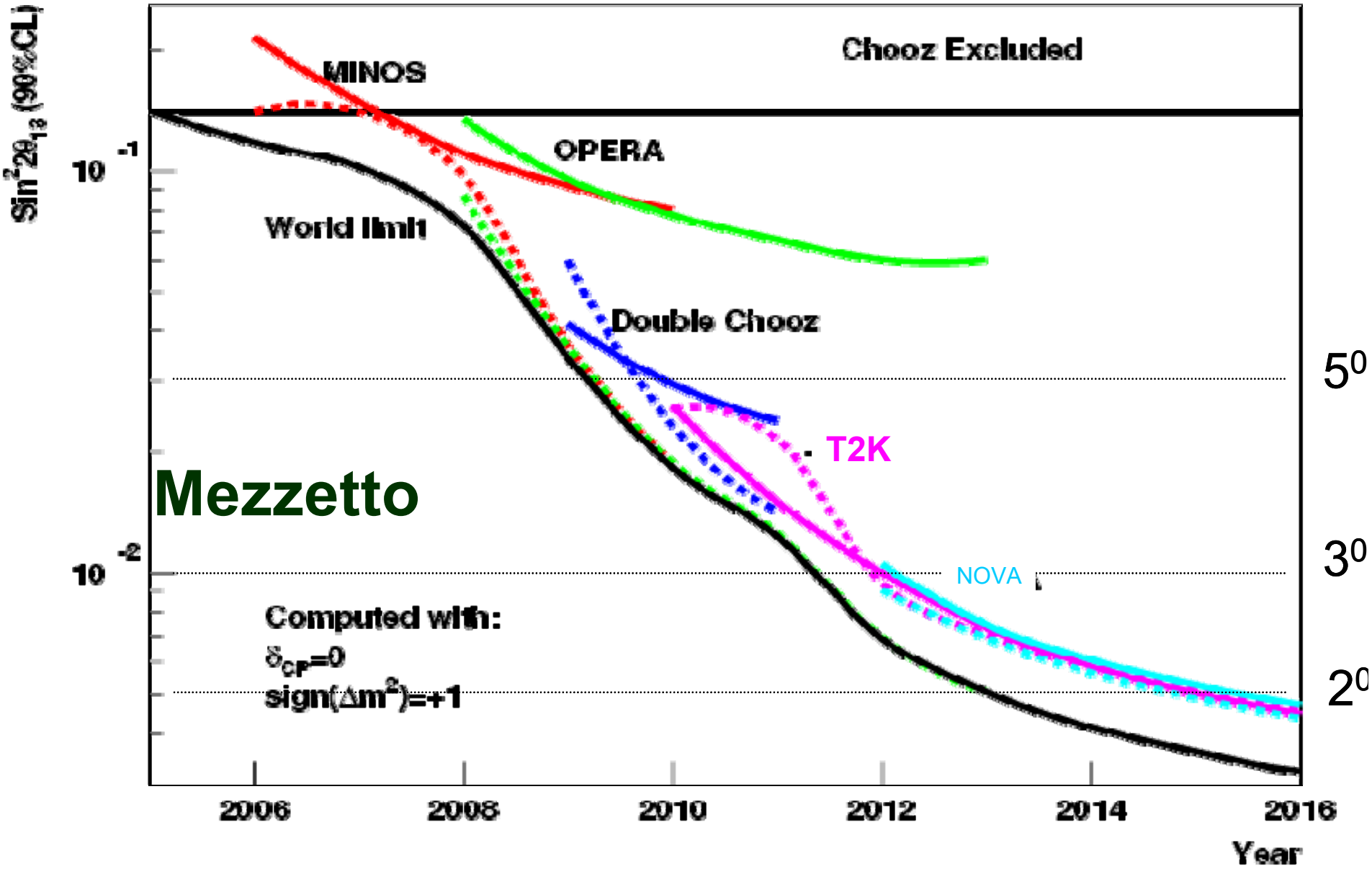
The Tokai to Kamioka (T2K) project



Long baseline neutrino oscillation experiment with an intense (0.75 MW) beam
Off-axis by 2.5° -> E_ν peaks at 0.75 GeV

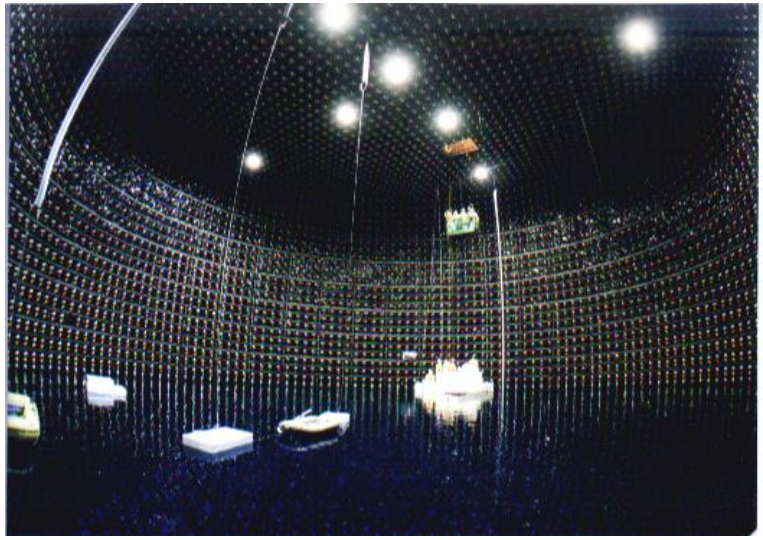


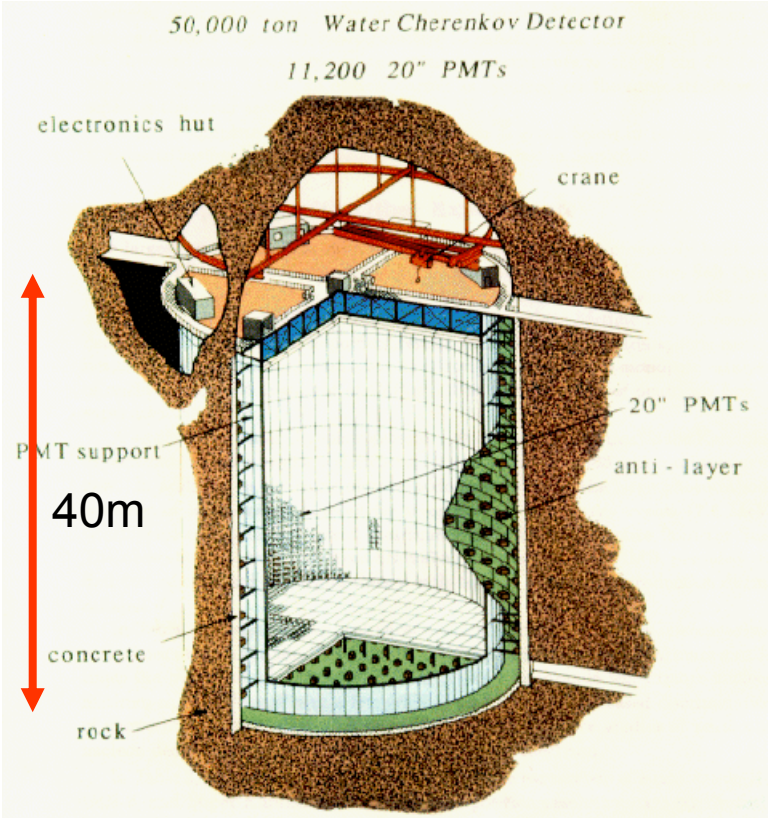
Sensibilité à θ_{13}



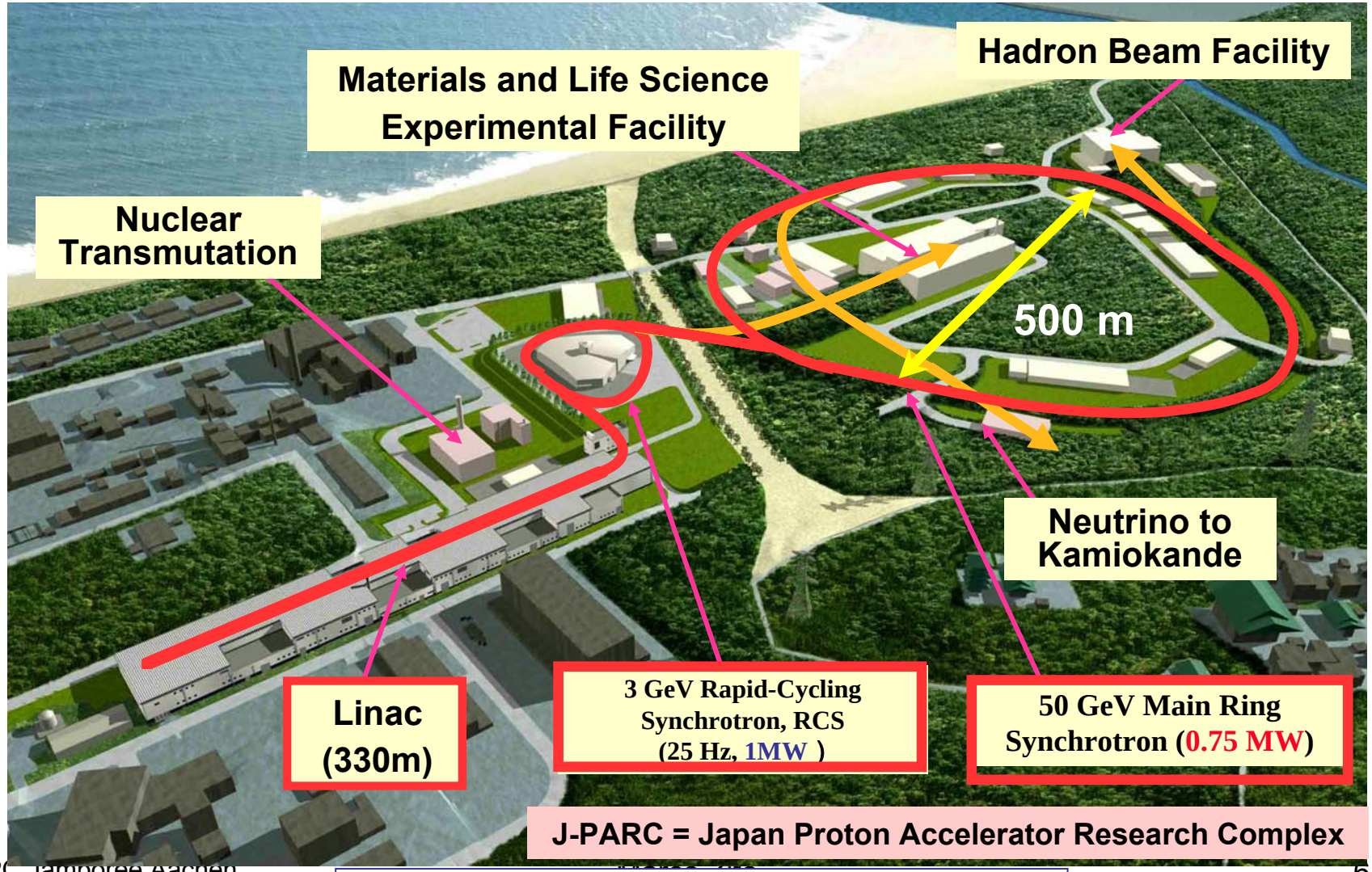
Scientific interest

- Precision measurement of the parameters θ_{23} et Δm^2_{23}
- Excellent sensitivity to θ_{13} : 10 x Chooz
- First step towards an experiment probing CP in the leptonic sector :
  - High intensity beam
  - Modern high performance near detector
  - Water Cherenkov technique (Mégatonne)



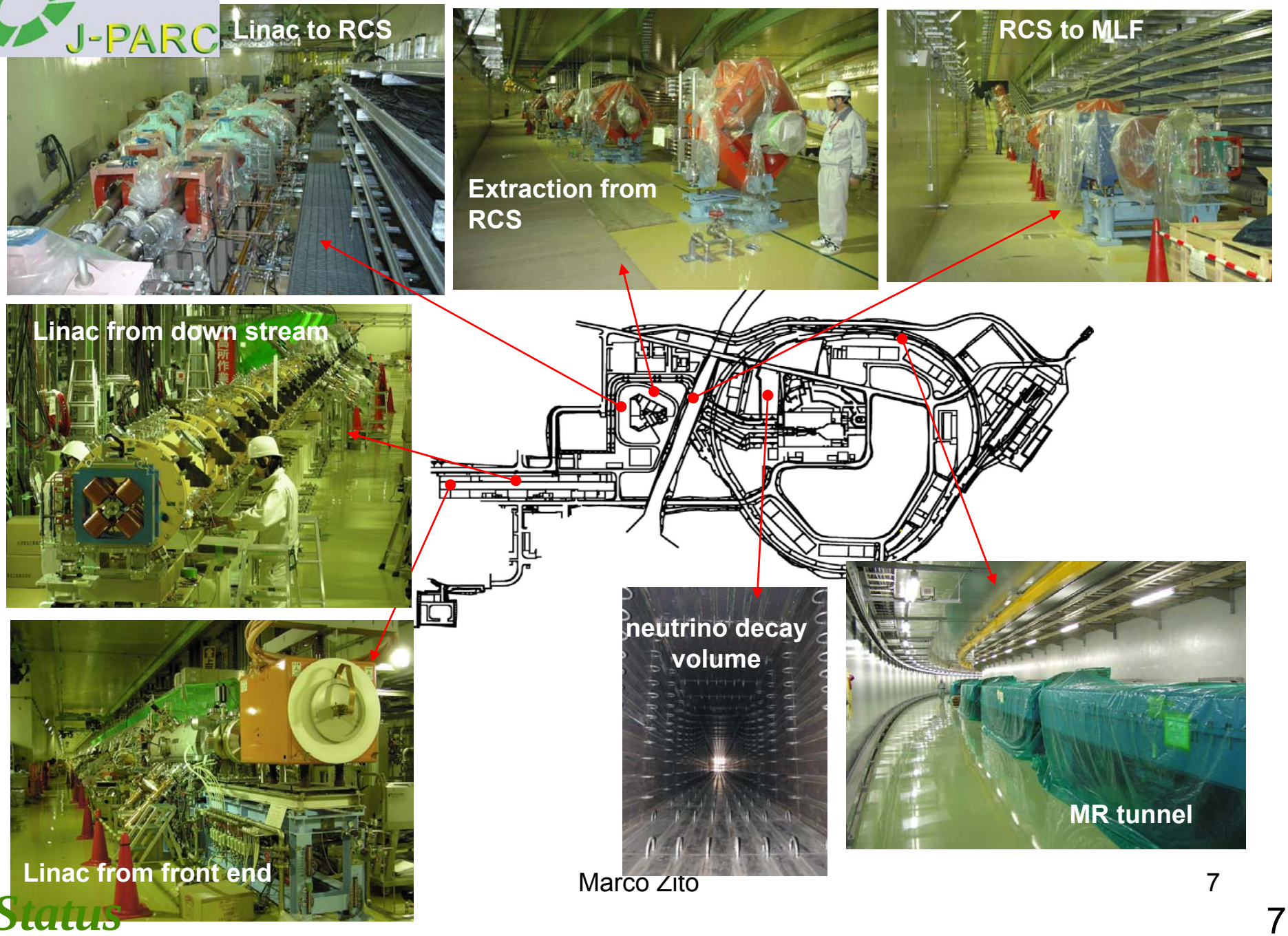


J-PARC Facility



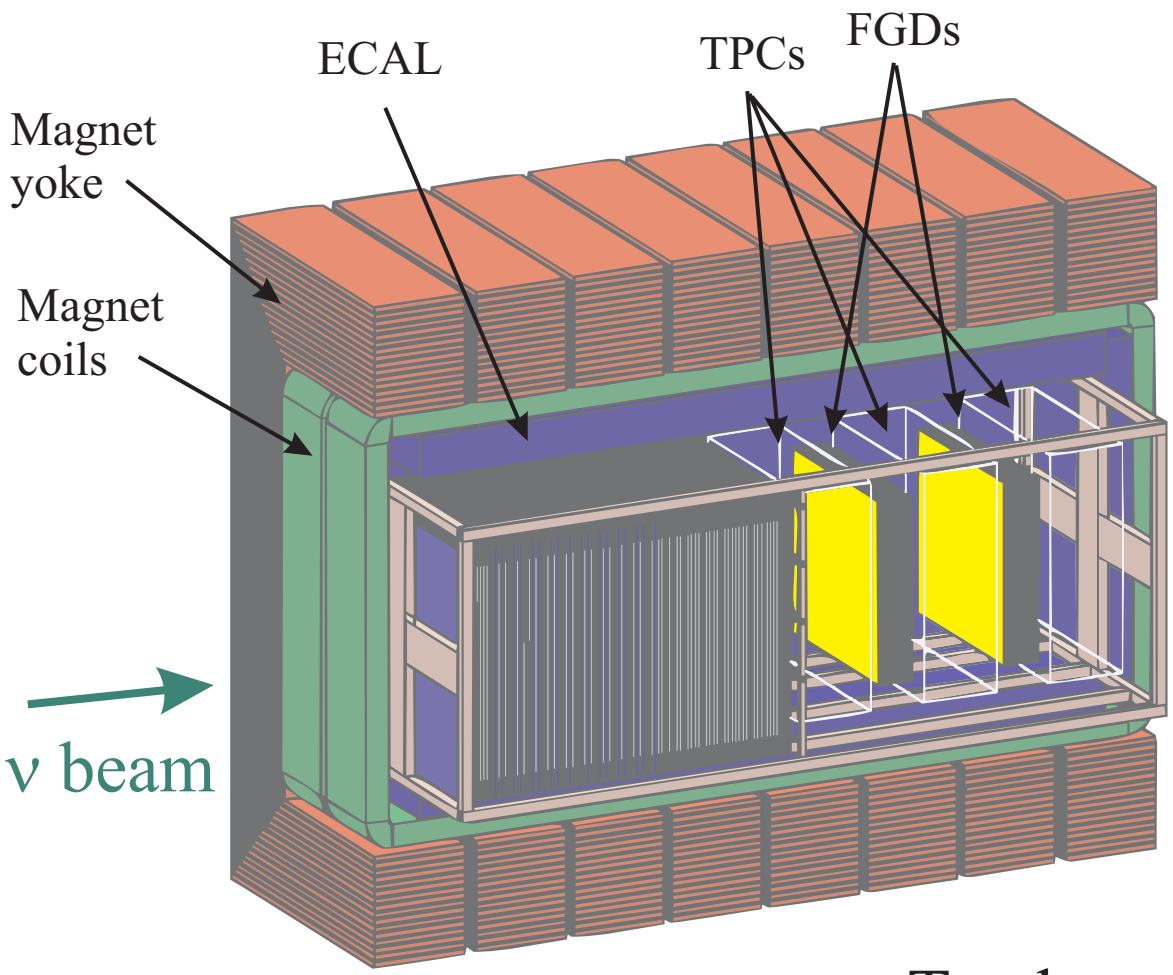
J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA


J-PARC
Linac to RCS
Extraction from RCS
RCS to MLF
Linac from down stream
neutrino decay volume
MR tunnel
Linac from front end

Status

The near detector at 280 m



Magnet: Europe
P0D : USA
ECAL: UK
FGD: Canada
TPC: Europe-Canada
SMRD: USA
INGRID: Japan-Corée-F

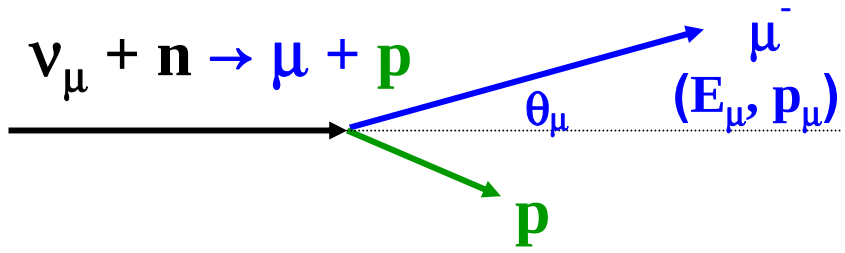
IN2P3contribution:
LPNHE,LLR

Pi-zero Detector

Tracker

T2K Neutrino Energy E_ν Reconstruction

CC quasi elastic (QE)



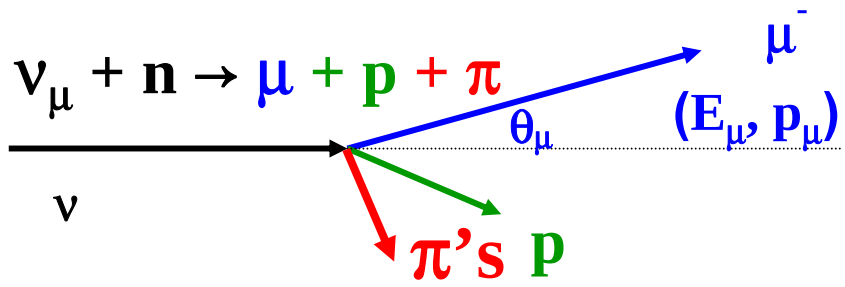
$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

