Geant4 Simulations of GeGa module behaviour under Proton Irradiation. II part: Tests of April 2005.

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First Version

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1 Related Documents

PACS-ME-TP-009, 2004, Katterloher R., Barl L., & Shubert J., *Test Plan and Procedures for Investigation of Glitch Event Rate during Proton Irradiation (Test Report)*
PACS-ME-TP-009, 2005, Katterloher R., Barl L., & Shubert J. *Test Plan and Procedures for Investigation of Glitch Event Rate and Collected Charge Variation in the Ge:Ga Detectors during Proton Irradiation at UCL-CRC (2nd test phase*, PACS-ME-TP-009, 2005 PICC-KL-TN-011, 2005, Royer P. *CQM Proton Irradiation Test Analysis*
PICC-KL-TN-012, 2005, Groenewegen M. *UCL-CRC Proton Tests of March 2004: glitch height distribution*
PICC-KL-TN-013, 2005, Royer P. *CQM Proton Irradiation Test Noise Evolution*
Technical Note, 2004, draft 1, Santin G., *Herschel PACS Photo-conductor: Simulation of the Proton Ground tests*
PICC-KL-TN-0yy, 2005, Groenewegen M. *Analysis of the April 2005 proton test data*
PICC-TS-SIM-002, 2005, Bongardo C. & Andreani P.M. *Geant4 Simulations of GeGa module behaviour under Proton Irradiation*, Version one, 2005

2 Aim of the Document

In this document we report on simulations, performed with the Geant4 code, of proton impact on a Ge:Ga module of the HERSCHEL/PACS Instrument. Simulations reproduce the instrumental setup as it is described in [4].

The PACS CQM Spectrometer Module was tested under proton irradiation at the Light Ion Facility of the Centre de Recherches du Cyclotron of the University Catholique de Louvain La Neuve (UCL-CRC), Belgium, in April 2004 and April 2005. 2004 results were already discussed in a previous report (PICC-TS-SIM-002), here we discuss the subsequent tests made in April 2005, those described in [4]. Details of the instrument setup may be found in [4]. Tests aims are the determination of glitch event rate and performance variation in the Ge:Ga photo-conductor module.

In particular in this draft we show comparison of simulated results with (a) the number and rates of detected events, (b) deposited energy on each pixel, (c) effects related to the geometry of the module, (d) effects on nearby pixels (cross-talks).

3 Test Specimen

The test specimen foreseen for the proposed investigations under proton irradiation is the detector module FM#12 with a CRE of the Qualification Model type, mounted in the centre of the module. The detector is in the high stress configuration. The module stood in a liquid He dewar operating at a temperature of (1.85±0.05) K.
The proton beam, before reaching the Ge:Ga crystals elements penetrate three concentric cylinders of Al (called hereafter Al1, Al2 and Al3) and one made of Cu. Al1 is 6 mm thick and has an external radius of 14.15 cm; Al2 1.5 mm with an external radius of 12.4 cm; Al3 is 1.5 mm thick and has external radius of 11.4 cm. The Cu cylinder is 0.5 mm thick and has external radius of 10.5 cm. The module is placed inside a box of Al 4 mm thick (*Al case*) so that half the foreoptics stands outside of it (see Fig. 4). The module is not placed at the centre of the cylinders.
During the test, a primary circular (10 cm ∅) proton beam of 70 MeV was used, with a beam line consisting of 4.94 m between the diffusion foils and the Device Under Test (DUT). Before the beam reached the dewar it crossed two layers, one made of steel, 60 μm thick, and one made of lead 0.12 mm thick. There is also a couple of steel collimators, that we designed as a box with a hole in its centre as large as the beam. The beam reaches the dewar (and the module) under an angle of 10°. We acknowledge dr. J. Cabrera[1] for giving us the

[1] We only changed the diameter of the diffusers, since we know the beam is 10 cm large; we made them slightly larger than the beam (Cabrera used a beam 8 cm large).

details of the experimental hall, via its C++ code.

4 The G4 Simulations

We first run 5 simulations of 10000 protons each, in order to have an idea of what occurs to the beam once it crosses all the layers. We assume that the beam has a Guassian shape with a standard deviation of 1 MeV. Before the first Al cylinder layer the energy of incoming beam computed with G4 is $\approx$ 58.09 MeV, which is slightly different from the J.Cabrera's computations of 63.74 MeV [4]. We ascribe this difference to the G4 version we used (6.2.02[2], gave $\approx$63.70 MeV). Our design of the dewar is by far much more accurate than that reported in [4]; we find as energy hitting the module 15.22$\pm$1.95 MeV. In Fig. 1 and 2 we plotted the degradation of the proton energy along the tracking inside the dewar.
10000 protons originate roughly 22300 secondary events. This is mainly due to the air leakage. After the Al box, $\approx$610 protons survive. But, after the Al box there are also $\approx$330 secondary events. The spectral range and type of these secondary events is strictly dependent of the reliability of the Geant4 models.

