# R&D of neutron beam monitor based GEM detector


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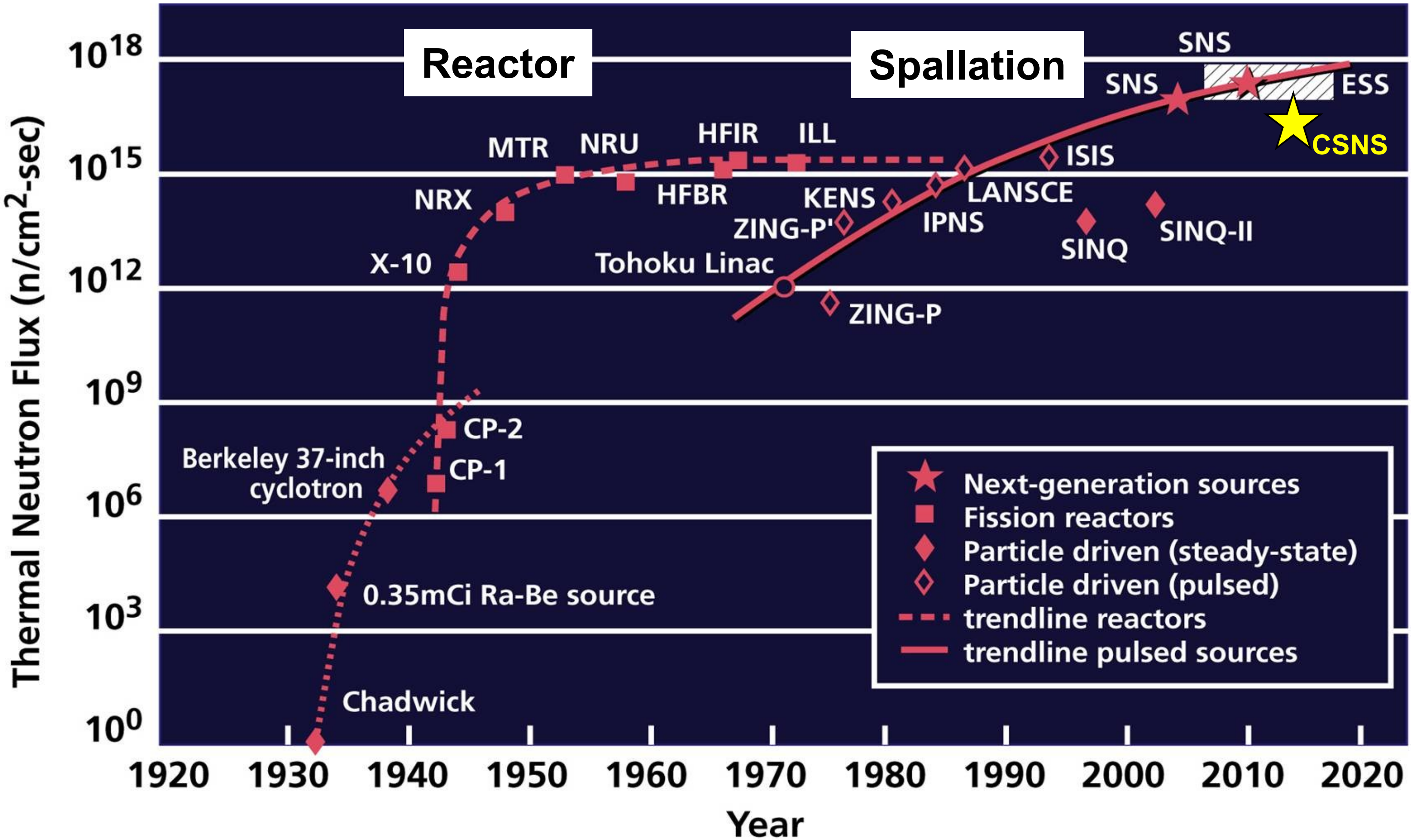
CSNS CHINESE ACADEMY OF SCIENCES

# Outline

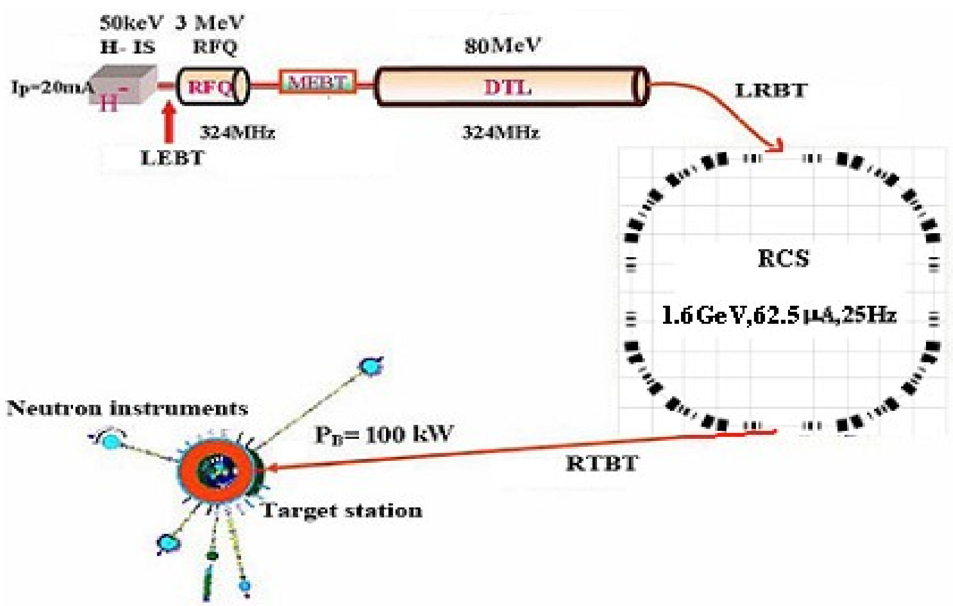
- Introduction to CSNS
- Neutron Beam Monitor
- Native THGEM
- Boron Coating Technology

# 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




# 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: ~4cm*4cm
- Flux at Guide Exit

  CSNS: ~$10^8$n/cm$^2$.s(MS, HIPD), ~$10^7$n/cm$^2$.s(SANS)

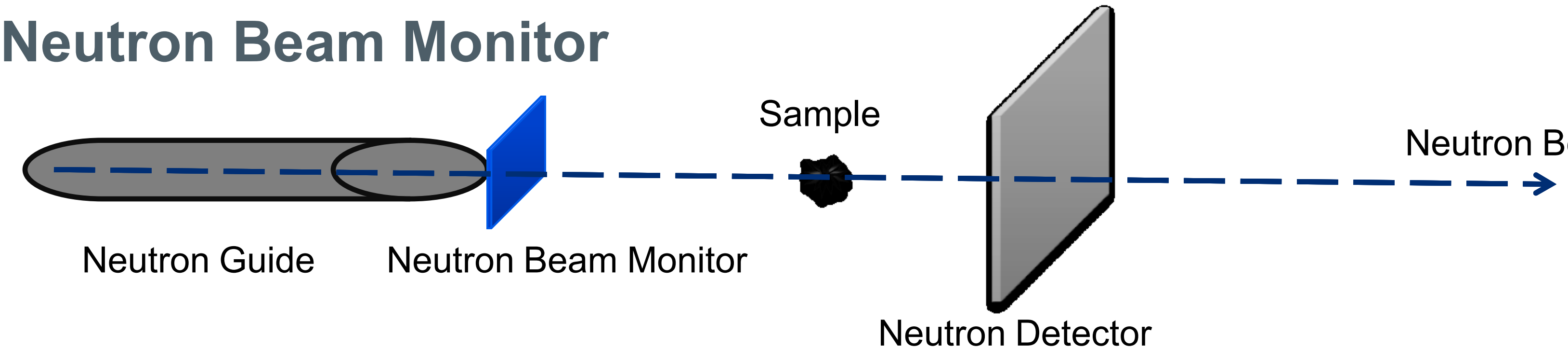
  Reactor: ~ $10^7$n/cm$^2$.s
- Repeated Pulse

  ~ms, CSNS: 40ms
- Wavelength Cutoff with Choppers/Velocity Selector

  Custom Extent: SANS 0.4~8 A

  HIPD 0.3~4.8 A MRS 1.9~6.2 A

# 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(~1μs)** → **Wavelength resolution**

– **Spatial resolution(1~10mm)** → **More accurate corrections**

– **Gamma to neutron separation** → **γ insensitivity**

– **High counting rate(~$10^6$Hz)** → **High intensity (>$10^9$n/ $cm^2$ . s)**

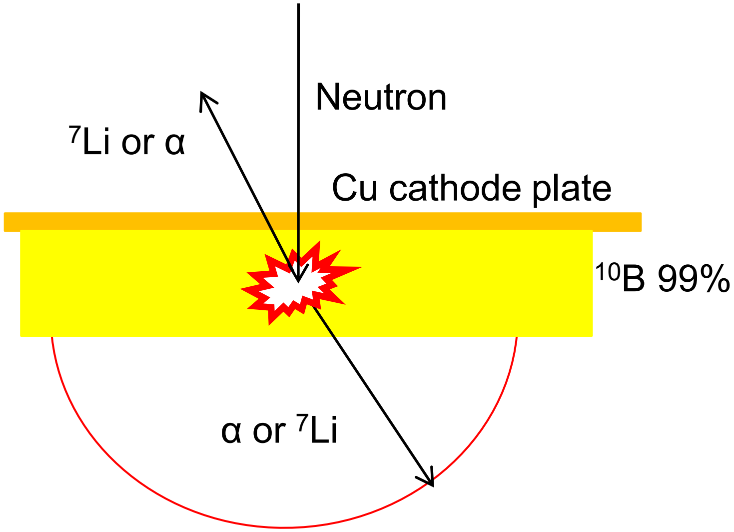
# History

| 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, Argorme | $^{3}He$ 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 | Micomegas with $^{235}U$、$^{10}B$ | <50μm | ~1MHz | Excellent in development |
| | SNS | Micomegas 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 Micomegas

# Neutron Convertor--$^{10}$B



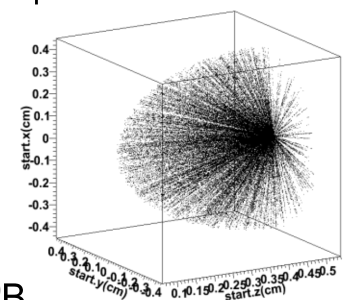

Due to the multiple Coulomb scattering:

1) Range of 1.47 MeV α : 3.6μm
   Range of 1 MeV $^{7}$Li : 2μm (SRIM)

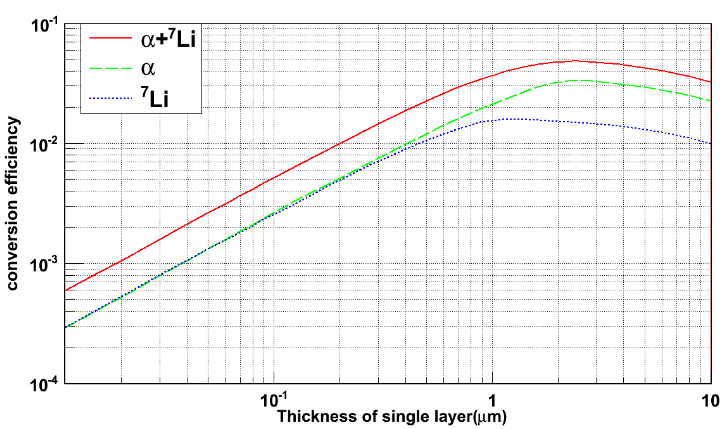
2)Maximum efficiency (~5%) for thermal neutrons: ~2.5 μm
   Low efficiency5‰: ~0.1 μm coated on Cu using evaporation or sputtering techniques.

