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MC simulations of FOCAL prototype

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Bergen, Norway

GATE simulation

Versions used:

- GATE 7.0 / 7.2
- Geant4 9.6 / Geant4 10.2

Physics models used:

- QGSP_BIC_EMY
- Production thresholds 100 µm
- Step sizes at most 50 µm (OPT3 – decreasing towards Bragg Peak)
- 100k primaries in water phantom: 6 min on my laptop

Optimization of GEANT4 settings for Proton Pencil Beam Scanning simulations using GATE

2.2. Physics-list selection

For medical physics applications the electromagnetic (EM) standard package with the option 3 (Opt3) parameters-list is recommended by the GEANT4 Electromagnetic Standard working group [7]. Opt3 refers to options/processes which are described in the next sections and proposes reference parameters to reach a high level of accuracy. Our physics-list is mainly based on a reference paper dedicated to proton-

		Default values	
	e^- / e^+	Proton	GenericIon
range cut	1 mm	-	-
stepping function - finalRange	1 mm	1 mm	0.1 mm
stepping function - dRoverRange	0.2	0.2	0.1
binning (bins/decade)	7	7	7
linear loss limit	0.01	0.01	0.15
stepping algorithm	safety	minimal	minimal
		GEANT4 Opt3	
	e^- / e^+	Proton	GenericIon
stepping function - finalRange	0.1 mm	0.05 mm	0.02 mm
binning (bins/decade)	20	20	20
stepping algorithm	distanceToBoundary	-	-

Table 1. Summary of the GEANT4.9.2 default and Opt3 parameters.

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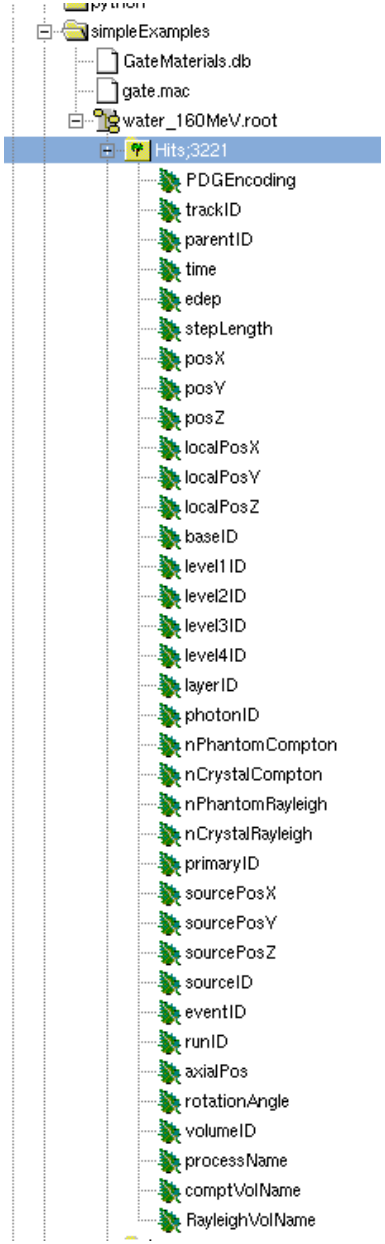
ROOT output

- 100k primaries @ 160 MeV: 232 MB ROOT-file
- List over *events* (one interaction / transport)
- Each event has a number of leafs:
  - Position, edep, particle ID, event ID, process type, volume ID, …….
  - «Layer» ID can be used to define ID of repeated volumes. E.g.:
    - → layer1 is layer lag 0→23 in FOCAL
    - → layer2 is module 0→1 in the layer
    - →layer3 is chip0→1 in the module
    - →layer4 is pixel number 0→640x640 in the chipen



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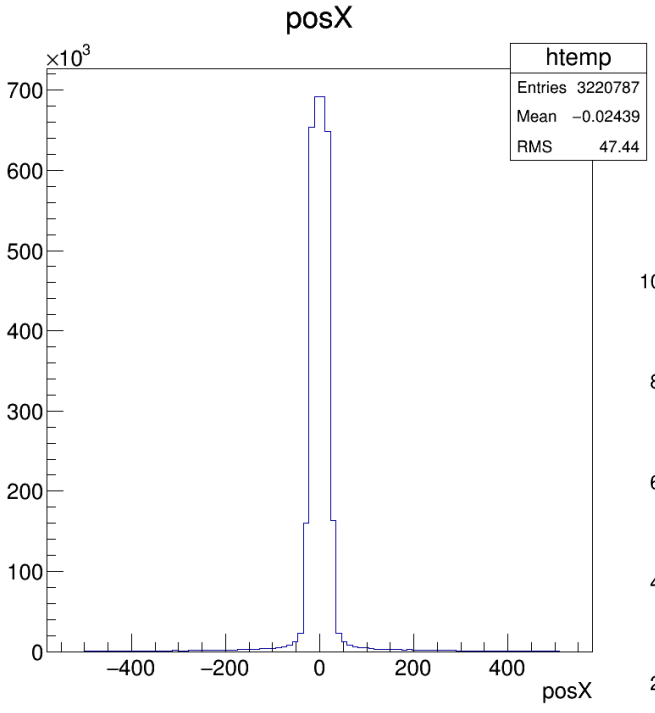
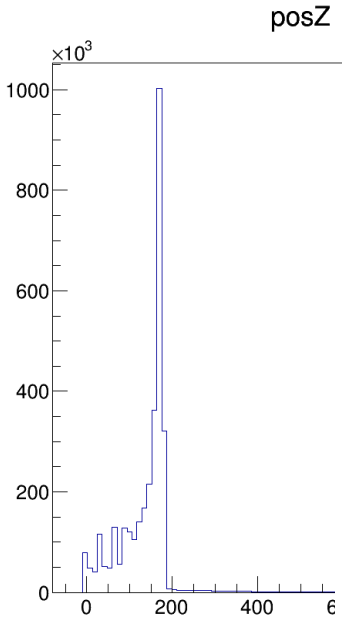
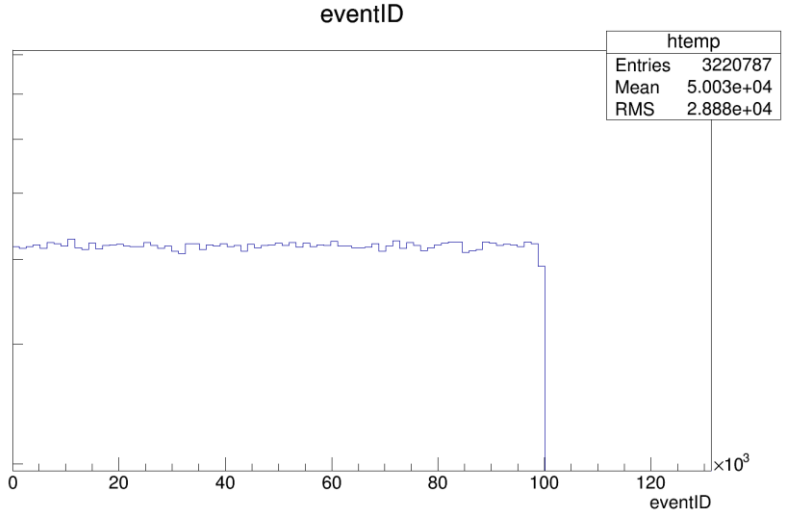


