

R&D of neutron beam monitor based GEM detector

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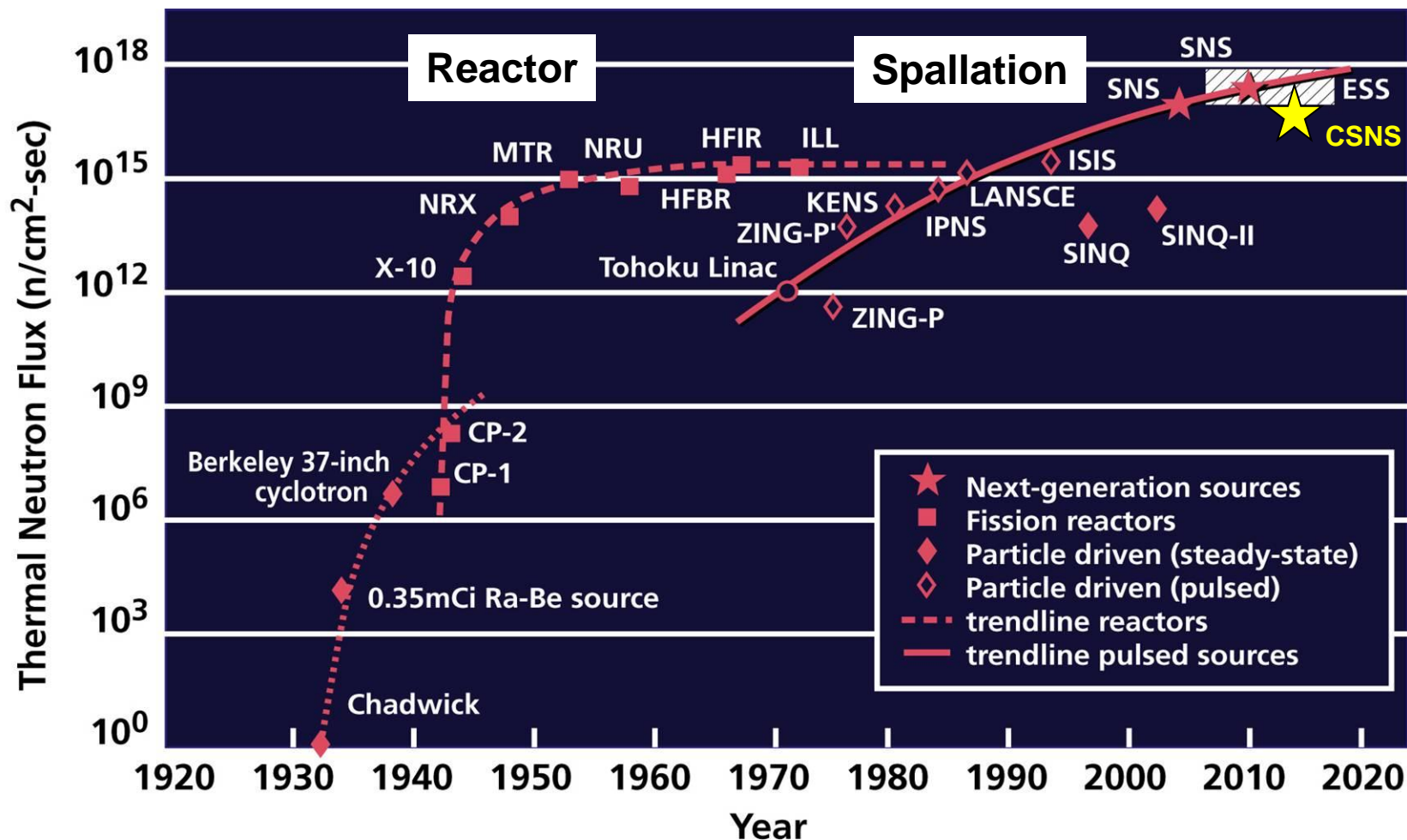


Institute of High Energy Physics
Chinese Academy of Sciences

Outline

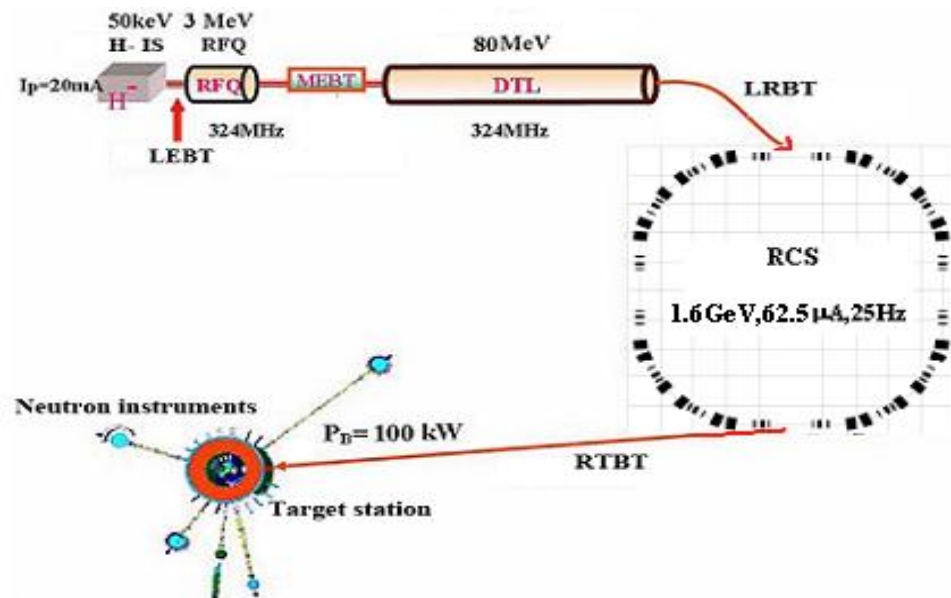
- **Introduction to CSNS**
- **Neutron Beam Monitor**
- **Native THGEM**
- **Boron Coating Technology**
- **Summary**
- **Other application @ IHEP & Gucas**

Development of Neutron Source



(Updated from *Neutron Scattering*, K. Skold and D. L. Price: eds., Academic Press, 1986)

China Spallation Neutron Source (CSNS), Budget > 2B CNY



中国散裂中子源装置地A点拍摄 (09.5.9)



Background

1. ^3He supply crisis for neutron scattering applications

- About 75% of neutron detector use ^3He
- alternative techniques to ^3He is critical

2. Higher Flux of neutron beam

ISIS, SNS, JPARC, CSNS, ESS....

3. CARR is running and CSNS is under construction

Object for Detection

- **Beam monitor for Spallation or Reactor Neutron Source**
- **Size of Beam: $\sim 4\text{cm} \times 4\text{cm}$**
- **Flux at Guide Exit**

CSNS: $\sim 10^8 \text{n/cm}^2 \cdot \text{s}$ (MS, HIPD), $\sim 10^7 \text{n/cm}^2 \cdot \text{s}$ (SANS)

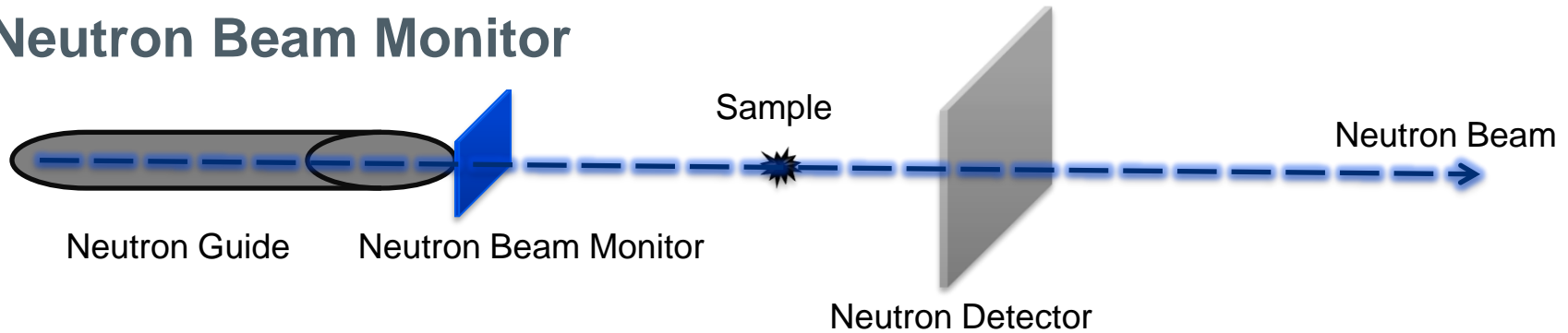
Reactor: $\sim 10^7 \text{n/cm}^2 \cdot \text{s}$

- **Repeated Pulse**
 $\sim \text{ms}$, CSNS: 40ms
- **Wavelength Cutoff with Choppers/Velocity Selector**

Custom Extent: SANS $0.4 \sim 8 \text{ \AA}$

HIPD $0.3 \sim 4.8 \text{ \AA}$ MRS $1.9 \sim 6.2 \text{ \AA}$

Neutron Beam Monitor



- Intensity fluctuations of the incident beam due to the accelerator or reactor power changes
- Need beam monitor to correct the experimental data of each neutron scattering instrument
- High transmission(>95%) & low efficiency(~1‰) for least perturbation
- Requirements to meet the need of new generation neutron facilities
- Timing resolution(~1 μ s) — ~~Wavelength resolution~~
- Spatial resolution(1~10mm) — ~~More accurate corrections~~
- Gamma to neutron separation — ~~γ insensitivity~~
- High counting rate(~10⁶Hz) — ~~High intensity (>10⁹n/ cm² . s)~~

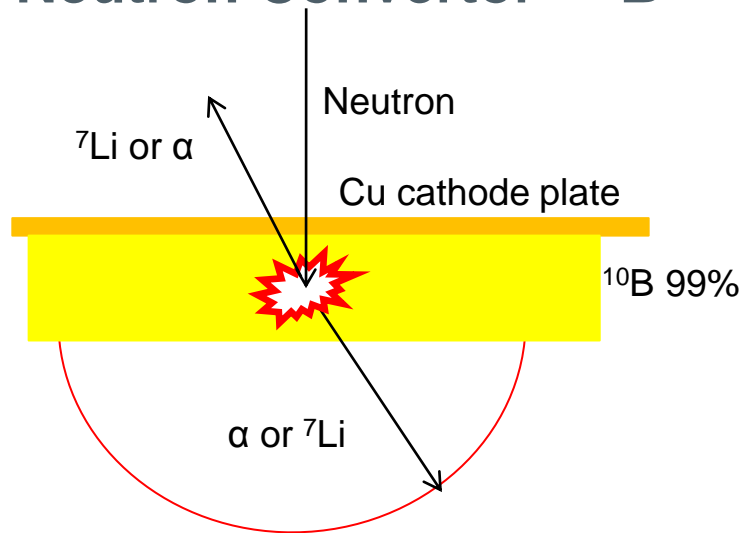
History

Year	Where	Style	Spatial Resolution	Counting rate	Performance
1942	Stanford University	BF ₃ ionization chamber	NO	Slow	
1970s 1980s	GE	BF ₃ Ionization chamber			Stable in practice
	EG&G Ortec	Si surface -barrier with ⁶ Li			Radiation damage
	IPNS, Argonne	³ He gas proportional counter			unknown composition plated on the anode
	ISIS	GS20 glass			Sensitive to gamma, in practice
1990s 2000s	Ordela, Canberra, Mirrotron	³ He gas proportional counter	No	10kHz	well in practice
	ISIS	³ He MSGD	σ=0.1mm	~100kHz	Well in development
	CERN	Micromegas with ²³⁵ U, ¹⁰ B	<50μm	~1MHz	Excellent in development
	SNS	Micromegas with ¹⁰ B		~1MHz	Excellent in development
	J-PARC	GEM with ¹⁰ B	~1mm	1MHz	Excellent in development

Why GEM?

