Application of MPGDs

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Lecture series on MPGD@SINP 22/10/2014

Contents

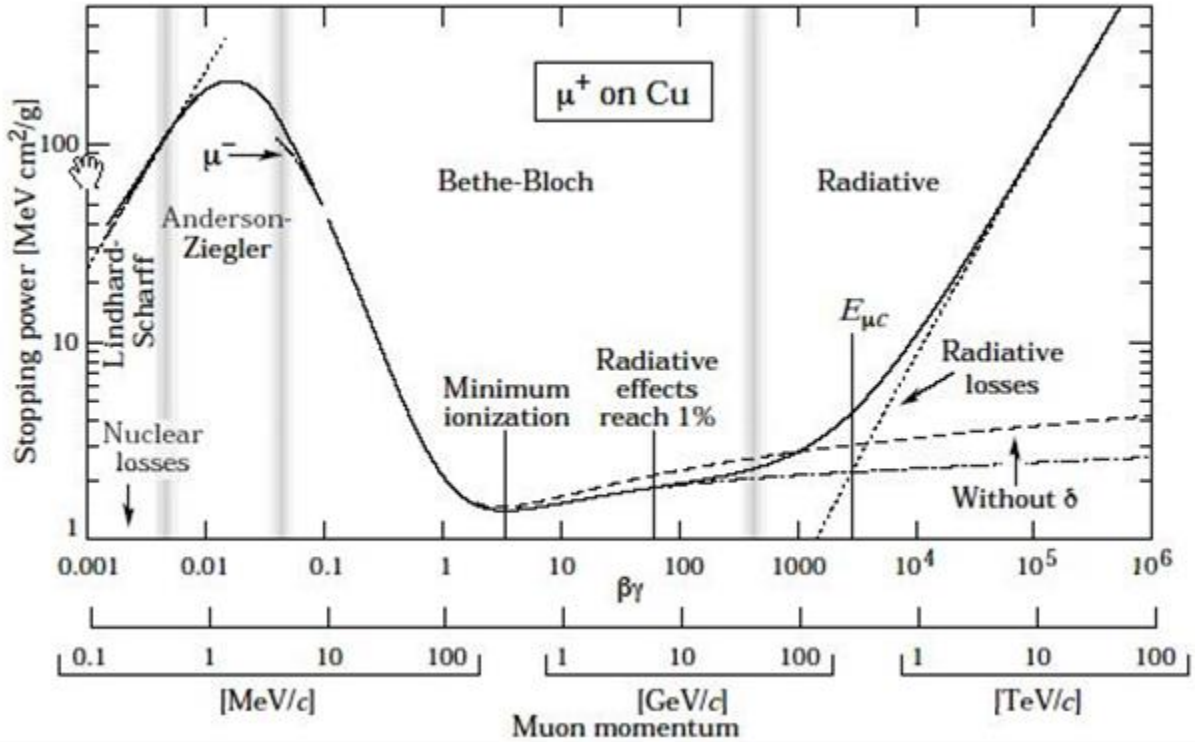
Introduction: What you want to see?

- Ionization process is needed to detect the particle
  - For not only gaseous detectors but also semiconductor, scintillator … etc.
- For charged particle …
  - We can detect it directly
  - Material (gas) is ionized along with the particle path.
    - Bethe-Bloch formula

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Bethe-Bloch formula

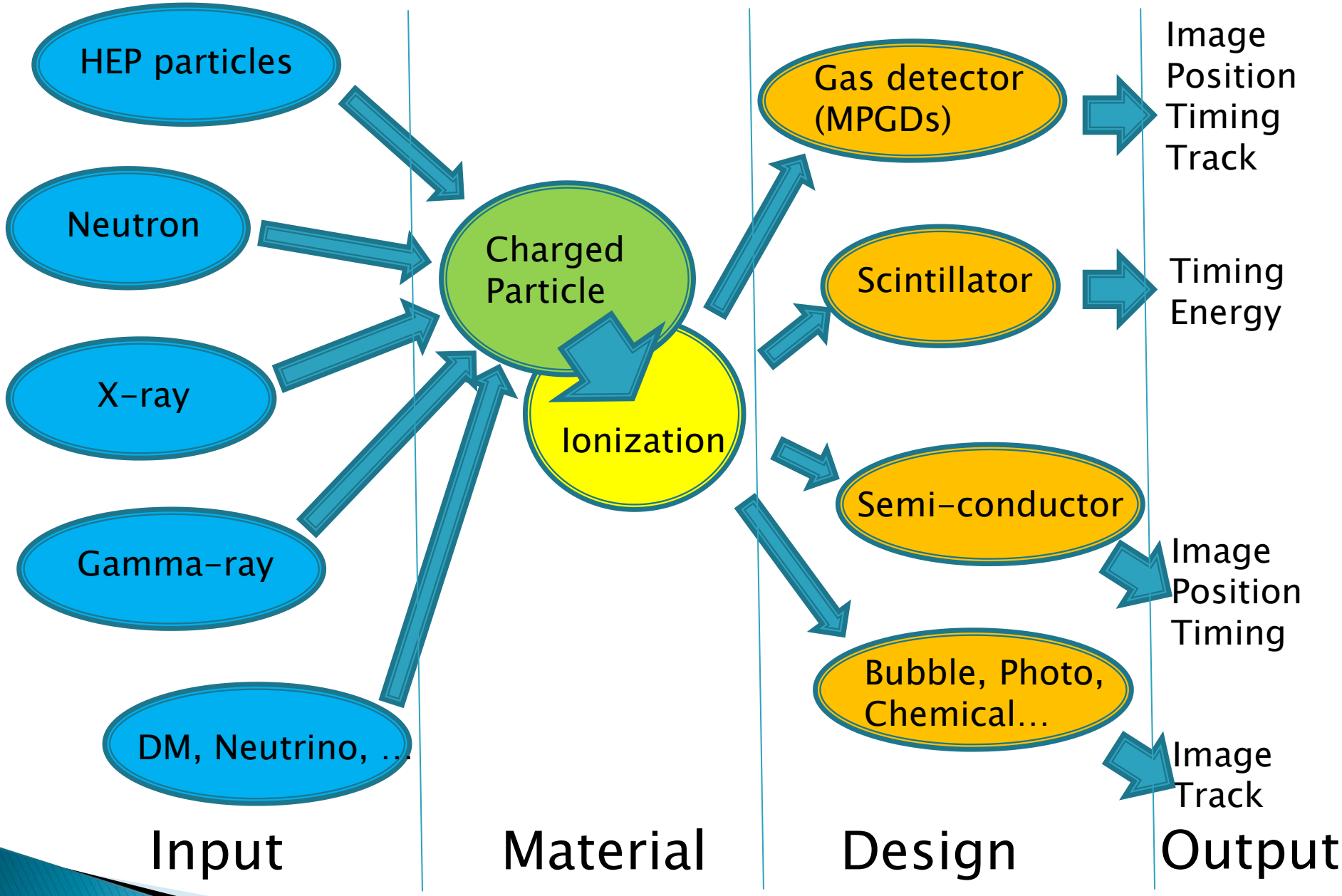
$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



What type of the particle do you want to see?

- dx/de is quite different between MIP and HIP (e.g. ~MeV muon, nucleus).
- What type of particle (MIP, HIP, MIP in HIP, high rate?) should be measure?
  - → Design of the detector
- For the neutral particle detection, we have to convert it into the charged particle to see.
- How to do this?

  The ideas are needed
- The application makes the detector structure to be new.


HEP particles
Neutron
X-ray
Gamma-ray
DM, Neutrino, …
Charged Particle
Ionization
Gas detector (MPGDs)
Scintillator
Semi-conductor
Bubble, Photo, Chemical…
Image
Position
Timing
Track
Timing
Energy
Image
Position
Timing
Image
Track
Input
Material
Design
Output

As for MPGDs …

- Is the MPGD is reasonable solution for your requirement ?

- Basic Properties of MPGDs
  - Typical position resolution : < 100 micron
  - Typical Timing resolution: < 100 ps
  - Possible size: > 1 m
  - Low cost (comparing with semiconductor)
  - High rate capability : > 10^7 counts/mm^2/sec

- Particle interaction with the gas
  - Charged particle: Direct ionizing along Bethe-Bloch fomula
  - X/Gamma-ray: Photoelectric effect, Compton scattering, Pair creation
  - Neutron: Nuclear reaction (slow), Nuclear recoil (fast)
  - Photon: Photoelectric effect on photo cathode
  - Unknown particle (Dark matter?) : Nuclear recoil

- Technology availability
  - Micro pattern fabrication: < 10 micron
  - Readout electronics and DAQ : Need many channels

High Energy Physics Experiment

- Charged particle detector
  - For LHC
  - Future detectors

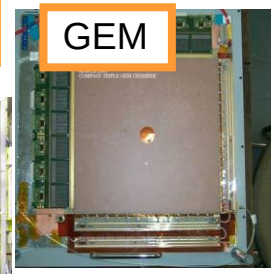
HEP & PARTICLES

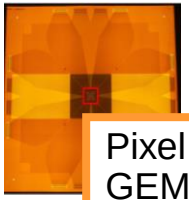
Completed / Running Experiments

COMPASS

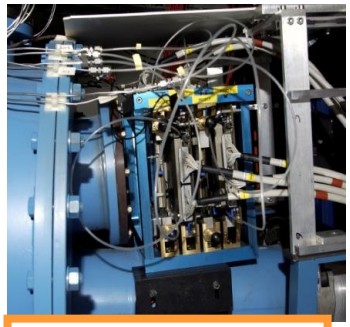
MM

GEM

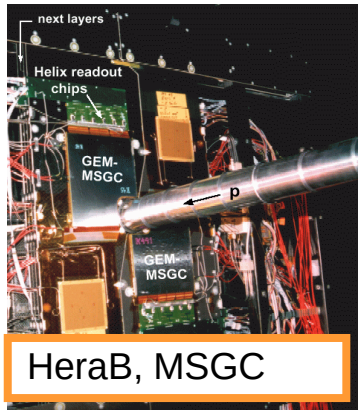




Pixel GEM



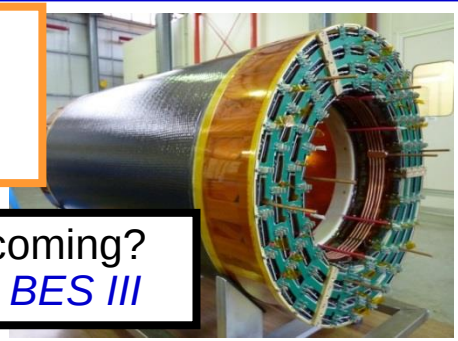
DIRAC, MSGC



HeraB, MSGC

LHCb, GEM

KLOE2:
triple cylindrical GEM
assembled: 14/3/2013

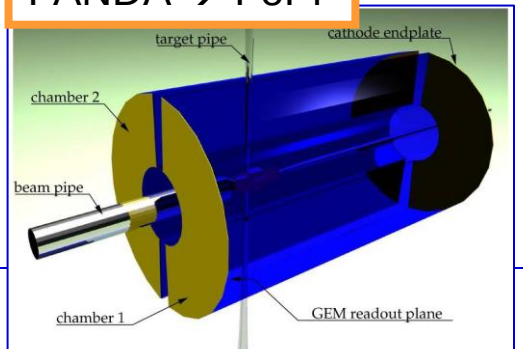


Other cylinders coming?
CMD-3 detector, BES III

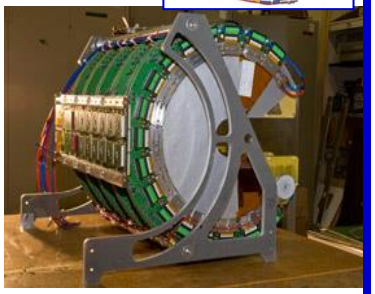
MM, T2K TPC read-out

CAST, MM

PANDA → FoPi



TOTEM, GEM



HEP & PARTICLE

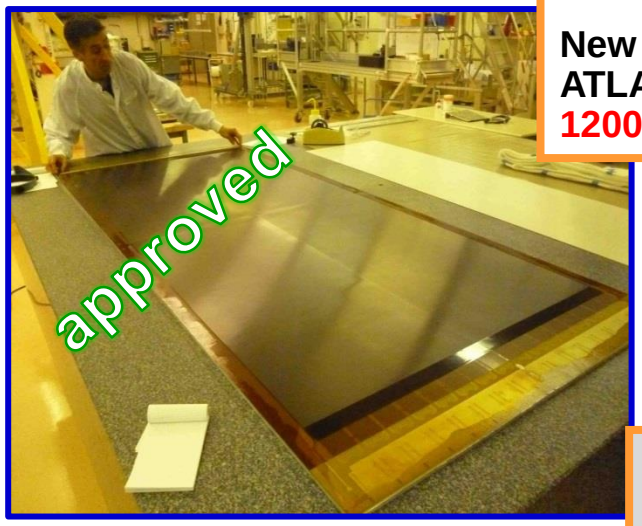
Future @ CERN
LHC & more

ATLAS – MAMMA project (MM)
Goal: ~1 x 2.5m^2

New Small Wheel,
ATLAS muon system,
1200 m^2, tracking & trigger

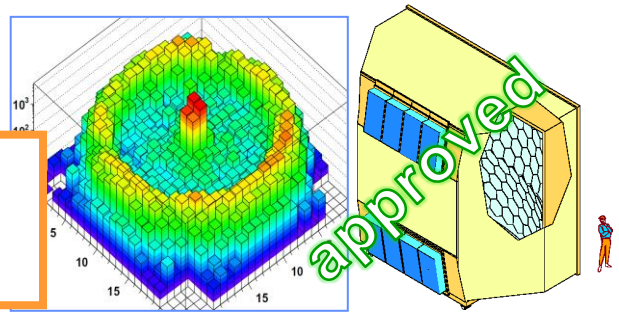
more GEM for
LHCb (LS3) ?

Goal: ~.6 x 0.3 m^2
~50-60 m^2 of GEM foils



COMPASS RICH-1 upgrade

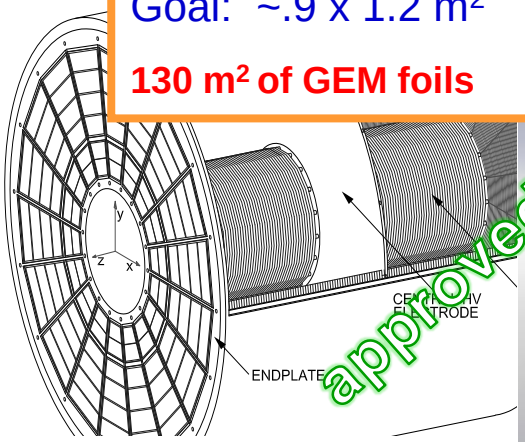
12 m^2 of THGEM plates

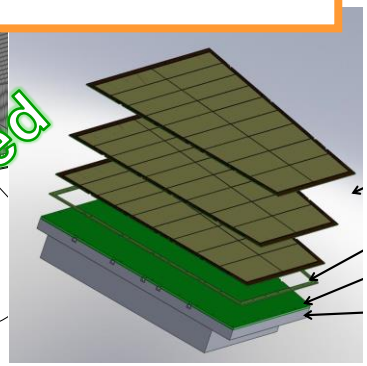


***A NEW FRONTIER:* THE MASS PRODUCTION**
→INDUSTRIALISATION IS AN ABSOLUTE MUST

ALICE – TPC r-O, upgrade (GEM)
Goal: ~.9 x 1.2 m^2

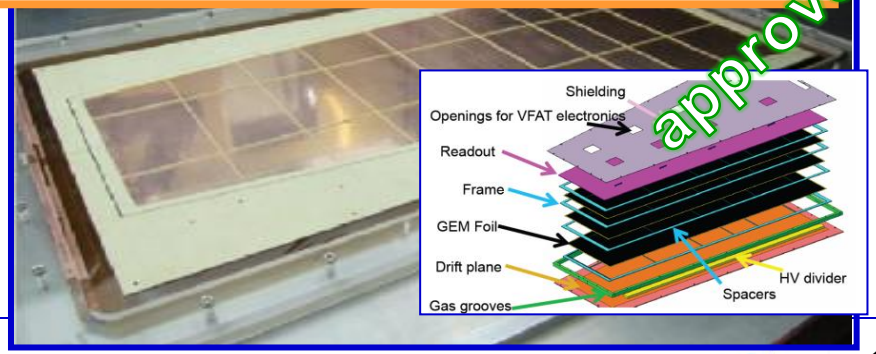
130 m^2 of GEM foils



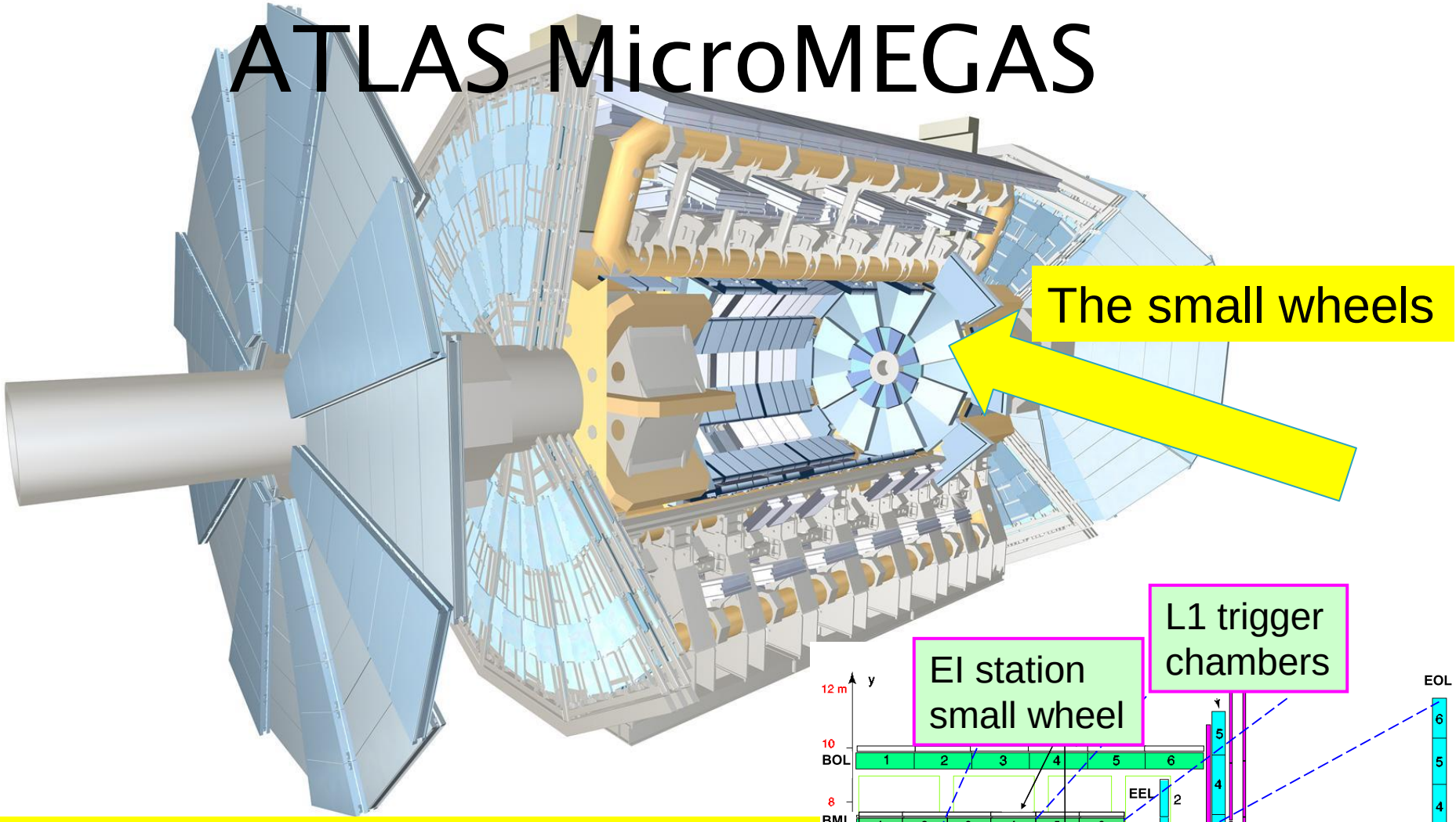


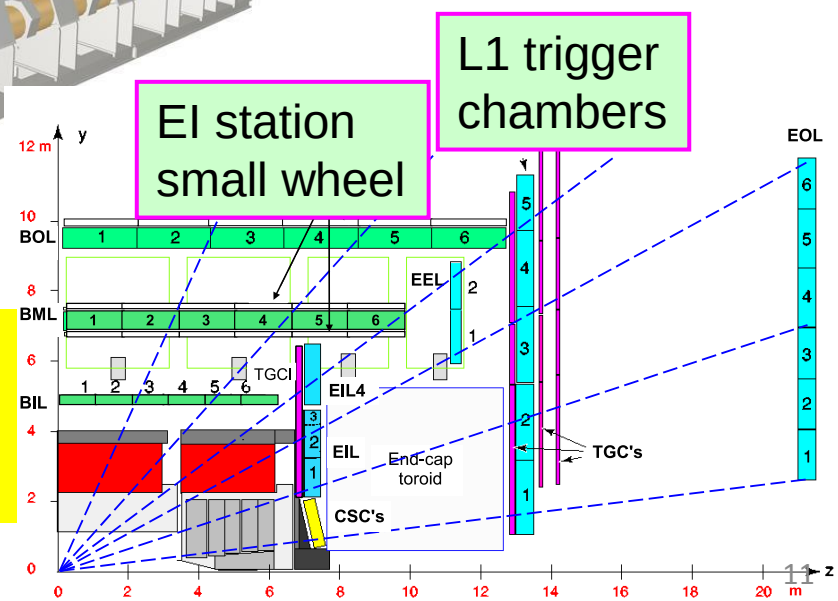
CMS – forward muon spectrometer (GEM)
Goal: ~1.2 x 2 m^2

1000 m^2 of GEM foils, tracking & trigger



ATLAS MicroMEGAS





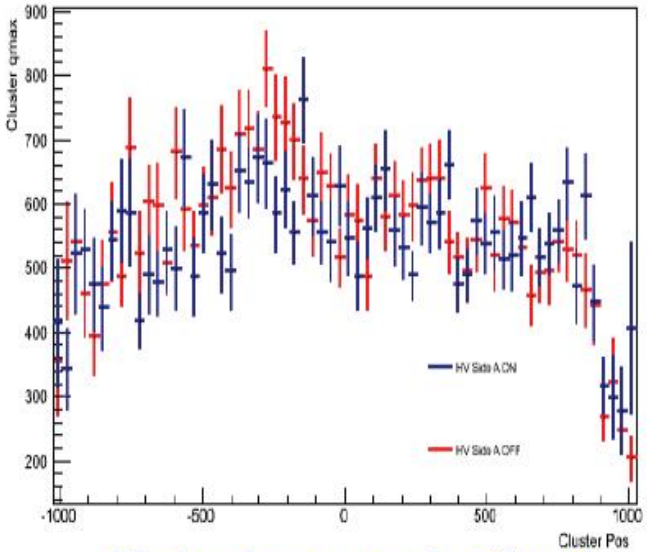
The innermost station of the muon endcap

Located between endcap calo and toroid

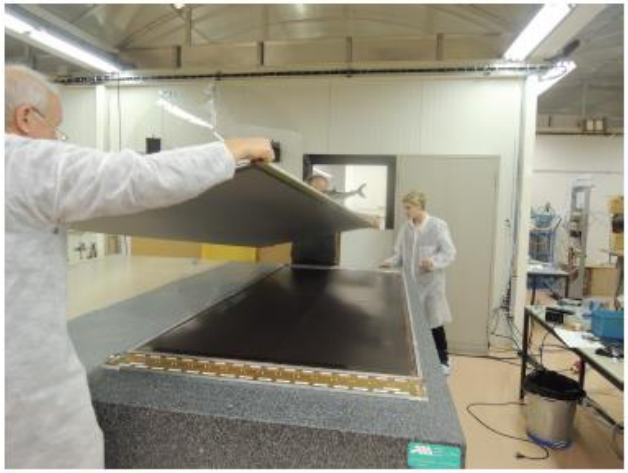
ATLAS-J UG review, Nov. 2013, T. Kawamoto

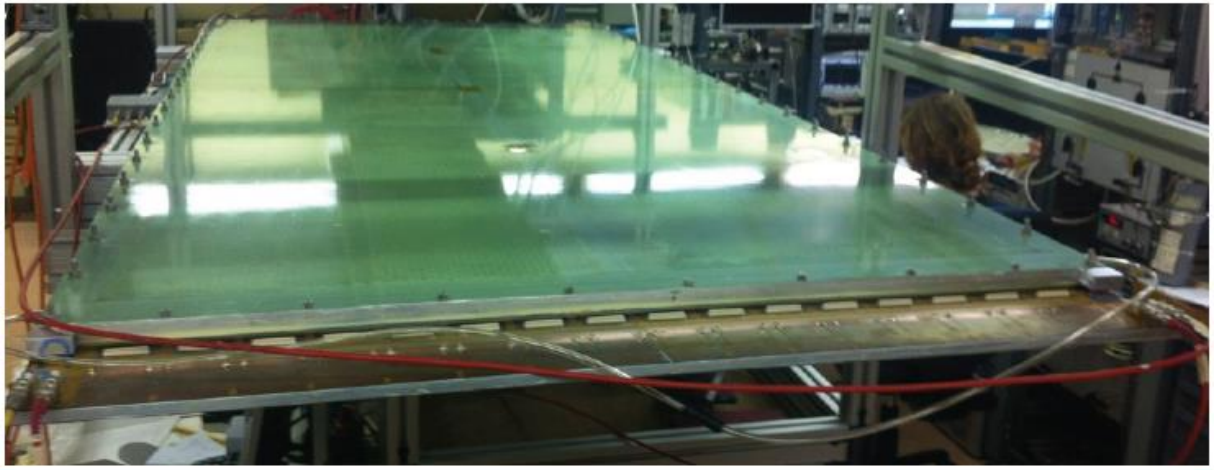
Micromegas Prototypes - 1.0 x 2.4 m^2

- Chambers dimensions: 1 x 2.4 m^2 (0.92 x 2.12 m^2 active area).
- Four PCBs (0.5 x 1.2 m^2, thickness 0.5 mm) glued to a 10 mm thick stiffening panel.
- 2 x 2048 strips (0.45 mm pitch), separated in the middle.
- Floating mesh, integrated into drift-electrode panel (15 mm thick).
- PCBs were made at CERN, resistive strips have been printed in industry using screen printing technique, with interconnects.
- Measured strip position accuracy within 10 μm.
- Good uniformity along the surface of the chamber.



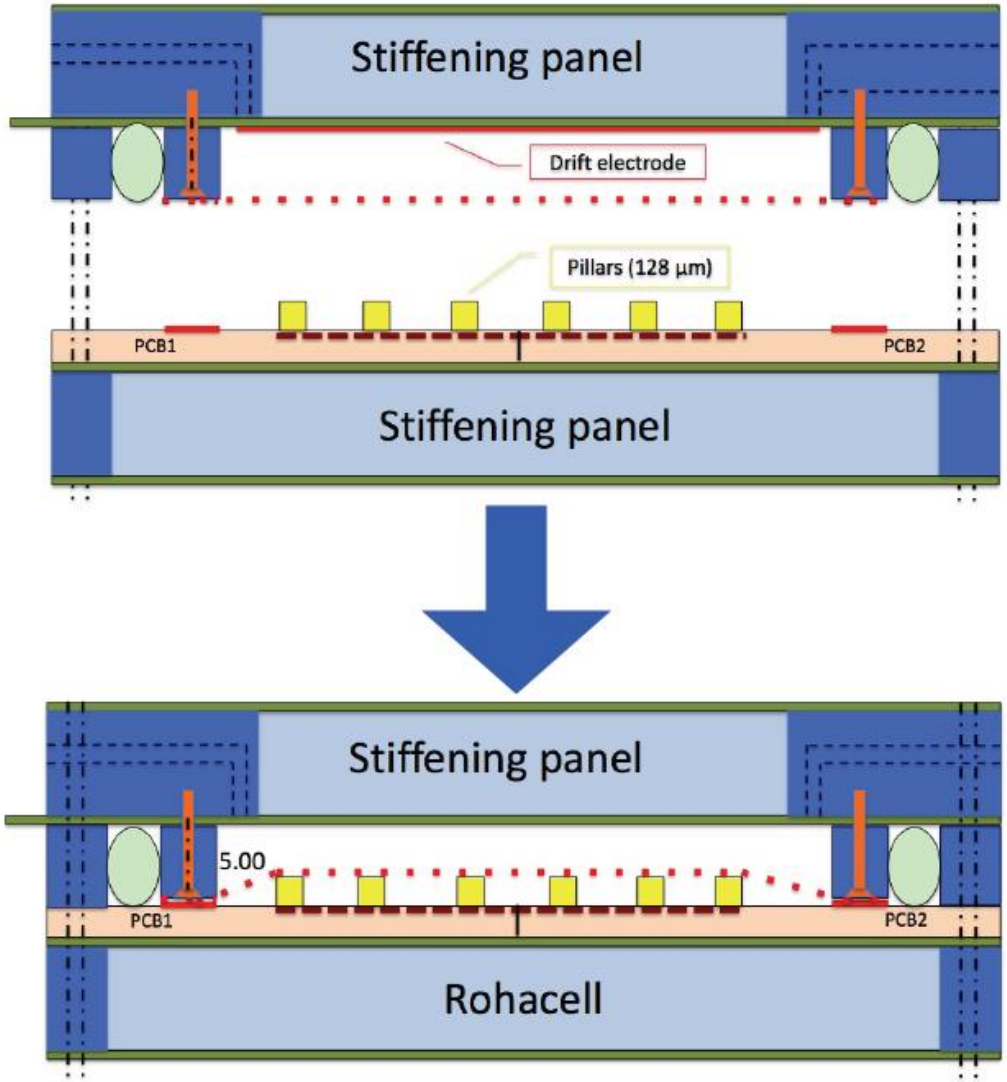
Cluster charge as a function of cluster position





Micromegas detectors assembly

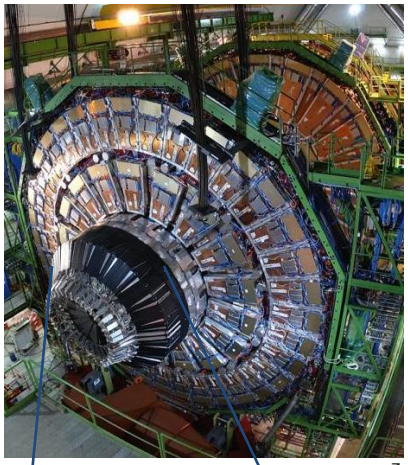
- The mesh is not fixed but integrated with the drift-electrode panel.
- It uses pillars to keep the mesh at a defined distance from the board.
- Placed on the pillars when the chamber is closed.

