Simulating Single Event Upset Effects in Photoreceivers

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Overview

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   - GEANT4 simulation
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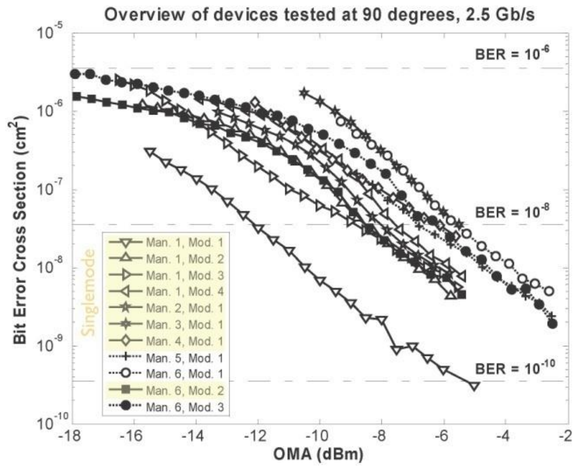
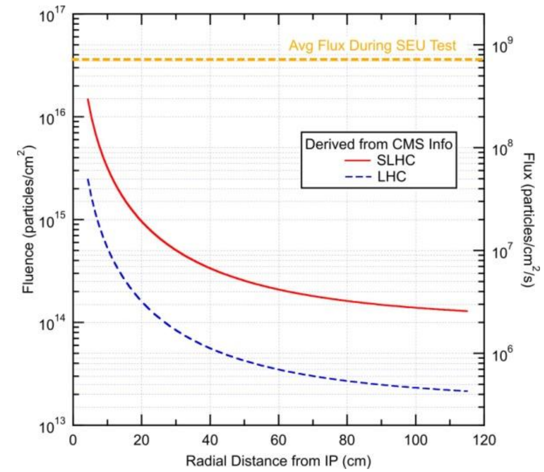
Background

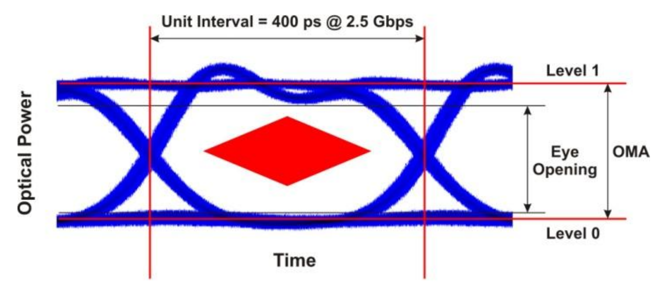
- High data rate optical systems widely deployed in current particle physics detectors
- Why SEU testing?
  - Photoreceivers are also good particle detectors
    - Causes errors
  - Prediction of SEU rates without testing not well established
- Irradiation tests in 2007 at PSI
  - 63 MeV protons
  - High flux: 10^8 p/cm^2/s
- Definition of terms
  - Eye Diagram
    - All possible transitions in communication channel
  - Optical Modulation Amplitude (OMA) = Level 1 – Level 0
  - Bit Error Rate (BER) = #erroneous bits/#transmitted bits



Overview of devices tested at 90°, 2.5 Gb/s



Expected flux at LHC and SLHC related to flux during SEU test



Motivation

- SEU paper[1] reviewer's question concerning the choice of protons as proxies
  - comparison of pion and proton energy deposit
  - referee expected that nuclear interactions of pions are more significant than those of protons
- To have a meaningful model of SEU processes for different photoreceiver geometries and incident particles