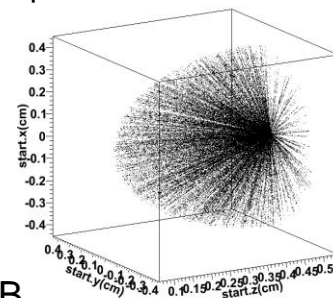
- **Fast signal: ~100ns**
- **High counting rate: 10MHz**
- **Flexible readout: pad, strip, CCD**
- **Convenient to use neutron convertor**
- **Spatial resolution: ~1mm(Neutron)**
- **γ insensitivity**
- **Radiation endurance**
- **Long life**
- **Cost less**
- **Safety compared with Micromegas**

Neutron Converter-- ^{10}B

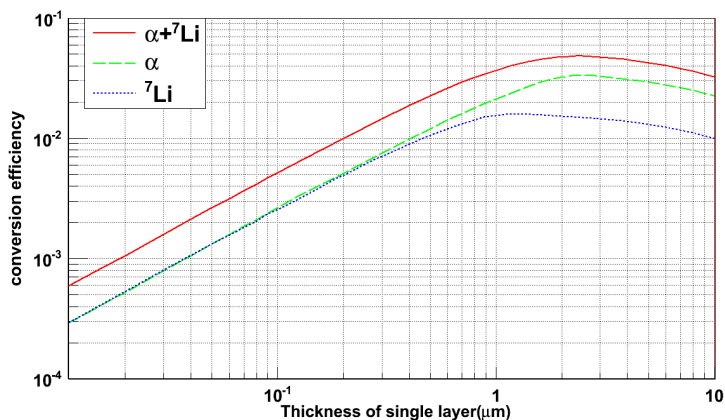


Due to the multiple Coulomb scattering:

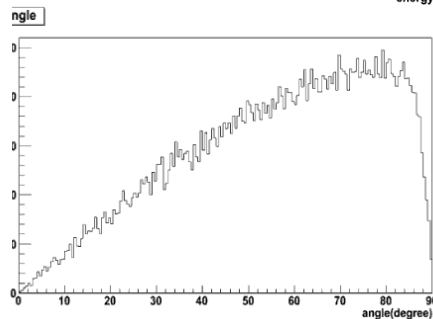
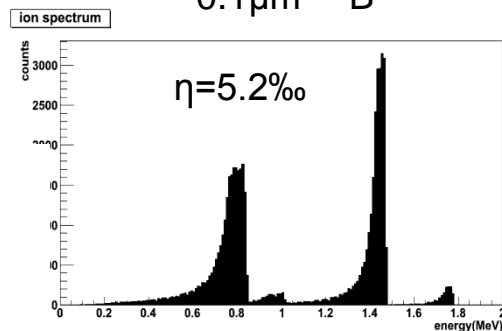
- 1) Range of 1.47 MeV α : $3.6\mu\text{m}$
Range of 1 MeV ^7Li : $2\mu\text{m}$ (SRIM)
- 2) Maximum efficiency ($\sim 5\%$) for thermal neutrons: $\sim 2.5\mu\text{m}$
Low efficiency 5% : $\sim 0.1\mu\text{m}$ coated on Cu using evaporation or sputtering techniques.
- 3) Energy of charged particles is extended down.
Thin foil can improve capacity of γ discrimination
- 4) Cone emission of α & ^7Li



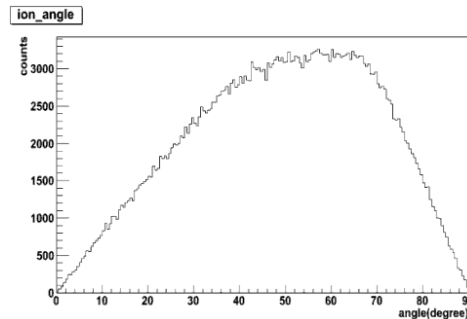
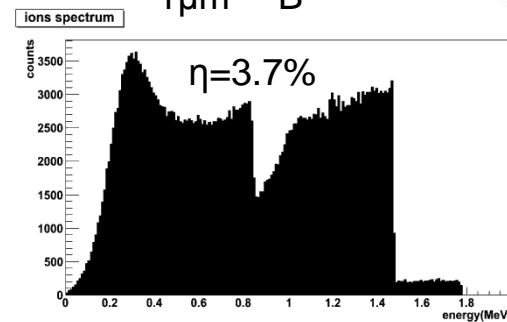
Geant4 Simulation for Thermal Neutron



$0.1\mu\text{m } ^{10}\text{B}$

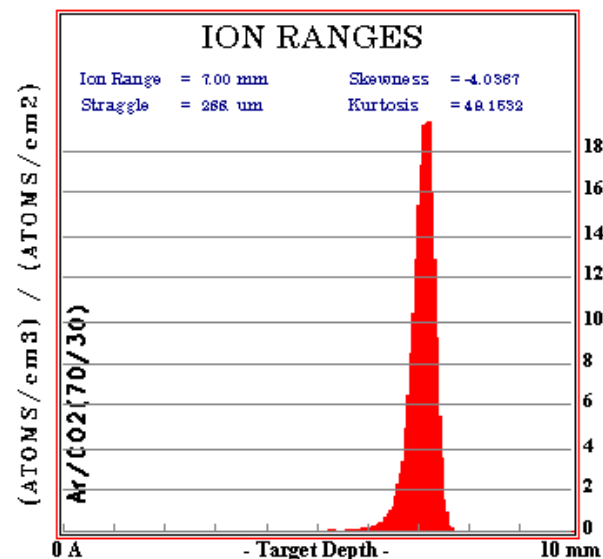
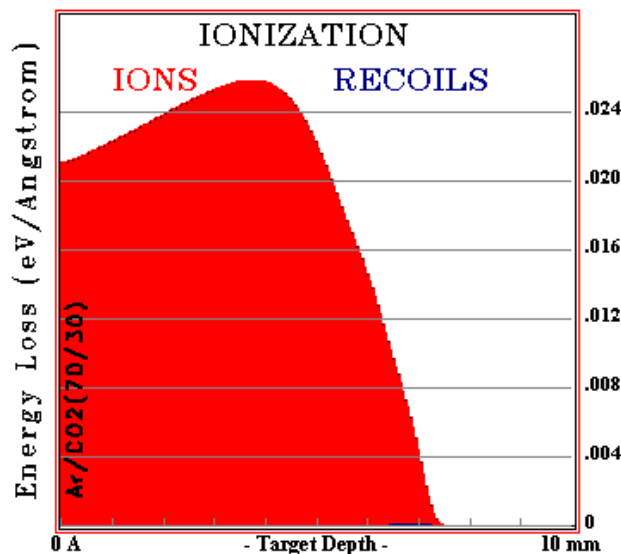


$1\mu\text{m } ^{10}\text{B}$



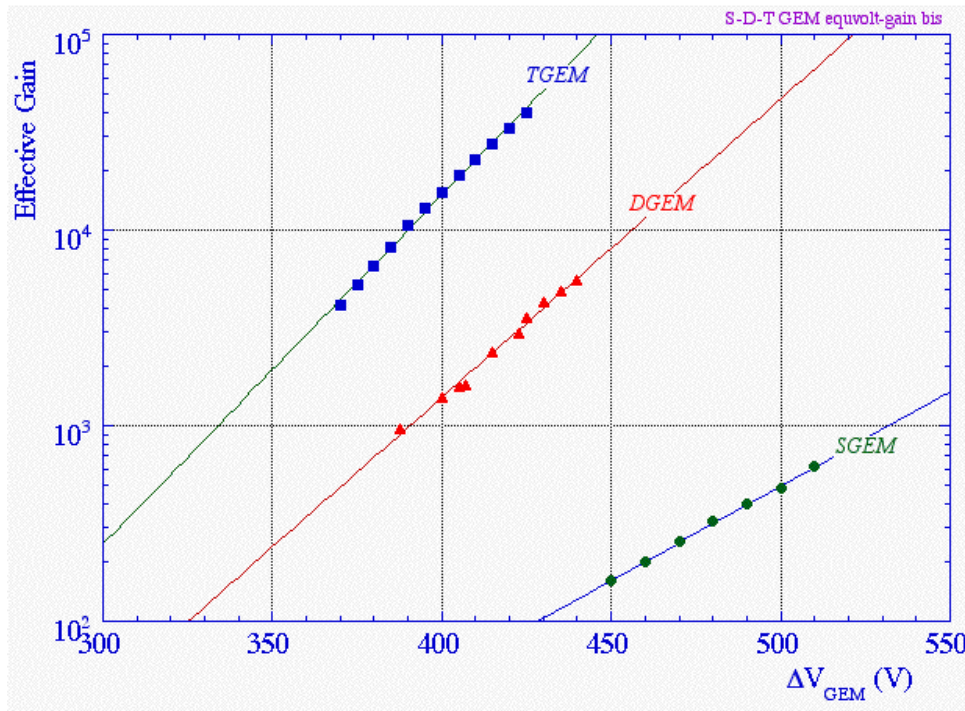
Range in Working gas

1.47 MeV α



- 1) Operation in flow mode with Ar /CO₂ (70/30) mixtures at atmospheric pressure to avoid ageing effects .
- 2) Range of 1.47 MeV α in the mixture gas is about 7 mm (SRIM).
- 3) If the drift gap is chosen corresponding to the range of the ions so as to energy deposited completely in the drift gas volume, the neutron can be detected with maximal pulse-height related to good γ discrimination.
- 4) Range of ions and emission direction determine spatial resolution.

Double GEM is enough to α or ${}^7\text{Li}$ ($\sim 1\text{MeV}$)



