Implementation and validation of CALET flight model in GEANT4 simulation

Presentation by

Lorenzo Pacini
Contents

- Calet flight model in GEANT4
- Benchmarks with electrons
- Benchmarks with protons
- Conclusion
Calet flight model in GEANT4

• Lorenzo Pacini
• Nicola Mori
• We developed the Calet flight model in GEANT4

• Shape and size of the supporting structures have been extracted from Epics config. files and replicated in details in the Geant4 geometry description.

• Some simplifications have been introduced (e.g.: honeycomb) as we did with FLUKA:

  1) honeycomb → homogeneous aluminum material, density = 0.3856g/cm³

  2) IMC and TASC lateral panel → single aluminum box
Calet simplified geometry: no supports and mechanical structures.

Calet new geometry (figures are not in scale)
Aluminum structures: lateral, base, top panel and PMT box in CHD and IMC
- Carbon fiber and honeycomb supports for scintillator (CHD, IMC, TASC)
- Scintillators and tungsten layers (also present in the simplified geometry).
CHD top panel, IMC lateral and base panel

- CHD top panel and PMT box
- IMC lateral and base panels
Legend:
- Tungsten
- Scintillator
- Carbon fiber
- Honeycomb
- Vacuum

- In IMC: the supports are thin carbon fiber layers and big honeycomb structures
- In TASC: The supports are carbon fibers (no honeycomb)
Calet flight model benchmark

• Lorenzo Pacini
• Caterina Checchia
• Francesco Palma
• Paolo Maestro
• Nicola Mori
To validate the new GEANT4 geometry we performed common benchmarks with FLUKA end EPICS:

- **Proton** and **Electron** @ 10, 100, 1000, 10000 GeV
- **Future works:** $^{12}\text{C}$ and $^{56}\text{Fe}$ @ 10, 100, 1000, 10000 GeV/n kinetic energy

**Particle:**
- Normal incidence
- Generated in 4x4 cm$^2$ area on top of CHD at the center of the detector

**Interesting quantities for this presentation:**
- Energy deposited in CHD, IMC and TASC.
- High energy trigger efficiency.

We also investigated the energy deposited in TASC, IMC layers, in IMC single fibers and TASC logs.
Software versions

- GEANT4-09-06-patch-02
  physics lists: FTFP_BERT

- EPICS9.167 Calet Cad model rev. 21 (COSMOS 7.645)
  hadronic interacting model: DPMJET-III

- FLUKA 2011.2c.0
  hadronic interacting model: DPMJET-III
All electrons @ 10 GeV. Total energy in TASC.

H.E triggered electrons @ 10 GeV. Total energy in TASC.

H.E. triggered particle table:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>GEANT4</td>
<td>8.569</td>
<td>0.3757</td>
<td>8.65</td>
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<tr>
<td>EPICS</td>
<td>8.618</td>
<td>0.4103</td>
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<td>FLUKA</td>
<td>8.571</td>
<td>0.3728</td>
<td>8.75</td>
<td>1.156</td>
</tr>
</tbody>
</table>

H.E. trigger efficiency
GEANT 87.1%
EPICS 85.3%
FLUKA 86.4%

25/06/2015
All electrons $10 \, @ \, \text{GeV}$.

TASC lateral distr.

All electrons $10 \, @ \, \text{GeV}$.

TASC longitudinal distr.

diff = EPICS/GEANT4  -  1  (rosso)
diff = FLUKA/GEANT4  -  1  (nero)
Calet in GEANT4  
Electrons benchmark  
Protons benchmark  
Conclusion

All electrons @ 10 GeV. Total energy in IMC.

H.E triggered electrons @ 10 GeV. Total energy in IMC.

**Electrons 10GeV**

**Simulation** | **mean[GeV]** | **RMS[GeV]** | **BinMax[GeV]** | **BinMax Diff. (%)**  
--- | --- | --- | --- | ---  
GEANT4 | 0.04197 | 0.01472 | 0.03802 | 0  
EPICS | 0.04023 | 0.01543 | 0.03211 | -15.54  
FLUKA | 0.04032 | 0.01416 | 0.03415 | -10.19  

GEANT4 blue  
EPICS red  
FLUKA black
All electrons @ 10 GeV. IMC lateral distr.

