Potential of KM3NeT to observe galactic neutrino point-like sources

A. Trovato, INFN-LNS (Italy)

on behalf of the KM3NeT Collaboration

Introduction

- KM3NeT: a multi-km^3 sized Neutrino Telescope in the Mediterranean Sea
- Cherenkov technique: ν_μ CC interaction is the "golden channel"

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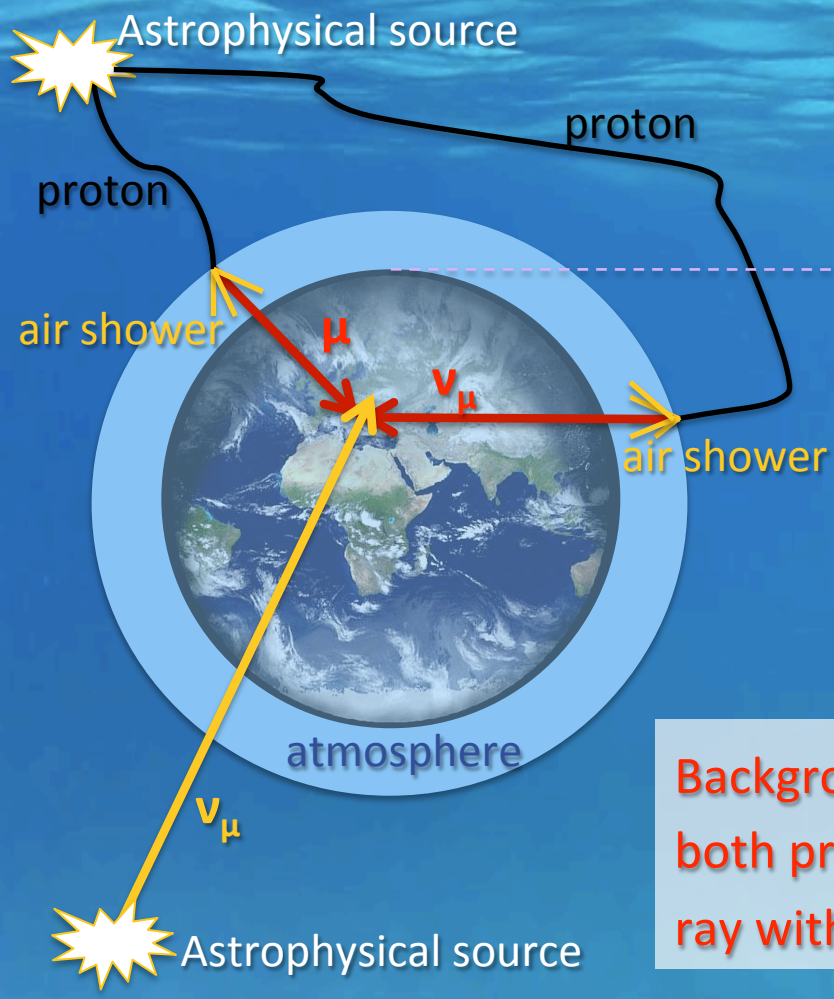
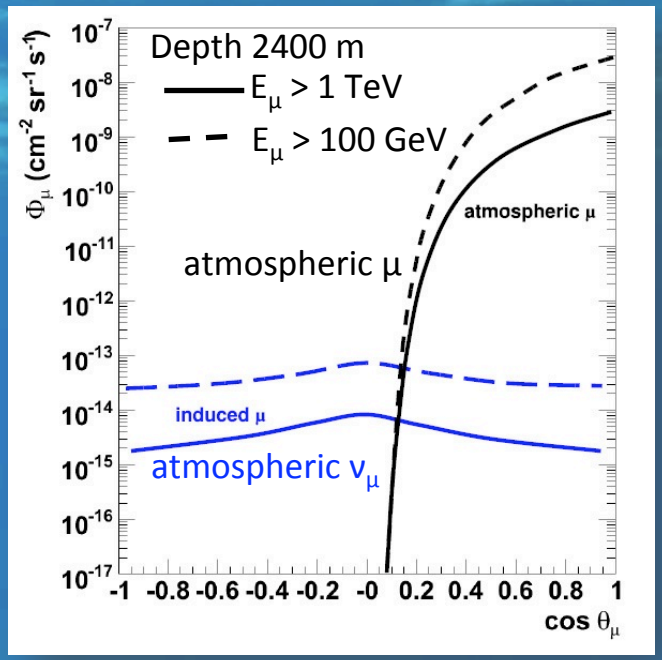


μ dominated

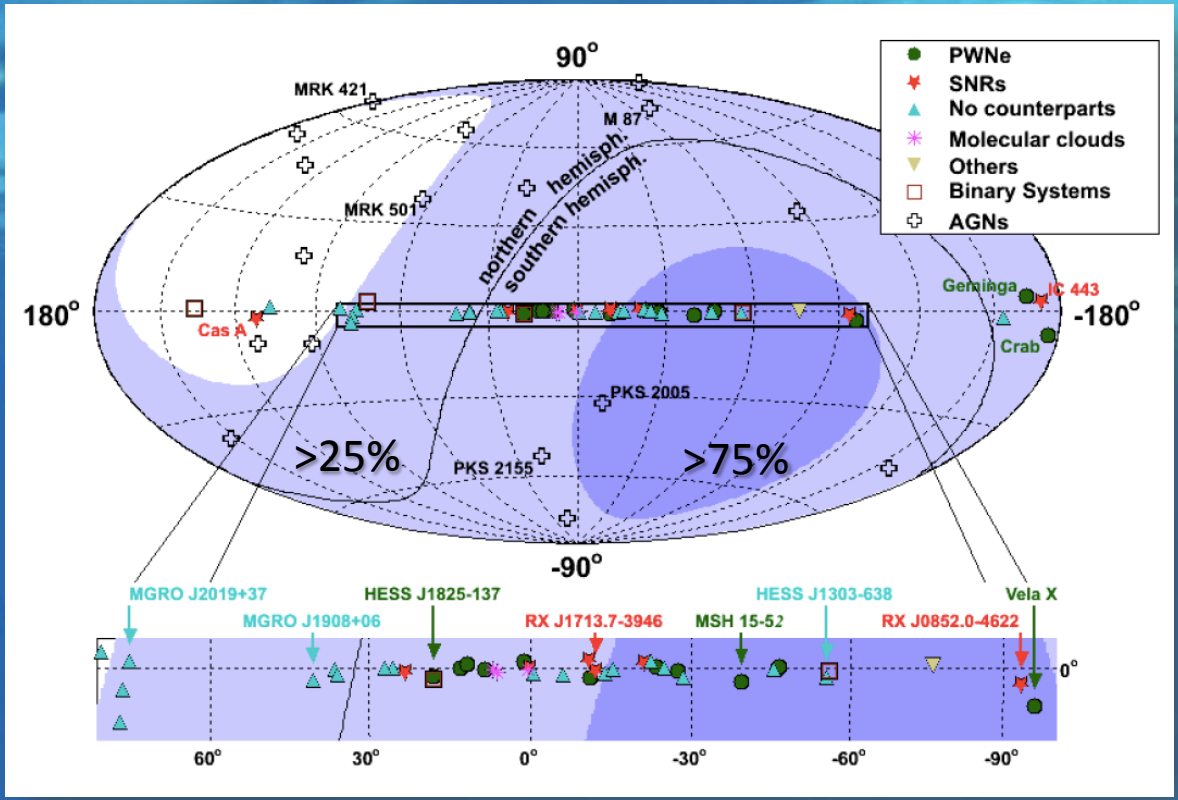
ν dominated

Focus on up-going tracks



Background due to atmospheric muons and neutrinos both produced by the interaction of primary cosmic ray with the atmosphere

Neutrino sky from the Mediterranean Sea



Visibility for up-going neutrinos from Mediterranean Sea

- KM3NeT observes a large part of the sky (~3.5π), in particular the galactic centre and most of the galactic plane
- KM3NeT complements the IceCube field of view
- This work focus on search for point-like sources (especially galactic) exploiting the good angular resolution in sea water

