Physics @ Neutrino Telescopes (NT)

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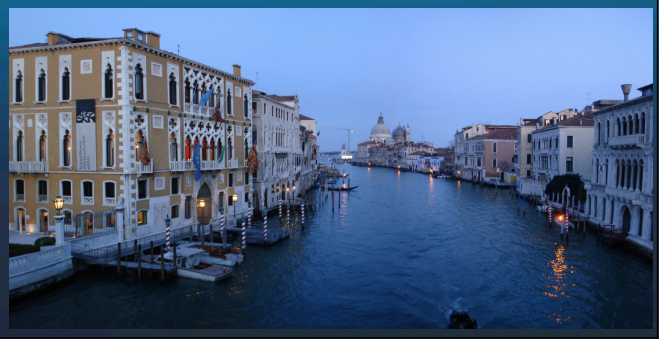
University of Wisconsin - Madison

(many of the results are by the IceCube and ANTARES Collaborations - highlighted main young authors)

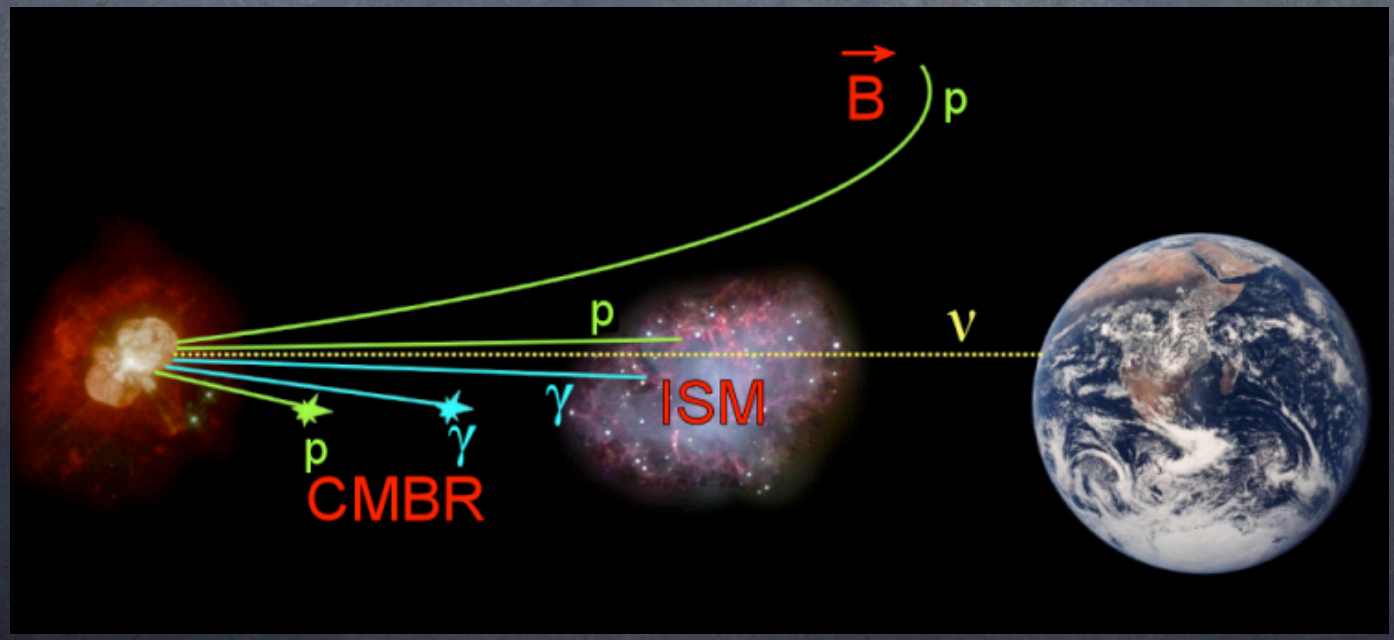
XIV Neutrino Telescope Workshop
Mar 18, 2011



Studying extreme beams from the Universe with NTs

1) **Particle Physics Instruments:** The study of **high-energy cosmic ray particles** was a **core element of the early development of particle physics**, as **beams of comparable energy could not be produced at accelerators**.

2) **Telescopes for Discovery:** In the modern era, the cosmic particles (both charged particles and gamma rays) are also **understood to be messengers from astrophysical accelerator** systems harboring **extreme conditions that are impossible to duplicate in terrestrial laboratories**. (PASAG report)



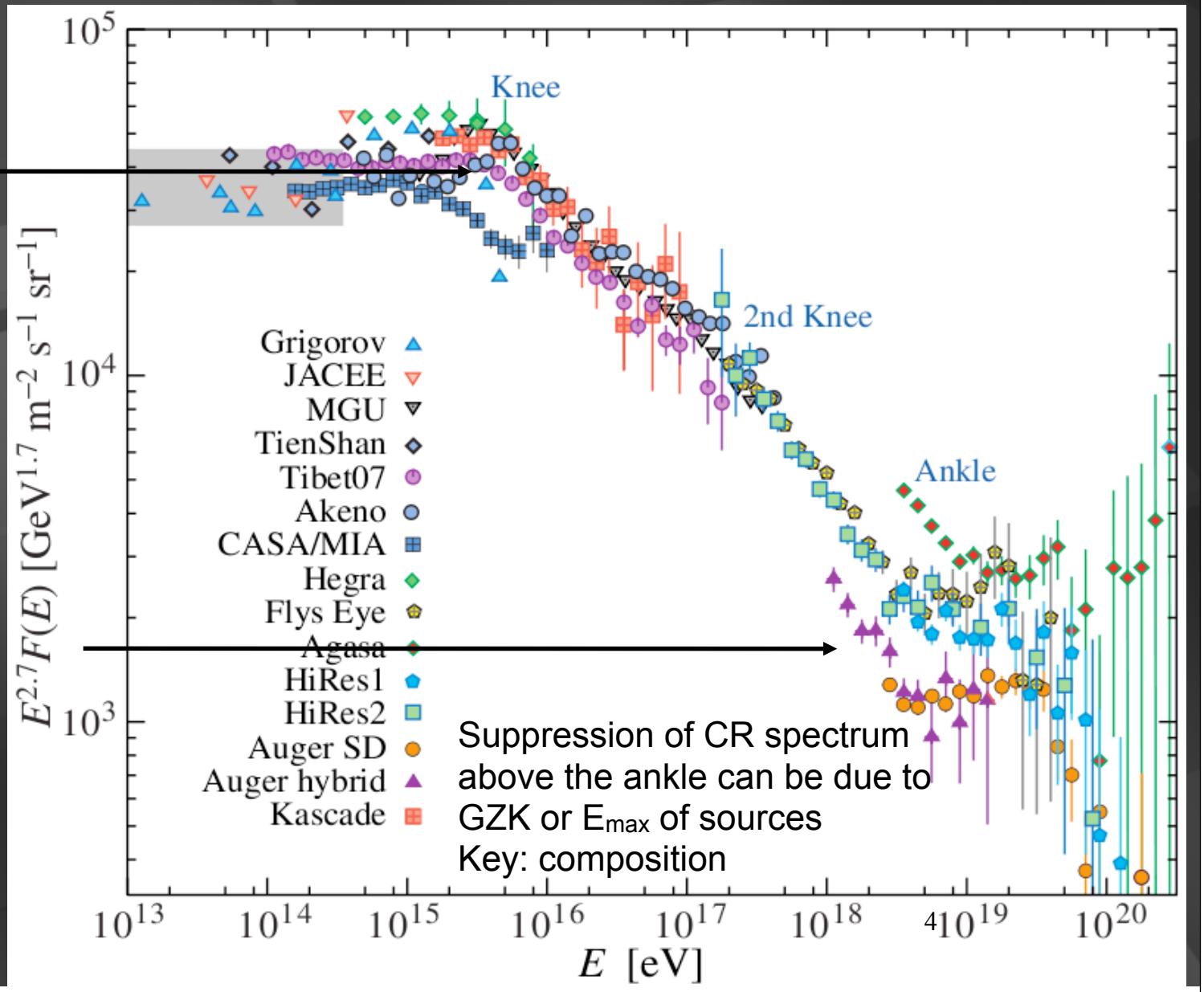
Themes I will cover

- The sources of Cosmic rays
- Golden channel: point sources.
- Expectations for Galactic sources
- What if sources are extended? the observation of CR anisotropies
- Extragalactic sources and Neutrinos from UHECR-CMB interactions
- Things to investigate better: definition of events and hit selections, muon energy losses and cascades, CR composition, neutrino cross sections, hadronic models
- Is x100 factor for neutrinos from GeV-EeV feasible?
- I had to leave out DM, atmospheric neutrinos (see T. Gaisser's talk) and SN monitoring but ask

At least we know we see them...but above the knee composition knowledge is a long standing problem...

Galactic: supernova remnants?

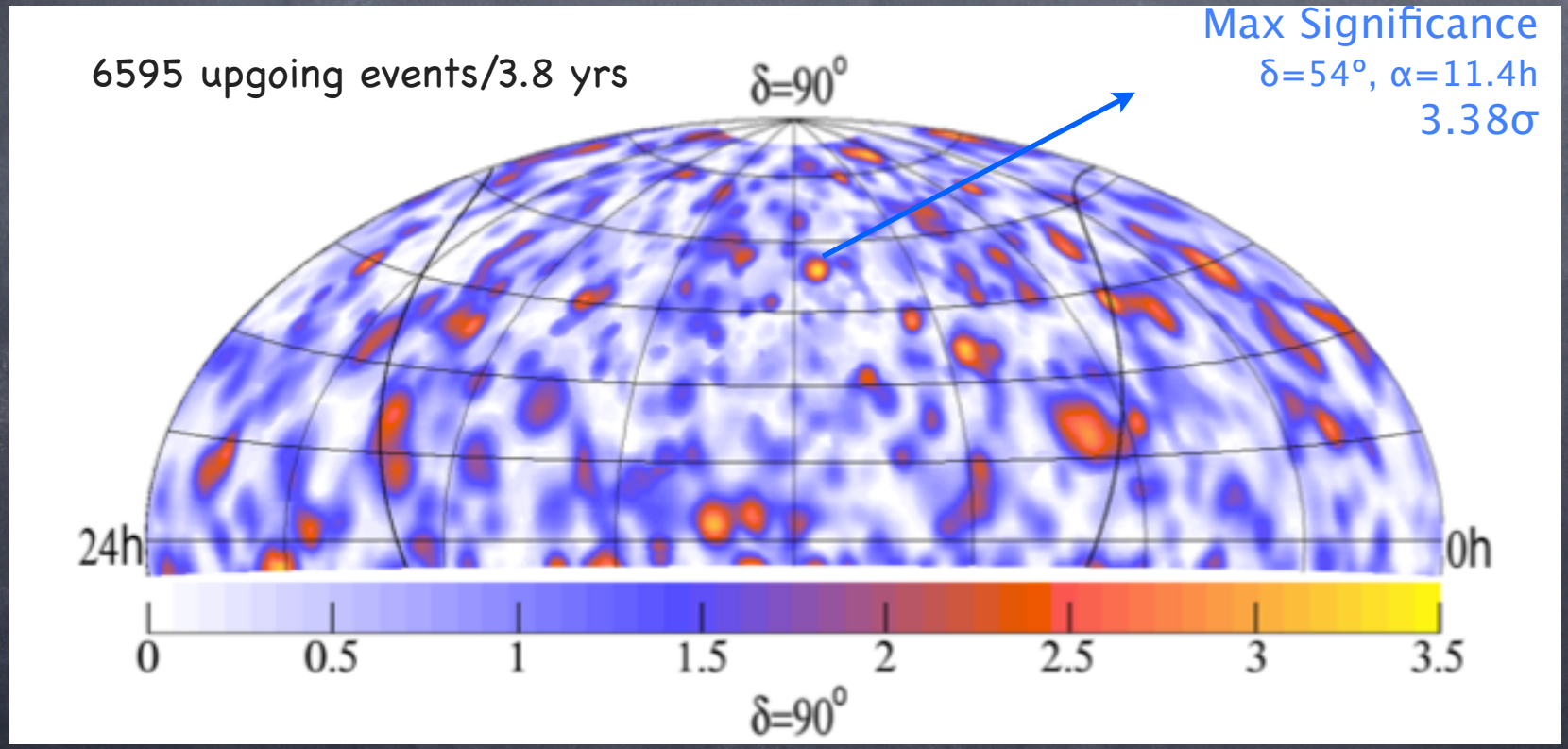
extragalactic: gamma ray bursts, AGNs, magnetars?



Suppression of CR spectrum above the ankle can be due to GZK or E_{max} of sources
Key: composition

The golden channel: point-sources

From AMANDA...



