Construction and Tests of MPGD TPC Endplate Prototypes for the ILC

-- Status and Perspectives --

Keisuke Fujii on behalf of the D-R&D 2 Team
FJPPL Workshop, '08
CNRS HQ: 15 May, 2008

We would like to dedicate this talk to Late Vincent Lapeltier

Vincent made invaluable contributions to the DELPHI-TPC and more recently to the R&D for the LC-TPC.

It was only two months ago when we discussed together in Japan the basic research on the gas multiplication processes and the future of the LC-TPC developments.

Introduction

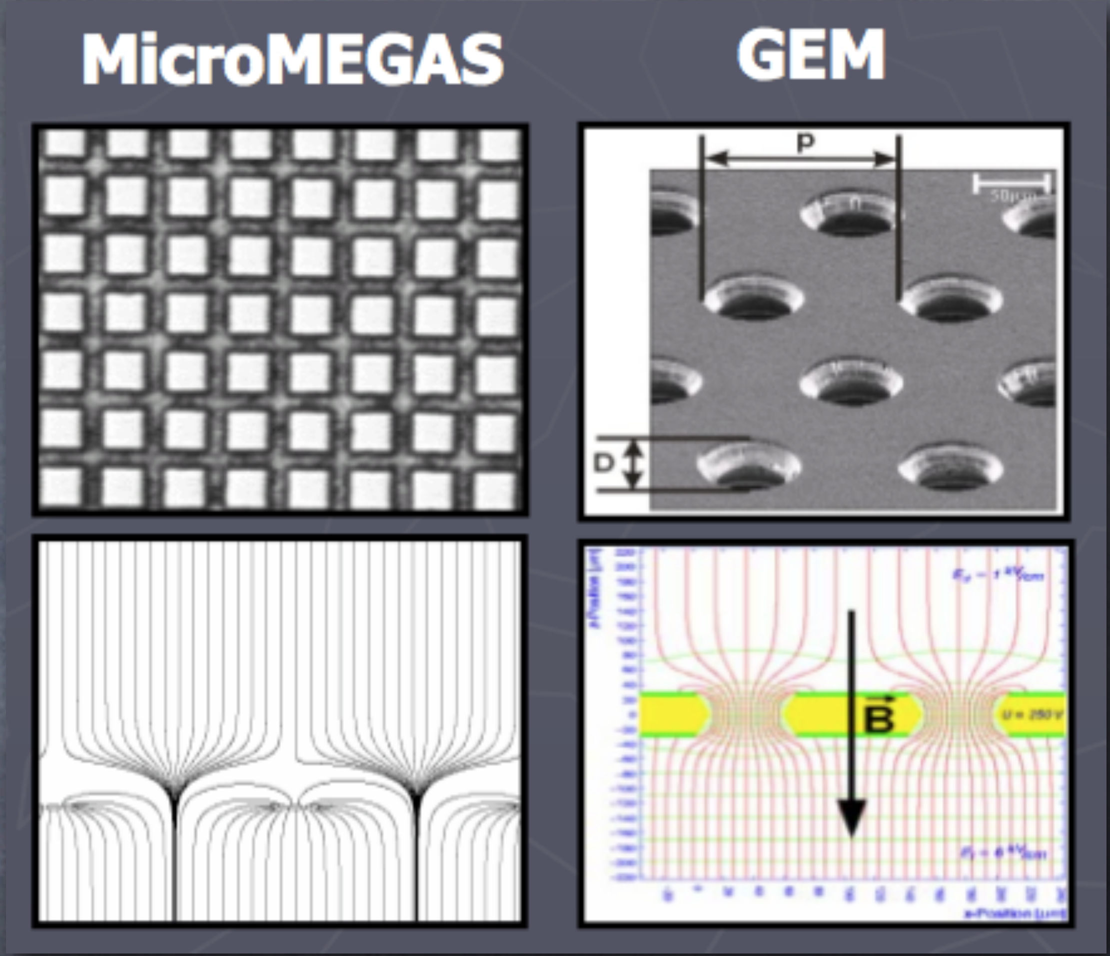
Performance Goals

for the LC-TPC

- >200 sampling points along a track with a spatial resolution better than ~100 microns in the XY plane over the full drift length of >200 cm
- 2-track separation better than ~2mm to assure essentially 100% tracking efficiency for jetty events
- High tracking efficiency also requires minimization of dead spaces near the boundaries of readout modules

Why MPGD readout?

- We need high (>3 T) B field to confine e+e- pair BG from beam-beam interactions, then ExB too big for conventional MWPC readout
- 2mm 2-track separation is difficult with MWPC readout
- Thick frames are unavoidable for MWPC readout



Micro-Pattern Gas Detectors

The Three R&D Phases for the ILC TPC

R&D Phase

1. Demonstration Phase: Provide a basic evaluation of the properties of an MPGD TPC and demonstrate that the requirements (at ILC) can be met using small prototypes.
2. Consolidation Phase: Design, build and operate a "Large Prototype" (of large number of measured points) at the EUDET facility in DESY.
3. Design Phase: Start working on an engineering design for aspects of the TPC at ILC.

We are mostly in the phase 2. However, there are still important studies of the phase 1 left, and the phase 3 is now starting together with the new ILD group.

The LC-TPC Collaboration

The F-J Team

The team

- FRANCE
  - CEA/Dapnia Saclay
    - M. Chefdeville
    - P. Colas
    - D. Attie
    - A. Giganon
    - I. Giomataris
    - M. Riallot
    - F. Sénée
    - S. Turnbull
  - CNRS/IN2P3 Orsay
    - (V. Lepeltier) (LAL)
    - Ph. Rosier (IPN)
    - T. Zerguerras (IPN)
- JAPAN
  - KEK/IPNS
    - K. Fujii
    - K. Ikematsu
    - M. Kobayashi
    - T. Matsuda
    - R. Yonamine
  - Saga
    - (A. Aoza)
    - T. Higashi
    - H. Kuroiwa
    - A. Sugiyama
    - H. Tsuji
    - H. Yamaguchi
  - Kinki U.
    - Y. Kato
    - T. Yazu
    - K. Hiramatsu
  - Hiroshima U.
    - T. Takahashi
  - Tokyo TUAT
    - M. Bitou
    - O. Nitoh
    - H. Ohta
    - K. Sakai
  - Kogakuin
    - T. Watanabe
  - Nagasaki
    - T. Fusayasu

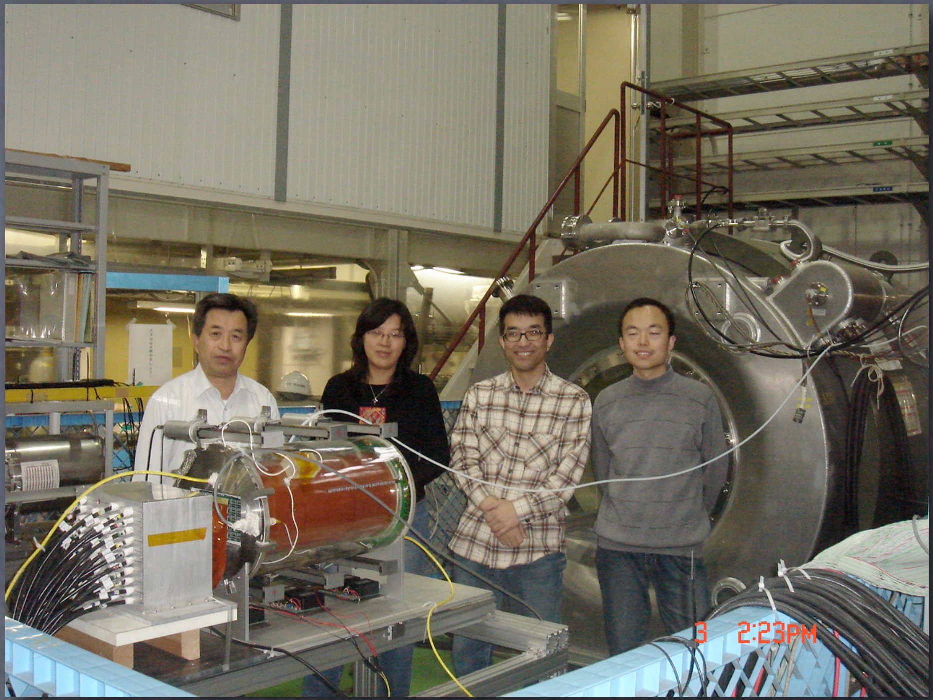
Activities

-- The past (about) one year --

- K. Fujii participated in a TPC analysis “Jamboree” in Aix-la-Chapelle in March 2007
- P. Colas participated in FJPPL and did some work at KEK in May 2007
- T. Matsuda visited Saclay as an LC-TPC coordinator in May 2007
- P. Colas visited KEK and did some work on MPPCs for the trigger system in Nov. 2007
- P. Colas, M. Chefdeville, T. Matsuda, T. Fusayasu, H. Tsuji, R. Yonamine and K.Fujii participated in Tsinghua TPC School in Jan. 2008
- V. Lapeltier participated in TIL08 in March 2008
- T. Matsuda visited Saclay and summarized LC-TPC activity at DESY PRC in April 2008

