Physics case and status of the **KM3NeT** neutrino telescope

Tommaso Chiarusi
INFN - Sezione di Bologna

Talk Overview

1. (Astro)Physics Case: why neutrinos?

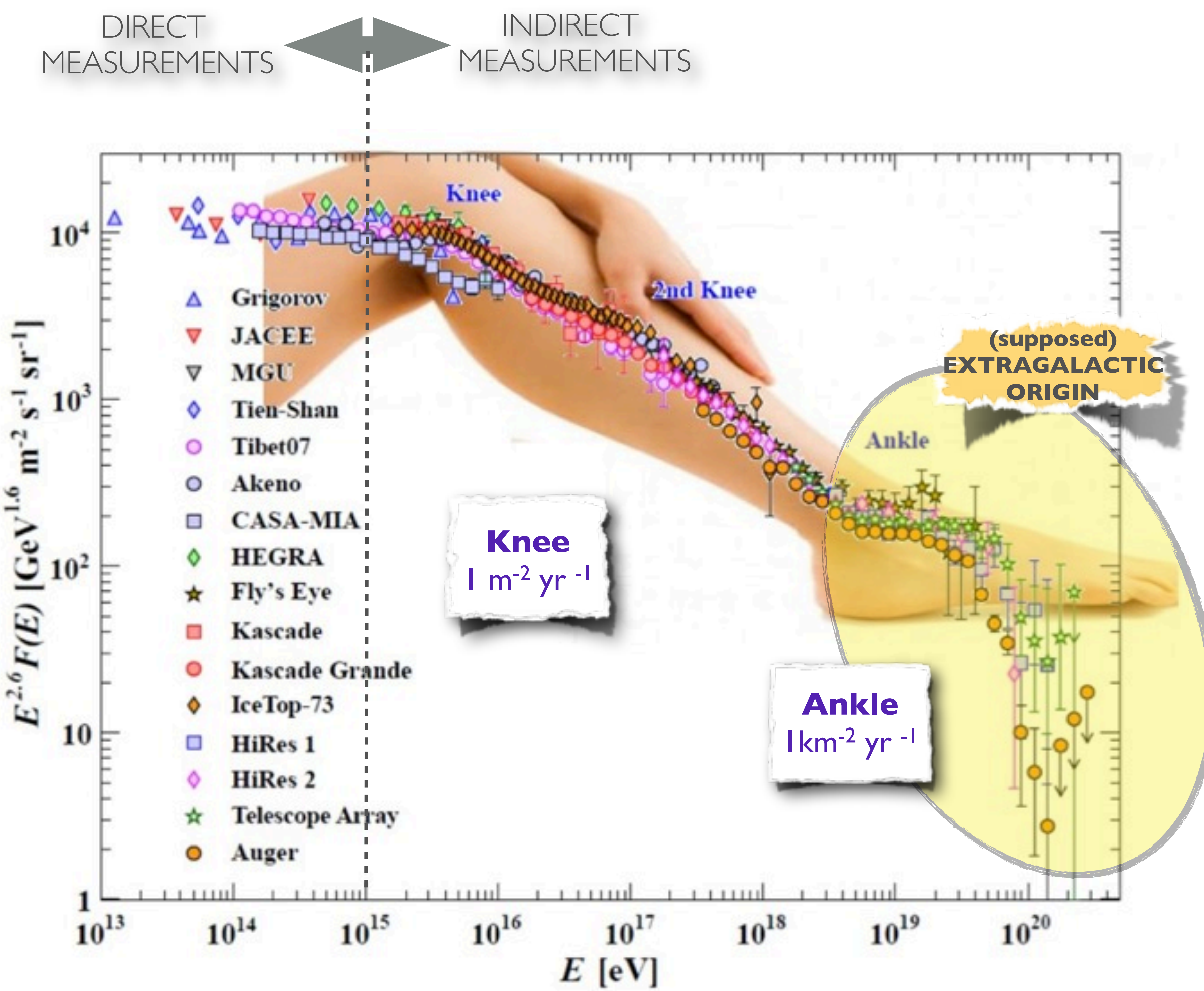
2. Comments about the recent findings with current telescopes

3. New generations of neutrino telescopes: **KM3NeT**

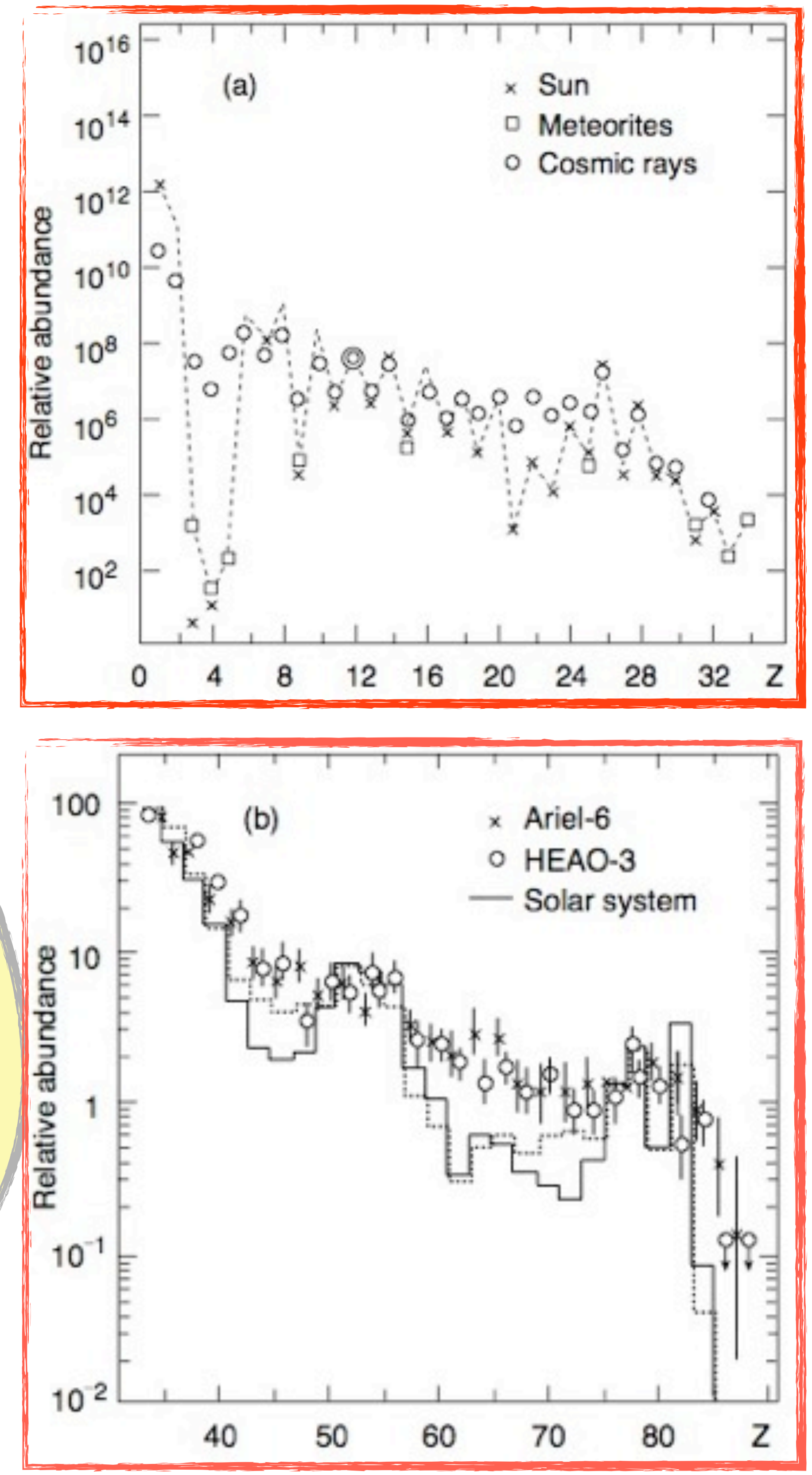
4 Trigger and Data Acquisition System for KM3NeT

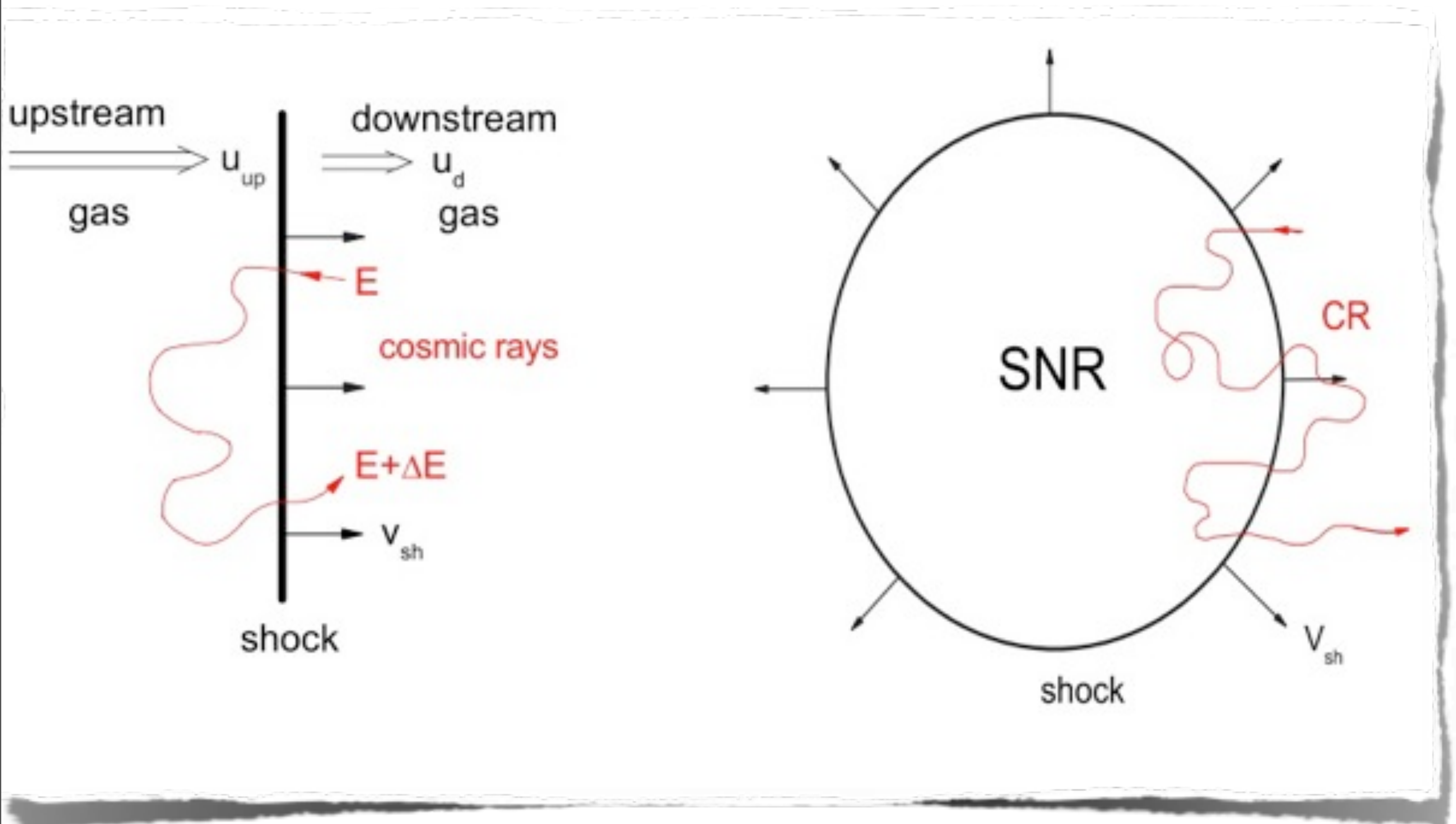
5. Recent achievments with the recently deployed string

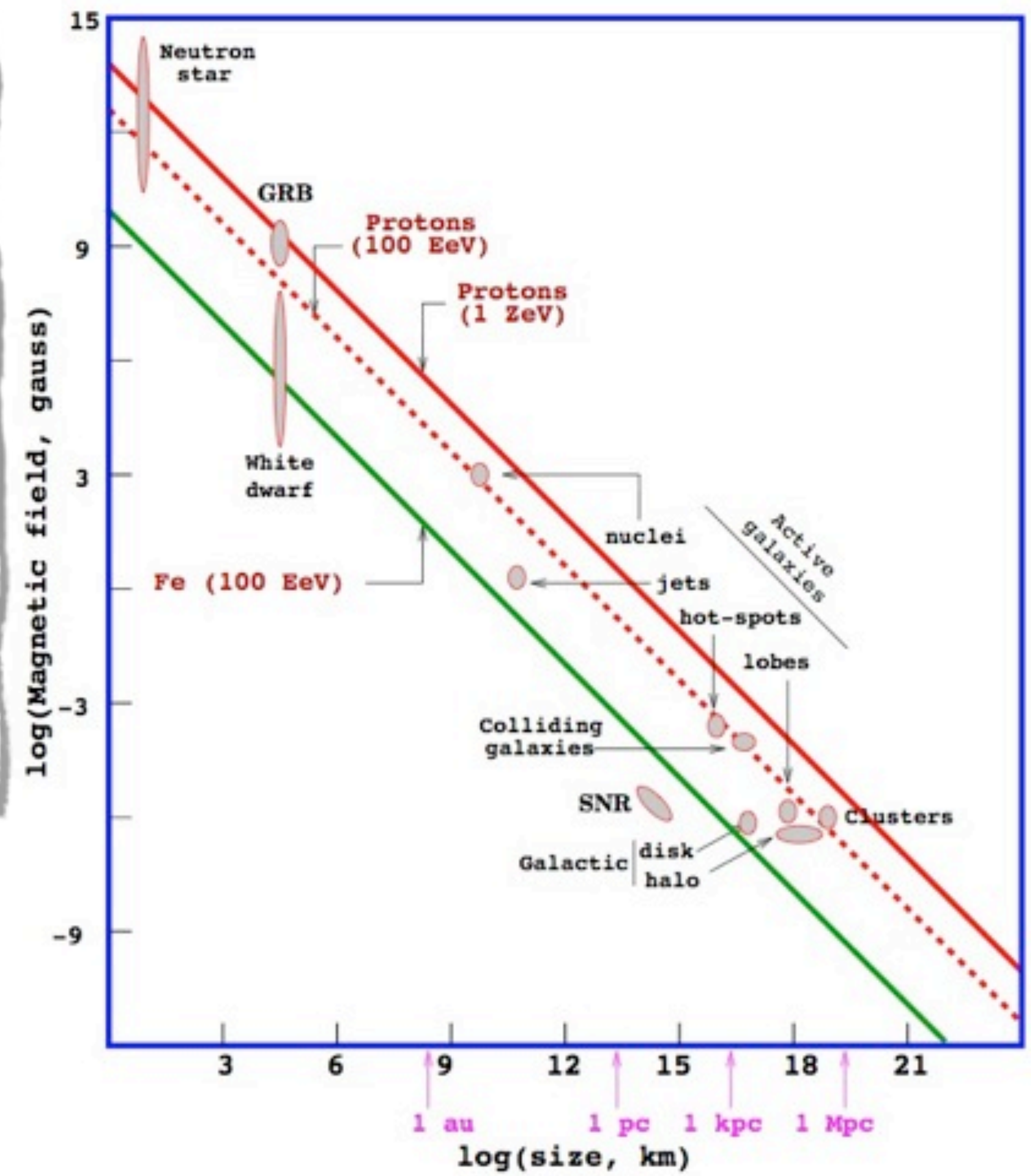
CR energy



CR abundances







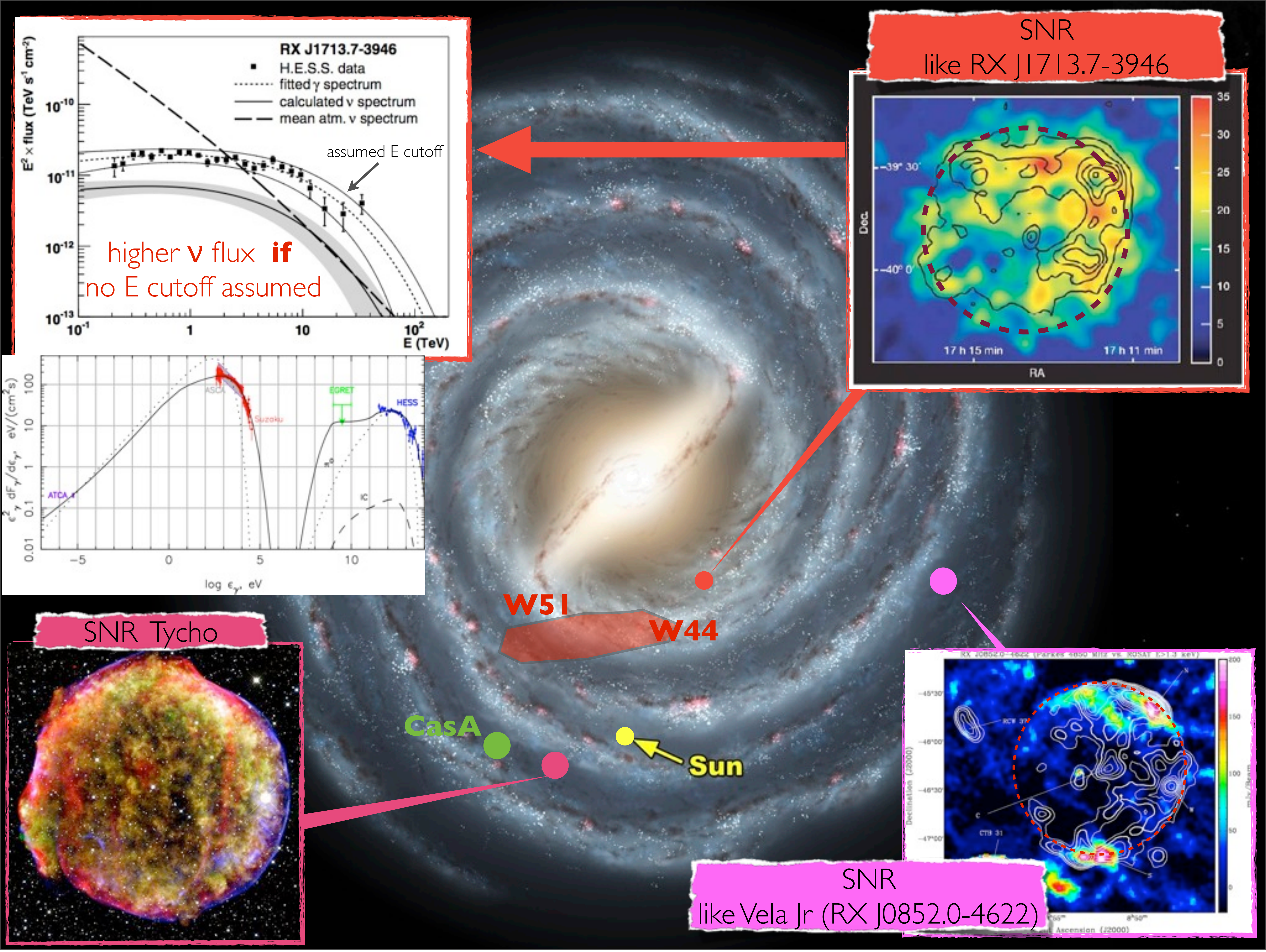
Fermi mechanisms

- Energy gain at each crossing $\Delta E/E \sim \beta = v_{sh}/c$, spectrum $N(E)dE \sim E^{-2}\,dE$ (see dedicated spare slide).

- **Galactic Sources:** $E_{max} \sim 10^{16}$ eV

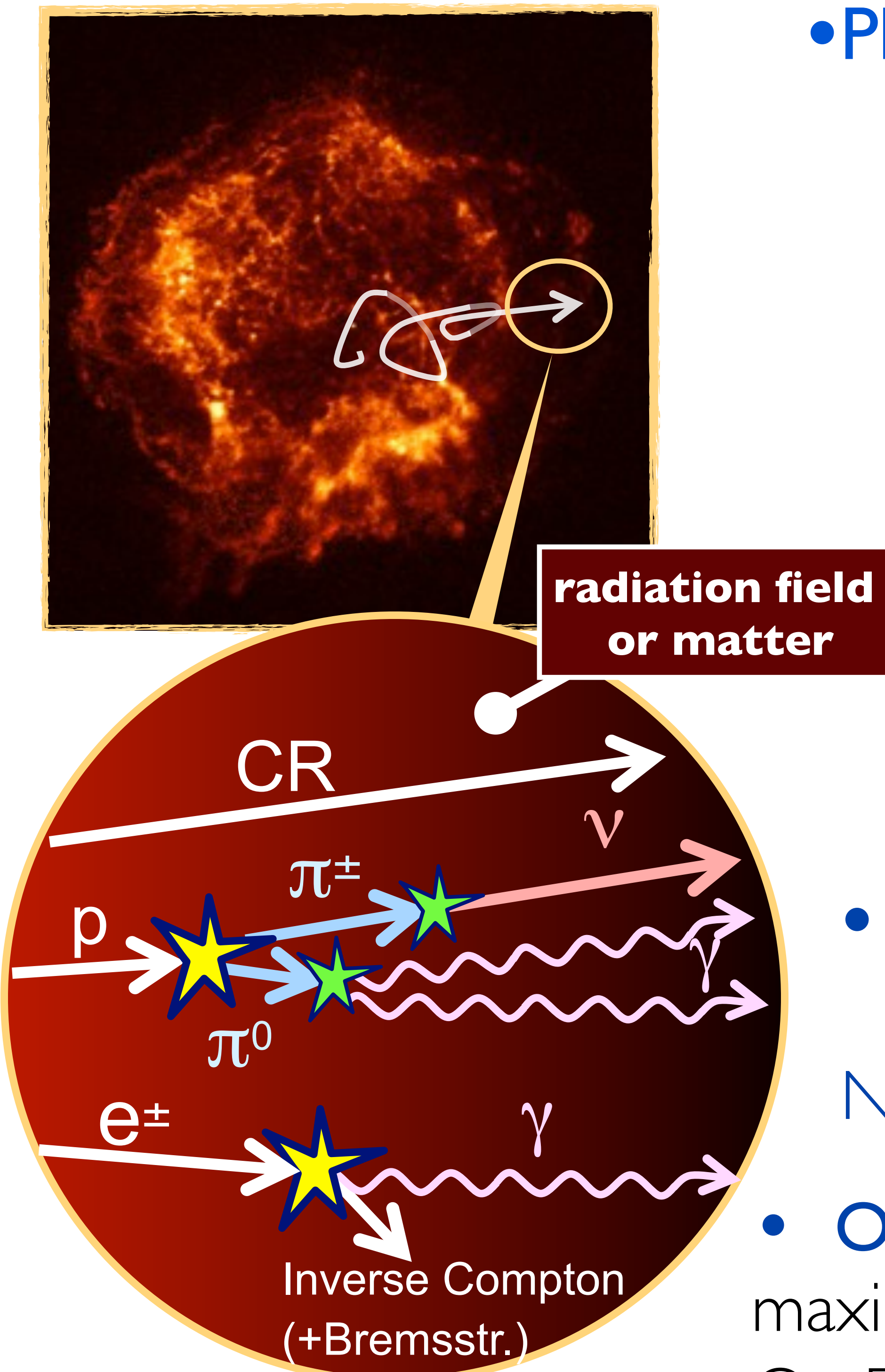
$$E(EeV) \sim \beta Z B_{\mu G} R_{kpc}$$

- **Extra Galactic Sources:** much more !


RX J1713.7-3946
H.E.S.S. data
fitted γ spectrum
calculated ν spectrum
mean atm. ν spectrum
assumed E cutoff
higher ν flux if
no E cutoff assumed
E² × flux (TeV s⁻¹ cm⁻²)
E (TeV)
SNR
like RX J1713.7-3946
Dec.
RA
17 h 15 min
17 h 11 min
ATCA
ASCA
Suzaku
EGRET
HESS
IC
log ε_γ, eV
W51
W44
CasA
Sun
SNR Tycho
SNR
like Vela Jr (RX J0852.0-4622)

Hadronic model vs. leptonic model

High energy interactions are - **so far** - revealed by gamma rays, but **neutrino production should take place...**



- Photo-disintegration: $p + \gamma \rightarrow \Delta^+$

$$|\Delta^+> = \sqrt{\tfrac{2}{3}}\,|\pi^o p\rangle + \sqrt{\tfrac{1}{3}}\,|\pi^+ n\rangle$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^o + p$$
$$\pi^o \rightarrow \gamma + \gamma$$

66.6 %

$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^+ + n$$
$$\pi^+ \rightarrow \nu_\mu + \mu^+$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

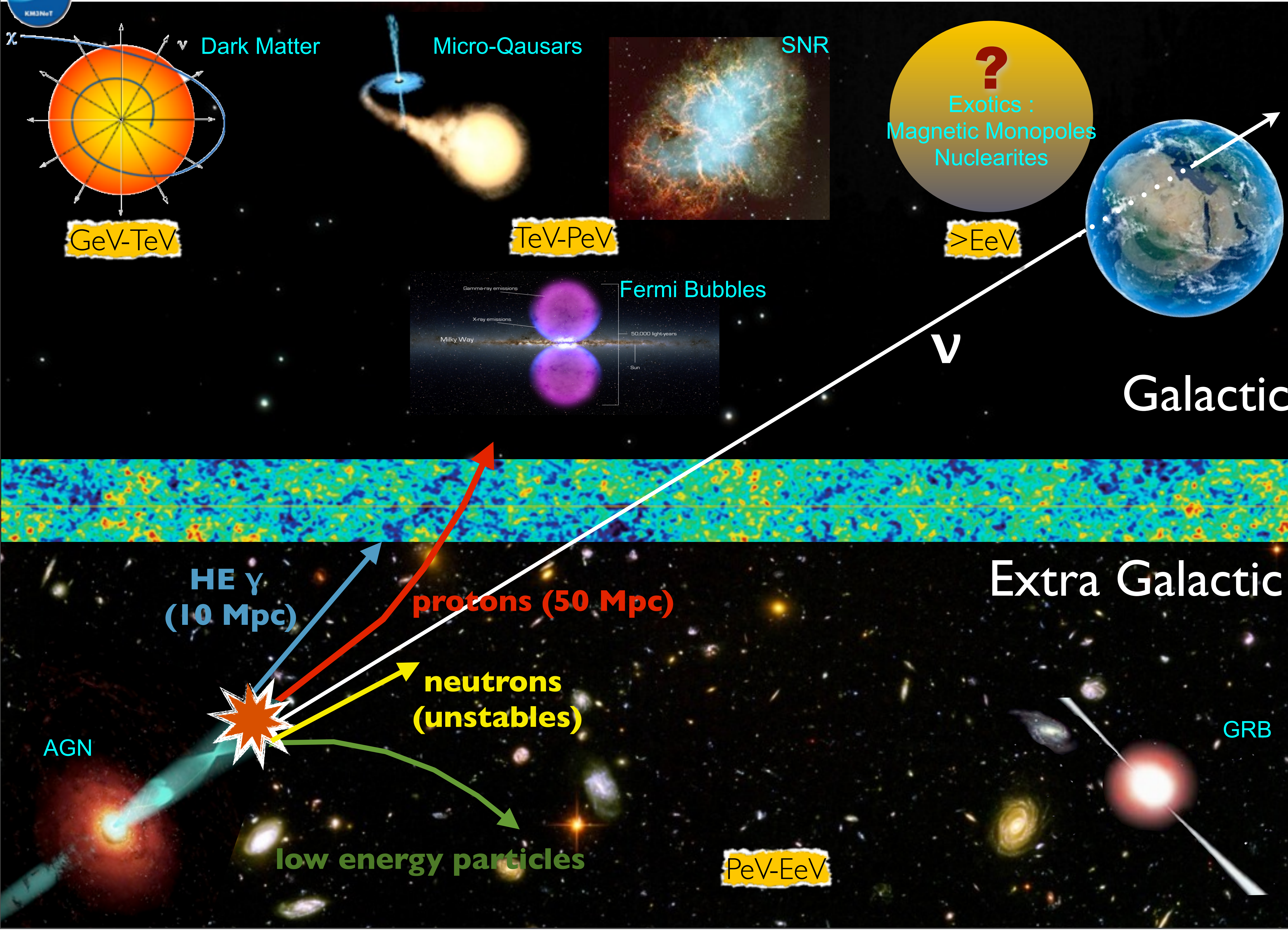
33.3 %

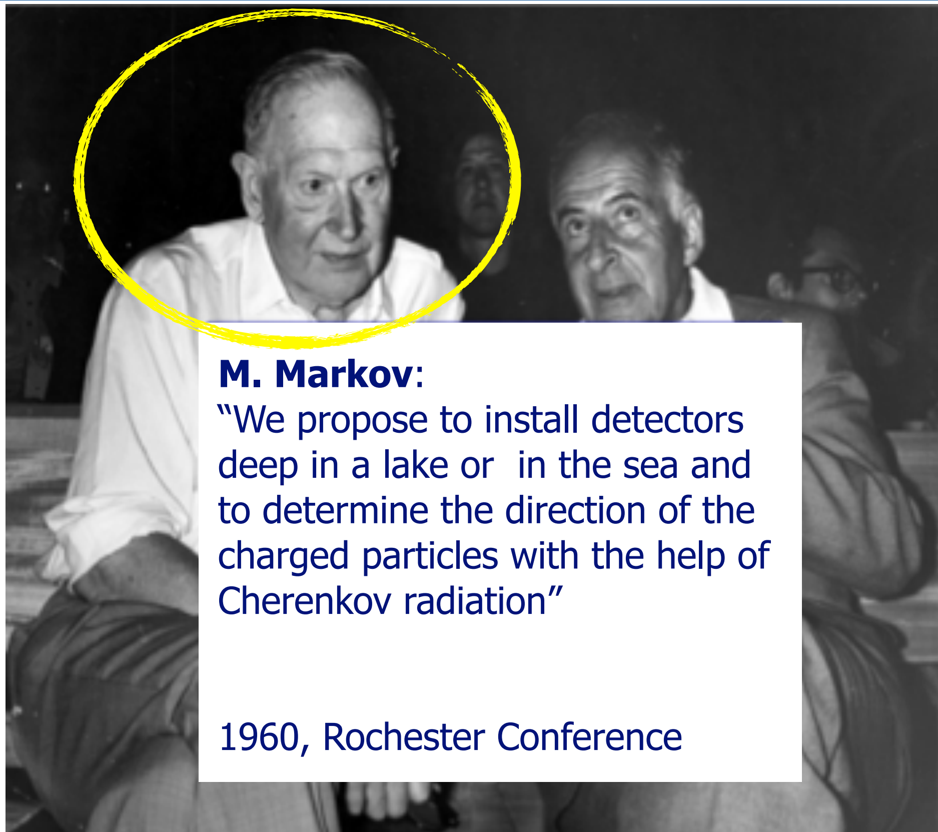
- *p-p* interactions: (leading ch.): $p\,p \rightarrow p(n) + m\,\pi^0 + 2\,m\,\pi^\pm$

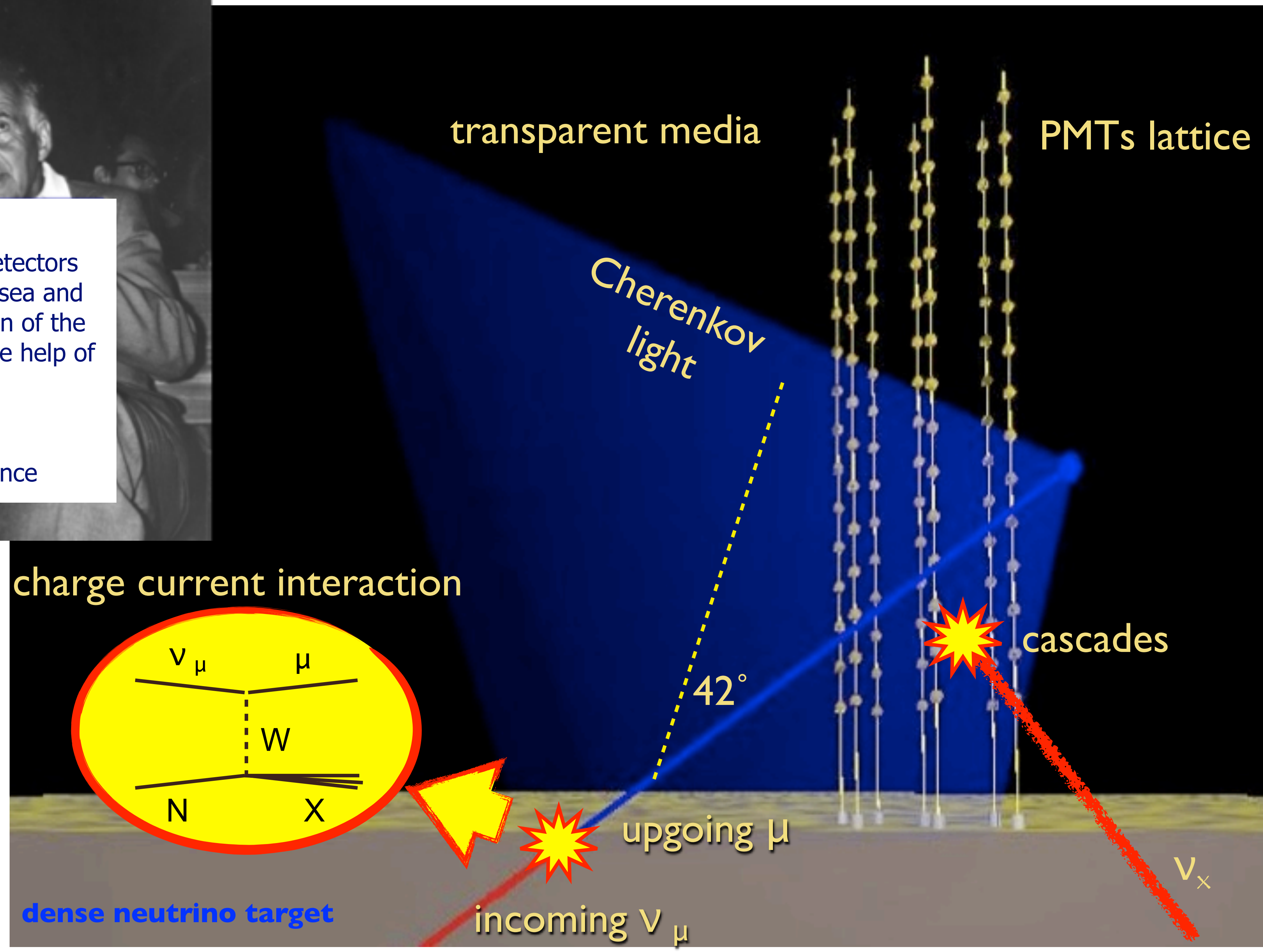
Neutrino at sources: *1* ν_e : *2* ν_μ : *0* ν_τ

- **Oscillation effect**: over cosmic distances, neutrinos have maximum mixing with no oscillation (decohernece effect). On Earth we expect to see *1* ν_e : *1* ν_μ : *1* ν_τ

Astrophysical neutrino source zoo



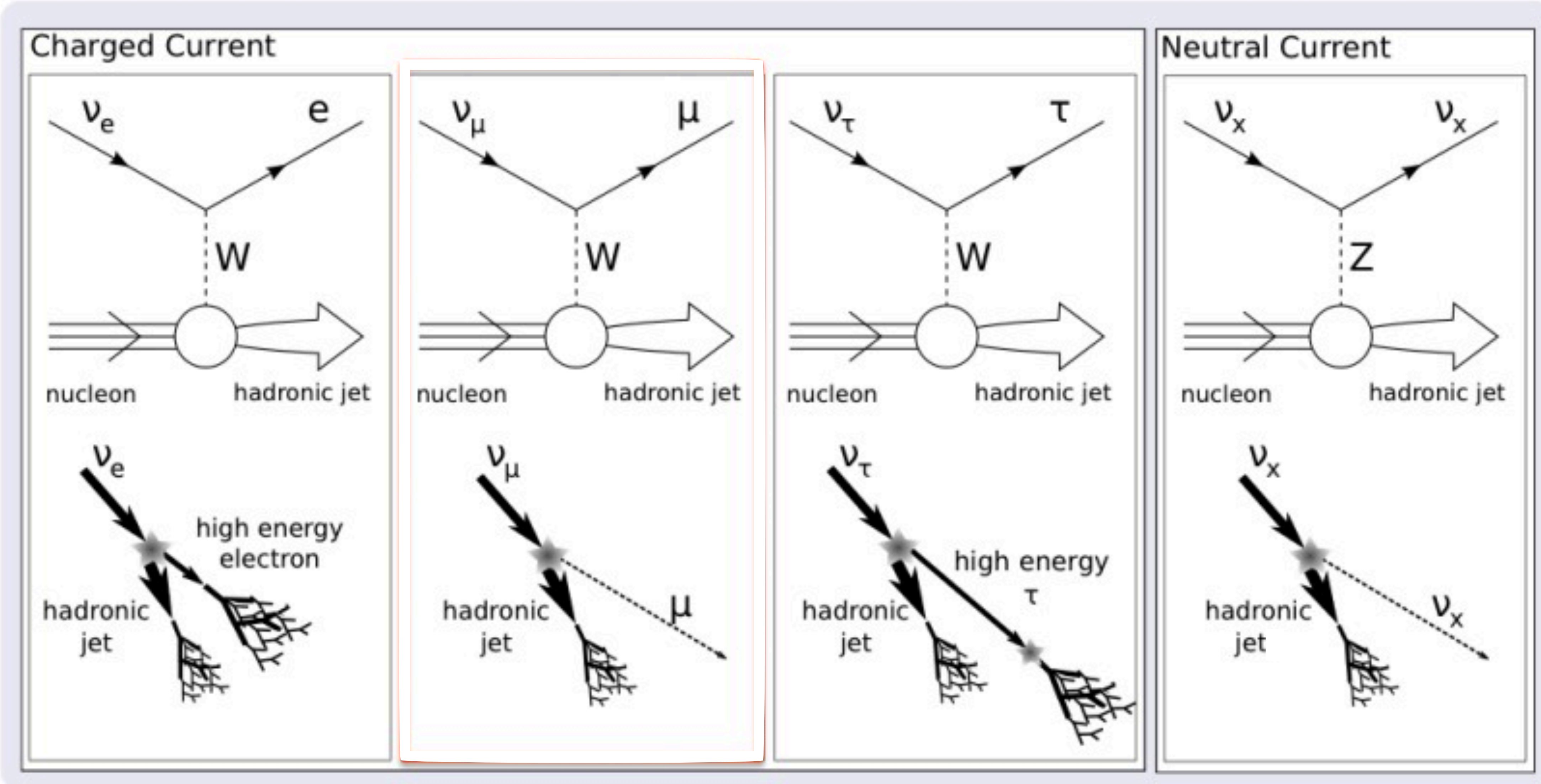




Very small neutrino cross-sections with matter $\sigma_{\nu N} \sim 7.8\ 10^{-36}\ (E^{0.36}/\ \mathrm{GeV})\ \mathrm{cm}^2$ for $E_\nu > 1$ TeV

Multi-km³ volume size detector for tens events/year

Neutrino interaction signatures

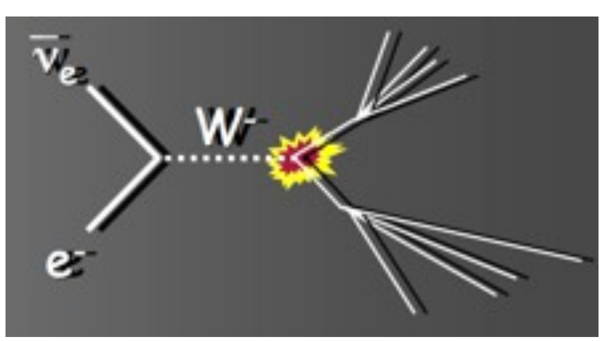


Best channel for Energy estimation

Golden channel for Astronomy (good angular res.)

