ILD Large Prototype TPC tests with Micromegas

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GEM & Micromegas options for ILC TPC

Micromegas panels for Large Prototype

Studies on resistive coatings

Installation at DESY

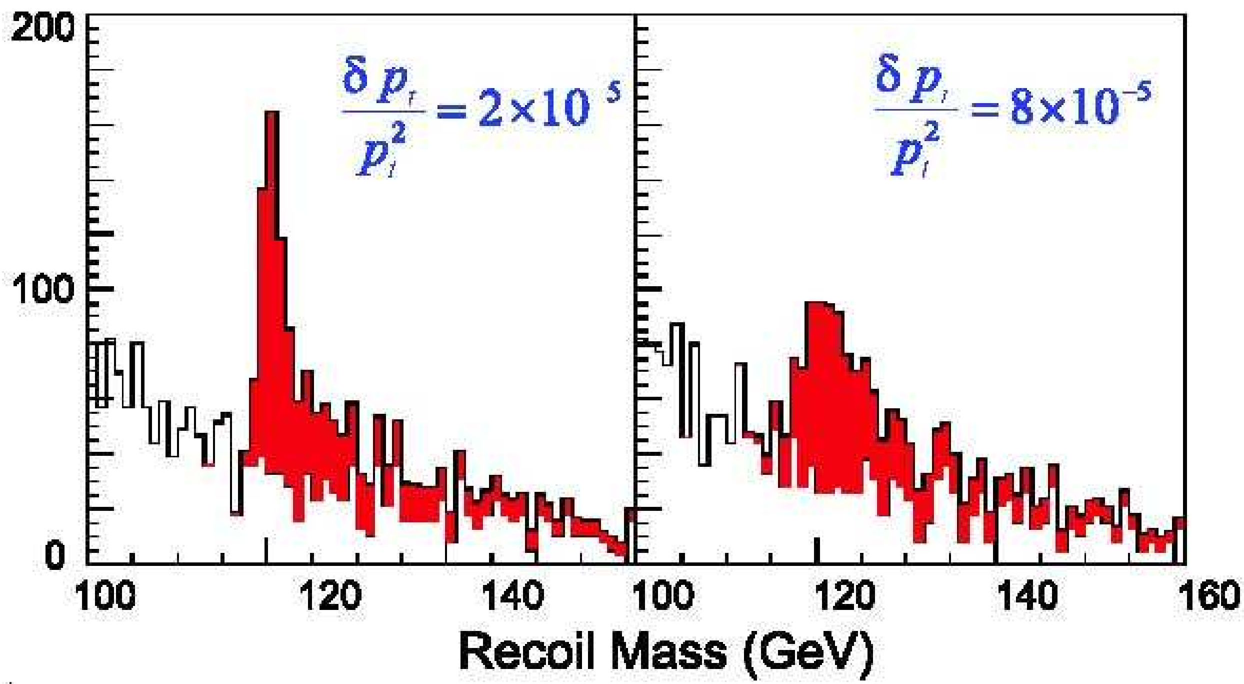
Software and simulation

Status of beam tests

ILC goal - to measure Higgs with precision limited only by the knowledge of beam energy

Puts unprecedented demands on the tracker resolution

$\Delta(1/p_T) \sim 2$ to 3×10^{-5} $(GeV/c)^{-1}$ more than 10 times better than at LEP!



$\mu^+ \mu^-$ recoil mass at $\sqrt{s}$ = 500 GeV. M_H = 120 GeV, for two values of the tracker resolution.

TPC development for the ILD central tracker

TPC an ideal central tracker for physics at ILC

- Low mass, minimal photon conversion
- High efficiency, high granularity continuous tracking,
- Excellent pattern recognition,
- Particle ID
- $\Delta(1/p_T) \sim 1 \times 10^{-4}$ (GeV^{-1}) (TPC alone)
  $\sim 3.10^{-5}$ (GeV^{-1}) (vertex + Si inner tracker + TPC)

TPC parameters:

- 200 track points
- **$\sigma(r, \varphi) \leq 100$ µm includes stiff 90° tracks ~ 2 m drift**
- $\sigma(z) \sim 1$ mm
- $\sigma_{2\ track}(r, \varphi) \sim 2$ mm
- $\sigma_{2\ track}(z) \sim 5$ mm
- dE/dx ~ 5%

Limits on achievable TPC resolution

- The physics limit of TPC resolution comes from transverse diffusion: $\sigma_x{}^2 \approx \frac{D_{Tr}^2 \cdot z}{N_{eff}}$ N_{eff} = effective electron statistics.
- For best resolution, choose a gas with smallest diffusion in a high B field

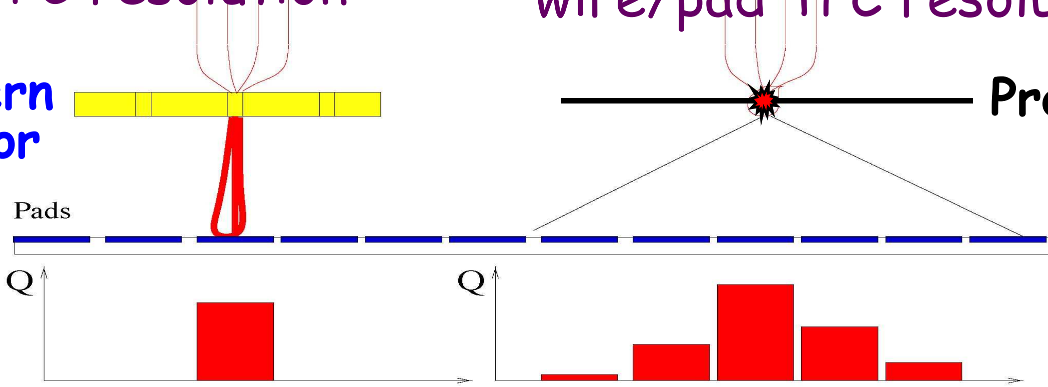
Pad width limits the MPGD TPC resolution

ExB systematics limits wire/pad TPC resolution

Micro Pattern Gas Detector

Proportional wire

Anode pads width w



Cathode pads width w

Direct signal on MPGD anode pads

Induced cathode signal determined by geometry

For small diffusion, less precise centroid for wide pads

Accurate centroid determination possible with wide pads

$$\sigma_x{}^2 \approx \sigma_0{}^2 + \frac{1}{N_{eff}}\left[D_{Tr}^2 z + w^2/12\right]$$

$$\sigma_x{}^2 \approx \sigma_0{}^2 + \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

Micro-Pattern Gas Detector R&D for ILD TPC

•2 mm x 6 mm pads (1,500,000 channels) with GEMs or Micromegas proposed initially (TESLA TDR)

•For the GEM, large transverse diffusion in the transfer & induction gaps provides a natural mechanism to disperse the charge improving centroid determination with wide pads.

•LC TPC R&D: 2 mm pads too wide with conventional readout. The GEM TPC readout will need ~ 1 mm wide pads to achieve the 100 μm ILC resolution goal (~3,000,000 channels)

•Even narrower pads needed for the Micromegas

Charge dispersion - a mechanism to disperse the MPGD avalanche charge so that wide pads can be used for centroid determination.

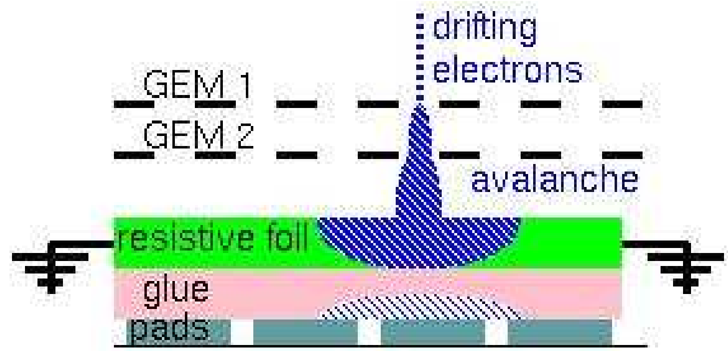
Charge dispersion in a MPGD with a resistive anode

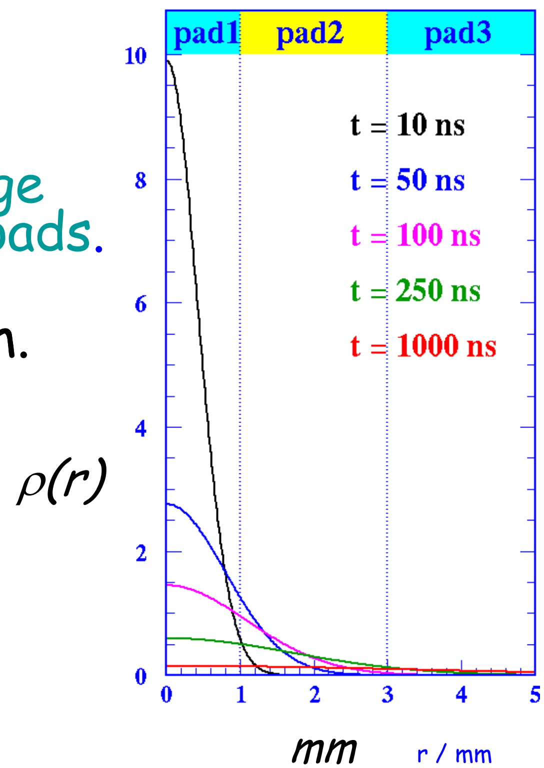
- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at r = 0 & t = 0 disperses with time.
- Time dependent anode charge density sampled by readout pads.

