Algorithm for muon bremsstrahlung shower reconstruction
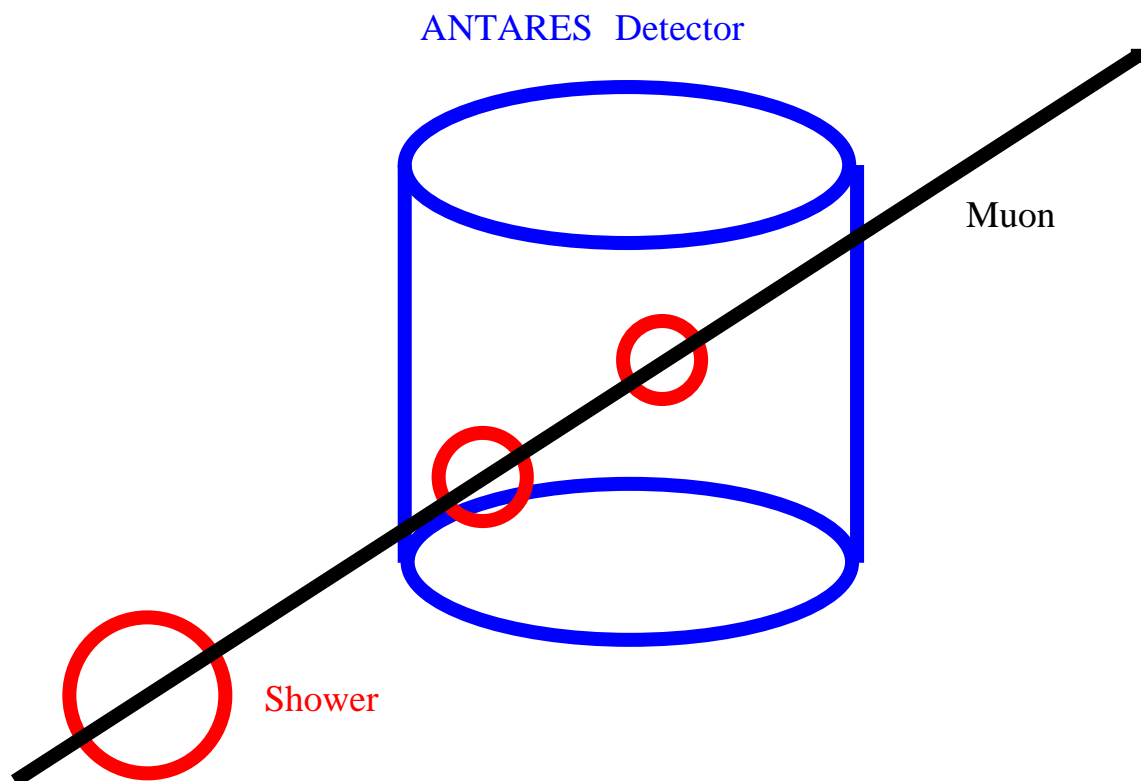
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on behalf of the ANTARES Collaboration

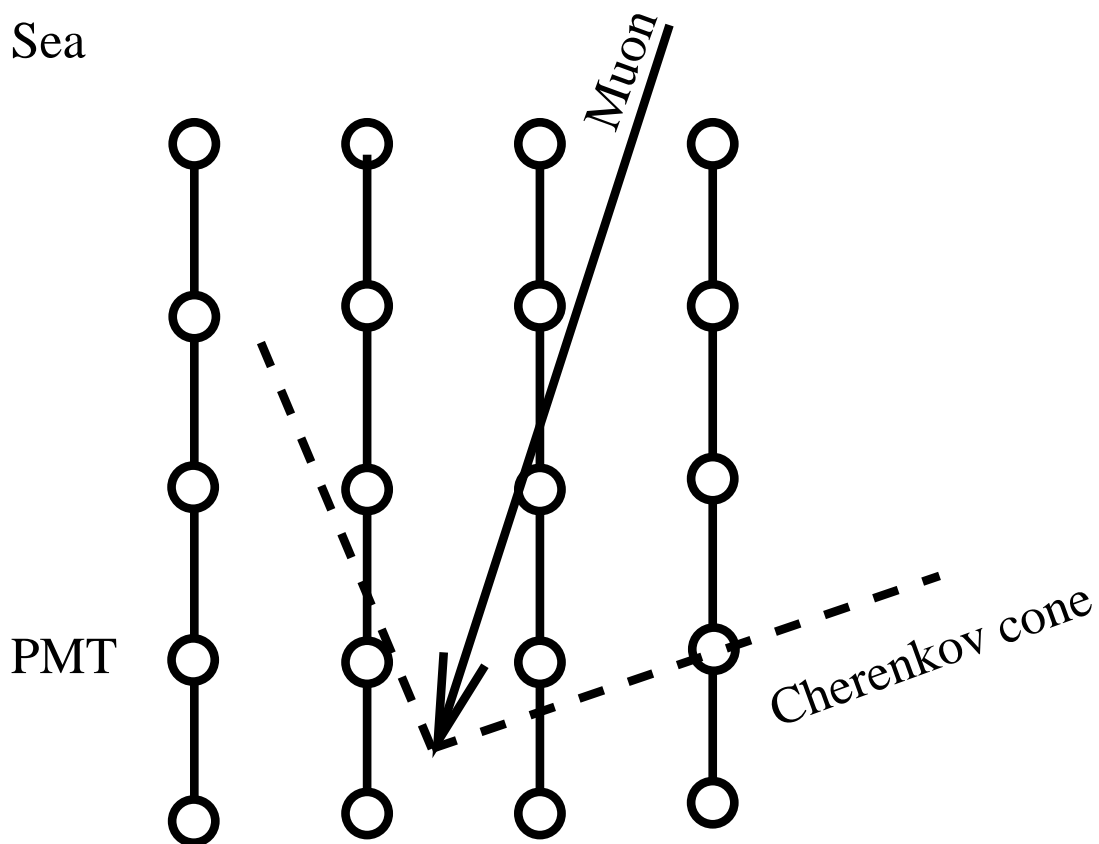- Motivation
- Method
- Event Display
- Results