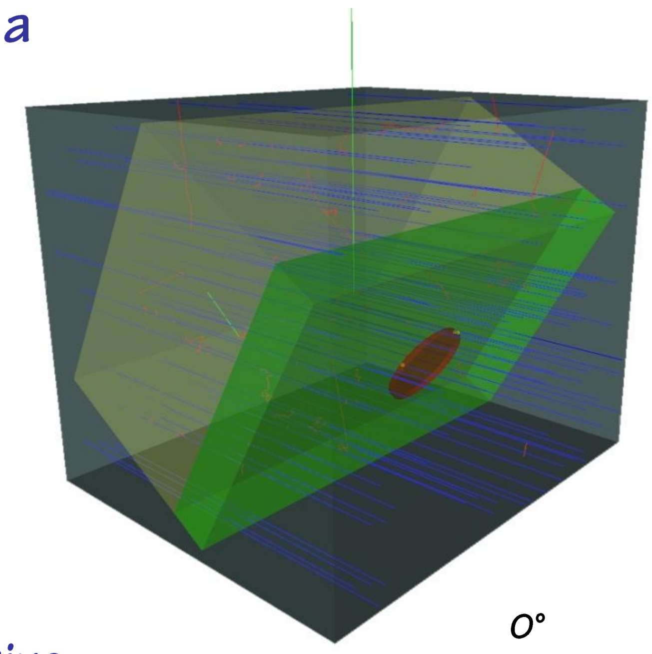
[1] Jimenez Pacheco, A., et al.: *Single-Event Upsets in Photoreceivers for Multi-Gb/s Data Transmission. IEEE Trans. on Nucl. Sci.*, In print, (presented at RADECS 2008)

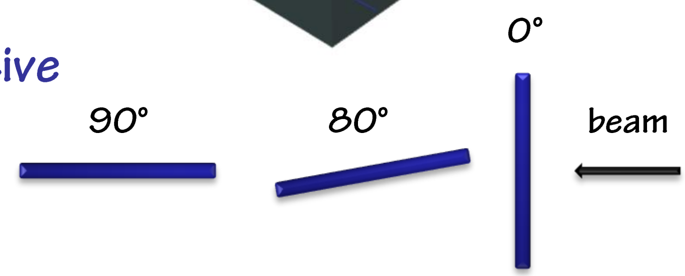
Methodology

- Simulate energy deposit in active volume
  - Calculate cross-section
- Convert the deposited energy to equivalent optical pulse
  - energy -> electron-hole pairs
  - electron-hole pairs -> power
- Compute Bit-error cross-section
  - Determine photoreceiver threshold using pulse injection test
- Compare with the measured data

GEANT4 Simulation

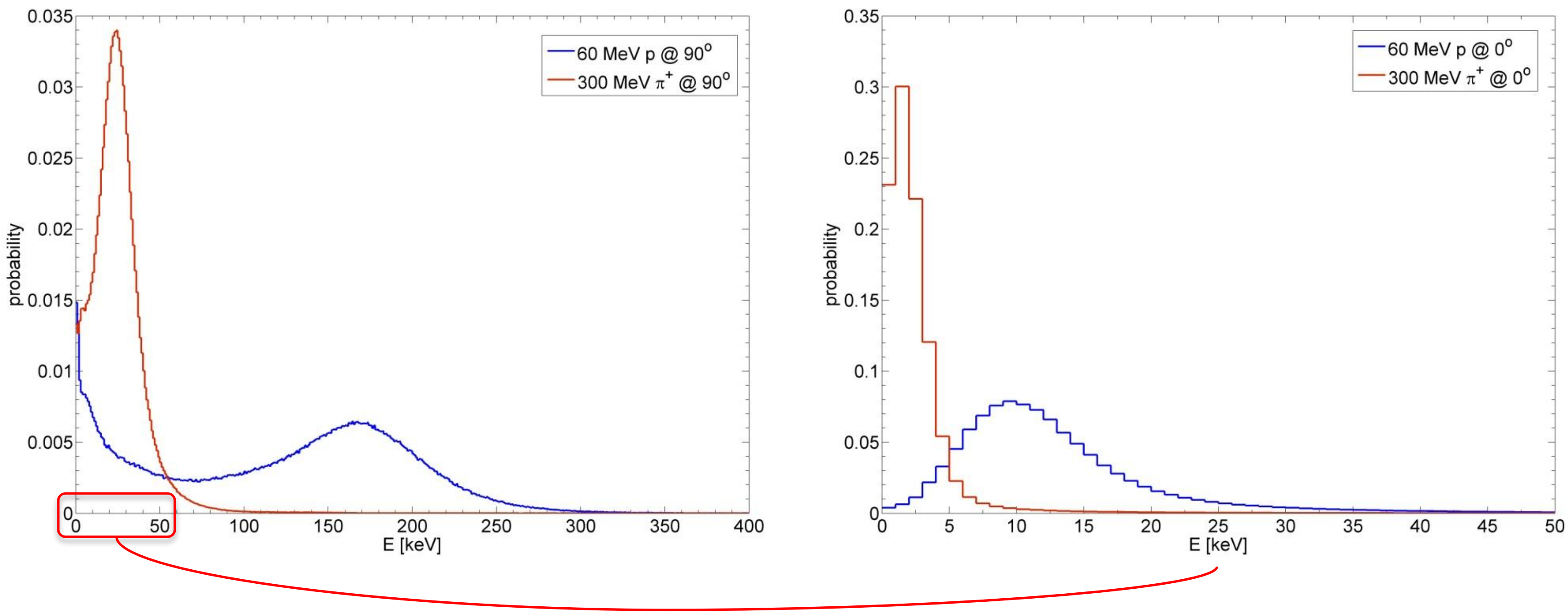
- ❑ Ø60×4 μm InGaAs active volume in 200×150×50 μm InP substrate used as a photoreceiver phantom
- ❑ QGSP_BIC_HP physics list[2]
- ❑ Simulation of energy deposit in active volume for different angles of detector rotation
- ❑ ~1 M hits (interactions) per run
  - Duration of 1 run ~2 days
- ❑ Interaction cross-section calculated as beam cross-section × #hits/#particles
  - corresponds to physical dimensions of active volume