J. Braun

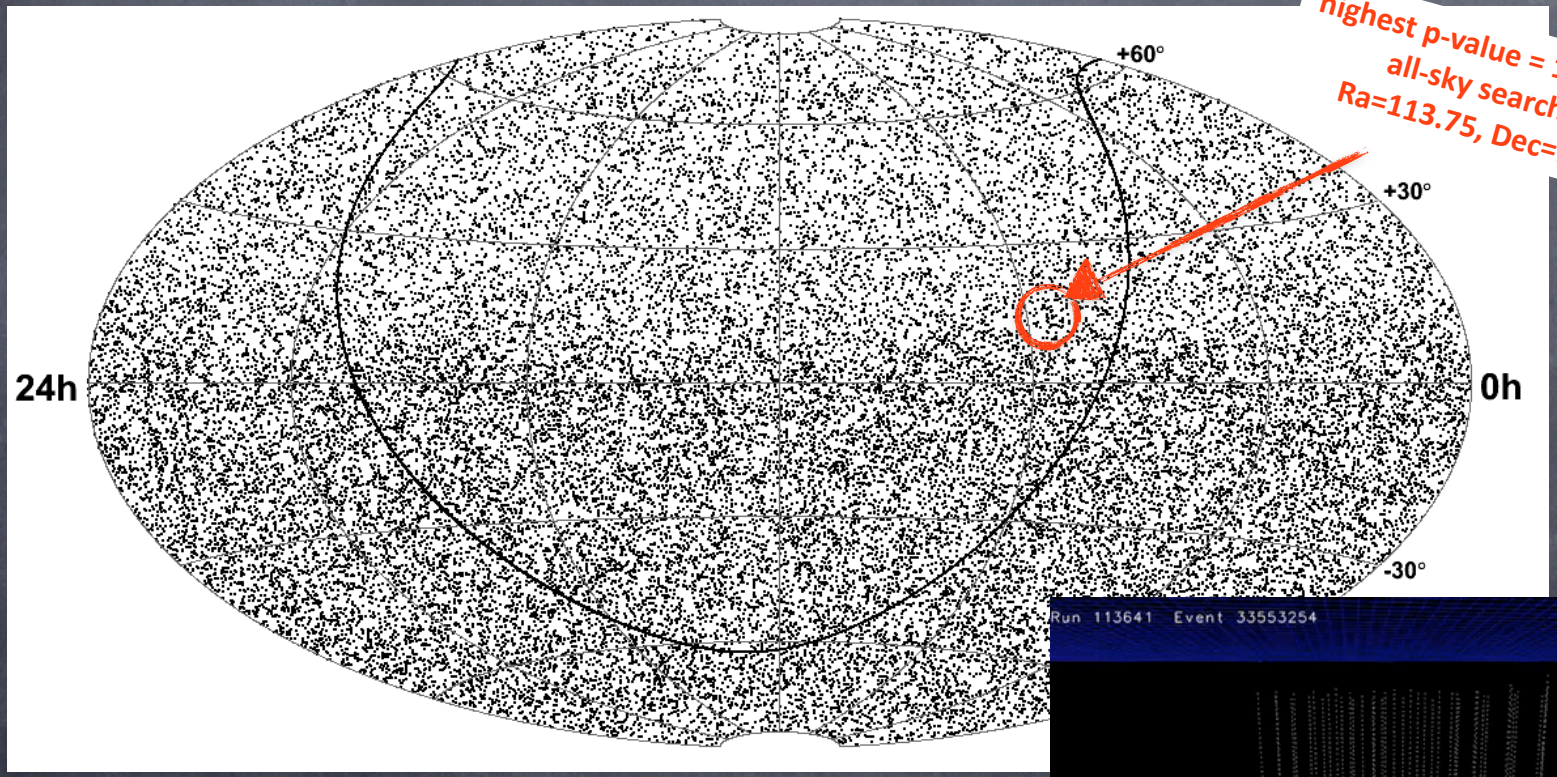
Observatory data: http://www.icecube.wisc.edu/science/data

…to 1/2 IceCube Map

14139 up-going (x2 from AMANDA in x3 less time), 23151 down-going in 375.5 d

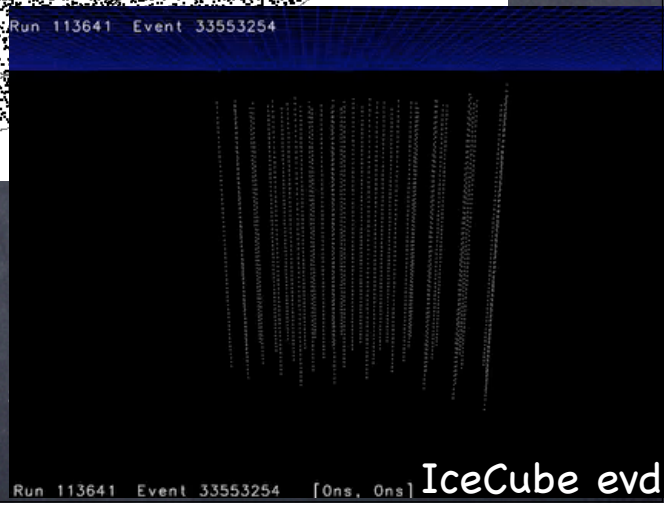
Atm. neutrinos

Atm. muons



highest p-value = 18% in the all-sky search is: Ra=113.75, Dec=15.15

J. Aguilar, M. Baker, C. Finley, J. Dumm



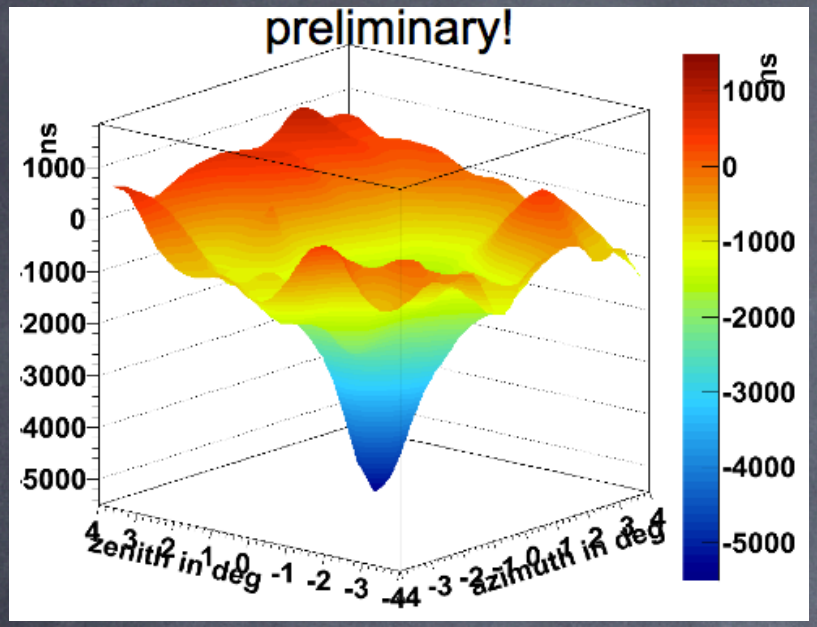
IceCube evd

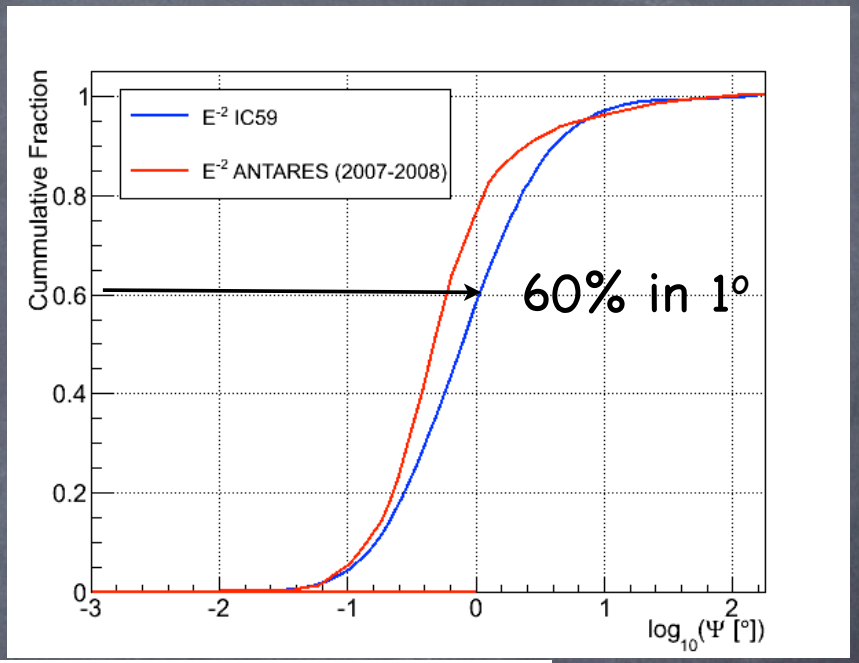
J. Braun et al. Astrop. Phys. 33 (2010) 175.; J. Braun et al. Astropart. Phys. 29 (2008) 299

