Low Momentum Muon and Pion Separation for Higgsino Reconstruction

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Collaborative Research Centre 676
Particles, Strings, and the Early Universe
The Structure of Matter and Space-Time

Outline

- Light Higgsino Scenario
- Production Processes & Decay Modes
- Muon & Pion Reconstruction in Full Simulation
- Muon & Pion Separation in Calorimetry
- Conclusion

Light Higgsino Scenario

Motivated by naturalness which requires μ at the electroweak scale

Scenario contains

- 3 light higgsinos: $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_1^0$ & $\tilde{\chi}_2^0$
- Almost mass degenerate: $\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ & $\Delta M(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ $\sim$ a (sub) GeV
- All other supersymmetric particles are heavy up to a few TeV

Benchmark point:

dm770

Mass Spectrum	
Particle	Mass (GeV)
h	127
$\tilde{\chi}_1^0$	166.59
$\tilde{\chi}_1^{\pm}$	167.36
$\tilde{\chi}_2^0$	167.63
H's	$\sim 10^3$
$\tilde{\chi}$'s	$\sim 2 - 3 \times 10^3$

$$\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 0.77 \text{ GeV}$$

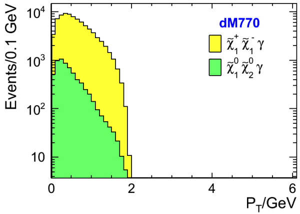
Production Processes & Decay Modes

Production Processes

- $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$
- $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0$

Decay Modes

- $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^{\pm *}$
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^{0*}$
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \gamma$



P_T dist. of final state particles at generator level

- Muons & Pions are very soft!

Separation of Signal Processes

Exclusive decay modes:

- $\tilde{\chi}_1^+\tilde{\chi}_1^+ \to 2\tilde{\chi}_1^0 \; W^{+*} \; W^{-*}$
  - semileptonic final state (35%)
- $\tilde{\chi}_1^0\tilde{\chi}_2^0 \to 2\tilde{\chi}_1^0 \; Z^{0*}/\gamma$
  - photonic final state (74%)

In semileptonic decays

- $\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \; \pi) \approx 60$ %
- $\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \; \mu^-\nu_\mu) \approx 13$ %

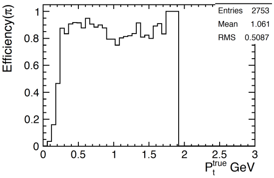
- Muon & Pion separation plays an important role in this analysis

Muon and Pion Reconstruction in Full Simulation

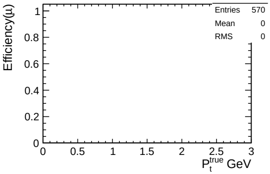
- Since muons are very soft, they don't leave a proper signature in the calorimeters. They get stuck in the ECAL or in the very first layer of the HCAL.
- In most of the cases they are reconstructed as pions

Reconstruction Efficiency of

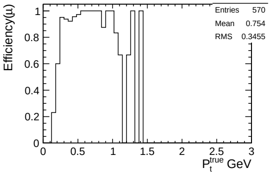
Pions



Muons



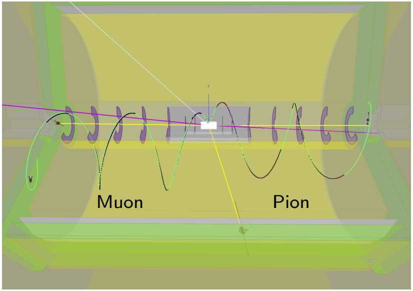
Muons as Pions

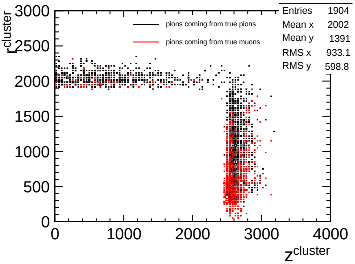


- Pandora PFO reconstruction does not work for separation of muon & pion at low momentum region
- Need to separate them

