Trendy w technice i technologii detektorów promieniowania jonizującego

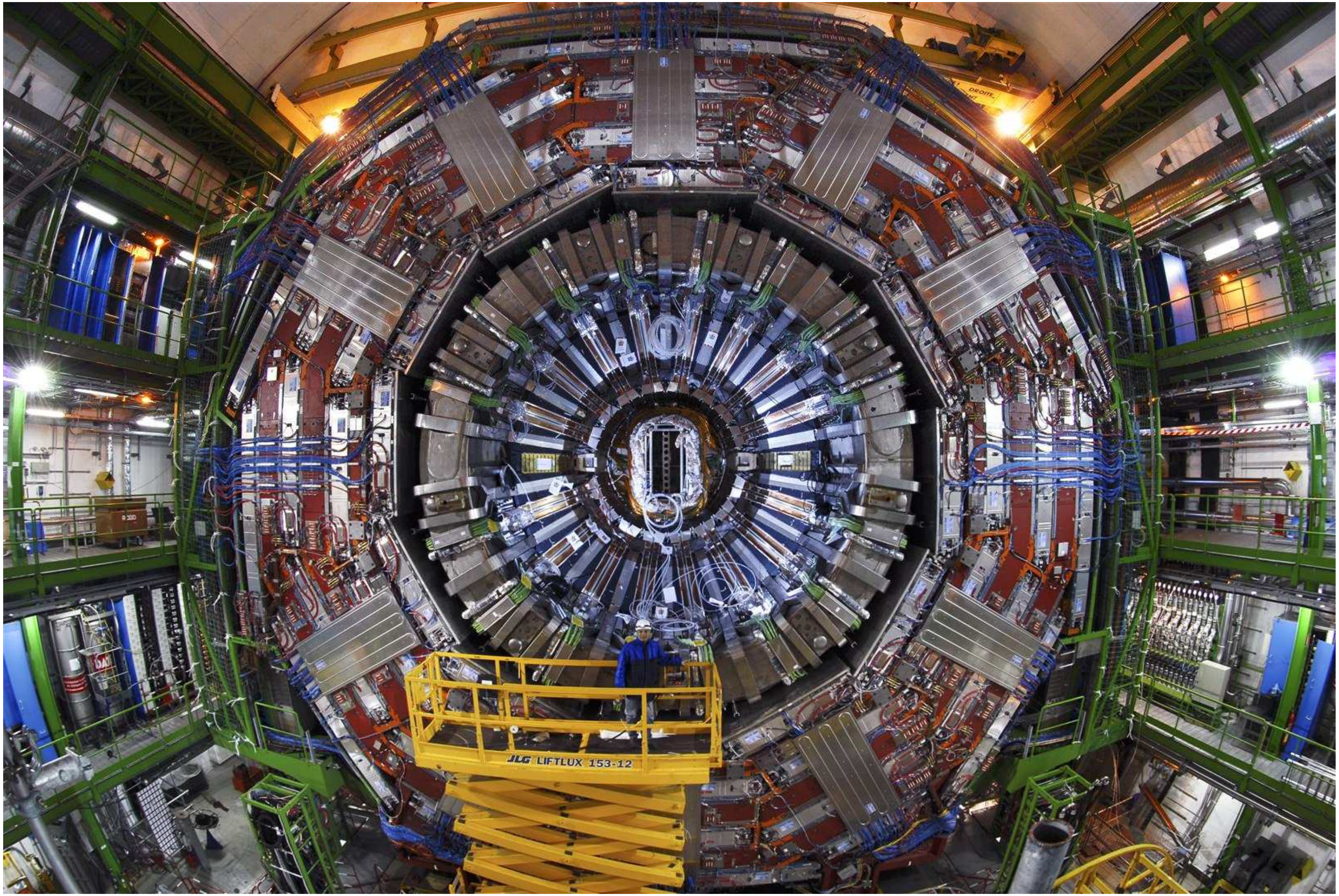
Odpryski z R&D doświadczalnej fizyki oddziaływań fundamentalnych

Detektory i elektronika odczytu:

- ✓ MicroPattern Gas Detectors (MPGD)
- ✓ Mikroelektronika
- ✓ Detektory fotonów
- ✓ Szybkie przetwarzanie danych (FPGA)

Wojciech DOMINIK

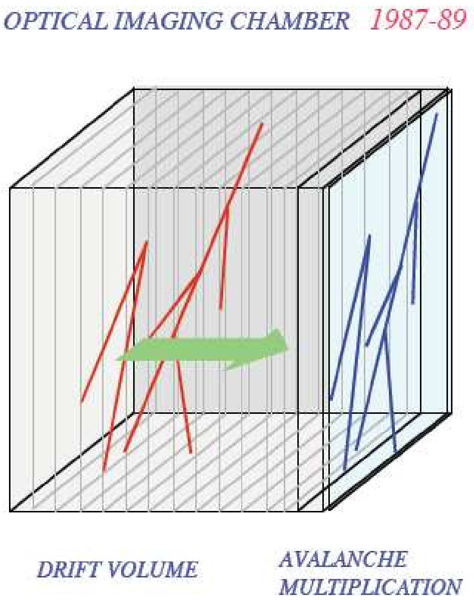
Seminarium ZSJ IFD, 19 listopada 2008

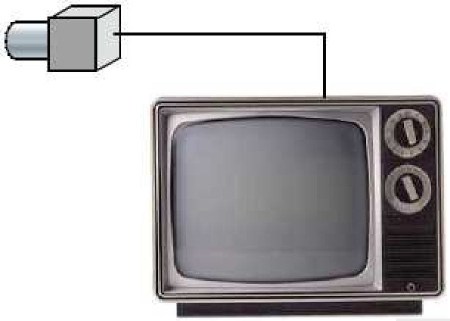


View of CMS detector at end of 2007

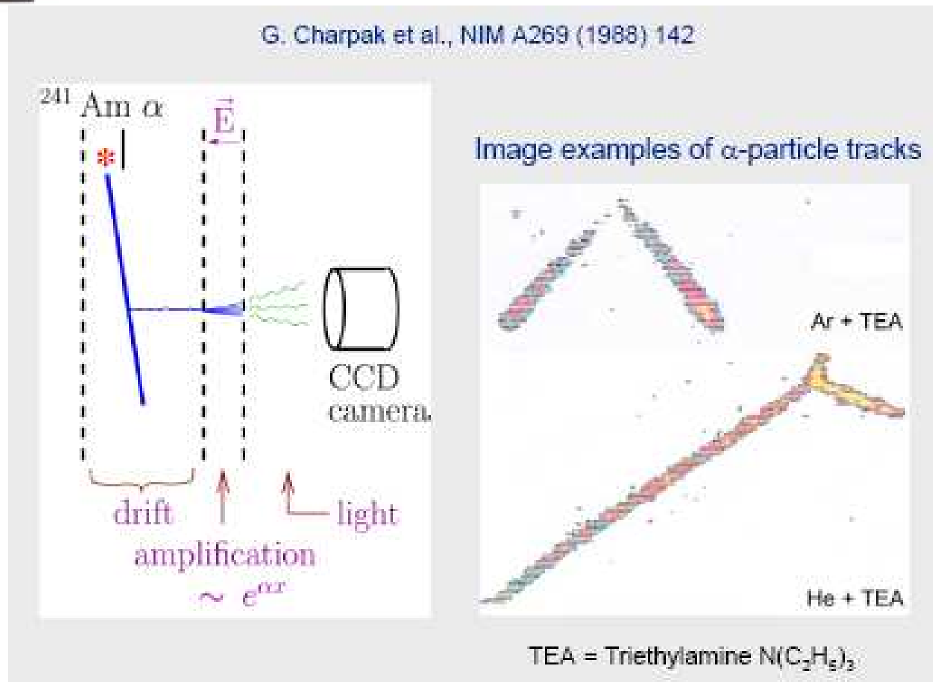
Gas Imaging Camber with Optical Readout 1986-1990

Precursor of micropattern gas detectors?

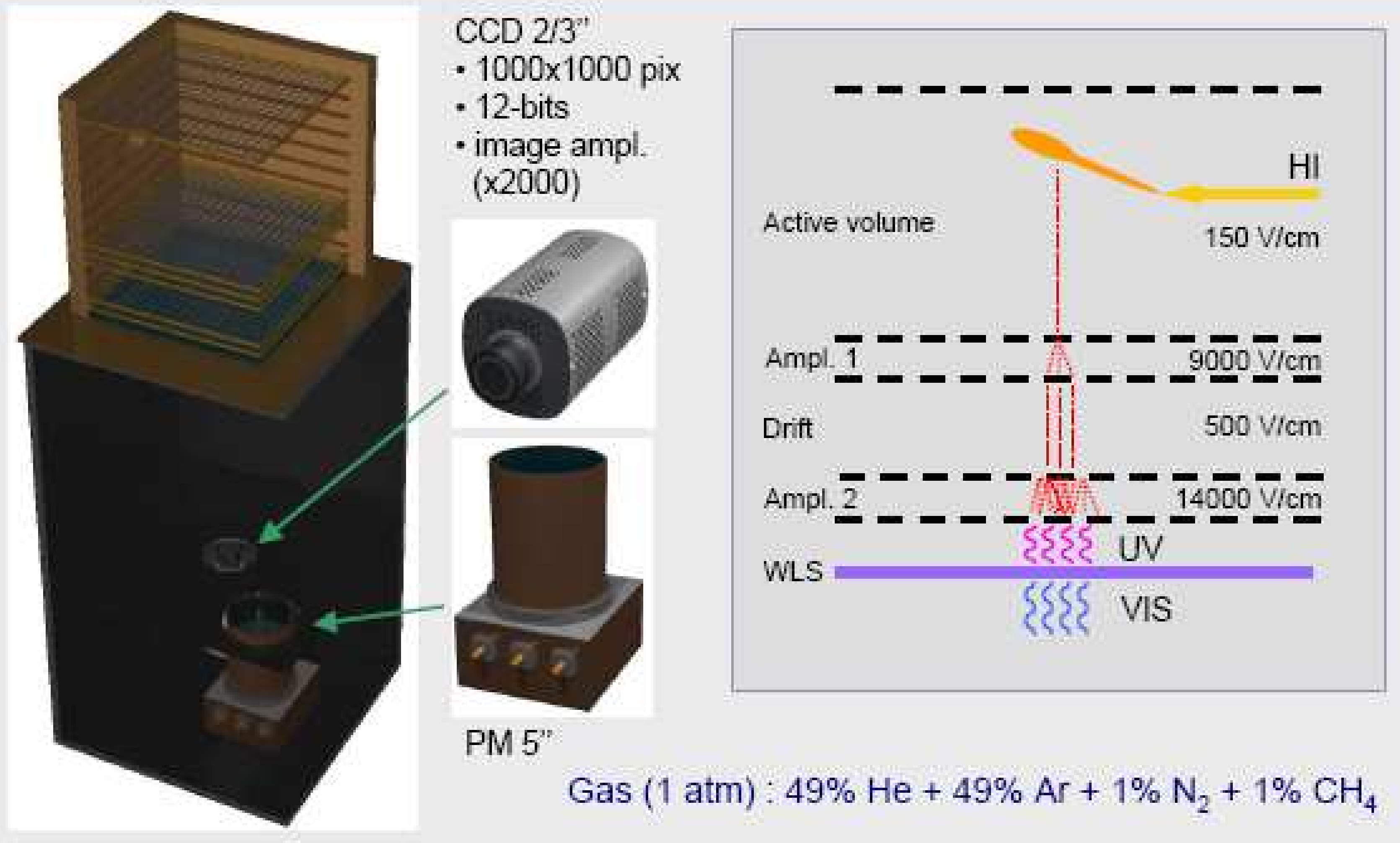




G. Charpak, J.P. Fabre, F. Sauli, M. Suzuki & W. Dominik, Nucl. Instr. and Meth. A258(1987)177

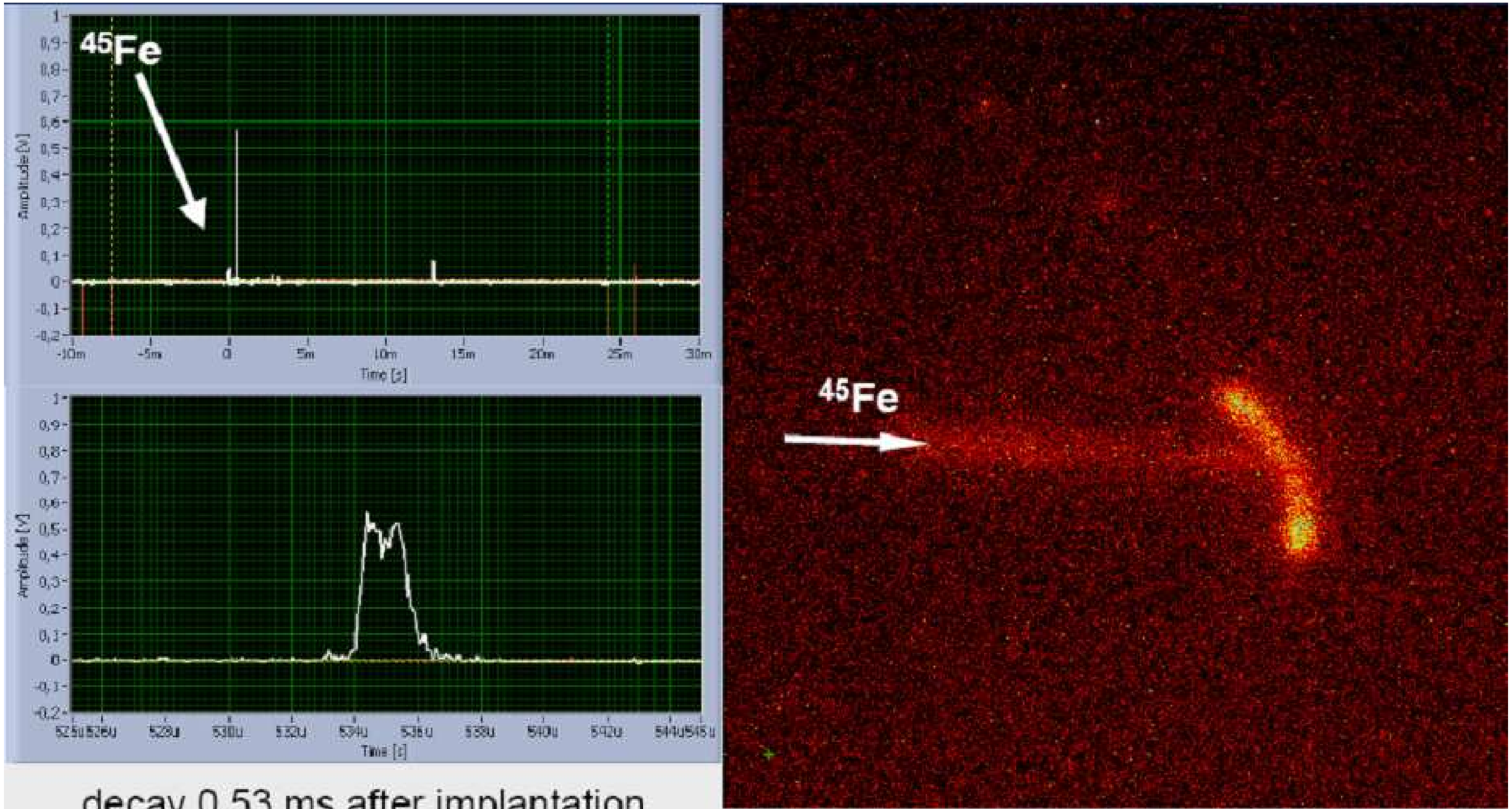


Optical Time Projection Chamber



K. Miernik et al, Nucl. Instr. Meth. A581(2007)194

Decay of ^{45}Fe in He +Ar (2:1)