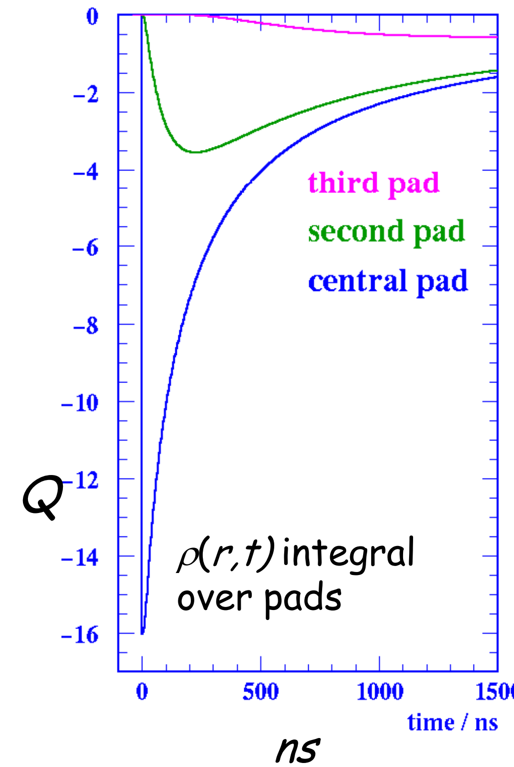
Equation for surface charge density function on the 2-dim. continuous RC network:

$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right]$$

$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$



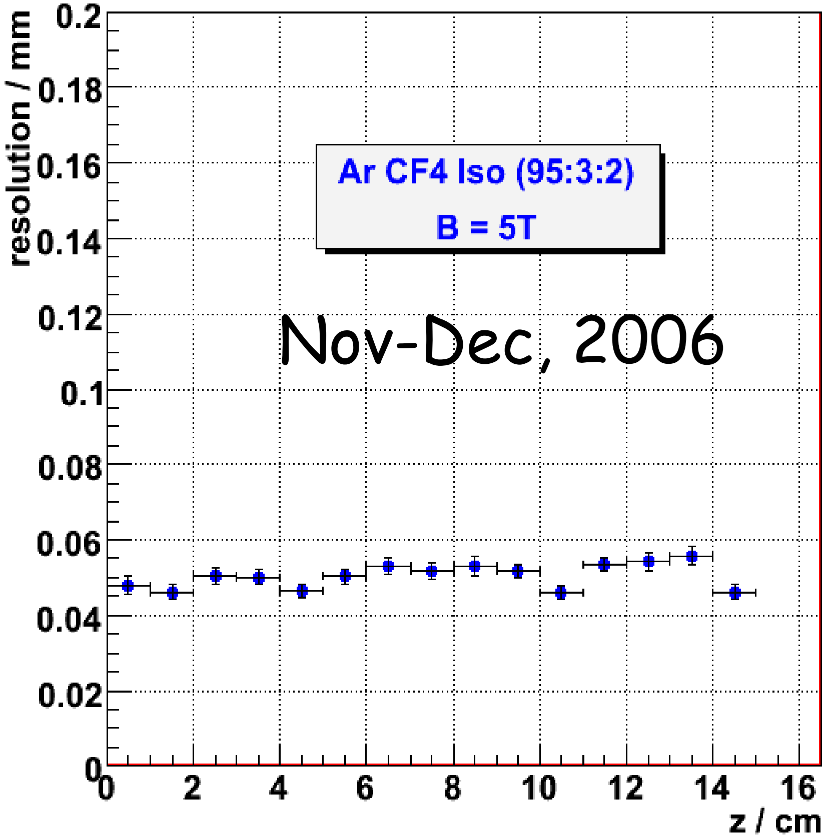




M.S.Dixit et.al., Nucl. Instrum. Methods A518 (2004) 721.

Cosmic ray tests at DESY in a 5 Tesla magnet Micromegas TPC with charge dispersion readout

D_{Tr} = 19 μm/√cm, **2 x 6 mm² pads**



M. Dixit et. al, NIM A 581, 254 (2007)

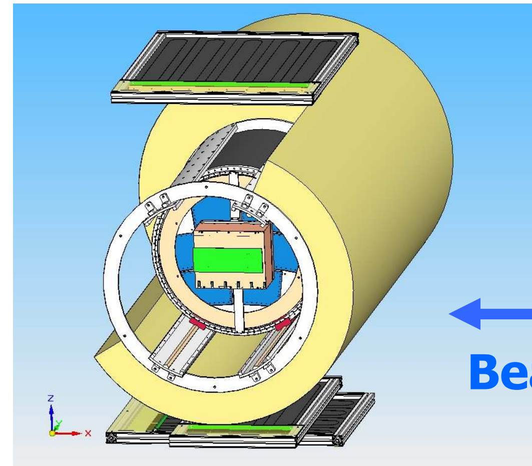
~ 50 μm av. resolution over 15 cm (diffusion negligible) 100 μm over 2 meters looks within reach!

TPC Large Prototype (LP) Beam Test at DESY by LC TPC Collaboration using EUDET Facility

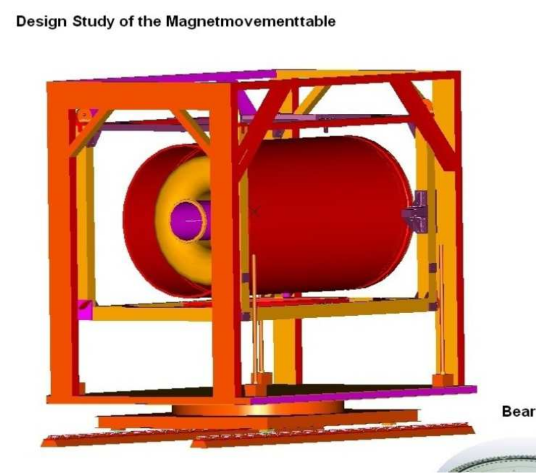
Goals

- **Study, in practice, design and fabrication of all components of MPGD TPC in larger scale; field cage, endplate, detector modules, front-end electronics and field mapping of non uniform magnetic field. (But not yet the engineering stage.)**
- **Demonstrate full-volume tracking in non-uniform magnetic field, trying to provide a proof for the momentum resolution at LC TPC.**
- **Demonstrate dE/dX capability of MPGD TPC.**
- **Study effects of detector boundaries.**
- **Develop methods and software for alignment, calibration, and corrections.**

(Beijing tracker review, Jan 2007)



