

GRAiNITA: A novel calorimeter design

The testbeam result and current status

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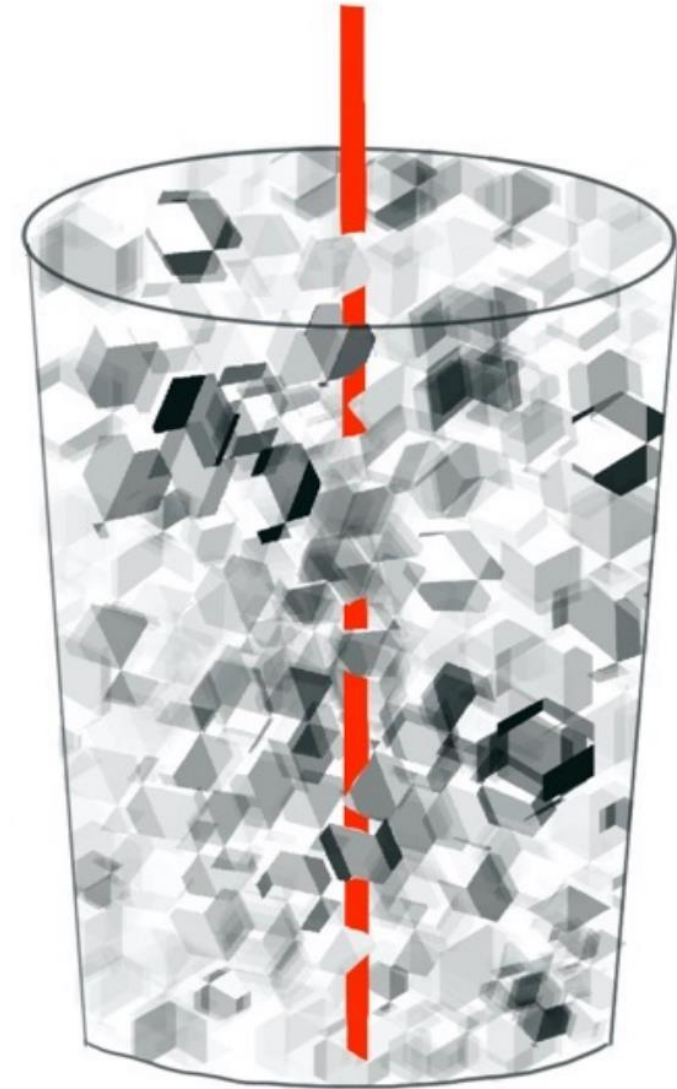
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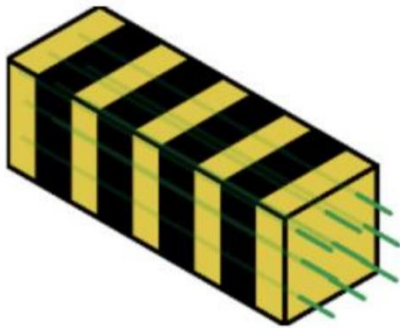
Outline

- The concept of GRAiNITA
- The energy resolution
- Future plans



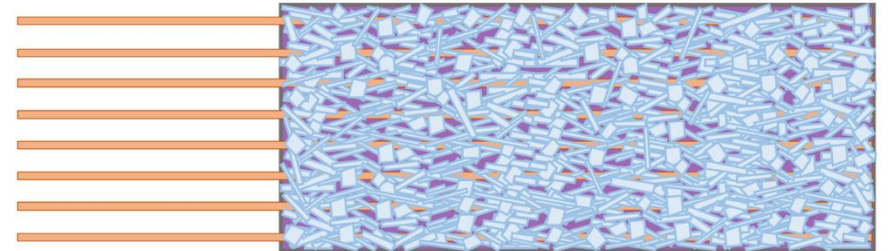
The concept of GRAiNITA

- Shashlik-like sampling:
 - Energy resolution:
($\sim 10\%/\sqrt{E}$)



Better
resolution
→
Lower cost
(vs homogeneous)

- GRAiNITA:
 - Mixture of scintillator grains and heavy liquid
 - Extremely fine sampling
+ Energy resolution ($\sim 2\%/\sqrt{E}$)



The concept of GRAiNITA

- The grains (produced by *ISMA)
 - Candidates:
 - ZnWO_4 and BGO (reference)
 - Size: ~1 mm
 - ZnWO_4 : produced via flux method by ISMA
 - BGO: produced via mechanical crushing

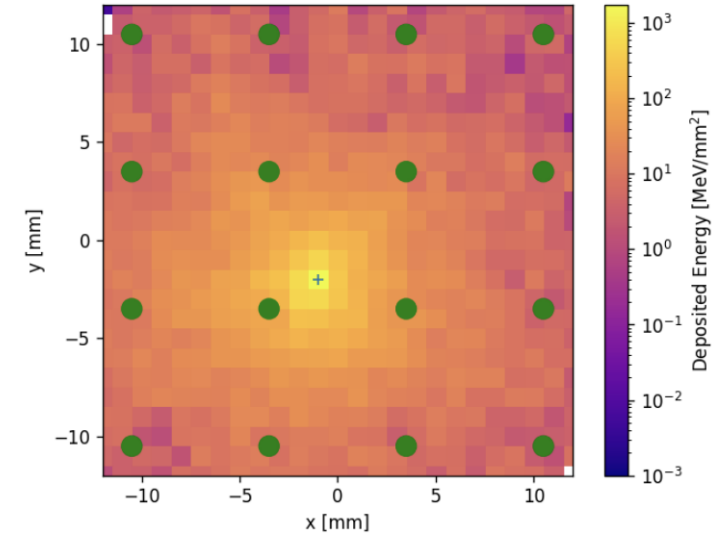


	BGO	ZnWO ₄
Effective Z	74	61
Density (g/cm^3)	7.13	7.87
Refractive index	2.15	2.0 - 2.3
Light yield (photons/MeV)	~ 9000	~ 9000
Peak emission wavelength (nm)	480	480
Decay time (μs)	0.3	20
Radiation length (cm)	1.12	1.20
Molière radius (cm)	2.26	1.98