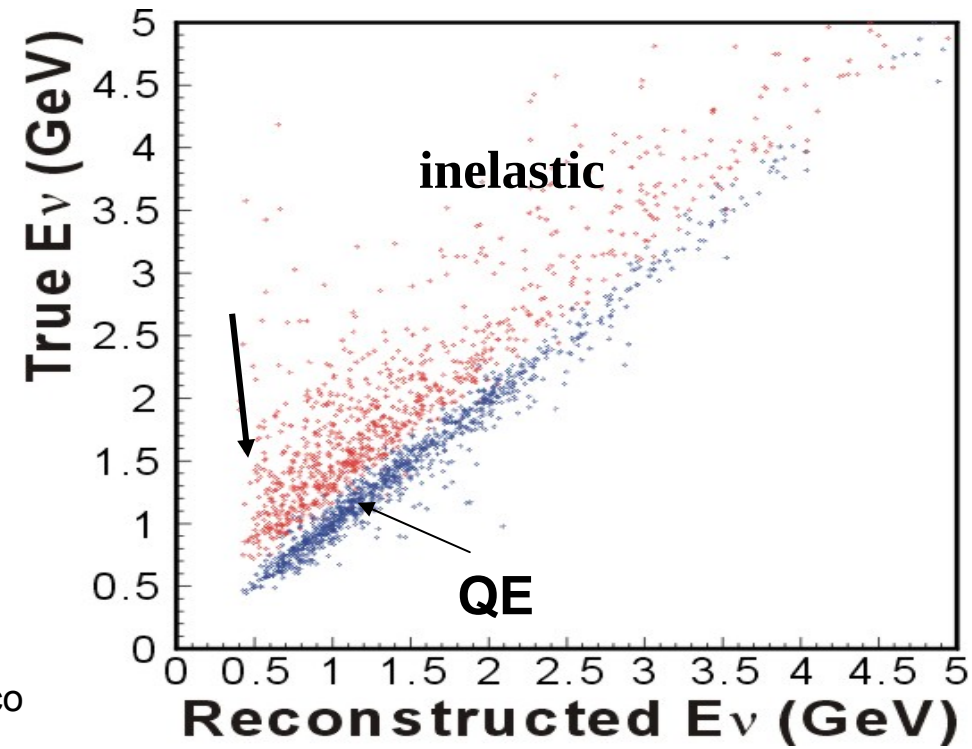
$$\text{Rate}(E\nu,\text{Near}) \rightarrow \underline{\phi(E\nu,\text{Near})}$$

$$\uparrow$$

$$\sigma(\text{QE}),\ \sigma(\text{nonQE})$$

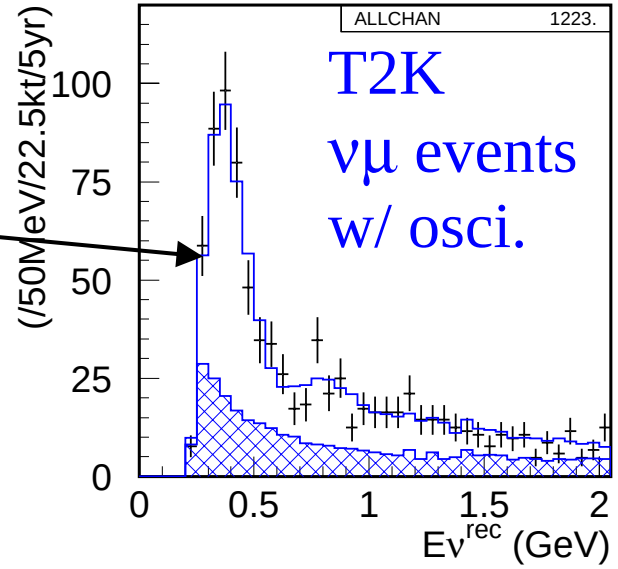
CC inelastic



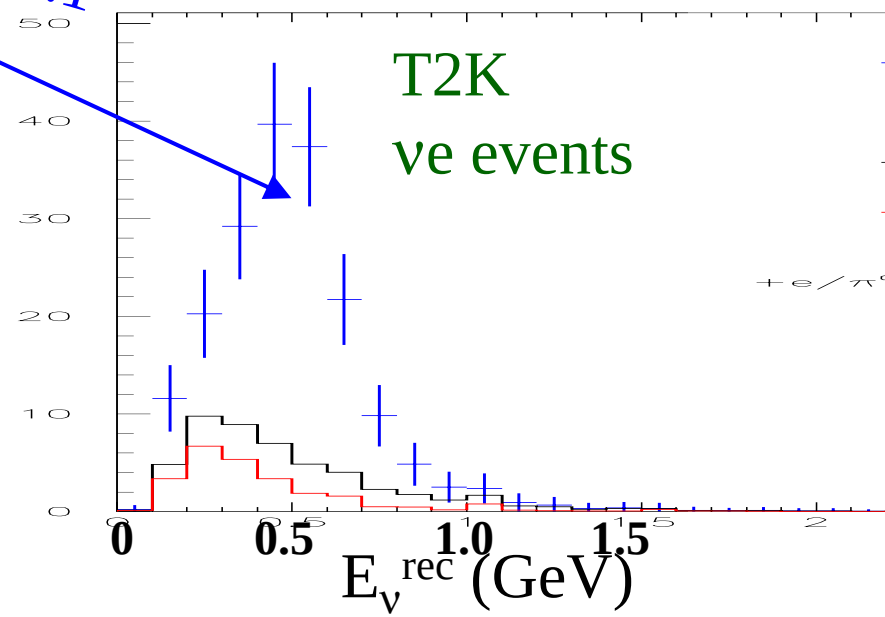


Impact of Neutrino Cross sections on oscillation measurements

- **$\nu_\mu \rightarrow \nu_\mu$: precision measurements (θ_{23} and Δm_{23}^2)**
  - Signal: CC-QE ($\nu + n \rightarrow \mu + p$)
    - Energy Reconstruction from μ kinematics
  - Background: Mainly CC-1$\pi^\pm$ ($\nu + N \rightarrow \mu + \pi + N'$)
- **$\nu_\mu \rightarrow \nu_e$: search for θ_{13}**
  - Signal: CC-QE ($\nu + n \rightarrow e + p$)
  - Background
    - Beam ν_e
    - NCπ^0
      - Cross section as a function of the momentum

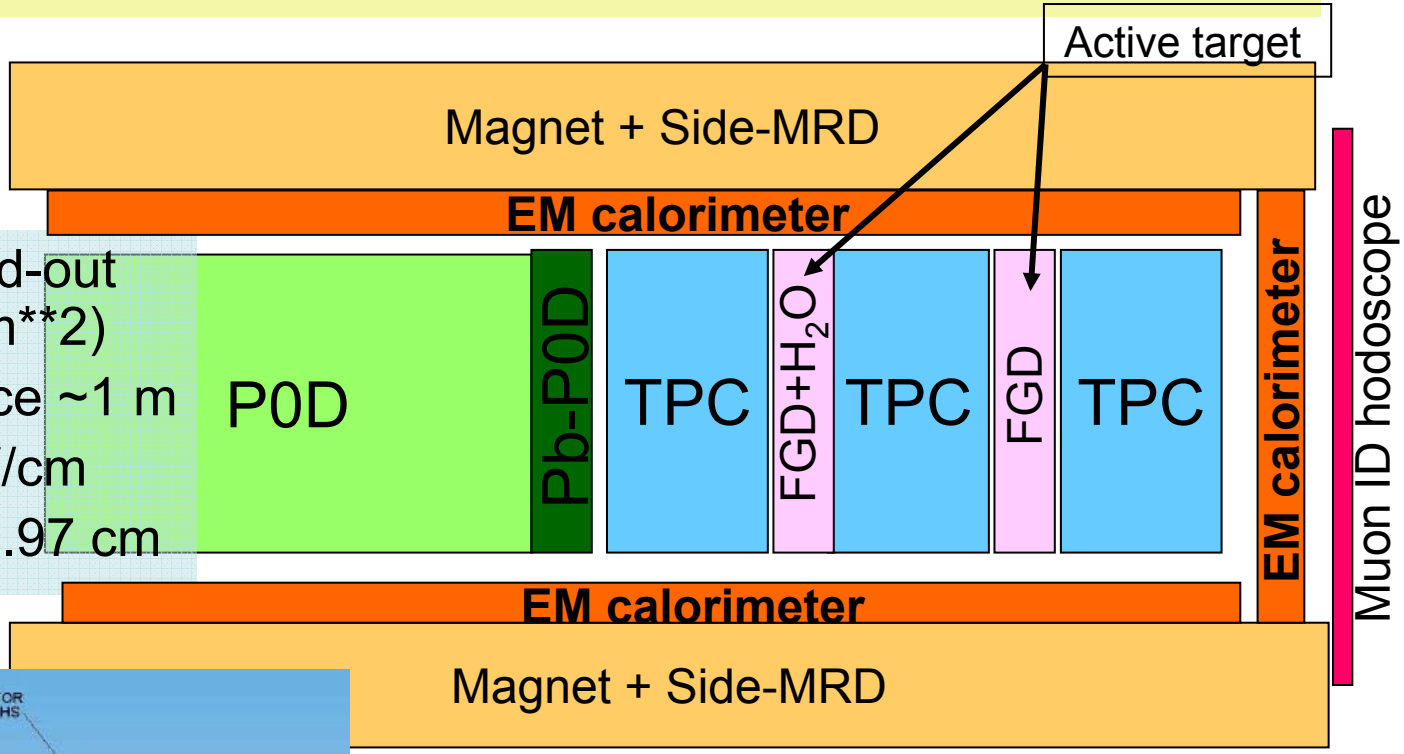


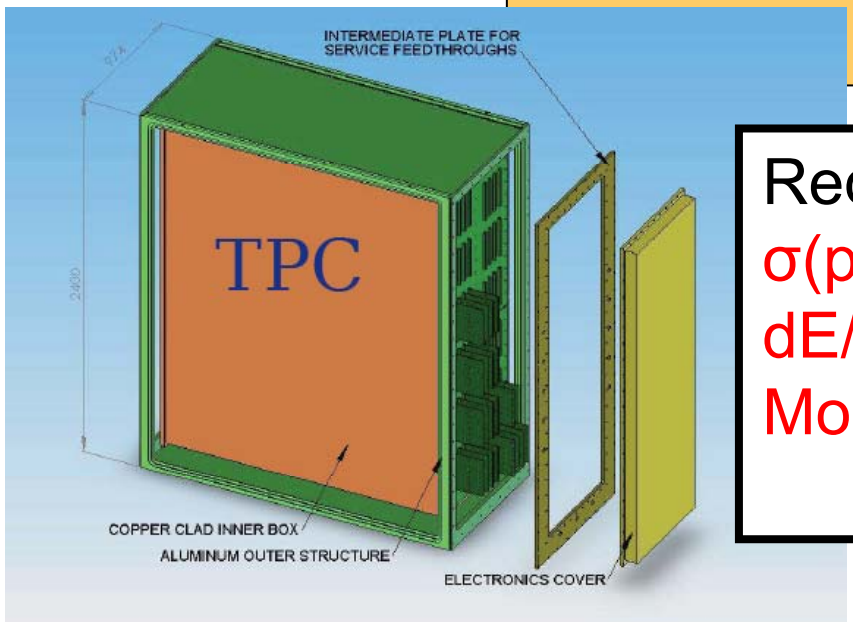
$\sin^2 2\theta_{13} = 0.1$



The T2K 280m TPC

- Instrument 6 read-out planes (~0.7x2 m**2)
- Total drift distance ~1 m
- B=0.2 T E=200V/cm
- Pad size: 0.69x0.97 cm





Requirements :

