Moon shadow observation with ANTARES and KM3NeT neutrino telescope

Matteo Sanguineti for the ANTARES & KM3NeT collaboration

Università degli Studi di Genova – INFN Genova

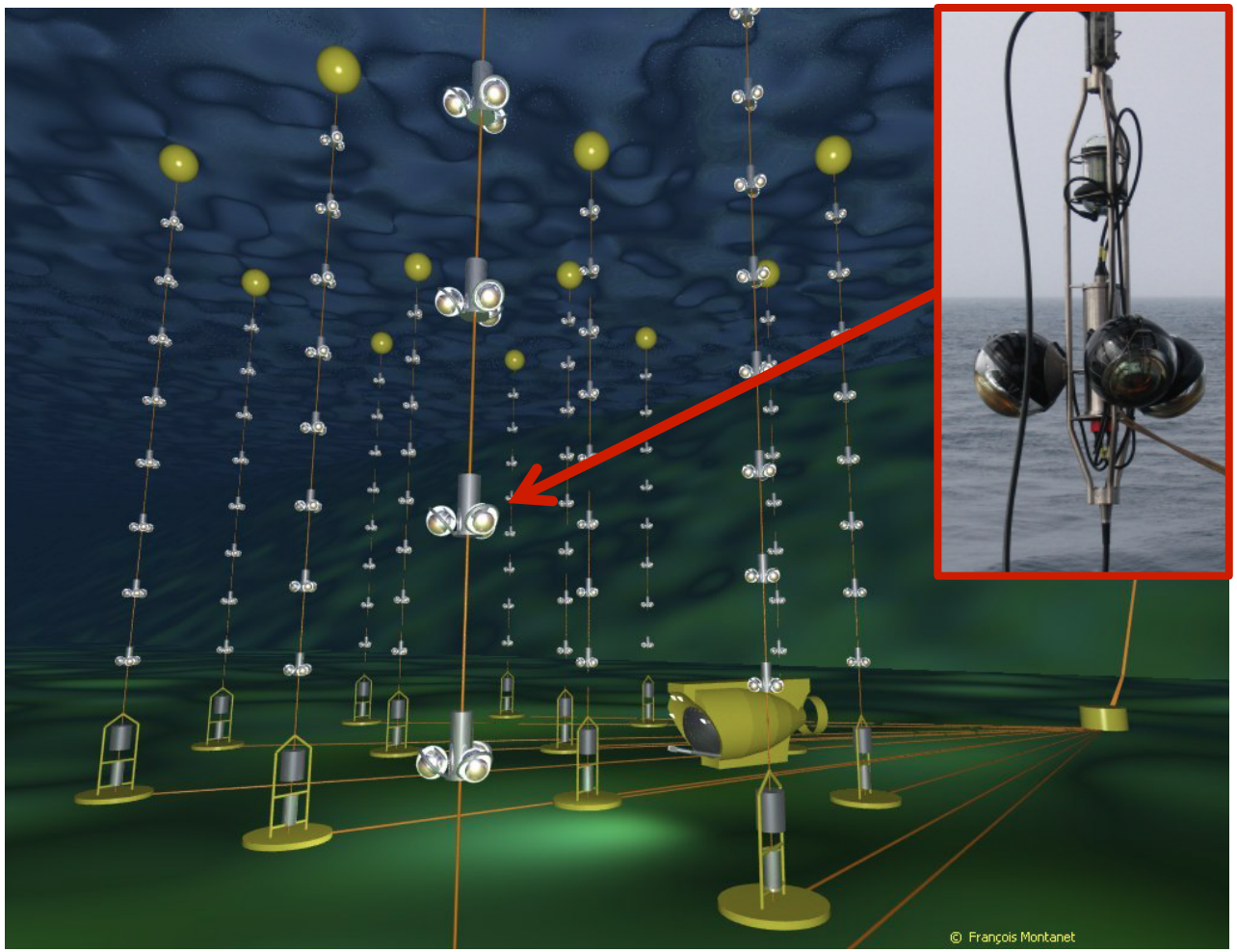
Outline

- ANTARES detector
- Moon shadow effect
- Antares Moon shadow analysis

- KM3Net detector
- KM3NeT Moon shadow simulation

- Conclusions

ANTARES detector



Components:

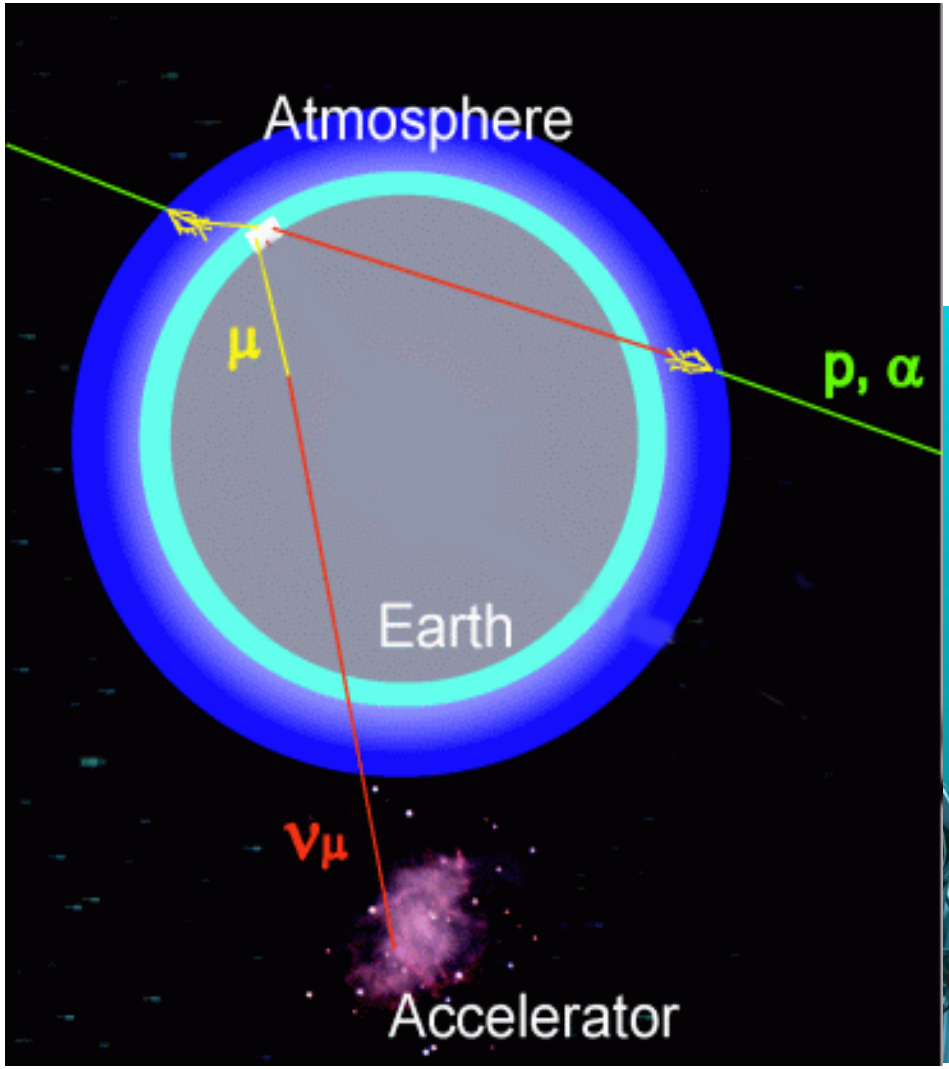
- 12 lines
- 25 storey/line
- 3 PMTs / storey
- 885 10” PMTs

