The BAND-GEM detector

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ESS pre-construction in-kind contract with CNR

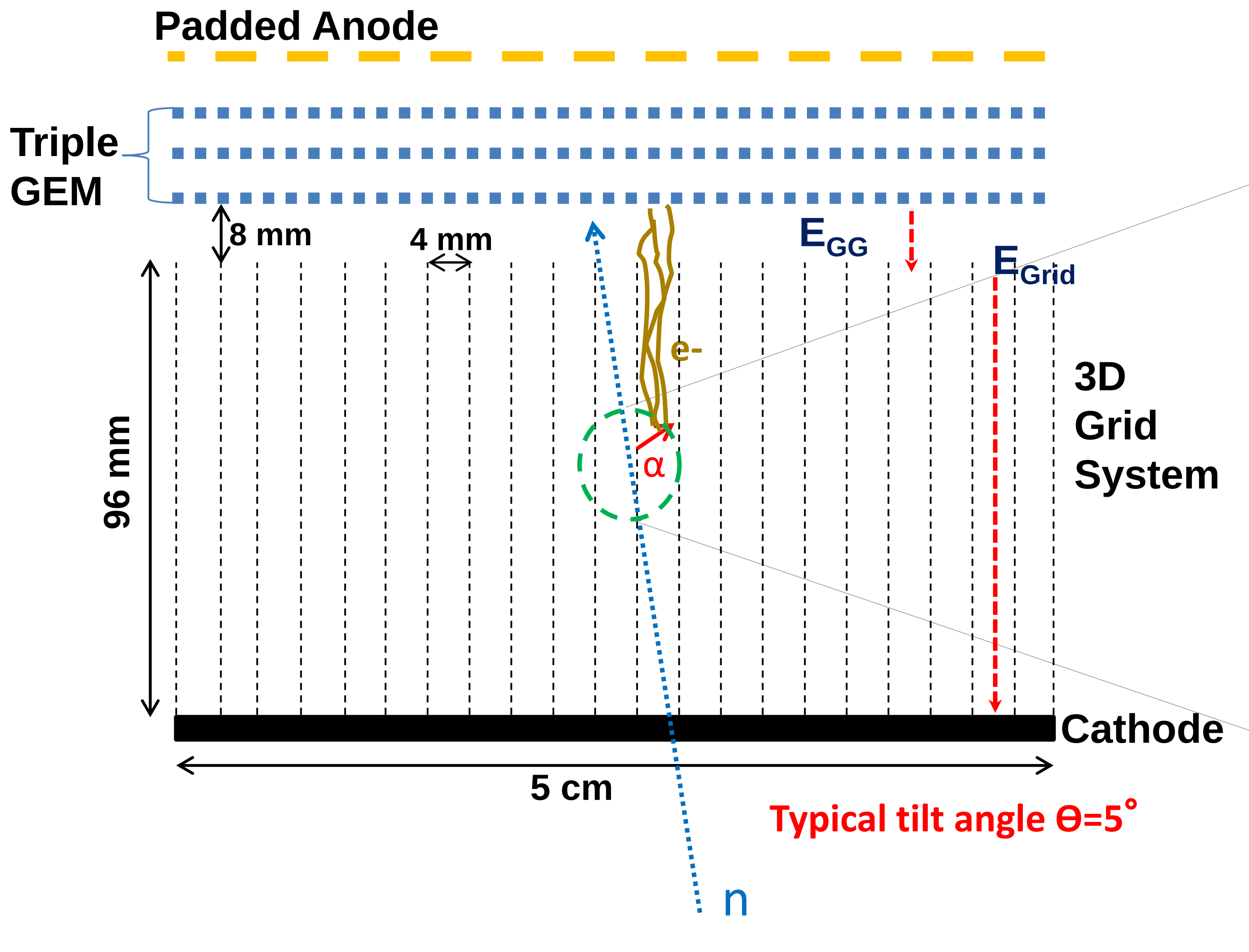
DETECTING THERMAL NEUTRONS WITH GEMS

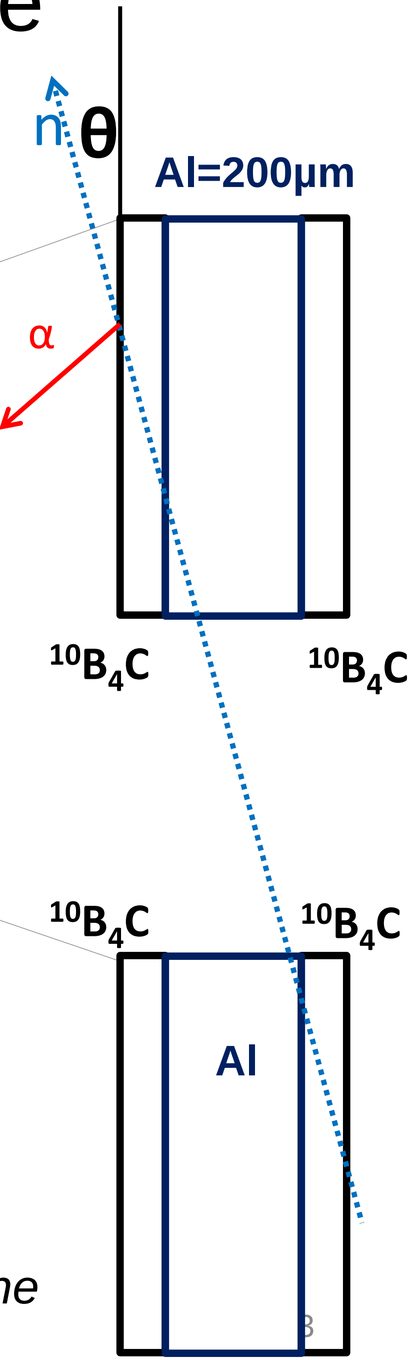
- GEM detectors born for tracking and triggering applications (detection of charged particles)....
- ...but if coupled to a solid state converter they can detect
  - Thermal Neutrons → ^{10}Boron converter

- GEMs offer the following advantages
  - High rate capability (up to MHz/mm^2)
  - Submillimetric space resolution (suited to experiment requirements)
  - Time resolution from 5 ns (gas mixture dependent)
  - Possibility to be realized in large areas and in different shapes
  - Radiation hardness
  - Low sensitivity to gamma rays (with appropriate gain)

G. Croci et Al JINST 7 C03010; *F. Murtas et Al*, JINST 7 P07021; *G. Croci et Al,* NIMA 720, 144;
G. Croci et Al, NIMA, 712, 108; *G. Croci et Al*, JINST 8 P04006; *G. Croci et Al*, NIMA 732, 217;
G. Albani et Al, JINST 10 C04040; *G. Croci et Al*, EPJP 130, 118 *G. Croci* et Al, EPL, 107 12001
G. Croci et Al, Prog. Theor. Exp. Phys. 083H01;

BAND-GEM detection principle



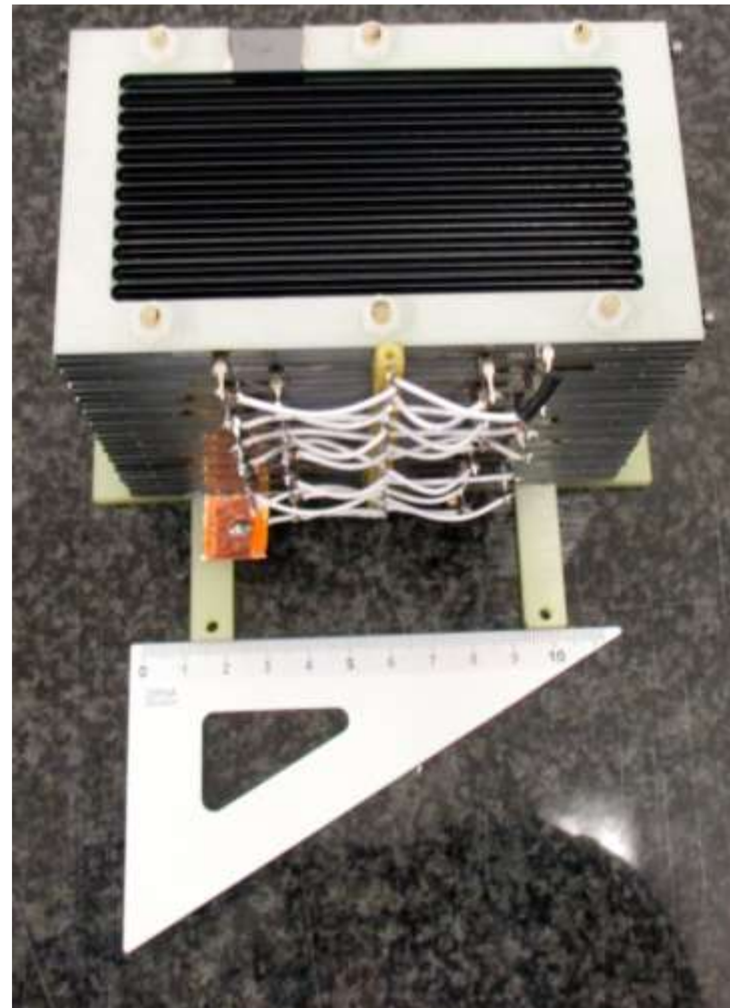


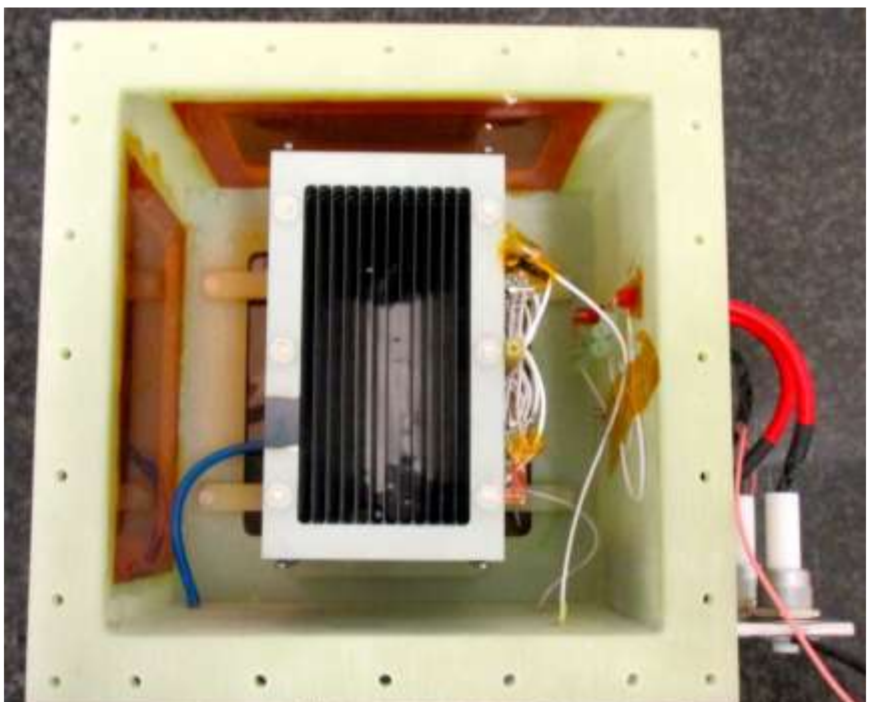
Alluminium grids coated on both sides with $^{10}B_4C$

Using low θ values (few degs) the path of the neutron inside the B_4C is increased → Higher efficiency when detector is tilted

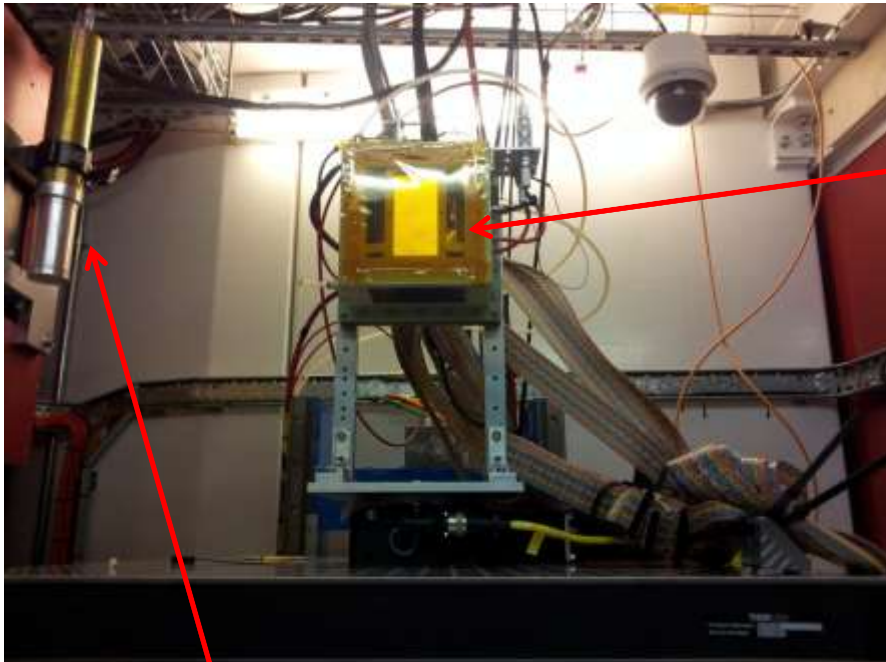
New BANDGEM detector assembly

Detector box equipped with three diagnostic windows 75 mm x 100 mm
Borated Grids – 0.5 to 0.6 µm of $^{10}B_4C$

