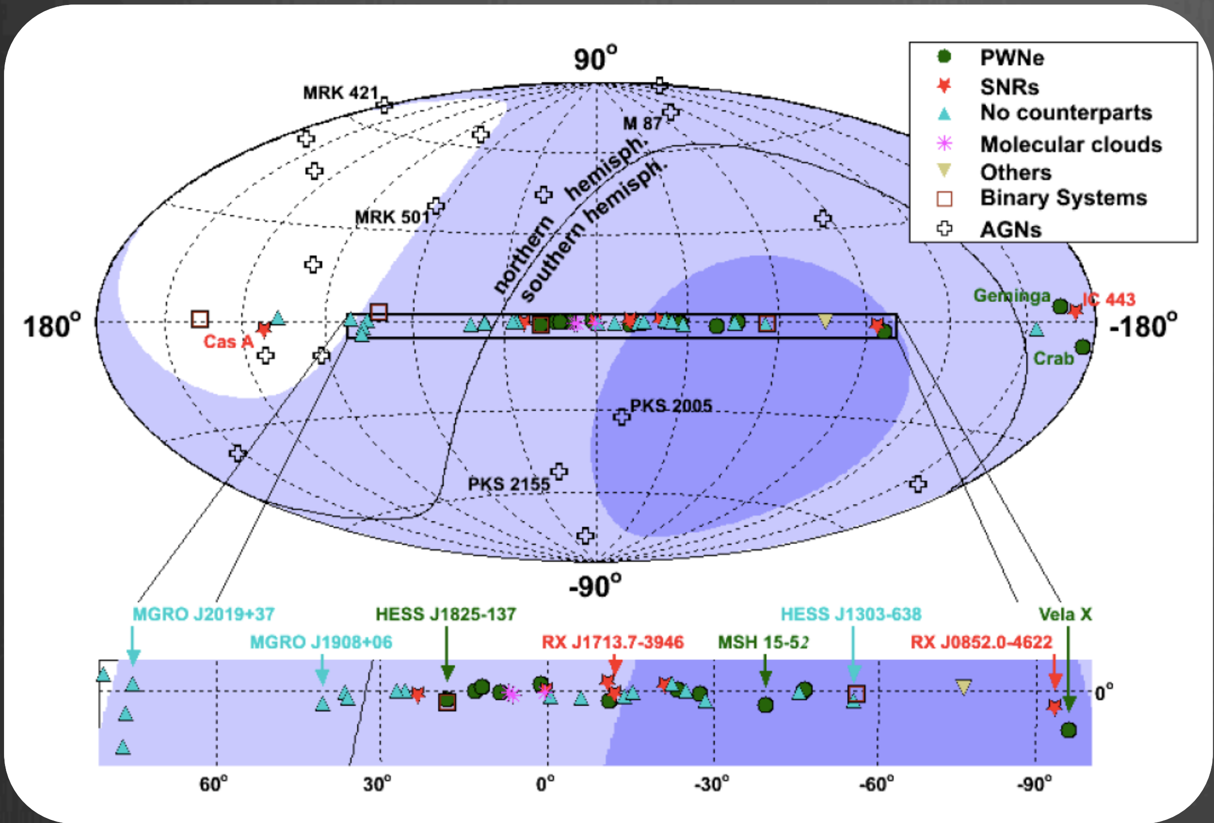
KM3NeT Neutrino Telescope

- KM3NeT: a multi-km^3 sized Neutrino Telescope in the Mediterranean Sea
- Cherenkov technique: ν_μ CC interaction is the "golden channel"
- Focus on tracks coming from below ➔ KM3NeT can observe most of the galactic plane including the galactic center



