

IceCube overview

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UNIVERSITET

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Outline

1 Introduction

- The IceCube Collaboration
- Physics Motivation
- The IceCube Detector
- Event Types

2 Neutrinos

- Search for a diffuse flux of HE neutrinos
- Search for point sources of HE neutrinos
- Southern Sky

3 Cosmic Rays

- Cosmic Ray Anisotropy
- Shadow of the Moon (and Sun)

4 Particle Physics

- Dark Matter, SUSY
- Magnetic Monopoles
- Neutrino Oscillation

5 Conclusions and Outlook

The IceCube Collaboration



Collaborating Organizations

China University

Clark Atlanta University

Deutsches Elektronen-Synchrotron

Ecole Polytechnique Fédérale de Lausanne

Georgia Institute of Technology

Humboldt Universität

Lawrence Berkeley National Laboratory

Ohio State University

Pennsylvania State University

Princeton University

Ruhr-Universität Bochum

RWTH Aachen University

Southern University and

A&M College

Stockholm University

Stony Brook University

Technische Universität München

Universität Bonn

Universität Dortmund

Universität Mainz

Universität Wuppertal

Université libre de Bruxelles

Université de Mons

Université de Québec à Montréal

University of Alberta

University of Alaska Anchorage

University of California-Berkeley

University of California-Irvine

University of Canterbury

University of Delaware

University of Geneva

University of Gent

University of Kansas

University of Maryland

University of Oxford

University of the West Indies

University of Wisconsin-Madison

University of Wisconsin-River Falls

Uppsala Universitet

Vrije Universiteit Brussel

International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)

Fonds Wetenschappelijk Onderzoek-Vlaanderen
(FWO-Vlaanderen)

Federal Ministry of Education & Research (BMBF)

German Research Foundation (DFG)

Deutsches Elektronen-Synchrotron (DESY)

Knut and Alice Wallenberg Foundation

Swedish Polar Research Secretariat

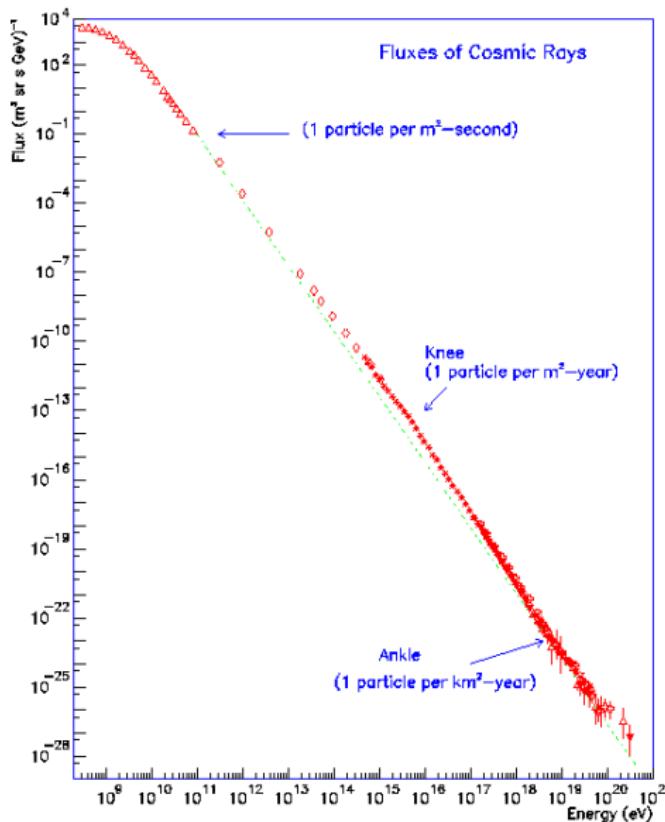
The Swedish Research Council (VR)

University of Wisconsin Alumni Research
Foundation (WARF)

US National Science Foundation (NSF)

- 286 names on authorlist
 - Uppsala: 7
 - Stockholm: 10
 - Rest of the world: 269
- 41 institutions:
 - Sweden: 2
 - Rest of Europe: 16
 - USA+Canada: 20
 - Japan, NZ, Australia: 3

What is the origin of UHE cosmic rays?



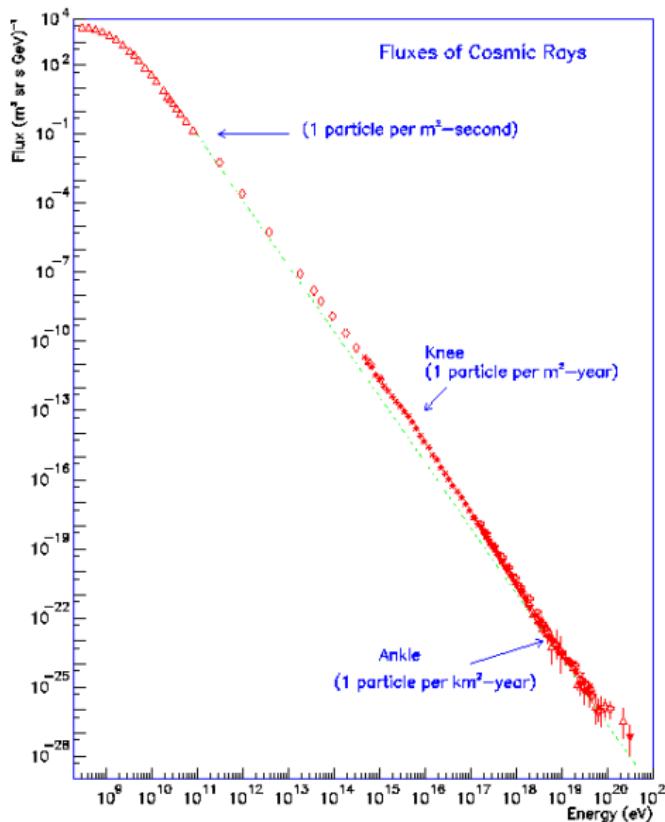
Questions:

- Sources?
 - Acceleration mechanisms?
- Hypotheses:
- AGN
 - GRB
 - SNR
 - ...
 - All of the above?

Cosmic messengers:

- Baryonic (protons, cosmic rays)? Deflected...
- Electromagnetic (gammas, photons)? Absorbed...
- Neutrinos! Challenging...

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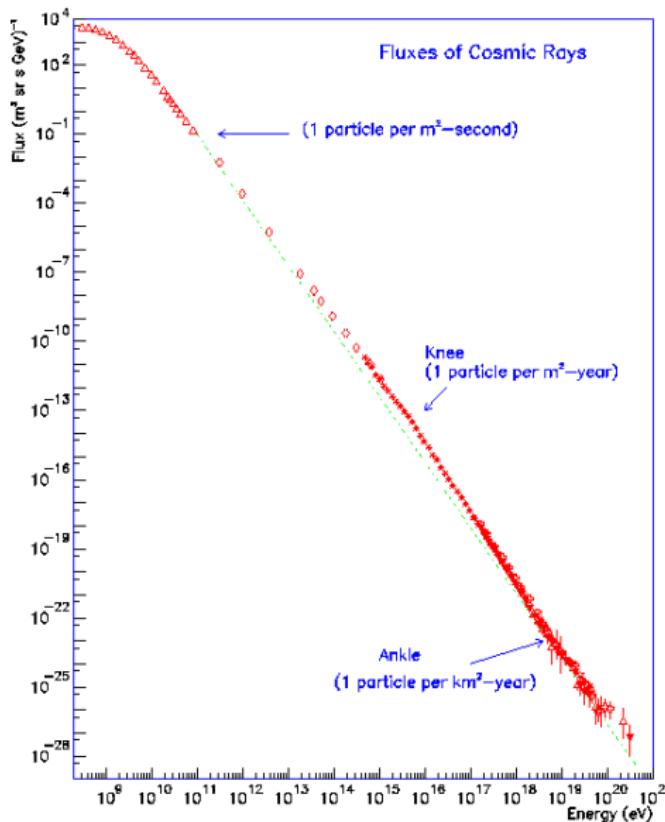
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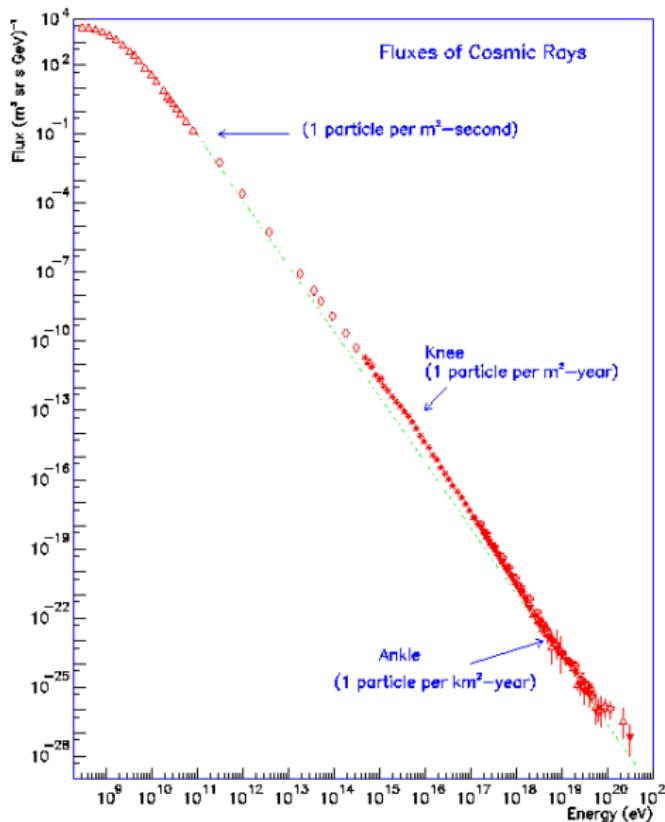
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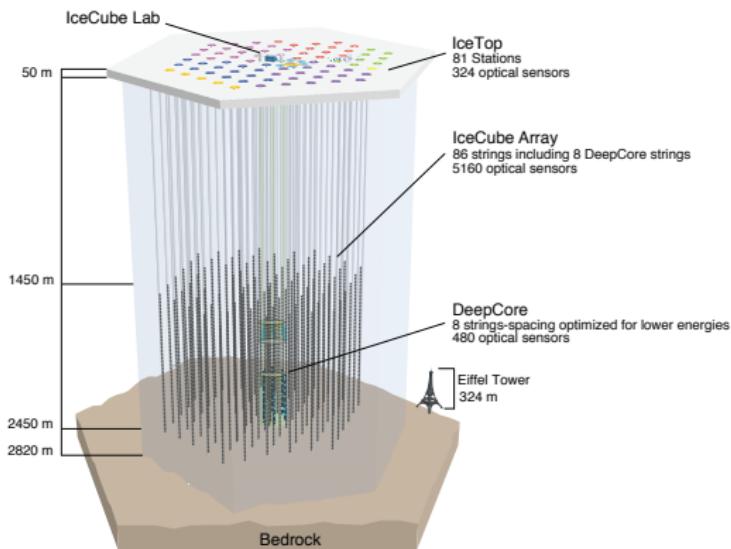
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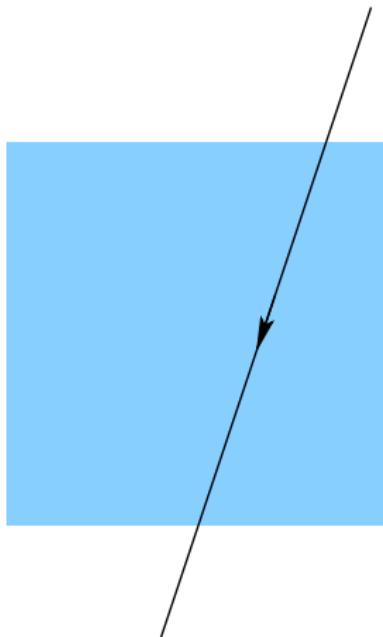
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- Trigger rate ~ 3 kHz.
- Average optical properties:
 - Scattering $\lambda_s^{eff} \approx 30$ m
 - Absorption $\lambda_a^{eff} \approx 100$ m
 - (For Antares/KM3NET it's the other way round, roughly.)
- Muon Tracks:
 - 4π acceptance
 - angular resolution $\mathcal{O}(1^\circ)$
- Energy threshold $\mathcal{O}(10\text{GeV})$
- Energy resolution: \sim factor of 2