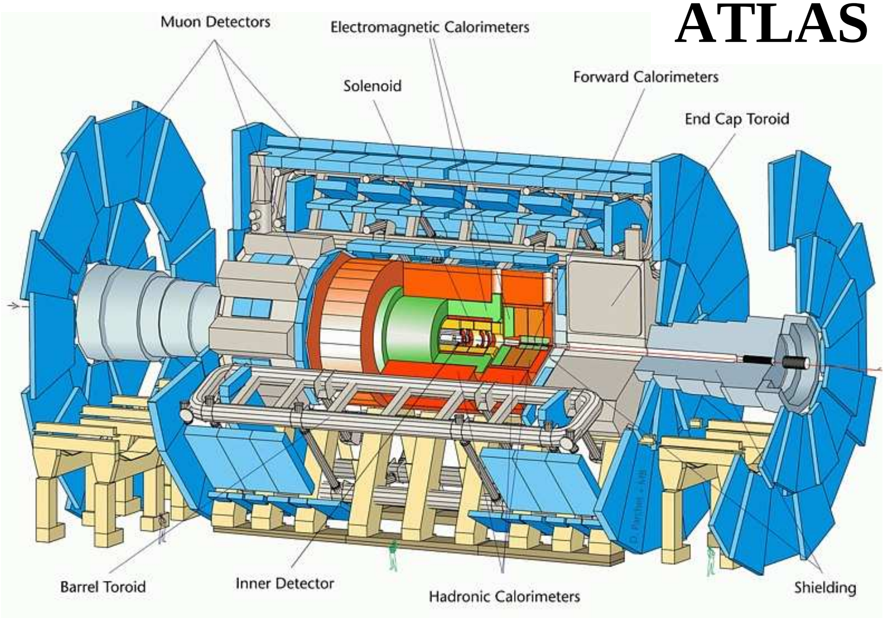


decay 0.53 ms after implantation

K. Miernik et al, Phys. Rev. Letters 99(2007),1-4

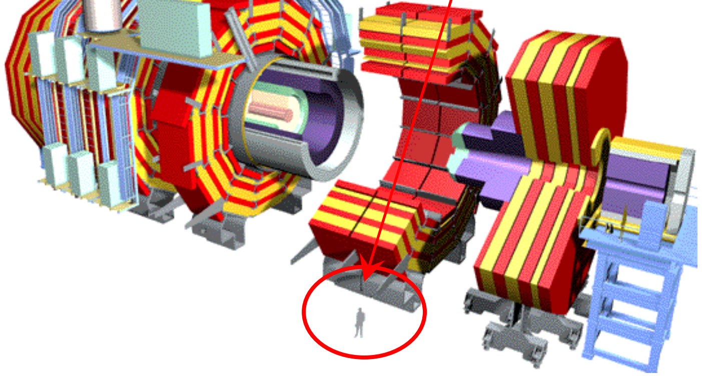
LHC experiments

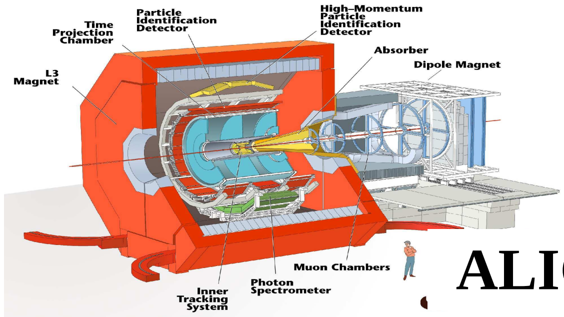
ATLAS



standard sized scientist

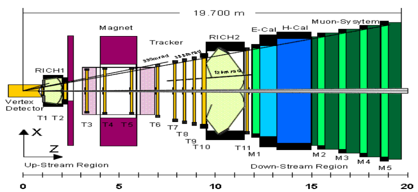
CMS



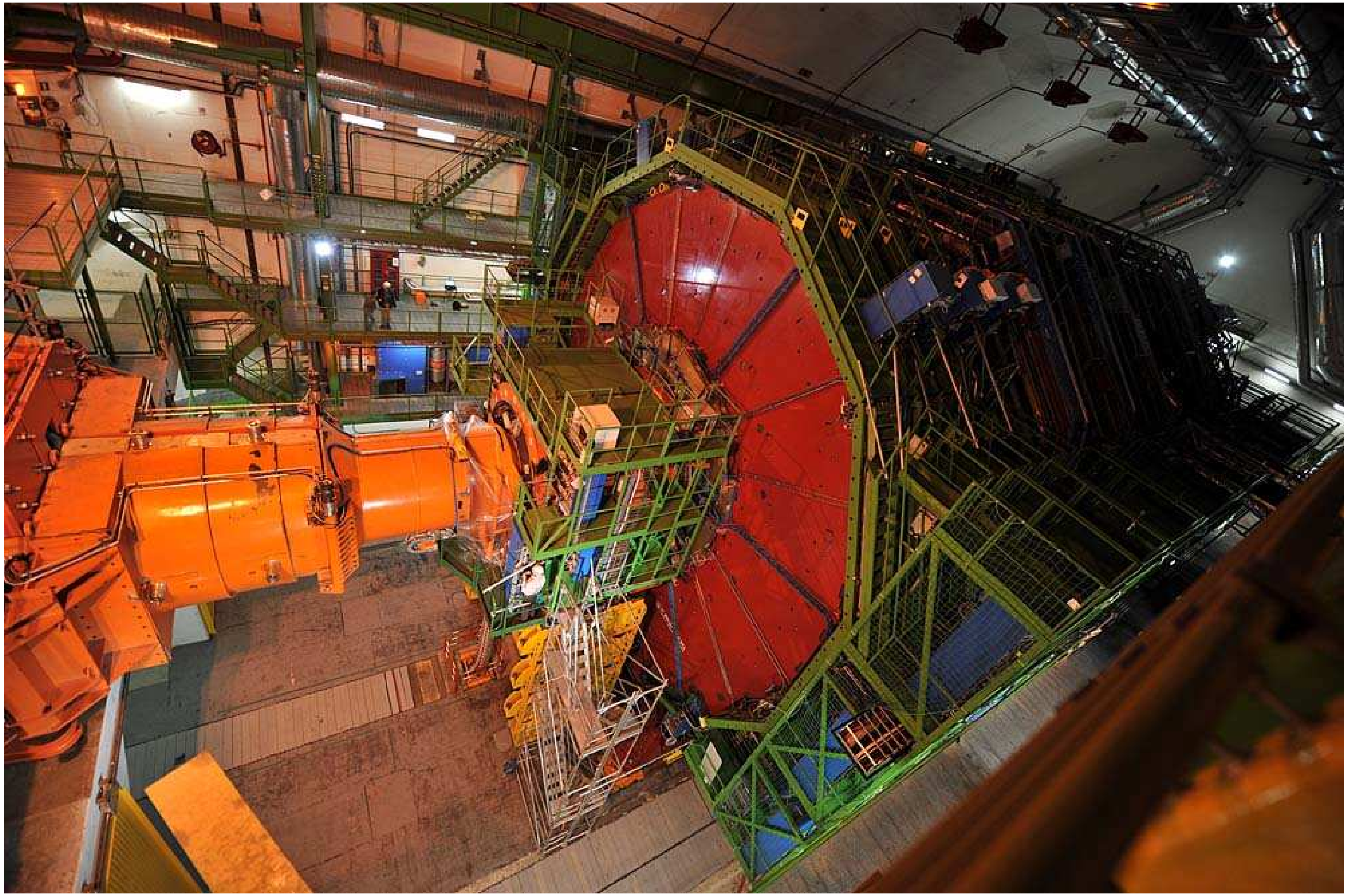


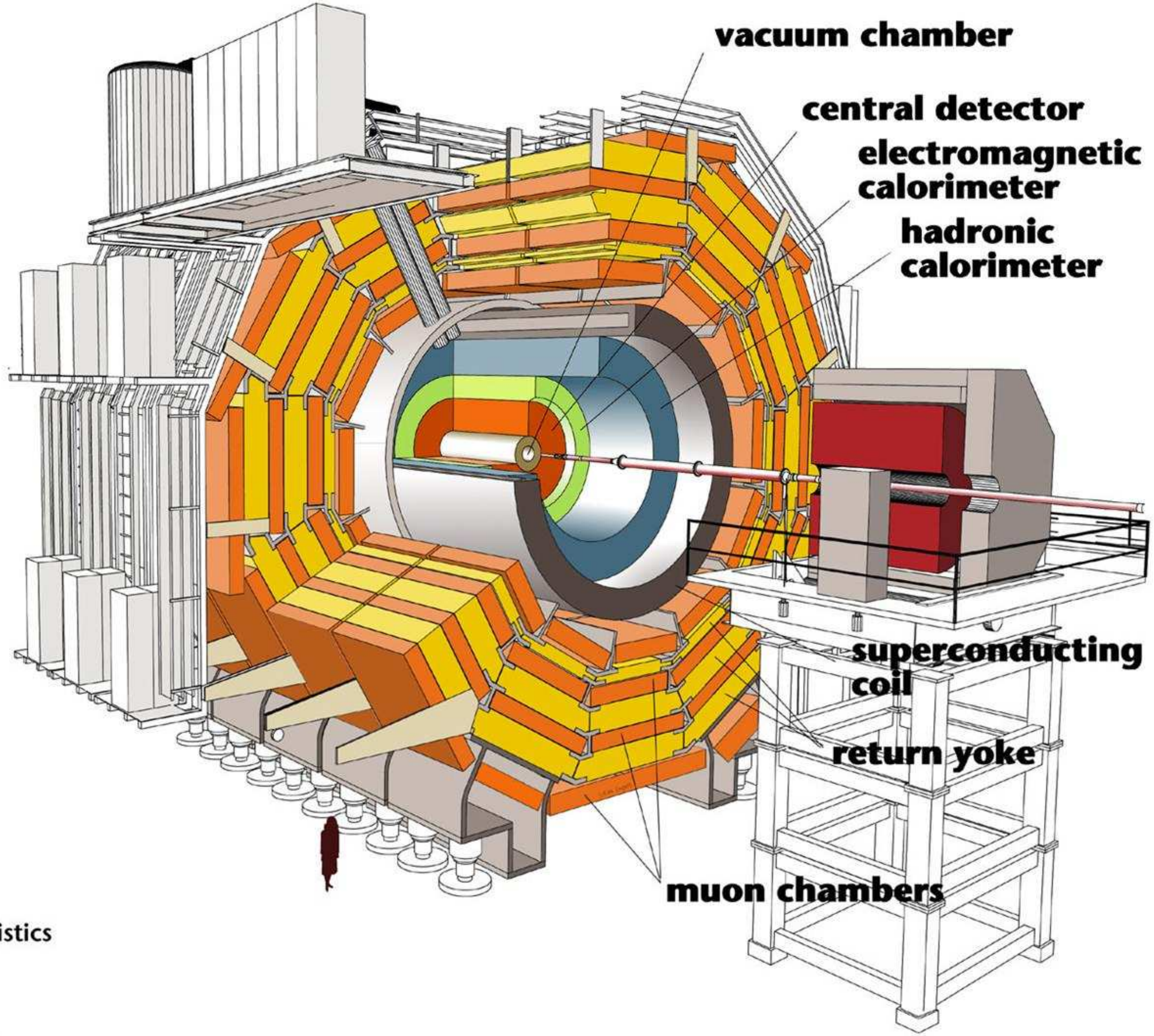
ALICE

LHC*b*



CMS - Detektor zamknięty (09.2008)



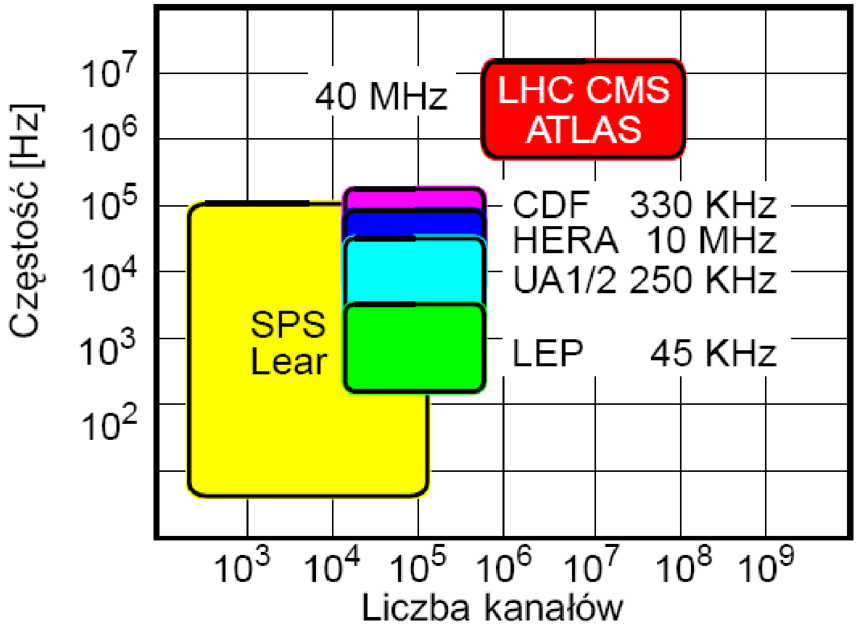


Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

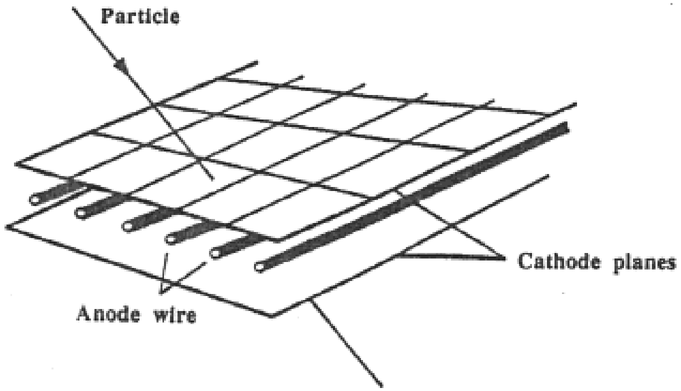
CMS a inne eksperymenty

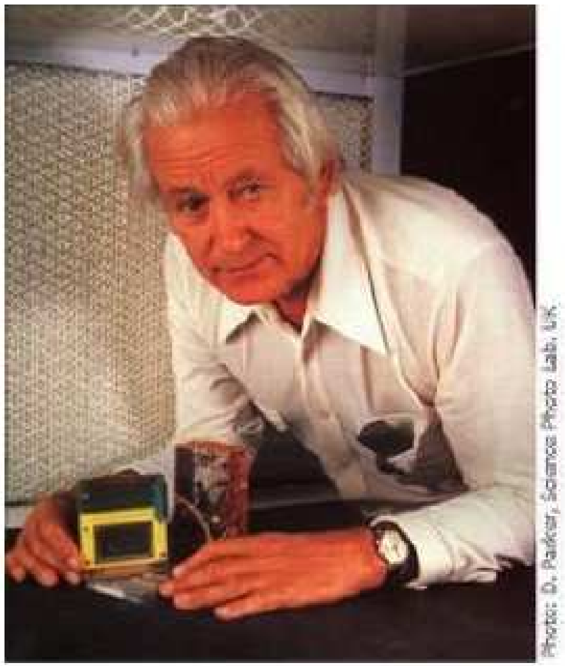
detektor	l. kanałów	zajętość	przypadek
mozaikowy	80 000 000	0.01 %	100 kB
mikropaskowy	16 000 000	3 %	700 kB
wczesnych kaskad	512 000	10 %	50 kB
kalorymetry	125 000	5 %	50 kB
mionowy	1 000 000	0.1 %	10 kB
całkowita wielkość przypadku			1 MB



Strumień danych kontrolnych CMS (temperatura, napięcie itp.) jest porównywalny ze strumieniem wszystkich danych jednego ze współczesnych eksperymentów LEP (100 kB/s)

MultiWire Proportional Chamber (Charpak 1968)





Georges Charpak
Nobel Prize in Physics 1992

NUCLEAR INSTRUMENTS AND METHODS 62 (1968) 262–268; © NORTH-HOLLAND PUBLISHING CO.

THE USE OF MULTIWIRE PROPORTIONAL COUNTERS TO SELECT AND LOCALIZE CHARGED PARTICLES

G. CHARPAK, R. BOUCLIER, T. BRESSANI, J. FAVIER and Č. ZUPANČIČ

CERN, Geneva, Switzerland

Received 27 February 1968

Properties of chambers made of planes of independent wires placed between two plane electrodes have been investigated. A direct voltage is applied to the wires. It has been checked that each wire works as an independent proportional counter down to separations of 0.1 cm between wires.

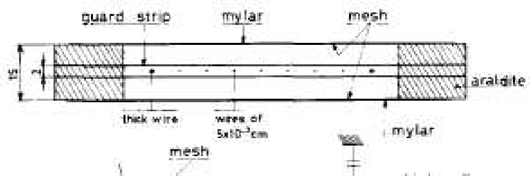
Counting rates of 10^5/wire are easily reached; time resolutions of the order of 100 nsec have been obtained in some gases; it is possible to measure the position of the tracks between the wires using the time delay of the pulses; energy resolution comparable to the one obtained with the best cylindrical chambers is observed; the chambers operate in strong magnetic fields.

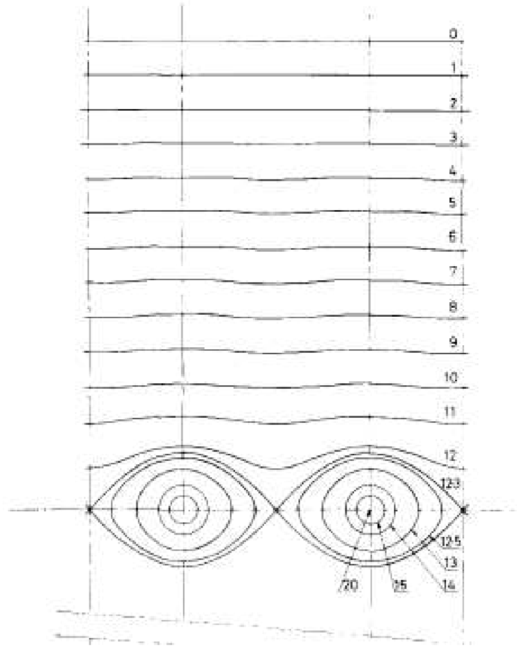
1. Introduction

Proportional counters with electrodes consisting of many parallel wires connected in parallel have been used for some years, for special applications. We have investigated the properties of chambers made up of a plane of independent wires placed between two plane electrodes. Our observations show that such chambers offer properties that can make them more advantageous than wire chambers or scintillation hodoscopes for many applications.

