Micropattern Readout Development for Gas Detectors

R.Majka, N.Smirnov
Nov 7, 2003, MIT

Why GEM ?

An intensive R&D of many groups demonstrated:

Detectors on a basis of GEM technology can be

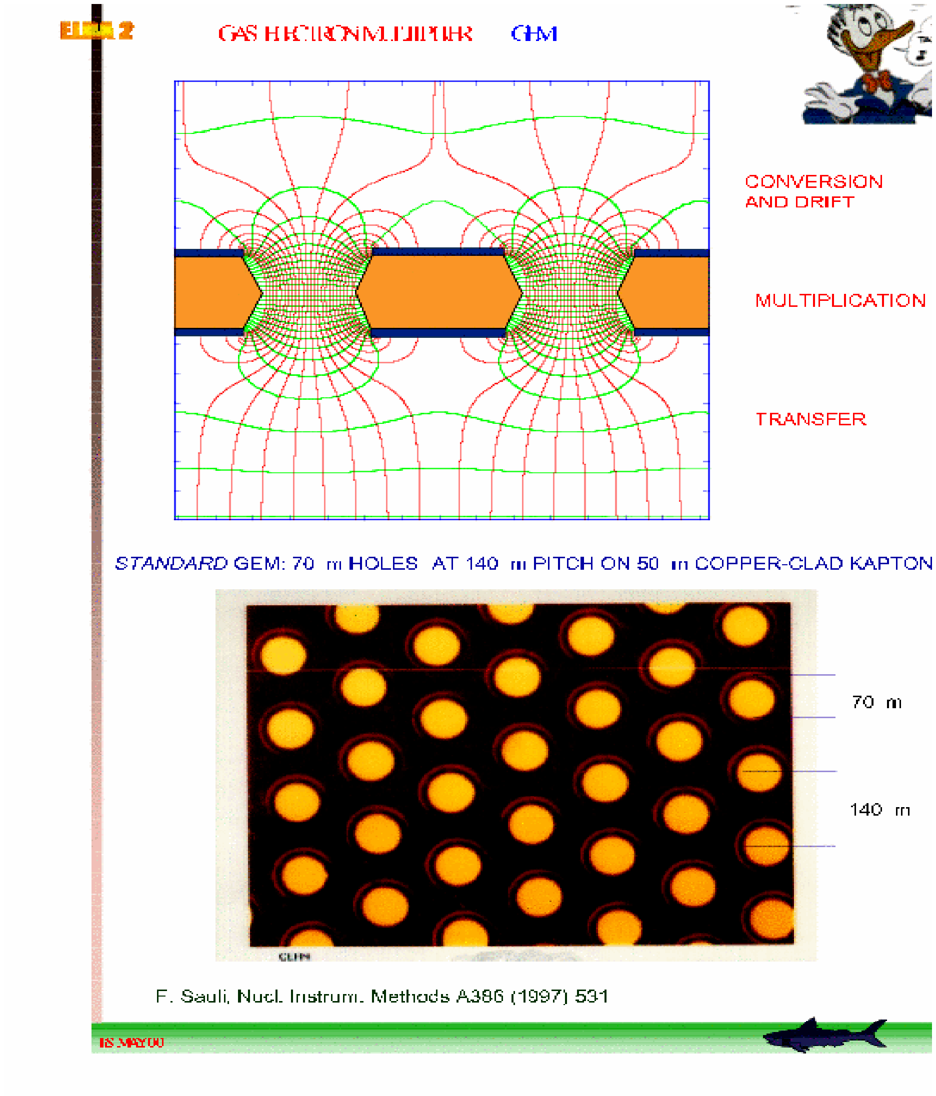
- reliable (COMPASS, two years experience)
- high gas amplification (multiple GEMs: up to 10^6)
- fast (< 20 ns FWHM, rate capability up to 10^5 Hz/mm²)
- low mass (50 µm Kapton+10 µm Cu; small thickness read-out plane; small size, low Z frame material)
- 1d-, 2d- good space resolution (~50 µm)
- not complicated and in-expensive in a construction

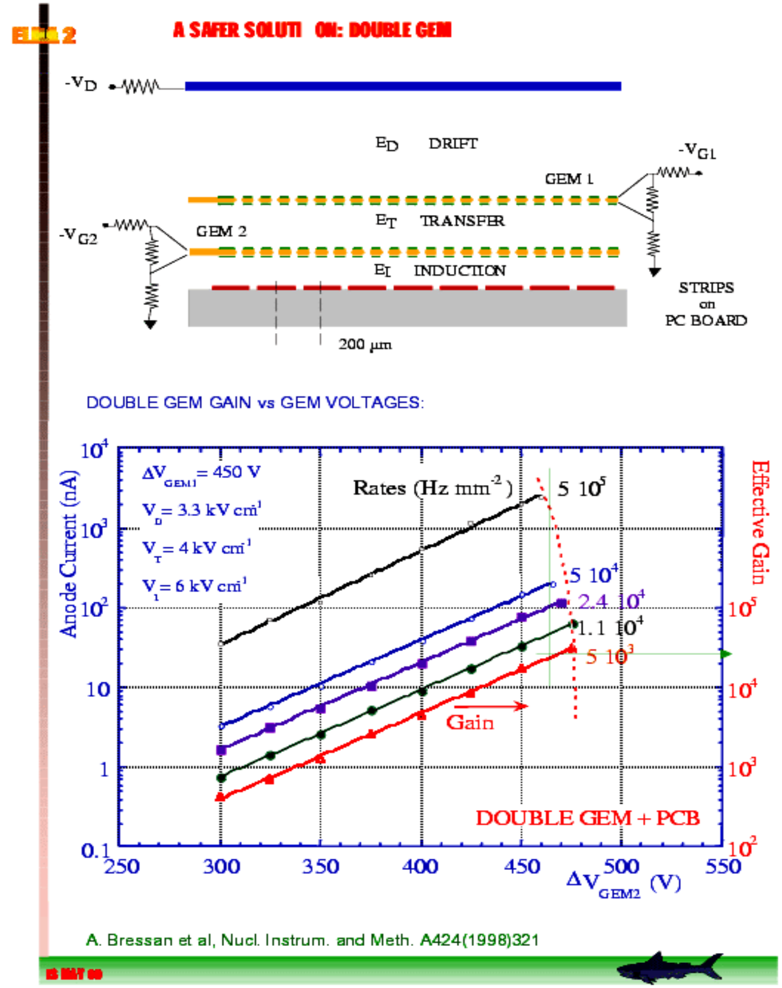
tracking devices that are working with different gases, inside of a strong magnetic field and for a very broad application variants.

Detector response simulation is in a “reasonable” shape.

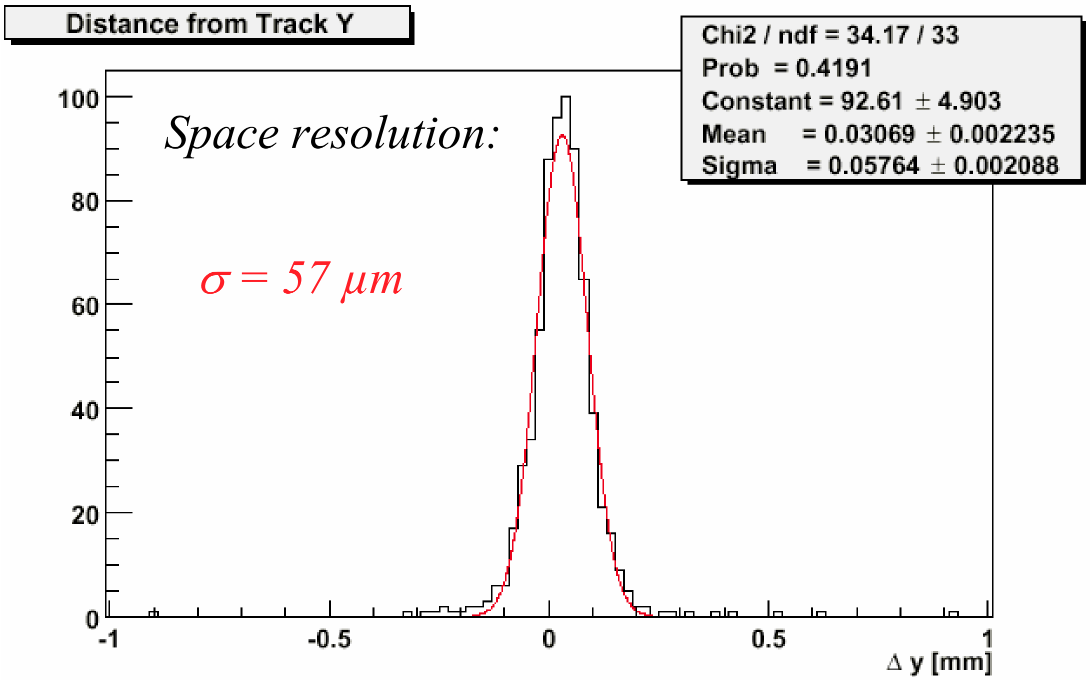
GEM Detector

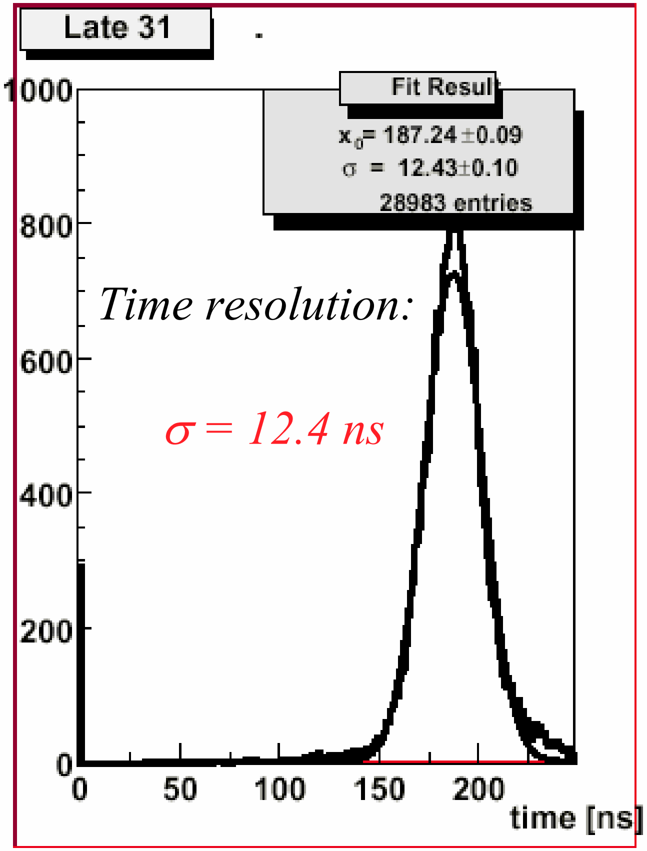
Low mass; fast; not “high” precision in construction and in-expensive; any shape and pad size; double, triple or more foils setup; checked and tested.





Space and time resolution (an example, not the record)





Read-out plane: pads, strips, 2D-strips with stereo angle, direct Si, …- choose pitch, technology and shape.

The GEM technology in TPC (motivation)

- Fast and “narrow” signal: electron collection, no ion tail
- Much easy “mechanical” construction, no wire tension – no “strong” frame; smaller thickness both field cage(s) and end-cup
- Flexible foil and pad geometry
- Ion feedback suppression
- Low distortions due to ExB (in amplification region)

The GEM technology in Pad (Strip) Detector (motivation)

- high precision
- low mass
- fast
- not “complicated” in a construction and in-expensive
- any shape and pad size
- double, triple or more foils setup
- can be used in a combination with another detectors

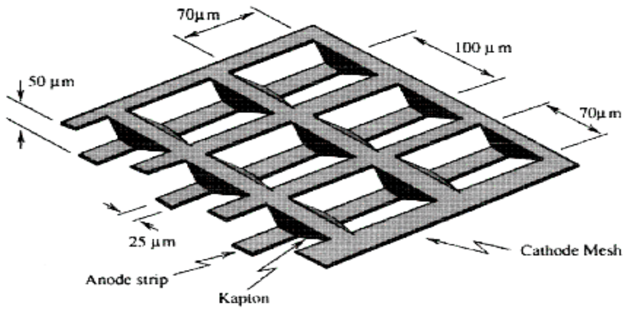
R&D activities: e+e- LC, LHCb, JLab, LEGS, PHENIX, STAR, …

- ✓ - GEM pad structure (TPC and Pad Detector)
- ✓ - “working” gas including UV transparency and scintillations properties
- ✓ - space and time resolution study
- ✓ - GEM mass production and dedicated Test Laboratory
- ✓ - photodetectors (Gas PMT)
- ✓ - FEE, DAQ, ….
- ✓ - prototypes
- ✓ - simulation / reconstruction software

Micro-wire, MIPA and MicroMeGas Detectors.

