Understanding Antares.

progress on data/mc agreement

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- Software & framework
- Progress on data/mc agreement
  - Motivation
  - Improvements:
    - Bugs
    - Refinements to background modeling and detector response
  - Current status
- Conclusion

Preamble: old software and new framework

red = in-house product

- currently: many different tools for data analysis, eg:
  - event generation : **GENNEU**, **CORSIKA**, **MUPAGE**
  - detector simulation : **KM3**, **GEASIM**
  - optical background, front-end en trigger simulation: **TriggerEfficiency**
  - muon reconstruction: **Strategy A** (CalReal/Aafit), **Strategy B** (BBFIT)

- SeaTray: Unified software framework to replace current loose-chain of tools
  - Based on IceCube framework (IceTray)
    - same philosophy
    - similar data format
  - Adopted as official framework by the Collaboration 1 yr ago.
  - Many tools have been transfered into the framework & new developers encouraged to use it.
  - Current work aimed at getting ready for mass-reconstruction of data

Introduction : data/mc agreement

- Neutrino astronomy requires knowledge of angular resolution and acceptance

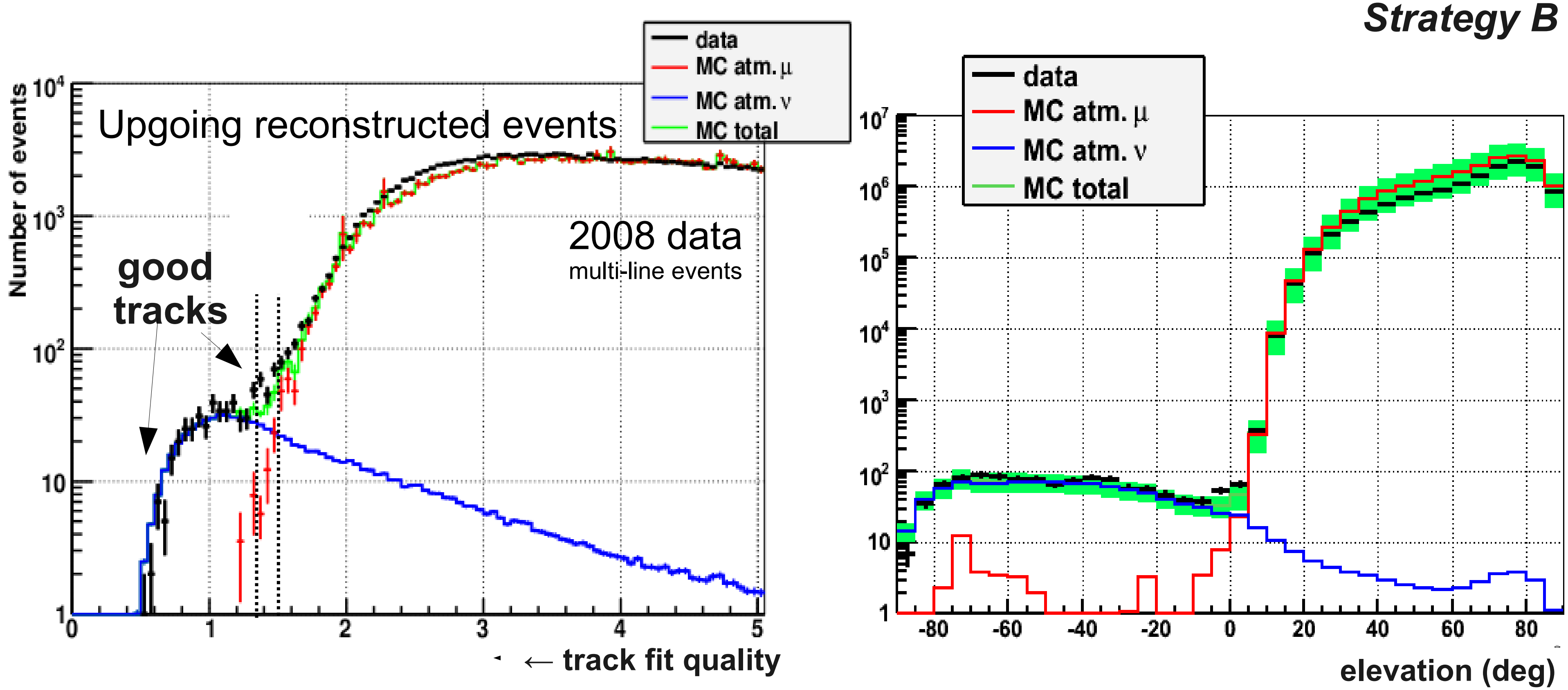
- Handles on acceptance :
  - down-going atmospheric muons:
    - detector is not up-down symmetric
      → down-going tracks sensitive to light hitting OM from behind
      → and scattering of light.
    - many are bundles
    - flux and properties not very well known
  - up-going atmospheric neutrinos
    - great sample, but not very many O(1000)/year
    - energy is factor 100 lower than for cosmic neutrinos → need to extrapolate
    - flux uncertainty ~20%

- result: neutrino astronomy *needs* to heavily rely on simulations to know acceptance and angular resolution.

  - Verify, as much a possible, that the simulations are correct checking using the signals that we do have.
    -> the simulations should describe the signals that we *can* check.
  - major aspect of any analysis.

Typical distributions

Strategy B

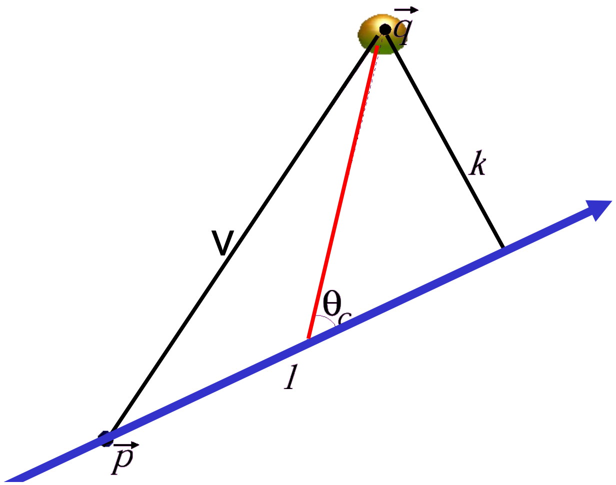


main challenge:

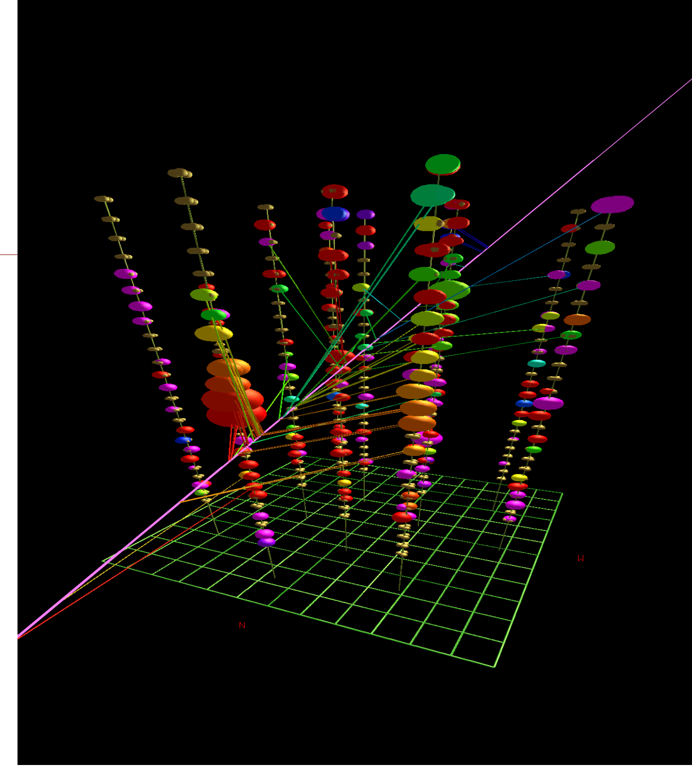
- distinguish upgoing muons from the huge amount of downgoing ones.
- need to cut on track-fit quality → care a lot about its modeling.
- test predictions of atmospheric muon and neutrino MCs.

