Track Reconstruction in Antares

Corey Reed (Nikhef)

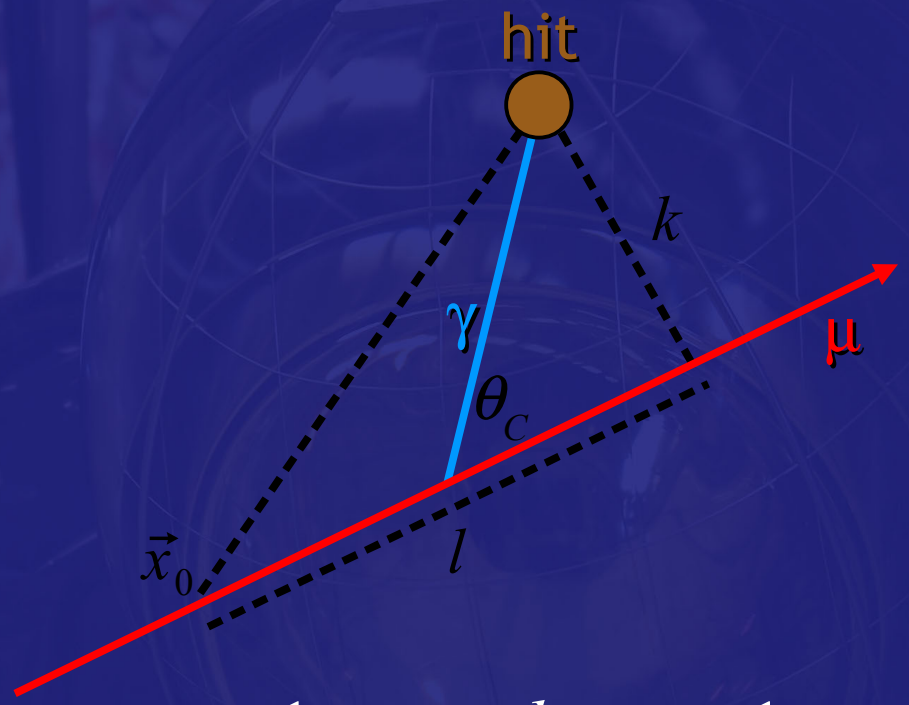
M.A.N.T.S. Berlin

Basic Idea

Familiar story

Predict hit time

Minimize residuals



$$t_{\mathrm{exp}} = t_0 + \frac{1}{c}\left(l - \frac{k}{\tan\theta_C}\right) + \frac{1}{v_g}\left(\frac{k}{\sin\theta_C}\right)$$

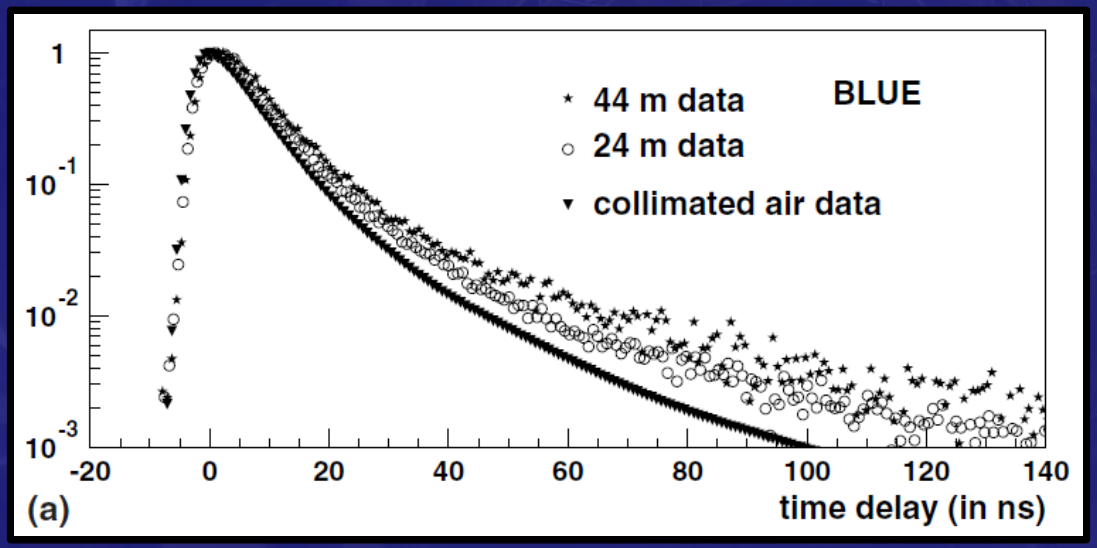
μ γ

Environment

Mediterranean Sea

Long scattering length in water

λ=473nm :



[Astropart. Phys. 23, 131]

Environment

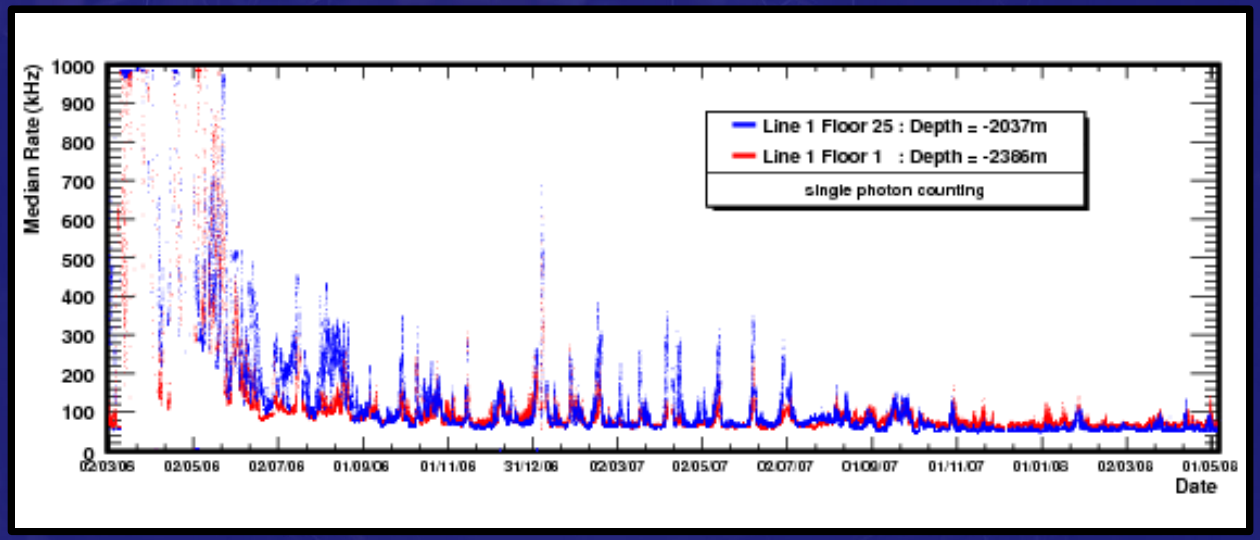
Mediterranean Sea

Background photons

- K40 decays
- Bioluminescence

~60-80 kHz

+ bio lum bursts



Antares Tracking

Residuals reliable, but how to deal with bkg?

- Option 1: strict hit selection
  - Try to ignore background hits
  - Use simple, quick fit

Antares Tracking

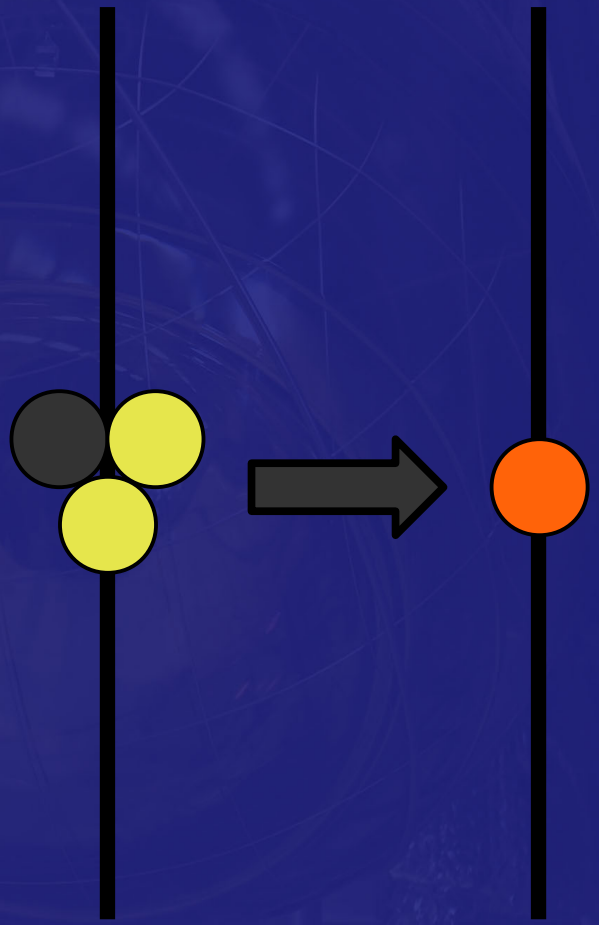
Residuals reliable, but how to deal with bkg?

