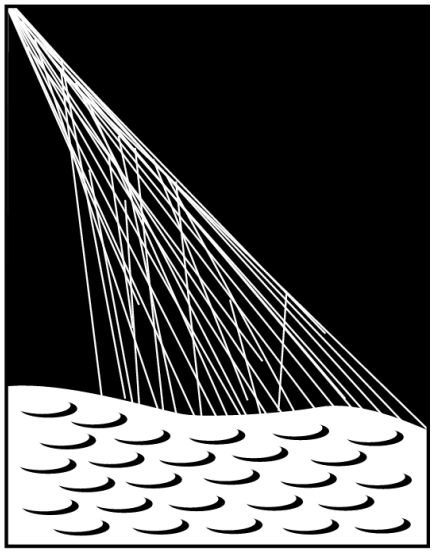


PIERRE AUGER OBSERVATORY

Down-Going UHE Neutrinos In The Pierre Auger Observatory + Neutrino Follow-Up Of GW

Michael Schimp on behalf of the Pierre Auger Collaboration

October 11, 2016

bmb+f

Großgeräte der physikalischen Grundlagenforschung

BERGISCHE UNIVERSITÄT WUPPERTAL

UHE (EeV) ν Searches With The Pierre Auger Observatory

BERGISCHE
UNIVERSITÄT
WUPPERTAL

Motivation

Probe / constrain, e.g.

- CR origin
  - ➔ Sources (opaque sources e.g. choked GRBs)
  - ➔ Top down / bottom up scenarios
- CR composition / propagation (GZK)
- Something new?

Motivation

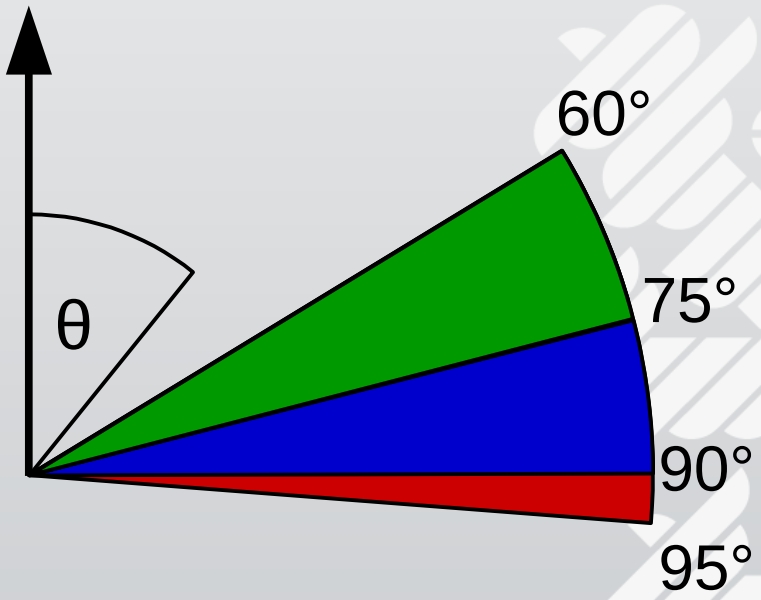
Probe / constrain, e.g.

- CR origin
  - ➔ Sources (opaque sources e.g. choked GRBs)
  - ➔ Top down / bottom up scenarios
- CR composition / propagation (GZK)
- Something new?

PAO: large acceptance
→ Essential for UHEν search

Overview

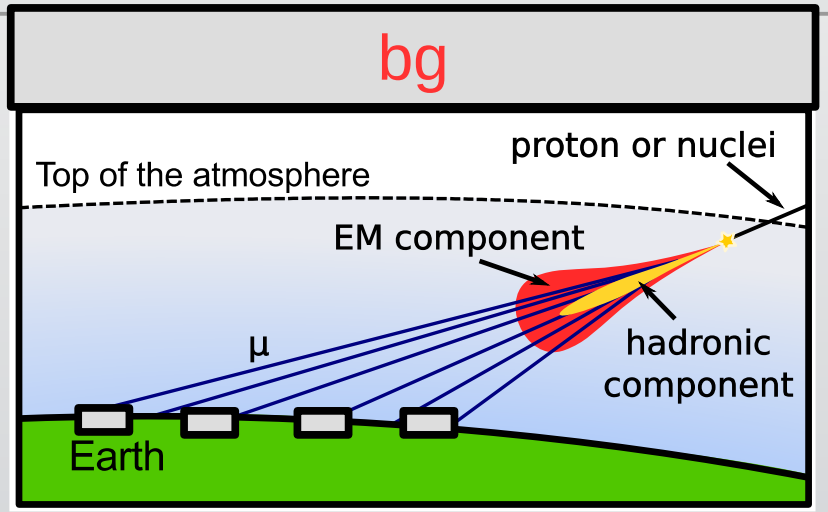
- Low zenith
- High zenith
- Earth-skimming ν_τ

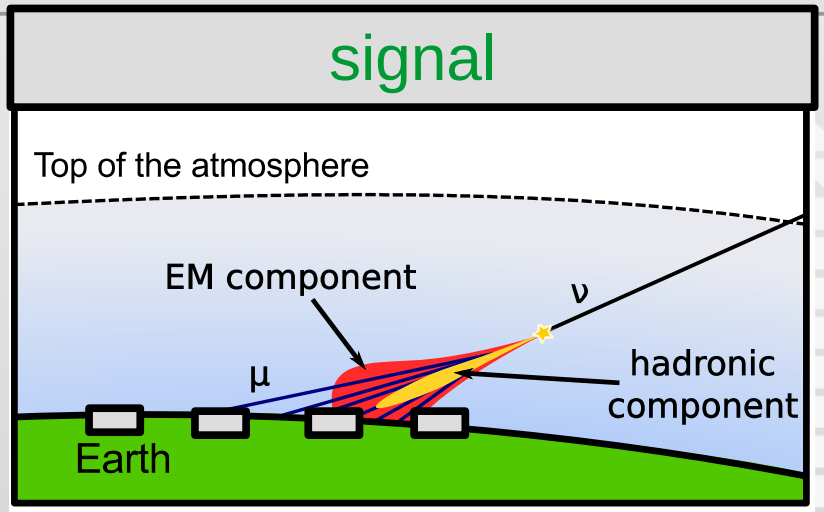


Follow-up of LIGO GW events

Yet only complete for $75° < \theta < 95°$

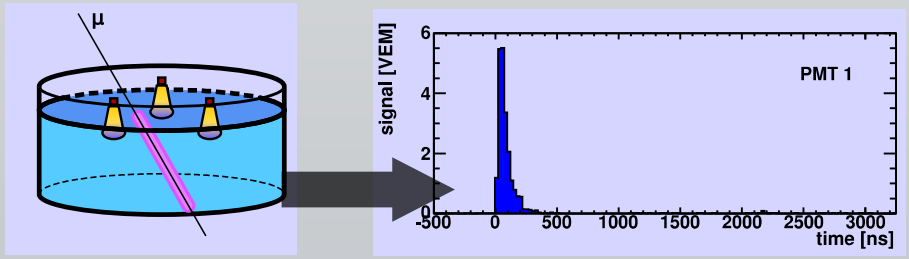
Down-Going UHEν Events

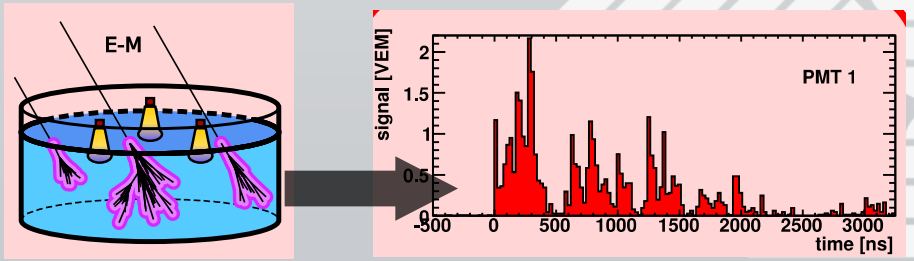




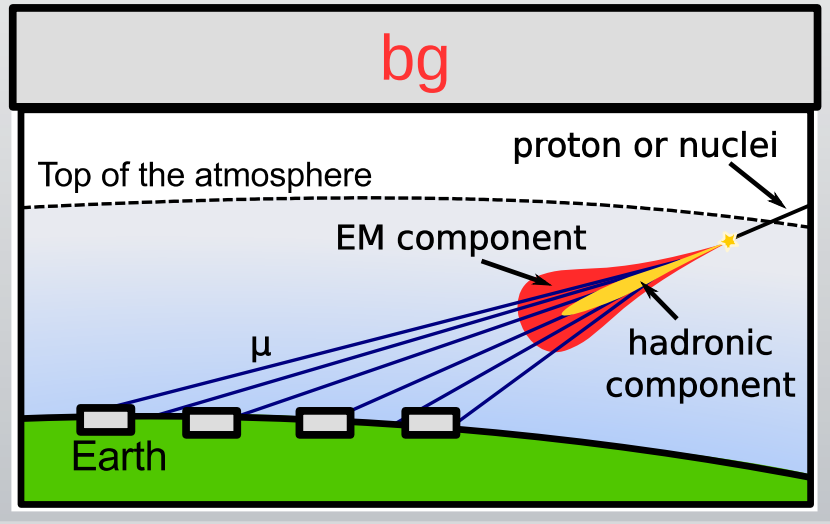
@ ground:
μ dominated

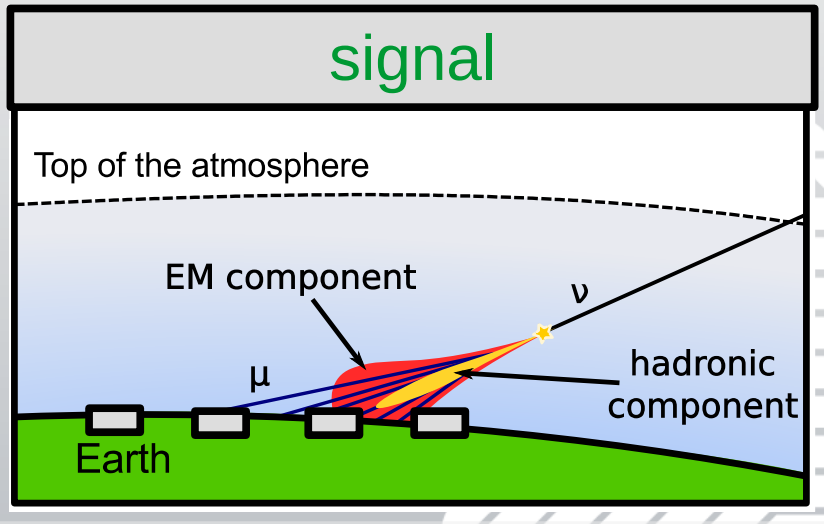
large EM fraction





Down-Going UHEν Events

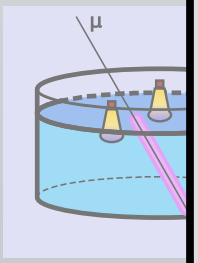


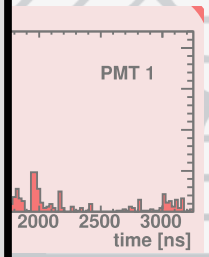


@ ground: large EM

Lower zenith → increasing background

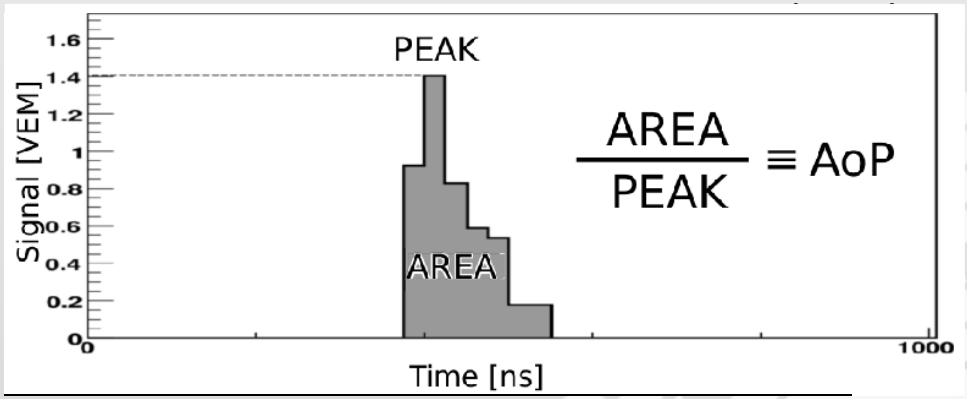
→ zenith dependent event selection
& ν identification
by PMT trace width + reconstruction quality