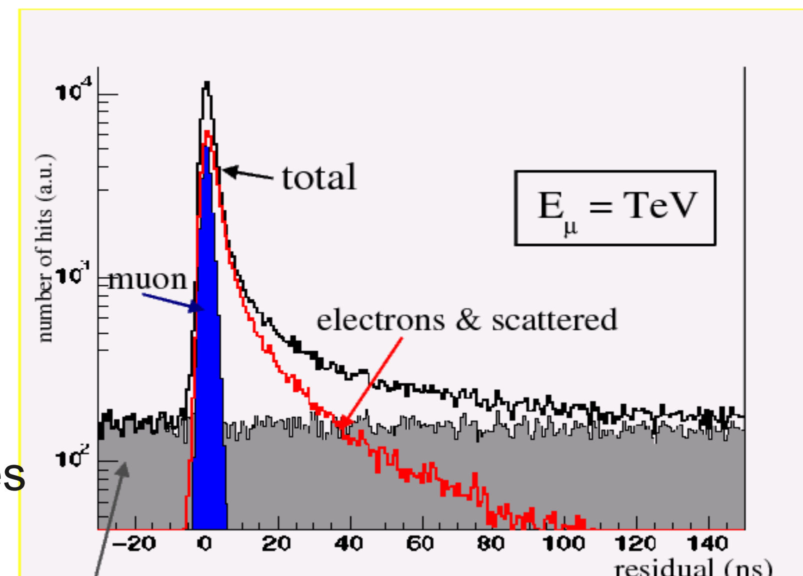
Track Reconstruction

Reconstruction relies on arrival times of Cherenkov photons



$$t^{\mathrm{exp}} = t^0 + \frac{1}{c}\left(l - \frac{k}{\tan\theta_C}\right) + \frac{1}{v}\left(\frac{k}{\sin\theta_C}\right)$$





Optical background due to decaying ^{40}K and bioluminescence.

two algorithms:

- Strategy A: tries to fully describe time residuals
- Strategy B: tries to reject background and minimizes residuals with a simple χ^2

Track Reconstruction: two algorithms

Strategy A

- developed on MC (top down)
- likelihood based: use all timing information
- inclusive hit selection, efficient but not pure
  - optical background modeled in likelihood
- aggressively uses amplitude information
- uses full alignment

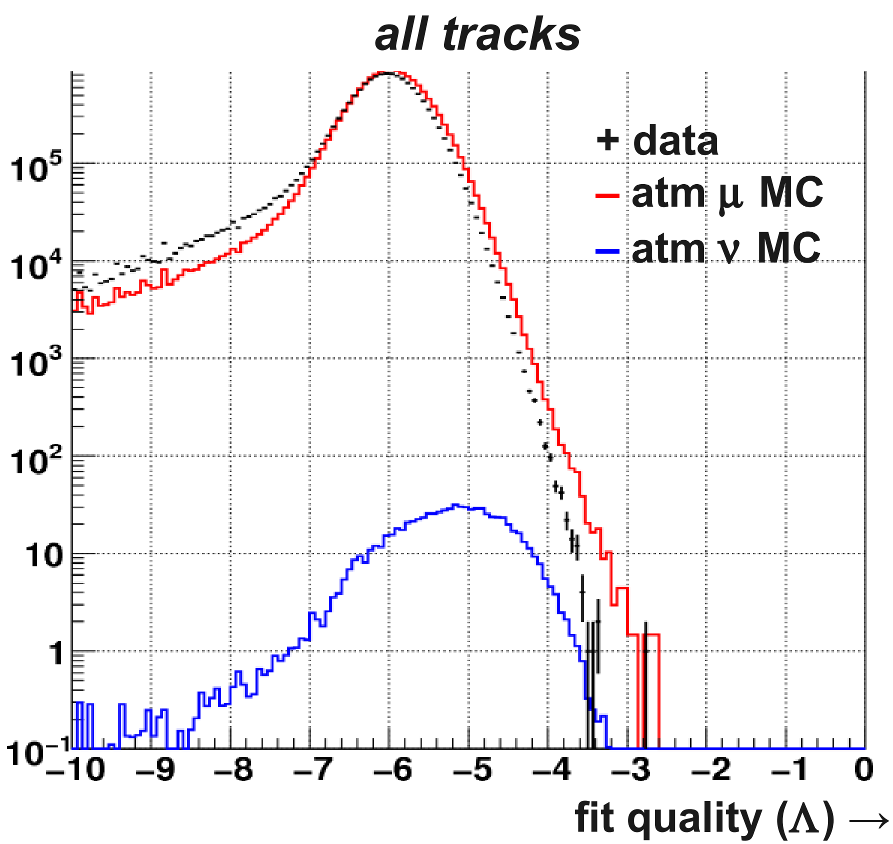
- angular resolution: 0.3°
- sensitive to mismodeling
  - bad: need to work on MC
  - good: handle to improve the MC

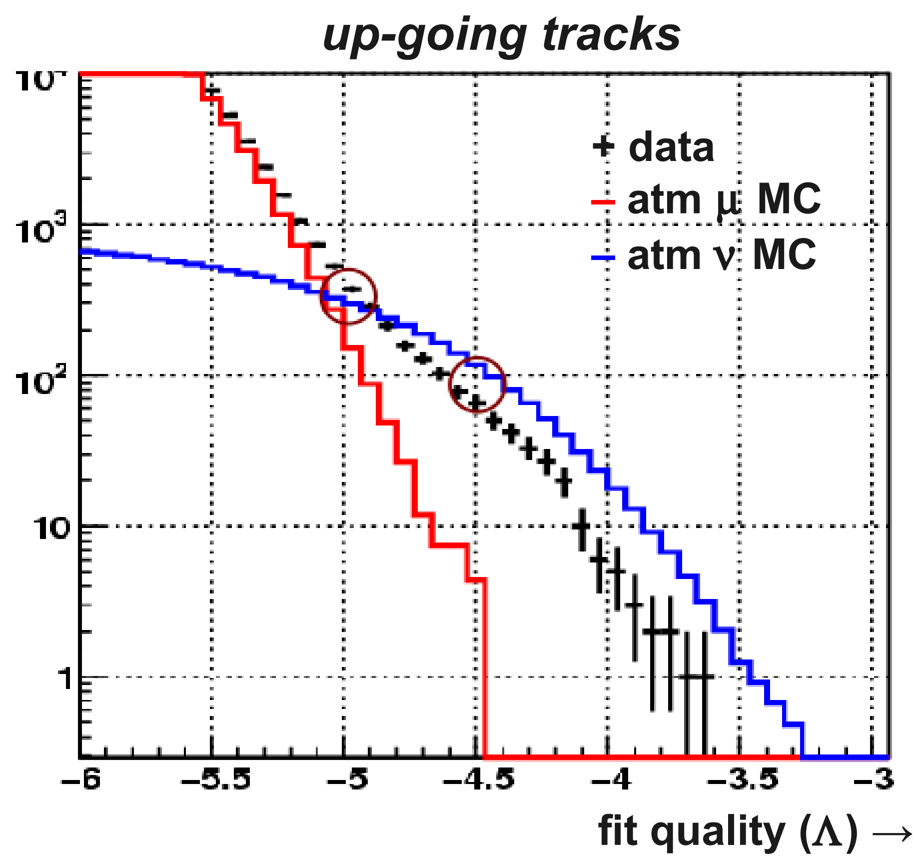
Strategy B

- developed on data (bottom up)
- χ^2 based (no fancy timing model)
- pure pattern-based signal hit selection
  - background hits are mostly rejected, but some signal hits too
- hit-amplitudes used moderately
- uses average detector geometry

- angular resolution: 1-3° depending on number of lines used in fit
- more robust against certain inaccuracies
  - good: get robust results soon

The problem (with the strategy A / the MC)





- Λ = ~ likelihood of fitted track
- less than satisfactory agreement
  - reason to revisit 5-Line point source analysis (see next talk)
- Rest of this talk is about effort MC in the context of strategy A.
  - strategy B is often robust, but
  - some changes in MC (bugs) also affect results from strategy B.

