TPC readout with Micromegas

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outlook:

- **Micromegas TPC for the ILC**
  - Micromegas
  - how to improve the spatial resolution?
  - cosmic rays studies with the Saclay-Orsay-Berkeley TPC prototype
  - beam measurements at KEK with the MPI-Munich TPC
- **resistive Micromegas read-out**
  - principle
  - beam measurements at KEK with the Carleton-Ottawa TPC (+MPI one)
- **pixel readout TPC**
- **bulk developments and Micromegas TPC for T2K**
- **conclusions**

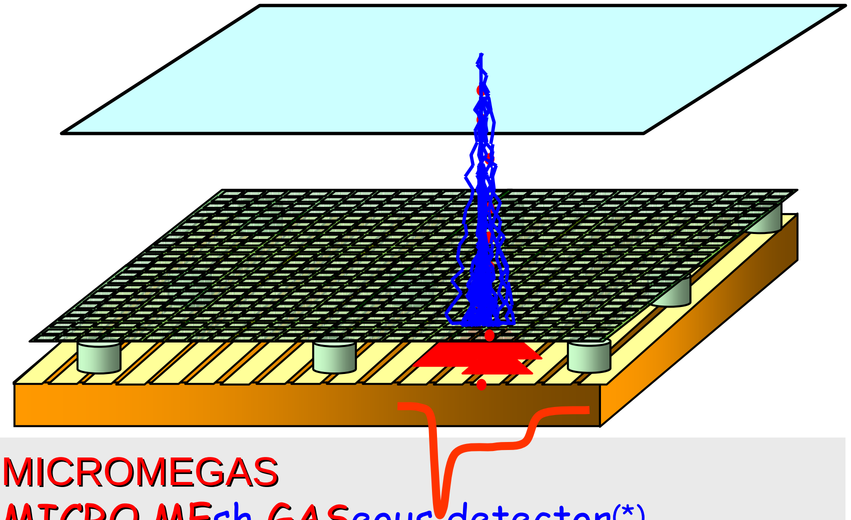
ILC-TPC readout with Micromegas

which constraints on the ILC TPC ?

most of them come from ILC physics and machine:

- excellent **separation between 2 tracks** (<3mm in r-Φ),
- **momentum resolution 10x** better than at LEP,
- very low **ion backflow** in the drift space,
- working **gas (nearly) without H** (n background)
- **high magnetic field B** (~4T) to remove background.

→ a **Micromegas TPC** has been proposed in 1999 by **DAPNIA and LAL** to fulfill these constraints.



MICROMEGAS

MICRO MEsh GASeous detector(*)

- a very thin metallic mesh (3 to 5 μm, Ni ou Cu), pitch from 20 to 100 μm located at a very small distance from the anode plane (50-100 μm)
- the very high electric field applied (40-80kV/cm) creates by avalanche the multiplication of electrons coming from drift space.

(*) I.Giomataris et al. Nucl. Instr. Meth.A376(1996)29

advantages:

☺ no ExB effect : excellent for 2-track separation and for spatial resolution
☺ high gain
☺ very fast signal on the anode plane
☺ very low ion back-flow into drift space
☺ cheap, robust and easy to implement

previous successful studies on:

☺ ion feedback
☺ gain stability, diffusion and drift velocities
☺ aging
☺ behaviour in the magnetic field
☺ attachment ($Ar\text{-}CF_4$)

using small Micromegas devices and various e sources (X-rays gun or source, B source, laser)

ILC-TPC readout with Micromegas

how to improve the **spatial resolution** of the TPC?

the ILC TPC:

- **L**~2x250cm, **Φ**=~300cm
- **pads** everywhere, **size** ~ 6x2 mm^2
- N_{pads} ~ 1-2 $x10^6$
- ~200-250 **pad rows**
- **resolution** per pad row ~100μm

point resolution for a pad:

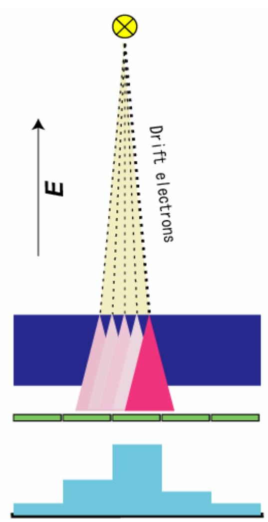
$$\sigma_X^2 = \sigma_0^2 + D_t^2 \times l_d / n_{eff}$$

σ_0 = constant term

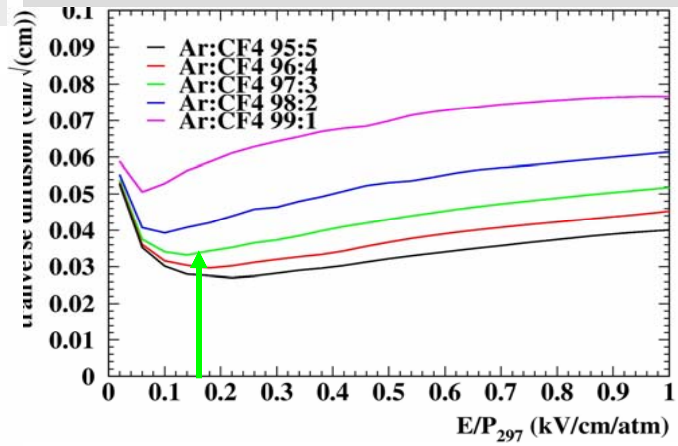
l_d drift distance

n_{eff} ≈ effective number of electrons contributing to the signal ~20-30 for 1cm

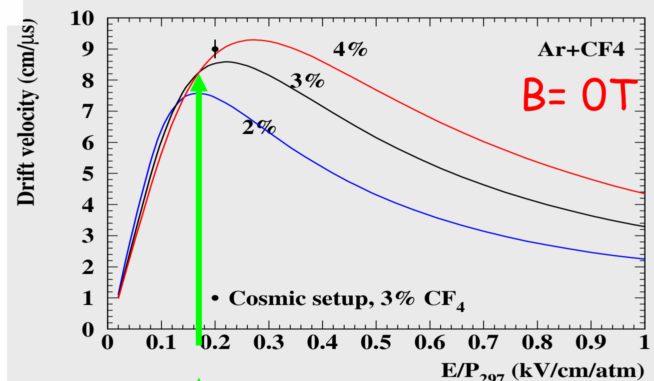
D_t transverse diffusion coefficient in the gas, decreased by the magnetic field



transverse diffusion vs electric field



drift velocity v_d vs electric field E



example: **Ar-CF_4** mixture (no **H**!)

at B=0T, D_t ~ 350μm/√cm@200V/cm

⇒for l_d=100cm, n_e ~ 25, resolution σ = 800μm

at B=4T: $D_t(B) = D_t(B=0)/\sqrt{(1+\omega^2\tau^2)}$ with $\omega\tau$ ≈(v_d/E)xB~20

⇒ Dt~20μm/√cm only, ie **200μm for 100cm**

⇒ resolution better by a factor 20!

potential resolution σ = 40μm@100cm (64μm@250cm)!

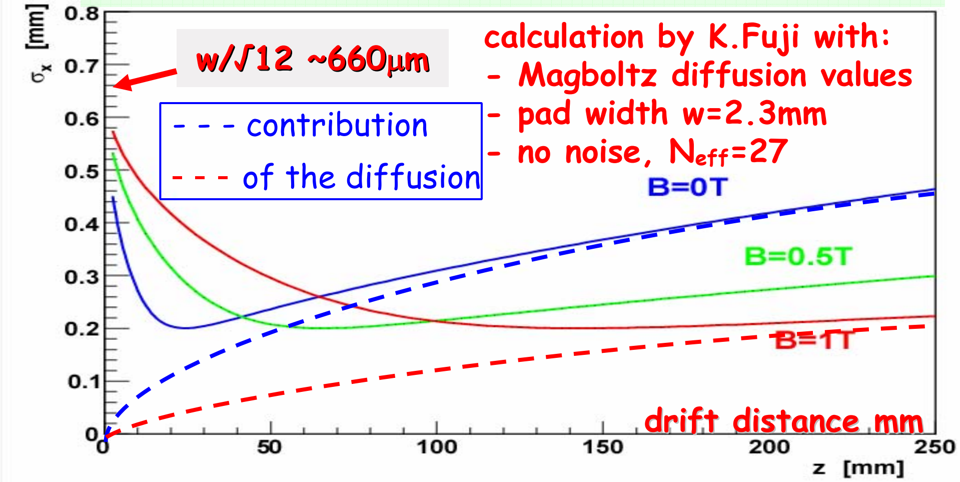
BUT the **pad width** (2mm) is **too large** as compared to **diffusion** !

