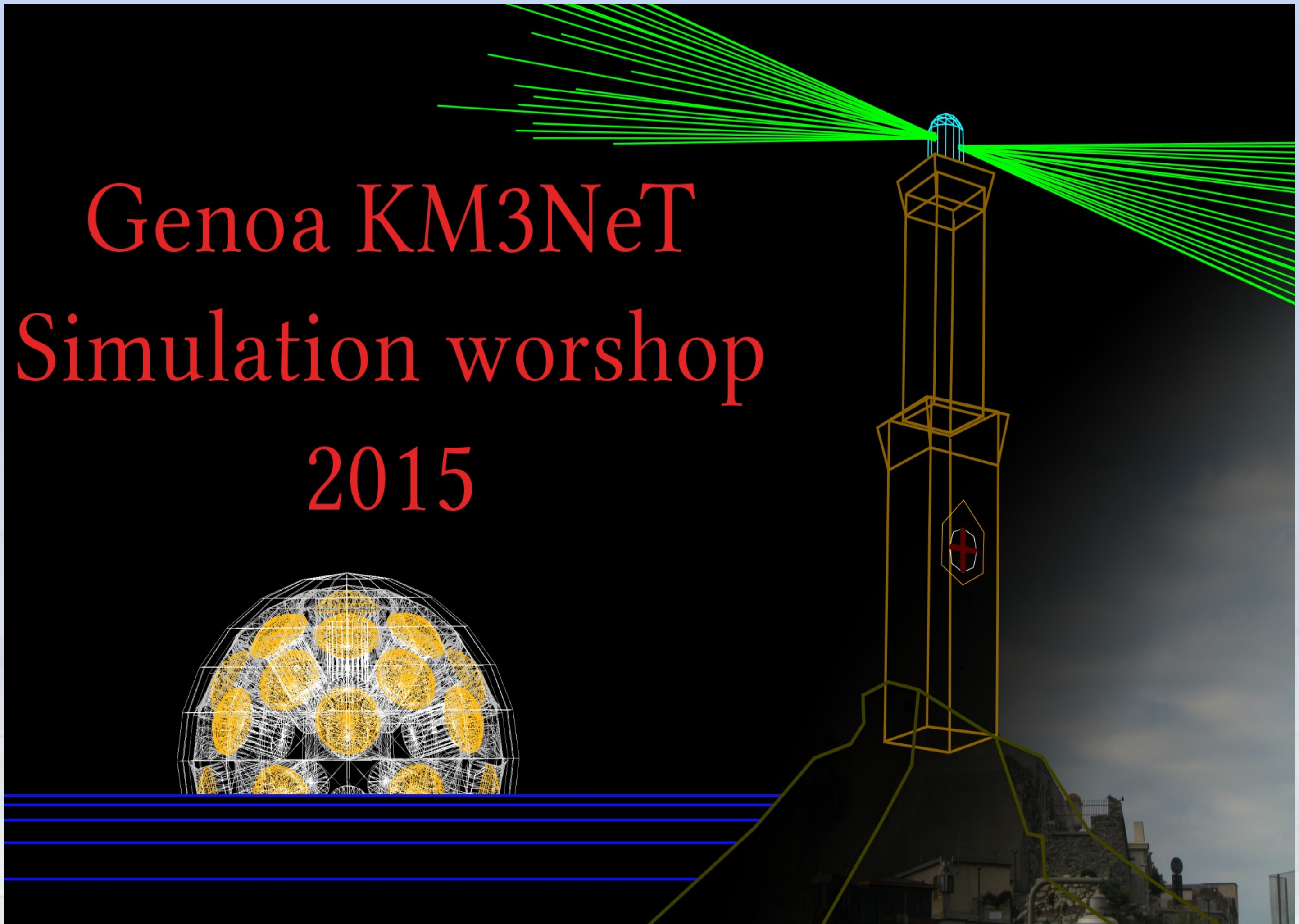
Physics, experiments and applications



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KM3NeT

Overview

- The primary application: km3 simulation
  - Presentation of km3
  - What KM3RTSim bring to it
- The ^{40}K
  - In situ reference
  - Water absorptions
- The water properties
  - Scatterings description
  - How to simulate it
- Under development applications
  - Wavelength shifter filter
  - Low energy electron in ORCA

Overview of the KM3 simulation

- Designed to simulate the light produced by the muons and secondary particles and its detection in function of the OM sensitivity
- Composed by 3 components
  - GEN: generate the photons field
  - HIT: Convert the photons fields to a detection probability
  - KM3MC: Define the detector geometry and the “global” detection probability along the muon propagation (using MUSIC)

The GEN concept

- GEANT3 Simulation of the Cerenkov photon generation from the charged particles in a given medium taking in account:
  - The scattering
  - The absorption
- It tabulate the result of the photon density and arrival time distribution in function of the distance and energy

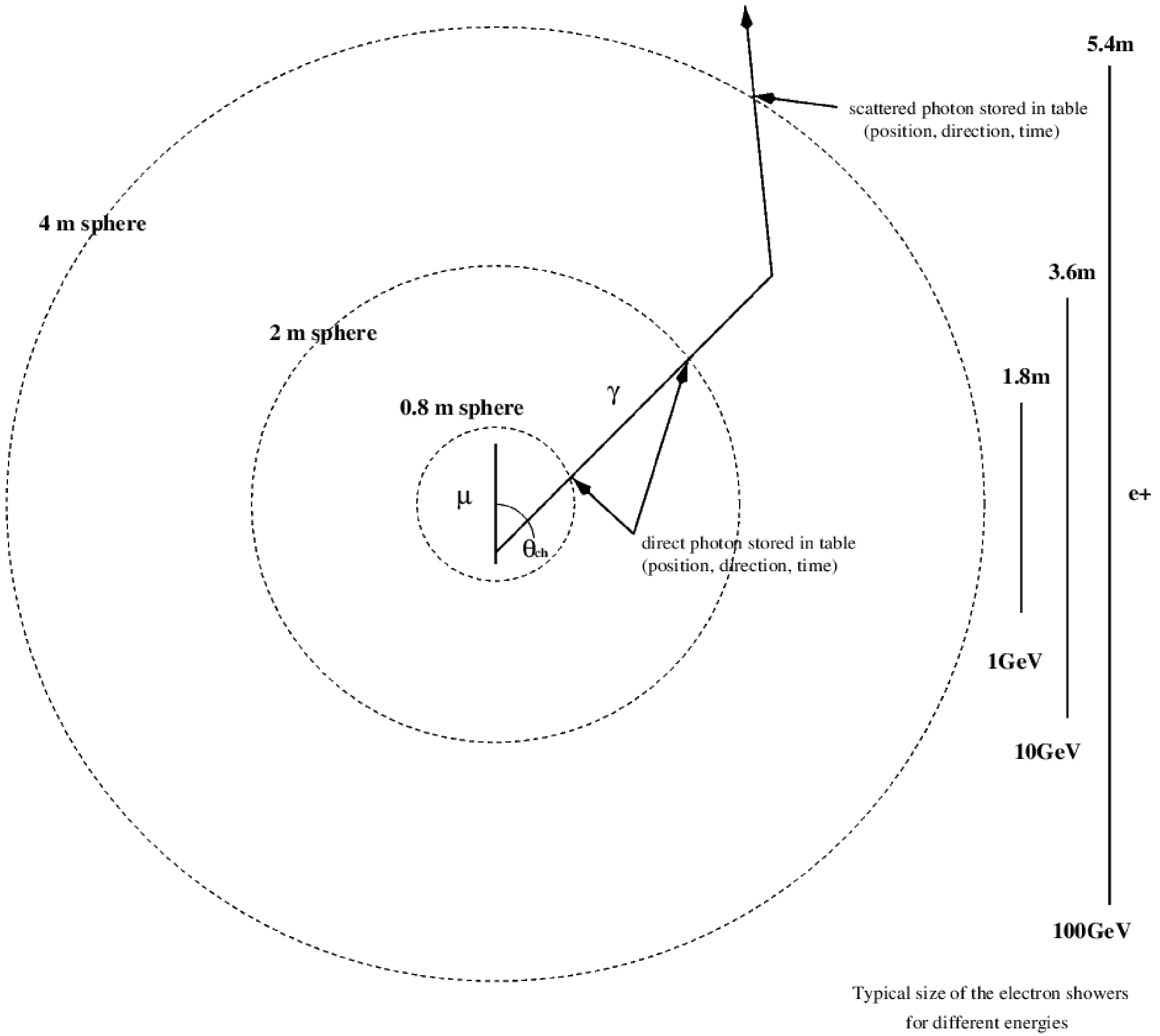


Figure 7: GEN program: Muons and electrons are propagated through the medium and Cherenkov photons stored in spheres at different distances.

The HIT concept

- Using the GEN results, for each case (energy, distance...), HIT keeps the relevant information and produces 4 tabulations:
  - The probability of a direct hit
  - The probability of a scattered hit
  - These both cases time distributions
- It uses the upstream calculation of the OM and PMT efficiencies

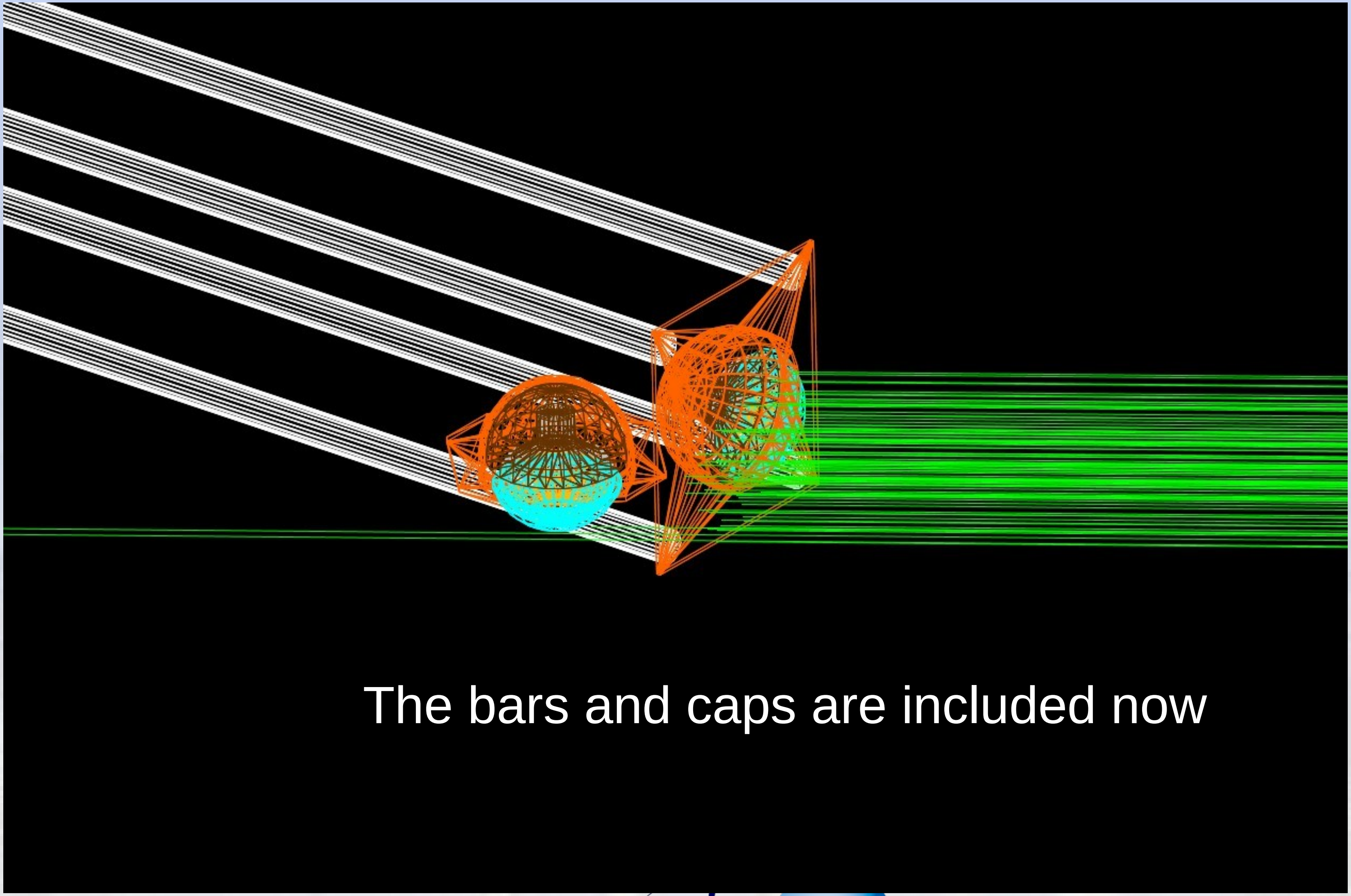
The KM3MC concept

- End-user interface
- Propagate the muons with the MUSIC package
- Define the OM position in function of the muon propagation from the geometry definition
- Use the GEN and HIT tables to generate the hits

Requirement

- A fine definition of the (D)OM efficiency in function of
  - The photon hit angle
  - The photon energy (new)
- Is done thanks to the KM3RTSim scan simulation that provide efficiency tables

