Report from the GWHEN working group

Focus: 2007 ANTARES-LSC analysis

A. Kouchner for the GWHEN group

Birth of the GWHEN working group

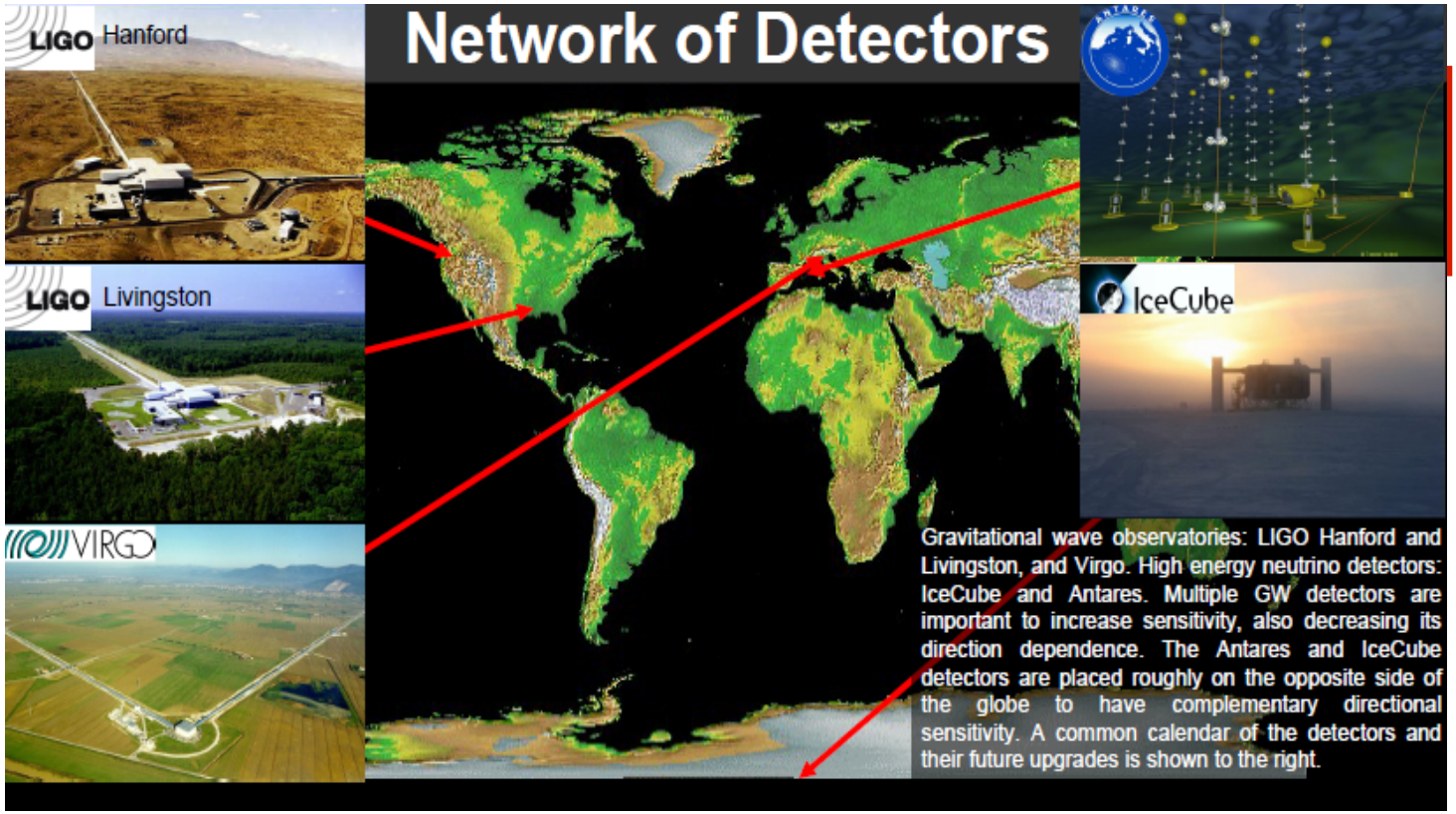
Objective: conduct a joint search for HE Neutrinos and Gravitational Waves
Original scientific workshop: http://gwhen-2009.org in APC Paris, May 2009

MoU between LVC and ANTARES in Sept 2009

MoU between IceCube and LVC in March 2010

No MoU between ANTARES and IceCube !

GWHEN team leaders :
T. Pradier(Antares)
C. Finley (IceCube)
E. Chassande Mottin (Virgo)
S. Marka (LIGO)



GWHEN group members

ANTARES participants :

Bruny Baret (reseacher at Astroparticule et Cosmologie [APC], Paris France)
Boutayeb Bouhou (grad student at APC, also member of the Virgo collaboration)
Corinne Donzaud (faculty at APC)
Antoine Kouchner (faculty at APC)
[Luciano Moscoso (researcher at APC)]
Thierry Pradier (faculty at IPHC, Strasbourg, France)
Véronique Van Elewyck (faculty at APC)
Antonio Capone (faculty at Roma 1, Italy)
Teresa Montaruli (U. Wisconsin)

Contact us at:
gwhen[at]gwhen-2009.org

Icecube participants :

Chad Finley (faculty, Stockholm)
Teresa Montaruli (U. Wisconsin)

LSC and Virgo participants :

Imre Bartos (grad student, Columbia)
Eric Chassande-Mottin (researcher, APC)
Alexander Dietz (postdoc, LAPP)
Irene Di Palma (grad student, AEI)
Shivaraj Kandhasamy (grad student, Minnesota U)
Sergei Klimenko (scientist, UF)
Vuk Mandic (faculty, Minnesota U)
Szabolcs Márka (faculty, Columbia)
Zsuzsa Márka (research scientist, Columbia)
Maria Alessandra Papa (faculty, AEI)
Patrick Sutton (faculty, Cardiff U)
Eric Thrane (postdoc, Minnesota U)
Maggie Tse (undergraduate student, Columbia U)
Roy Williams (staff, Caltech)

Regular phone calls

2011 – 2012 Academic Year Teleconferences

- **September 12, 2011**, teleconference: agenda, minutes. Convener: Eric Chassande-Mottin, APC, France.
- **October 10, 2011**, teleconference: agenda, minutes. Convener: Szabolcs Marka, Columbia University, New York, USA
- **October 24, 2011**, teleconference: agenda, minutes. Convener: Thierry Pradier, Strasbourg University, France
- **November 7, 2011**, teleconference: agenda, minutes. Convener: Chad Finley, OKC, Sweden
- **November 21, 2011**, teleconference: agenda, minutes. Convener: Eric Chassande-Mottin, APC, France.
- **December 5, 2011**, teleconference: agenda, minutes. Convener: Szabolcs Marka, Columbia University, New York, USA
- **December 19, 2011**, teleconference: agenda, minutes. Convener: Thierry Pradier, Strasbourg University, France

2010 – 2011 Academic Year Teleconferences

- **September 9, 2010**, teleconference: agenda, minutes. Convener: Szabolcs Marka, Columbia University, New York, USA
- **September 27-28 2010**, F2F: homepage organized by APC
- **October 20, 2010**, teleconference: agenda, minutes. Convener: Thierry Pradier, Strasbourg University, France
- **November 15, 2010**, teleconference: agenda, minutes. Convener: Eric Chassande-Mottin, APC (France)
- **December 6, 2010**, teleconference: agenda, minutes. Convener: Eric Chassande-Mottin, APC (France)
- **December 20, 2010**, teleconference: agenda, minutes. Convener: Szabolcs Marka, Columbia University, New York, USA
- **January 17, 2011**, teleconference: agenda, minutes – Convener: Thierry Pradier, Strasbourg University, France
- **January 31, 2011**, teleconference: agenda, minutes – Convener: Eric Chassande-Mottin, APC (France)
- **February 14, 2011**, teleconference: agenda, minutes – Convener: Thierry Pradier, Strasbourg University, France
- **February 28, 2011**, teleconference: agenda, minutes – Convener: Szabolcs Marka, Columbia University, New York, USA
- **March 14, 2011**, teleconference: CANCELLED (due to LV meeting)
- **April 4, 2011**, teleconference: agenda, minutes – Convener: Chad Finley, OKC (Sweden)
- **April 18, 2011**, teleconference: agenda, minutes – Convener: Eric Chassande-Mottin, APC (Fr
- **May 9, 2011**, teleconference: agenda, minutes – Convener: Eric Chassande-Mottin, APC (Frar
- **May 23, 2011**, teleconference: agenda, minutes – Convener: Chad Finley, OKC (Sweden)
- **June 6, 2011**, teleconference: CANCELLED (due to ANTARES and LV meeting)
- **June 27, 2011**, teleconference: agenda, minutes – Convener: Eric Chassande-Mottin, APC (Fr