4.1 The Geometry of the Ge:Ga module

The UCL-CRC investigation considered only one single module of the effective 25$\times$16 Ge:Ga photoconductor arrays. The detector material and amount of stress defines the wavelength range of the instrument. Light cones in front of the actual detector block provide area filling light collection in the focal plane feeding the light into the individual integrating cavities around each separate pixel. The detector crystals are connected to the input of the CRE (Cryogenic Readout Electronic). The high stressed module is cooled down to 1.8 K, the readout electronics (FEE) to 4 K.
For a detailed description of the geometry of the module, at least as we designed it in the Geant4 environment, see [1].

4.2 Thresholds

We have set different production thresholds (hereafter cuts) for each geometrical region. We first ran our G4 code with the default cut value of 0.7 mm for all volumes and then tuned them according to the module geometry. We identified groups of volumes with the same thicknesses: in particular we defined 6 different regions with rather the same thickness (see Table 1)[3]. Results are robust since they do not depend on the cut values, both default ones and the chosen ones lead to similar outputs, but a slight increasing of the secondary event production. On the one hand this was expected, since most of the volumes have still the same default cut value, 0.7 mm. On the other hand it is possible that Ergal thresholds have already achieved convergence at the defaults value, that is we are very slightly tuning them. Although results are pretty similar those with our chosen cuts allow a better tracking inside the sensitive detector volume.
As regard air leakage, we set air cuts as longer as we can, in order not to have a massive secondary event generation, that is 2.5 m.

In Tab. 2 the UCL-CRC experiment as performed at Louvain cyclotron [4].

4.3 The definition of a glitch

A glitch on the photo-conductor is an unexpected voltage jump during the integration ramp. Along a single ramp, that lasts 250 ms, the voltage with a 64 readout sequences decreases monotonically. Whereas the voltage

[2]Furthermore the 6.7.01 gave a very rare crash, probably due to a bug in the Hadronic Physics for the High Precision neutrons: with this new version we switched off such a physics.

[3]We decided not to use very small cut values (below 1-2 μm), since this could affect the validity of physical models at such small steps (Ivantchenko, private communication).

