SEARCH for PeV PHOTONS

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for the Carpet Collaboration

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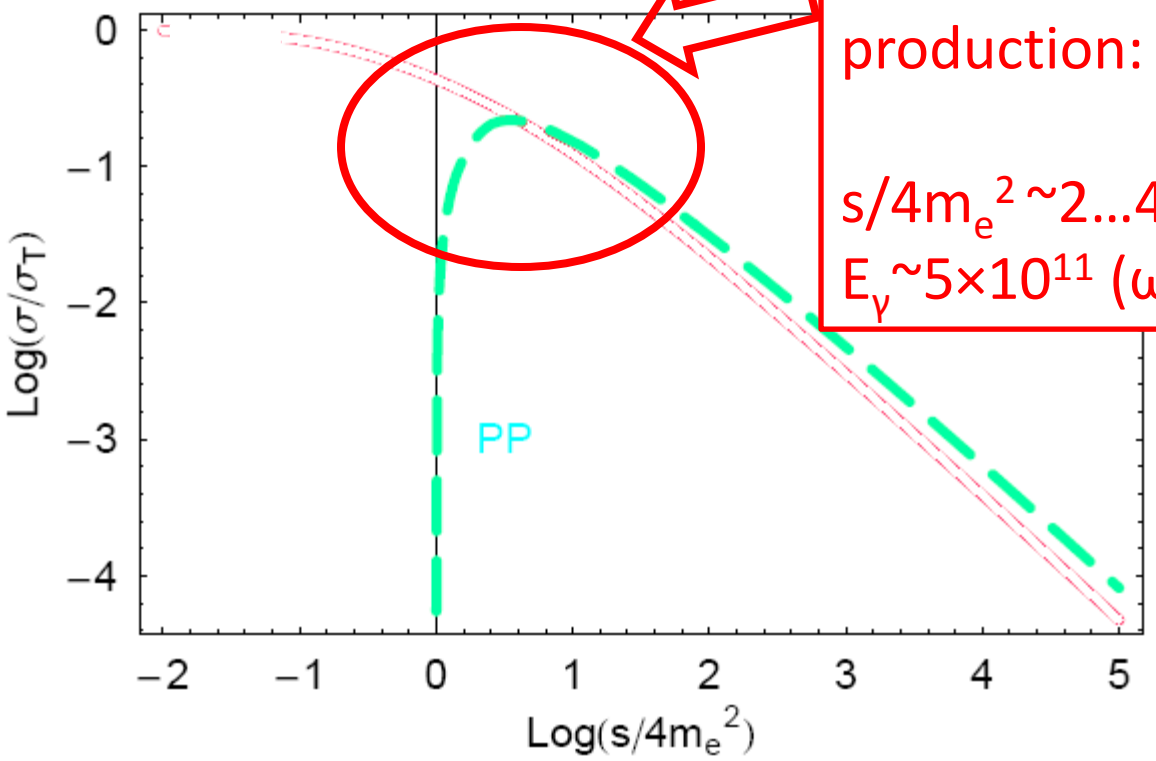
INR, Baksan & Moscow

Photon cascades

Pair production on background radiation

Nikishov 1962

pair-production cross section (PP):



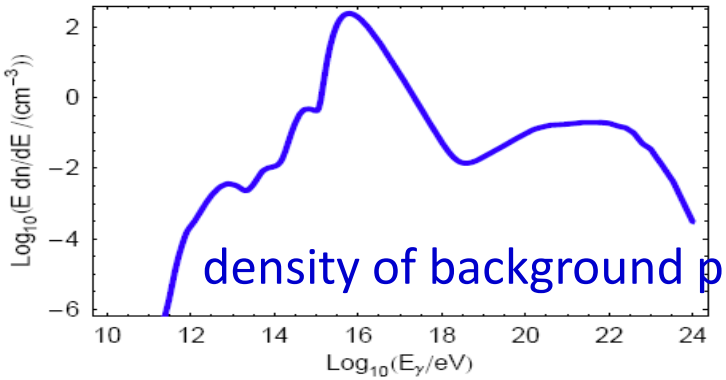
the most intense pair production:

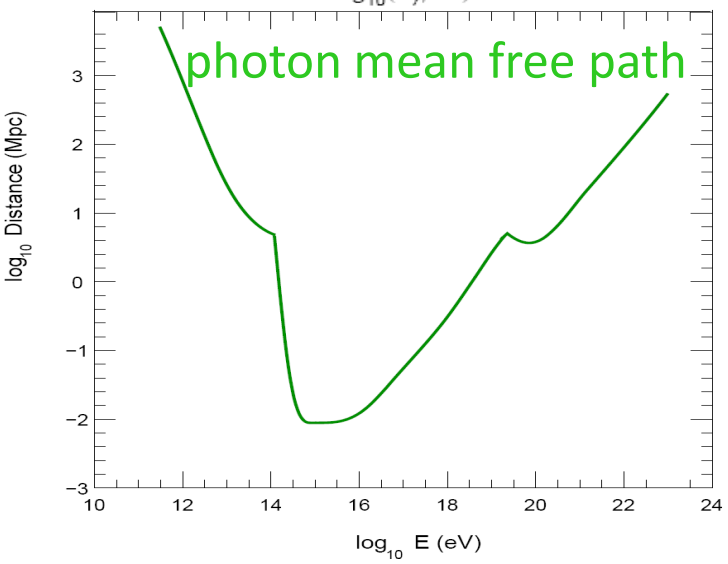
$s/4m_e^2 \sim 2...4$

$E_\gamma \sim 5\times10^{11}\ (\omega/eV)^{-1}\ eV$

Photon cascades

Pair production on background radiation



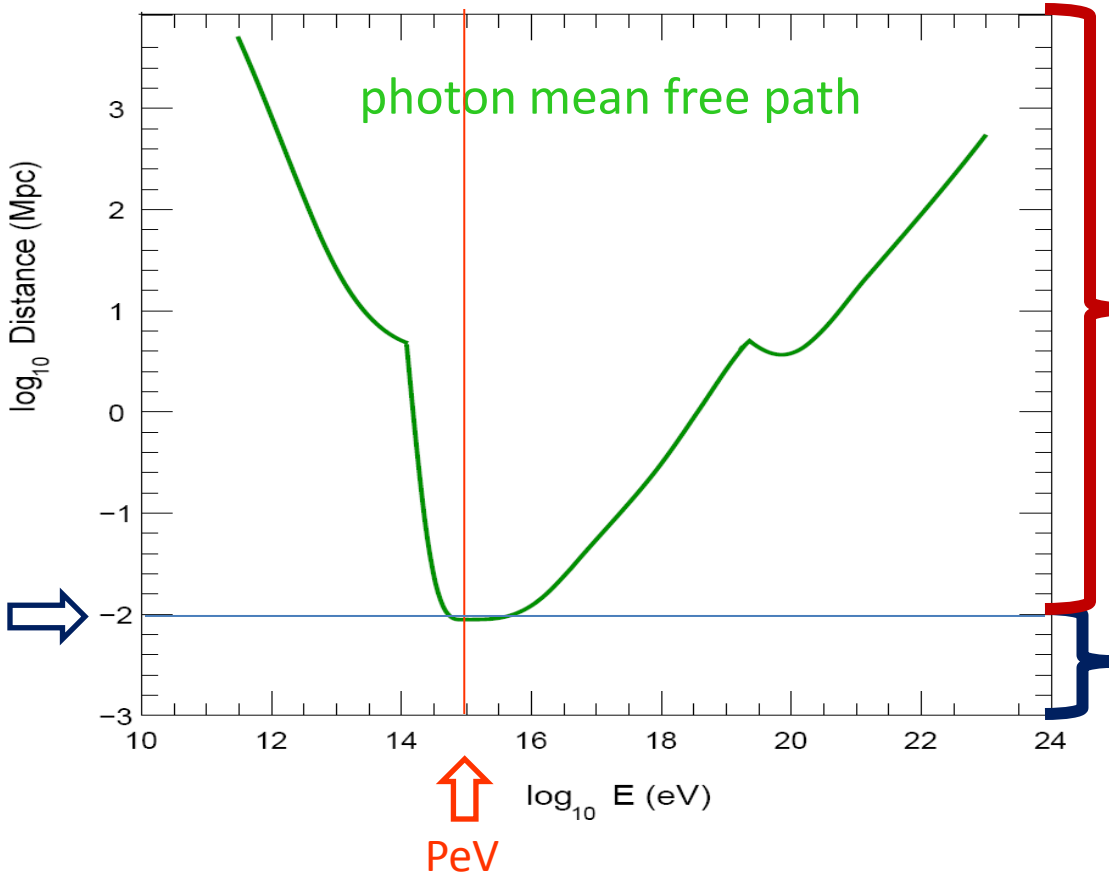


$E_\gamma \sim 5\times10^{11}\ (\omega/eV)^{-1}\ eV$

PeV photons produce pairs on CMB!

Fate of PeV photons

Pair production on background radiation

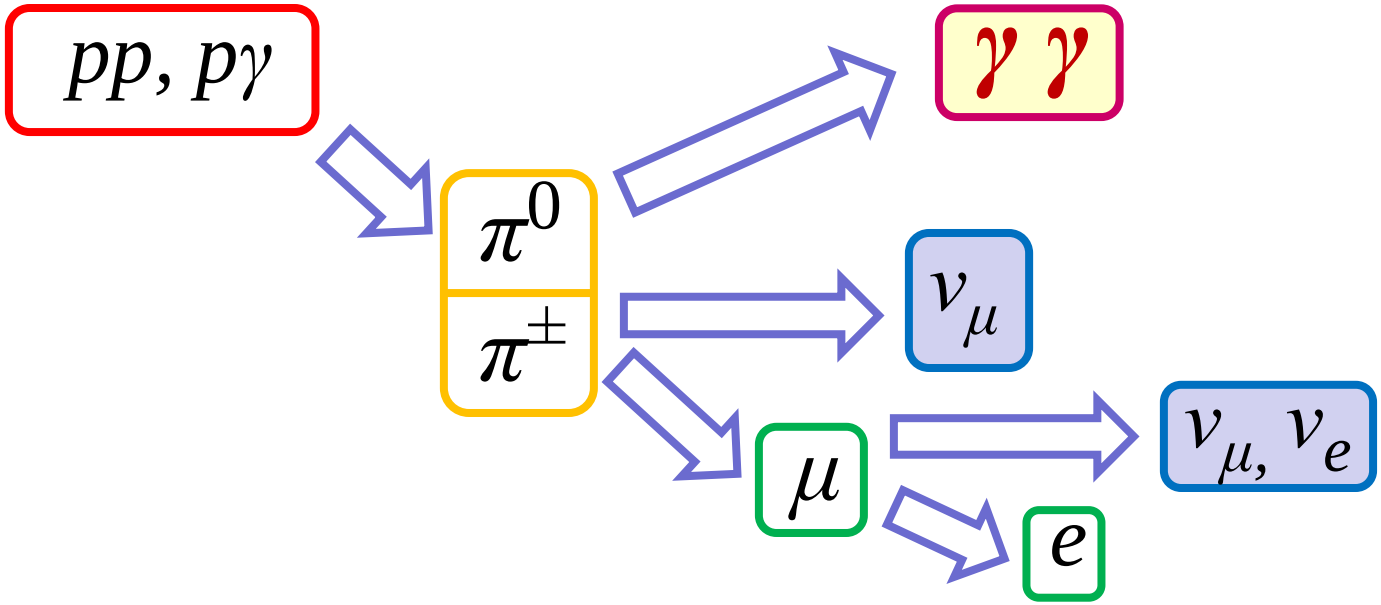


~ 10 kpc ⇨

Extragalactic PeV photons cascade, degrade in energy, contribute to the diffuse ~(1-100) GeV background

Galactic PeV photons reach the observer

Why expect any PeV photons?



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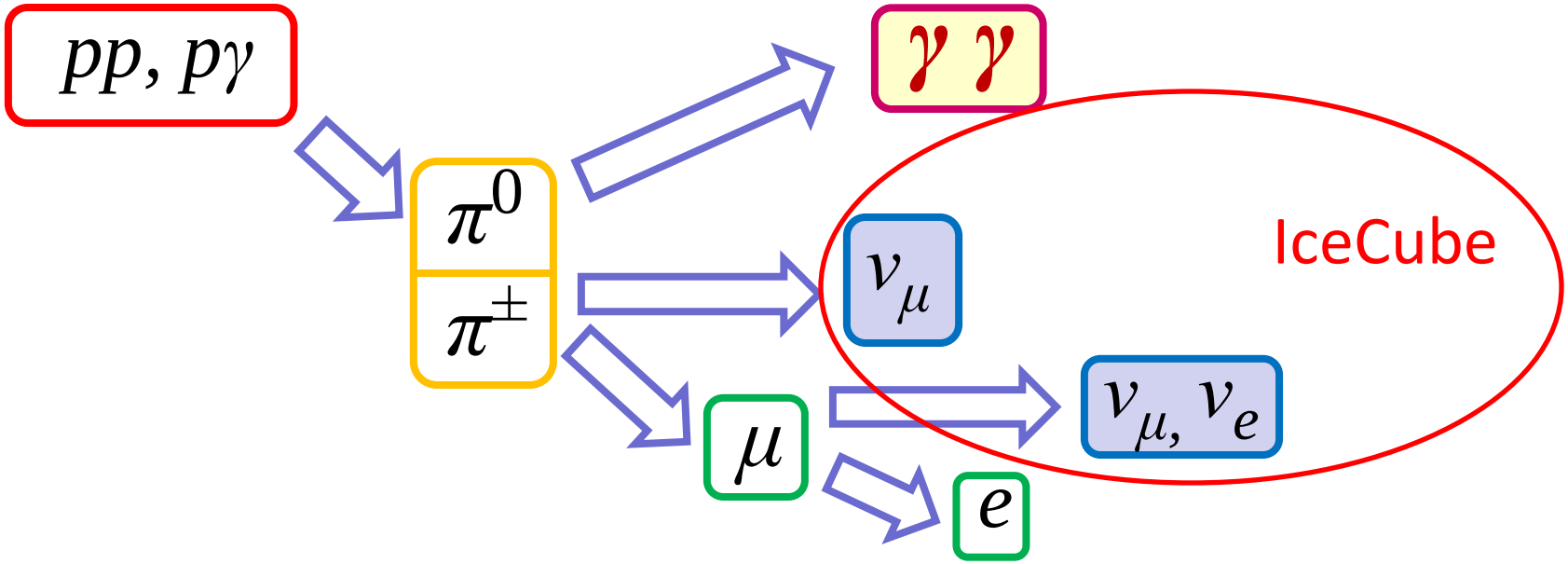


✓ High-energy (E>100 TeV) neutrinos are accompanied by HE photons (if from π mesons)

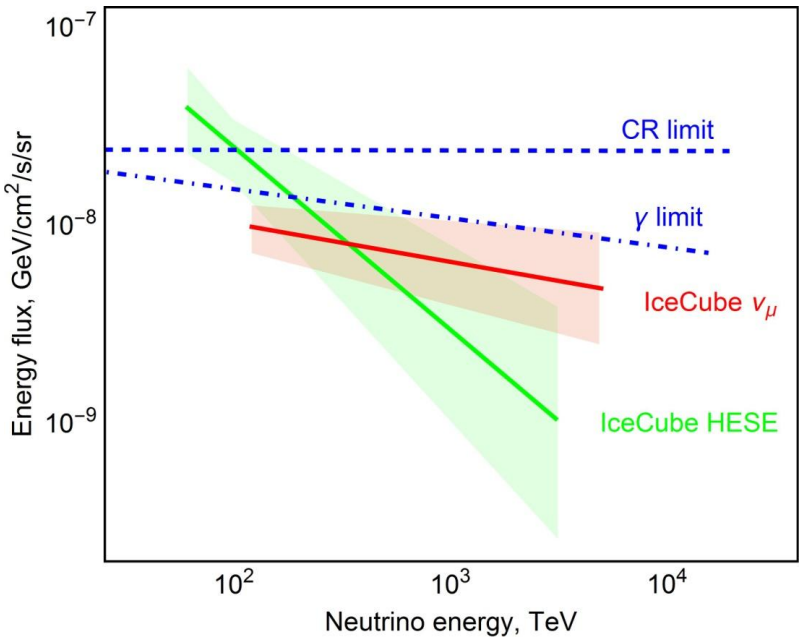
✓ Cascades on CMB ⇨ strong suppression for extragalactic sources

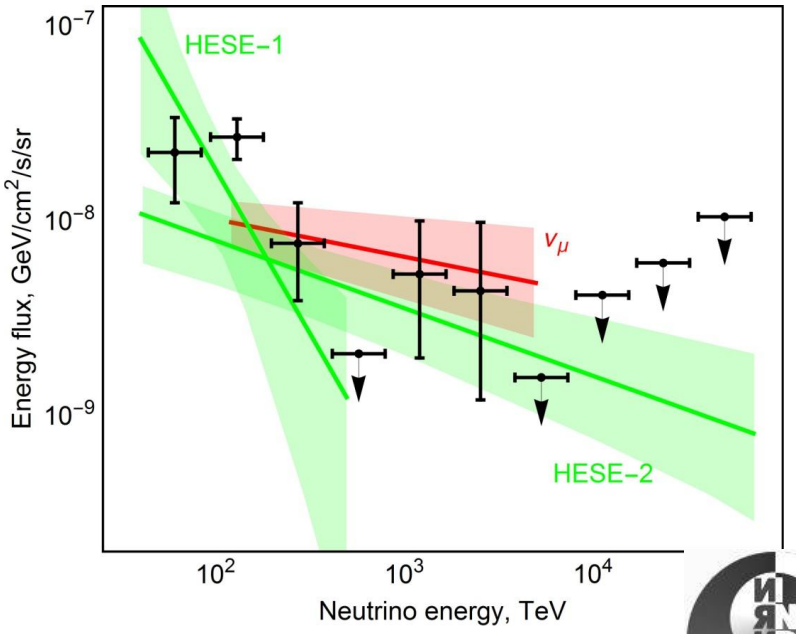
⇩

Searches for the HE photons distinguish between galactic and extragalactic origins of IceCube astrophysical neutrinos

IceCube

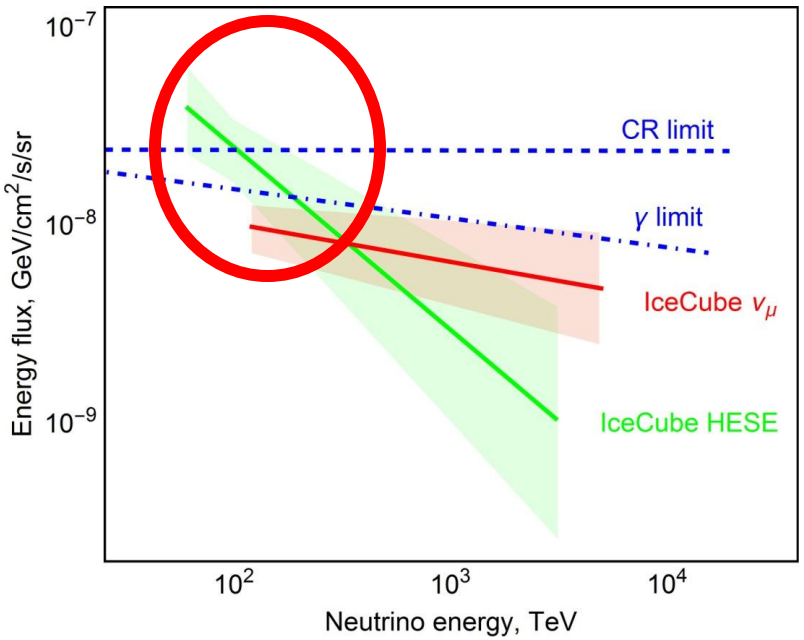
- +/- isotropic flux of high-energy (60 TeV – a few PeV) neutrinos
- no Galactic disk excess
- if extragalactic origin, then problems with the Fermi-LAT diffuse gamma-ray background
- excitement with a 3-sigma coincidence with a blasar flare, but <7% of the flux from blazars
- a certain disagreement in spectra below and above ~200 TeV (two components?)

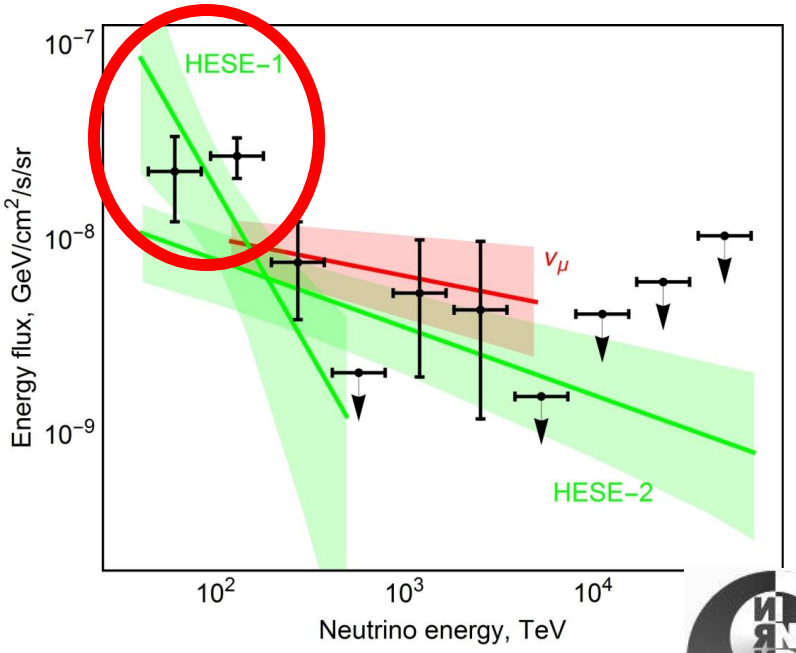




IceCube

- the low-energy component should be Galactic to avoid Fermi-LAT constraints!

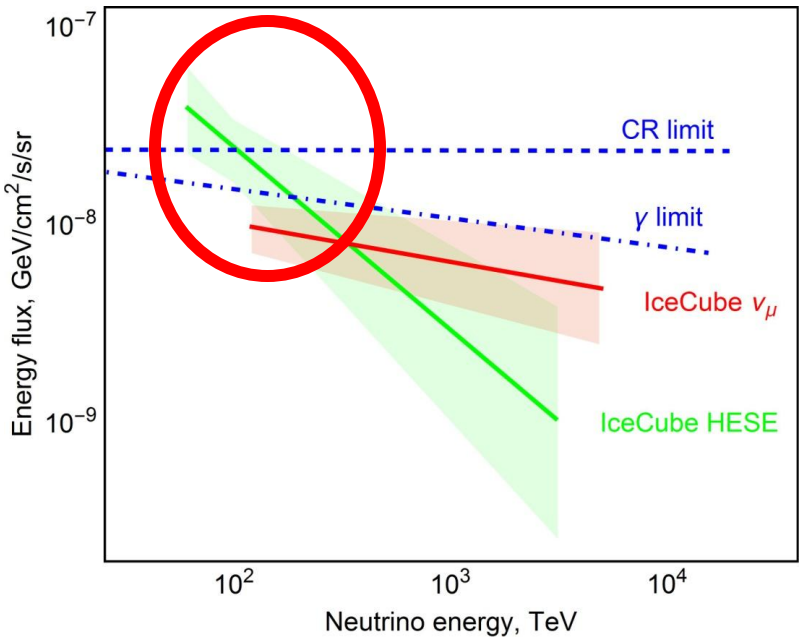


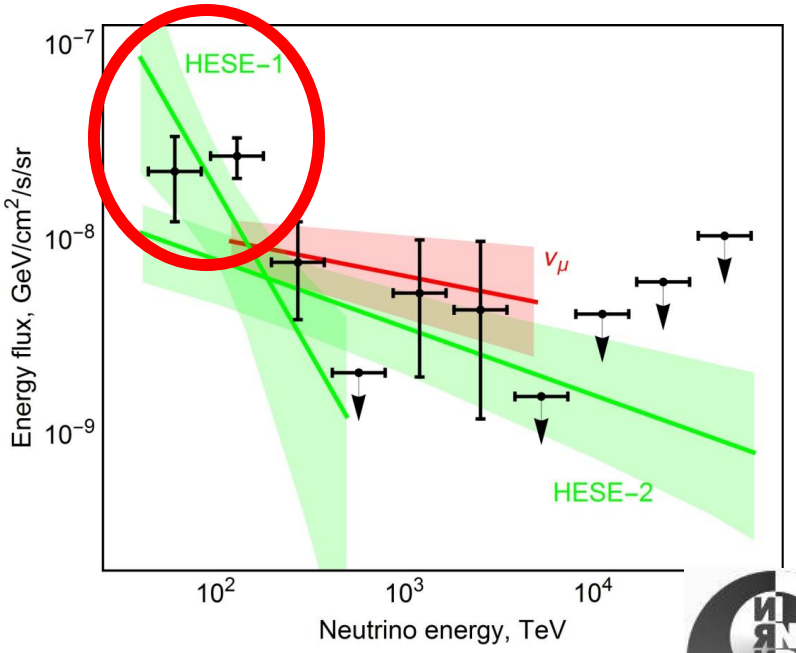


IceCube

- the low-energy component should be Galactic to avoid Fermi-LAT constraints!

- diffuse flux:
  - ✓ dark matter? heavy dark matter decays
  - ✓ local source? “local bubble”
- numerous point sources?





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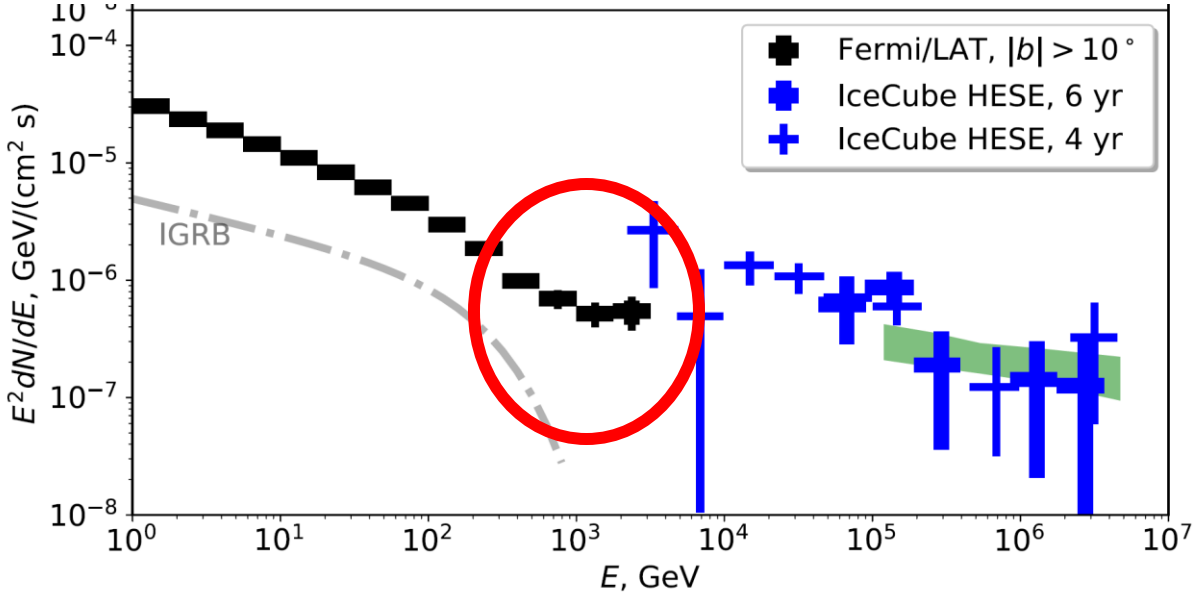

Kachelriess, Neronov, Semikoz 2018

How to find PeV photons?

- PeV photons produce extensive air showers in the atmosphere
- Low fluxes, need an EAS array like those used for cosmic-ray searches
- Need to separate primary photons from cosmic-ray protons/nuclei
- The best separation strategy: muons

γ-ray air showers are **muon-poor**

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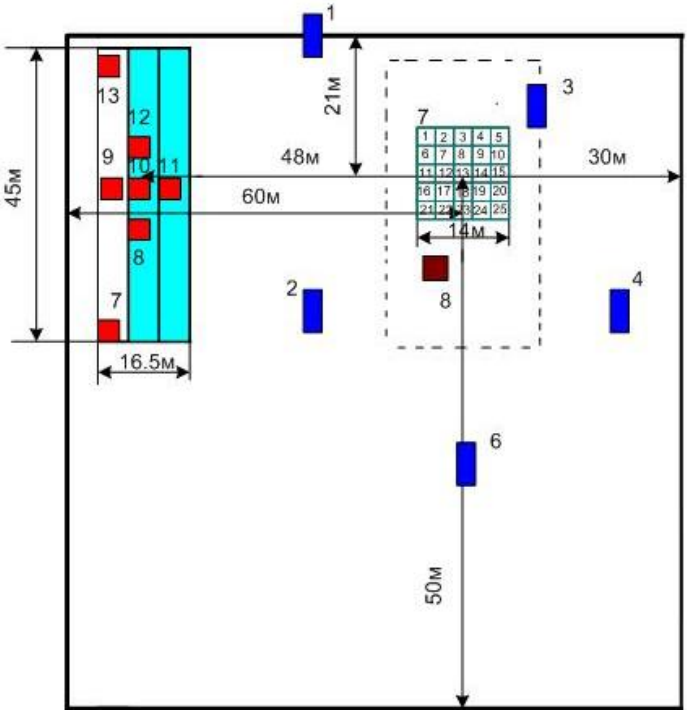
Next: results of the real search for PeV photons based on this strategy

EAS+muon detector installation

Carpet-2: air-shower array @ Baksan Neutrino Observatory

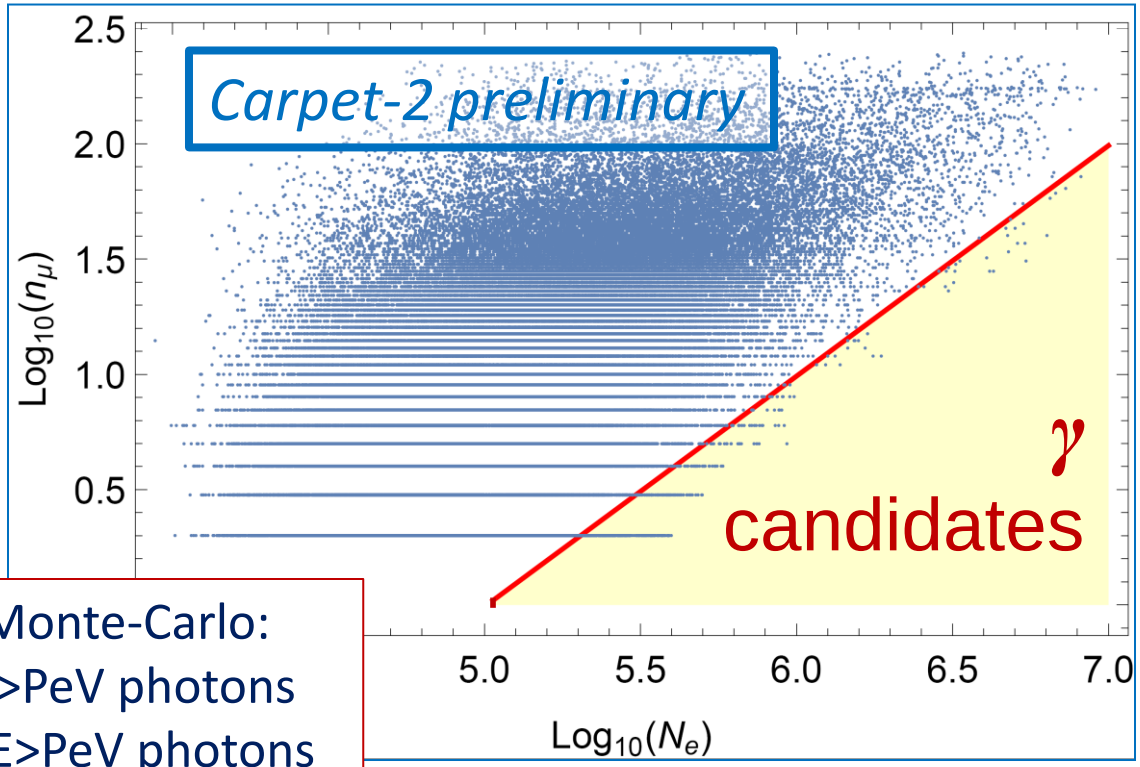
- ✓ surface scintillator detector
- ✓ 175 m^2 muon detector (E_μ>1 GeV)
- ✓ ~10 years of data



Search for PeV photons with Carpet

γ-ray showers are **muon-poor**

- 3080 days live
- ZA<40° = DEC>0°
- angular resolution 1.7°
- efficiency (ZA, E)
- 115821 events
- 523 photon candidates



photon candidate cuts from Monte-Carlo:

✓ min N_e to include 90% of E>PeV photons

✓ max n_μ/N_e to include ½ of E>PeV photons

Search for PeV photons with Carpet, results

• point sources:
correlate arrival direction of photon candidates with source positions in the sky

- ➢ pre-defined list of 4 sources
- ➢ stacked arrival directions of IceCube events
- ➢ IceCube alerts (direction+time)

• diffuse flux:
need to be careful with hadronic backgrounds, more Monte-Carlo to come

Stacked arrival directions of IceCube events

ID	R.A.	DEC	Error
HES13	67.9	+40.3	1.2
HES38	93.34	+13.98	1.2
HES47	209.36	+67.38	1.2
HES62	187.9	+13.3	1.3
HES63	160.0	+6.5	1.2
HES82	240.9	+9.4	1.2
DIF2	298.21	+11.74	0.45
DIF4	141.25	+47.80	0.43
DIF5	306.96	+21.00	2.13
DIF7	266.29	+13.40	0.54
DIF8	331.08	+11.09	0.55
DIF10	285.95	+3.15	1.09
DIF12	235.13	+20.30	1.71
DIF13	272.22	+35.55	0.85
DIF16	36.65	+19.10	1.96
DIF17	198.74	+31.96	0.96
DIF20	169.61	+28.04	0.85
DIF23	32.94	+10.22	0.52
DIF24	293.29	+32.82	0.56
DIF25	349.39	+18.05	2.70
DIF27	110.63	+11.42	0.37
DIF28	100.48	+4.56	1.08
DIF29	91.60	+12.18	0.40
DIF30	325.5	+26.1	1.62
DIF31	328.4	+06.00	0.55
DIF32	134.0	+28.00	0.45
DIF33	197.6	+19.9	2.33
DIF34	76.3	+12.6	0.66
DIF35	15.6	+15.6	0.53
EHE3	46,58	+14.98	0.78
EHE5	77.43	+5.72	0.83
EHE6	340.0	+7.40	0.47
AHES1	240.57	+9.34	0.60
AHES4	40.83	+12.56	0.88

34 IceCube tracks
in the Carpet field of view

- expected γ candidates: 38.1
- observed γ candidates: 34

stacked flux limit:
$<1.4\times10^{-14}$ cm^{-2} s^{-1}
(90% CL)

Carpet-2 preliminary

Direction+time: IceCube alerts

Only one IceCube track in the (live) Carpet field of view

16/12/10	UT 20:07:16	RA=46,58°	DEC=+14,98°

- ±3 days, observed γ candidates: 0

  E>PeV γ fluence limit: <0.2 GeV cm^{-2} (90% CL, E^{-2})

Carpet-2 preliminary

Predefined point sources

source	photon candidates		Flux (E_γ >PeV), 95% CL upper limit, $\mathrm{cm}^{-2}\mathrm{s}^{-1}$
	expected	observed	
Crab	0.17	0	2.2×10^{-13}
Cyg X-3	0.46	1	1.3×10^{-13}
Mrk 501	0.46	0	7.7×10^{-14}
Mrk 421†	0.43	2	1.9×10^{-13}

Carpet-2 preliminary

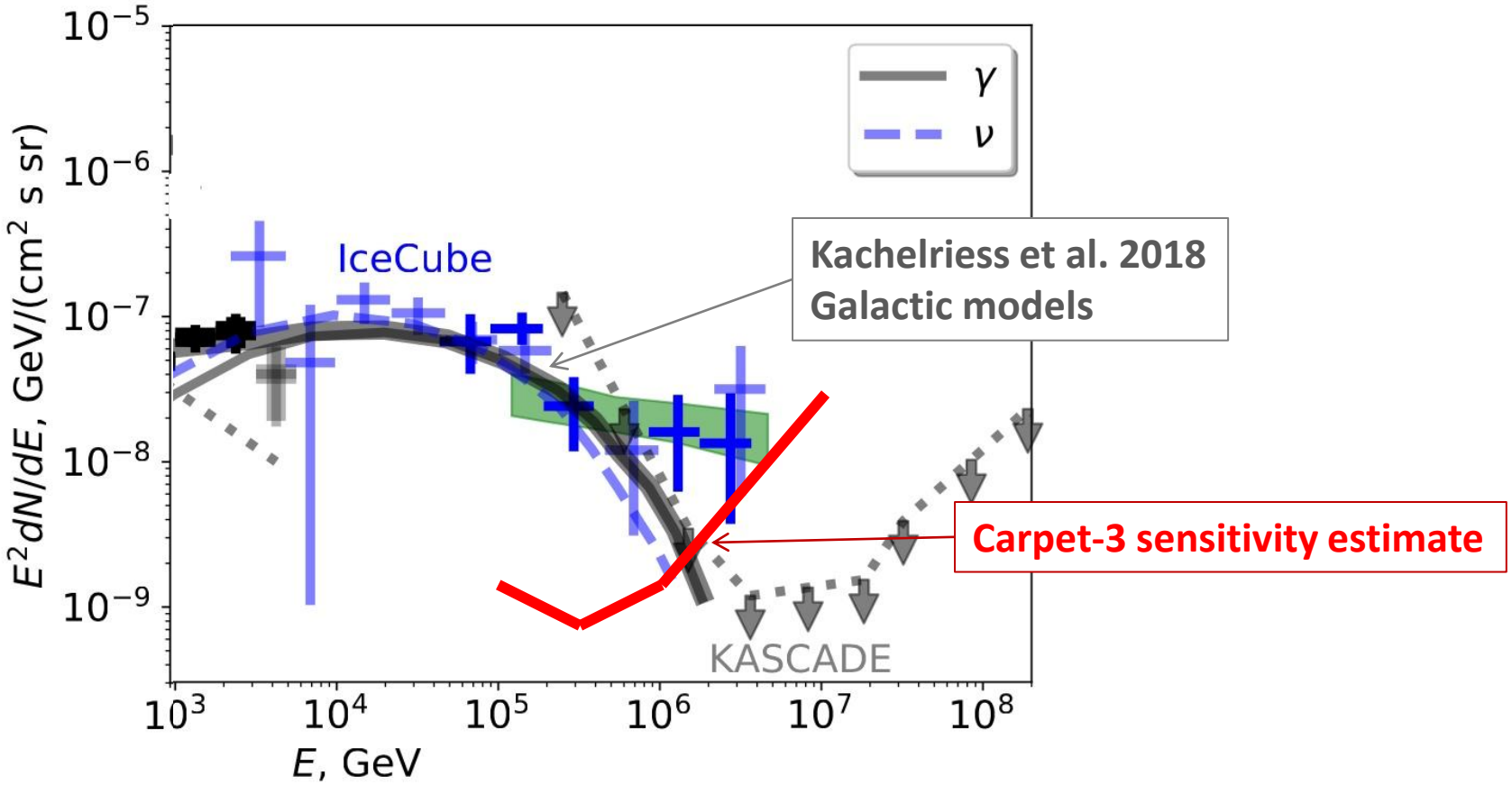
† Mrk 421, 2.6σ detection, best-fit flux 4.7×10^{-14} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Upgrade to Carpet-3

- 410 m^2 muon detector
- increased surface area
- assembled, to be commissioned by 12/2018

Target: diffuse photons above 100 TeV

Expected sensitivity to diffuse photons



Conclusions

- motivation to search for PeV photons
  - ✓IceCube neutrinos, origin unclear
- first ever results for PeV photons associated with IceCube events
  - ✓34 stacked directions + 1 event in the field of view
- first limits on PeV point-source fluxes
  - ✓Crab, Cyg X-3, Mrk 501, Mrk 421
- Carpet-3 upgrade and diffuse fluxes to come soon!

STAY TUNED!