IceCube overview

David Boersma (UU)

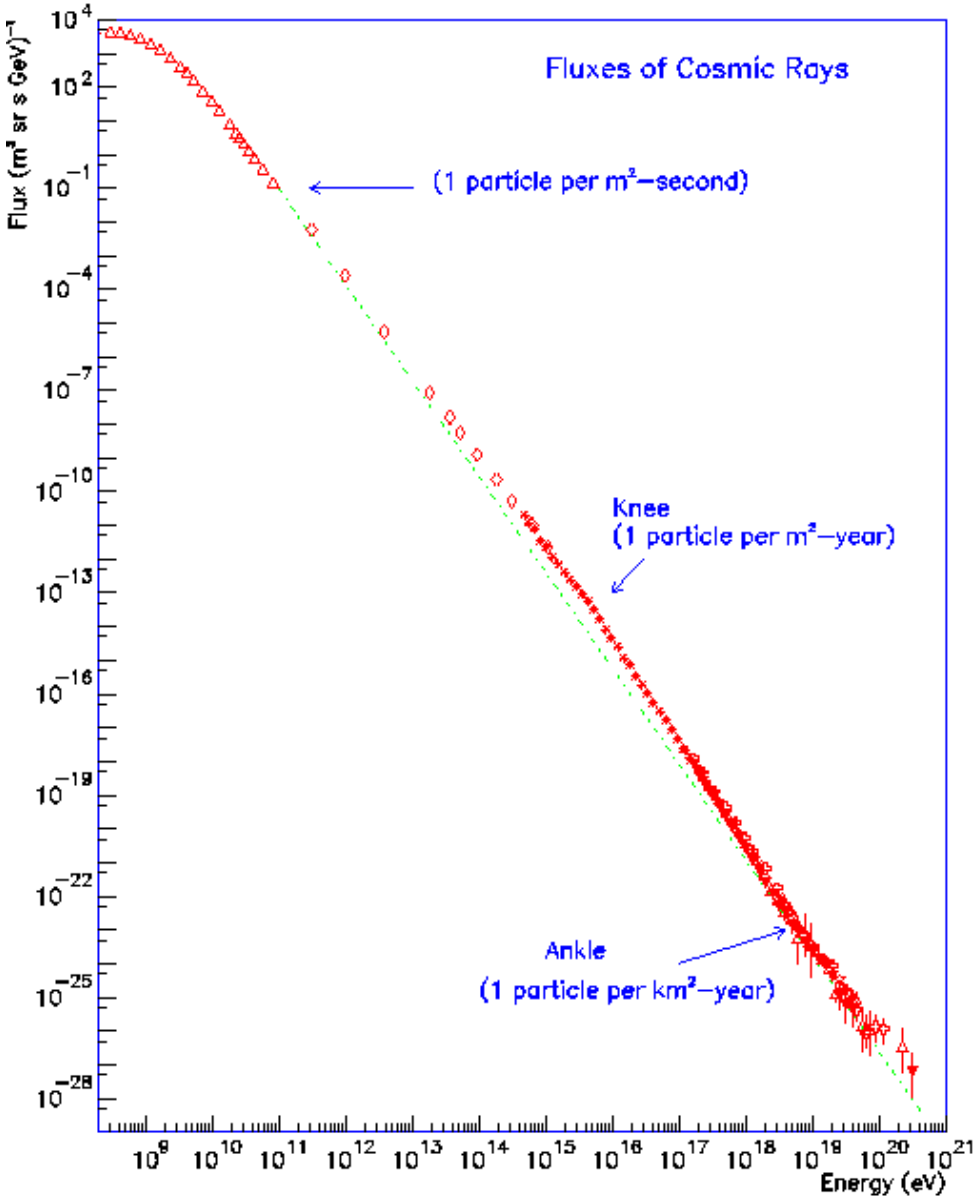
Partikeldagarna, Stockholm 2012

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

- 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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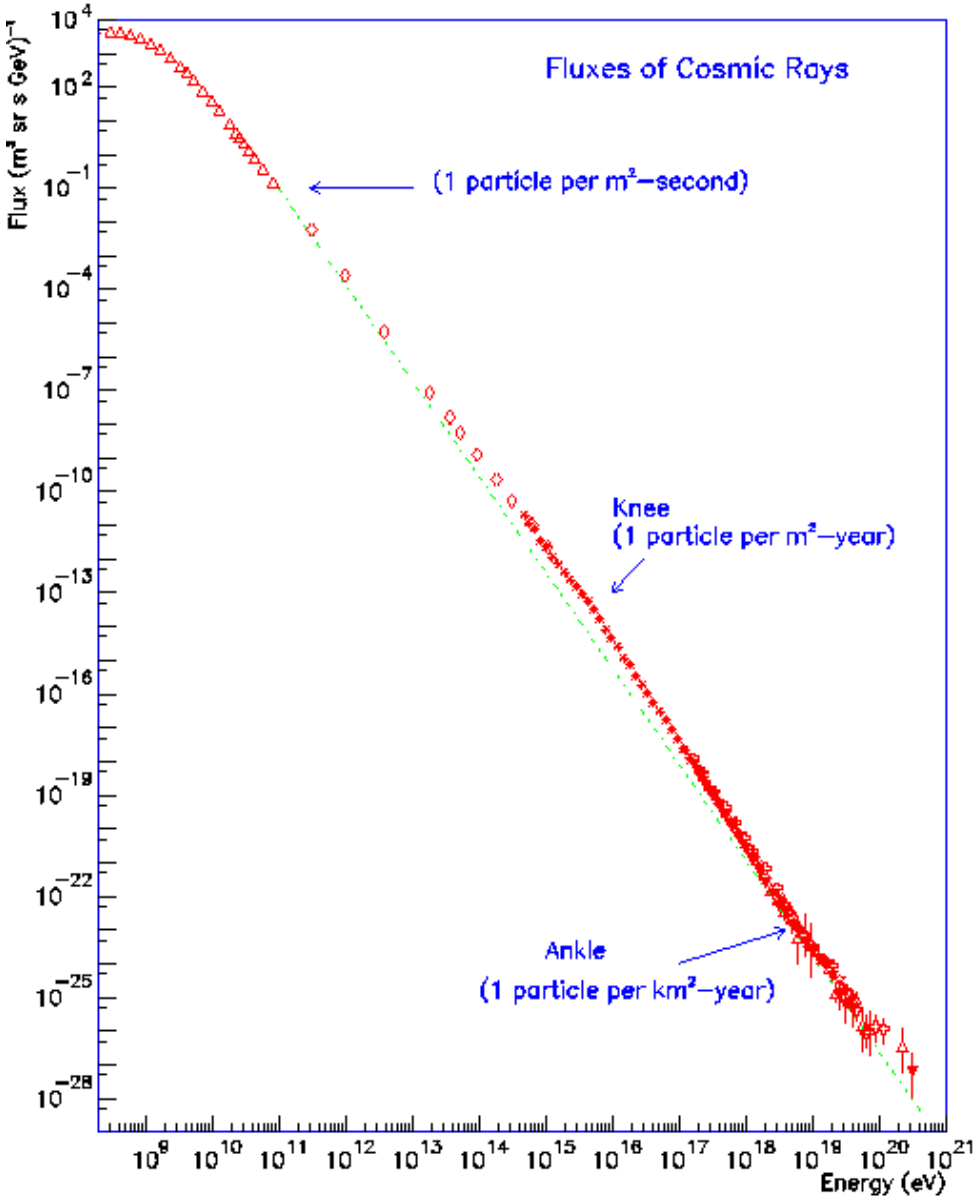

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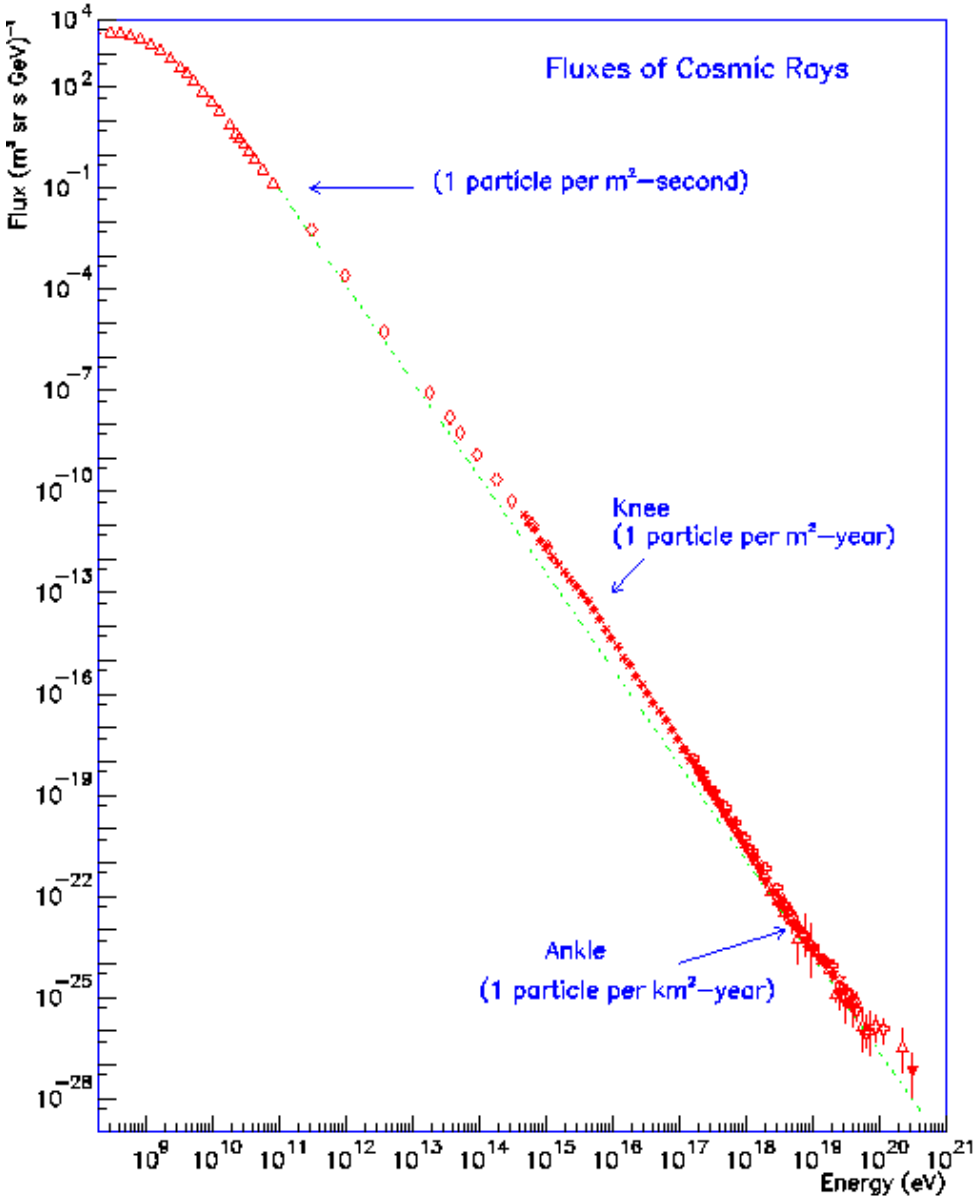

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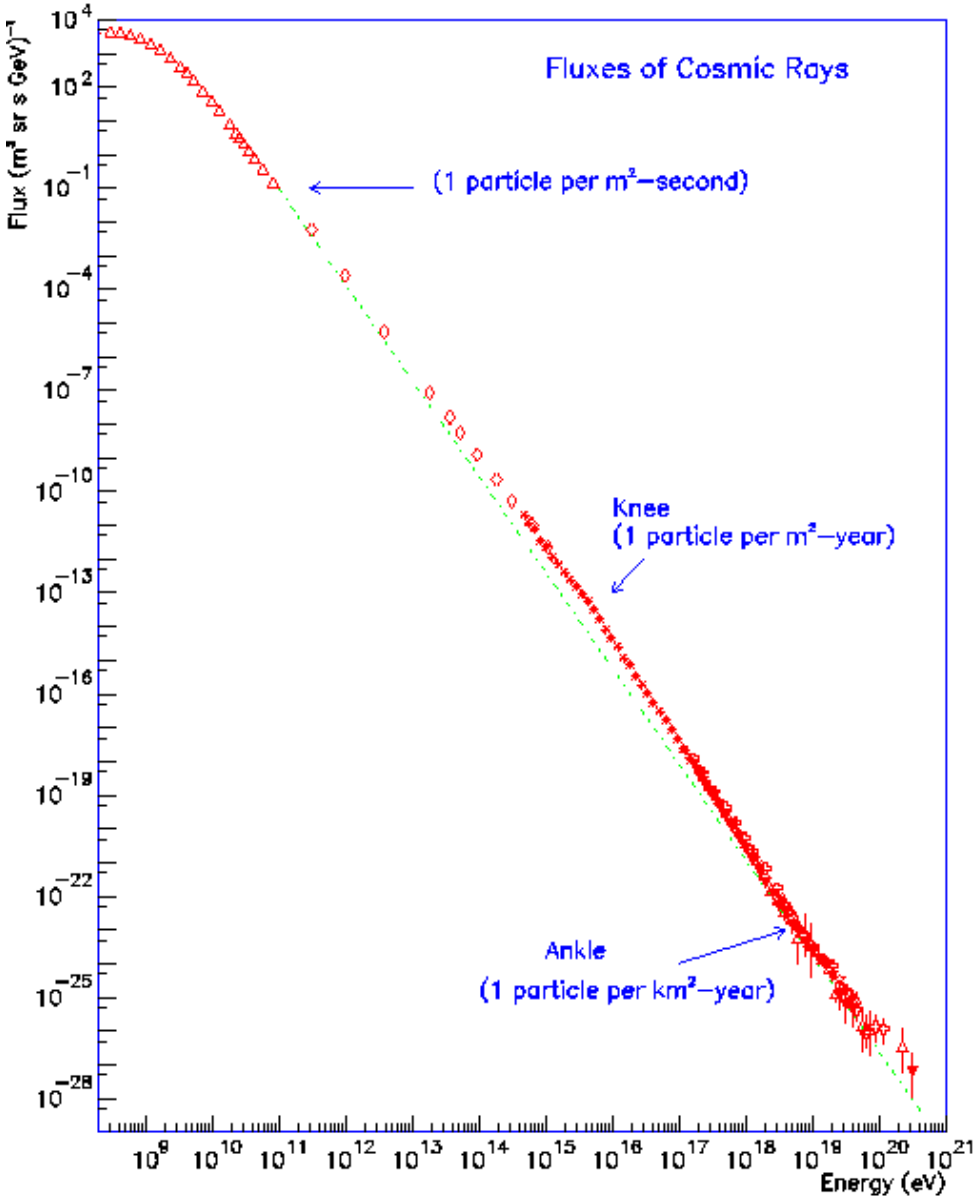

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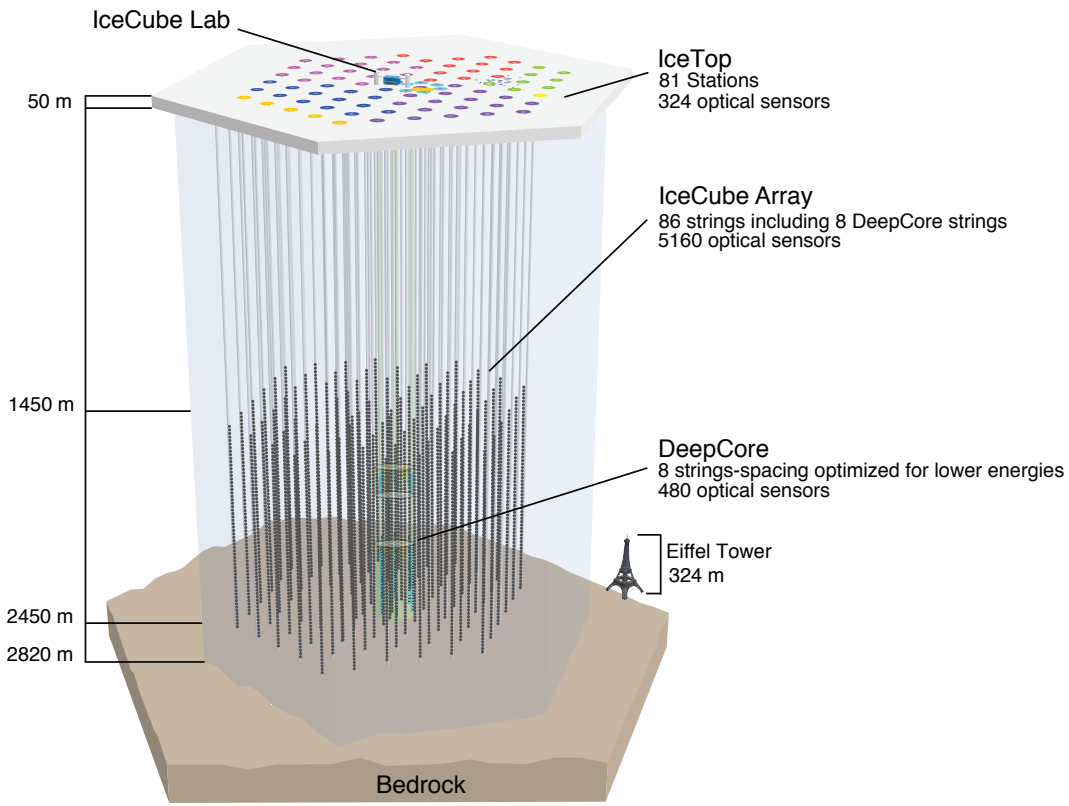
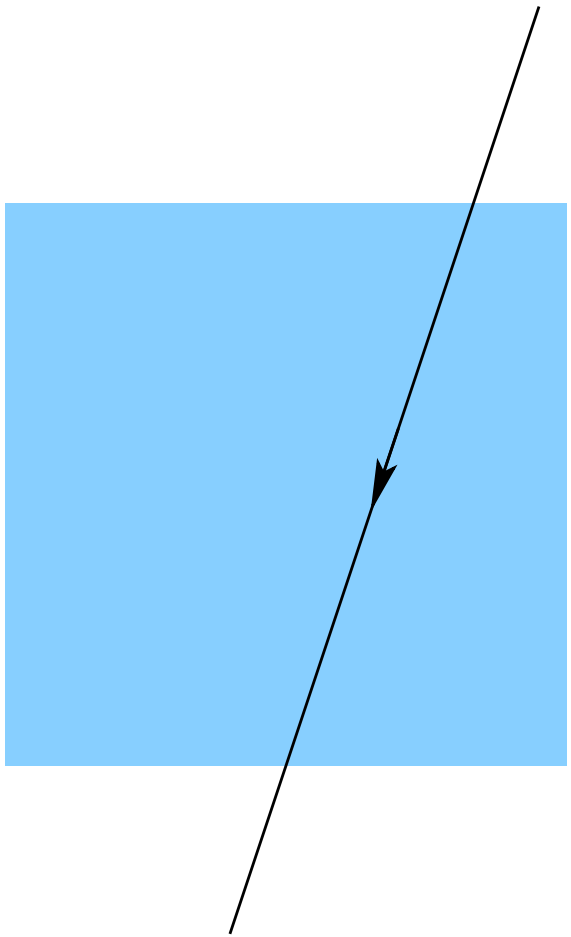
- Trigger rate $\sim$ 3 kHz.
- Average optical properties:
  - Scattering $\lambda_s^{eff} \approx 30\,\mathrm{m}$
  - Absorption $\lambda_a^{eff} \approx 100\,\mathrm{m}$
  - (For Antares/KM3NET it's the other way round, roughly.)
- Muon Tracks:
  - 4π acceptance
  - angular resolution $\mathcal{O}(1^\circ)$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



