Physics Observables and Flavour Tagging

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Overview

- Particle ID performance

  Jacopo Nardulli

- Lepton energy resolution in slepton events

  Jean-Jacques Blaising

- Flavour tagging performance

  Tomas Lastovicka, Marco Battaglia

- Summary

Particle ID in PandoraPFA

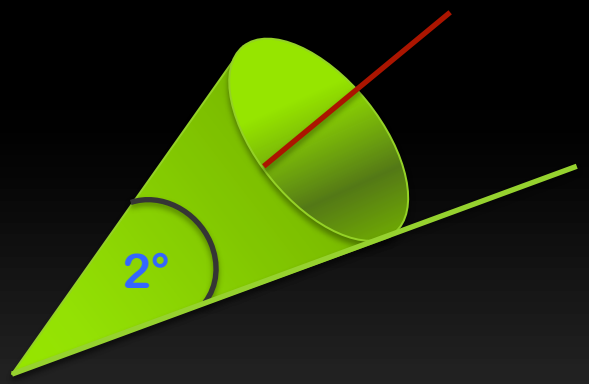
- Default particles: $\pi^{\pm}$ and n for charged / neutral hadrons
  - Calorimeters are in general not compensating
  - Hit energy depends on whether hits belong to EM or HAD shower
- Strategy:
  - First, identify muons
  - Then identify EM clusters
    - Photons without matched tracks
    - Electrons with matched track

Particle ID Studies

- Single particles of known type
  - Isotropic and uniformly in energy
  - Evaluate PandoraPFA response to single
    - Photons
    - Electrons
    - Pions
    - Muons
- Muons in physics samples without and with background

Truth Matching Criteria

$$\text{Efficiency} = \frac{\text{matched particles}}{\text{findable particles}}$$

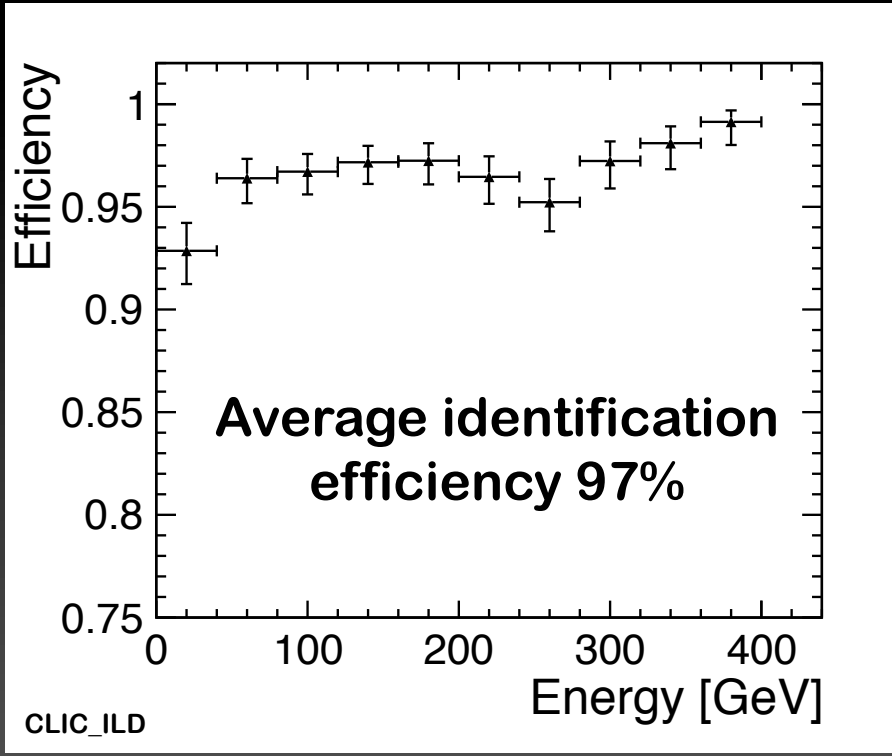


Find a match between generated and reconstructed particles

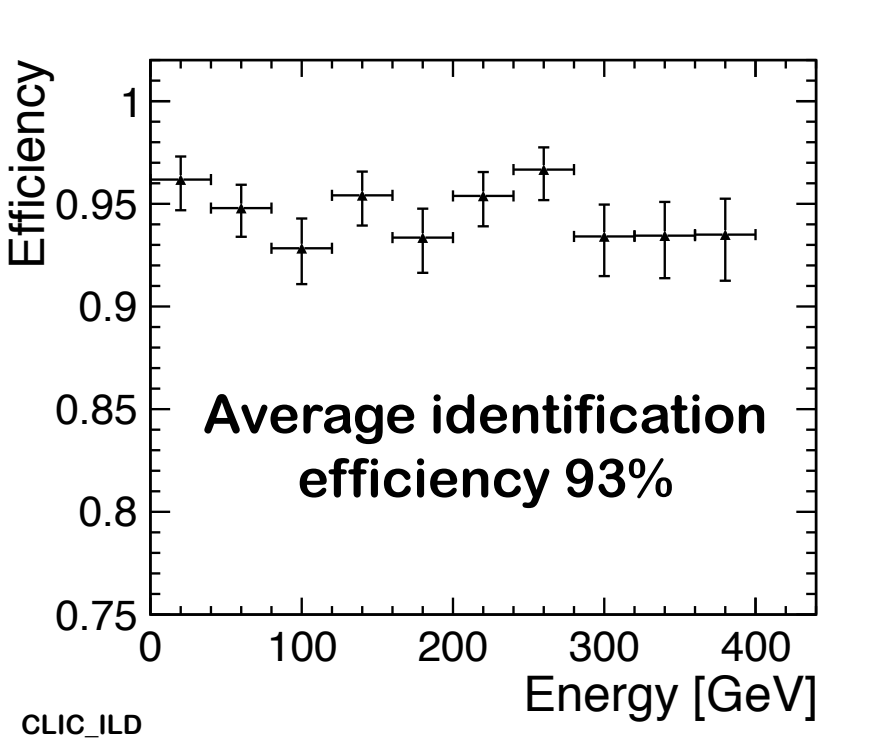
- **Findable (generated) particles:**
  - **E > 7.5 GeV**
  - **$8° < \theta < 90°$**
- **Matched (reconstructed) particles:**
  - **Within 2° cone around generated particle**
  - **Same type and charge**

