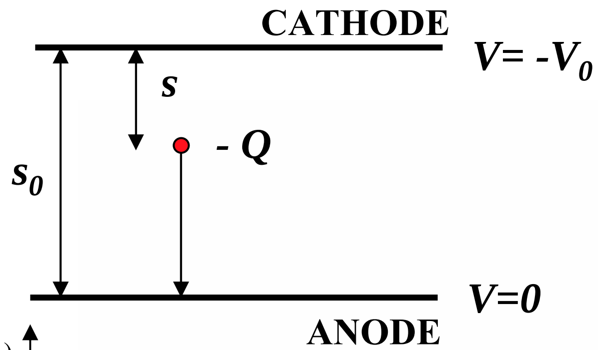
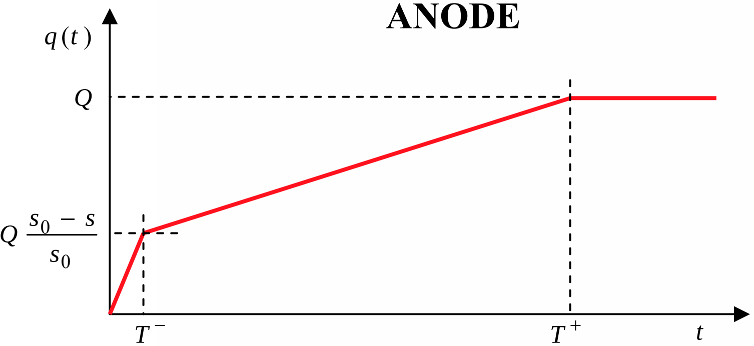
Gaseous detectors and rare event search

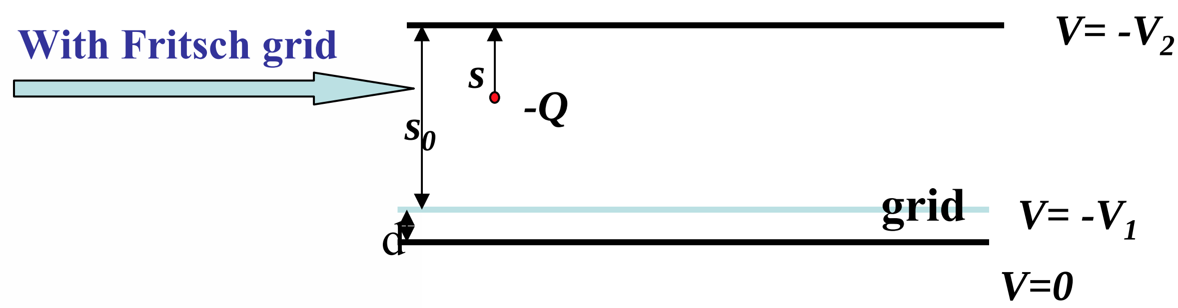
Ioannis Giomataris- Saclay

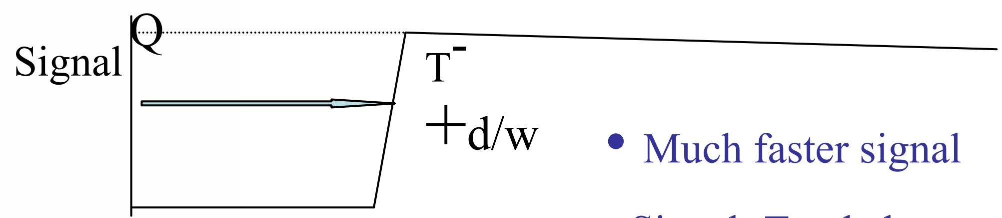
- **History of gaseous detectors**
- **Novel MPGD detectors**
- **Axion search**
- **Gamma polarization measurement**
- **dark matter and low energy neutrino search**
- **New spherical detector**
- **Optimization of double beta decay experiments**

IONIZATION CHAMBER

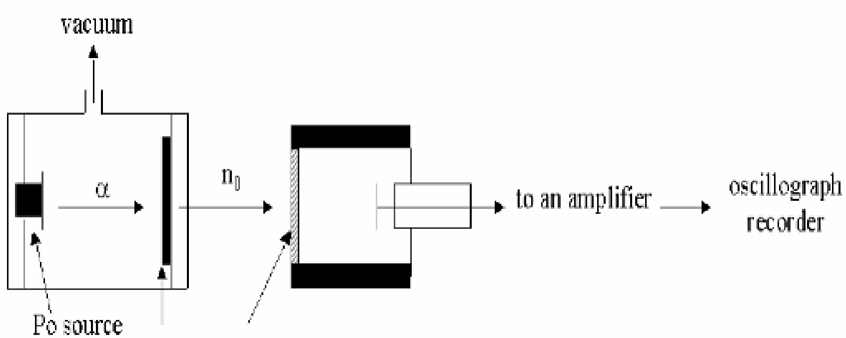








- Much faster signal
- Signal=Total charge

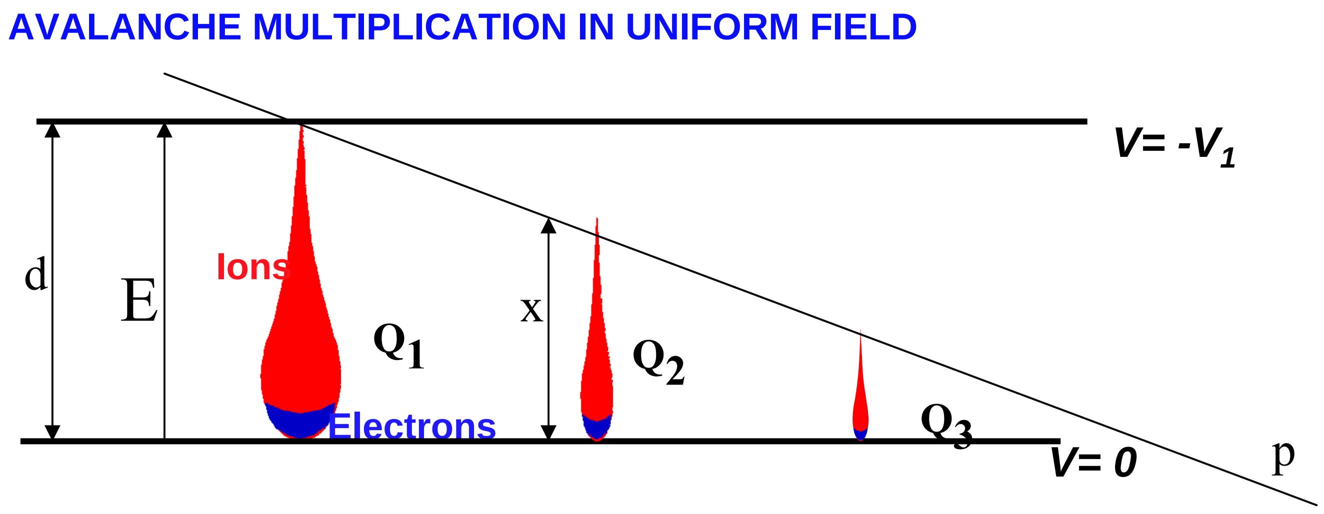


IONIZATION CHAMBER

Used by J. Chadwick (in 1932)

neutron discovery

Parallel Plate Avalanche Chamber (PPAC)



$$dn = n\,\alpha\,dx$$

$$n(x) = n_0 e^{\alpha x}$$

Multiplication factor or Gain

$$M(x) = \frac{n}{n_0} = e^{\alpha x}$$

Korff's approximation $$\frac{\alpha}{p} = Ae^{-Bp/E}$$

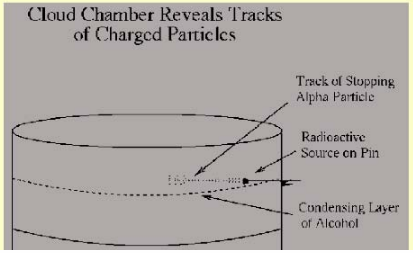
Where *A* and *B* are gas dependent constants and *p* is the pressure.

- Obviously $Q_1 > Q_2 > Q_3$
- PPAC is not a proportional counter
- When QM > 10^8 Break down

Cloud Chamber

Cloud chamber

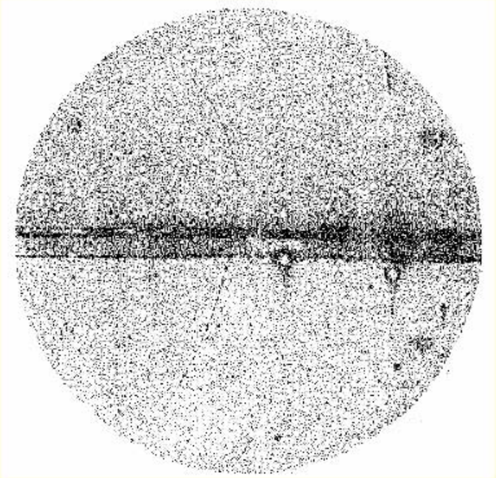
- Container filled with gas (e.g. air), plus vapor close to its dew point (saturated)
- Passage of charged particle ⇒ ionization;
- Ions form seeds for condensation ⇒ condensation takes place along path of particle ⇒ path of particle becomes visible as chain of droplets



Anderson and his cloud chamber

Positron discovery

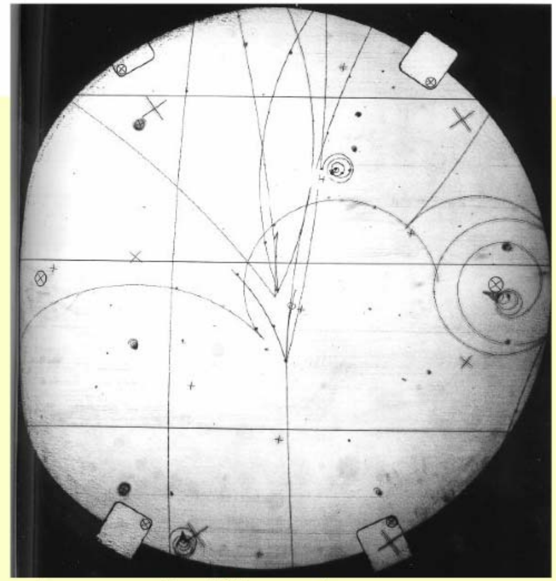
- Positron (anti-electron)
  - predicted by Dirac (1928) -- needed for relativistic quantum mechanics
  - existence of antiparticles doubled the number of known particles!!!



- positron track going upward through lead plate
  - photographed by Carl Anderson (August 2, 1932), while photographing cosmic-ray tracks in a cloud chamber
  - particle moving upward, as determined by the increase in curvature of the top half of the track after it passed through the lead plate,
  - and curving to the left, meaning its charge is positive.

Bubble chamber

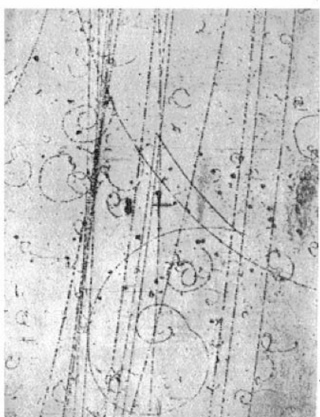
- bubble chamber
  - Vessel, filled (e.g.) with liquid hydrogen at a temperature above the normal boiling point but held under a pressure of about 10 atmospheres by a large piston to prevent boiling.
  - When particles have passed, and possibly interacted in the chamber, the piston is moved to reduce the pressure, allowing bubbles to develop along particle tracks.
  - After about 3 milliseconds have elapsed for bubbles to grow, tracks are photographed using flash photography. Several cameras provide stereo views of the tracks.
  - The piston is then moved back to recompress the liquid and collapse the bubbles before boiling can occur.
- Invented by Glaser in 1952 (when he was drinking beer)

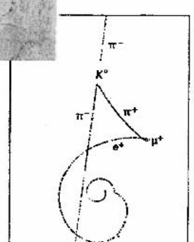


- pbar p $\to$ p nbar $K^0 K^- \pi^+ \pi^- \pi^0$
- nbar + p $\to$ 3 pions
- $\pi^0 \to \gamma\gamma$, $\gamma \to e^+ e^-$
- $K^0 \to \pi^+ \pi^-$

"Strange particles"

- Kaon: discovered 1947; first called "V" particles





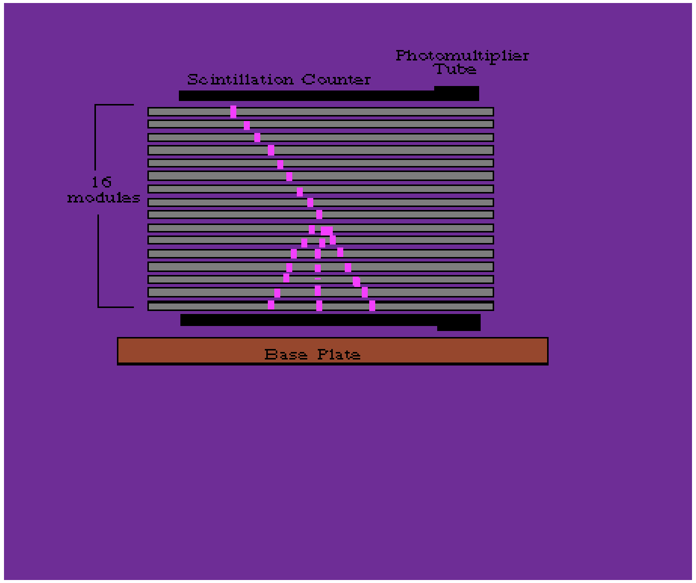
K^0 production and decay in a bubble chamber

Discovery of neutral current in CERN with GARGAMELLE

A. Lagarrigue, A. Rousset and Paul Musset et al., 1972-1973

Spark chamber

– gas volume with metal plates (electrodes); filled with gas (noble gas, e.g. argon)
– charged particle in gas **-** ionization **-** electrons liberated;
– passage of particle through “trigger counters” HV between electrodes **-** strong electric field;
– electrons accelerated in electric field can liberate other electrons **“**avalanche of electrons”,
- plasma between electrodes along particle path; electric breakdown **-** discharge- spark

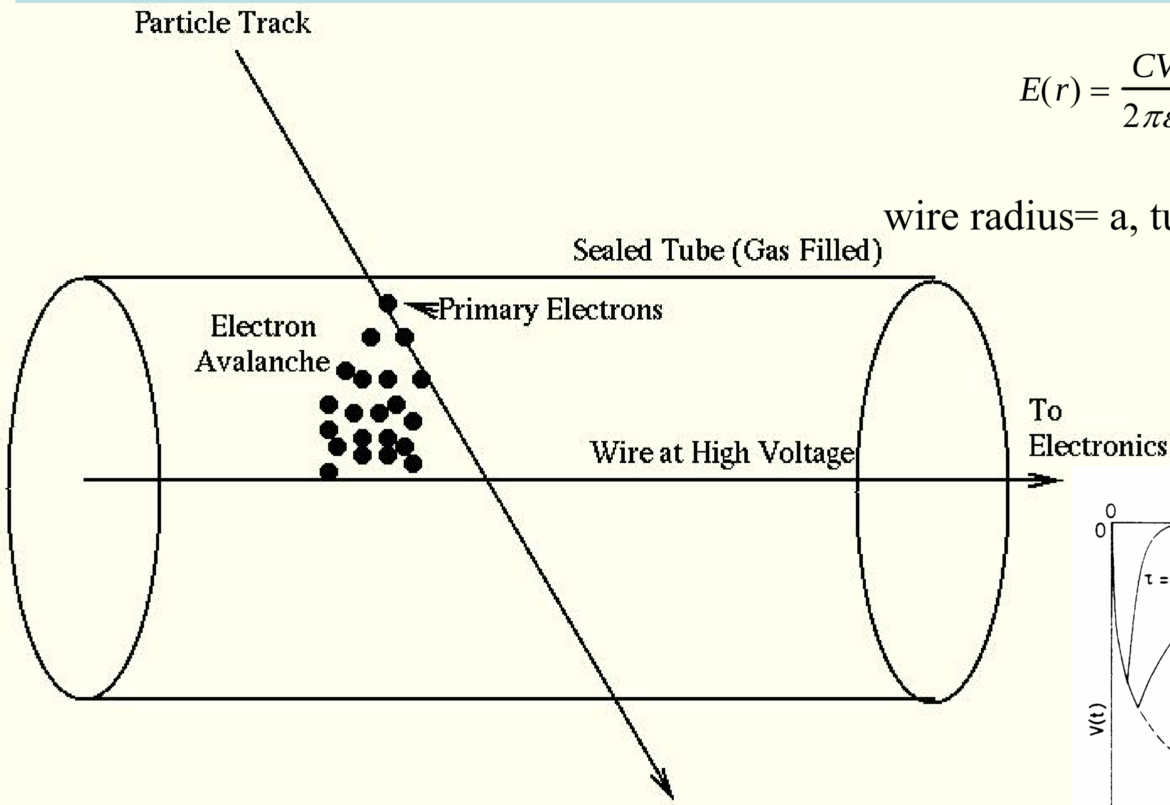


1962 Neutrino muon discovery

OBSERVATION OF HIGH-ENERGY NEUTRINO REACTIONS AND THE EXISTENCE OF TWO KINDS OF NEUTRINOS.

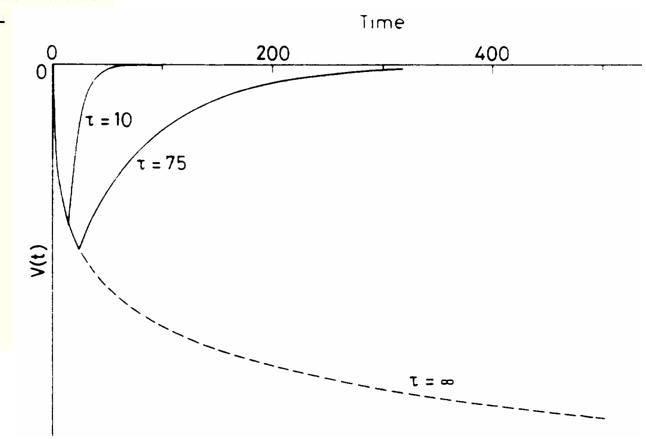
G. Danby, J.M. Gaillard, Konstantin Goulianos, L.M. Lederman, N. Mistry, M. Schwartz, J. Steinberger (Columbia U. & Brookhaven),. 1962. Phys.Rev.Lett.9:36-44,1962

Cylidrical proportional counter



$$E(r) = \frac{CV_0}{2\pi\varepsilon L}\frac{1}{r} \qquad C = \frac{2\pi\varepsilon L}{\ln(b/a)}$$

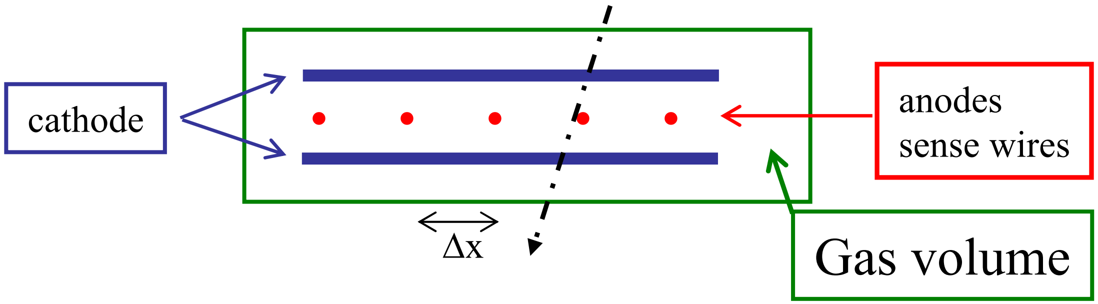
wire radius= a, tube radius=b, length of tube= L



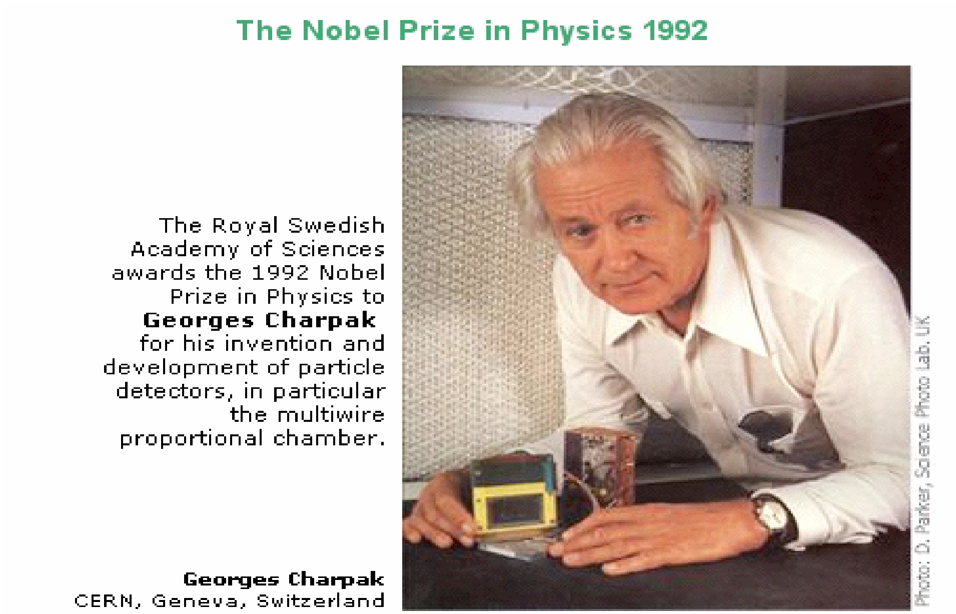
2nd revolution: Multiwire Proportional Chamber (MWPC)

In late 1960's early 1970's techniques were developed that allowed many sense wires (anodes) to be put in the same gas volume. The MWPC was born!

