RWTHAACHEN IceCube

Search for Diffuse Neutrino Emission from the Galactic Plane with 7 Years of IceCube Data

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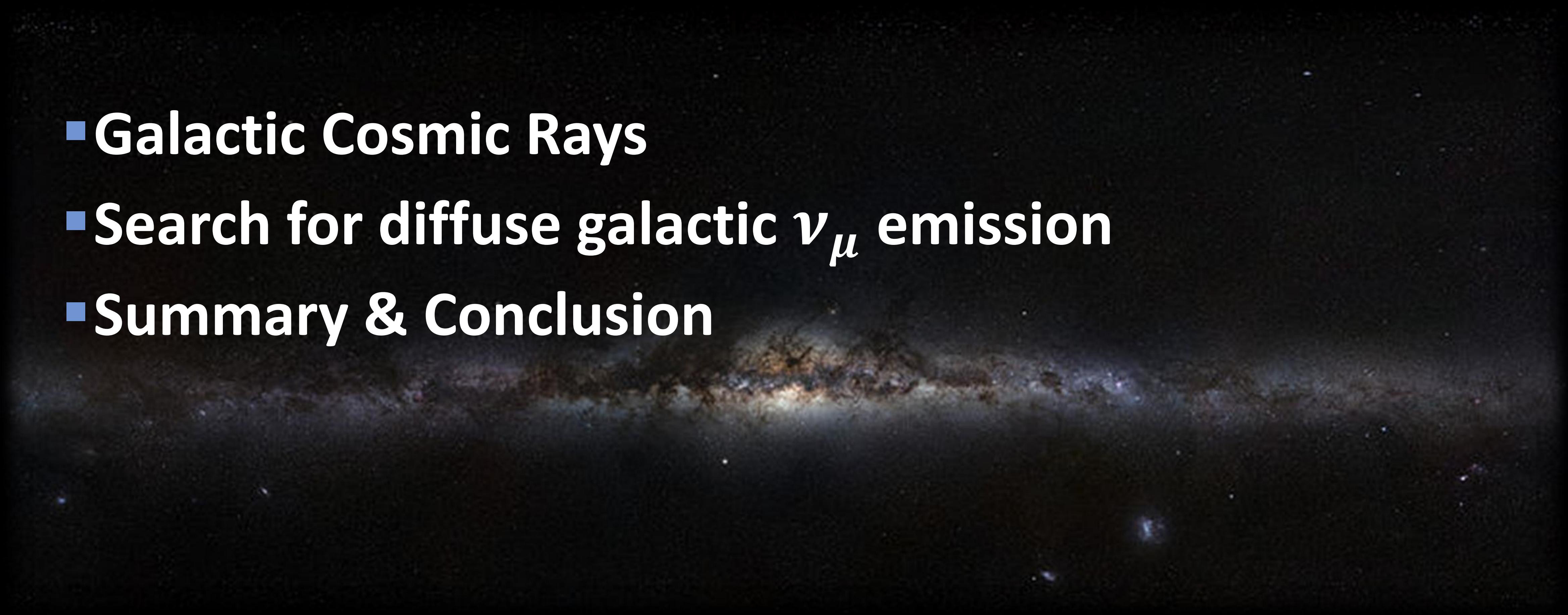
Allianz für Astroteilchenphysik