[2] *Geant4 Reference Physics Lists.* <http://geant4.web.cern.ch/geant4/support/proc_mod_catalog/physics_lists/referencePL.shtml>

Energy Deposit

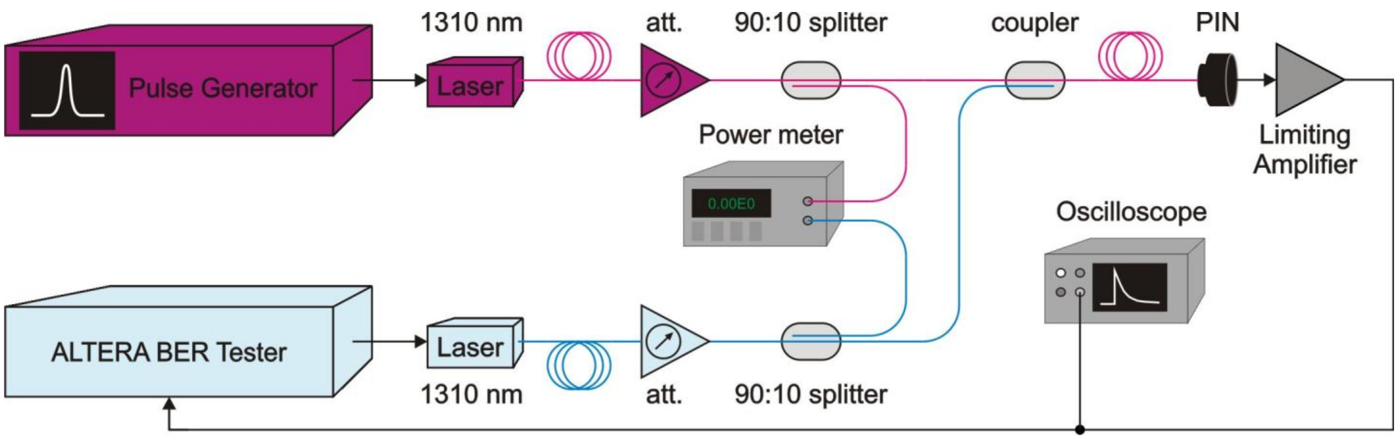


90° orientation

0° orientation

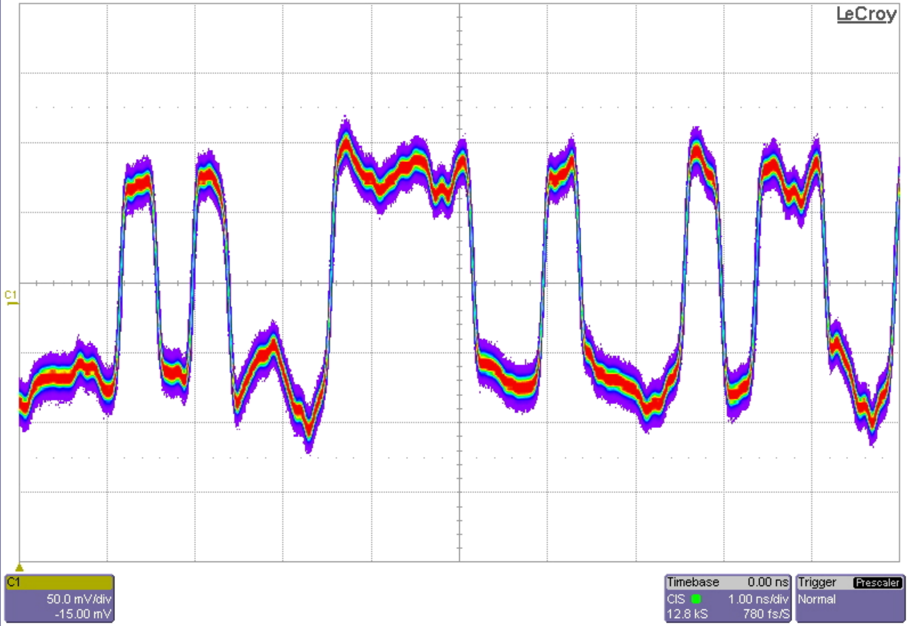