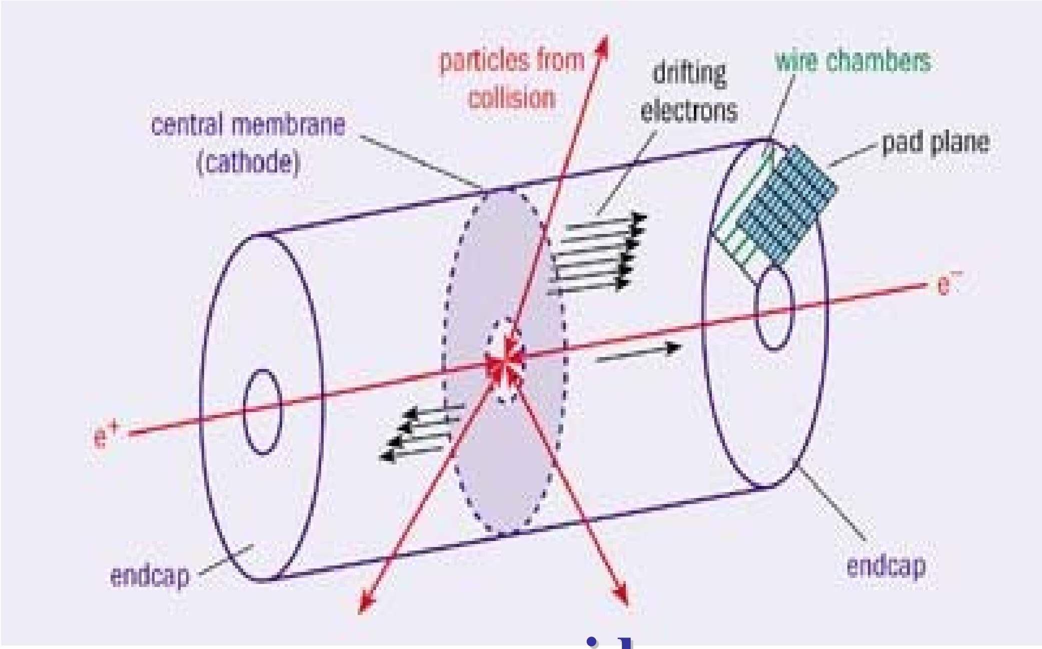
The spatial resolution (σ) of an MWPC is determined by the sense wire spacing (Δx): $\sigma = \frac{\Delta x}{\sqrt{12}}$



Highest flux
10^4/mm^2/s



TIME PROJECTION CHAMBER (TPC), D. NYGREN, LBL ~1976



idea:

to replace for ionisation the thin gas layer of the MWPC (typically ~ 1cm) by a large volume of gas, and to drift the electrons through the gas to the MPWC anode plane by applying a constant electric field.
Using the property that the drift velocity of electrons ve is constant, from the drift time t measurement you will get the third coordinate z :

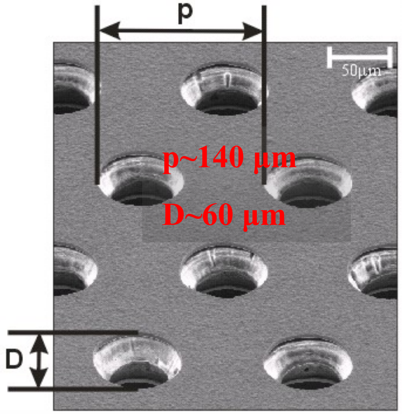
z=vt

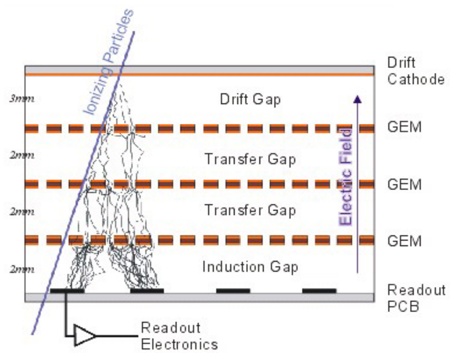
- ⇨ **ideal 3D detector.**
- ⇨ **Possible to get large volumes**

3rd revolution: the **MPGD** **M**icro **P**attern **G**as **D**etectors **1990's:**

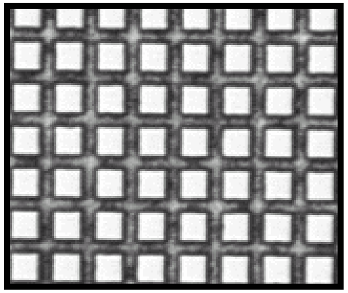
Micromegas (1996), GEM (1997)

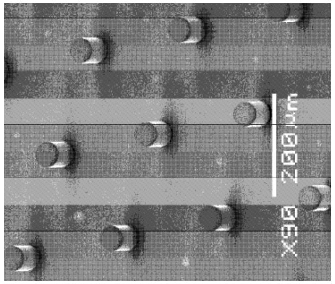
GEM: **2 copper** foils separated by kapton,
multiplication takes place in holes,
use of 2 or 3 stages

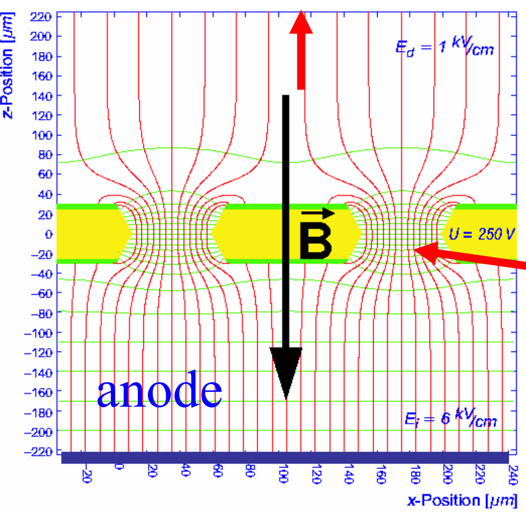




Micromegas:
metallic micromesh (typical pitch **50µm)**
sustained by 50µm pillars,
multiplication between anode and mesh,
high gain, one stage only

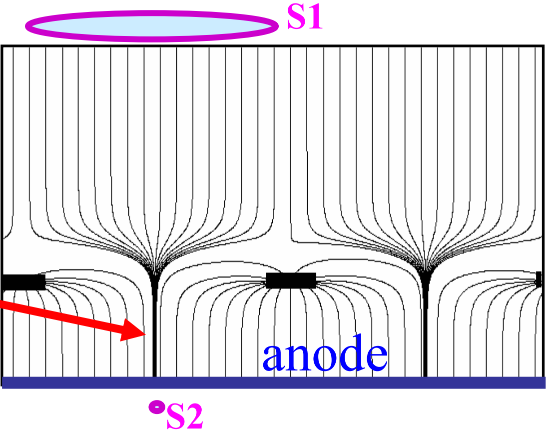




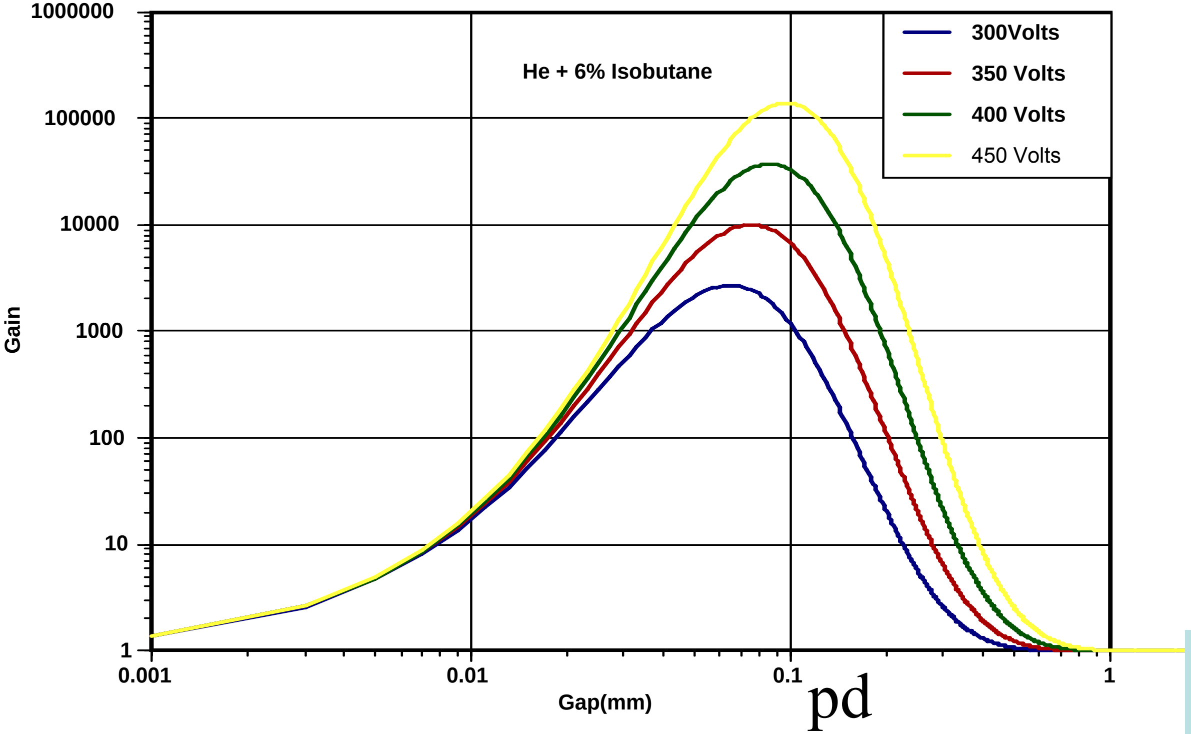


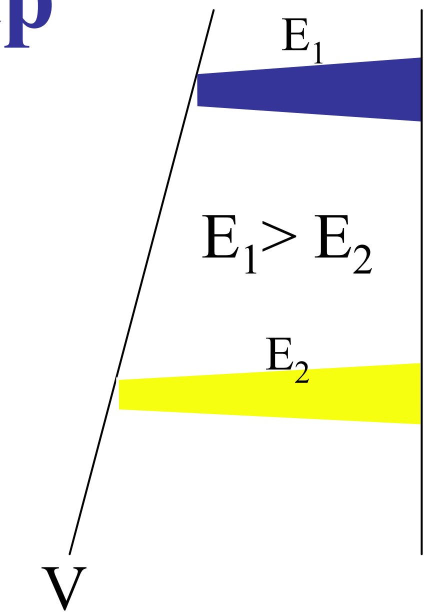
avalanche

$S1/S2 \sim E_{amplif} / E_{drift}$



A great motivation
Virtue of the small gap





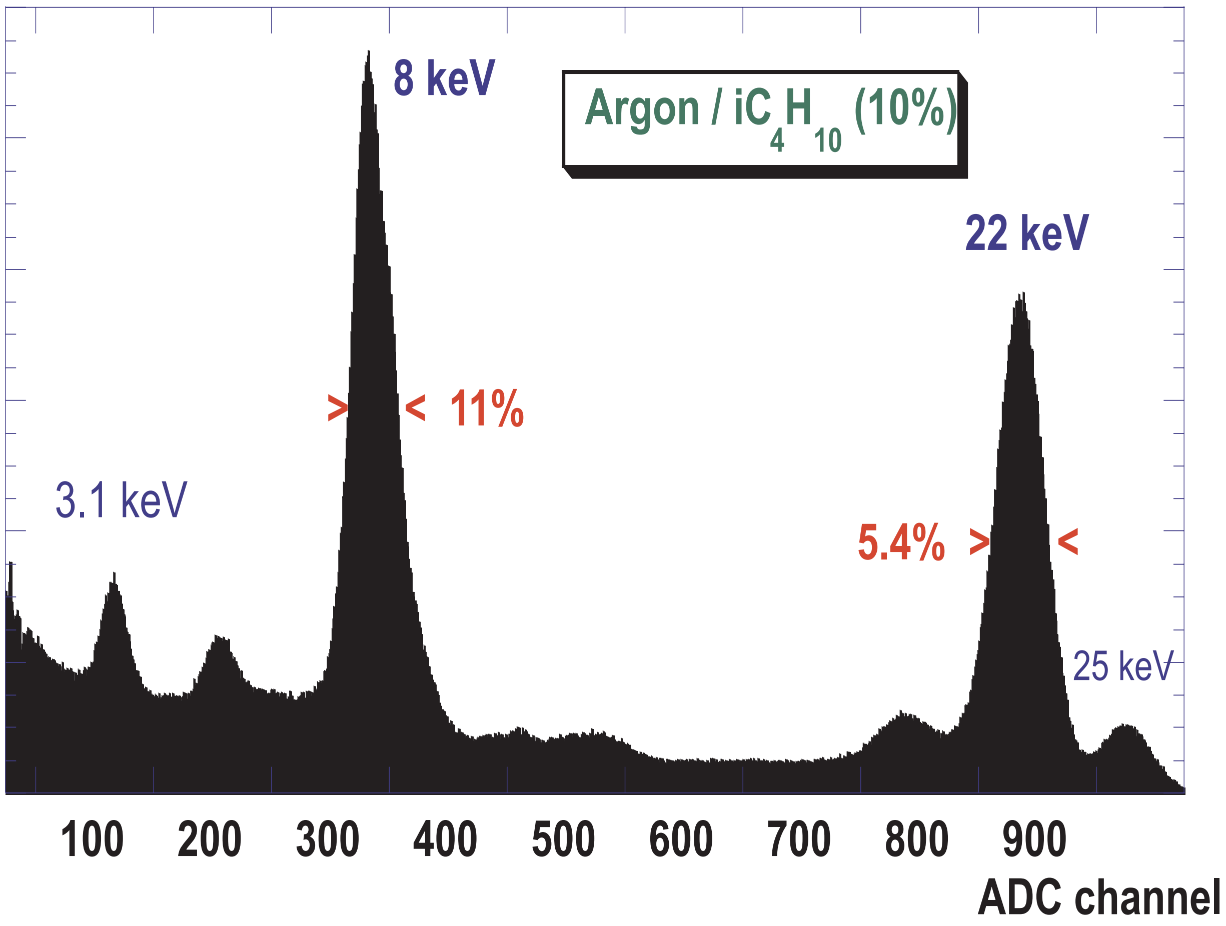
Optimal liquide gap < 10 µm

Optimum gap : 30 - 100 microns

Ref: Y. Giomataris, NIM A419, p239 (1998)

- **Stable gain and relative immunity to flatness defects or temperature and pressure variation**
- **Good energy resolution**

Good energy resolution



A. Delbart, R. de Oliveira, J. Derre, Y. Giomataris,
F. Jeanneau, Y. Papadopoulos, P. Rebourgeard
Nucl.Instrum.Meth.A461:84-87,2001

MPGD performances

- **Spatial resolution better than 50 μm**
- **Time resolution better than 1 ns**
- **High rate capability** >10^6/mm^2/s
- **Good aging properties**

MPGD applications

- **HEP experiments**
- ***COMPASS, NA48, LHCb, n-TOF,RHIC, SLHC…***
- **Non accelerator experiments**

CAST, T2K, DRIFT, MiMac, MiMAC….