Outline

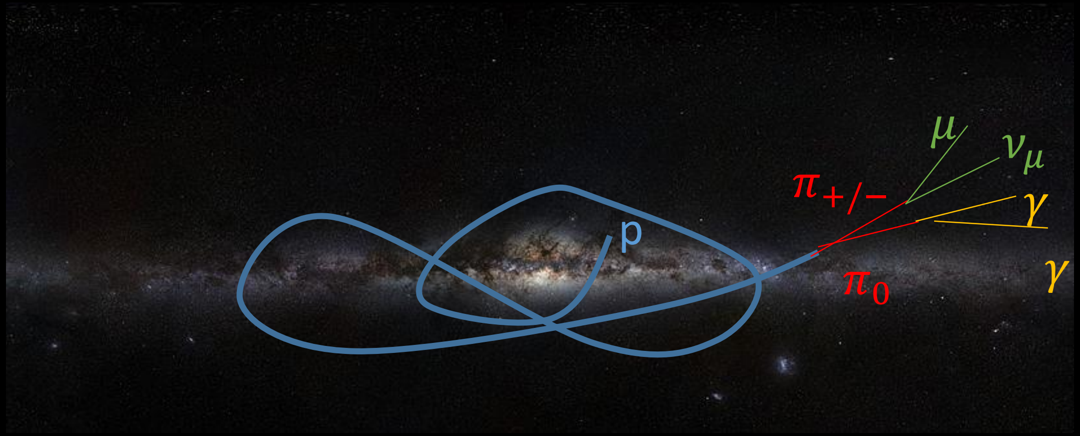


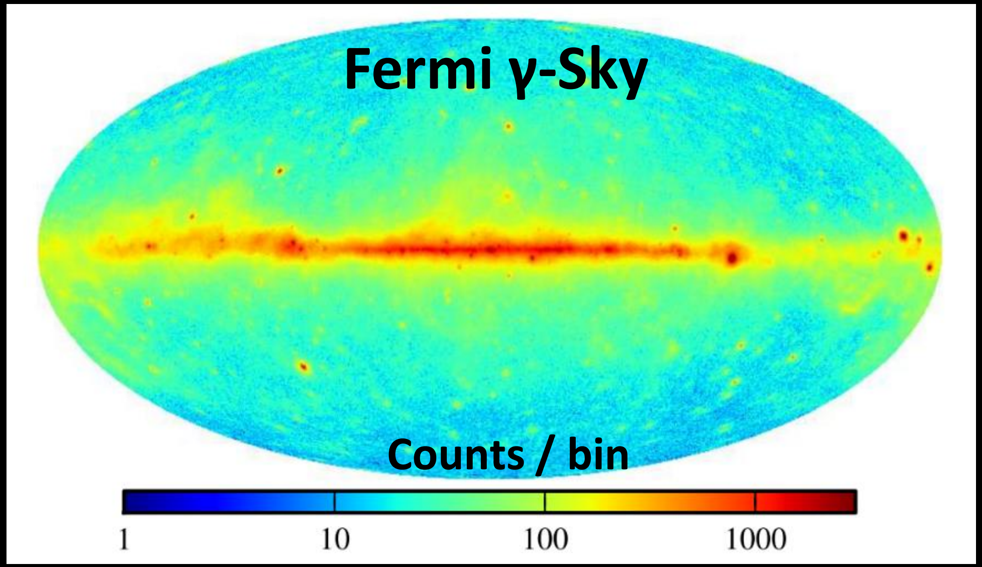
- Galactic Cosmic Rays
- Search for diffuse galactic ν_μ emission
- Summary & Conclusion

Galactic Cosmic Rays

Galactic Cosmic Rays

- Supernova remnants are main candidates for galactic CR production
- Propagation on galactic scales is modelled by energy-dependent diffusion models
- Conventional models assume spatially constant diffusion coefficcient
- During propagation protons interact with material near the source or interstellar gas
- Interactions produce pions which decay into γ and ν
  →**Diffuse γ / ν emission**