AA illustration for NEMO



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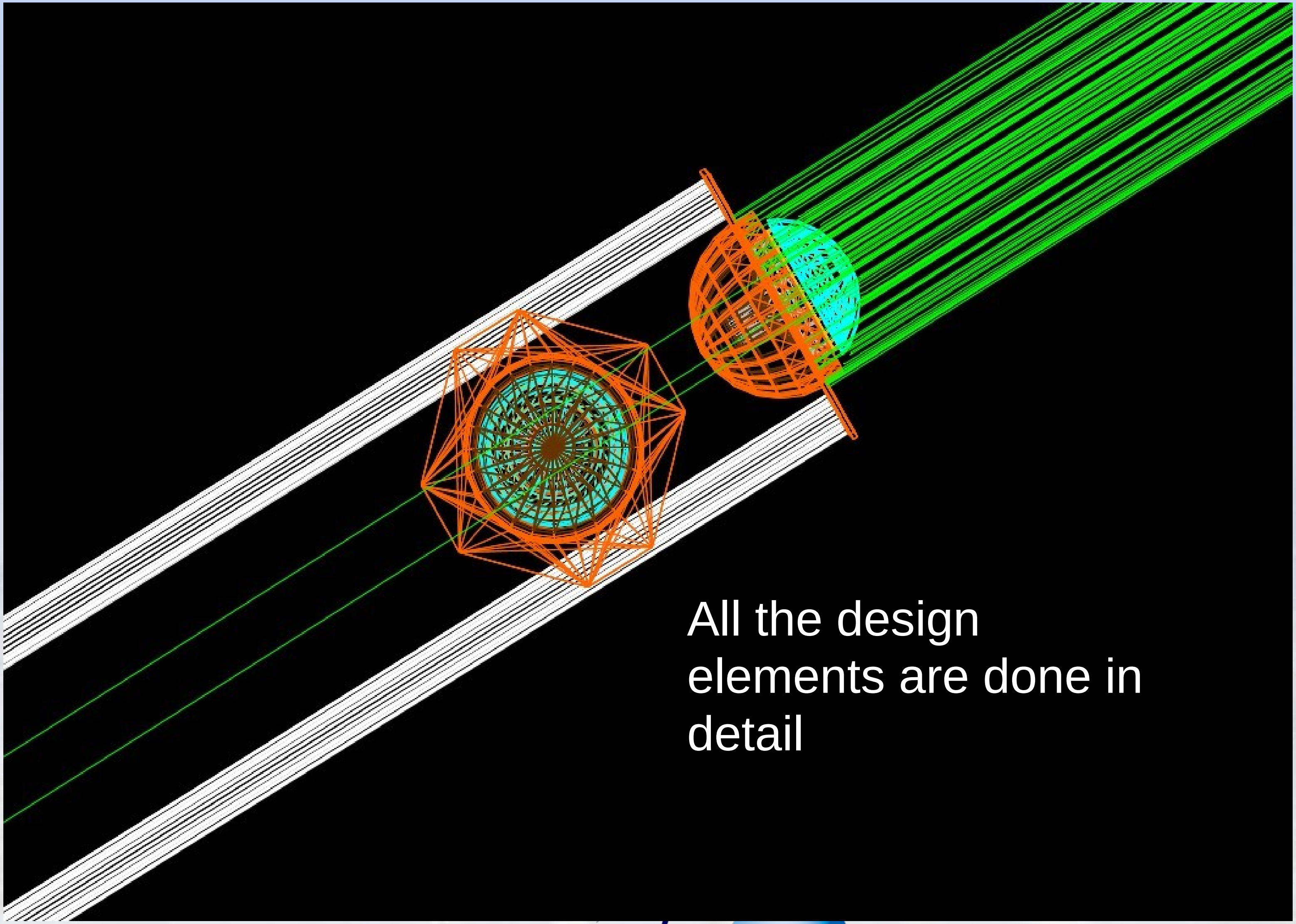
KM3NeT

AA illustration for NEMO



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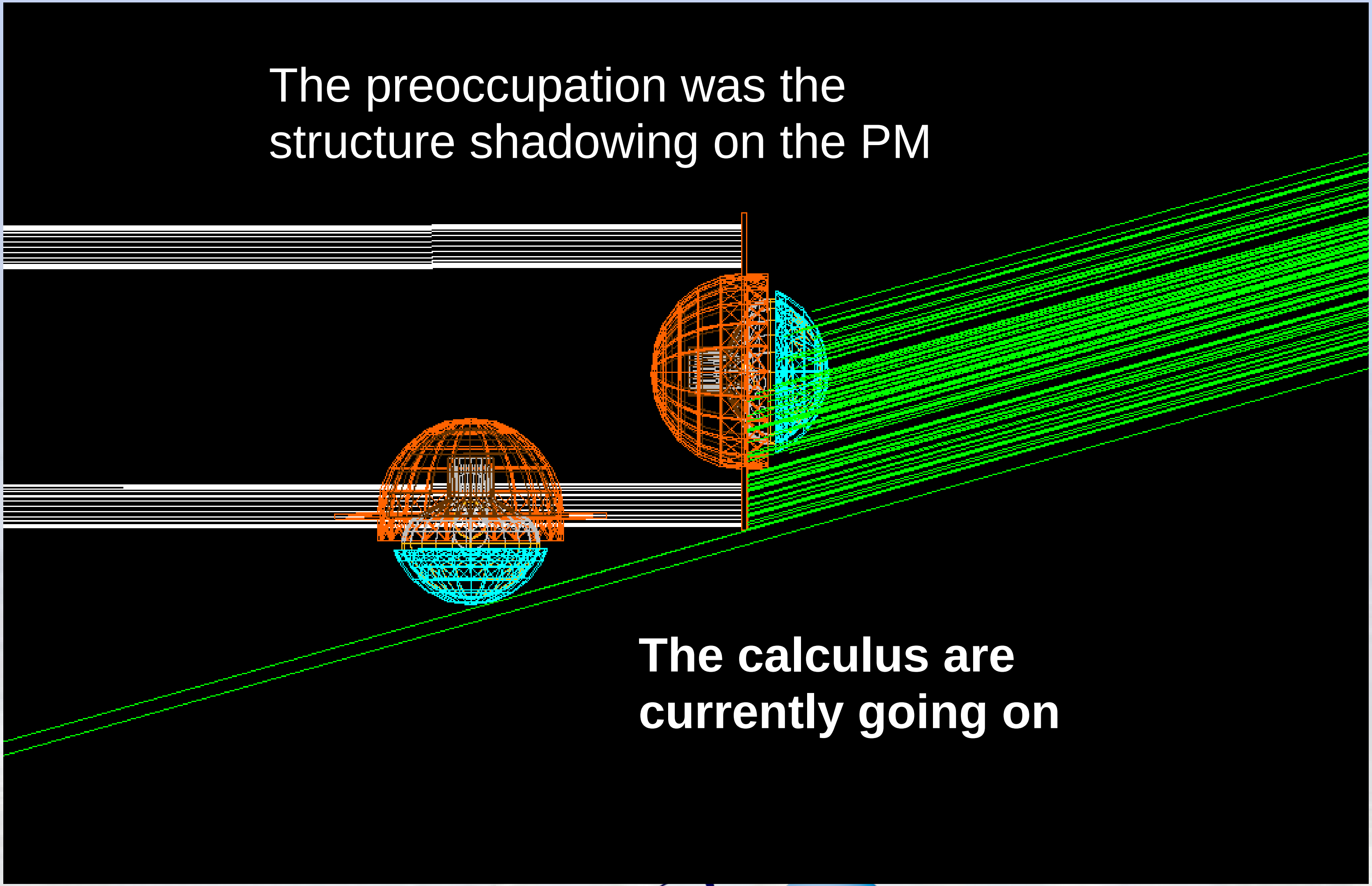
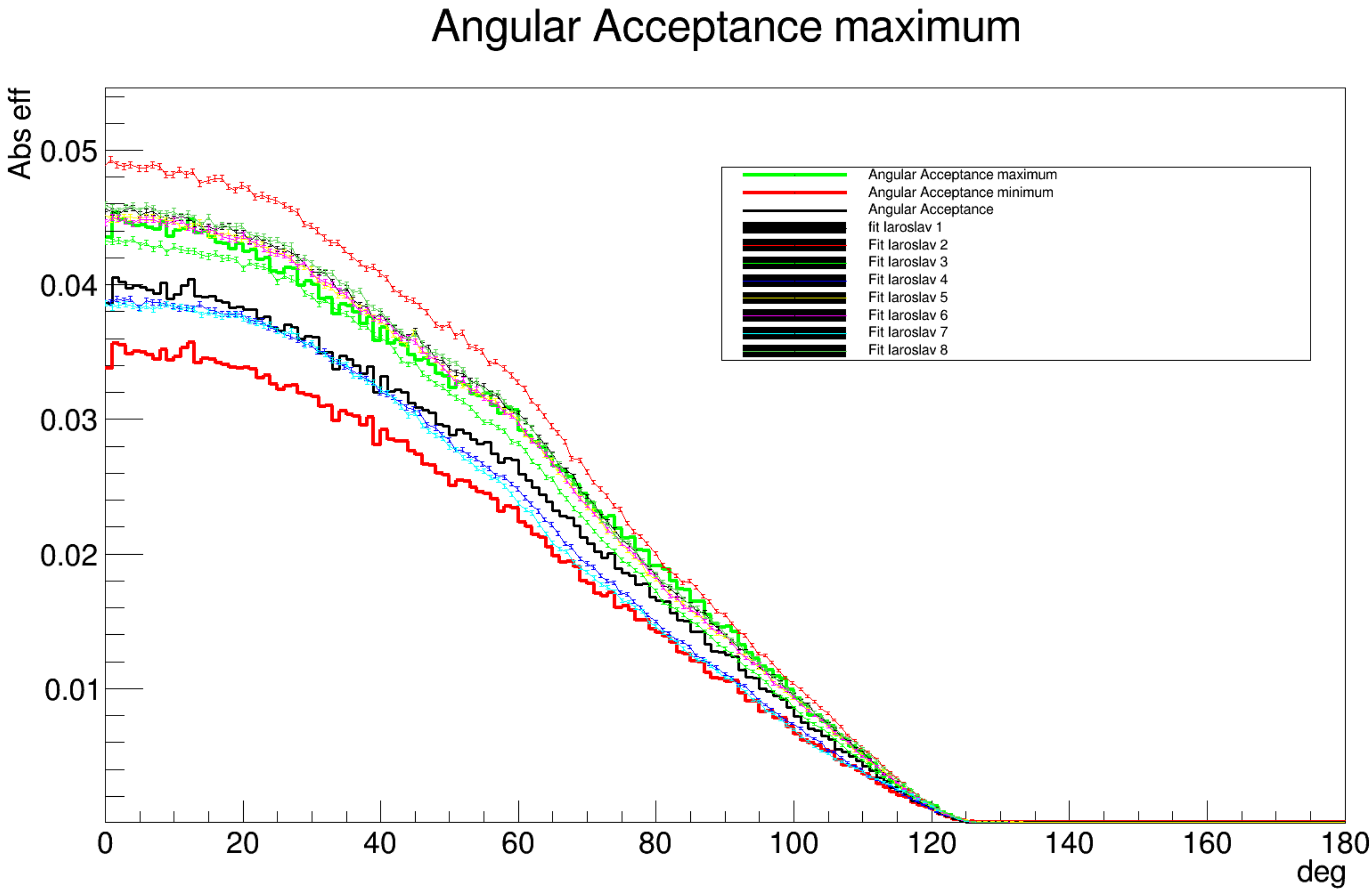
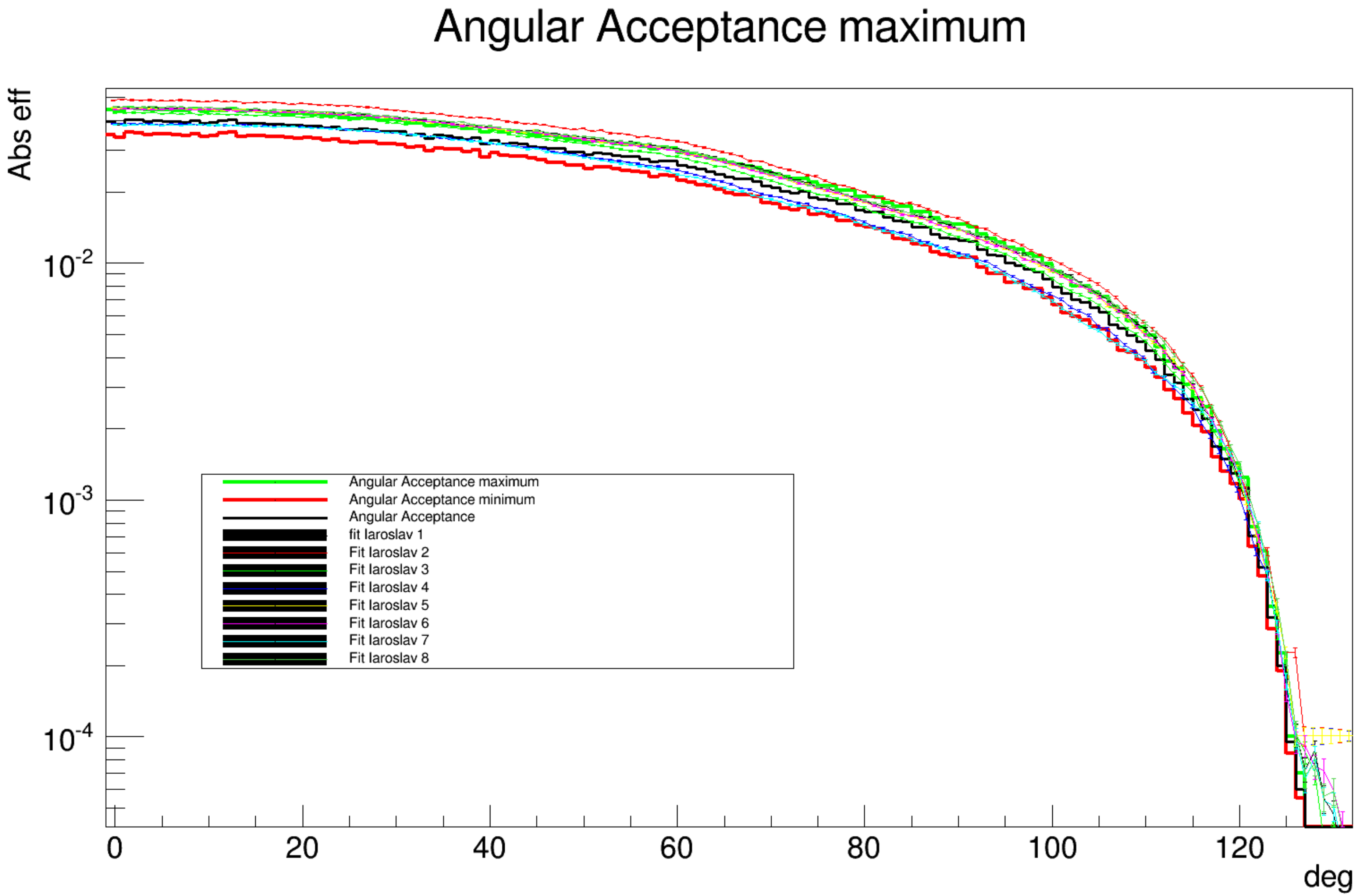


