# An analysis chain for CTA to test novel methods

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SAp PostDoc Seminar
2016-12-06

# The Road so far

**2006 – 2011:** Physics at TU Dresden

- specialisation: nuclear and particle physics
- diploma thesis on ATLAS detector

**2012 – 2016:** ANTARES at Nikhef, Amsterdam

- event reconstruction,
- neutrino point-source search
- first prototype optical module for KM3NeT
- **2016-05:** PhD thesis defended

**2016-04:** CTA at CEA

- working with Thierry Stolarczyk
- implementing analysis chain for CTA
- testing impact of novel methods on:
- event reconstruction, gamma-hadron separation, sensitivity
- Room Number: 120

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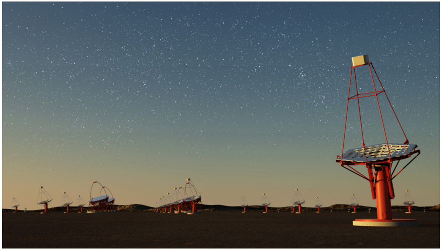
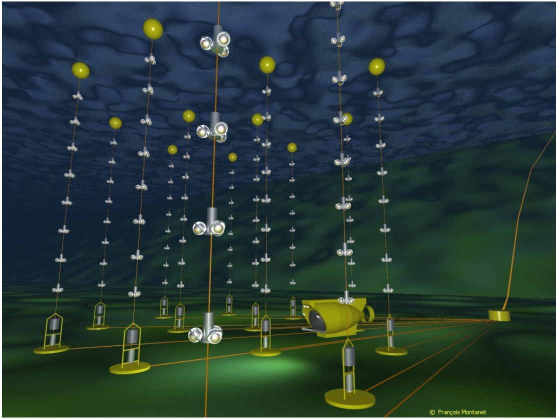


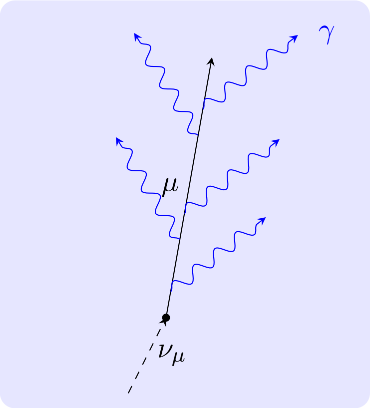
# ANTARES – The Detector



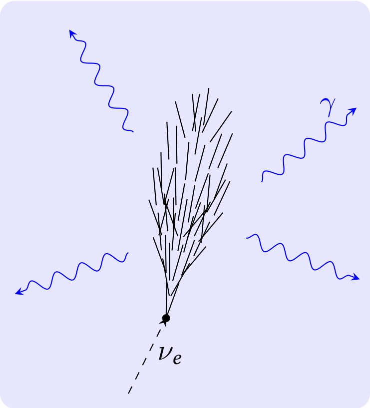

- 2500 m below sea surface
- 40 km off the coast of Toulon, France
- connected via electro-optical cable

- complete since 2008-05
- 12 Lines, 885 PMTs
- radius: 90 m
  height: 400 m
- 0.5 ns time resolution
- $<$ 10 cm acoustic positioning

Muon:

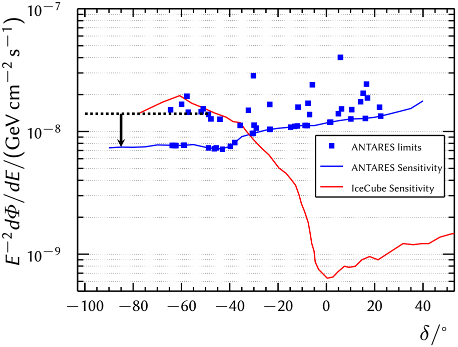



em-Shower:



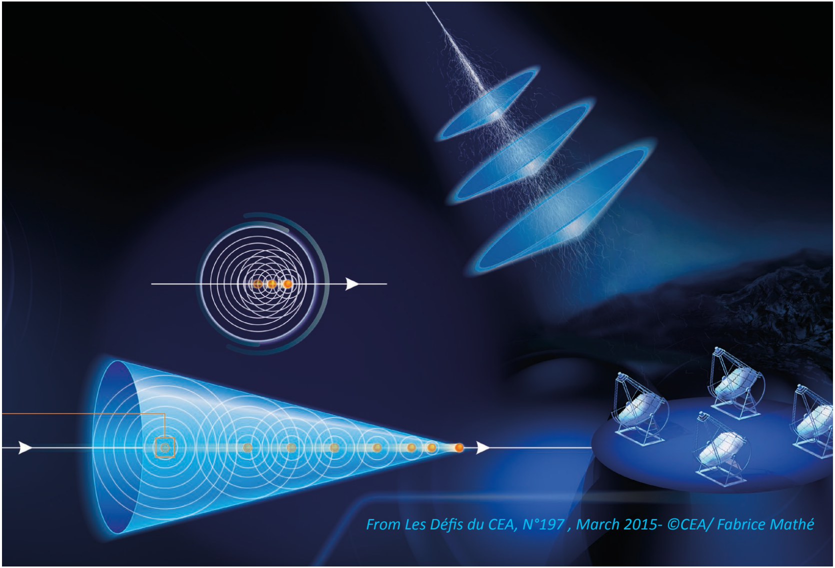
## Sensitivity and Limits

- no significant cluster in Full Sky Search
- Sensitivity improved from $1.4 \times 10^{-8}$ GeV cm$^{-2}$ s$^{-1}$ to $7.2 \times 10^{-9}$ GeV cm$^{-2}$ s$^{-1}$
- best limits for many candidates in galactic region from single experiment
- challenged only by combined ANTARES/IceCube analysis

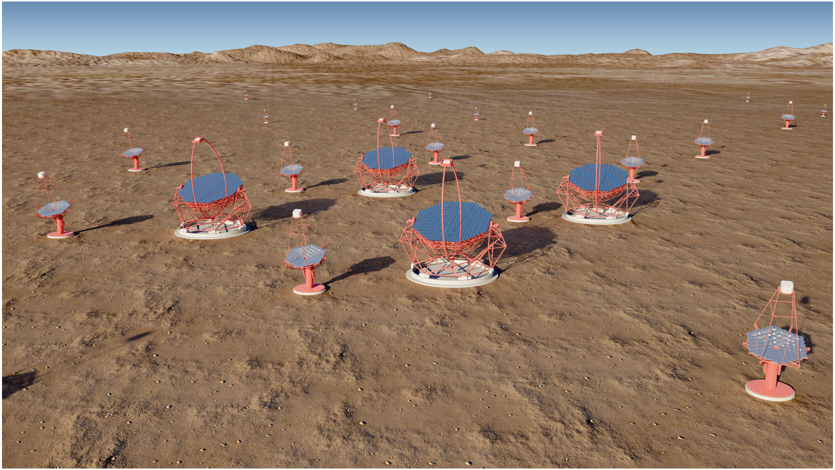



cta
cherenkov telescope array
credit: DESY/Milde Science Comm./Exozet

# CTA – Detection Principle



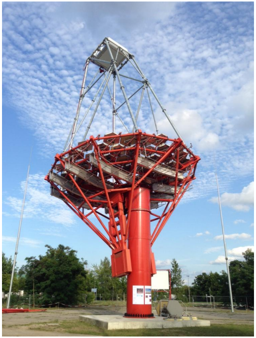
# CTA – Telescope Array



- sites chosen:

  La Palma, Spain and Paranal, Chile

- many prototypes already built
- construction of first foundation started



# CTA – Telescope Sizes

LST

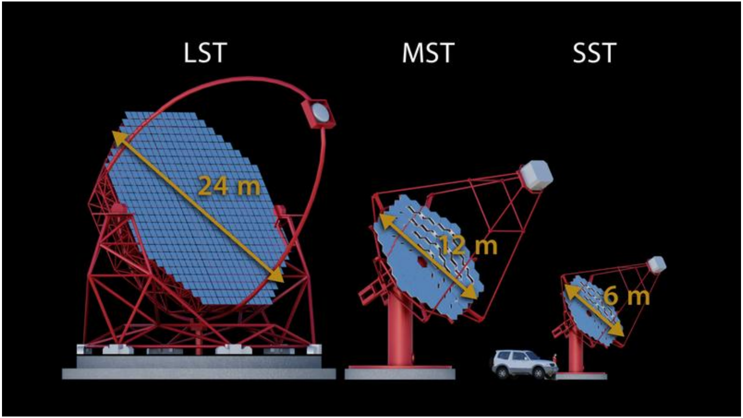
- 4 at both sites
- $E_\gamma < 0.1\,\text{TeV}$
- FoV: 4.5°

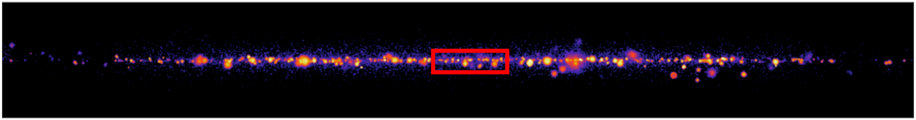
MST

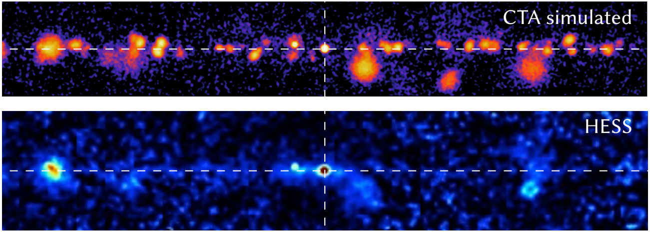
- 25 at south; 15 at north site
- $0.1 < E_\gamma/\text{TeV} < 100$
- FoV: $> 7°$

SST

- 70 south site only
- $E_\gamma > 10\,\text{TeV}$
- FoV: 10°



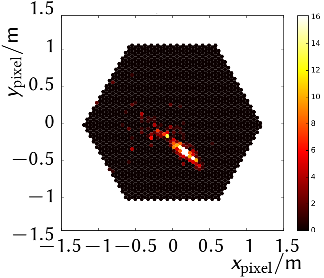





- better sensitivity and resolution w.r.t. HESS
- resolve overlapping extended sources
- viewing distance of 20 kpc
- expect population increase $\times 5$

# How the Signal looks like

Shower Signal



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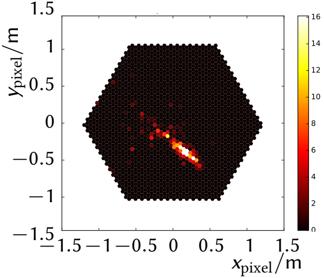
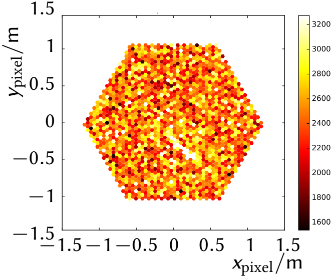



Stars, Clouds, Electronics etc.

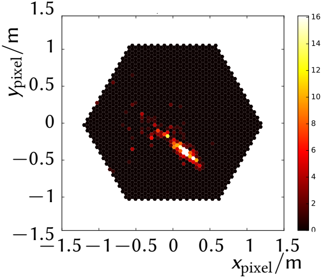
$\longrightarrow$

Detector Response



# How the Signal looks like

Shower Signal



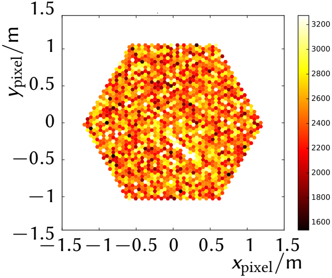

Stars, Clouds, Electronics etc.

⟶

⟵

How to get back?

