GFLASH – parameterised electromagnetic shower in CMS

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Outline

I. Short Introduction to GFLASH shower parameterisation

II. Parameterisation a la GFLASH in Geant4

III. Results with GFLASH in CMS

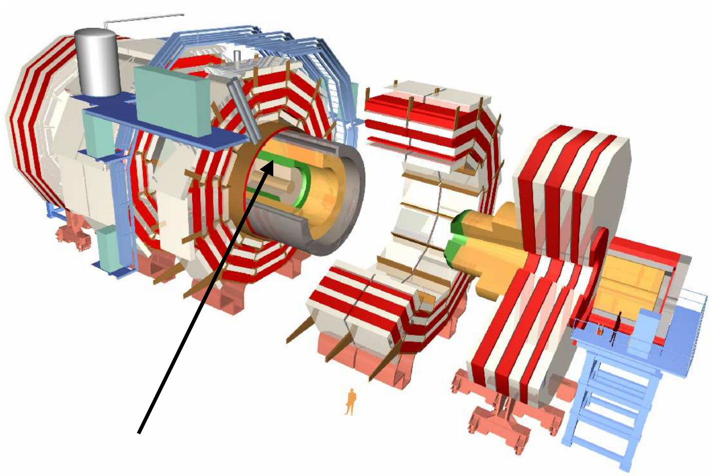
1. Tuning of the radial profiles

2. Timing and Physics performance

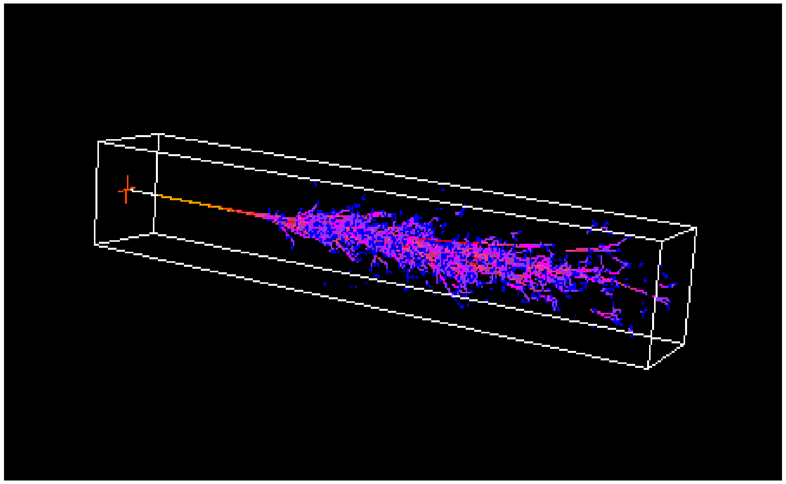
IV. **Conclusion and Outlook**

I. Short introduction to GFLASH shower parameterisation

What is GFLASH ?



CMS ECAL made of $PbWO_4$ crystals



Problem:

- Full simulation of pp events at the LHC (14 TeV) is very time consuming (O (minutes/event)) *
- Much CPU time is spent in simulating electromagnetic shower

Aim: Speed up full detector simulation in CMS (and other experiments) in the electromagnetic calorimeter

A Solution: GFLASH package (used in H1):
substitutes full tracking of high energy electrons/positrons in electromagnetic shower inside the ECAL with a parameterised shower profile
-> significant gain in speed,
not much sacrifice in precision

*Detector simulation based on Geant4

Theoretical Background

Spatial energy distribution of electromagnetic showers is given by three probability density functions:

$$dE(\vec{r}) = E f(t)\,dt\, f(r)\,dr\, f(\phi)\,d\phi$$

In ϕ the energy is assumed to be distributed uniformly: $f(\phi) = 1/2\pi$

The longitudinal profile is described by a gamma distribution:

t[Xo]: longitudinal coordinate in units of radiation length

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

The average radial energy profile can be described by (with $0 \leq p \leq 1$) :

r[Rm]: radial coordinate in units of Moliere radius

$$f(r) = \left\langle \frac{1}{dE(t)}\frac{dE(r,t)}{dr} \right\rangle = p\frac{2rR^2_{C(ore)}}{(r^2+R^2_{C(ore)})^2} + (1-p)\frac{2r\,R^2_{T(ail)}}{(r^2+R^2_{T(ail)})^2}$$