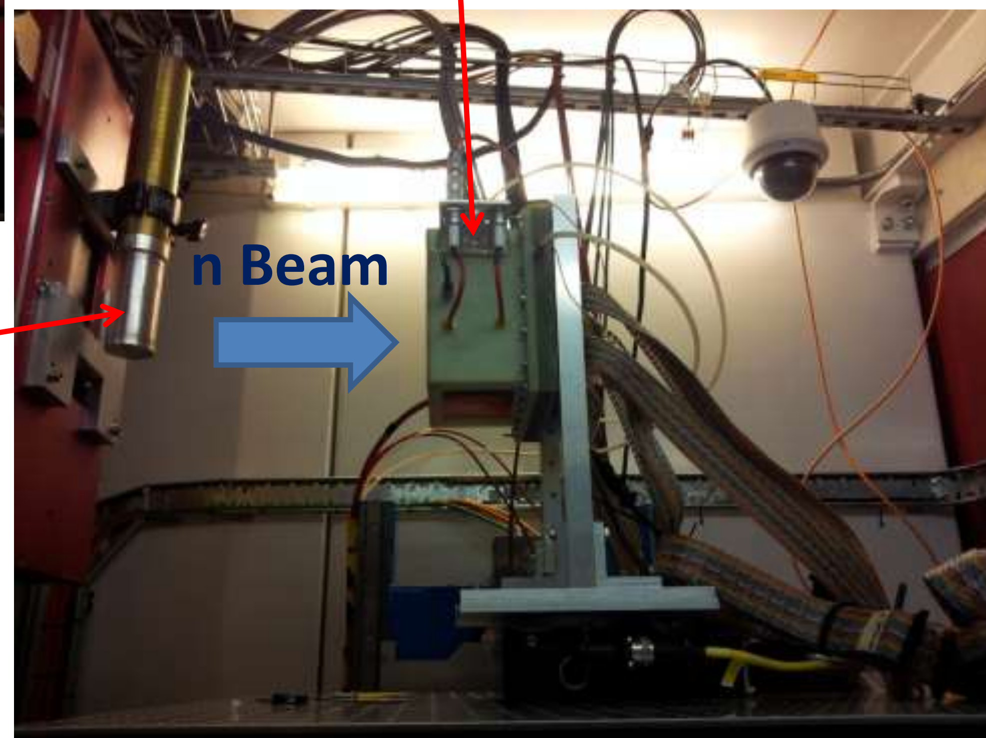




Experimental Setup @ EMMA, ISIS

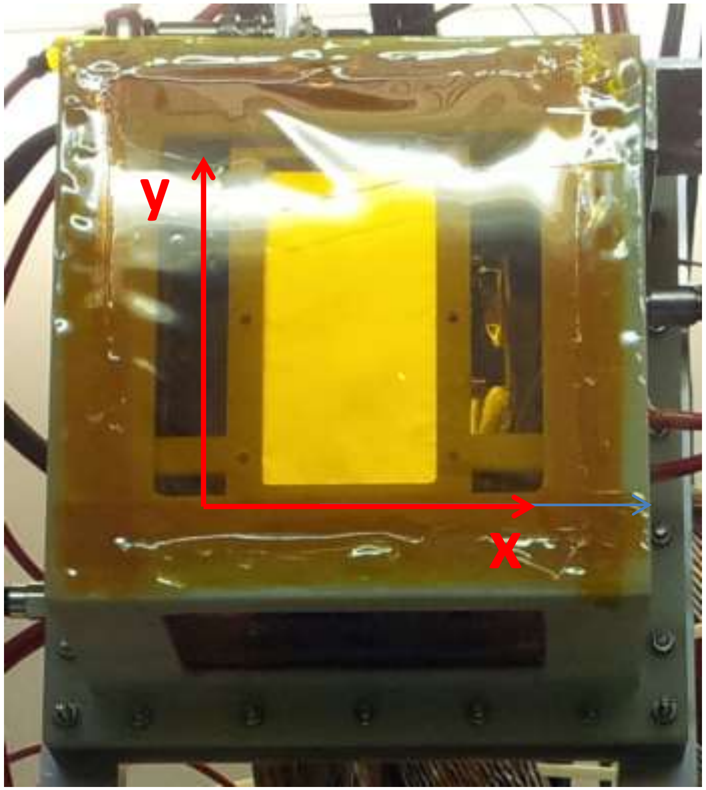


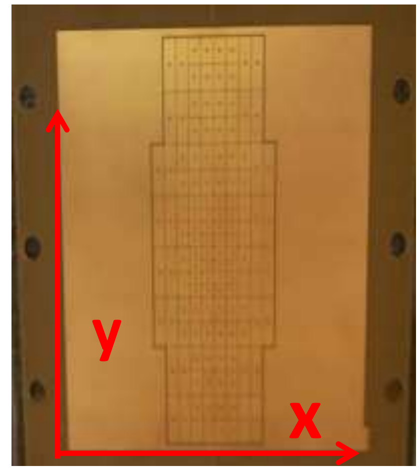
BAND-GEM
on turntable

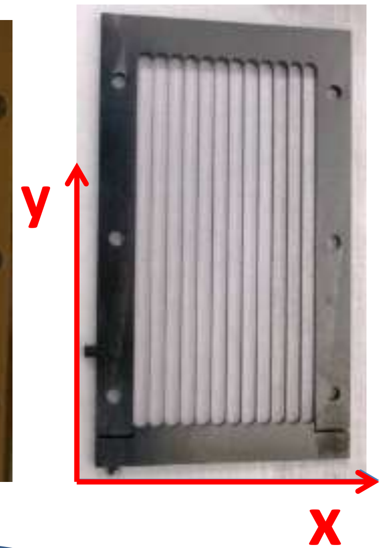


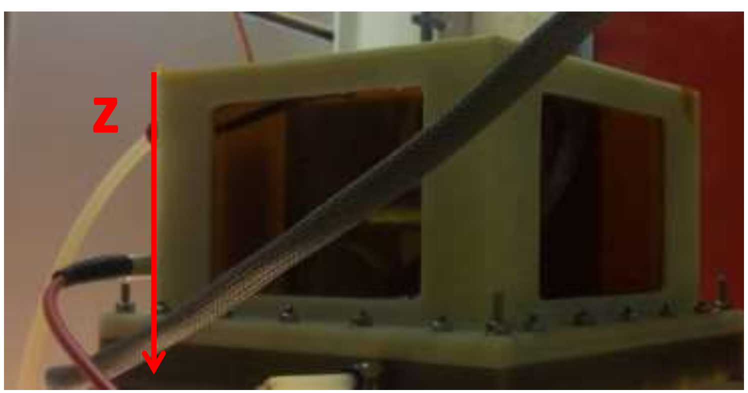
BEAM MONITOR
GS-20 Lithium Glass Scintillator
ε(1 Å) = 0.6%

Experimental Setup Scheme

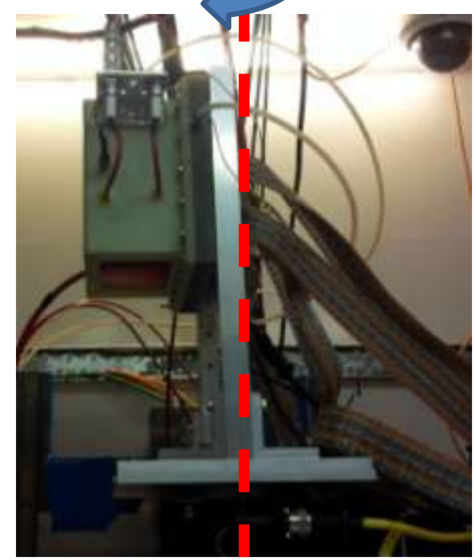




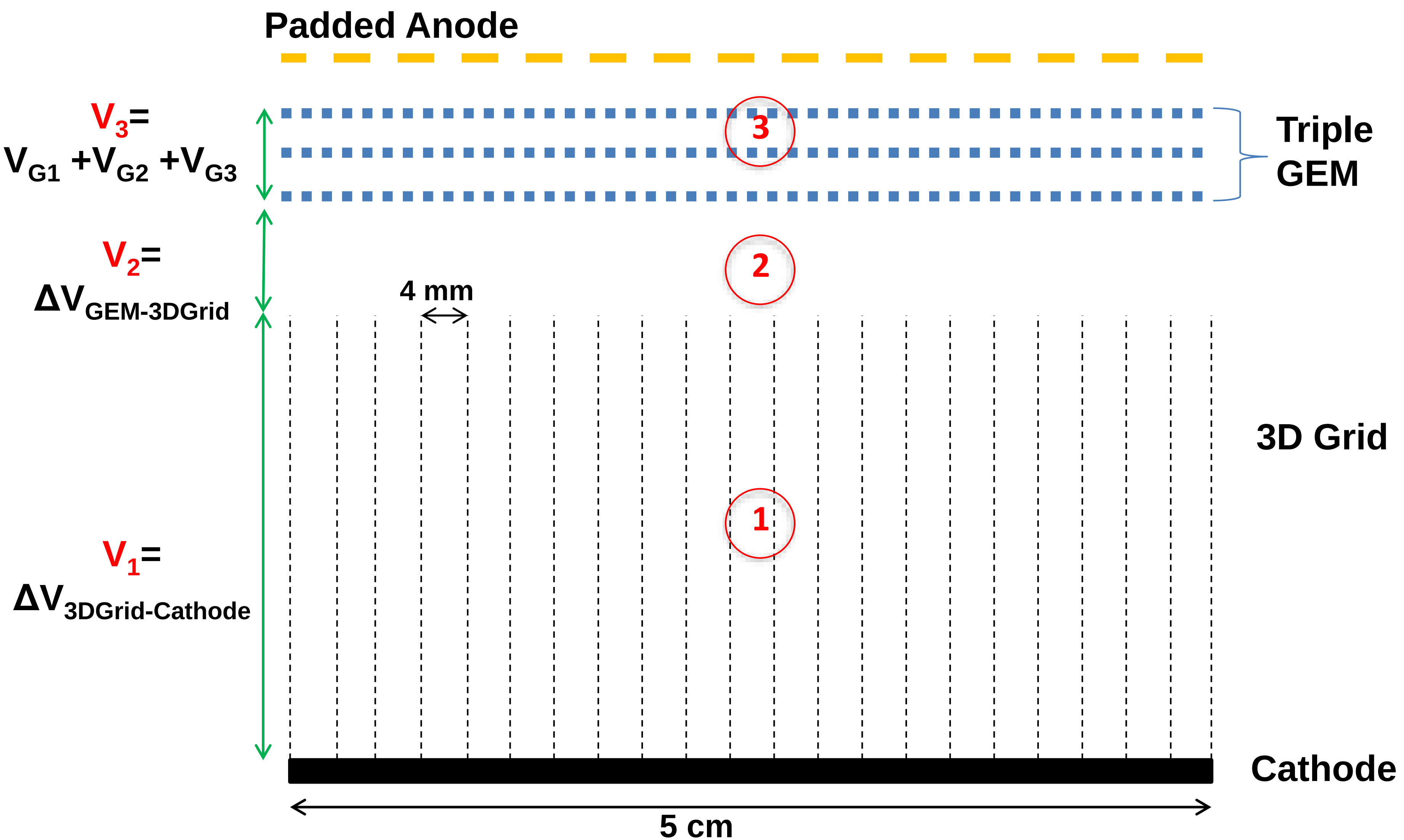




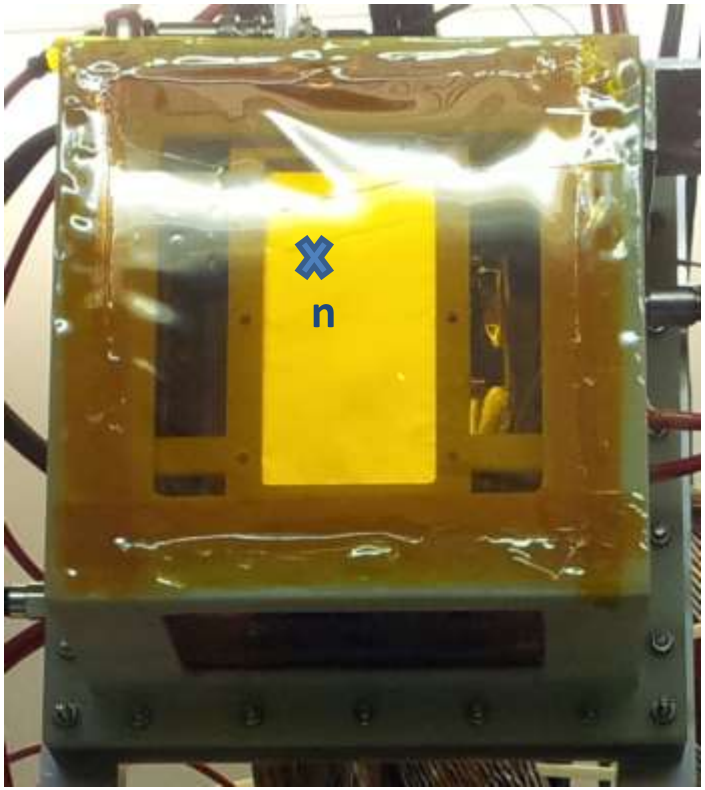
Tilt Angle θ

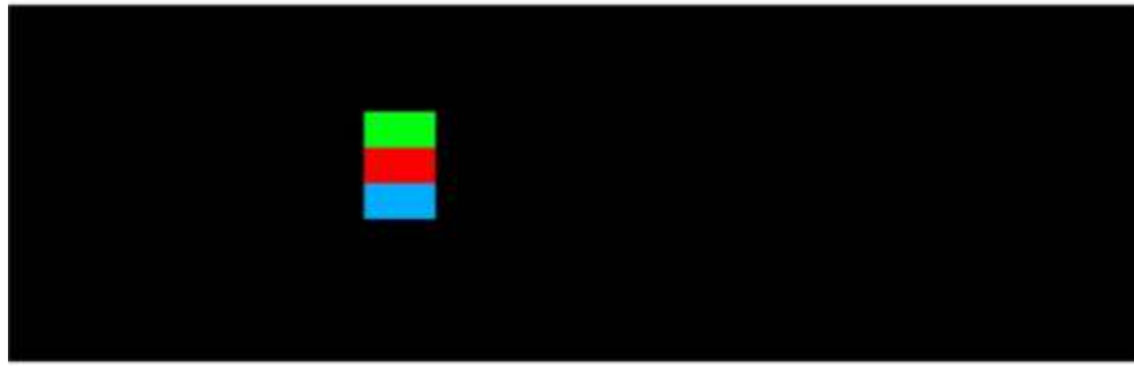


Electrical Scheme



Beam footprint





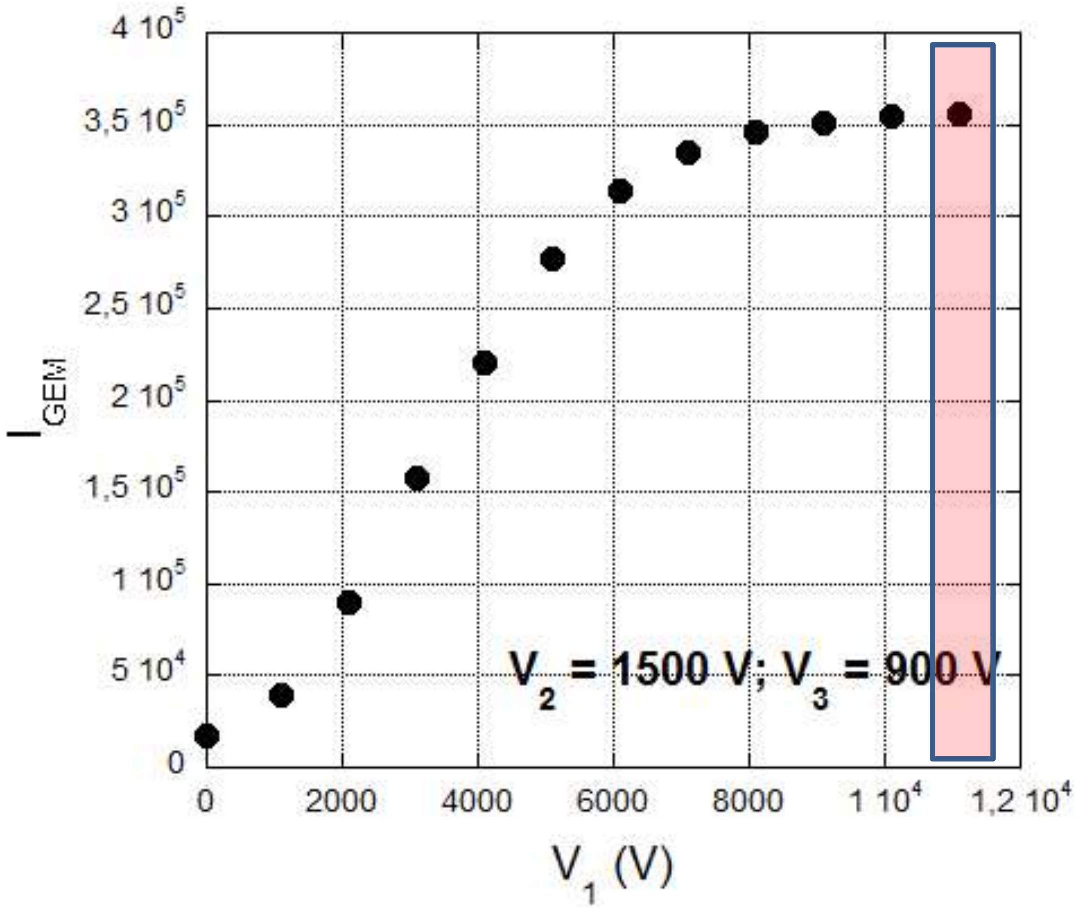
$$I_{GEM} = \sum_{ON-pads} \int_{t=4\,ms}^{t=20\,ms} BandGEM(t)dt$$