Detector Response



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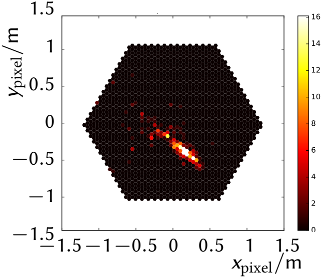


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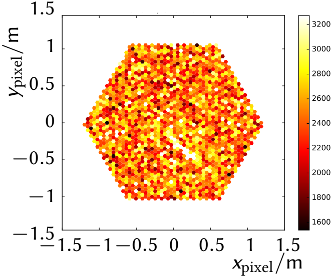
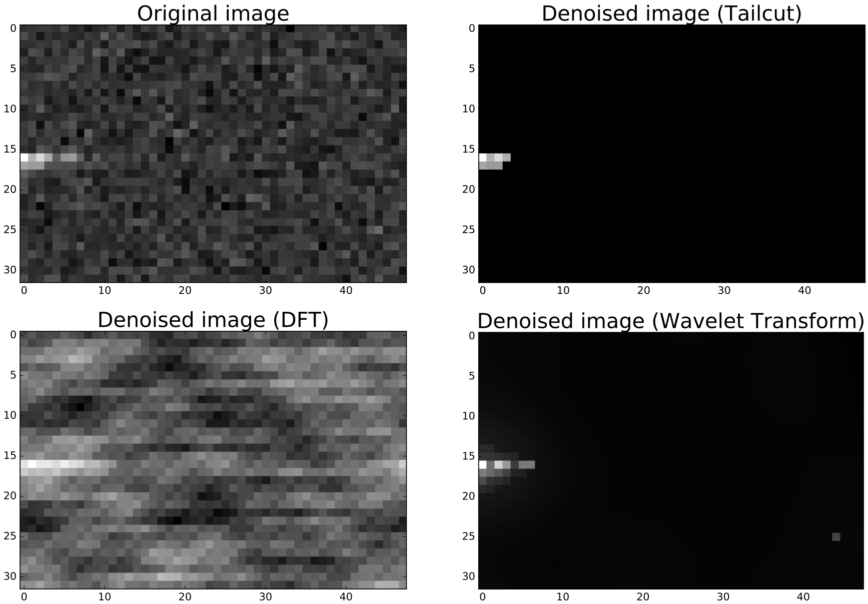


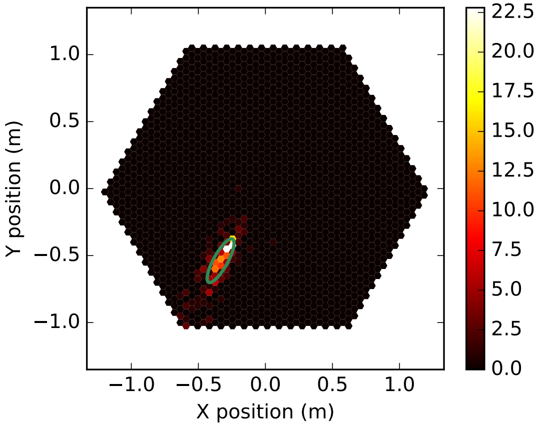

possible solutions:

| | |
|---|---|
| Tail-Cuts | Used by H.E.S.S.: Cut away all pixels below a given threshold<br>– possibly recover neighbouring pixels through second, lower threshold. |
| Fourier Trans. | Decompose image into Fourier coefficients and cut in Fourier space. |
| Wavelet Trans. | Decompose image into waveletes (in contrast to waves) and cut there. |