- Option 1: strict hit selection
  - Try to ignore background hits
  - Use simple, quick fit
- Option 2: account for background
  - Use PDF which includes background hits
    - Maximize likelihood of residual distribution
  - Use multiple pre-fits to get close to global max

Simple Fit

Strict hit selection

- Combine hits on a floor
  - Within 20 ns
  - Position = floor center
  - Time = first hit time
  - # pe's = sum



Simple Fit

Strict hit selection

- Find floors with signal
  - Multiple hits
  - Big hits

Simple Fit

Strict hit selection

Find clusters of such hits

Separation +/- 2 floors

Causally connected

$\Delta t : (-N_{floors} \cdot 10ns, N_{floors} \cdot 80ns)$

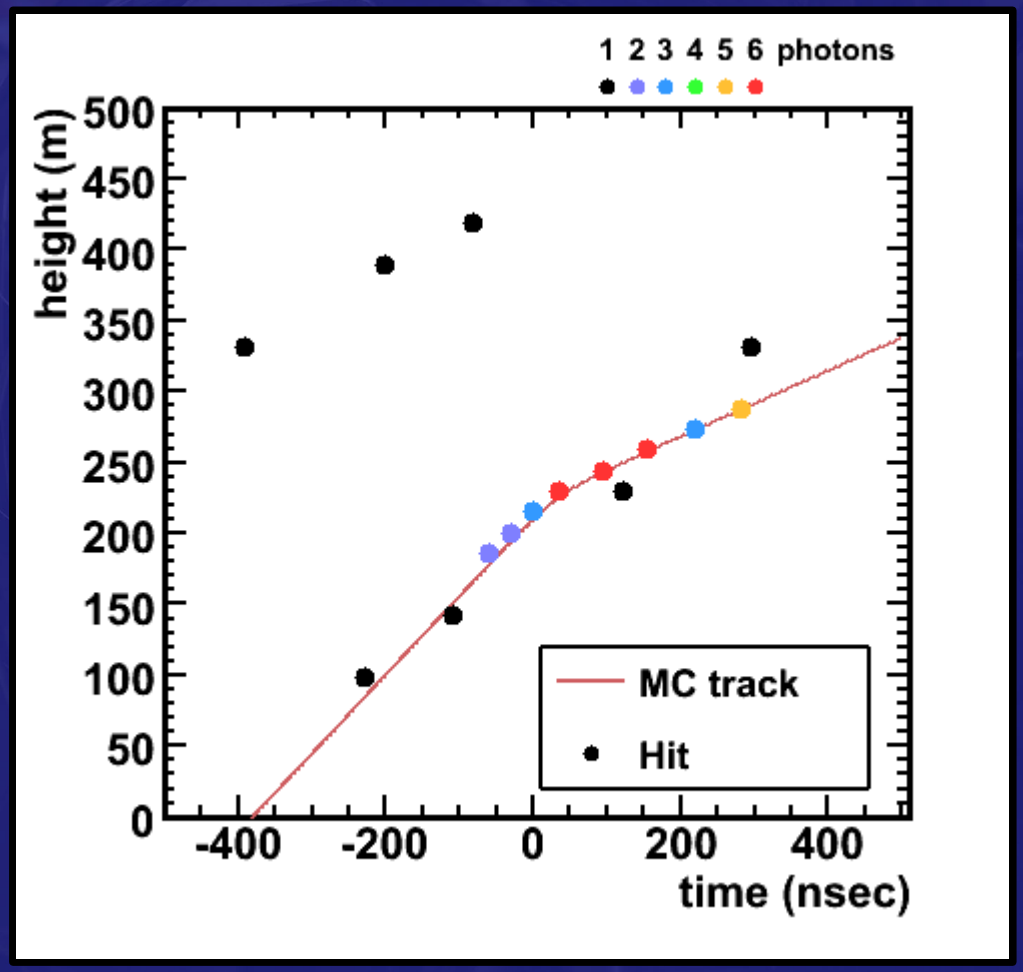
Simple Fit

Strict hit selection

Clusters should be signal

Use (merged) hits in cluster

Plus (merged) hits causally connected to cluster



Simple Fit

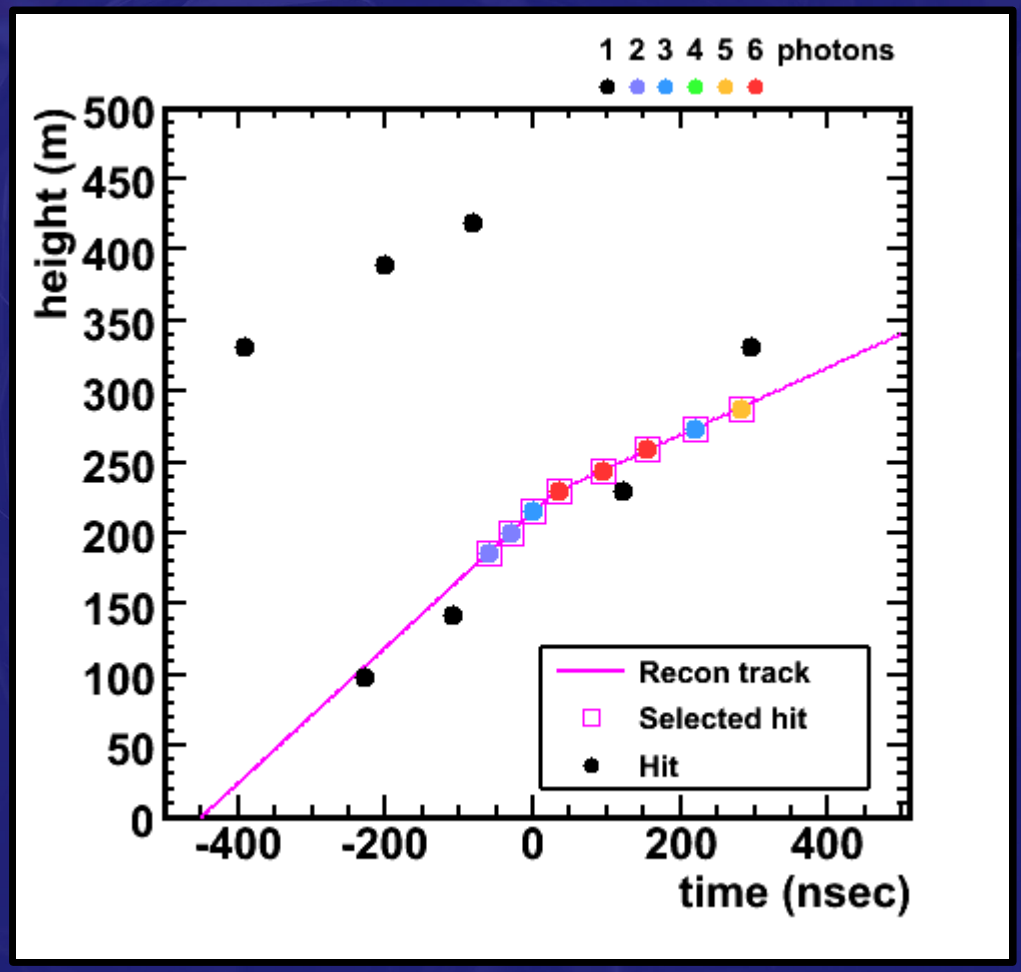
Strict hit selection

Clusters should be signal

Use (merged) hits in cluster

Plus (merged) hits causally connected to cluster

Attempt to follow Cherenkov cone



Simple Fit

Minimize χ^2 – like function

Small time residual

Large number photons $\Rightarrow$ close to OM

$$\chi^2 = \sum_{hit} \left[\frac{(t_{\exp} - t_{hit})^2}{\sigma^2} + \alpha\, q_{hit}\, d_{hit} \right]$$

