Parametric simulation of the SCT detector

Belozyorova Maria, Razuvaev Georgiy, Vorobiev Vitaly
BINP

Introduction

A detector simulation is one of the most important stages of its design. Traditionally, the GEANT4 is used for this, but it requires large computing, time and human resources, while the parametric simulation does not suffer from such issues and can fulfil initial needs.

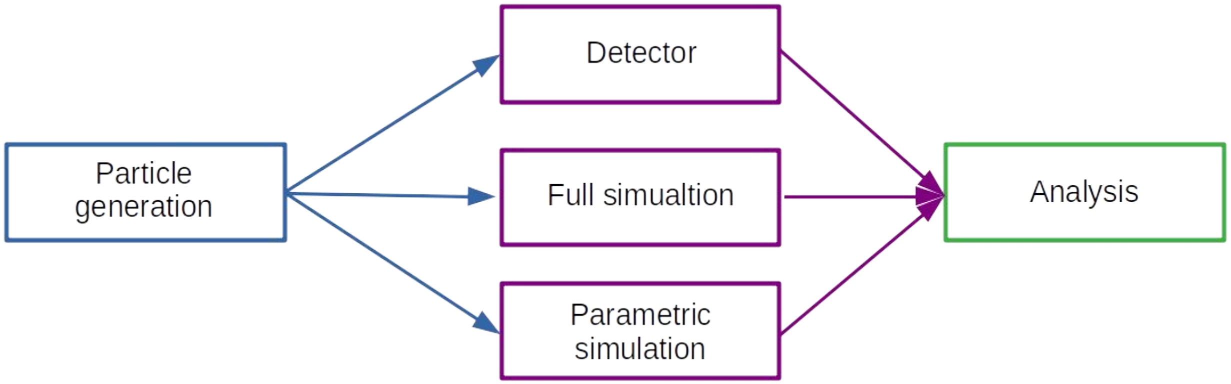
The software for parametric simulation can already be used to make critical decisions on the detector design or to develop analysis software.