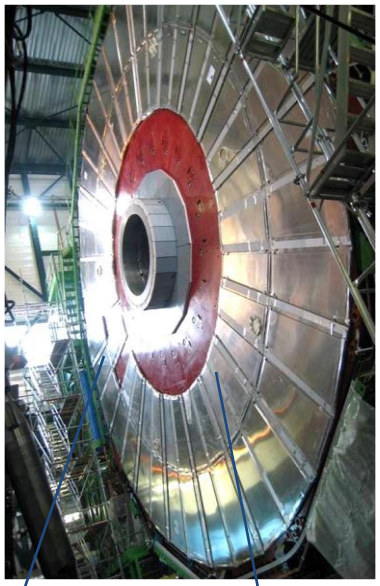


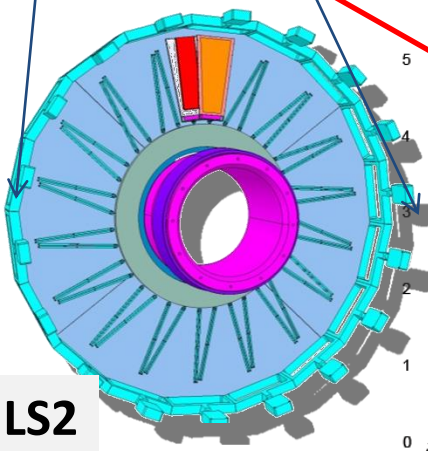
The CMS GEM Project

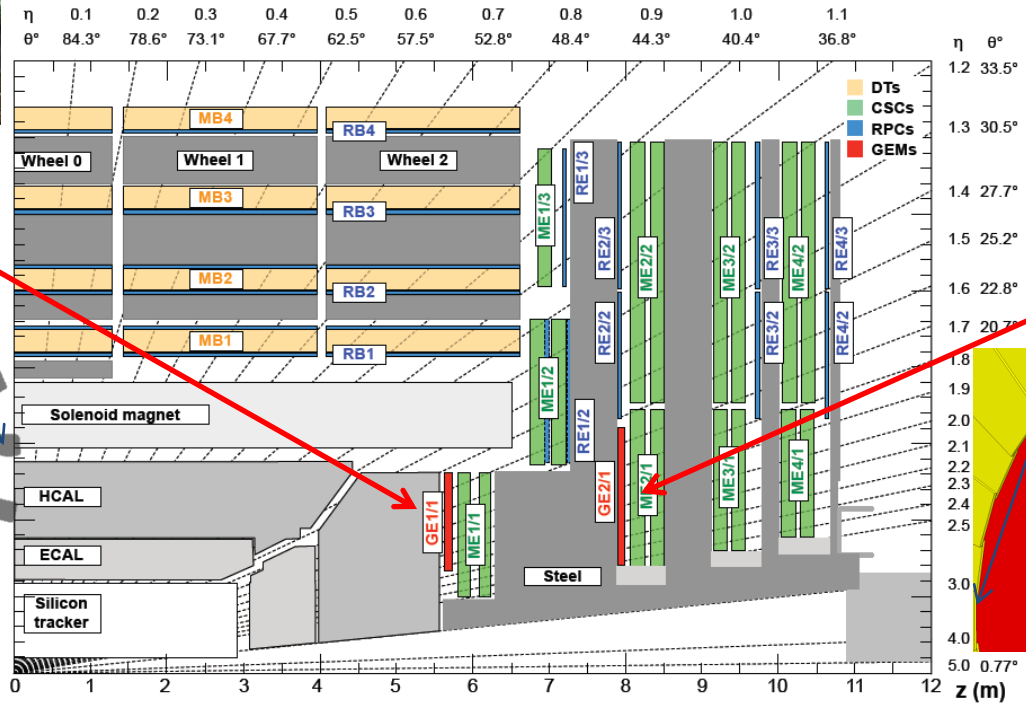
Install triple-GEM super chambers (double stations) in 1.6<|η|<2.1-2.4 endcap region:

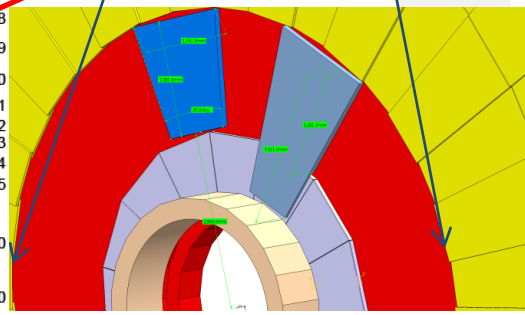
- Restore redundancy in muon system for robust tracking and triggering during HL-HLC
- Improve L1 and HLT muon momentum resolution to reduce or maintain global muon trigger rate
- Ensure ~ 100% trigger efficiency in high PU environment





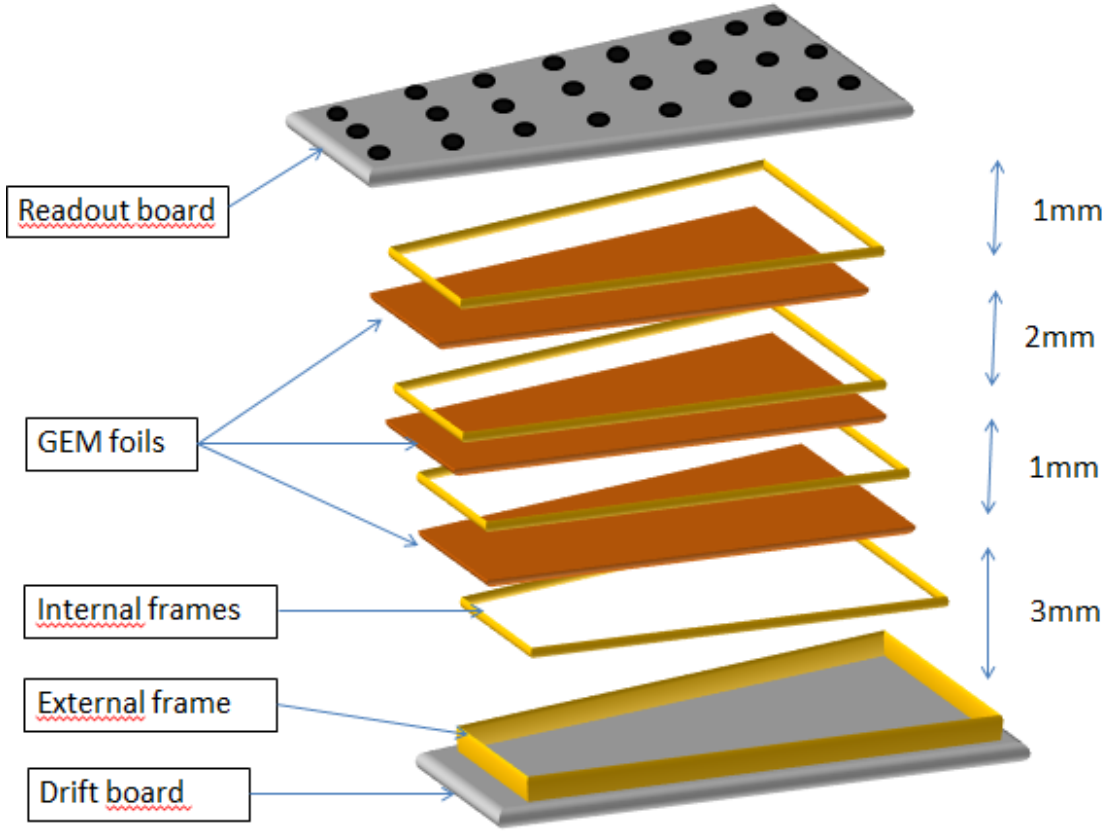


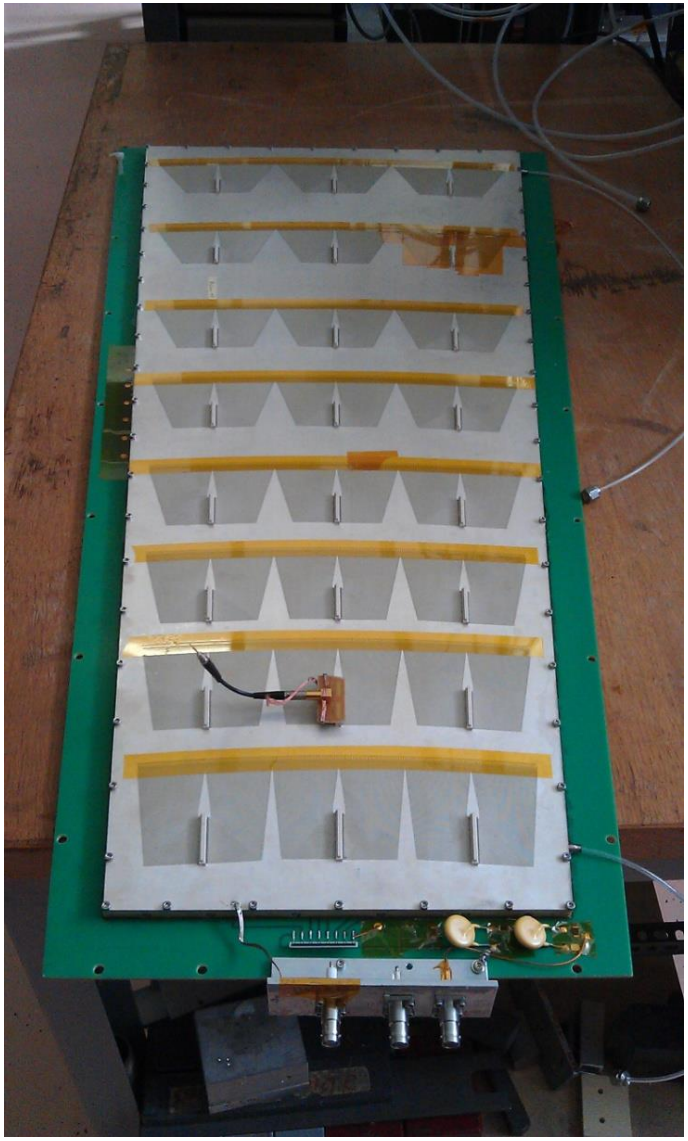




GEMs: R&D Project CMS 10.02; The LS2 Project

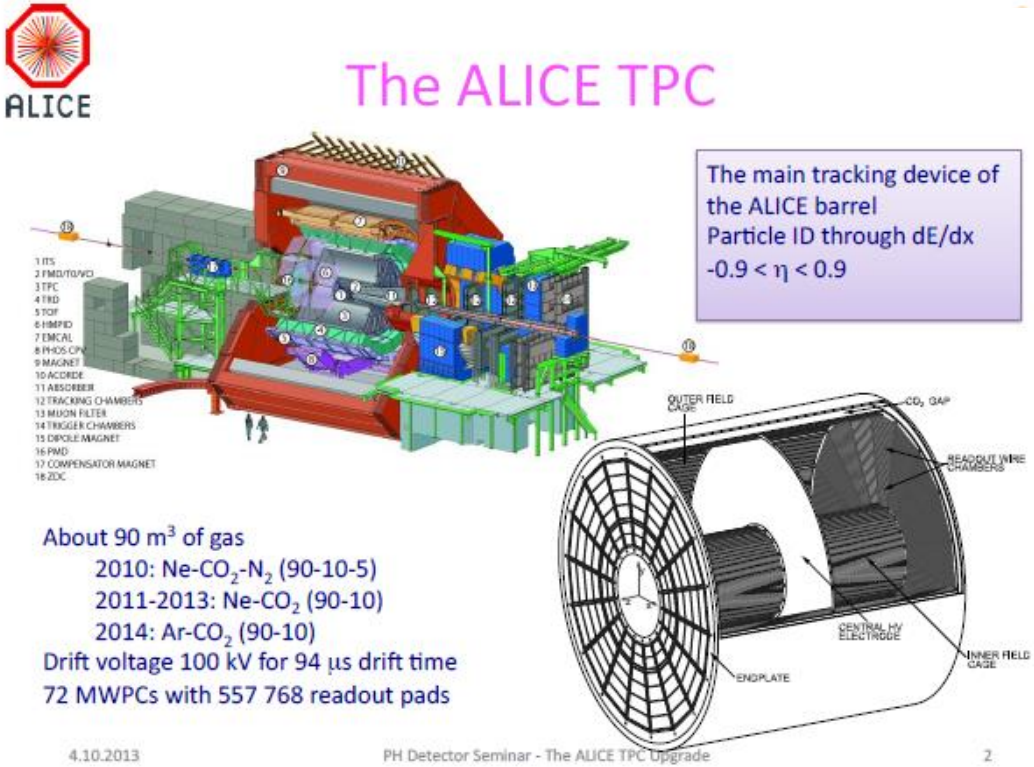
Current GE1/1 Detectors

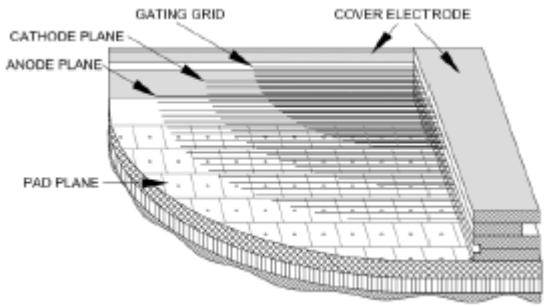


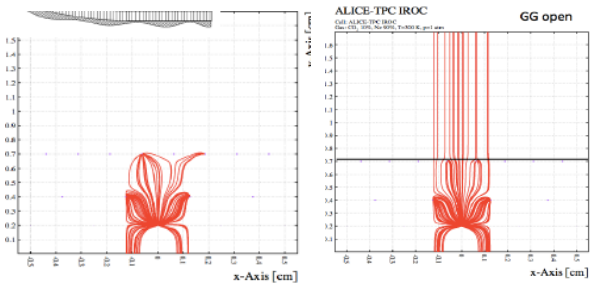


- **Single-mask & self-stretching techniques**
- **Gap sizes: 3/1/2/1 mm**
- **Sectors : 3 columns x (8-10) η partitions**
- **Strip pitch: 0.6-1.2mm**
- **1D readout of up to 3840 channels**
- **35 HV sectors**

Current ALICE TPC

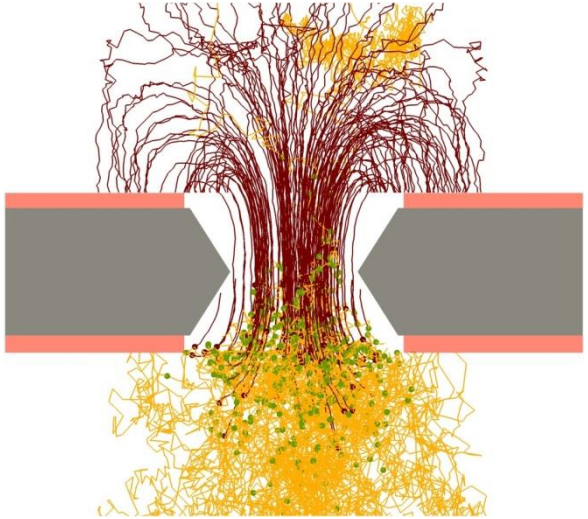






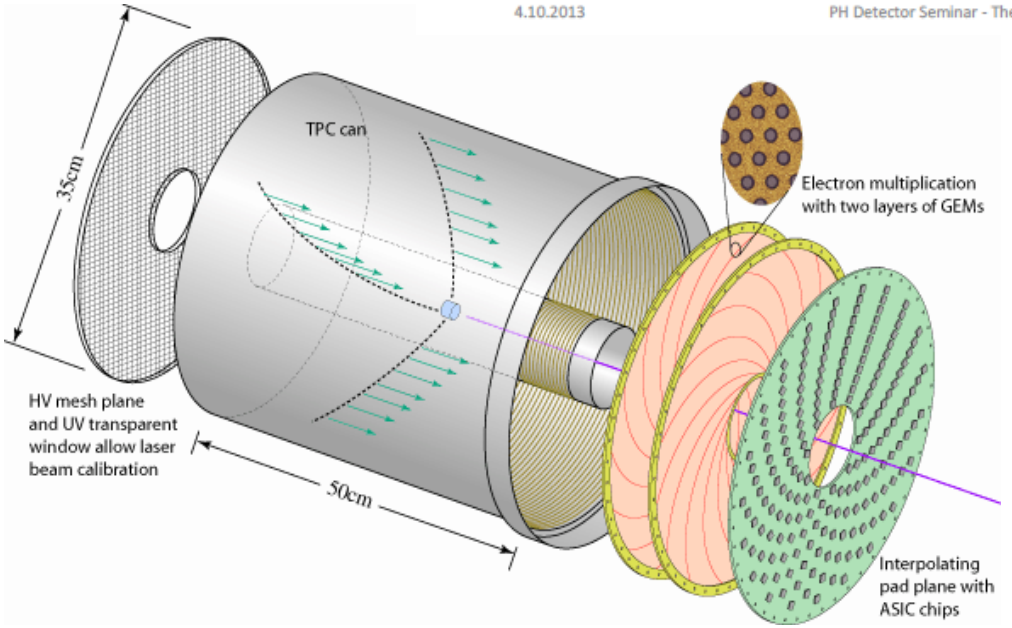
IBF suppression 10^{-4},
Gate opening time 100μs

R&D issues with GEMs



- Most GEM detectors are triple stacks operated with a standard HV configuration with a standard gas
  - IBF is several %, OK for position resolution
- A different configuration is necessary for minimizing IBF
  - Study IBF: goal is below 1%, ε below 20, for which distortions are ~10 cm
- Therefore stability of operation has to be re-demonstrated
- dE/dx resolution has to be proven
  - maintain the current performance

Definitions: $IBF = I_{drift}/I_{anode} = (1+\varepsilon)/gain$



The idea of the GEM-based TPC
(it is not ALICE TPC!)

Modified by us Breskin review/table on IBF measurements

	TPC (E_{drift}=0.1-0.2kV/cm, Gain=10^4)		GPM (E_{drift}=0.5kV/cm, Gain=10^5)	
Detector type	IBF	Collection efficiency	IBF	Collection efficiency
2GEM	4%@0.4kVcm	100%	5% (20%)*	100%
3GEM	0.5%	100%	5% (20%)*	100%
4GEM		100%	2% (0.01%)**	100%
R-MHSP/ GEM/MHSP	0.08%	100%	0.1%	100%
F-R-MHSP/ GEM/MHSP	0.015%	100%	0.03%	100%
"Cobra"/ 2GEM	0.0027%	20%	0.0003%	20%

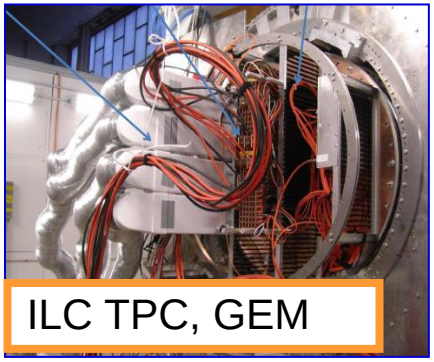
* Reflective PC **Gated mode

At what current measurements were done!?

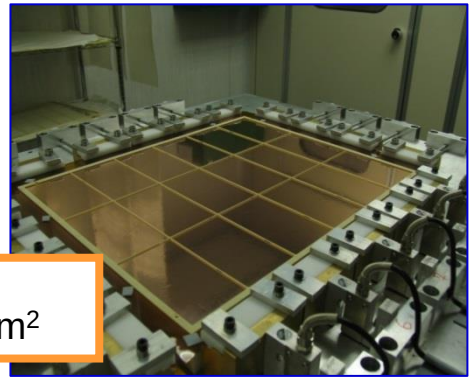
HEP & PARTICLES

More about Future

ILC TPC, MM

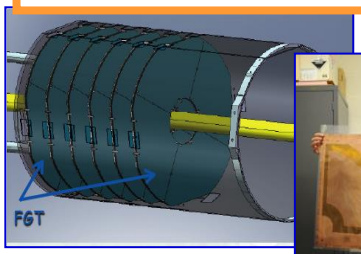


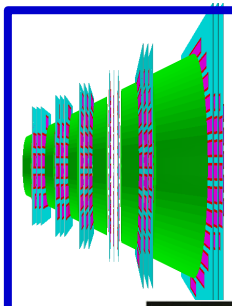
ILC TPC, GEM

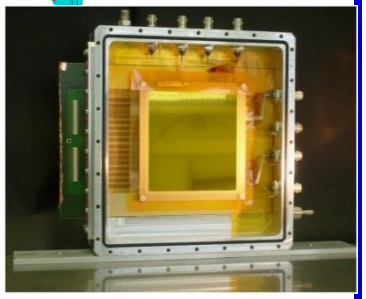


JLab Hall A
GEM 40 x 50 cm^2

STAR - Forward GEM Tracker

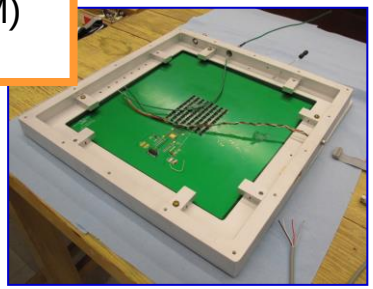


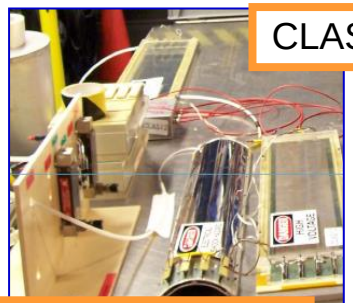




CBM: GEMs for tracking

H calorimetry(GEM) (ATLAS, ILC)





CLAS12

Cylidrical MM

MM forward tracking

Neutron detector

- Recoiled nuclei detection
- Nuclear reaction
- ^{3}He detector

Fast Neutron detection

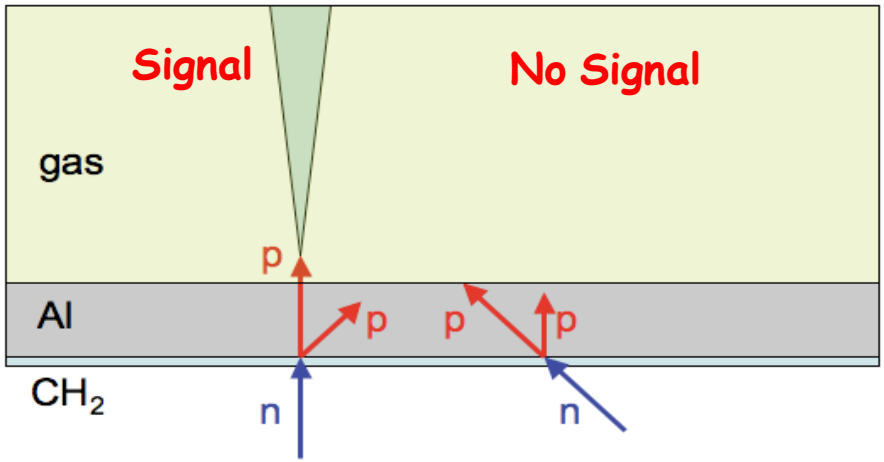
Frascati Neutron Generator (ENEA)
Neutron Spallation Source ISIS (UK)
and n-TOF (CERN)

Polietylene Converter Cathode

2.5 MeV Neutrons interact with CH_2, and, due to elastic scattering processes, protons are emitted and enter in the gas volume generating a detectable signal.

Aluminum thickness ensures the directional capability,

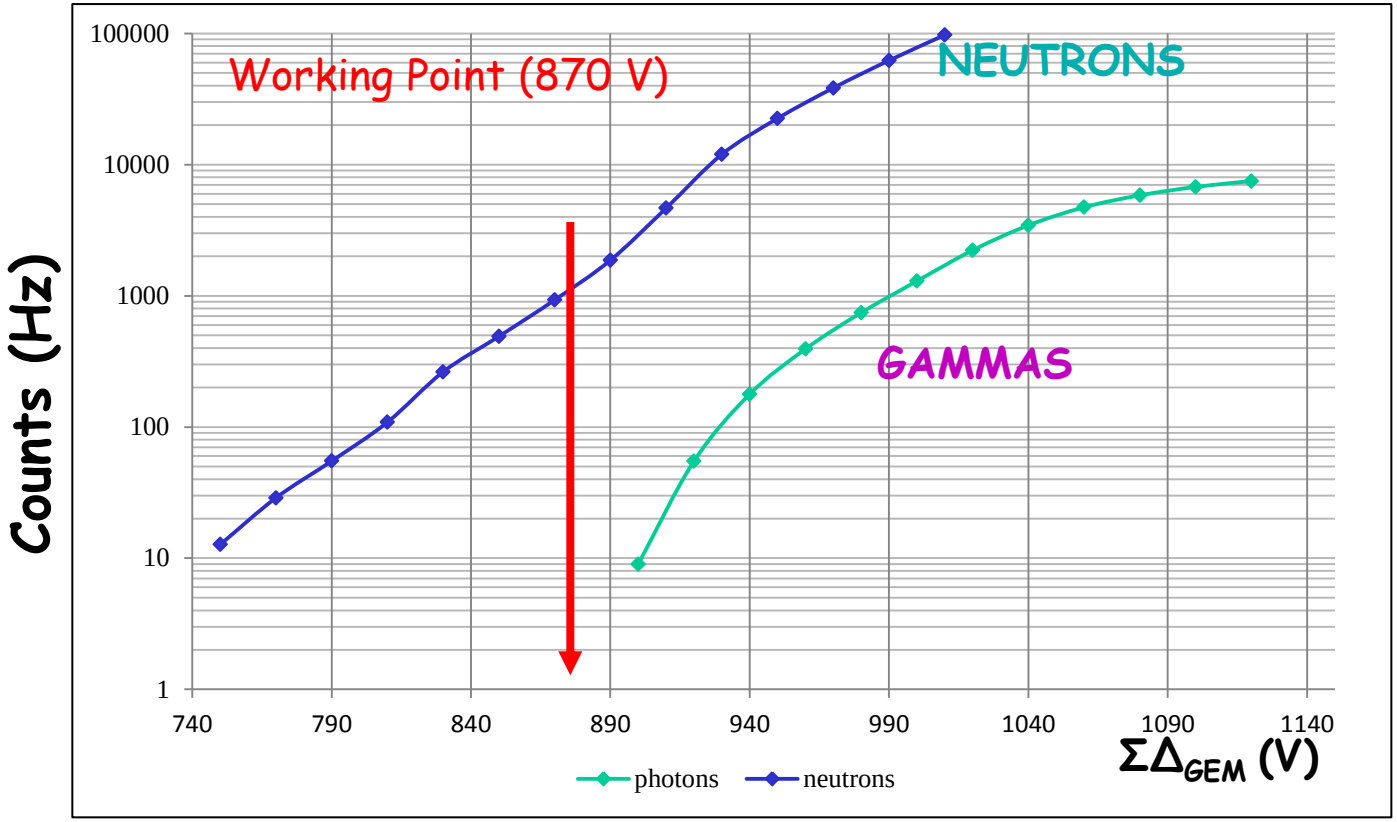
stopping protons that are emitted at a too wide angle.