3)Energy of charged particles is extended down.
   Thin foil can improve capacity of γ discrimination

4) Cone emission of α & $^{7}$Li

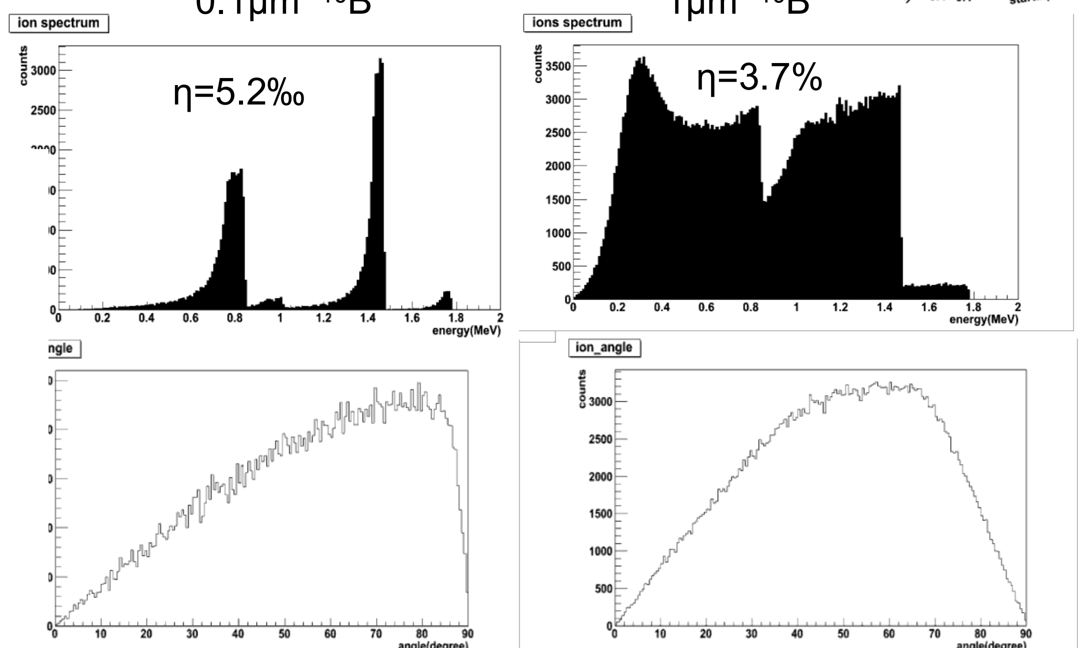



Geant4 Simulation for Thermal Neutron



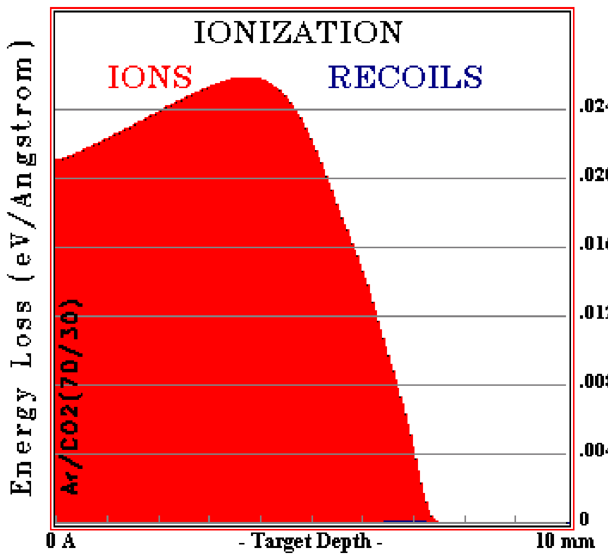

0.1μm $^{10}$B

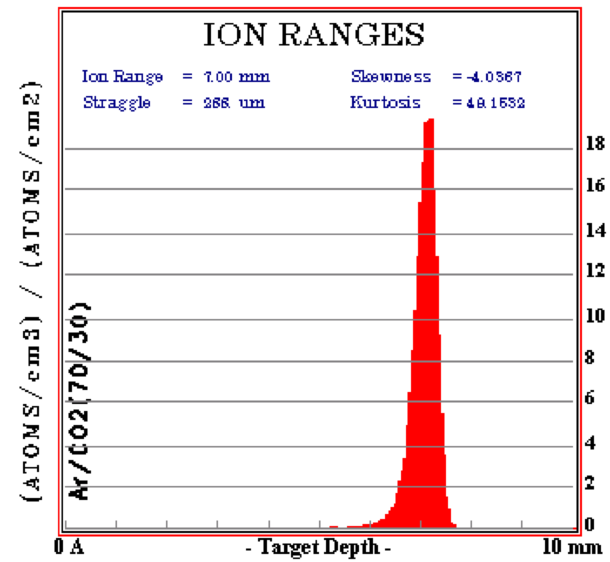
1μm $^{10}$B



# Range in Working gas

**1.47 MeV α**



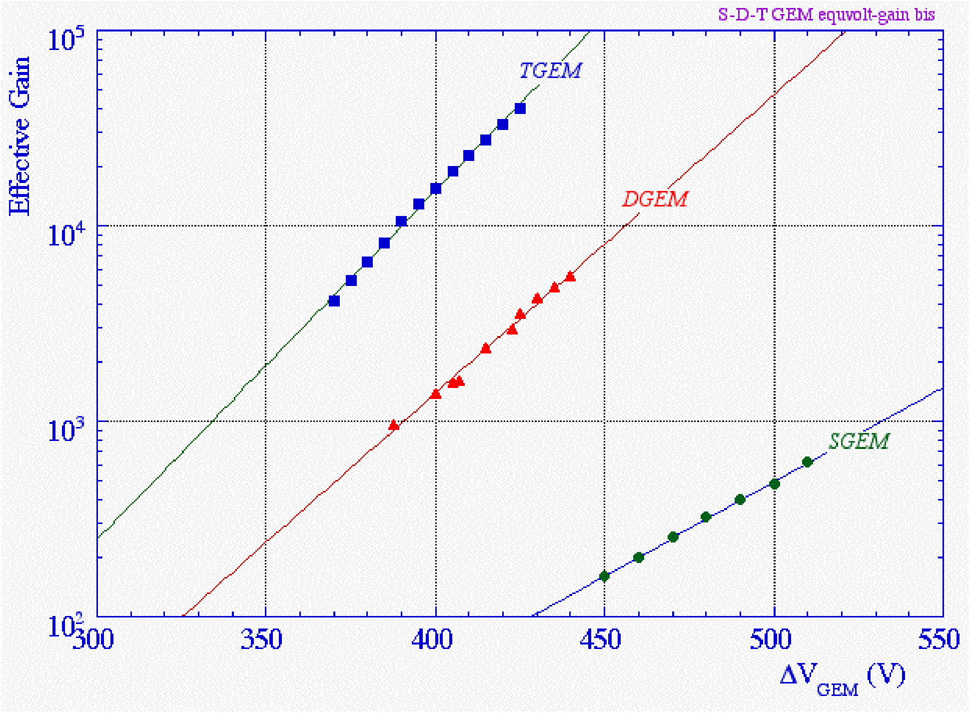

1) Operation in flow mode with Ar /$CO_2$ (70/30) mixtures at atmospheric pressure to avoid ageing effects .

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 $^{7}$Li (~1MeV)

