Algorithmic differentiation in a granular calorimeter

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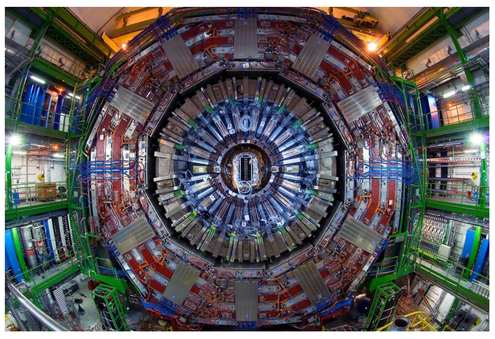
Summary

- Initial work on differentiating Geant4 simulations on electromagnetic and hadronic shower.
- Simulated single particle in a homogenous calorimeter (related work by E. Lupi and A. De Vita).
- On going investigation of remaining effects.



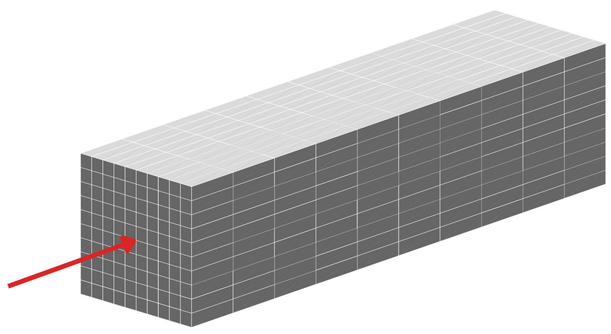
Source: https://w3.lnf.infn.it/research/particle-physics/cms/

- **Integration of Algorithmic Differentiation**: Successfully incorporated an AD tool into Geant4 framework.
- **Performance Validation**: Demonstrated the effectiveness of the AD tool in computing the derivative in a complex colorimeter geometry.
- **Potential Application**: AD could be used for optimize calorimeter designs and detector performance in the future experiments.

Introduction

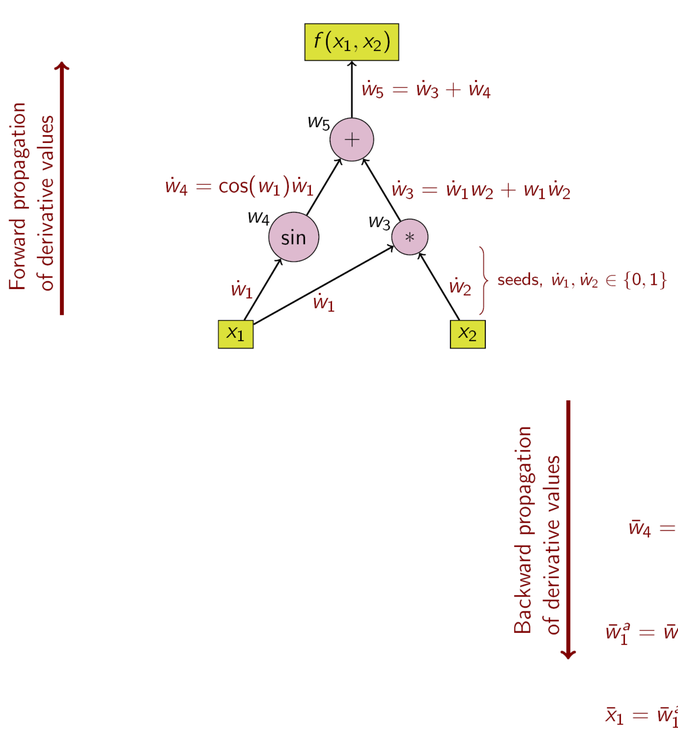
- **Algorithmic Differentiation (AD)** efficiently computes derivatives and its vital for optimization.
- **In high-energy physics**, AD can enhance detector design through end-to-end simulation.
- The work in this poster integrate AD tool within Geant4 and validate the performance and shows the potential benefits for optimizing detector design.

Calorimeter geometry



Parameters	Values
Kinetic energy of primaries	10 000 MeV
Cell size thickness (x, y)	3 mm
Cell size thickness (z)	12 mm
Number of cell (x, y, z)	100 x 100 x 100
Type of primary particles	Electrons
Type of material	$PbWO_4$