Tsinghua TPC School Jan. 2008 in Beijing

2 French, 5 Japanese, and >40 Chinese



TU-TPC Test at KEK Cryo-center with a PC-Mag Dec. 2007

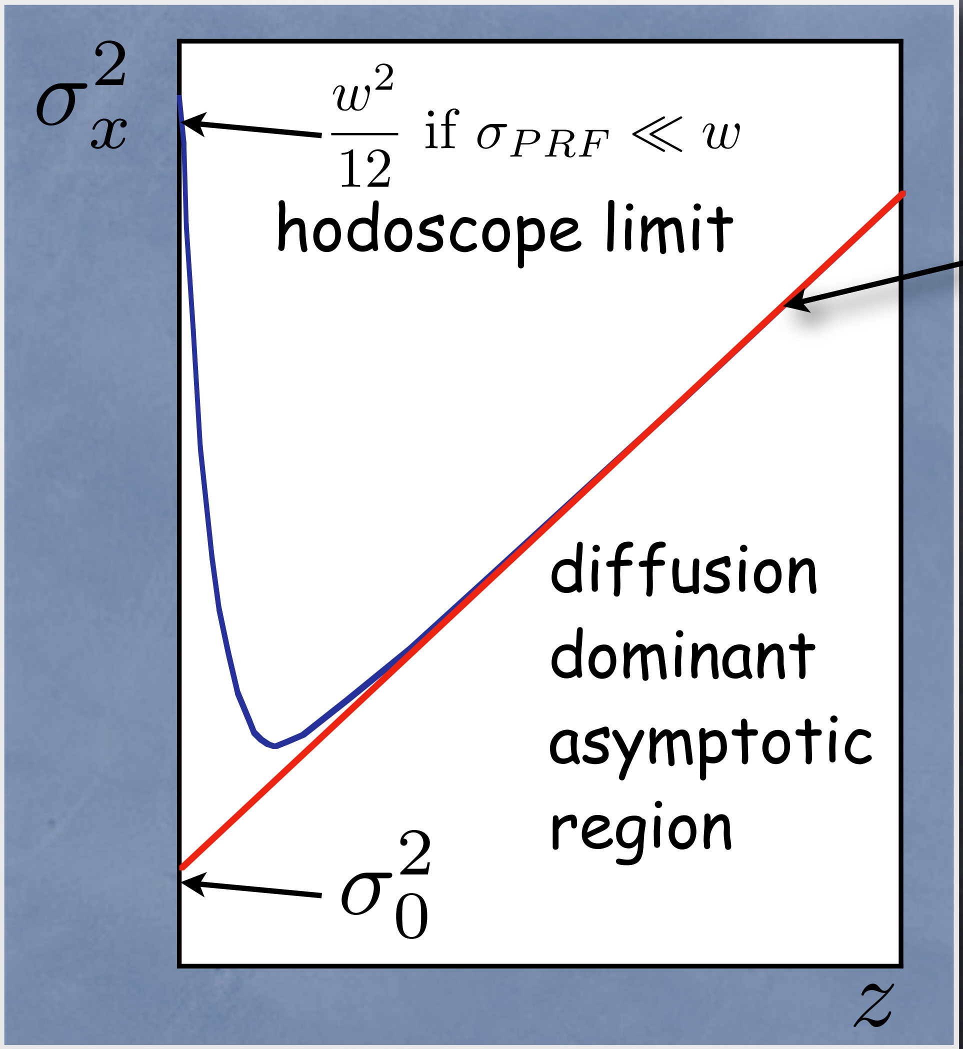
It's now becoming the F-J-C team !

Small Prototype Tests

There have been many small prototype tests
of which the KEK beam test of a micromegas TPC was
worth special mention since
an analytic formula was born from the beam test
that clarified fundamental limitations to spatial resolution
and decided the R&D directions for the LC-TPC.

Two Mysteries

Generic behaviors of resolution with an MPGD endplate when the lateral avalanche spread is smaller than or comparable to the pad width



$$\sigma_x^2 = \sigma_0^2 + C_d^2 z / N_{eff}$$

- Why $N_{eff} < \langle N \rangle$?
- What is the origin of $\sigma_0 \equiv \sigma_x(z = 0)$?

It's there even if electronic noise is negligible!

Ionization Statistics

Ideal Readout Plane: Coordinate = Simple C.O.G.

PDF for Center of gravity of N electrons

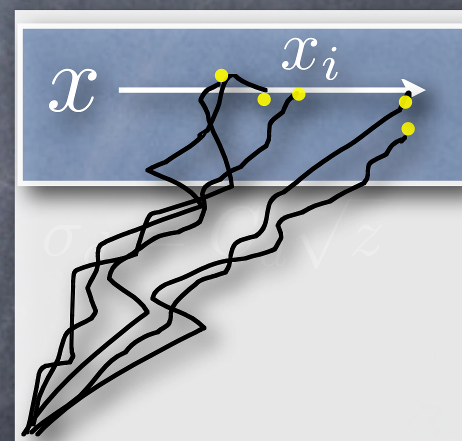
$$P(\bar{x}) = \sum_{N=1}^{\infty} P_I(N;\bar{N}) \prod_{i=1}^{N} \left(\int dx_i P_D(x_i;\sigma_d) \right) \delta \left(\bar{x} - \frac{1}{N} \sum_{i=1}^{N} x_i \right)$$

Ideal readout plane

Gaussian diffusion

$$P_D(x_i;\sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d} \exp\left(-\frac{x_i^2}{2\sigma_d^2} \right)$$

$$\sigma_d = C_d \sqrt{z}$$



$$\sigma_{\bar{x}}^2 \equiv \int d\bar{x}\, P(\bar{x})\, \bar{x}^2 = \sigma_d^2 \left\langle \frac{1}{N} \right\rangle \equiv \sigma_d^2 \frac{1}{N_{eff}}$$

$$N_{eff} \equiv 1/\left\langle 1/N \right\rangle < \left\langle N \right\rangle$$

Gas Gain Fluctuation

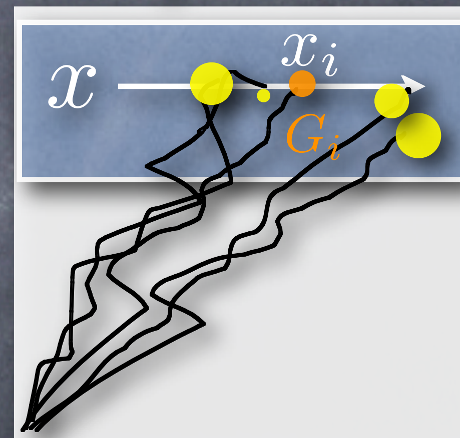
Coordinate = Gain-Weighted Mean

PDF for Gain-Weighted Mean of N electrons

$$P(\bar{x}) = \sum_{N=1}^{\infty} P_I(N;\bar{N}) \prod_{i=1}^{N} \left(\int dx_i P_D(x_i;\sigma_d) \int d(G_i/\bar{G})\, P_G(G_i/\bar{G};\theta) \right) \delta \left(\bar{x} - \frac{\sum_{i=1}^{N} G_i\, x_i}{\sum_{i=1}^{N} G_i} \right)$$

Gaussian diffusion as before

Gain-weighted mean



Gas gain fluctuation (Polya)

$$\theta = \begin{cases} 0 & : \ \text{exp.} \\ \infty & : \ \delta\text{-fun} \end{cases}$$

$$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)} \left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$$

$$\sigma_{\bar{x}}^2 \equiv \int d\bar{x}\, P(\bar{x})\, \bar{x}^2 = \sigma_d^2 \left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}}\right)^2 \right\rangle \equiv \sigma_d^2 \frac{1}{N_{eff}}$$

$$N_{eff} = \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}}\right)^2 \right\rangle \right]^{-1} = \frac{1}{\left\langle \frac{1}{N} \right\rangle} \left(\frac{1+\theta}{2+\theta} \right) < \langle N \rangle$$