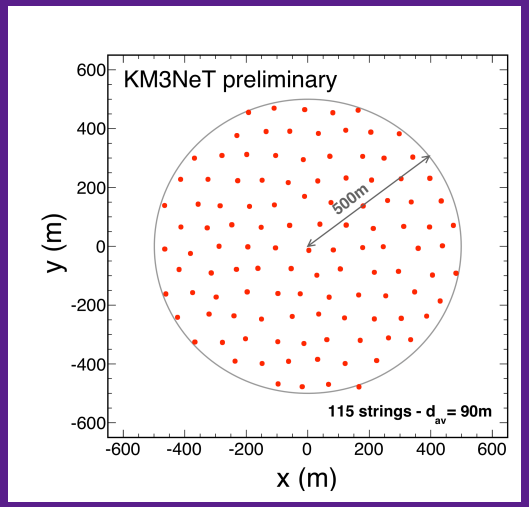
An artist impression of KM3NeT

3D-array of optical sensors

Building block concept:
Full detector → 6 blocks

KM3NeT building block:

- ✓ 115 DUs
- ✓ 18 DOMs/DUs
- ✓ 36 m DOM spacing
- ✓ ~0.6 km³



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

Detection Unit (DU)

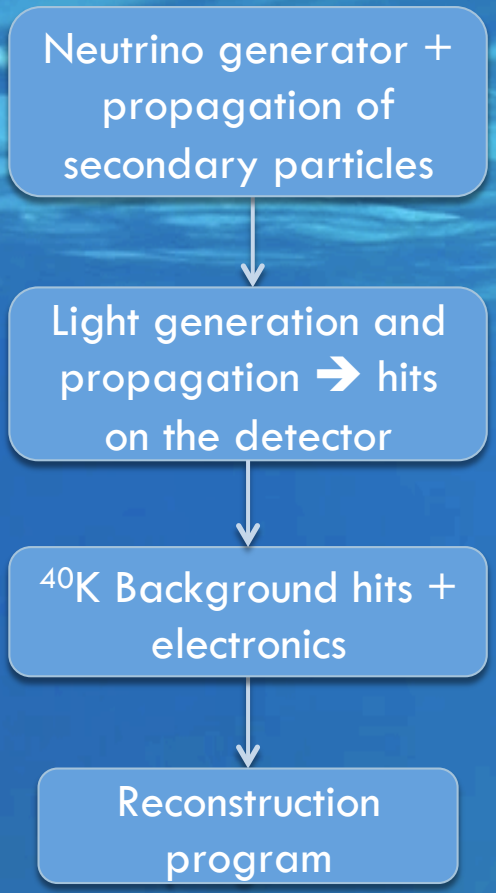
- Optical Module (DOM) = pressure resistant glass sphere containing PMTs and electronics
- Detection Units (DU) = vertical string like structures hosting DOMs, environmental sensors, …

Impact of IceCube results

- ✓ IceCube observation of 37 cosmic ν events open the field of neutrino astronomy
- ✓ This result confirms that Gton detectors are needed

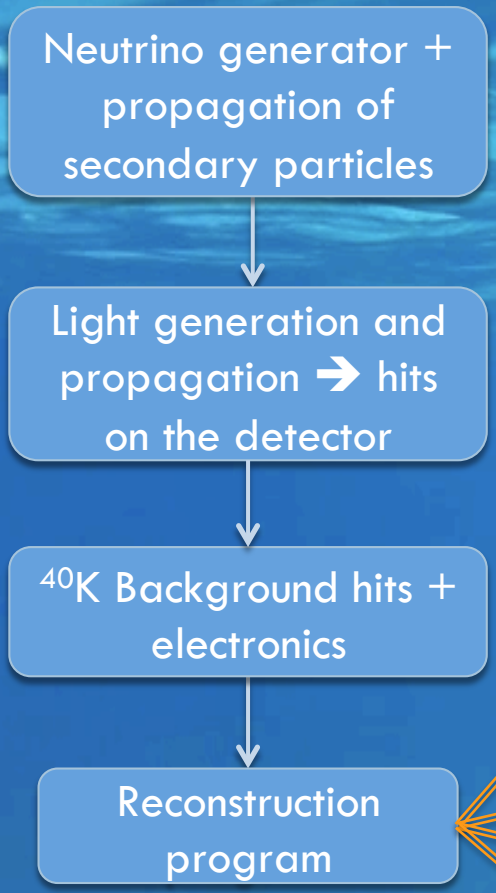
- ✓ **KM3NeT phase1.5**
  - ➢ KM3NeT phase 1.5 = 2 building blocks ≈ $1km^3$
  - ➢ Measurement of cosmic neutrinos with a Gton telescope in the Mediterranean Sea and comparison with the IceCube results
  - ➢ Neutrino diffuse flux → see L. Fusco poster
  - ➢ Results for the point source analysis presented here both for the full detector (phase2) and for the phase1.5

Simulation programs



- Simulation programs of ANTARES modified for a km^3-scale detector
- Trigger, Hit Selection and Reconstruction radically modified to exploit Multi-PMT peculiarities

Simulation programs



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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 procedure, three of them based on a maximum likelihood fit

Simulation programs

Neutrino generator + propagation of secondary particles

↓

Light generation and propagation ➔ hits on the detector

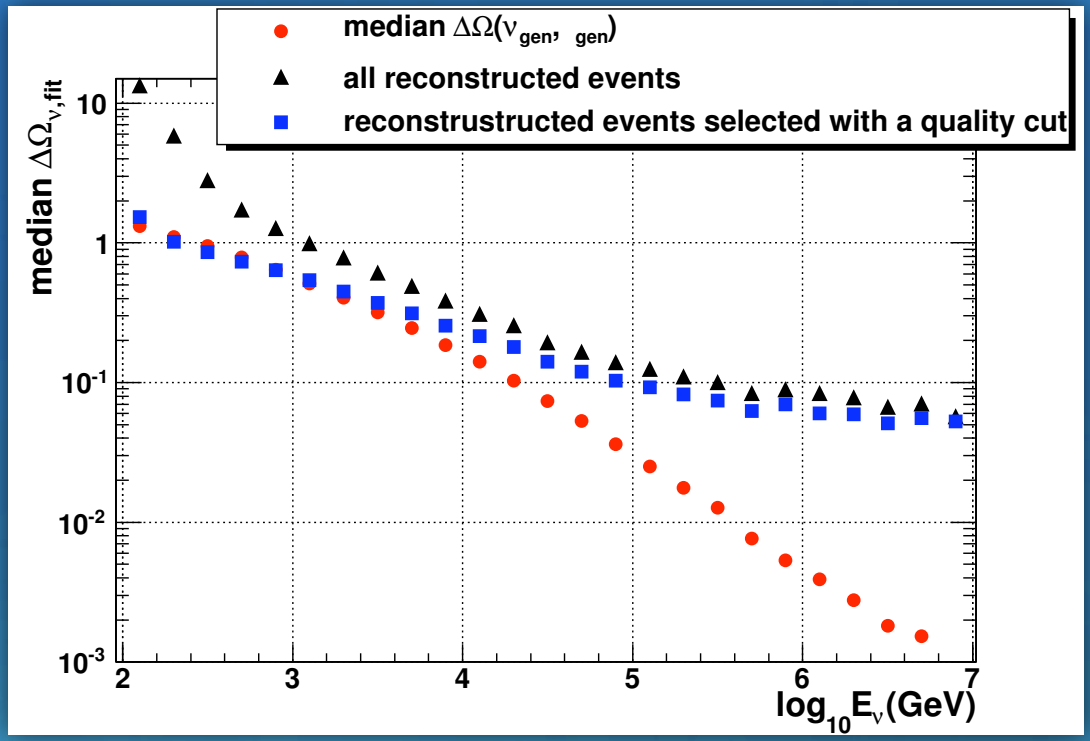
↓

^{40}K Background hits + electronics

↓

Reconstruction program

- Simulation programs of ANTARES modified for a km^3-scale detector
- Trigger, Hit Selection and Reconstruction radically modified to exploit Multi-PMT peculiarities



Analysis

- Point source searches: look in a narrow region of the sky around the location of the source for a statistical excess above the large background of atmospheric muons and neutrinos

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.

