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Muon Energy Loss in the Hadron Calorimeter and Muon Momentum Resolution

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Abstract:

Muons can undergo catastrophic energy loss in a hadron calorimeter. This energy loss is mainly photoproduction of hadrons for the very catastrophic events. bremsstrahlung contributes at the lower energy losses. The measured energy loss in the calorimeter must be added to the muon momentum measured outside the calorimeter. A detailed GEANT simulation with energy resolution sigma / E = 50% / sqrt (E) + 2%, no depth segmentation, and light attenuation in the fibers take into account shows that the fiber hadron calorimeter does not contribute to the muon momentum resolution except for 100 GeV muons where its contribution is 1.1%. This is of the same magnitude as the momentum resolution at 100 GeV and does not significantly affect the mass resolution at the Z^0 mass.

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MUON ENERGY LOSS IN THE HADRON CALORIMETER AND MUON MOMENTUM RESOLUTION

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1. Introduction.

Muons can undergo catastrophic energy loss in a hadron calorimeter. This energy loss is mainly photoproduction of hadrons for the very catastrophic events. bremsstrahlung contributes at the lower energy losses. The measured energy loss in the calorimeter must be added to the muon momentum measured outside the calorimeter.

A detailed GEANT simulation with energy resolution $\sigma_E/E = 50\%/\sqrt{E}+2\%$, no depth segmentation, and light attenuation in the fibers taken into account shows that the fiber hadron calorimeter does not contribute to the muon momentum resolution except for 100 GeV muons where its contribution is 1.1%. This is of the same magnitude as the momentum resolution at 100 GeV and does not significantly affect the mass resolution at the Z^0 mass.

2. Overview

In general the muon will loose only a fraction of its energy in the calorimeter so even if its measurement is not very precise, its error does normally not contribute fully to the corrected muon momentum.

As the catastrophic muon energy loss can happen with equal probability anywhere along the depth of the calorimeter, the light attenuation of the fibers gives rise to a constant term in the energy resolution. It can easily be shown that the constant term is 15% for 2 m long fibers with a light attenuation length of 4 m. The stochastic term was taken to be $50\%/\sqrt{E}$ for both (!) electromagnetic and hadronic energy deposits. The muon spectrometer's momentum resolution was taken to be $\sigma_p/p = 10^{-4}p$ (5% at 500 GeV). In Fig. 1 we show the momentum resolution of the corrected muon momentum as function of the relative energy loss E'/P for muon momenta $P = 100, 500$ and 2500 GeV. It is seen that the error is quite large for large values of E'/P but also that the calorimeter helps at muon momentum of 5000 GeV.

Fortunately, large values of E' are less probable than low values of E'. The Particle Data Group, see Ref. 1 states that the radiative tail consists almost entirely of bremsstrahlung for most of the 10% muons that lost more than 2.8% of their energy. For more catastrophic energy loss they find that most of the 3.3% muons that experienced more than 10% energy loss did so by photonuclear interactions. The bremsstrahlung leads to electromagnetic showers while photonuclear interactions will lead to hadronic showers. As the muon momentum resolution is most affected by the large energy losses in the calorimeter, see Fig. 1, the hadronic energy resolution is essential and not the electromagnetic one. Compensation is therefore very helpful in the measurement of muon energy loss.

To get quantitative answers, we used GEANT.

3. Hadron Calorimeter and GEANT MC.

We have taken a semi-infinite solid mass of lead or copper, 12 nuclear interaction lengths deep. GEANT was used to simulate the energy loss of 100 and 500 GeV muons. The energy resolution was taken to be

$$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} + 2\%$$

for electromagnetic and hadronic energy deposits. The attenuation of light as it is transported through the fibers to the photomultiplier is taken to be exponential with a characteristic attenuation length of 4 m.

The results are shown in Table 1 for 100 and 500 GeV and lead and copper absorbers. Each resolution is calculated from $\pm 4\sigma$ truncated distributions. The event losses caused by the $\pm 4\sigma$ cuts are shown too. The three sections of the Table are respectively for the complete simulation, simulation without light attenuation in the fiber, and simulation without correcting the muon momentum with the energy loss in the calorimeter. In addition the last section of the Table also shows what happens to the muon momentum resolution if the last three interaction lengths of the calorimeter are not instrumented.

It is seen that the calorimeter resolution has a negligible effect at muon momenta of 500 GeV. In the 100 GeV region a 1.1% effect is seen. This must be added in quadrature to the 1% momentum resolution from the muon spectrometer. It does not seem to matter for the muon momentum resolution whether the last three interaction lengths are read out or not.

4. Discussion

One may argue however that the momentum resolution does not have to be better than required to measure the Z^0 mass without affecting its resolution. The natural width of the Z^0 is 2.5 GeV so a deterioration of the momentum resolution from 1% to 1.4% for 100 GeV muons should not matter.

The dominant photonuclear interactions will lead to hadronic showers while bremsstrahlung leads to electromagnetic showers. Compensation is therefore very helpful in the measurement of muon energy loss. Note that to reduce the influence of the energy resolution of the calorimeter, one needs to improve the hadronic energy resolution, not the electromagnetic one.