Galactic Cosmic Rays

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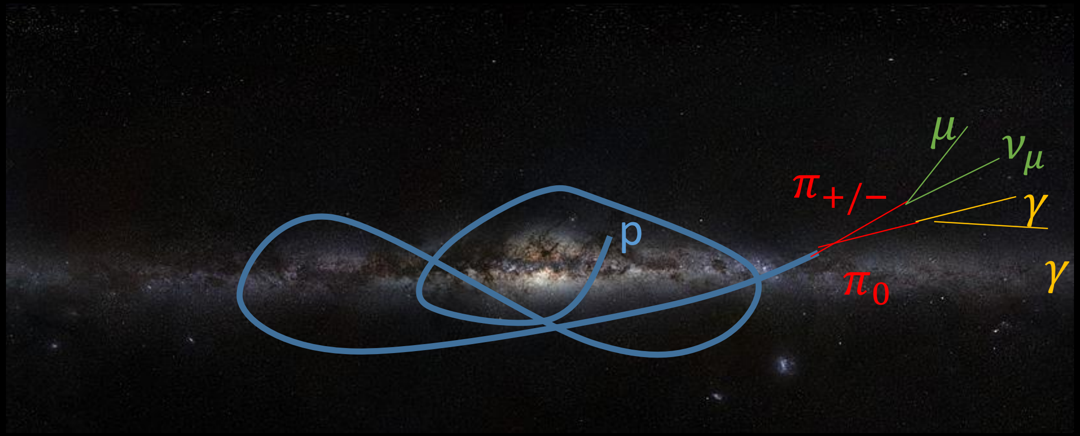
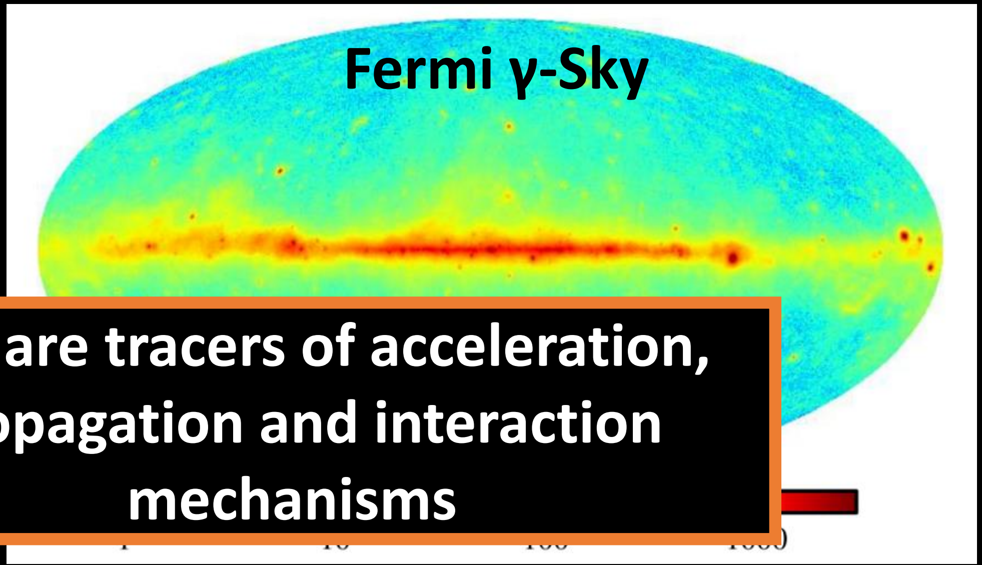
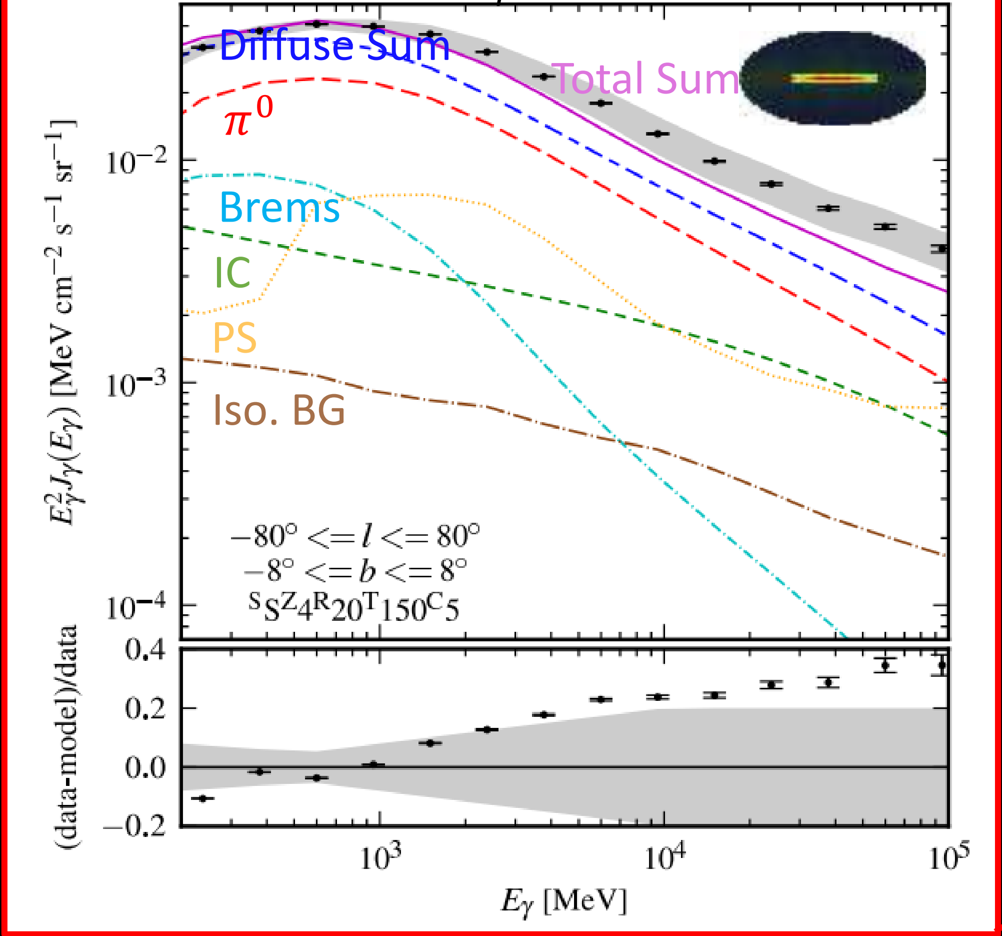




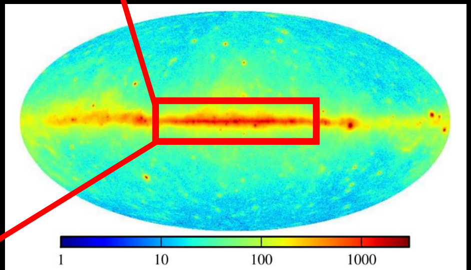
γ / ν are tracers of acceleration, propagation and interaction mechanisms