Charge output = initial Charge * Gain

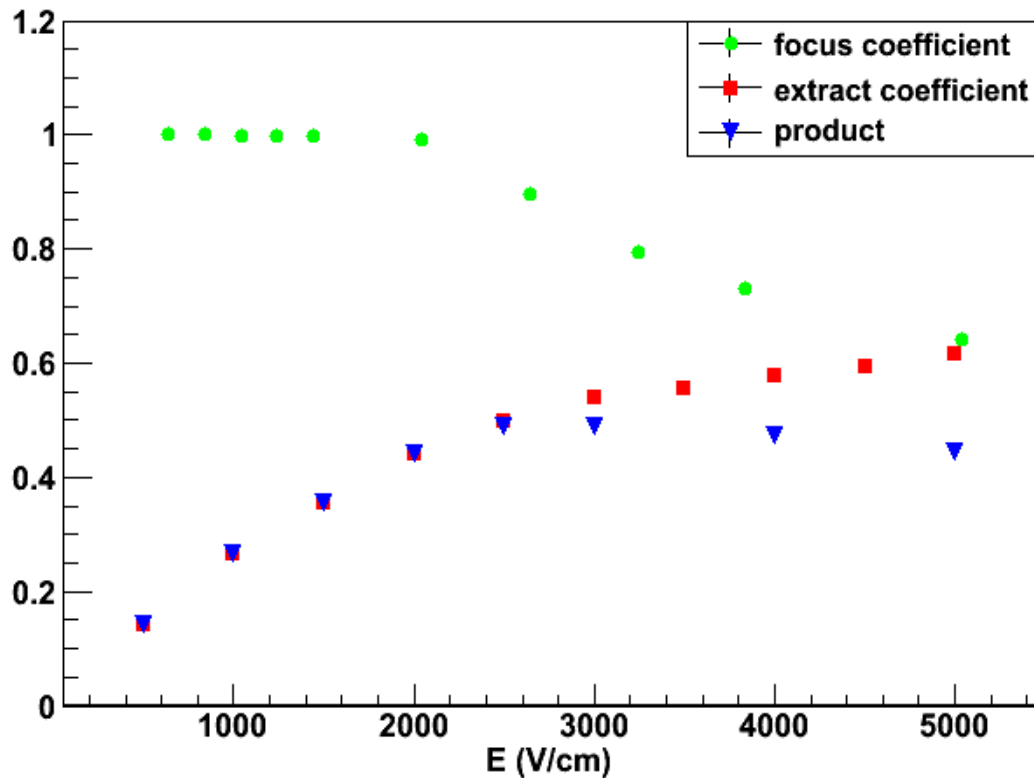
Initial charge: 1~5fC

Gain: 100~500

Charge output: $\sim 1000\text{fC}$

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

E for drift, transfer and induction



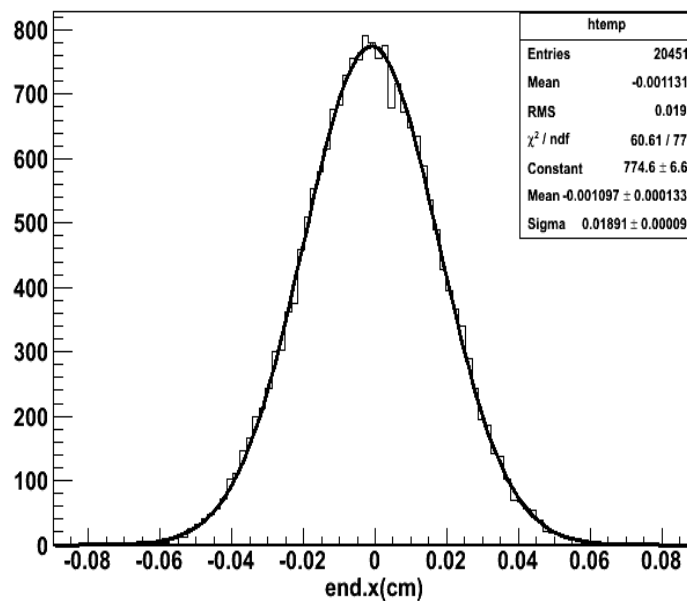
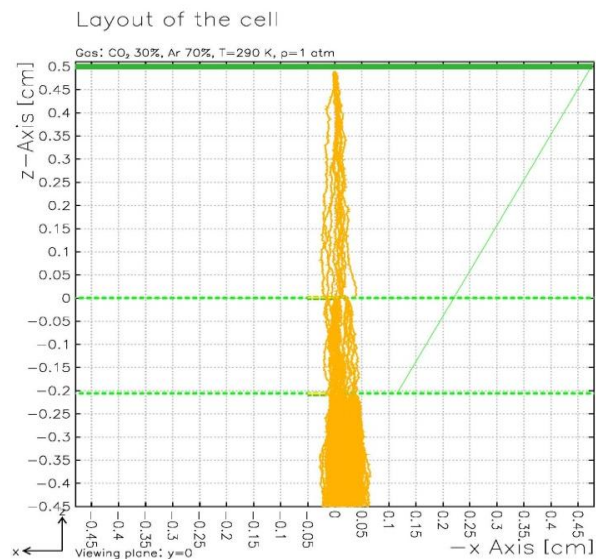
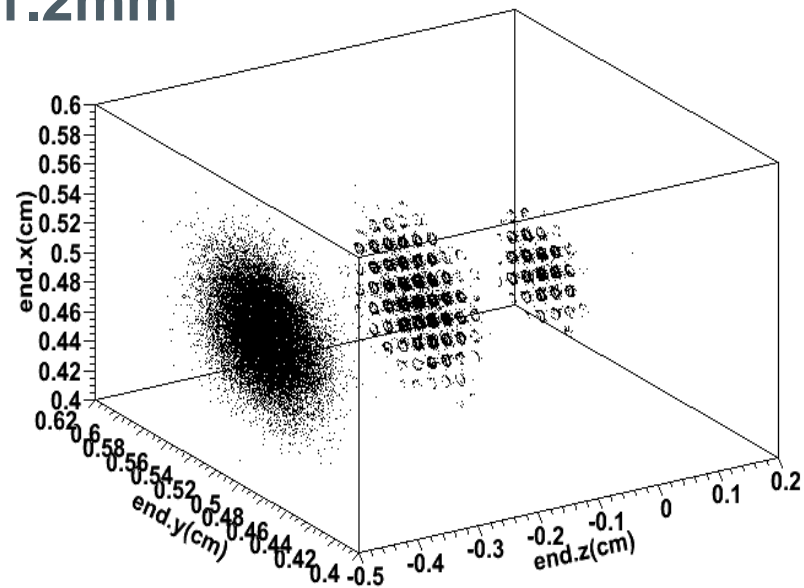
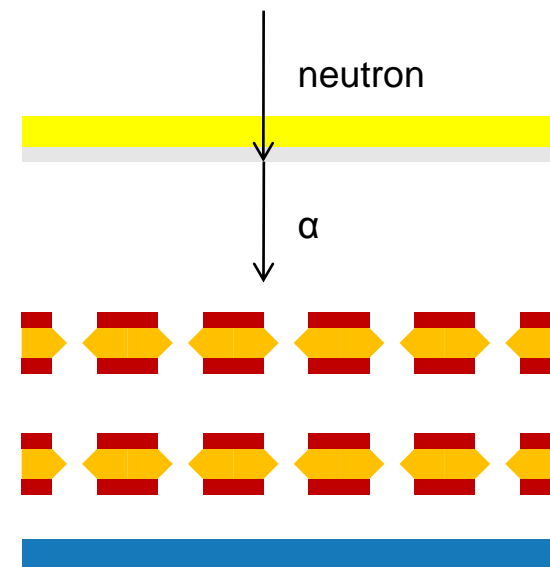
— E_{drift} : 1~2kV/cm

$V_{\text{GEM}}=380\text{V}$

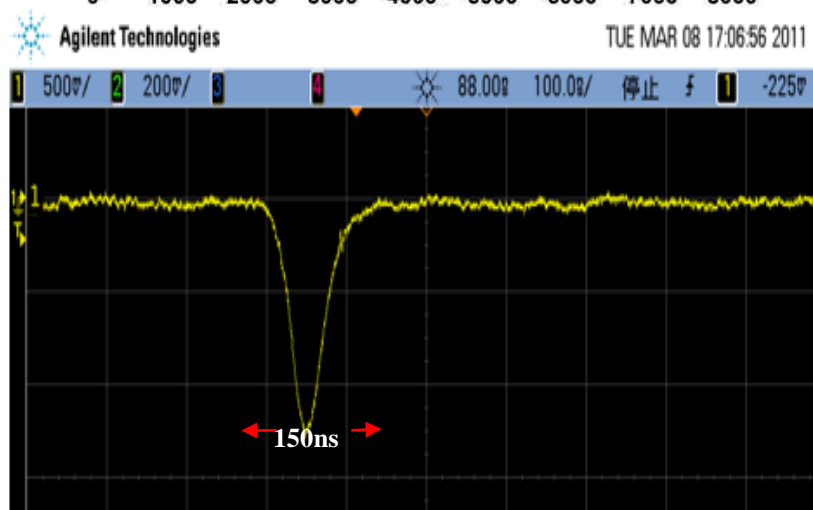
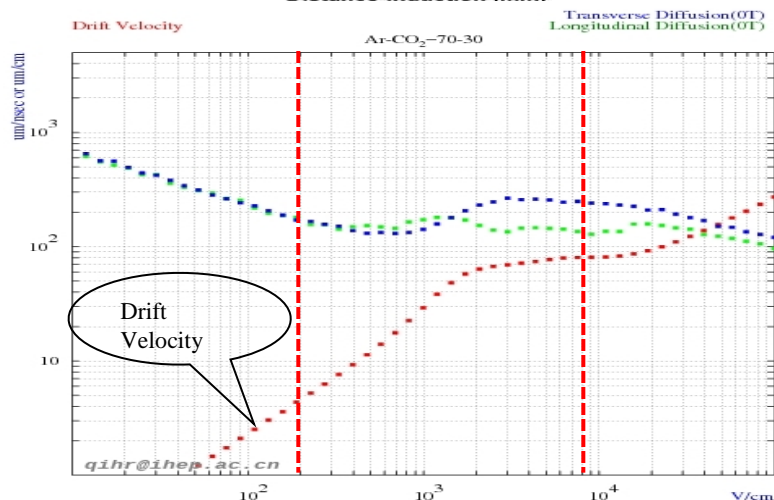
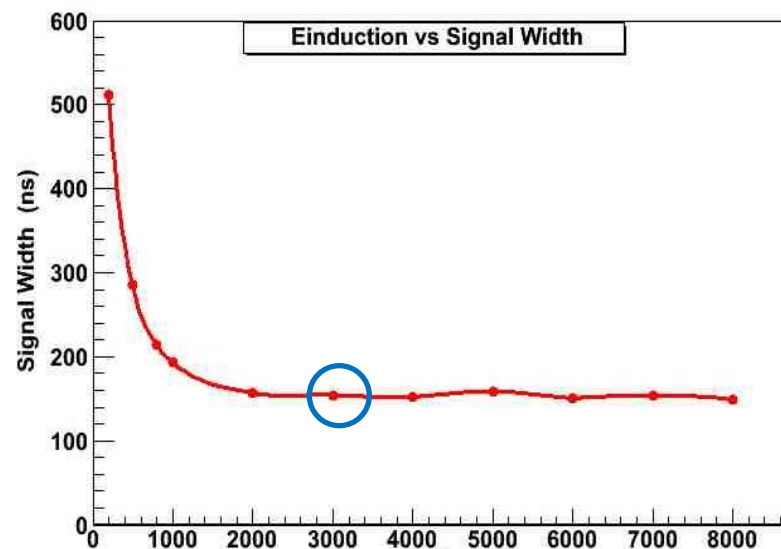
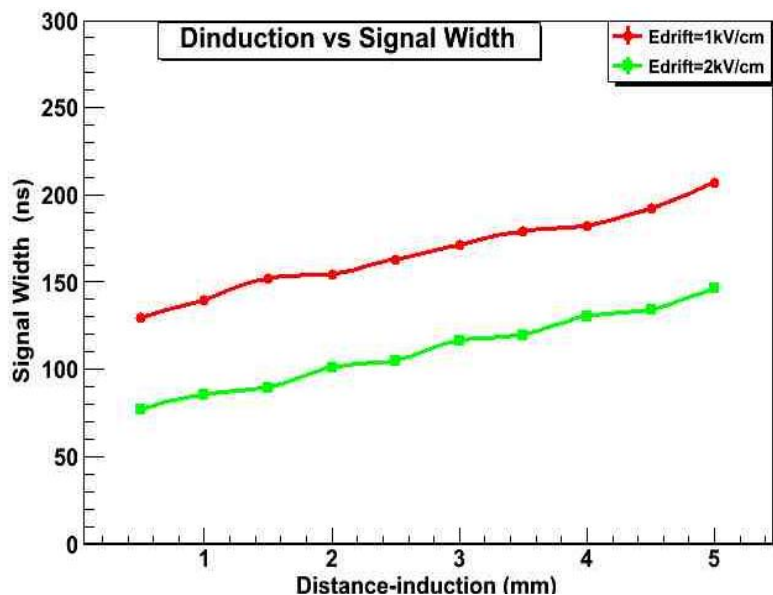
— E_{transfer} : ~3kV/cm

— $E_{\text{induction}}$: ~3kV/cm

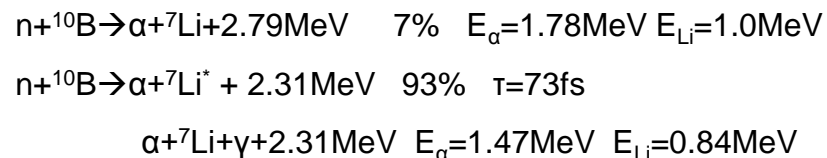
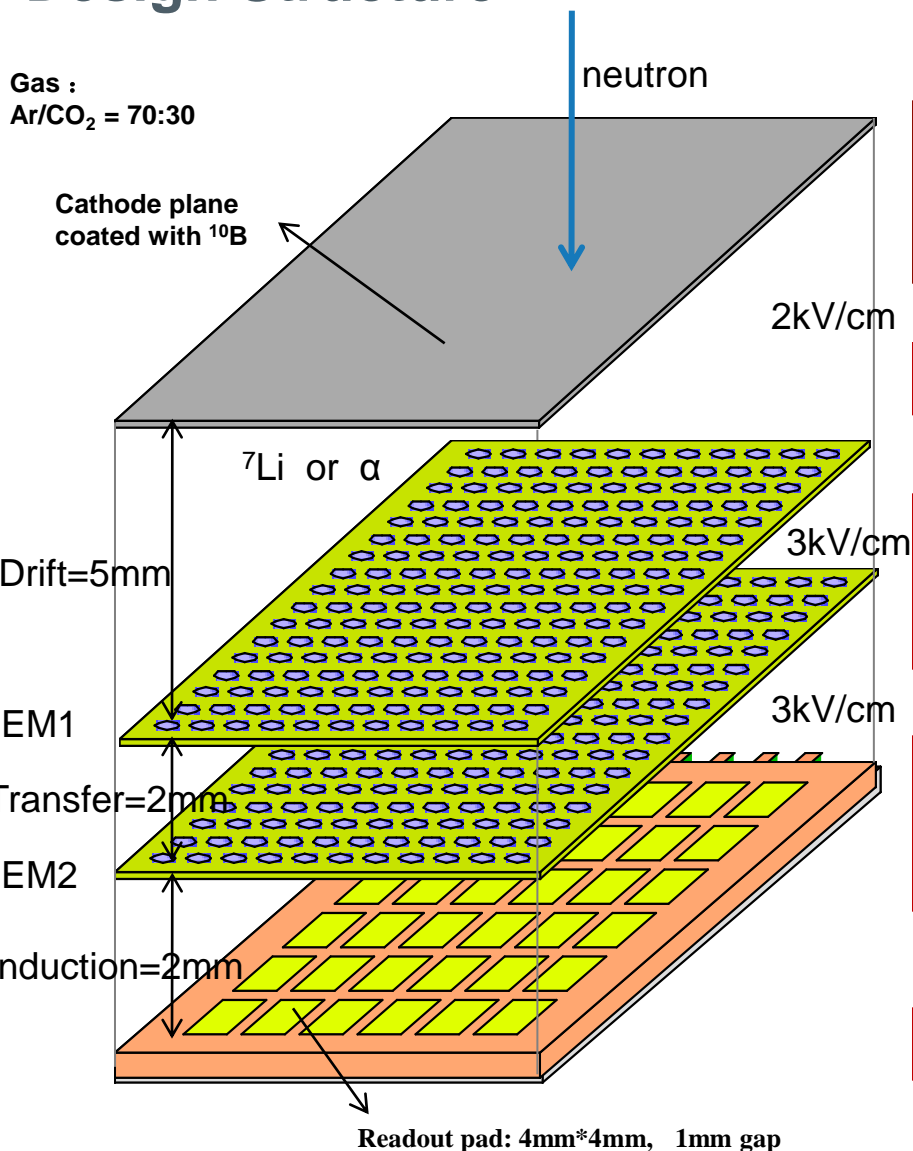
Transverse drift of electron~1.2mm