"Double bang" resolved @ E>1PeV (tau range >50 m) so rare events

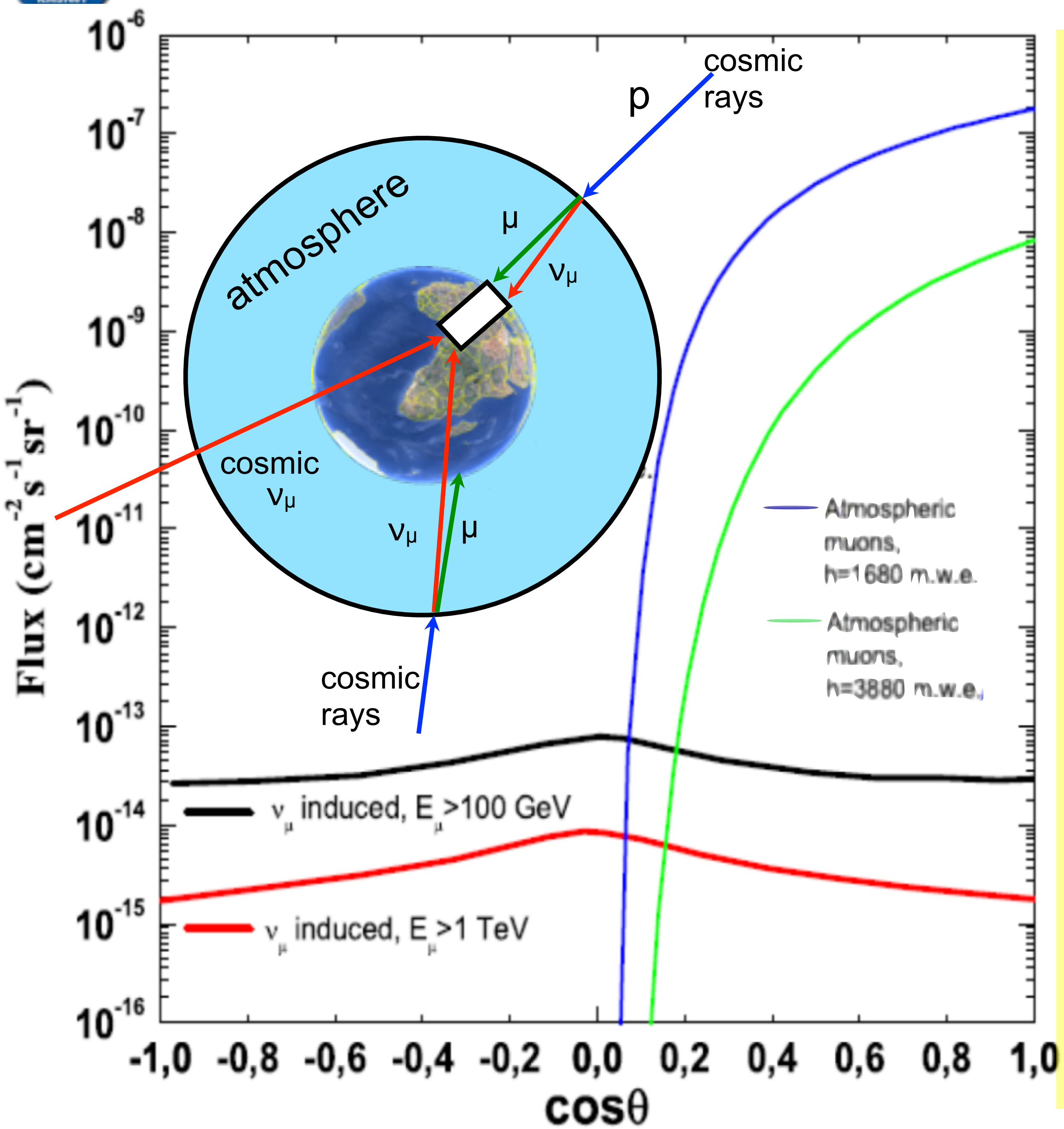
Partial energy information



Glashow Resonance

Enhancement of cross-section in the anti-ν_e - e^- interaction @ ~10^6 GeV

Good for energy calibration



- Astronomy:

↓ μ_{atm} ⇨ looking for upgoing (↑)

- Energy spectrum deformation

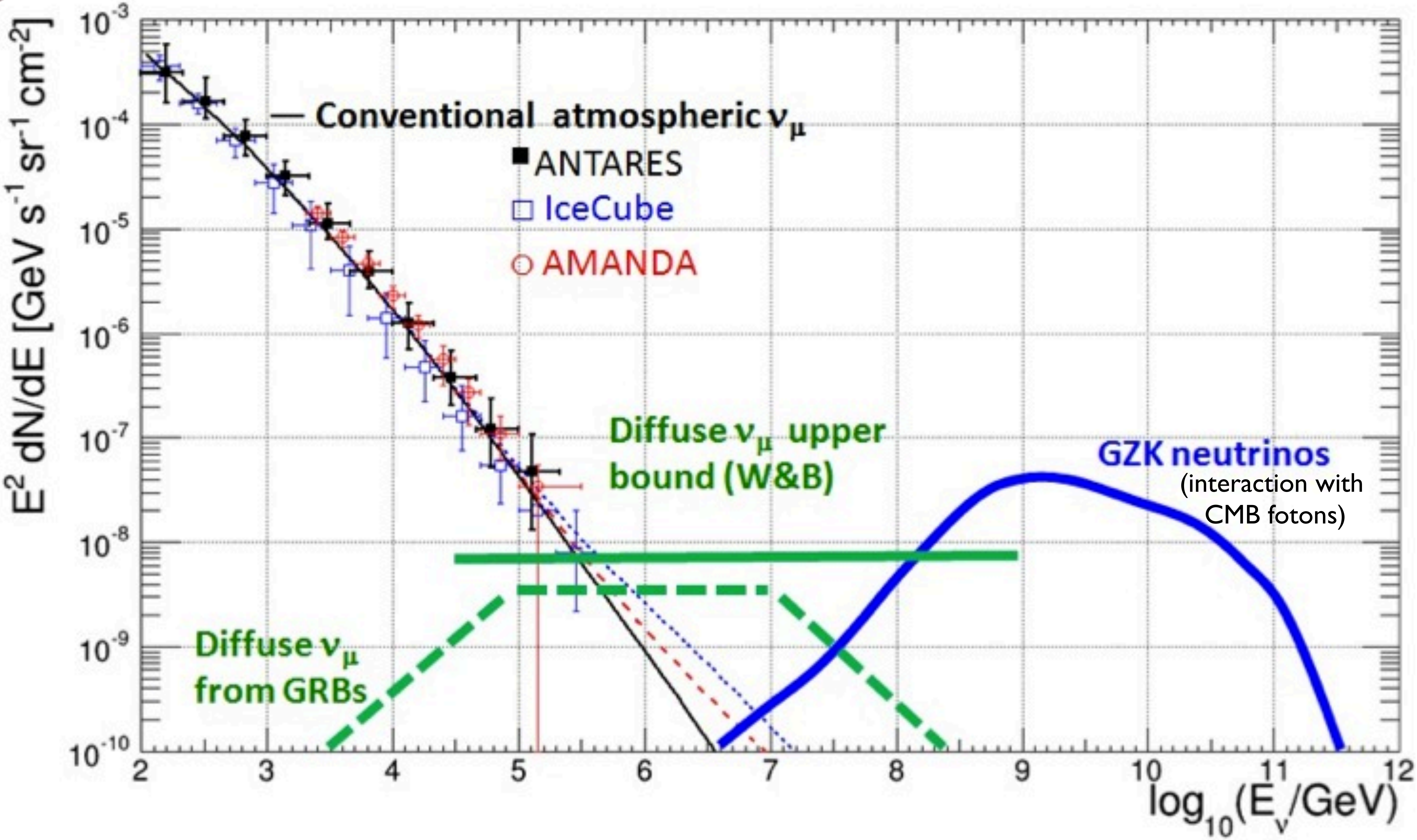
↕ ν_{atm} ⇨ energy cuts (E>10-100 TeV)

Quantity of detected light is a good **energy proxy.** In case of cascades the telescope can act as a calorimeter. Strong demand for large volumes.

Exploiting the background:

μ_{atm} ⇨ study of sytematics
ν_{atm} ⇨ neutrino oscillations

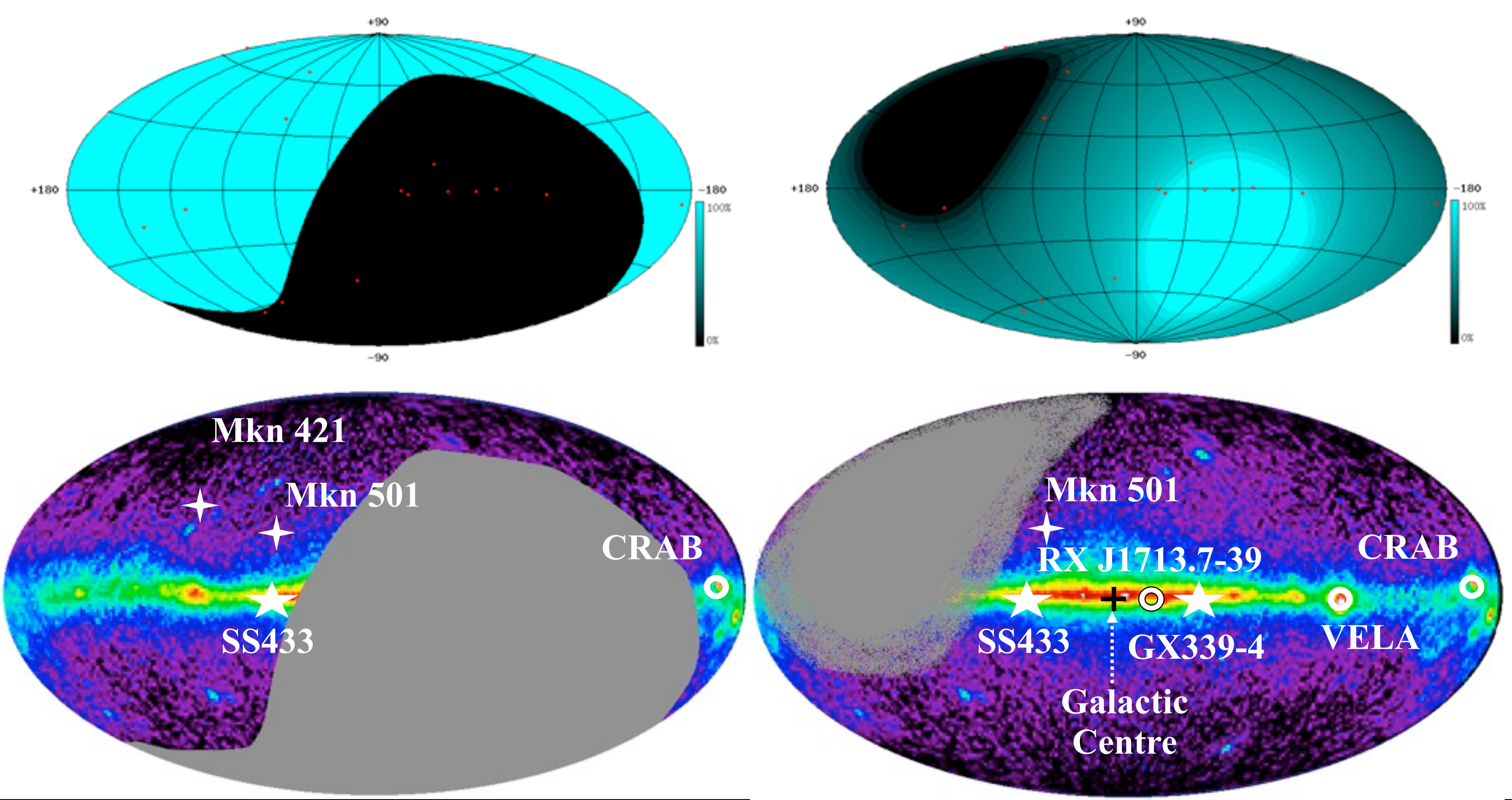
Astrophysical neutrino expected fluxes



Waxman-Bachall reference flux: $\frac{dN_\nu}{dE} \sim 9.0\ 10^{-9} \left(\frac{E}{\mathrm{GeV}}\right)^{-2}$ [GeV^{-1} cm^{-2} s^{-1} sr^{-1}]

Sky coverage for different telescope locations

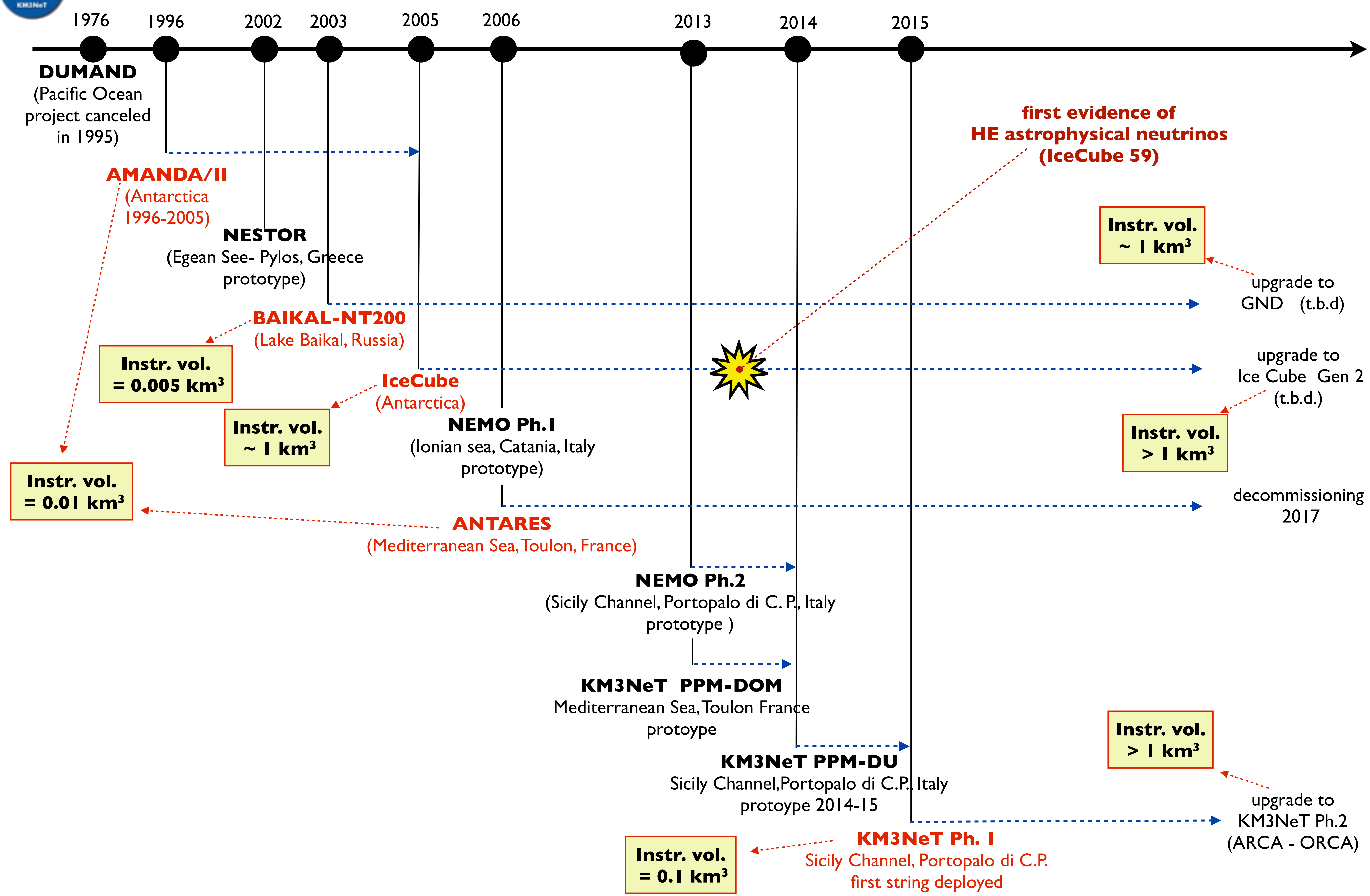
Under-ice: IceCube (South Pole) | Under-water: ANTARES/KM3NeT (43°North)



pros: low optical bkg due to natural radioactive decays or bioluminescence
cons: poor angular resolution (small scattering lengths)

pros: large optical bkg due to natural radioactive decays or bioluminescence
cons: good angular resolution (large scattering lengths)

Timeline of the Neutrino Telescopes

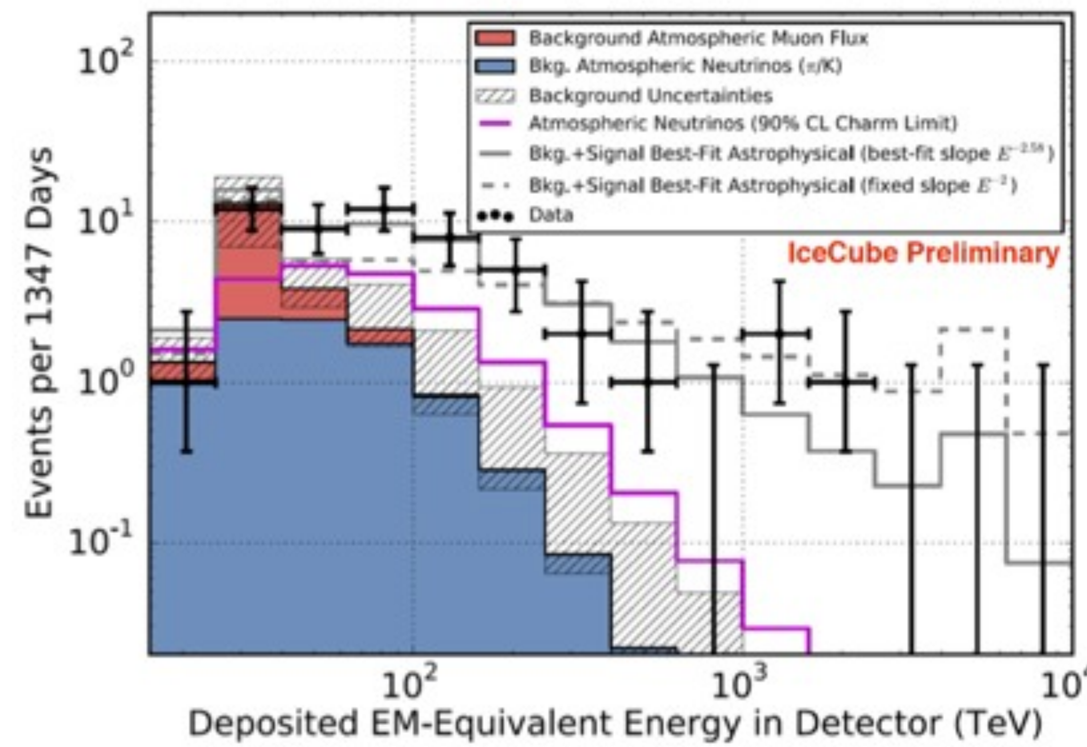


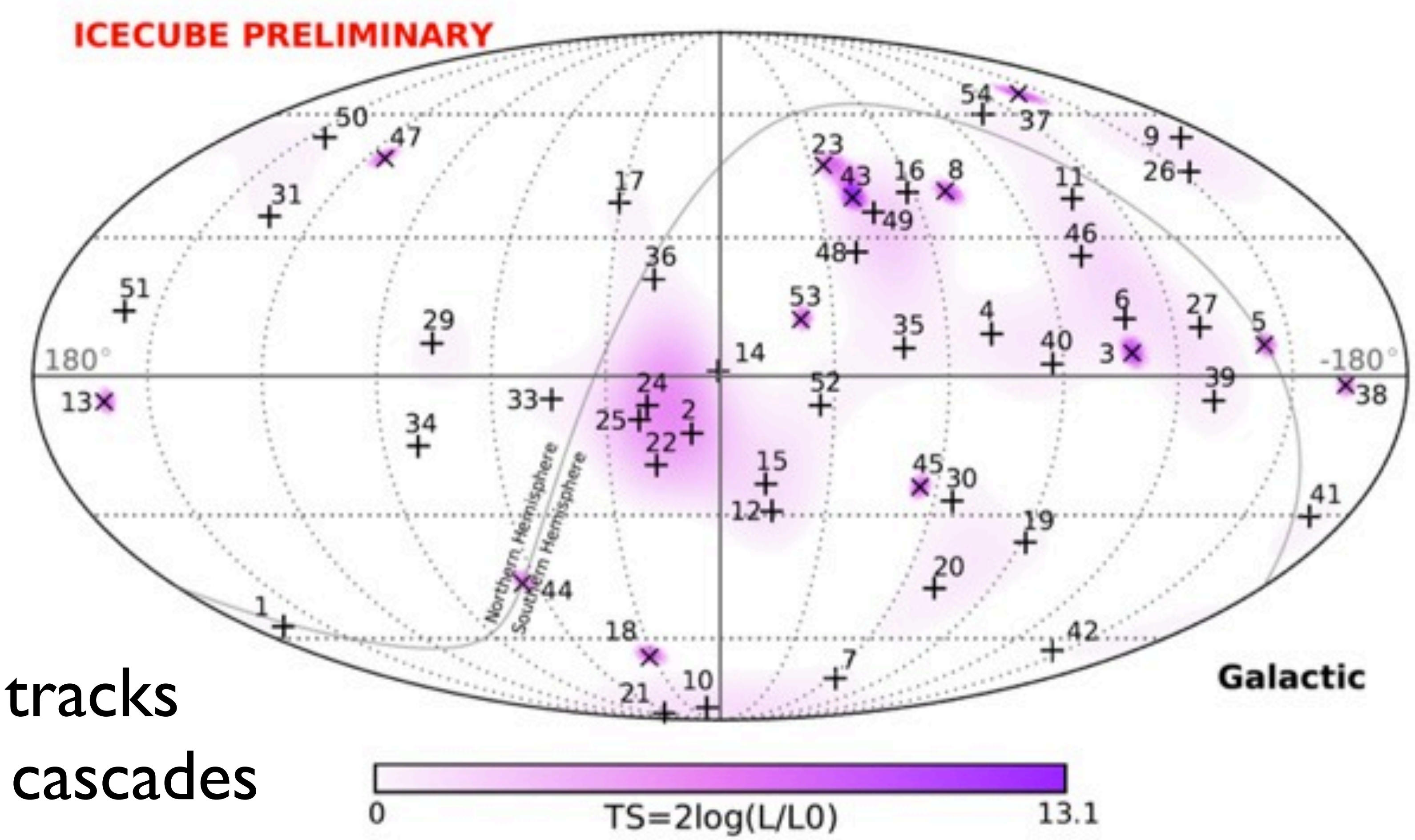
Recent findings from IceCube

IceCube: for >50 candidates, rejected atm. neutrinos H_0 with significance ranging [3.7σ - 6.5σ]

-Energy range: **100 TeV ≤ *E* ≤ 1 PeV** for tracks, **E > (35) 10 TeV** with (partially) contained cascades:

54 HESE events (High Energy Starting Event) analyses imply **vetoing approach**, which reduce the IceCube effective area. Most of them are cascades for which the angular resolution is >10°

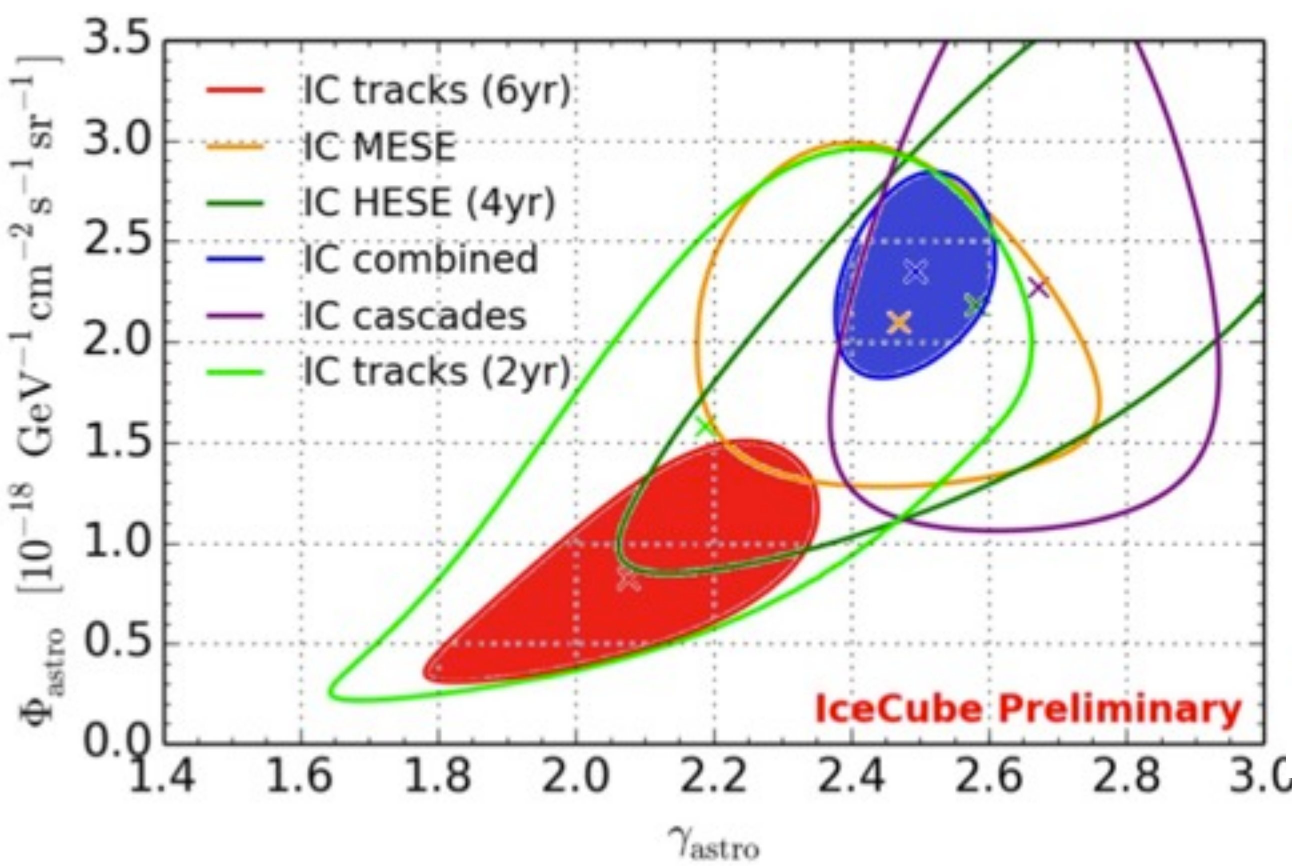




x tracks

\+ cascades

Hot spot in the Galactic Center: ANTARES has excluded at 90% C.L. the possible match of events with point sources (see dedicated spare slide)



All sky cascades

$$\frac{dN_\nu}{dE} = \left(2.3^{+0.7}_{-0.6}\right) 10^{-18}\,\mathrm{GeV^{-1}\,cm^{-2}\,sr^{-1}} \left(\frac{E_\nu}{100\ \mathrm{TeV}}\right)^{-\left(2.67^{+0.12}_{-0.13}\right)}$$

High Energy Starting Entry events (HESE, *downgoing*)

$$\gamma_{astro} = 2.58 \pm 0.25$$

Upgoing Tracks (i.e. from Nothern Hemisphere)

$$\frac{dN_\nu}{dE} = \left(0.66^{+0.40}_{-0.30}\right) 10^{-18}\,\mathrm{GeV^{-1}\,cm^{-2}\,sr^{-1}} \left(\frac{E_\nu}{100\ \mathrm{TeV}}\right)^{-(1.91\pm0.20)}$$

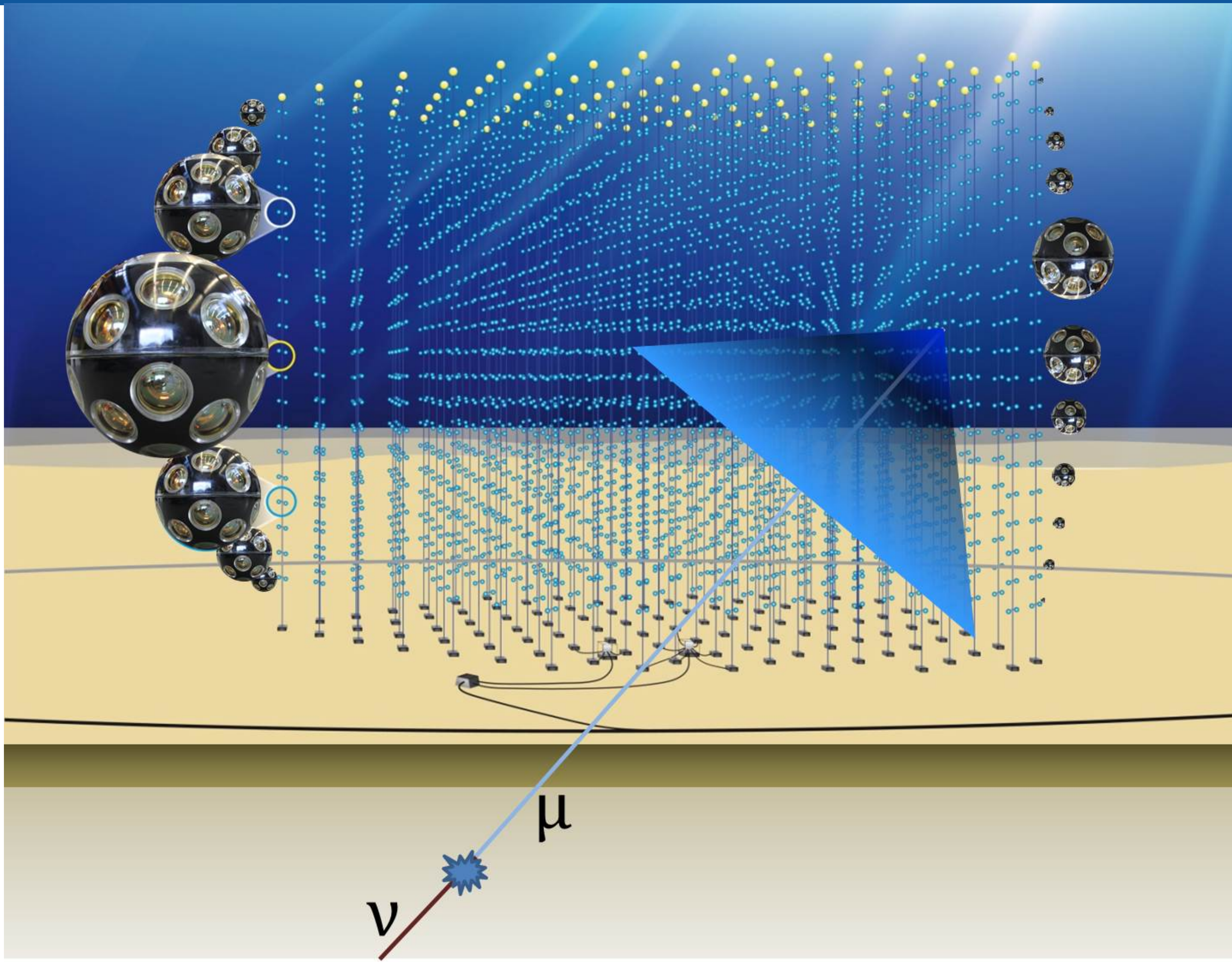
A tension at level of >3.6σ is apparent.

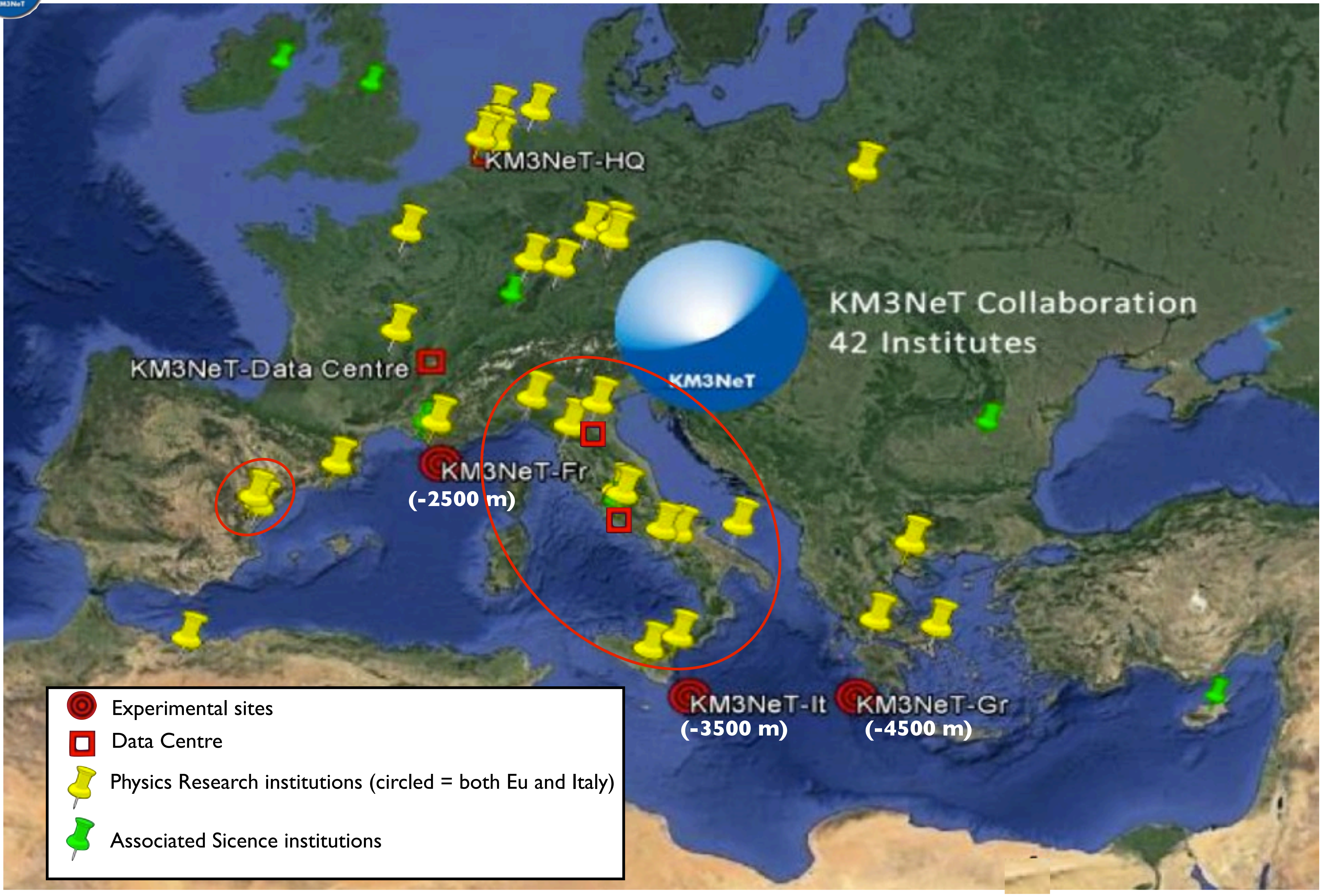
ANTARES, with full statistics,

- could confirm a signal of diffuse E^{-2} flux from the Southern Sky (should be the same);
- is at the edge of sensitivity for expected Galactic Center events.

Compelling request for a larger neutrino telescope in the Nothern hemisphere with optimum angular and energy resolution...