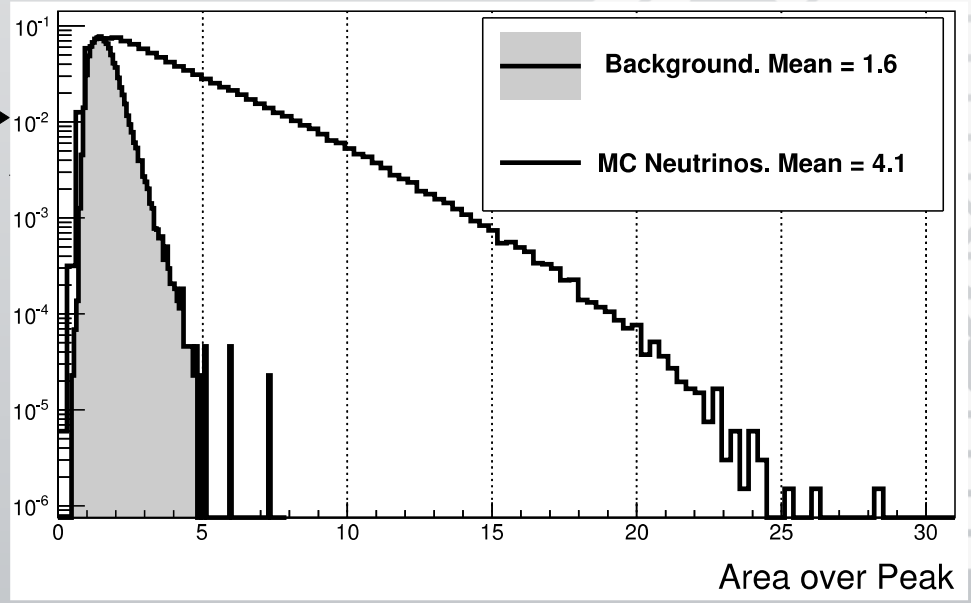


(Low-Zenith) UHEν Identification

Fisher MVA
→ Input: **Early** stations' AoP



Stations' AoP for signal / bg



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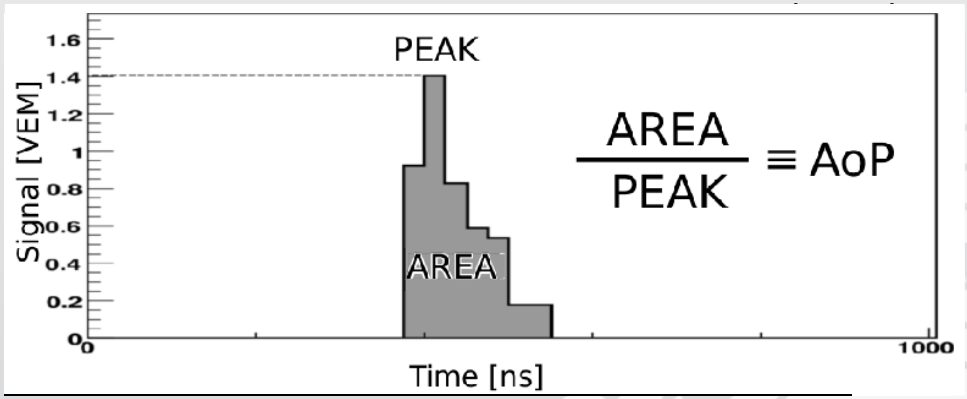
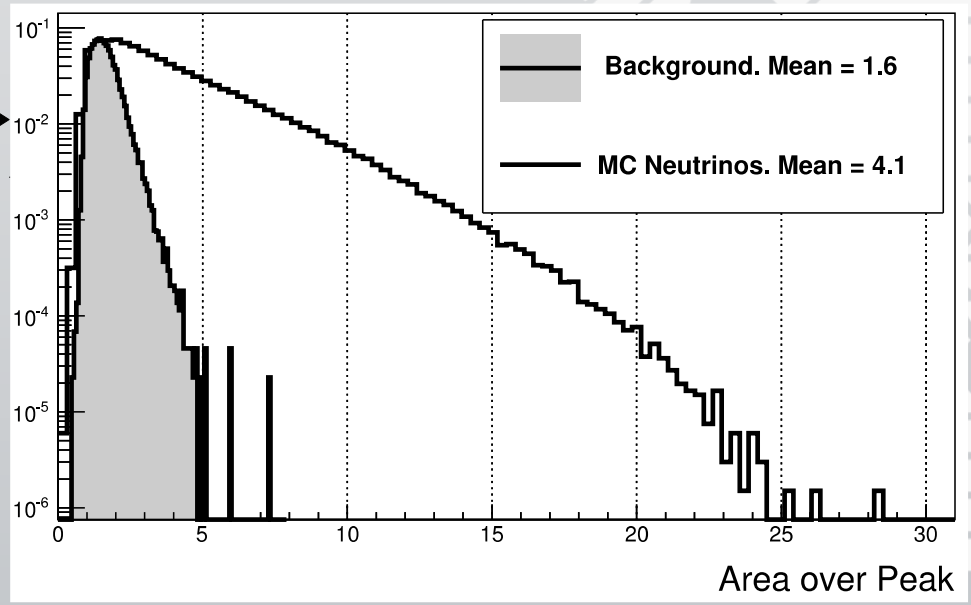




Identification:
1 expected bg event in 20 years of full operation

GW Follow-Up

GW Follow-Up—Why?

Commonly:
"BH merger → no ν!"

- **No prompt PeV ν** after GW150914 (IceCube, ANTARES)
- **Fermi GBM detection 0.4 s** after GW150914, compatible direction

GW Follow-Up—Why?

Commonly:
"BH merger → no ν!"

⟷

UHEν emission predictions
Vietri, Waxman, Murase, Kotera, Silk

- **No prompt PeV ν** after GW150914 (IceCube, ANTARES)
- **Fermi GBM detection 0.4 s** after GW150914, compatible direction

Upcoming LIGO events: probably further types!
(e.g. NS mergers)

Default neutrino analysis, but consider only

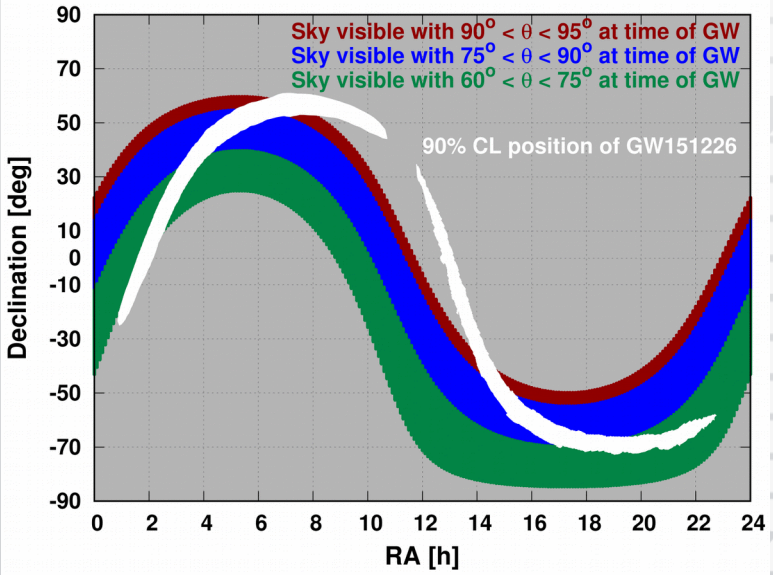
- [–500 s, +1 day] around a GW event

GW Follow-Up—How?

Default neutrino analysis, but consider only

- [–500 s, +1 day] around a GW event

- Directional correlation
  → Binary decision: Is part of the 90% confidence region visible?

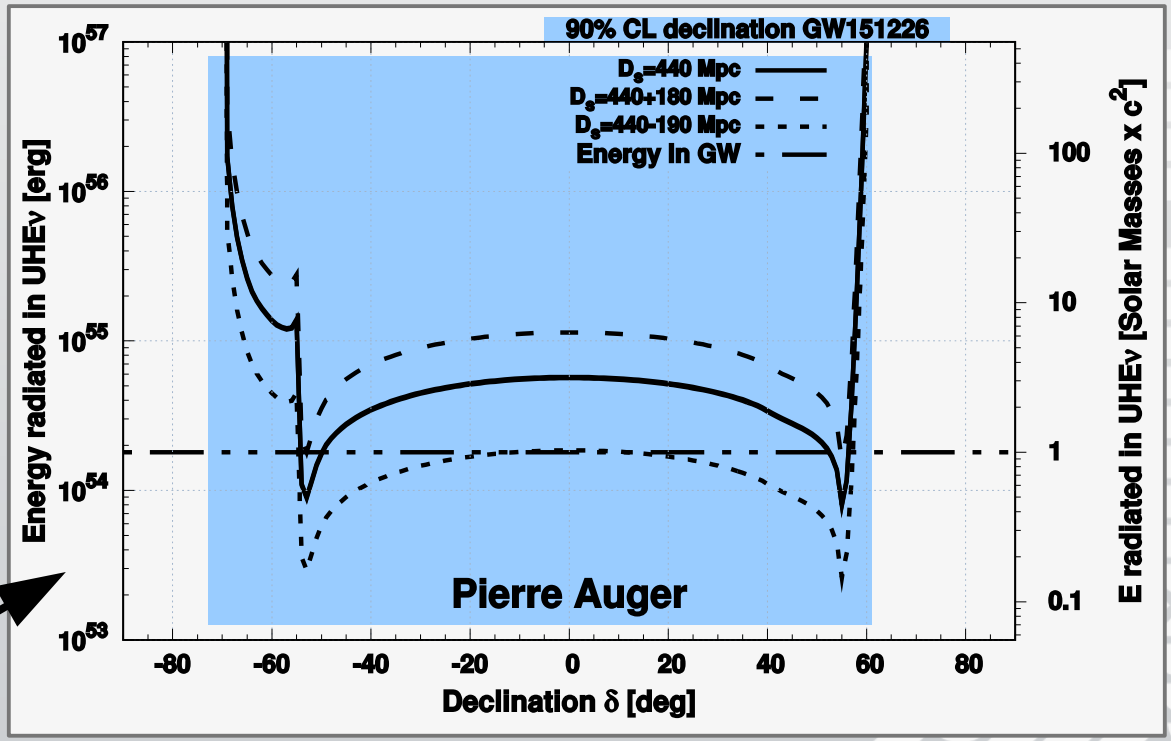


Visible solid angle moves during the day

GW Follow-Up Results (Earth-Skimming ν_τ + Down-Going High-Zenith)

Consider only time+directionally correlated events

No candidates
→ Event number limit + Exposure (δ)
→ Limit on emitted UHEν energy



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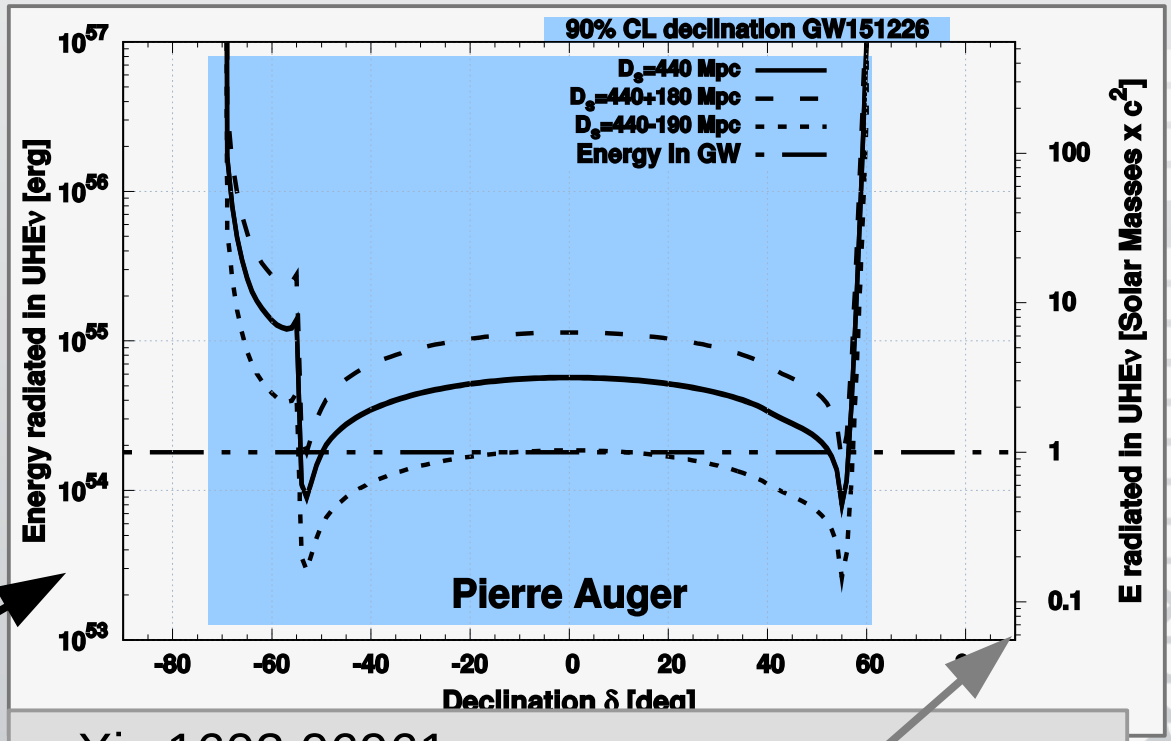

arXiv:1602.06961:
Binary BHs could produce the measured UHECR flux up to 100 EeV!
→ Needs ~ 3% efficiency (E_{UHECR}/E_{GW})