ANTARES Detector

Muon

Shower

ANTARES detector

- **underwater** cherenkov detector

- Mediterranean sea at 2500 m depth

- array of photomultiplier tubes
  $\Rightarrow$ reconstruction muon trajectory

Sea

Muon

PMT

Cherenkov cone
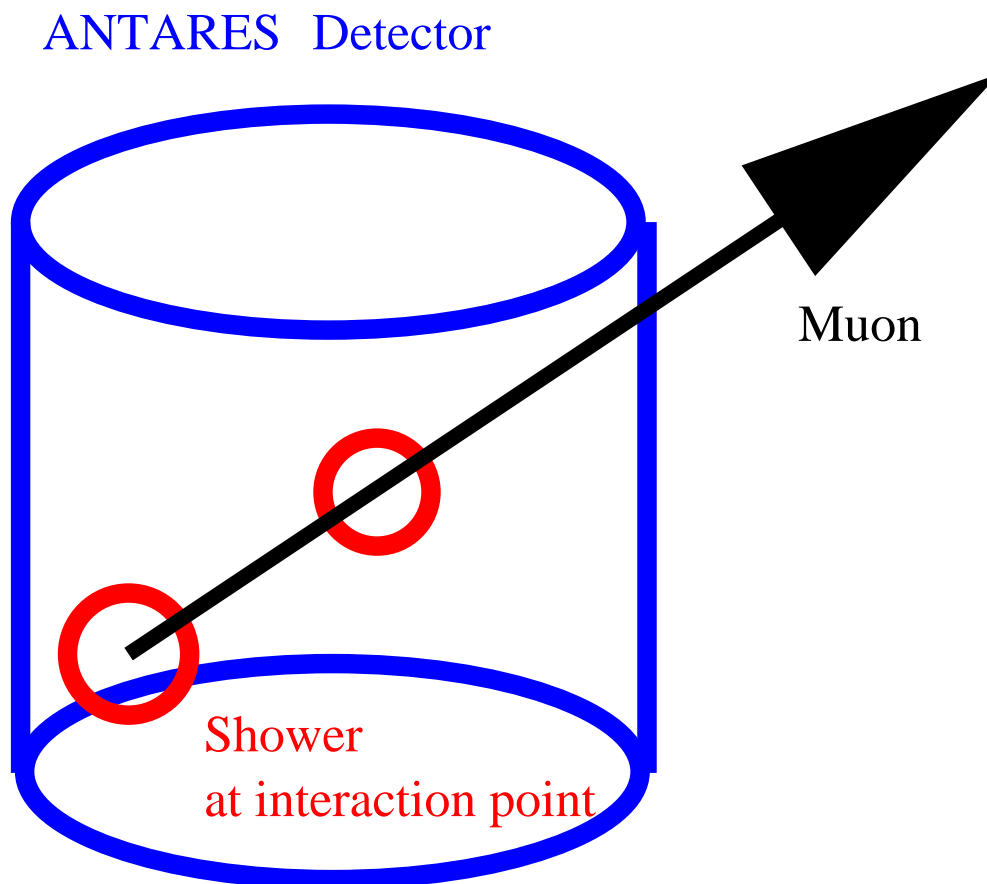
This talk:

bremsstrahlung showers from muons

Motivation

- Extract more information:
  - many μ's have showers
  - additional variables (shower multiplicity)

- Not explored yet
  - number of showers per track length
    $\Rightarrow$ energy estimator
  - distinguish event topologies

ANTARES Detector

Muon

Shower
at interaction point

Identify showers in three analysis steps

1. Basic selection

   muon candidates

2. 1-dimensional pre-selection

   select hits with associated shower(s)

   $\Rightarrow$ shower candidates

3. Final selection

   3-dimensional fit of pre-selected hits
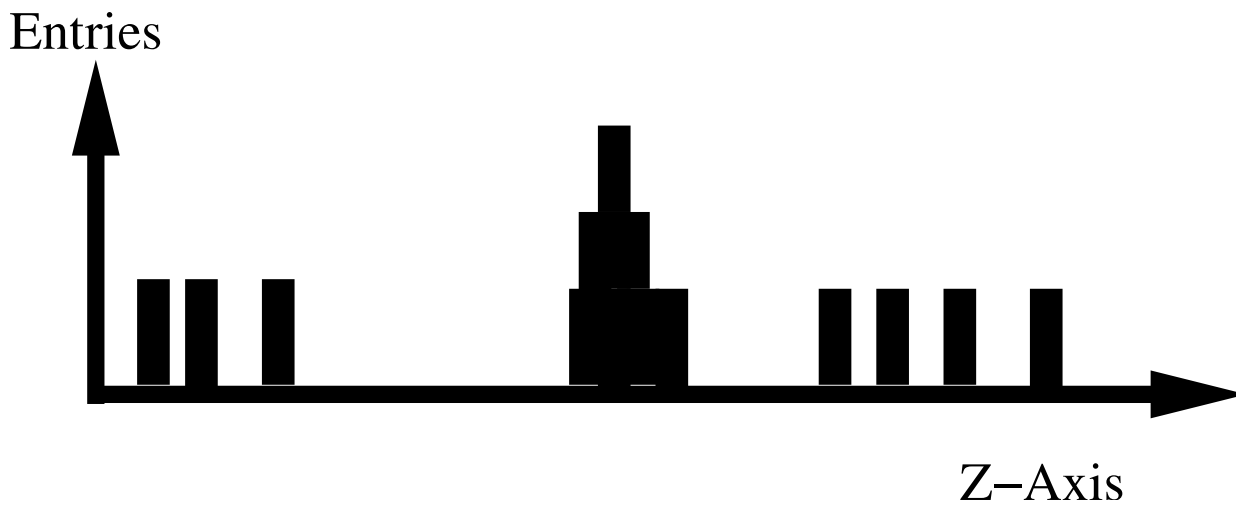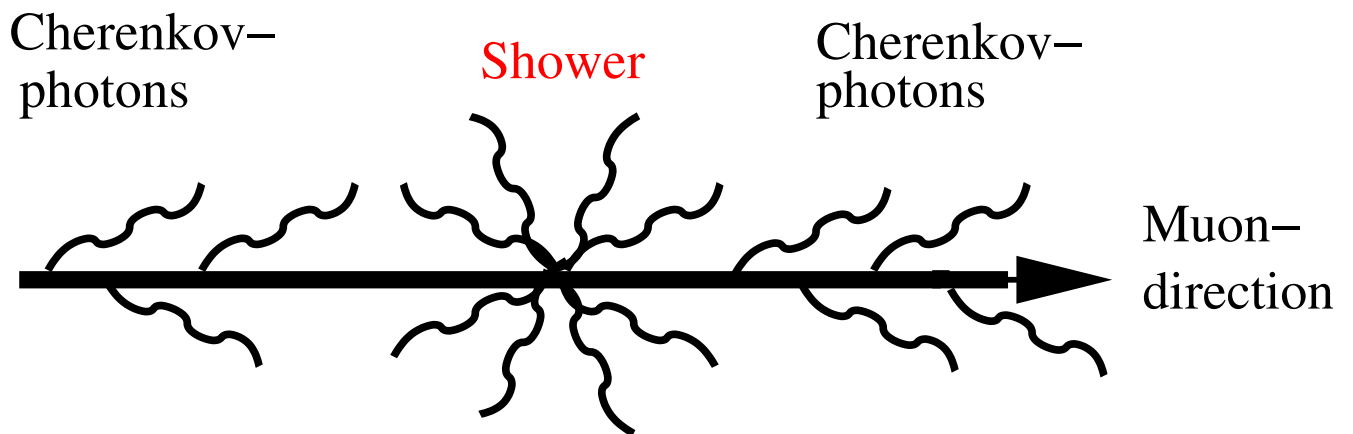
   $\Rightarrow$ shower candidates with 3D position