*ISMA: Institute for Scintillation Materials, Kharkiv, Ukraine

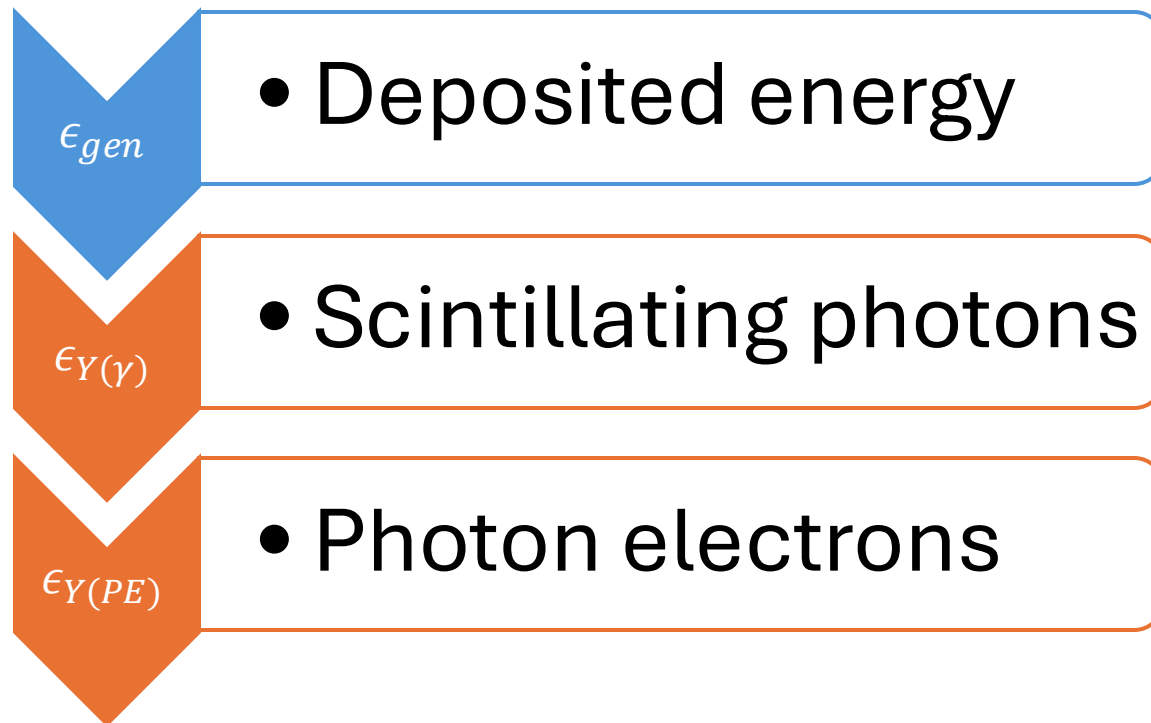
To estimate the energy resolution

- The GRAiNITA prototype design
 - Size: 168 mm x 168 mm x 400 mm
 - Filled with ZnWO_4 grains (~ 1 mm) and heavy liquid
 - Scintillating photons are read out by WLS fibers
- Simulation setup
 - Scintillators are simplified as virtual strips for now
 - ZnWO_4 (79.24%) + Heavy liquid (20.76%)
 - WLS fibers were simulated as cylinders ($d=1$ mm) and filled with carbon-hydrogen plastic
 - Scintillating process is not switched on and simulated for now



To estimate the energy resolution $\frac{\sigma_E}{E}$

- From deposited energy to measured energy



↓ Take the deposited energy E_{Dep} from simulation

↓ Take $\epsilon_{data} = \epsilon_{Y(\gamma)} \cdot \epsilon_{Y(PE)}$ from beamtest data