Fermi Diffuse γ Model

M. Ackermann *et al* 2012 *ApJ* **750** 3



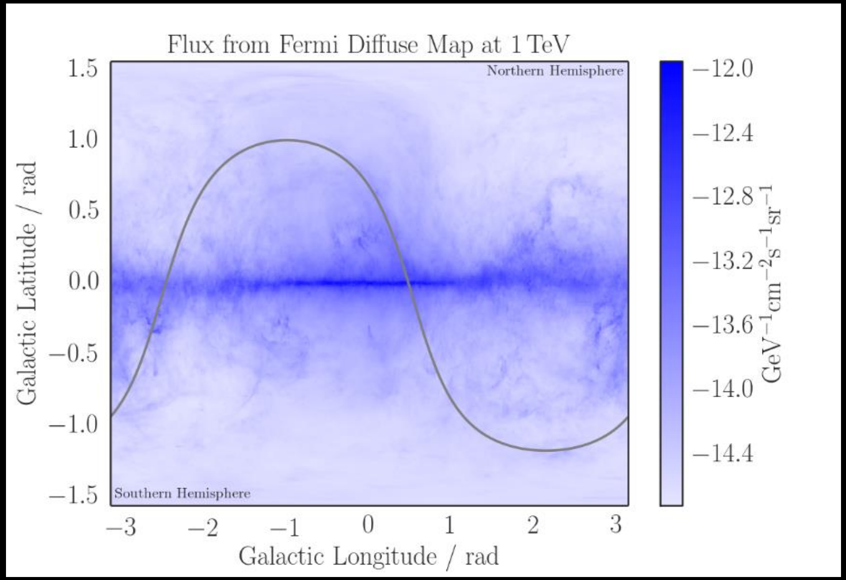
- Fermi LAT provides a full model for galactic γ emission
- Modelling of CR injection, transport and interaction with interstellar matter

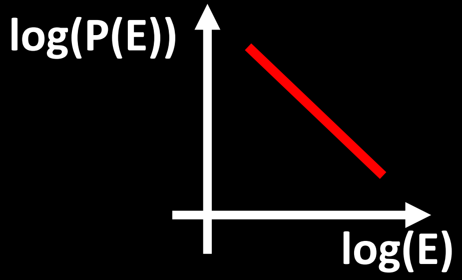


→ Model has difficulties explaining the total diffuse γ emission accurately

Modelling Galactic Neutrinos

- Diffuse galactic γ and ν are created by π-decays -> Same spatial distribution
- Simple model:
  Spatial: π^0-component of Fermi diffuse γ background model
  Energy: $E^{-\gamma}$ powerlaw
- No prediction for flux normalization





Sophisticated Models

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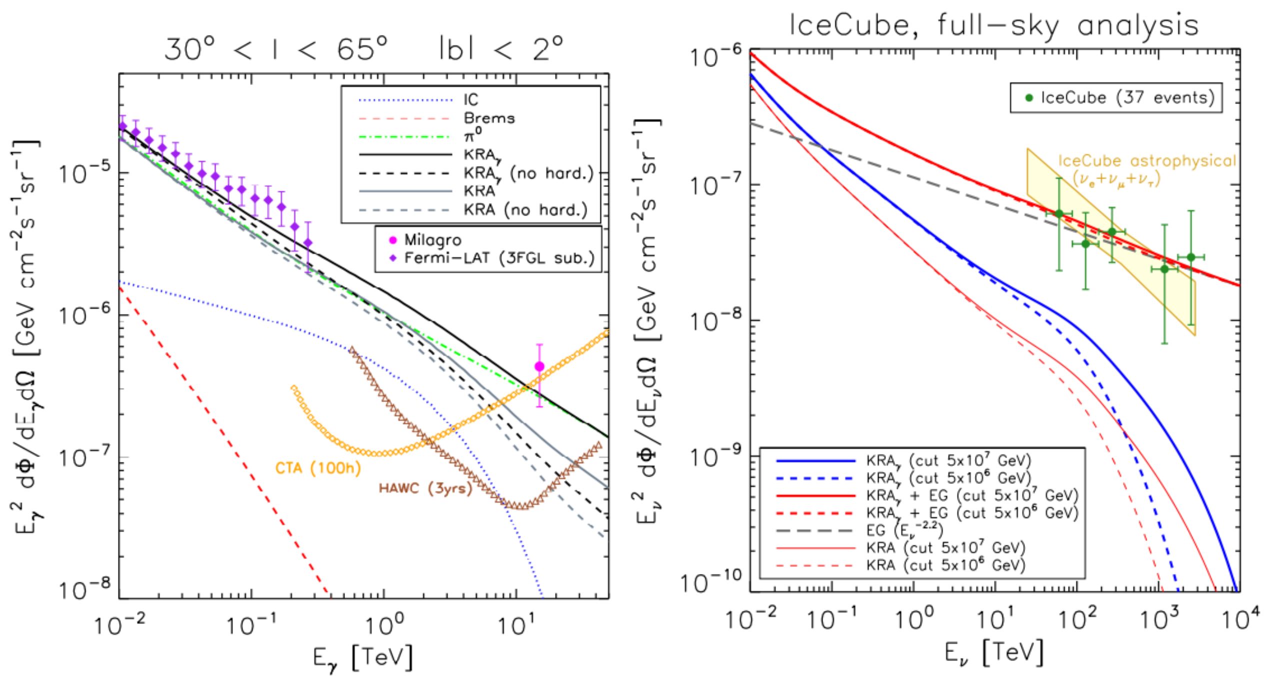
- Model by Gaggero et. al. provides consistent picture of ν and γ diffuse emission
- Based on KRA_γ CR-diffusion model: Assumes diffusion coefficient depending on galiocentric radius)
- Developed to solve problems of conventional propagation models (e.g. „Milagro excess“)

Daniele Gaggero *et al* 2015 *ApJL* **815** L25

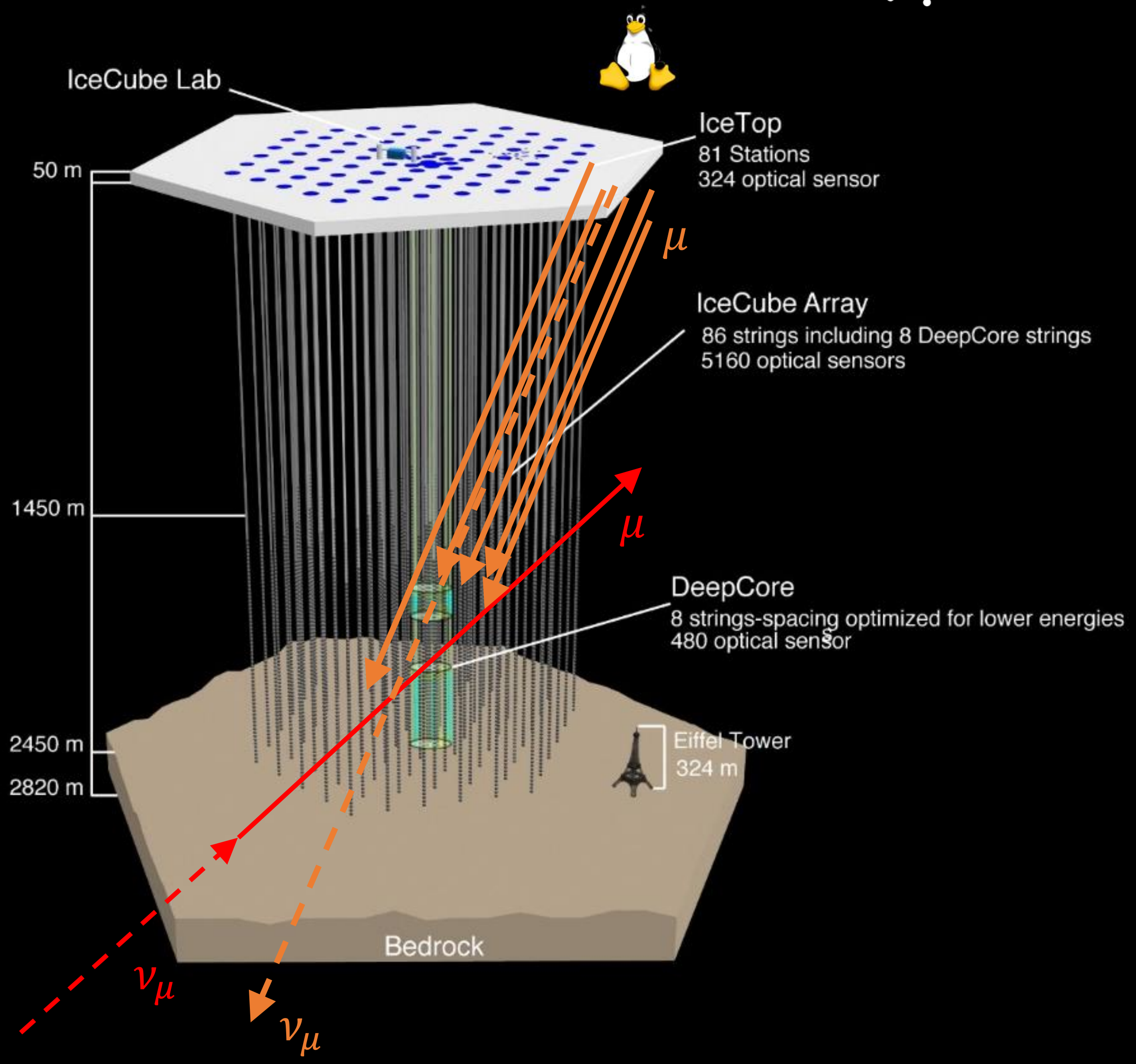


→ν measurement can provide valuable insight into CR injection, propagation and interaction mechanism