Cuts on:

reconstructed zenith angle θ_{rec} , radius of the search cone, reconstruction quality parameter Λ, number of hits N_{hit}

Unbinned method:

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

Figure of merit:

- **Discovery potential** (signal flux required to obtain an observation at a significance level of 5σ, or 3σ, in 50% of the experiments)

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 ($\mathbf{P_{sig}}$) and background ($\mathbf{P_{bg}}$) events estimated from the MC as a function of the distance from the source **α**
- 50000 background samples with n events created and for each sample the maximum value of likelihood ratio LR found ($\mathbf{n_{sig}}$ is a free parameter):

hypothesis of signal+background

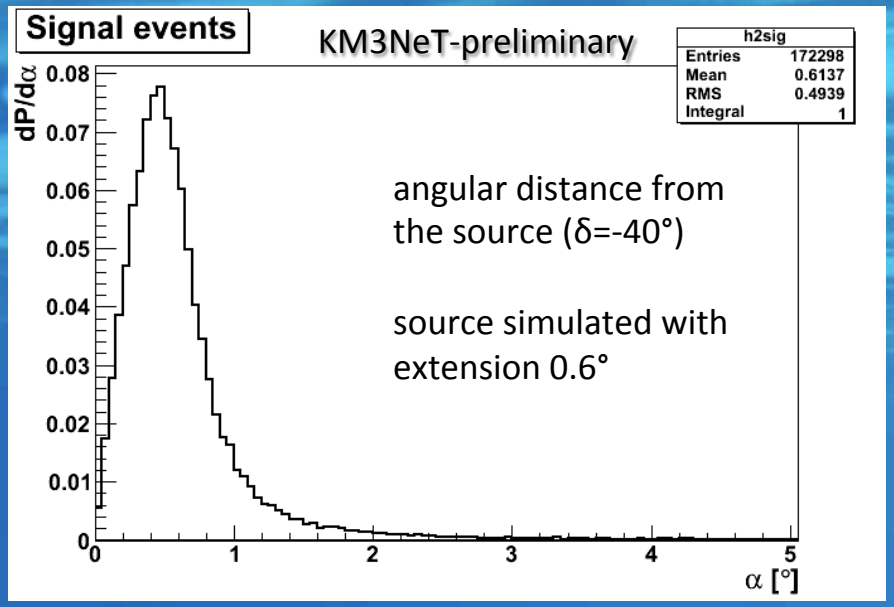
$$LR = \log\left[\frac{P(data \mid H_{bkg+sig})}{P(data \mid H_{bkg})}\right] = \sum_{i=1}^{n} \log \frac{\frac{n_{sig}}{n} \times P_{sig}(\alpha_i, Nhit_i) + \left(1 - \frac{n_{sig}}{n}\right) \times P_{bkg}(\alpha_i, Nhit_i)}{P_{bkg}(\alpha_i, Nhit_i)}$$

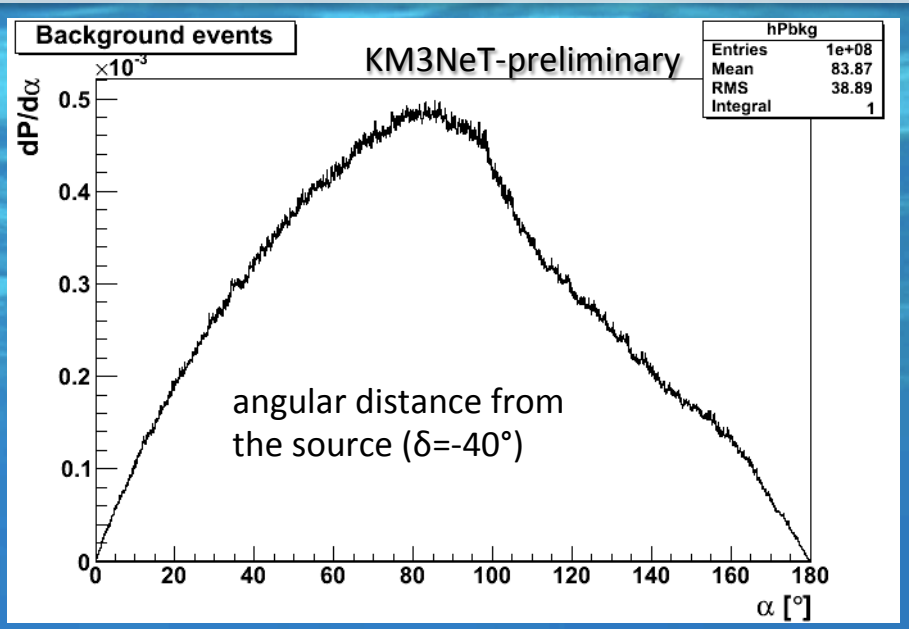
hypothesis of background only

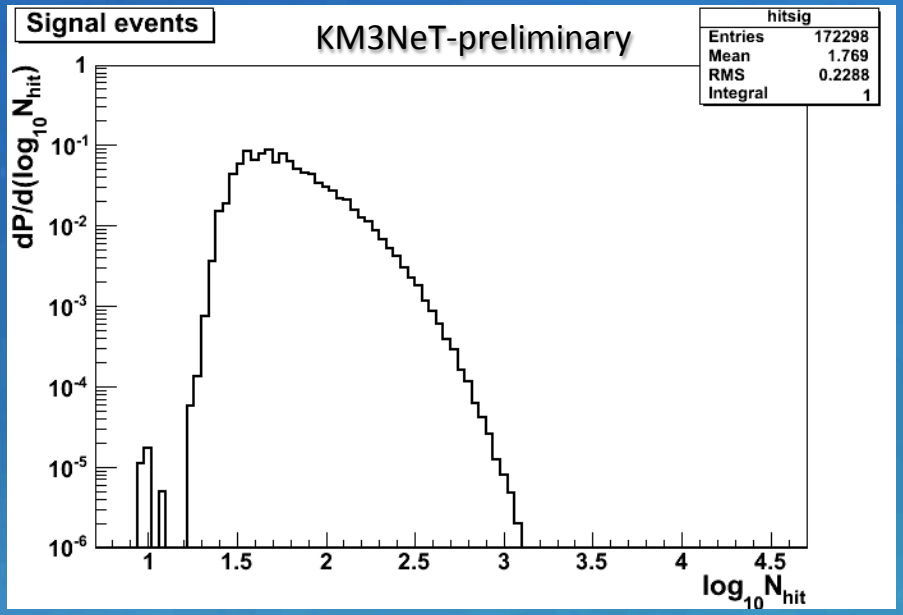
P(α,Nhit)=P(α)*P(Nhit)

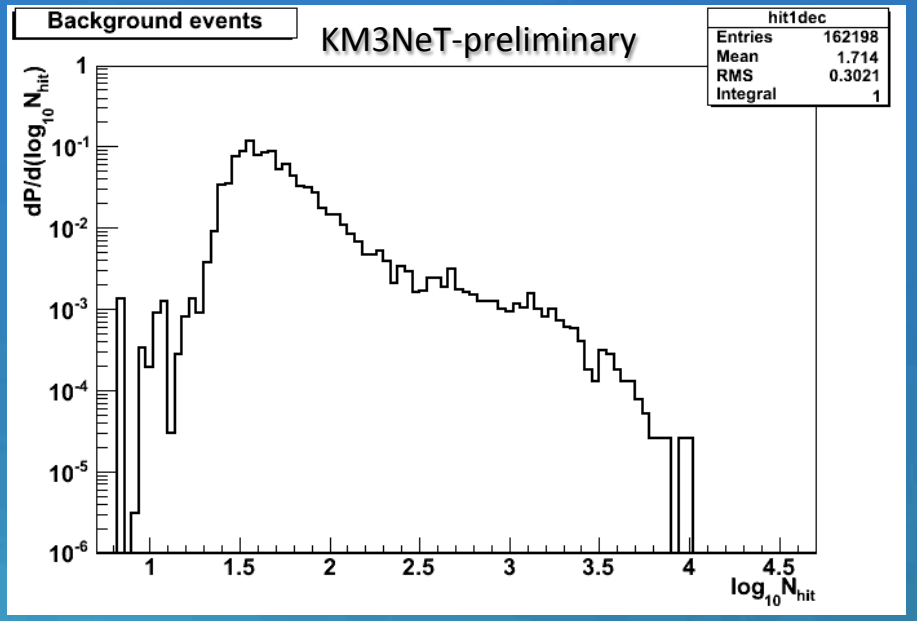
- LR evaluated for samples containing only bkg events and for samples with signal events added to the bkg events
- LR used as a test statistic