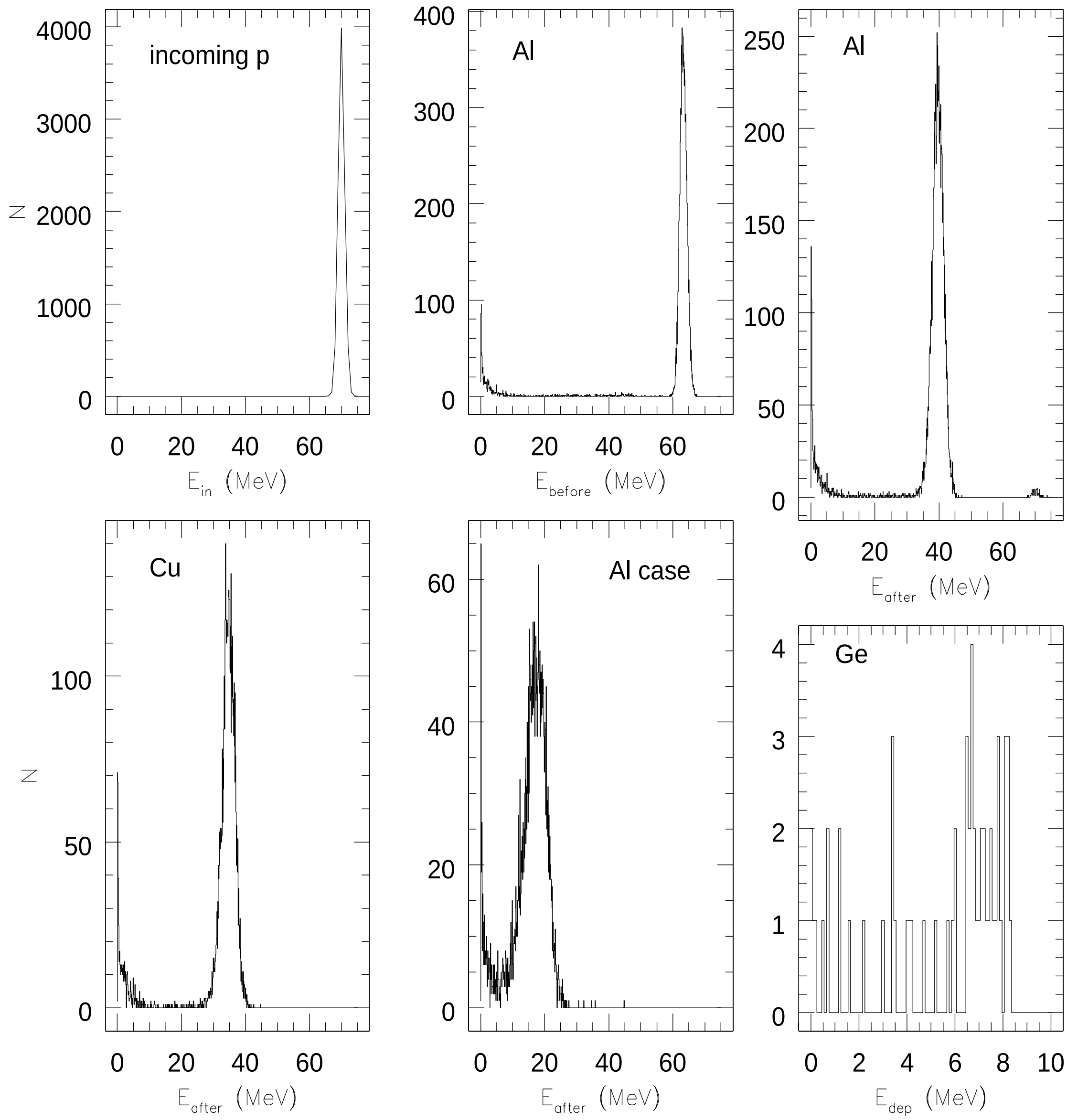

Figure 1: Degradation of the proton energy across the dewar layers: from the top-left panel, the energy of the incoming proton flux, the flux before and after the the Aluminum shields, after the Cu case and the final detector case. The last panel refers to the energy deposition on the Ge:Ga material.

Region	Cut Value	Thickness
Default	2.5 m	(air)
Dewar	1.5 mm	$\geq$ 4.1 mm
High_mm	0.7 mm	3.02 - 4.1 mm
Low_mm_a	0.3 mm	0.73 - 2.1 mm
Low_mm_b	0.1 mm	300 - 600 μm
High_mic	5 μm	20 μm
Low_mic	3 μm	10 μm

Table 1: The six geometrical regions of the module and their specific cut values.