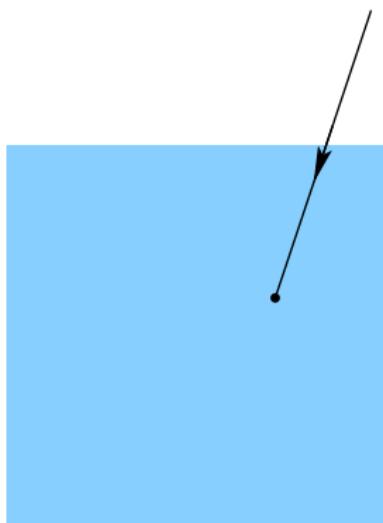


Event Types (1): cosmic ray muons



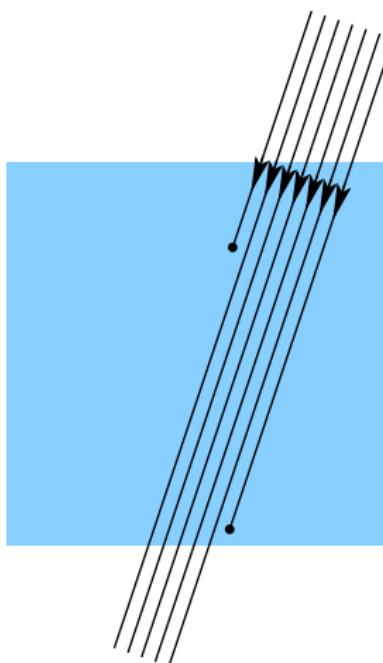
- $\text{CR} \rightarrow \mu$
- $\text{CR} \rightarrow \mu$ (LE)
- $\text{CR} \rightarrow \mu$ bundle
- $\text{CR} \rightarrow \mu$ (high p_T)
- $\text{CR} \rightarrow \mu$ (corner)
- $2\text{CR} \rightarrow 2\mu$ (coinc)

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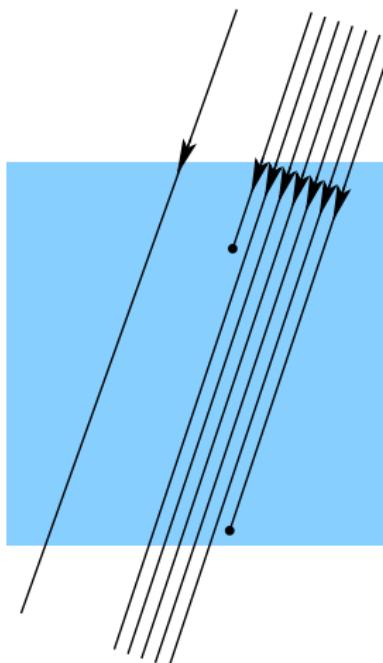
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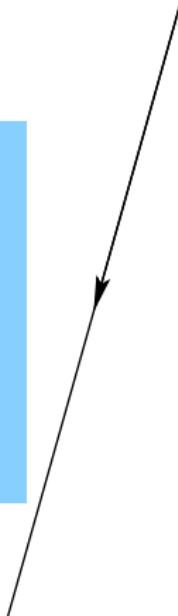
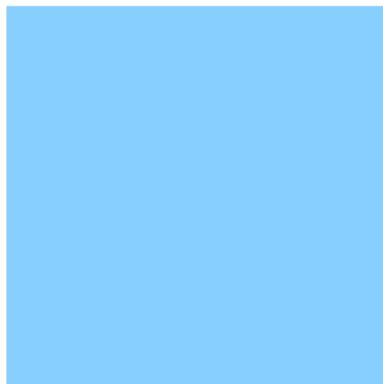
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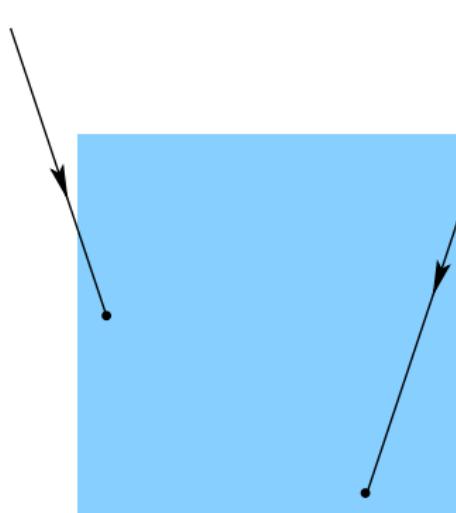
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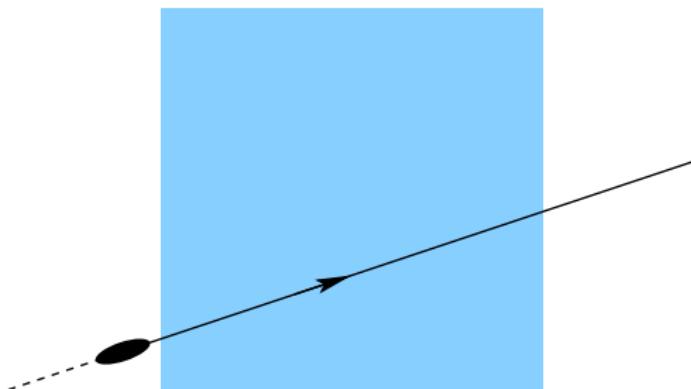
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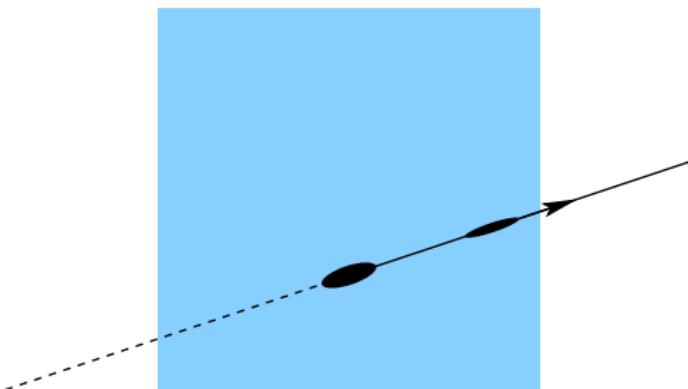
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Event Types (2): neutrinos



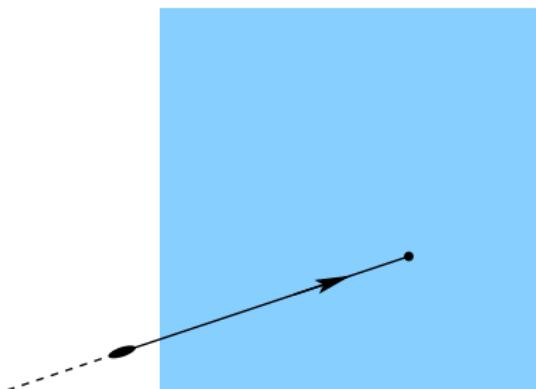
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Event Types (2): neutrinos



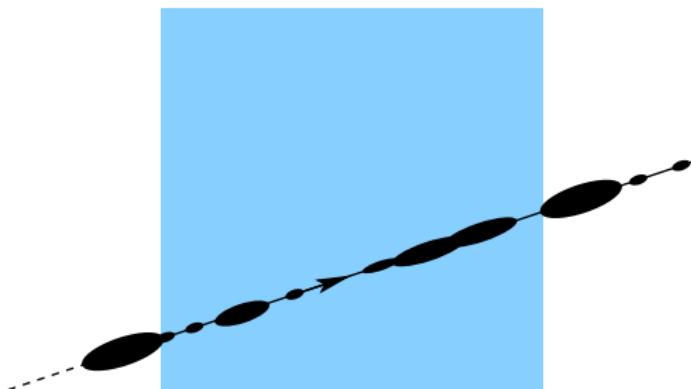
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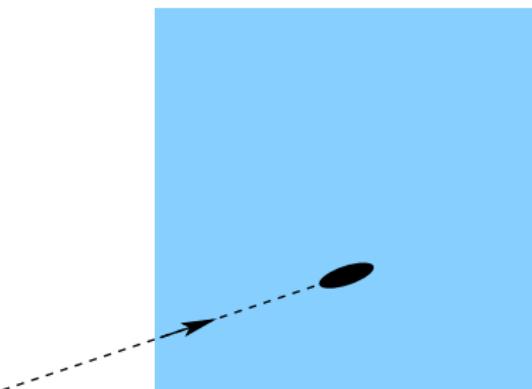
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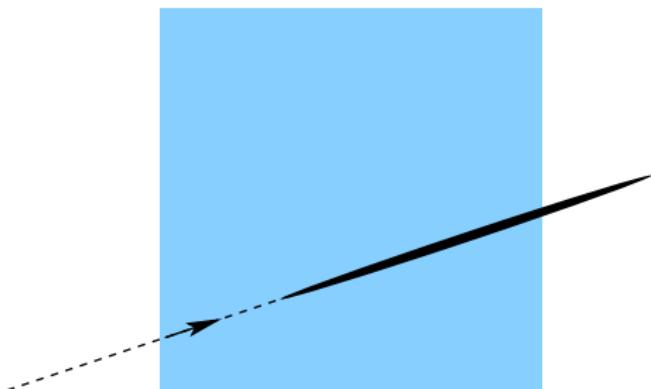
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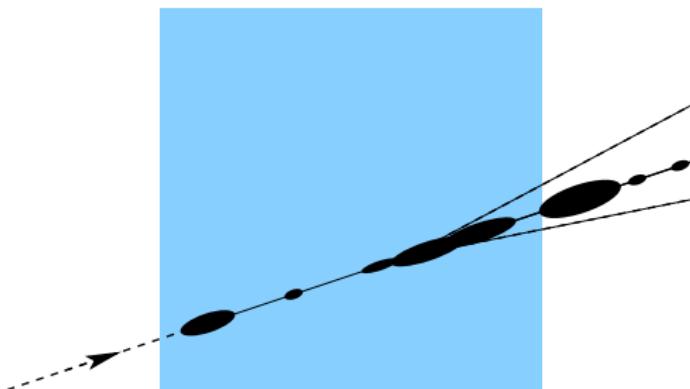
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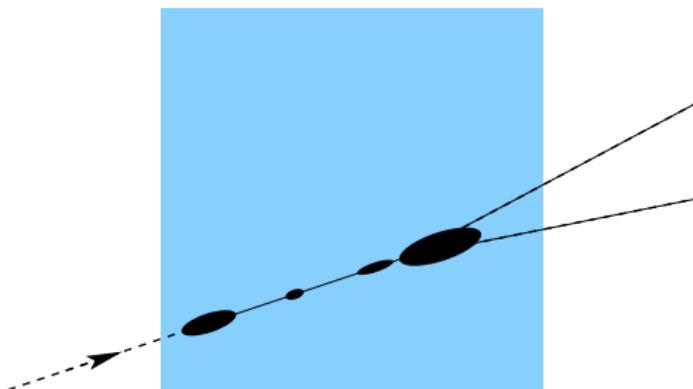
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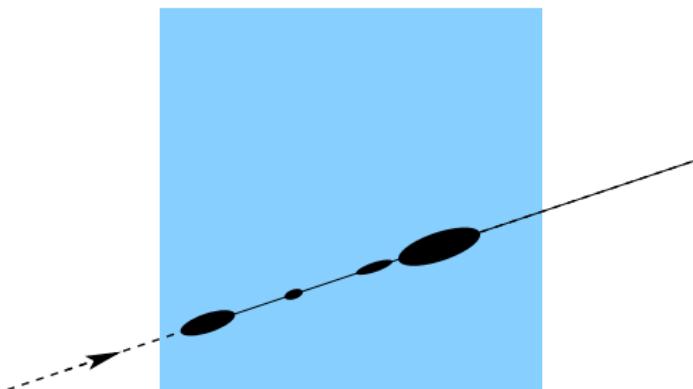
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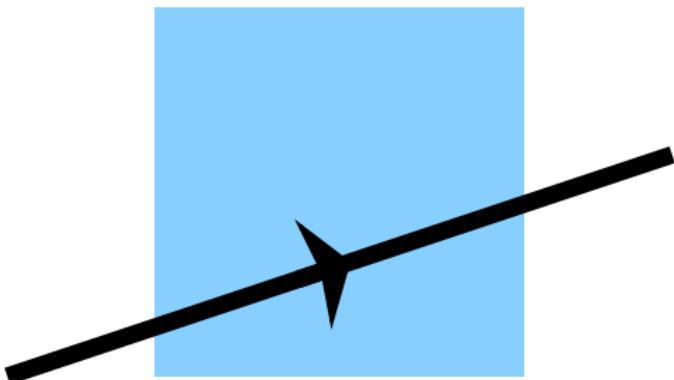
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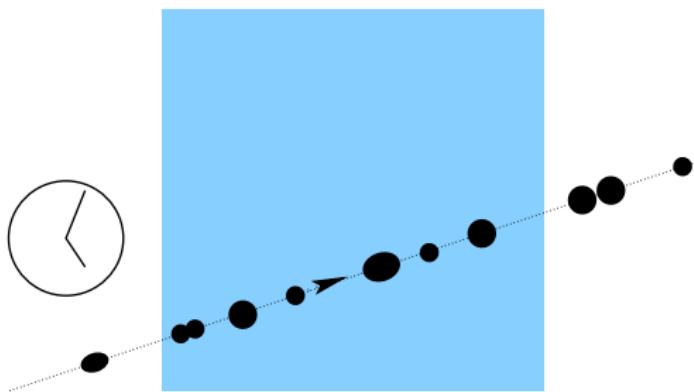
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Event Types (3): Exotics