T. Gaisser's talk

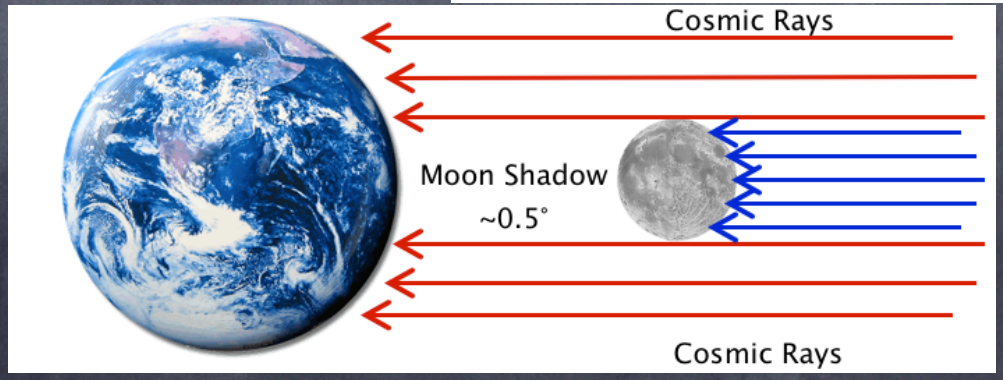
Sub-degree Pointing

from Moon shadow analysis



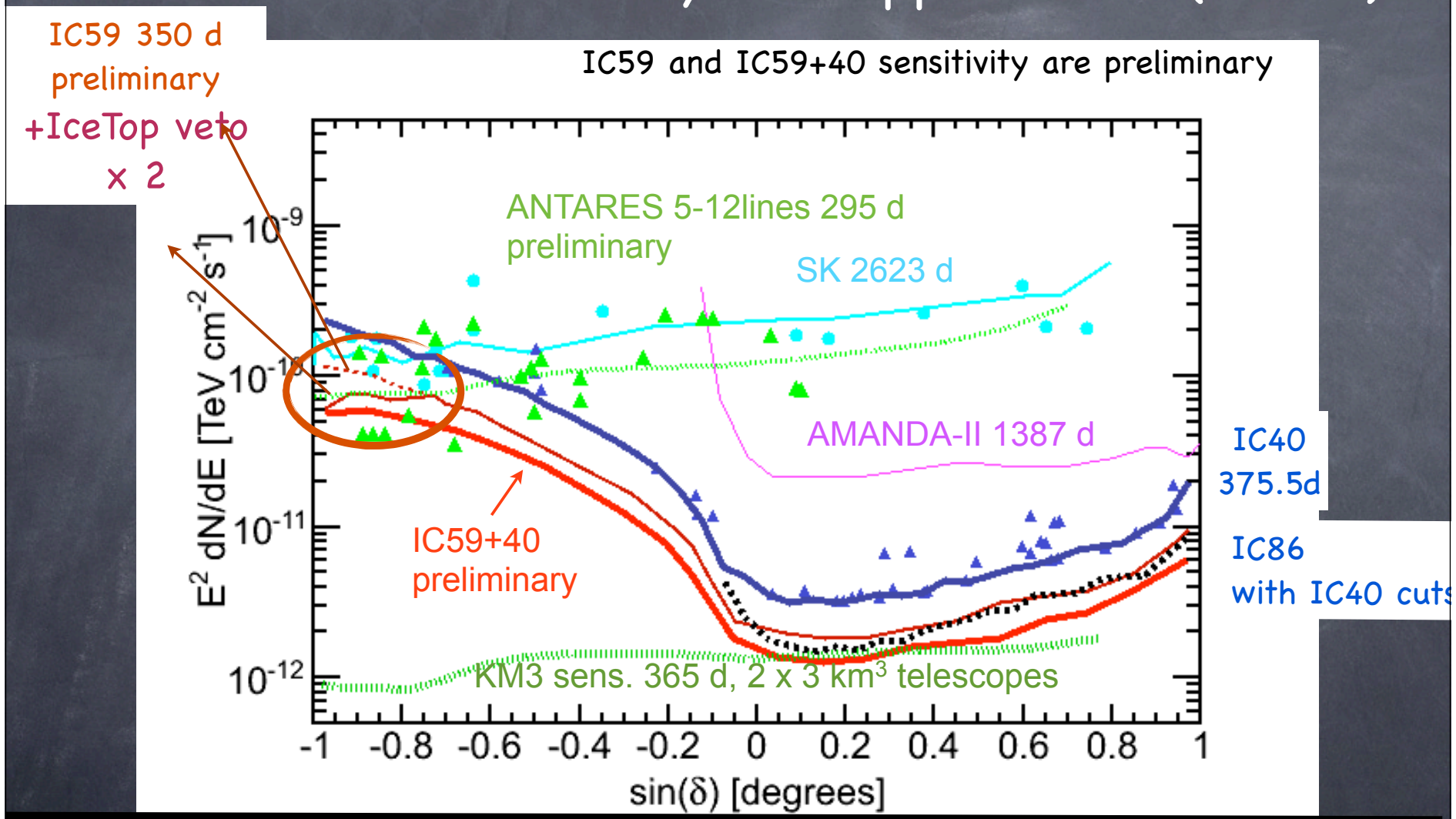


D. Boersma, L. Gladstone



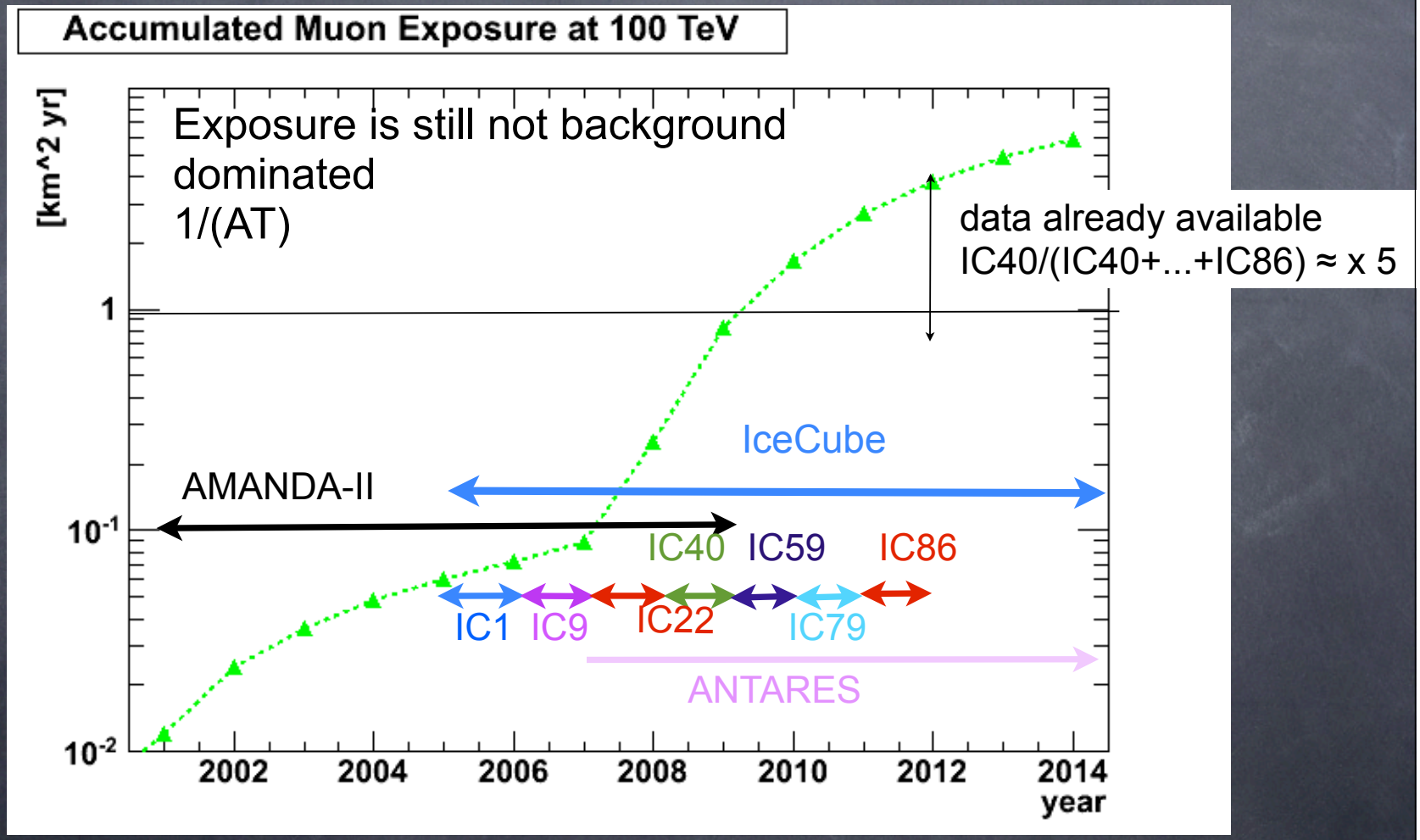
In 14 lunar months 6.8 σ deficit observed with 40 IceCube strings. LH analysis finds10 σ

E^{-2} median sensitivity and upper limits (90%cl)



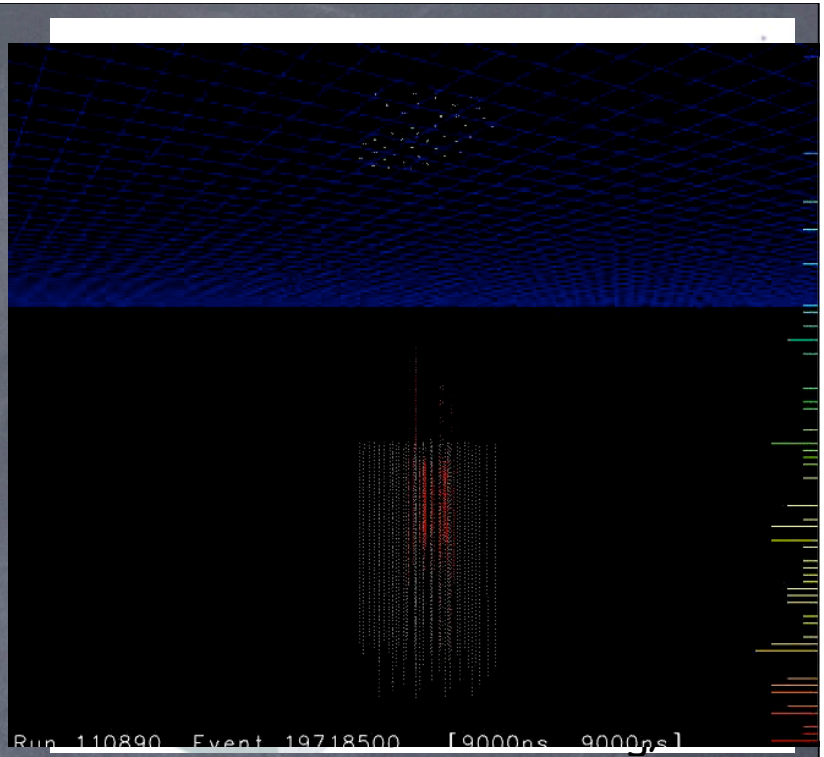
IC59 BDT analysis and improved cuts (x2 IC40). Combine samples: 40+59 strings (x3 IC40) = better than preliminary estimates of full IceCube
IC40+IC59+IC79+IC86 = about factor of 5 from the blue curve (IC40)

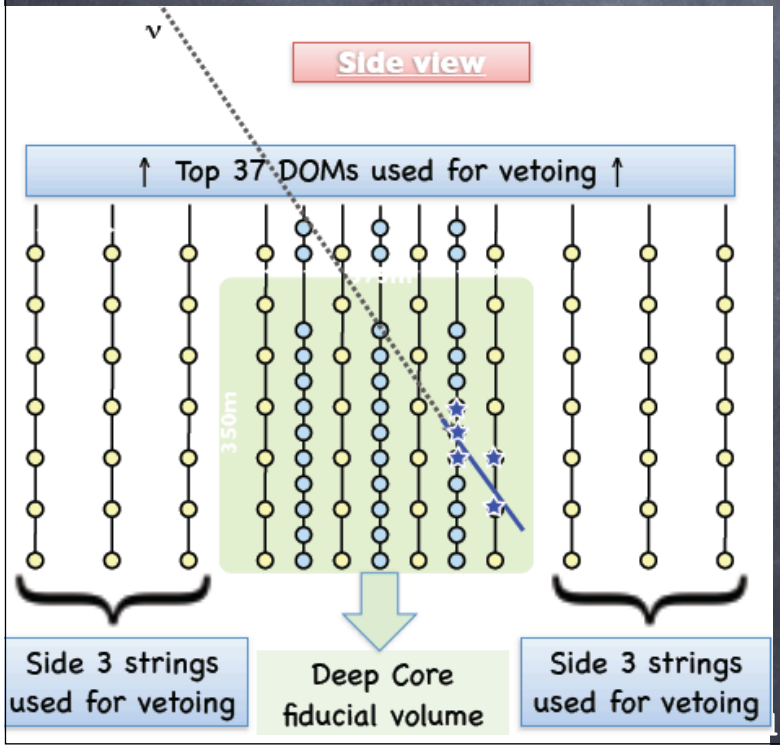
The exposure growth



Vetoing Neutrino detection

- surface arrays to reject muons
  - radio (E threshold and self-triggers solvable but challenging)
  - complement with conventional: satellite connections, increasing tank distance since inclined events penetrate at larger energies.

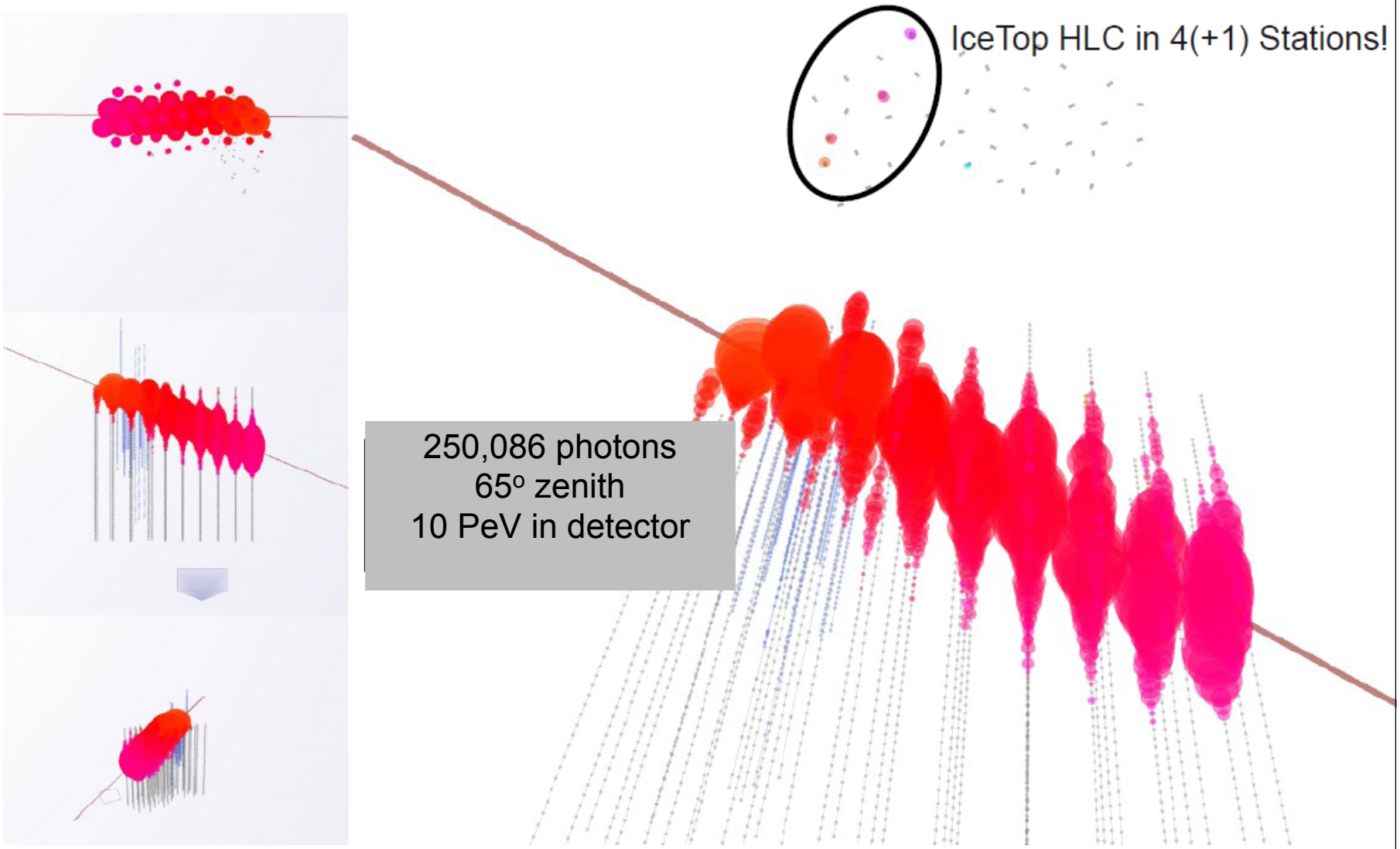




- Dense core arrays (DeepCore) to reject muon atmospheric events in the energy region where spectra are high (100 GeV-10 TeV). Fiducial volume helps rejecting backgrounds for cascade events.

SK has a veto too!

