Study of Backscattering Effects on the Particle Identification

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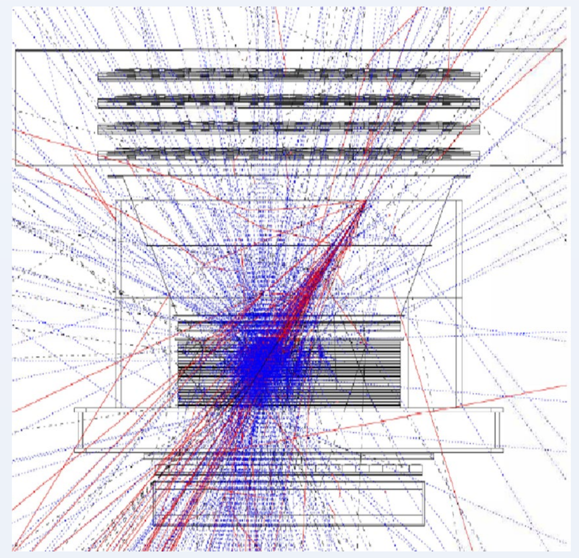
INTRODUCTION

- One of the consequences of having a high-density calorimeter as part of an experiment is a large number of secondary shower particles generated in the calorimeter -- some of which scatter back up towards the charge measurement devices.
- This so-called "backscatter effect" can interfere severely with accurate charge measurement of the primary nucleus, especially at high energies, as the number of backscattered particles increases with the incident energy.
- In this presentation, we will discuss the effect of backscattered particles on particle identification by simulating the ISS-CREAM instrument model detector response.

MONTE CARLO SIMULATION

- Simulate the detector response using GEANT3 Monte Carlo Simulation toolkit [1] with FLUKA hadronic interaction package [2][3].
- Generate protons isotropically over an incident range from 100 GeV to 500 TeV.
- A typical event passes first through the charge module, then interacts in the carbon target, and finally develops a shower in the calorimeter.

200 GeV proton incident



An example of simulated event: gamma (blue), charged particles except muons (red), neutral hadrons or neutrinos (black) [4]

EVENT SELECTION

The Simulation results presented here were obtained by selecting events that enter the SCD, pass through all the layers of the calorimeter, have their first interaction in the carbon target, and deposit significant amounts of energy in many layers of the calorimeter for tracking.