Algorithmic differentiation

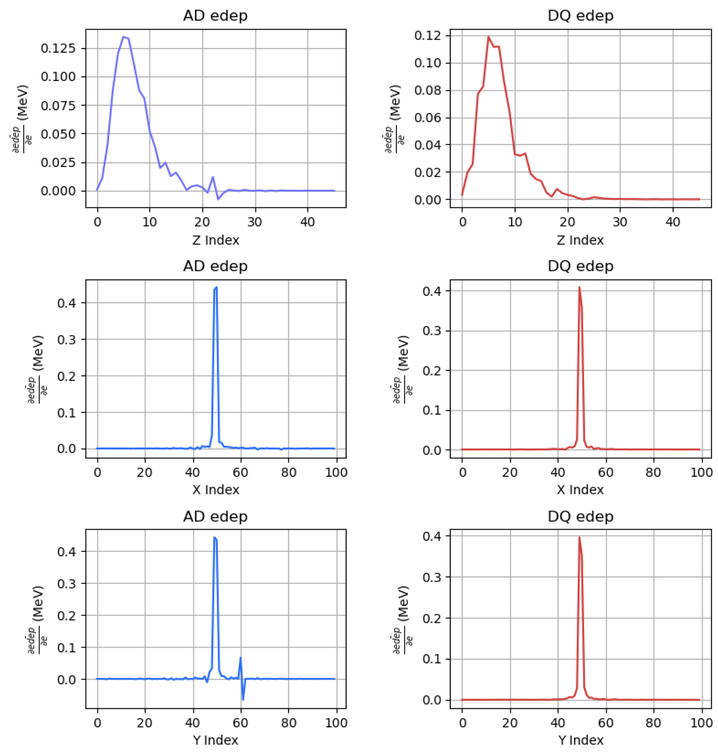


Griewank, A., & Walther, A. (2008). *Evaluating Derivatives: Principles and Techniques of Algorithmic Differentiation* (2nd ed.). SIAM.

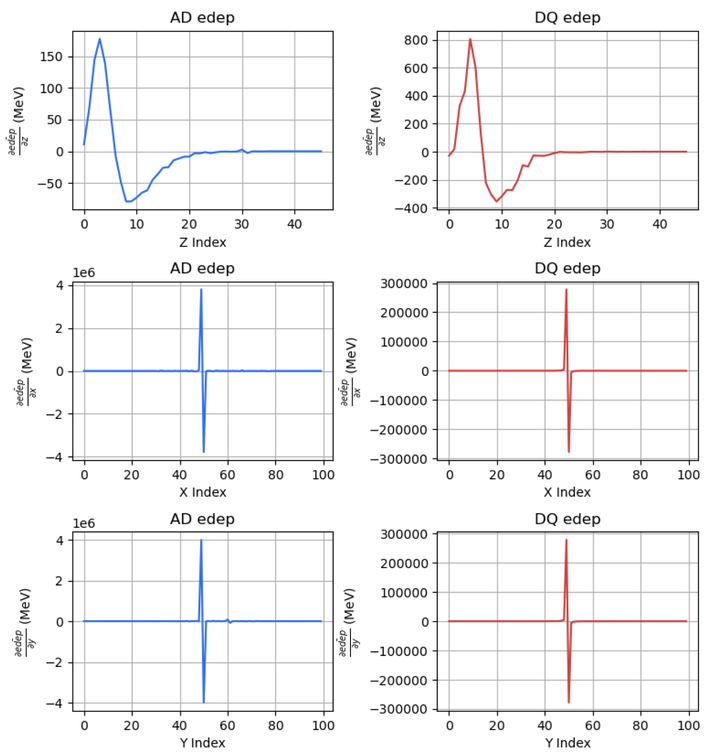
Current Results

Derivative of edep w.r.t initial energy

- Energy deposit (edep) is shown as function of X, Y, Z indices.
- The incoming primary particle: e^-, e^+, γ (gamma rays).
- Multiple scattering (MSC) are disabled.
- Run with ~8000 events in Geant4.



Derivative of edep w.r.t detector's geometry



- Energy deposit (edep) is shown as function of X, Y, Z indices.
- The incoming primary particle: e^-, e^+, γ (gamma rays).
- Multiple scattering (MSC) are disabled.
- Run with ~8000 events in Geant4.

Future work

- Refine the **AD implementation** to improve accuracy, especially for geometry-sensitive derivatives.
- Extend the use of AD to more **complex detector geometry** and setup.
- Develop AD capacities to be able to compute the derivatives for **hadronic showers**.
- This is the first step using **AD tool** for precise detector optimization.

References

1. *M. Aehle et al., 2024, "Efficient Forward-Mode Algorithmic Differentiation of Geant4", arXiv:2407.02966 [physics.comp-ph].*
2. *M. Aehle et al., 2024, "Optimization Using Pathwise Algorithmic Derivatives of Electromagnetic Shower Simulaitons", arXiv:2405.07944 [physics.comp-ph].*
3. *T. Dorigo et al., "Toward The End-To-End Optimization of Particle Physics Instruments With Differentiable Programming", Reviews in Physics Volume 10, June 2023, 100085.*

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