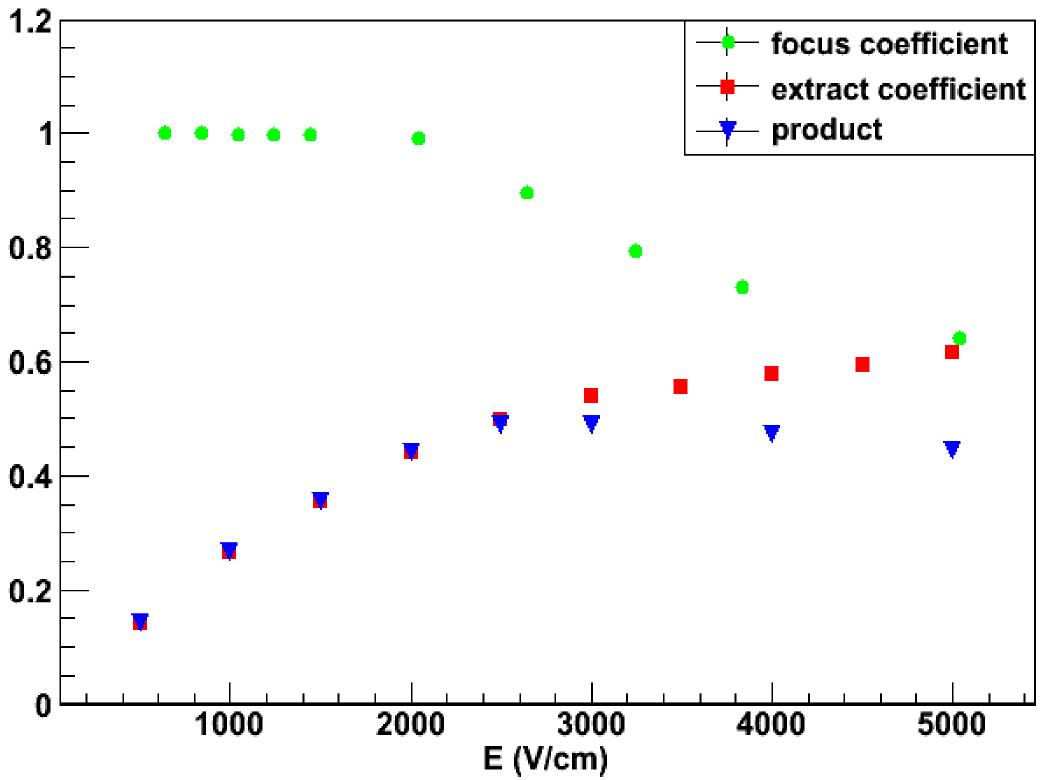



**Charge output=initial Charge*Gain**

**Initial charge: 1~5fC**
**Gain:  100~500**
**Charge output: ~1000fC**

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

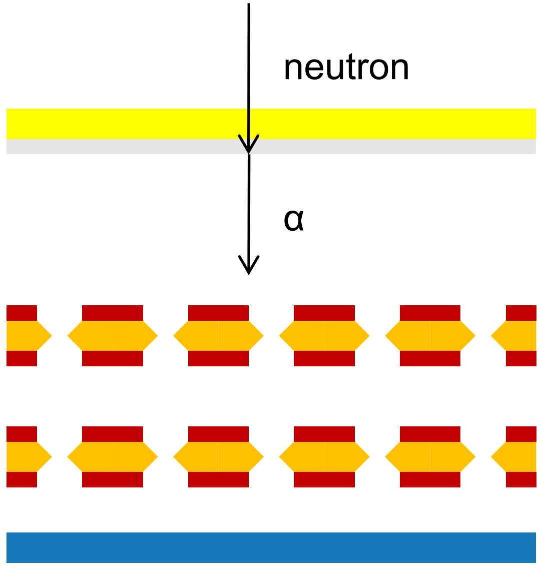
# E for drift, transfer and induction

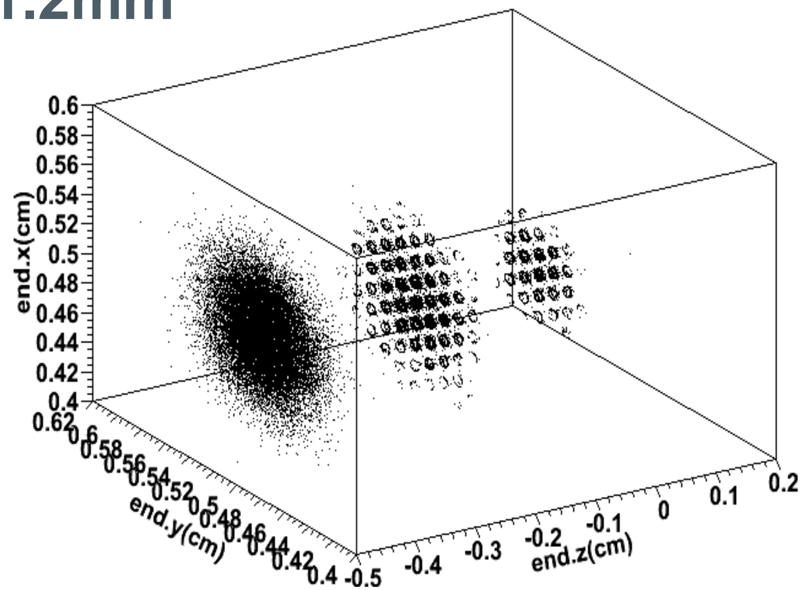


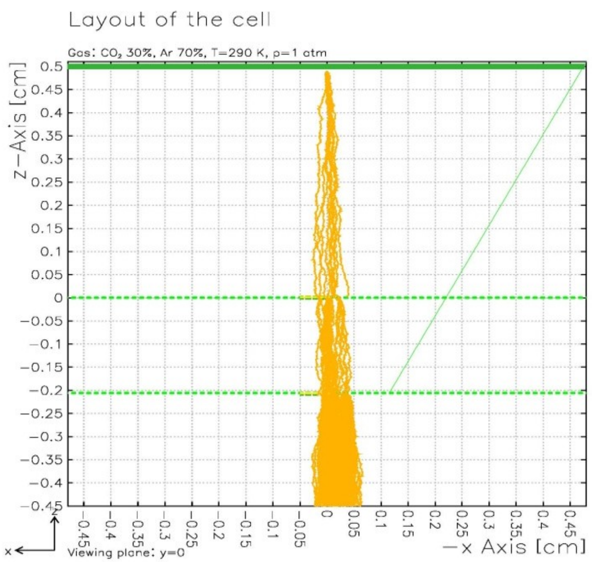

- $E_{drift}$: 1~2kV/cm
- $E_{transfer}$: ~3kV/cm
- $E_{induction}$: ~3kV/cm

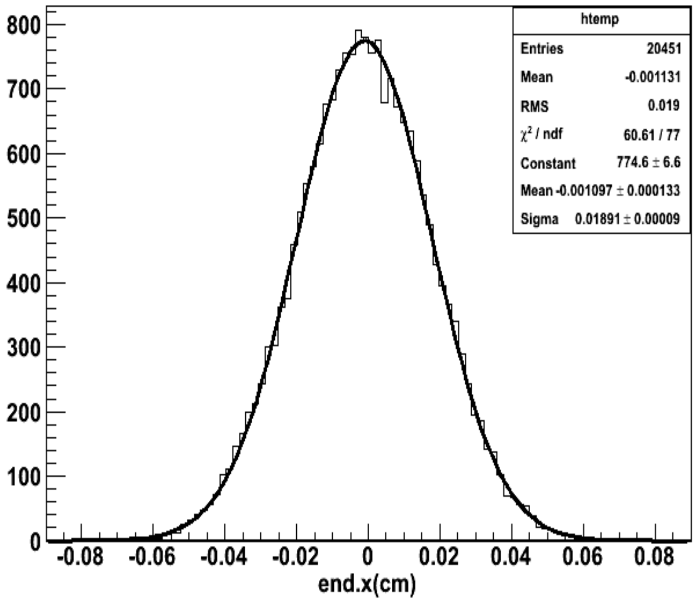
$V_{GEM}$=380V

# Transverse drift of electron~1.2mm

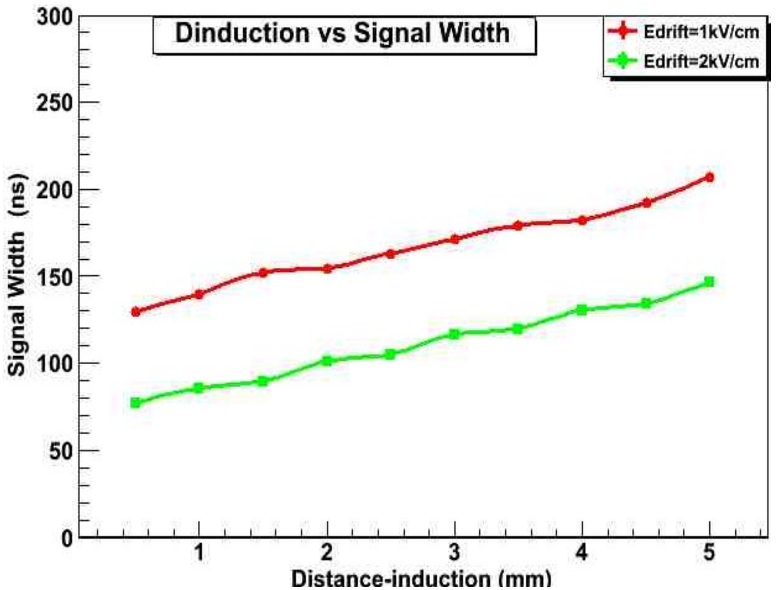


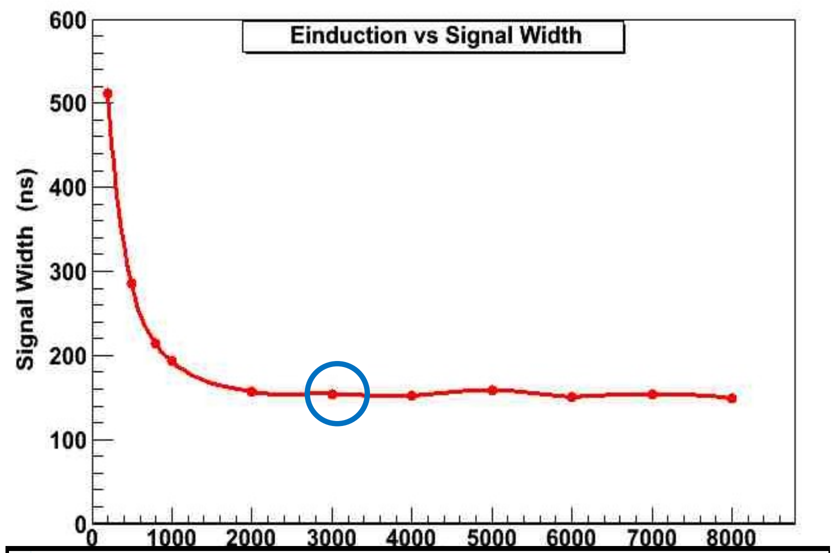



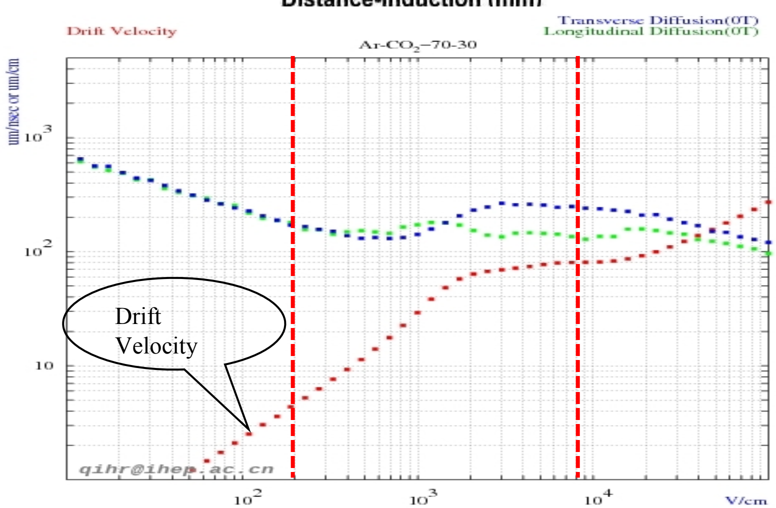



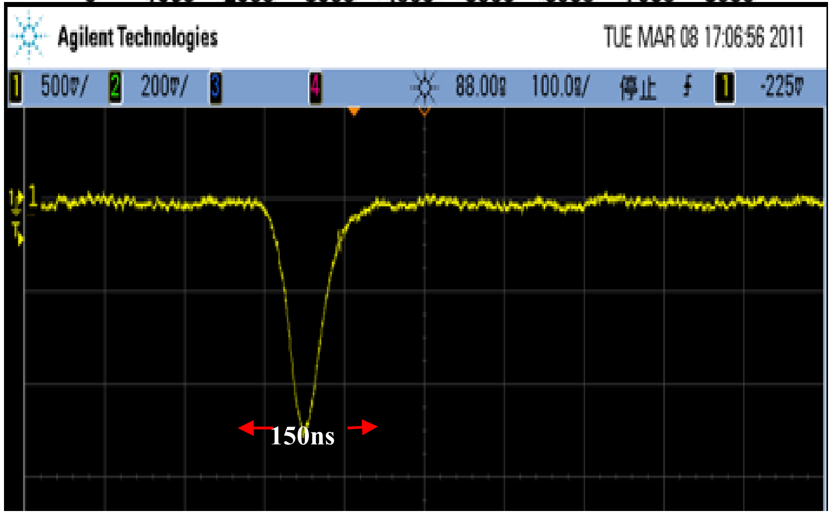



# Signal induced by neutron~ 150ns wide

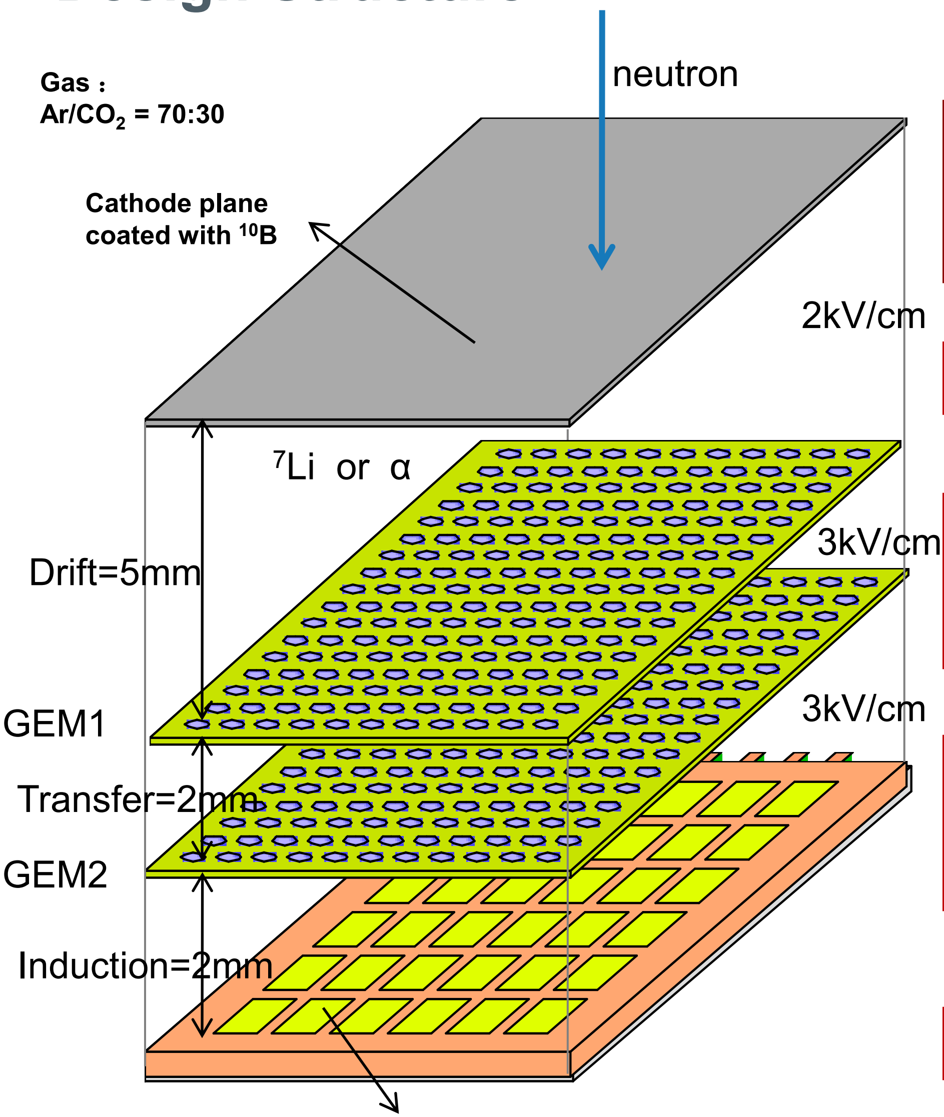


# Design Structure




$n + {}^{10}B \rightarrow \alpha + {}^{7}Li + 2.79MeV$ 7% $E_{\alpha}=1.78MeV$ $E_{Li}=1.0MeV$

$n + {}^{10}B \rightarrow \alpha + {}^{7}Li^{*} + 2.31MeV$ 93% $\tau=73fs$

$\alpha + {}^{7}Li + \gamma + 2.31MeV$ $E_{\alpha}=1.47MeV$ $E_{Li}=0.84MeV$