q_{hit} = *normalized hit amplitude*

d_{hit} = *normalized distance to line*

Simple Fit

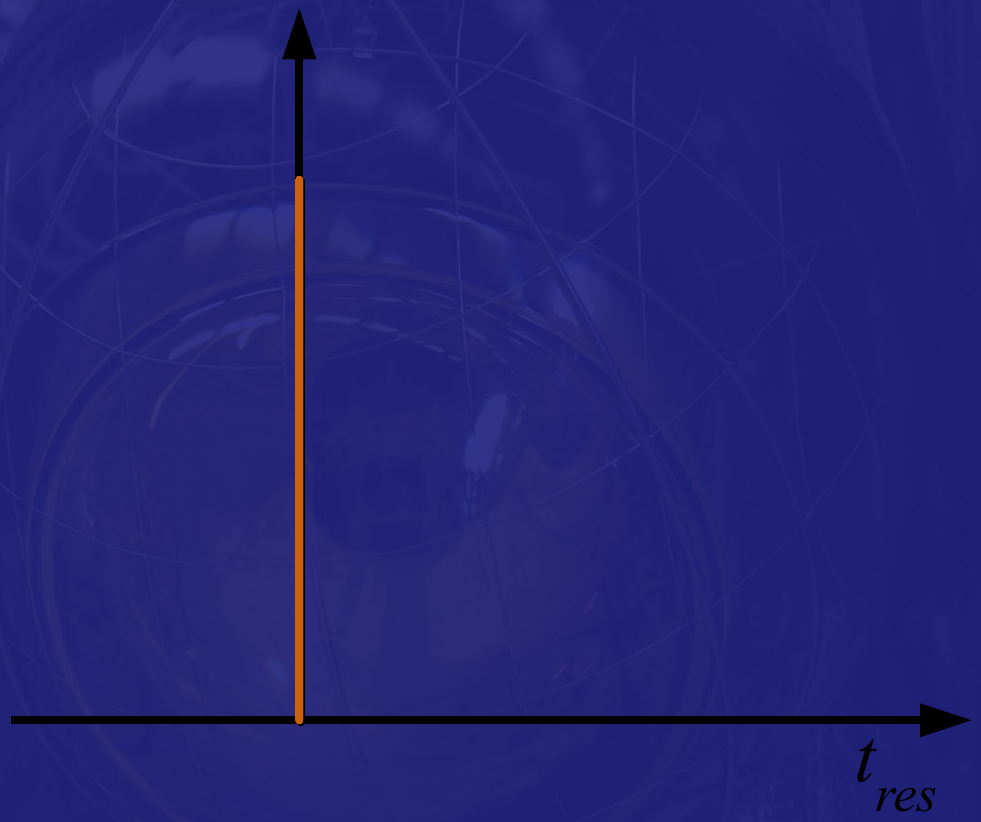
Advantages

- Fast
  - Can be used as part of a trigger
- Knowledge of background not essential
  - Compares well to simulations