Analysis Idea

Hit information (3D position and time)

↓

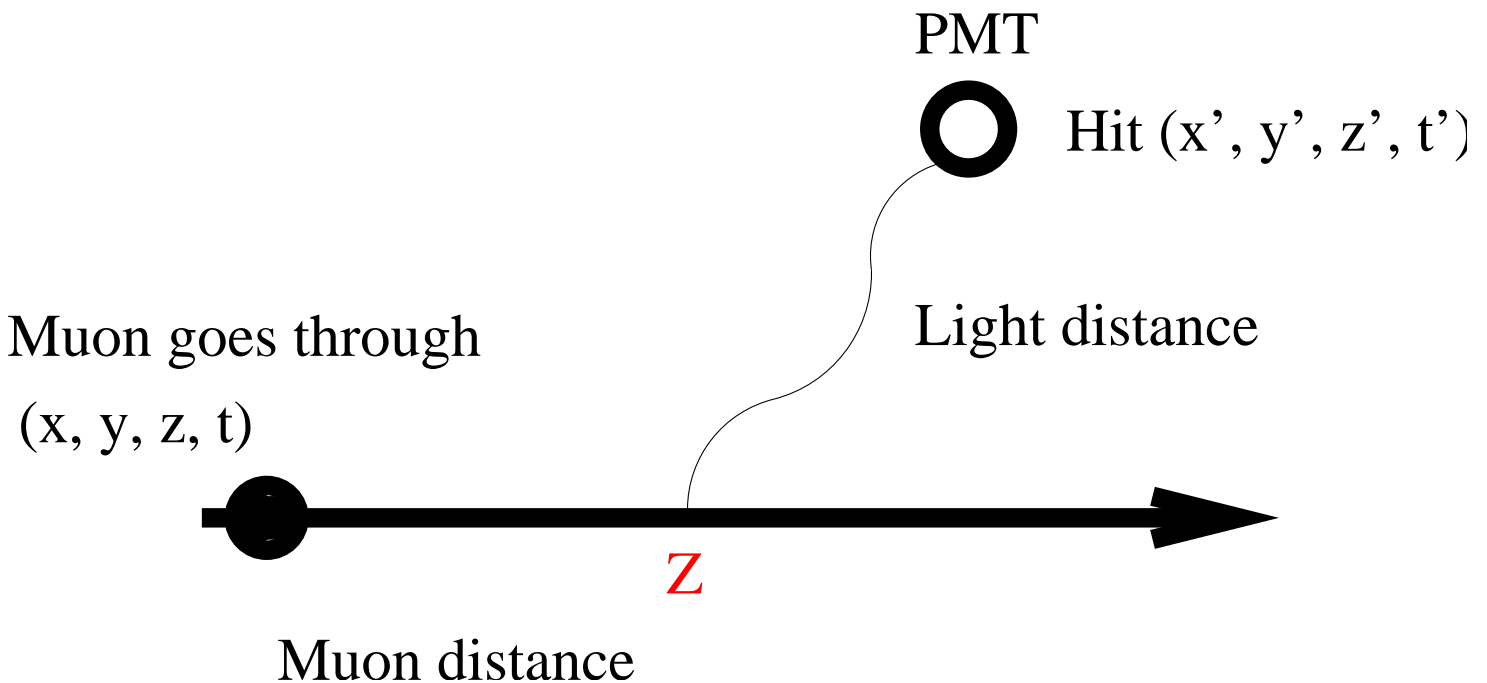reduce to one dimensional problem
by projection on muon direction

use peak finder ⟹ shower Z-position

From hit information to Z position

Z-calculation in rotated system:

$$t' = t + \underbrace{\frac{Z - z}{c}}_{\mu \text{ time}} + \underbrace{\frac{n}{c}\sqrt{(x' - x)^2 + (y' - y)^2 + (z' - Z)^2}}_{\text{time for light in water}}$$

PMT

Hit (x', y', z', t')

Muon goes through

(x, y, z, t)

