IMPROVING HF GFLASH SIMULATIONS AT CMS

EDUARDO IBARRA GARCÍA PADILLA
UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

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OUTLINE

• LHC and CMS
• Hadron Forward Calorimeter
• EM Showers
• GFlash
• Improving speed
• Tuning GFlash
INTRODUCTION

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

Located at CERN Switzerland-France.
ALICE, ATLAS, CMS, LHCb
LHC NOW

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Proton-Proton collisions
- Center of mass energy: 8 TeV
  - Signatures of the Higgs boson
  - Super-symmetric particles
  - Extra dimensions
  - Dark matter
  - Etc…
LHC FUTURE

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- 2019
- Center of mass energy: 14TeV
  - Better measurement techniques
  - Faster and more accurate simulations

Illustration of a result from the CMS experiment at the LHC, gathered on May 27, 2012.
SOLENOID

CMS DETECTOR
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

STEEL RETURN YOKE
- Weight: 12,500 tonnes

SILICON TRACKERS
- Pixel (100x150 μm) ~16 m² ~66M channels
- Microstrips (80x180 μm) ~200 m² ~9.6M channels

MUON CHAMBERS
- Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
- Silicon strips ~16 m² ~137,000 channels

FORWARD CALORIMETER
- Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
- ~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels

4 Tesla to bend particles’ paths
SILICON TRACKER

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SUPERCONDUCTING SOLENOID
- Niobium titanium coil carrying ~18,000A

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measure the positions of passing charged particles allows us to reconstruct their tracks.
ECAL

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measure the energies of electrons and photons
HCAL

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measure the energies of hadronic particles such as pions
MUON CHAMBERS

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**Tracks muon trajectories**

**PRESHOWER**
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**FORWARD CALORIMETER**
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HF CAL

CMS DETECTOR
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measure the energies of electromagnetic and hadronic particles
HF CALORIMETER

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- 11.15m away from the interaction point
- Pseudorapidity region $3 < |\eta| < 5$.
- Steel absorbers and quartz fibres

Pseudorapidity diagram and location of HF Calorimeter
HF CALORIMETER

HF Calorimeter wedges. In white, PMT's.
EM SHOWERS

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Electrons radiate photons
- Photons pair produce
- Number of particles increases exponentially.
- Each pair production and Bremsstrahlung radiation the energy of the particles reduces.

Electron EM Shower diagram and EM Shower profile simulation
EM SHOWERS & HF CAL

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Long (L) and short (S) fibres to differentiate showers from electromagnetic and hadronic particles

- 165 cm (L) and 143 cm (S)
Why do we need GFlash?

- Full Geant4 simulation → might need days to simulate 1 event.
- Previous CMS Simulation has a problem to simulate HF Noise because it killed particles immediately when they entered detectors and replaced them with Shower Library.
The spatial energy distribution of EM Showers is given by 3 Probability Distribution Functions (pdf)

\[ dE(r) = Ef(t)f(r)f(\phi)dt\,d\phi \]

- \( t \) = Longitudinal shower distribution
- \( r \) = Radial shower distribution
- \( \Phi \) = Azimuthal shower distribution (assumed to be distributed uniformly)

The average longitudinal shower profile (in units of radiation length):

\[
\left\langle \frac{1}{E} \frac{dE(t)}{dt} \right\rangle = f(t) = \frac{(\beta t)^{\alpha-1} \beta \exp(-\beta t)}{\Gamma(\alpha)}
\]

The average radial energy profile (in units of Moliere radius):

\[
f(r) = \frac{1}{dE(t)} \frac{dE(t,r)}{dr}
\]
GFLASH 2012

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Tested against:
  - Test Beam Data
  - Collision Data
  - Shower Library (previous HF CMS Simulation)

- Noises simulation

- Very high energy particles

- Better agreement to Test Beam Data

- Good agreement to CMS Collision Data

- 10000 times faster than Geant4.