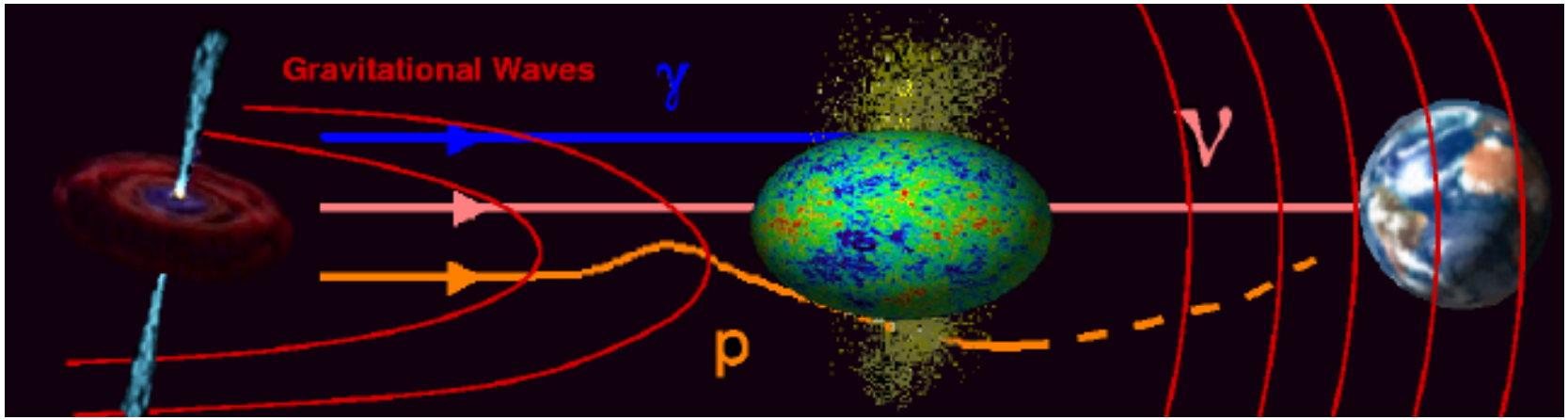
2009 – 2010 Academic Year Teleconferences

- F2F, Rome Jan 25, 2010: minutes
- telecon Feb 18, 2010: minutes
- telecon Feb 25, 2010: minutes
- telecon Mar 11, 2010: agenda, minutes
- telecon Apr 1st, 2010: agenda, minutes
- telecon Apr 15, 2010: agenda, minutes
- telecon Apr 29, 2010: agenda, minutes
- telecon May 27, 2010: CANCELLED
- telecon Jun 03, 2010: agenda, minutes
- telecon Jun 24, 2010: CANCELLED because
- telecon Jul 15, 2010: agenda, minutes

Minutes of the meetings are available on the web.

Very active group!

Motivations for GWHEN astronomy



- **Long-range messengers:** no interactions (or weak ones) with ambient matter, no deflection by magnetic fields:
  GW and HEN travel undeflected over cosmological distances
- **Deep-source messengers:** carry information on the internal processes of the astrophysical engines, unaccessible through photons or hadrons
- **Discovery potential for hidden/unknown sources** (difficult to detect through photon/cosmic ray astronomy)
- **Plausible common sources:** **galactic** (microquasars, SGRs) & **extragalactic** (GRBs)

- **Main requirements for joint GW/HEN detection:**

massive, compact & relativistic objects	+	sudden (< 1s)	+	baryon loaded	+	close & frequent enough

Coincidence window

📖 *GWHEN group, Astropart. Phys. 35 (2011) 1-7*

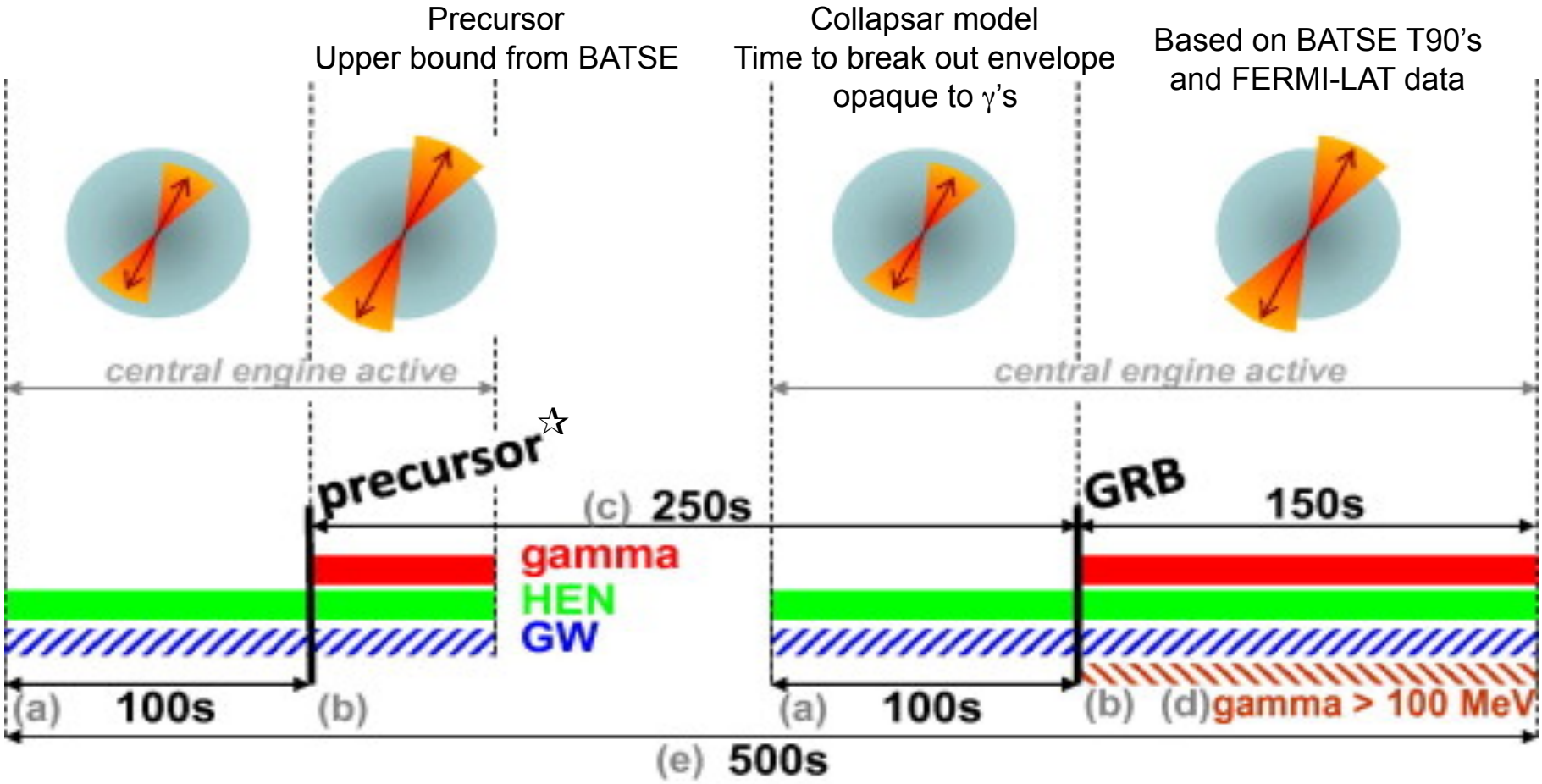
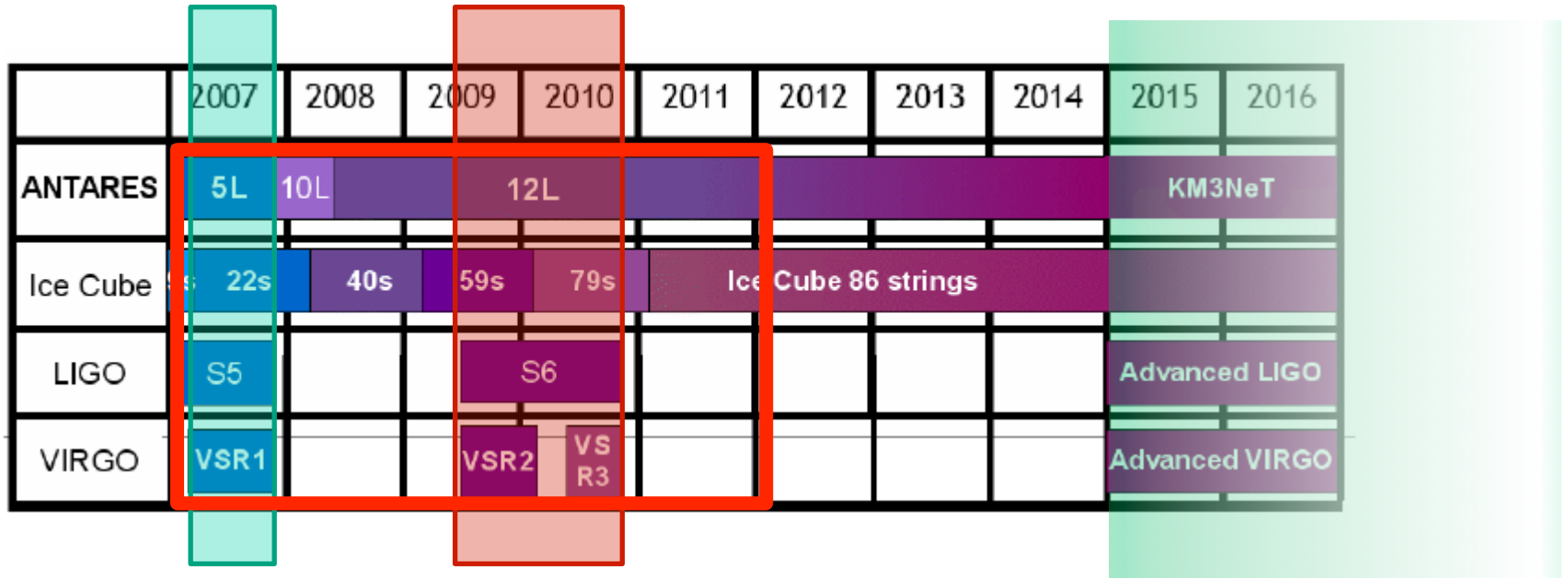