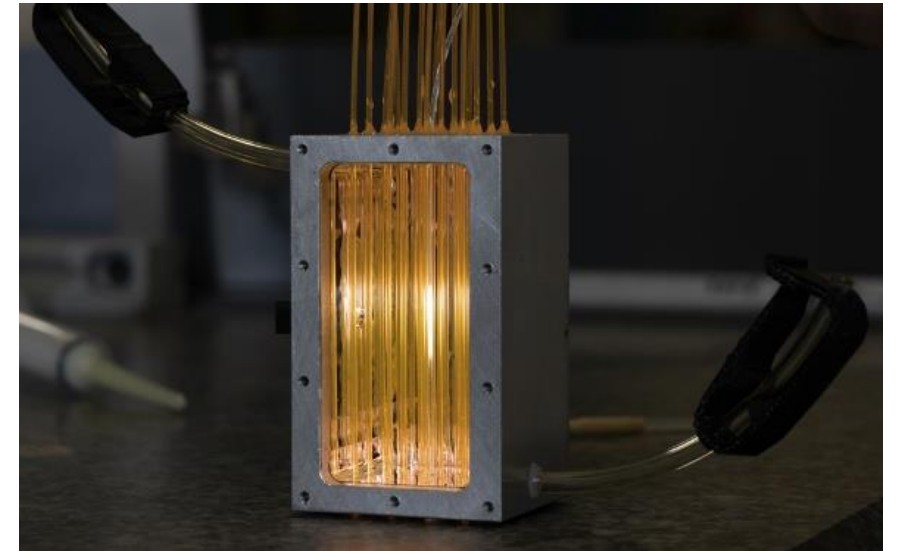
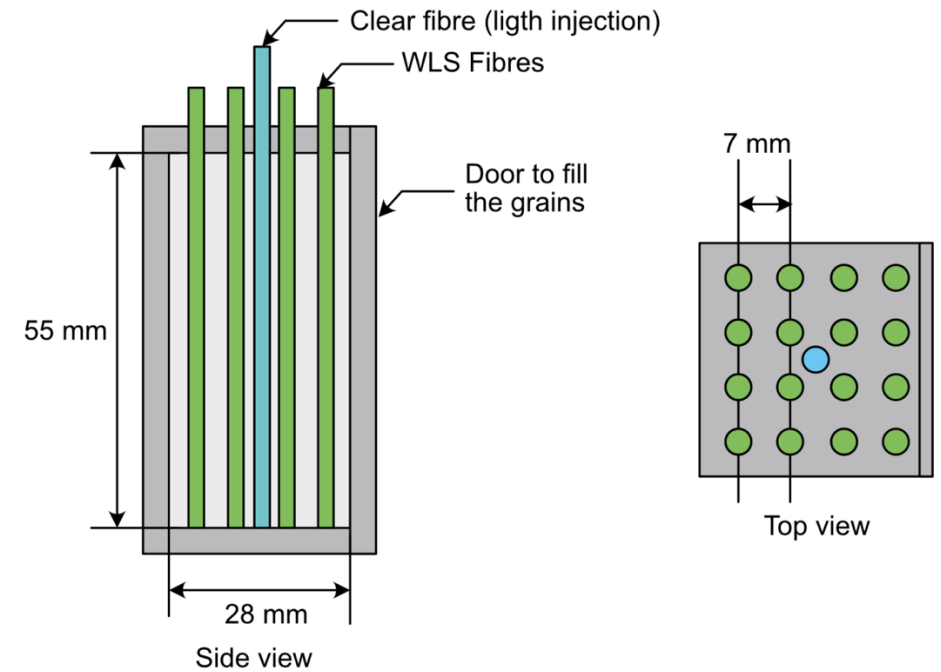
↓ Get the measured energy as:

$$E_{Rec} = E_{Dep} \cdot \epsilon_{data}$$

↓ Get the resolution from E_{Rec}

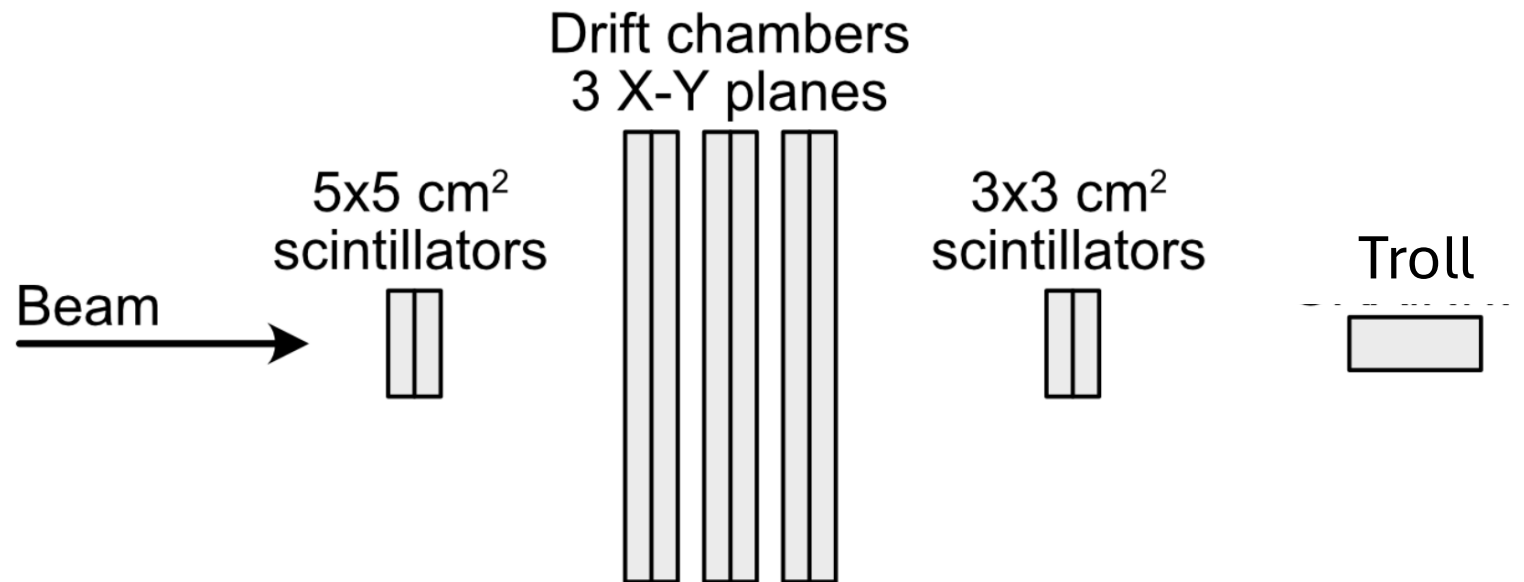
A pre-prototype: Troll

- Size: 28 mm x 28 mm x 55 mm module
- Material: ~ 200 g ZnWO₄ and heavy liquid (water, as reference)
- Readout by 16 WLS and SiPM
 - +1 clear fiber in the center for LED light injection