Location:

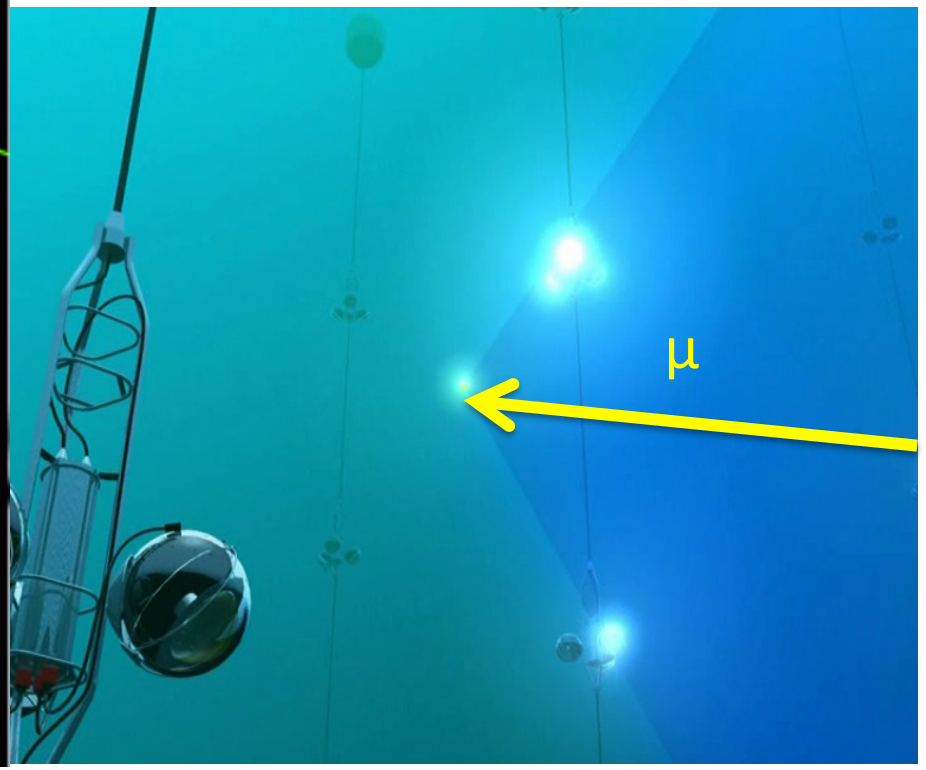
- Mediterranean Sea
- 2475 m depth

5-line setup in 2007, completed in 2008

Detection principle



- Cosmic neutrino
- Atmospheric neutrino
- Atmospheric muon



ANTARES researches

- Neutrino astrophysics
  - Point-like sources
  - Extended sources
  - Multi-messenger searches
  - …
- Dark matter searches
- Atmospheric neutrino studies
- Sea science
- …

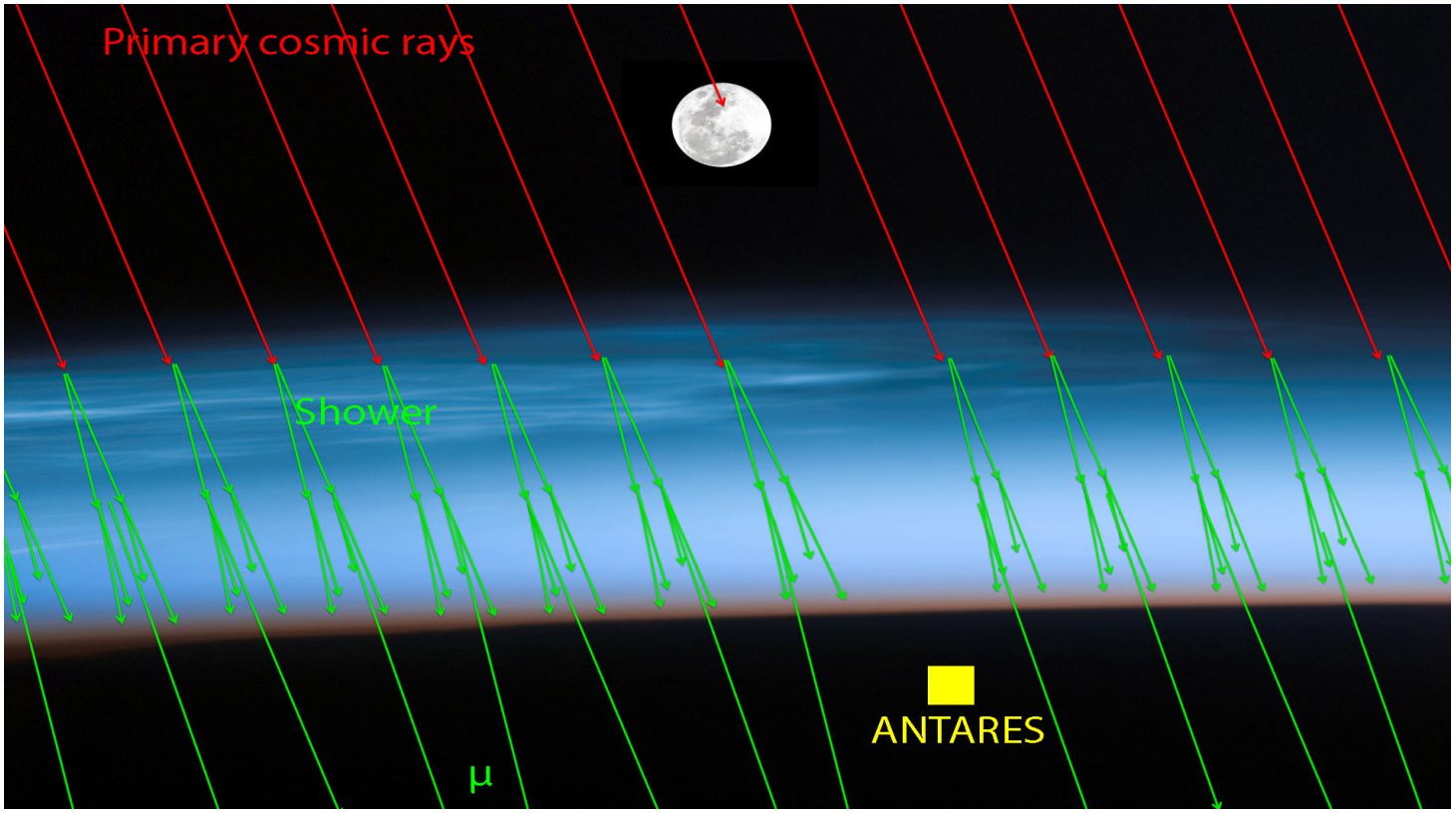
Pointing performance

The measure of the pointing performance is really critical for this kind of detector:

- **Relatives delays of**
  - **optical sensors within each detector line**
  - **optical sensors between the lines**
- **Instantaneous shape**
- **Absolute orientation of the detector lines**

The cosmic ray Moon shadow analysis is an efficient method to infer the pointing performance of a neutrino telescope

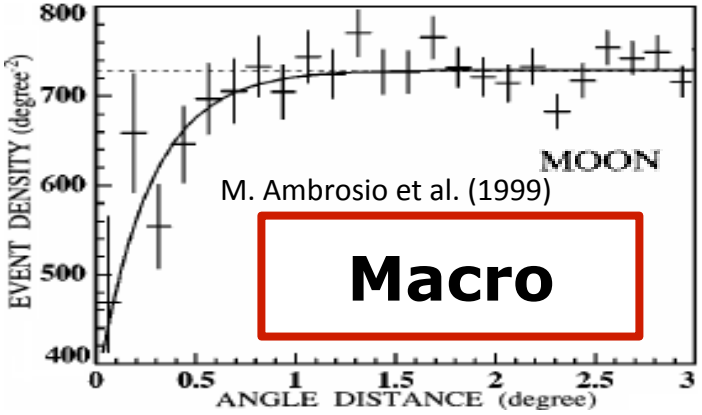
Moon shadow effect



A deficit in the event density of the atmospheric muon flux corresponding to the direction of the Moon disk is expected.

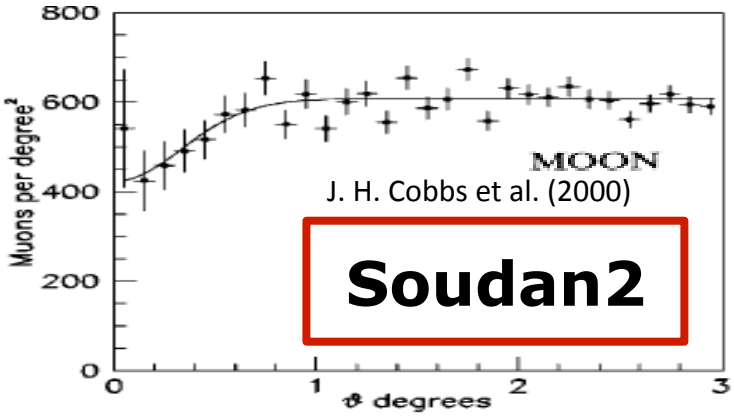
Moon shadow effect

Several experiments used the Moon shadow effect to test the pointing performance of the detector.



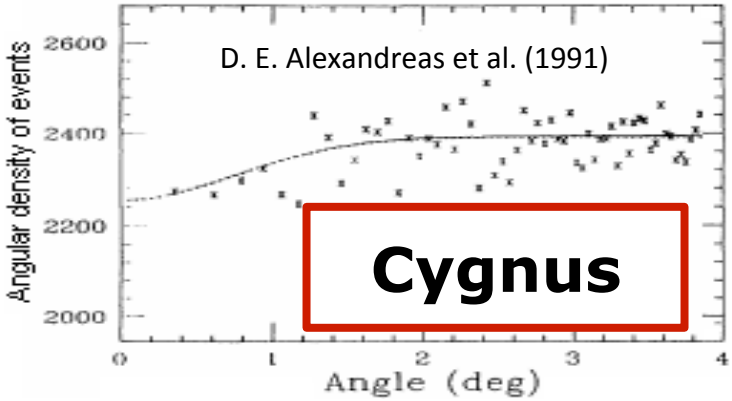
M. Ambrosio et al. (1999)

Macro



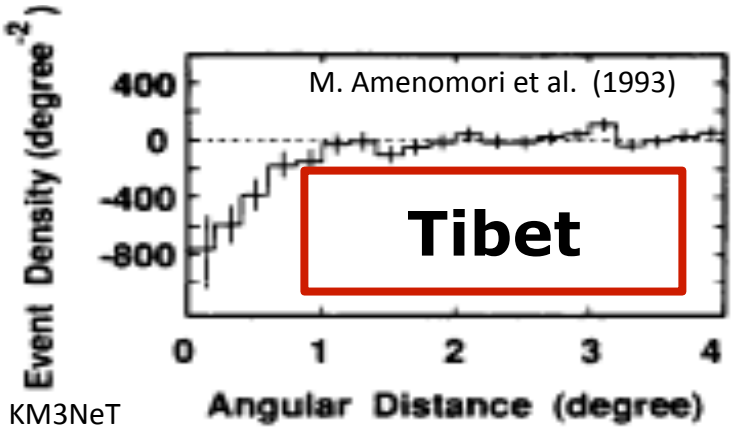
J. H. Cobbs et al. (2000)

