Search for tau neutrinos with the MAGIC telescopes: the quest continues

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And the nu team: Dariusz Gora, Elisa Bernardini, Michele Doro, Martin Will, Javier Rico, Saverio Lombardi, Dorota Sobczynska for the MAGIC Collaboration

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Croatian Science Foundation

-- 05/09/18 RICAP 2018, Roma Tre University --

Multi-messenger astronomy: time for neutrinos!

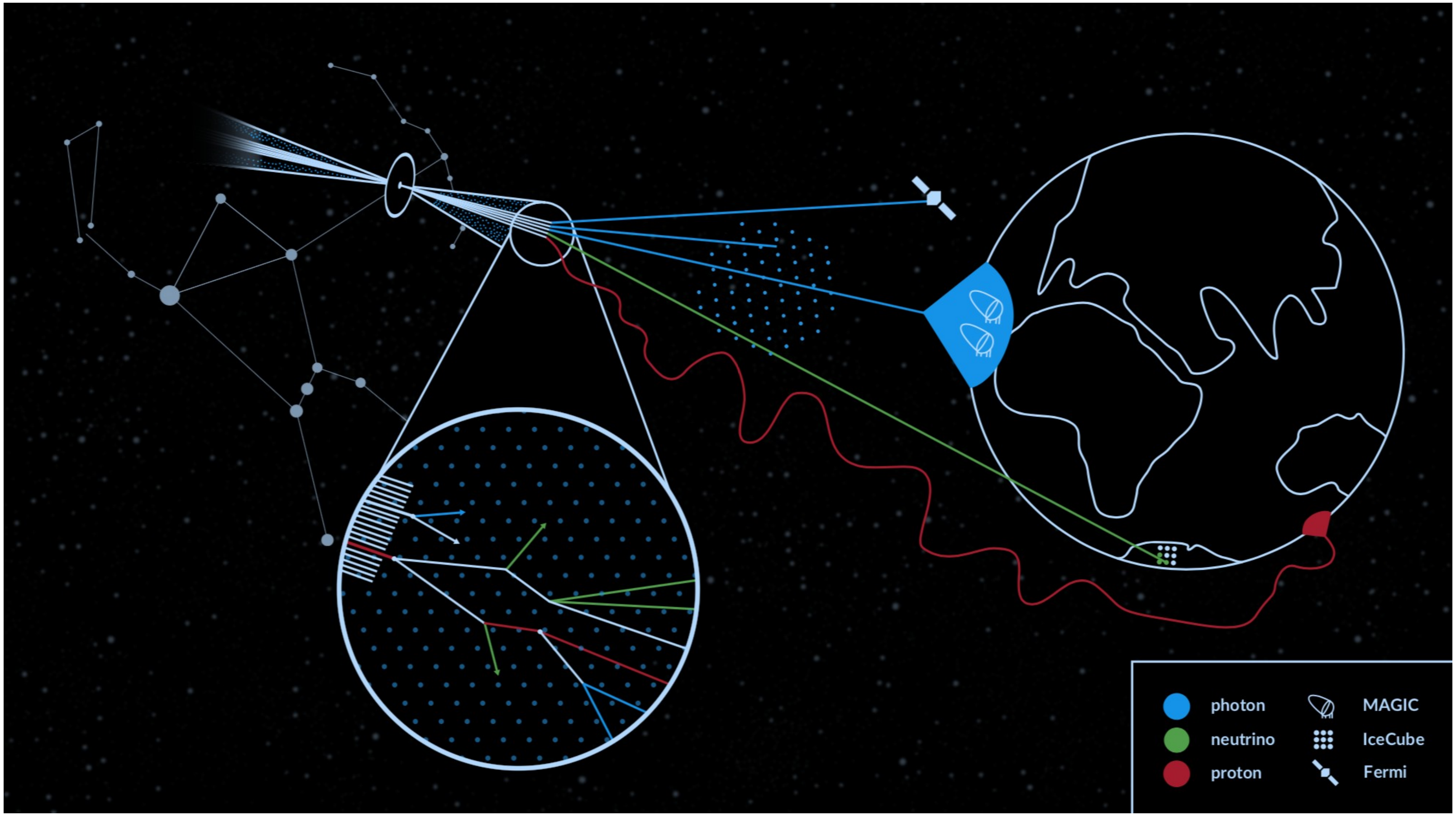
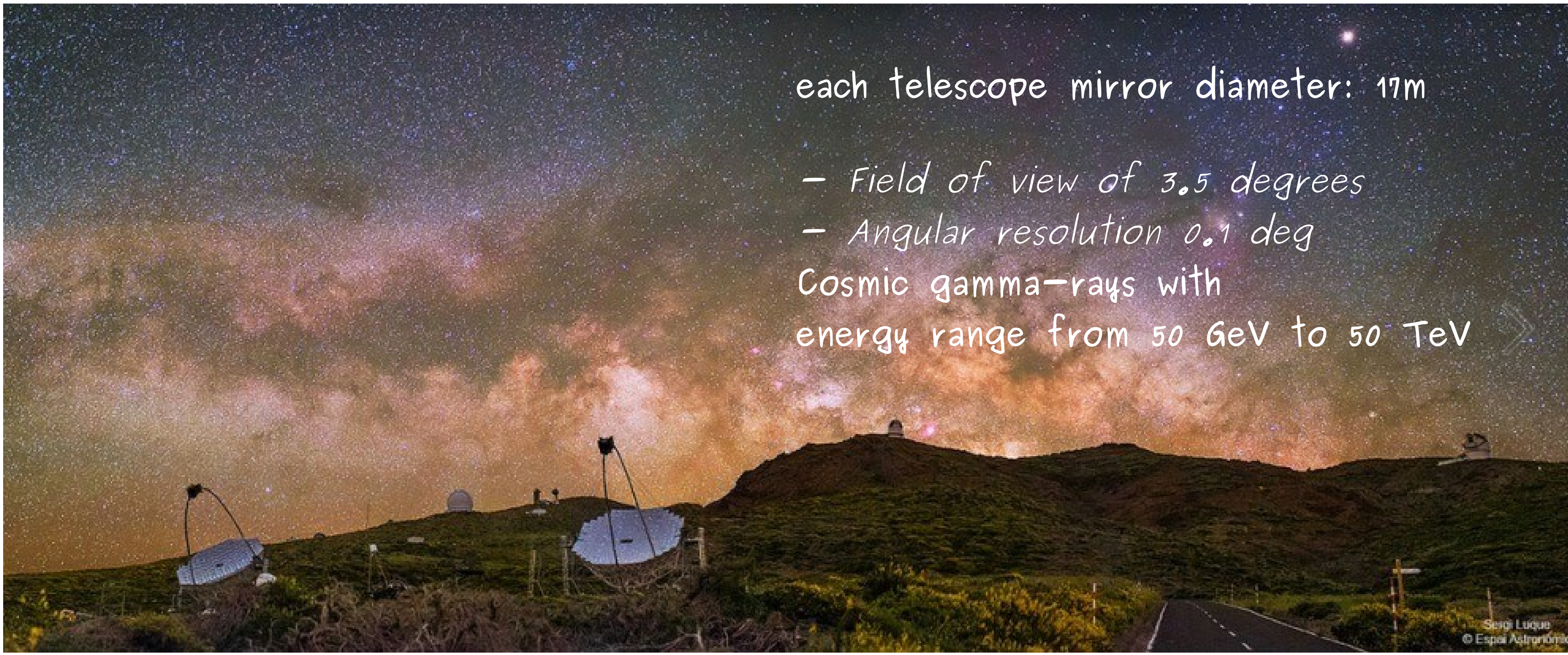