Event Types (1): cosmic ray muons



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

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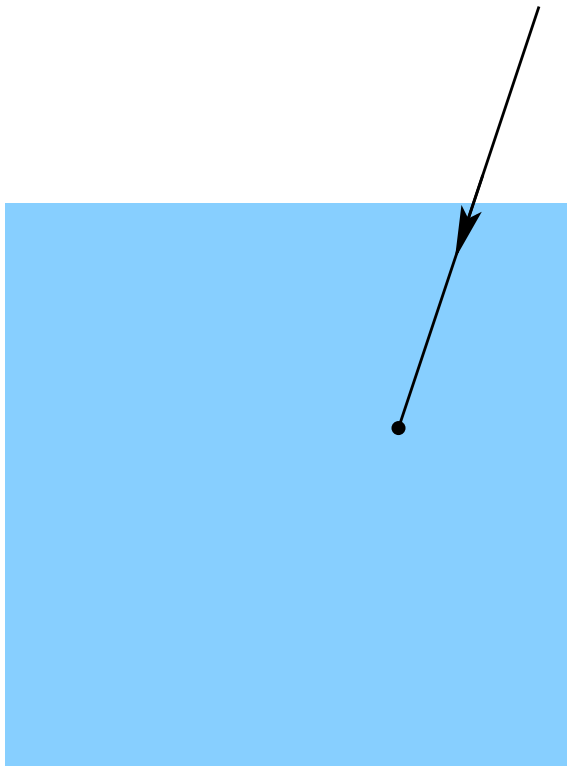

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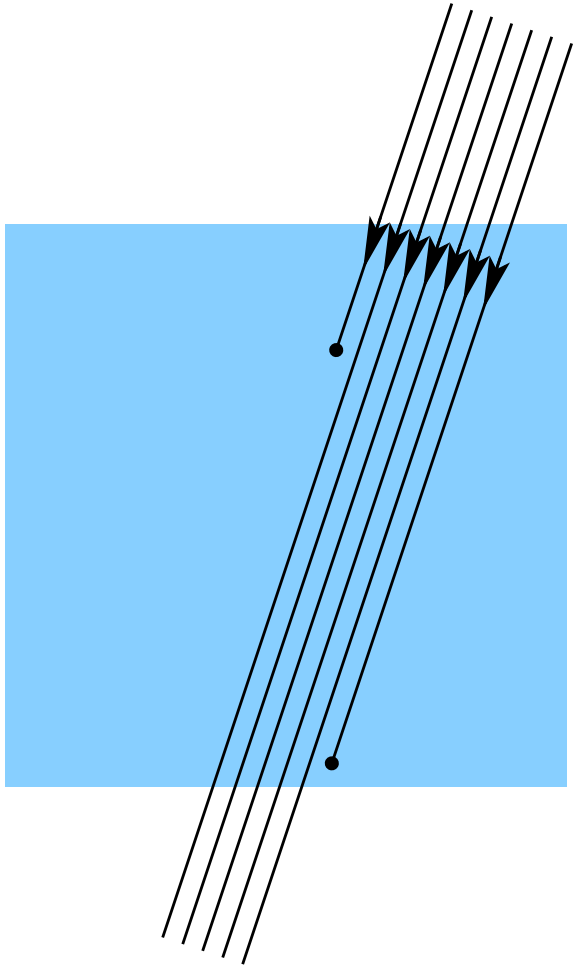

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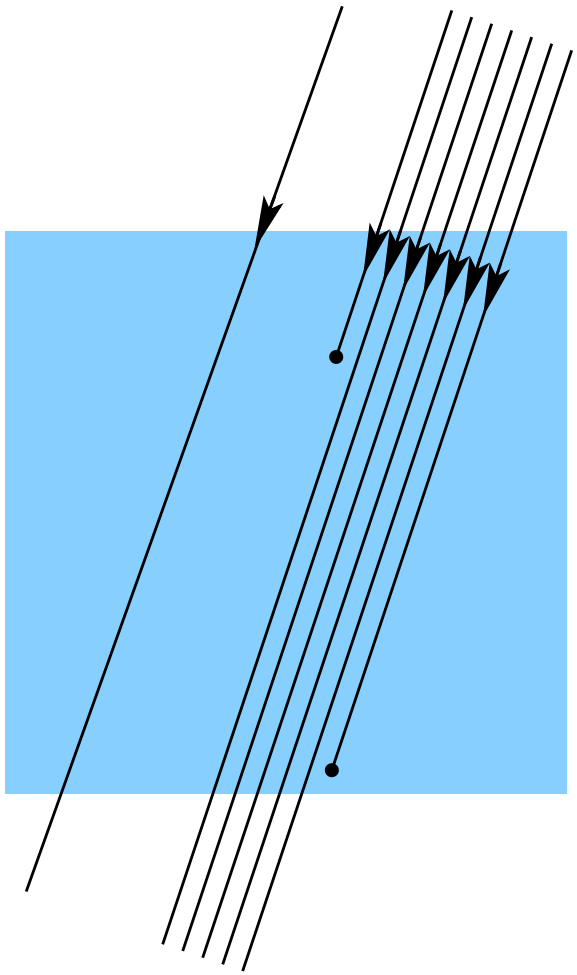

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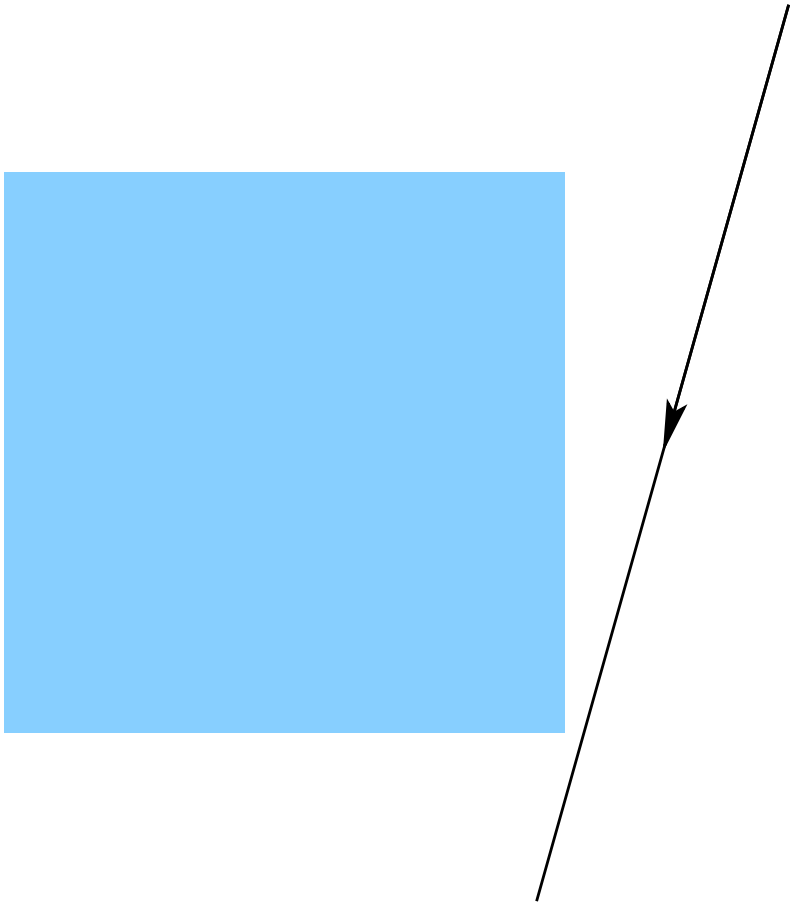

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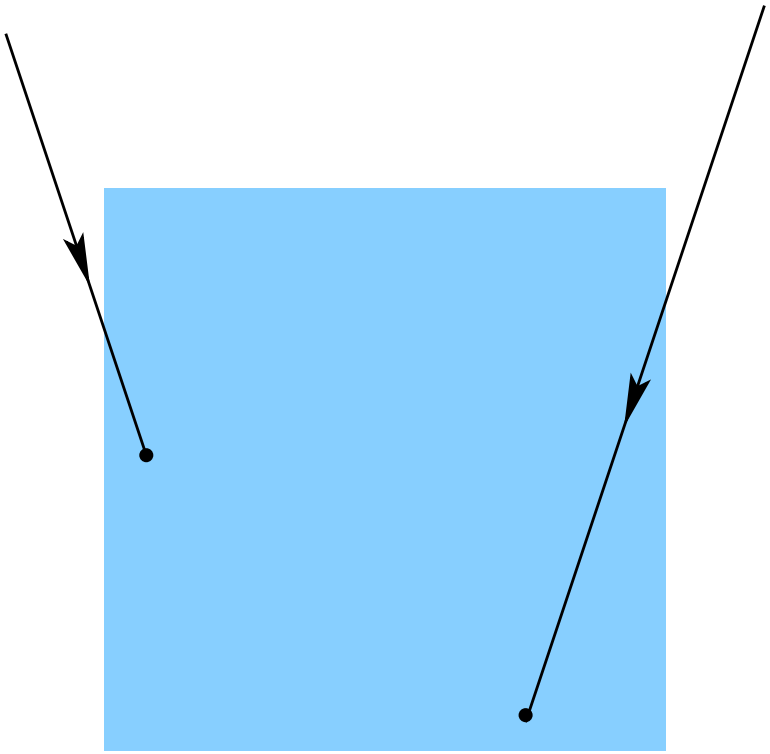

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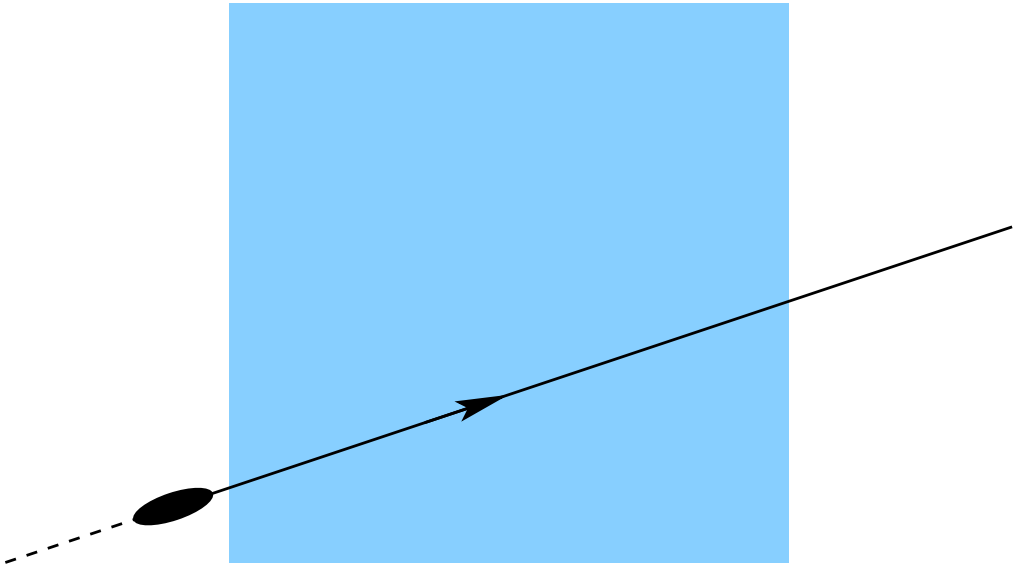
Event Types (2): neutrinos



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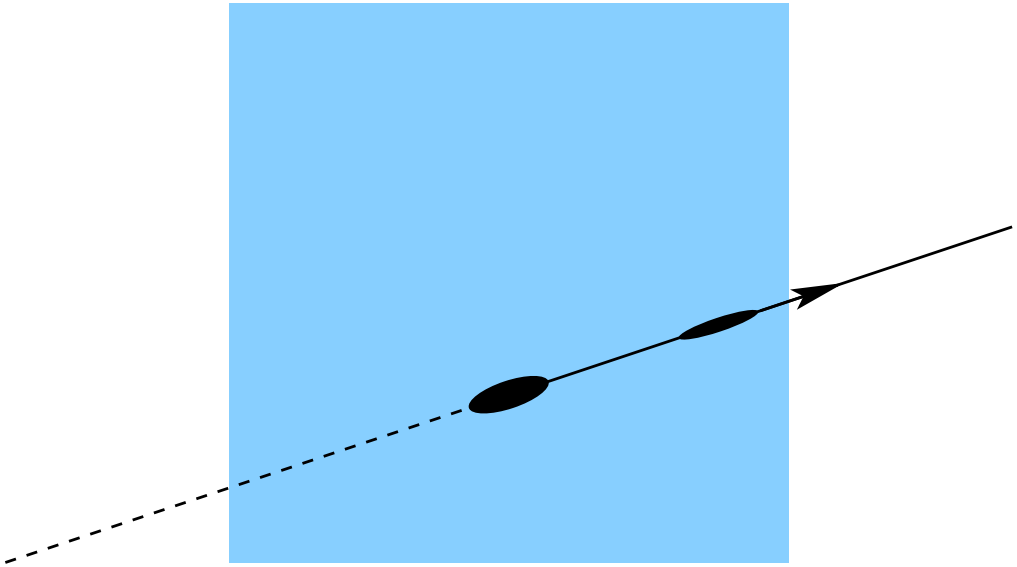

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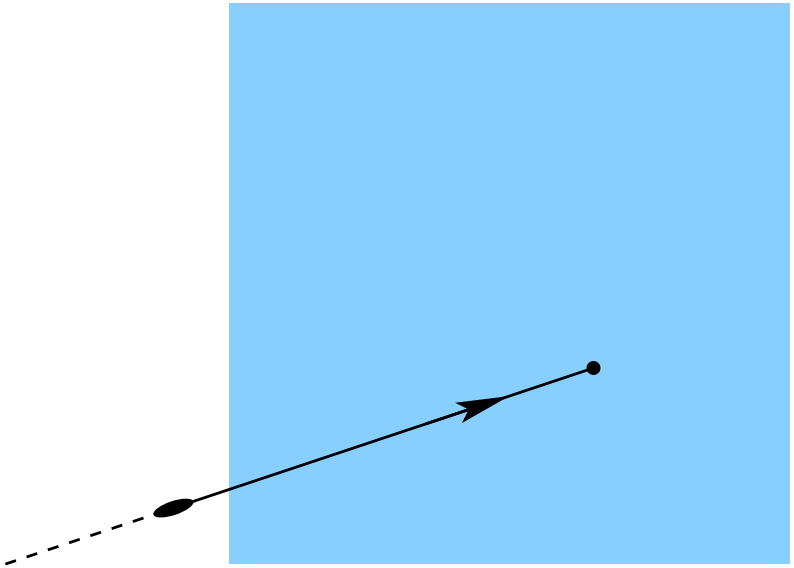

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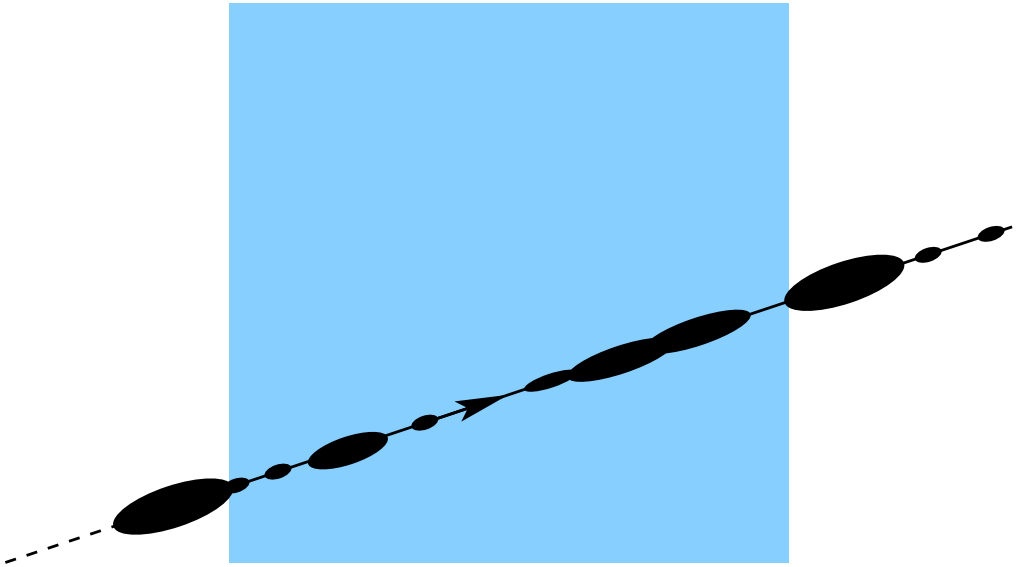

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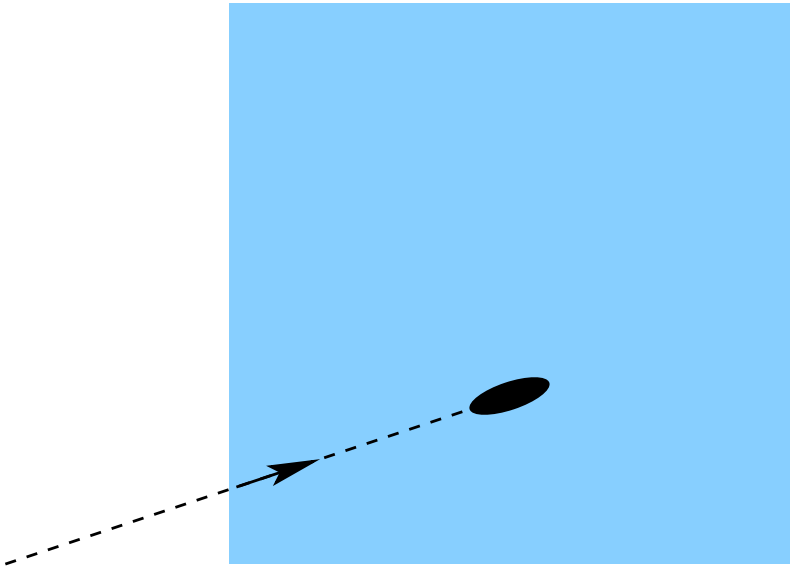

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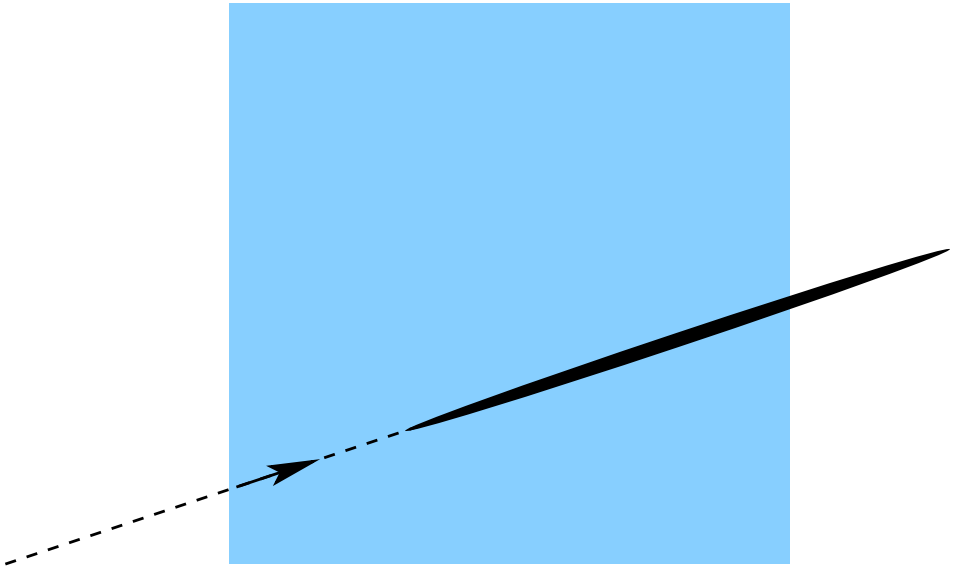