Beam

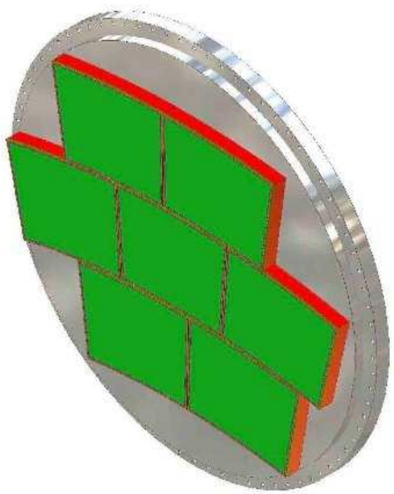


From Takeshi MATSUDA - 2nd RD51 Collaboration Meeting Paris 13 Oct, 2008

GEMs & Micromegas both being developed presently

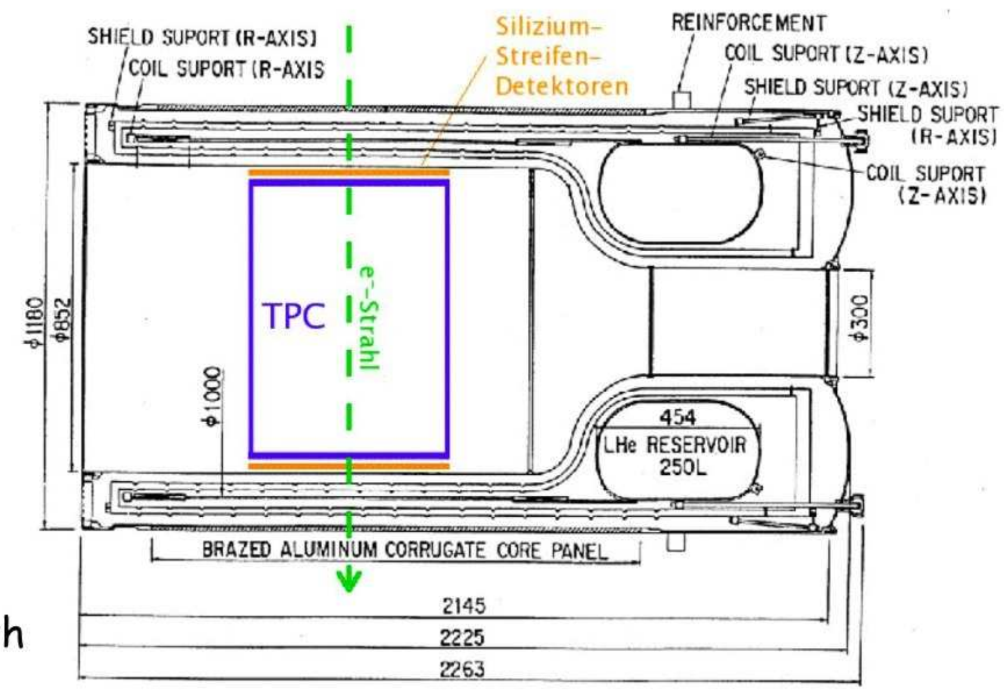
GEMs readout with ~ 1 mm wide pads

Micromegas with 2-3 mm wide pads charge dispersion readout



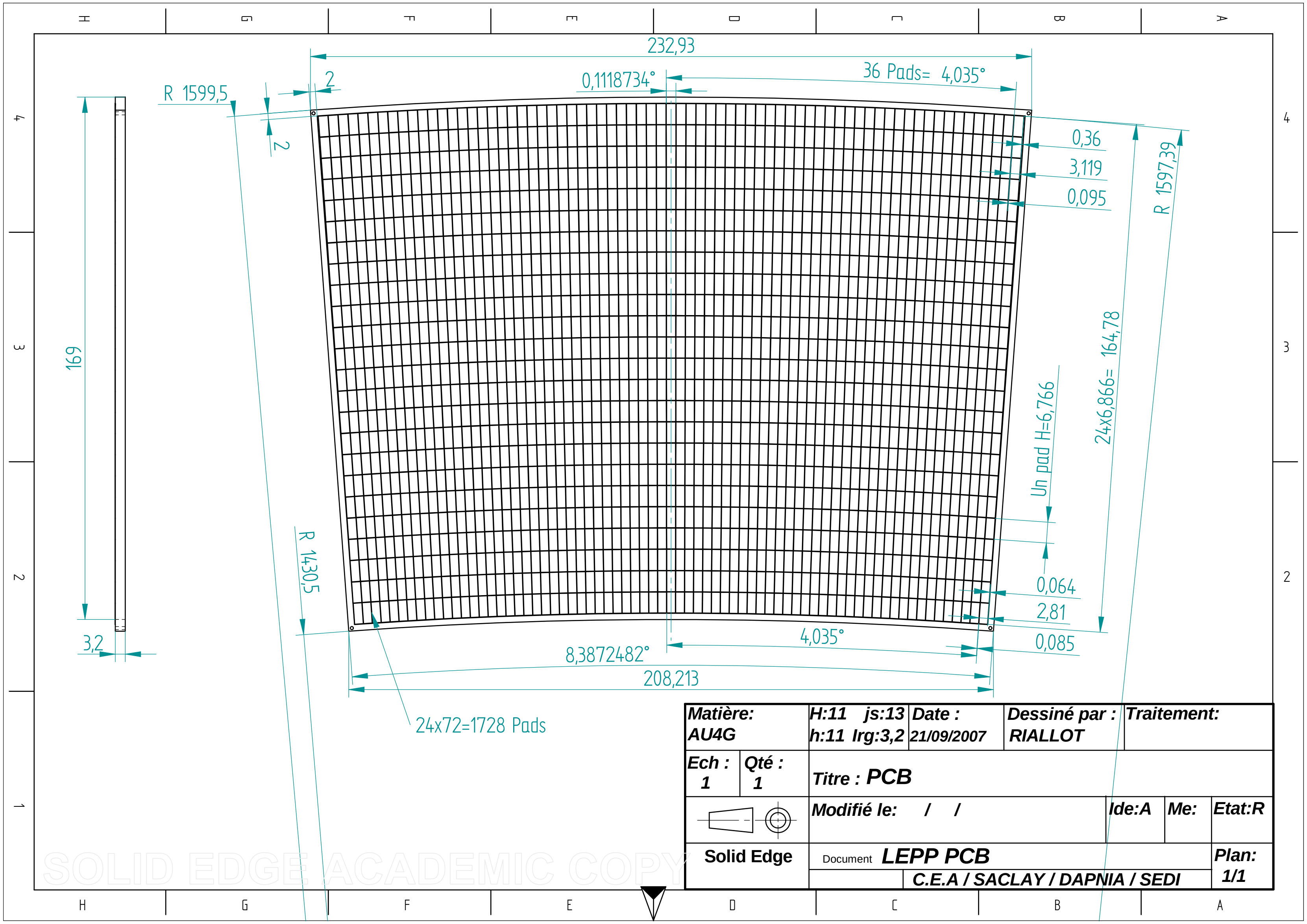
TPC endplate: 7 modules with Micromegas with charge dispersion readout.

To be built by Canada and France



Large prototype in the 1 T magnet PCMAG. The 6 GeV electron beam will enter through the magnet coil transverse to the drift direction. The magnet has no iron.

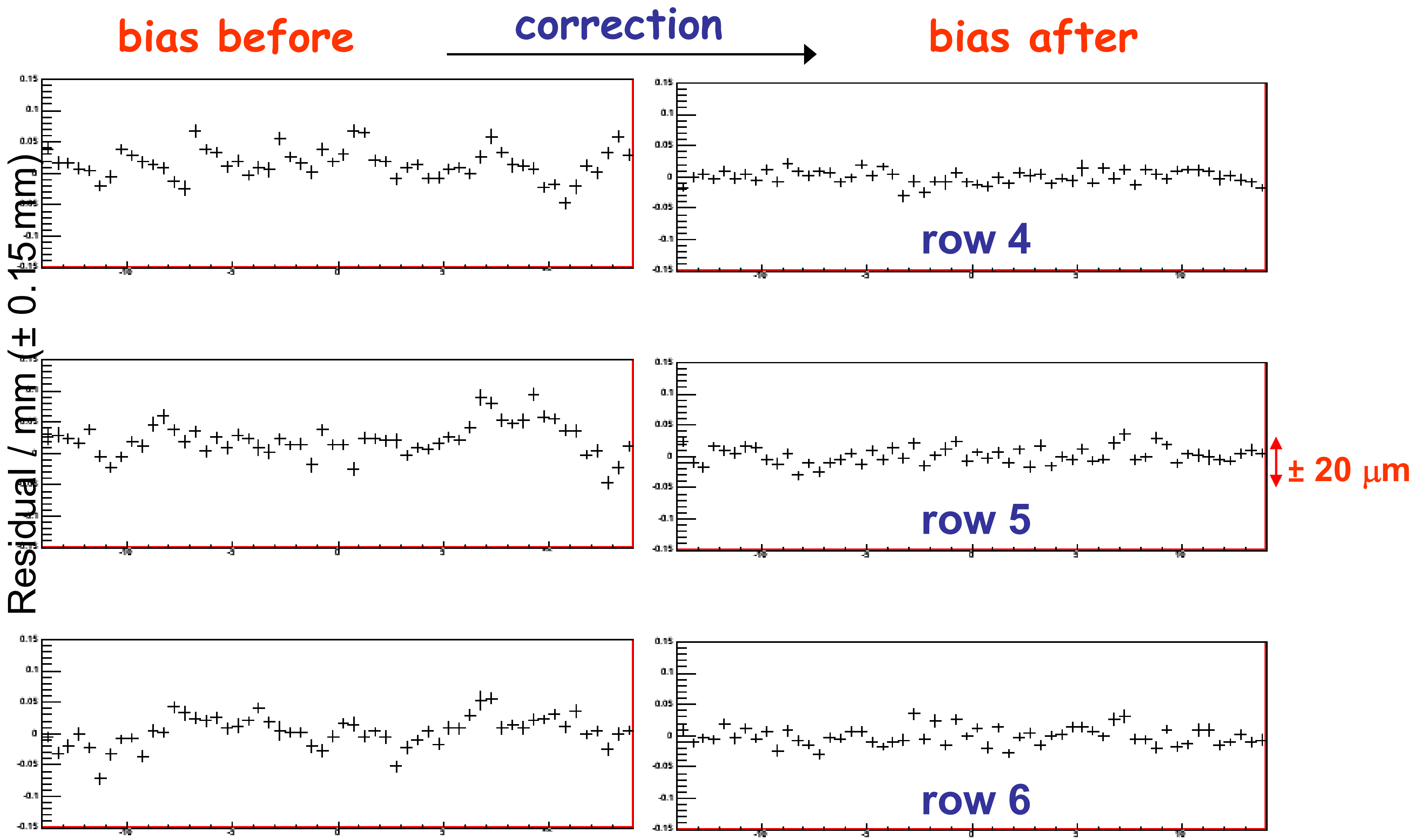
Micromegas panel designed & fabricated at Saclay



R&D specific to LP Micromegas panels

- Point to point variations of surface resistivity (R) and capacitance density (C) of anode pad readout structure must be minimized
- Non-uniform RC response leads to systematic bias in position determination
- Bias easy to correct for small 10 cm x 10 cm Micromegas tested so far
- Development of Bulk Micromegas with resistive anode readout
- AFTER front-end based on T2K readout electronics

Bias correction for 10x10 cm^2 Micromegas with charge dispersion readout



Correction will be cumbersome for the larger area LP panels

Development of uniform high surface resistivity anode films

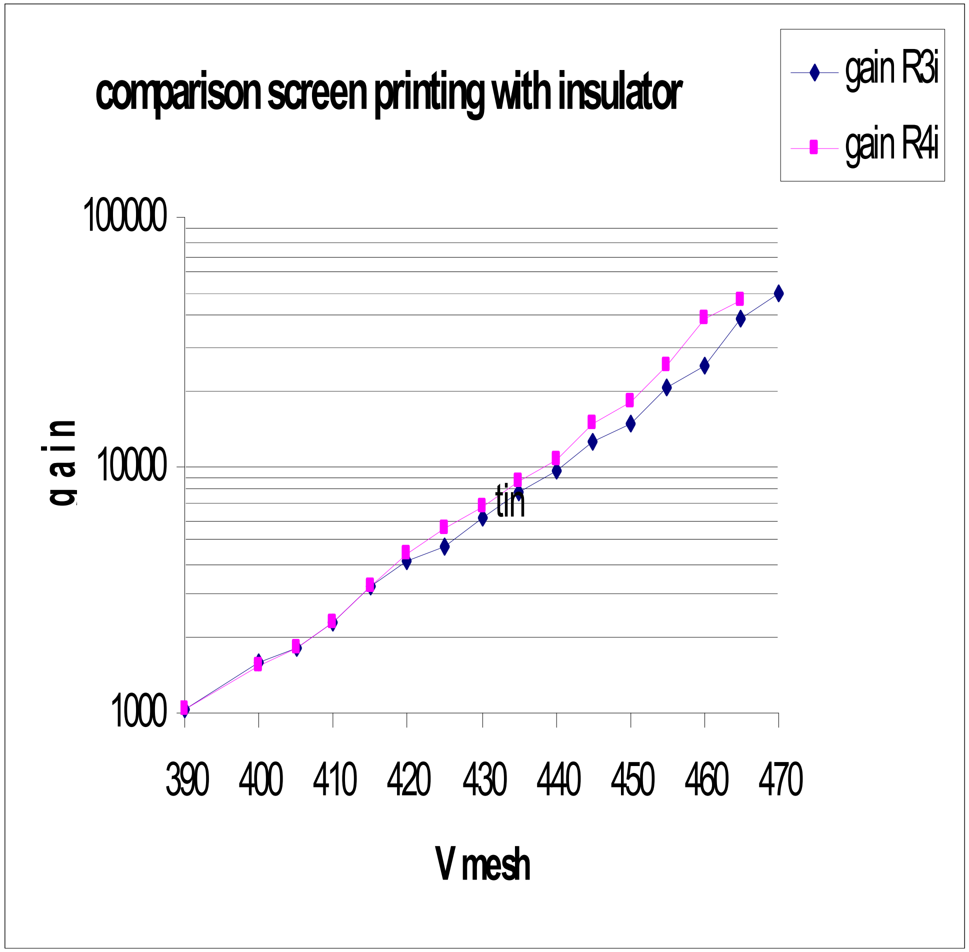
Several techniques are being tested for the resistive anode coating

1) Carbon-loaded Kapton. An old technique first tested at Carleton applied to bulk Micromegas with improvement in laminating resistive film to pad readout PCB

First results promising. One panel produced.