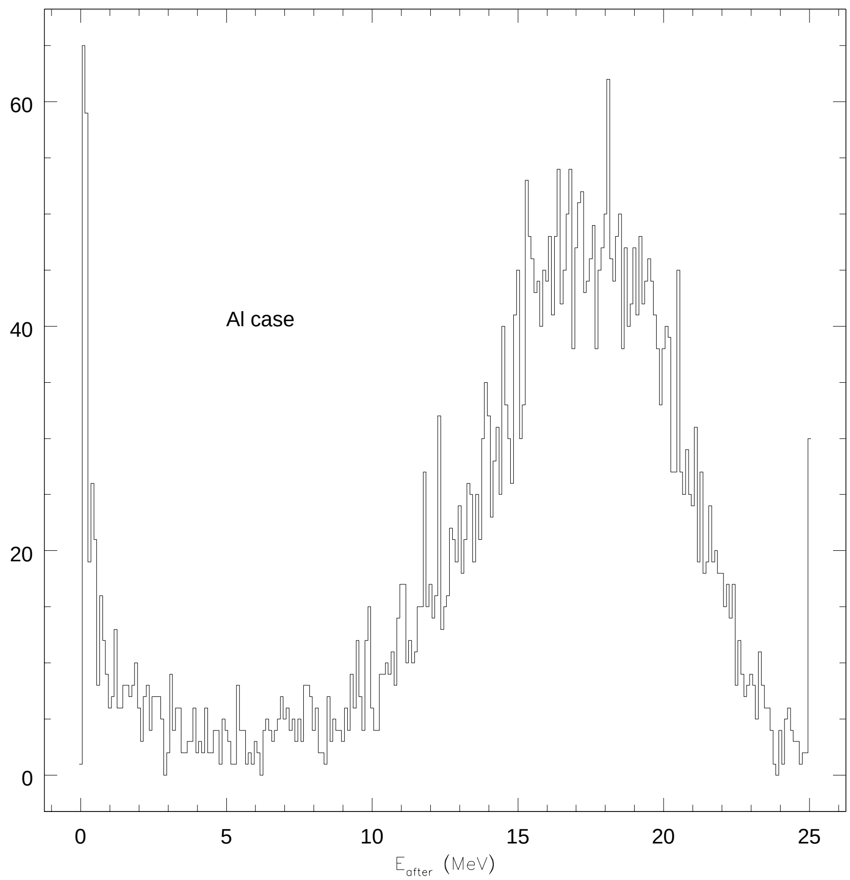

Figure 2: Degradation of the proton energy across the dewar layers: the detail of the proton and secondary particles energy after the Al case.

Exp.	BIAS (mV)	t_{ramps} (ms)	C (pF)	N_{ramps}	N_{rep}	Flux ($cm^{-2}s^{-1}$)
#L1	50	250	1.09	1024	35	10
	50	250	1.09	1300	3	10
	30	250	0.23	1024	23	10
	20	250	0.23	1024	4	10
	40	250	0.23	1024	1	10
	50	250	0.23	1024	1	10
	70	250	0.43	1024	1	10
	30	250	0.23	512	2	10
#H1	30	250	0.23	1024	18	400

Table 2: Summary of proton seed and photo-conductor module setup during UCL-CRC experiments. Column # 1 reports the identifier of the chosen setup, # 2 the value of the bias voltage of the FEE circuit, # 3 the duration of each integration ramp, # 4 the integrator capacitor, # 5 the number of ramps, # 6 the number of repetition with the same measurement setup, # 7 the proton flux.