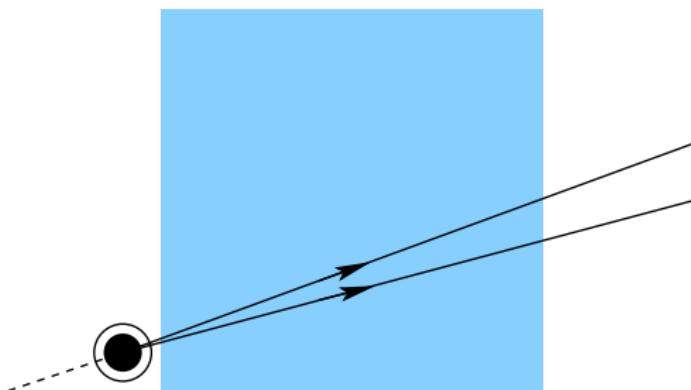
- relativistic magnetic monopoles
- slow magnetic monopoles
- microscopic black holes
- ...

Event Types (3): Exotics



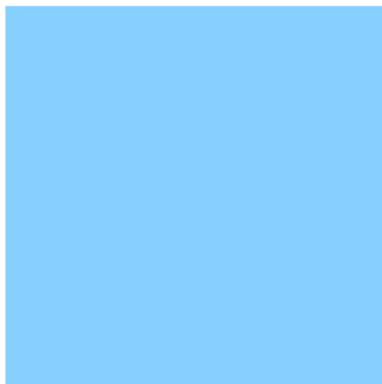
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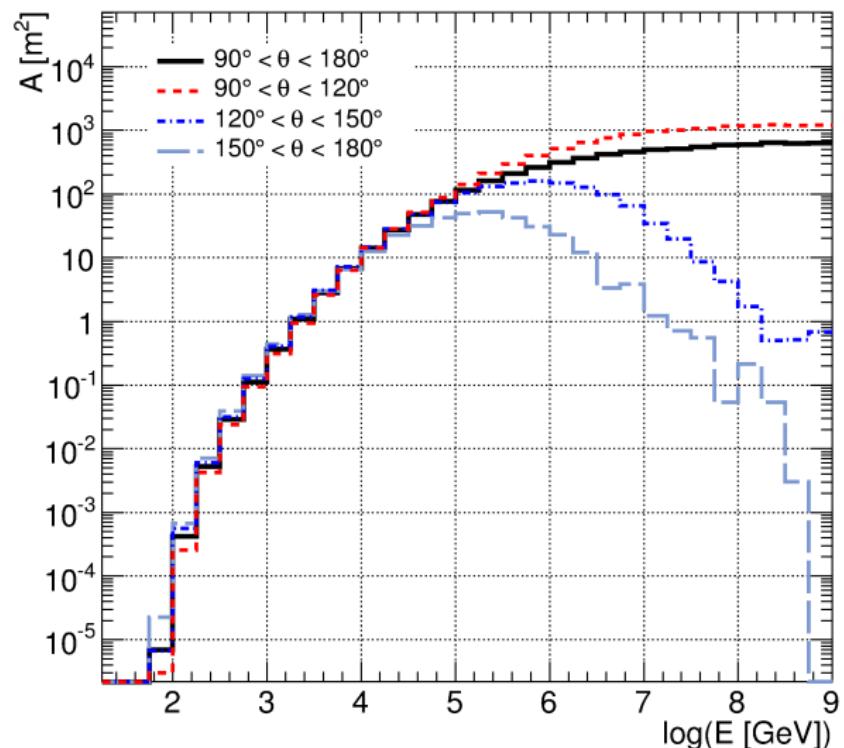
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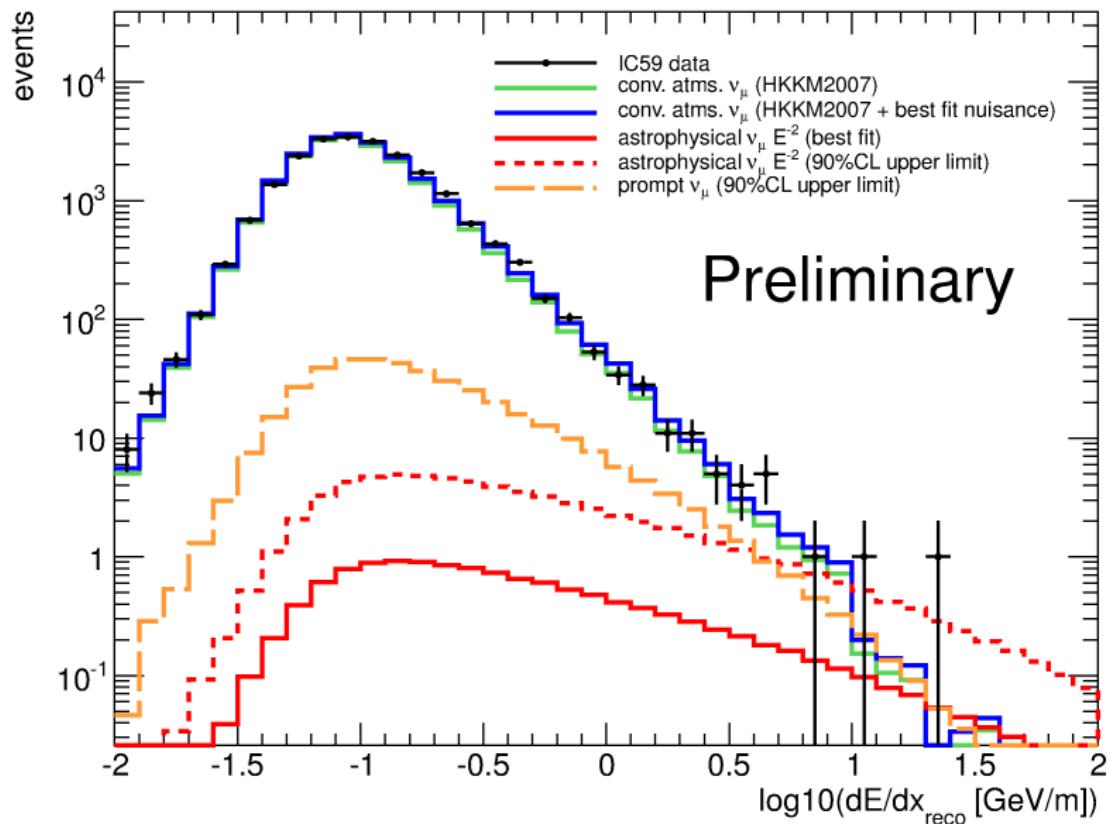


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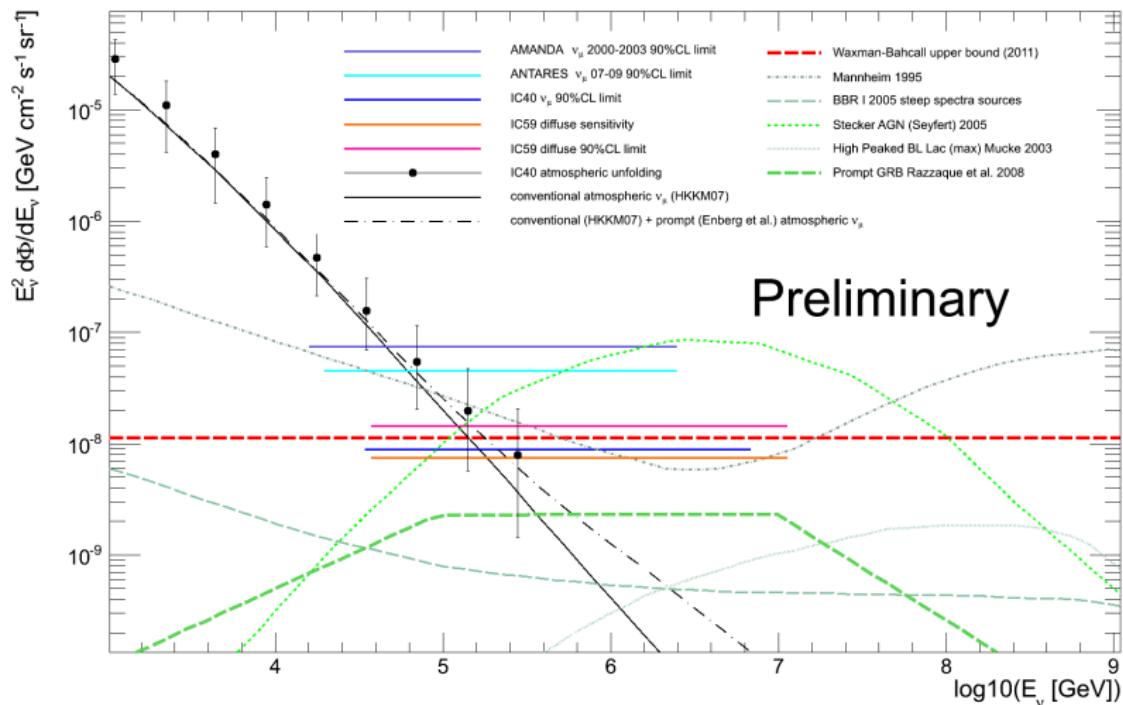
Search for a diffuse flux of HE neutrinos (IC59)