Light distance

Z

Muon distance

Rewrite to quadratic equation $aZ^2 + bZ + c = 0$
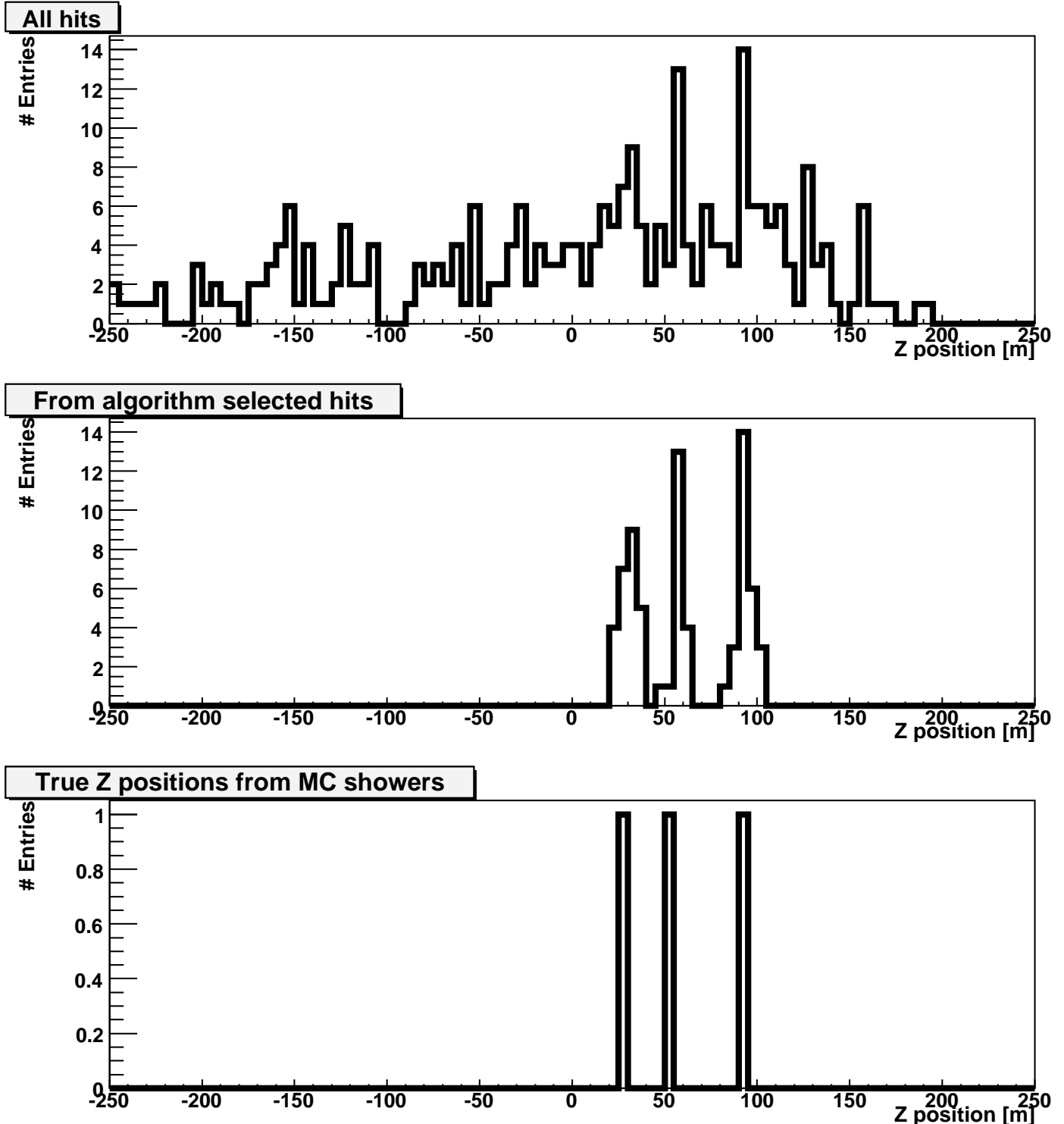
Algorithm to find showers

- Algorithm

  1. take direction of muon
  2. calculate Z-positions
  3. search shower candidates
  4. eliminate background
  5. fit 3-dimensional position