Signal induced by neutron ~ 150ns wide



Design Structure



¹⁰B: easy to get, cost less, chemical stability

Gain: $<10^3$
Charge output: 0.1~1 pC
Pulse: ~100ns wide

With the thin conversion layer, the time and the location of the emitted α or ⁷Li can be just treated as those of incident neutron.

Active area: 50mm*50mm

Efficiency Linearity

$$\Phi(x, y, t) = \Phi_0(x, y, t) \left(1 - \int S(E, x, y, t) e^{-n\sigma(E)d(x, y)} dE \right)$$

$$\eta[d(x, y), S(x, y, t)] = \frac{\Phi}{\Phi_0} = 1 - \int S(E, x, y, t) e^{-n\sigma(E)d(x, y)} dE$$

Φ_0 : Flux of incident neutron,

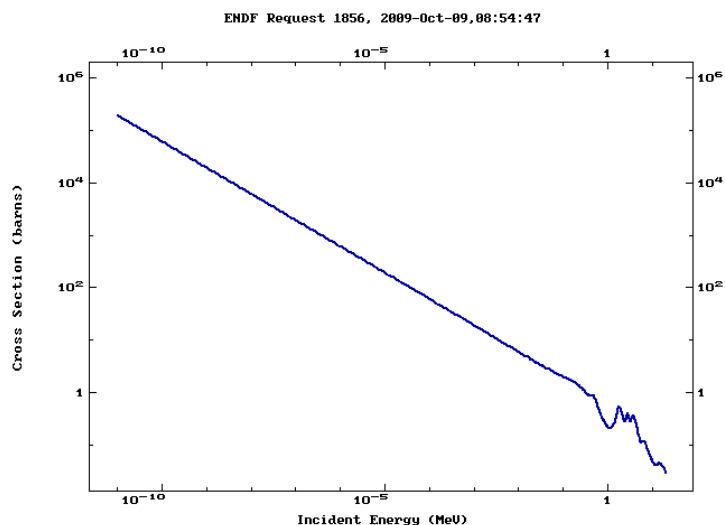
Φ : Reaction rate, η : Conversion efficiency

S : energy spectrum of incident neutron

$\sigma(E)$: Cross section with energy

n : Atomic density of ^{10}B , d : Thickness of ^{10}B

Energy Linearity:

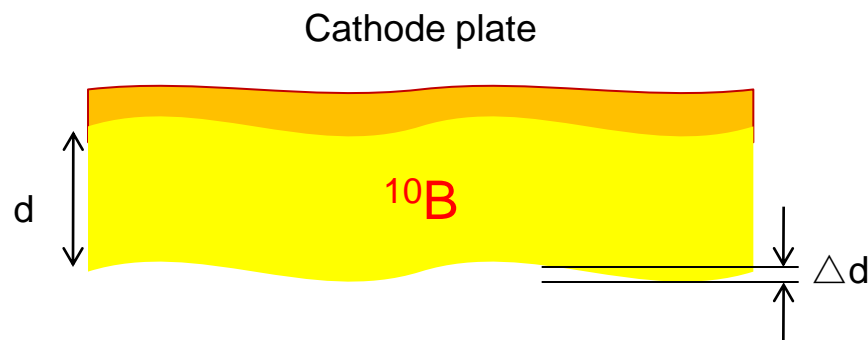


Uniform d : if energy spectrum $S(E)$ is uniform in 2-dimensional cross section, Conversion η is constant.

Intensity Linearity:

Determined by counting rate of detector and readout speed of electronics

Spatial Linearity:



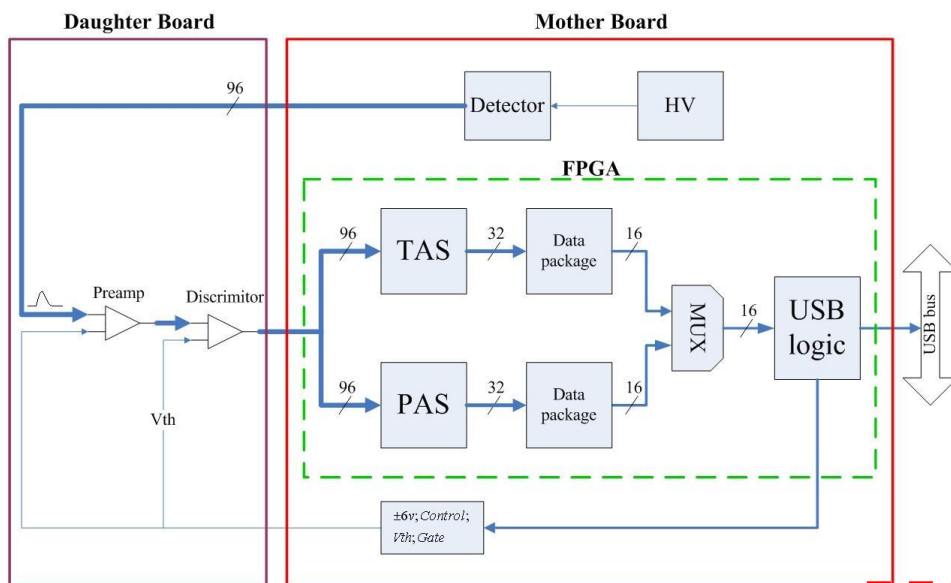
$$d \rightarrow 0, \eta(x, y) = d(x, y) \int S(E, x, y) n \sigma(E) dE$$

Uniform $S(E)$:

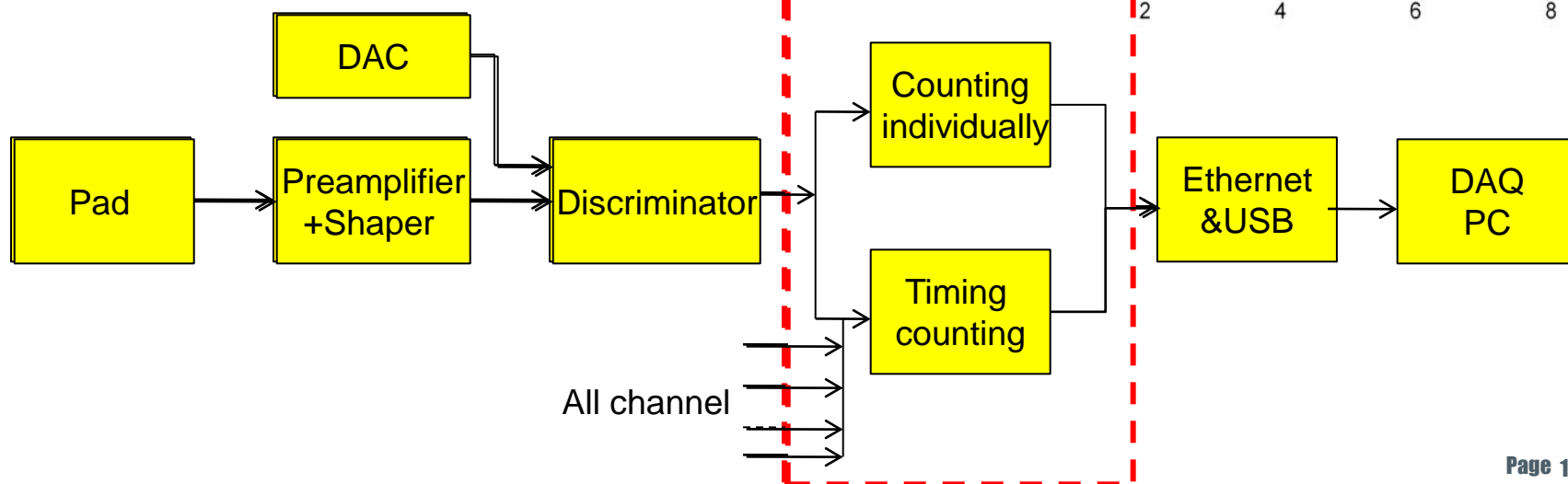
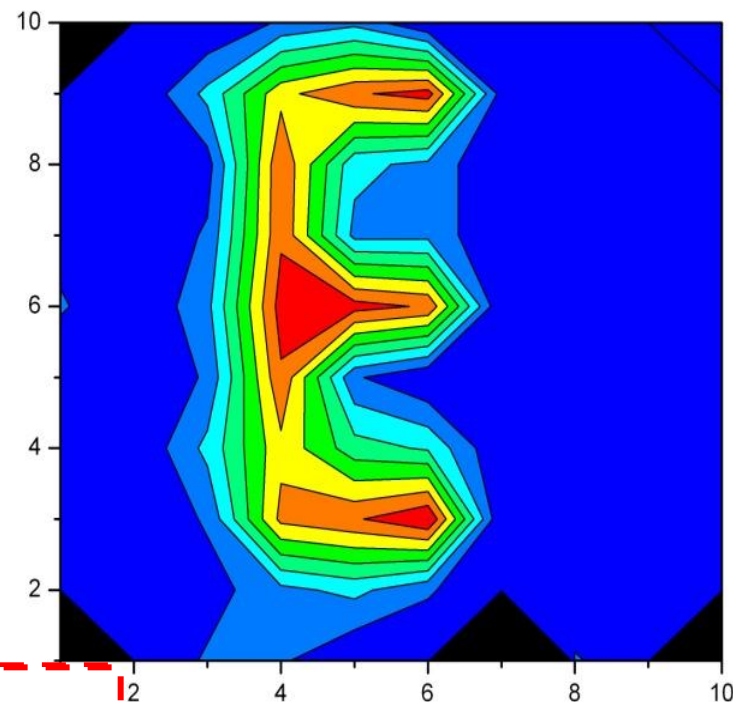
$$\frac{\Delta \eta}{\eta} = \frac{\Delta d}{d}, \quad d = 0.1 \mu\text{m}, \quad \Delta d = 5 \text{nm}, \quad \frac{\Delta \eta}{\eta} = 5\%$$

