Muon Track Reconstruction

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Code Organization: Software Principles

- Open Source from A to Z
- Heavy reliance on well trusted tools (Geant4, ROOT)
- OO design
- Modularity
  - Common Data Classes (Track, Hit, RecTrack etc) used throughout the project
  - Common Geometry Classes (Detector description)
- Basic characteristic of all Data & Geometry classes: REDUNDANCY. Geometry description classes MUST be versatile enough to be used by
  - All possible geometric configurations (Strings, floors, single or multi PMT),
  - All Simulations
  - All Reco strategies.
- One ID number is not enough for all of these!
- Develop now, Optimize later
- Proposal for KM3Tray geometry classes.

Reconstruction Software

✴Fitting Algorithm

Using MINUIT implements a χ^2 minimization technique to estimate the parameters of the track and their errors. The χ^2 estimator is defined as

$$\chi^2 = \sum_{i=1}^{N_{hit}} \left(\frac{t_i^{exp} - t_i^{data}}{\sigma_i^{data}} \right)$$

- t_i^{data} : time measured,
- Nhit : number of the hits used for the track reconstruction,
- t_i^{exp} $(\theta,\varphi,V_X,V_\psi,V_Z)$: expected arrival time of the i^{th} hit, assuming that the pulse is the PMT response to the Cherenkov light produced by a muon track with zenith angle θ, azimuthal angle φ and pseudovertex coordinates $\{V_X,V_\psi,V_Z\}$,
- σ_i^{data} : resolution in measuring the arrival time of the i^{th} hit.

Pattern Recognition on Tower Geometries

- Clusterize signals per floor. Form clusters of 2 or more signals in time per floor.
  - Find the maximum signal of each tower.
- Within a single tower combine the maximum charge cluster with clusters of signals of the two neighboring floors.
  - Only Consider Combinations with more than 5 signals
  - Form track segments in that tower by fitting the resulted combinations of signals.
- Only successfully fitted track segments are passed to the next stage of the Pattern Recognition.

Pattern Recognition on Tower Geometries

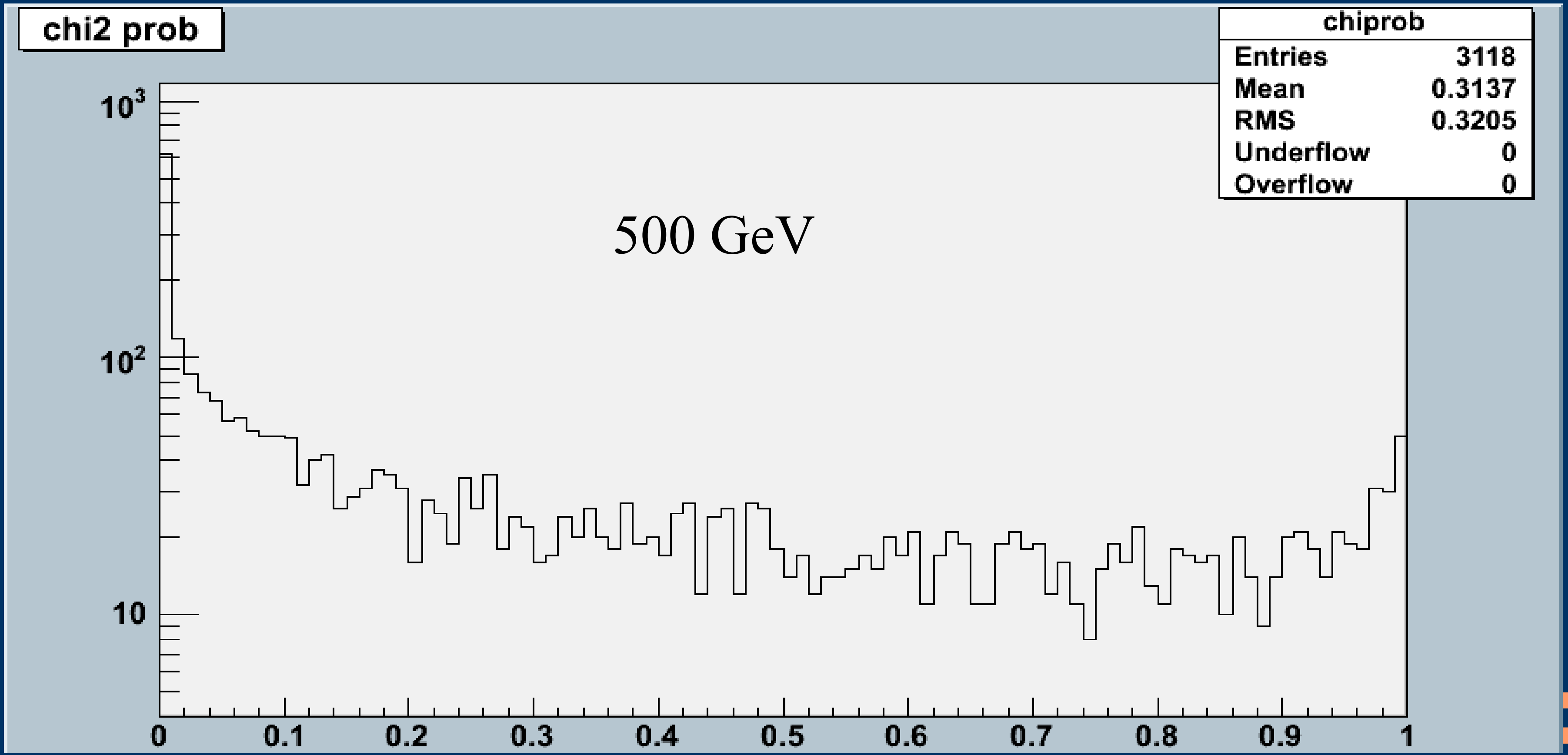
- Combine track segments of neighboring towers and form new track segments by fitting the combination of their signals.
  - Only successfully fitted track segments are passed to the next stage of the pattern recognition, together with the track segments of the previous step whose signals were not used.
- On the track segments of the previous step, associate signals that were not used on the track segment under consideration.
  - Fit the resulted combination of signal producing track candidates.
- At the end the program output both:
  - track candidates, and
  - those track segments that do not have signals already associated to a track.