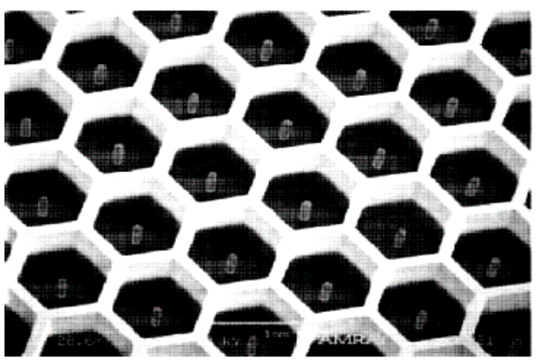
NEW MICROPATTERN DETECTORS - 3

MICRO-WIRE CHAMBER:



B. Adeva et al, Nucl. Instr. and Meth. A435(199)402 A. Iglesias

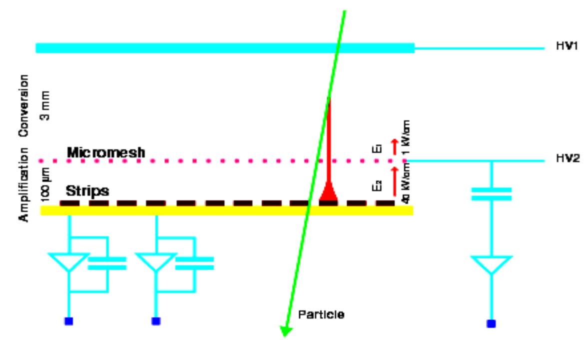
MIPA: MICRO PIN ARRAY DETECTOR (SILICON TECHNOLOGY)



P. Rehak et al, IEEE Nucl. Sci. Symposium Seattle 1999

Micromegas

- NIM A376 (1996) 29
- A $15 \times 15 cm^2$ detector has been tested at PSI in a low energy hadron beam and at CERN PS with 10 GeV/c π^+
  - 100 μm amplification gap, 317 μm strip pitch



- At PSI a very high discharge probability per particle was observed
  - With $Ar - CO_2$ (60-40) at a gain of 6000 $P = 1.1 \times 10^{-5}$
  - With 50 KHz/mm^2 proton beam the sparking rate was as high as 3 KHz and the current was 2 mA
- No damage to the chamber has been observed

STAR Detector R&D

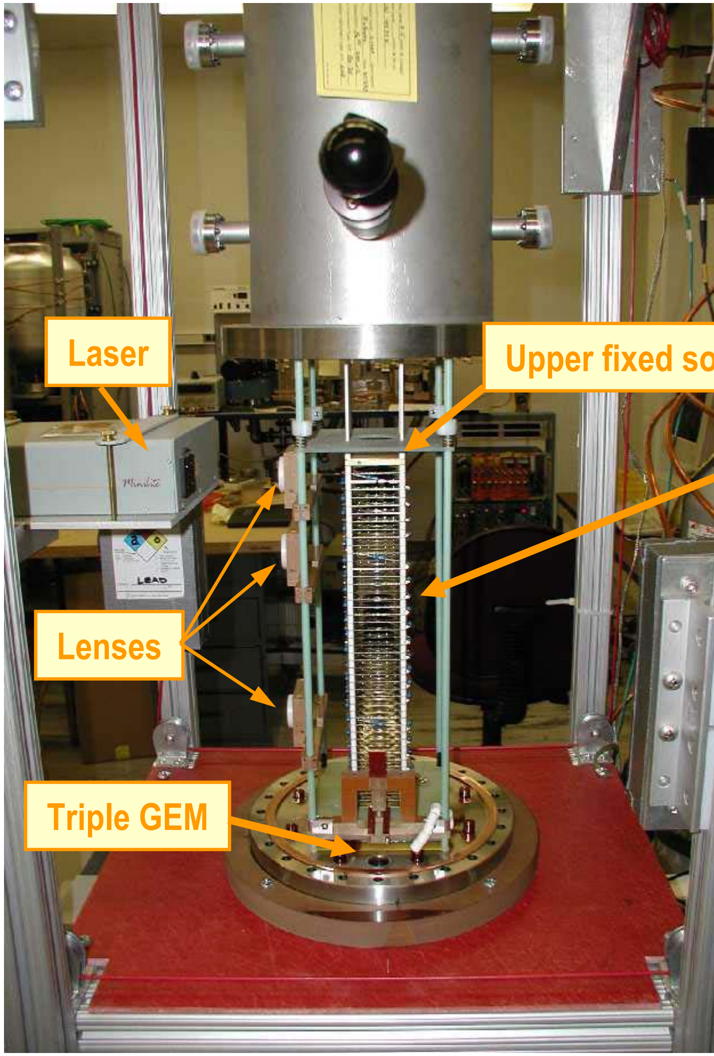
Installed R&D Laboratory at BNL (with very low funding so far) as a joint activity with BNL Instrumentation Division, PHENIX, LEGS.

Accomplishments:

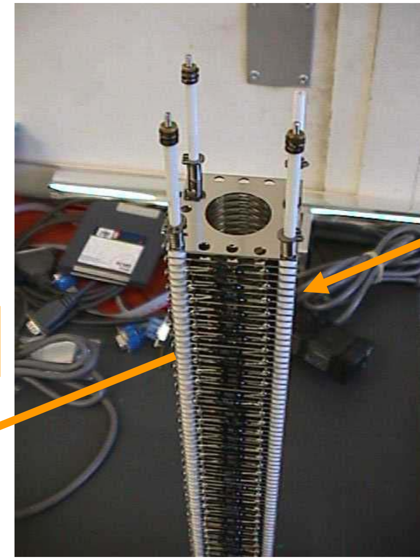
- ✓ "working" gas including UV transparency and scintillations properties
- ✓ GEM pad structure (TPC and Pad Detector)
- ✓ GEM mass production and dedicated Test Laboratory (at Yale ?)
- ✓ UV photoconverters
- ✓ FEE, DAQ, …. (first prototype)
- ✓ full scale prototypes (E-field simulation, construction approaches)
- ✓ simulation / reconstruction software

but we need "STAR R&D team"

Test Drift Cell

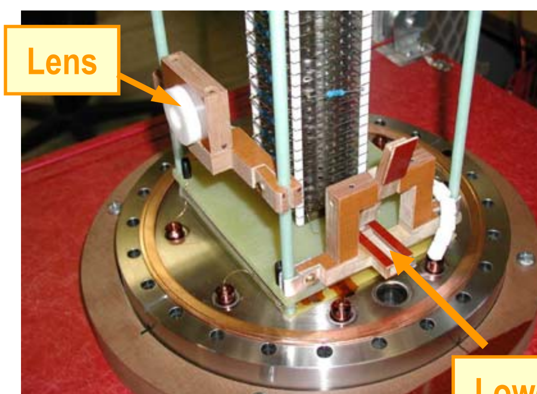


Lab 2-86 in Physics



Drift Stack

presently 29 cm drift

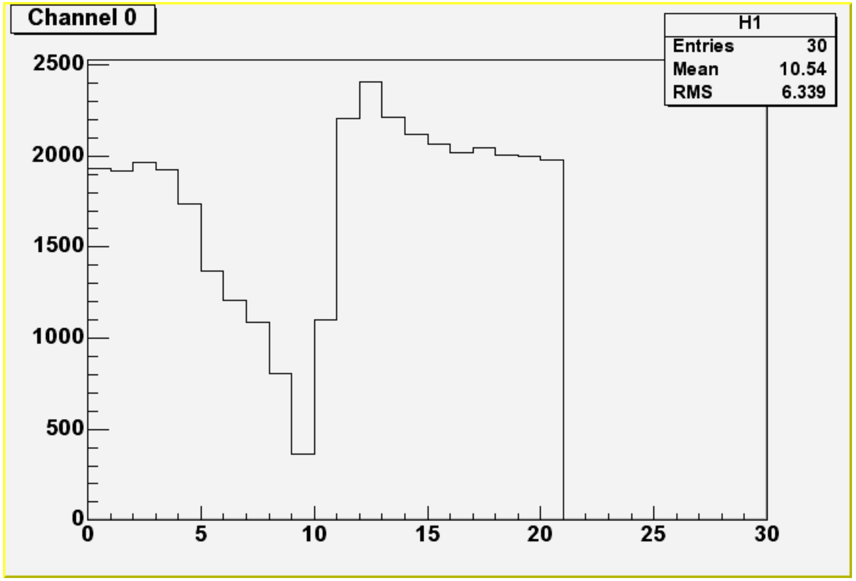


Used to study

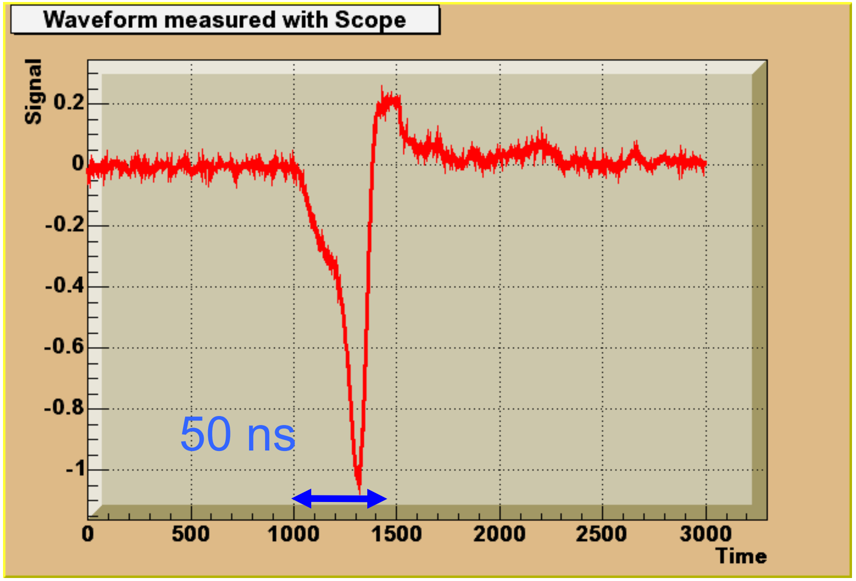
- Drift velocities
- Diffusion parameters
- Energy loss (dE/dx)
- Study impurities
- Readout structures
- Field cage design

Readout Electronics

^{55}Fe source with 10x10 cm^2 triple GEM, one pad (0.2x1. cm^2) signal



FADC readout (10 ns bins)

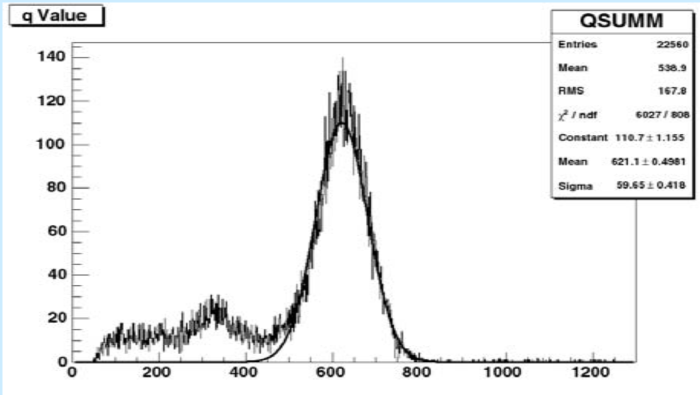


Digital scope trace

Currently reading out GEM TPC with 100 MHz FADC
(SIS 3300 8 channel, 12 bit VME module)

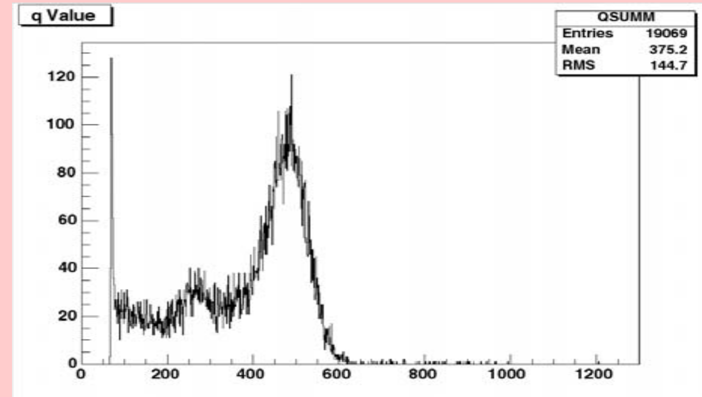
Drift Cell Measurements

Ar/CO_2 (80/20)



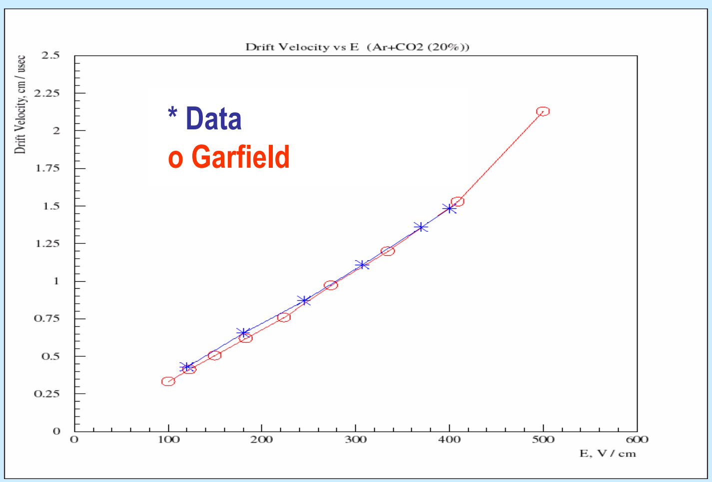
22% FWHM/mean

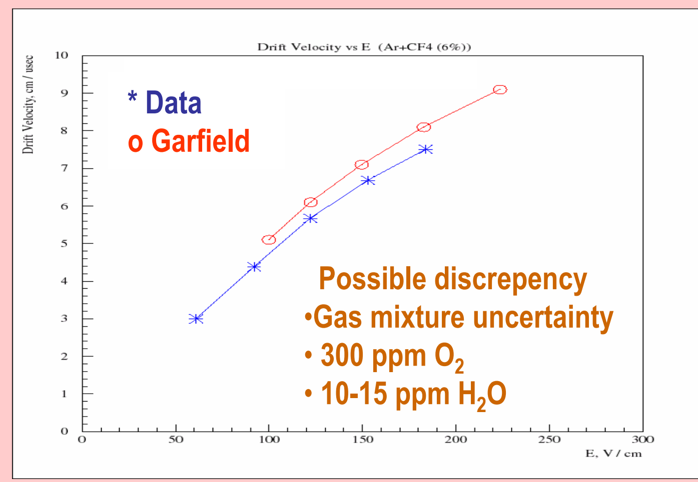
Ar/CF_4 (95/5)



28% FWHM/mean

Energy Resolution
(Top ^{55}Fe source)