Finite Size Pads

Coordinate = Charge Centroid

Charge on Pad j

Electronic noise

$\langle \Delta Q^2 \rangle = \sigma_E^2$

$$Q_j = \sum_{i=1}^{N} G_i \cdot f_j(\tilde{x} + \Delta x_i) + \Delta Q_j,$$

track position

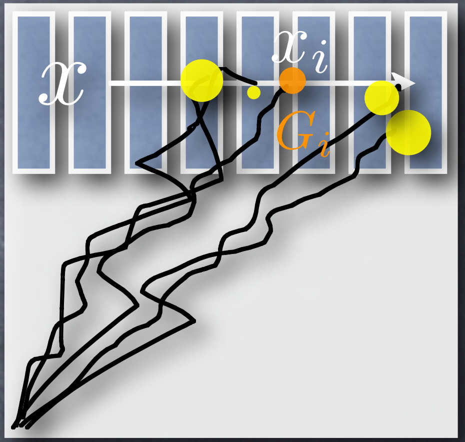
$x_i = \tilde{x} + \Delta x_i$

diffusion

$\langle \Delta x^2 \rangle = \sigma_d^2 = C_d^2 z$

Normalized response fun. for pad j

$$\sum_j f_j(\tilde{x} + \Delta x_i) = 1$$



Charge Centroid

Pad pitch

$$\bar{x} = \sum_j Q_j\,(wj) / \sum_j Q_j$$

PDF for Charge Centroid

$$\begin{aligned} P(\bar{x};\tilde{x}) \quad = \quad & \textstyle\sum_{N=1}^{\infty} P_I(N;\bar{N}) \prod_{i=1}^{N} \left(\int d\Delta x_i P_D(\Delta x_i;\sigma_d) \int d(G_i/\bar{G})\, P_G(G_i/\bar{G};\theta)\right) \\ & \times \prod_j \left(\int d\Delta Q_j\; P_E(\Delta Q_j;\sigma_E)\; \int dQ_j\; \delta\left(Q_j - \textstyle\sum_{i=1}^{N} G_i \cdot f_j(\tilde{x} + \Delta x_i) - \Delta Q_j\right)\right) \\ & \times \delta\left(\bar{x} - \frac{\sum_j Q_j\,(wj)}{\sum_j Q_j}\right) \end{aligned}$$

Full Analytic Formula

$$\sigma_{\bar{x}}^2 \equiv \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \int d\bar{x}\, P(\bar{x};\tilde{x})\, (\bar{x}-\tilde{x})^2 = \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left[[A] + \frac{1}{N_{eff}} [B] \right] + [C]$$

- Purely geometric term

$$[A] = \left(\sum_j (jw)\, \langle f_j(\tilde{x}+\Delta x) \rangle - \tilde{x} \right)^2$$

- Diffusion, gas gain fluctuation & finite pad pitch term

$$[B] = \sum_{j,k} jkw^2\, \langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x) \rangle - \left(\sum_j jw\, \langle f_j(\tilde{x}+\Delta x) \rangle \right)^2$$

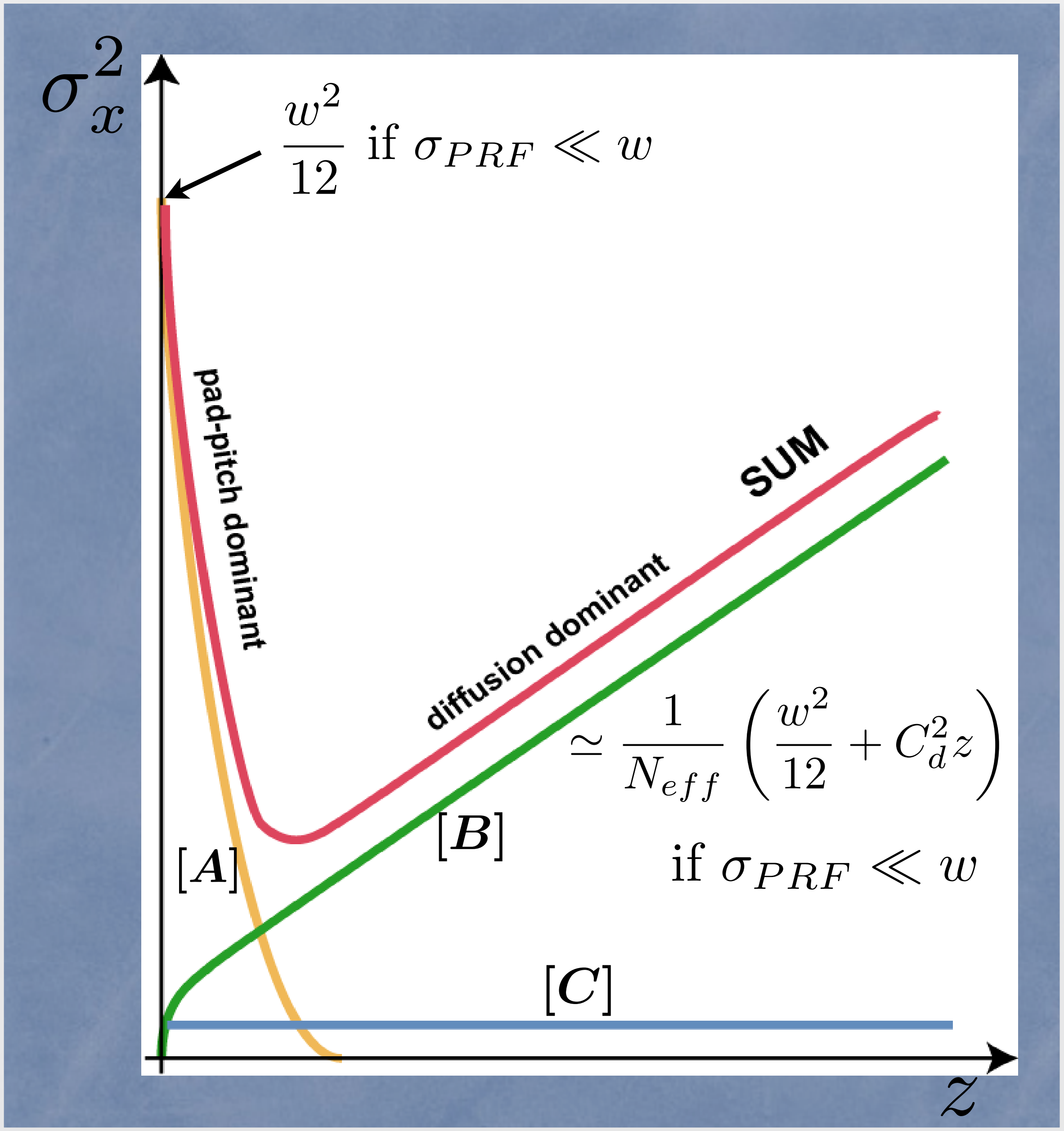
$$\langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x) \rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)\, f_k(\tilde{x}+\Delta x)$$

$$\langle f_j(\tilde{x}+\Delta x) \rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)$$

- Electronic noise term

$$[C] = \left(\frac{\sigma_E}{\bar{G}}\right)^2 \left\langle \frac{1}{N^2} \right\rangle \sum_j (jw)^2$$

Interpretation



[A] Purely geometric term (S-shape systematics from finite pad pitch): rapidly disappears as Z increases

[B] Diffusion, gas gain fluctuation & finite pad pitch term: scales as $1/N_{eff}$, for delta-fun like PRF asymptotically:

$$\sigma_{\bar{x}}^2 \simeq \frac{1}{N_{eff}}\left(\frac{w^2}{12} + C_d^2 z\right)$$

[C] Electronic noise term: Z-independent, scales as $\langle 1/N^2 \rangle$

Importance of the Analytic Formula

- We can now analytically estimate the spatial resolution

drift distance

$$\sigma_x = \sigma_x(z; w, C_d, N_{eff}, [f_j])$$

pad pitch

pad response function

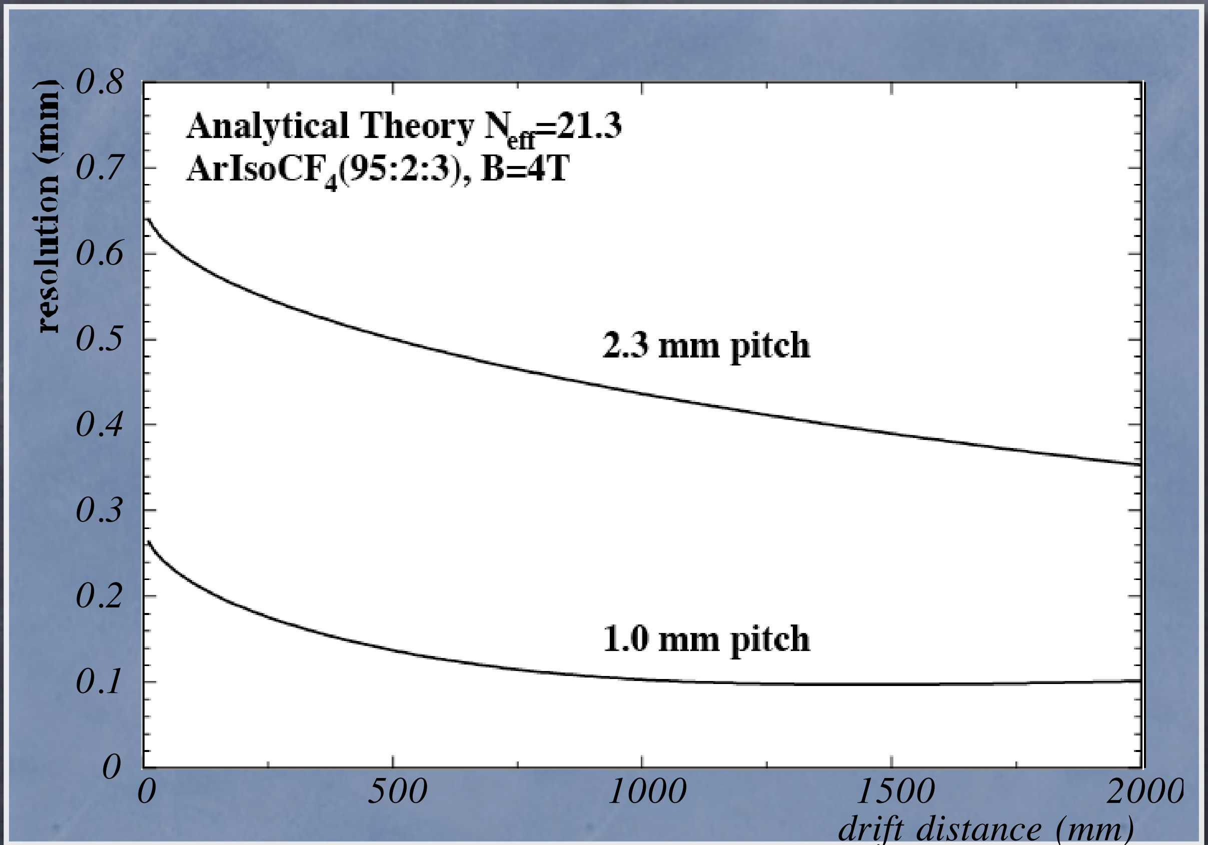
diffusion const.