Fig. 1. (a) active central engine before the relativistic jet has broken out of the stellar envelope; (b) active central engine with the relativistic jet broken out of the envelope; (c) delay between the onset of the precursor and the main burst; (d) duration corresponding to 90% of GeV photon emission; (e) time span of central engine activity.

☆ Precursors were observed for ~15% of GRBs (long and short (8%))
Emission mechanisms might be that of prompt GRBs: same model

Data sets and agreed analysis plan

Period covered by current ANTARES/LIGO/VIRGO MoU. Renewal?

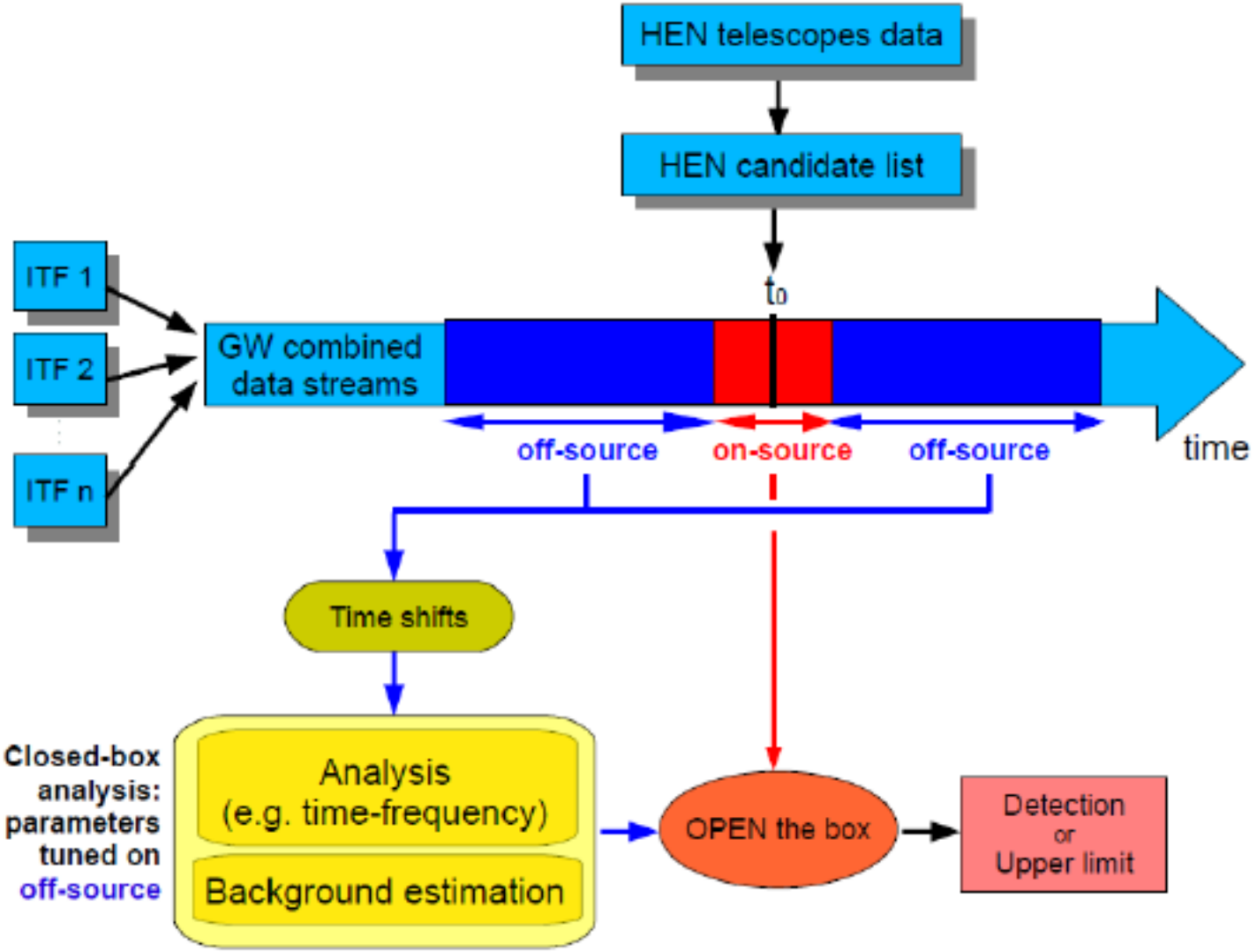


Analysis plan:

1. ANTARES 5 line / S5-VSR1 : triggered search (B. Bouhou & I. di Palma)
   ☞ this talk
2. IceCube – LVC (I. Bartos & C. Finley)
   ☞ Imre's talk today
3. Improved ANTARES – LVC analysis (all data set – B. Bouhou)
4. Other analyses

Philosophy of the triggered search

Not optimized in a combined way but uses already available/used tools (e.g. X-pipeline)
➔ First analysis with 2007 data set



2007 analysis : data and MC samples

Data sample

- The coincident period of 5L/S5/VSR1 is between January 27th and September 30th, 2007
- lifetime of the selected data sample: 103.281 days

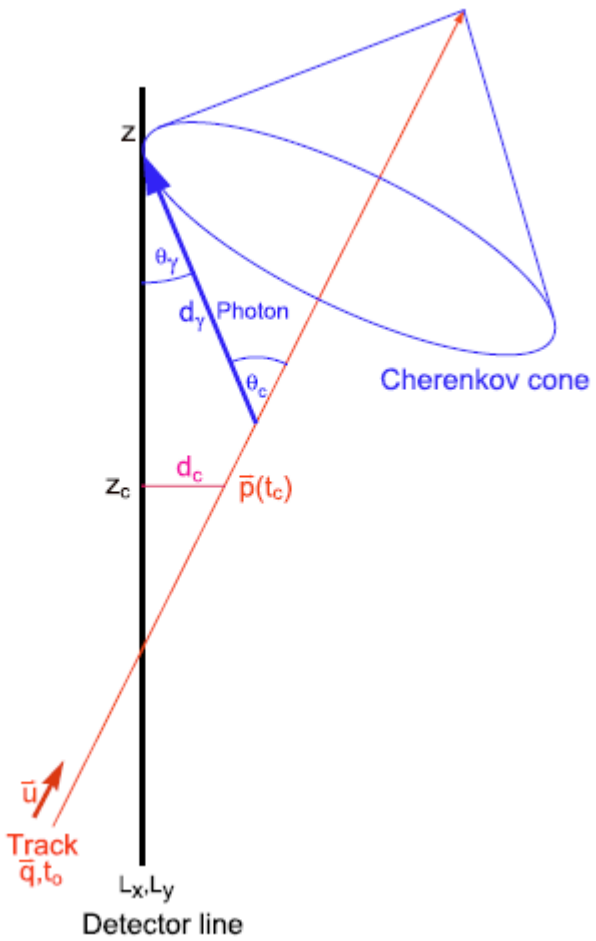
MC sample

- Atmospheric neutrinos :
  - → Simulation package: Genhen, weight : Bartol flux
  - → energy range between 10 GeV and 10^7 GeV
- Atmospheric muons:
  - → Simulation package : Corsika, weight : Battistoni's parameterization
- Cosmic neutrinos :
  - → Simulation package: Genhen
  - → weighted with a E^{-2} energy spectrum
    - Data and MC sample are reconstructed with the BBfit reconstruction package (v3r6)

Reconstruction used

Astropart. Phys. 34 (2011) 652–662

- Event triggering is based on local coincidences.

