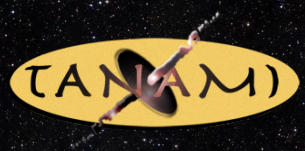

High-Fluence Blazars as Possible PeV Neutrino Sources: Synergies with MeV

(arXiv:1602.02012)

Roopesh Ojha

for the LAT and TANAMI Collaborations

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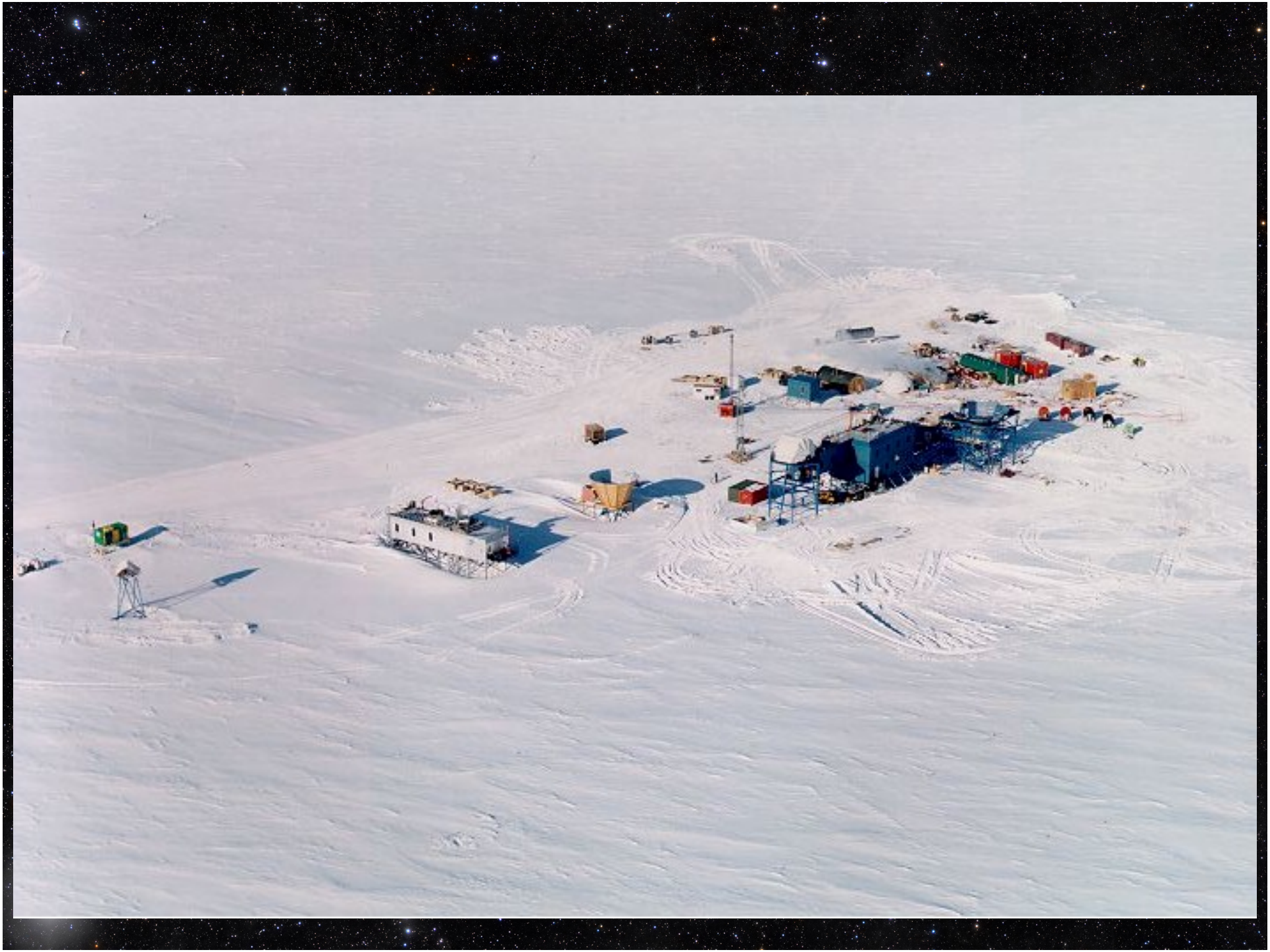
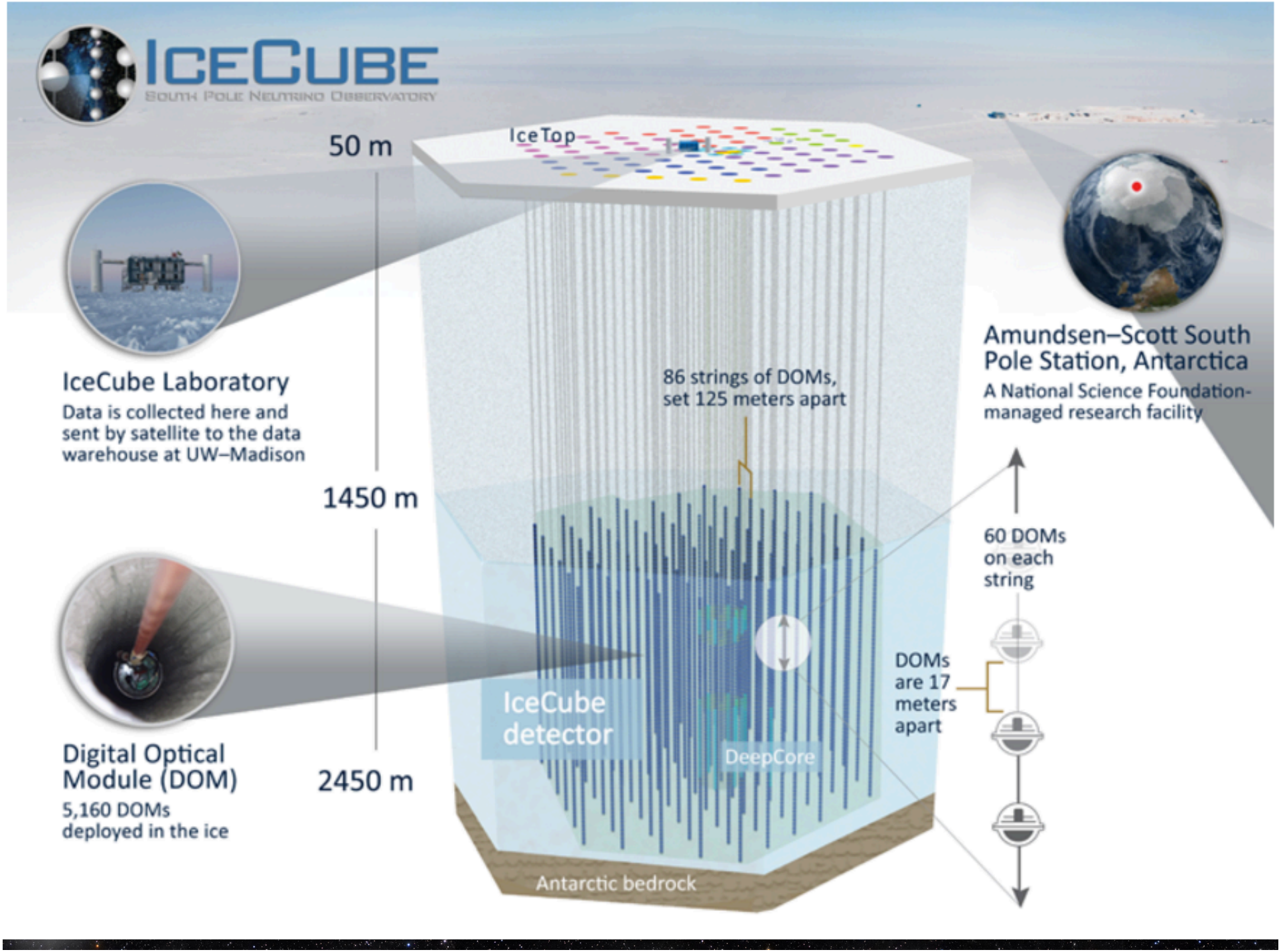
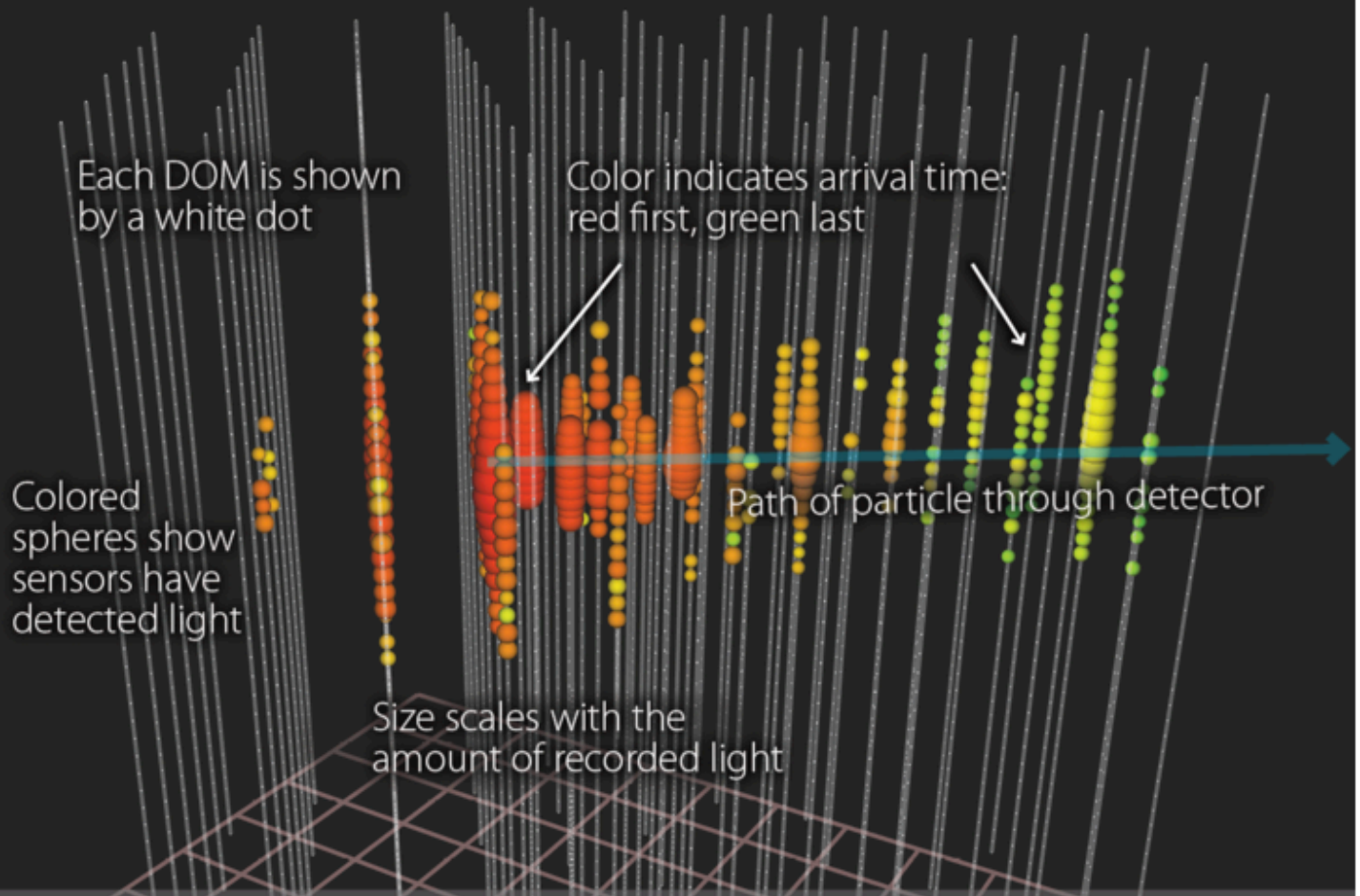



IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
86 strings of DOMs, set 125 meters apart
1450 m
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock

How does IceCube work?

When a neutrino interacts with the Antarctic ice, it creates other particles. In this event graphic, a muon was created that traveled through the detector almost at the speed of light. The pattern and the amount of light recorded by the IceCube sensors indicate the particle's direction and energy.

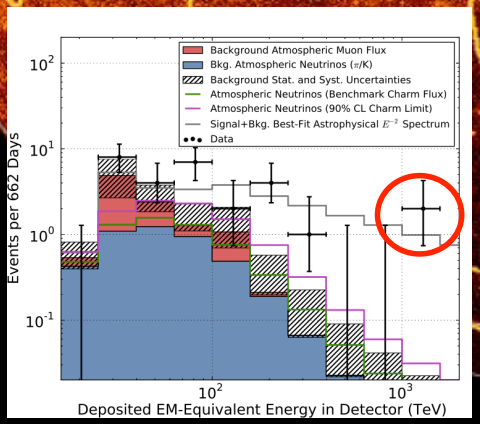


date: **November 12, 2010** duration: **3,800 nanoseconds** energy: **71.4 TeV**
declination: **-0.4°** right ascension: **110°** nickname: **Dr. Strangepork**

Take Home Message

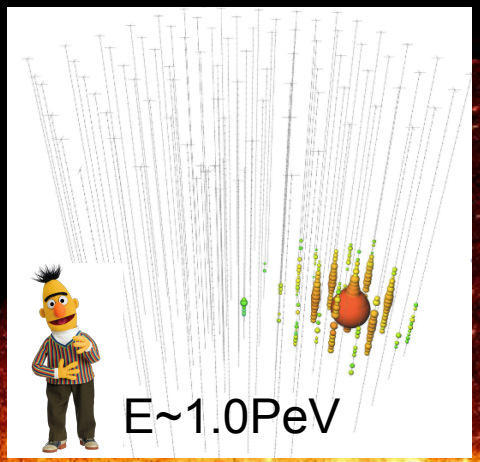
- Integrated flux of FSRQs can explain the IceCube signal
- First time that a single blazar can explain an individual PeV neutrino (~5% chance coincidence)
- The MeV flux is the best proxy for the neutrino flux

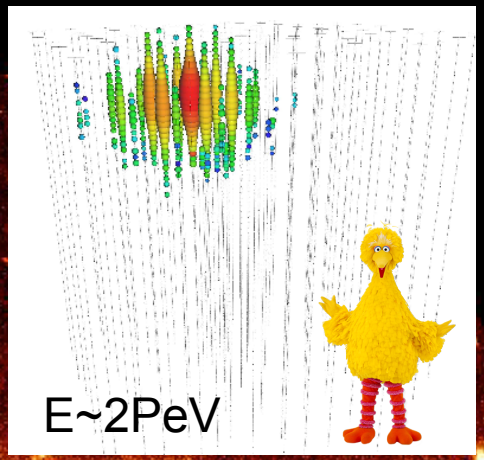
Evidence of High-Energy Extraterrestrial Neutrinos

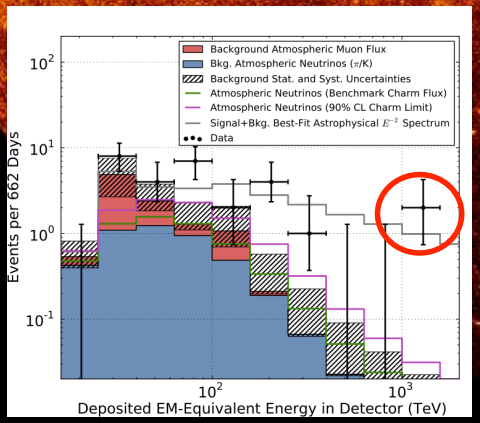


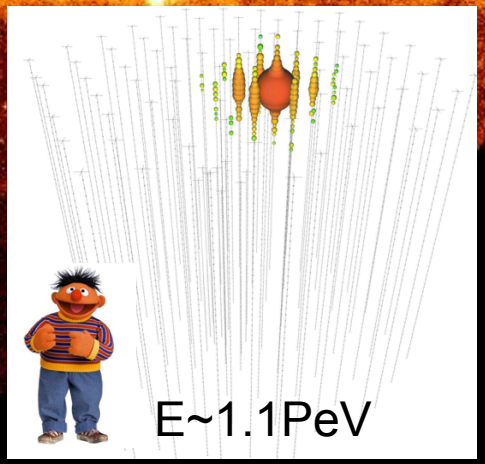
IceCube Collaboration 2013; Aartsen et al. 2014