KM3NeT




KM3NeT-HQ
KM3NeT Collaboration
42 Institutes
KM3NeT
KM3NeT-Data Centre
KM3NeT-Fr
(-2500 m)
KM3NeT-It
(-3500 m)
KM3NeT-Gr
(-4500 m)
Experimental sites
Data Centre
Physics Research institutions (circled = both Eu and Italy)
Associated Sicence institutions

"Nu-Telescope" group (ANTARES - NEMO - KM3NeT)

Historical group

S. Cecchini : Former ANTARES Quality Manager

T. Chiarusi : KM3NeT DAQ system coordinator

A. Margiotta : team leader, Montecarlo Simulations coordinator of the ANTARES Coll.

M. Spurio : deputy spokesman of the ANTARES Coll.

L. Fusco : post-doc (diffuse flux analysis)

C. Pellegrino : PhD student (DAQ software and trigger algorithms design)

F. Versari : undergraduate student

in strict collaboration with CNAF people for DAQ design and realization:

M. Favaro, **F. Giacomini**, **M. Manzali**: software design

L. Chiarelli, **S. Zani**: networking

Strong support from the Electronics and IT Division in Sezione di Bologna

Fruitful collaboration also with Oceanography Group of UniBo: N. Pinardi, **M. Zavatarelli**

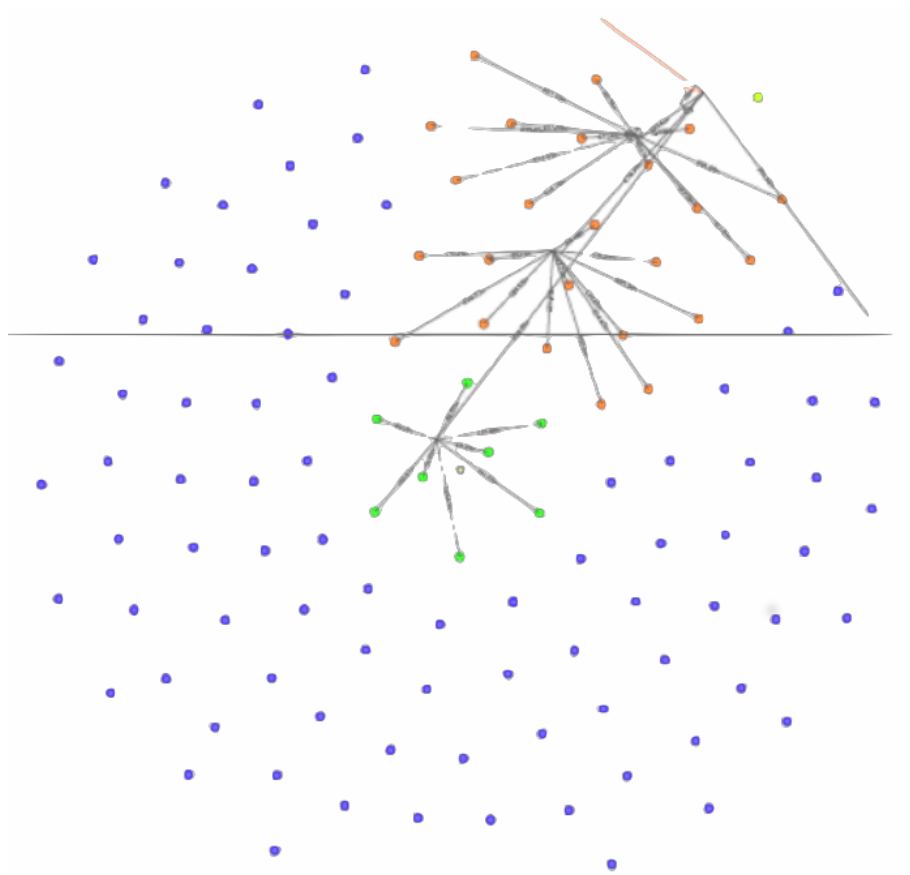
KM3NeT Europe: 2 sites distributed experiment

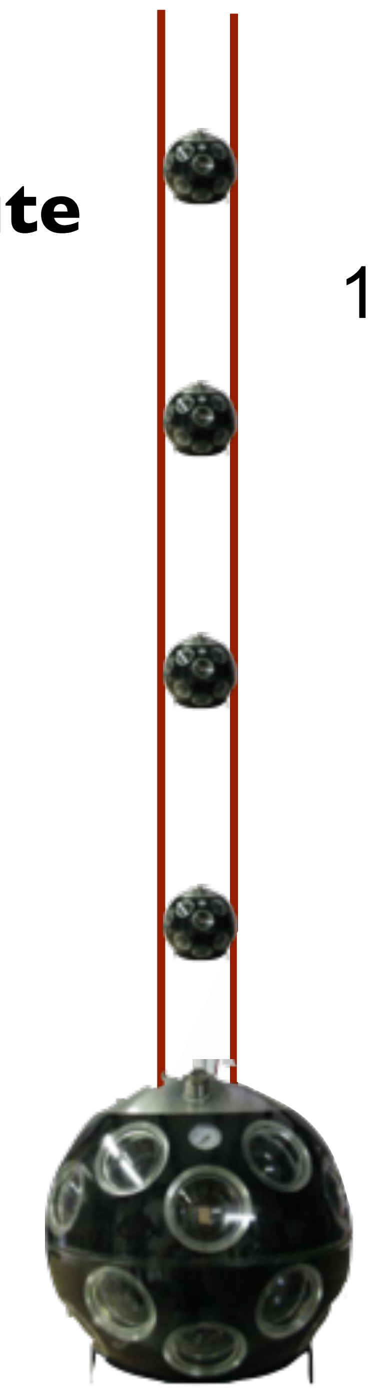
The common element is the Detection Unit (DU): vertical structure hosting 18 Digital Optical Modules (DOMs) each one equipped with 31 3" PMTs and 1 piezo acoustic sensor for the positioning system.

Astronomy **R**esearch with **C**osmics in the **A**byss (**ARCA**)

2 string *building blocks* +
8 towers*-deep core in the **Italian site**
string vertical spacing: **36 m**
string horizontal spacing: **~100 m**

2 x

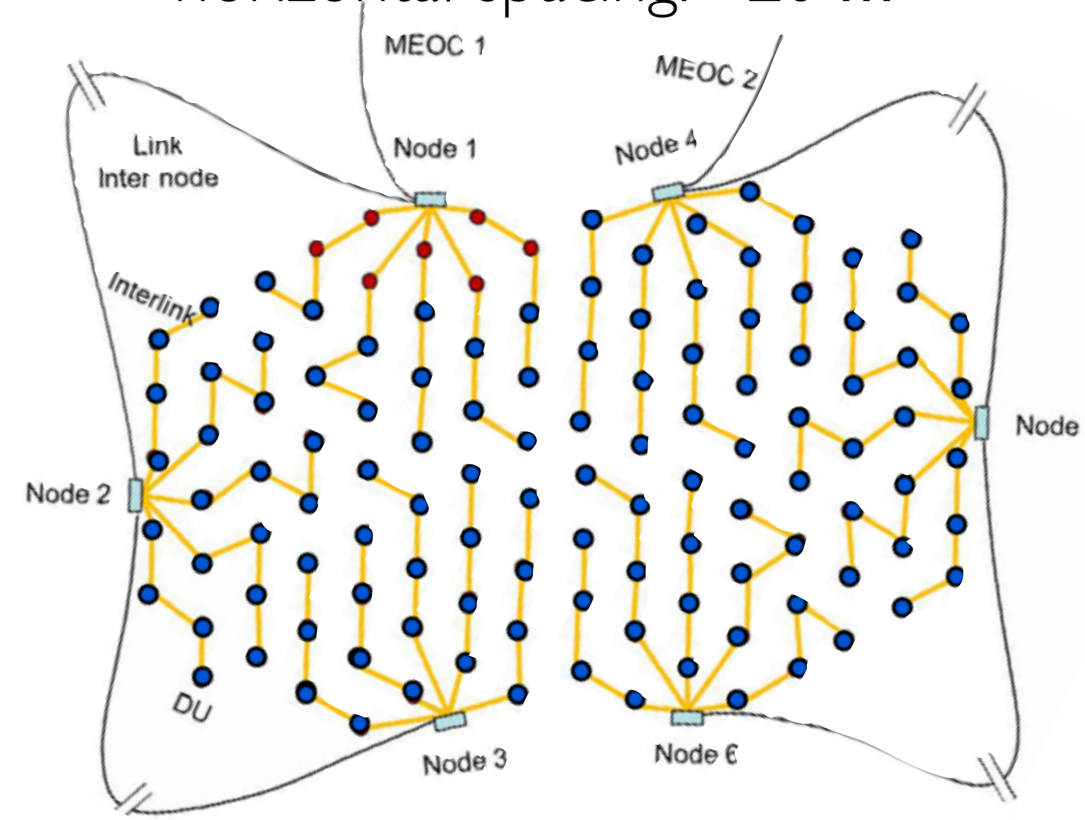




Oscillation **R**esearch with **C**osmics in the **A**byss (**ORCA**)

Study of neutrino mass hierarchy
(not presented today)

1 string *building block* in the **French site**
vertical spacing: **~6 m**
horizontal spacing: **~20 m**



1 building block (b.b.)=115 strings

KM3NeT- EU Development

Phase	Blocks/ strings	Primary deliverables / site(s)	Funding
1	0.2/31 7 (Fr) + 24(It) *	Proof of feasibility and first science results; KM3NeT-Fr + KM3NeT-It sites	Fully funded
2.0	2/230	Measurement of neutrino signal reported by IceCube; All-flavor neutrino astronomy; KM3NeT-It site	Applications pending
	1/115	Neutrino mass hierarchy; KM3NeT-Fr site	
3	6+1/805	Neutrino astronomy including Galactic sources; Multiple sites	Future

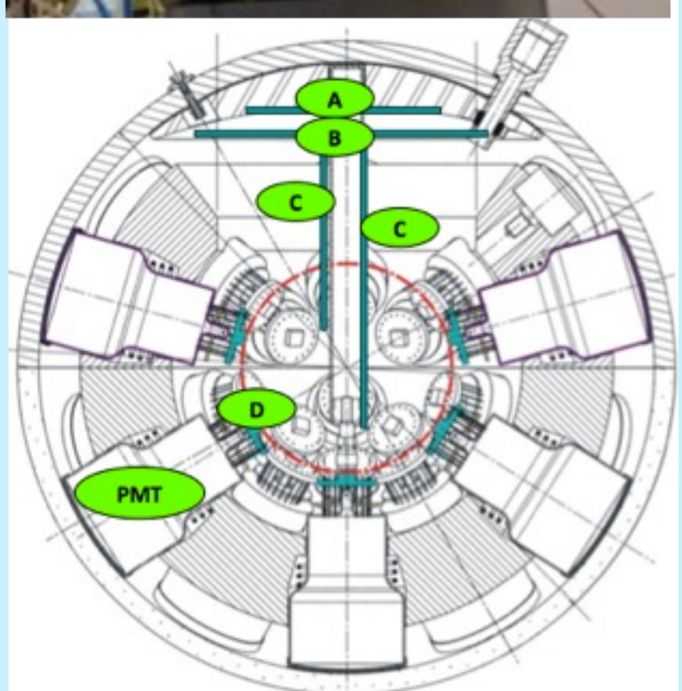
(* plus 8 Towers, fully funded as well)

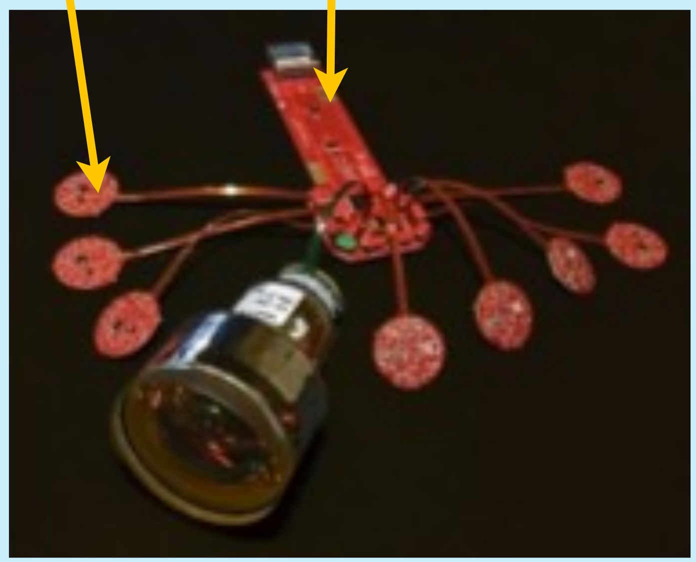
The KM3NeT Europe - Digital Optical Modules (DOM)

31 3" PMTs in 17" glass sphere (cathode area~ 3x10" PMTs)
- 19 in lower, 12 in upper hemisphere
- Al cooling shield **(A)**
- Central Logic Board (CLB) **(B)**
- Front-end electronics **(C) "Octopus board"**
- 31 PMT bases (total ~140 mW) **(D)**

1-vs-2photo-electronseparation
→better sensitivity to coincidences

Better discrimination of the light due to environmental BKG





High Voltage for PMTs discrimination w.r.t. predefined threshold

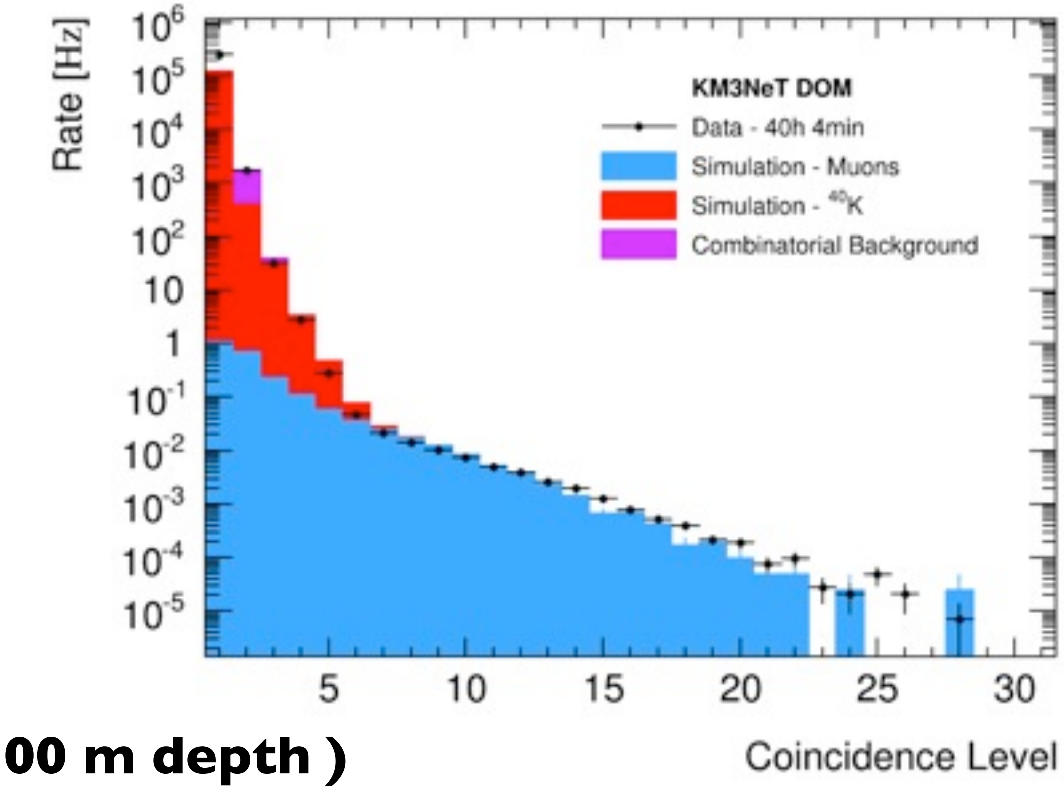
Central Logic Board (CLB)

FPGA (Kintex 7) for:
- TDC (time & time over threshold),
- time stamping (1 ns precision);
- interface for time synchronisation (White Rabbit)
- control of calibration devices (I^2C bus);
- Ethernet communication;

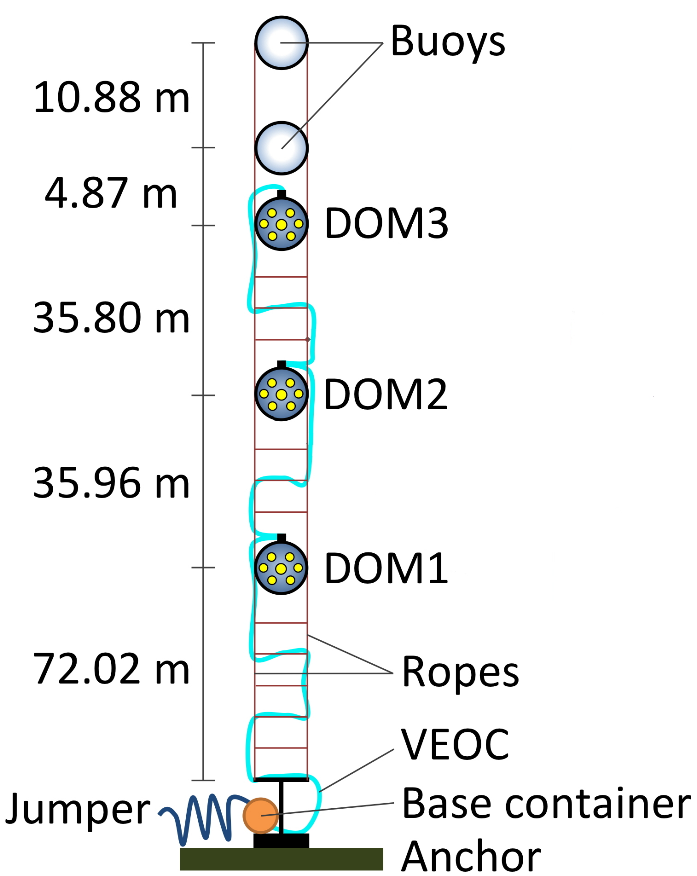
NOTE: the DOM is a node of a submarine network which is directly connected to the TRIgger and Data Acquisition System LAN, on-shore.

PPM-DOM
in the KM3NeT-Fr site (2500 m depth)

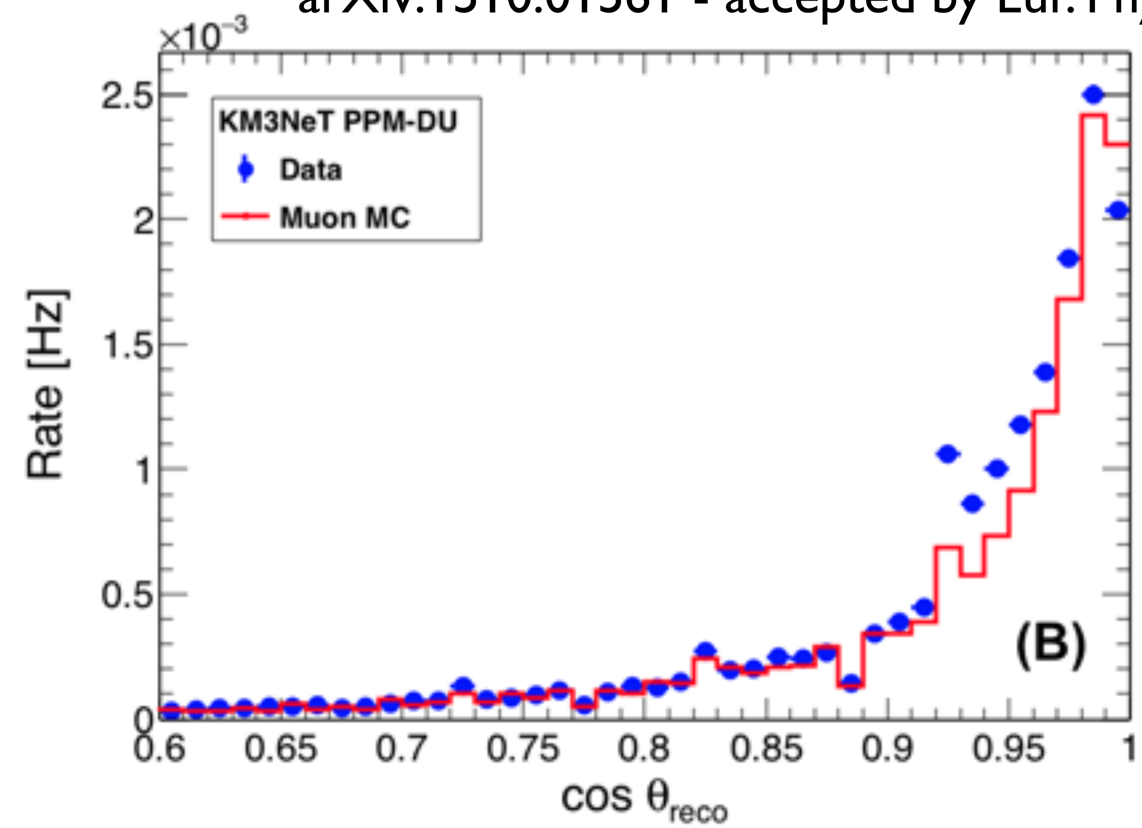
Eur.Phys.J. C74 (2014) 3056



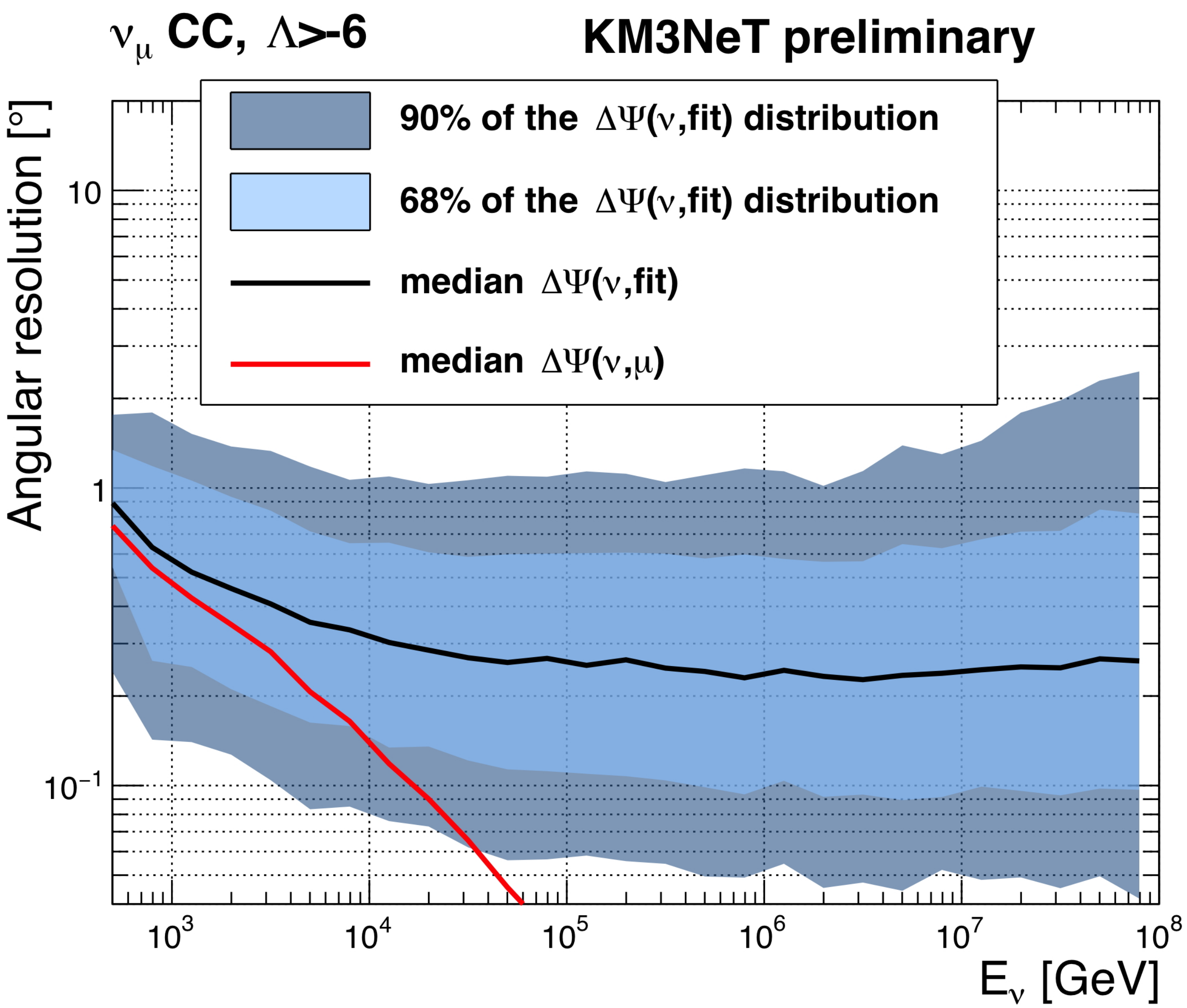
PPM-DU
in the KM3NeT-IT site (3500 m depth)

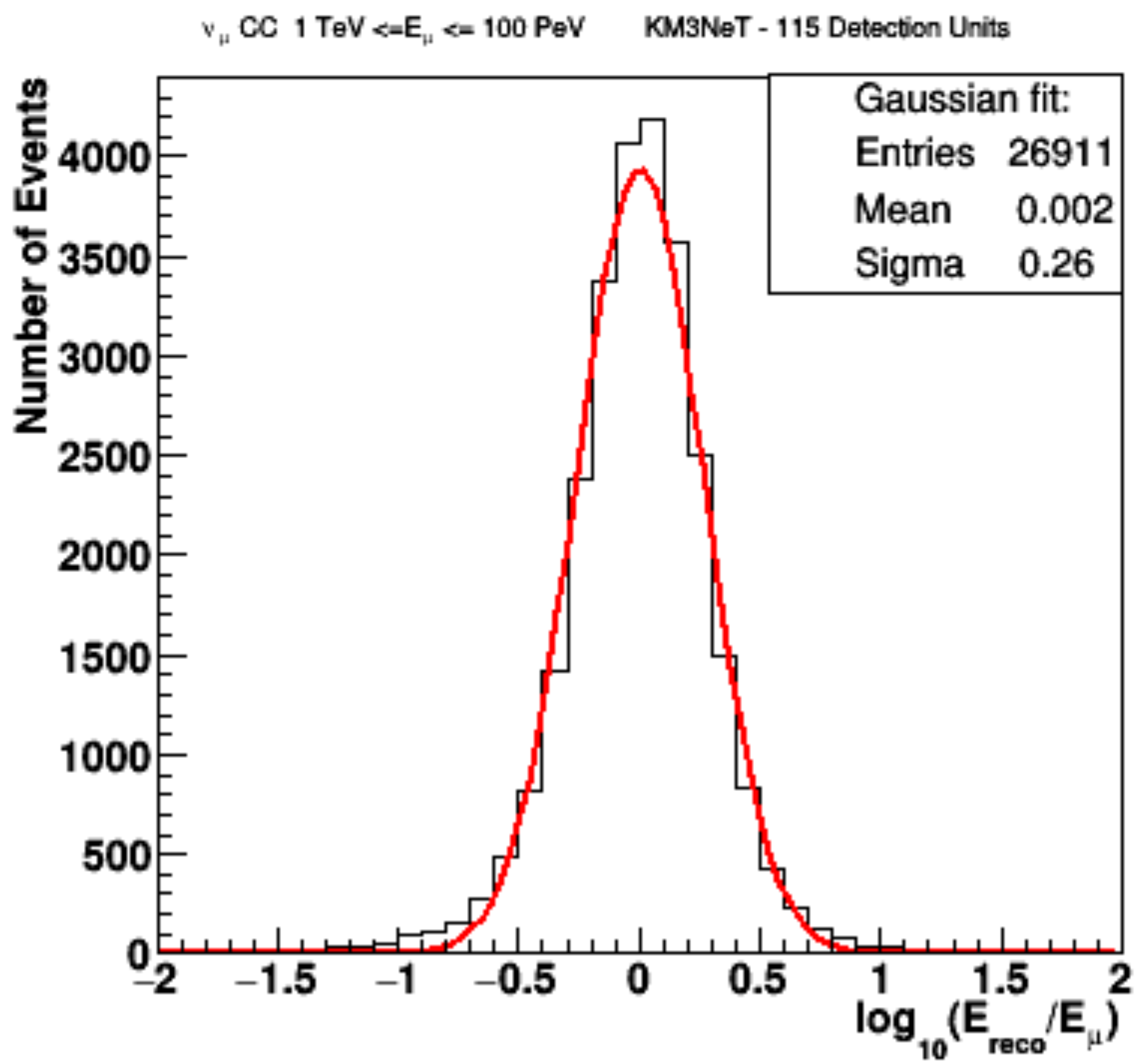


arXiv:1510.01561 - accepted by Eur. Phys. J. C



After cuts optimized for track reconstruction



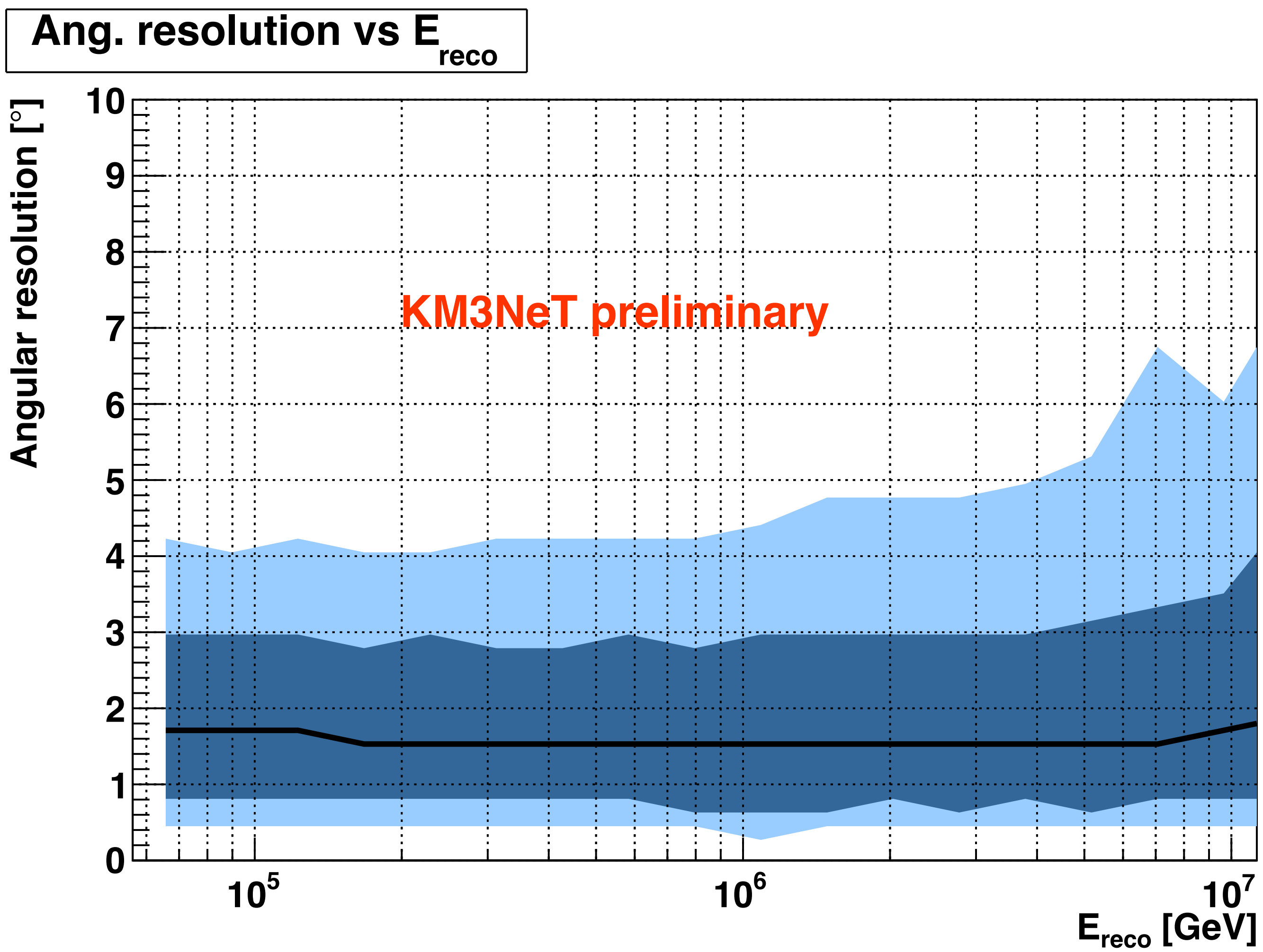


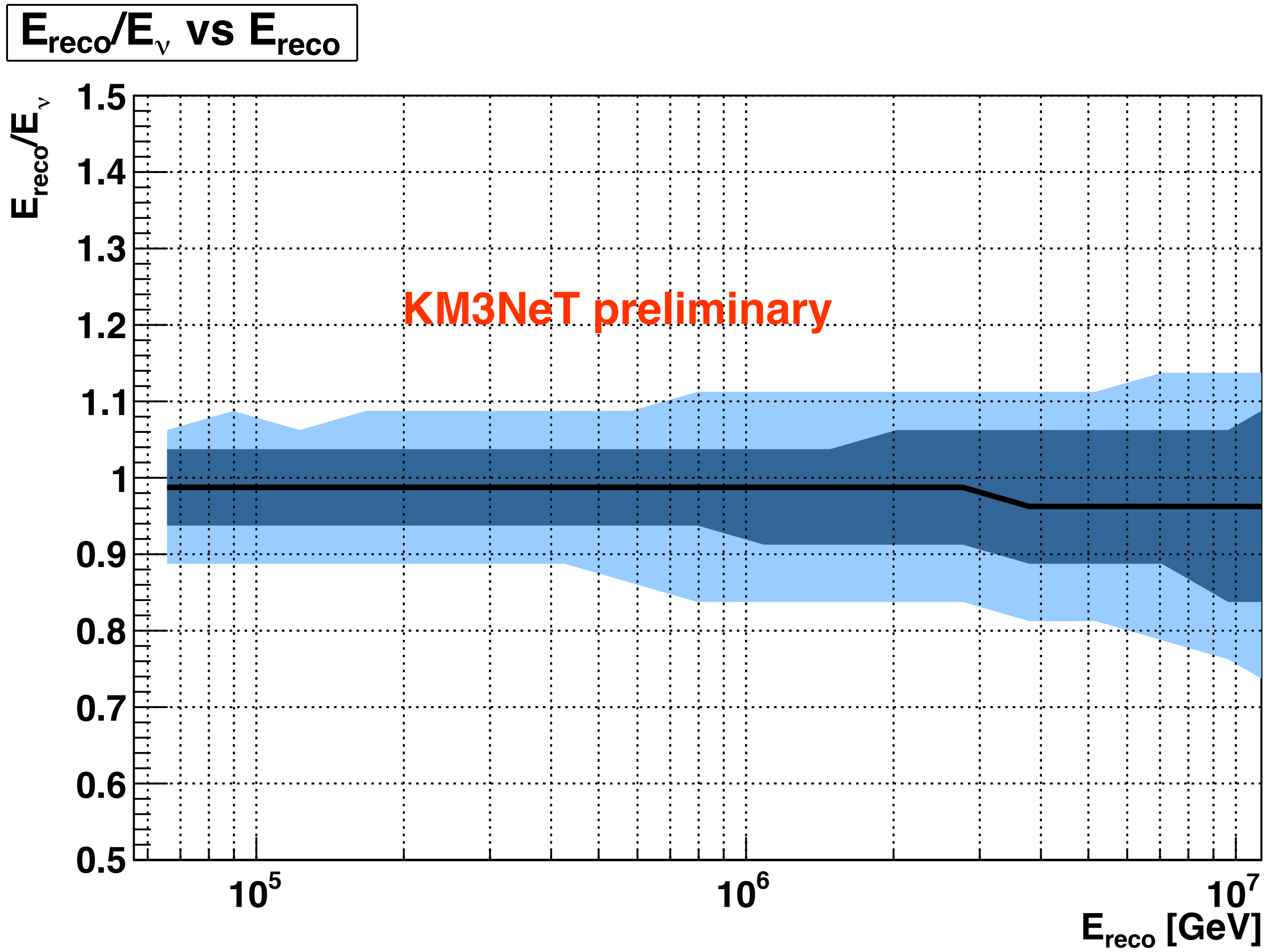
Angular resolution
about 0.2° (E_ν>10 TeV)

Energy resolution
0.26 in $\log E_\mu$
(1 TeV < E_ν < 100 PeV)

(**note**: IceCube ang. resolution about 2°)