Full Fit

Build expected residual distribution

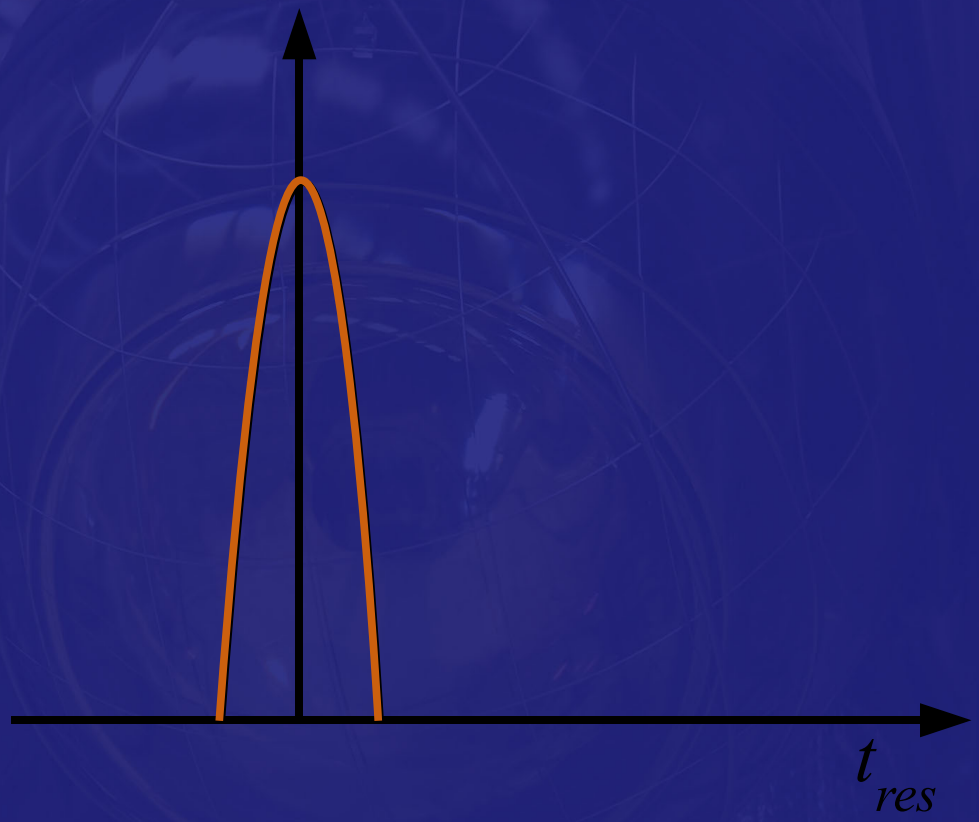
Cherenkov photons



Full Fit

Build expected residual distribution

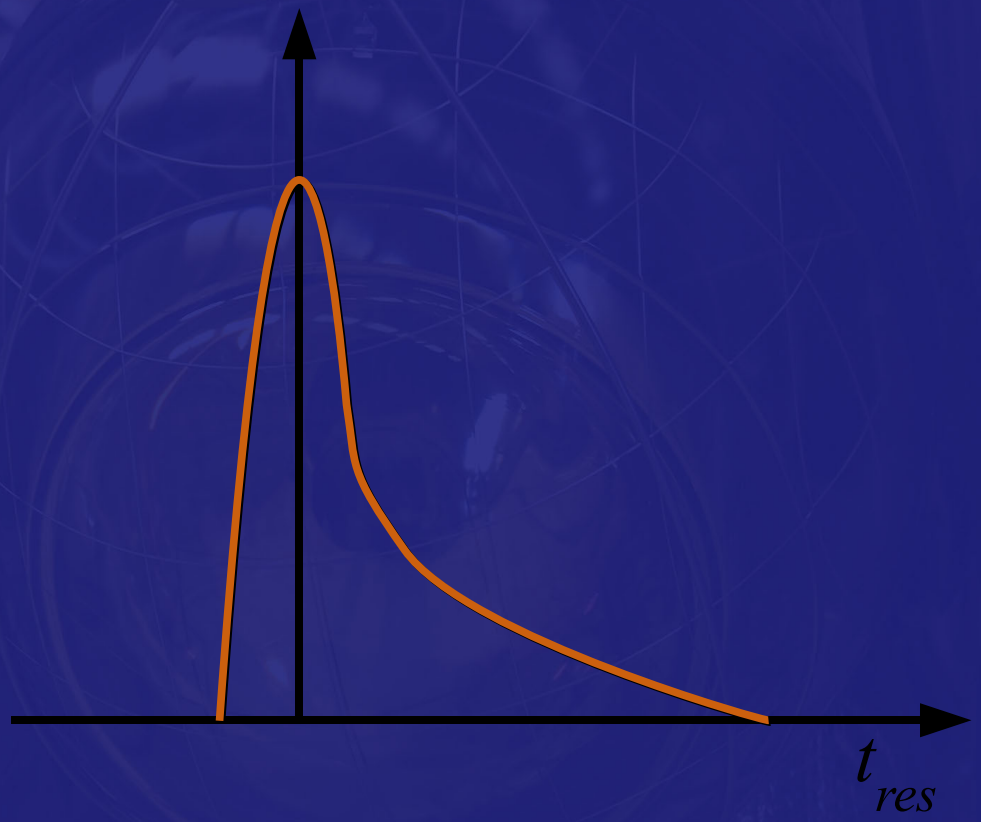
- Cherenkov photons
- Detector smearing



Full Fit

Build expected residual distribution

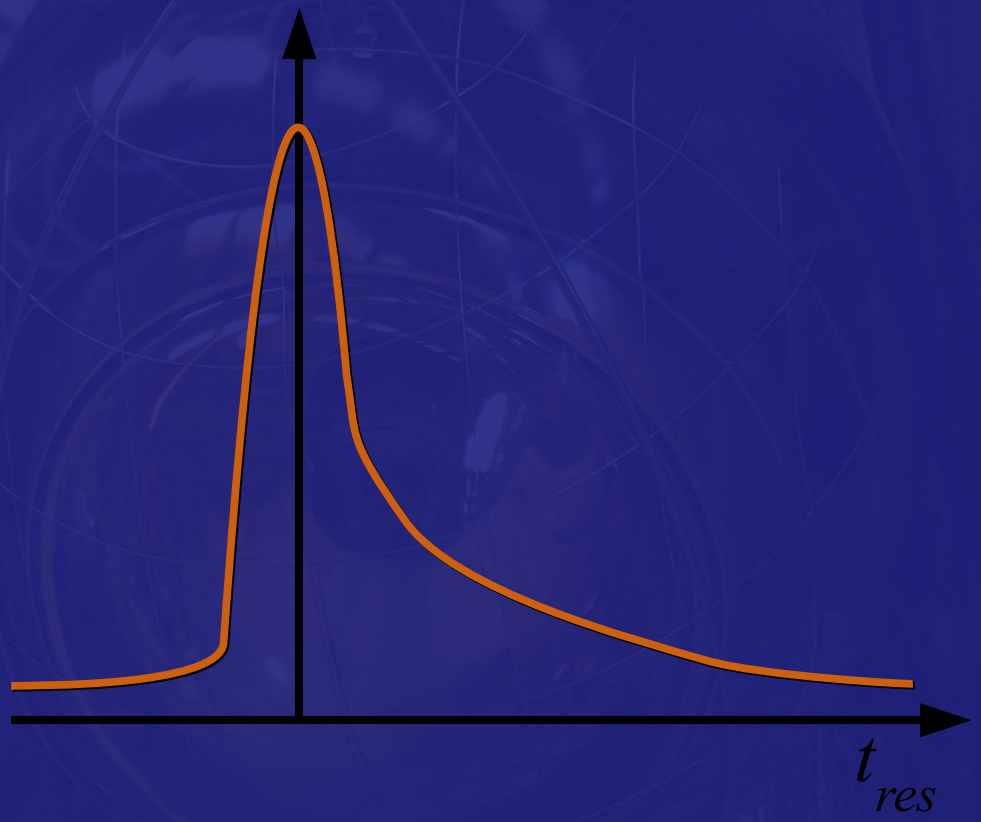
- Cherenkov photons
- Detector smearing
- Shower + scattered photons



Full Fit

Build expected residual distribution

- Cherenkov photons
- Detector smearing
- Shower + scattered photons
- Background photons
  - K40, biolum



Full Fit

Given hits, track parameters...

- Obtain residual distribution

Find track parameters such that...

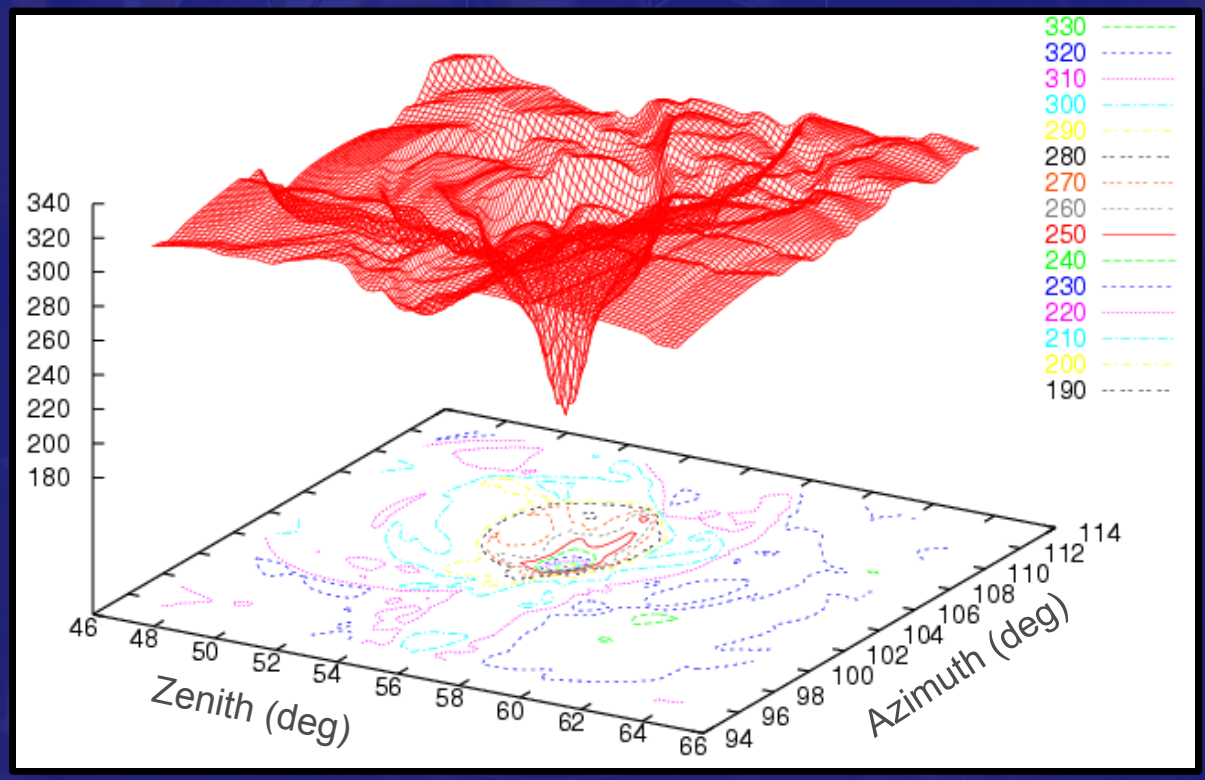
- Observed residuals best match expected dist.

Full Fit

Slight complication

Many local minima

Need to start close to global min



Full Fit

Fit in stages

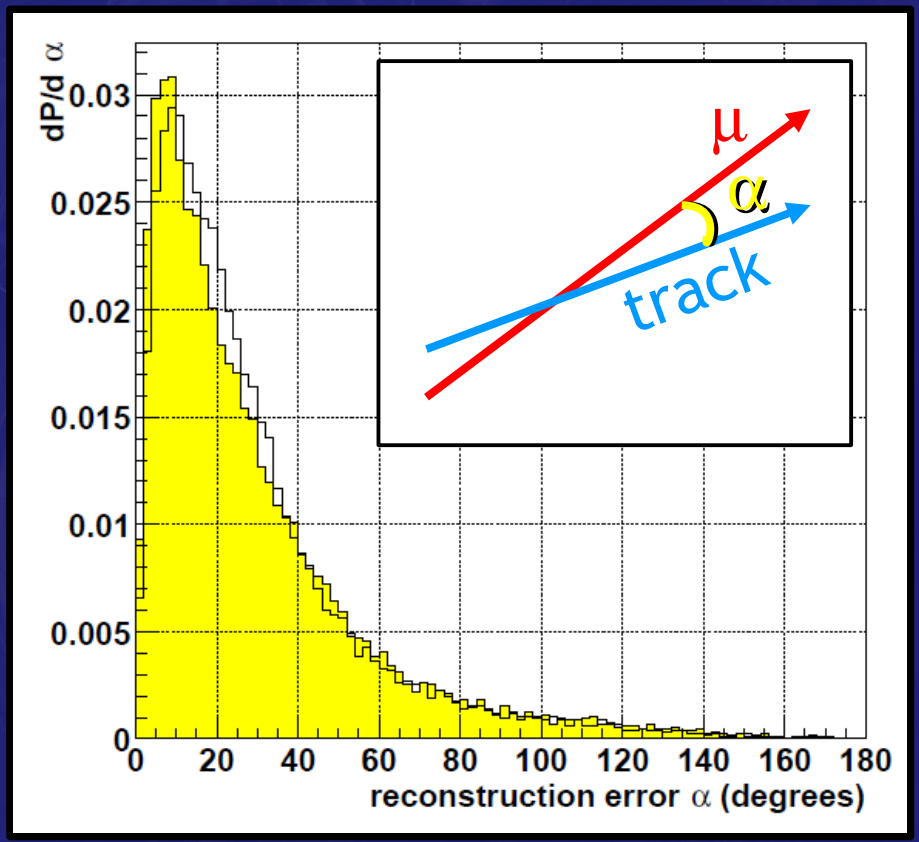
1. Linear pre-fit

Assume hits on track

Use “likely hit position”

OM position + ave. dist.