ON-pads are defined as pads whose intensity is > 1% of the pad with the max intensity

Beam dimension 4 mm (t) x 4 mm (y)

Colour = I_{GEM}/Pad Area

Working Point determination – V_1 scan



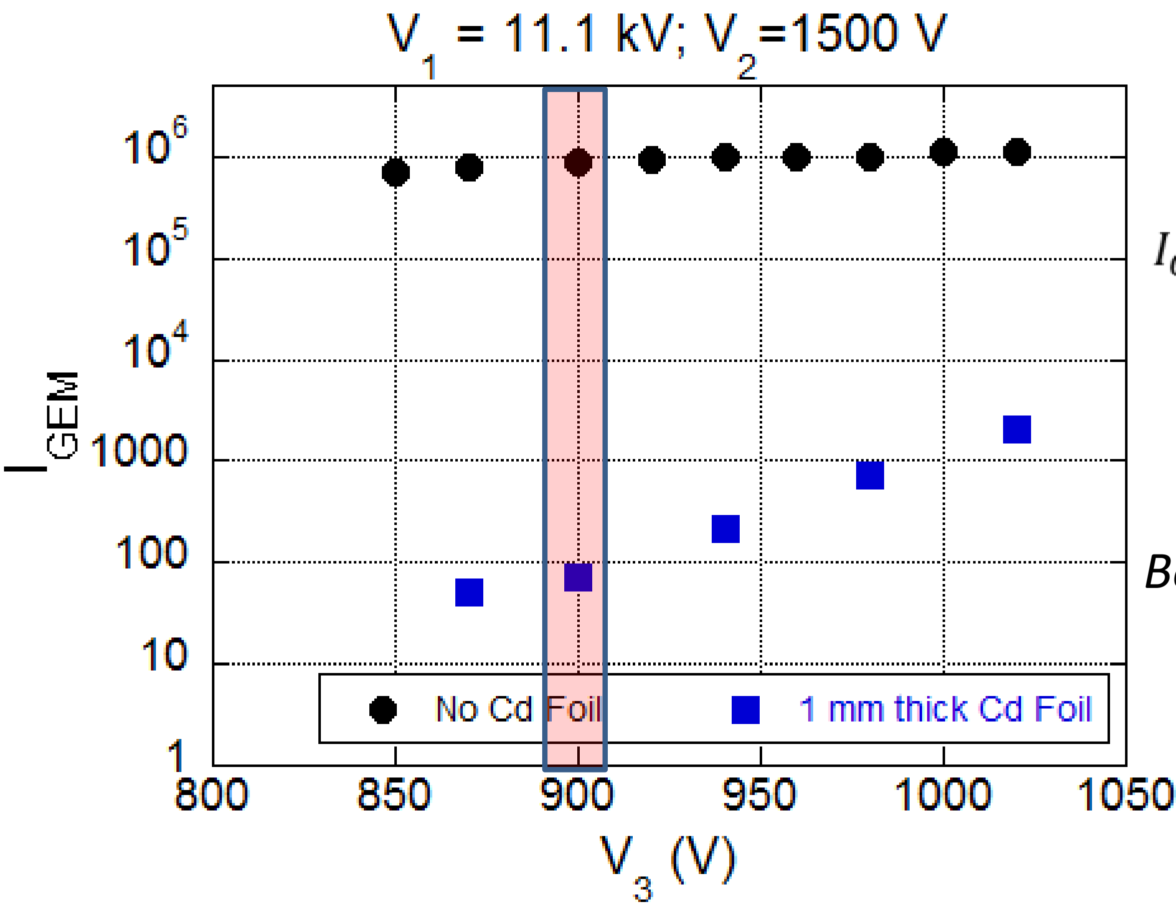
$$I_{GEM} = \int_{t=4\,ms}^{t=20\,ms} BandGEM(t)dt$$

Θ = 5 °

Beam dimension = 4 mm x 4 mm

- Values up to 15 kV were applied to the cathode thanks to new HV Module
- Plateau observed for V_1> 8 kV
- Working point selected: **V_1 = 11.1 kV**

Working Point determination – V_3 scan



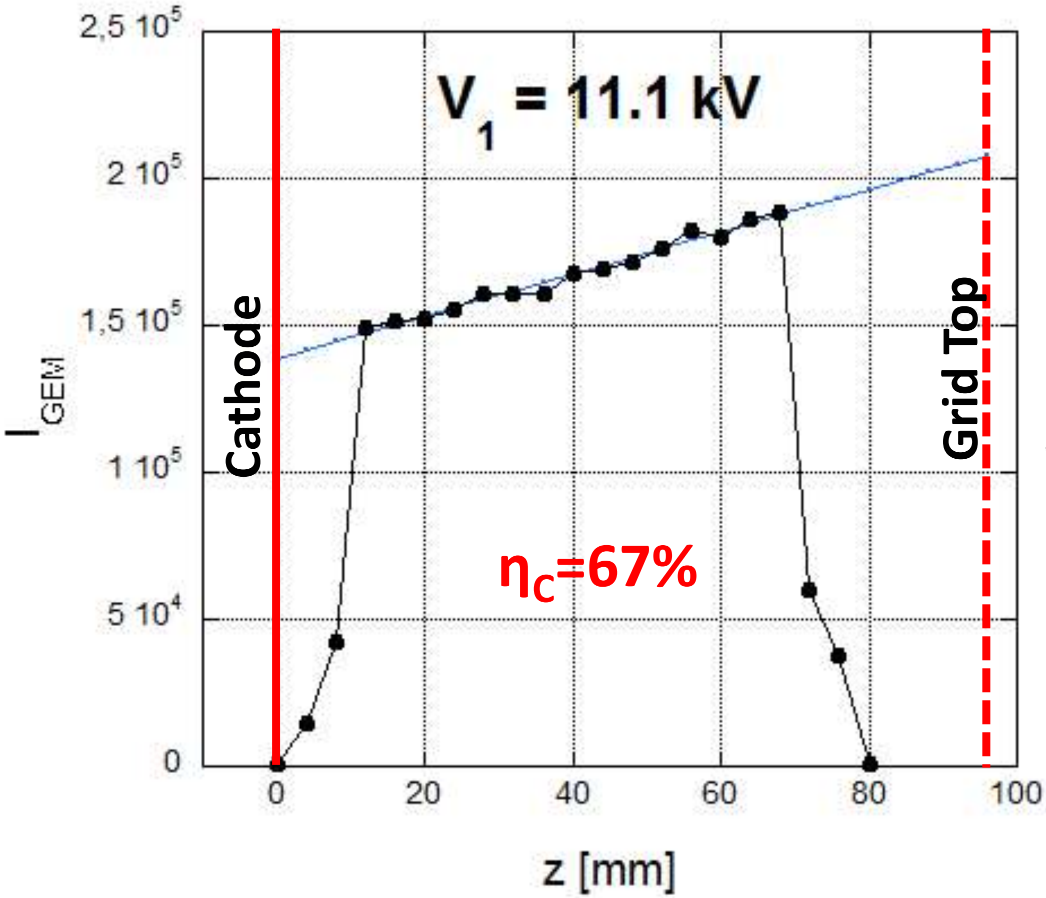
$$I_{GEM} = \int_{t=4\,ms}^{t=20\,ms} BandGEM(t)dt$$

Θ = 5°

Beam dimension = 4 mm x 4 mm

- BAND-GEM detector sensitive to gamma rays (in this case produced by 1mm Cd sheet inserted in the beam) for V_3 > 900 V (gain > 200).
- Working Point selected at **V_3 = 900 V**
- Full study of gamma-ray sensitivity to be completed in 2017 using a strong (100 MBq) source (e.g. Cobaltissimo @ POLIMI).

Relative (bottom/top) Charge Extraction Efficiency



Beam entering from the side ϴ=90˚

Considering all ON-pads for IC_{GEM} calculation

$$I_{GEM} = \sum_{ON-Pads} \int_{t=4\,ms}^{t=20\,ms} BandGEM(t)dt$$

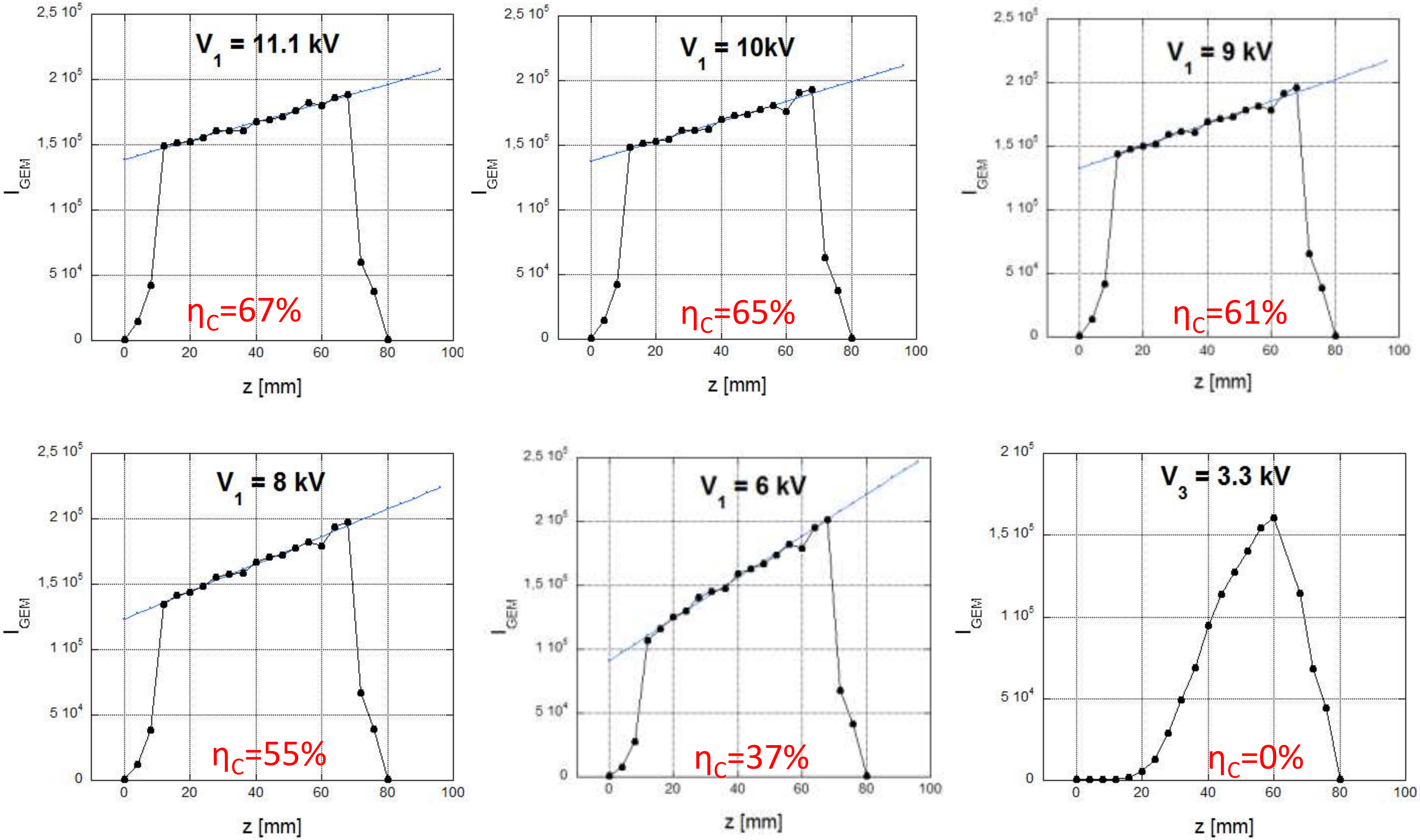
Relative Extraction Efficiency @ Cathode

$$\eta_C = \frac{I_{GEM}(z = 0\,mm)}{I_{GEM}(z = 96\,mm)}$$

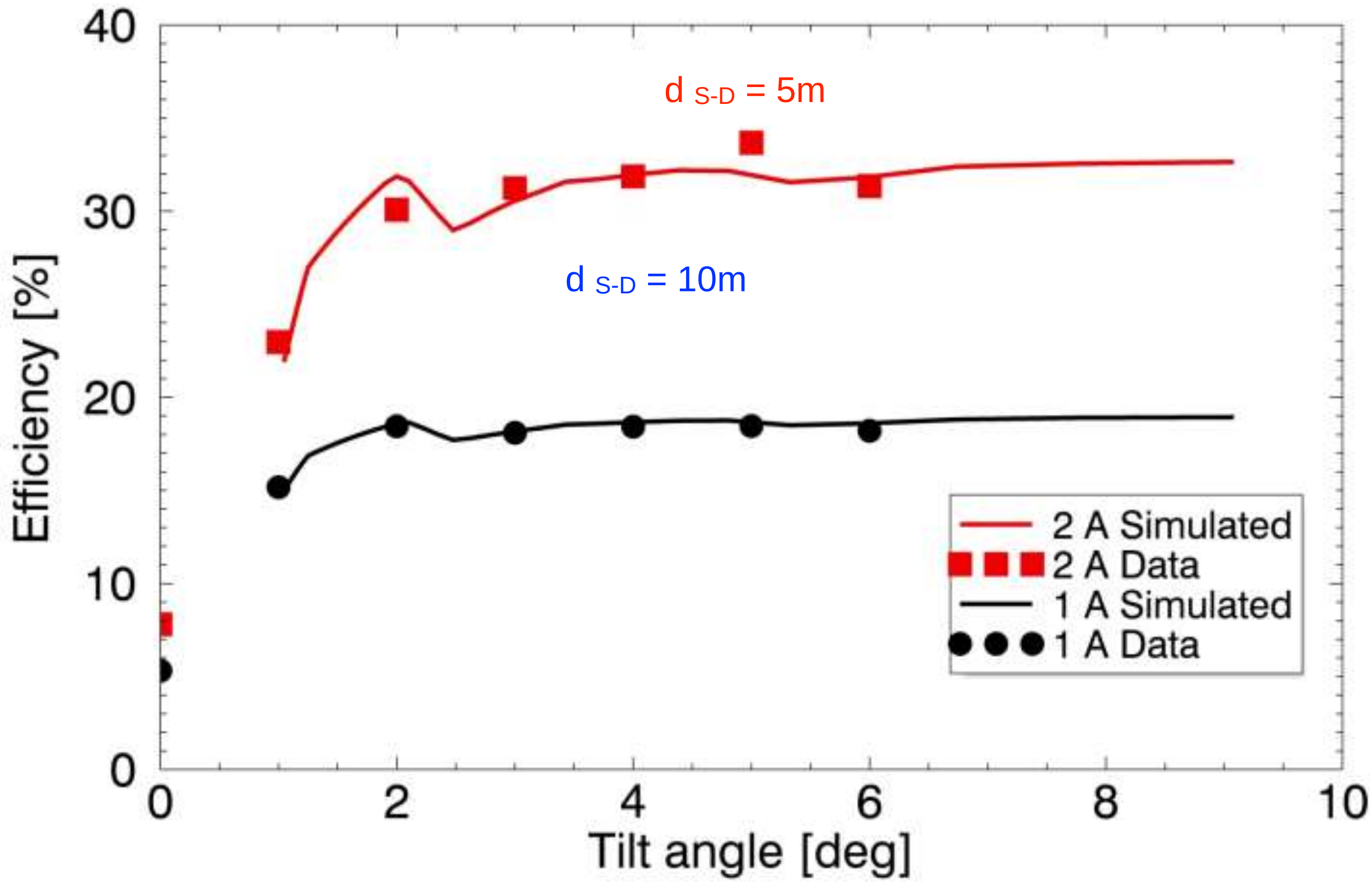
Width of lateral diagnostic window = 75 mm

