Geant4-based simulation studies

Markus Röhrken

CERN

UIb/II ECAL Upgrade Meeting

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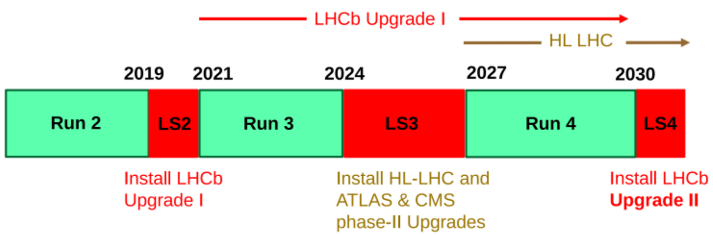
Geant4-based simulation studies

- The HL upgrade of the LHC will require operation of the ECAL of LHCb in extreme conditions.

- An upgrade of the ECAL during LS3 can (ideally) provide:
  - Radiation hardness
  - Better energy and spatial resolution
  - Fast timing



- Opportunity to improve on ECAL-related physics:
  - Final states with π^0, soft and hard γ, and electrons

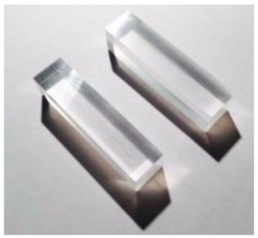
- I'm working on the Geant4-based simulations to study possible upgrade options:

  1. "Shashlik"-type sampling calorimeter
  2. Single large scintillating crystals
  3. "SpaCal"-type sampling calorimeter (fibers of scintillating crystals in absorber)

→ The aim of the Geant4-based simulation studies is to estimate the ECAL performance for various detector options and physics cases at the upgrade conditions.

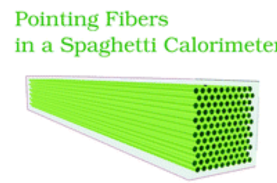
Various effects and details need to be considered in the simulation studies:

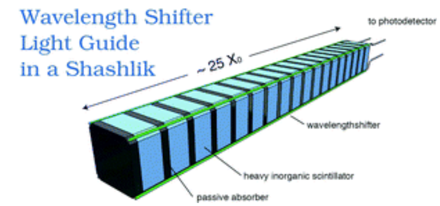
Scintillator:
- Light yield
- Energy& time resolution
- Radiation hardness, …



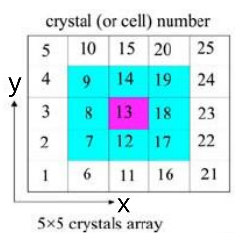
Absorber:
- Molière radius
- Sampling & resolution
- Size of the ECAL modules

Single modules:
- Choice of geometry:
  Single crystal, Shashlik, SPACAL, ACAL, …
- Light propagation and readout
- Lateral and longitudinal shower shape, energy, and time resolution

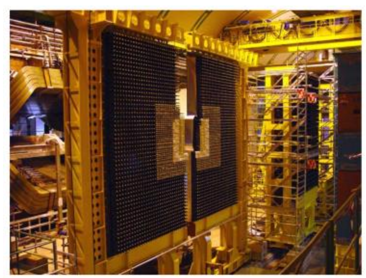




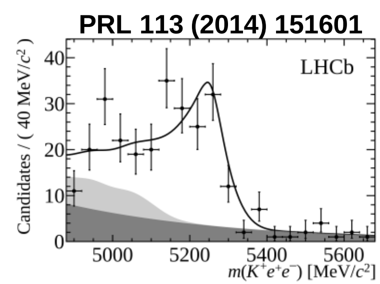
Array of modules:
- Reconstruction of energy of primary particles from clusters of detected scintillation light
- Backgrounds, occupancies, …