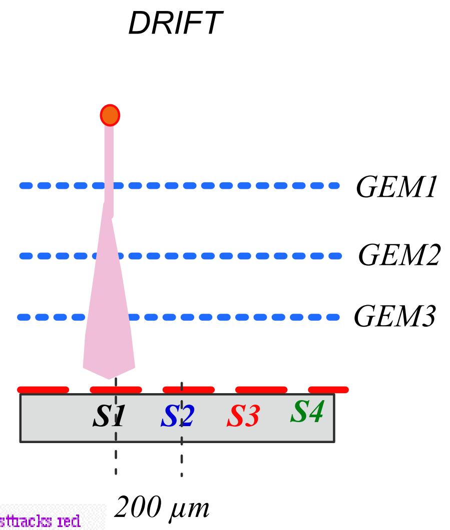


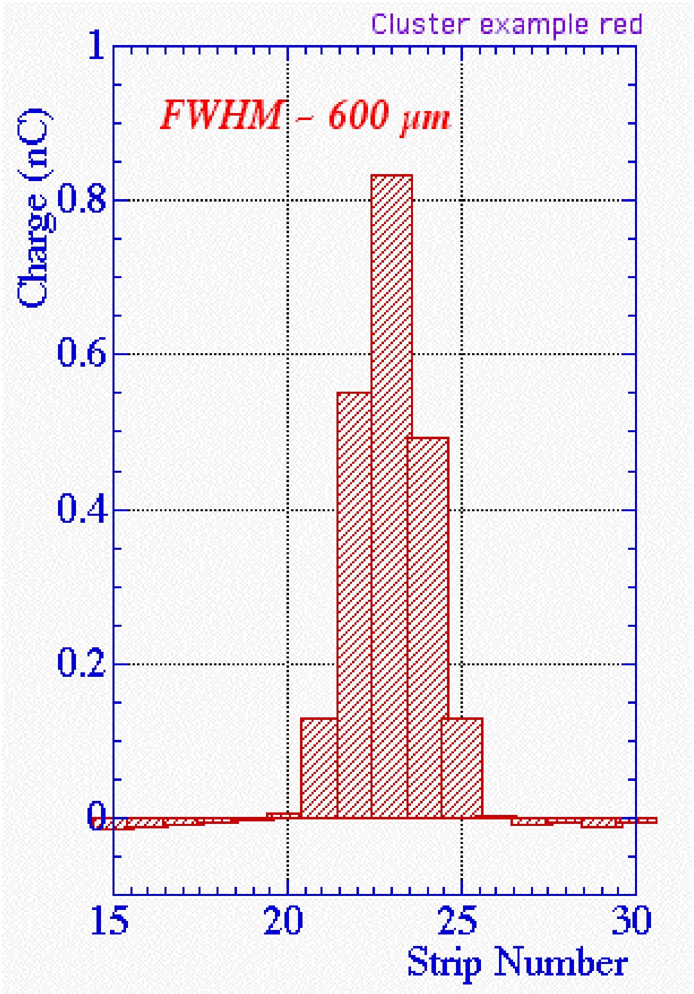
Drift Velocities (laser)

GEM Detector with 200 μm strip readout

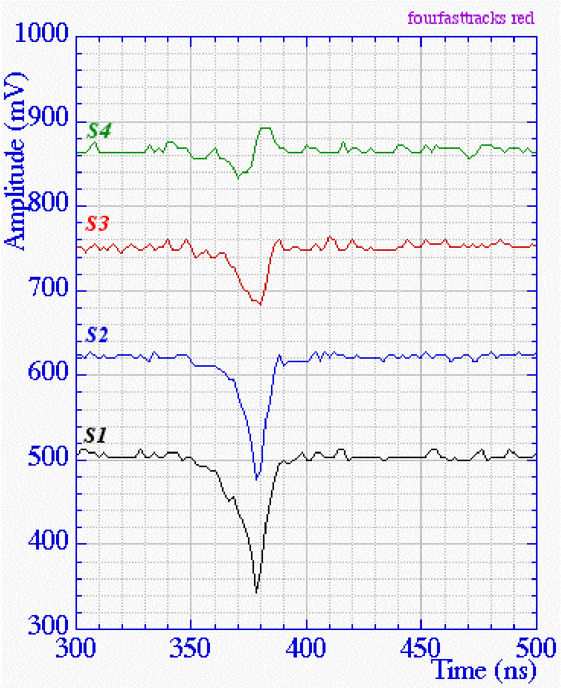
Narrow pad response function ($\Delta s \sim 1$ mm):

Improved multi-track resolution





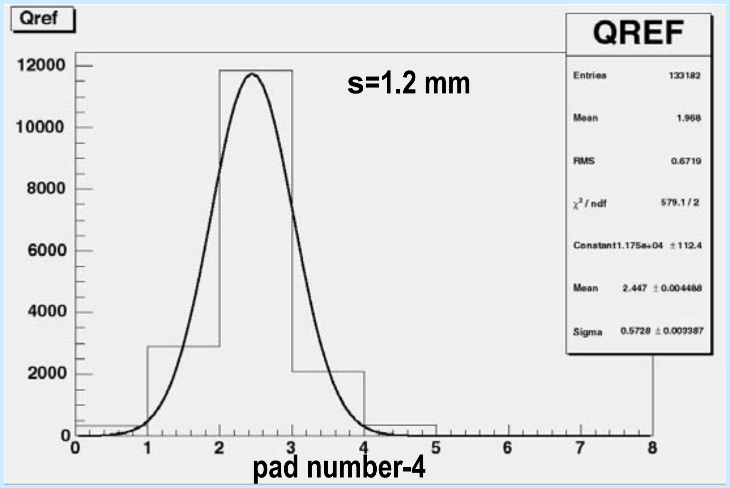
Fast signals (no ion tail)
$\Delta T \sim 20$ ns :



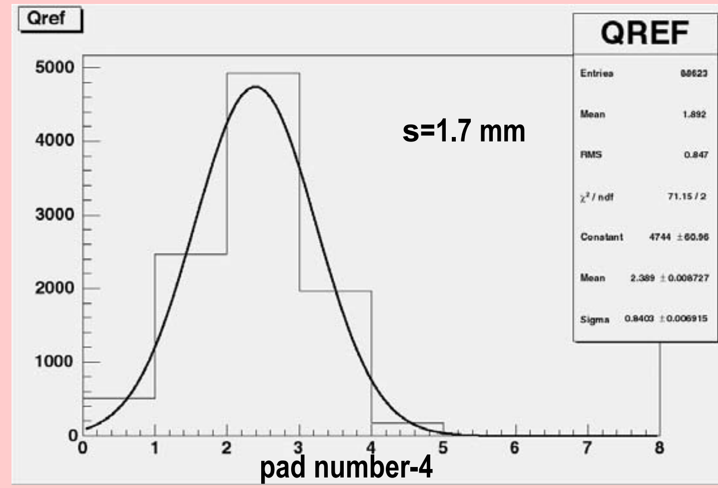
☞ Intrinsic multi-track resolution $\Delta V \sim 1\ mm^3$
(Standard MWPC TPC ~ $1\ cm^3$)

Charge Distribution from Drift Cell
top source (29 cm drift), 2 mm pad readout

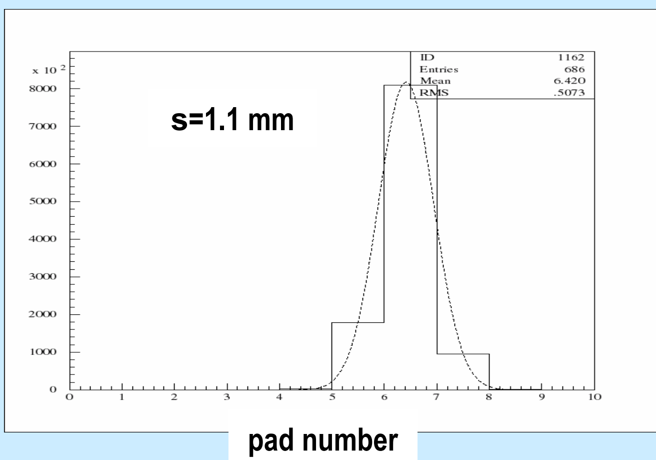
Ar/CO_2 (80/20)



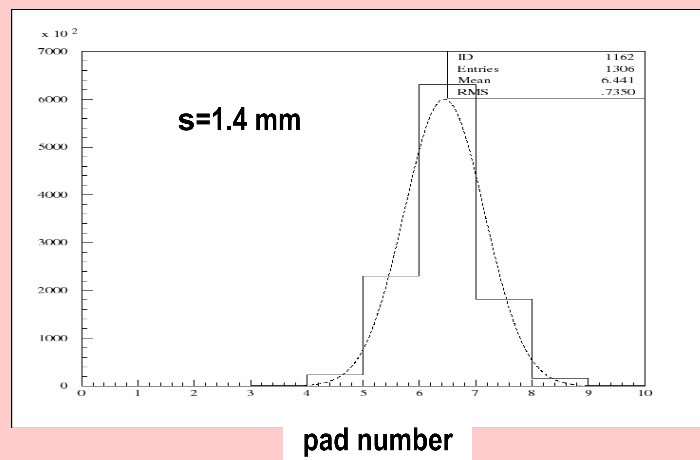
Ar/CF_4 (95/5)



Measured

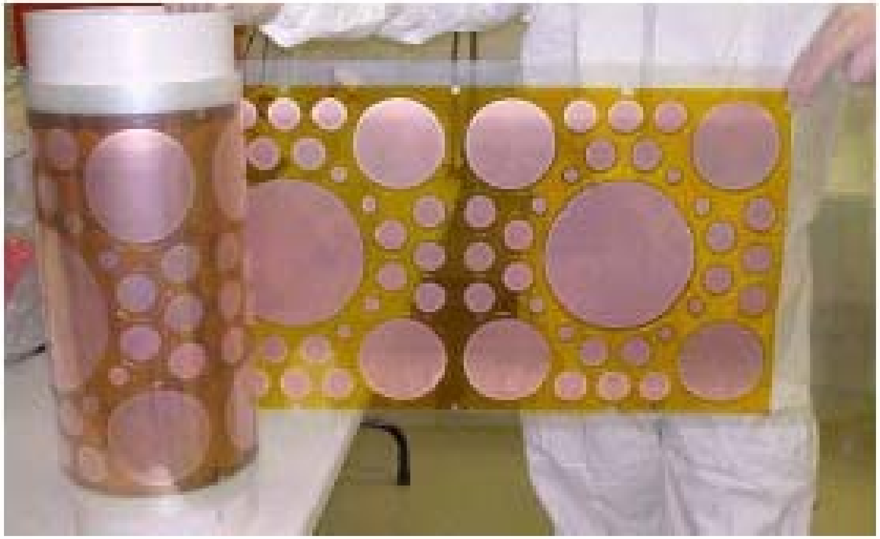


Simulation



New GEM Foils from 3M

3M Microinterconnect Systems Division, Austin, TX
In collaboration with Univ. Chicago (J.Collar)
hep-ex / 0304013 (April 2003)