Our Galaxy is KM3NeT prime field of operation

High Energy Gamma observation

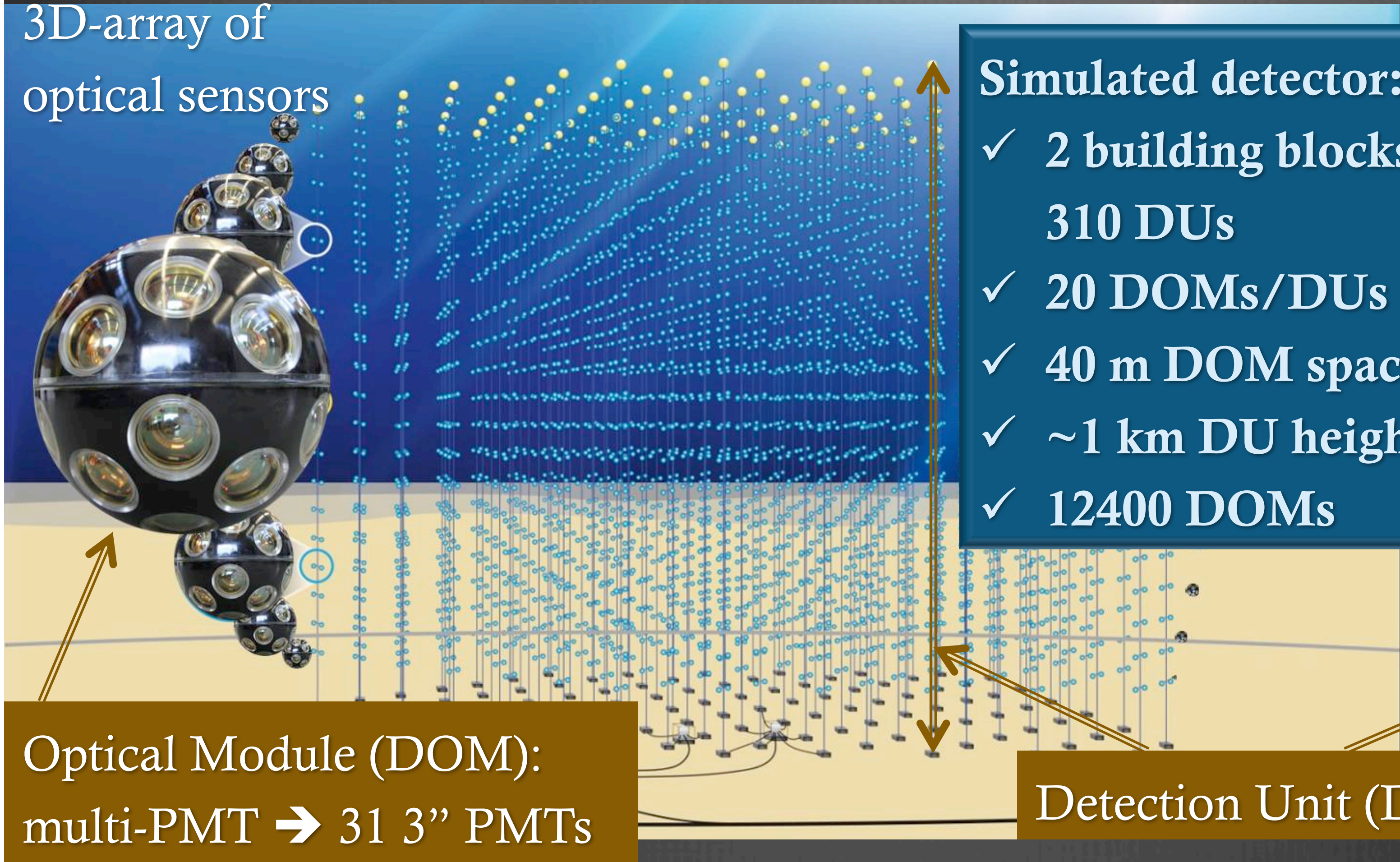
- ✧ The Galactic plane contains the possibly brightest source of neutrinos in the sky. High intensity gamma spectra measured by Fermi LAT, HESS, MAGIC, VERITAS….
- ➢ High-energy gammas of leptonic or hadronic origin? If gammas are originated from π^0 decay also neutrinos should be present.

↓

- ➢ FERMI collaboration (Nature 2013): "Clear pion-decay signature in IC443 and W44 SNR"
- ✧ Estimate of neutrino spectrum based on high-energy gamma observation
- ✧ High energy gamma measurement needed.

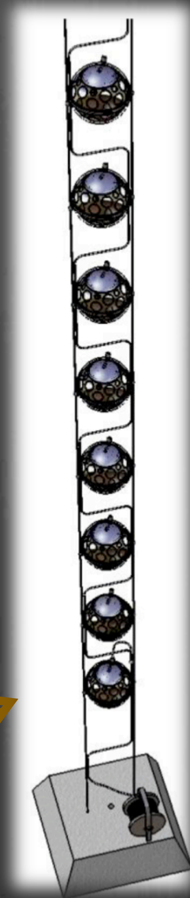
An artist impression of KM3NeT

3D-array of optical sensors



Simulated detector:

- ✓ 2 building blocks with 310 DUs
- ✓ 20 DOMs/DUs
- ✓ 40 m DOM spacing
- ✓ ~1 km DU height
- ✓ 12400 DOMs