The ECAL:
- Interplay with other detectors
- PID, Trigger, …



Physics:
- Performance in physics analyses
- Decay mode specific

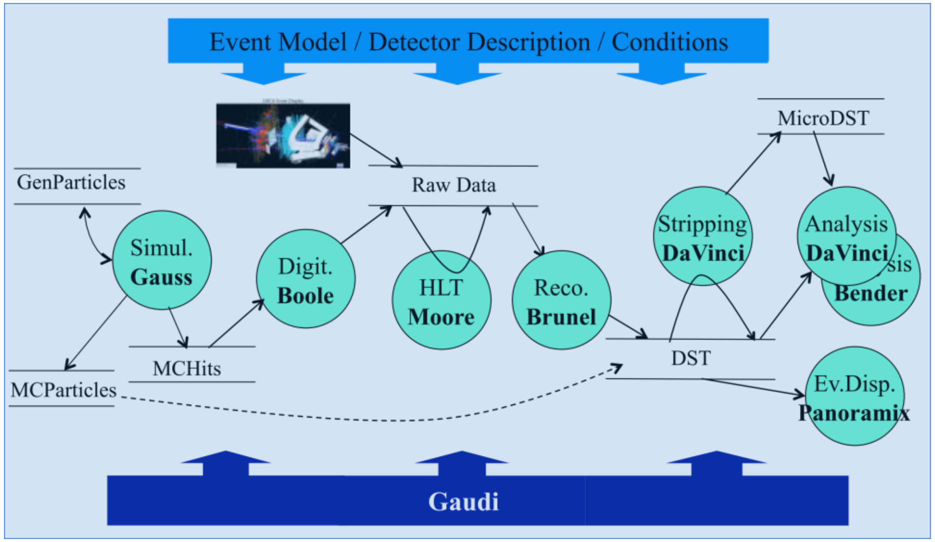


Complexity

→ The simulation and optimization studies require to account for various physics processes and a complex configuration space (nothing above is fixed)

Geant4-based simulation studies

- Initially, we attempted to perform the studies completely within the LHCb framework.
- From last meeting:



- Conventional chain:

  Gauss (Geant4) → Boole (digitization) → Moore (recon.) → DaVinci (ntuple)

- Problems with this approach:
  - The modules in this chain are hard wired to the current lead+plastic ECAL, for example the extrapolation of the light transfer and PMT response in Boole.
  - In Gauss, the ECAL code contains approximations specific for the current ECAL, i.e. with respect to timing, energy deposit, Birck's law, …

Geant4-based simulation studies

- After initial attempts to perform the studies completely within the LHCb framework, a bottom up approach turned out to be more reliable and flexible.

- Steps of the bottom up approach:

  1) Simulate and characterize individual ECAL modules for various topologies, materials and geometries in Geant4.

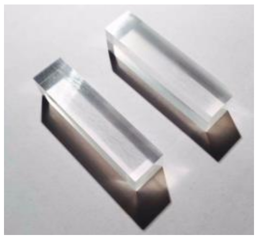
  2) Estimate expected background composition and rates at the calorimeter entrance.

  3) Assemble arrays of ECAL modules. Study their properties for various physics cases in presence of background to estimate the ECAL performance.

Options for the ECAL modules

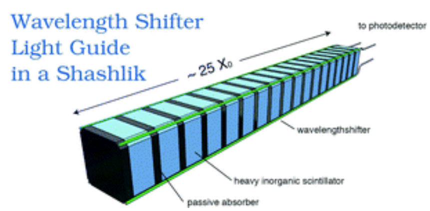
- Various topologies, and scintillator and absorber materials are considered.
- <u>Topologies</u>:

Single scintillating crystals:



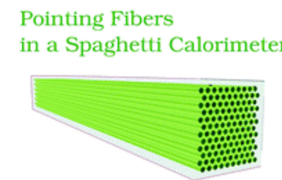
- Very good energy resolution
- Bulky, not compact
- Might be expensive

Shaslik sampling:



- Yet unsolved problem of radiation hard WLS fibres for light transport

SPACAL:



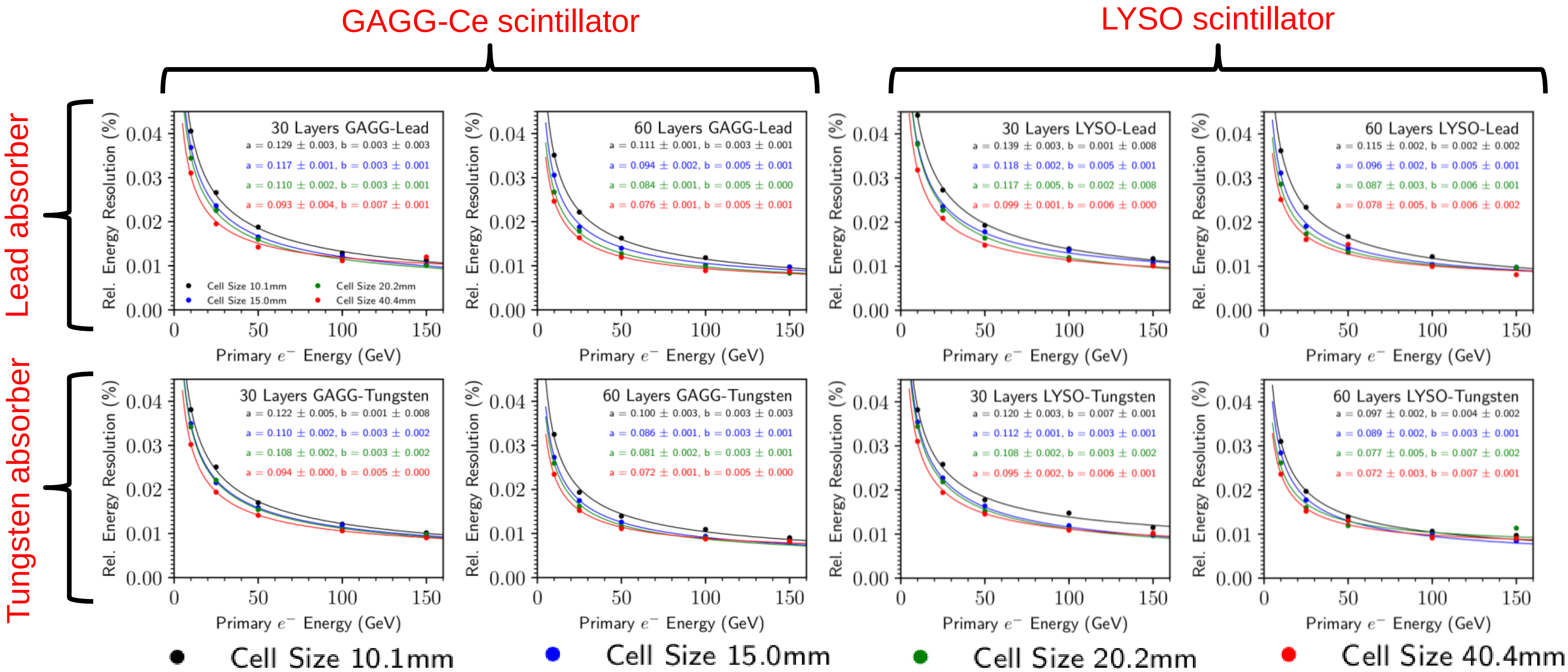
→ Please see SPACAL talk by Evgenii Shmanin

- <u>Scintillator materials</u>:
  - LYSO (rad. hard, much light, fast decay time, expensive)
  - GAGG-Ce (properties similar to LYSO, cheaper, but experimental)
  - CsI, $PbWO_4$ (for single crystal options)
  - …

- <u>Absorber materials</u>:
  - Lead
  - Tungsten
  - Addition of Cu
  - …

1) Simulation and characterization of individual ECAL modules

- Examples of single "Shashlik" sampling calorimeter cells of different sizes, absorber materials (tungsten and lead), and scintillators (GAGG-Ce and LYSO):
- Starting point is a module with 30 layers of 2mm GAGG-Ce and 4mm lead (total 25 X_0)



- The energy resolution depends on: $\frac{\sigma_E}{E} \propto \frac{a}{\sqrt{E}} \oplus b$ (a: stochastic term, b: constant term)

→ A stochastic term <10% and a constant term <1% is reachable.

2) Estimation of the background of the ECAL at upgrade conditions

- Idea by Vanya Belyaev, realization by Zhihong Shen (Tsinghua University) as summer student project.
- The idea is to “measure” the particle flow on the ECAL in simulations run at upgrade conditions (up to $\mathcal{L} = 2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$):

  1) A plane is placed on the ECAL front-face as a sensitive detector in Gauss.

  2) Info on all particles hitting the plane is written to ntuples.