Effective No. track electrons

→ **Theoretical basis for how to improve the spatial resolution!**

Possible improvement of theory: angle effects

Extrapolation to LC TPC



- Need to reduce pad size relative to PRF

  - MM + resistive anode
  - MM + digital pixel readout, ideal to avoid effect of gain fluctuation if feasible
  - GEM with defocusing + narrow (~1mm) pads

The 3 Solutions

The three solutions have been tested with small prototypes.

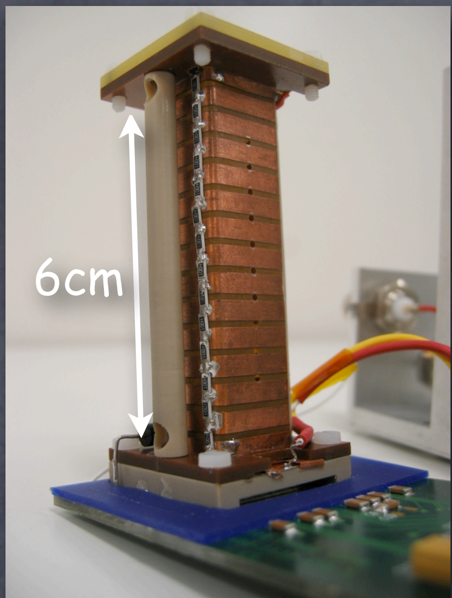
--> demonstration phase

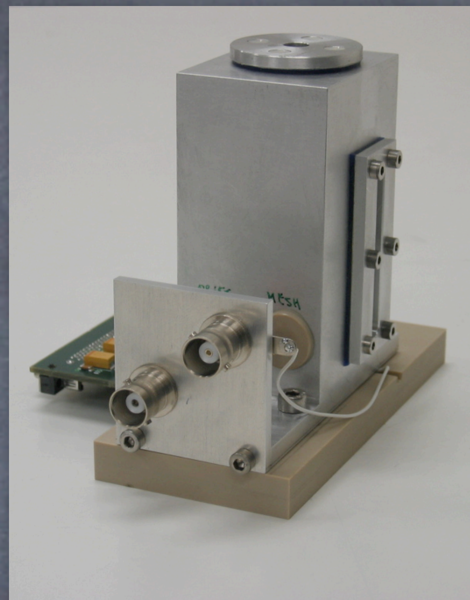
We now need to test them with a larger prototype.