Strong Signal of PeV-Energy Extraterrestrial Neutrinos



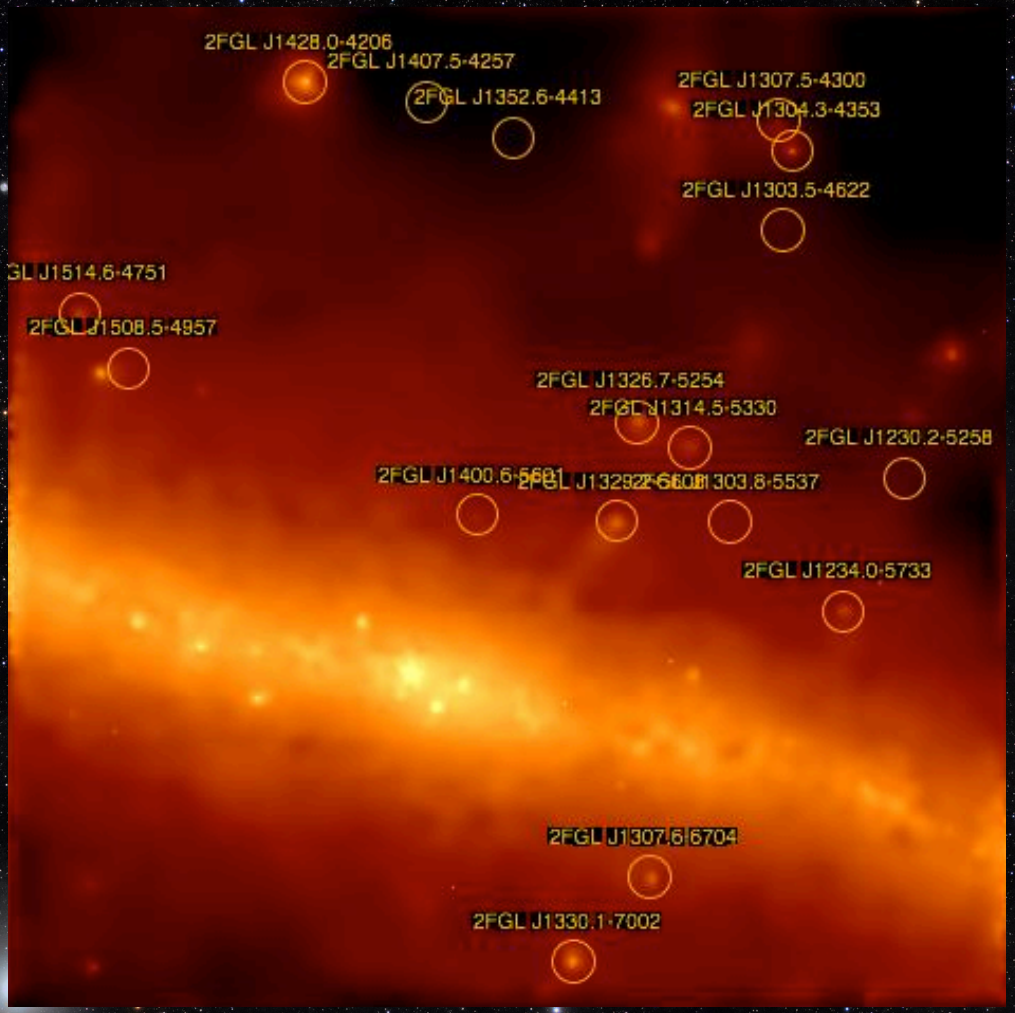






IceCube Collaboration 2013; Aartsen et al. 2014

Astrophysical Sources Inside the PeV-Neutrino Fields



Median pos. uncertainty of 2PeV event: 15.9deg

111 known γ-ray point sources:

- 53 unidentified
- 23 Galactic
- 35 extragalactic

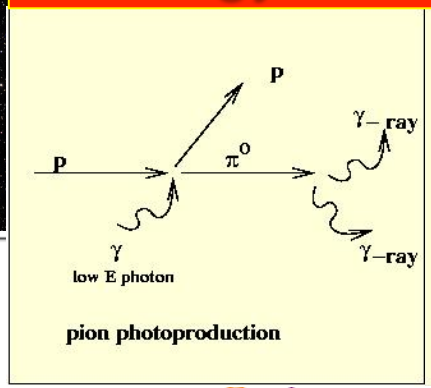
2LAC AGN:

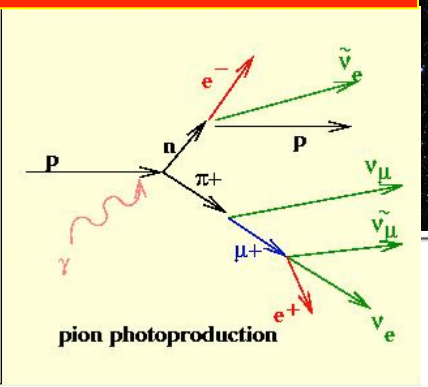
- 1 SB, 2 RGs
- 17 blazars

Basic Model: Photopion Production

Energy threshold: ~2PeV

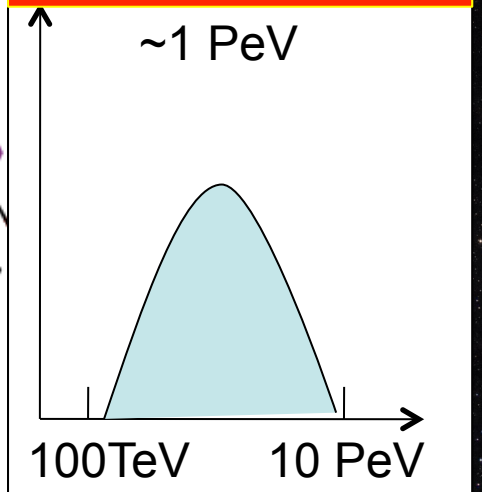
Rel. protons (jet)





Neutrino Spectrum

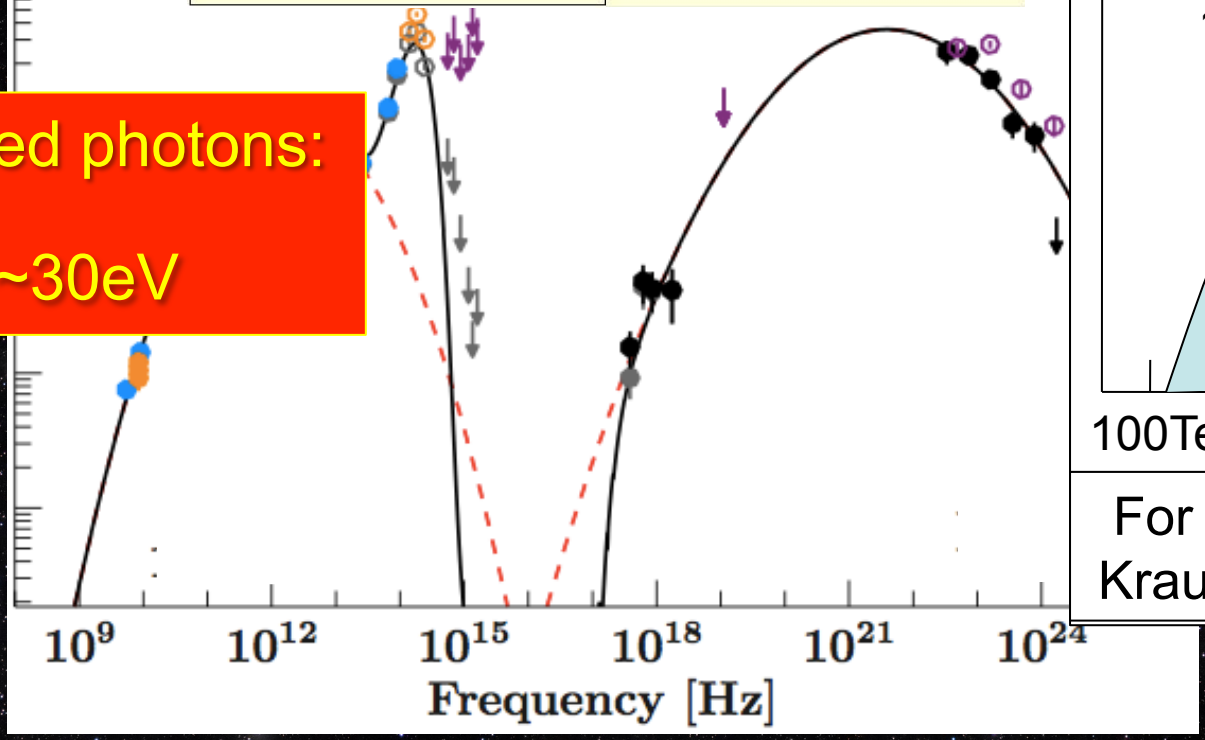
(Γ~10, θ varies)