New development
Bulk Micromegas

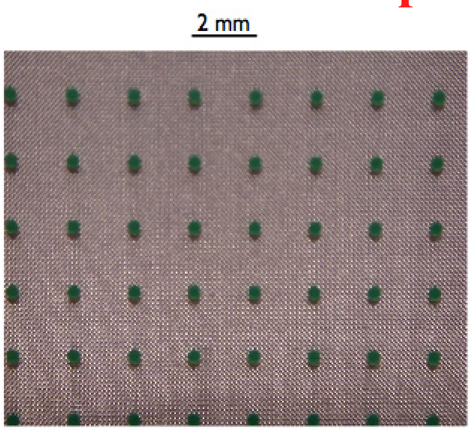
I. Giomataris, R. De Oliveira et al., DAPNIA-2004

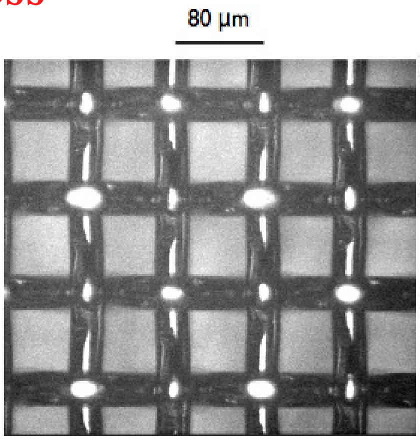
- **Large area and robustness**

  Easy implementation

  Low cost

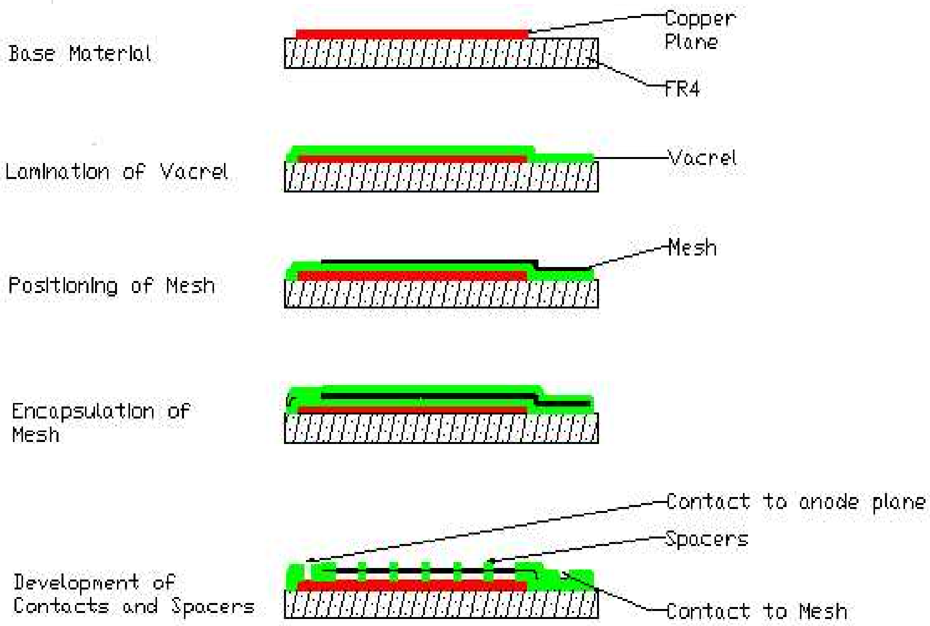
  Industrial process





- Bulk Micromegas obtained by lamination of a woven grid on an anode with a photo-imageable film

« Bulk » : construction process

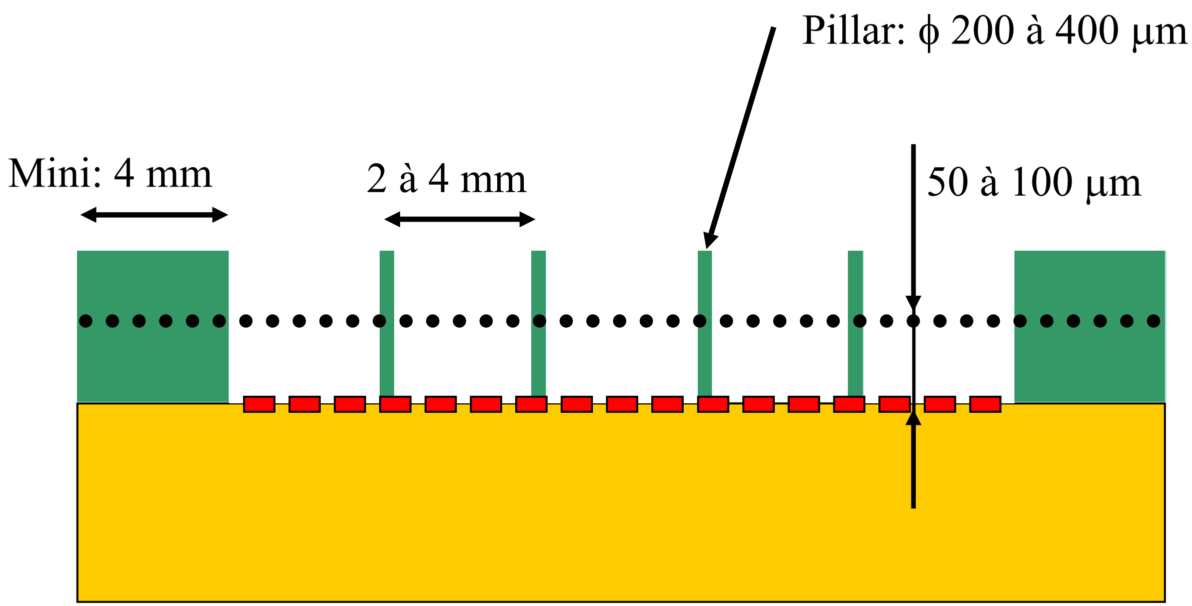


- **Low material detectors**

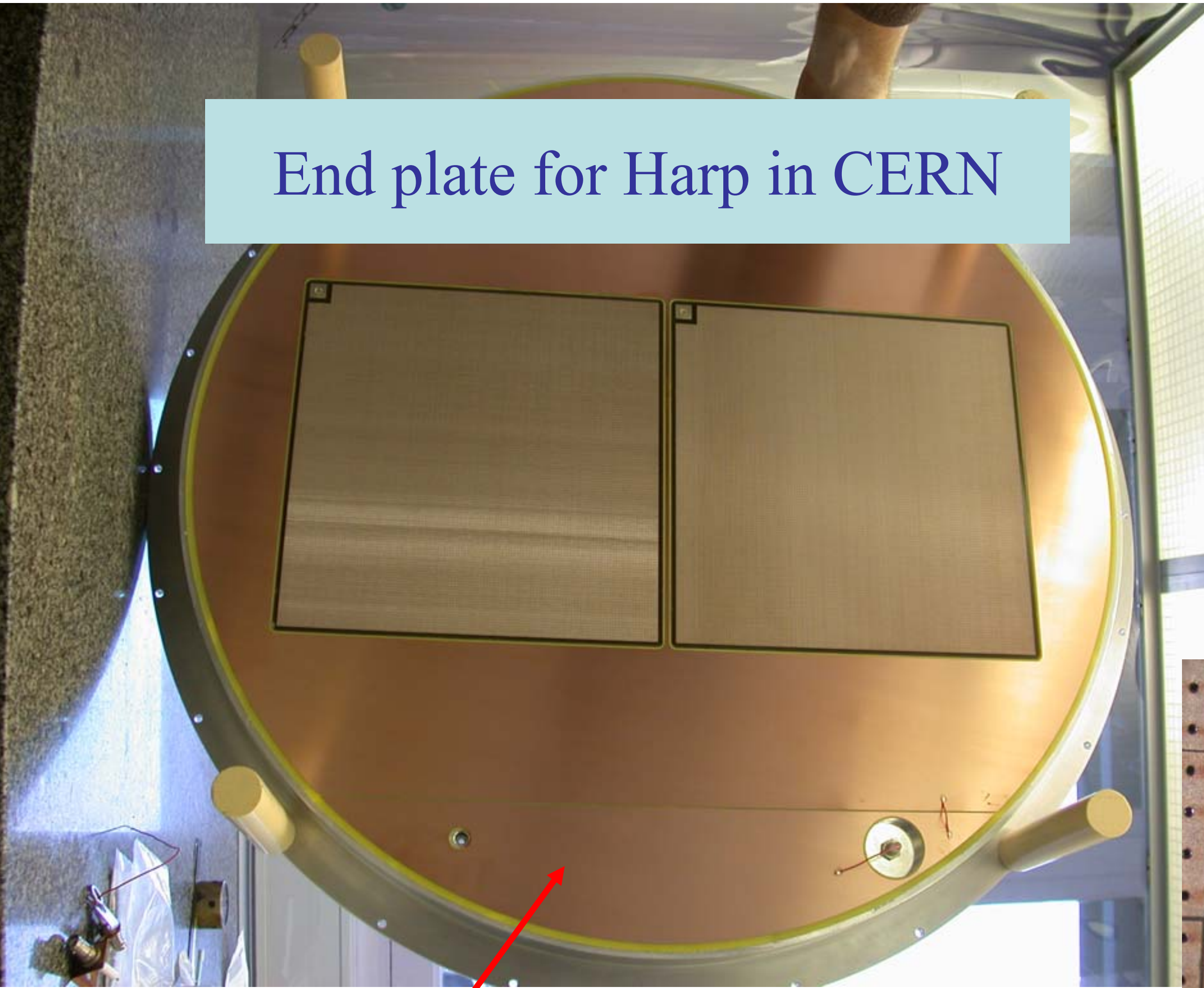
Goal : 5-10 lower of a standard silicon detector

Bulk fabrication process

1) **PCB**
2) **Photoresistive film lamination** (50 à 150 microns)
3) **Mesh lamination** (ϕ 19 microns, 500 LPI)
4) **Photoresistive film lamination** (50 à 150 microns)
5) **UV insulation through masque**
6) **Development** (chemical solution)

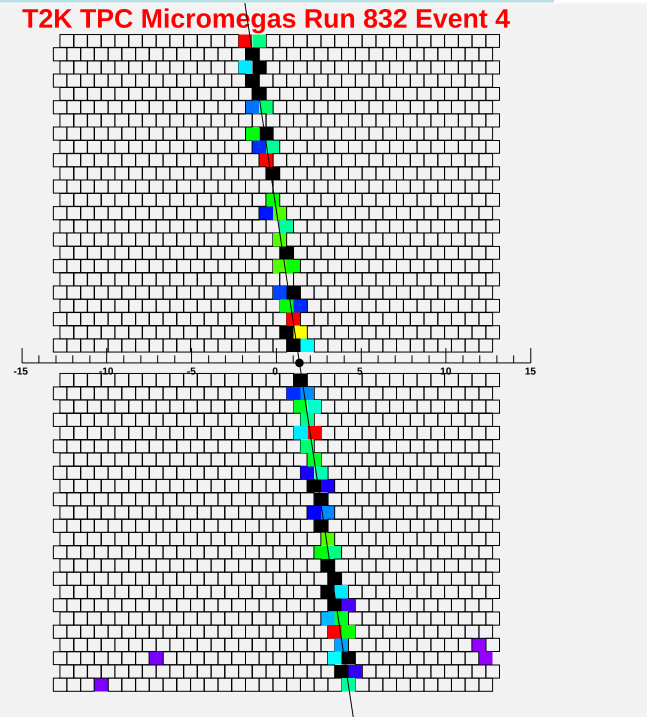


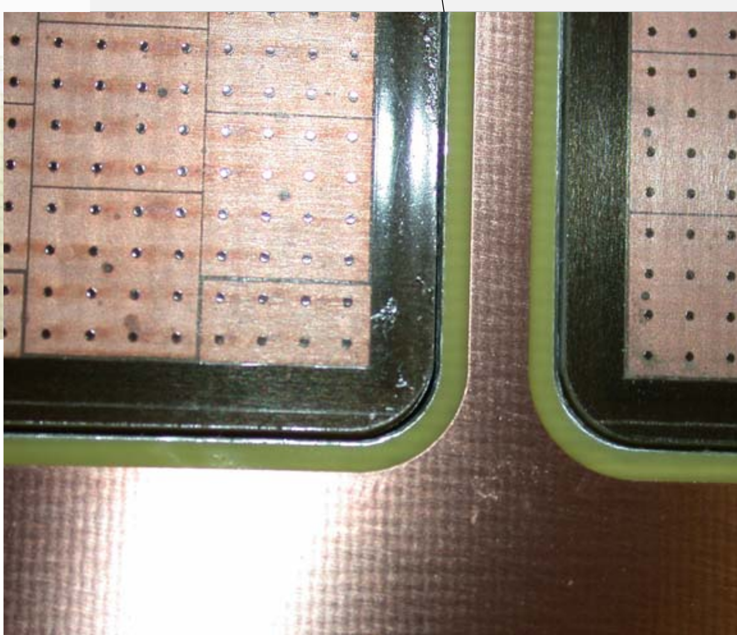
T2K Micromegas TPC project : about 15 m^2 detector surface



End plate for Harp in CERN

Inner surface covered by PCB for E-field termination

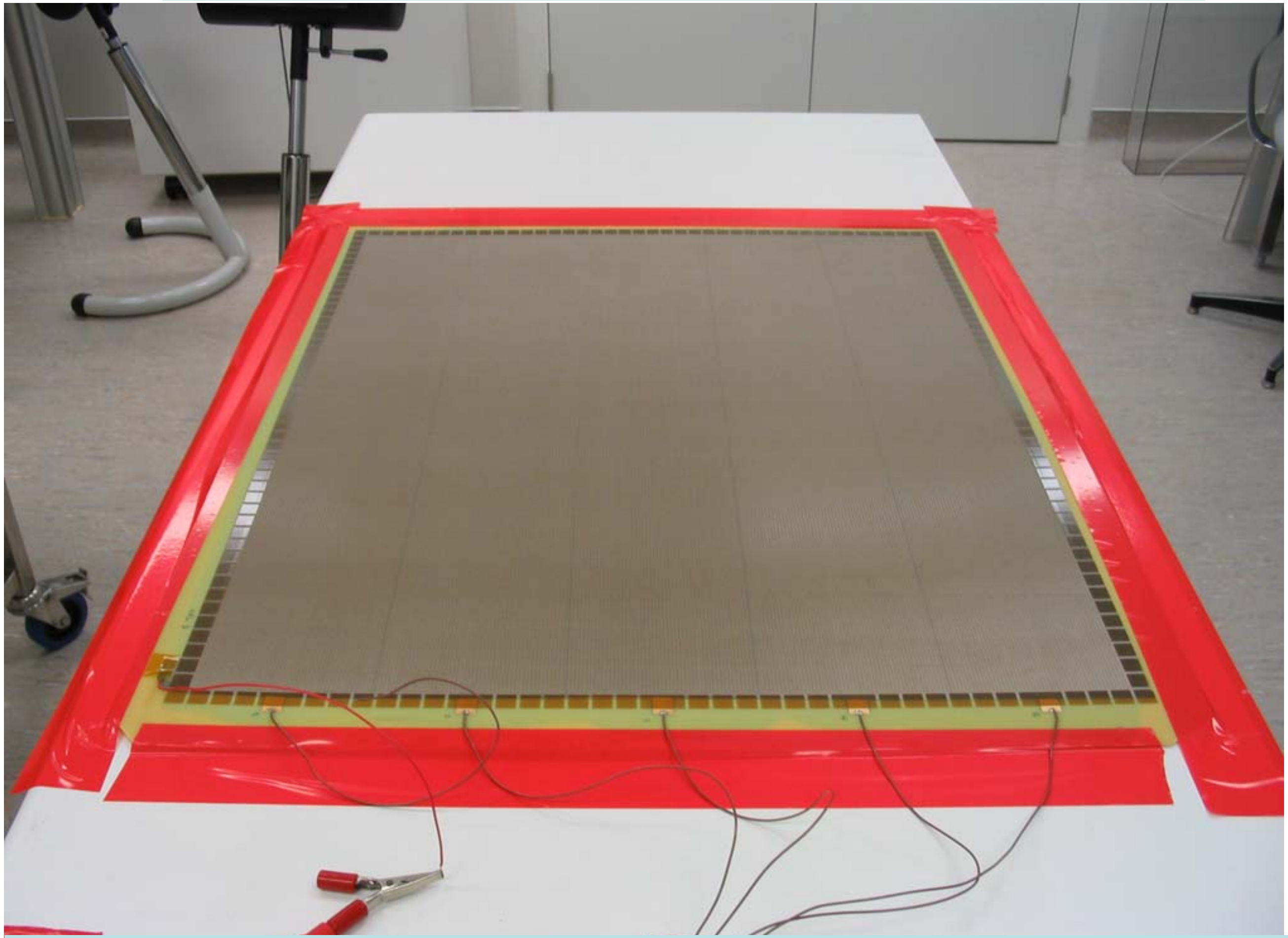




50x50 cm2 under study for ILC-HCAL by Annecy-Lyon

Towards larger Micromegas

New 50x65 cm^2



Well adapted to SLHC muon tracking system with

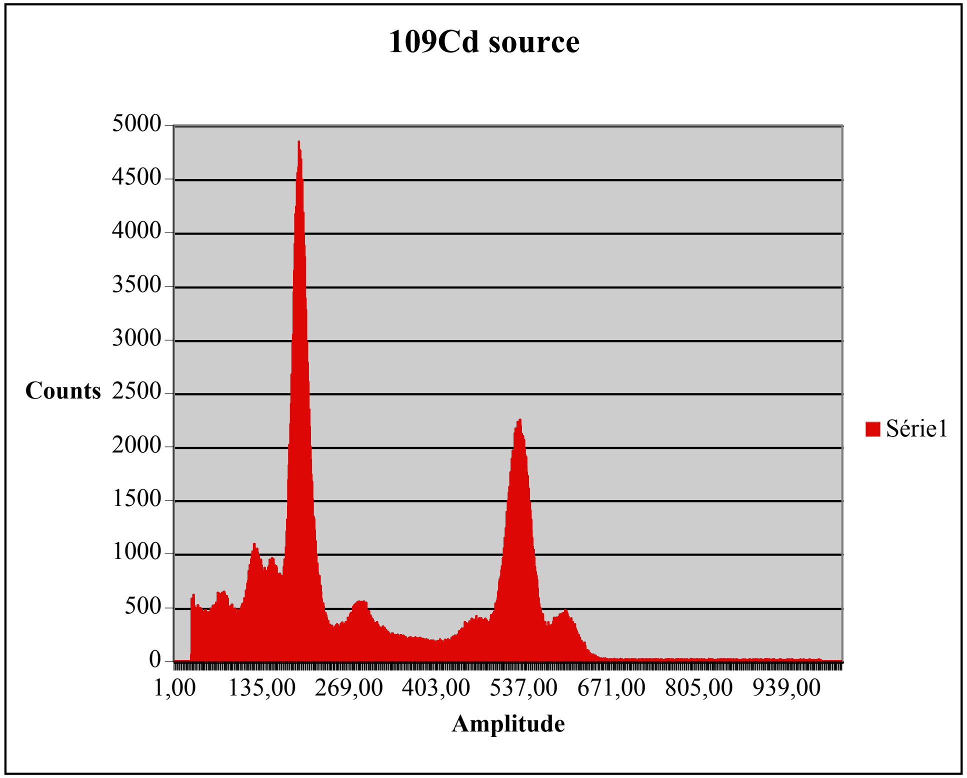
100 µm gap, 3-5 mm drift, Ar or CF_4 gas mixture