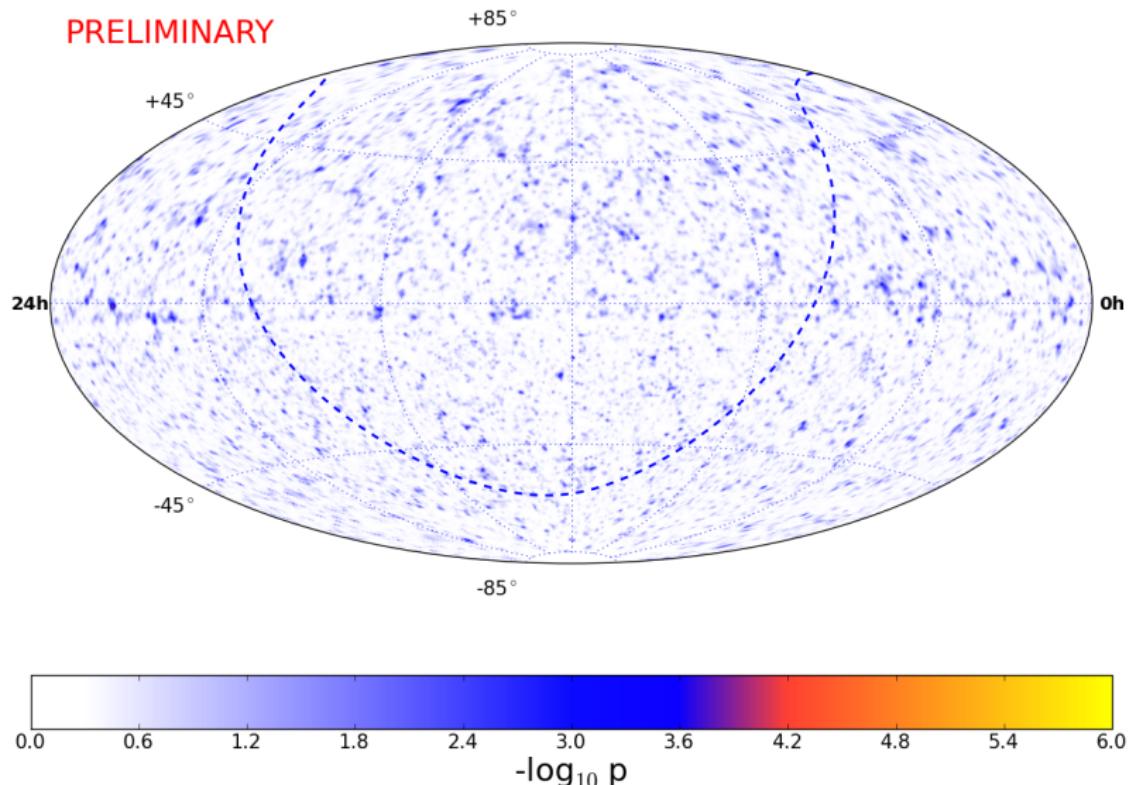
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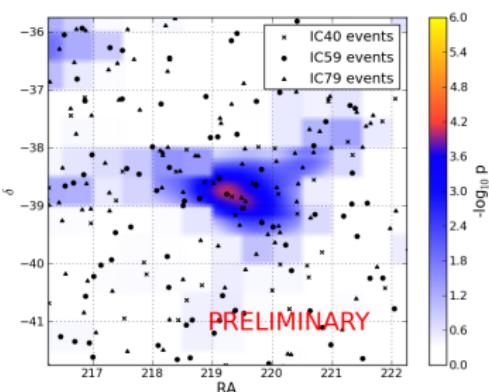
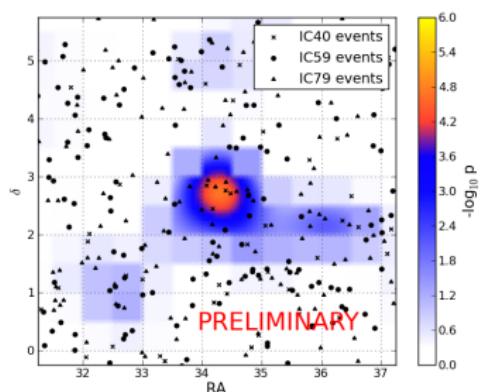
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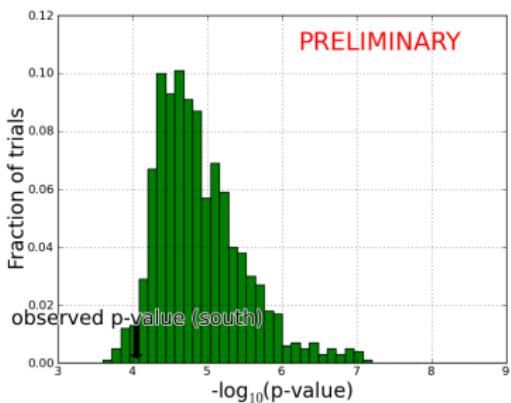
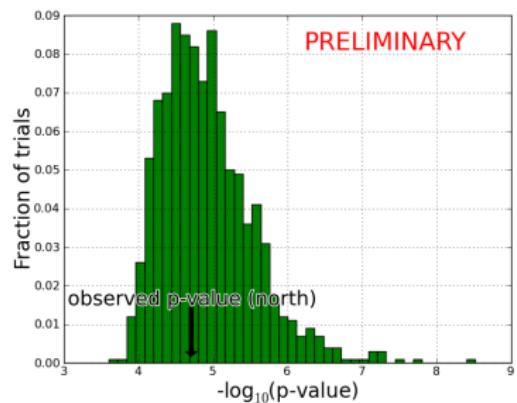
Search for point sources of HE neutrinos



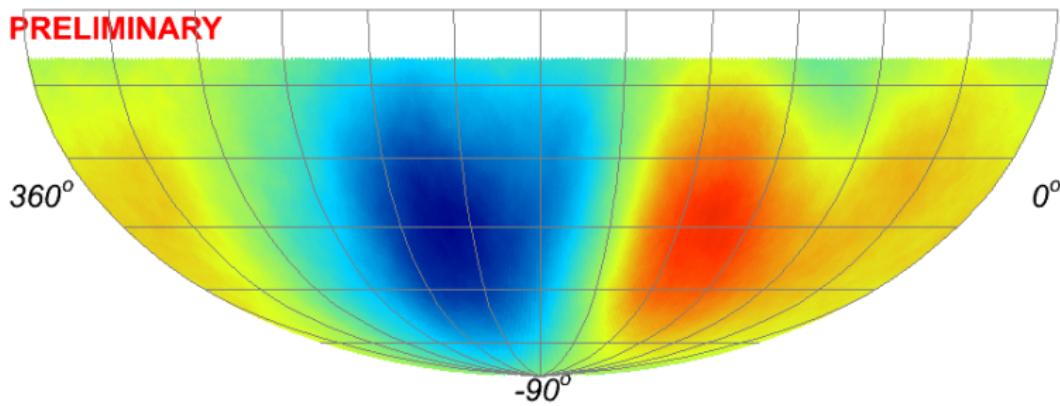
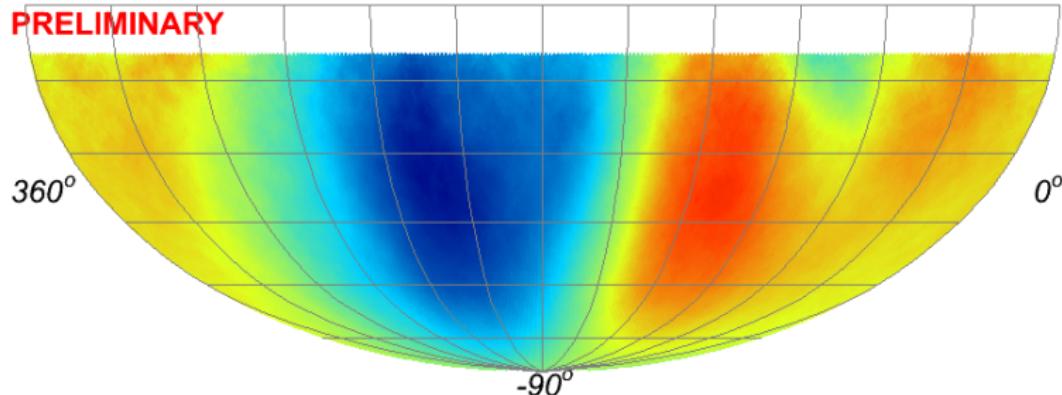
Hot spots



Post-trial significance



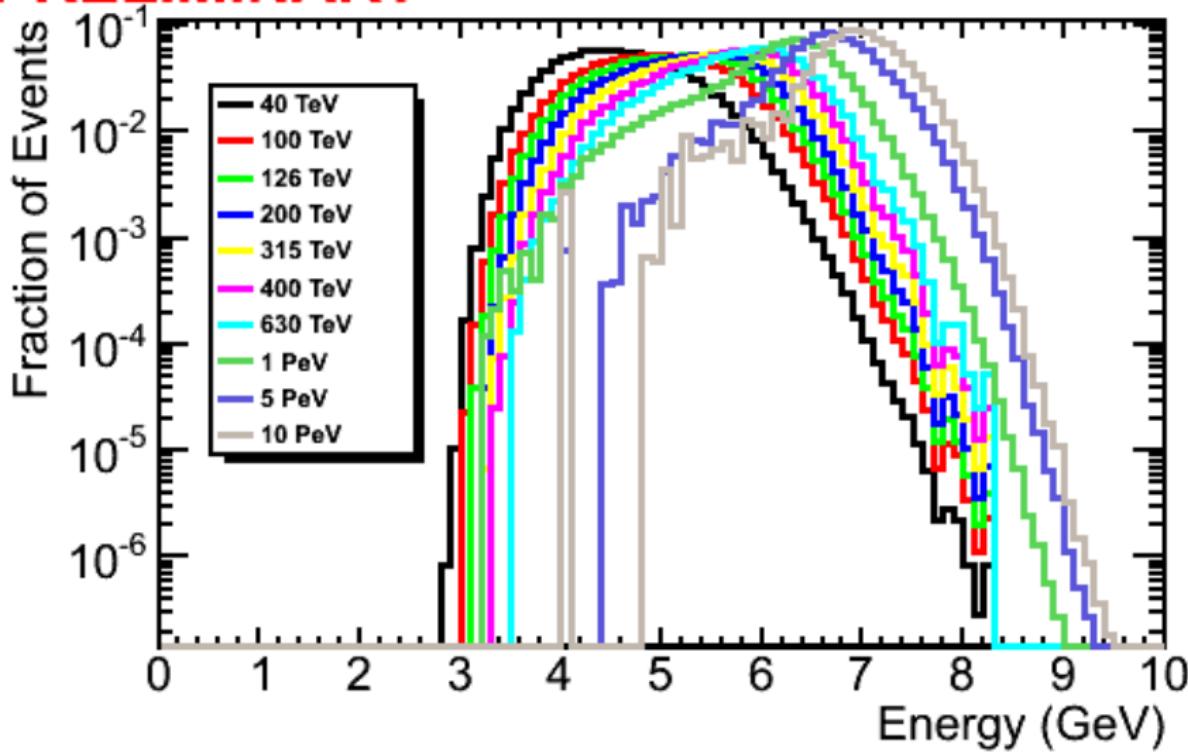
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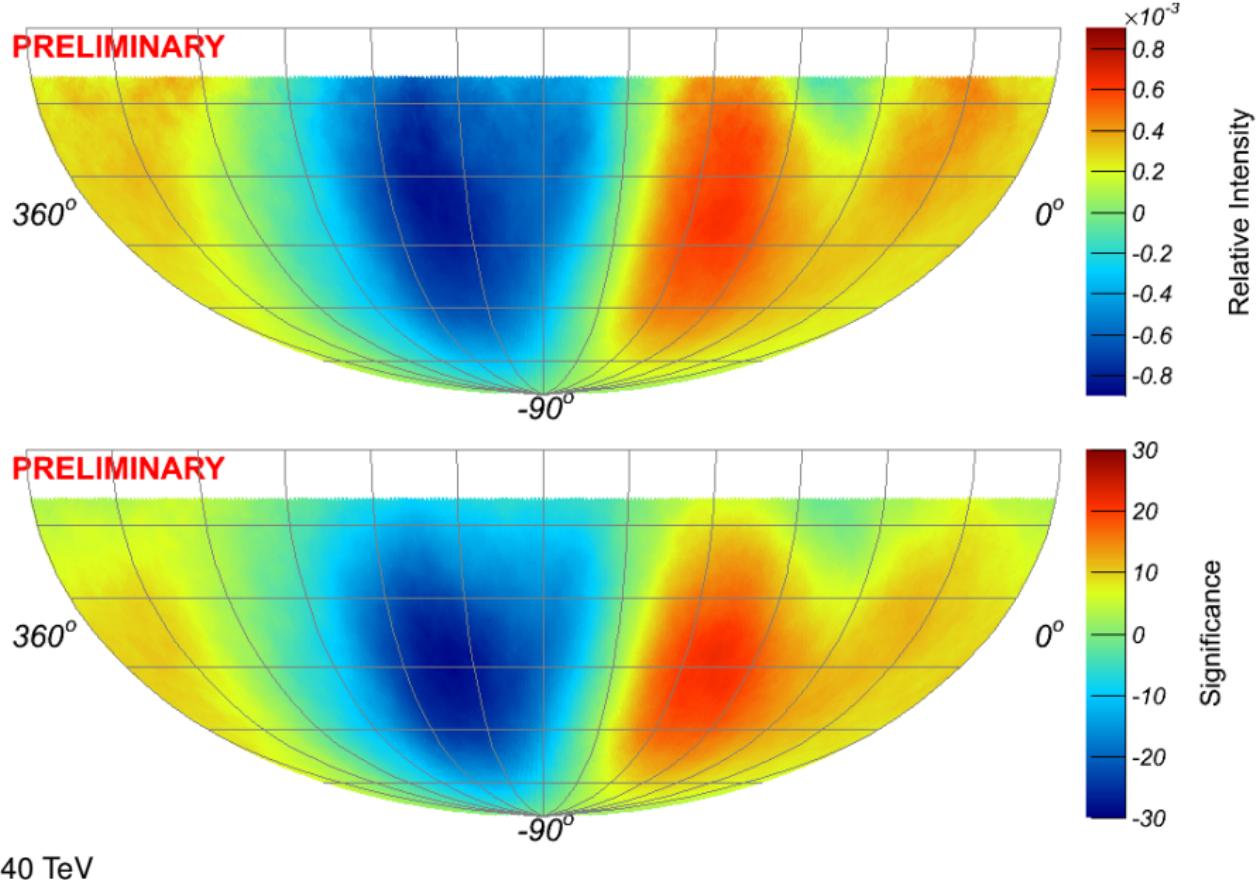


