Abstract

1 Introduction

Full simulation of the response of large detectors components to high energy particles requires a lot of computing resources. Moreover, a good knowledge of the exact geometry of subdetectors and dead material content is mandatory.

Fast simulation can be a powerful predictive tool for typical response of a large detector in high energy collider.

The fast simulation of the detector response takes into account geometrical acceptance of sub-detectors and their finite energy resolution, no smearing is applied on particle direction. Charged particles, once are in the fiducial volume of the detector are assumed to be reconstructed with 100% probability. The energy of each particle produced after hadronization, with a lifetime $c\tau$ bigger than 10 mm is then smeared according to detectors along particule's direction. For particles with a short lifetime such as the K_s, the fraction of electromagnetic or hadronic energy is determined according to its decay products. The calorimeter is assumed to cover the pseudorapidity range $|\eta| < 3$ and consists in an electromagnetic and an hadronic part. The energy resolution is given by $\sigma_E/E = 0.05/\sqrt{E} \oplus 0.25/E \oplus 0.0055$ for the electromagnetic part and by $\sigma_E/E = 0.91/\sqrt{E} \oplus 0.038$ for the hadronic part, where the energy is given in GeV. A very forward calorimeter is assumed to cover $3 < |\eta| < 5$ with an electromagnetic and hadronic energy resolution function given by $\sigma_E/E = 1.5/\sqrt{E} \oplus 0.06$ and $\sigma_E/E = 2.7/\sqrt{E} \oplus 0.13$ respectively.

Figure 1: detectorAng.eps

The acceptance cuts applied on leptons and jets used in this section are the following :

- Electrons and muons are reconstructed if they fall into the acceptance of the tracker, assumed to be $|\eta| < 2.5$, and have to have a transverse momentum above 10 GeV (the energy resolution of muons is taken to be the same as for electrons). Lepton isolation demands that there is no other charged particles with $p_T > 2$ GeV within a cone of $\Delta R < 0.5$ around the lepton.

- Jets are reconstructed using a cone algorithm with $R = 0.7$ and make only use of the smeared particle momenta. The reconstructed jets are required to have a transverse momentum above 20 GeV and $|\eta| < 3.0$. A jet is tagged as b-jets if its direction lies in the acceptance of the tracker, $|\eta| < 0.5$, and if it is associated to a parent b-quark. A b-tagging efficiency of 40% is assumed if the jet has a parent b quark. For c-jets and light/gluon jets, a fake b-tagging efficiency of 10% and 1% respectively is assumed.

- A jet is tagged as a τ-jet if more than 90% of its energy is localized in a cone of $\Delta R = 0.15$ around its axis. Moreover, this jet must have its direction in the acceptance of the tracker and have exactly one charged particle with $p_T > 2$ GeV within a cone $\Delta R < 0.4$ around the jet axis. This procedure selects taus decaying hadronically with a typical efficiency of 60%. Moreover, the minimal p_T of the τ-jet is required to be 10 GeV.

2 implementation

2.1 Electron smearing

The smearing of the electron 4-momentum p^μ is - if the electron is in the tracker ($\eta < MAX\_TRACKER$) Gaussian smearing with $\sigma = ELG_C cen * E \oplus ELG_N cen \oplus ELG_S cen * \sqrt{E}$ - else Gaussian smearing with $\sigma = ELS_C fwd * E \oplus ELG_S fwd * \sqrt{E}$ function `SmearElectron` Only the energy E is smeared, but neither η nor ϕ. No negative values for the energy after smearing. If so, the 4-momentum is set to $(0,0,0,0)$. **For the moment, electrons with $|\eta| > 5$ are also smeared !!!**

2.2 Muon smearing

The smearing ot the muon 4-momentum p^μ is given by a Gaussian smearing of the p_T function `SmearMuon` Only the p_T is smeared, but neither η nor ϕ. No negative values for the energy after smearing. If so, the 4-momentum is set to $(0,0,0,0)$.

2.3 Hadron smearing

The energy of the hadron is smeared in the following ways: - if the hadron is in the central calorimeter (eta ¡ MAX_CALO_CEN) Gaussian smearing with $\sigma = HAD_C hcal * E_{hcal} \oplus HAD_N hcal \oplus HAD_S hcal * \sqrt{E_{hcal}} + HAD_C ecal * E_{ecal} \oplus HAD_N ecal \oplus HAD_S ecal * \sqrt{E_{ecal}}$ where $E_{hcal} + E_{ecal} = E$. As some long-living particles decay in the calorimeters, some of them decay mostly in the ECAL, some mostly in the HCAL. E_{hcal} and E_{ecal} are given by $E_{hcal} = E \times F$ and $E_{ecal} = Etimes(1 - F)$, where F is a fraction $0 \leq F \leq 1$ describing each particles. By default, $F = 1.$ but is $F = 0.7$ for K_S^0 and Λ. - if the hadron is somewhere else (**even outside the forward calorimeters !!!**) Gaussian smearing with $\sigma = HAD_C hf * E \oplus HAD_N hf \oplus HAD_S hf * \sqrt{E}$

Ainsi, pour les particules considÃ©rÃ©es comme stables par PYTHIA mais non stables dans un dÃ©tecteur tel CMS ($c\tau < 4m$), les dÃ©pÃ´ts laissÃ©s dans les diffÃ©rents dÃ©tecteurs sont directement liÃ©s aux modes de dÃ©sintÃ©grations de ces particules. Les hypothÃ¨ses des dÃ©pÃ´ts d'Ã©nergie sont donnÃ©es dans le tableau 1.