Relative Charge Extraction Efficiency

Beam entering from side. **z = 0 mm (Cathode); z = 96 mm Grid Top**. Working point as before

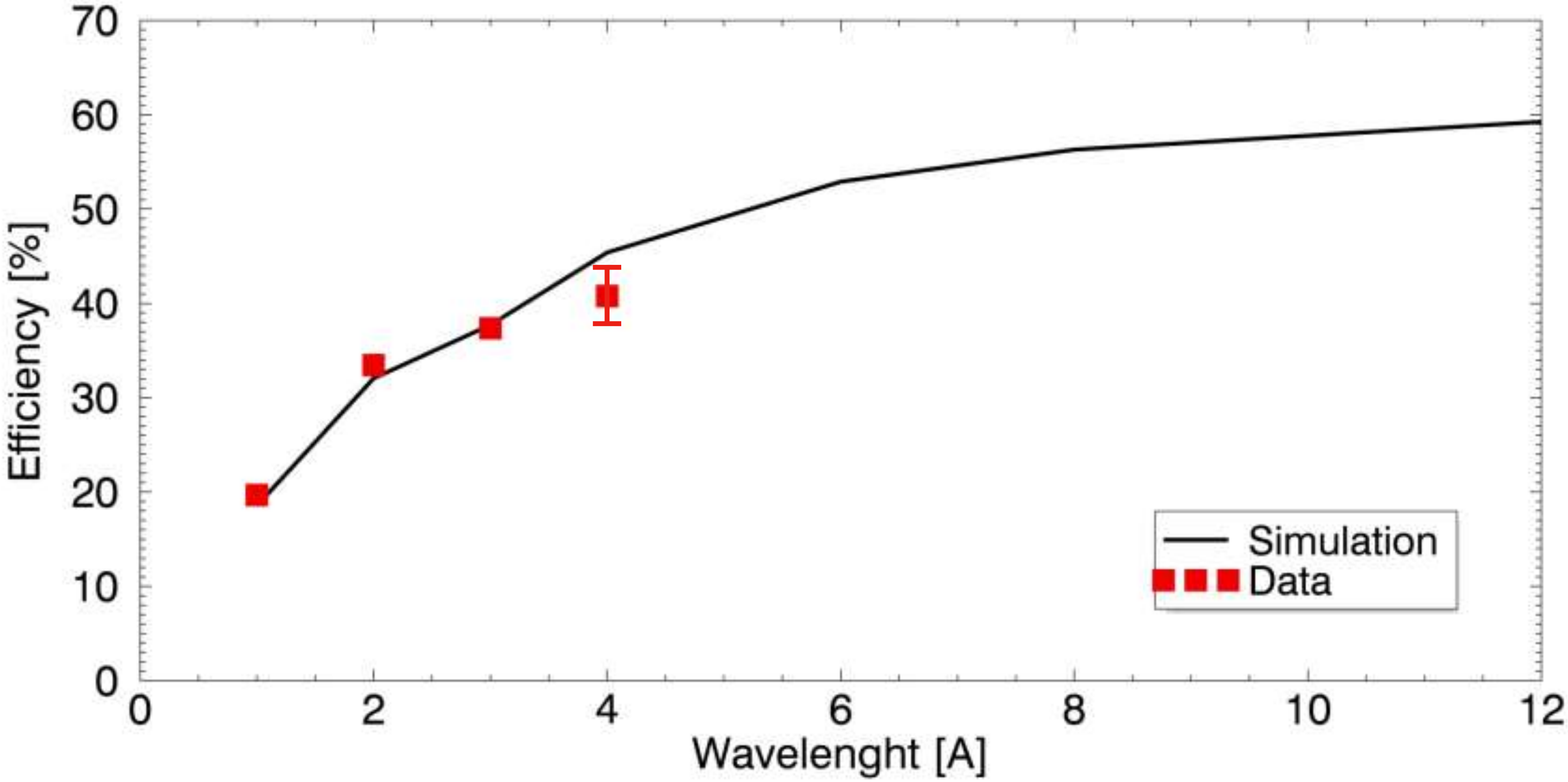


Efficiency (at 1 and 2 A) vs tilt angle



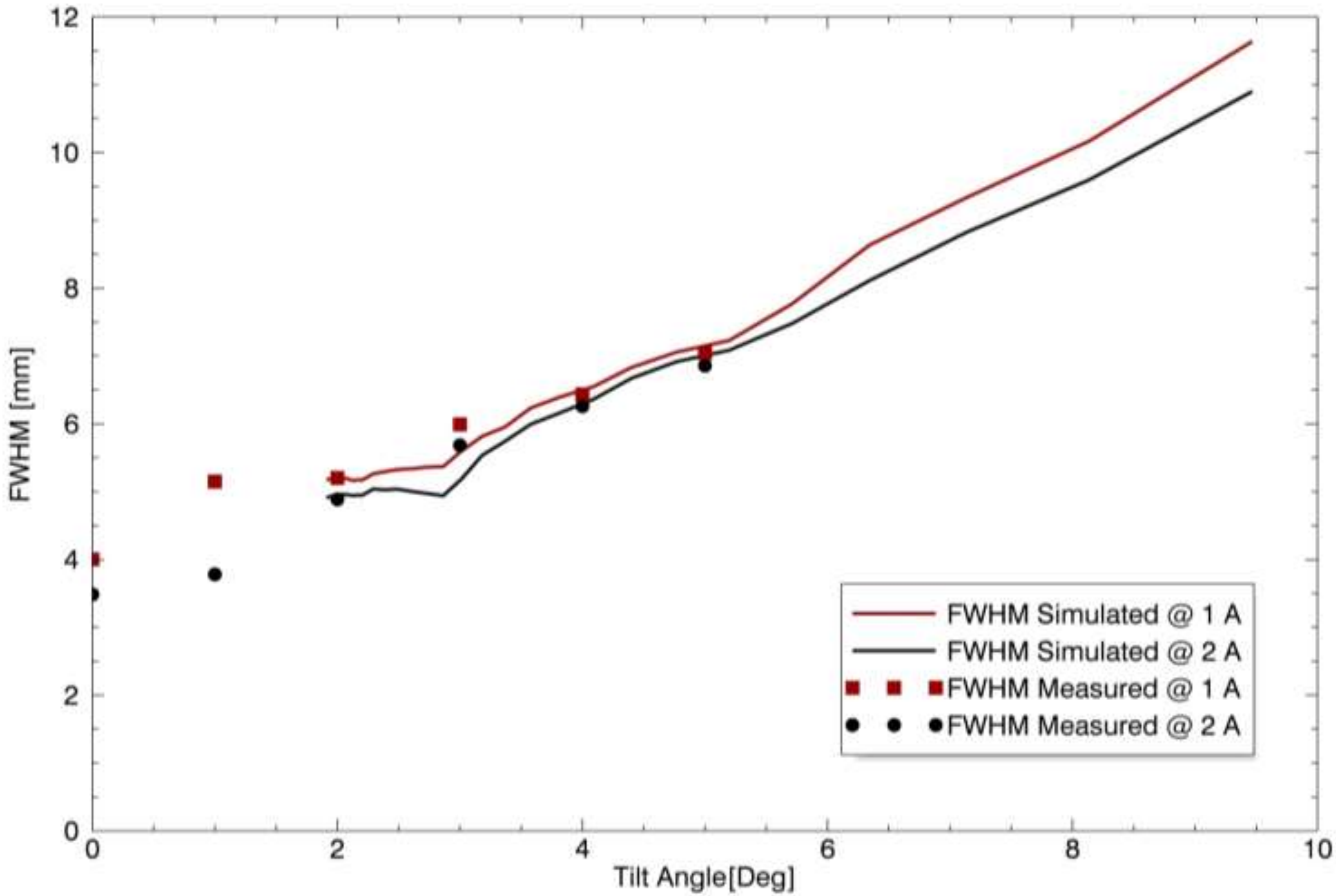
Good agreement with simulated values

Efficiency as a function of λ



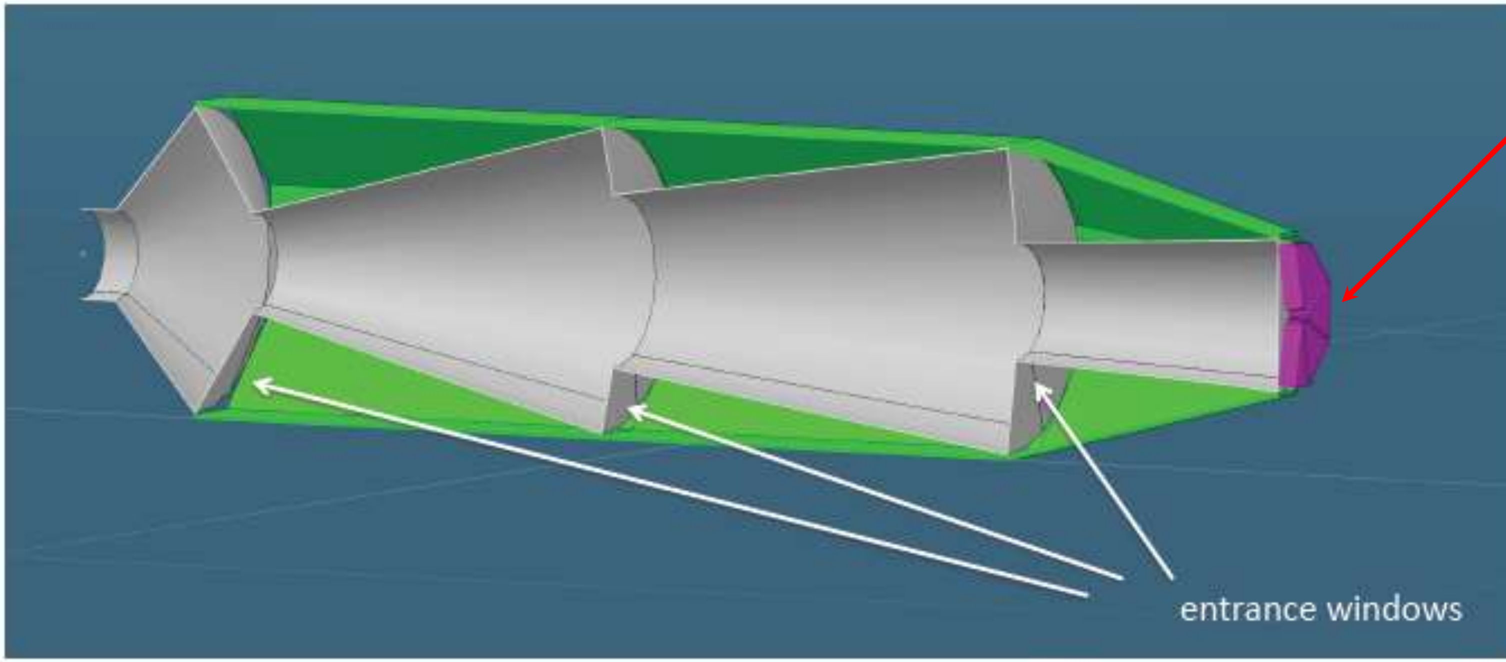
- Alpha and Li ion escape efficiency from a 850 nm thick $^{10}B_4C$ layer = 73%
- Assumes the measured extraction efficiency in the simulation model

FWHM vs tilt angle – Space resolution



Good agreement with simulated values
Experimental corrected for offset by about 5 degrees
Effective resolution ~ independent of λ