Single Electrons and Photons

Electrons

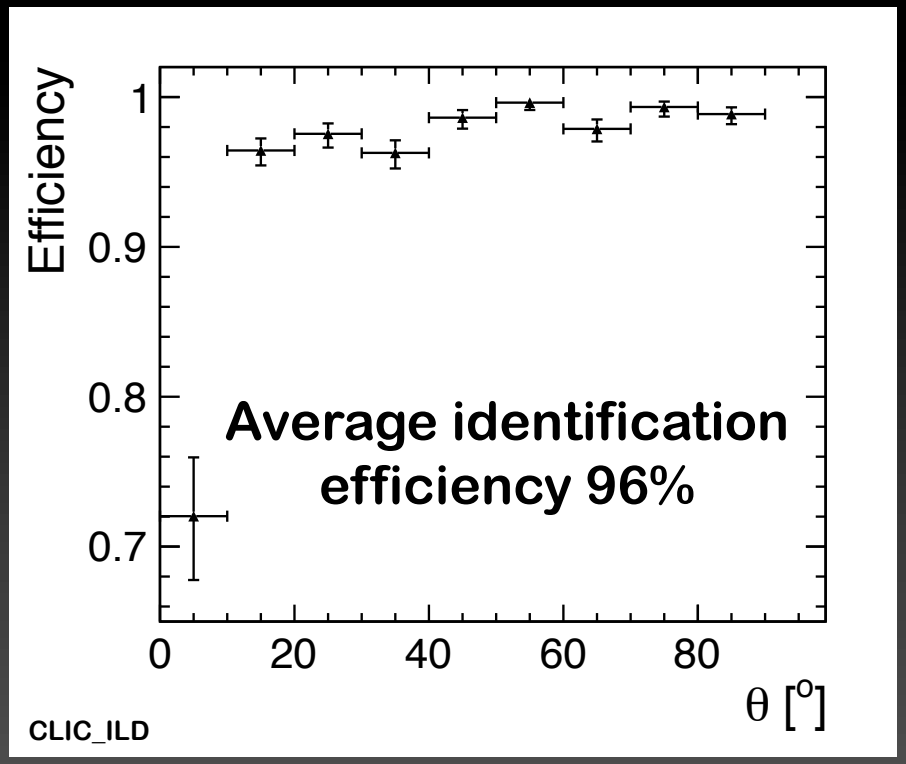


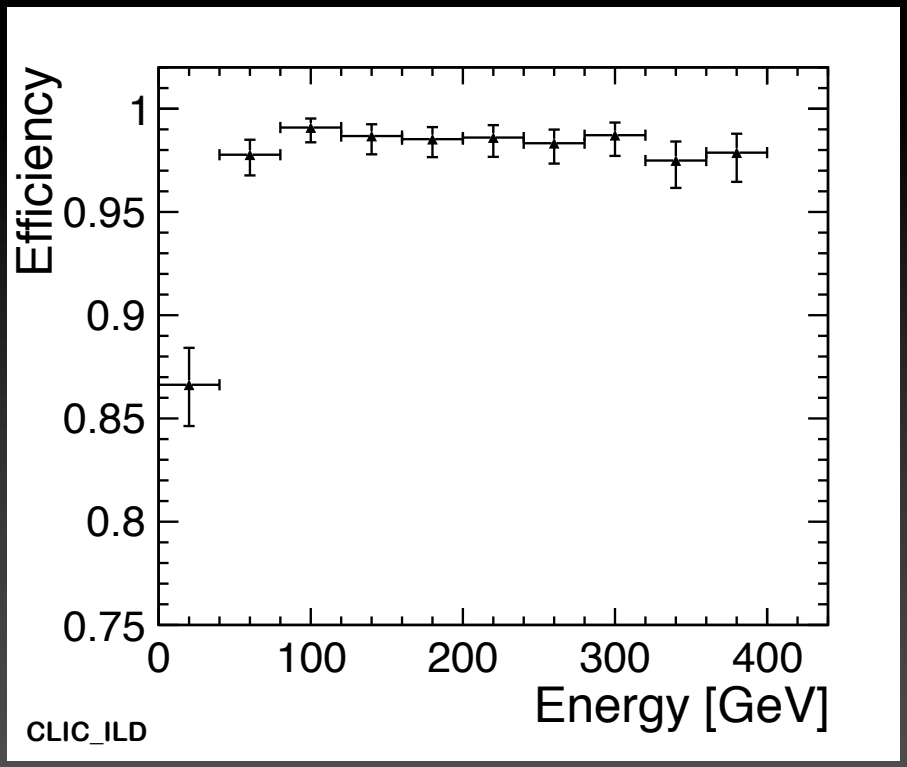
Photons



CDR Figure 12.1

Single Charged Pions



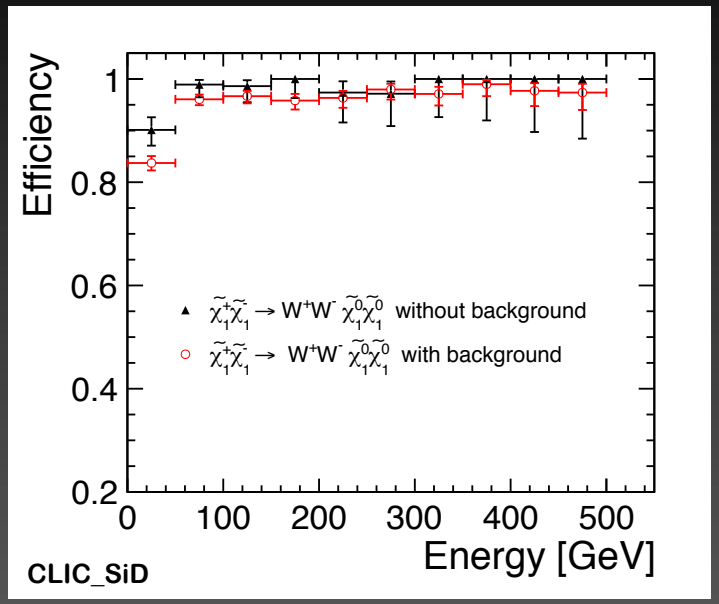


CDR Figure 12.2

Muons

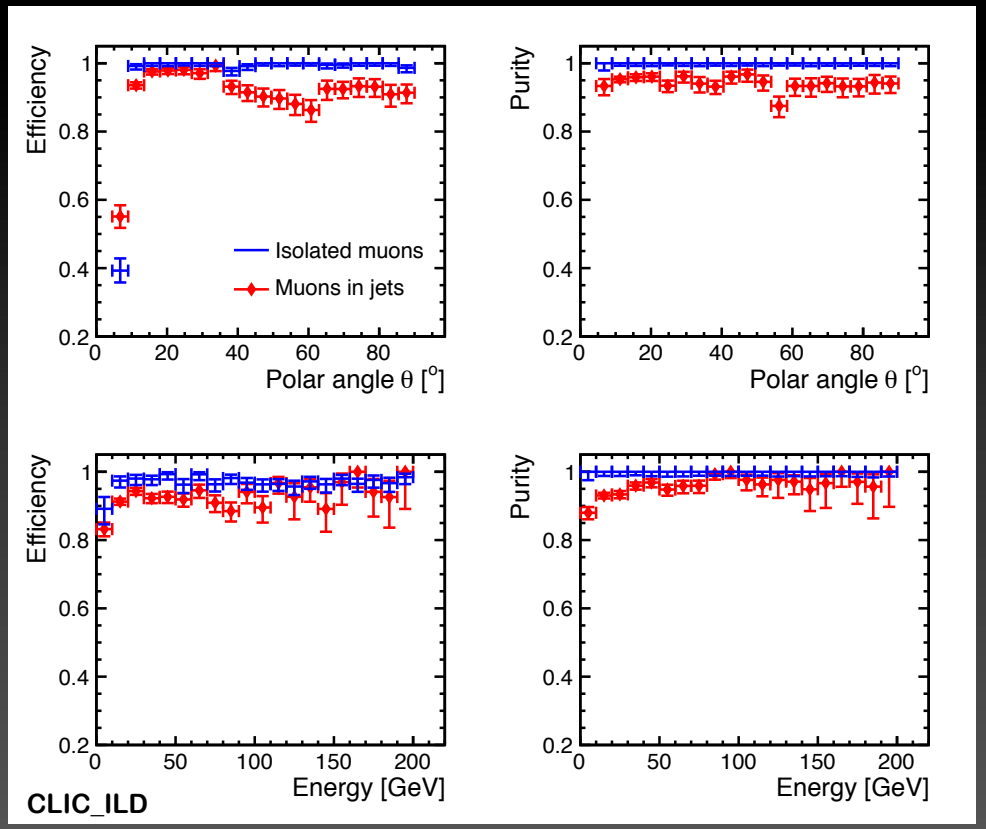
Average identification efficiency for single muons without background is 99%

Over 90% in presence of background



CDR Figure 12.3

Average identification efficiency > 90% for muons in high-multiplicity events (Z* → bb at 1.5 TeV)

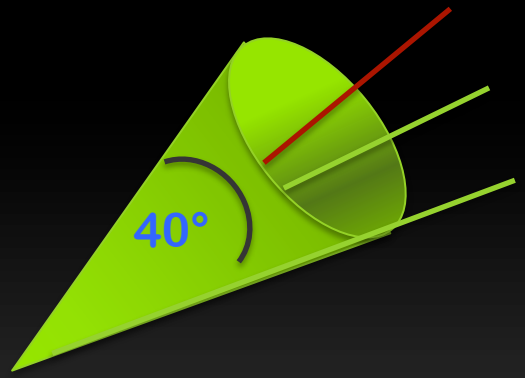


CDR Figure 8.4

LEPTON ENERGY RESOLUTION

Bremsstrahlung Recovery

- Lepton momentum measured in the tracking detector(s)
- Energy needs to be corrected for emission of photons
- Bremsstrahlung recovery by adding photons and conversion pairs in 40° cone around lepton