Soudan2



D. E. Alexandreas et al. (1991)

Cygnus

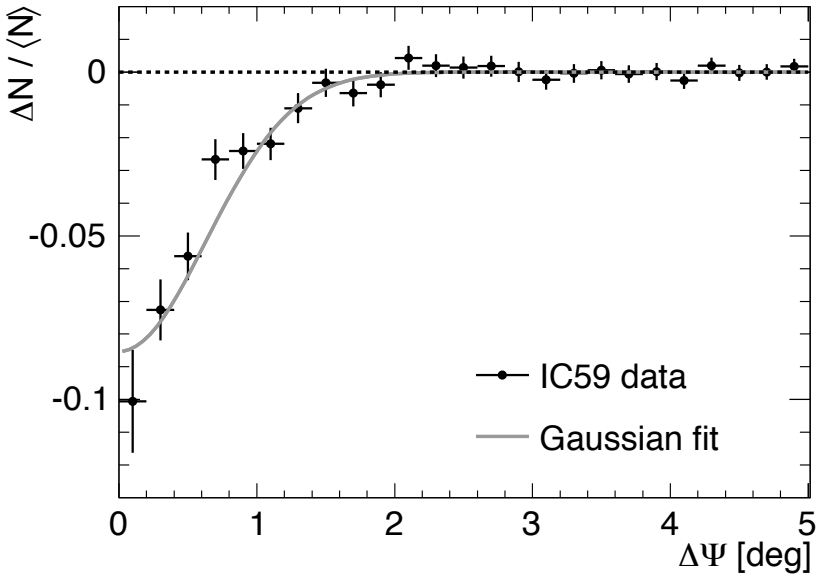


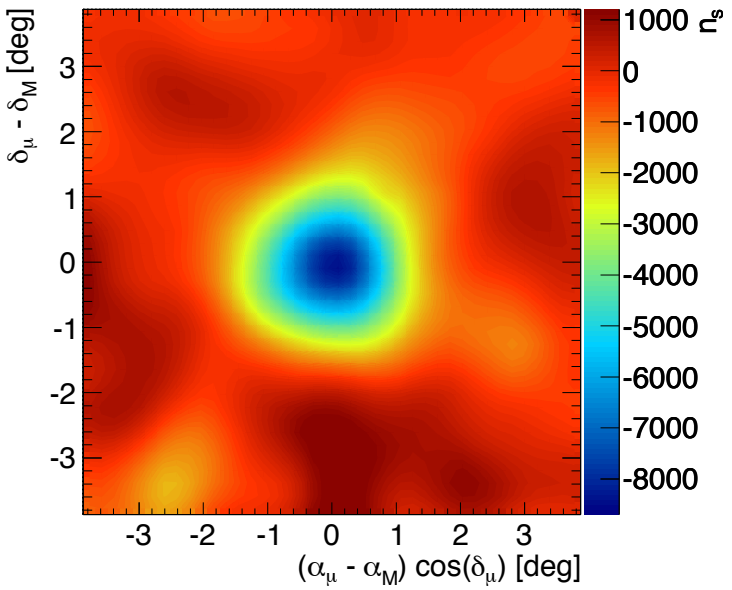
M. Amenomori et al. (1993)

Tibet

Moon shadow effect

The Moon shadow effect has been used also by the ICECUBE .





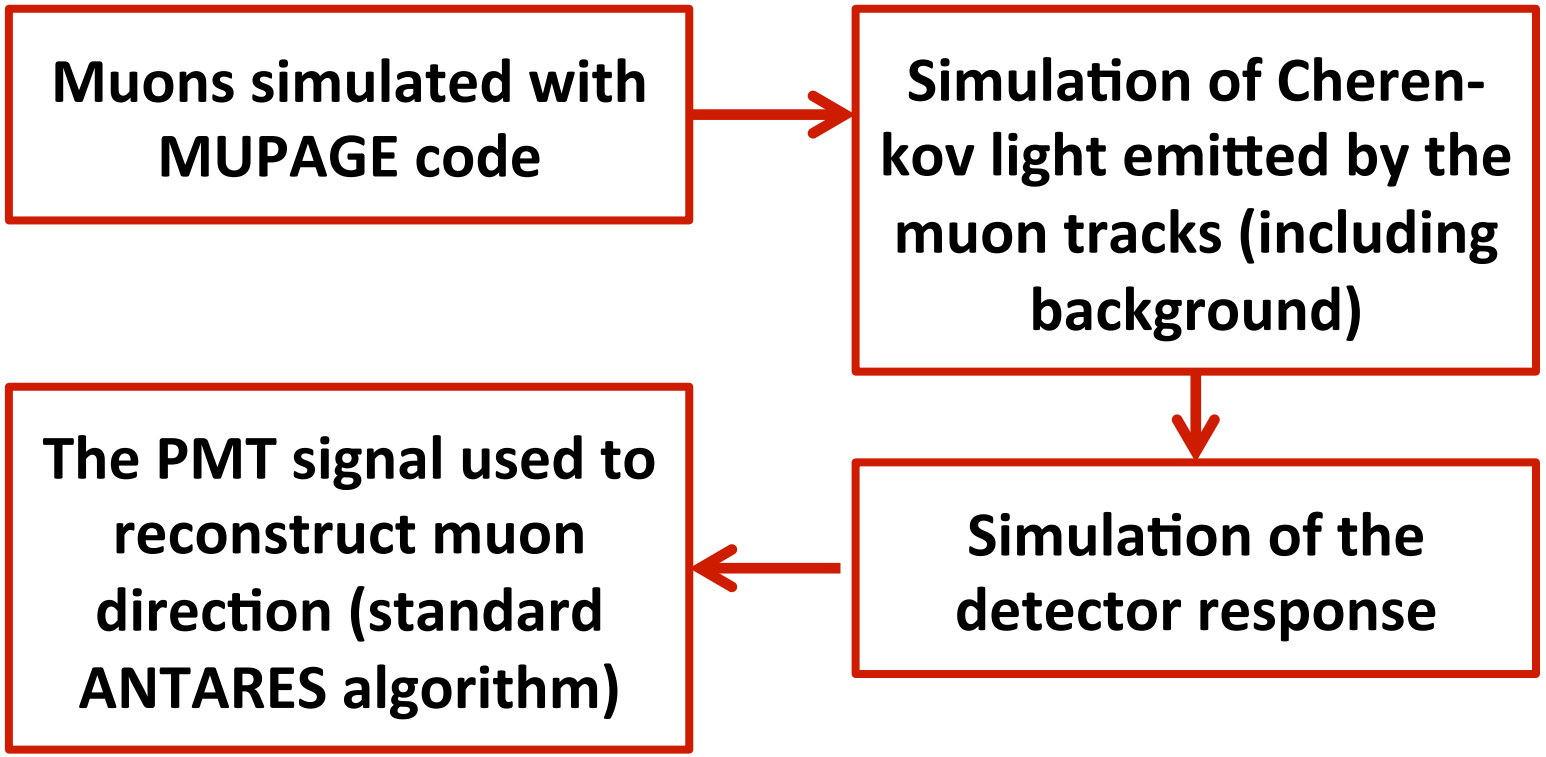
M.G. Aartesen et al. (2013), arXiv:1305.6811