REFERENCES

1) Particle Data Group, Phys. Rev. D45 (1992), p.II.17 or pocket booklet, p.116

FIGURE CAPTIONS

1. Muon momentum resolution as function of the relative energy loss in the calorimeter.

TABLE 1

Effect of calorimeter energy resolution on muon momentum resolution.

Energy (GeV)	Condition	Pb-Absorber		Cu-Absorber	
		sig/P	ev-loss	sig/P	ev-loss
100	complete simulation	1.4%	3.4%	1.1%	0.9%
500	same	1.5%	0.1%	0.8%	0.0%
100	no light attenuation	1.4%	2.1%	1.1%	0.5%
500	same	0.7%	0.0%	0.4%	0.0%
100	no calorimeter correction	1.4%	14.5%	0.9%	5.8%
500	same	2.7%	3.4%	1.6%	1.0%
100	last 3 int.l not instrumented	0.8%	3.7%	0.5%	1.4%
500	same	1.3%	0.6%	0.8%	0.2%

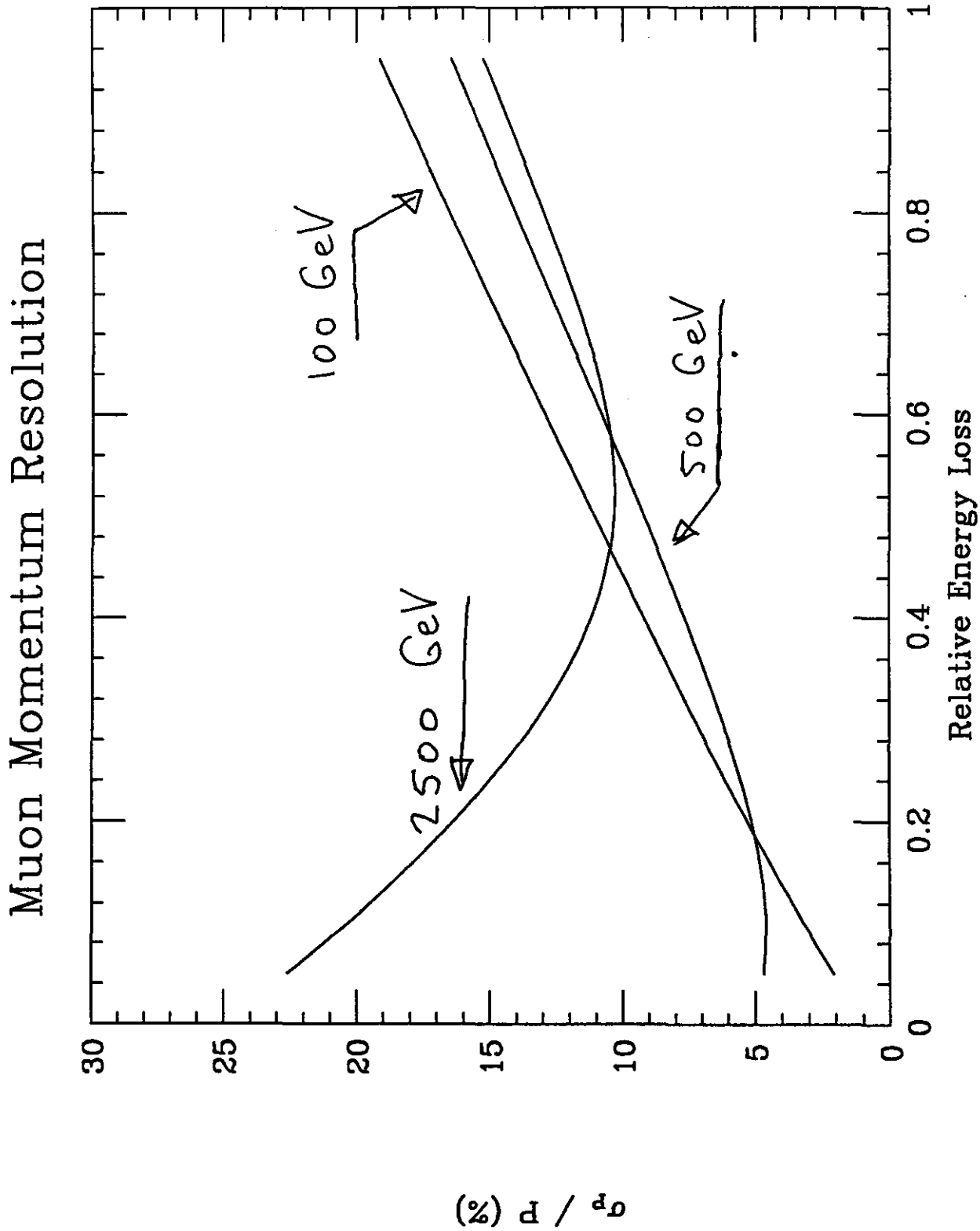
Muon Momentum Resolution
100 GeV
500 GeV
2500 GeV
Relative Energy Loss
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
σp / p (%)

Fig. 1