Conclusions

Summary

- PAO seems well capable to measure UHE neutrinos
- No UHEν candidates so far
- Follow-up search on the published LIGO GW events unblinded → sensitive down to $< E_{GW}$

Prospects

- Improve analysis
  - More sophisticated MVA
  - GW follow-up: Fold PAO field of view with LIGO's confidence region

- Apply GW follow-up in low-zenith region

- “UHEν monitor”
  → Frequently apply predefined analyses instead of unblinding

The End

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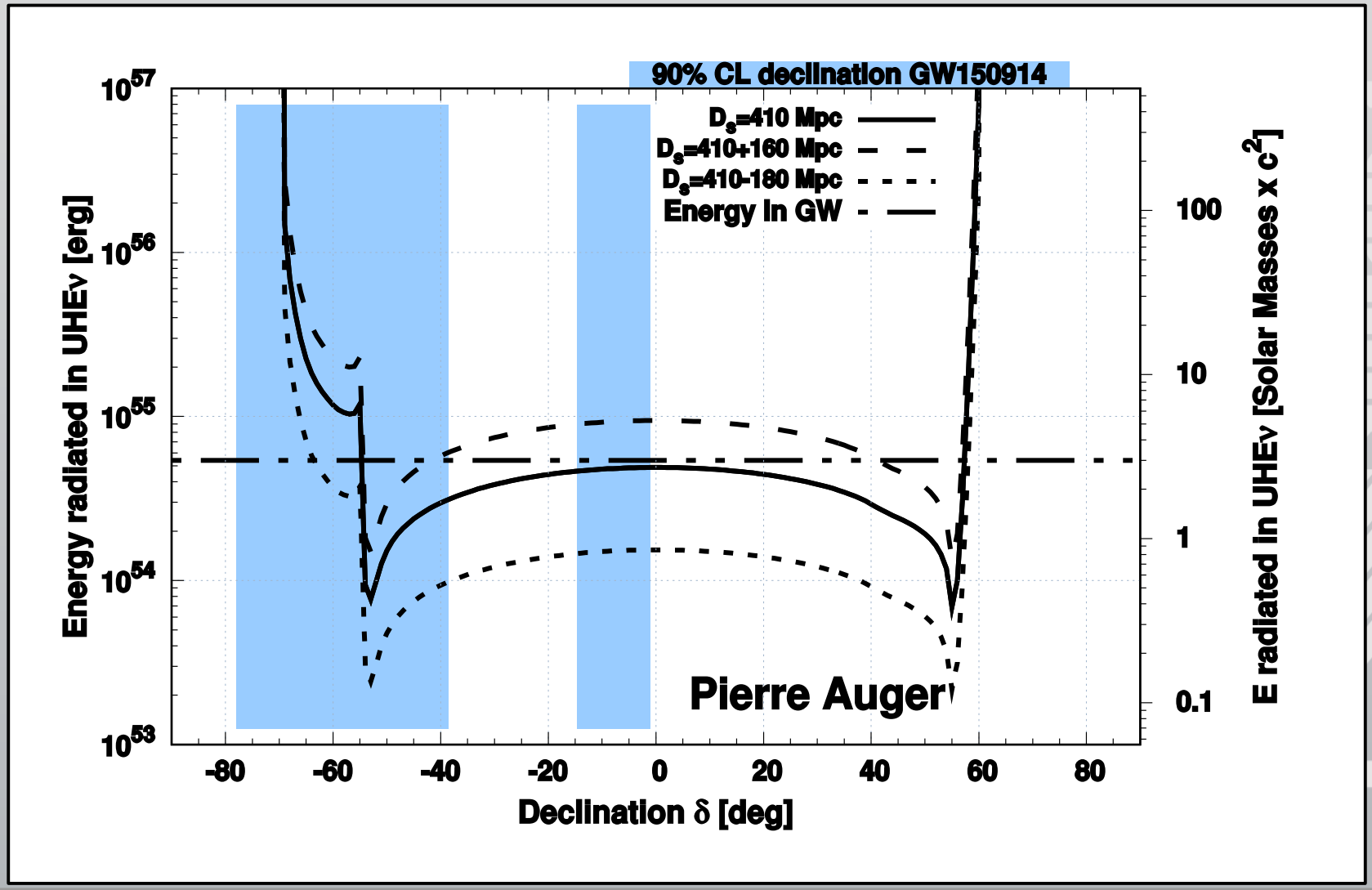
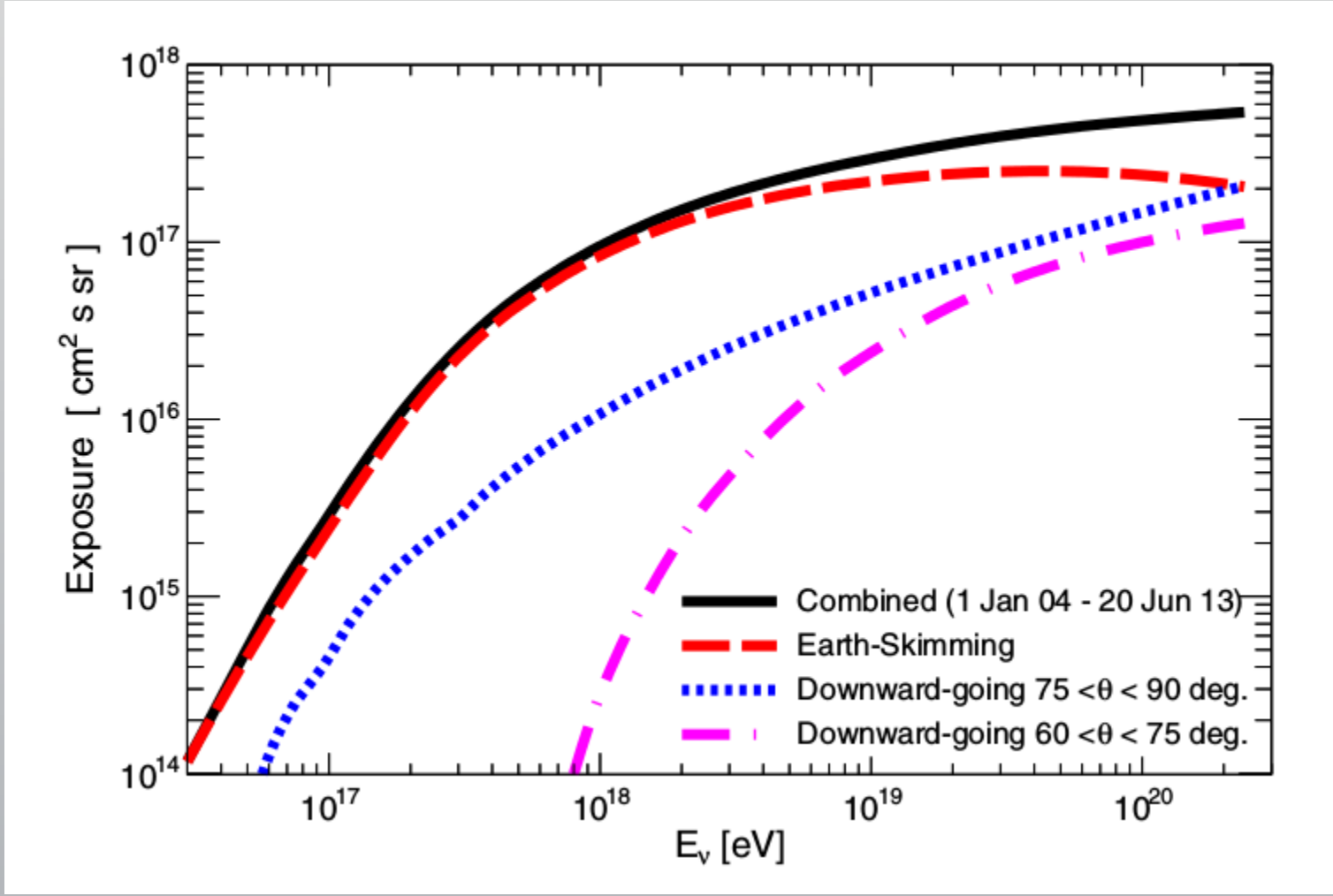
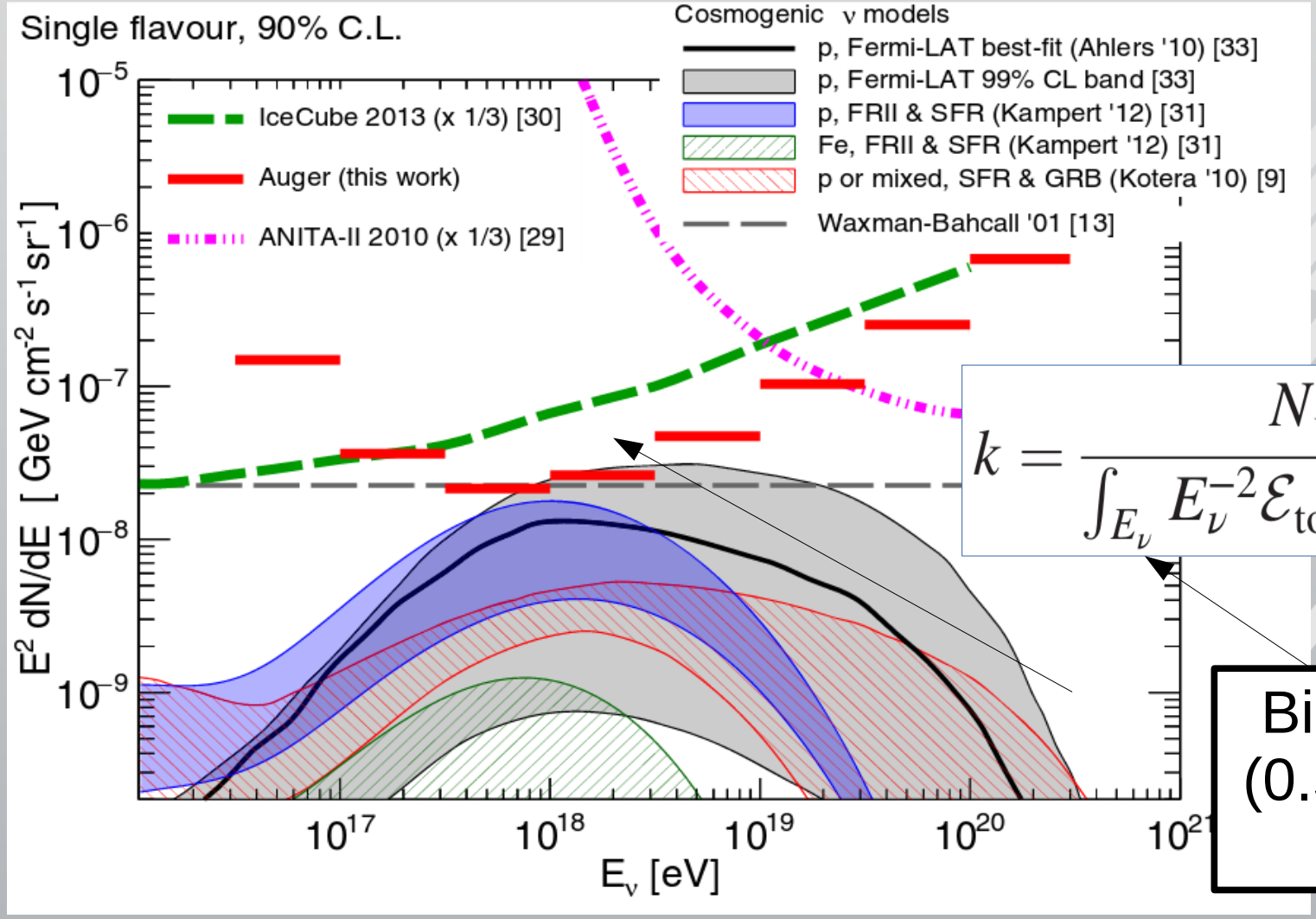
GW Follow-Up Result On GW150914