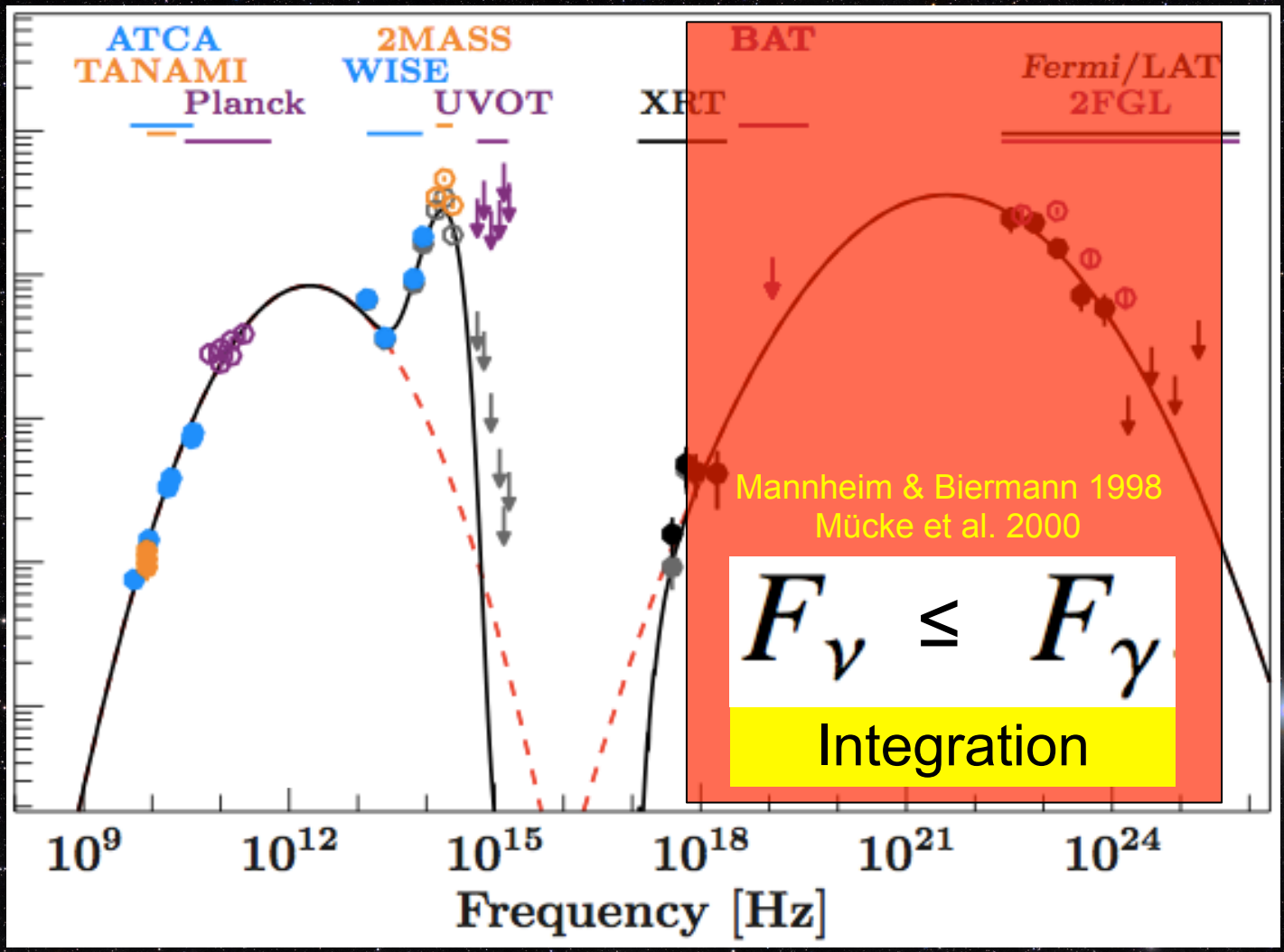
For details, see Krauß et al. 2014

UV seed photons:

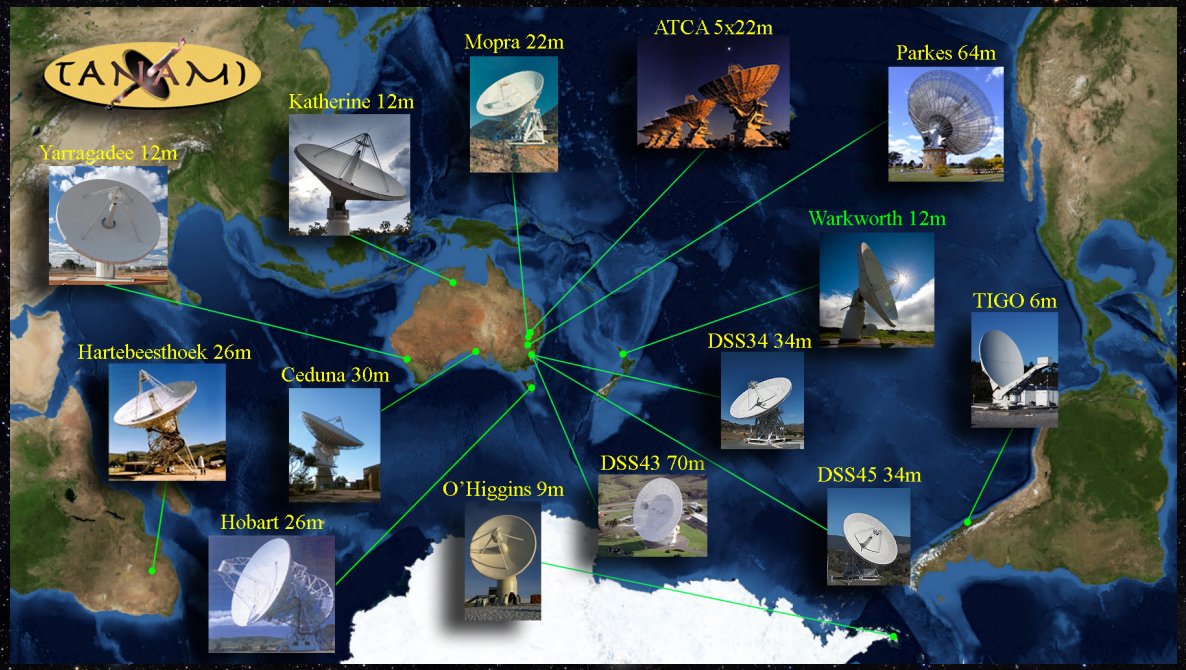
ε~30eV



Maximum Neutrino Output



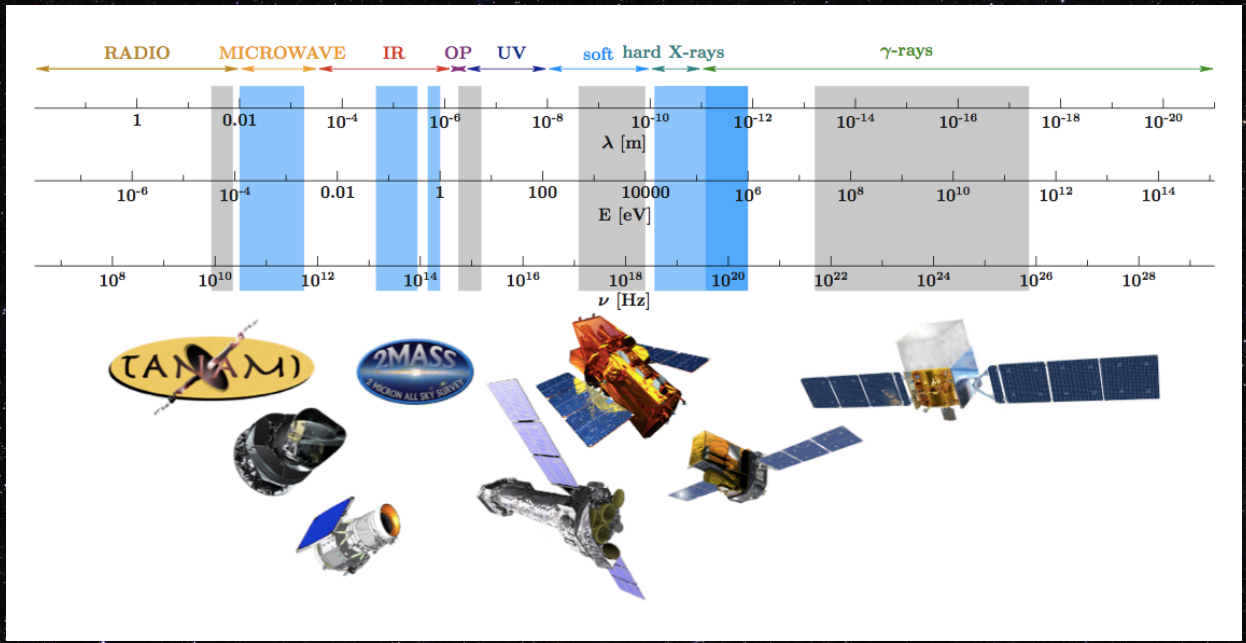
$$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = A_{\mathrm{eff},\nu_e} \cdot \left(\frac{F_\gamma}{E_\nu}\right) \cdot \Delta t$$ ➔ need high-fluence!