Since fall last year...

- Certain analyses use strategy B for fast results
- In Parallel: effort to improve MC and strategy A in order to use the ultimate detector performance offered by Antares.

bugs:

- ***missing photons in detector simulation***
- ***wrong OM orientation in reconstruction of MC***

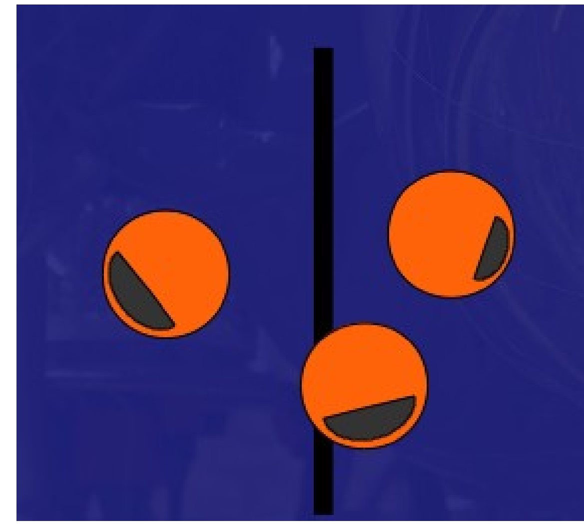
refinements in the simulation:

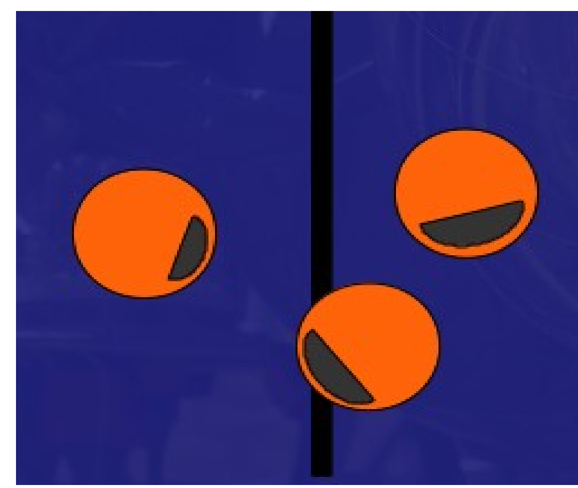
- ***angular acceptance function***
- ***amplitude of optical background hits***
- ***front-end read-out thresholds***
- ***data-driven simulation of detector conditions***

Bugs : OM orientations

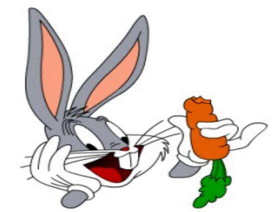
- Detector geometry in reconstruction
  - read from data-base for data
  - read from file for simulated events
- Orientations of OMs not correctly read in from detector file.
- Affects reconstruction of MC events
  - Positions and timing not affected

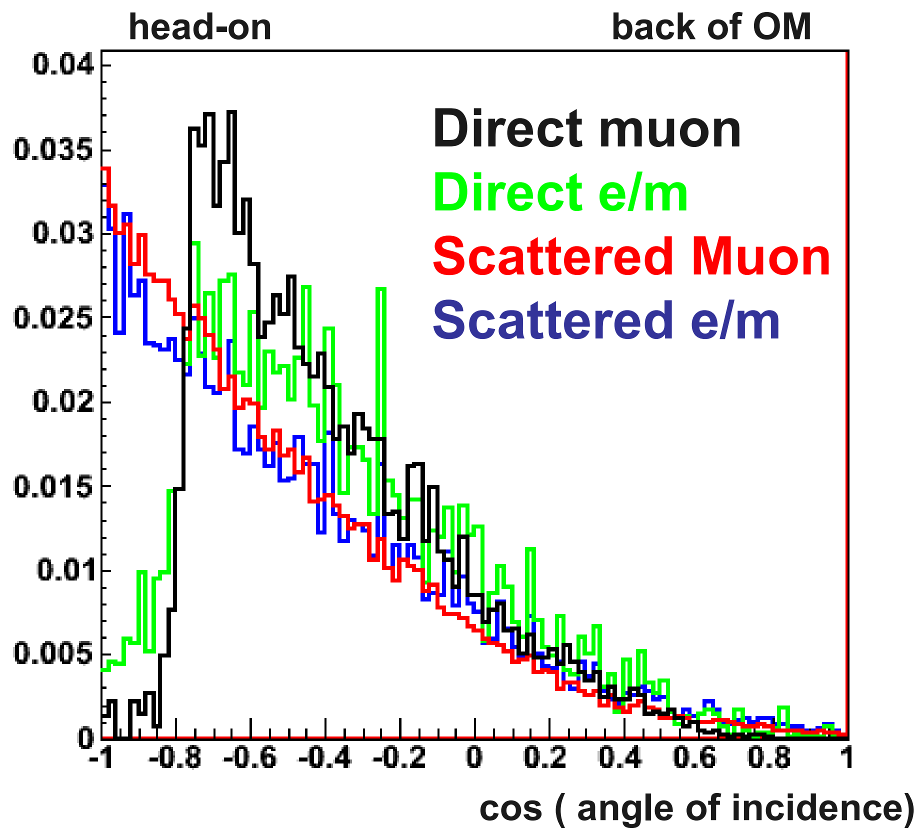
    → quite small effect (4% for ν, 15% for μ)
  - Easy to fix
- Now using same code for data and MC.
  - new detector description for MC with same mappings as on-line.
  - more robust against future changes.