- Aim ➔ Faster and more precise
METHODOLOGY

1. Gathering previous results of GFlash simulations.
   1. Photoelectron (p.e.) counts varying the incoming energy of the particle $E_o$.
   2. p.e. counts varying the $\eta$ of entrance.
   3. p.e. counts for both $e^-$ and $\pi^+$.

2. Set a soft neutron threshold. We varied the energy of this threshold from 1.0 GeV to 1.5 GeV.

3. Comparing the obtained data we determined the threshold that is more convenient.

4. Compare average computing times with and without the cut and test the results obtained with the 1.2 cut vs Test Beam Data.

5. Tune the simulation using the Test Beam Data.
1.2 GEV CUT RESULTS

- Plot the ratio:
  - p.e. (1.2 cut)/p.e. (no cut) vs $\eta$
  - 100 to 1000 GeV
  - $\pi^+$
- % Discrepancies < 4%
- Simulation runs 76% faster

Plot p.e. ratio vs $\eta$ for 100 GeV pions
Plot p.e. ratio vs $\eta$ for 100, 250, 500 and 1000 GeV pions
SOFT NEUTRON THRESHOLD RESULTS

<table>
<thead>
<tr>
<th>Energy [GeV]</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Faster</td>
<td>30</td>
<td>45</td>
<td>76</td>
<td>81</td>
<td>84</td>
<td>86</td>
</tr>
<tr>
<td>Mean Ratio</td>
<td>1.000</td>
<td>1.003</td>
<td>0.999</td>
<td>0.997</td>
<td>1.002</td>
<td>0.997</td>
</tr>
<tr>
<td>Mean Relative Error %</td>
<td>1.15</td>
<td>1.04</td>
<td>1.24</td>
<td>1.36</td>
<td>1.34</td>
<td>1.32</td>
</tr>
<tr>
<td>Std. Dev. RE</td>
<td>0.59</td>
<td>0.49</td>
<td>0.32</td>
<td>0.42</td>
<td>0.80</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 1: Soft Neutron Threshold results
TUNING THE SIMULATION

- 4 responses:
  - Ratios of the energies deposited in Long and Short fibres for electrons and pions.
    - $Se/Le$
    - $Lp/Le$
    - $Sp/Le$
    - $Sp/Lp$
  - $e \rightarrow$ electron, $p \rightarrow$ pion, $S \rightarrow$ short fibres, $L \rightarrow$ long fibres
TUNING THE SIMULATION

• 10 parameters
• $3^k$ Factorial design experiment:
  • Define 3 levels for each factor (+, =, -)
  • $3^{10}$ experiments to be done!!!!
• Defined 3 blocks (3,4,3)
  • Do all possible combinations per block and find correlations between those parameters.
• Define new levels and blocks. Repeat.
• Wrote a program that aided us in doing statistical analysis.
• 1.15% mean discrepancy when compared to Test Beam Data.
• Reduced the error by 55% after tuning.
TUNING THE SIMULATION

Se/Le Ratio plot

- Test Beam Data
- GFlash
- Old GFlash
- Shower Library

Energy [GeV]

Se/Le
TUNING THE SIMULATION

Lp/Le Ratio plot

- Test Beam Data
- GFlash
- Old GFlash
- Shower Library

Energy [GeV]
TUNING THE SIMULATION

Sp/Le Ratio plot

- Test Beam Data
- GFlash
- Old GFlash
- Shower Library

Energy [GeV]
TUNING THE SIMULATION

Sp/Lp Ratio plot

- Test Beam Data
- GFlash
- Old GFlash
- Shower Library

Energy [GeV]
TUNING THE SIMULATION

### 30 GeV

<table>
<thead>
<tr>
<th>Ratio</th>
<th>HF GFlash</th>
<th>Test Beam</th>
<th>Old HF GFlash</th>
<th>Shower Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se/Le</td>
<td>0.2032</td>
<td>0.2034</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Lp/Le</td>
<td>0.6307</td>
<td>0.6237</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sp/Le</td>
<td>0.4464</td>
<td>0.4441</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sp/Lp</td>
<td>0.7079</td>
<td>0.7120</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