Pattern Recognition on String Geometries

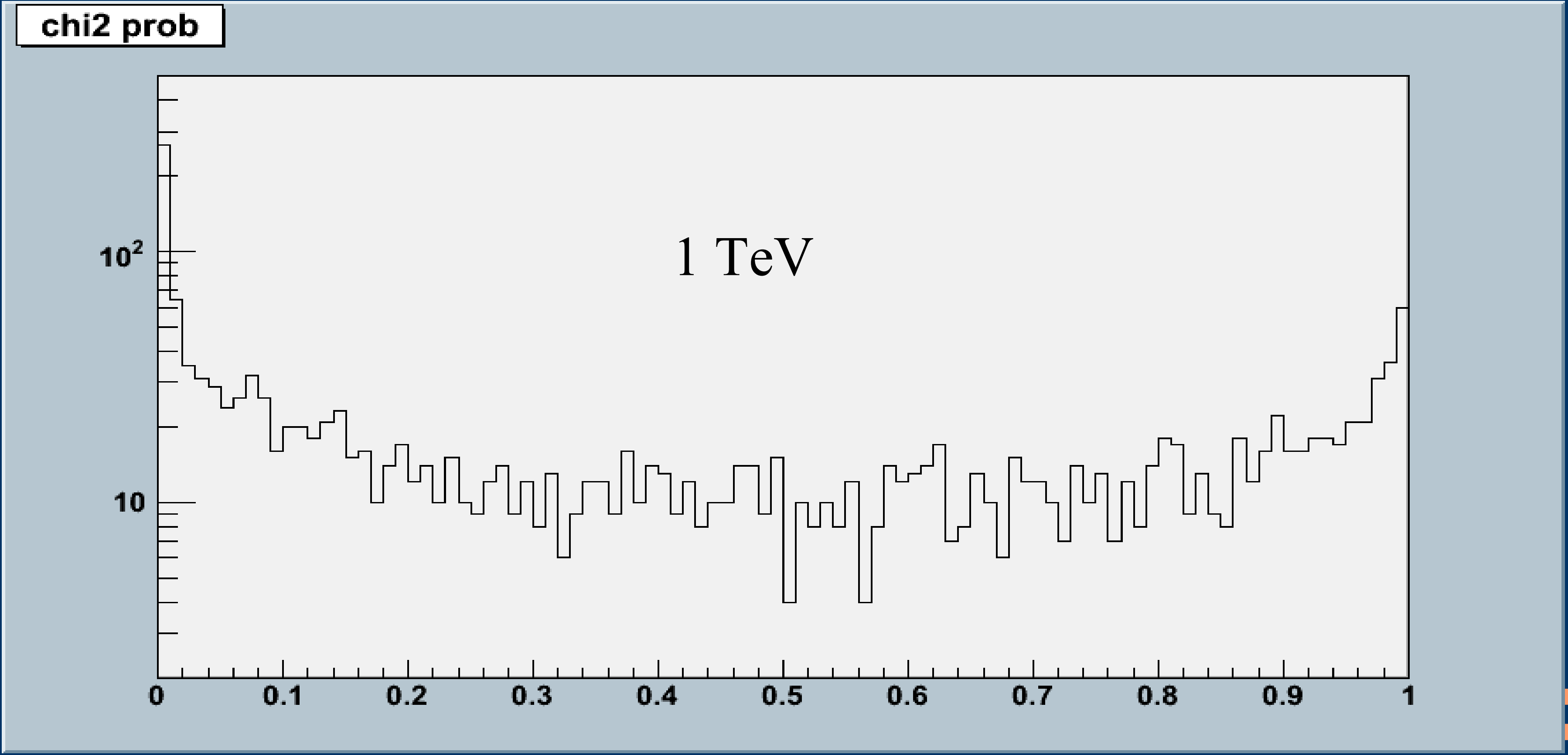
- Find "Large" OMs with many Hits (Assume multi-hit OMs to be real)
  - Eliminate ^{40}K (coincidence window $\Delta T \sim$ OM dimensions as per XML Description file)
- Loop over neighbouring OMs (or OMClusters) and find real hits there (Causality criterion: $\Delta T \sim \Delta R$, ΔR = OM Distance)
- Create Track segments by combining these local bundles of hits
- Recognize among them track segments that belong to the same track and combine them.
- Output reconstructed tracks (with their hits).