σ(p)/p < 10 % @ 1 GeV/c

dE/dx capability(10%) separate e from μ

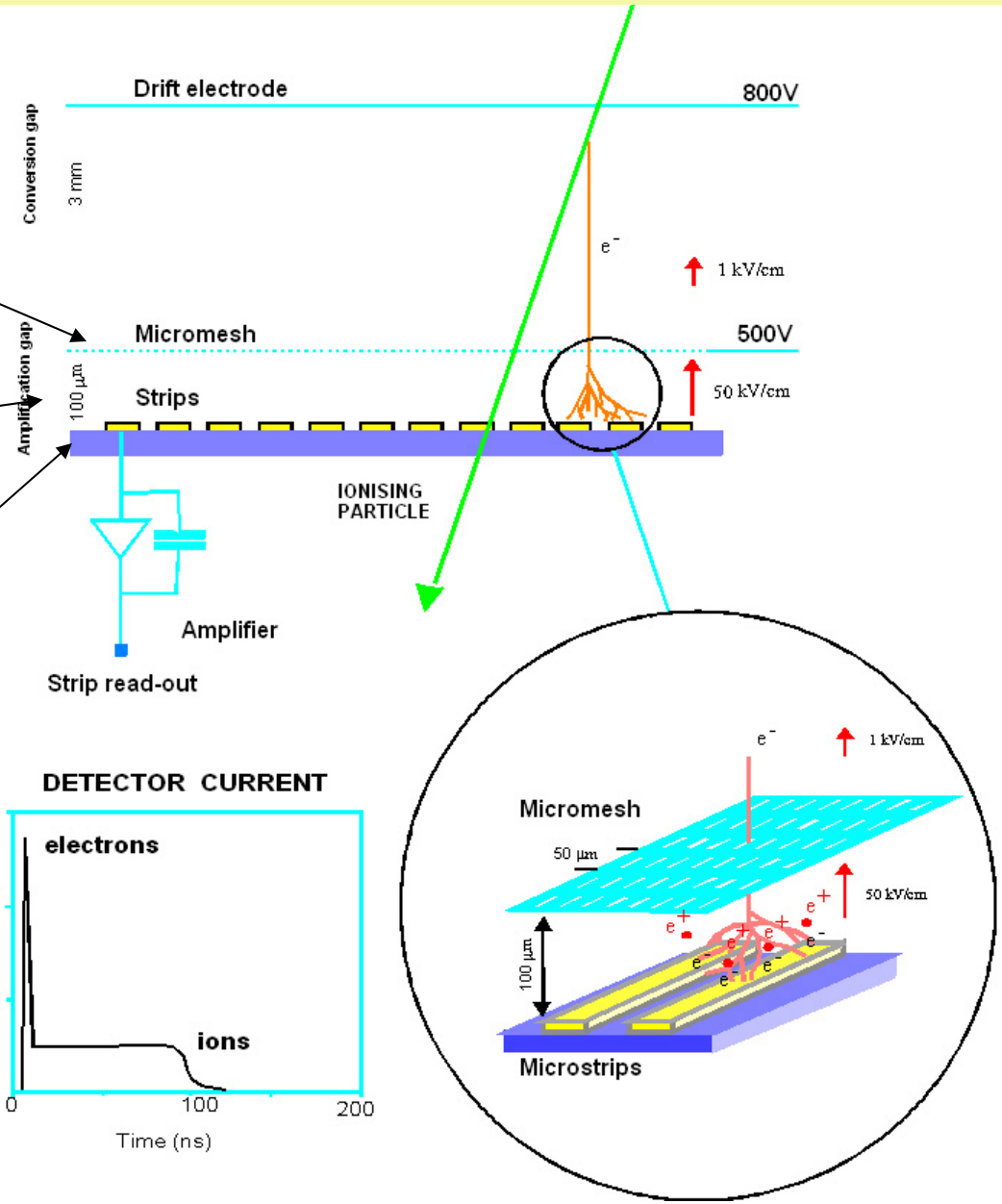
Momentum scale: 2 %

Micromegas concept

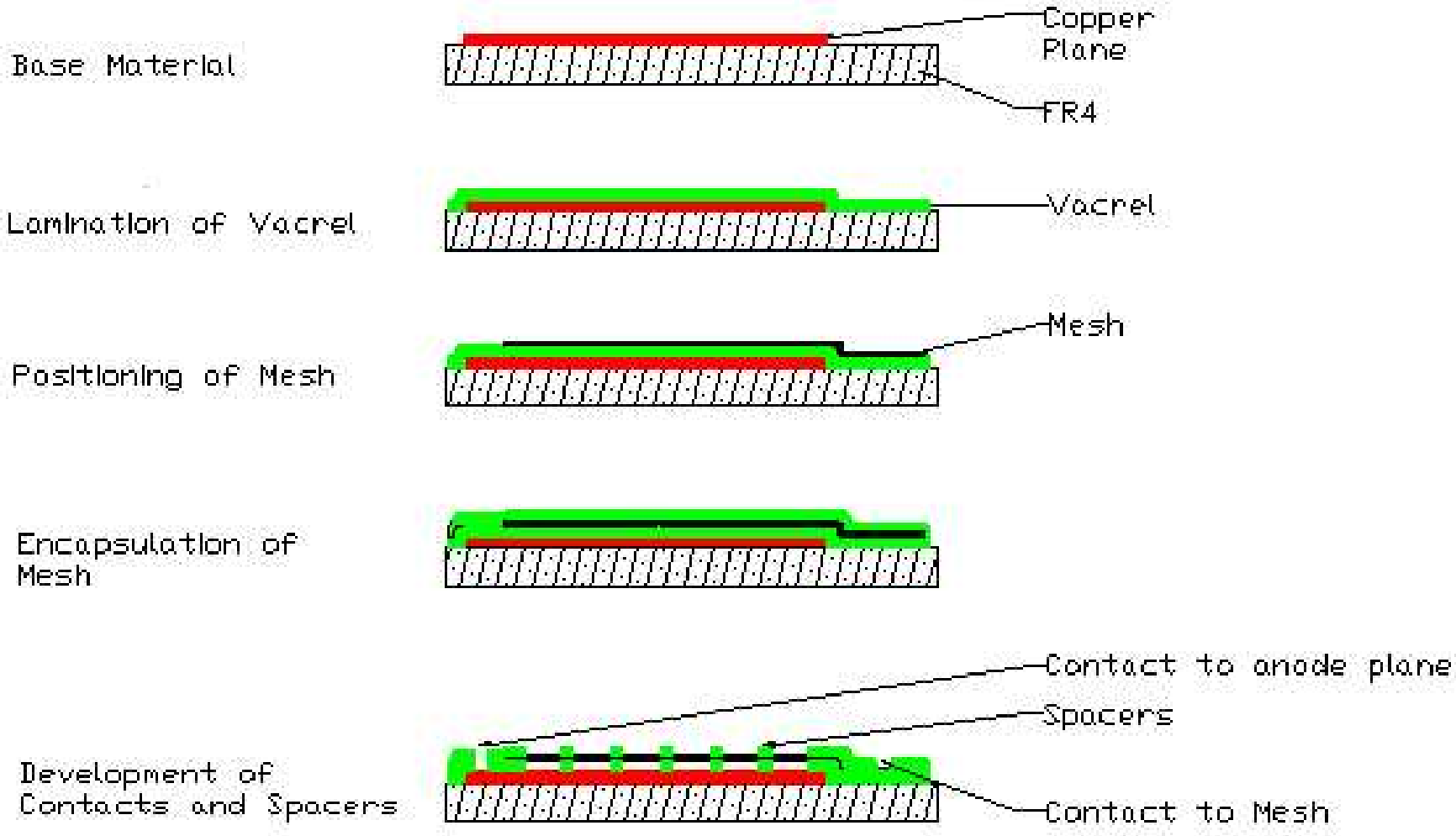
Micromesh

Amplification region: 100µm, 40-70kV/cm

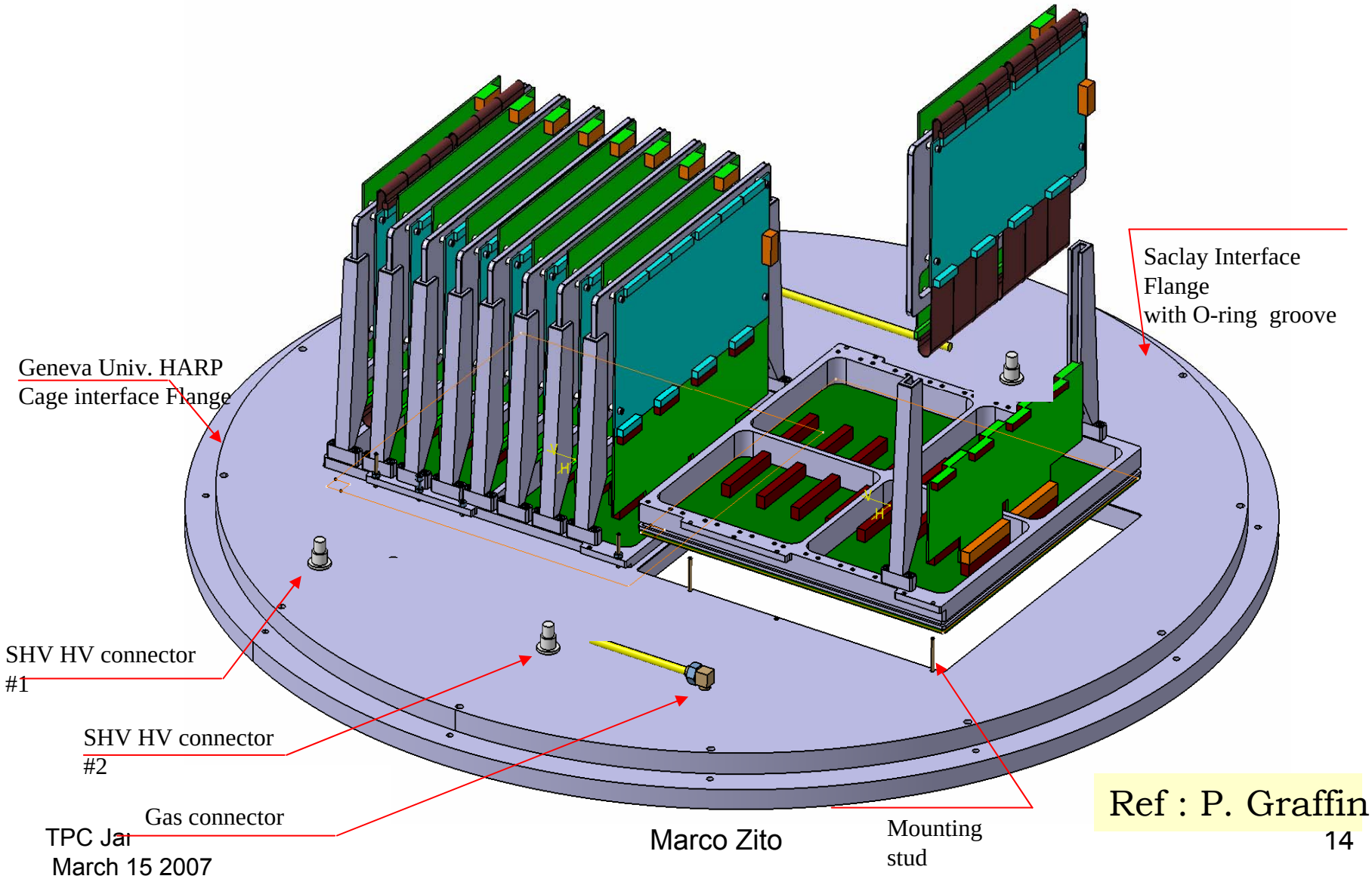
Anode : strips, pads



Bulk Micromegas

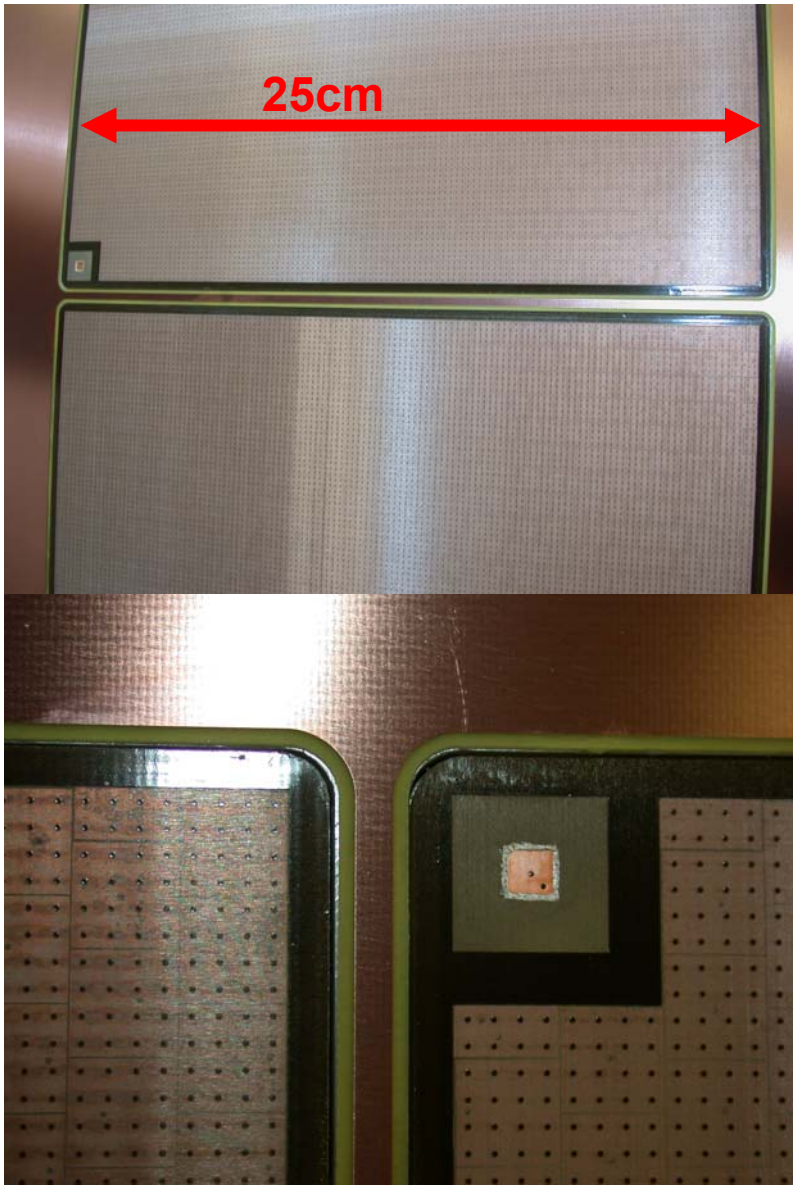


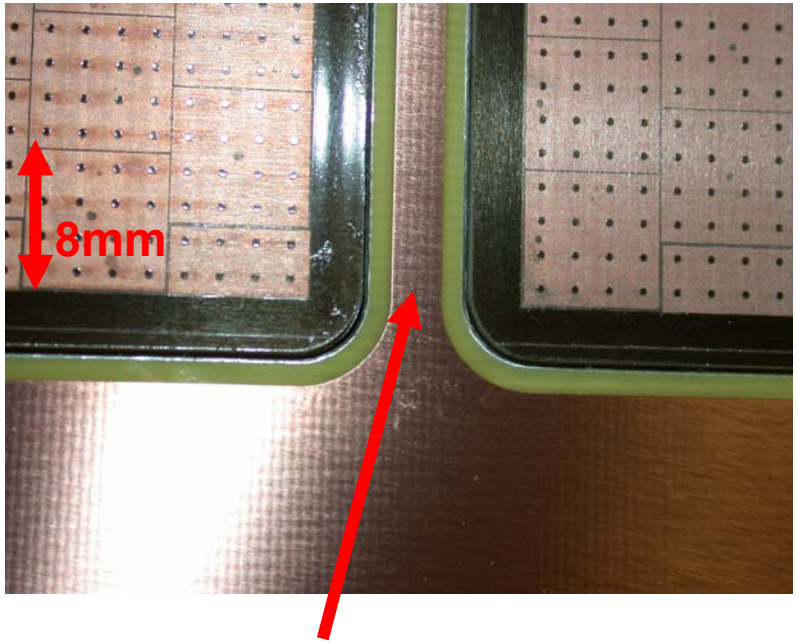
Two Micromegas on the Saclay flange



Ref : P. Graffin

Close-up of the two MM modules



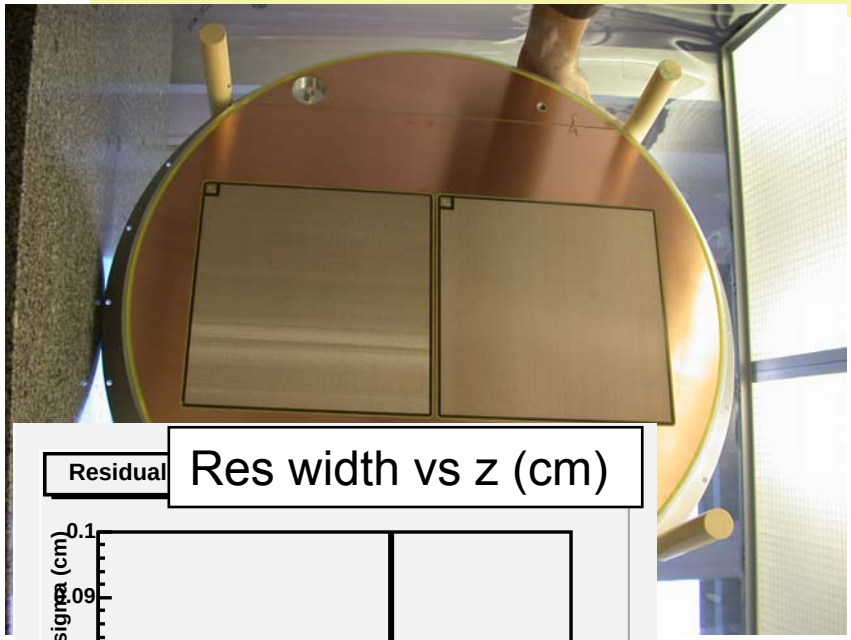


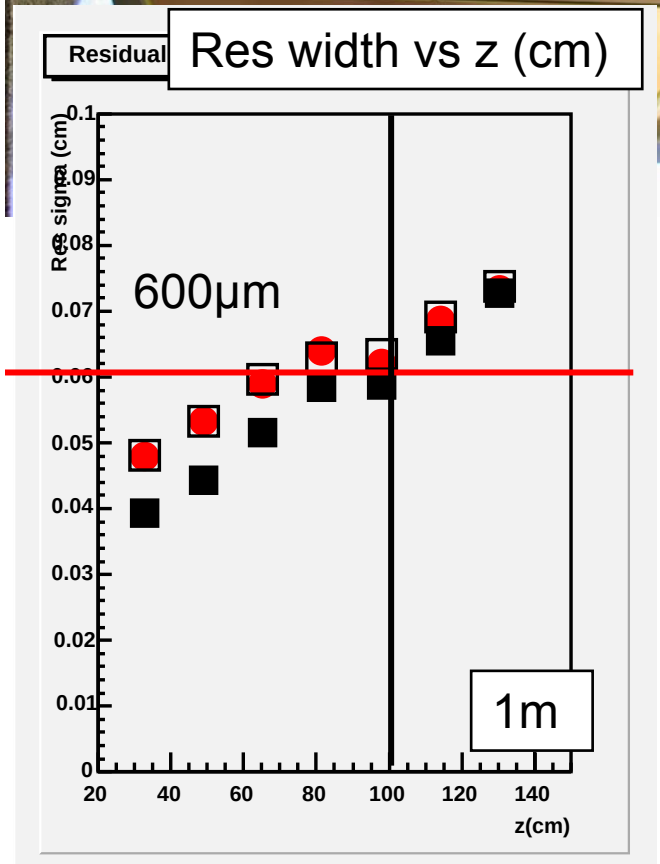
12mm dead region

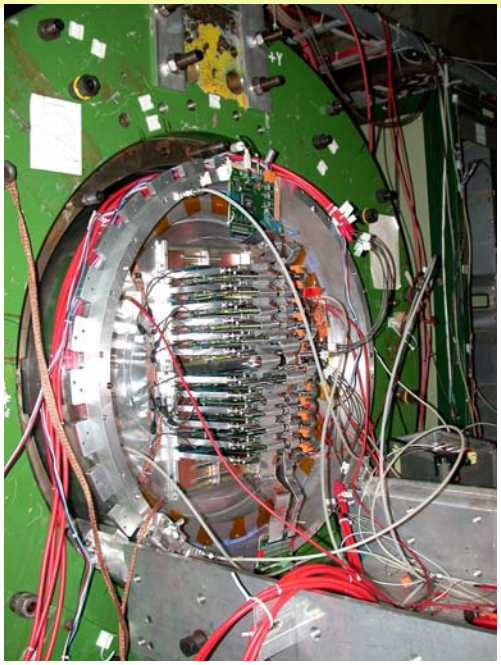
Compact, flexible and modular solution

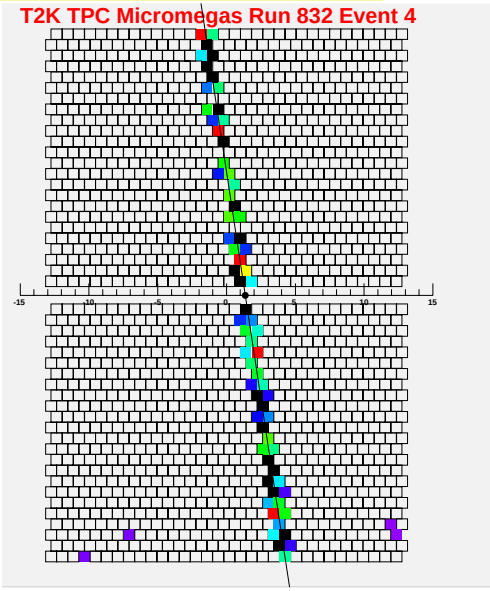
NB : for the prototype square pads 8x8mm**2

The Micromegas prototype : test at CERN



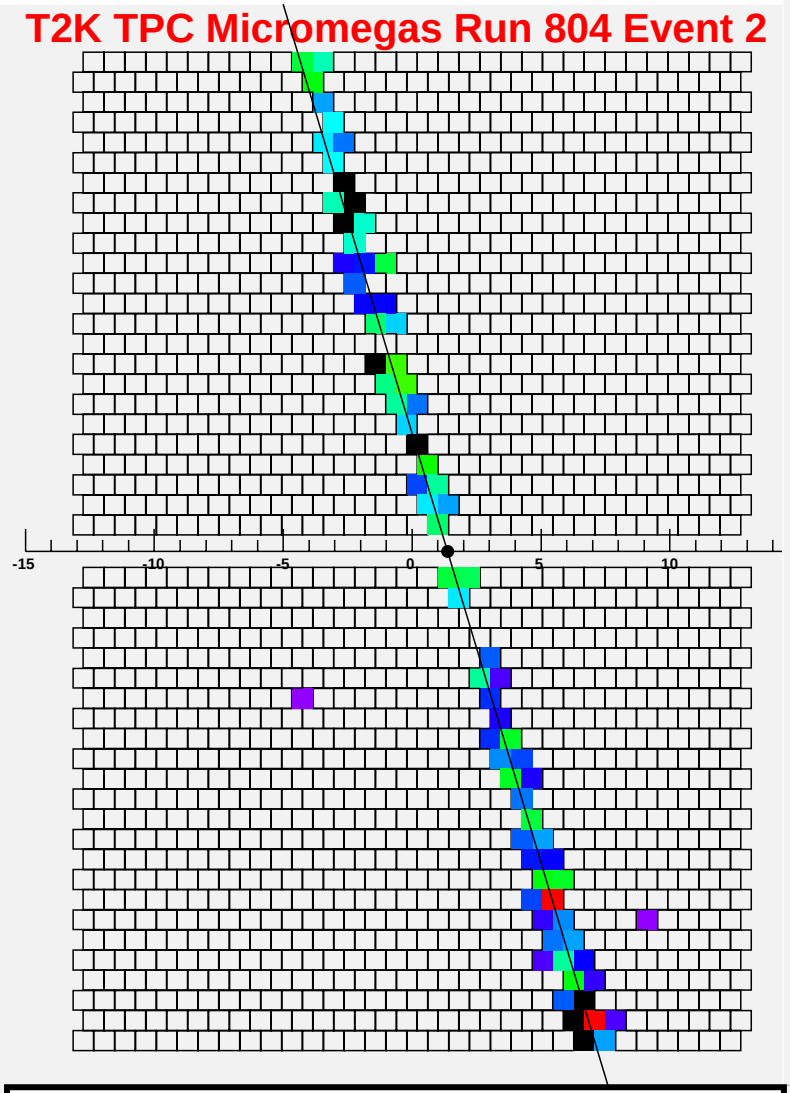


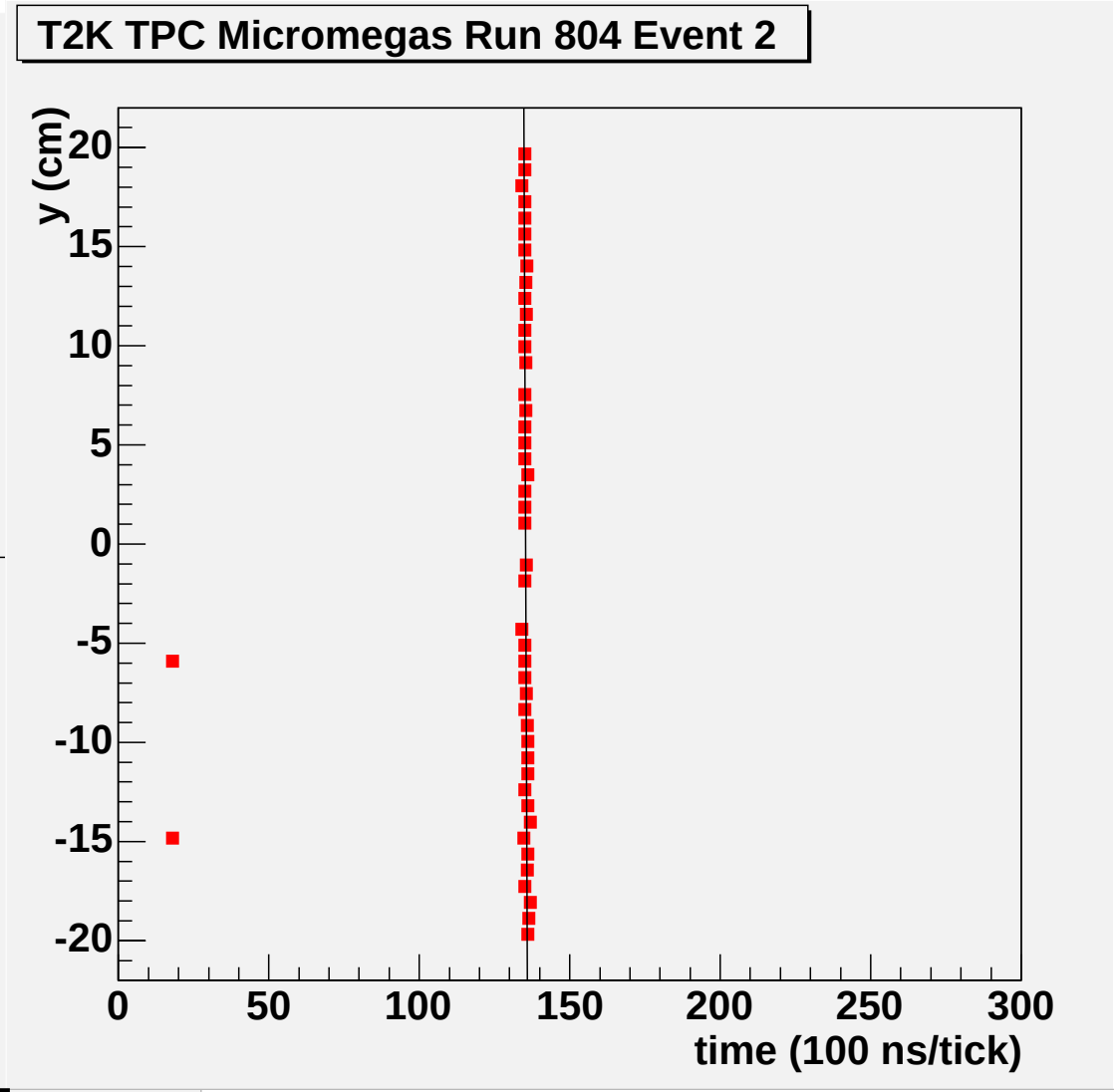




- Feasibility of large bulk detectors (25x25 cm**2)
- Innovative solution for instrumenting a large surface
- Validating the detector performances
- NIM article(Dapnia 07-02) accepted