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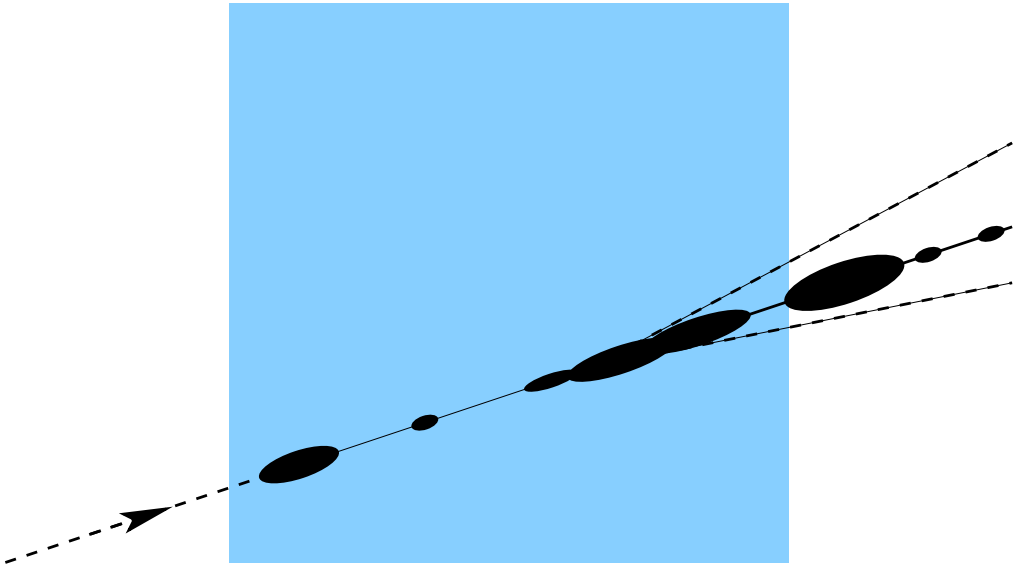

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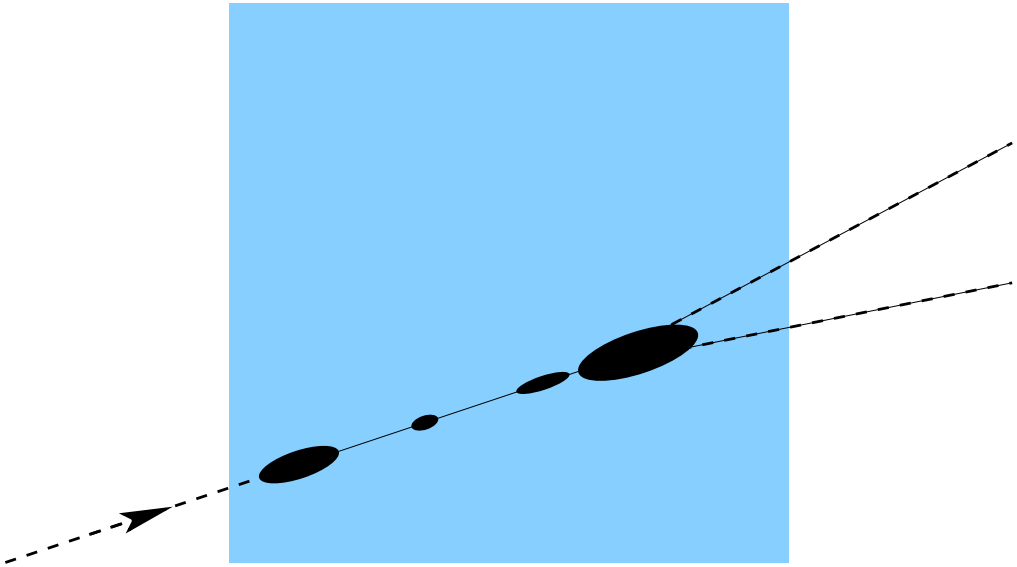

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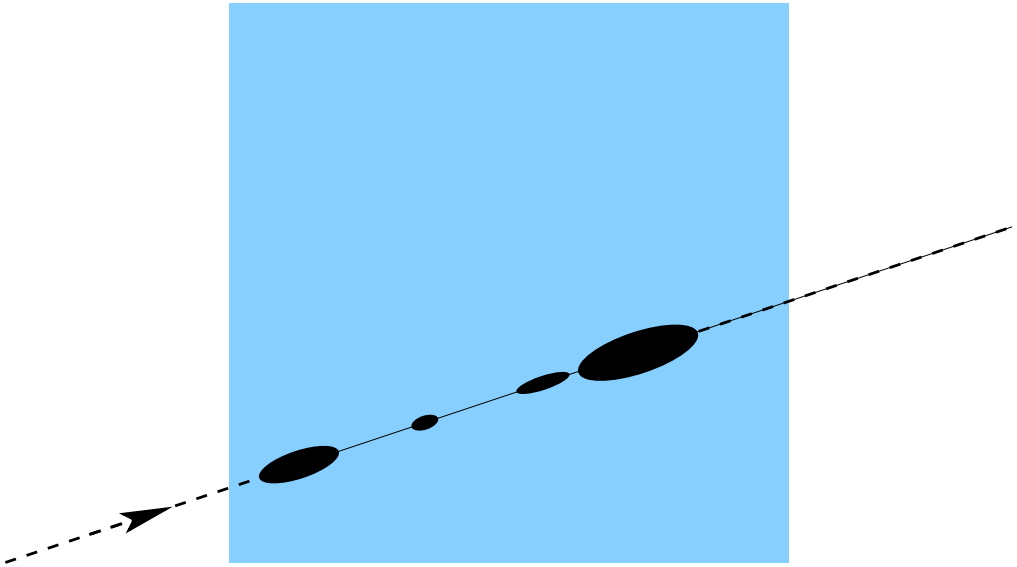

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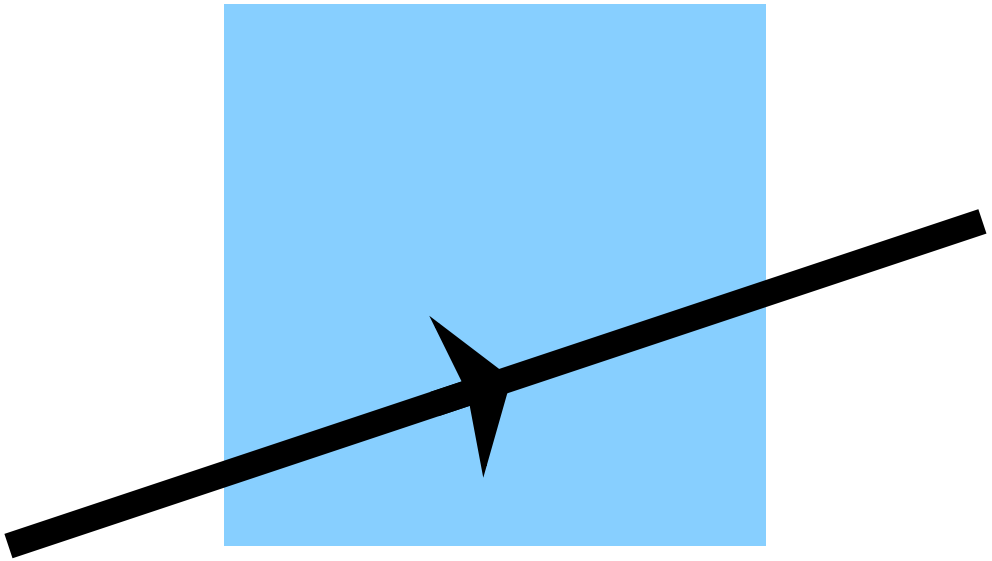

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- slow magnetic monopoles
- microscopic black holes
- ...

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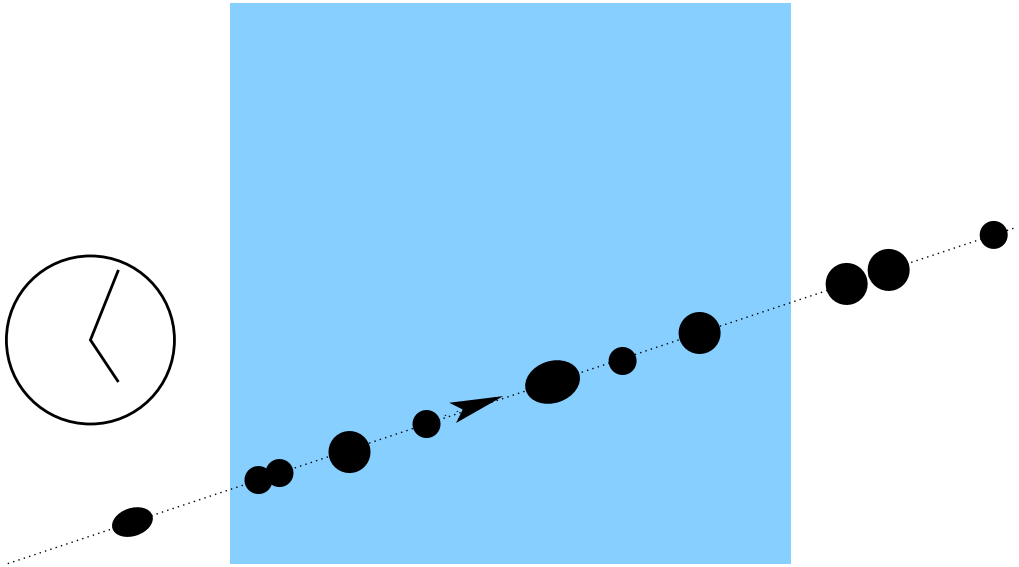

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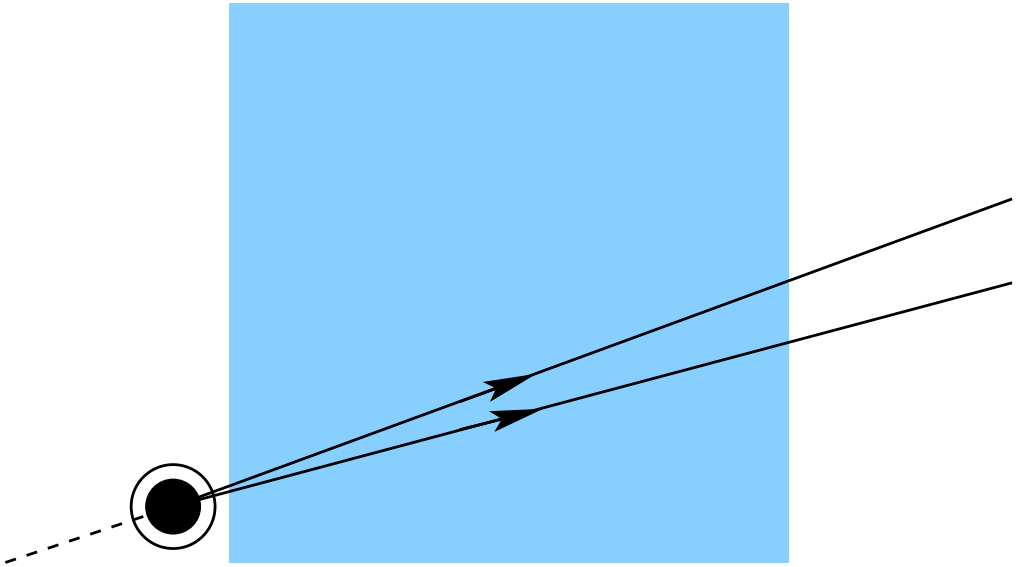

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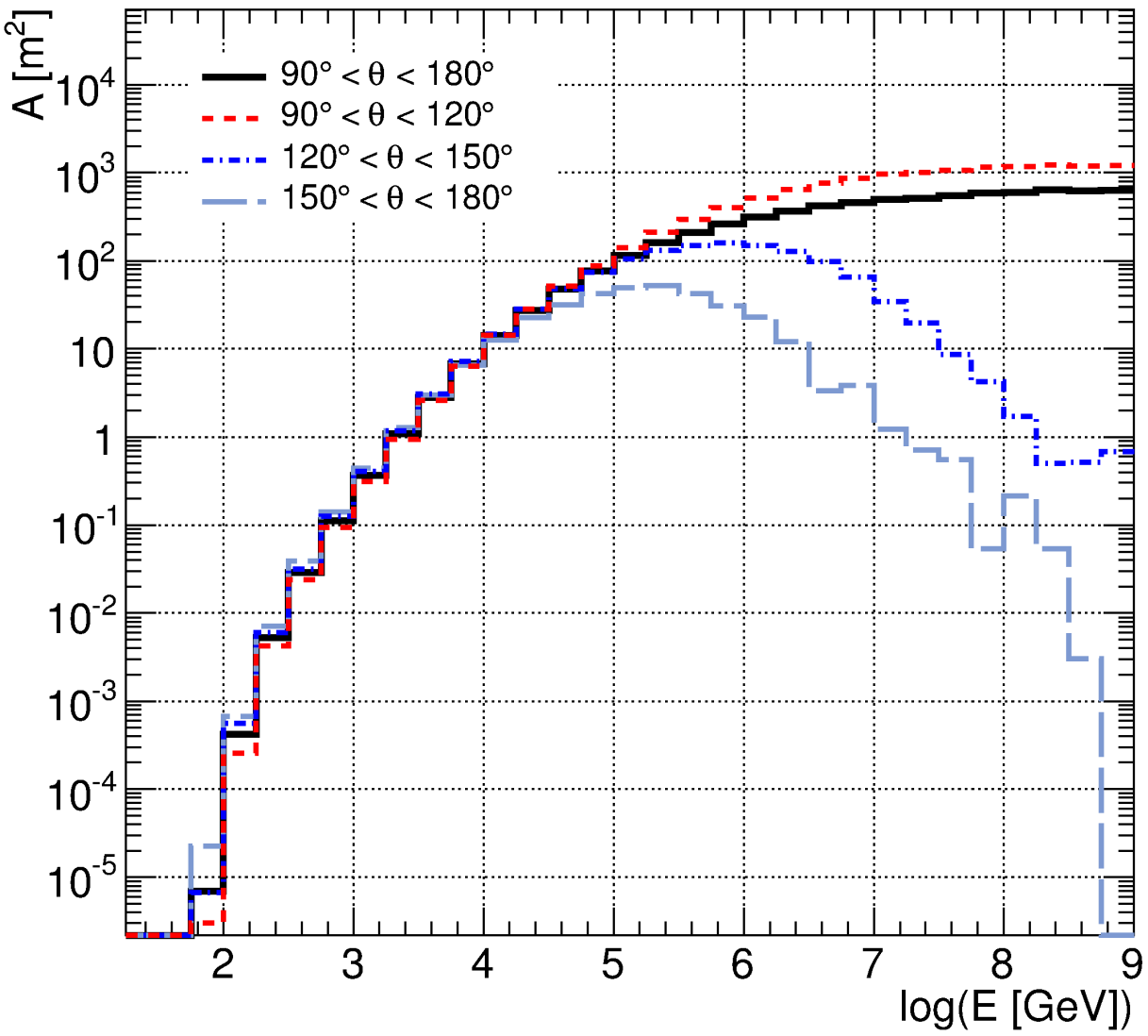

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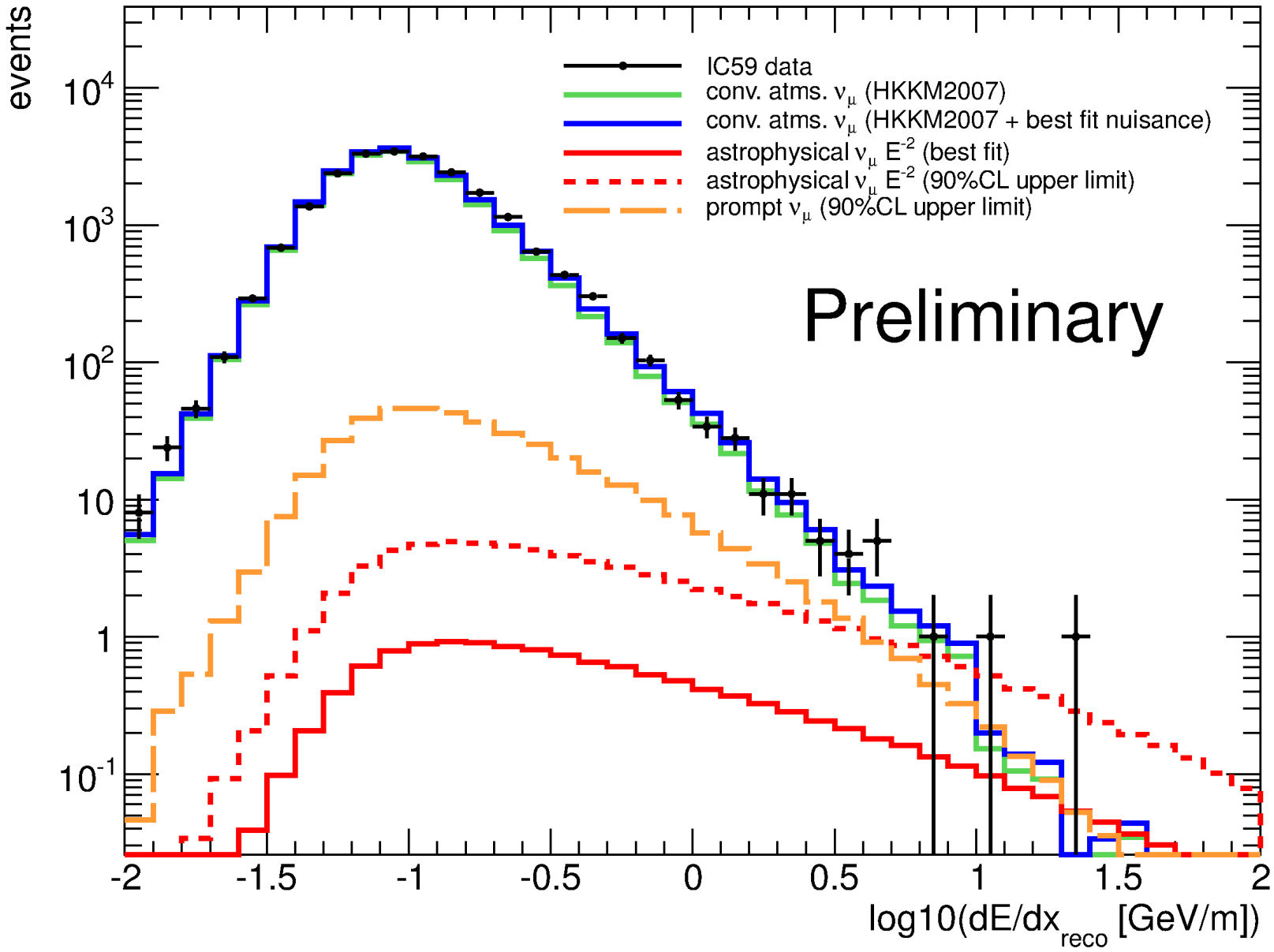