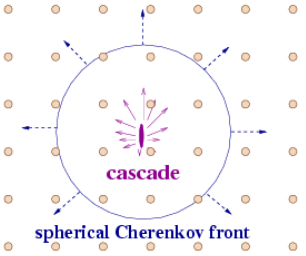


- Geometrical approximations (for real time application):
  - Detector lines are considered to be perfectly vertical.
  - Each storey considered as a single centered OM. Hits are merged ($Q = \Sigma q_i$) if within 20 ns
- Further hit selection (reject optical bkg and scattered hits)
  - Find cluster of hits in each line
  - Add hits causally compatible with the cluster
- Track fitting procedure
  - Keep event with more than 5 selected hits
  - Track model $\vec{p}(t) = \vec{q} + c(t - t_0)\vec{u}$.

$$\vec{u} = \{\cos\theta\cos\phi, \cos\theta\sin\phi, \sin\theta\}$$

zenith azimuth

- Bright point fit (apply for shower event, or LED beacons)
  - 4 parameters only : its position $\vec{q}$ and its time t_0
  - Used to reject background



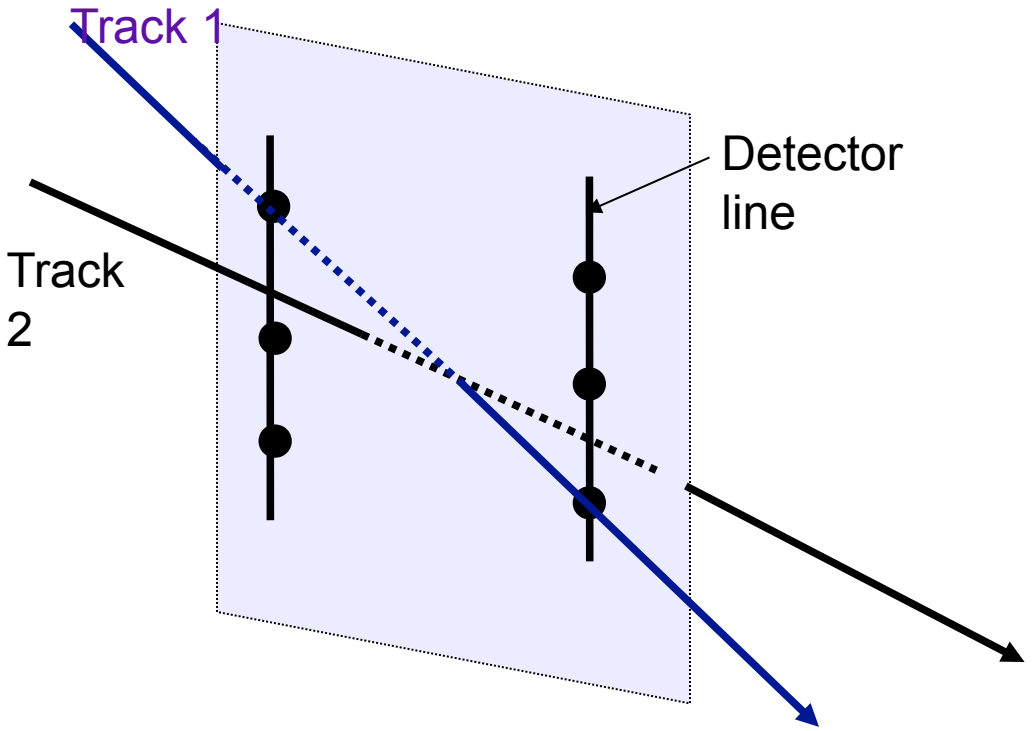
Reconstruction used

== Due to simplified detector geometry ==

- Events reconstructed with 2 lines

Two possible tracks
(Mirror solutions)

Two possible azimuth values
(Same zenith)

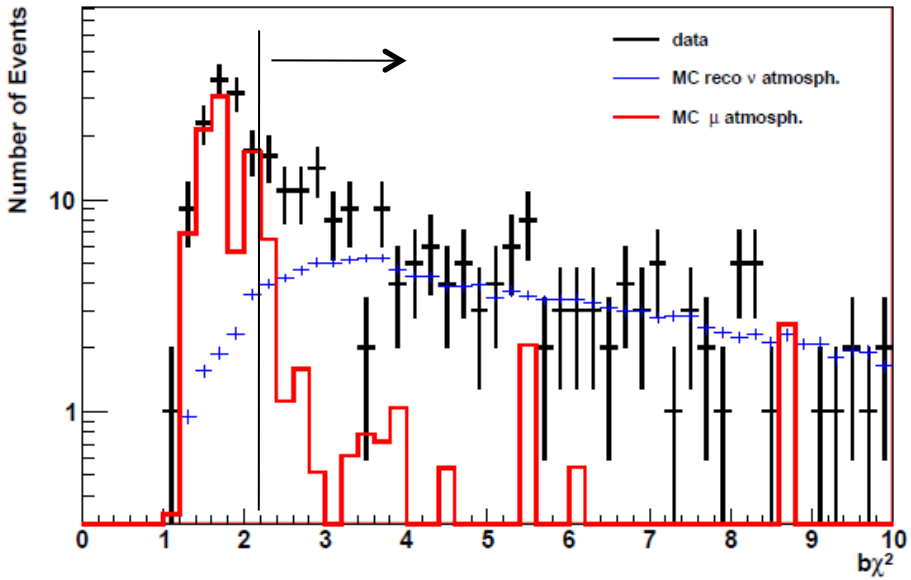


- The version of the reconstruction offers the possibility to get the azimuth of the mirror solution in the case of events reconstructed with two lines

☞ Better angular accuracy than if taking random track solution

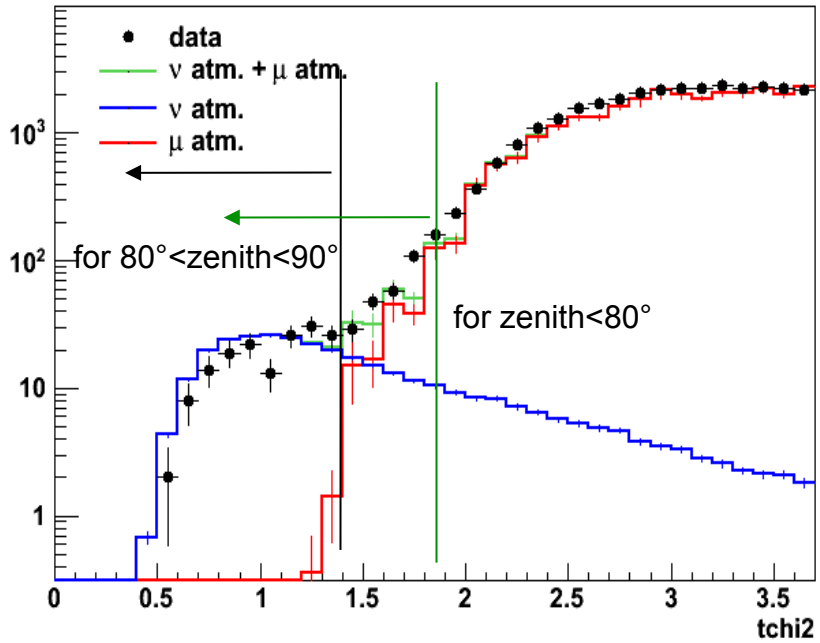
☞ Smaller search box for GW detectors

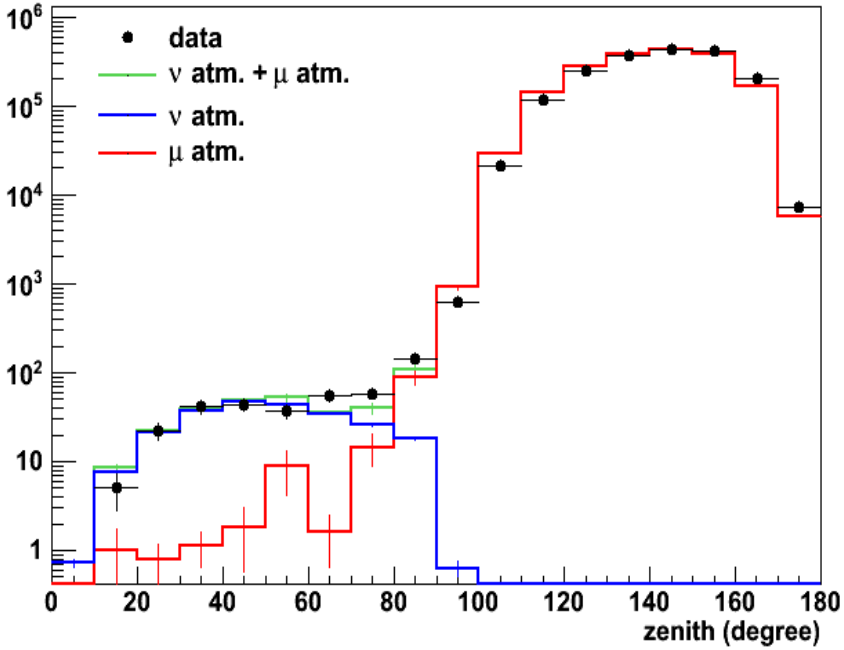
Chosen cuts (up-going events)