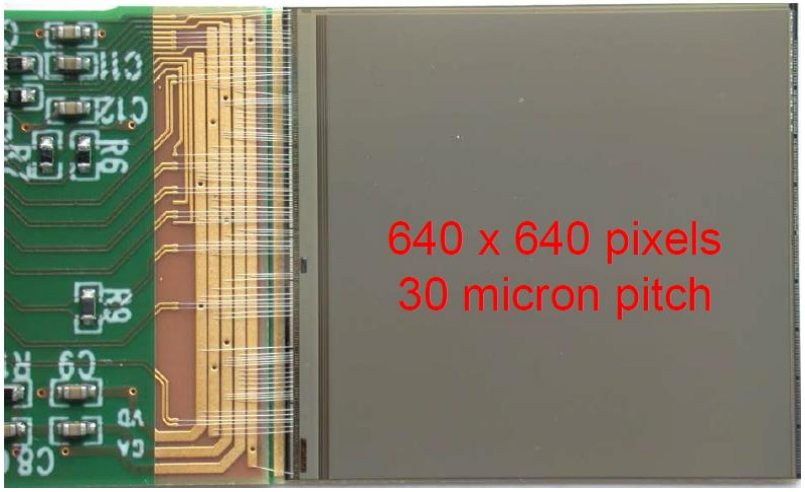


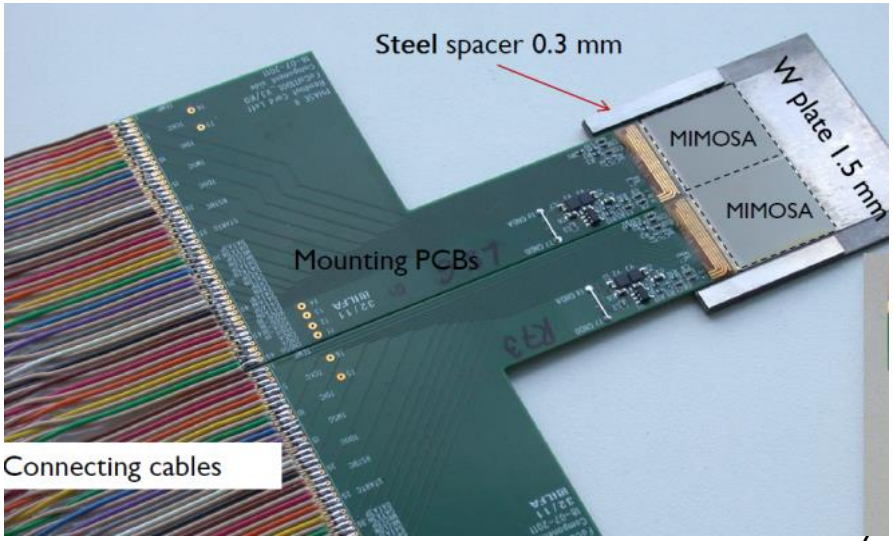


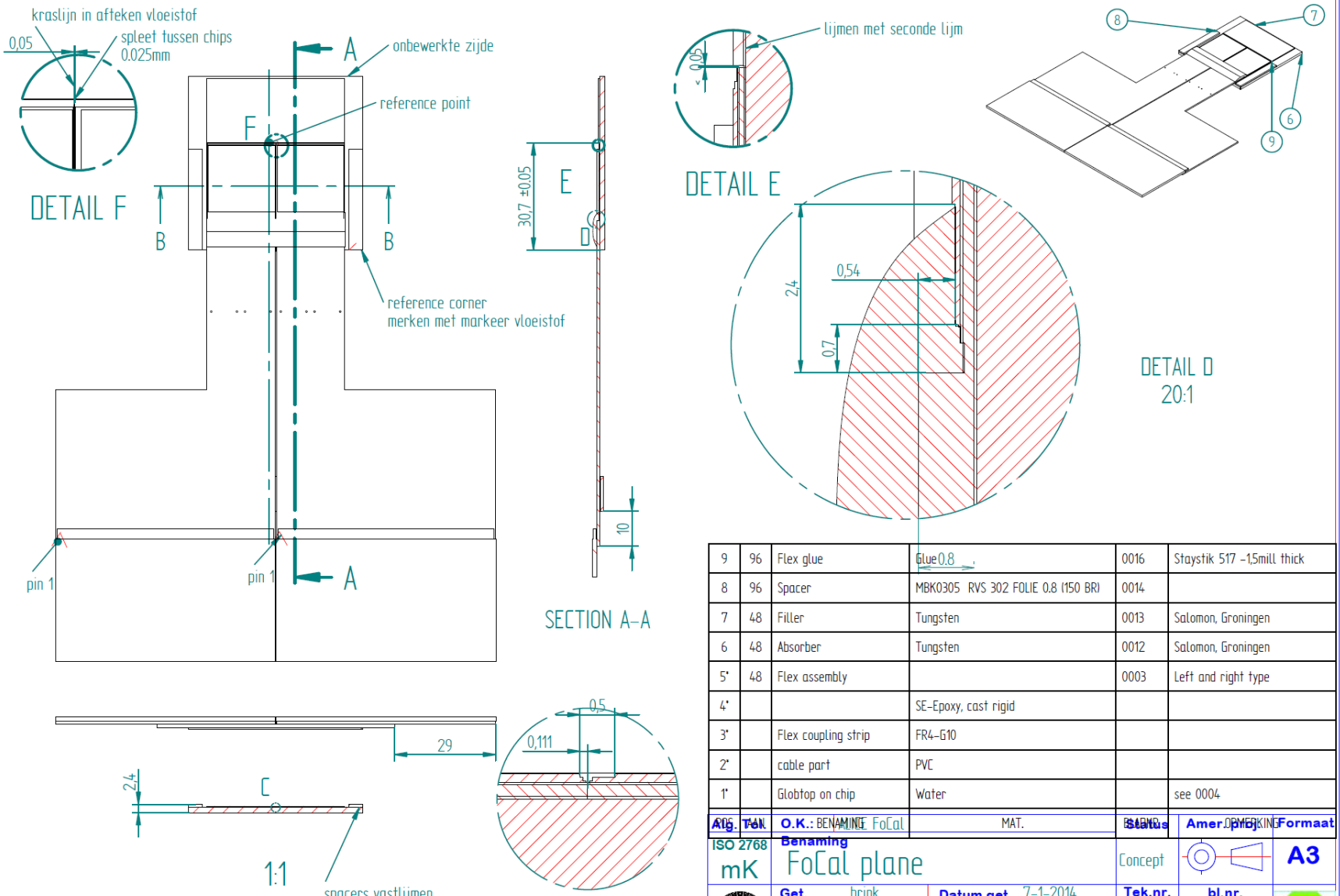
The FOCAL prototype

The detector is

- **Digital**: 1 bit readout per pixel, radiation hard, ~inexpensive
- **Fast**: 640 µs, rolling shutter readout
- **High-resolution**: 30 µm pitch
- **Small:** 4x4 cm^2 active area (4 chips x 2x2 cm^2)
- **Layered**: 24 sensor layers
- **Sampling calorimeter**: 3.3 mm Tungsten absorber for each sensor layer



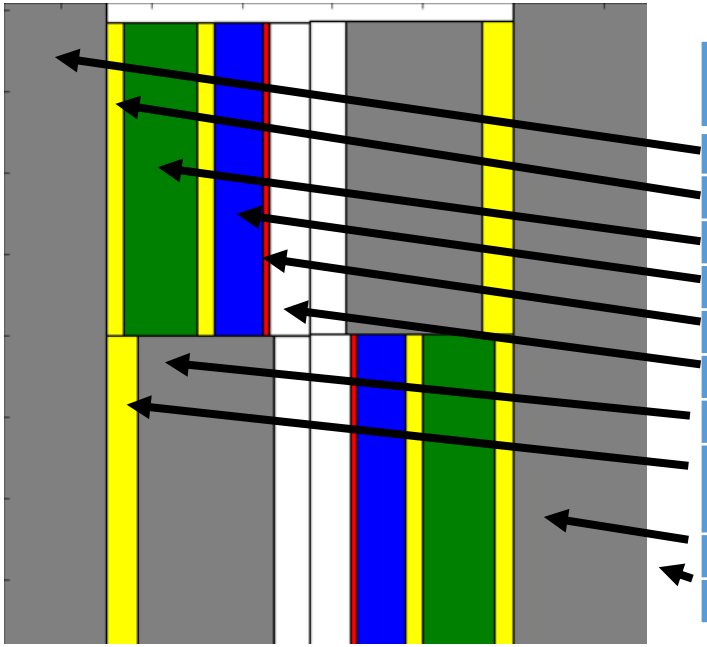




9	96	Flex glue	Glue 0.8	0016	Staystik 517 -1,5mill thick
8	96	Spacer	MBK0305 RVS 302 FOLIE 0.8 (150 BR)	0014	
7	48	Filler	Tungsten	0013	Salomon, Groningen
6	48	Absorber	Tungsten	0012	Salomon, Groningen
5*	48	Flex assembly		0003	Left and right type
4*			SE-Epoxy, cast rigid		
3*		Flex coupling strip	FR4-G10		
2*		cable part	PVC		
1*		Globtop on chip	Water		see 0004

Alg. Tol.	O.K.: BENAMING FoCal	MAT.	Status	Amer.	ORMERKING	Formaat
ISO 2768 mK	Benaming FoCal plane		Concept			A3
	Get. brink	Datum get. 7-1-2014	Tek.nr. 10424	bl.nr. 0004		
	Schaal 1:1	Datum rev. 28-5-2013				
	UTRECHT UNIVERSITY/NIKHEF					

Material and geometric details



Material	Thickness [µm]	Radiation thickness	Density [g/cm^3]
W absorber	1500	0.428 X_0	19.30
Silver glue	40	0.001 X_0	3.2
PCB	160	0.002 X_0	1.85
Silver glue	40	0.001 X_0	3.2
MIMOSA23	120	0.005 X_0	2.33
Air gap	170	6E-06 X_0	0.001
W absorber	300	0.086 X_0	19.30
Cyano-acrylate glue	70	0.0002 X_0	1.0
W absorber	1500	0.428 X_0	19.30
Air gap	75	3E-06 X_0	0.001