ANTARES analysis

Outline of the ANTARES Moon shadow analysis

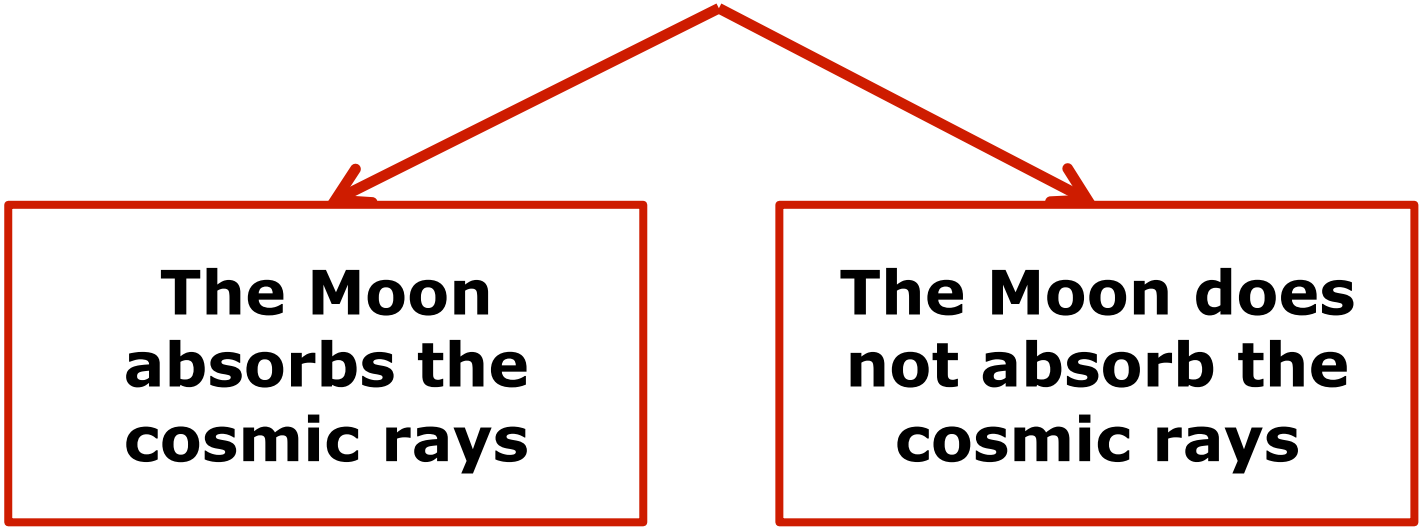
- Data sample 2007-2012
- Dedicated Monte Carlo simulation
- Opportune statistical method
- Optimization of the selection criteria on the tracks included in the analysis
- Results

Monte Carlo simulation



The dedicated simulation has higher statistic in the direction of the Moon with respect to standard ANTARES Monte Carlo.

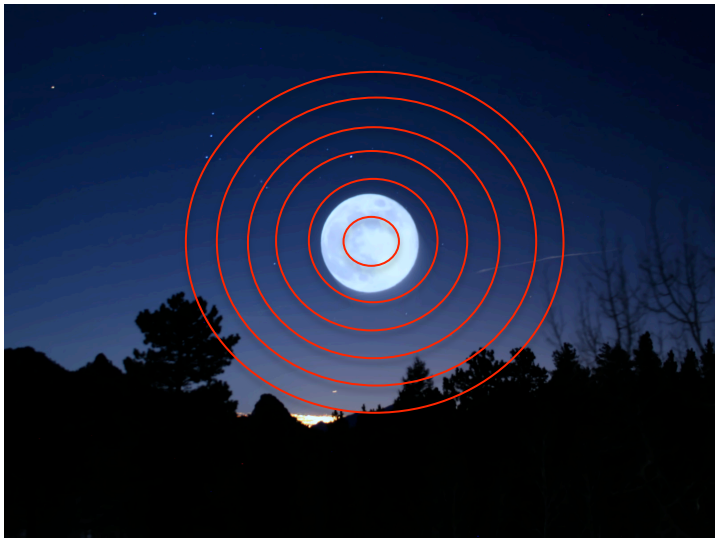
Monte Carlo simulation



The two set will be used to derive the expected events distribution in the two different hypothesis

Test statistic function

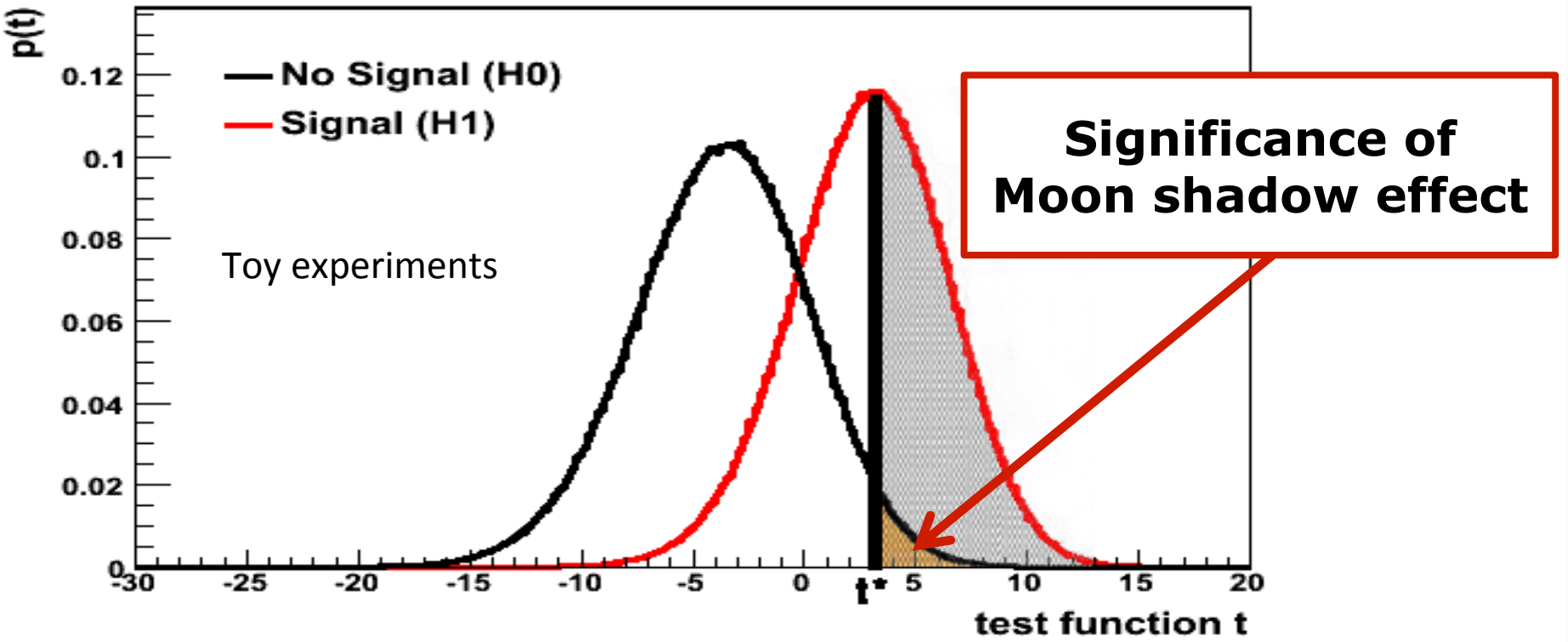
The region of the sky around the Moon centre is divided in concentric rings with increasing radius.