variation of thickness: $< 5 \text{nm}$

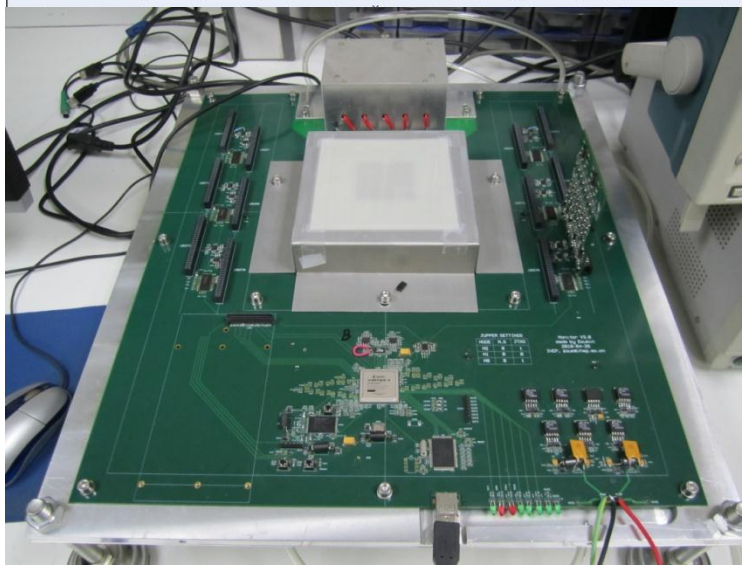
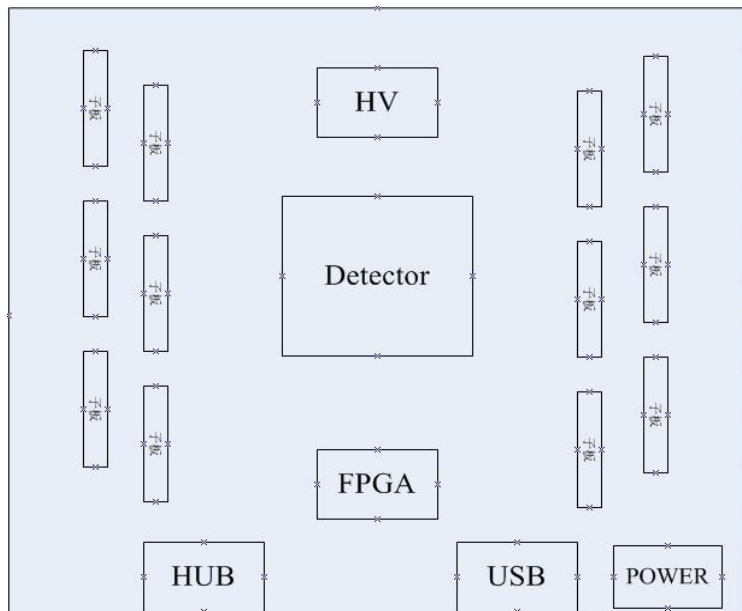
Readout electronics



FPGA



Compact Prototype



Native THGEM (Dr. H.B. Liu, GUCAS)

(a)



Copper 20 μ m

FR4 160 μ m

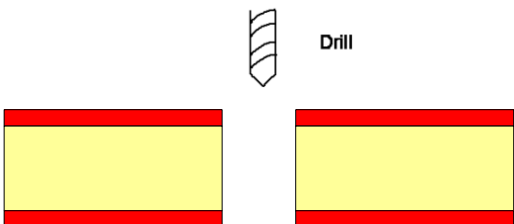
Thickness 200 μ m

Hole 200 μ m

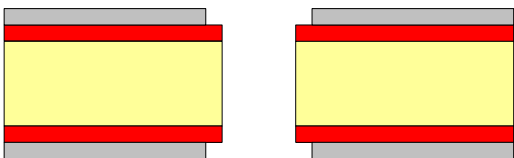
pitch 500 μ m



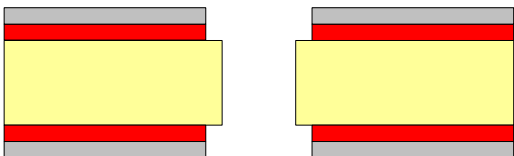
(b)



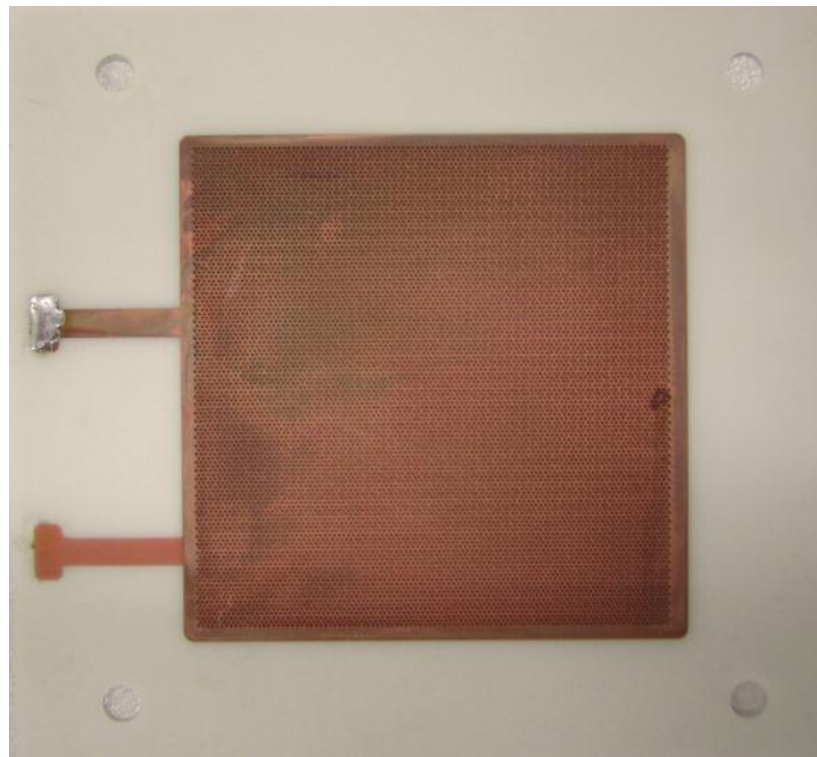
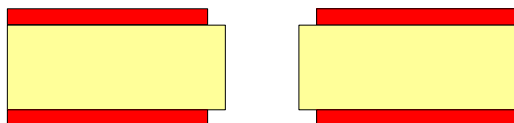
(c)



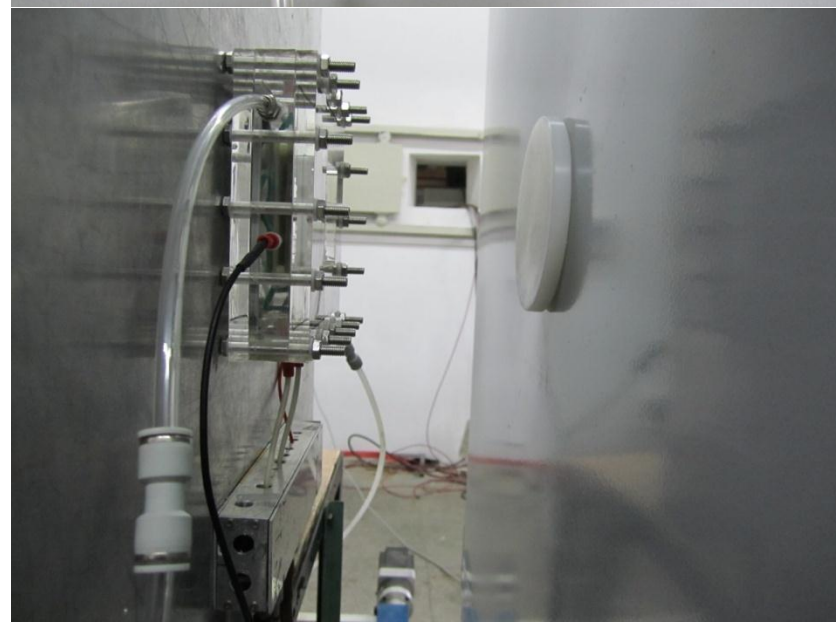
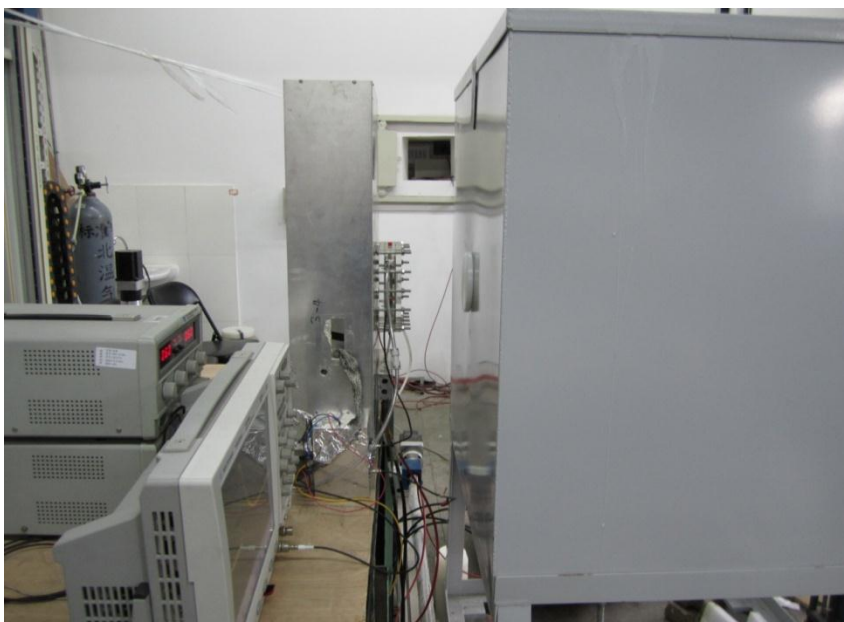
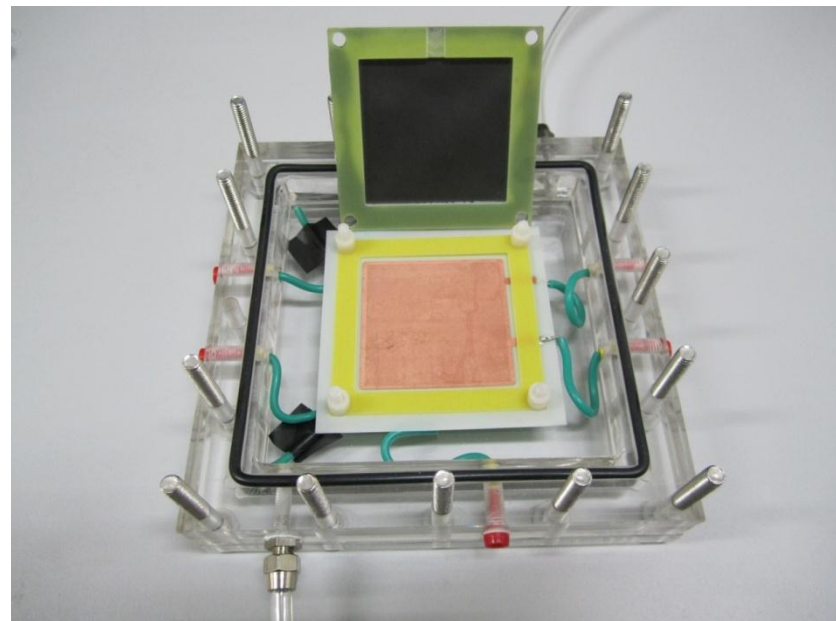
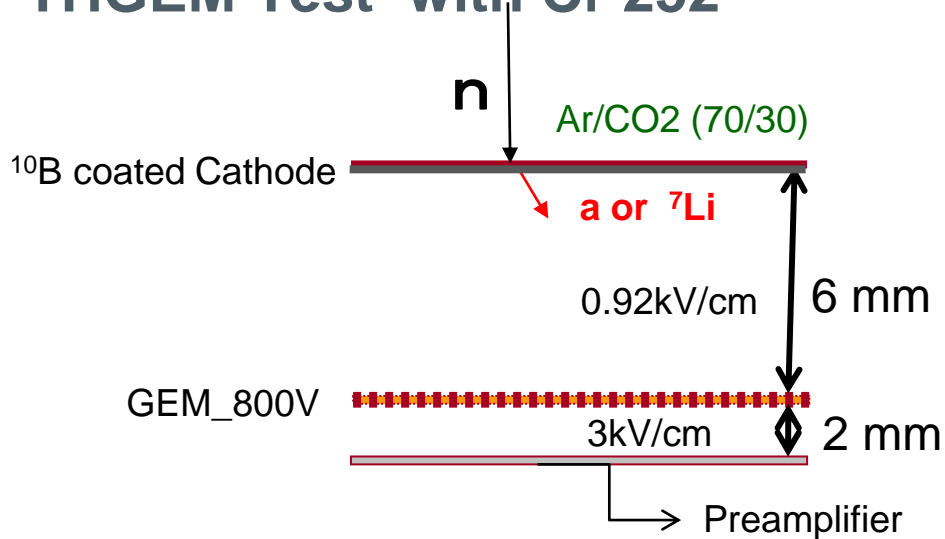
(d)



