Saturation and Radiation Doses in the ECal

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CERN-PH-LCD

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Section 1:

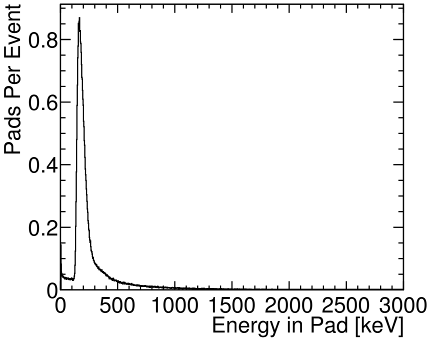
1 Maximum Energy Deposits

Maximum Energy Deposits in the ECal

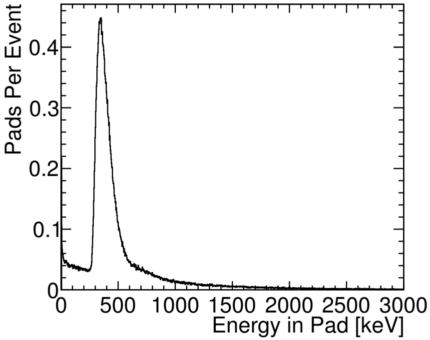
- To dimension the dynamic range of the SiPM, we have to know the maximum energy deposit expected in individual pads
- Estimate by simulation high energy e.m. showers
  - Highest energy e.m. showers can be expected from Bhabha scattering events
- Simulated 0.5 TeV, 1.0 TeV, 1.5 TeV photons, and 50 GeV muons (to estimate MIP peak) all with $|\cos\theta| < 0.7$
- Simulation Parameter
  - ECal Models with 1 mm and 2 mm Scintillator Thickness Parameters
    ```
    /Mokka/init/globalModelParameter Ecal_Sc_number_of_virtual_cells 1
    /Mokka/init/globalModelParameter Ecal_Sc_Si_mix 333333333333333
    ```
  - Absorber: 20×2.1 mm tungsten 9×4.2 mm tungsten
  - Scintillator Pad size: 10×10 mm^2 and 20×20 mm^2

MIP Peaks

- Simulated muons to estimate energy per MIP
- Take centre of bin with most entries
- Now normalise all energy deposits to MIPs



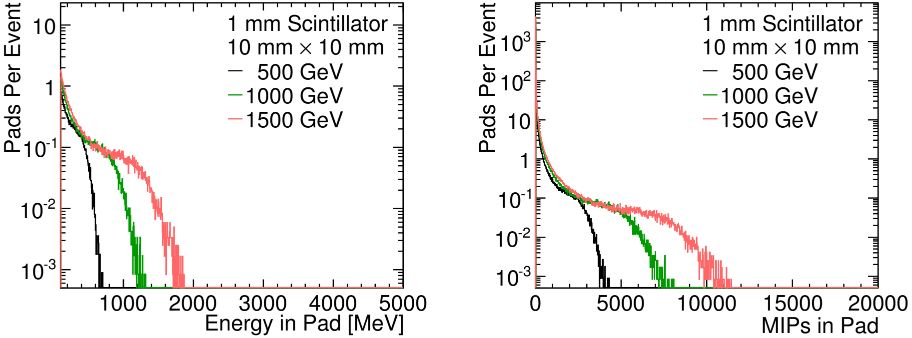
1 mm thickness → 165 keV



2 mm thickness → 345 keV

Energy Deposit per Pad and Event

- Distribution of Energy or MIPs per Pad
- Maximum of more than 15000 MIPs in single pad for 1 mm thickness and 20×20 mm^2 pads, largest pads and densest showers
- Maximum energy deposit between 2 GeV and 4 GeV