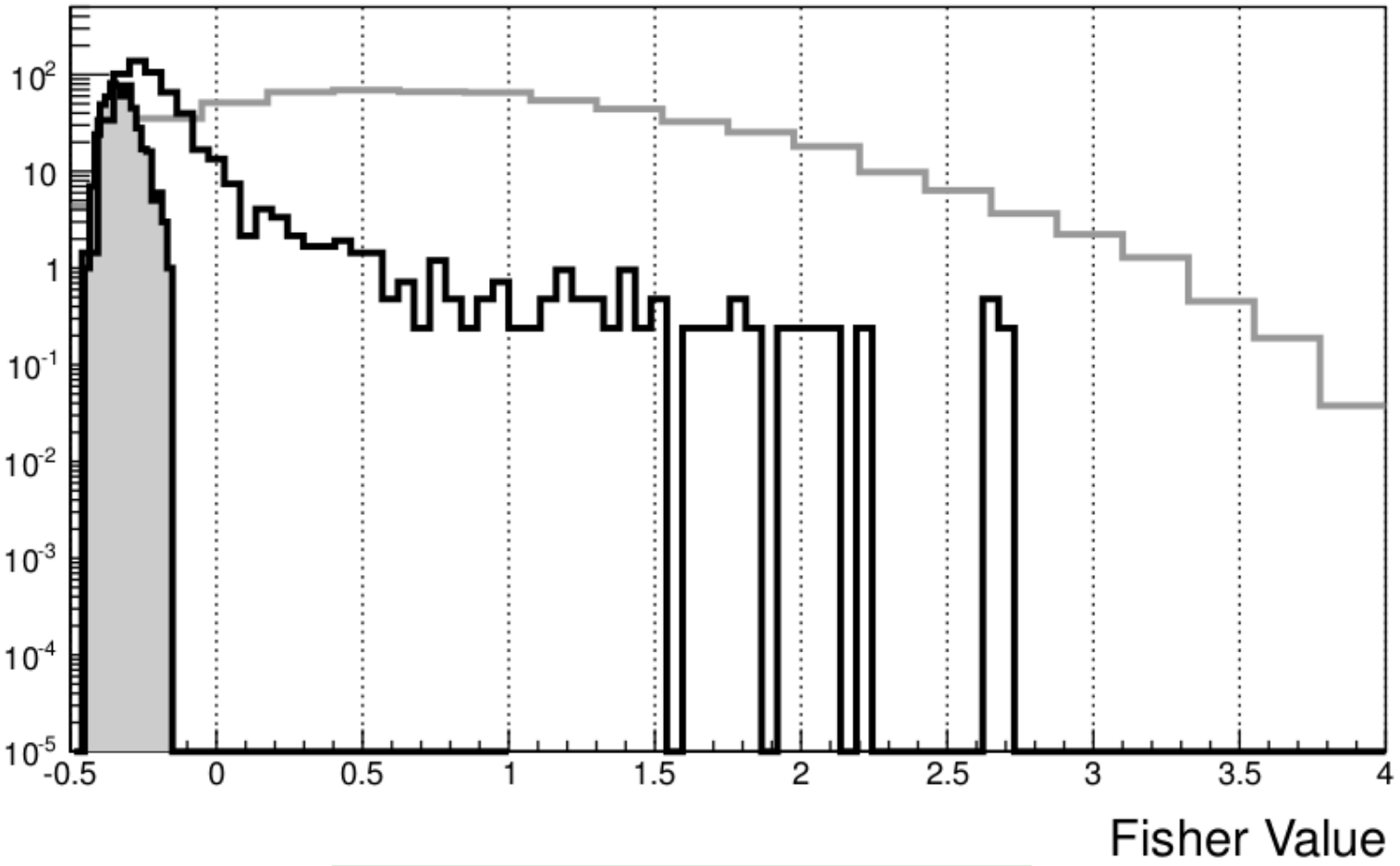
Energy Dependence Of Diffuse Exposure (Phys Rev D 91, 092008 (2015))



Binned Diffuse Flux Limits (Phys Rev D 91, 092008 (2015))

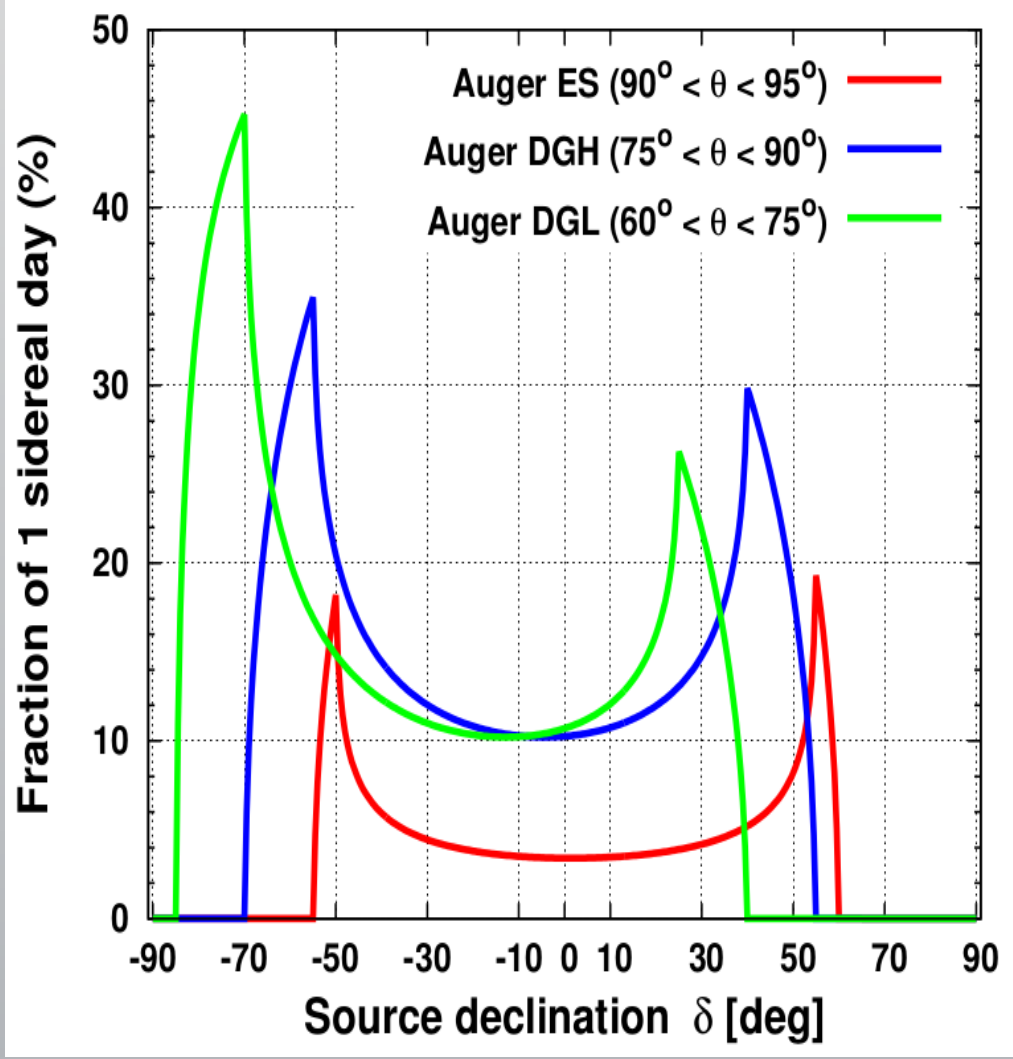


UHE Photon Background

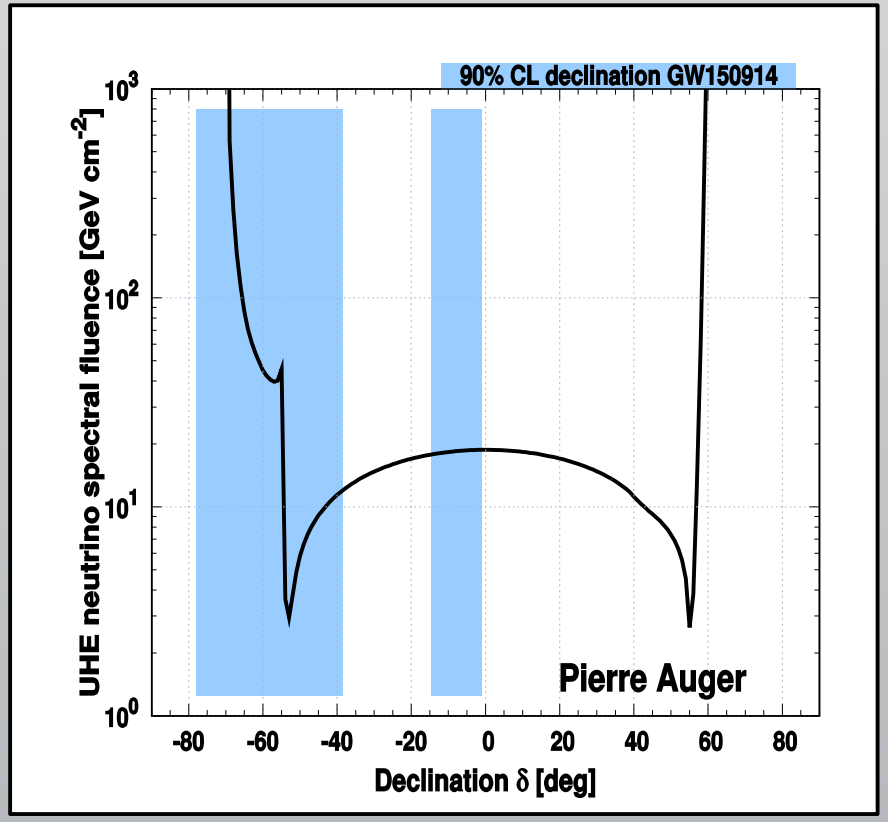


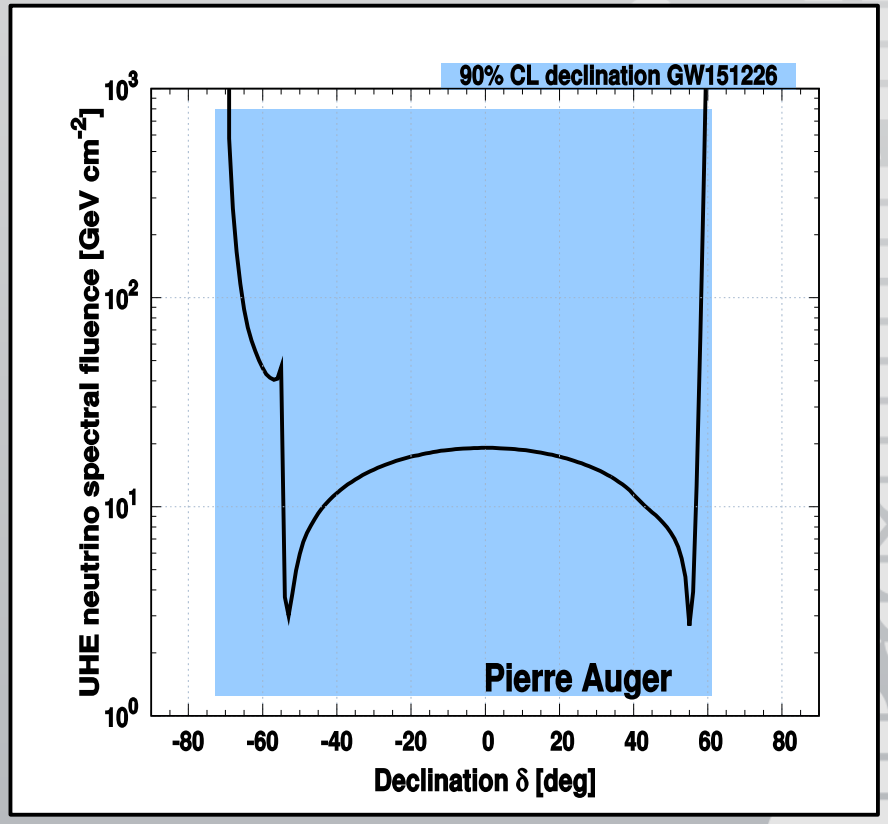
(d) $67.5^\circ < \theta_{\mathrm{Rec}} \leq 70.5^\circ$

Visible Solid Angle



Fluence Upper Limits

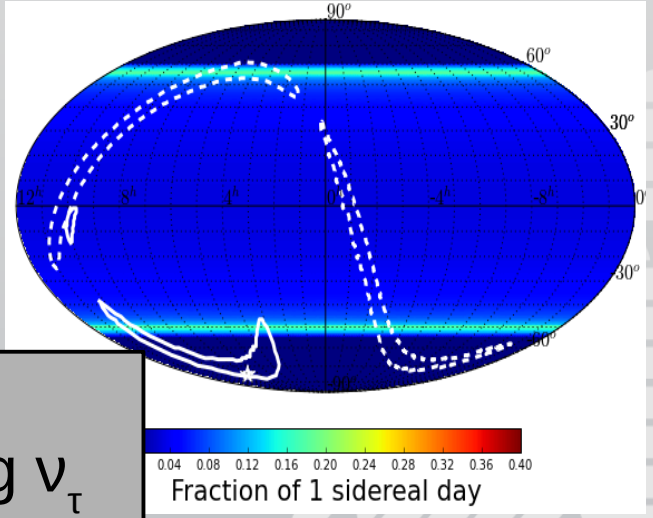




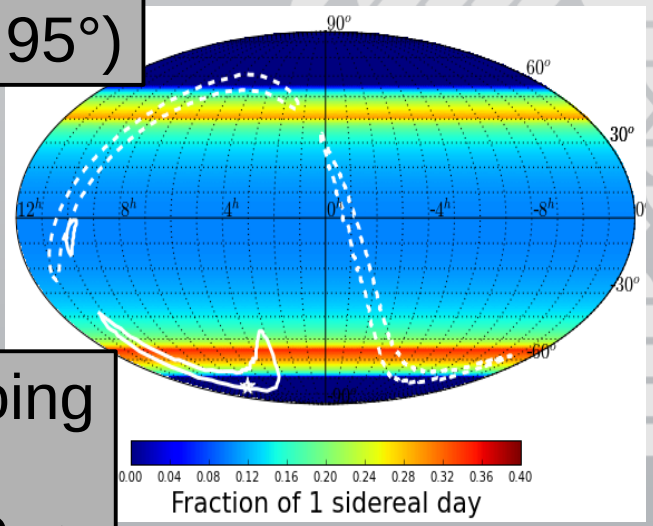
GW Follow-Up

No candidate in [–500 s, 1 day] around GW events
→ Calculate **exposure** taking into account