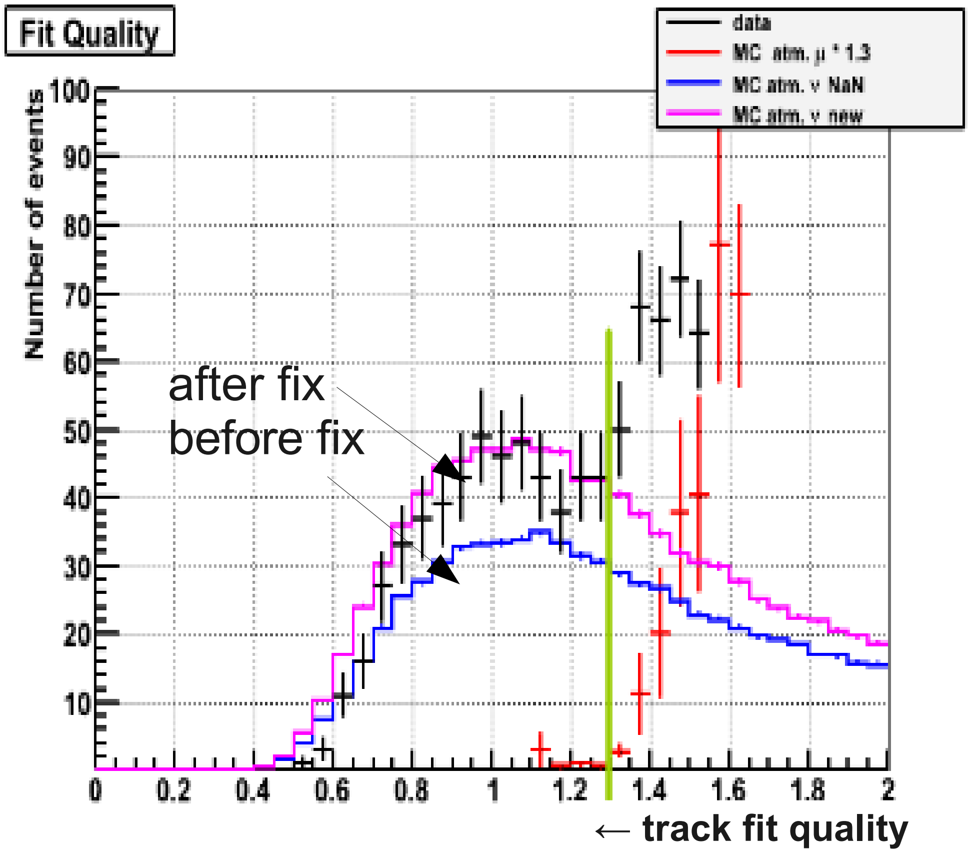




Bugs : photon tables

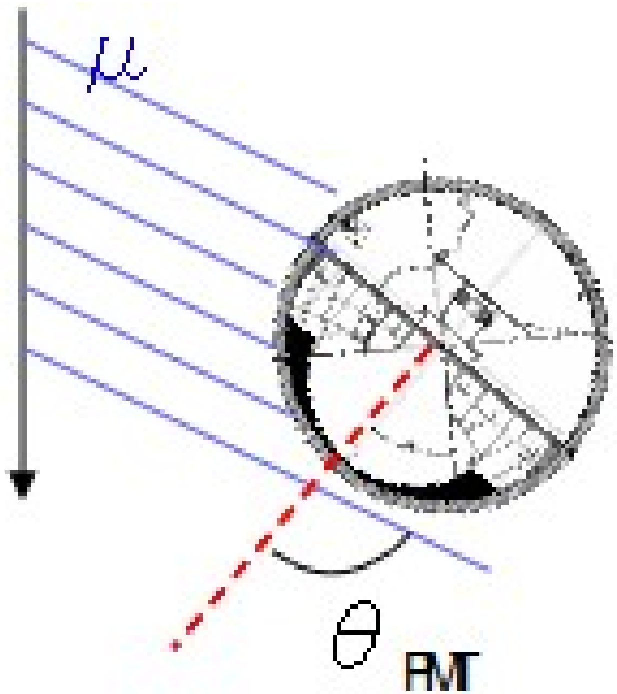


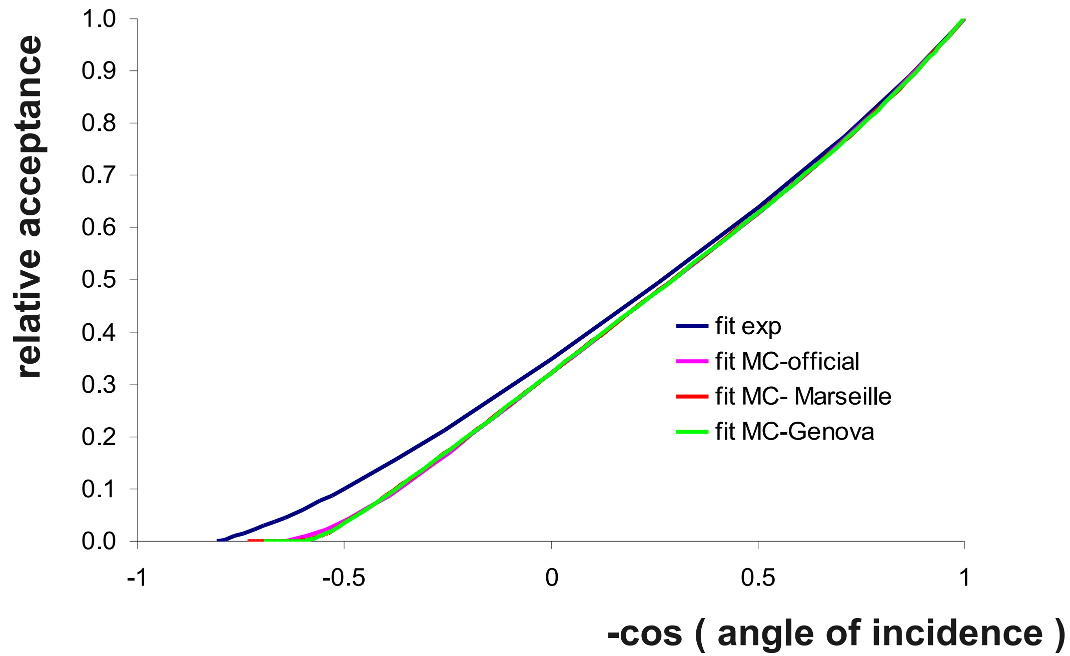




- in **KM3** program : non-scattered photons missing when hitting OM head-on!
- related to numerical problem in photon tables generation
- easy to fix, but large impact on all Neutrino MC's (+41% events)
- down-going muons ~not affected (muon paper = ok)