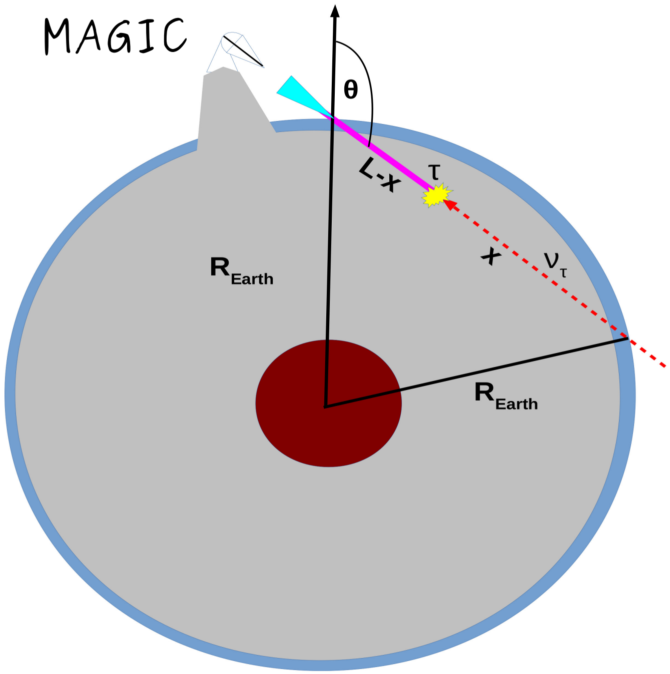
Image Credit: E. Bernardini, K. Satalecka (DESY); Weronika Racz, Igor Rams, Bartosz Wyszynski (graphics and animation, PJATK)

- Science 361 (2018) 6398, 147
- Ansoldi et al., ApJL 863, 1

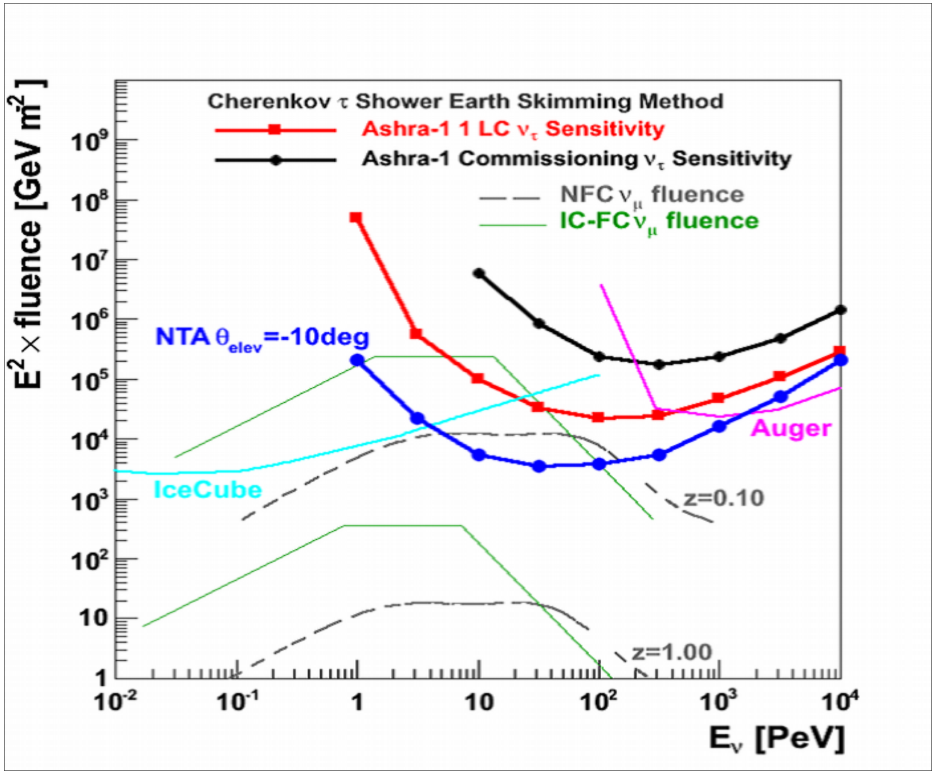
MAGIC telescopes,
La Palma, Roque de Los Muchachos :
2200 m a.s.l.



Earth-skimming neutrinos



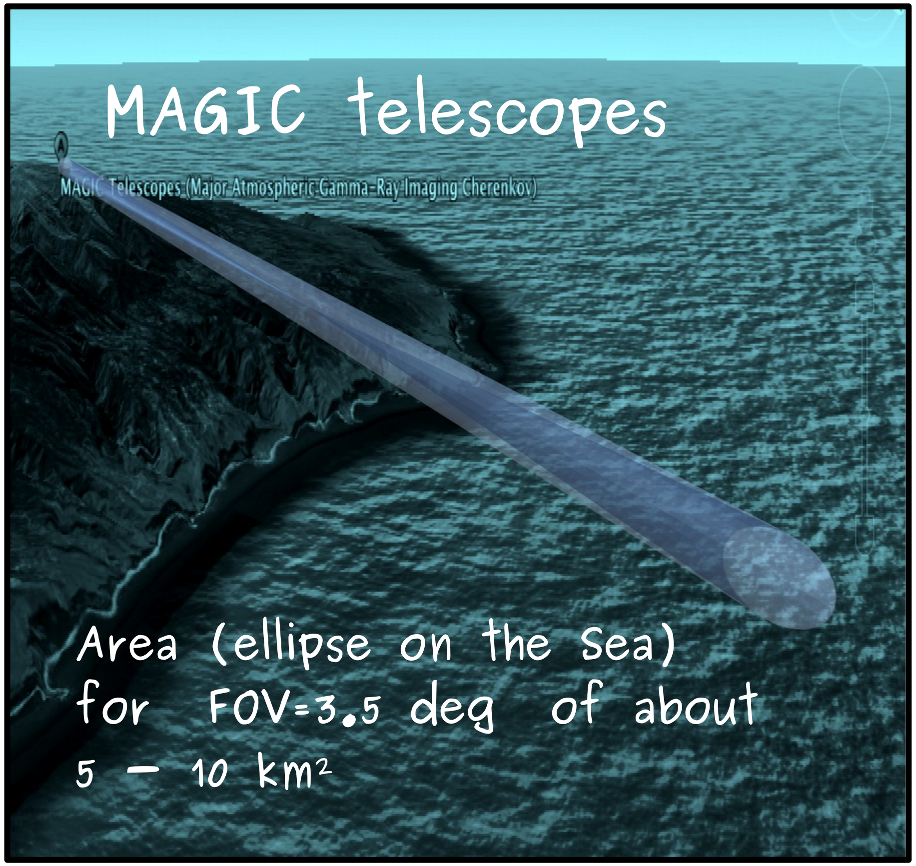
Technique:
D. Fargion, Astrophys.J. 570, 909 (2002).
X. Bertou et al., Astropart.Phys. 17, 183 (2002).