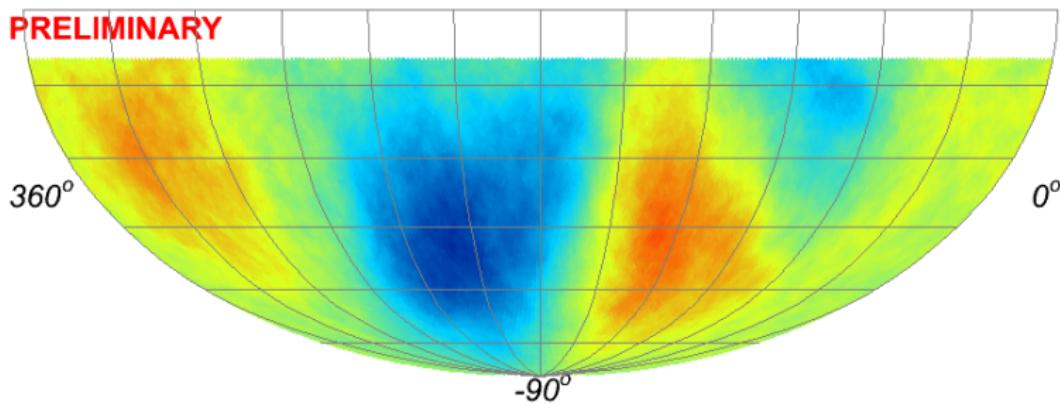
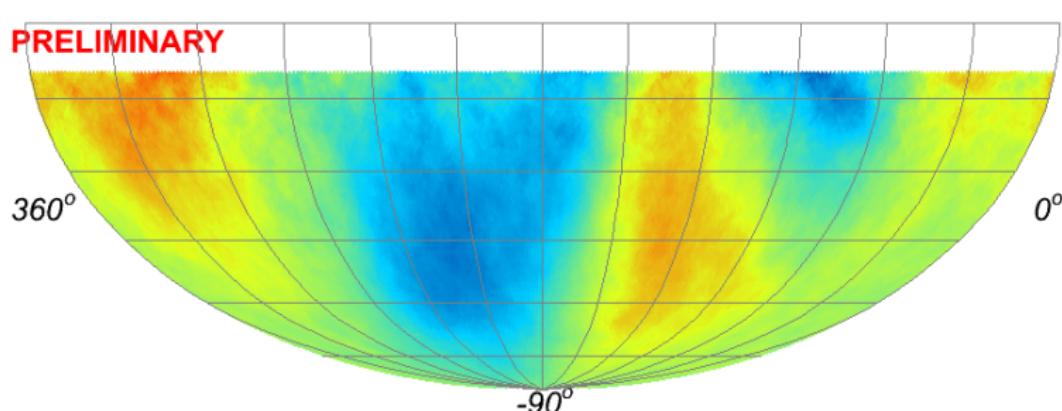
40 TeV

"Energy" selection

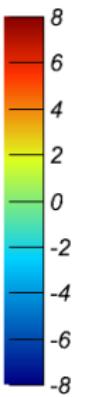
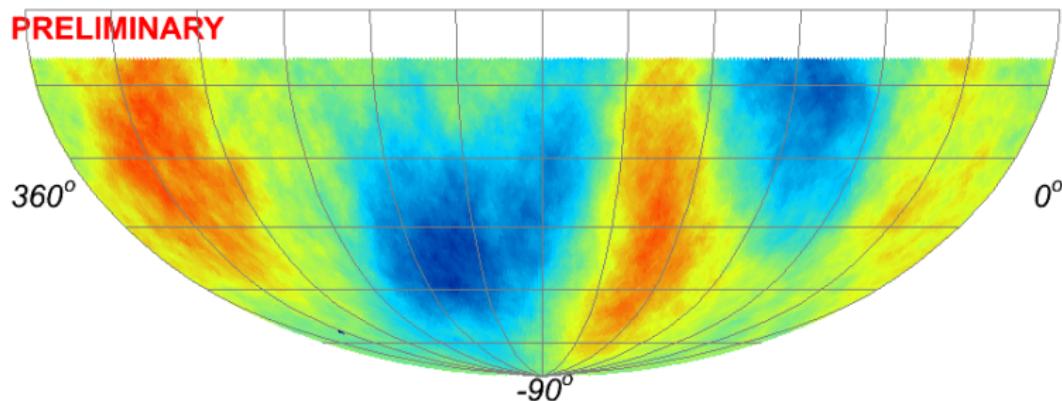
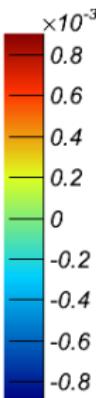
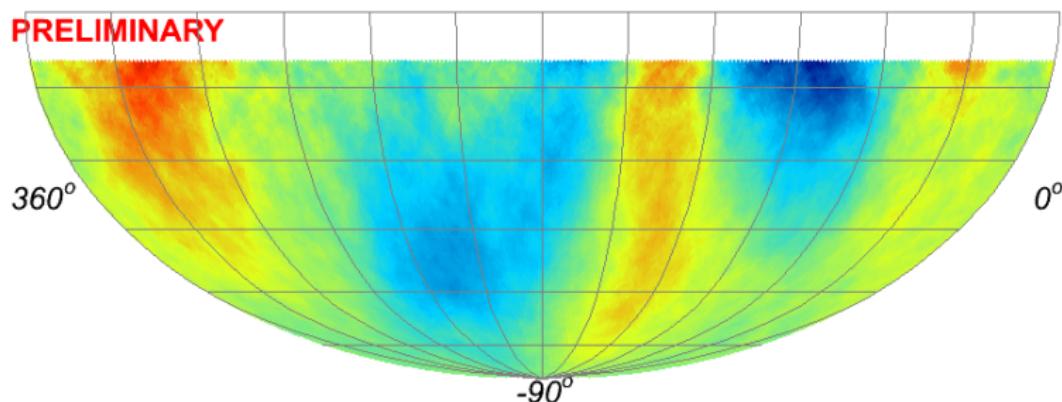
PRELIMINARY



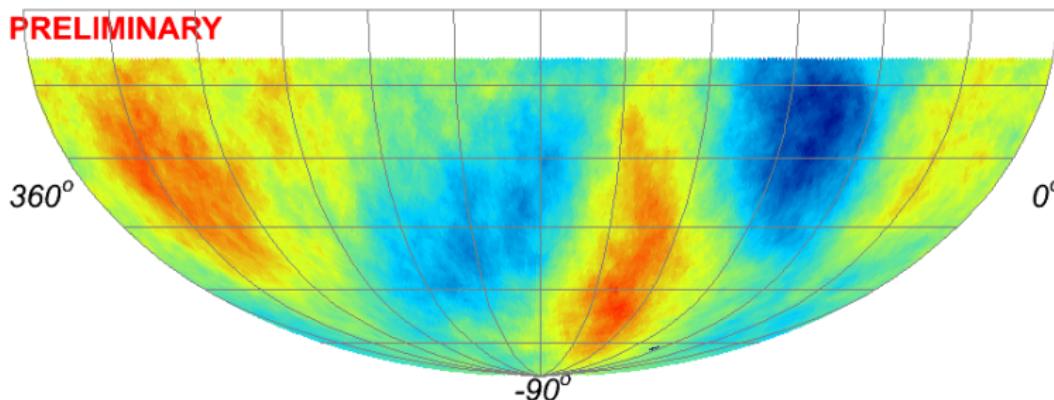
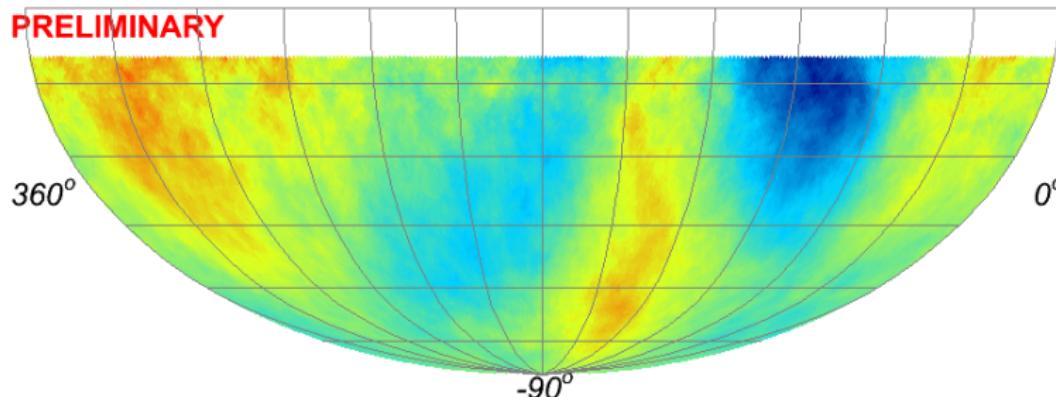




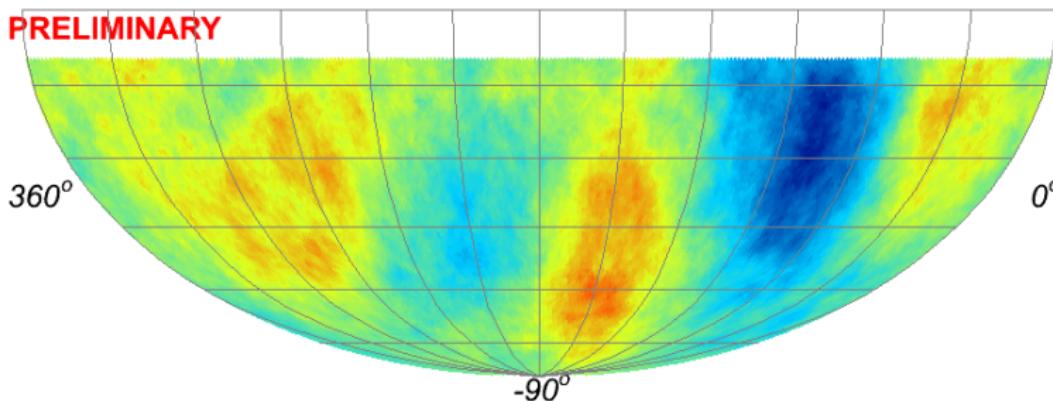
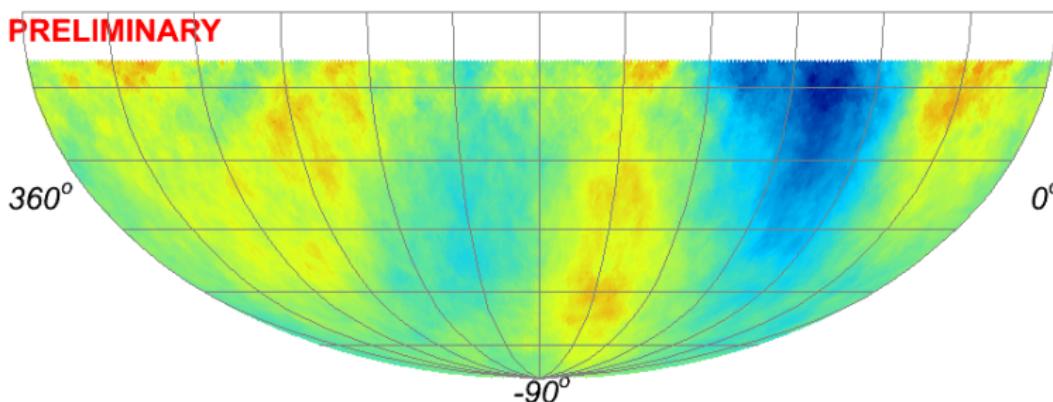
100 TeV