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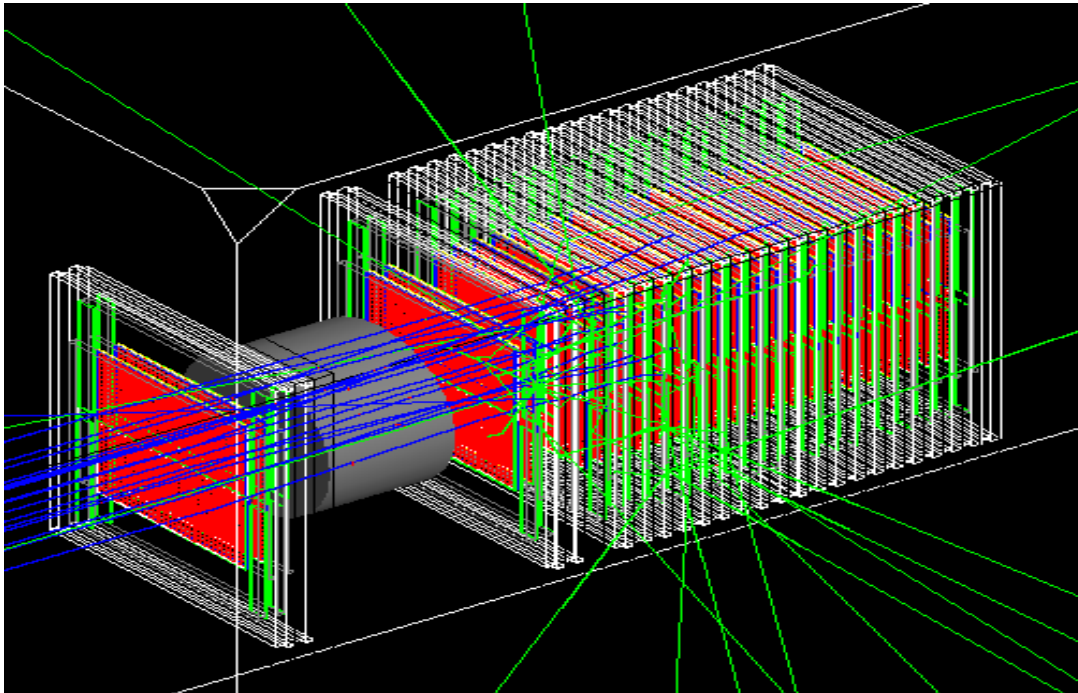
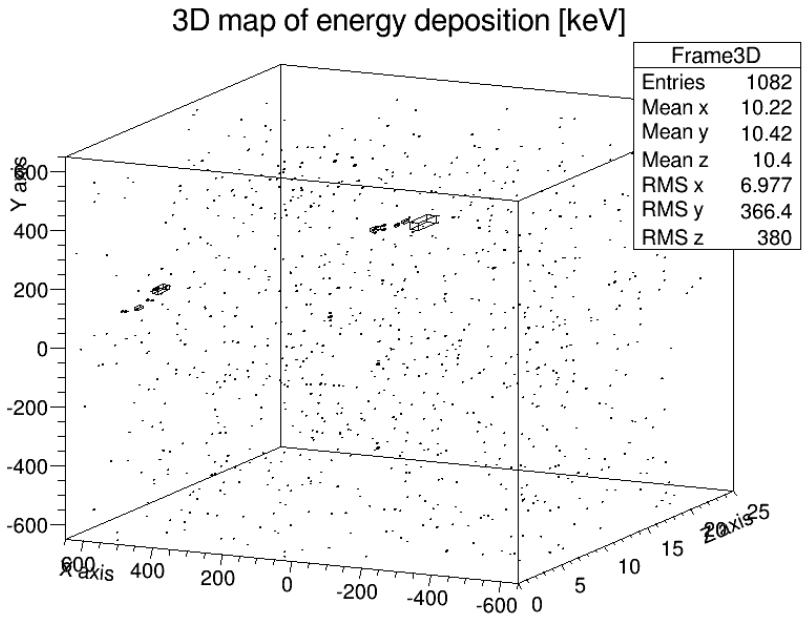
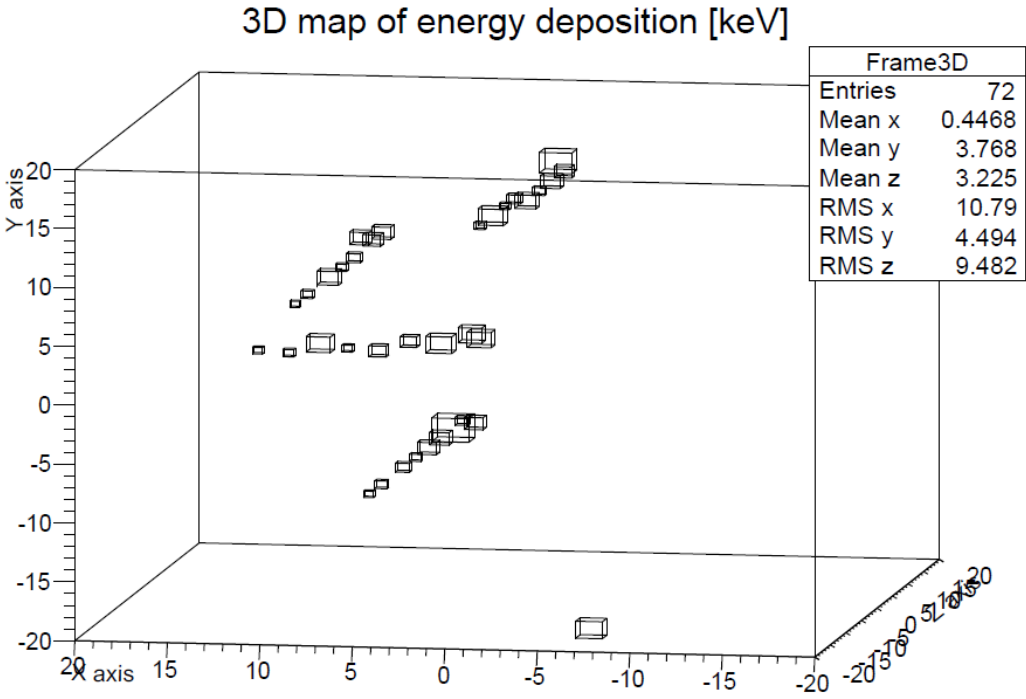
MC vs beam data