The test statistic function t:

$$t = \sum_{rings} \frac{(n_m - n_{exp,\ NO\ Moon})^2}{n_{exp,\ NO\ Moon}} - \frac{(n_m - n_{exp,\ Moon})^2}{n_{exp,\ Moon}}$$

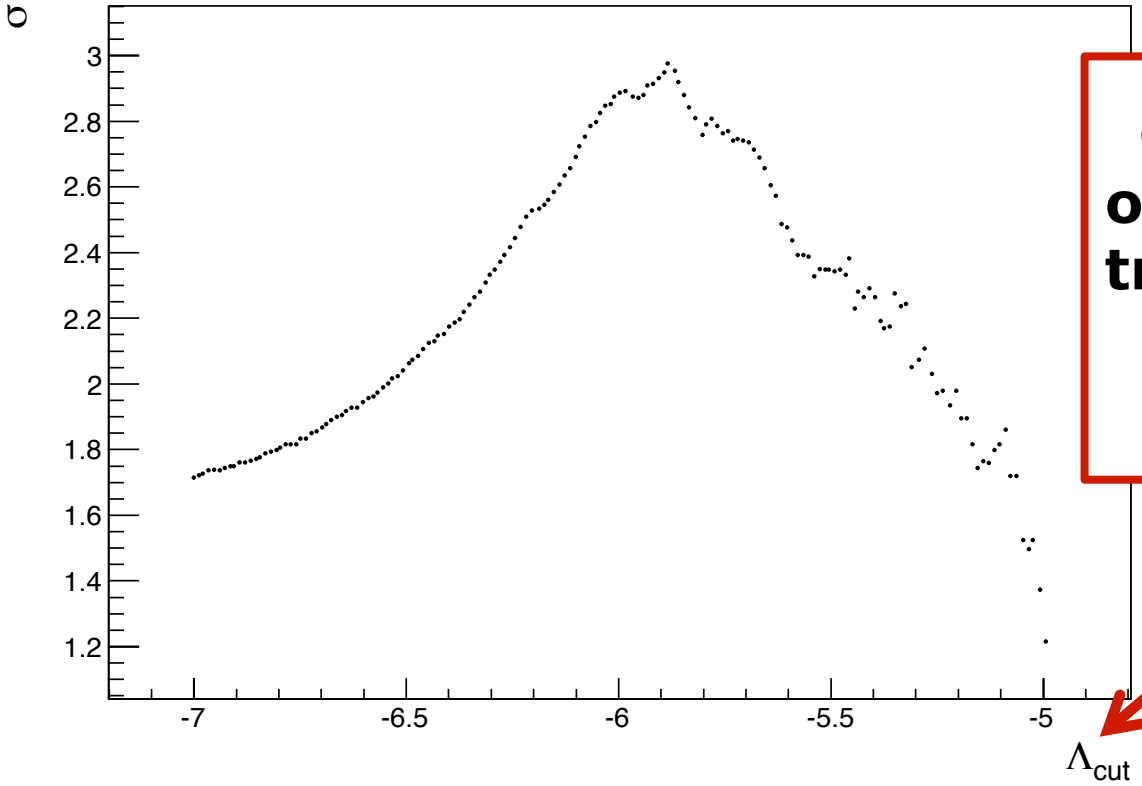
Test statistic function



Red: Moon shadow hypothesis

Black: No Moon shadow hypothesis

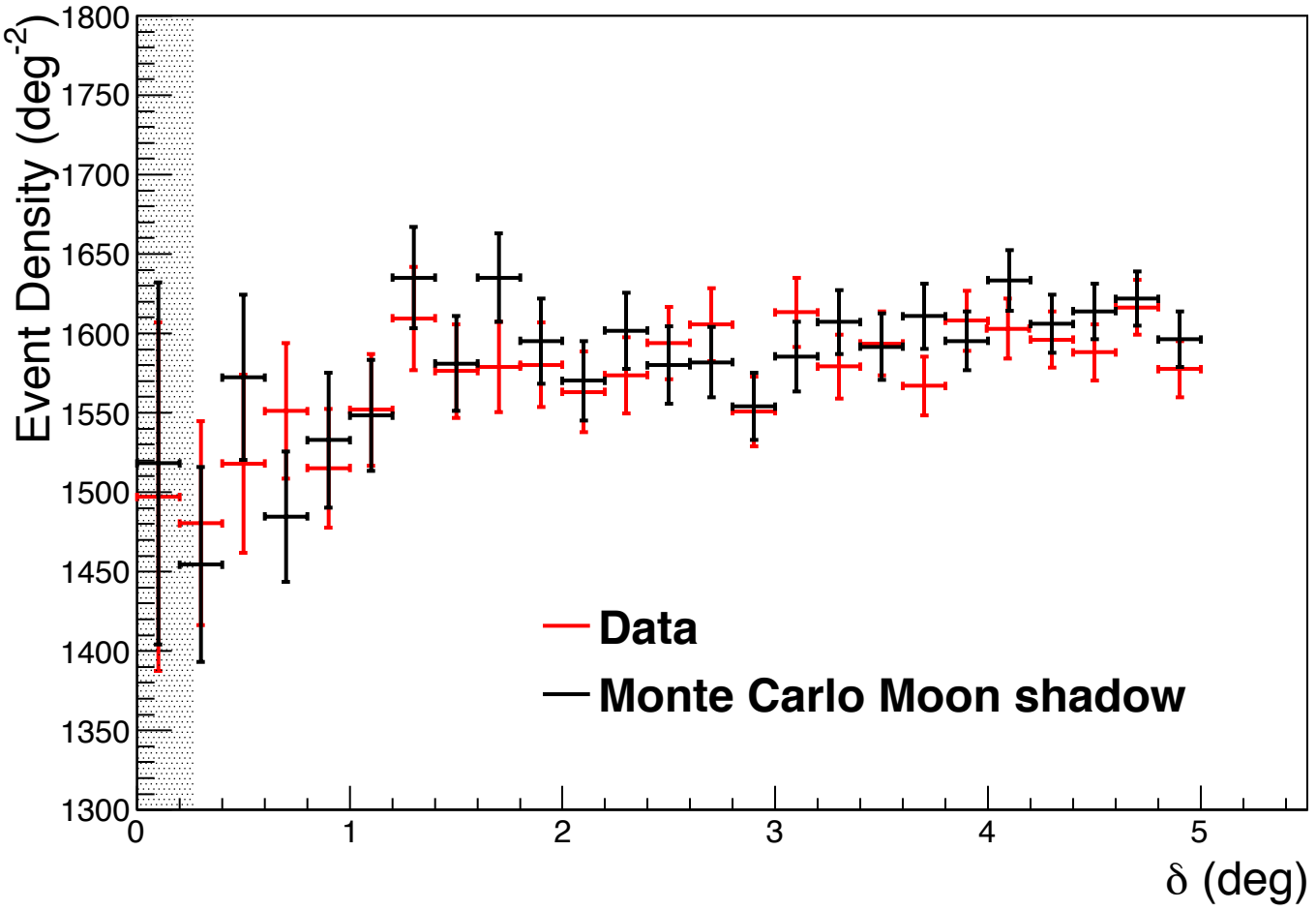
Selection optimization



Quality parameter of the reconstructed track (log-likelihood per degree of freedom)