2) Prepreg+ screen printing

Tried initially at CERN. Two prototypes of 10 cm x10 cm (2 and 8 MOhm/sq) have been tried at Saclay. Not clear if that they sparks are damped. One detector damaged by sparking Still such a layer will be applied to a CERN panel.

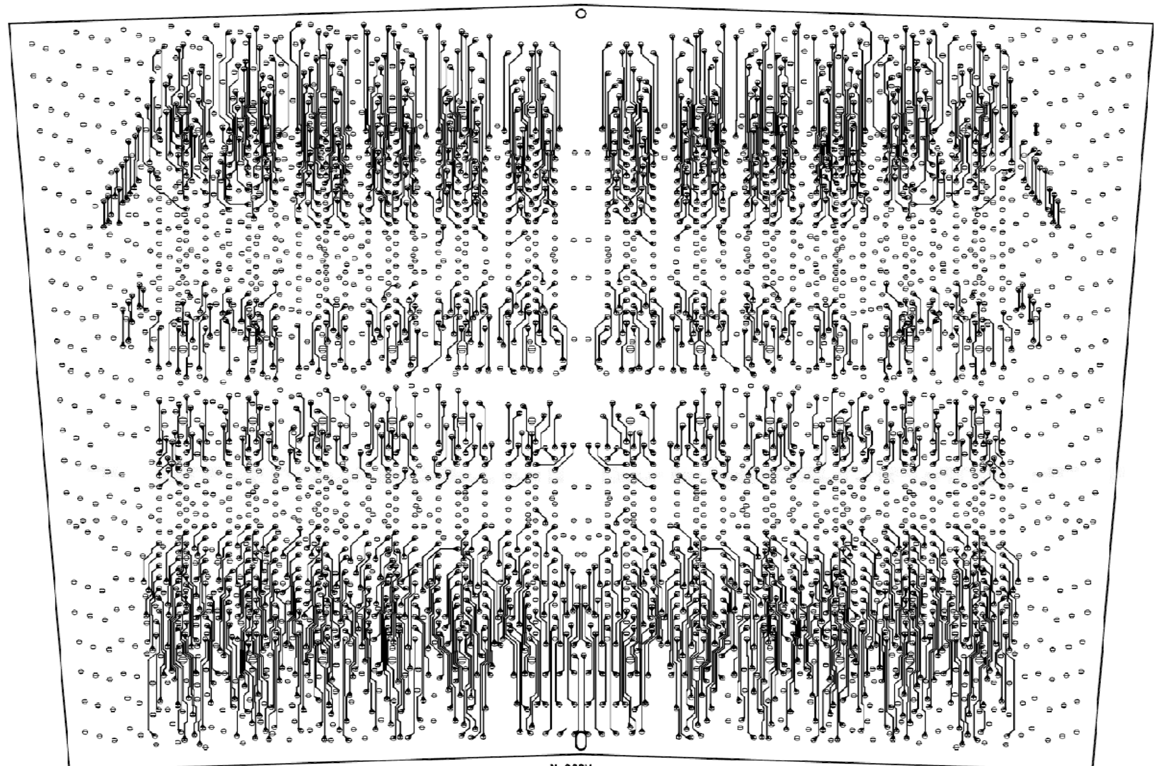


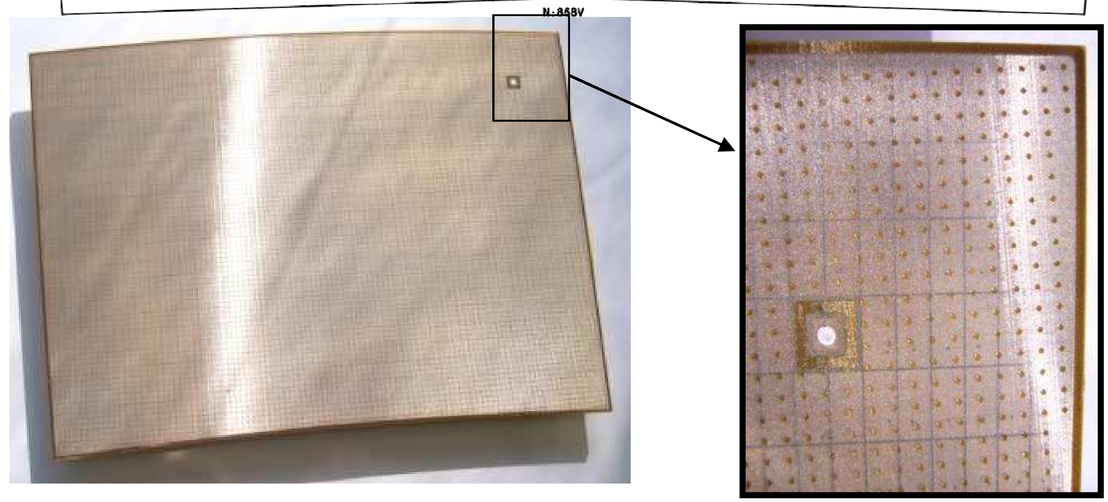
The panels

PCBs have been produced

4 with the Saclay routing in 6 layers

4 with the CERN routing with 4 layers





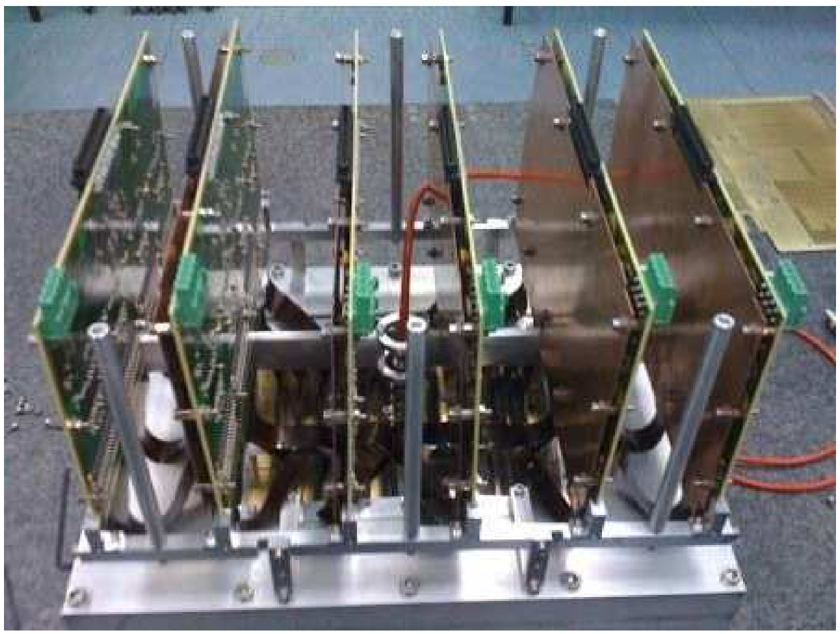
Two panels ready and tested at DESY

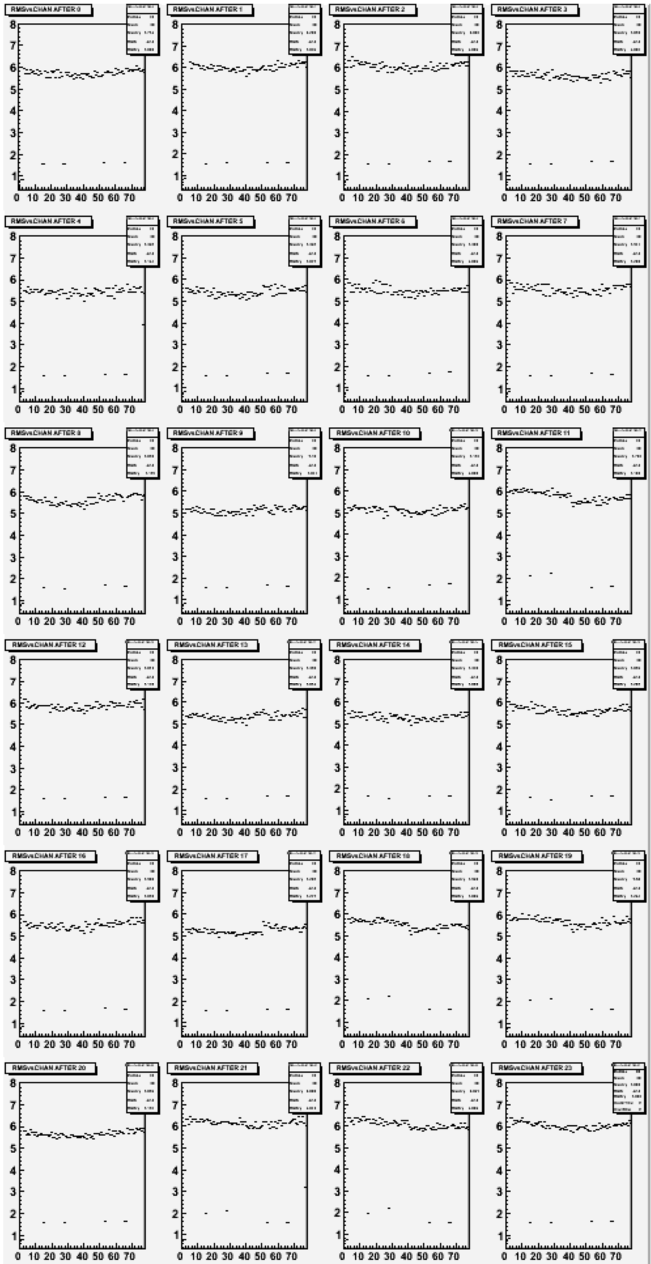
One with standard pads, one with resistive anode (C-loaded Kapton)

Two more panels under construction, one with screen printing resistive anode, one with deposited layer