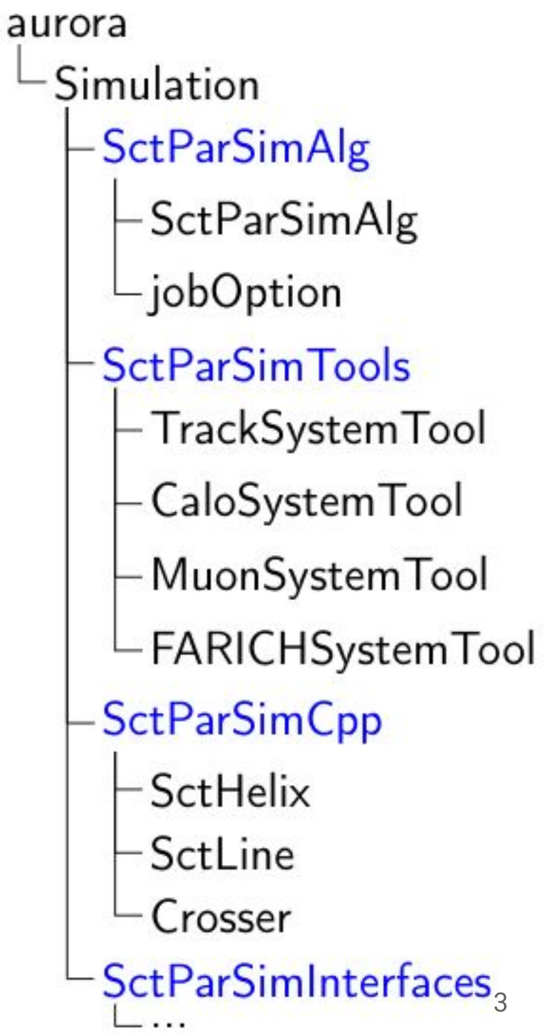
Parametric simulation

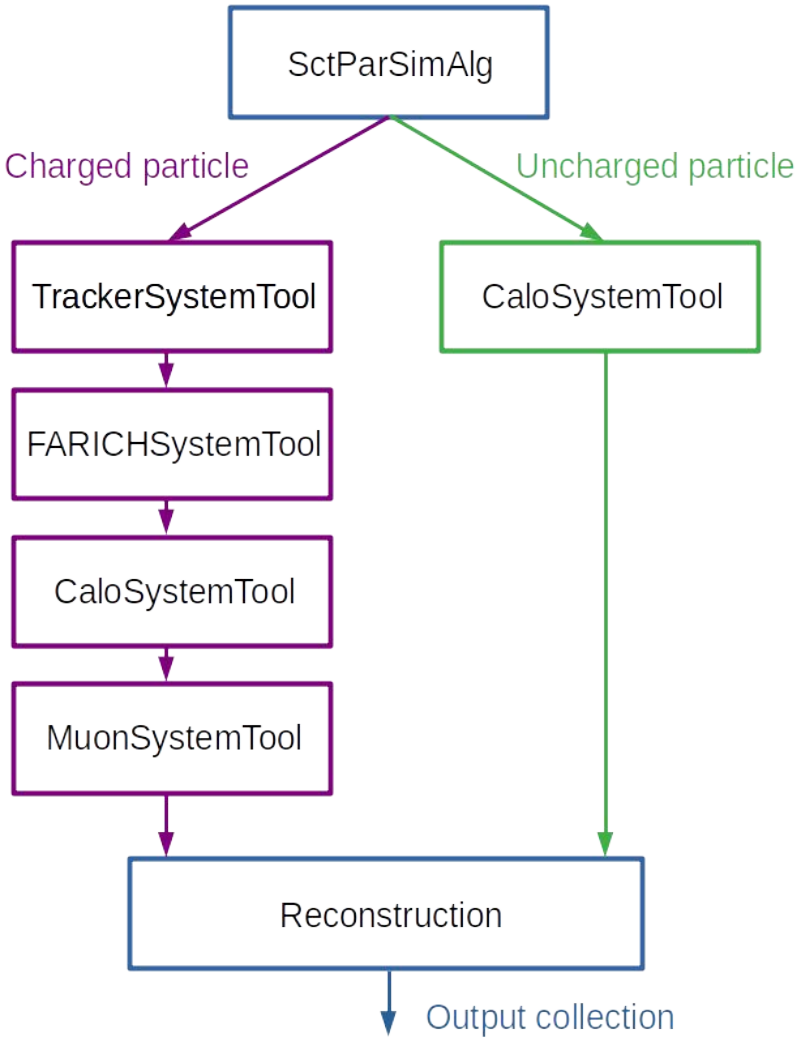
The parametric simulation is developed using the Aurora framework and written in C++.

The software uses elements of a fast simulation for subsystems whose work is well known

The simulation yields the detector response in the same manner as the result of the full simulation.







The parametric simulation simulates the whole detector. There is no detailed description of the particle interaction with matter. For example, there are no particle decays.

The main algorithm collects responses from each detector subsystem for each primary generated particle. The responses are stored in an output collection, while input particles can be generated in advance or just in time.

The subsystems parameters

Main algorithm

- Detector magnetic field
- The type of most probable particle

Track system

- Geometric sizes
- Registration probabilities for different momentum
- Resolution parameters
- Radius and location of wire layers

FARICH PID

- Geometric sizes
- The path to the file with response histograms of FARICH

Calorimeter system

- Geometric sizes
- Cluster sizes (separately for gammas and other particles)
- Resolution parameters
- Minimum detectable energy

Muon system

- Geometric sizes
- The path to the file with response histograms of muon system (pions and muons)