Pitch < 1 mm to get resolution < 100 µm

Or use resistive layer and larger strip pitch

New Micro-Bulk,

I. Giomataris- R. De Oliveira idea



High energy resolution

-10.5% at 5.9 keV

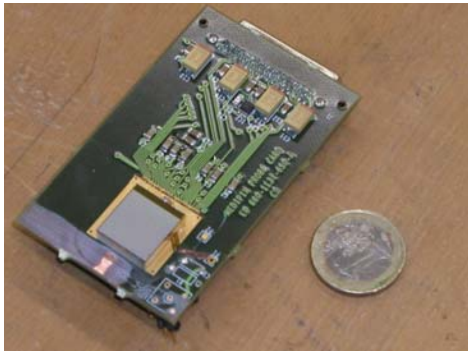
- 5.5 at 22 keV

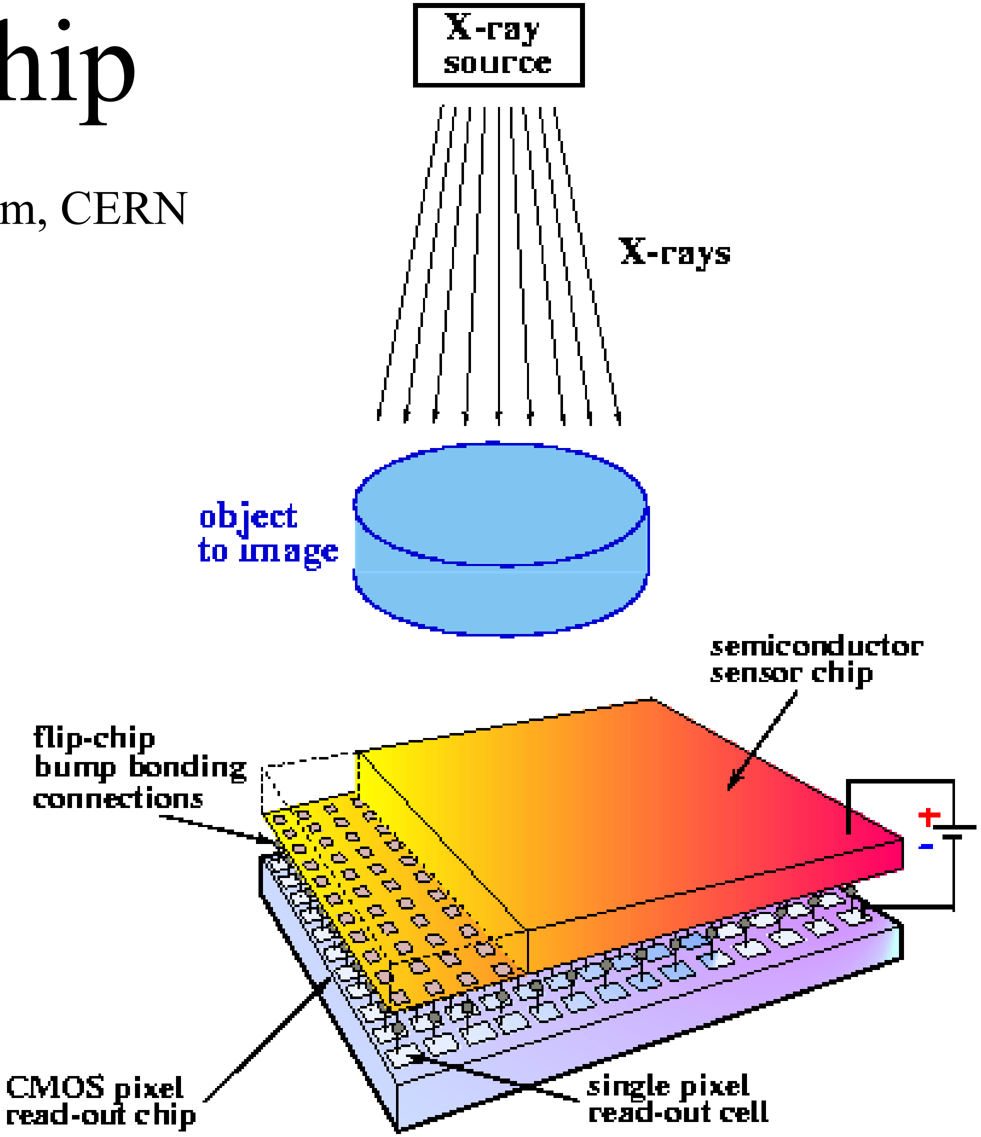
- <1.5% with Am alpha source

We must measure resolution at higher pressure and Xenon mixtures

The Medipix2 chip

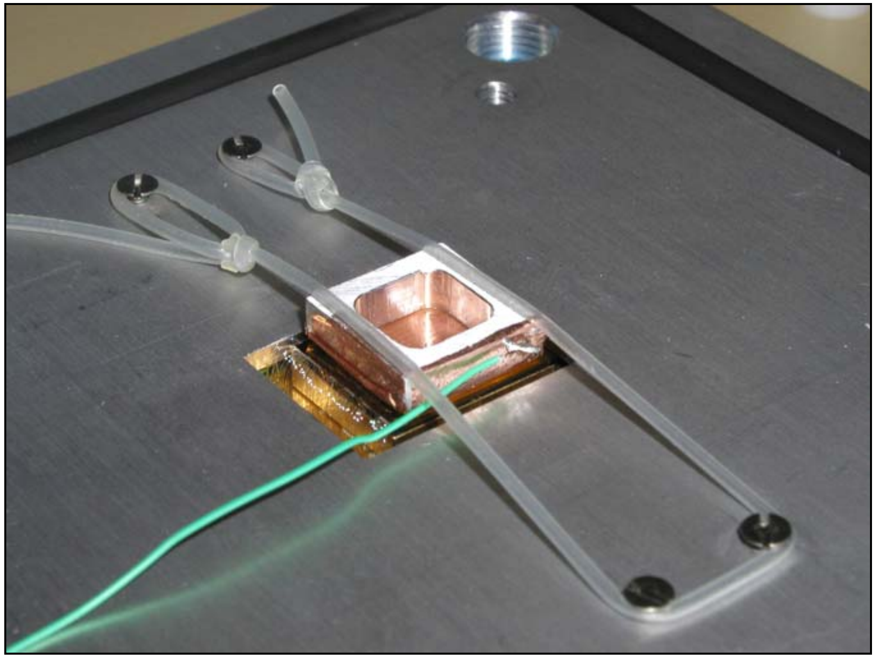
- Developed by the Medipix consortium, CERN
- Chip layout:
  - 1.4 x 1.6 cm^2 area
  - 256 x 256 pixel matrix
  - 55 x 55 μm^2 pixels
- On each pixel:
  - Preamp. + shaper
  - 2 discri. (thresholds)
  - 14 bit counter

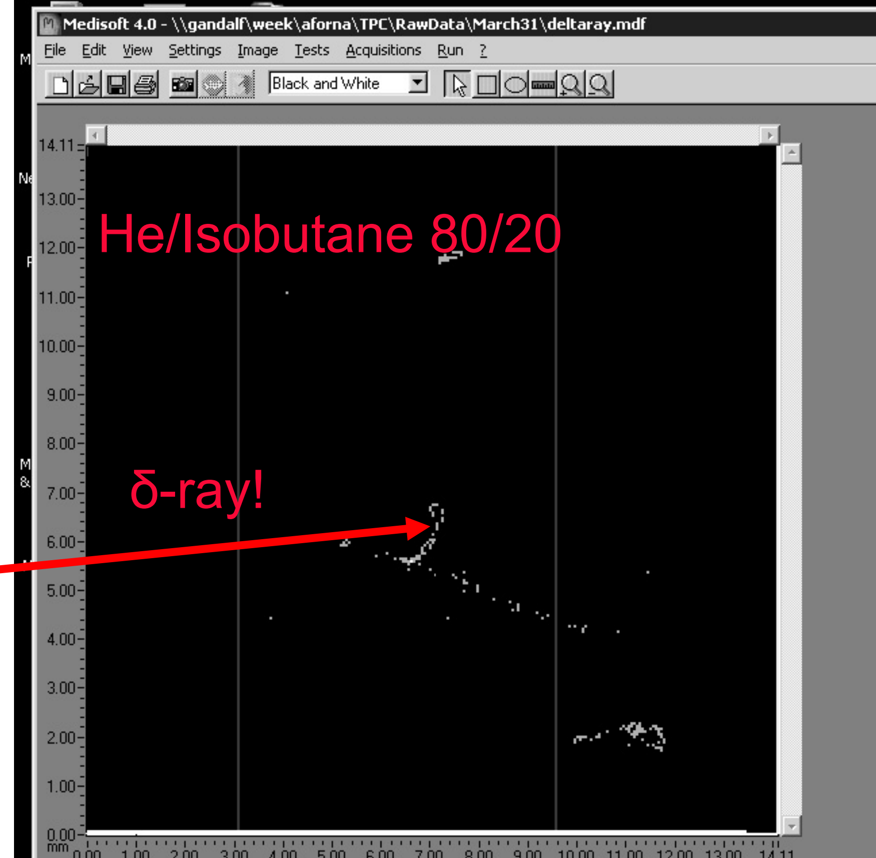




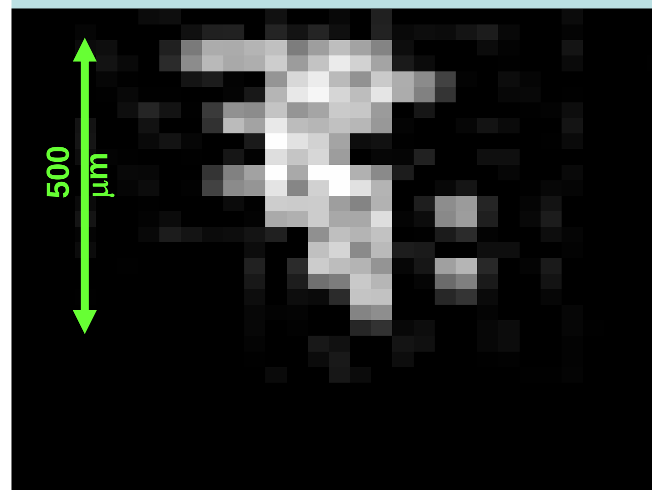
Use the "naked" chip as the detector anode

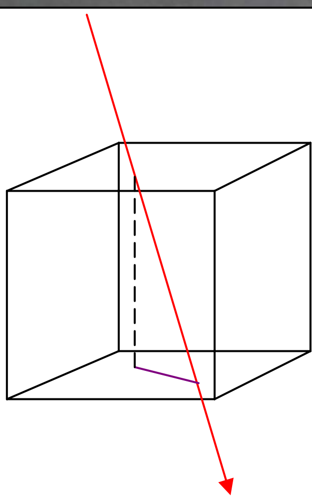
Medipix2 & Micromegas





5.9 keV photoelectron in Argon

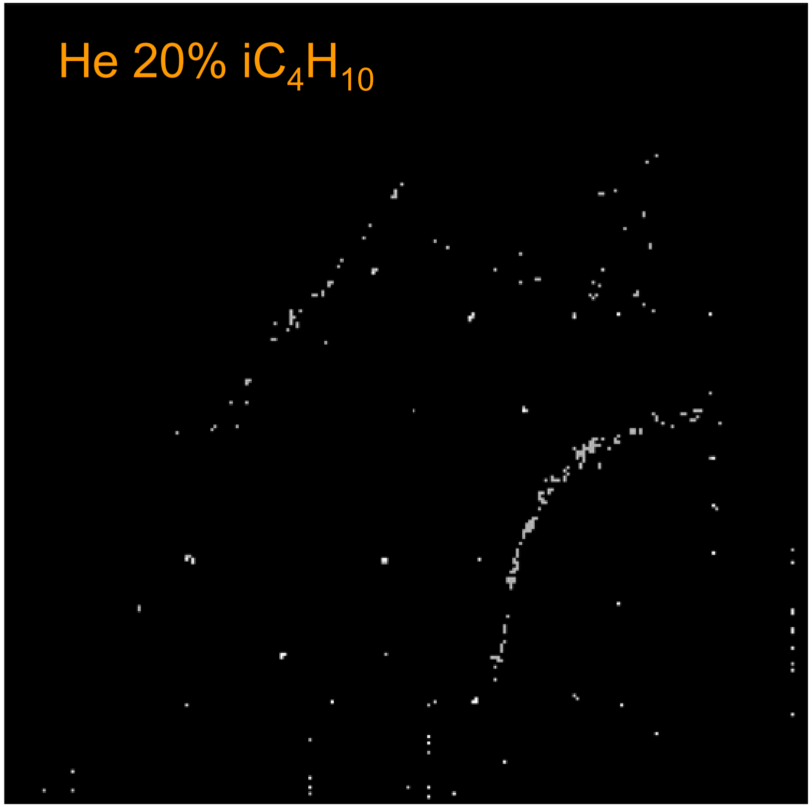


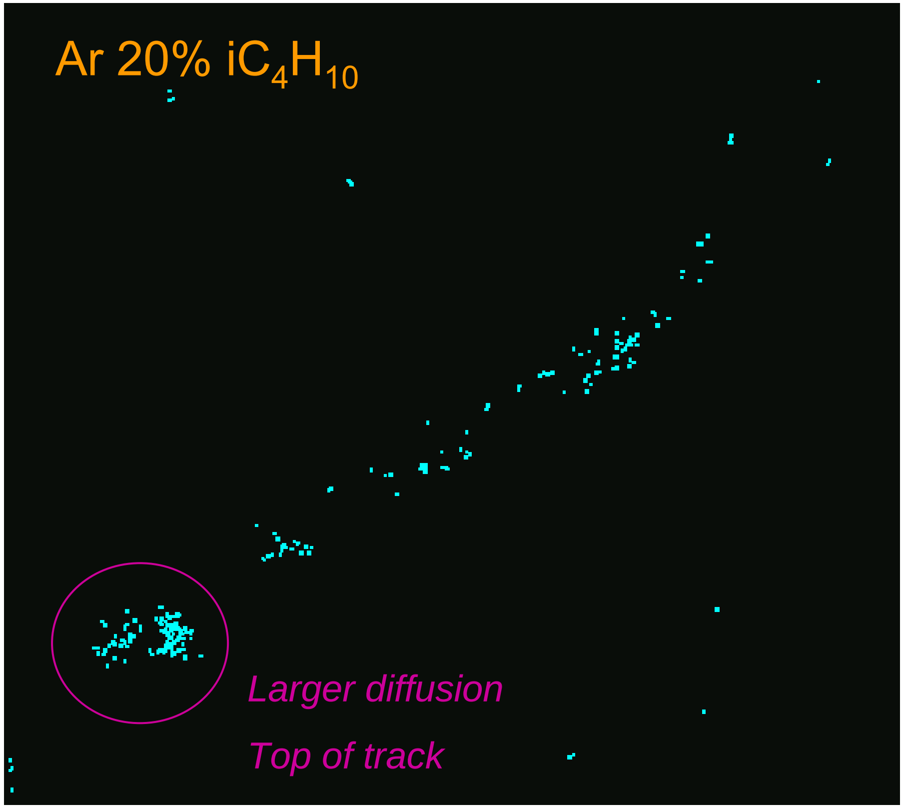


Efficiency for detecting single electrons: > 90 %

Helium VS Argon mixtures

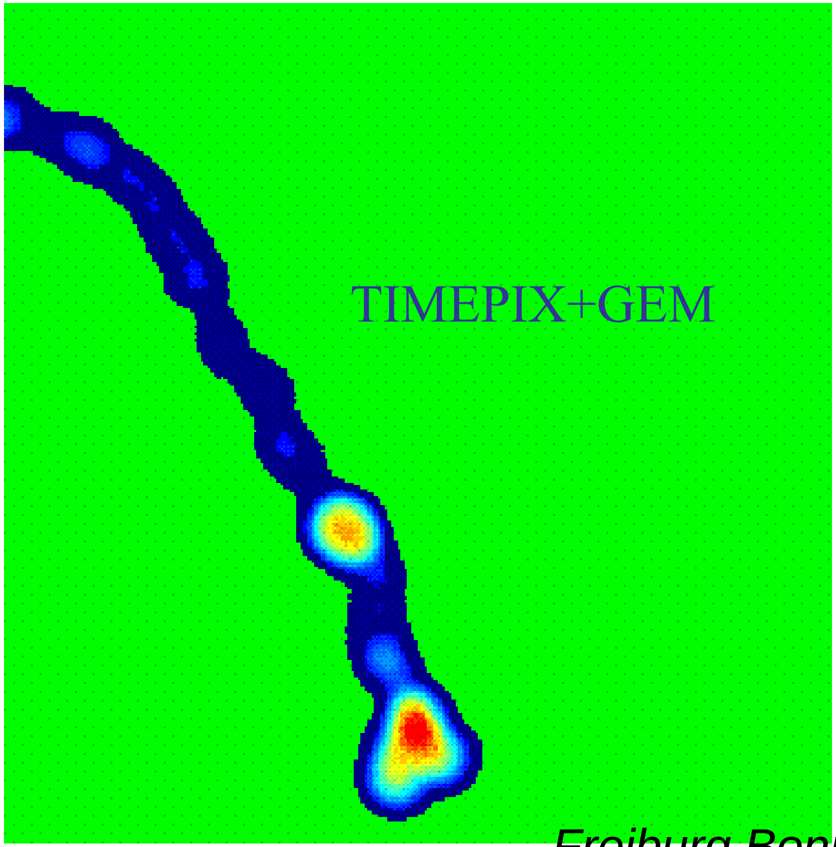
- Argon: larger primary statistic & transverse diffusion



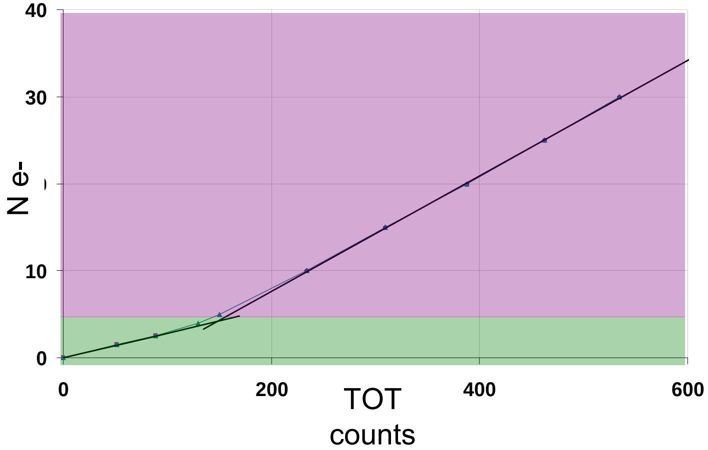


Interesting tool to study ionization statistic of photons & charged particles …

MEDIPIX + Micromegas or GEM tested
TIMEPIX is under development



Freiburg Bonn



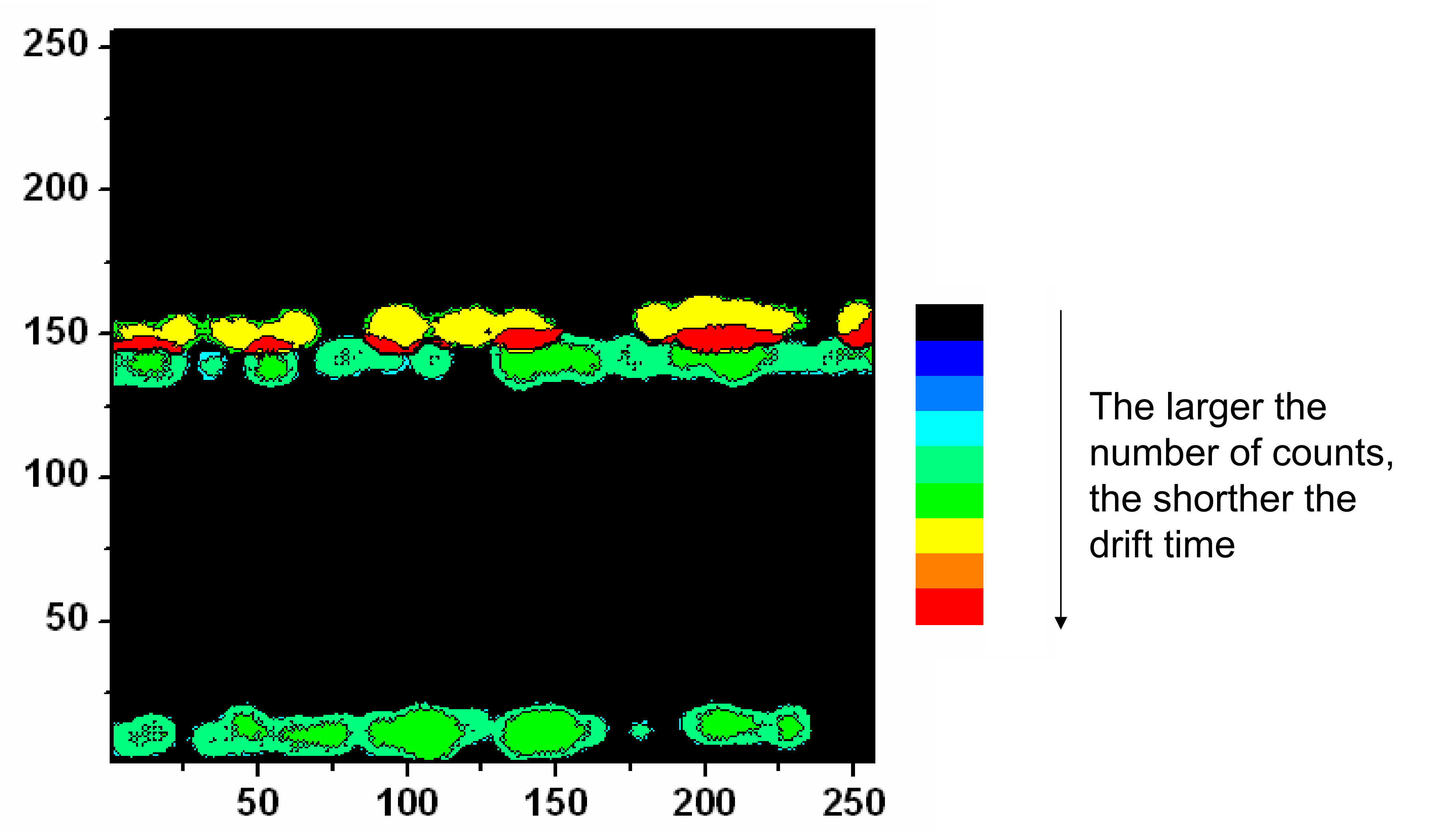
TOT linear above ~ 4 ke-

Better calibration to come…

- Ar CO_2 70/30
- No time information (2D)
- Charge information should improve spatial resolution