- $b\chi^2$ >2.2 (reduced contamination of atmospheric muons)
- $t\chi^2$ <=1.8 for zenith<80°
- $t\chi^2$ <=1.4 for 80°<zenith<90°

- 20% contamination from atmospheric muons





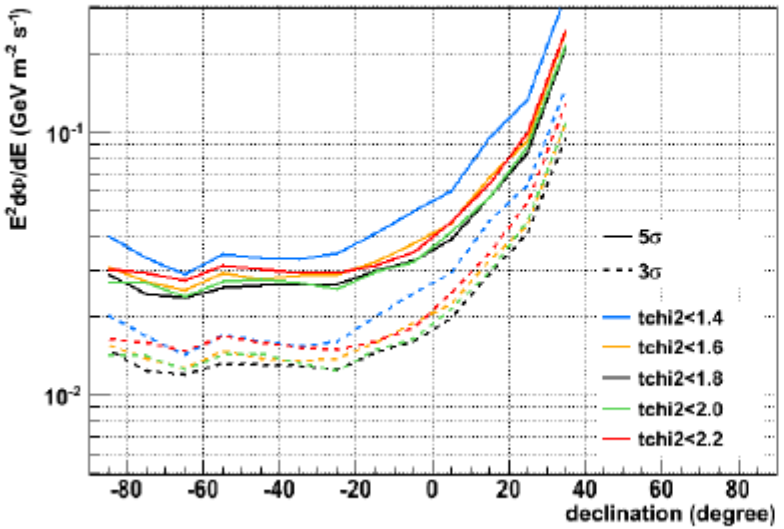
Cut optimization

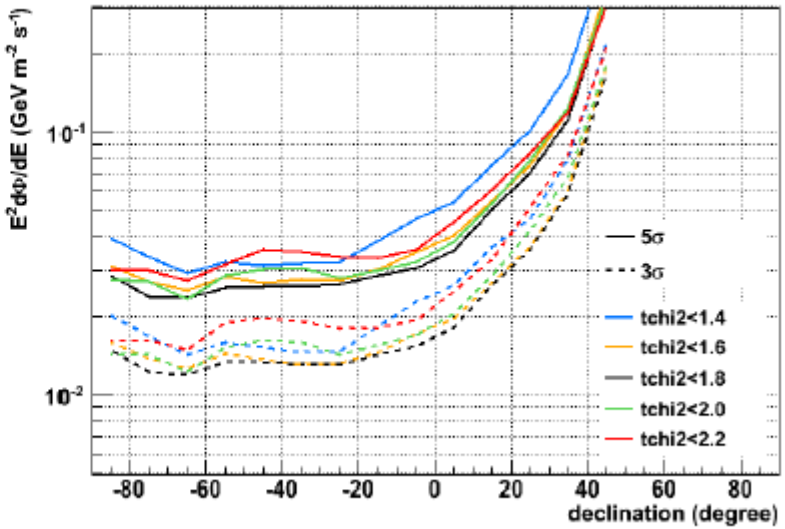
Cut are applied to maximize the discovery potential in search for E^{-2} point sources
Only up-going events are considered.

Method : test statistics LR to get optimum n_{sig}

$$E^{\gamma}\frac{d\Phi(\delta)}{dE} = \frac{\langle n_{\mathrm{sig}}\rangle(\delta)}{A_{eff}(\delta)\times t\times V(\delta)\times\int_{E_{\min}}^{E_{\max}} E^{-\gamma}dE}$$

Different values of track and bright point χ^2 for different zenith angles were tested

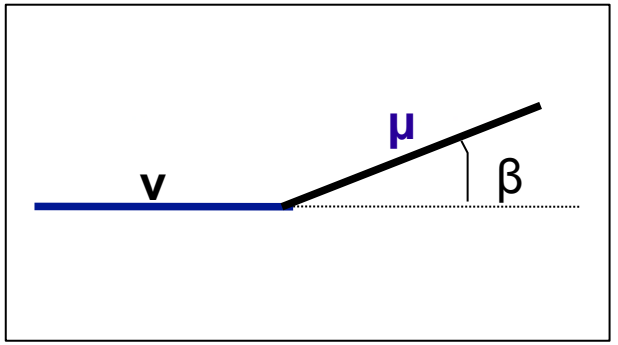




📖 G. Halladjian, Ph. D, University Marseilles, Dec 2010

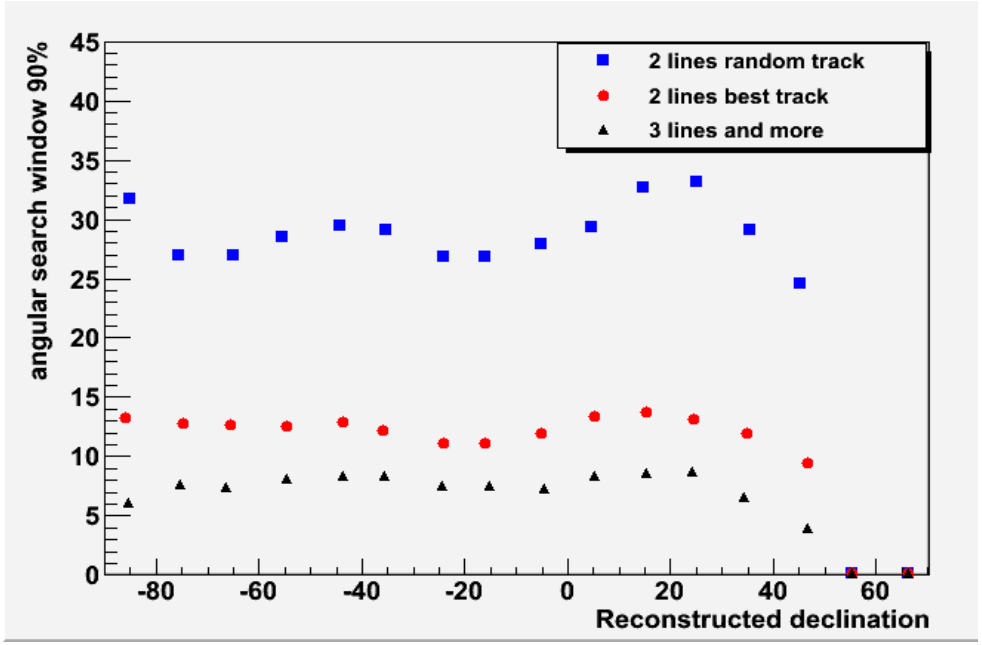
Angular search window

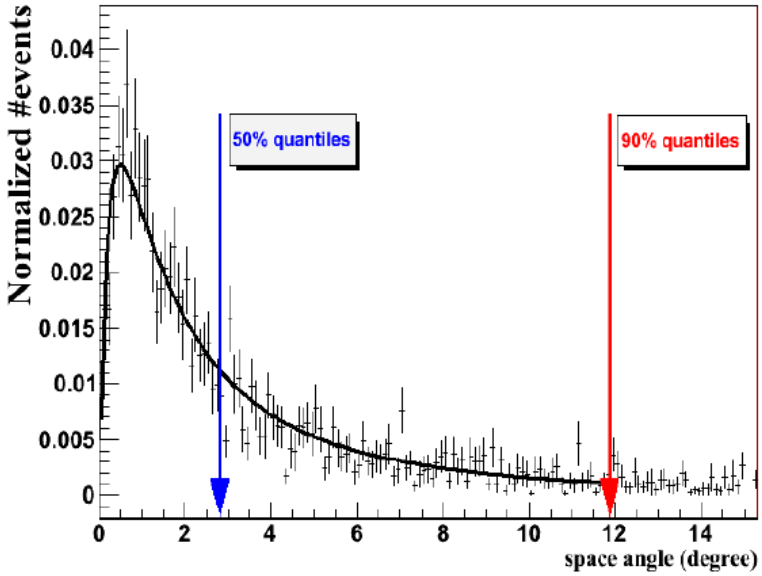
- The space angle β between the true neutrino direction and the reconstructed muon direction (E^{-2} spectrum) defines the angular accuracy