TANAMI

Multiwavelength Monitoring of ~90 AGN Jets South of -30°

Includes the radio- and γ-ray brightest AGN in the IceCube PeV neutrino fields



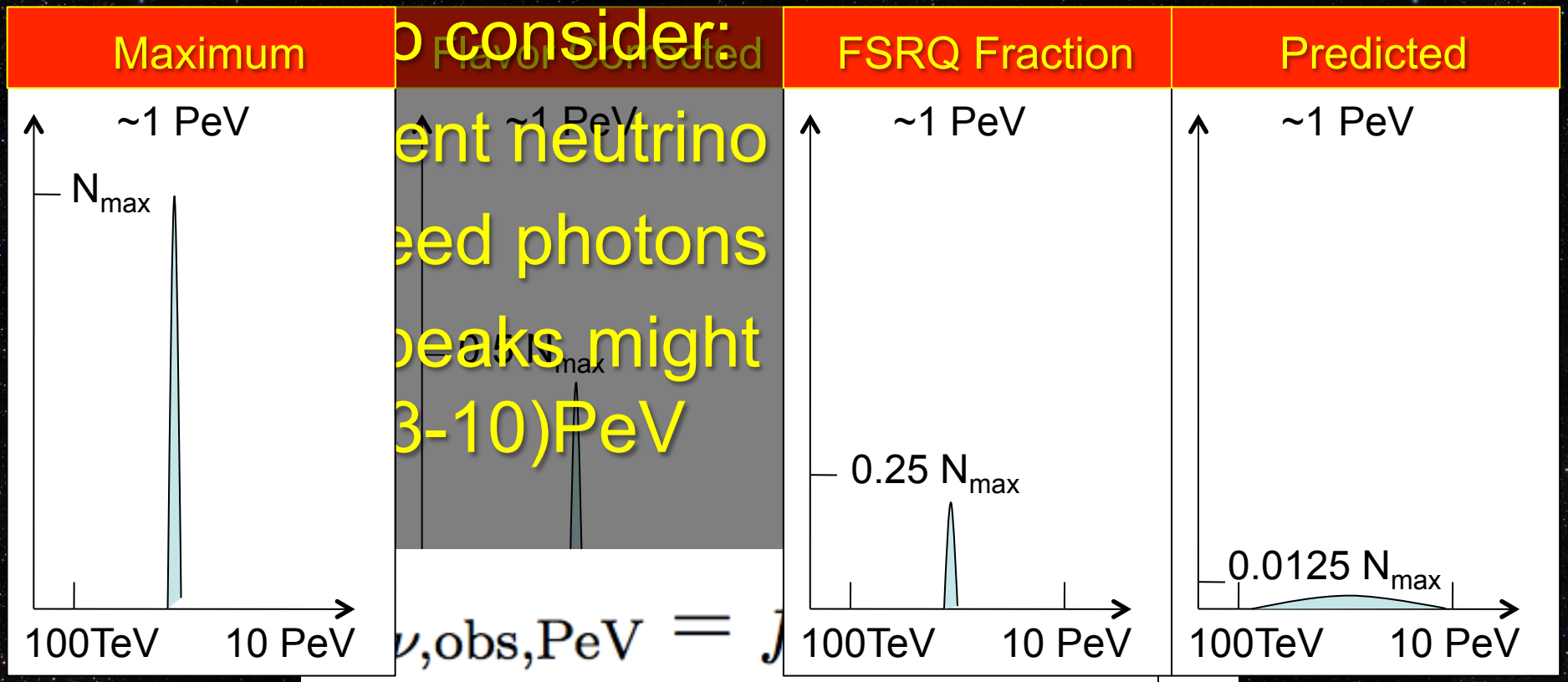
R50 confidence region of HESE-35 (BigBird)

- Median pos. uncertainty: 15.9deg
  ⇒ 17 gamma blazars (2LAC) + EGB
- Compiled and integrated all SEDs
  - Prediction: 13 events
- Use this field to determine empirical scaling factor:

$$N_{\nu,\,\mathrm{PeV}}^{\mathrm{max}}(2\pi) = 13 \cdot \frac{2\pi}{\Omega_{\mathrm{IC\,35}}} \sim 336$$

$$f_{\mathrm{emp}} = \frac{N_{\nu,\,\mathrm{PeV}}^{\mathrm{obs}}(2\pi)}{N_{\nu,\,\mathrm{PeV}}^{\mathrm{max}}(2\pi)} \sim \frac{3}{336} \sim 0.009$$

Theoretical Scaling Factor



o consider:

ent neutrino

eed photons

peaks might

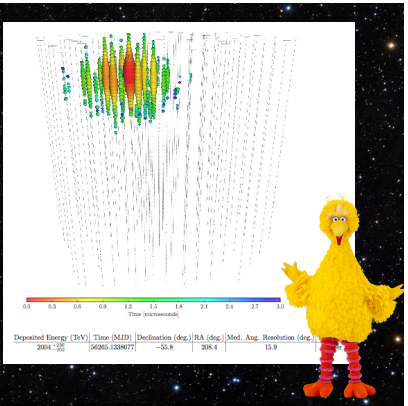
3-10)PeV

$\nu,\mathrm{obs,PeV} = j$

$$f_{\mathrm{th}}\, f_{\mathrm{th}} = 0.5 \cdot 0.5\,).05 \sim 0.0125$$

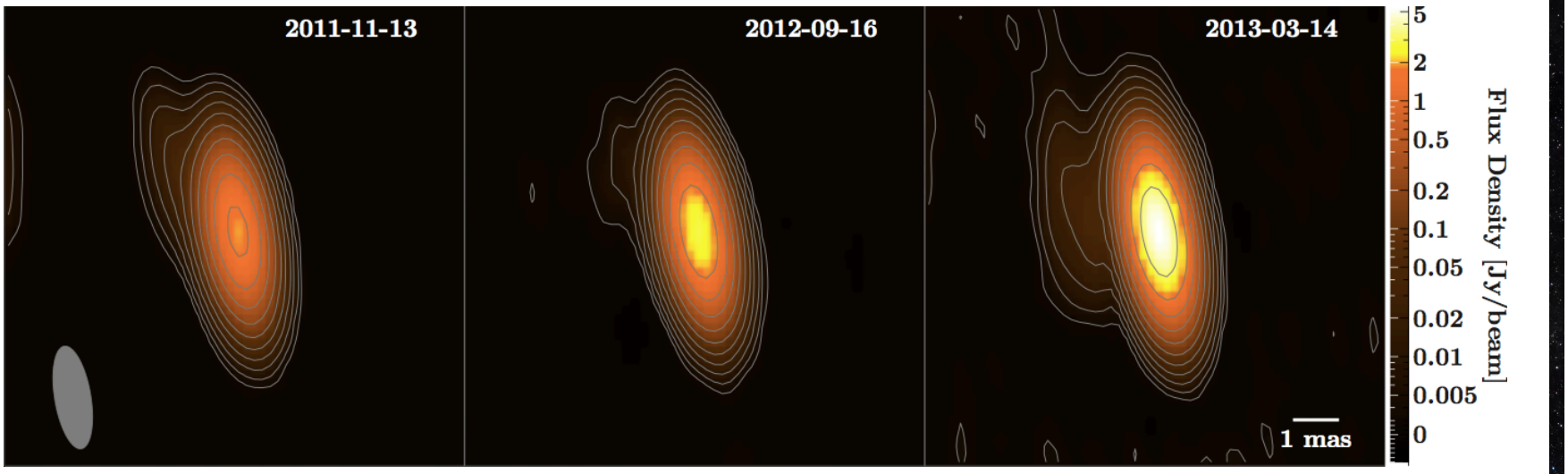
Calorimetric Output in BigBird field dominated by a single source:

PKS B1424-418



Major Radio Outburst:

- Radio core flux density increased from 1.5Jy to 6Jy in late 2012 to early 2013
- Strongest outburst ever seen by TANAMI



Calorimetric Output in BigBird field dominated by a single source:

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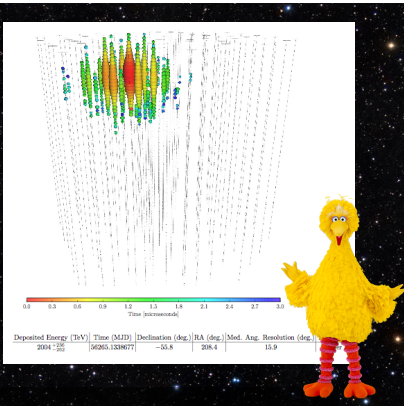
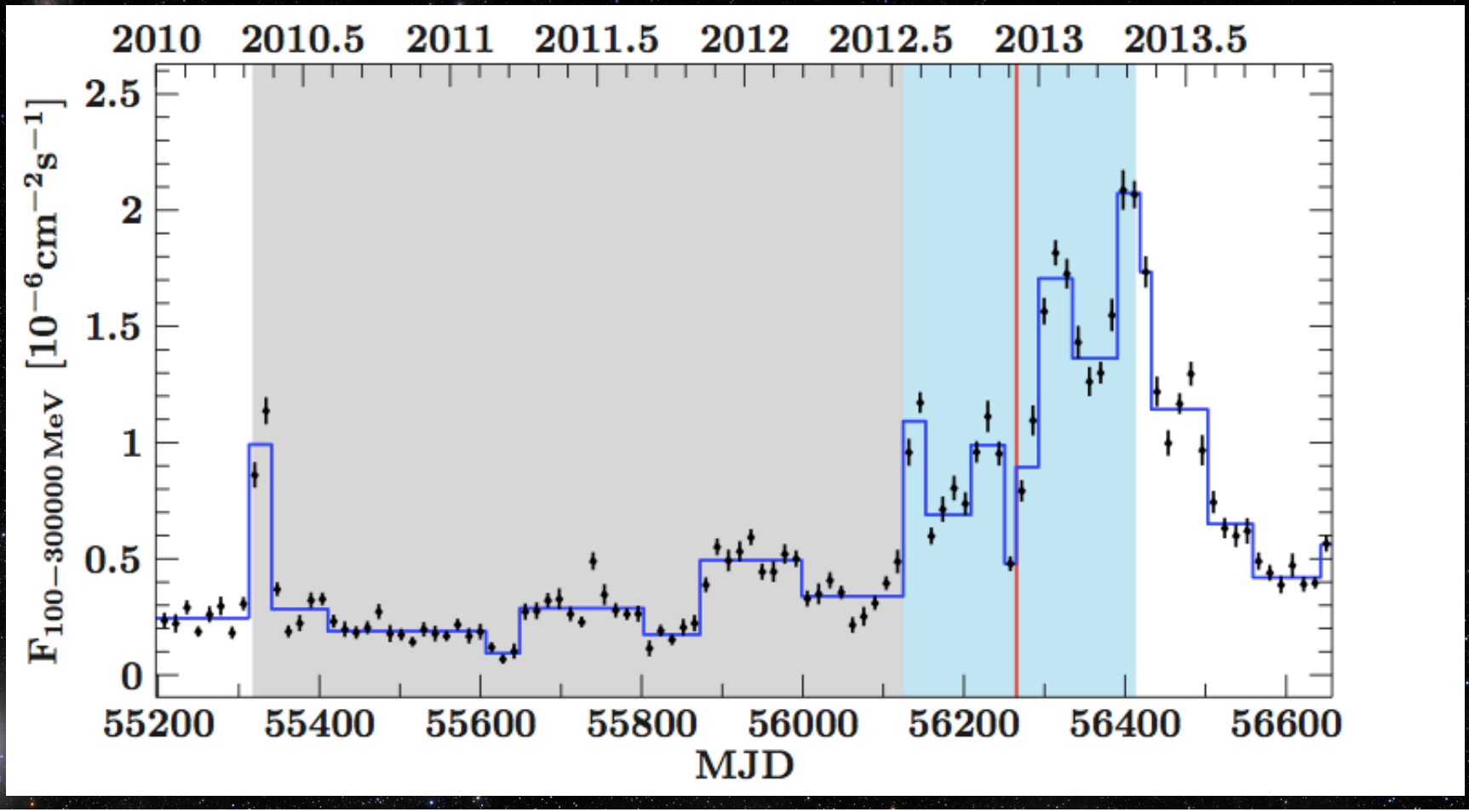
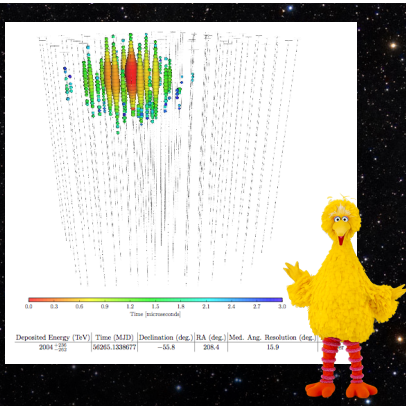


Gamma Outburst coincident with BigBird arrival time

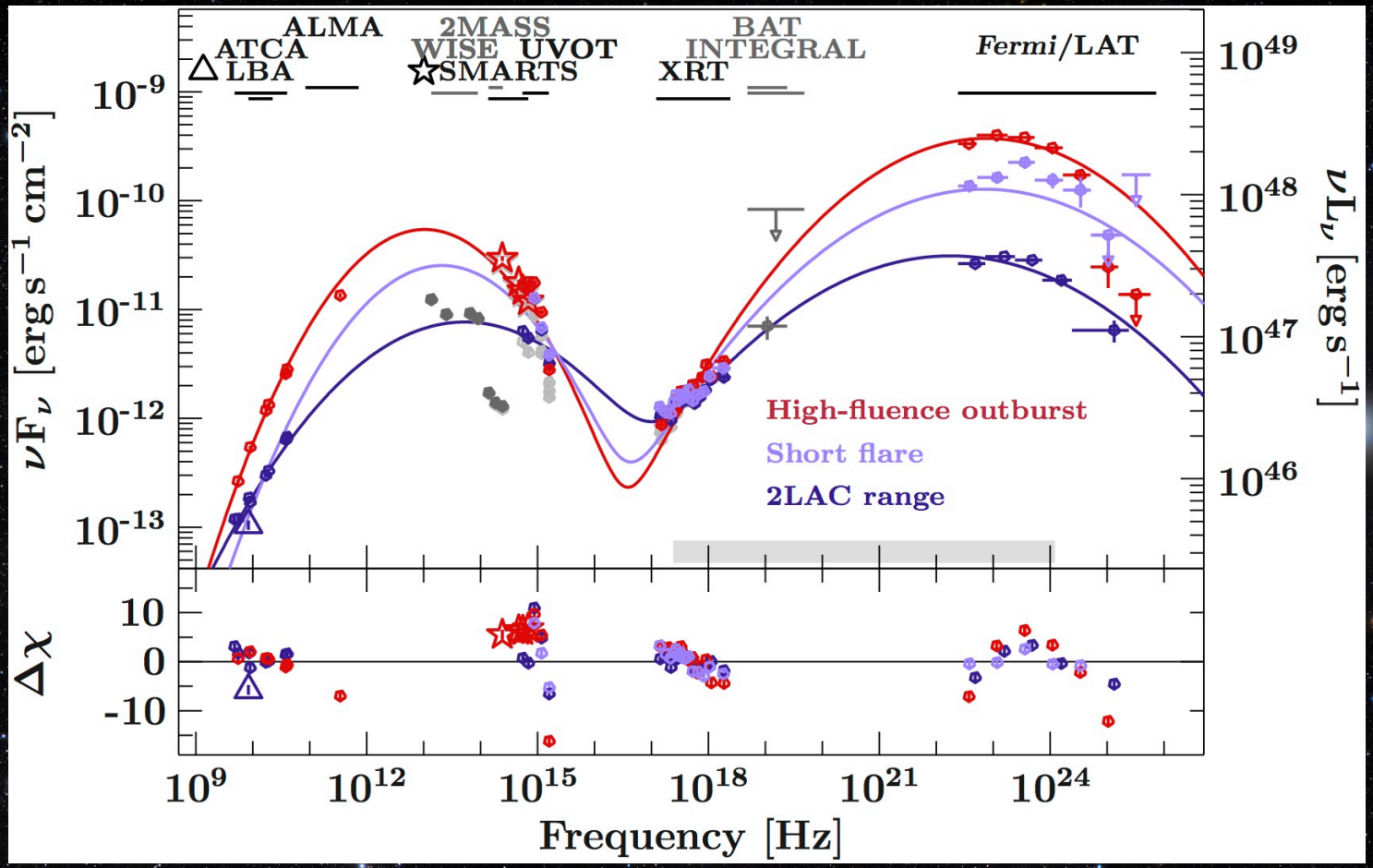


Calorimetric Output in BigBird field dominated by a single source:

PKS B1424-418

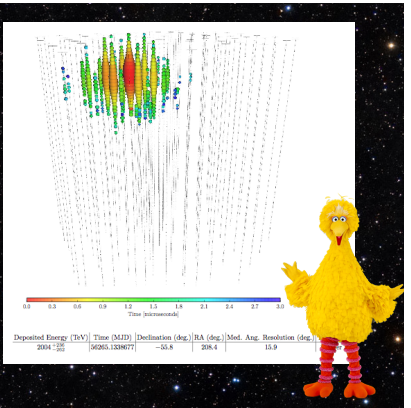


SED: High state over months ➔ High fluence



Calorimetric Output in BigBird field dominated by a single source:

PKS B1424-418



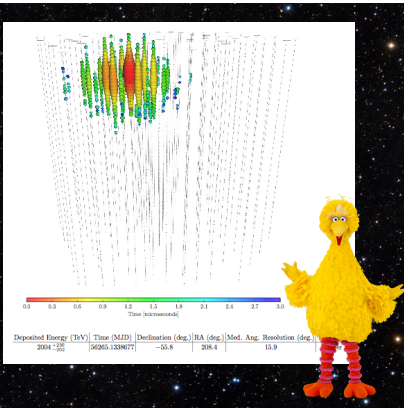
9-month outburst yields highest predicted neutrino count:

$$N^{\max}_{\nu,\mathrm{PeV}} \sim 4.5,\ N^{\mathrm{pred}}_{\nu,\mathrm{PeV}} \sim 0.11$$

Poisson probability: ~11%

Calorimetric Output in BigBird field dominated by a single source:

PKS B1424-418



Chance Coincidence?