  3) The background is characterized and used as input in the standalone Geant4 simulations of various upgrade options, in addition to the signal.

→ This allows to estimate the performance of the ECAL upgrade options with realistic background and occupancy conditions.

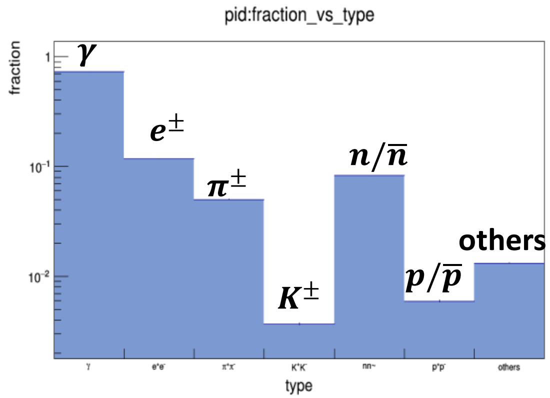
- The background maps might be also useful to Adam’s DELPHES-based parameterized simulations.
- Please also see the detailed presentation by Zhihong Shen:

https://indico.cern.ch/event/751271/contributions/3120297/attachments/1706245/2749873/calorimeter_meeting.pdf

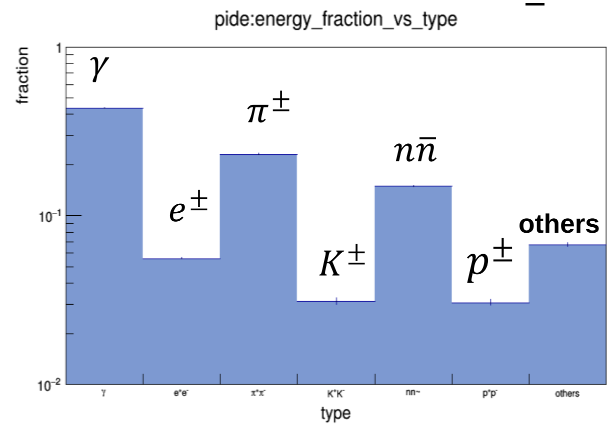
2) Estimation of the background of the ECAL at upgrade conditions

- A few plots taken from Zhihong's presentation in the calorimeter meeting:

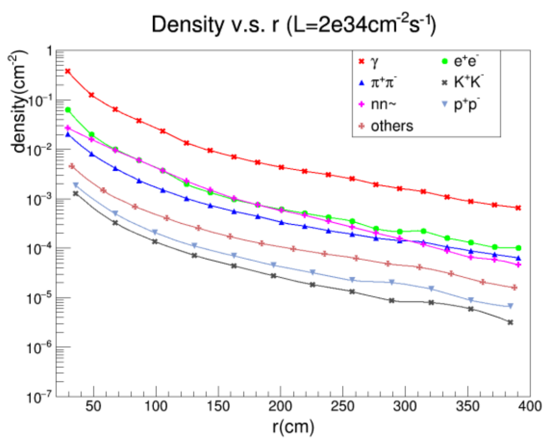
  [Please see also:
  https://indico.cern.ch/event/751271/contributions/3120297/attachments/1706245/2749873/calorimeter_meeting.pdf]



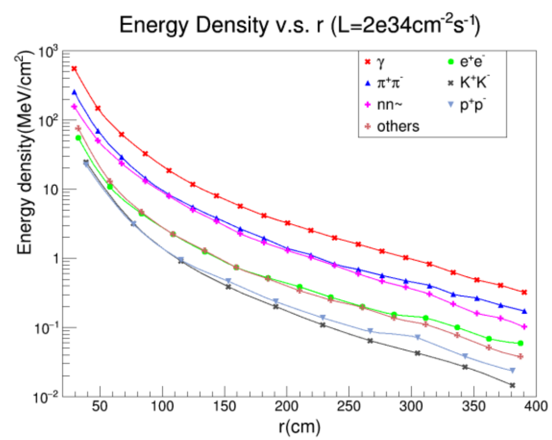
Fraction of particles



Energy fraction of particles



Occupancy



Energy flow

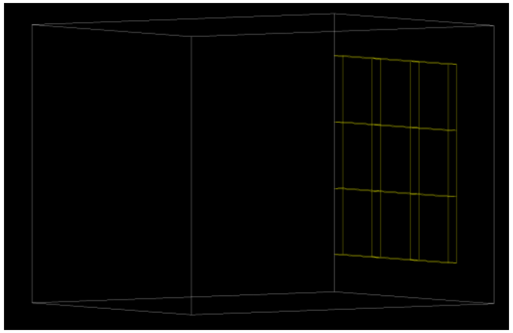
- I'm currently trying to increase the statistics of the background samples on the HTCondor systems.