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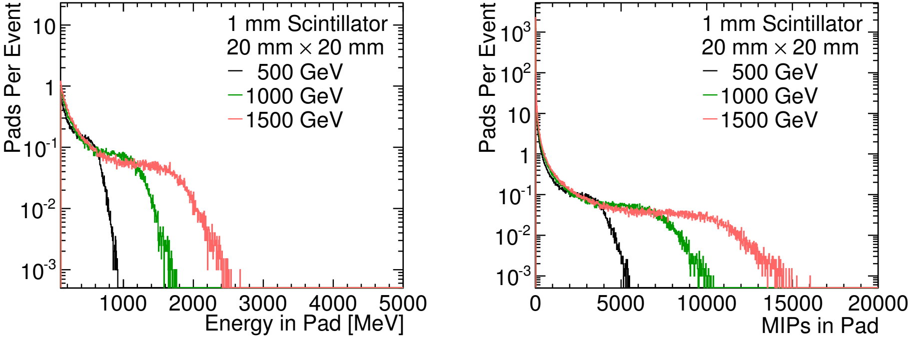

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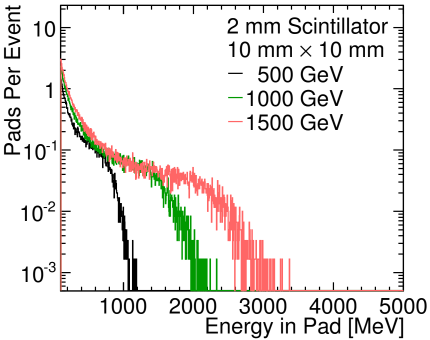

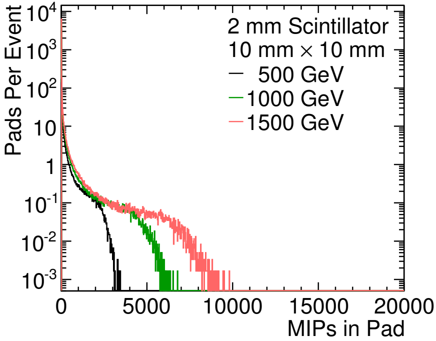

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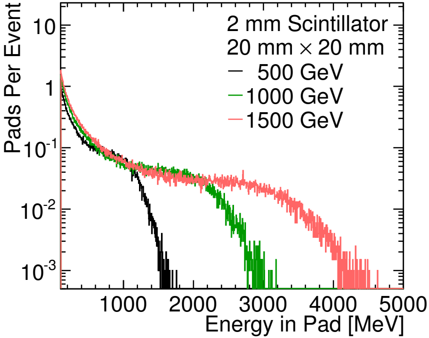
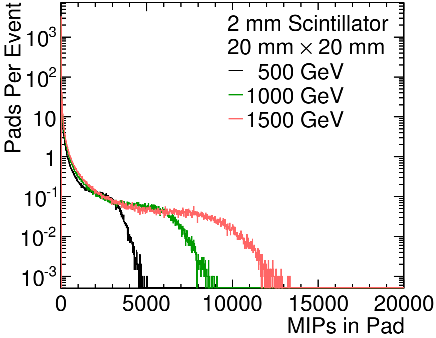
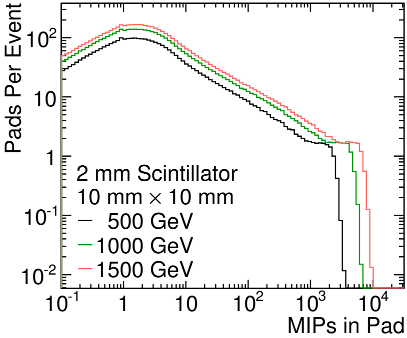




Rate of Highest Energy Deposits

- *Multiple pads in every shower will have this very high energy deposit*
- And these pads contain a large fraction of the total deposited energy