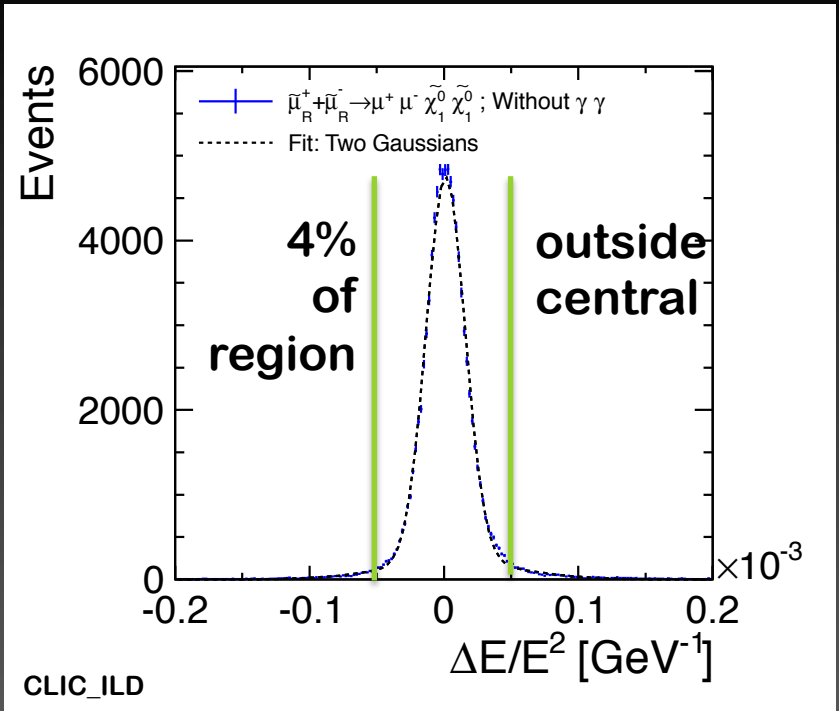
Lepton Energy Resolution

Isolated leptons and missing energy – signal events only

Muons + missing energy

Width of narrow peak: 1.5x10^{-5} GeV^{-1}

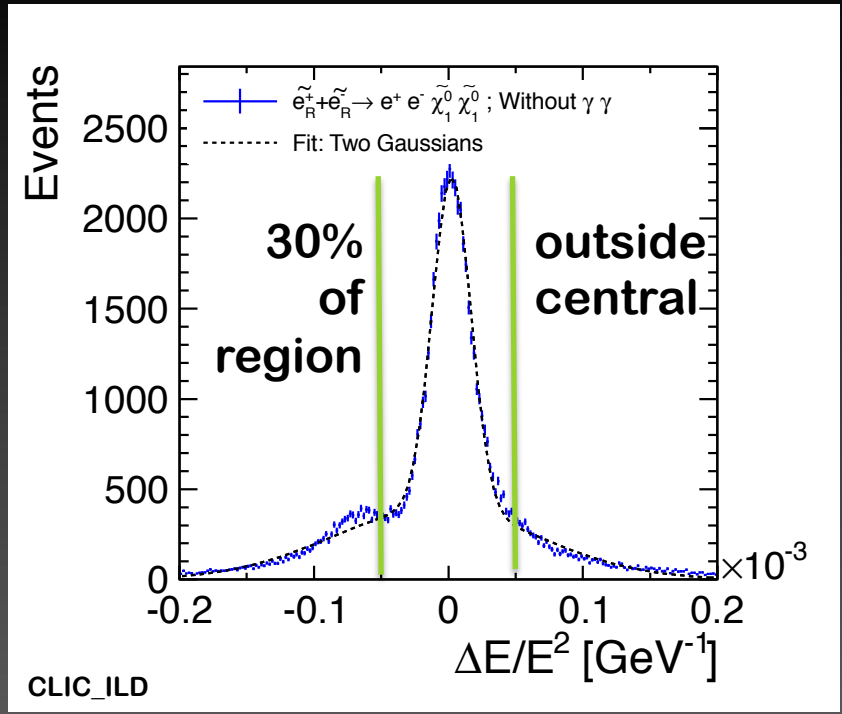
Width of second peak: 4.9x10^{-5} GeV^{-1}



Electrons + missing energy

Width of narrow peak: 1.4x10^{-5} GeV^{-1}

Width of second peak: 7.7x10^{-5} GeV^{-1}

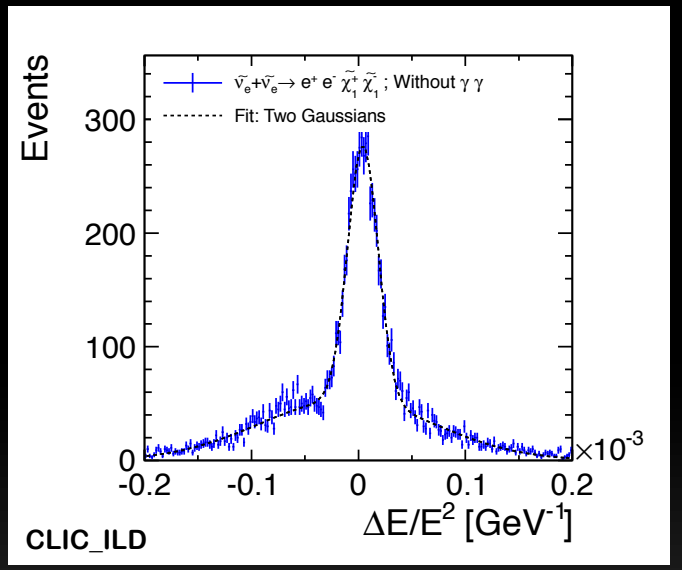


CDR Figure 12.4

Lepton Energy Resolution (II)

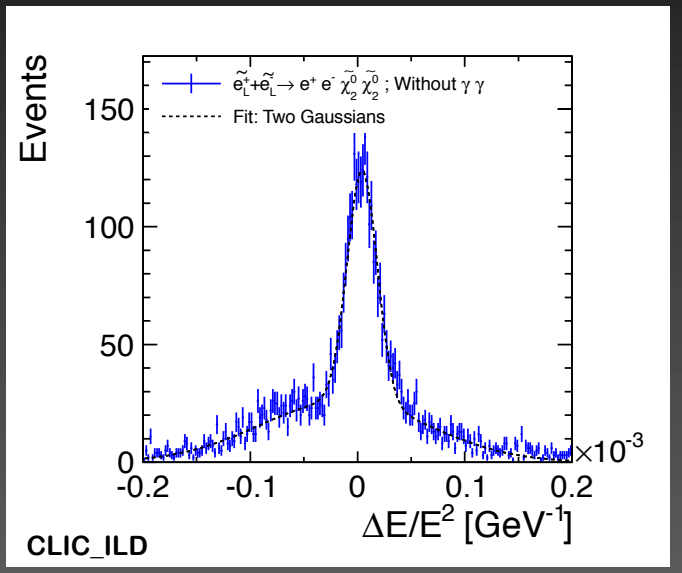
- Energy resolution of isolated electrons in events with two isolated electrons, four jets and missing energy
- Signal events only
- Similar performance to events with isolated electrons and missing energy

$\chi_1^0\chi_1^0 e^+e^-(Z/Zh/h)$



CDR Figure 12.5

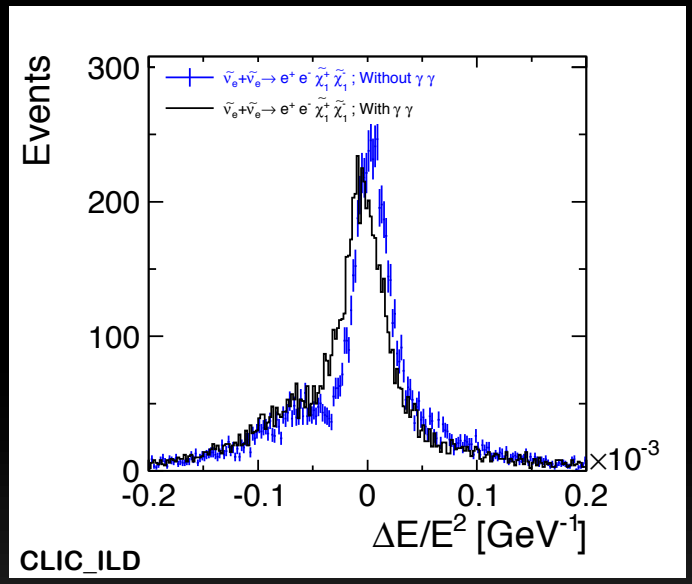
$\chi_1^0\chi_1^0 e^+e^-W^+W^-$



Lepton Energy Resolution (III)

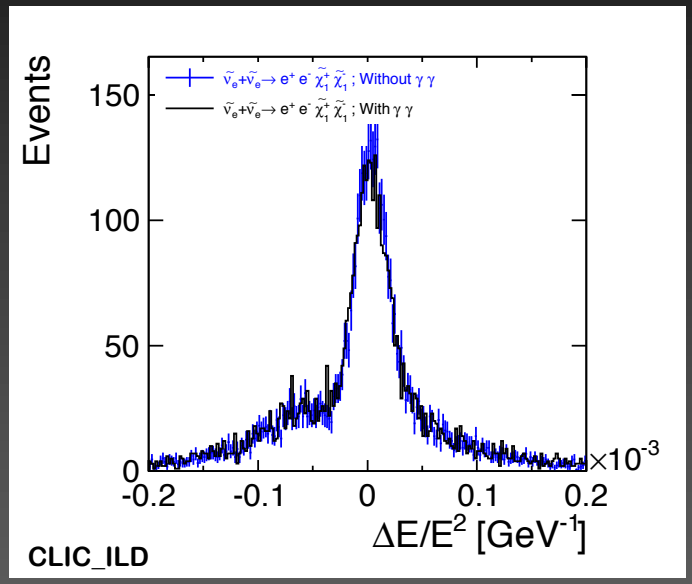
- Background from 60 bunch crossings introduce bias
- Tight timing selection cuts recover the mean