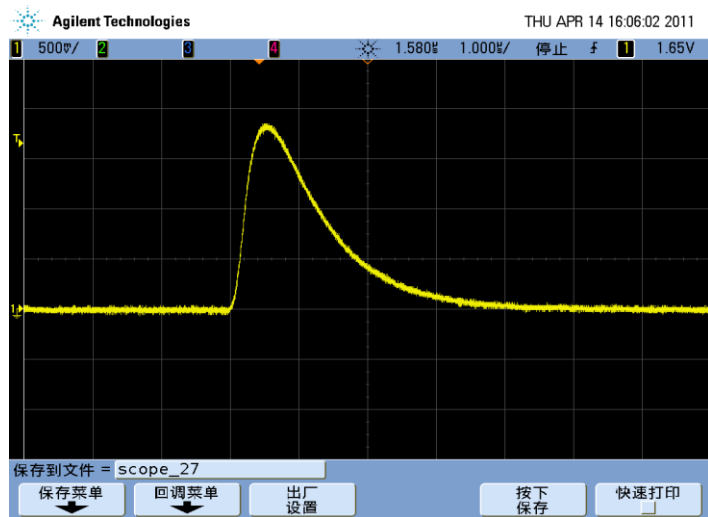
(e)



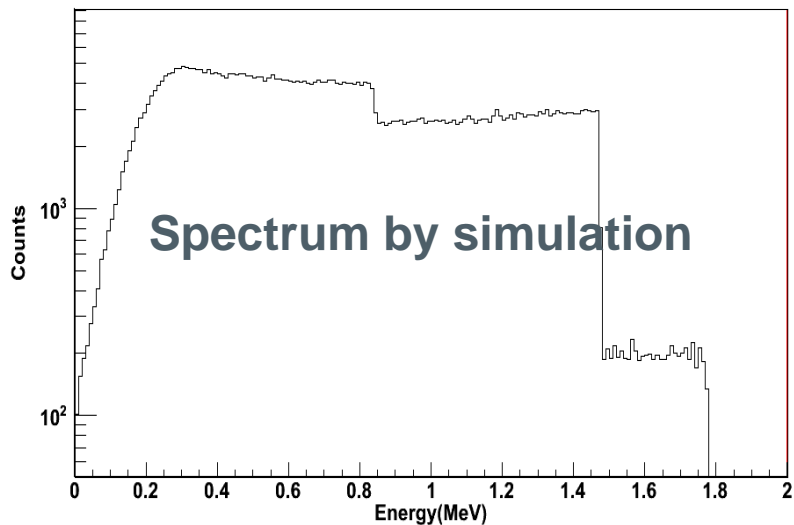
THGEM Test with Cf-252



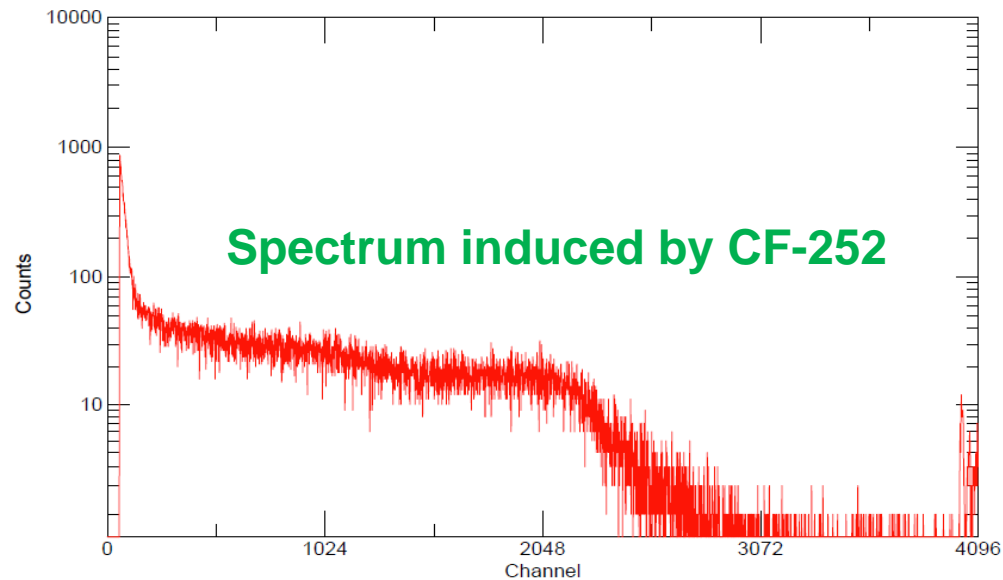
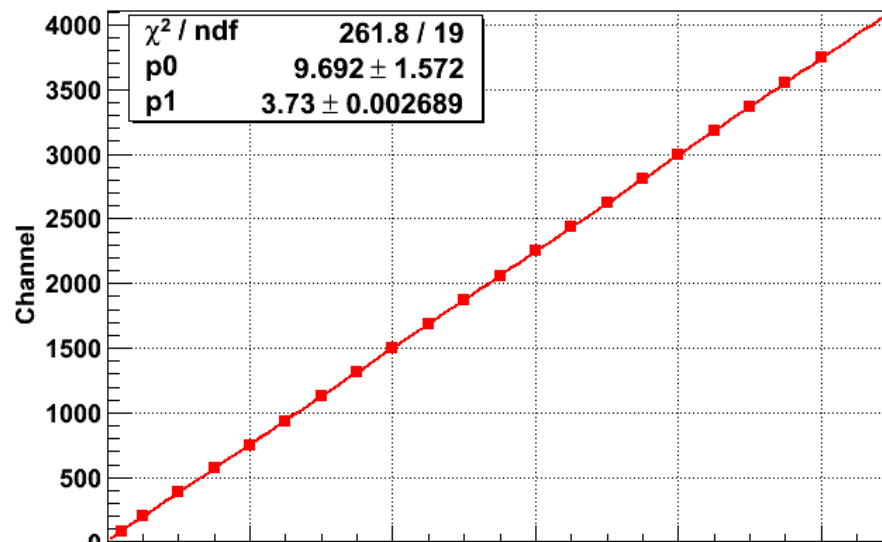
THGEM Test with Cf-252