Difference with respect to GEANT4

**diff** = EPICS/GEANT4 - 1 (rosso)
**diff** = FLUKA/GEANT4 - 1 (nero)
Calet in GEANT4    Electrons benchmark    Protons benchmark    Conclusion

**All electrons @ 10 GeV.**
Total energy in CHD.

**H.E triggered electrons @ 10 GeV.**
Total energy in CHD.

---

**H.E. triggered particle table:**

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<td>0.004909</td>
<td>0.001613</td>
<td>0.003669</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
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<td>FLUKA</td>
<td>0.004837</td>
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<td>0.004302</td>
<td>17.24</td>
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</tbody>
</table>

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25/06/2015  
Electrons 10GeV
Electrons @ 10 GeV results

- **TASC total energy**: very similar distributions, difference between bins with the highest energy deposit is 1-2%.

- TASC lateral and longitudinal distributions: good agreement around the maximum of the distributions; difference of order 10% in the low energy tails.

- **IMC total energy**: the shape of the distributions are very similar. The maximum position is about 10% higher in Epics and Fluka with respect to Geant4.

- IMC lateral and longitudinal distributions: quite good agreement, with discrepancies only in the low energy tails.

- **CHD total energy**: very similar distributions, the shape of the distributions are very similar.
Electrons @ 100 GeV results

- The results from the comparison of the three simulations are similar to the 10 GeV case (plots and tables are in the backup slides)

- **TASC total energy: very similar distributions**, difference between bins with the highest energy deposit is about 0.7 % for EPICS with respect to GEANT4 and FLUKA

- TASC lateral and longitudinal distributions: large differences (10%) only for layers with low energy deposited

- **IMC total energy: distributions have similar shapes**, difference between maximum energy bins is about 20 % for EPICS with respect to GEANT4 and

- IMC lateral and longitudinal distributions: large difference (20%) only for layers with low energy deposited

- **CHD total energy: very similar distributions**, difference between maximum energy bins is about 2%
- **TASC total energy and distributions:** similar results to the ones obtained at 10 and 100 GeV (plots and tables are in the backup slides).

- **IMC total energy:** the shape of the EPICS distributions is remarkably different with respect to the GEANT4 and FLUKA ones; the difference between the maximum energy bin is about 30% with respect to GEANT4 and FLUKA (see next slides).

- **CHD total energy:** the shape of the EPICS distributions is remarkably different with respect to the GEANT4 and FLUKA ones; the difference between the maximum energy bin is about 30% with respect to GEANT4 and FLUKA (see next slides).
All electrons @ 1 TeV. Total energy in IMC.

H.E triggered electrons @ 1 TeV. Total energy in IMC.

EPICS distributions are not in agreement with GEANT4 and FLUKA.

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</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.2263</td>
<td>0.1057</td>
<td>0.1844</td>
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<tr>
<td>EPICS</td>
<td>0.2169</td>
<td>0.139</td>
<td>0.1266</td>
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</tr>
<tr>
<td>FLUKA</td>
<td>0.2316</td>
<td>0.1031</td>
<td>0.1844</td>
<td>-0.042</td>
</tr>
</tbody>
</table>

H.E trigger efficiency
GEANT 99.9%
EPICS 99.9%
FLUKA 99.9%
All electrons @ 1 TeV.
Total energy in CHD.

H.E triggered electrons @ 1 TeV.
Total energy in CHD.

EPICS distributions are not in agreement with GEANT4 and FLUKA.

H.E. triggered particle table:

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<tbody>
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<td>GEANT4</td>
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<td>EPICS</td>
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<td>0.0206</td>
<td>-4.088</td>
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</table>
In order to understand these large differences in CHD (and IMC) distributions we have studied the energy deposited in the CHD paddle directly hit by the primary particle.