Biggest Shower in IC40 EHE Analysis



A. Ishihara, S. Yoshida
the event is rejected by blind cuts

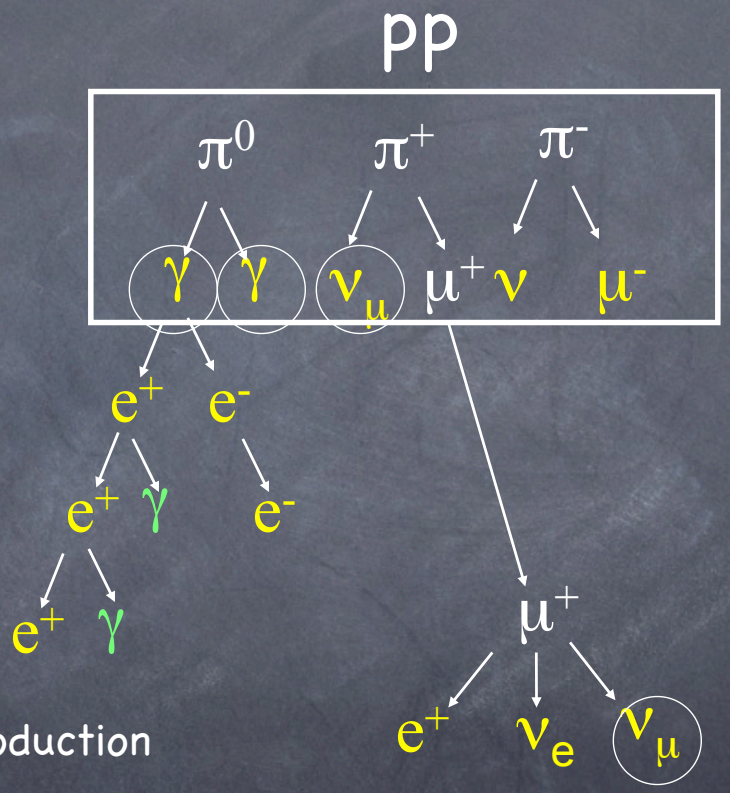
Expected ν - observed γ

F. Aharonian's talk

neutral pions
are observed as
gamma rays

charged pions
are observed as
neutrinos

$\nu_\mu + \nu_\mu = \gamma + \gamma$

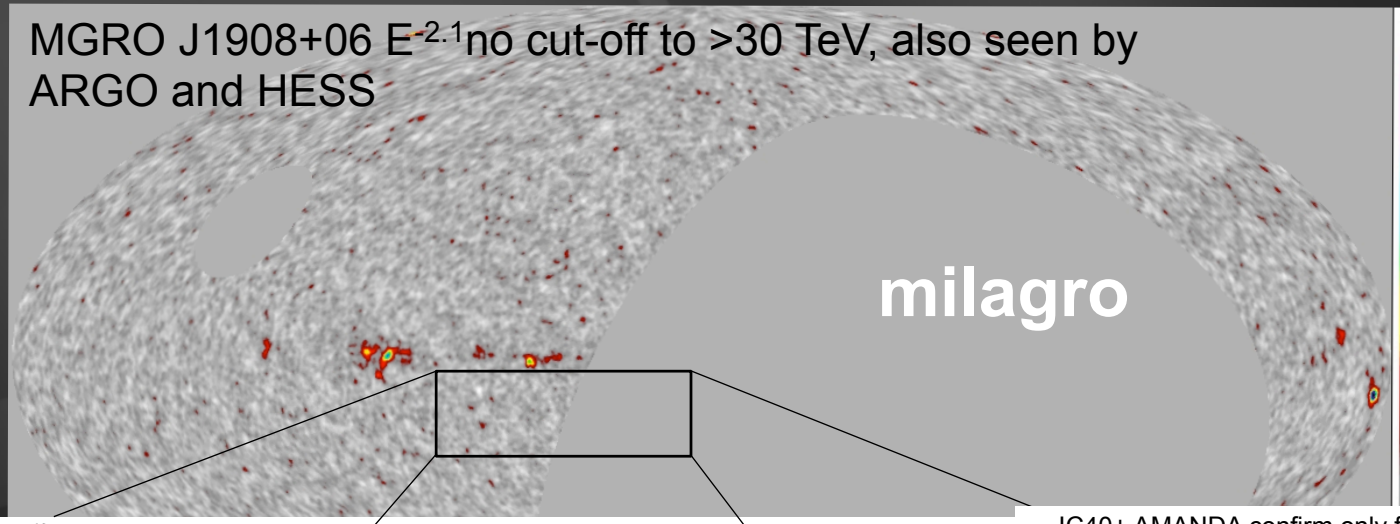


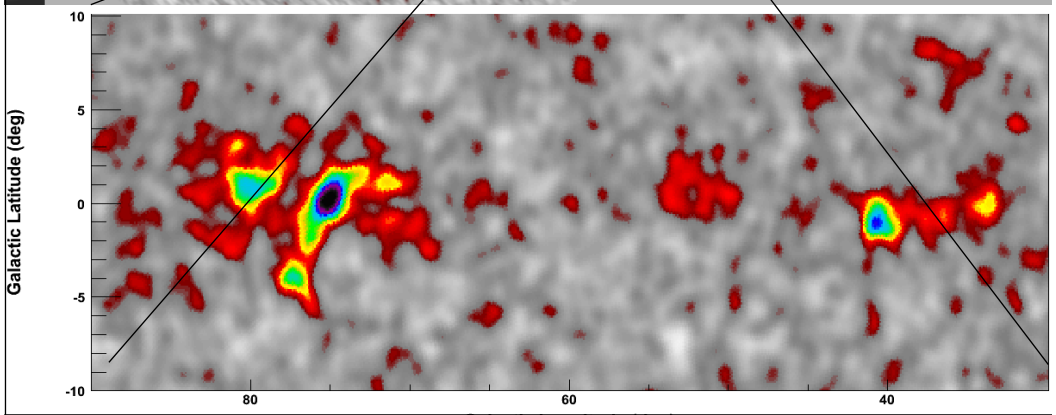
p-gamma is similar through Delta production

Energy and multiplicity in photons and neutrinos is about the same.
Gamma fluxes suppressed by absorption in sources and propagation.
Neutrino Fluxes on Earth suppressed by oscillations.

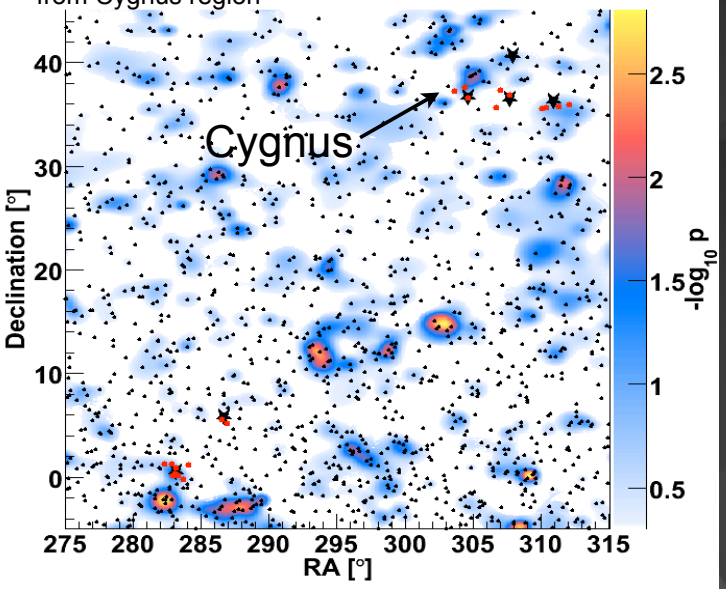
Stacking the Milagro Pevatrons (SNR in molecular clouds)

MGRO J1908+06 $E^{-2.1}$ no cut-off to >30 TeV, also seen by ARGO and HESS





IC40+ AMANDA confirm only fluctuations of background from Cygnus region

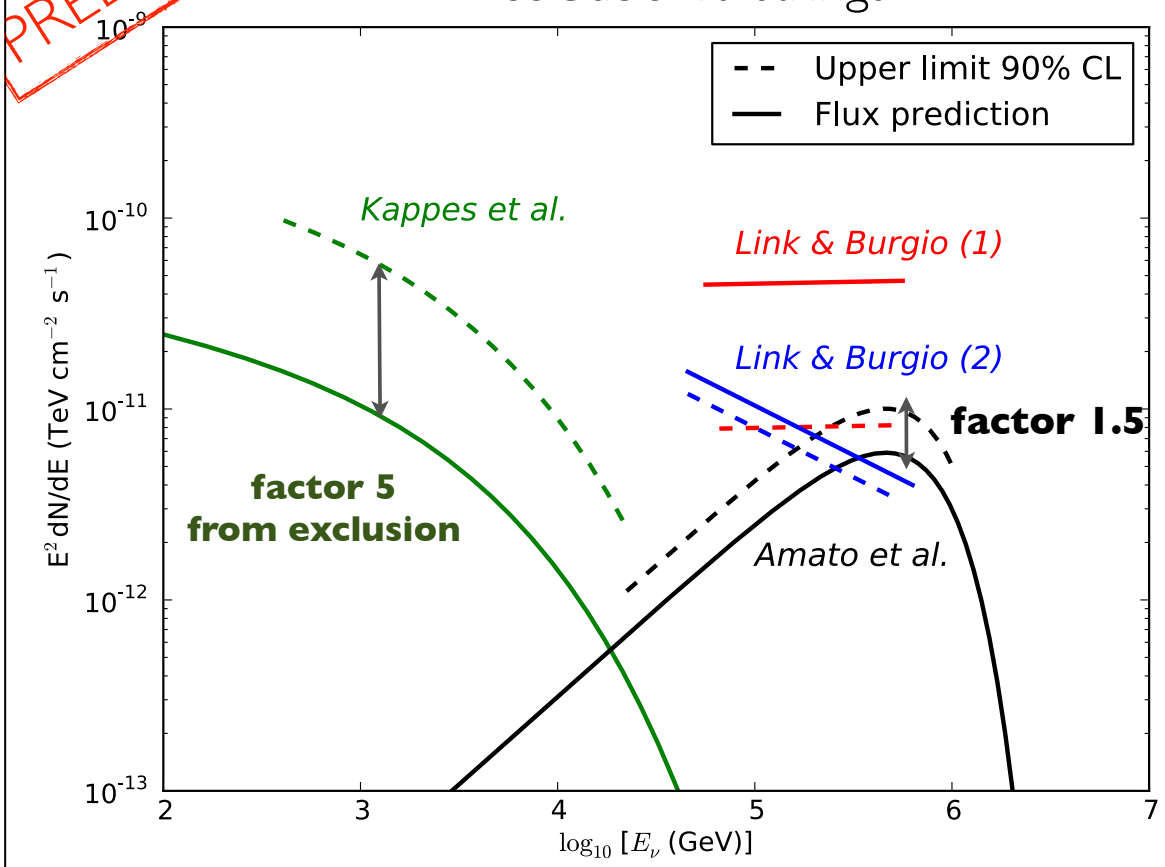


Catalogue	Med Sens	upper limit (90%cl)
6 Milagro SNR	2.9x prediction	7.2 x prediction

Model (Gonzalez-Garcia, Halzen,Mohaptra arXiv:0902.1176): if E^{-2} cut-off at 300 TeV 5σ in 3 yr of IceCube

CRAB (STEADY EMISSION)

PRELIMINARY



probe models assuming significant fraction of spin-down energy into neutrinos from p/ nuclei acceleration.

L&B 2006: ions accelerated to Δ threshold with constant E-field (1) or linearly increasing E-field (2) with height above n star surface. Most optimistic predictions rejected @> 90% cl

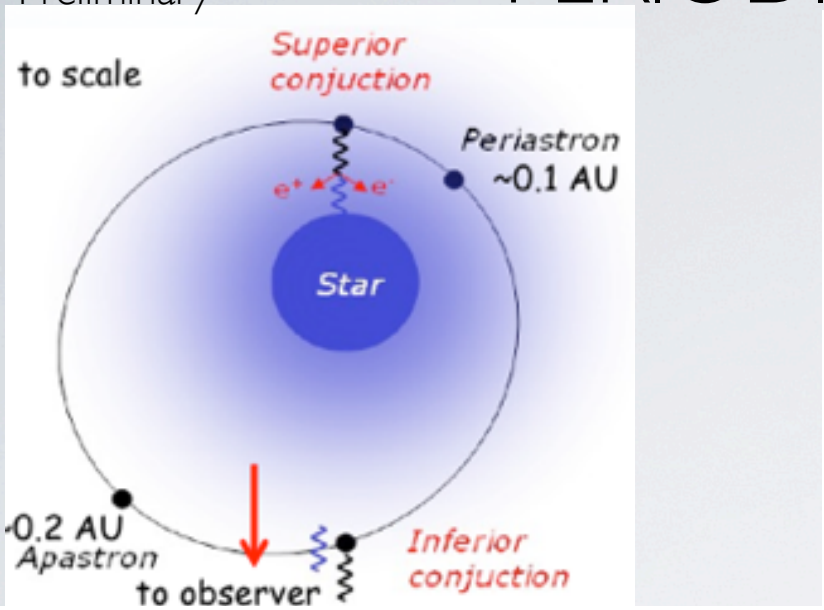
Blasi & Amato 2003: close to exclude most optimistic values of the plerion wind Lorentz factor (10^7) and of effective target density for protons.

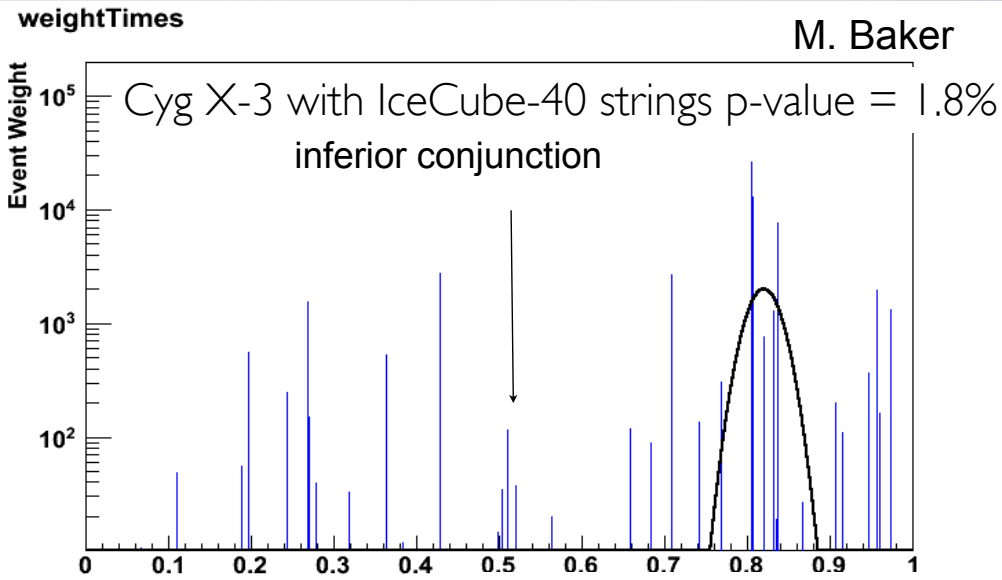
Kappes et al, 2007: protons and fit HESS gamma spectrum

$$\frac{dN_p}{dE_p} = k_p \left(\frac{E_p}{1\,\mathrm{TeV}}\right)^{-\alpha} \exp\left(-\frac{E_p}{\epsilon_p}\right) \quad \Rightarrow \quad \frac{dN_{\gamma/\nu}}{dE_{\gamma/\nu}} \approx k_{\gamma/\nu} \left(\frac{E_{\gamma/\nu}}{1\,\mathrm{TeV}}\right)^{-\Gamma_{\gamma/\nu}} \exp\left(-\sqrt{\frac{E_{\gamma/\nu}}{\epsilon_{\gamma/\nu}}}\right)$$