  ⇒ muon with at least one shower

- Simple algorithm with few parameters

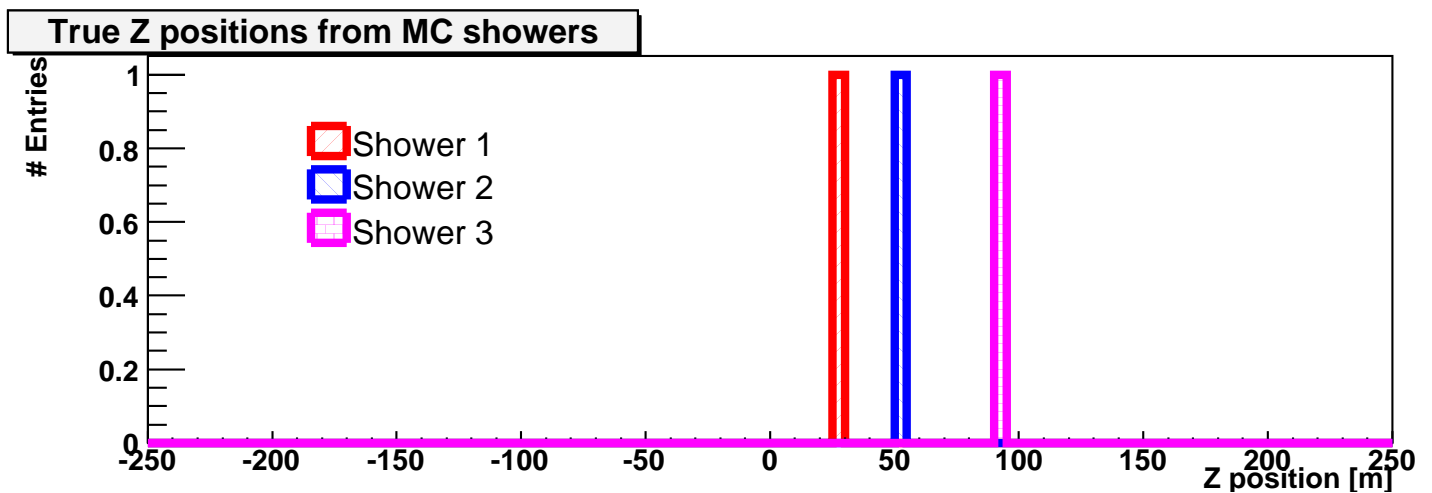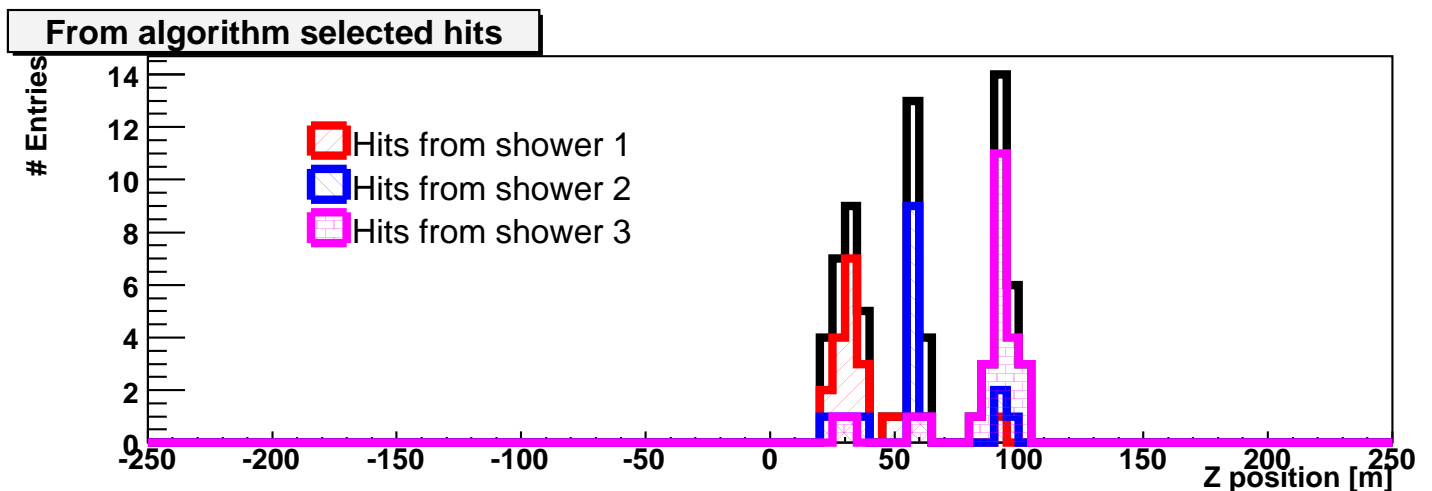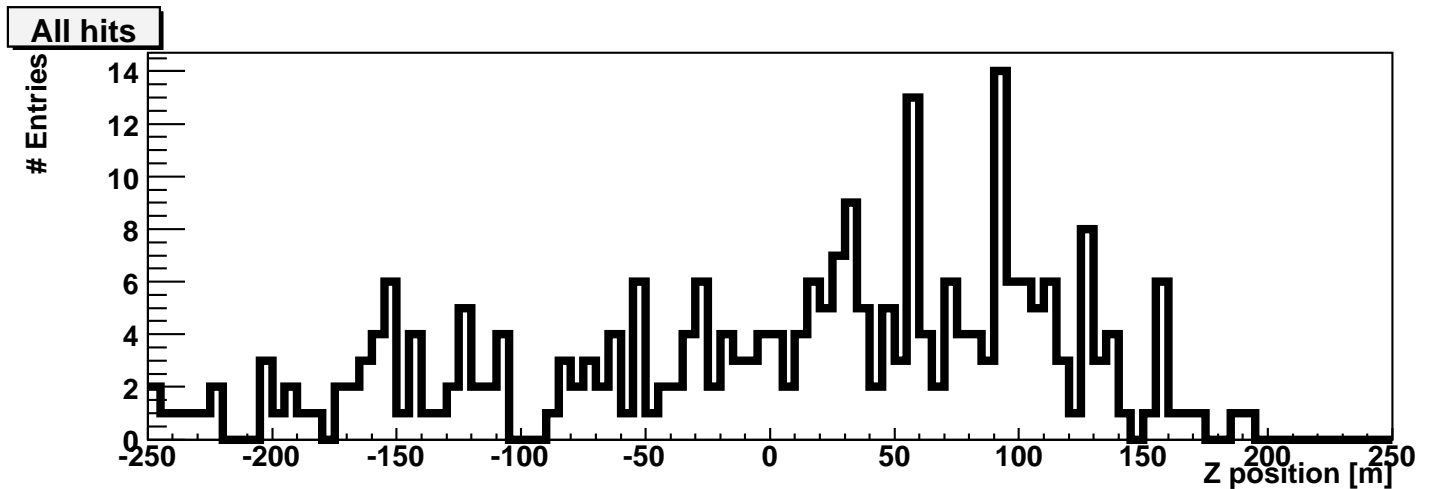 – width and significance of the peak
  – Z selection
  – fit probability

Z-Display for one MC event

atmospheric muon MC including background
reconstruction: peak width 20 m and > 10 hits