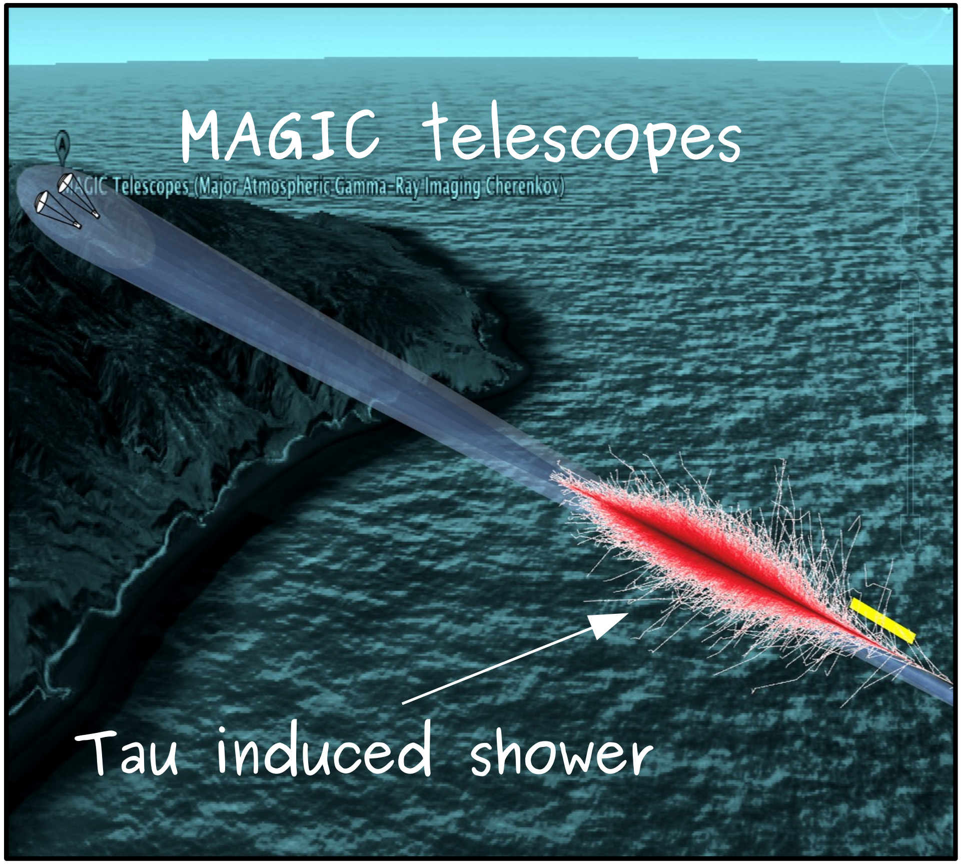


This method has been used succesfully by ASHRA-1

- APJ 736 L12;
- Astropart. Phys. 41 (2013) 7

MAGIC as a neutrino detector!



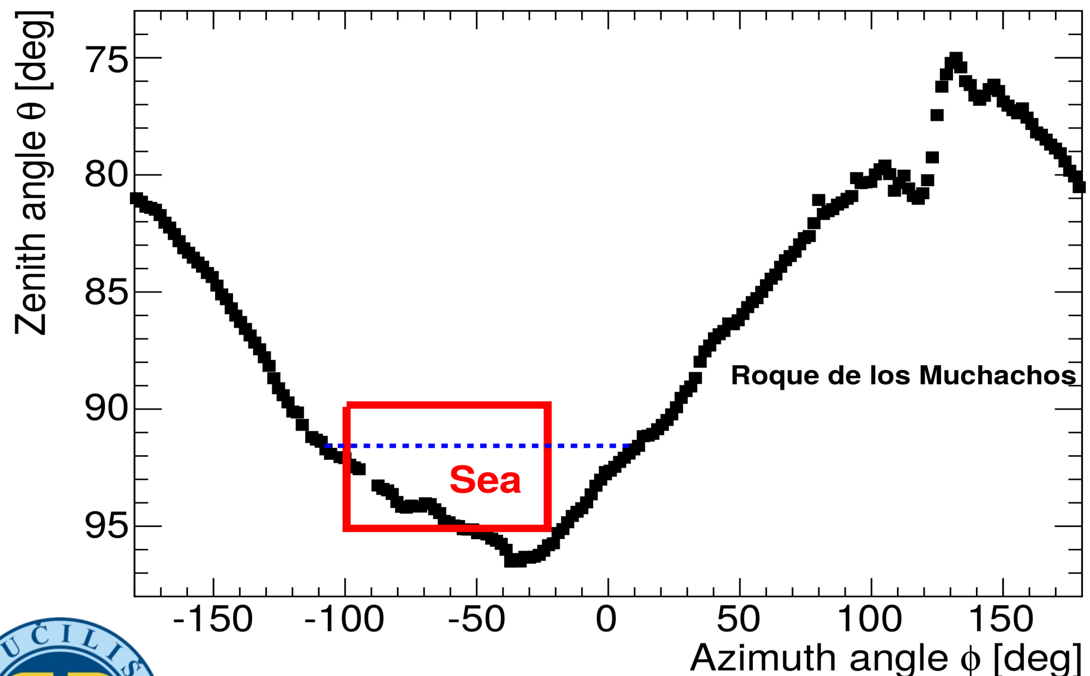


Sometimes nights with high clouds prevent observation of γ-ray sources , for MAGIC of about ~ 60 – 100 hours/year. Possibility to collect large amounts of data while not wasting "expensive dark time" of MAGIC

The horizon seen from the MAGIC telescopes: 3 different sets of observations

1 direction slightly above the Sea (SeaOFF)
ZA=87.5 deg
AZ=−30 deg
deg Time= 9.2 h

2 : direction of the Sea (SeaON)
ZA=92.5 deg
AZ=−30 deg
deg Time= 29 h



3 : Towards the Roque
ZA=92.5 deg
AZ=170
deg Time= 7.5 h

MAGIC as a neutrino detector!

Analytical calculations: M. Gaug et al., ICRC 2007 arXiv:0709.1462

- **sensitivity [100 TeV – 1 EeV]**
- ~10^{-4} **events/year** for diffusse neutrino flux given by Engel, Stanev & Stecker (GZK neutrinos) model
- ~10^{-2} **events/year** are predicted for the Waxmann & Bahcall neutrino model from GRBs, for an average GRB located at z=1
- some data (a few minutes) were taken, but at that time no Monte Carlo to interpret those data

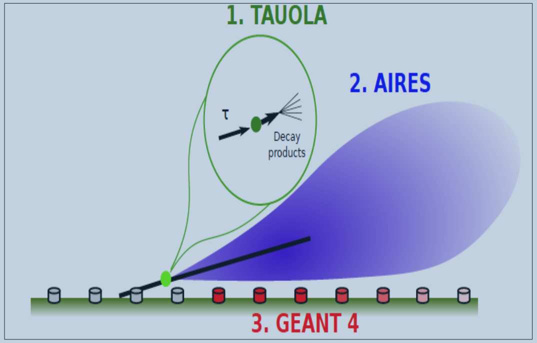
Monte Carlo simulation chain:

1: Propagation of neutrino through the Earth


ANIS:
All Neutrino Interaction Simulation
Marek Kowalski
DESY-Zeuthen
Workshop on Ultra High Energy Neutrino Telescopes
Chiba, 30.7.2003