Search for diffuse galactic ν_μ emission

The IceCube Neutrino Observatory

- Cherenkov detector at the geographic South Pole
- 5160 **D**igital **O**ptical **M**odules (PMT with onboard digitization)
- 86 Strings in a depth of 1450m to 2450m
- 125m string spacing
- **Detection Principle:** Cherenkov emission of secondary particles produced by ν-interaction in or near the detector
- Energy threshold ~10GeV (with DeepCore)

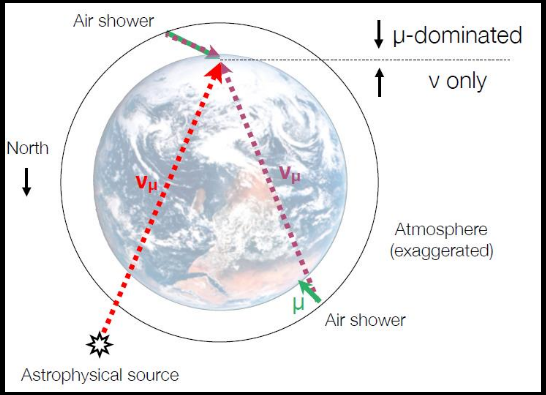


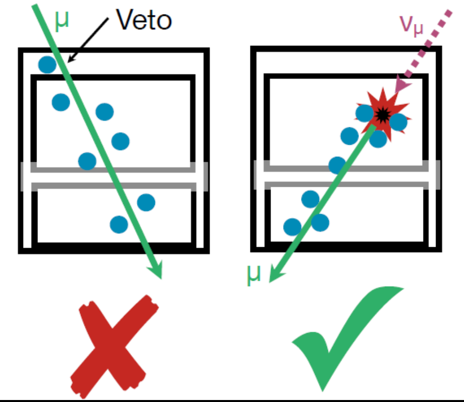
Background reduction techniques

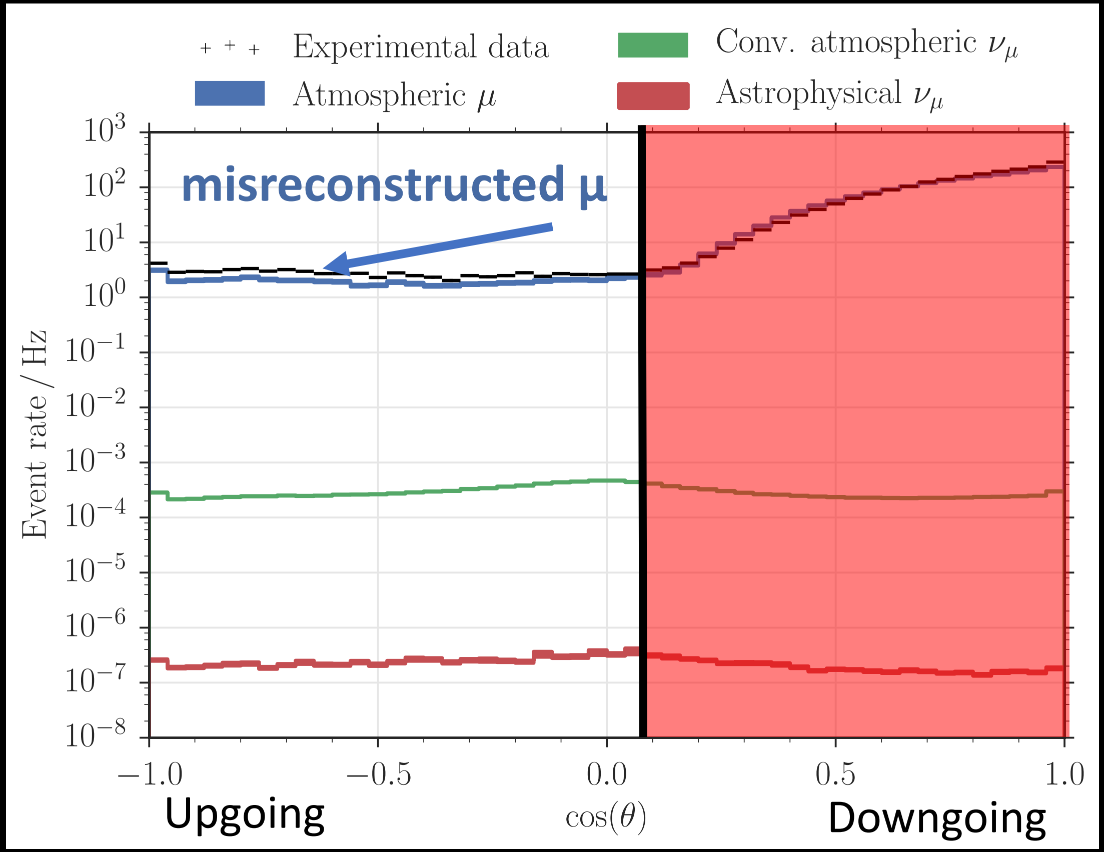
Two Strategies

Upgoing Neutrinos (ν_μ)
- Track Signature
- Good Angular Res.
- Bad Energy Res.