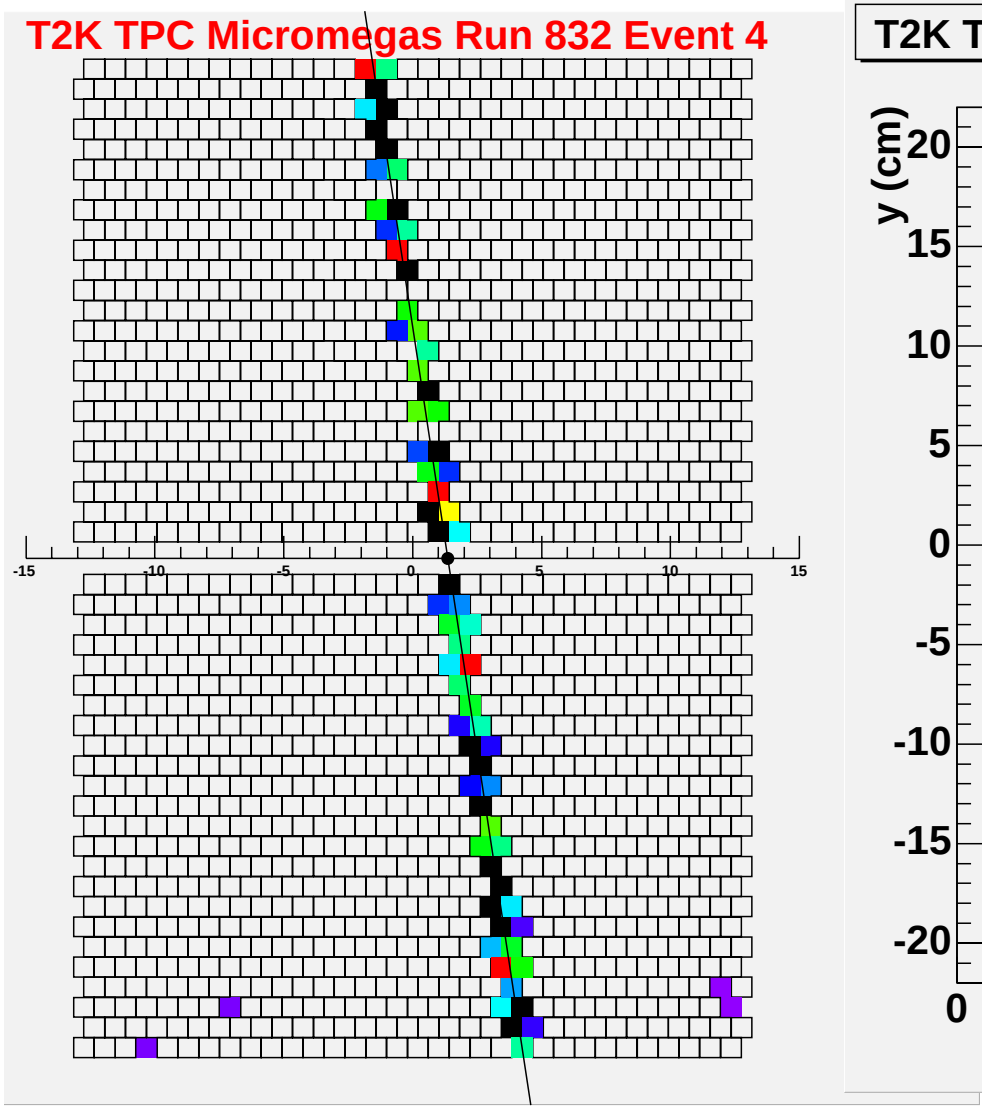
Cosmic track display-B=0

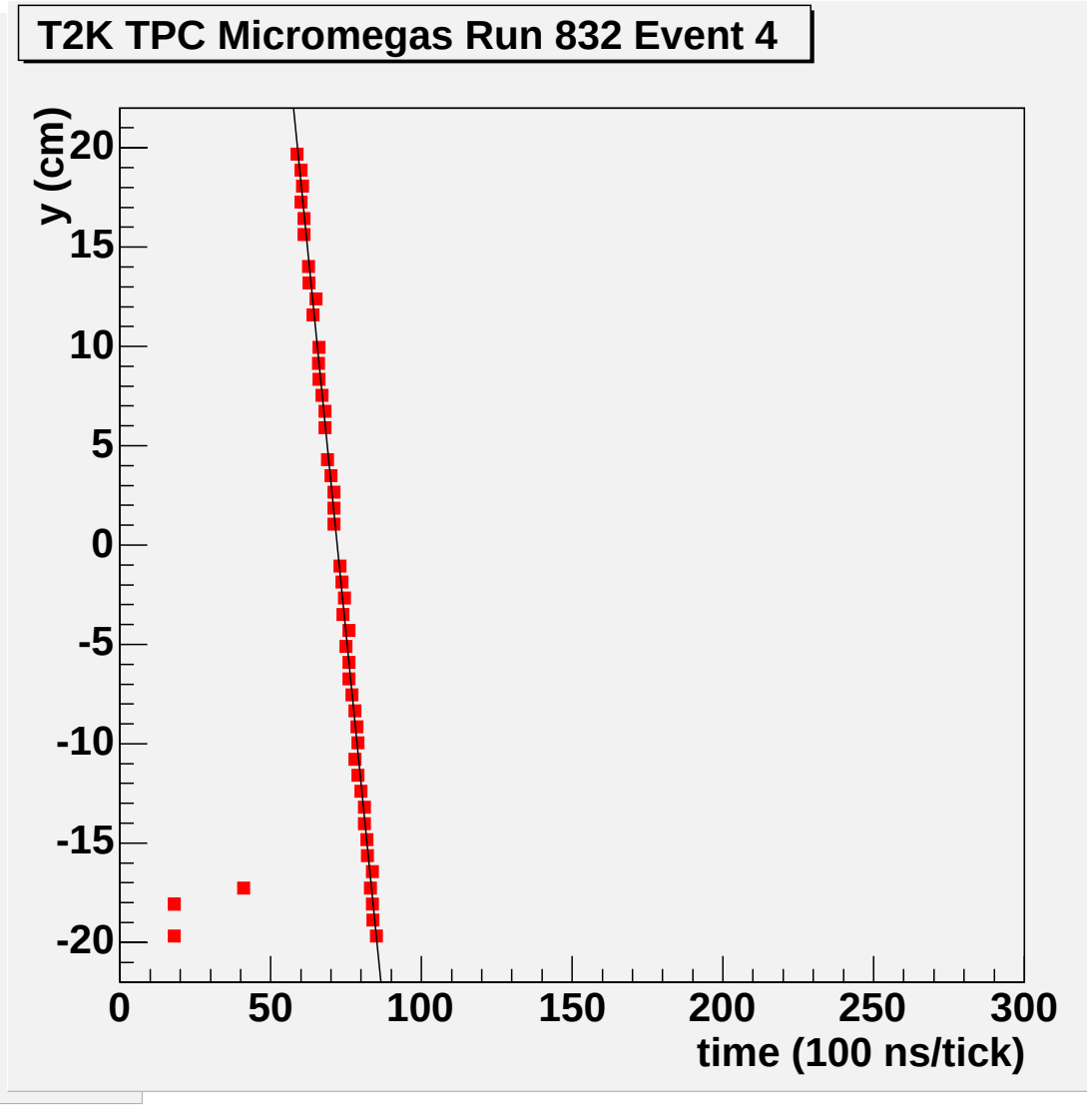




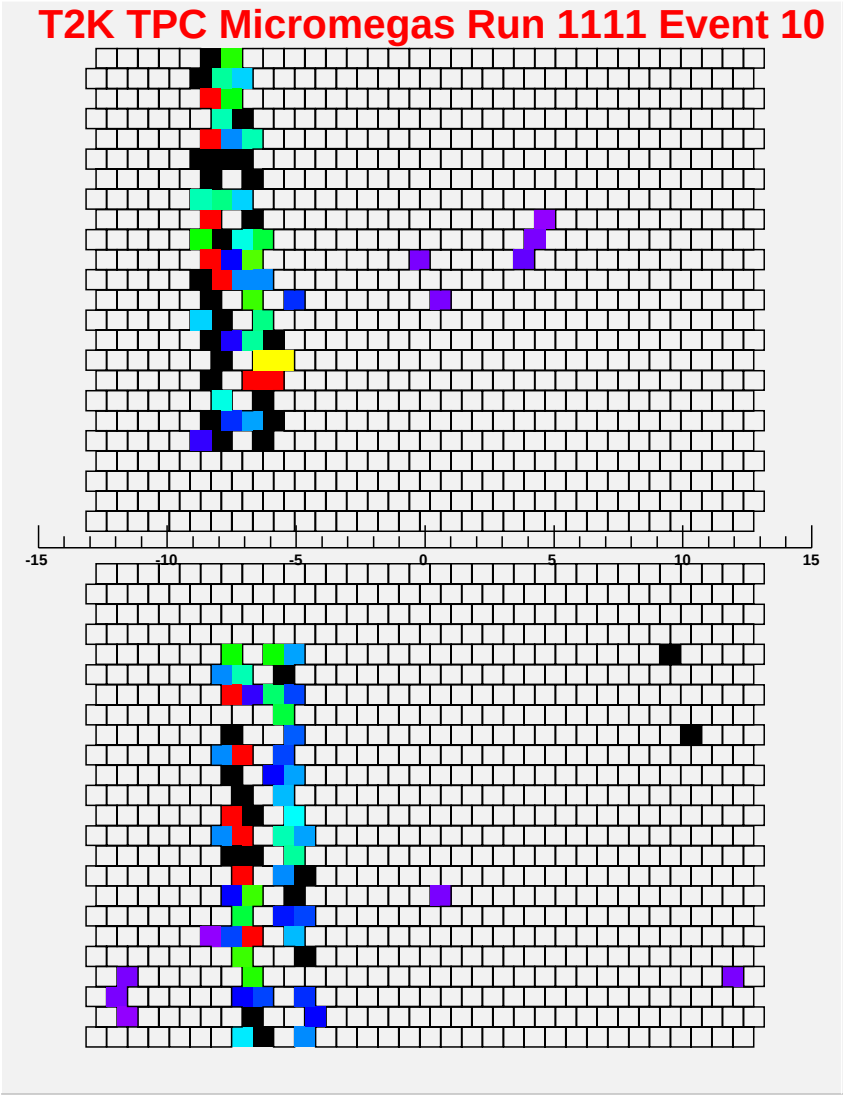
Shades of blue to green <150ADC
Black > 150, red>200 ADC

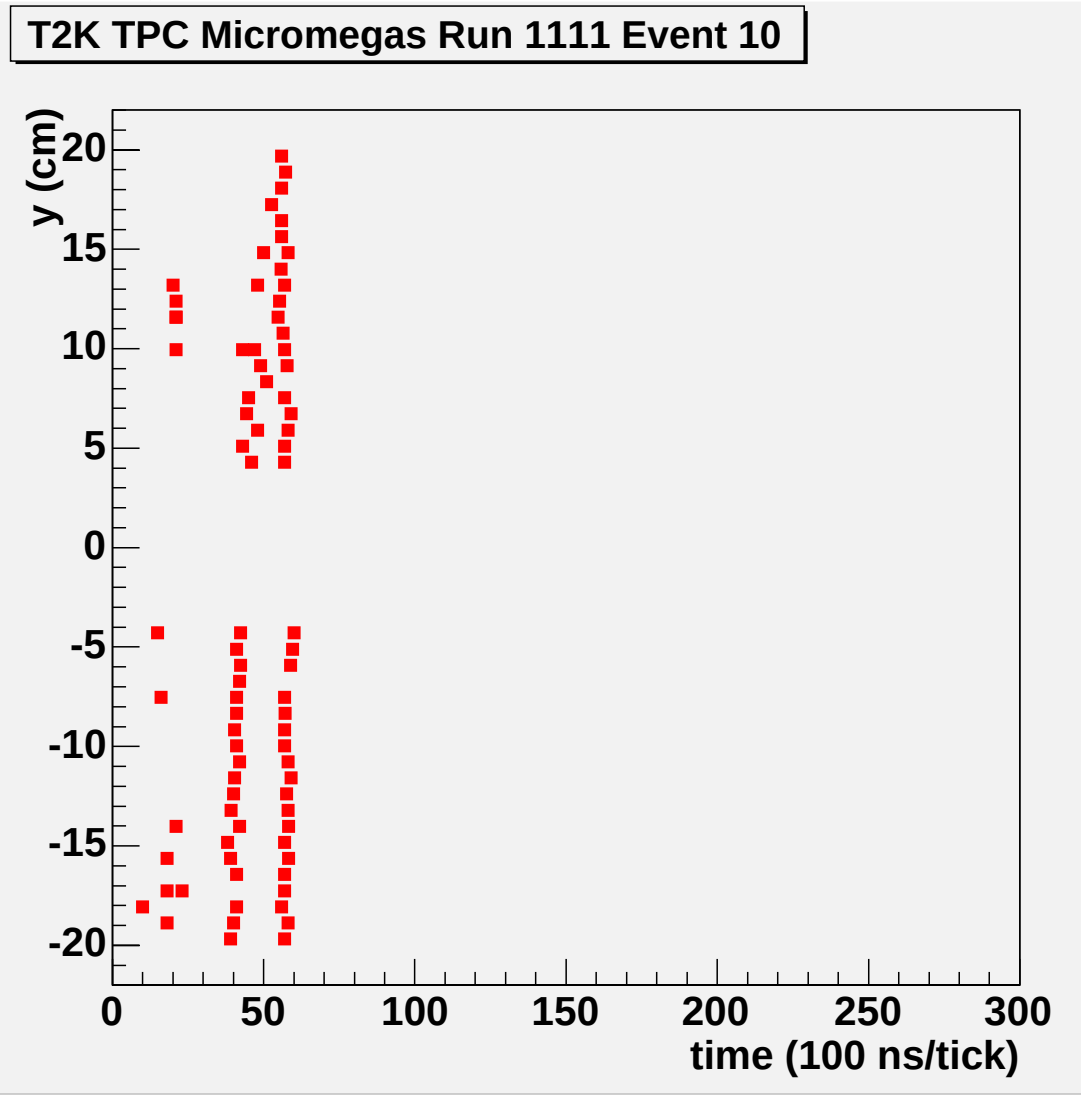
Cosmic track display-B=0.2





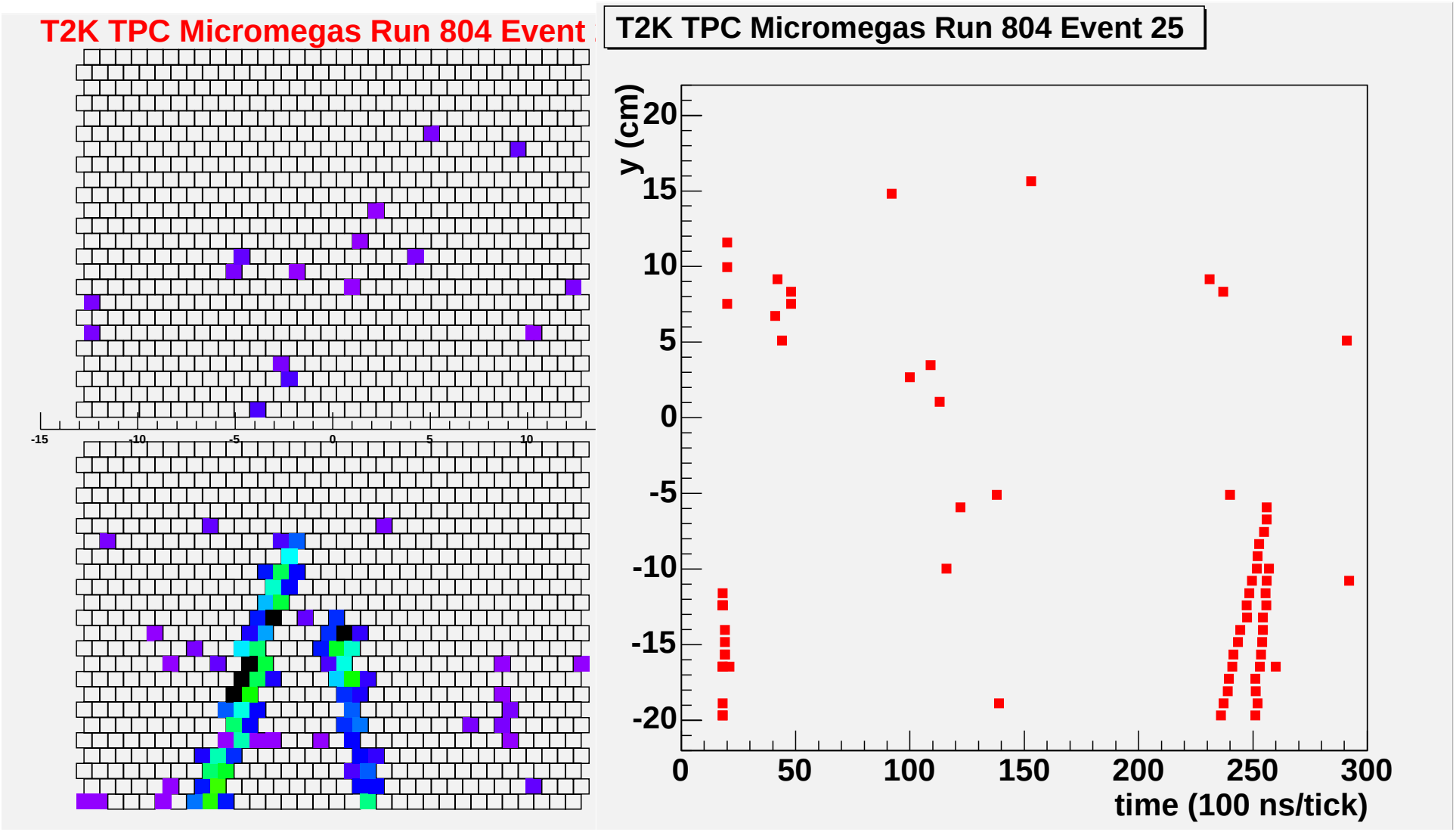
Cosmic track display-B=0 Ar-CO2



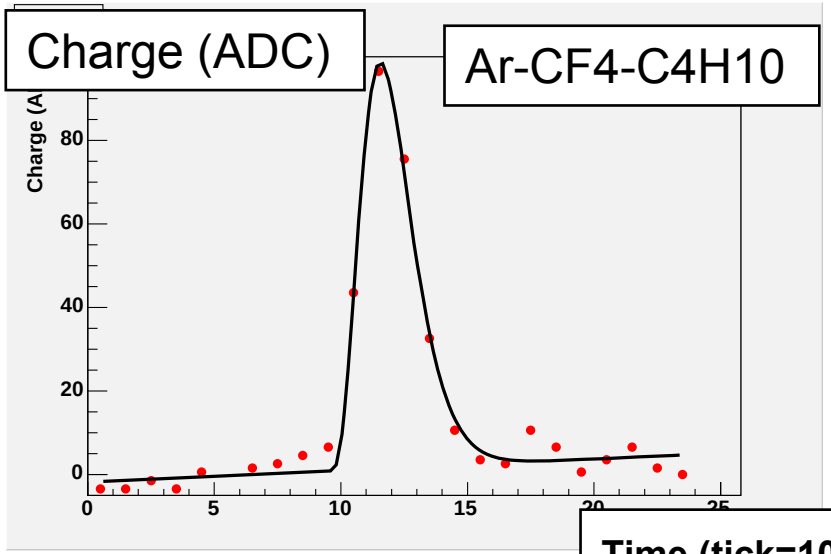


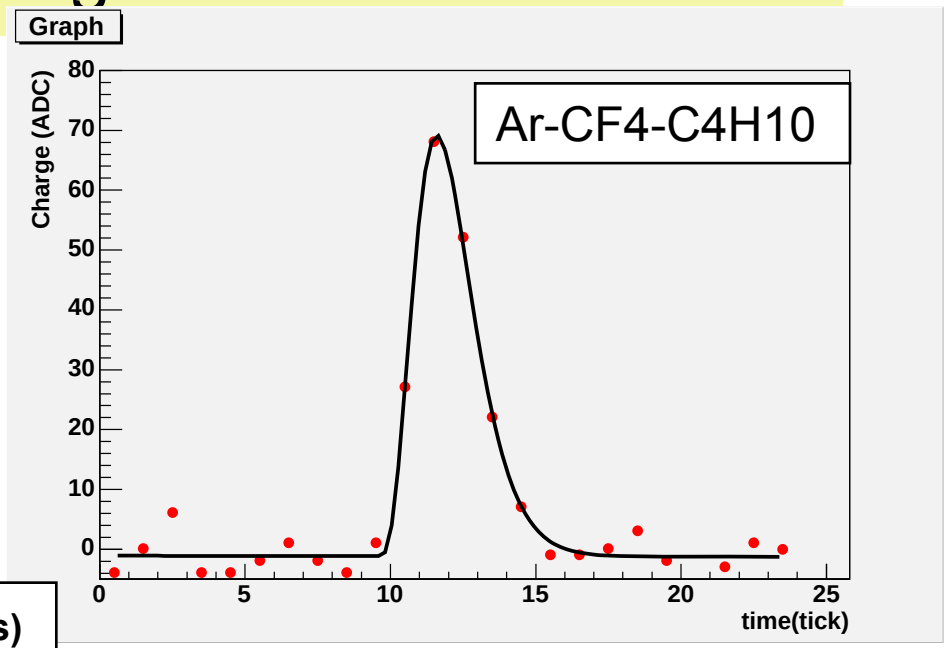
Entering the TPC from the cathode

- Vdrift = 6.42±0.05 cm/μs (Magboltz 6.5)

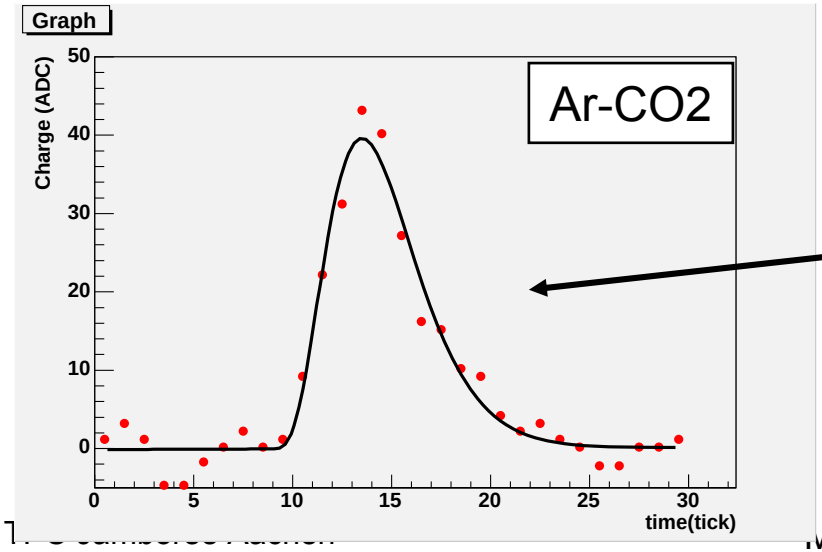


Digitized signals





Time (tick=100ns)



Fit with C(t/tau)**4exp(-4t/tau)
Fourth order semi-gaussian filter
Tau ≈200ns
Longer pulses with Ar-CO2

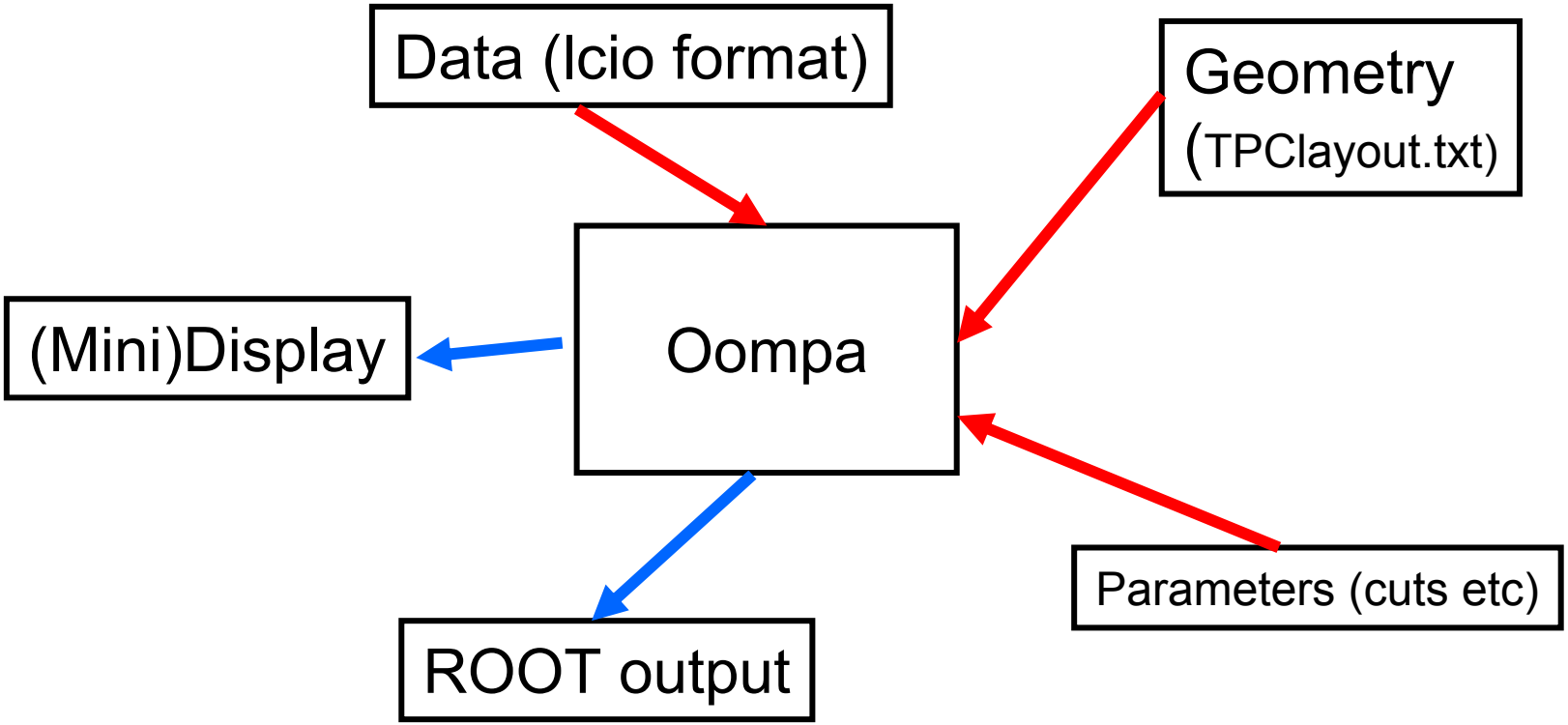
Aim of the S/W package

- A simple and portable package
- Based on C++
- Modular
- Crucial : know what is inside, ready to be adapted

Features :

1. Monitoring
2. Event display (minimal)
3. Track Fitting

Overview-1


Data (Icio format)
Geometry
(TPClayout.txt)
(Mini)Display
Oompa
Parameters (cuts etc)
ROOT output