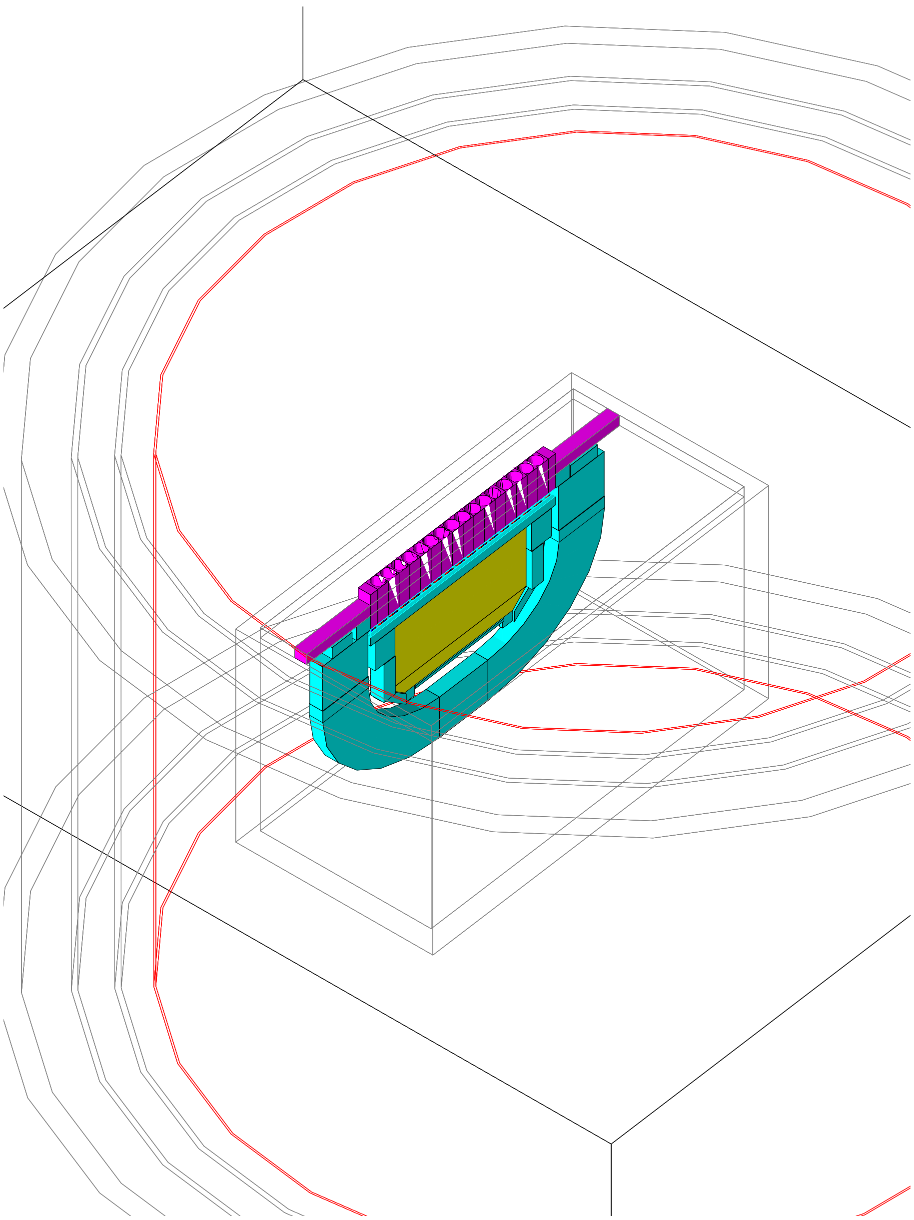

Figure 3: A single PACS high stress module, Magenta: the foreoptics, Yellow: the gold coating of the FEE and the active pixel. Red: the CuBe2 contacts. Blue: the Al_20_3 insulator. Gray: the cylindrical steel segment. Cyan: ergal components.

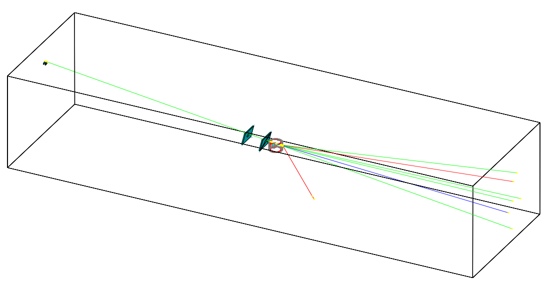

Figure 4: A single PACS high stress module, in the Louvain cyclotron configuration.

Exp.	N_{rep}	$G4_{rep}$	Flux ($cm^{-2}s^{-1}$)	t_{rad} (s)	N_p	$\langle events \rangle$	Rate ($s^{-1}cm^{-2}$)
#L1	35	35	10	256	200960	251.83	3.53
	3	6	10	325	255125	328.00	3.63
	23	23	10	256	200960	252.87	3.55
	4	8	10	256	200960	255.38	3.58
	1	5	10	256	200960	267.20	3.75
	1	5	10	256	200960	250.60	3.52
	1	5	10	256	200960	253.20	3.55
	2	10	10	128	100480	129.10	3.62
#H1	18	18	400	256	8038400	9948.06	139.58

Table 3: The UCL-CRC experiment output with Geant4.

jump overtakes 4 or 6 times (in sigma units) the mean jump that represents a glitch.
The exact electronic behaviour is not reproducible with Geant4, we only collected the energy depositions on the pixels. The energy deposited on the pixels is transformed [2] in Volt following:

$$\Delta E(MeV) = C\Delta V(Volt)E_g/(e \times g) \quad (1)$$

whereas g comes out from the photoconductive gain: R=$\eta ge/(h\nu)$ = 30 A/W at λ=170 μm (η = 0.3, with a large error bar). E_g is the energy gap and it is equal to 2.9 eV and C is the detector capacity. For C = 3 pF we get: $\Delta V = 0.0134\Delta E$.

4.4 The Geant4 results

We ran the same experiments under the Geant4 tool. For low proton fluxes we ran 5 simulations, in order to have better statistics; for the higher proton fluxes we ran only 2 or 1 simulations. This was done because simulations with high number of primaries are a) time consuming and b) self consisting. Results are summarized in Tab. 3. In Fig. 5 we plot the energy deposition onto the 16 pixels in the H1 test.
Here we found 3 peaks. The major one, is clearly due the primary proton beaming. The one at low energies, is due to the secondary events generated along the tracking of the protons along all the components we described before. The peak at higher energy could be due to the fact that the pixel are inside a non uniform cavity: due to the inclination of the beam there is a part of it that cross the cavity in its thinner part, that is: pixel are hit by more energetic protons.

5 Comparison with measurements

A preliminary analysis of these data was made by [3]. We decide in order not to make further assumptions on our results to leave the outputs in energy. In the report [3] the value used is 1.34. We show in Figure 6 the energy distribution of the glitches (in our cases the number of hits reaching the detector module). Many glitches occur at low energy and the distribution is asymmetric with a peak at ≈7 MeV. The glitch detection dependends on the algorithm used to de-glitch the data (Table 9 of [3]) and it is not straightforward to compare experimental and simulated data.