BANDGEM application @ LOKI, ESS

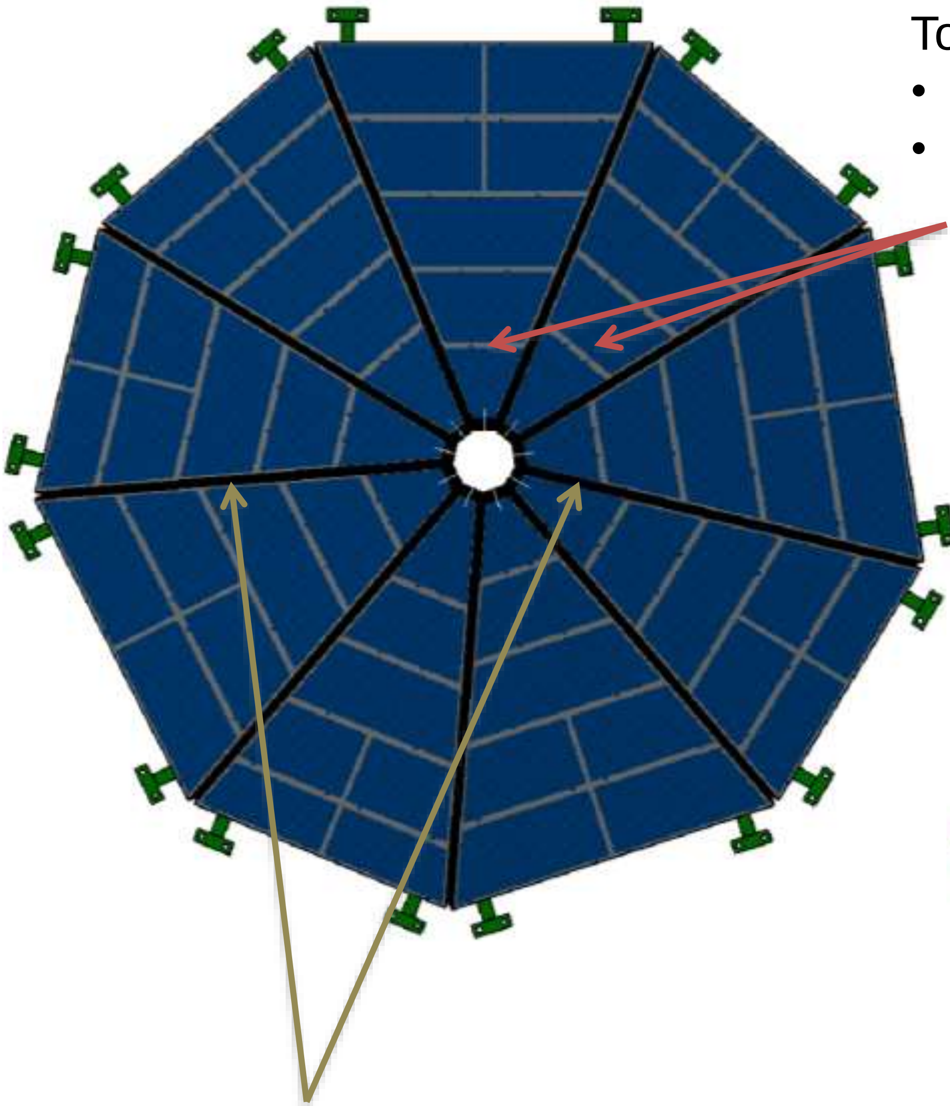


BANDGEM Modules As rear detector panels

Requirements for rear detector panel
- Rate Capability = 40 kHz/cm^2
- Time resolution better than 1 ms
- Efficiency >40% at 4 Å
- X-Y Space resolution of about 6 mm

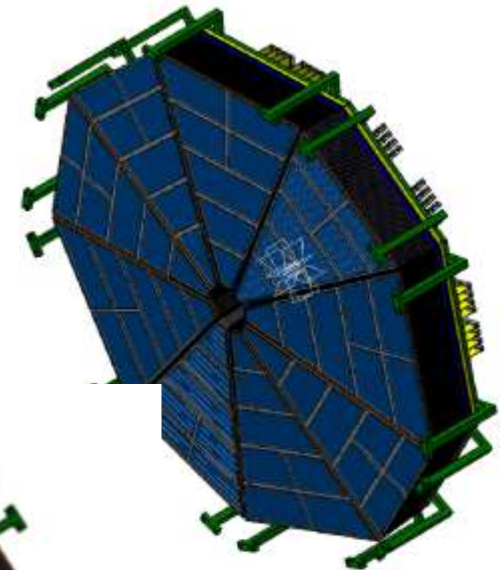
Construction of BANDGEM full module for LOKI as an upgrade of the first prototype

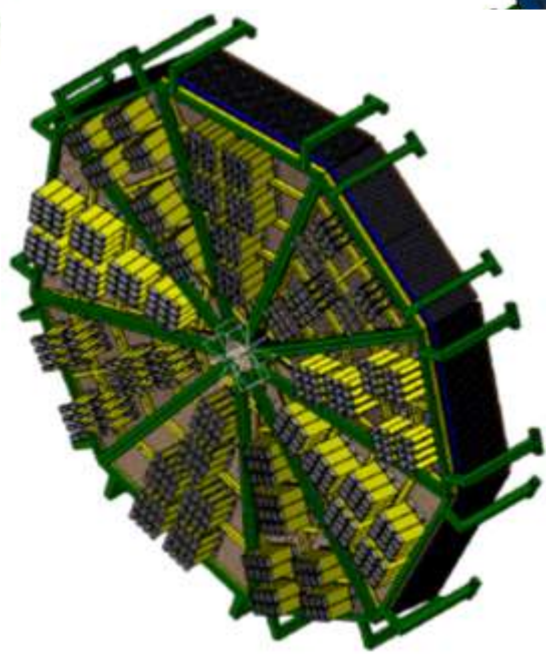
Rear Detector



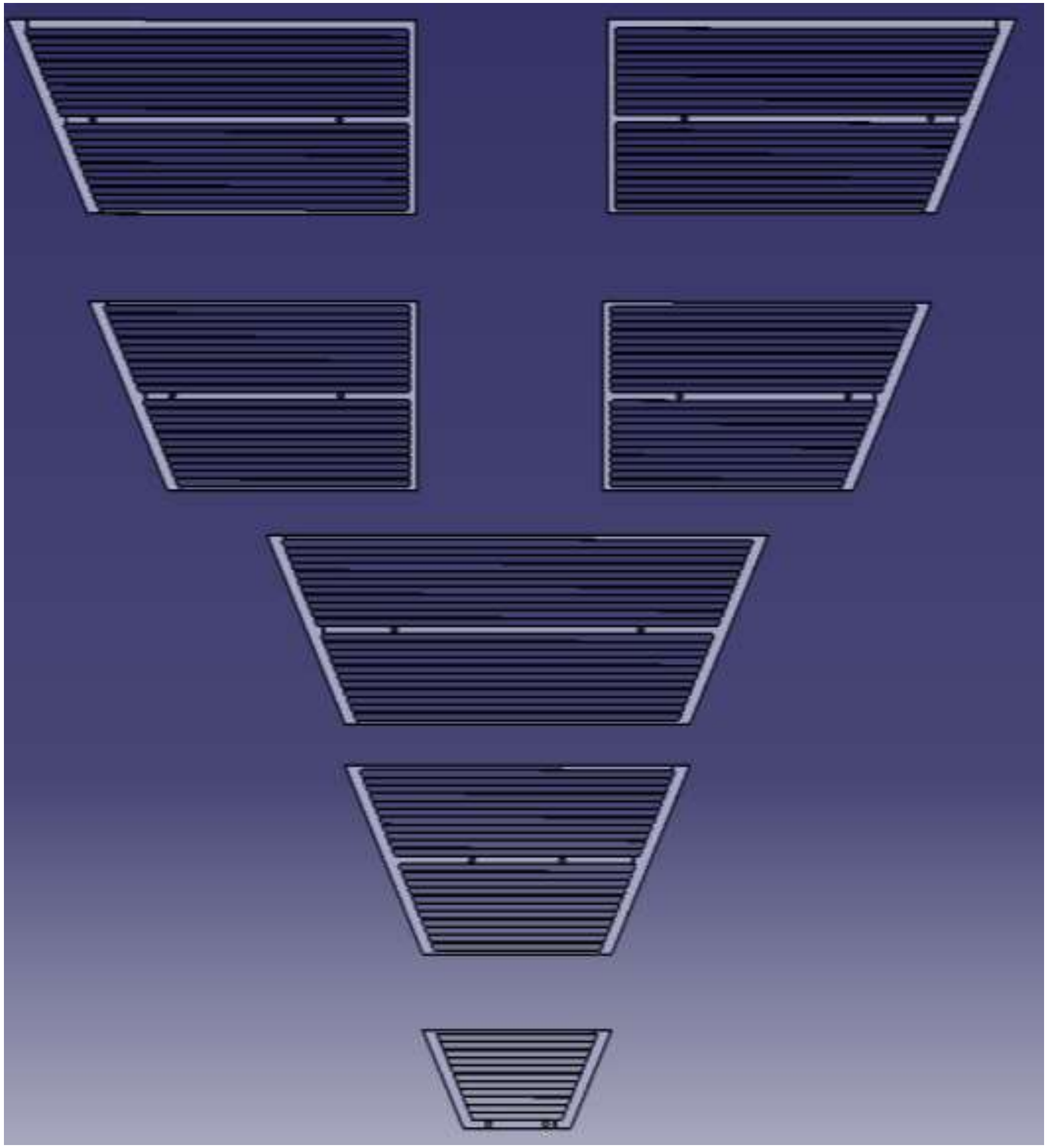
To cover the required area:

- N.4 45 Degrees detectors
- N.5 36 Degrees Detectors



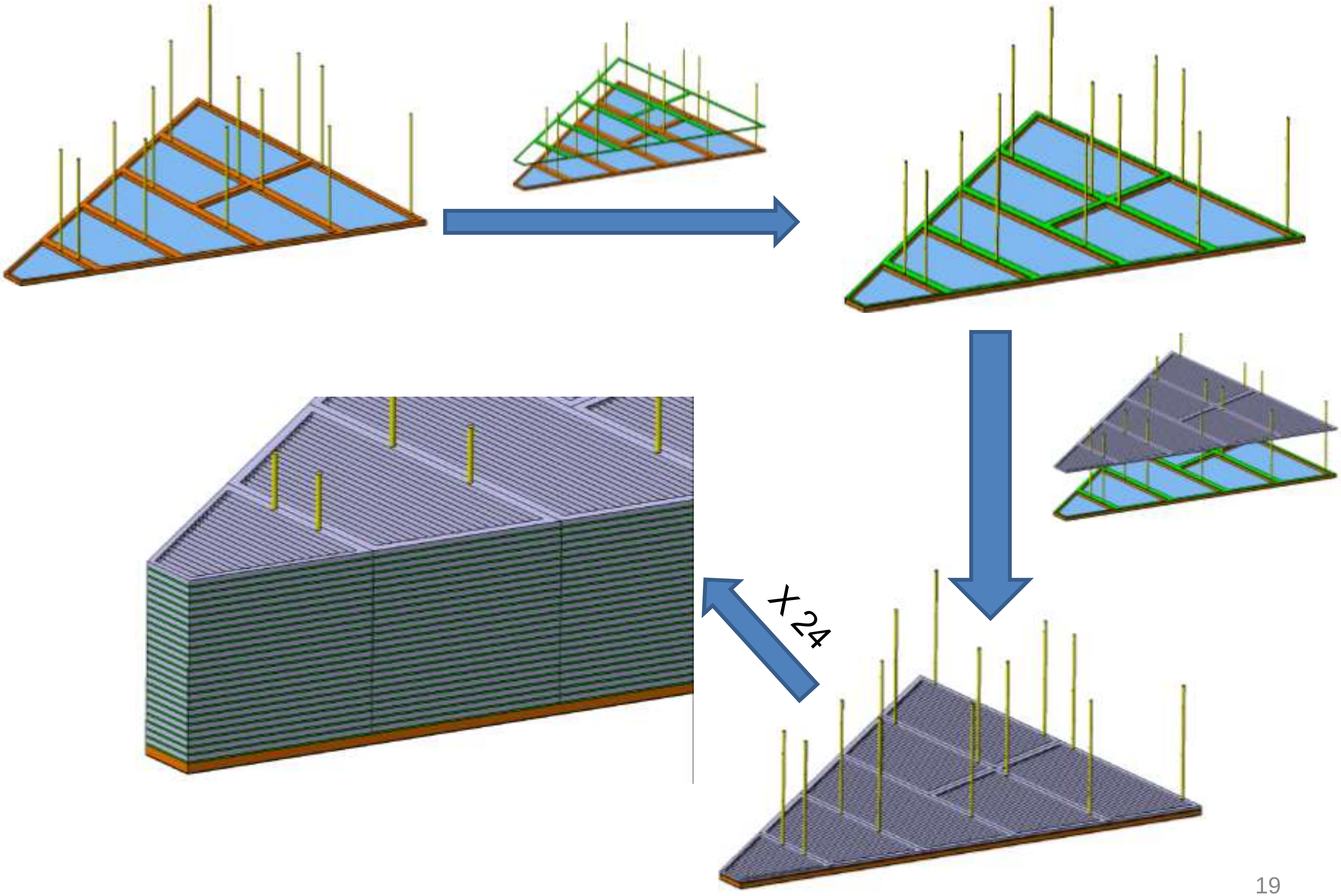


Converter Grids

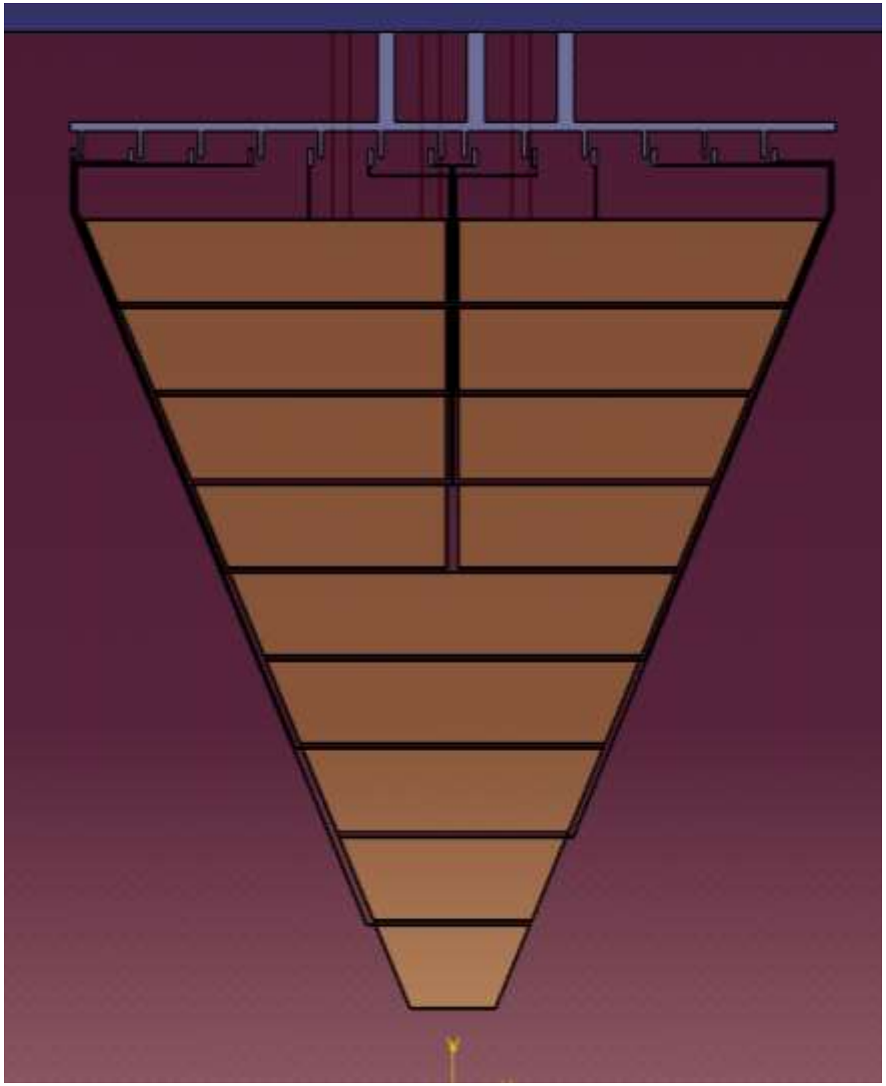


Material: Aluminum
Coating: 850 nm of B_4C
Thickness: 3 mm
Thickness of the strips:
200 um (max)