$\mu = v_d/E \sim 5T^{-1}$

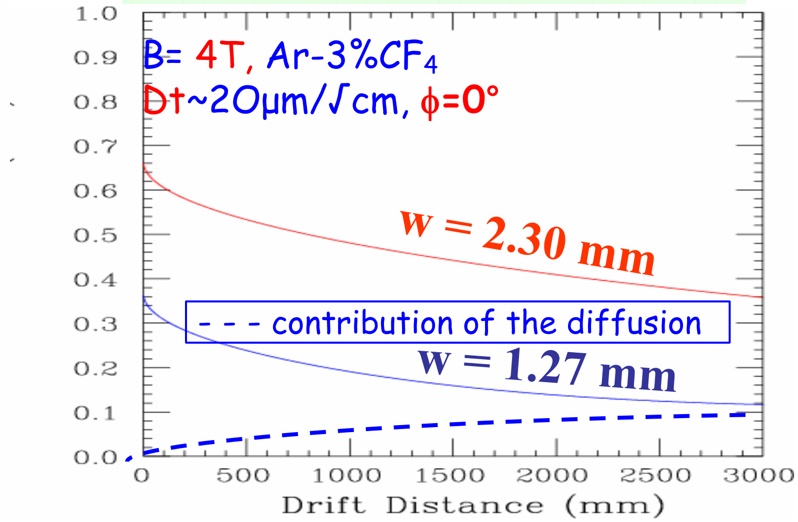
⇒ $\omega\tau$ ≈20 at 4T

TPC readout with Micromegas

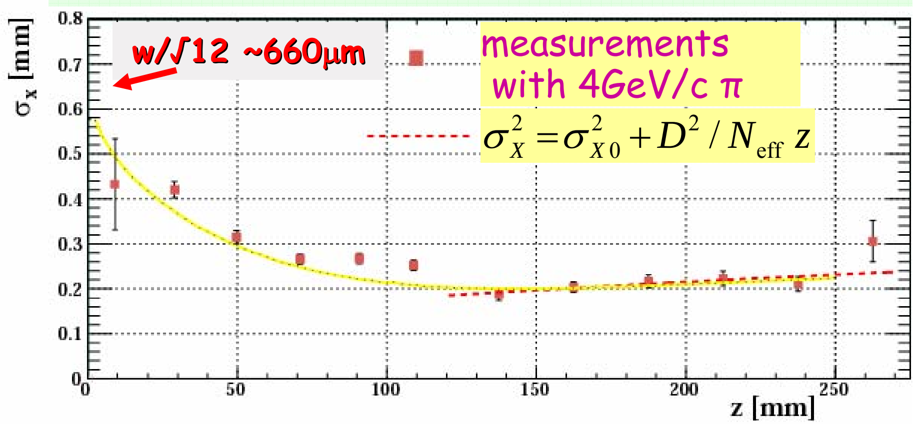
calculation: B =0, 0.5, 1T, ϕ=0° Ar-5% iso-C_4H_{10}



extrapolation to ILC case



data: Micromegas B =1T ϕ=0° Ar-5% iso-C_4H_{10}



solutions?

1. **decrease** by a huge factor **the pad width** ←
→ **new very promising concept of digital TPC minipads** (<<1mm²), with **single electron detection.**
2. **diffuse electrons AFTER** multiplication «impossible» for Micromegas, difficult for GEM
3. bond a **resistive foil** on the anode plane ←
proposed by Madhu Dixit (Carleton, Ottawa) ~ 2000

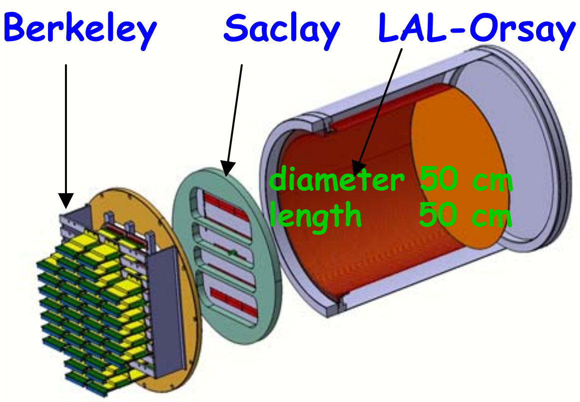
see presentation by Makoto Kobayashi , LCWS06@Bangalore, March 06

results of a Micromegas TPC cosmic test

Saclay-Orsay-Berkeley

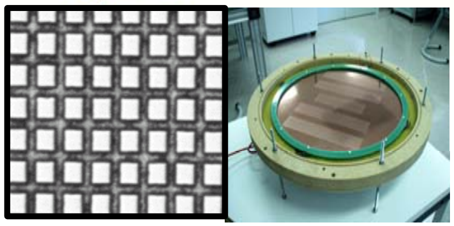
more explanations on poster # 153 by Mike Ronan

P. Colas[5], I. Giomataris[5], V. Lepeltier[4], M. Ronan[1], K. Sachs[2], T. Zerguerras[3]
1) LBNL Berkeley, 2) Carleton Univ., 3) IPN Orsay, 4) LAL Orsay, 5) DAPNIA Saclay + many other people

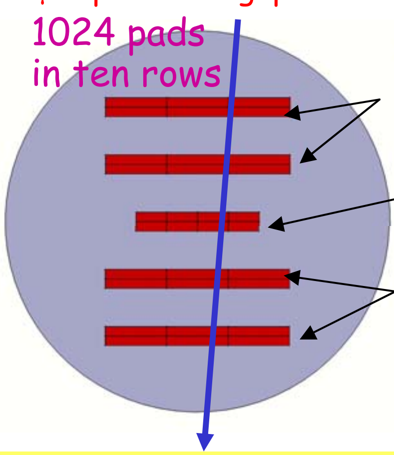


TPC built in 2003

data taking mainly in april-may 04:
≈ 150 k cosmic tracks registered
B= 0.1, 0.3, 0.5, 0.7, 1, 1.5 & 2 Tesla
gas mixtures : Ar + CF_4 / CH_4/ iso-C_4H_{10}
3% 10% 5%

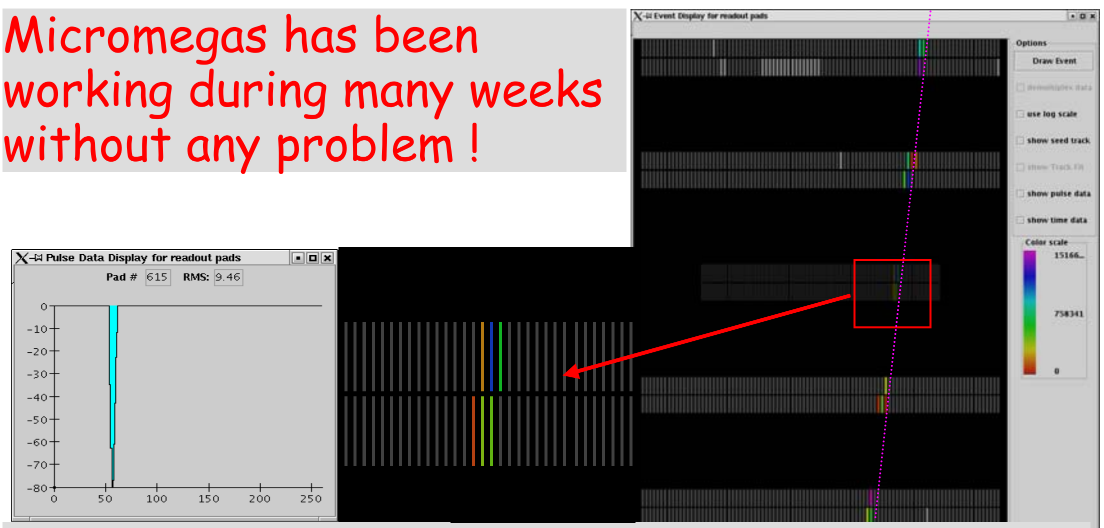


Cu mesh CERN
50 μm pitch and gap



readout anode pad plane

Micromegas has been working during many weeks without any problem !



time distribution@20MHz

online event display

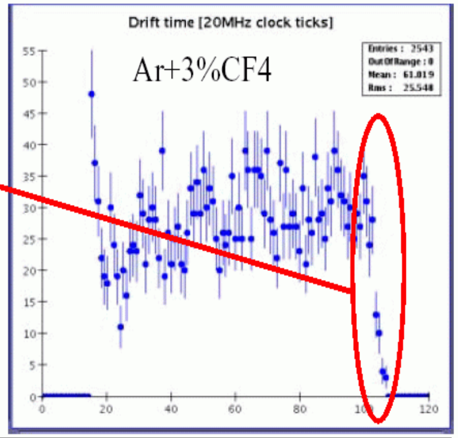
(software from D. Karlen, adapted by M. Ronan)

results of a Micromegas TPC cosmic test
Saclay-Orsay-Berkeley

Drift velocity measurements

Select tracks near the far end. Look at the time at which they exit the chamber. Add offset 200+-100 ns (trigger delay)

Divide by the length (47.9 cm)



Excellent agreement with Magboltz

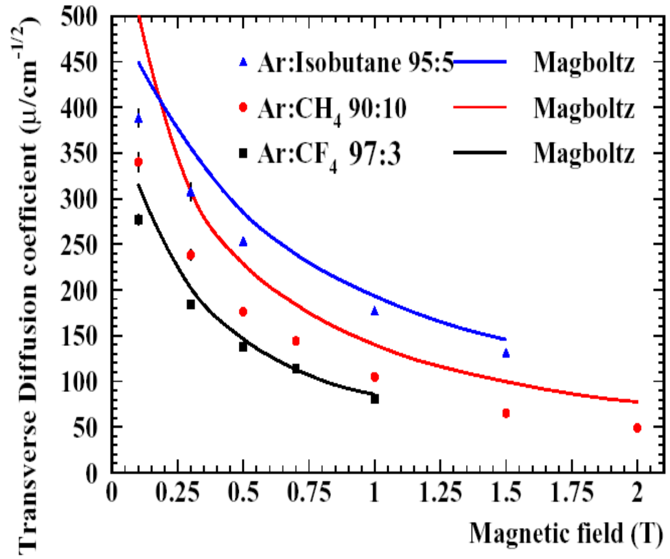
(S. Biaggi, 2004)

within 2% accuracy!