- Time-dependent apertu (area x solid angle)
- ν-nucleon cross section efficiencies (E,δ)



Earth-skimming ν_τ ($90° < \theta < 95°$)



Down-going ν ($75° < \theta < 90°$)

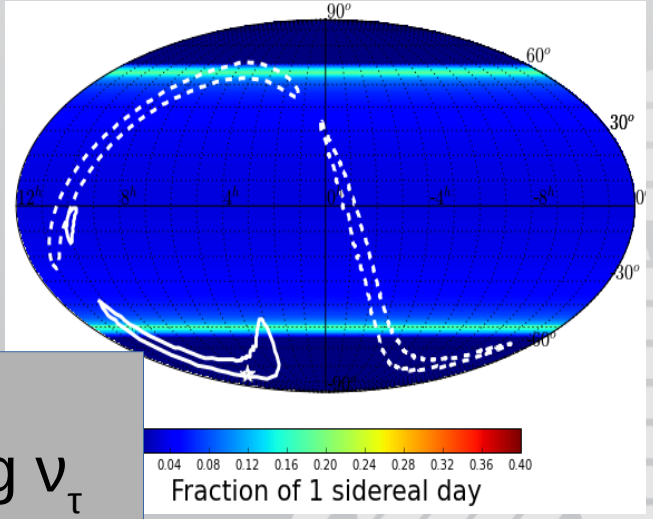
GW Follow-Up

No candidate in [–500 s, 1 day] around GW events

→ Calculate **exposure** taking into account

- Time-dependent apertur (area x solid angle)
- ν-nucleon cross section efficiencies (E,δ)

→ Calculate upper limits on **energy radiated in UHEν** (δ) (E^{-2} spectrum)



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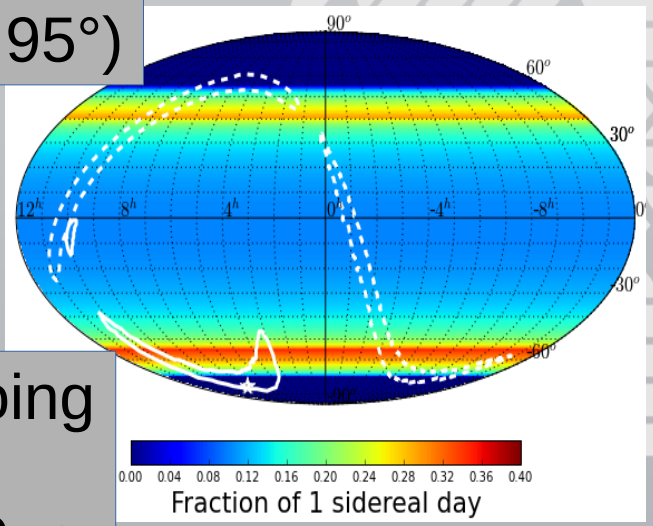
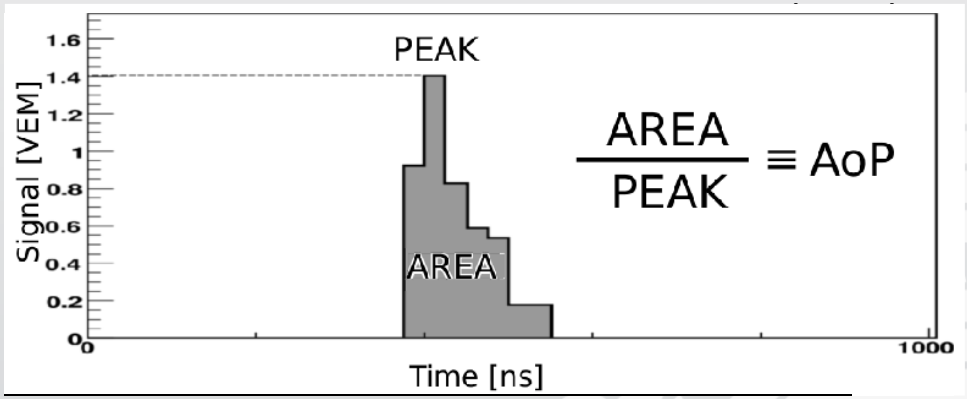


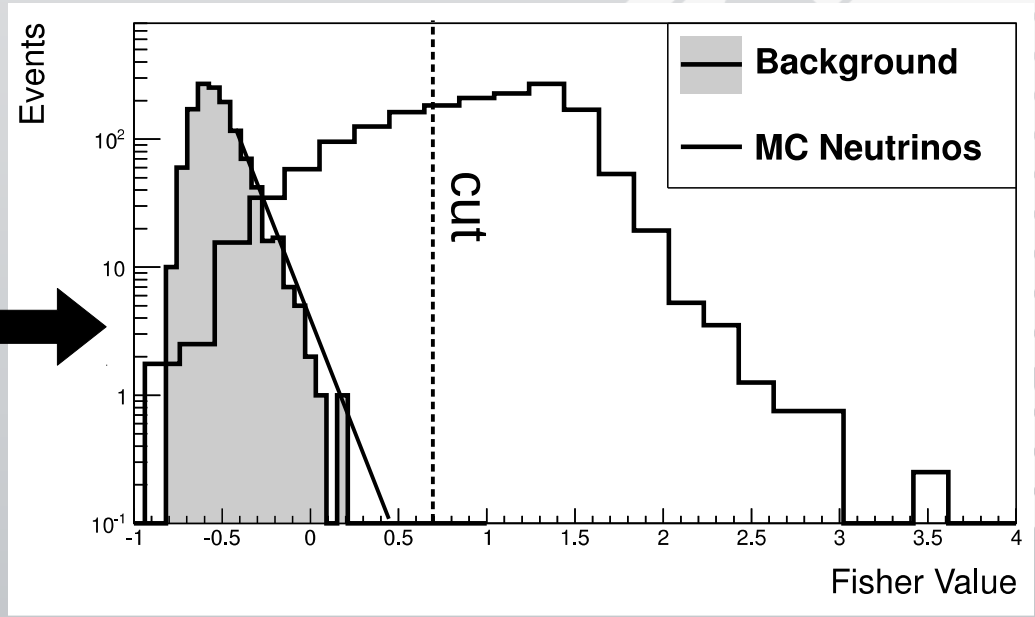
Down-going ν ($75° < \theta < 90°$)

Down-Going Low-Zenith UHEν Event Selection

Fisher MVA
→ Input: **Early** stations' AoP



60°+-1.5°
(lowest zenith
= “worst” background)



Down-Going Low-Zenith UHEν Event Selection

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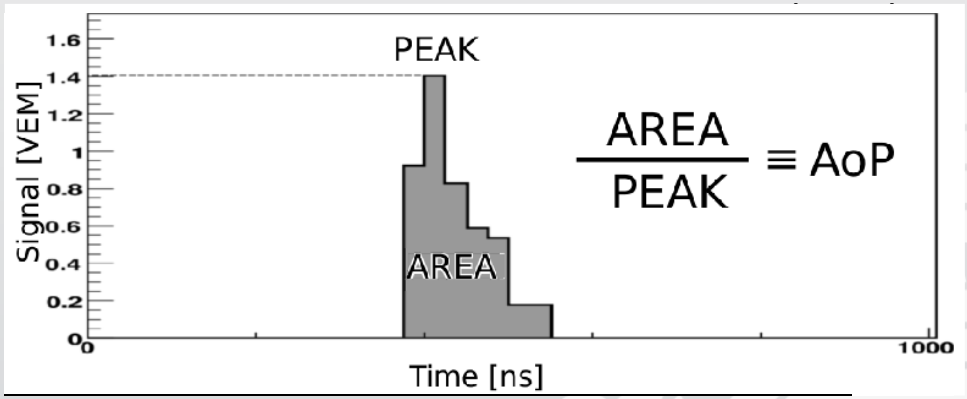
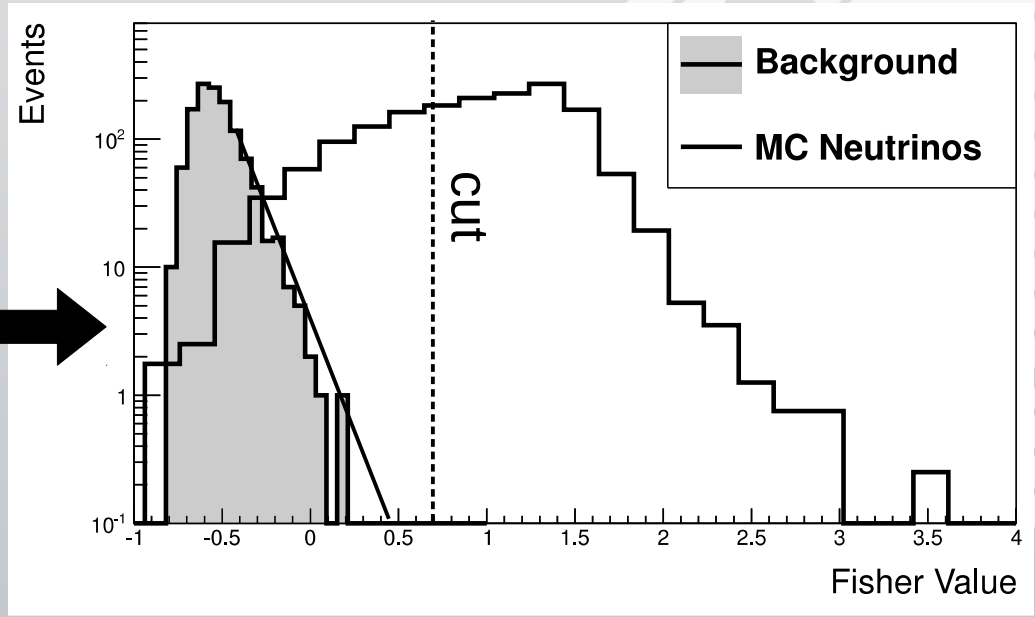
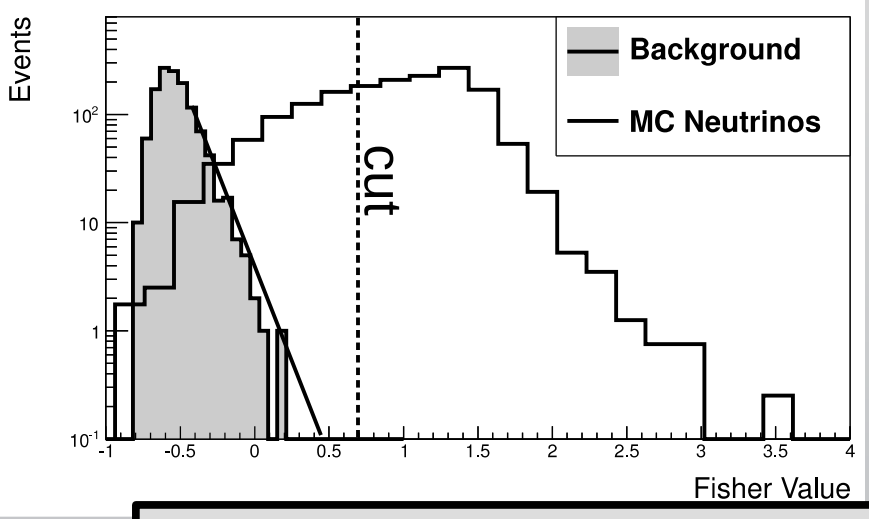
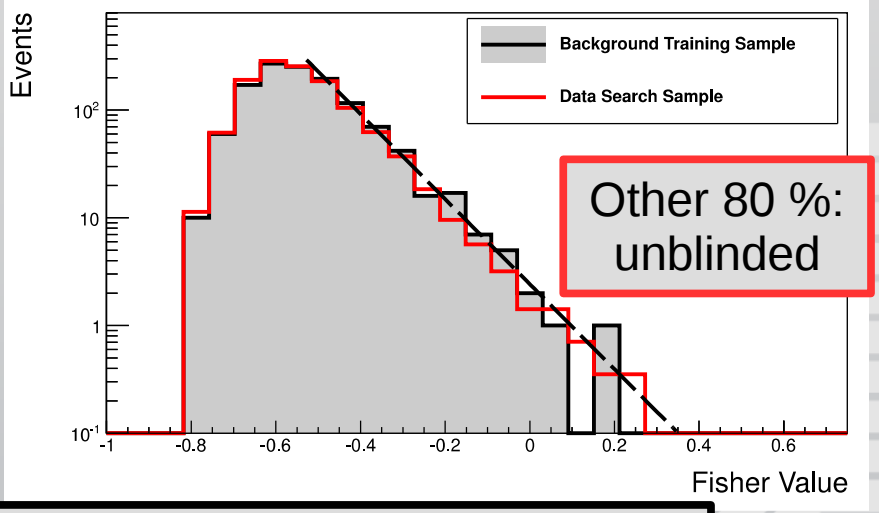