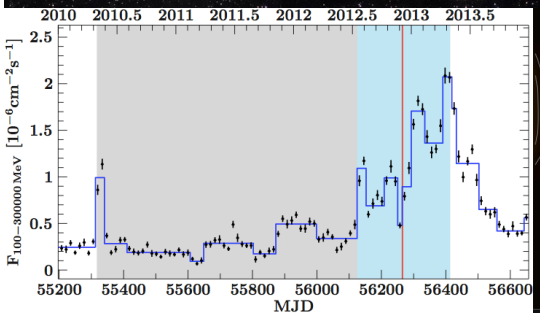
~5%

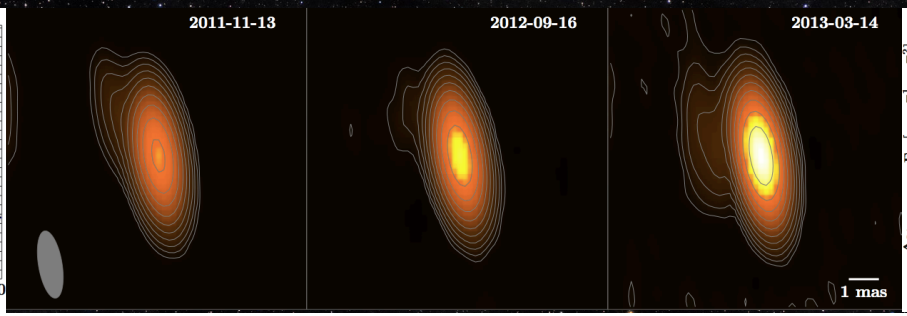
Highest-energy neutrino (seen in the southern sky)

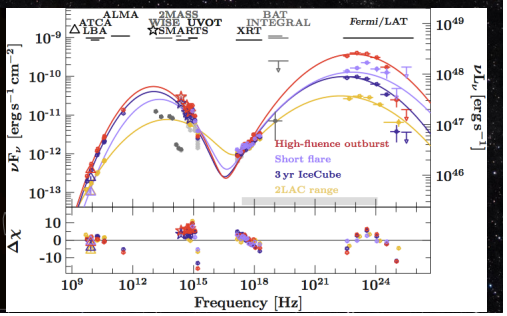
Most dramatic blazar outburst of the (far) southern sky

Summary

- Integrated flux of FSRQs can explain the IceCube PeV signal
- First time that a single blazar can explain an individual PeV neutrino (~11% detection probability; 5% chance coincidence)
- Association expected for ~50% of all PeV events







Synergy with MeV: “Classical” Argument

- Most powerful sources have their emission maximum in the MeV range (Dave T.)
- Measuring and modeling their SED in this range vital to constrain emission models.

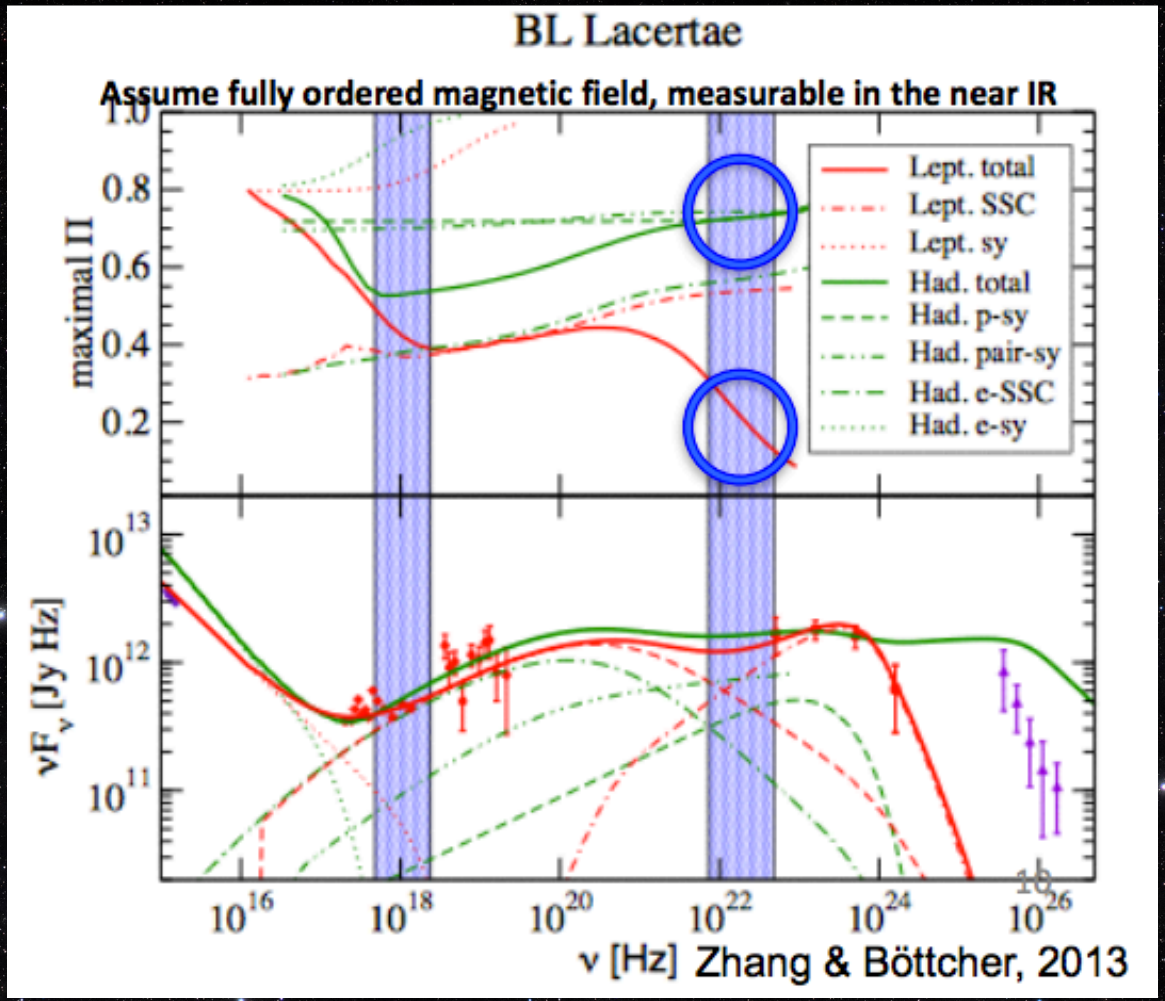
Synergy with MeV: “Neutrino” Argument

- Our model: FSRQ neutrino spectra should have a strong peak in the PeV range
- FSRQ flux should be proportional to the integrated keV through GeV EM flux
- The MeV range is the central piece of this interval and is where the SED maximum is located