II. Parameterisation a la GFLASH in Geant4

Geant 4

“GFLASH” in Geant4

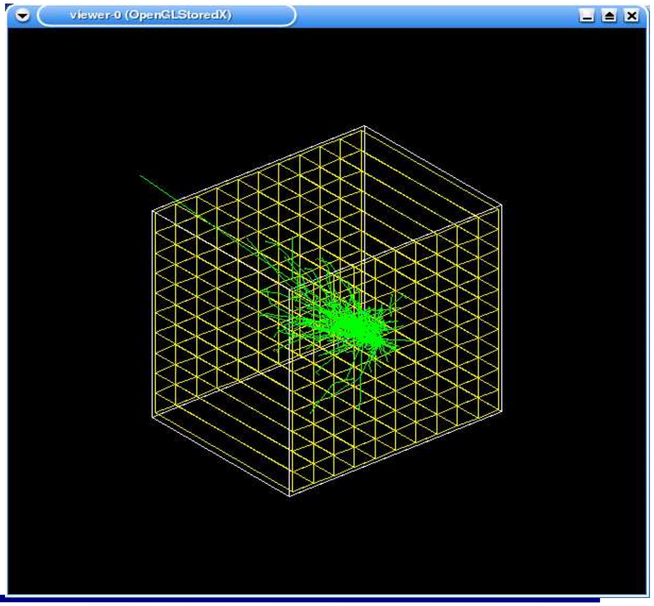
(CMS Contribution to Geant4)

Starting point: GFLASH package from H1, written in Fortran and working within the framework of GEANT3 (also Fortran)

Work done:

- Equations and parameters from GFLASH implemented in C++
- Complete object oriented redesign of the original package and integration of main ideas into the Geant4 framework
- Tests of the performance within the Geant4 framework in simple and complex use cases

➔ New implementation of 'GFLASH' (with original parameter) now available in Geant4.7.0
(geant4/parametrisations/gflash in g4 repository)*
➔Example showing how to use GFLASH library included
(geant4/examples/extended/parameterisations/gflash in g4)*



- Detailed studies / comparisons whether shower parametrization concepts used in GEANT3 still works in Geant4

Geant 4 *http://geant4.web.cern.ch/geant4/

Some technical details

- **The Parameterisation is assigned to a G4LogicalVolume (in version 4.7)) which is called the ' Parameterisation envelope'**

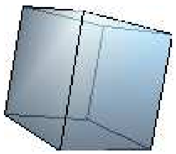
- **Energies and regions to parameterise:**
if a shower is below a (user defined) minimum energy or not fully contained (= 95 %)   in envelope -> full simulation.

- **For showers starting before the calorimeter:**
particles are tracked with full simulation until they reach the calorimeter volume, then they are parameterised one by one if they satisfy the conditions.
When a fully contained secondary is produced it is parameterised as well.

- **Photons:**
as soon as they produce $e^{+/-}$ pair, they are parameterised if they satisfy the dynamic conditions

- **Critical regions:**
critical geometrical regions can be excluded from the parameterisation

Timing



CPU time of full Geant 4.7.0 simulation and shower parameterisation for a single electron (Pentium III @ 1Ghz) in an $PbWO_4$ cube:

Electron Energy	Time / event full simulaton	Time / event GFLASH	Speed-up Factor
1 GeV	0.10	0.01	16.5
5 GeV	0.46	0.01	48.6
10 GeV	0.92	0.01	67.3
50 GeV	4.60	0.04	102.9
100 Gev	9.37	0.08	117.1
500 GeV	46.50	0.31	149.2
1000 GeV	91.75	0.57	162.0