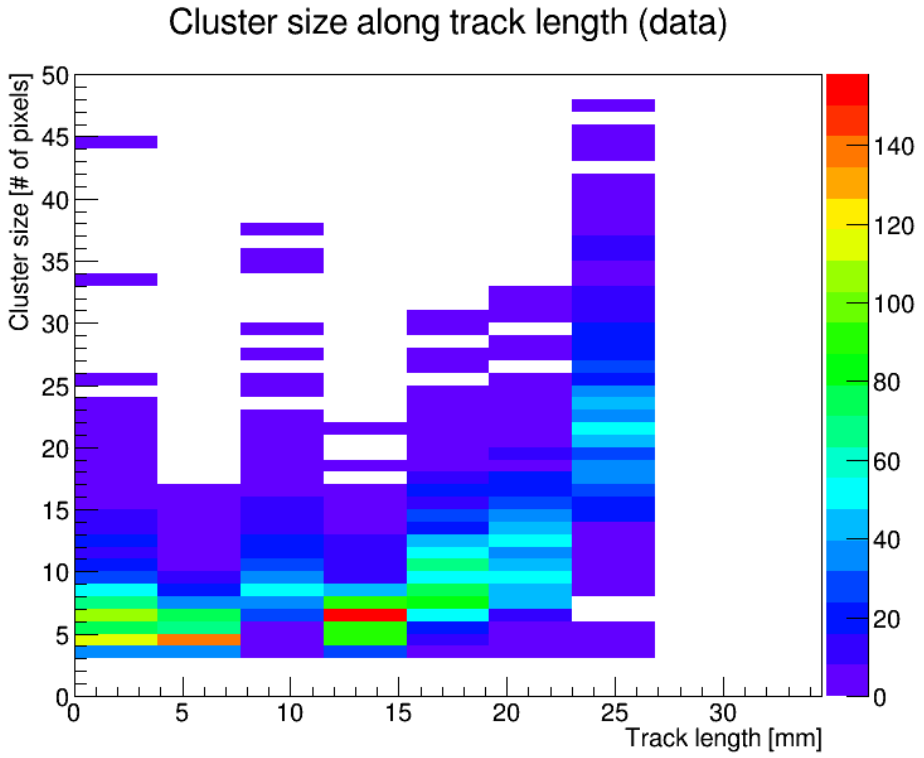


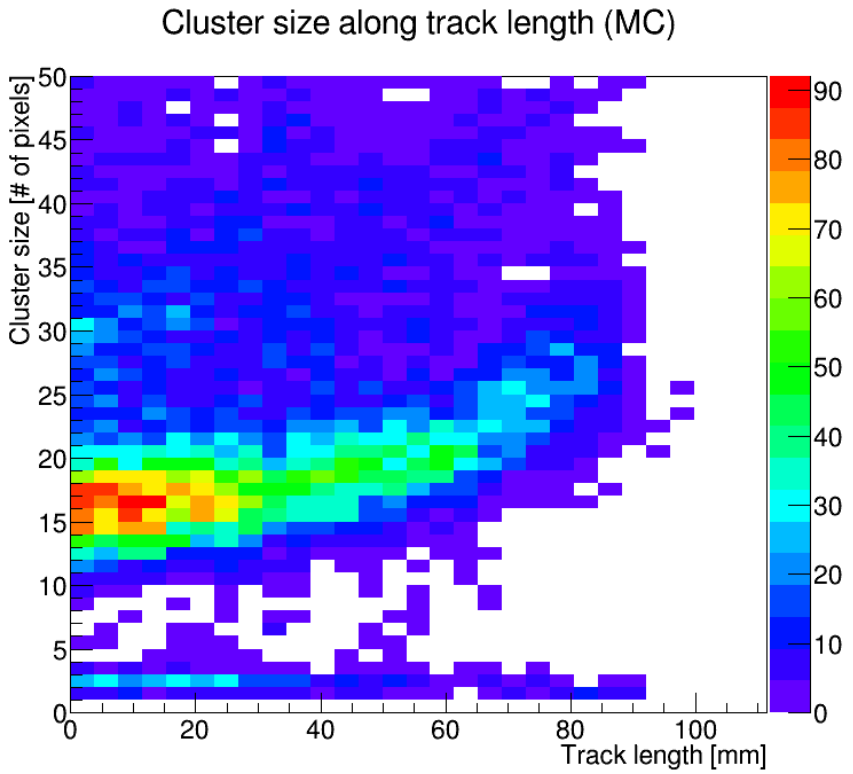
Exp. hit data – MC



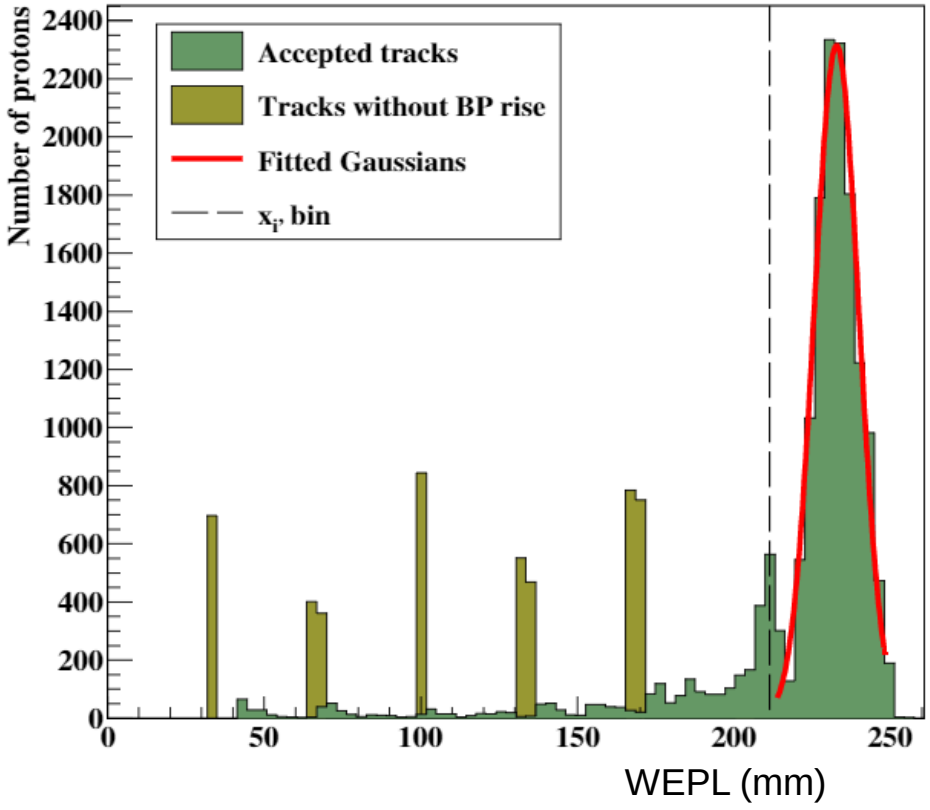