Unbinned method

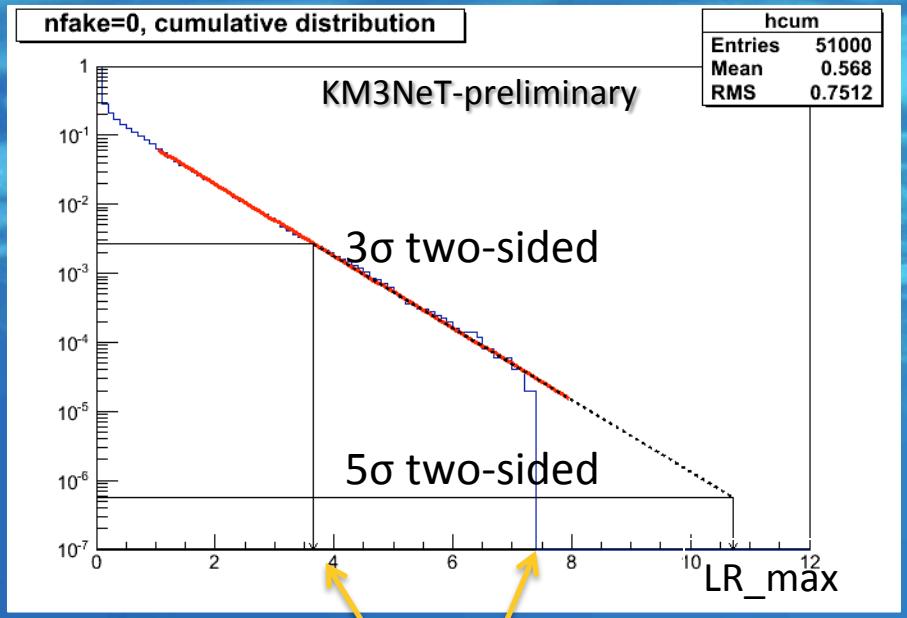


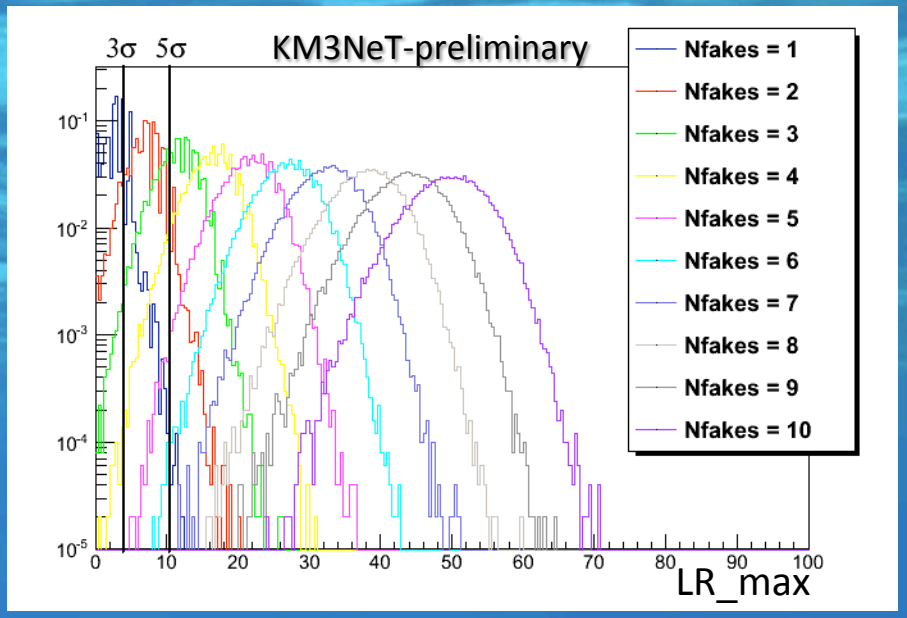




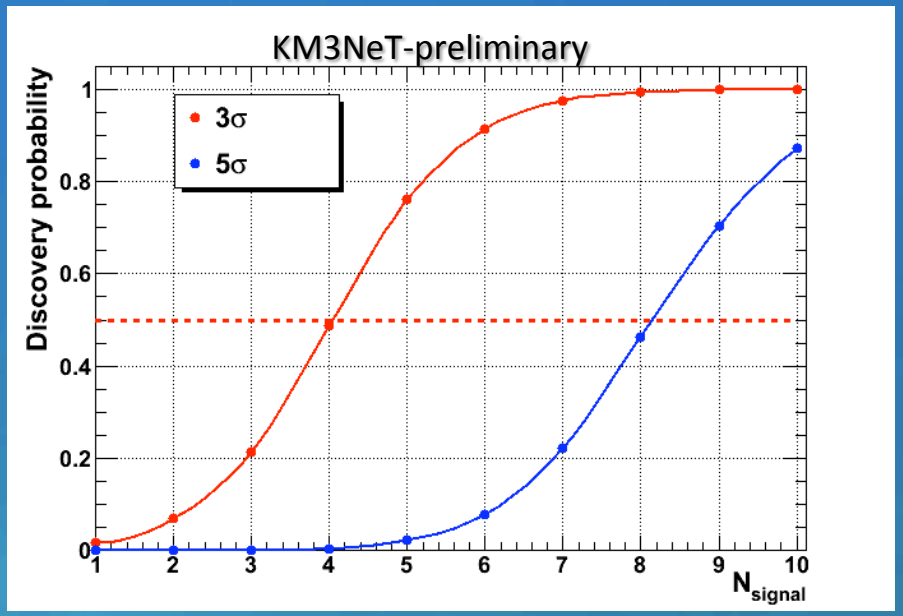


Unbinned method





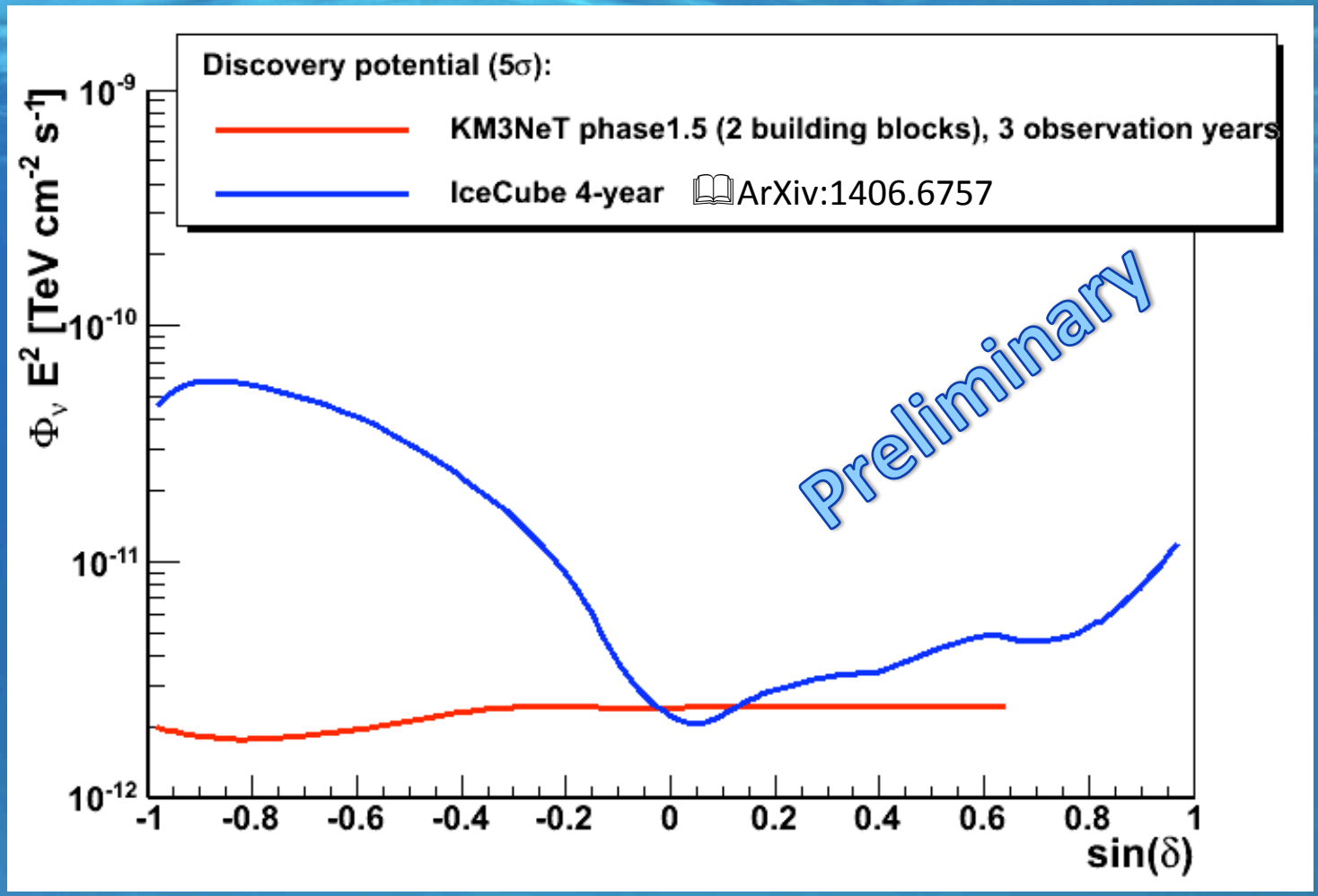
- Critical values LR3σ LR5σ extracted from the analysis of sample with only background events
- The LR_max distributions for each number of "Nfake" signal events added to the background sample are integrated for LR_max>LR3σ and LR_max>LR5σ obtaining the discovery probability



Discovery for point source E^{-2} spectrum as a function of δ

Discovery potential as a function of the declination:

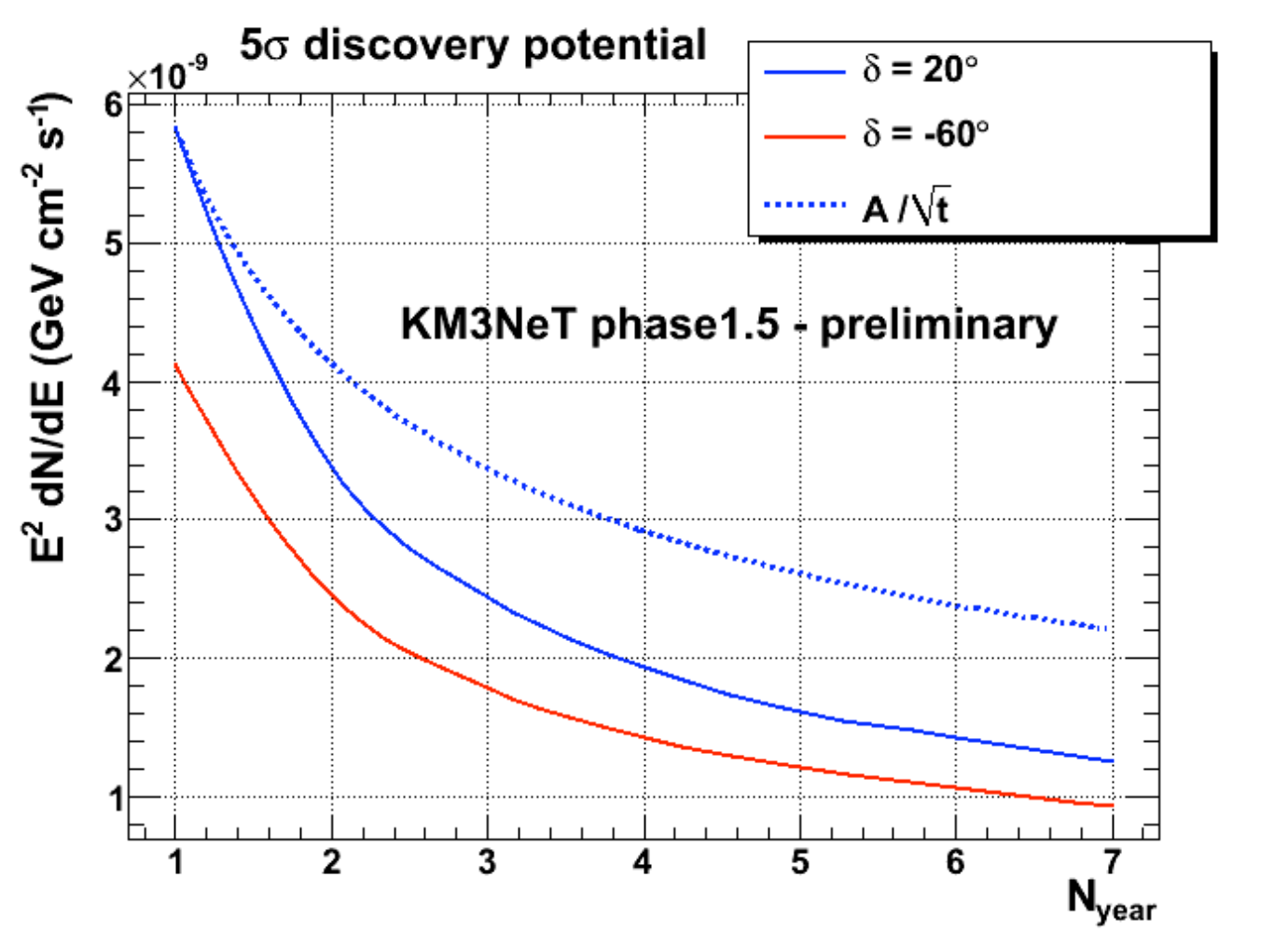
- point-source with E^{-2} spectrum



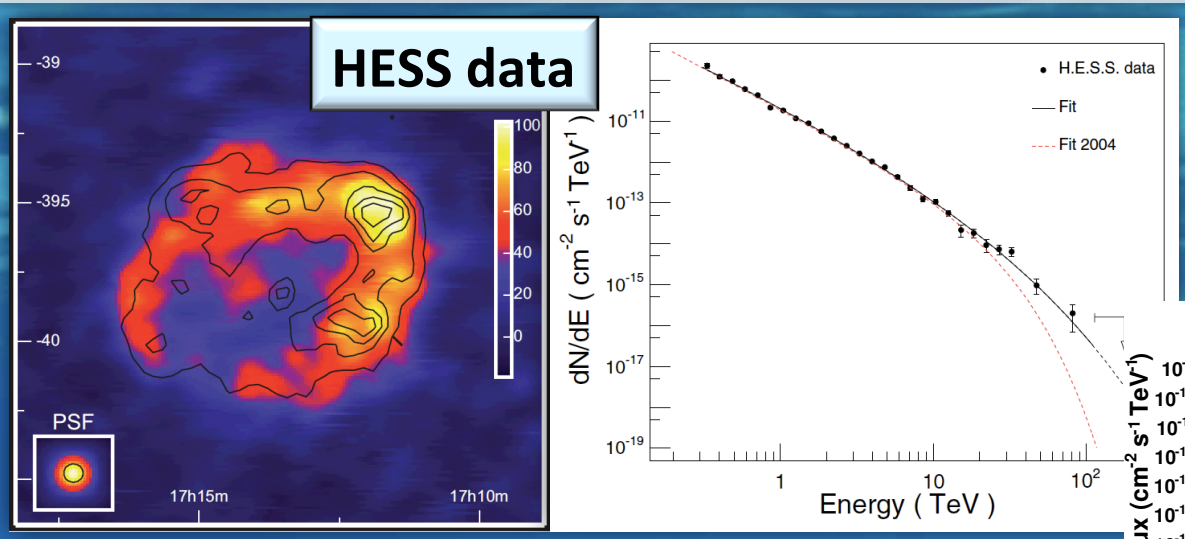
Discovery vs observation years

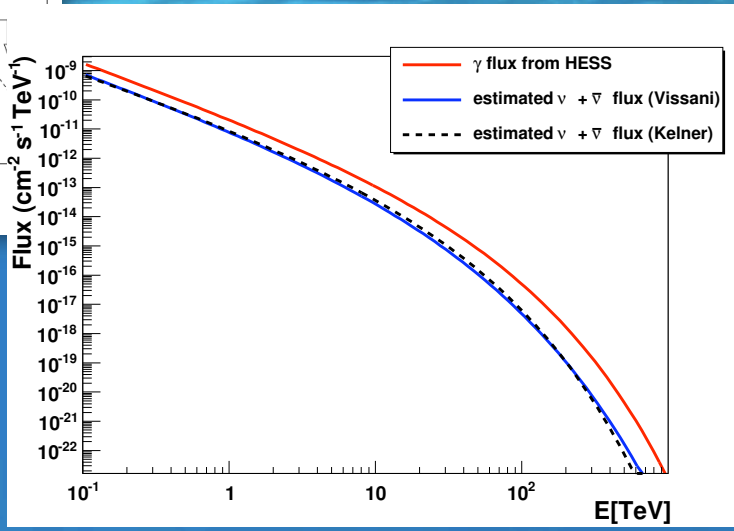
Discovery potential as a function of the observation years:

- point-source with E^{-2} spectrum
- for reference the 1/√time is plotted



SNR RXJ1713.7-3946





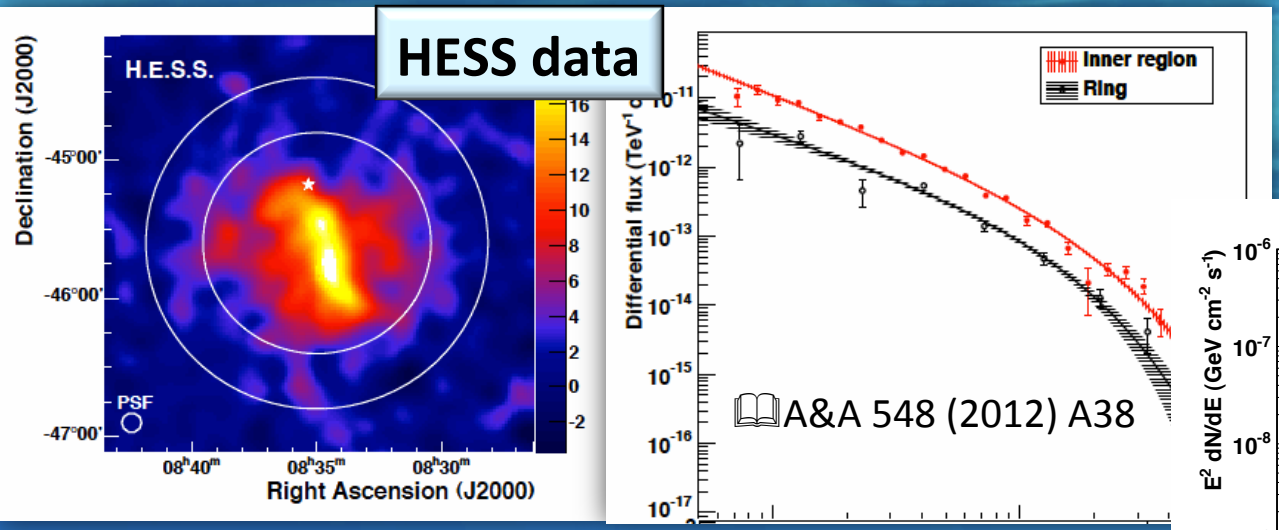
Good reference case:

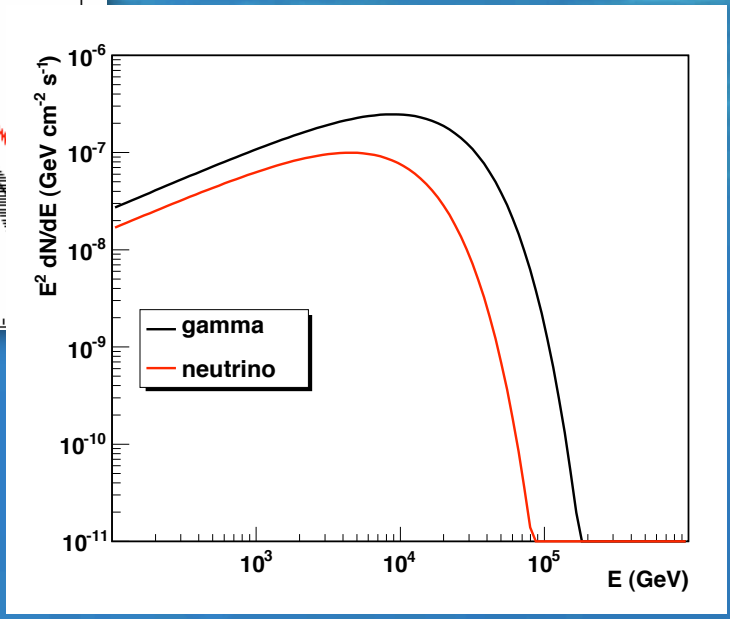