Mechanical support of electronics

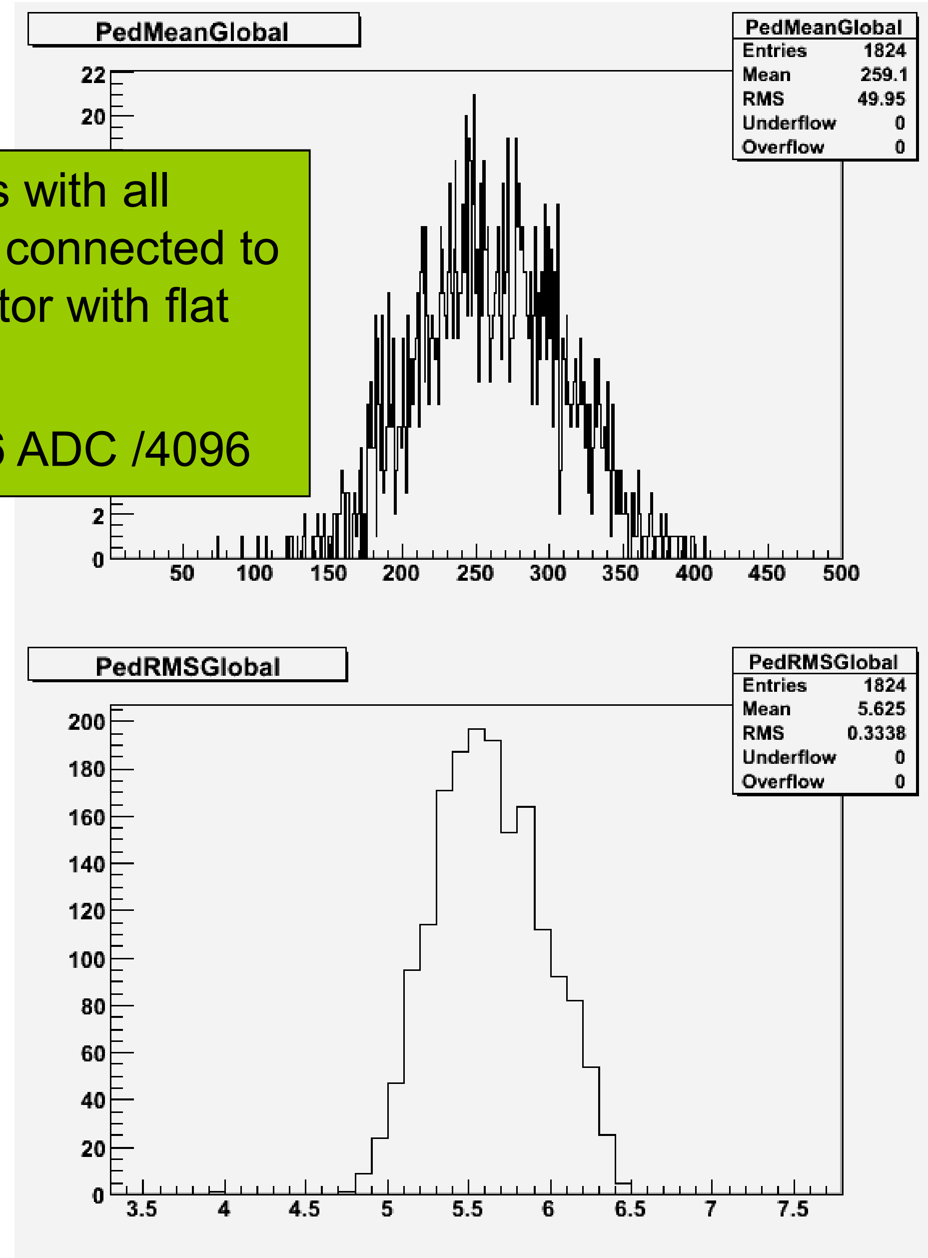
Shielding, Faraday cage, flat cables, gas box…



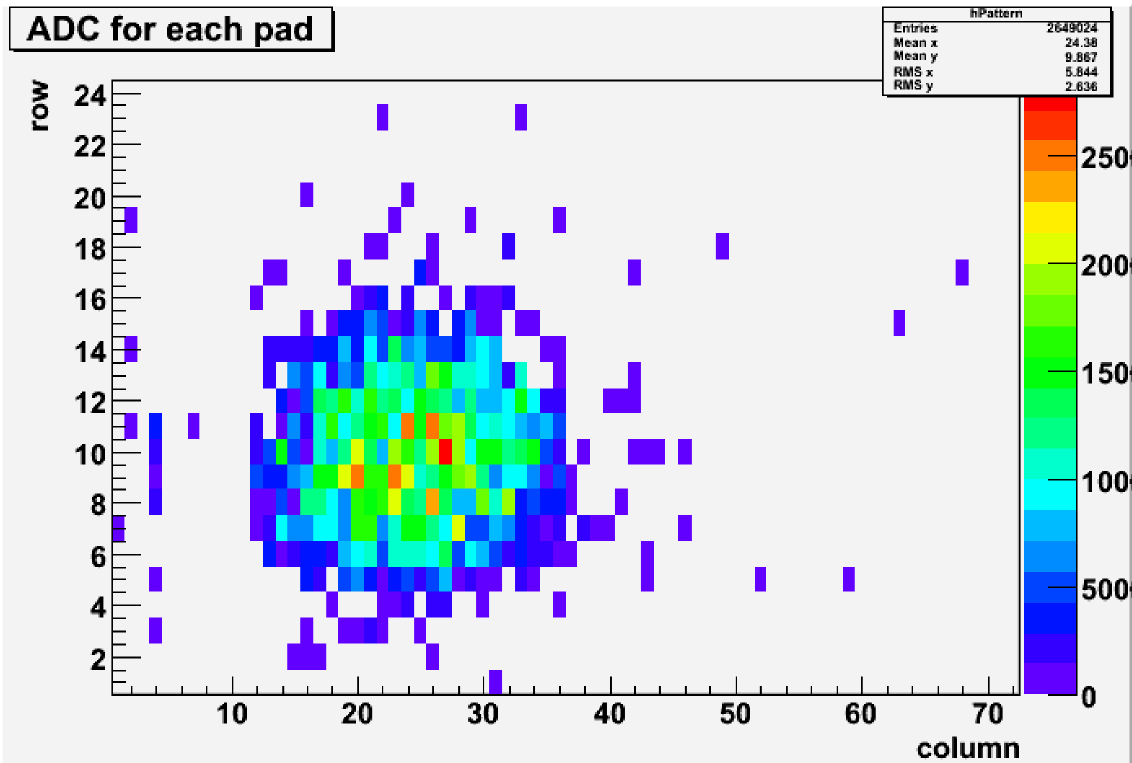


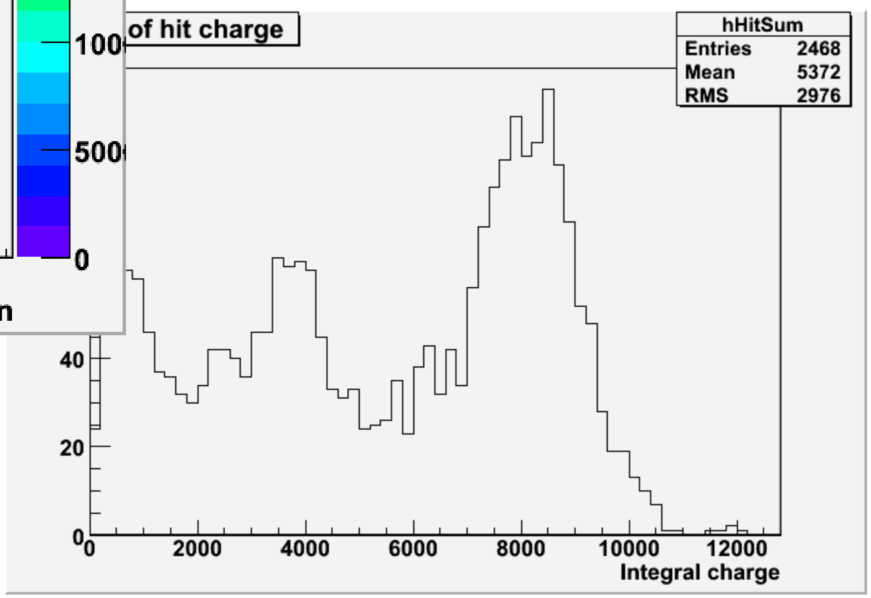
Pedestals with all channels connected to the detector with flat cables