${}^{10}B$: 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 ${}^{7}Li$ can be just treated as those of incident neutron.

Active area: 50mm*50mm

# Efficiency Linearity

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

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

$\Phi_0$ : Flux of incident neutron,

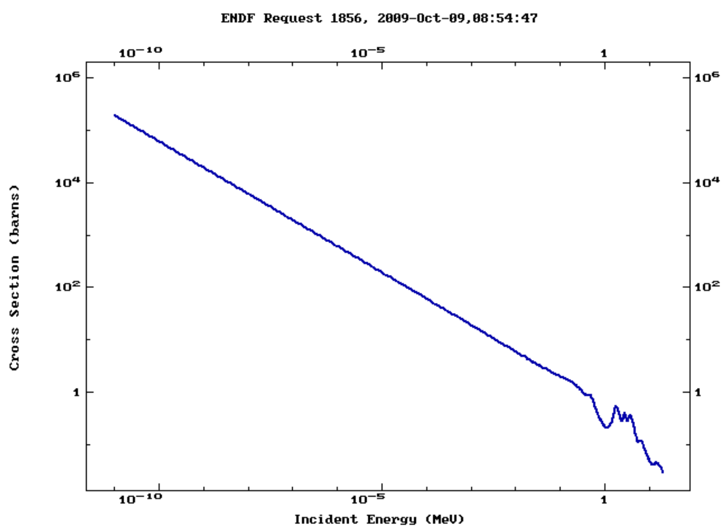
$\Phi$ : Reaction rate, η: Conversion efficiency

S : energy spectrum of incident neutron

σ(E) : Cross section with energy

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

**Energy Linearity:**



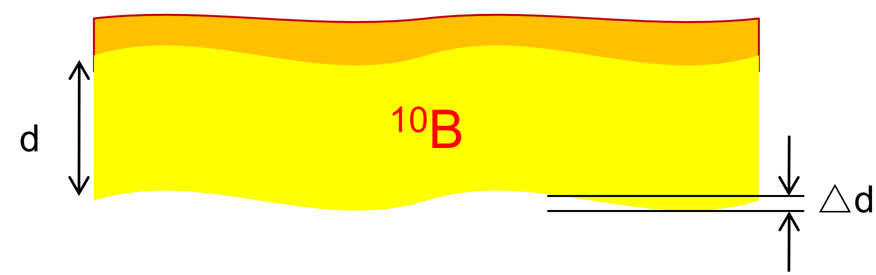

Uniform d: if energy spectrum S(E) is uniform in 2-dimensional cross section, Conversion η is constant.

**Intensity Linearity:**

Determined by counting rate of detector and readout speed of electronics

**Spatial Linearity:**

Cathode plate



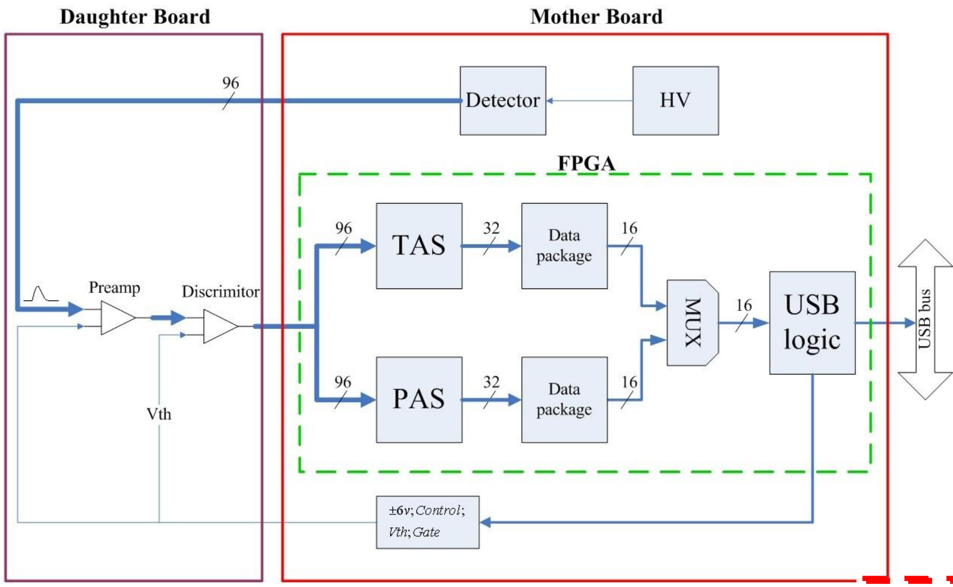

$$d\to 0,\ \eta(x,y)=d(x,y)\int S(E,x,y)n\sigma(E)dE$$

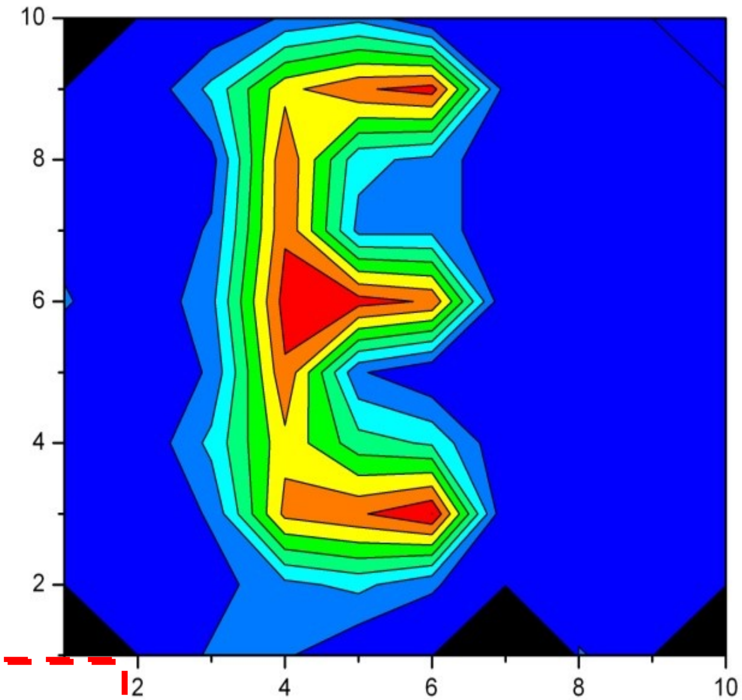
$Uniform\quad S(E):$

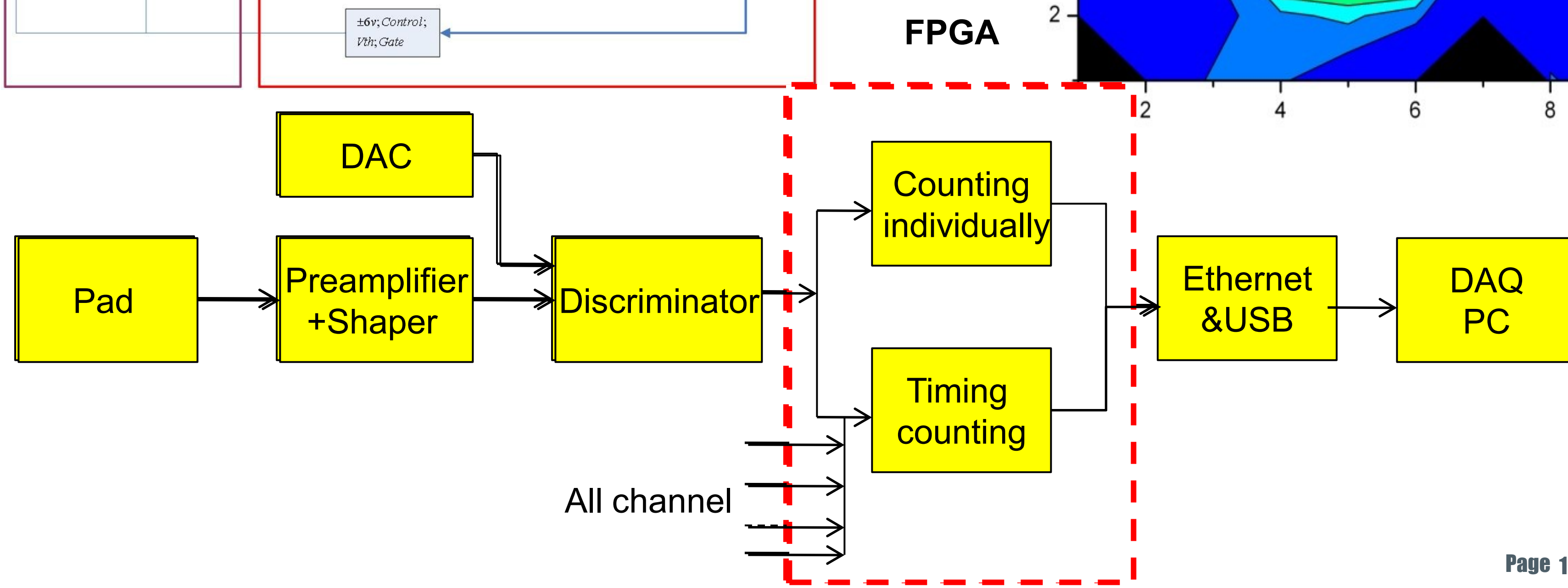
$$\frac{\Delta\eta}{\eta}=\frac{\Delta d}{d},\ d=0.1\mu m,\ \Delta d=5nm,\ \frac{\Delta\eta}{\eta}=5\%$$