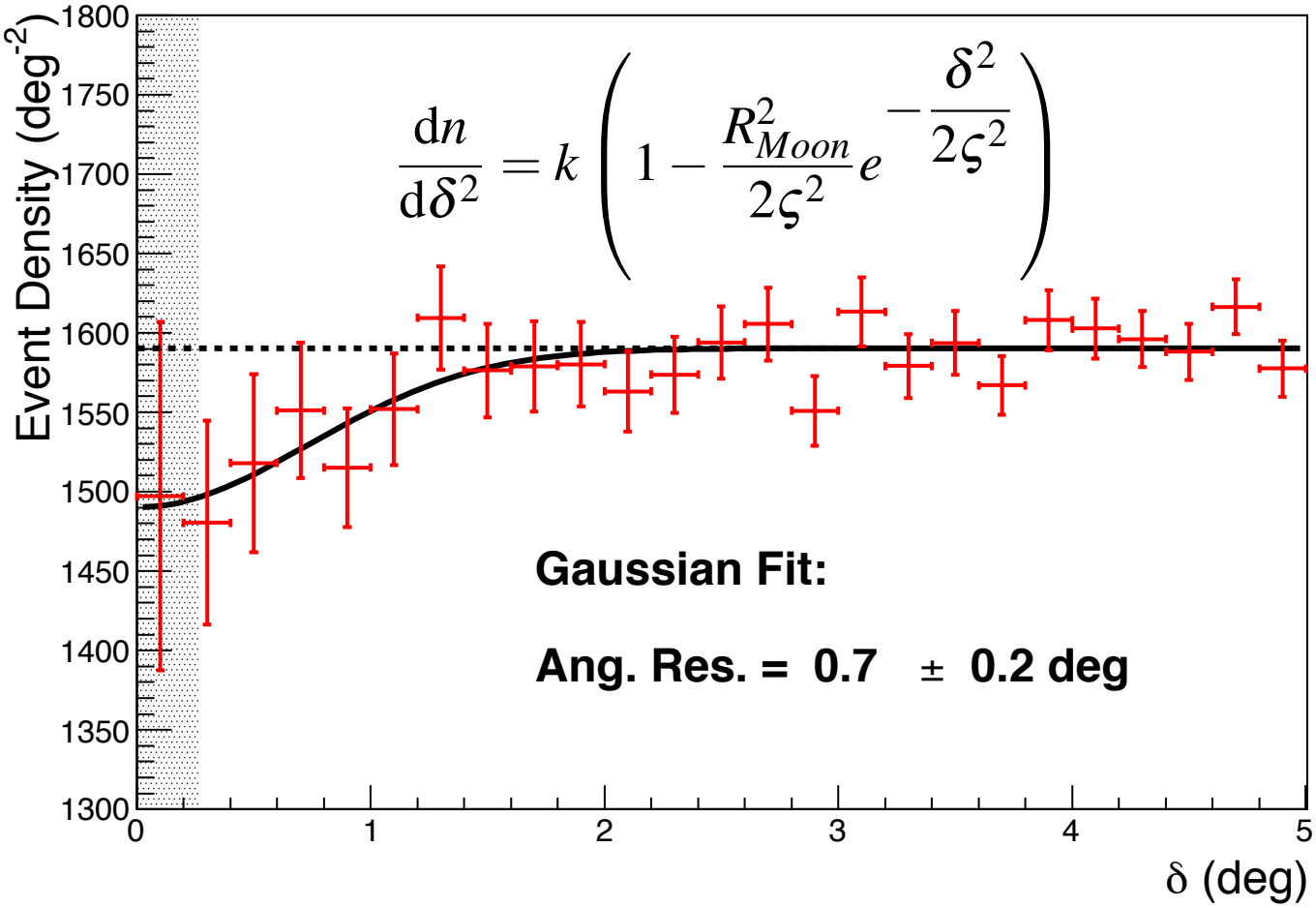
The expected significance with the best selection criteria is 2.9 σ