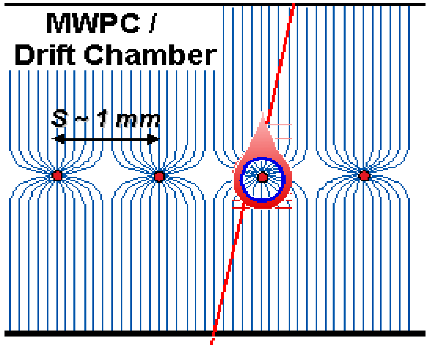
2. Construction

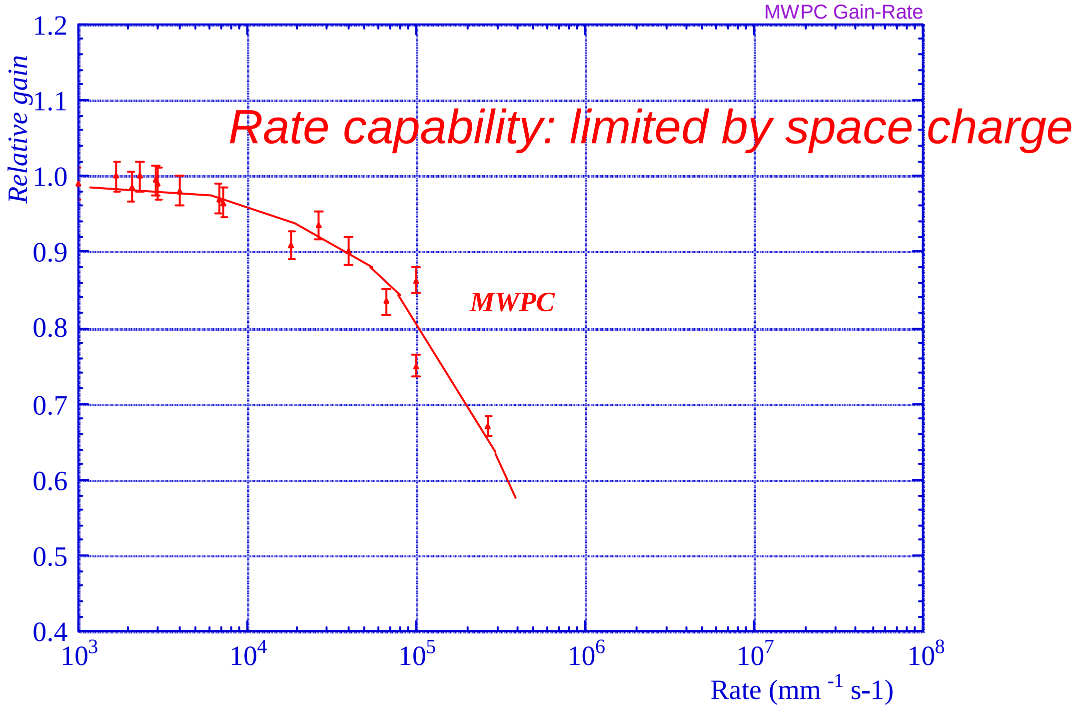
Wires of stainless steel, 4×10^{-3} cm in diameter, are stretched between two planes of stainless-steel mesh, made from wires of 5×10^{-3} cm diameter, 5×10^{-2} cm apart. The distance between the mesh and the wires is 0.75 cm. We studied the properties of chambers with wire separation $a = 0.1$, 0.2, 0.3 and 1.0 cm. A strip of metal placed at 0.1 cm from the wires, at the same potential (fig. 1), plays the same role as the guard rings in cylindrical proportional chambers. It protects the wires against breakdown along the dielectrics. It is

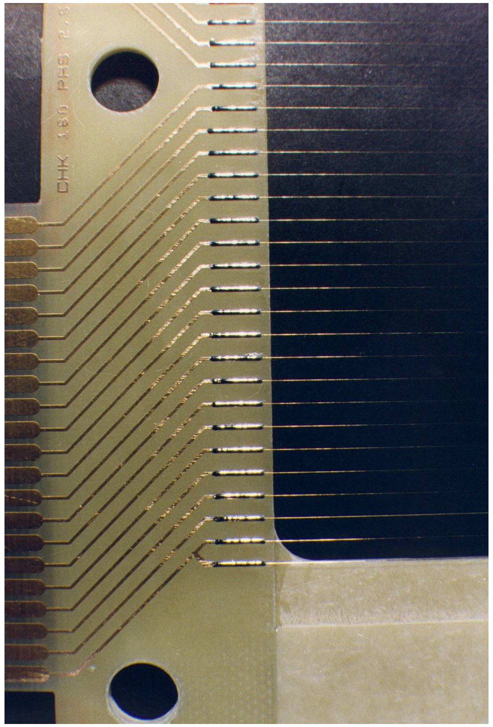




MWPC LIMITATIONS





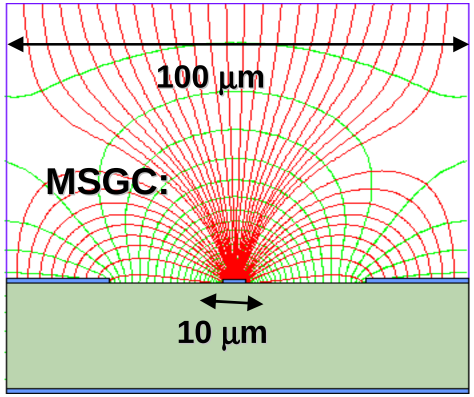


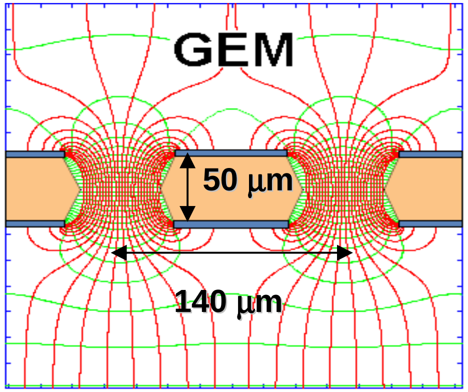
Wire spacing 1 -2 mm

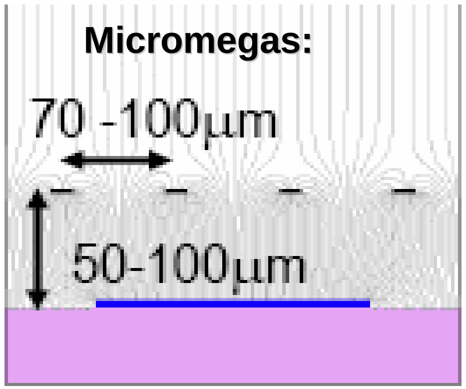
Drift Chamber at the Musée des Arts et Métiers in Paris - 2008

New developments in Gas Detectors

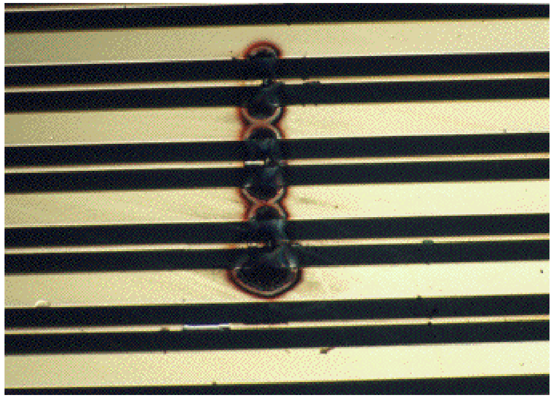
LHC experiments driven: Challenges of Large Systems







1988



DEAD !

Micro-Pattern Gas Detectors (GEM, Micromegas)

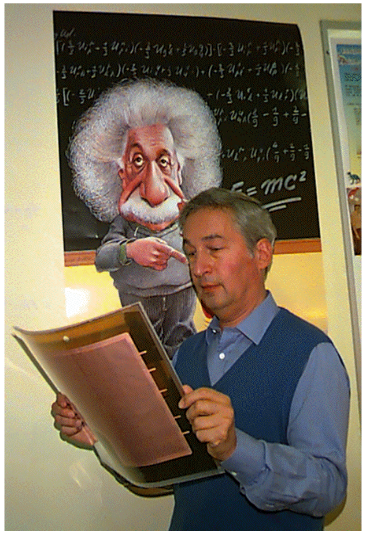
- **High Rate Tracking and Triggering**
- **Time Projection Chamber Readout**

Pixel Readout for Micro-Pattern Gas Detectors

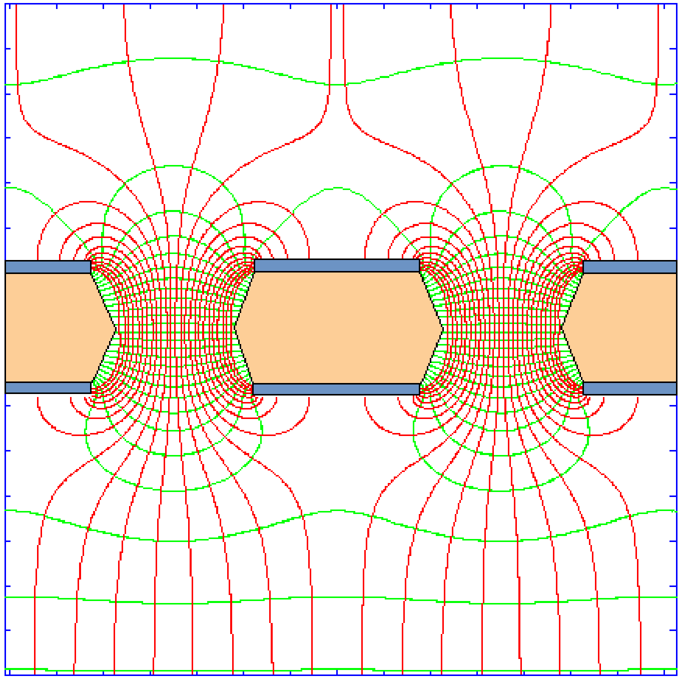
None of them is used by the LHC large experiments !

Gas Electron Multiplier (GEM) foils

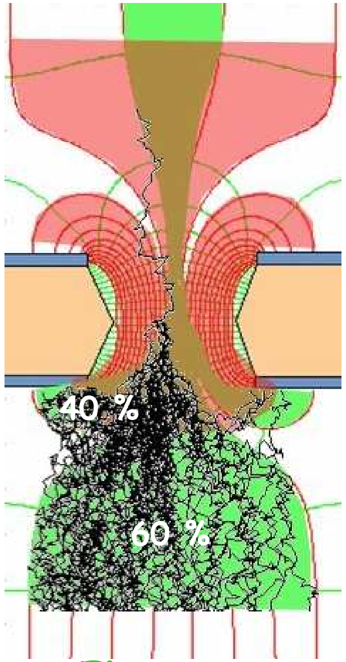
(Fabio Sauli 1995)



- Thin double-sided metal-coated polymer foil chemically pierced by a high density of holes.
- On application of a voltage gradient local dipoles created in an uniform electric field.



F. Sauli, Nucl. Instrum. Methods A386(1997)531



GEM Manufacturing

50 μm Kapton
5 μm Cu both sides

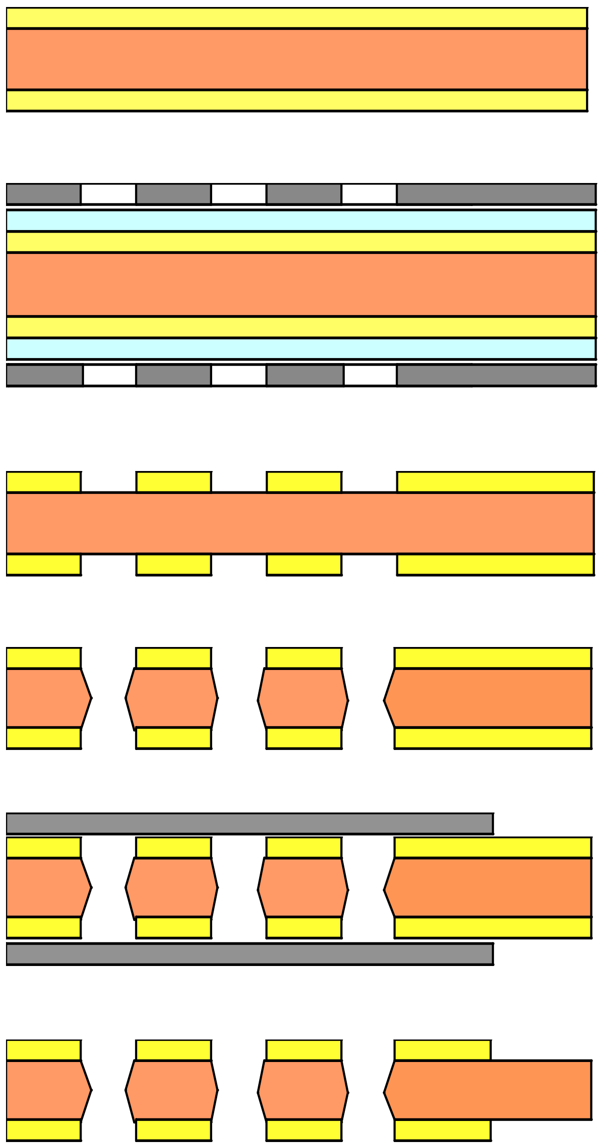
Photoresist coating, masking and exposure to UV light

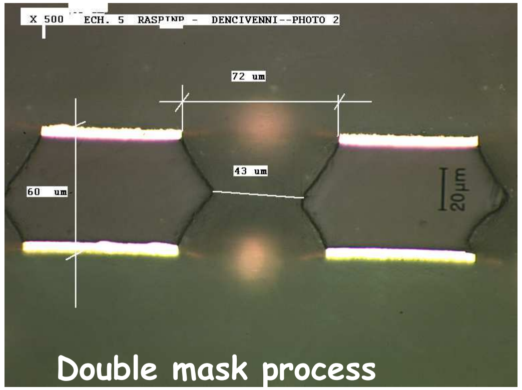
Metal etching

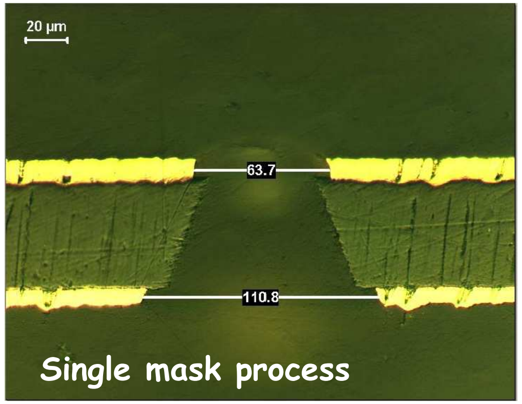
Kapton etching

Second masking

Metal etching and cleaning







Today:

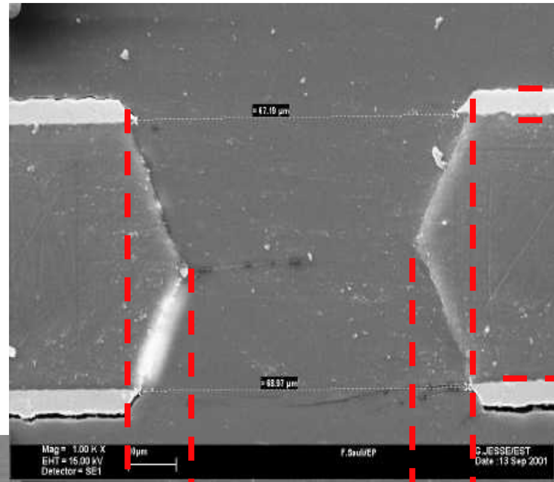
Maximum size ~ 30 *30 cm^2

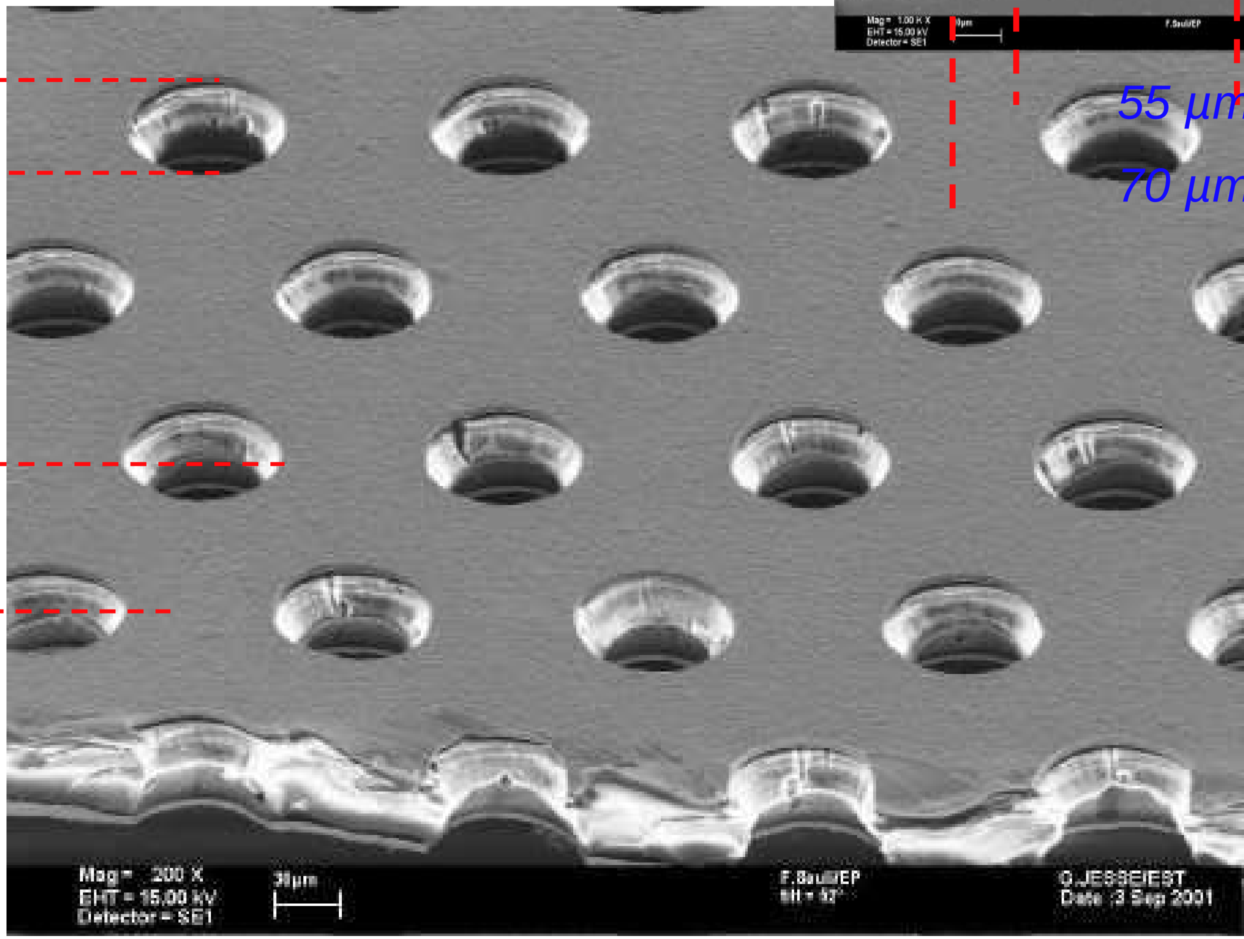
Technology developed at CERN by Rui De Oliveira