Starting Events (all-flavor)
- Cascade Dominated
- Bad Angular Res.
- Good Energy Res.

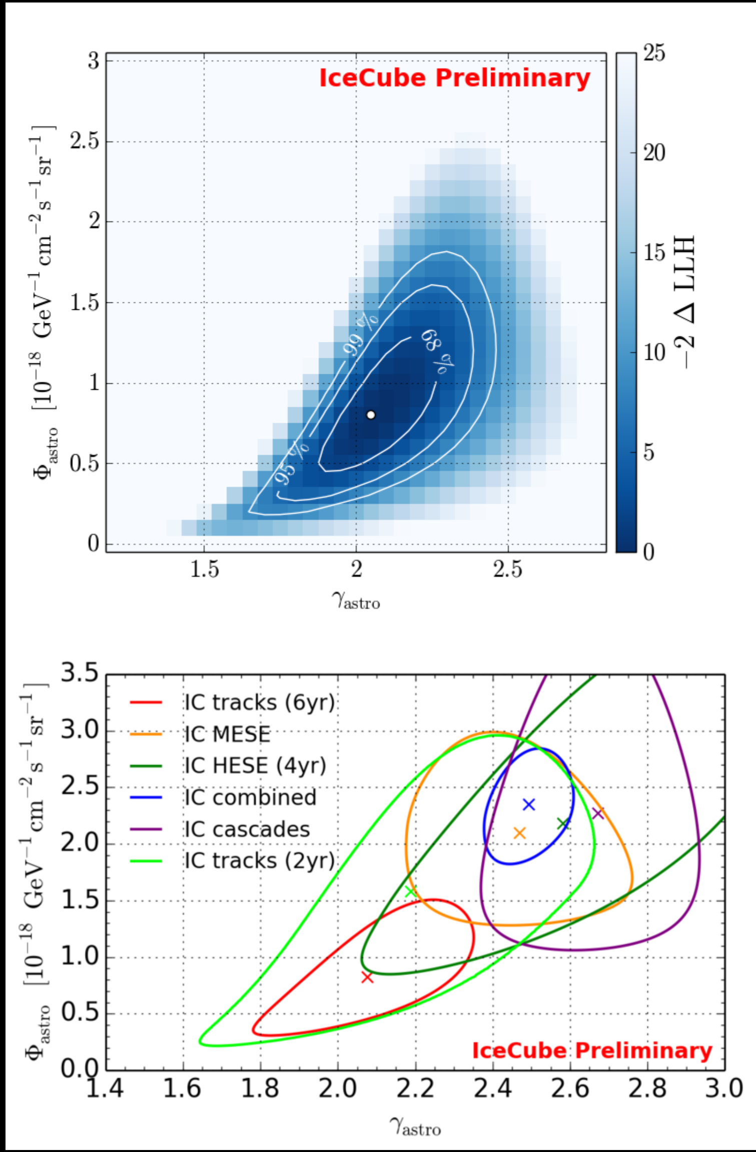






Recent IceCube Results

- Latest, most precise characterization of the astrophysical ν_μ flux using six years of data in *Astrophys.J. 833 (2016) no. 1, 3*
- No associated ν point sources found
- Result is in tension to other IceCube analyses (3σ compared to global analysis based mainly on lower energies)
- Might be an indication for second component in neutrino spectrum



Analysis Methods

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Q: Does the data include a contribution of galactic neutrinos?

„Simulation Background" Method

- Binned poissonian template fit in energy and direction
- Signal & background PDF calculated from MC
- Systematic uncertainties included as continuous nuisance parameters
- Fits flux parameters of conventional + prompt atmospheric, isotropic + galactic astrophysical