Angular acceptance function

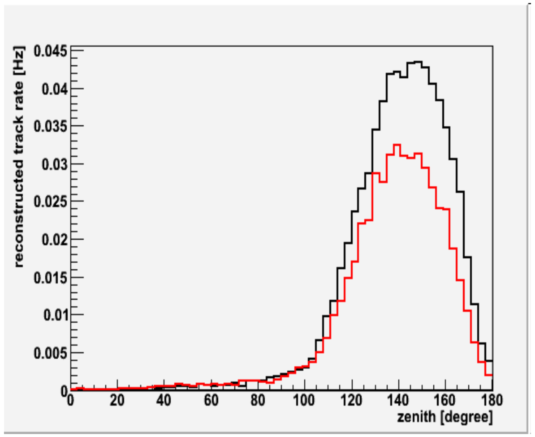




Acceptance of optical module as function of angle of incidence of the photon

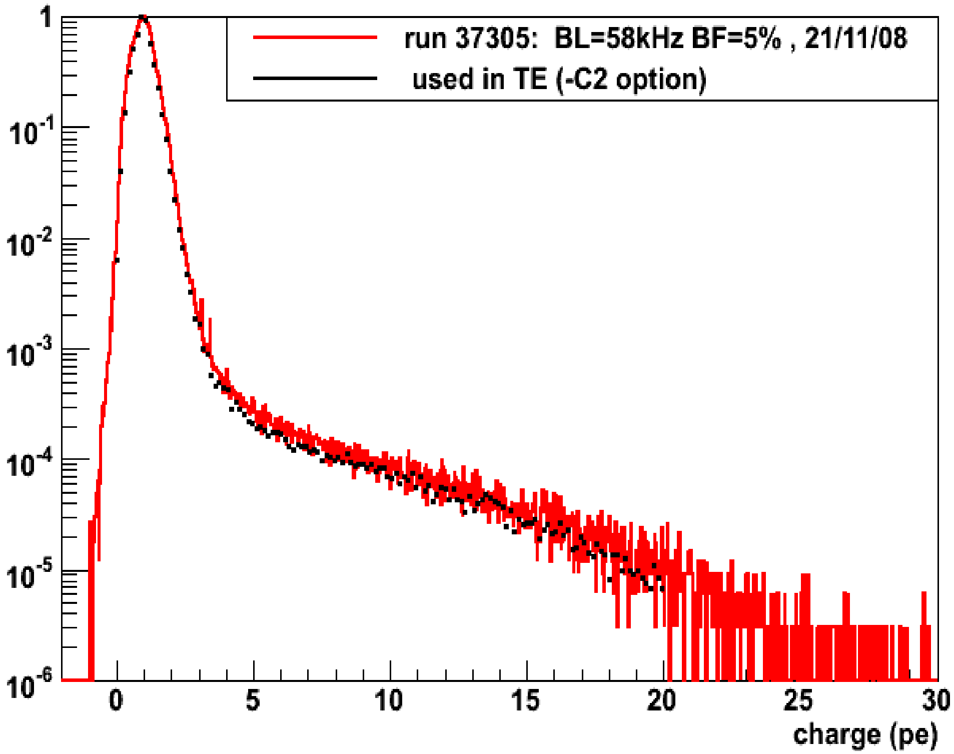
- important for down-going atmospheric muons

- previous acceptance curves based on measurements
  - hard to measure exactly the desired quantity (plain wave)
- now: acceptance from detailed ray-tracing simulations
- ~30 effect on down-going muons
  - remains large systematic for down-going μ analyses
  - far less crucial for neutrinos.



Optical background modeling

- noise hits are added to the physics simulation with rates that are measured in data.
- amplitude: assumed to be single photo-electron pulses



- charge-distribution of background hits measured in zero-bias data obtained during trigger-less data taking
- contribution of high-charge pulses was not modeled by the MC
- Bad news for 'strategy A' which classified all high-amplitude hits as signal.

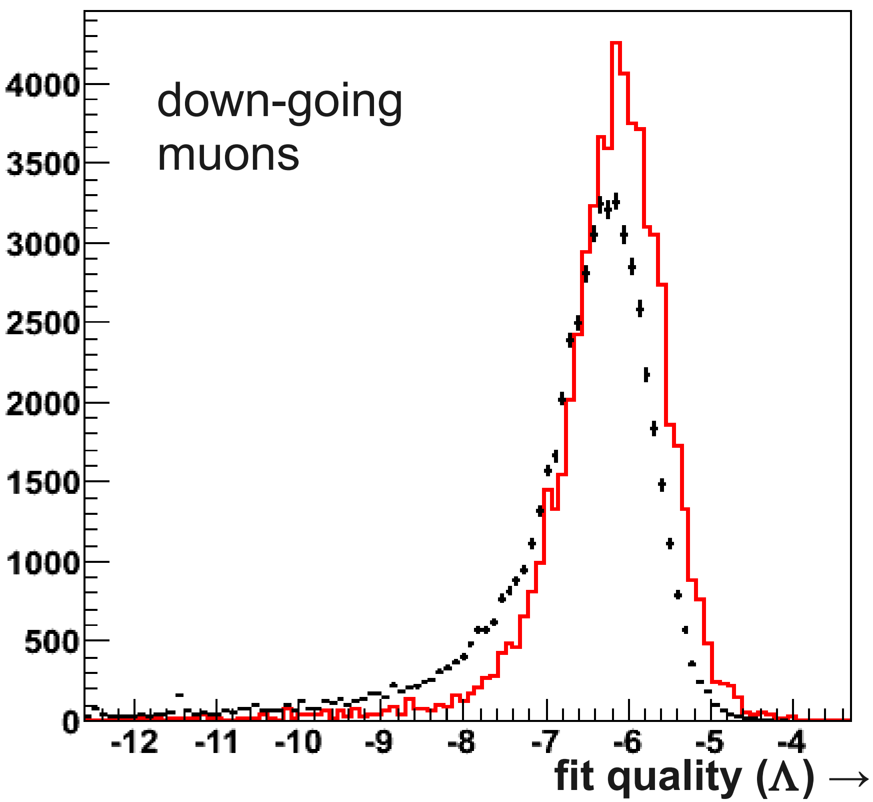
actions:

- model background hits using measured distribution
- revise *reconstruction algorithm* for reduced dependence on hit amplitudes.

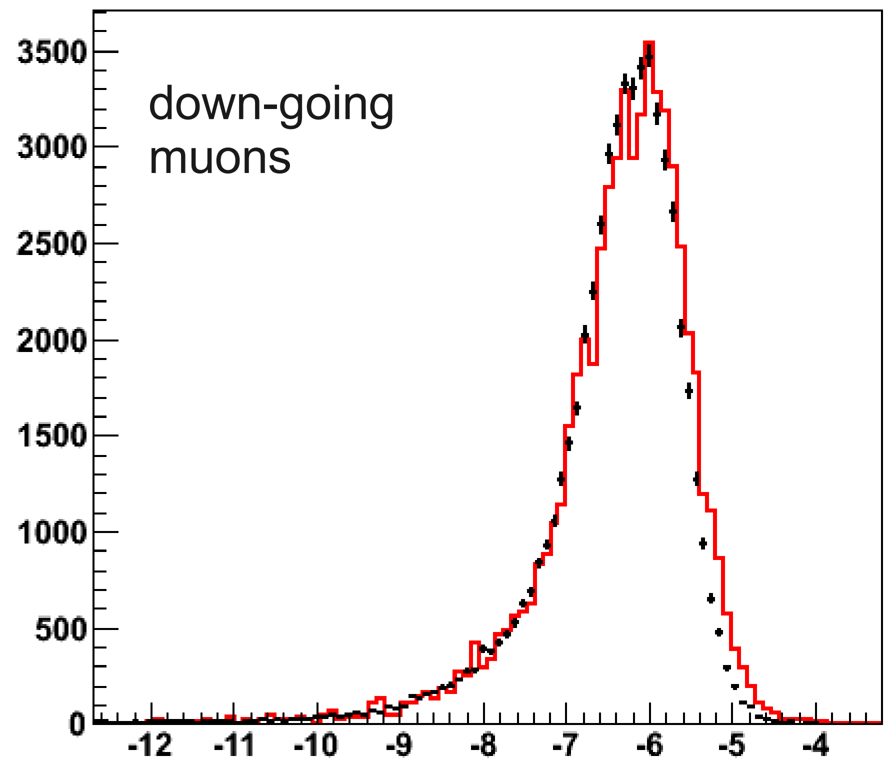
Optical background modeling

- Effect evaluated for down-going muons.
- Observe much improved description of the data when using strat A.
- Minor effect on strat. B.