The tracker

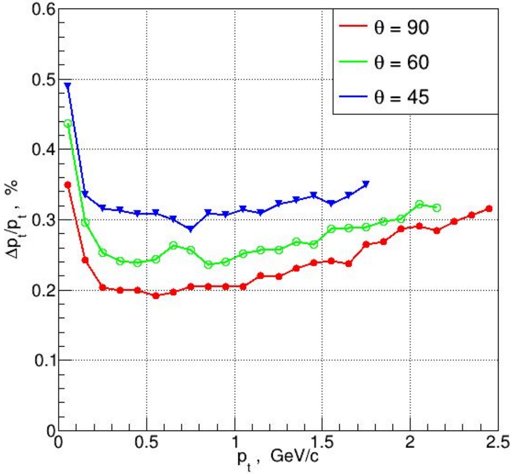
The track resolution is

$$\sigma(p_t) = p_t\sqrt{(\alpha p_t)^2 + \beta^2},$$

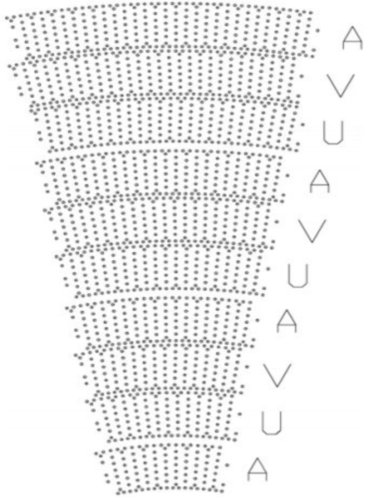
$$a = a_0\frac{L_0^2}{L^2}\sqrt{\frac{42}{N+1}}$$

$$b = \frac{0.0539}{\beta B}\frac{(1+cos^2\theta)^{3/4}(1+ln\frac{L_{tr}}{X_0}))}{\sqrt{LX_0 sin\theta}}$$

where B - the magnetic field strength, X_0 - the radiation length, θ - the particle departure angle to the drift chamber axis, β - the particle speed, N - the number of hits, $L_0 = R_{max} - R_{min}$, L_{tr} - the track length



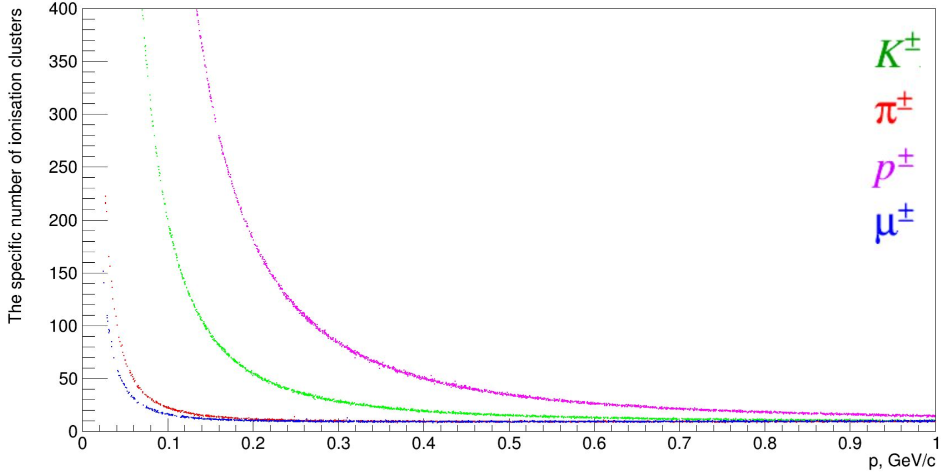
Momentum resolution as a function of momentum depending on polar angle for π^+



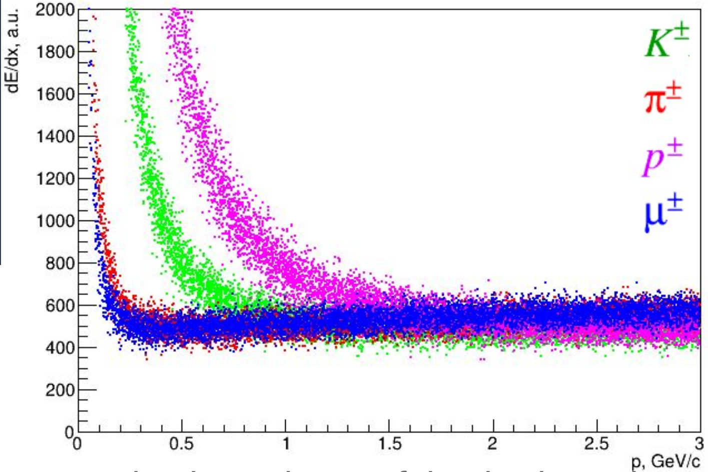
The tracker wire structure

dE / dx and dN_{clust} / dx

The parametric simulation has two options in the tracker to the particle identification: an ionisation clusters counting (dN_{cl}/dx) and dE/dx.