GEM: Gas Electron Multiplier

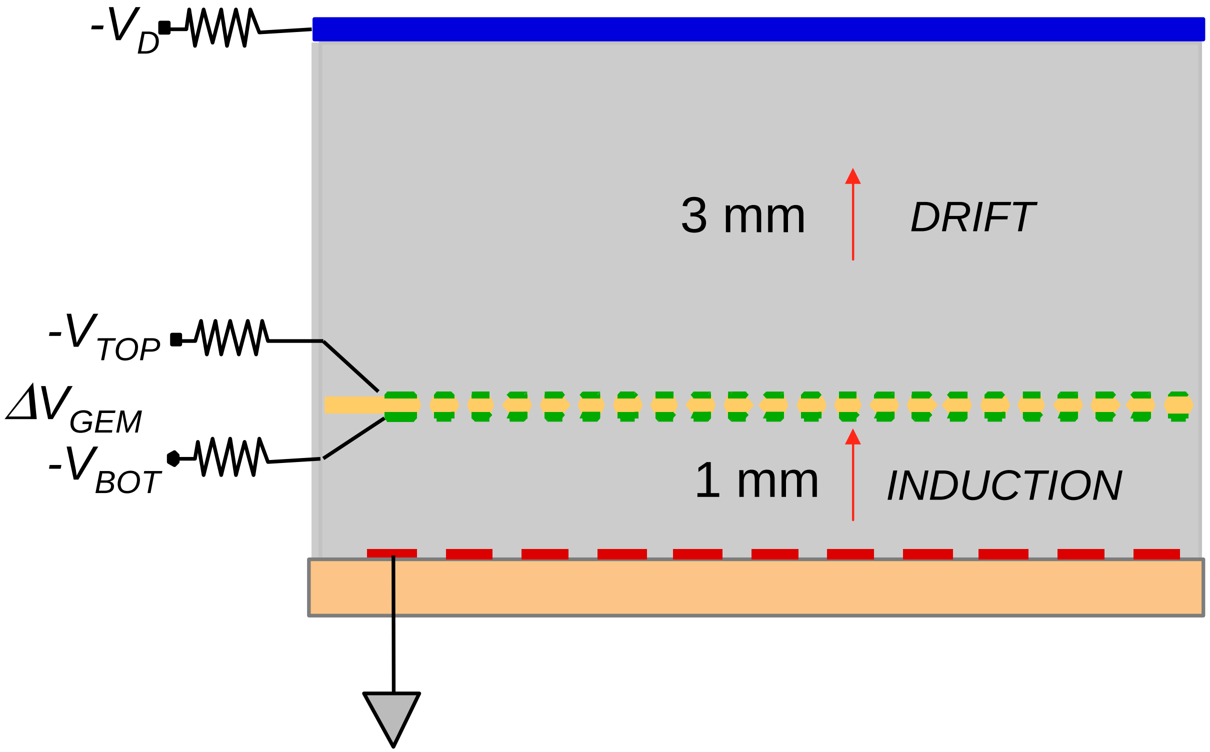
High density of holes (50-100/mm^2)

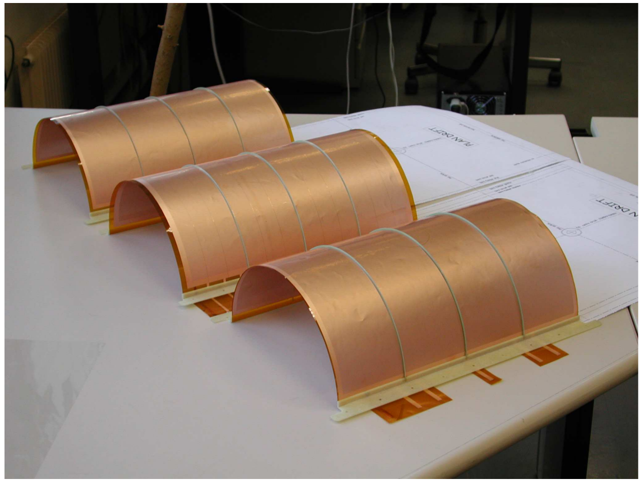
Typical geometry: 5 µm Cu on 50 µm kapton
70 µm holes
140 µm pitch





BASIC GEM DETECTOR





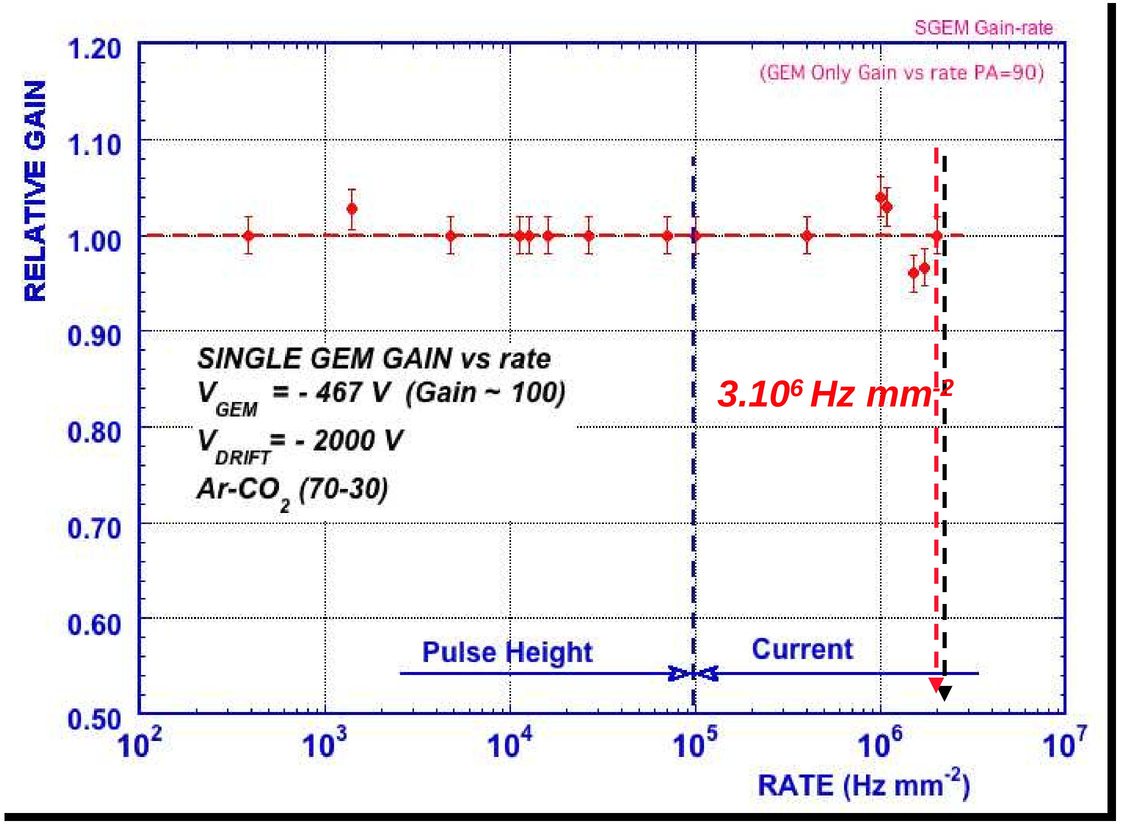
Advantages:

- ❑ Freedom in shape of the detector (including non-planar)
- ❑ Readout separated from multiplying electrodes
- ❑ Multiple cascaded structures possible (large gains)

GEM DETECTORS

~ 5,000 INDEPENDENT PROPORTIONAL COUNTERS / cm^2 !!!

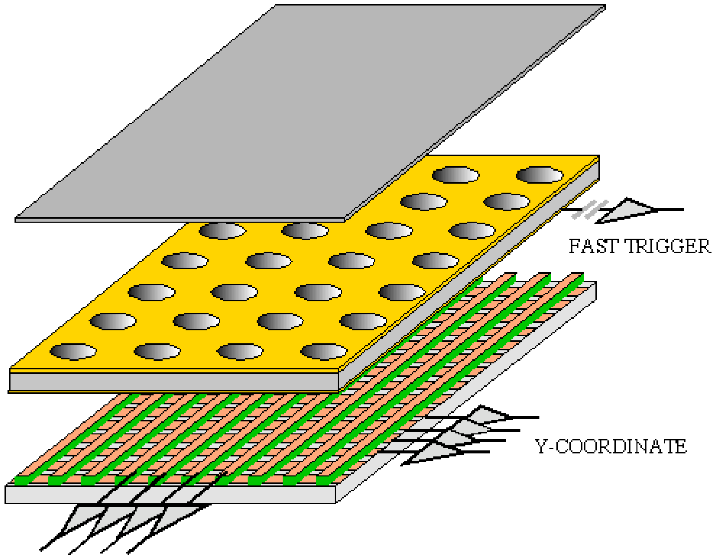
VERY HIGH RATE CAPABILITY:

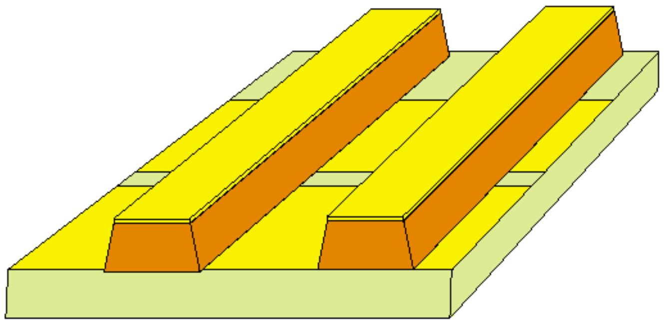


C. Büttner et al, Nucl. Instr. and Meth. A409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A438(1999)376

Two-Dimensional signal readout

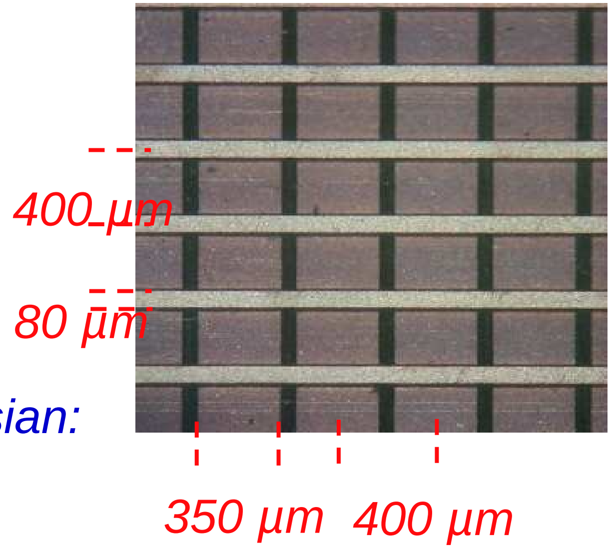
Electrons collected on patterned readout boards



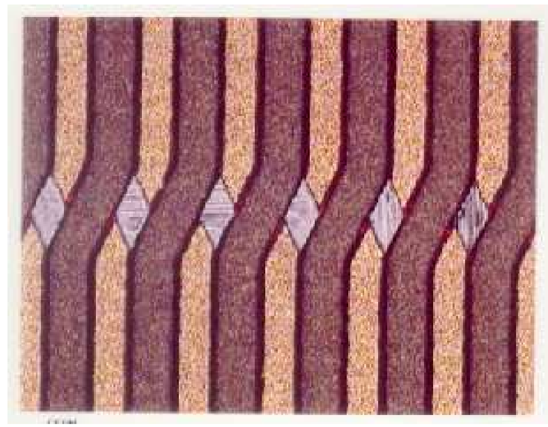


C. Altumbas et al, NIM A490(2002)177

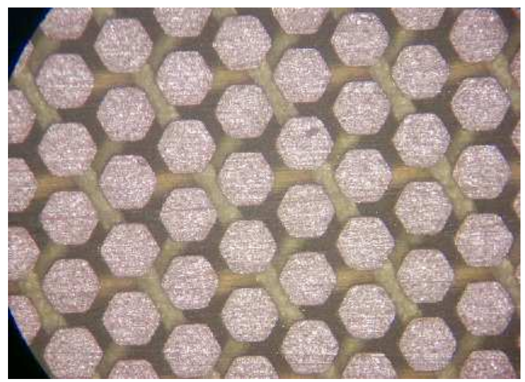
Cartesian:



Small angle:



Pads:

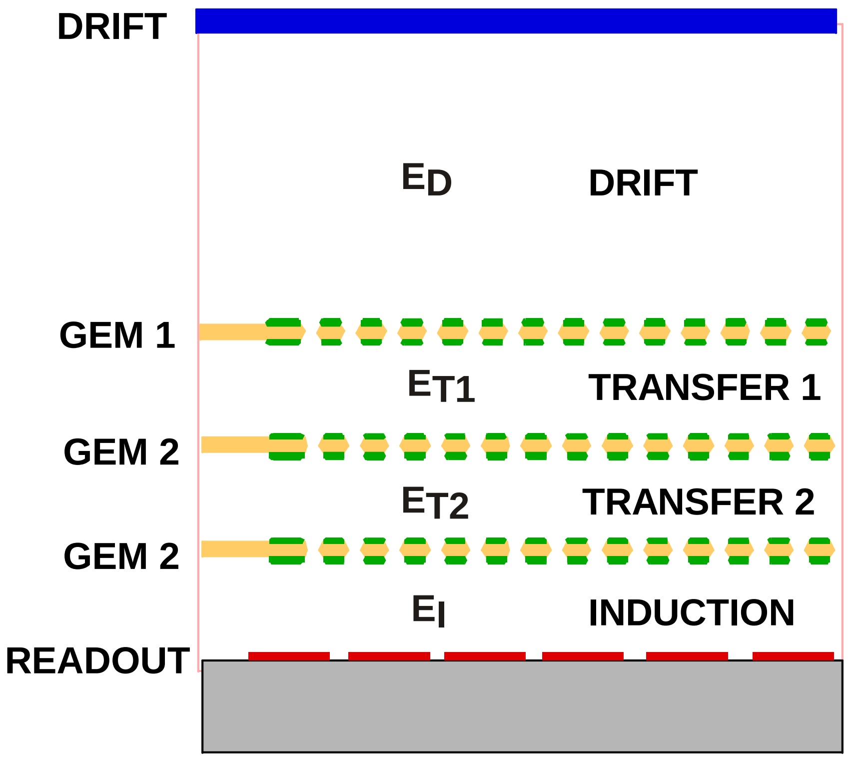


A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

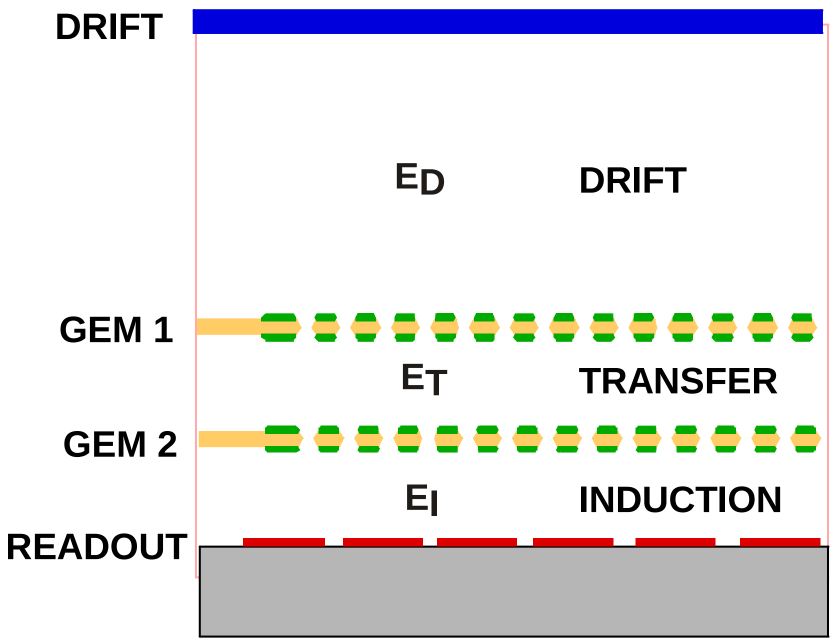
MULTI-GEM DETECTORS

Cascaded GEMs: larger gains, safer operation, larger dynamic range

Triple GEM (TGEM)



Double GEM (DGEM)