Optimized CH_2-Al thicknesses (50 μm-50 μm) determined by simulations (MCNPX-GEANT4)

Efficiency of $4\ 10^{-4}$

Detector Working Point

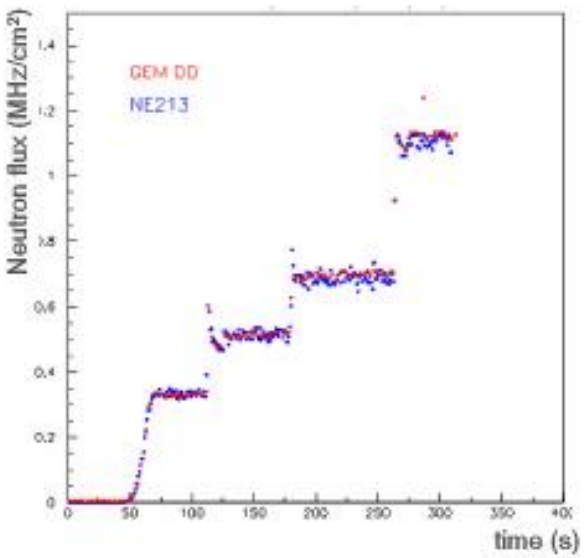


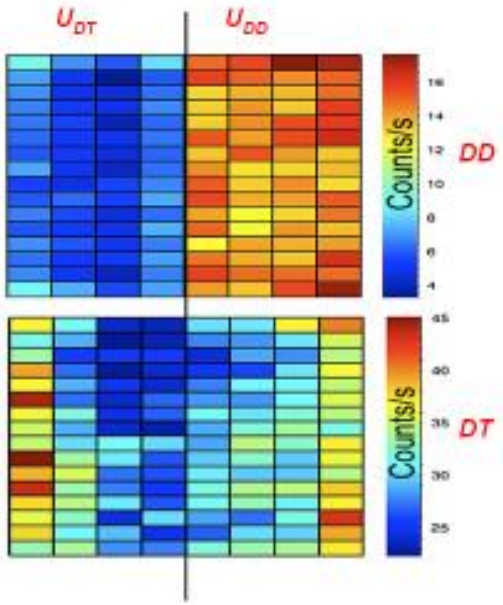
Counting rate Vs chamber gain: up **to 890 V** the chamber is sensitive to fast neutron but not to gamma rays.

Neutron diagnostics at Frascati Tokamak

The active area of this neutron monitor has been divided into two parts with the polyethylene converter optimized for the two energies (2.4 and 14 MeV from DD and DT nuclear interaction respectively)

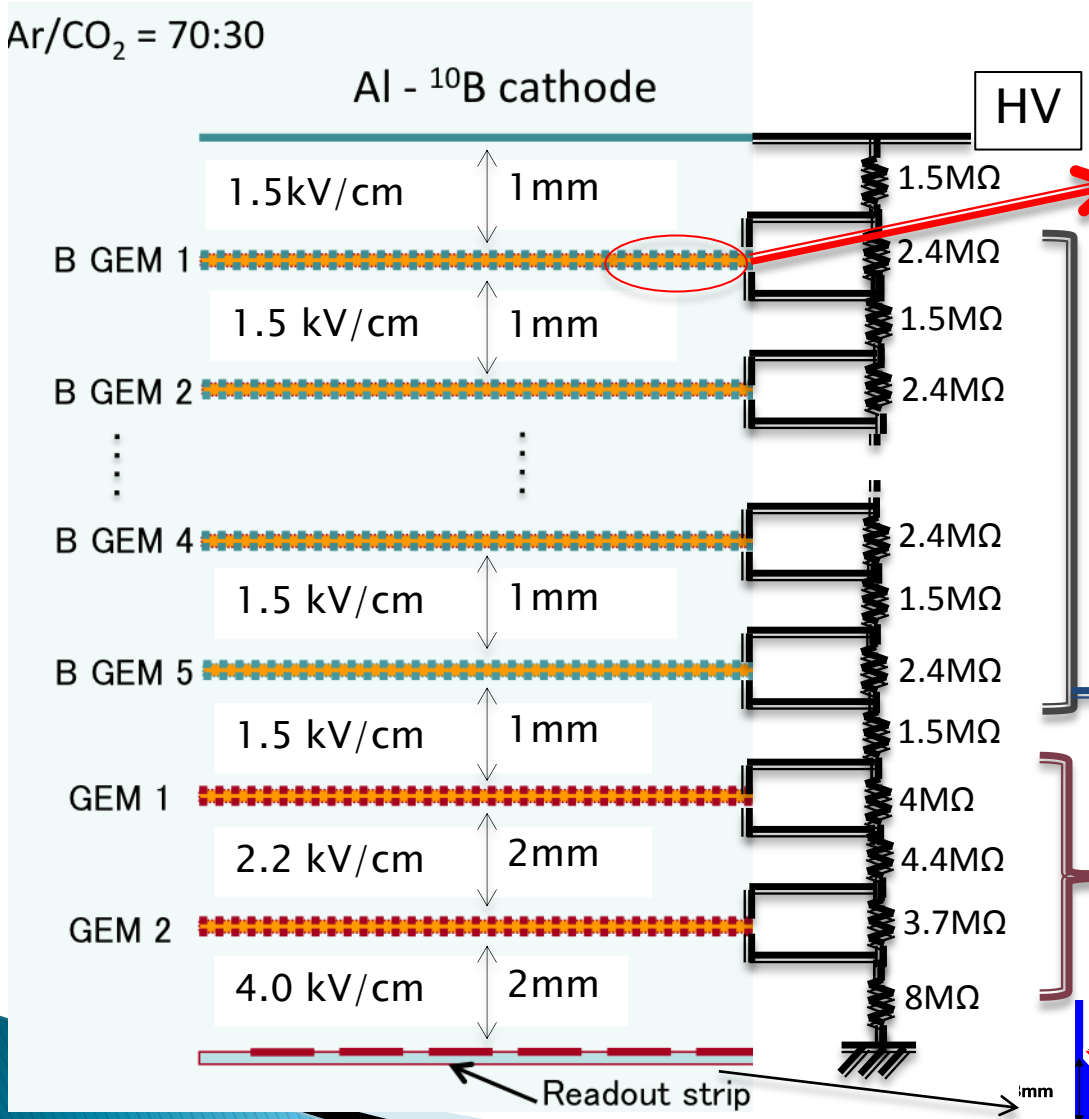
Measurements at Frascati Neutron Generator (ENEA)

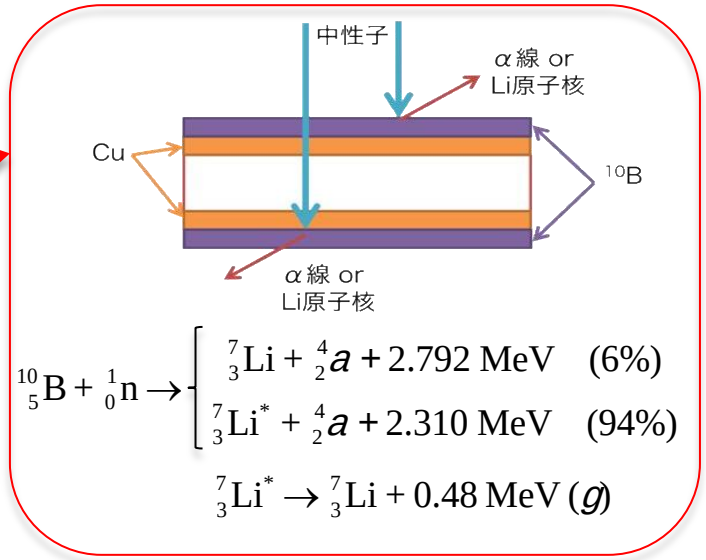




Design of a GEM-based detector for the measurement of fast neutrons
B.Esposito et al NIM A, Volume 617, Issues 1–3, 11–21 May 2010, Pages 155-157

Neutron radiography (low energy)
KEK Detector Technology Project

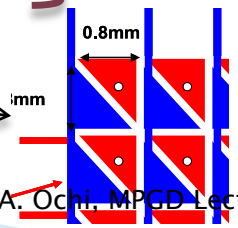




B-GEM
増幅率:1

B-GEM 5枚
変換効率:15%

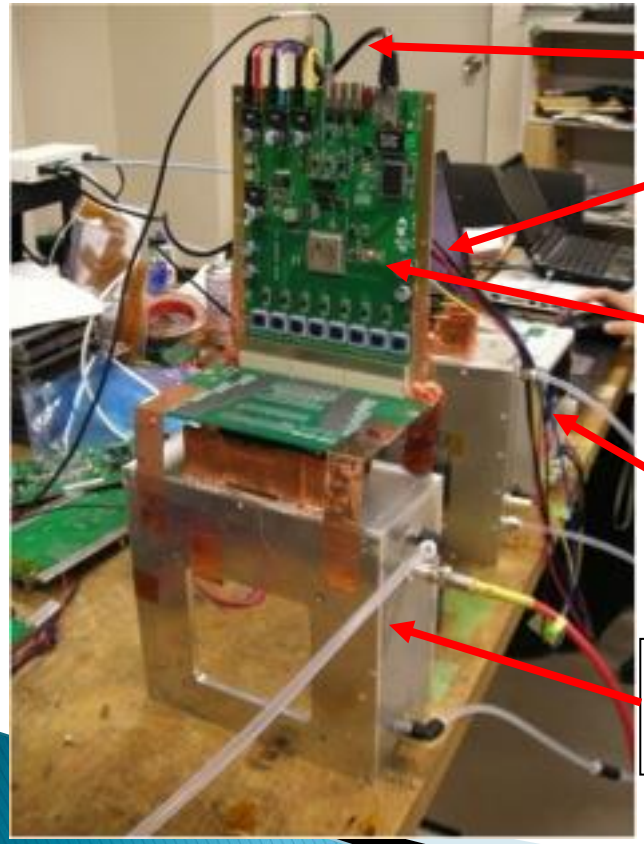
増幅用のGEM
増幅率:400



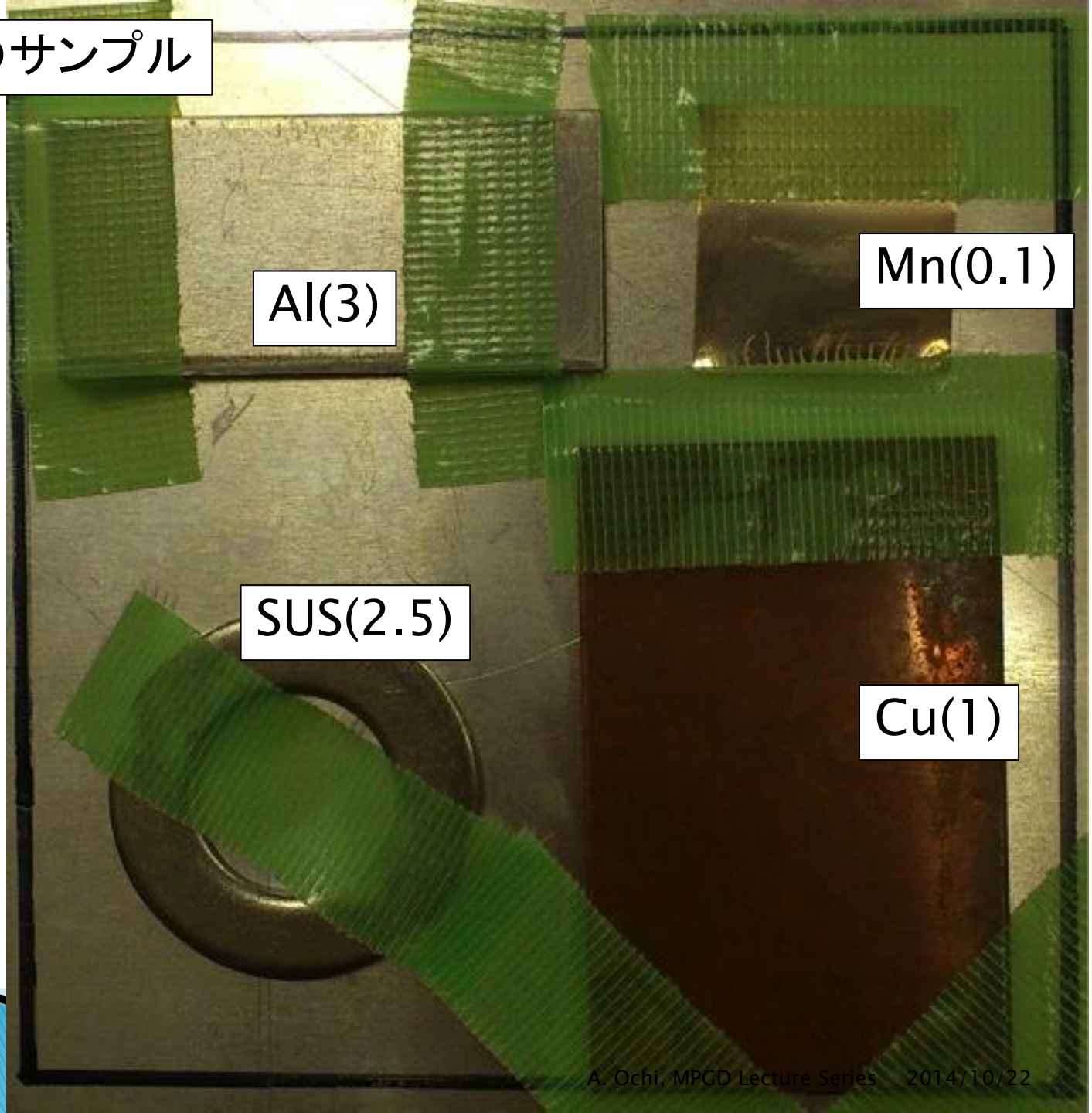
J-PARC BL10 中性子照射実験

検出器システム

検出器サイズ150mm×150mm×510mm



2つ目のサンプル

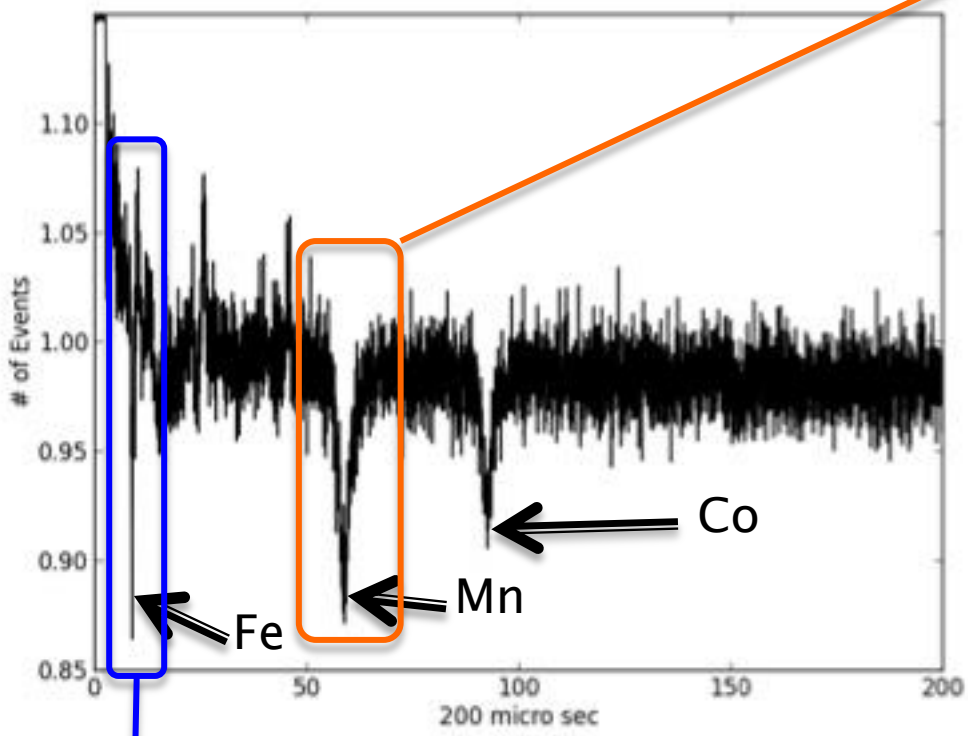


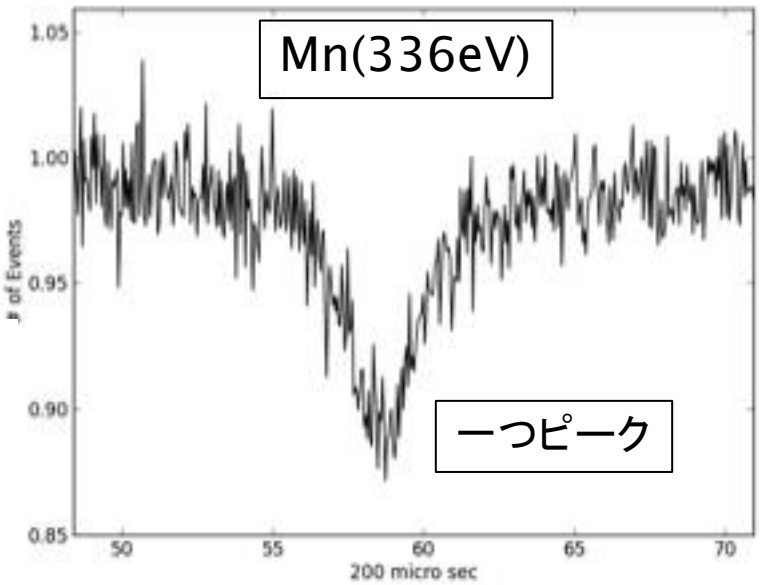
SUSのTOF（サンプル有り/無し）

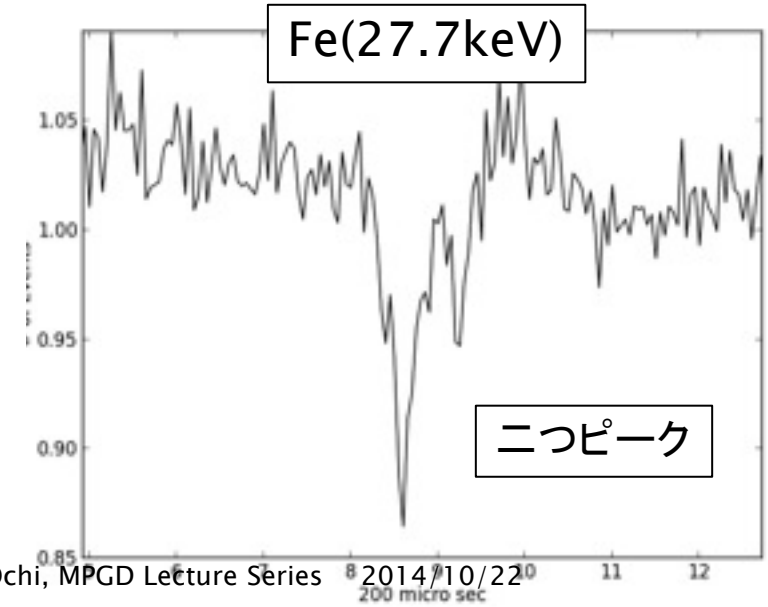
SUS304の主な化学成分　（単位：%）

Fe	Ni	Cr	Mn
68〜73	8〜10	18〜20	～2

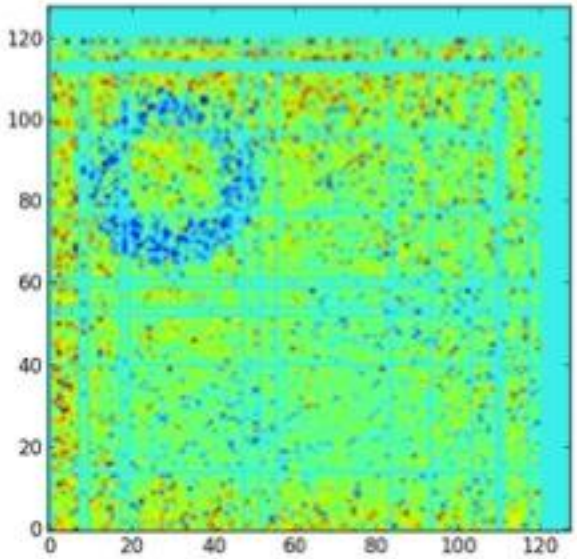
（CoはNi原料中に含有）



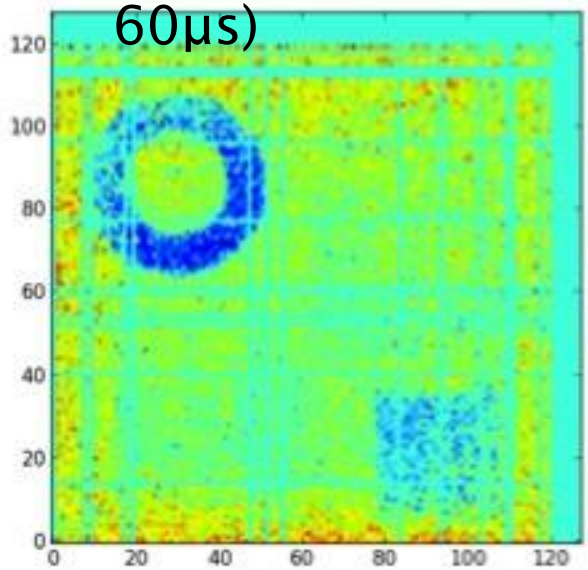




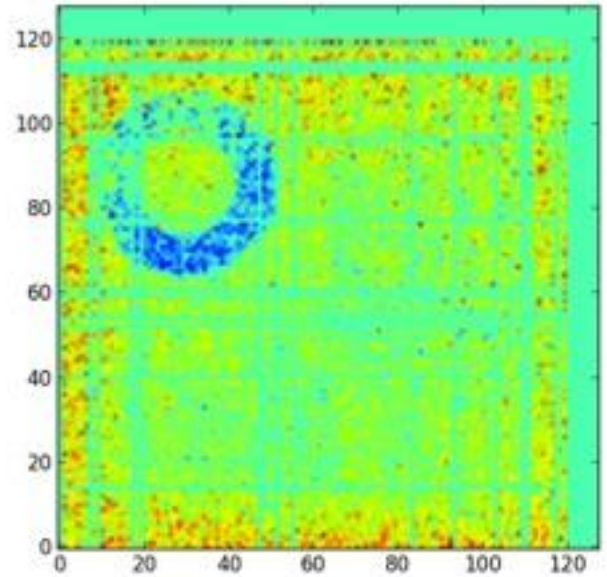
Fe試料(8.3～9.4μs)



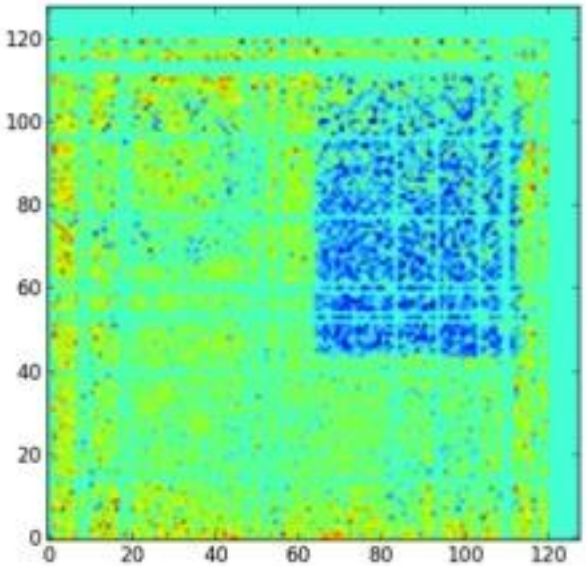
Mn試料(57.5～60μs)



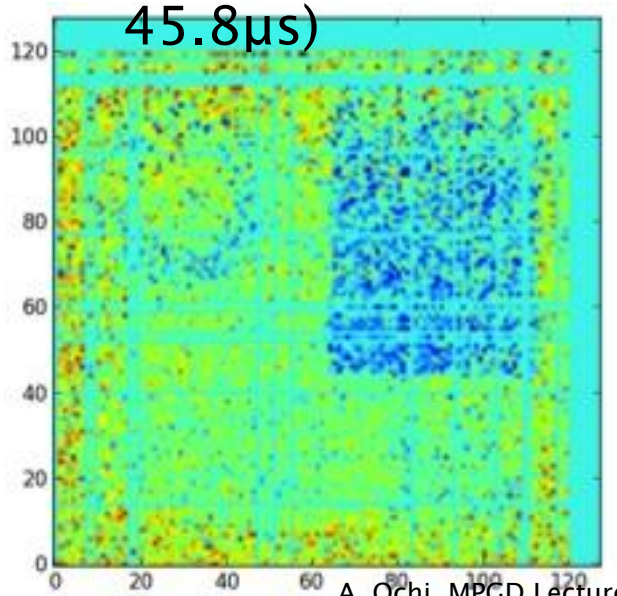
Co試料(91～93μs)



Cu試料(25～25.8μs)



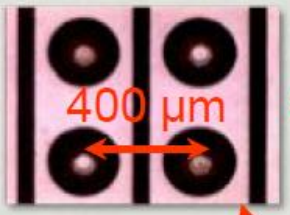
Cu試料(45～45.8μs)



サンプル有り/無し

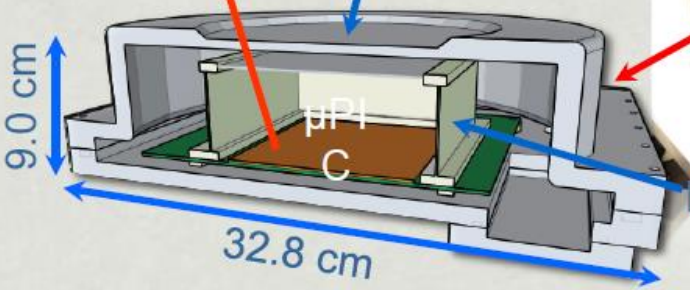
Time-resolved neutron imaging detector

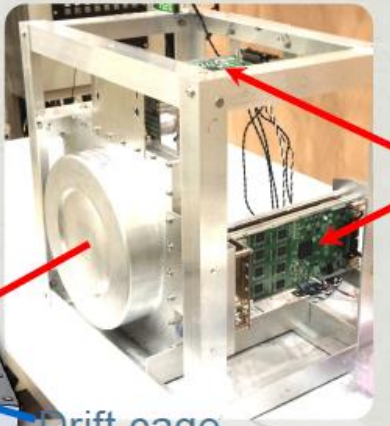
Kyoto University



10 × 10cm² active area

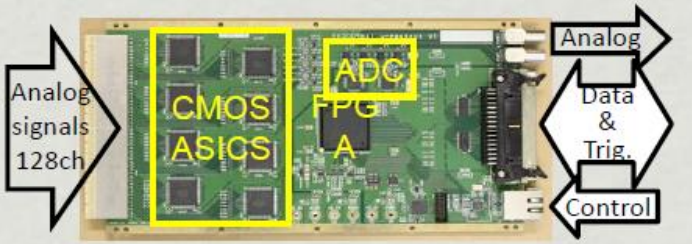
Aluminum vessel





Drift cage

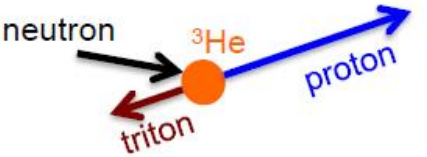
FPGA-based data encoders



ASICs and FPGA on single board

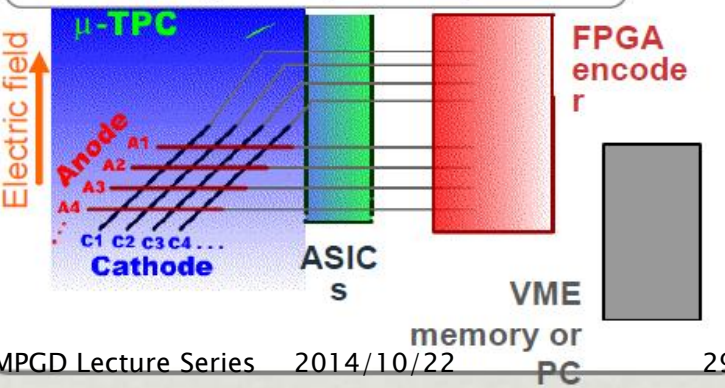
- 10 × 10cm² μPIC (mfd. by DaiNippon Printing Co.)
  - Inexpensive PCB technology, up to 30 × 30cm²
- Ar:C_2H_6:^{3}He (63:7:30) gas mixture at 2 atm
  - Efficiency of 18% at 25.3 meV
  - Low gain, good stability against discharge
  - >2 years operation with single gas filling
- Compact, high-speed FPGA-based DAQ system
  - Capable of ~Mcps data rates
  - Energy deposition via time-over-threshold

Detecting neutrons with a Time Projection Chamber (TPC)



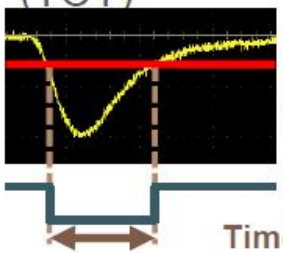
Typical track length ~8mm in 2atm gas.