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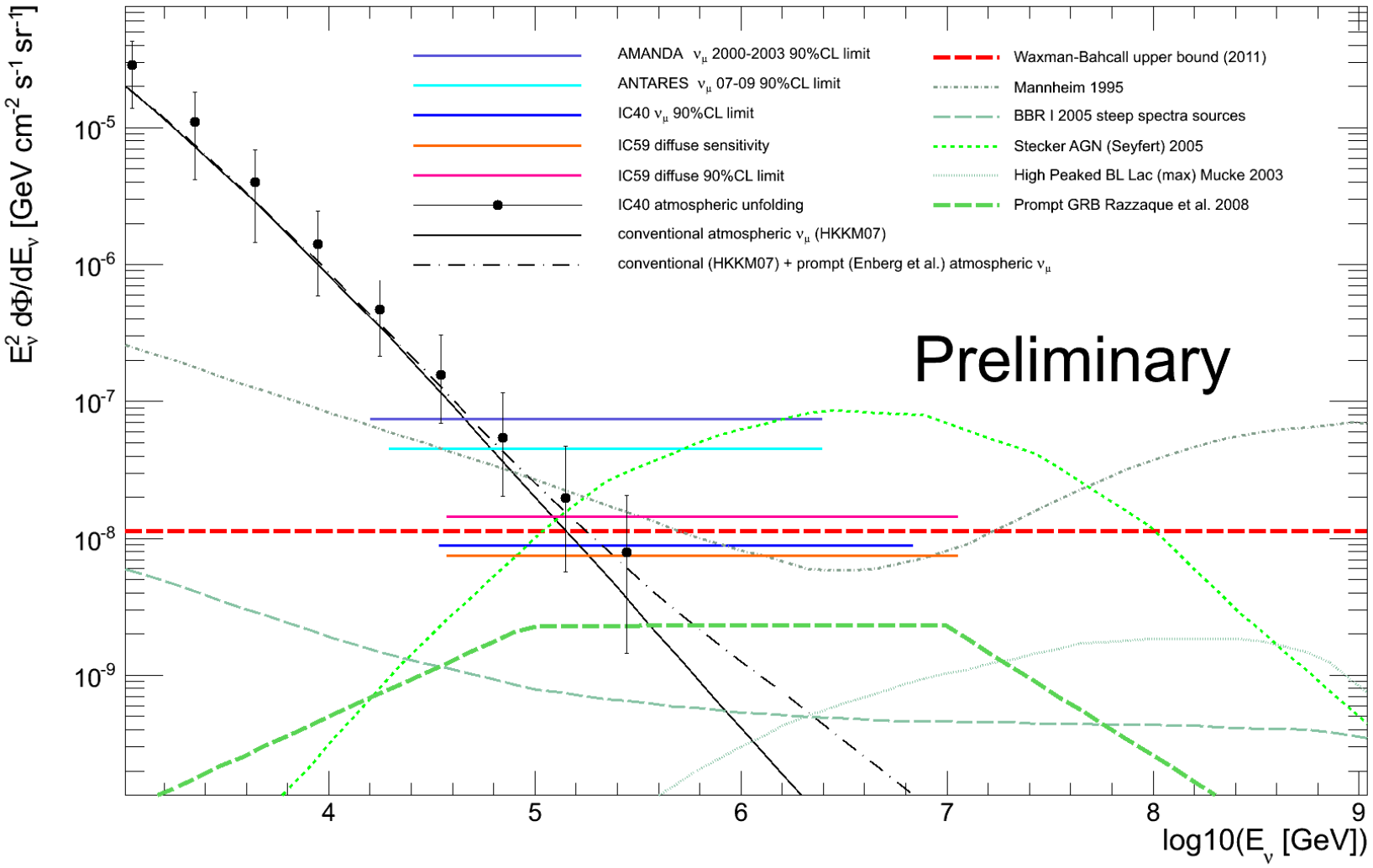
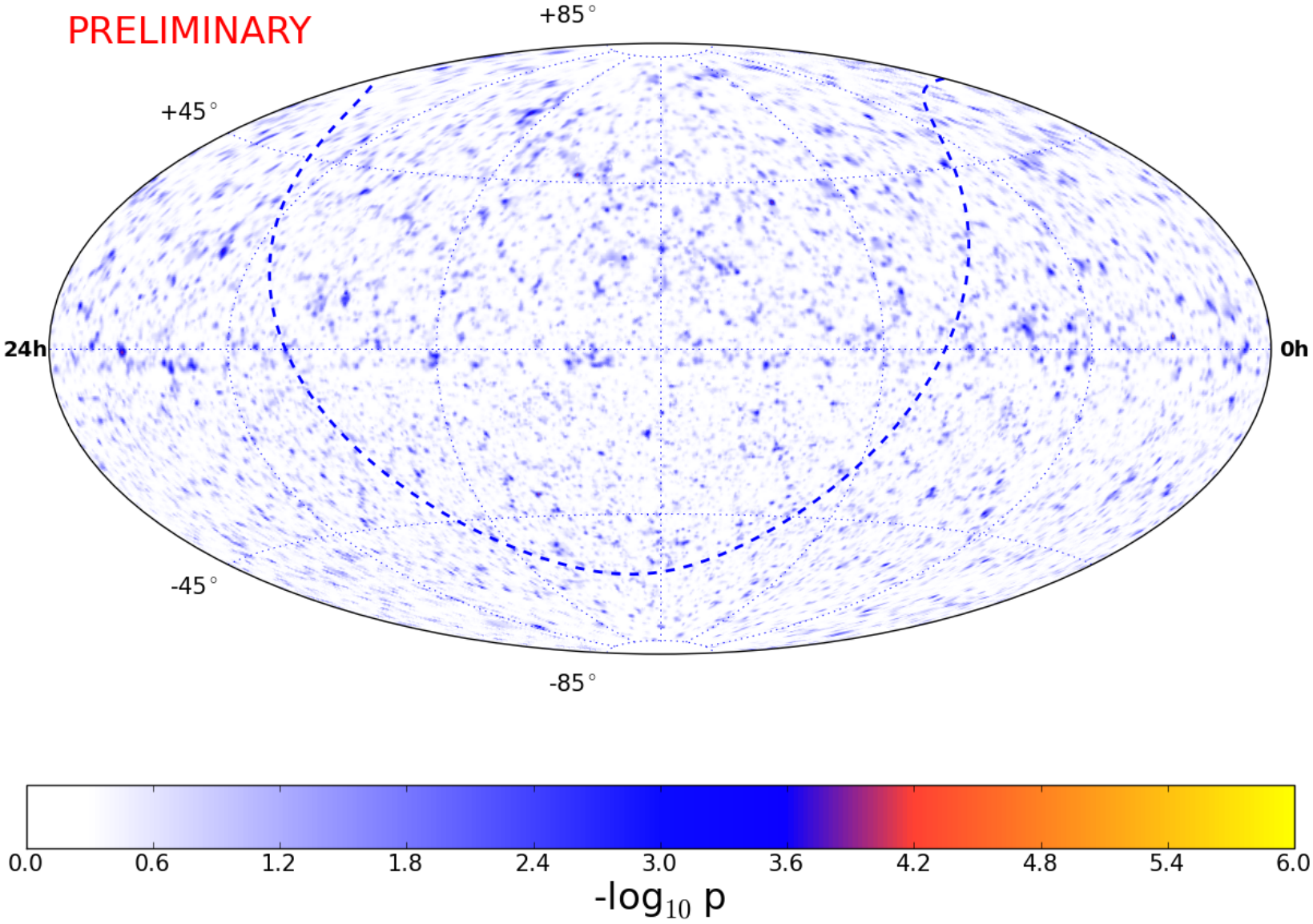
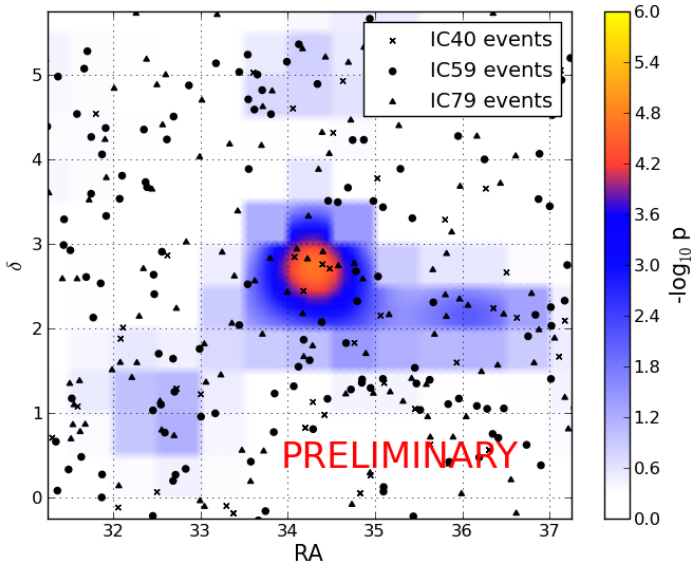
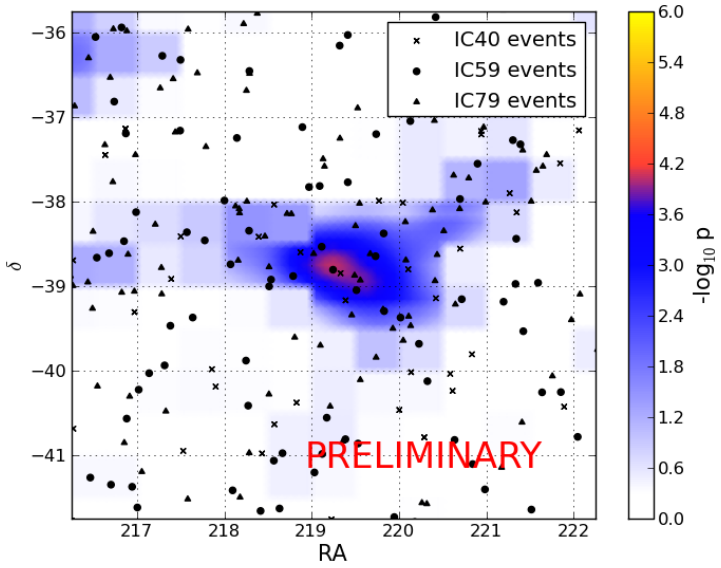


Search for point sources of HE neutrinos



Hot spots


IC40 events
IC59 events
IC79 events
PRELIMINARY
RA
δ
-log10 p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IC59 events
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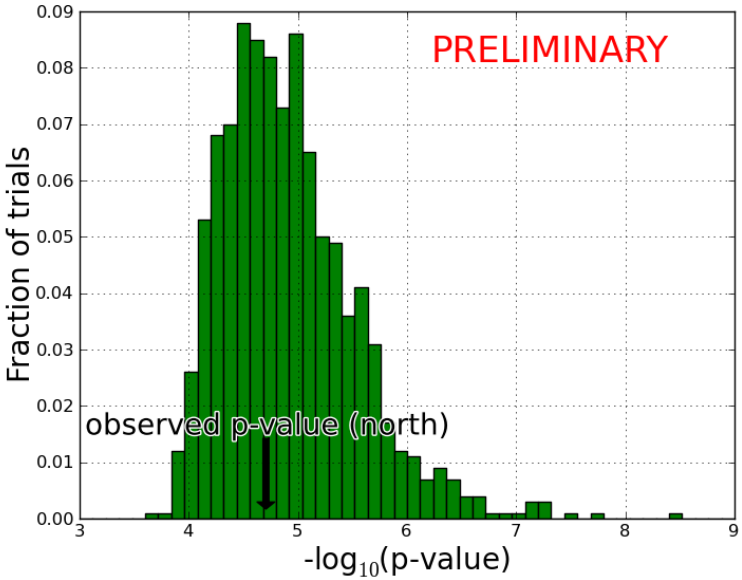
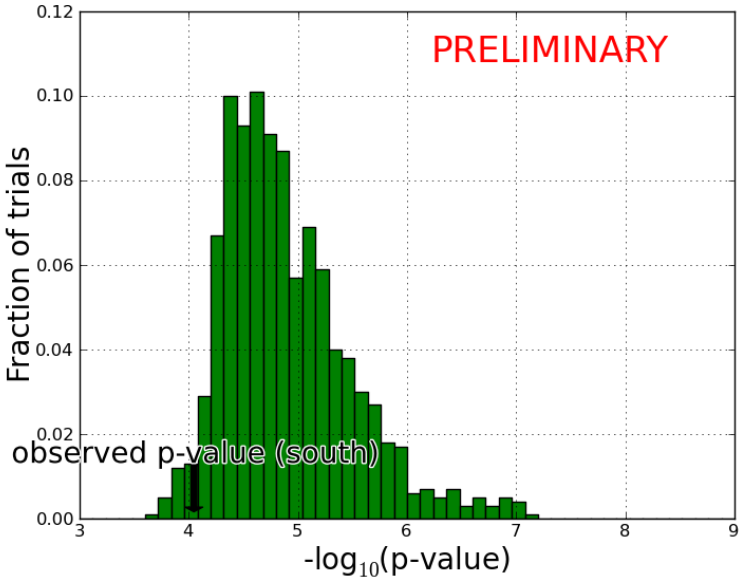
Post-trial significance





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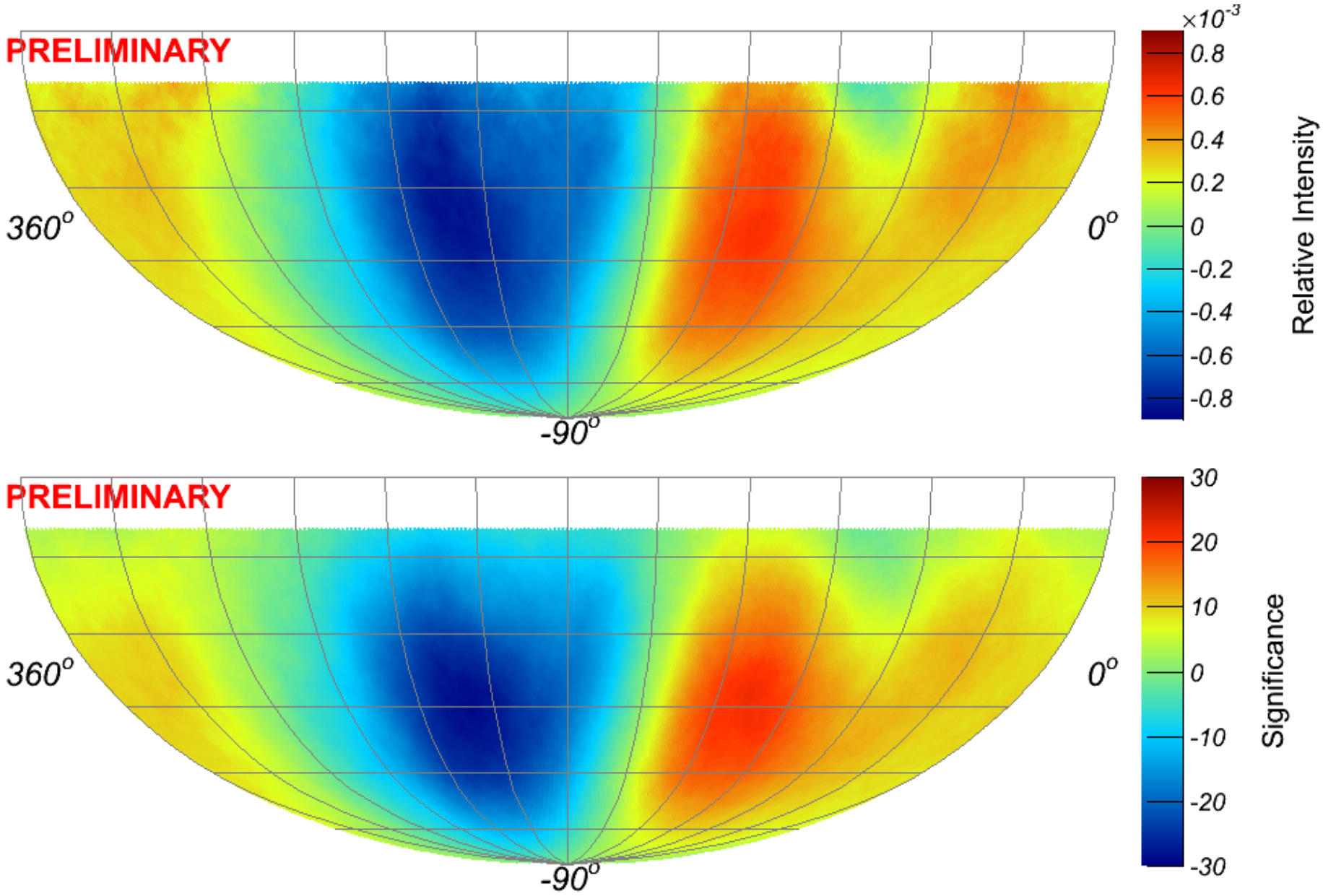
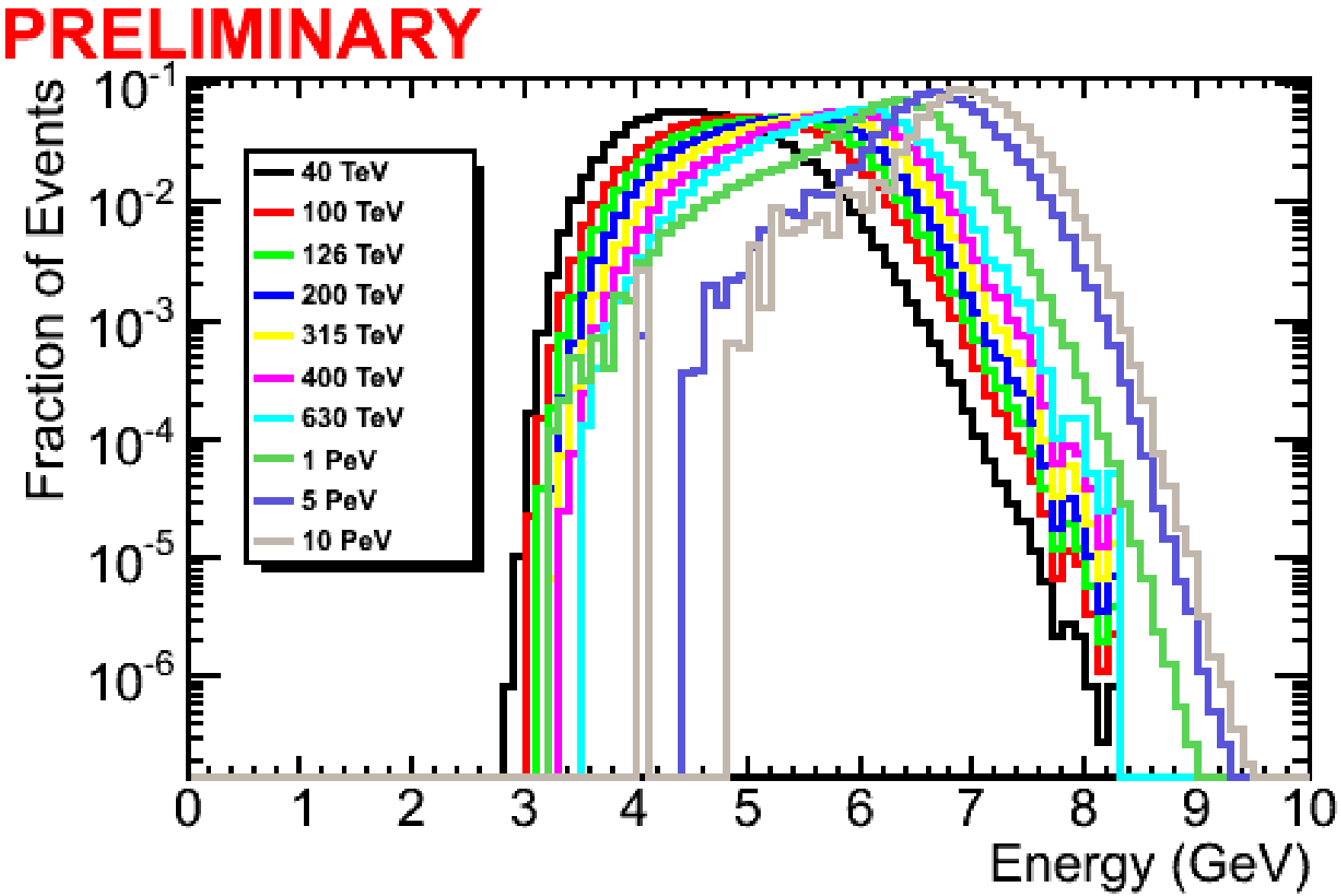
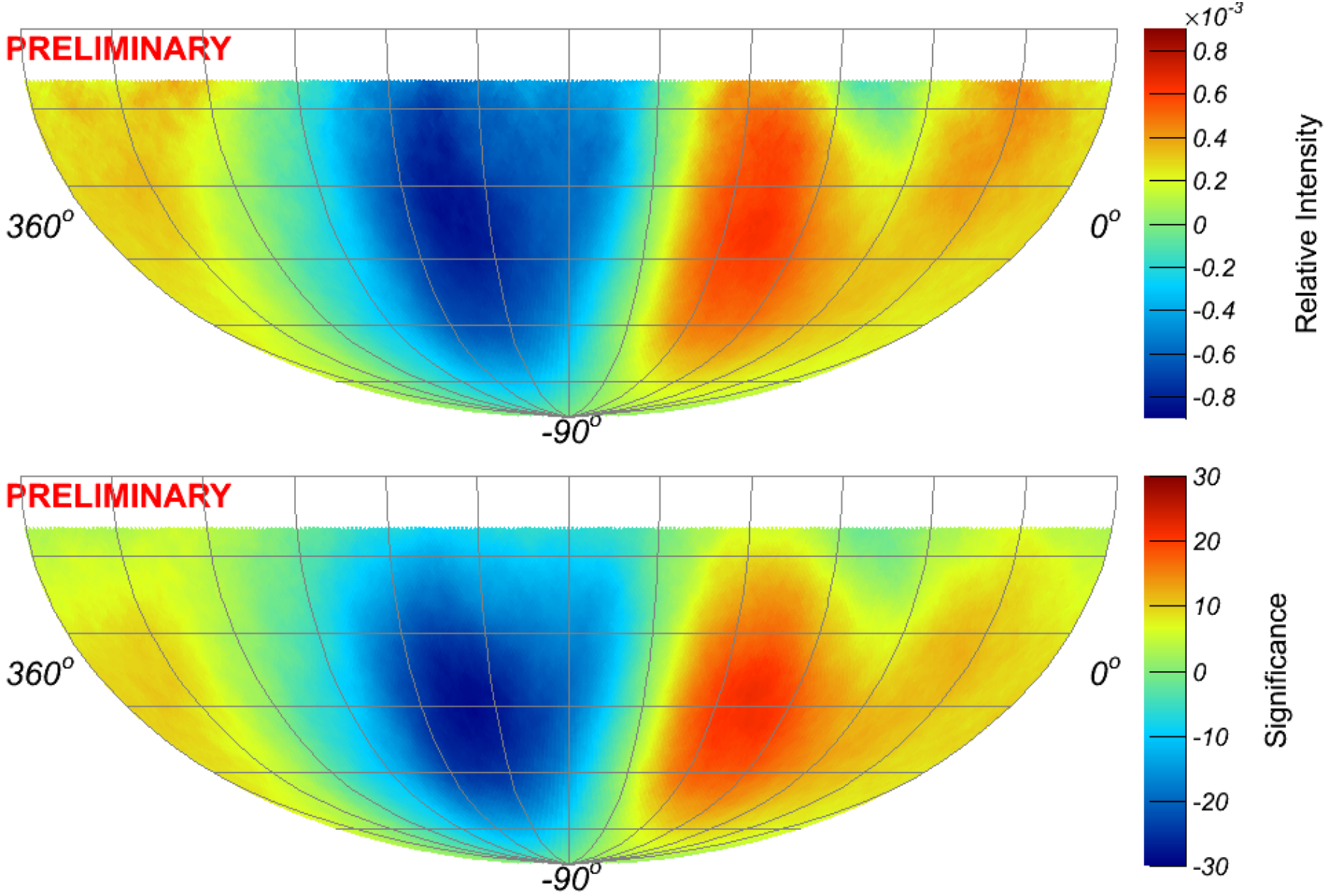