Overview-2

Methods

OoTrackFinder | OoClusterer | OoDataReader | OoGeometryReader

Base classes

OoTrack | OoCluster | OoHit | OoPad

Services

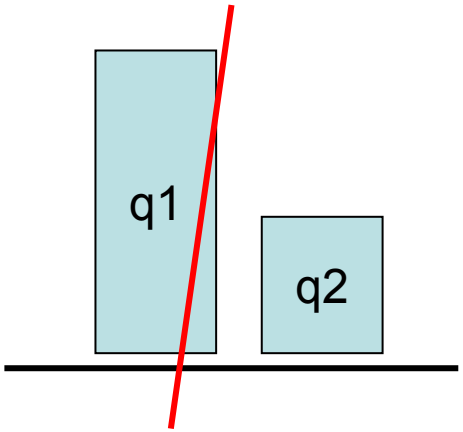
OoAnalysisManager

Track Fit

- Keep it simple : do space points (one point per row) and then least squares fit
- Based on Minuit (with TMinuit interface)
- Residuals : redo the fit without the cluster in that row
- Two track finders :
  - Cut in time projection around max
  - Use first and last 2 rows as seeds

Data analysis

- New C++ package Oompa used (ROOT, Minuit, STL)
- Exercised and debugged using ILC TPC prototype data
- Build clusters in each row : adjacent pads close in time
- Track finder : full length across the two modules, based on a road from seeds in the top-bottom rows
- Track fitting : χ^2 fit in the two projections (x-y, y-t)
- Crucial ingredient : how to compute the position for a cluster with two pads hit



The charges q1 and q2 can be computed from the integral of the track width S_T over the pad boundaries
Relation between r=q1/(q1+q2), S_T and the track position x

r measured, S_T from Magboltz -> measure x for two pads clusters (numerical method)

Electron cloud and charge sharing

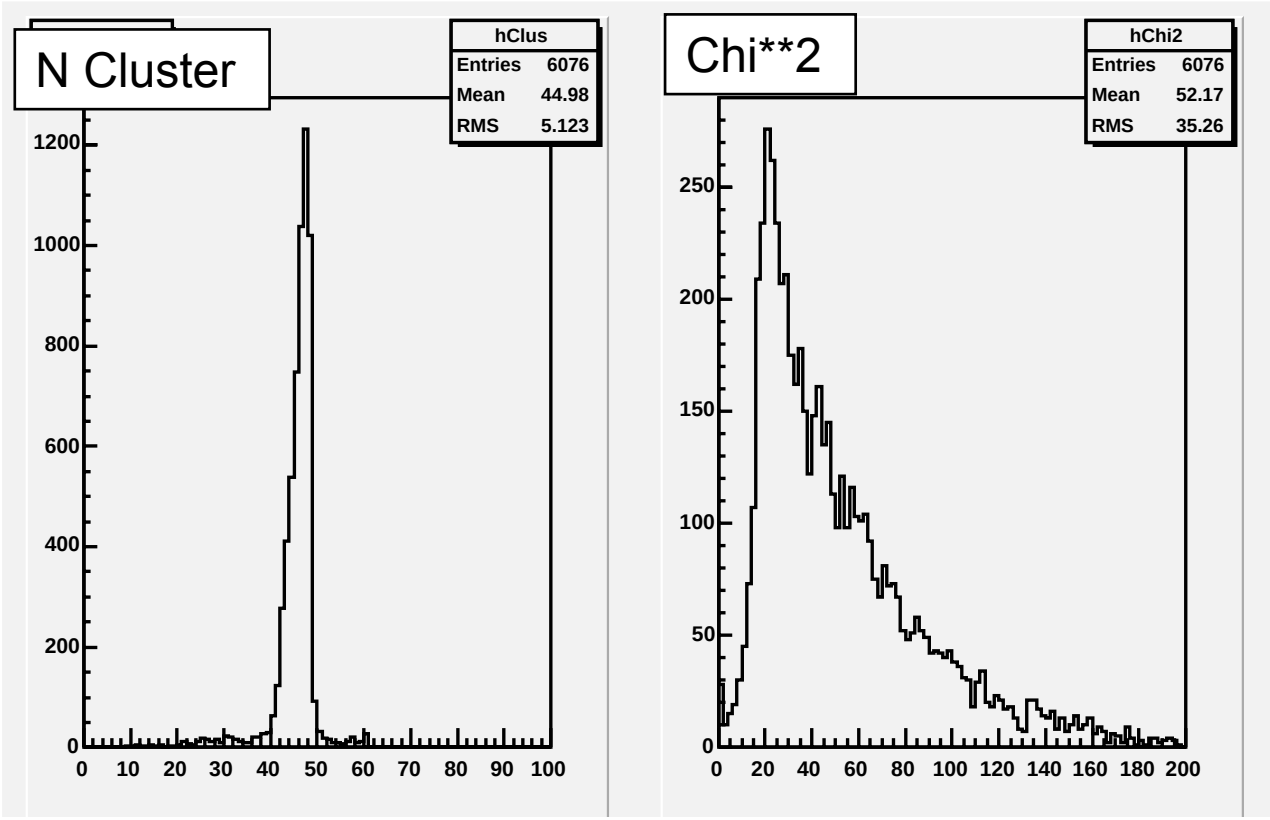
$$\frac{q}{q+q'} = \frac{\int_{x_p}^{x_p+\Delta_p} G(u, x_t, w_t)\,\mathrm{d}u}{\int_{x_p}^{x_p+\Delta_p} G(u, x_t, w_t)\,\mathrm{d}u + \int_{x_p-\Delta_p}^{x_p} G(u, x_t, w_t)\,\mathrm{d}u} \qquad (1)$$

Case 1 (space point reconstruction): assume the cloud width w_t is known (diffusion+drift) => solve for x_t

Case 2 (study of gas properties): assume x_t known (from global track fit) => solve for w_t

NB still to do : case of large track angle !

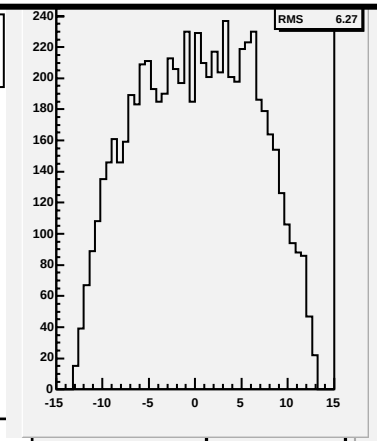
Track parameters

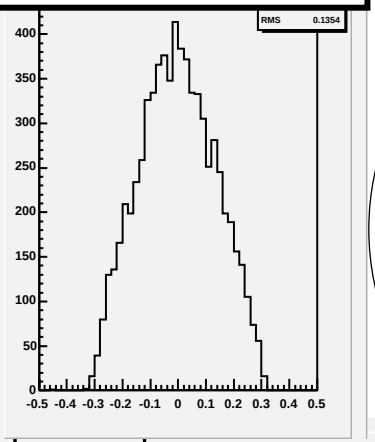


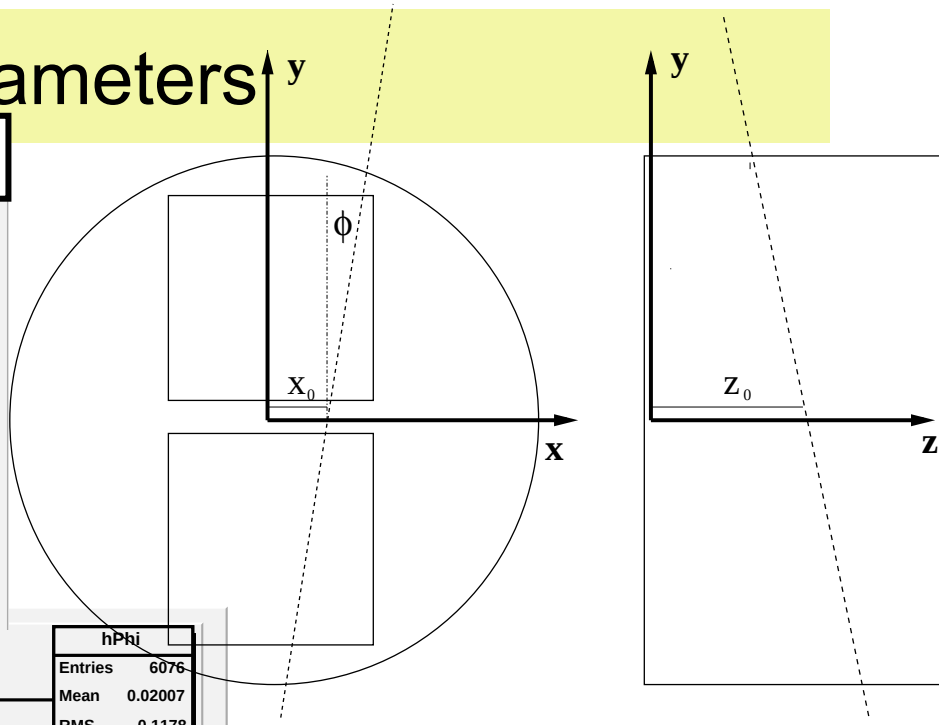
Track parameters

Same distributions from Geant4 MC

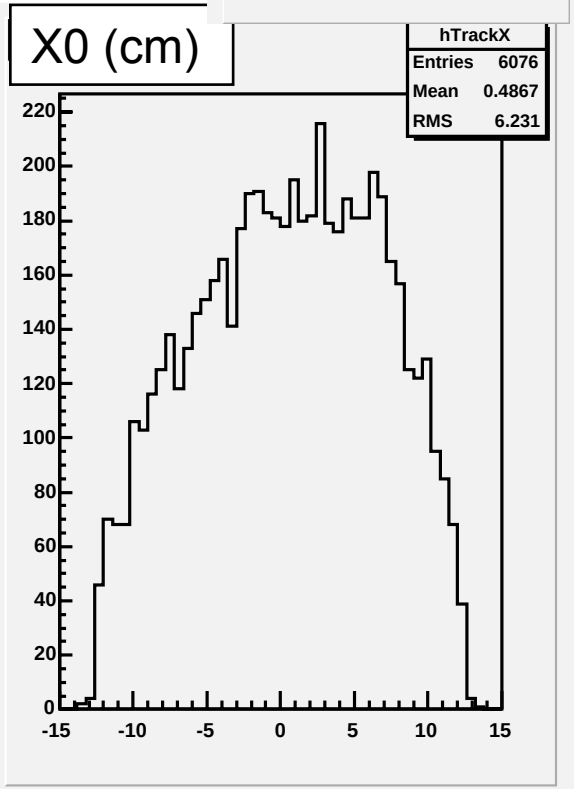
A. Sarrat



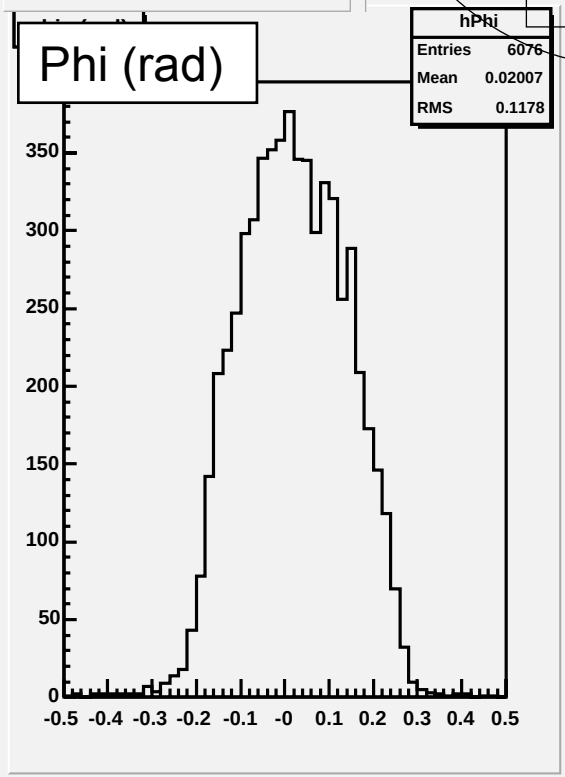




X0 (cm)

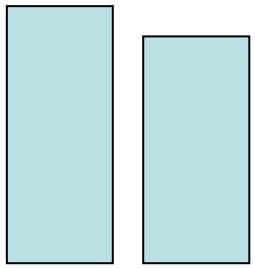


Phi (rad)

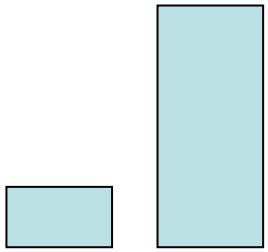


Two pad position uncertainty

- The position uncertainty of two pad clusters varies widely



Almost symmetric charge ratio:
good precision



Very asymmetric charge ratio:
poor precision, large fluctuations on the lower charge

•Also dependence on total charge, track width, electronic noise …

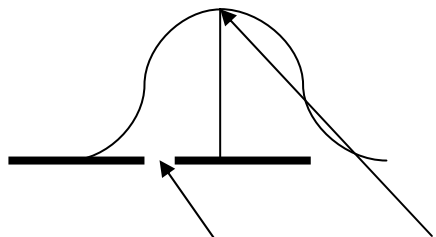
•Can be parametrized with a simple model !

Estimating the position uncertainty

$$q_1 = \int G(x_t, w_T)\,dx$$

over pad boundaries

$$f = \frac{q_1}{q_1 + q_2}$$

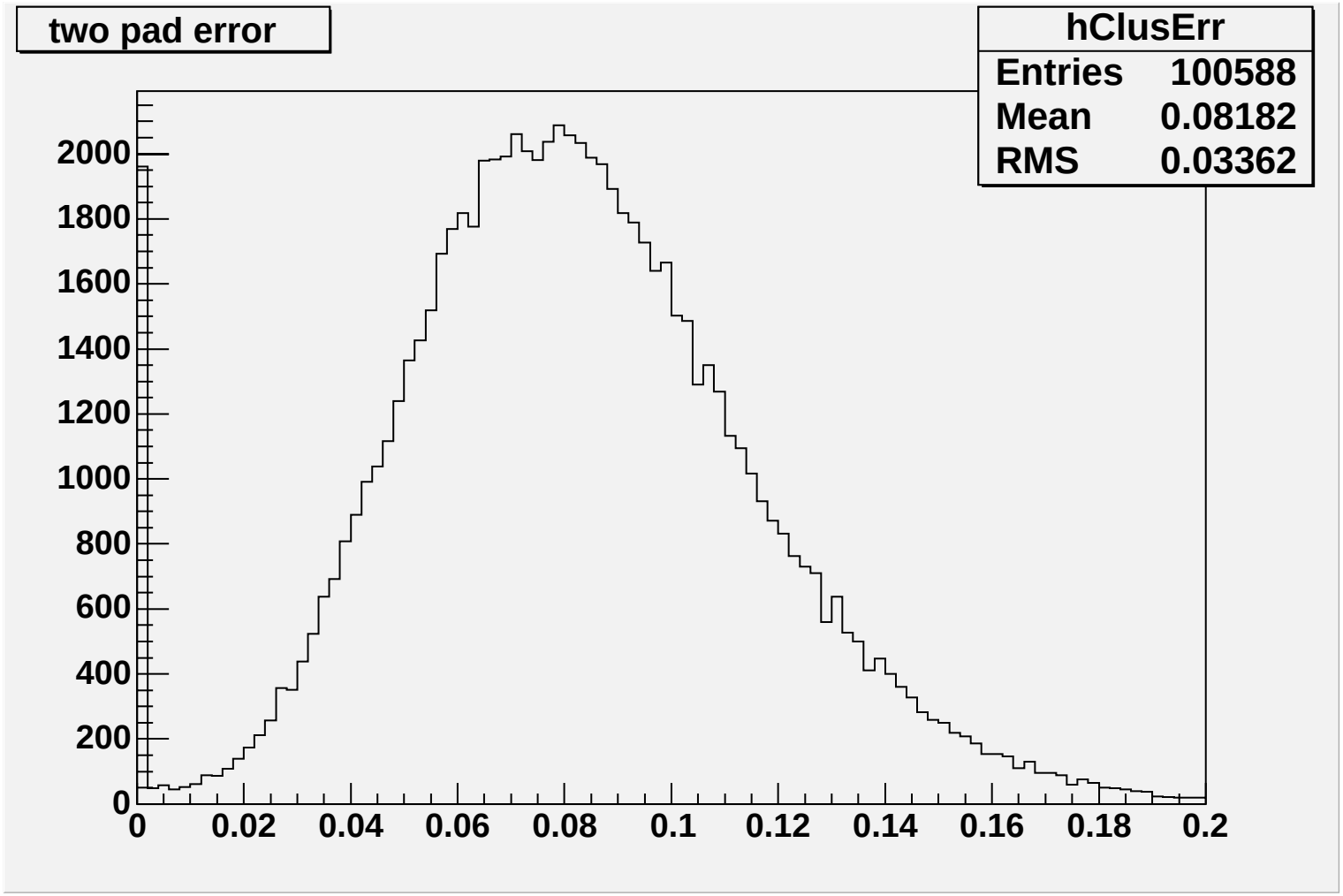


X_t gaussian center
Xp pad boundary

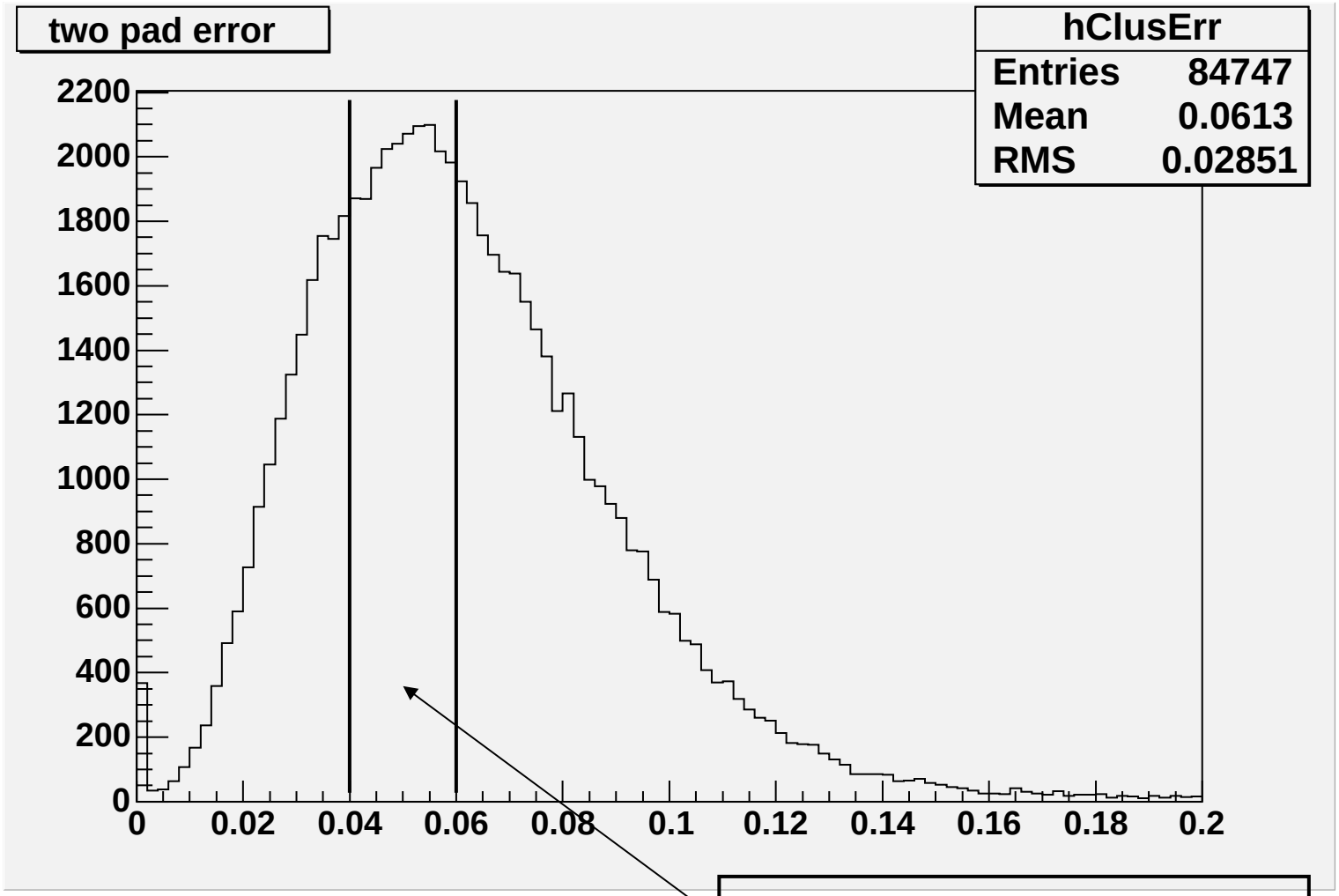
$$\frac{d\,q_1}{d\,x_t} = \frac{1}{\sqrt{2\pi}\,w_T}\left(\exp\left(-\frac{(x_t - x_p)^2}{2\,w_T^{\,2}}\right) - \ldots\right)$$

$$\sigma_x = \sqrt{2\pi}\,w_t\,e^{(x_t - x_p)^2/2w_t^2}\sqrt{\frac{f(1-f)}{\alpha N_p}}$$