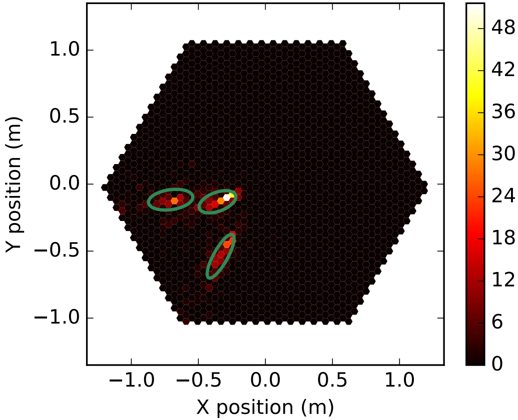
# Comparing Methods



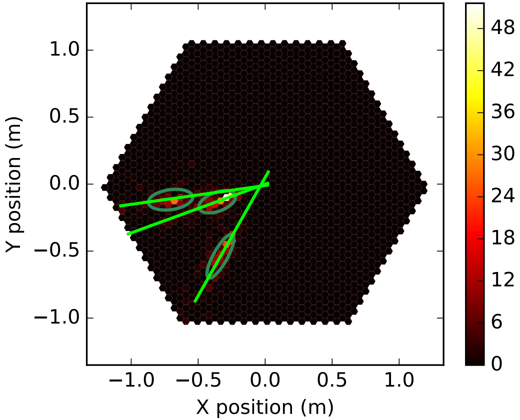
# Shower Reconstruction



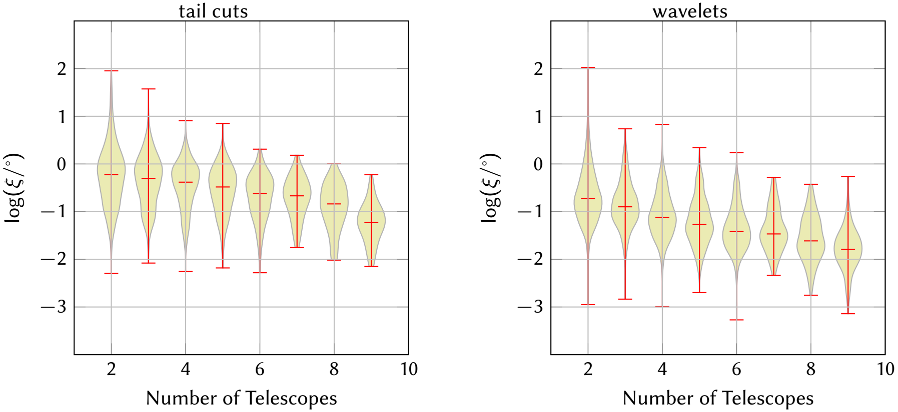

- construct an ellipsis with moments of the shower image: *Hillas Parametrisation*




- construct an ellipsis with moments of the shower image: *Hillas Parametrisation*
- combine images from different cameras




- construct an ellipsis with moments of the shower image: *Hillas Parametrisation*
- combine images from different cameras
- intersection of their ellipsis axes is the shower origin



tail cuts
wavelets
log(ξ/°)
2
1
0
−1
−2
−3
2
4
6
8
10
Number of Telescopes

# Next Steps

Photon / Proton Discrimination

- Protons pose major background
- Event rate about $10^5$ times above Photons

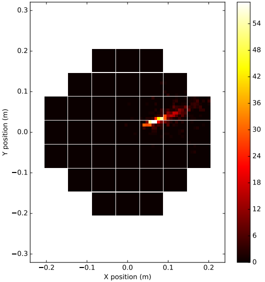
H.E.S.S. methode:

- reducing total signal on camera, length and width of ellipsis and their variances from all telescopes into one parameter to cut on

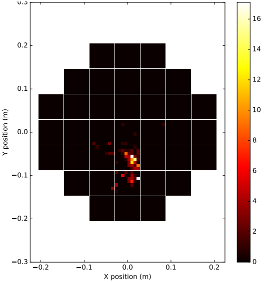
here instead:

- Discrimination with Random Forest Classifier fed with width, length, ... of Hillas ellipsis from each camera image