PRELIMINARY
360°
0°
-90°
×10^-3
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Relative Intensity
PRELIMINARY
360°
0°
-90°
30
20
10
0
-10
-20
-30
Significance

40 TeV

"Energy" selection

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Relative Intensity
PRELIMINARY
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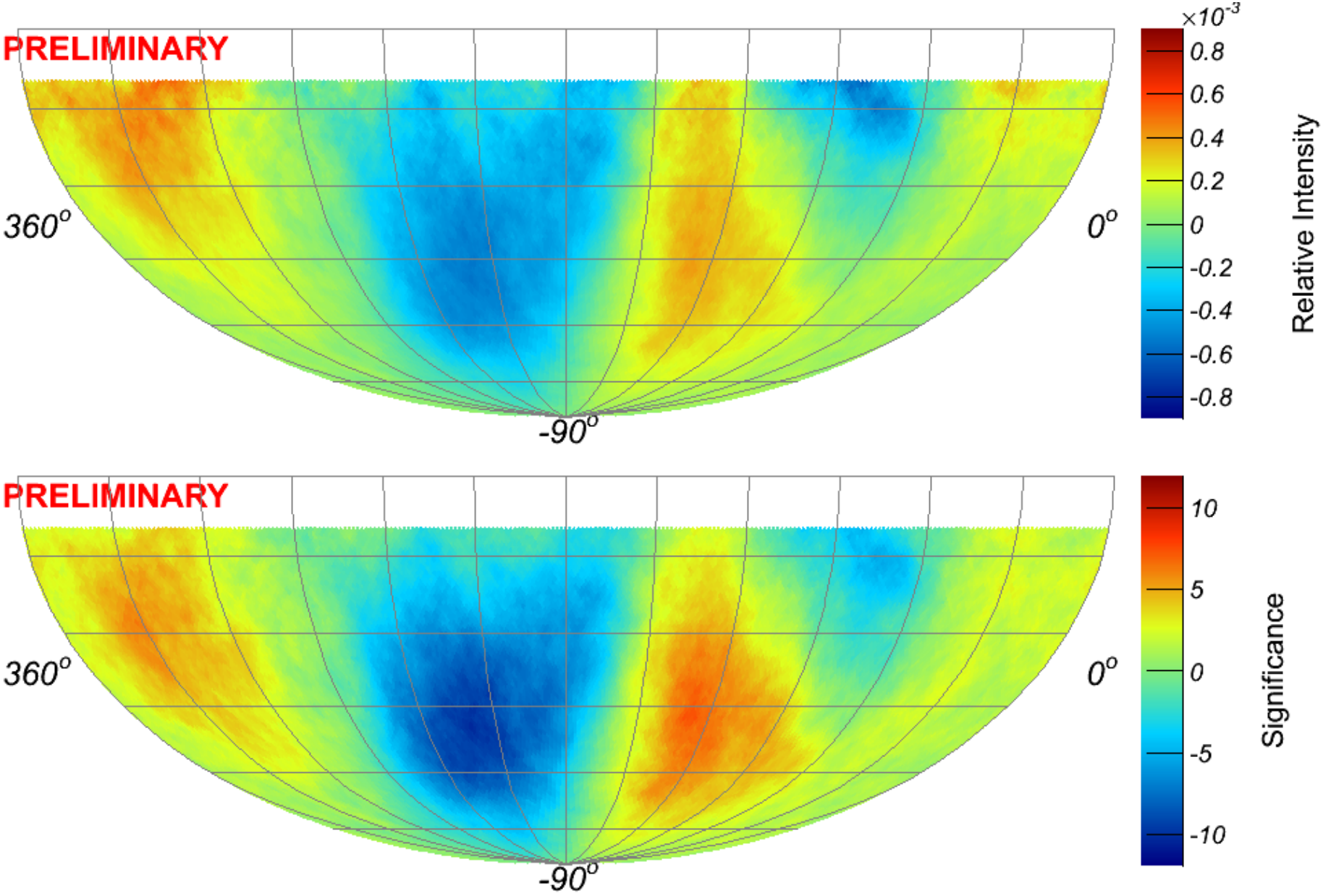
30
20
10
0
-10
-20
-30
Significance

40 TeV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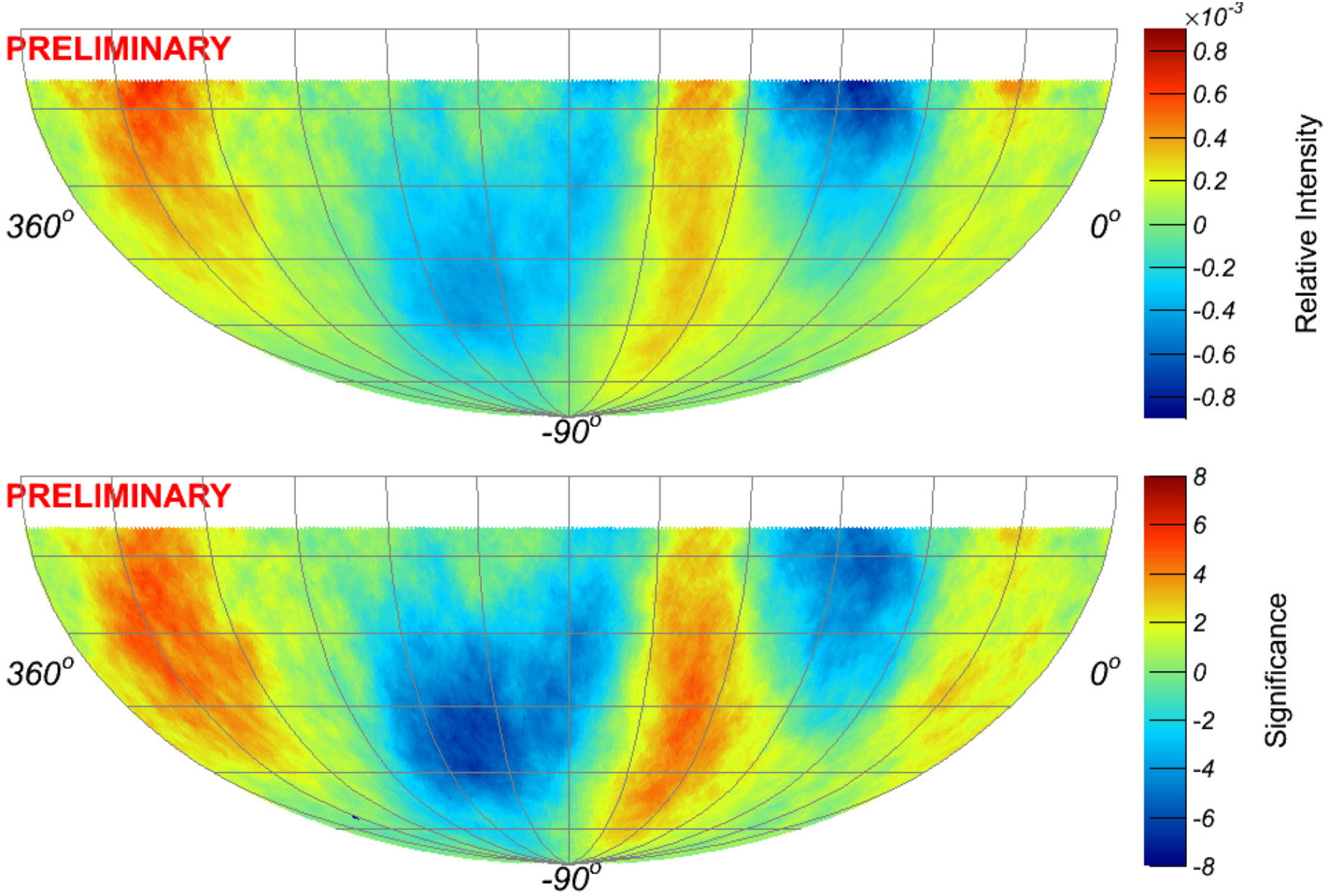
0°
-90°
×10^-3
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Relative Intensity
PRELIMINARY
360°
0°
-90°
10
5
0
-5
-10
Significance

100 TeV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×10^-3
0.8
0.6
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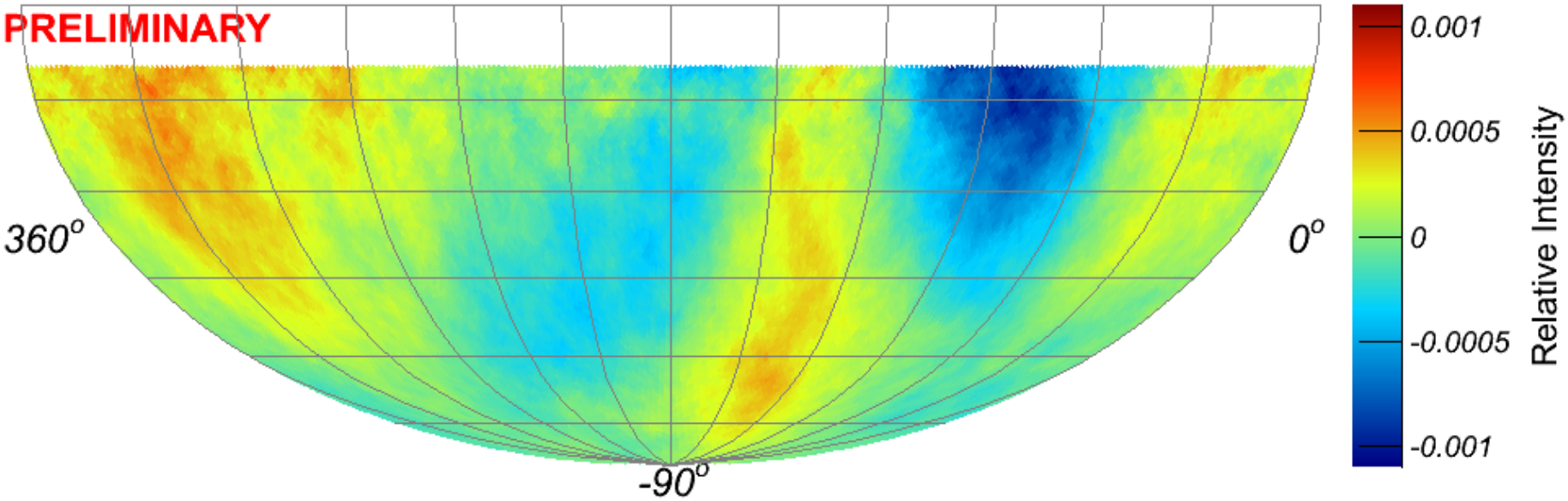
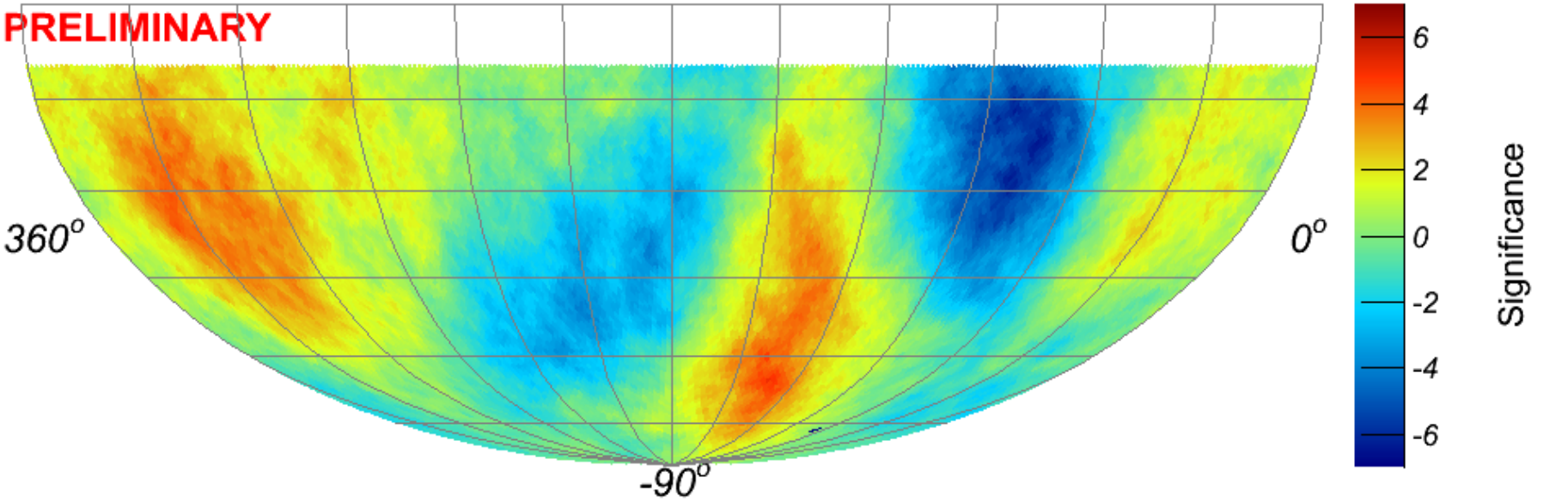
0.2
0
-0.2
-0.4
-0.6
-0.8
Relative Intensity
PRELIMINARY
360°
0°
-90°
8
6
4
2
0
-2
-4
-6
-8
Significance

126 TeV


PRELIMINARY
360°
0°
-90°
0.001
0.0005
0
-0.0005
-0.001
Relative Intensity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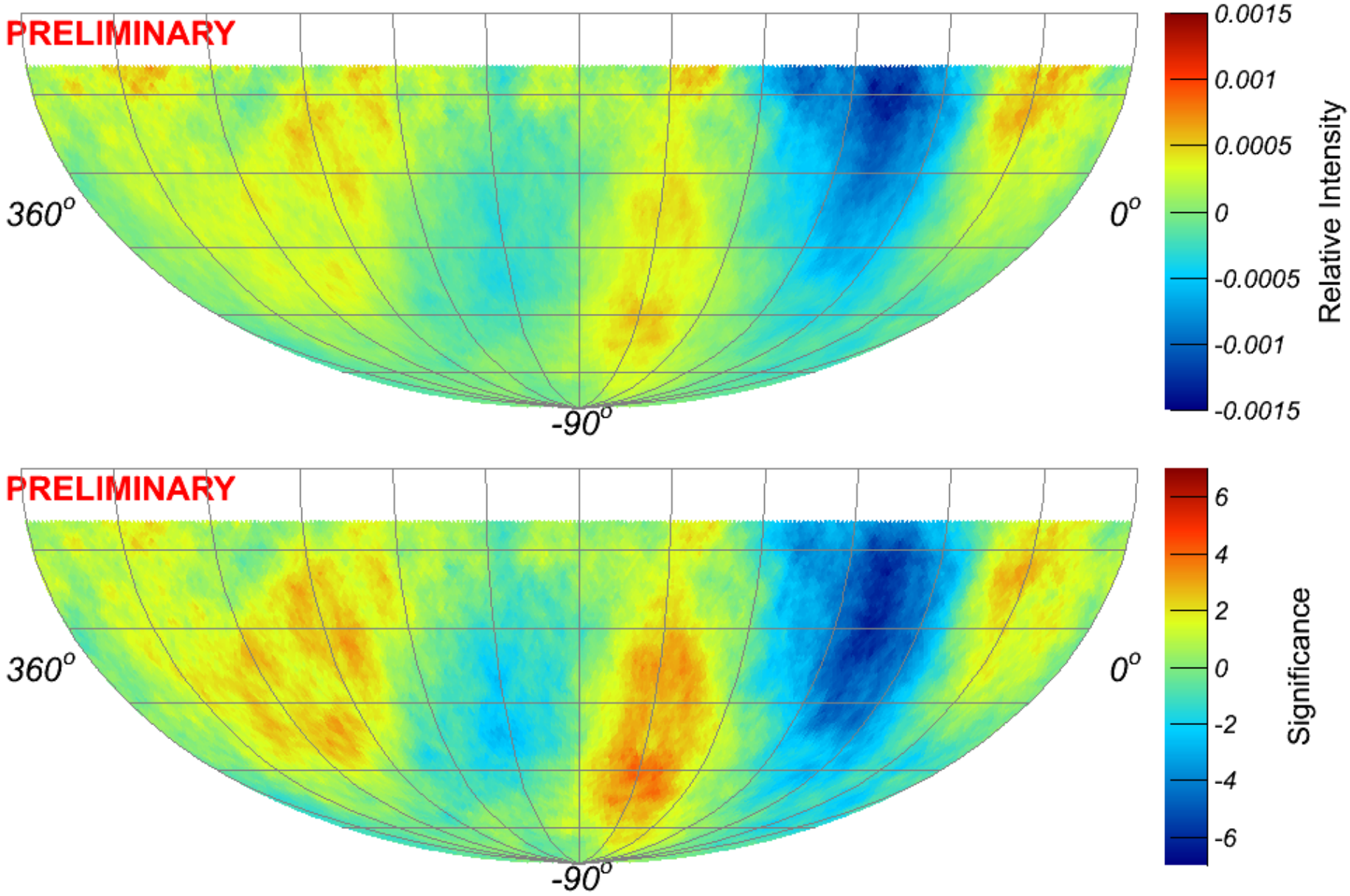
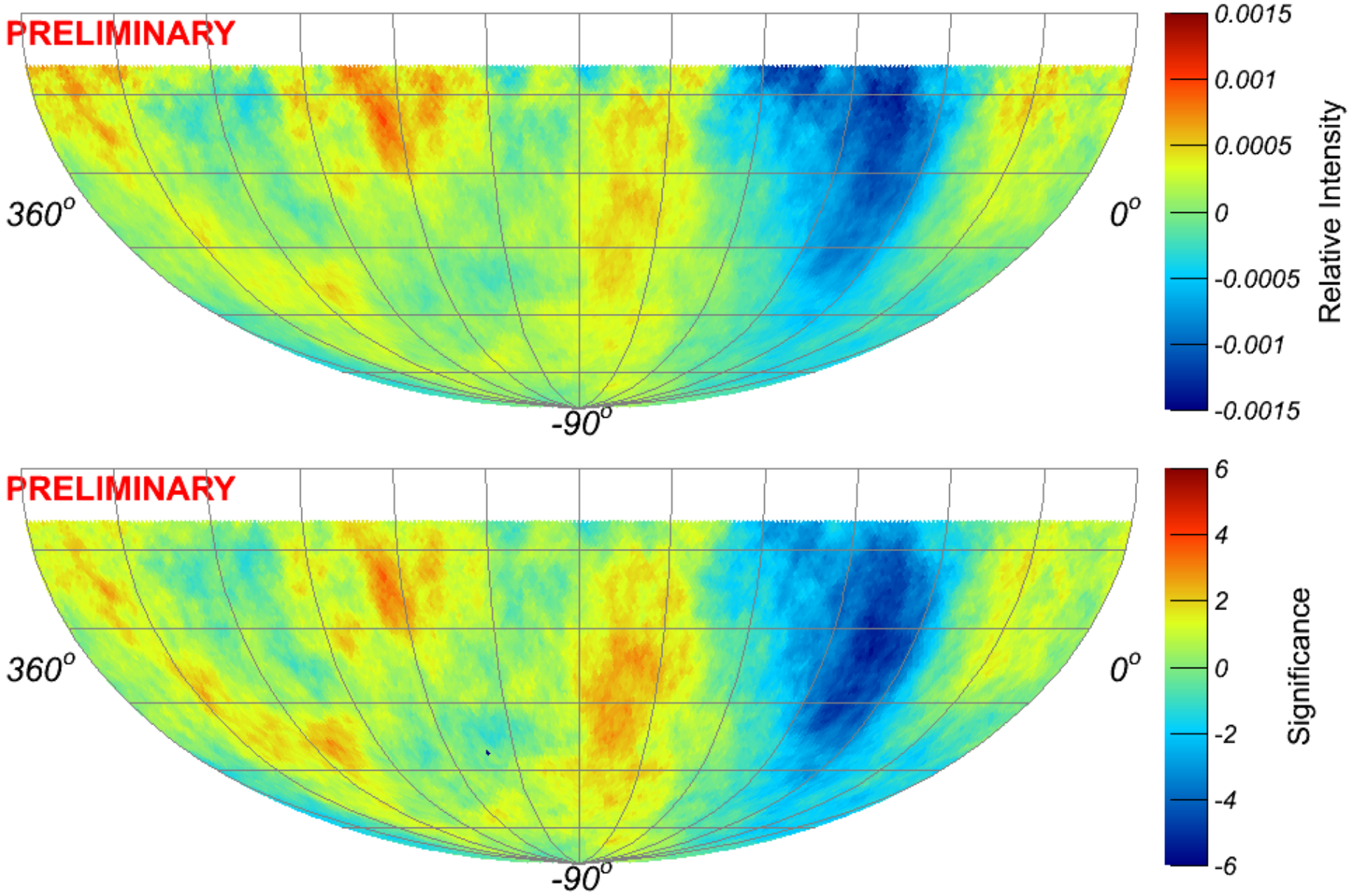
360°
0°
-90°
6
4
2
0
-2
-4
-6
Significance