MIP deposits with log X-axes and variable width binning

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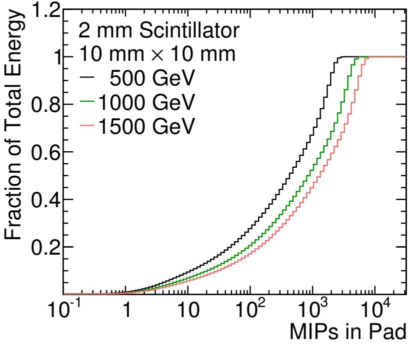
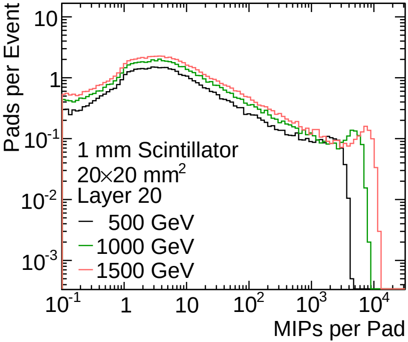


Cumulative MIP deposits with log X-axes and variable width binning

Maximum Deposits vs. Layer

- The maximum deposit extends to layers for in the back of the ECal
- Rate becomes much lower in the rear layers
- Should study energy resolution with proper digitisation to estimate impact



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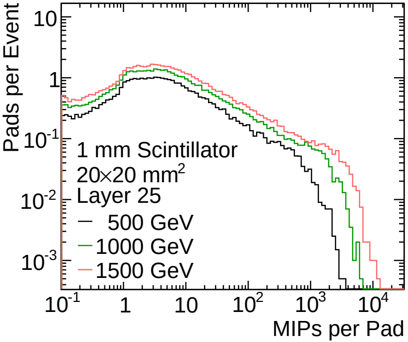

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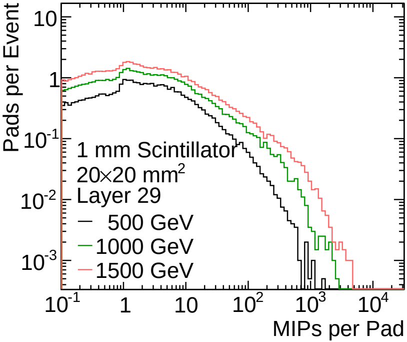
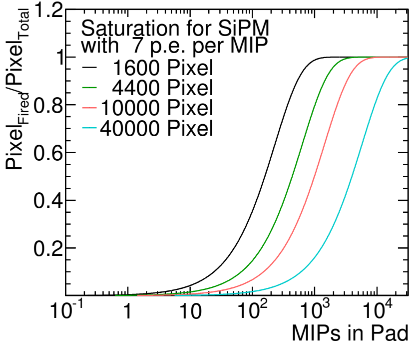


SiPM Saturation

- When we assume 7 pixels firing per MIP (which is needed to reject noise and cut at 0.5 MIP), we probably need a SiPM with more than 10 000 pixel
- Otherwise the SiPM is fully saturated in these cases



Saturation function:

$$\frac{N_{\text{Pixel}}^{\text{Fired}}}{N_{\text{Pixel}}^{\text{Total}}} = 1 - \exp\left(-N_{\text{p.e. per MIP}} \cdot \frac{N_{\text{MIPs}}}{N_{\text{Pixel}}^{\text{Total}}}\right)$$

Section 2:

2 Scintillator Saturation

Scintillator Saturation

- Maximum deposited energy in 1×1 cm^2 about 1 GeV to 2 GeV, or 10 000 MIPs, depending on thickness
- Particle energy in these pads is probably in the tens to hundreds of MeV range
- Does this combined effect saturate the *scintillator* and lead to a non-linear response?

Literature Review

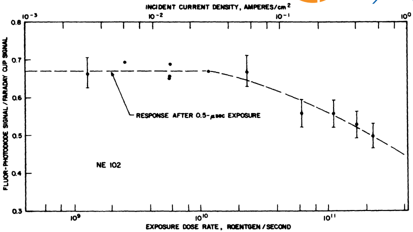
- Dose Rate Saturation has been studied in the 1970s to study behaviour for ‘high-intensity radiation bursts’. Two of the papers:
  - Stevens and Knowlen: Transient Nonlinear Response of Plastic Scintillators (IEEE Transactions on Nuclear Science (Volume:15, Issue: 3)) Link
  - Powell and Harrah: Nonlinear Responses of Poly(vinyl toluene) Plastic Scintillators at High Excitation (Journal of Chemical Physics (Volume:55, Issue: 4)) Link

  study different scintillators and the response to different electron doses.
- Other studies use gamma rays, those did not obverse saturation effects