A. Gazizov, M.P. Kowalski Comput.Phys.Commun. 172 (2005) 203

2: Simulation of tau-induced shower in air at high zenith angles



CORSIKA

D. Heck, et al., Report FZKA 6019 (1998) 3

Compiled: with **CURVED-EARTH, TAULEP, CHERENKOV/IACT, THIN** option

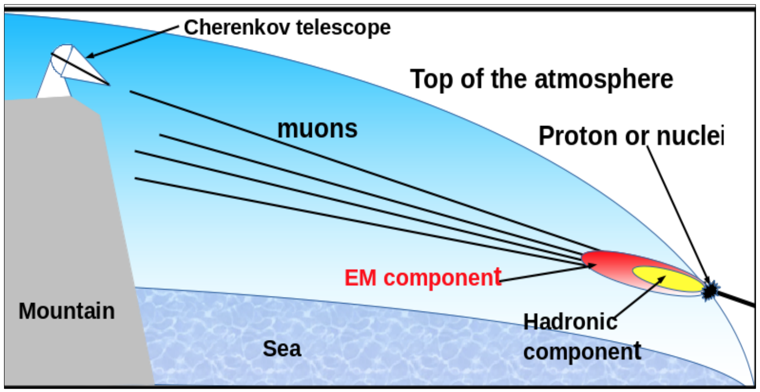
3: Simulation of MAGIC response

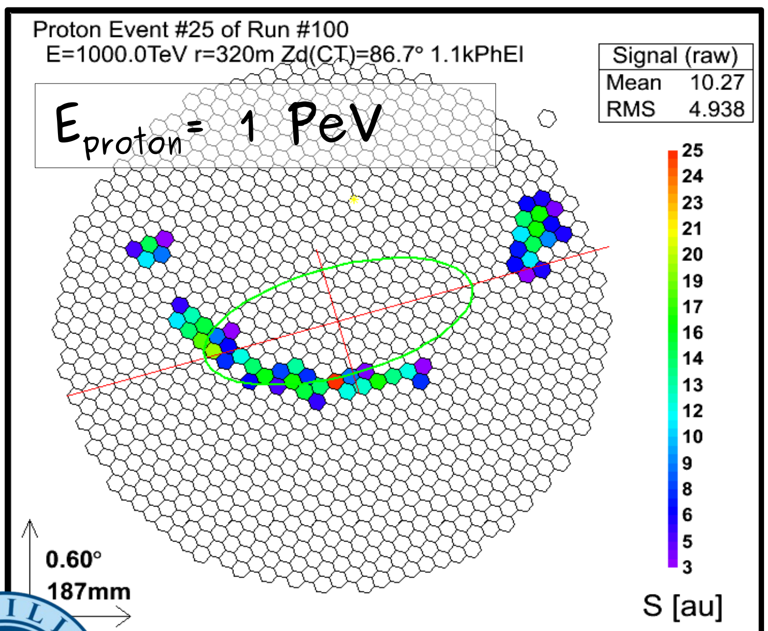
MARS (MAGIC analysis suite)

R. Zanin, et al. 2013 ICRC 2013

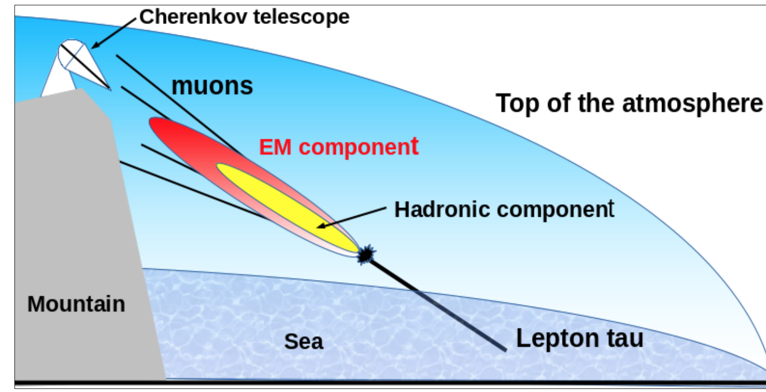
MonteCarlo simulation chain

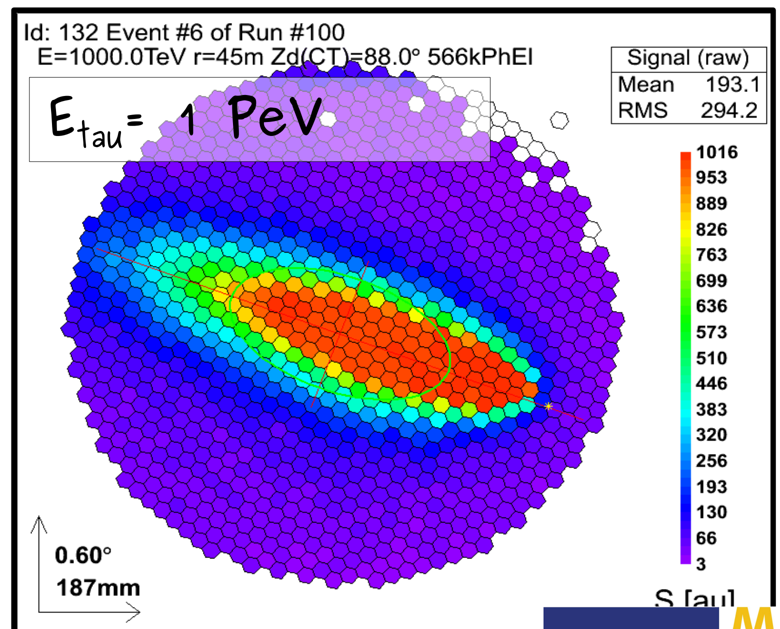
Proton injected at the top of the atmosphere
(~800 km to the detector for 87°)





Deep tau-induced shower
(~50 km to the detector)