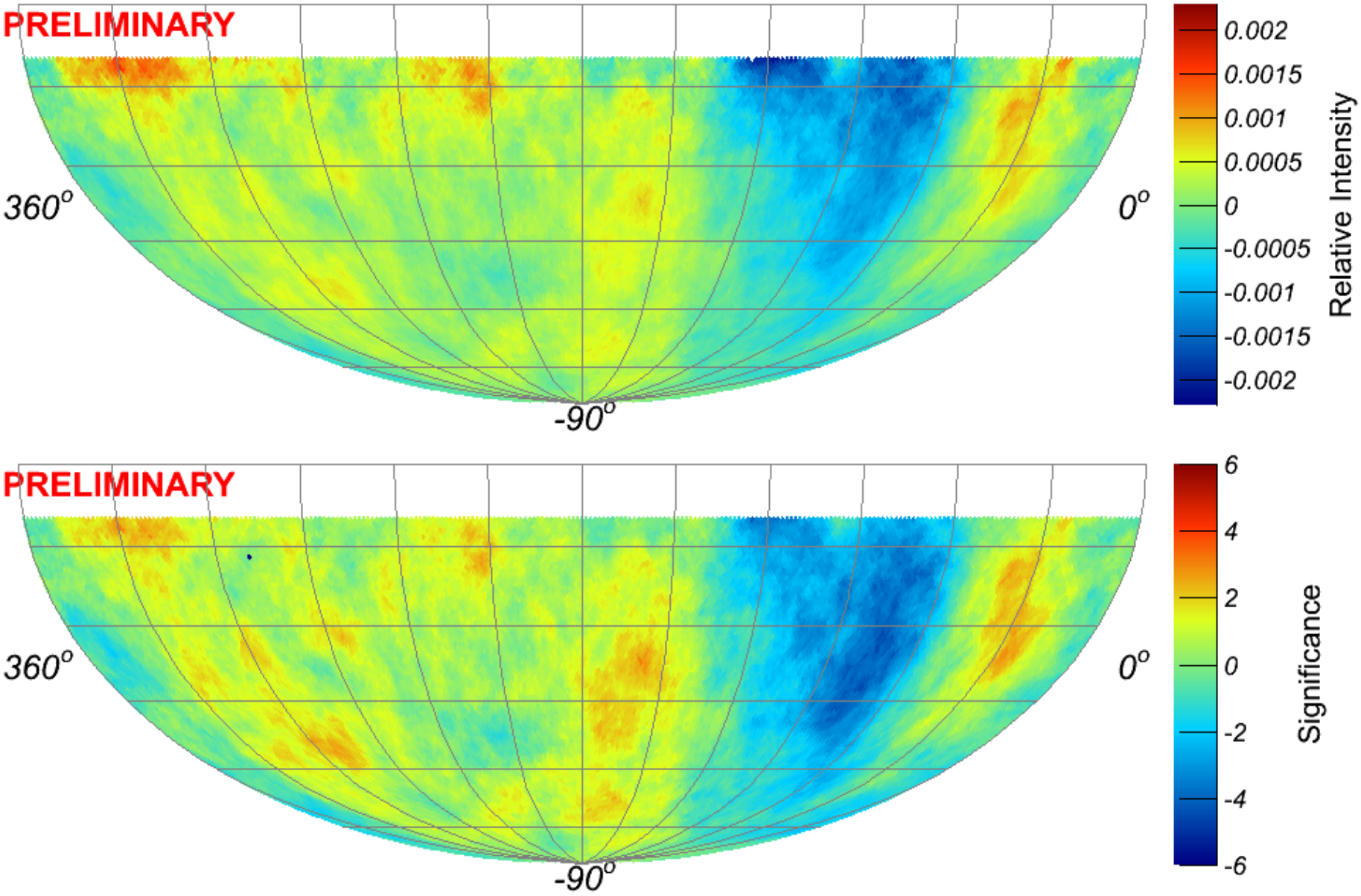
200 TeV


PRELIMINARY
360°
0°
-90°
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015
Relative Intensity
PRELIMINARY
360°
0°
-90°
6
4
2
0
-2
-4
-6
Significance

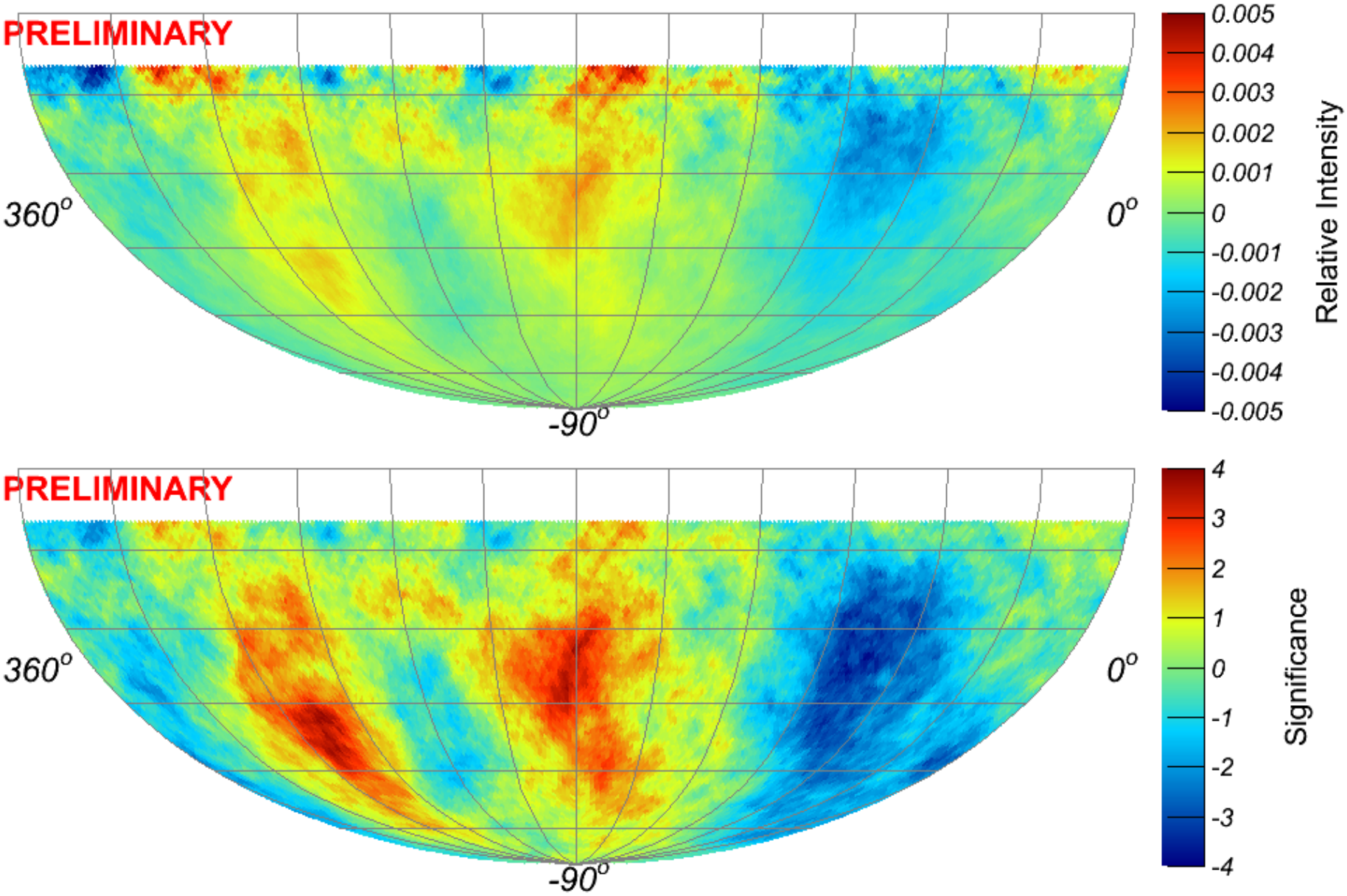
316 TeV


PRELIMINARY
360°
0°
-90°
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015
Relative Intensity
PRELIMINARY
360°
0°
-90°
6
4
2
0
-2
-4
-6
Significance

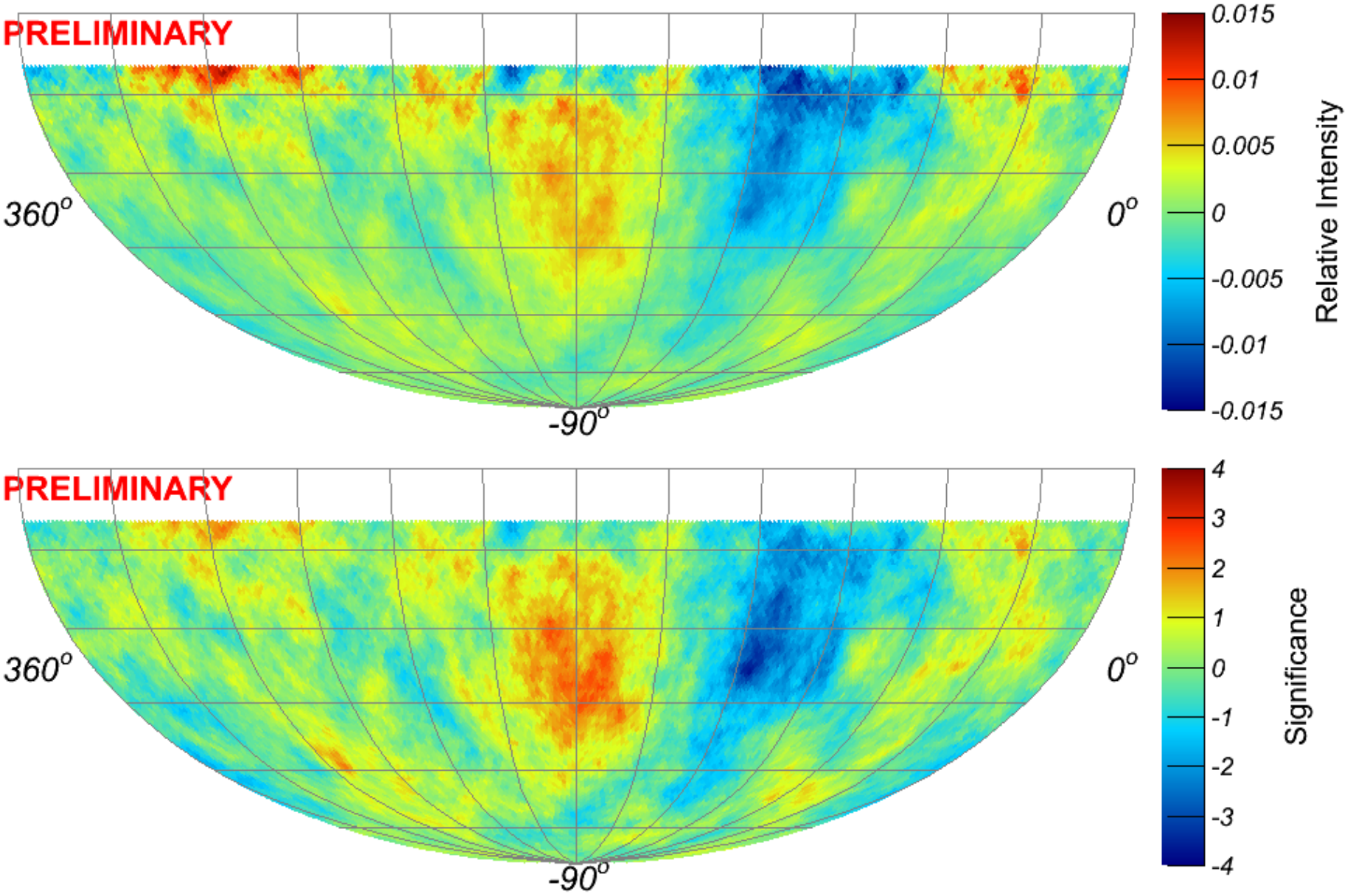
400 TeV


PRELIMINARY
360°
0°
-90°
0.002
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015
-0.002
Relative Intensity
PRELIMINARY
360°
0°
-90°
6
4
2
0
-2
-4
-6
Significance

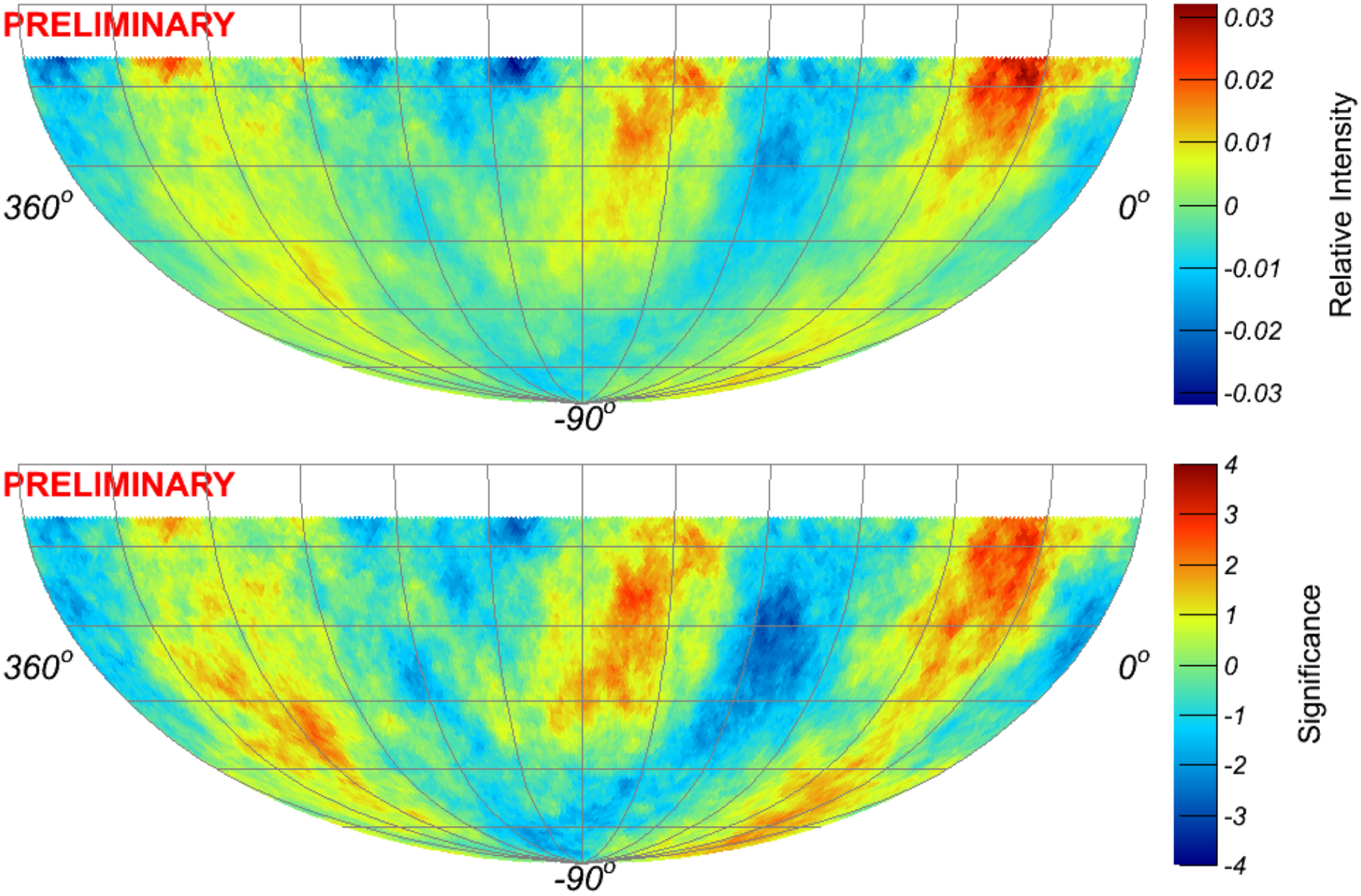
630 TeV


PRELIMINARY
360°
0°
-90°
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004
-0.005
Relative Intensity
PRELIMINARY
360°
0°
-90°
4
3
2
1
0
-1
-2
-3
-4
Significance