Identification: Fit Tail, Cut for 1 bg event in 20 years



Down-Going Low-Zenith UHEν Analysis





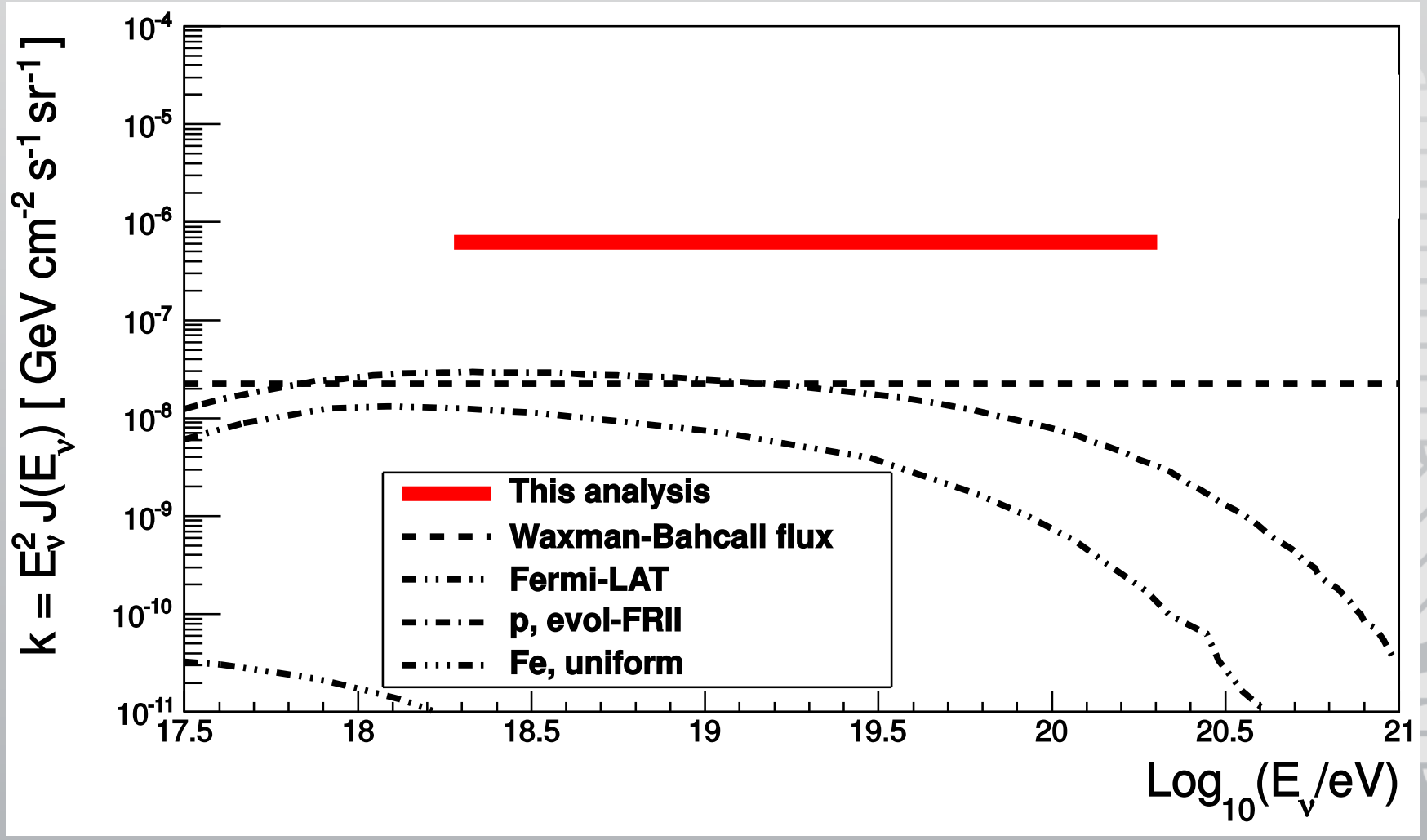
60°+-1.5° (most vertical = most signal-like)

Found nothing → calculate limit

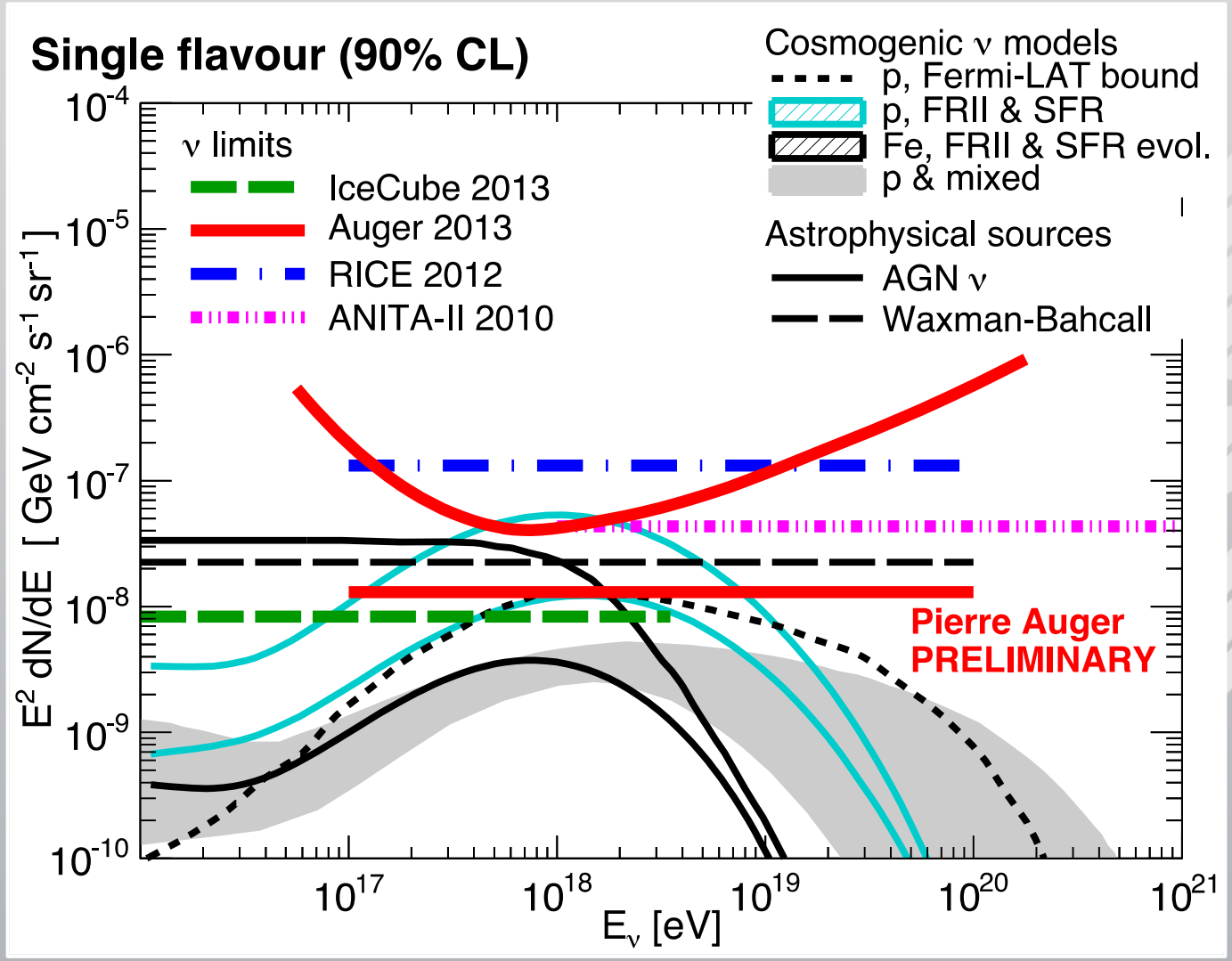
- Feldman-Cousins, 0 signal, 0 bg expected
- Stat. + syst.: Rolke & Conrad approaches
- Calculate exposure ξ
  → Diffuse flux limit ~ $N_{90\%CL,upper}$ / ξ