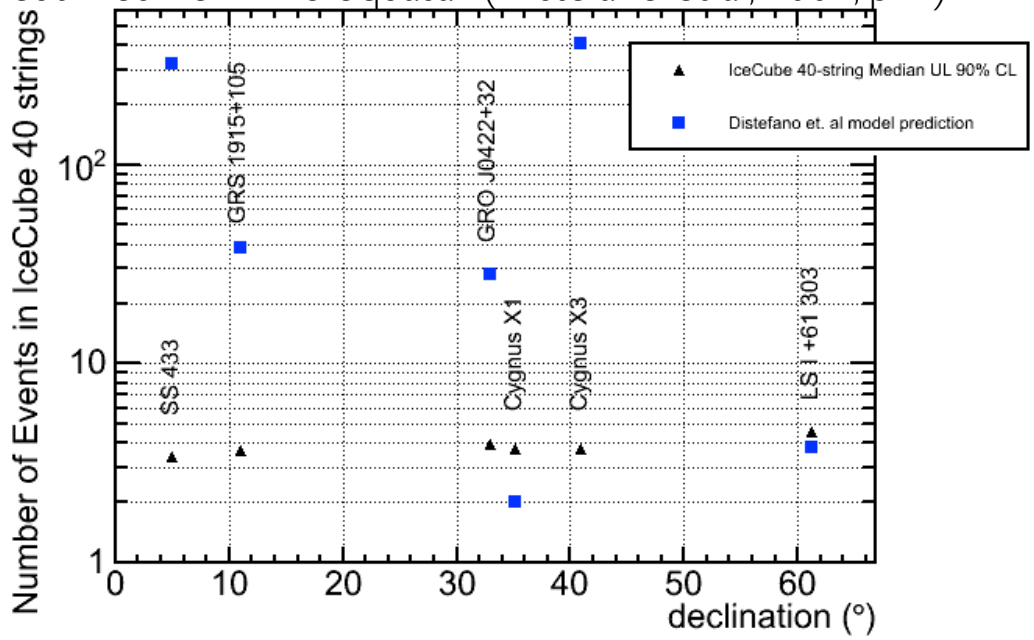
Preliminary

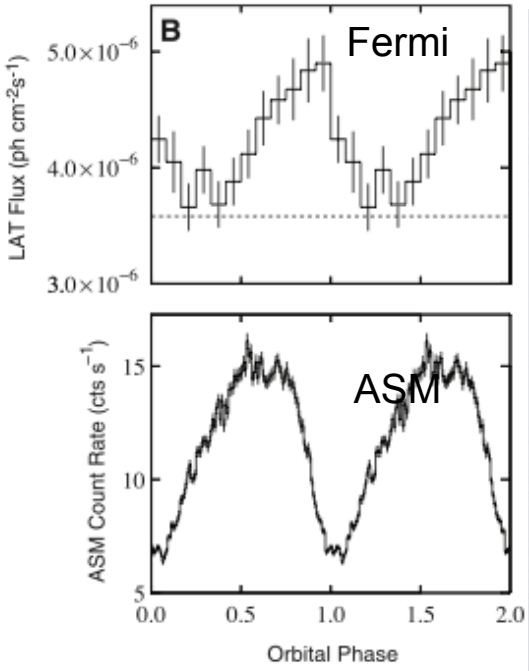
PERIODIC SYSTEMS





Neutrinos from Microquasar (Distefano et al, 2002, p-ϒ)



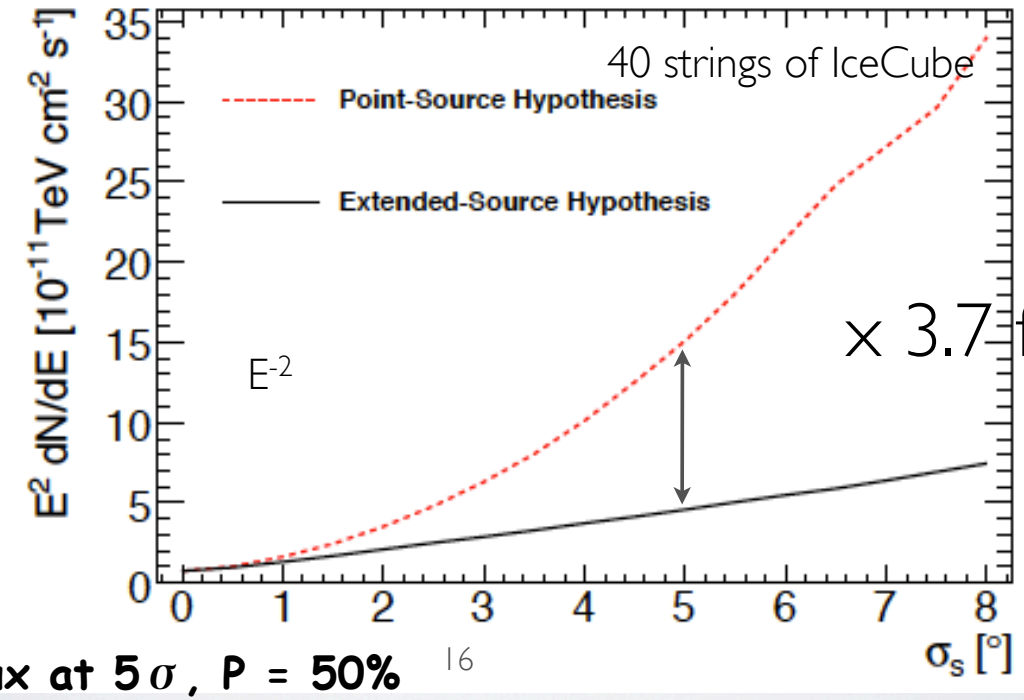


EXTENDED SOURCES OF CRs?

Beyond the myth of the supernova-remnant origin of cosmic rays (Y. Butt Nature 2009)

The origin of Galactic cosmic-ray ions has remained an enigma for almost a century. Although it has generally been thought that they are accelerated in the shock waves associated with powerful supernova explosions ...**we may be on the wrong track altogether in looking for isolated regions of cosmic-ray acceleration.** Possible candidates: superbubbles of O(1,000) SNRs.

J. Dumm

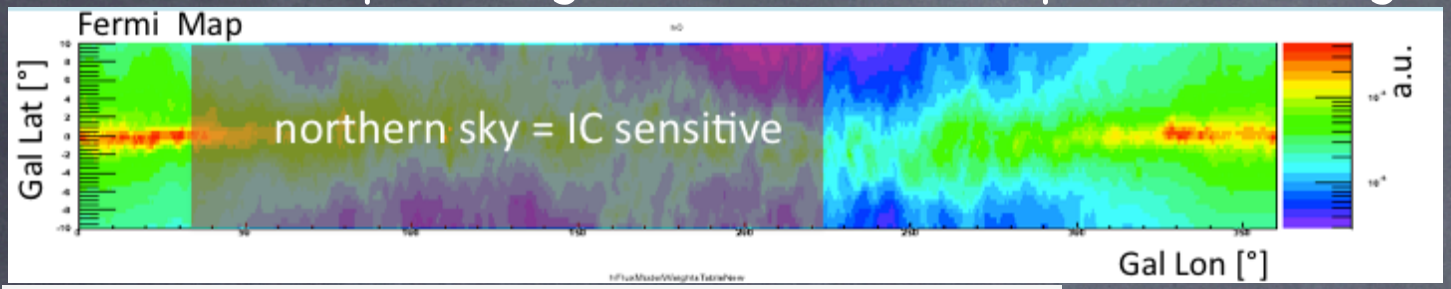


x 3.7 for σ =5°

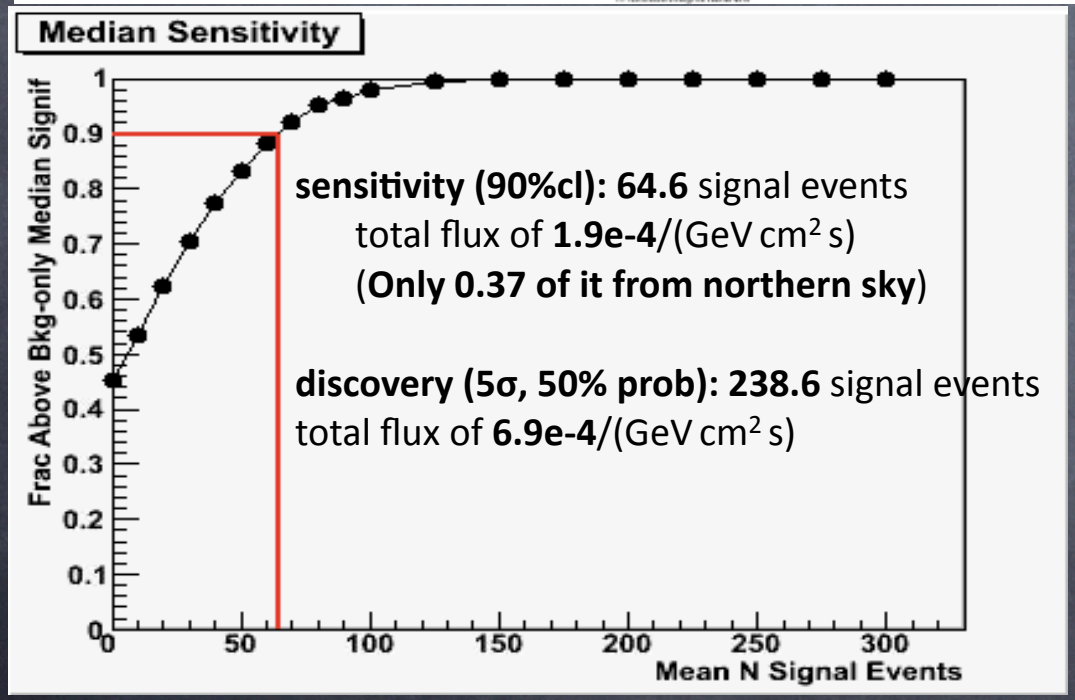
discovery potential flux at 5 σ , P = 50%

The galactic guaranteed source: neutrinos from CR interactions in the Galactic plane

Used model: shape of signal from Fermi maps (65% of signal in 4.4°)



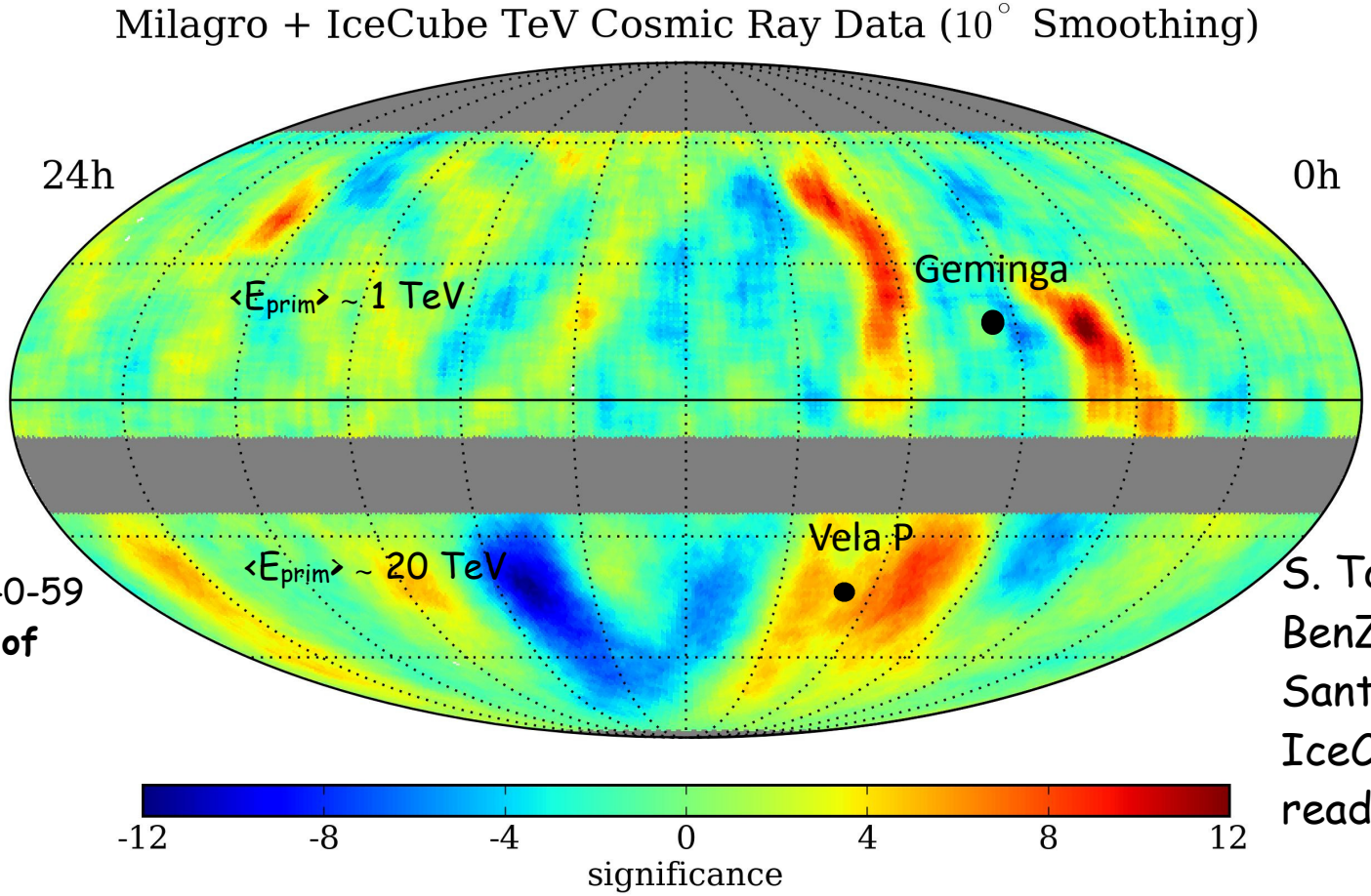
$E^{-2.7}$



Ingelman& Thunman 1996 prediction: 8 events.
x 8 from sensitivity
x 30 from discovery
Warning: the prediction is not up to date. Galprop could easily be modified to produce neutrinos...