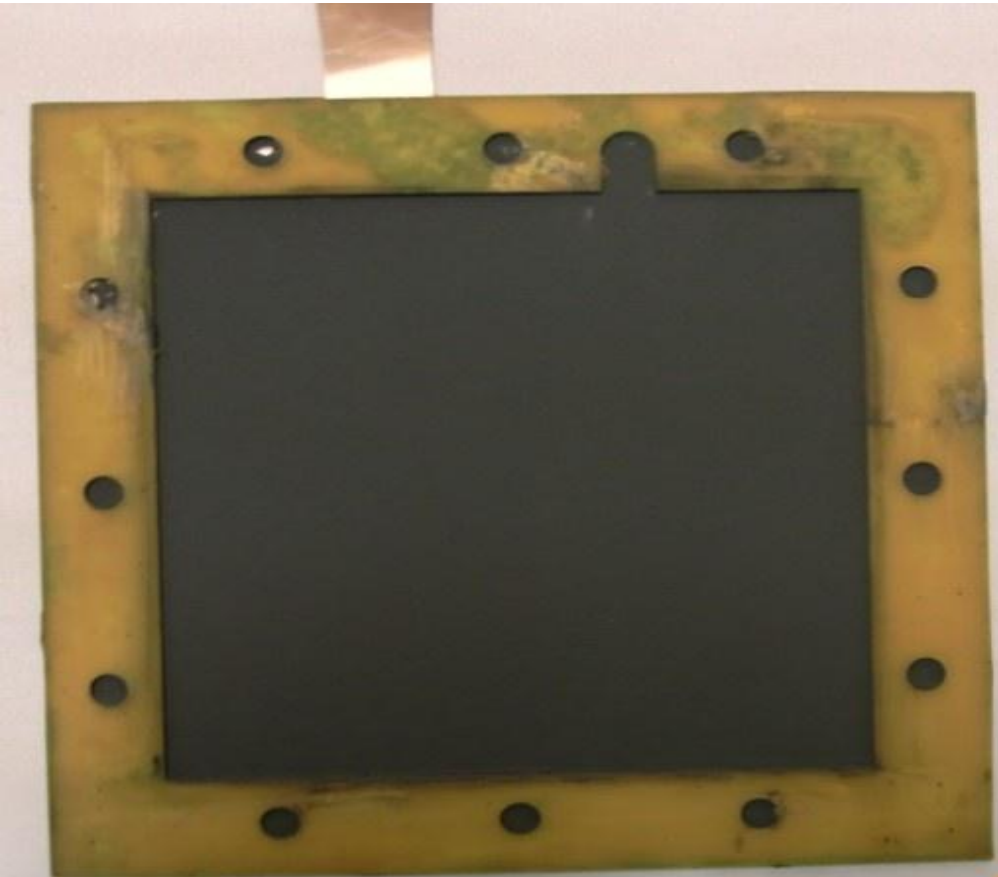
ion spectrum



Calibration for MCA



Drift Cathode with Boron Coating



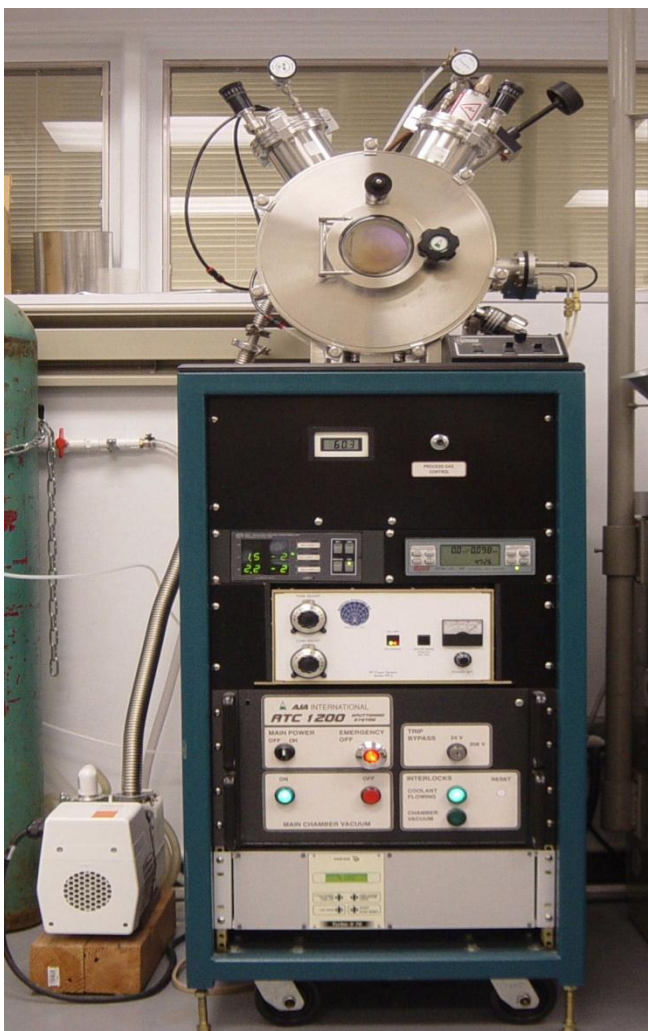
Electrophoresis in 261 Corporation



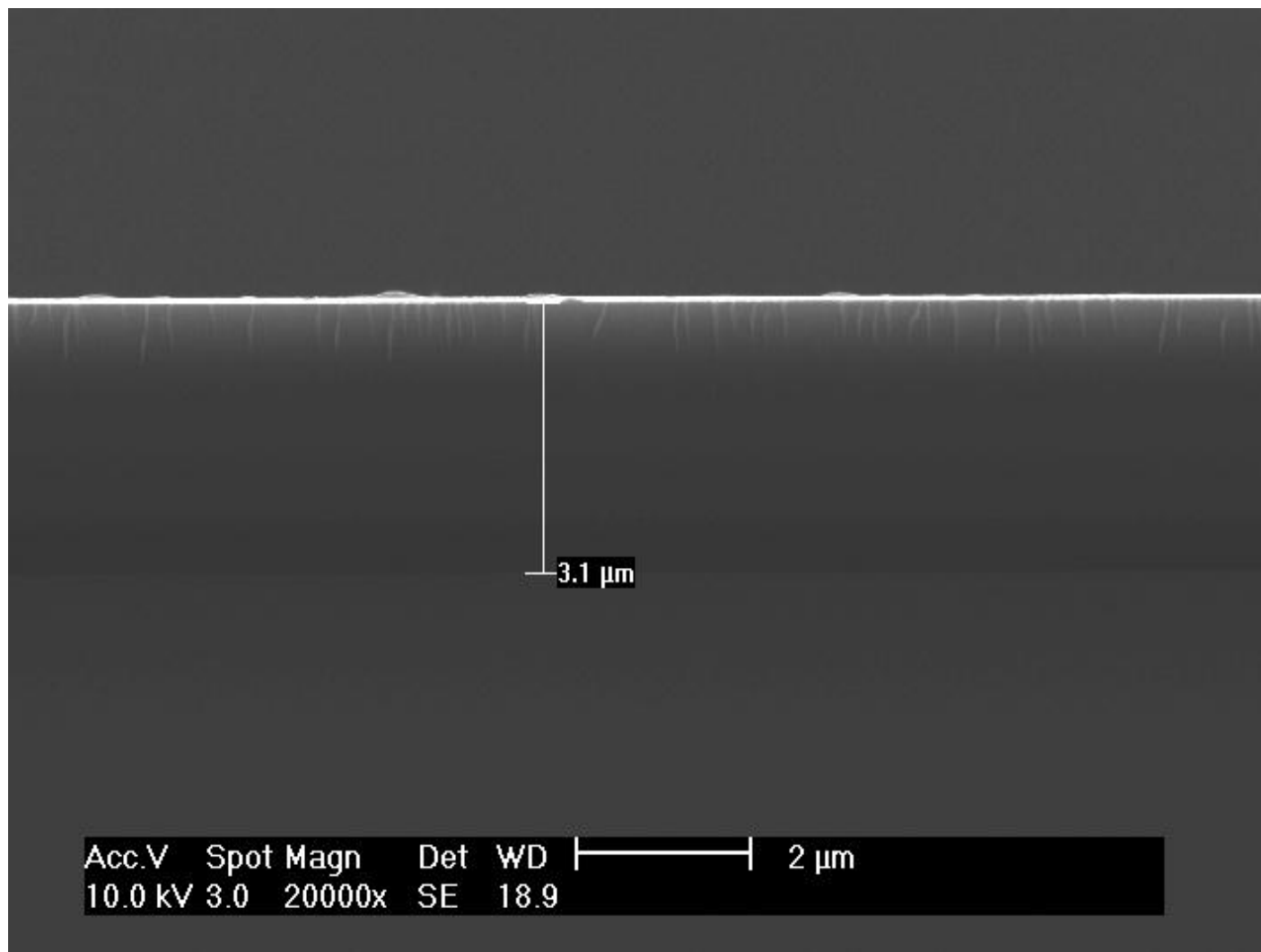
CDT GmbH, Heidelberg

Boron Coating Technology(Pro. X.G. Diao, BUAA, China)

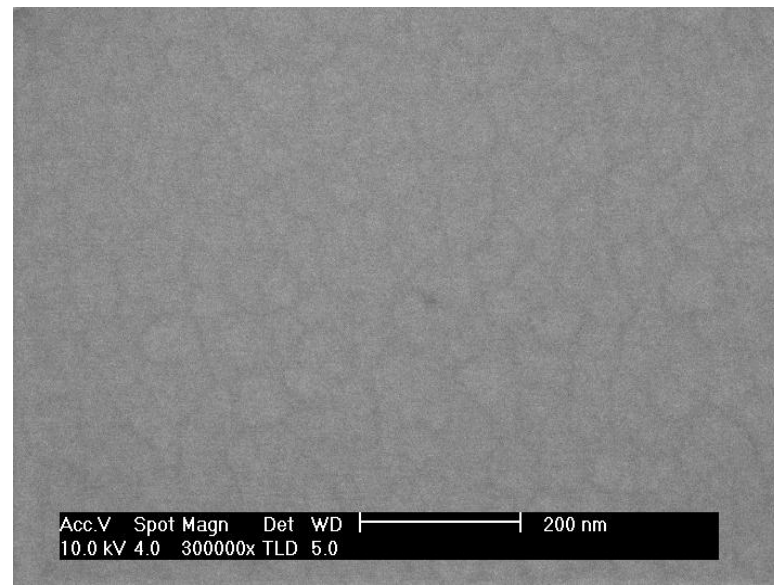
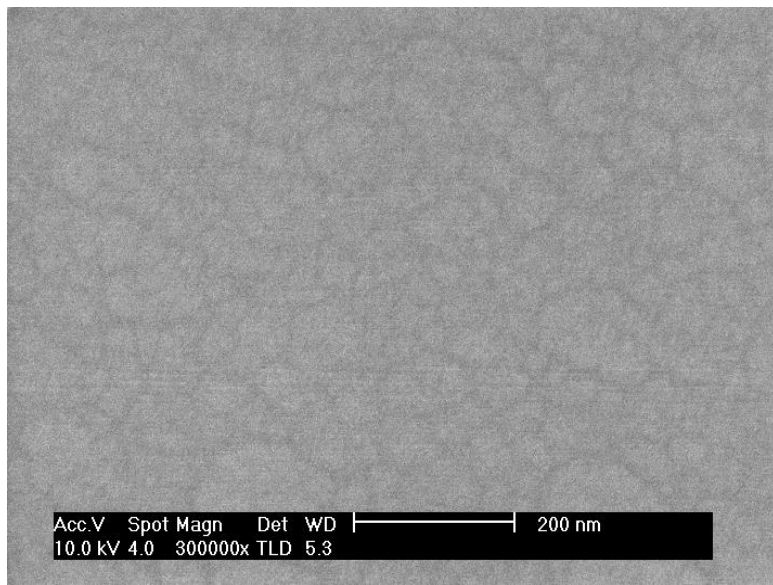
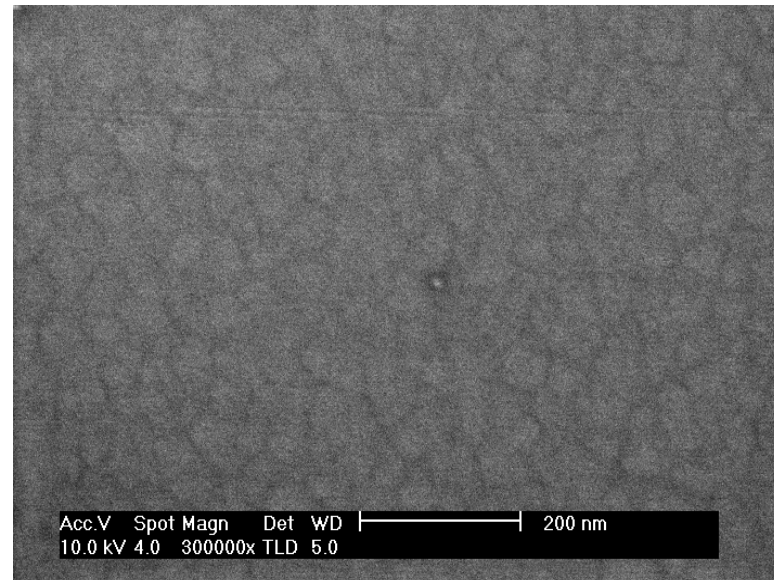
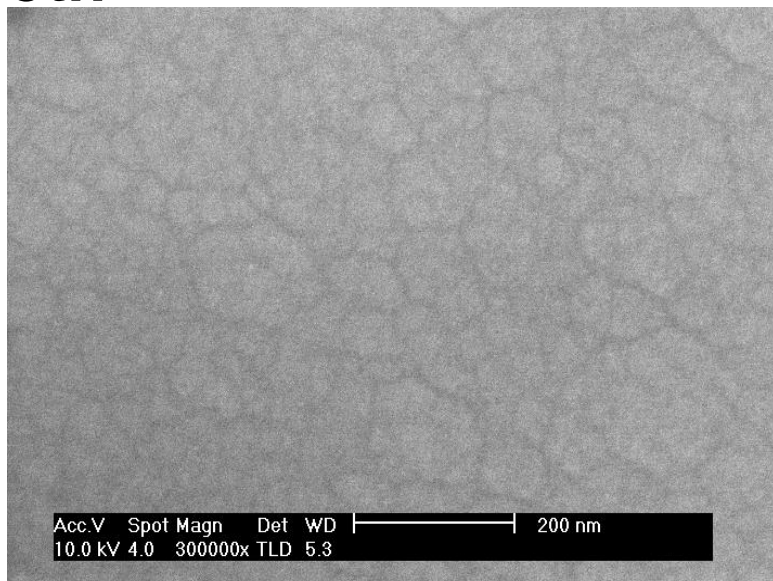
Magnetron Sputtering System