variation of thickness : < 5nm

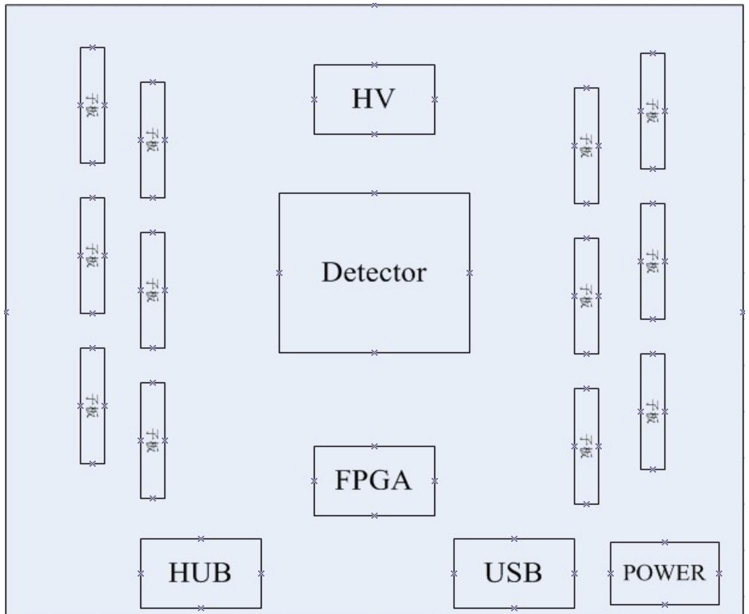
# Readout electronics



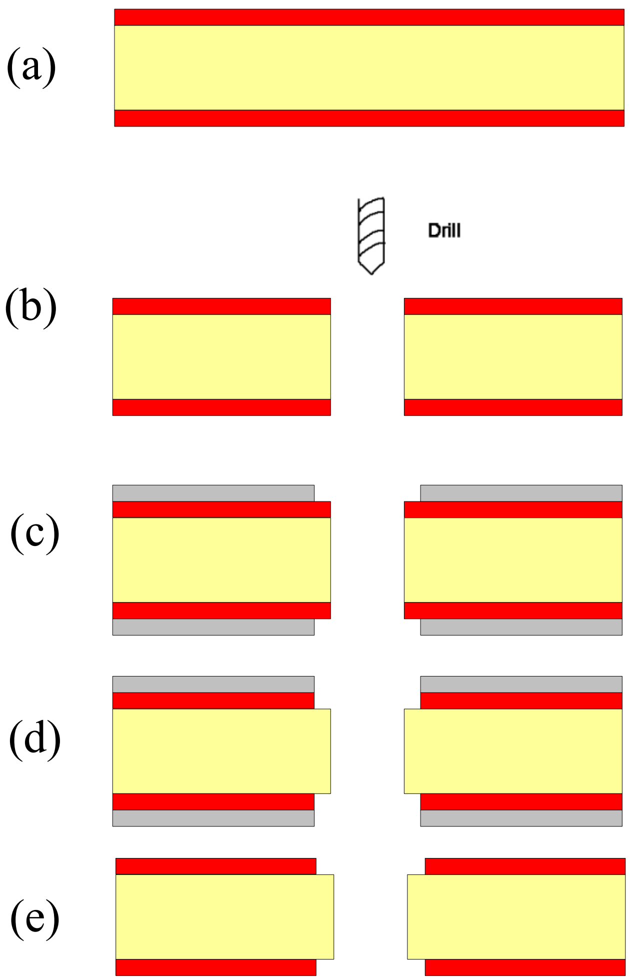



# Compact Prototype




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



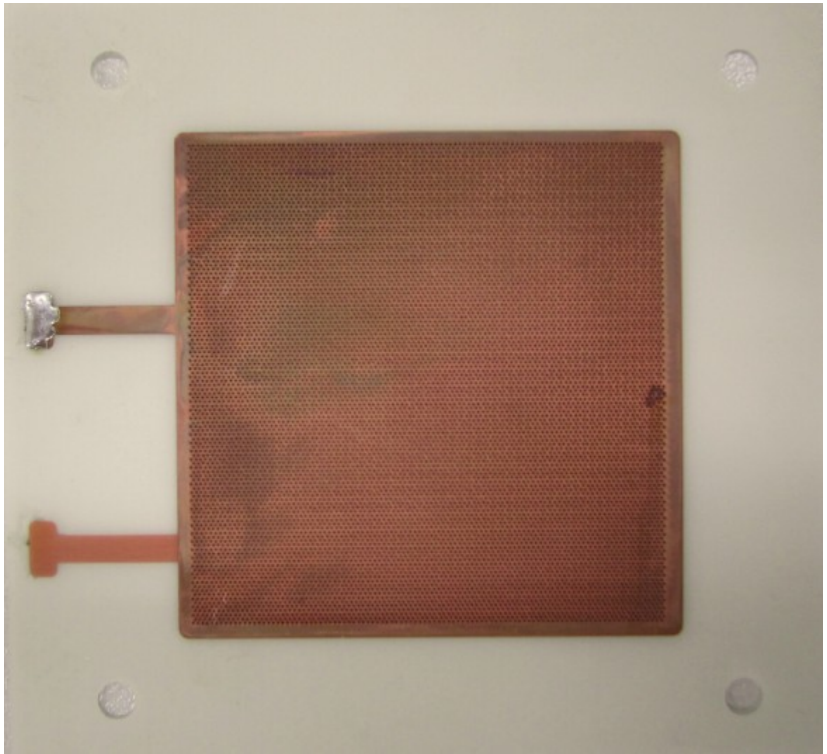

Copper 20μm

FR4 160μm

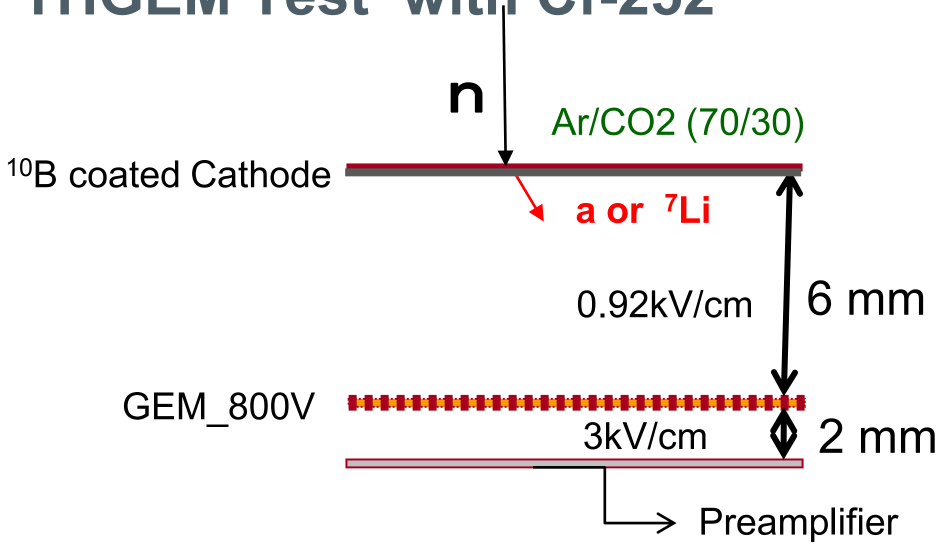
Thickness 200μm

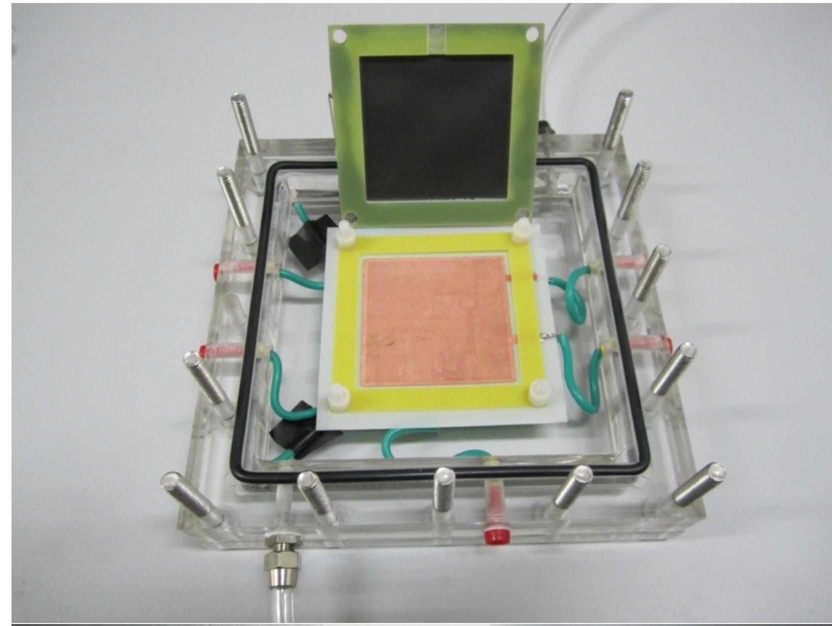