- ✓ High γ-ray flux measured
- ✓ γ-ray spectrum measured up to about 100 TeV
- ✓ Visible for about the 80% of the time by KM3NeT

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

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

Vela X





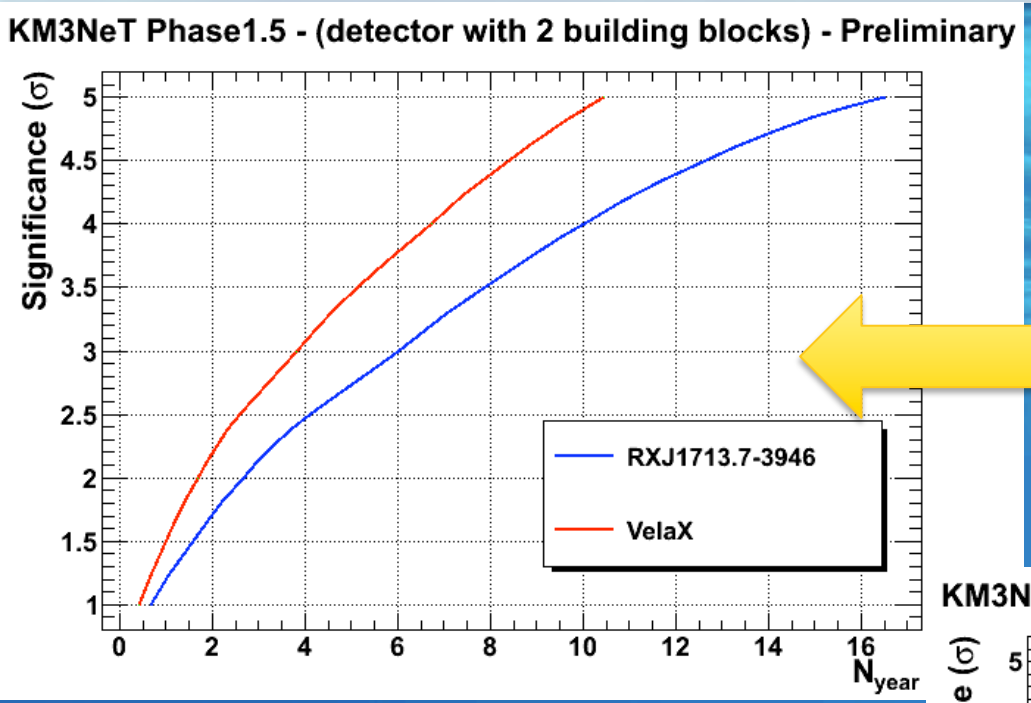
- Neutrino spectrum calculated following Vissani at al. prescription[1] assuming a 100% hadronic emission and a transparent source