5.1 Events and rates

The number of events observed in files L26-L29 were 755, corresponding to a rate of 3.1 $s^{-1}cm^{-2}$. If corrected for the detection efficiency of the detection algorithm it becomes 3.9 $s^{-1}cm^{-2}$. For such a dataset, G4 finds 853 events and a rate of 3.53. The number of events observed in files H3-H6 is 29008, G4 has 29430 events.

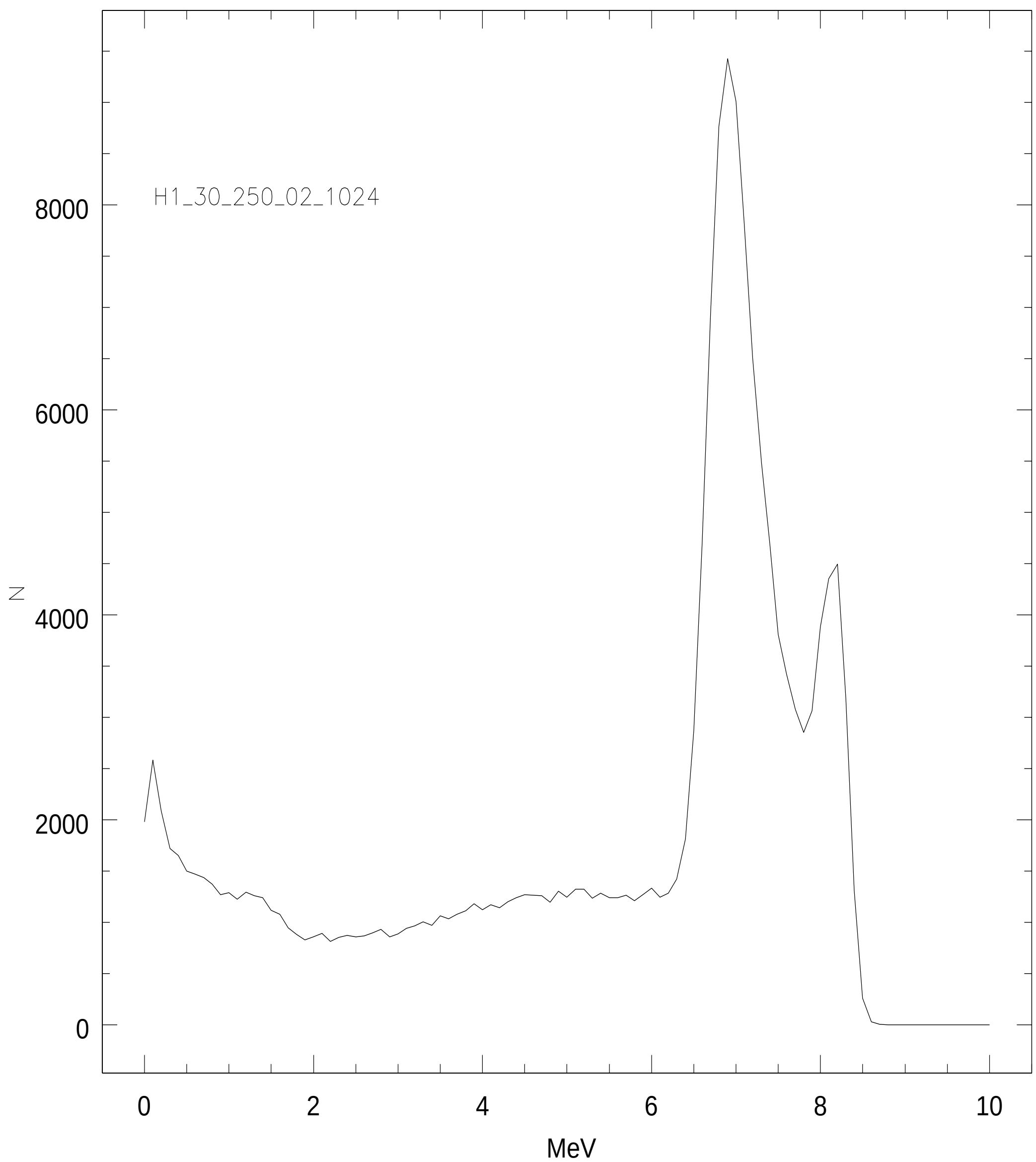

Figure 5: Energy deposition for one of the H1 test.