Depends on hit amplitude



[A. Heijboer, PhD Thesis]

Full Fit

Fit in stages

2. "M-estimator" fit

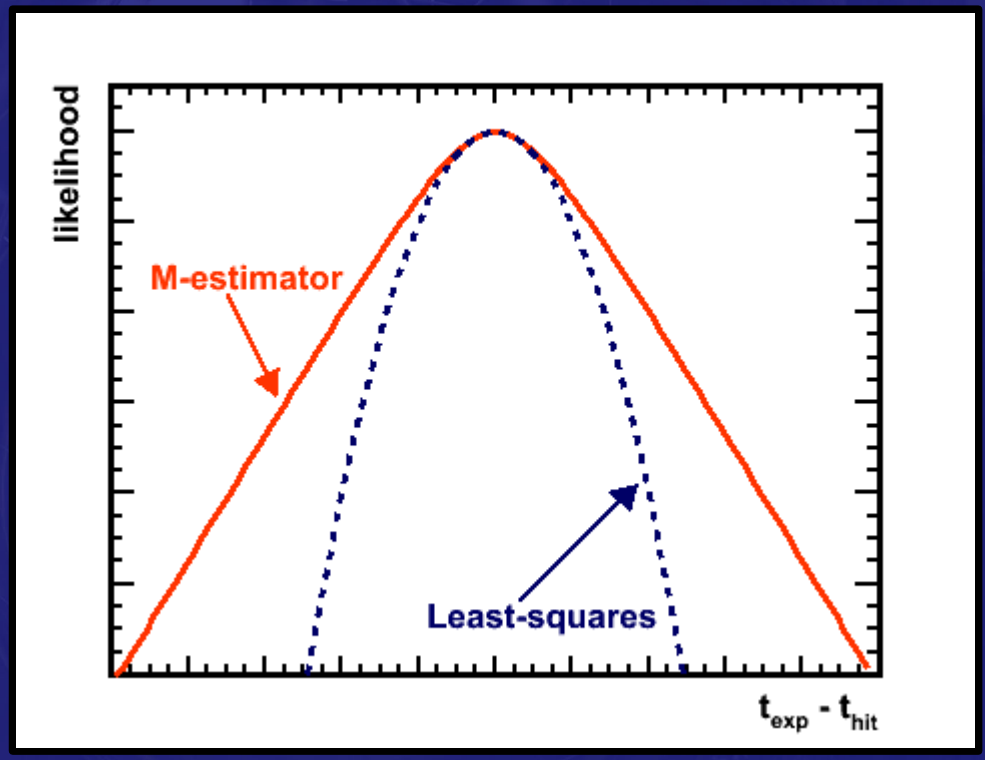
Assume Cherenkov only

Prevent large residuals from affecting fit much

- Small Δt : quadratic
- Large Δt : linear

Weight by hit amplitude

- Account for PMT response



Full Fit

Fit in stages

2. “M-estimator” fit

Assume Cherenkov only

Prevent large residuals from affecting fit much

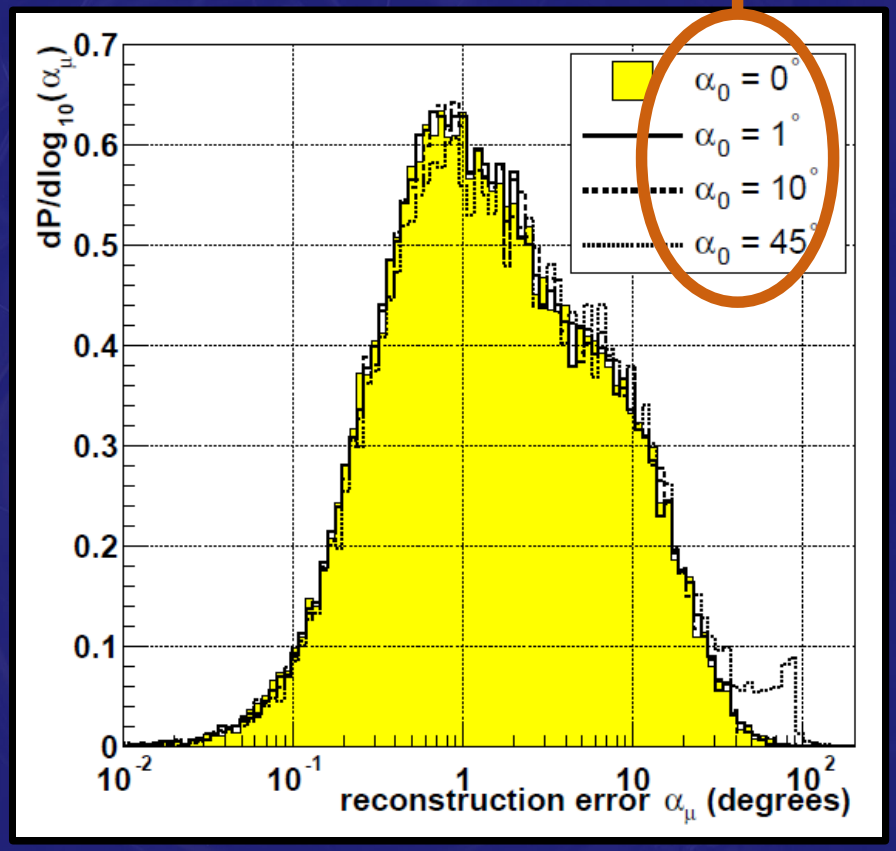
Small Δt : quadratic

Large Δt : linear

Weight by hit amplitude

Account for PMT response

Starting distance from truth



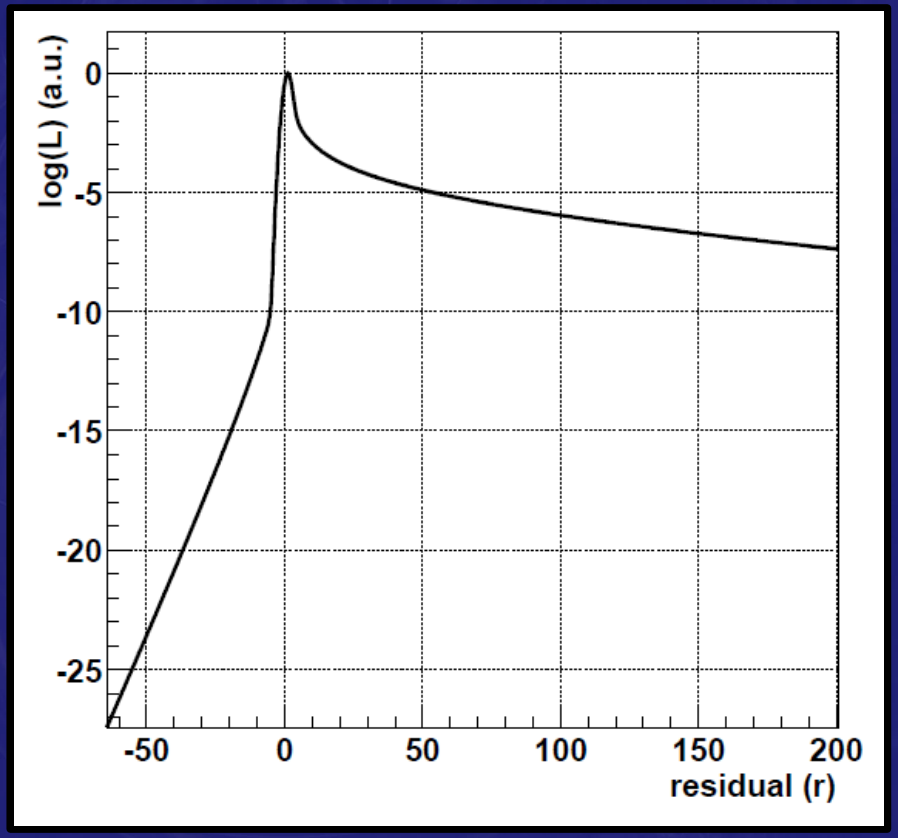
[A. Heijboer, PhD Thesis]