Gas mixture	E drift (V/cm)	V_{drift} (cm/µs)	Magboltz
Ar+5%iso	210	4.24±0.08	4.17
P10	66	4.43±0.07	4.46
P10	150	5.61±0.09	5.50
Ar+3%CF_4	200	8.8±0.2	8.51

Transverse diffusion Results

PRELIMINARY

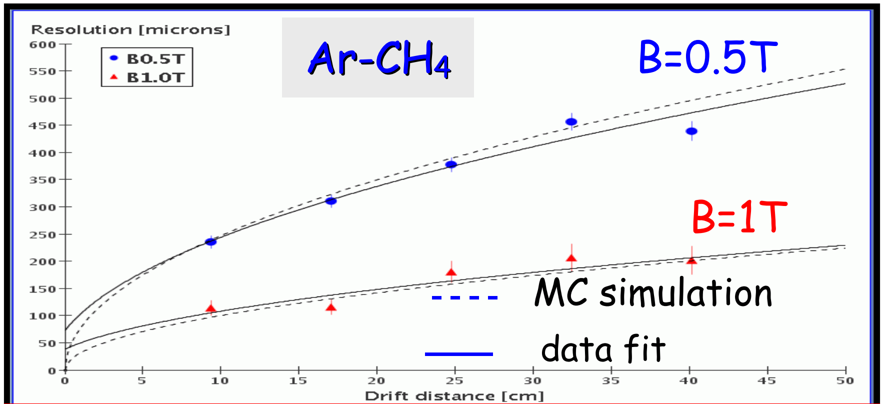


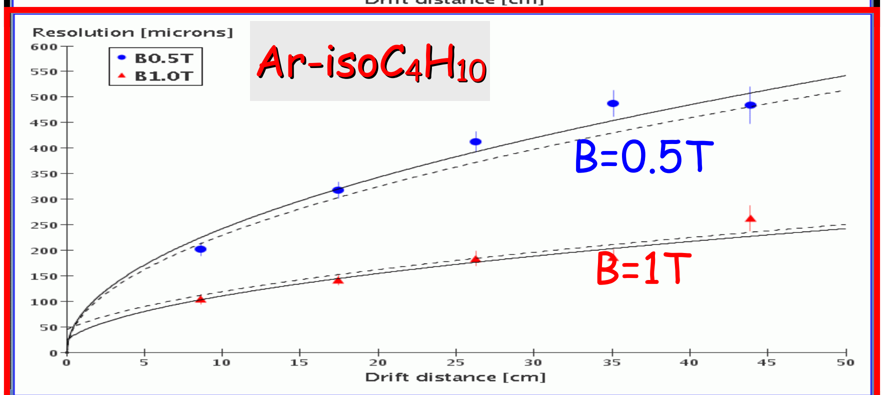
drift velocities:
perfect agreement between measurements and Magboltz simulations

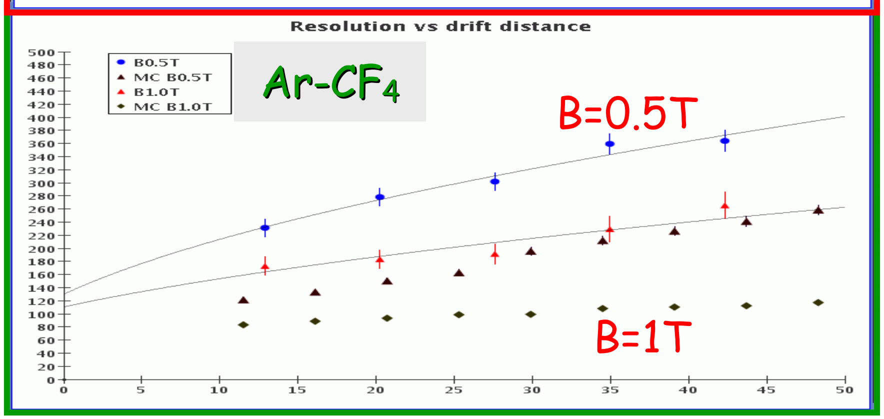
diffusion:
quite in good agreement for the three gas mixtures

results of a Micromegas TPC cosmic test

Saclay-Orsay-Berkeley







resolution vs drift distance

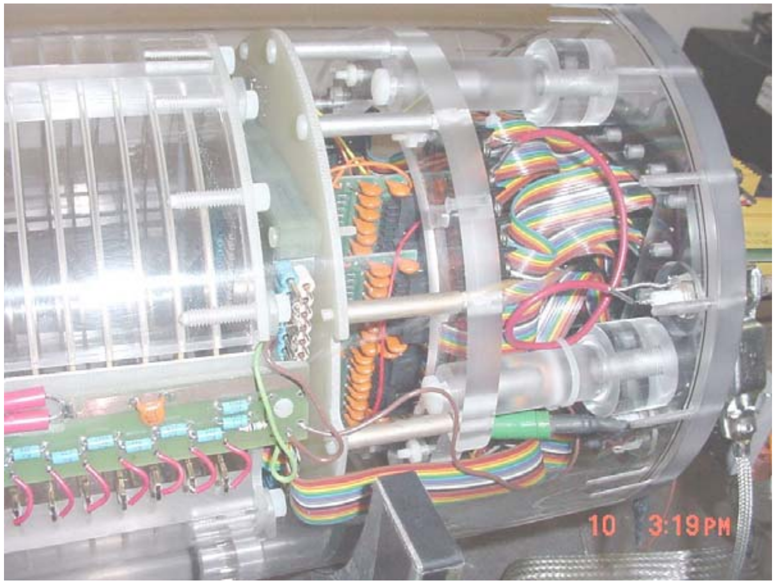
- **good agreement** between MC and data for $Ar\text{-}CH_4$ and $Ar\text{-}isoC_4H_{10}$

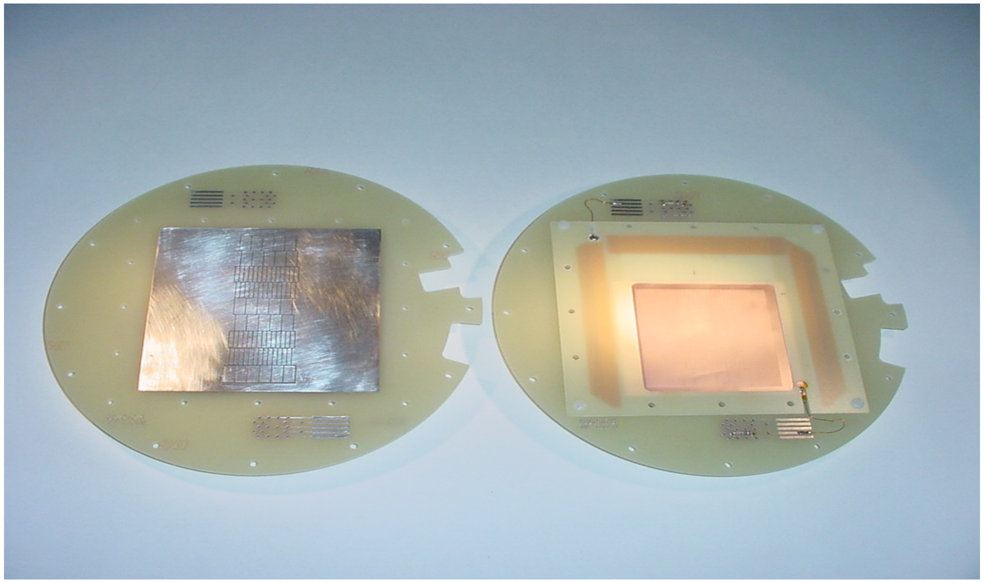
- extrapolated **value at zero drift** very small (≈ 50 μm)

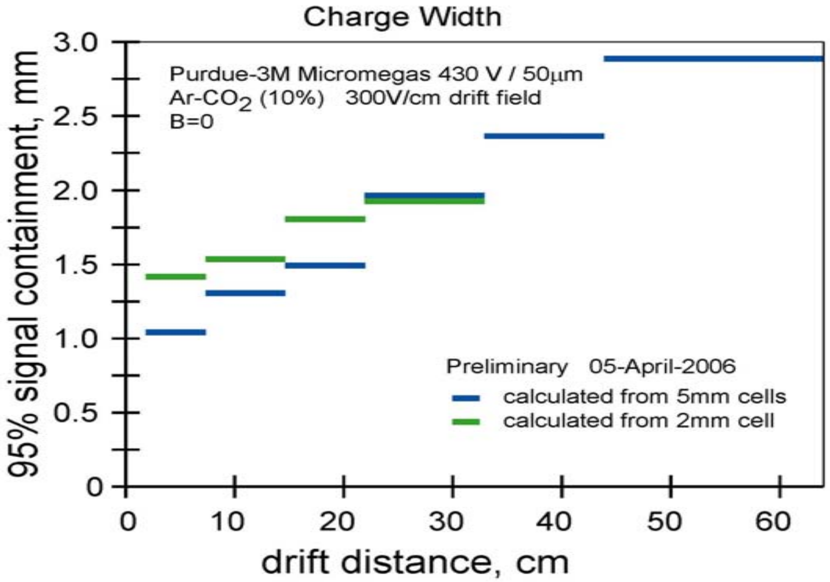
- **large** disagreement (**factor 2!**) for $Ar\text{-}CF_4$
  since the diffusion is well reproduced, N_e is two times too small as expected:
  no **attachment** ⇒ **bad quenching**?