No timing selection cuts



CDR Figure 12.6

Tight timing selection cuts



FLAVOUR TAGGING

Flavour Tagging

LCFI package:

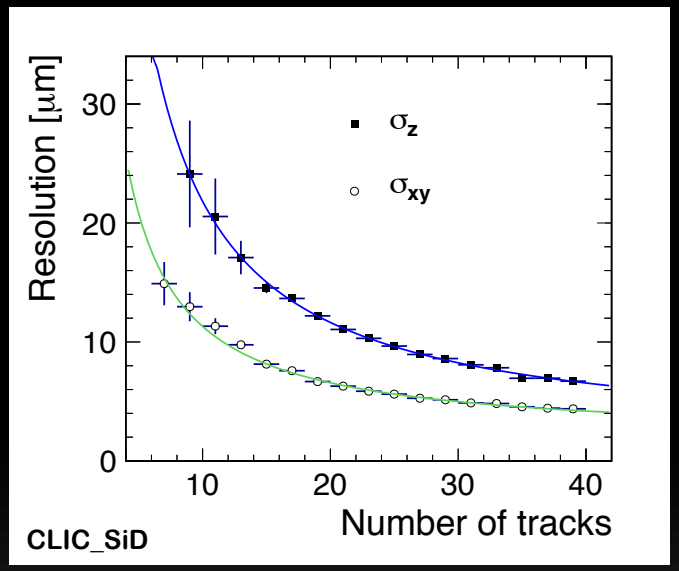
- ZVTOP topological vertex finder
  - D. Jackson, NIM A388:247-253, 1997
- Jet-based tagging
  - Find vertices in tracks belonging to a jet
- Multivariate classifiers for flavour tagging
  - 16 input variables per jet

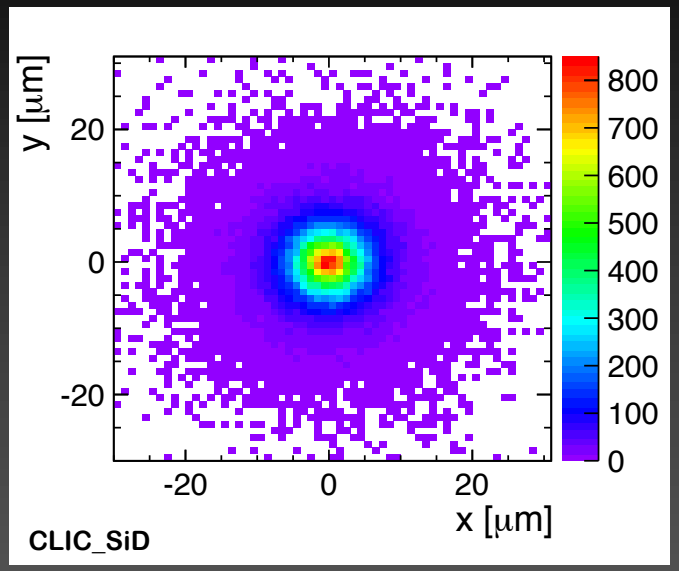
Vertex Resolution

- Using vertex fitting code in LCFI package to fit primary vertex
  - Kalman filter implementation
- In each bin of number of tracks, fit resolution
  - In z with two Gaussians
    - Shown width is weighted average of the two
  - In xy with one Gaussian

$qq\nu\nu$ events with similar kinematic properties as SM Higgs sample

- Mean jet energy 130 GeV
- $\gamma\ \gamma$ → hadron background included





CDR Figure 12.11

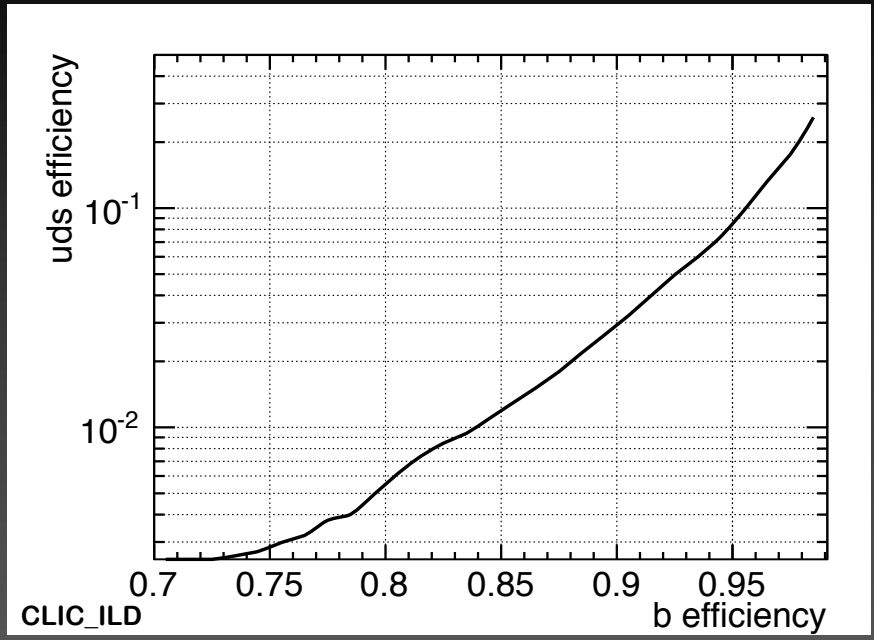
Position of primary vertices with more than 20 tracks

Tagging of High-pt Jets

Challenging task:

- 30% of secondary tracks originate from a decay beyond the innermost vertex layer
- Jets without secondary vertex account for 20-30% of energetic b jets and 90% of light jets

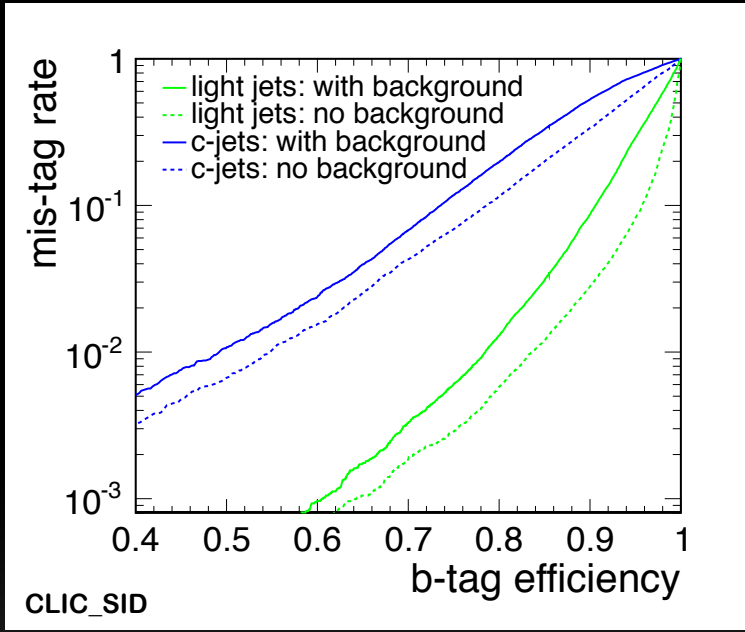
Jet-based tagging variables were augmented with track-based and particle ID in the heavy Higgs analysis



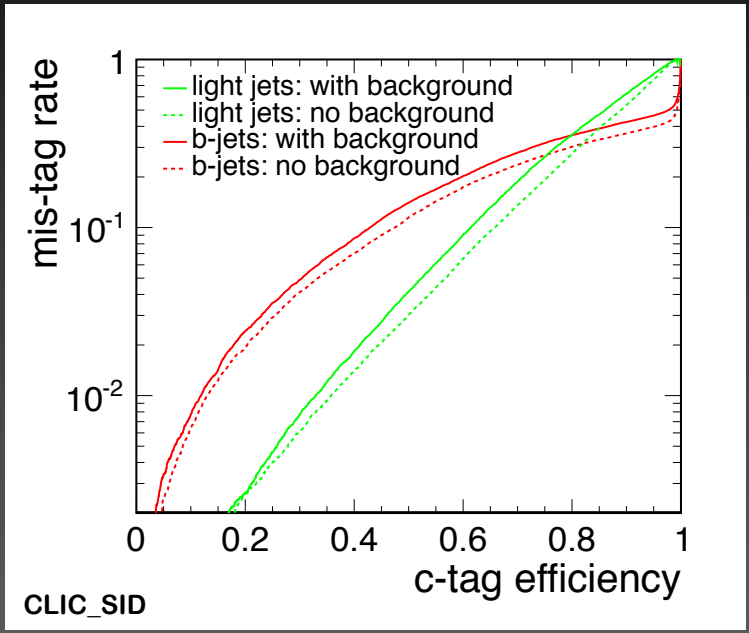
CDR Figure 12.13

Tagging of Low-p_T Jets

- Hadronic SM Higgs decays
  - M_{higgs} = 120 GeV, mean Jet energy 130 GeV
- 80% b-tag efficiency at ~ 1% mis-tag rate
- 40% c-tag efficiency at ~ 1% mis-tag rate