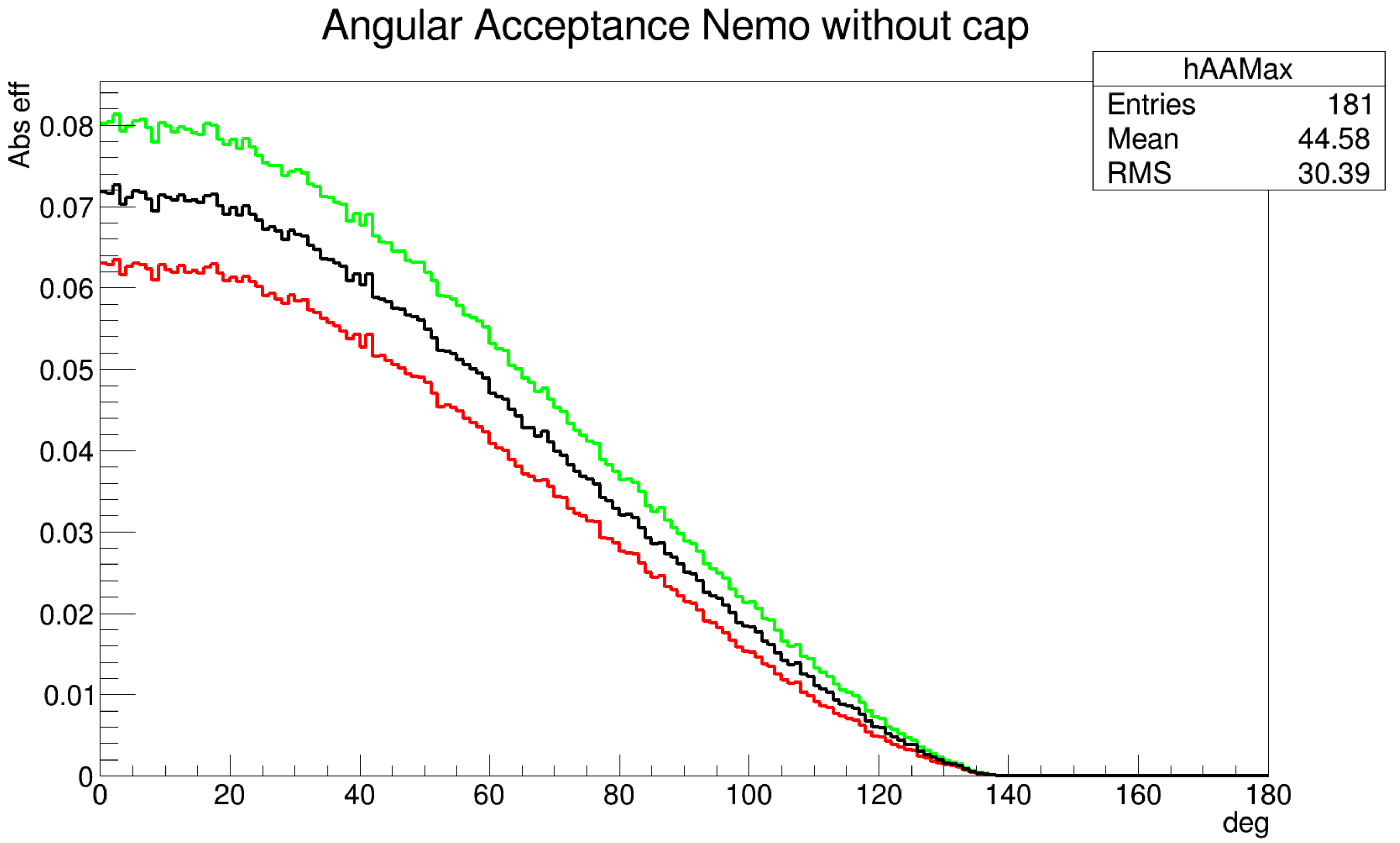
Angular acceptance antares



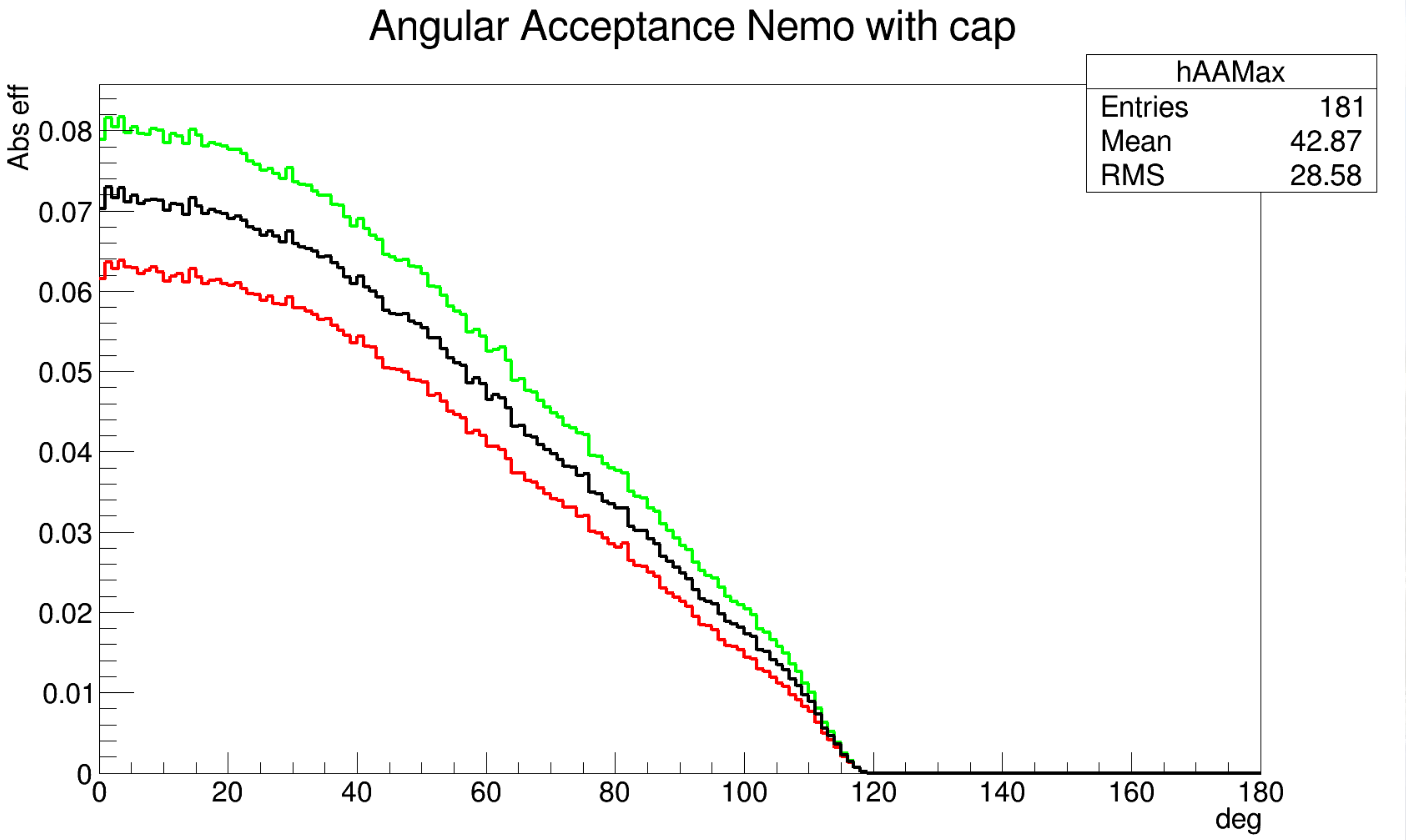
Angular acceptance antares



Angular acceptance nemo



Angular acceptance nemo



The ^{40}K rate calculation

- Permanently present in sea water, represents 1.11% of the salinity
  - Measured at the ANTARES site at 0.03845%
  - Measured at the Capo Passero site at 0.03875%

$$N = r_{K^{40}} \cdot r_K \cdot \rho \cdot \frac{\ln 2}{\tau} \cdot \frac{N_A}{A}$$

- ANTARES site at 13,750 Bq/m^3
- Capo Passero site at 13,860 Bq/m^3

What to extract from the ^{40}K?

- Check of the PM efficiency thanks to the coincidences
  - Independent to the water properties (too close)
  - Independent to the OM/PM noise (small window)
- Estimate the water absorption thanks to the single rate
  - The single rate is independent to the water scattering
  - The noises are well known and measured

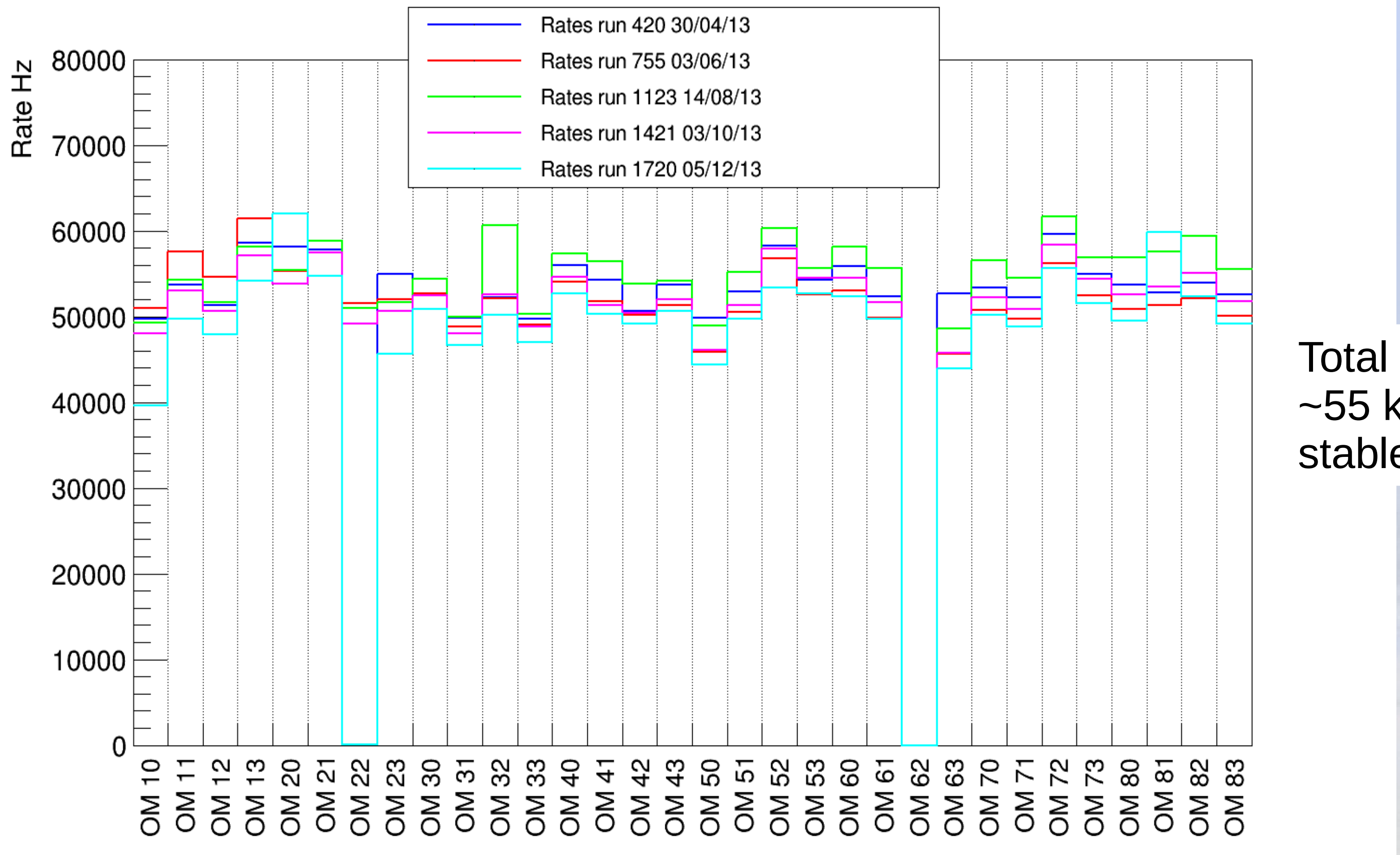
Few word about the analysis

- The used software is NReader
  - Presented in previous collaboration meetings
  - Code and full documentation available here:

    http://www.ge.infn.it/~chugon/NReader/documentation/html/
- Only events from the random trigger are kept
- The data are from April to December 2013
- An other analysis is available and cross check this one:

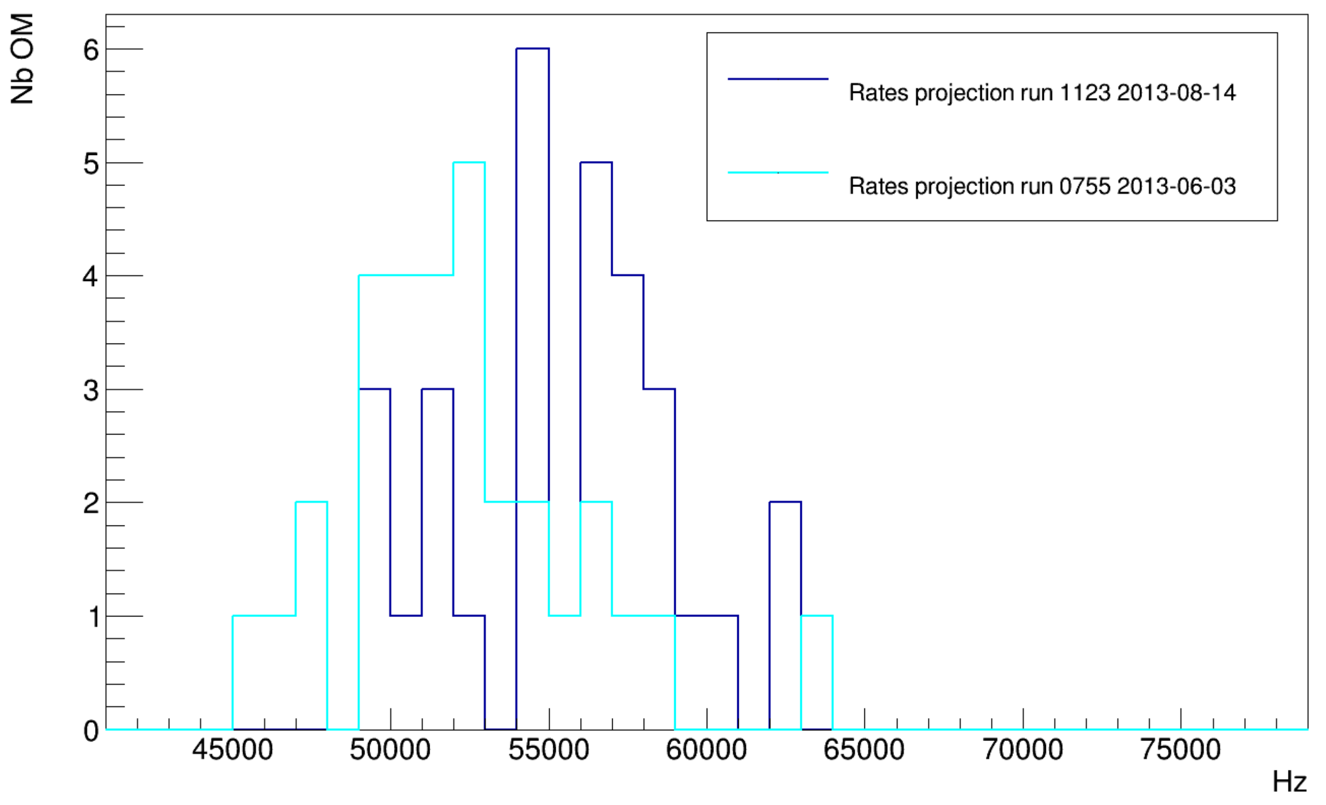
  http://wiki.infn.it/_media/cn/csn2/km3/k40.pdf

Total rate



Total rate at ~55 kHz. Quite stable in time.