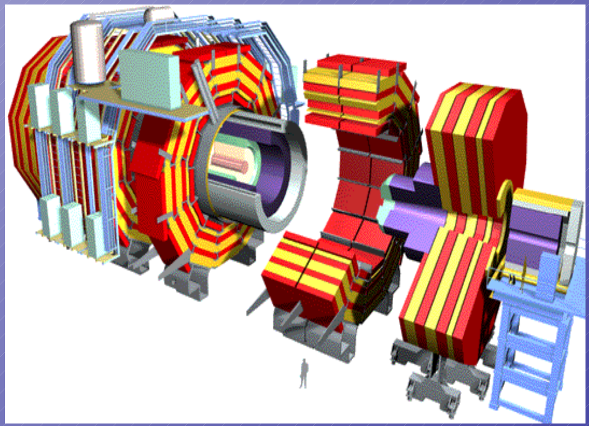
Results impressing

NEWS for Geant 4.8.0:

- GFLASH based parameterisation for sampling calorimeter now available
- GFLASH based library ported to new region based concept:

G4LogicalVolume -> G4Region as Envelop for parameterisation

III. Shower parametrization in CMS



Full integration of shower parameterisation into simulation framework of CMS (OSCAR)

- Parameterisation is triggered in the CMS barrel and endcap calorimeter
- Detailed comparisons between full and fast simulation in $PbWO_4$ were performed

- **As Test Setup for shower shape comparisons a modified version of the Geant4 example has been chosen:**

It is a simplified model of CMS ECAL module - a cube of 10 x 10 PbWO4 crystals

⇨ the model is technically easy to handle and simulation studies on this simple geometry save a lot of CPU time

Assumptions:

- Results obtained on this model can be transferred to the CMS calorimeter and its simulation with OSCAR
- (Thin) aluminium matrix between crystals is not simulated in the model and ignored for computation of material dependent parameters

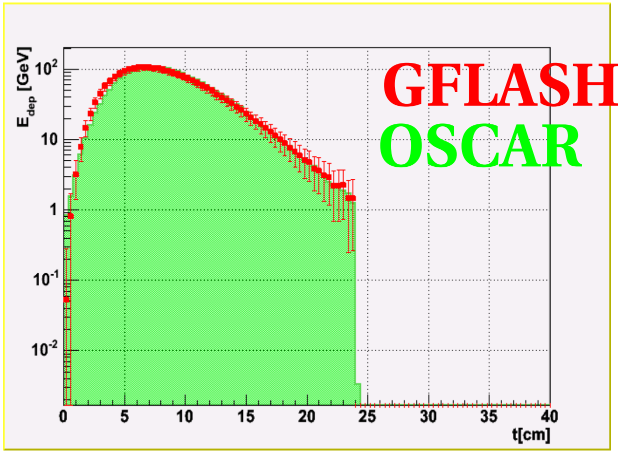
Tested scenarios:

- The performance on the model is independent of the angle between the electron trajectory and the calorimeter surface
- The performance is equally good near the crystal borders and get worse only if one shoots exactly in the crack
- The magnetic field does not have a significant influence

General observation: Parameterisations tuned on GEANT3 may need retuning to get sufficient agreement with G4, especially for the radial profiles

In CMS case:

- Longitudinal profile acceptable: ⟷



- Radial profile not correctly described, too much energy in shower core;