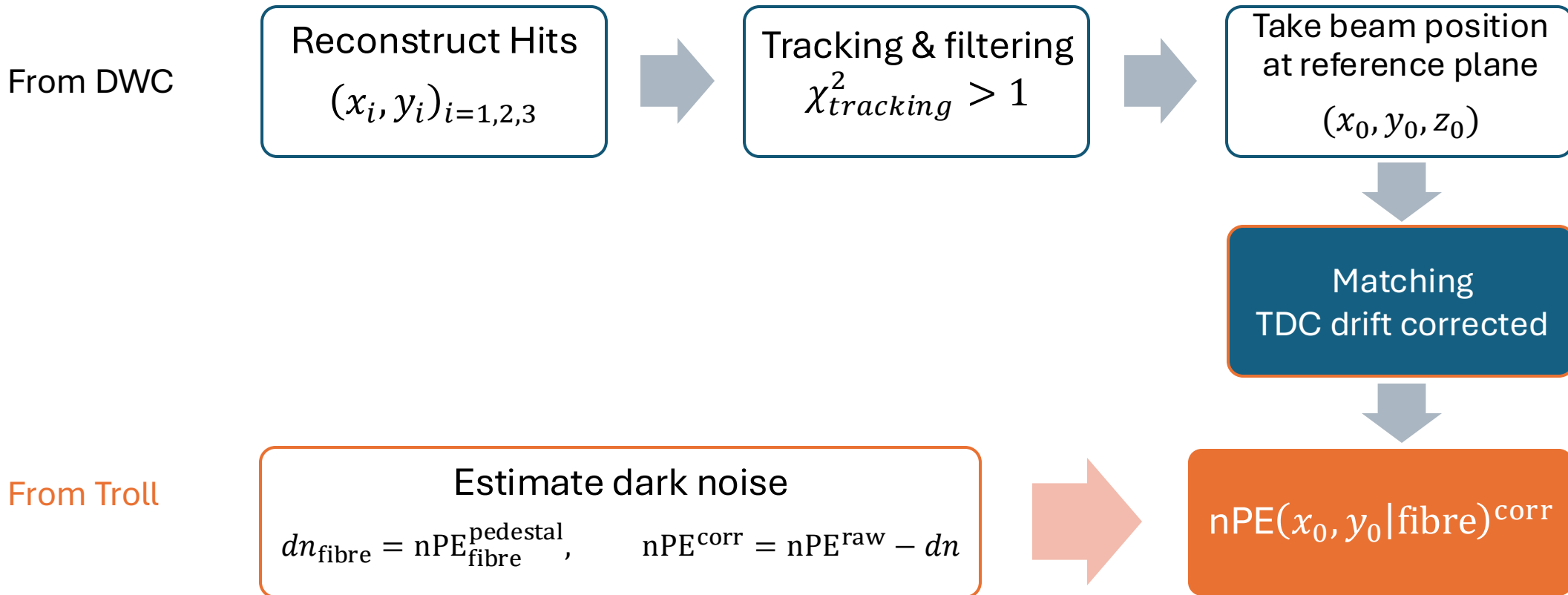


Testbeam setup

- Beam tracking: 3 layer wire drift chamber (DWC)
- Triggers: 2 dual scintillators, one next to Troll, one before DWC
- Beam: pion beam (more statistics) and muon beam