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

  - $N = 0.72\ 10^{-14}\ GeV^{-1}s^{-1}cm^{-2}$
  - $\Gamma = 1.36$
  - $E_{cut} = 7$ TeV
- Source simulated as a neutrino emitting homogeneous disk of 0.8° radius

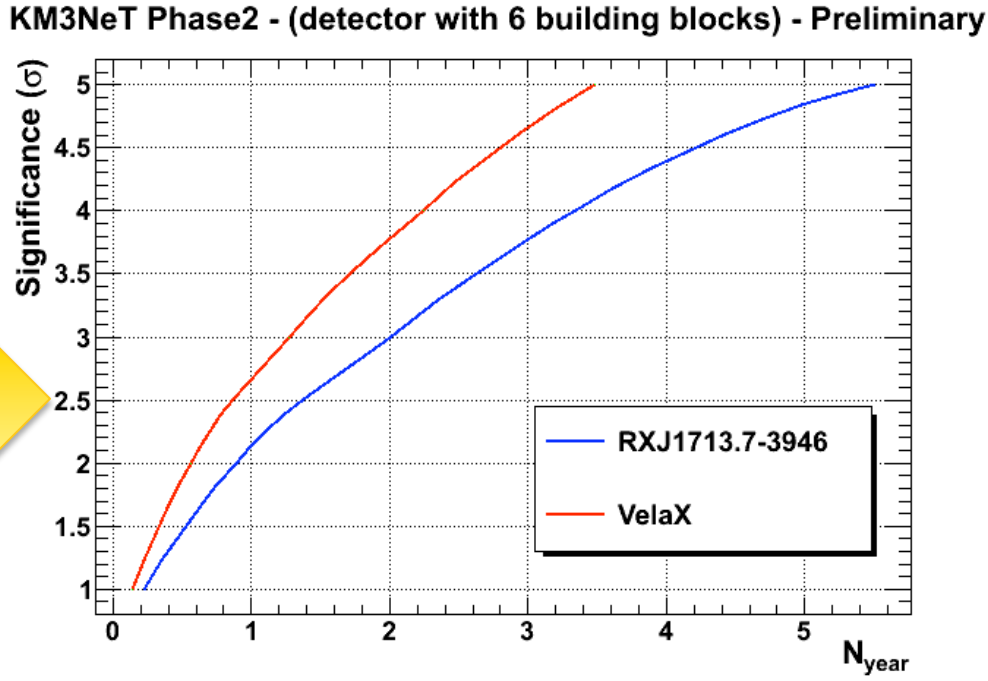
① F.L. Villante and F. Vissani, PRD 78 (2008) 103007; F. Vissani and F.L. Villante, NIM A588 (2008) 123; F. Vissani, Astr. Phys. 26 (2006) 310

Vela X and RXJ1713.7-3946 disc. years



3σ in about 4years for the VelaX and 6years for the RXJ1713.7-31946 for KM3NeT phase1.5

5σ in about 3.5years for the VelaX and 5.5years for the RXJ1713.7-31946 for KM3NeT phase2



Conclusions

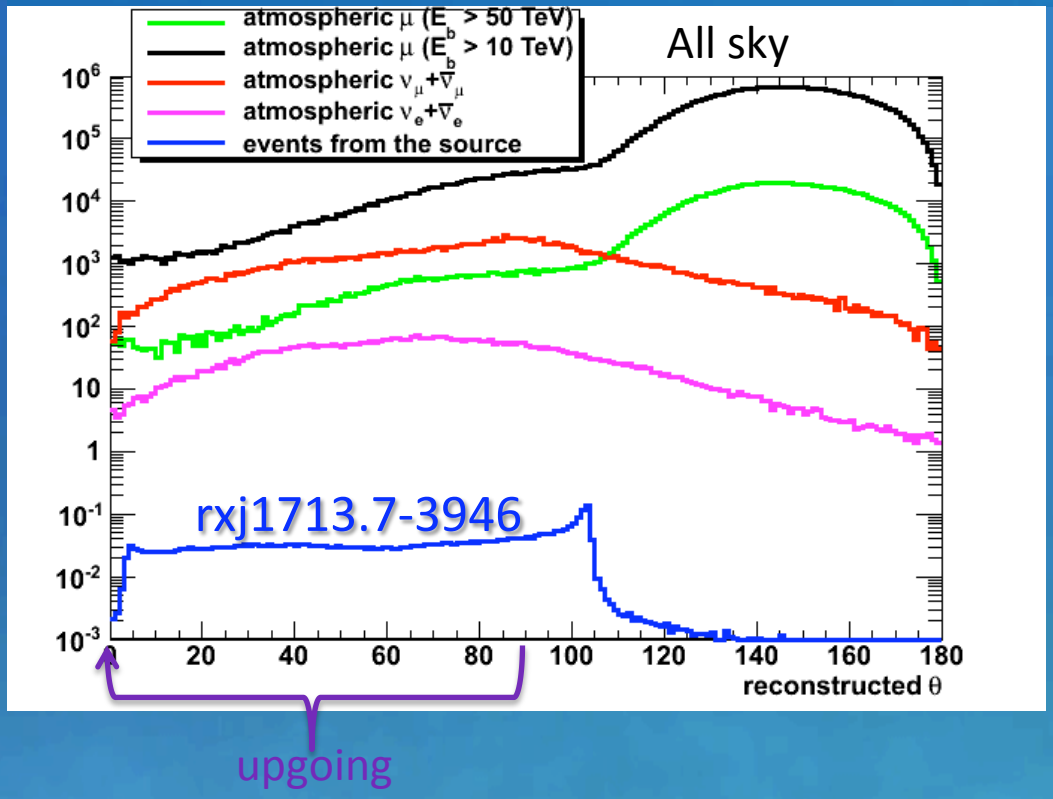
- ✓ Discovery potential of KM3Net for a generic point like source with an E^{-2} spectrum and for the specific galactic sources RXJ1713.7-3946 and Vela X evaluated
- ✓ At least the more intense galactic point-like source within reach of KM3NeT in few years of operation
- ➢ Work in progress:
  - ➢ Study other sources and stack analysis
  - ➢ Boost decision tree technique to improve the signal-to-background ratio

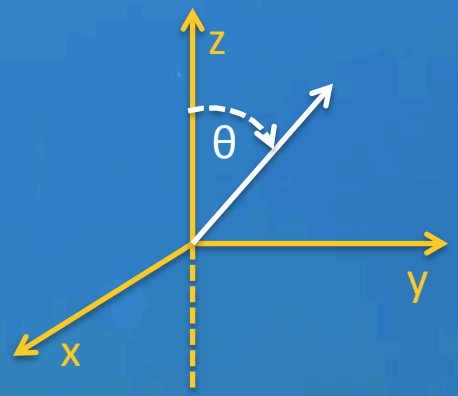
Backup slides

Theta distributions

Background added

- Atmospheric muon and electron (anti-)neutrinos weighted with Honda+ Enberg + knee correction (PRD 89 (2014) 062007)
- Atmospheric muons generated with two thereshold 10 TeV (livetime 34 days) and 50 TeV (livetime 3 years)