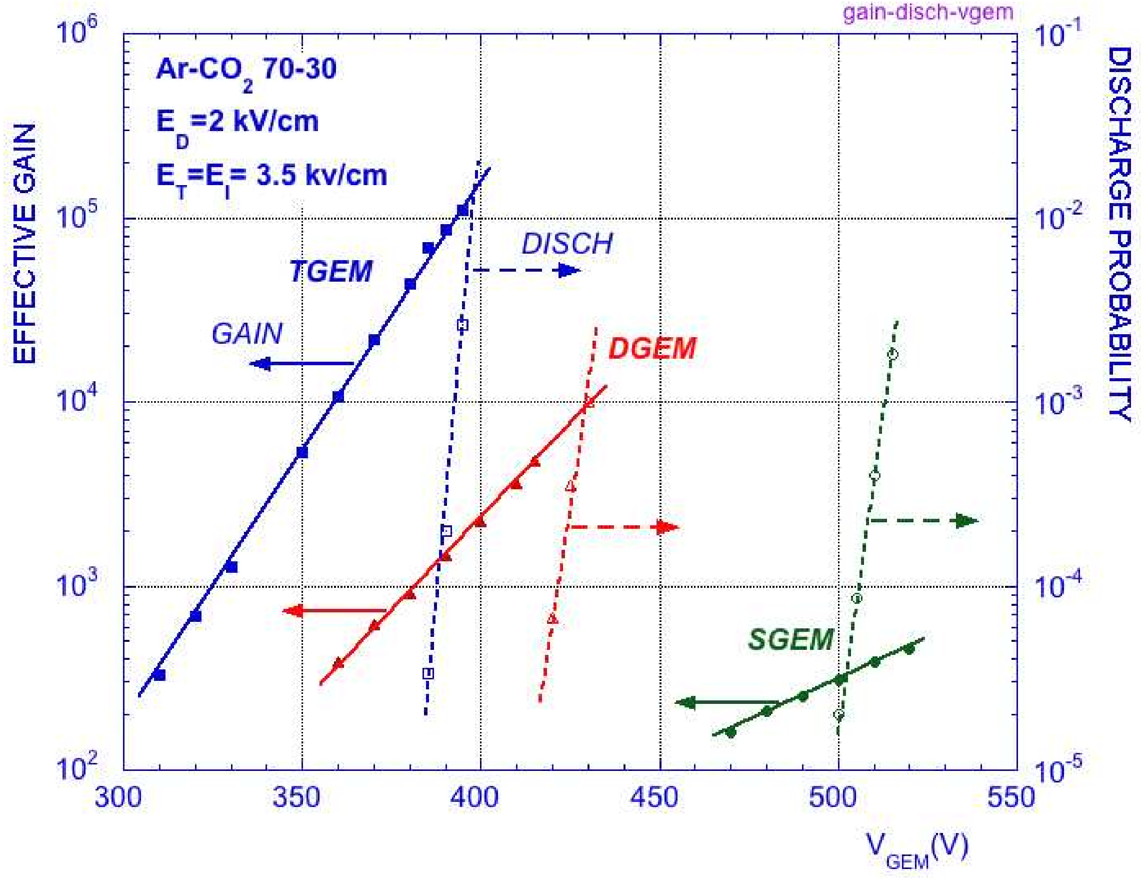


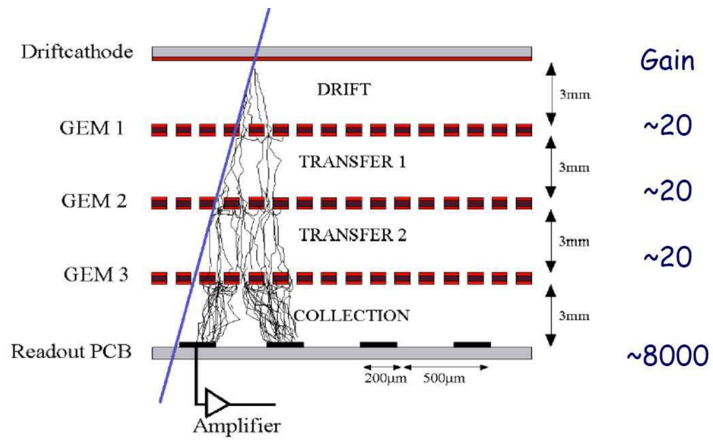
C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

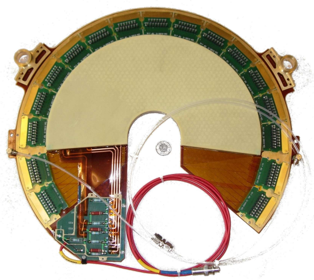
Multi-GEM Detectors

Discharge Probability on Exposure to 5 MeV Alphas

Multiple structures provide equal gain at lower voltage.
Discharge probability on exposure to α particles is strongly reduced.





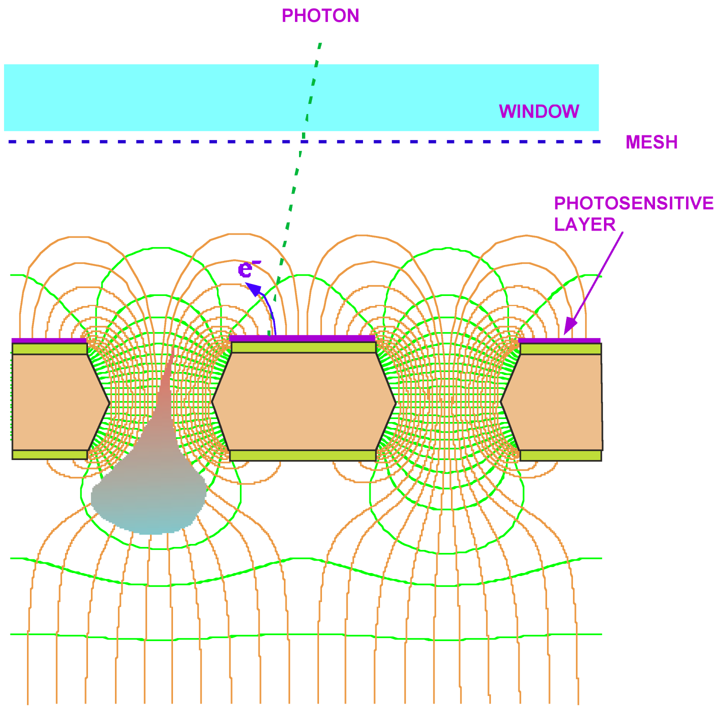


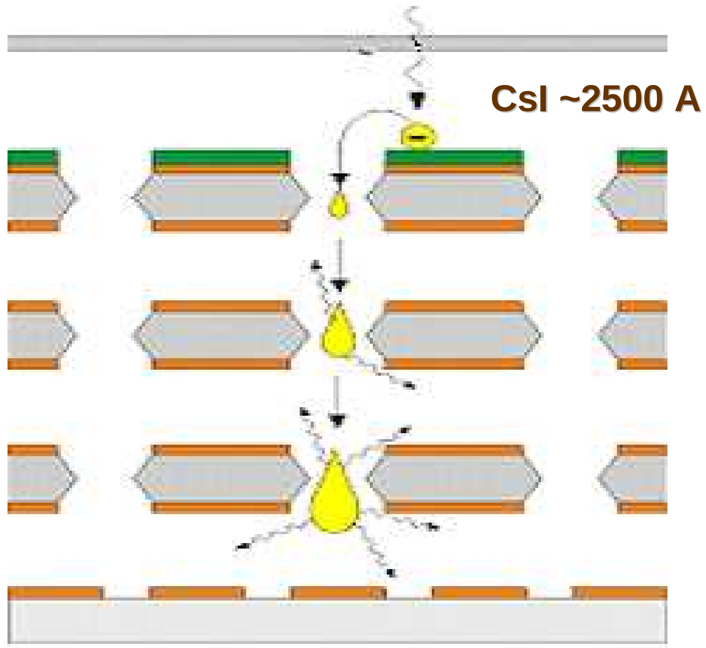
S. Bachmann et al Nucl. Instr. and Meth. A479(2002)294

UV PHOTON DETECTION WITH GEM

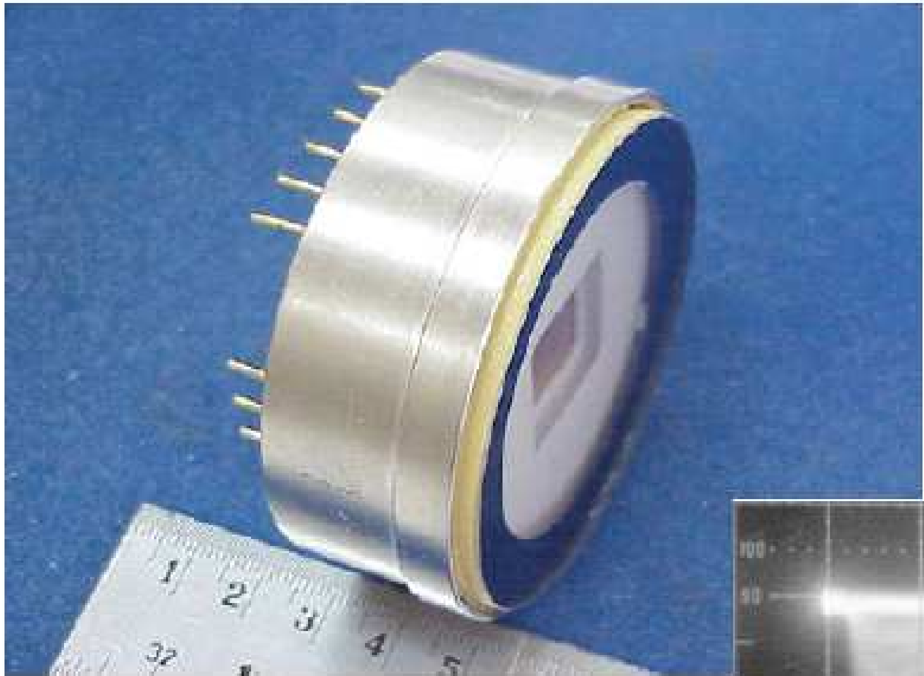
Reflective photocathode:

Smaller surface than semitransparent
Higher quantum efficiency





SEALED GAS ELECTRON MULTIPLIER PHOTOMULTIPLIER

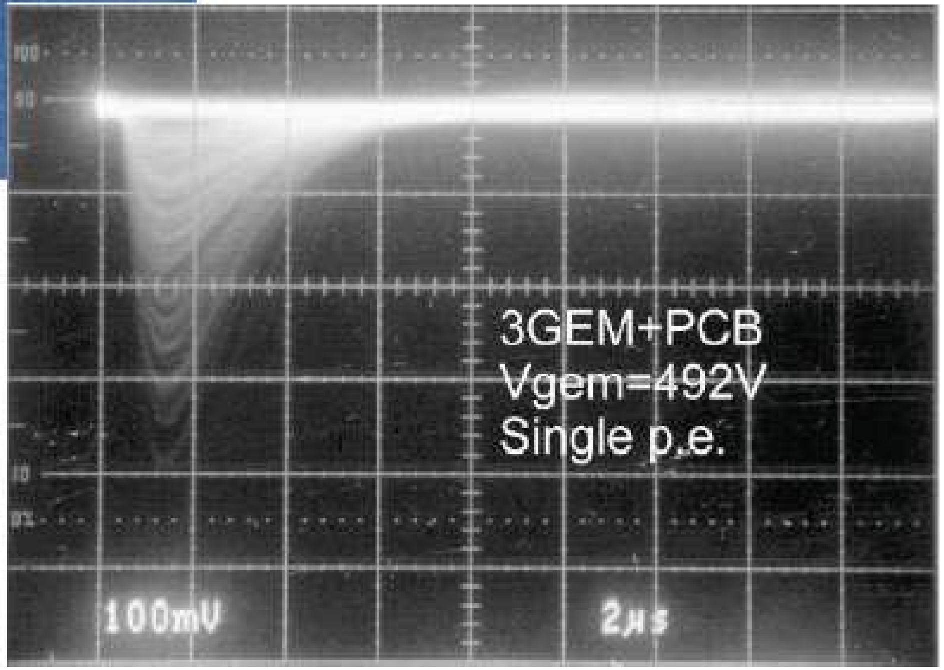


Semi-transparent CsI photocathode

Gas filling:

Ar + 10% CH_4 (atmospheric pressure)

Single photo-electron signals:



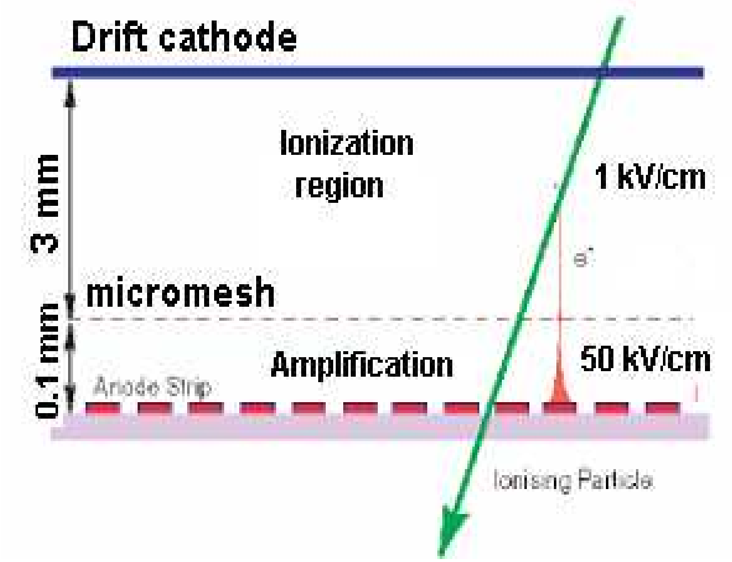
A. Breskin et al,
Nucl. Instr. and Meth. A478(2002)225

Multi-GEM Gaseous Photomultipliers:
- **Largely reduced photon feedback**
- **Fast signals [ns] → good timing**
- **Excellent localization response**
- **Able to operate at cryogenic T**

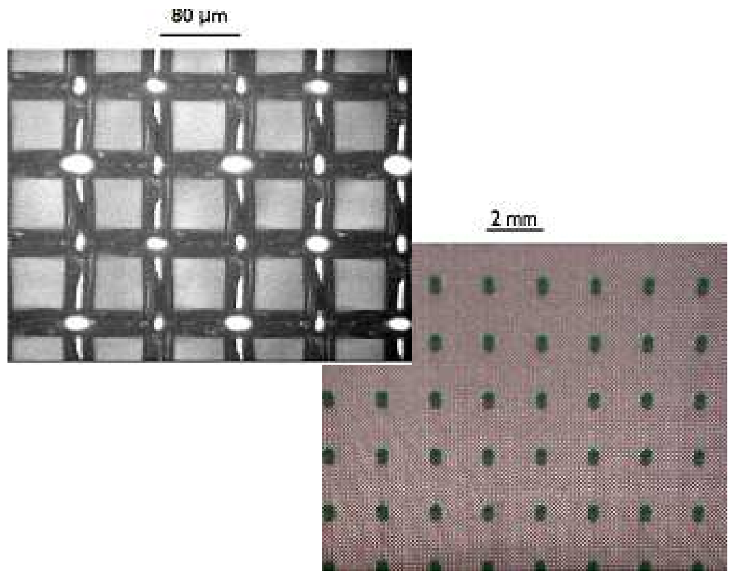
MICROMEsh GAseus Structure (Micromegas)

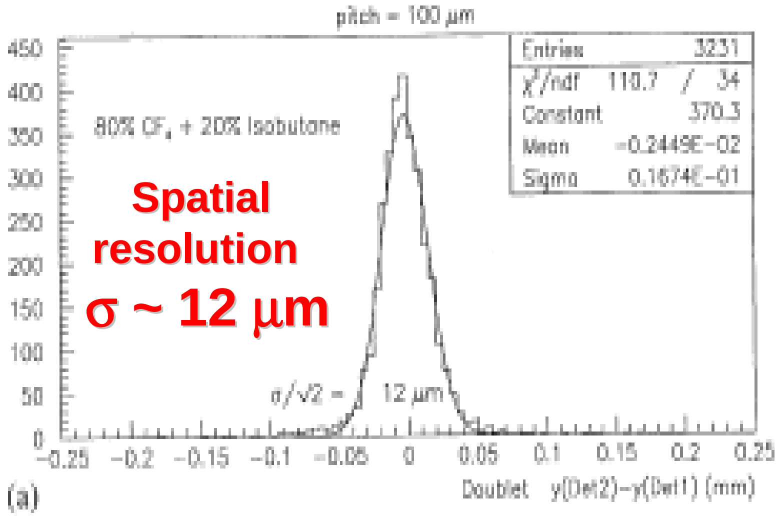
Y. Giomataris, NIM A376(1996) 29

Parallel plate multiplication in thin gaps between a fine mesh and anode plate



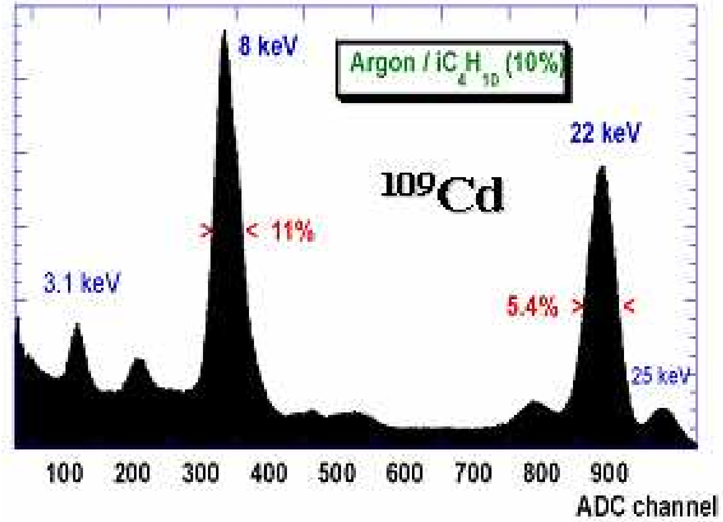
"Bulk" Micromegas:





J. Derre et al, NIM A459 (2001) 523

Small gap→ good energy resolution

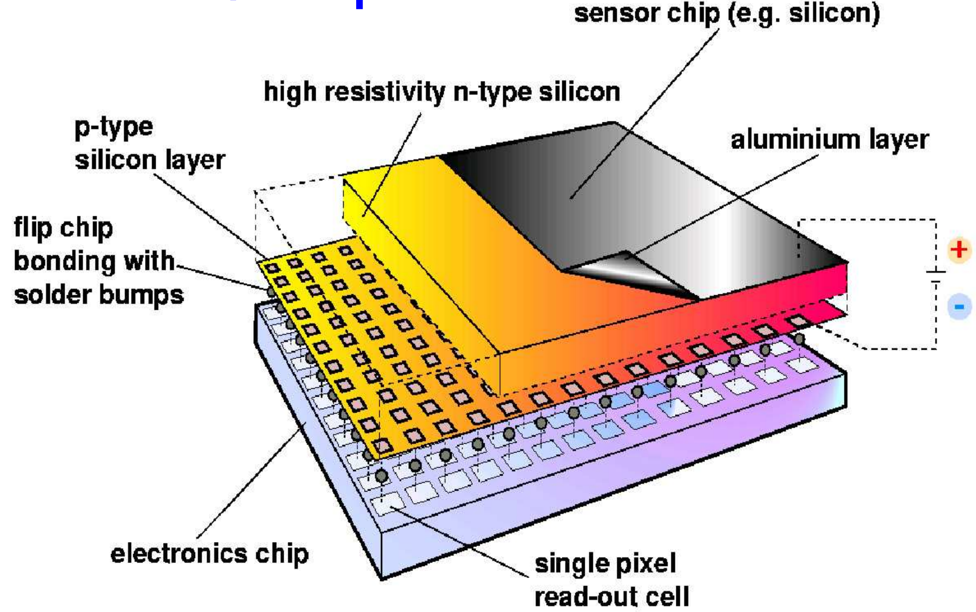


Pixel Readout for Gaseous Detectors

Use ‘naked’ CMOS pixel readout chip as anode

Medipix2 collaboration **http://www.cern.ch/Medipix**

- Form by 17 institutes (16 EU and 1 US)
- Applications:
  - Dental radiography
  - Mammography
  - Angiography
  - Dynamic autoradiography
  - Tomosynthesis
  - Synchrotron applications
  - Electron-microscopy
  - Gamma camera
  - X-ray diffraction
  - Neutron detection
  - Dynamic defectoscopy
  - Adaptative optics
  - Radiation monitor



Square pixel size of 55 μm

256 x 256 pixels

14-bit counter per pixel with overflow control

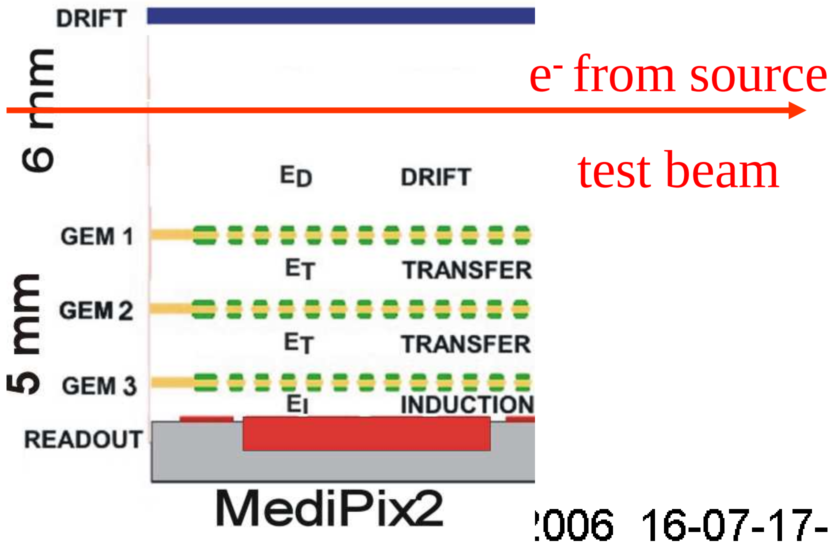
Serial readout <5ms@180MHz

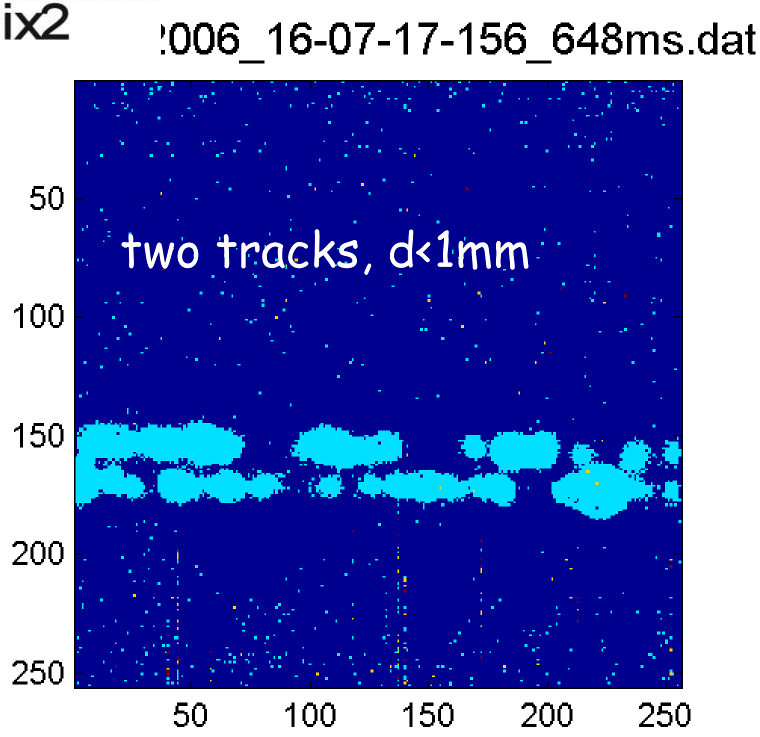
Parallel readout <300us@120MHz (>1KHz frame)

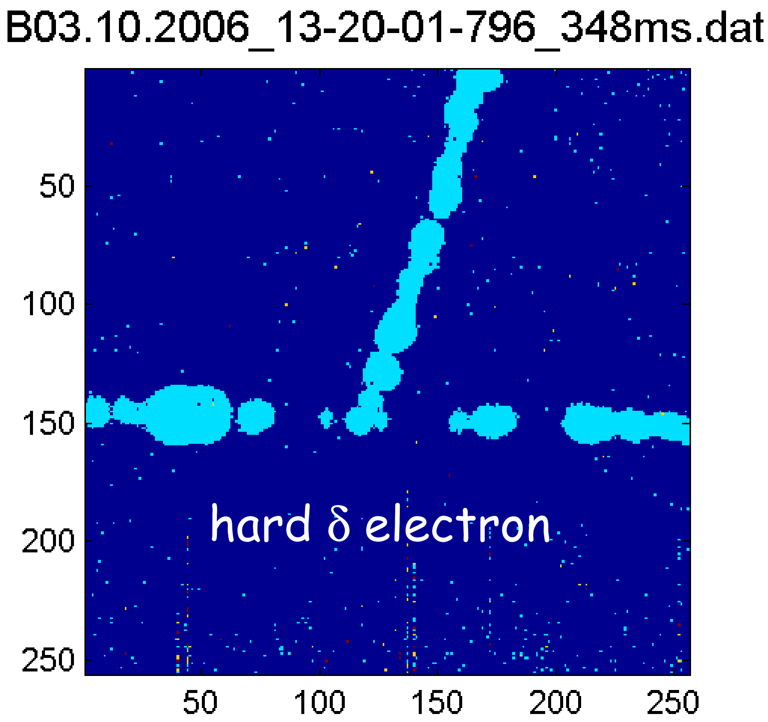
Sensitive area ~2cm^2

3-GEM+Medipix

Freiburg
Bonn







Testbeam at DESY

From Medipix to TimePix

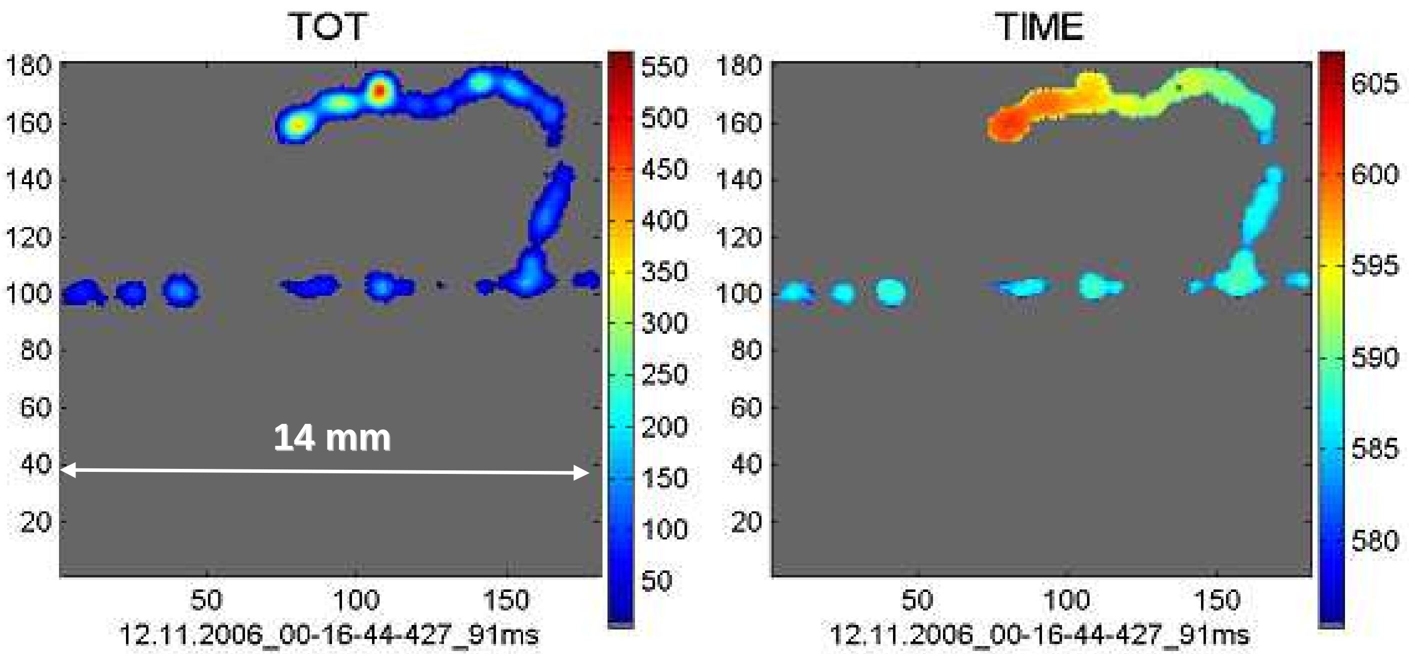
TimePix (EUDET: Bonn, Freiburg, Saclay, CERN, NIKHEF)

TIMEPIX Chip: Add 3rd coordinate (TIME) and TOT

TIME Mode → determine time arrival of electron
(clock ~ 48 MHz, 580-600 counts range → ~ 400 ns)

FINE GRANULARITY
3D TRACKING
+ TOT Information :

TimePix + GEM setup



DESY
Test Beam:
5 GeV
electrons

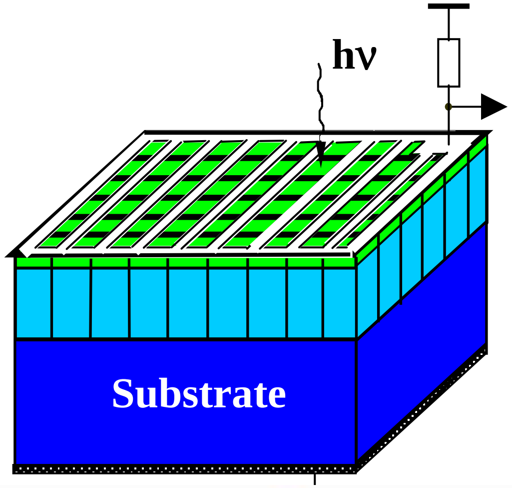
Freiburg Bonn

X. Llopart
M.Titov

SiPM - SOLID STATE PHOTON DETECTORS

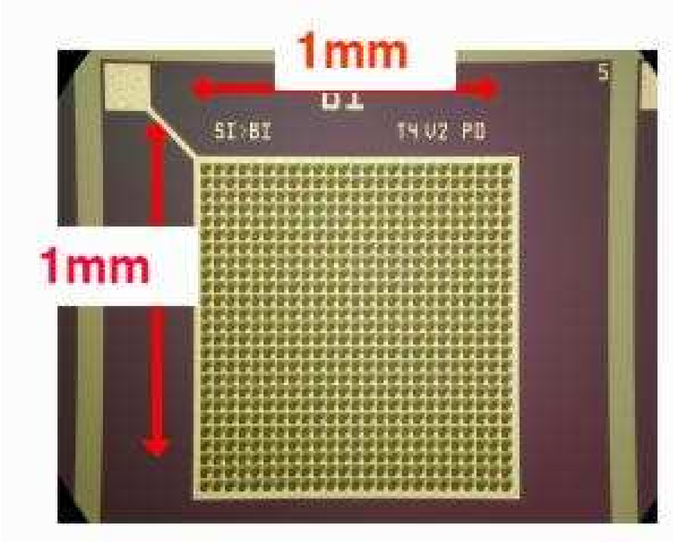
First proposed by Golovin and Sadygov in the 90's

MATRIX OF INDEPENDENT GEIGER PHOTODIODE PIXELS



NAMED :

SILICON PHOTOMULTIPLIER (SiPM)
MULTI-PIXEL PHOTON COUNTER (MPPC)
AVALANCHE MICROCHANNEL PHOTODIODE (AMPD)
GEIGER MODE AVALANCHE PHOTODIODES (G-APD)
MULTIPIXEL AVALANCHE PHOTODIODE (MAPD)

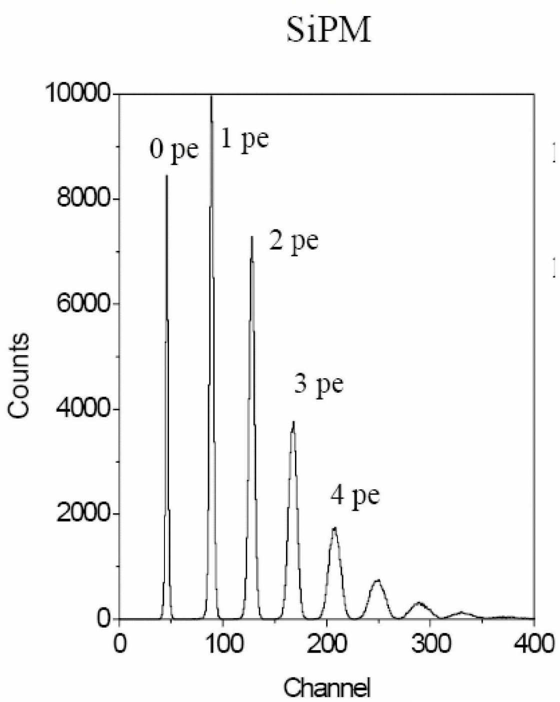


- SINGLE PHOTON SENSITIVITY
- VERY GOOD TIME RESOLUTION: 50-100 ps
- "PROPORTIONAL" TO INPUT SIGNAL
- HIGH Q.E. ~ 80% (POTENTIALLY)
- OPERATION IN HIGH MAGNETIC FIELD
- LOW COST

HIGH SINGLE ELECTRON NOISE (100 kHz-1MHz)

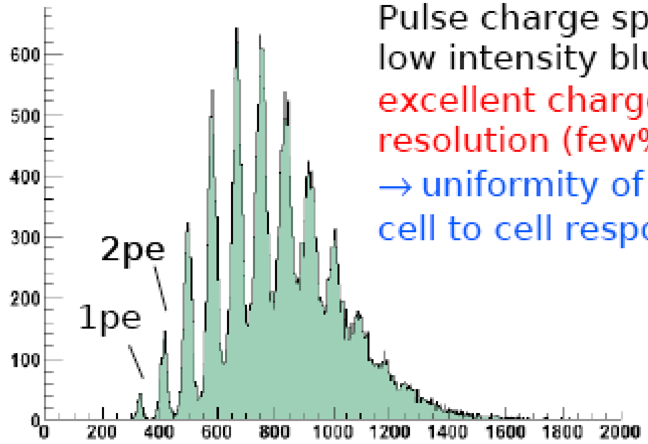
From PM to SiPM

Single photons clearly can be detected with SiPM's. The pulse height spectrum shows a resolution which is even better than what can be achieved with a hybrid photomultiplier.