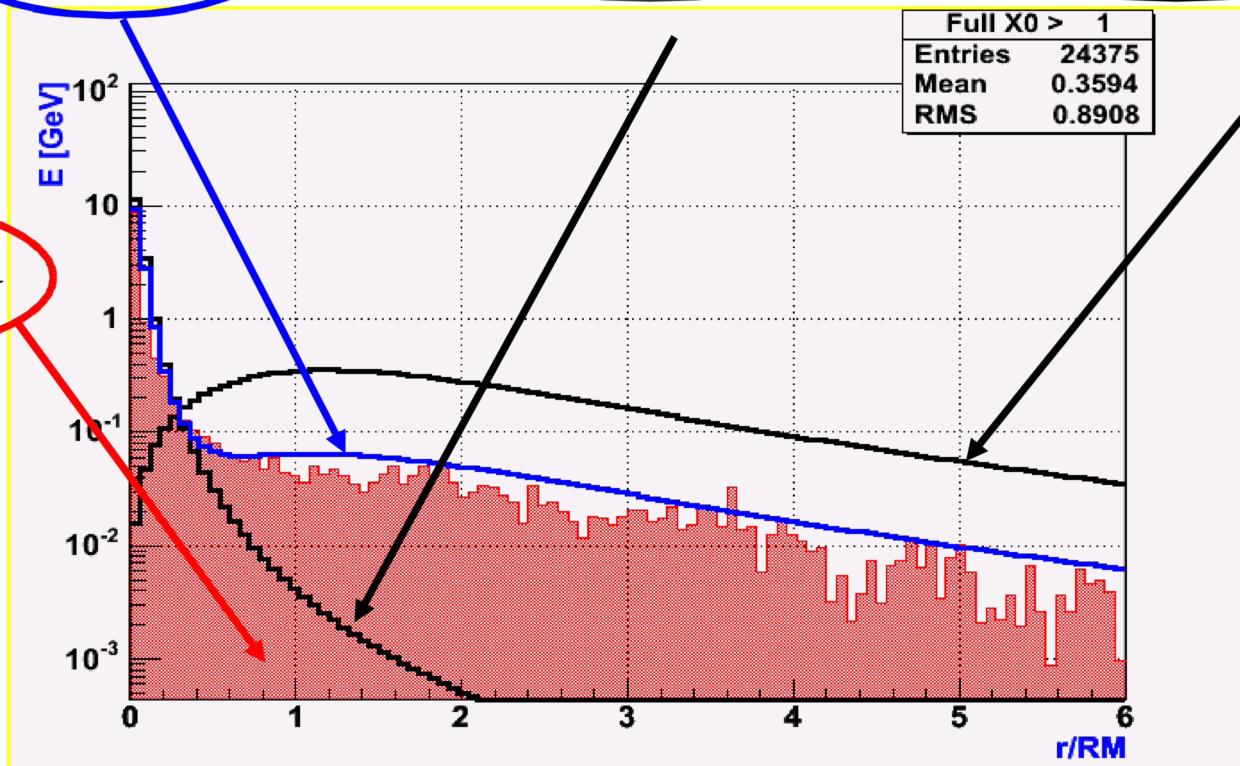
Idea: Introduce correction function for the weight function p:

$$<\frac{1}{dE(t)}\frac{dE(r,t)}{dr}> = f(r) = (p*cor)\frac{2rR^2_{C(ore)}}{(r^2+R^2_{C(ore)})^2} + (1-(p*cor))\frac{2r\,R^2_{T(ail)}}{(r^2+R^2_{T(ail)})^2}$$

Tuning of the radial profile

$$< \frac{1}{dE(t)} \frac{dE(r,t)}{dr} > = f(r) = (p*cor)\frac{2rR_{C(ore)}^2}{(r^2+R_{C(ore)}^2)^2} + (1-(p*cor))\frac{2r\,R_{T(ail)}^2}{(r^2+R_{T(ail)}^2)^2}$$

Full G4 data



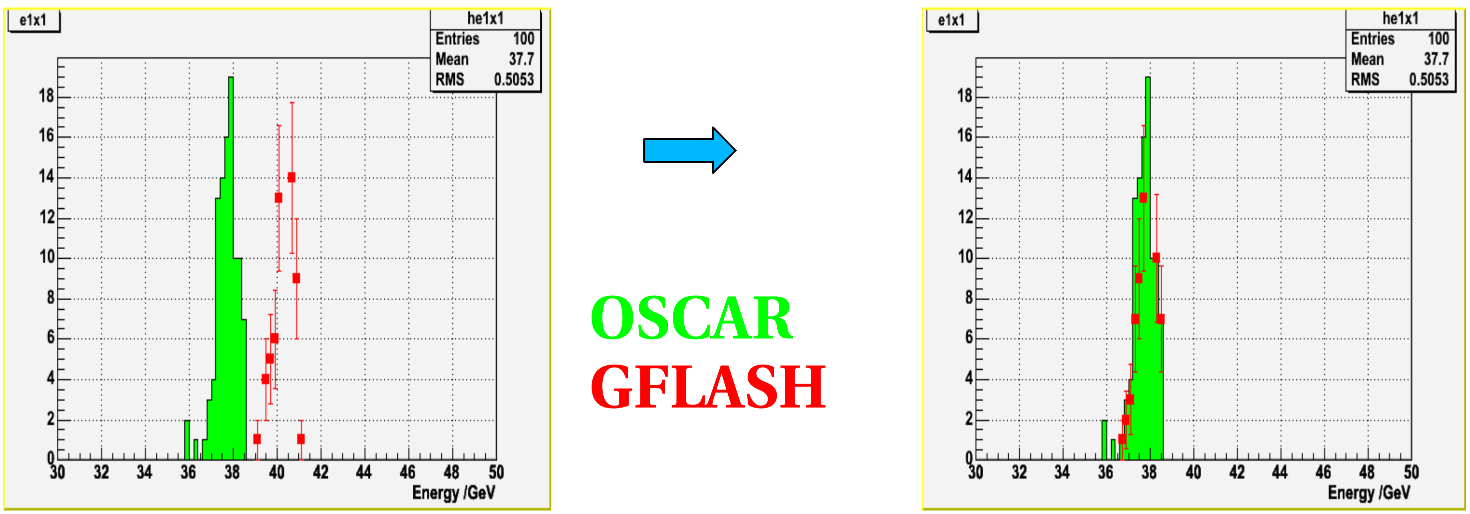
cor is the weight of the radial component as a function of t