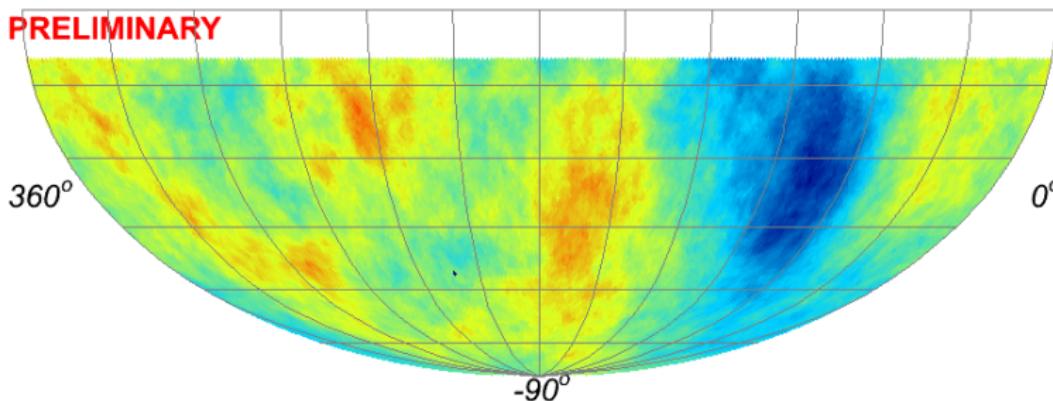
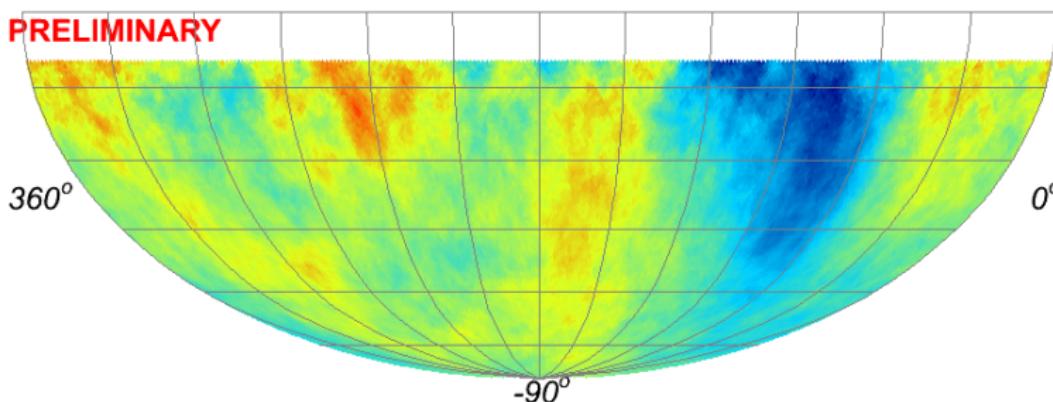
126 TeV



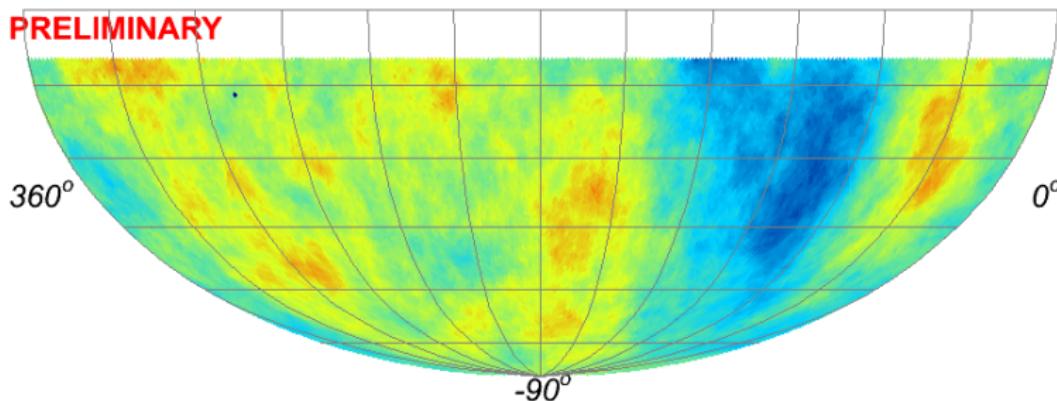
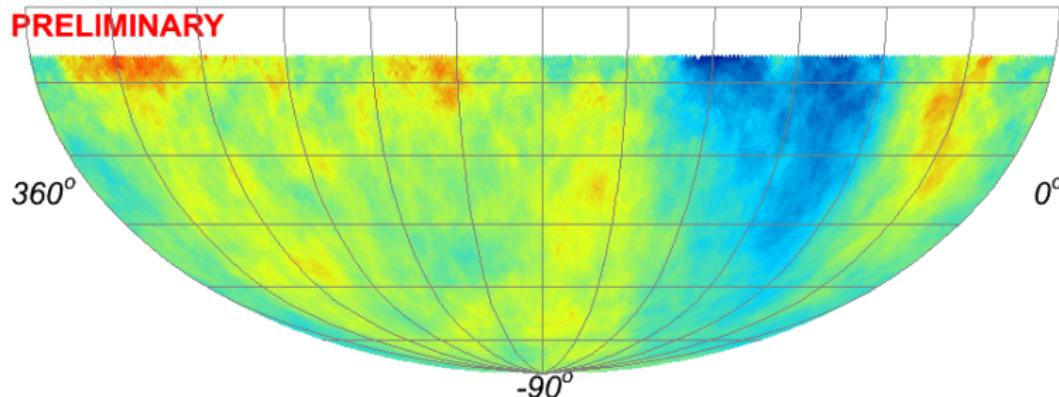
200 TeV



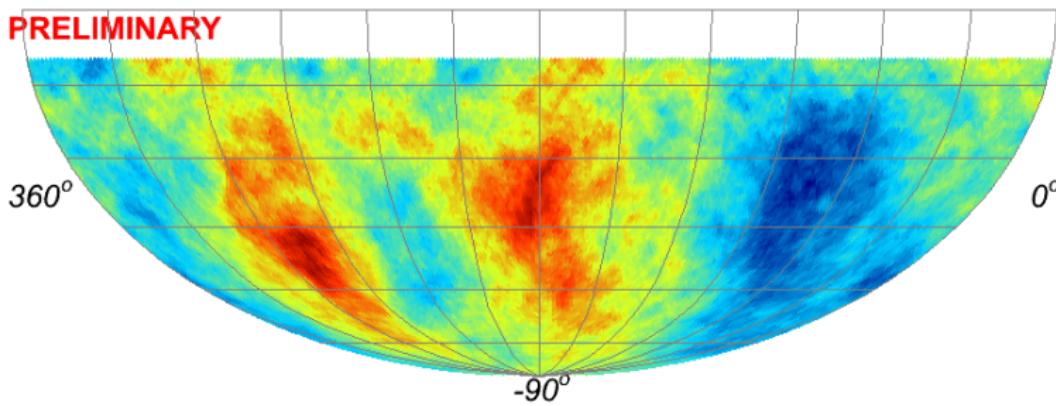
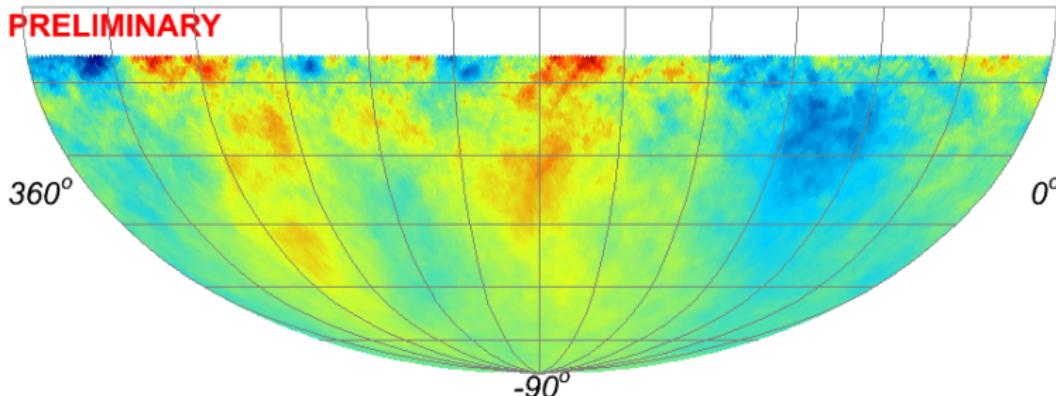
316 TeV



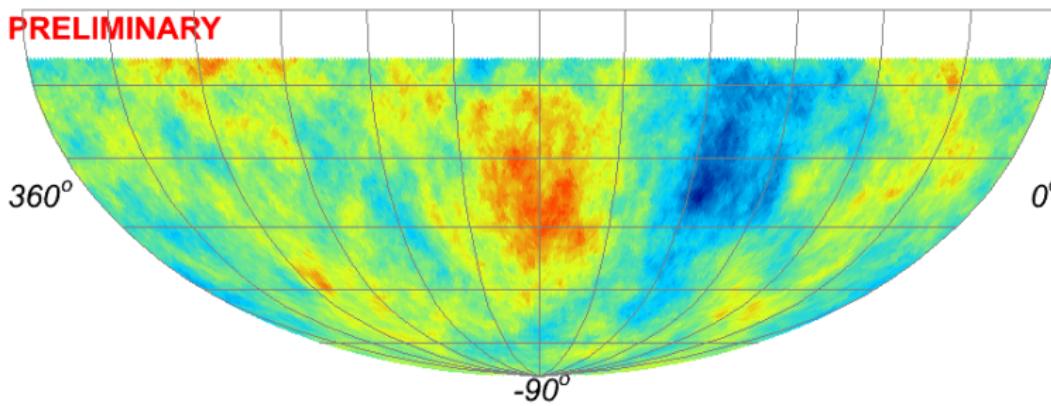
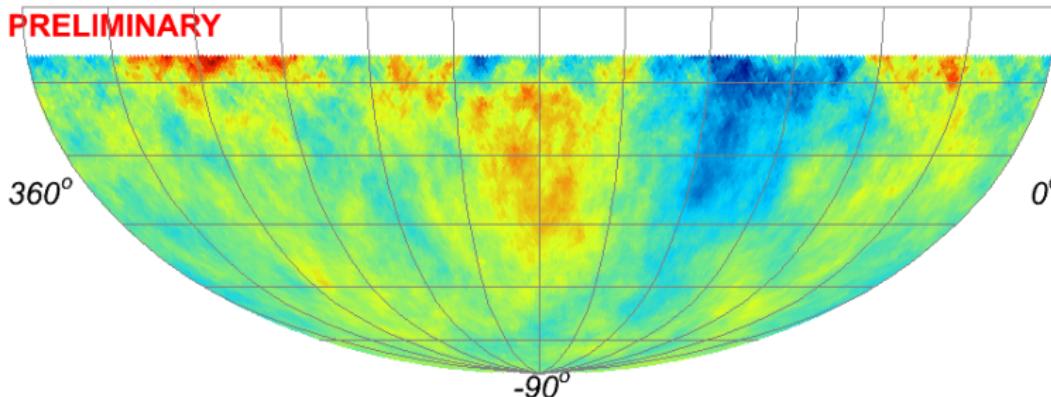
400 TeV



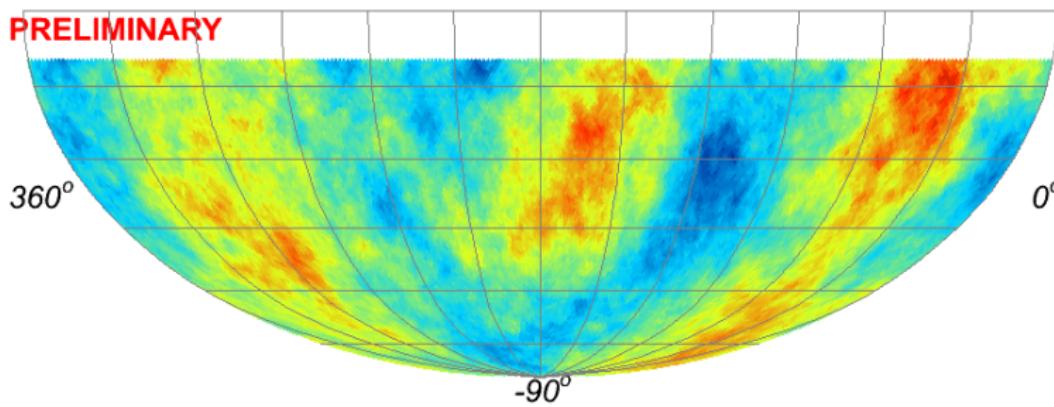
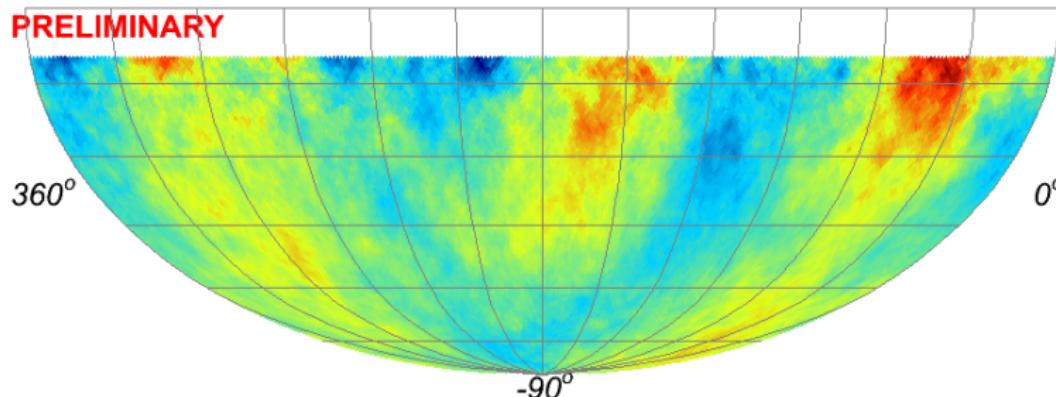
630 TeV