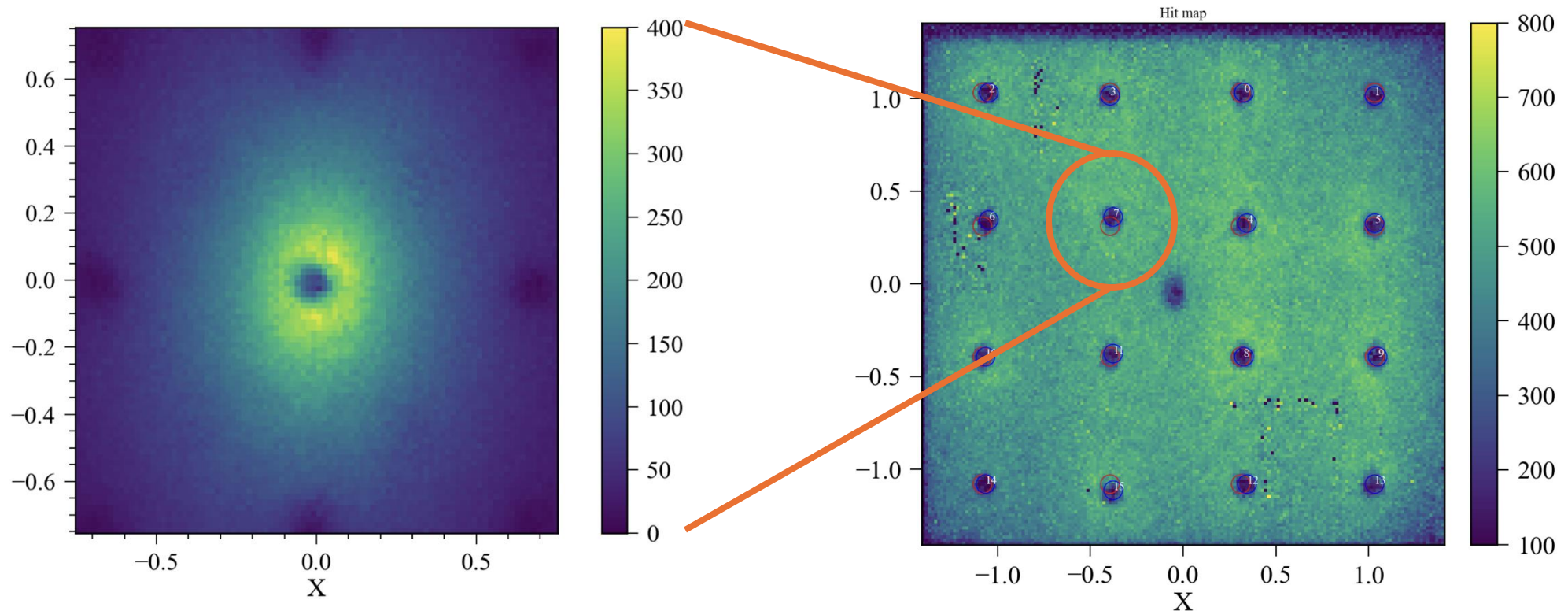


Roadmap to the nPE map



Roadmap to the nPE map

- Accurate fibre position: the minimum nPE bins in neighbour areas



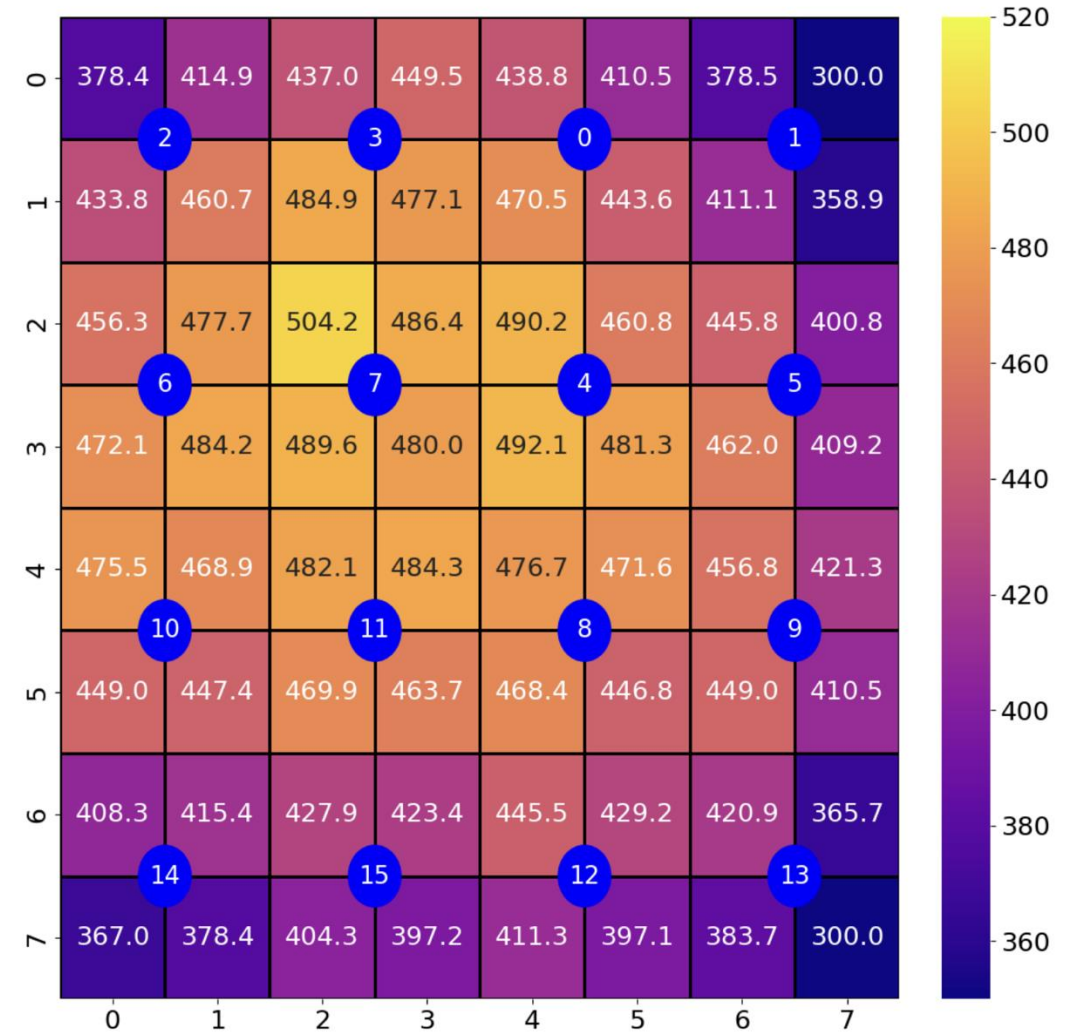
Roadmap to nPE map

- Homogenisation of fibre responses

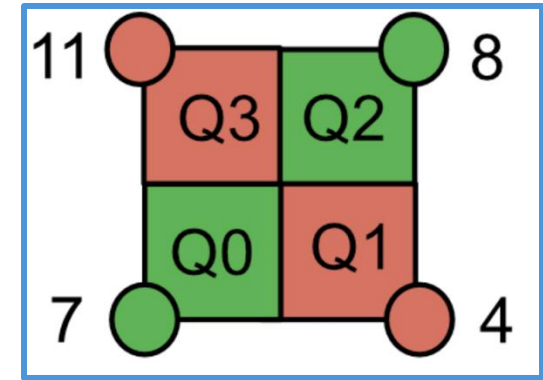
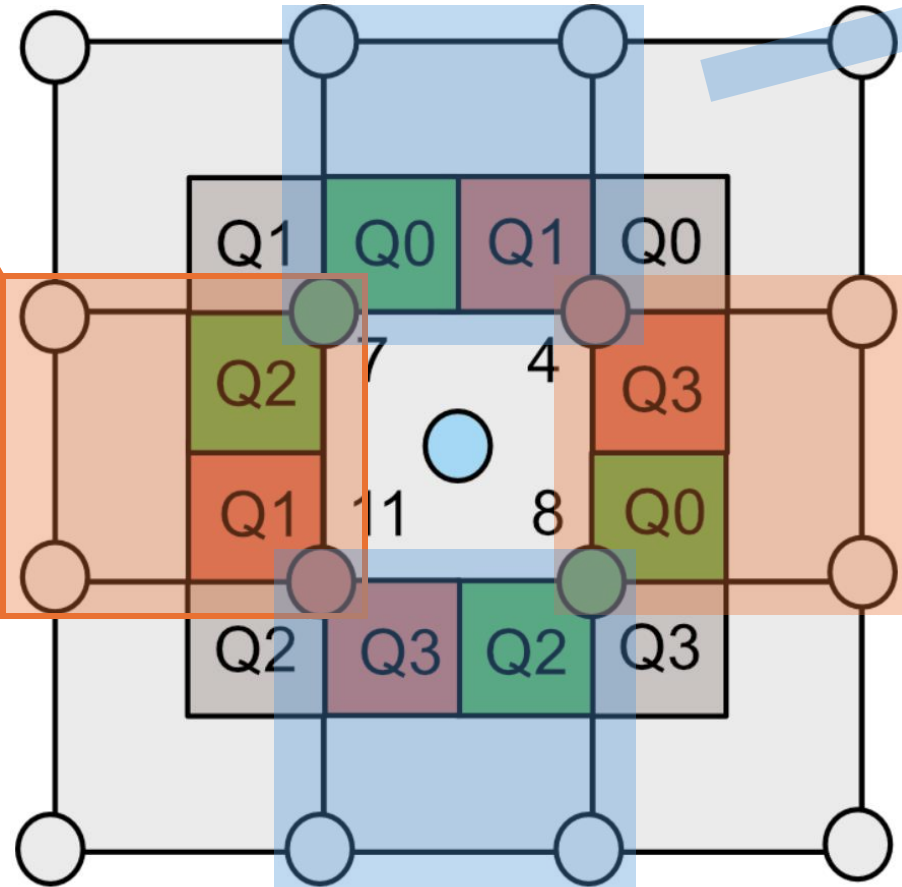