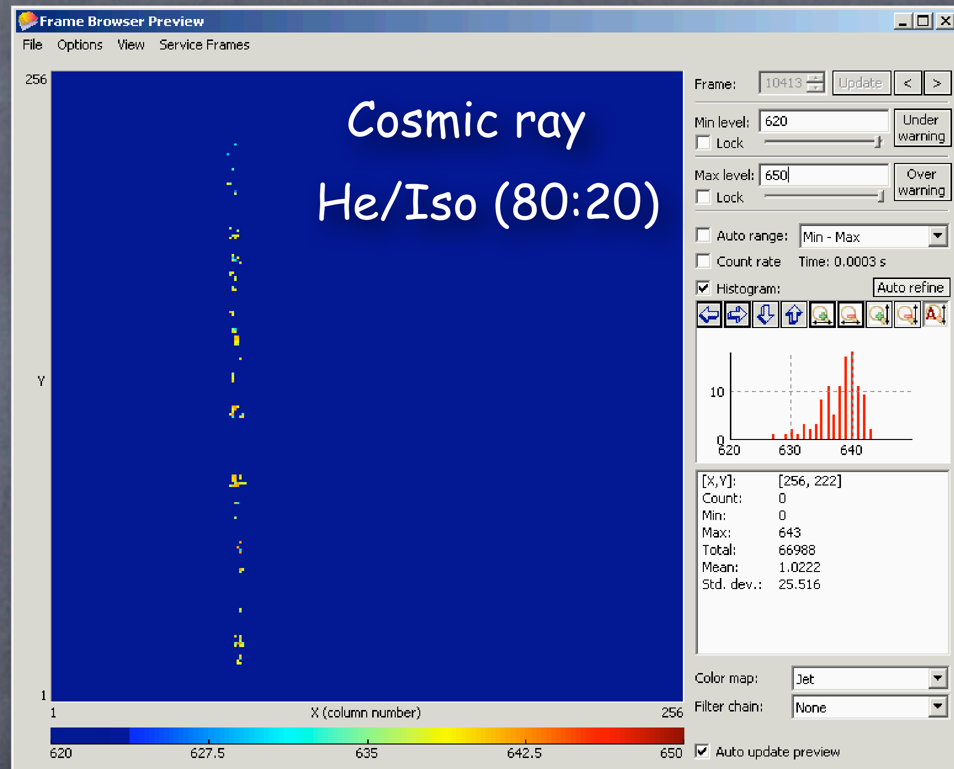
--> consolidation phase

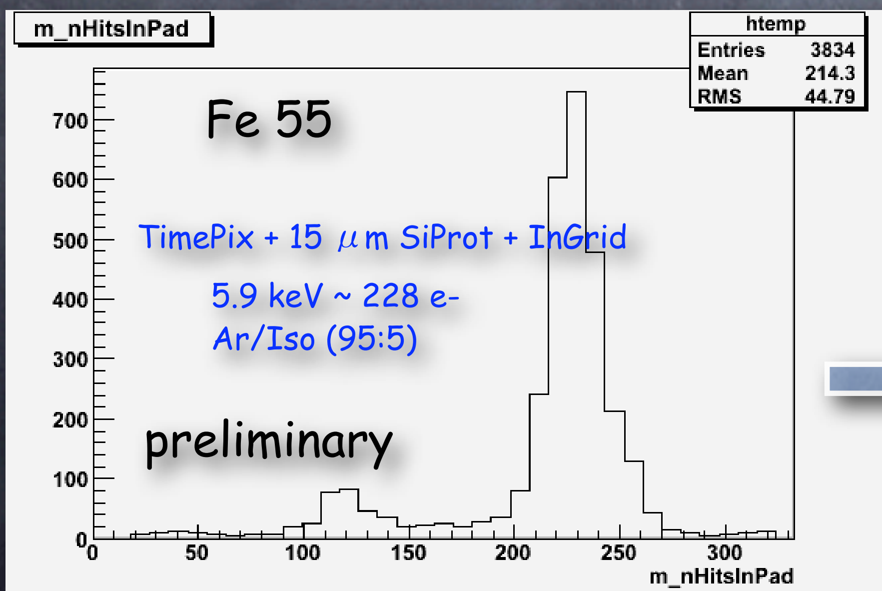
Micro-TPC: MM+TimePix

Saclay/NIKHEF









Very powerful tool to study basic gas properties

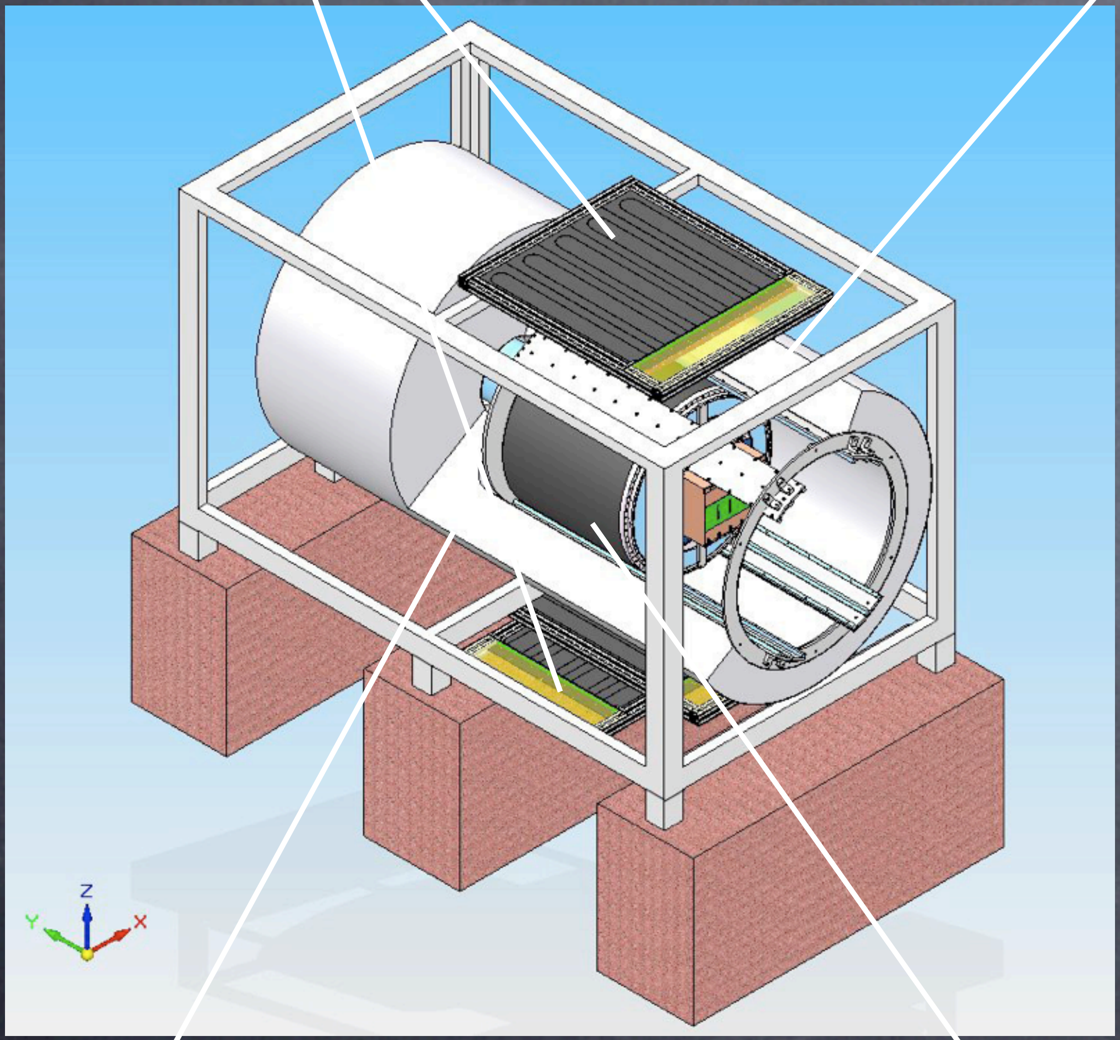
D. Attie @ LPNHE, Mar. 2008

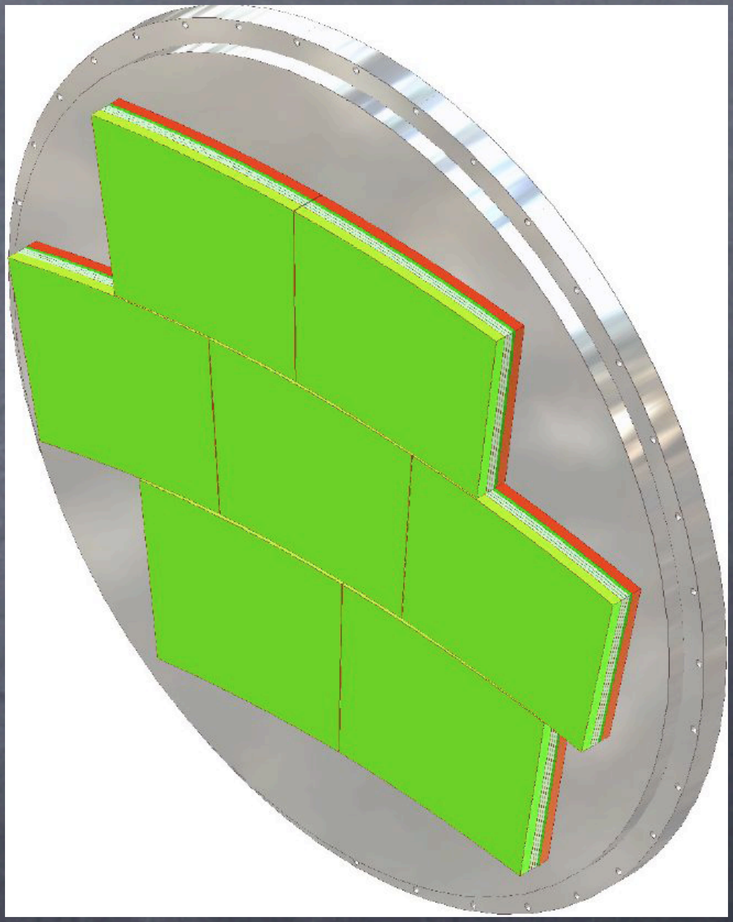
Large Prototype Tests

Cosmic ray trigger counters
with MPPC readout system

Endplate to house
7 Interchangeable readout modules

GEM+1mm pads, MM+RA, MM+TimePix





Field cage : 75 cm phi & 61 cm long

Thin (0.2X0) superconducting magnet (PCMAG from KEK) : B_max=1.25 T

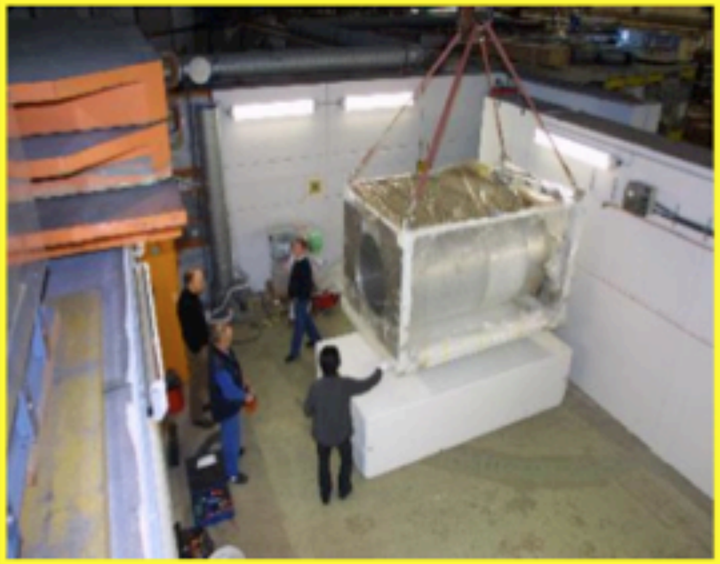
Consolidation Phase
TPC Large Prototype Beam Test at DESY

Pixel beam telescope (EUDET)

Si strip detector (EUDET/SiLC)

Magnet: PCMAG (LC TPC/EUDET)

Field cage & All Mechanics (EUDET)



Endplate (LC TPC)

Gas system (EUDET)

MPGD Detector Modules (LC TPC)

Test beam (DESY)

DAQ & Monitoring (EUDET)

Cosmic trigger (LC TPC)

Readout electronics (EUDET & LC TPC)

Software development (EUDET & LC TPC)