Full Fit

Fit in stages

3. Simplified PDF

Peak + tail



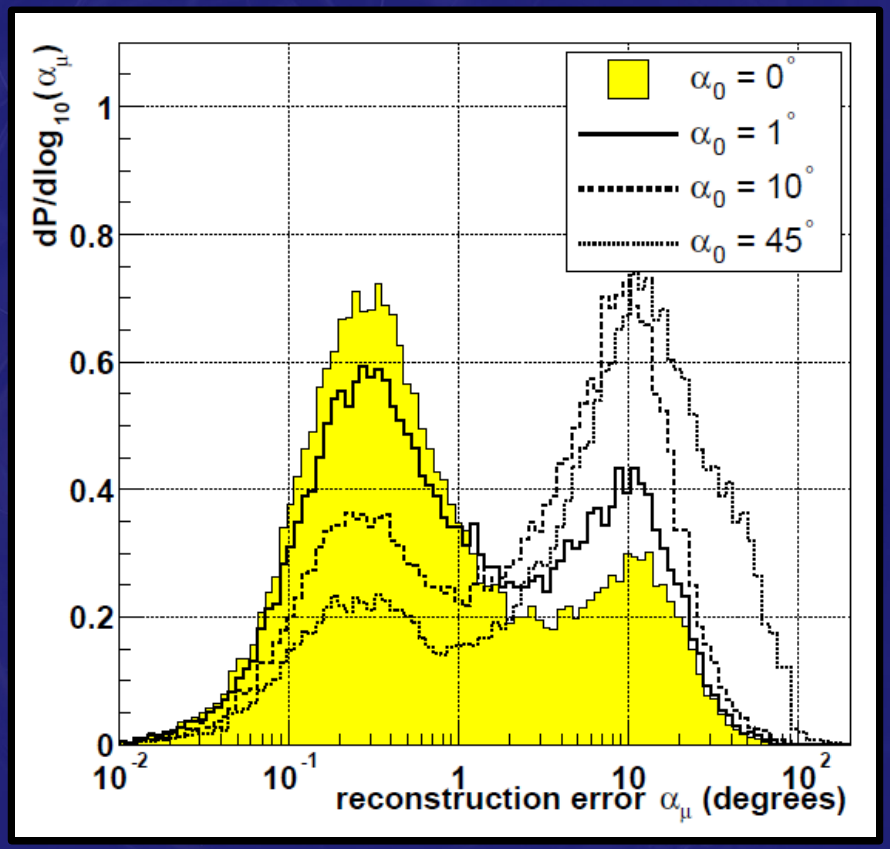
[A. Heijboer, PhD Thesis]

Full Fit

Fit in stages

3. Simplified PDF

Peak + tail



[A. Heijboer, PhD Thesis]

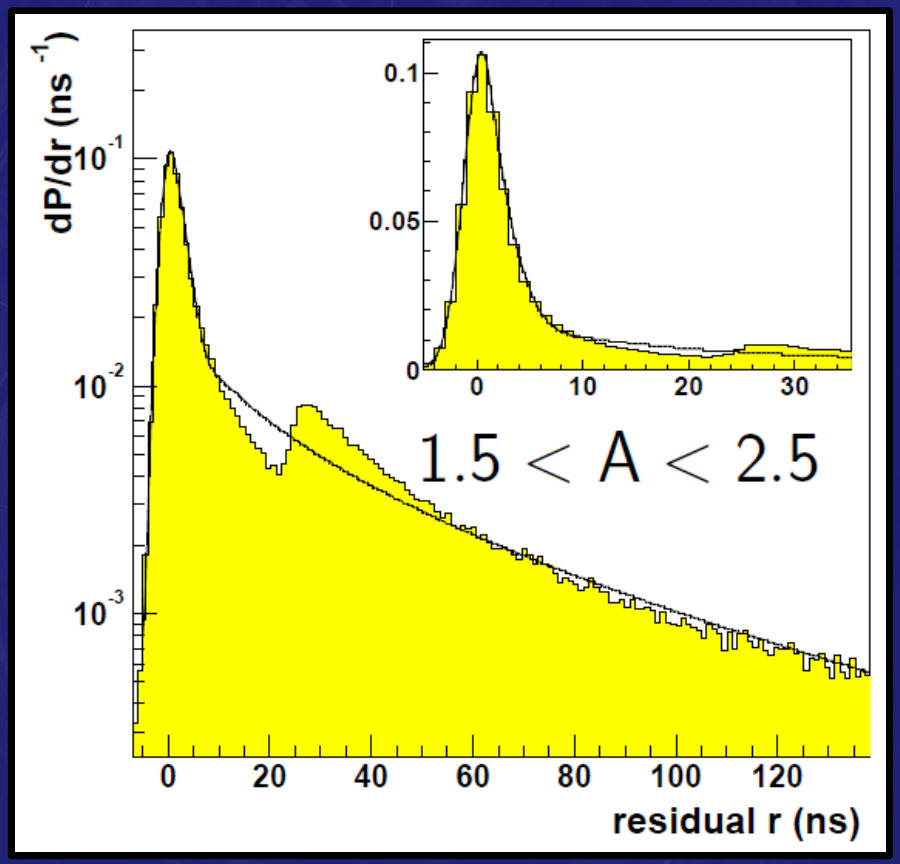
Full Fit

Fit in stages

4. Full PDF

Peak + tail + background

Several PDFs, for bins in hit amplitude



[A. Heijboer, PhD Thesis]

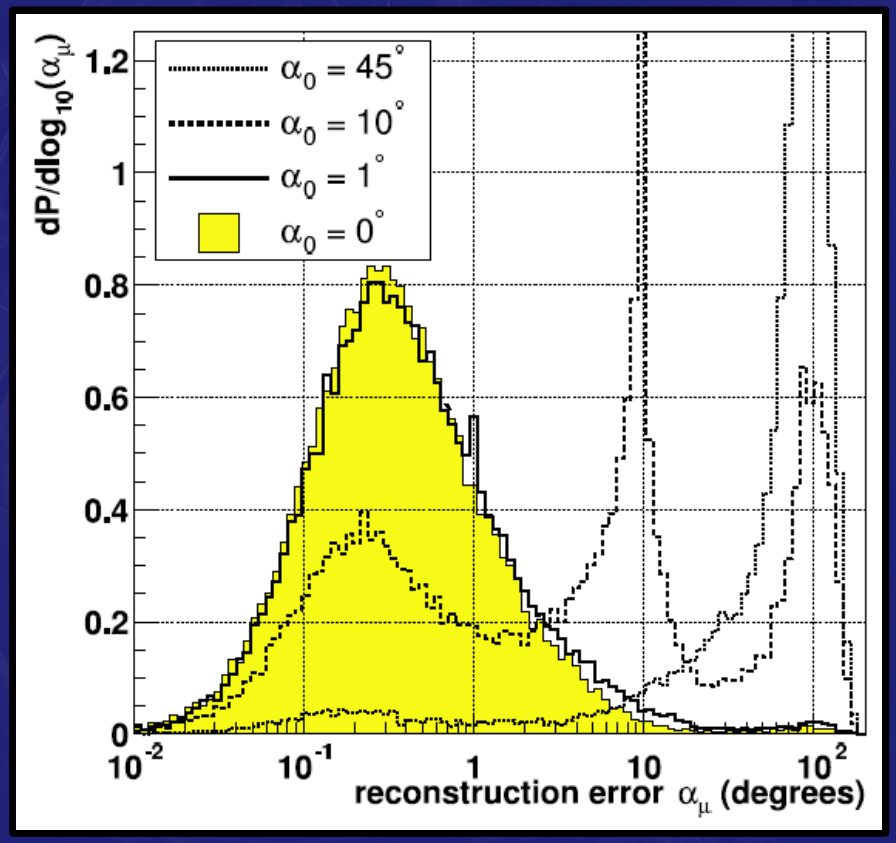
Full Fit

Fit in stages

4. Full PDF

Peak + tail + background

Several PDFs, for bins in hit amplitude



[A. Heijboer, PhD Thesis]

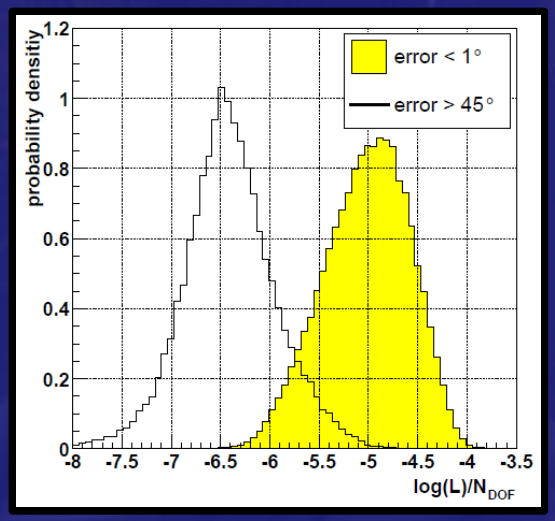
Full Fit

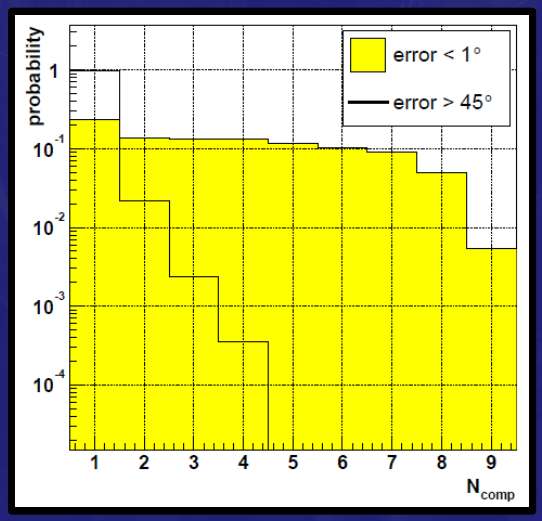
Quality parameter "Λ"

Log likelihood per D.O.F.