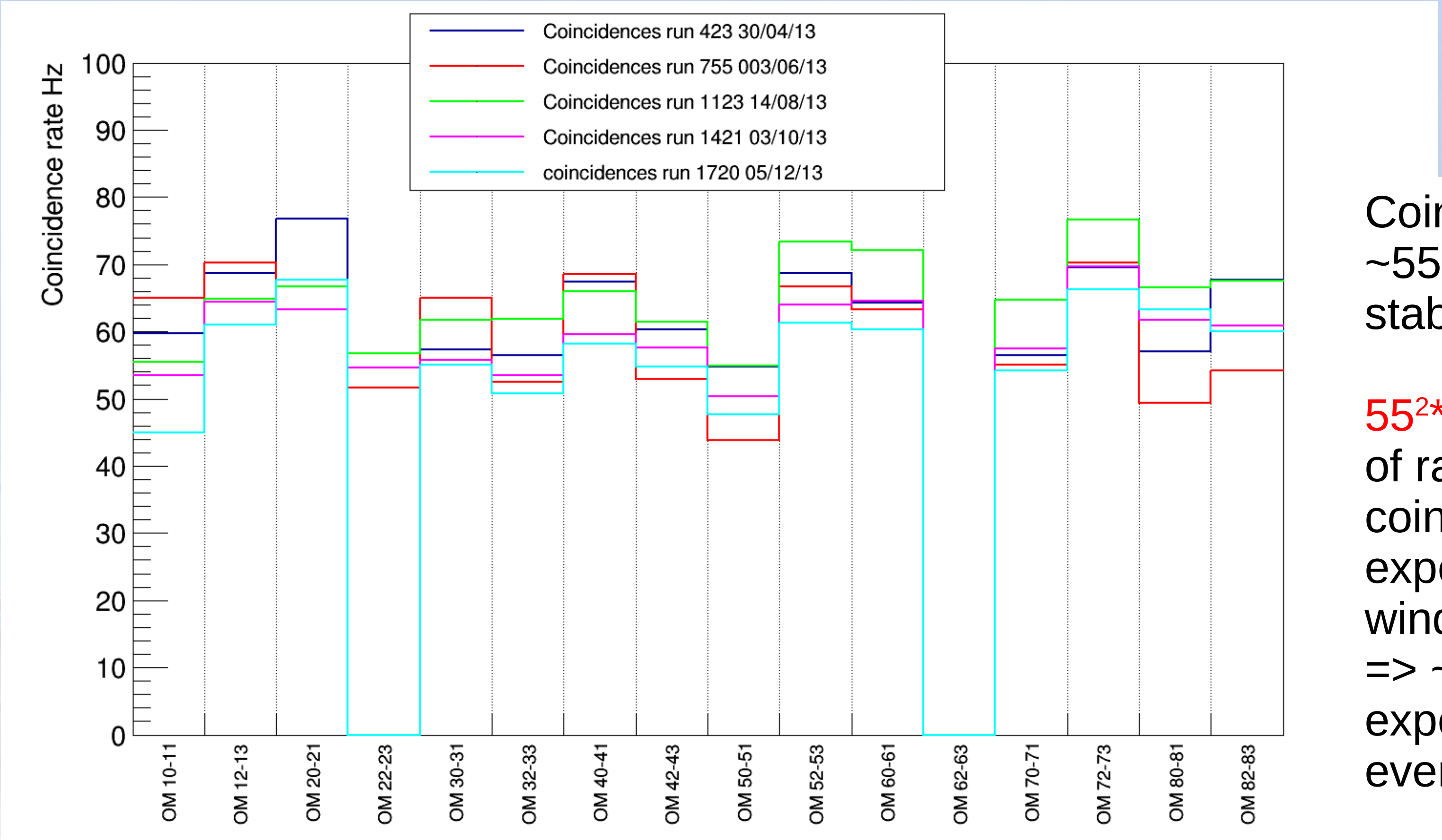
Total rate



Example of projection for two runs

Total rate at ~55 kHz. Quite stable in time.

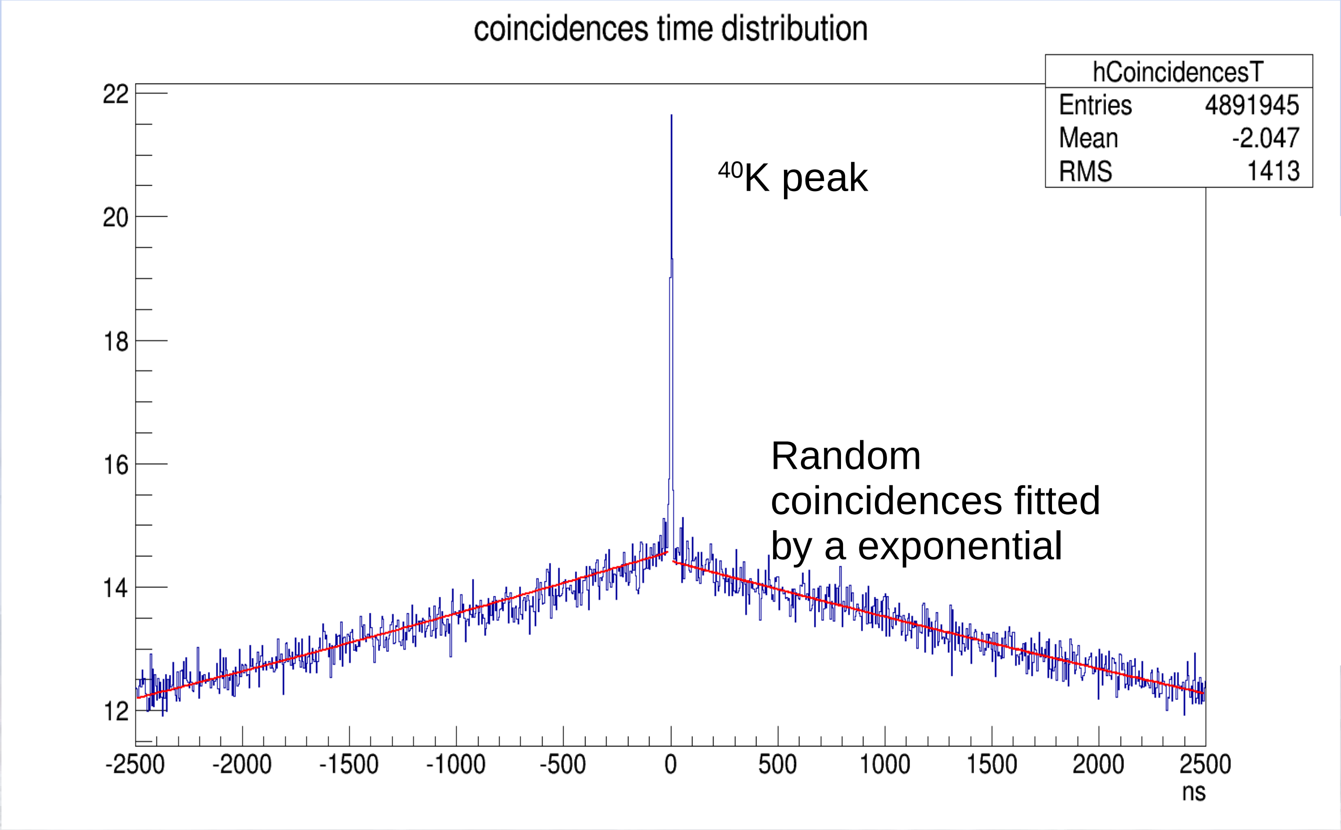
Coincidence rate raw estimation



Coincidence rate at ~55 Hz. Quite stable in time.

$55^2 * 10\text{ns} = 30$ Hz of random coincidence expected in a 10 ns window
=> ~25 Hz of expected ^{40}K events

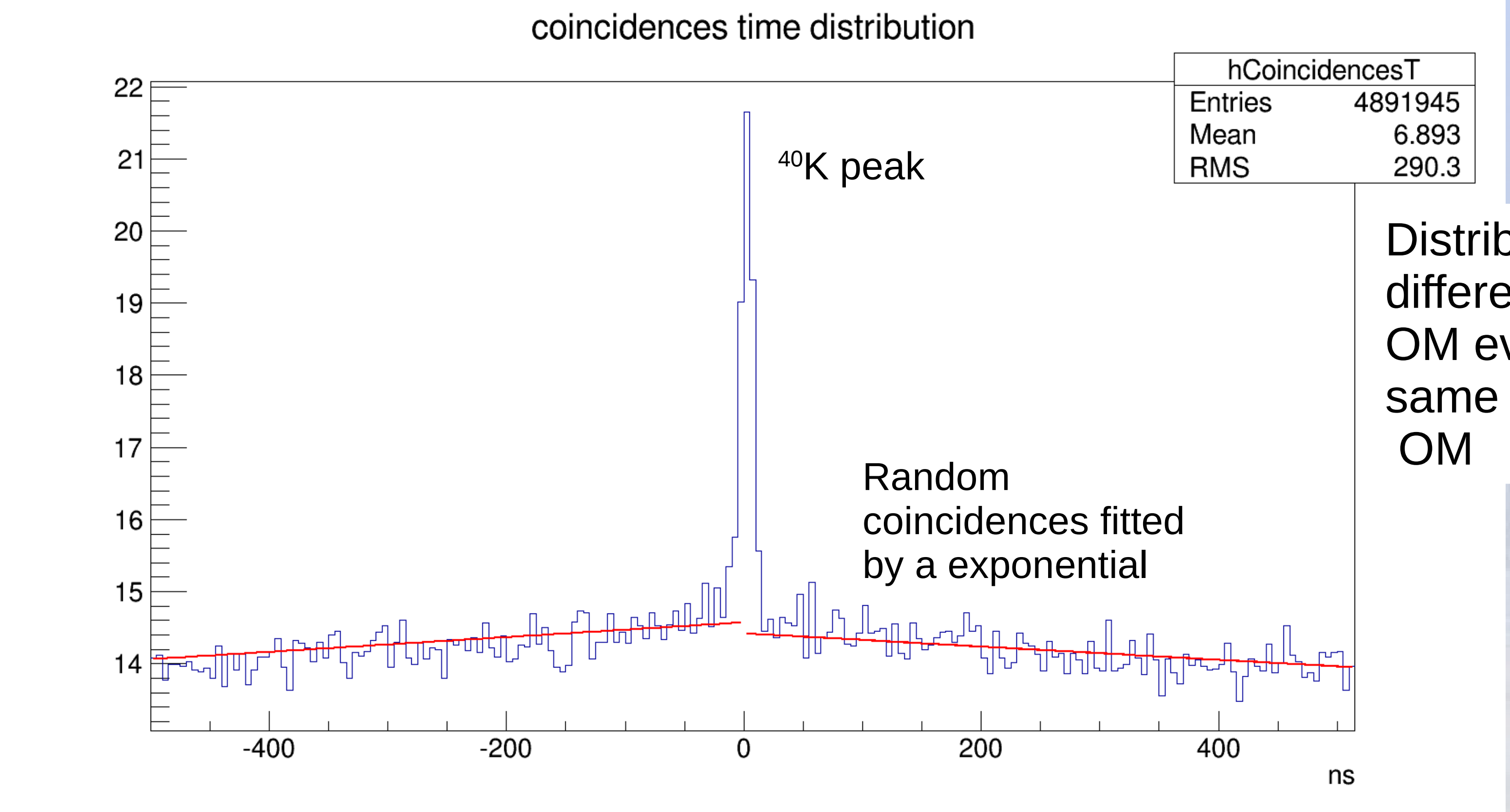
Precise ^{40}K estimation from fit



Run 1023 is taken for the illustration.