The single bar distribution is in agreement with the MIP energy release, (mean ~ 2-3 MeV)

The CHD total energy is bigger than the MIPs energy release in the crossed bars (20 MeV vs. 4-6 MeV)
A possible explanation of these differences are:

- The total energy released in CHD (IMC) includes both the energy deposited by the primary particle in the two crossed paddles (fibers), and the signals due to backscatter particles in the nearby bars (fibers).

- The latter is expected to increase with the primary particle energy.

- The lower total energy deposited in IMC and CHD observed with Epics might be related to a different treatment of the backscatter particles with respect to GEANT4/FLUKA.
The results from the comparison of the three simulations are similar to the 1 TeV case (plots and tables are in the backup slides).

- TASC total energy and distributions: similar results to the ones obtained at 10, 100 and 1000 GeV

- IMC total energy: the shape of the EPICS distributions is remarkably different with respect to the GEANT4 and FLUKA ones; the difference between the maximum energy bin is about 44% with respect to GEANT4 and FLUKA

- CHD total energy: the shape of the EPICS distributions is remarkably different with respect to the GEANT4 and FLUKA ones; the difference between the maximum energy bin is about 42% with respect to GEANT4 and FLUKA (see next slides)
The TASC energy distributions of the three simulations are in good agreement at all the energy (see Maestro's presentations at the last TIM in Waseda).

IMC and CHD show large discrepancies, especially for triggered proton.

I will show the plots for protons @ 1TeV. The other energies are in the backup slides.
All protons @ 1 TeV. Total energy in TASC.

H.E triggered protons @ 1 TeV. Total energy in TASC.

H.E. triggered particle table:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>GEANT4</td>
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<td>370.1</td>
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<tr>
<td>EPICS</td>
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<td>134.4</td>
<td>330.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>FLUKA</td>
<td>352.9</td>
<td>141.5</td>
<td>350.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

H.E.trigger efficiency
GEANT 27.1%
EPICS 24.3%
FLUKA 27.4%
**Calet in GEANT4**  **Electrons benchmark**  **Protons benchmark**  **Conclusion**

**All protons @ 1 TeV. TASC lateral distr.**

![TASC lateral distribution in layer with max energy](image)

**All protons @ 1 TeV. TASC longitudinal distr.**

![TASC longitudinal distribution in layers](image)

**Conclusion**

All protons @ 1 TeV. TASC longitudinal distr.

\[ \text{diff} = \text{EPICS/GEANT4} - 1 \text{ (rosso)} \]

\[ \text{diff} = \text{FLUKA/GEANT4} - 1 \text{ (nero)} \]
All protons @ 1 TeV. Total energy in IMC.

H.E triggered protons @ 1 TeV. Total energy in IMC.

H.E. triggered particle table:

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<tr>
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<tr>
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<td>0.2391</td>
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</tr>
<tr>
<td>FLUKA</td>
<td>0.2972</td>
<td>0.229</td>
<td>0.1031</td>
<td>-9.035</td>
</tr>
</tbody>
</table>
**Calet in GEANT4**  
**Electrons benchmark**  
**Protons benchmark**  
**Conclusion**

**All protons @ 1 TeV. IMC lateral distr.**

**All protons @ 1 TeV. IMC longitudinal distr.**

**IMC lateral distribution in layer with max energy**

**IMC longitudinal distribution in layers**

Very big differences in IMC for EPICS simulation with respect to FLUKA and GEANT4

25/06/2015  
Protons 1TeV
All protons @ 1 TeV. Total energy in CHD.

H.E triggered protons @ 1 TeV. Total energy in CHD.