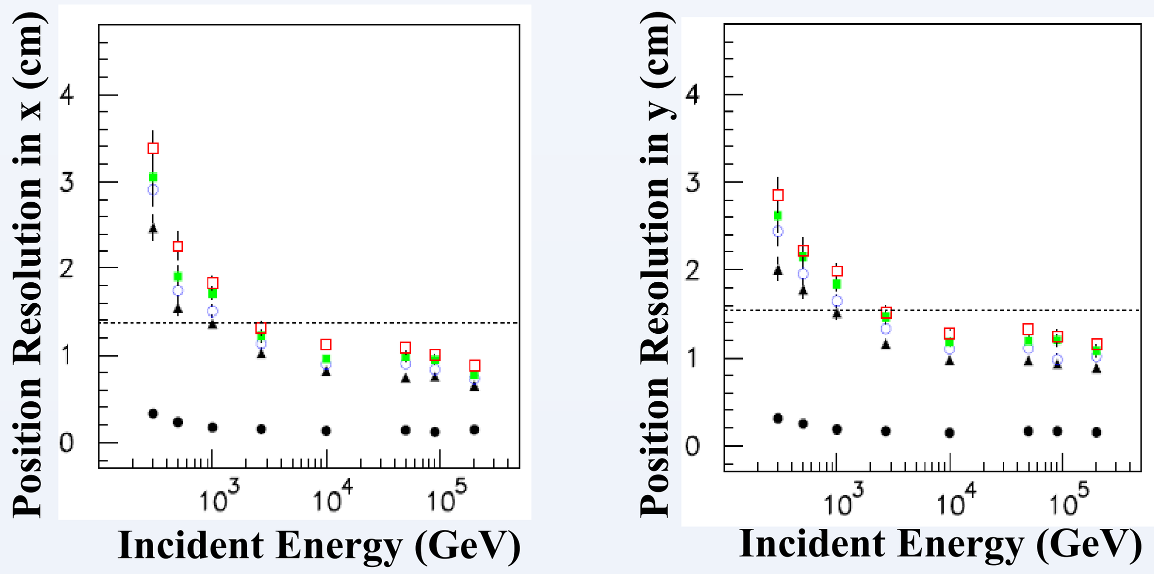
EVENT RECONSTRUCTION

Shower-axis Reconstruction

- To determine the X, Y coordinates of the shower core in each CAL layer, the center of mass concept was used.
- To reconstruct the shower axis, a linear fitting of these X, Y coordinates was used.
- Requirements:
  - ✓ Each CAL layer used in the fitting is required to have an energy deposit greater than 3% of total energy deposit in CAL
  - ✓ An event is accepted if it has at least 3 CAL layers that satisfied the above condition in X and Y each direction: otherwise, it is rejected.

Trajectory Resolution (cm)

- After shower reconstruction, extrapolate the shower axis for the entrance position.
- Position resolution is a sigma of the deviation between the actual incident position and the reconstructed position.
  - ➢ ~0.18cm at the top of the calorimeter
  - ➢ Worse on the SCDs due to long lever arm
  - ➢ Not good at low energies since shower core is not well-developed



Incident energy dependence of the position resolution for incident protons; calorimeter (filled black circles), distance from top of the calorimeter 38.45 cm (open red squares), 34.65 cm (filled green squares), 30.85 cm (open blue circles), 27.05 cm (filled black triangle), dotted lines: SCD pixel width (*left*) and length (*right*)

CHARGE DETERMINATION ALGORITM

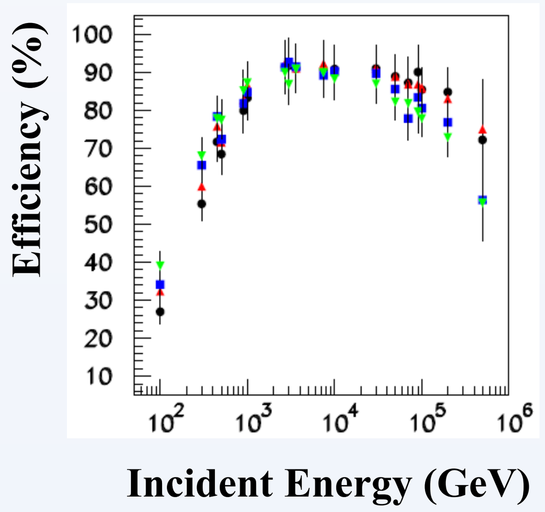
1. Exrapolate the reconstructed shower axis to SCD.
2. Select the pixel with the highest signal in 10 cm x 10 cm area of circle of confusion, centered on the extrapolated position [5]. (pixel size = 2.12 cm^2)
3. Correct the highest signal for the particle path length.
4. Z = sqrt(HighestSignal/ PathLength/ SCDmip)
5. Identified as proton if $0 < Z \leq 1.732$

DISTANCE FROM CALOROMETER AND BACKSCATTERING EFFECT

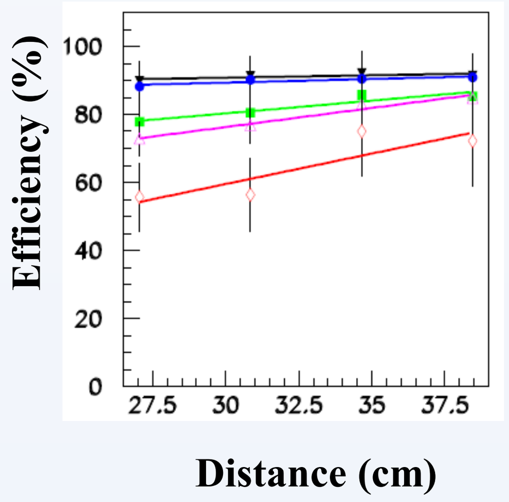
Charge Determination Efficiency.