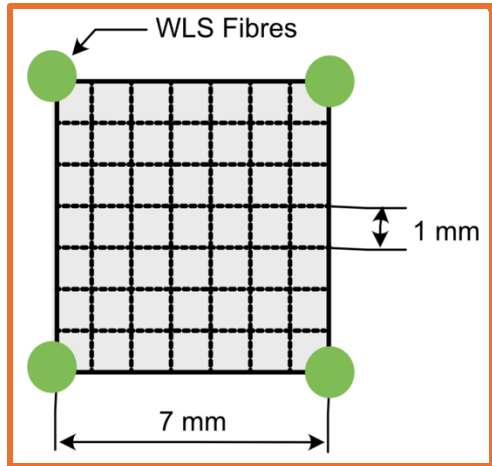
- Take $\langle nPE_{\text{global}}^{\text{corr}} \rangle$ as normalization number.
- Get the homogenisation factor of fibre i .

$$s_i = \frac{\langle nPE_i^{\text{corr}} \rangle}{\langle nPE_{\text{global}}^{\text{corr}} \rangle}$$

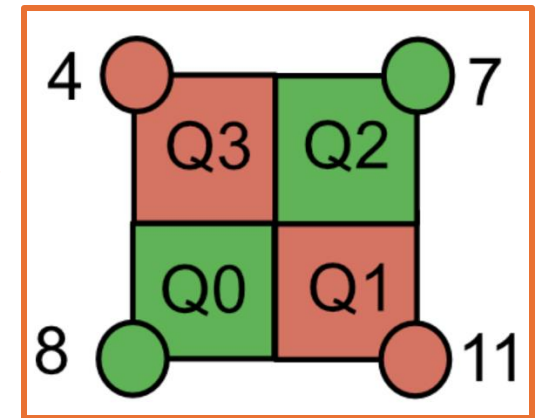
- $nPE(x, y) = \sum \frac{nPE_i^{\text{corr}}(x, y)}{s_i}$.