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</thead>
<tbody>
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<td>EPICS</td>
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<tr>
<td>FLUKA</td>
<td>0.06843</td>
<td>0.04656</td>
<td>0.04241</td>
<td>27.3</td>
</tr>
</tbody>
</table>
Summary plots

In order to summarize electrons and protons results I will show you some plots with the differences of EPICS and FLUKA with respect to GEANT4:

- Maximum energy bins deposited in TASC vs Energy, for H.E. triggered protons and electrons
- Maximum energy bins deposited in IMC vs Energy, for H.E. triggered protons and electrons
- Maximum energy bins deposited in CHD vs Energy, for H.E. triggered protons and electrons
- Trigger efficiency vs Energy, for H.E. triggered protons and electrons
Electrons: difference in TASC total energy maximum

Electrons: difference in IMC total energy maximum

The shape of the distributions for EPICS is very different compared to GEANT4 and FLUKA ones.
The shape of the distributions for EPICS is very different compared to GEANT4 and FLUKA ones.
Calet in GEANT4
Electrons benchmark
Protons benchmark

Conclusion

Protons: difference in TASC total energy maximum

The shape of the distributions for EPICS is very different compared to GEANT4 and FLUKA ones.

Protons: difference in IMC total energy maximum
Protons: difference in CHD total energy maximum.

Protons: difference in High Energy trigger efficiency

The shape of the distributions for EPICS is very different compared to GEANT4 and FLUKA ones.
Good agreements among the three simulations about the energy deposited in TASC and trigger efficiency.

As far as CHD and IMC response is concerned, we notice a quite good agreement between FLUKA and Geant4.

Instead there are significant differences between GEANT4 and EPICS, more and more pronounced as the primary particle energy increases.

Because of the good agreement between FLUKA and GEANT4, we can consider the new GEANT4 CALET flight model validated.

Discrepancies with EPICS need to be investigated accurately.
1) Different implementation of some volumes of the CALET Flight model in FLUKA/GEANT4 with respect to EPICS?

- The most important simplification is Honeycomb.

2) Possible differences in the simulation of the back scattering particles?

- It seems that in Epics the amount of backscatter in CHD and IMC is lower.

To check the conjecture 1) we also simulated electrons and protons with FLUKA, EPICS and GEANT4 using the Calet simplified geometry (Pisa model). The results of this simulations are shown in Caterina's presentation.
End Of Presentation

Any questions?
Backup slides
This is the main trigger mode for CALET

- By requiring a large energy deposit in the middle of the detector,
- Energy in last 2 X layers of IMC > 7.5 MIPs
- Energy in last 2 Y layers of IMC > 7.5 MIPs
- Energy in the first X layers of TASC > 55 MIPs

Questa slide può essere utile ma non è strettamente necessaria. La tolgo?
Electrons plots and tables: 10, 100, 1000, 10000 GeV
All electrons @ 10 GeV.
Total energy in TASC.

H.E triggered electrons @ 10 GeV.
Total energy in TASC.

H.E triggered particle table:

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H.E. trigger efficiency
GEANT 87.1%
EPICS 85.3%
FLUKA 86.4%
**Calet in GEANT4**

**Electrons benchmark**

**Protons benchmark**

**Conclusion**

---

**All electrons 10 @ GeV. TASC lateral distr.**

![Graph showing electron lateral distribution with comparison to GEANT4, EPICS, FLUKA]

**All electrons @ 10 GeV. TASC longitudinal distr.**

![Graph showing electron longitudinal distribution with comparison to GEANT4, EPICS, FLUKA]

**Difference with respect to GEANT4**

- **EPICS**
- **FLUKA**

**Difference %**

- **EPICS**
- **FLUKA**

\[
\text{diff} = \frac{\text{EPICS/GEANT4} - 1}{\text{GEANT4}} \quad (\text{rosso})
\]

\[
\text{diff} = \frac{\text{FLUKA/GEANT4} - 1}{\text{GEANT4}} \quad (\text{nero})
\]
Calet in GEANT4  Electrons benchmark  Protons benchmark  Conclusion

All electrons @ 10 GeV.
Total energy in IMC.

H.E triggered electrons @ 10 GeV.
Total energy in IMC.

**H.E. triggered particle table:**

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<td>-10.19</td>
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GEANT4 blue
EPICS red
FLUKA black
Calet in GEANT4  
Electrons benchmark

Protons benchmark  
Conclusion

All electrons @ 10 GeV.
IMC lateral distr.