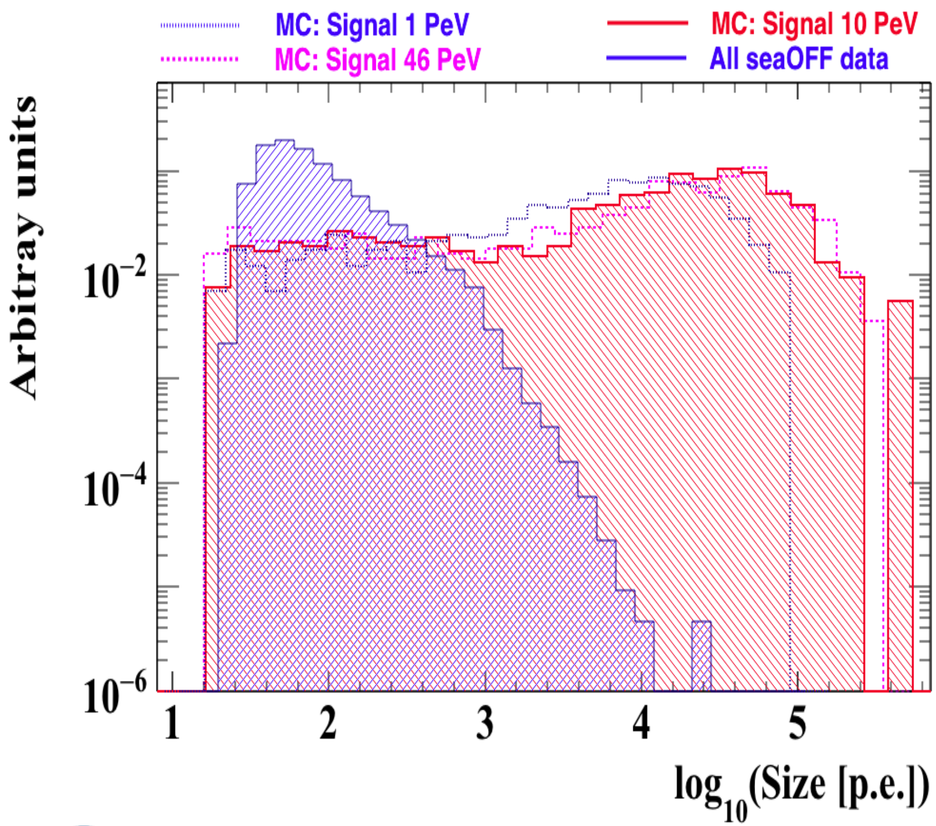


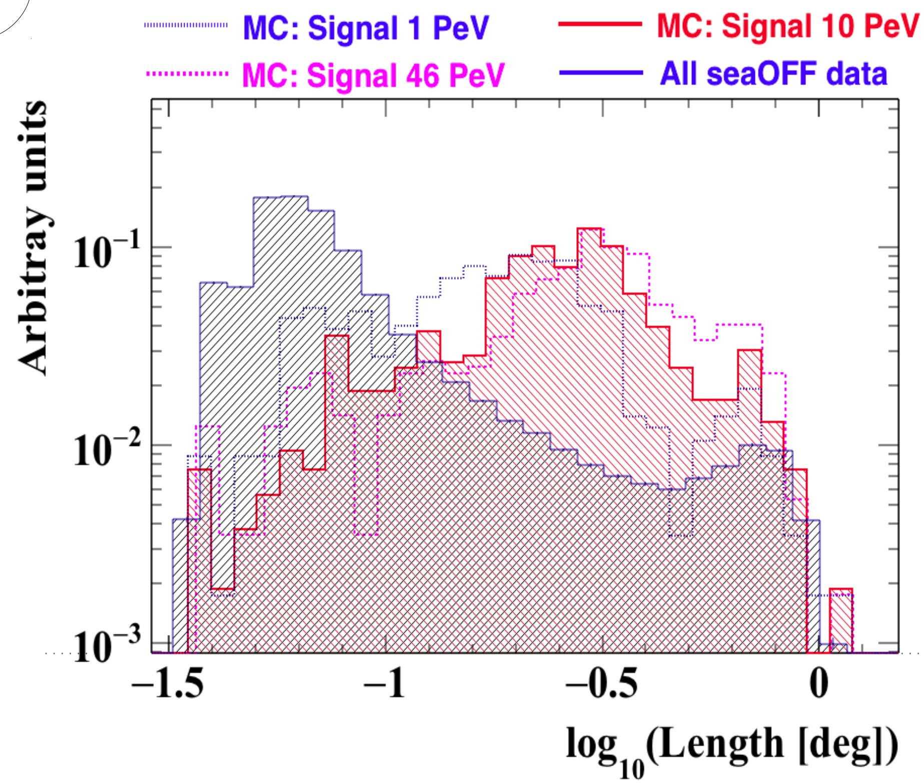


Hillas parameters choosen for the cuts

SIGNAL MC simulations:
- deep tau-induced shower
- distance to the detector < 100 km,
- tau-decay branching ratio included in MC

BACKGROUND:
- seaOFF data (9.2 hours)





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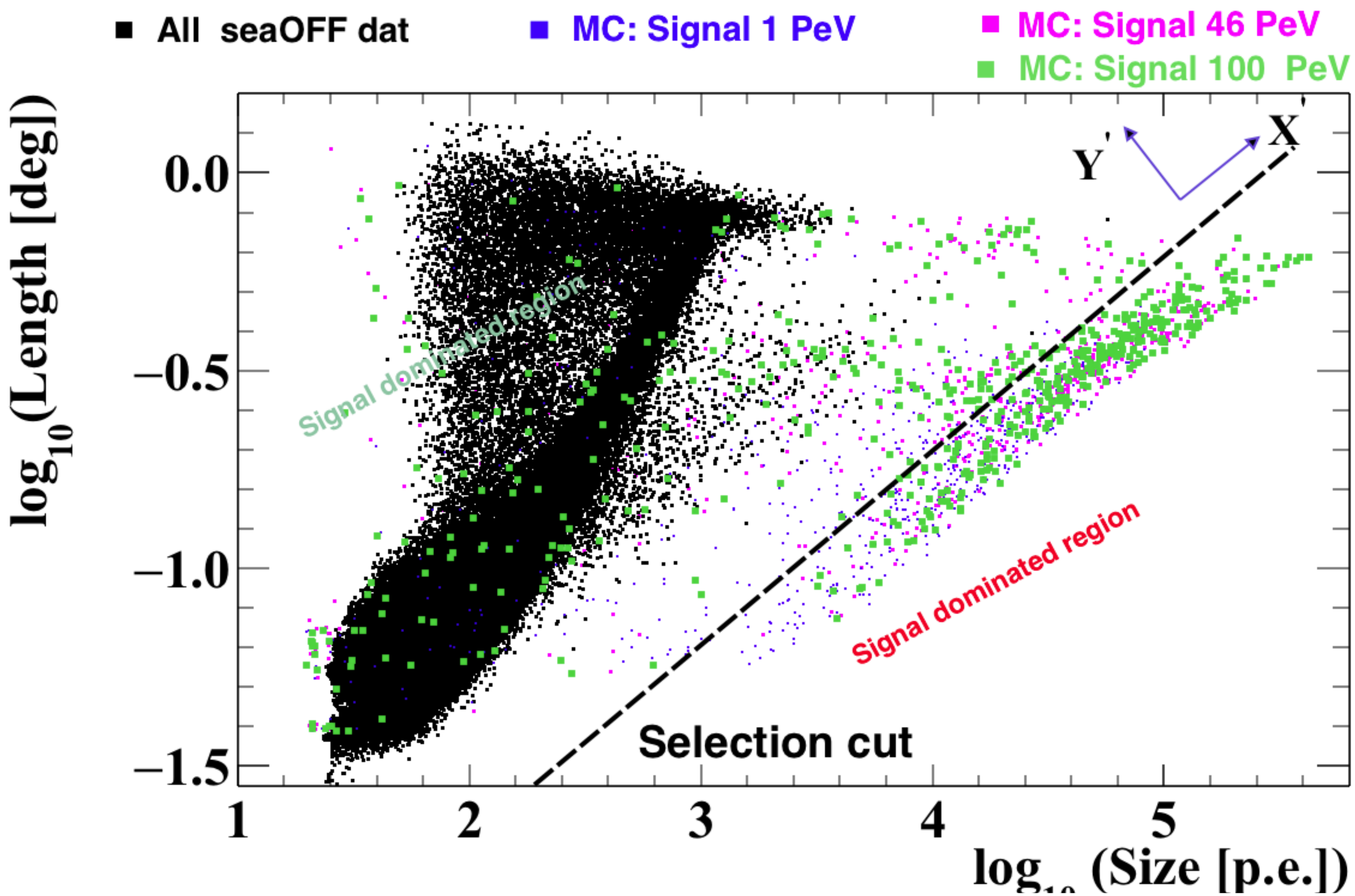
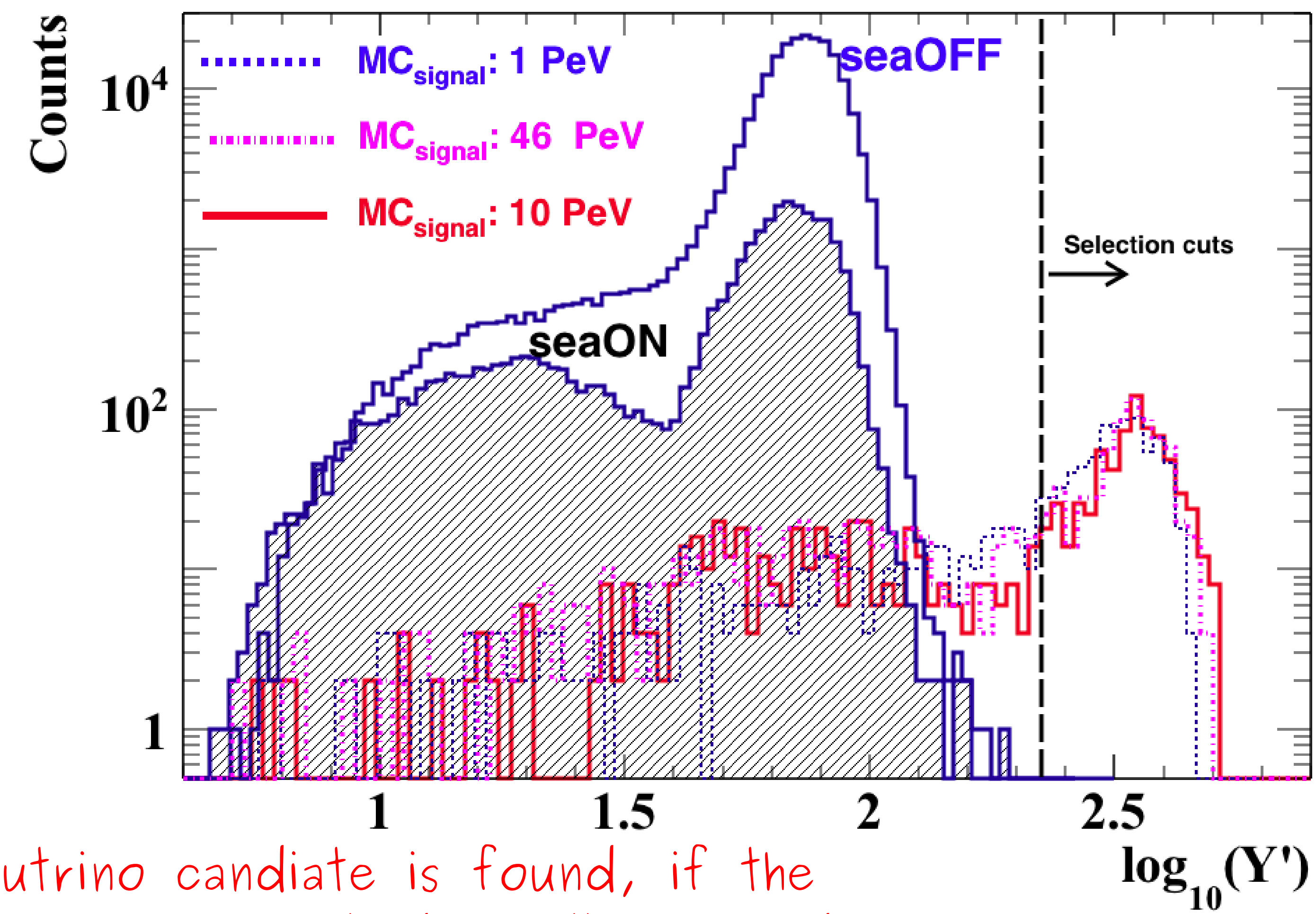
Selection criterion