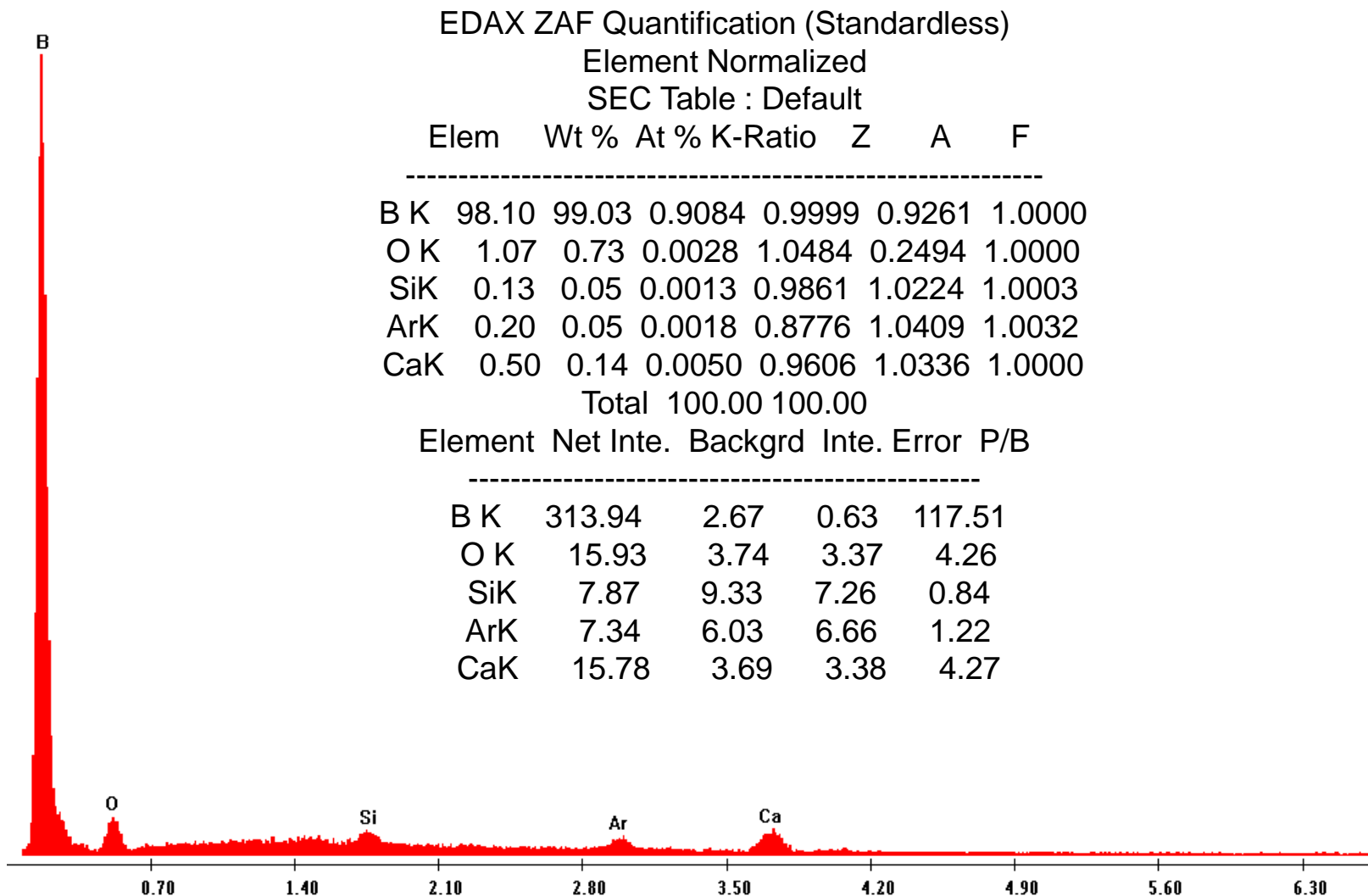
SEM



Smooth



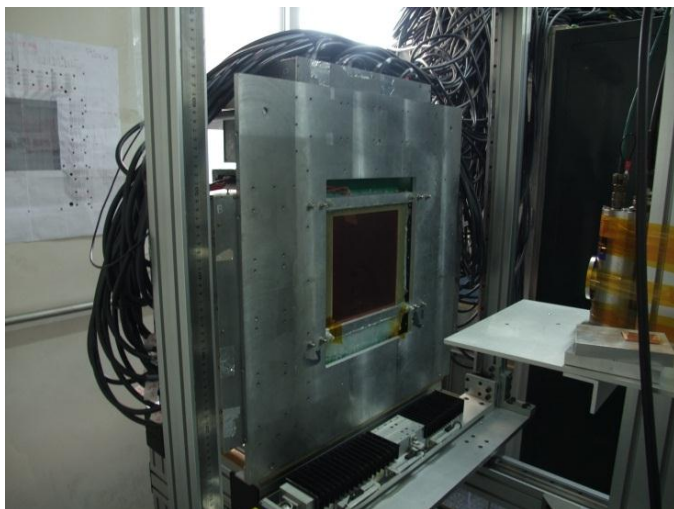
EDS



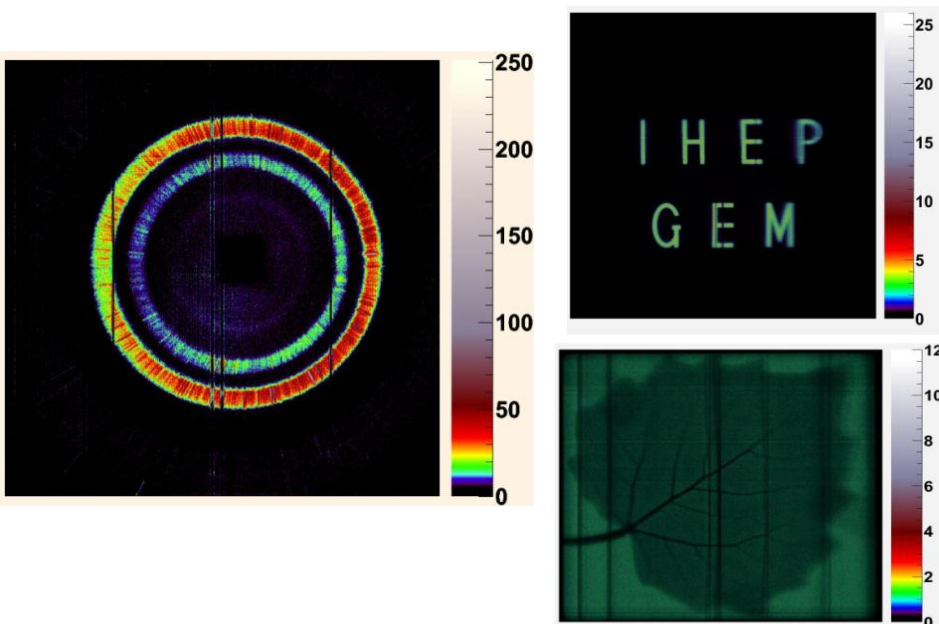
Summary

- **Neutron beam monitor detector based GEM was constructed**
 - Detector was carefully studied by M.C simulation
 - Tested by neutron source Cf-252
 - Wide of pulse induced by neutron ~ 150ns
 - 8 channels of read out electronics was tested
 - Boron coating technology
- **Next step**
 - Produce the whole electronics
 - Test the detector by neutron beam

Other application @ IHEP & Gucas



- Triple GEM(CERN provide),
20x20 cm²
- good spatial resolution
 $\sigma \sim 60 \mu\text{m}$
 - 437chs @X(pitch 0.457mm)
 - 267chs @Y(pitch 0.752mm) :



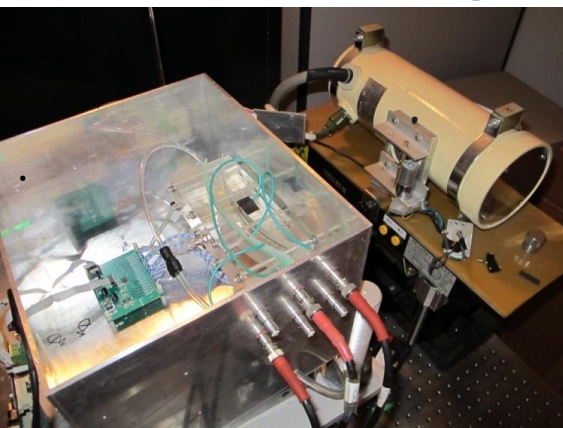
- by X-ray
“IHEP, leaf and diffraction images”

Lv.X.Y Qi H.R. provided

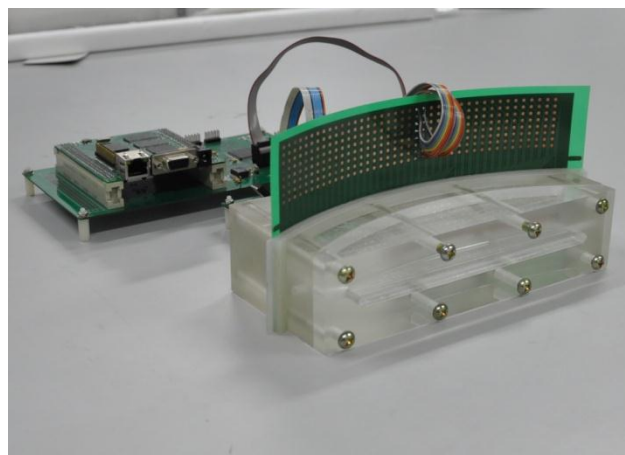
Recent results of THGEM (0.2mm thick) detectors (by GUCAS)

One dimension curved chamber for Diffraction spectrometer of synchrotron radiation. (Liu H.B Chen.S provide)

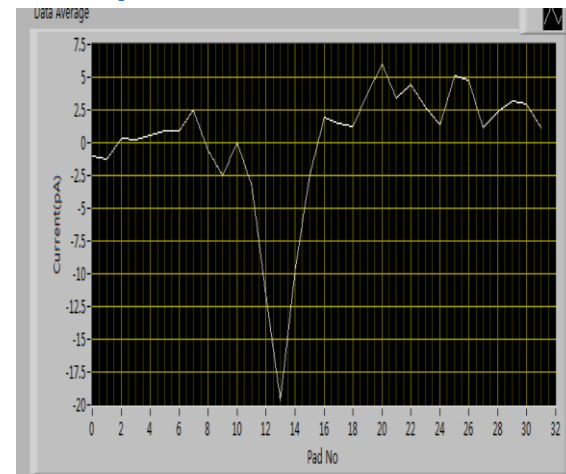
- THGEM boards collaborating with 699 factory of Aeronautic Research Institute
- **0.2 mm THGEM thinner board easy to be curved.**
- Spatial resolution: $\sigma \sim 0.5\text{mm}$
- all now using direct current mode (1-3 kHz, 64 readout)



Test with x-ray tube
(Mo target 17 keV)



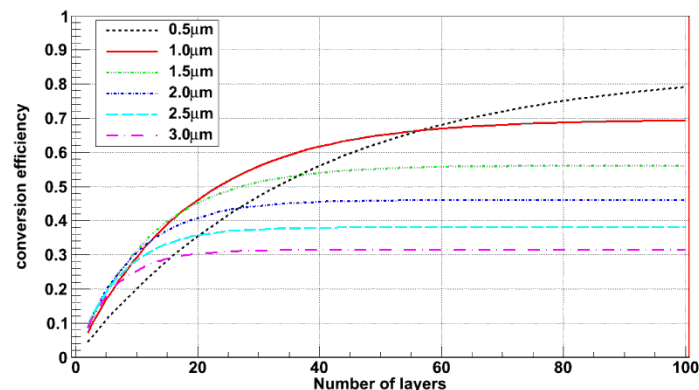
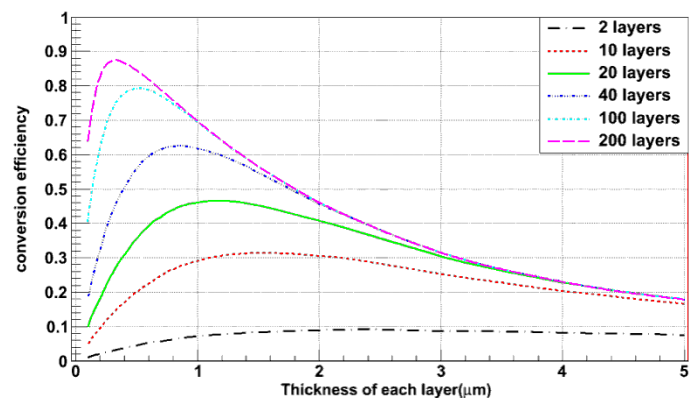
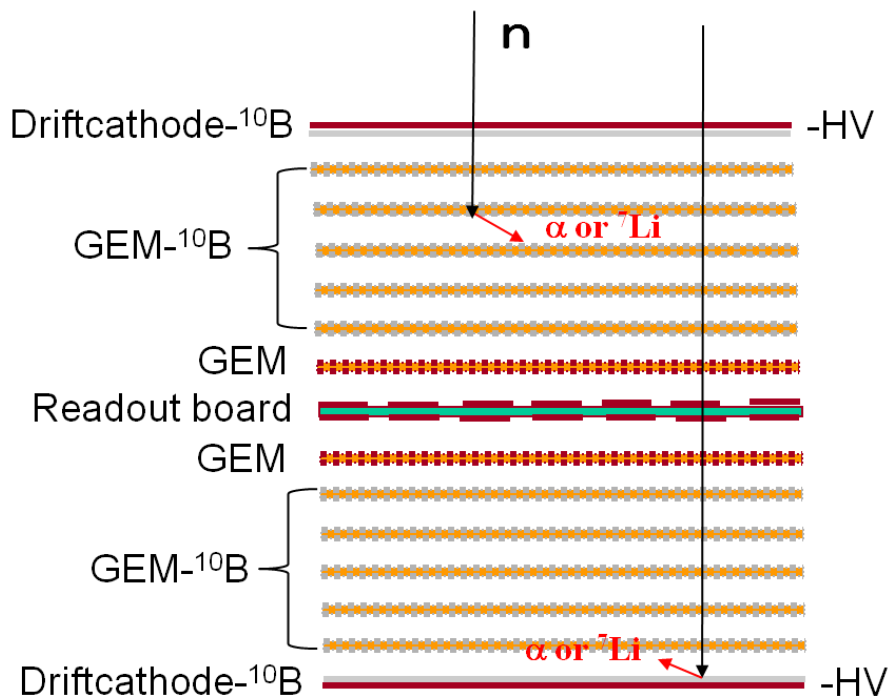
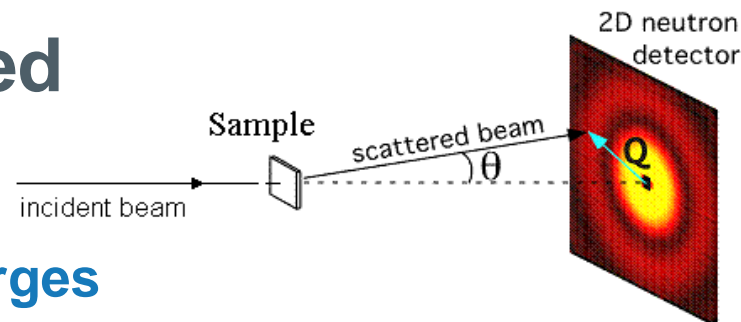
Curved chamber
27cm radius, 64 anode readout strips
pitch 0.5mm (strip~0.4mm).



intensity distribution along
3 strips (slit width 0.5mm)

Multi layer GEM with B10 coated

- Each GEM carries two Boron Layers
- GEMs are operated transparent for charges
- Thus single layer detection efficiencies are accumulated up to 40% for 1.8Å
- Last GEM is operated as amplifier



THANKS !

谢谢！