⇒ we are investigating this gas mixture
⇒ add 1% $isoC_4H_{10}$?

1rts results of the Purdue-3M Micromegas Cornell TPC
(Ian Shipsey, Dan Petersen et al.)







resolution vs drift distance

1rt measurement (April5th!)

Ar-CO2 mixture
E=330V/cm (430V)
B=0T
resolution at Z=0: ~150μm

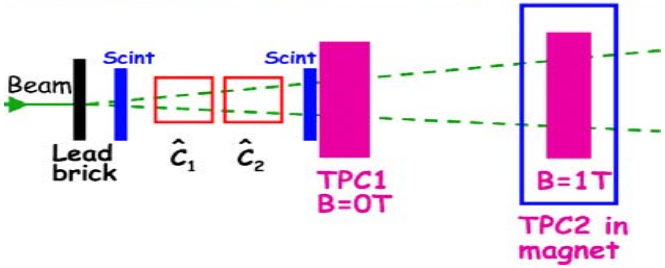
beam measurements at KEK with a Micromegas TPC

june 05

Canada, France, Germany, Japan, Philippines collaboration

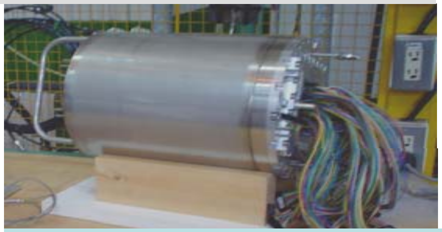
KEK, TUAT Tokyo Univ., Hiroshima Univ., Kogakuin Univ.
Kinki Univ., Saga Univ.,Tsukuba Univ., Japan, MSU, Philippines,
Carleton Univ.of Ottawa,Univ. de Montréal, Canada,MPI, Germany,
DAPNIA-CEA, Saclay, IN2P3-LAL and IPN, Orsay, France

T. Araki, D. C. Arogancia, A.M. Bacala, A. Bellerive, K. Boudjemline, D. Burke, P. Colas, M. Dixit, H. Fujishima, K. Fujii, A. Giganon, I.Giomataris, H. C. Gooc, M. Habu, T. Higashi,Y. KatoM. Kobayashi, K. Kodomatsu, H. Kuroiwa, V. Lepeltier, J.Miyamato, J.-P. Martin, T. Matsuda, S. Matsushita, K. Nakamura, E. Neuheimer, O. Nitoh, J. Pouthas, R. L. Reserva, E. Rollin, Ph. Rosier, K. Sachs, R. Settles, Y. Shin, A. Sugiyama, T. Takahashi, Y. Tanaka, T. Watanabe, A. Yamaguchi, T. Yamamoto, H. Yamaoka, Th. Zerguerras



JACEE magnet

L=1m, Φ=85cm, B=1.2T



MPP MPI+Saclay-Orsay

pad plane

- Micromegas 10 x10 cm^2
- drift distance 26 cm
- 24x16=384 pads 2.3x6.3 mm^2/16 rows
  ALEPH preamps (500ns shaping time)
- 11 MHz ALEPH Time Proj. Digitizers

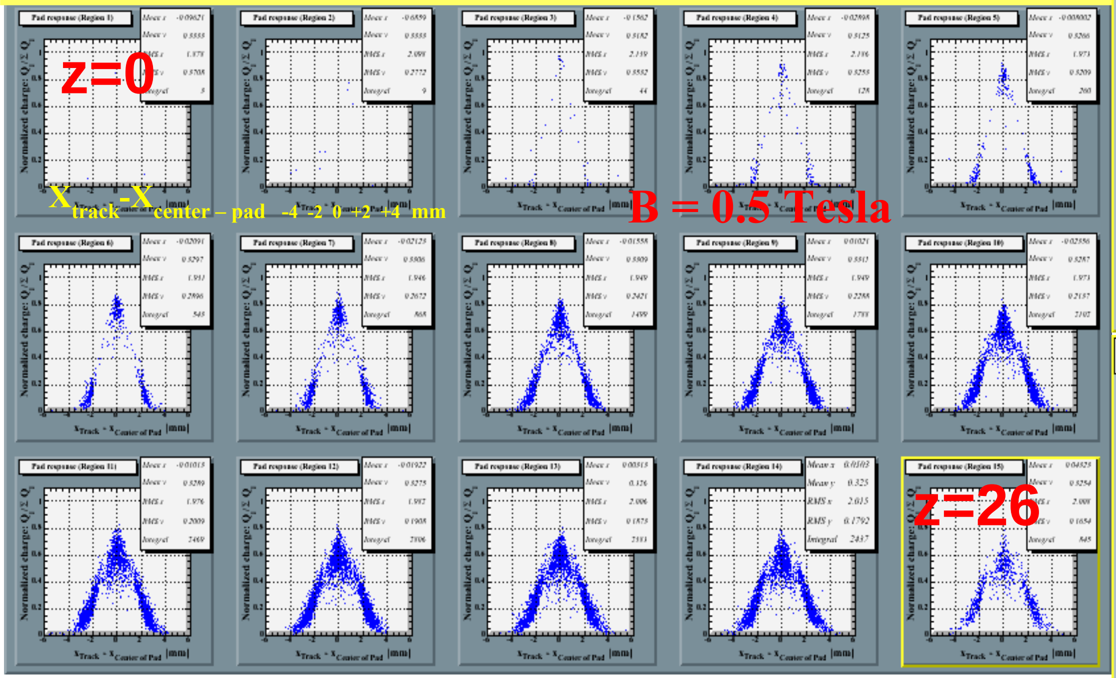
- beam : 4GeV/c,π-
- gas Mixture: Ar+5% Isobutane
- E=220V/cm , B = 0, 0.5 & 1Tesla
- gain = 10,000

see presentation by Rosario Reserva at LCWS06@Bangalore March 2006

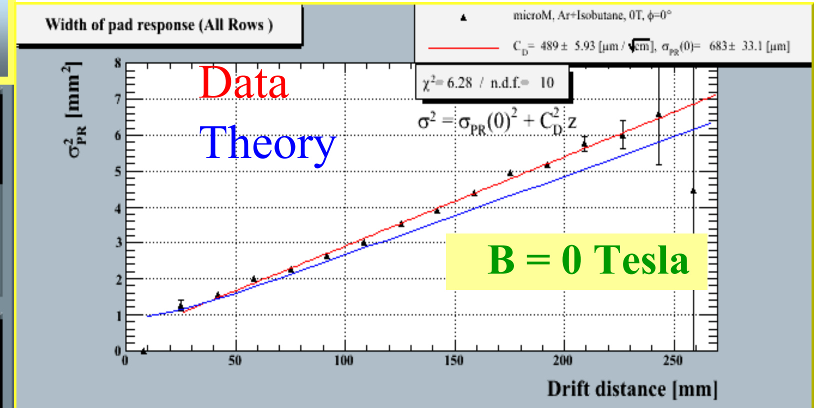
beam measurements at KEK with a Micromegas TPC

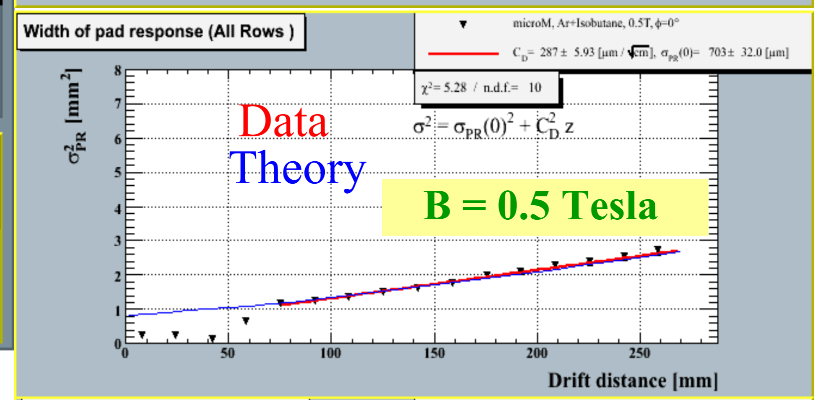
june 05

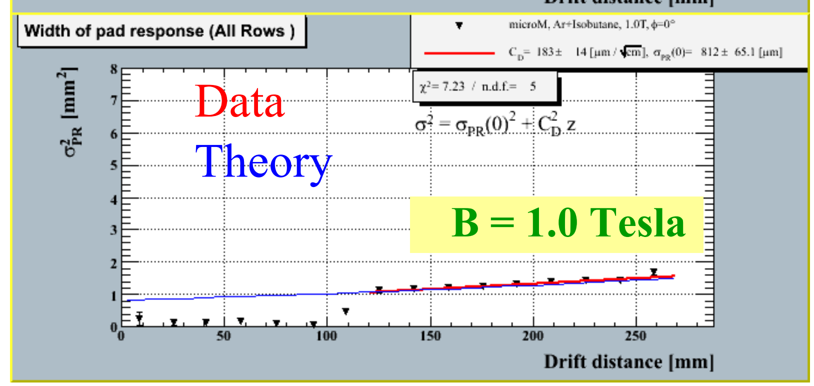
Charge Width Measurement vs Z



B	C_D Magboltz µm/√cm	C_D meas.
0T	469	489
0.5T	285	287
1T	193	189







beam measurements at KEK with a Micromegas TPC
june 05

B	$\sigma_x(0)$ µm/√cm measured	$\sigma_x(0)$ fit
0T	154 ± 22.3	132 ± 2
0.5T	199 ± 15.2	127 ± 2
1T	134 ± 76.2	128 ± 2