Simulated energy deposit in ∅ 60×4 μm InGaAs active region

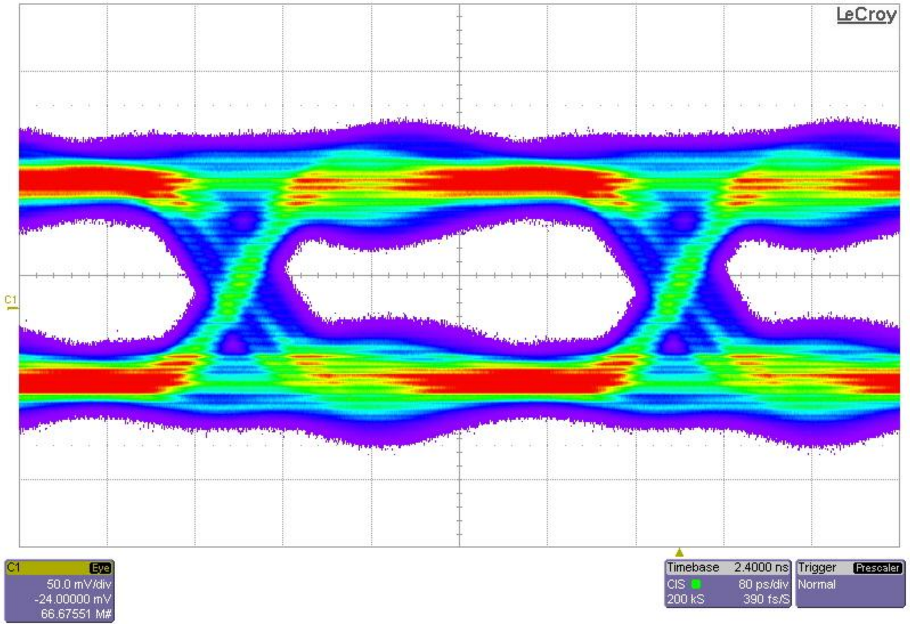
Pulse Injection Test



- Random data pattern – 2.5 Gbps
- 1 pulse & 9 zeros – 12.5 Gbps
- Pulses not synchronized with data pattern
- BER curves measured for 3 different data pattern attenuations