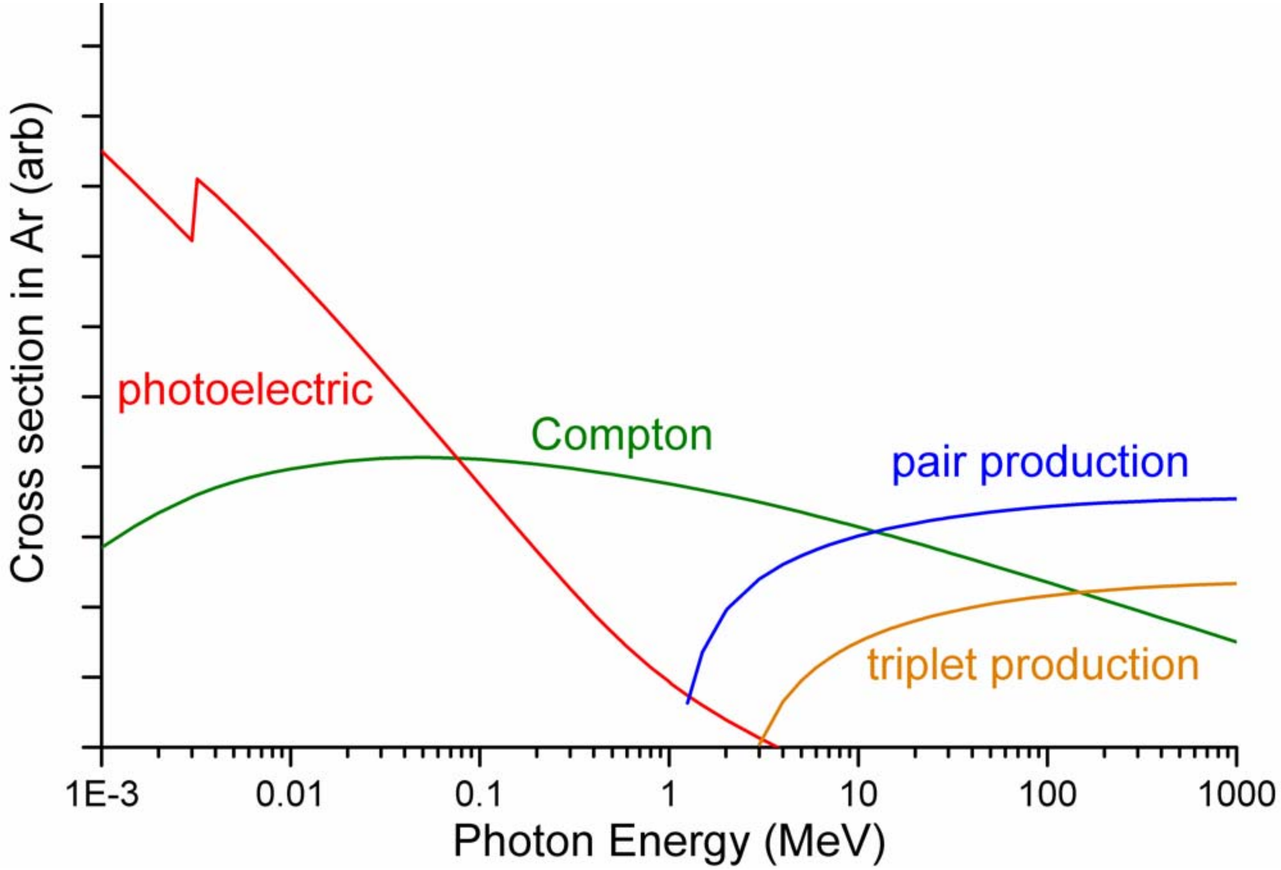
Beam test in DESY

- Every fired pixel counts till the end of a 12 μs shutter window
- Tracks parallel to the pixel plane (same color)



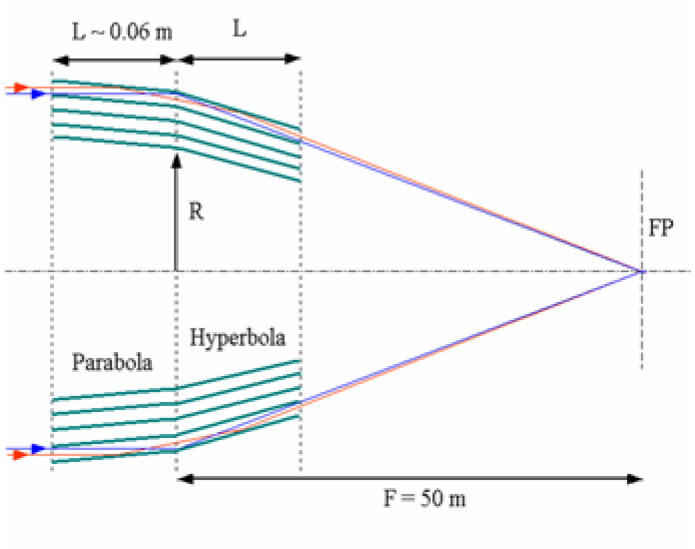
Challenges in Gamma ray detection in astronomy:

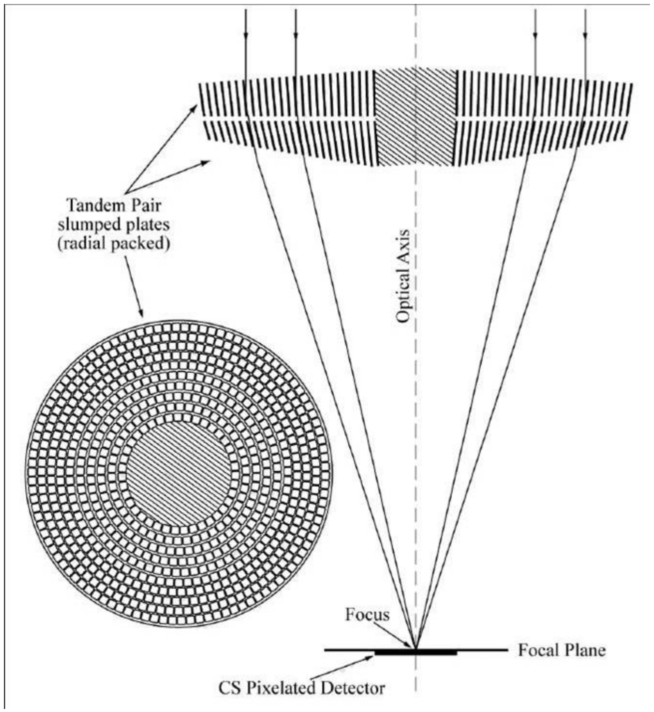
- **Angular resolution**
- **Polarization**



Photoelectric X-ray detection

- direction through X-ray optics





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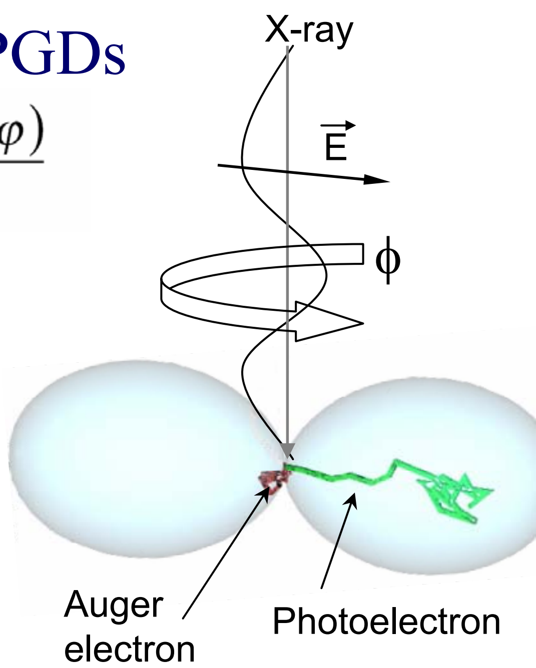
•Polarizaion: under investigation using novel MPGDs

$$\frac{\partial\sigma}{\partial\Omega} = r_0^{\,2}\,\frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2}\frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$

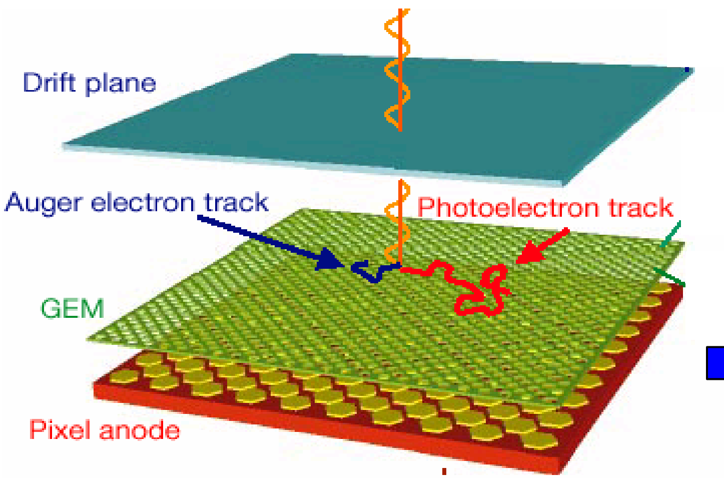


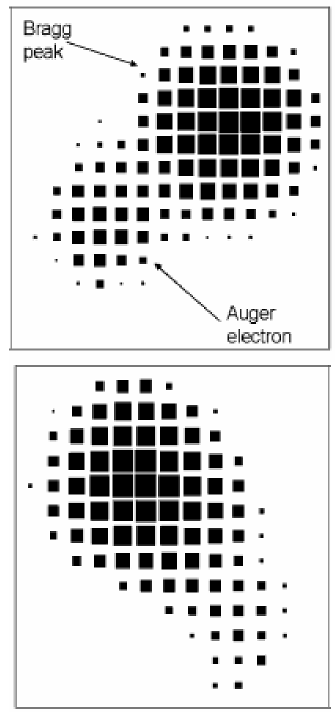
- Based on: correlation between the X-ray electric field vector and the photoelectron emission direction
- Challenge: both good modulation and high QE
  - Scattering mean free path < 0.1% X-ray absorption depth

High precision detector for X-ray Polarimetery with Time Projection Chambers Photoelectric polarimetery with a pixelized micropattern gas detector

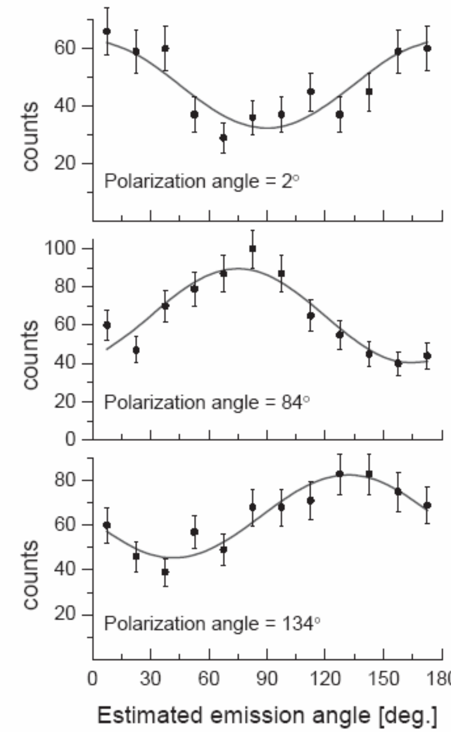
Highly sensitive technique first demonstrated by Bellazzini et al (2001)

and K. Black, K. Jahoda, P. Deines-Jones et al., NASA



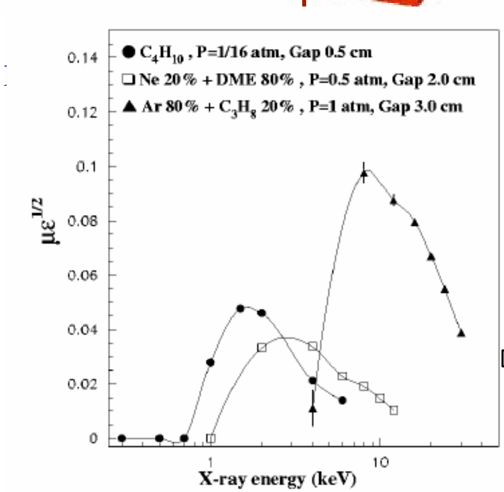


Track images



Modulation

Gas

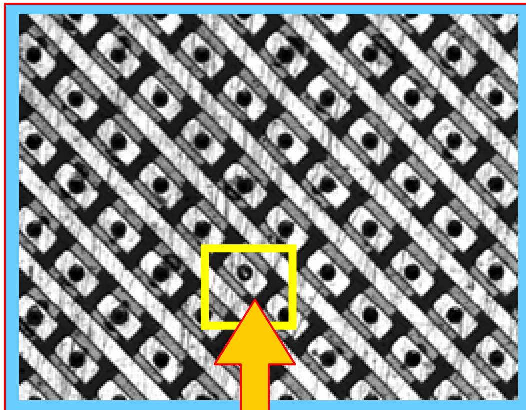


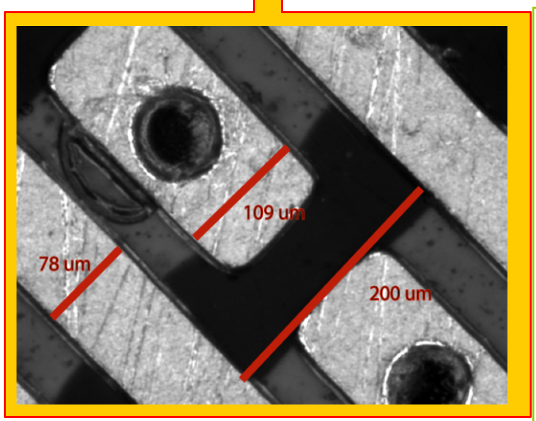
Polarimeter figure-of-merit vs energy

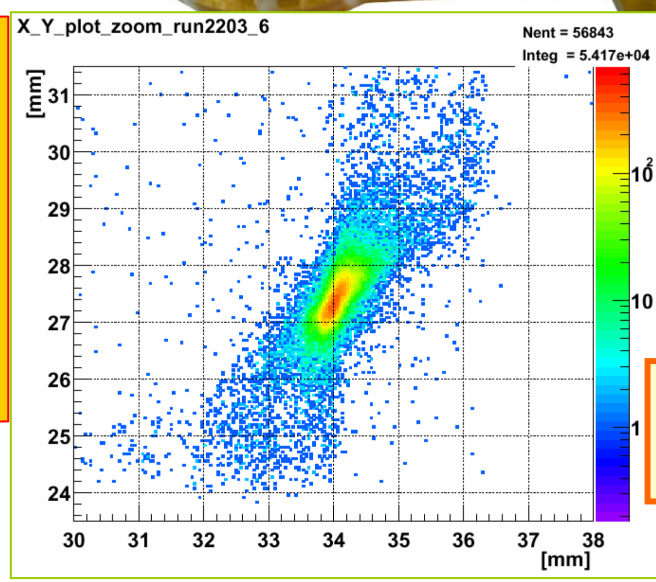
Electron diffusion in the drift region creates a tradeoff between quantum efficiency, modulation

Rare event search

Micromegas in CAST

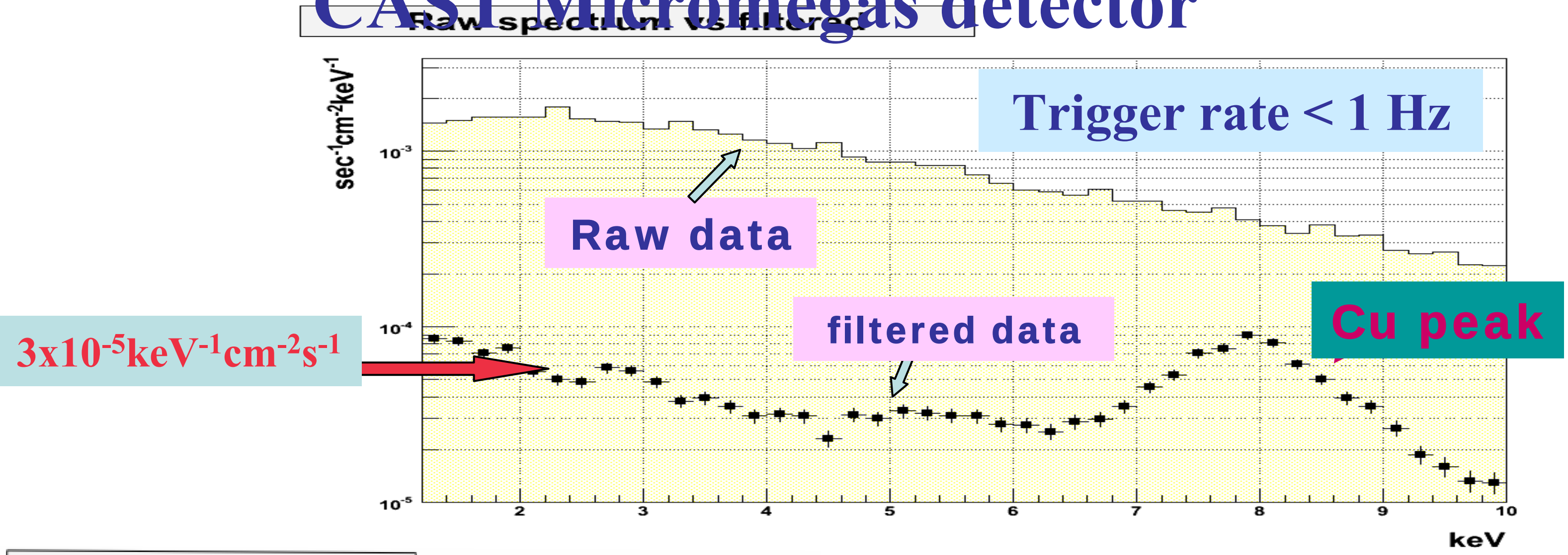


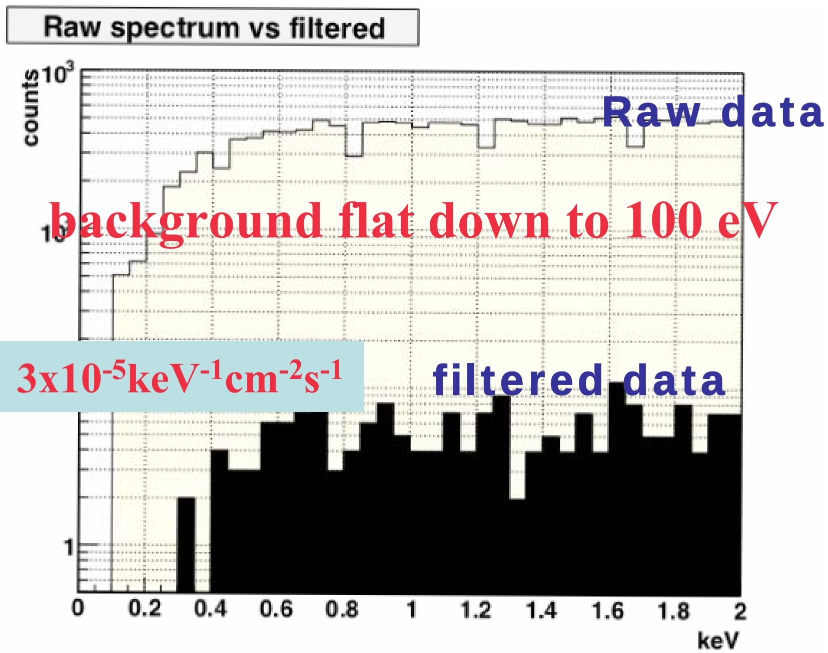




x-y image of 6.4 KeV X-ray beam in MicroMegas chamber (log scale for density)