1 PeV

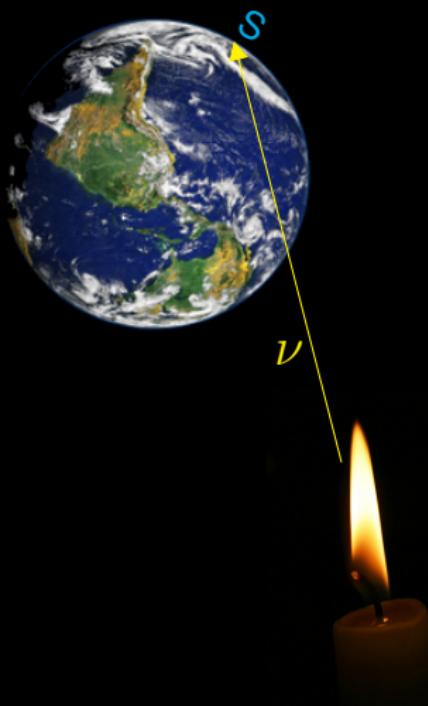


5 PeV



10 PeV

Test “beam”



Test "beam"



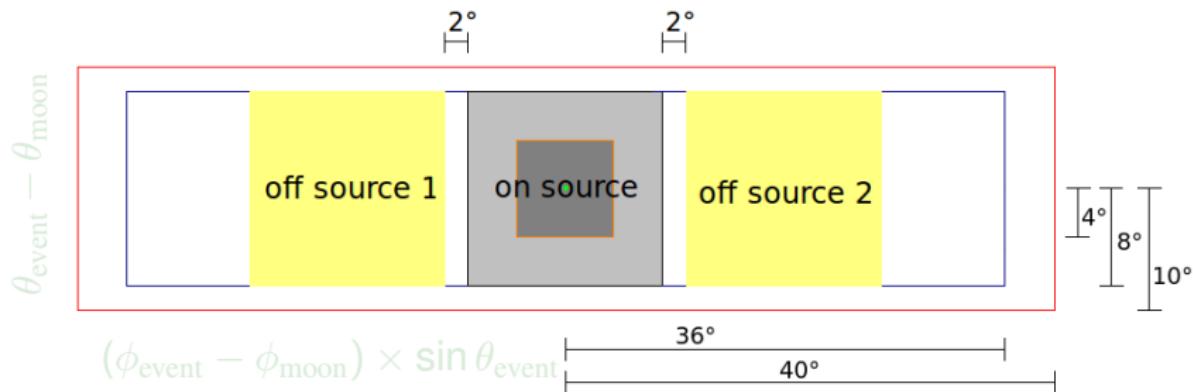
- Shadow depth
- Shift
- Shape

(G.W. Clark, 1957)

Event selection

Online/ Offline

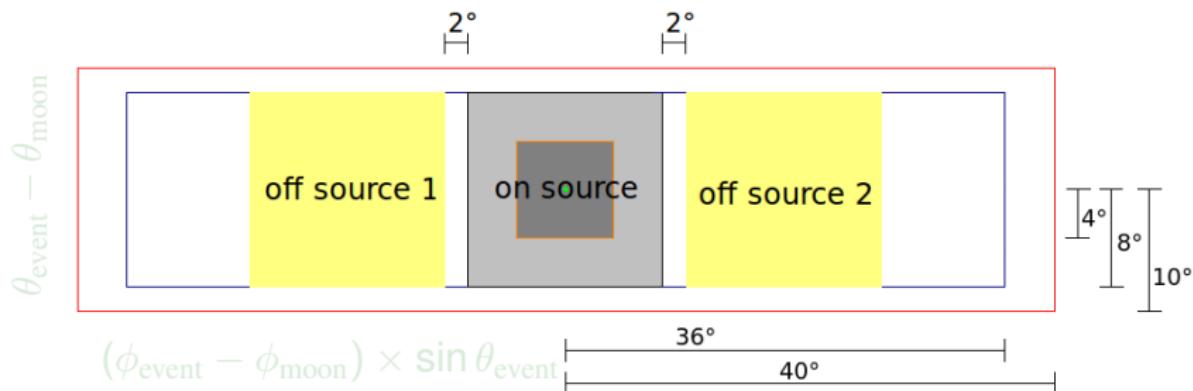
- Moon at least 15° above horizon
 - \rightarrow one Moon rise+set per orbital period of 27.3 days
- Minimum event brightness (≥ 12 hit DOMs on at least 3 strings)
- Angular window (online track fit)
 - \rightarrow w.r.t. the *nominal* Moon position (computed from event time)
- Estimated angular error $0.075^\circ \leq \sigma \leq 1.5^\circ$
- Good track quality
- Angular window (offline track fit)



Event selection

Online/ Offline

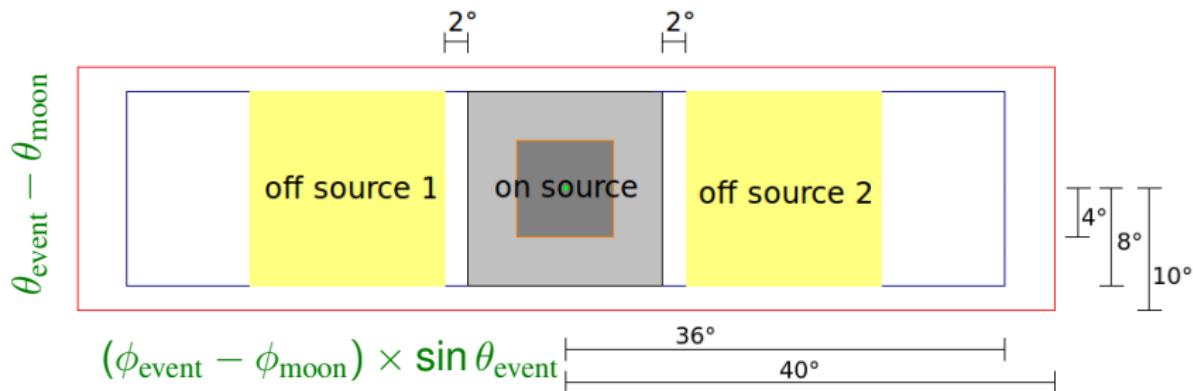
- Moon at least 15° above horizon
 - \rightarrow one Moon rise+set per orbital period of 27.3 days
- Minimum event brightness (≥ 12 hit DOMs on at least 3 strings)
- Angular window (online track fit)
 - \rightarrow w.r.t. the *nominal* Moon position (computed from event time)
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Event selection

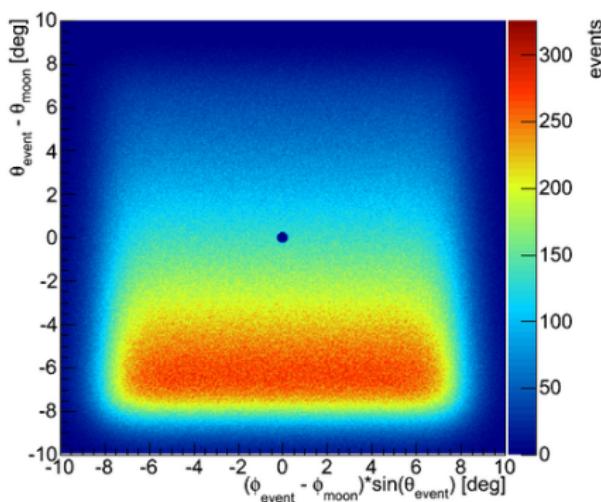
Online/ Offline

- Moon at least 15° above horizon
 - → one Moon rise+set per orbital period of 27.3 days
- Minimum event brightness (≥ 12 hit DOMs on at least 3 strings)
- Angular window (online track fit)
 - → w.r.t. the *nominal* Moon position (computed from event time)
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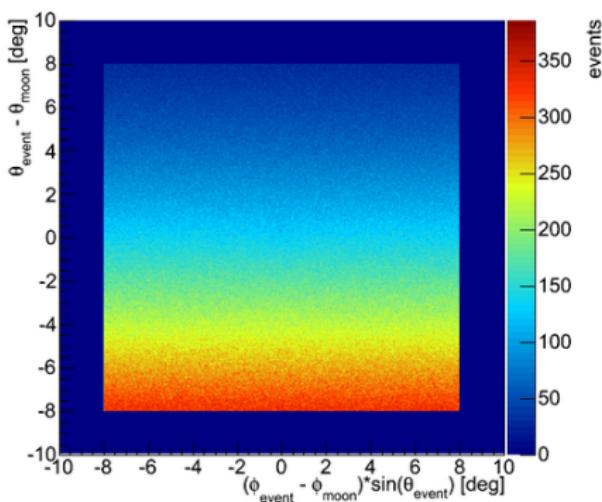


Challenge (illustrated with *simulated* data)

“true” CR directions



reconstructed μ directions



Likelihood analysis of the Moon shadow

$$-\log(\mathcal{L}(\vec{x}_s, n_s)) = -\sum_{i=1}^{N_{\text{events}}} \log \left(\frac{n_s}{N_{\text{events}}} S_i(\vec{x}_i, \sigma_i, \vec{x}_s) + \left(1 - \frac{n_s}{N_{\text{events}}}\right) B_i(\vec{x}_i) \right)$$

\vec{x}_s = Shadow center relative to nominal Moon pos.

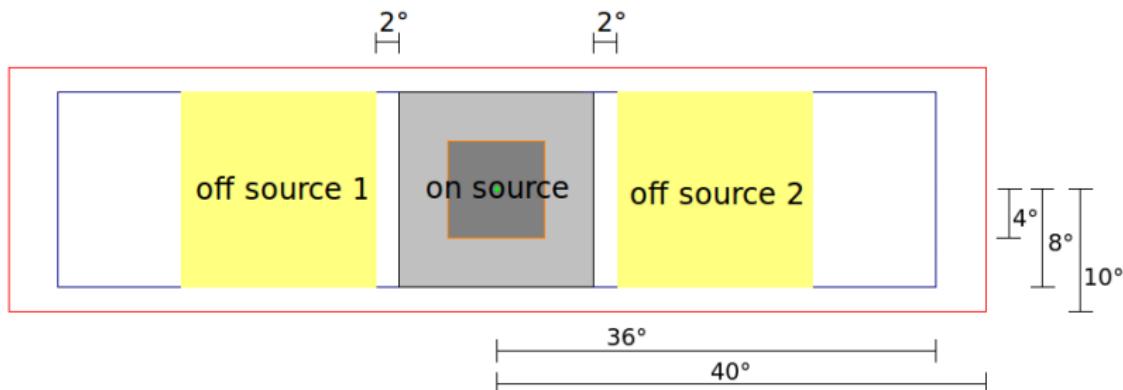
n_s = Number of source events (negative for shadow)

$S_i(\vec{x}_s)$ = 2D Gaussian using paraboloid error

B_i = Normalized zenith distribution (from off-source)

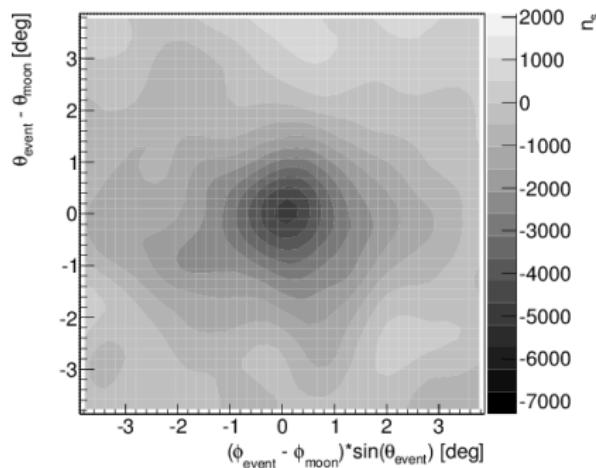
N_{events} = # good events in on-source sample ($\sim 8.4\text{M}$ in IC40, $\sim 11.7\text{M}$ in IC59)

– $\log(\mathcal{L})$ is minimized w.r.t. n_s on a $\pm 4^\circ \times \pm 4^\circ$ grid (31×31 points) around the Moon.