Tuning of the radial profile

Tuning performed on simplified model:

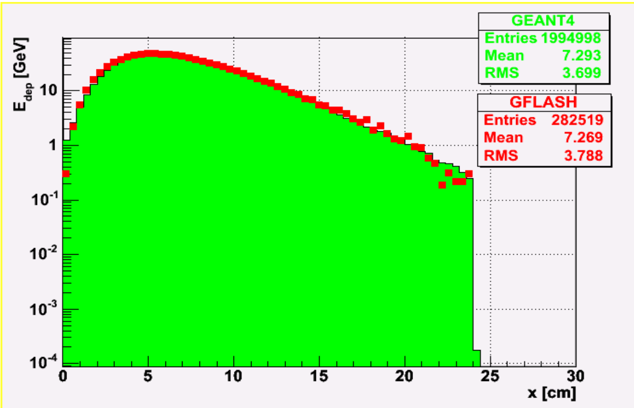
- Plot the radial profile t times in intervals of one Xo for 0 <t < n
- Fit the radial profile function in each longitudinal interval, leaving all parameter fixed and only cor free
- Fit the obtained n corrections as function of t
- Look at the energy dependence of the obtained function

-> Improved radial profile description, better agreement for energy distribution in the crystals (too much energy in the central crystal before tuning)

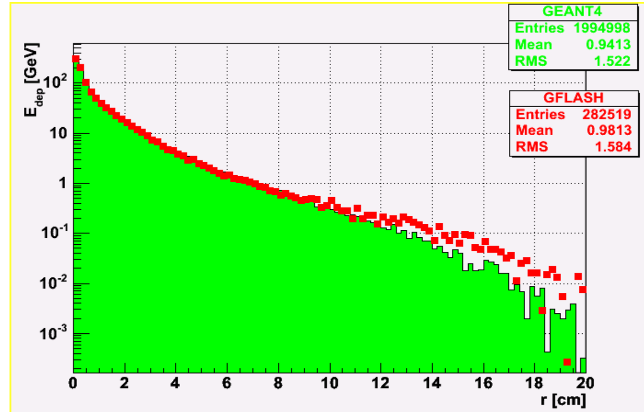


(Energy deposit in hottest crystal before and after tuning)