A better sensitivity to low energy neutrinos from the Southern hemisphere (IceTop + DeepCore) would greatly improve the sensitivity.

Observation of small scale anisotropies



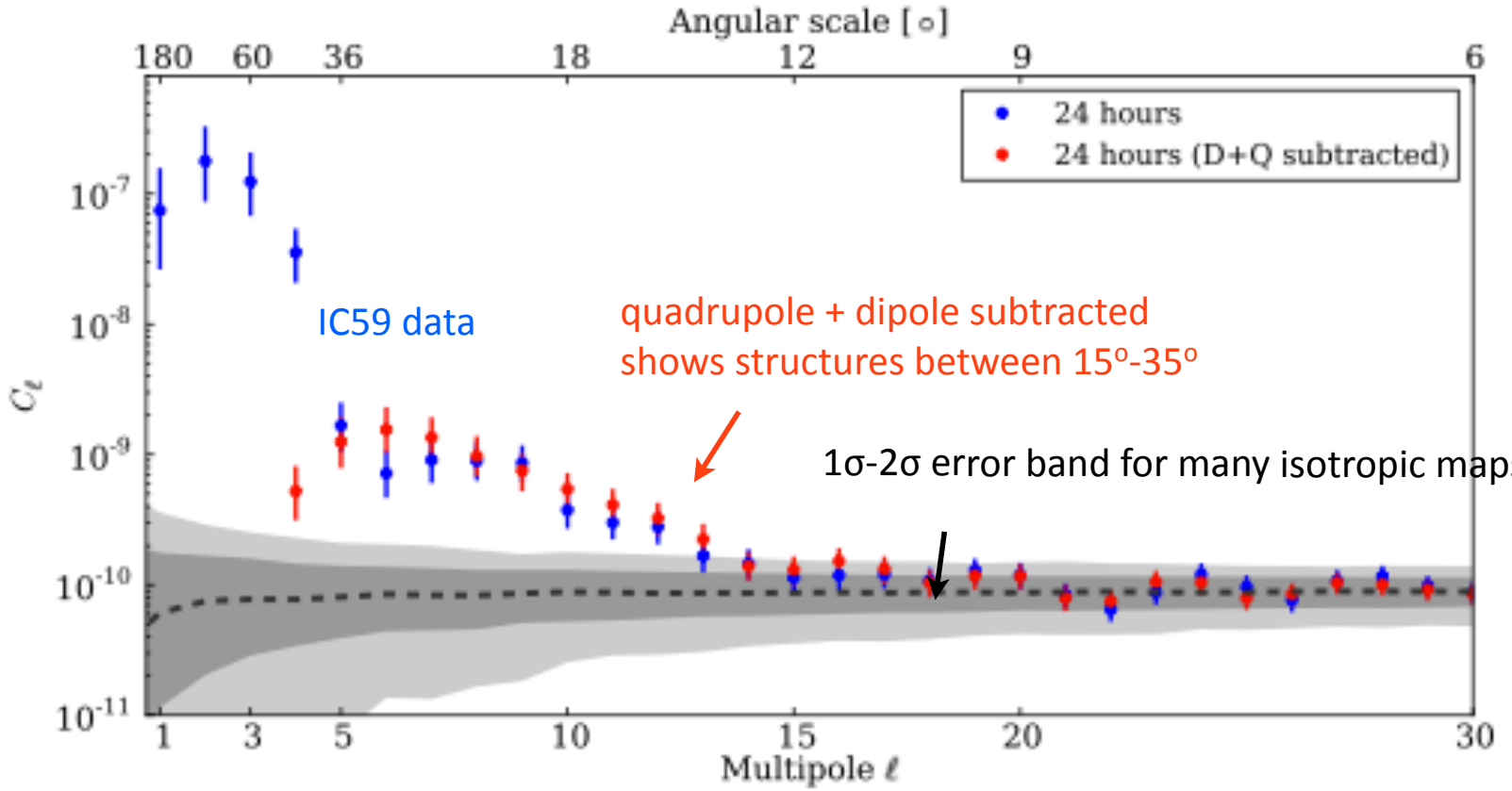
Milagro observed by ARGO too

IceCube 22-40-59 **55.8 billions of muons!**

S. Toscano, S. BenZvi, M. Santander IceCube paper ready

Muons with E > 20 TeV have a gyroradius of less than 0.1 pc. The Vela pulsar is at ~300 pc. Particles may point back to sources only in the presence of unconventional propagation mechanism in B-fields is assumed.

Angular power spectrum



Dependency on time and energy of the anisotropy not yet clear.

UHE neutrinos

- solve the enigma on the drop-off of the UHECR spectrum: is it E_{max} of sources of GZK cut-off?
- p or Fe produce the same spectral shape but Fe would not point back to sources due to the deflection in B-fields
- If UHECR are heavy ⇔ no neutrinos
- If UHECR are heavy ⇔ no anisotropies in UHECR CRs and neutrinos
- If UHECR sources are GRBs, no neutrinos in the direction of UHECR protons because protons take much longer to reach us than neutrinos
- New Physics (x-section beyond the SM and Violation of Lorenz Invariance)

Extragalactic sources of UHECR: GRBs?

Expect almost **15 events** (7 from a tighter cut analysis using T90) in IC59+IC40 for gamma normalized (Guetta et al. 2004) calculations and **25 from Waxman and Bahcall model**, **seen 0!**

What are `tunable' parameters?

1) maybe sources are not only GRBs, but AGNs, magnetars...

2) model is well constrained: flux neutrinos ≈ flux CRs ≈ flux gammas

$p + \gamma \rightarrow n + \pi^+$ $\rightarrow p + \pi^0$

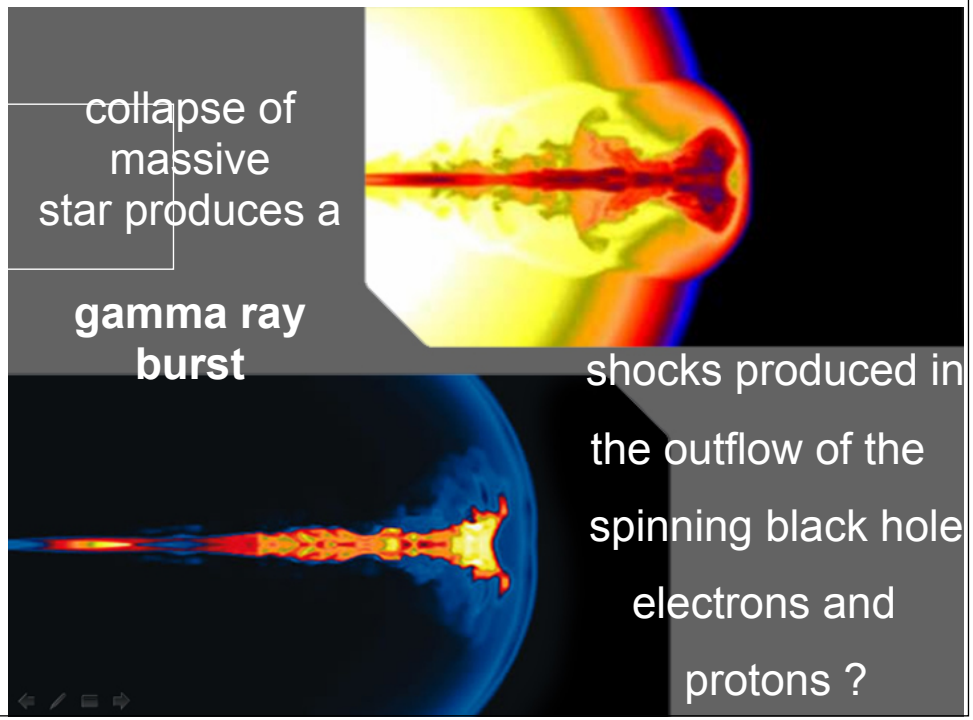
normalize to Fermi diffuse (tricky because gamma cascade and galactic point source flux subtraction)

~ **cosmic ray + neutrino** ~ **cosmic ray + gamma**

normalize to CR spectrum $\gtrsim 10^{18}$ eV

source cosmological evolution

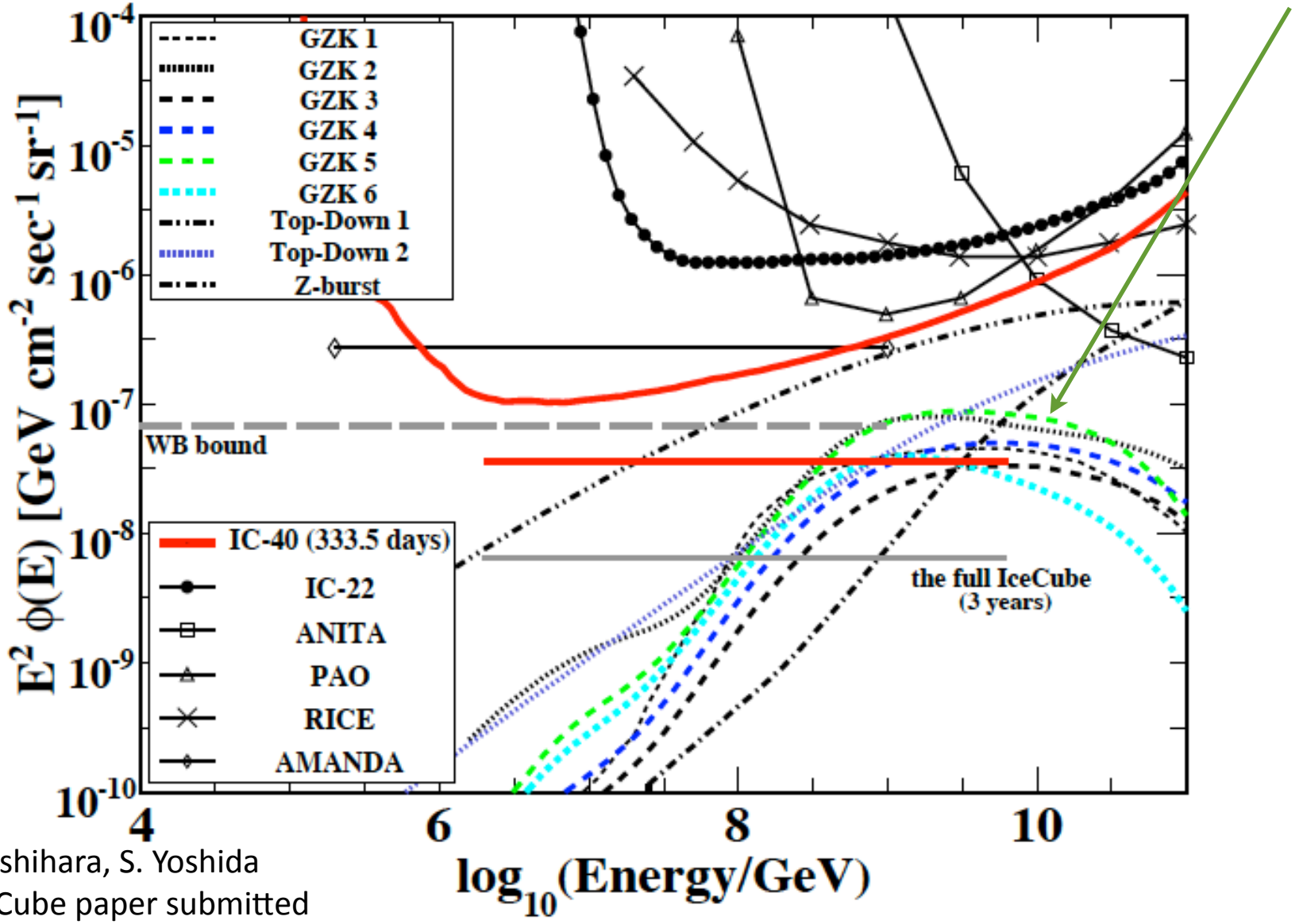
3) Lorenz gamma (assumed 300), fraction of protons in the fireball (assumed 0.1), density that determines proton interactions



Cosmogenic Neutrinos

W&B with cosmological evolution: 24.5 events in IC86/3 yrs (4.5 in IC40)

GZK 5 (M. Ahlers, et al., 2010): 4.8 events in IC86/3 yrs (using constrain from Fermi diffuse gammas)