After cuts optimized for cascade reconstruction





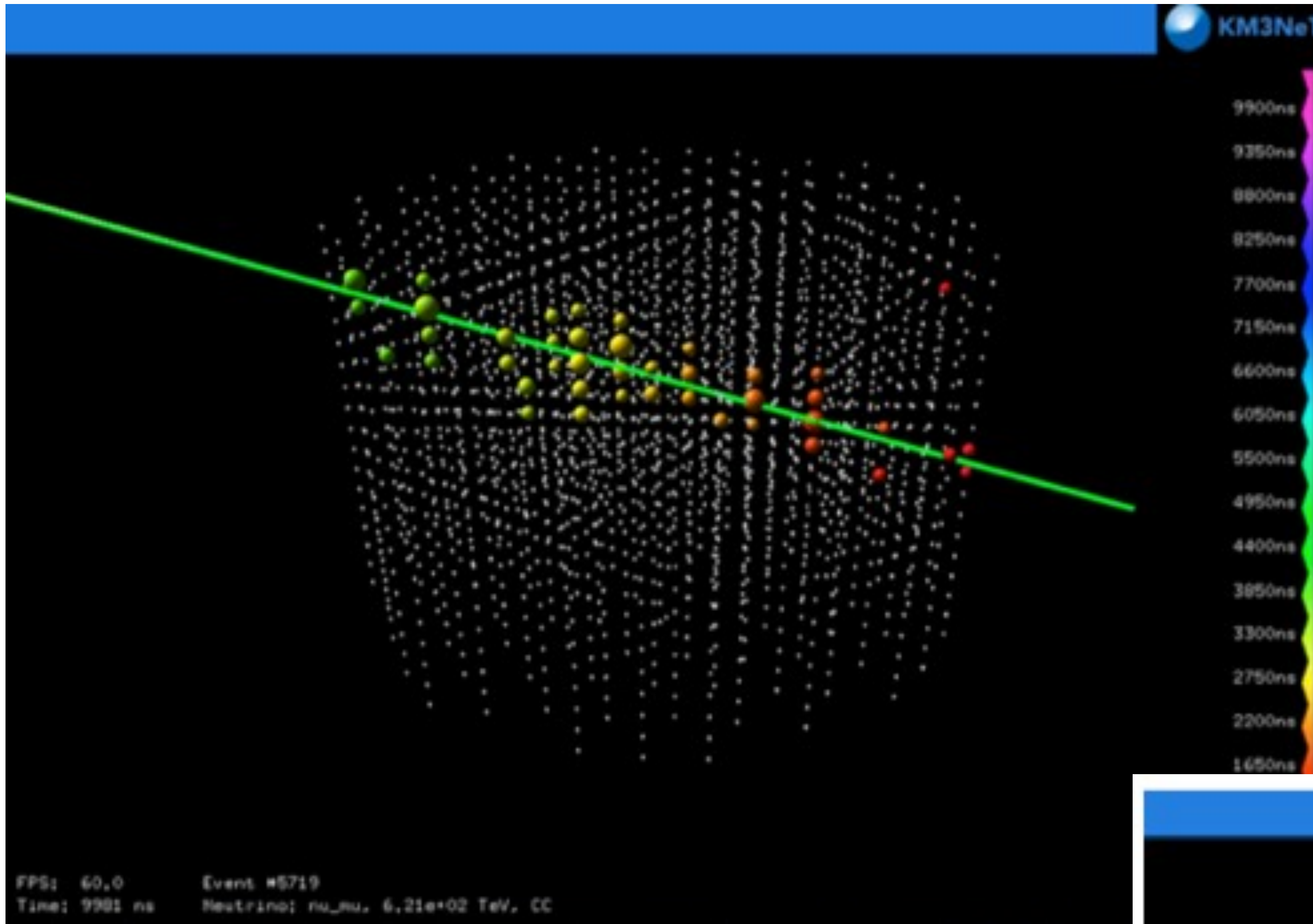
Angular resolution about 2°

Energy resolution < 10%

(**note**: IceCube ang. resolution about 10°-20°)

Displayed tracks and cascades

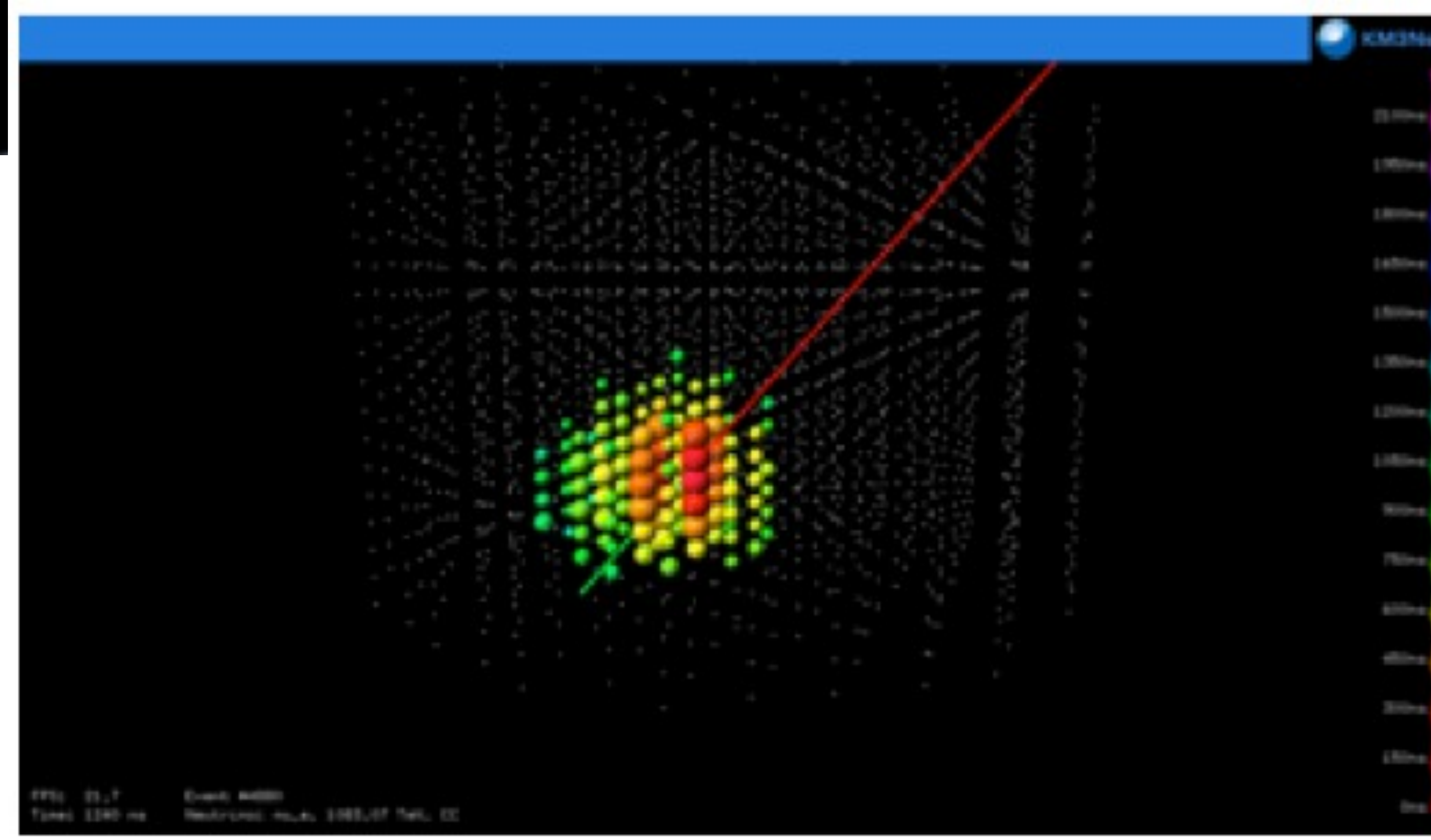
Muon tracks (range > 1 km @ 100 GeV)



620 TeV CC ν_μ event

Cascades

(size O(10 m) -- elongation with LPM effect)

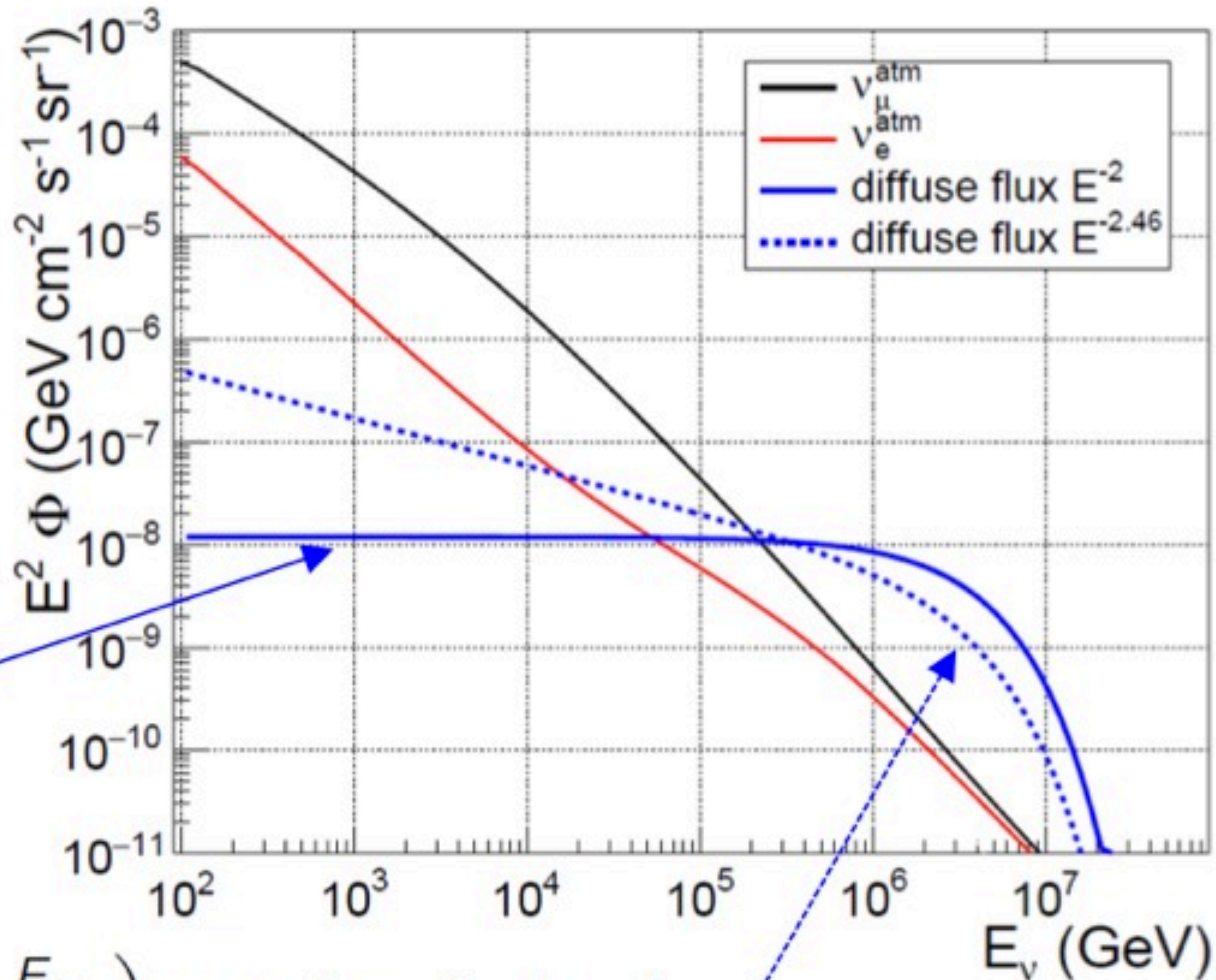


1.8 PeV CC ν_e event

Search for extragalactic neutrino flux ARCA - 2 B.B.

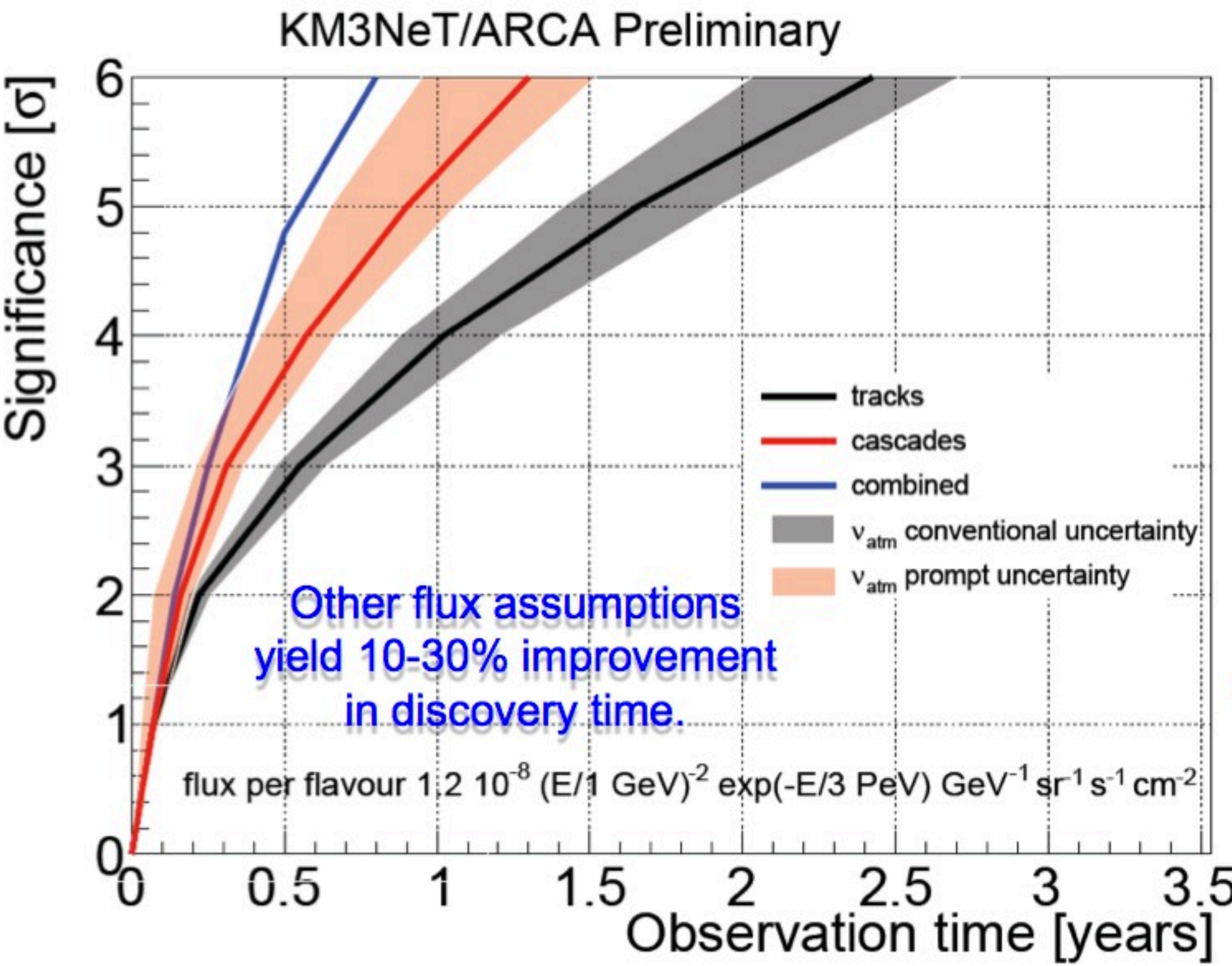
Assumptions:

1. Flavour-symmetric
2. Isotropic
3. Energy spectrum consistent with IceCube findings



$$\Phi(E_\nu) = 1.2 \times 10^{-8} \cdot \left(\frac{E_\nu}{\mathrm{GeV}}\right)^{-2} \cdot \exp\left(-\frac{E_\nu}{3\,\mathrm{PeV}}\right)\ \mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$$

$$\Phi(E_\nu) = 4.11 \times 10^{-6} \cdot \left(\frac{E_\nu}{\mathrm{GeV}}\right)^{-2.46} \cdot \exp\left(-\frac{E_\nu}{3\,\mathrm{PeV}}\right)\ \mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$$



Event numbers (cut&count):

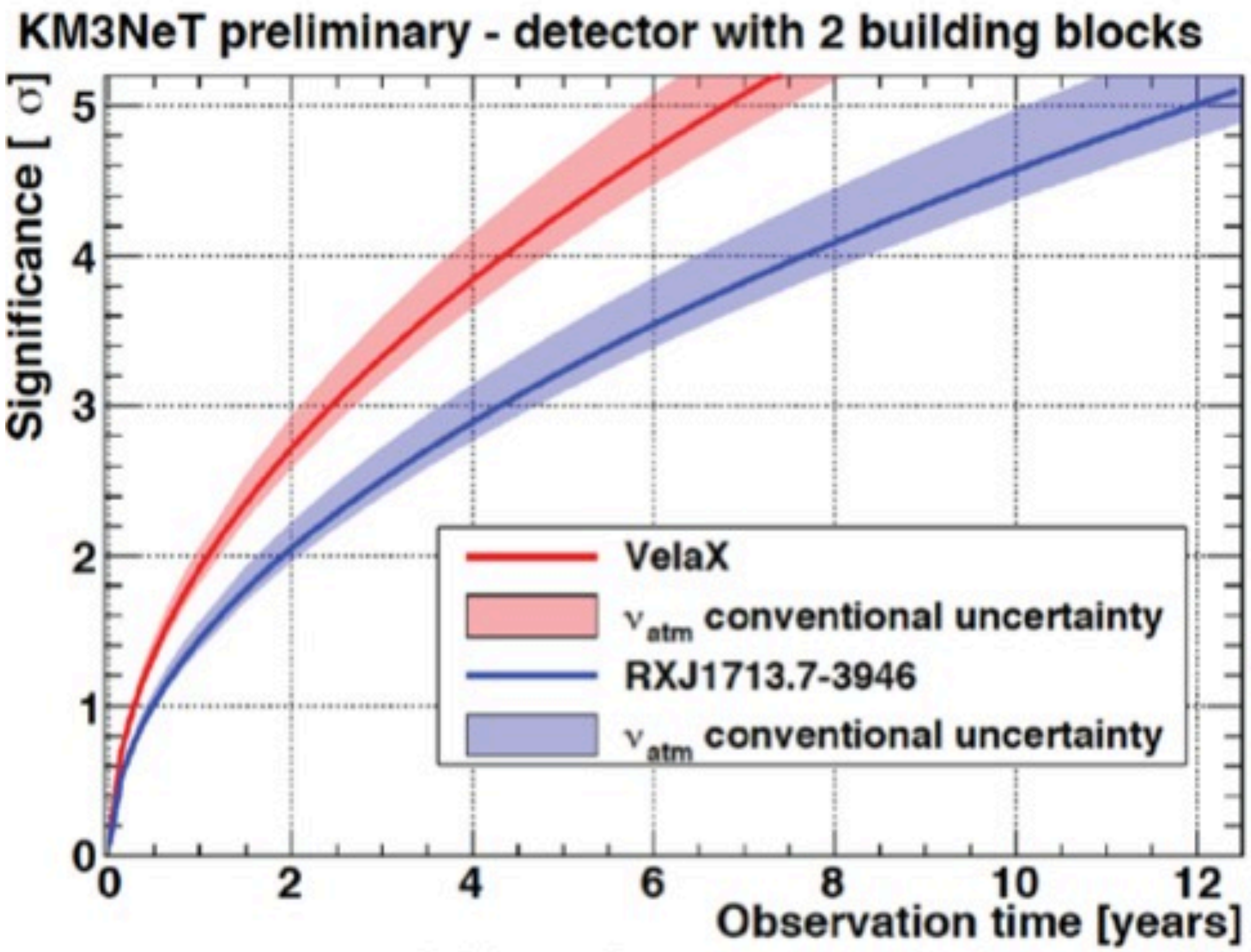
16/9 cascades

7.5/5 track-like

(signal/background per ARCA year)

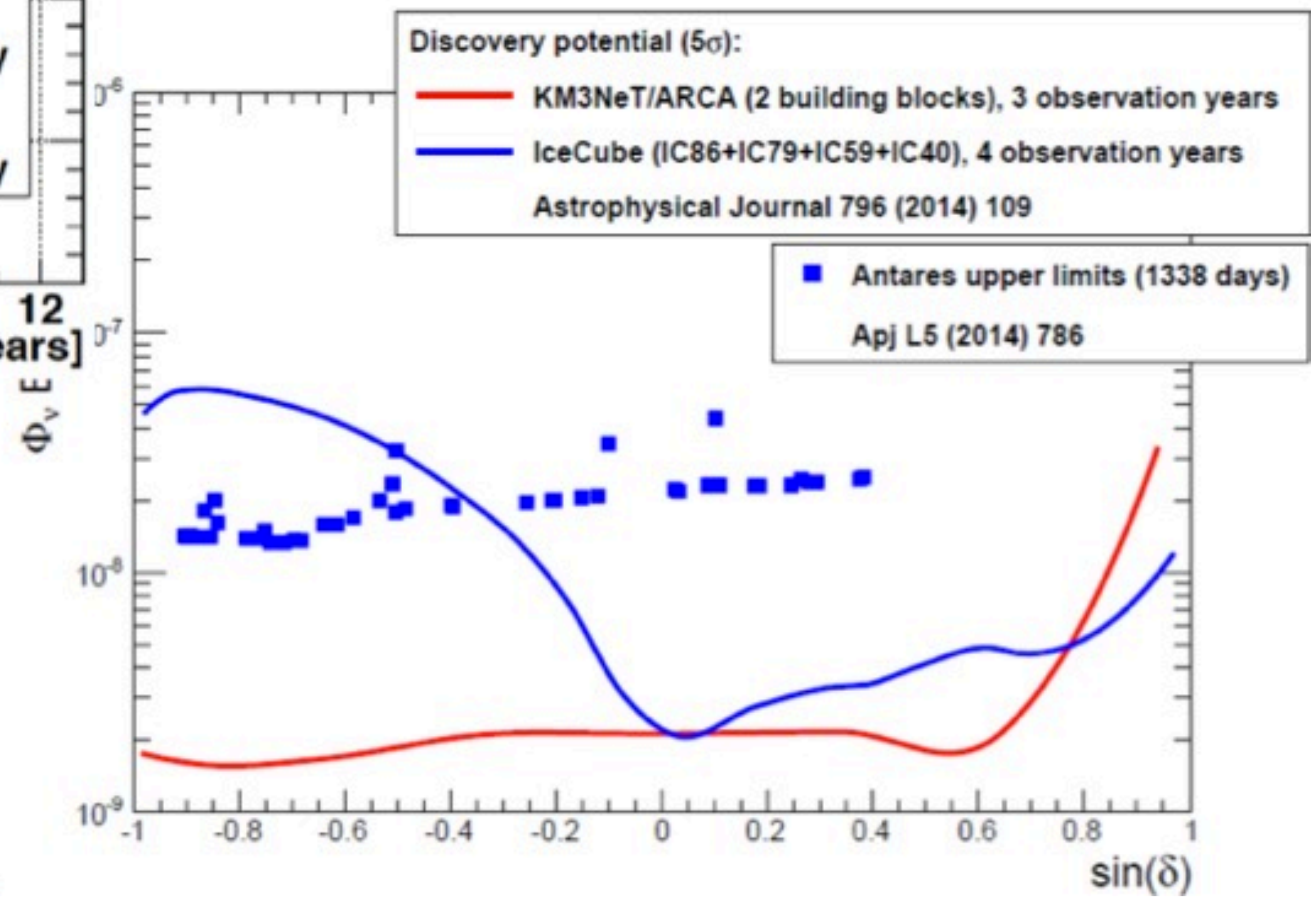
Note:

For each energy, direction and flavour KM3NeT is complementary to IceCube

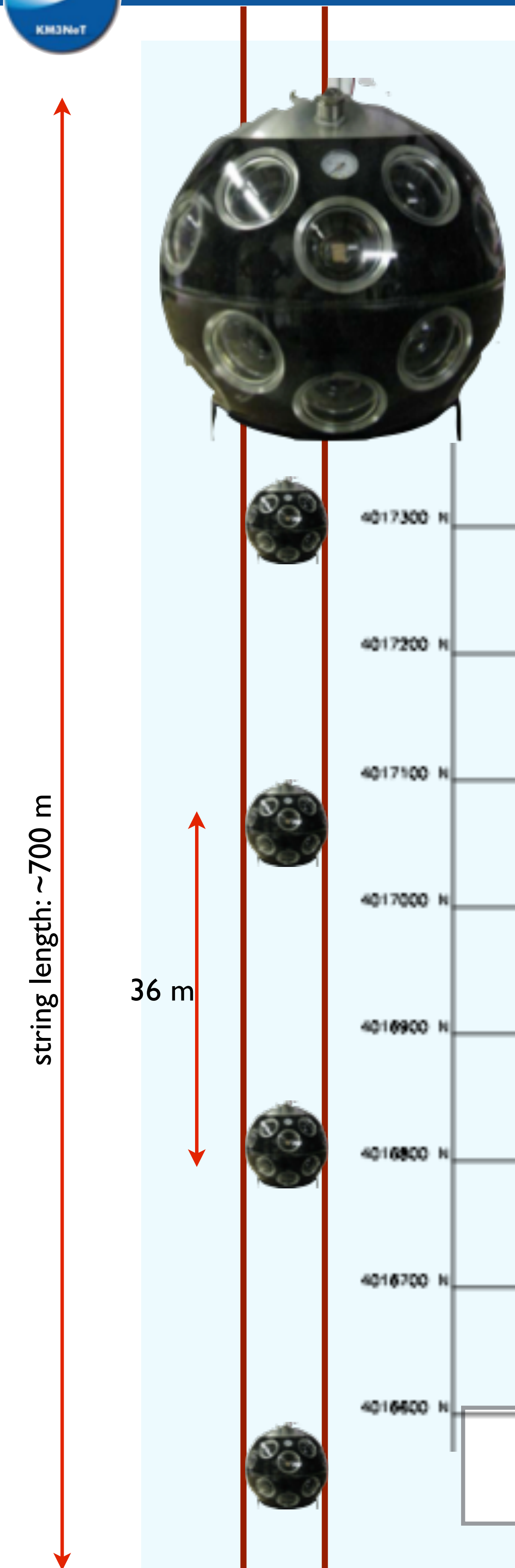


- Galactic sources in reach

- Significant discovery potential for extragalactic sources



KM3NeT-Italy: 8 Towers deep core of ARCA

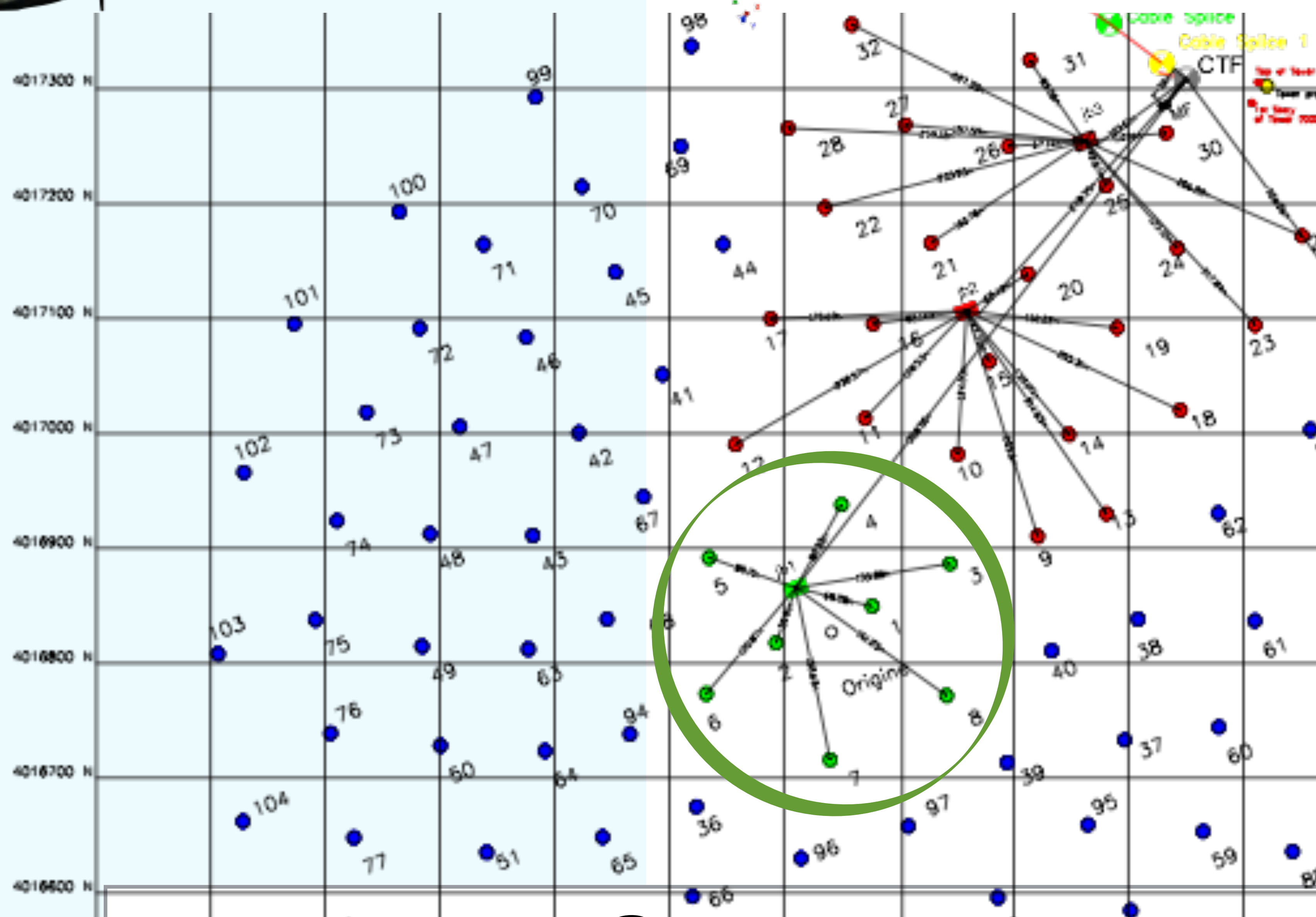


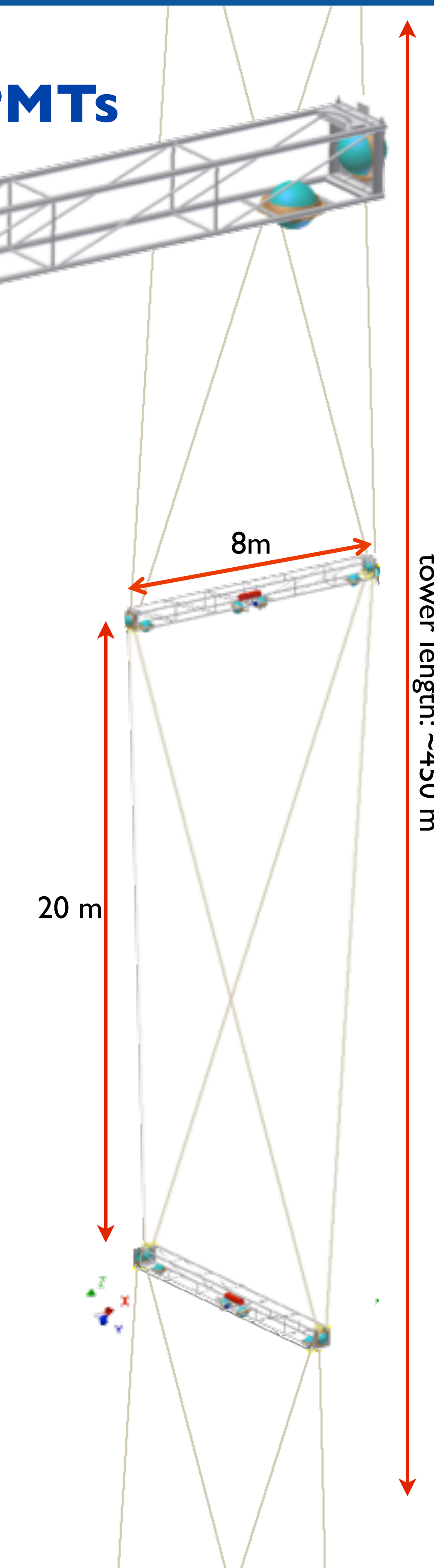
31 PMTs/DOM
18 DOMs/string

558 PMTs/string
64170 PMTs/b.b.

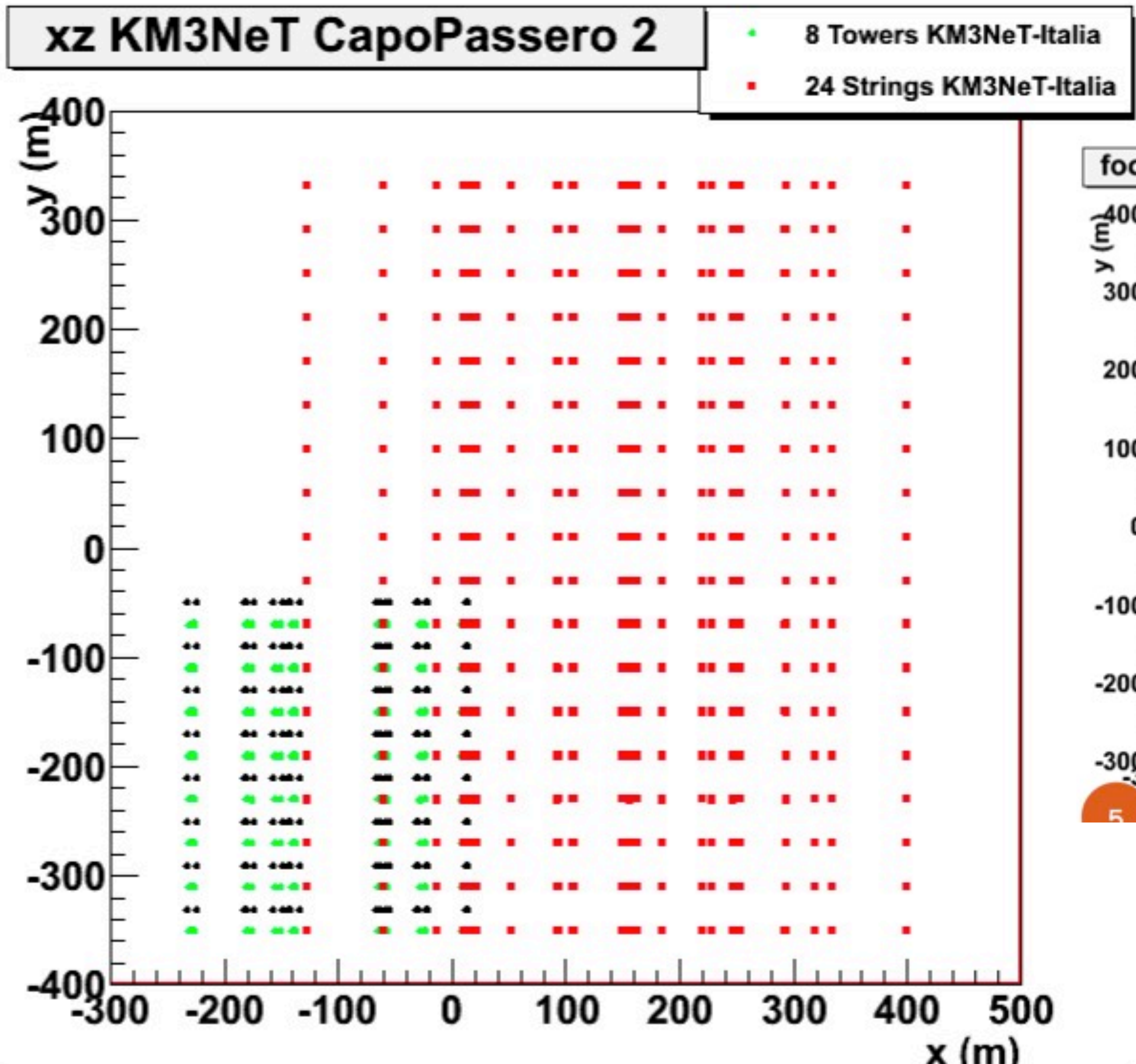
6 PMT-OM/Floor
14 Floors / Tower
8 Towers

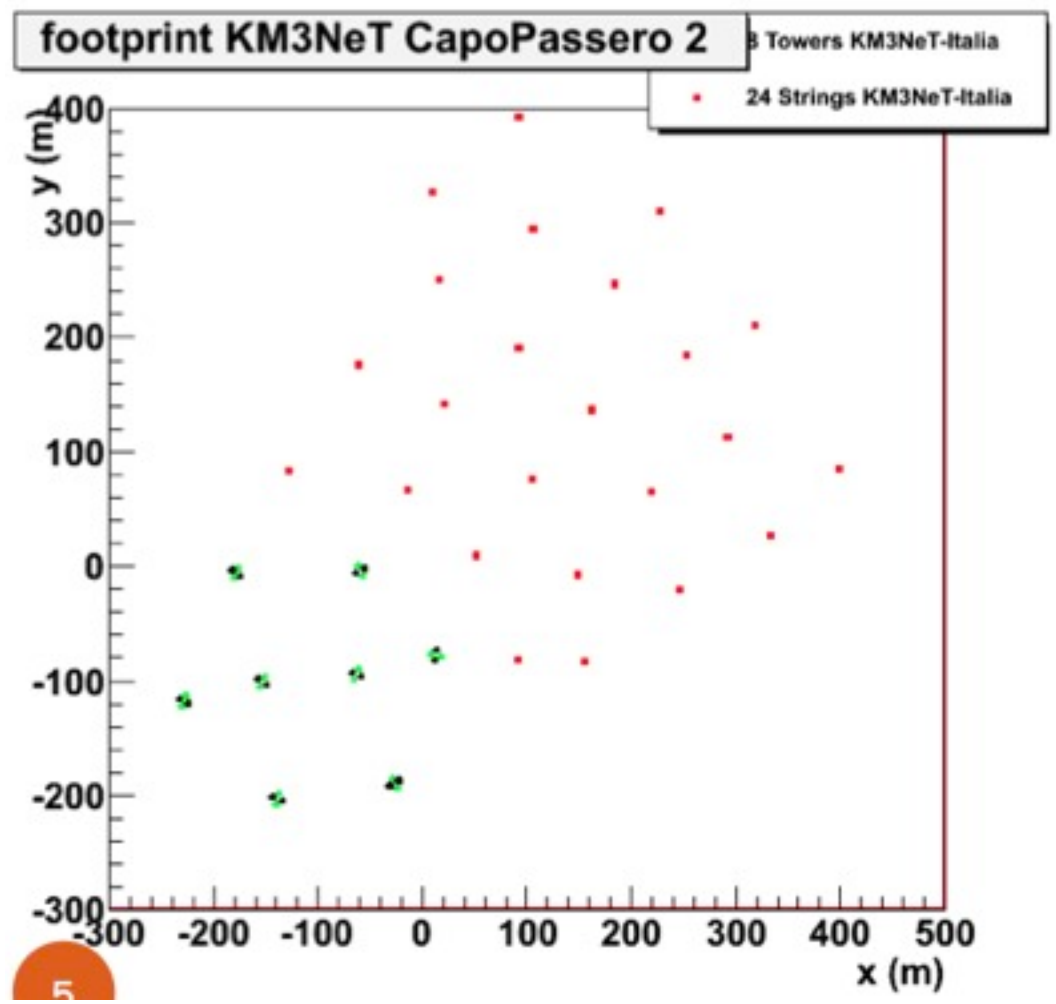
Tot: **672 PMTs**





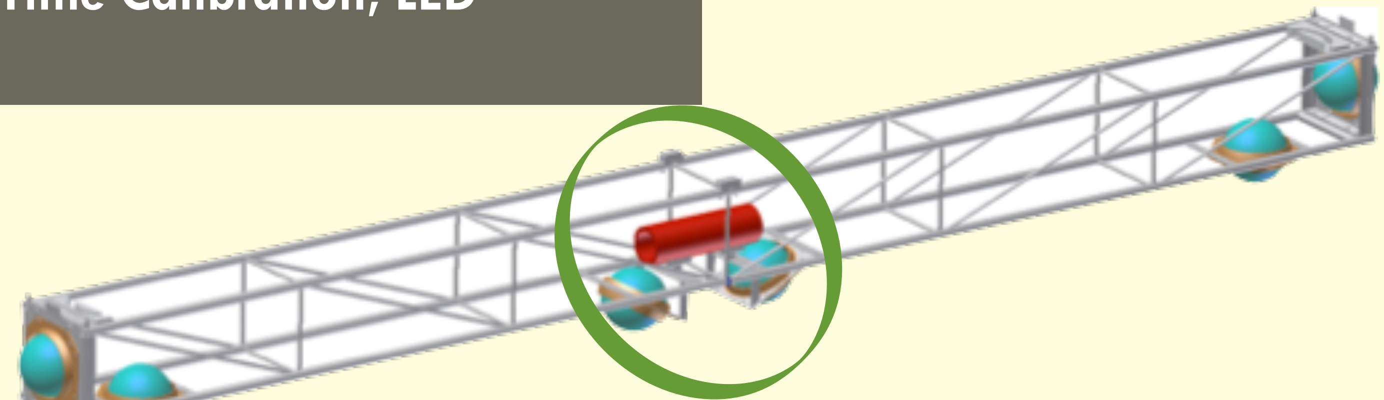
Foot print @ KM3NeT-It site

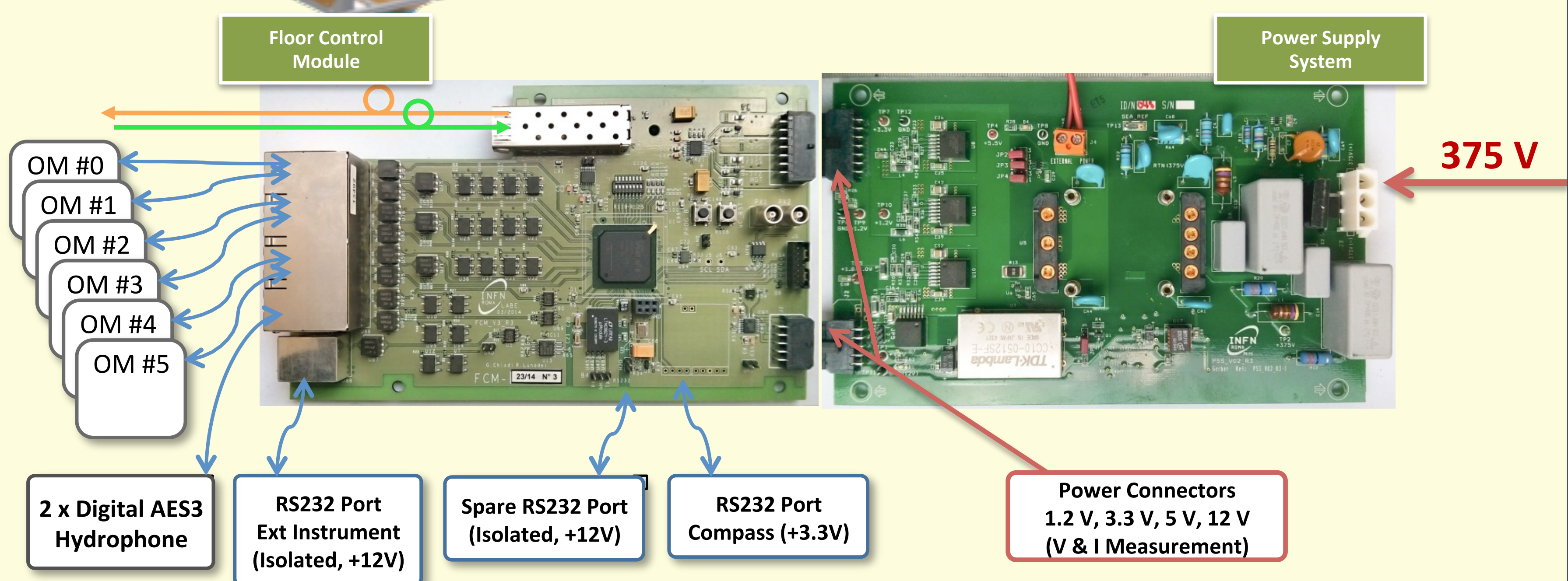

xz KM3NeT CapoPassero 2
8 Towers KM3NeT-Italia
24 Strings KM3NeT-Italia
y (m)
x (m)


footprint KM3NeT CapoPassero 2
24 Strings KM3NeT-Italia
y (m)
x (m)

The KM3NeT Italy - Optical Module (OM) and Floor Control Module (FCM)

The OM: 10" Hamamatsu R7081, Front End Module, Time Calibration, LED beacons



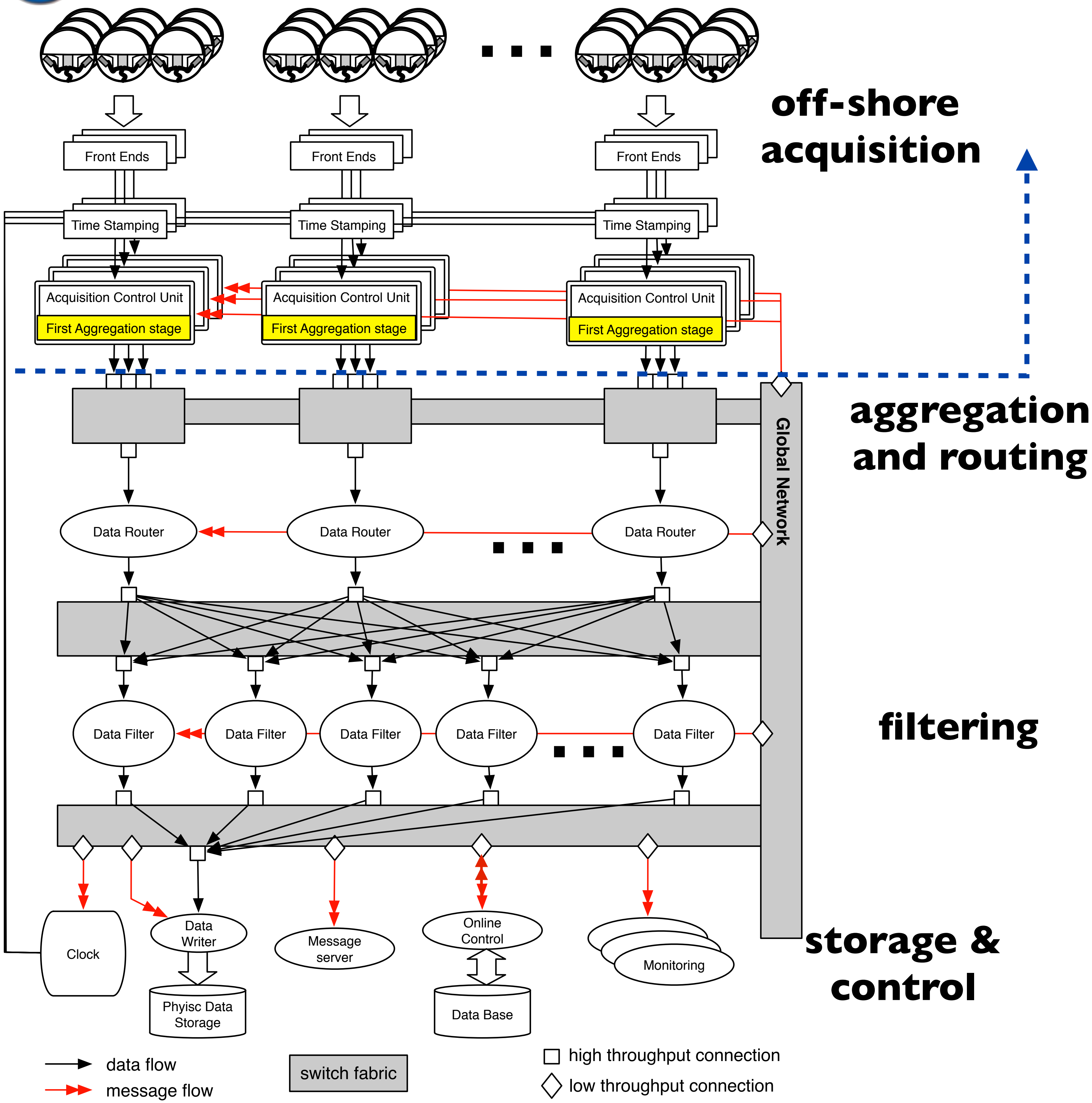


Spartan 6 FPGA

- Fixed-latency transceiver
- No external PLL
- 6 x OM interfaces (clock distribution, data rx / tx), 2 x AES3
- Host a **microblaze-based system on-chip**
  - Slow control communication
  - Slow-control functions (OM power control and monitoring)
  - Voltage and Current Monitoring
  - I2C bus, Serial Ports
  - Flash Read/Write
- Full remote safe reprogrammability with multiboot (3 full images + data)

NOTE: in this case, the FCMs are point-to-point connected onshore to custom ASICS (NaNet3) onboard of servers for managing the DWDM data stream

DAQ model: all data to shore, triggering on shore



The DAQ model is applied to both strings and towers, with due differences.

For historical reasons, the readout electronics and the DAQ systems of strings and towers are different.

a) Both systems ***exploit fixed latency electronics*** for clock distribution but with due differences.

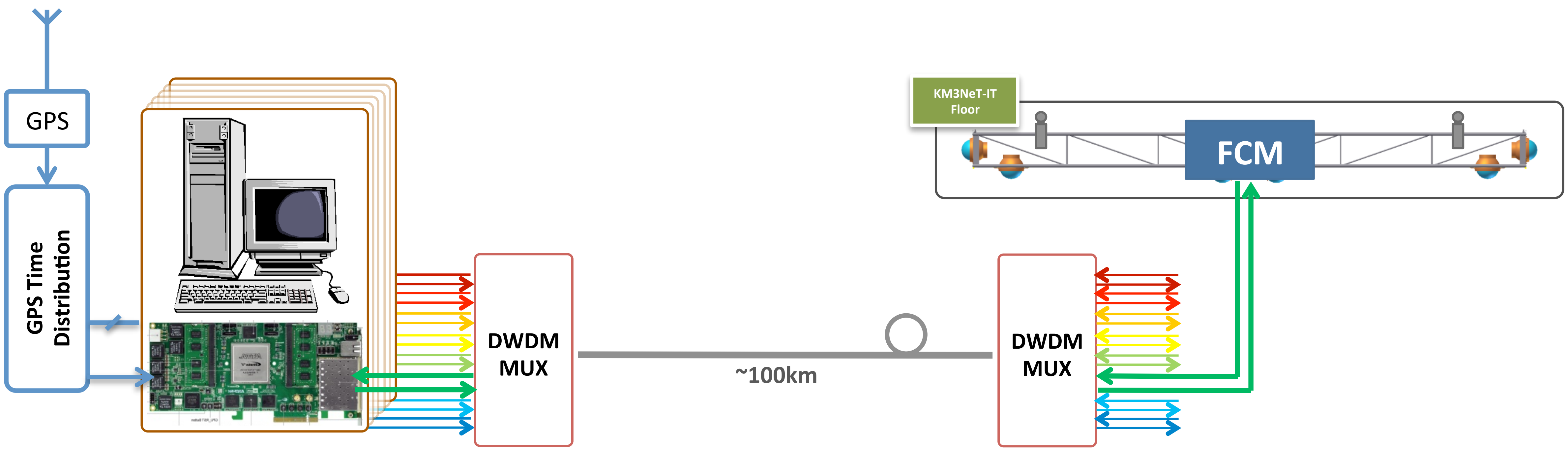
b) The recorded type and number of information per PMT hit are different.

c) The implementation of the computing resources on shore present some differences.

Towers:

-use a **point to point** connections;

-sinchronous timestamp distribution embedded in a continuous framed (125 us) data stream from on- and off-shore. Maximum supported throughput per Tower 2 Gbps



Point to point link

Each Floor is assigned a couple of lambdas (rx/tx) in DWDM spectrum

Standard component

Lambda drift monitoring and tuning

Fully synchronous link

Clock, Data and Timing embedde in a single 8b/10b stream

Each device is time-stamp aware

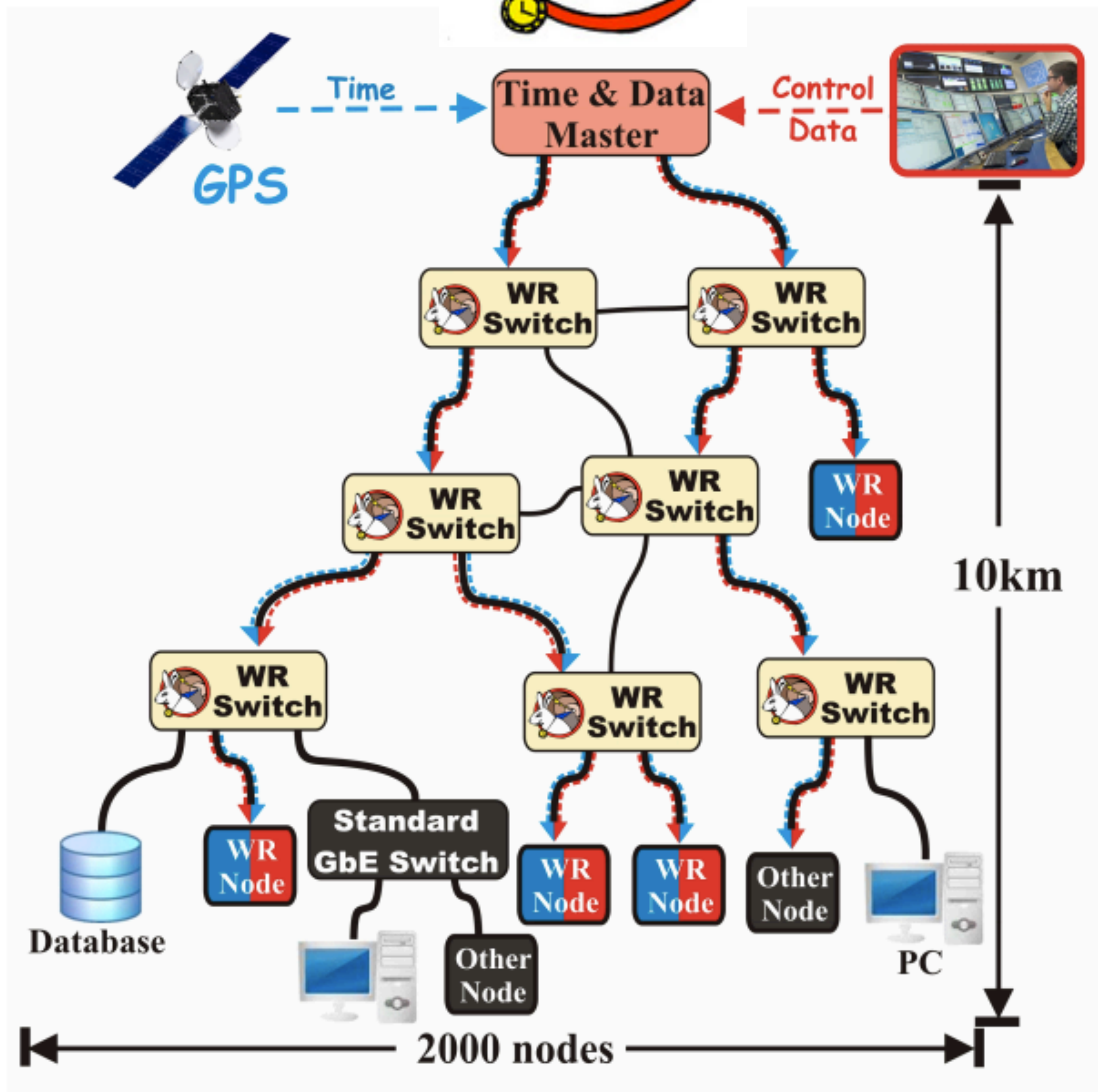
Fixed latency

Round-trip time monitoring + pre-deployment calibration

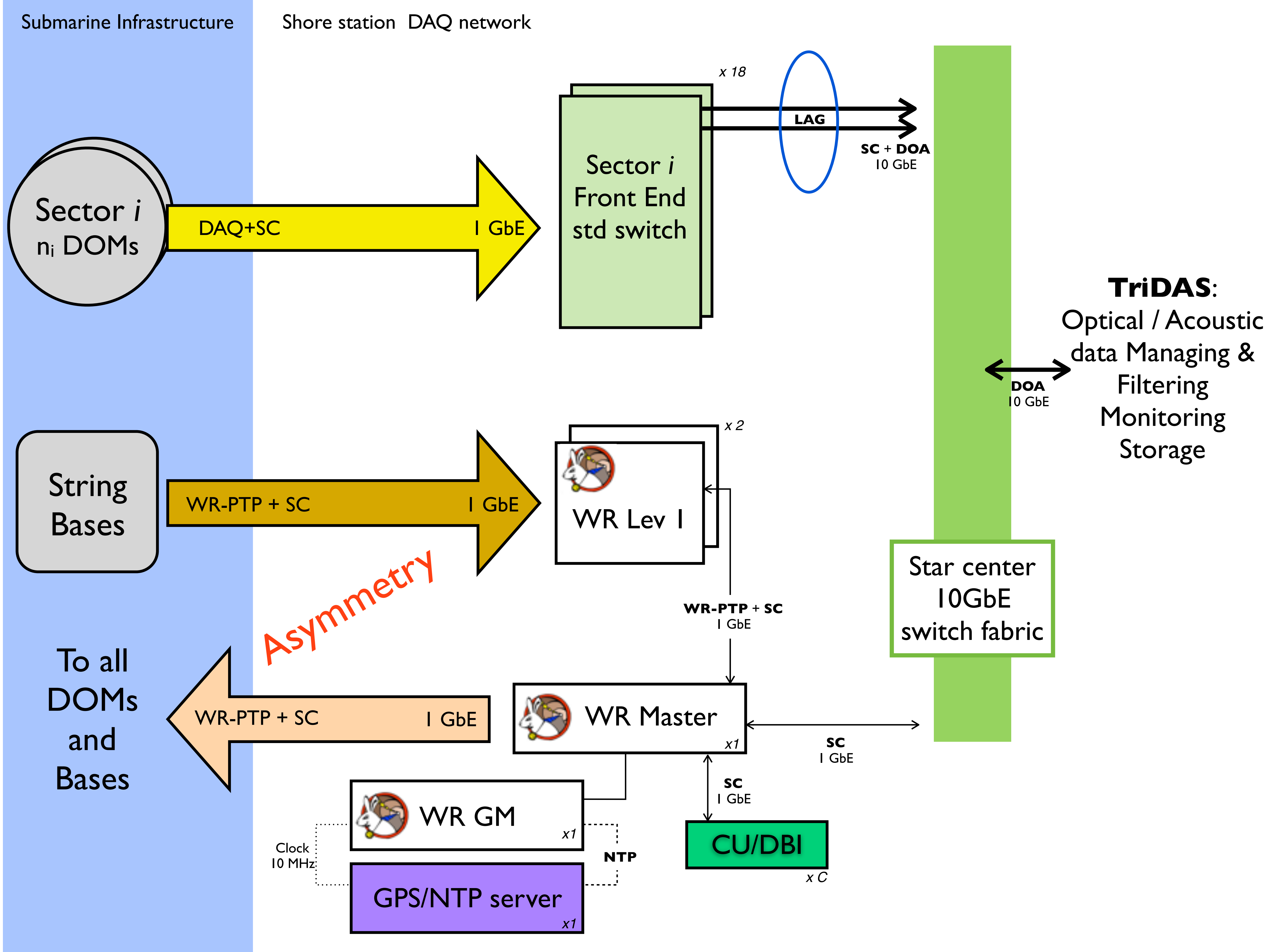
White Rabbit and the Network architecture

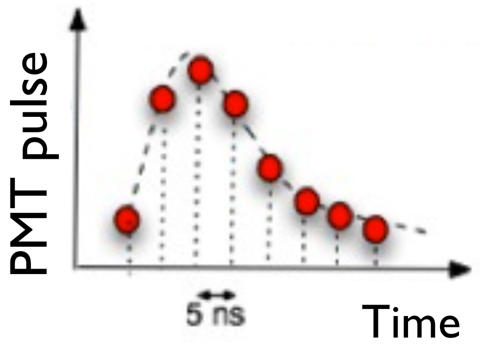
Two separate services (enhancements to Ethernet) provided by WR:

- Synchronization: accuracy better than 1 ns precision (tens of ps sdev skew max)
- Deterministic, reliable and low-latency Control Data delivery



Credit: White Rabbit for Time Transfer, Erik van der Bij at TIPP'14

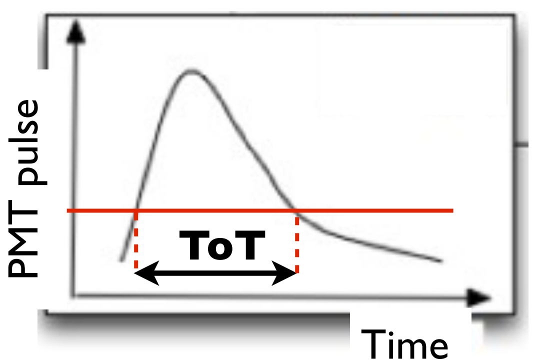

Submarine Infrastructure
Shore station DAQ network
Sector i
n$_i$ DOMs
DAQ+SC
1 GbE
x 18
Sector i
Front End
std switch
LAG
SC + DOA
10 GbE
TriDAS:
Optical / Acoustic
data Managing &
Filtering
Monitoring
Storage
DOA
10 GbE
String
Bases
WR-PTP + SC
1 GbE
x 2
WR Lev 1
Asymmetry
WR-PTP + SC
1 GbE
Star center
10GbE
switch fabric
To all
DOMs
and
Bases
WR-PTP + SC
1 GbE
WR Master
x1
SC
1 GbE
SC
1 GbE
WR GM
x1
Clock
10 MHz
NTP
CU/DBI
x C
GPS/NTP server
x1



pulse waveform sampled

Mean Size of hit: 50 B

Towers		Expected (ν_{single} = 50 kHz)	Conservative (ν_{single} = 70 kHz)	Maximum (ν_{single} = 150 kHz)
10" PMT (0.25 p.e thresh.)	(Mbps)	19.0	26.0	56.0
Floor (6 PMT/Floor)	(Mbps)	110.0	160.0	330.0
Std Tower (14 Floors)	(Mbps)	1600.0	2200.0	4700.0
NEMO Phase 2 (8 Floors– 4 PMT/Floor)	(Gbps)	0.6	0.8	1.8
Full Detector (8 Std Towers)	(Gbps)	12.0	17.0	37.0



Fixed size of hit: 6 B

Strings		Expected (ν_{single} = 6 kHz)	Conservative (ν_{single} = 15 kHz)	Maximum (ν_{single} = 65 kHz)
3" PMT (0.25 p.e. thresh.)	(Mbps)	0.3	0.8	3.3
DOM (31 PMT)	(Mbps)	9.3	23.0	100.0
String (18 DOM)	(Mbps)	170.0	420.0	1800.0
Phase 1,It (24 strings)	(Gbps)	4.0	10.0	44.0
Phase 1,Fr (7 strings)	(Gbps)	1.2	2.9	13.0
Block (115 strings)	(Gbps)	19.0	48.0	210.0
ARCA (230 strings)	**(Gbps)**	**38.0**	**96.0**	**420.0**

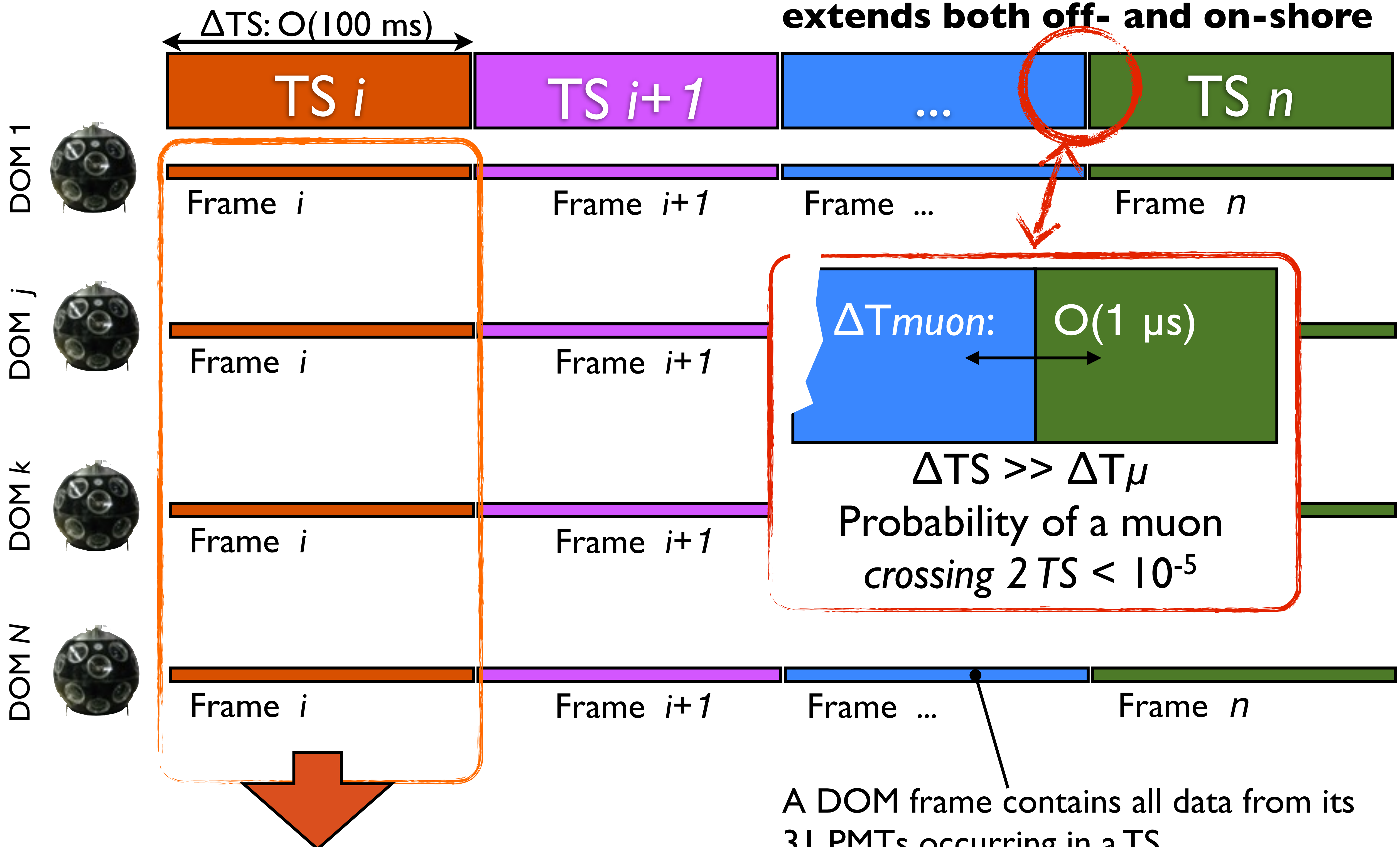
Note: data throughput from the acoustic positioning system can be of the same order of magnitude.

Technical solution: use ≥ 10 GbE networking infrastructure.

But that's not all...

TimeSlice concept

- Time-slicing performed off-shore by DOMs: **a DOM is a node of a LAN which extends both off- and on-shore**



on shore: the whole TS gathered and processed by one Filtering process

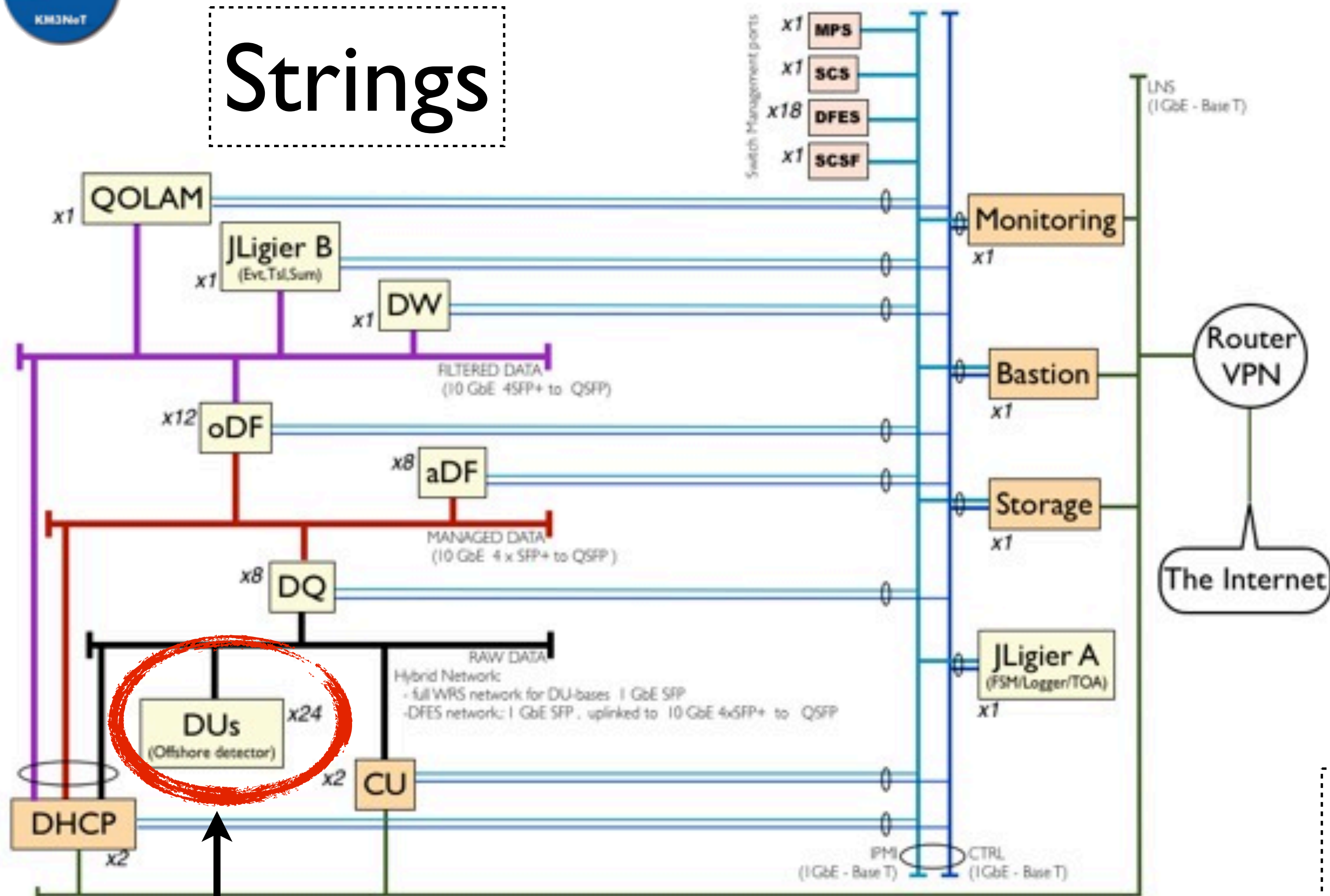
Trigger levels:

Level 0 : all hits before further classifications
Level 1 : find the seeds of simple local coincidences within close PMTs
Level 2 : find combinations of Level 1 seeds and (occasionally) complementary L0 hits

Motivation	Topological Trigger	Simple Causality Trigger	Sky Scan Trigger	Tracking	Stack-Analysis	Vertex / Inertia
muon	✔	✔	✔	✔	✔	✔
cascades	✔	✔	✔	✔		✔
slowly moving particles	✔	✔	✔	✔		✔
sources	✔			✔	✔	✔

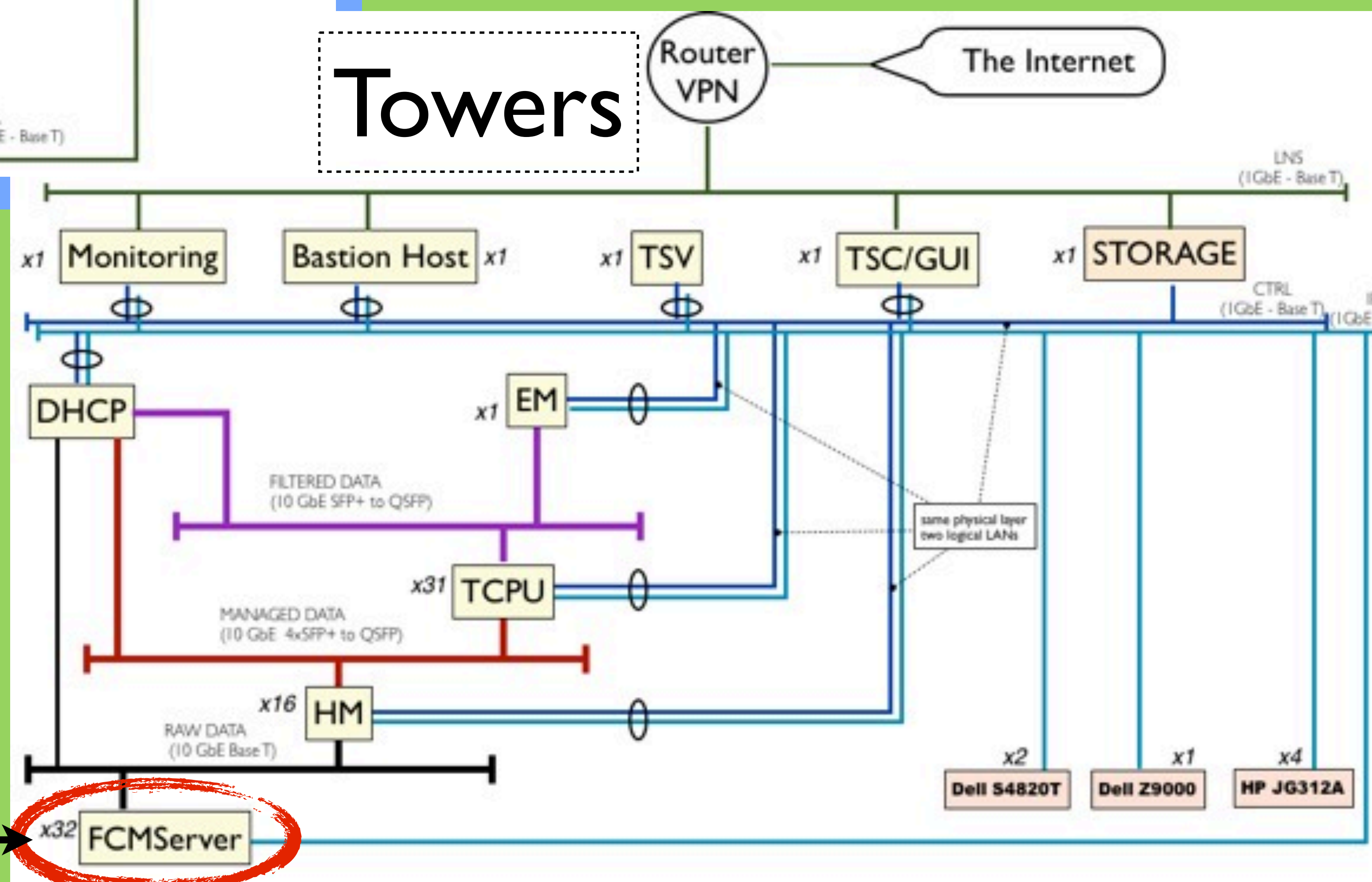
B. Bakker Thesis, *Trigger studies for the Antares and KM3NeT neutrino telescopes, Nikhef 2011*

When adding further trigger algos, the processing of a Timeslice gets more time consuming:
ADD MORE FILTERING PROCESSES AS IT IS NECESSARY (*Granny* recipe!)



Reciprocal trigger calls

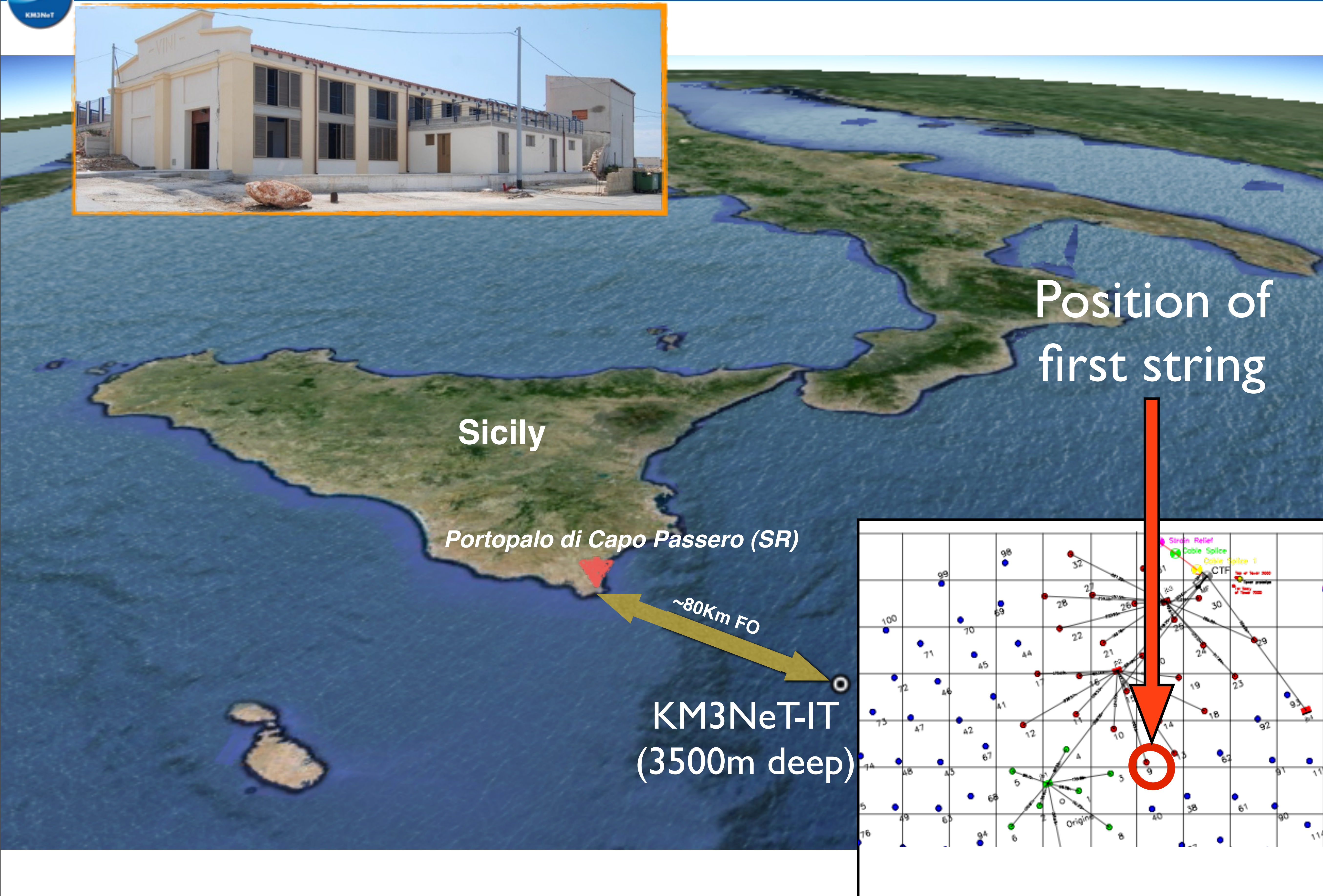
Combining alerts at higher level. Tower and Strings as subdetectors of a whole.



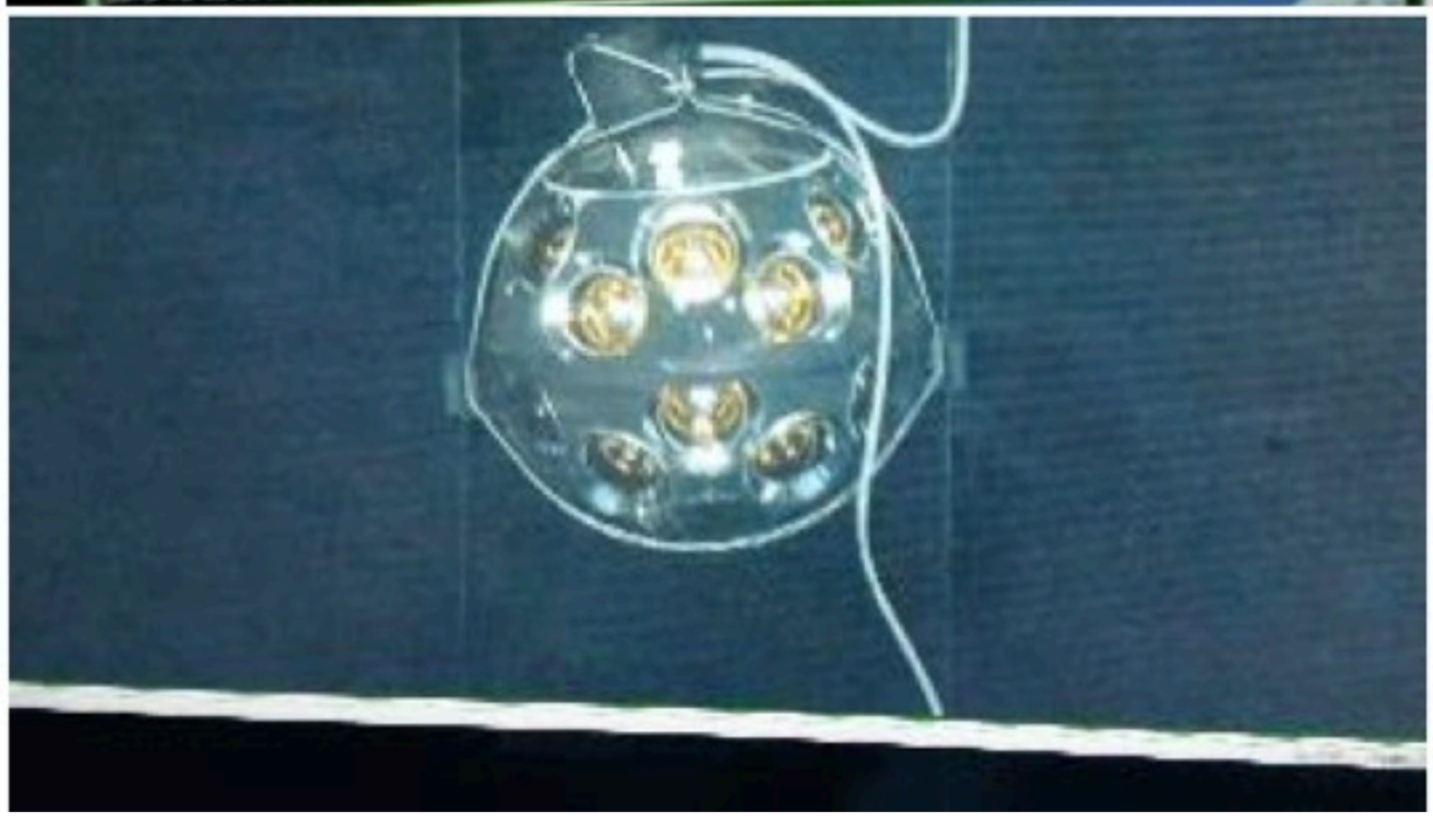
Note: the Offshore detector is part of one LAN segment

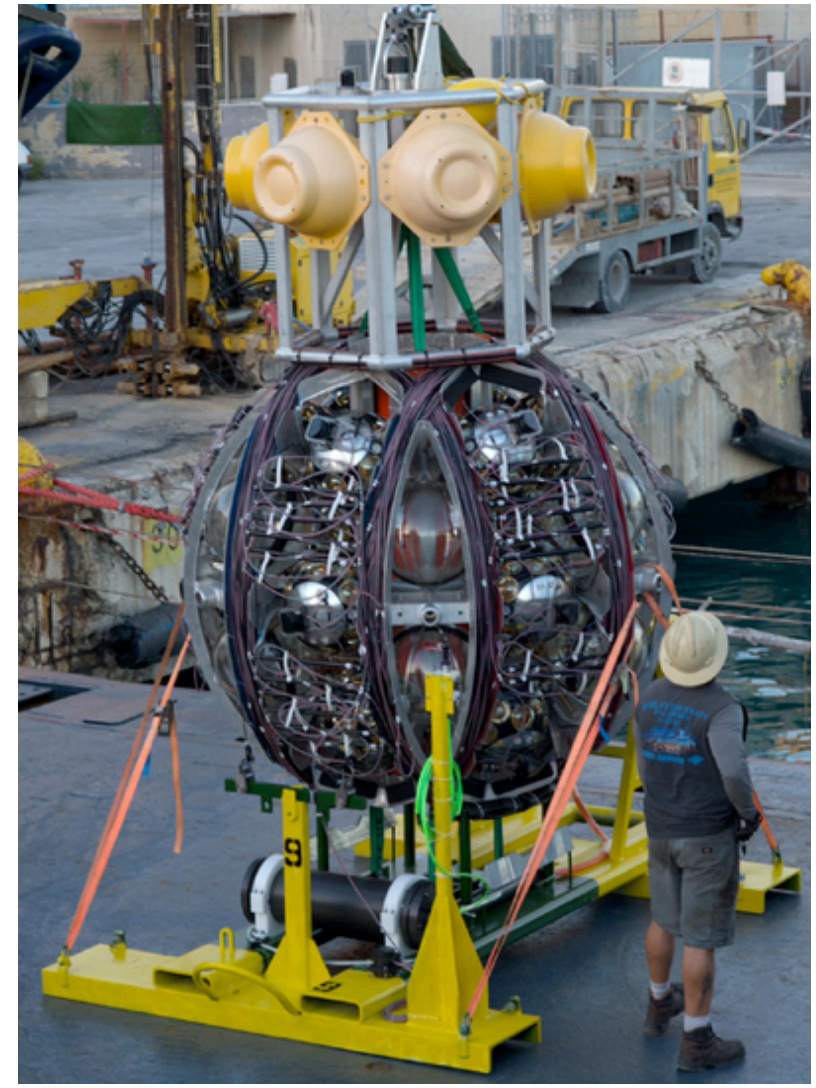
Note: the towers data are managed by the FCMServers before entering the TriDAS LAN

Deployment of the first string at the KM3NeT-IT site



December 3rd, 2015: deployment of the first string at the KM3NeT-IT site





- Smooth operations
- All PMTs alive
- data taking started immedeately after the deployment

Astrophysics with high energy neutrinos is an extremely interesting and still challenging research field

The KM3NeT neutrino telescope has entered its first construction phase:

- Results from prototypes and first string very encouraging
- ARCA & ORCA to follow in 2016-20, sensitivity complementary to IceCube
- Priority science goals:
  - All-flavour neutrino astronomy
  - Measurement of the neutrino mass hierarchy

Exciting physics prospects

Investigate the neutrino sky with unprecedented resolution and sky coverage

Thank you !

SPARES

Giustification of the Power Law with exponent = -2

$$\epsilon \sim O\left(\frac{v_{shockl}}{c}\right).$$

$$E_n = E_0(1+\epsilon)^n,$$

$$P_n = P_{esc}(1-P_{esc})^n$$

$$\Rightarrow \quad n = \frac{\ln\left(\frac{P_n}{P_{esc}}\right)}{\ln(1-P_{esc})} = \frac{\ln\left(\frac{E_n}{E_0}\right)}{\ln(1+\epsilon)} \quad \Rightarrow \quad P_n = P_{esc}\left(\frac{E_n}{E_0}\right)^{\frac{\ln(1-Pesc)}{\ln(1+\epsilon)}}$$

$$\frac{dN}{dE} \sim \frac{N_{n+1}-N_{n-1}}{E_{n+1}-E_n} = \frac{N_0\, P_n}{E_0\,(1+\epsilon)^{n+1} - E_0\,(1+\epsilon)^n} = N_0\,\frac{P_{esc}\left(\frac{E_n}{E_0}\right)^{\frac{\ln(1-Pesc)}{\ln(1+\epsilon)}}}{E_n\,\epsilon} = \frac{N_0}{\epsilon\, E_0^{\frac{\ln(1-Pesc)}{\ln(1+\epsilon)}}}\, E_n^{-1+\frac{\ln(1-Pesc)}{\ln(1+\epsilon)}}$$

assuming P_{esc} and $\varepsilon << 1$

$$\frac{dN}{dE} \sim K\,E^{-1+\frac{(-P_{esc})}{\epsilon}} = K\,E^{-1-\frac{P_{esc}}{\epsilon}}$$

hypotesys on the biatomic molecula (such as for H_2): $(P_{esc}/\varepsilon) \sim 1$

$$\frac{dN}{dE} = K\,E^{-2}$$

BACK

Taking into account the long path neutrino oscillation, on Earth we expect to see

$$1\,\nu_e : 1\,\nu_\mu : 1\,\nu_\tau$$

Hadronic Model implies a ***neutrino-gamma connection***.

$$m\,\nu_x : n\,\gamma$$

where *m* and *n* can be tuned upon specific assupmtion, source by source.
This means that astrophysical **neutrino fluxes can be estimated via the gamma measurements at given sources.**

The not-breaking **Feynman's scalying** implies $\sigma_{int} = \sigma(p_{//} / p_{prog})$

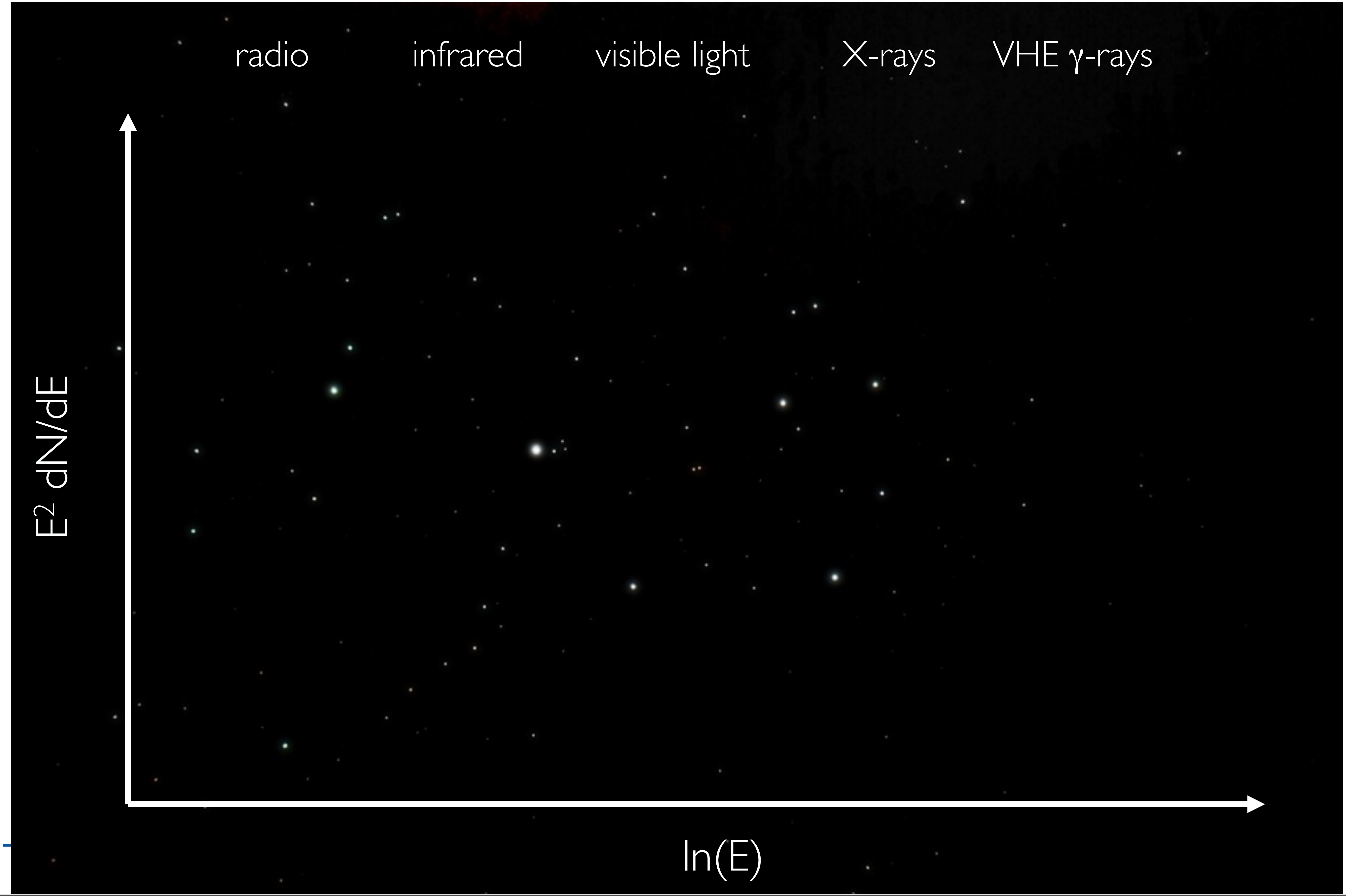
→ ν flux does not breake the progenitor's energy dependence.
This means that for shock accelerated CR, **the corresponding neutrino flux has the same power low dependence** ($\sim E^{-2}$).

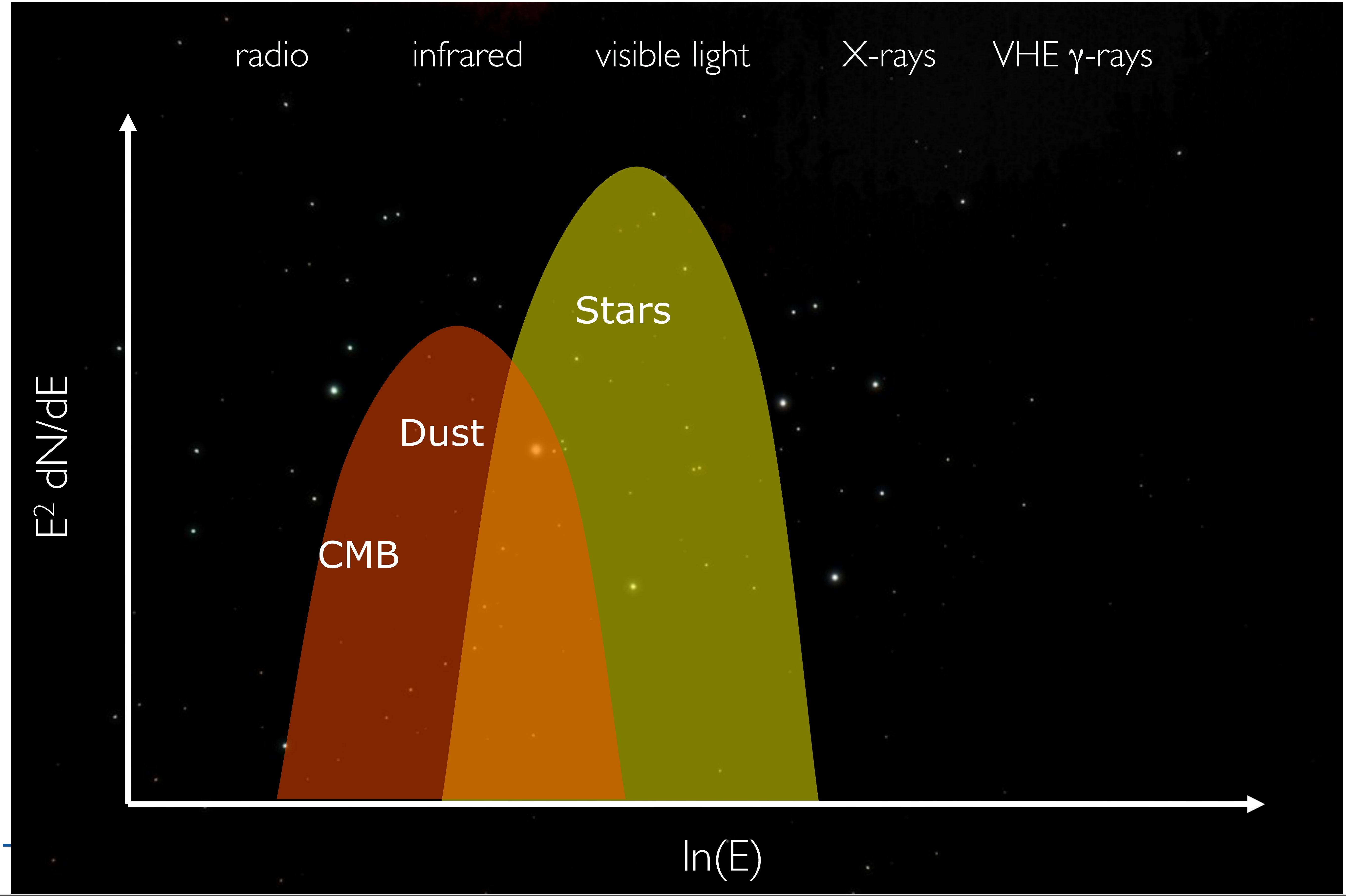
RX J1713-3946 expectations: $\frac{dN_\nu}{dE} \sim 1.8\ 10^{-8} \left(\frac{E}{\mathrm{GeV}}\right)^{-2} [\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$

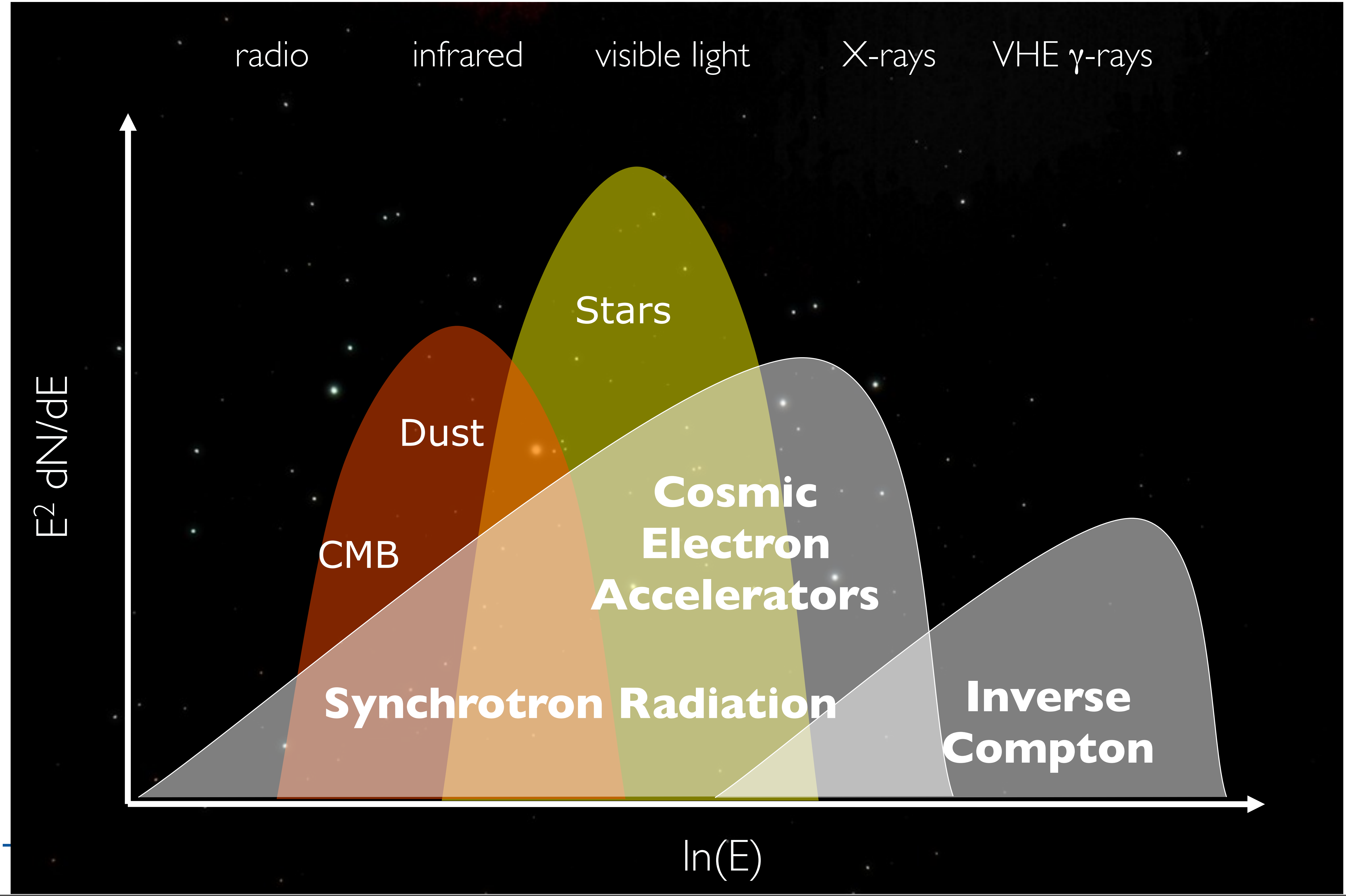
Extragalactic ν sources can be extremely far for resolving them
→ **diffuse neutrino flux** is expected on Earth.
→ the ***neutrino - CR*** (energy density) ***connection***: $\omega_\nu = \omega_{CR}$

Waxman-Bachall reference flux: $\frac{dN_\nu}{dE} \sim 9.0\ 10^{-9} \left(\frac{E}{\mathrm{GeV}}\right)^{-2} [\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}]$

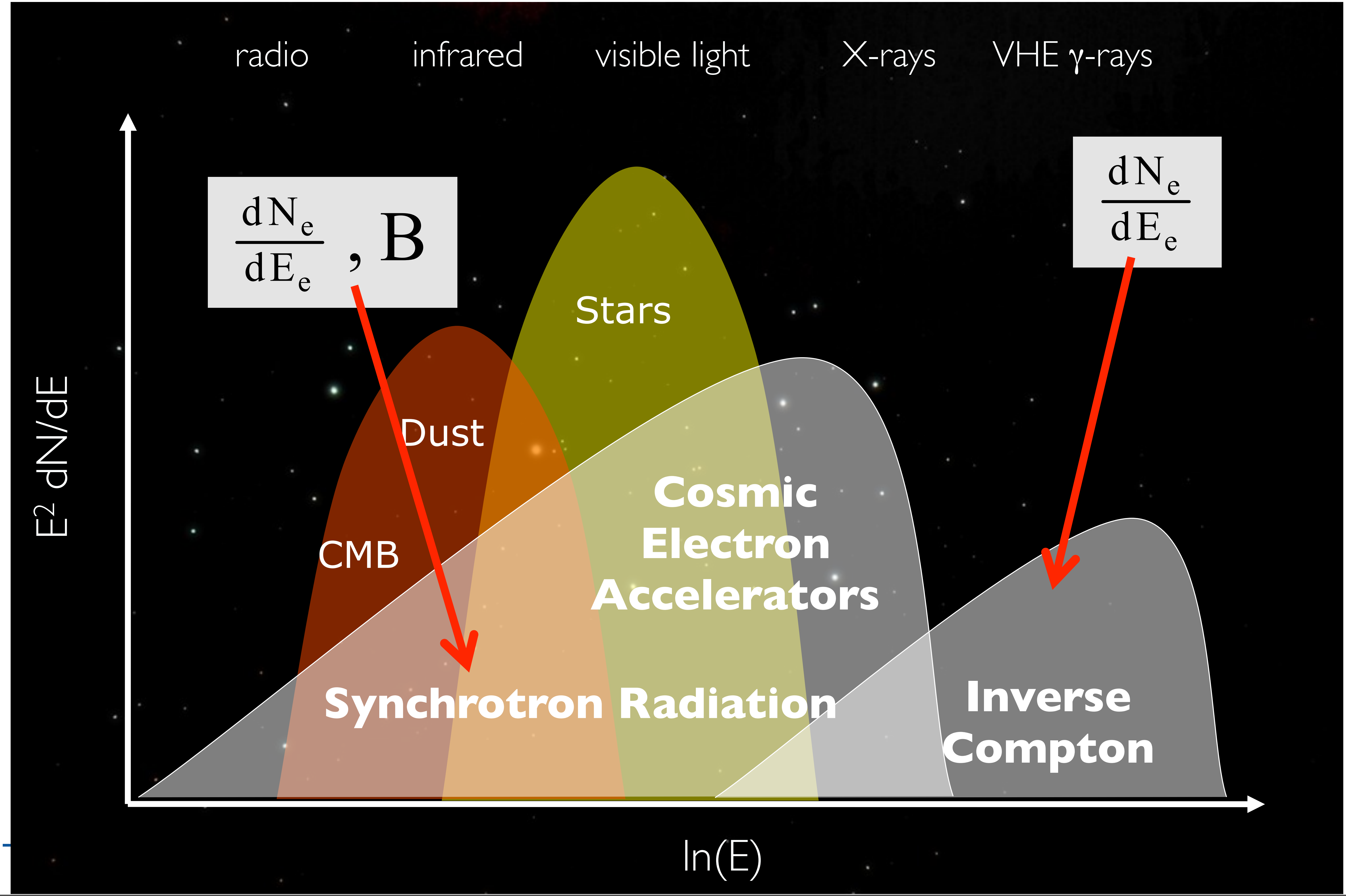
Hadronic and Leptonic models



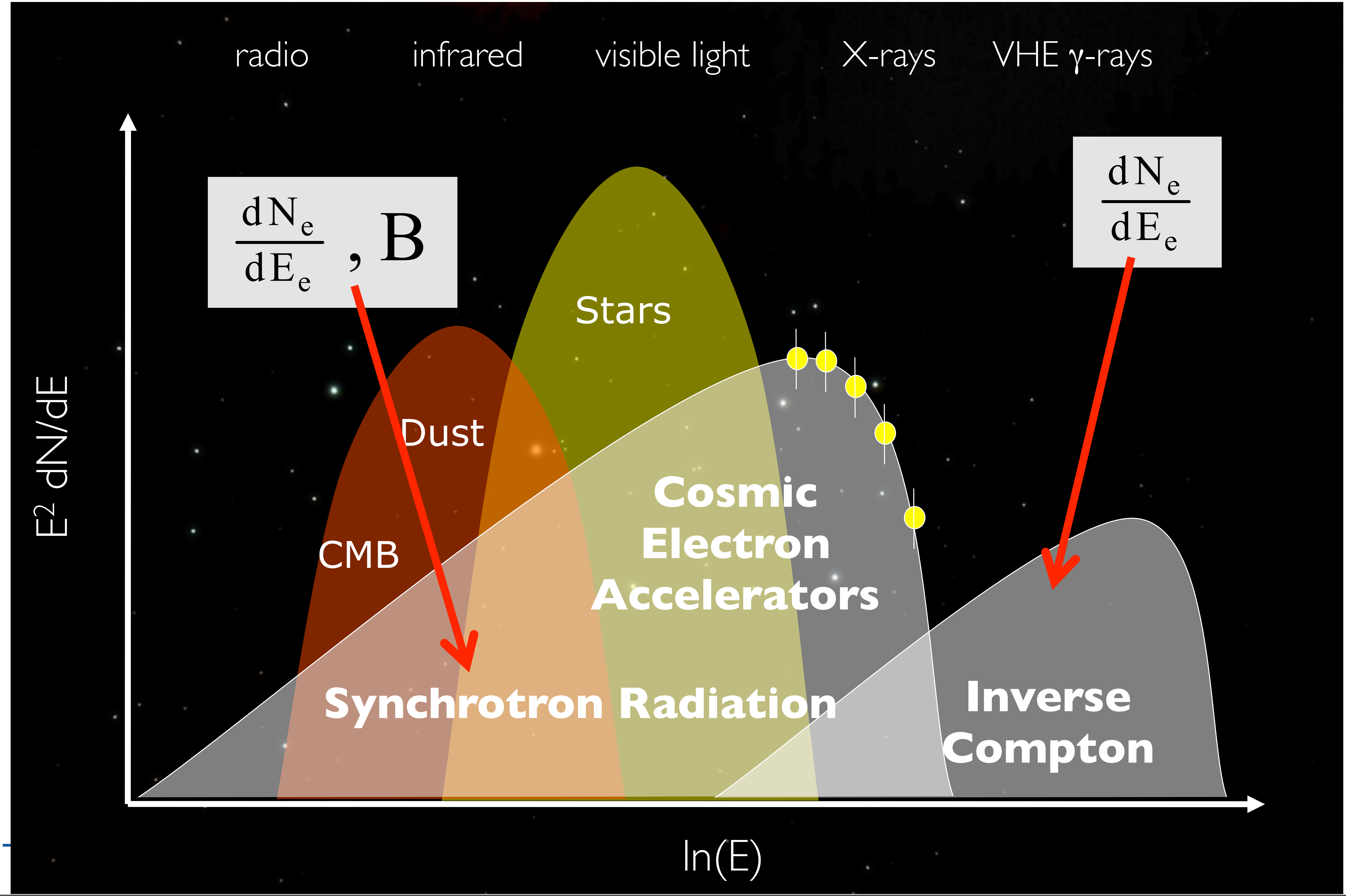

radio
infrared
visible light
X-rays
VHE γ-rays
Stars
Dust
CMB
E2 dN/dE
ln(E)


radio
infrared
visible light
X-rays
VHE γ-rays
E2 dN/dE
Stars
Dust
CMB
Cosmic
Electron
Accelerators
Synchrotron Radiation
Inverse
Compton
ln(E)