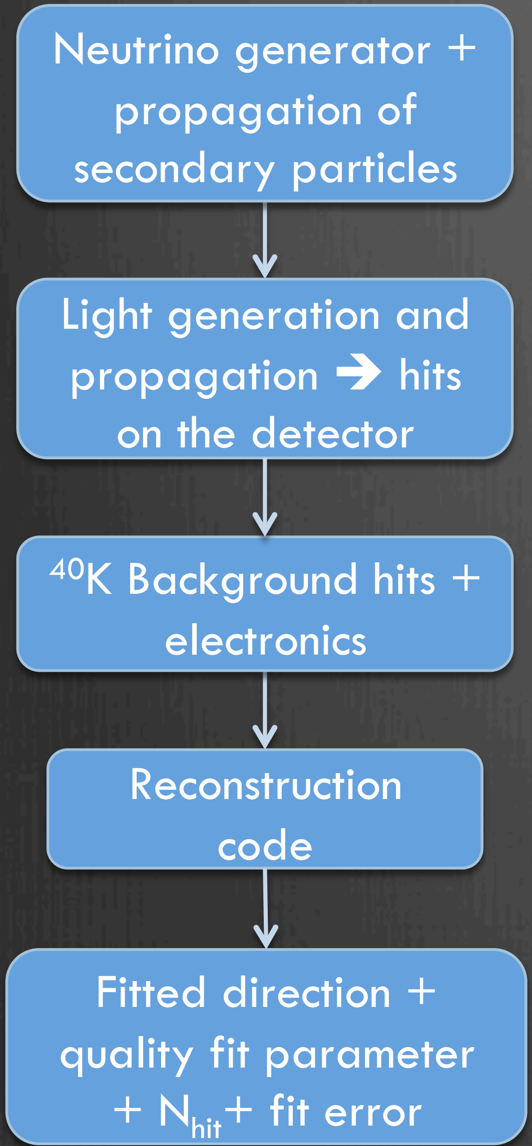


Optical Module (DOM): multi-PMT → 31 3” PMTs

Detection Unit (DU)

- Optical Module (DOM) = pressure resistant glass sphere containing PMTs and electronics
- Detection Units (DU) = vertical string like structures hosting DOMs, environmental sensors, …

Simulation codes



- Codes from Antares modified for a km^3-scale detector
- Trigger, Hit Selection and Reconstruction radically modified to exploit Multi-PMT capabilities

Simulation codes

Neutrino generator + propagation of secondary particles

↓

Light generation and propagation → hits on the detector

↓

^{40}K Background hits + electronics

↓

Reconstruction code

↓

Fitted direction + quality fit parameter + N_{hit} + fit error

- Codes from Antares modified for a km^3-scale detector
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Trigger and hit selection based on space-time coincidences between hit on the same OM (hit amplitude neglected)

Hit accepted in a reduced PMT field of view

Sky scanning with a grid of 3° by 3°

Four consecutive fitting procedures, three of them based on a maximum likelihood fit