Measurement by Stevens and Knowlen

Setup:

- 80 mil (about 2mm) thick scintillators (NE 102, MEL 150C), 1 inch diameter
- 12 MeV electrons, different rates, different pulse length
- Shortest pulse 0.5 ns



From Stevens and Knowlen, Figure 8: 0.5 ns pulse read out after 0.5 μs

Result:

- Non-linear response starts at 10^{10} Roentgen per second, or 3×10^{-2} Ampère/cm^2

Unit conversions:

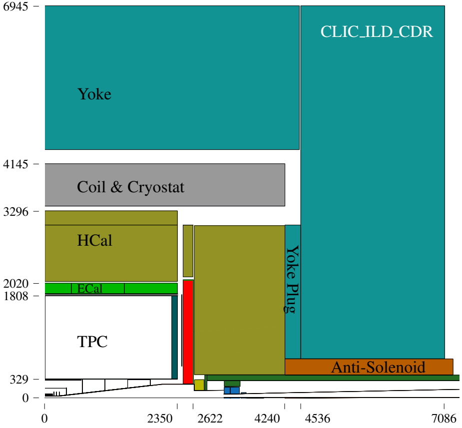
- Ampère is Coulomb per second, so this is 1.8×10^8 particles per (cm^{2}ns)
- Or, taking the area/mass of the sample, and 0.01 Gray per Roentgen, I estimate the dose at which saturation starts to be 2.5×10^5 GeV/(cm^{2}ns)
- The saturation starts about 4 orders of magnitude above the expected energy deposits at CLIC

Section 3:

3 Radiation Doses

Radiation Doses

- Estimate radiation dose (total ionising dose and equivalent neutron flux) in the *ECal endcap* for 3 TeV CLIC
  - CLIC_ILD_CDR detector model with default Silicon ECal
- Simulated 67 000 $\gamma\gamma \to$ hadron events (3.2 events per bunch crossing) and 1500 bunch crossings of incoherent pairs



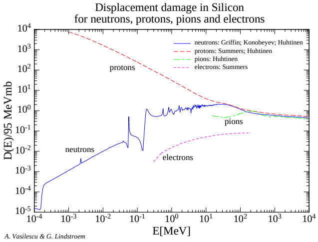
Method

Total ionising dose:

- Sum up the deposited energy
- Divide by the mass of the sensitive detector

Equivalent neutron flux:

- Adapted `sensitive detectors` to store the *damage factor* weighted pathlength in the sensitive material
- Divide the total sum of weighted pathlengths by the volume of the sensitive detectors



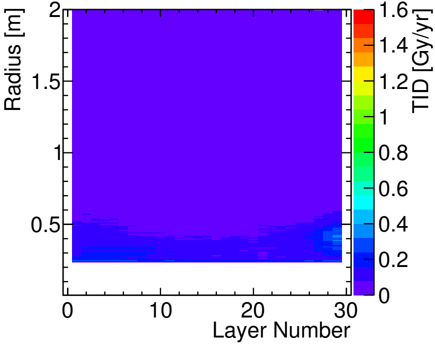
Silicon damage factors for neutrons, protons, pions, and electrons

`http://sesam.desy.de/members/gunnar/Si-dfuncs.html`

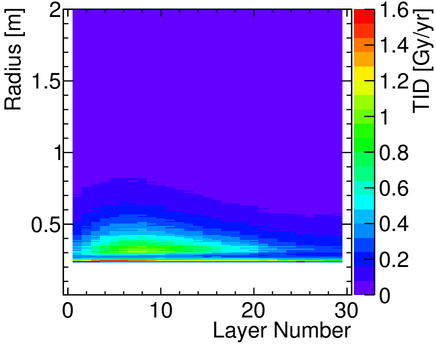
Total Ionising Dose per Layer and Radius