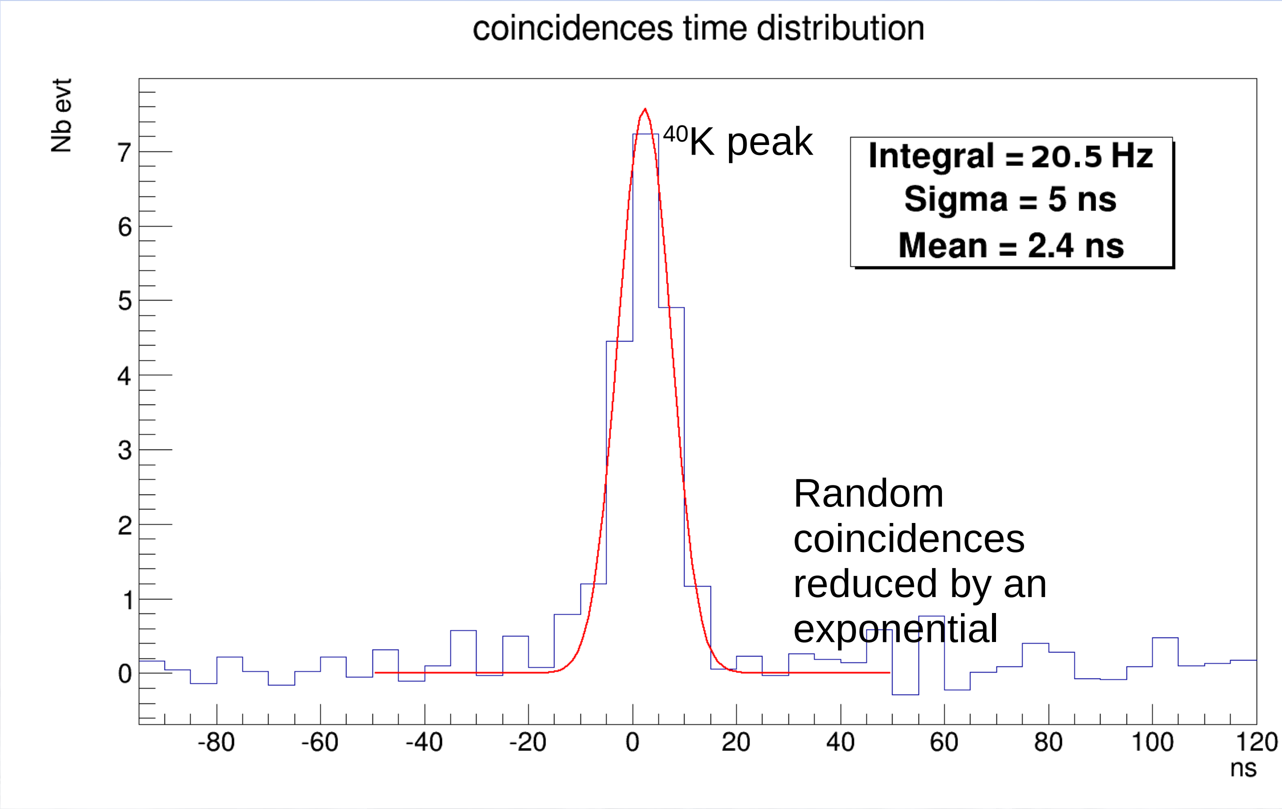
Distribution of difference of times of OM event between same floor same side OM

^{40}K estimation from fit



Distribution of difference of times of OM event between same floor same side OM

^{40}K estimation from fit

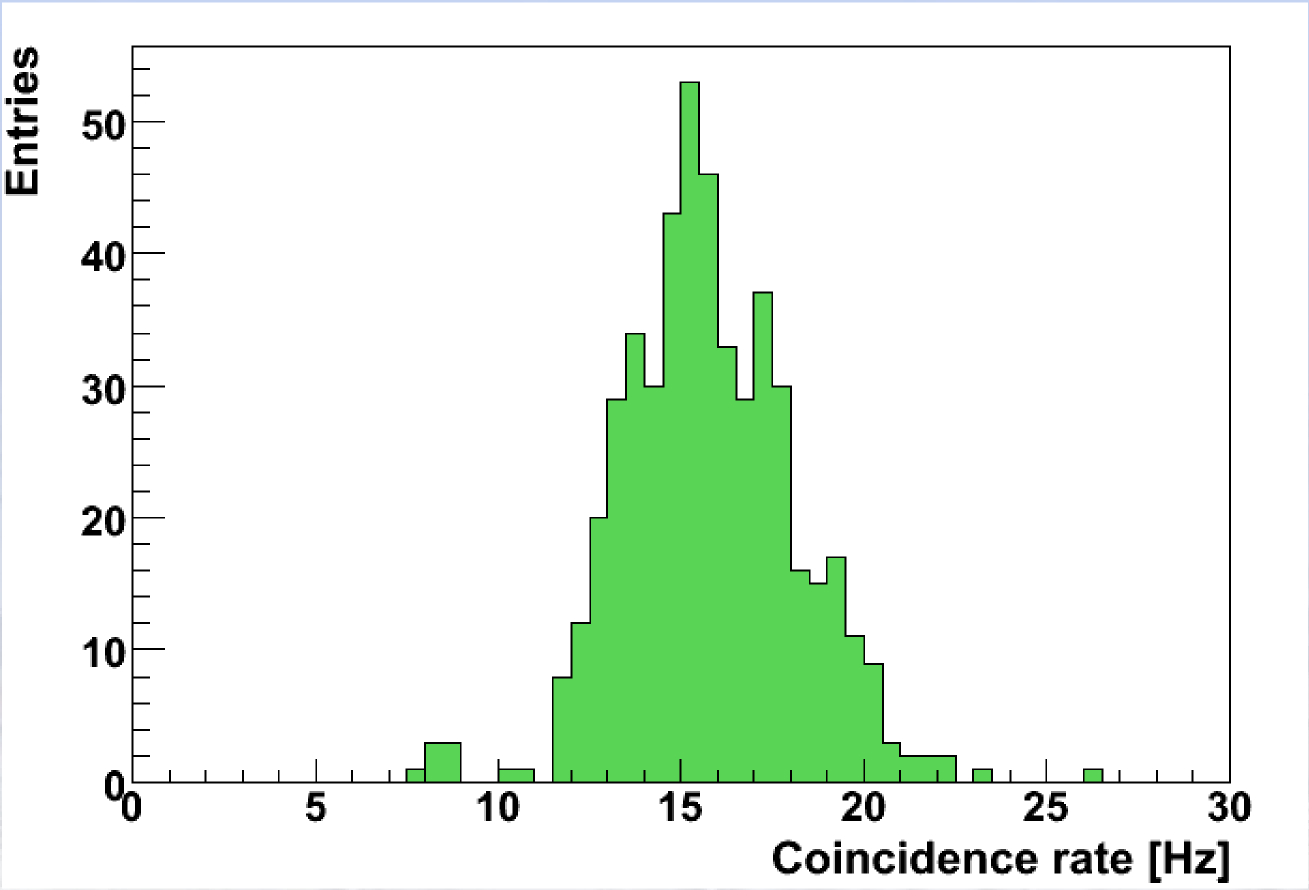


Enough significant bins to be meaningful (should be at least >3 for a Gaussian fit)

Distribution of difference of times of OM event between same floor same side OM

20.5 Hz of ^{40}K coincidences

Coincidence rate in ANTARES



Analysis of D. Zaborov:
Full ANTARES detector coincidence rate in 2008 (in CDS)

Other years analysis from “**40K data for ANTARES 2010 2011 & 2012 from R. Richter, Update on 40K calibration, Collaboration meeting 2012 at CERN”**

The ^{40}K measurement with NEMO

- The ^{40}K rates are a reference
- They are known for NEMO ANTARES and KM3NeT (DOMs)

The simulation should fit these constraints

Simulation and data confrontation

Detector	set	2009	2010	2011	2012
ANTARES	coincidence rate	15.8 Hz	15.5 Hz	14.82 Hz	X
	simulation	43 ± 3 kHz	42 ± 3 kHz	41 ± 3 kHz	X
	data	51 kHz	49 kHz	46 kHz	47 kHz
	diff	8 kHz (2.7 σ)	7 kHz (2.3 σ)	5 kHz (1.7 σ)	X
KM3NeT-it	coincidence rate	X	21.6 Hz		X
	simulation	X	54 ± 3 kHz		X
	data	X	52 kHz		X
	diff	X	-2 kHz (0.7 σ)		X

The ^{40}K coincidence rate is used to calibrate the simulation,
We observe a regular decrease of the efficiency.
We consider 3 kHz of noise for ANTARES and 3.6 kHz for NEMO (glass ^{40}K and dark current)

The ANTARES rate is in agreement with the numerical calculus (J. Brunner)
An underestimation of the ANTARES rates is observed.
A very good agreement is found for NEMO

The water properties

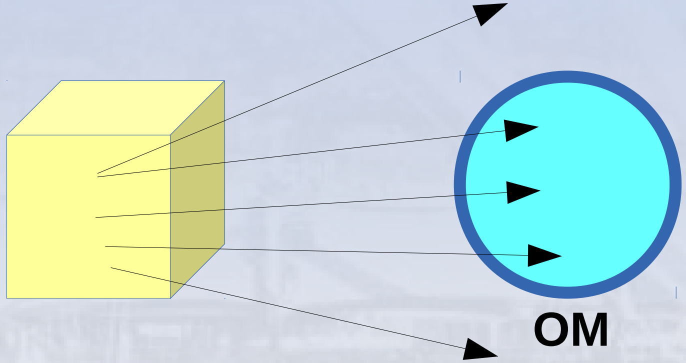
- Why the absorption is independent on the scattering?
- Description of the scattering mecanism

Why the single rate is independent on the scattering?

The attenuation length is expressed by:

$$\lambda_{att} = 1/\lambda_S \cdot 1/\lambda_{abso}$$

Contribution of an unit volume:



$$R \propto \int d\lambda \cdot \lambda_{att} \Phi D_{eff}$$

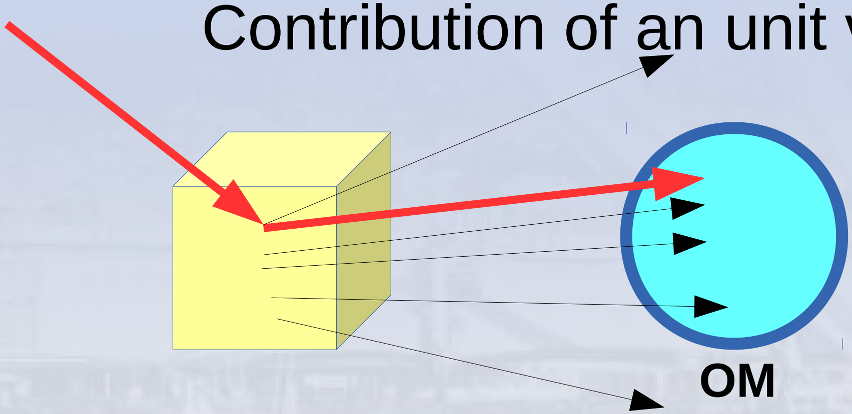
With λ the wavelength, Φ the unit volume flux and D_{eff} the detection probability of the flux

Why the single rate is independent on the scattering?

One can demonstrate that the scattered contribution is:

$$\Phi' = \Phi \cdot \frac{\lambda_S + \lambda_{abso}}{\lambda S}$$

Contribution of an unit volume:



$$R_{tot} \propto \int d\lambda \cdot \lambda_{att} \Phi' D_{eff} = \int d\lambda \cdot \lambda_{abso} \Phi D_{eff}$$

With λ the wavelength, Φ the unit volume flux and D_{eff} the detection probability of the flux

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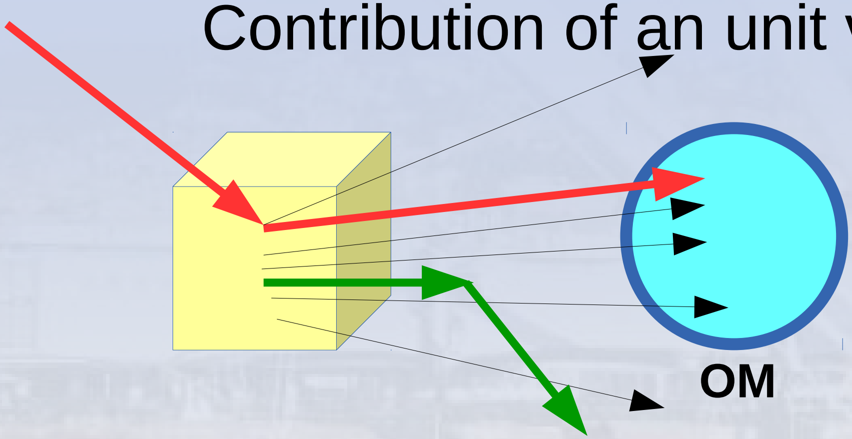

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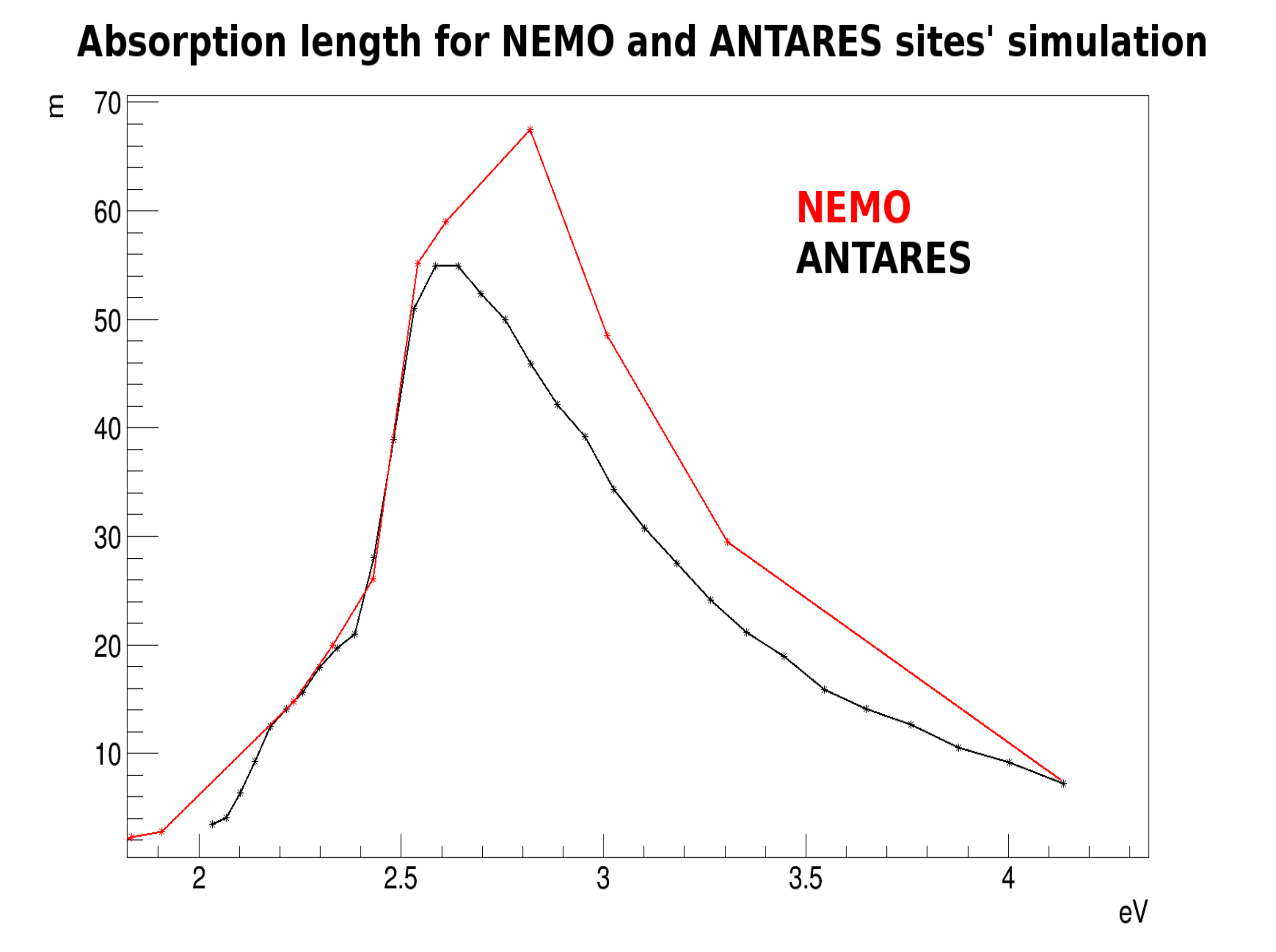
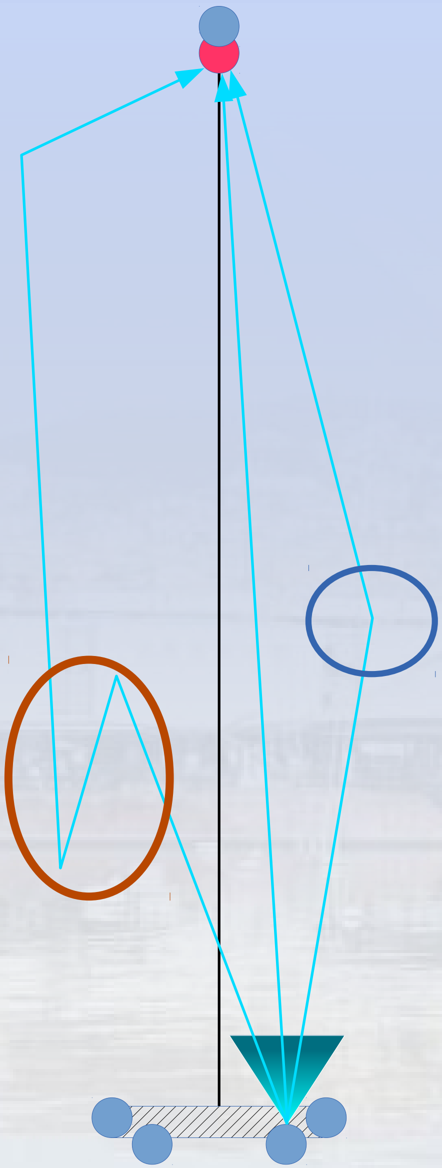
Measured absorption