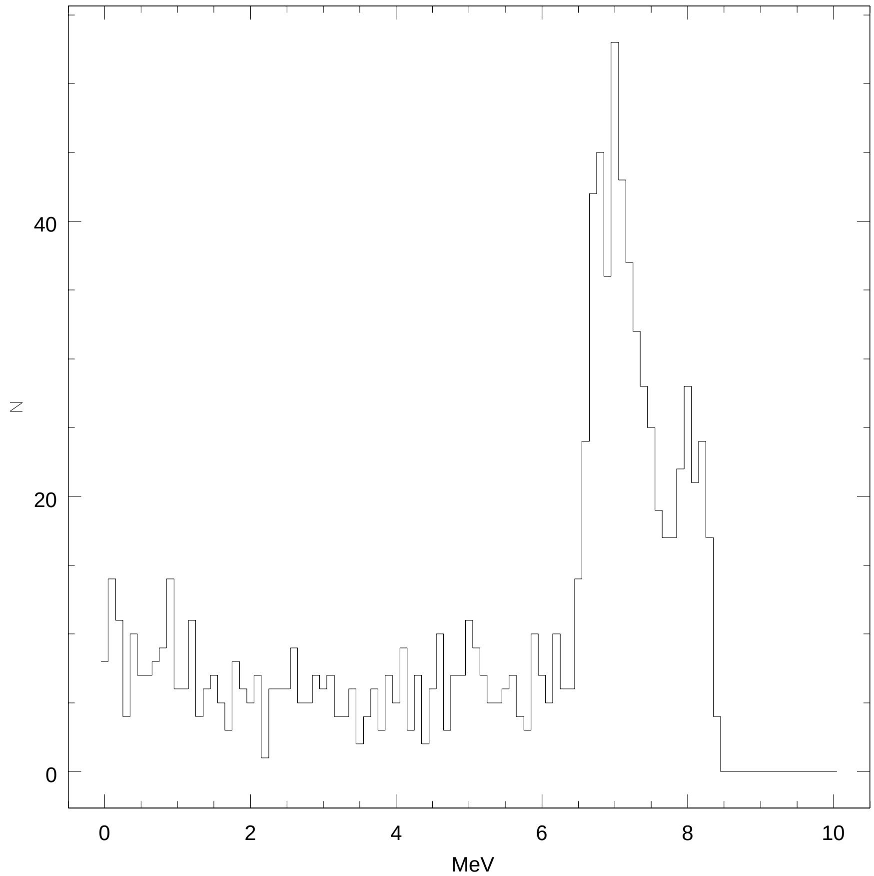

Figure 6: The energy distribution of glitches as found with G4 for files L26,L27,L28 and L29.

Within the uncertainties we claim that these values are compatible. Then we are able to understand the basical physical processes occuring in this experiment and the physical behaviour of the material.

5.2 Deposited energy

In Figure 6 we plot the distribution of the predicted deposited energy for the files L26,L27,L28 and L29. The shape of the distribution is asymmetric and has a peak around ≈7 MeV, to compare the horizonthal scale with the corresponding figure in [3] (Figure 9). As already stated above, the glitch detection dependends on the algorithm used to de-glitch the data If for instance we apply a cut value around ≈6 MeV the distribution of glitches would be more similar to the observed one. This latter is however skewed toward high values. Such an asymmetry is not seen in the simulated data. Experimental data show a secondary peak, that seems to favour our interpration of it (see §4.4). On the other hand, the experimental distribution has a peak at low energy, with a rather long tail towards the highest ones. The simulated distribution gave first the tail, then the two peaks.

5.3 Boundary effect

[1] were not able to reproduce the boundary effect showed by [6]. This is certainly due to the fact that we were not able to design the exact experimental setup, since no information was provided about the thickness and position of the polystyrene foils. The simulations reported in this draft design better the experimental hall. Figure 7 shows the number of detected glitches per detector: a clear *boundary effect* is seen and is due to a