### 50 GeV

<table>
<thead>
<tr>
<th>Ratio</th>
<th>HF GFlash</th>
<th>Test Beam</th>
<th>Old HF GFlash</th>
<th>Shower Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se/Le</td>
<td>0.2395</td>
<td>0.2419</td>
<td>0.24</td>
<td>0.20</td>
</tr>
<tr>
<td>Lp/Le</td>
<td>0.6584</td>
<td>0.6593</td>
<td>0.67</td>
<td>0.63</td>
</tr>
<tr>
<td>Sp/Le</td>
<td>0.5036</td>
<td>0.5040</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>Sp/Lp</td>
<td>0.7648</td>
<td>0.7645</td>
<td>0.76</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Tables 2,3: Comparison of energy response ratio between HFGFlash, Old HFGFlash, Test Beam (reference) and Shower Library using 10000 electrons and pions at 30 and 50 GeV
TUNING THE SIMULATION

<table>
<thead>
<tr>
<th>Ratio</th>
<th>HF GFlash</th>
<th>Test Beam</th>
<th>Old HF GFlash</th>
<th>Shower Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se/Le</td>
<td>0.2924</td>
<td>0.3000</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Lp/Le</td>
<td>0.6898</td>
<td>0.7020</td>
<td>0.70</td>
<td>0.67</td>
</tr>
<tr>
<td>Sp/Le</td>
<td>0.5554</td>
<td>0.5650</td>
<td>0.57</td>
<td>0.56</td>
</tr>
<tr>
<td>Sp/Lp</td>
<td>0.8052</td>
<td>0.8048</td>
<td>0.82</td>
<td>0.84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>HF GFlash</th>
<th>Test Beam</th>
<th>Old HF GFlash</th>
<th>Shower Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se/Le</td>
<td>0.3264</td>
<td>0.3380</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>Lp/Le</td>
<td>0.7102</td>
<td>0.7297</td>
<td>0.71</td>
<td>0.70</td>
</tr>
<tr>
<td>Sp/Le</td>
<td>0.5936</td>
<td>0.5976</td>
<td>0.60</td>
<td>0.56</td>
</tr>
<tr>
<td>Sp/Lp</td>
<td>0.8358</td>
<td>0.8189</td>
<td>0.82</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Tables 4,5: Comparison of energy response ratio between HFGFlash, Old HFGFlash, Test Beam (reference) and Shower Library using 100000 electrons and pions at 100 and 150 GeV
SANITY CHECK

GFlash has a linear energy response for electrons and pions with energies from 30 to 1000 GeV.

Linear response

- $e^- \ L$
- $e^- \ S$
- $\pi^+ \ L$
- $\pi^+ \ S$

Energy [GeV]
The normalized response for electrons and pions as a function of beam energy for our simulation.
SANITY CHECK

The normalized response for electrons and pions as a function of beam energy test beam data results.
The L+S response of the detector for electrons and pions are shown as a function of beam energy. In the left our simulation, in the right test beam data results.
The $e/\pi$ ratio varies from 1.14 to 1.01 in the tested energy range, and is essentially flat at high energies.
LOOKING FOR NON SM HIGGS

Higgs “bump”, What if the bump is a superposition of several Higgs bosons? Feynman diagram of a typical diphoton decay
CONCLUSIONS AND FORTHCOMING RESEARCH

• We were able to tune HF Gflash simulations:
  • Reduced the error by 55%.
  • Runs 76% faster.
  • With 1.15% mean discrepancy when compared to Test Beam Data.

• Extend the simulation to the other calorimeters.
• Span a wider η range.
• Aim for a better precision.
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• Tanja Waltrip, Kappy Sherman
REFERENCES

• Performance of HFGFlash at CMS, Rahmat Rahmat, EPJ Web of Conferences 49, 18805 (2013).