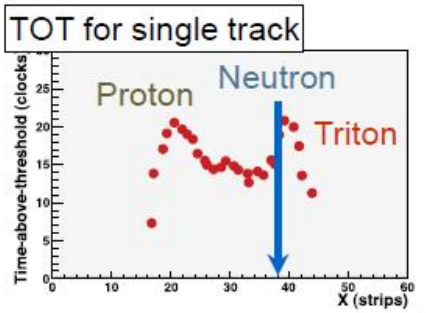
TPC measures 3D track of proton and triton (2D strip + time)



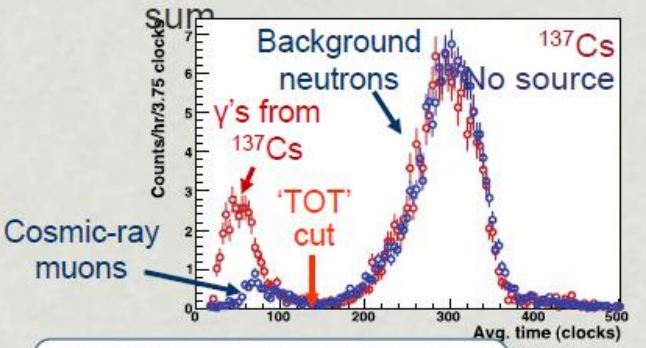
Time-resolved neutron imaging

FPGA encoder with time-over-threshold (TOT)





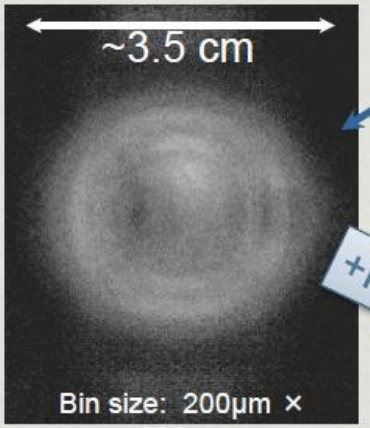
Event-by-event TOT sum



Good separation of gammas and neutrons in 'total TOT'

Neutron position reconstruction with template fitting

TOT templates determined by GEANT4 simulation



Position from mid-point of track.

Resolution: ~1mm(σ)

+Fit

Resolution with fitting: 100 to 120μm(σ)
(Final resolution depends on tracking cuts.)

Image data taken at NOBORU J-PARC in Feb. 2011

TPC with 3D tracking + Energy deposition via time-over-threshold

= 100μm-level spatial resolution

= Gamma sensitivity of $<10^{-12}$

+ 0.6μm time resolution

+ Mcps rate capability

+ Large area at low cost

X-ray detector

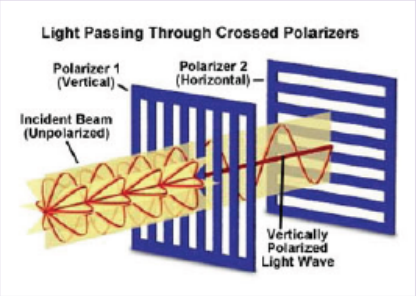
- Photoelectric effect
  - X-ray polarimetry for astro physics
  - Plasma diagnosis
  - X-ray crystalography

NASA / RIKEN

Polarization

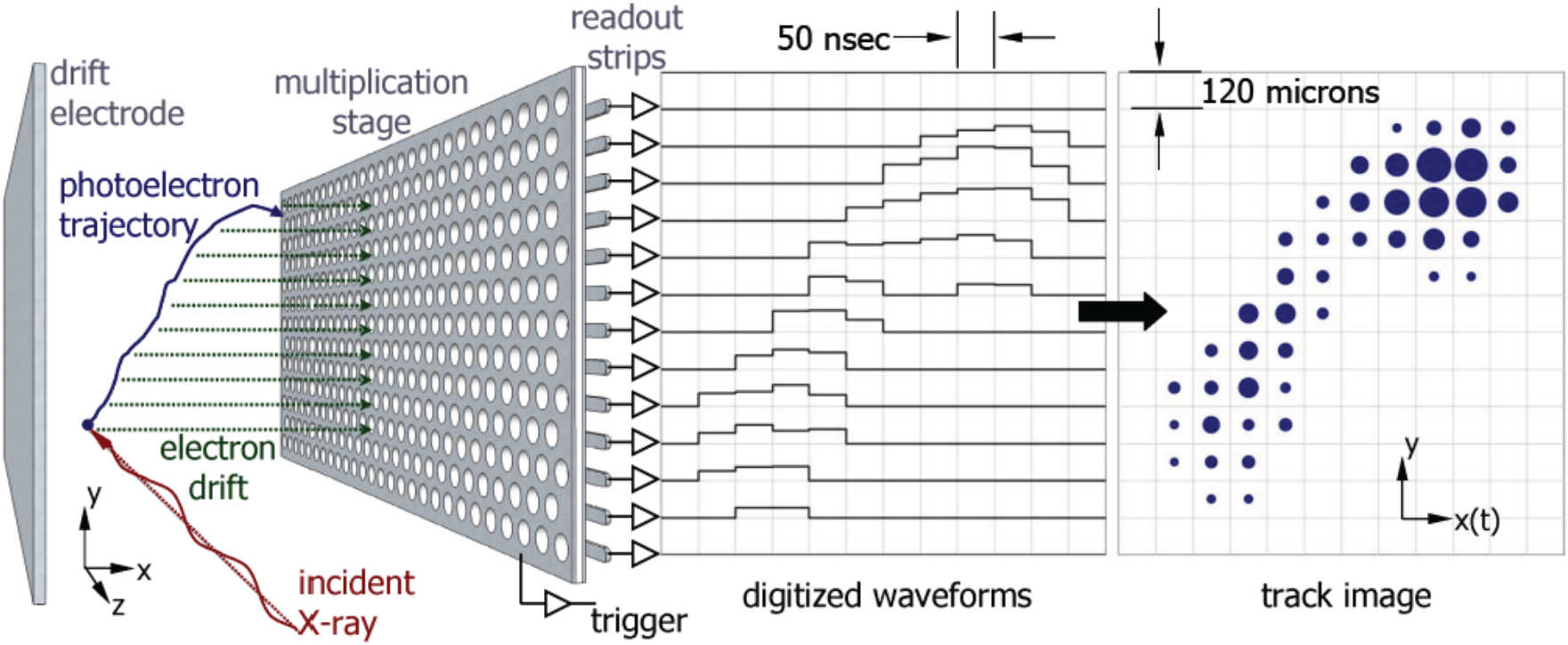
- New dimension
- Final frontier in X-ray Astrophysics

Polarimetry is technically easy in radio and optical, but not in X-ray/gamma-ray. We should know electric vector photon-by-photon.



2.3 Design of GEM-TPC polarimeter

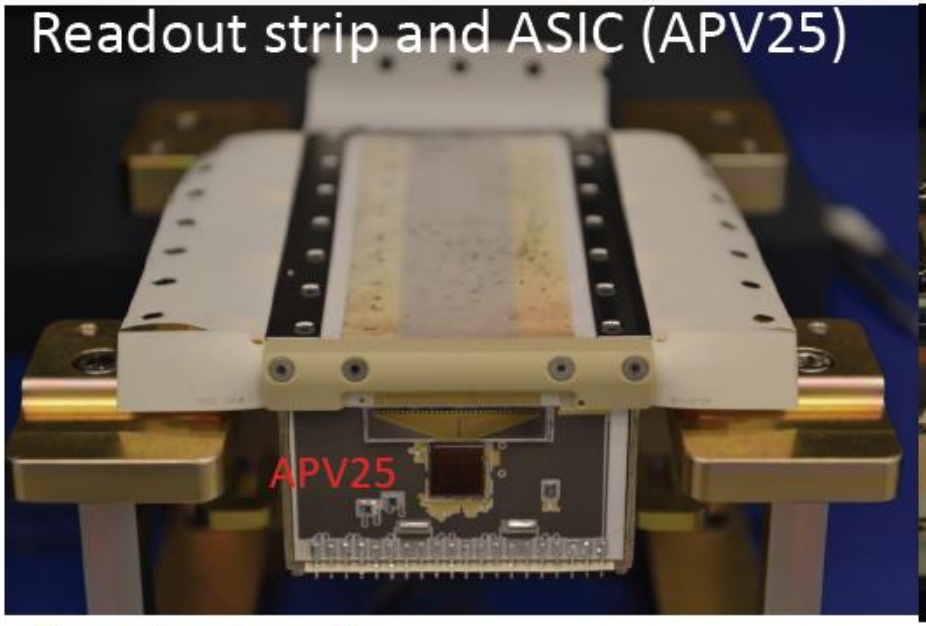
GEM-TPC as a photoelectron track imager (Black+2007)

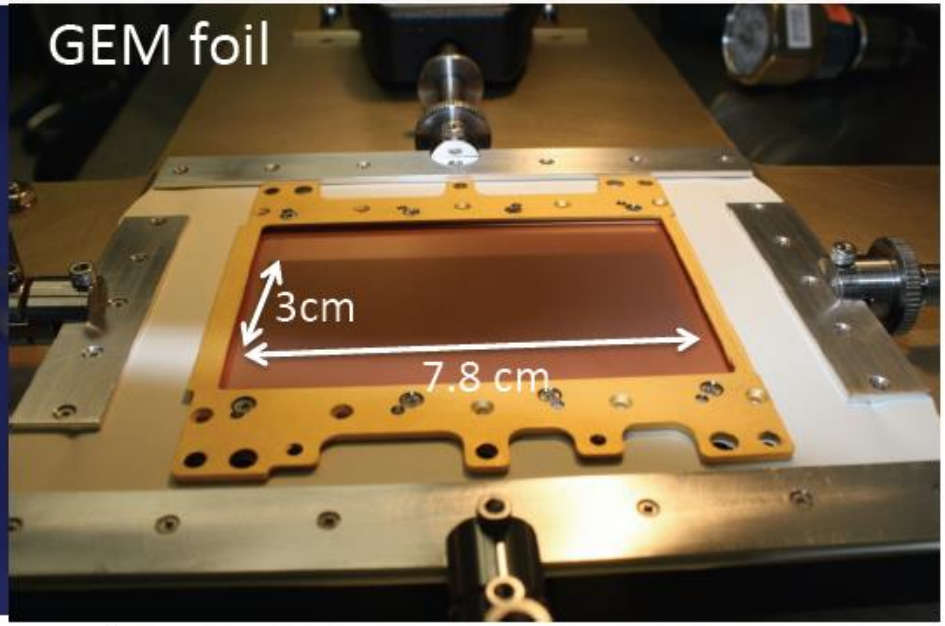


A time-projection technique creates pixel images from a 1D readout.

- Pure DME (C_2H_6O), 190 Torr to obtain longer photoelectron tracks
- Longer (>30cm) effective volume along the optical-axis for good detection efficiency
- Slow drift velocity of DME = spacing of strips (0.25cm/us * 20 MHz = 120 micron)

2.5 Readout strip and GEM foils



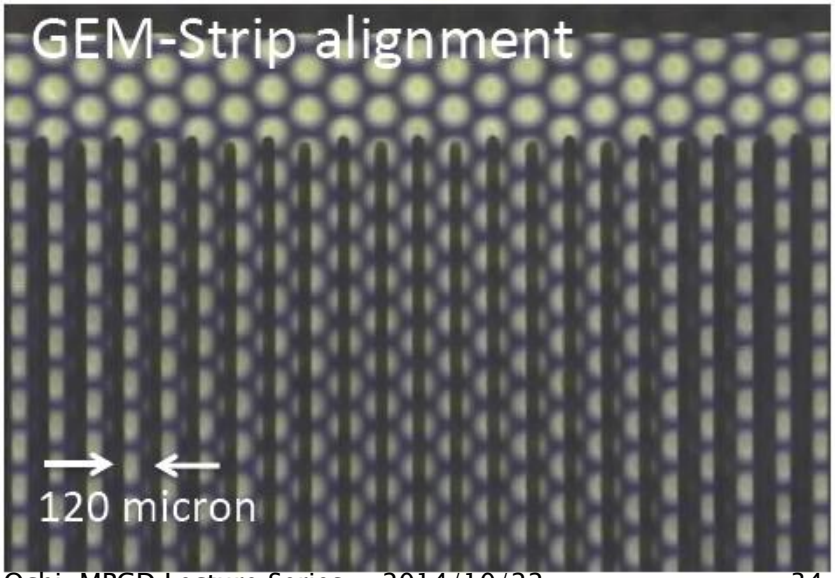


Readout strip

- 128 strips (pitch 120, width 60 micron, 7.8 cm long)
- veto region in both side
- connecting to APV25 (20 MHz clock)

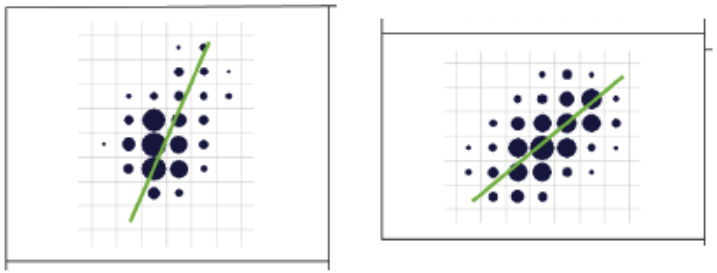
GEM foil

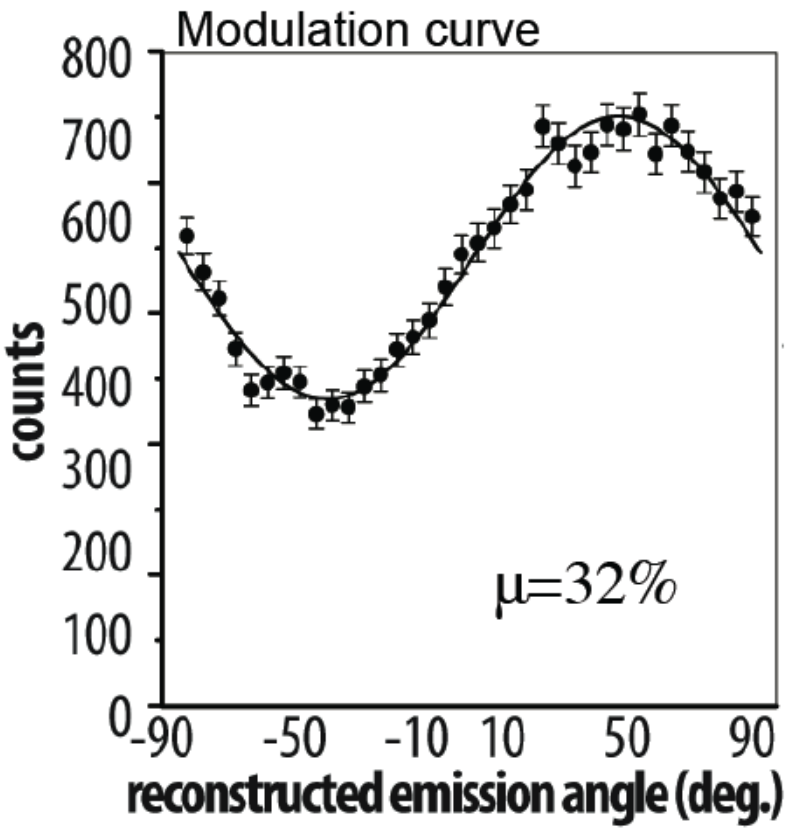
- LCP-GEM
- 140 micron pitch, 70 micron hole
- 100 micron thick



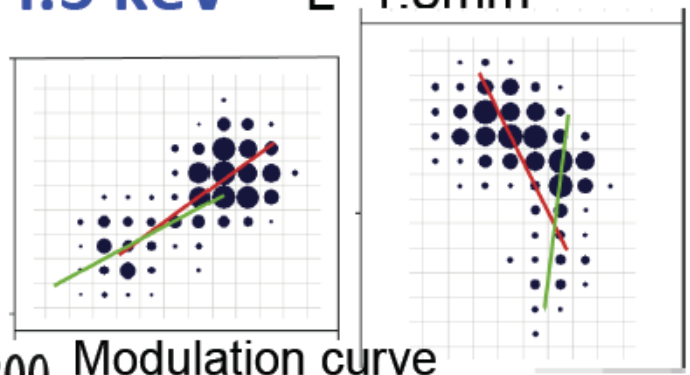
3.1 Track image and modulation curve

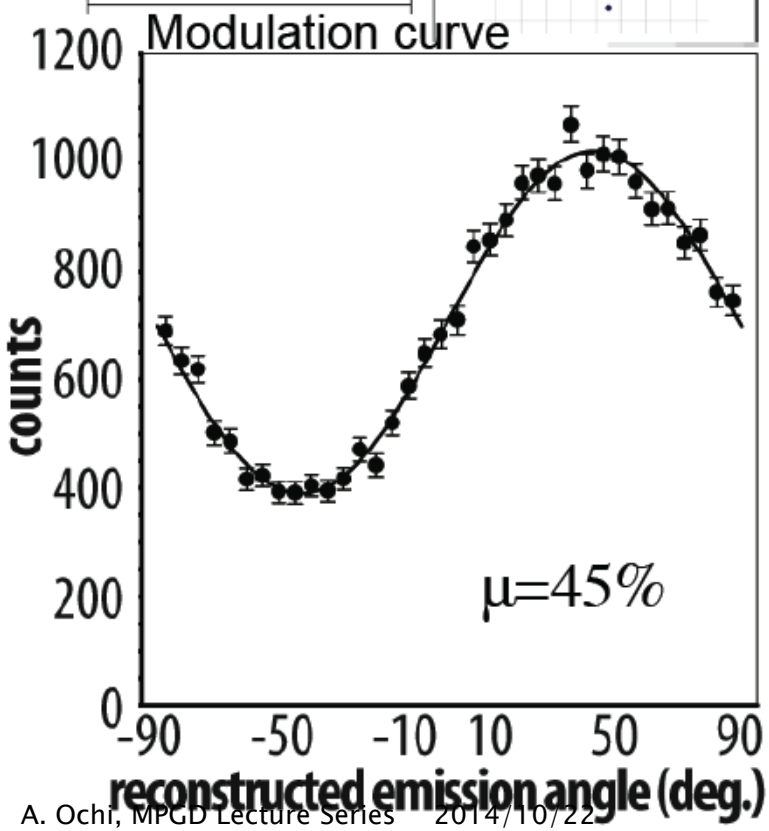
2.7 keV L=600um



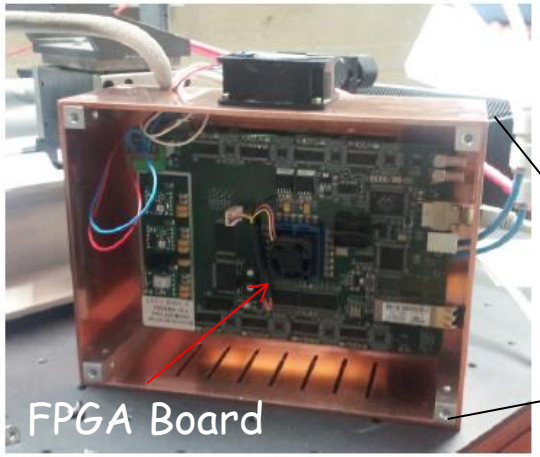


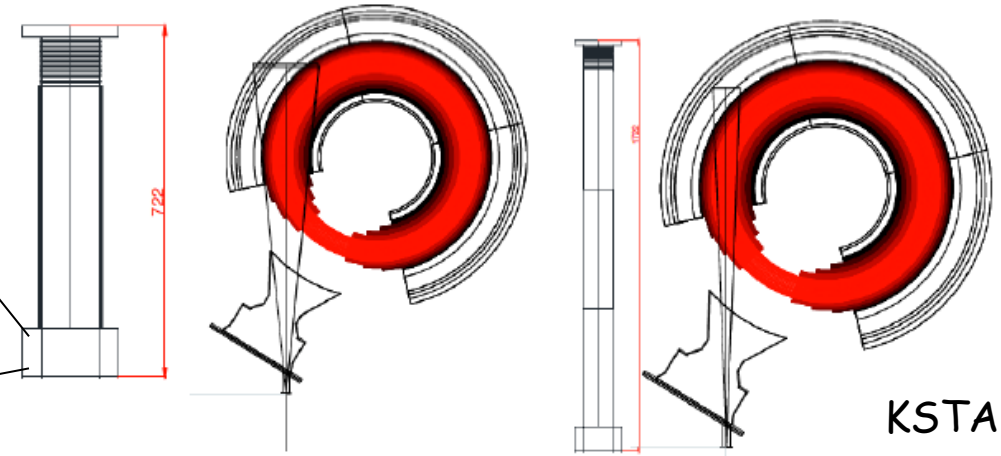
4.5 keV L=1.5mm

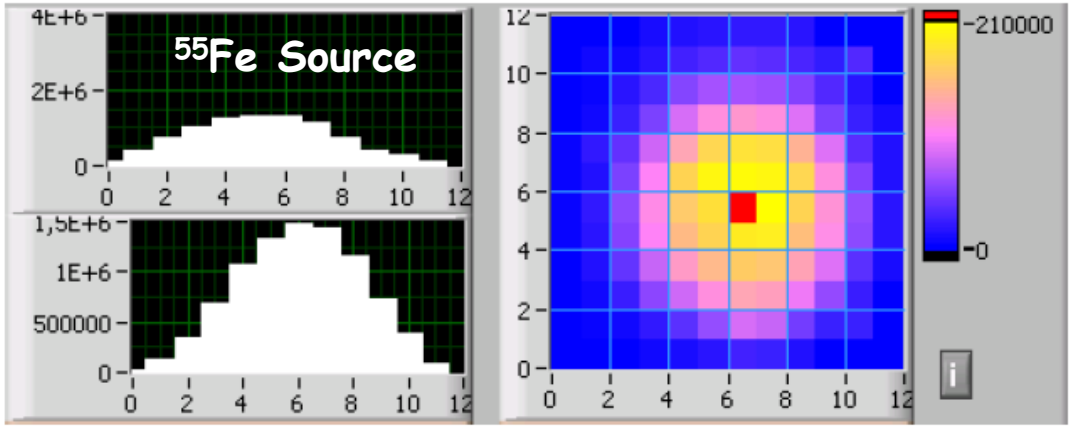




Tokamak diagnostics at KSTAR (KOREA)







The system firmware is able to produce a movie of 65000 frames of 1 ms.
The 2013 KSTAR data taking will start in few weeks.

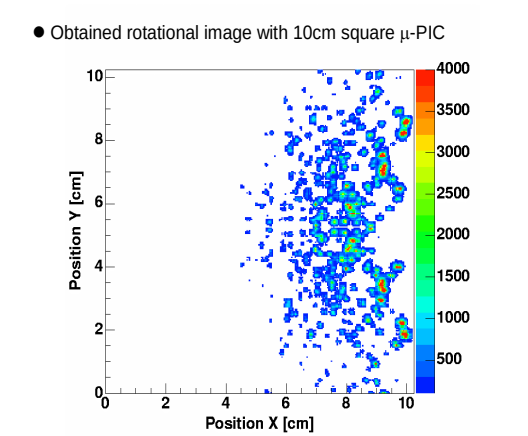
D. Pacella et al. :
GEM-based Energy Resolved X-ray Tangential Imaging System at KSTAR

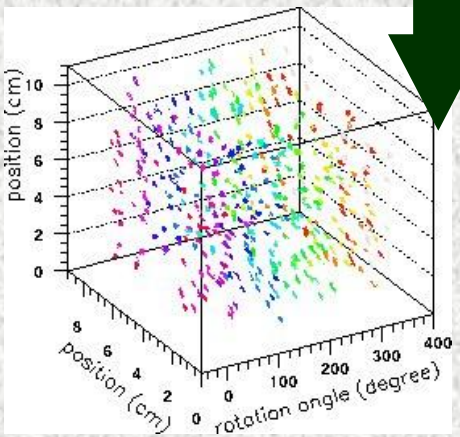
Time resolved X-ray Crystallography (photo-counting Imaging)

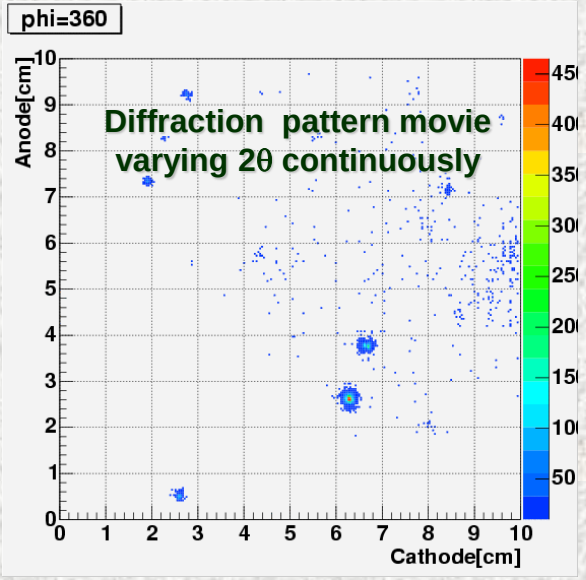
Kyoto Univ,
Tokyo Inst of Tech.

- Dynamic Range 10^6 (better than IP)
- Rint <3% (smaller systematic than C

(Journal of Synch. Takeda et al. 2005)





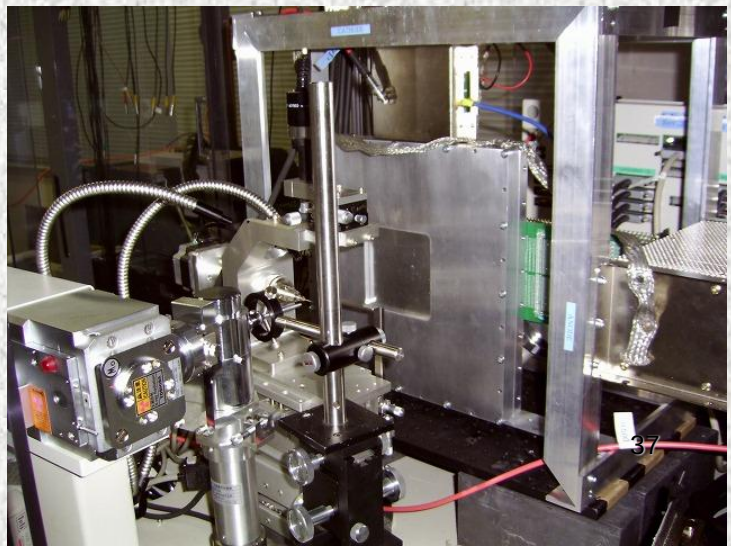


100MHz peak counting
30MHz average counting

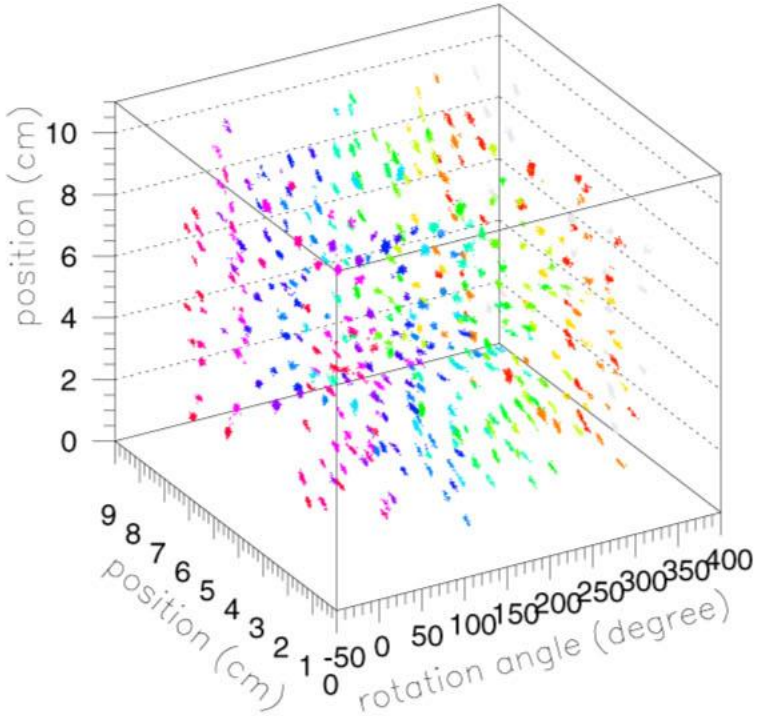
Very Quick Measurement !