Reconstruction Results: 1 NESTOR Tower Geometry

Monoenergetic down-going muons of 100 GeV, 500 GeV, 1 TeV and 10 TeV (10000 events each energy) uniformly distributed between 90° and 180° in θ and between 0° and 360° in φ and reconstructed them. The successfully fitted track candidates with probability(χ^2) greater than 1% are considered as tracks.



Reconstruction Results: km³ Multi-pmt



Reconstruction Efficiency and Misreconstructed Tracks

- **Reconstruction efficiency**:
  ratio of the number of events with one reconstructed track with probability(χ^2) > 1%
  to the number of events that have more than
  - 5 signals (tower)
  - 6 signals on 2 or more strings,

  produced by non-background/noise photons.

- **Misreconstructed tracks:**
  ratio of the events which have
  θ-resolution worse than 5º to the number of events with one reconstructed track with probability(χ^2) > 1%.

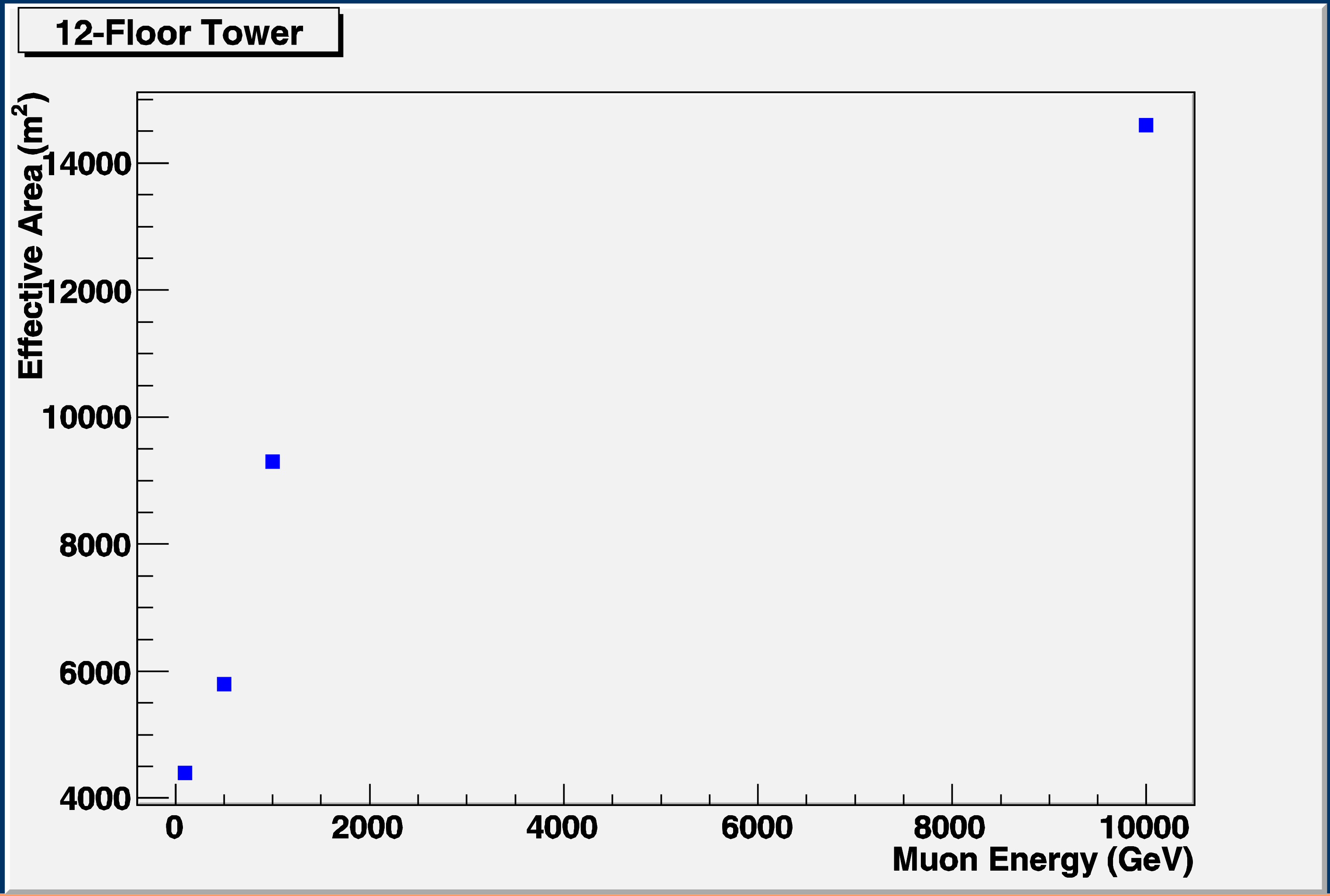
Reconstruction Efficiency and Misreconstructed Tracks (Nestor Tower)