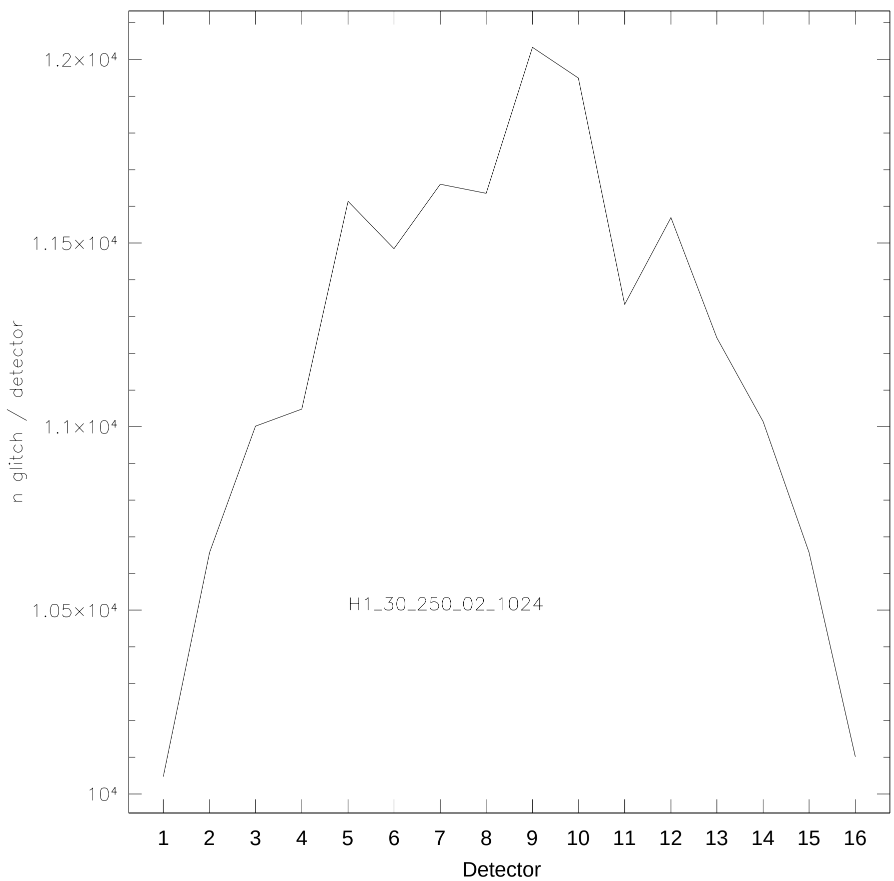

Figure 7: Number of Geant4 simulated glitches (i.e. the number of hits) per detector (pixel) in the H1 setup.

differential incident proton flux with respect to the detector position (Figure 12 in [4]). We find a different of the hit numbers of 20% while the measured beam intensity difference between the central pixel and the outer ones is 10%. This is a geometrical effect and does not correspond to a different behaviour of the single chip.

5.4 Cross-talks

We checked whether in the G4 outputs there are coincidences (*cross-talks*) between adjacent pixels. This means that we searched for those events happening in one pixel which then affect also nearby pixels. We find that whenever a pixel is hit the probability that the adjacent one is subsequently hit by the same incoming particle is negligible. Being the flux beamed in a given direction and each pixel is distant from the adjacent one, we do not detect any correlation between hits, i.e. each hit is independent and occurs only in one pixel. In addition in vacuum the produced secondary particles have scattering angles similar to those of the primary protons, making their effect on adjacent pixels negligible.

6 Conclusions

We have simulated the experiment carried out at UCL-CRC and compared as far as possible the simulation outputs with the measurements reported in [3]. We find similar rates and events (see Table 4 and §5) on each pixel. The energy distribution differs substantially from that taken from the measurements.

Files	[3] Events	G4 Events
L26-L29	755	853
H3-H6	29008	29430

Table 4: Measured versus predicted event values. Column 2 shows the measured ones, column 3 those obtained from the G4 simulations. Within the uncertainties these values are the same.

We tried to ascribe these differences to the following causes:

1. As far as the event number and rate is concerned it may be possible that the chosen cuts are rather large. But due to the complexity of the experimental hall it is hard to tuning them optimally. We would need information on the intermediate passage of the beam through matter. A simple correction could be a slight increase of the Ge cuts. A clear benchmark would be the comparison between the energy distributions.

The presence of a primary and a secondary peaks seems to be the only feature common between experimental and simulated data. What it is not clear is why, due to the crossing through matter, the gaussian beam is (*must be*) transformed as in Figure 1, that is first a tail, then a peak. On the pixels the tail is close to the major peaks. Either Ge has some physical properties which are not included in the G4 Physics List, or the deglitching algorithm used is not correct.

We claim here that the deglitching algorithms may not work at their best.
In addition this work does not (and cannot) take into considerations how glitches can be removed from the data and how the corrupted signal can be recovered.

References

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