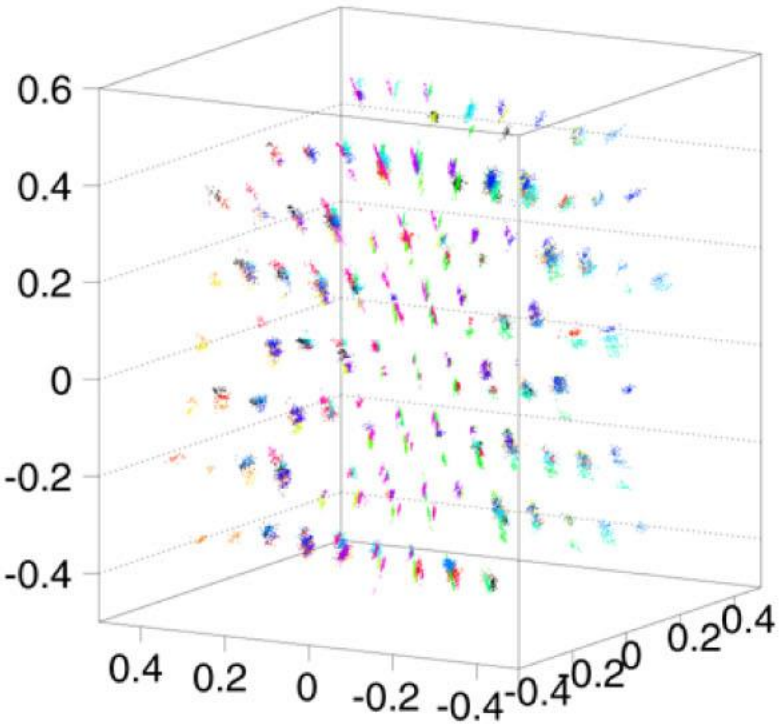
Ochi et al NIM-A (2001)

Crystal	Ref. #	R-factor (I > 2σ)	time (sec.)
$C_4H_9NO_6$	1,406	7.9%	2.1
$C_{20}H_{37}CoN_6O_4$	4,361	9.8%	300
$C_{25}H_{26}O_4$	4,565	8.4%	80



3-dimensional peak search and indexing

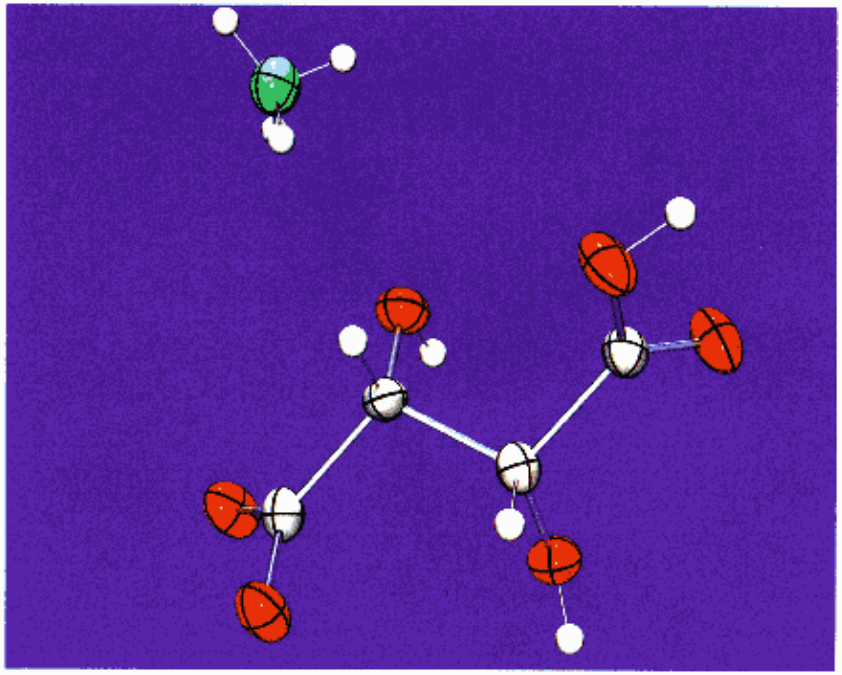




Diffraction spots in
Real space (x,y,t space)

Translated to reciprocal lattice

Very Rapid Structure Analysis



- Ammonium Bitartrate
- $C_4H_9NO_6$, $P2_12_12_1$, Z=4
- a=7.893, b=7.622, c=11.138Å, V=676.3Å^3
- Sphérized crystal (D=1mm)

- ***2.1 sec.*** measurement
- 1521 refs. Measured, 753 refs. Uniq. $2\theta_{max}$=55°, completeness=82%
- Rint=16%, Rsigma=18%
- R1=7.9% / 376 refs.
- (IP: R1=2.9%/900refs; 3.5hr)
- usual direct method, refined anisotropically: C, N, O

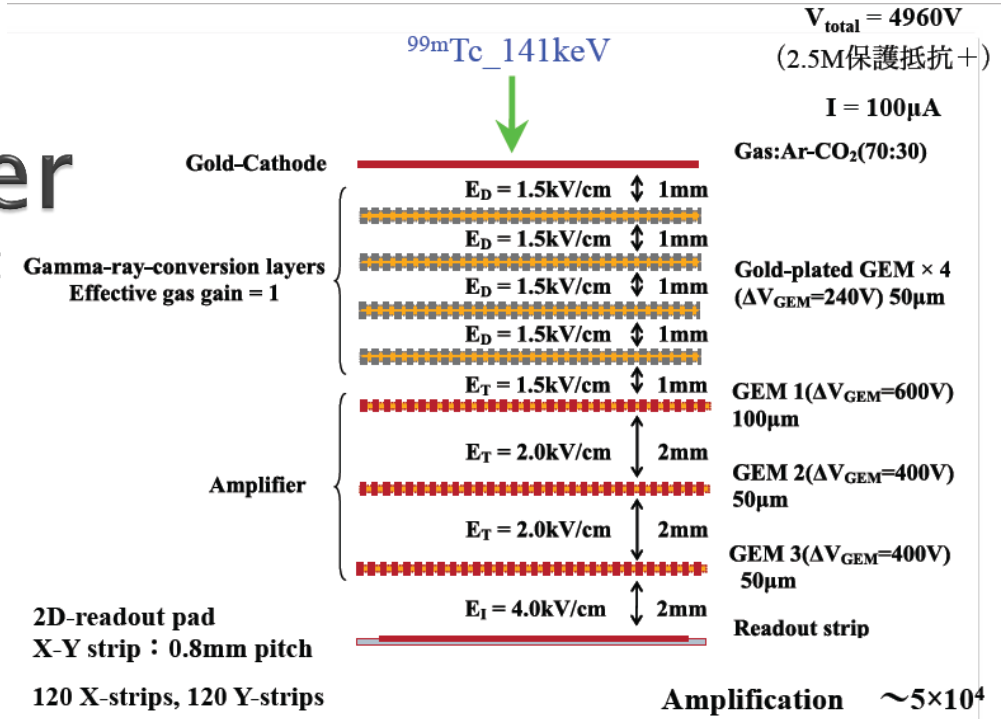
γ-ray detector

- Photoelectric effect
- Compton camera

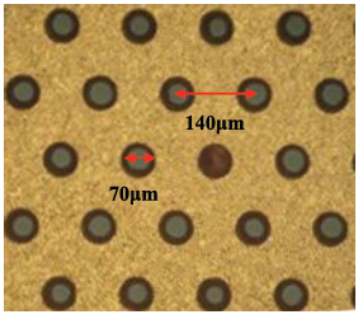
γ-ray imager using γ converter

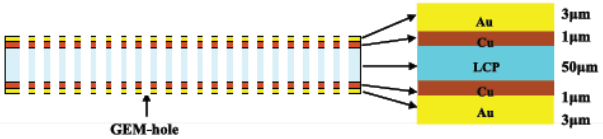
KEK Detector Technology Project

- Au plated GEM or porous converter
  - γ-ray → electrons
  - GEM signal is read by 2-dimensional readout system

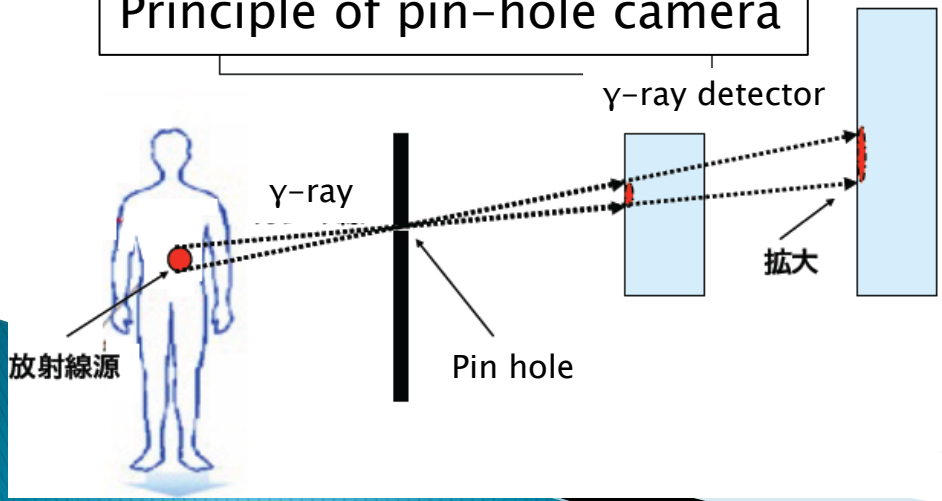


Au-GEM(Gold-plated)



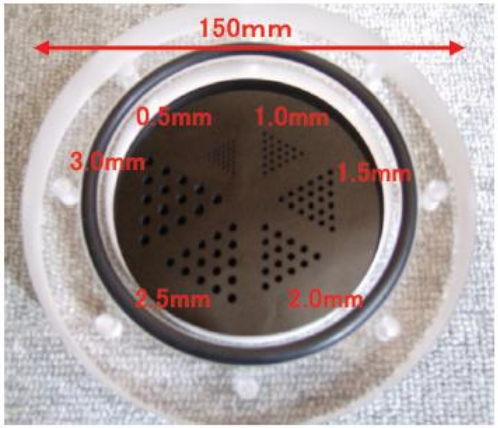


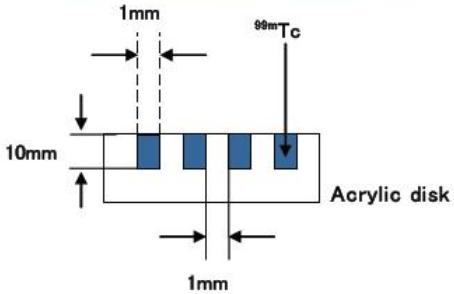
Principle of pin-hole camera



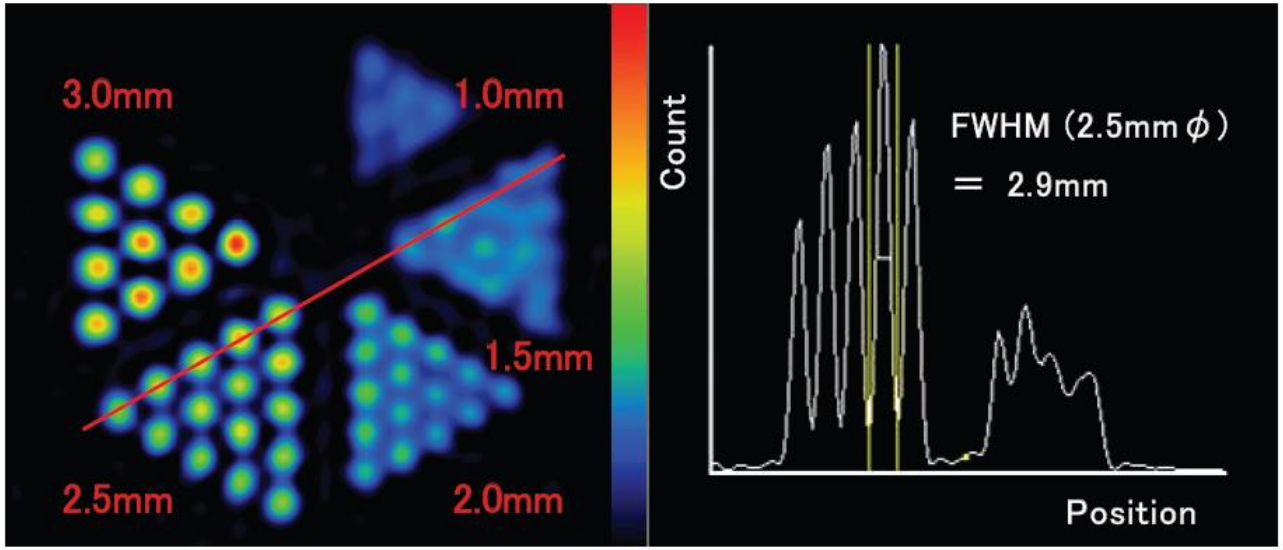
γ-ray imager using γ converter

^{99m}Tc phantom source





Cross section of 1mm-hole

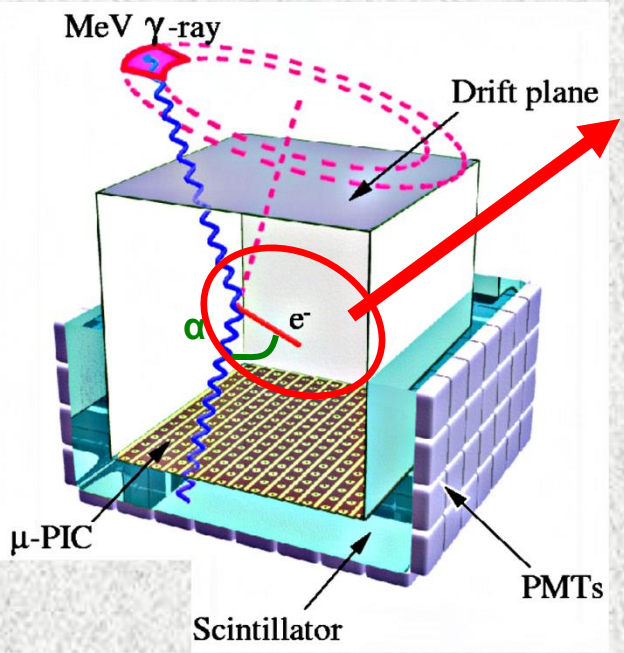


Acquisition time: 60min
Image filter: Butter worth: cut off frequency = 0.20 cycle/cm
Window level: Lower 5%cut

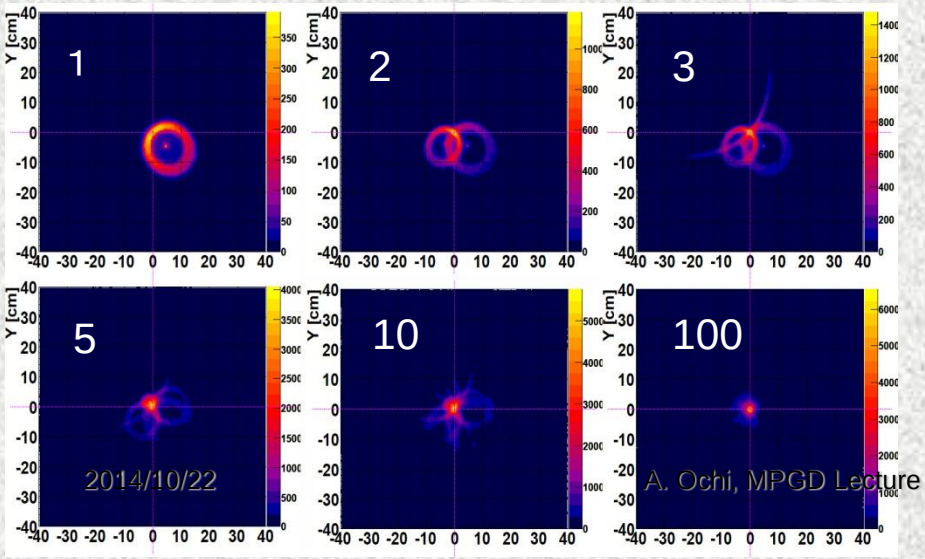
- Position resolution: 2.9mm

Electron Tracking Compton Camera(ETCC)

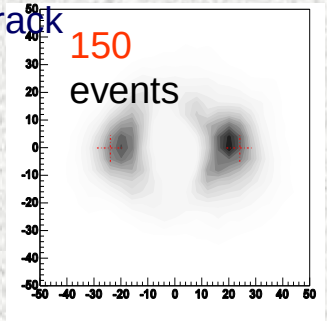
Kyoto University



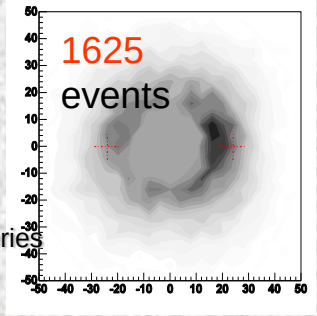
1. Determination of the direction of each gamma ray
2. Noise Reduction by Kinematics(α)
3. Large FoV. ~3str
4. For All Sky MeV-γ Survey with >10 better than COMPTEL



In use of electron track



no use of electron track



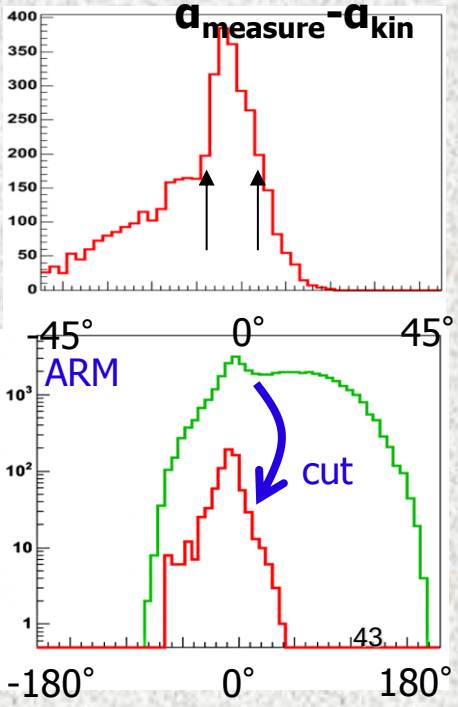
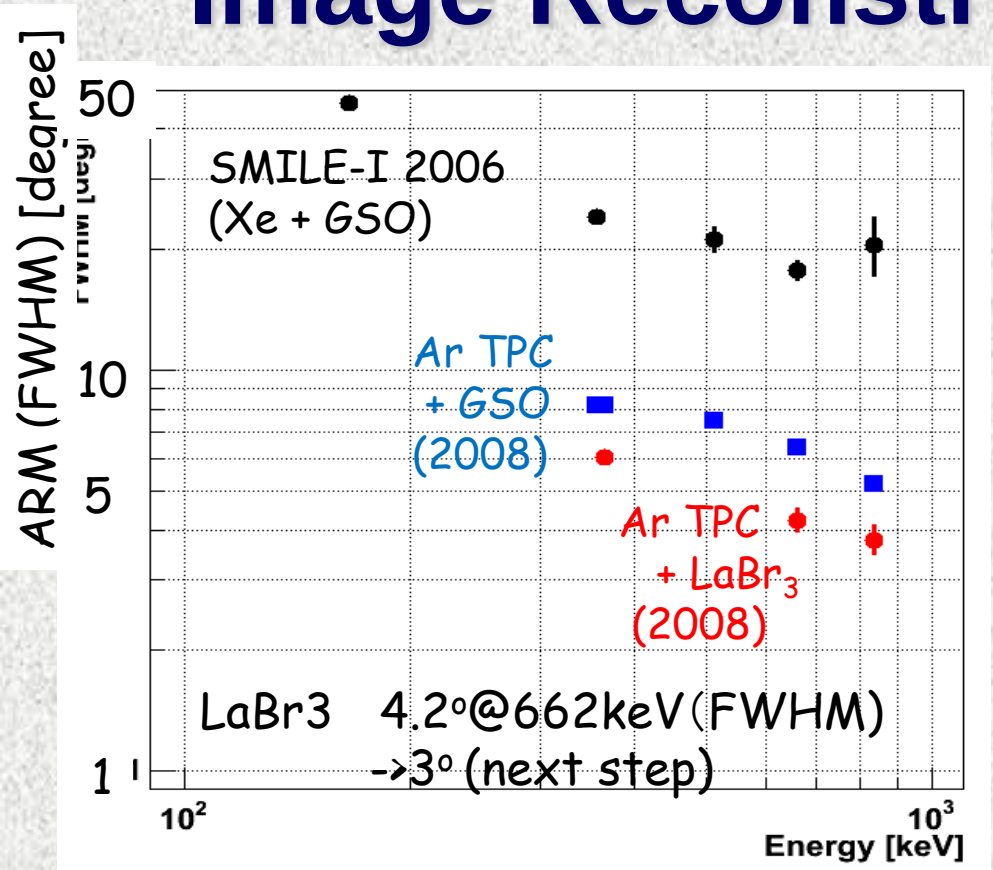
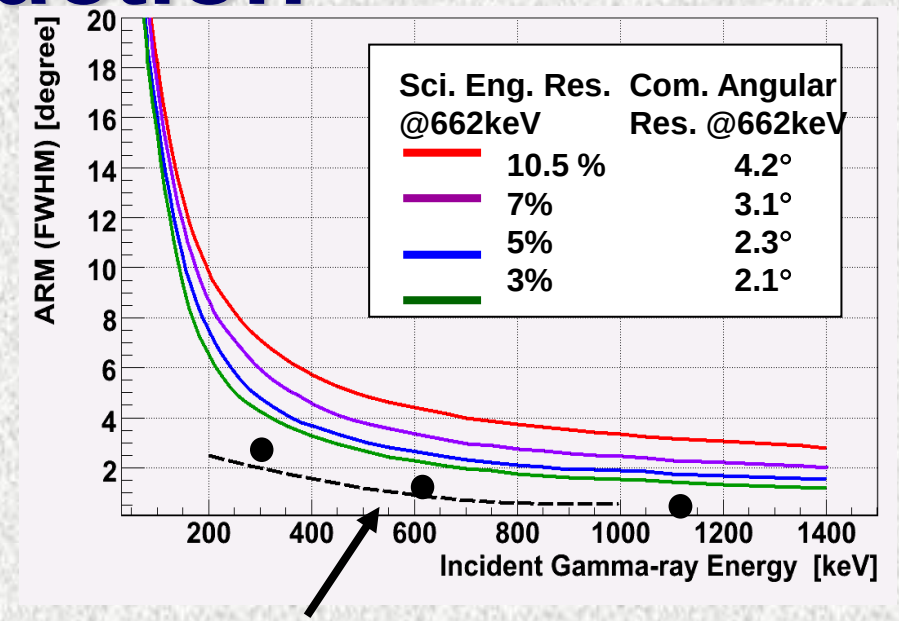
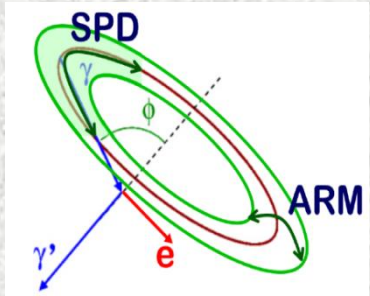


Image Reconstruction



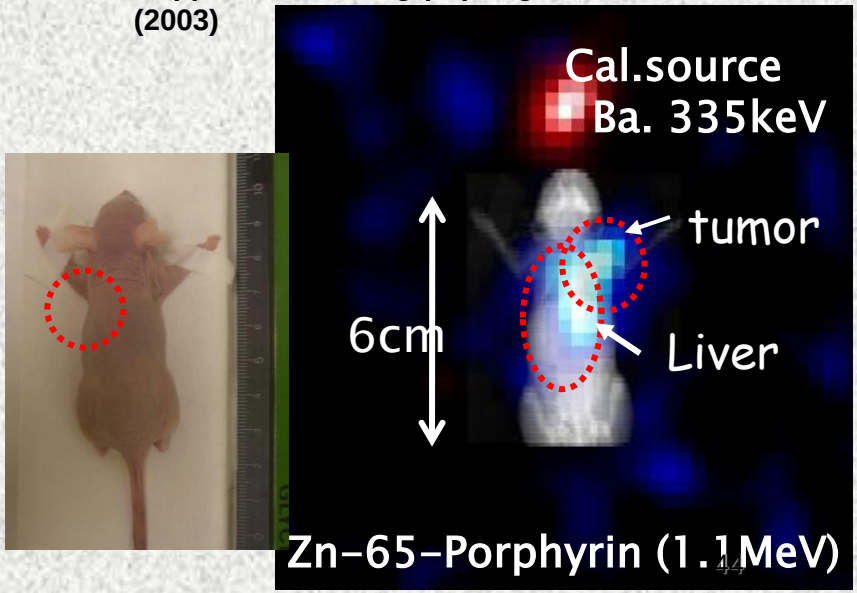


Doppler broadening (Ar) Zoglauer *et al.* (2003)



SPD~100°(FWHM)

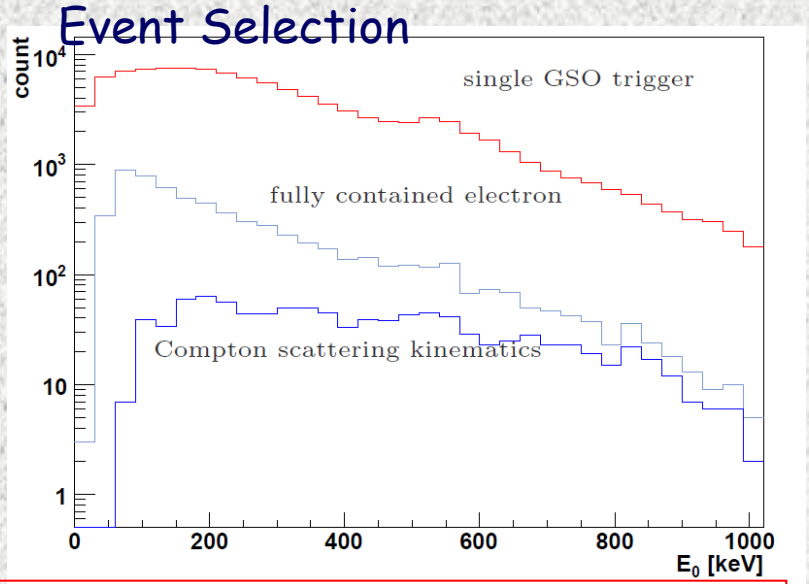
Integral SPI(Ge)
~3°@662keV



Best performance C.C. in Medical use

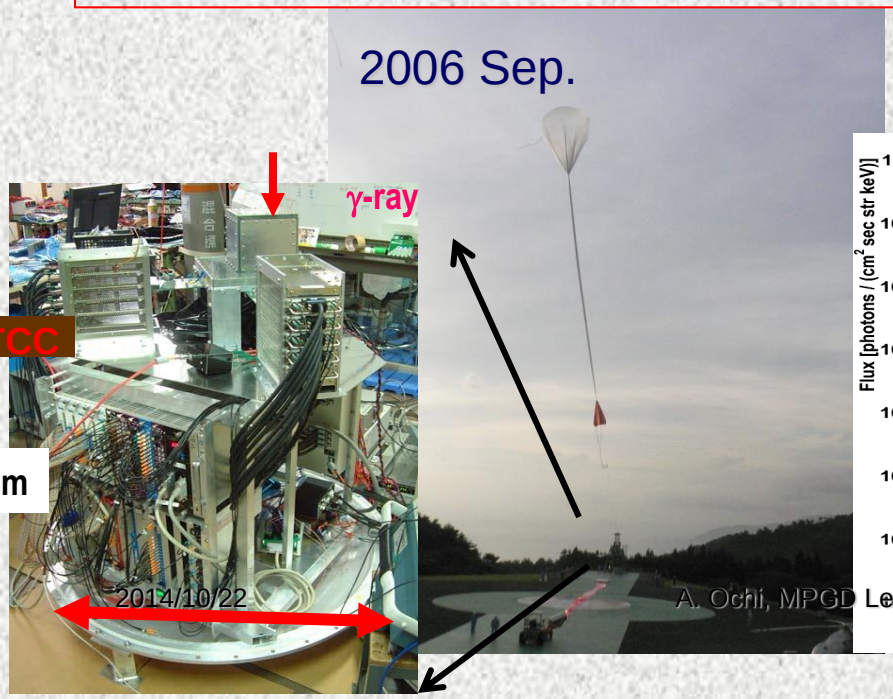
First Balloon Experiment (Smile-I)

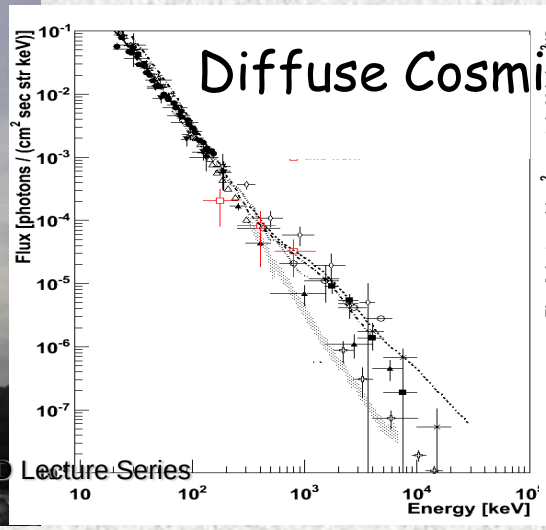
Test flight using 10cm cube ETCC to measure
Diffuse Cosmic and
Atmospheric gamma rays in 0.1-1MeV
3hours observation @35km