The dependence of the specific number of ionization clusters on the momentum in the tracker system



The dependence of the dE/dx on the momentum in the tracker system

The dN_{cl}/dx is distributed over the Poisson distribution with parameter

$$\sigma\left(\frac{dN_{cl}}{dx}\right) = (\delta_{cl} L_{track})^{-1/2}\left(\frac{dN_{cl}}{dx}\right)$$

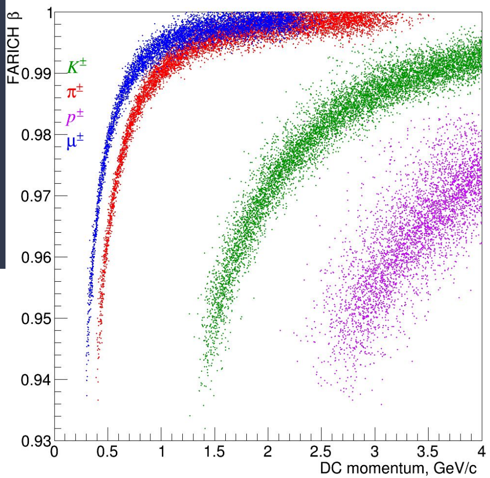
where δ_{cl} = 12.5 / cm for He/iC_4H_{10} = 90/10, L_{track} - the particle track length in the tracker.

The σ(dE/dx) is parameterized as

$$\sigma\left(\frac{dE}{dx}\right) = \alpha\left(\frac{dE}{dx}\right)^{\beta} dx^{\gamma}$$

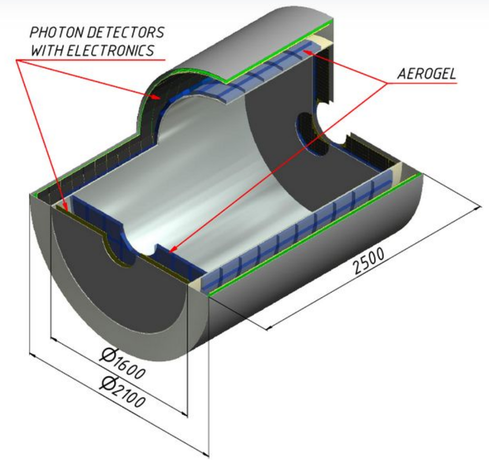
where α, β, γ is tuned on BaBar data.

The FARICH PID system

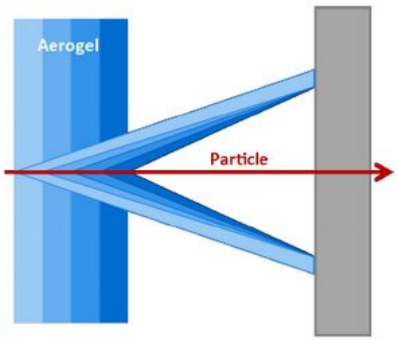


The dependence of the particle β factor on the momentum in the FARICH PID system

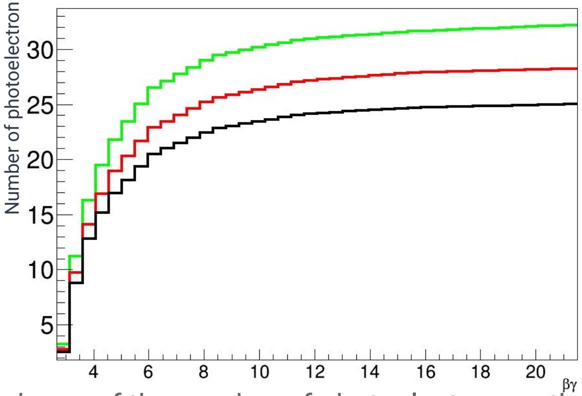
The FARICH PID system works using the results of the full GEANT4 simulation. The system output is the particle speed and number of photons.