Muon and Pion Separation in Calorimetry

Checked the behaviours of muon and pion using event display

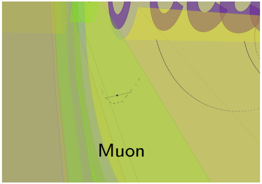


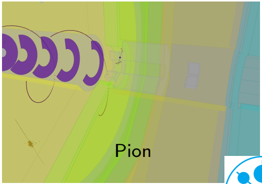


- The particles curl and travel along the magnetic field lines, and hit the endcap calorimeters

Cluster properties are studied

- Observed that the cluster shape of muon and pion is different





Expected and Observed Differences in Cluster Shape

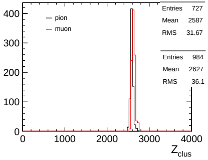
To examine the cluster shape in detail, generate pure μ and π samples using particle gun with 1 GeV and 0.5 GeV in IP with fixed angles $(\theta = 35, \phi = 45)$

- Checked different variables
- Variables which show differences of the cluster shapes:

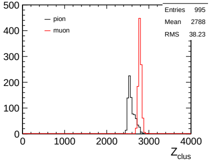
** Z position of cluster

- @ 0.5 GeV, the Z position is very close to each other
- @ 1 GeV, muons are shifted to the right, more muons end up on the HCAL

0.5 GeV P



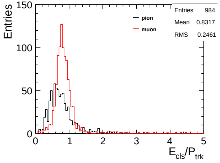
1 GeV P



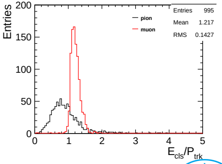
** Cluster energy / track momentum

- @ 1 GeV, surprisingly cluster energy is larger than track momentum for muons
- Energy Scales are different for lept & had
  - leptons : $E^l_{ECAL} = 1, \quad E^l_{HCAL} = 1.2$
  - hadrons : $E^h_{ECAL} = 0.8, \quad E^h_{HCAL} = 1$

0.5 GeV P



1 GeV P



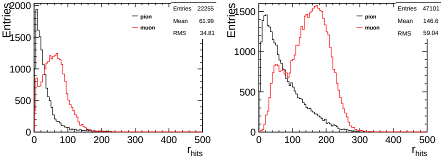
Expected and Observed Differences in Cluster Shape

** Radius distribution of hits considering cluster position as a reference point

$r_{hit} = \sqrt{((x_{hit} - x_{clus})^2 + (y_{hit} - y_{clus})^2)}$

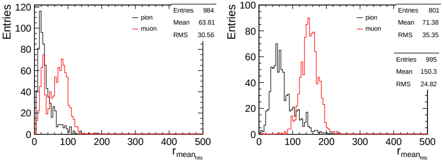
- Muons & Pions have a different structure as expected from event display
- To have a variable changes per cluster one could consider the below variables

0.5 GeV P   1 GeV P



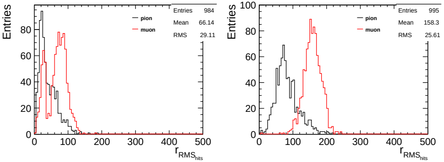
Mean Value of R_{hits}

0.5 GeV P   1 GeV P



RMS Value of R_{hits}

0.5 GeV P   1 GeV P



Generation of Samples with Particle Gun

After having an idea about the structure of the cluster shapes, more samples are generated with Particle Gun in below cases:

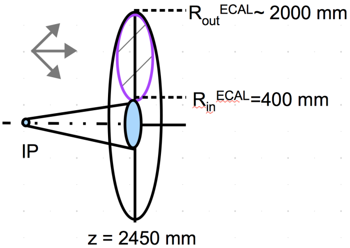
- From 0.2 GeV to 2 GeV momentum in the interval of 0.1 GeV
- Shot gun directly to the calorimetry to get rid of decaying of particles & curling of low energetic particles during their way on TPC

Position

Start : x=400, y=400, z= 2450 (mm)
Scan x & y from 400 to ∼ 1900 mm
with a constant step

Direction

Scan Φ in 360 degrees
Scan θ in 90 degrees
homogeneously



- Observed that at low momentums most of the events don't have any reconstructed particles, & any particles in the MC Skimmed collection
- Therefore, generate more of them to have equal number of particles in each momentum, which means 10000 μ & 10000 π

Muon and Pion Separation in Calorimetry

To determine the differences of the cluster shape, likelihood method is used

- TMVA toolkit is used for application of likelihood method

Procedure is given as following:

- Choose discriminative variables
- Obtain likelihood distribution using these variables
- Determine cut value to separate signal and background
- Run application of TMVA on a different sample, and store new PID values

The likelihood ratio

$$y_{\mathcal{L}} = \frac{\mathcal{L}_S}{\mathcal{L}_S + \mathcal{L}_B}$$

where

$$\mathcal{L}_{S/B} = \Pi_{k=1}^{nvar} \; p_{S/B,k}(x_k)$$

$p_{S/B,k}$ is the signal(background) PDF for the kth input variable x_k

Likelihood Method – TMVA

Choose 4 variables which have different behaviour for μ and π

- Depth of the particle on cluster
- Cluster Energy/Track Momentum(True Mom.)
- Mean value of the radius of the hits
- RMS value of the radius of the hits

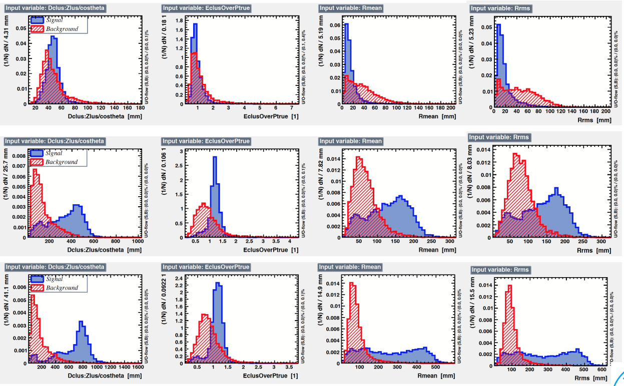
In the analysis:

- Signal : Muon
- Background : Pion

0.2 GeV P

1 GeV P

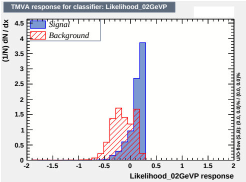
2 GeV P

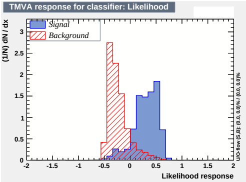


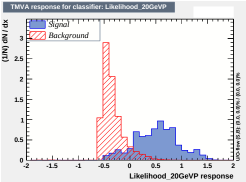
Likelihood Method – TMVA

➤ Train samples and obtain Likelihood distribution

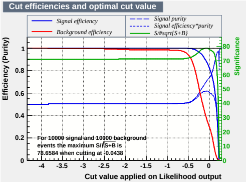
0.2 GeV P **1 GeV P** **2 GeV P**

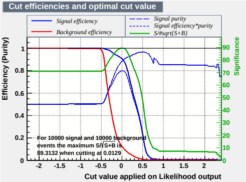


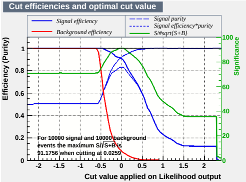




➤ Determine the cut value to separate muon and pion (use the value given in the cut efficiency plot)







➤ @ high momenta, separation looks better

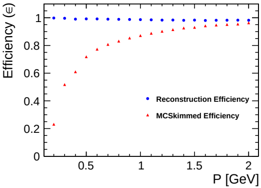
TMVA Application for Particle Gun Samples

- Run samples for each momentum and store new PID
- Obtained efficiency and purity values for each momentum is given in the following figures.
- Efficiency is calculated in three different ways
  - MC Skimmed Efficiency, since not all particles have reconstructed ones and so no particles in MC skimmed collection
  - Reconstructed Efficiency showing how many of the skimmed particles are reconstructed at all
  - Identification Efficiency (ID) explaining how efficient the separation is.
- For ID efficiency and purity 10000 muons & 10000 pions are considered

** Reconstruction Efficiency

- $\epsilon_{MC_{skimmed}} = \frac{N_{MC_{skimmed}}}{N_{MC_{generated}}}$
- $\epsilon_{Reco} = \frac{N_{MC_{Reco}}}{N_{MC_{skimmed}}}$