The fraction of events identified as a proton among the reconstructed events that traverse SCD active area

- ➢ At lower energies (< 2.7 TeV) charge determination efficiency increases as energy increases mainly due to tracking uncertainty
- ➢ At higher energies (> 30 TeV) the efficiency decreases as energy increases due to more backscattered particles.
- ➢ At mid range (2.7 TeV ~ 30 TeV) the efficiency is about 90 %, quite independent of the incident energy.
- ➢ The efficiency is better as distance (from the calorimeter) increases due to reduced backscattered particles.



Charge determination efficiency over incident energy; distance from top of the calorimeter is 27.05 cm, 30.85 cm, 34.65 cm, and 38.45 cm

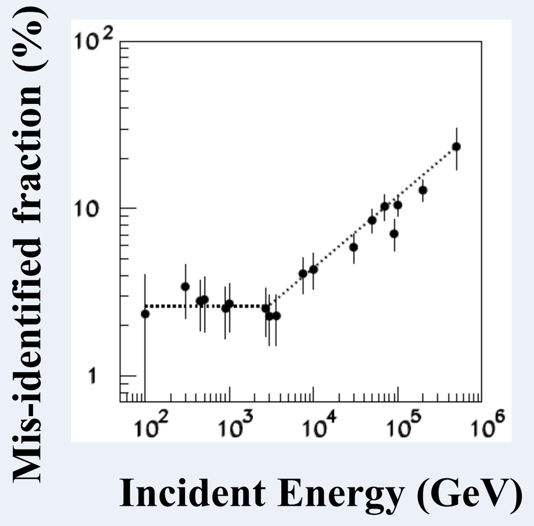


Charge determination efficiency over distance from top of calorimeter; incident energy 2.7 TeV, 10 TeV, 100 TeV, 200 TeV and 500 TeV

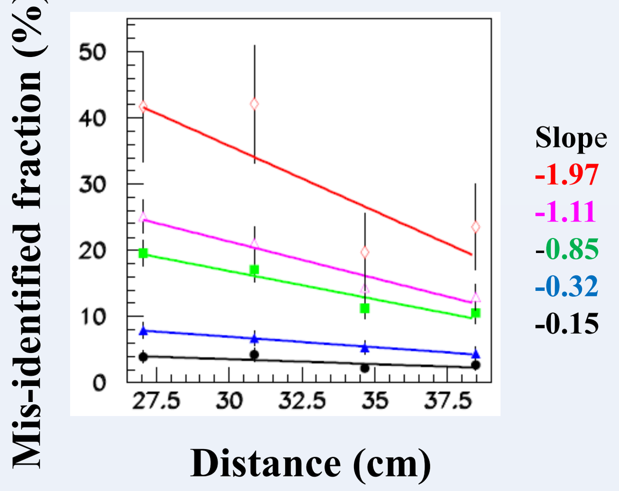
Mis-identified Fraction.

The mis-identified proton (Z >1.732) fraction among the reconstructed events with Z>0

- ➢ Up to ~3 TeV incident energy the mis-identified fraction is ~2.75 %.
- ➢ Over the higher energy ranges the mis-identified fraction increases as energy increases due to more backscattered secondary particles with higher incident energy. The fraction in % is proportional (slope of 0.58e-4) to the incident energy in log scale.
- ➢ The mis-identified fraction linearly decreases as distance (from the top of calorimeter) increases with incident energy.