$$\log_{10}(Y') = \log_{10}(\text{Size}[\text{p.e.}]) * \cos(\alpha) - \log_{10}(\text{Length}[\text{deg}]) * \sin(\alpha),$$
where $\alpha = 63.435°$



Clear discrimination of tau neutrinos from background of hadronic showers!

Selection criterion



NO neutrino candiate is found, if the selection cut is applied to all seeON data

Signal efficiency after the cut $\log_{10}(Y') > 2.35$ about 20–25 % for shower with impact distances smaller than 0.3 km, otherwise $\log_{10}(Y') > 2.10$ was used

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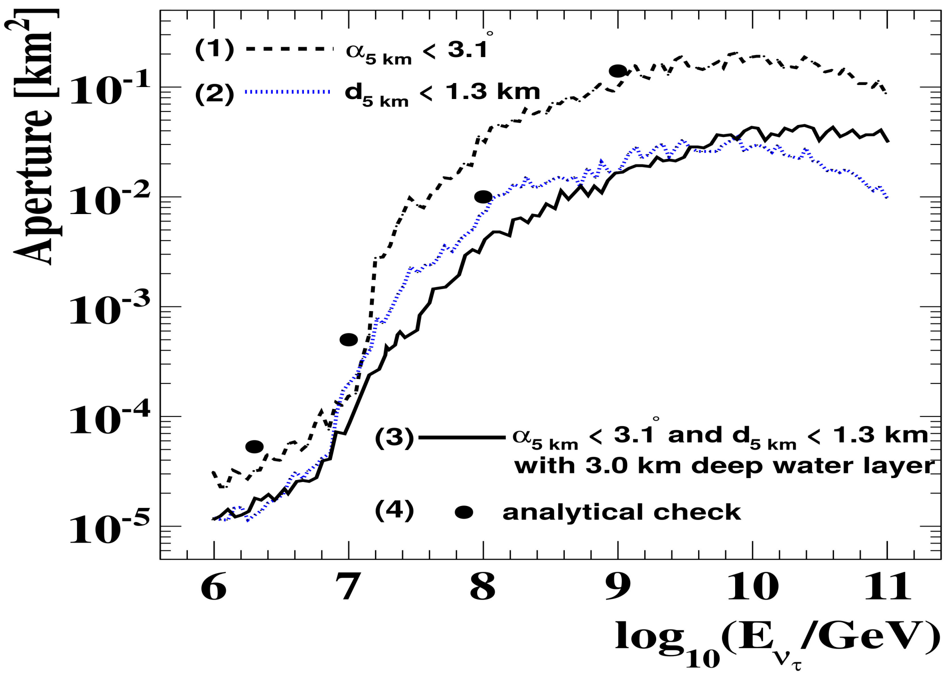
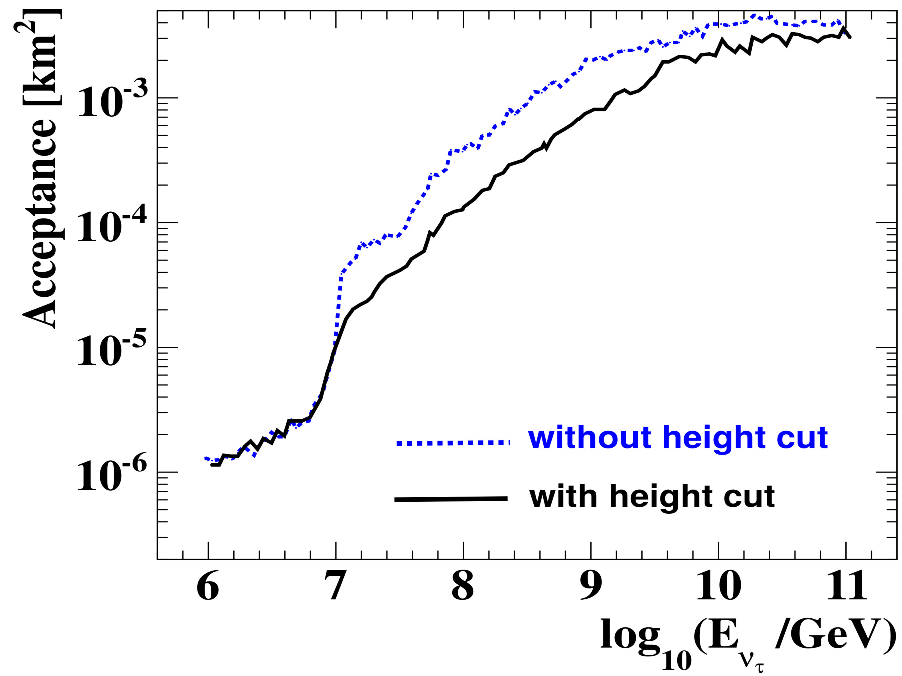
Results!

Tau neutrino point source acceptance for MAGIC

Ahnen et al., Astropart. Phys. 102 (2018) 77–88





E_{ν_τ} (PeV)	$\sigma_{CC}(E_{\nu_\tau})$ (pb)	λ_{ν_τ} (km)	λ_τ (km)	$P(E_{\nu_\tau}, E_\tau, \theta)$	A_{geom} (km^2)	$A(E_{\nu_\tau})$ (km^2)	$A^{ps}(E_{\nu_\tau})$ (km^2)
2	950	6596	0.073	1.0×10^{-5}	5.33	5.3×10^{-5}	1.5×10^{-4}
10	1900	3298	0.367	9.4×10^{-5}	5.33	5.0×10^{-4}	2.7×10^{-4}
100	4800	1305	3.670	1.9×10^{-3}	5.33	1.0×10^{-2}	8.0×10^{-3}
1000	11000	569	36.70	2.6×10^{-2}	5.33	1.4×10^{-1}	2.6×10^{-2}

Comparison of the effective area with our MC estimate

Event rate calculations

Neutrino flux

$$N = \Delta T \times \int_{E_{th}}^{E_{max}} A^{PS}(E_{\nu_\tau}) \times \Phi(E_{\nu_\tau}) \times dE_{\nu_\tau}$$