CDR Figure 12.12



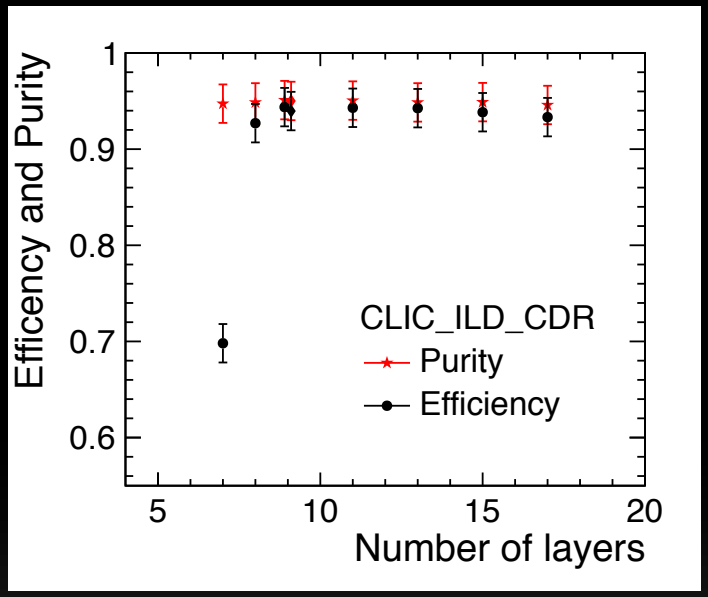
Summary

- Particle ID performance over 90% in a realistic CLIC environment for photons, electrons, pions, muons
- Lepton energy resolution 1.5×10^{-5} GeV^{-1} with bremsstrahlung recovery
  - Timing cuts allow to remove bias in presence of background
- 80% b-tag efficiency at ~ 1% mis-tag rate over large energy range and with background
- 40% c-tag efficiency at ~ 1% mis-tag rate

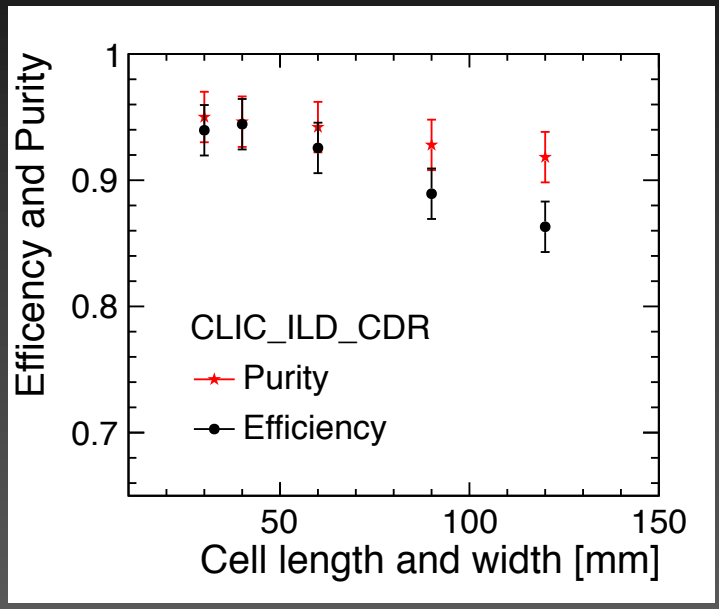
SUPPLEMENTARY MATERIAL

Effect of segmentation on Muon Identification performance

- 750 GeV jets from Z → bb sample
- Measure purity and efficiency of PandoraPFA muon identification algorithm in different geometries



CDR Figure 8.1



CDR Figure 8.3

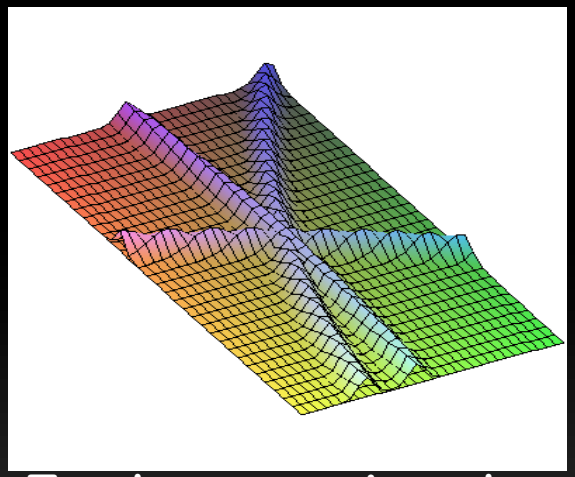
Flavour Tag Input

- Joint Probability r-ϕ
- Joint Probability z
- d_0 significance x 2
- z_0 significance x 2
- Momentum x 2
- Number of tracks in vertex
- Raw momentum
- Decay length
- Decay length significance
- p_T-corrected mass
- Secondary vertex probability
- Number of (secondary) vertices
- Decay length of seed vertex to IP

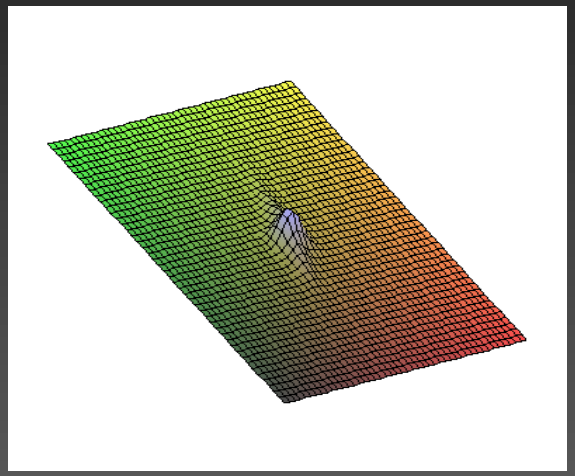
The Algorithm – ZvTop

D. Jackson, NIM A388:247-253, 1997

- Topological Vertex Finding
- Looks for overlap of Track probabilities in the Jet
- Resolves ambiguities with a resolution criterion
- Tracks are fitted to the point of highest overlap



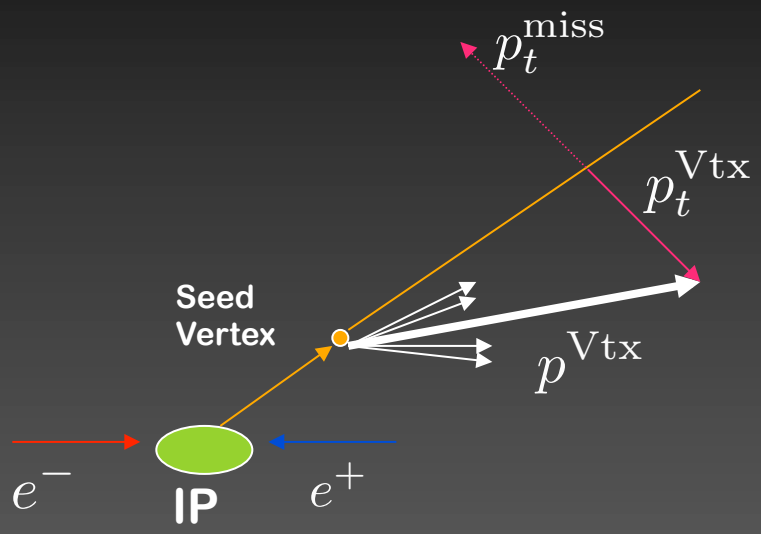
Tracks are assigned Gaussian Tubes



The maximum overlap is calculated

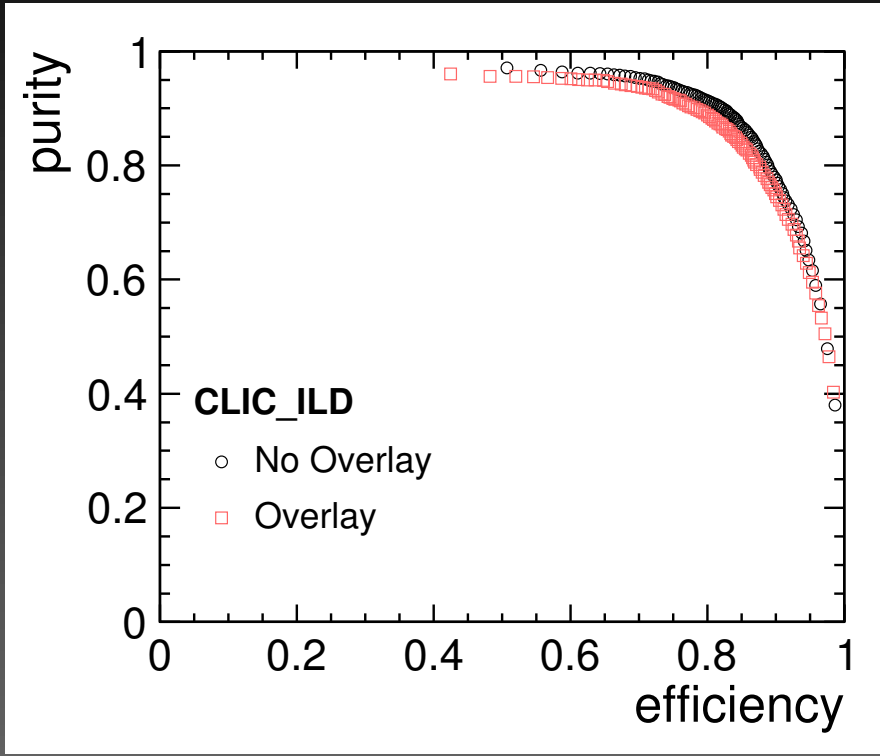
Correcting the vertex mass for neutral particles