Hole 200μm

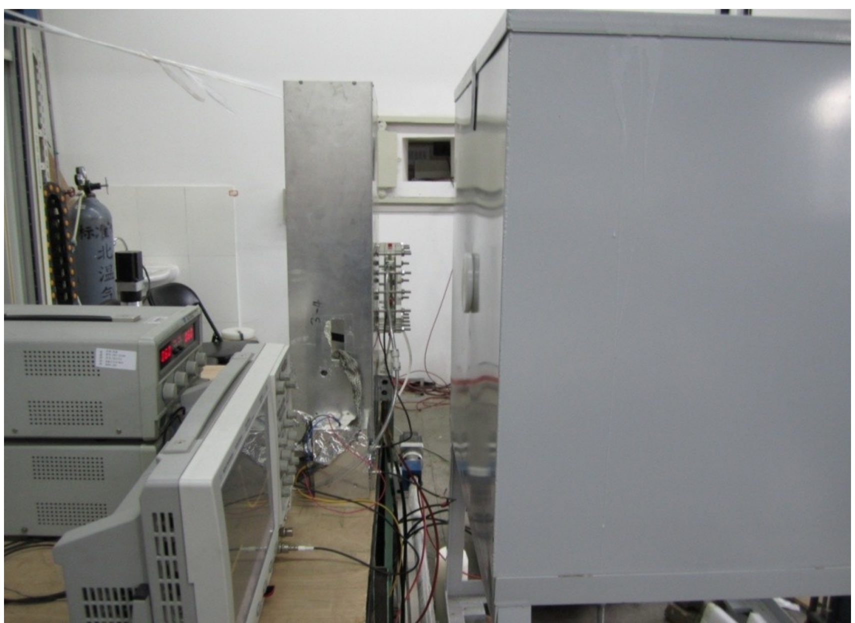
pitch 500μm

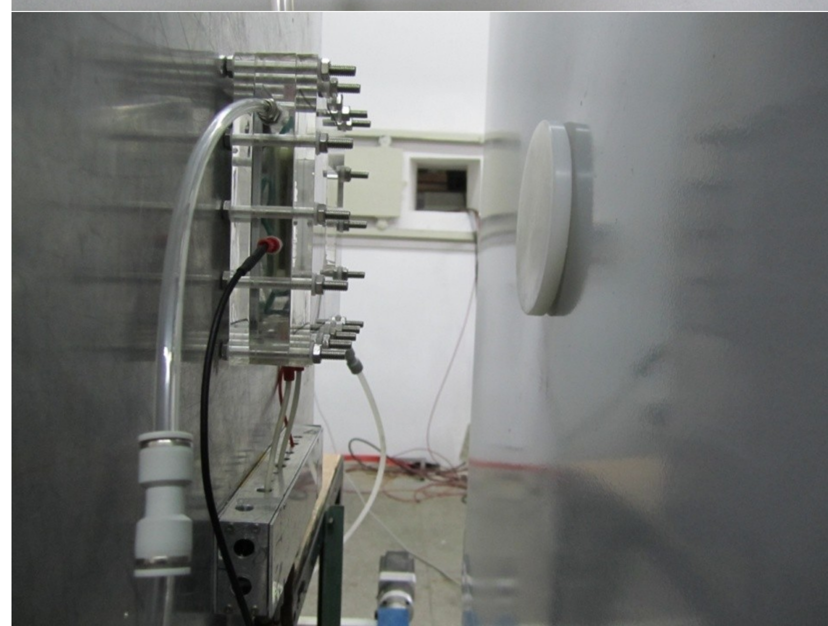


# THGEM Test with Cf-252

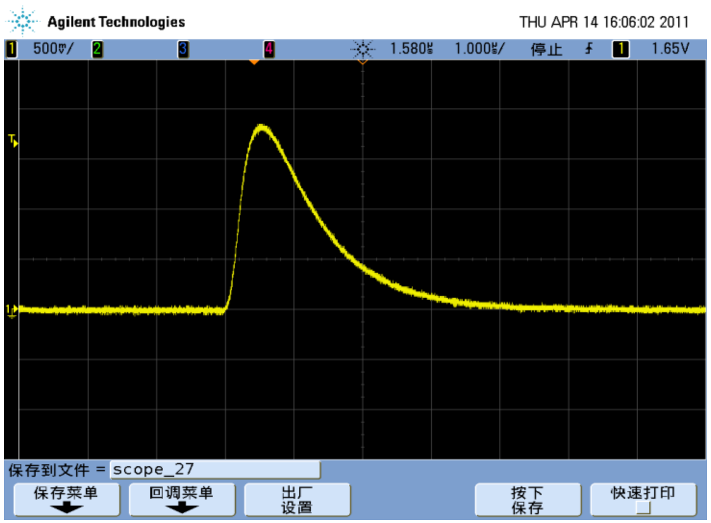


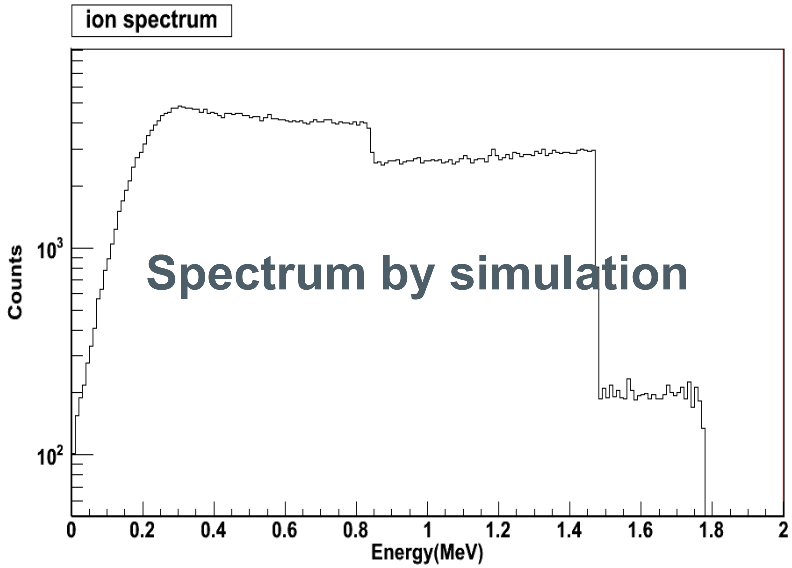





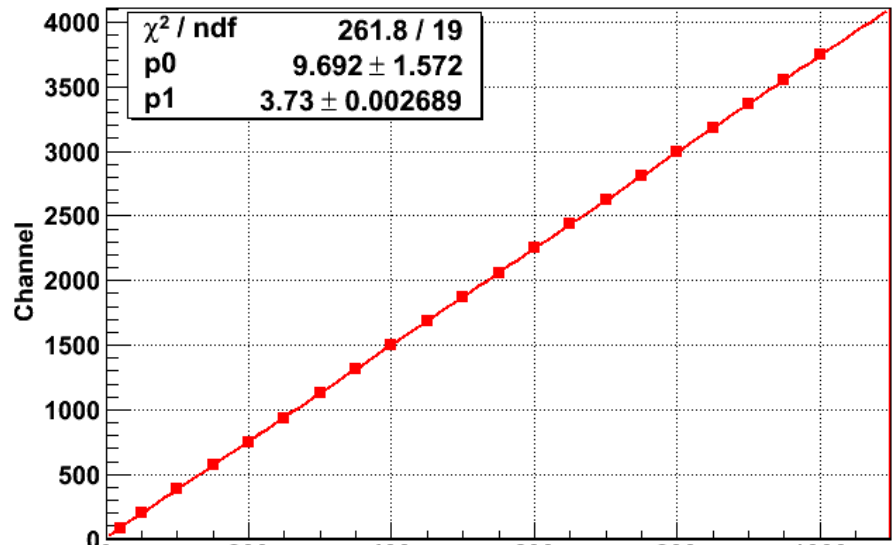


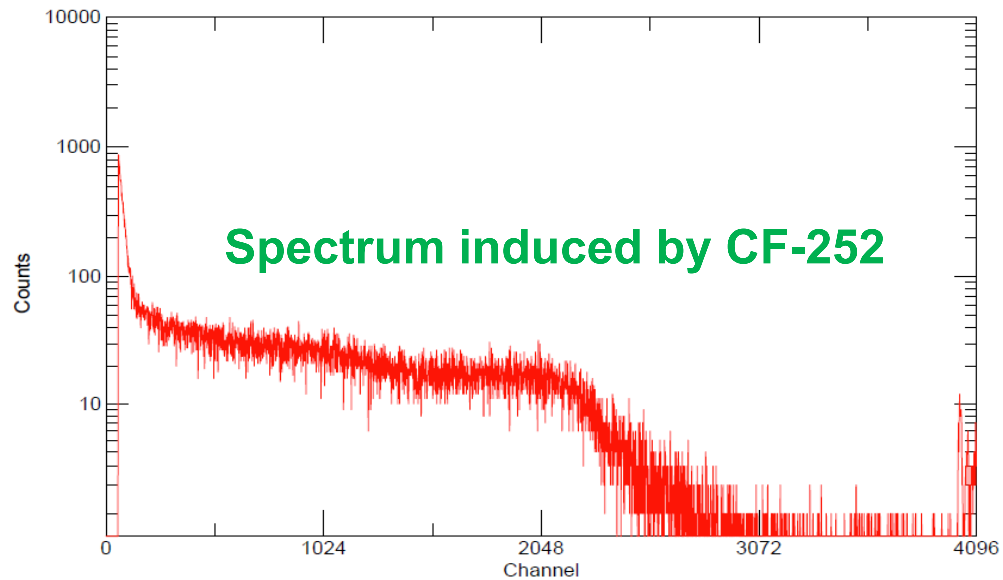
# THGEM Test with Cf-252



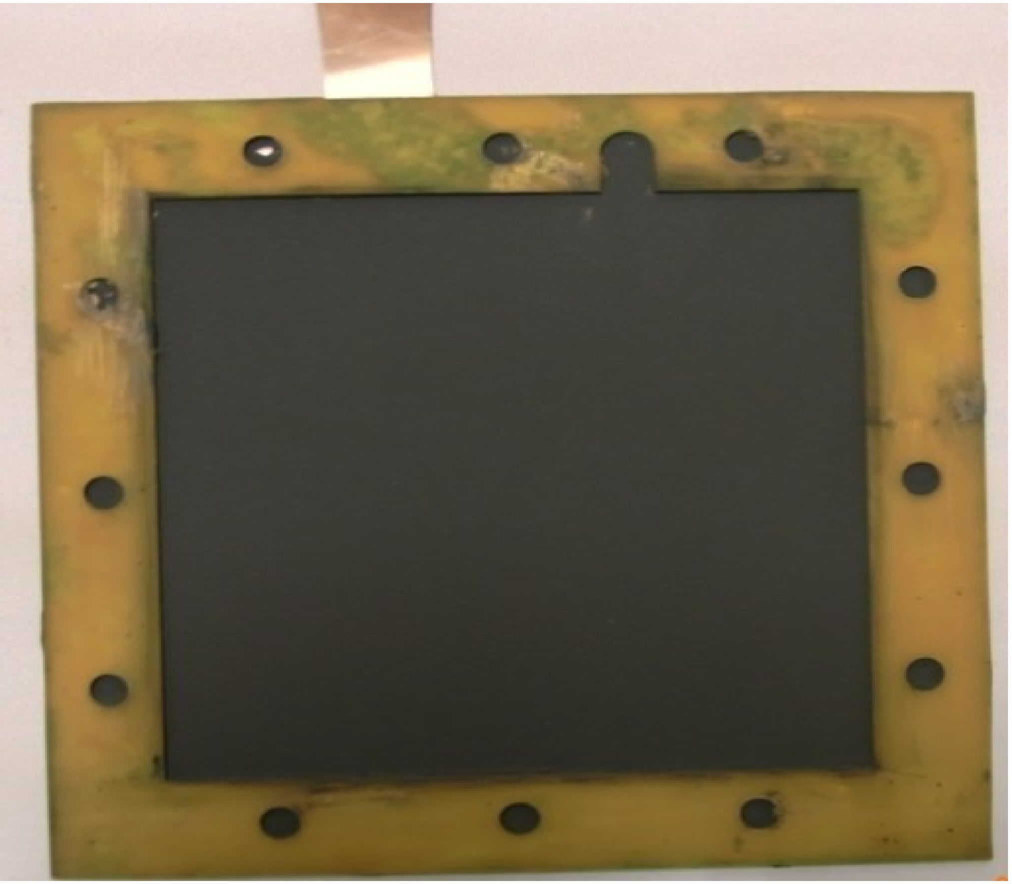