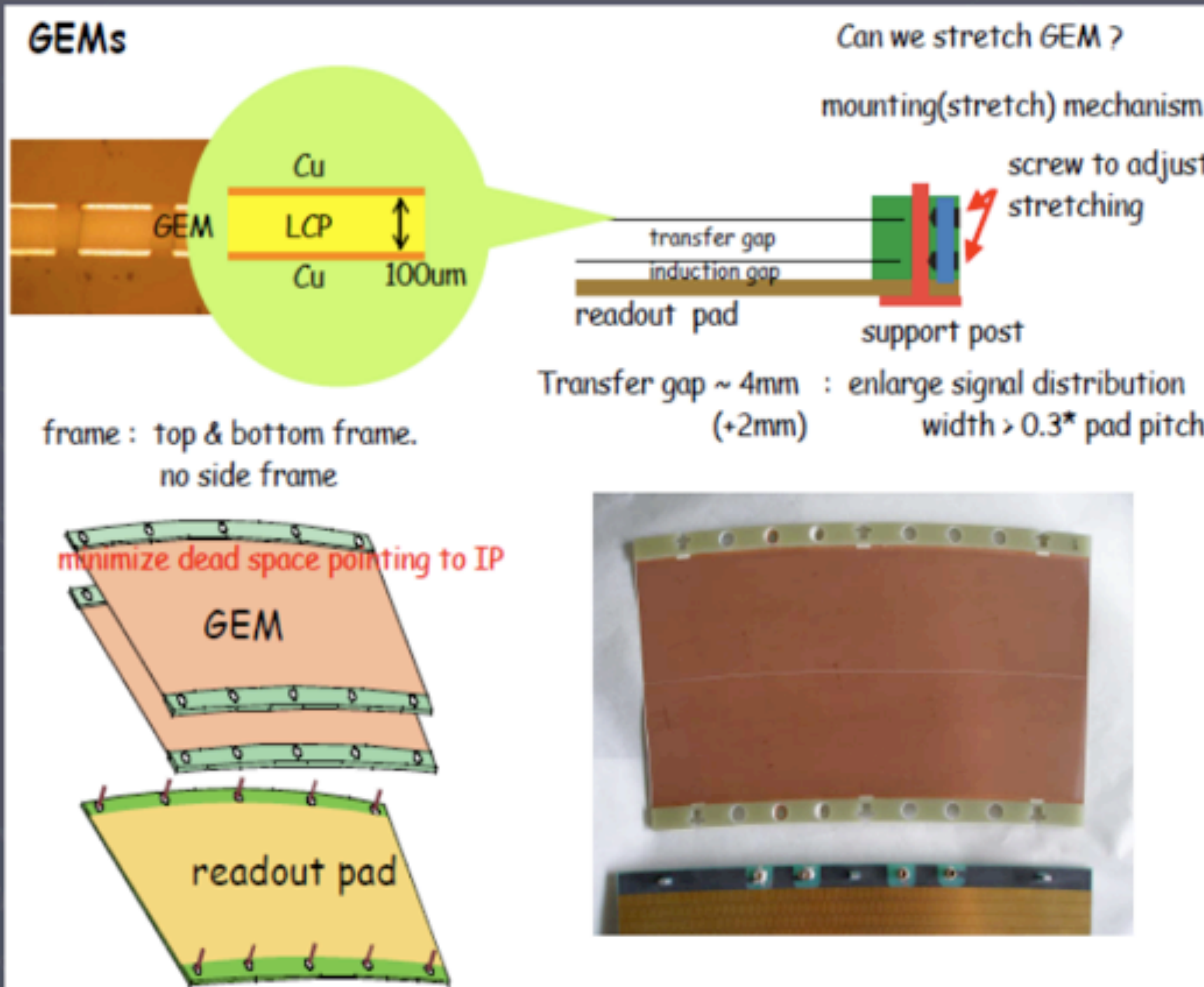
GEM Solution

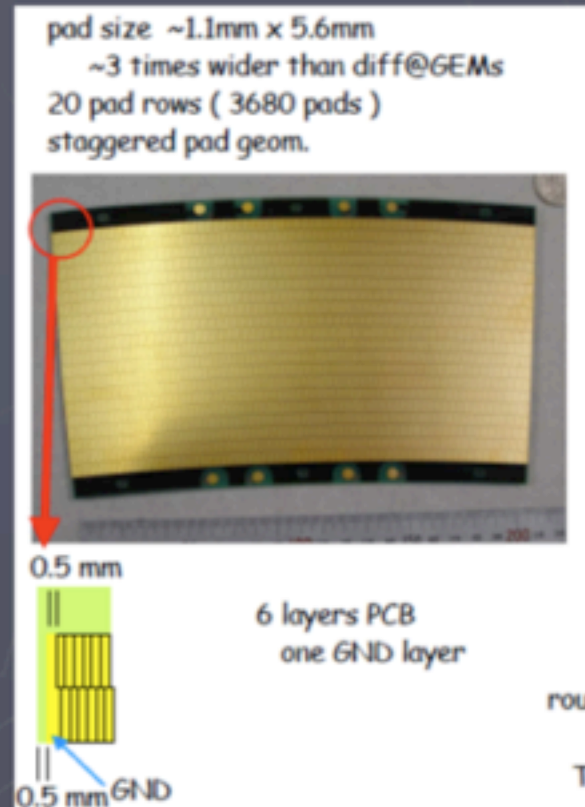
Detector Module: Double GEM with a gating GEM

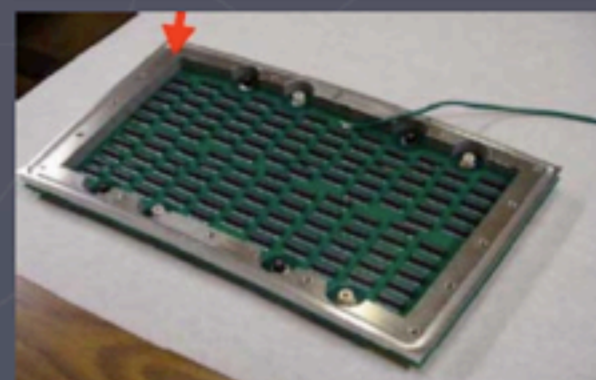
Saga, Tsinghua

(1) Double thick (100 μm) GEM with a (thin) gating GEM:

(Gating GEM is not drawn)







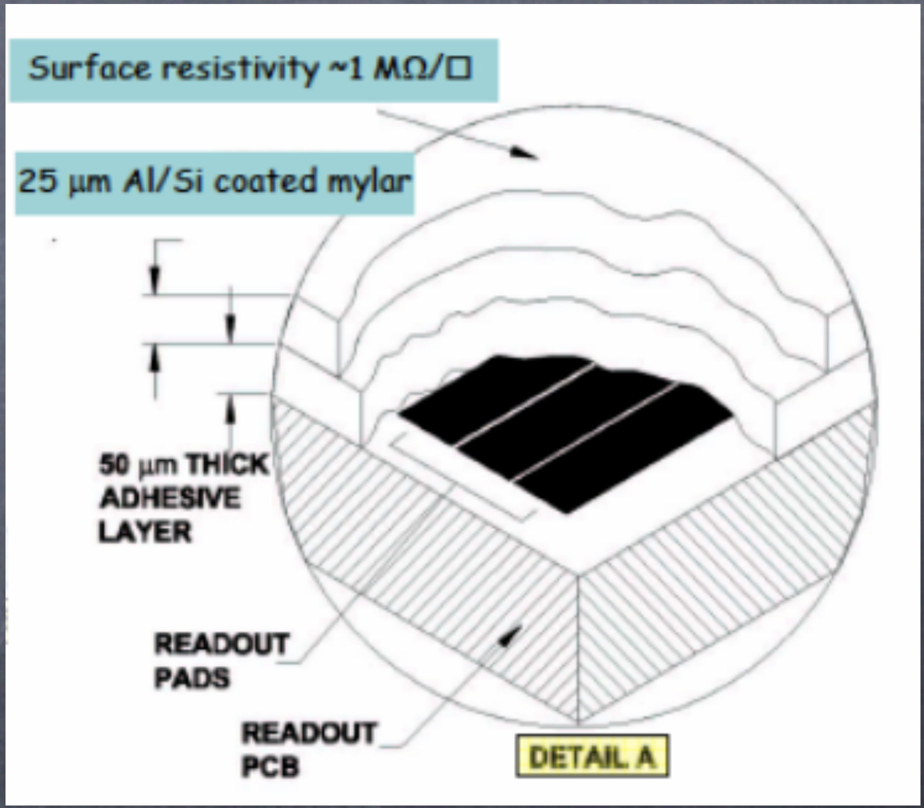
Micromegas with Resistive Anode

Micromegas with R.A.

3 techniques to make resistive anode for the bulk MM

- Kapton foil laminated and covered with a resistive layer (Carleton)
- 2 deposited layers of amorphous Si doped to adjust conductivity: 10^4 ohm cm on 10^11 ohm cm (Neuchatel)
- Screen printing of resistive pastes: 2-8M ohm/square (CERN)