Reconstruction Efficiency



TMVA Application for Particle Gun Samples

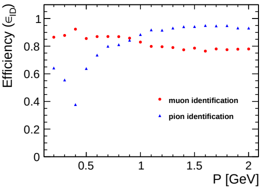
** Identification Efficiency

- $\epsilon^{\pi}_{ID} = \frac{N_{MC_{\pi(rc\pi)}}}{N_{MC_{\pi(rc\pi)}} + N_{MC_{\pi(rc\mu)}}}$
- $\epsilon^{\mu}_{ID} = \frac{N_{MC_{\mu(rc\mu)}}}{N_{MC_{\mu(rc\mu)}} + N_{MC_{\mu(rc\pi)}}}$

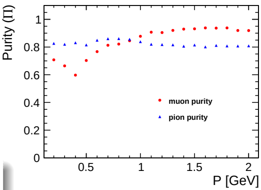
** Purity : How many of the reconstructed muons/pions comes from true muons/pions

- $\Pi^{\pi}_{ID} = \frac{N_{MC_{\pi(rc\pi)}}}{N_{MC_{\pi(rc\pi)}} + N_{MC_{\mu(rc\pi)}}}$
- $\Pi^{\mu}_{ID} = \frac{N_{MC_{\mu(rc\mu)}}}{N_{MC_{\mu(rc\mu)}} + N_{MC_{\pi(rc\mu)}}}$

Identification Efficiency



Purity



- Identification is around 80 % generally
- @ low momentum, pions has low ID efficiency – might be due to transition of variables
- Purity also changes around 80 % ± 10 % esp. for μ

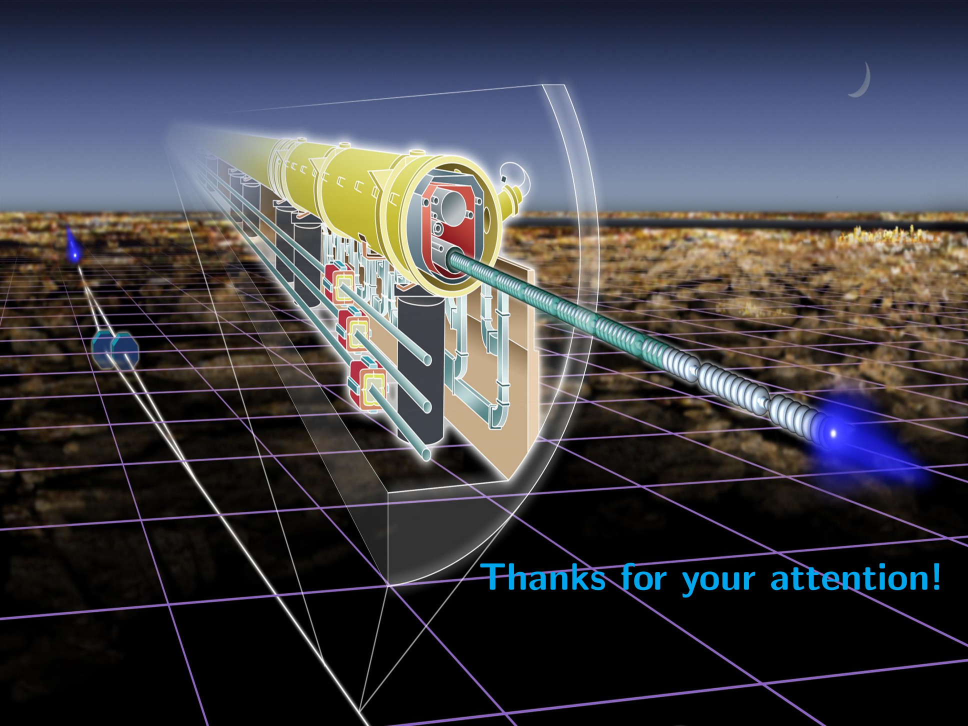
Summary & Outlook

Summary:

- In full simulation, pandora PFO cannot reconstruct low energetic muons properly
- To reconstruct them properly is a crucial point for Higgsino study
- Studied the separation of muons & pions in calorimeter using cluster shape
- It is possible to get around 80 % efficiency and purity in particle gun samples

Outlook:

- Do the separation for higgsino samples
  - First trial results: $\epsilon^{\mu}_{ID} = 0.78\%$, $\epsilon^{\pi}_{ID} = 0.56\%$


Thanks for your attention!