1 PeV

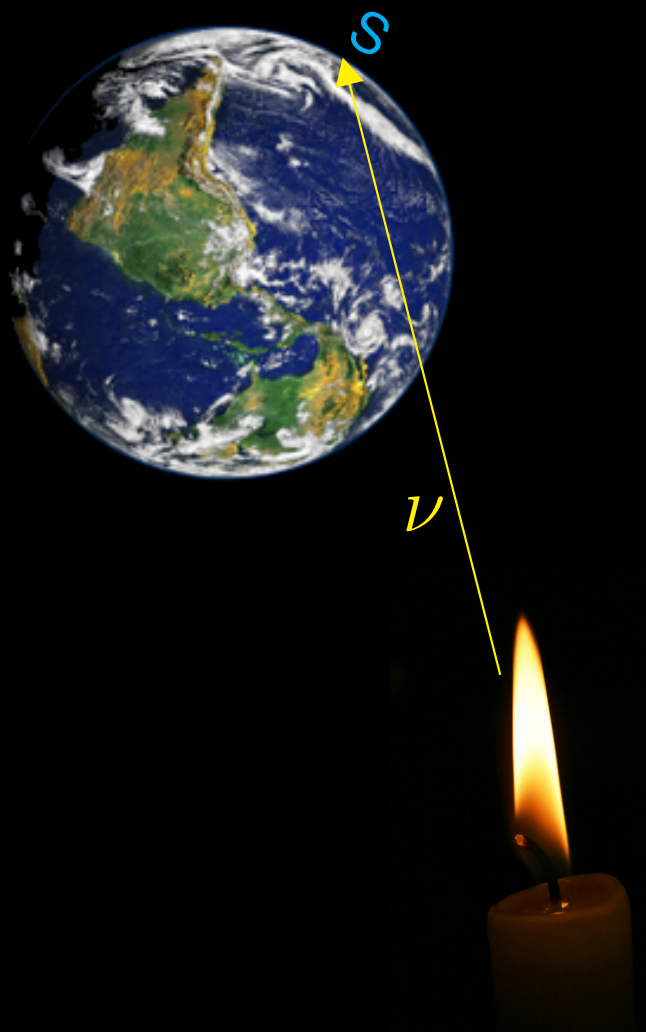

PRELIMINARY
360°
0°
-90°
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
Relative Intensity
PRELIMINARY
360°
0°
-90°
4
3
2
1
0
-1
-2
-3
-4
Significance

5 PeV

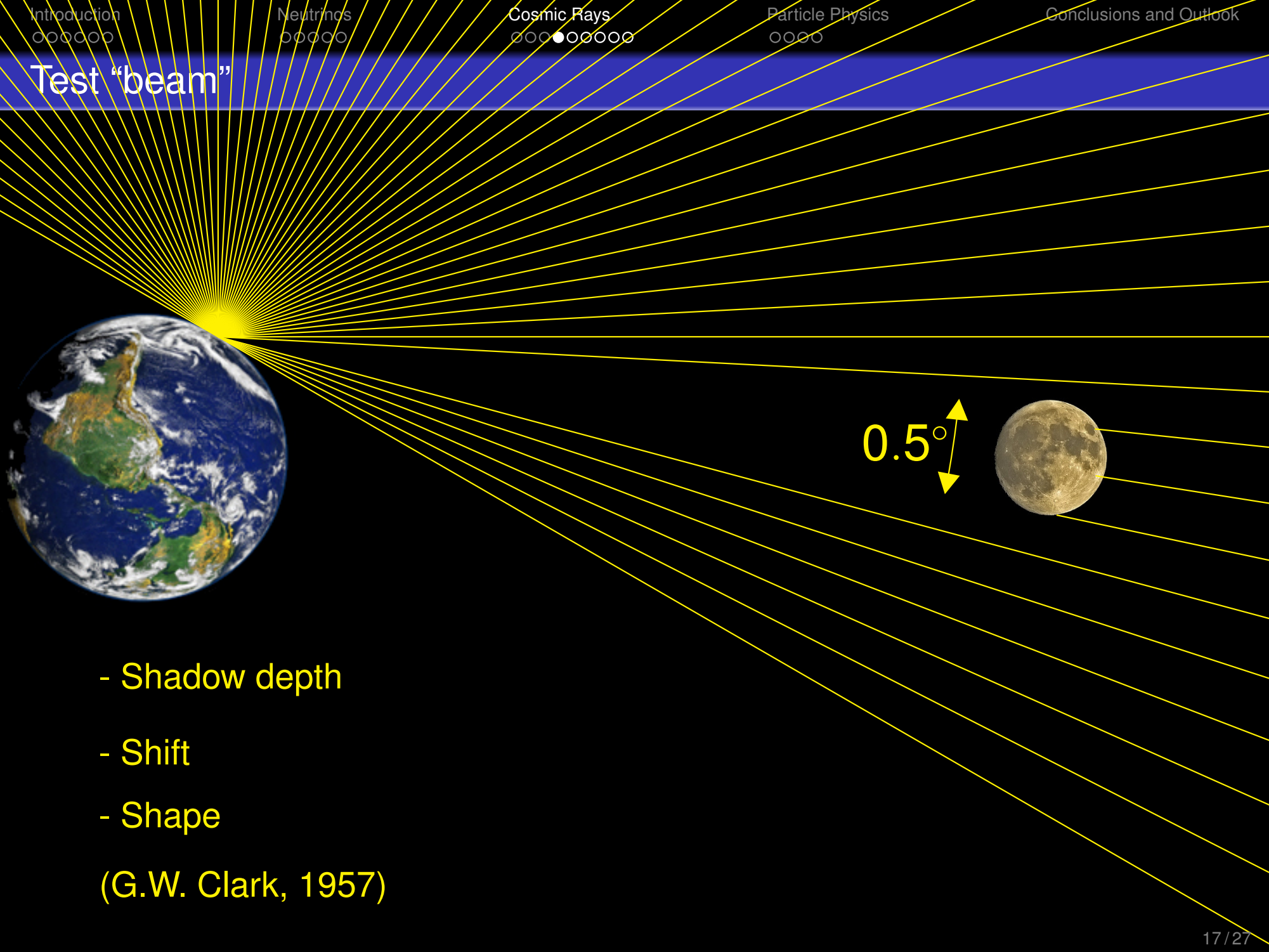

PRELIMINARY
360°
0°
-90°
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
Relative Intensity
PRELIMINARY
360°
0°
-90°
4
3
2
1
0
-1
-2
-3
-4
Significance

10 PeV

Test “beam”



Test “beam”



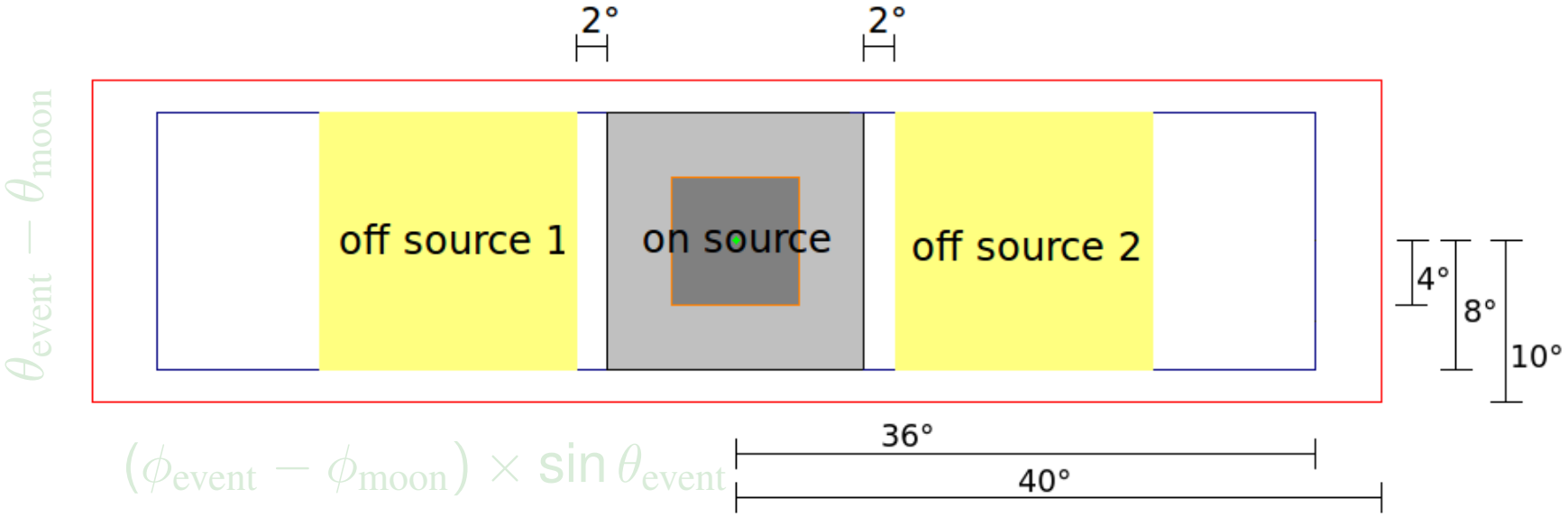
- Shadow depth
- Shift
- Shape

(G.W. Clark, 1957)

Event selection

Online/ Offline

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



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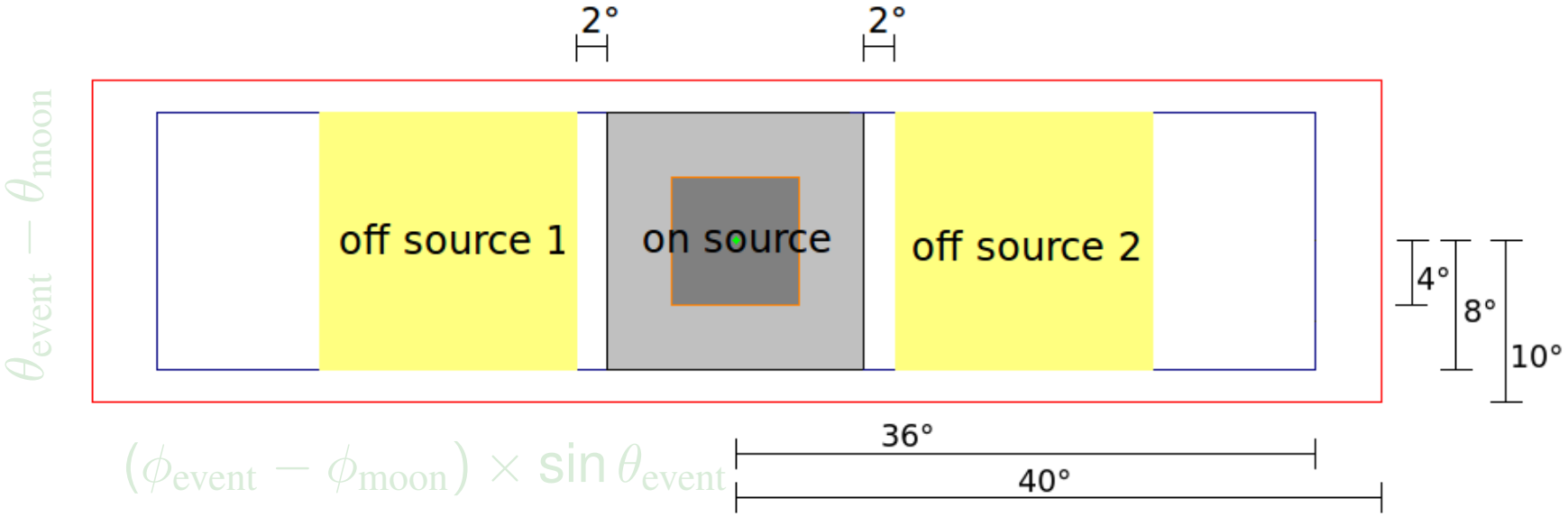

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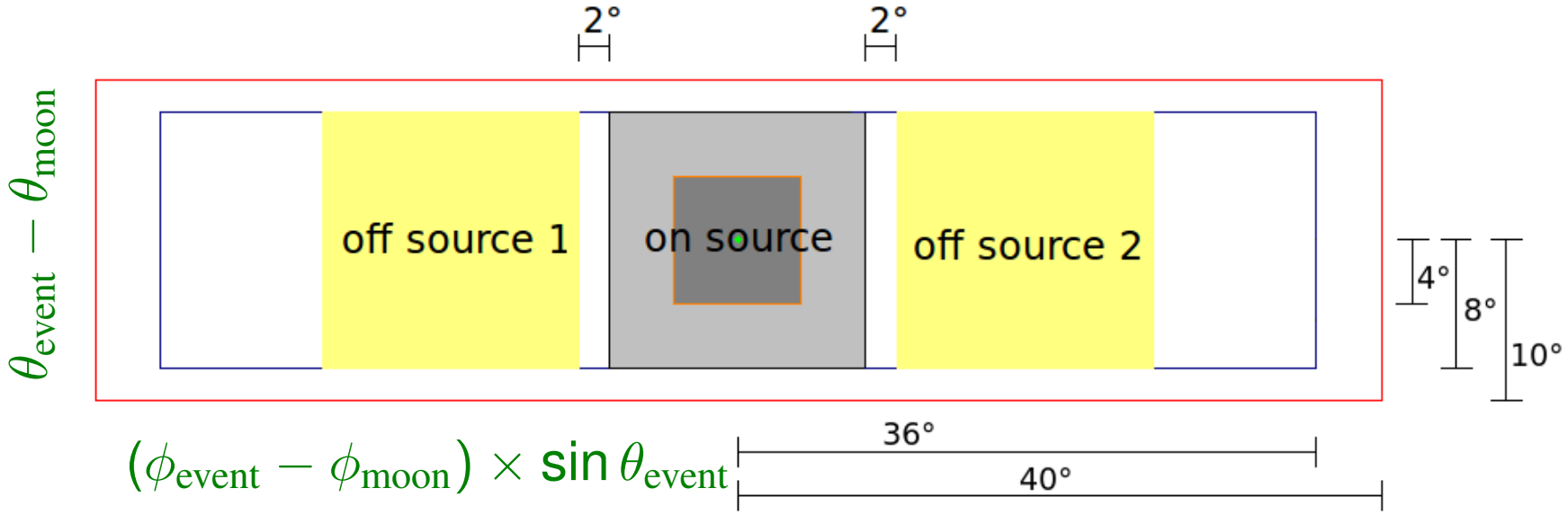
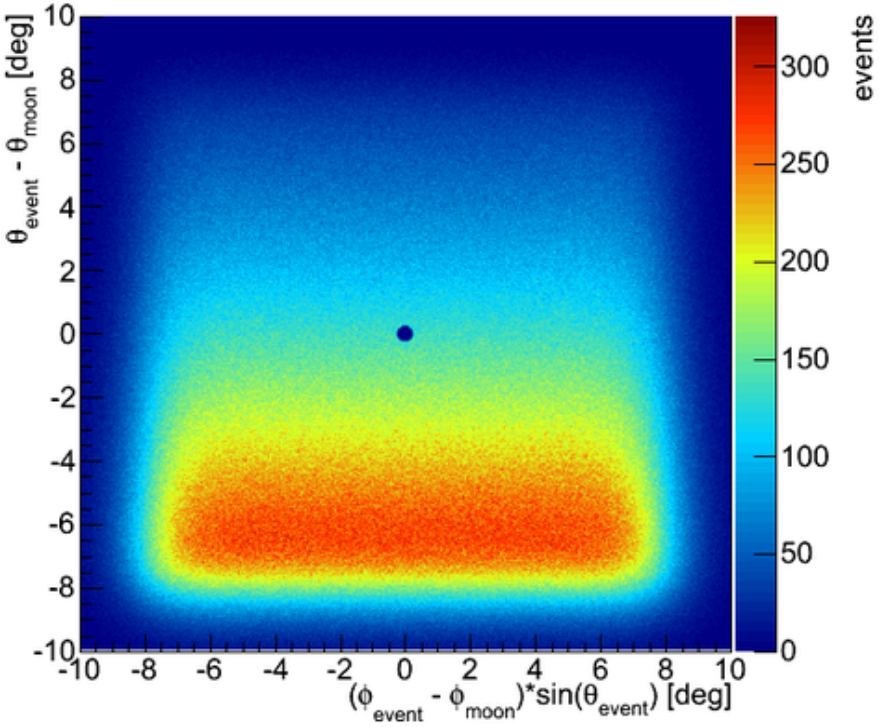
- Angular window (offline track fit)

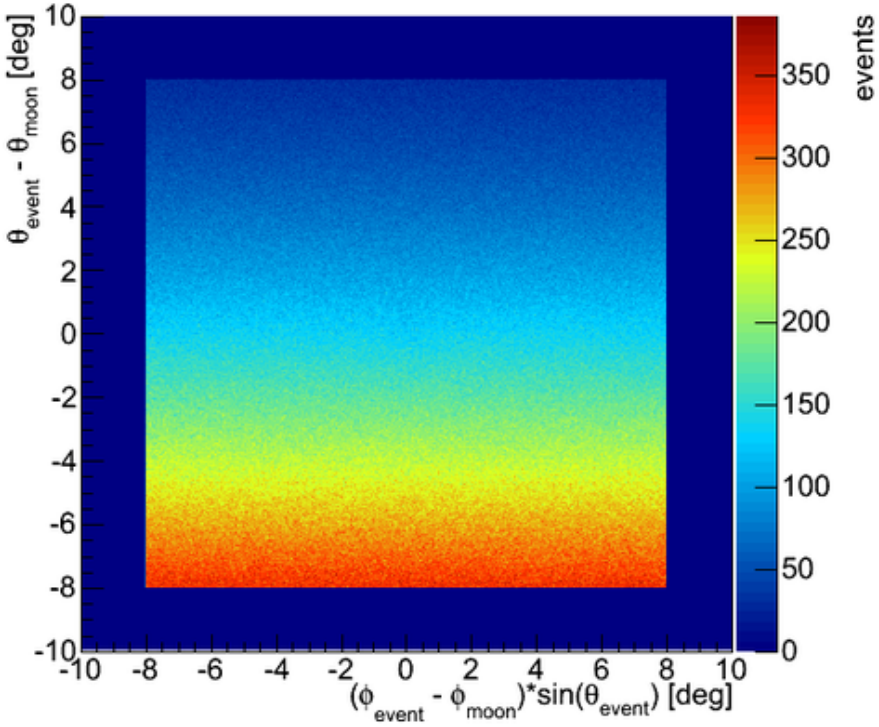


Challenge (illustrated with *simulated* data)

"true" CR directions



reconstructed μ directions



Likelihood analysis of the Moon shadow

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

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

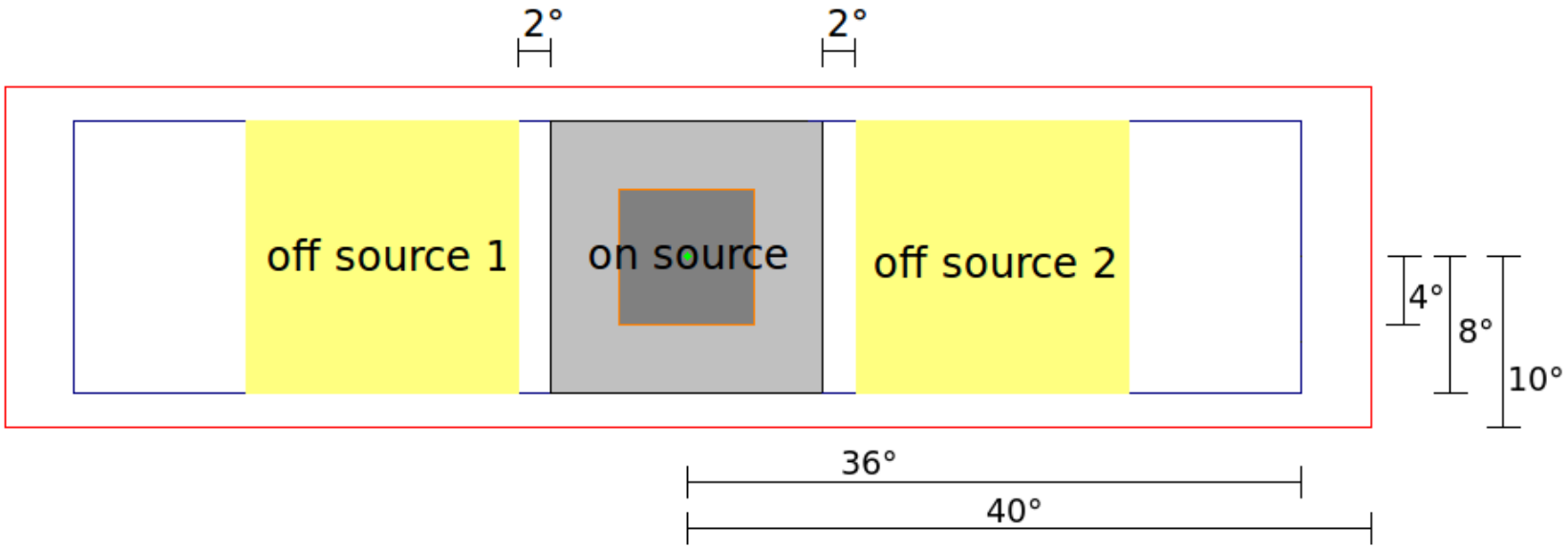
n_s = Number of source events (negative for shadow)