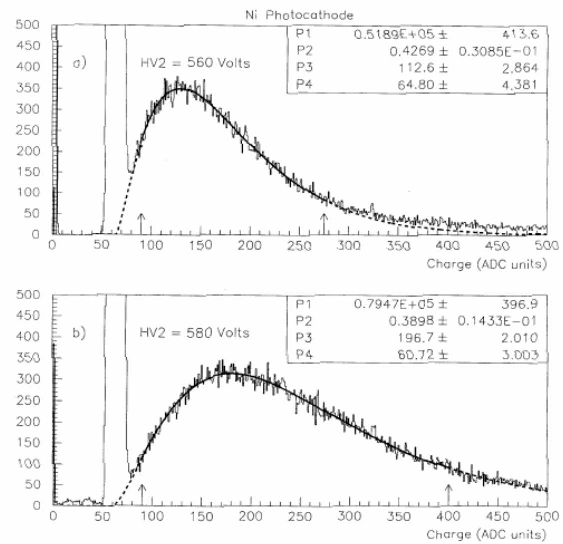
Background shape at low energy with CAST Micromegas detector





Single electrons

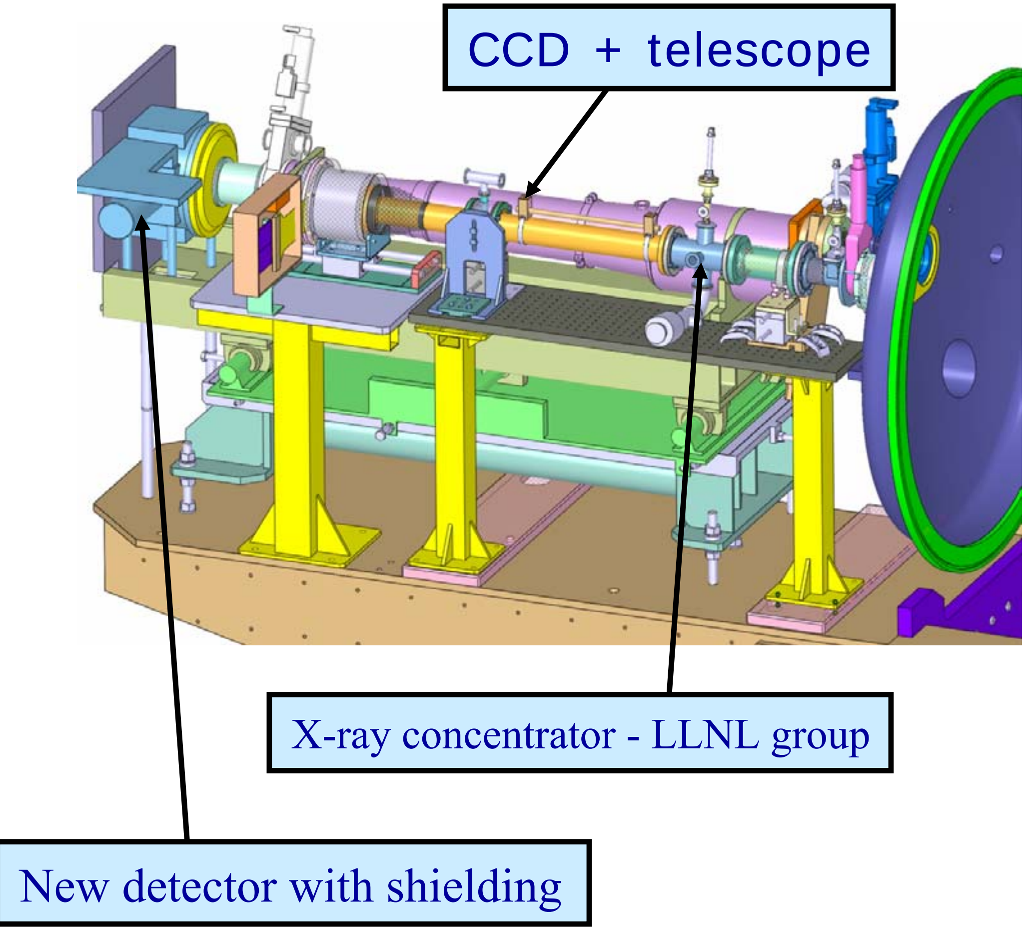
dark count:about 1Hz/m²

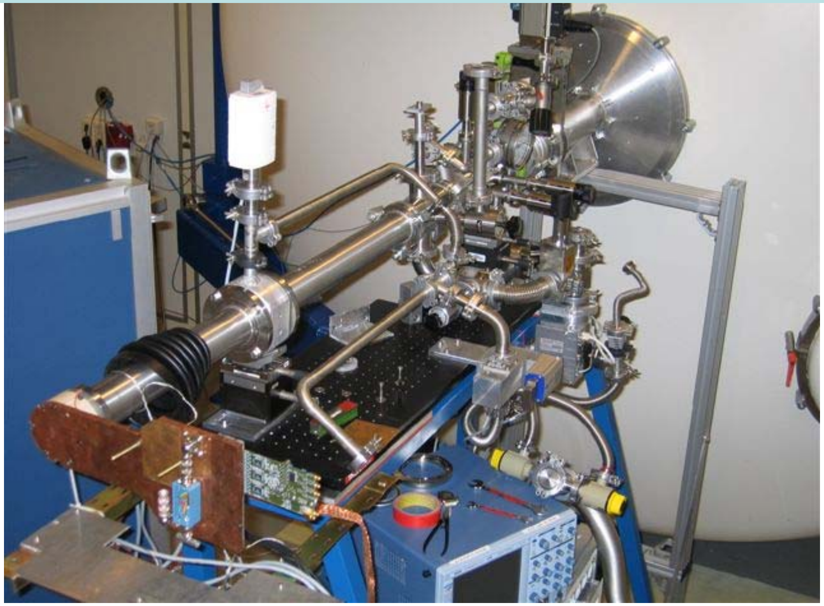


Micromegas + optics
New Micromegas line

X-ray beam test (PANTER, Munich)

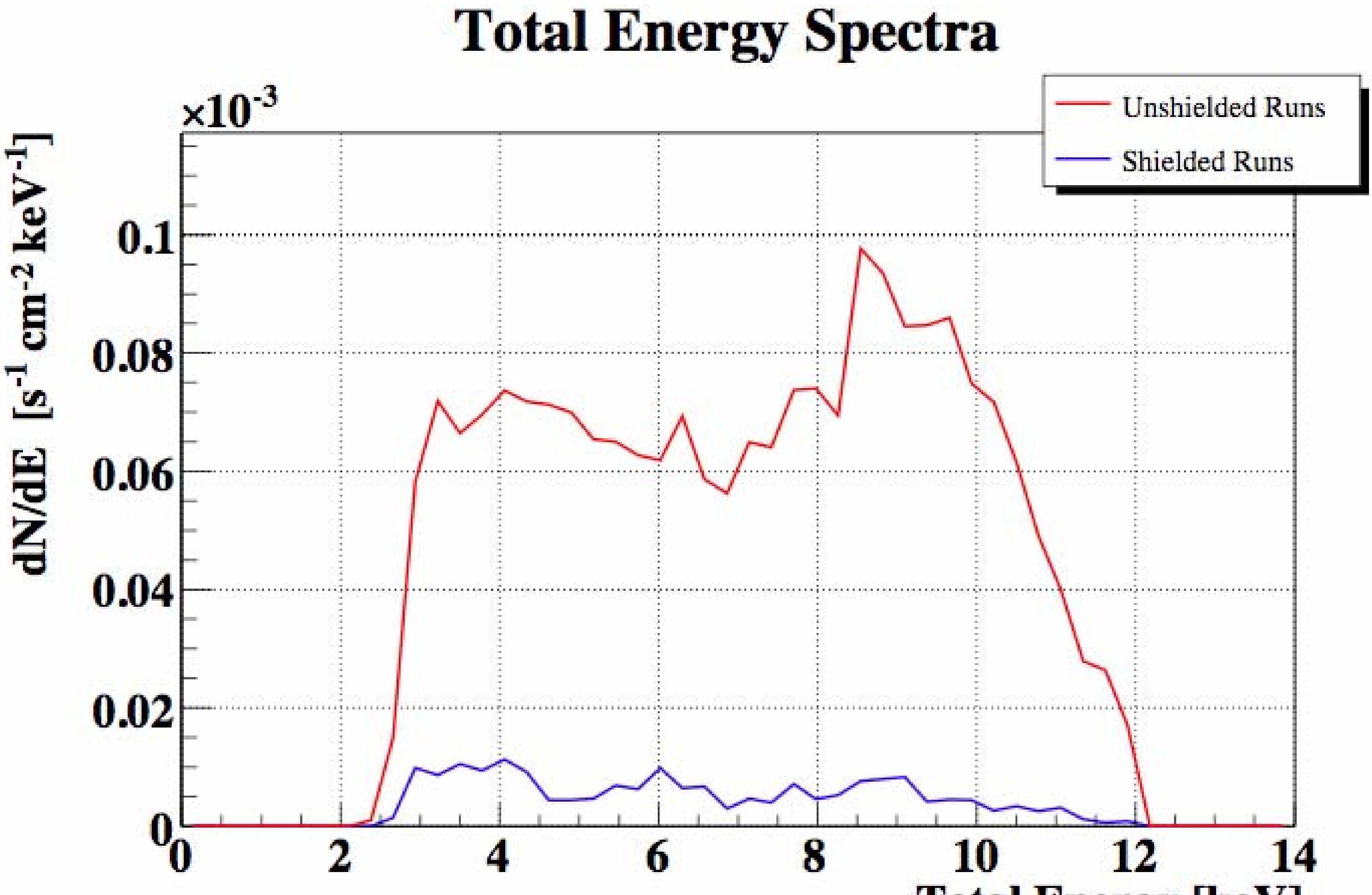
•Full system aligned and tested





Great background reduction with appropriate shield

→ Replace TPC by two Micromegas (micro-Bulk)



Low background- low energy applications

Low energy neutrino physics, WIMP-axion search, double-beta decay

http://www.unine.ch/phys/Corpus/TPC/purpose.html "WORKSHOP ON LARGE TPC FOR LOW ENERGY RARE EVENT DETECTION"

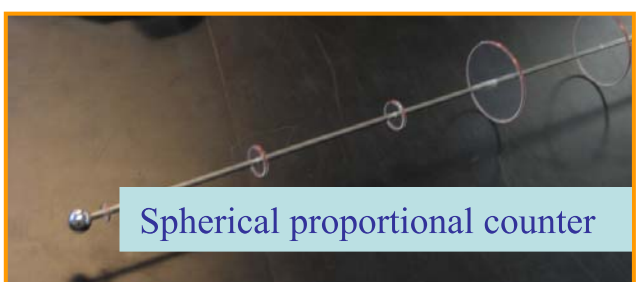
Gaseous TPCs :

- **T2K TPC, neutrino oscilations, double beta decay.**
- **DRIFT project : Large Scale Directional WIMP TPC.**
- **MIMAC-He3 :MIcro-tpc Matrix of Chambers of 3He.**
- **Gamma polarization measurement.**

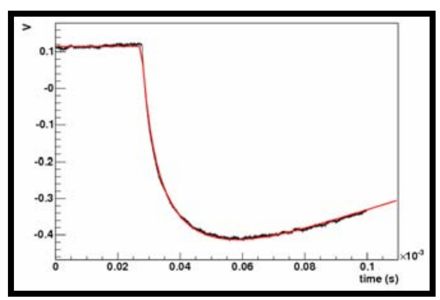
New Spherical TPC

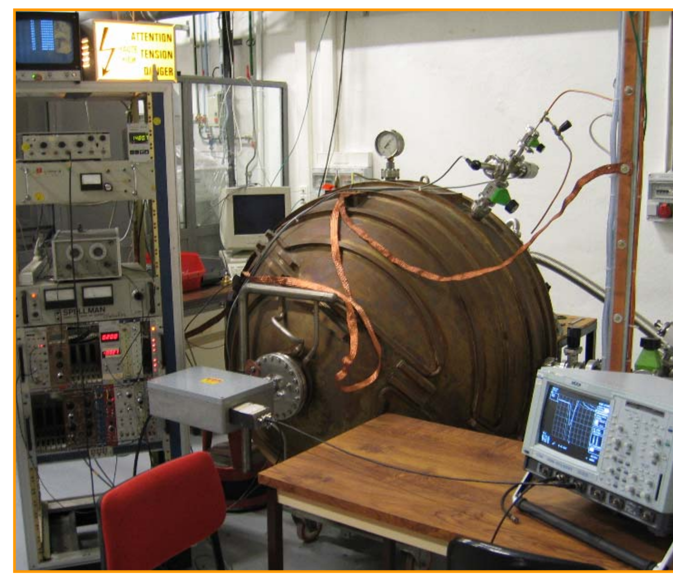
I. Giomataris, J Vergados, Nucl.Instrum.Meth.A530:330-358,2004

Neutrino coherent scattering, oscillations, magnetic moment, supernova



Spherical proportional counter

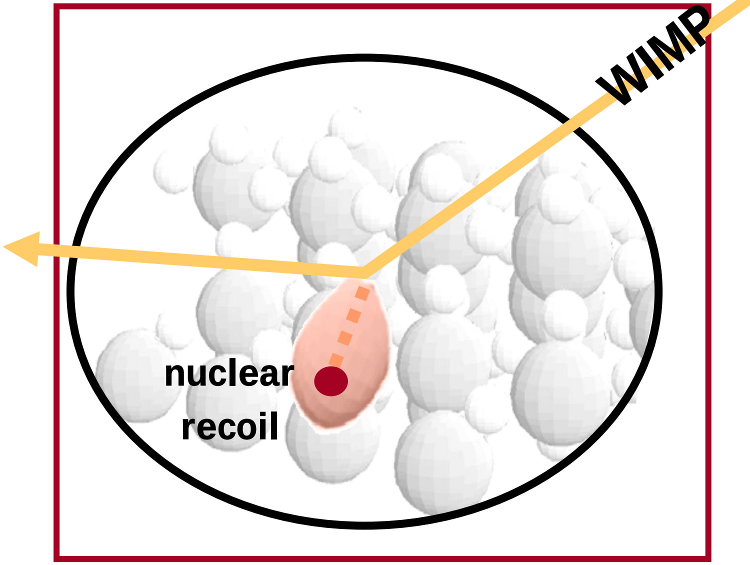


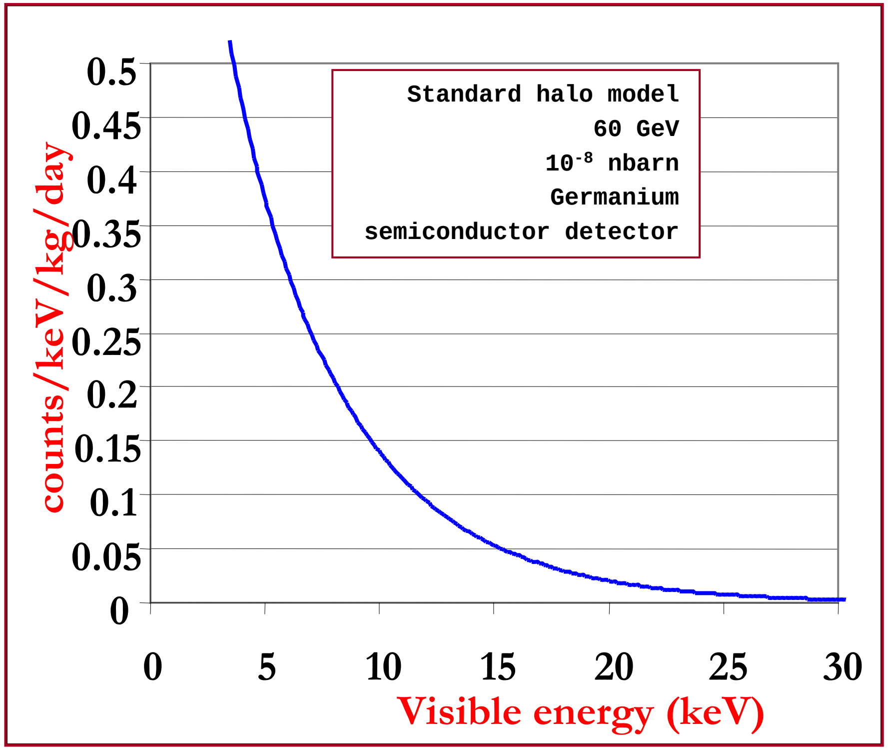


Dark matter detection

- Expected signal:

rare low energy event





Specific challenges:

✓Low threshold (~keV)

✓Reasonable energy resolution

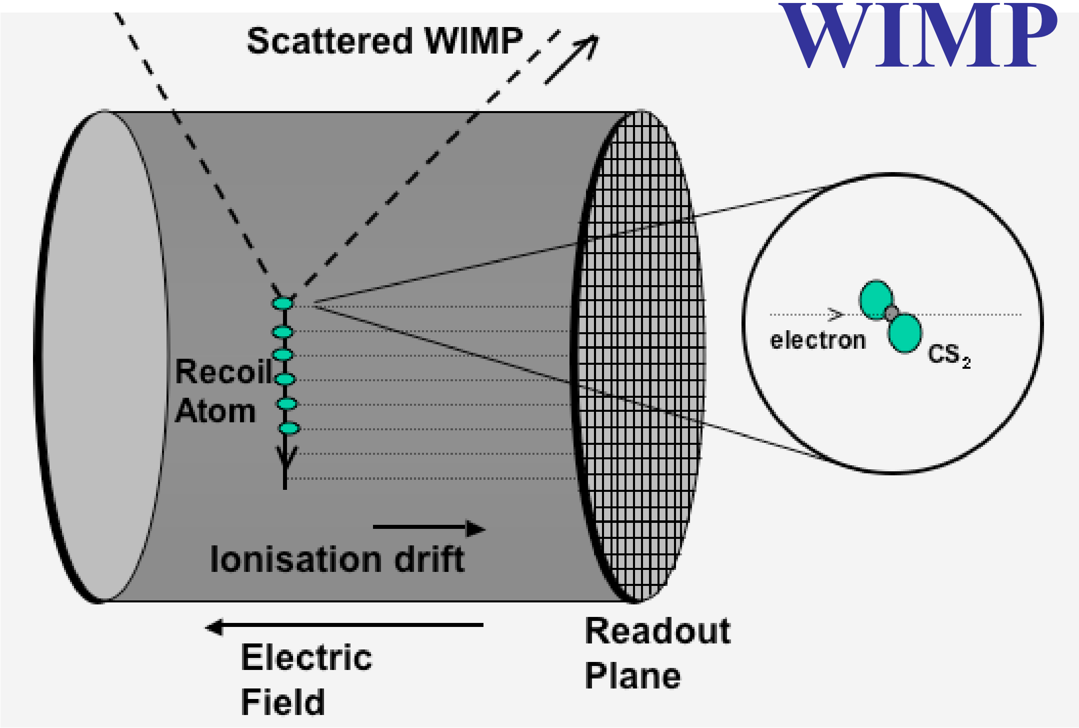
✓Very low background at keV scale:

- ✓Radiopurity & rejection techniques

✓Aim for large detector masses

✓Great stability over time.