Results



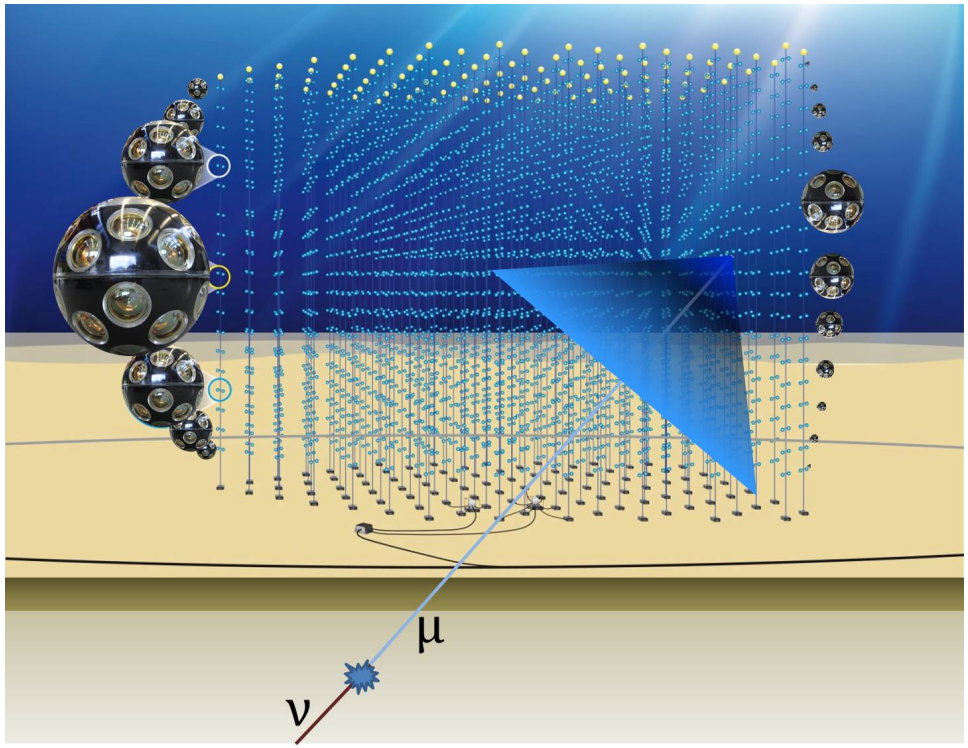
Data Moon shadow significance: 3.1 σ

Angular resolution



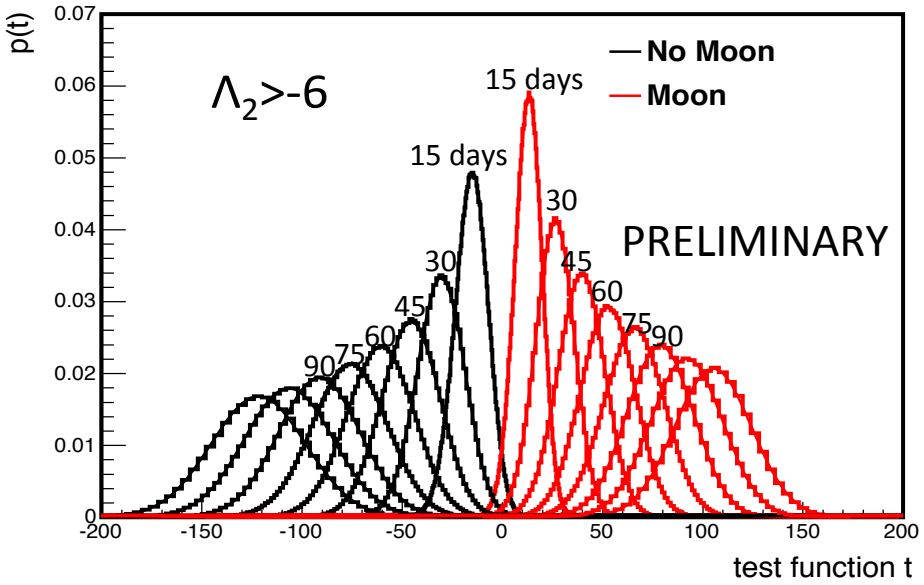
KM3Net Moon shadow

The same approach has been used to estimate the expected Moon shadow significance with the KM3Net detector.



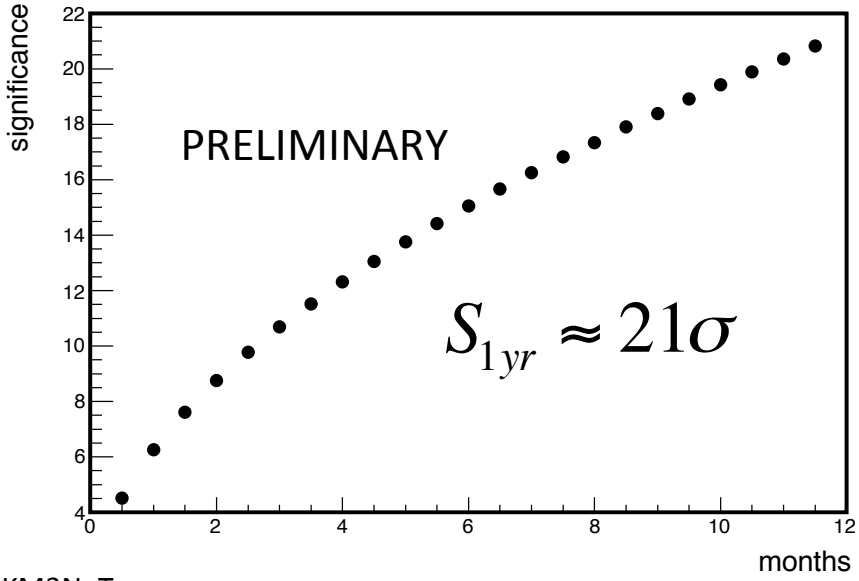
KM3NeT-ARCA
@ Capo Passero

KM3Net simulation

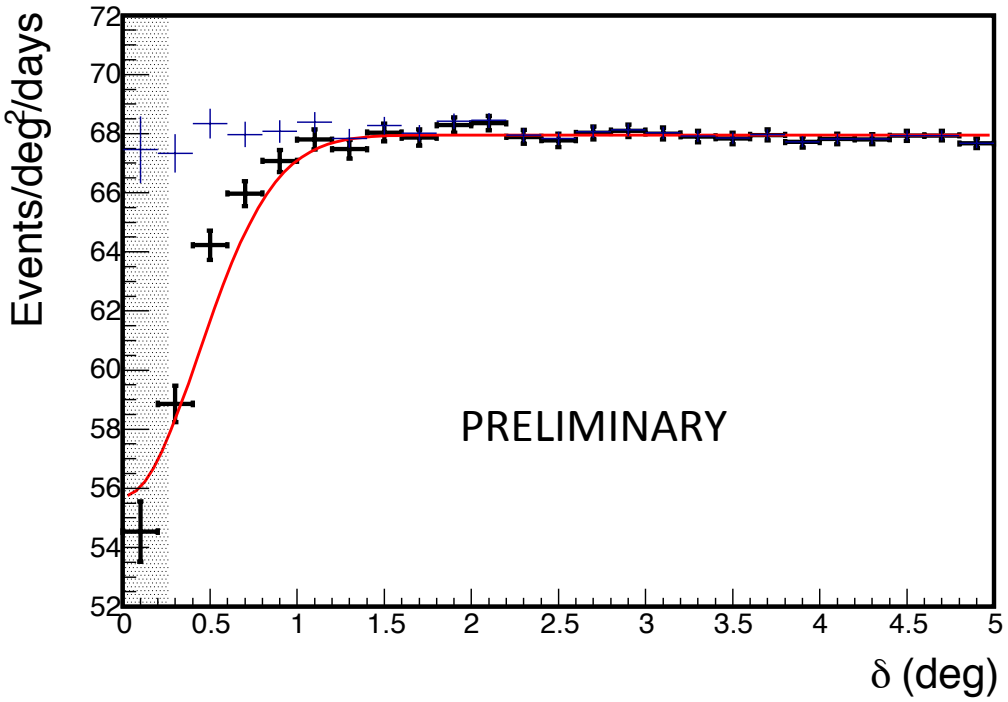


Test statistic function distribution as a function of the measure time

Moon shadow significance as a function of the measure time



KM3NeT ang. res.



Black: Moon shadow Monte Carlo

Blue: No Moon shadow Monte Carlo

Red: Fit

$$\frac{\mathrm{d}n}{\mathrm{d}\delta^2} = k\left(1 - \frac{R_{Moon}^2}{2\varsigma^2} e^{-\frac{\delta^2}{2\varsigma^2}}\right)$$

Angular resolution:

0.43° ± 0.01°

Conclusions

- The Moon shadow observation is a good way to estimate the pointing performance of neutrino telescopes
- It has been observed with a 3.1 σ in the ANTARES data sample 2007-2012
- No relevant pointing systematic have been observed, the angular resolution is 0.7°
- A 21 σ significance is expected with 1 year of KM3NeT data, the expected angular resolution is 0.43°