3D converter assembly

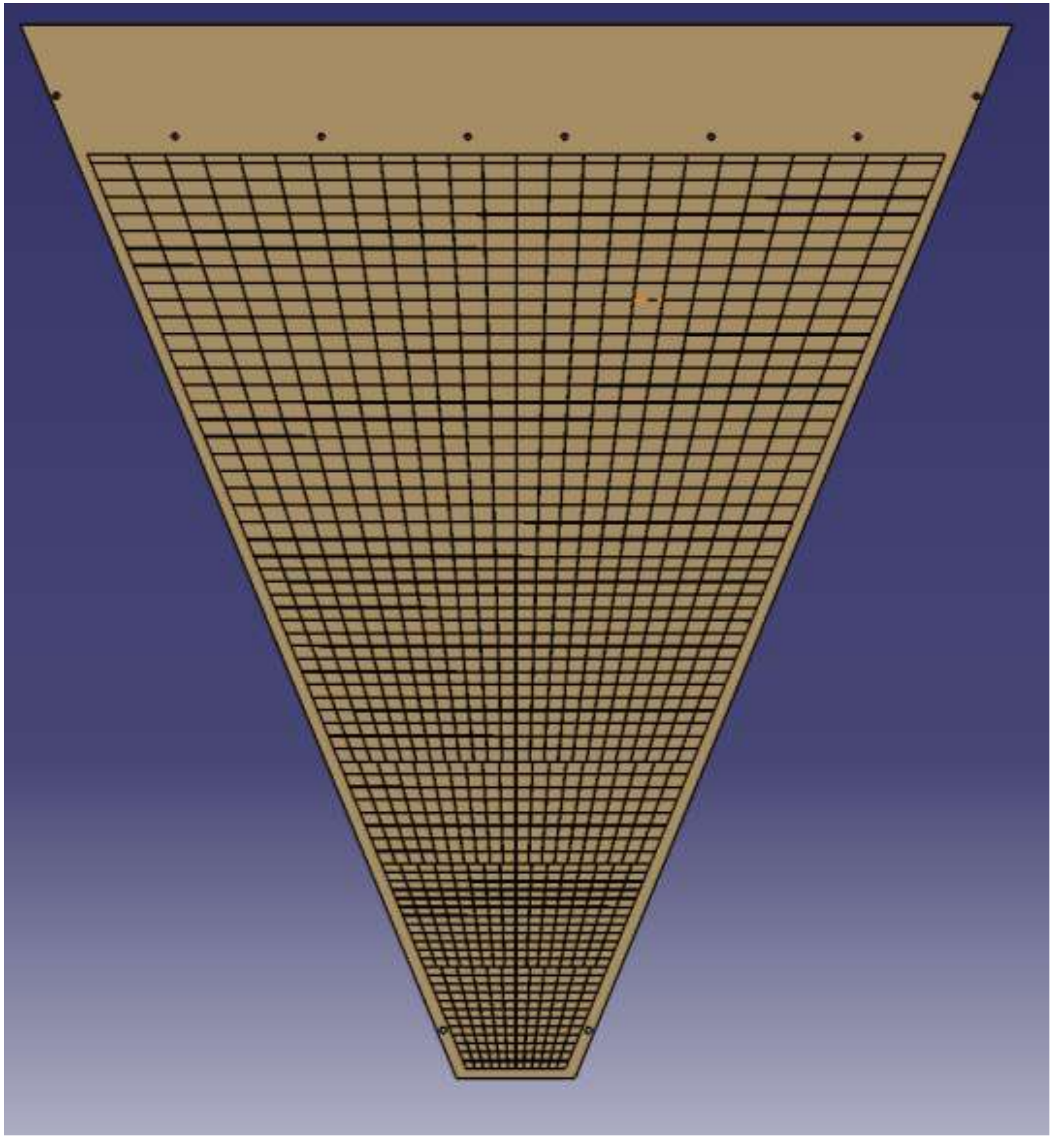


Sectorized GEM foil and frame

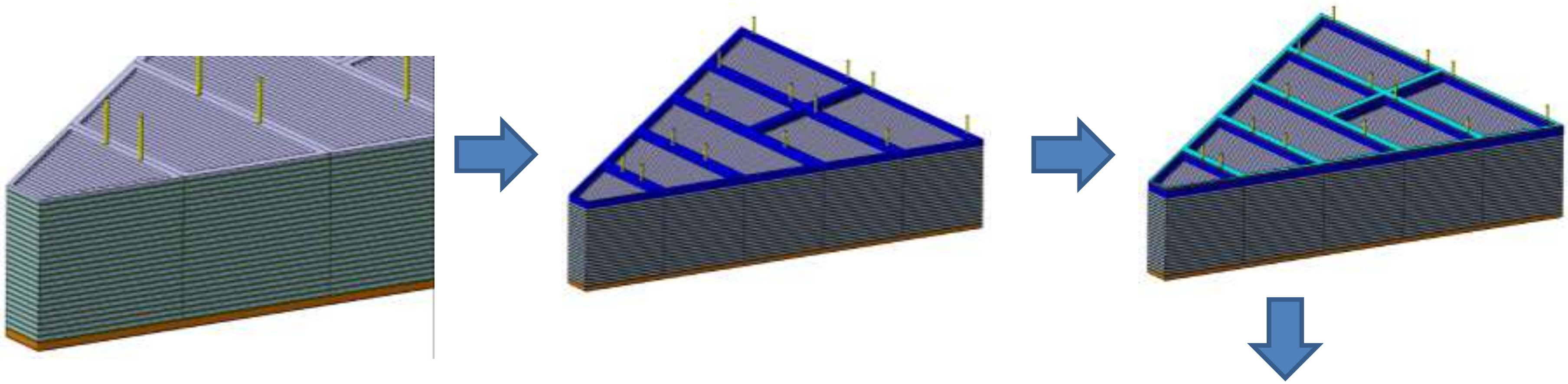


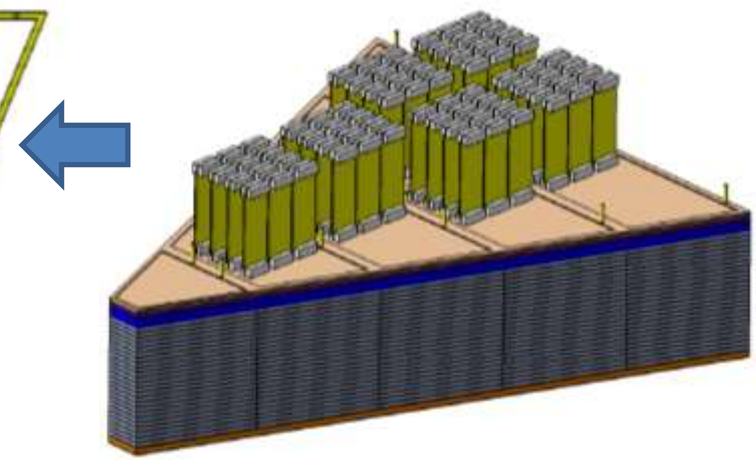
GEM foil stretched and glued to its frame as usual.

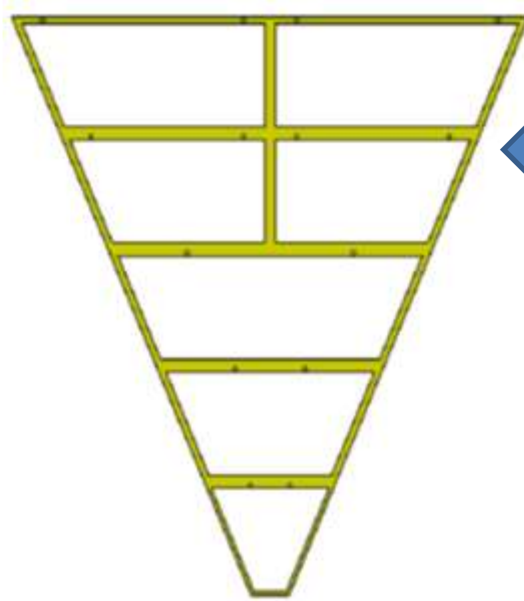
ReadOut Anode

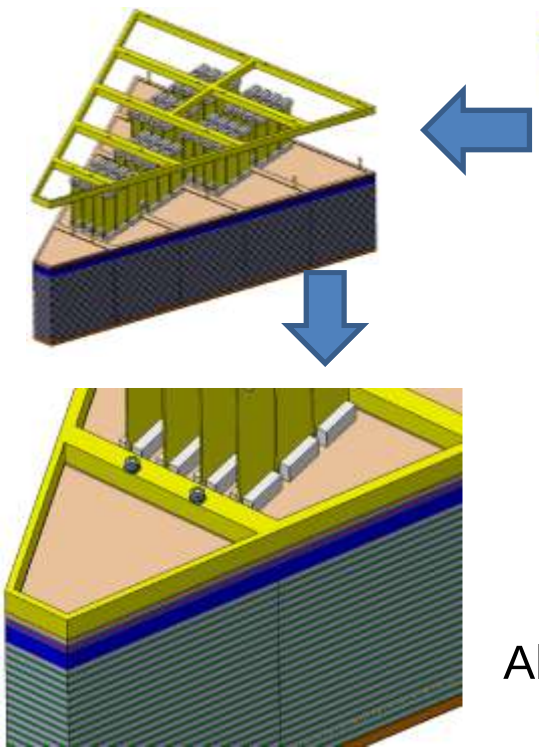


45 degrees Detector: Detector Assembly

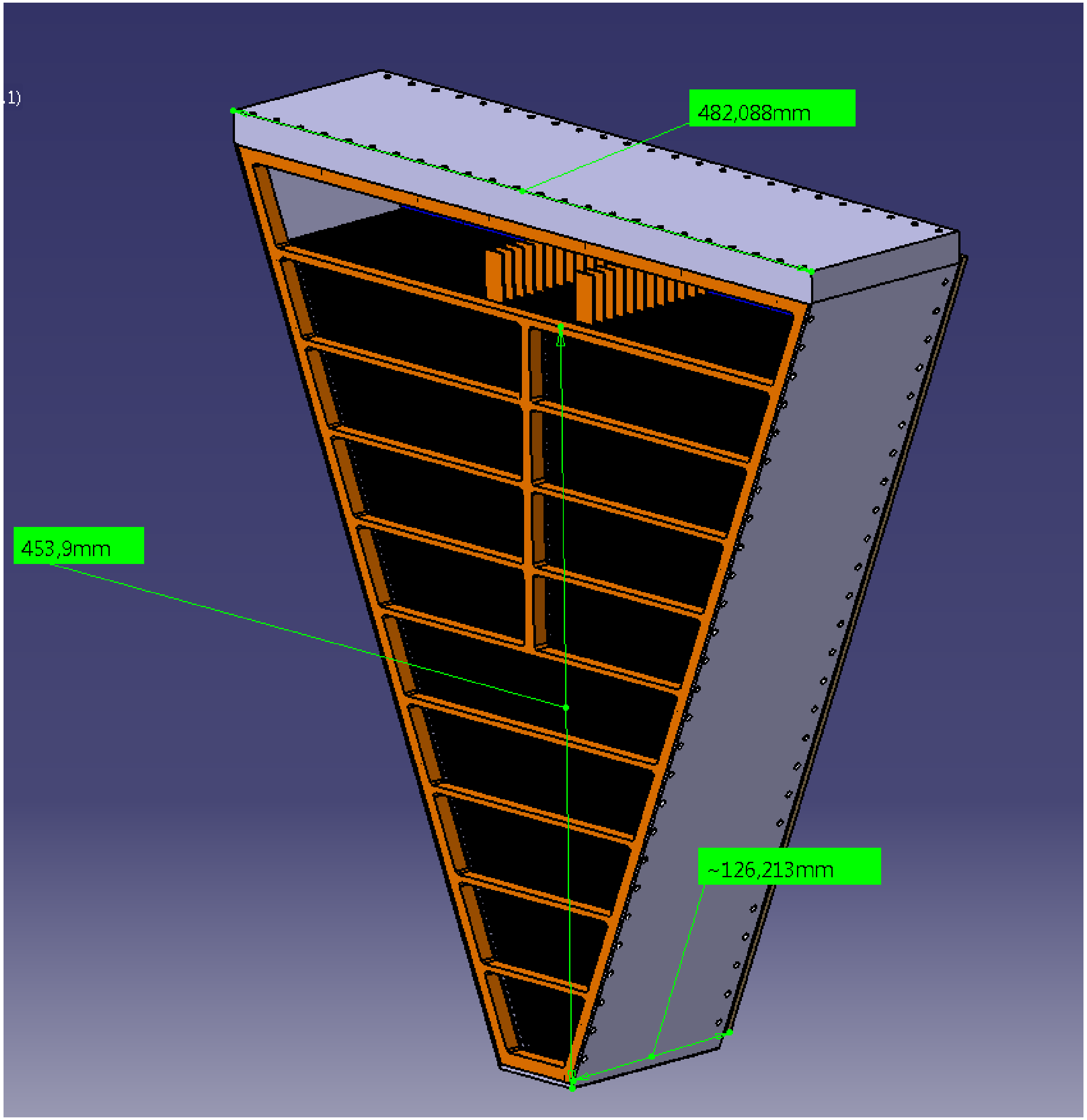






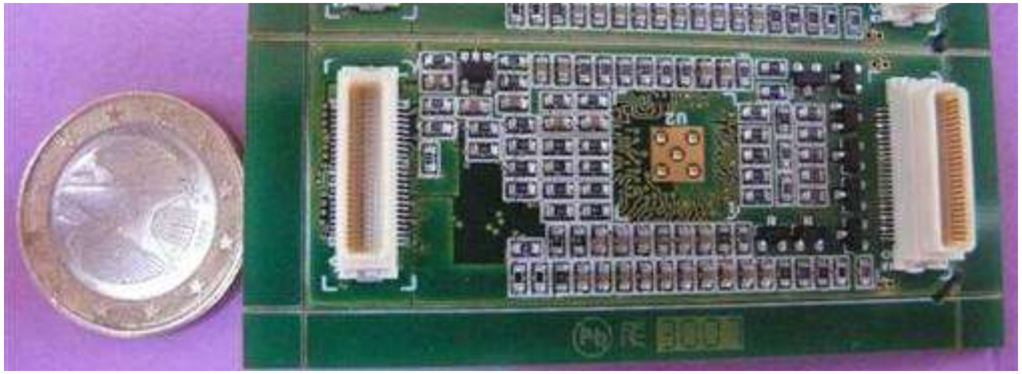


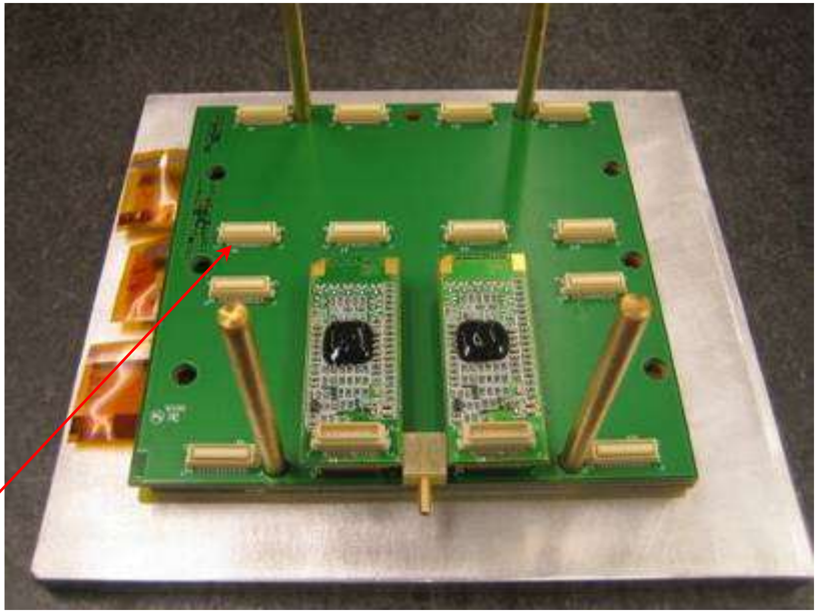
Aluminum frame (thickness: 10 mm)