Simulation codes

Neutrino generator + propagation of secondary particles

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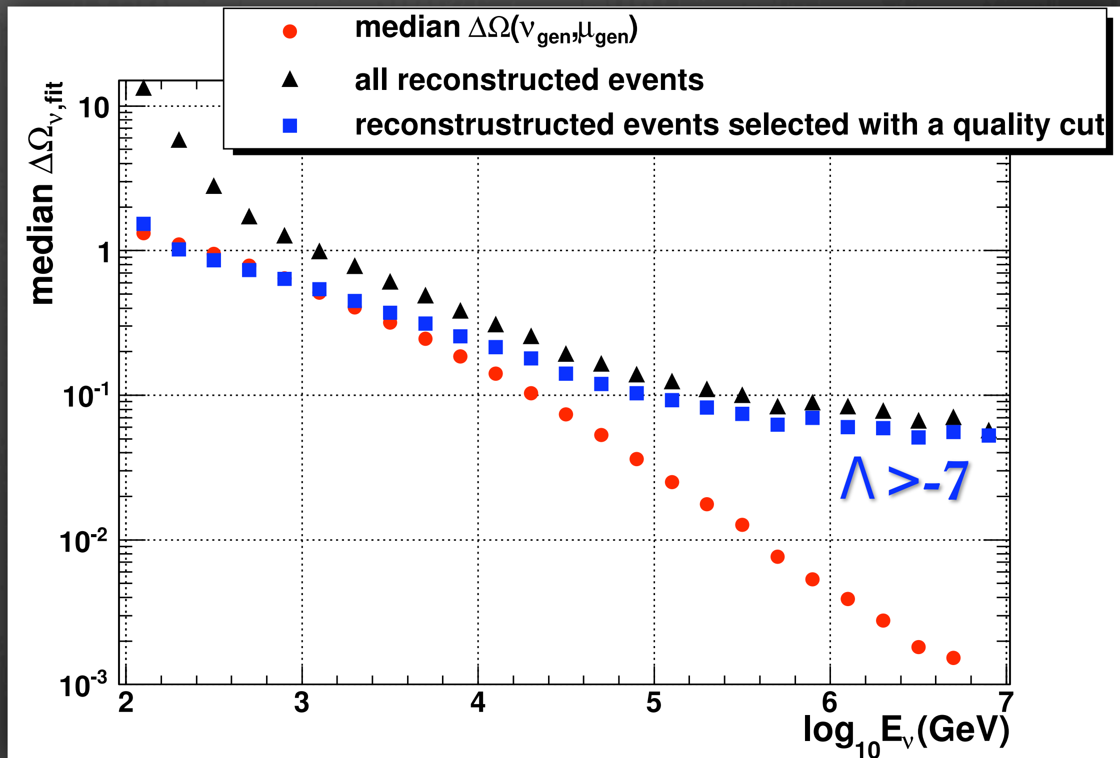
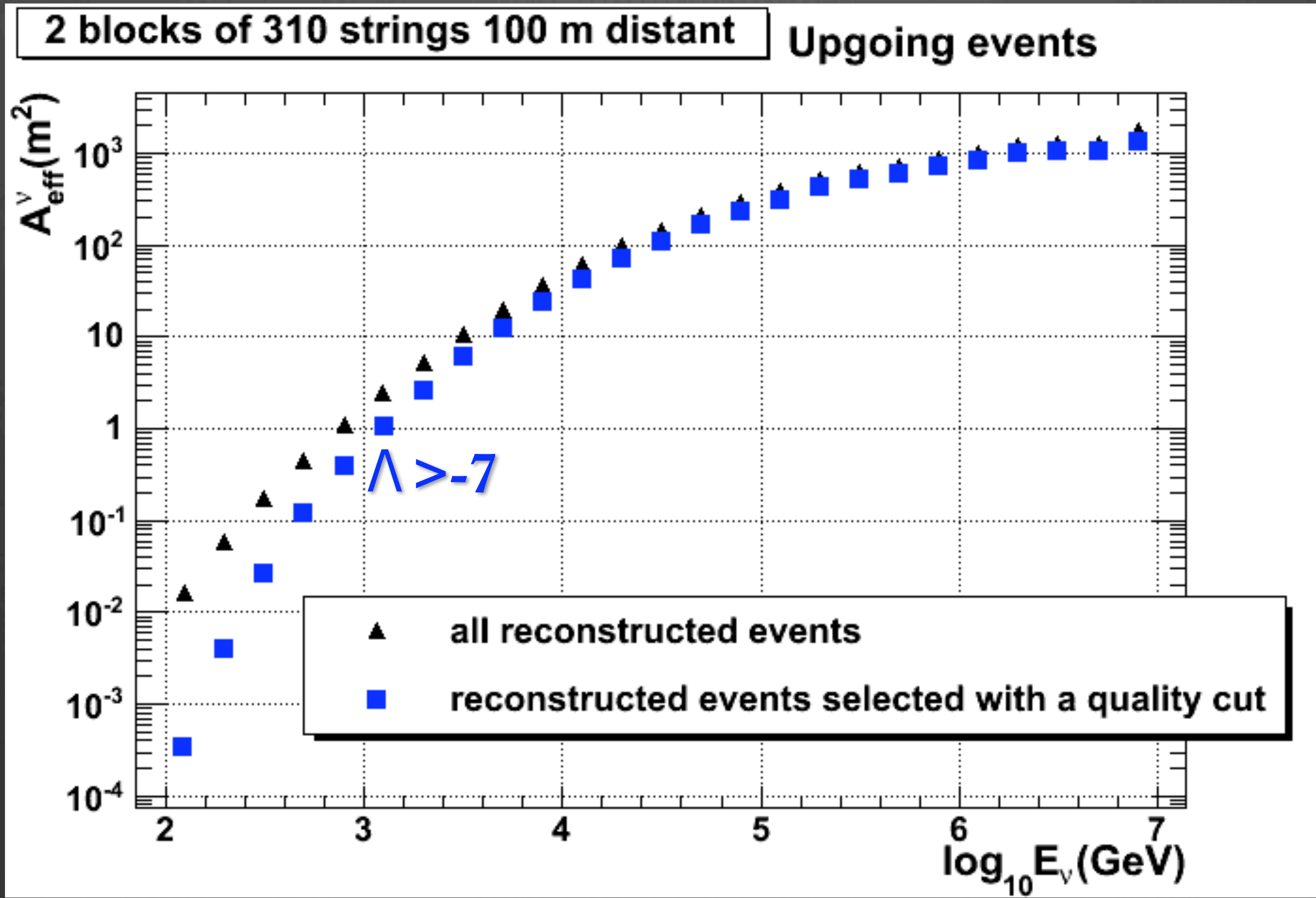