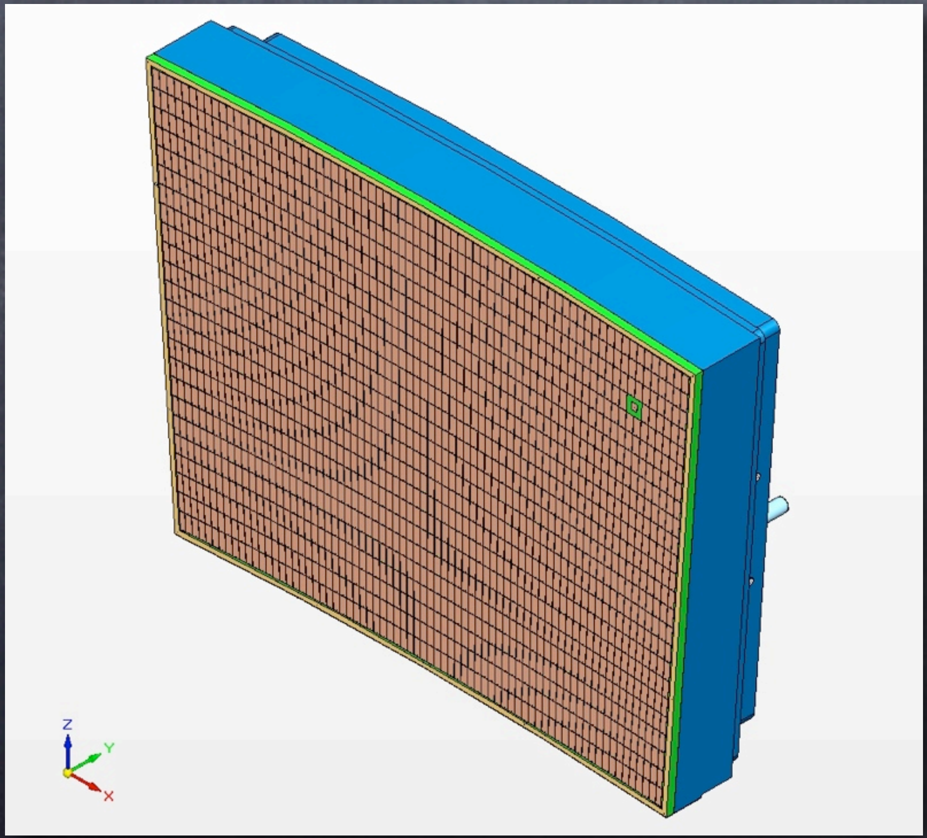
Saclay, Carleton

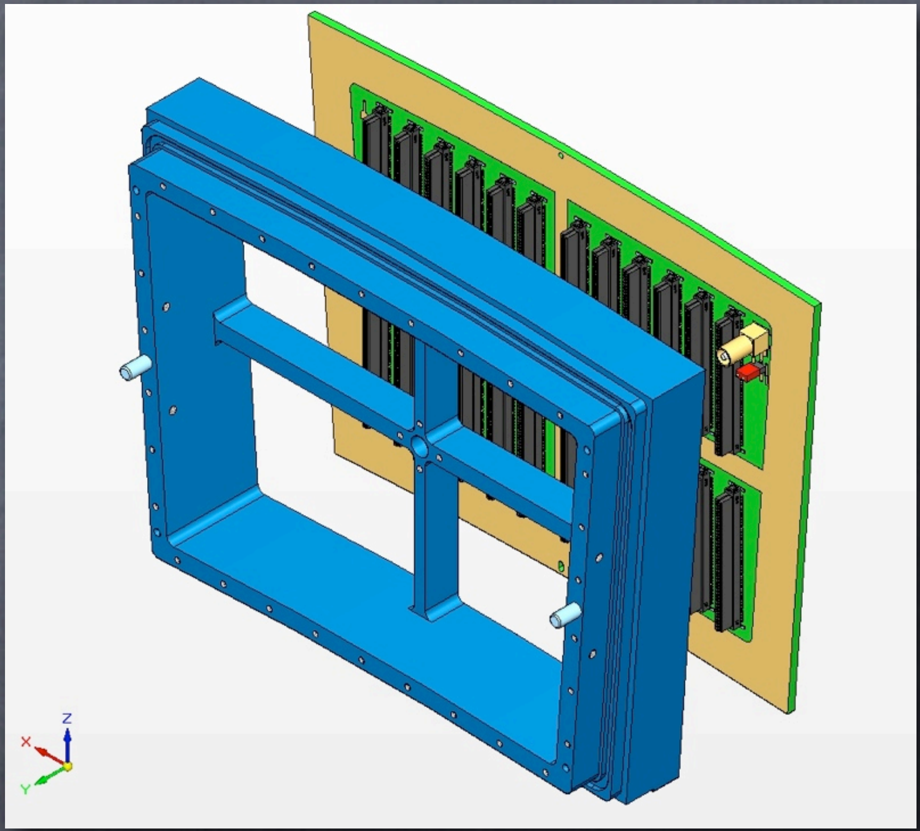


Micromegas with R.A.

