KLOE Calorimeter Simulation with Virtual Monte Carlo

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Abstract

The calorimeter of KLOE at INFN-LNF is a high-sampling, lead/scintillating-fiber calorimeter primarily designed to detect photons with very high efficiency. During a KLOE study of kaon interactions in the apparatus walls, hints of a high efficiency for low energy neutrons (<20 MeV) were observed and confirmed by the experiment simulation. A more systematic study, involving exposing the prototype on a dedicated neutron test beam at TSL, Uppsala and detailed simulations with Geant3 and Fluka concluded on a possible explanation for the increased efficiency, mainly due to increased neutron inelastic scattering on lead and the high sampling ratio. In this study we repeat the simulation using the Virtual Monte Carlo interface as a front-end to Geant3 and Geant4 and compare with existing simulation results and test beam data.

The KLO(n)E calorimeter

The KLONE (KLOe Neutron Efficiency) group has measured the neutron detection efficiency of a KLOE calorimeter prototype, at The Svedberg Laboratory (TSL), Uppsala,
Oct 2006 – Jun 2007, performing also the whole simulation of the experiment.

Motivations:

✓ Detection of neutrons of few to few hundreds of MeV is traditionally performed with organic scintillators (elastic neutrons scattering on H atoms ⇒ production of protons detected by the scintillator itself) ⇒ efficiency scales with thickness ⇒ ~1%/cm

✓ Preliminary measurement at KLOE (neutron from K^- beam pipe interactions) showed an efficiency of ~40% for $E_{kin} \leq 20$ MeV. An efficiency of ~10% would be expected if the response were only due to the equivalent amount of scintillator in the calorimeter

✓ Enhancement of neutron detection efficiency for fast neutron is observed in presence of medium-high Z materials, particularly lead, as in the extended range rem counters for radiation protection

✓ The KLOE e.m. calorimeter has an excellent time resolution, good energy resolution, and high efficiency for photons. If a high neutron detection efficiency were observed, this could also be the first of a novel kind of neutron detectors

Neutron detection is important for the DAFNE-2 program @ LNF:

- AMADEUS: study of deeply bounded kaonic nuclei
- DANTE: measurement of nucleon time–like region e.m. form factors

Active material:

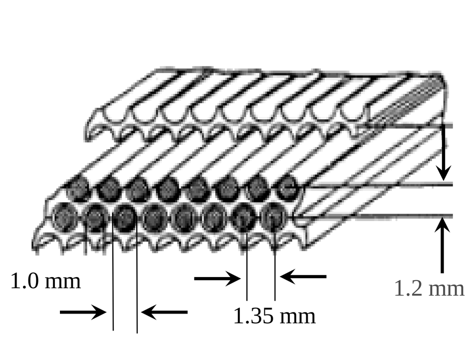
- 1.0 mm diameter scintillating fiber (Kuraray SCSF-81, Pol.Hi.Tech 0046), emitting in the blue-green region: I_{Peak} ~ 460 nm
- Core: polystyrene, r=1.050 g/cm³, n=1.6

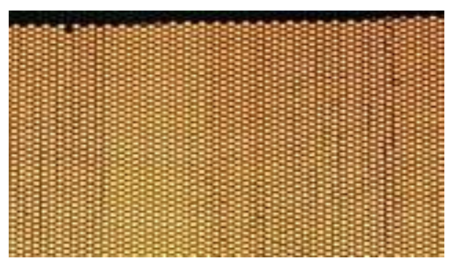
High sampling structure:

- 200 layers of 0.5 mm grooved lead foils (95% Pb and 5% Bi)
- Glue: Bicron BC-600ML, 72% epoxy resin, 28% hardener
- Lead:Fiber:Glue volume ratio = 42:48:10

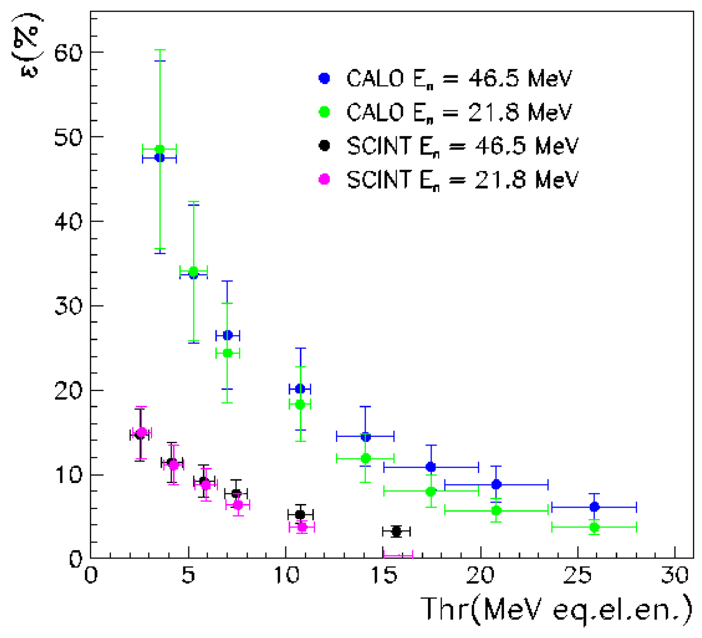
Good time resolution, energy response and high photon efficiency