Energy	Percentage of evts with > 5 Hits (%)	Reconstruction efficiency (%)	Misreconstructed $\Delta\theta > 5^o$ (%)
100 GeV	20	77	34
500 GeV	31	80	27
1 TeV	31	78	27
10TeV	49	72	29

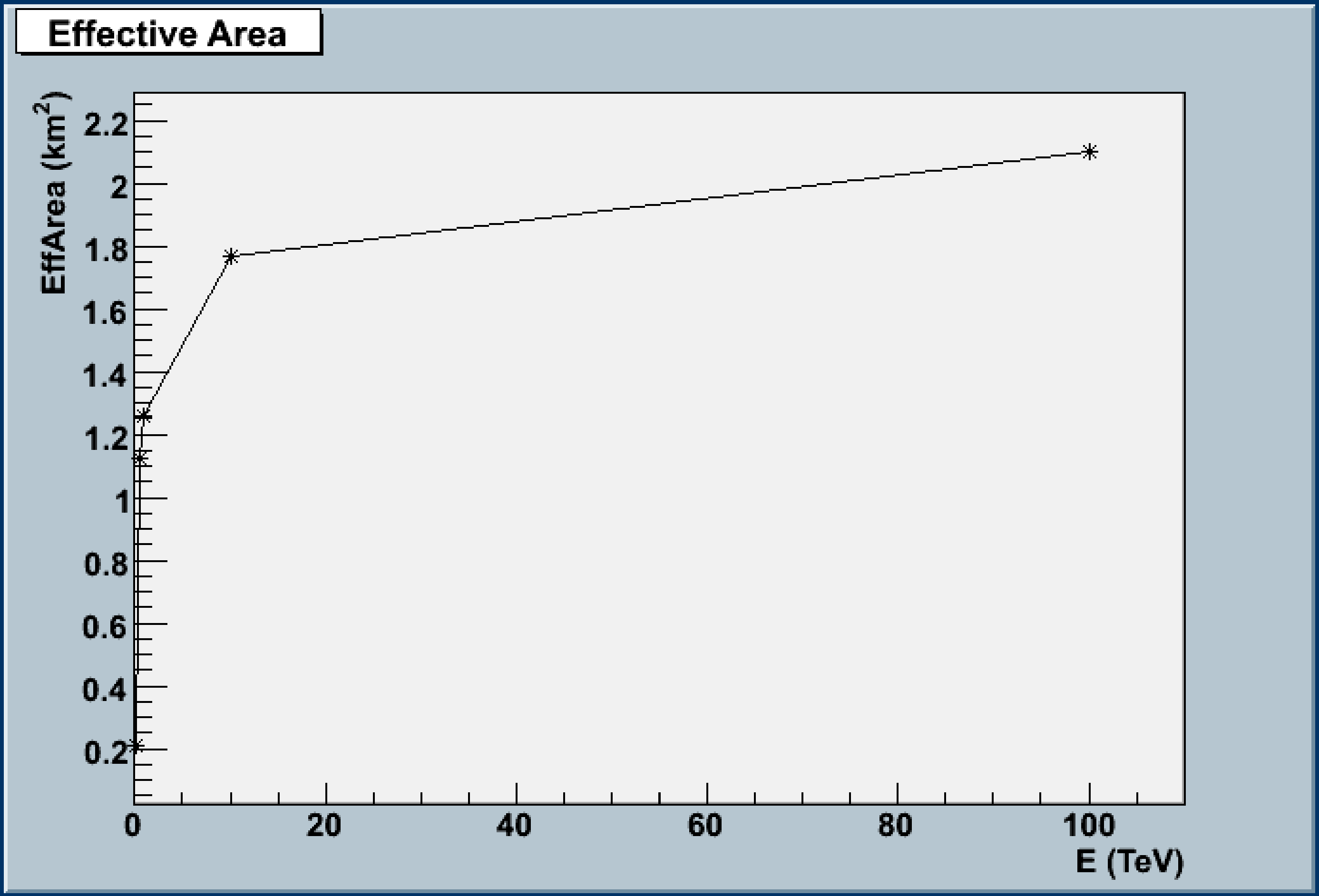
Reconstruction Efficiency and Misreconstructed Tracks (km^3 multi pmt)