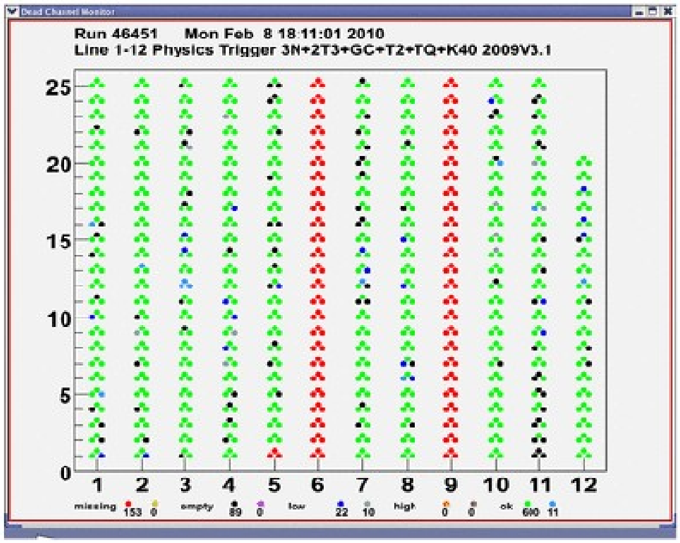
before changes

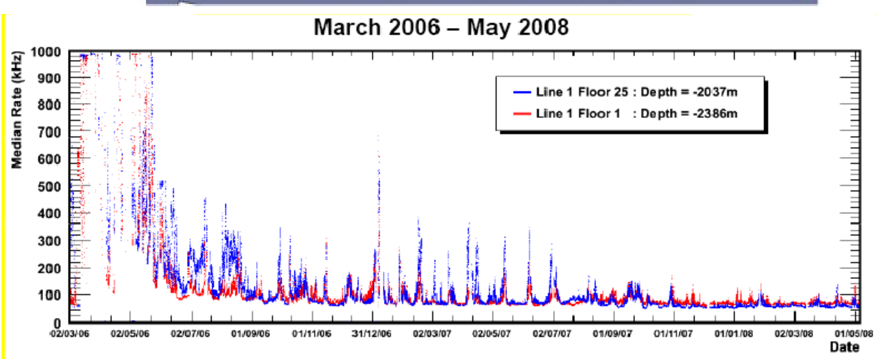


realistic simulation & robuster reco.



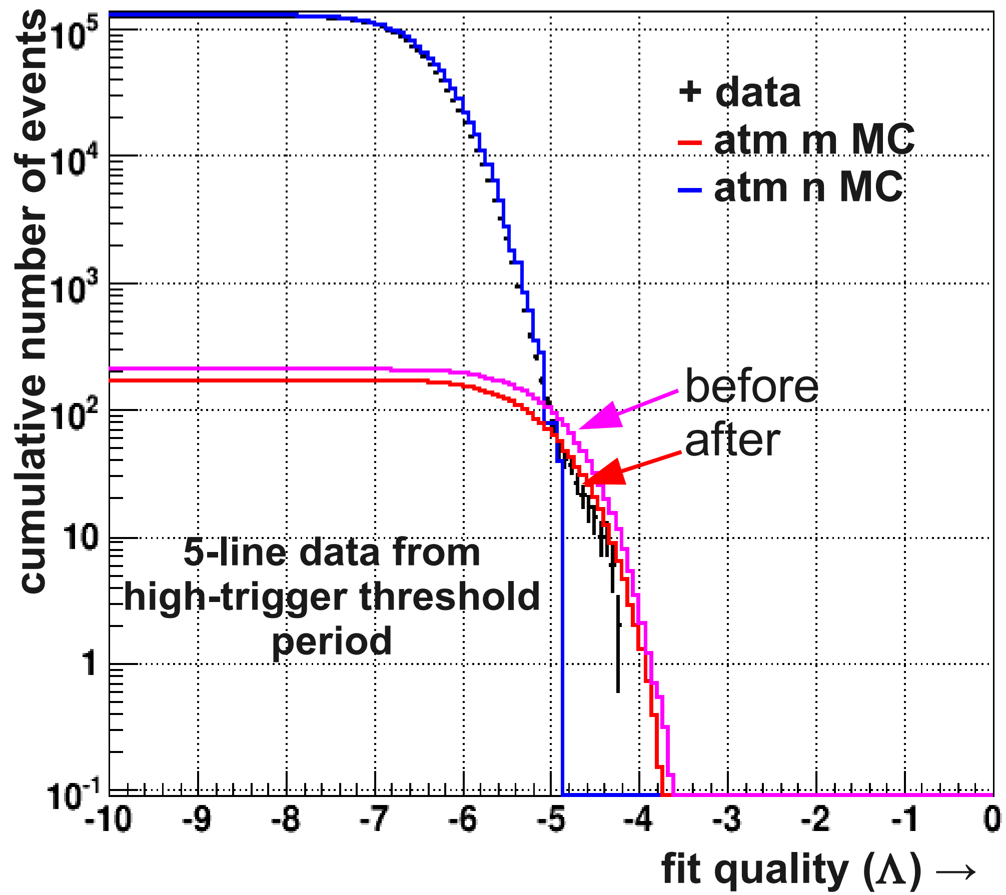
Simulation of data-taking conditions



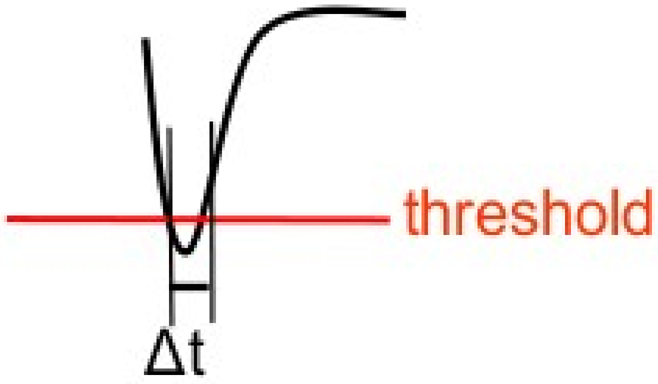


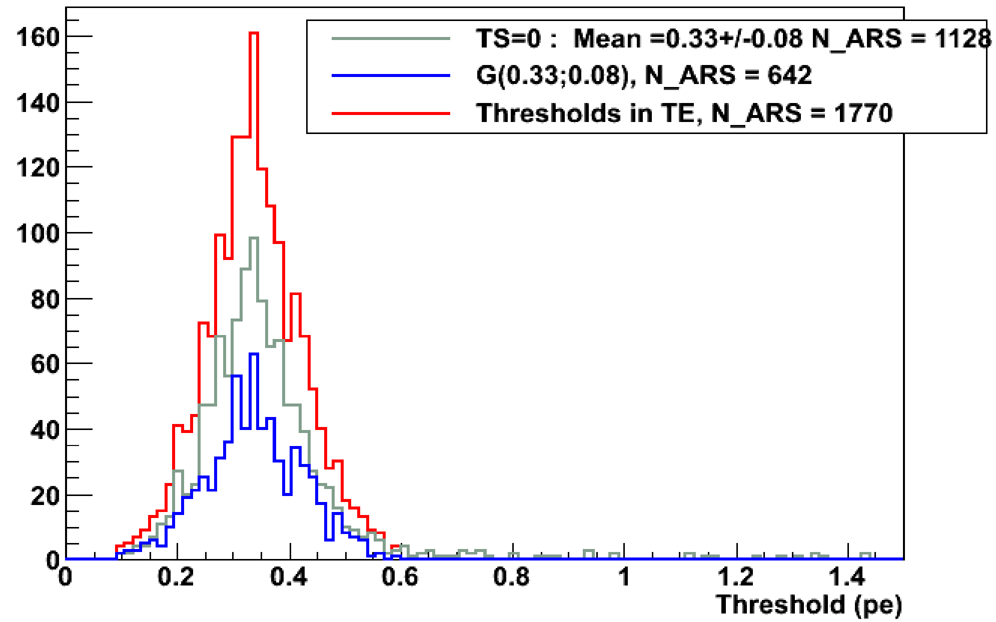
- Crucial aspect of simulation:
  - Addition of noise hits
  - Masking of dead/problematic OMs
- Both are highly variable
- based on count-rates measured in data

new: course, but fair sampling of all the rate-information from the full data-taking period.