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

B_i = Normalized zenith distribution (from off-source)

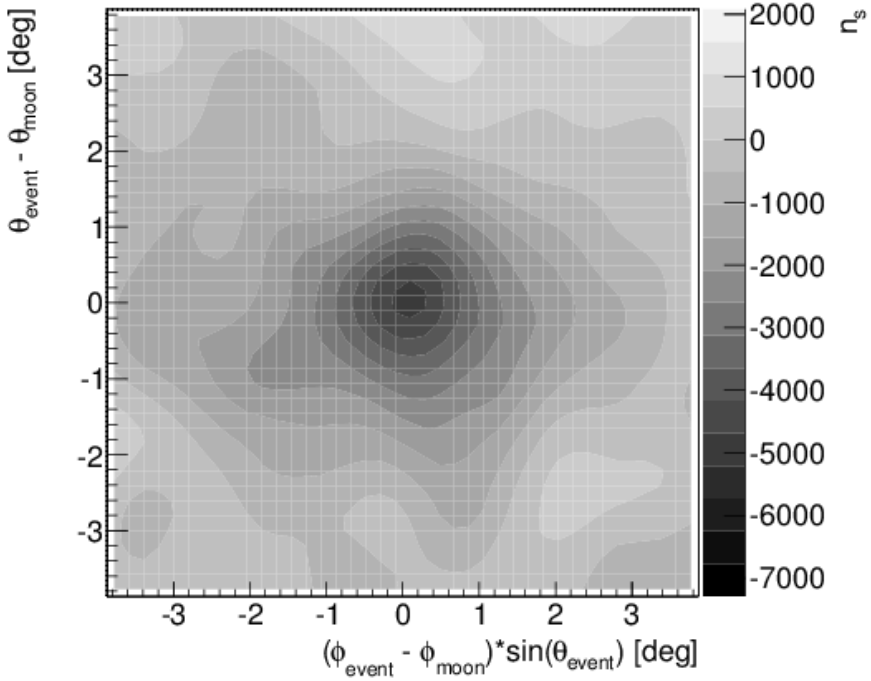
N_{events} = # good events in on-source sample ($\sim$8.4M in IC40, $\sim$11.7M in IC59)

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



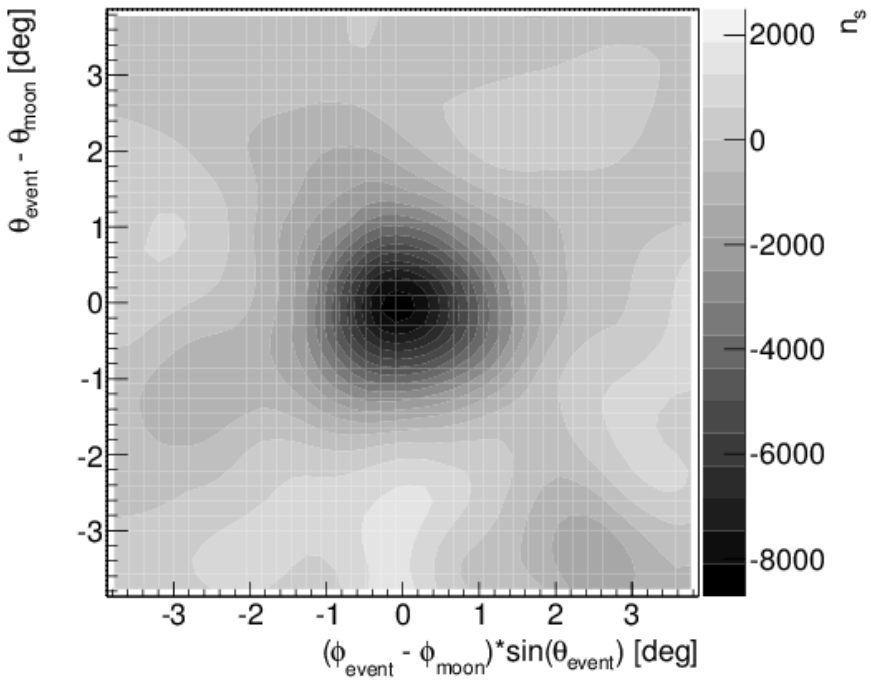
Results: shadow depth and shift

40 strings (2008-2009)



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

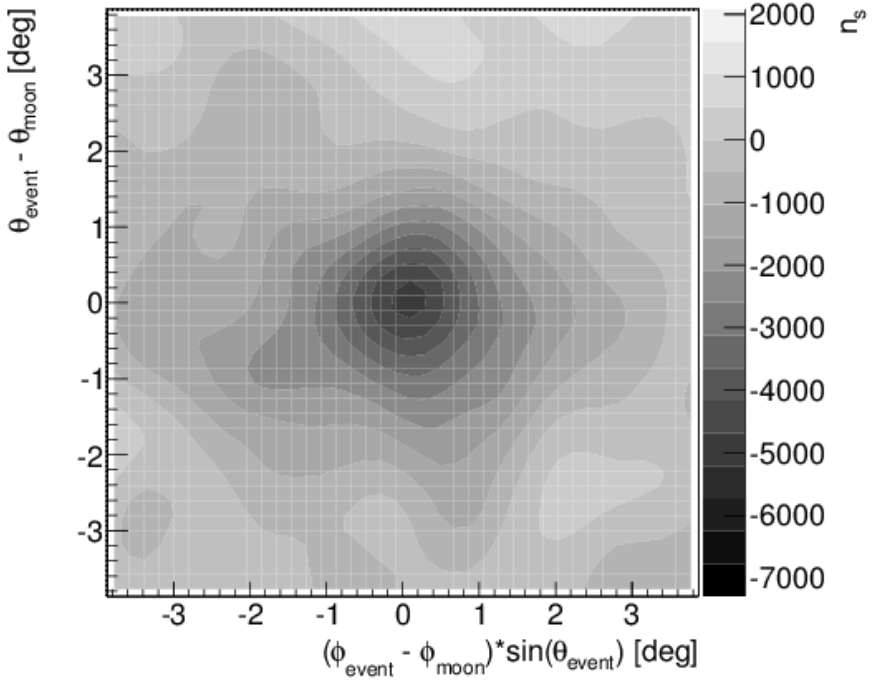
59 strings (2009-2010)



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

Results: shadow depth and shift

40 strings (2008-2009)



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

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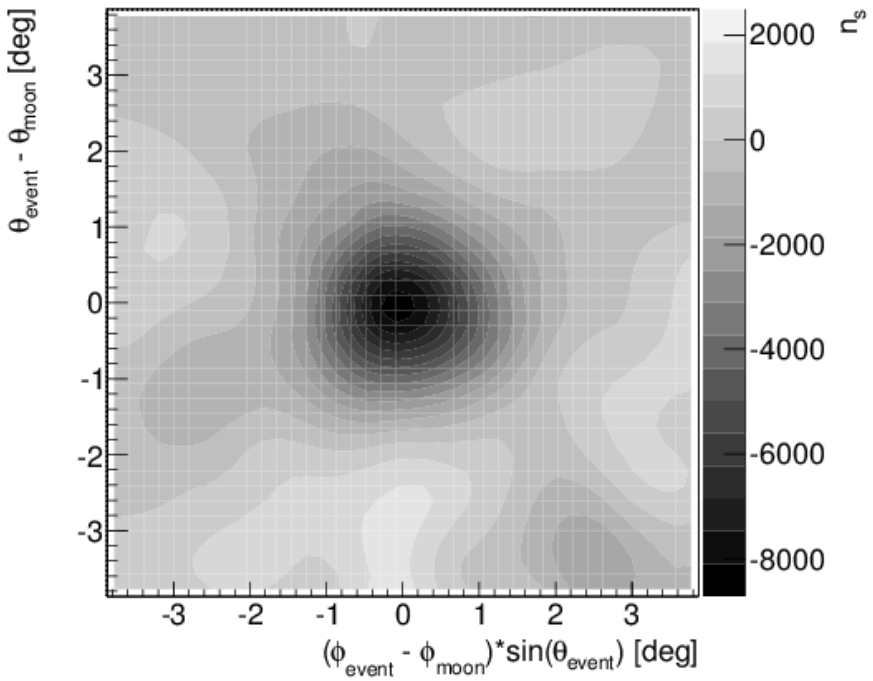
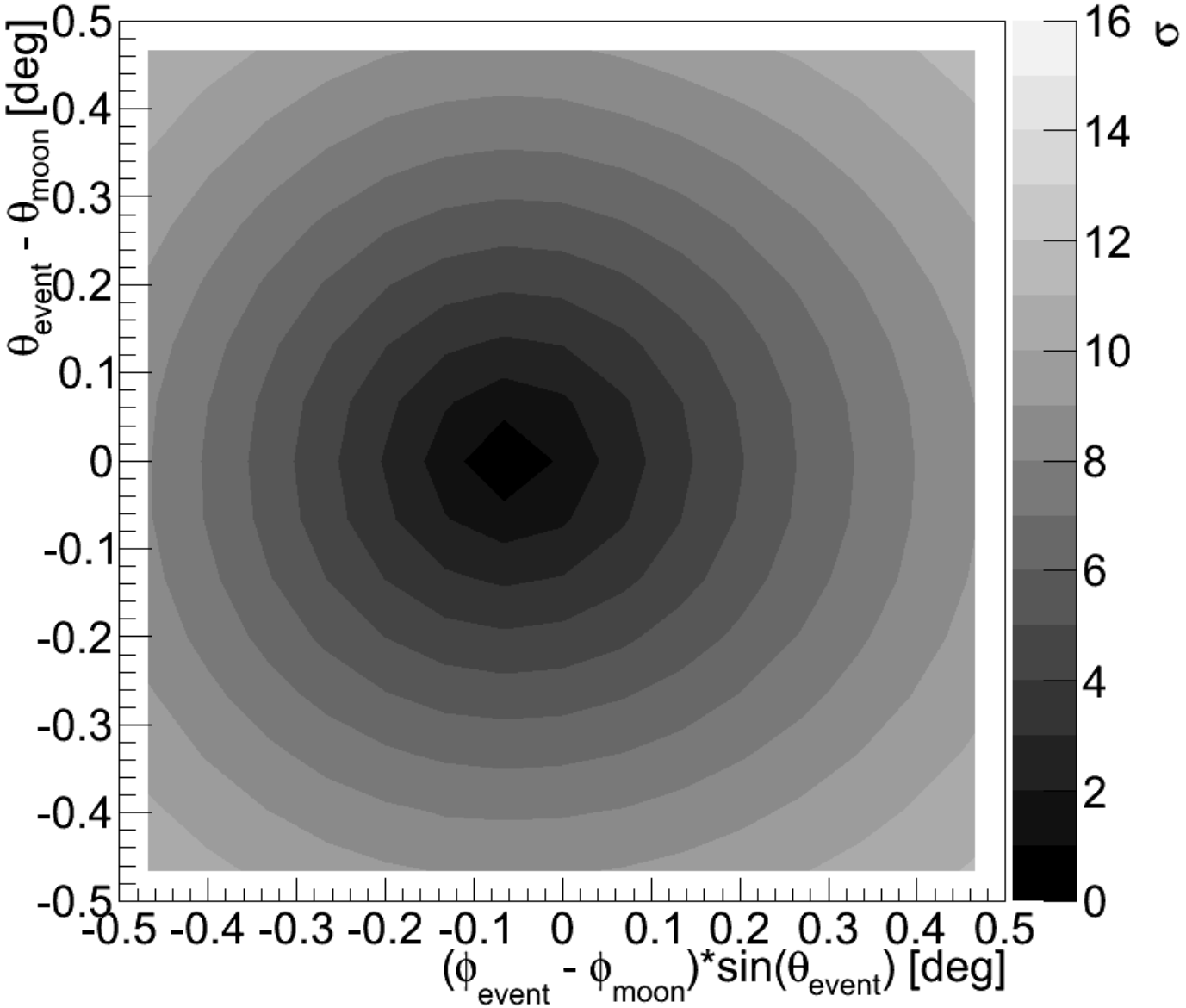


- $n_s^{\text{obs}} = -8660 \pm 565 \pm 681$
- $n_s^{\text{exp}} = -8192 \pm 91$
- $\vec{x}_s^{\text{obs}} = (-0.1^\circ \pm 0.1^\circ, 0.0^\circ \pm 0.1^\circ)$

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

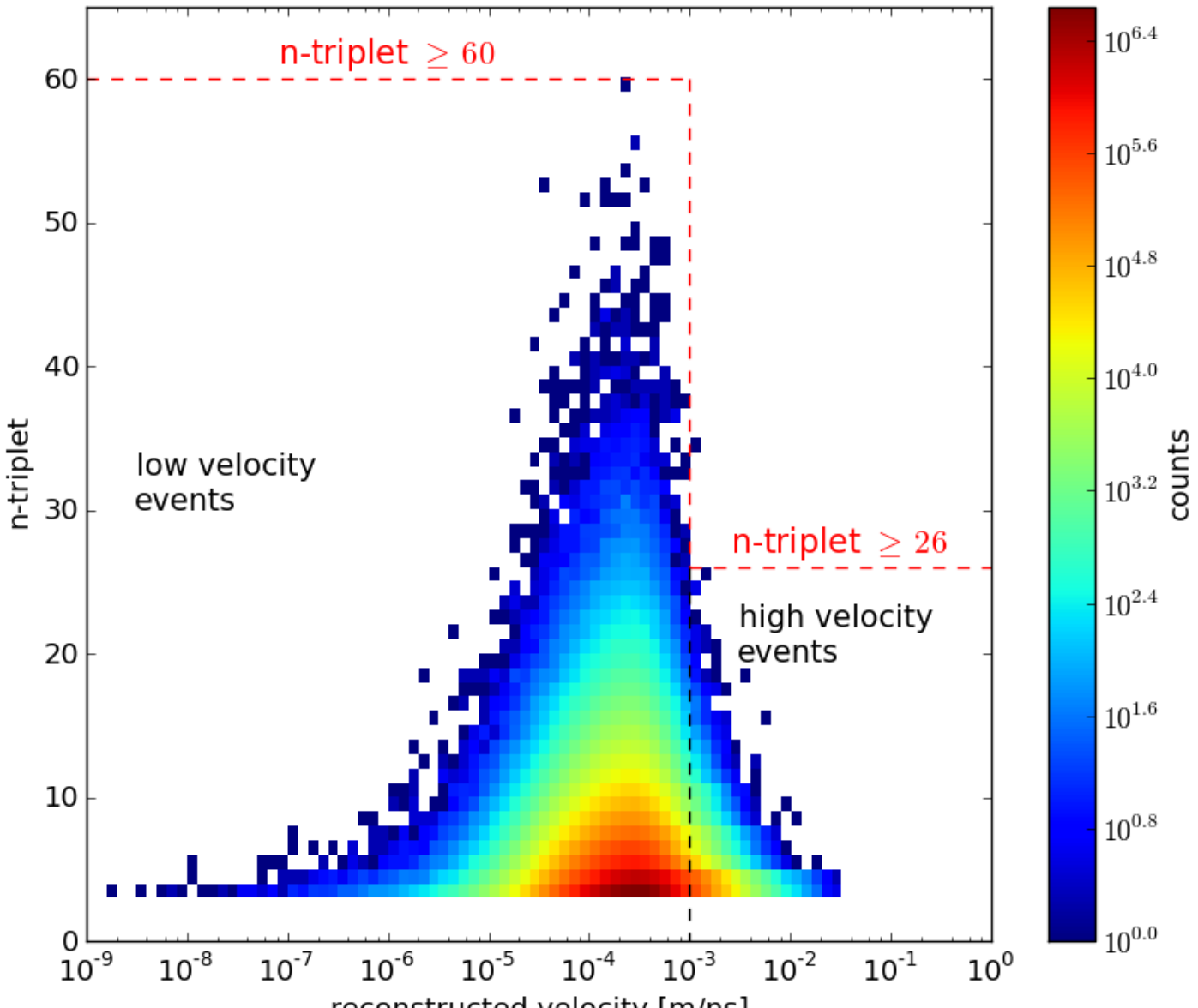


Search for particle-like dark matter

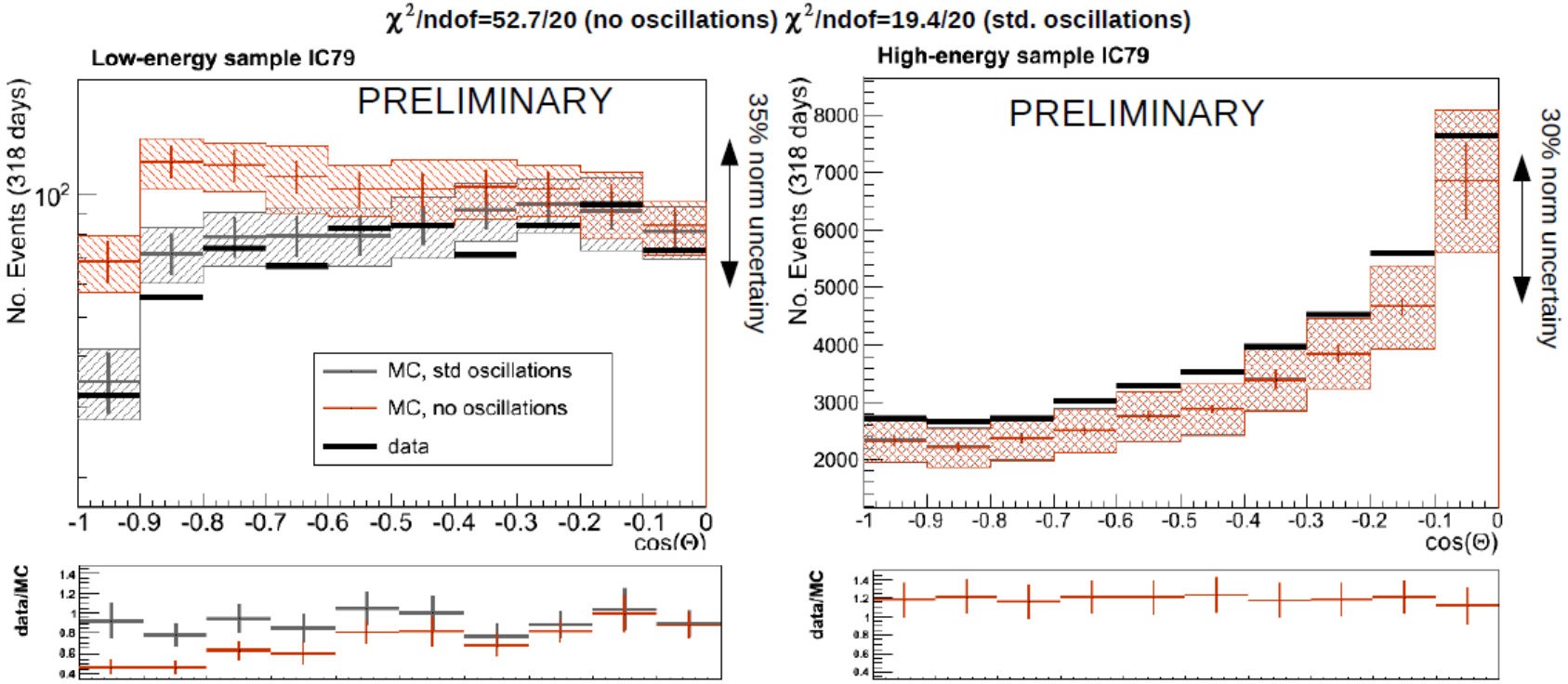
- Earth WIMPs
- Solar WIMPs ($\rightarrow$ Matthias)
- Galactic WIMPs

- 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, $\rightarrow$ Per Olof)