$<\sigma>$ = 5.6 ADC /4096

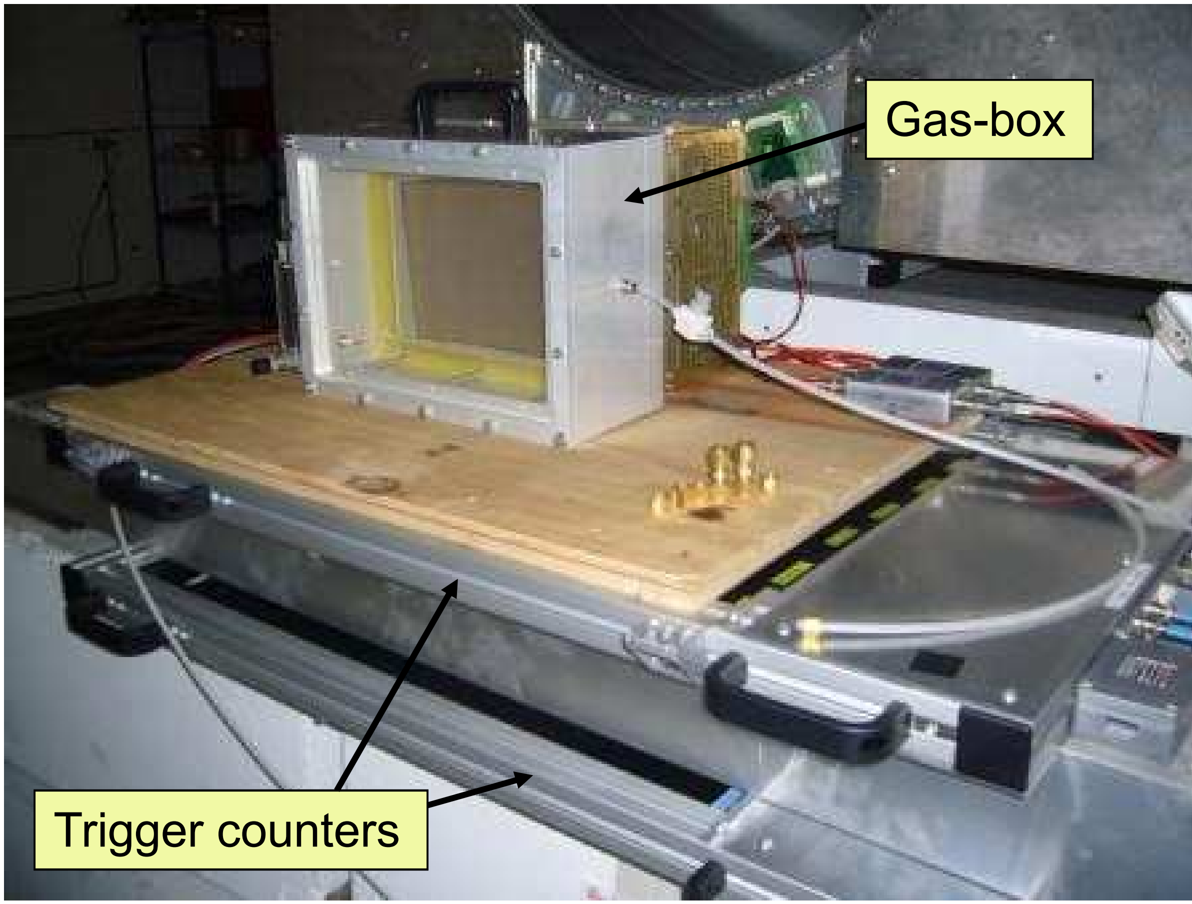


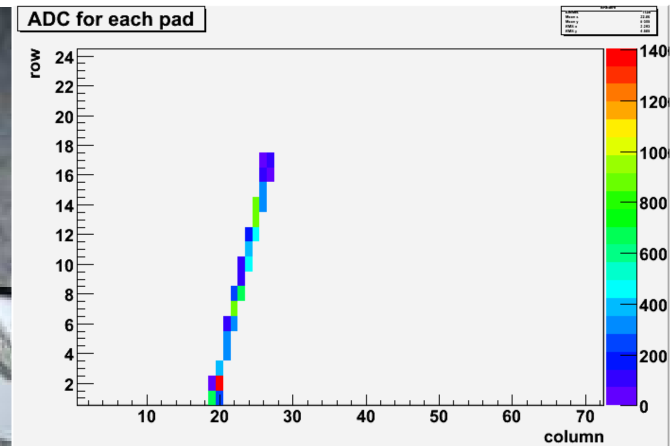
Tests at Saclay with a ^{55}Fe source

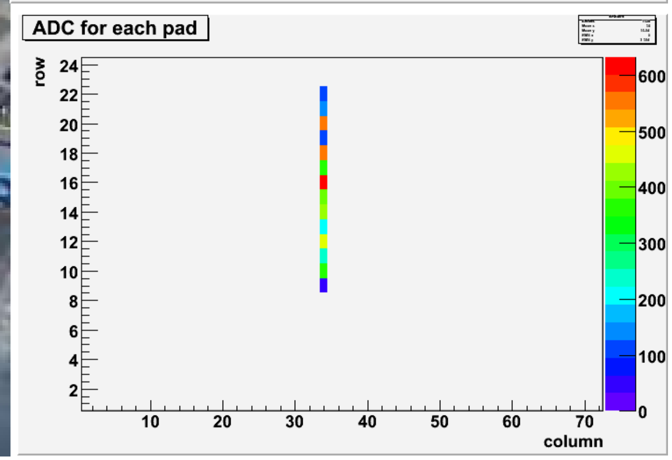


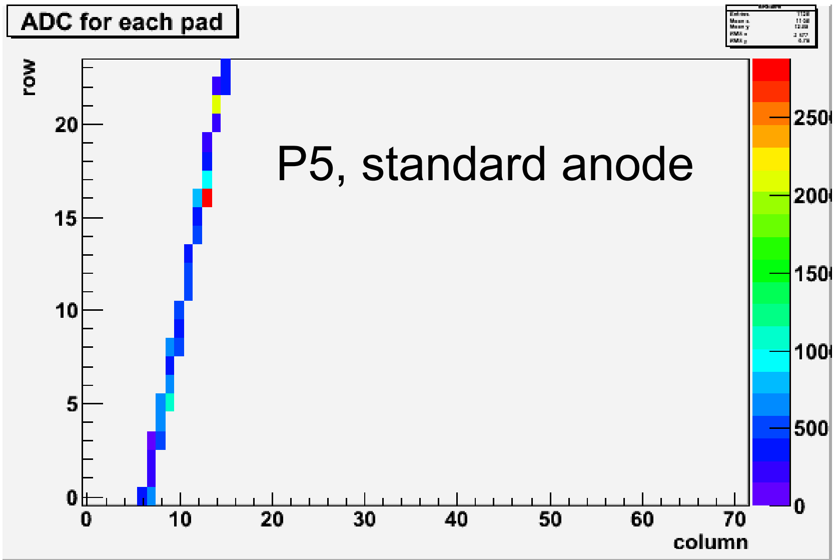


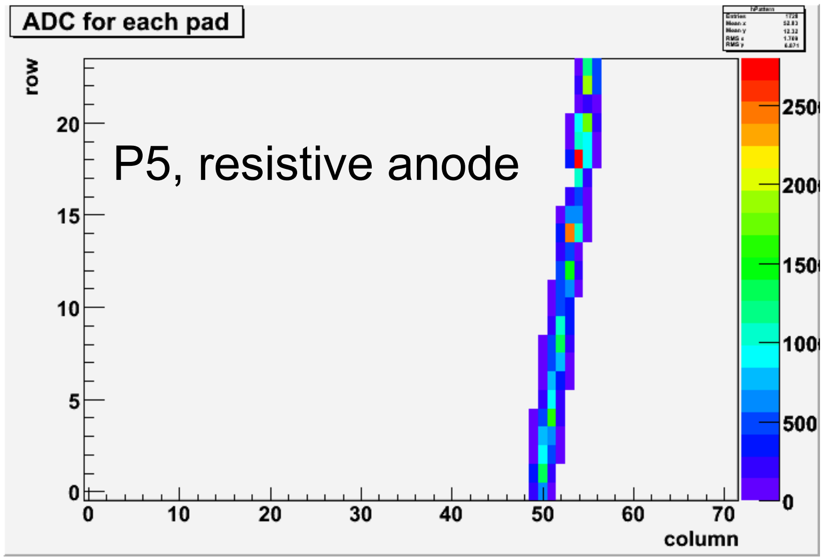
In-situ cosmic ray tests in test box at DESY