$\Rightarrow$ MeV flux is the best proxy for the neutrino flux

Polarization

- Only hadronic models predict neutrinos and high polarization in the MeV band



Neutrino

EM

Grav. Waves

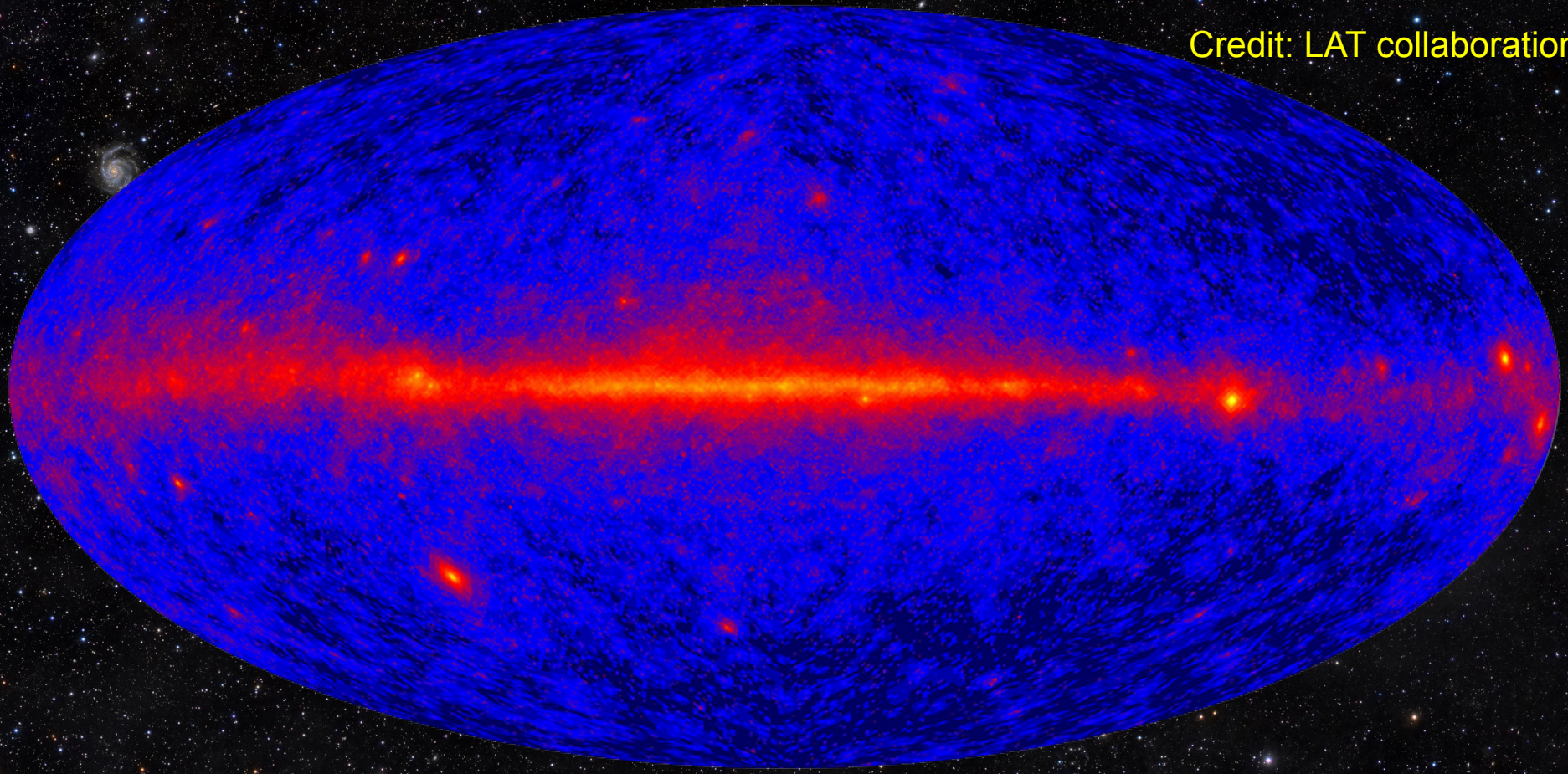

RENEGADE

Take Home Message

- Integrated flux of FSRQs can explain the IceCube signal
- First time that a single blazar can explain an individual PeV neutrino (~5% chance coincidence)
- The MeV flux is the best proxy for the neutrino flux


BACKUP!

Could We Prove Blazar Population from 22(+15) Gamma Photons?

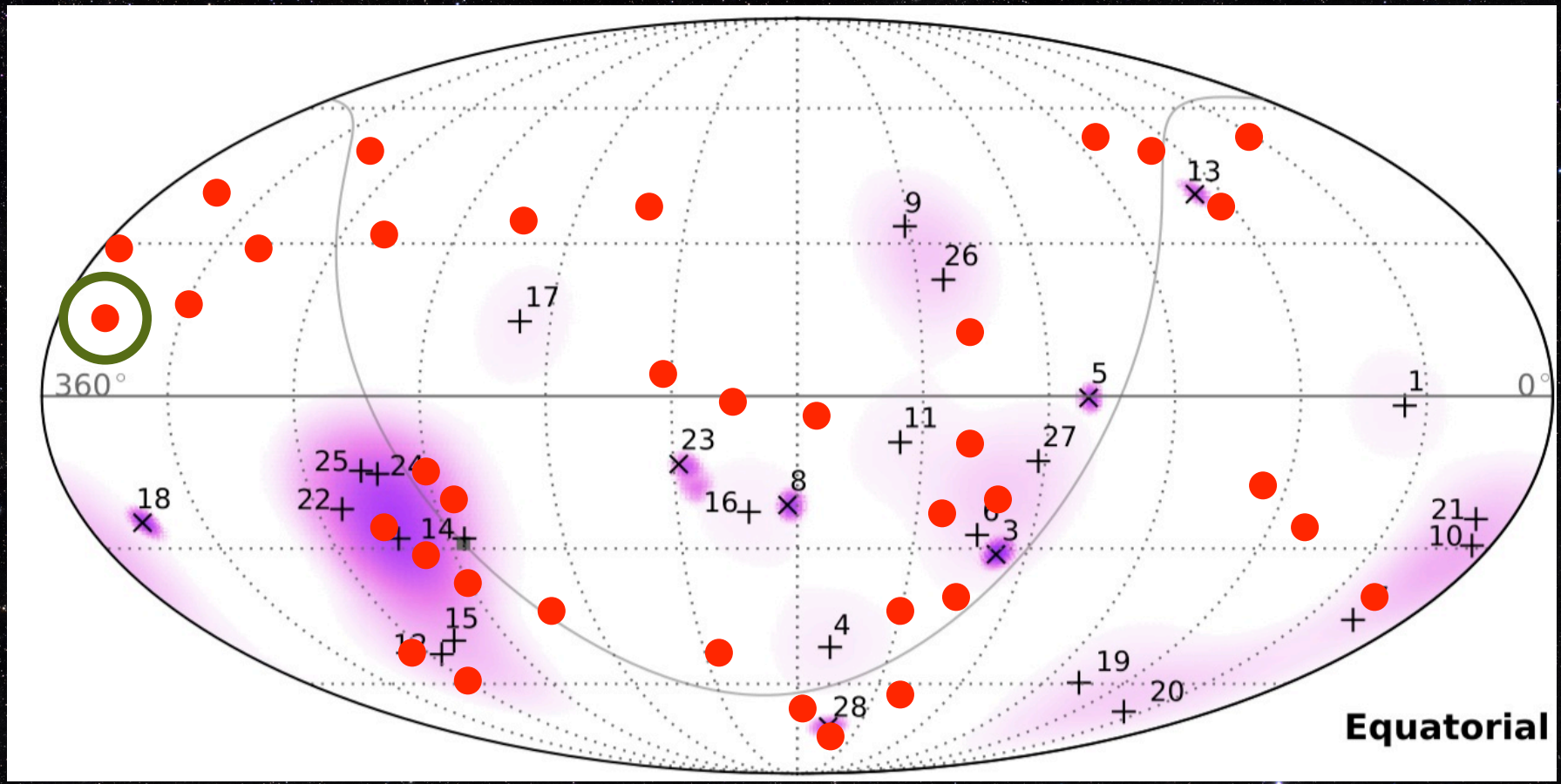


Credit: LAT collaboration

- Pick 22 random gamma-ray photons
- Add 15 random-position fake events

Could We Prove Blazar Population from 22(+15) Gamma Photons?

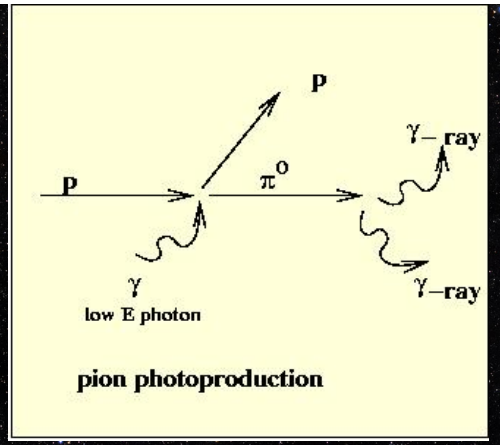
Aartsen et al. 2014

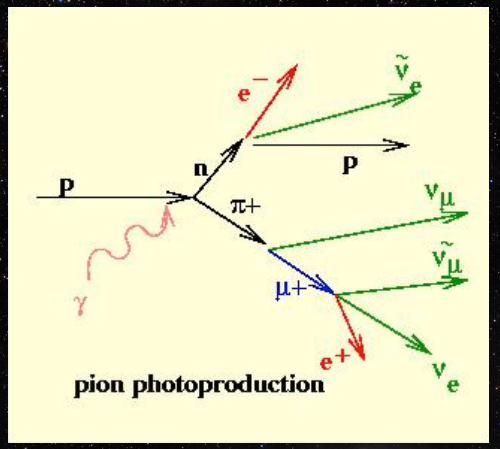


- Slight preference for Gal. plane; consistent with isotropy
- ➢ Only one coincidence with a bright blazar: 3C454.3

Pion Photoproduction

1. Assume presence of accelerated protons (hadronic jet models)
2. Pion photoproduction
3. Estimate neutrino flux from bolometric high-energy flux





$$F_\gamma = 1/3 \cdot F_\pi + 1/4 \cdot 2/3 \cdot F_\pi = 1/2 \cdot F_\pi$$

$$F_\nu = 2/3 \cdot 3/4 \cdot F_\pi = 1/2 \cdot F_\pi$$

$$F_\nu = F_\gamma$$