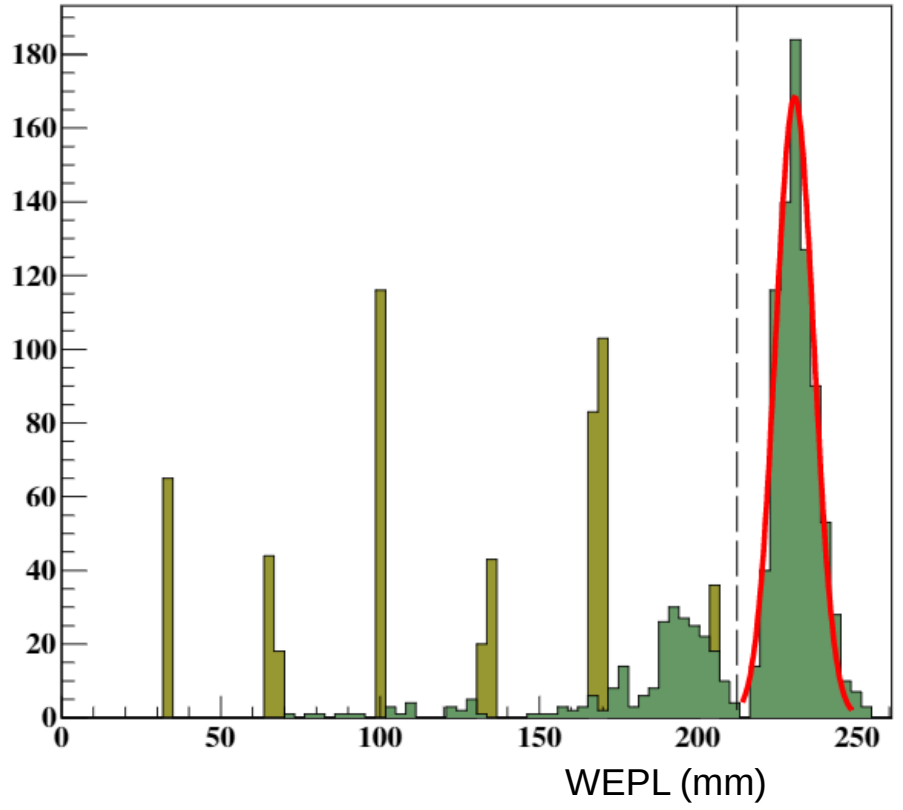
Cluster sizes exp. data - MC





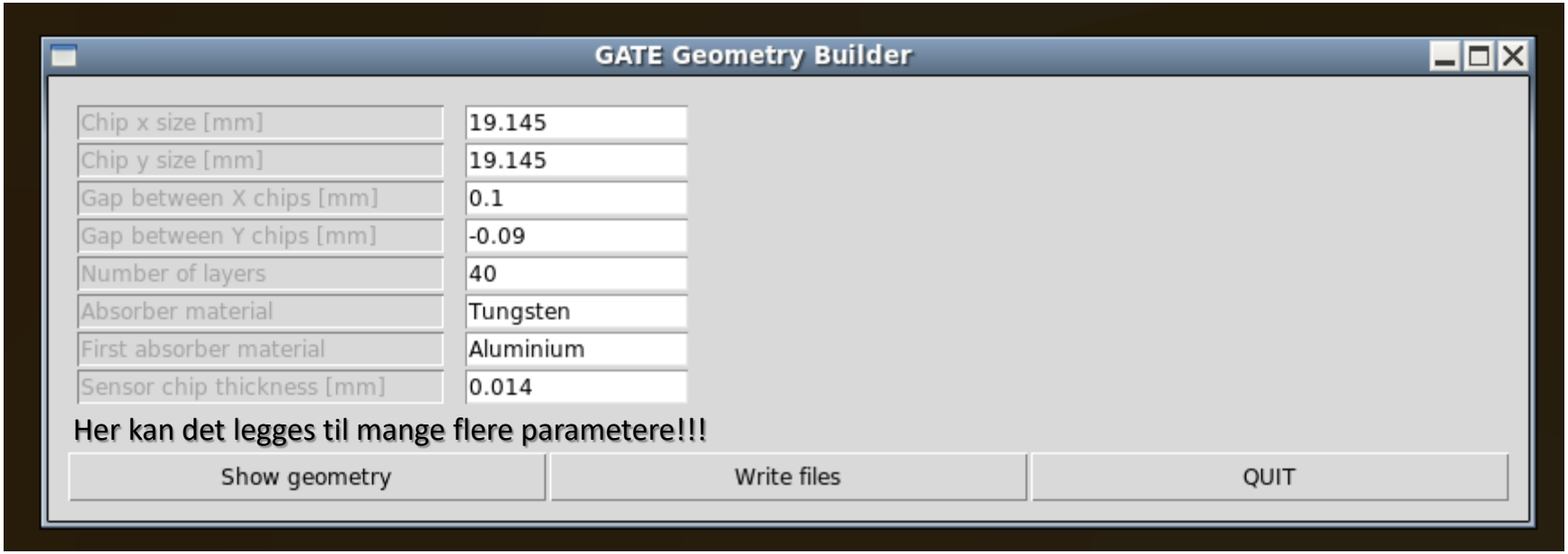
Finding average energy from many protons