$$m_{p_t} = \sqrt{(\sum_{\text{tracks}} m_{\pi^\pm})^2 + |p_t|^2} + |p_t|$$

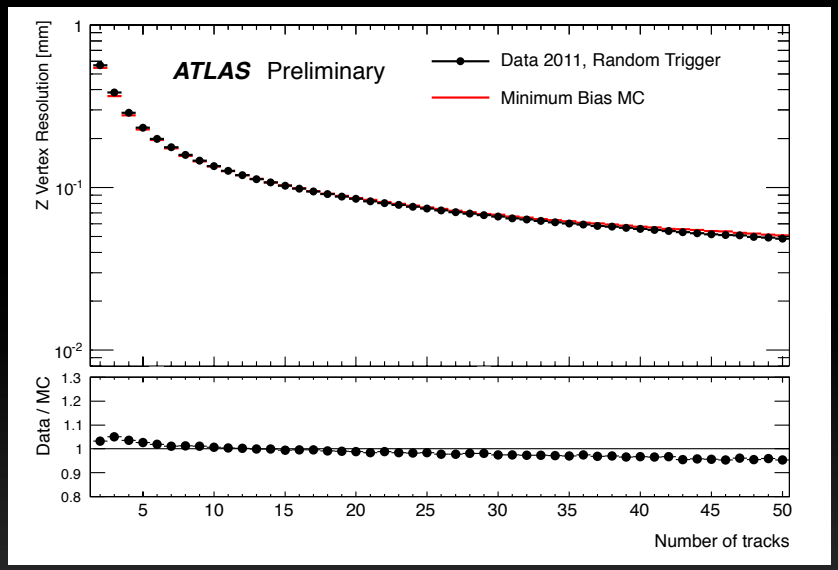


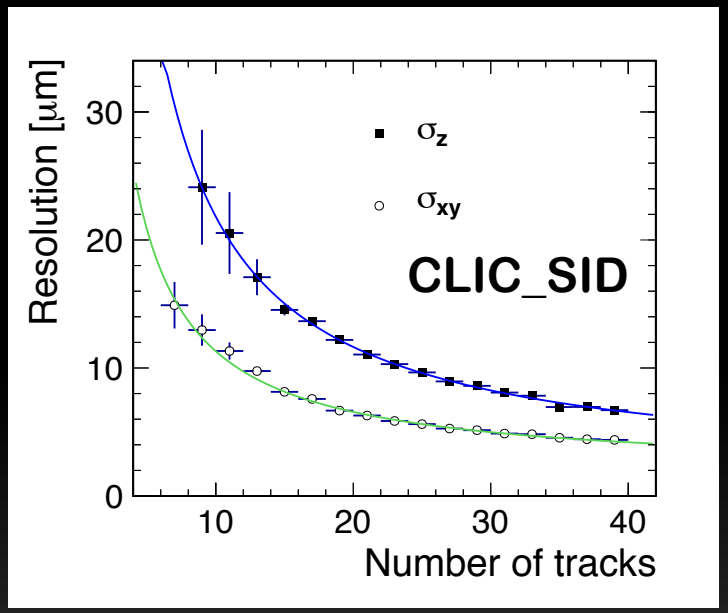
Flavour Tagging in ttbar events

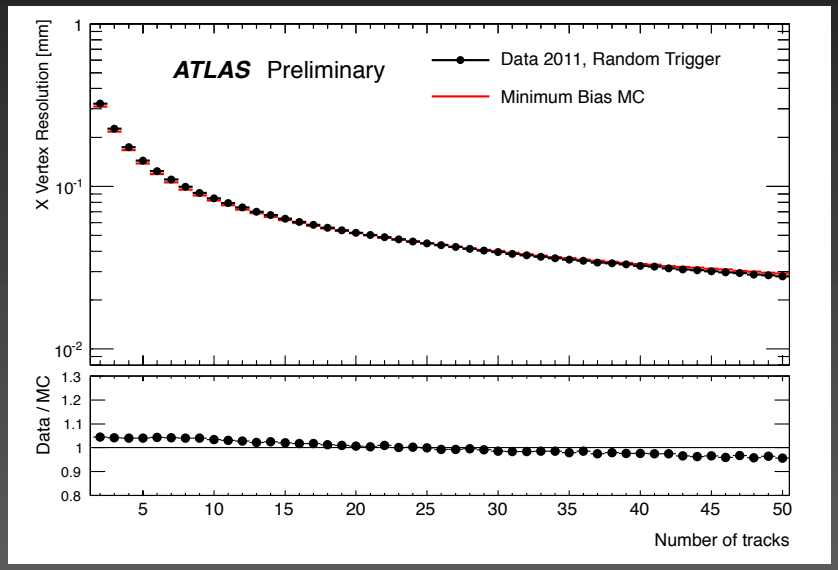
- Ttbar at 500 GeV
- Modified Vertex detector
  (inner layer 3.1 cm → 2.5 cm)