Effective area

The number of signal and background events depends on the ν effective area:

$$\frac{dn}{dt} = \iint dE_\nu \, d\Omega_\nu A^{\nu}_{eff}(E_\nu, \theta_\nu) \frac{d\Phi_\nu}{dE_\nu d\Omega_\nu}$$



Analysis

Statistical technique required to distinguish a neutrino source signal from the background of atmospheric neutrinos (atmospheric muons not considered in this analysis)

Binned method:
analyze the fluctuations on the number of events detected inside a search cone around the source position, assuming a Poisson distribution of the events

Unbinned method:
Maximize a likelihood ratio to evaluate the probability that a set of events is compatible with the hypothesis of "signal+background" instead of background only

Figures of merit:

- **Discovery potential** (signal flux required to obtain an observation at a significance level of 5σ, or 3σ, in 50% of the experiments)
- **Sensitivity** (average upper flux limit that can be given on a neutrino flux model from a source in case of no signal detection; Feldman-Cousins approach used)

Binned method

- Discovery potential and sensitivity minimized selecting events with cuts on:
  - R_{bin}: angular radius of the search cone centred on the source
  - Λ=logL/N_{DOF} (goodness of fit criterion)
  - N_{hit}: number of hits used to reconstruct the event (related to the neutrino energy)
  - $\beta = \sqrt{(\Delta\theta)^2 + (\sin\theta)^2(\Delta\varphi)^2}$ (angular fit error)

Unbinned method

- Number (n) of expected background events in the detector for a chosen time window calculated with the cuts fixed from the binned analysis
- Probability density function for signal (P_{sig}) and background (P_{bg}) events estimated from the MC as a function of the distance from the source α
- Many background samples with n events created and for each sample the maximum value of likelihood ratio LR found (n_{sig} is a free parameter):

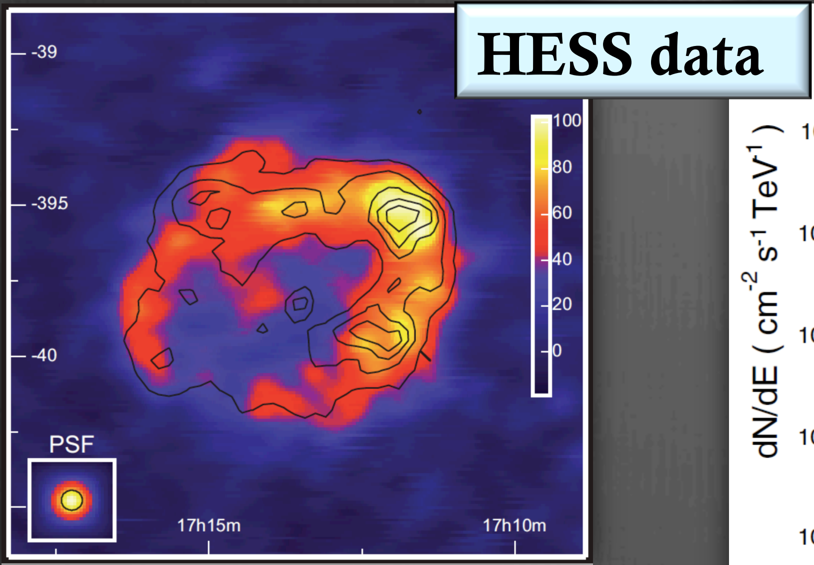
hypothesis of signal+background

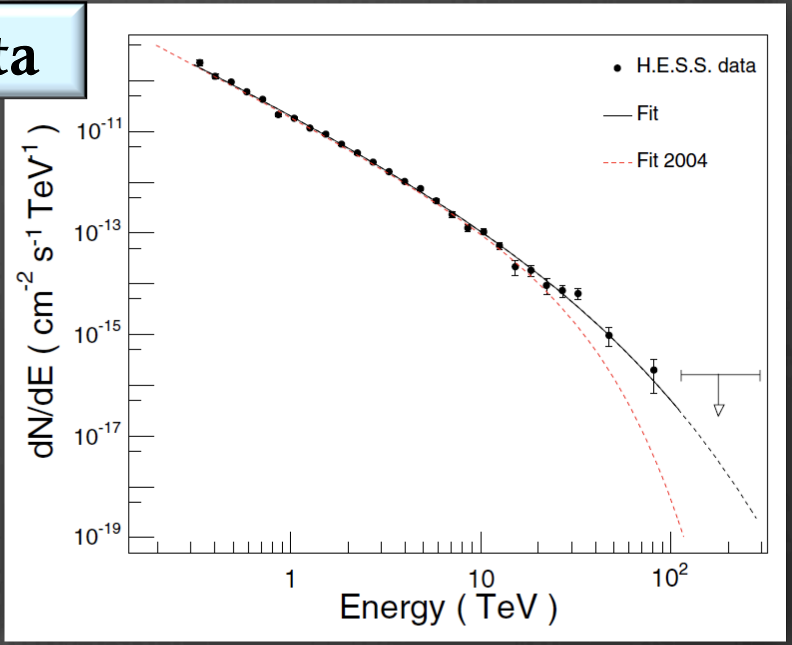
$$LR = \sum_{i=1}^{n} \frac{P(x_i \mid H_{sig+bg})}{P(x_i \mid H_{bg})} = \sum_{i=1}^{n} \log \frac{\frac{n_{sig}}{n} \times P_{sig}(\alpha_i) + (1 - \frac{n_{sig}}{n}) \times P_{bg}(\alpha_i)}{P_{bg}(\alpha_i)}$$