WIMP directional TPCs



DRIFT PROJECT

N. Spooner et al.

MIMAC-He3

MIcro-tpc Matrix of Chambers of He3

A new ^{3}He detector for non-baryonic dark matter search

Micromegas read-out

D. Santos et al.

Low energy neutrino search

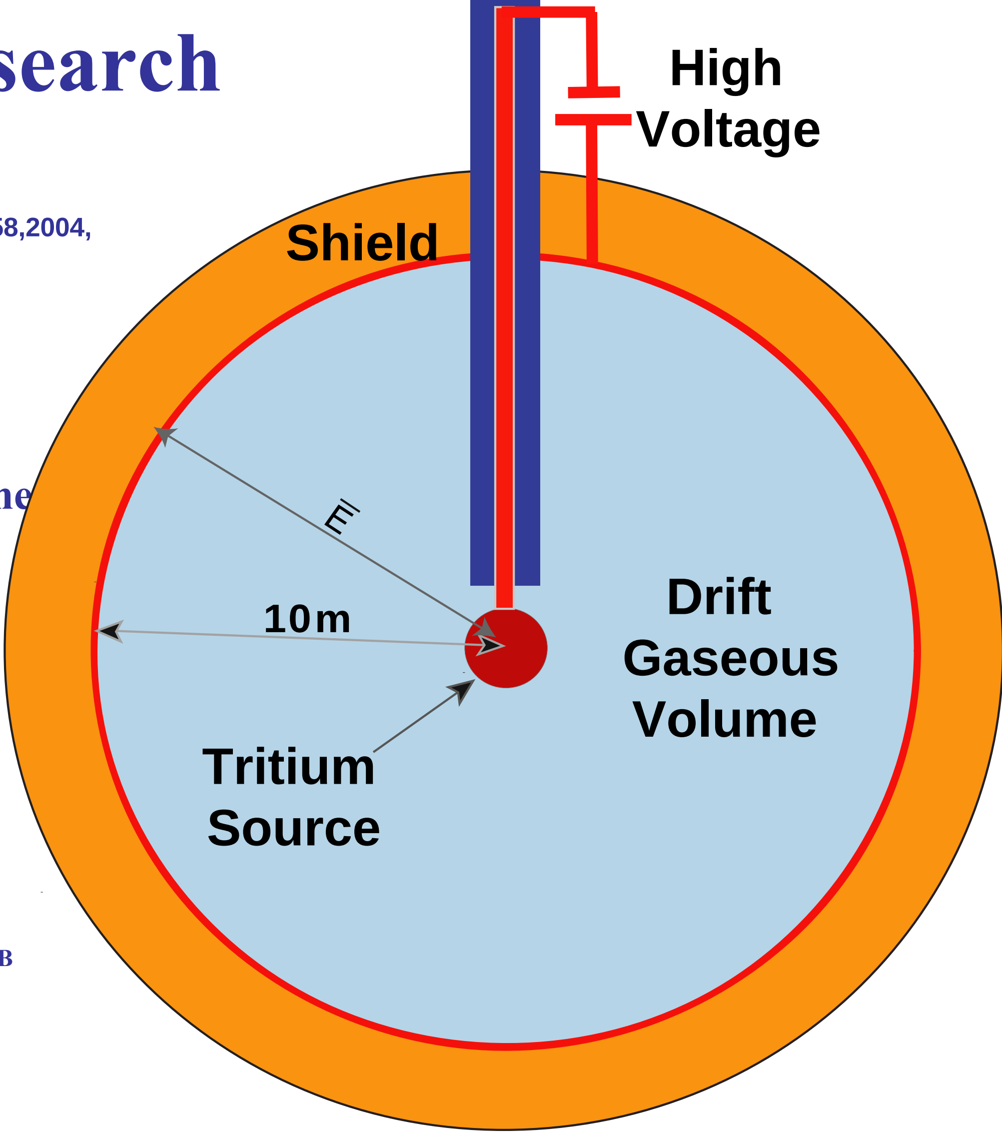
Idea of a spherical detector

I. Giomataris, J. Vergados, Nucl.Instrum.Meth.A530:330-358,2004,

S. Aune et al., Conf.Proc.785:110-118,2005

- Large Spherical TPC 10 m radius
- 200 MCi tritium source in the center
- Neutrinos oscillate inside detector volume L_{23}=13 m

$$P(\nu_e \to \nu_{\mu,\tau}) = \sin^2 2\theta_{13} \sin^2 \pi \frac{L}{L_{23}}$$



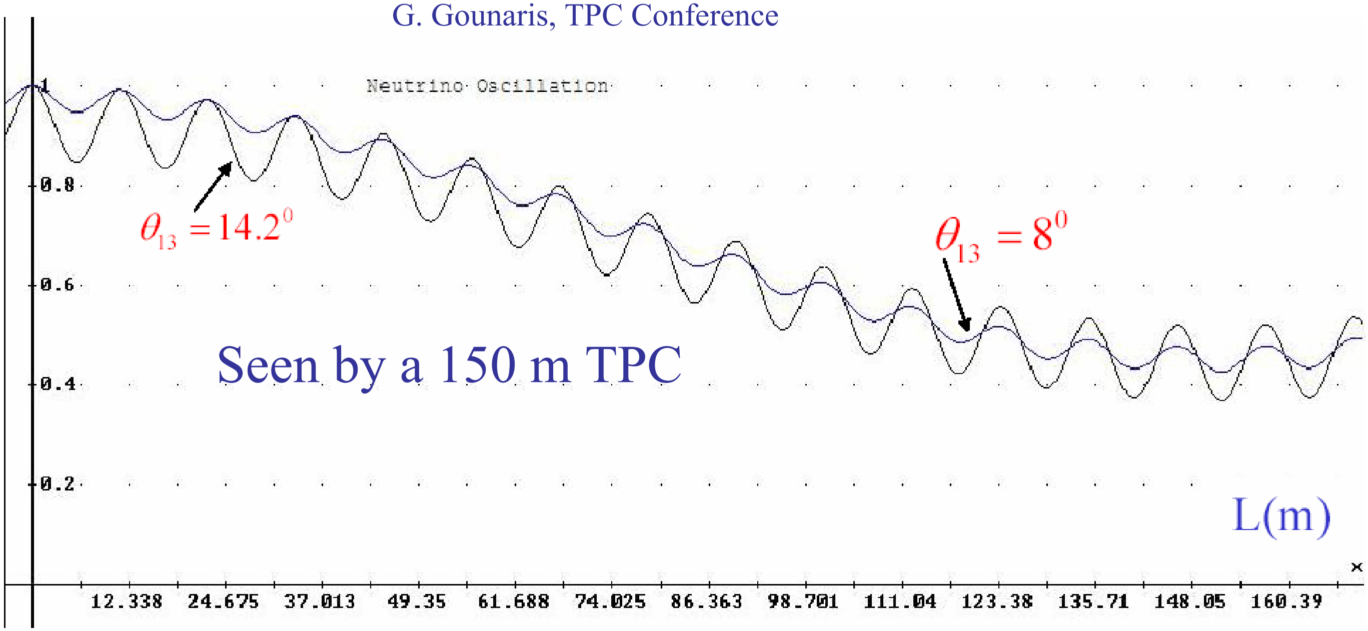
Objectives

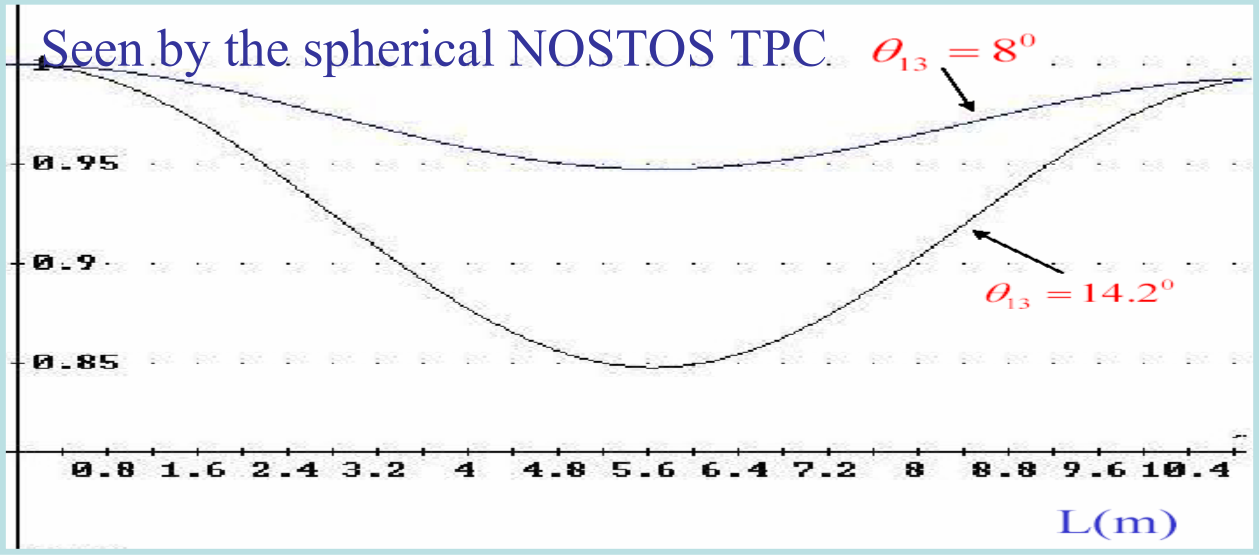
- Measure θ_{13} (systematic free)
- Neutrino magnetic moment studies << 10^{-12} μ_B
- Measurement of the Weinberg angle at low energy

Challenge : detect electron recoils down to T=100 eV (T_{max}=1.27 eV)
Low background level (to be measured and subtracted)
Measure the radial depth of the interaction

Room size oscillations

G. Gounaris, TPC Conference





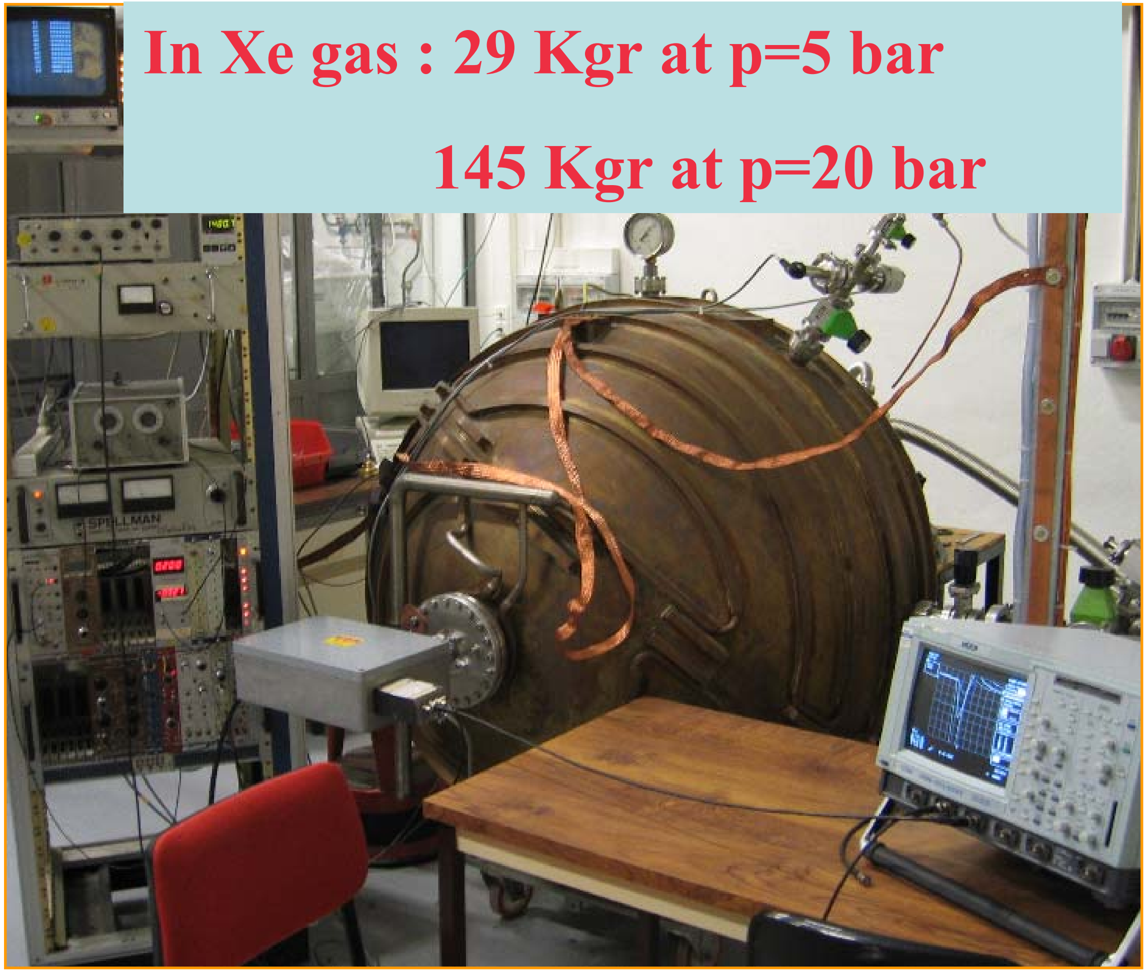
New The spherical detector

I. Giomataris, I. Irastorza, I. Savvidis et al.,

- D=1.3 m
- V=1 m^3
- Spherical vessel made of Cu (6 mm thick)
- P up to 5 bar possible (up to 1.5 tested up to now)
- Vacuum tight: ~10^{-6} mbar (outgassing: ~10^{-9} mbar/s)

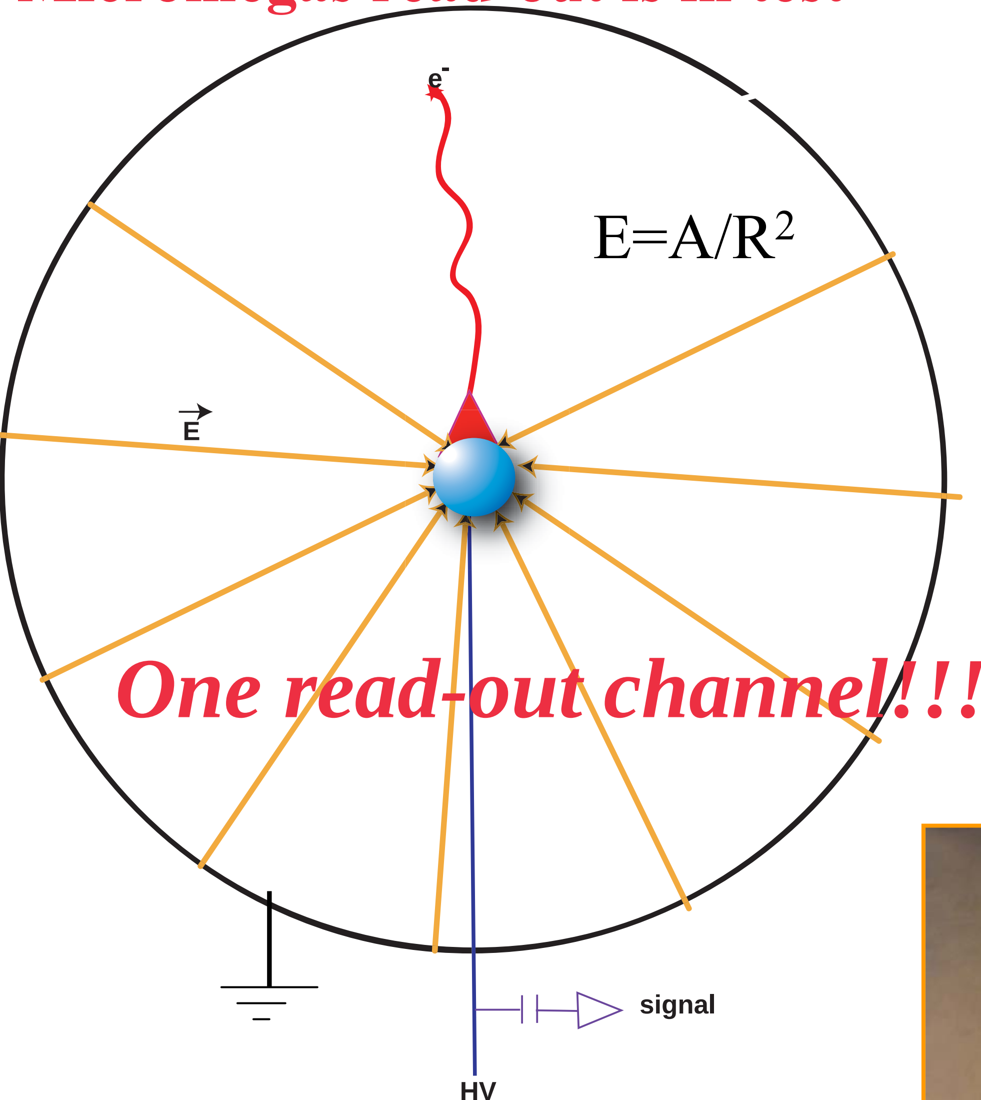
In Xe gas : 29 Kgr at p=5 bar

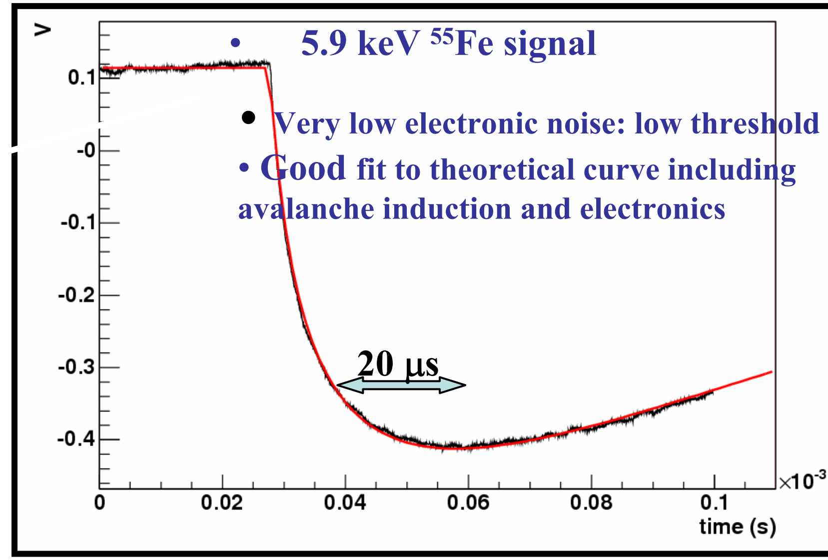
145 Kgr at p=20 bar

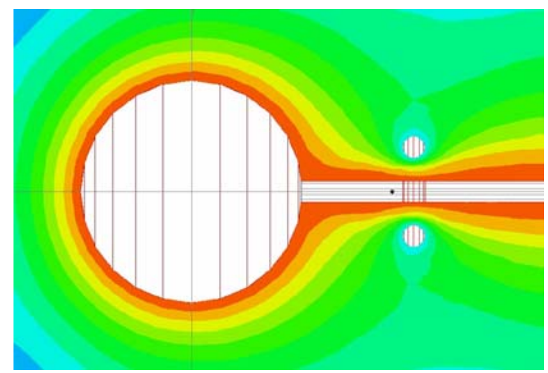


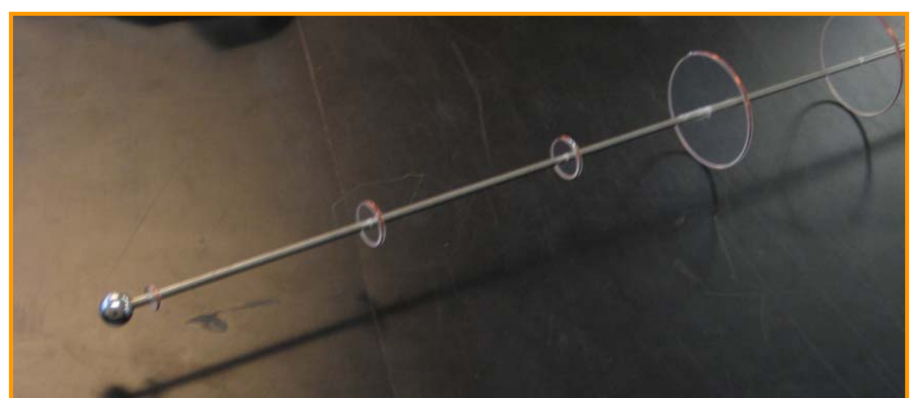
Spherical TPC with spherical proportional counter read-out