The scheme of the SCT detector FARICH system



The Focusing Aerogel RICH concept

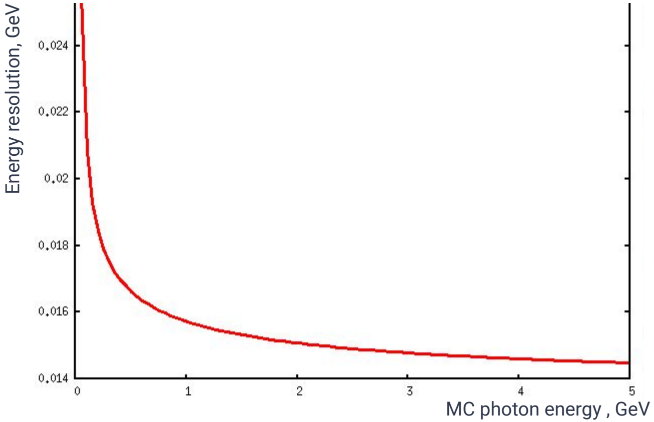


The dependence of the number of photoelectron on the βγ factor in the FARICH PID system for different angles (black - 10°, red - 30°, green - 45°)

The calorimeter

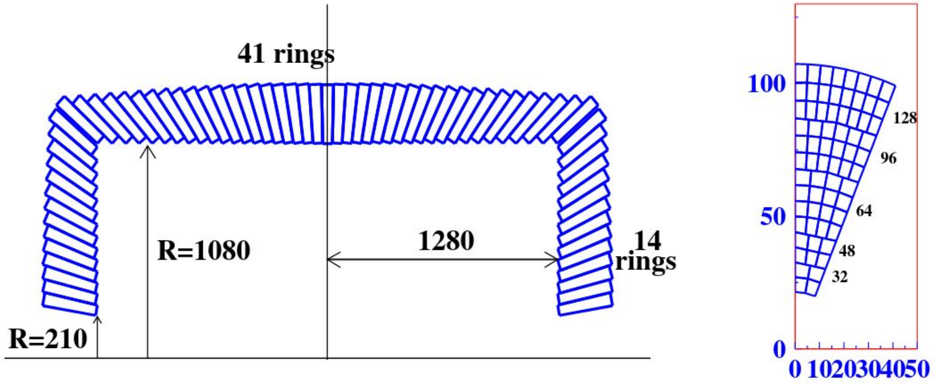
The calorimeter resolution is

$$\sigma_E = E\sqrt{0.000134^2 + \left(\frac{0.00066}{\sqrt{E}}\right)^2 + \left(\frac{0.00081}{\sqrt[4]{E}}\right)^2}$$



Energy resolution

The calorimeter based on CsI scintillating crystals. The crystals form is truncated pyramid.