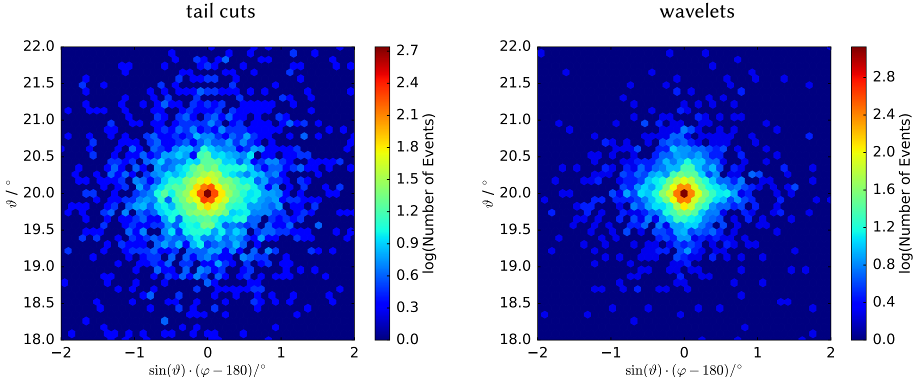
photon




proton



# Skymap of a point-source



- apply analysis chain to full array
- investigate
  - impact on overlapping sources
  - real-time analysis
  - $\rightarrow$ reduction of data flow

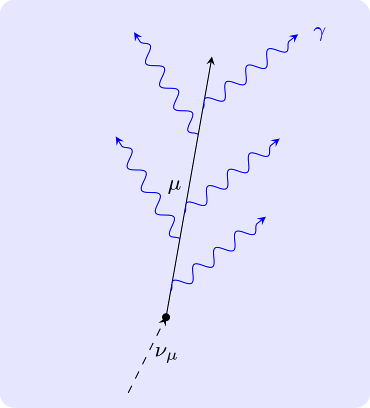
- for more information on wavelets:
  see Jérémie's talk in February
- will be here for another 1,5 years

# Backup

- muon track reconstruction already well established
- muons can pass through detector
- Cherenkov radiation along track
- photons emitted at $\varphi_{\text{Ch}} \approx 42^{\circ}$
- clean signature

- maximum likelihood fit based on hit time residuals
- median angular resolution $\approx 0.4^{\circ}$

- limit us to $\nu_\mu \to \mu$ (and $\nu_\tau \to \tau \to \mu$) interactions

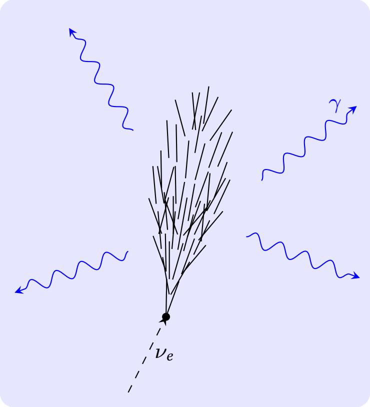


- shower events open window to
  $\nu_e \rightarrow e$
  $\nu_x \rightarrow \nu_x + hadr.$
  $\nu_\tau \rightarrow \tau \rightarrow e/hadr.$

- cascade of particles within few metres
- can be approximated as point source
- emits shell of light in all directions
- still, more light emitted under “Cherenkov angle”

in ice:

- effect almost completely gone due to scattering



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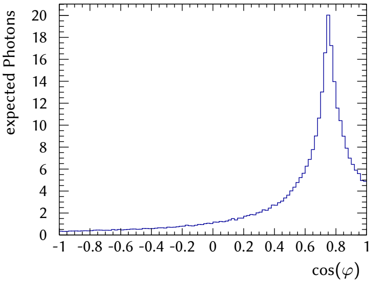
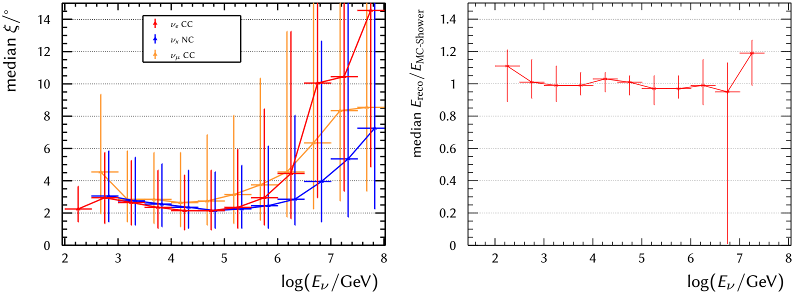



expected number of Photons from a 1 TeV shower on a PMT in 100 m distance

# Shower Reconstruction – Performance: Direction & Energy




- position of shower position reconstructed with accuracy of about 1 m
- median angular error $\xi \approx 2°$ in relevant energy range (compared to 15° for IceCube)
- energy resolution of 5 % – 10 %