All electrons @ 10 GeV.
IMC longitudinal distr.

Difference with respect to GEANT4

\[
\text{diff} = \text{EPICS/GEANT4} - 1 \quad (\text{rosso})
\]
\[
\text{diff} = \text{FLUKA/GEANT4} - 1 \quad (\text{nero})
\]
All electrons @ 10 GeV. Total energy in CHD.

H.E triggered electrons @ 10 GeV. Total energy in CHD.

**Electrons 10GeV**

**H.E. triggered particle table:**

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<td>0.004837</td>
<td>0.001612</td>
<td>0.004302</td>
<td>17.24</td>
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</tbody>
</table>
All electrons @ 100 GeV.
Total energy in TASC.

H.E triggered electrons @ 100 GeV.
Total energy in TASC.

H.E. triggered particle table:

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</thead>
<tbody>
<tr>
<td>GEANT4</td>
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<tr>
<td>EPICS</td>
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<td>FLUKA</td>
<td>94.13</td>
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</tbody>
</table>

H.E. trigger efficiency
GEANT 99.7%
EPICS 99.7%
FLUKA 99.7%
All electrons @ 100 GeV. TASC lateral distr.

All electrons @ 100 GeV. TASC longitudinal distr.

\[ \text{diff} = \text{EPICS/GEANT4} - 1 \] (rosso)
\[ \text{diff} = \text{FLUKA/GEANT4} - 1 \] (nero)
All electrons @ 100 GeV. Total energy in IMC.

H.E triggered electrons @ 100 GeV. Total energy in IMC.

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<tbody>
<tr>
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<td>FLUKA</td>
<td>0.1026</td>
<td>0.0415</td>
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</table>
Calet in GEANT4        Electrons benchmark        Protons benchmark        Conclusion

All electrons @ 100 GeV. IMC lateral distr.

All electrons @ 100 GeV. IMC longitudinal distr.

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All electrons @ 100 GeV. Total energy in CHD.

H.E triggered electrons @ 100 GeV. Total energy in CHD.

GEANT4 blue
EPICS red
FLUKA black

H.E. triggered particle table:

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</thead>
<tbody>
<tr>
<td>GEANT4</td>
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<td>0</td>
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<tr>
<td>EPICS</td>
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<td>0.002509</td>
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<tr>
<td>FLUKA</td>
<td>0.007591</td>
<td>0.002814</td>
<td>0.005686</td>
<td>1.48</td>
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</tbody>
</table>
All electrons @ 1 TeV. Total energy in TASC.

H.E triggered electrons @ 1 TeV. Total energy in TASC.

**Simulation** | **Mean [GeV]** | **RMS [GeV]** | **BinMax [GeV]** | **BinMax Diff. (%)**
--- | --- | --- | --- | ---
GEANT4 | 962.8 | 7.748 | 968.8 | 0
EPICS | 963.5 | 8.226 | 968.8 | 0
FLUKA | 961.4 | 7.526 | 966.3 | -0.258

H.E. triggered particle table:

GEANT4 blue
EPICS red
FLUKA black

**H.E. trigger efficiency**

GEANT 99.9%
EPICS 99.9%
FLUKA 99.9%
All electrons @ 1 TeV. TASC lateral distr.

TASC lateral distribution in layer with max energy

All electrons @ 1 TeV. TASC longitudinal distr.

TASC longitudinal distribution in layers

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
**Electrons benchmark**

All electrons @ 1 TeV.
Total energy in IMC.

![Graph showing energy distribution]

**Electrons benchmark**

H.E triggered electrons @ 1 TeV.
Total energy in IMC.

**H.E. triggered particle table:**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.2263</td>
<td>0.1057</td>
<td>0.1844</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.2169</td>
<td>0.139</td>
<td>0.1266</td>
<td>-31.34</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.2316</td>
<td>0.1031</td>
<td>0.1844</td>
<td>-0.042</td>
</tr>
</tbody>
</table>
Calet in GEANT4  Electrons benchmark  Protons benchmark  Conclusion

All electrons @ 1 TeV. IMC lateral distr.

