H4sim, a Geant4 simulation program for the CMS ECAL supermodule

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Outline

The CMS electromagnetic calorimeter

Geant4 implementation

Comparison with test beam data: electrons

Comparison with test beam data: pions

Precalibration with cosmic muons
The CMS electromagnetic calorimeter

Compact Muon Solenoid at CERN LHC (2007)
7+7 TeV p-p, heavy ions

ECAL : 75848 lead tungstate crystals
22×23×230 mm³
Density = 8.28 g/cm³
$X_0 = 0.89$ cm
$R_M = 2.10$ cm
Fast $< 15$ ns
Radiation hard
20 interactions/25 ns
The CMS electromagnetic calorimeter

Barrel 36 supermodules, 2 end-caps

Non-pointing geometry $3^\circ$ in $\eta$ (beam axis) and in $\phi$

120 GeV $e^-$
The CMS electromagnetic calorimeter

Movable table:
Used to reproduce for the impinging particle the same almost pointing geometry of CMS

Readout Electronics: 2 avalanche photodiodes + MGPA (multi gain pre-amplifier) 3 gains (12,6,1), 10 samples

4 photoelectrons / MeV  35.6 MeV / ADC count
The CMS electromagnetic calorimeter

Test in the H4 beam at CERN SPS since 1997: electrons 20 to 250 GeV, pions, muons, laser light

Energy and position resolution, containment, cracks, irradiation recovery

Precalibration with electrons in the H4 beam: 2004 - 2006

Precalibration with cosmic muons: 2004 - 2006

In situ monitoring with laser

In situ calibration with electrons from Z, W, …
Geant4 implementation

CMS has a Geant4 simulation program, OSCAR, for the complete detector, interfaced with the reconstruction H4sim is a standalone simulation of one supermodule in H4 Geometry description by Geant4 data cards with a text file DDD (Detector Description Database) in XML format

Aluminium frame
Geant4 implementation

No magnetic field (time consuming tracking)
No matter behind the crystals
Can add specific H4 devices, e.g. hodoscopes
Output of the crystal energies in a ROOT file, interface to RRF (Raw Root File) to simulate beam data
Geant4 implementation
Geant4 implementation

Version 6.2. p 02

Production cuts:
1mm for e-, e+ and γ correspond to:
~ 1.15 MeV for electrons in PbWO₄
~ 0.59 MeV in Al

Execution time: 1.4 s for 50 GeV on 2 GHz
Geant4 implementation

- Interactive version
  - graphical interface & visualization
- Batch version
- Special H4sim commands
Geant4 implementation
Geant4 implementation

100 GeV $\rightarrow \pi$

500 GeV $\mu^-$
Electron beam data

TEST BEAM
E25 = 97,5 %
E9 = 94,5 %
E1 = 78,9 %

MONTE CARLO
E25 = 97,5 %
E9 = 94,6 %
E1 = 78,9 %
Electron beam data

Position scan at centre of crystal 204

X (mm)  Test beam
Simulation

Y (mm)  Y good
X ~ 2 %
Electron beam data

3x3 crystals impact position measured by log($E_2/E_1$) function
Electron beam data

\begin{equation}
\left( \frac{\sigma}{E} \right)^2 = \left( \frac{S}{\sqrt{E}} \right)^2 + \left( \frac{N}{E} \right)^2 + C^2
\end{equation}

3X3

\begin{align*}
S &= 2.96 \pm 0.1 \text{ (\%)} \\
N &= 166 \pm 3.4 \text{ (MeV)} \\
C &= 0.32 \pm 0.01 \text{ (\%)}
\end{align*}

5X5

\begin{align*}
S &= 2.35 \pm 0.12 \text{ (\%)} \\
N &= 250 \pm 3.0 \text{ (MeV)} \\
C &= 0.33 \pm 0.01 \text{ (\%)}
\end{align*}
Electron beam data

ECAL used in trigger

Simulation of the TPG linearity (Trigger Primitive Generator)
Pion beam data

5x5 energy for 50, 120 & 180 GeV pions

E25 with beam energy 50, 120, 180 for xtal 204
Pion beam data

Compare the mean values $\mu \pm \sigma$ of Landau-fit for 4 crystals @ 3 energies
Pion beam data

Minimum ionizing particle (mip) are visible

50 GeV

$\lambda \sim 23 \text{ cm}$

$E = 270 \text{ MeV}$
Almost constant, as it should be for mips

Less good agreement for crystals 1104 & 1404

3 energies for 4 crystals
Precalibration by cosmic muons

- Raise the APD gain by a factor 4
- Select the muons parallel to the crystal axis
- Veto neighbouring crystals
Precalibration by cosmic muons

Module 1

Event selection: E1 > 10 ADC counts & E2 < 3 ADC counts
Precalibration by cosmic muons

More difficult for module 4 (eta angle) ⇒ incline the supermodule by 10 degrees

Intercalibration precision of 2-3% can be reached with 1 week of continuous cosmic ray data taking
Precalibration by cosmic muons

Peak after final selection:

good agreement between data (after calibration) and MC

Data: \(<\text{evts/xtal/day}> = 55 \pm 2\)  
MC: \(<\text{evts/xtal/day}> = 61 \pm 2\)

Disagreement \(~ 10\%\) due to trigger inefficiency and uncertainty on the overall normalization
Conclusion

Geant4 based H4sim is widely used by the ECAL CMS community
Interpretation of test beam data
Test of algorithms and cosmic precalibration

Acknowledgments to: