Connecting neutrino Astrophysics to Multi-TeV to PeV gamma-ray Astronomy with TAIGA

Astrophysics and Experiments

Martin Tluczykont

Magellan Workshop
Hamburg 2016

- Overview UHE gamma-ray regime
- Connecting multi-TeV/PeV neutrinos with gamma-rays
- Status of TAIGA

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Physics and sources of UHE gamma-rays

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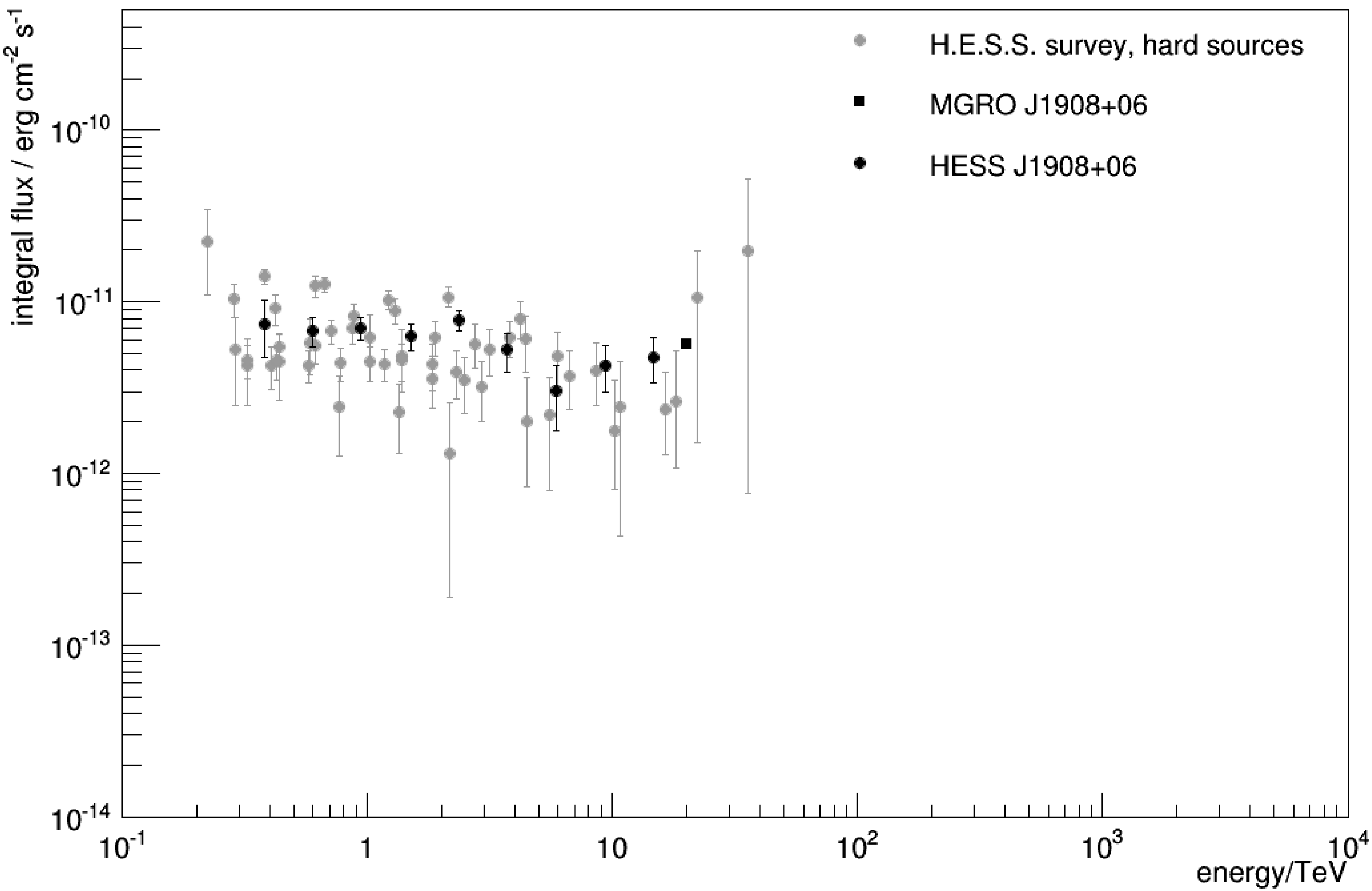
VHE-UHE Gamma-ray astronomy



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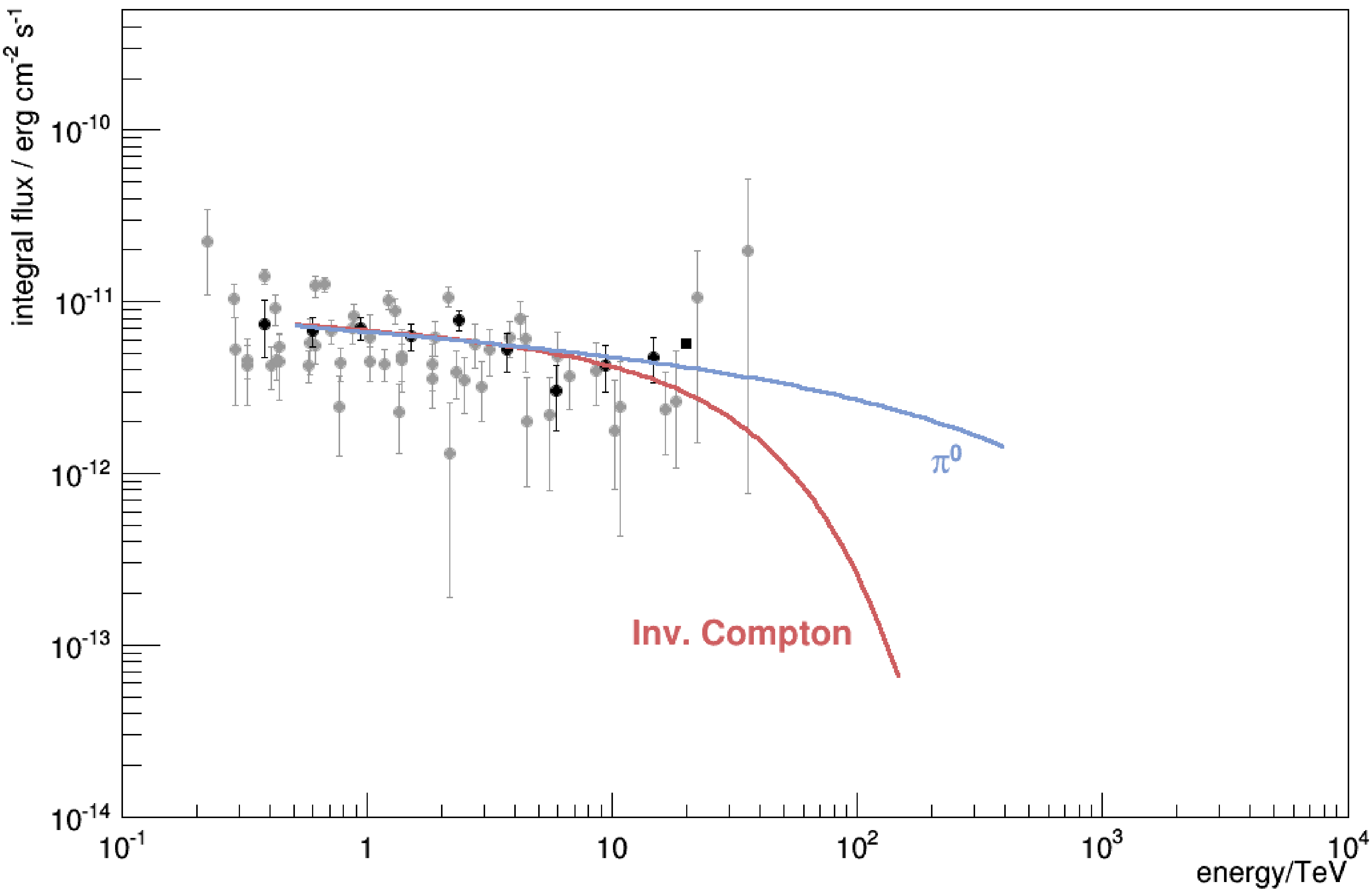

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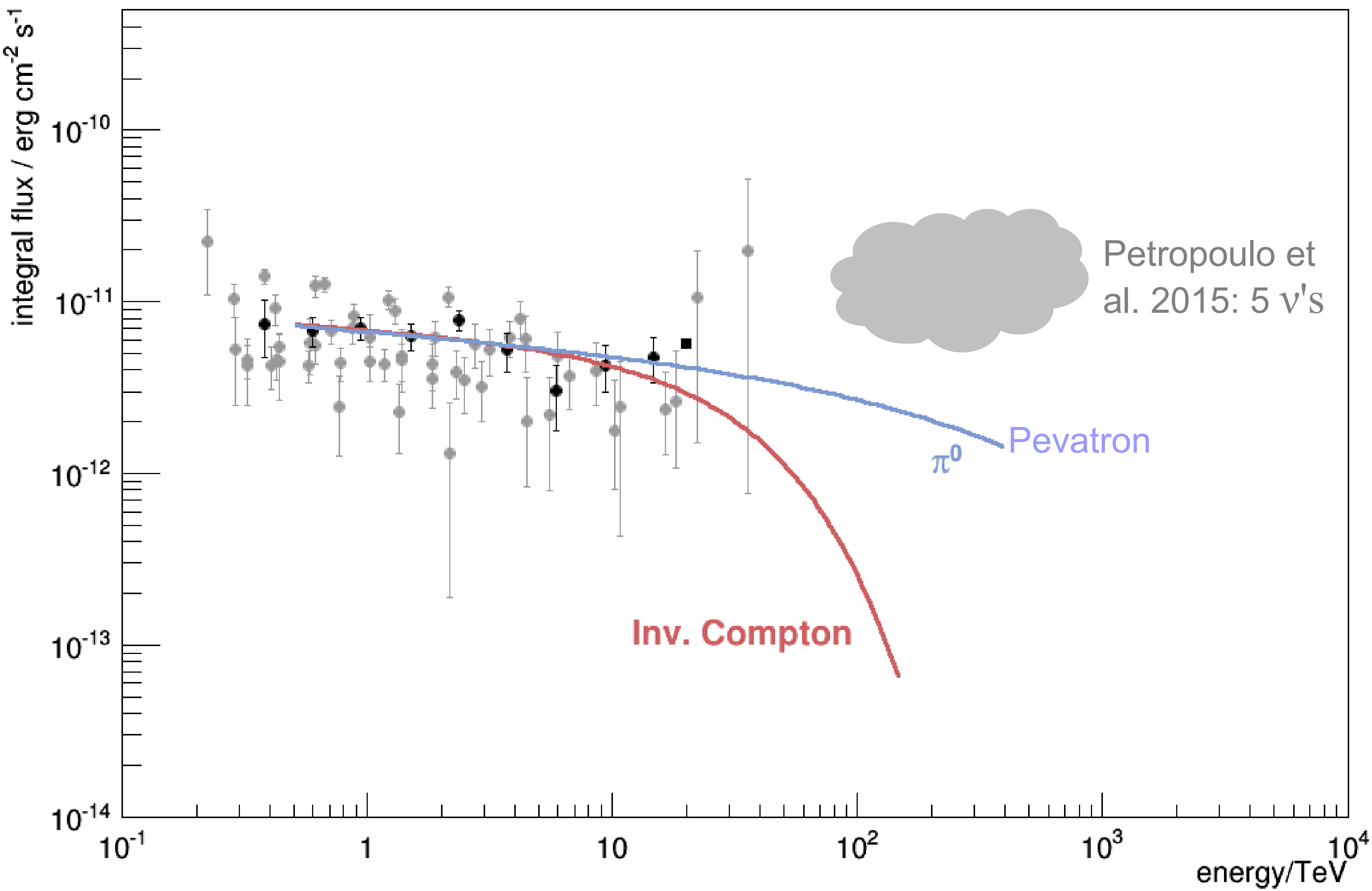
VHE-UHE Gamma-ray astronomy