Bonus if diff. starting values → same minima

$$\Lambda \equiv \frac{\log(L)}{N_{DOF}} + 0.1 \cdot (N_{Comp} - 1)$$

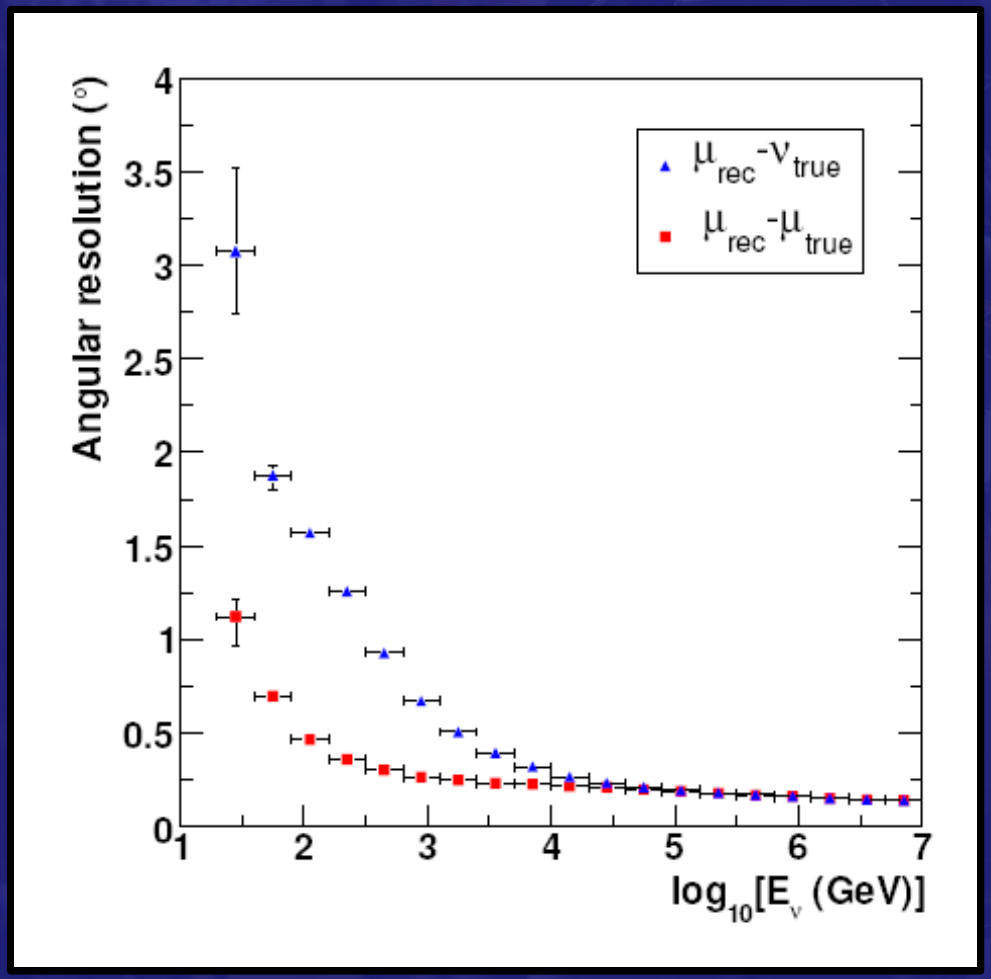




[A. Heijboer, PhD Thesis]

Full Fit

Expected performance (12-line)



Scan Fit

PDF gives best final fit.

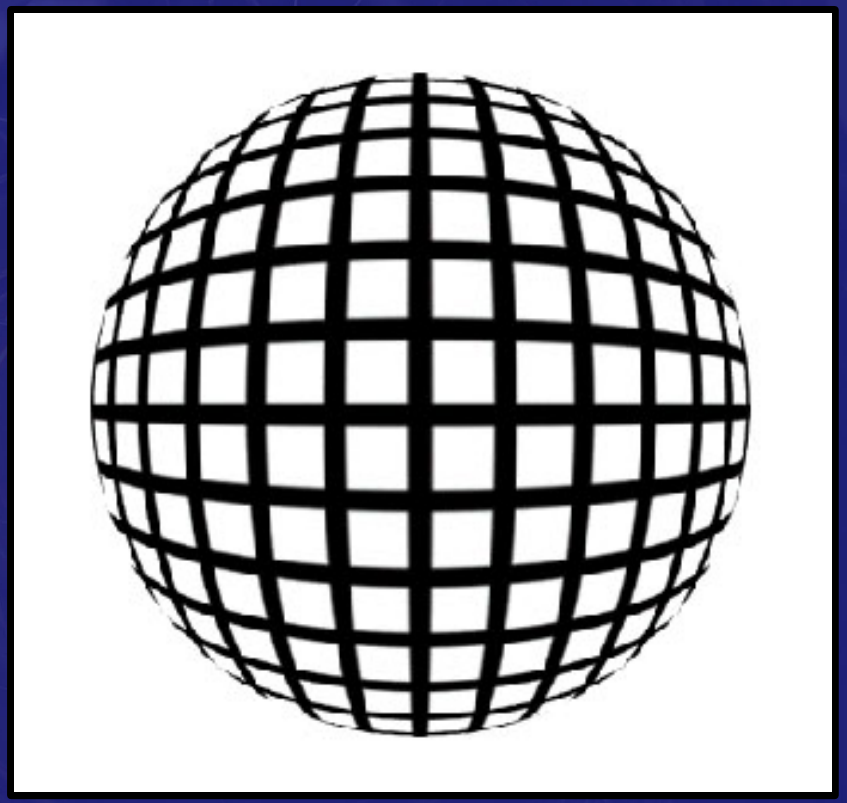
BUT... needs good start.

Can improve on linear fit!

Scan Fit

Idea: scan phase space

- Divide into grid
- Take zenith, azimuth
- Linear fit to find x_0

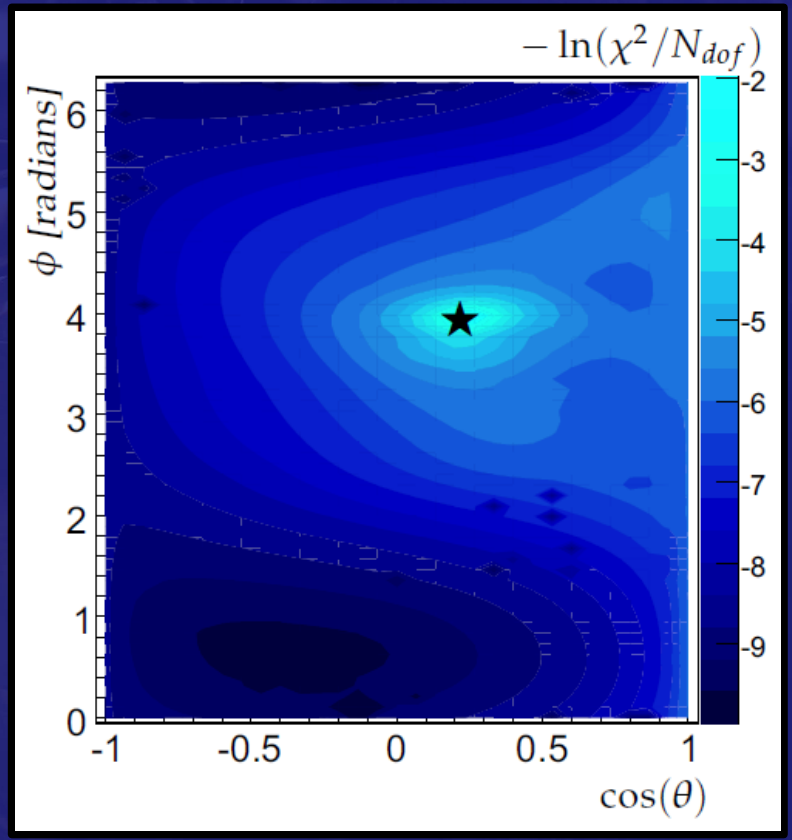


Scan Fit

Always have multiple solutions

Order by fit quality

Keep if have 1 best fit



[R. Bruijn, PhD Thesis]