The ANTARES absorption length is extrapolated from the Baker and Smith's value to fit to the on site measurements.

Scattering process



$$b_P = 1.34\,\nu_S \left(\frac{550\,nn}{\lambda}\right)^{1.7} + 0.312\,\nu_l \left(\frac{550\,nm}{\lambda}\right)^{0.3}$$

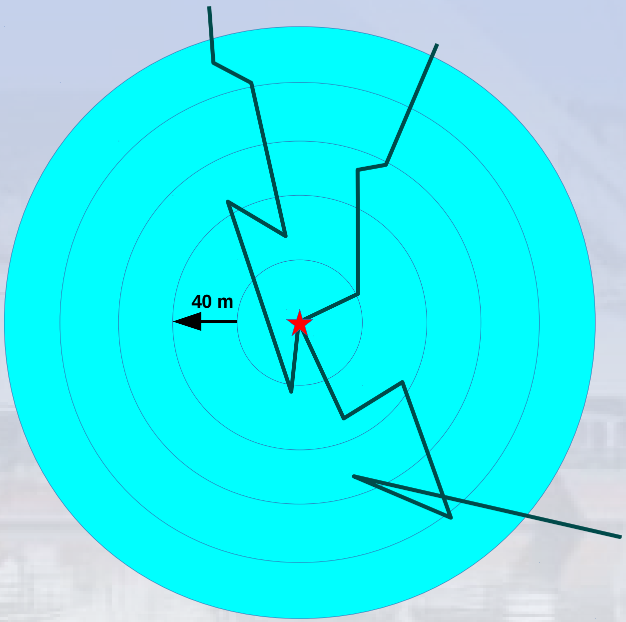
Clancy W. James
Km3 internal note

- 2 components to the scattering :
  - On molecule (isotropic angular distribution)
  - On particles (Forward going angular distribution)
- The both processes depend on the wavelength on a different exponent.
- They imply a delay in time arriving
  - In function of distance
  - In function of wavelength

Need to know the timing to deduce the water properties.
The fit method can help to extract the timing delay to the ns.

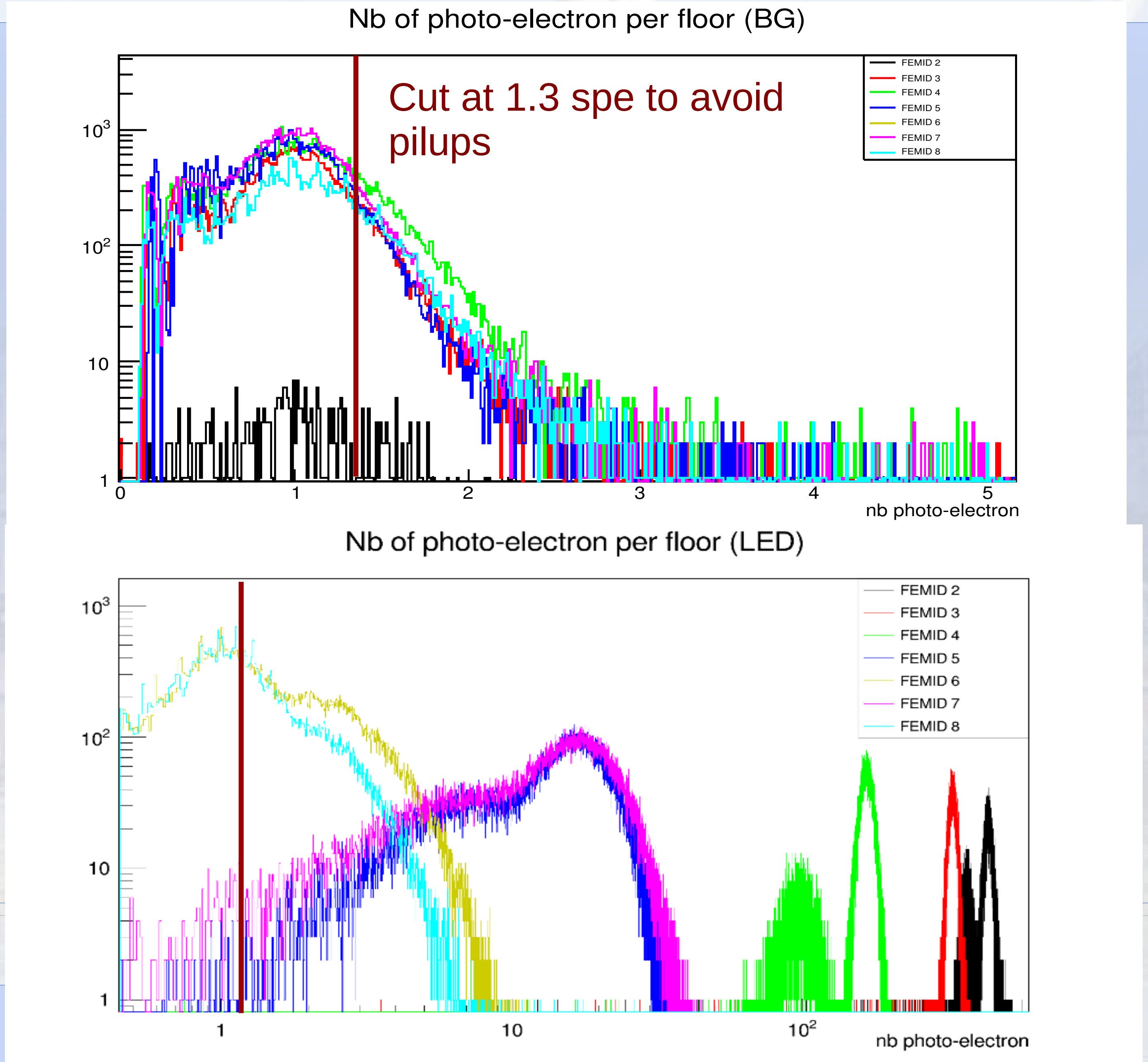
How to simulate it with KM3RTSim

Principle illustration

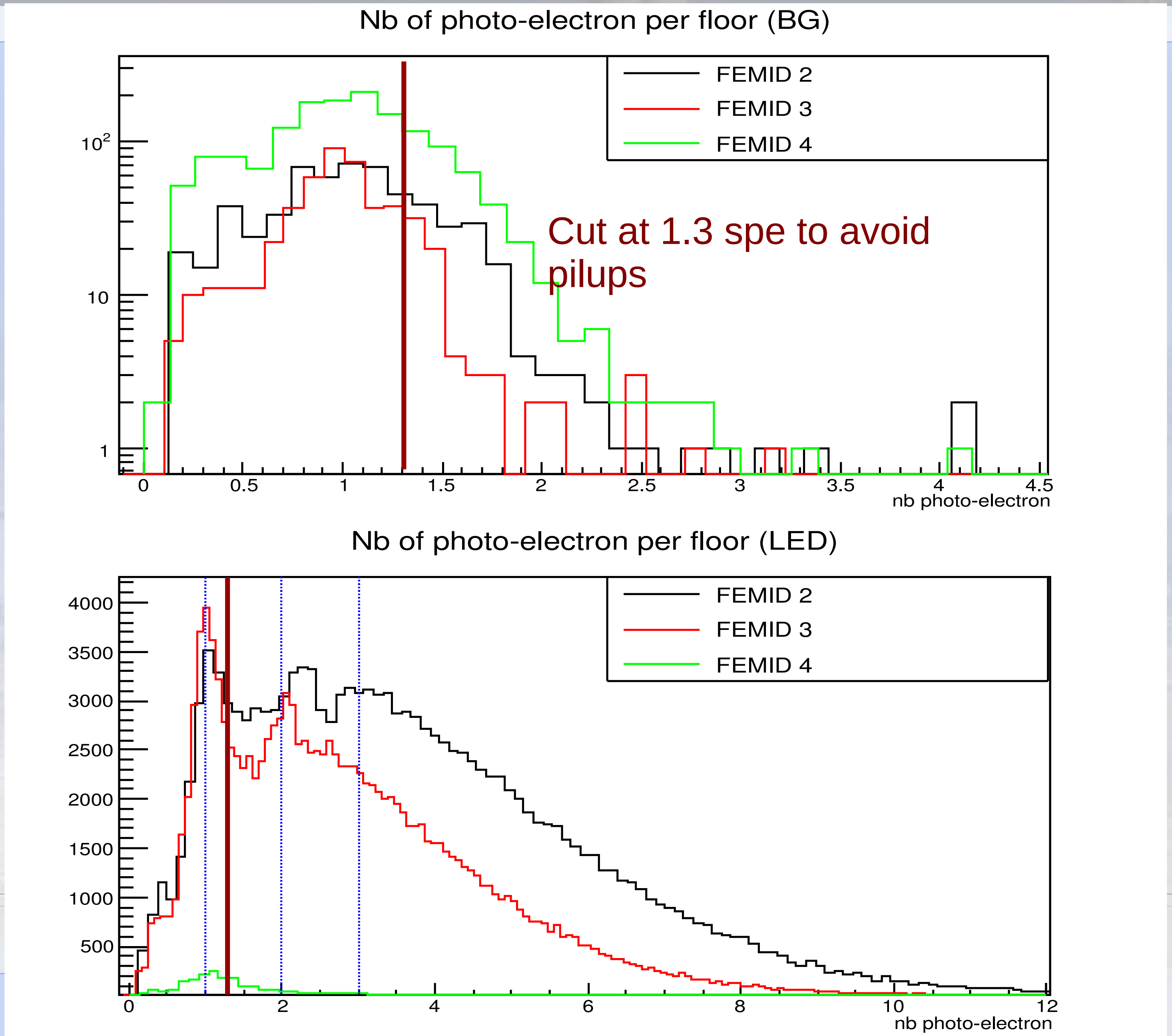


- Concentric detection sphere
  - Separated by the real floor to floor distance
- The source is in the center
- Send photons
- All the photons are kept at each level. Data kept
  - Emission direction (in fact always (0,0,1)
  - Time arrival at each sphere
  - Angle arrival
  - Incident angle
- Then the AA and LED emission are used to put a weigh to the arrival

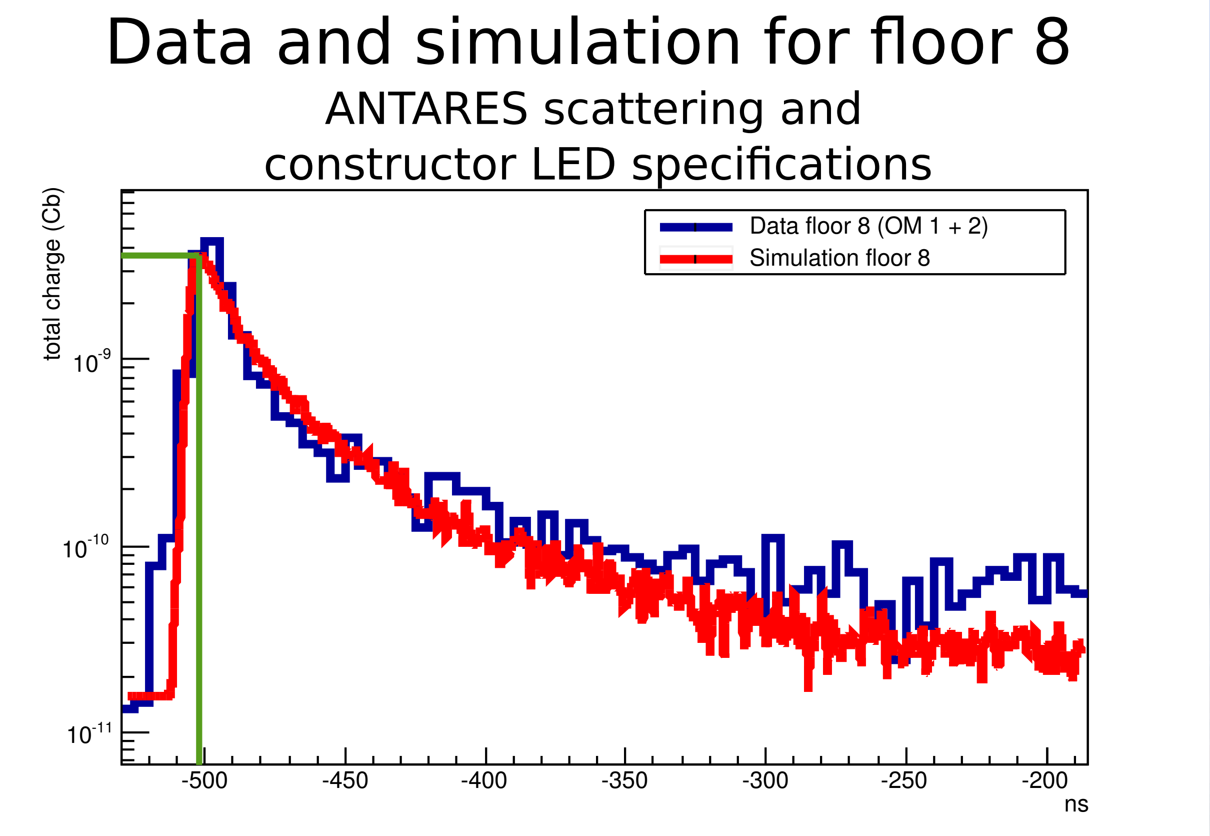
SPE measurement High LED intensity



SPE measurement low LED intensity



Raw result illustration on the floor 8



Timing and amplitude are used for the simulation adjustment on the data (green, chi2 minimization)