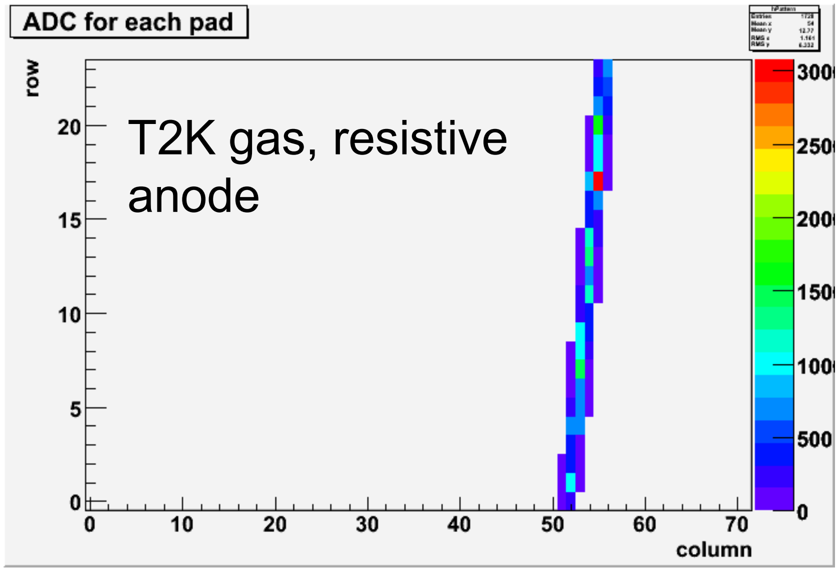






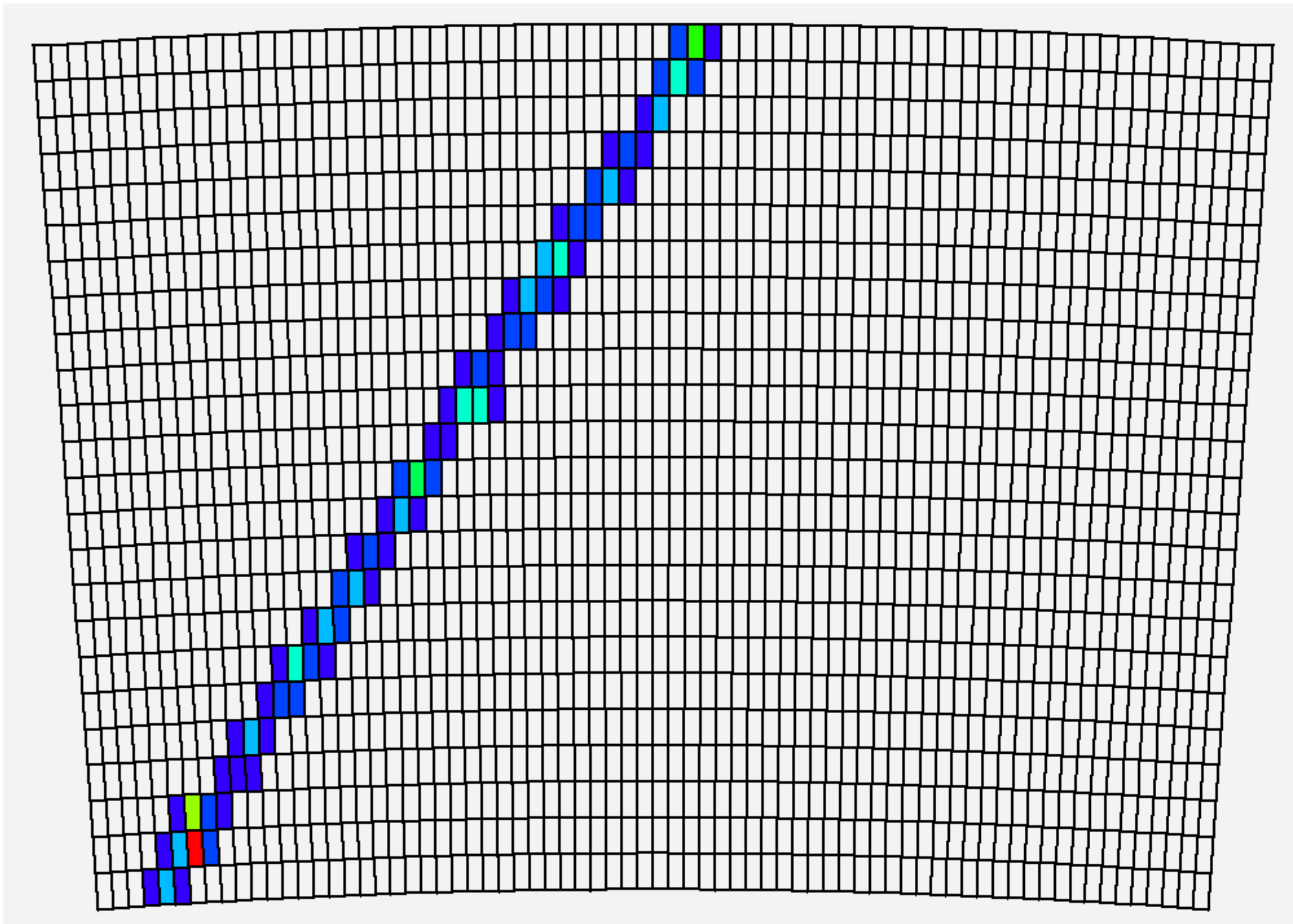






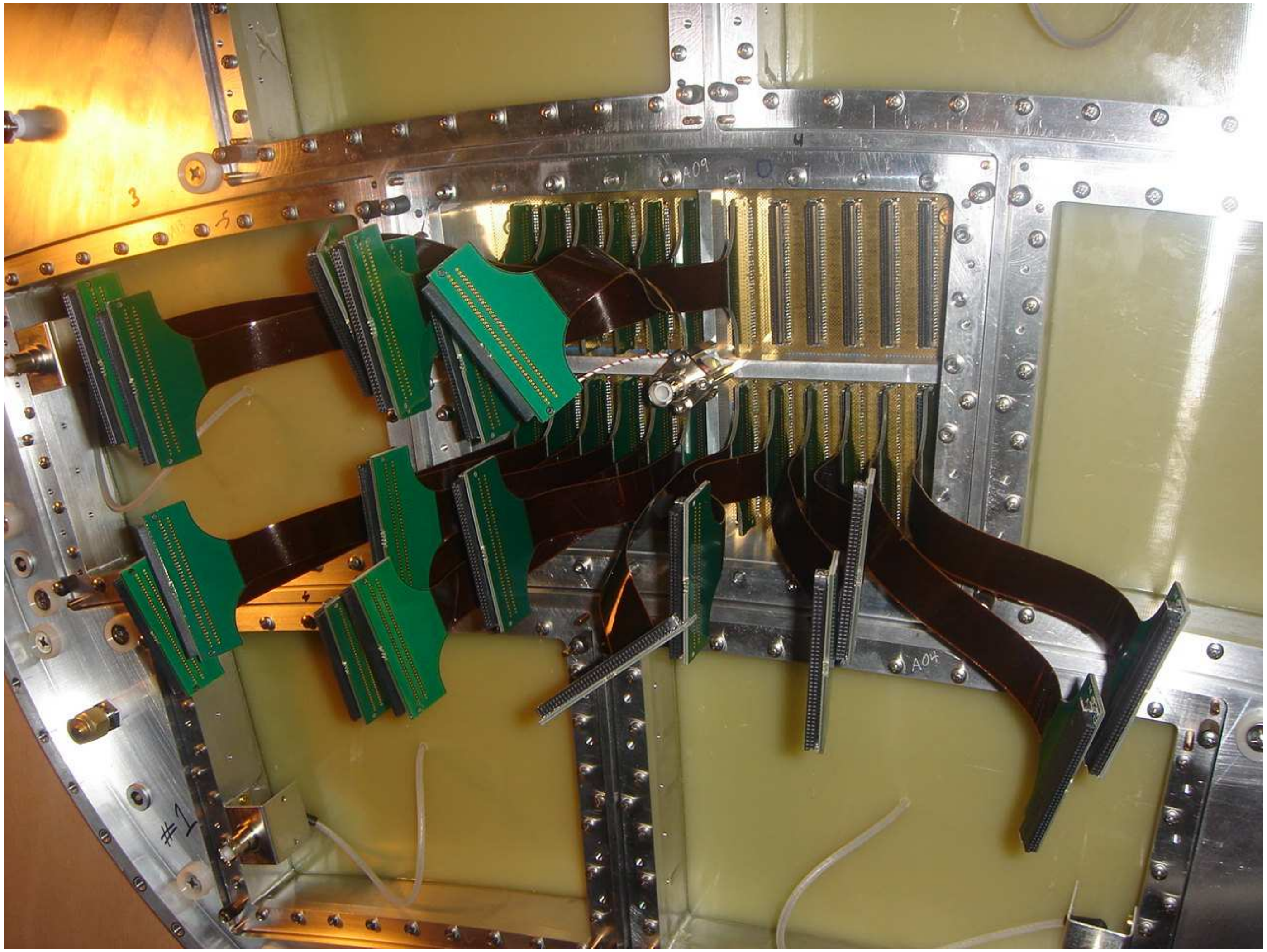
Data taken at 50 and 100 MHz, with shaping times of 200 ns, 400 ns, 1 & 2 μs

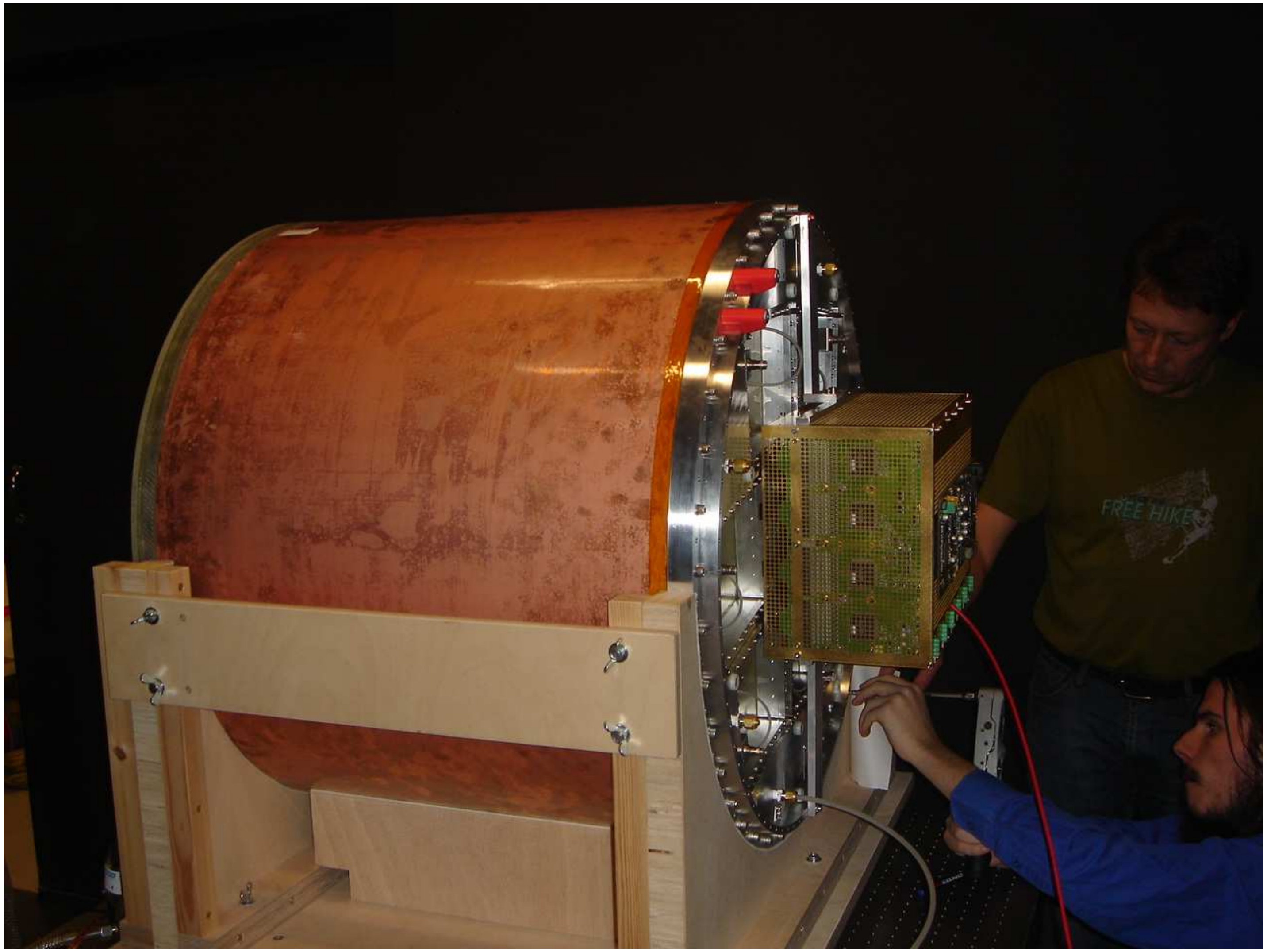
Event display



Presently developing software and analysis tools (D. Attié, S. Turnbull, Yun-Ha Shin, with Martin Killenberg): LCIO converter, JTPC, Marlin

AFTER electronics installation




FREE HIKE

Simulation for the LP keystone pads - New C++ program

Charge dispersion equation:

$$\frac{\partial \rho}{\partial t} = h\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \rho}{\partial r}\right)\right);\text{ here } h = 1/RC\,.$$