Micromegas read-out is in test









How to get simple and cheap Supernova counter

Neutrino-nucleus coherent elastic scattering

$\sigma \approx N^2E^2$, *D. Z. Freedman, Phys. Rev.D,9(1389)1974*

Supernova neutrino detection with a 4 m spherical detector

Y. Giomataris, J. D. Vergados, Phys.Lett.B634:23-29,2006

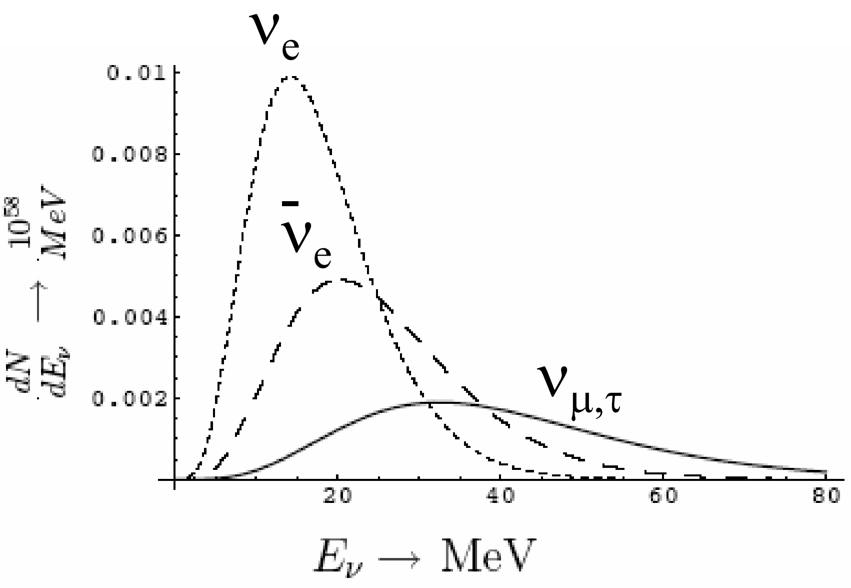
For E_ν = 10 MeV $\sigma \approx N^2E^2 \approx 2.5 \times 10^{-39}$ cm^2, T_{max} = 1.500 keV

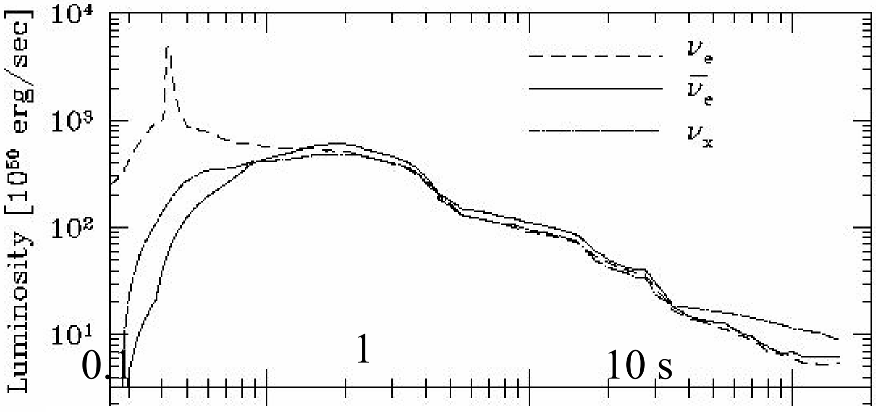
For E_ν = 25 MeV $\sigma \approx 1.5 \times 10^{-38}$ cm^2, T_{max} = 9 keV

Expected signal : 100 events (Xenon at p=10 bar) per galactic explosion

Idea : A European or world wide network of several (tenths or hundreds) of such dedicated Supernova detectors robust, low cost, simple (one channel)

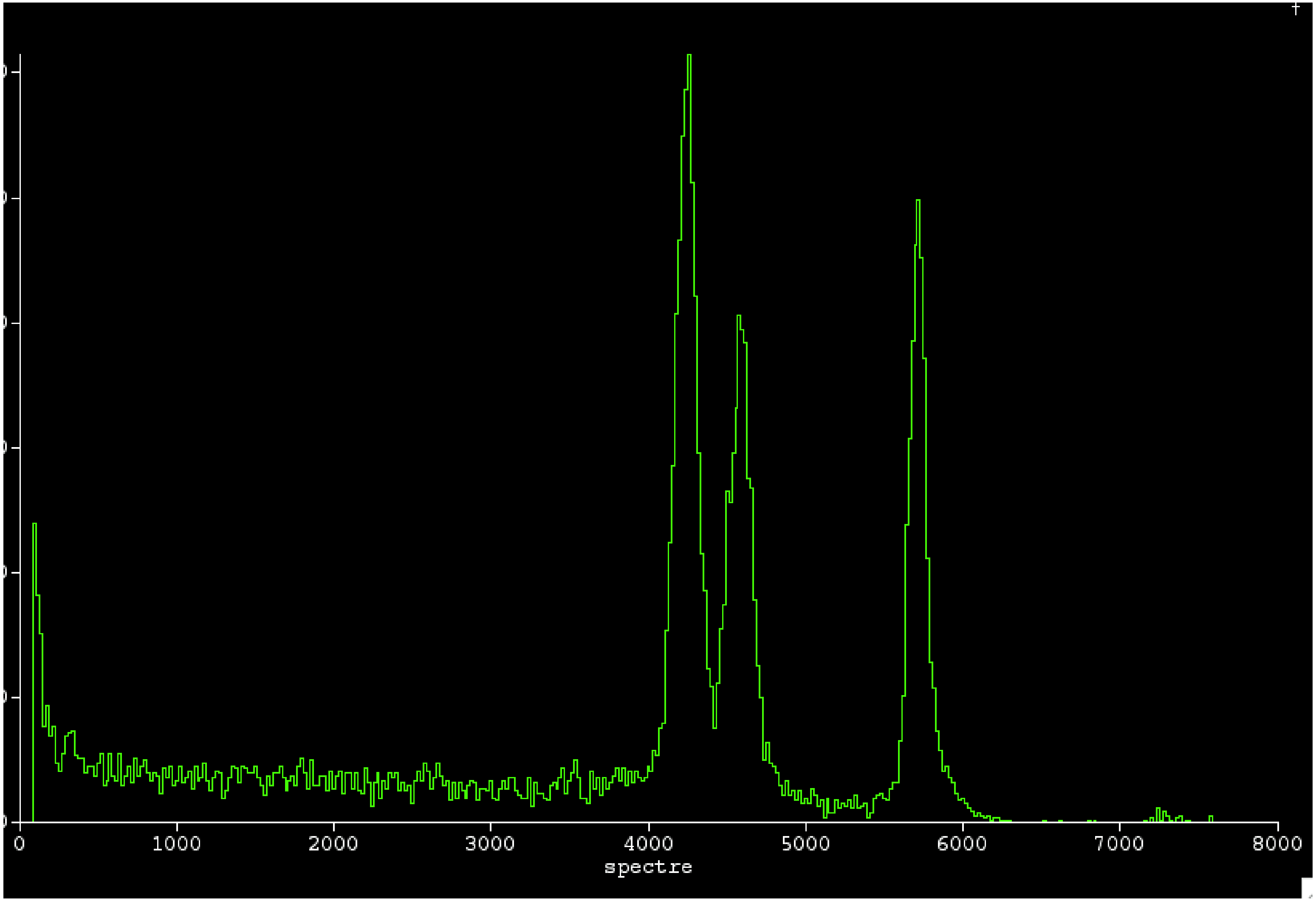
To be managed by an international scientific consortium and operated by students





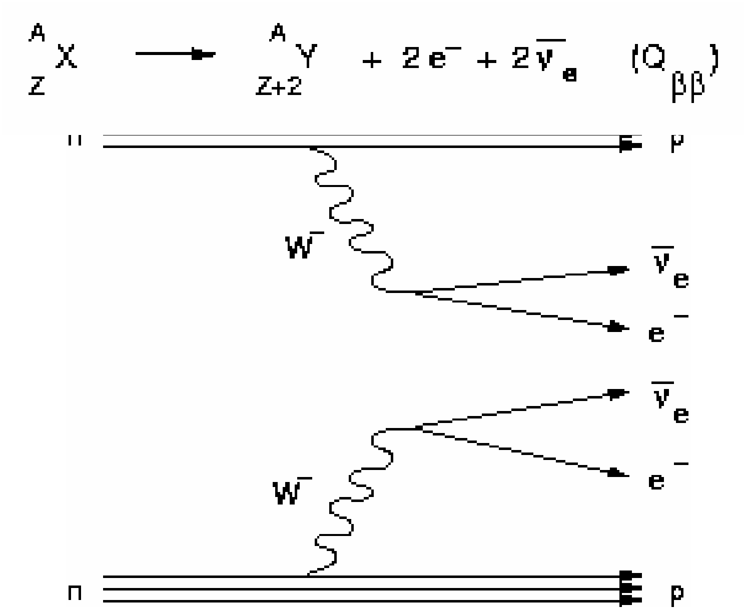
NEW Excellent energy resolution

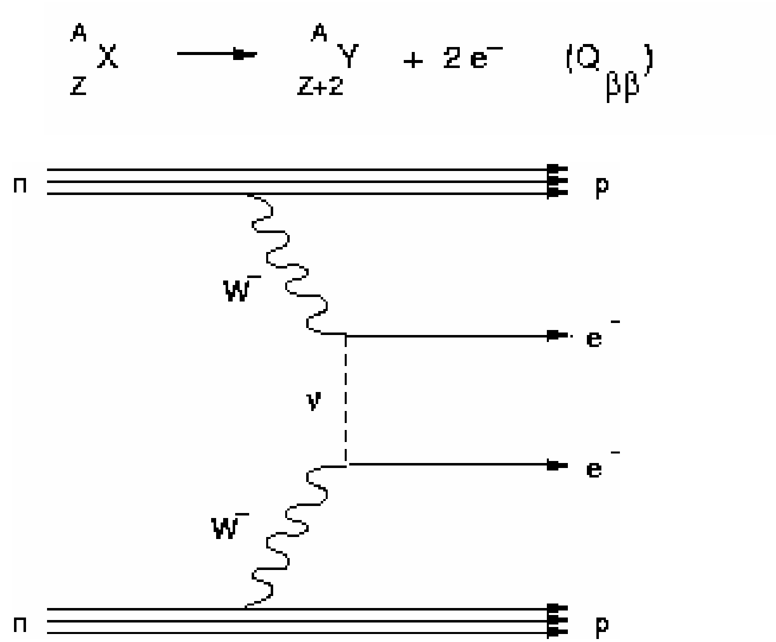
Measured Radon gas emission spectrum with spherical detector



Energy resolution under amplification: a world record !!

Double beta decay process





An observed “background” process and an important calibration tool

This process not yet observed
particle = antiparticle

$$\frac{1}{T_{\frac{1}{2}}} = G \times \|\mathrm{M}\|^2 \times m_{\bar{\nu}}{}^2$$

If 0-ν decays occur, then:

– Neutrino mass $\neq 0$ (now we know this!)

– Decay rate measures neutrino mass

– Neutrinos are Majorana particles

– Lepton number is not conserved

$$\frac{1}{T_{\frac{1}{2}}} = G \times \|M\|^2 \times m_{\bar{\nu}}{}^2$$

- Actual experiments are giving a limit of $m_\nu < .3$ eV

- To reach a sensitivity of $m_\nu = 10$ meV

→ Enriched target mass > 10,000 Kgr!!!

Double Beta TPC experiment using filled with ^{136}Xe gas

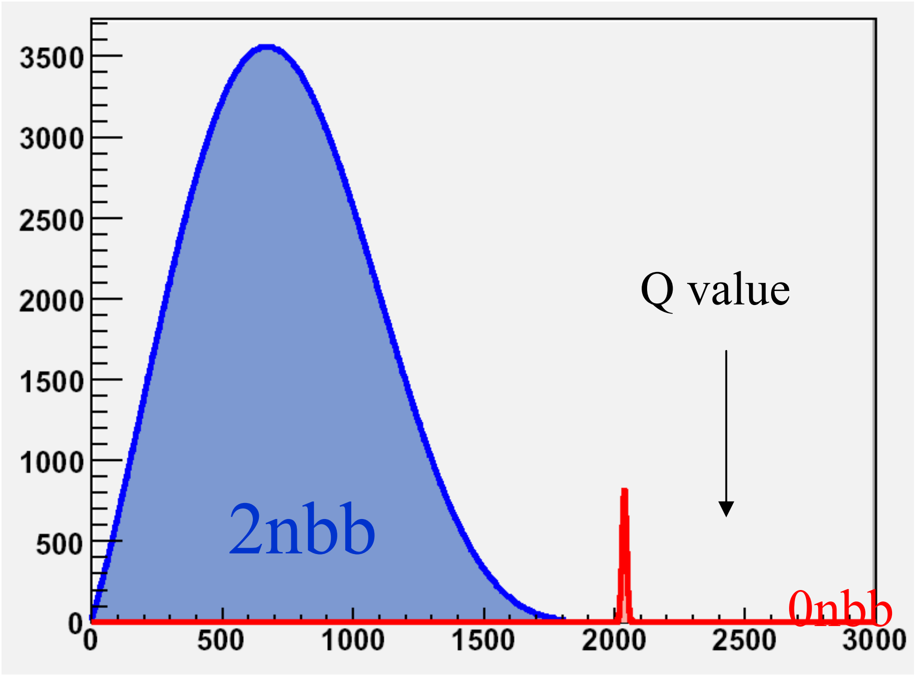
^{136}Xe: $Q_v = 2.48$ MeV

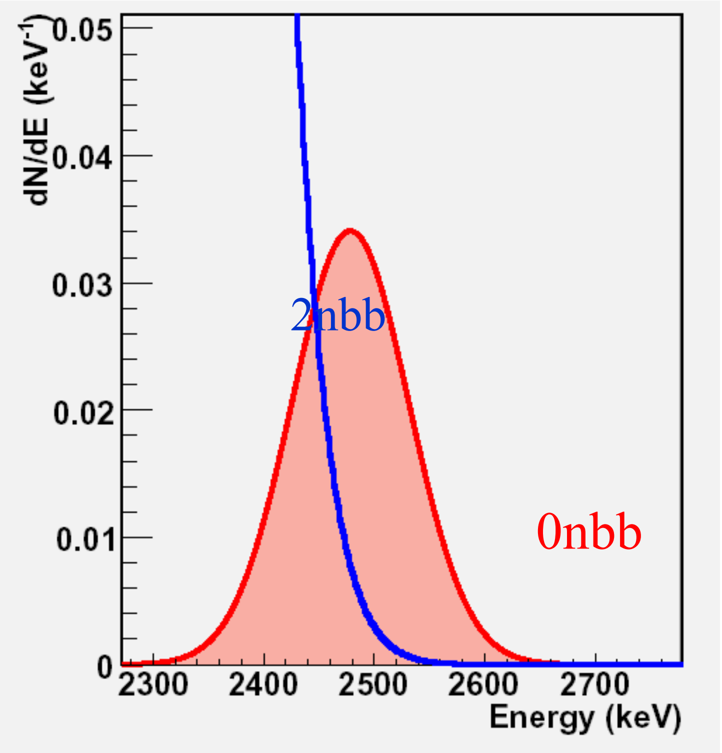
- xenon is relatively safe and easy to enrich
  - Natural abundance of ^{136}Xe is ~ 8%
  - EXO has 200 kg highly enriched in ^{136}Xe
- Two electron reconstruction through TPC

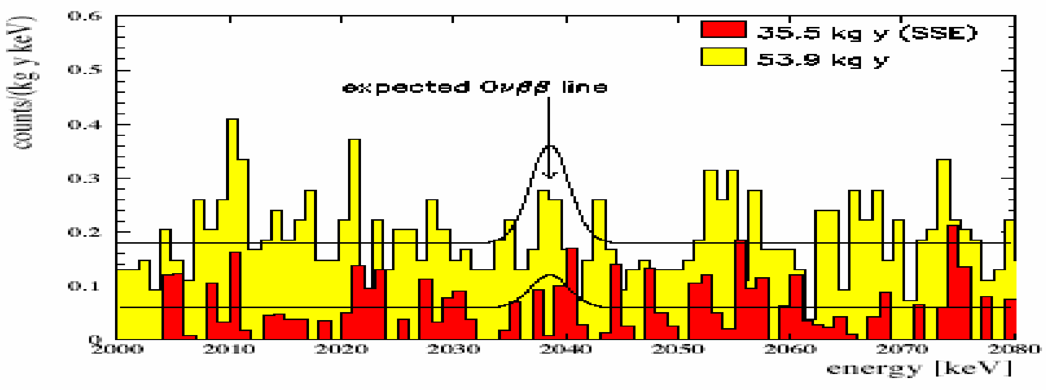
  → Good background rejection
- Good energy resolution is mandatory

Energy resolution very important. Only way to distinguish between both processes

- "Visible" energy (i.e. the 2 e^-) spectrum:

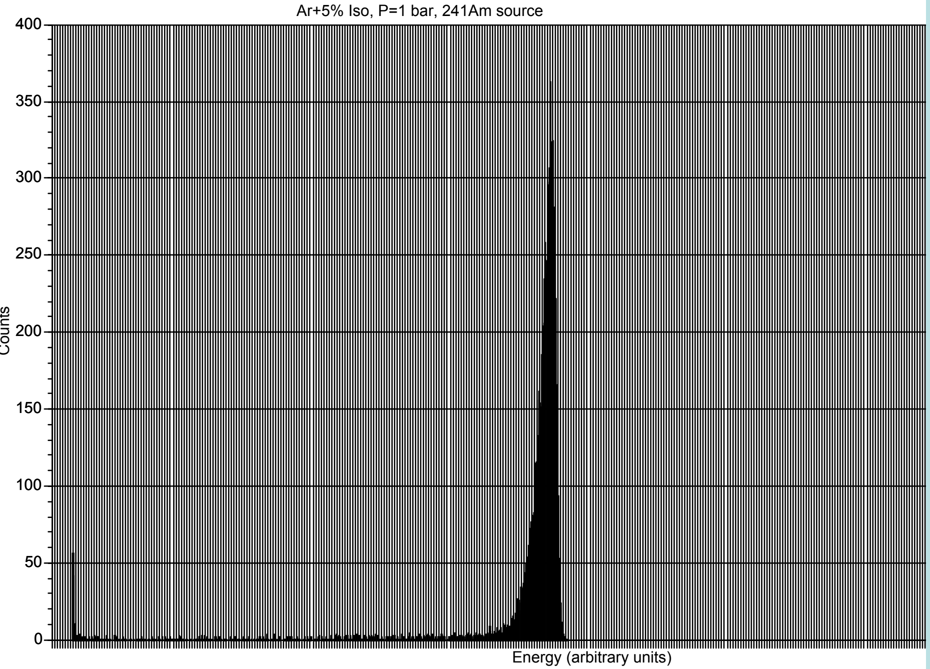






Spectra from Klapdor Kleingrothaus et. al.

Hunting the best resolution in gaseous detector



Results in Saclay

New micro-bulk micromegas and a small laboratory TPC

1.3 % with ^{241}Am
Promising to be improved

Collaboration : Saclay-Saragoza-Valencia- Barcelona, Ottawa

GOALS:

- **Improve energy resolution**
- **Get in high pressure Argon**
- **Get it in high pressure Xenon**

Preliminary conclusions:

A resolution of <1% could be reached by a gaseous TPC

Conclusions

- **Important impact of gaseous detectors in particle physics**
- **Novel MPGD detectors are promising**
- **Many applications: CAST, WIMP search, gamma ray polarization measurement,**
- **Low energy neutrino search with a spherical detector**
- **Virtue of Double beta decay TPC using enriched Xenon**