Same Z-Display with hit information

$\Rightarrow$ high hit purity for each shower

MC Event Display
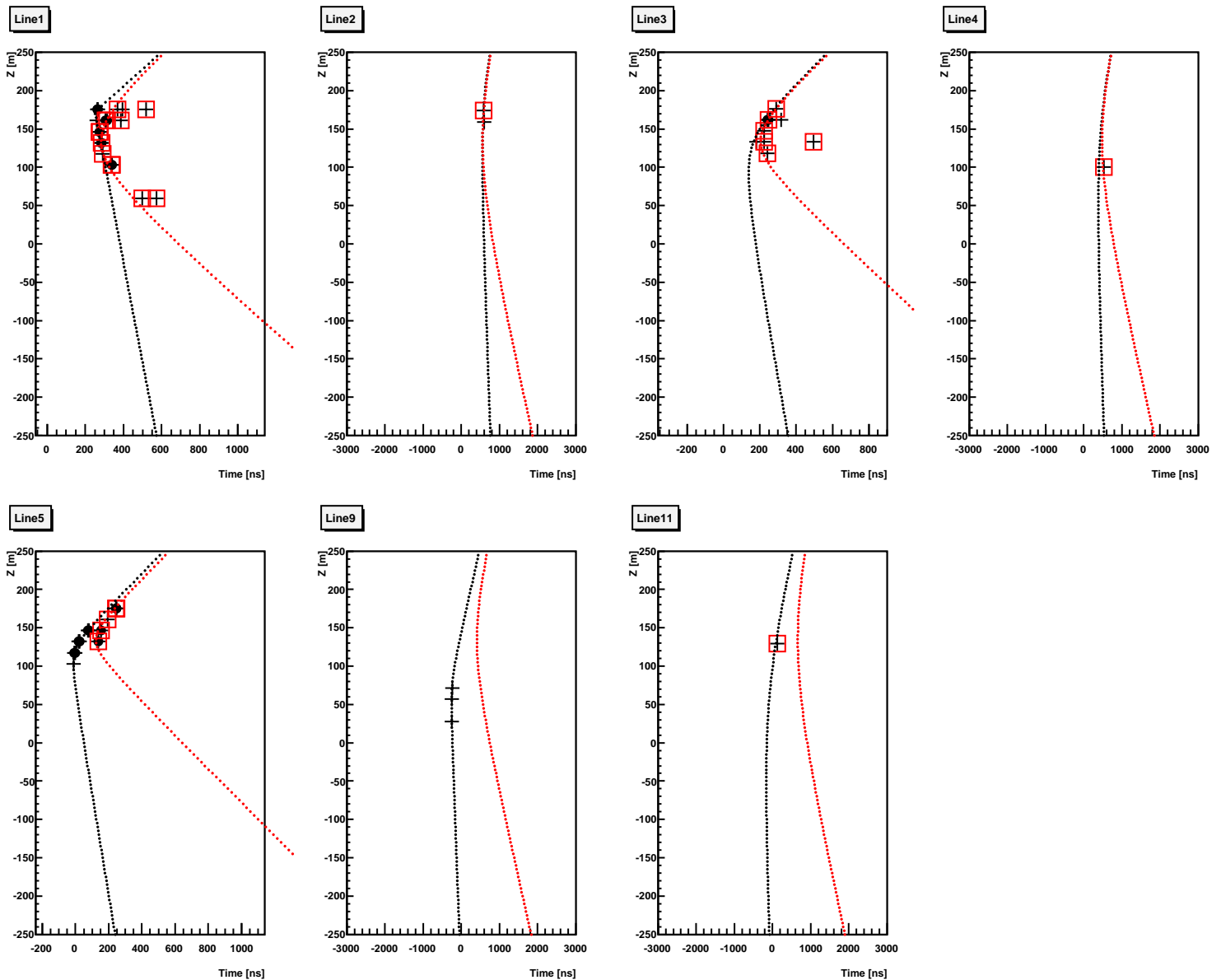
dots = two photon hits

crosses = one photon hits

black Line = Cherenkov light ⟷ red Line = shower light

red box for hits from shower

Run : 1234 Event : 2263 FrameTarget : 0 FrameIndex : 51029

Data Event Display
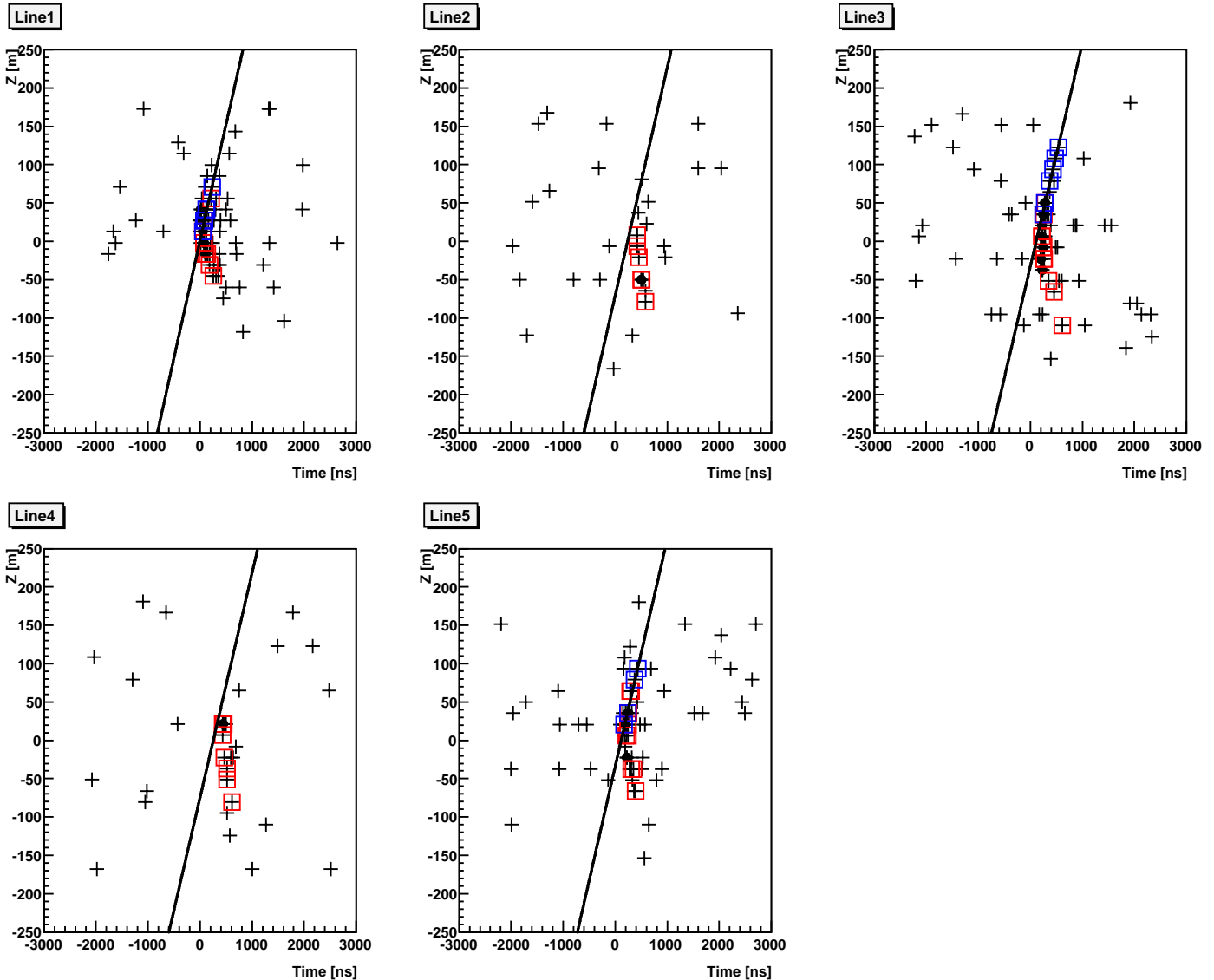
dots = two photon hits