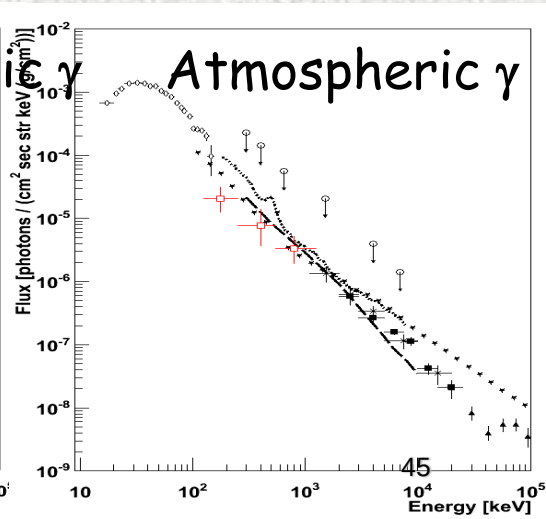


All Trigger enent 2.3×10^5 events

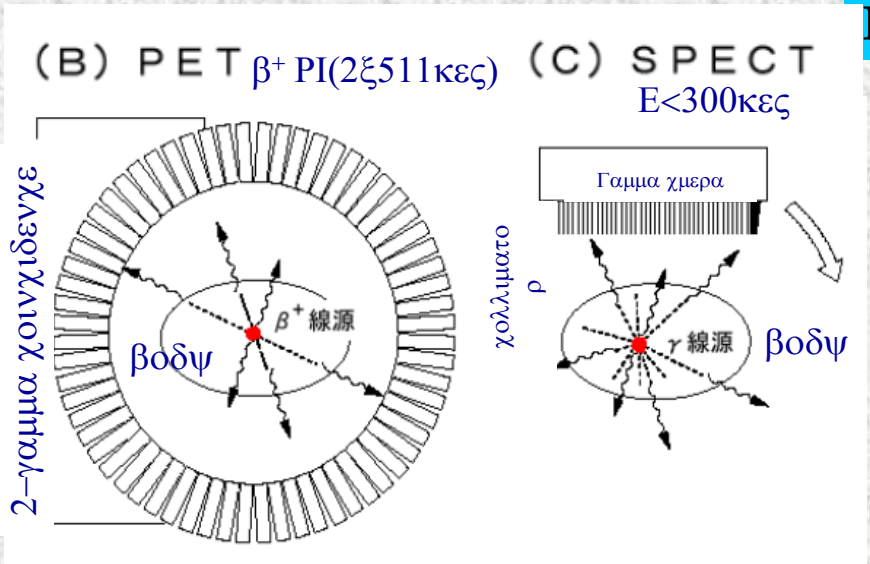
Signal ⇒ ~420 events Simulation ⇒ ~400events (GEANT4 base)



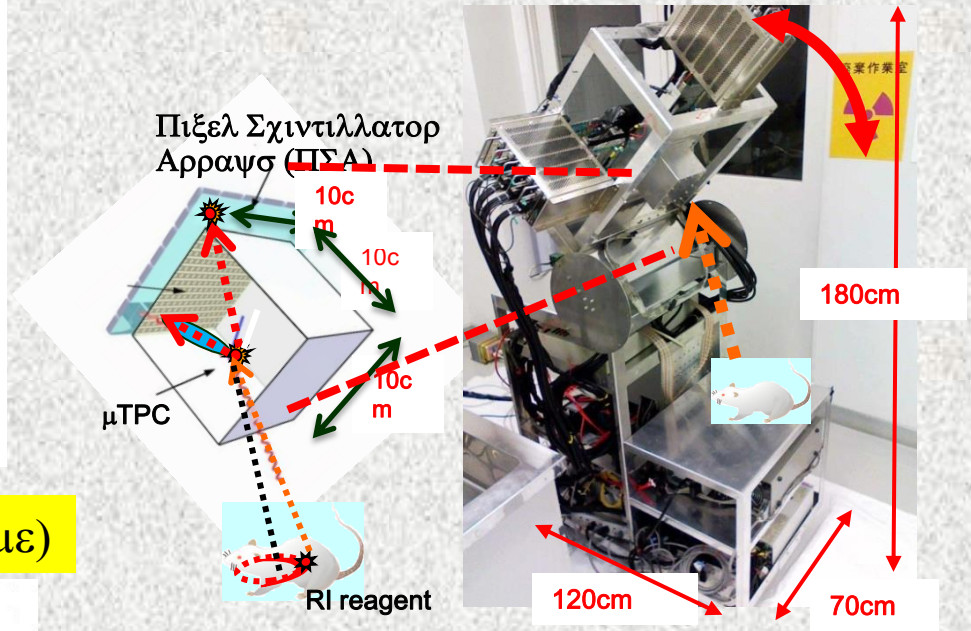




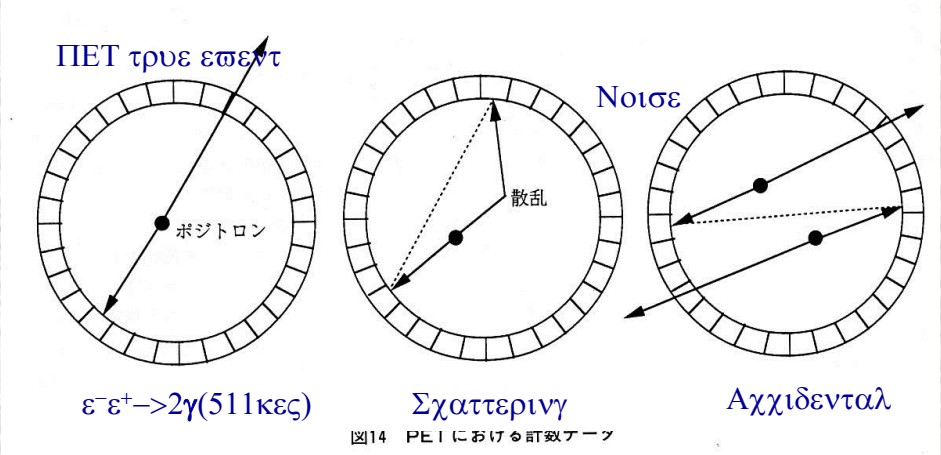
Medical Imaging for ETCC

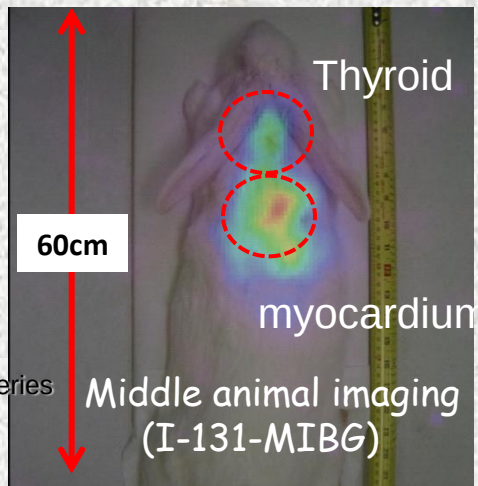


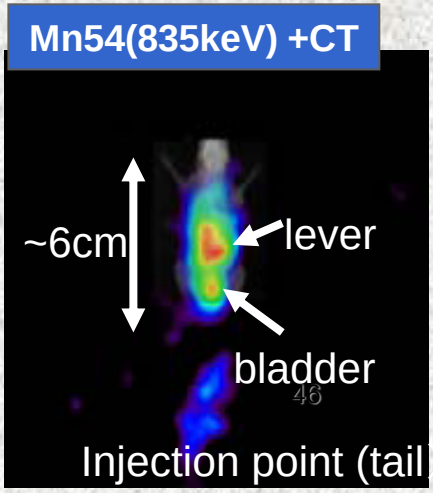
Μοβιλε ΕΤΧΧ φορ σμαλλ ανδ μιδδλε ανιμαλσ



^{18}Φ ^{11}X (β+ εμιττινγ PI, σηορτ ηαλφ τιμε)





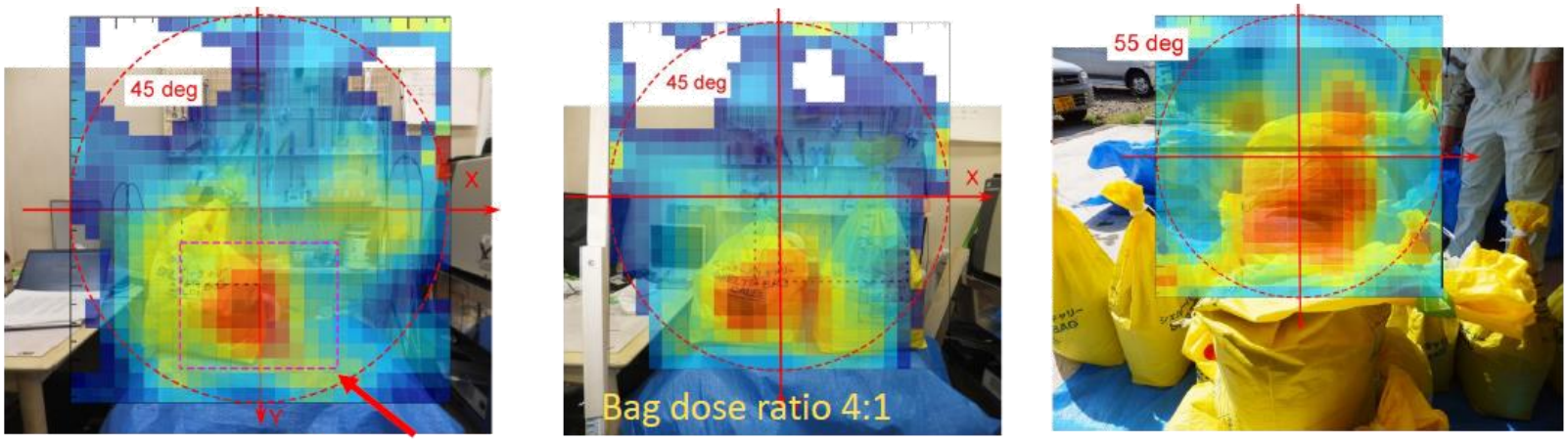


Gamma-ray camera for radiation contaminated soil

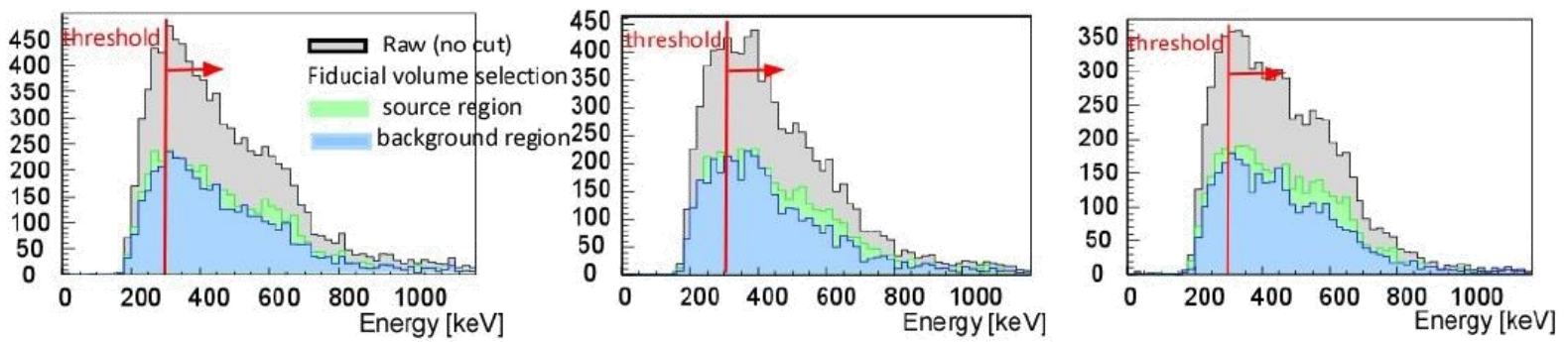
One bag

Two bags

Many bags



Fiducial volume cut region



- excess (source region – background region) observed

D. Tomono et al., 10th MPGD workshop in Japan (Dec. 2013)

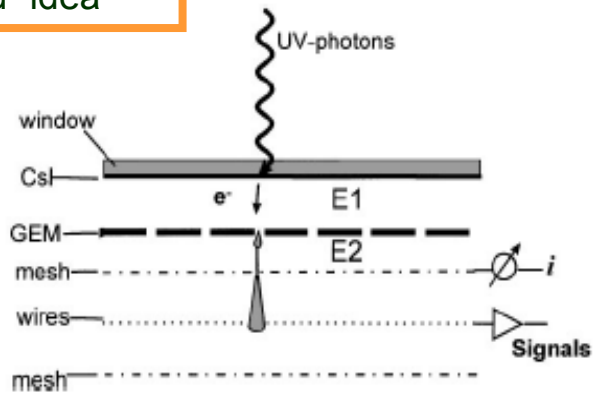
Photon detector

- Photoelectric effect on cathode
  - Gas photomultiplier
  - RICH detector
  - Lq. Xe detector

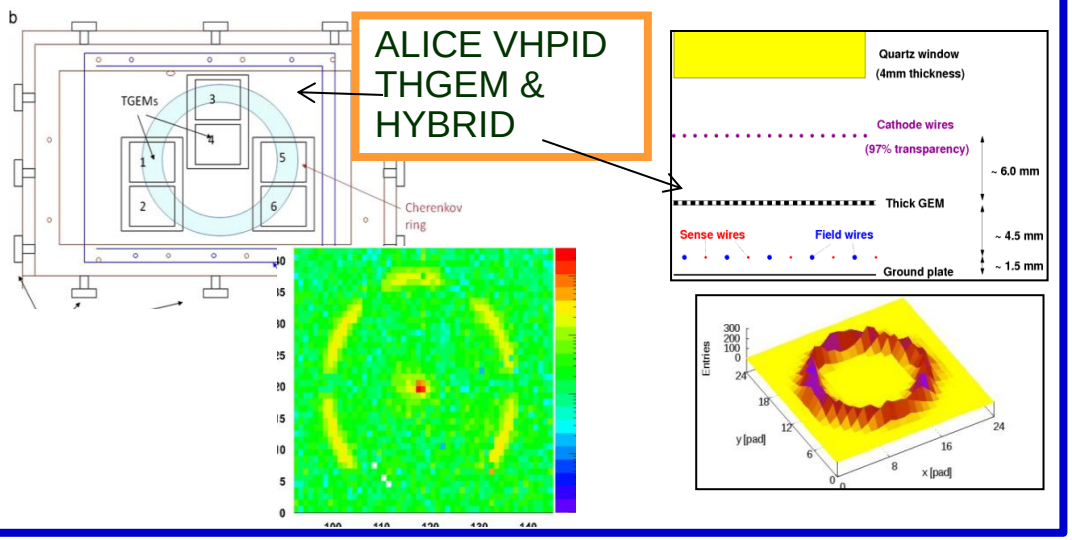
HEP & PARTICLES

PHOTON detection

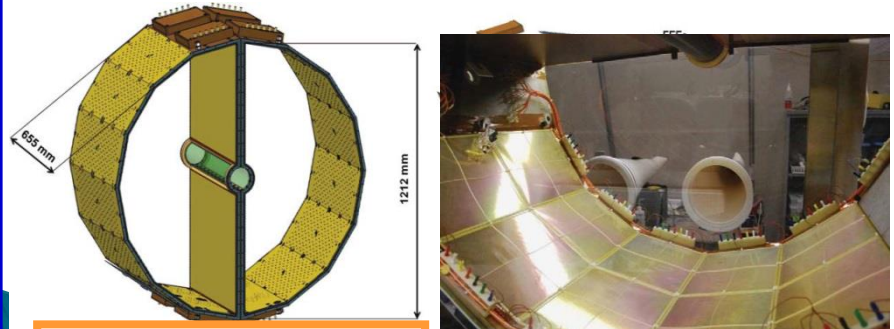
An “old” idea



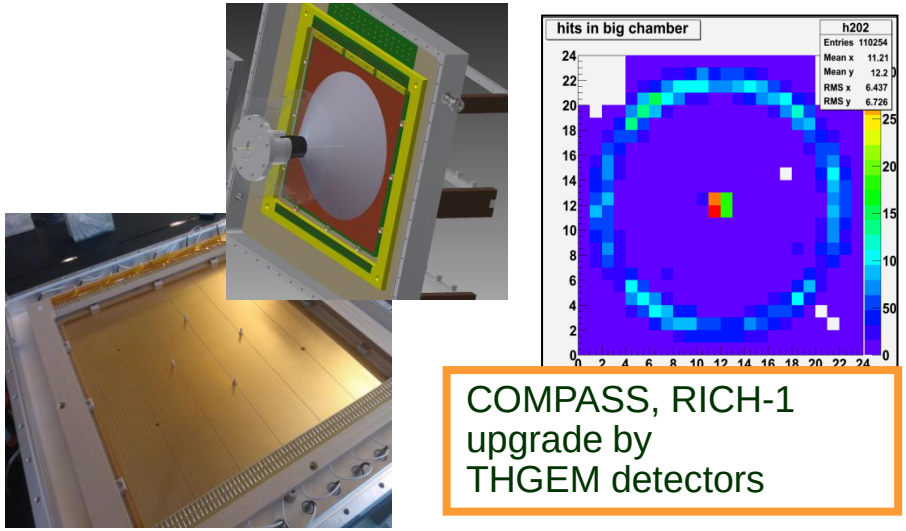
R. Chechwik et al., NIM A 419 (1998) 423



ALICE VHPID THGEM & HYBRID



PHENIX HBD, GEM



COMPASS, RICH-1 upgrade by THGEM detectors

Gaseous PMT

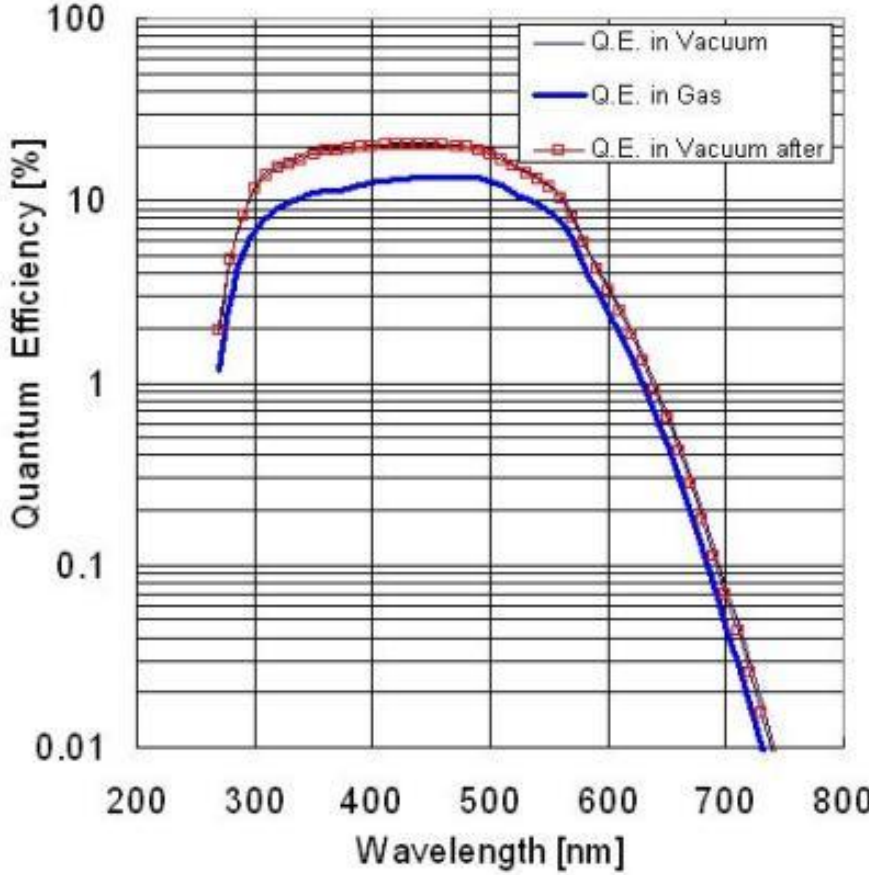
Yamagata U. TMU, HAMAMATSU

Sensor type	Sensitivity	Position Resolution	Timing Resolution	Uniformity	Price	Magnetic Field	Effective Area
Vacuum PMT	◎	△	◎	△	○	△	○
CCD / CMOS	△	◎	×	◎	△	◎	×
Gaseous PMT	○	○	○	○	◎	◎	◎

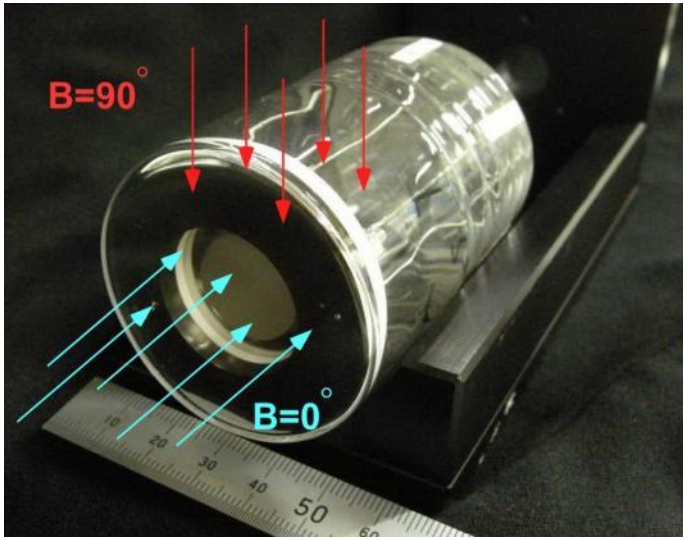
- The advantage of the **gaseous PMT**:
  - ✓It can achieve a **very large effective area** with moderate **position** and **timing** resolutions.
  - ✓It can be easily operated under a **very high magnetic field**.

Characteristic of gaseous PMT

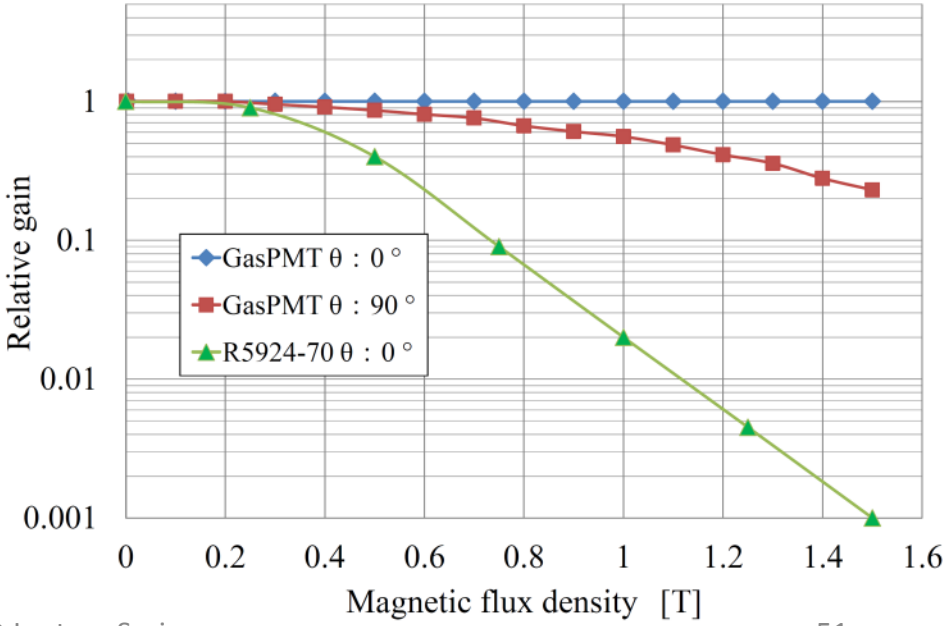
QE for gaseous PMT



Operation in magnetic field environment

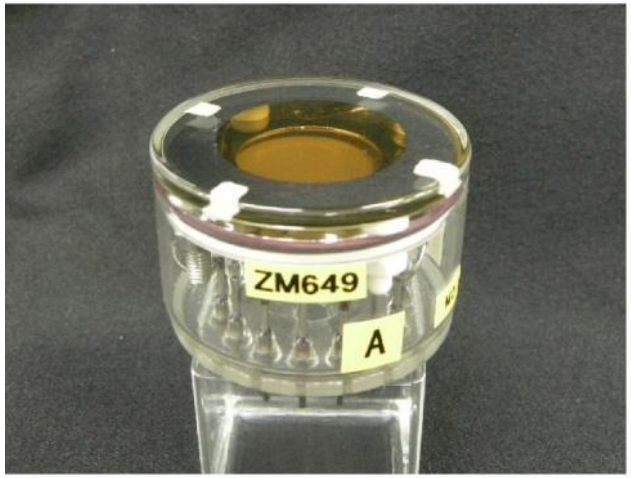


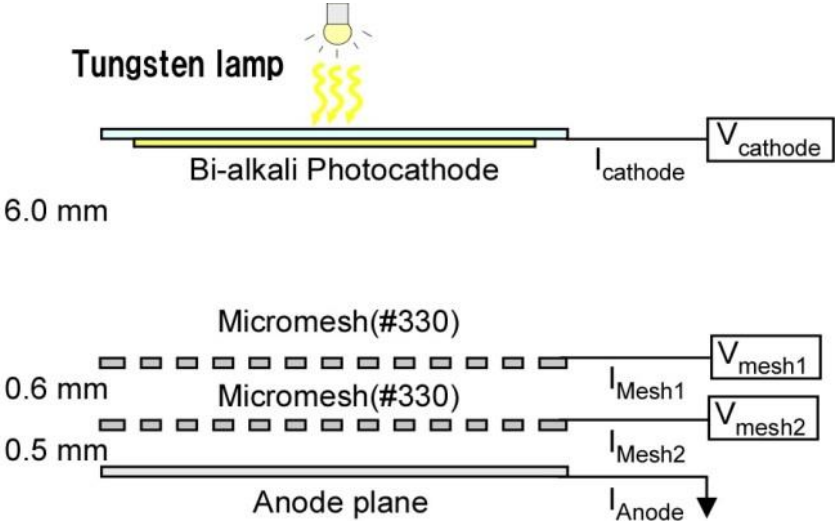
Ar(90%)+CH_4(10%) 1気圧

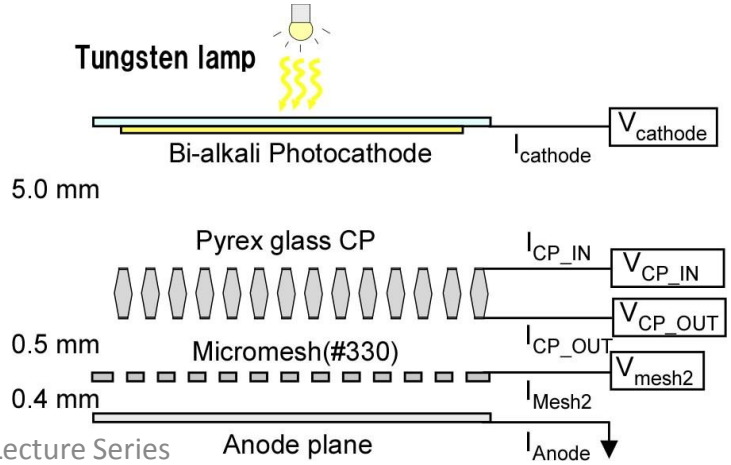


✓**QE 13%@400-500nm**

- To suppress the ion- and photon-feedback,we have been developing a gaseous PMT using MPGDs such as GEM, Micromegas and glass capillary plate (CP).