A. Ishihara, S. Yoshida

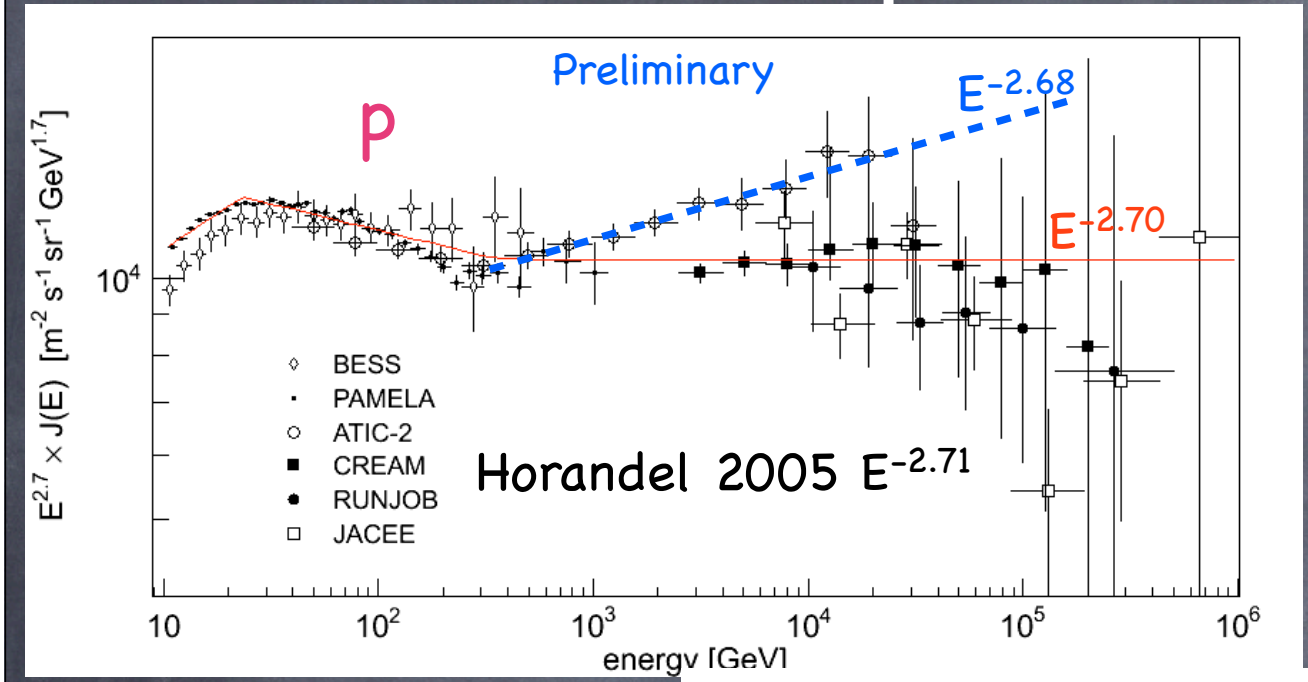
IceCube paper submitted

Detector understanding & systematic errors

Critical for diffuse fluxes (J. Brunner talk) using muons and even more critically cascades

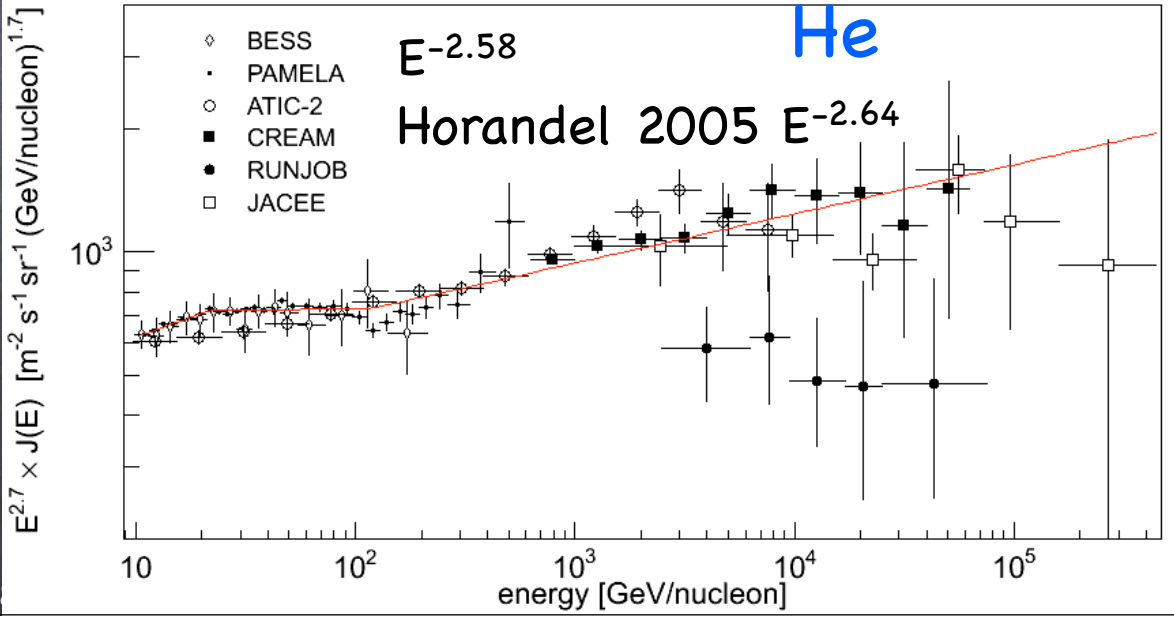
A long list typically summed to a 15-20%

Composition



Fits are unstable due to small errors of Pamela and poor agreement of CREAM and ATIC

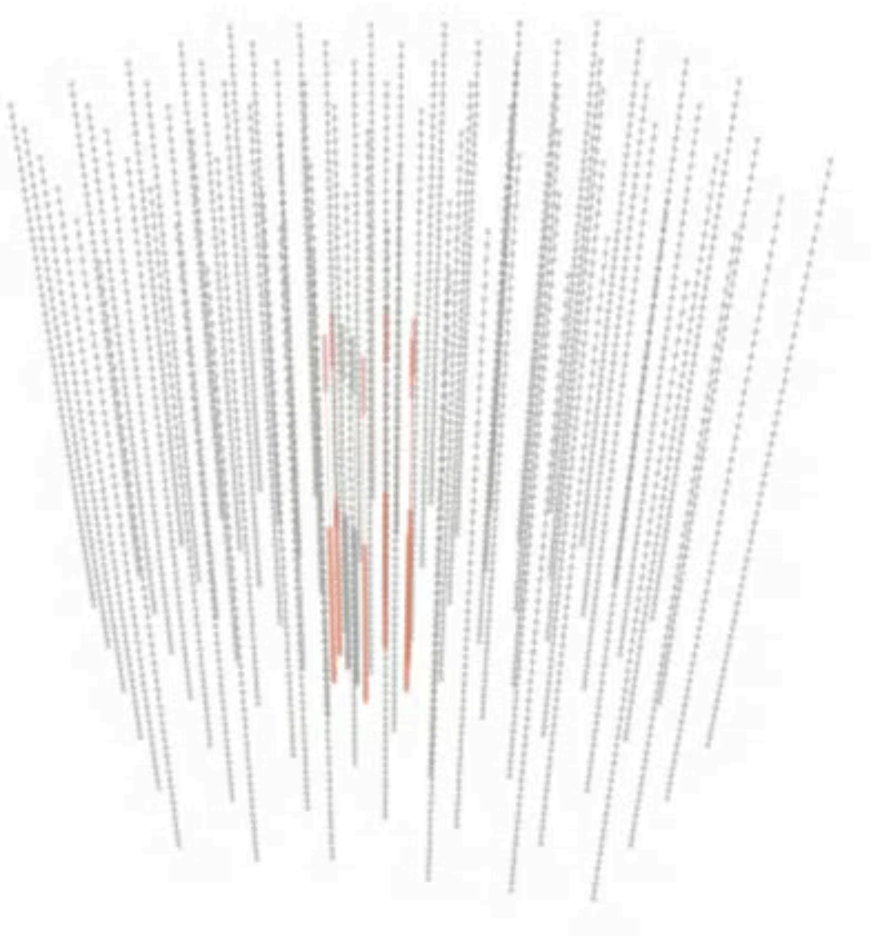
S. BenZvi, TM

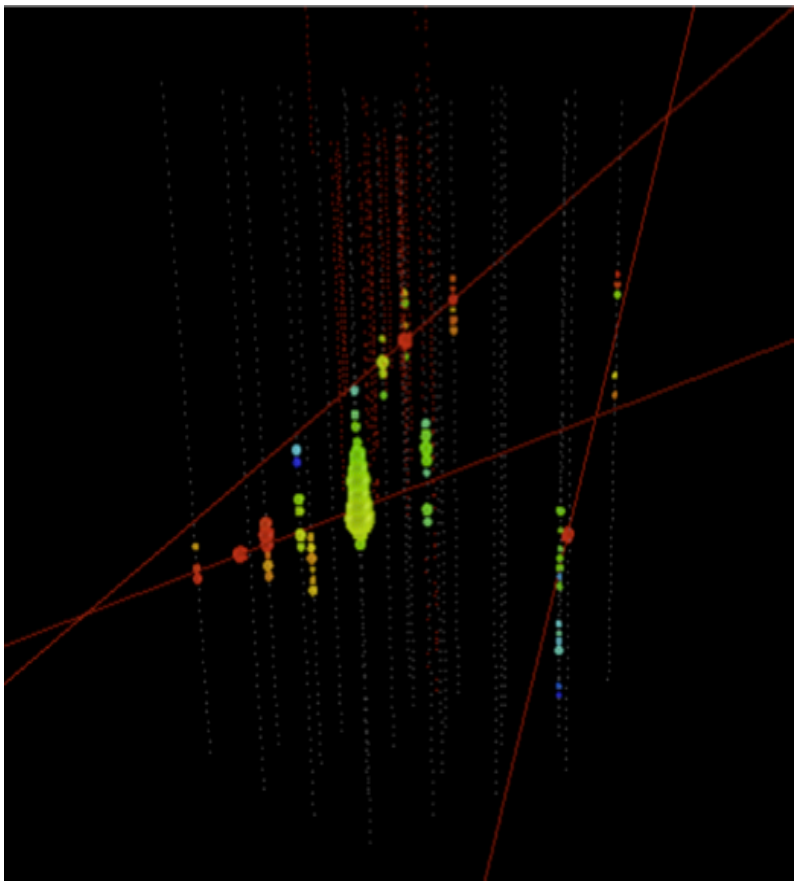


PAMELA, Science, Mar 2011
CREAM, ApJ 2010
ATIC-2 Bulletin of Russian Acc. 2009
BESS-TeV Nucl. Phys B 2007
JACEE Astrop. Phys. 2008

Large detector: 1 readout window ≠ 1 physics event

Topological triggers and Hit cleanings

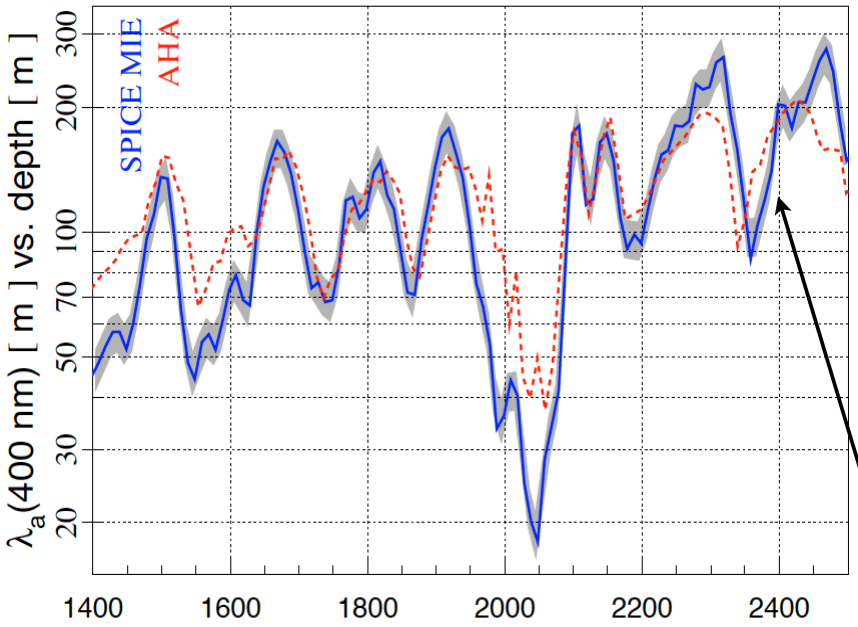




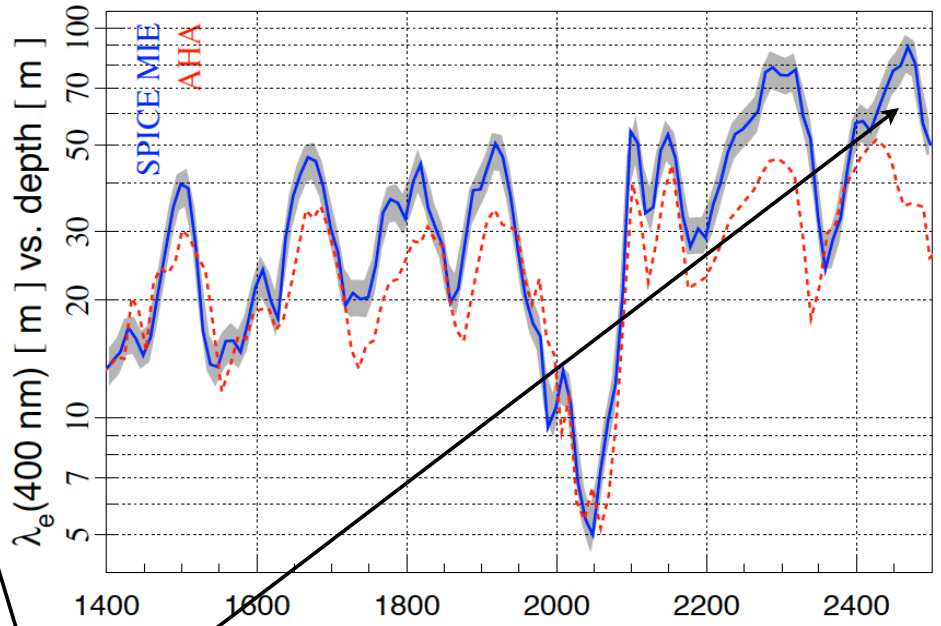
N. Kurahashi, J. van Santen, N. Whitehorn