crosses = one photon hits

black Line = result of μ-reconstruction

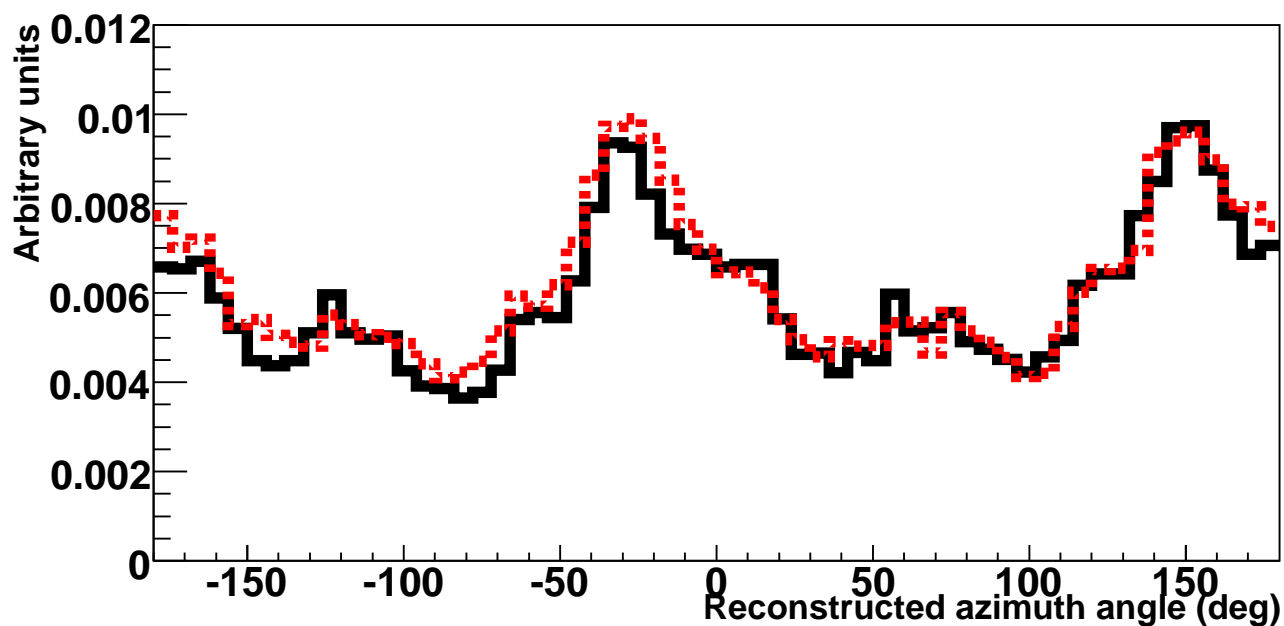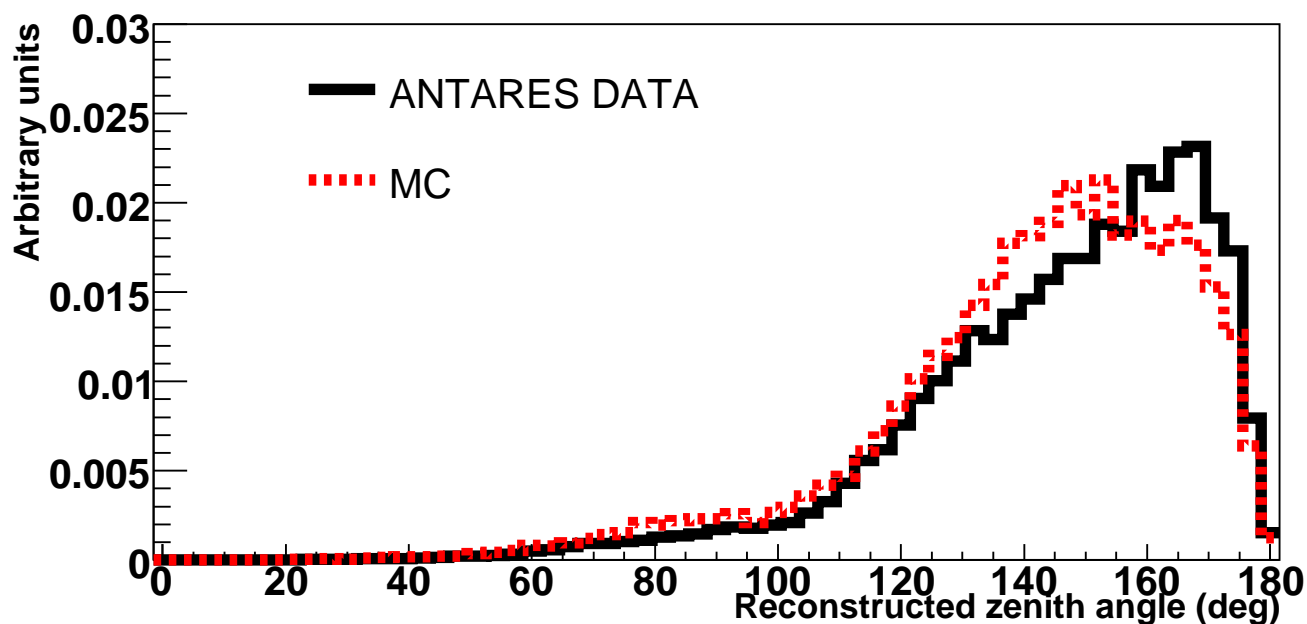blue box for hits used in μ-reconstruction