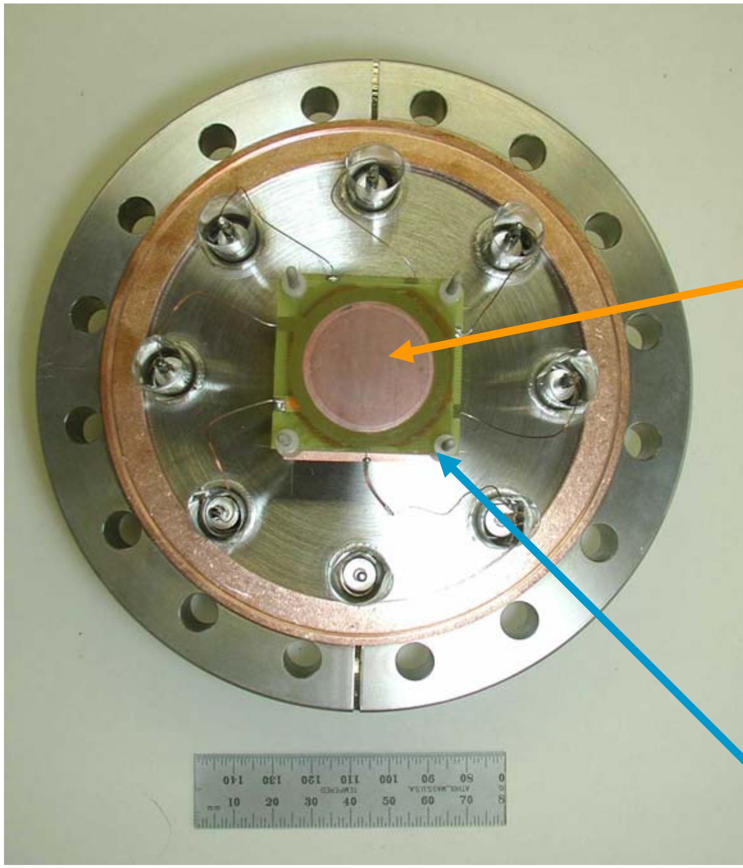


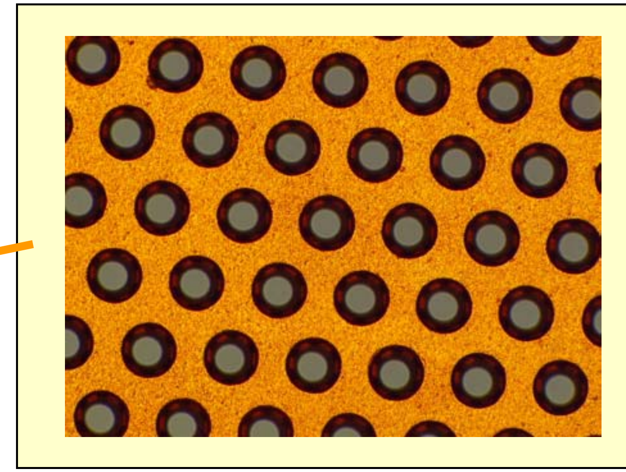
Roll-to-roll process

Limited to 12" width

Mass GEM foils production can be started in Russia and Japan this year

Testing Small 3M Foils





80 mm (55 mm) holes spaced in a hexagonal pattern with 140 mm pitch

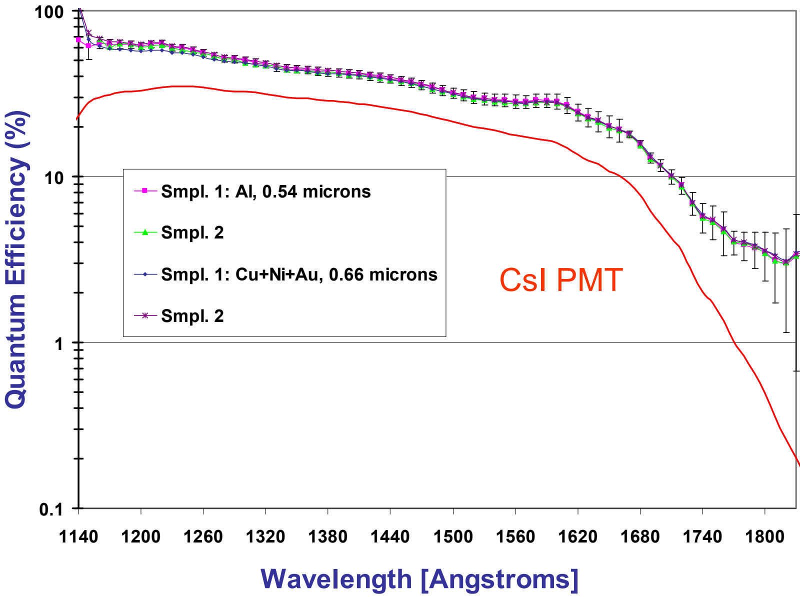
Visually looks to be excellent quality

3 stage GEM with three 1” dia. 3M foils

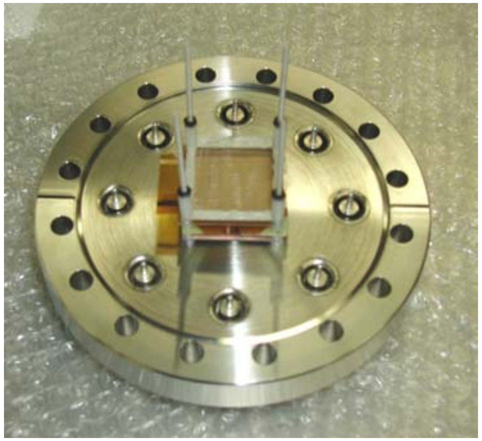
Will compare with CERN foils in Ar/CO_2 & CF_4

Absolute Quantum Efficiency of CsI photocathodes

Comparison of our CsI photocathodes with a calibrated CsI PMT



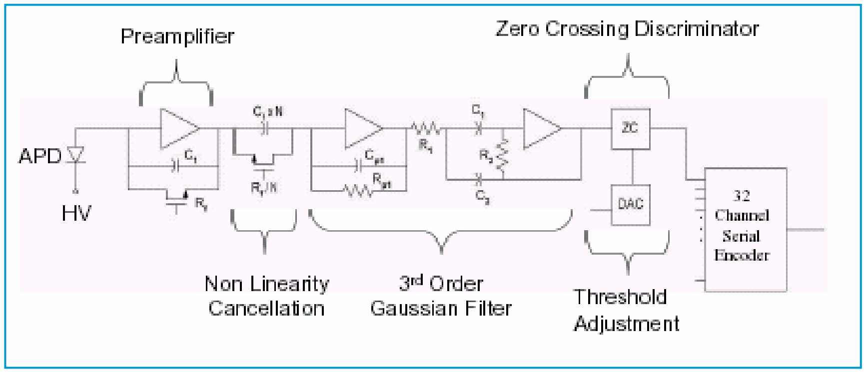
Stack with Au coated GEM foil for depositing CsI photocathode

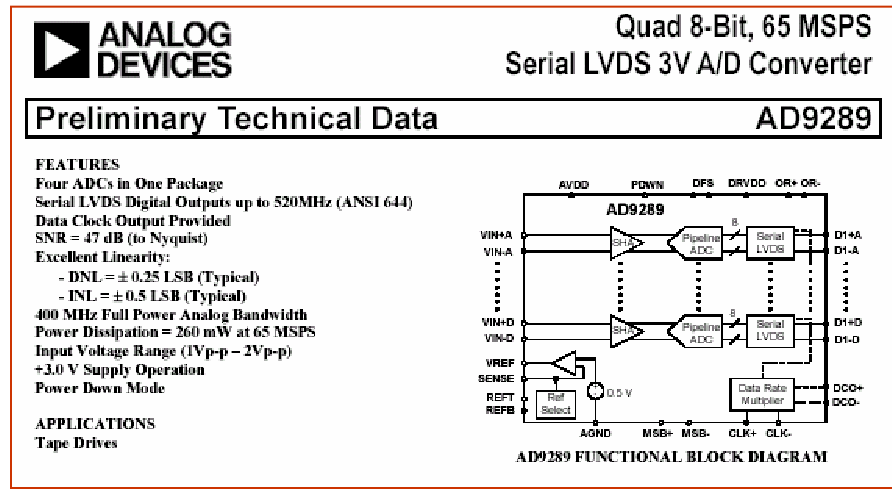


Good quality CsI photocathodes are now being made at Stony Brook

Future TPC readout electronics development (BNL Instrumentation Division, Nevis, Stony Brook)

Try and utilize existing or soon to be available components
Perhaps can use FADC to provide time information





ANALOG DEVICES

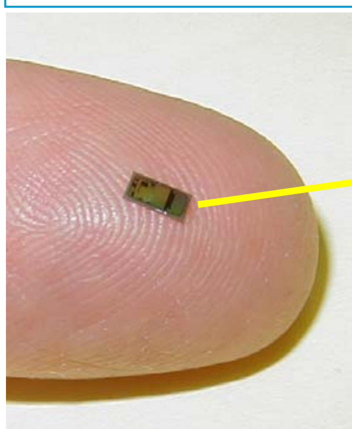
Quad 8-Bit, 65 MSPS Serial LVDS 3V A/D Converter

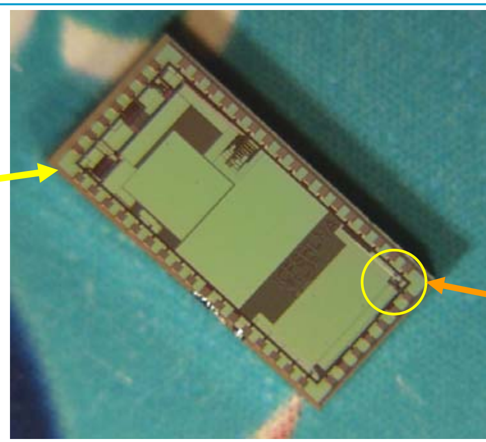
Preliminary Technical Data **AD9289**

FEATURES
- Four ADCs in One Package
- Serial LVDS Digital Outputs up to 520MHz (ANSI 644)
- Data Clock Output Provided
- SNR = 47 dB (to Nyquist)
- Excellent Linearity:
  - DNL = ± 0.25 LSB (Typical)
  - INL = ± 0.5 LSB (Typical)
- 400 MHz Full Power Analog Bandwidth
- Power Dissipation = 260 mW at 65 MSPS
- Input Voltage Range (1Vp-p – 2Vp-p)
- +3.0 V Supply Operation
- Power Down Mode

APPLICATIONS
- Tape Drives

AD9289 FUNCTIONAL BLOCK DIAGRAM





65 MHz FADC available soon

32 ch preamp/shaper for APD readout
0.18 mm CMOS, 125 mW per chip
Final ASIC 4.3 x 1.6 mm^2

STAR Detector R&D Plan for Next 2-3 Years

- Build and install in STAR GEM Pad Detector(s) (FEE, DAQ, ….?)

- Build and test miniTPC & Cherenkov Detector prototypes

- Locate and build a GEM foils testing and calibration facility (at Yale, MIT ?) (for many today and future applications and experiments).

- Complete design of a readout electronics “first prototype” (IC or …?)

- Start engineering design of TPC/Cherenkov Detector system

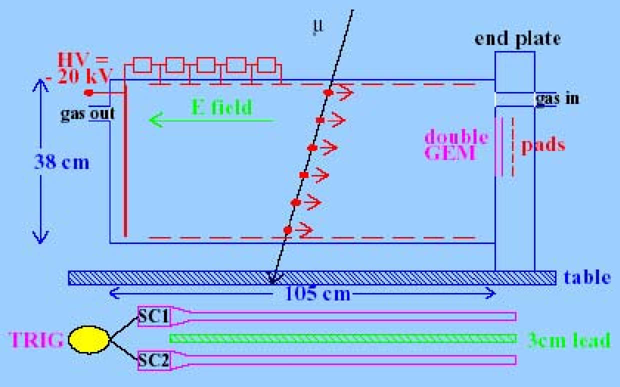
- Continue software activity
  - E-field quality, field cage variants, distortions, ExB, “space charge”, mechanical stability, …
  - Detector response simulation.
  - Experiment performance study for different Physics goals.

But still in STAR:
No R&D team
No $$$
No needed support

Many new approaches, hard work and a lot of enthusiasm has been demonstrated

Our 3 years old, “fresh” ideas became “good” ones; ~6 R&D teams are very active

DESY/Hamburg large Gem prototype (B=0)

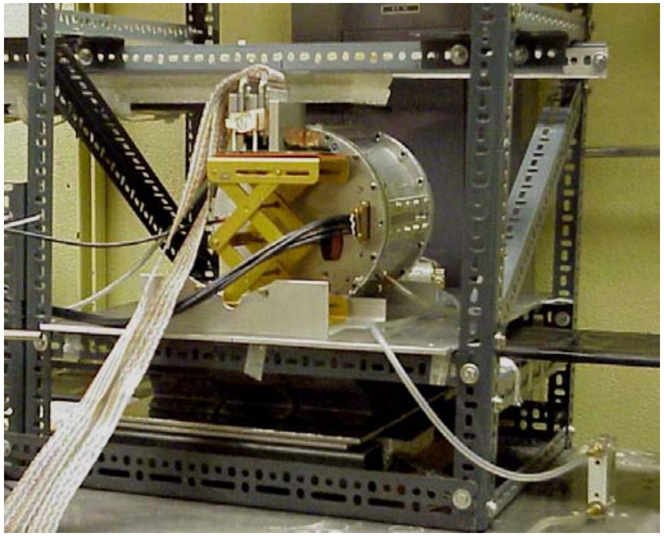


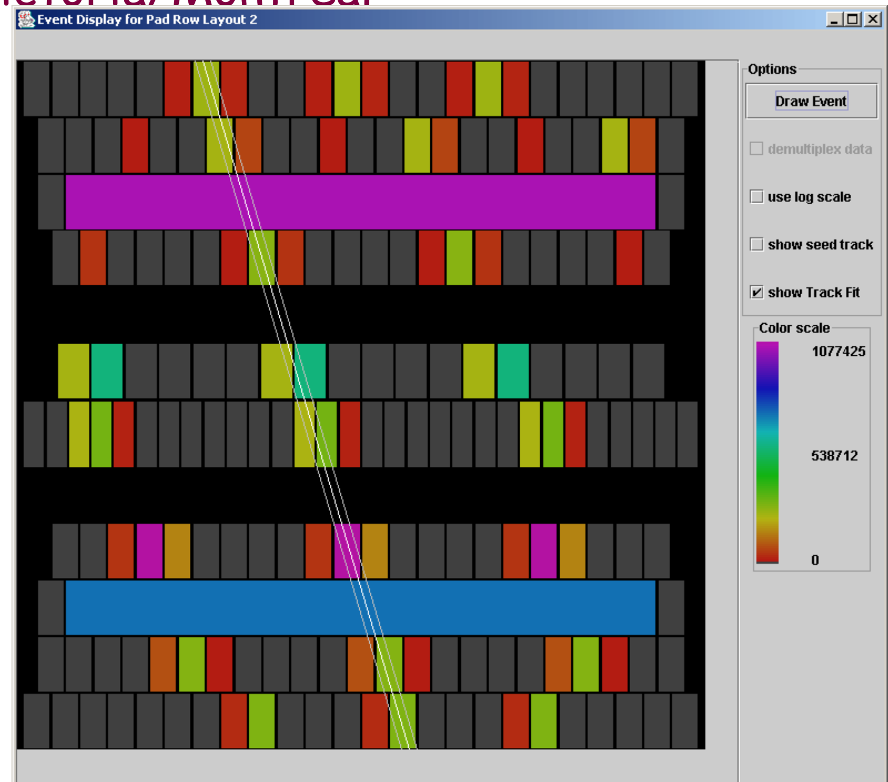
- gas: Ar-CH_4-CO_2 (93-5-2)
- cosmic muons
- readout: ALEPH preamps + TPD + MAC II + Labview
- double GEM structure
- trigger: 2 scintillators

Several TPC prototypes, large and small, are now in operation. Shown here is the large one in DESY/Hamburg which uses cosmic rays to study the tracking characteristics using GEM gas-amplification. Obviously these studies are with no magnetic field. The size of the chamber is suitable for studies of gas properties and of the impact of readout geometry on the coordinate resolution.