## Calibration for MCA

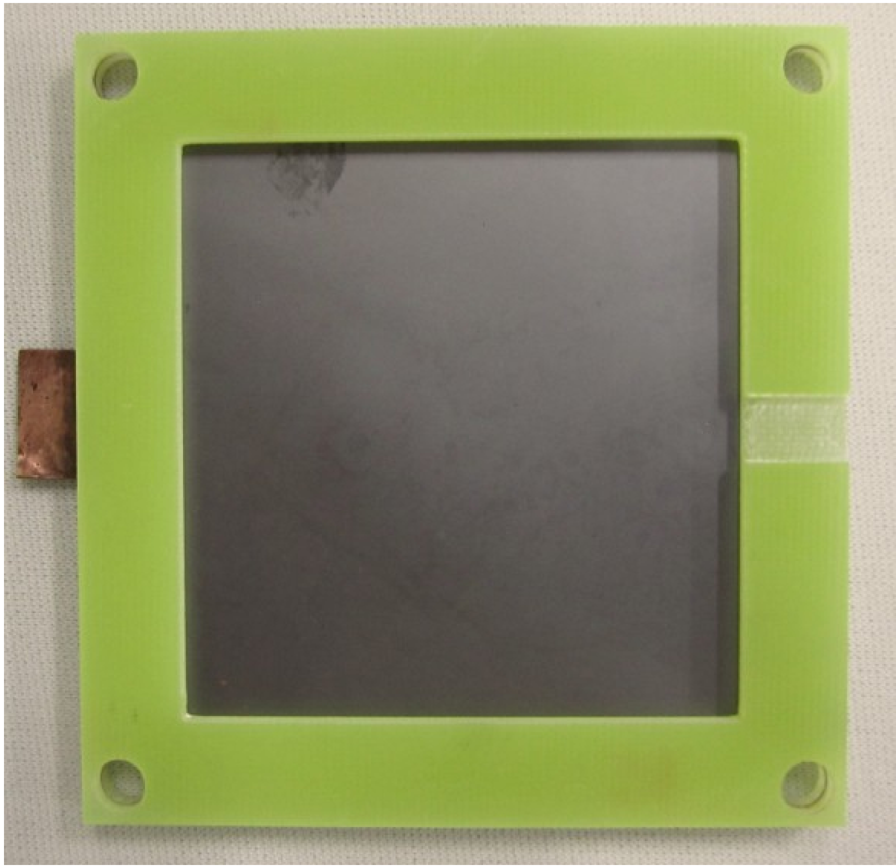


# Drift Cathode with Boron Coating



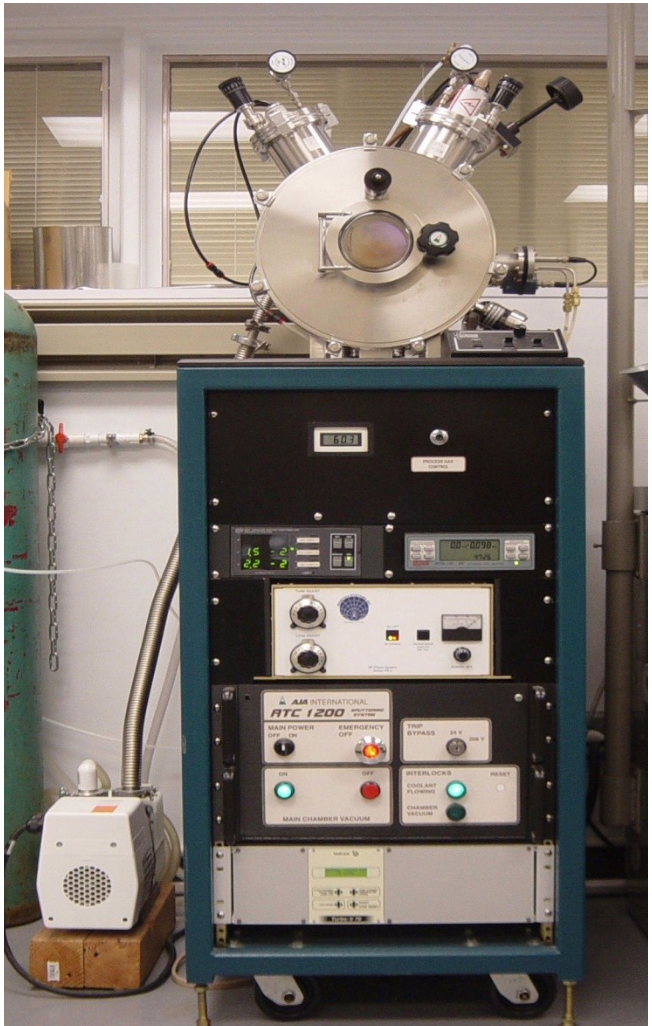
Electrophoresis in 261 Corporation

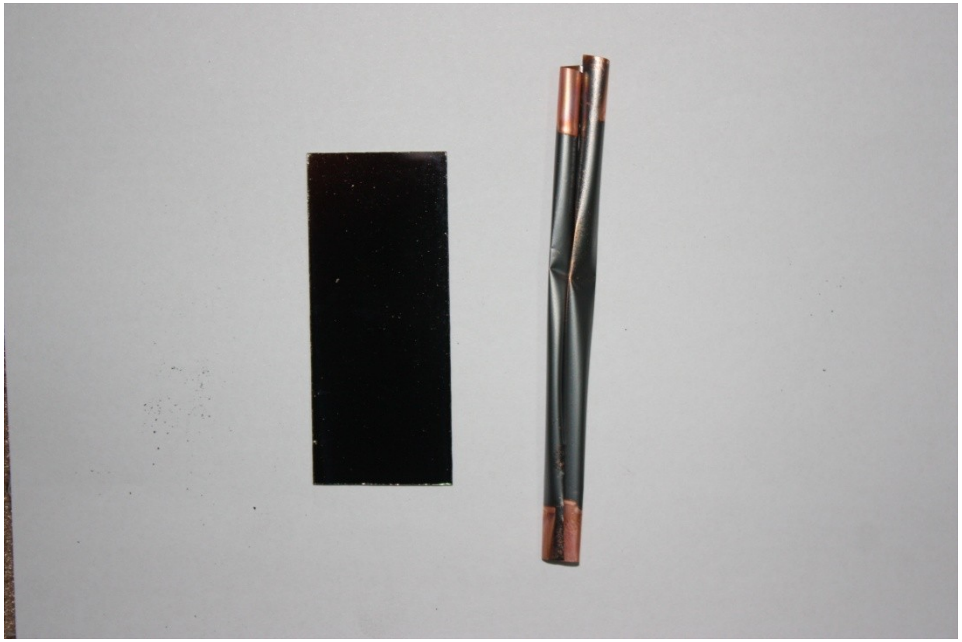


CDT GmbH, Heidelberg

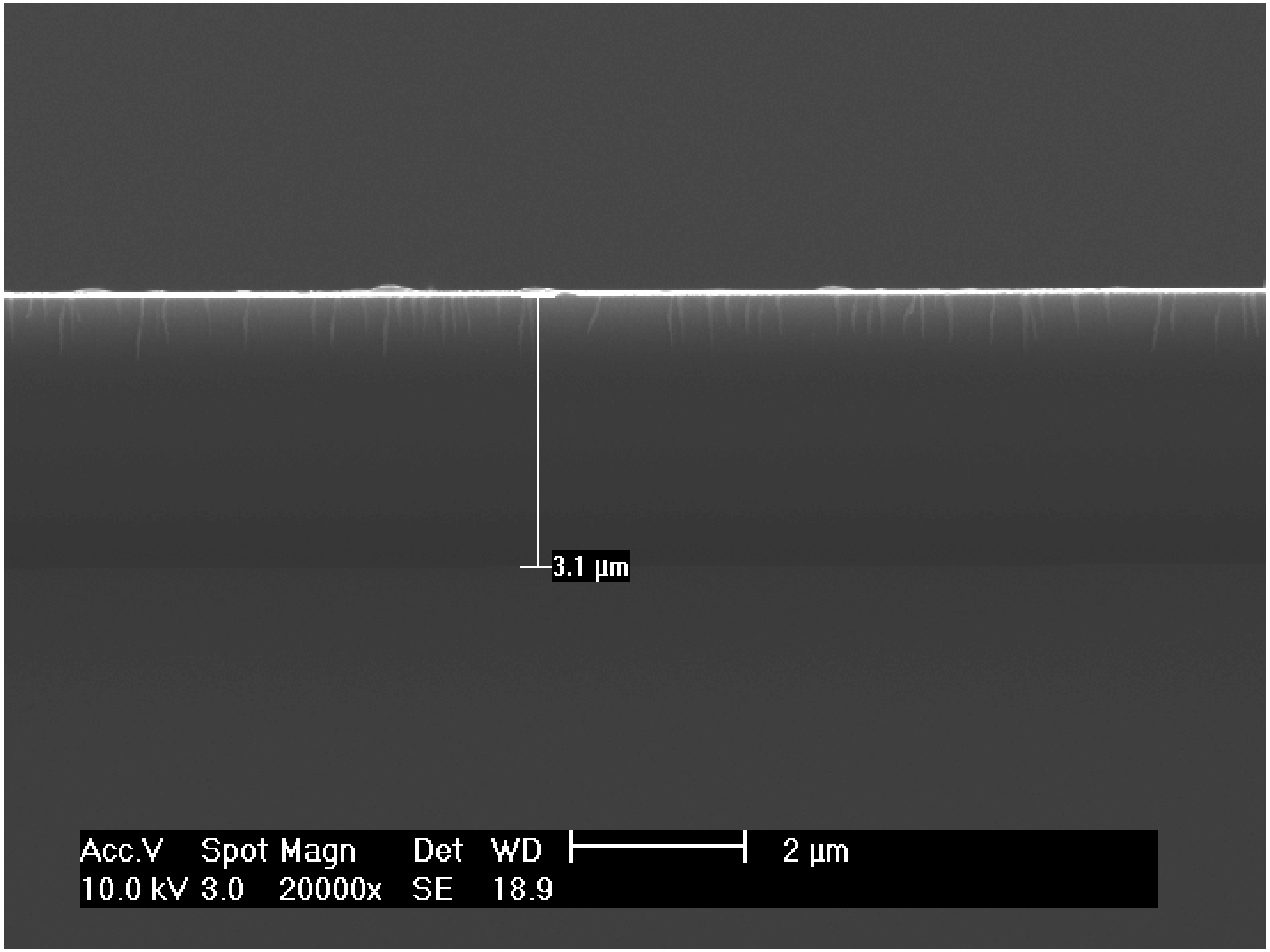
# Boron Coating Technology(Pro.  X.G. Diao, BUAA )