Two pad cluster error distribution B=0

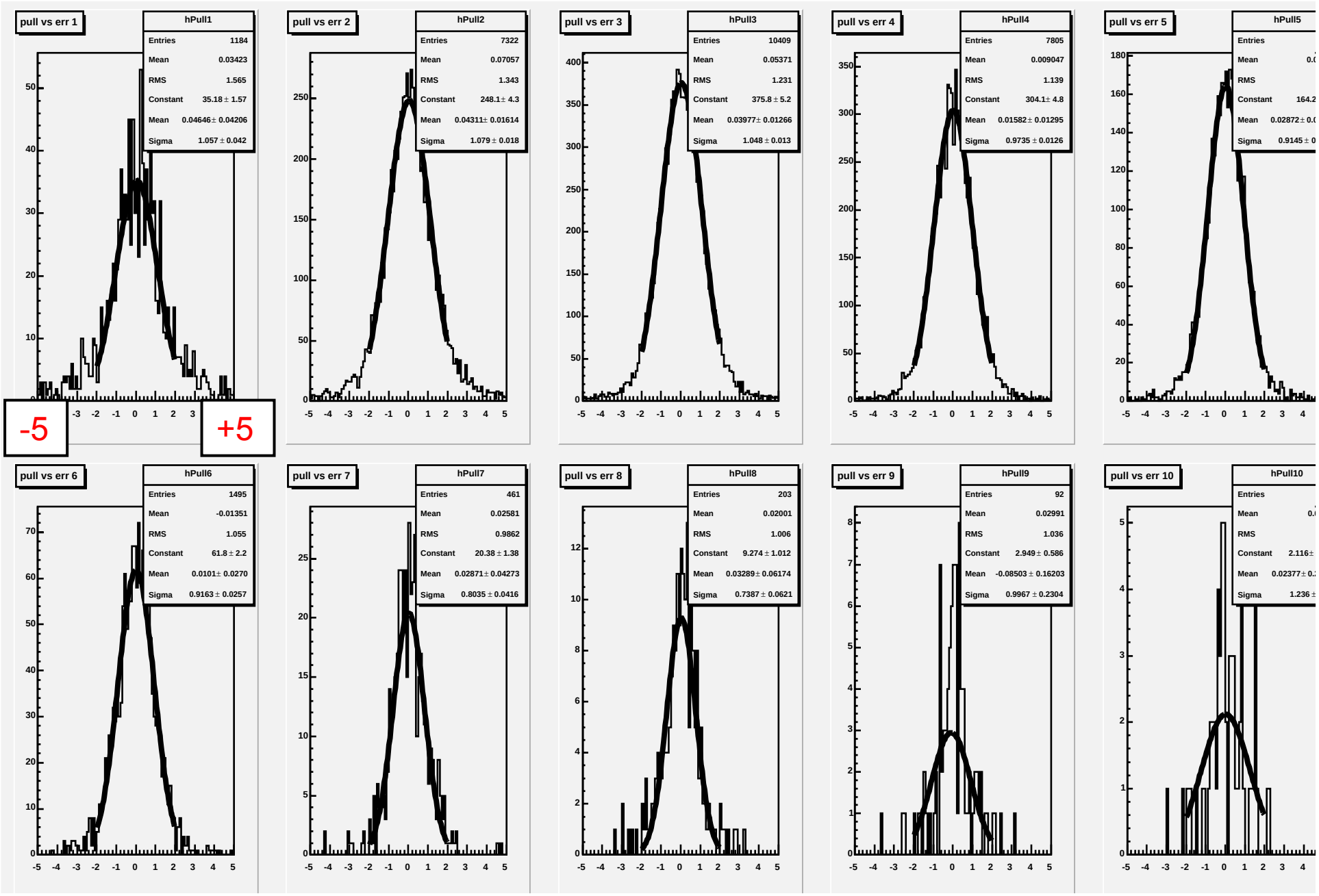


Two pad cluster error distribution B=0.2

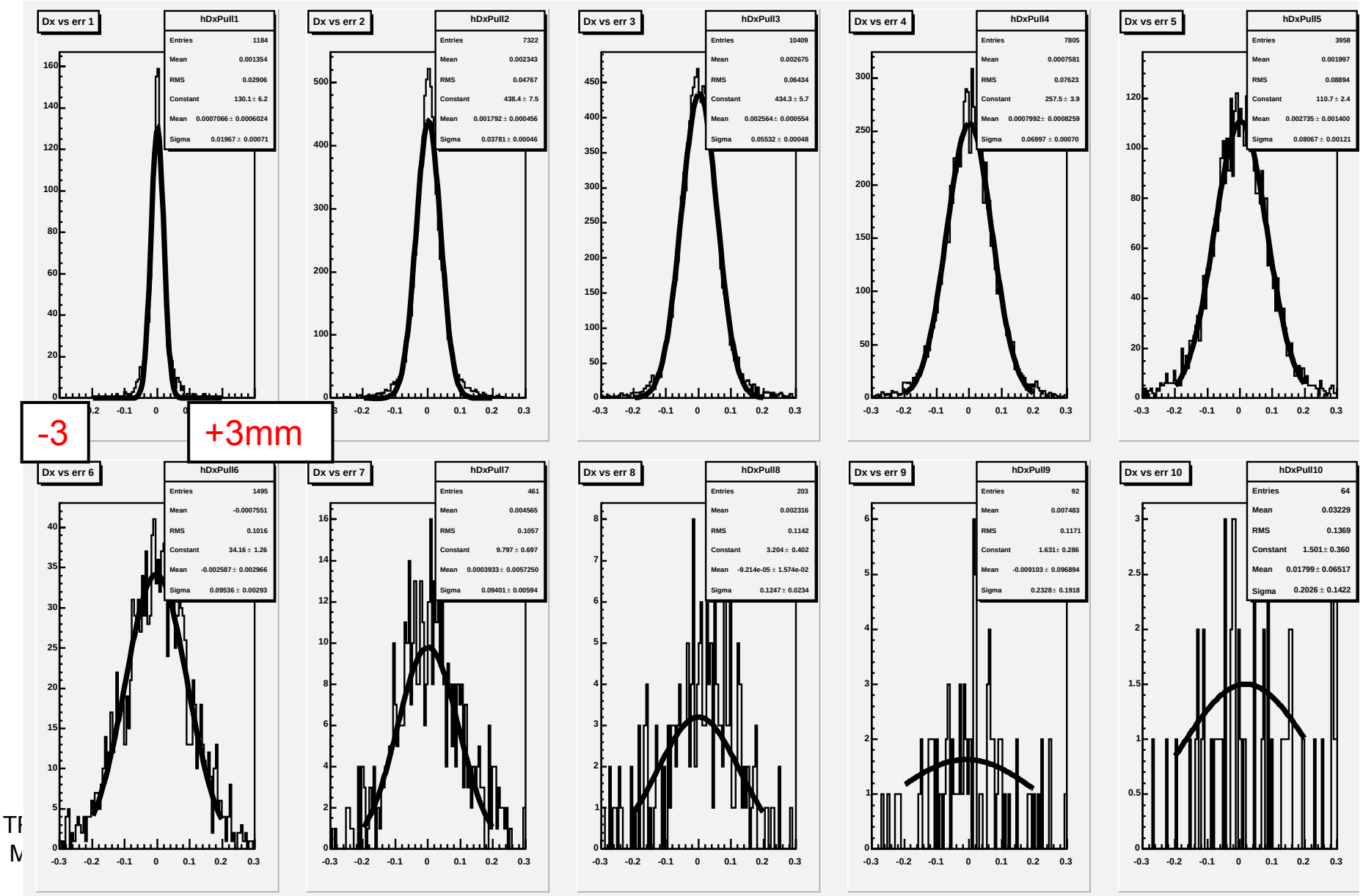


Bin of 200 mum for later plots

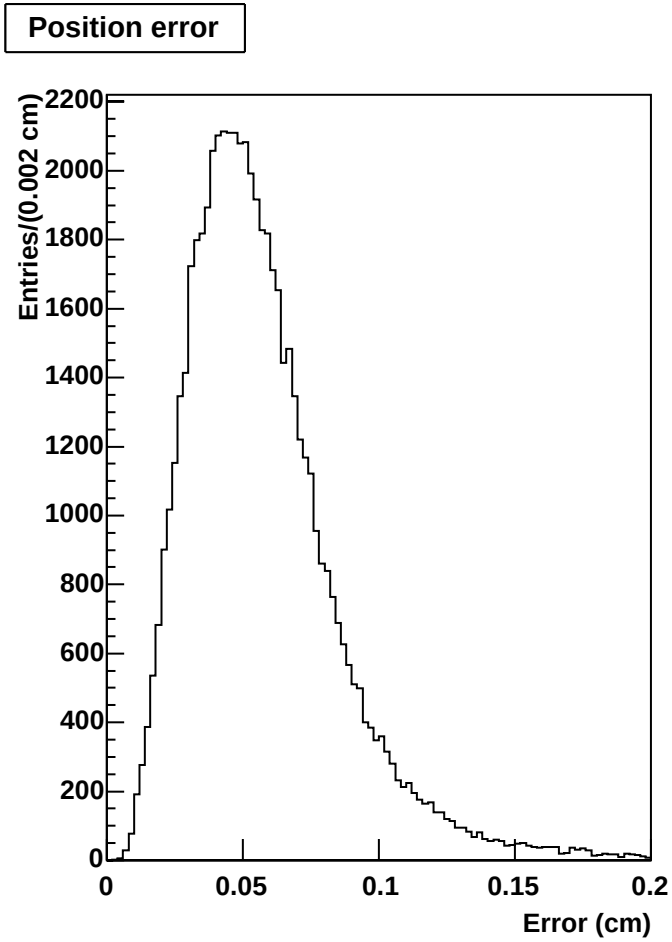
Does the model work ? Pull distribution in bins of 200μm

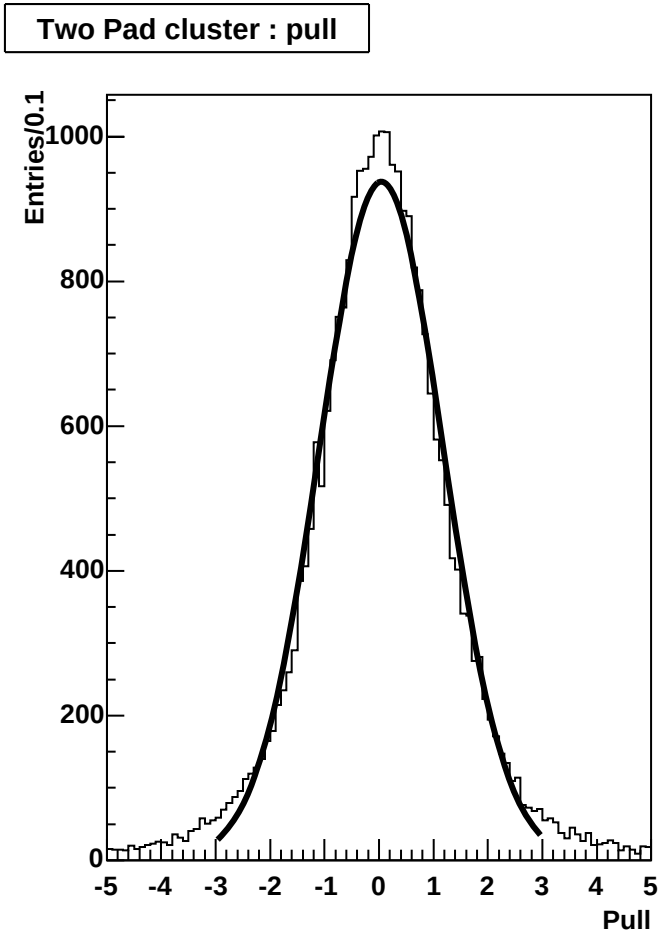


Does the model work ? Residual distribution in bins of 200μm



Pull


Position error
Entries/(0.002 cm)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.05
0.1
0.15
0.2
Error (cm)

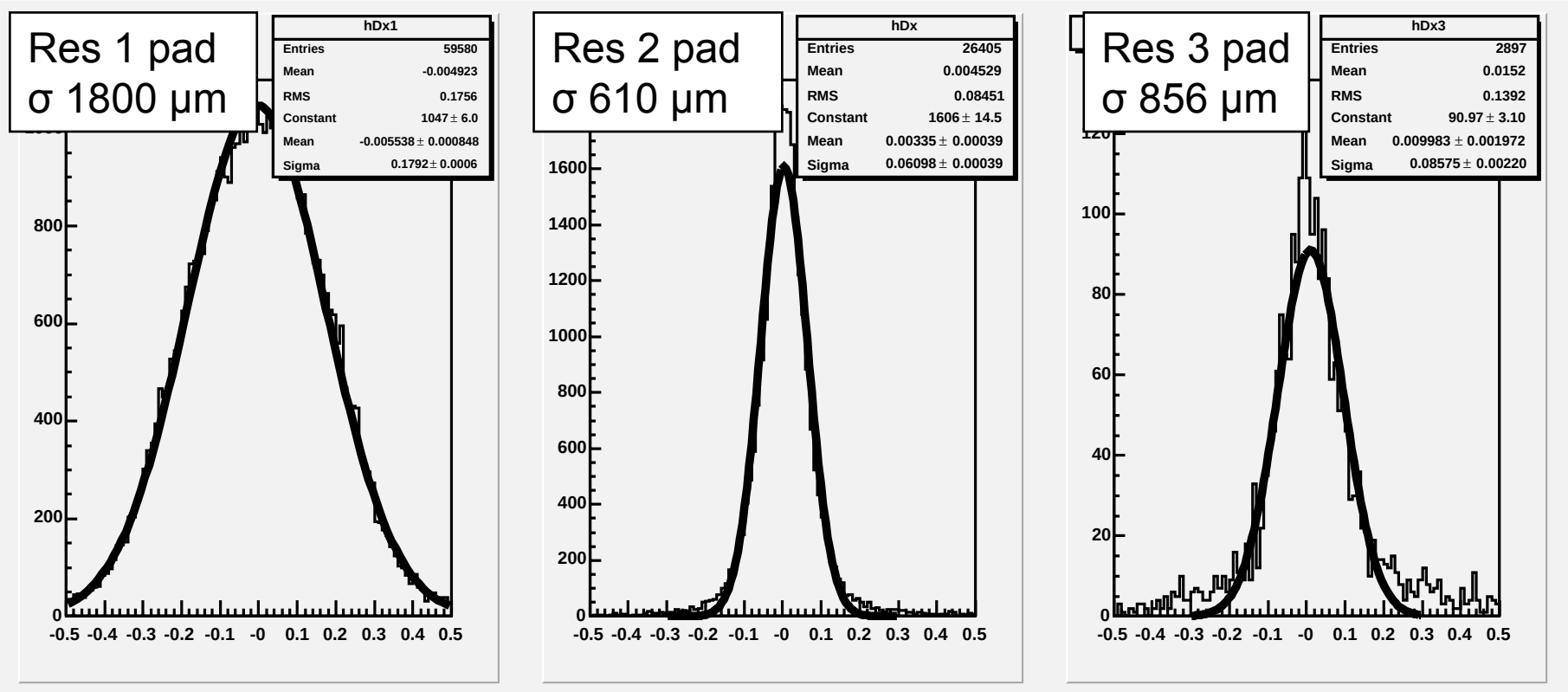

Two Pad cluster : pull
Entries/0.1
1000
800
600
400
200
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Pull

Resolution study

- Consider these distributions for clusters with two pads only:
  - Residual cluster-track : track refitted without the cluster info
  - Residual cluster-track : cluster info in track fit
  - [Residual cluster-track (row i)] - [Residual cluster-track (row i+2)] =double residual (divide width by sqrt(2))
- The double residual is insensitive to track extrapolation uncertainty (200-300μm), alignment, track model systematics
- Fit gaussian width as a function of z

Resolution study

Little information in clusters with one pad hit.
Distribution integrated over z. Need to study residuals vs z



Resolution study B=0

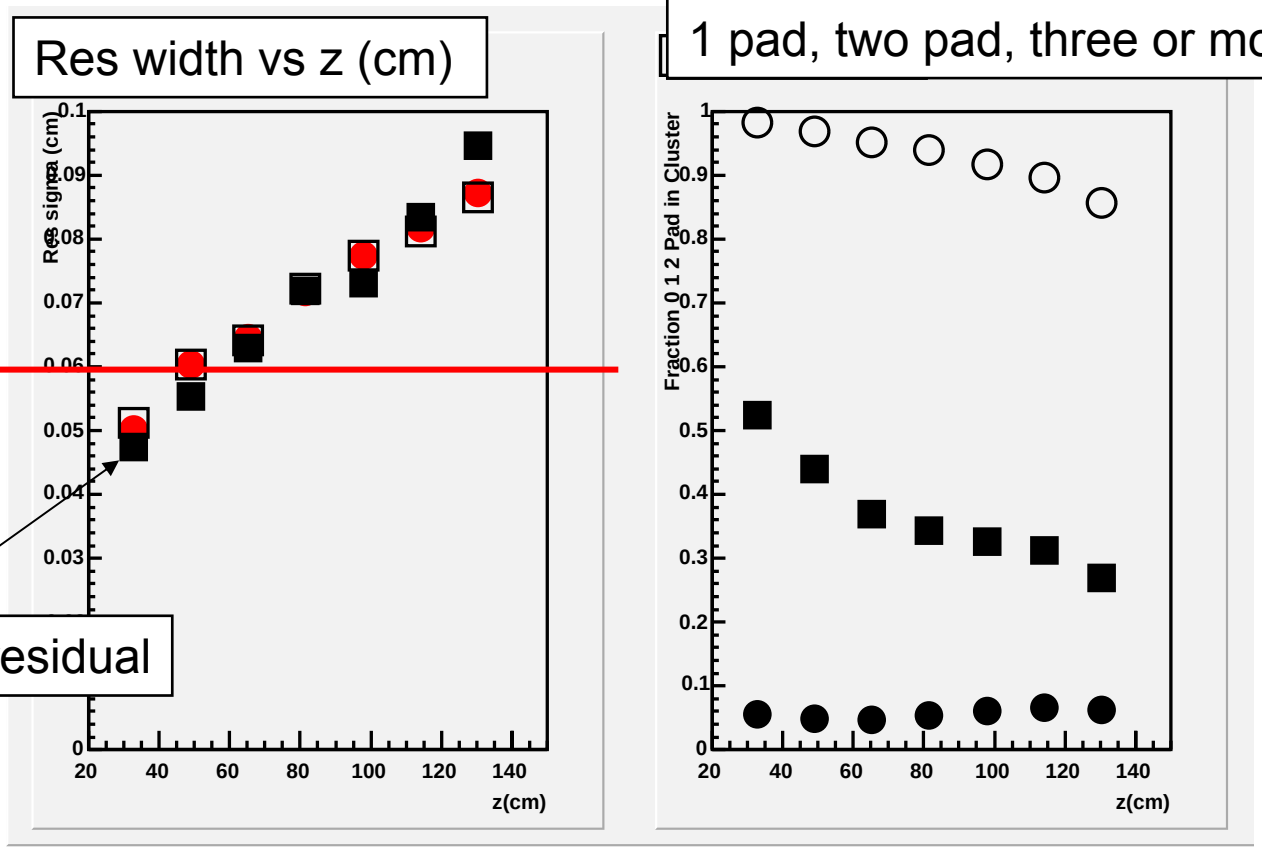
Ar-CF4-C4H10

Cumulative fraction of rows with no hit,
1 pad, two pad, three or more pad cluster

Res width vs z (cm)

600µm

Double residual



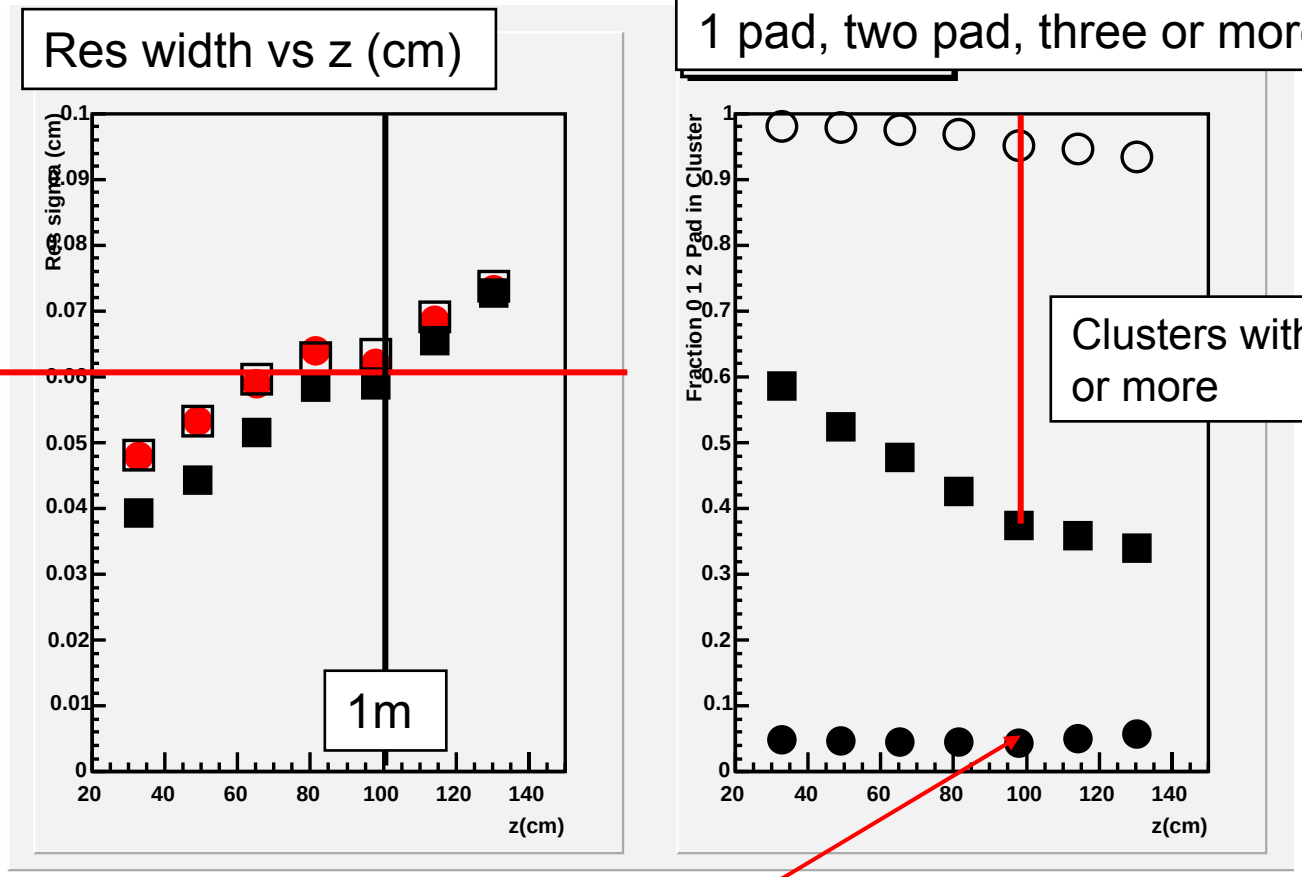
Resolution study B=0.2T

Ar-CF4-C4H10

Cumulative fraction of rows with no hit, 1 pad, two pad, three or more pad cluster