Double GEM TPC Cosmic Ray Tests

Carleton/Victoria/Montreal





- Aleph TPC preamps + Montreal 200 MHz FADCs
- 15 cm drift (no **B** field)
- **Pads can share track charge due to transverse diffusion**
  - Ar CO_2(90:10), small σ_T ~ 200 μm / √cm
  - P10 Ar CH_4(90:10), large σ_T ~ 500 μm / √cm
- Compute pad centroids, measure resolution for different width pads

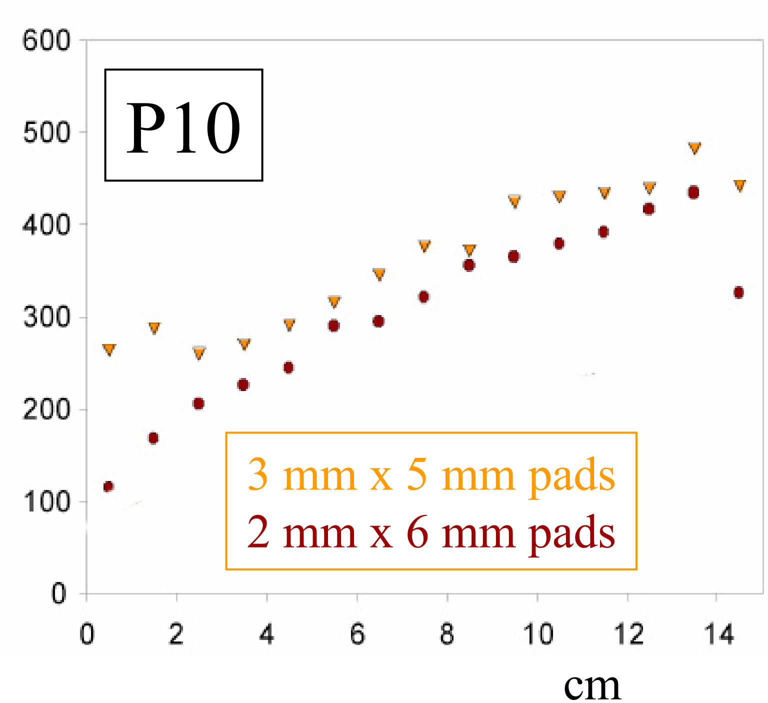
The photograph shows the Carleton test chamber using GEMs. Again there is no magnetic field, and the pad layout is with 3x multiplexed readout (thus the mirrored hits in the right diagram). Drift distances up to 15cm, two different gases (Argon with CO2 or CH4) and resolution with different pad widths (2mm and 3mm) have been studied; the pads were rectangular and charge sharing took place via transverse diffusion in the induction gap (between GEM and anode). The track was defined by outer rows (3 on each side) and the resolution measured on the middle rows.

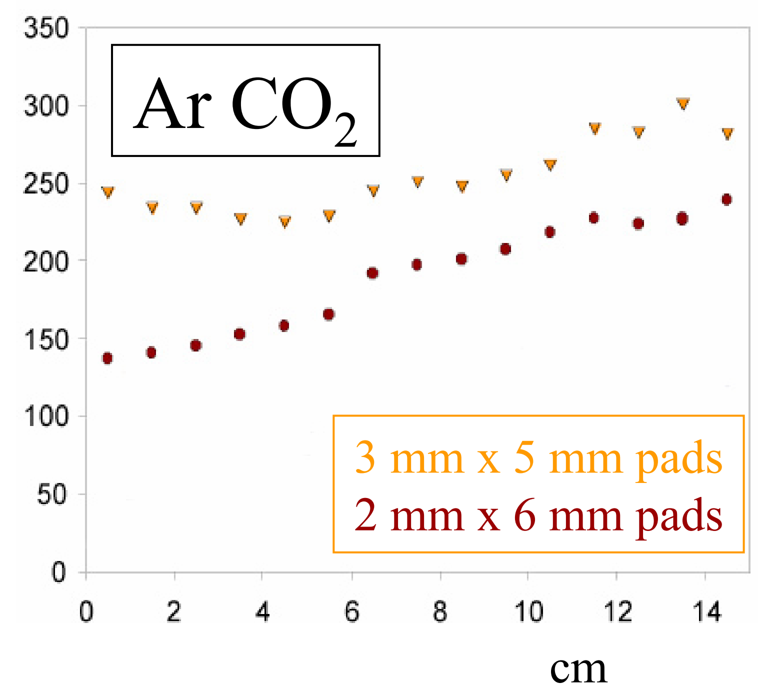
SET-UP FOR DIFFERENT PAD GEOMETRIES

Resolution vs Drift Distance for Different Pad Widths

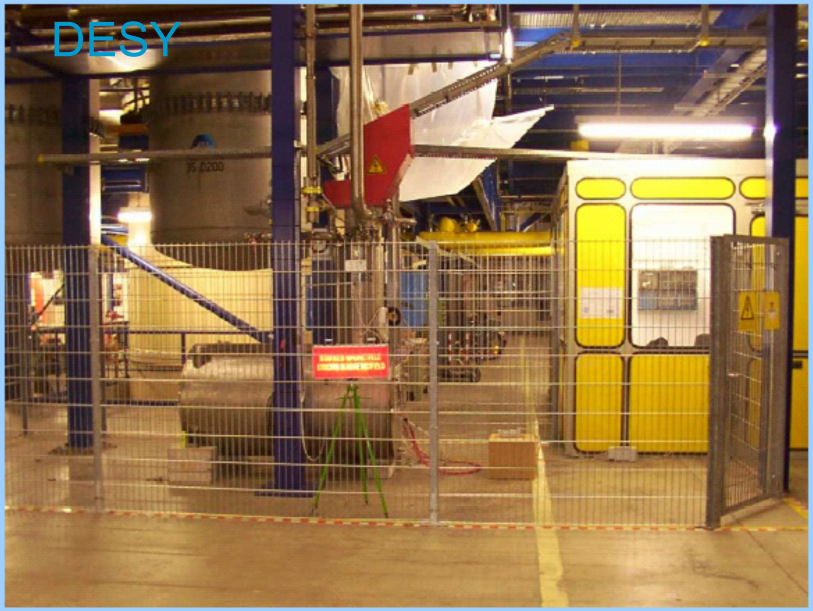
$|\varphi| < 0.1$

Carleton/Victoria/Montreal





Single pad row resolution measurements from the Carleton TPC . Tracks are formed from the outer 6 rows, and residuals calculated for each of the two inner rows with 2mm x 6mm (triangles) and 3mm x 5mm (circles) pads. The residuals are fit to Gaussians, and the standard deviations (in microns) is shown here for different drift distances.



- Max. magnetic field > 5 T
- Diameter of opening 28 cm
- Total length 187 cm

Left: The 5T superconducting solenoid at DESY which started operation at the end of last year. First tests (see below, p.11) were made using a small GEM device built at Aachen to allow measurement of all currents in order to derive the charge-transfer characteristics. Similar measurements had previously been carried out in a 2T magnet at Jülich.

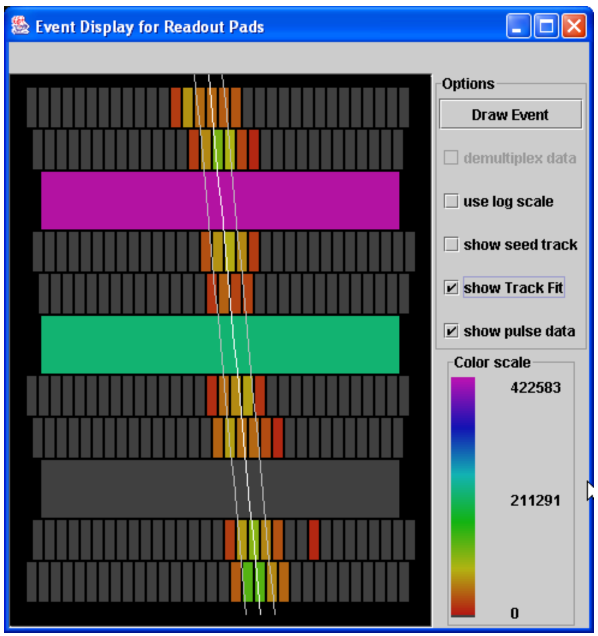
First TPC studies in the magnet on December 18, 2002

Right: The 2T superconducting solenoid magnet in operation in Saclay has a 53 cm bore diameter and a length of 150 cm. It has been used for testing two Micromegas TPCs and a wire TPC built by Saclay/Orsay using current measurements. It is now being equipped with a 1000-channel cosmic ray Micromegas prototype with a 50 cm drift length.