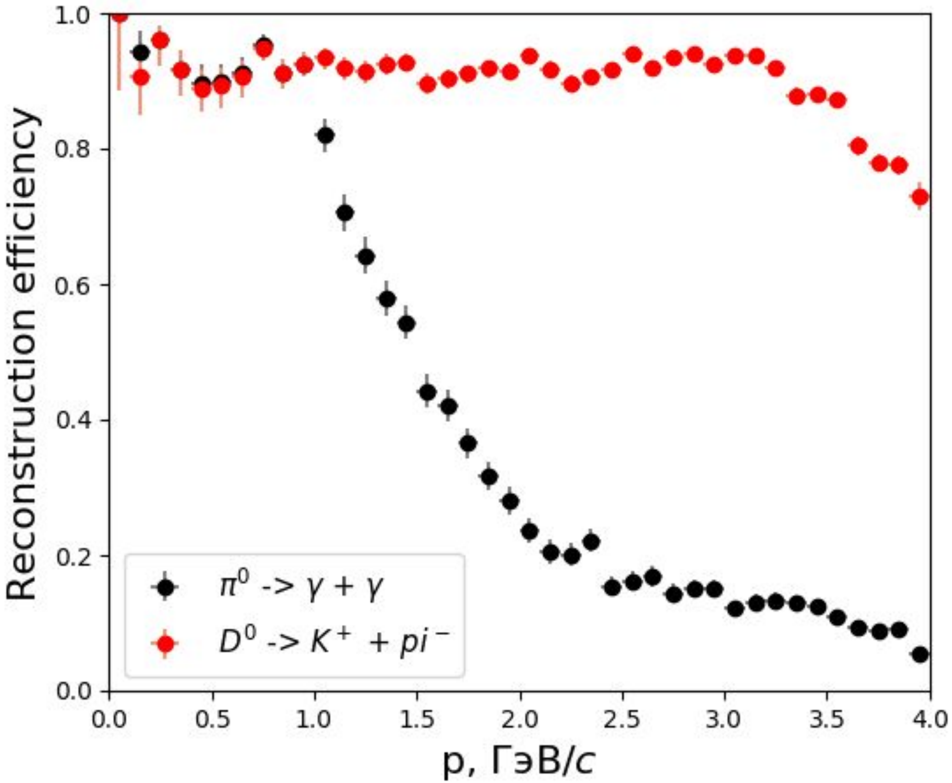


Disposition of the counters in the calorimeter: Z-projection (left), one sector of the endcap calorimeter (right)

The cross-linking data obtained by the track system and the calorimeter is implemented. This is implemented taking into account the geometric intersection of the calorimeter clusters.

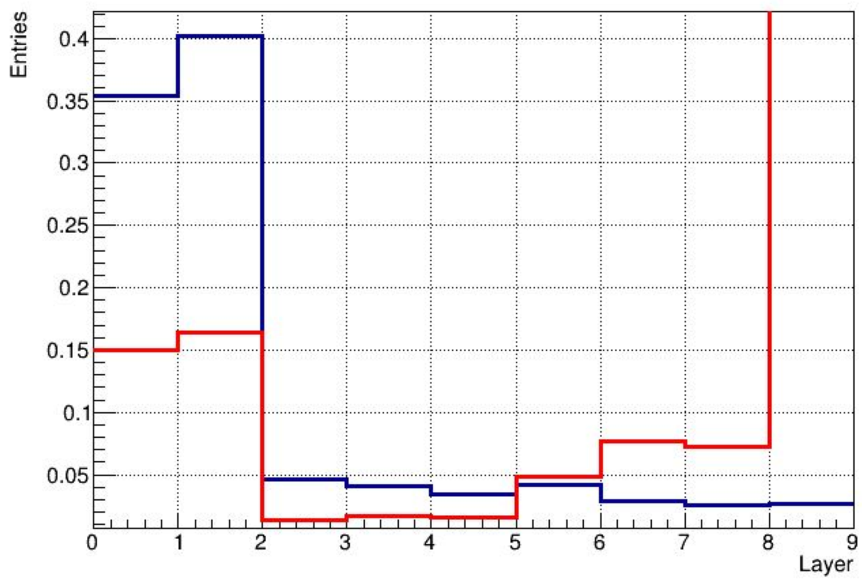
The algorithm for the cross-linking data obtained by the track system and the calorimeter:

- union of geometrically intersecting calorimetric clusters
- finding a match between calorimetric clusters and tracks
- recalculating cluster characteristics (time, energy, cluster size, conversion point)



The reconstruction efficiency for different particle types

The muon system

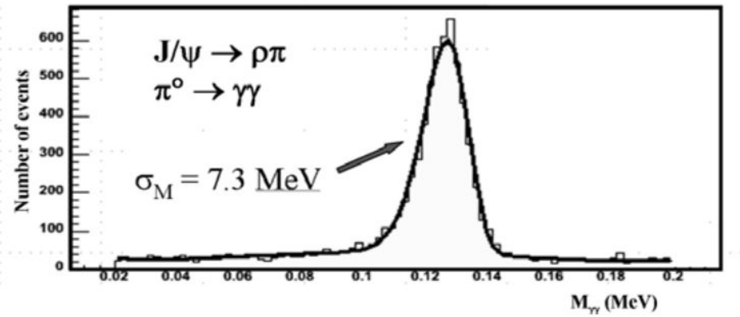


The probability distribution for muons and pions to reach a certain layer in the muon system