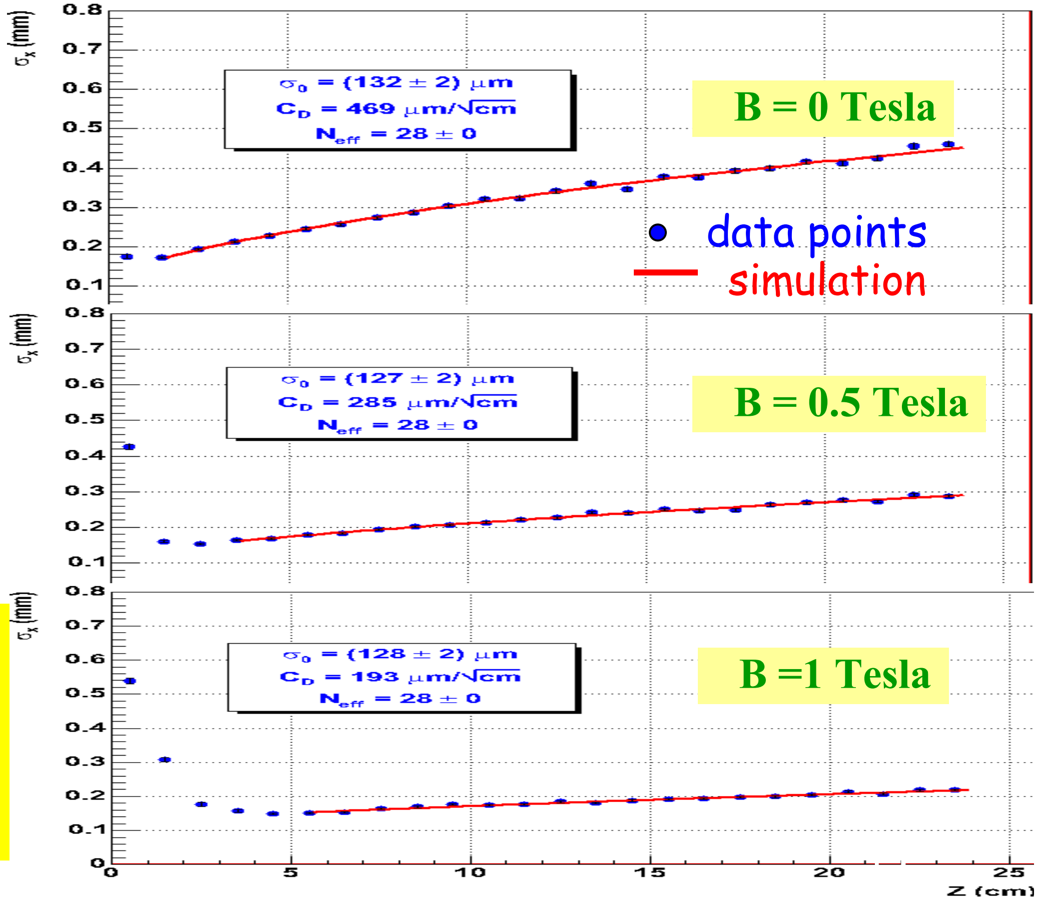
constant term σ_0 in good agreement with analytical calculation

$\sigma_0 = 2.3\ \text{mm} / \sqrt{(12 \times 28)} = 126\ \mu\text{m}$

pad width (2.3 mm)

N_e (28)

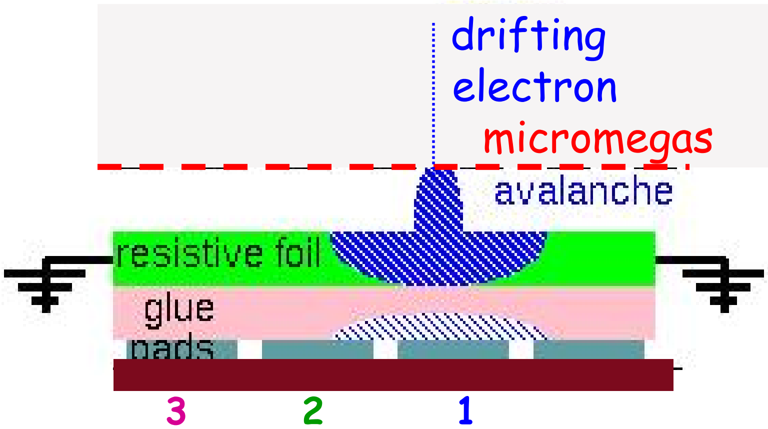
Spatial Resolution $\sigma_x(z)$



simulation by Khalil Boudjemline (Carleton Univ)

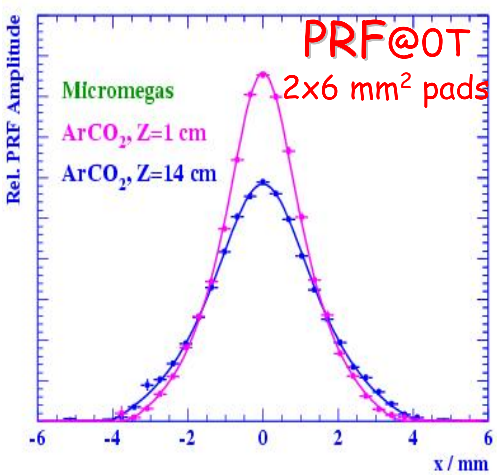
charge dispersion with a resistive anode

the avalanche charge is spread by coating the anode plane with a highly resistive foil (1MΩ/☐ Al-Si Cermet) 50µm + 50µm glue



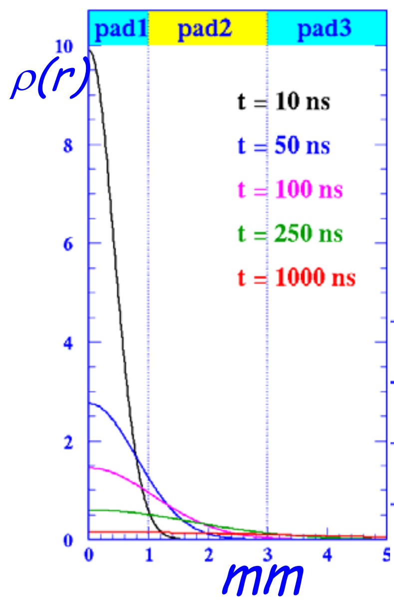
- 2-dimensional continuous RC network defined by material properties(R) & geometry (C).
- point charge at *r = 0 & t = 0* disperses with time.

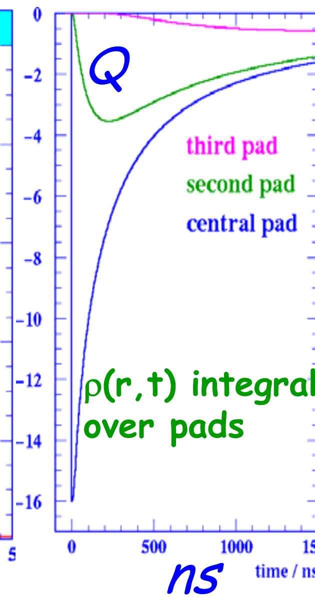
the charge evolution in r and t is the "telegraph" equation, governed by the RC time constant parameter:



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

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





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

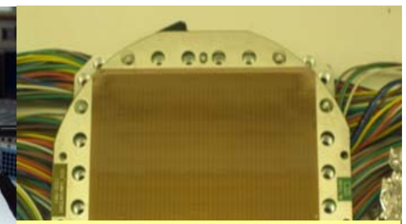
beam tests at KEK with a resistive anode
(october 05)


Carleton-Ottawa TPC

- Micromegas 10 x10 cm^2
- Drift distance: 16 cm
- 126 pads 2x6 mm^2/7 rows
- ALEPH preamps
- 25 MHz FADCs

same people, same beam at KEK, same magnet, but…
- a 2nd small **TPC from Carleton** in addition to MPI one
- both equiped with **Micromegas + resistive foil**
- TPCs in the beam, alternately inside the 1T-magnet