- TID averaged over azimuthal angle
- Dose from pairs via backscatters coming from the BeamCal
- Maximum about 2 Gy/yr (without safety factors)

Incoherent Pairs



$\gamma\gamma \rightarrow$ Hadron



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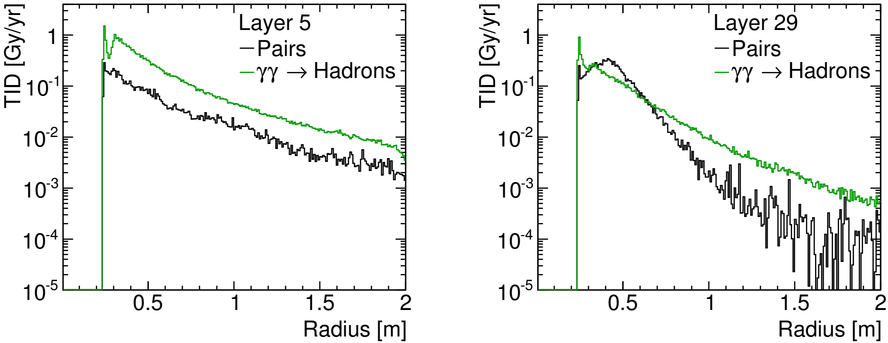

Equivalent Neutron Flux per Layer and Radius

- Equivalent neutron flux averaged over the azimuth
- Backscattering neutrons from the BeamCal
- Maximum about 2×10^{10} $\text{cm}^{-2}\text{yr}^{-1}$ (without safety factors)

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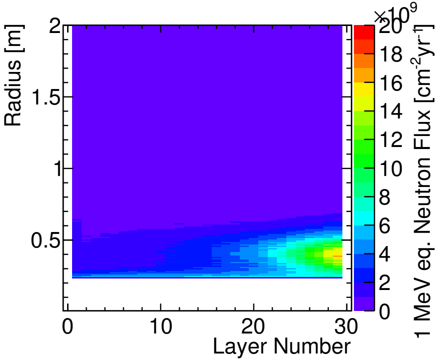

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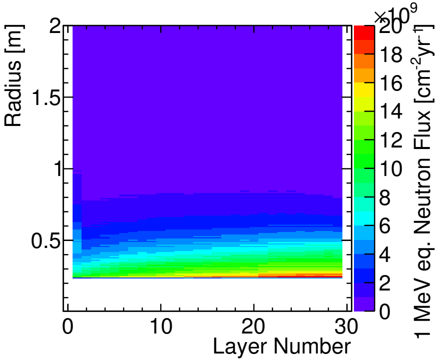

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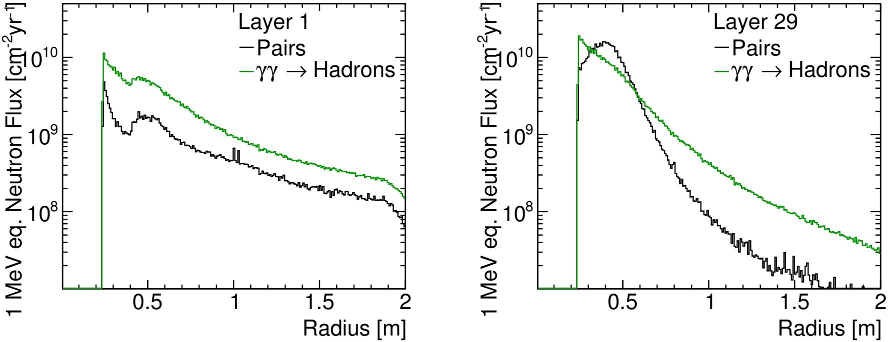

Section 4:

4 Summary

Summary and Conclusions

- Maximum energy deposit in ECal are about 4 GeV or 15 000 MIPs
  - Need a large number of pixels to avoid total saturation of the SiPM
- The *scintillator* will not show signs of saturation
- Expected neutron flux in the ECal endcap at 3 TeV CLIC is a few 10^{10} 1 MeV-neutron-equivalent, and only a few Gray per year of total ionising dose