hypothesis of background only

- LR evaluated for samples containing only bkg events and for samples with signal events added to the bkg events
- LR used as a test statistic

RX J1713.7-3946





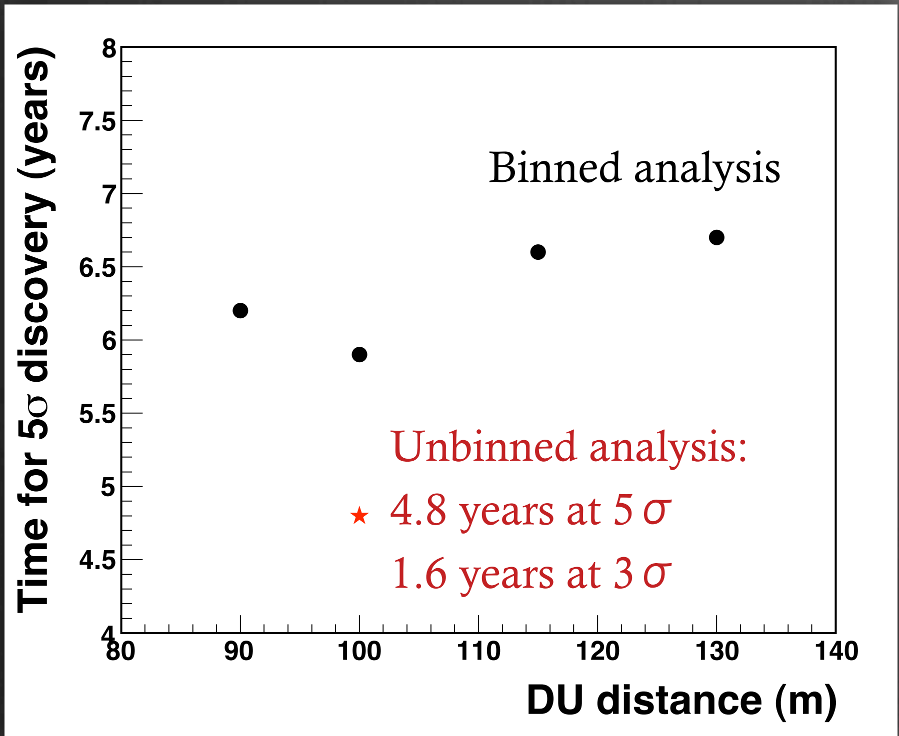
Good reference case:

- ✓ High γ-ray flux measured
- ✓ γ-ray spectrum measured up to about 100 TeV
- ✓ Visible for about the 75% of the time by KM3NeT