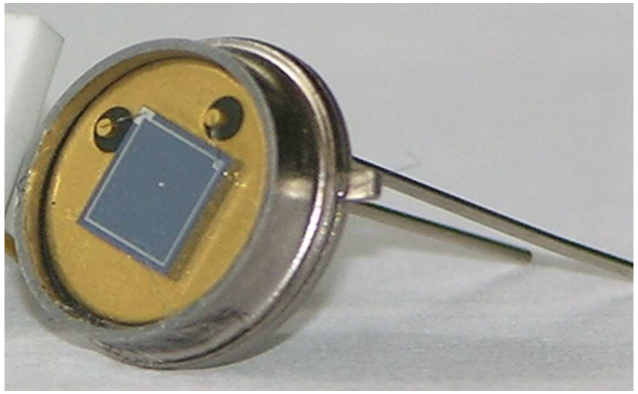
Picture taken from B. Dolgoshein's presentation in Beaune 2002 (NIM A 504 (2003) 48)

G. COLLAZUOL (ITC-irst)
INFN Pisa
2007



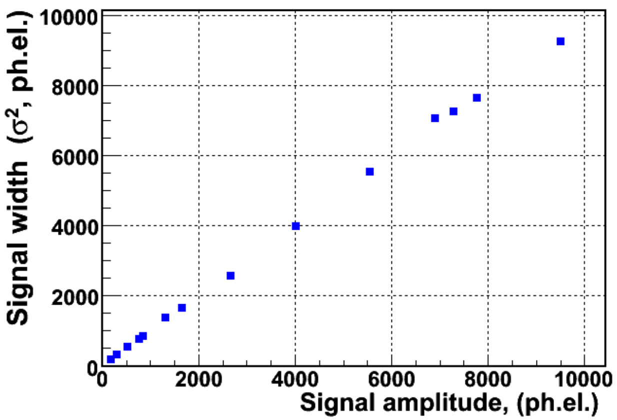
Pulse charge spectrum
low intensity blue LED
excellent charge resolution (few%)
→ uniformity of cell to cell response

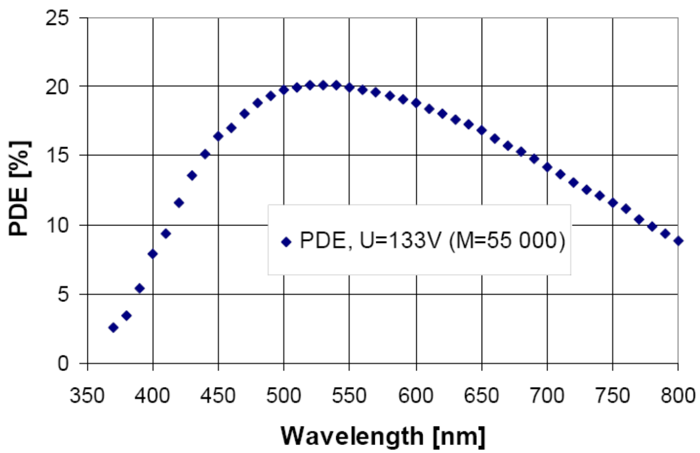
Properties of MAPDs



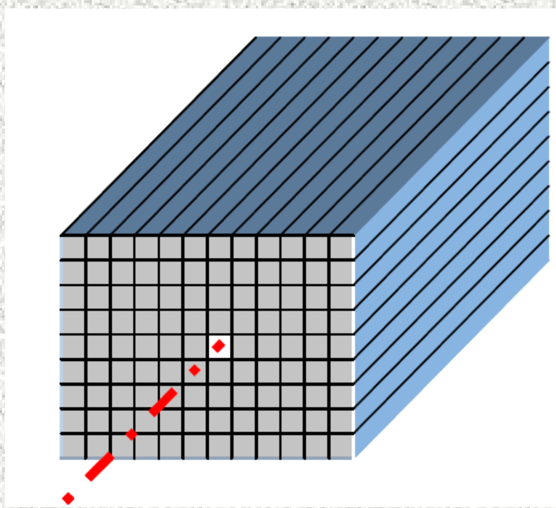
New generation of micro-pixel APD produced in Singapore by Zecotek

- Active area: 3x3 mm^2
- Number of pixel: up to 40000/mm^2
- Gain ~ few x 10^4
- Voltage ~65 V
- Dark current ~50 nA
- High stability

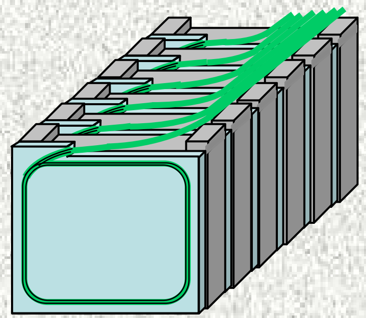


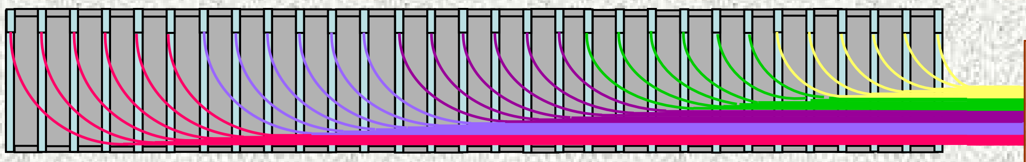


Projectile Spectator Detector – NA61 calorimeter



- 60 lead/scintillator sandwiches
- 10 longitudinal sections
- 6 WLS-fiber/MAPD
- 10 MAPDs/module
- 10 Amplifiers with gain~40





MAPDs and amplifiers.

F. Guber, A. Ivashkin - INR, Moscow

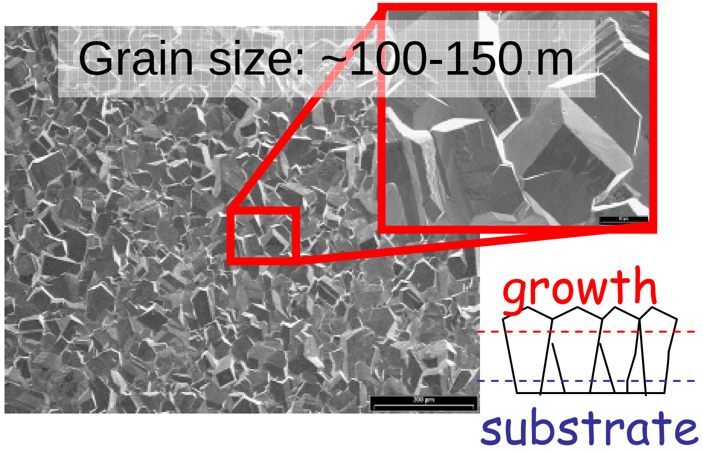
PROGRESS IN SOLID STATE DETECTORS

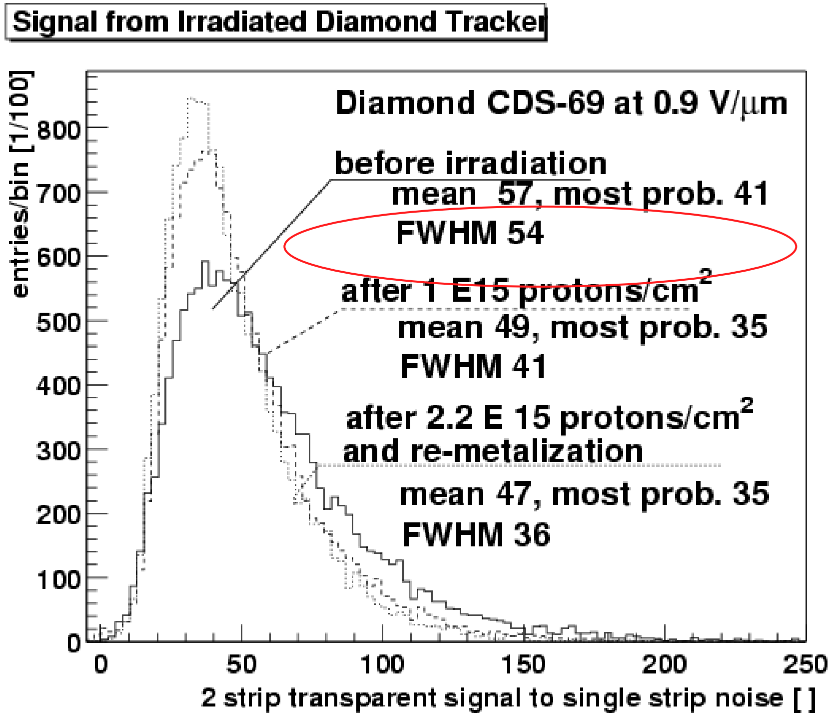
RADIATION TOLERANCE: THE SLHC CHALLENGE

NEW MATERIALS: **DIAMOND**

RADIATION HARDNESS:

Polycrystalline Diamonds traditionally grown by CVD





SINGLE CRYSTAL DIAMOND DETECTORS 14x14 mm^2 HAVE BEEN MADE

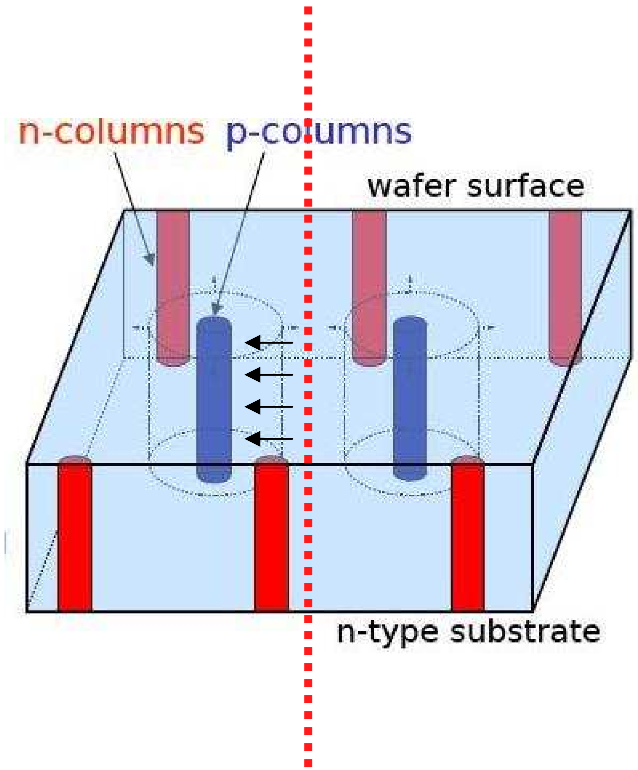
VERY PROMISING, BUT:

- HIGHER IONIZATION ENERGY (LOWER SIGNALS)
- CVD DEFECTS
- HIGH COST

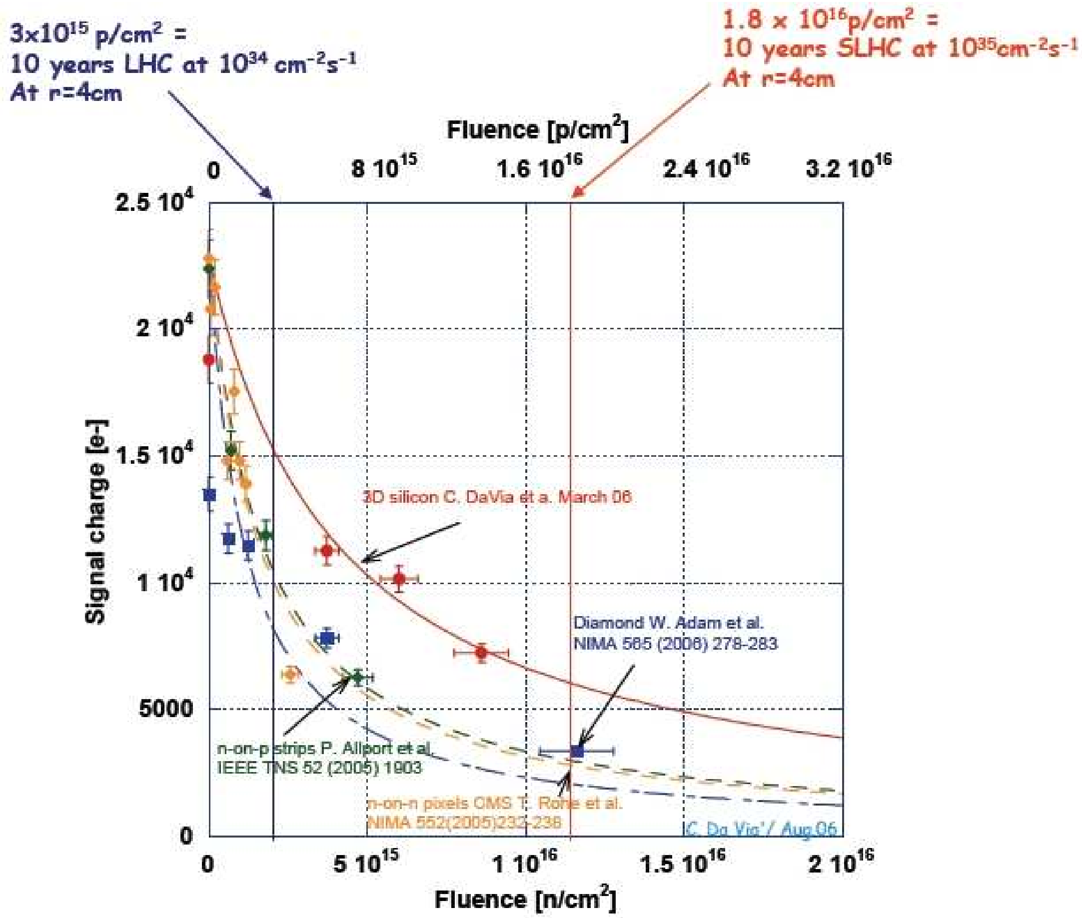
PROGRESS IN SOLID STATE DETECTORS

3-D SILICON DETECTORS

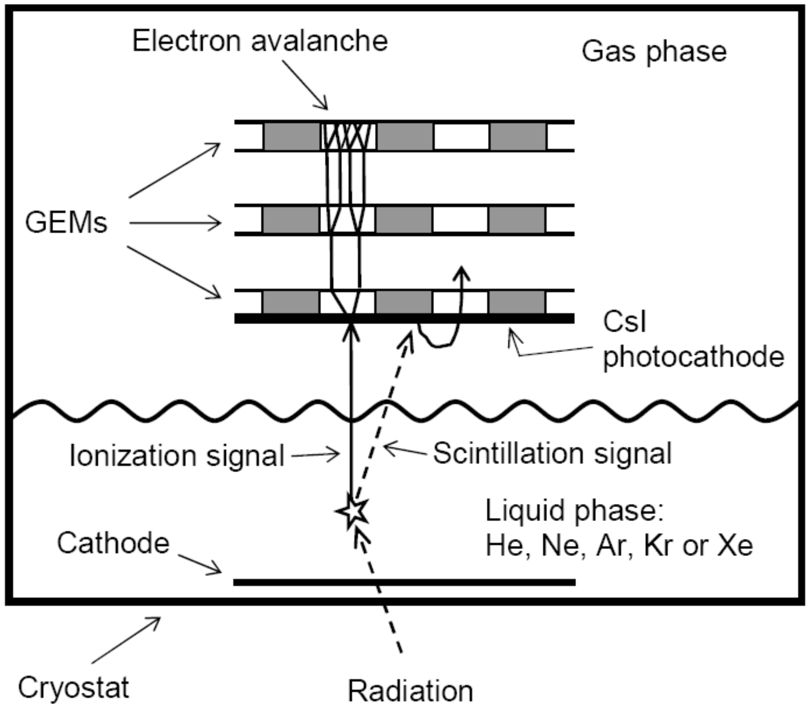
IMPROVED GEOMETRY - RD50

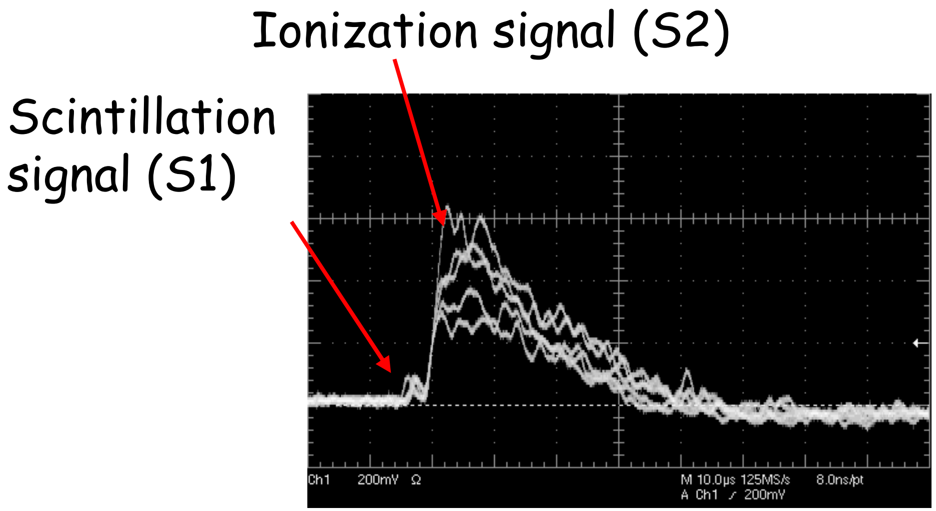


RADIATION HARDNESS:



Two-phase Ar avalanche detector with CsI photocathode





Bondar et al., NIM A 556(2006)237

Dark matter search

A two-phase Ar (Xe) avalanche detector

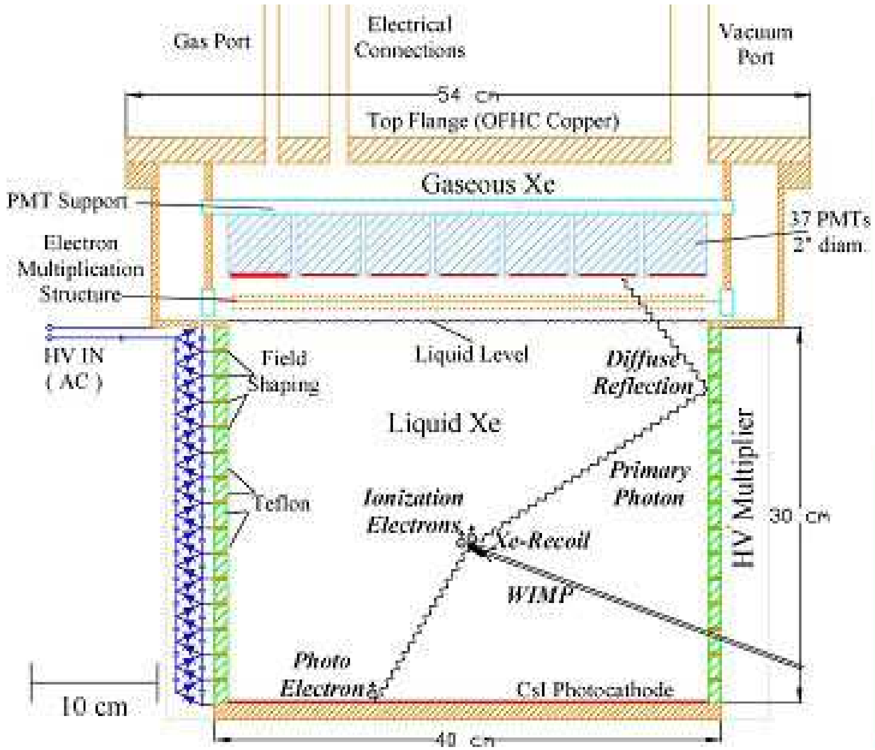
Needs:

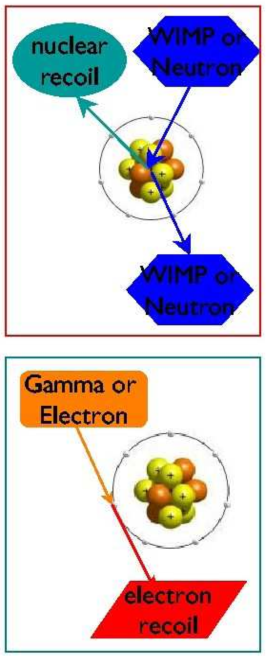
Internal amplification

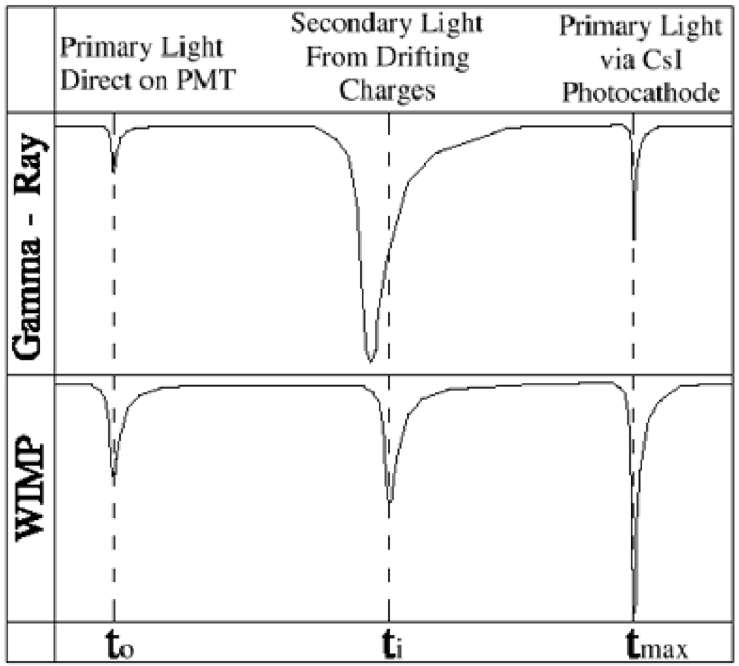
Efficient exploitation of signals

Motivation:

primary ionization (and scintillation) signal is weak: of the order of 1, 10 and100 keV for coherent neutrino, dark matter and solar neutrino respectively





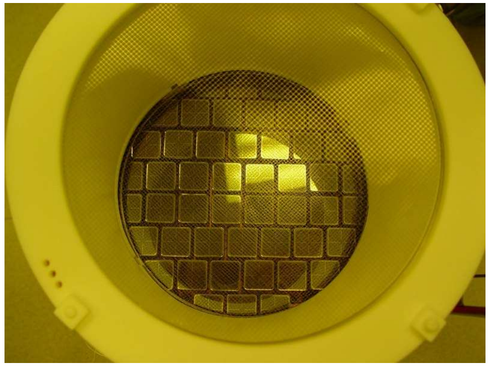


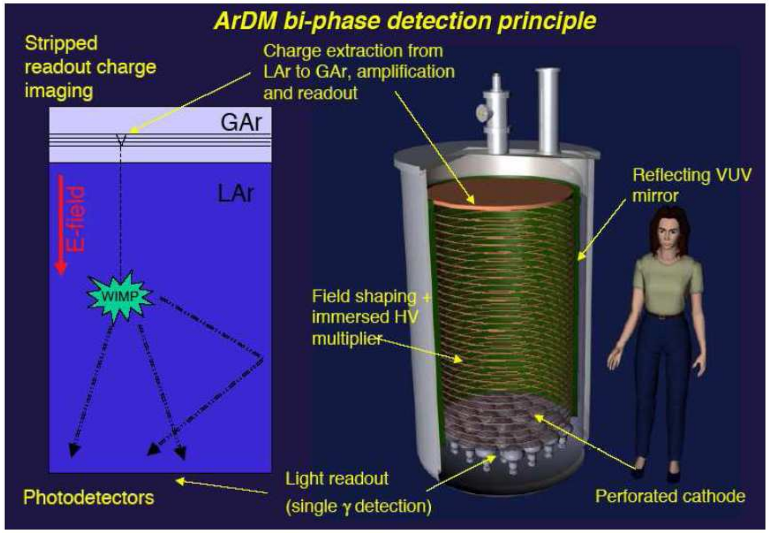
Dark matter search with two-phase detectors

XENON-100

100 kg of ultra pure liquid xenon

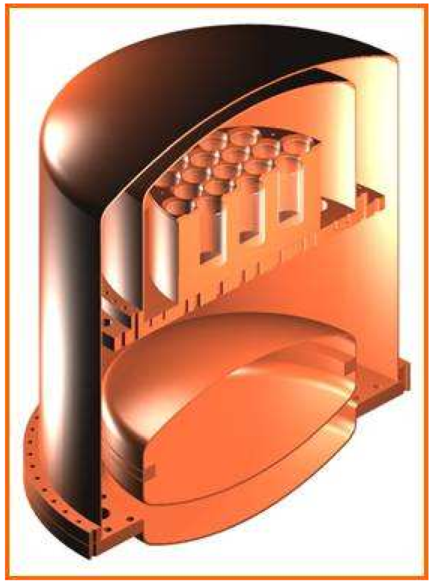
Expected rate: < 1event/kg/day





Two-phase Ar detectors for dark matter search using thick GEM readout *Rubbia et al., Eprint hep-ph/0510320*

ZEPLIN-III - two-phase xenon detector
WIMP target consists of 12 kg liquid xenon
Boulby Underground Laboratory, North Yorkshire, UK



Procesory bieżącej analizy danych i selekcji przypadków

Programmable Logic Device (PLD)

FPGA - Field-Programmable Gate Array

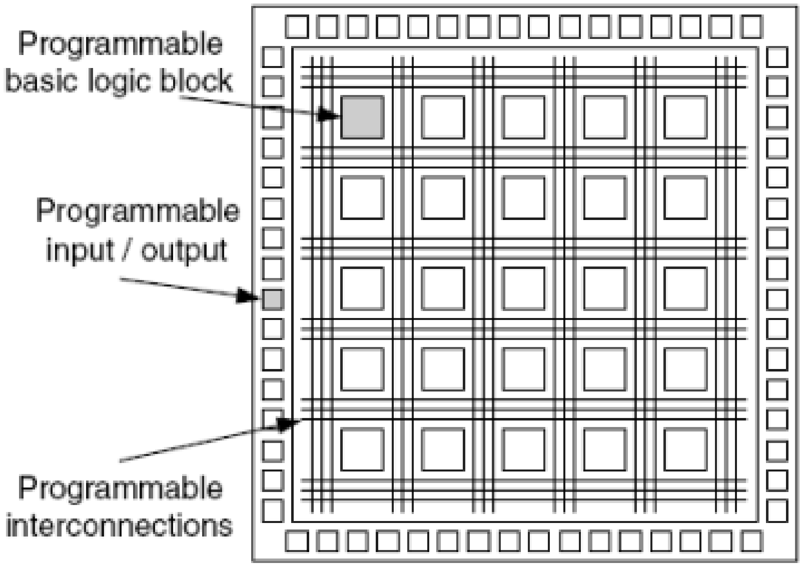
Przetwarzanie sygnałów analogowych i cyfrowych

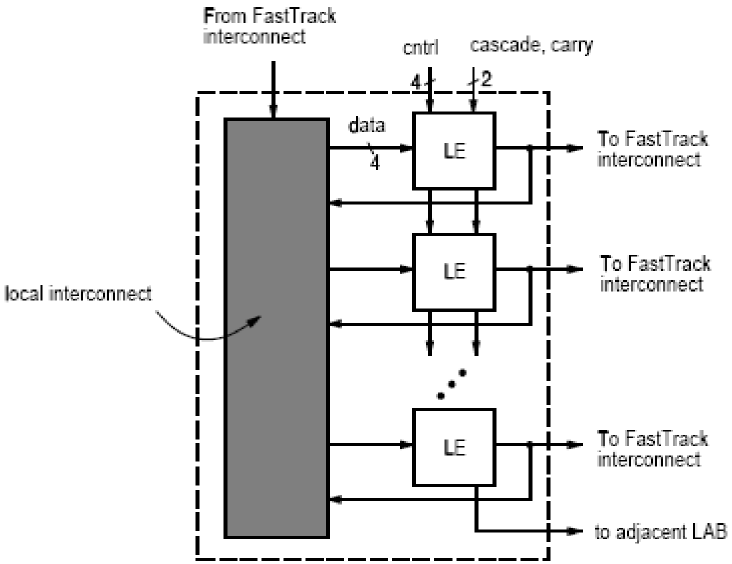
Rekonfigurowalny komputer

Zastosowania:

- prototypowanie wielkoseryjnych układów ASIC
- urządzenia produkowane w krótkich seriach
- testowanie nowych technologii, algorytmów
- praca w systemach podlegających sprzętowej rekonfiguracji

FPGA - Field-Programmable Gate Array





Altera → www.altera.com

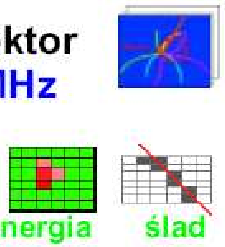
Xilinx → www.xilinx.com

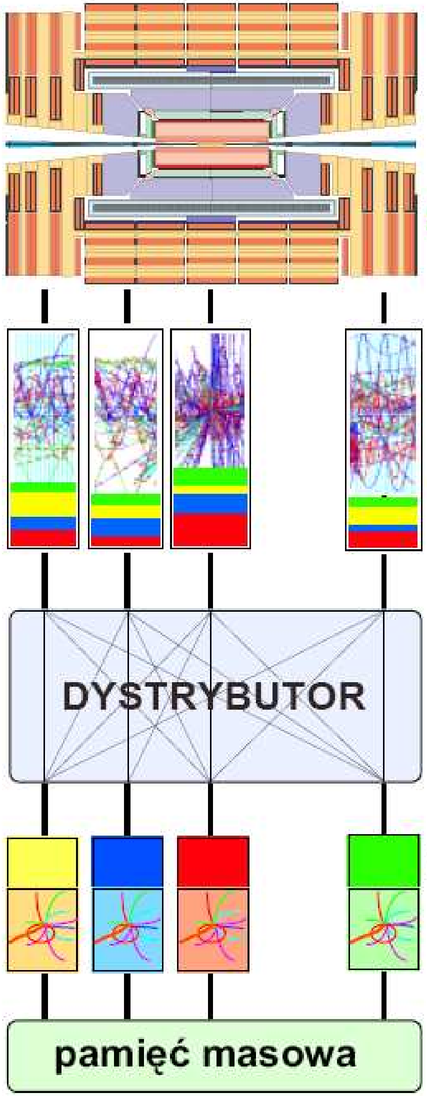
do 338.000 LE, zegar do 600MHz, >1200 I/O pins

Przepływ danych w CMS

detektor
40 MHz

100 M kanałów
3 GB buforów





I st. trygera
100 kHz

1 MB/przypadek

50 000 kanałów
1 Terabit/s

200 GB buforów
w 512 modułach

dystrybutor
500 Gigabit/s

512 wejść
512 wyjść

II, ... st. trygera
100 Hz

5000 procesorów
o mocy 1 GIPS
= 5 TIPS

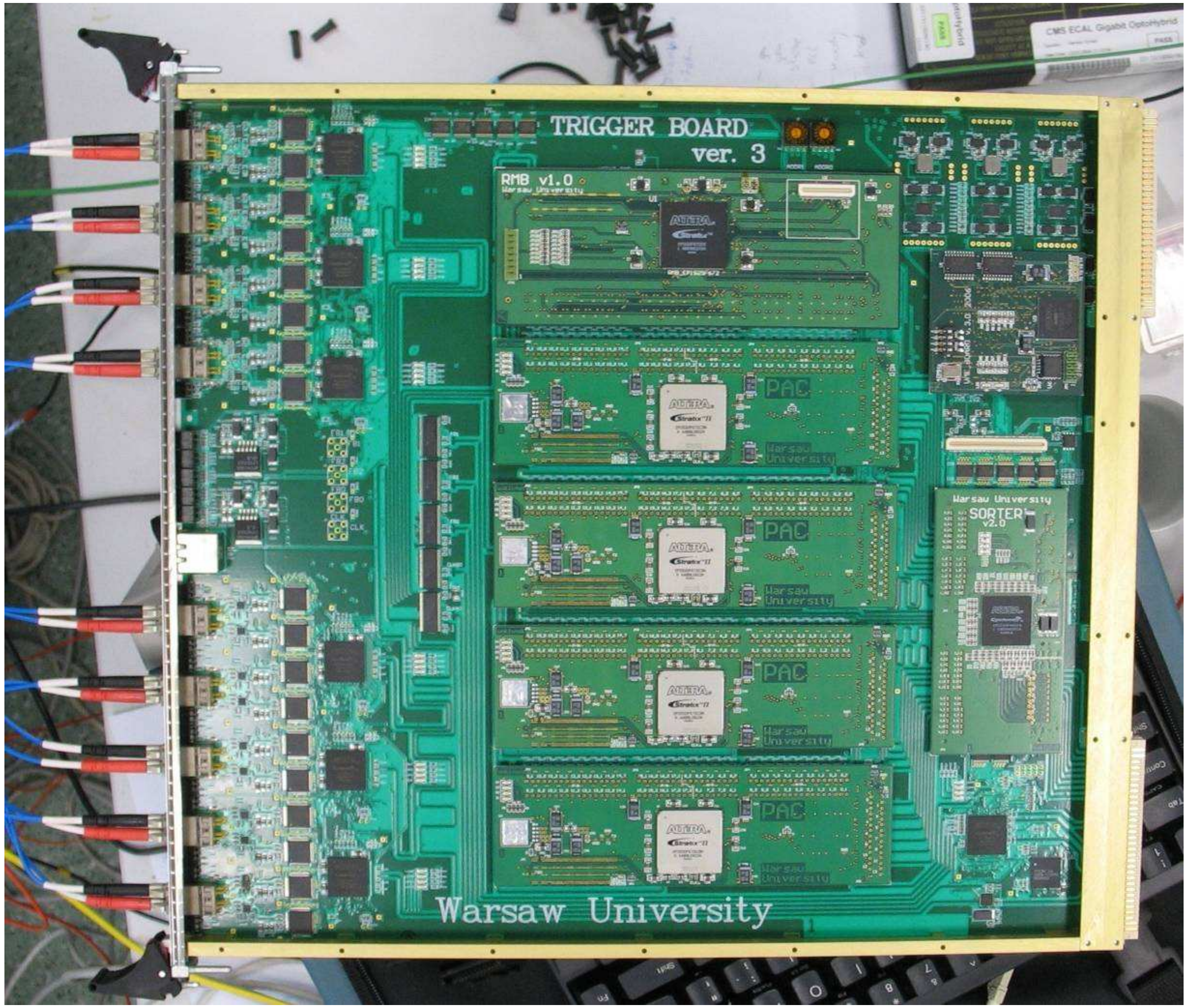
1 Gigabit/s =
10 TB/dzień =
1 PB/rok

np. dziennie
1000 kaset DLT
po 10 GB każda

1 TB = 1 terabajt = 10^{12} bajtów
1 PB = 1 petabajt = 10^{15} bajtów

1 GIPS = 10^{9} instrukcji/s
1 TIPS = 10^{12} instrukcji/s

RPC PACT (TC i TB)



Dzieło Maćka
Kudły & co.

Zamiast podsumowania

- ***Technologia Micro-Pattern Gas Detectors rozwija się szybko dzięki wysiłkowi wielu grup doświadczalnych (RD-51 w CERN)***
- ***GEM and MICROMEGAS - technologie dojrzałe***
- ***Mikroelektronika zwiększa obszar zastosowań MPGD***
- ***SiPM – nowy standard detekcji w kalorymetrii?***
- ***Siła napędowa rozwoju technik detekcyjnych:***
  - ***Zastosowania w medycynie i przemyśle***
  - ***Super LHC***
  - ***Internatinal Linear Collider***
  - ***Dark matter experiments***
- ***Programowalne Układy Logiczne podstawą szybkiej analizy i selekcji zdarzeń***