Energy	Percentage of evts with > 6 Hits > 1 string	Reconstruction efficiency (%)	Misreconstructed $\Delta\theta > 5^o$ (%)	up/down misses (%)
100 GeV	23	25	26	5
500 GeV	59	52	9	2
1 TeV	61	56	7	1
10TeV	69	69	6	1
100 TeV	76	75	3	1

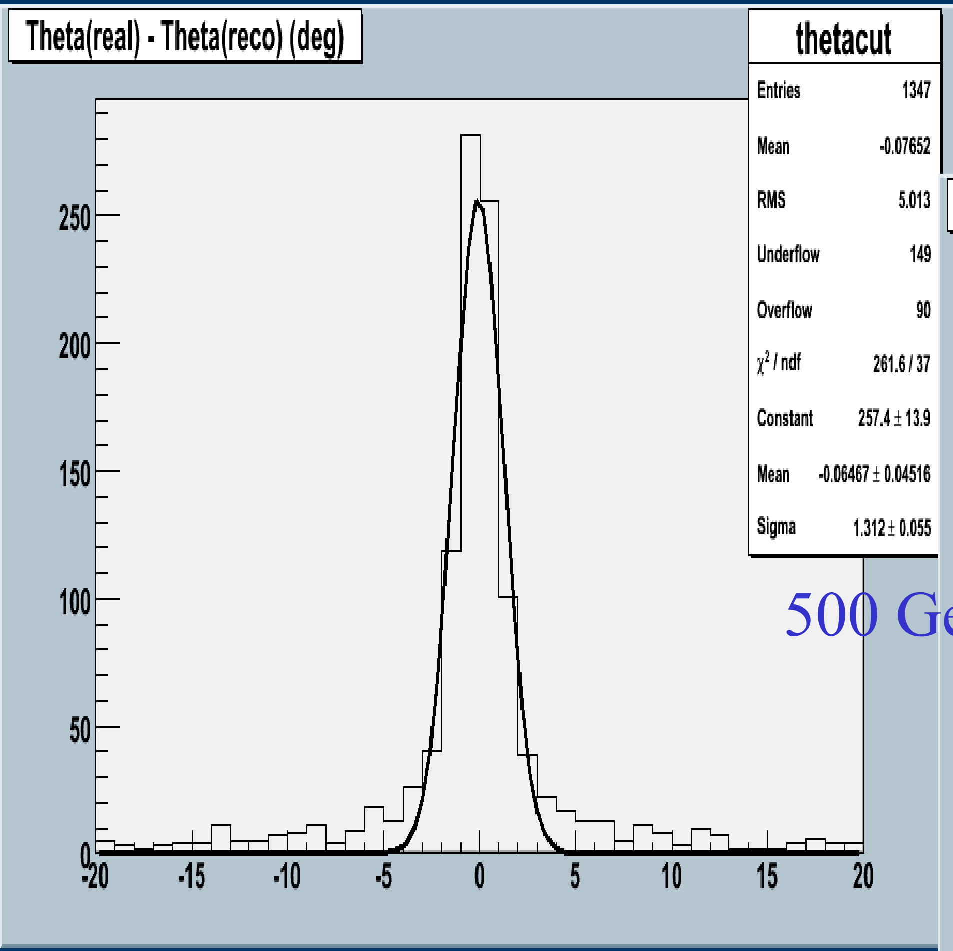
Effective Area (Nestor Tower)