Particules stables dans PYTHIA	*Stable dans CMS*	*Mode de desintÃ©gration*	Γ_i/Γ	*DÃ©pot ECAL*	*DÃ©pot HCAL*
$\pi^{\pm}$	oui			0	1
$K^{\pm}$	oui			0	1
K_S^0	non	$\gamma\gamma\gamma\gamma$ $\pi^+\pi^-$	0.31 0.69	0.3	0.7
K_L^0	oui			0	1
Λ^0	non	$\pi^- p/\pi^+ \overline{p}$ $n\pi^0$	0.64 0.36	0.3	0.7
γ	oui			1	0

Table 1: HypothÃ¨ses des dÃ©pÃ´ts d'Ã©nergie pour les particules les plus abondantes des jets.

function `SmearHadron` There is no ecal-hcal separation in the forward calorimeter. No negative values for the energy after smearing. If so, the 4-momentum is set to $(0, 0, 0, 0)$.

2.4 Calorimetric towers

All final particles, which are neither muons nor neutrinos are produce a calorimetric tower. The same particles enter in the calculation of the missing transverse energy. *what is used is the particle smeared momentum, not the calorimetric towers!*

2.5 Tracks

All final charged particles

2.6 Time of flight

Some subdetectors have the ability to measure the time of flight of the particle. This correspond to the delay after which the particle is observed in the detector, after the bunch crossing. The time of flight measurement of ZDC and FP420 detector is implemented here. For the ZDC, the formula is simply

$$t_2 = t_1 + \frac{1}{v} \times \left(\frac{s - z}{\cos\theta}\right), \quad (1)$$

where t_2 is the time of flight, t_1 is the true time coordinate of the vertex from which the particle originates, v the particle velocity, s is the ZDC distance to the interaction point, z is the longitudinal coordinate of the vertex from which the particle comes from, *theta* is the particle emission angle. This assumes that the neutral particle observed in the ZDC is highly relativistic, i.e. travelling at the speed of light c. We also assume that $\cos\theta = 1$, i.e. $\theta \approx 0$ or equivalently η is large. As an example, $\eta = 5$ leads to $\theta = 0.013$ and $1 - \cos\theta < 10^{-4}$. The formula then reduces to

$$t_2 = \frac{1}{c} \times (s - z) \tag{2}$$

NB : for the moment, only neutrons and photons are assumed to be able to reach the ZDC. All other particles are neglected

To fix the ideas, if the ZDC is located at $s = 140$ m, neglecting z and θ, and assuming that $v = c$, one gets $t = 0.47$ μs.

2.7 Tau identification

Two ways to identify a tau : using the energy inside a cone or the number of tracks in the cone.

- From the energy in the cone of radius TAU_CONE_ENERGY. To be taken into account, a calo tower should (1) have a transverse energy $E_T = \sqrt{E_X^2 + E_Y^2}$ above a given threshold M_SEEDTHRESHOLD, (2) be inside a cone with a radius R and the axis defined by (eta,phi).
- From the number of tracks in the cone of radius TAU_CONE_TRACKS. To be taken into account, a track should (1) have a transverse momentum $p_T = \sqrt{p_X^2 + p_Y^2}$ above a given threshold, (2) be inside a cone with a radius R and the axis defined by (eta,phi).

Figure 2: detectorAng.eps

To identify a tau, one requires the *electromagnetic collimation* and the *tracking isolation*. The electromagnetic collimation is a kind of calorimetric isolation required around the jet axis. One requires that most of the energy of the cone is located in a small cone in the middle of the jet cone:

$$\sum E_T^{cell}(\Delta R = CONE\_RADIUS) > TAU\_EM\_COLLIMATION \tag{3}$$

Typical values are TAU_CONE_ENERGY=0.15 , CONE_RADIUS=0.7 and TAU_EM_COLLIMATION = 0.95. No further calorimetric isolation is required.

The tracking isolation for the tau identification requires that the number of tracks associated to a particle with $p_T > PT\_TRACK\_TAU$ is one and only one in a cone with $\Delta R = TAU\_CONE\_TRACKS$. This cone should be entirely included in the tracker to be taken into account. Typical calues are $TAU\_CONE\_TRACKS = 0.4$ and $PT\_TRACK\_TAU = 2GeV$.

2.8 B-tagging

The simulation of the b-tagging is based on the detector efficiencies assumed (1) for the tagging of a b-jet and (2) for the mis-identification of other jets as b-jets. This relies on the TAGGING_B, MISTAGGING_C and MISTAGGING_L constants, for (respectively) the efficiency of tagging of a b-jet, the efficiency of mistagging a c-jet as a b-jet, and the efficiency of mistatting a light jet (u,d,s,g) as a b-jet. The (mis)tagging relies on the particle ID of the most energetic particle within a cone around the observed (eta,phi) region, with a radius CONERADIUS.

3 Validation

4 conclusion

Attention : in SmearUtil::NumTracks, the function arguments 'Eta' and 'Phi' have been switched. Previously, 'Phi' was before 'Eta', now 'Eta' comes in front. This is for consistency with the other functions in SmearUtil. Check your routines, when using NumTracks !

In the list of input files, all files should have the same type

Attention : in SmearUtil::RESOLution::BJets, the maximal energy was looked in CONERADIUS/2 instead of CONERADIUS. This bug has been removed.

Attention : for the tau-jet identification : CONERADIUS /2 was used instead of CONERADIUS !