Micromegas 500 lpi
Saclay

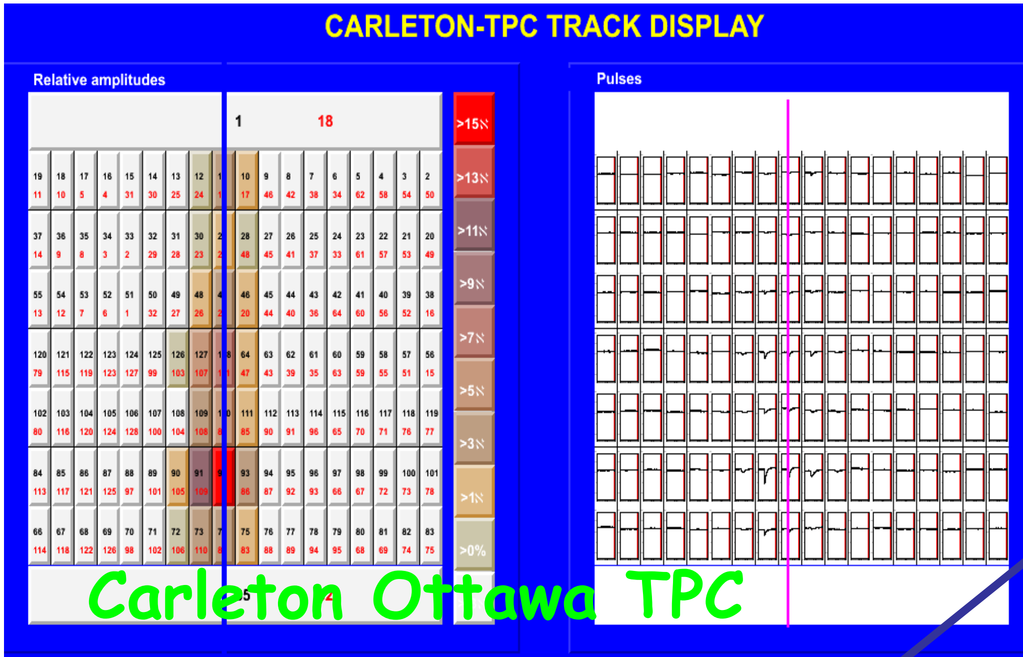

charge dispersion
readout endplate

people …working

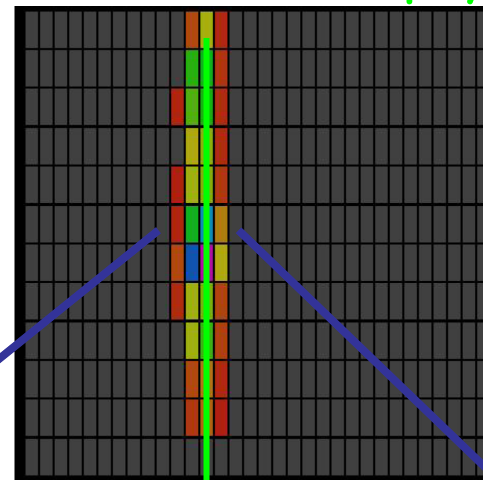
…discussing

…and … drinking

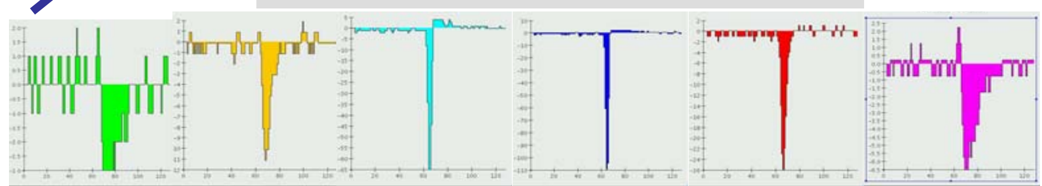
beam tests at KEK with a resistive anode
(october 05)



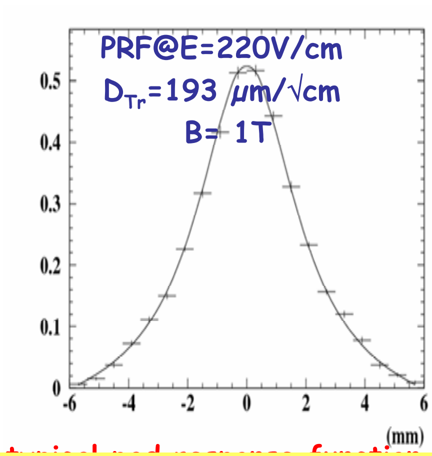
MPP TPC event display

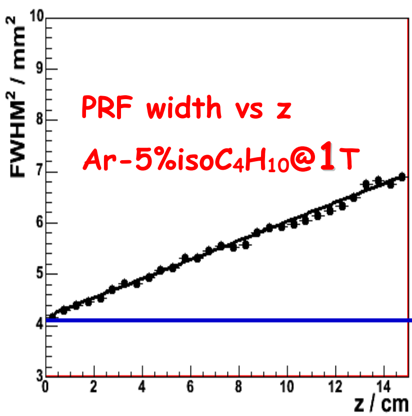


amplitude vs time distributions



charge spreading due to resistive foil is effective on at least 4 pads





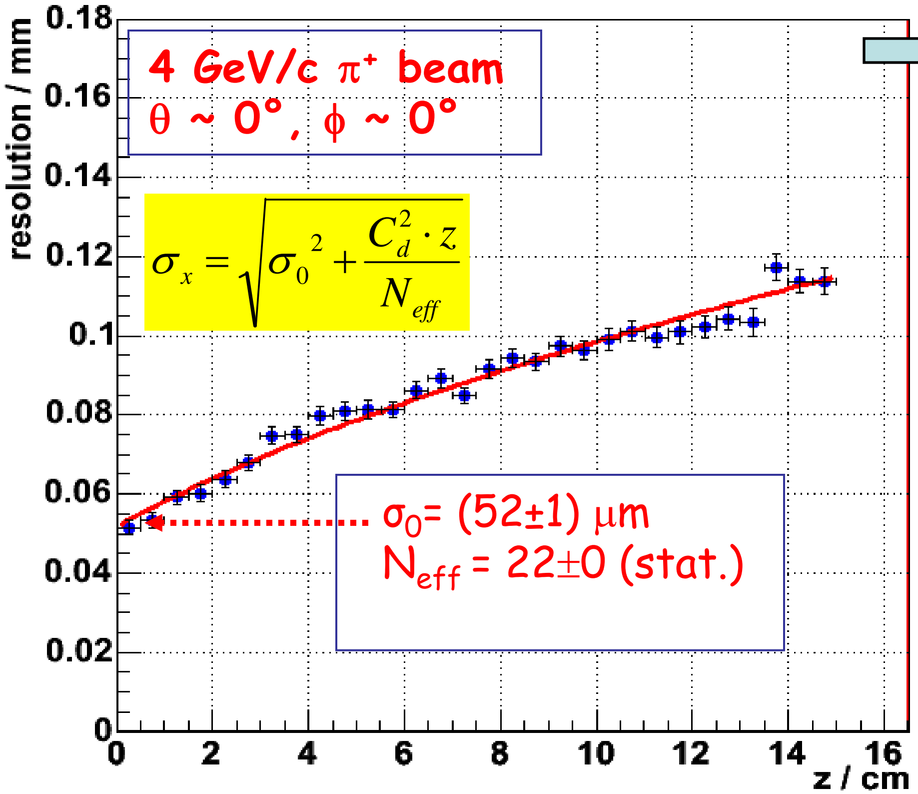
expected PRF vs z
Ar+3%CF_4@4T

beam tests at KEK with a resistive anode

(october 05)

preliminary results on resolution vs Z

transverse spatial resolution C_d = 125 µm/√cm (Magboltz)
for: Ar+5%iC4H10, E=70V/cm, B= 1T
Carleton TPC with Micromegas+ resistive layer 2 x 6 mm² pads



conclusions

1. **NO pad width** limitation
2. **extrapolation** from present data to
   B = 4T and C_d = 25 µm/√cm :
   $\sigma_t \approx$ **100 µm @2.5** m drift and 2x6 mm pads
   60 " 1m " "

near future for the Carleton group

- next summer: **4T cosmic tests at DESY** with various gas mixtures
- this year: develop a 25 MHz digitizer
- next year: **study 2-track resolution** with a beam (or a laser)

the digital TPC

idea: (see presentation by Paul Colas at LCWS06)

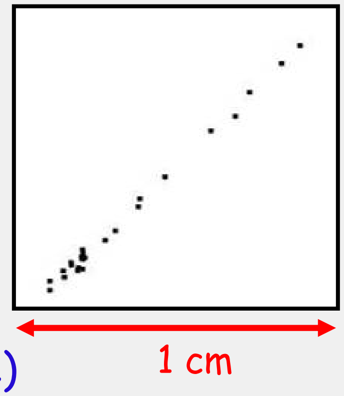
- reconstruct a track **electron by electron** (or cluster by cluster)
- the **pixel size** and **gas choice** should be a compromise between ionisation and diffusion (300 to 50 μm?, He based mixture?)
- the **whole coverage** of the ILC-TPC end plate surface

  $\Rightarrow 10^8$ to $\mathbf{10^9}$ **channels!** (instead of ~10^6), but all digital (1/0)

  ☻ insensitive to **gain fluctuations** (1/0)

  ☻ optimal **dE/dx** resolution (for the ILC-TPC: ~5% $\rightarrow$ ~2%?)