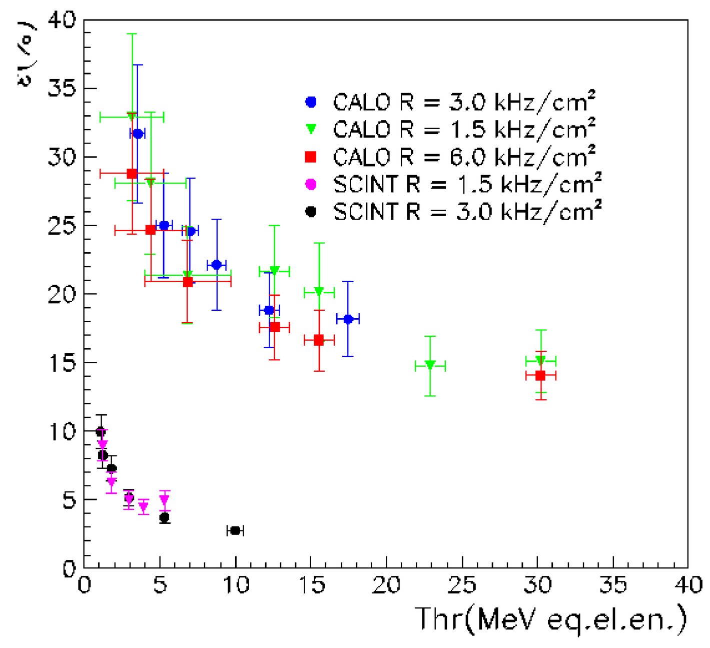
$s_E/E = 5.7\% / \sqrt{E(GeV)}$ *$s_T = 54$ ps $/ \sqrt{E(GeV)}$*





- Energy scale set using MIP calibration of all channels, and using the MIP/MeV scale factor of the KLOE experiment
- Energy cut-off introduced by the trigger evaluated by fitting with a Fermi-Dirac function the ratio of total/cluster energy at different thresholds
- Systematic errors on vertical scale dominated by halo subtraction and absolute neutron flux
- Systematics on horizontal scale conservatively assigned by the difference between cut-off determined with an independent method (cosmics and neutron data triggered with an .OR. Between scintillators and calorimeter)
- Stability w.r.t. very different run conditions: a factor 4 variations of live time fraction (f_{LIVE}=0.2 → 0.8) and beam intensity (3 → 10 kHz/cm²)





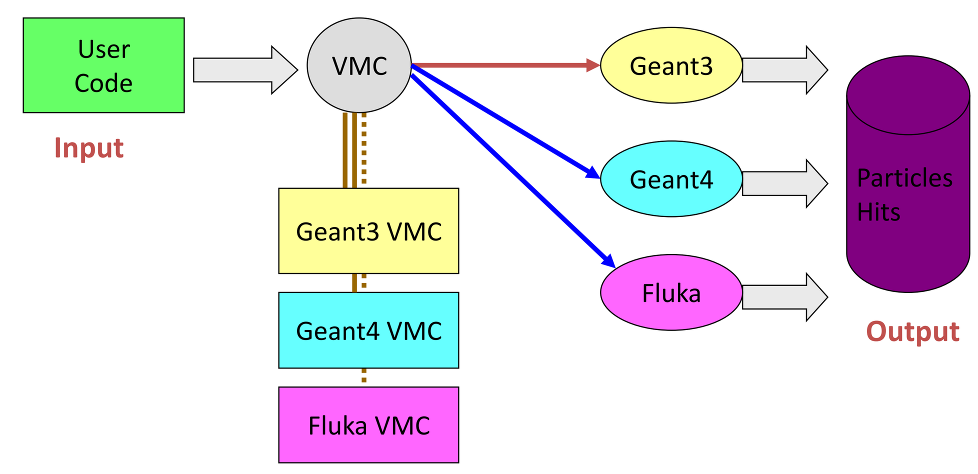
Very high efficiency,
about 4 times larger than what expected if only the amount of scintillator is taken into account (~ 8% for 8 cm of scintillating fibers)

The Virtual Monte Carlo

The problem: Consistent detector description for several MC particle transport codes