Res width vs z (cm)

600μm



Clusters with two pads or more

Overall inefficiency≈5% including electronics, analysis

Momentum resolution

With Gluckstern formula

$$\sigma_\rho = \frac{\sigma_{\text{point}}}{L^2}\sqrt{\frac{720}{N+4}}$$

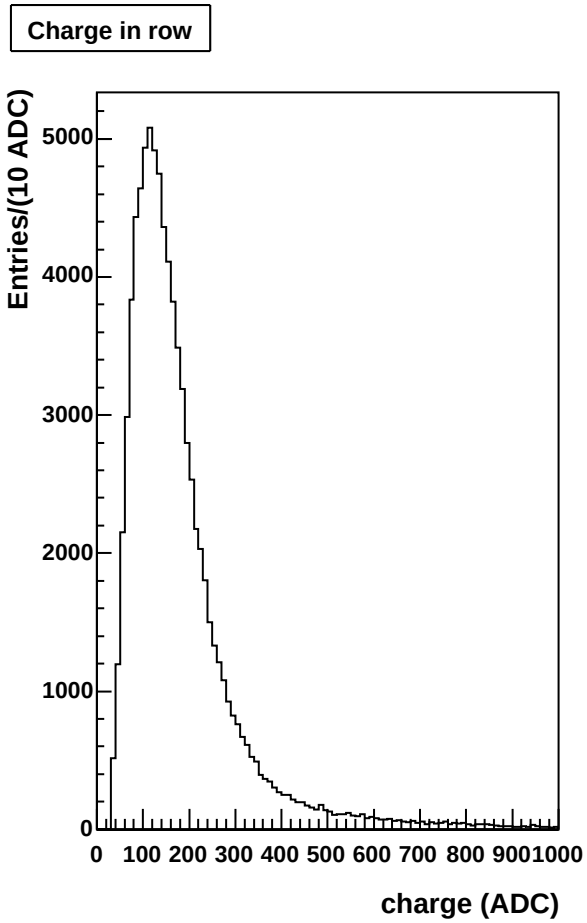
we use σ_{point}=700μm, N=(3/4)*72, L=70cm and obtain

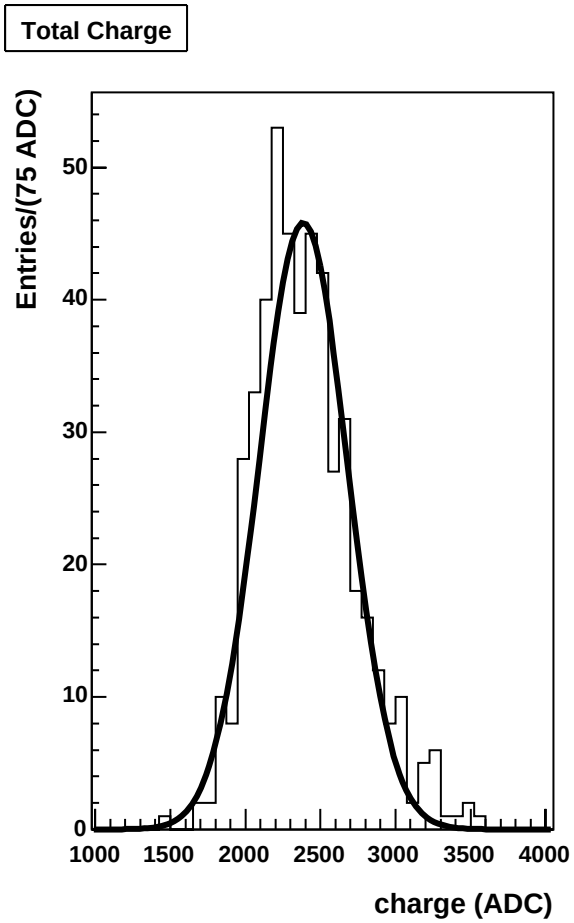
σ_p/p<=8.3% at 1 GeV/c, 1 m drift distance for B=0.2 T

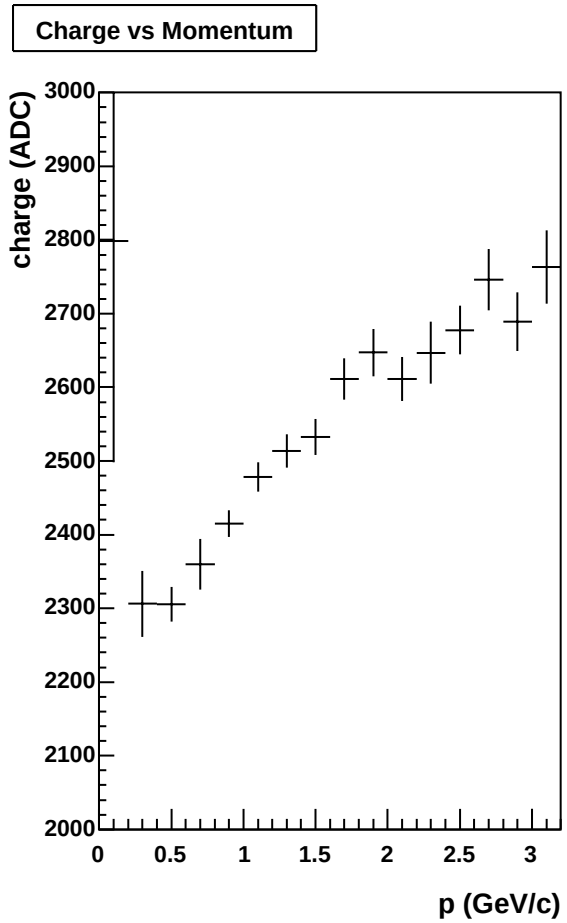
- lower noise in electronics (600 vs 2000 e RMS) -> lower threshold->more clusters with two pads-> better momentum resolution
- Other possible improvements for T2K : longer track length, smaller pads, elongated pads …

dE/dX

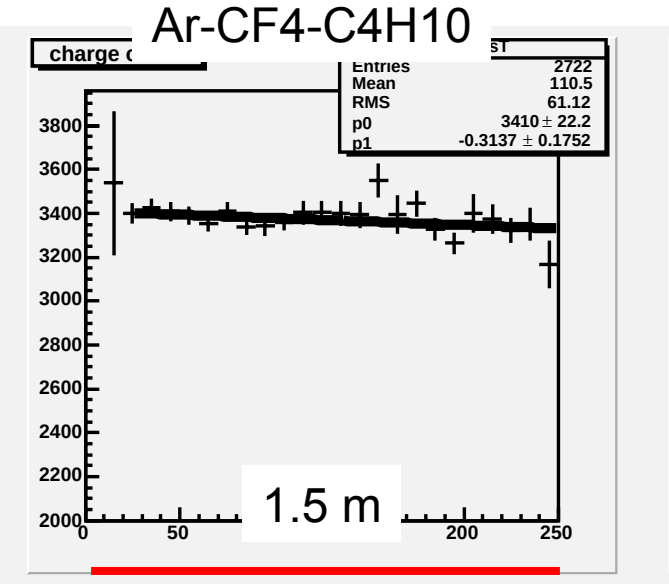
Truncated mean (80%), resolution 12% (on prototype, L=38cm, 48 sam.)
=> σ<10% for T2K (L=70cm, 72 sam.)



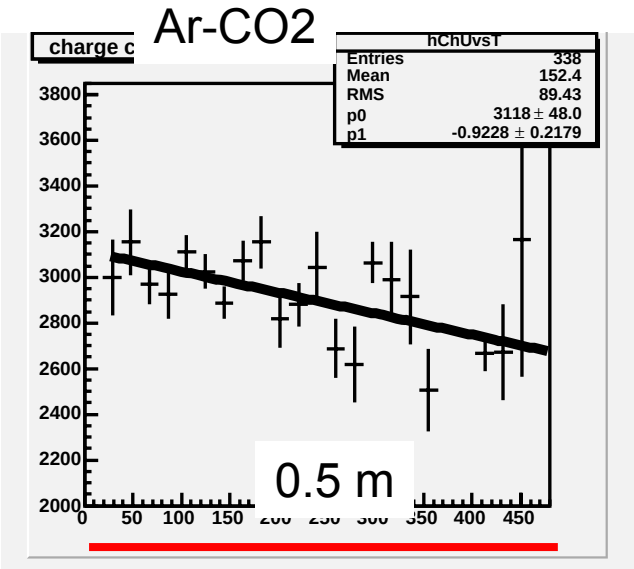




Attenuation



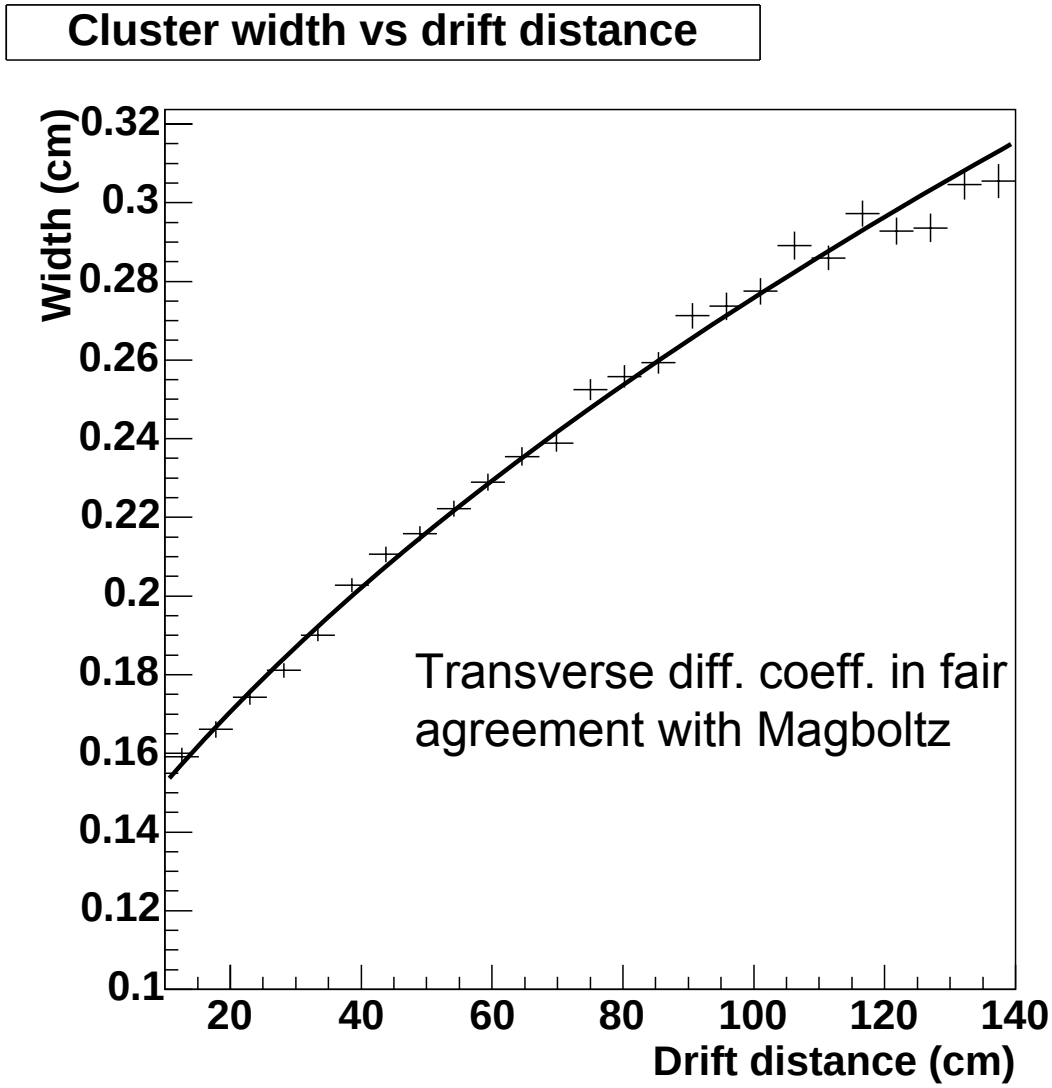
Attenuation length> 33m



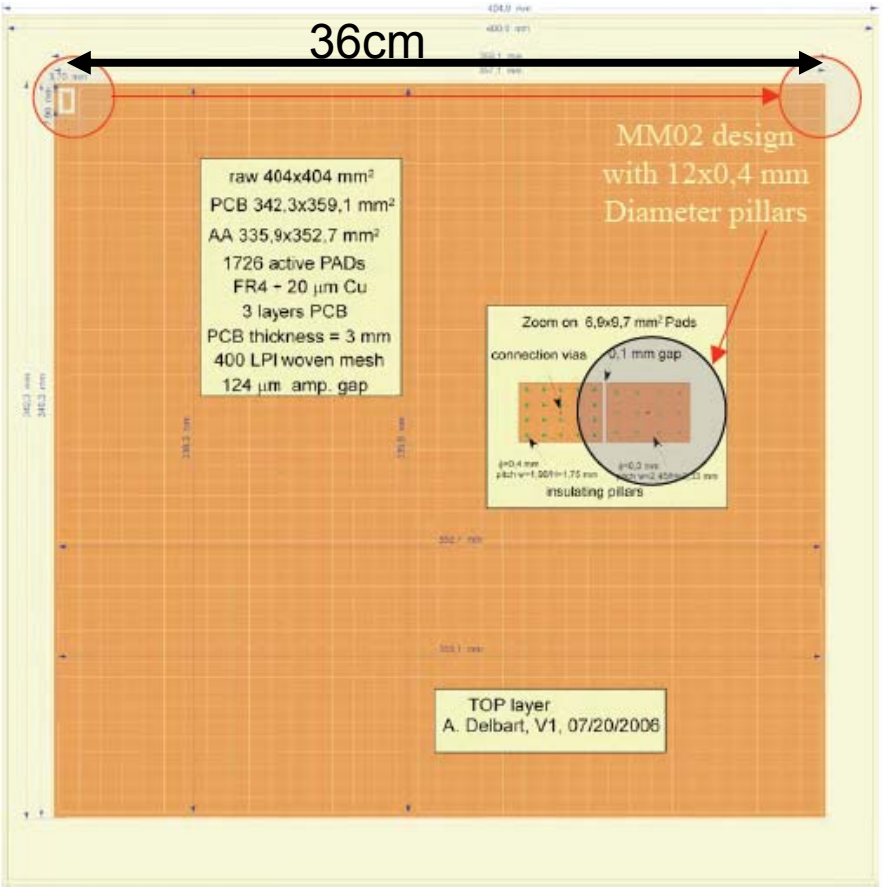
Attenuation length: 3.4m

Micromegas works fine with Ar-CO2 but
electron capture on oxygen traces is a serious problem

Study of transverse diffusion

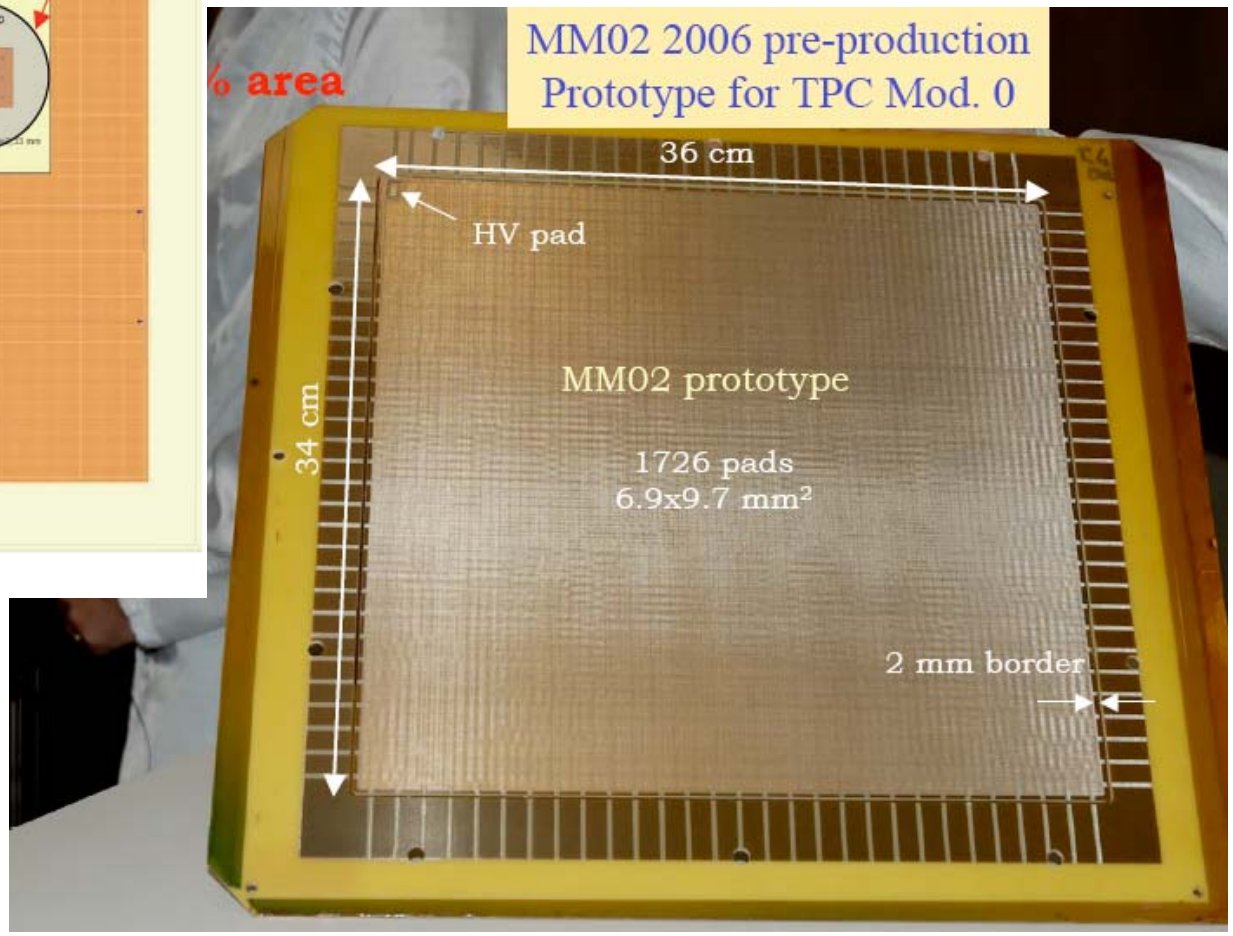


Micromegas Modules

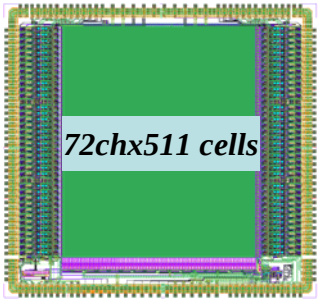


First large Micromegas module produced at CERN

4 pre-series MM to be produced in the next weeks

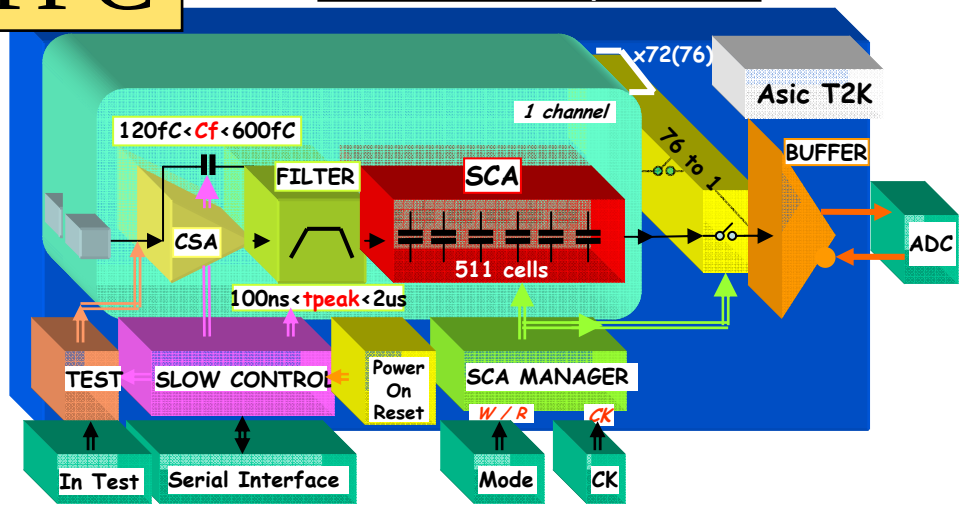


AFTER asic for T2K's TPC



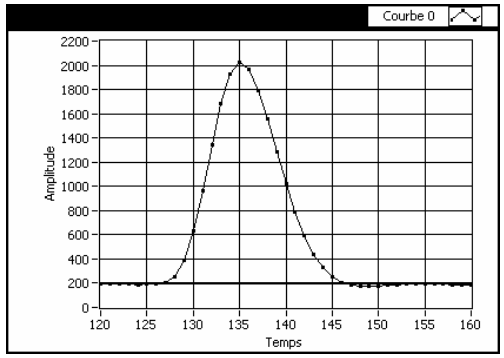
Technology: *AMS CMOS 0.35µm*
Area: *7546µm x 7139 µm*
Package:
LQFP 160 pins
Number of transistors: *400,000*