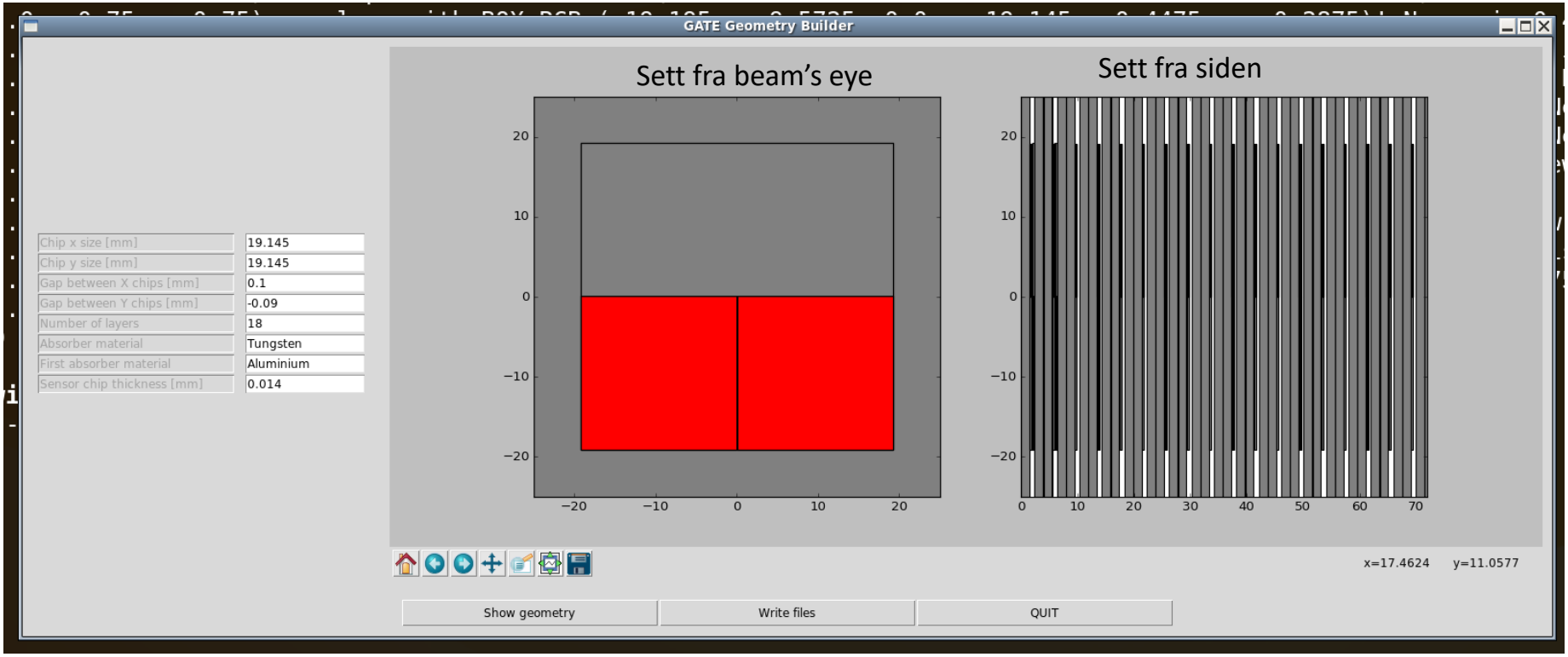


Left: *188 ± 3 MeV from a 188 MeV MC simulated mono-energetic beam.* **Right:** *187 ± 3 MeV from the 188 MeV beam taken during the KVI Groningen beam test.*