$N_{90\%CL,upper}$ =2.37

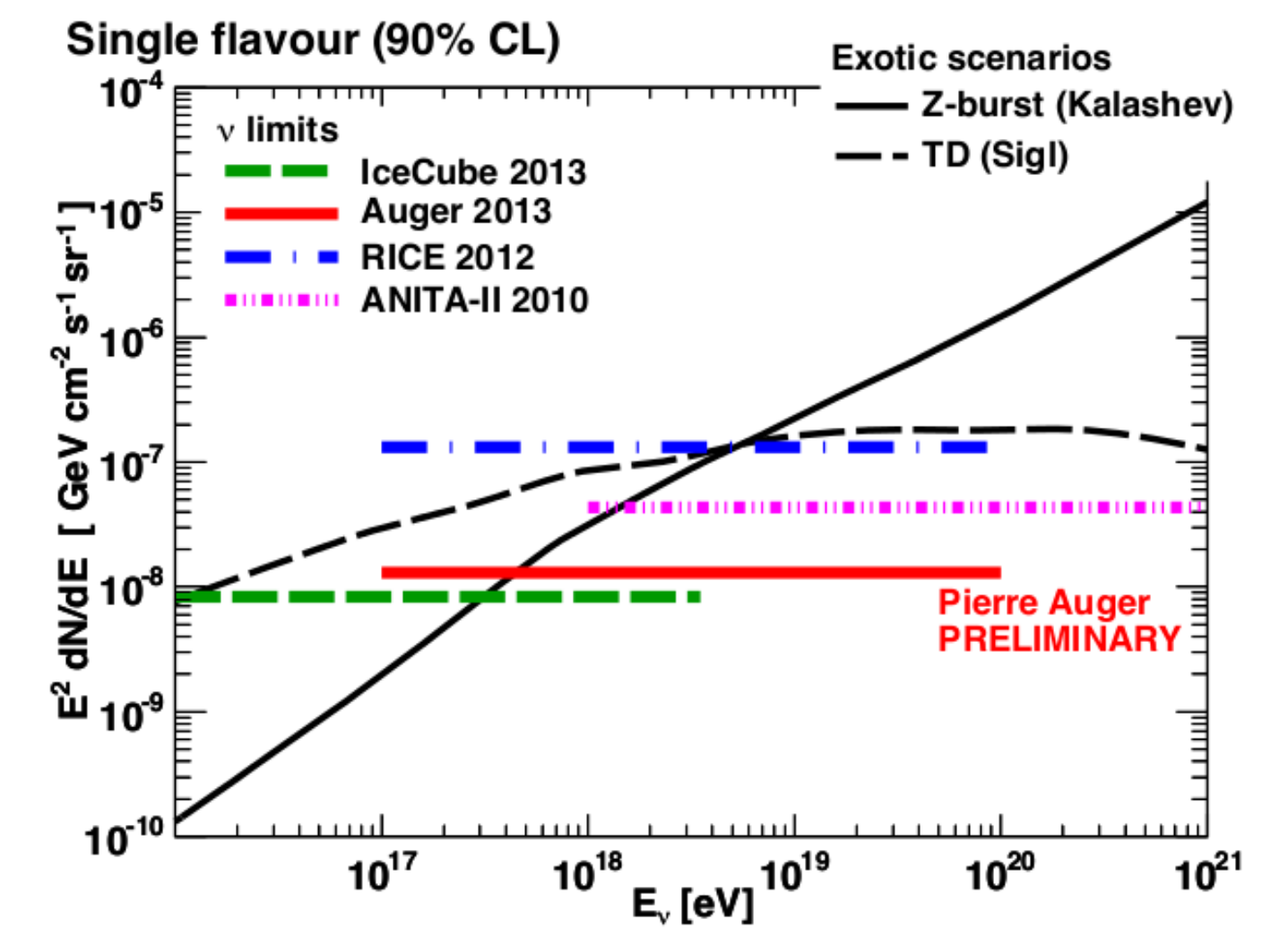
Down-Going Low-Zenith UHEν Results



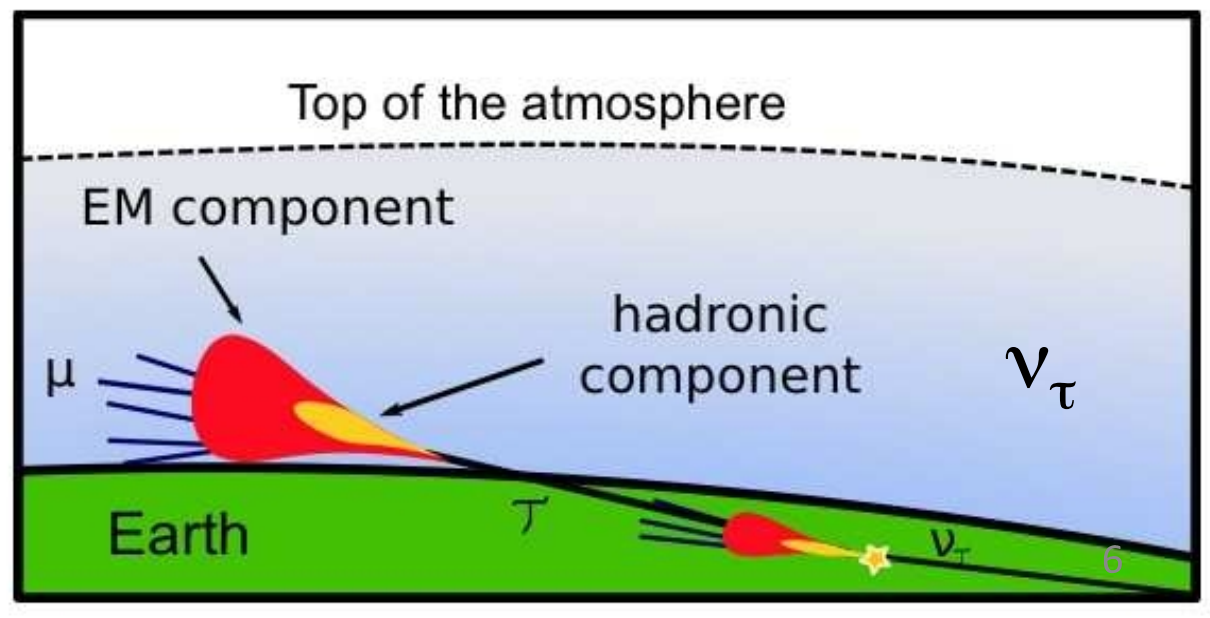
Global UHEν Results



Global UHEν Results



Earth-Skimming ν_τ Search



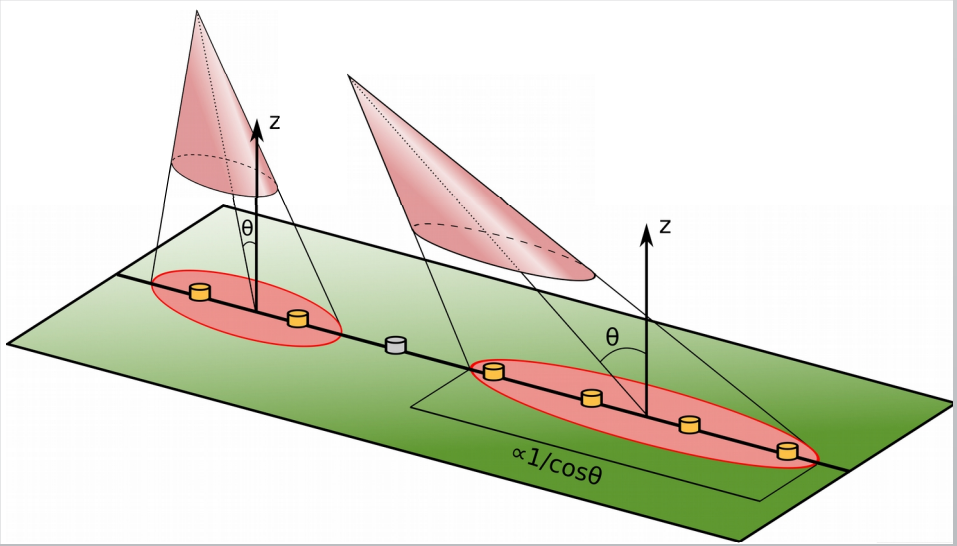
Earth skimming events dominated by ν_τ

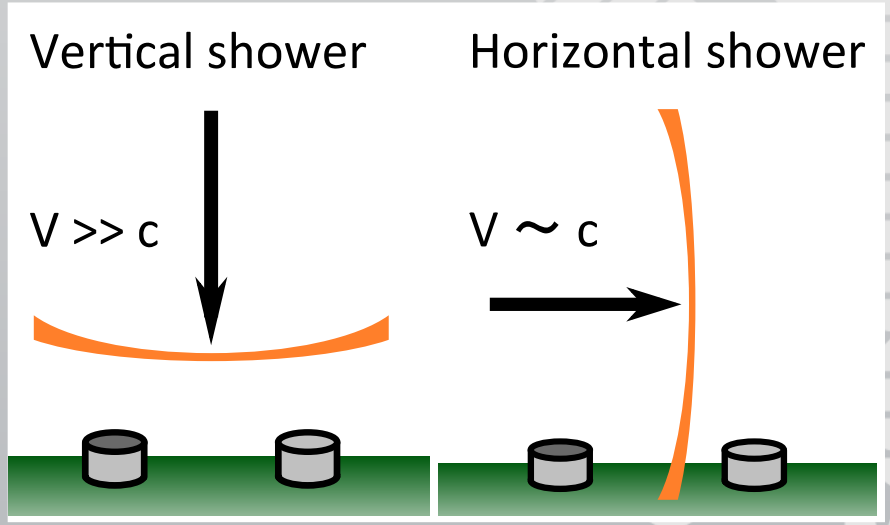
- ν interaction enhanced in Earths crust (producing e, μ, τ, nuclear fragments)
- Only τ can travel long distance through Earth and induce EAS (by decaying after ~ 48 km @ 1 EeV)

Earth-Skimming ν_τ Selection

Inclination: 90° < θ < 95°

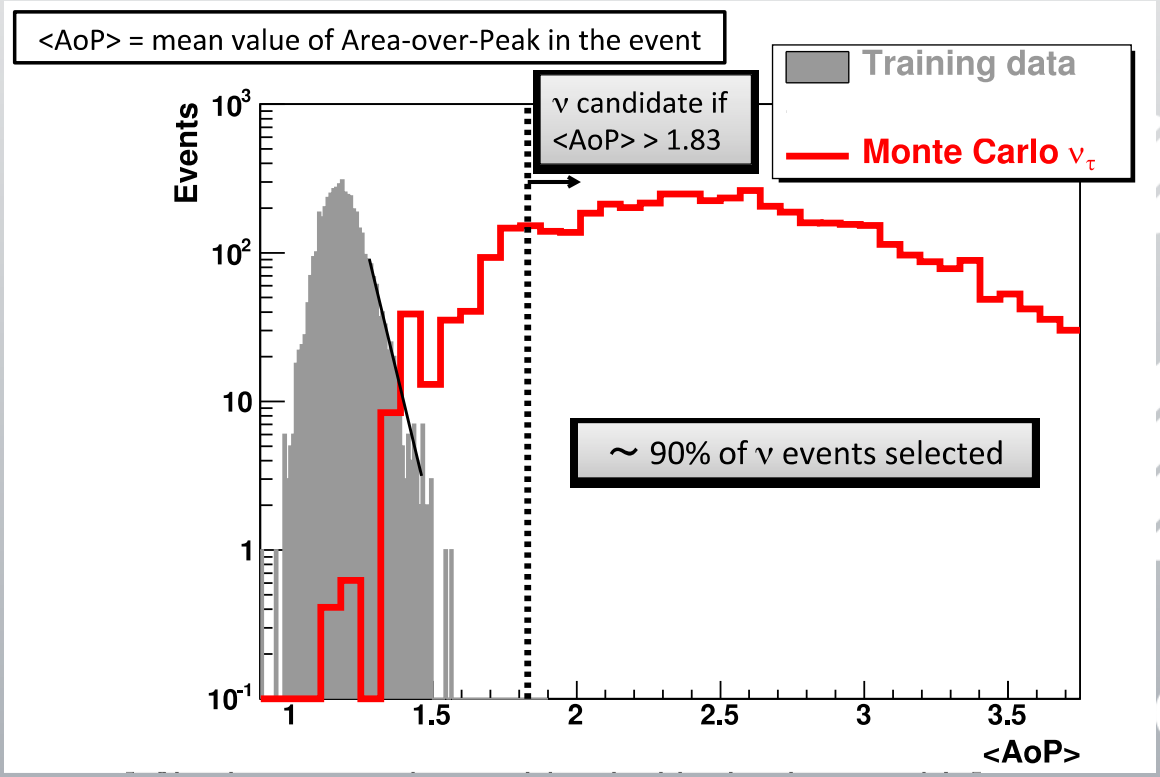
- Elongated footprint
- “Ground signal speed” ~ c





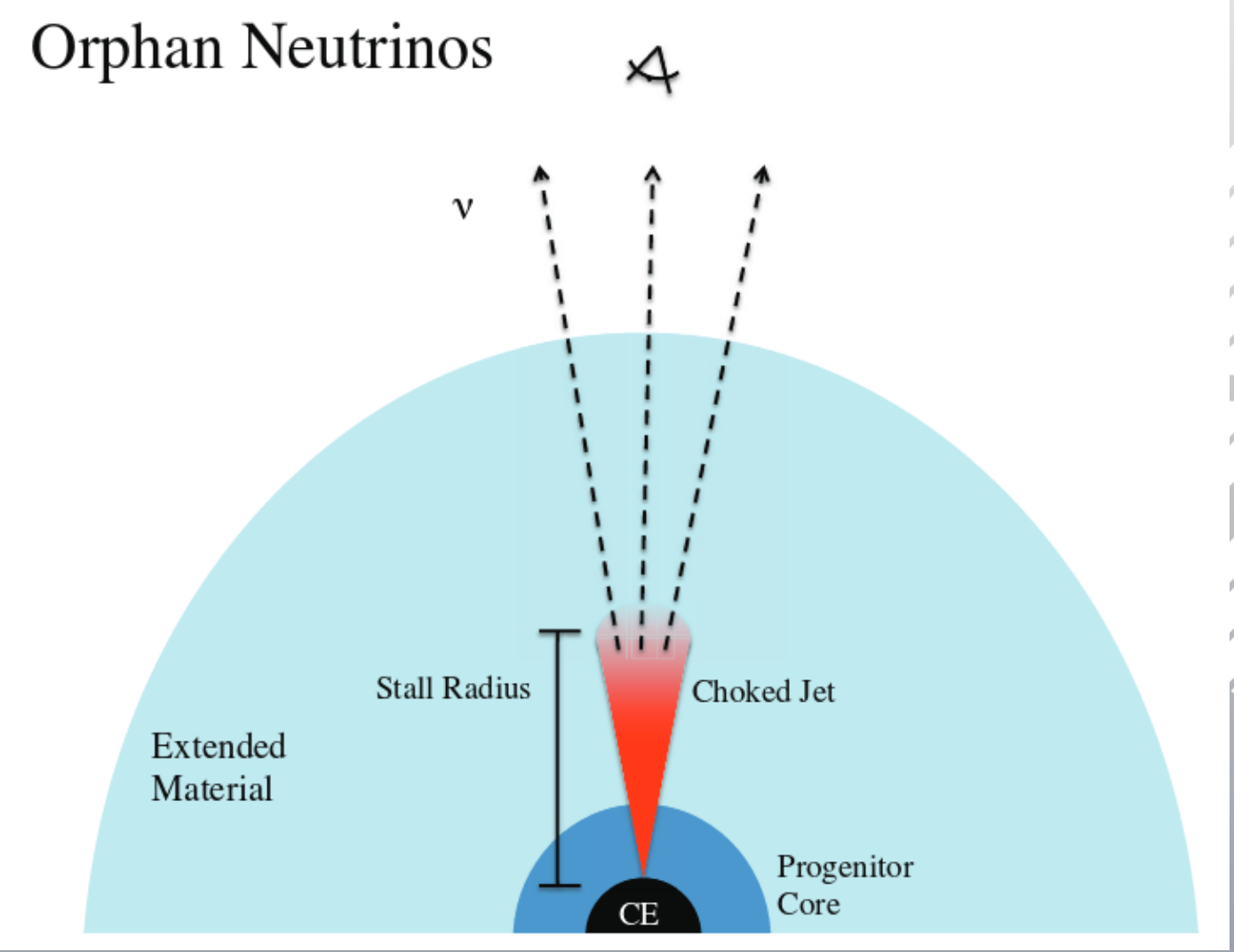
Reject “muonic” events → > 60 % stations ToT triggered