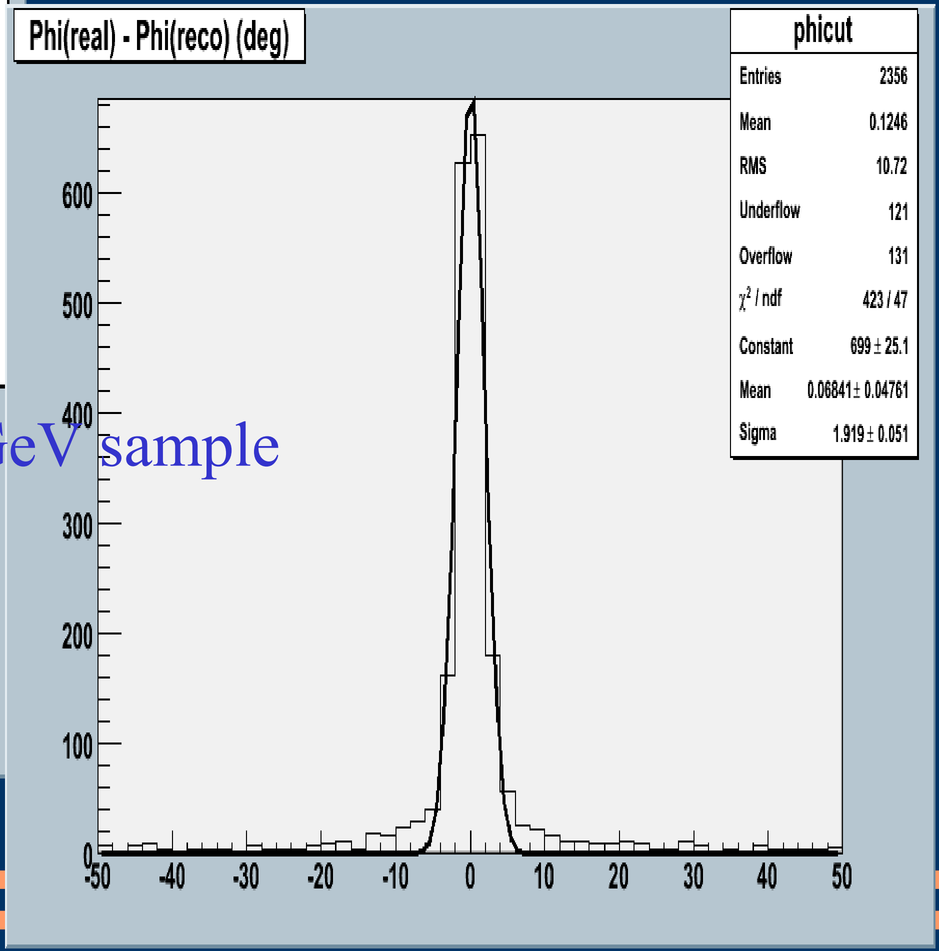
Effective Area (Cabled multi pmt)



θ,φ Resolutions (Nestor Tower)