Example events at ~25 cm drift

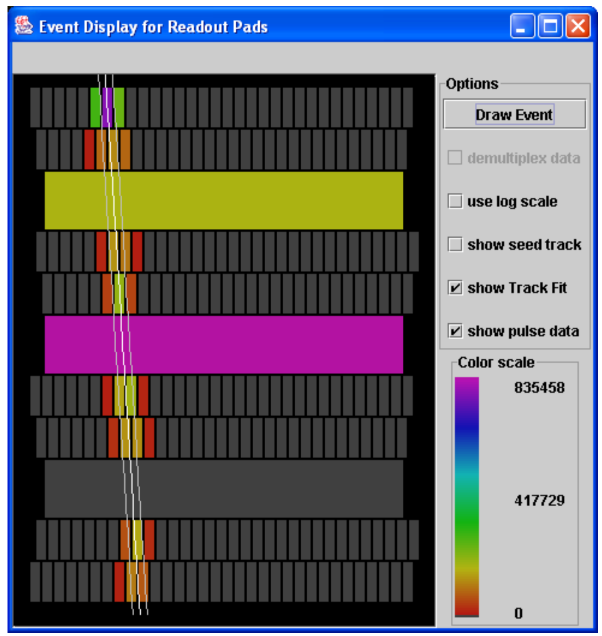
Gas: P10

0 Tesla



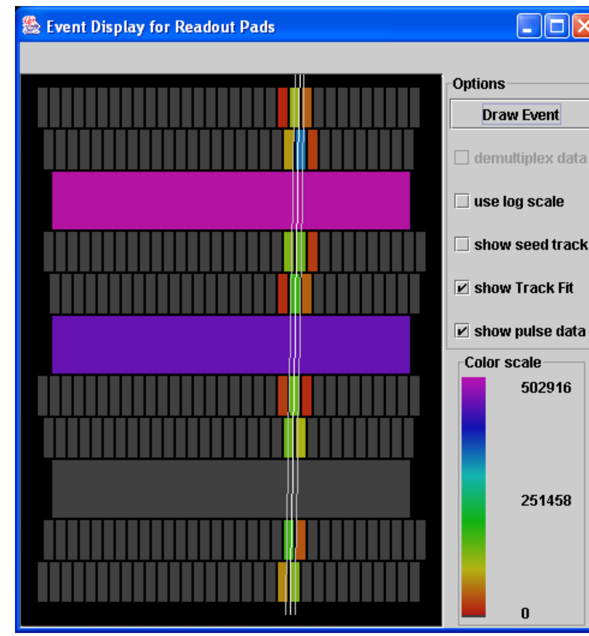
σ = 2.3 mm

0.45 Tesla



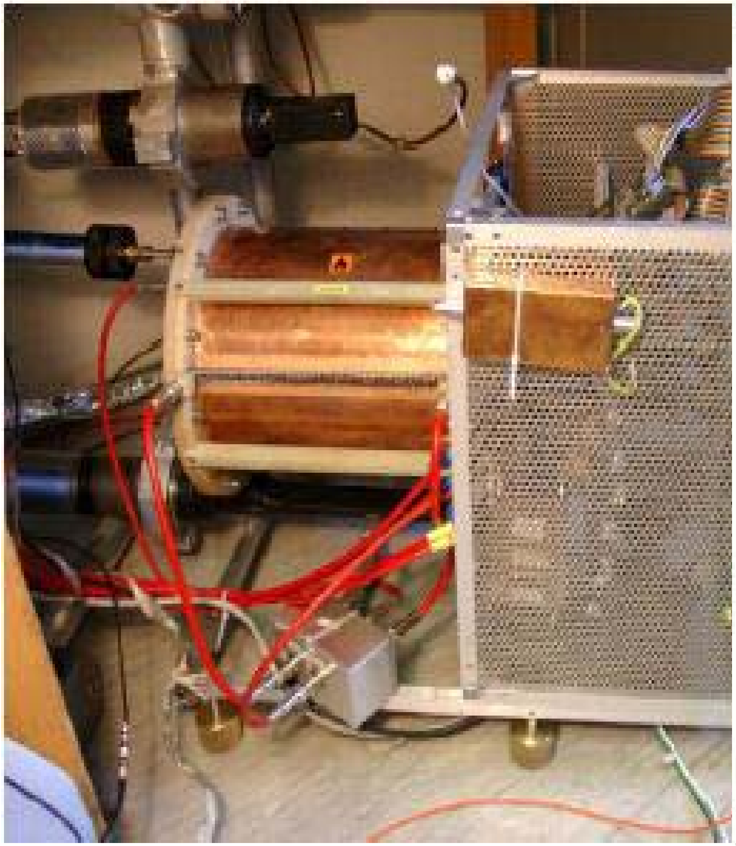
σ = 1.2 mm

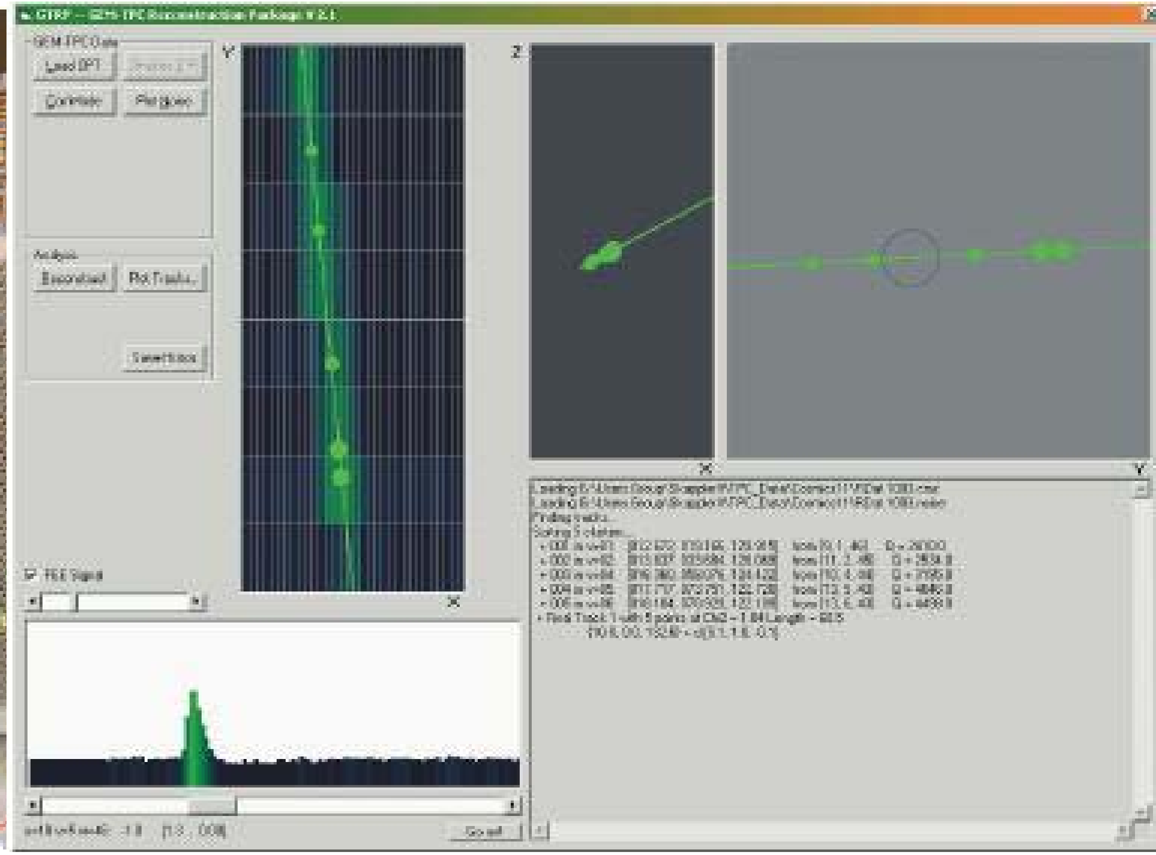
0.9 Tesla



σ = 0.8 mm

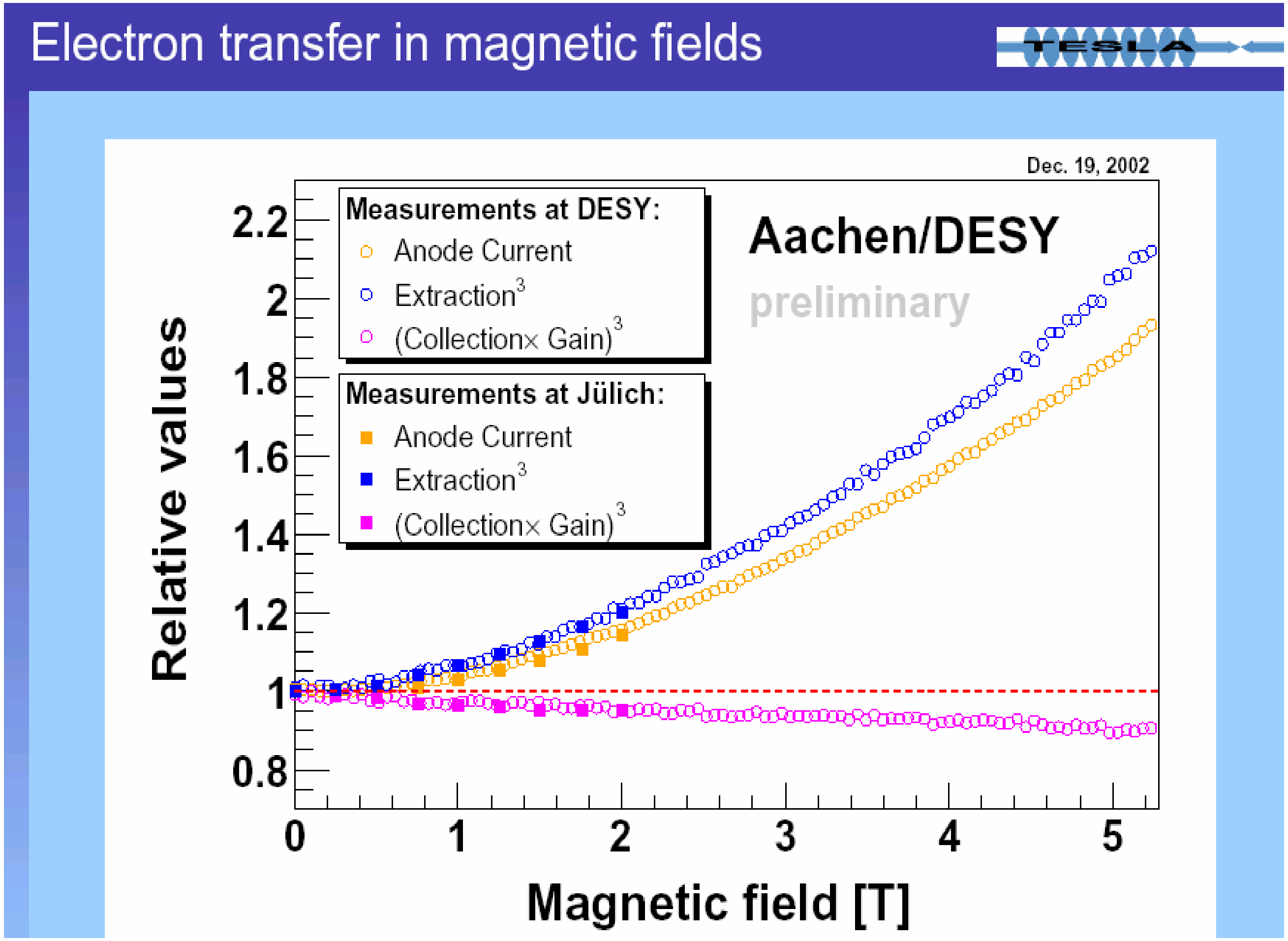
TPC cosmic tests at Karlsruhe





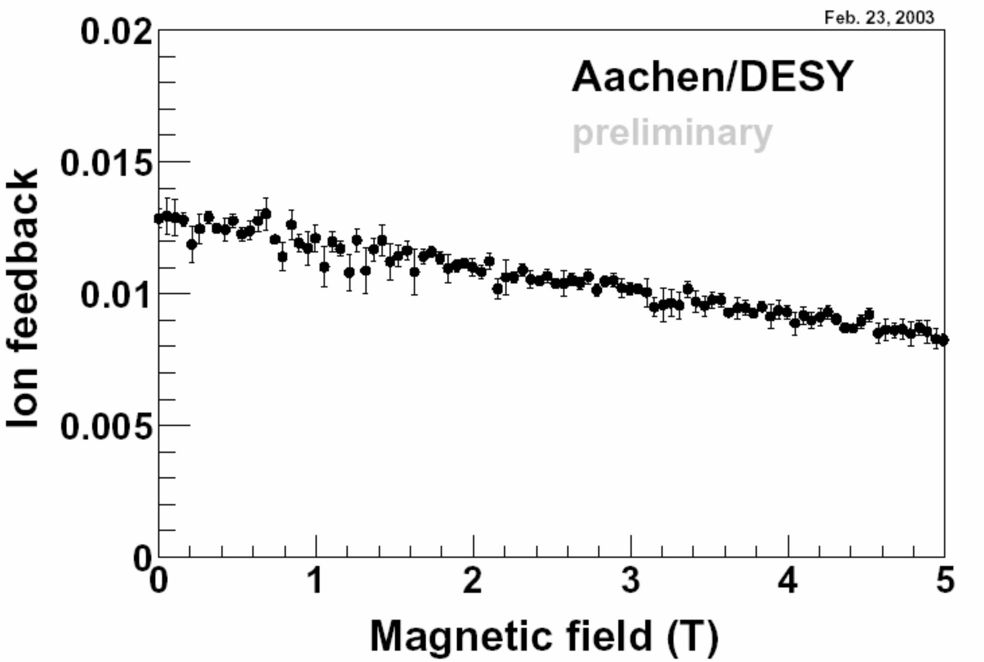
Cosmic ray setup using STAR electronics
Measured resolution 124 μm, S/N = 18:1

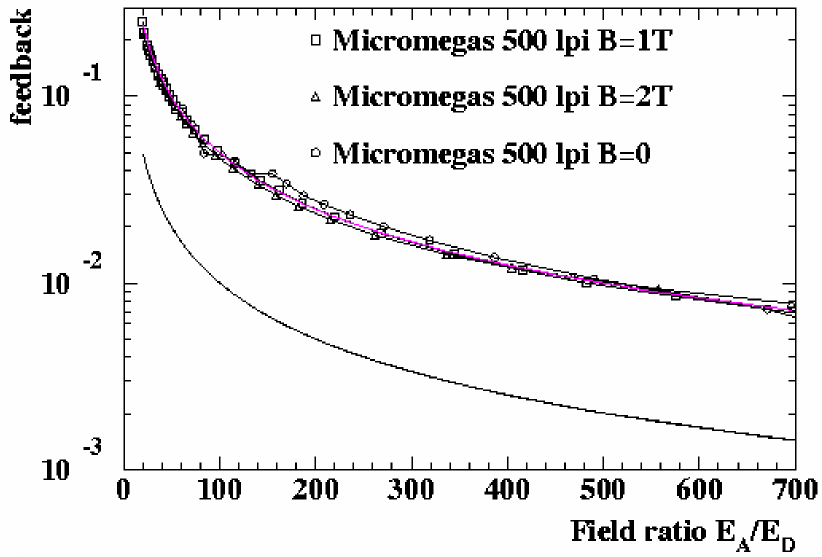
The Karlsruhe test chamber with GEMs (left) has recorded cosmics and was also exposed to a test beam in CERN. The figure on the right shows a measured track. The readout took place using the STAR electronics test-stand supplied by LBNL. The tests were with no magnetic field, but the chamber can fit into the 5T magnet at DESY.



Here are the results mentioned above (p.10) which were obtained with the Aachen test chamber in the DESY magnet, and which confirm and extend previous measurements carried out at Julich. The various currents arise from an Fe55 source. The anode current (electrons arriving at pads) rises significantly with B-field. In order to understand this, the triple-GEM structure was operated with symmetric settings (GEM voltages at 330V and transfer fields at 1kV/cm) so that all GEMs have equal collection efficiency C, gain G and extraction efficiency X, and the anode current was the primary current times $C^3G^3X^3$. The collection times gain drops slightly while the extraction improves, meaning only few primary electrons are lost during collection at 5T while the net gain of the overall structure increases at higher B-fields.

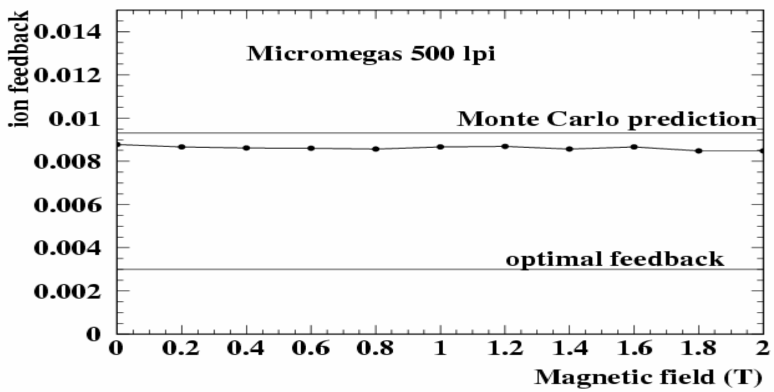
GEM CURRENTS VS B-FIELD





Left: the ion-feedback improves at high magnetic field in GEMs, as seen from the Aachen/DESY measurements described on pp.10-11.

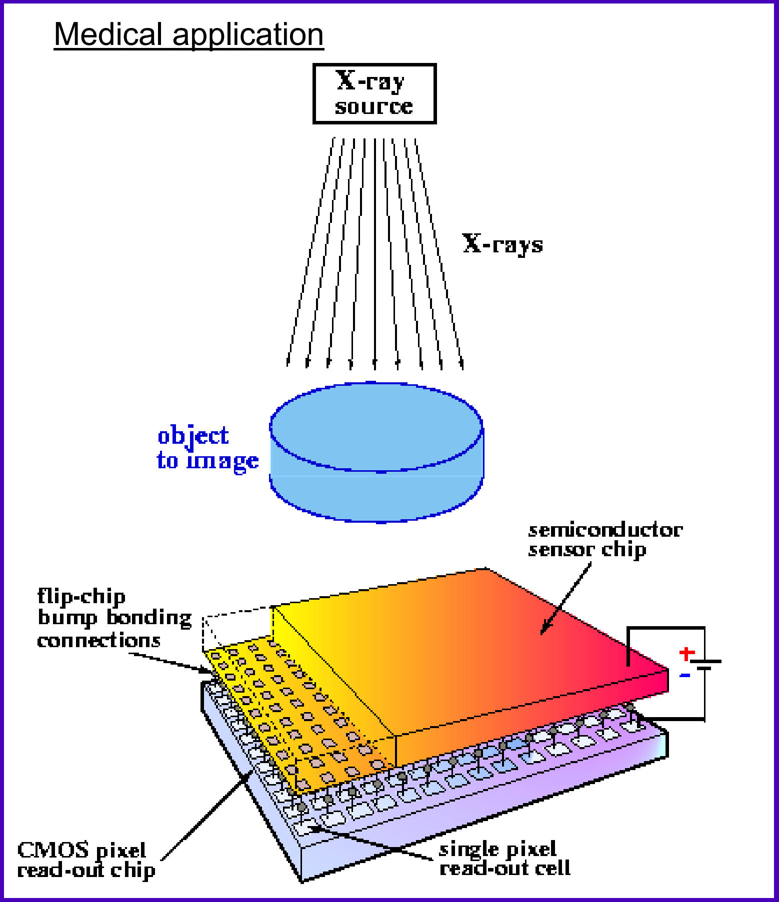
Right: Positive ion feedback fraction as a function of magnetic field, as measured in the 15cm Orsay/Saclay Micromegas TPC.
No dependence on the magnetic field is observed, consistent with expectations, and it is about 3 times the optimal feedback due to the use of a relatively coarse micromesh (500 lines per inch). A finer mesh (1000 lpi) should allow reaching the optimal feedback with this gas (Ar10%CH4).