3) Simulation of the ECAL

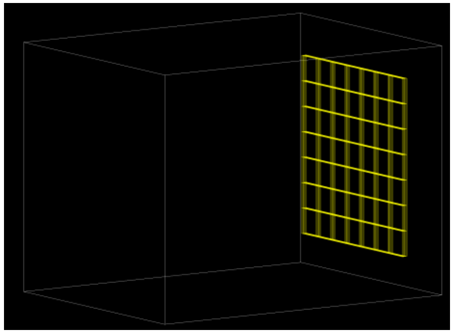
- I wrote a framework/setup to simulate arrays of arbitrary ECAL modules in Geant4:
  - The individual ECAL modules defined and characterized in Step 1) are replicated using the geometry of LHCb.
  - A modified event generator gun is used to create primary electrons and photons, together with background particles randomly sampled from Step 2).
  - All info of the simulated electromagnetic showers is written out to ntuples. (I.e. the momenta, positions, energy deposits and timing information of all secondary particles.)
- Cluster finding algorithms and the estimation of the ECAL performance (energy, spatial and timing resolution, and efficiencies as a function of spatial coordinates and incident particle's energy) is performed on these ntuples. (Work in progress.)

3) Simulation of the ECAL

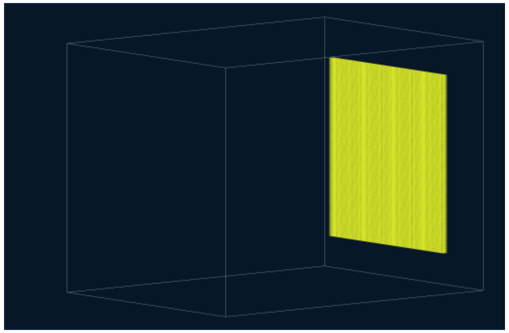
- The simulations use an adaptive x, y and z binning for the geometry, for example, to be able to optimize the ECAL cell sizes at a later step.



N_{bins} in x, y, z: 3x3x1

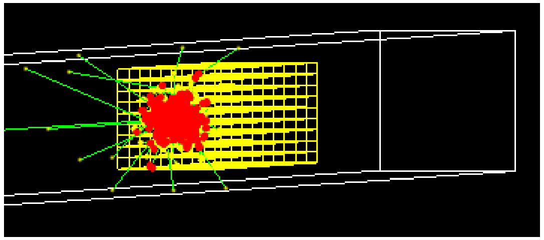


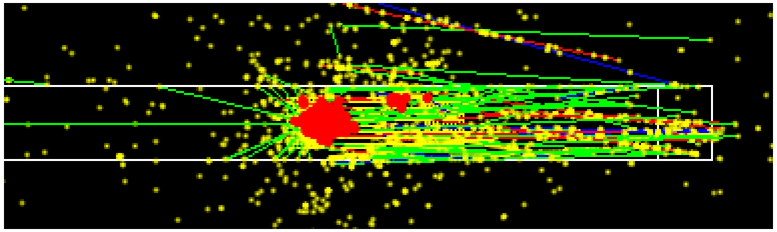
7x7x5



99x99x9

- Examples of showers wo/ and w/ background mixed under the signal event.





To do next & open issues:

- Continue on the cluster finding and analysis algorithms.
- Characterize the performance for various ECAL topologies and materials using the common setup.
- The current work focused on the simulation of the energy measurements. In addition, study effects of timing, for example using additional sub-detectors such as crystal- or silicon-based timing layers.
- Reintegrate promising ECAL configurations and algorithms back the LHCb framework to study interplay with the experiment.
- Problem of light transport, readout and digitization needs to be addressed.
- Provide Adam the info he needs for the DELPHES-based simulations.