Base units for uniformity maps



Map 2



Map 1

Include uniformity map $C(x, y)$ in simulation

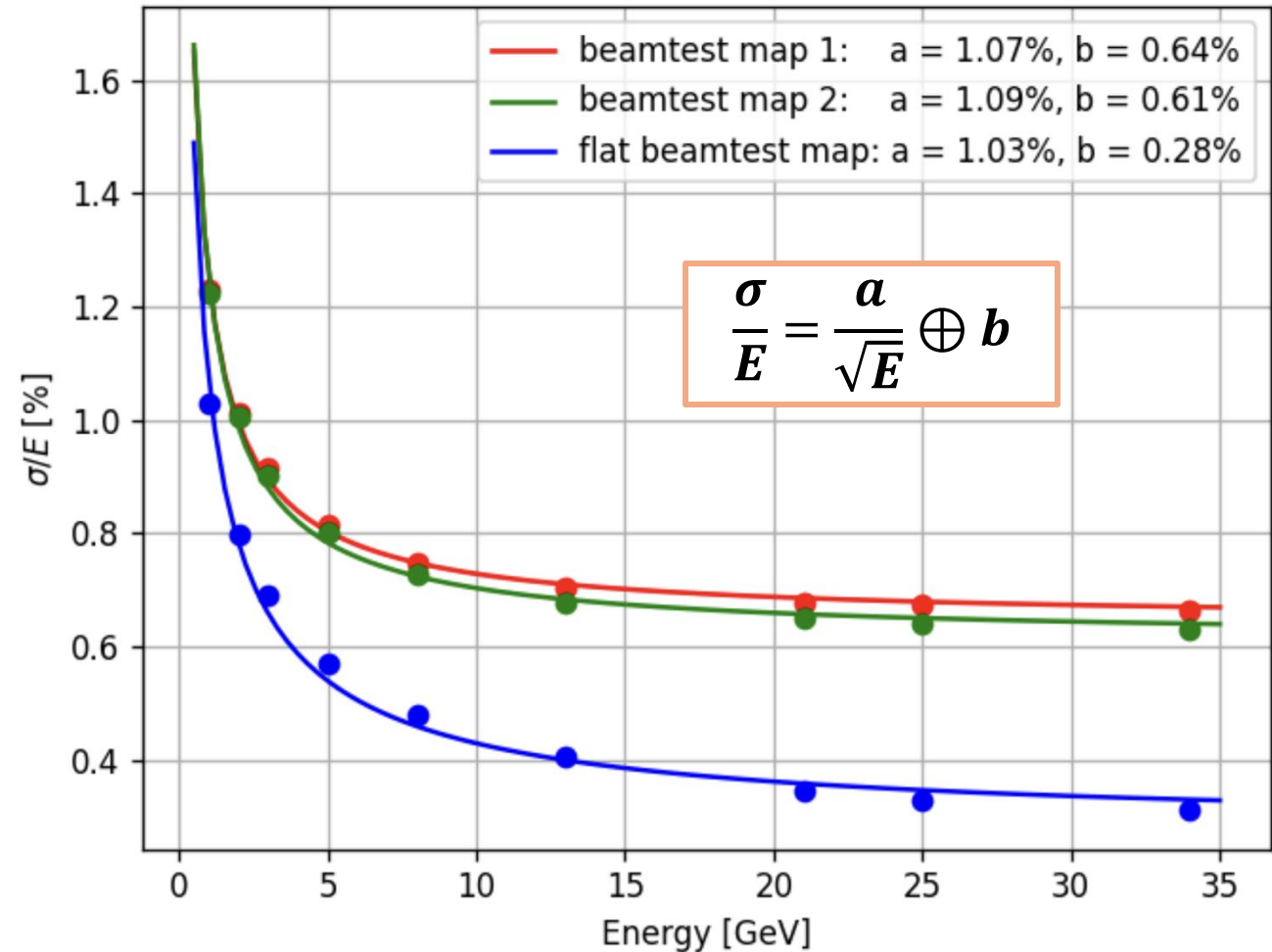
- The effected deposited energy:

$$E_{Dep}^{\text{eff}}(x, y) = E_{Dep}(x, y) \cdot C_{Dep}(x, y)$$

- ⇒ (x, y) : The position of primary particles
- ⇒ E_{Dep} : Deposited energy from Geant4 simulation
- ⇒ C_{Dep} : Relative uniformity map of deposited energy, assuming it's the same as nPE relative uniformity map

Energy resolution

- Consider map1, map2 and a flat map as reference
- The stochastic term a is map-independent, $\sim 1\%$ as preliminary result
- The constant term $b < 1\%$, expectedly larger with non-flat maps than the flat map