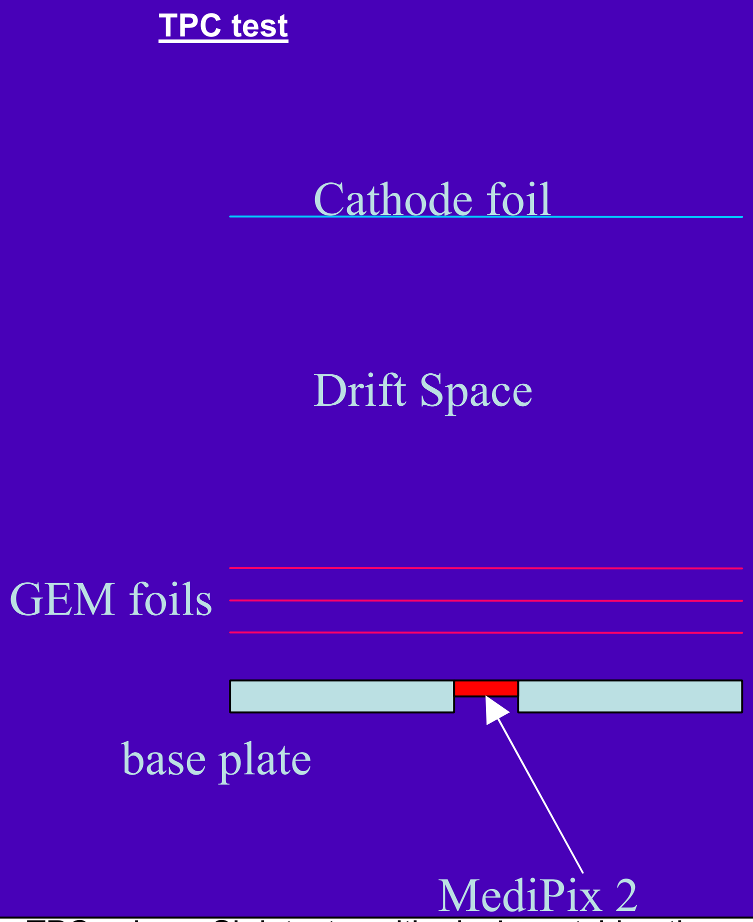


Orsay/Saclay

NIKHEF

MediPix2 Si-pixel detector

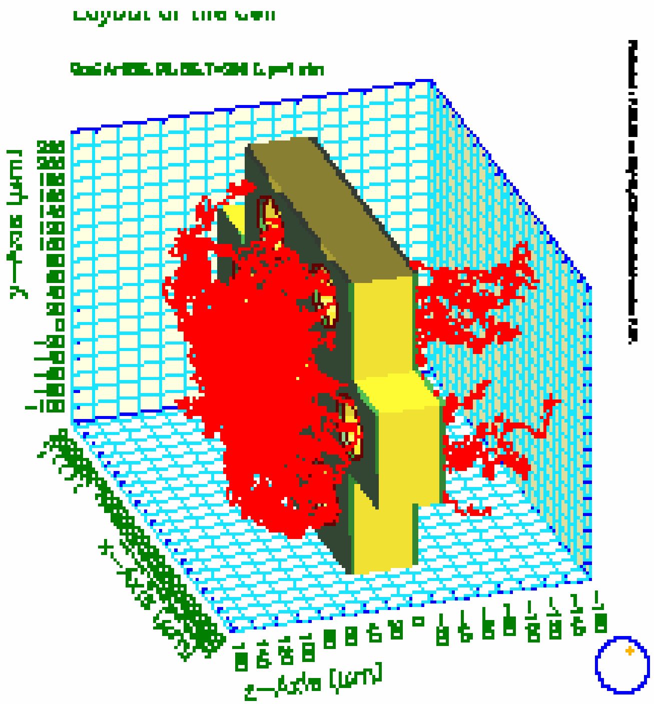


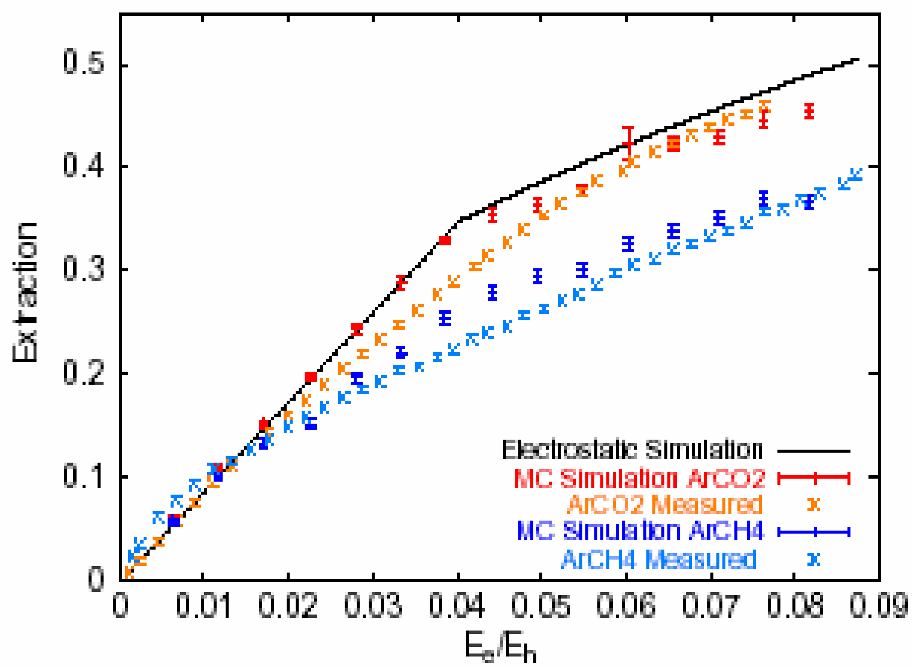


At NIKHEF a new idea is being tried out, namely to read out a TPC using a Si detector with pixels matching the GEM-hole pitch. Left: the MediPix2 chip has 256 x 256 pixels of 55 x 55 μm², low noise and a minimum threshold of about 1000 electrons. Right: schematic view of the one liter test TPC with a triple-GEM arrangement and an insert in the base plate for the MediPix2 chip.

GEM response simulation

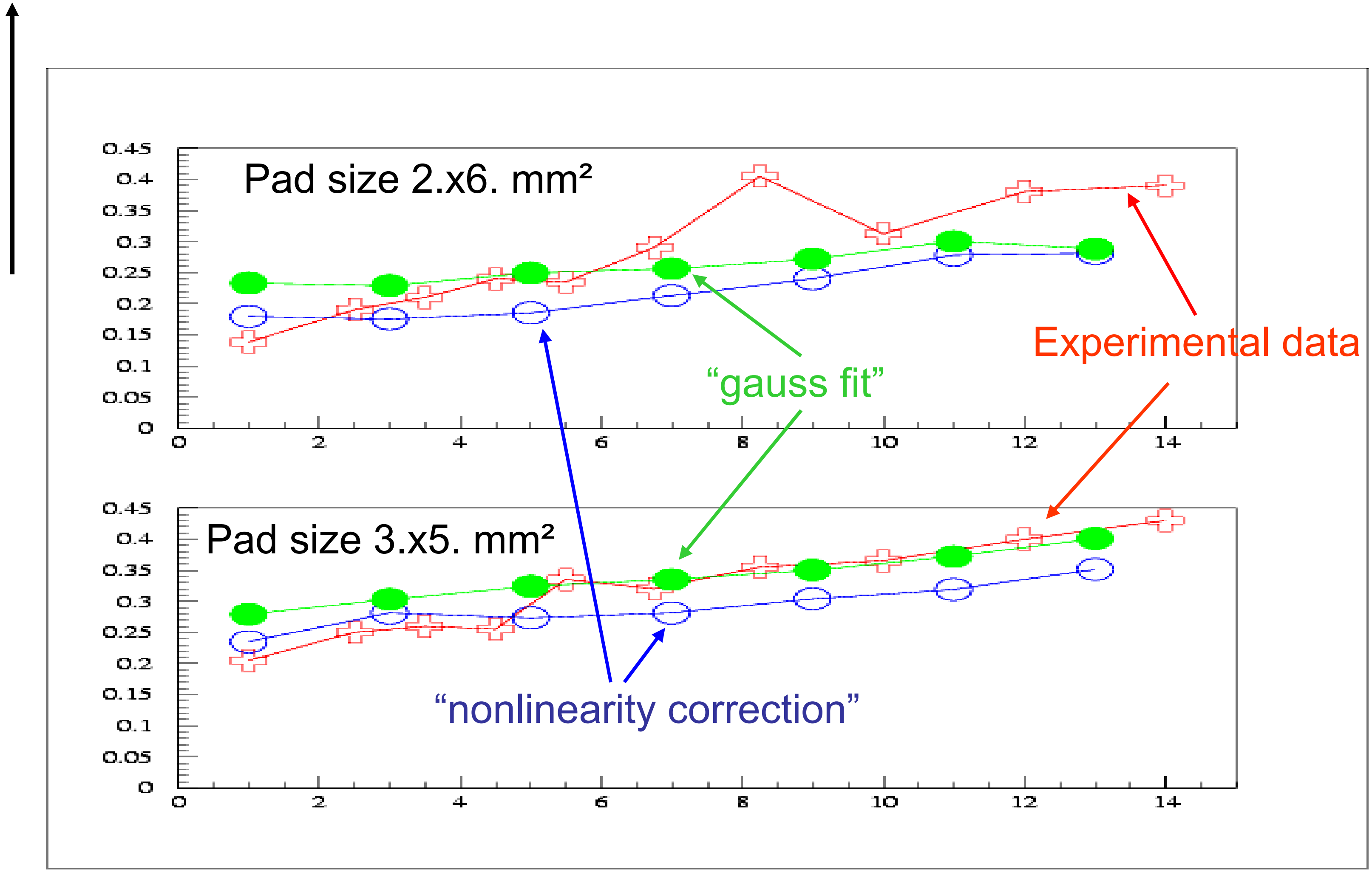
Aachen



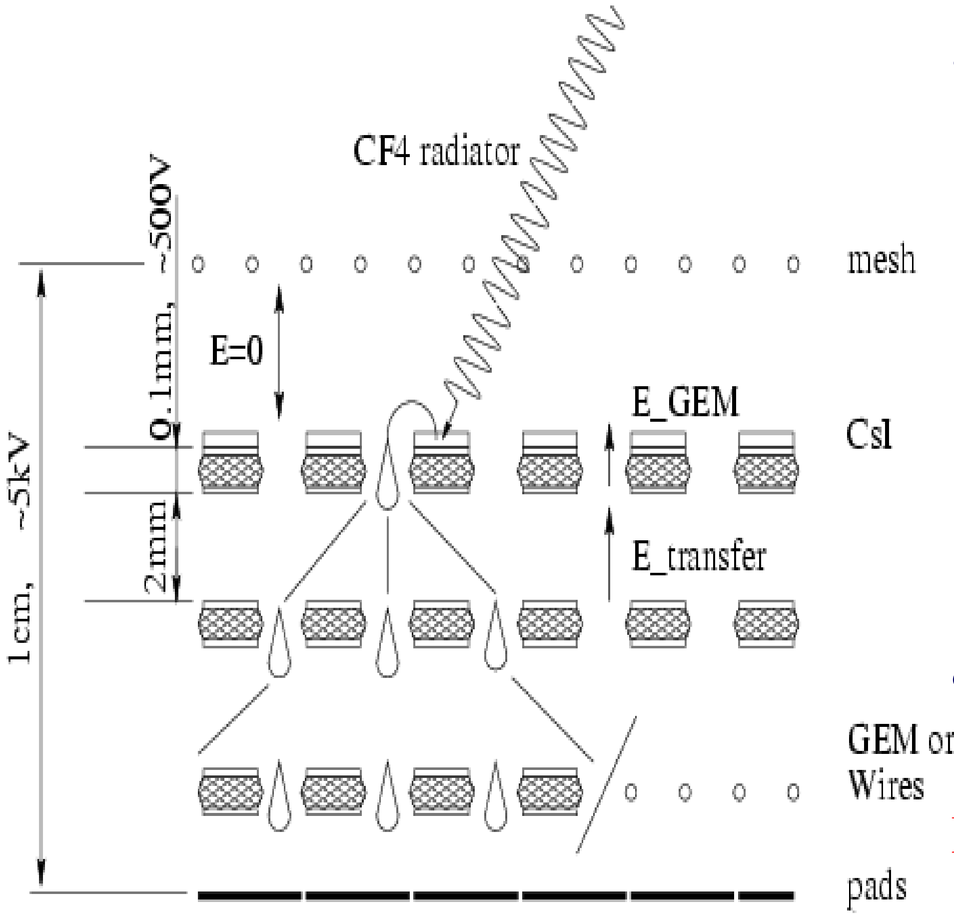


Three test chambers have been built in Aachen (see also below) and detailed simulations on GEM properties are also being carried out. On the left are the simulated electron-drift trajectories in a GEM using the programs MAXWELL and GARFIELD, and on the right is the calculated extraction efficiency compared with measurements. The black curve is a parameterization of results from simulation with MAXWELL only, which is adequate for gases with small diffusion. The data points labeled “MC simulation” are due to the combination of MAXWELL+GARFIELD so that diffusion is included. That simulation and results agree well will be important for the final optimization of a GEM TPC readout.

Simulation (NS) – Data (“Canada”)
small TPC, double GEM, 5 pad rows, P10, cosmic



GEMs + CsI as UV Detector



- **Windowless Cherenkov detector**
- **Radiator and detector gas: CH_4, CF_4 ..**

⇒ Large bandwidth:

in a case of CF_4; $N_0 \approx 960$ and $N_{pe} \approx 40$!!