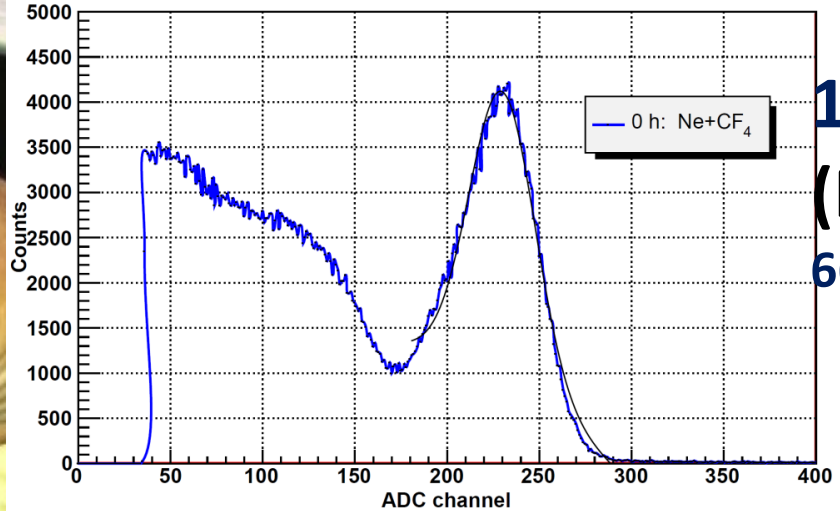






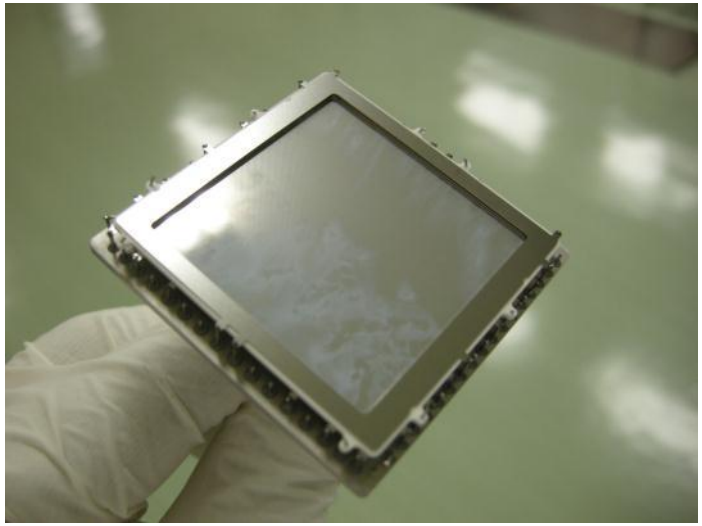
^{137}Cs : 662 keV γ-ray → NaI Scinti. + Gas PMT

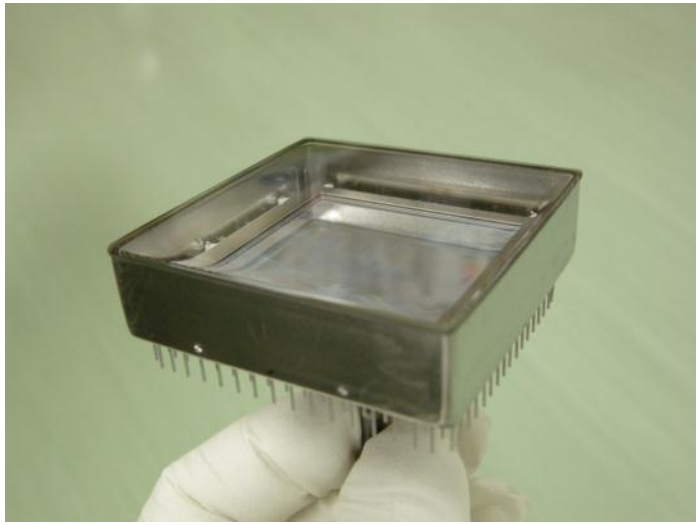
- Sealed gaseous PMT with a bialkali photocathode and double Micromegas detector was connected to a NaI(Tl) crystal, and irradiated with a ^{137}Cs source.

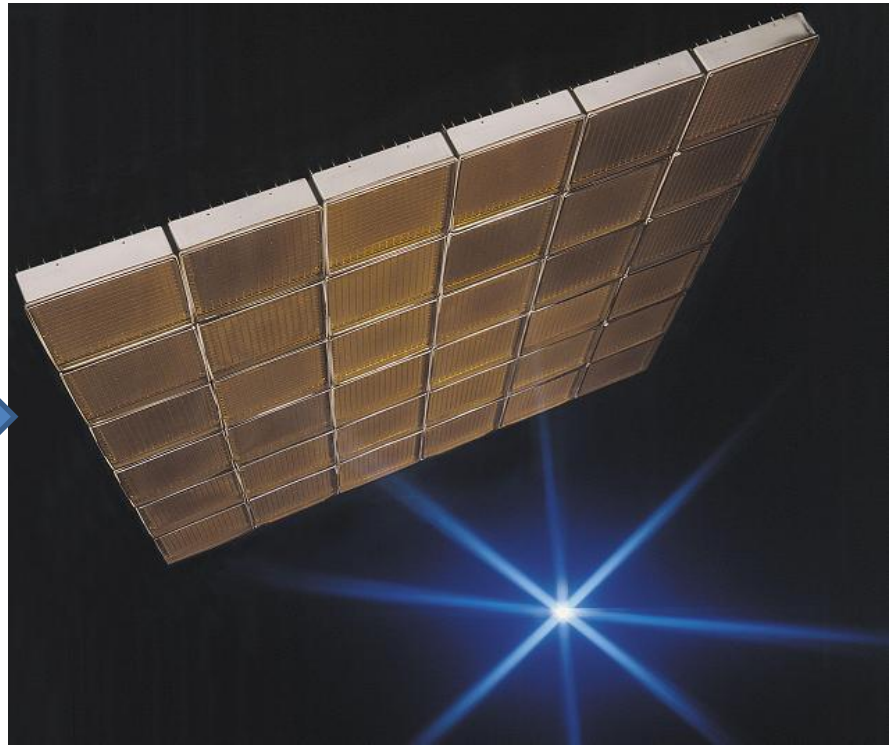


18.2 %
(FWHM)
662 keV

Large flat Gas PMT is being developed

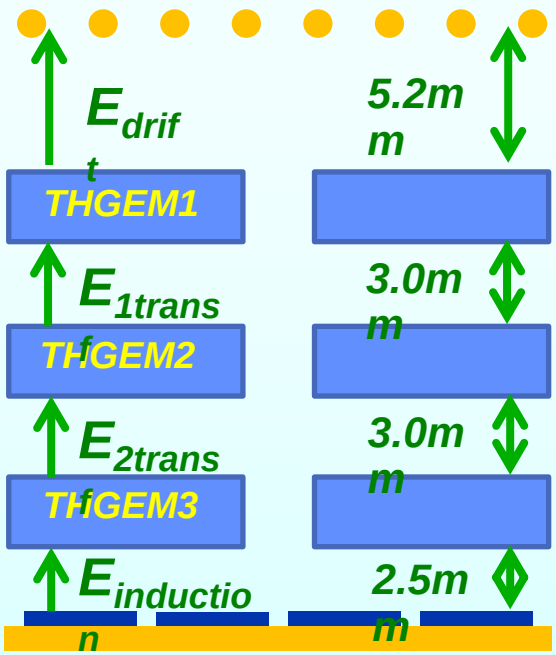




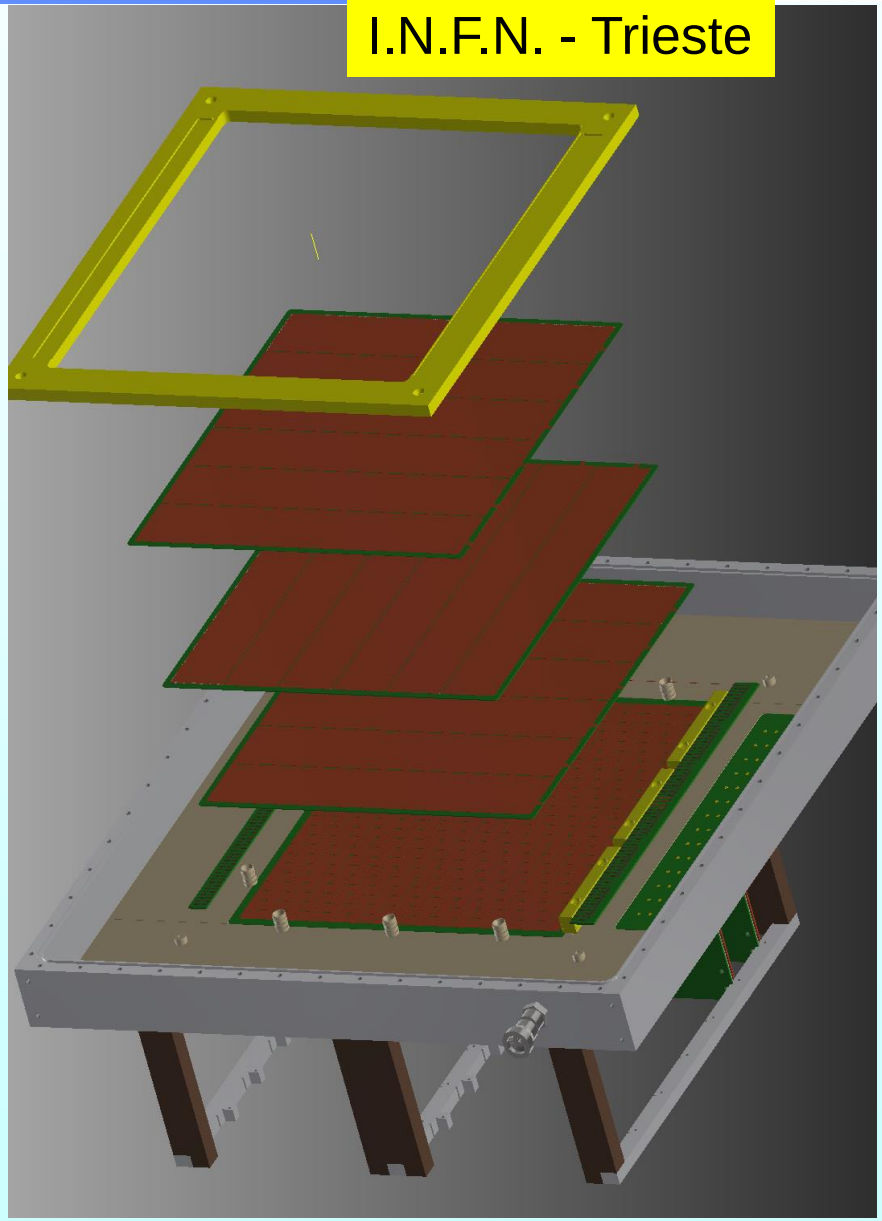


Triple THGEM 300 mm x 300 mm

I.N.F.N. - Trieste



Layer	Pitch / mm	$Ø_{hole}$ / mm	Thickness / mm	RIM / µm
THGEM1	0.8	0.4	0.4	< 5
THGEM2	0.8	0.4	0.8	< 5
THGEM3	0.8	0.4	0.8	< 5



HADRON PID IS PROVIDED BY RICH-1

COMPASS RICH-1: a large gaseous RICH with two kind of photon detectors providing:

hadron PID from 3 to 60 GeV/c

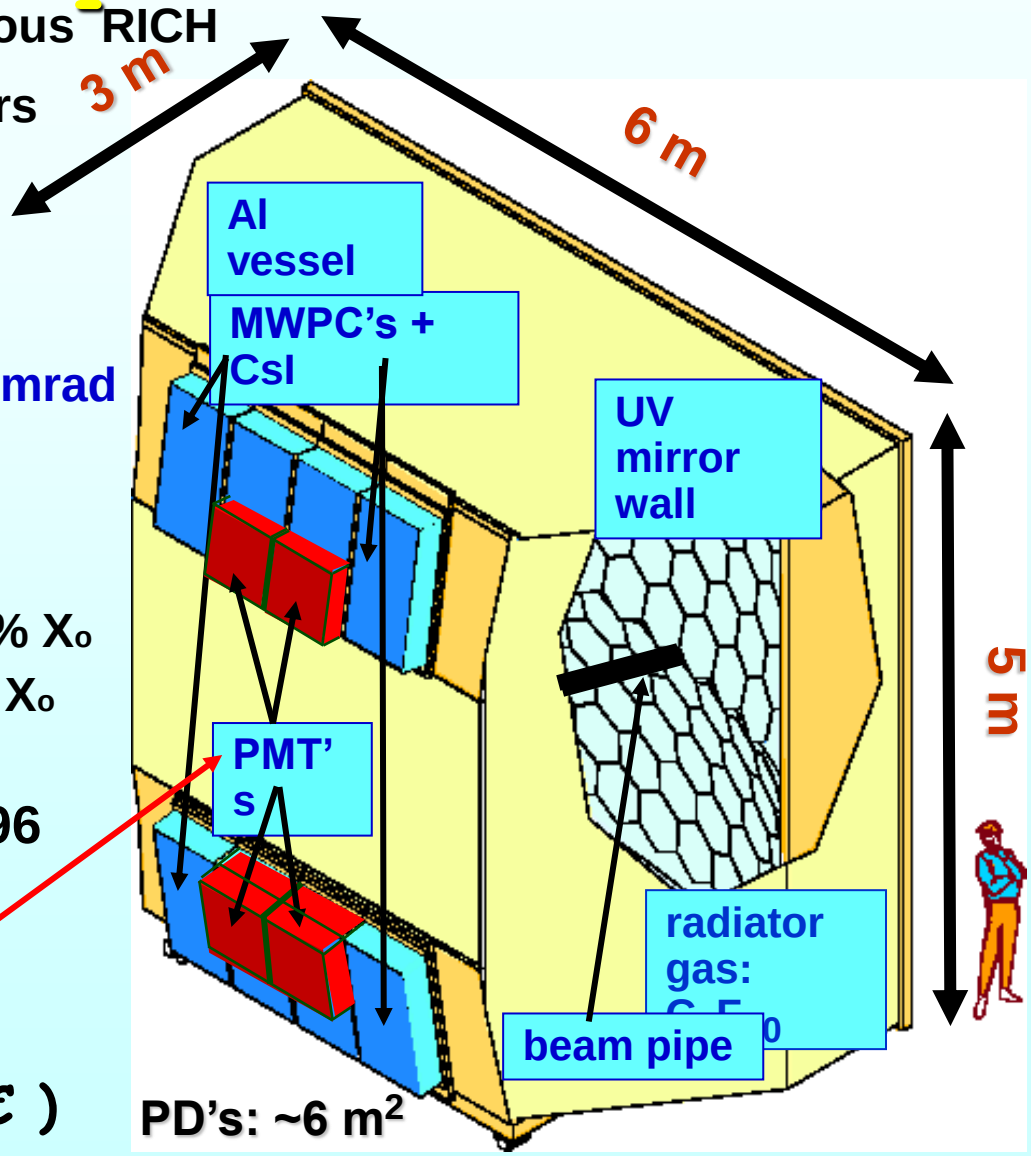
acceptance: H: 500 mrad V: 400 mrad

trigger rates: up to ~100 KHz
beam rates up to ~10^8 Hz

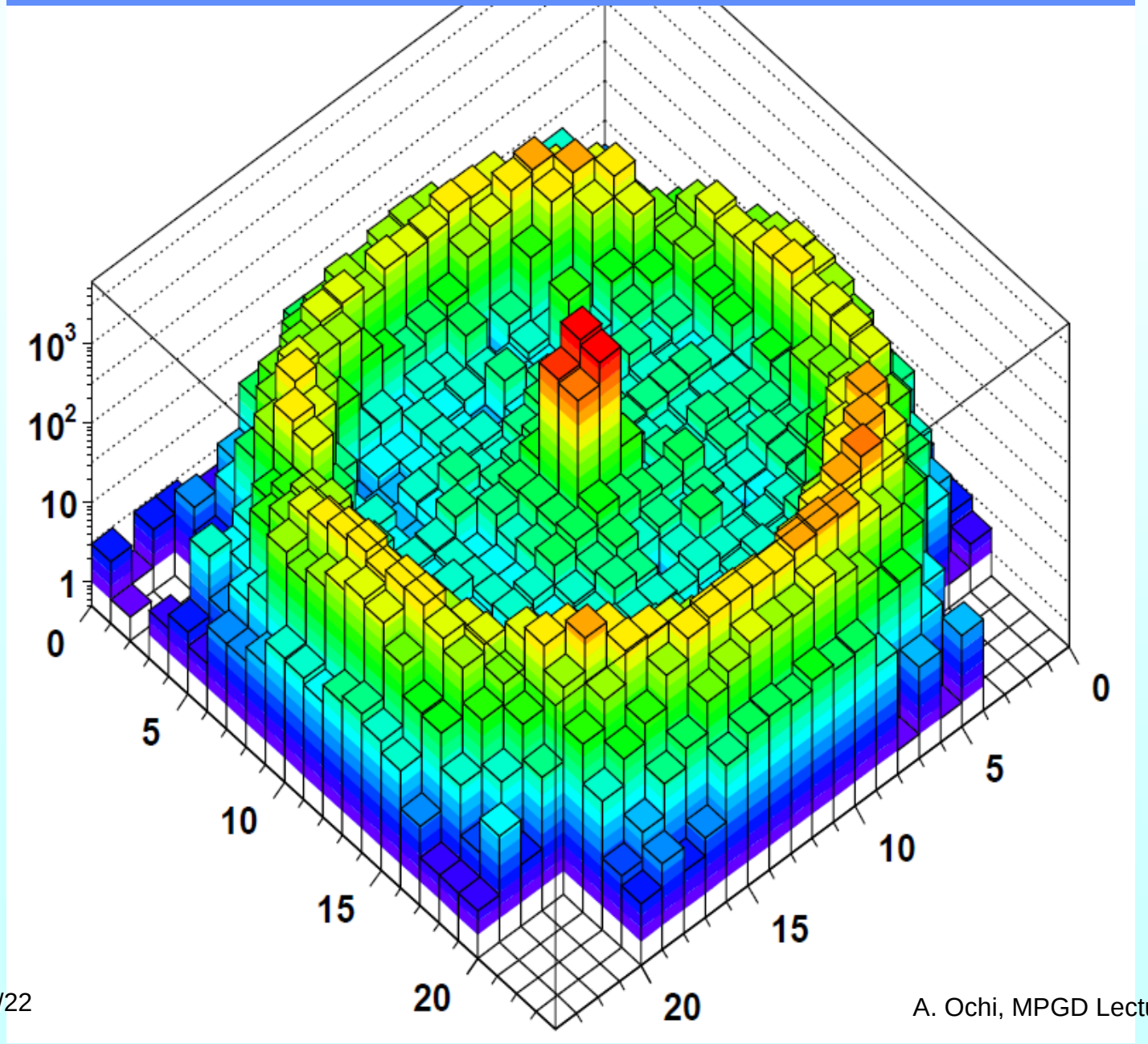
material in the beam region: 2.4% X_0
material in the acceptance: 22% X_0

detector designed in 1996
in operation since 2002
first PD upgrade in 2006

(total investment: ~ 4 M €)

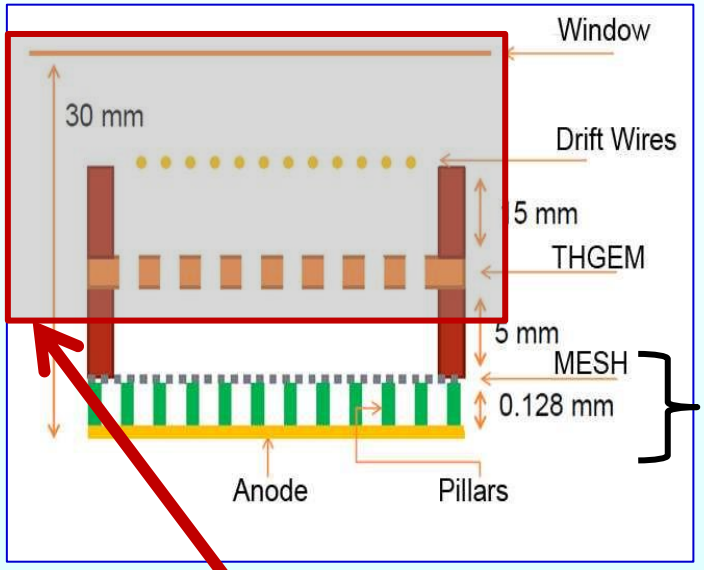


Sum of the events in a run



Hybrid THGEM + Micromegas PD

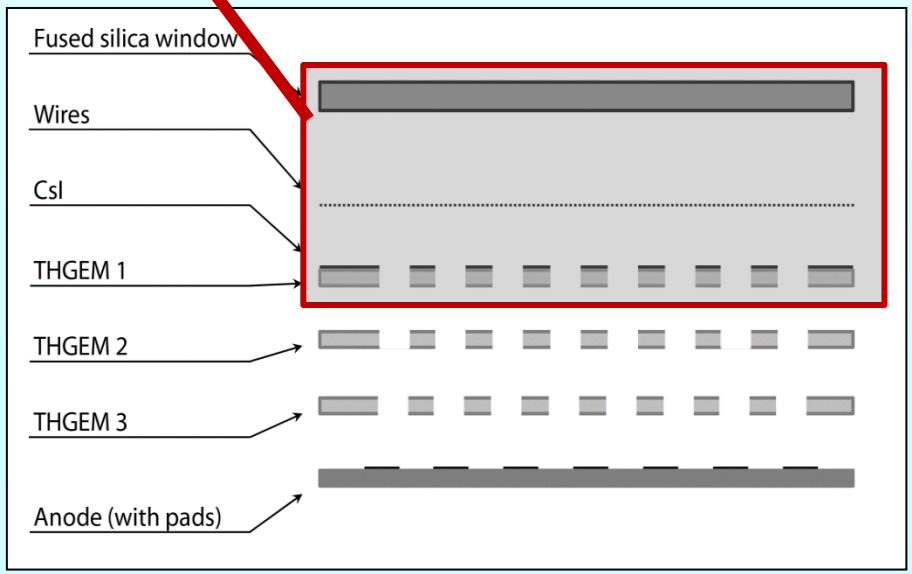
I.N.F.N. - Trieste

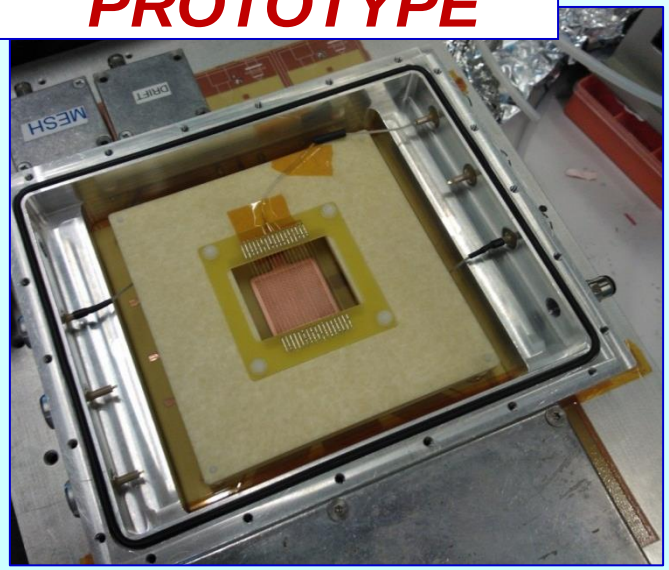


Hybrid detector

MICROMEGAS stage

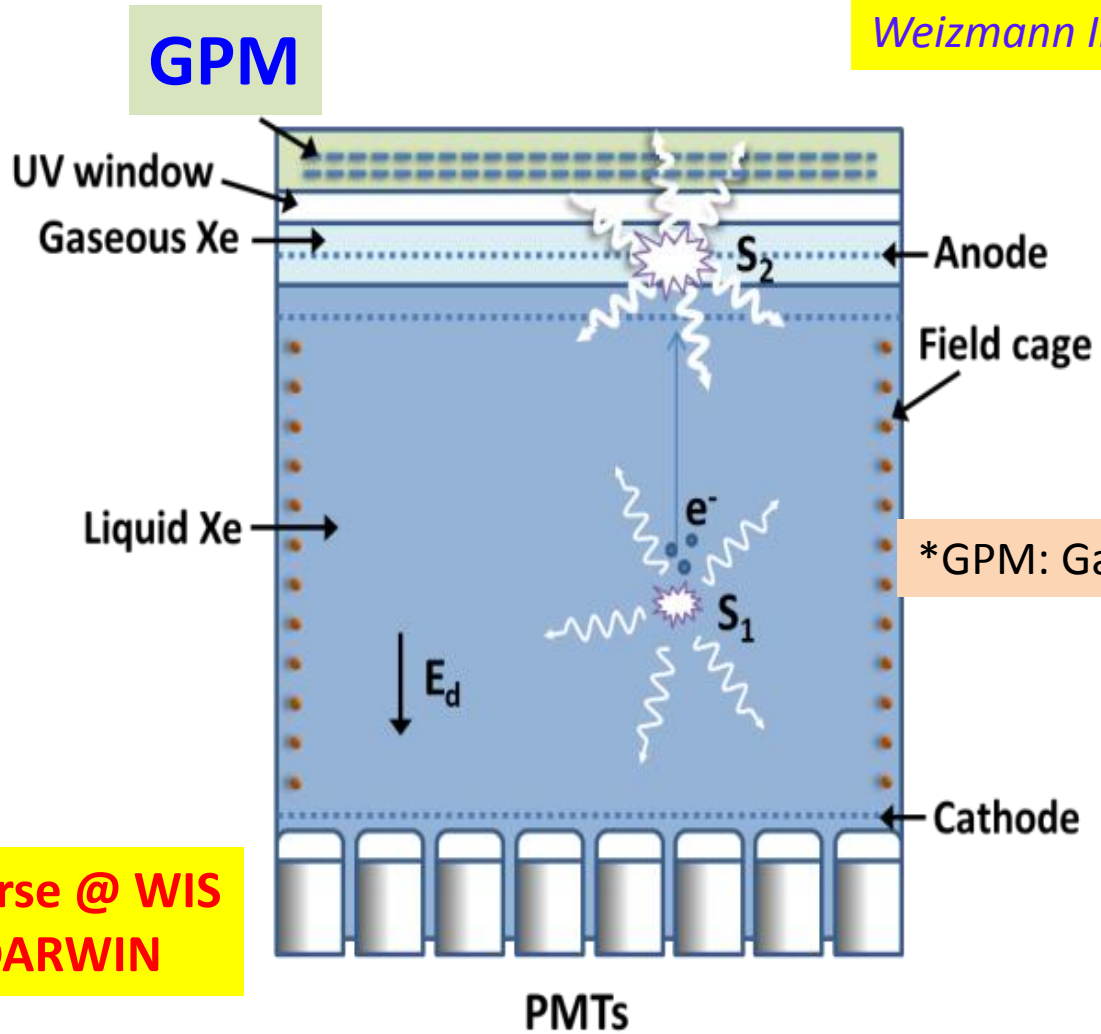
PRELIMINARY PROTOTYPE





Dual-phase TPC with GPM* S2 sensor

Weizmann Institute of Science



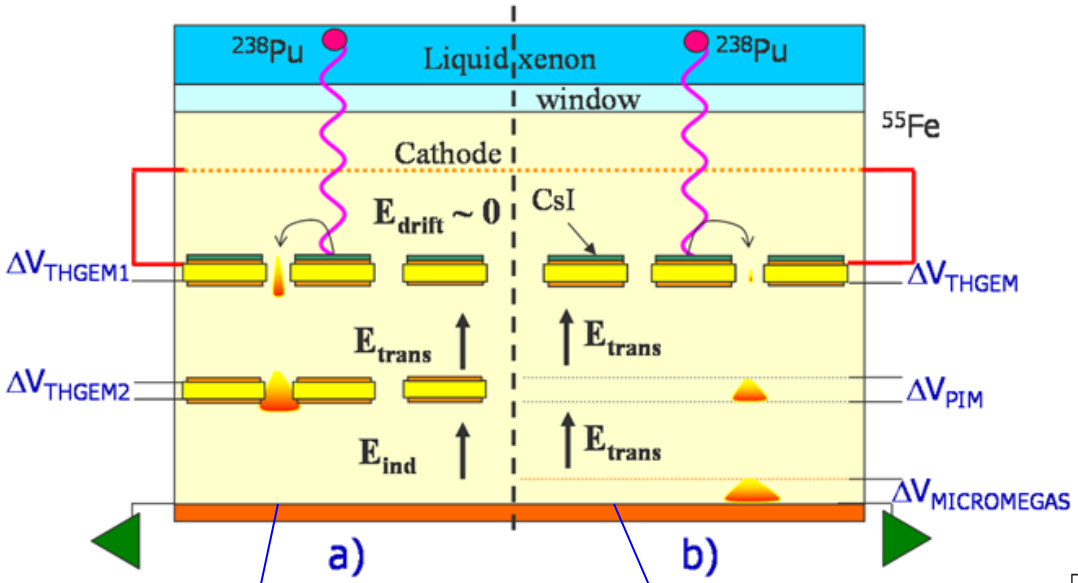
*GPM: Gaseous Photomultiplier

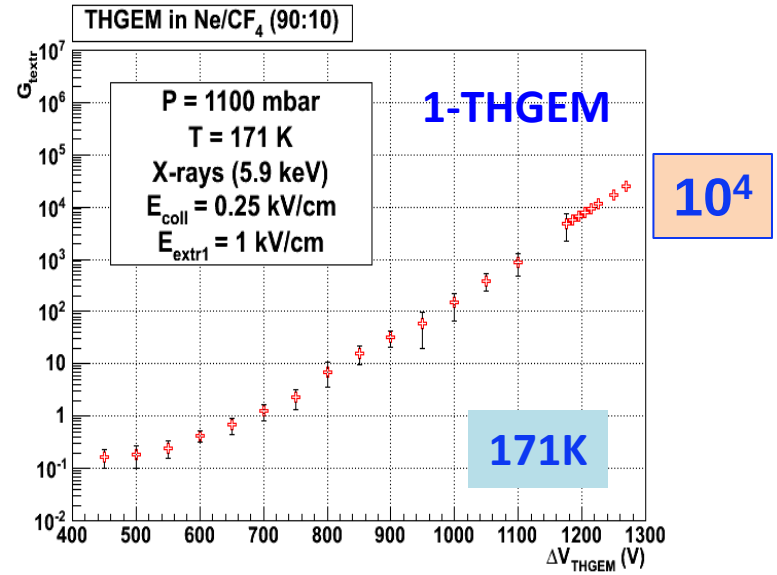
R&D in course @ WIS Within DARWIN

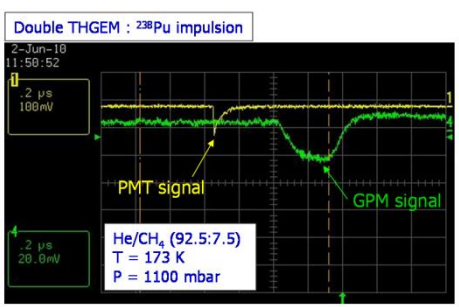
A proposed concept of a dual-phase DM detector. A large-area Gaseous Photo-Multiplier (**GPM**) (operated with a counting gas) is located in the saturated gas-phase of the TPC; it records, through a UV-window, and localizes the copious electroluminescence S2 photons induced by the drifting ionization electrons extracted from liquid. In this concept, the feeble primary scintillation S1 signals are preferably measured with vacuum-PMTs immersed in LXe.