Time dependent surface charge density function:

$$\rho(r,t) = Ke^{-r^2/\alpha 2}.\text{ Here } K = Nq_e/\pi\alpha^2\ \&\ \alpha^2 = 2(2ht + w^2)\,.$$

w is the RMS cluster size at t = 0

For charge cluster at (r_0, ϕ_0), the signal on pad i at (r_i, ϕ_i) is:

$$Q_i(t) = \iint \rho(r,\phi,t)\,r\,dr\,d\phi$$

$$= I_1(r_i + l, \omega_i) - I_1(r_i, \omega_i) + I_2(r_i, \omega_i) - I_2(r_i + l, \omega_i)$$

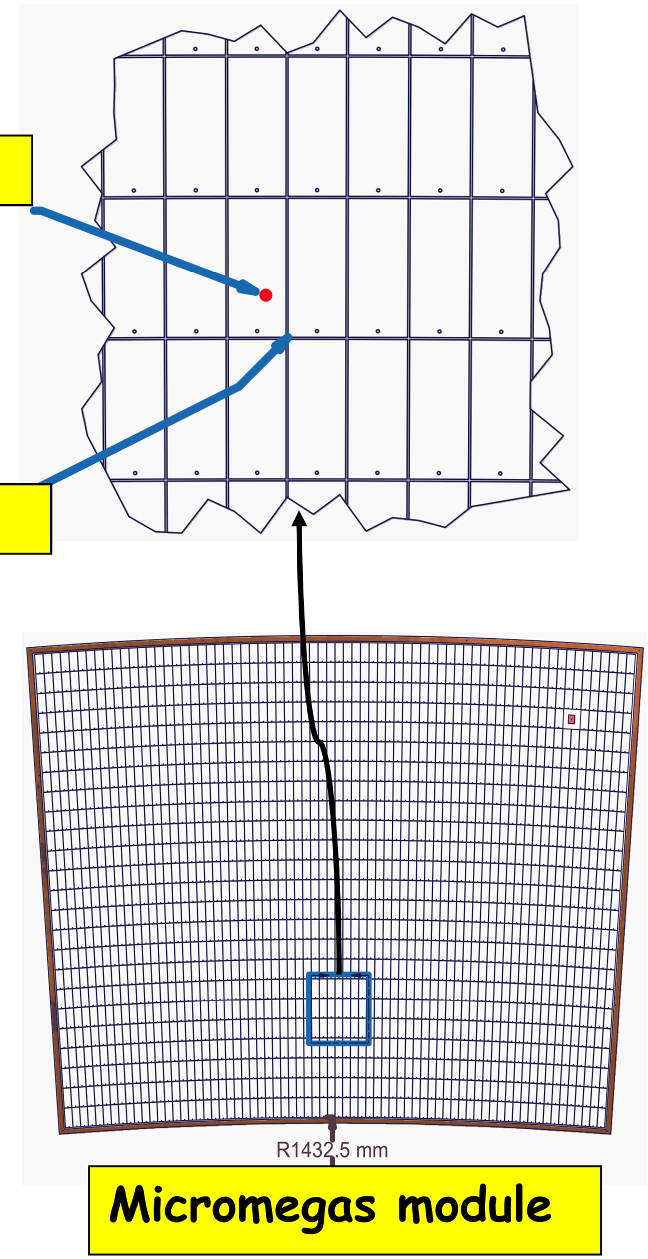
where l is the pad length, $\omega = \phi - \phi_0\ \&\ \omega_i = \phi_i - \phi_0$;

The functions I_1 and I_2 are defined by:

$$I_1(r_i,\omega_i) = \frac{K}{2}\sqrt{\pi}\alpha \int_{\omega_i}^{\omega_i+\delta} r_0 \cos(\omega) e^{-r_0^2 \sin^2(\omega)/\alpha^2}\, erf\left(\frac{r_i - r_0\cos(\omega)}{\alpha}\right) d\omega$$

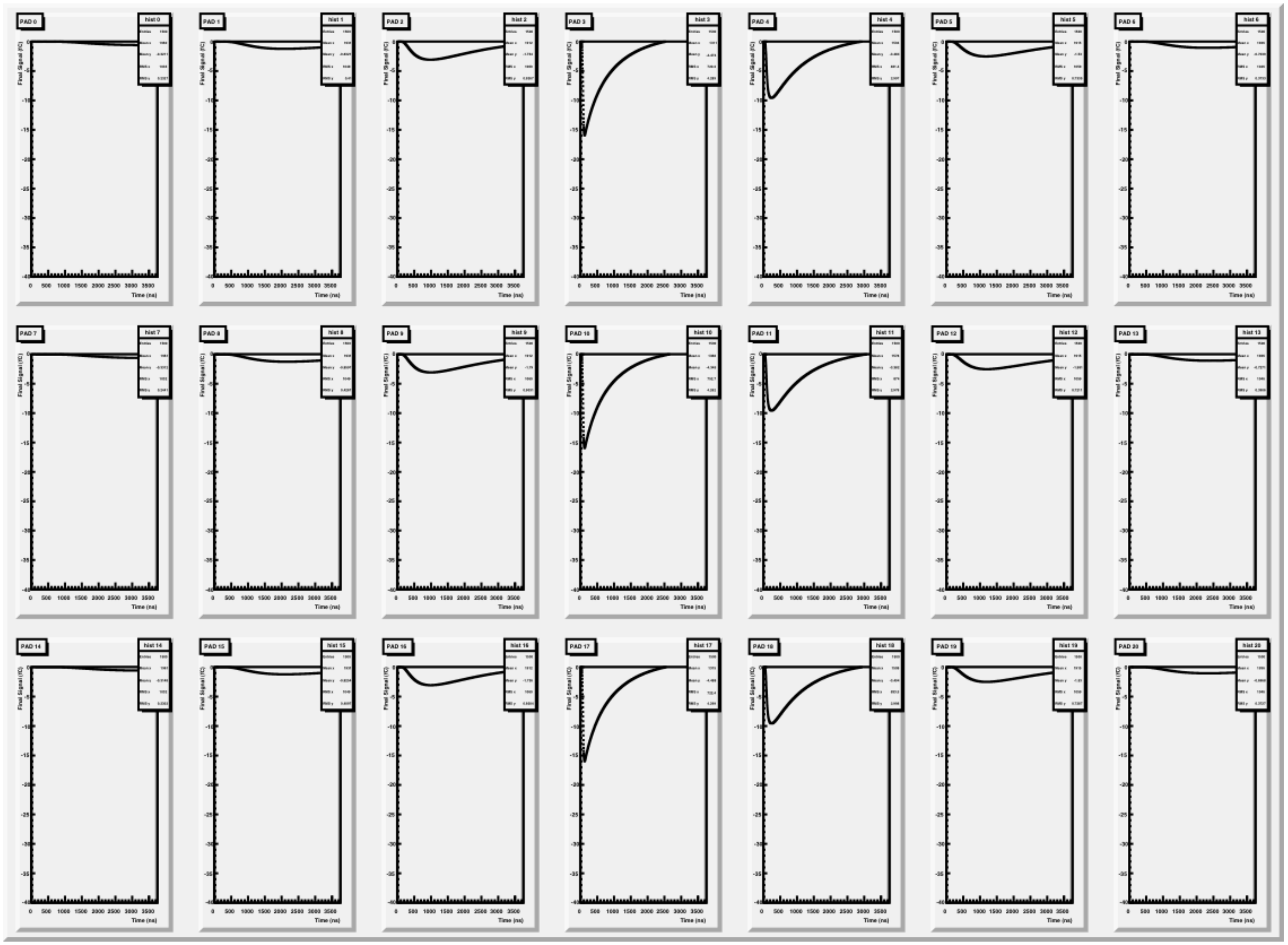
$$I_2(r_i,\omega_i) = \frac{K}{2}\alpha^2 \int_{\omega_i}^{\omega_i+\delta} e^{\left(-r_0^2 - r_i^2 + 2r_i r_0 \cos(\omega)\right)/\alpha^2}\, d\omega$$

where δ is the angular pad width in radians

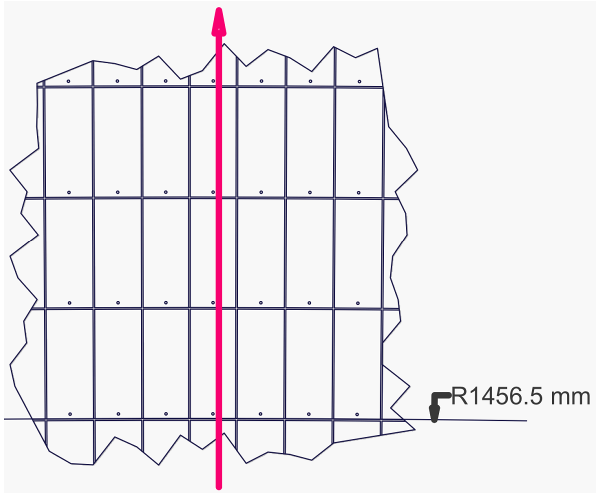


High momentum simulated track signal B = 4 T (keystone pads)

$Ar/CF_4/C_4H_{10}$ 95/3/2, E = 200 V/cm, v_{drift} = 73 μm/ns D_T = 23 μm/√cm D_L =249 μm/√cm



Pad dimensions
Length = 6 mm
Width 1.984 mrad



Micromegas risetime 50 ns, preamp rise time 40 ns, preamp decay time 2 μs, Anode resistivity 1 MΩ/□, Dielectric gap = 75 μm, dielectric constant 1.85

Present status and plans

- TPC field cage tested to 19 kV in air and is presently being flushed with gas
- Magnet is ready
- Move TPC to beam area
- Initial data taking with standard readout
  - Cosmic rays
  - With beam
  - With beam and magnet
  - Switch to resistive anode readout

Future plans

Start R&D for electronics on a mezzanine PCB. Planned for early 2010.

- R&D to optimize protection, compactness
- Development to test AFTER chips at the wafer level
- new card design

Make 7 fully equipped modules

Start cooling and integration studies