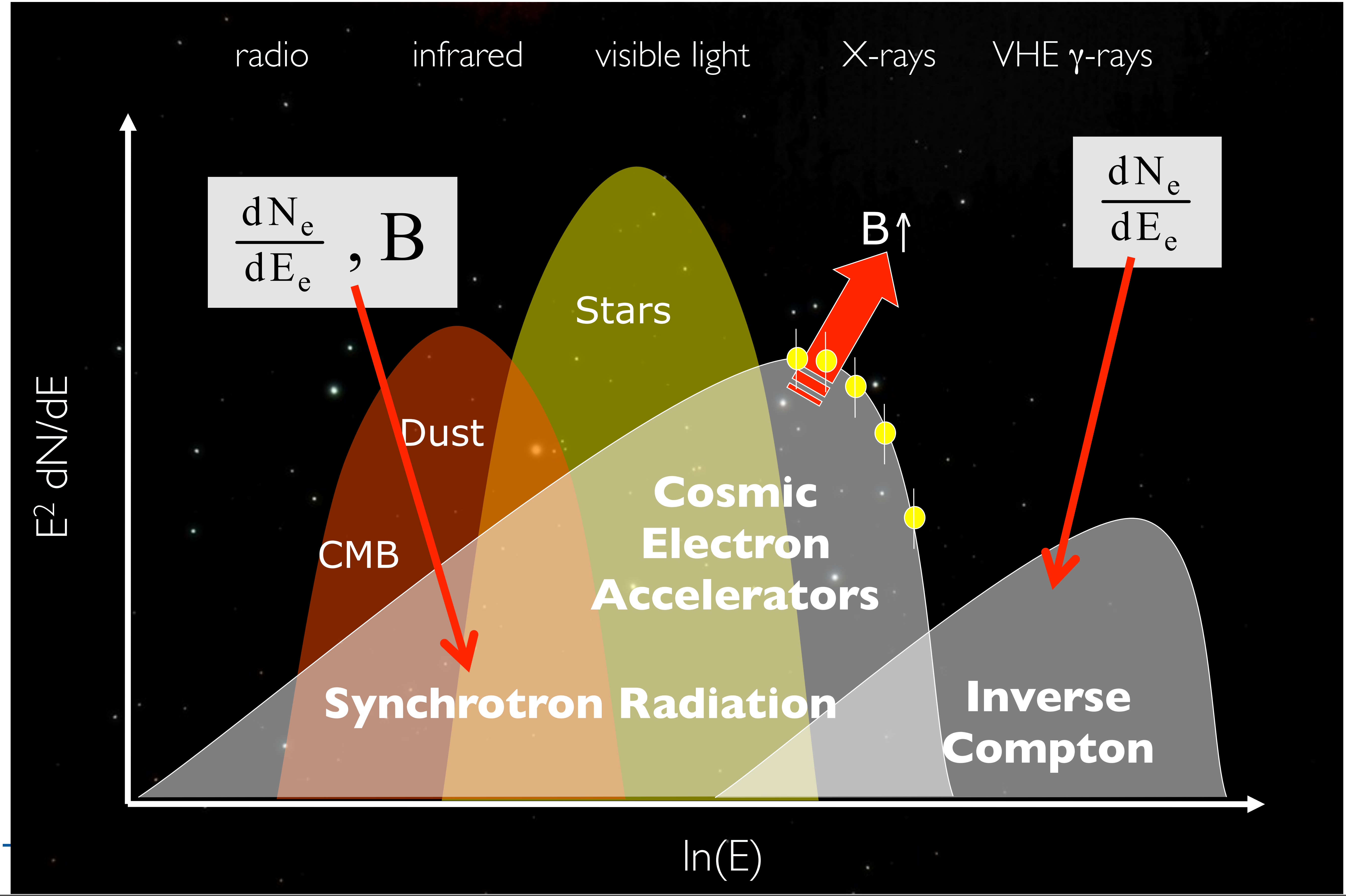
Hadronic and Leptonic models



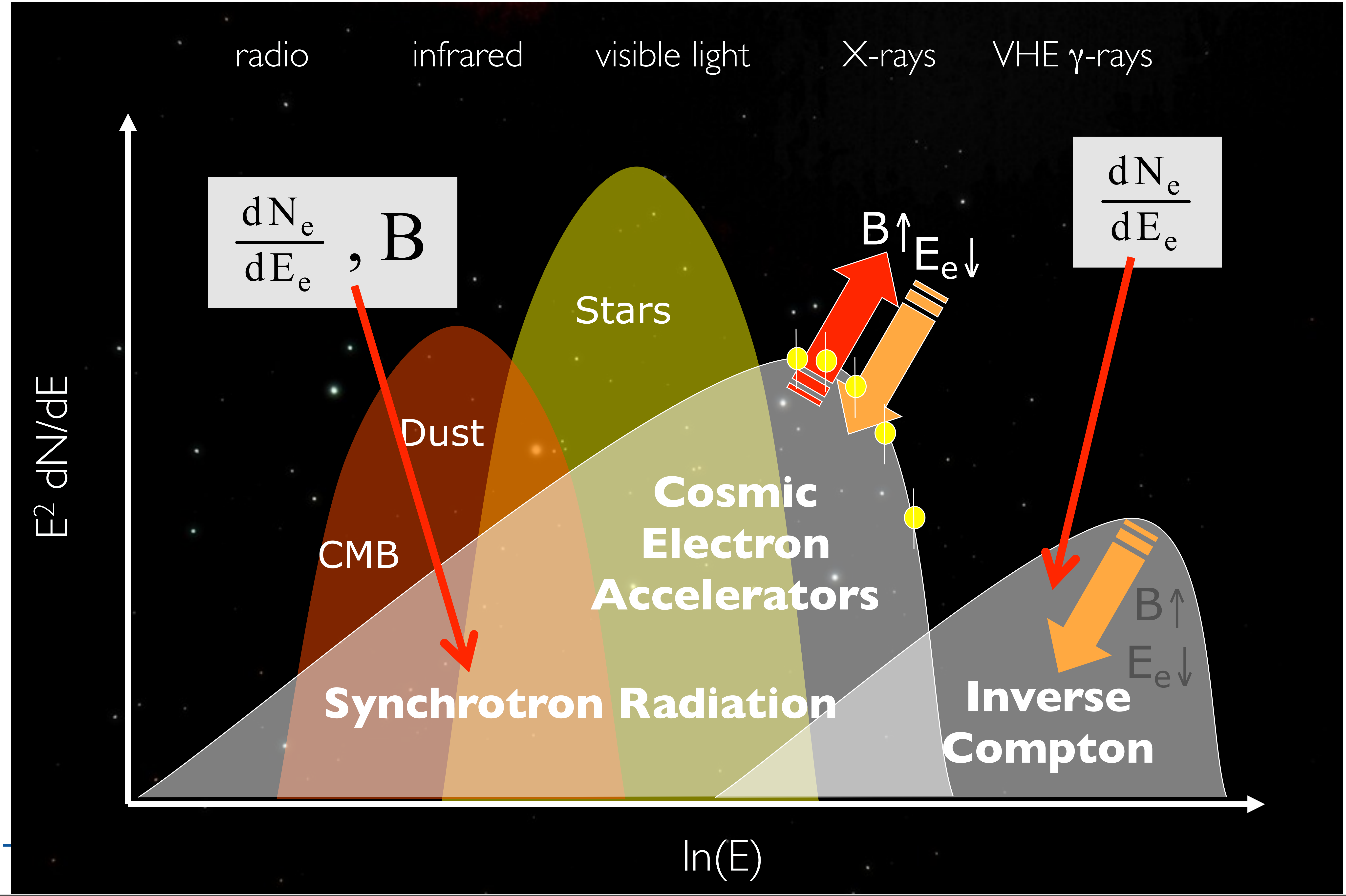
Hadronic and Leptonic models



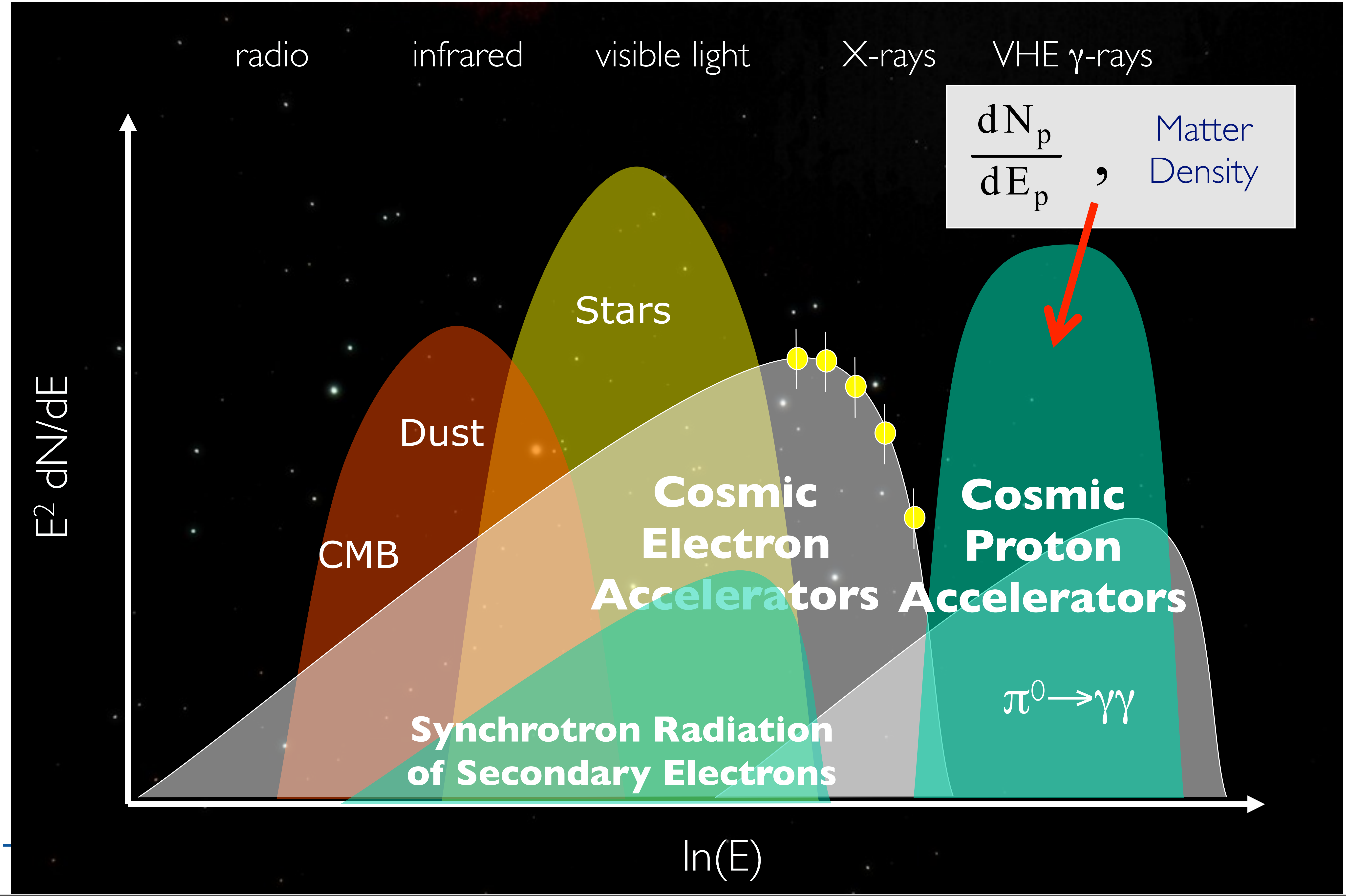
Hadronic and Leptonic models



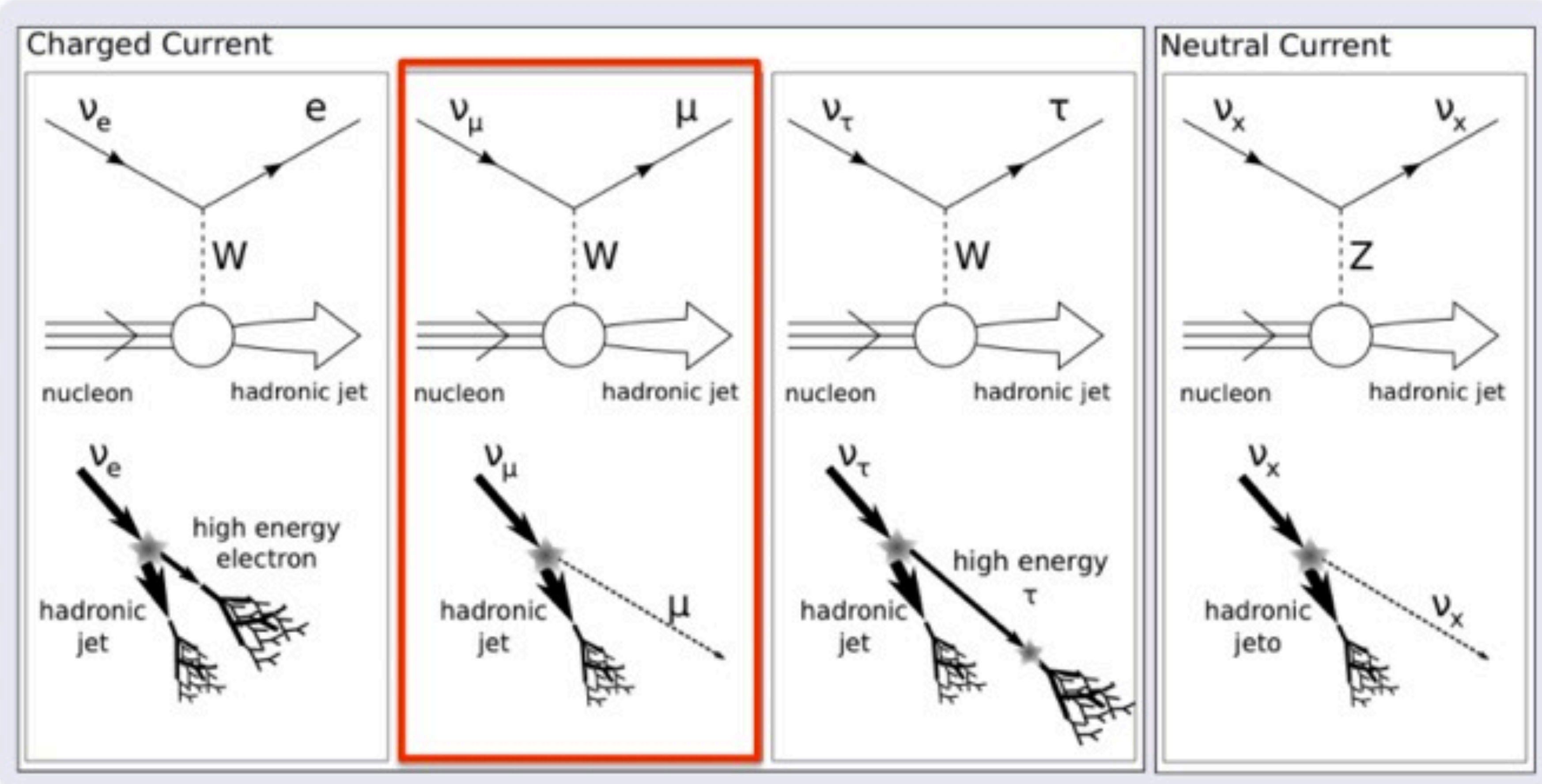
Hadronic and Leptonic models

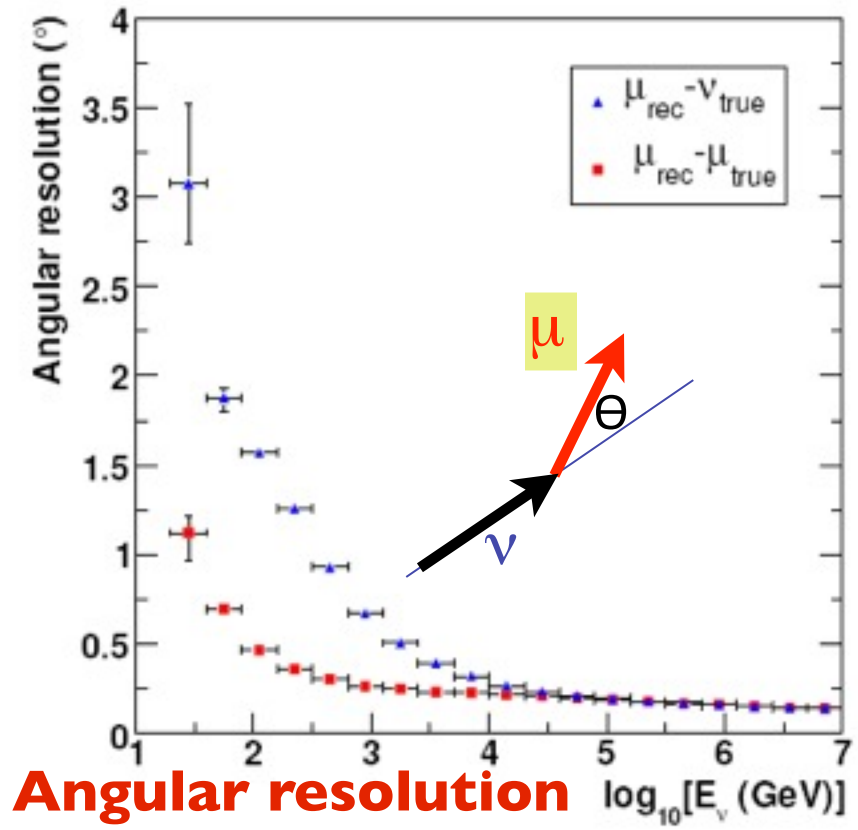


Hadronic and Leptonic models



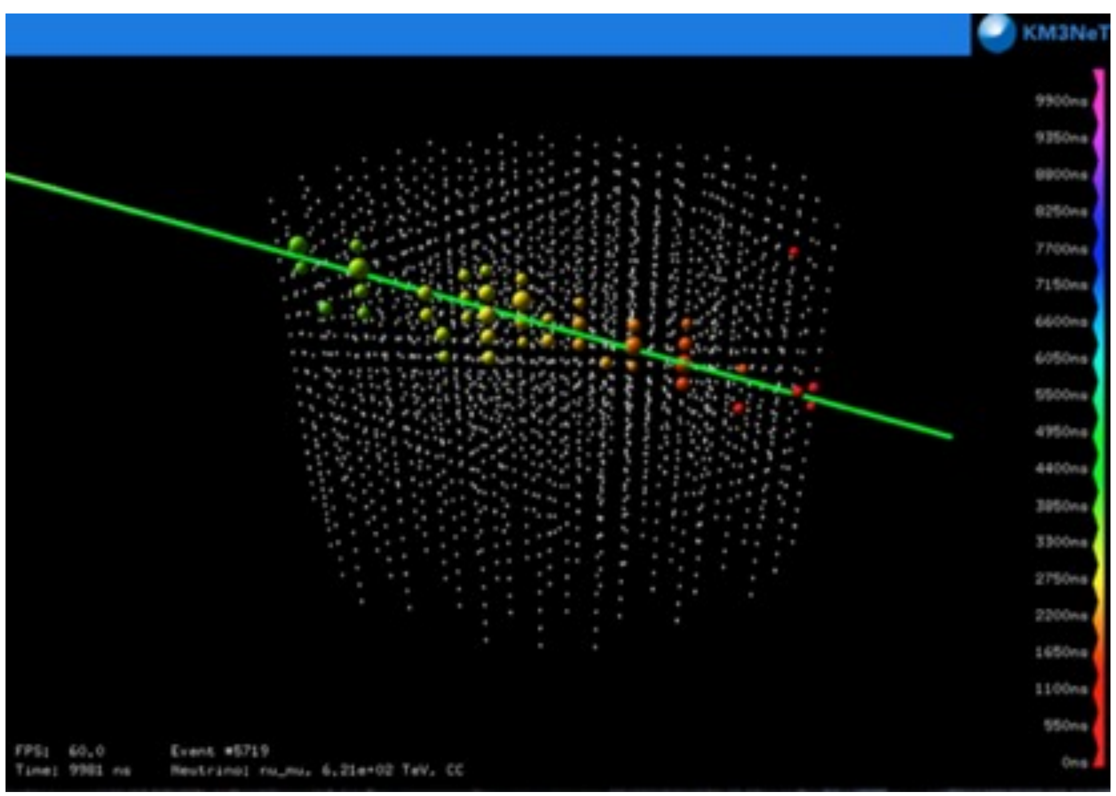
Detection signatures and Figures of Merit



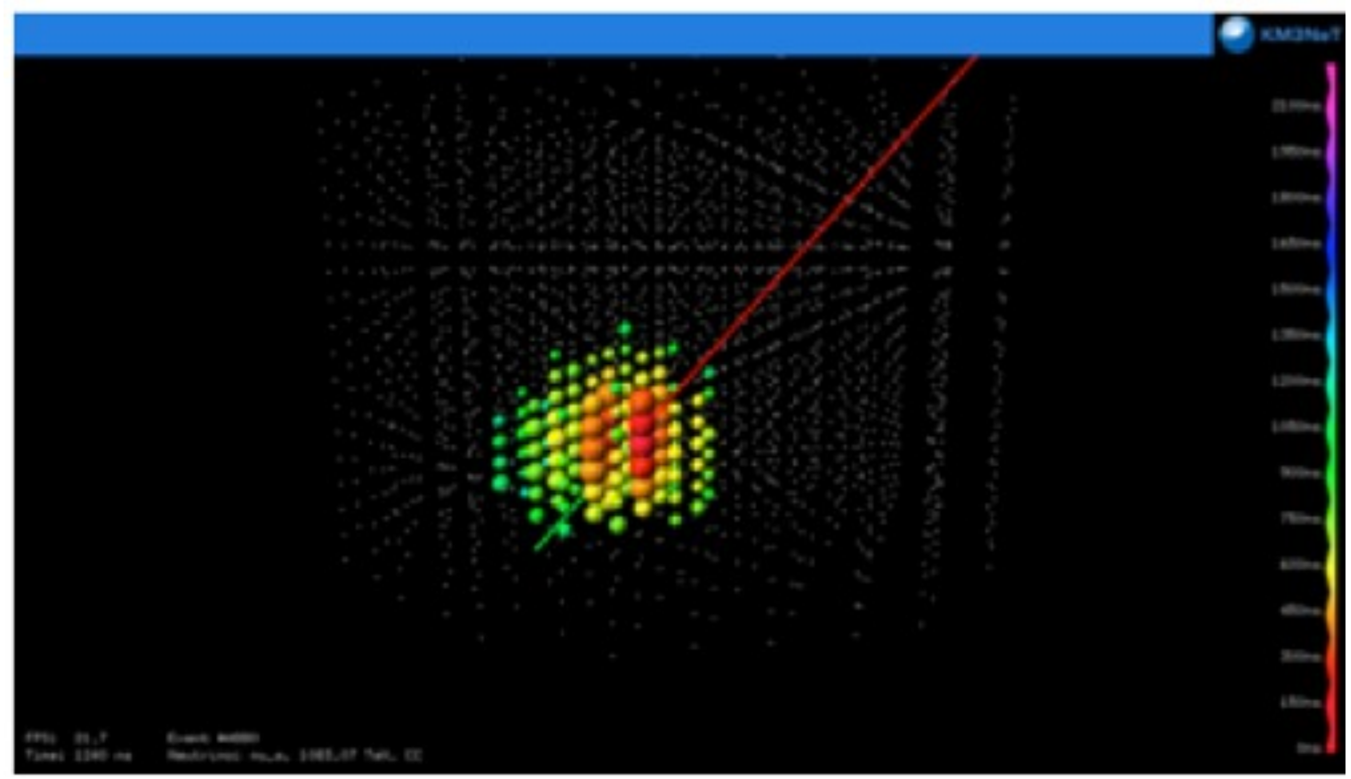


Angular resolution

Muon tracks (range > 1 km @ 100 GeV)



Cascades (size O(10 m) -- elongation with LPM effect)



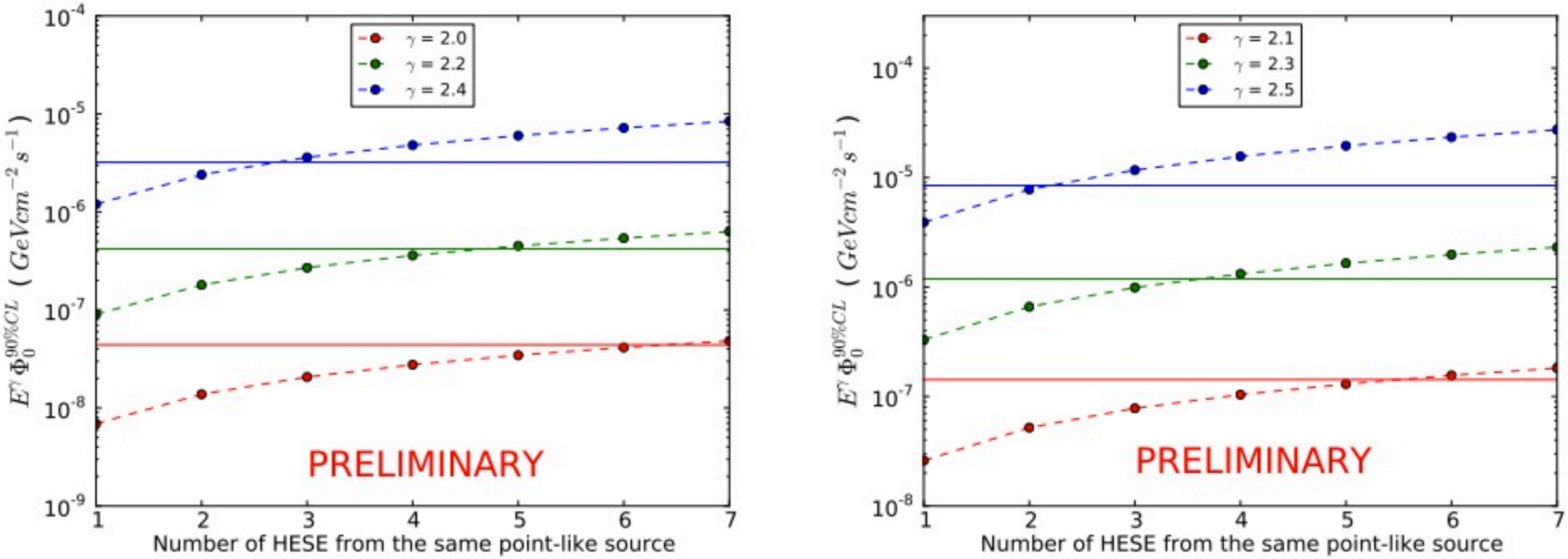
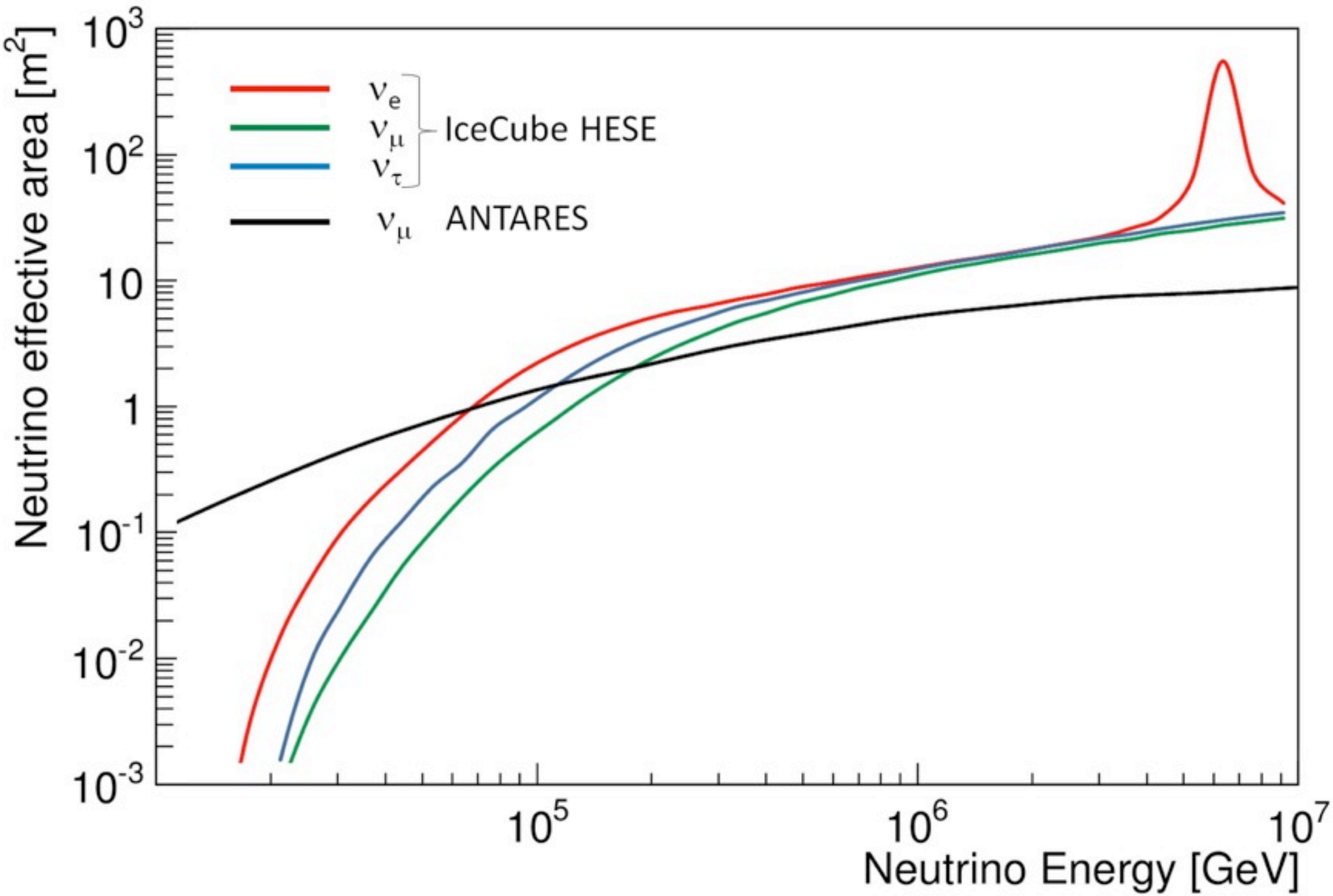


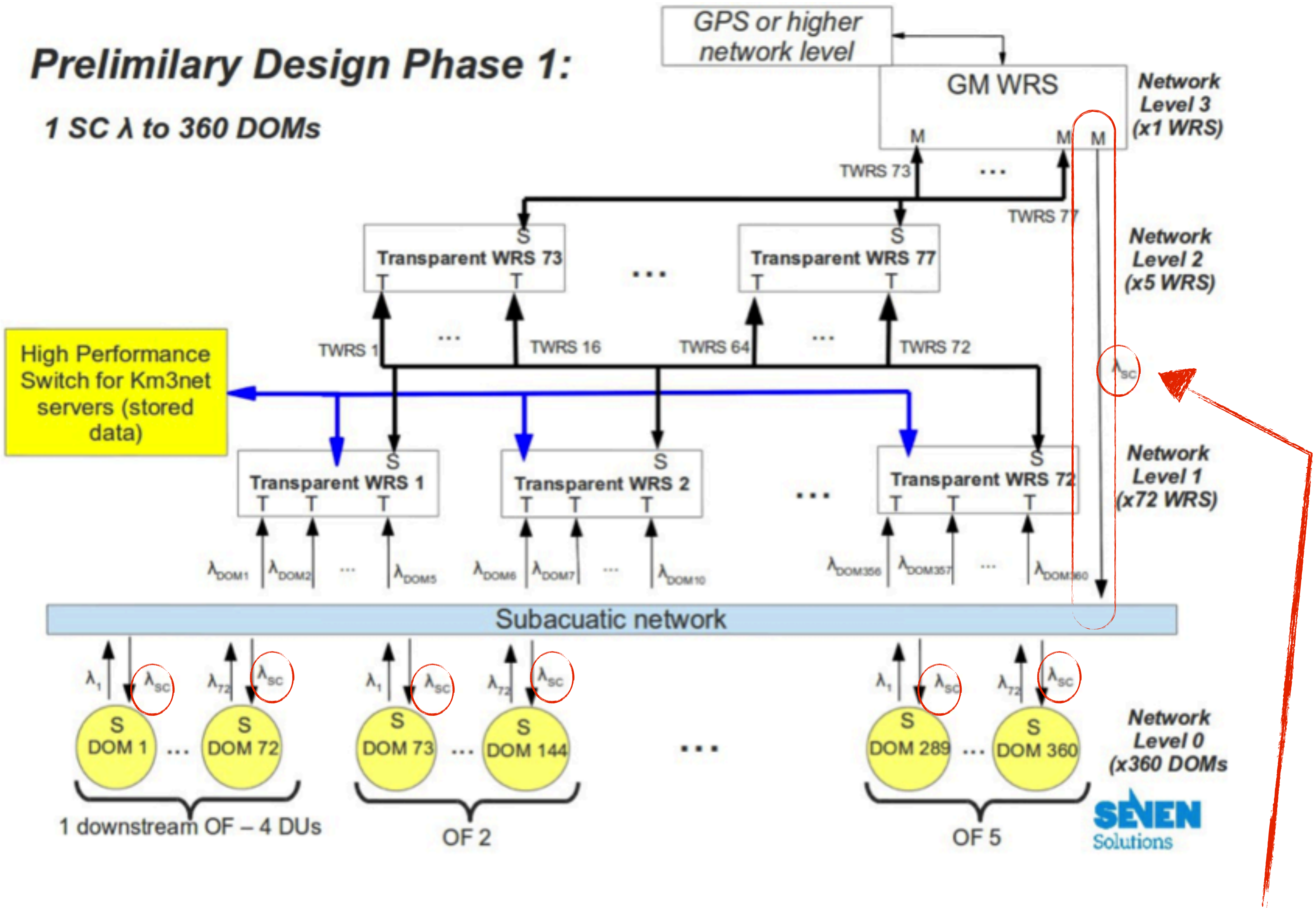
Figure 4: Solid lines: 90% C.L. upper limits for source spectra between 2.0 and 2.5 and a source declination of $\delta = -29°$. The figure on the left contains the values for $\gamma = 2.0$, 2.2, and 2.4, whereas the figure on the right contains the ones for $\gamma = 2.1$, 2.3 and 2.5. Dashed lines: expected flux normalisation of the proposed source as a function of the number of HESE events coming from this source. Values above the solid lines are disfavoured with a confidence level larger than 90%.

BACK

Effective Areas

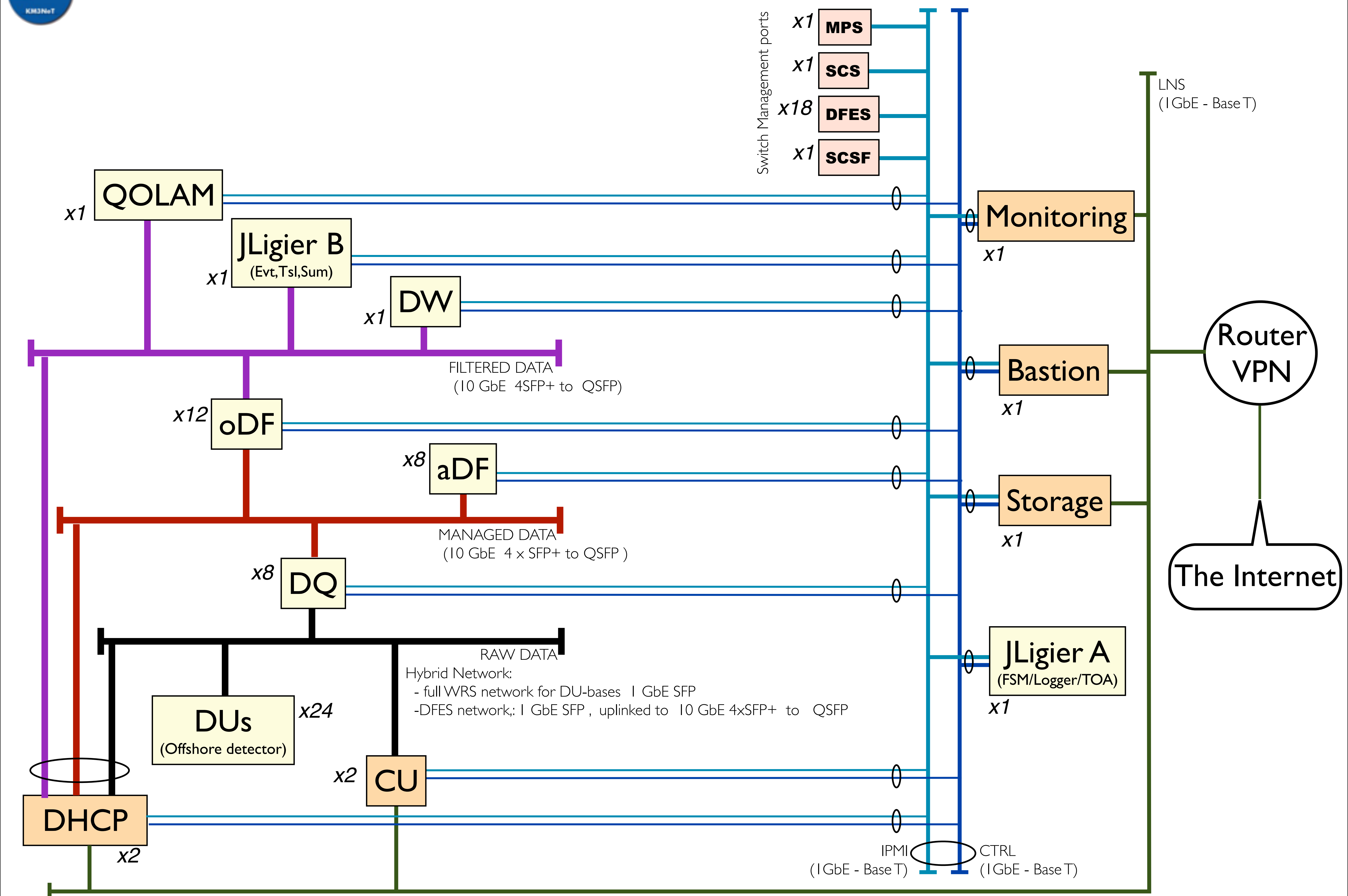


WR infrastructure in the Shore Station

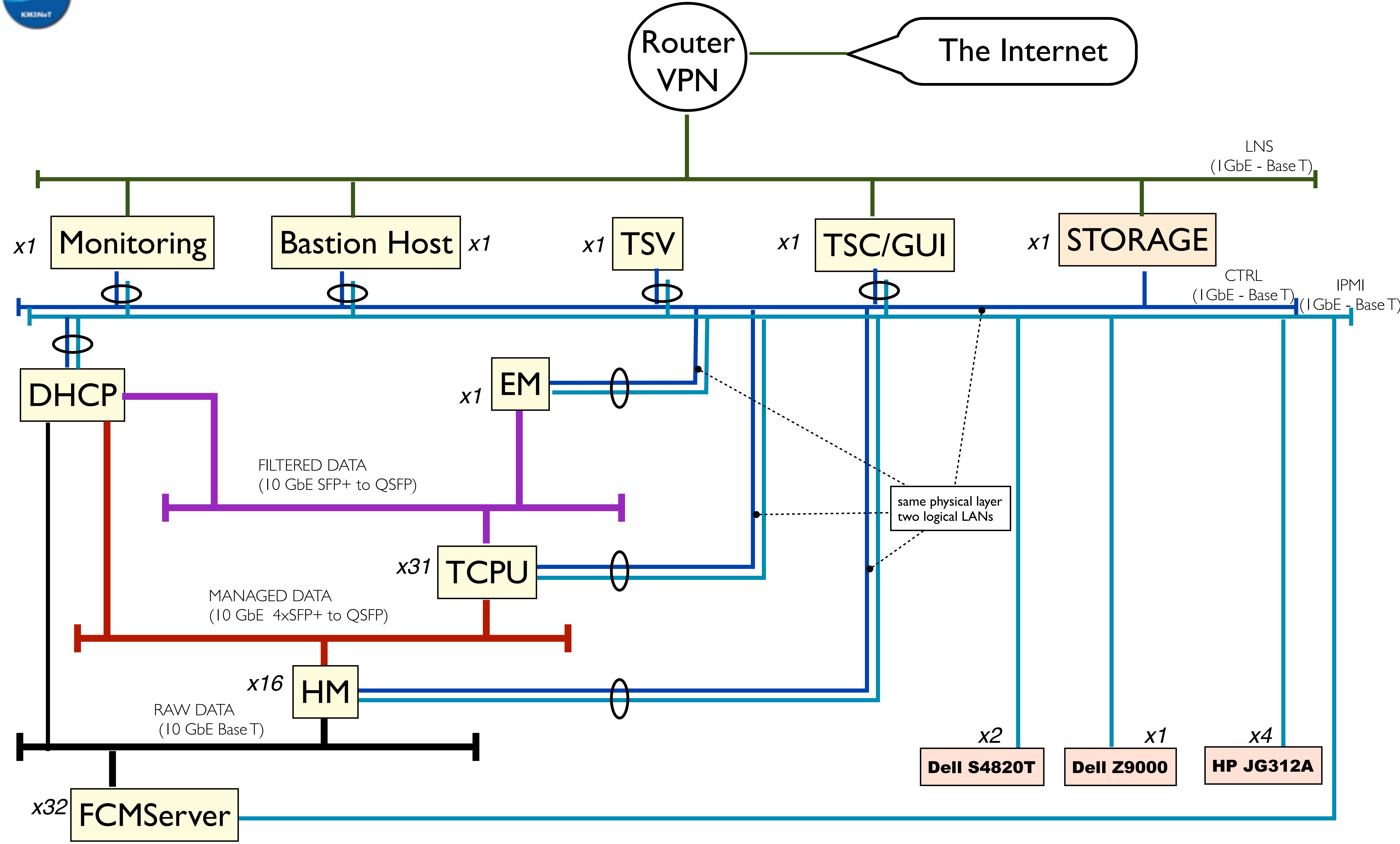


The "broadcast" channel (from on shore to offshore) implies an asymmetry for DOM send/return. Since WRPTP uses Ethernet, there has been a deep customization of WR swtich at software and gateware level