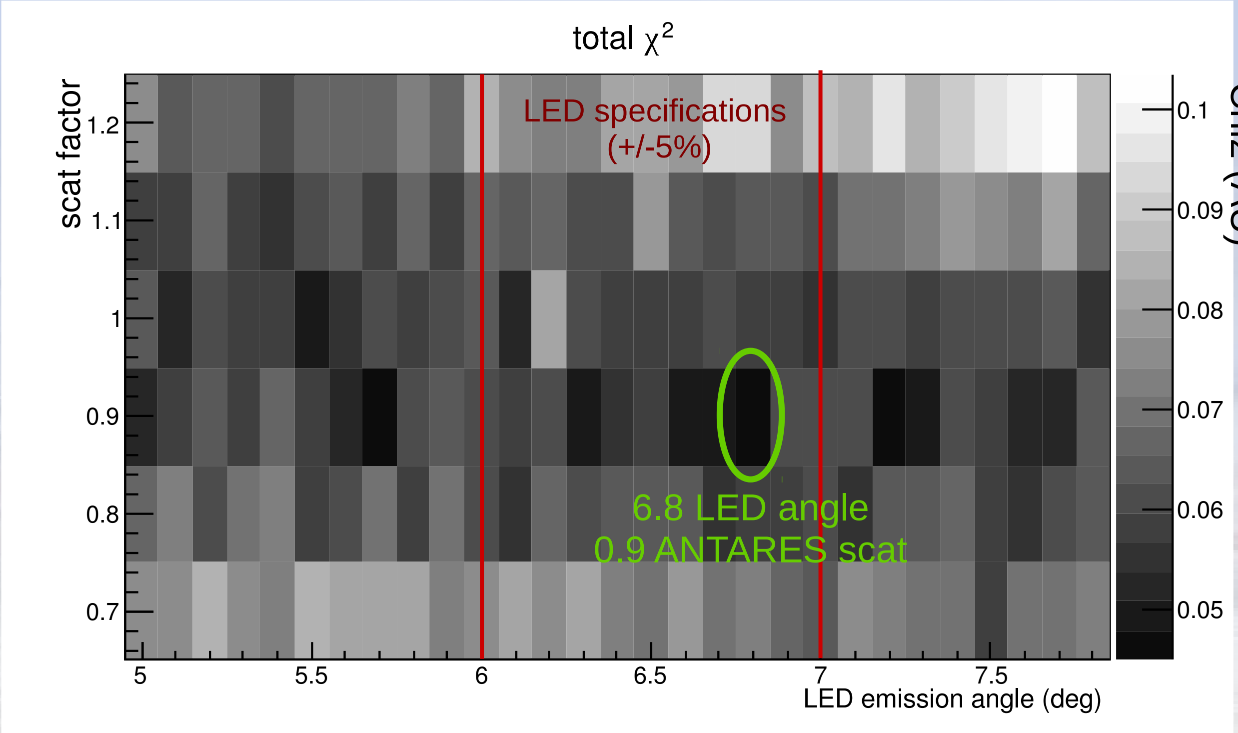
With the exact antares scattering and LED specifications.

=> Research of the minimum chi2 in function of scattering and LED angular emission

Current very preliminary results ongoing work

Water scattering of ANTARES
Events with charge < 1.3 spe
LED specifications from constructor
LED emission angle (refraction)

Under simulation:
Table of chi2 for scattering values
The preliminary best is around
0.9 X ANTARES scattering



The total chi2 is calculated as

$$\mathrm{Sqrt}\,(\mathrm{chi2(floor8)}^2 + \mathrm{chi2(floor7)}^2 + \mathrm{chi2(floor6)}^2)$$

The chi2 is calculated comparing data and simulation the weighted with the number of events

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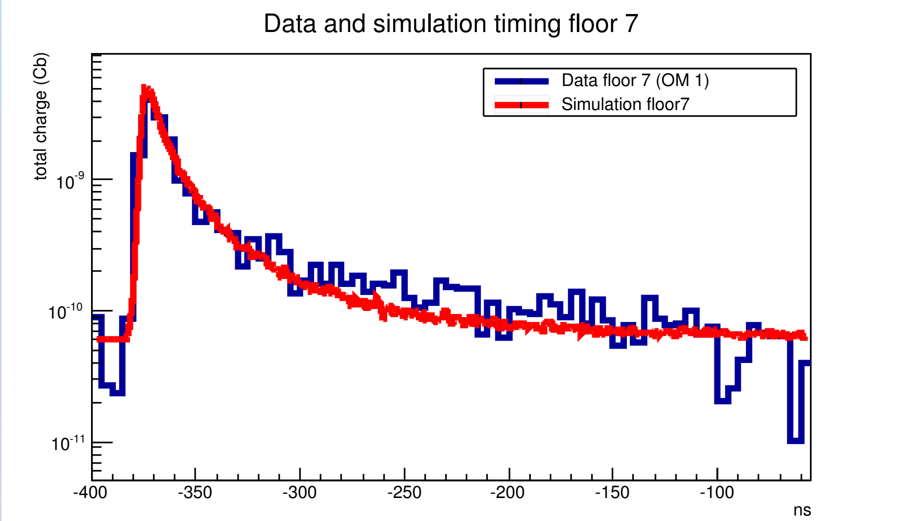
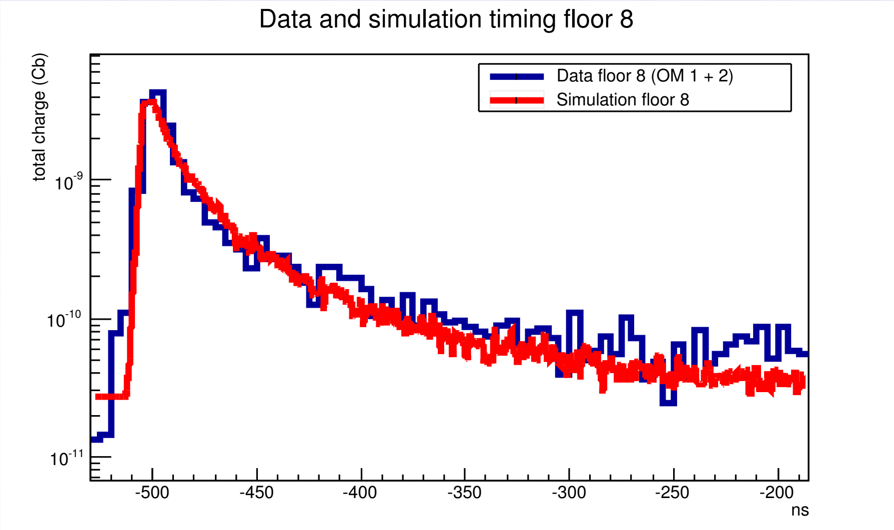
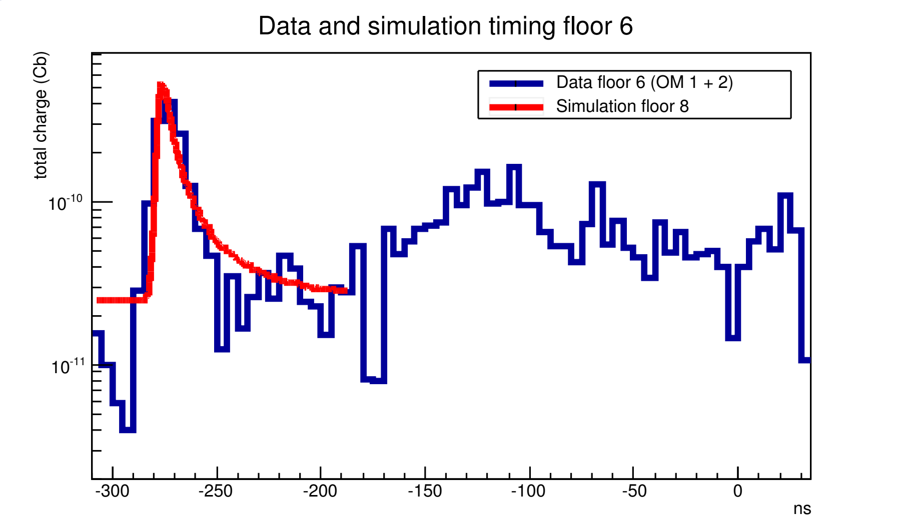
0.8-0.9 x ANTARES one







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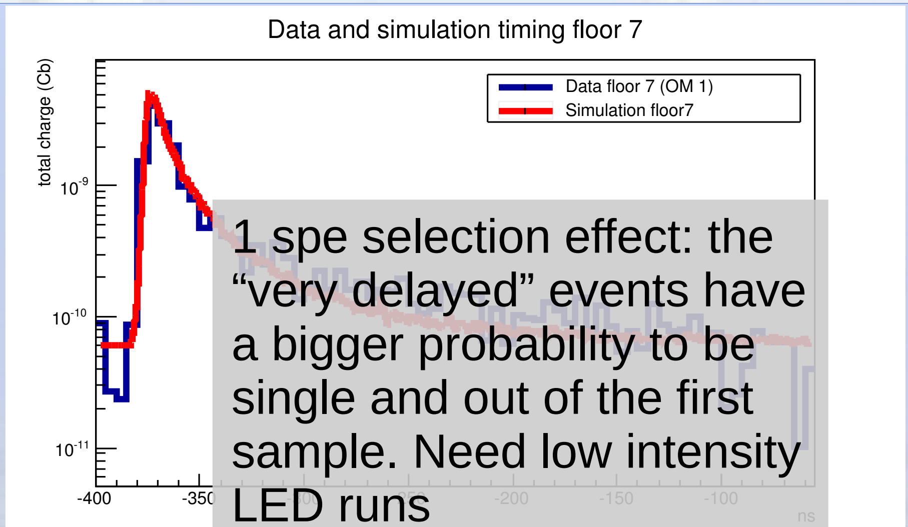
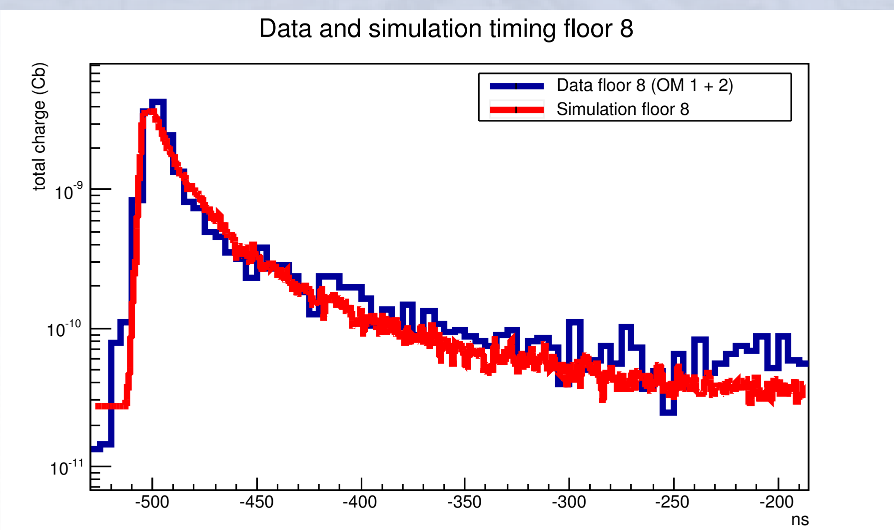
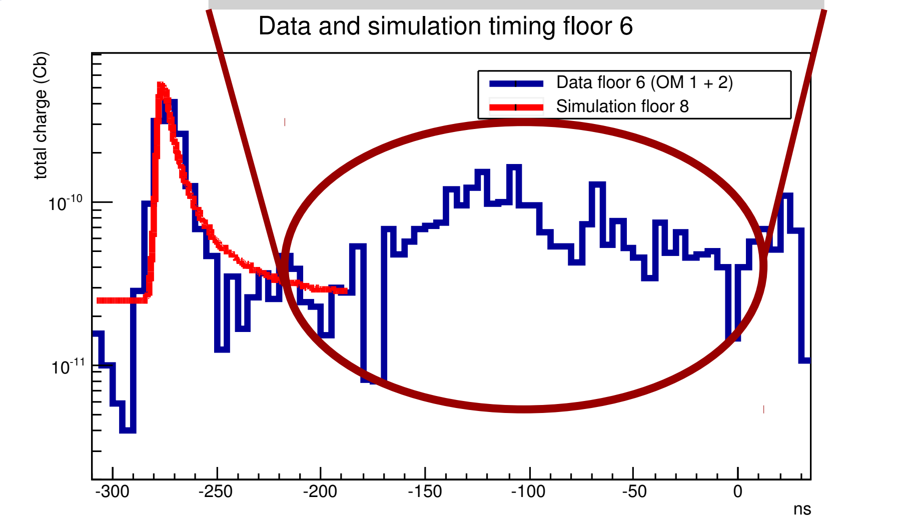