- 17″glass sphere
- 31 3″ PMTs, 5 rings with 6 PMTs + 1

- 1 DOM equivalent to 3 ANTARES OMs (cheaper)
- but only one penetrator per floor (less risky)
- low power consumption (<10 W per DOM)

- covers almost whole solid angle
- directional information
- background reduction from PC segmentation

- prototype deployed on Instrumentation Line within ANTARES

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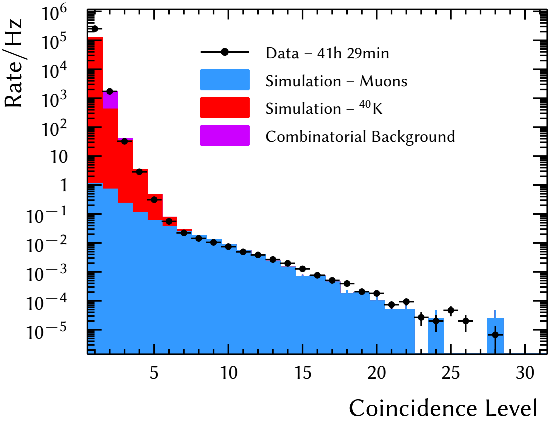
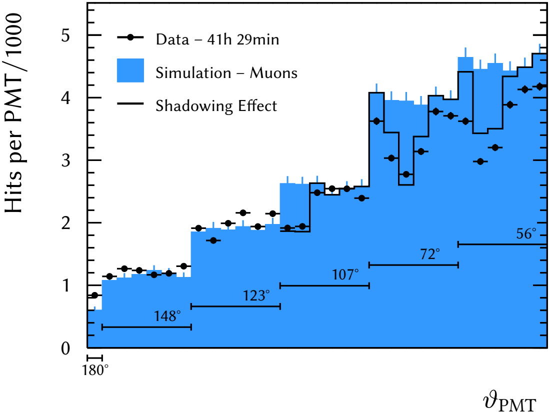
# Rate of different Coincidence Levels

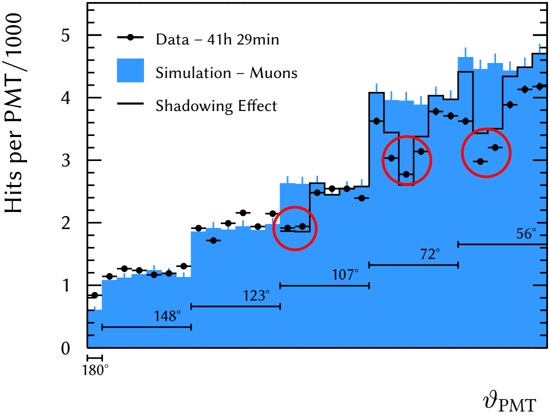



- Coincidence Level: # of Hits within 20 ns
- Combinatorial Background: estimate for coincidences caused by multiple single hits
- derived from average PMT rate in data

→ European Physical Journal C (2014) 74:3056




- Coincidence Level > 7
- clear asymmetry towards upwards looking PMTs
- drops due to LCM shadowing
- we can "see" the LCM
- → directional information from single storey

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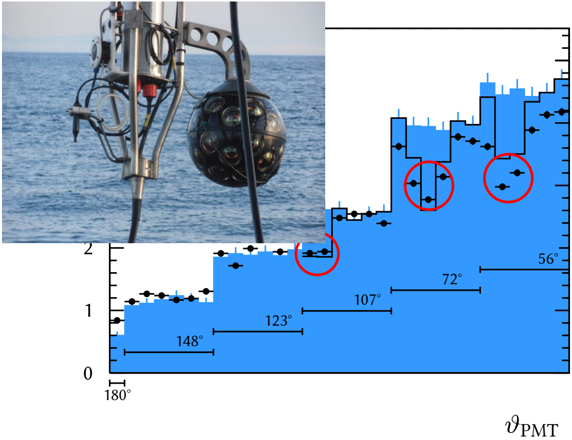


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