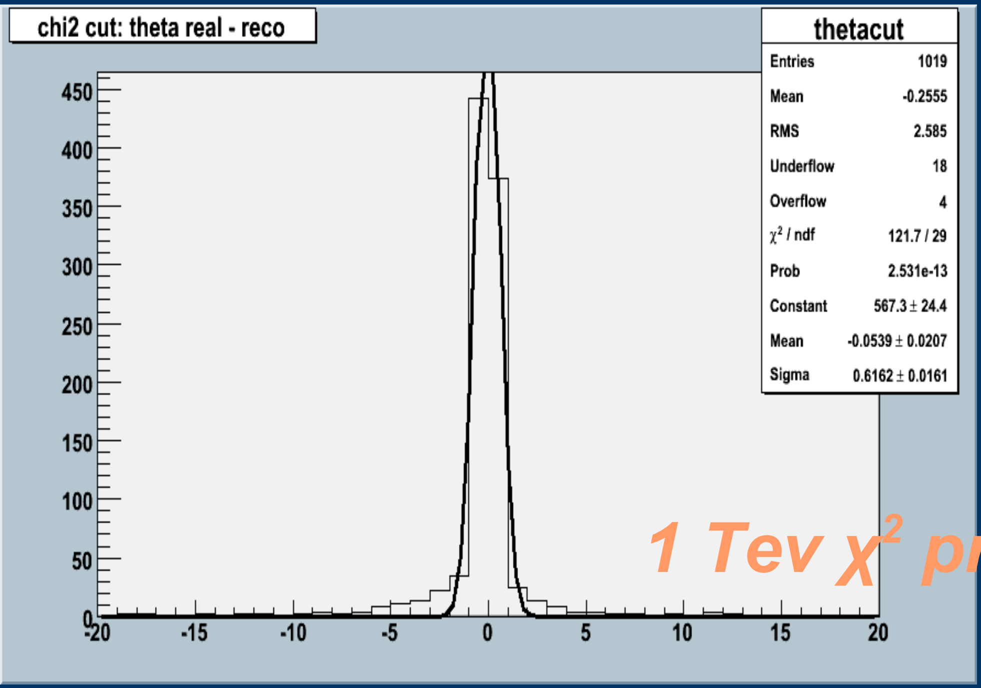
500 GeV sample



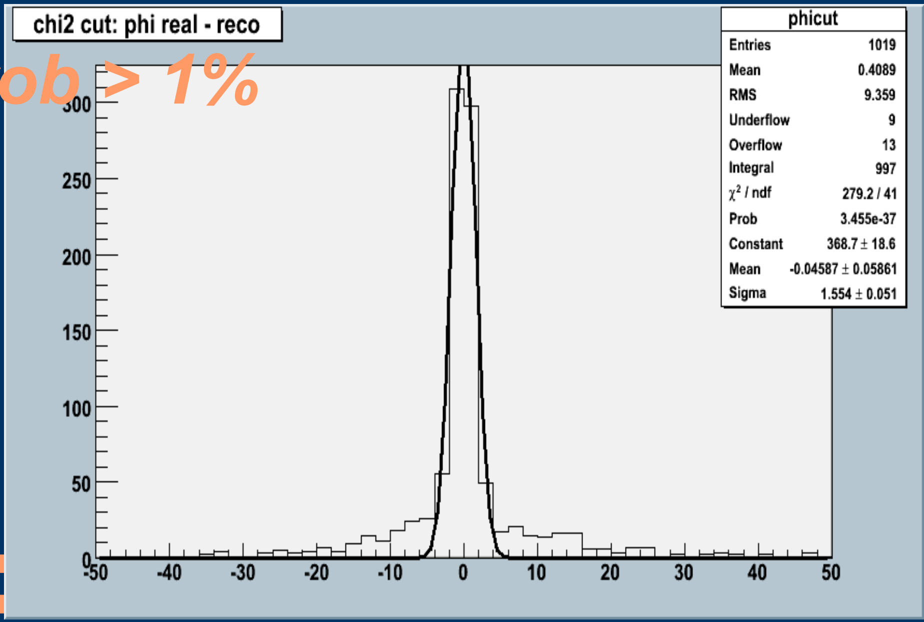
θ,φ Resolutions (Nestor Tower)

Energy	σ(θ) (deg)	# of events beyond 3σ (%)	σ(φ) (deg)	# of events beyond 3σ (%)	median (deg)
100 GeV	1.3	34	3.5	30	1.4
500 GeV	1.0	31	1.9	28	1.0
1 TeV	1.0	30	1.8	27	1.0
10TeV	0.8	35	1.7	29	0.9

θ,φ Resolutions (cabled multi pmt)