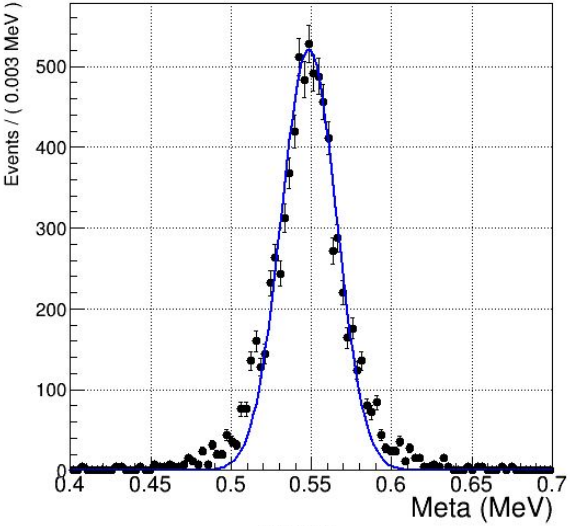
The muon system works using the results of a reconducted stand-alone simulation on G4BeamLine. The system is a cylinder of eight absorber and sensitive polystyrene layers. The absorber is iron.

The example

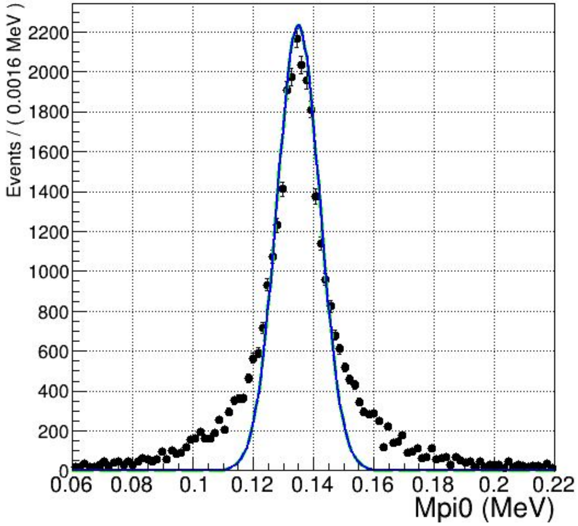
```
# Connecting libraries
...
# EvtGen
evtgen = EvtGenInterface('SignalProvider')
gen = GenAlg('EvtGenAlg', SignalProvider=evtgen)
...

# HepMC3 to PODIO
edm = HepMCToEDMConverter("Converter")
...

# SctParSim
sct_alg = SctParSimAlg('SctAlg')
sct_alg.CaloSystemTool.caloClSizeEGamma = 0.2
# Example how to change a subsystem parameter

# Analysis tool
evlo = EventLoader('EvtLoader')
cmbr = ParticleCombinerAlg(.....)
tupl = NtupleAlg('piTuple')
...

# Description of options for running algorithms
options= {
   'TopAlg' : [gen, edm, sct_alg, evlo, cmbr, tupl],
   'EvtSel' : 'NONE',
   'ExtSvc' : [particlePropertySvc, podioevent],
   'EvtMax' : eventNumber,
   'StatusCodeCheck' : True,
   'AuditAlgorithms' : True,
   'AuditTools'      : True,
   'AuditServices'   : True,
   'OutputLevel'     : INFO
}

ApplicationMgr(**options)
```



Results of Monte Carlo simulation: the mass resolution of reconstructed π° masses (BESIII)



The η-meson invariant mass (σ = 17 MeV)



The π^0 invariant mass (σ = 7,1 MeV)

Results and plans

Results

- the main algorithm for parametric simulation had been implemented
- the tracker, calorimeter with cluster overlapping, FARICH PID and muon systems had been implemented
- launch examples had been added (to generate particles, to read from a ROOT-file)
- tests for classes working with geometry had been added

Plans

- to implement an inner tracker, FDIRC
- to write a documentation
- to add new examples
- to improve parameterization

References

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