![Graph showing IMC lateral distribution for electrons at 1 TeV.]

All electrons @ 1 TeV. IMC longitudinal distr.

![Graph showing IMC longitudinal distribution for electrons at 1 TeV.]

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All electrons @ 1 TeV. Total energy in CHD.

H.E triggered electrons @ 1 TeV. Total energy in CHD.

EPICS distributions are not in agreement with GEANT4 and FLUKA.

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.02272</td>
<td>0.008622</td>
<td>0.02148</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.017</td>
<td>0.006434</td>
<td>0.01531</td>
<td>-28.74</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.02292</td>
<td>0.008225</td>
<td>0.0206</td>
<td>-4.088</td>
</tr>
</tbody>
</table>
All electrons @ 10 TeV. Total energy in TASC.

H.E triggered electrons @ 10 TeV. Total energy in TASC.

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>9540</td>
<td>117.5</td>
<td>9638</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>9560</td>
<td>115.4</td>
<td>9638</td>
<td>0</td>
</tr>
<tr>
<td>FLUKA</td>
<td>9539</td>
<td>110.8</td>
<td>9638</td>
<td>0</td>
</tr>
</tbody>
</table>

GEANT4 blue
EPICS red
FLUKA black

H.E. trigger efficiency
GEANT 99.9%
EPICS 99.7%
FLUKA 99.9%
Calet in GEANT4  Electrons benchmark  Protons benchmark  Conclusion

All electrons @ 10 TeV.
TASC lateral distr.

All electrons @ 10 TeV.
TASC longitudinal distr.

Diff = EPICS/GEANT4 - 1 (rosso)
Diff = FLUKA/GEANT4 - 1 (nero)
All electrons @ 10 TeV. Total energy in IMC.

H.E triggered electrons @ 10 TeV. Total energy in IMC.

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.4408</td>
<td>0.2067</td>
<td>0.3182</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.37</td>
<td>0.2877</td>
<td>0.1777</td>
<td>-44.17</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.4913</td>
<td>0.2133</td>
<td>0.3469</td>
<td>9.024</td>
</tr>
</tbody>
</table>
Calet in GEANT4  Electrons benchmark  Protons benchmark  Conclusion

All electrons @ 10 TeV. IMC lateral distr.

All electrons @ 10 TeV. IMC longitudinal distr.

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All electrons @ 10 TeV. Total energy in CHD.

H.E triggered electrons @ 10 TeV. Total energy in CHD.

GEANT4 blue
EPICS red
FLUKA black

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.09315</td>
<td>0.03309</td>
<td>0.09495</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.05781</td>
<td>0.02428</td>
<td>0.05555</td>
<td>-41.5</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.1027</td>
<td>0.03337</td>
<td>0.1099</td>
<td>15.76</td>
</tr>
</tbody>
</table>
Protons plots and tables: 10, 100, 1000, 10000 GeV
All protons @ 10 GeV. Total energy in TASC.

H.E. triggered protons @ 10 GeV. Total energy in TASC.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>4.645</td>
<td>0.8497</td>
<td>4.701</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>4.999</td>
<td>1.097</td>
<td>4.701</td>
<td>-0.002489</td>
</tr>
<tr>
<td>FLUKA</td>
<td>4.865</td>
<td>1.045</td>
<td>4.701</td>
<td>-0.002489</td>
</tr>
</tbody>
</table>

H.E. trigger efficiency
GEANT 2.4%
EPICS 1.3%
FLUKA 1.8%

25/06/2015
All protons @ 10 GeV.
TASC lateral distr.

Protons benchmark

All protons @ 10 GeV.
TASC longitudinal distr.

Difference with respect to GEANT4

\[ \text{diff} = \text{EPICS/GEANT4} - 1 \quad \text{(rosso)} \]
\[ \text{diff} = \text{FLUKA/GEANT4} - 1 \quad \text{(nero)} \]
Calet in GEANT4      Electrons benchmark      Protons benchmark      Conclusion

All protons @ 10 GeV.
Total energy in IMC.