read-out thresholds

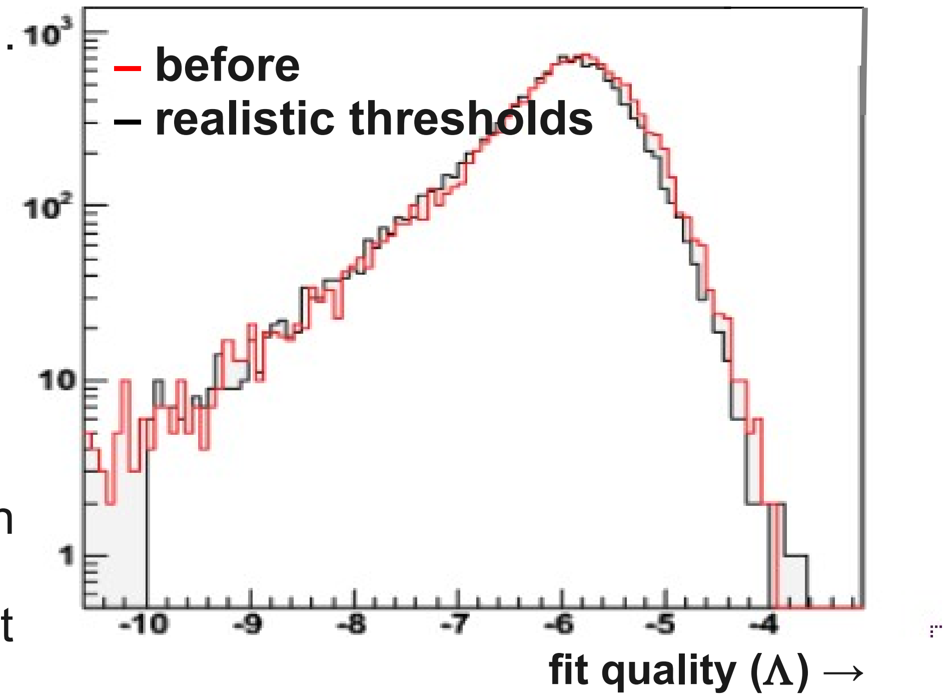




front-end electronics (ARS chip) decides to read out a hit when a voltage threshold is reached.

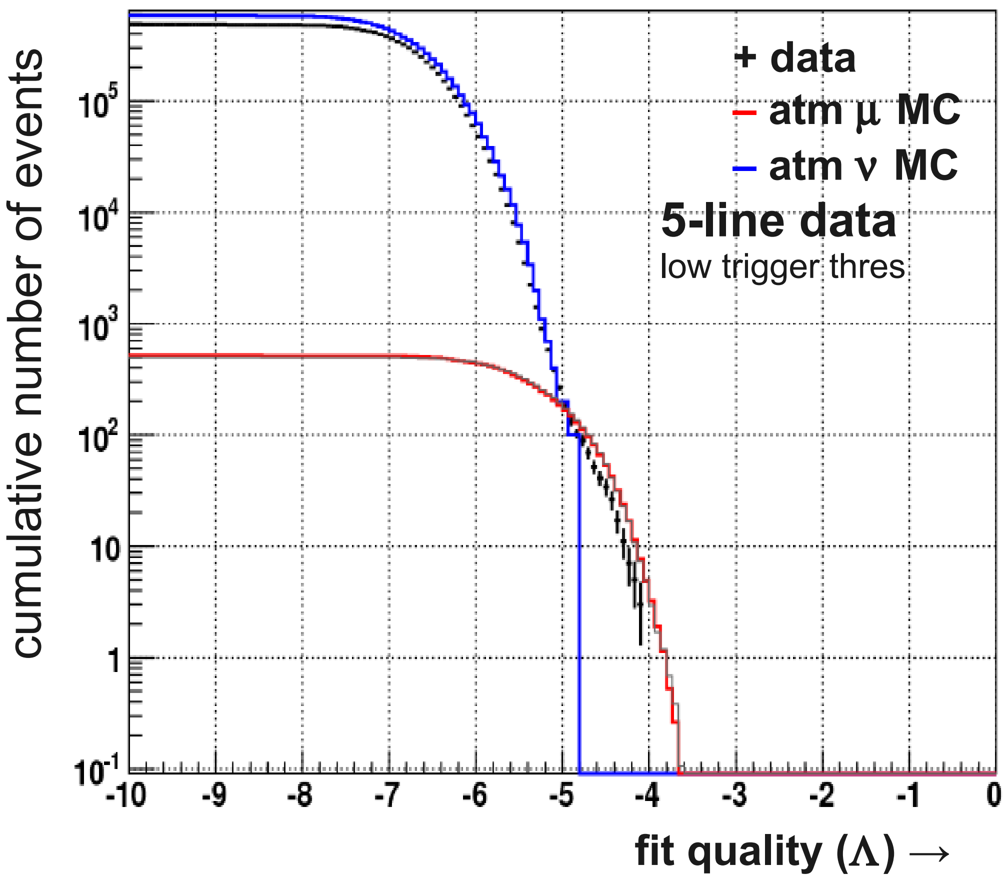
- translates to threshold in hit-charge, but mapping is non-trivial
- use measured charge-threshold distribution from data
- small, but significant effect on distribution of quality variable.

- near future: also include more realistic simulation of calibration constants and their uncertainties
  - improve simulation of amplitude measurement and its dynamic range.