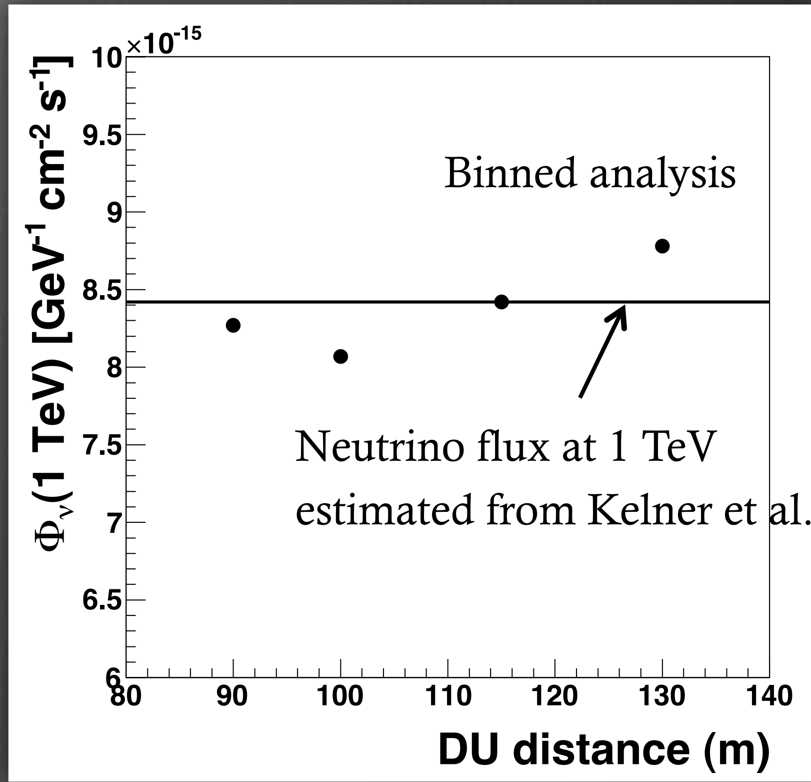
Source simulated as a neutrino emitting homogeneous disk of 0.6° radius and a neutrino spectrum calculated following Kelner et al., PRD 74 (2006) 034018 (100% hadronic emission)

$$\Phi(E) = 16.8 \times 10^{-15} \left[\frac{E}{TeV}\right]^{-1.72} e^{-\sqrt{\frac{E}{2.1 TeV}}} GeV^{-1} s^{-1} cm^{-2}$$

RX J1713.7-3946



Number of years required to claim a discovery as a function of DU distance



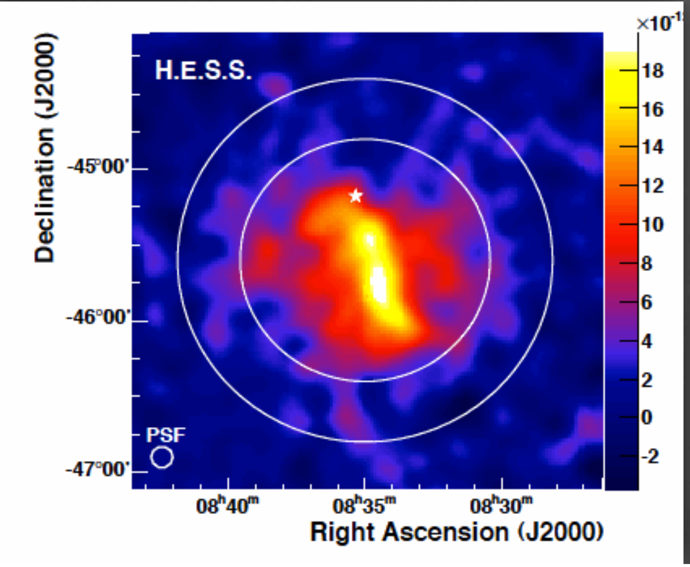
Flux sensitivity (90% CL) at 1 TeV as a function of DU distance (time=1 year)

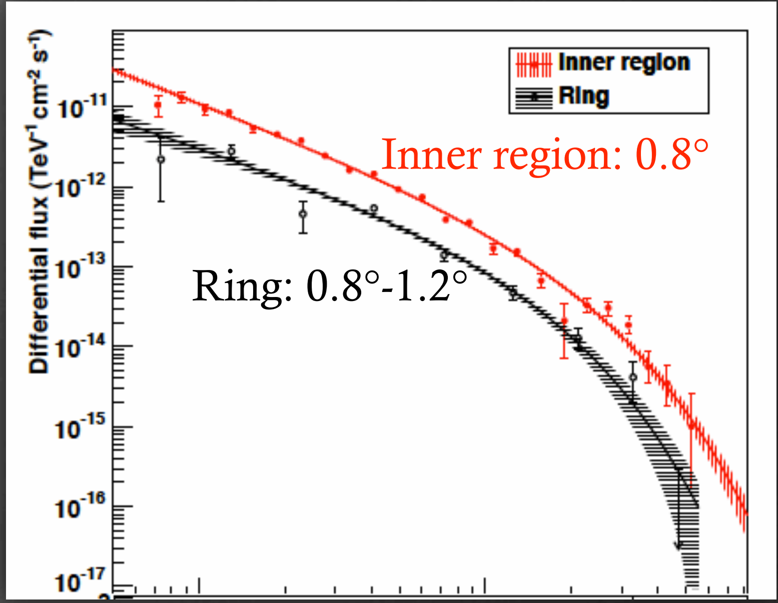
Best performance found for a detector with an average inter-DU distance of 100 m:

➔ Discovery of RXJ1713.7-3946 after about 5 observation years

Vela X

- Vela X: Pulsar Wind Nebula at δ=-45.6°
- First VHE γ-ray emission reported by HESS in 2006
- New analysis in 2012 (Aharonian et al. A&A 548 (2012) A38)
  ➔ higher flux and harder energy spectrum



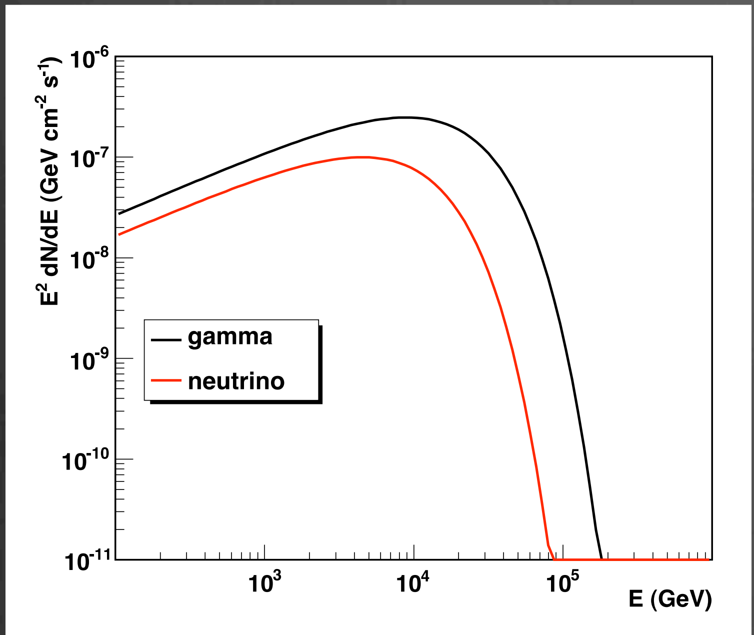


$$d\Phi/dE = N_0 (E/1\text{TeV})^{-\Gamma} \exp(-E/E_{cut})$$

Region	Γ	E_{cut} (TeV)	N_0 (10^{-12} cm^{-2} s^{-1} TeV^{-1})	$\Phi_{>1TeV}$ (10^{-12} cm^{-2} s^{-1})
Inner	$1.36 \pm 0.06_{stat} \pm 0.12_{sys}$	$13.9 \pm 1.6_{stat} \pm 2.6_{sys}$	$11.6 \pm 0.6_{stat} \pm 2.4_{sys}$	$16.0 \pm 1.3_{stat} \pm 3.3_{sys}$
Ring	$1.14 \pm 0.2_{stat} \pm 0.12_{sys}$	$9.5 \pm 2.7_{stat} \pm 1.7_{sys}$	$3.3 \pm 0.6_{stat} \pm 0.7_{sys}$	$4.9 \pm 1.4_{stat} \pm 1.1_{sys}$
Total	$1.32 \pm 0.06_{stat} \pm 0.12_{sys}$	$14.0 \pm 1.6_{stat} \pm 2.6_{sys}$	$14.6 \pm 0.8_{stat} \pm 3.0_{sys}$	$21.0 \pm 1.9_{stat} \pm 4.4_{sys}$

Vela X

- Source simulated as a neutrino emitting homogeneous disk of 0.8° radius (inner region)
- Neutrino spectrum derived using the Vissani prescription* (hypothesis of transparent source and 100% hadronic emission)



* F.L. Villante and F. Vissani, PRD 78 (2008) 103007; F. Vissani and F.L. Villante, NIM A588 (2008) 123; F. Vissani, Astr. Phys. 26 (2006) 310

$d\Phi_\nu/dE_\nu = N * (E_\nu/1TeV)^{-\Gamma} \exp(-E_\nu/E_{cut})$

- $N = 0.72\ 10^{-14}\ GeV^{-1}s^{-1}cm^{-2}$
- $\Gamma = 1.36$
- $E_{cut} = 7$ TeV

Preliminary results with a binned analysis (100 m DU distance):

➔ Discovery at 5 σ (3 σ) after 3.3 (1.2) observation years

Conclusions and perspective

- ✓ Optimization aiming at the detection of galactic point-like sources using as test cases RXJ1713.7-3946 and Vela X
- ✓ <u>At least the more intense galactic point-like source within reach of KM3NeT in few years of operation</u>
- ➢ Work in progress: Consideration of more realistic source morphologies extrapolated from the HE gamma-ray maps, study of other sources, stacking analysis

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- ✧ KM3NeT technology has been developed ➔ Validation process of DOM and DUs ongoing
- ✧ New reference detector defined taking into account technical constraints (6 building blocks of 115 DUs each, 18 DOM/DU, 38 m DOM spacing, 90 m DU spacing)
- ✧ Funds available to start the construction