H.E triggered protons @ 10 GeV.
Total energy in IMC.

Protons 10GeV

H.E. triggered
particle table:

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.05263</td>
<td>0.03522</td>
<td>0.03156</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.05283</td>
<td>0.02944</td>
<td>0.0378</td>
<td>19.76</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.06132</td>
<td>0.03392</td>
<td>0.05507</td>
<td>74.49</td>
</tr>
</tbody>
</table>
Calet in GEANT4  
Electrons benchmark  
Protons benchmark  
Conclusion

All protons @ 10 GeV. IMC lateral distr.

All protons @ 10 GeV. IMC longitudinal distr.

\[ \text{diff} = \frac{\text{EPICS/GEANT4} - 1}{\text{FLUKA/GEANT4} - 1} \]

\[ \text{diff} = \frac{\text{EPICS/GEANT4} - 1}{\text{FLUKA/GEANT4} - 1} \] (rosso)

\[ \text{diff} = \frac{\text{FLUKA/GEANT4} - 1}{\text{FLUKA/GEANT4} - 1} \] (nero)
All protons @ 10 GeV. Total energy in CHD.

H.E triggered protons @ 10 GeV. Total energy in CHD.

**Protons benchmark**

GEANT4 blue
EPICS red
FLUKA black

Low Numbers of triggered protons

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.0168</td>
<td>0.01347</td>
<td>0.01034</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.01273</td>
<td>0.01491</td>
<td>0.002905</td>
<td>-71.89</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.01706</td>
<td>0.01617</td>
<td>0.005719</td>
<td>-44.68</td>
</tr>
</tbody>
</table>
All protons @ 100 GeV. Total energy in TASC.

H.E triggered protons @ 100 GeV. Total energy in TASC.

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>39.29</td>
<td>13.05</td>
<td>37.01</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>39.56</td>
<td>12.87</td>
<td>39.01</td>
<td>5.404</td>
</tr>
<tr>
<td>FLUKA</td>
<td>41.32</td>
<td>13.14</td>
<td>41.01</td>
<td>10.81</td>
</tr>
</tbody>
</table>

H.E. trigger efficiency:
- GEANT 25.5%
- EPICS 19.4%
- FLUKA 21.4%
Calet in GEANT4      Electrons benchmark      Protons benchmark      Conclusion

All protons @ 100 GeV. TASC lateral distr.

All protons @ 100 GeV. TASC longitudinal distr.

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All protons @ 100 GeV. Total energy in IMC.

H.E triggered protons @ 100 GeV. Total energy in IMC.

H.E. triggered particle table:

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.1579</td>
<td>0.1063</td>
<td>0.04561</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.1165</td>
<td>0.08671</td>
<td>0.02266</td>
<td>-50.32</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.14</td>
<td>0.09585</td>
<td>0.05305</td>
<td>16.3</td>
</tr>
</tbody>
</table>
All protons @ 100 GeV. IMC lateral distr.

Difference with respect to GEANT4

All protons @ 100 GeV. IMC longitudinal distr.

Difference with respect to GEANT4

\[ \text{diff} = \text{EPICS/GEANT4} - 1 \] (rosso)

\[ \text{diff} = \text{FLUKA/GEANT4} - 1 \] (nero)
All protons @ 100 GeV. Total energy in CHD.

H.E triggered protons @ 100 GeV. Total energy in CHD.

GEANT4 blue
EPICS red
FLUKA black

### Protons benchmark

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.03878</td>
<td>0.03113</td>
<td>0.01927</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.02431</td>
<td>0.02704</td>
<td>0.003234</td>
<td>-83.22</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.0329</td>
<td>0.02759</td>
<td>0.01331</td>
<td>-30.96</td>
</tr>
</tbody>
</table>
All protons @ 1 TeV.
Total energy in TASC.

H.E triggered protons @ 1 TeV.
Total energy in TASC.