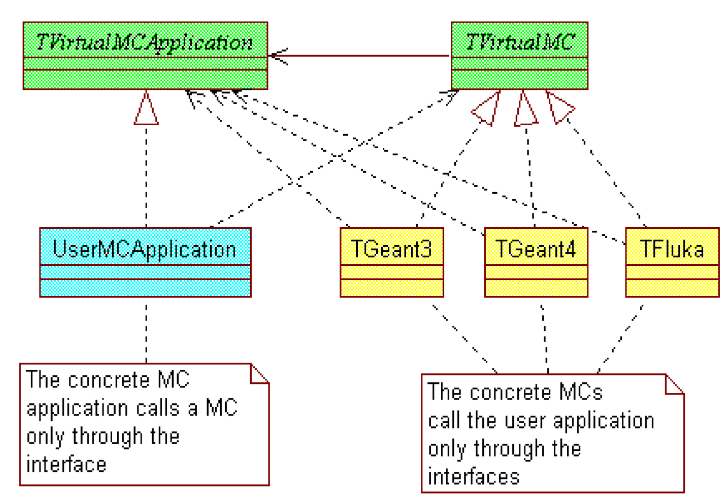
- GEANT3: The de-facto standard for many years
  - Excellent handling of EM physics
  - Hadronic physics not really including newer models
- Geant4: mature enough to replace GEANT3 in most applications from the point of view of physics simulation and detector description
  - Modern, modular C++ design and newer physics models
  - Many interfaces for I/O and visualization
- FLUKA: Quite advanced physics models quoted
  - Rather unique I/O structure makes interaction with other packages challenging
  - FLUGG interface quoted as unstable for ALICE detector and has not been recently maintained
  - Flair seems convenient for standalone FLUKA usage though…
- Each framework has its own way of defining geometries, materials boundaries and interaction limits!

VMC Concept (The ALICE-LHC collaboration)



(Schematic courtesy of VMC developers)

VMC Design (The ALICE-LHC collaboration)



(Schematic courtesy of VMC developers)

Application of VMC for the KLOnE calorimeter

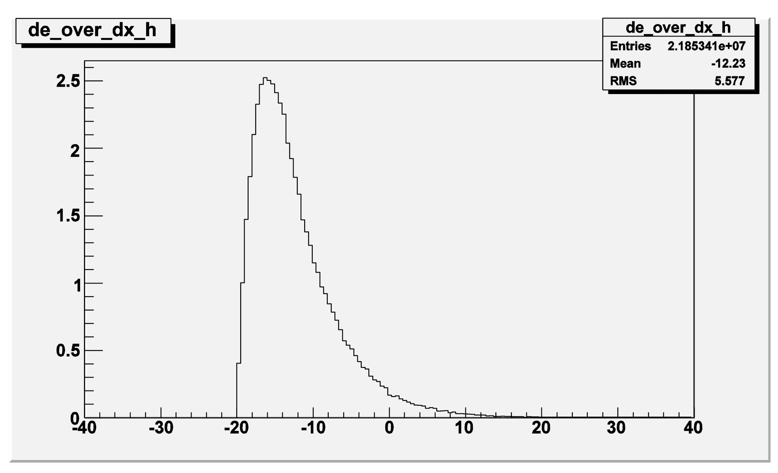
Specific advantages in using VMC

- ✓ GEANT3 and Geant4 interfaces tested by ALICE collaboration. In fact, early VMC API was based on GEANT3 API (now obsolete) and ROOT Geometric Modeller is based on Geant4 (replaced the GEANT3-like VMC API). FLUKA interface was also created by ALICE-FLUKA collaboration
- ✓ Front-end is ROOT C++ code. User creates geometry in ROOT Geometric Modeller. Can be saved as .root file, .xml file, visualized within ROOT
- ✓ Change of all parameters (materials, geometry, active physics processes) from within a unique set of C++ macros
- ✓ Except the Geant4 and Fluka simulation requirement, GEANT3 simulation comes "as a bonus"