The optical properties of the medium and calibrations

absorption length



scattering length



at least comparable to water

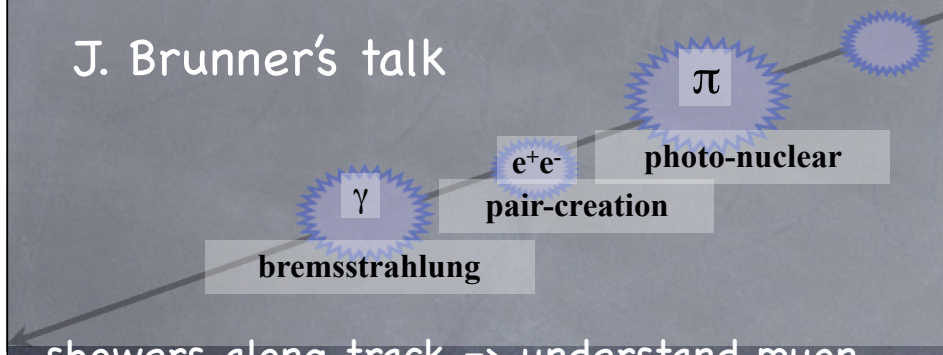
D. Chirkin

Depth dependency of Ice is challenging: use in situ flashers (water is easier - uniform)

calibration tools help establishing the absolute energy scale

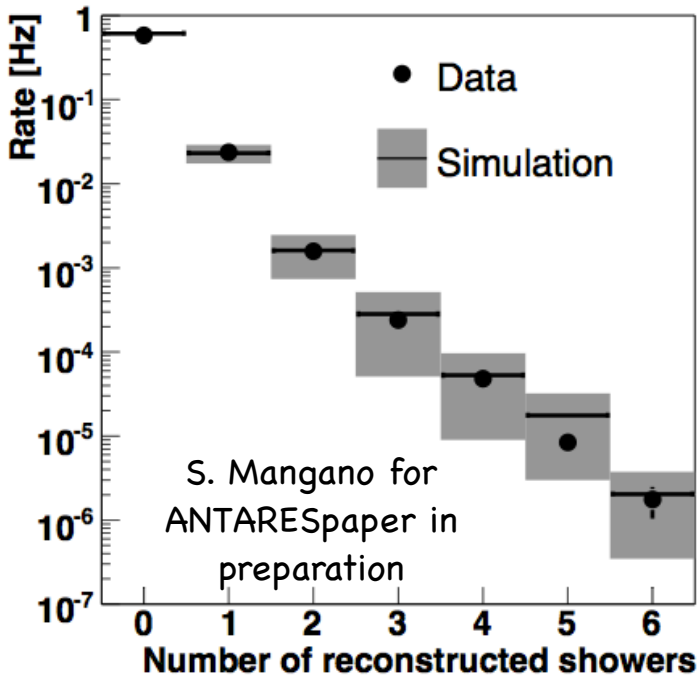
Bckg discrimination and energy estimation

J. Brunner's talk



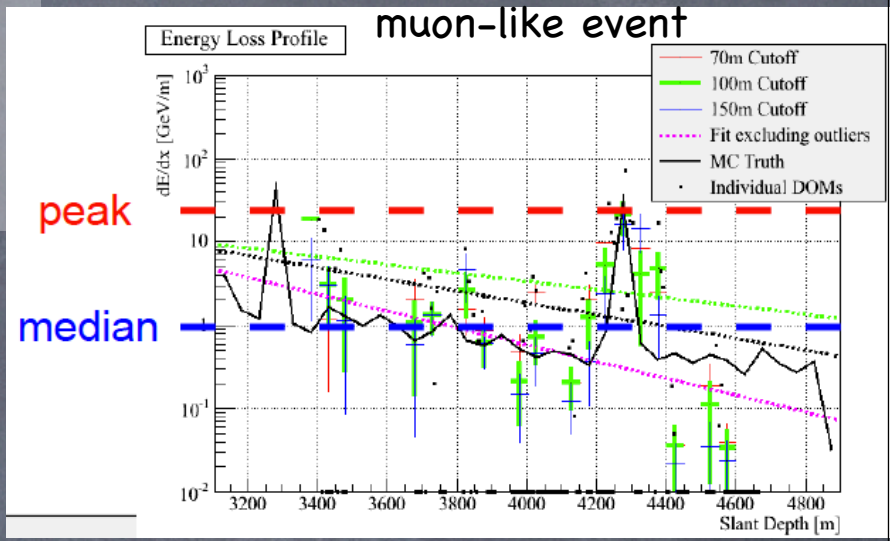
showers along track => understand muon bckg

distinguish γs continuously emitted along track (ionization) from showers

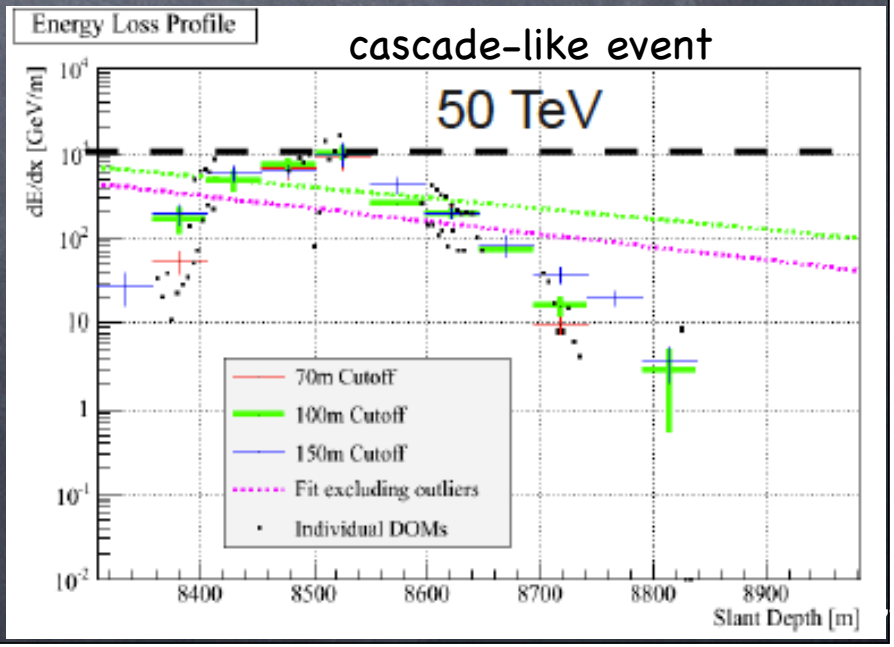


P. Berghaus

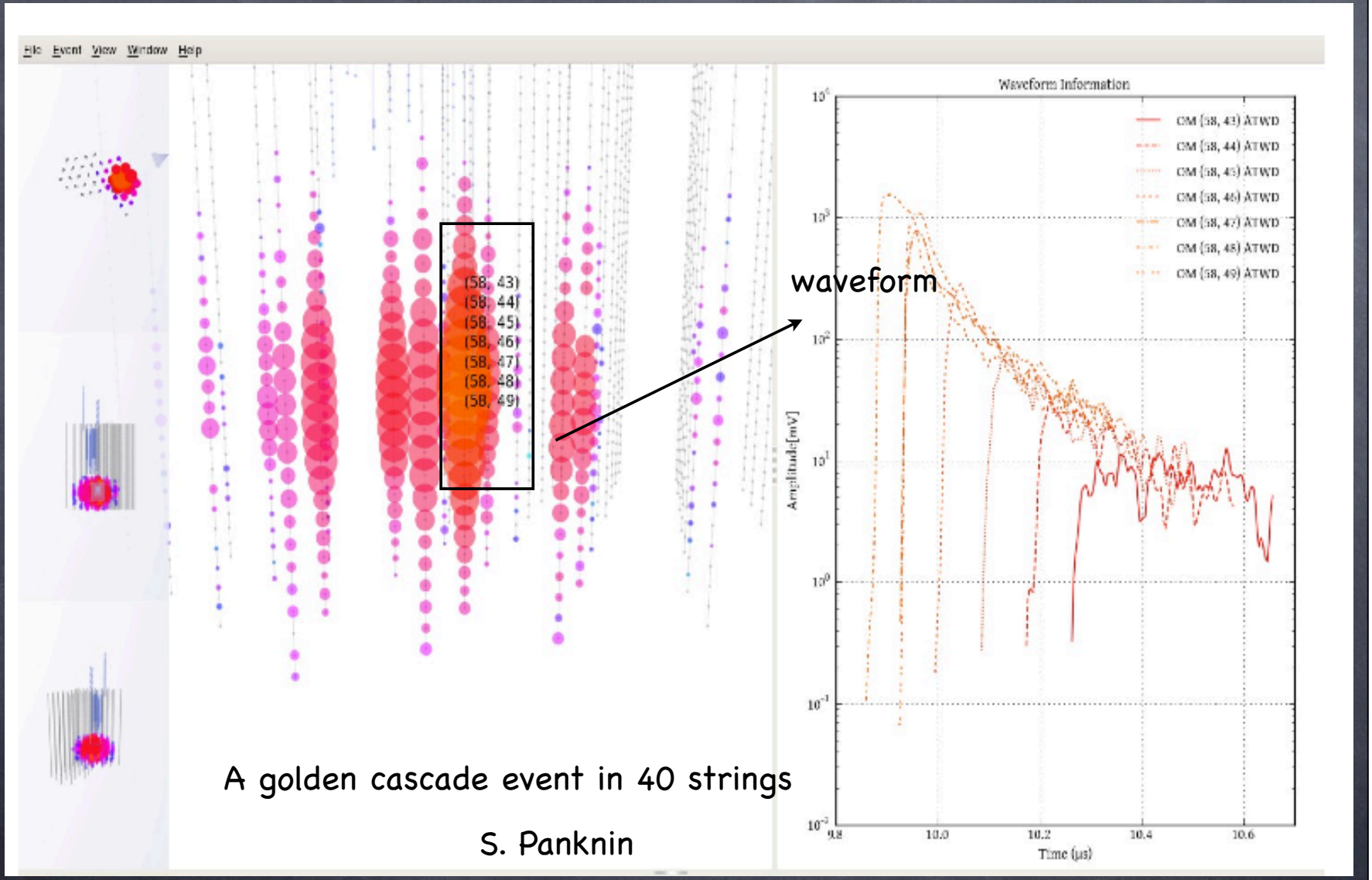
muon-like event



cascade-like event



Waveforms



A golden cascade event in 40 strings

S. Panknin

My Conclusions

A scientific program on **gamma astronomy without neutrino astronomy** is a SHORT-SIGHTED program.

Neutrinos are the **smoking gun** for understanding matter acceleration in the Universe and gammas cannot provide such CLEAR evidence.

A factor **x 100 IceCube** is possible in 1GeV-100 TeV. Easier in a **SITE** were a **VETOED** neutrino astronomy is possible.

`Eyes' of (x1/5-1/10)$ make a giant detector possible.

Veto requires a large **`energy dependent' surface array** + a **deep compact core** that can address **MULTIPLE** topics:

astrophysical sources and galactic plane, oscillations, SN neutrinos, proton decay, long baseline for CP violation.

This would nicely complement an UHECR neutrino radio array 100 km^2

New Photodetectors

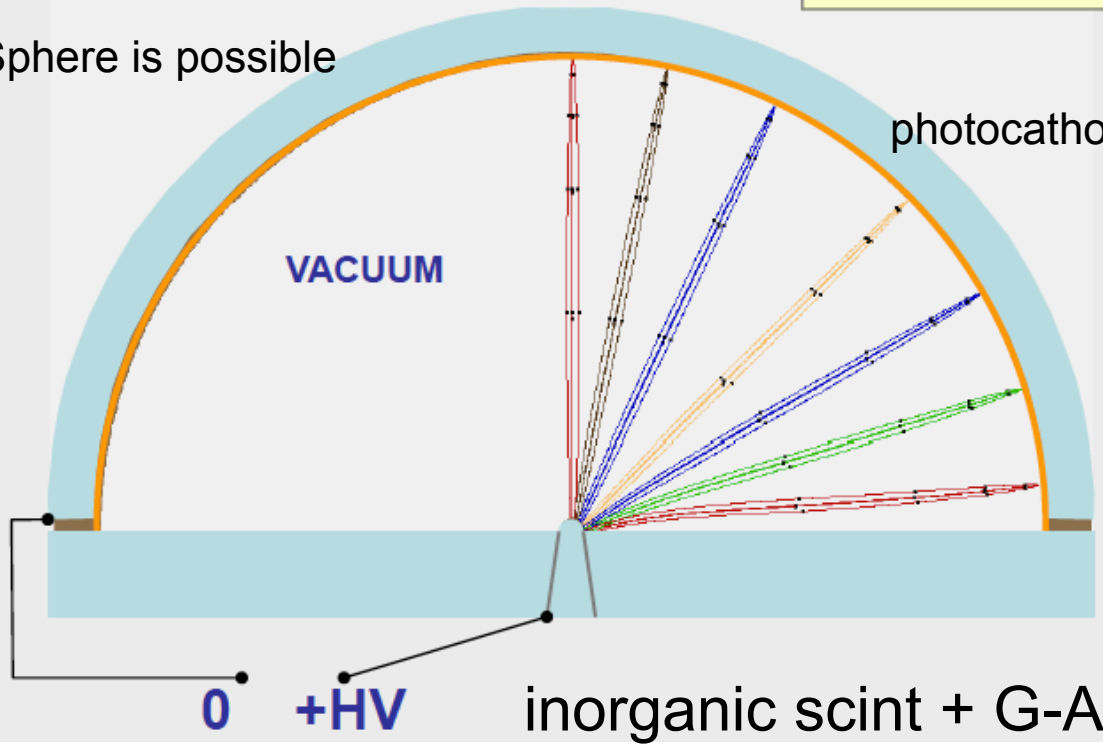
D. Ferenc

ABALONE

- → 5-inch diameter
- → 20 kV
- → 45 deg. angular spread
- → 0.25 eV initial electron energy

Cr-In-Au Vacuum Seals
=
Voltage Feedthroughs

Sphere is possible



inorganic scint + G-APD

Prototype phase started

See KM3NeT talk

17" sphere containing 31 PMT's of 3"