482,088mm
453,9mm
~126,213mm

The Front End Electronics

The first prototype electronics is based on Carioca Chip. Total dimension : 3x6 cm^2





Digital Chip with 8 channels
Equips the LHCb GEM detectors
Fast chip – used for triggering
Adapted from MWPC

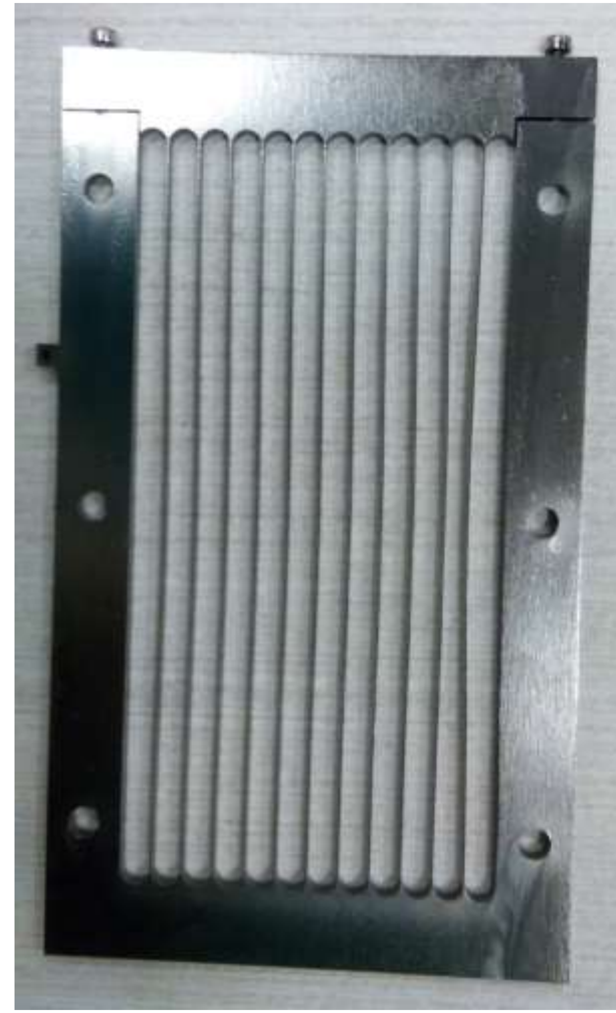
A new chip is available: the GEMINI chip.
Mixed analog and digital chip that
Has 16 channels/chip.
Especially developed for GEM detectors

Conclusions

- Improved construction design using waterjet-cut grids
- Needs very high voltage for operation= 15 kV in total
- Needs to be tilted by about 5 degrees for operation
- Detector response:
  - Efficiency @ 4 A > 40%
  - Resolution (FWHM) @ Θ = 4˚ : 6 mm
- Competivite for SANS (Small angle neutron scattering applications)
- “Full module” for LOKI designed; under construction

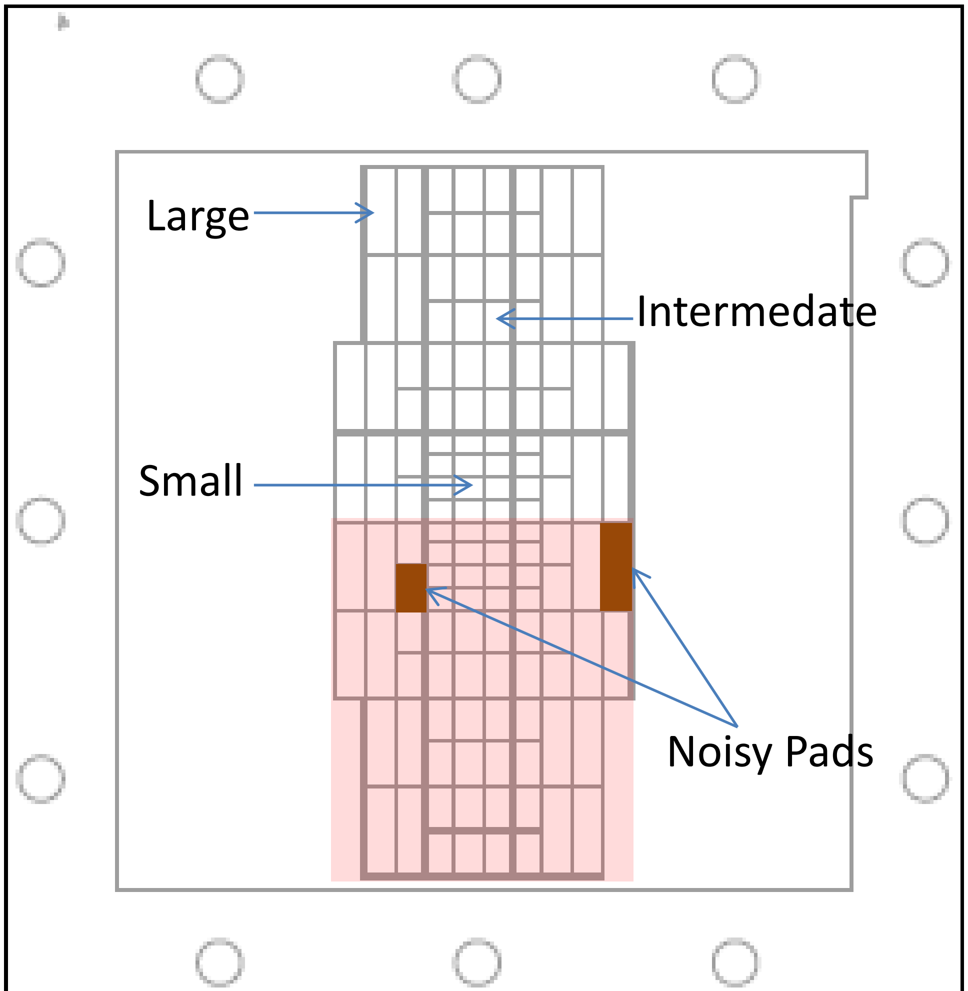
SPARE SLIDES

Nominal 1 µm of $^{10}B_4C$ DEPOSITION @ ESS Workshop (Linkoeping)



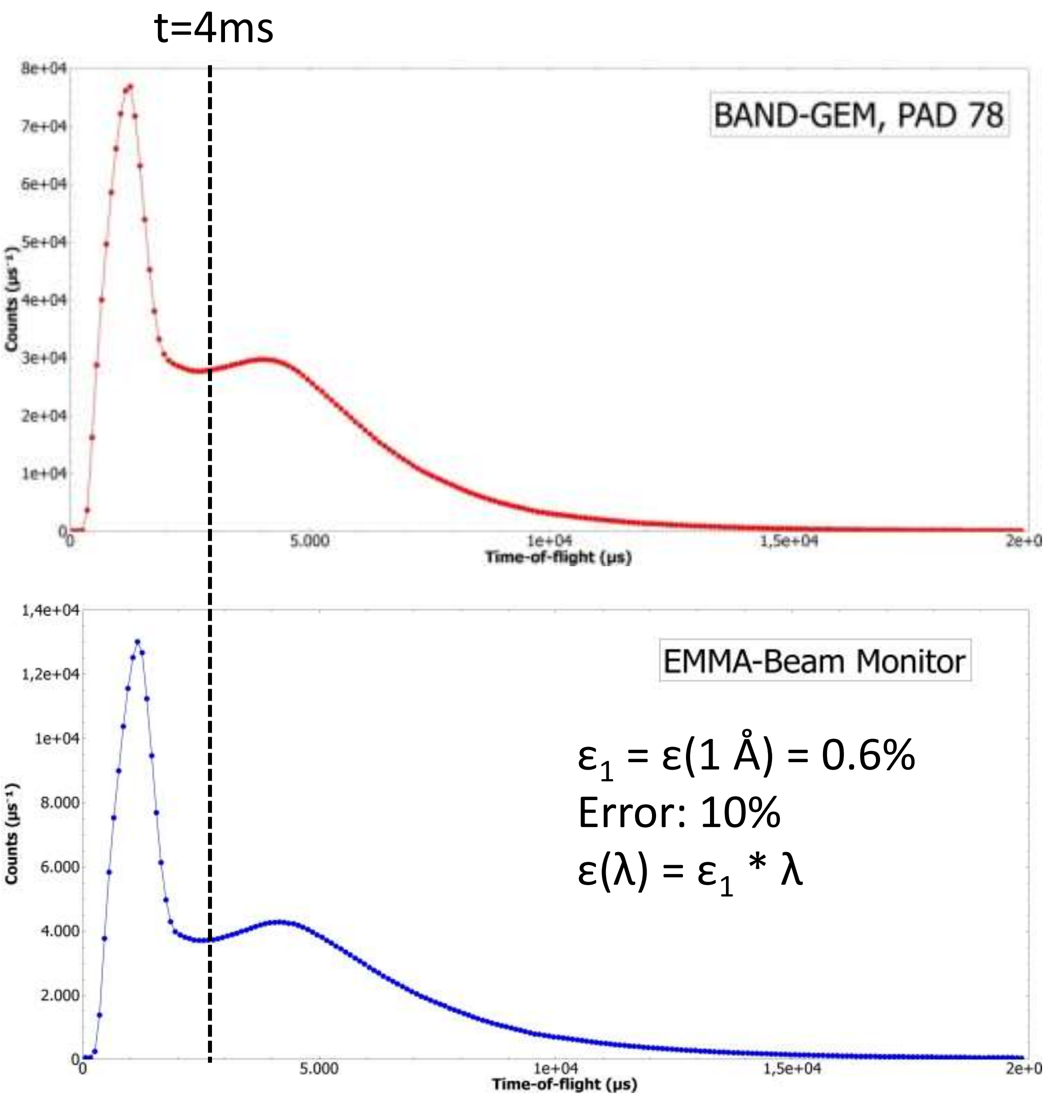
B4C thickness 600 nm in center, 500 at edge
measured @ Linkoeping University using SEM

Detector Anodic Pads – 5x10 cm^2 active area



- Three different types of pads *representative of final geometry*
  - Small 4x3 mm^2
  - Intermediate 4x6 mm^2
  - Large 4x12 mm^2
- 64 BANDGEM pads (half detector) connected to DAE
- For each pad (from 65 to 128) DAE-TOF spectra are produced:
  - Single hits
  - Multiple hits (channel number > 128): more than one pad hit in same time-bin
- 2 noisy pads

Time of Flight Spectra – EMMA 1 Å < λ < 4 Å



$\varepsilon_1 = \varepsilon(1\text{ Å}) = 0.6\%$

Error: 10%

$\varepsilon(\lambda) = \varepsilon_1 * \lambda$

$$C_{BANDGEM,PAD\ i}(t=\lambda) = \int_{t=t_1\ ms}^{t=t_2\ ms} BandGEM_{\ i}(t)dt$$

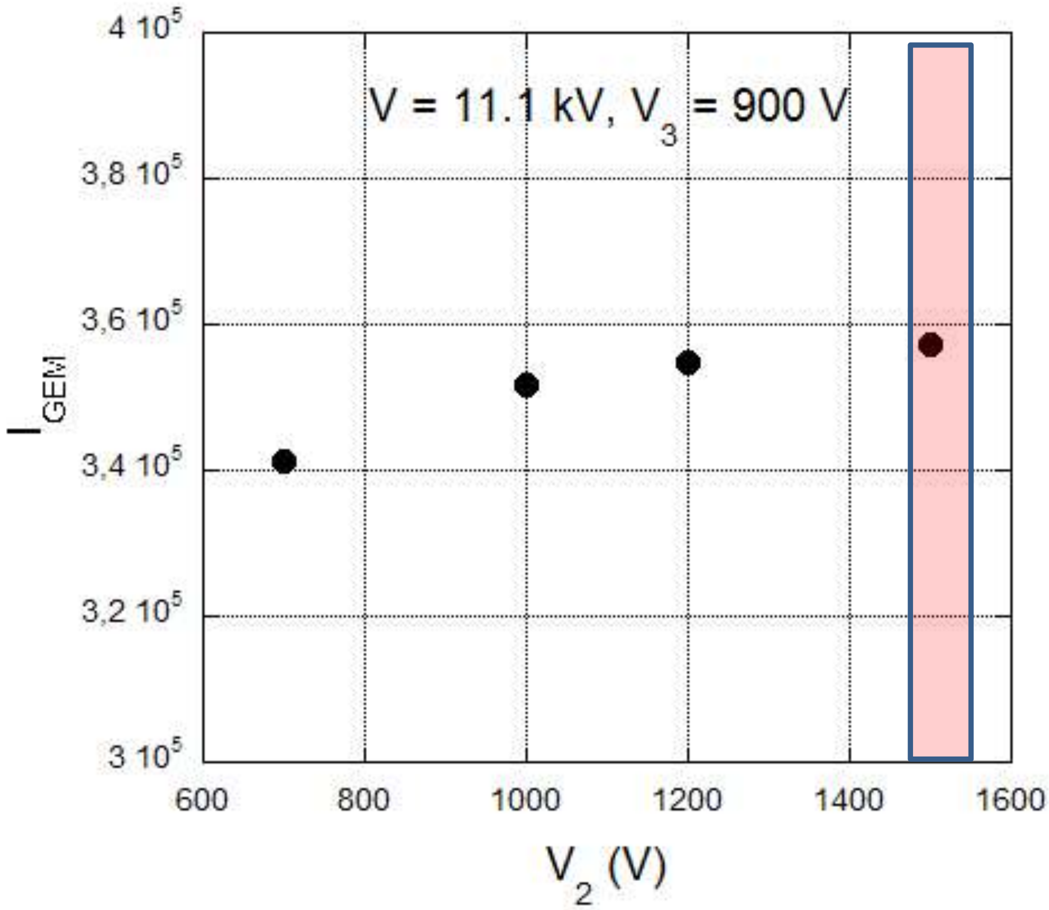
$$C_{Mon}(t=\lambda) = \int_{t=t_1\ ms}^{t=t_2\ ms} Monitor(t)dt$$