Longitudinal profile



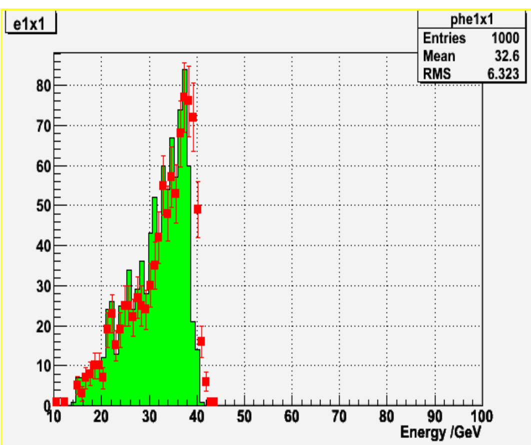
Radial profile

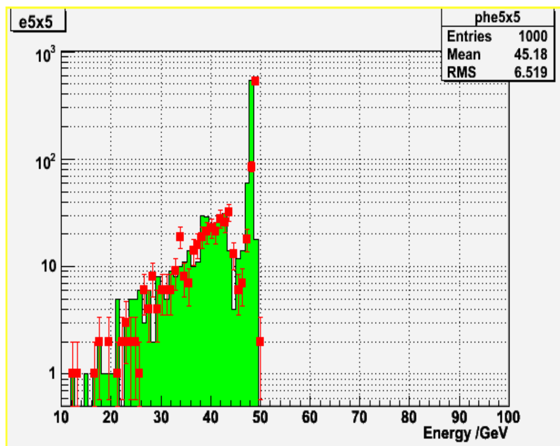


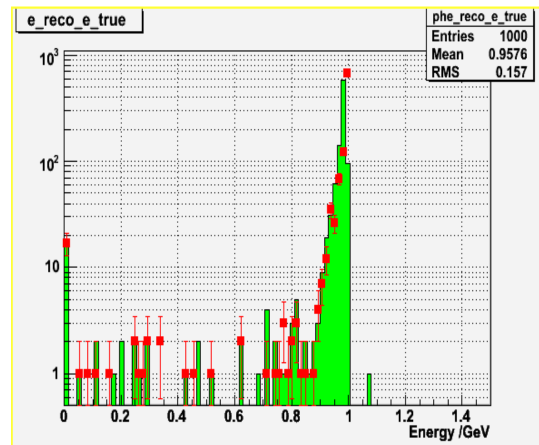
OSCAR
GFLASH

Energy deposit for single electrons (OSCAR) in

central crystal — **3x 3 matrix** — **$E_{reconstructed} / E_{generated}$**







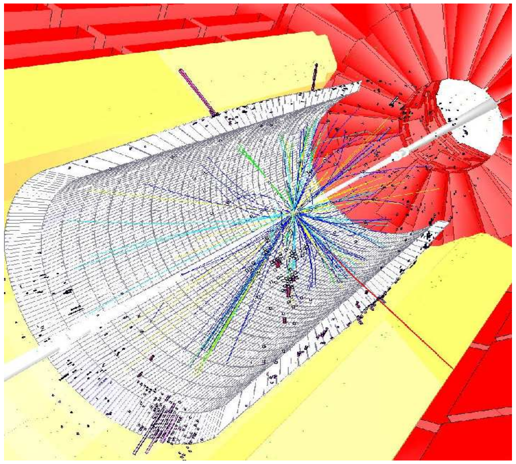
-> Agreement on percent level

Timing performance

Speed-Up in OSCAR_5_0_0 (CMS detector simulation):

• Single Electrons, flat eta distribution, fixed energy, from centre point :
(Speed-up about the same for gammas)

Electron Energy	Speed-up Factor
50 GeV	2.0
100 Gev	3.8
500 GeV	11.8
1000 GeV	7.0



•Full full LHC events :

Event	Speed-up Factor
H->4 e, Higgs mass 300 GeV	2.0
ADD Gamma (P_T > 1000 GeV)+ Graviton	3.3

(numbers of the same order in ATLAS (Barberio et al.))

-> Ongoing effort between ATLAS, CMS and Geant4 to gain more speed up and optimize physics performance

Conclusions and Outlook

Conclusions:

1. GFLASH equations and parameters implemented in C++ inside the framework of Geant4
2. GFLASH library & example for homogeneous calorimeter included in Geant4 release (from Geant 4.7.0 on)
3. Sampling calorimeter parameterisation and new region based concept available from Geant 4.8.0 on
4. Integration of shower parameterisation in the simulation framework of CMS
5. Detailed tests in physics and timing performance on simple and complex geometries
6. Tuning of the radial profile

Outlook :

- ✔ Combined effort of ATLAS, CMS and Geant4 to still speed the parametrisation
- ✔ Moving to new G4 concept of using regions instead of logical volumes inside CMS (CMS simulation based at 4.7.0 version at the moment)
- ✔ Porting GFLASH to the new CMS framework CMSSW
- ✔ Test Beam comparison inside CMSSW
- ✔ Long term: more speed-up of full events by parameterising electromagnetic sub shower in hadron calorimeter