- **Reflective CsI photocathode**

⇒ No photon feedback

- **Proximity focus → detect "blob" or "road"**

⇒ And can or can't be "sensitive" to MIP

- **Detector element: multi - GEM**

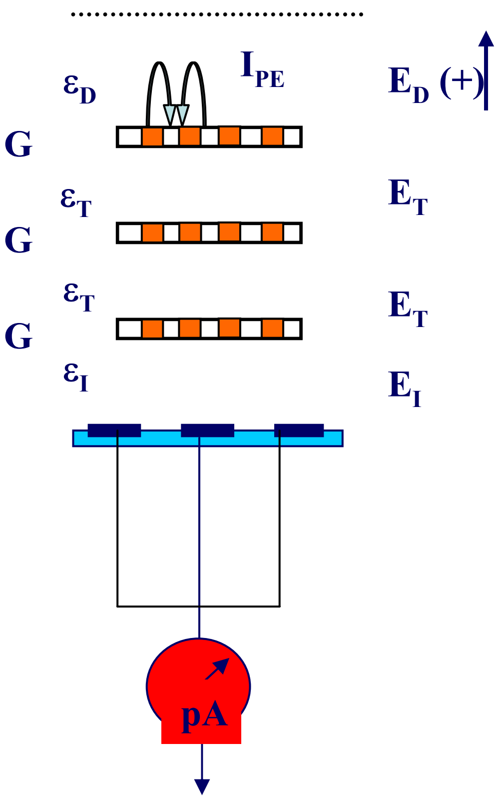
⇒ stable operation at high gain

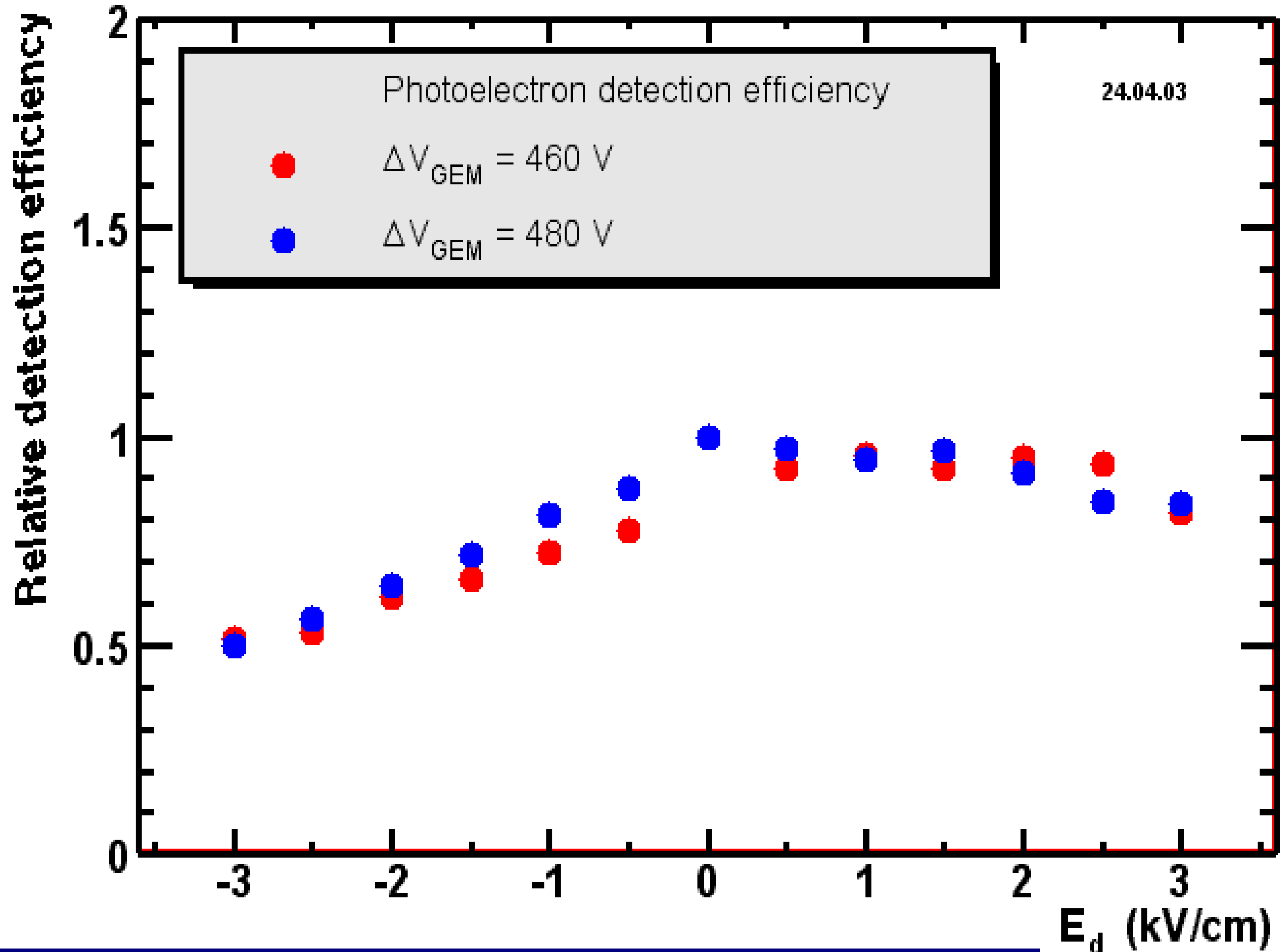
Novel but very challenging. MWPC with Pad readout is the "standard" solution

Single Photoelectron Detection Efficiency

measure detector response vs E_D at fixed gain

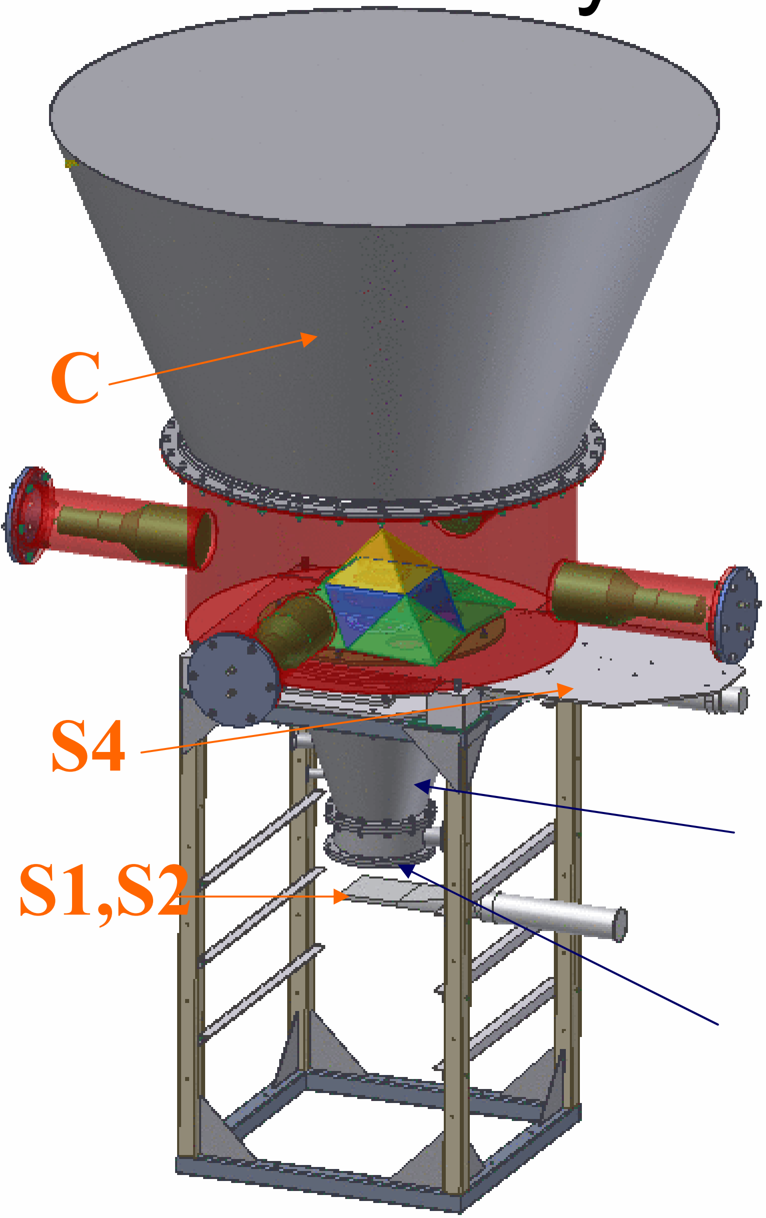
(Weizmann Inst of Science)





Very efficient detection of photoelectrons even at negative drift fields !!

Cosmic ray tests: Experimental Set-up



Cosmic trigger S1.S2.S4

C: CO_2 radiator

- p_{th} ~ 3.8 GeV
- 1.30 m long
- rate ~ 1/min

CF_4 Radiator

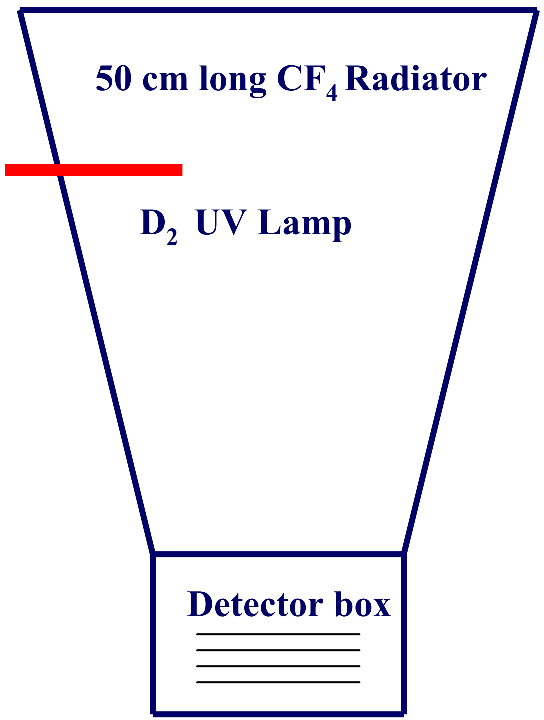
- 50 cm long
- directly coupled to detector

Detector Box

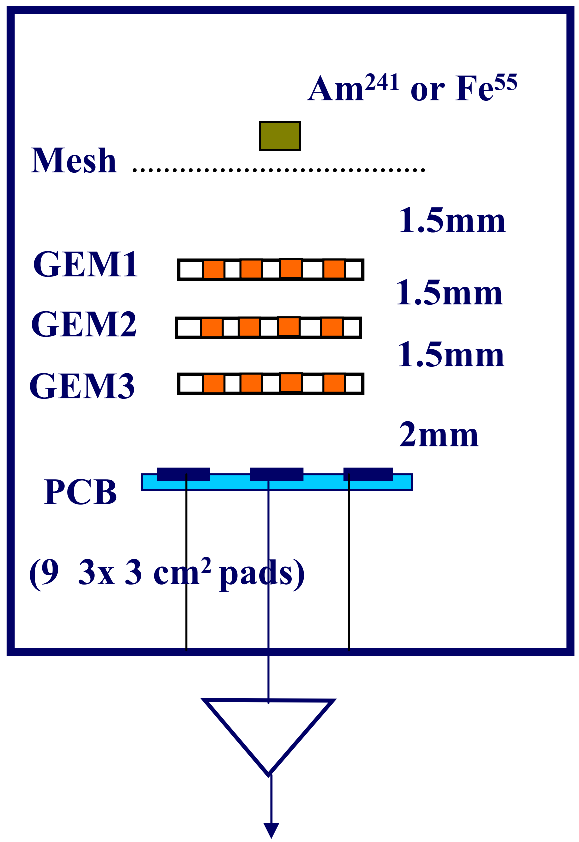
- triple GEM + CsI
- test with Fe^{55}, UV lamp, α

Set-up

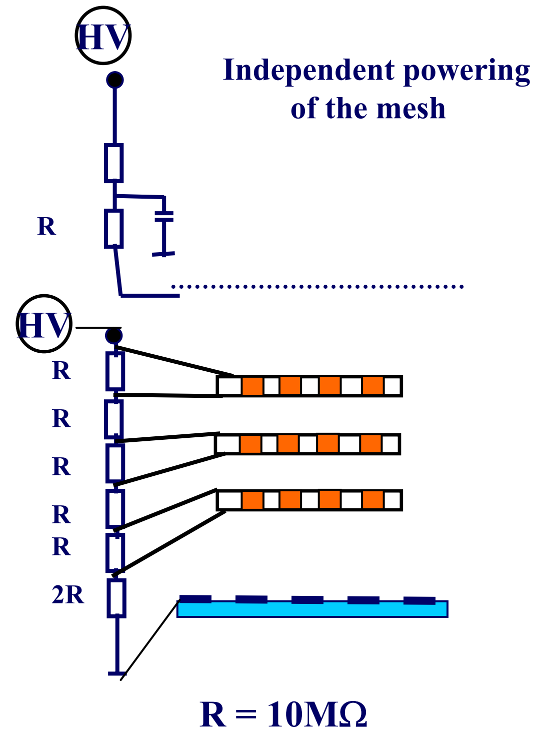
Overall Set-up



Detector Box



Powering scheme



Resistive chain
Powering of triple GEM

Possible detector combinations

GEM +

- MicroMegas
- microstrip
- 4 more GEMs + photoconverter → "gas phototube"
- Si pixel

(photon polarization, neutron detector, liquid drift detector, ….)

GEM development and R&D Laboratory

GEM foils mass production; “crucial step”: foils → Detector

- CERN, COMPASS experience
- US company was found (we hope) to produce high quality and needed size GEM foils. Foil samples are under study now ?
- **Locate** and **build** a GEM foil **testing** & **calibration facility** (at Yale, MIT ?)

Very promising and interesting future

- STAR tracking and PID
  - barrel
  - “EEMC direction”
  - “very forward” coverage
  - miniTPC
- eRHIC tracking and PID
- ee LC
- Medical Imaging
- Student education
- and much more

Final Comment

Please, take a decision, timing is crucial

“The steed of the Time is tirelessly racing on a clock-face of the Eternity”
Peter Estenhazy.