**H.E triggered particle table:**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>354.6</td>
<td>133.6</td>
<td>370.1</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>352.3</td>
<td>134.4</td>
<td>330.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>FLUKA</td>
<td>352.9</td>
<td>141.5</td>
<td>350.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

H.E. triggered efficiency
- GEANT 27.1%
- EPICS 24.3%
- FLUKA 27.4%
All protons @ 1 TeV.
TASC lateral distr.

All protons @ 1 TeV.
TASC longitudinal distr.

---

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All protons @ 1 TeV. Total energy in IMC.

GEANT4 blue
EPICS red
FLUKA black

H.E. triggered particle table:

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<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.3163</td>
<td>0.243</td>
<td>0.1133</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.2391</td>
<td>0.2293</td>
<td>0.02014</td>
<td>-82.23</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.2972</td>
<td>0.229</td>
<td>0.1031</td>
<td>-9.035</td>
</tr>
</tbody>
</table>
All protons @ 1 TeV.
IMC lateral distr.

All protons @ 1 TeV.
IMC longitudinal distr.

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All protons @ 1 TeV.
Total energy in CHD.

H.E triggered protons @ 1 TeV.
Total energy in CHD.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.07708</td>
<td>0.0523</td>
<td>0.03331</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.03766</td>
<td>0.04058</td>
<td>0.00871</td>
<td>-73.85</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.06843</td>
<td>0.04656</td>
<td>0.04241</td>
<td>27.3</td>
</tr>
</tbody>
</table>
All protons @ 10 TeV. Total energy in TASC.

H.E triggered protons @ 10 TeV. Total energy in TASC.

**Calet in GEANT4**

**Electrons benchmark**

**Protons benchmark**

**Conclusion**

---

**H.E. triggered particle table:**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>3349</td>
<td>1230</td>
<td>2901</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>3277</td>
<td>1336</td>
<td>3101</td>
<td>6.894</td>
</tr>
<tr>
<td>FLUKA</td>
<td>3191</td>
<td>1369</td>
<td>3101</td>
<td>6.894</td>
</tr>
</tbody>
</table>

---

**H.E. trigger efficiency**
- GEANT 37.1%
- EPICS 31.4%
- FLUKA 34.2%

---
All protons @ 10 TeV. TASC lateral distr.

Difference with respect to GEANT4

\[
\text{diff} = \text{EPICS/GEANT4} - 1 \quad \text{(rosso)}
\]

\[
\text{diff} = \text{FLUKA/GEANT4} - 1 \quad \text{(nero)}
\]
**Calet in GEANT4**

**Electrons benchmark**

**Protons benchmark**

**Conclusion**

All protons @ 10 TeV. Total energy in IMC.

H.E triggered protons @ 10 TeV. Total energy in IMC.

**Particle table:**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.5799</td>
<td>0.4726</td>
<td>0.2214</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
<td>0.4399</td>
<td>0.4984</td>
<td>0.03238</td>
<td>-85.37</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.6217</td>
<td>0.4838</td>
<td>0.2293</td>
<td>3.572</td>
</tr>
</tbody>
</table>
Calet in GEANT4

Electrons benchmark

Protons benchmark

Conclusion

All protons @ 10 TeV.
IMC lateral distr.

All protons @ 10 TeV.
IMC longitudinal distr.

**Protons 10 TeV**

diff = EPICS/GEANT4 - 1 (rosso)
diff = FLUKA/GEANT4 - 1 (nero)
All protons @ 10 TeV.
Total energy in CHD.

H.E triggered protons @ 10 TeV.
Total energy in CHD.

### Simulation Results

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>GEANT4</td>
<td>0.1821</td>
<td>0.112</td>
<td>0.1183</td>
<td>0</td>
</tr>
<tr>
<td>EPICS</td>
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<td>0.07872</td>
<td>0.01749</td>
<td>-85.22</td>
</tr>
<tr>
<td>FLUKA</td>
<td>0.1701</td>
<td>0.1033</td>
<td>0.1203</td>
<td>1.673</td>
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</tbody>
</table>