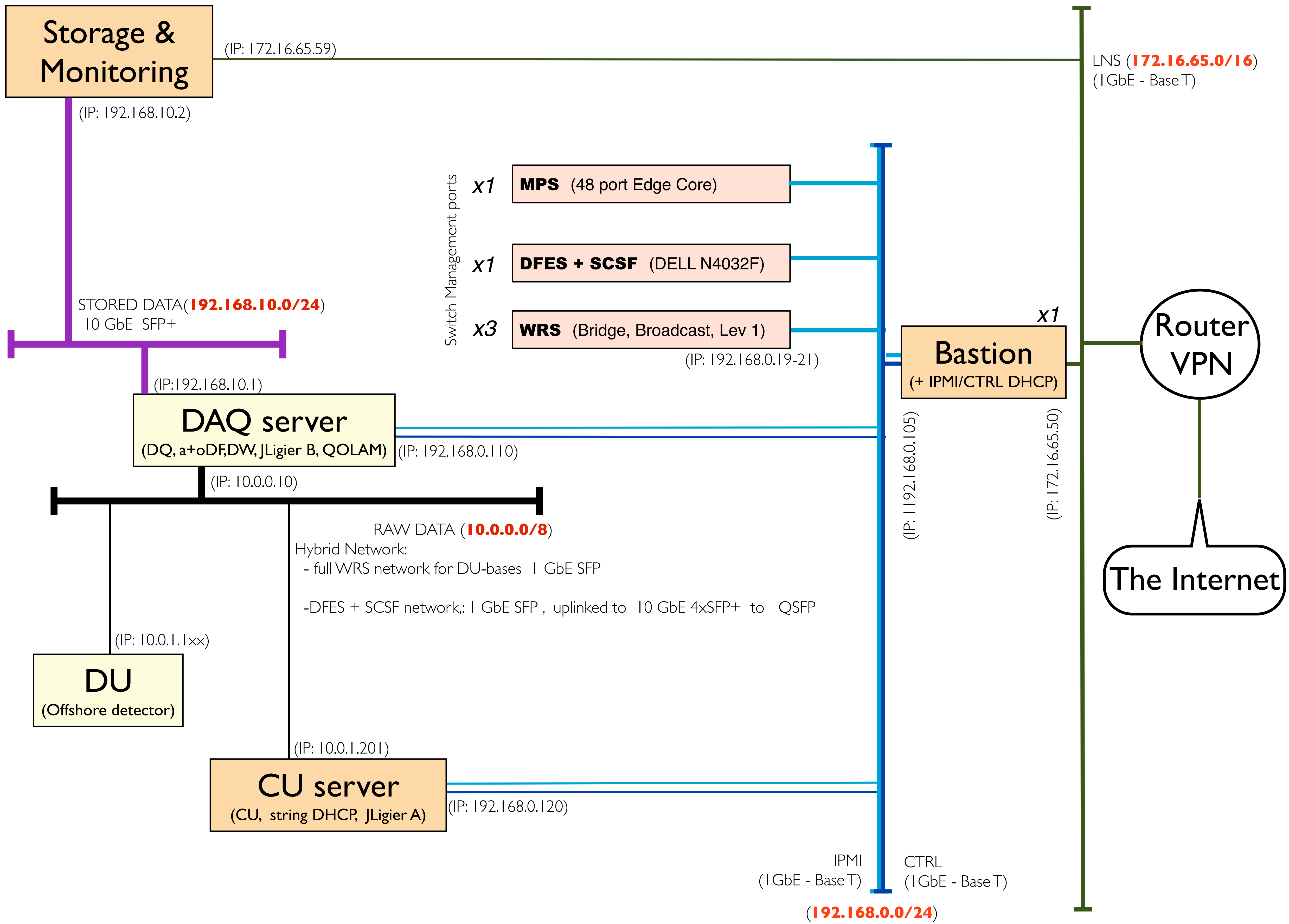
KM3NeT-Full Phase I Network design



KM3NeT-Italy : TriDAS Network Layout in Portopalo



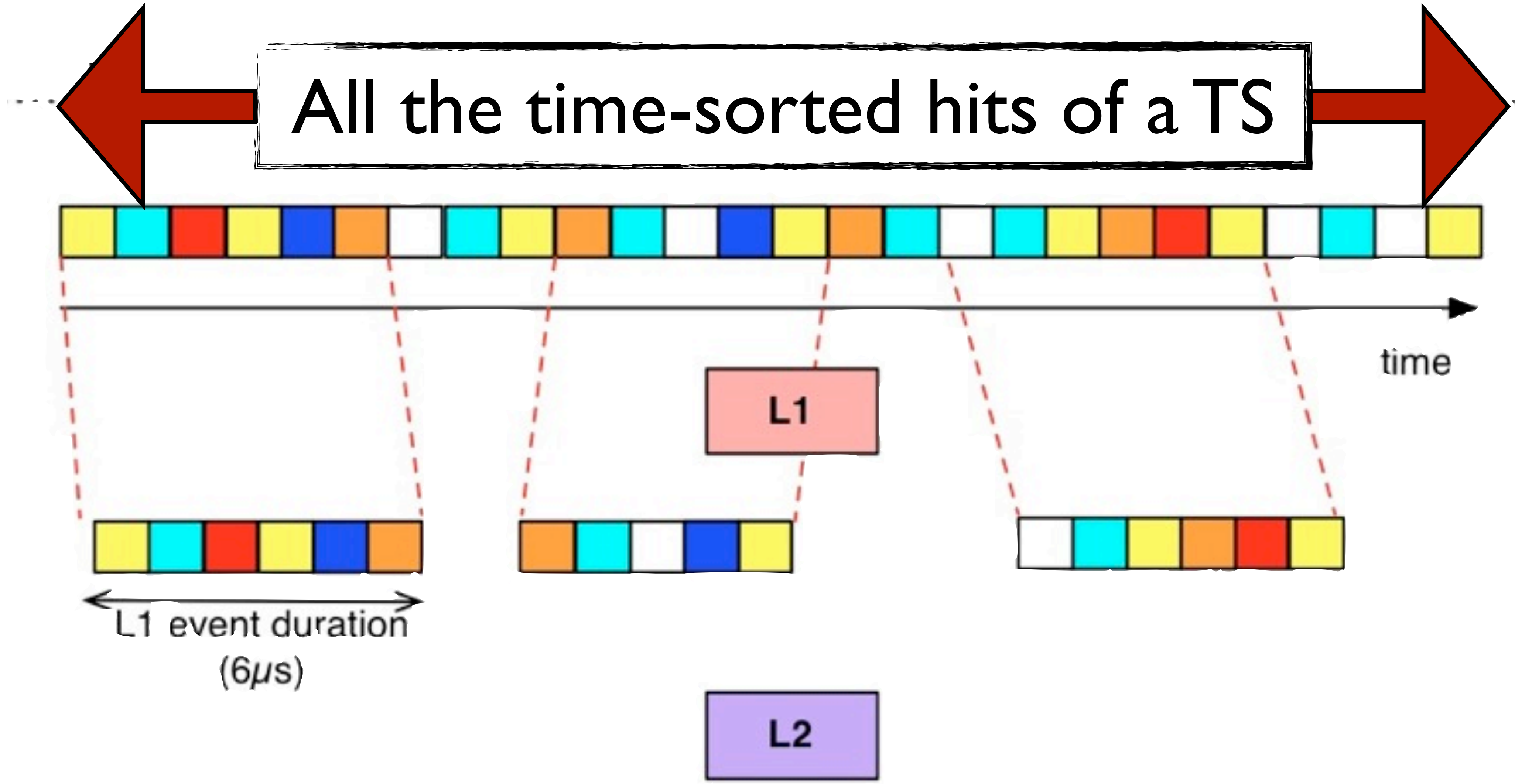
ARCA001 Network implementation



Strategies for combining Towers and Strings data

Strategy	Building stage	Purposes	Context	operations on DAQ data	Impact on DAQ	requirements of infrastructure implementatio	problems by DAQ design	Feasibility
Correlated events	offline	bundles, VHE/UHE events diffuse flux	correlation of absolute time	none	none	none	none	for free
Correlated DAQ	offline	sgmented events, (any events)	external trigger (follow-up);	none	rate of follow-up, managing of dedicated buffers	shared TriDAS switch fabric	none	medium
Integrated DAQ	online	any	standard triggers	Tower 2 String conversion on HMs	computing power at aggregation stages (HMs)	shared TriDAS switching and computing resources	none	complex

Trigger Levels



L1 = PRESELECTION

L2 = Dedicated Trigger Algorithm

✔ Most of the algorithms reported here are currently working in ANTARES

L1 - PRESELECTION

A

Simple Coincidences

$\Delta T \leq 10$ ns

B

large ToT hit

$\sim Q > Q_{th}$

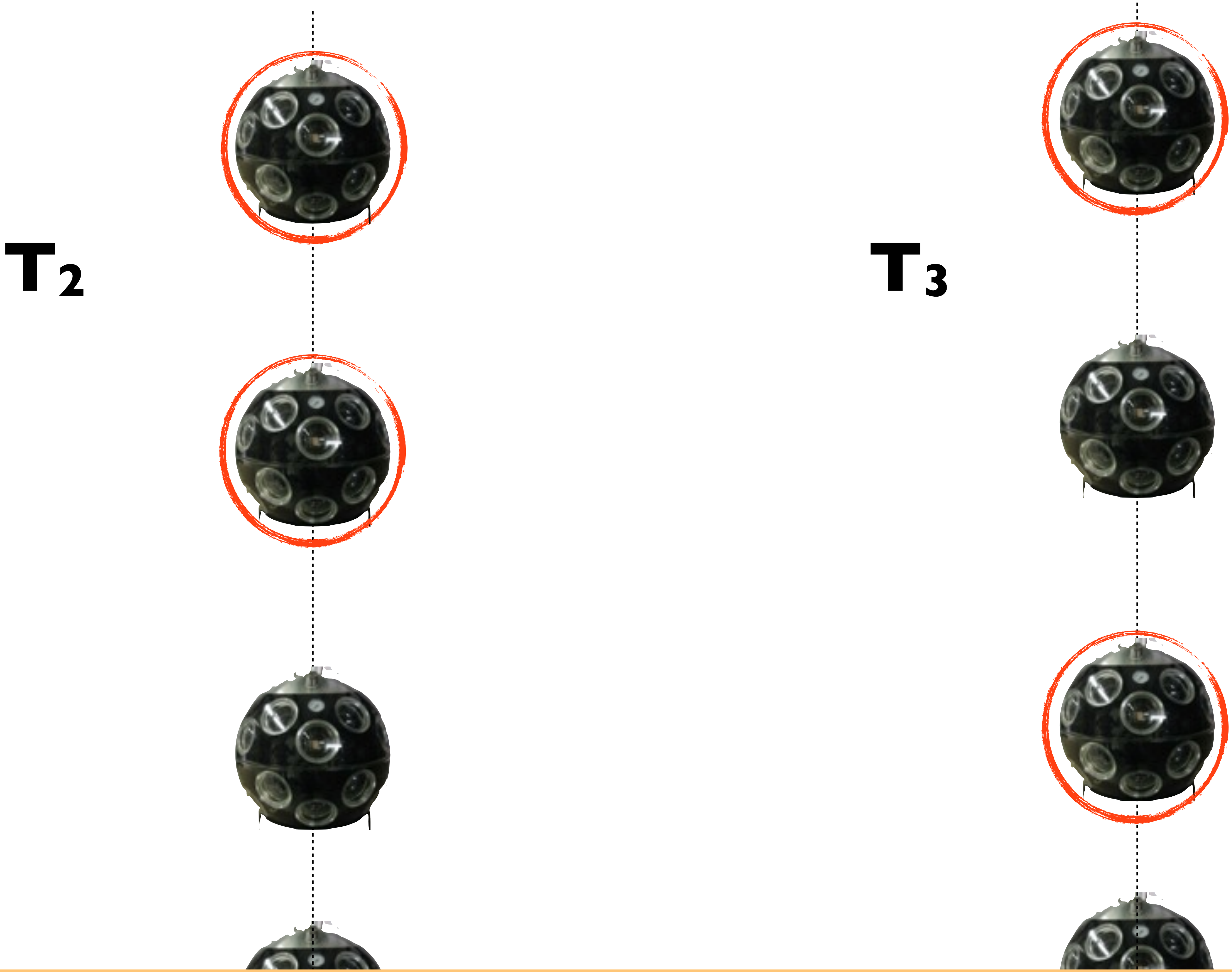
$$\nu_{out} = \frac{1}{\Delta T}\binom{n}{k}p^k(1-p)^{n-k}, \qquad p = 1 - e^{-\Delta T\,\nu_{bkg}}$$

Sampling Window ΔT

n = n. involved PMTs

k = minimum searched hits within ΔT

✔ L2 - **T-trigger**: clusters of *L1*s



The trigger is set when the n. of consecutive T_2 or T_3 pairs is $\geq N_{th}$ within a certain time-window ΔT

✔ L2 - Simple causality trigger

1. A minimum n. of ***consecutive*** L1s ≥ N_{th} within a ΔT (at least $n_{PMTs} \geq 5$)

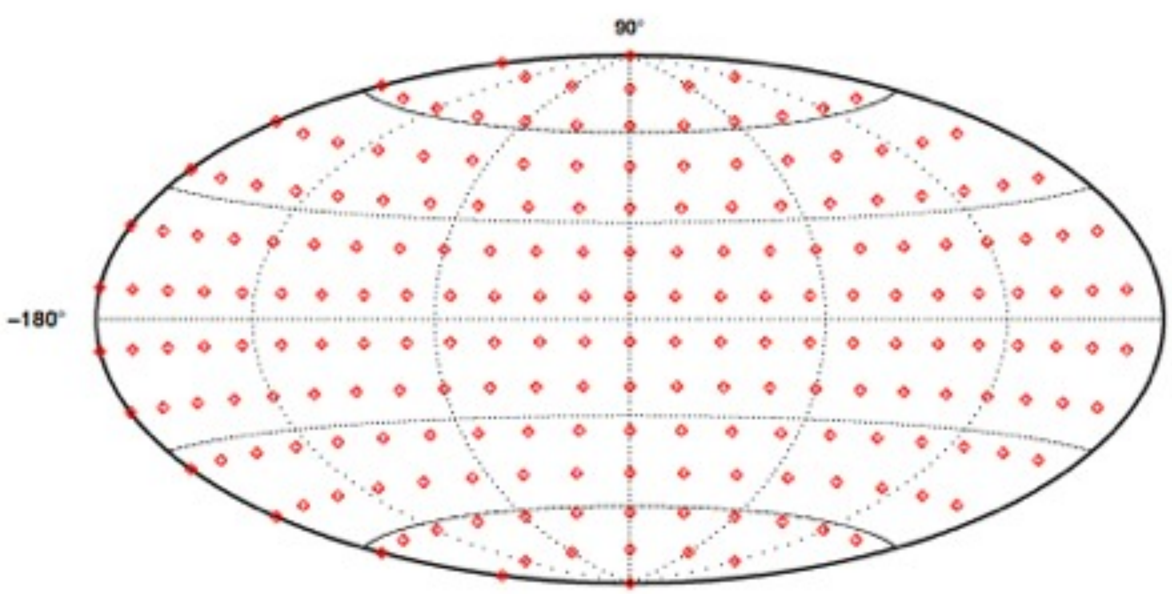
2. *3D*-causality filter : $$\left| t_i - t_j \right| \leq \left| \vec{x}_i - \vec{x}_j \right| \frac{n}{c}$$

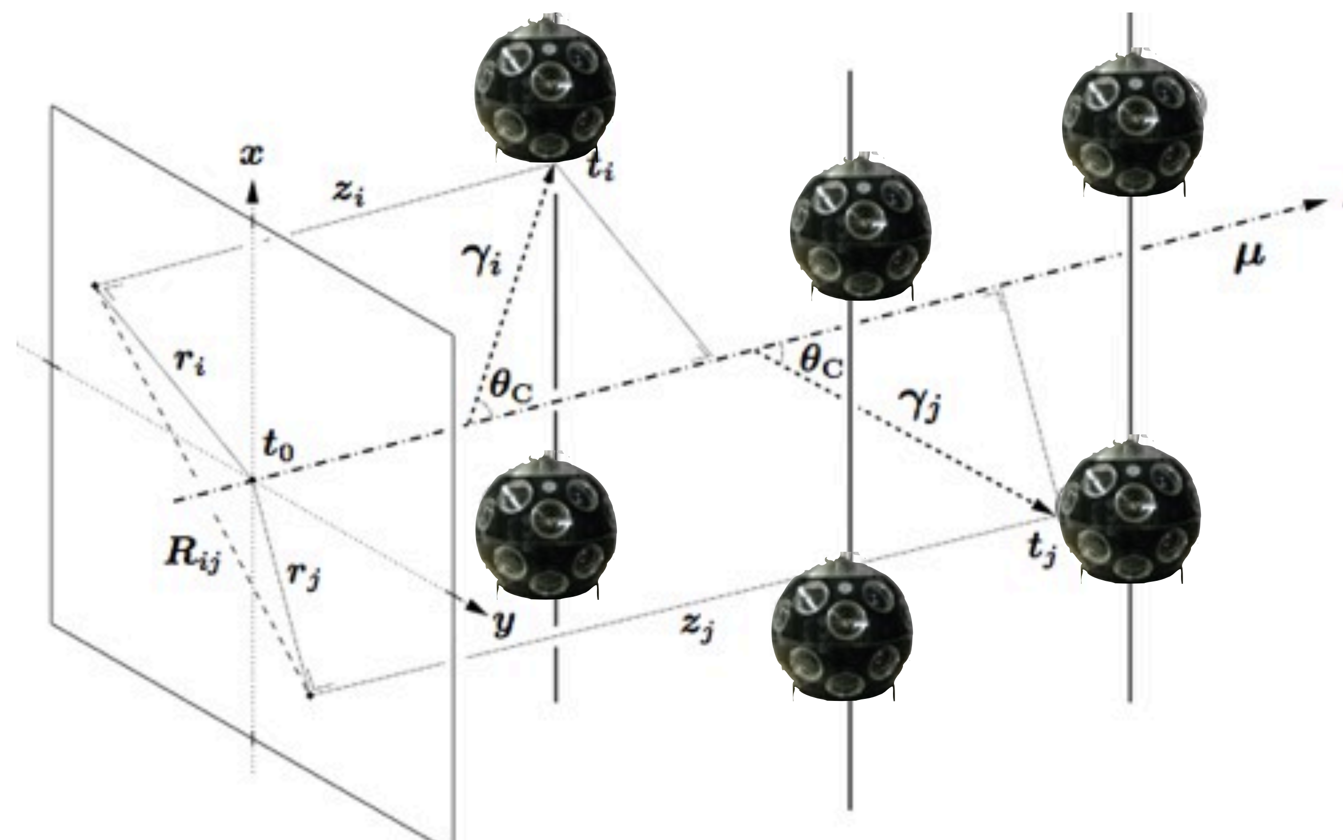
3. The trigger is set if the n. of satisfying hits is ≥ N'_{th}

✔ L2 - Sky scan trigger

1. A minimum n. of ***consecutive*** L1s ≥ N_{th} within a ΔT (at least $n_{PMTs} \geq 5$)

2. A homogeneous sky survey is done → "***rotation***" *procedure:* μ // z

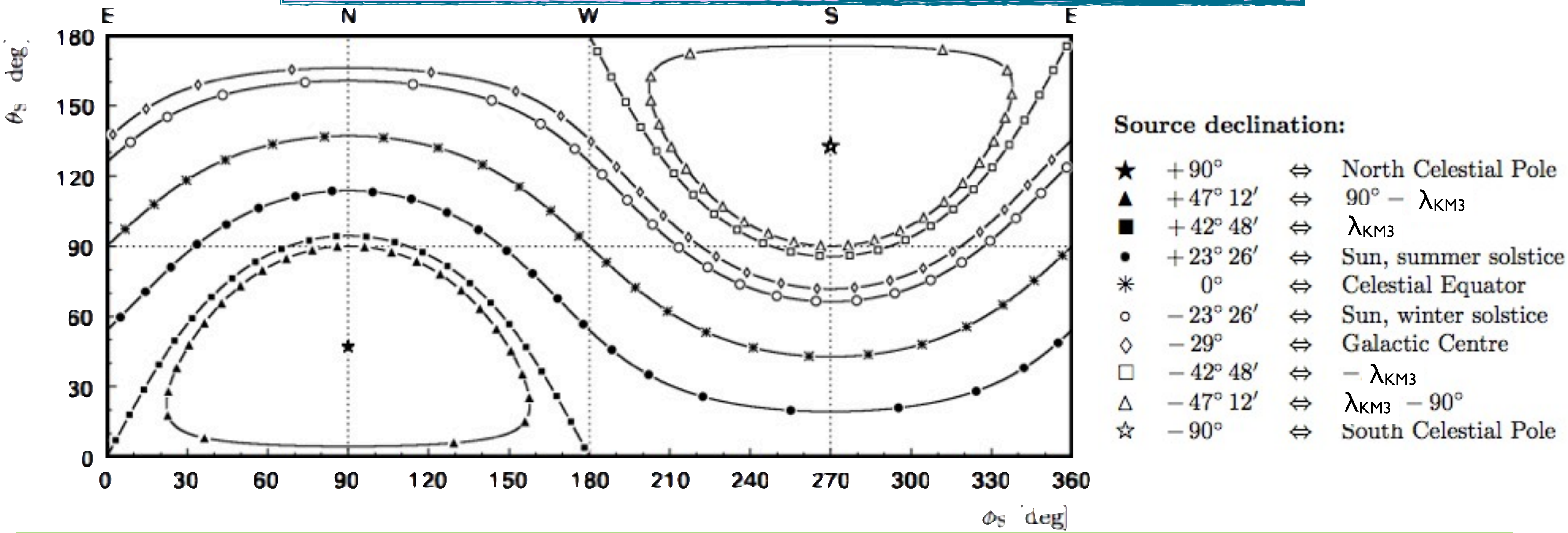




$$|(t_i - t_j)c - (z_i - z_j)| \leq \tan\theta_c \sqrt{[(x_i - x_j)^2 + (y_i - y_j)^2]} = \tan\theta_c \, |R_{ij}|$$

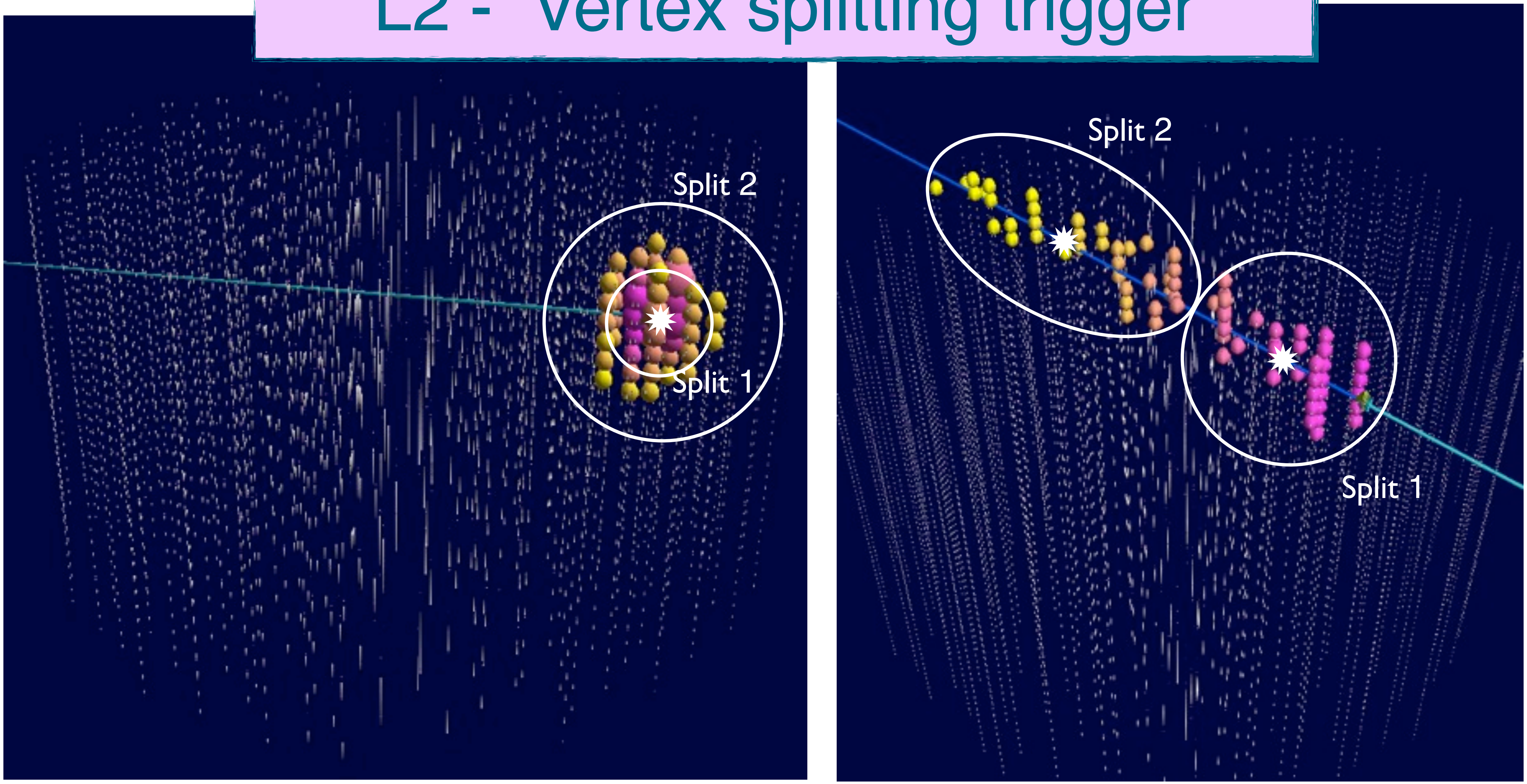
3. The trigger is set if the n. of satisfying hits is ≥ N'_{th}

✔ L2 - Source tracking trigger



1. From **GPS** time of timeslice → **source direction**
2. L1 preselected events with **even one seed** are accepted.
3. **All hits** of each event are tested with the "**rotation**" procedure (**road-width** R_{max} restriction w.r.t. direction)
4. A *cluster* is formed when found $\mathbf{N_{min}}$ **consecutive hits**, **L1 seed included**.
5. If **time-overlap** among clusters → **clusters are merged** into one only bigger cluster.
6. **Small clusters** are treated with a **quick reconstruction** (to avoid accidental clustering of bkg)
7. The trigger is set if PMT ***surface density*** (w.r.t. the convex hull ⊥ direction) $\geq \sigma_{th}$

L2 - Vertex splitting trigger

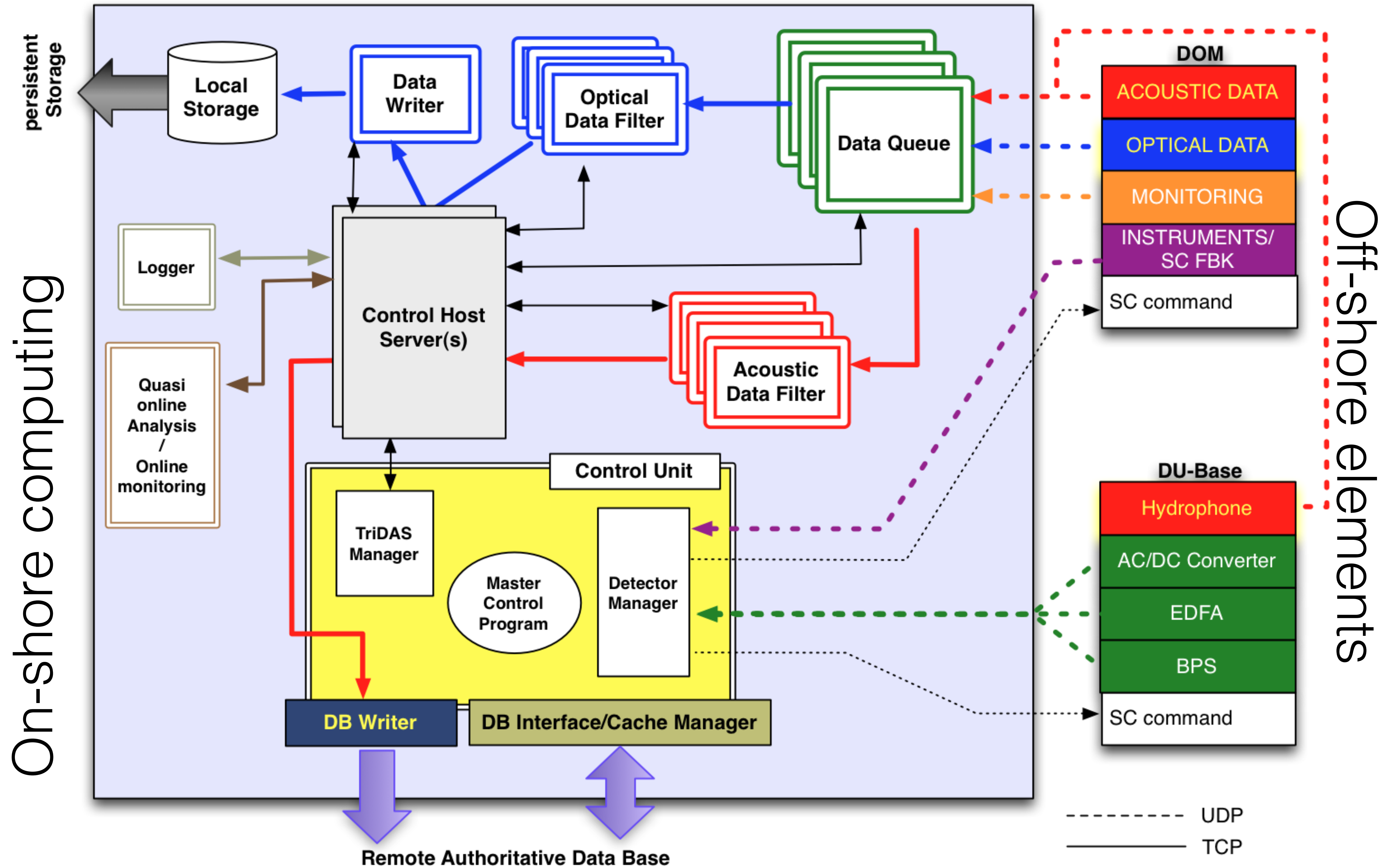


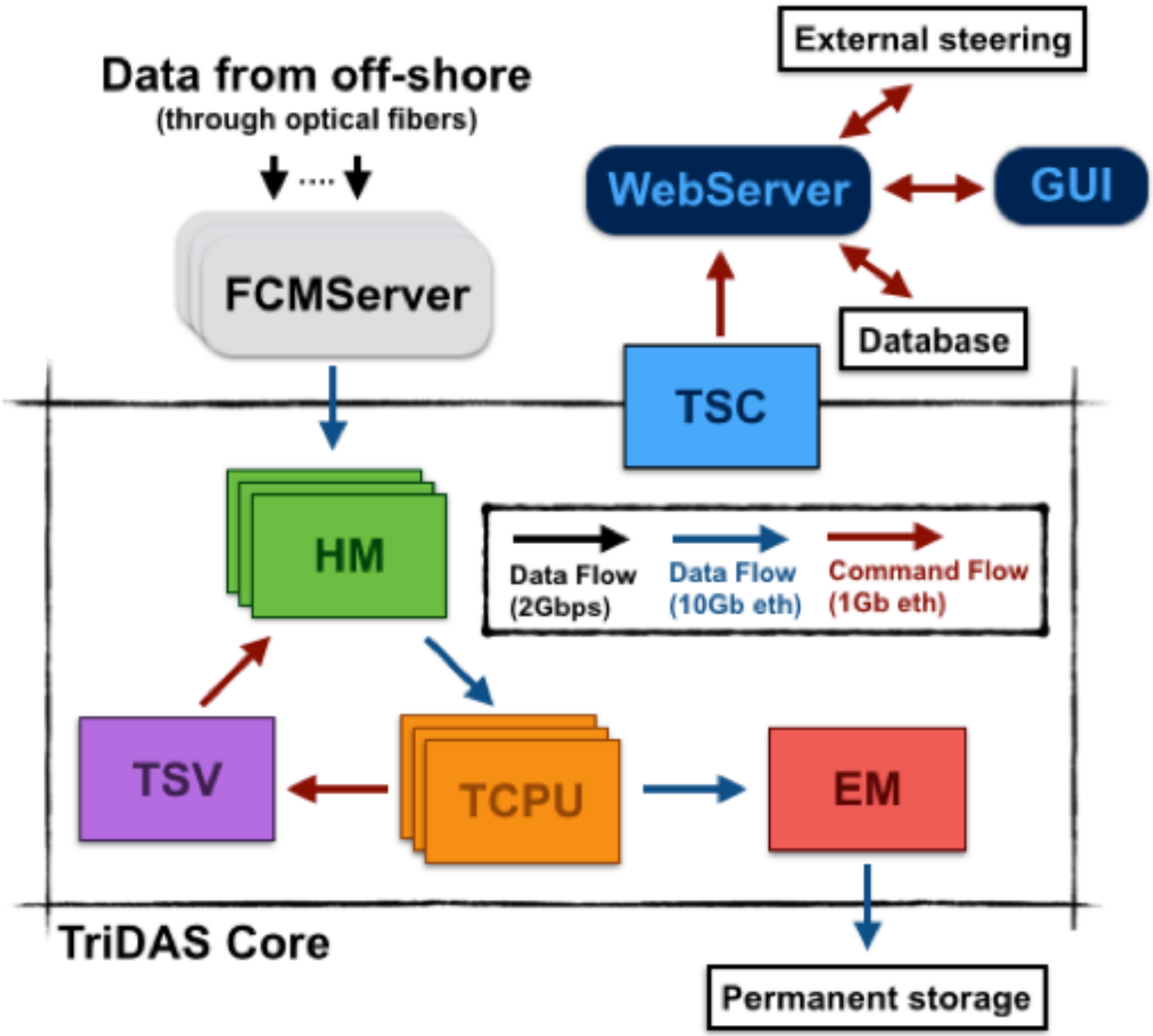
1. Subdividing all the event hits in 2 time splitted groups
2. Vertexes reconstruction and vertex position discrimination
3. “Inertia” tensor eigenvalues ratio

$$I^{k,l} = \sum_{i=1}^{N} A_i(\delta^{k,l}\mathbf{r_i^2} - r_i^k r_i^l), \qquad \mathcal{T} = \frac{I_1}{I_1 + I_2 + I_3}.$$

inspired by IceCube

The KM3NeT Europe - Trigger and Data Acquisition System (TriDAS)




External steering
Data from off-shore
(through optical fibers)
WebServer
GUI
FCMServer
Database
TSC
HM
Data Flow
(2Gbps)
Data Flow
(10Gb eth)
Command Flow
(1Gb eth)
TSV
TCPU
EM
TriDAS Core
Permanent storage

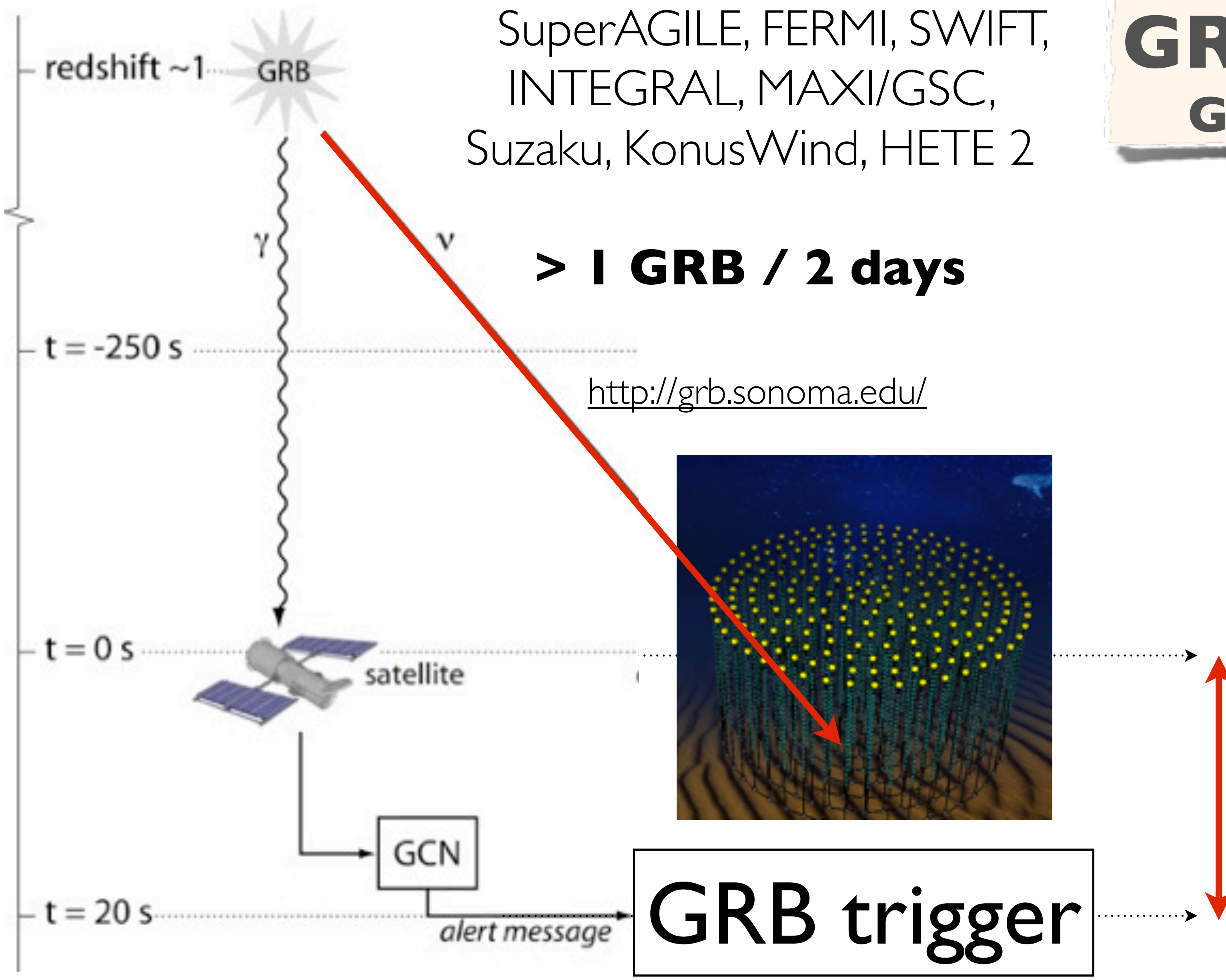
✔ L2 - Follow-up trigger

GRB alert system within the GRB Coordinate Network

SuperAGILE, FERMI, SWIFT, INTEGRAL, MAXI/GSC, Suzaku, KonusWind, HETE 2

> 1 GRB / 2 days

http://grb.sonoma.edu/



requested at least 20s of buffered data

... Buffering in the DataFilter .

... offline stack-analysis