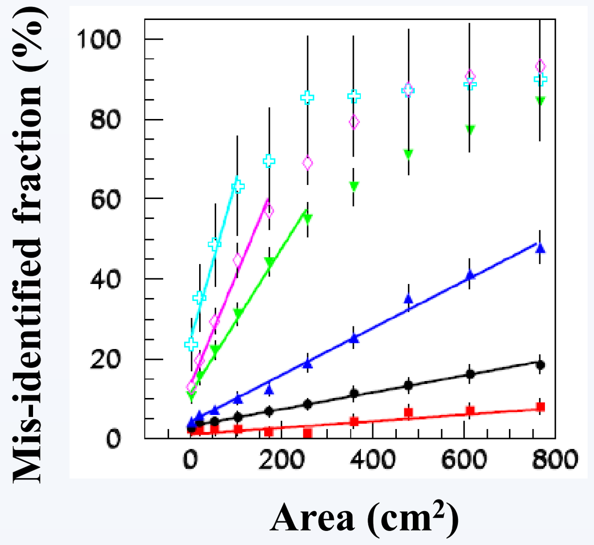
Mis-identified fraction at 38.45 cm from top of the calorimeter



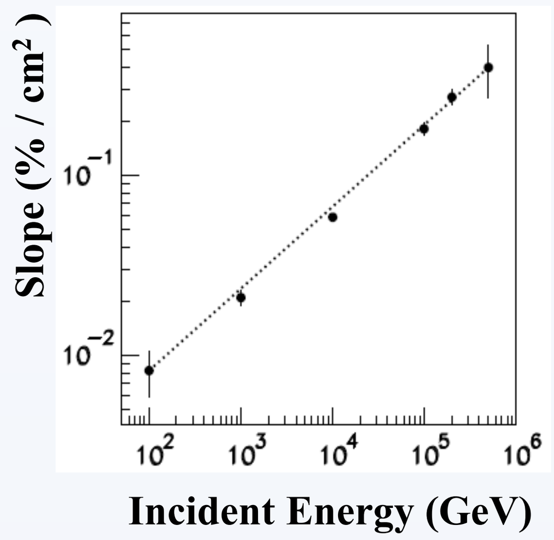
Mis-identified fraction: 1 TeV, 10 TeV, 100 TeV, 200 TeV, 500 TeV

SEGMENTATION AND BACKSCATTERING EFFECT

- ISS-CREAM charge detector has 2.12 cm^2 of fine segment.
- Backscattering effect with bigger segments is compared to check segment size dependence.



Mis-identified fraction over segment size at distance 38.45 cm: incident energy 100 GeV, 1 TeV, 10 TeV, 100 TeV, 200 TeV, 500 TeV



Segment size dependence of mis-identified fraction over incident energy. Dotted line is a guide to eyes

- ➢ Mis-identified fraction increases as area increases, and the area dependence is stronger for higher incident enegy.
- ➢ Area dependence increases as energy increases.
- ➢ For 100 GeV the fraction is 2.4 % with 2.12 cm^2 and increases up to 7.9 % with 766.2 cm2 while for 500 TeV, 23.5 % and up to 93.3 %, respectively.

SUMMARY

- ➢ Backscattering effect increases with the incident energy.
- ➢ The mis-identified fraction in ISS-CREAM SCD (with 2.12 cm^2 of fine segment) is 2.71 % at 1 TeV and increases up to 12.93 % at 200 TeV.
- ➢ Backscattering effect increases as the segment size increases.
- ➢ With 256.82 cm^2 segment mis-identified fraction is 8.57 % at 1 TeV and increases up to 69.03 % at 200 TeV.
- ➢ For the larger segment the energy dependence is even stronger.

REFERENCES

[1] R. Brun, *et al., GEANT User's Guide*, CERN, DD/EE/84-1, 1984.
[2] P.A. Arino, *et al., FLUKA User's Guide*, CERN, TIS-RP-190, 1987.
[3] E.S. Seo, *et al., in Proc. of SPIE 2806*, 134-144, 1996.
[4] J. Wu, et al., *in Proc. of 36th Int. Cosmic Ray Conf.* Pos(ICRC2019)154
[5] Y.S. Yoon, *et al., The Astrophys. J.*, 728, 122, 2011..

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