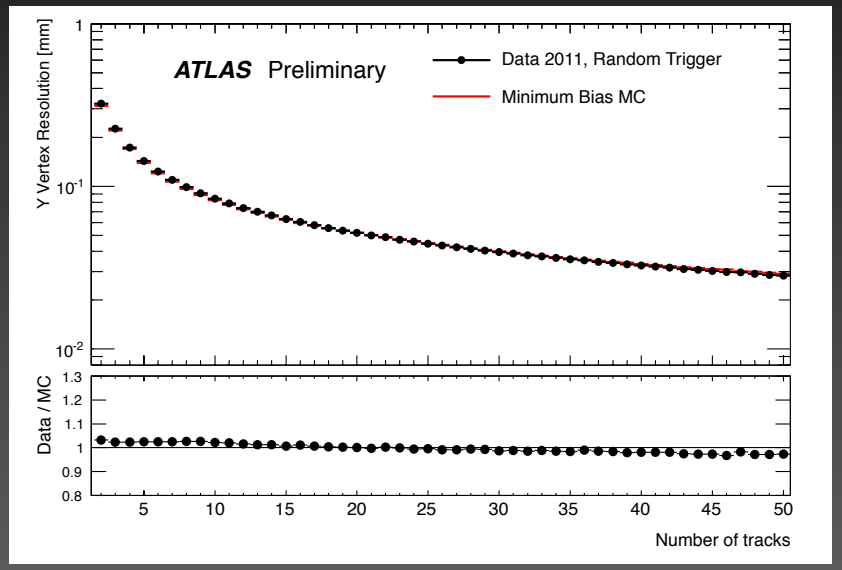


Comparison of Primary Vertex Resolution

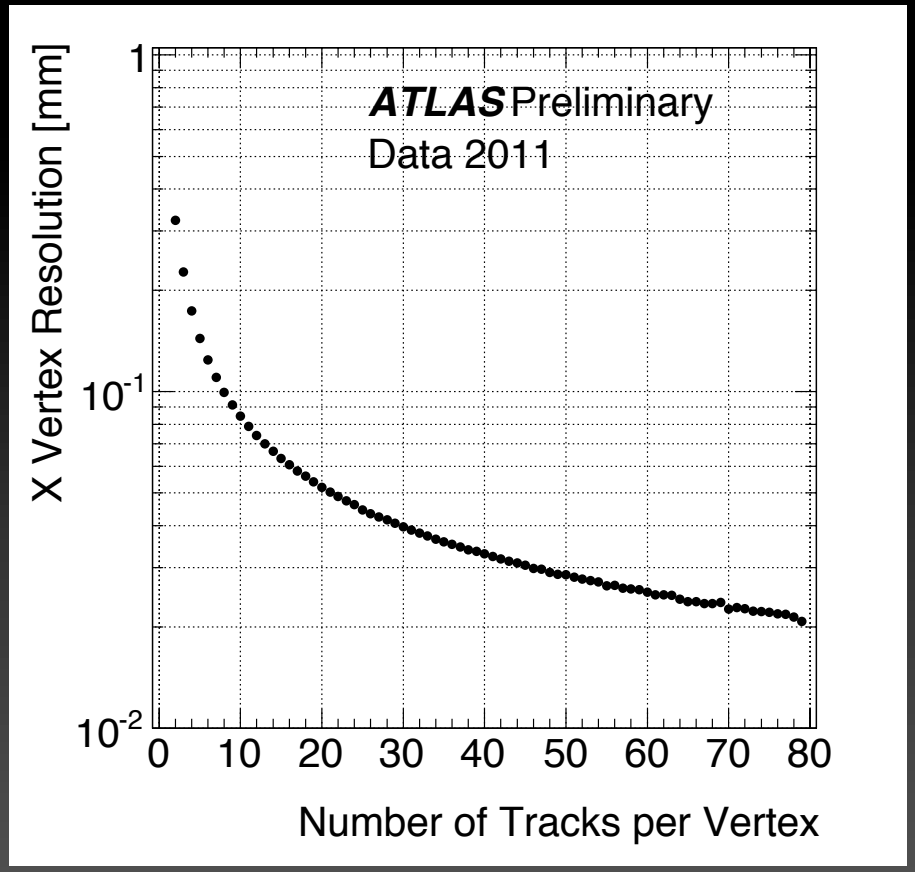


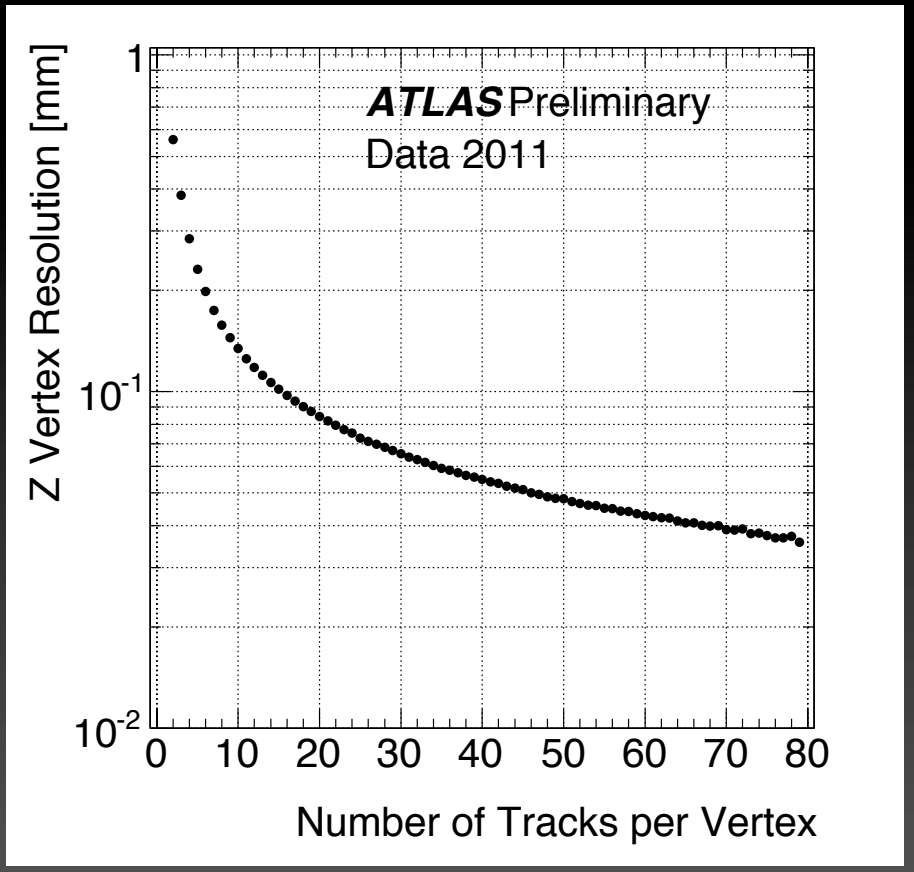




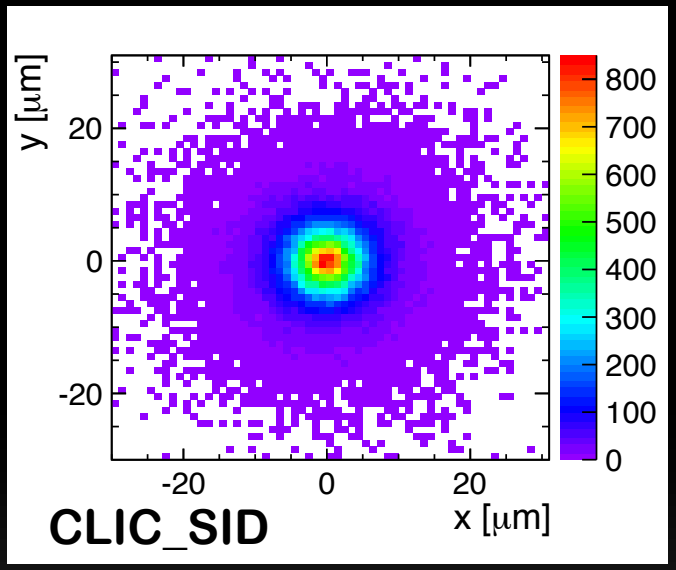


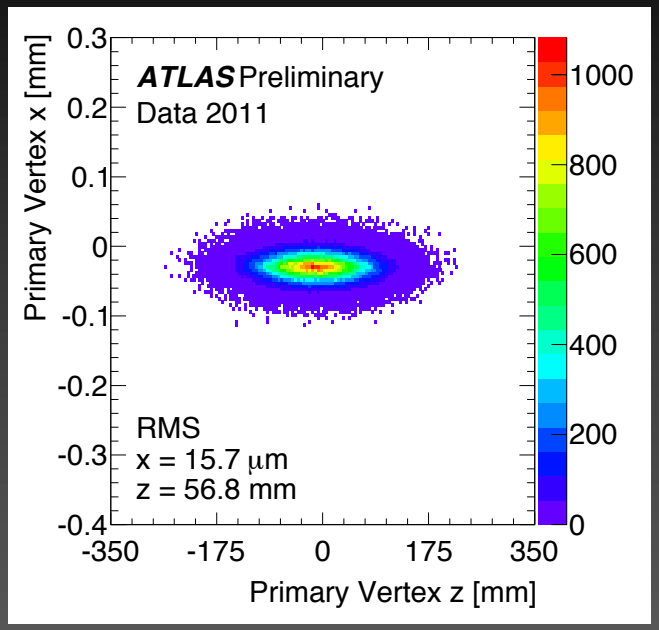
Atlas Secondary Vertex

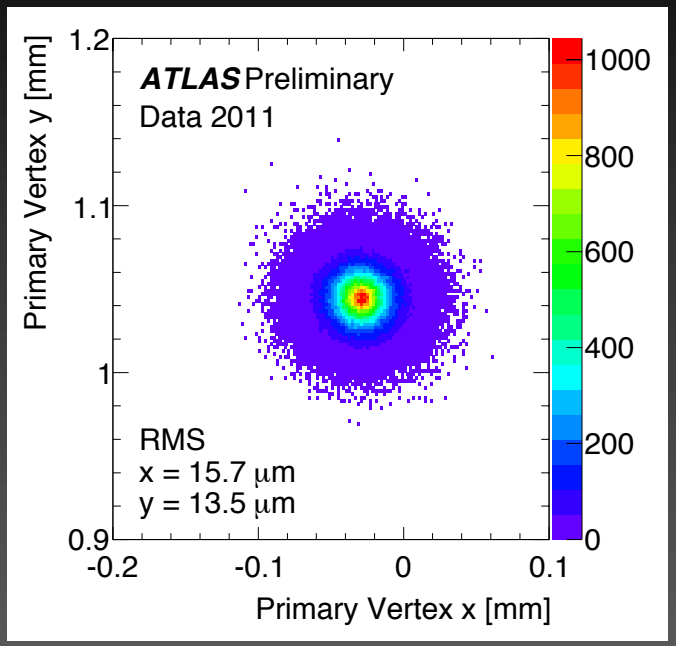




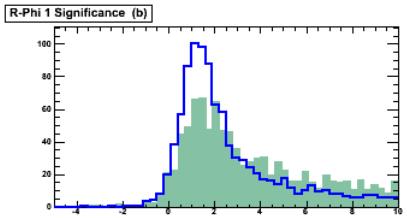
Primary Vertex Position

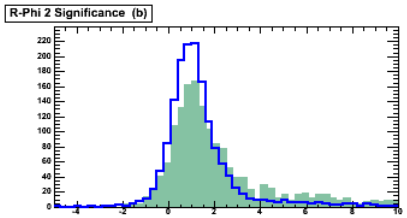


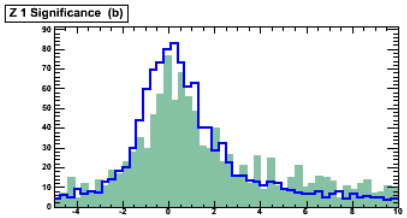


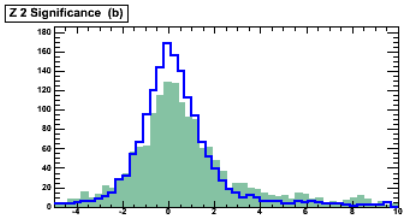


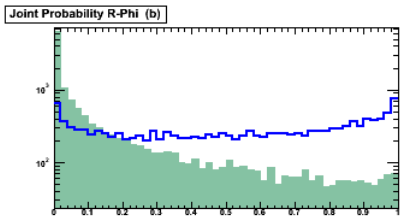
Neural Net Inputs – ILD

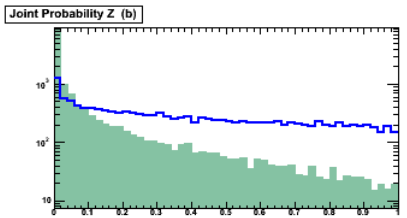


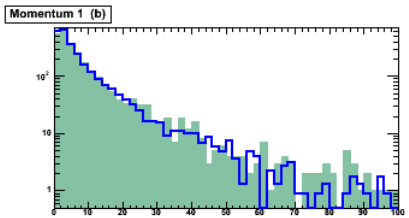


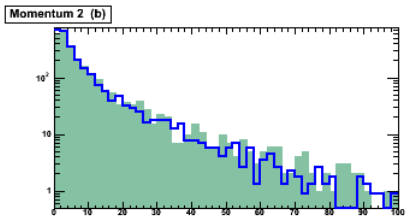


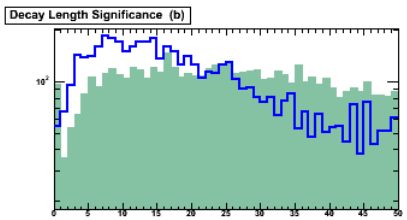


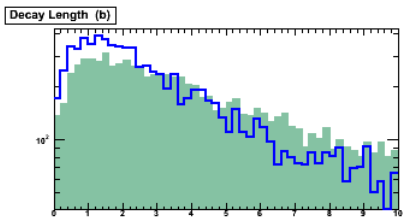


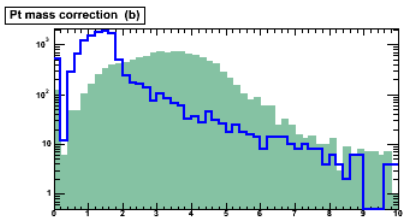


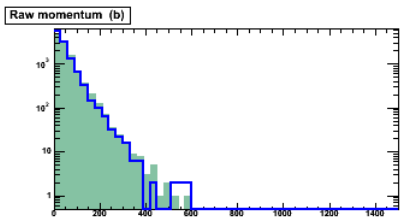


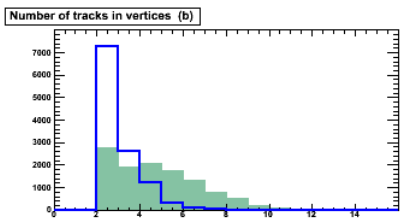


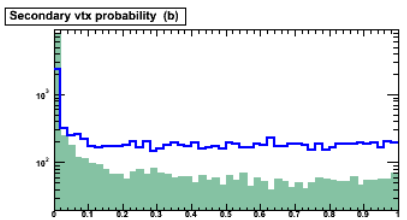


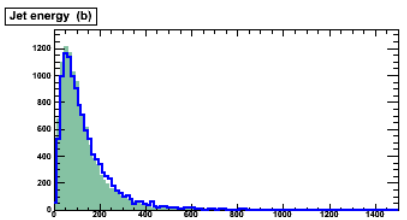


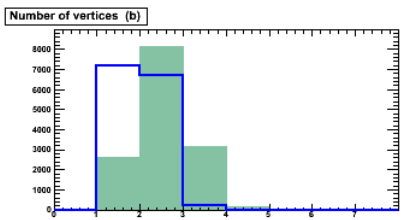












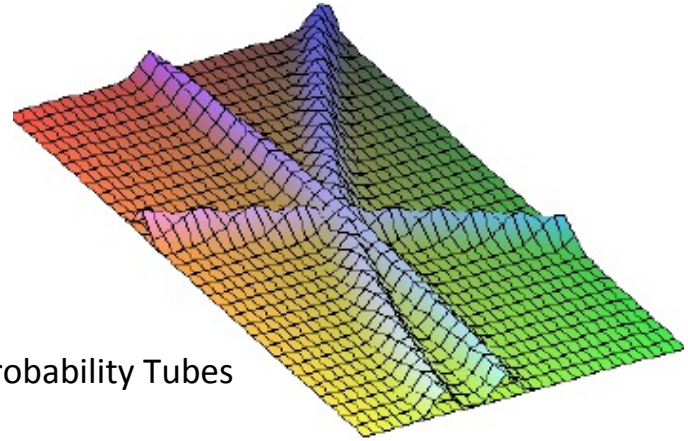
The inputs are not all very similar to the SiD.

Kolmogorov test shows very similar b/c separation to the SiD (except p_T mass correction, where the ILD does better).

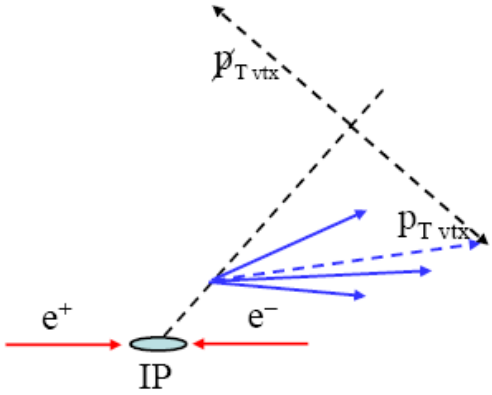
Tomas Lastovicka

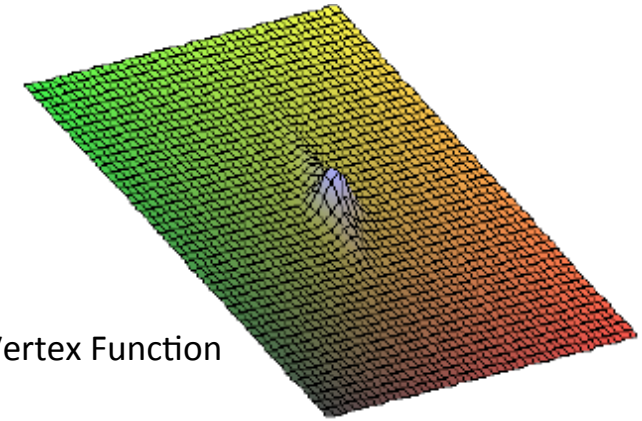
LCFI Jet Flavour Tag Package

- Used for jet flavour tagging and secondary vertex reconstruction.
- Topological vertex finder ZVRES.
- Standard LCIO input/output