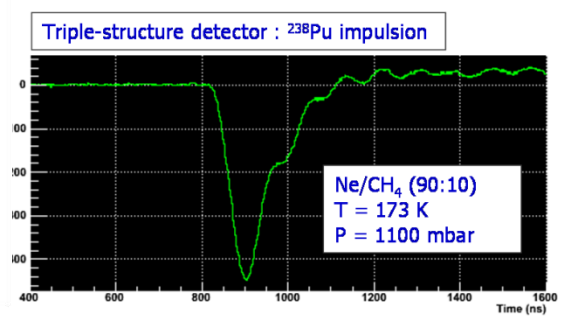
Nantes/Weizmann

LXe-TPC/GPM

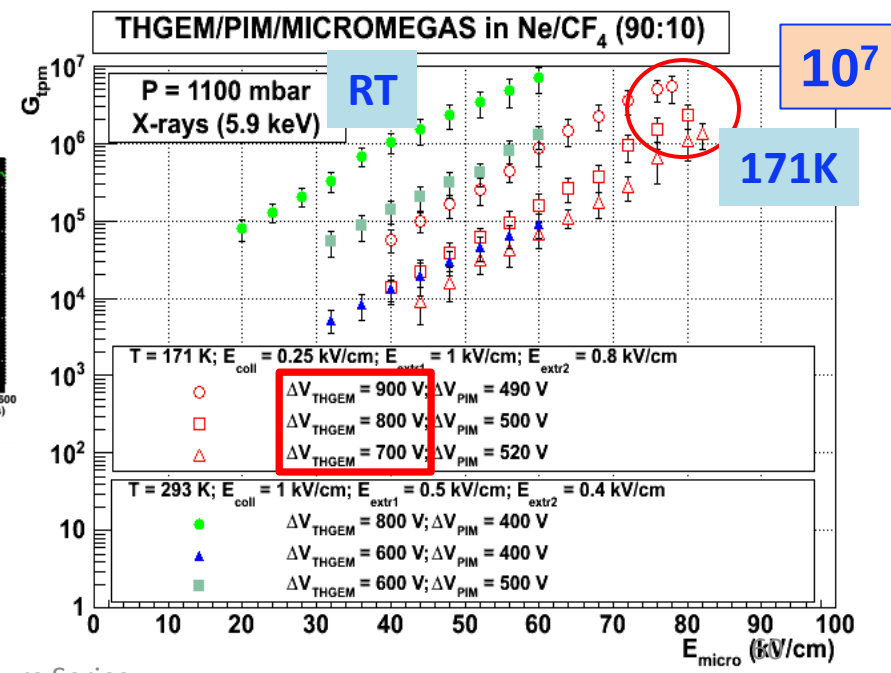






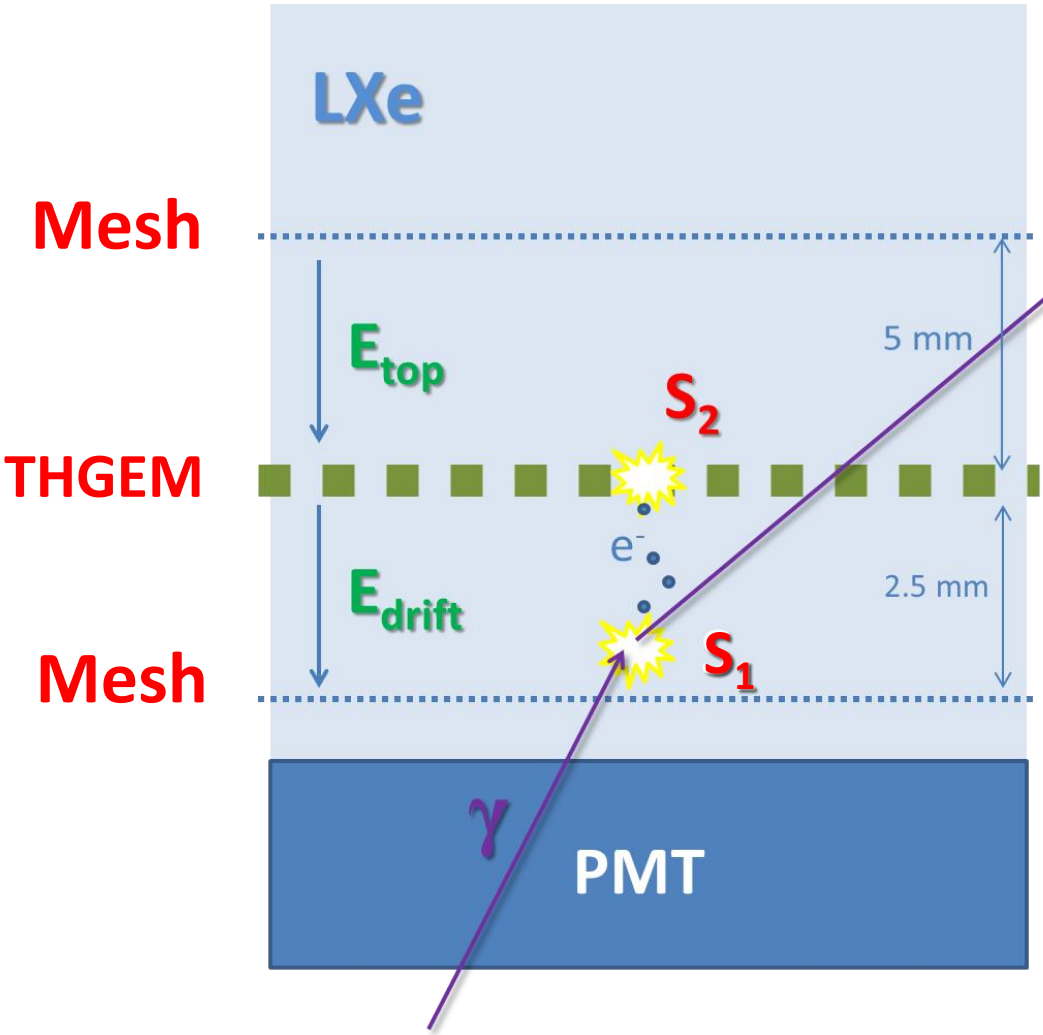


173K, 1100mbar

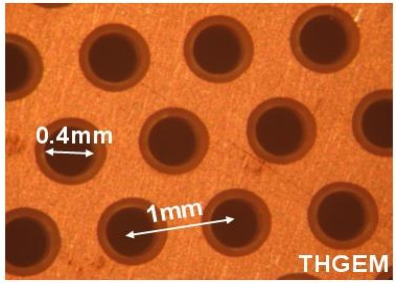


Duval 2011 JINST 6 P04007

Single-THGEM in LXe: Gammas setup



Thickness 0.4mm

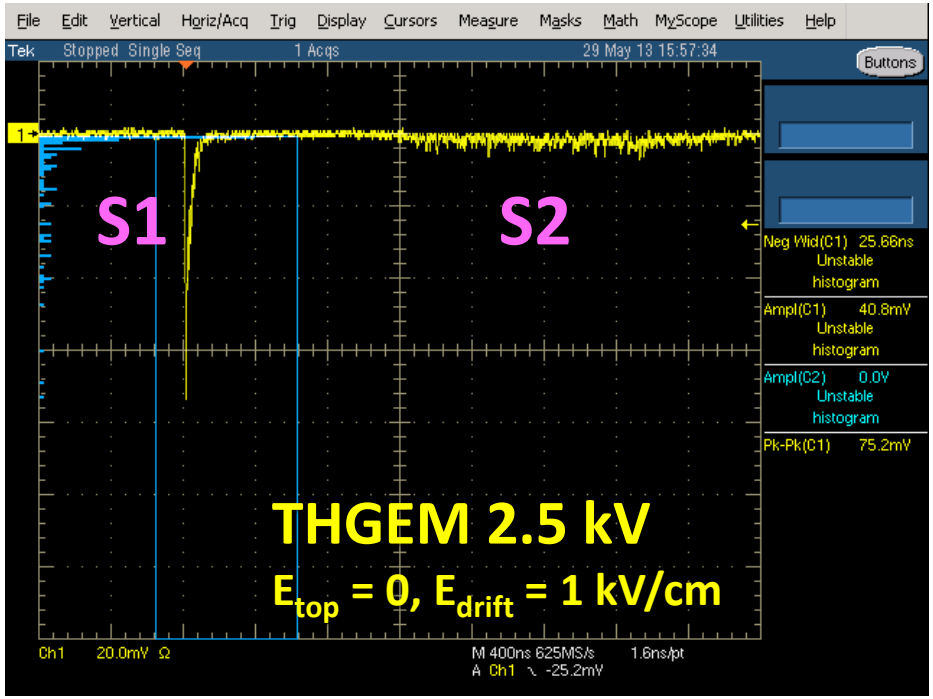


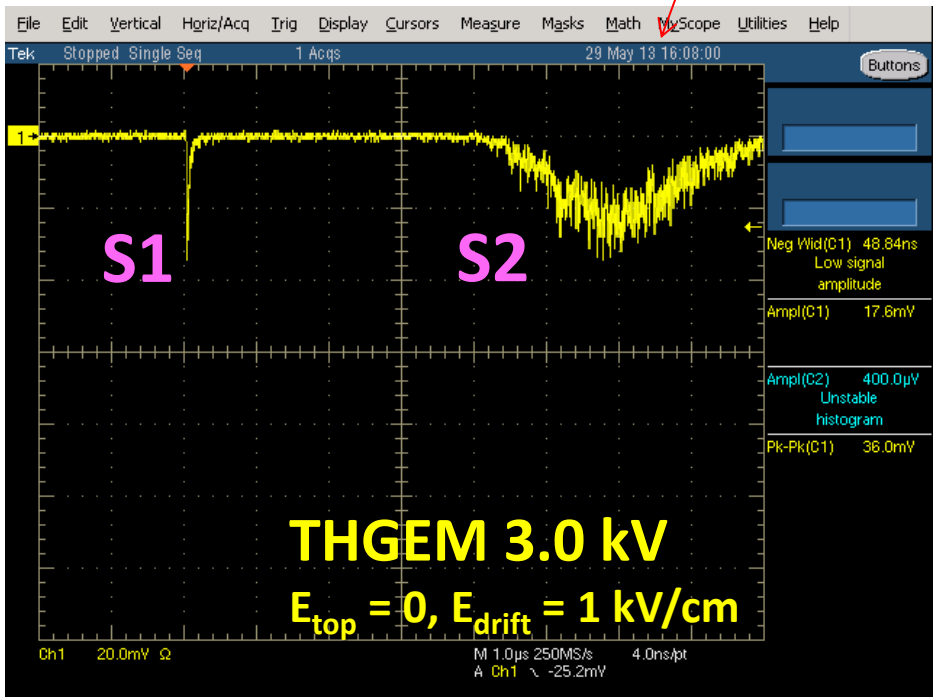
THGEM:
t=0.4, d=0.3,
a=1, h=0.1

Hamamatsu
R6041-06 2"dia

THGEM immersed in LXe:
First electroluminescence events - Gammas

May 29 2013





THGEM: t=0.4, d=0.3, a=1, h=0.1

E_{THGEM}~70kV/cm

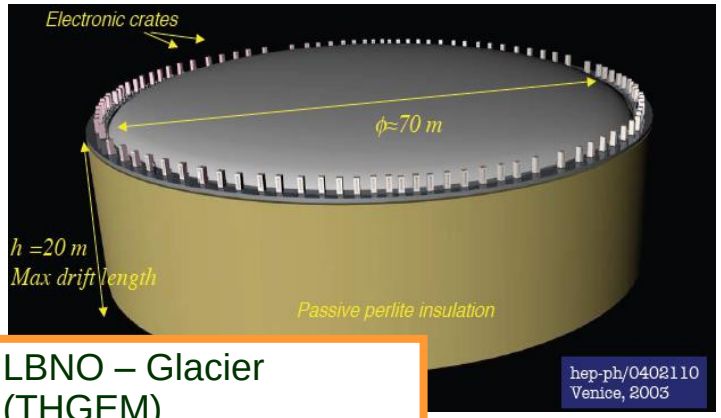
LXe purity unknown

Further application

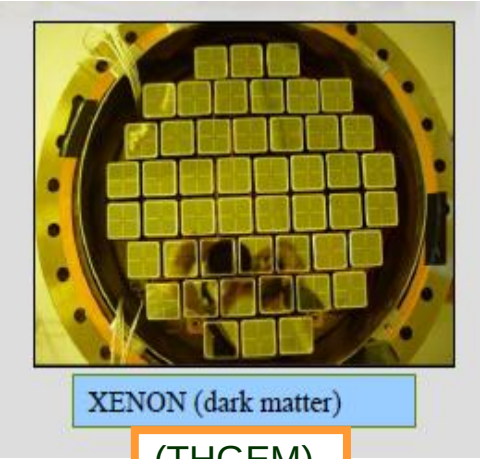
- Rare event
  - Dark matter search
  - Axion search
- Dosimeter
  - In the space

HEP & PARTICLES

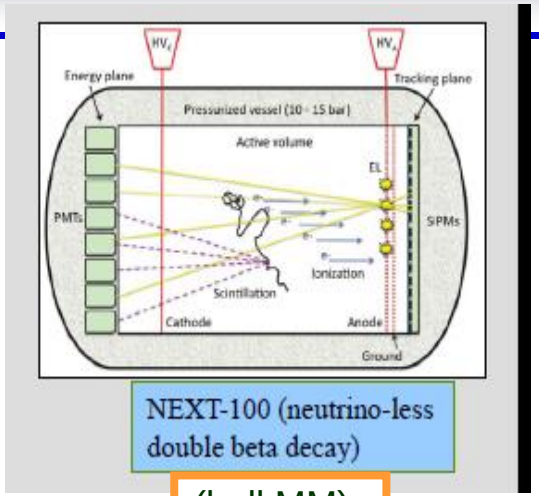
Very rare events



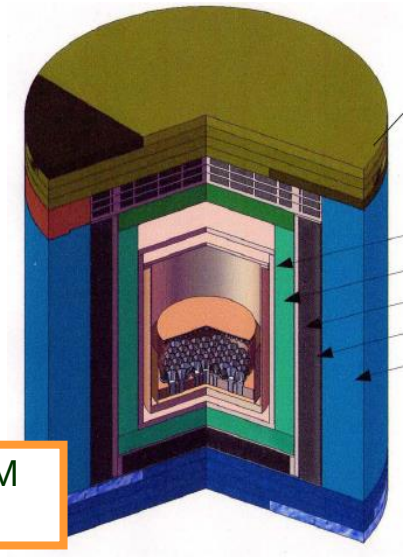
LBNO – Glacier
(THGEM)



(THGEM)

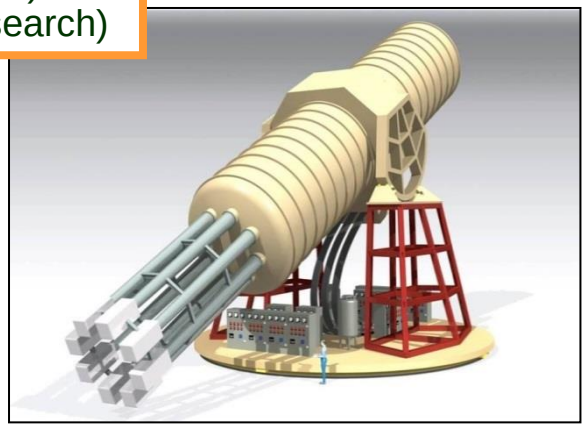


(bulkMM)



Panda-X, THGEM + MM
(dark matter)

IAXO (MM)
(assion search)



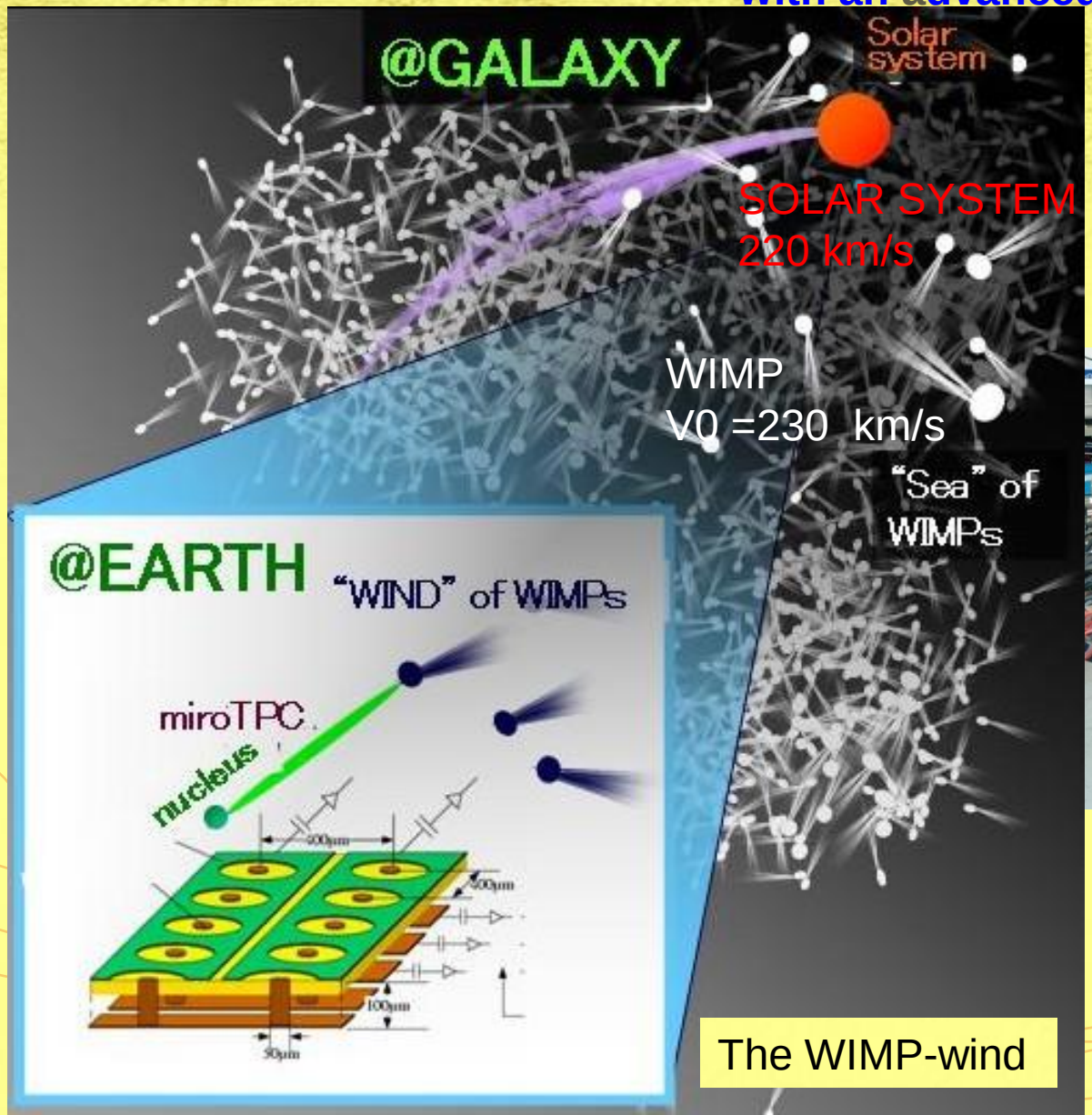
NEWAGE (MPGD for Dark Matter)

Recent Status of Development

Kyoto Univ. / Kobe Univ.

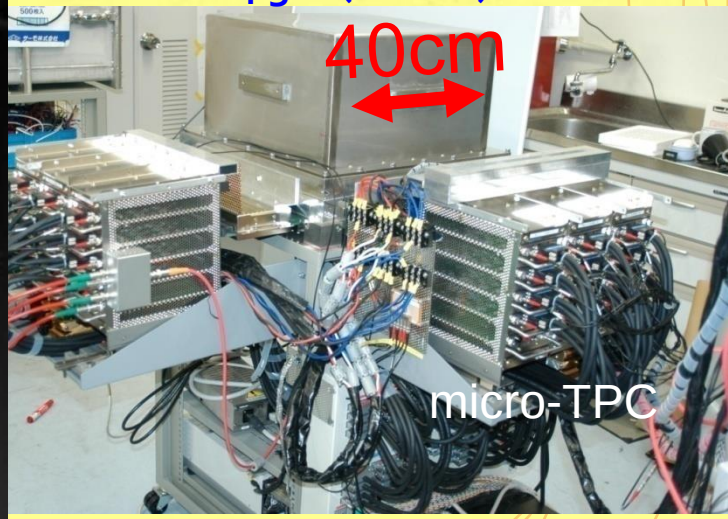
(New generation WIMP search with an advanced gaseous tracker experiment)

latest results PLB 686 (2010) 11 (Miuchi *et.al.*)



The WIMP-wind

- **Micro-TPC (time-projection-chamber)**
  - **gaseous 3D tracking device**
  - **CF_4 gas (0.2 bar)**



NEWAGE: Purpose

"WIMP-wind" detection

= Direction-sensitive DM search

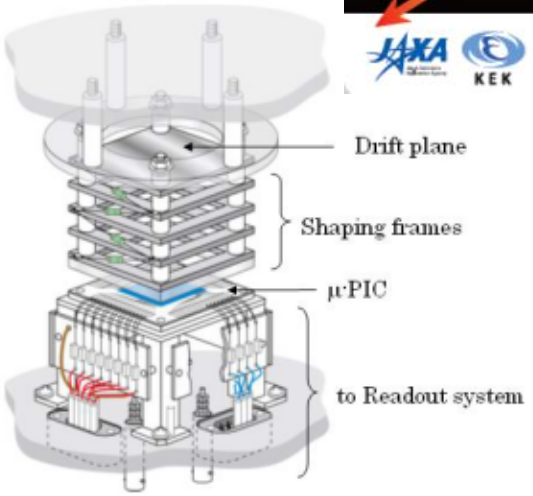
MPGD(μ-PIC)の応用

PS-TEPC

Concept of PS-TEPC

1. Active counter made of tissue-equivalent (TE) materials capable to measure both deposit energy and tracks of the particle simultaneously
2. Can measure directly LET in the range :
   0.2 (minimum ionizing particle (MIP)) ～ 1000 keV/μm-water (heavy charged particle)
3. Position sensitivity with a resolution of ~1mm
4. Time resolution in micro seconds
5. Structure as simple as possible for use in space

Time projection chamber using micro-pixel chamber (μ-PIC)



The structure of PS-TEPC

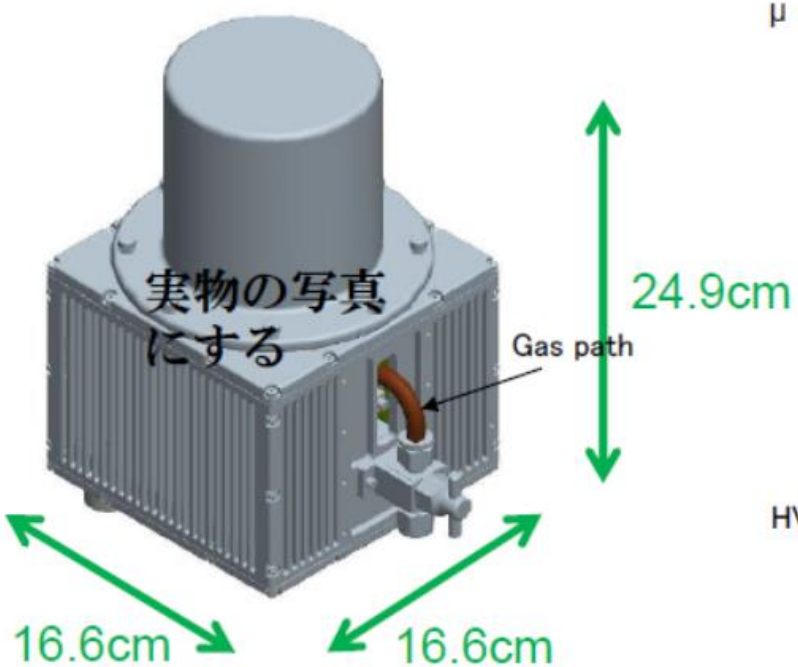
Characteristics of PS-TEPC

- μ-PIC : Anode 64 strips, Cathode 64 strips
  Read-out : 32ch (4 strips/ch)
- Detection Volume : $2.6 \times 2.6 \times 5.0\ cm^3$
- Electrodes Including Shaping frames :
  Tissue- equivalent plastic (A-150)
- Gas: (P- and M-) Tissue-equivalent gases

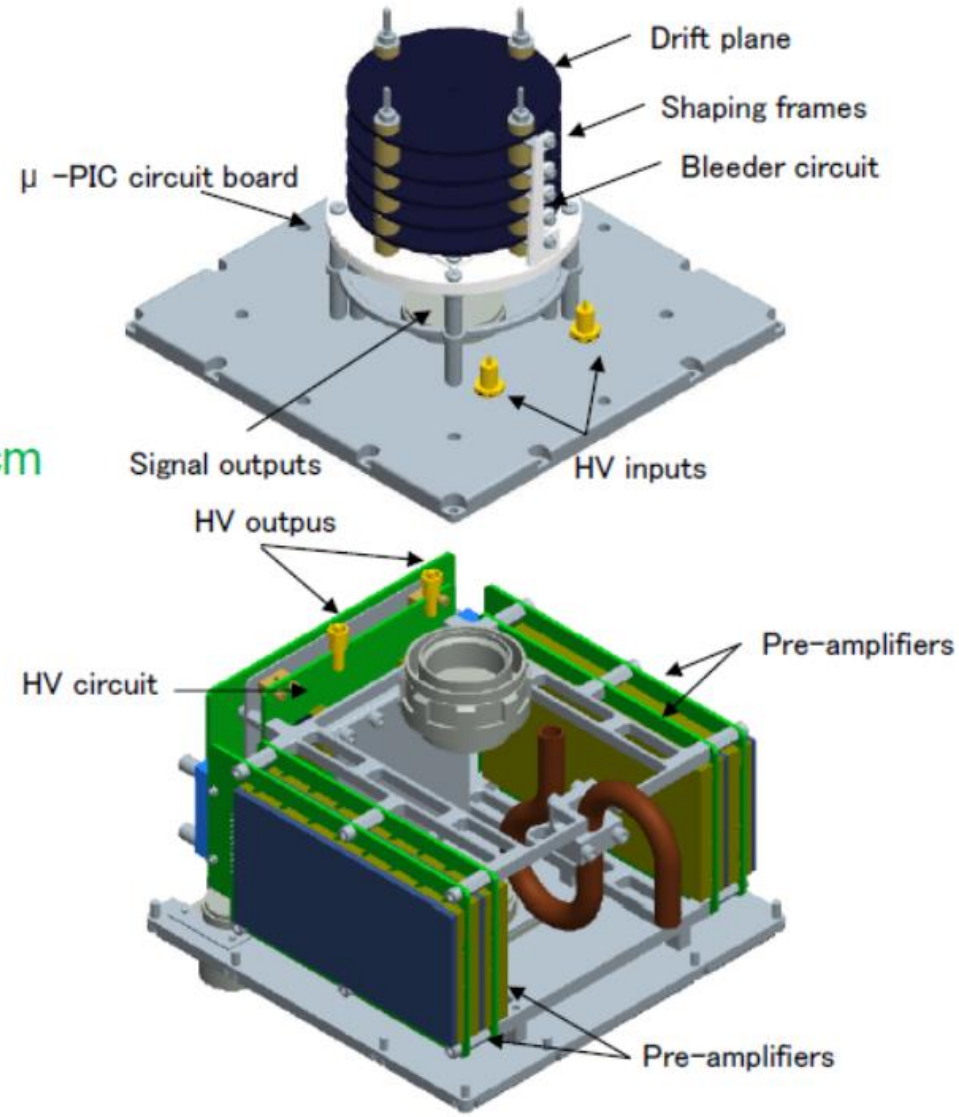
P-TE gas (N_2 :5.4%, CO_2:39.6%, C_3H_8:55%)
M-TE gas (N_2 :3.2%, CO_2:32.4%, CH_4:64.4%)

Development of flight model

Pre-flight model



Weight : 4.4kg
Power consumption : 8.99W



The experiment in ISS using PS-TEPC is scheduled to start on 2015.

Conclusion

- There are many applications using MPGDs.
  - Not only High energy physics …
  - Neutron, Gamma-ray, X-ray, Dark matter … etc.
  - Nuclear phys., Astrophysics, Material science, medical, non-destructive inspection … etc.
  - There are many applications other than today story.

Thank you for listening