LP1 detector module

- 24 rows x 72 pads
  Av. pad size ~ 3.2x7 mm^2

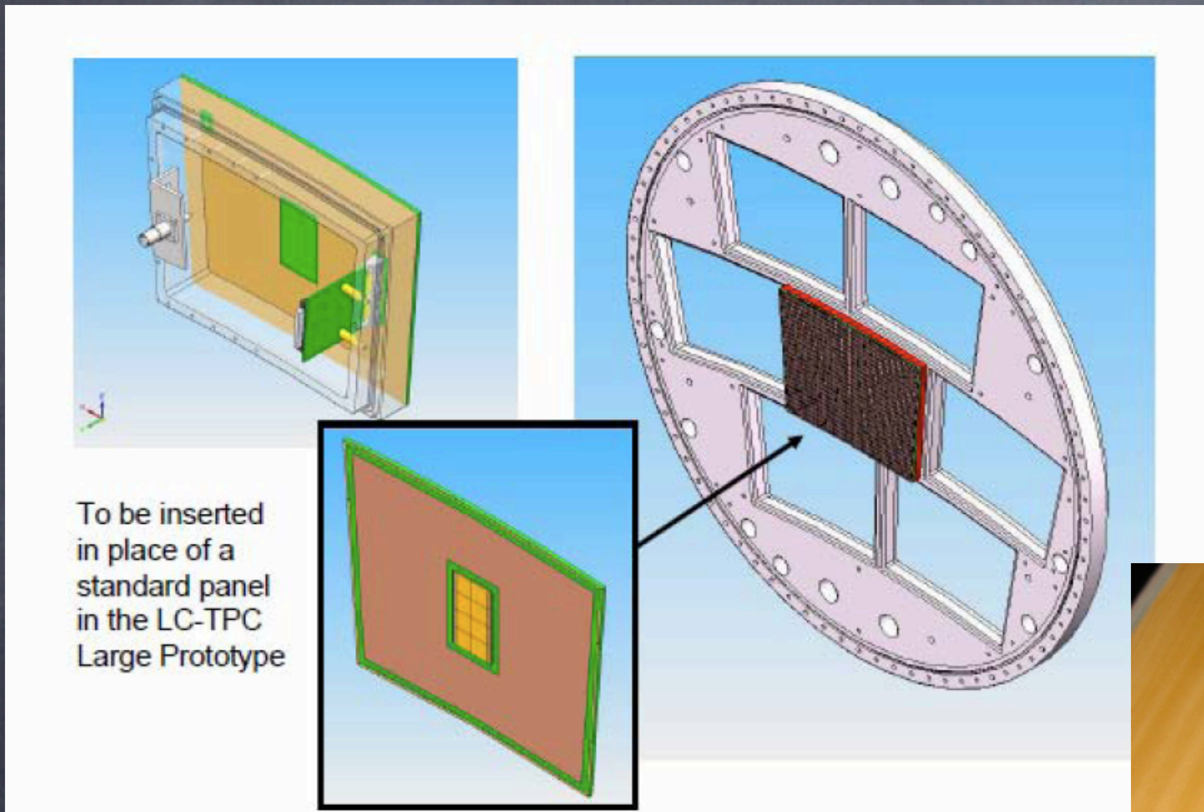


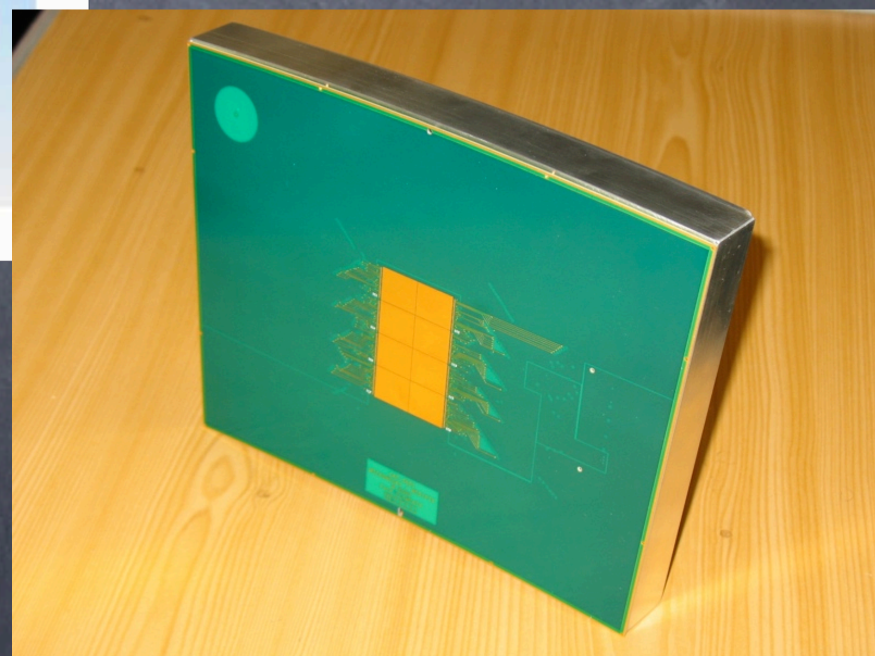


Micromegas with TimePix

Micromegas with TimePix

Saclay/NIKHEF

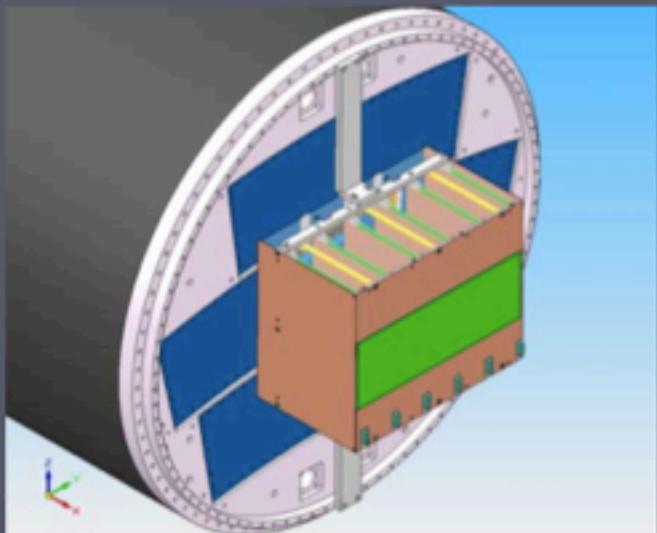




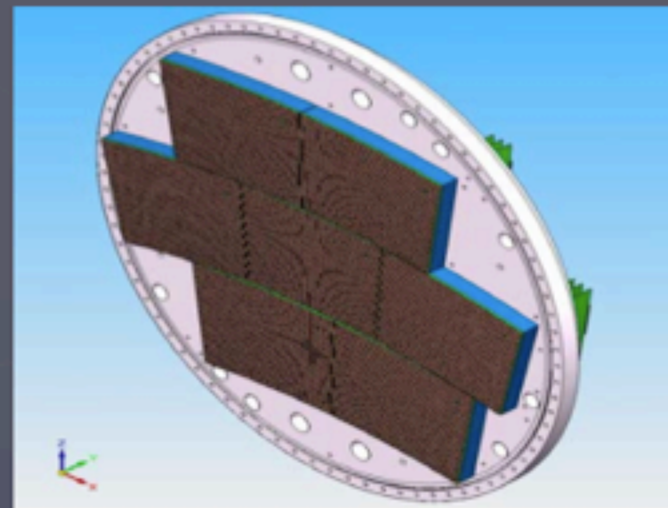
EUDET

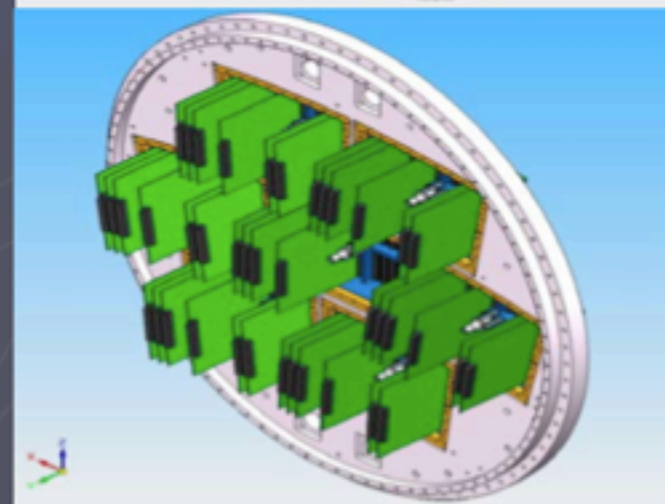
Readout Electronics

TPC Readout Electronics: After Electronics



In 2008 with one detector module This version is essentially ready by now except the mounting Structure on the endplate.



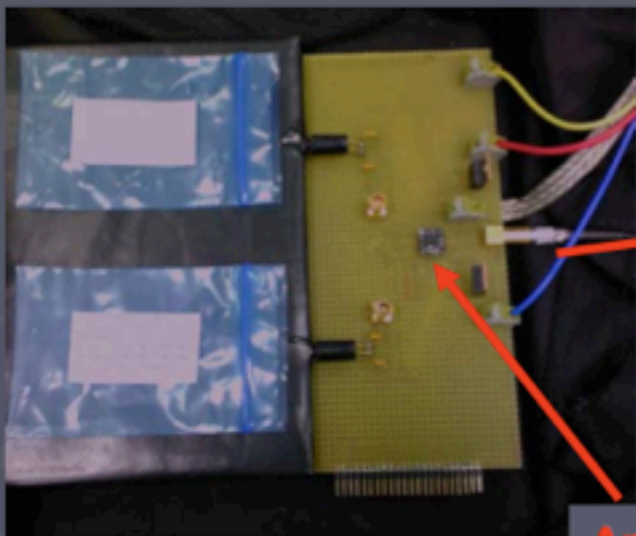


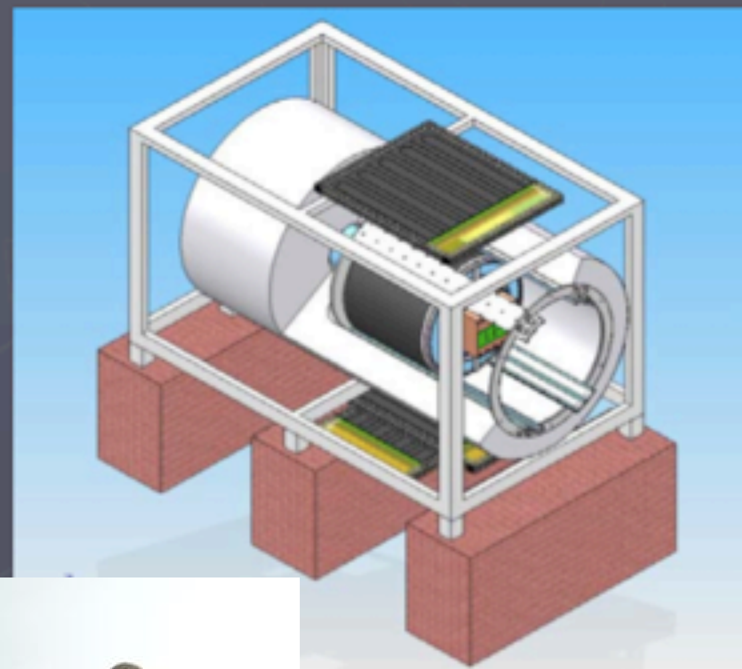
In 2009 with 7 detector modules. There is an option of the surface mounting of chips.

Cosmic Ray Trigger Counters with MPPCs

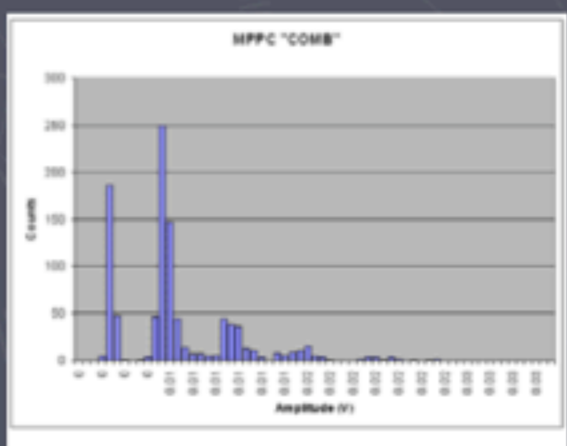
Cosmic Ray Trigger Counters with MPPC for LP1

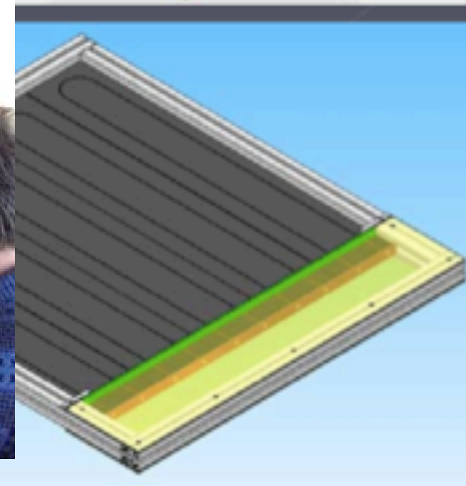
Scintillator Slabs(from INR Moscow),
MPPC (KEK)
Preamp, Temp. control by Pelletier device and assembly (Saclay)
Ready in May





~20 p.e. per fiber end





Summary

- We are busy preparing for the large prototype (LP1) beam test at DESY starting late this year.
- The LP1 data will be invaluable to prepare ourselves for the design phase.
- Hope we can show some LP1 data at the next FJPPL WS.
- We continue small prototype tests for
  - understanding of gas multiplication processes
  - optimization of gas mixtures
  - gating, ...
- We continue more R&D for MM+TimePix since it is theoretically the best choice.