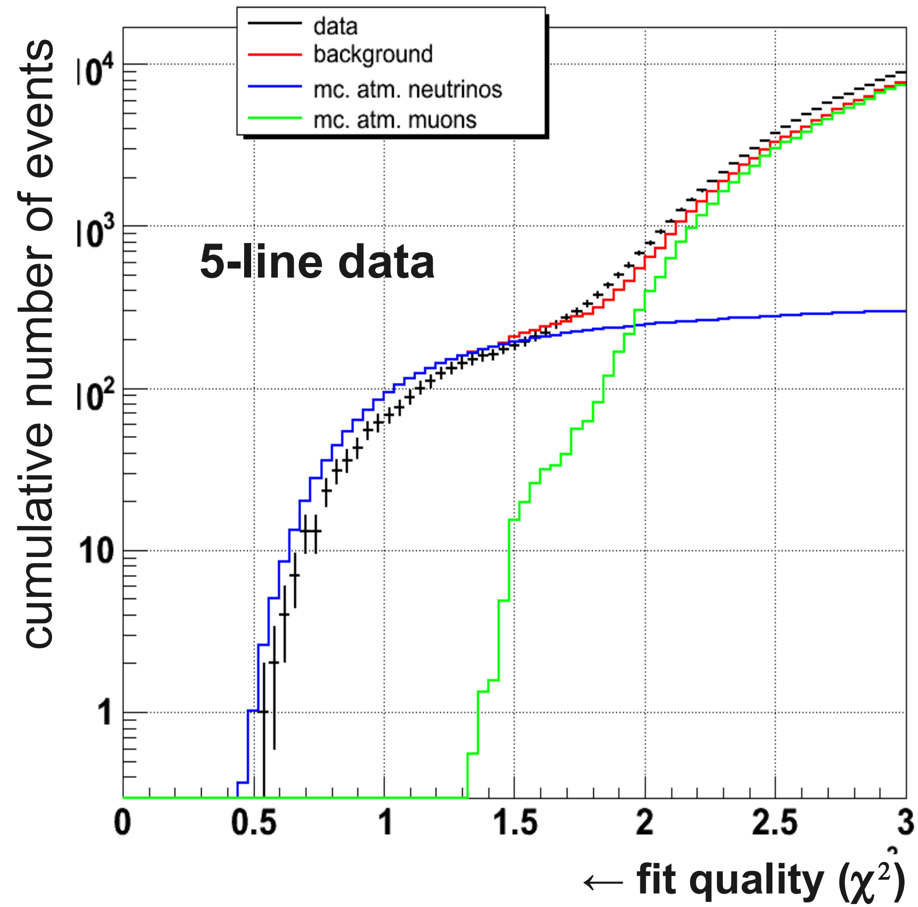


Current Status

Strategy A

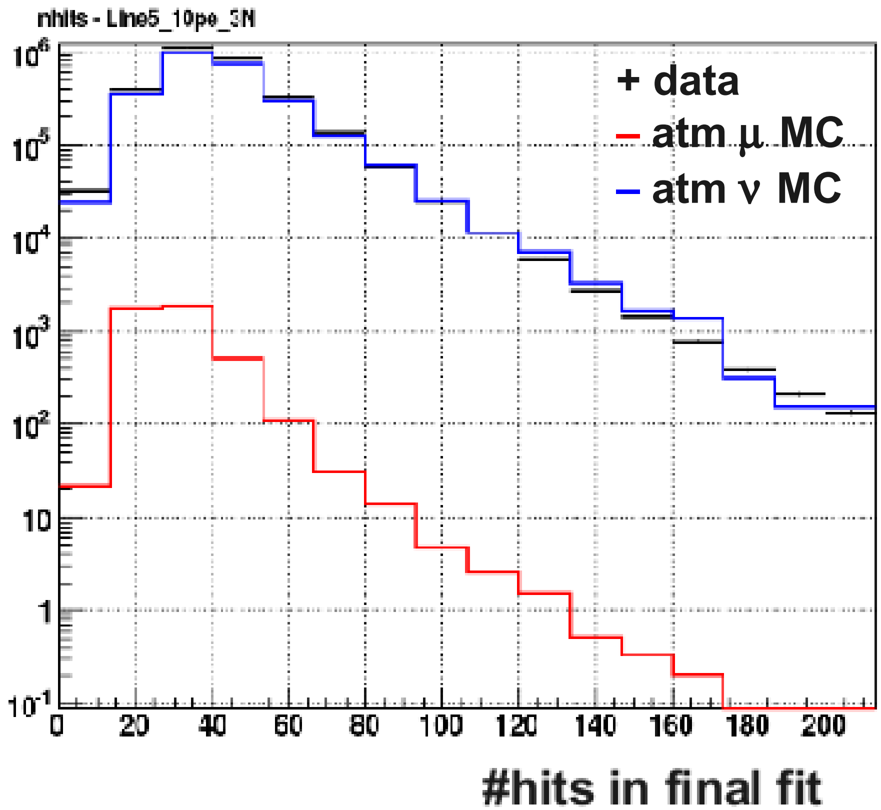


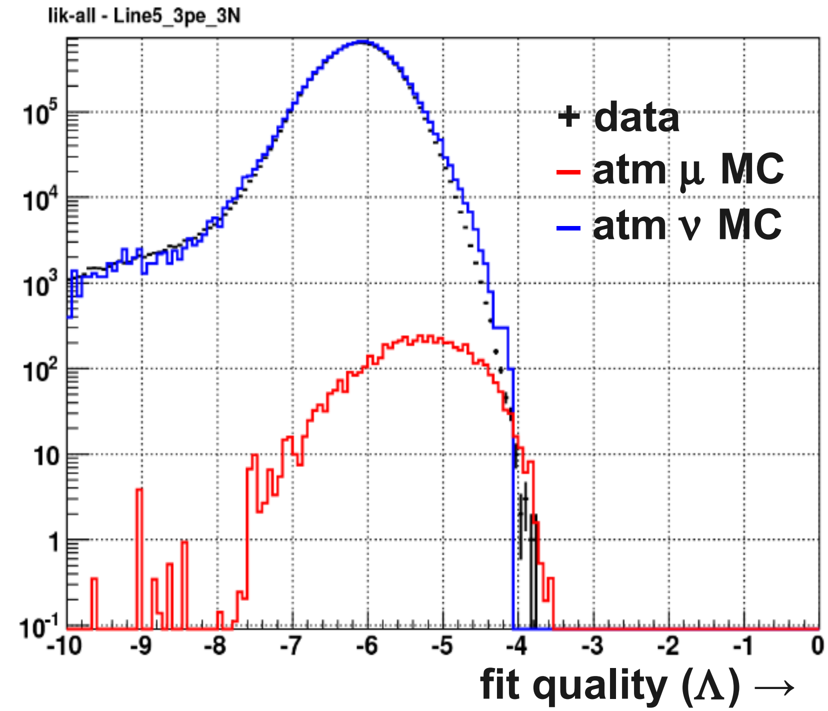
Strategy B

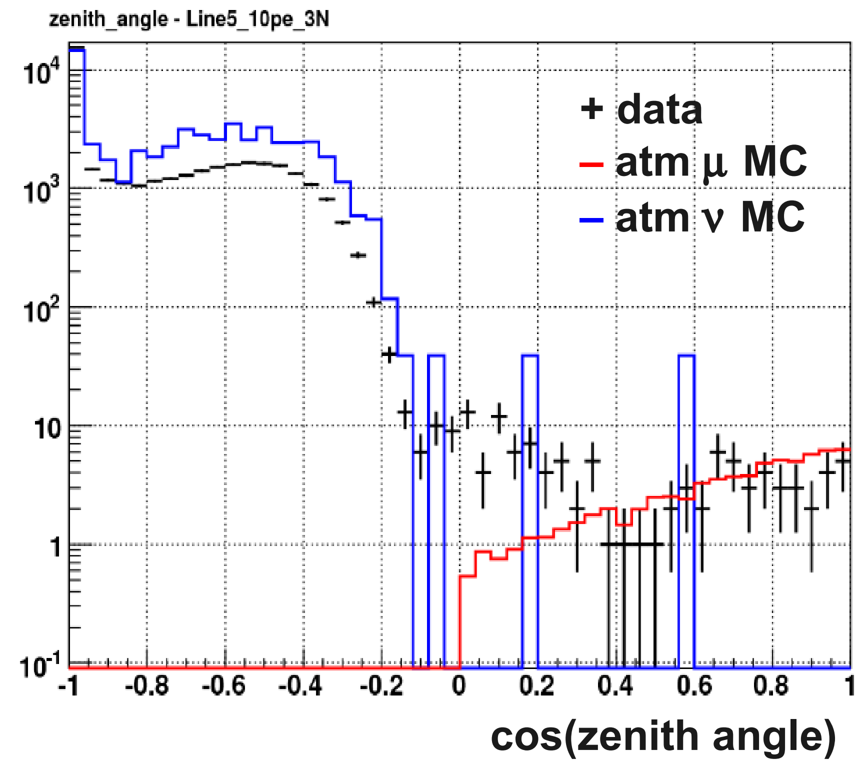


- Both reconstruction strategies now show ~similar level of agreement with MC
- MC & Strategy A are close to ready for next analysis steps

Current Status







good description of many aspects of the data , but not all of them.

Conclusions

- Confidence in MC simulation is crucial for making believable statements on acceptance and angular resolution.

- Handles to check correctness of MC:
  - down-going muons
  - atmospheric muon-neutrinos

- Two different reconstruction algorithms with different susceptibility to imperfections in the MC simulation
  - Strategy B: robuster, but inferior angular resolution -> used for first analyses
  - Strategy A: ultimate angular resolution, but higher demands on detector simulation

- Over past months efforts to do analysis with ultimate resolution yielded
  - several refinements of the MC
  - and a few errors/bugs, which have been fixed
  - robuster version of Strategy A, without sacrificing performance

- Status:
  - Gap between the strategy A and B closing (if not closed)
  - Expect optimal-resolution analyses completed on time-scale of a few months.