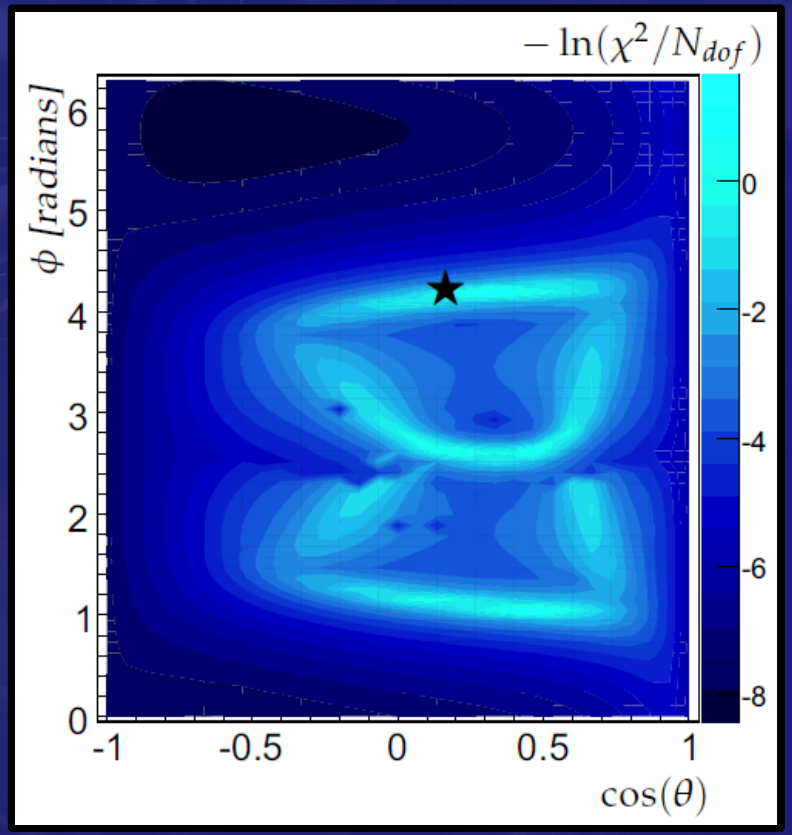
Scan Fit

Always have multiple solutions

Order by fit quality

Keep if have 1 best fit

Multiple, equally good solutions ⇒ ambiguous



[R. Bruijn, PhD Thesis]

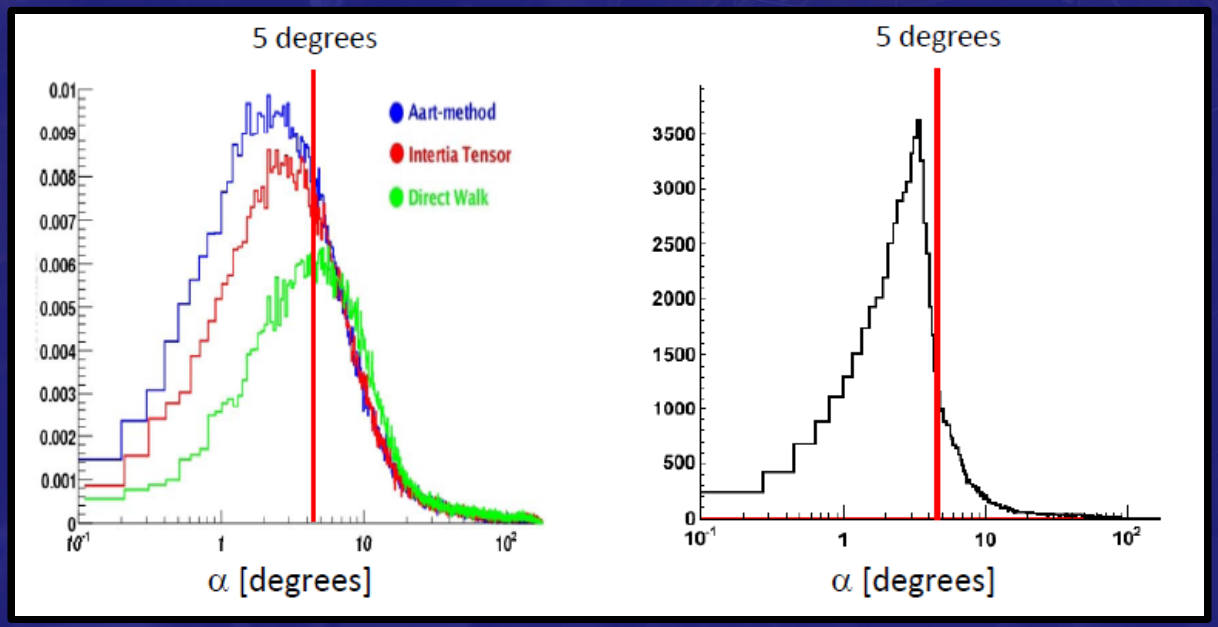
Scan Fit

Ambiguous

- Many local minima

Unambiguous

- Great pre-fit : 90% unamb. evts w/in 12°



Summary

Can see direct Cherenkov hits

But also background hits (K40, biolum.)

Different strategies

- Strict hit selection, simple fit
  - Fast, easy to understand behavior
- Loose hit selection, likelihood fit
  - Best angular resolution
  - Requires accurate PDFs

Backup Slides

Simple Fit

2007 (5 line) + 2008 (9-12 line) data

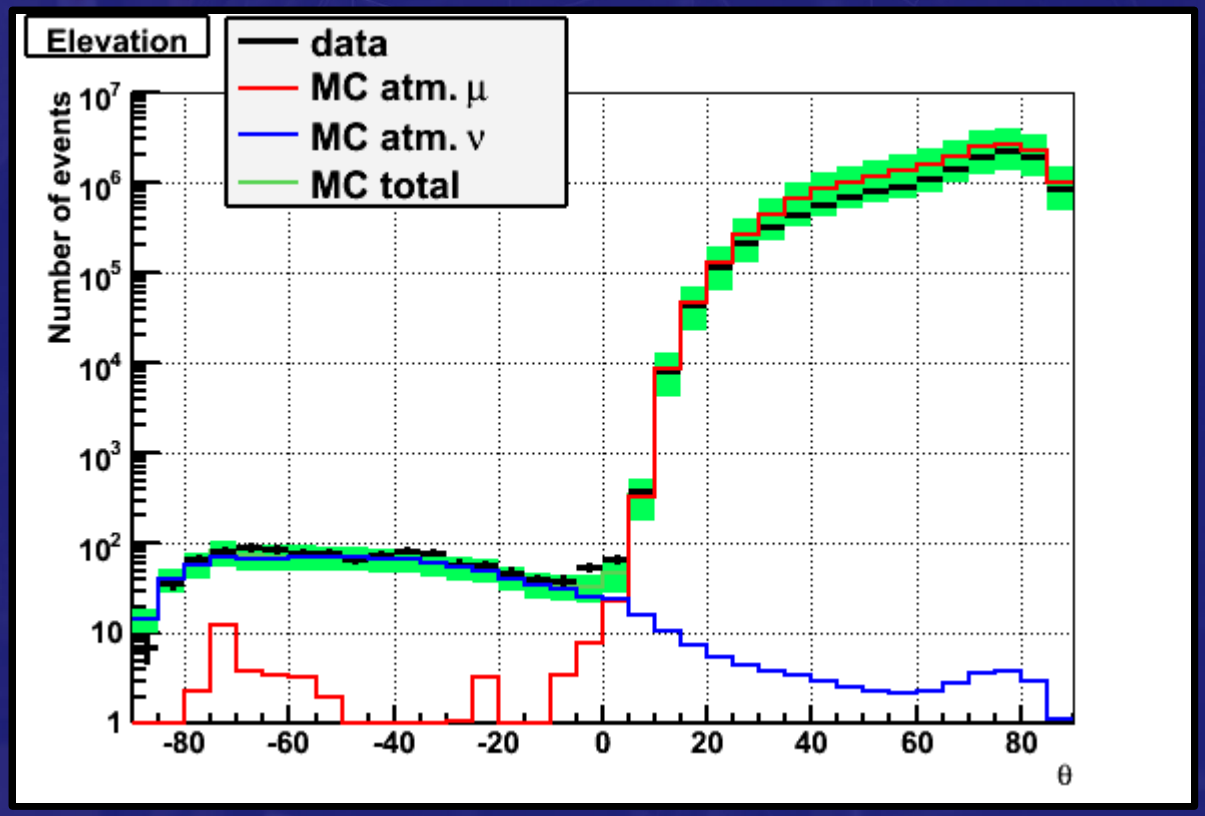
341 days livetime

1096 upgoing tracks in data

In MC:

916 atm nu's

40 atm muons



Full Fit

Fit in stages

1. Linear pre-fit

Assume hits on track

Use “likely hit position”

OM position + ave. dist.

Depends on hit amplitude