λ(Å)	TOF (μs)
1	4000
2	8060
3	12560
4	17060

$$\varepsilon_{GEM}(\lambda) = \frac{C_{GEM}(t=\lambda)}{C_{Mon}(t=\lambda)} * \varepsilon_1$$

Monitor Efficiency previously calibrated using ^{3}He tube

Working Point determination – V_2 scan



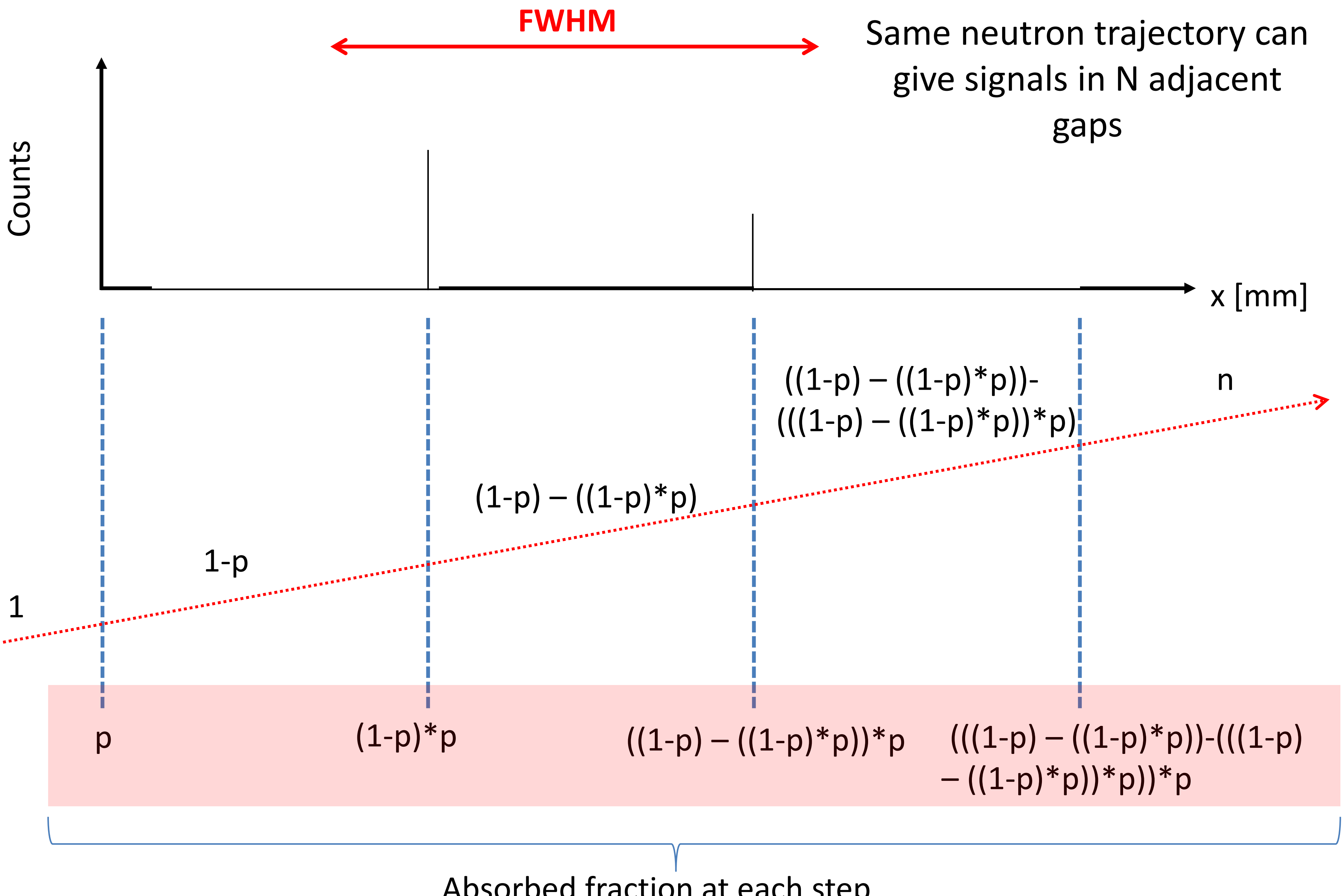
$$I_{GEM} = \int_{t=4\,ms}^{t=20\,ms} BandGEM(t)dt$$

$\Theta = 5°$

Beam dimension = 4 mm x 4 mm

- Counting rate depends weakly on the field between the 3DGrid and the first GEM foil
- Working point selected: **V_2 = 1500 V**

FWHM ESTIMATE (2)



FWHM ESTIMATE (2)

$$p(x) = \begin{cases} p & 0 \text{ mm} < x < 4 \text{ mm (GAP 1)} \\ p*(p\text{^}2 -3p +2) & 4 \text{ mm} < x < 8 \text{ mm (GAP 2)} \\ p*(-p\text{^}3 + 3p\text{^}2 -3p +1) & 8 \text{ mm} < x < 12 \text{ mm (GAP 3)} \end{cases}$$

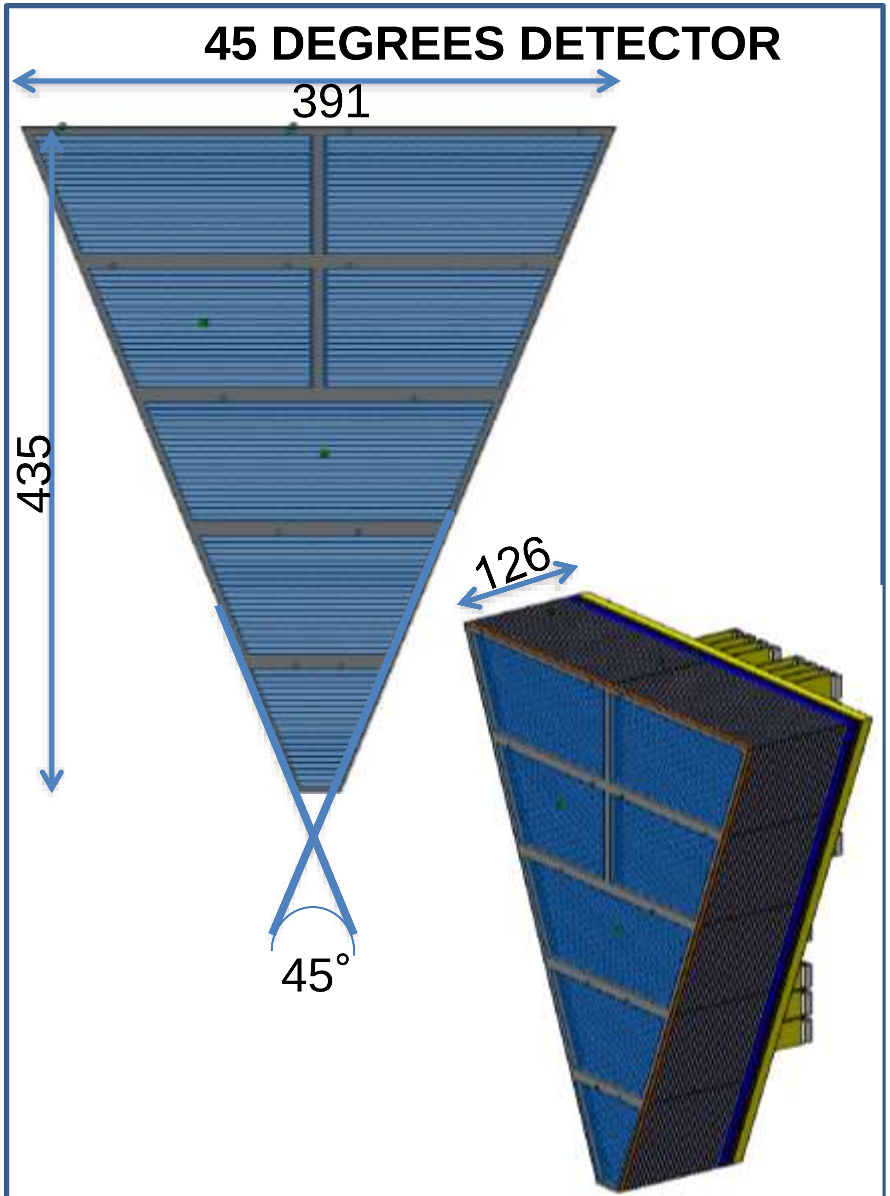
$$\int p(x)dx = -4p^4 + 16p^3 - 24p^2 + 16p$$

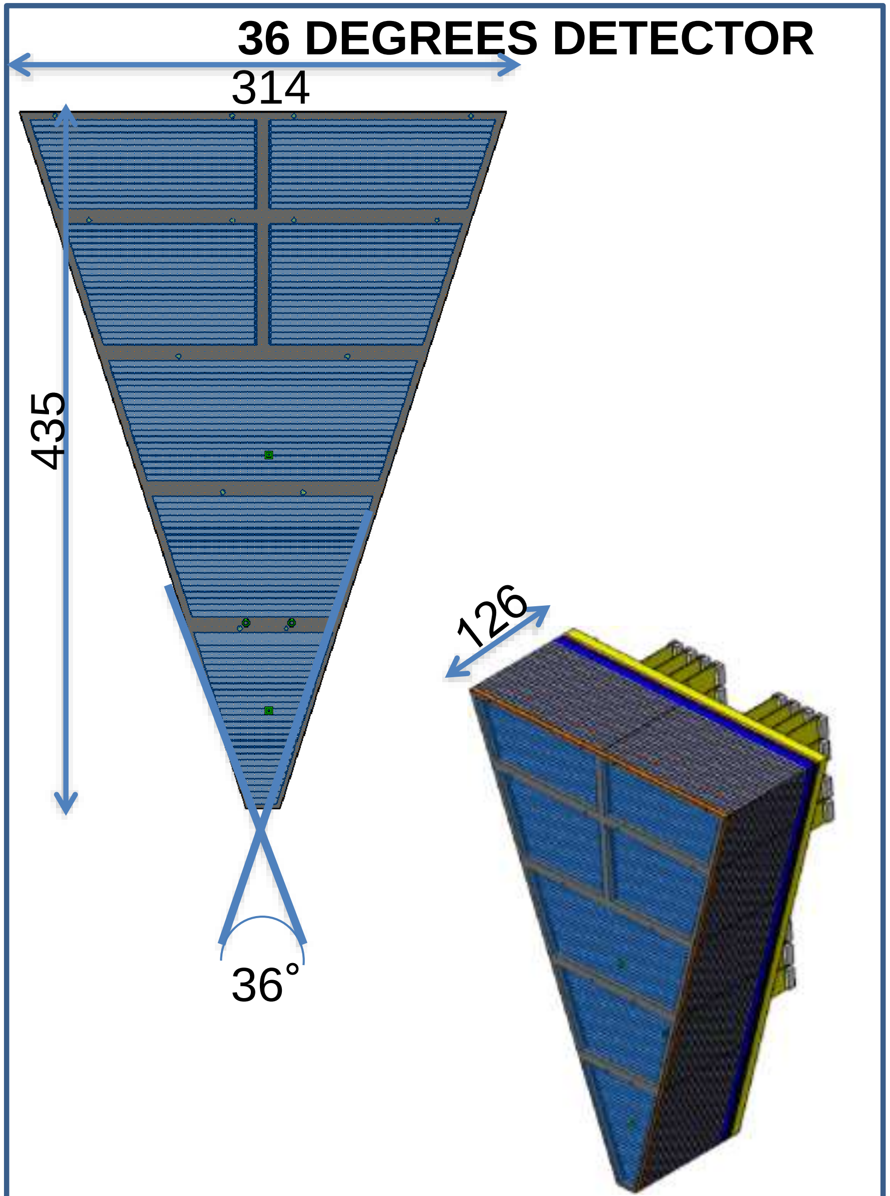
$$\mu = \frac{\int x * p(x)dx =}{\int p(x)dx =} = \frac{-10p^3 + 36p^2 - 48p + 24}{-p^3 + 4p^2 - 6p + 4}$$

$$p(x) = \begin{cases} p(p^2 \\ p\left(-p^3 - \right. \end{cases}$$

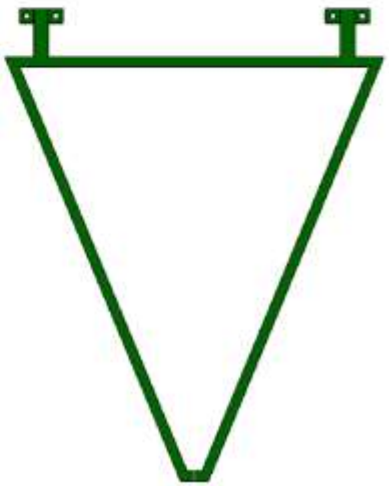
$$\sigma^2 = \frac{\int (x-\mu)^2 * p(x)dx}{\int p(x)dx} \qquad FWHM = 2.35\sqrt{\sigma^2}$$

Detector overview

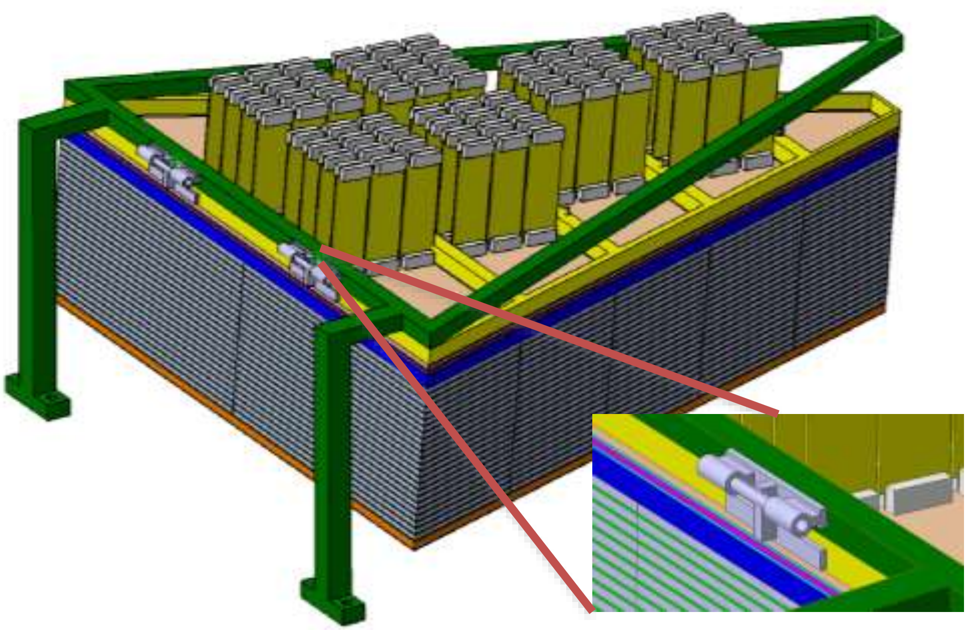




45 degrees Detector: Tilting system



Aluminum frame bolted to the vacuum box surface (thickness: 10 mm).



Vacuum Box (reference plane orthogonal to the beam direction)