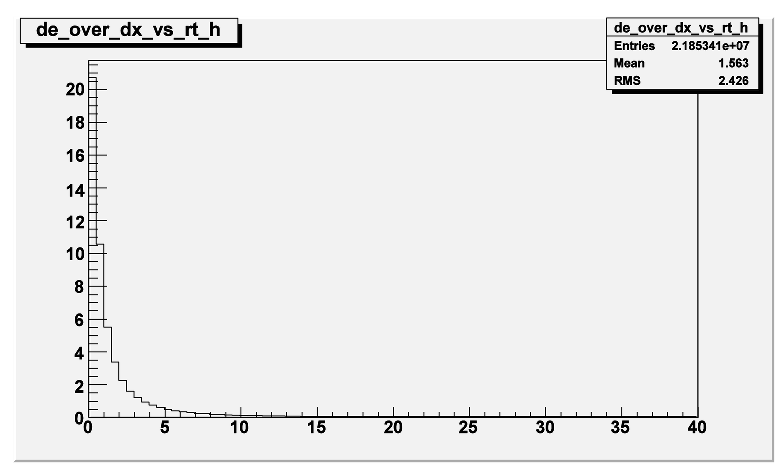
Strategy for using VMC

- Built a VMC application, following one of the existing examples from geant4_vmc (they are backend-independent, can be used by Geant4 and Fluka)
  - Essentially a list of C++ files that build into an executable linking with dynamic libraries (VMC, MC, ROOT) and some configuration scripts
  - An SVN repository was setup for code versioning
  - Use KDevelop as IDE for development under GNU/Linux (SLC4/5)
- Defined the geometry in ROOT Geometric Modeller, using as input the G3 simulation code and documentation
  - The geometry is essentially C++ code, one or more dynamically loadable C++ macros
- Have to check the feasibility of a good neutron source simulation within this framework
  - For the moment a simple "momentum-space box"
  - This should be also part of the VMC application code
- The physics processes and materials are loadable C++ macros, no need for rebuilding the application
- Define the metrics, ie histograms and other useful output. This is partly in the VMC application and partly in C++ macros that contain the actual analysis
- Run TGeant4 (VMC for Geant4) simulation and validate against existing results. Repeat with TGeant3 and TFluka. Do this for various materials, physics lists and geometries as needed

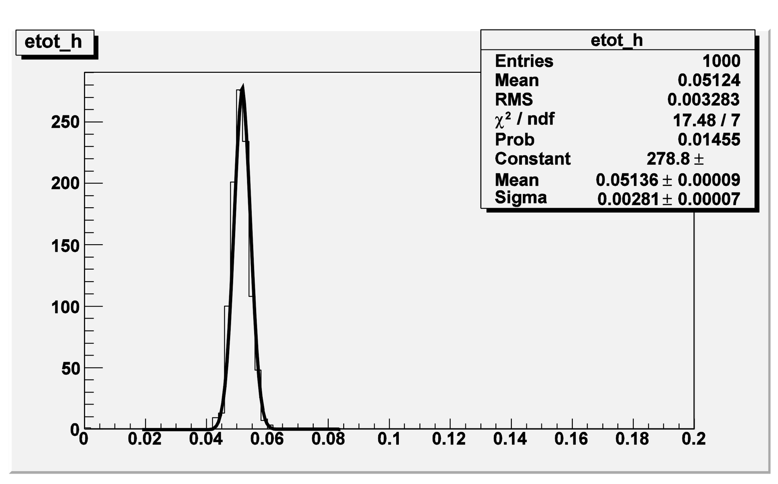
Preliminary validation results (sample analysis)



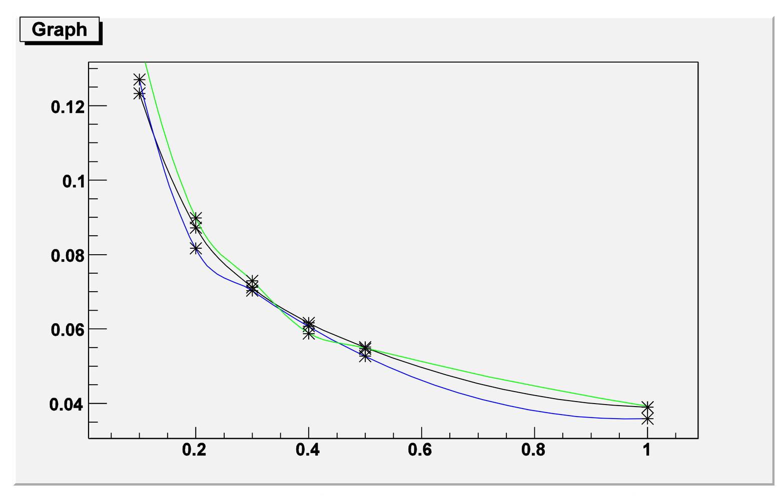
Longitudinal shower profile, GEANT3, 1000 events of 500 MeV e-



Lateral shower profile, GEANT3, 1000 events of 500 MeV e-



Example of resolution calculation for an energy slot



Preliminary comparison of resolution obtained with GEANT3 (green), Geant4 (blue) versus test beam data

Conclusions and Plans

- ✓ A generic VMC application has been developed that allows the simulation of an arbitrary detector geometry without need to rebuild
- ✓ Preliminary results for electromagnetic showers show agreement between GEANT3, Geant4 and test beam data
- ✓ The "hits" part of the simulation is more or less complete. Need to implement the digitization of the signal, from the scintillation to the PMT readout
- ✓ After validation of the electromagnetic calorimeter, move to proton/neutron projectiles to simulate hadronic calorimetry

References

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