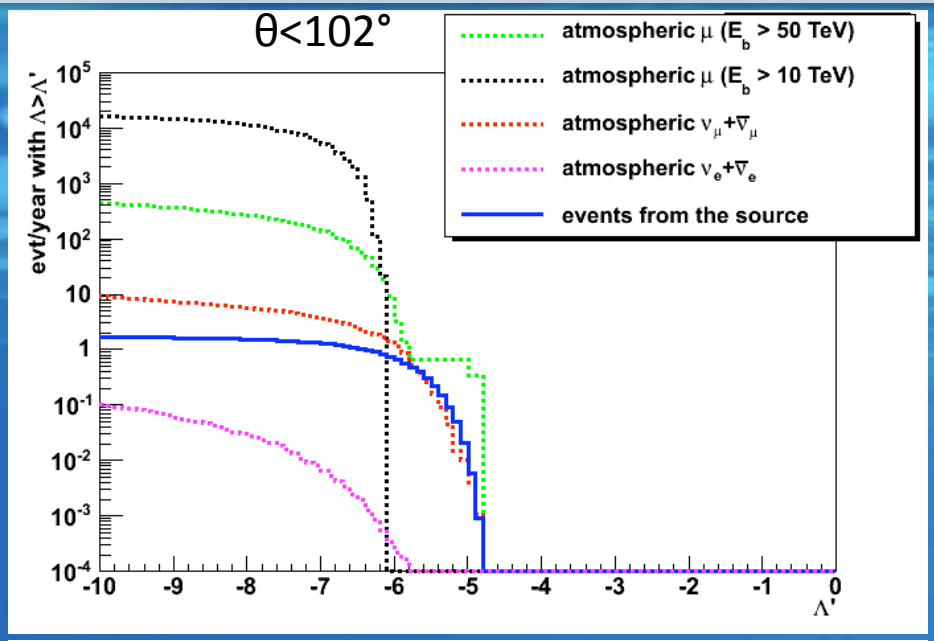


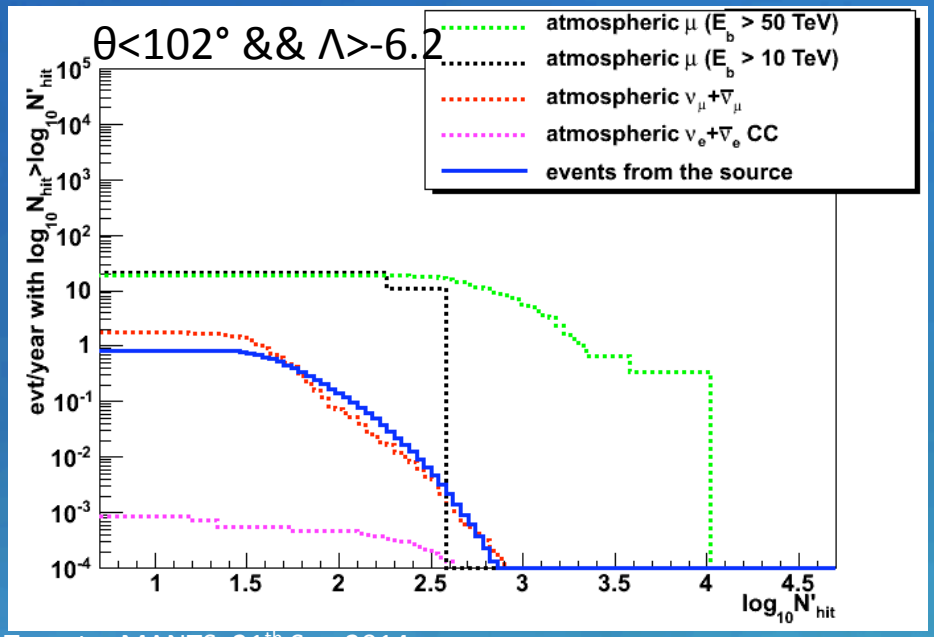


events for 1 block and 1 observation year

Optimal cut θ<102° (preliminary cut-and-cout analysis)

Lambda and Nhit distributions (1° from RXJ1713.7-3946)



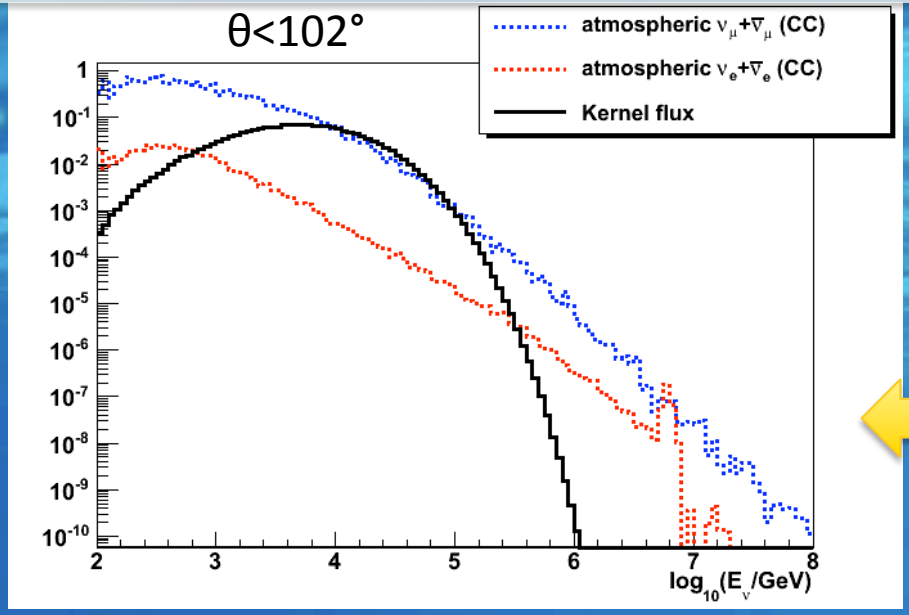


Cumulative Λ distribution:
Λ → goodness of fit criterion

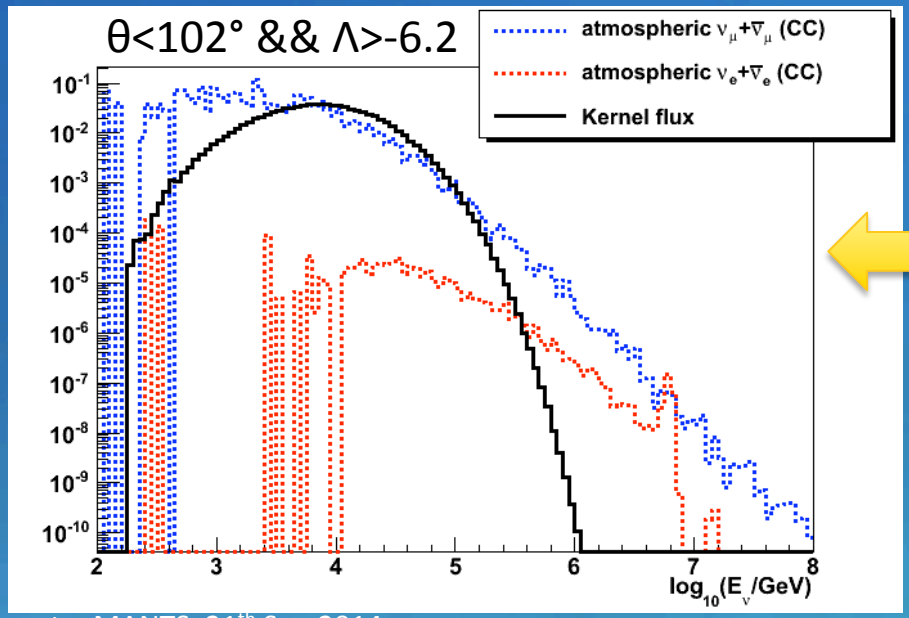
Optimal cut Λ >-6.2 (preliminary cut-and-cout analysis)

Cumulative N_{hit} distribution:
N_{hit} → rough energy estimate

Energy distributions (1° from RXJ1713.7-3946)



After the cut on θ



After the cut on Λ