  ☻ probably a better **position** resolution (for one e: diffusion$\otimes$pixel size)



- **questions**:

  costing: 1rst attempts show that it should be less expensive than a standard readout

  efficiency: should be large enough for single e detection (gain vs threshold)

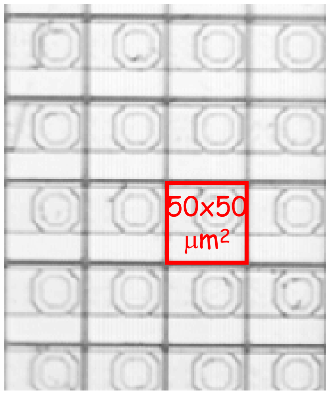
- **ILC**: full coverage or replace a few pad-rings by digital anode chips (gas "club sandwich")?

a CERN, Freiburg, MESA+/Twente, NIKHEF, Saclay collaboration

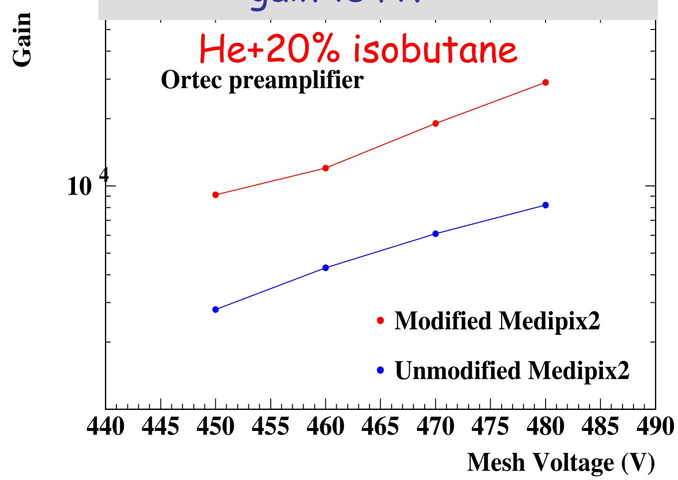
A. Bamberger, D. Burke, M. Campbell, M. Chefdeville, P. Colas, K. Desch, A. Giganon, I. Giomataris, M. Hauschild, E. Heijne, X.Lloppart, S. van der Putten, C. Salm, J. Schmitz, S. Smits, H. Van der Graaf, J. Timmermans, M. Titov, J. Visschers, P. Wienemann

the digital TPC

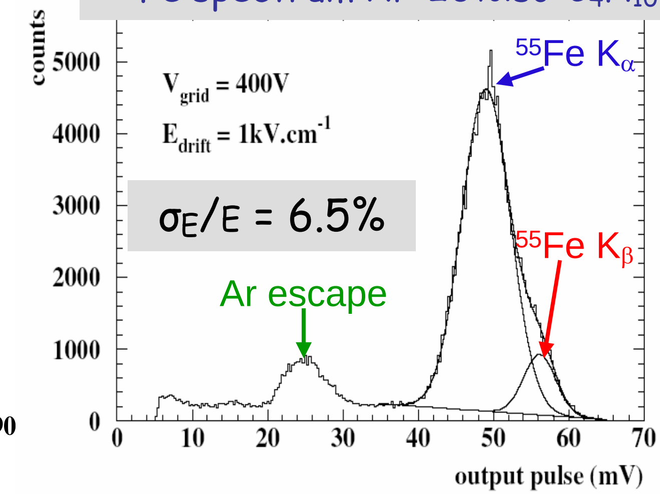
Micromegas + Medipix (~55μm pitch) ☹ no time measurement!



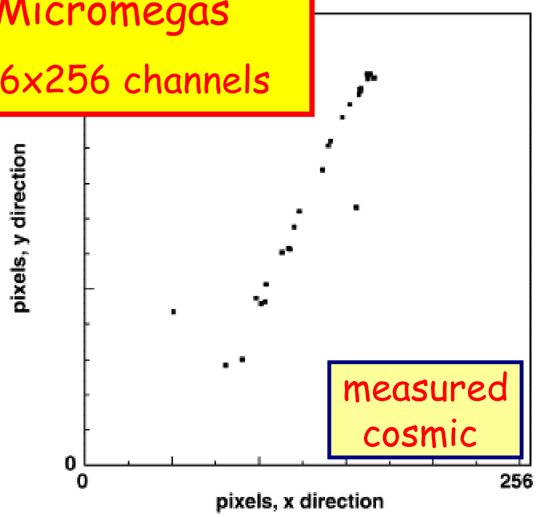
gain vs HV

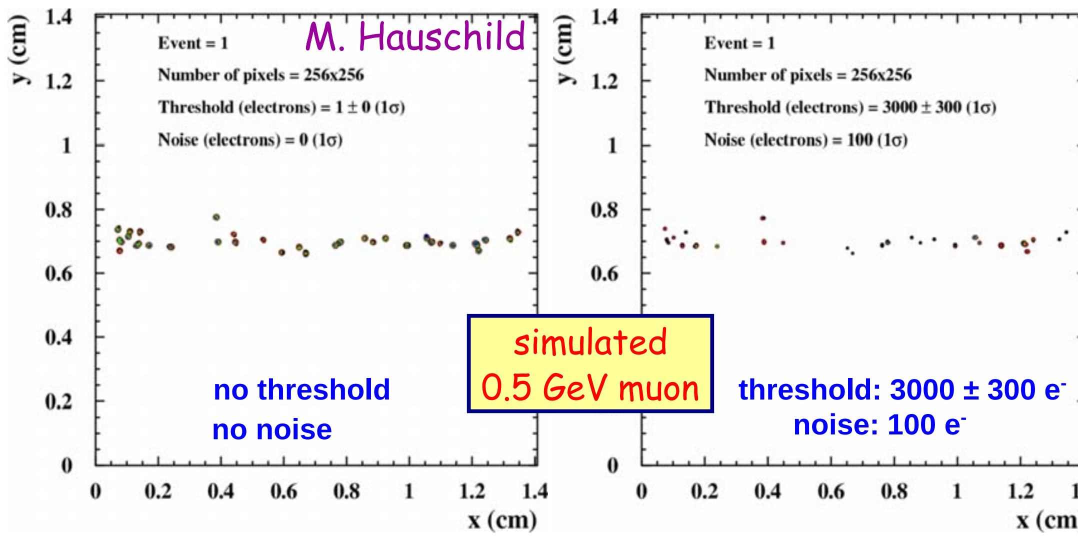


^{55}Fe spectrum Ar-20%iso-C_4H_{10}



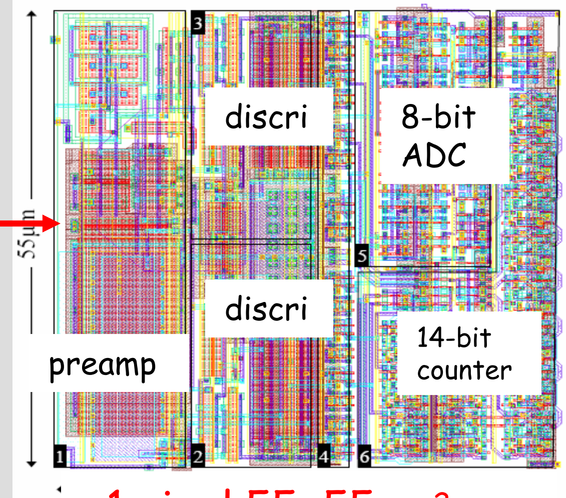
Micromegas
256x256 channels





the digital TPC

- Medipix collaboration: 17 institutes, since 1999
- CMOS chip, 0.25μ technology, 65000 pixels on $2cm^2$
- Upgrade of Medipix2: MXR version, less sensitive to temperature, under development at Saclay
- Also new readout board/card: USB



1 pixel 55x55μm^2

- next step: from **Medipix2** to **Timepix** (time measurement)
- more tests with smaller gaps (40 μm already successful)
- study of the gas gain fluctuations in progress

EUDET European Detector for the ILC (4 years EC action)

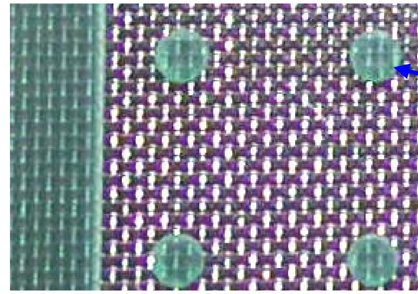
CERN-Freiburg-NIKHEF-Saclay-Bonn?-Bucarest? 2M€ (850 k€ allocated by EC)

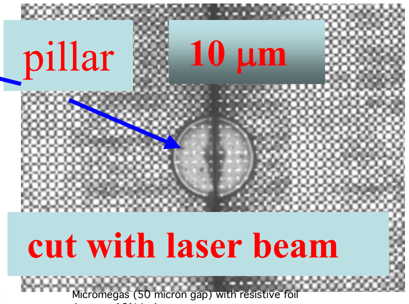
program: TimePix design at CERN,
develop post-processings for protection and mesh integration
build a detector (deliverable in 2 years),
watch the outcome of 130 nm and 90 nm technologies (CERN), etc