Architecture of AFTER



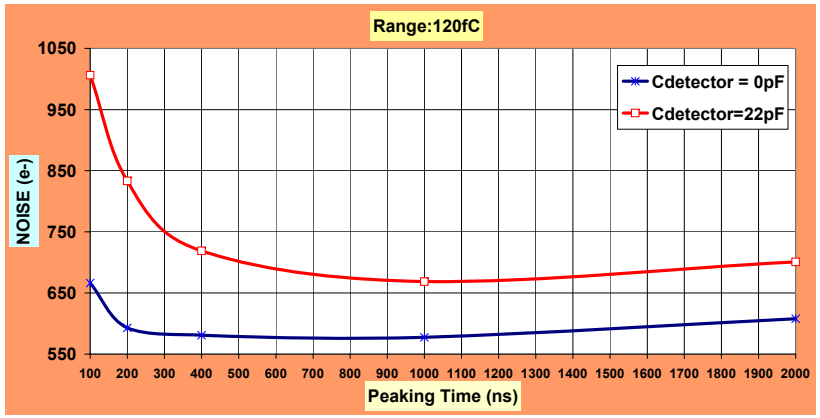
Number of channels	*72*
Number of time bins	*511*
Dynamic Range/Gains	*120fC to 600fC (4 values) on 12 bits*
Max Range/Noise with detector (Requirements)	*1000 (750 e- rms noise for 120fC range)*
I.N.L	*< 1.5%*
Power Consumption	*# 7mW / channel*
Sampling Frequency	*1MhHz to 50MHz*
Readout Frequency	*20 – 25MHz*
Shaping: *Unipolar; Semi-Gaussian;* 16 peak times: *100ns to 2µs*	
Signal Polarity	*Negative or Positive*
Calibration Mode	*1 common external cap.*
Test Mode	*1 cap. For each channel*

The main performances



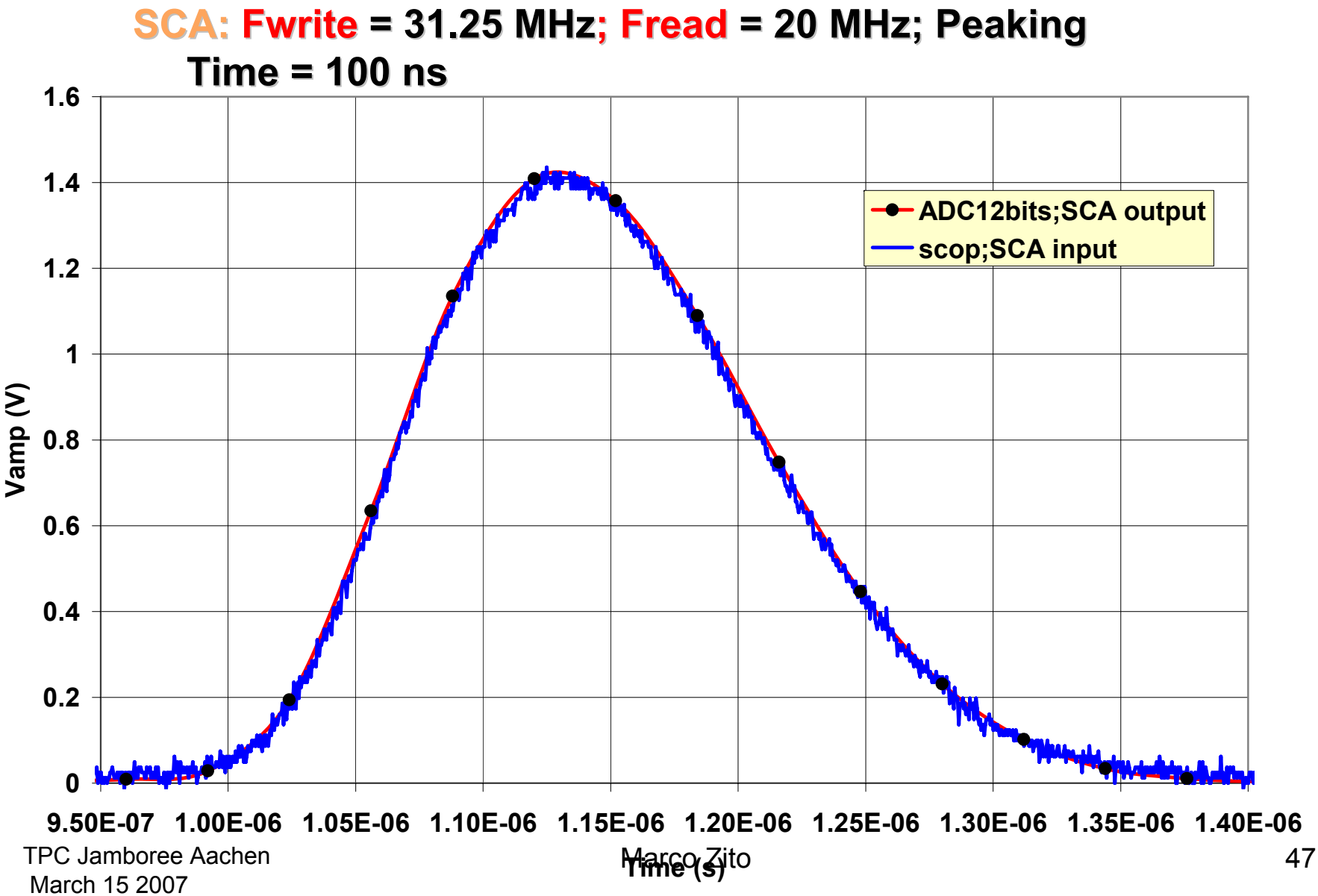
AFTER signal Shape:

- *Detector + source*
- *Tpeak: 100ns*
- *Time bin: 20ns*
- *ADC bin: 169 e-*

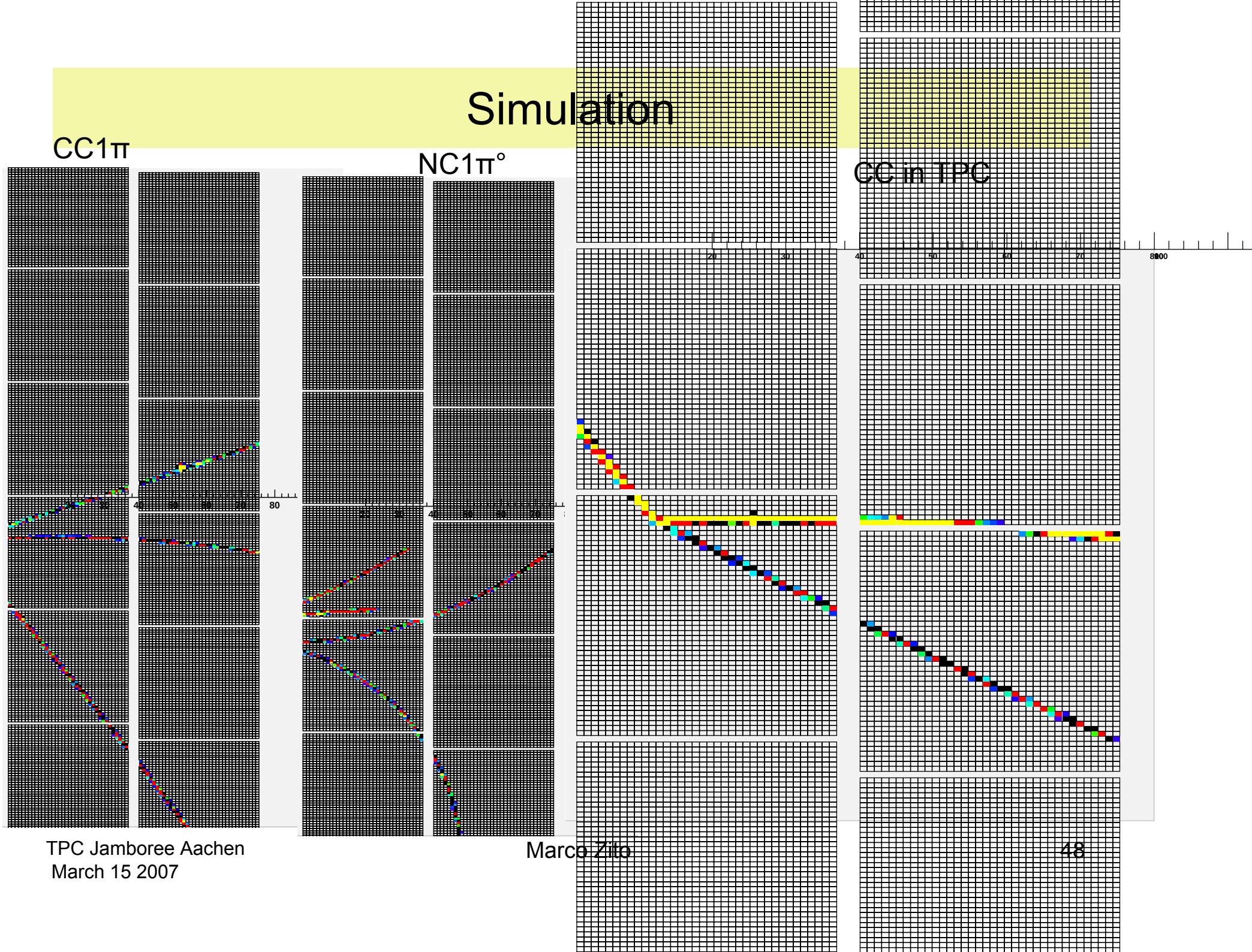


Noise versus: Peaking Time &C detector

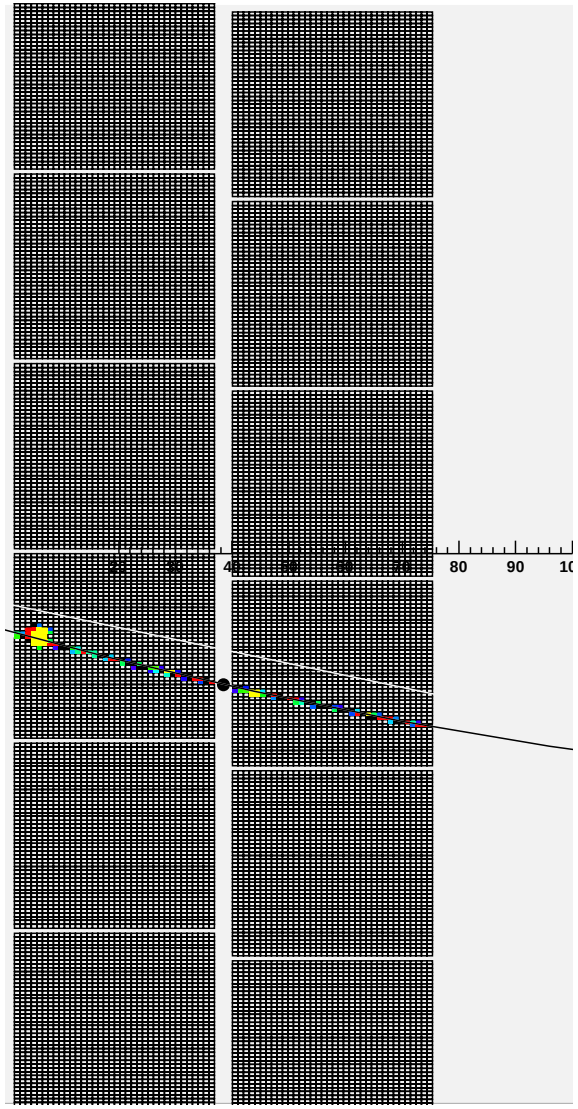
First Test Results



Simulation

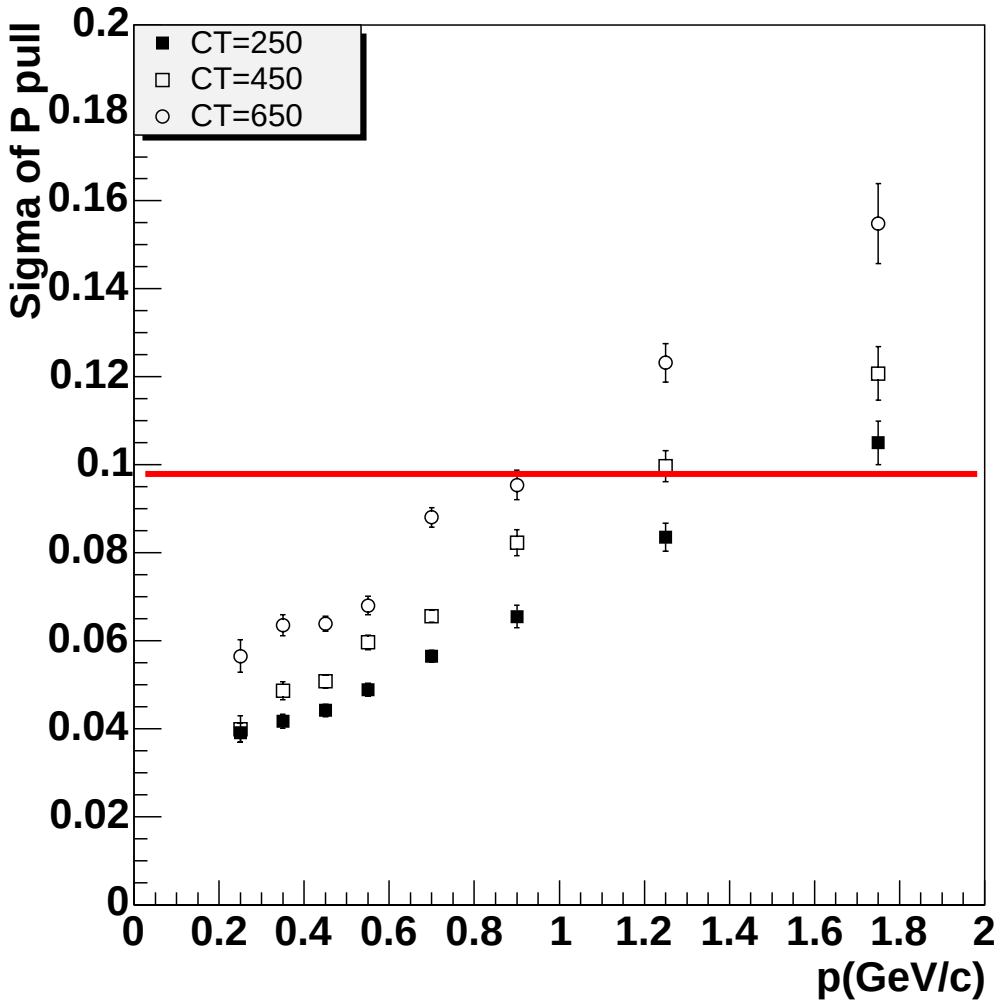


Simulation-Reconstruction



Momentum resolution

A. Sarrat, M.Z.



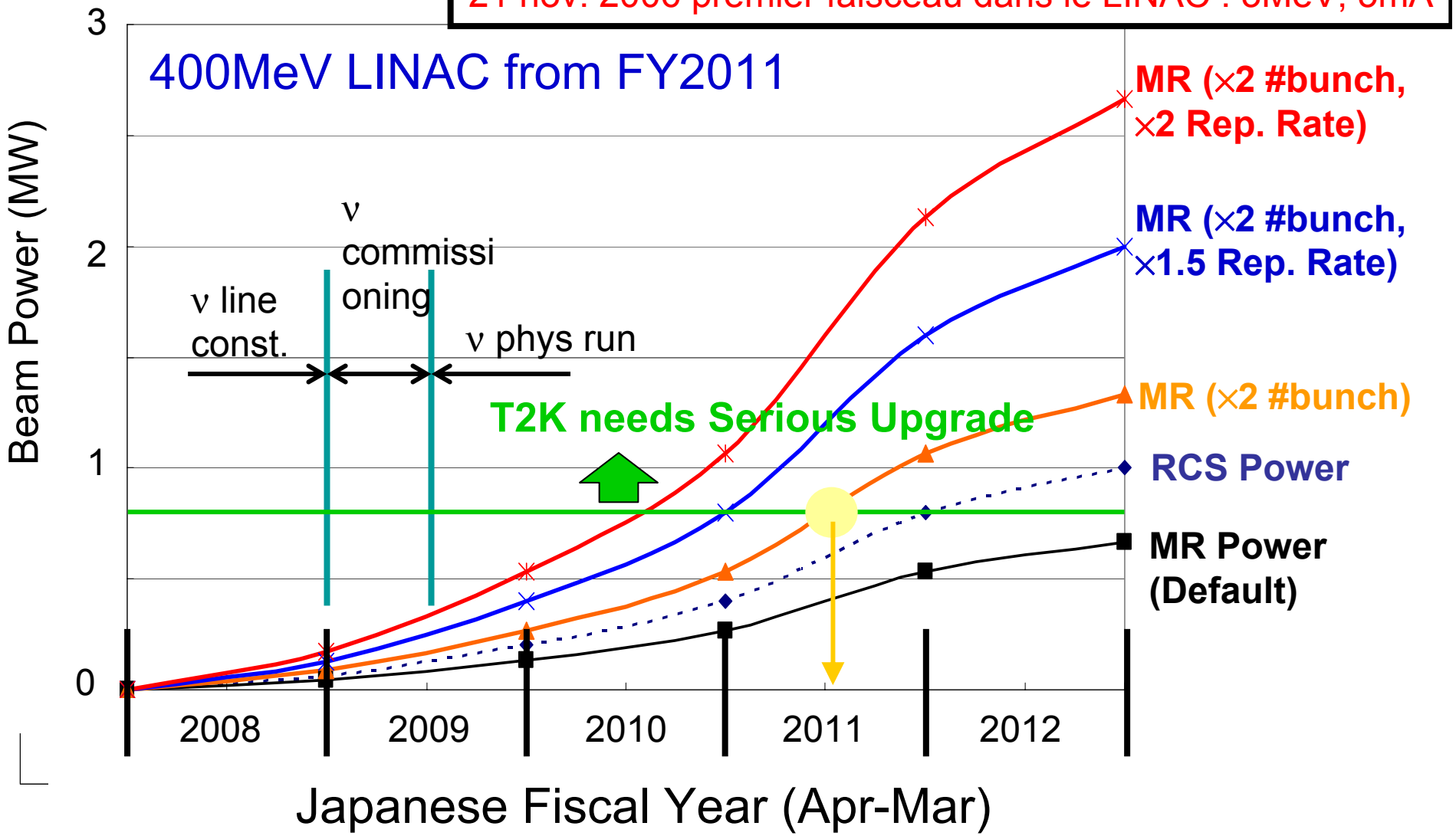
Conclusions

- Prototype has demonstrated the Micromegas solution
- Performance satisfy the T2K physics requirements
- Space point reconstruction and $\chi 2$ method used
- 2007-2008 Construction (Micromegas, electronics)
- April 2009 : first neutrinos !

Linac Beam Commissioning: Dec., 2006
RCS Beam Commissioning: Sep., 2007
MR Beam Commissioning: May, 2008
Experiment: April 2009

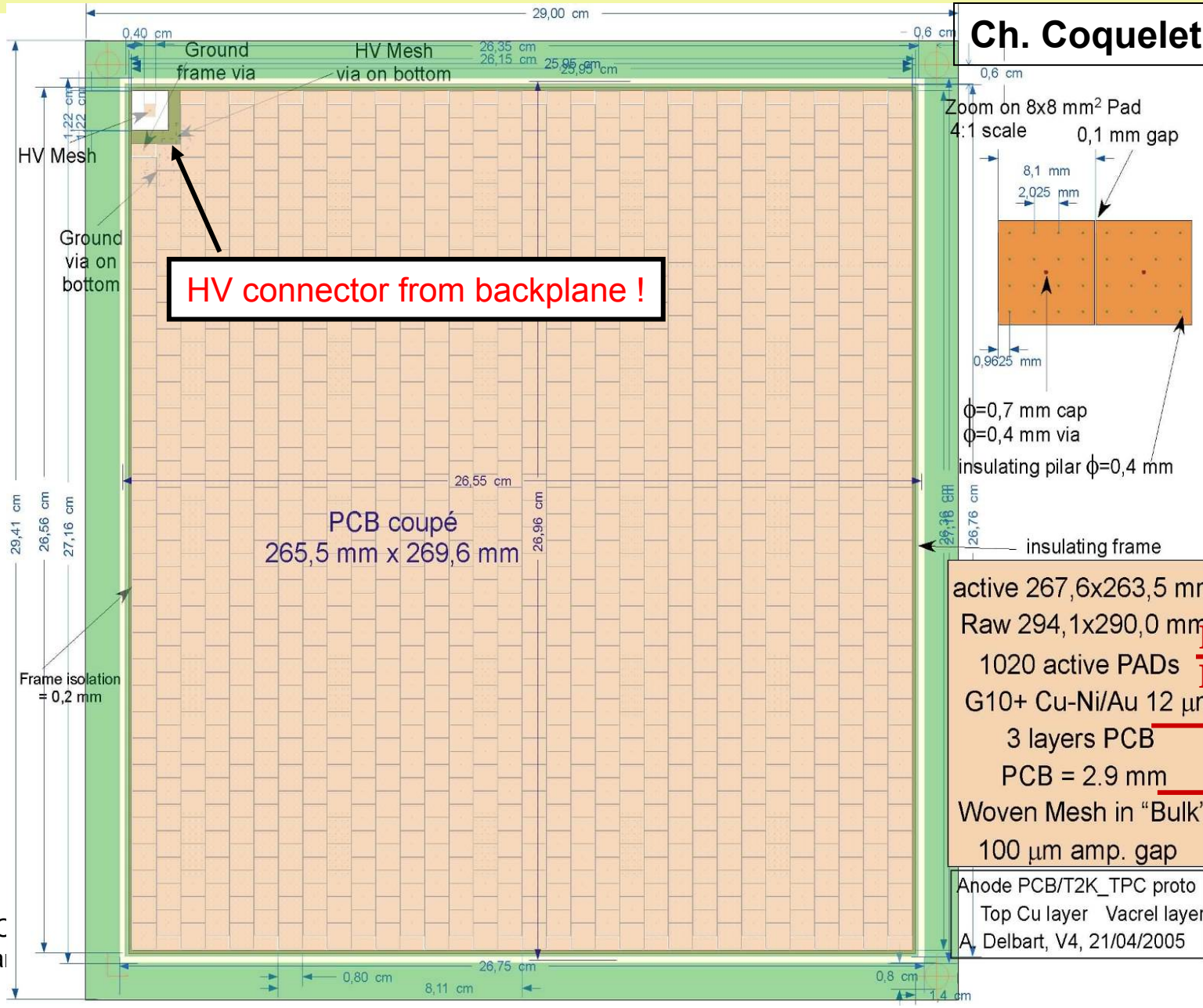
J-PARC beam power plan

21 nov. 2006 premier faisceau dans le LINAC : 3MeV, 5mA



T2K Micromegas 1020 pads PCB

Ch. Coquelet, A. Delbart



Done

FR4 ~20 µm

Passivated Cu

~3.2 mm

124 µm