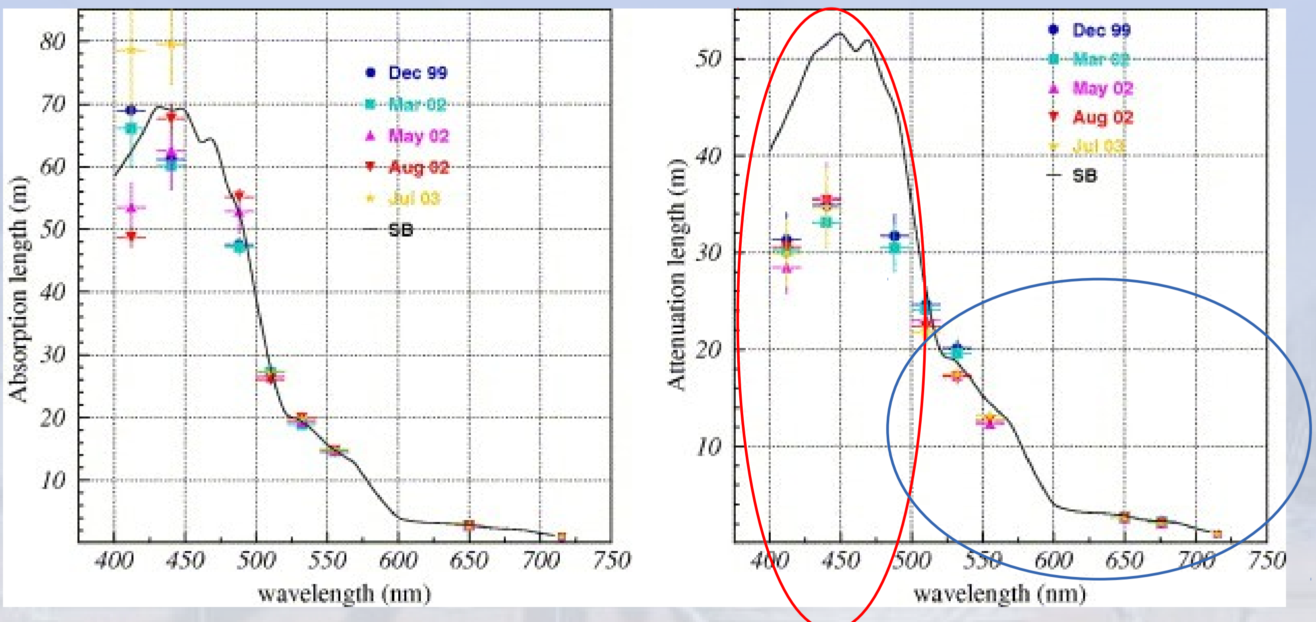
1 spe selection effect: the “very delayed” events have a bigger probability to be single and out of the first sample. Need low intensity LED runs





Discussion

Distribution of the scattering length?
=> test with the measured values at the capo passero site



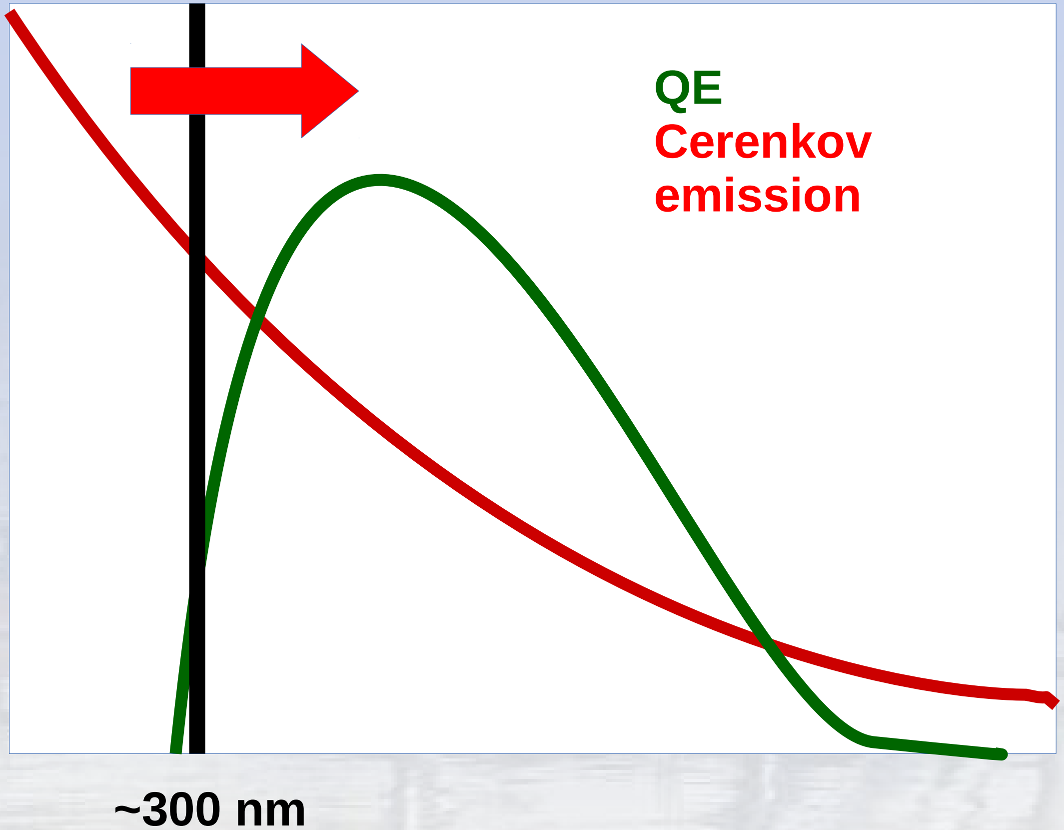
doi:10.1016/j.astropartphys.2006.08.006
Average absorption and attenuation lengths measured with the AC9
A solid black line indicates the values for pure seawater reported (Smith and Baker).

Perspectives

- Increase the angle and scattering range
- Single LED beacon is more difficult to analyze
- Try to use the measured attenuation from the site
  - Extraction of the scattering on particle (the molecule one is considered to be always constant)
  - Try a best fit with the same method with this distribution

Under development: wavelength shifters

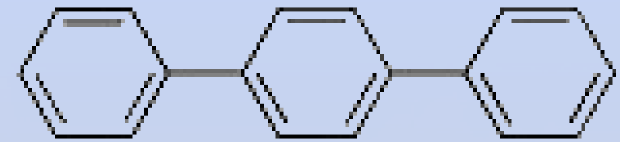
Principle



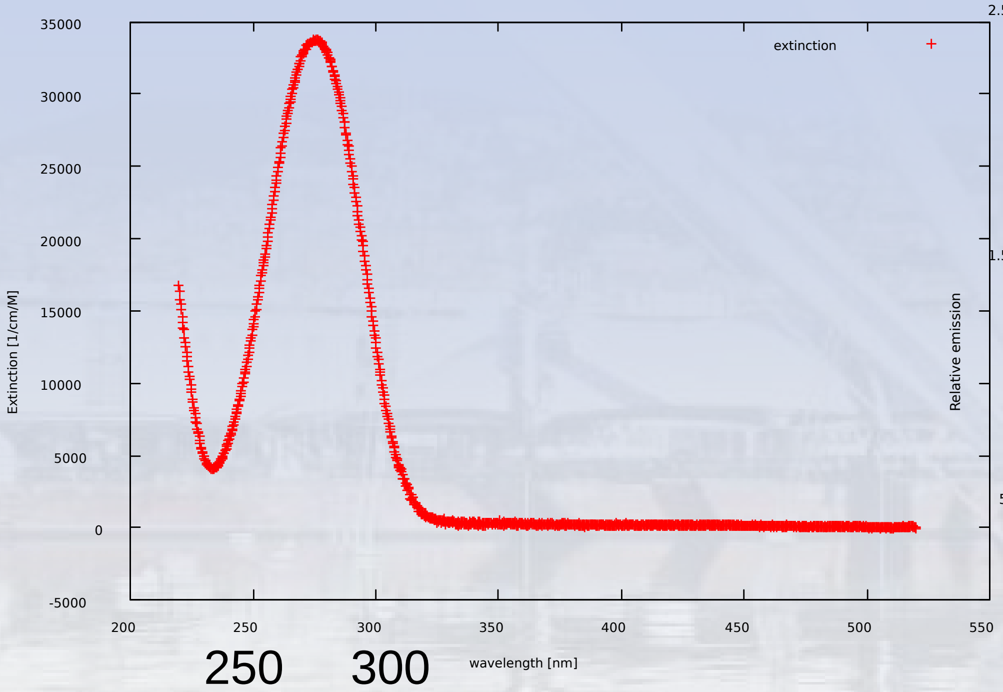
Use WLS filter from low wavelength to high wavelength to increase the detection probability

Under development: wavelength shifters

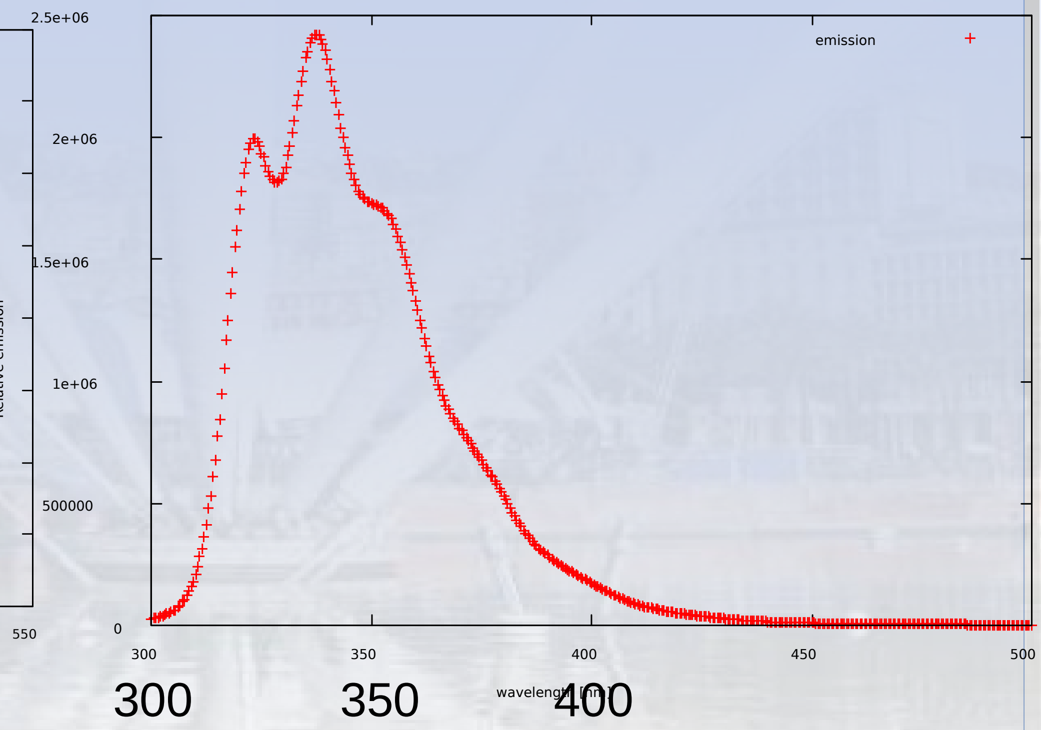
Preliminary selected WLS: p-Terphenyl



Extinction



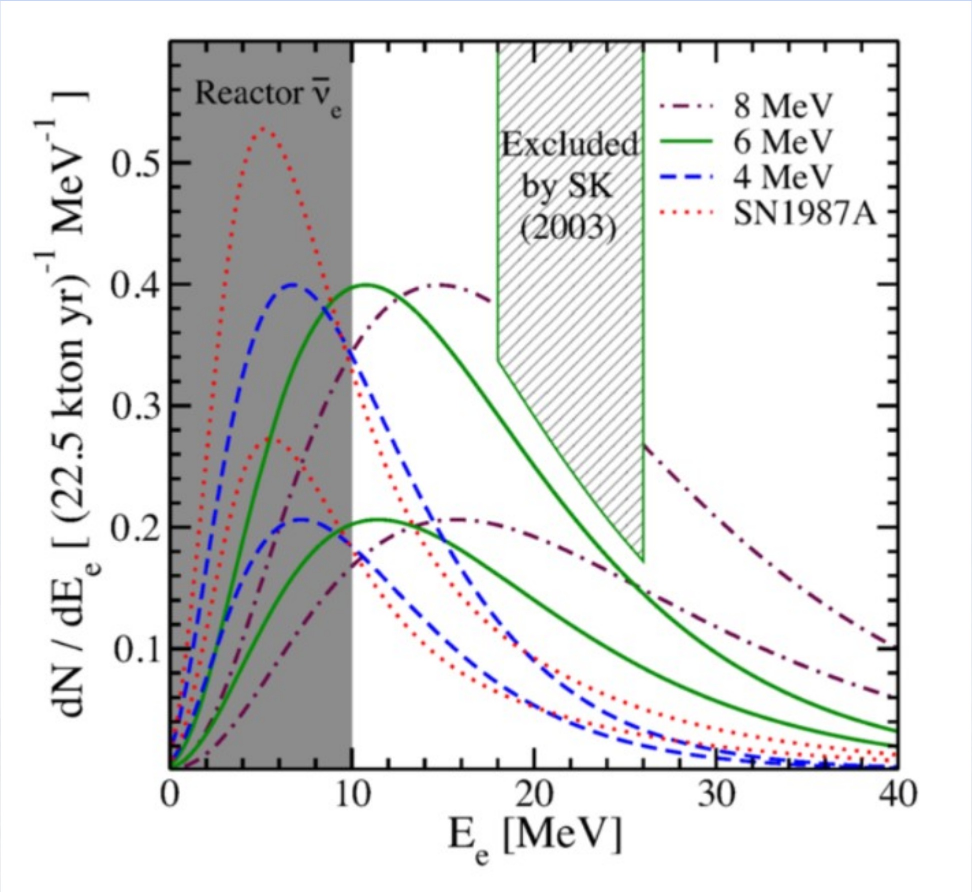
Emission



Perspectives

- Add it on the DOMs
  - On the PM surface
  - In the gel
  - On the Glass surface
- Evaluation of the gain
- Evaluation of the time delay
- Evaluation of the ratio BioLum/Cerenkov

Under development: Low energy electrons



Models predict anti-neutrinos emission while the core collapsing

Are they detectable by ORCA?

Simulation of the probability of detection of Cerenkov light from low energy electrons

Predicted neutrino detection in superkamiokande in function of the model
S. Horiuchi, J. F. Beacom and E. Dwek, Phys. Rev. D79, 083013 (2009)

Conclusion

- KM3Sims like simulation is essential for the global Cerenkov detector, but
- It can do more
  - characterization of the sites (water properties)
  - Test of setups, geometries, new ideas (WLS)
  - Direct physics with some specific case studies (detection sensitivity of low energy electrons)
- A lot was done, but even more can be done, a lot of available work!