red box for hits in peak

Run : 26248 Event : 7404 FrameTarget : 0 FrameIndex : 114521
a: -29.9512 b: -24.849 t0: 45919349.19 θ: -0.03245 ϕ: -1.6757 fit : 1/1
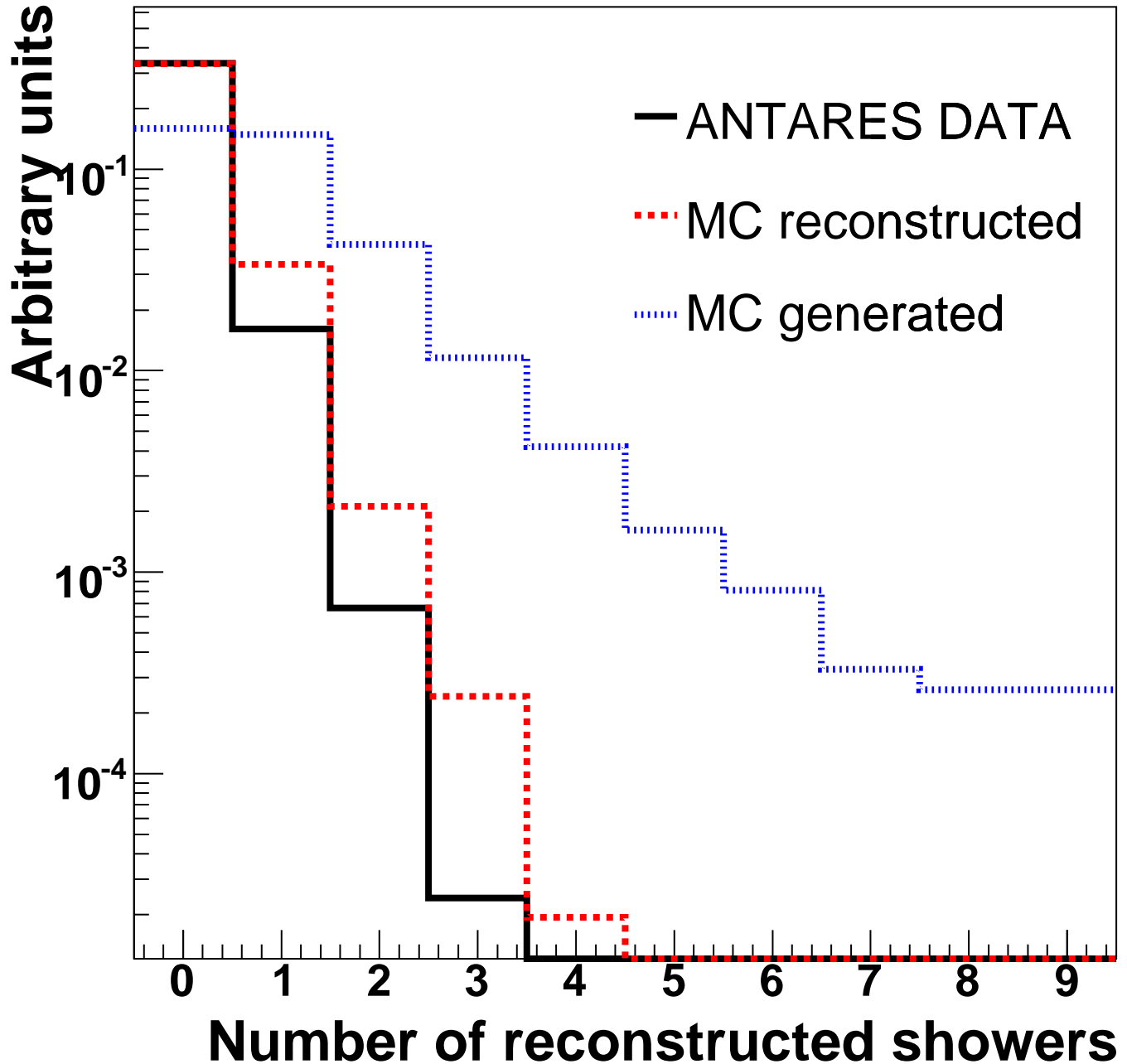
Muon candidates: DATA-MC comparison

multiple atmospheric muon event generator

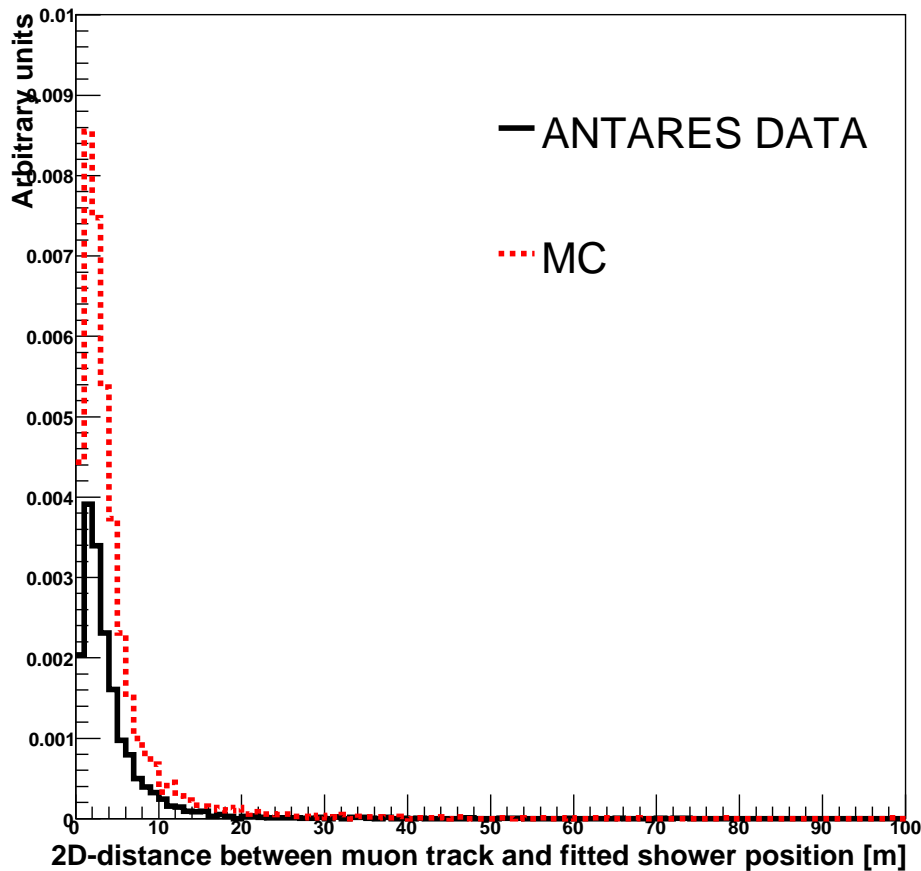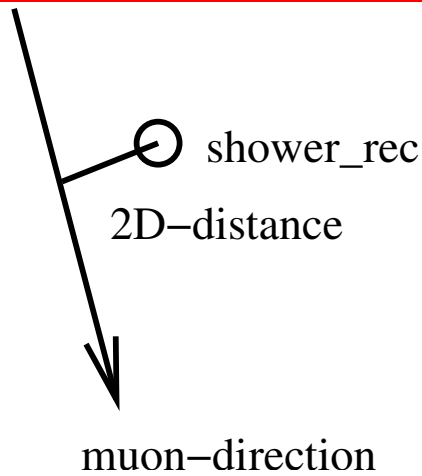reconstructed zenith and azimuth angle of muons

Number of showers per muon

MC close to DATA

$\sim 5\%$ (0.5%) of muons have one (two) rec. showers

Showerfitresult: 2D-distance per shower

shower_rec

2D−distance

muon−direction

- ANTARES DATA
- MC

Arbitrary units

2D-distance between muon track and fitted shower position [m]

This variable tells that shower comes from the right track!

Conclusions

- Analysis Idea:

  – project hit information to μ-axis

  – search significant peaks

  – make 3-dimensional fit

  $\Rightarrow$ identification of μ's with showers

- ANTARES sees bremsstrahlung showers from μ's:
  shower multiplicity fairly well reproduced by MC

- Outlook: use shower information
  for energy and event topology