- The angular search window is defined as 50% quantile (or 90% quantile) of the β distribution in bins of reconstructed declination (10°) and number of hits

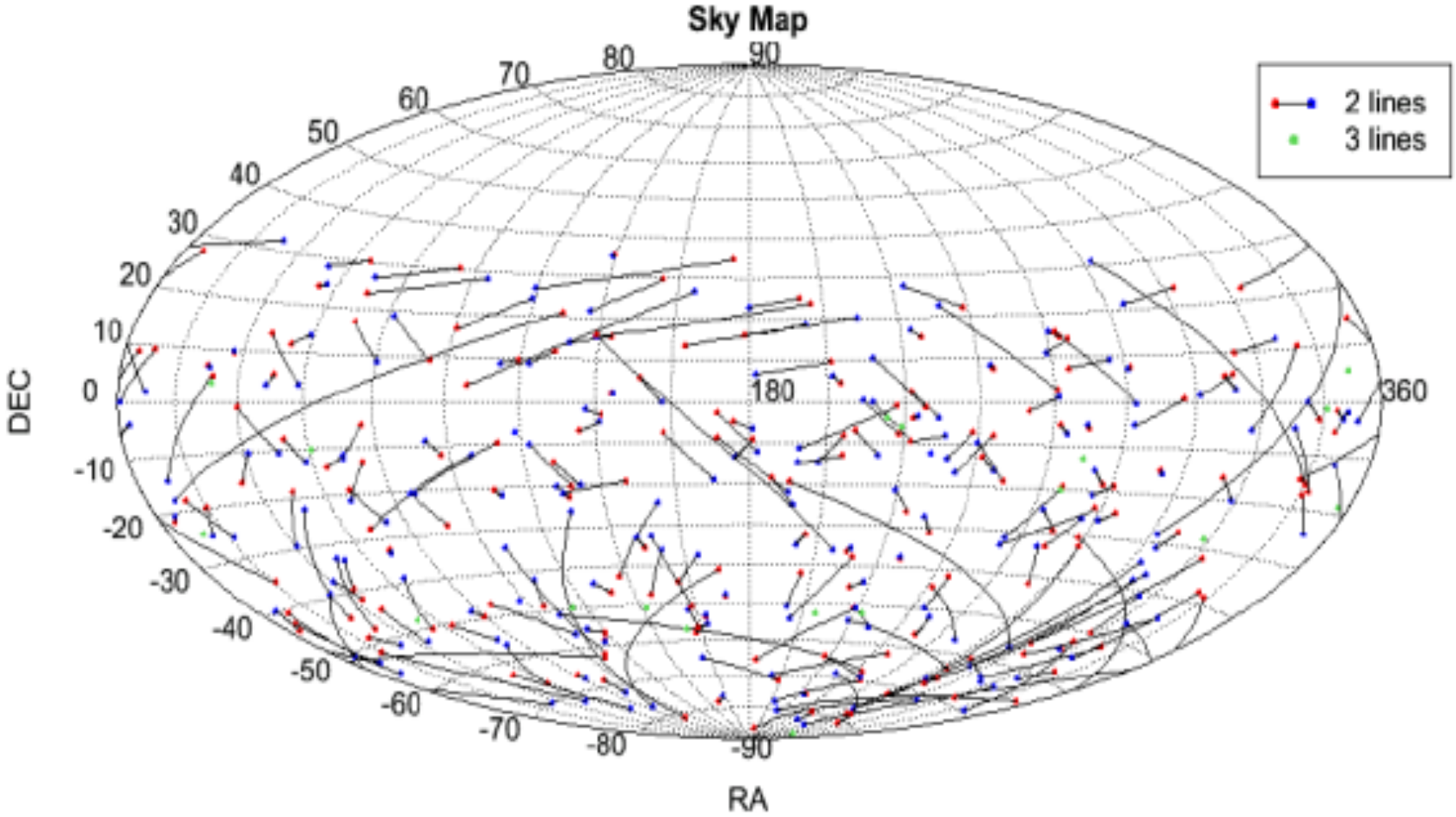
- Log-normal (instead of Fisher) distributions are fitted and provided for processing with X-pipeline (weight the scan directions inside the angular window)





The HEN candidate list

- 18 events reconstructed with 3 lines and more.
- 198 events reconstructed with exactly two lines : 2 solutions
- Total number of events (18 + 2*198)



The HEN candidate list

- 18 events reconstructed with 3 lines and more.
- 198 events reconstructed with exactly two lines : 2 solutions
- Total number of events (18 + 2*198)

reconstructed from 2 Lines

# neutrinos	4 IFOs	3 IFOs	2 IFOs
143	60	58	25

55 triggers cannot be analyzed because there aren't enough IFOs in network.

reconstructed from 3 Lines

# neutrinos	4 IFOs	3 IFOs	2 IFOs
14	3	7	4

4 triggers cannot be analyzed because there aren't enough IFOs in network.

Search for GW bursts

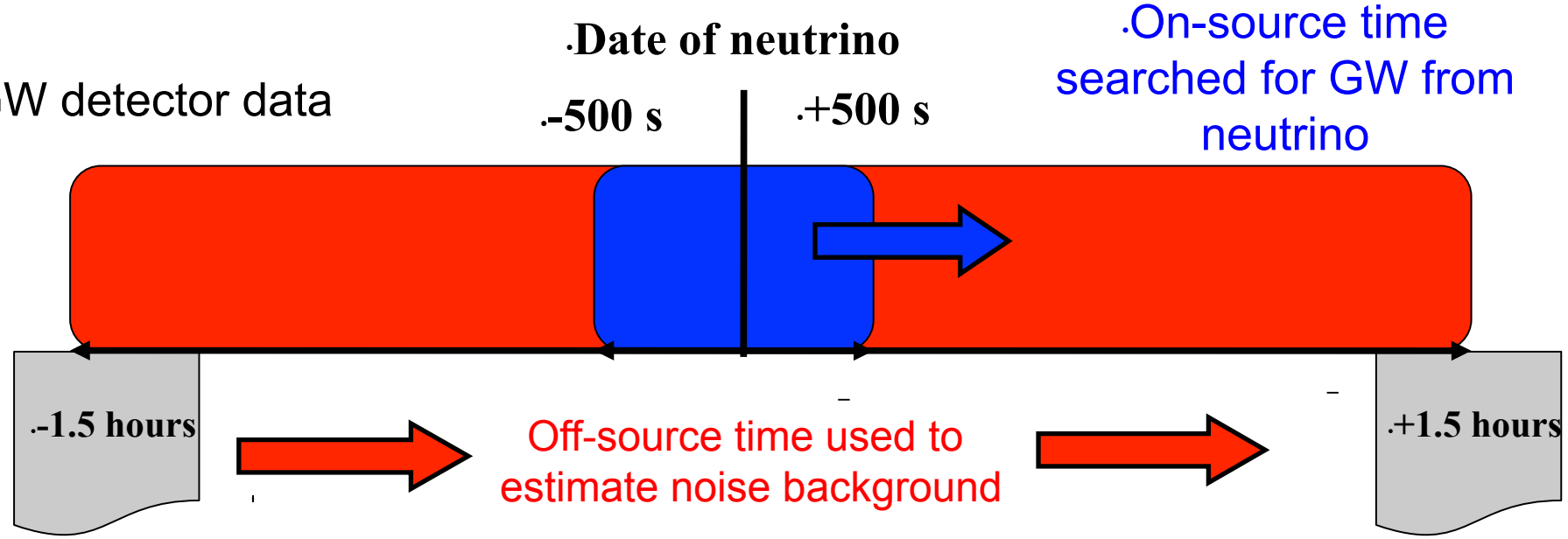
📖 astro-ph.0908.3824v1

Coherent network method:

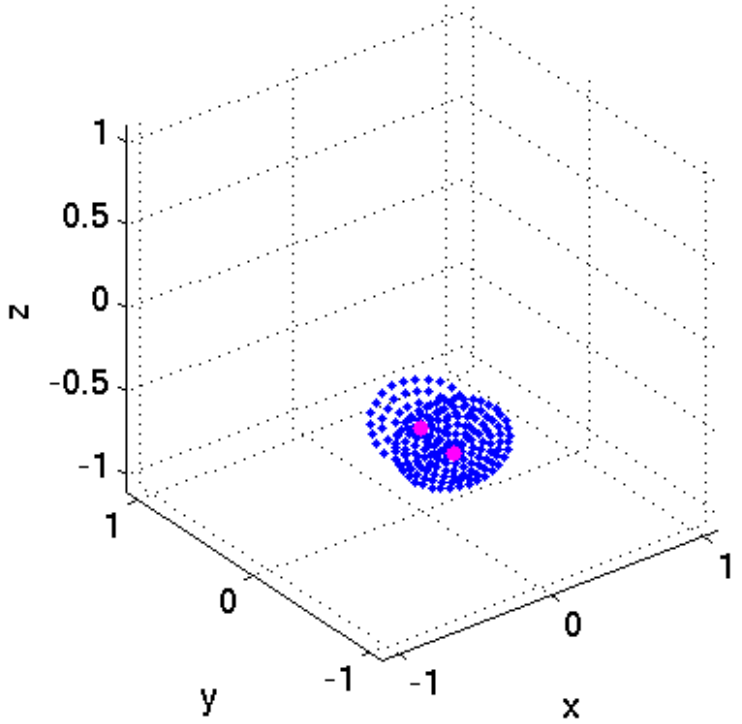
- X Pipeline is a matlab-based software package for performing coherent searches for gravitational-wave bursts in data multiple detectors, weighted by relative sensitivity to the sky location of the neutrino.

- It constructs linear combinations of data streams: those that maximize the signal to noise ratio (SNR) of any GW signal present. Search time-frequency map of that data for excess energy.

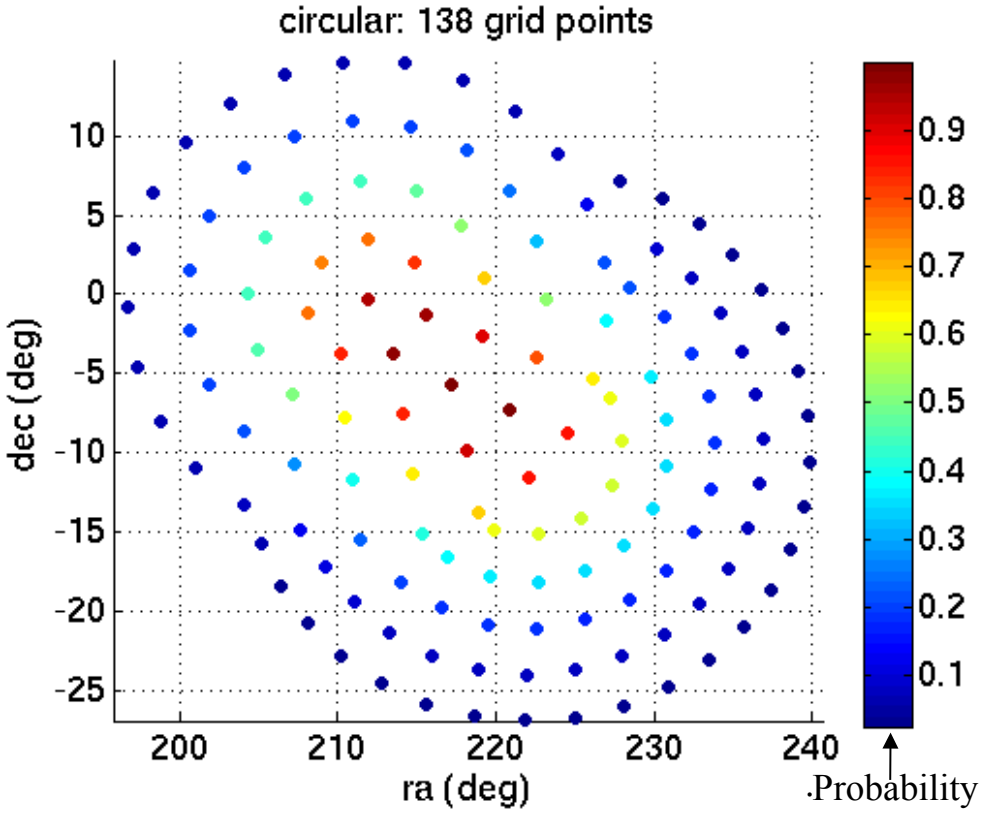
- Then, the energies in the streams are compared to attempt to discriminate between true Gravitational Wave Bursts and background noise fluctuations.



Implementation within X-pipeline



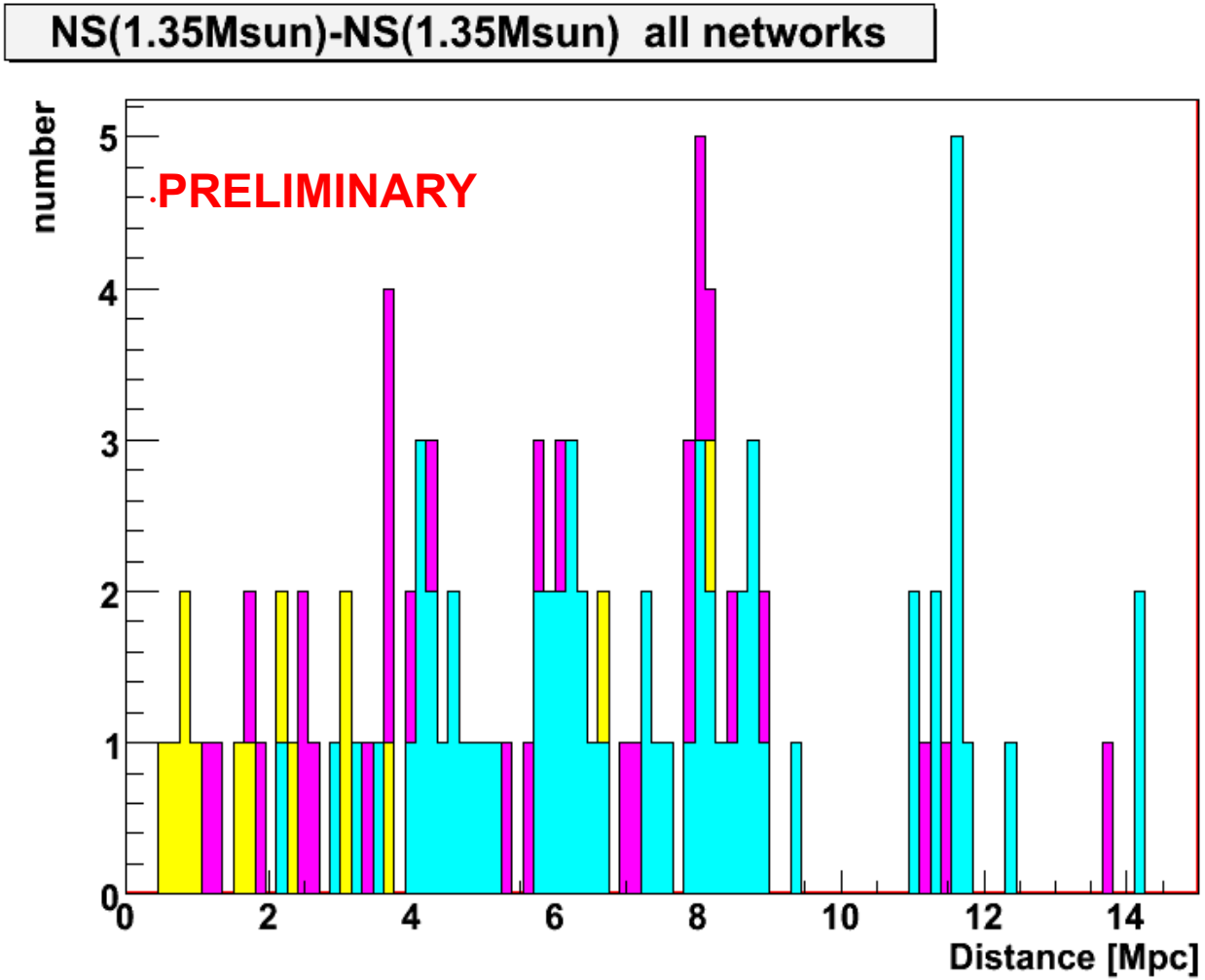
- ra1 = '221.99' ; dec1 = '-9.38'; [deg]
- ra 2= '211.85'; dec2 = '-0.36'; [deg]
- gps = '864109778';
- sigma_deg = '10~10';



- Given the estimated locations and errors in sky location measurement, the code generates a list of sky positions which we should search over to keep time-delay errors into account.

Exemple of results

Review of the analysis is ongoing (well advanced).
Paper draft available.