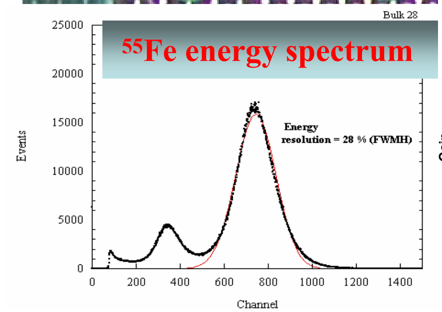
other Micromegas developments: bulk

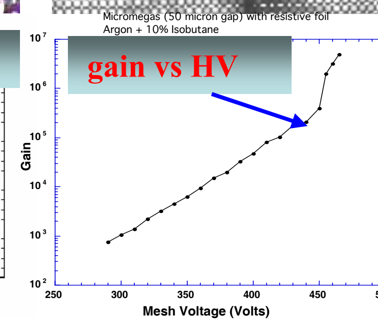
I. Giomataris (Saclay), Rui de Oliveira (CERN), and many other people, DAPNIA 04-80 see poster #221 by Paul Colas

1) cleaning of PCB (strips, pixels,…)
2) photoresist lamination (50 to 150μm)
3) woven mesh deposition (inox 19μm, 500 lpi)
4) photoresist lamination (50 to 500 μm)
5) UV insolation through a mask
6) development (sodium carbonate)
7) solidification (UV and hoven)



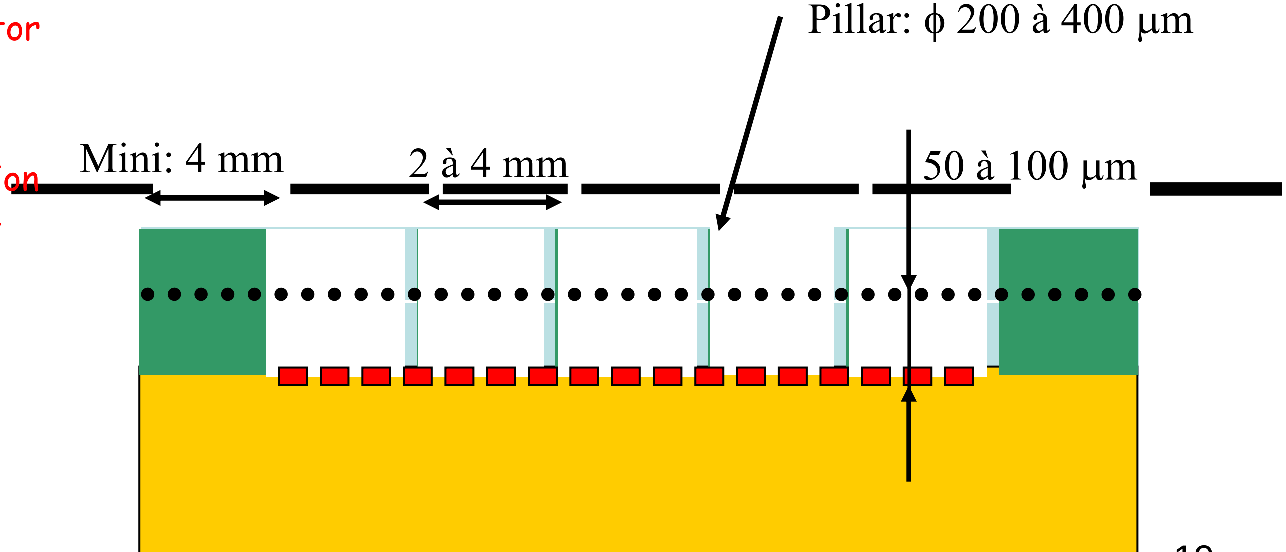






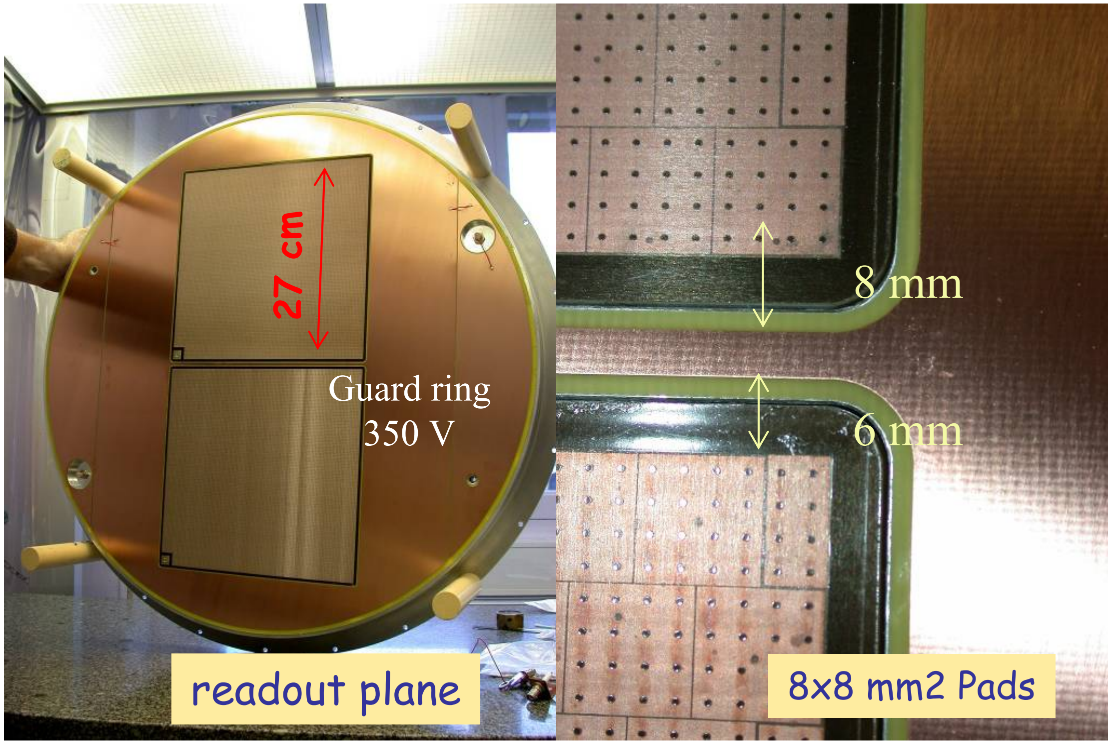
many advantages:

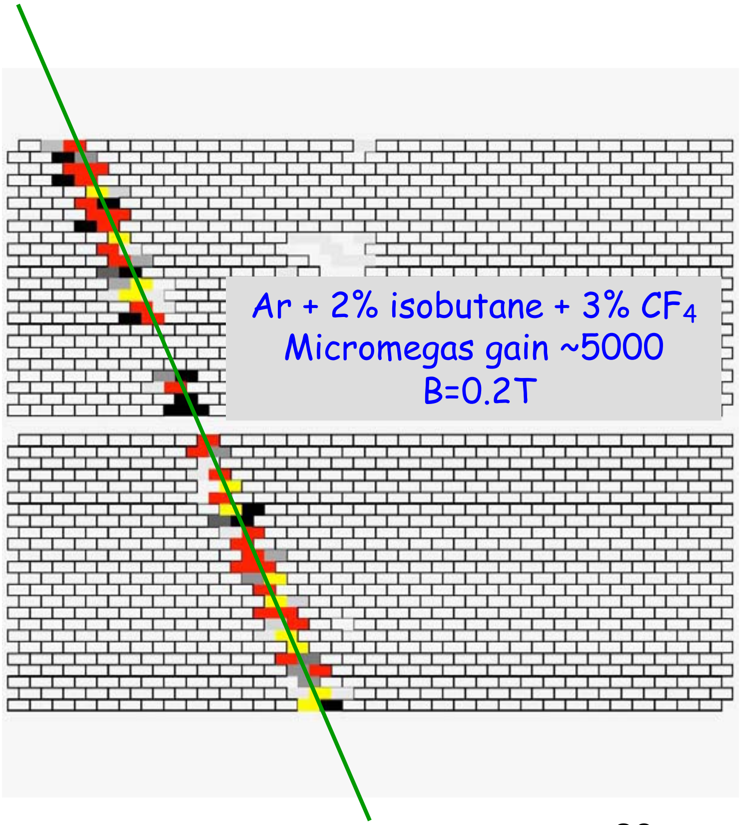
clean and well protected detector
no frame needed,
large areas available
low cost and very fast realisation
robustness , easy to implement
can be cut easily!



other Micromegas developments

T2K cosmic tests in the HARP/TPC
at CERN (november 05)





CONCLUSION

1. **Micromegas** has been successfully working on a few TPCs for long period.

2.the measured **spatial resolution** are in good agreement with the expected values.

all ingredients of the spatial resolution are quite well understood

(pad width, number of effective electrons, etc.)

4. for the **pad width limitation**, very critical for the ILC-TPC, it has been

demonstrated that it is necessary to **diffuse the electrons after the avalanche…**

5. **resistive deposition on the anode** is a good solution to overcome this limitation, it works very well, more tests will be performed very soon.

4. **pixellised readout**: lot of progress since two years,

more expected in the future, very promising application to tracking.

5. **new developments**:

it will be possible in the near future to produce large surfaces of **unexpensive**, robust, made "à la carte", **easy to implement**, and potentially **very transparent** Micromegas detectors ("bulk") including all processes in a short time.