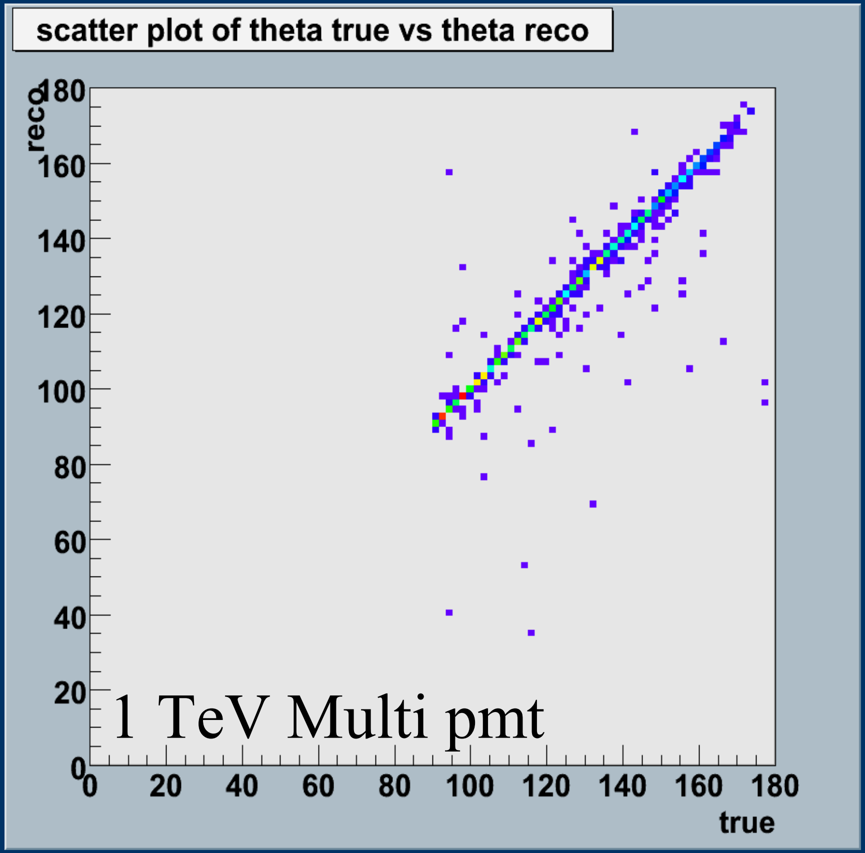
1 Tev χ^2 prob > 1%



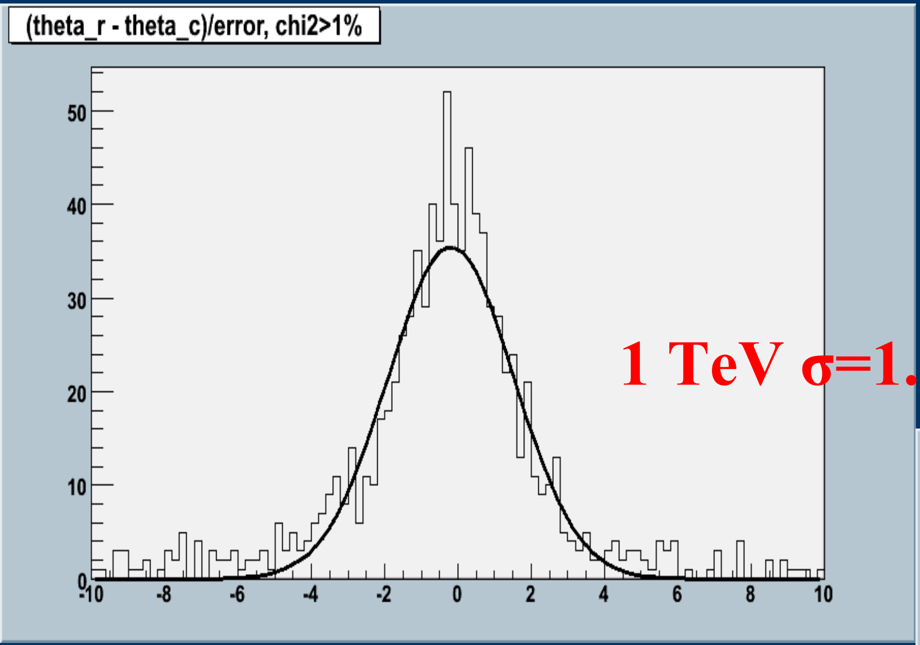
θ,φ Resolutions (cabled multi pmt)

Energy	σ(θ) (deg)	# of events beyond 3σ (%)	σ(φ) (deg)	# of events beyond 3σ (%)	median (deg)
100 GeV	1.1	31	8.7	9	4.1
500 GeV	0.6	16	7.0	7	0.6
1 TeV	0.6	15	1.6	28	0.4
10TeV	0.6	12	1.2	27	0.2
100 TeV	0.5	5	1.0	15	0.1

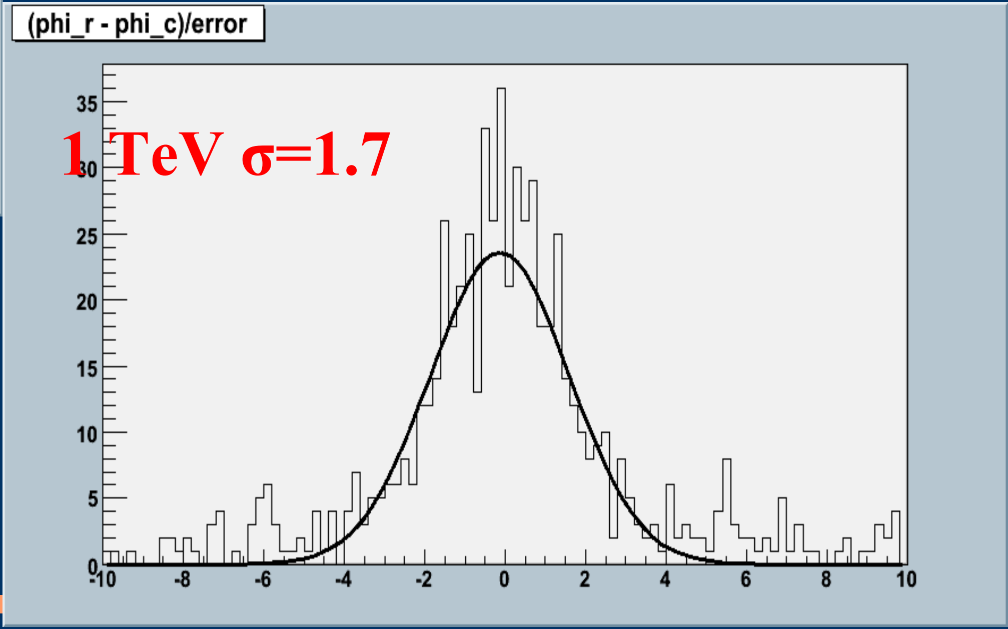
Reconstruction Results



θ, φ angle pulls



1 TeV σ=1.5



1 TeV σ=1.7

To Do List

- KM3Tray
- Go Public
- Use SIRENE (fast!)
- Test and validate the reconstruction algorithms on multi-muon events.
- Study in detail the effect of the sea depth on the background rejection
- Study the performance of tower like geometries

What is not right with Chameleon?

- It **can** compare different geometries,but...

It cannot perform comparisons with other reconstructions

We have (for the moment) at least :

- 4 Geant4 sims
- 1 sirene
- 3 Recos

AND THEY CANNOT COMMUNICATE!

Need for:

1. ***A common data set for input in Simulation***

2. ***A common data set for input in Reco***

3. ***A way to compare results***