  - Marlin environment (used for both ILD/SiD)
- Flavour tagging based on Neural Nets.
  - Combine several variables…



Probability Tubes





Vertex Function

NN Input Flavour Discriminating Variables

- Currently, there are 14 flavour discriminating variables

  Rφ- and Rz- significance for 2 tracks with the highest impact parameter significance in Rφ ("leading tracks")

  Relative momenta of the leading tracks (relative to jet energy)

  Joint Probability in Rφ and Rz

  Decay length and decay length significance (relative to jet energy)

  Pt-corrected vertex mass

  Secondary vertex probability

  Relative total momentum of non-primary vertex tracks and their number

  - These inputs are re-normalised and transformed by tanh() - except joint and secondary vertex probabilities.
  - Tracks/vertices have to pass some minimal selection cuts.

NN Input Flavour Discriminating Variables

- Inputs are sent to 3 neural networks (8 inputs each) according to the number of secondary vertices found in a given jet
  - 0 vertices:

    Rφ-, Rz- significance and momenta for 2 leading tracks

    Joint Probability (Rφ, Rz)
  - 1 vertex and >1 vertices:

    Decay length, decay length significance, pt-corrected vertex mass,

    Total momentum of non-primary vertex tracks and their number,

    Joint Probability (Rφ, Rz), Secondary vertex probability

- This is not a dogma, inputs can be added/removed
  - Not that trivial inside the package, requires some coding.
  - Studies better done outside the package (I fancy FANN package for this purpose).