Signal Output of Limiting Amplifier

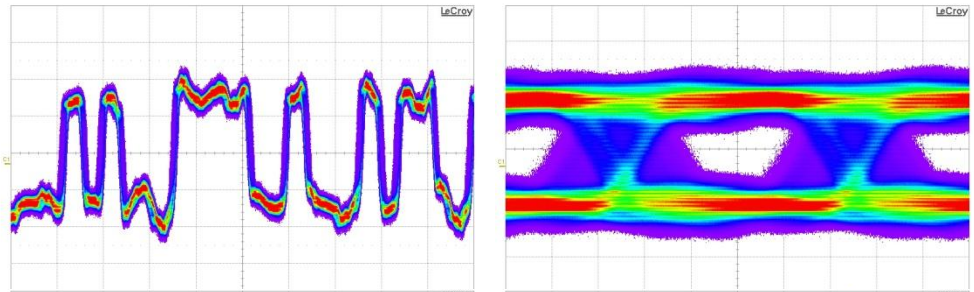




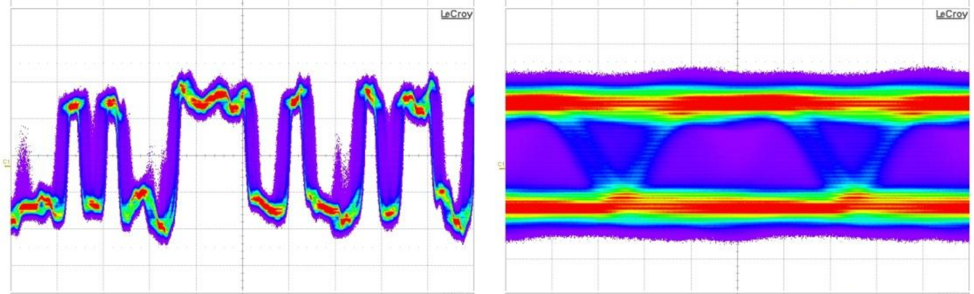
Data pattern signal with OMA = -12.4 dBm without error pulses.

Signal Output of Limiting Amplifier

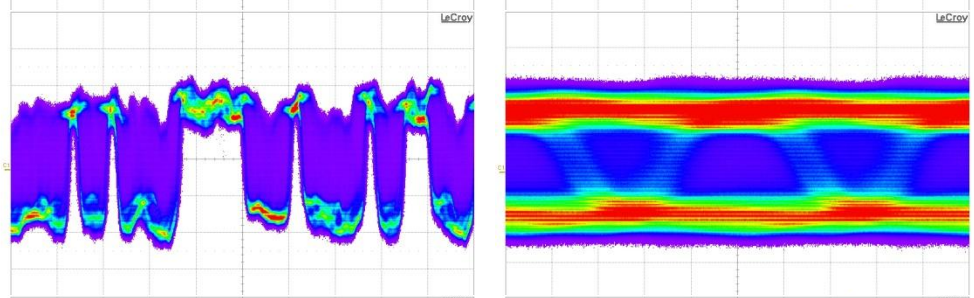
Error pulse with OMA = -13.4 dBm superimposed on data pattern signal with OMA = -12.4 dBm



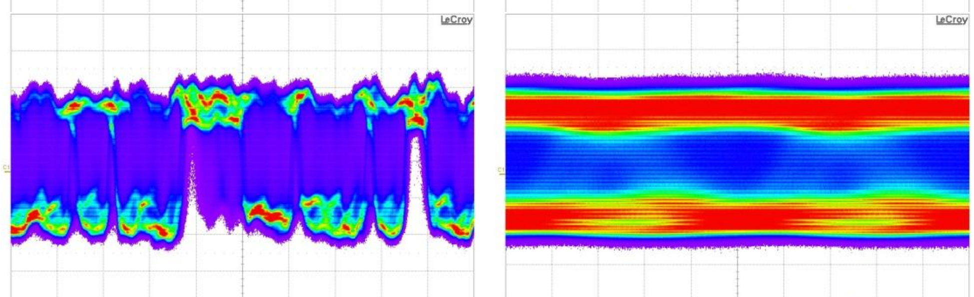
Error pulse with OMA = -11.4 dBm superimposed on data pattern signal with OMA = -12.4 dBm