Earth-Skimming ν_τ Analysis

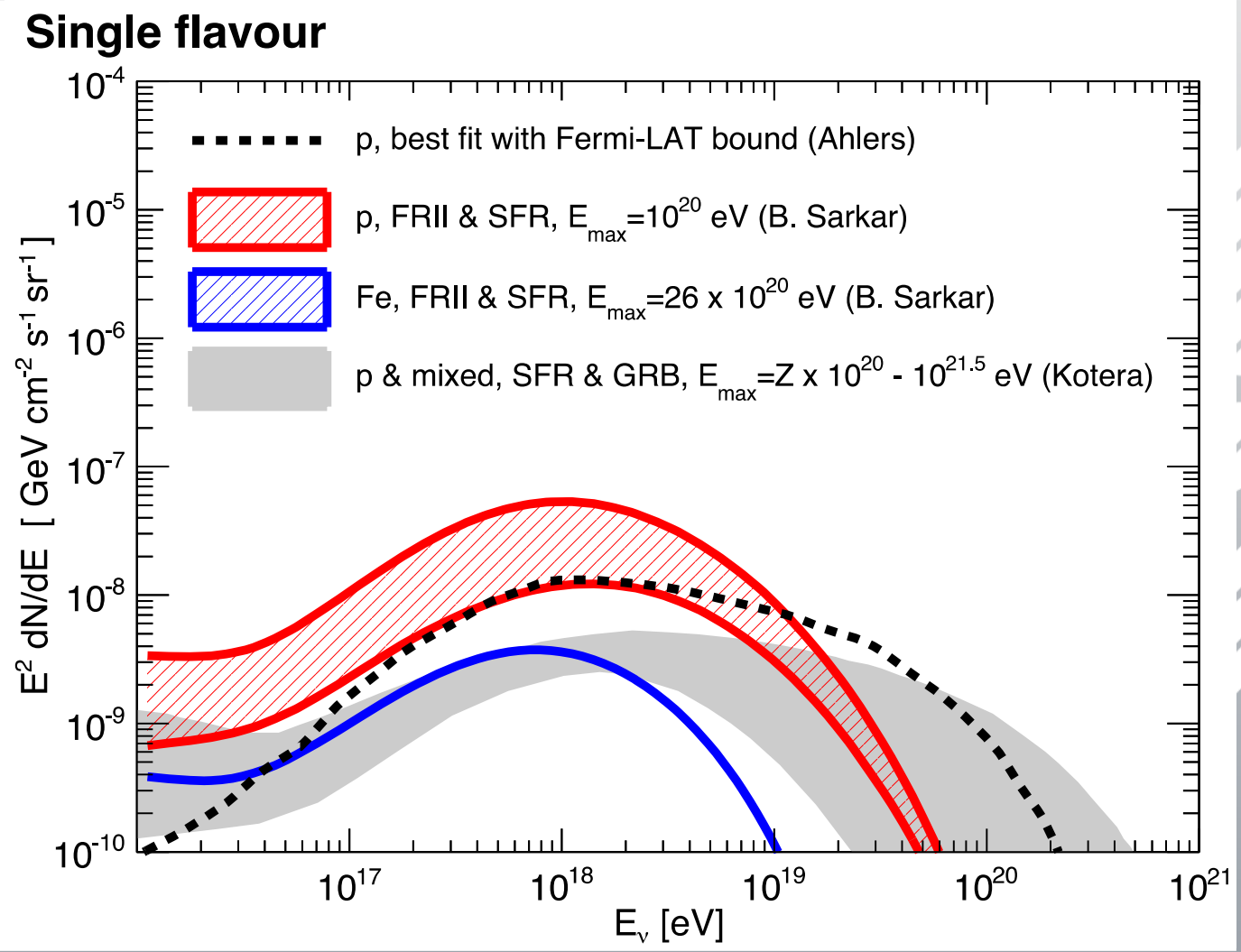


No event after <AoP> cut → calculate exposure
→ flux limit ~ event count limit / exposure

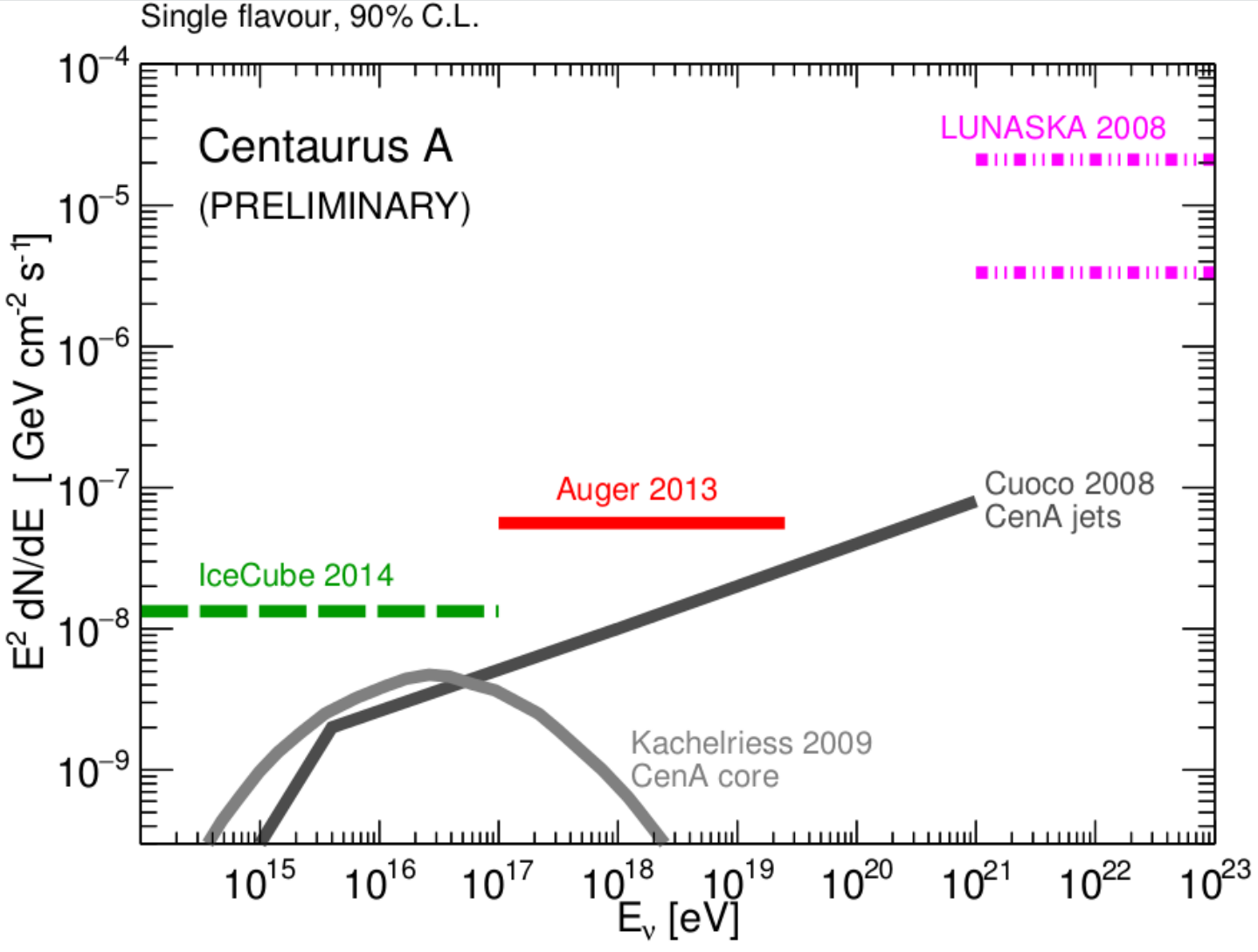
Choked jets


Orphan Neutrinos
ν
Stall Radius
Choked Jet
Extended
Material
Progenitor
Core
CE

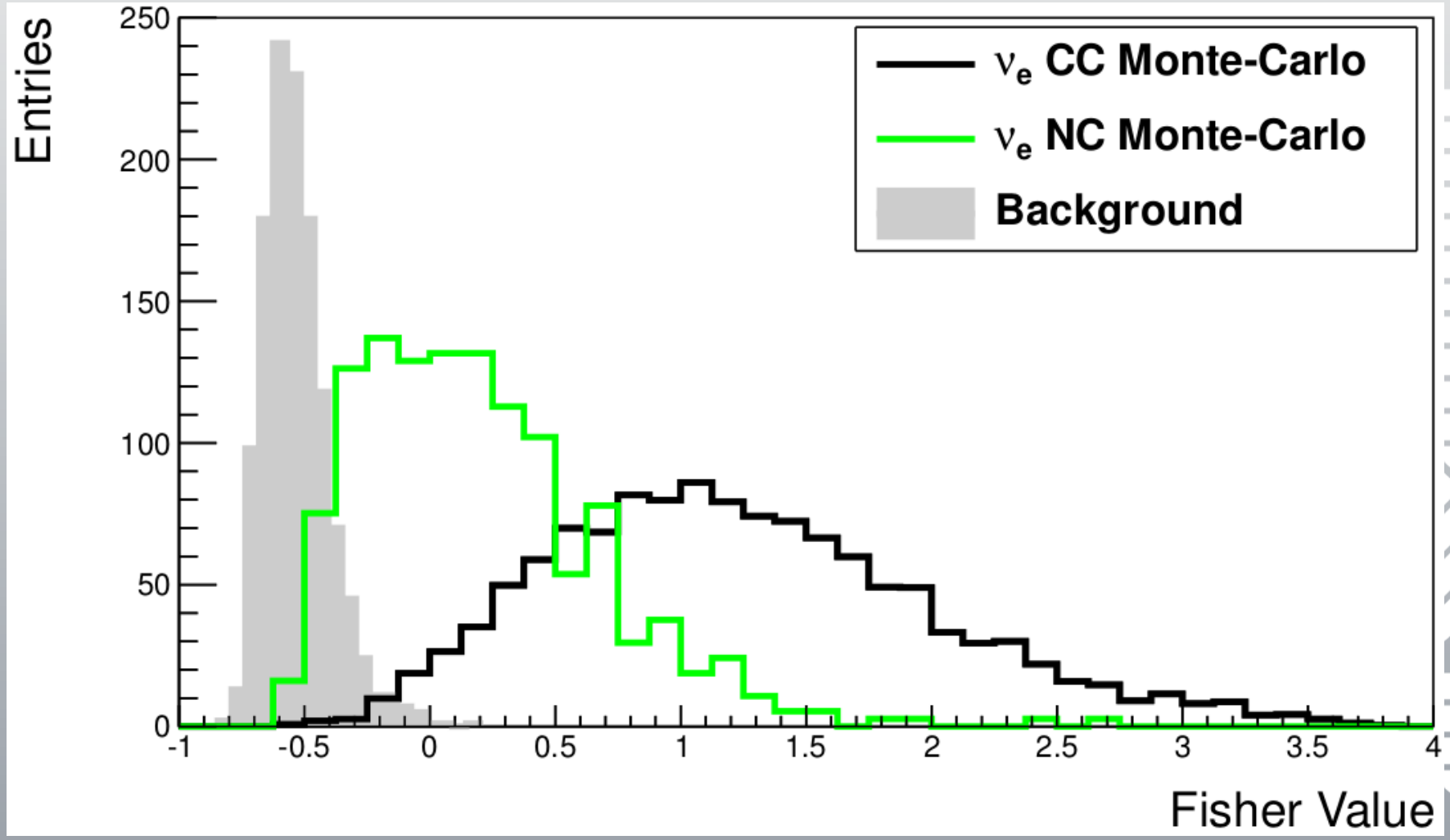
Theoretical Predictions



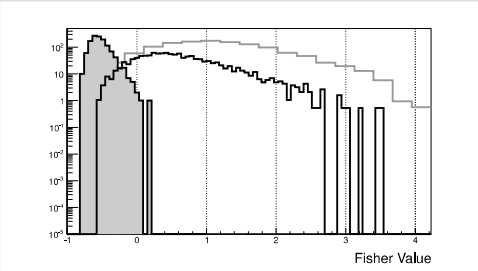
Neutrinos from Cen A



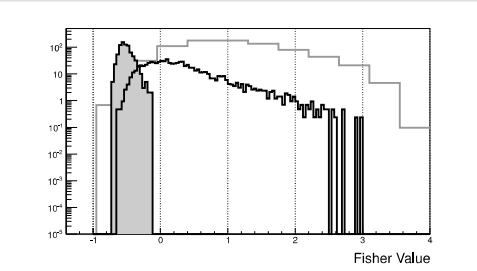
CC vs NC Fisher Values



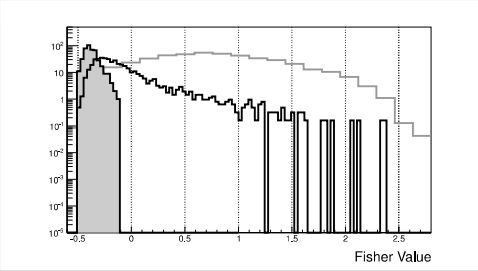
Neutrinos vs. Photons



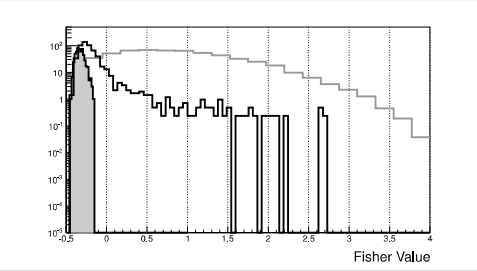
(a) $58.5^\circ < \theta_{\mathrm{Rec}} \leq 61.5^\circ$



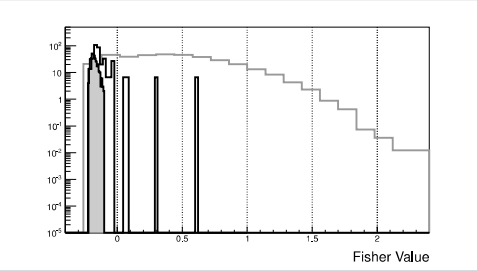
(b) $61.5^\circ < \theta_{\mathrm{Rec}} \leq 64.5^\circ$



(c) $64.5^\circ < \theta_{\mathrm{Rec}} \leq 67.5^\circ$



(d) $67.5^\circ < \theta_{\mathrm{Rec}} \leq 70.5^\circ$



(e) $70.5^\circ < \theta_{\mathrm{Rec}} \leq 76.5^\circ$