Observation time

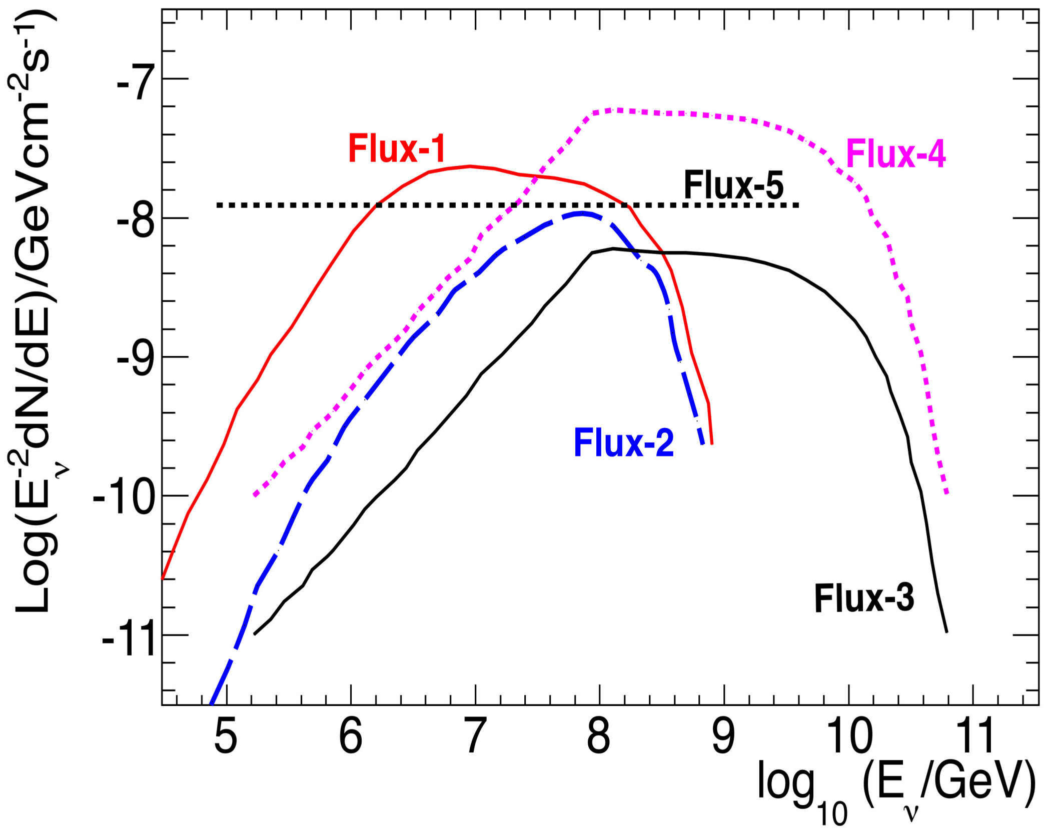
Photo hadronic interactions in AGNs

Flux-1 and Flux-2: 3C 279

Flux-3 and Flux-4: PKS 2155-304

Flux 5: 3C279

Ahnen et al., Astropart. Phys. 102 (2018) 77-88



		Flux-1 ($\times 10^{-5}$/3 hrs)	Flux-2 ($\times 10^{-5}$/3 hrs)	Flux-3 ($\times 10^{-5}$/3 hrs)	Flux-4 ($\times 10^{-5}$/3 hrs)	Flux-5 ($\times 10^{-5}$/3 hrs)
N_{Events}	without height cut	2.4	1.4	0.74	7.4	2.4
N_{Events}	with height cut	1.1	0.6	0.30	2.9	1.2

Flux limit for a point source

$$\phi(E_\nu) = k \times \phi_0 \times E_\nu^{-2}$$
$$\phi_0 = 1 \times 10^{-8}\ [\mathrm{GeV\ cm^{-2}\ s^{-1}}]$$

$$k = \frac{2.44^*}{N_{event}}$$ (90%C.L.)

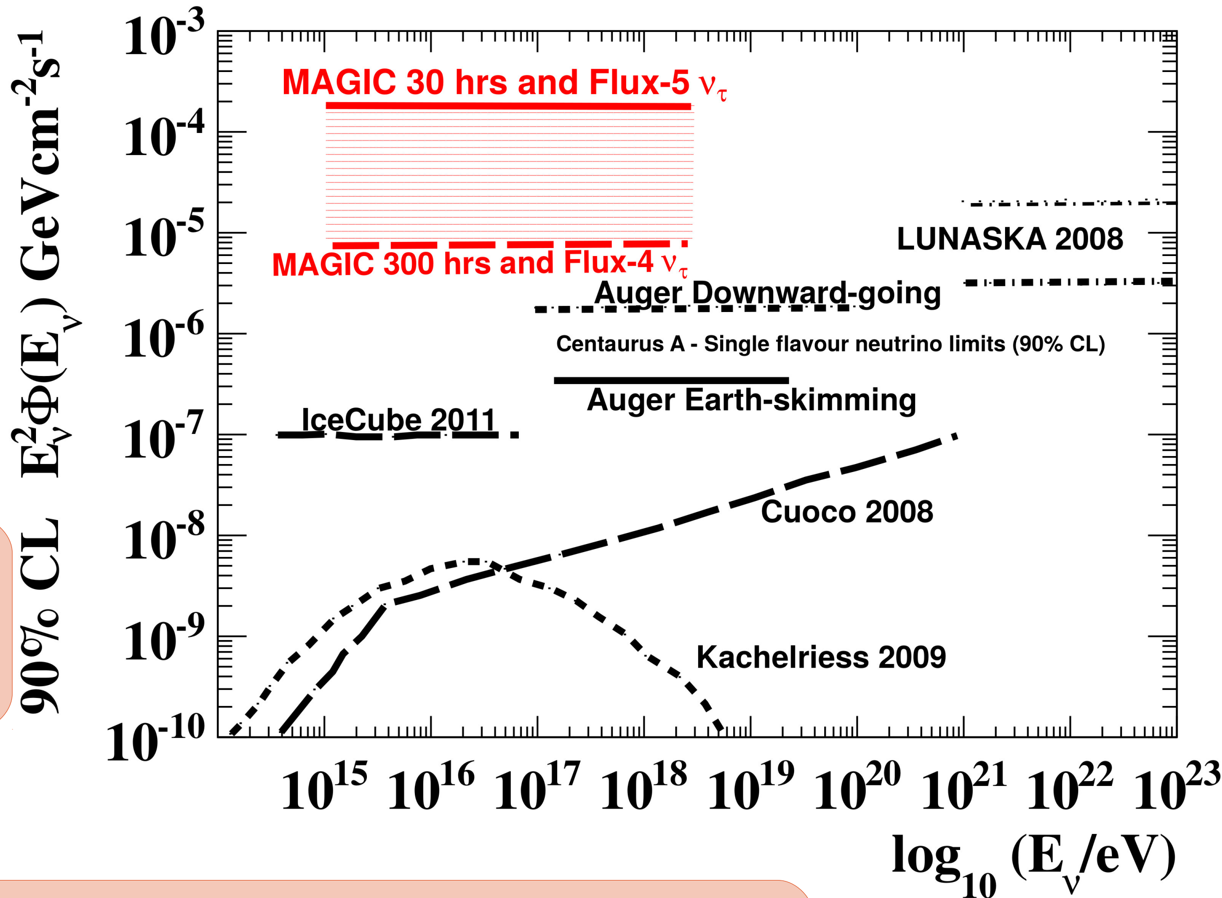
$$\mathrm{N_{event}} = 1.2 \times 10^{-4}$$

30 h

For a Flux-5 like

$$E^2_{\nu_\tau}\Phi^{ps}(E_{\nu_\tau}) < 2.0 \times 10^{-4}\ \mathrm{GeV\ cm^{-2}\ s^{-1}}$$

Ahnen et al., Astropart. Phys. 102 (2018) 77–88



300 h

$$E^2_{\nu_\tau}\phi(E_{\nu_\tau}) < 5.8 \times 10^{-6}[\mathrm{GeV\ cm^{-2}\ s^{-1}}]$$

Summary

- A considerable amount data at horizontal directions (~40 hours) has been collected by MAGIC.

- we show that MAGIC can identify tau neutrino showers from the background of proton showers

- For 30 hours of observation the MAGIC sensitivity for tau neutrinos is at level:

$$E_{\nu_\tau}^2 \Phi^{ps}(E_{\nu_\tau}) < 2.0 \times 10^{-4}\ \text{GeV cm}^{-2}\ \text{s}^{-1}$$

- This is the first time that the sensitivity is calculated with full simulations and with background measurements for IACTs

- more possibilities to detect tau neutrinos with CTA!!!