Summary

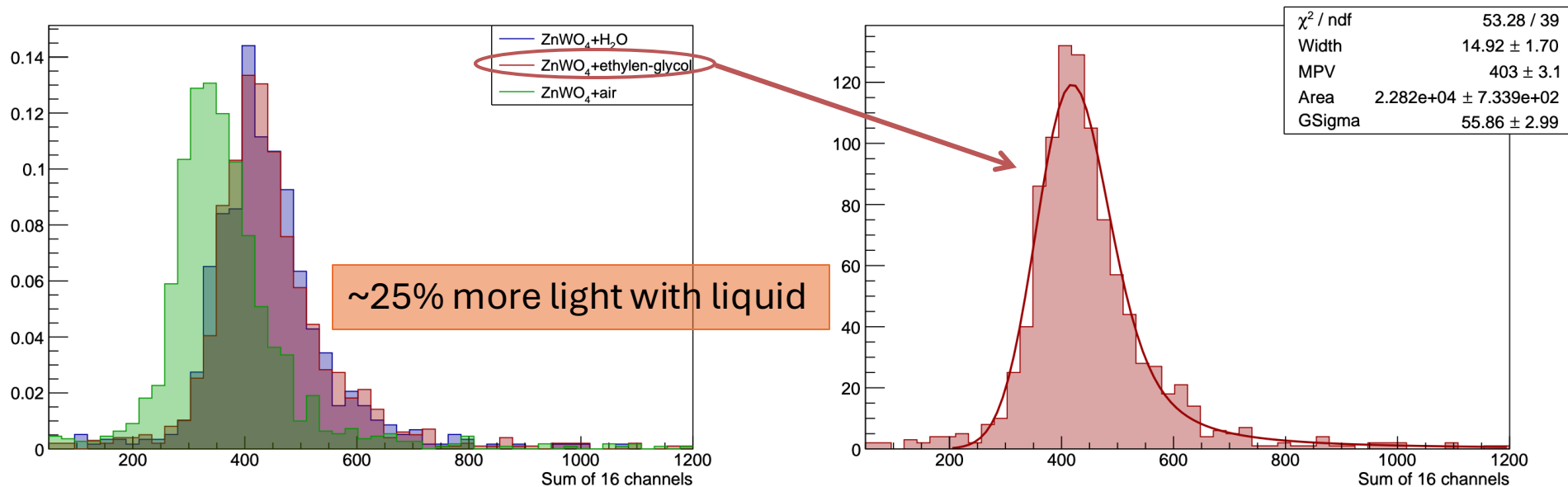
- An analysis to testbeam data was done to extract uniformity map inside GRAiNITA prototype, then applying to the simplified simulation samples to determine the related energy resolution
- The statistics of detected nPE is measured in this test as $\sim 1\%/\sqrt{E}$
- The constant term due to non-uniformity is evaluated as $< 1\%$
- Other terms to the energy resolution
 - Deposited energy variation between ZnWO₄ grains and heavy liquid
 - Studied with simulation of grain-size cube shows $\sim 2\%/\sqrt{E}$
 - The statistic of scintillating photon generation (on-going)

Outlook

- Got a grant to build a full-size module to address all the components of the resolution 🎉
 - 168 mm x 168 mm x 400 mm
 - 45 kg ZnWO₄ grains , heavy liquid, 576 fibres, 36 SiPMs
- A more detailed simulation is under development
 - Simulate the realistic grains: construct and fill in the geometry box
 - Including scintillating process
- Goal is to have module built in 2028
 - Tests with cosmics, beams, etc.

Backup

Cosmic ray test result



- The signal yield is larger when the medium refractive index is better matched with the grains.
- ~10000 PE/GeV is expected based on the result.
- Opens the road to a statistical fluctuation of $1\%/\sqrt{E}$ due to photon statistics

Definition of quarters

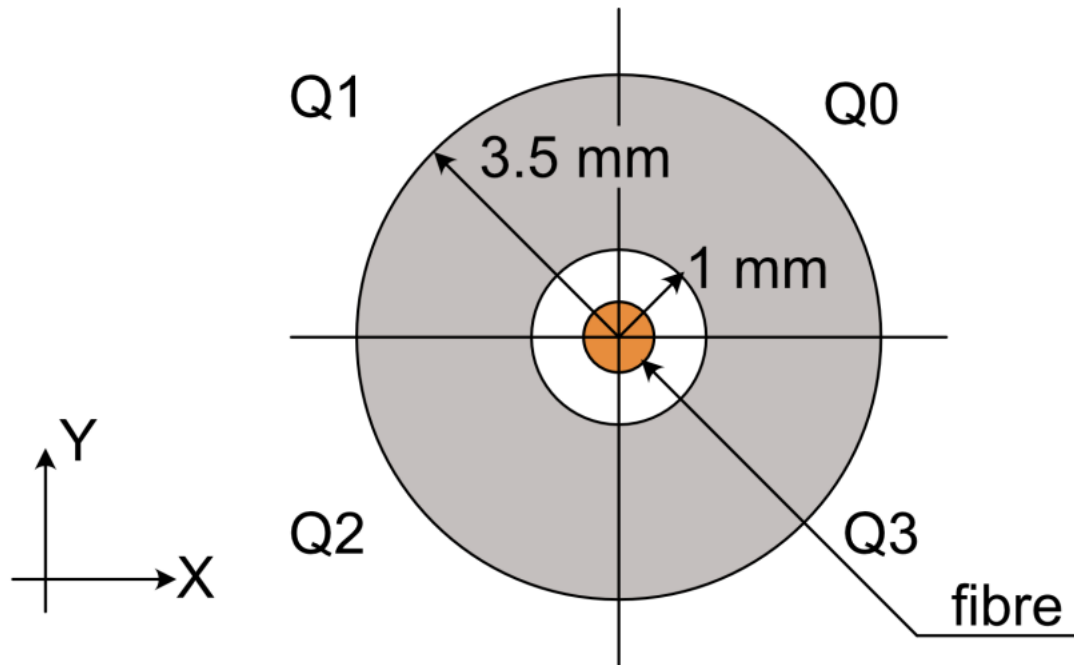


Figure 19: Quarter definition.

Fit to muon and pion nPE

- Muon: Landau \otimes Gauss; Pion: Landau \otimes Gauss + CB