- CLOSED-BOX RESULTS

- 2 detectors in network:
  - mean = 4.4 Mpc
- 3 detectors in network:
  - mean = 6.0 Mpc
- 4 detectors in network:
  - mean = 7.6 Mpc

Foreseen and unforeseen difficulties

This is the first analysis of this kind!

Review ongoing by LSC. Soon public.

- Difficult to cope with the review/publication rules of each experiment.
  Ex: LSC produces paper draft to review an analysis while ANTARES first wants to review an analysis before proposing a paper.

- Pending questions relating to publication rules.
  - ANTARES-LSC MoU says

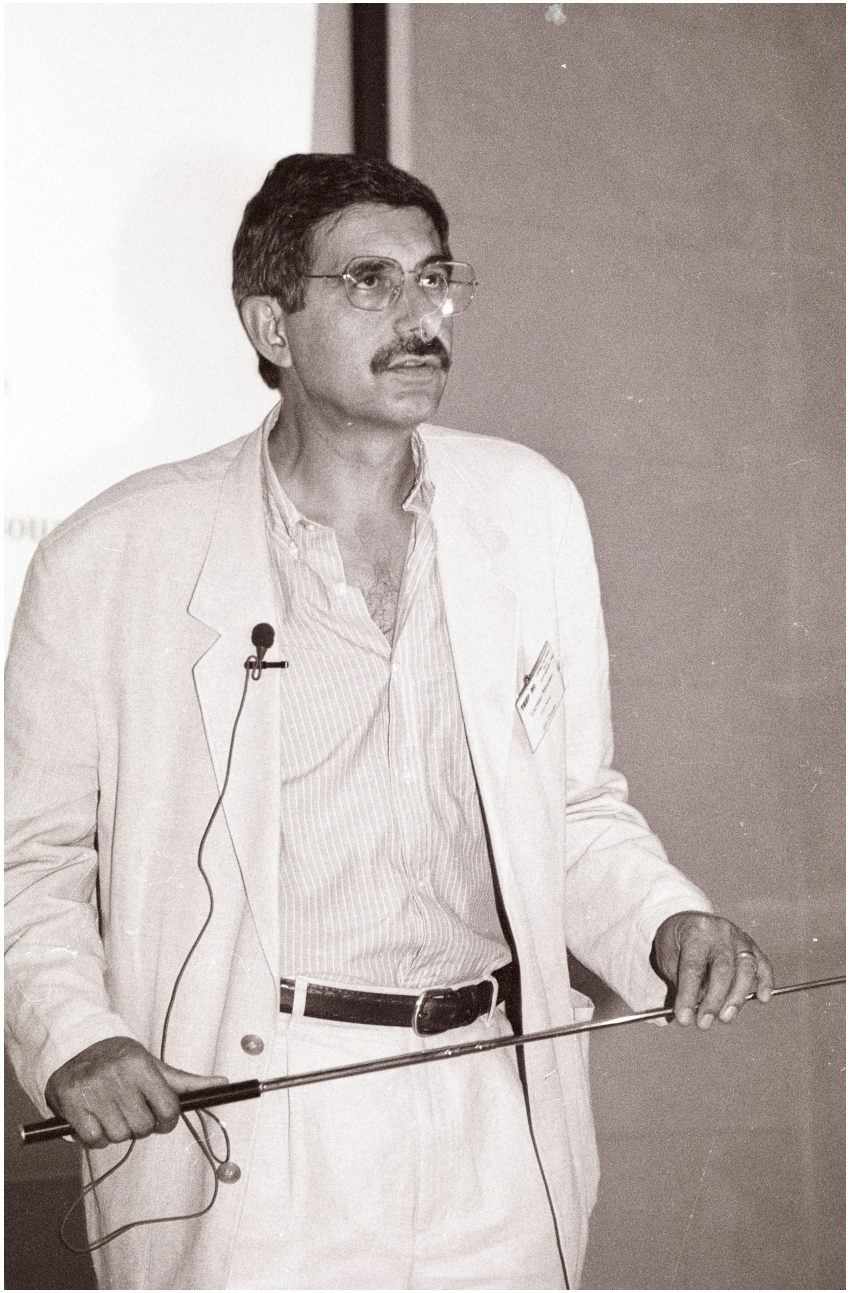
> A separate author list showing the ANTARES authors (and according to the ANTARES policies for author listing) under "ANTARES Collaboration" and the LIGO and Virgo authors under "LIGO Scientific Collaboration" and "Virgo Collaboration" according to the joint LIGO-Virgo MOU[2] for author listing will be used. The ANTARES Spokesperson will

  - Then which collaboration first?

  - 2 Corresponding authors (one for each collab) should be accepted by the journal

  - How to arrange convergence after remarks from each publication committees?
    Ex: ANTARES editorial board includes LSC member involved in the review of the analysis.

Luciano Moscoso 1940 - 2011



"One of the founders of Neutrino Astronomy and ANTARES in particular"

"Outstanding role in ANTARES and Neutrino Astronomy"

"The ANTARES success is in great part due to Luciano"

"Neutrino Astronomy loses one of his most convinced and convincing supporter."

"Distinguished colleague", "a reference",
"One of the pioneers in our field"

"Extraordinary scientist and a very good man"
"We shared work, dreams and hopes."

"His Humanism, kindness and superb smile"

"Brilliant physicist with amazing charm"

"A joy to discuss things with him. He really was a true *savant".*

"A man of principles" "The spirit of collaboration."

"High esteem in which we hold him"

"Our community is poorer without Luciano"

"We will miss his enthusiasm, his advise, his warm personality"

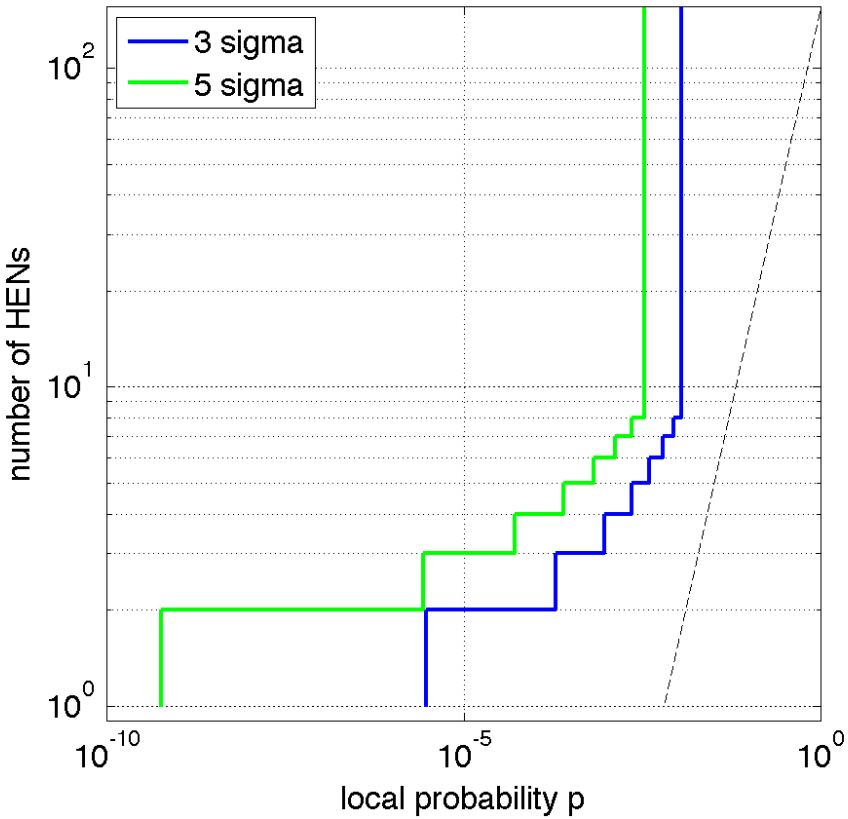
"We will sorely miss his guidance, his clear views and statements and his sense of humour"

"His example, his smile, his kind behaviour will be always with us".

When would we declare a discovery?

📖 Phys.Rev.D77:062004,2008

A discovery is made when a 5σ effect is reached, ie the FAP of the entire set < 5.7e-7. The set of N=155 p-values are subjected to the “binomial test” to test for an deviation from the null hypothesis.



Briefly, the FAPs are sorted in increasing order p1 < p2 < p3 < … . One then computes the binomial probability that out of N draws from the uniform distribution, (1) the lowest draw will be less than p1, (2) the two lowest draws will be less than p2, …
The test selects the lowest of these probabilities and then computes the FAP given that you tested the 1, 2, …, N_{tail} values.
The binomial test has the advantage that it can detect both a single loud GW-HEN outlier event, but also a collection of weak events.