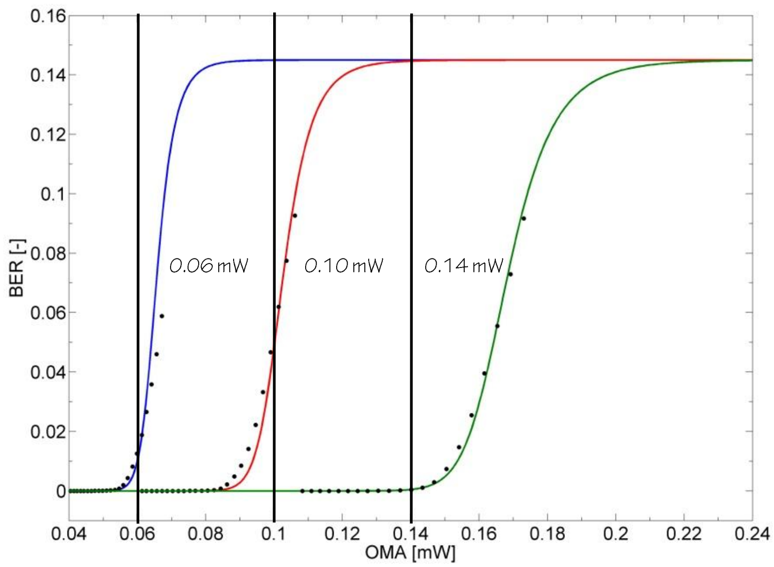
Error pulse with OMA = -9.4 dBm superimposed on data pattern signal with OMA = -12.4 dBm



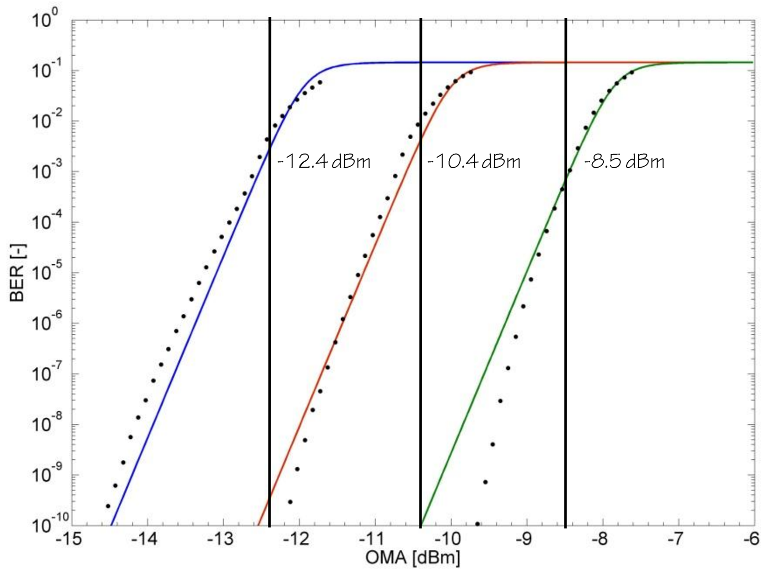
Error pulse with OMA = -7.4 dBm superimposed on data pattern signal with OMA = -12.4 dBm