## Magnetron Sputtering System

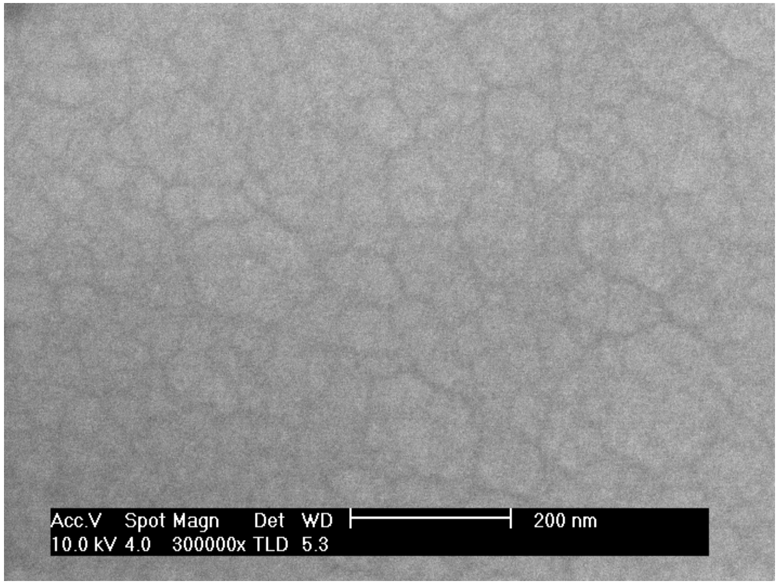


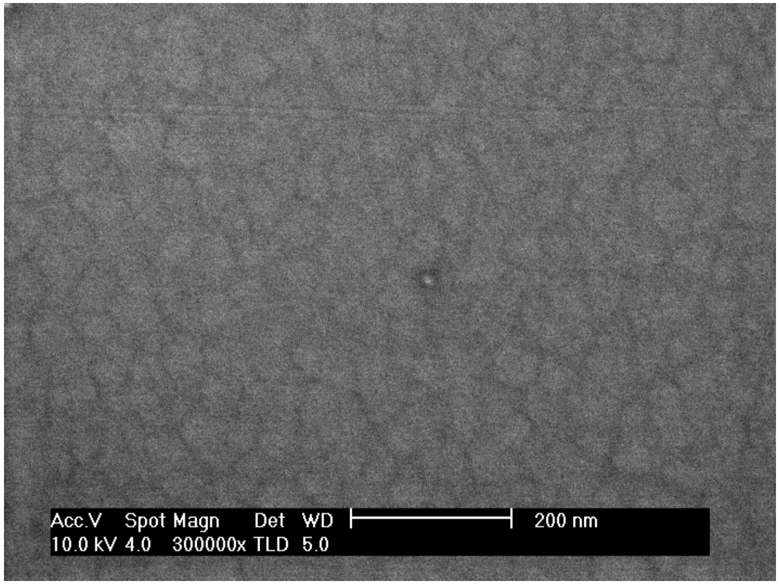



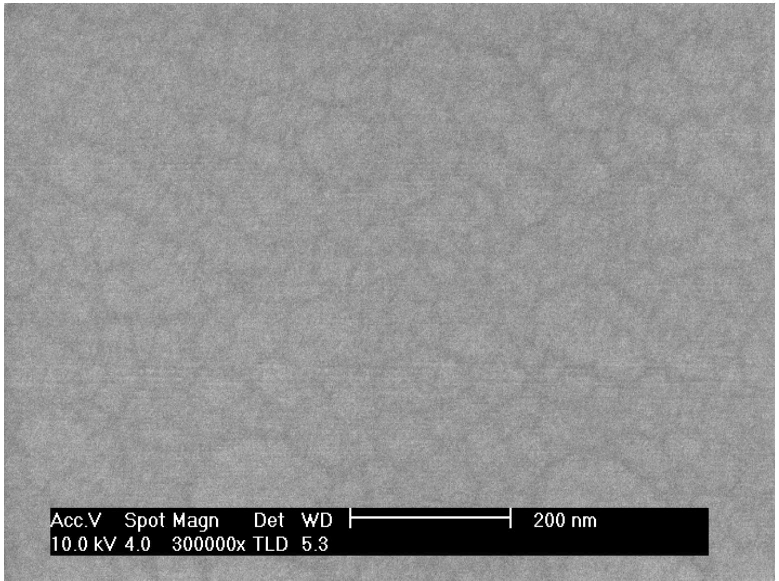
# SEM

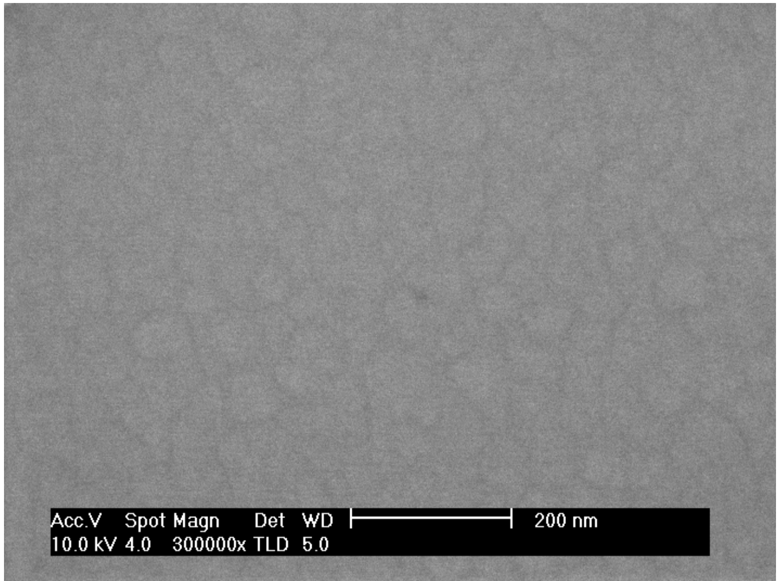


# Smooth

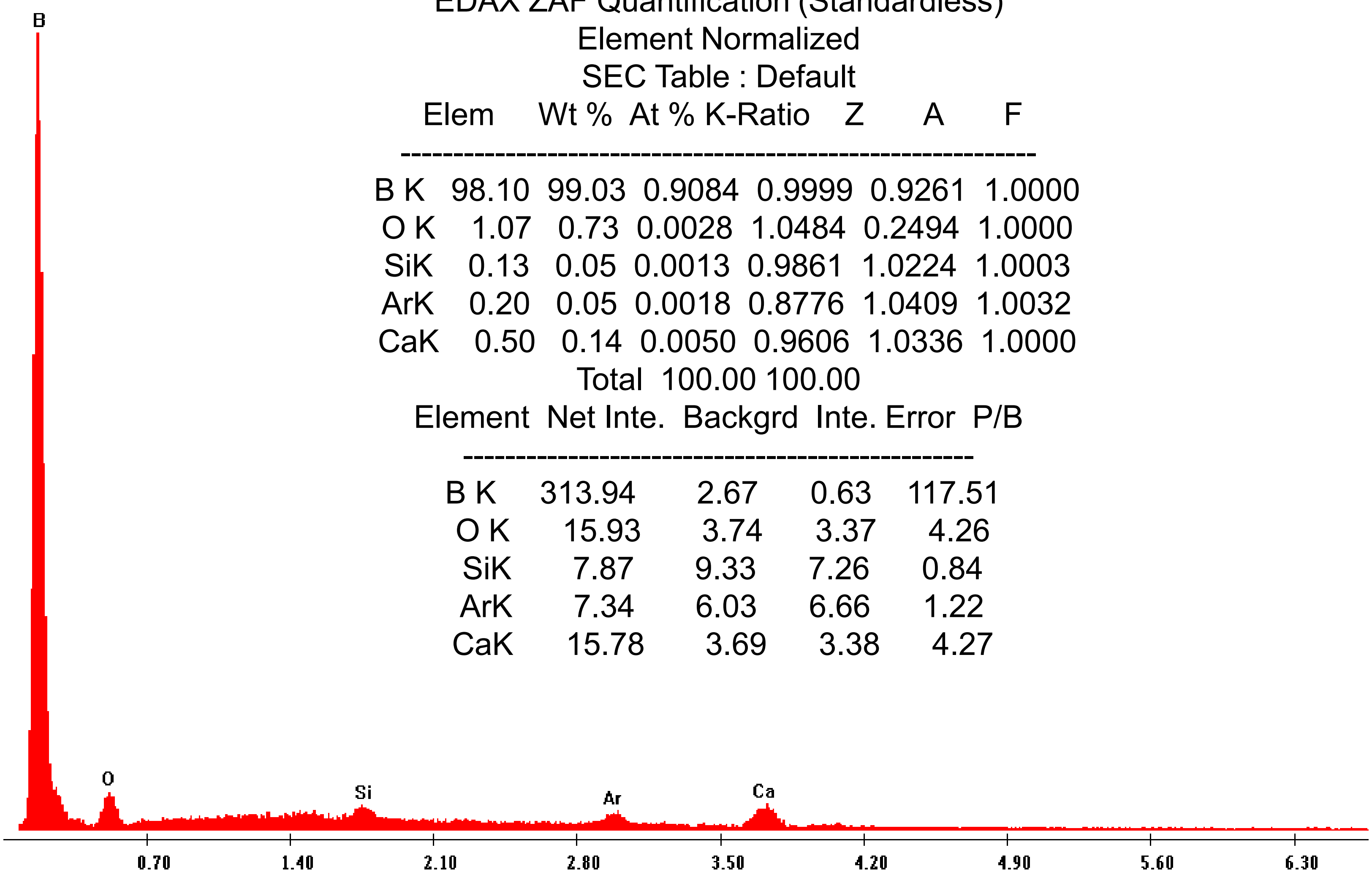

Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 300000x TLD 5.3


Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 300000x TLD 5.0


Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 300000x TLD 5.3


Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 300000x TLD 5.0

# EDS




EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

| Elem | Wt % | At % | K-Ratio | Z | A | F |
|---|---|---|---|---|---|---|
| B K | 98.10 | 99.03 | 0.9084 | 0.9999 | 0.9261 | 1.0000 |
| O K | 1.07 | 0.73 | 0.0028 | 1.0484 | 0.2494 | 1.0000 |
| SiK | 0.13 | 0.05 | 0.0013 | 0.9861 | 1.0224 | 1.0003 |
| ArK | 0.20 | 0.05 | 0.0018 | 0.8776 | 1.0409 | 1.0032 |
| CaK | 0.50 | 0.14 | 0.0050 | 0.9606 | 1.0336 | 1.0000 |
| Total | 100.00 | 100.00 | | | | |

| Element | Net Inte. | Backgrd | Inte. Error | P/B |
|---|---|---|---|---|
| B K | 313.94 | 2.67 | 0.63 | 117.51 |
| O K | 15.93 | 3.74 | 3.37 | 4.26 |
| SiK | 7.87 | 9.33 | 7.26 | 0.84 |
| ArK | 7.34 | 6.03 | 6.66 | 1.22 |
| CaK | 15.78 | 3.69 | 3.38 | 4.27 |

# Summary

- **Neutron  beam monitor detector based GEM was constructed**
  - Detector was careful 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

# THANKS!

# 谢谢！