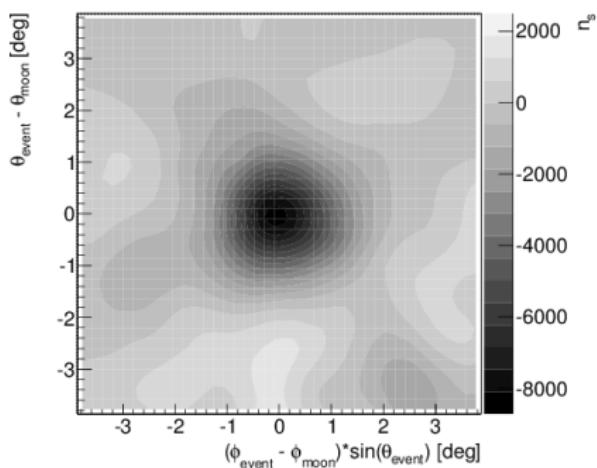


Results: shadow depth and shift

40 strings (2008-2009)



59 strings (2009-2010)

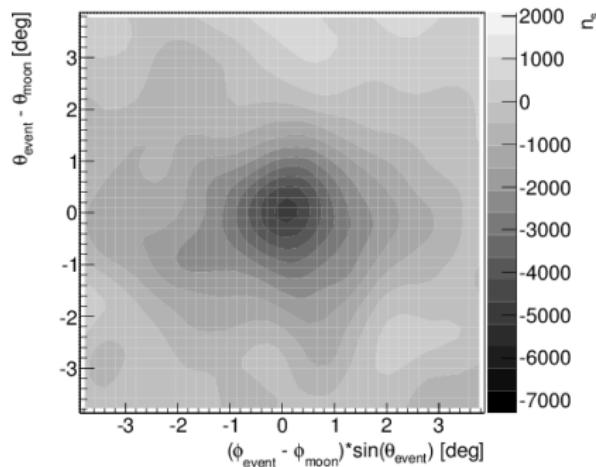


- $n_s^{\text{obs}} = -5326 \pm 544 \pm 498$
- $n_s^{\text{exp}} = -5734 \pm 76$
- No shift

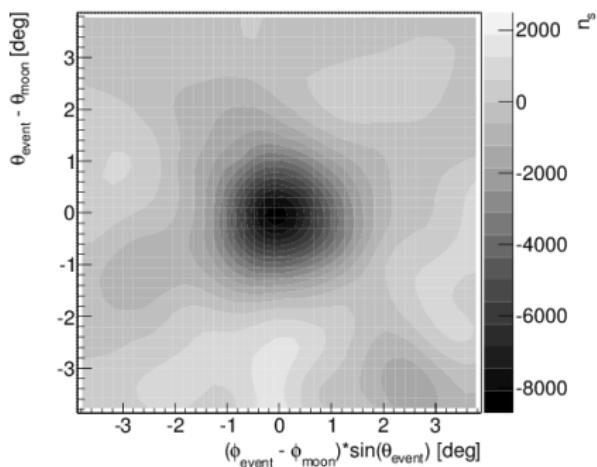
- $n_s^{\text{obs}} = -8660 \pm 565 \pm 681$
- $n_s^{\text{exp}} = -8192 \pm 91$
- $\vec{x}_s^{\text{obs}} = (-0.1^\circ \pm 0.1^\circ, 0.0^\circ \pm 0.1^\circ)$

Results: shadow depth and shift

40 strings (2008-2009)



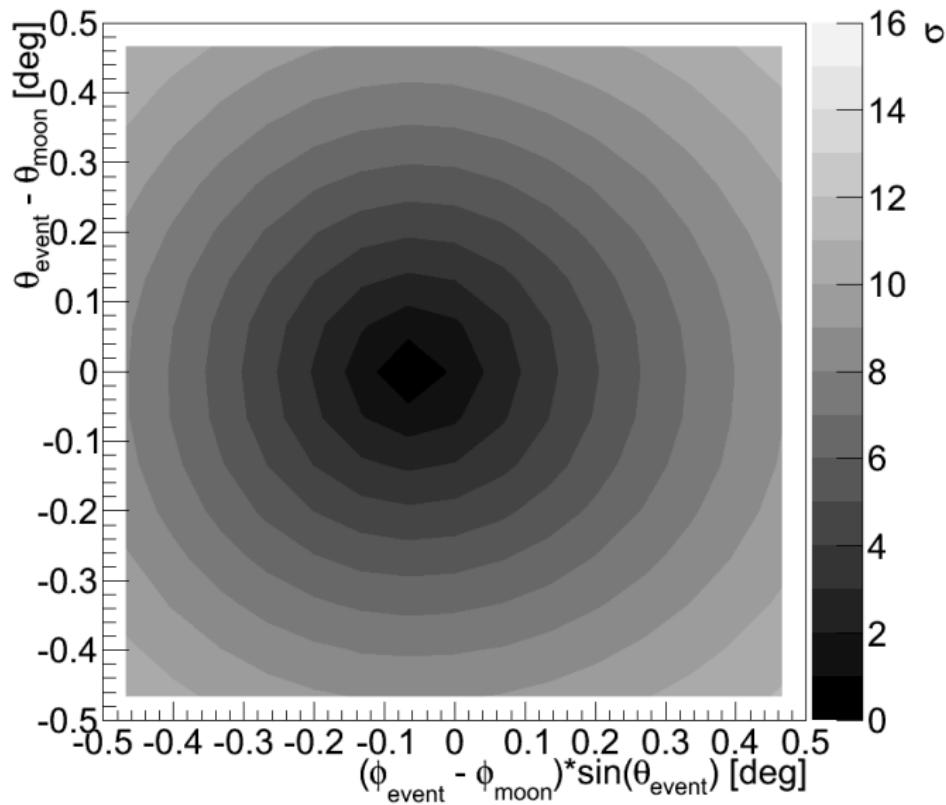
59 strings (2009-2010)



- $n_s^{\text{obs}} = -5326 \pm 544 \pm 498$
- $n_s^{\text{exp}} = -5734 \pm 76$
- No shift

- $n_s^{\text{obs}} = -8660 \pm 565 \pm 681$
- $n_s^{\text{exp}} = -8192 \pm 91$
- $\vec{x}_s^{\text{obs}} = (-0.1^\circ \pm 0.1^\circ, 0.0^\circ \pm 0.1^\circ)$

Results: $CL = \sqrt{-2 \log(L)}$

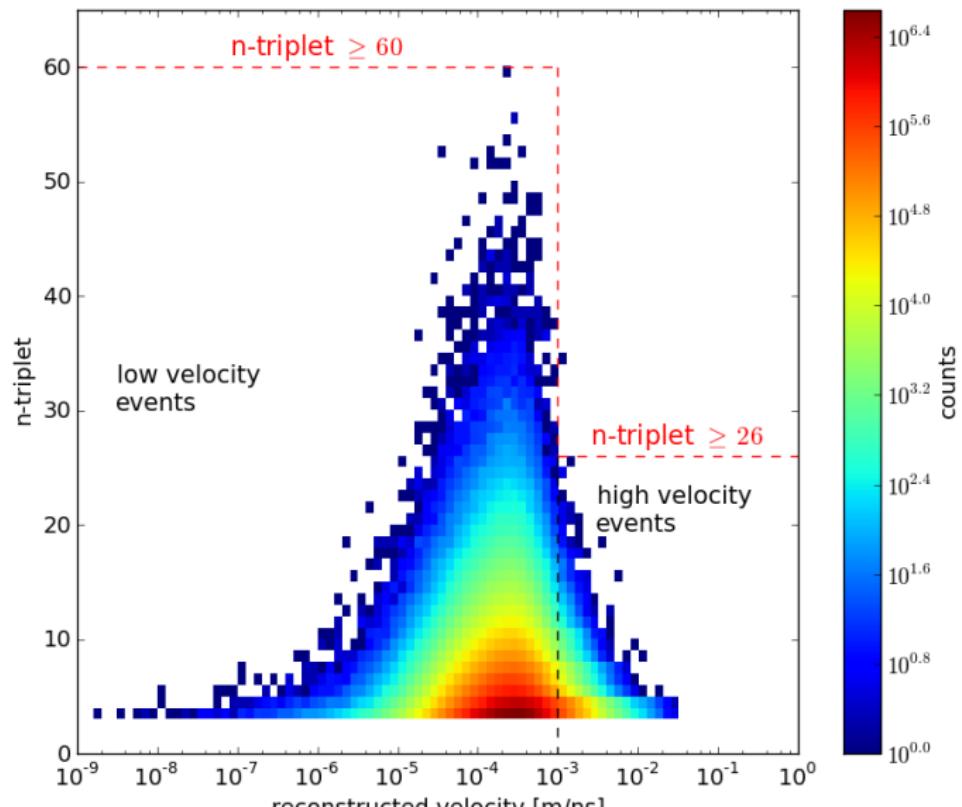


Search for particle-like dark matter

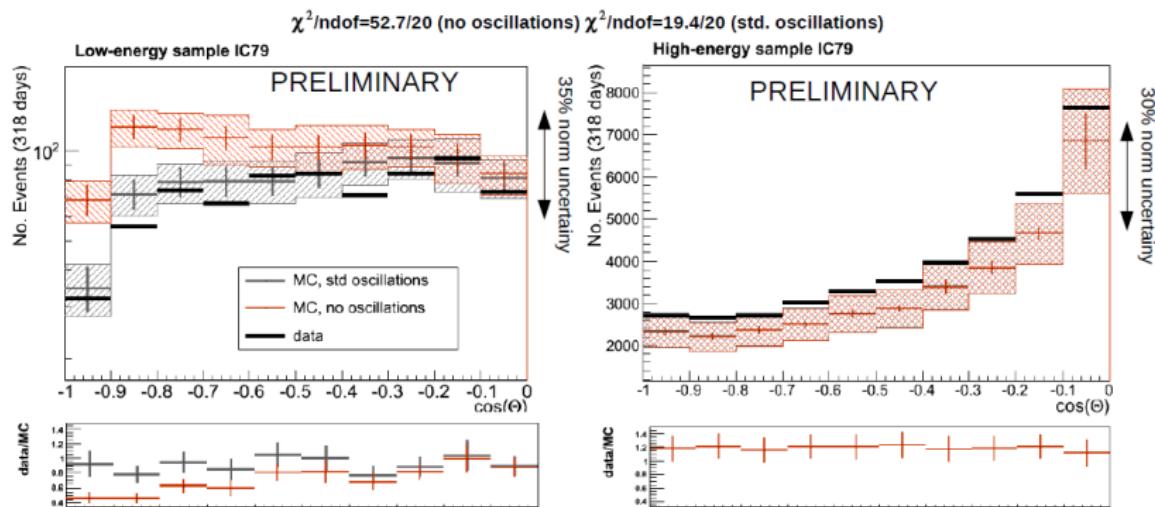
- Earth WIMPs
- Solar WIMPs (\rightarrow Matthias)
- Galactic WIMPs

- Slow ($\beta < 0.1$)
- Relativistic ($\beta > 0.5$)

Snapshot: slow monopole search result



One slide about neutrino oscillations



- IceCube is in great shape
- Large data sample of (atmospheric) neutrinos
- No discoveries yet, only upper limits
- Developments to extend, upgrade IceCube:
 - Radio array (ARA, RASTA)
 - Very low energy subarray (PINGU, → Per Olof)