Measured Pulse BER Curves



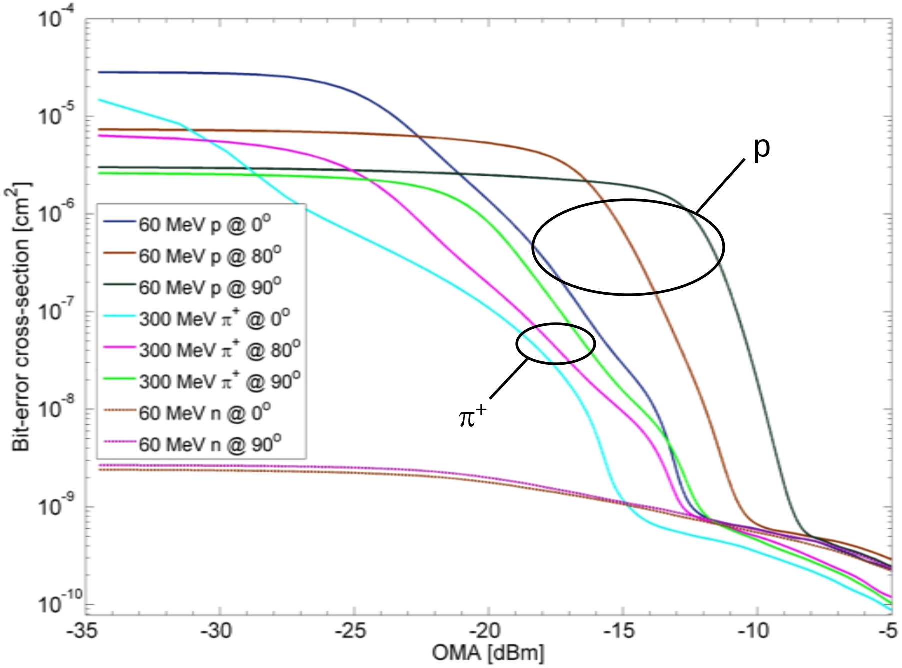
Fitted pulse BER curves with pattern OMA as a parameter (linear scale)

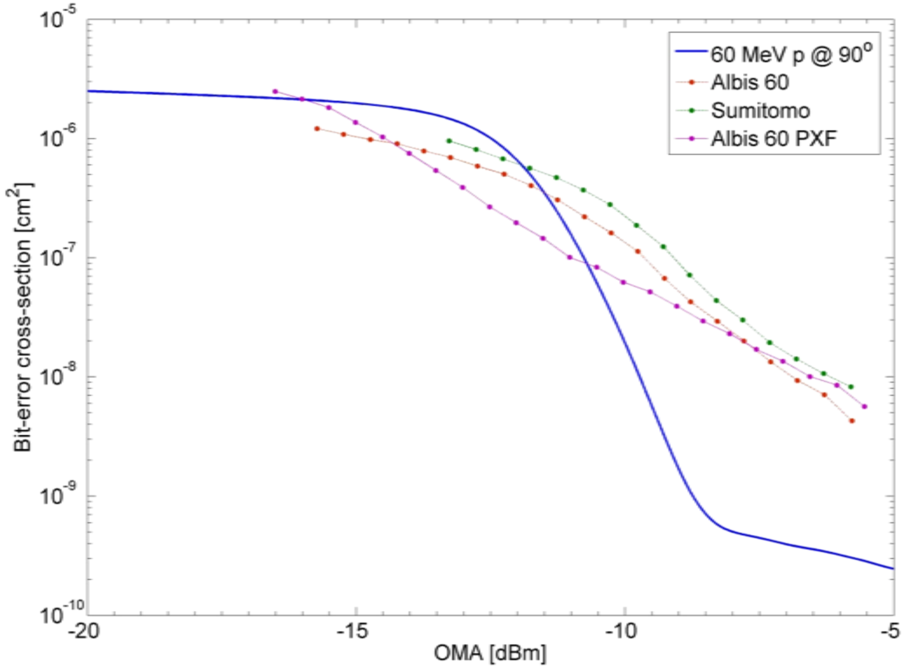


Fitted pulse BER curves with pattern OMA as a parameter (log scale)

- Data fitted by: $$H(x) = \frac{(x/b)^{34}}{1 + (x/b)^{17} + (x/b)^{34}}$$
- For this particular case, a parameter *b* is directly proportional to OMA of the data pattern signal

Results





- Shape of a detector threshold curve doesn't have a relevant effect on calculated bit-error cross-section
- Nuclear interactions of pions are less significant than those of protons – to be experimentally confirmed
- Missing some energy deposit?

Future Plans

- Obtain more realistic physical model of photoreceiver
  - Include all surrounding materials
  - CAD conversion to GEANT4 friendly format
- Based on simulation data, try to choose optimal material for PIN casing