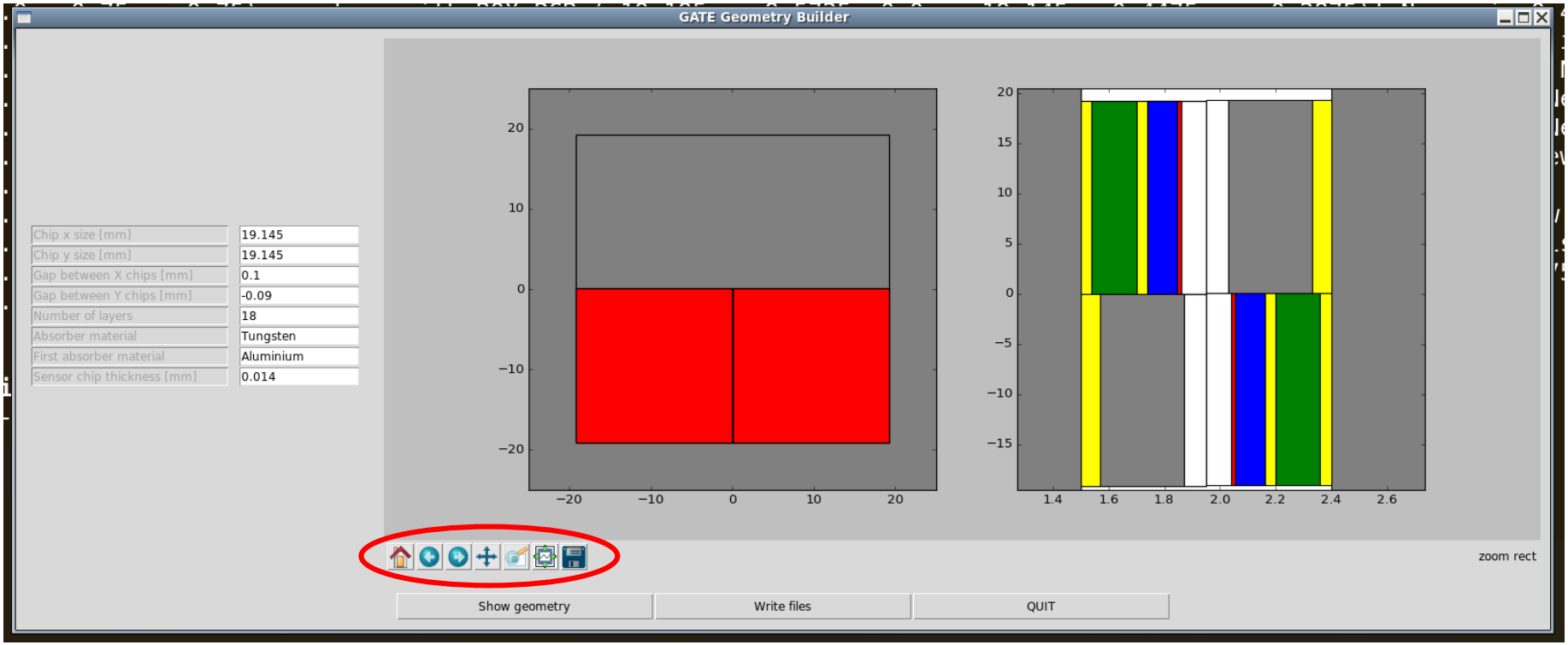
GATE Geometry Builder



Automatic accumulating depth positioning of elements (+ rotation, repetition, …)



With working geometry display built in Python



The result is a working GATE input geometry file, excellent tool for prototyping of different geometries

```
/gate/FirstModule/daughters/name FM_Layer
/gate/FirstModule/daughters/insert box
/gate/FM_Layer/geometry/setXLength 60.0 mm
/gate/FM_Layer/geometry/setYLength 60.0 mm
/gate/FM_Layer/geometry/setZLength 3.975 mm
/gate/FM_Layer/placement/setTranslation 0 0 1.9875 mm
/gate/FM_Layer/vis/setVisible false

/gate/Layer/daughters/name FM_Absorber1
/gate/Layer/daughters/insert box
/gate/FM_Absorber1/geometry/setXLength 50.0 mm
/gate/FM_Absorber1/geometry/setYLength 50.0 mm
/gate/FM_Absorber1/geometry/setZLength 1.5 mm
/gate/FM_Absorber1/placement/setTranslation 0 0 0.75 mm
/gate/FM_Absorber1/setMaterial Aluminium
/gate/FM_Absorber1/setColor grey

/gate/DigitalTrackingCalorimeter/daughters/name FirstModule
/gate/DigitalTrackingCalorimeter/daughters/insert box
/gate/FirstModule/geometry/setXLength 60.0 mm
/gate/FirstModule/geometry/setYLength 60.0 mm
/gate/FirstModule/geometry/setZLength 3.975 mm
/gate/FirstModule/placement/setTranslation 0 0 1.9875 mm
/gate/FirstModule/vis/setVisible false

/gate/FirstModule/repeaters/insert genericRepeater
/gate/FirstModule/genericRepeater/setPlacementsFilename geometry/Module.placements

/gate/FirstModule/daughters/name FM_PCBGlue
/gate/FirstModule/daughters/insert box
/gate/FM_PCBGlue/geometry/setXLength 38.39 mm
/gate/FM_PCBGlue/geometry/setYLength 19.145 mm
/gate/FM_PCBGlue/geometry/setZLength 0.04 mm
/gate/FM_PCBGlue/placement/setTranslation 0 9.5725 1.52 mm
/gate/FM_PCBGlue/setMaterial Glue
/gate/FM_PCBGlue/setColor yellow
```

```
/gate/Module/daughters/name AirGapAfterFiller
/gate/Module/daughters/insert box
/gate/AirGapAfterFiller/geometry/setXLength 38.39 mm
/gate/AirGapAfterFiller/geometry/setYLength 19.145 mm
/gate/AirGapAfterFiller/geometry/setZLength 0.08 mm
/gate/AirGapAfterFiller/placement/setTranslation 0 -9.5725 1.91 m
/gate/AirGapAfterFiller/setMaterial Air
/gate/AirGapAfterFiller/vis/setVisible false

/gate/Layer/daughters/name Absorber2
/gate/Layer/daughters/insert box
/gate/Absorber2/geometry/setXLength 50.0 mm
/gate/Absorber2/geometry/setYLength 50.0 mm
/gate/Absorber2/geometry/setZLength 1.5 mm
/gate/Absorber2/placement/setTranslation 0 0 3.15 mm
/gate/Absorber2/setMaterial Tungsten
/gate/Absorber2/setColor grey

/gate/Module/repeaters/insert linear
/gate/Module/linear/setRepeatNumber 40
/gate/Module/linear/setRepeatVector 0 0 3.975
```