Thank you!

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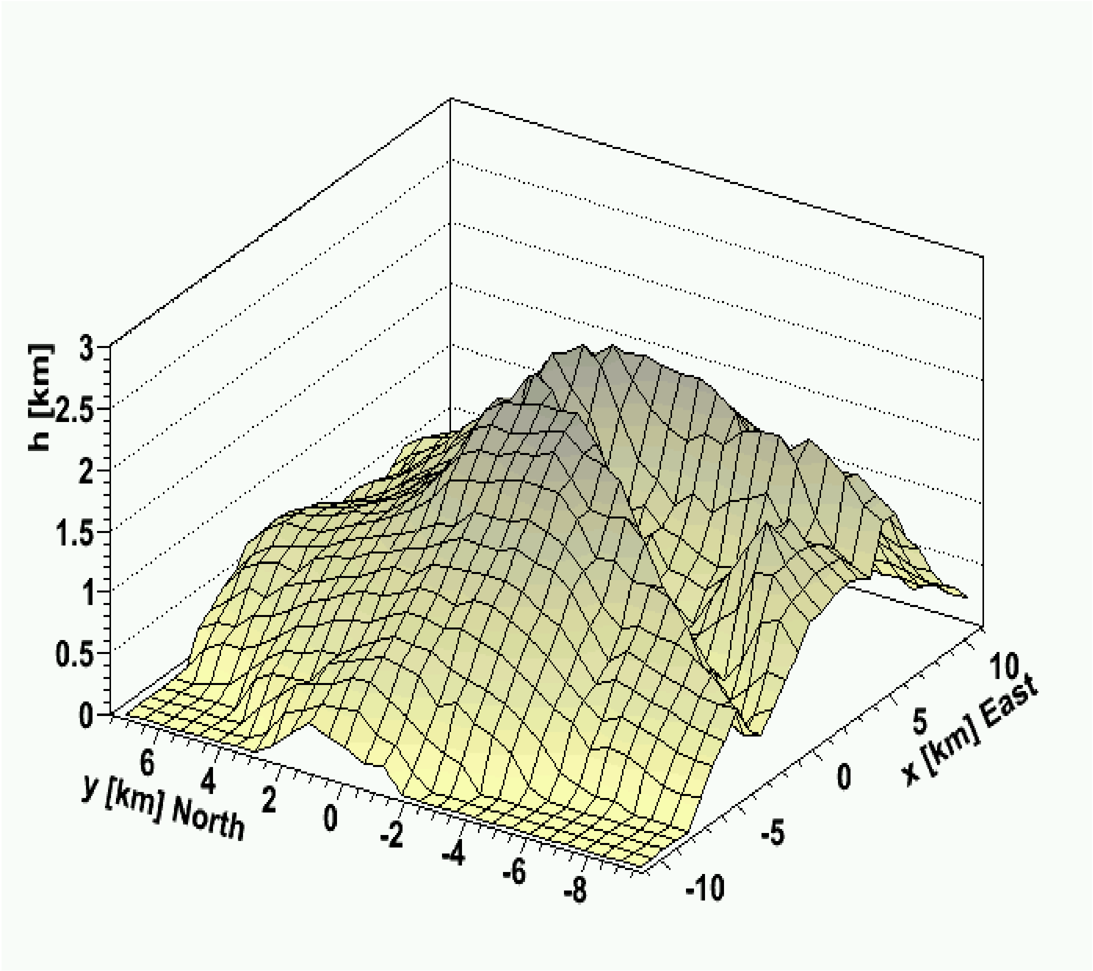
Backup

Orography of MAGIC site



-included in ANIS simulation

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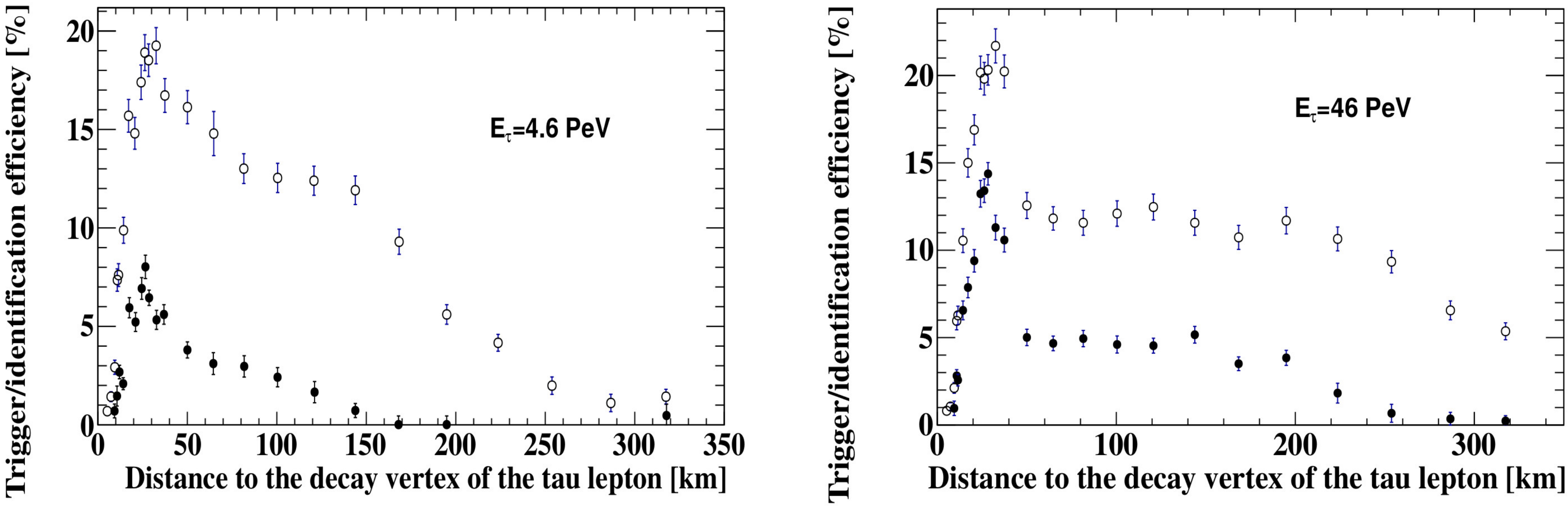
Tau- lepton decay channels implemented

Decay	Secondaries	Probability	Air-shower
$\tau \to \mu^- \bar{\nu}_\mu \nu_\tau$	μ^-	17.4%	weak showers
$\tau \to e^- \bar{\nu}_e \nu_\tau$	e^-	17.8%	1 Electromagnetic
$\tau \to \pi^- \nu_\tau$	π^-	11.8%	1 Hadronic
$\tau \to \pi^- \pi^0 \nu_\tau$	$\pi^-, \pi^0 \to 2\gamma$	25.8%	1 Hadronic, 2 Electromagnetic
$\tau \to \pi^- 2\pi^0 \nu_\tau$	$\pi^-, 2\pi^0 \to 4\gamma$	10.79%	1 Hadronic, 4 Electromagnetic
$\tau \to \pi^- 3\pi^0 \nu_\tau$	$\pi^-, 3\pi^0 \to 6\gamma$	1.23%	1 Hadronic, 6 Electromagnetic
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$	$2\pi^-, \pi^+$	10%	3 Hadronic
$\tau \to \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	$2\pi^-, \pi^+, \pi^0 \to 2\gamma$	5.18%	3 Hadronic, 2 Electromagnetic

-D. Fargion et el., ApJ, 570 (2002) 909

Trigger/identification efficiency

Ahnen et al., Astropart. Phys. 102 (2018) 77–88



An estimate of thetypical distance for tau-induced showers seen by MAGIC

Yes

No