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Neutrinos and Gamma-Rays

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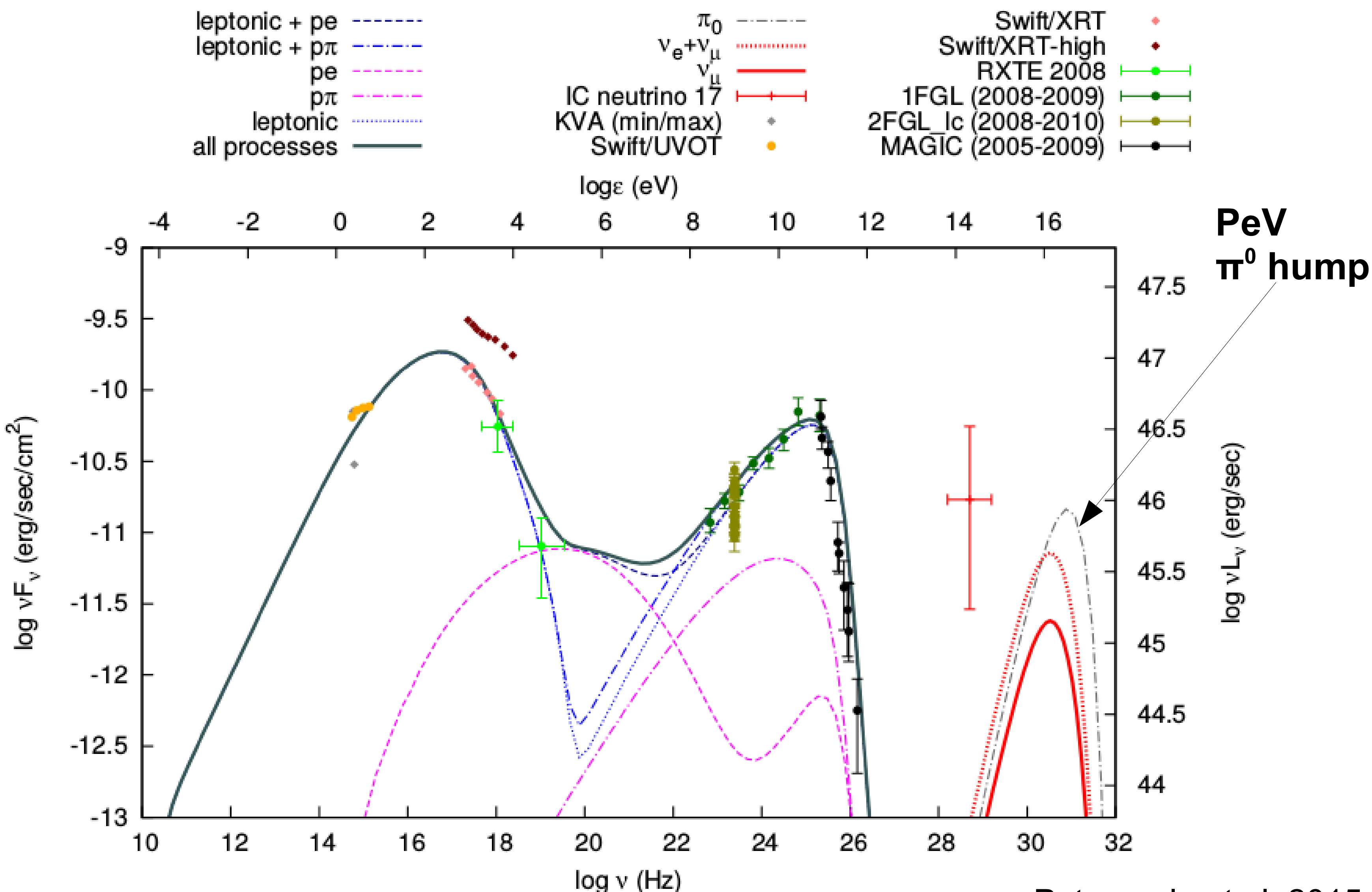
Neutrinos & UHE gamma-rays

- **The IceCube signal (Aartsen et al. 2013, 2014)**
  - 1st 3 years of full IceCube data: 37 UHE neutrinos (30 TeV – 2 PeV)
  - Presence of astrophysical component favoured (5 σ).
  - 8 BL Lac objects ***possibly*** **neutrino event counterparts** (Padovani&Resconi 2014)

- **Lepto-hadronic emission model (Petropoulo et al. 2015)**
  - Blob + B-field with Doppler factor δ, isotropic proton and electorn injection interaction with B-field and secondaries → particle populations:
  - Protons (Sy., pair production, photopi)
  - Electrons and positrons (Sy., IC)
  - Photons (+ neutrons, neutrinos)

PG 1553+113 (z = 0.4)



Petropoulo et al. 2015

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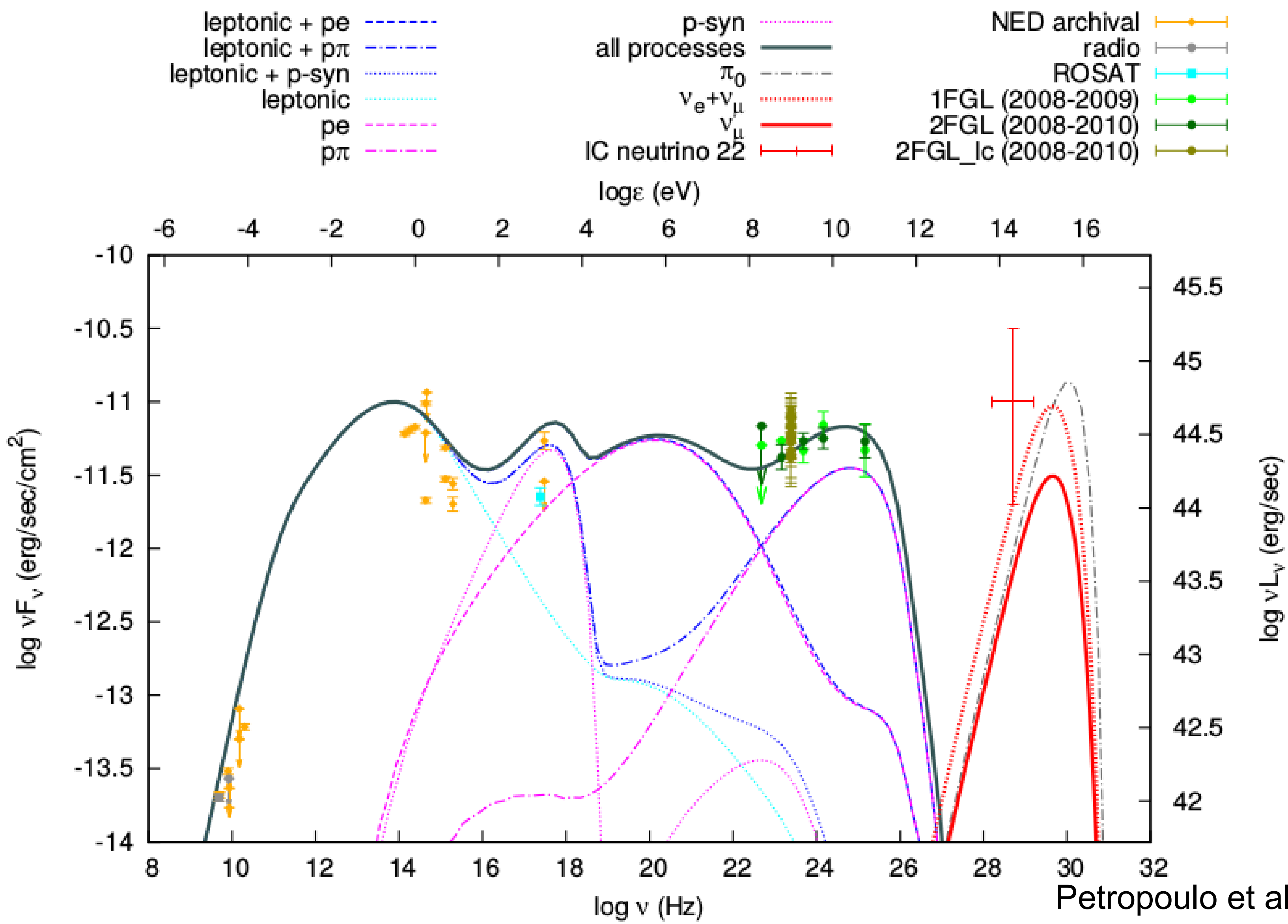
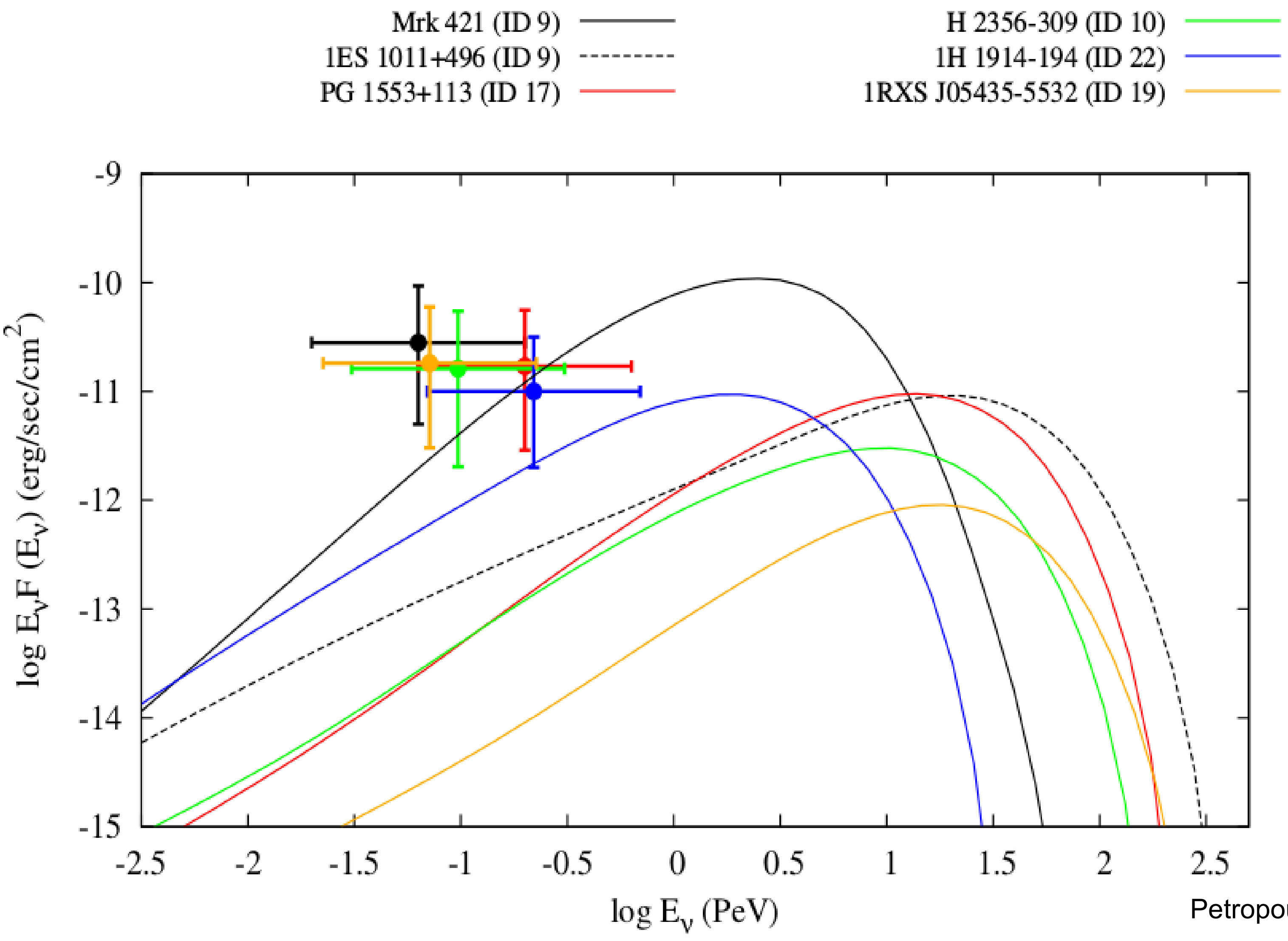
H 1914-194 (z=0.137)



Petropoulo et al. 2015

π^0 hump and neutrino event fluxes



Petropoulo et al. 2015

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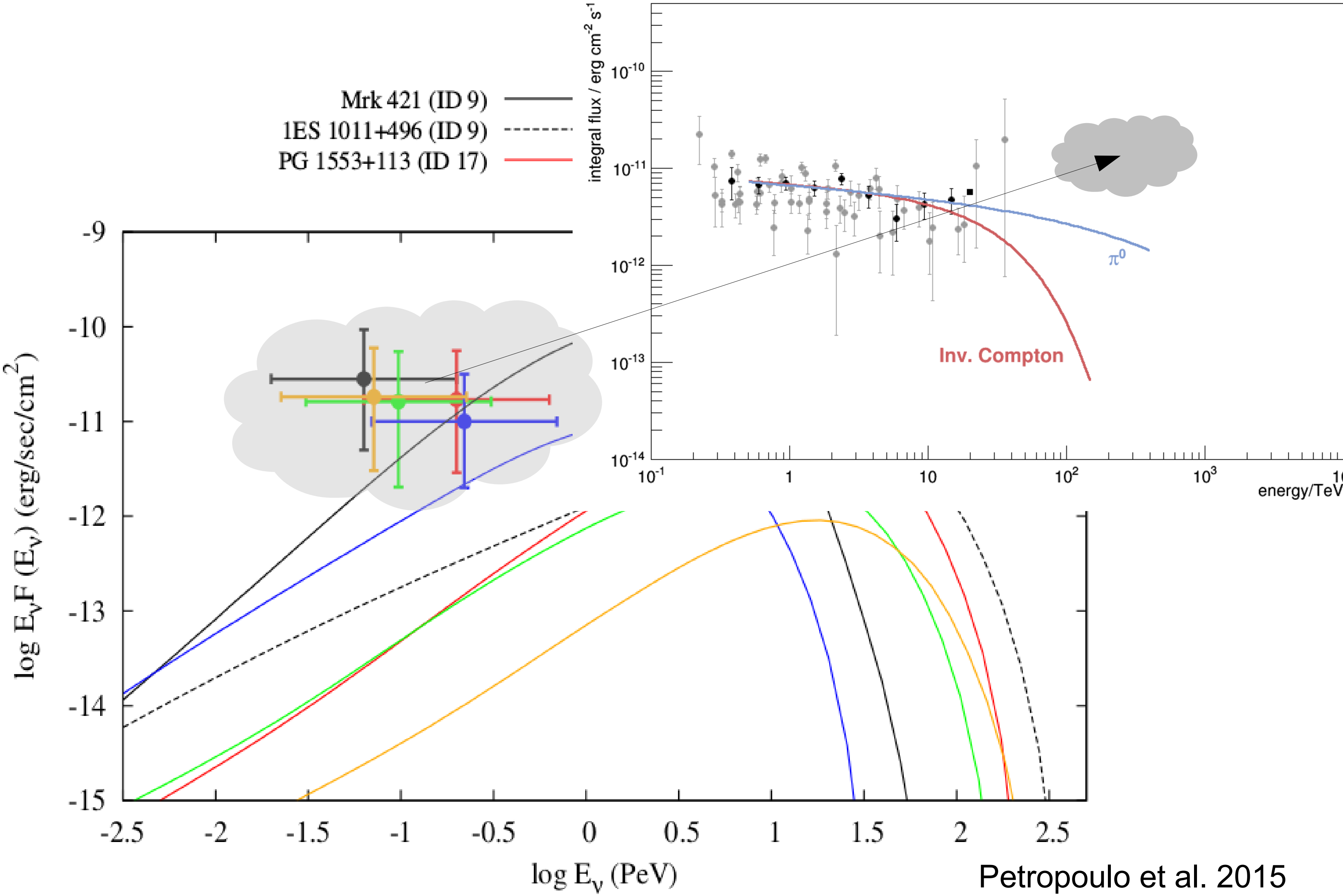

Petropoulo et al. 2015

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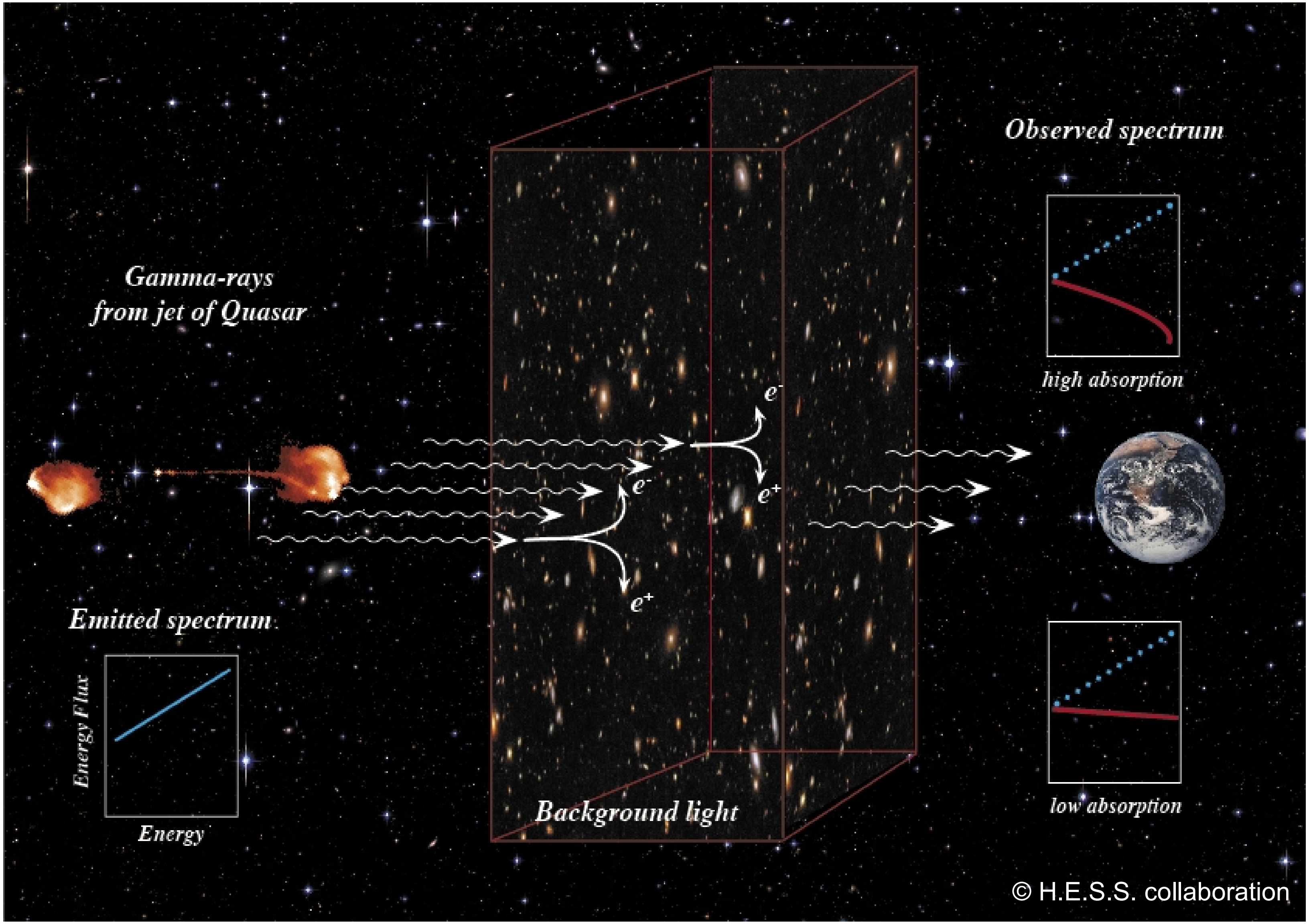
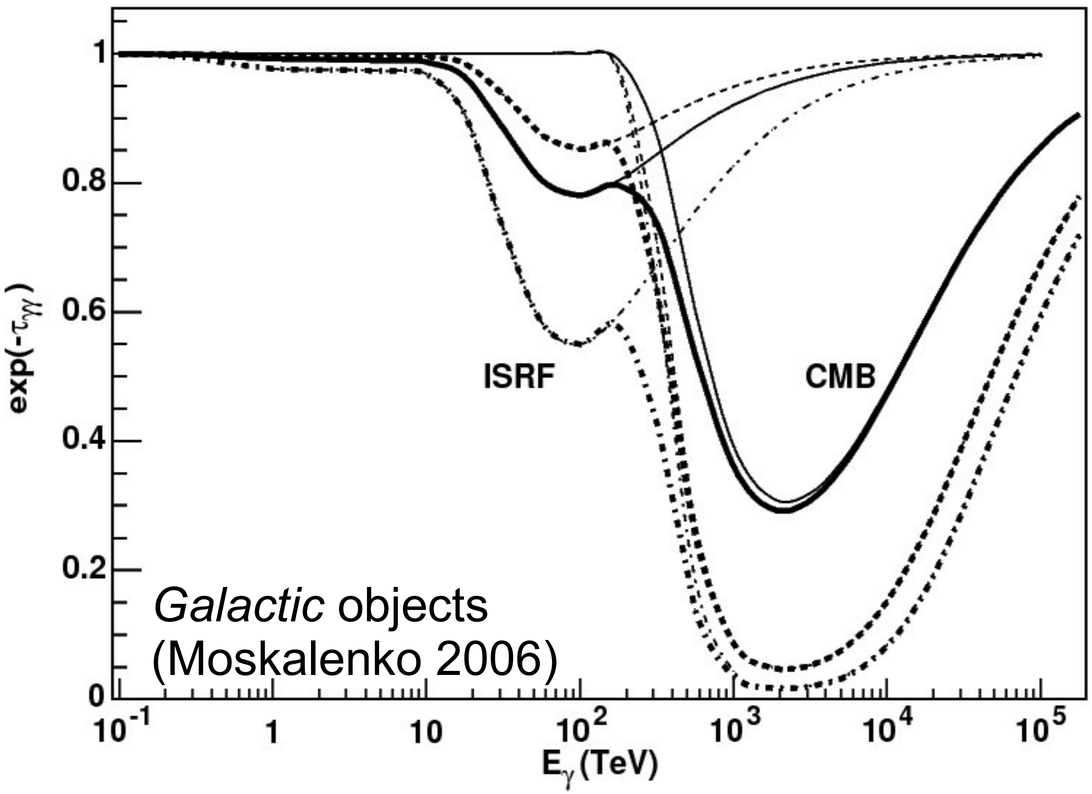
e^+e^- pair production: opacity problem & opportunity

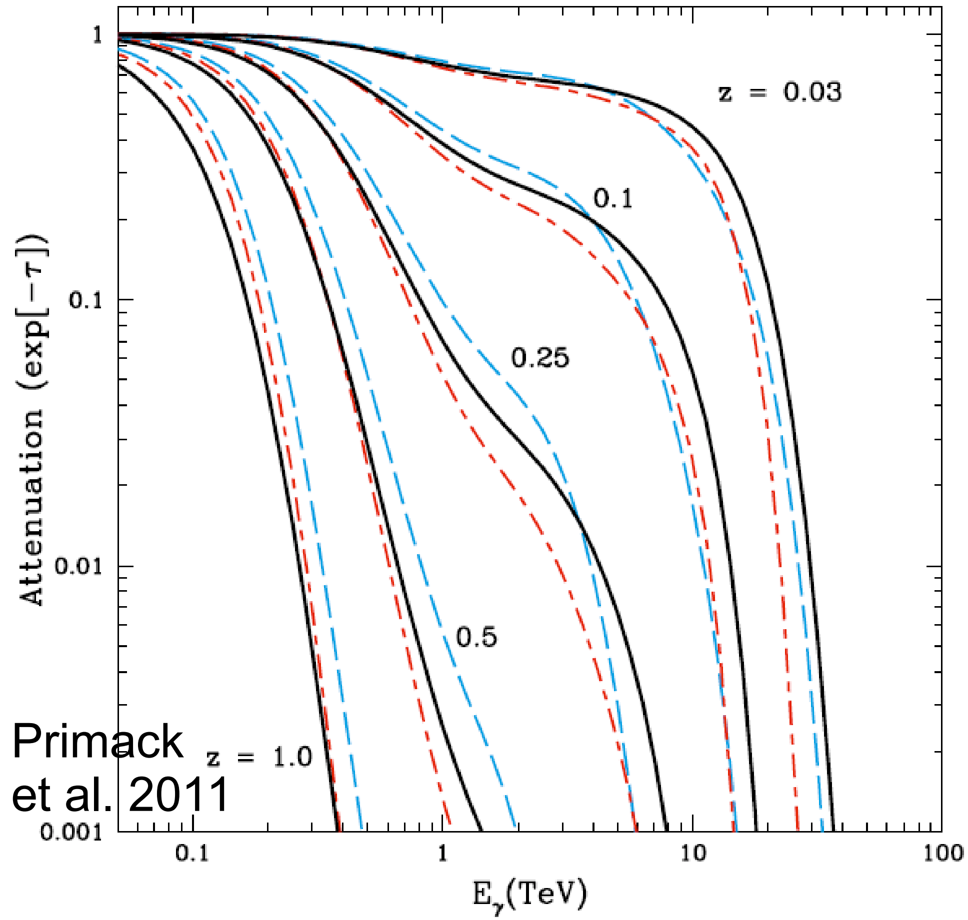


Attenuation from production of e^+e^-

Galactic objects



extragalactic objects



Modifications of absorption

- Axion-like particles:
  absorption-free propagation

  $\gamma \rightarrow X$ - - - - - - - - - - - - - - - - - - - $X \rightarrow \gamma$

- Lorentz Invariance violation
  (e.g. Colladay et al. 1998, Protheroe&Meyer 2000, Kostelecky et al. 2011, Rubtsov et al. 2014, Fairbairn et al. 2015)

Lorentz Invariance Violation (LIV)

- LIV: modified dispersion relation / momentum-dependent photon mass
  $\rightarrow$ modified kinematics:

$\beta_\gamma^2 = 1 - (E\gamma / M_{LVn})^n$
$m_\gamma 2 = E_\gamma^{2+n} / (M_{LVn})^n$

$$x_{\gamma\gamma}(E_\gamma)^{-1} = \frac{1}{8{E_\gamma}^2\beta_\gamma}\int_{\varepsilon_{\min}}^{\infty} d\varepsilon \frac{n(\varepsilon)}{\varepsilon^2}\int_{s_{\min}}^{s_{\max}(\varepsilon,E_\gamma)} ds\,(s - m_\gamma^2(E_\gamma)c^4)\sigma(s)$$

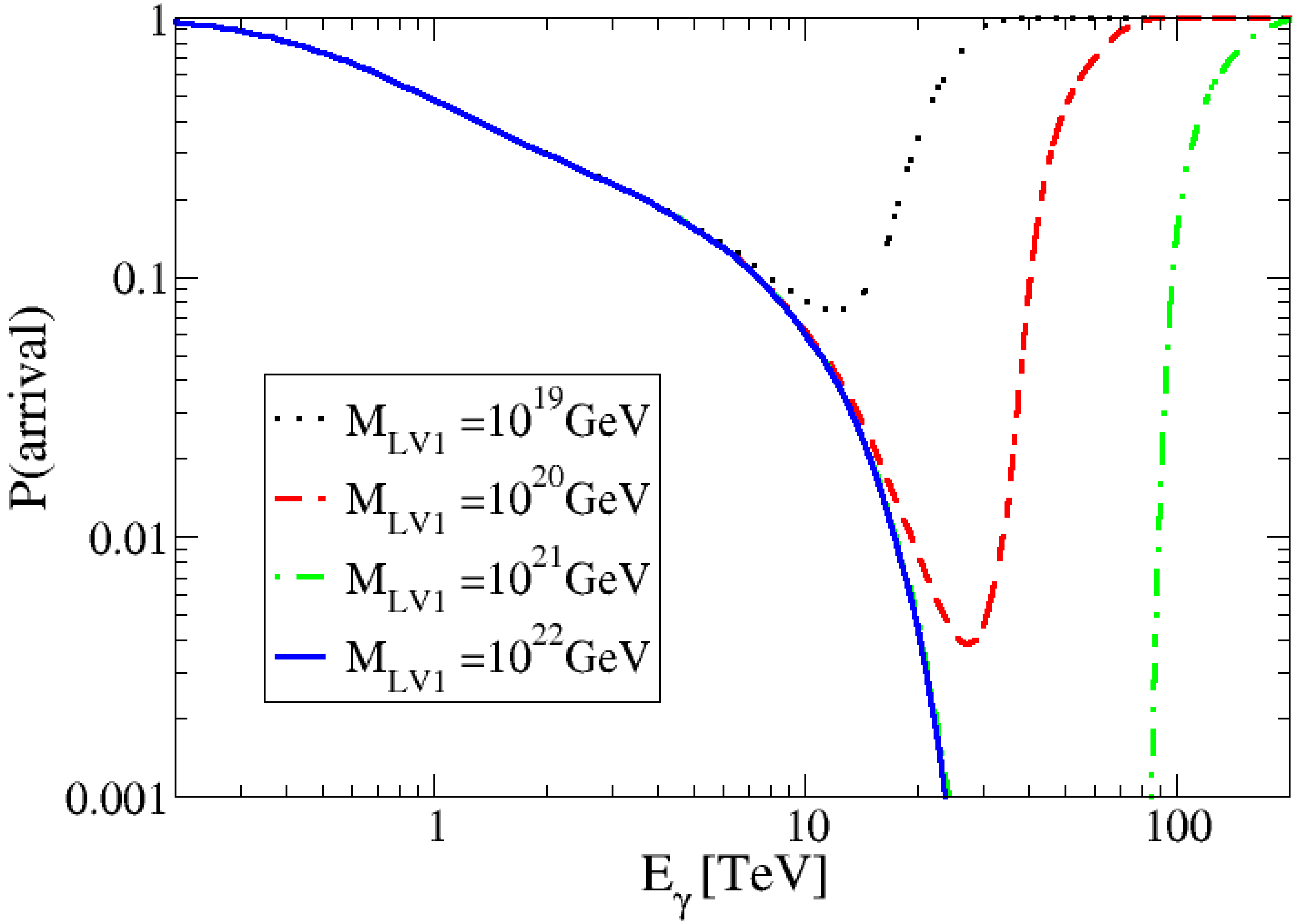
$s_{min} = 4m_e^2$,
$s_{max}(\varepsilon,E_\gamma) = m_\gamma^2(E_\gamma) + 2\varepsilon E_\gamma(1 + \beta_\gamma)$,
$\varepsilon_{min} = [s_{min} - m_\gamma^2(E_\gamma)] / [2E_\gamma(1 + \beta_\gamma)$

$\rightarrow$ modified kinematically allowed range
$\rightarrow$ **suppression of e^+e^- pair production cross section**

Fairbairn et al. 2015

LIV effect on attenuation

sources considered:
z < 0.1



Fairbairn et al. 2015

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Observatories for UHE gamma-rays

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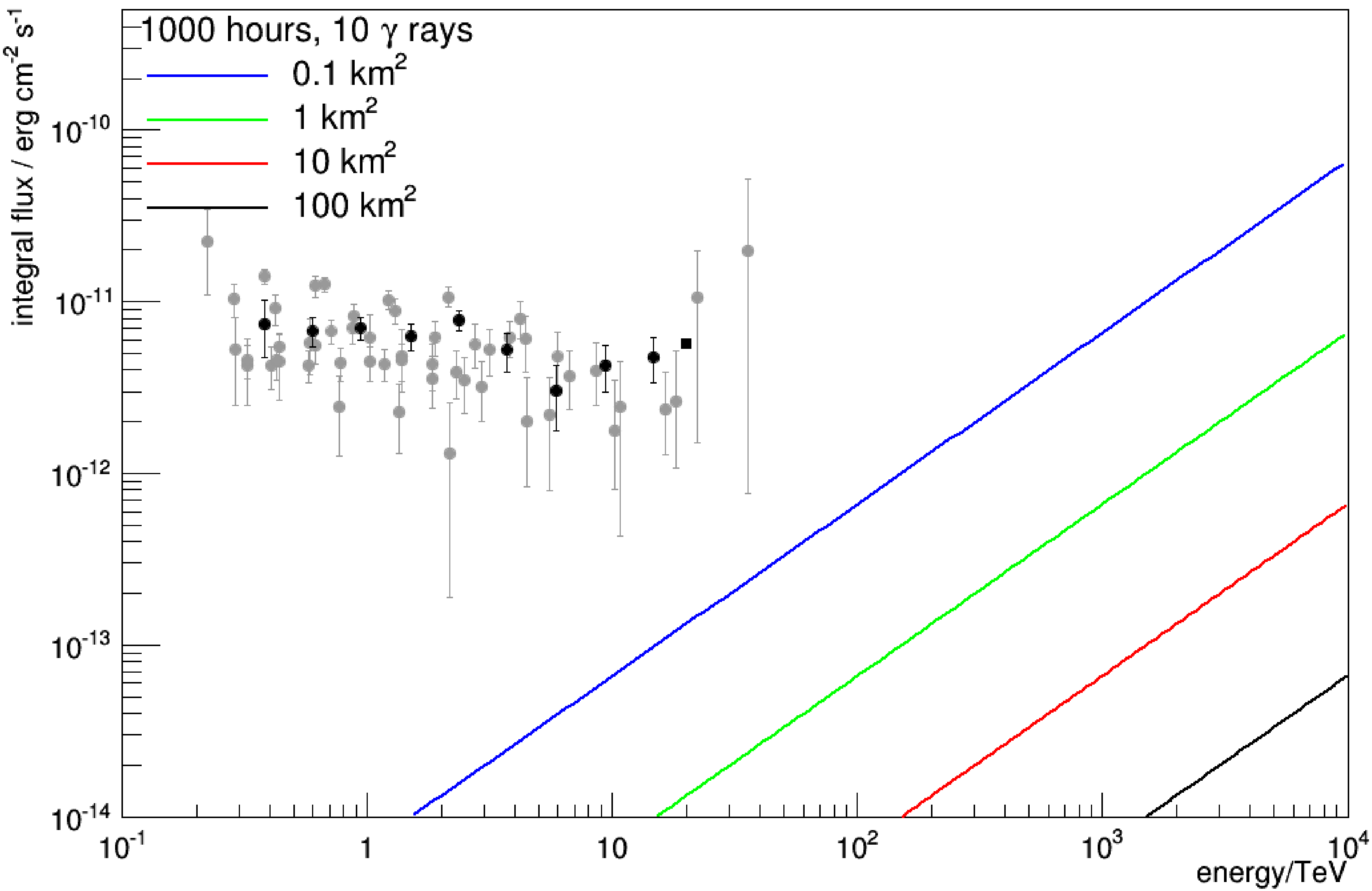
Key to Multi-TeV-PeV: Area



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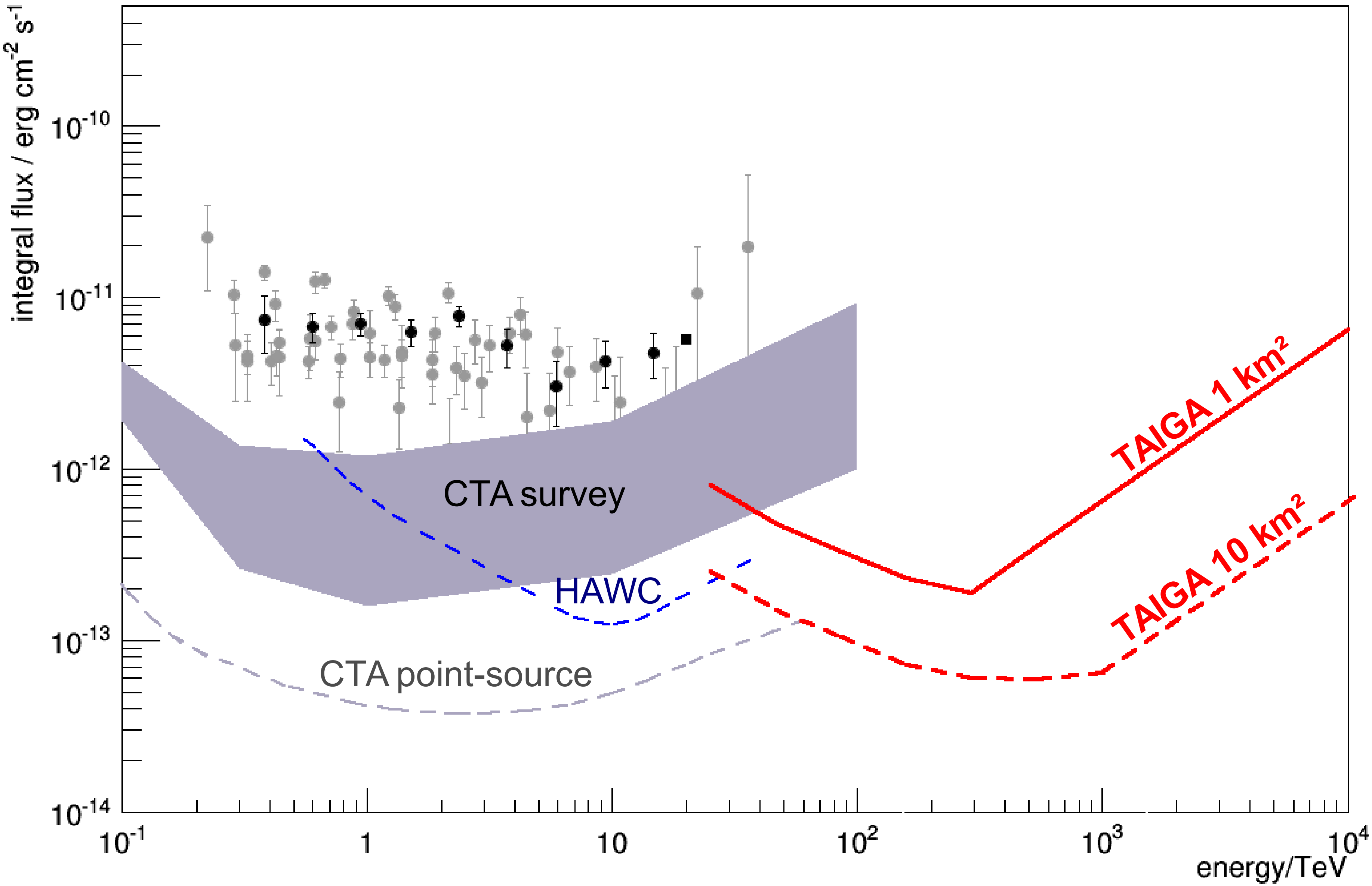
VHE-UHE Gamma-ray Astronomy



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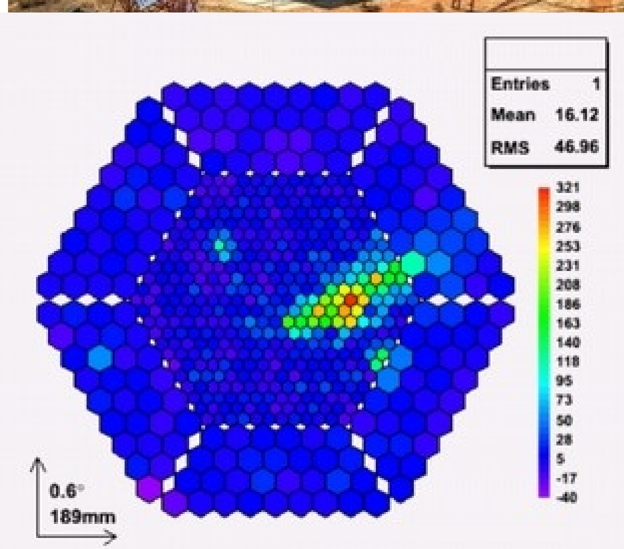
Tunka-HiSCORE → TAIGA (ТАЙГА)

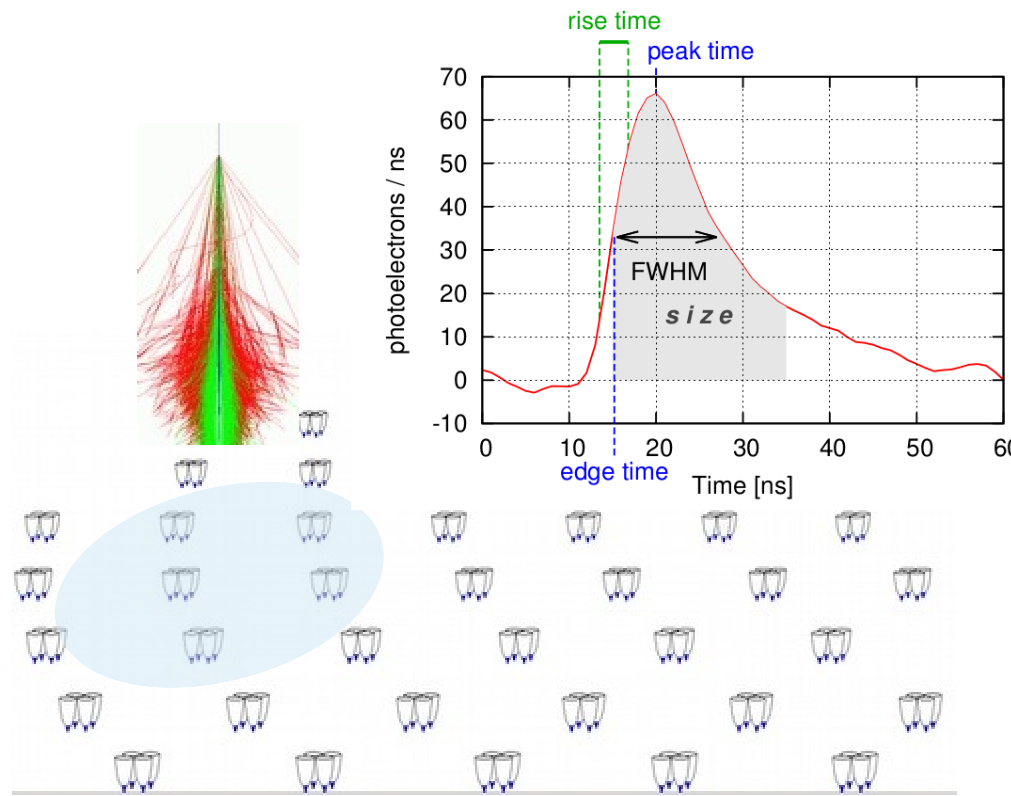
Air Cherenkov imaging and timing

Imaging arrays



MAGIC camera image

Timing arrays (non-imaging)



Past: Themistocle, AIROBICC
Today: HiSCORE, TAIGA

TAIGA

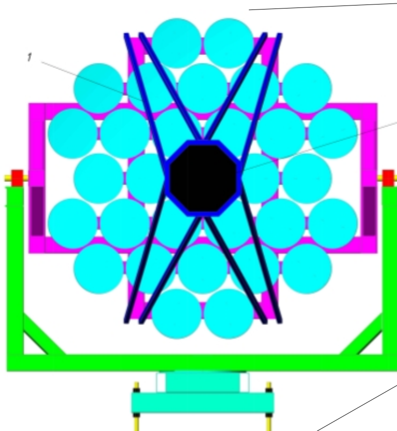
Tunka Advanced Instrument for Gamma ray and cosmic ray physics

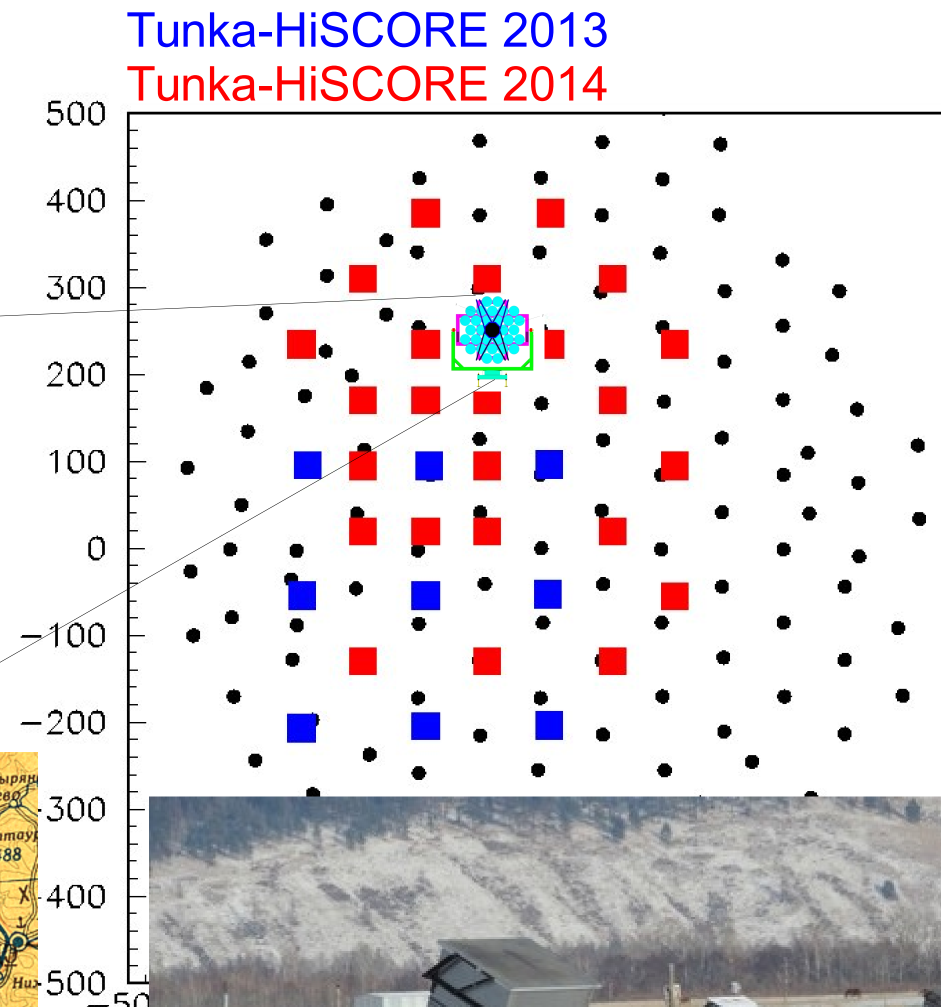
Since 2014

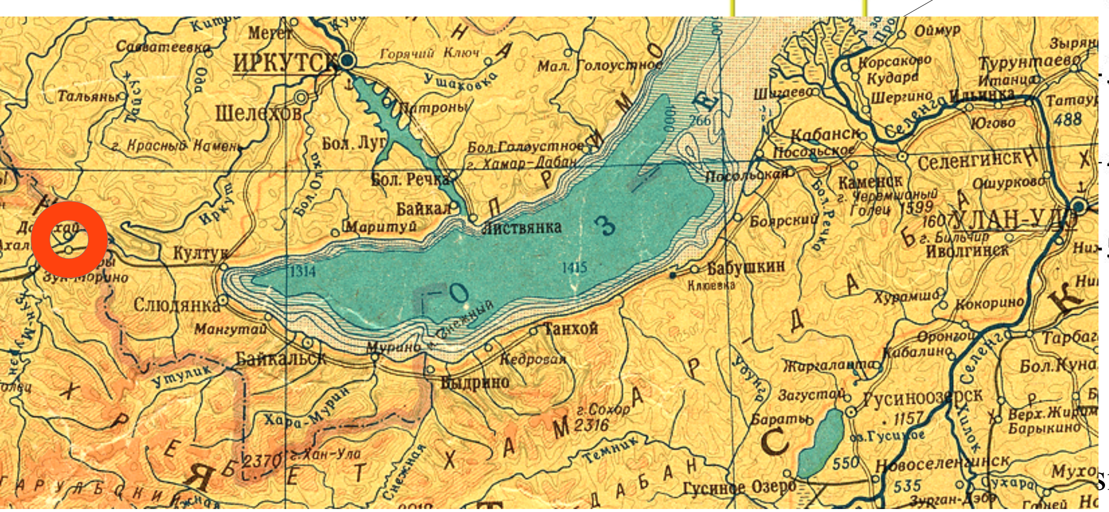
- Total: 28 stations
- Tilting mode
- 0.25 km²

2016:

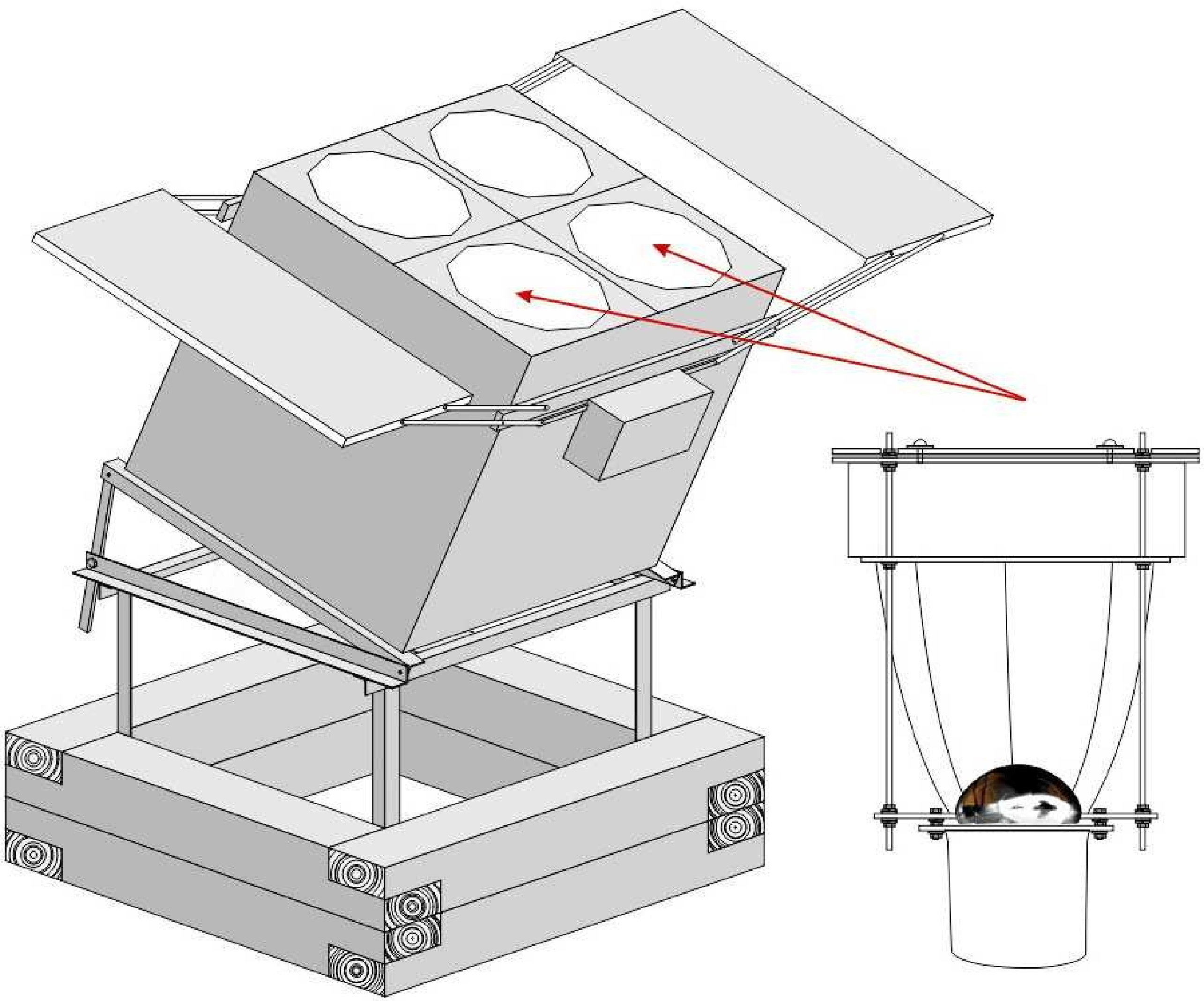
- First telescope under construction
- Hybrid timing+imaging







TAIGA timing stations



- Four 8'' PMTs
- Winston cones, light collection 0.5 m²
- GHz readout
- 60° FoV
- “Tilting” for extension of sky coverage
- **Sub-ns** time resolution & array-wide time synchronization

2 systems: O(500 ps)

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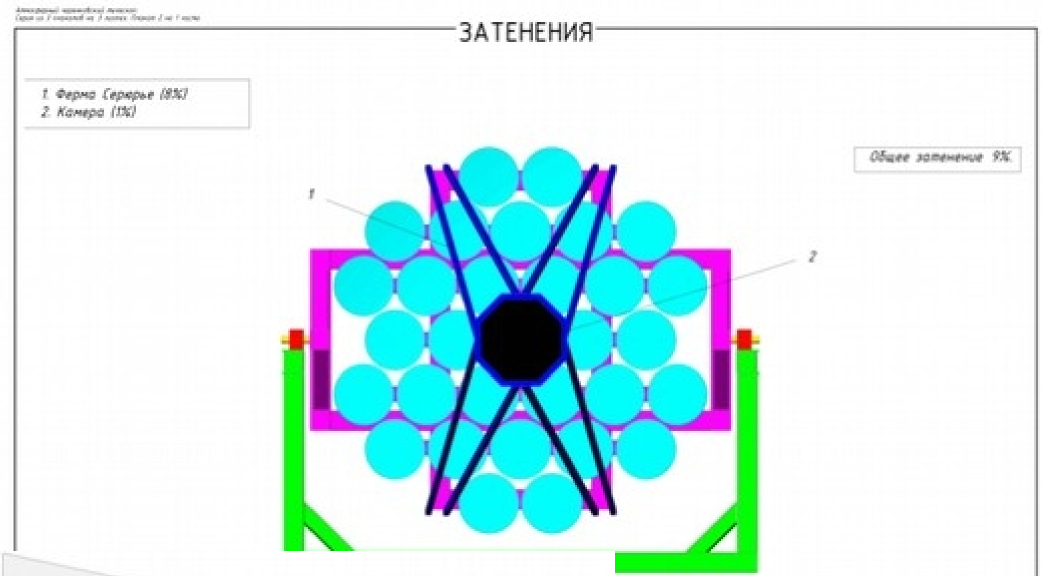
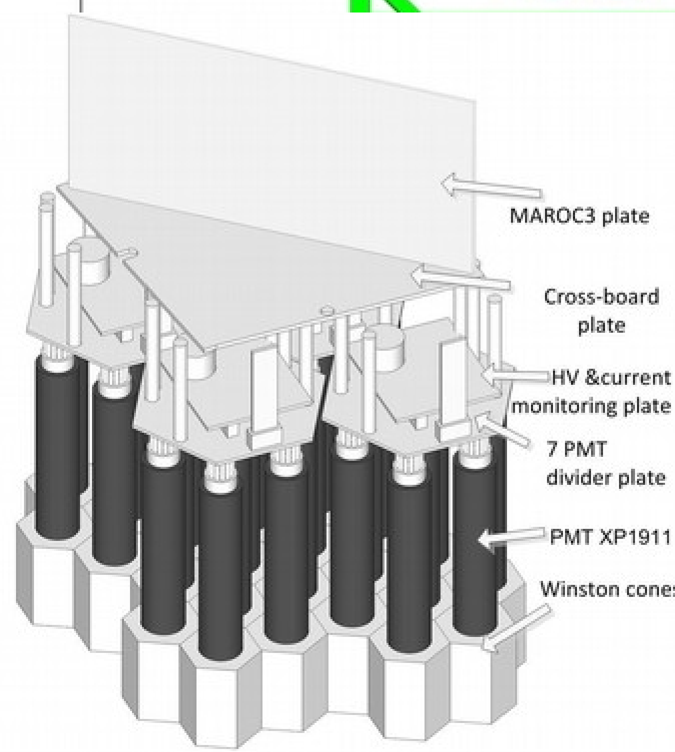
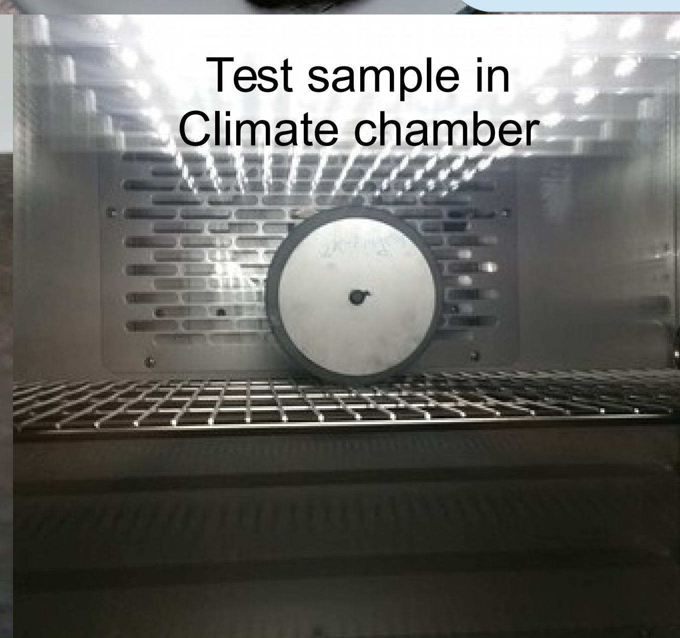
TAIGA Imaging Telescopes

- Dish: Davies-cotton tesselated, 34 mirrors (60cm)
- 4.3 m dish diameter
- 4.75 m focal length
- F/D ~ 1.2
- 397 PMT camera foV 10°
- Proven design components





Construction activities @ IExpPh, Hamburg



Timing and imaging hybrid detection

First-time implementation with TAIGA

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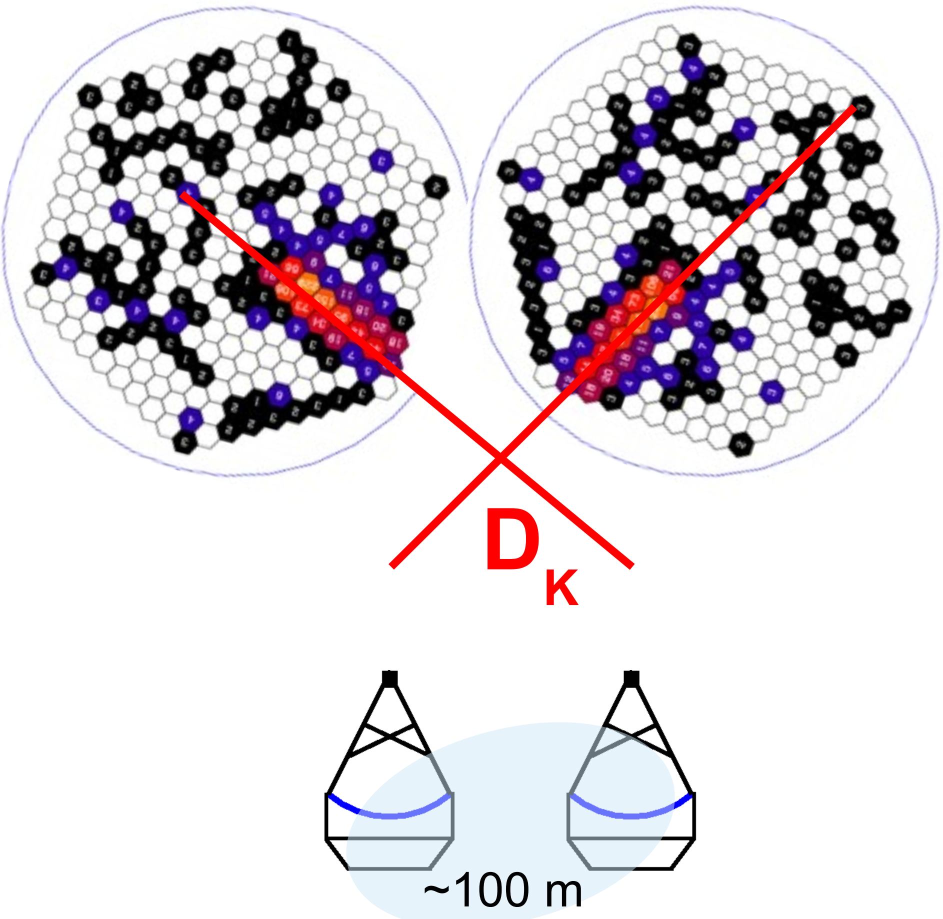
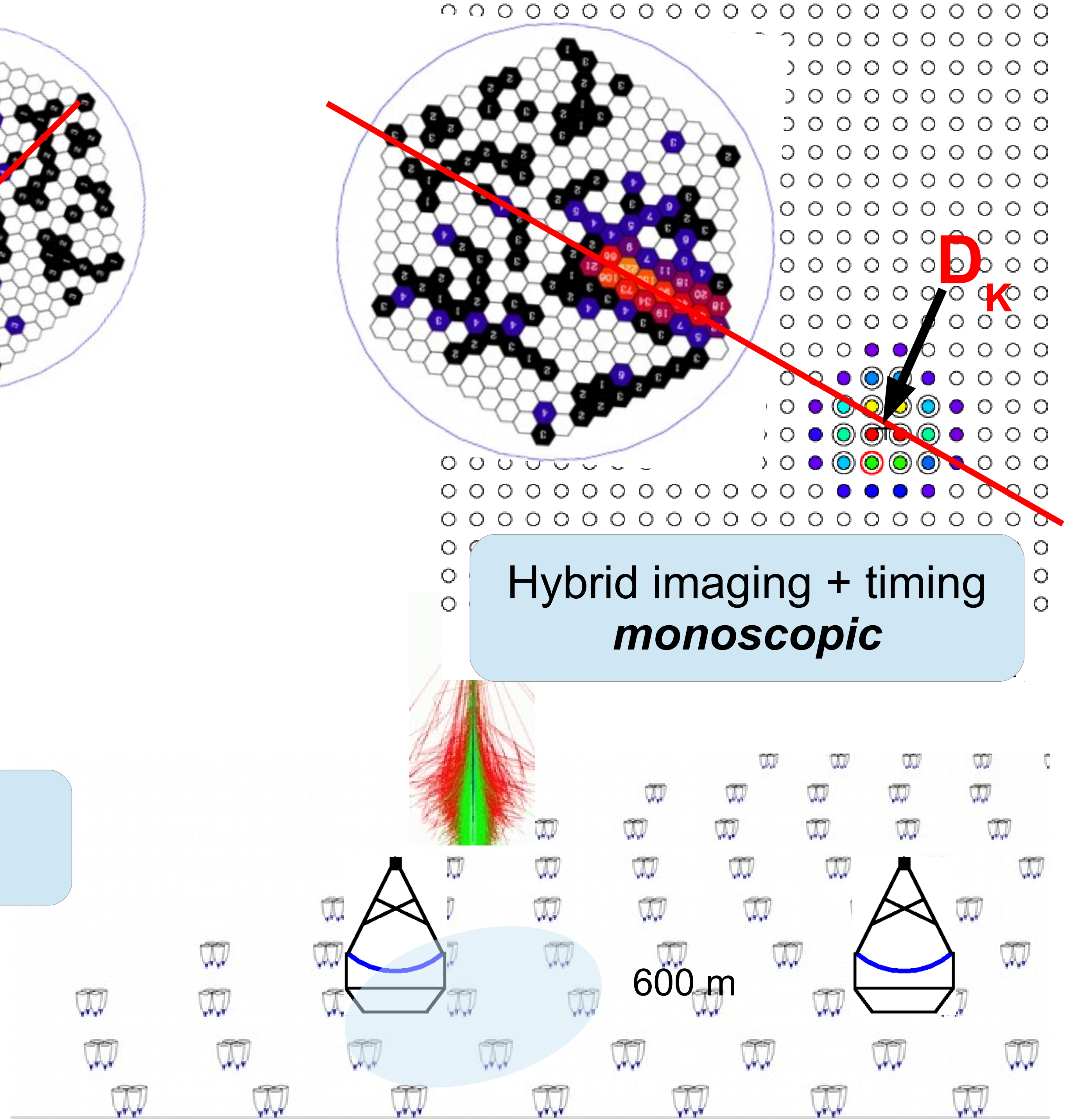


Classical Imaging
stereoscopic



Hybrid imaging + timing
monoscopic

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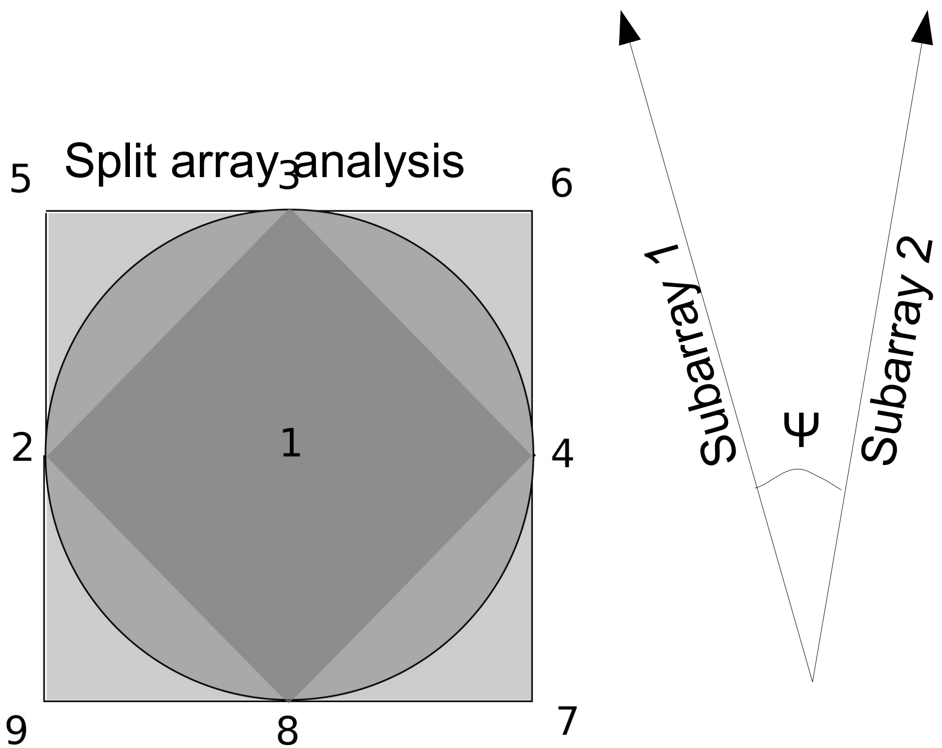
Real data



Reconstruct using two different subarrays

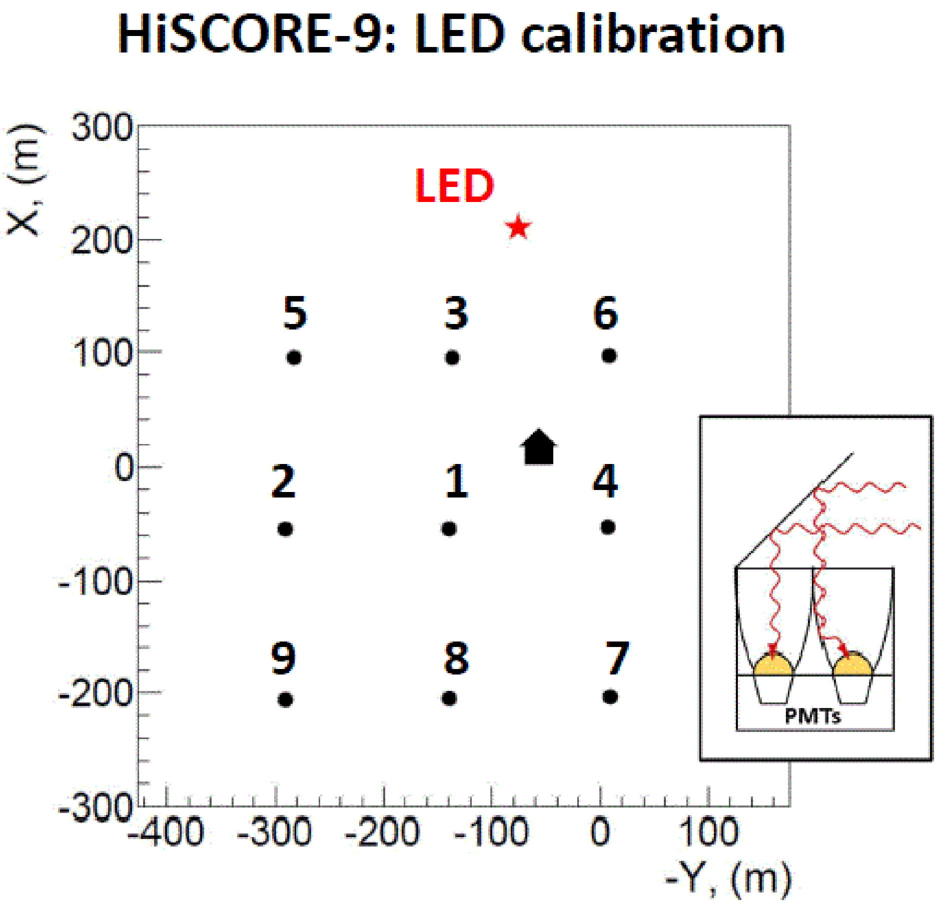
Tested for 9-station array

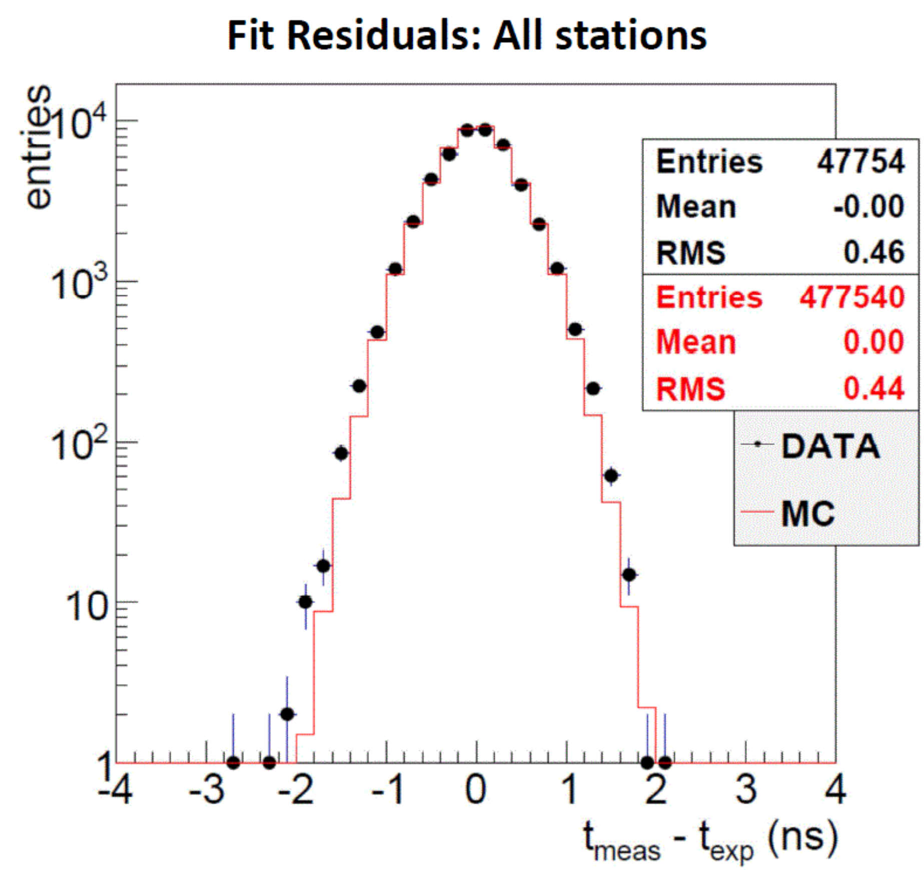
Resulting resolutions (hadrons):

- Direction: 0.19°
- Core position: 4m
- Energy: 10%

Epimakhov et al.
Porelli et al.
@ PoS, ICRC 2015

Time calibration





T-cal systems yield comparable accuraccies (<0.5 ns)

White Rabbit in laboratory: <60 ps resolution achievable (PoS ICRC 2015, Wischnewski et al.)

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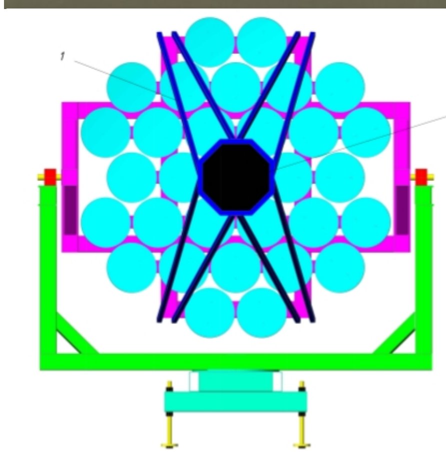
Summary



- Access to UHE gamma-ray regime
  Motivation also from neutrino events
- TAIGA timing array operational, 0.25 km^2
- 1st TAIGA IACT under construction
- New hybrid imaging+timing operation
  Goal: 10^{-13} erg cm^{-2} s^{-1} @ 100 TeV
- Future: muon detectors

2015: Journal of Physics: Conference Series (2015) 632 012042
2015: PoS(ICRC2015)1041
2014: Astroparticle Physics, 2014arXiv1403.5688T
2013NIMPA.712..137H, arXiv:1302.3957
2013: ICRC 1146, 1158, and 1164
2011AdSpR..48.1935T, astro-ph/1108.5880
http://wwwiexp.desy.de/groups/astroparticle/score/
http://tunka-hrjrg.desy.de/

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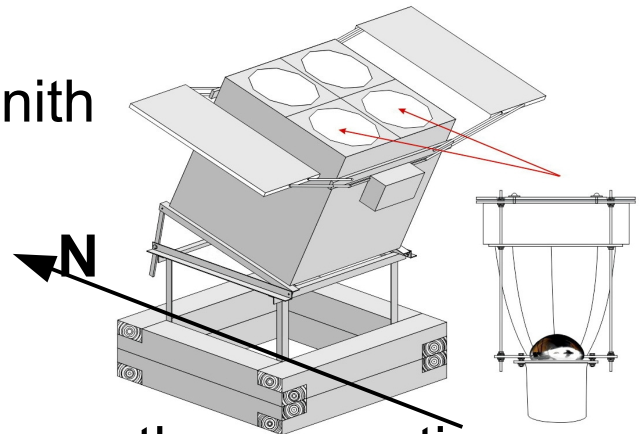
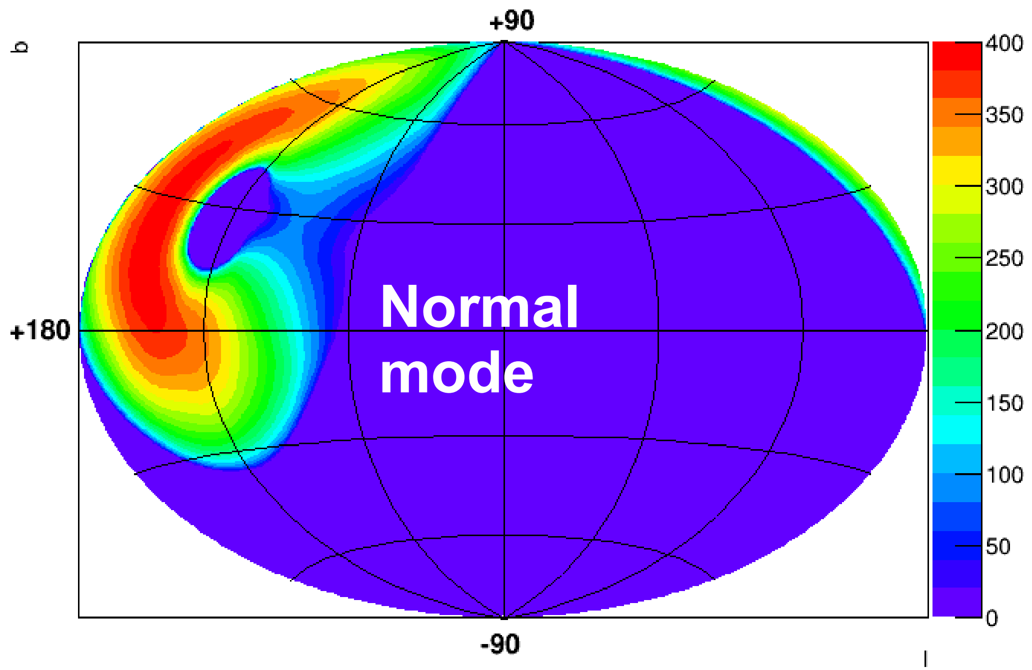
Sky coverage

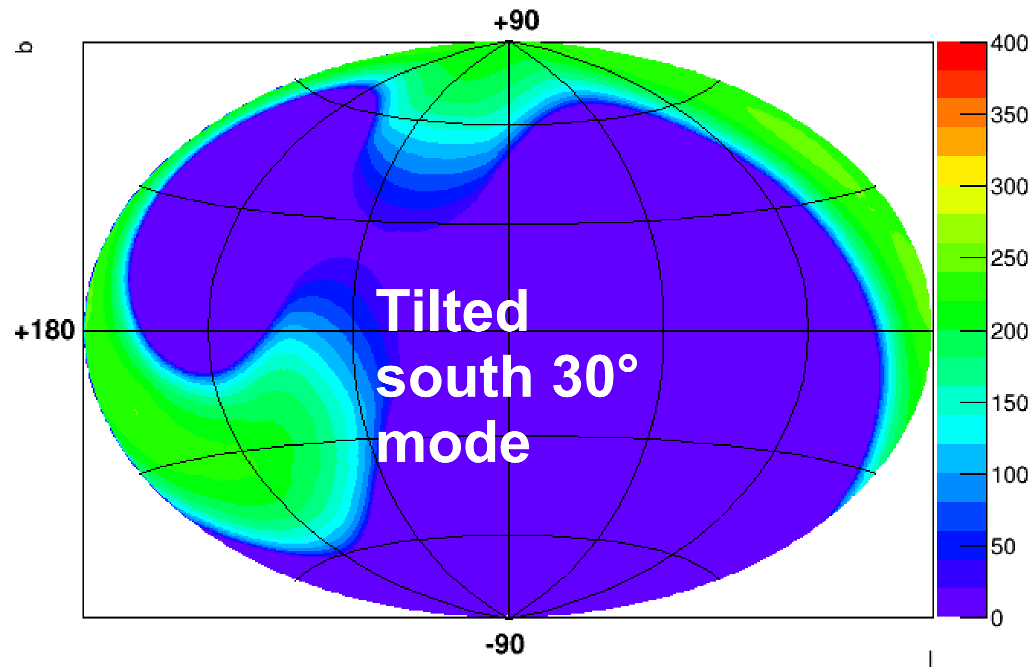
Standard observation mode: station points to zenith
Tilted mode: inclined along the north-south axis.

Tilting: coverage of different parts of the sky.



Tilted south mode: 110 h on the Crab Nebula, after weather corrections.





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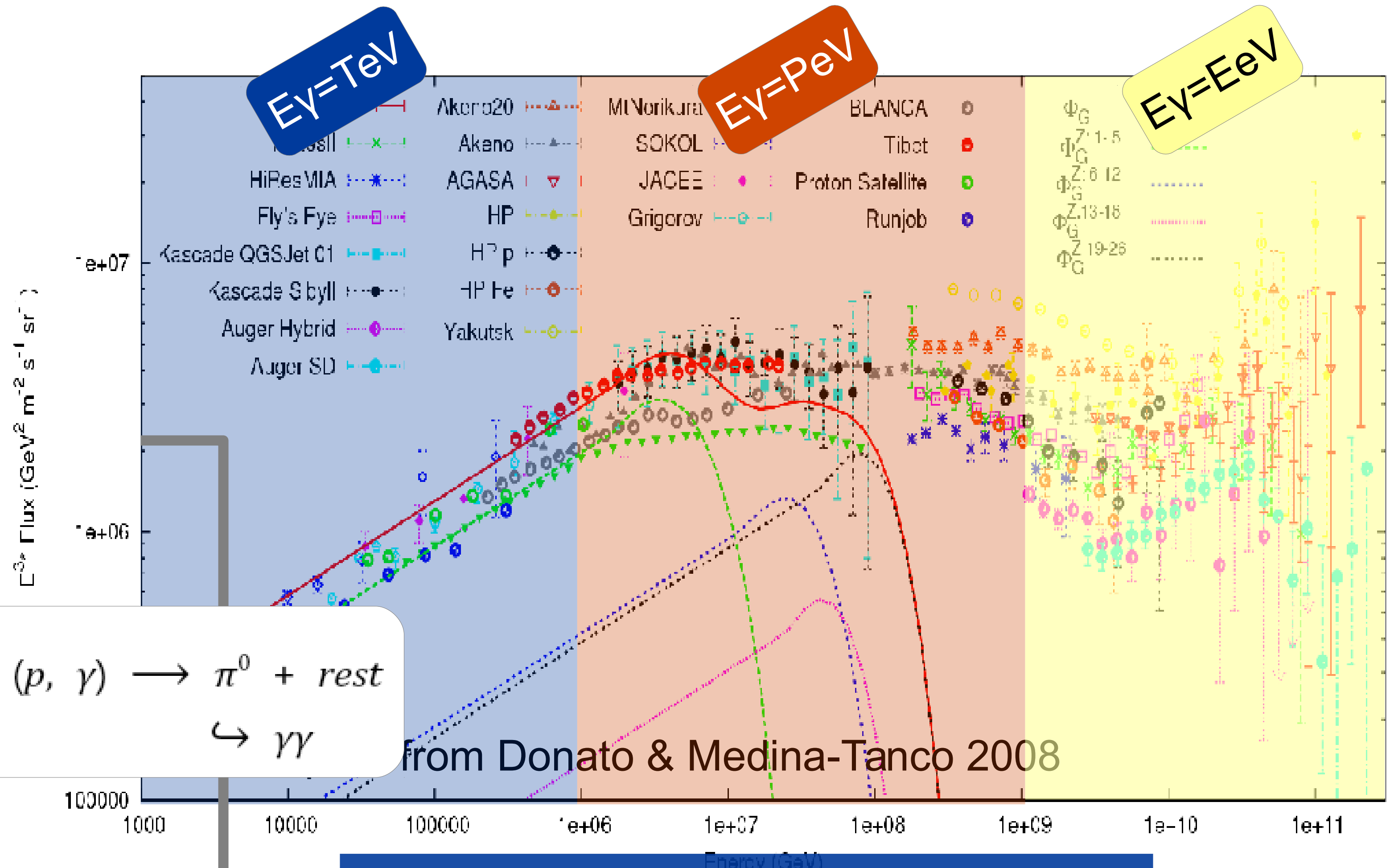
Cosmic ray origin

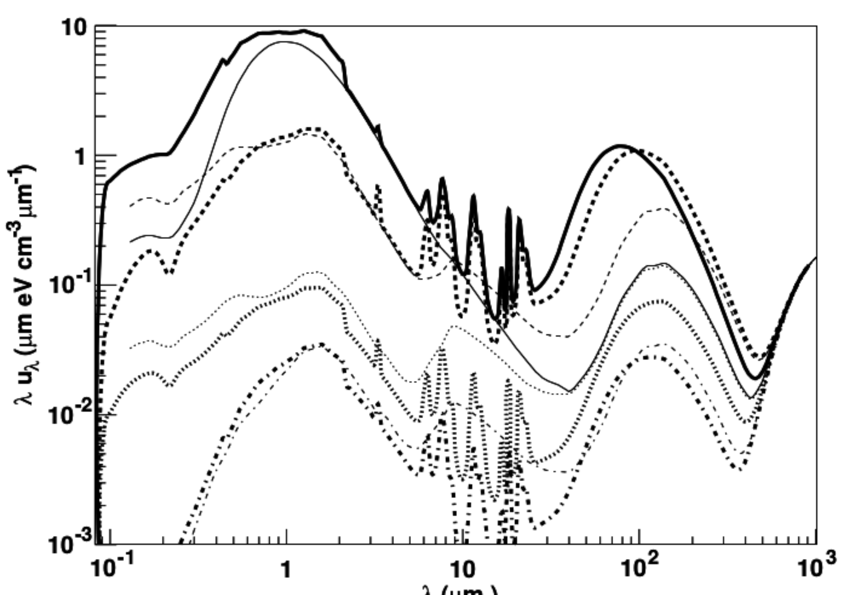


$$p\ (p,\ \gamma) \longrightarrow \pi^0 + rest$$
$$\hookrightarrow \gamma\gamma$$

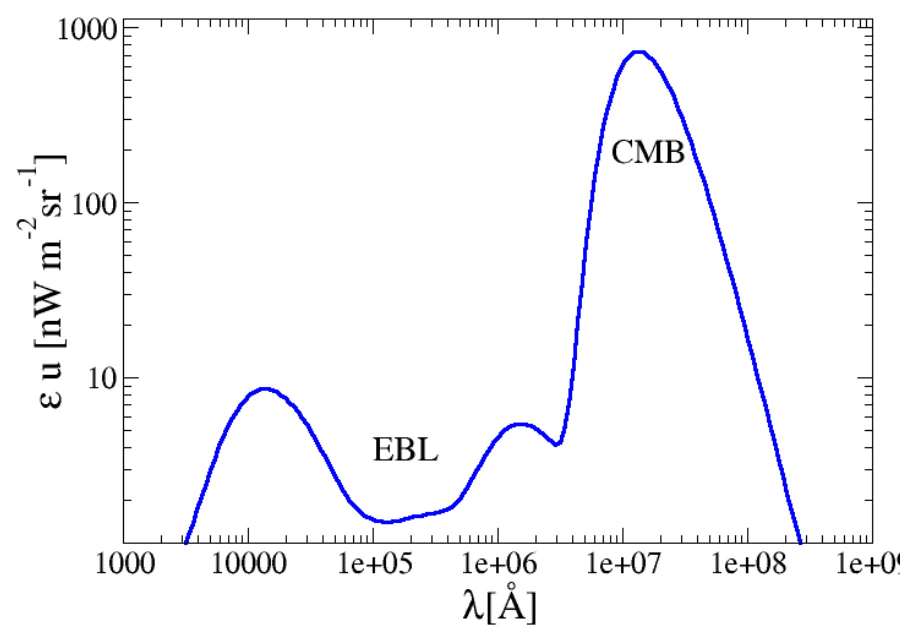
Gammas from Galactic Cosmic rays:
$E_\gamma \sim E_{CR}/10$

Radiation fields

- Interstellar radiation field (ISRF)
- Extragalactic background (EBL)
- Cosmic microwave background (CMB)



ISRF (Moskalenko 2006)



EBL & CMB
(Fairbairn et al. 2014)

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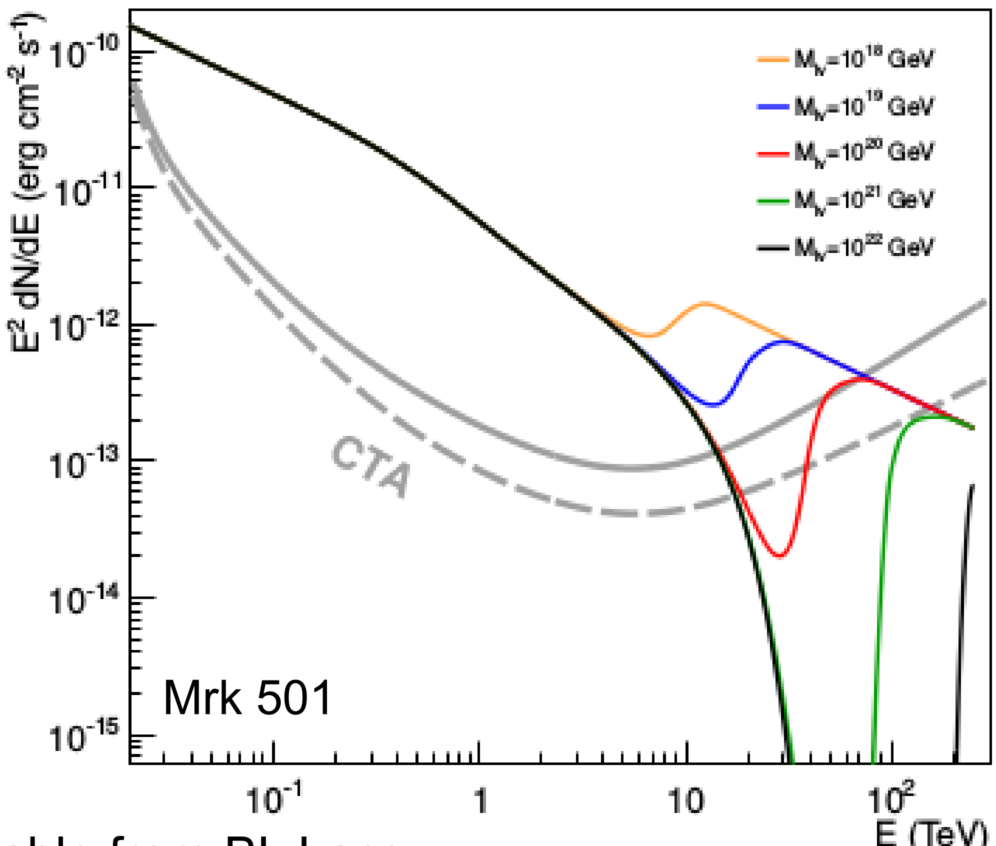
LIV sensitivity from gamma-rays

- **Current limits (γ-velocities):**

  M_{LV1} = 9.23 × 10^{19} GeV, M_{LV2} = 1.3 × 10^{11} GeV
  (Fermi GRBs, Vasileiou et al. 2013)
  M_{LV1} = 2.1 × 10^{18} GeV, M_{LV2} = 6.2 × 10^{10} GeV
  (AGN, Abramowski et al. 2011).

- **VHE: (CTA, Fairbairn et al. 2015)**

  expect competitive limits on $M_{\mathbf{LVn}}$
  ~ 10^{19} (n = 1)
  ~ 10^{12} (n =2)



- **VHE / UHE:**
  LIV → gamma-rays >10 PeV might be detectable from BL Lacs

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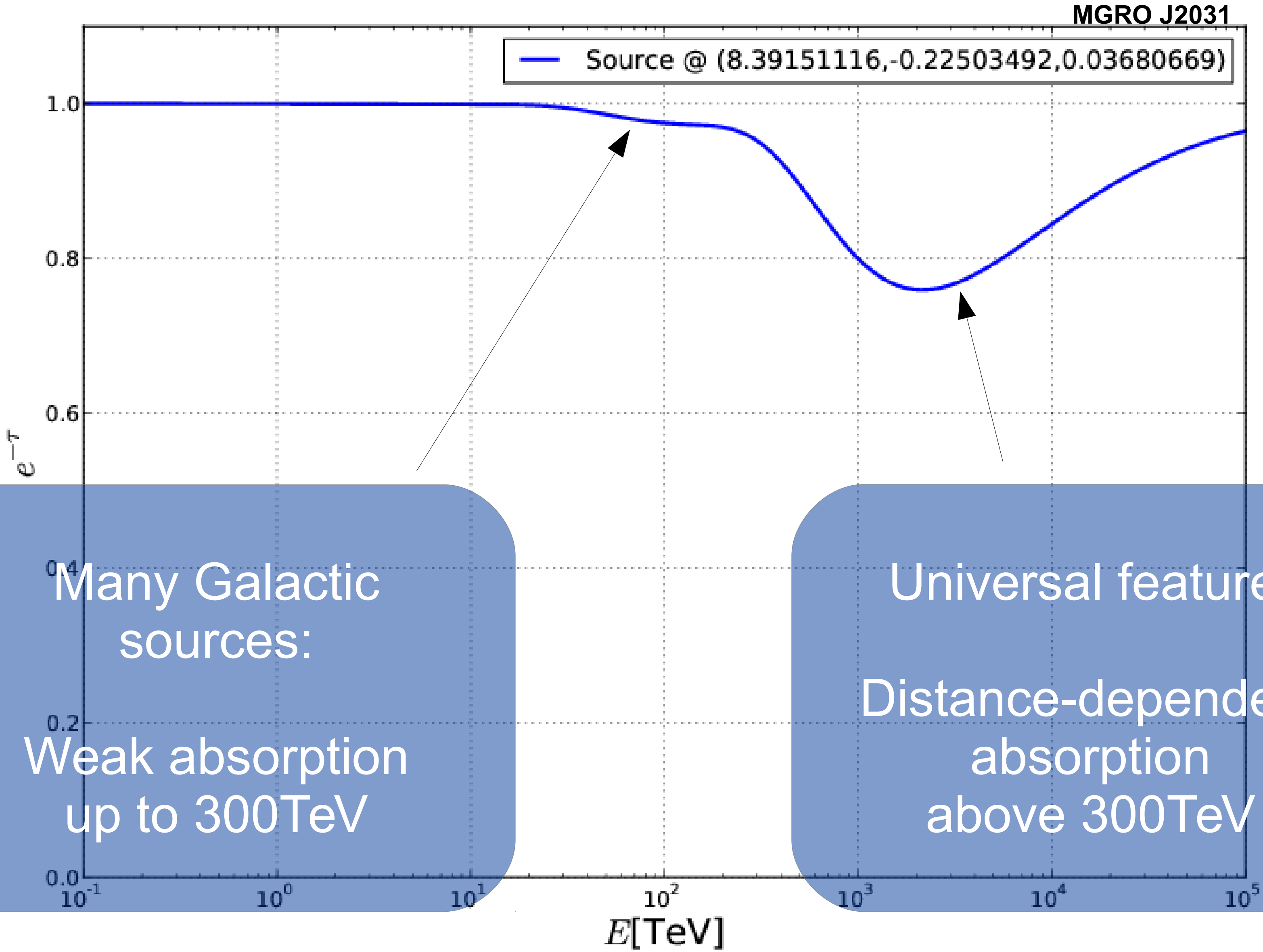
Absorption (e^+e^-), Galactic

A. Maurer



Many Galactic sources:

Weak absorption up to 300TeV

Universal feature:

Distance-dependent absorption above 300TeV

M

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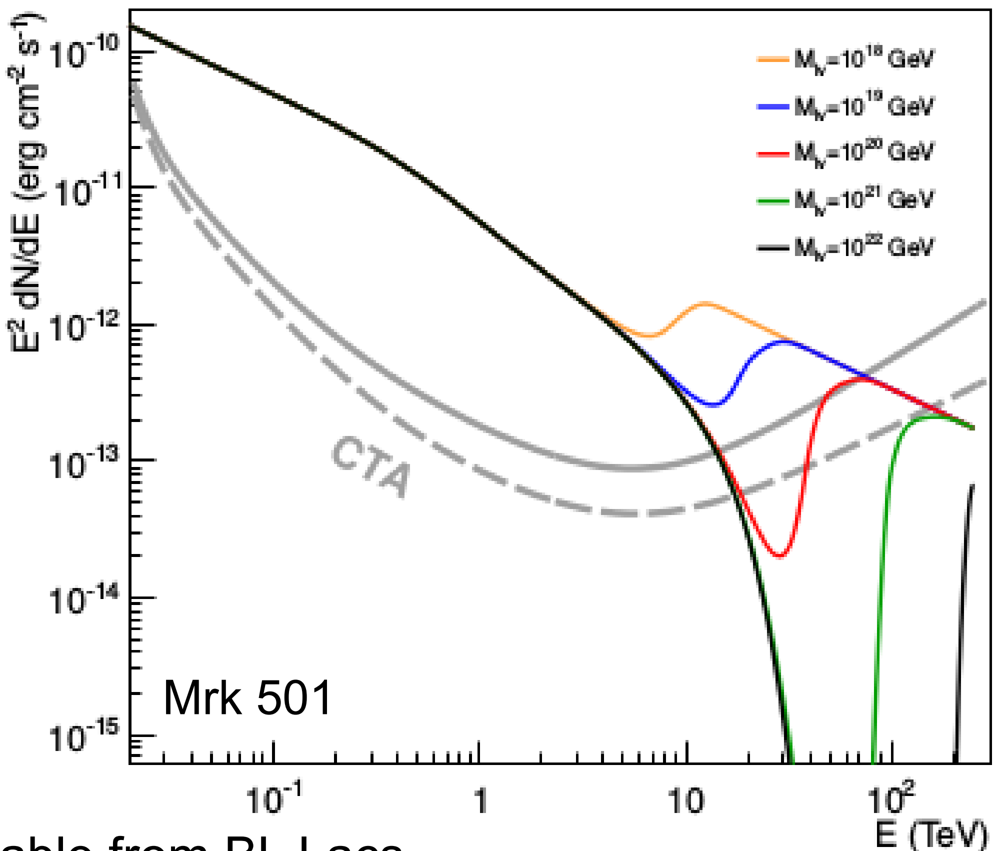

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