Consistent picture of all neutrino fluxes

„Data Background" Method

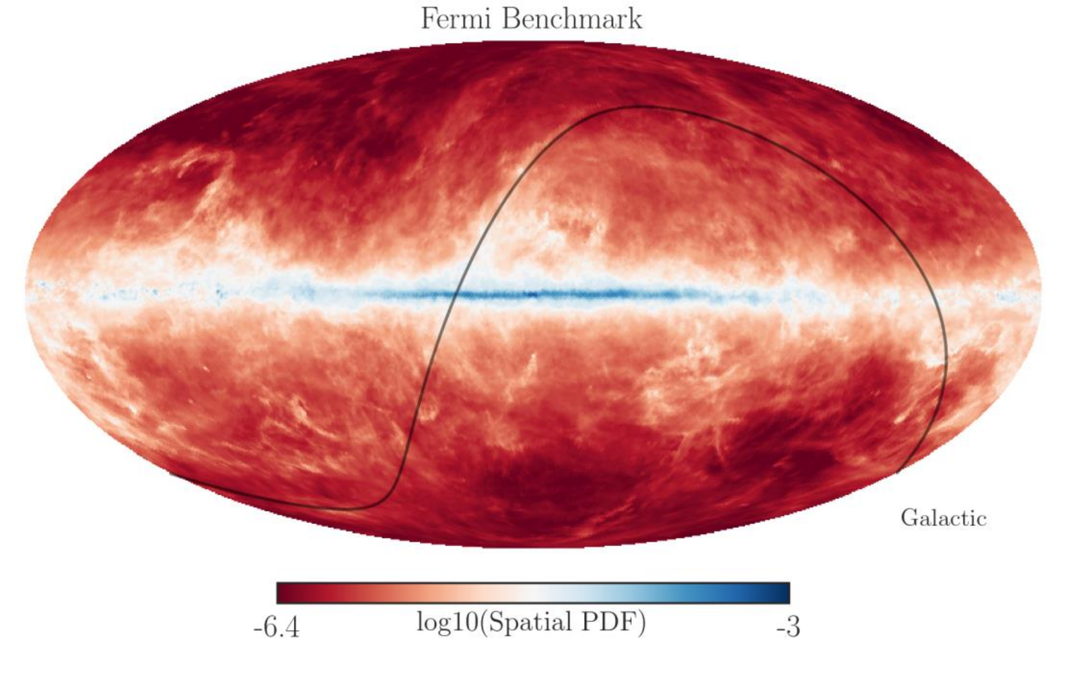
- Unbinned spatial LH fit with energy weighting
- Data-driven background model
- Fits anisotropic galactic plane contribution in isotropic background

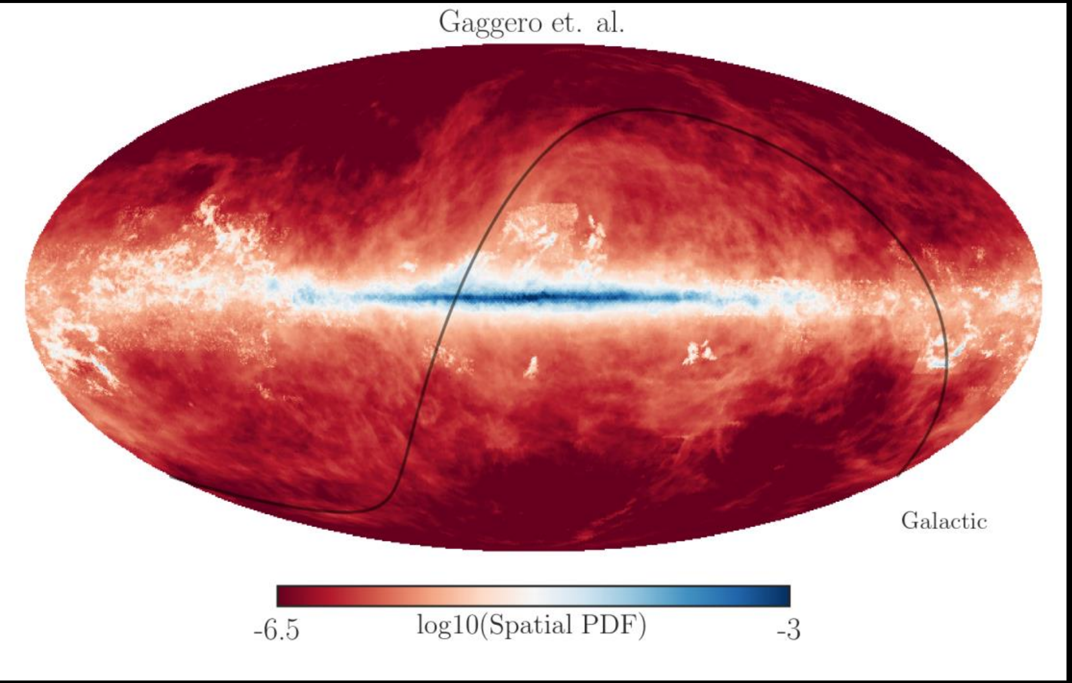
~10% better Sensitivity

Galactic Plane Templates

Baseline Model
Fermi π^0 spatial template
$E^{-\gamma}$ energy spectrum (baseline: $\gamma = 2.5$)
Normalization: ~ 55 ν_μ/yr

KRA$_\gamma$
Spatial template from tuned diffusion model
$E^{-\gamma}$ energy spectrum ($\gamma \sim 2.45$)
Prediction: ~ 30 ν_μ/yr





Galactic Plane Templates

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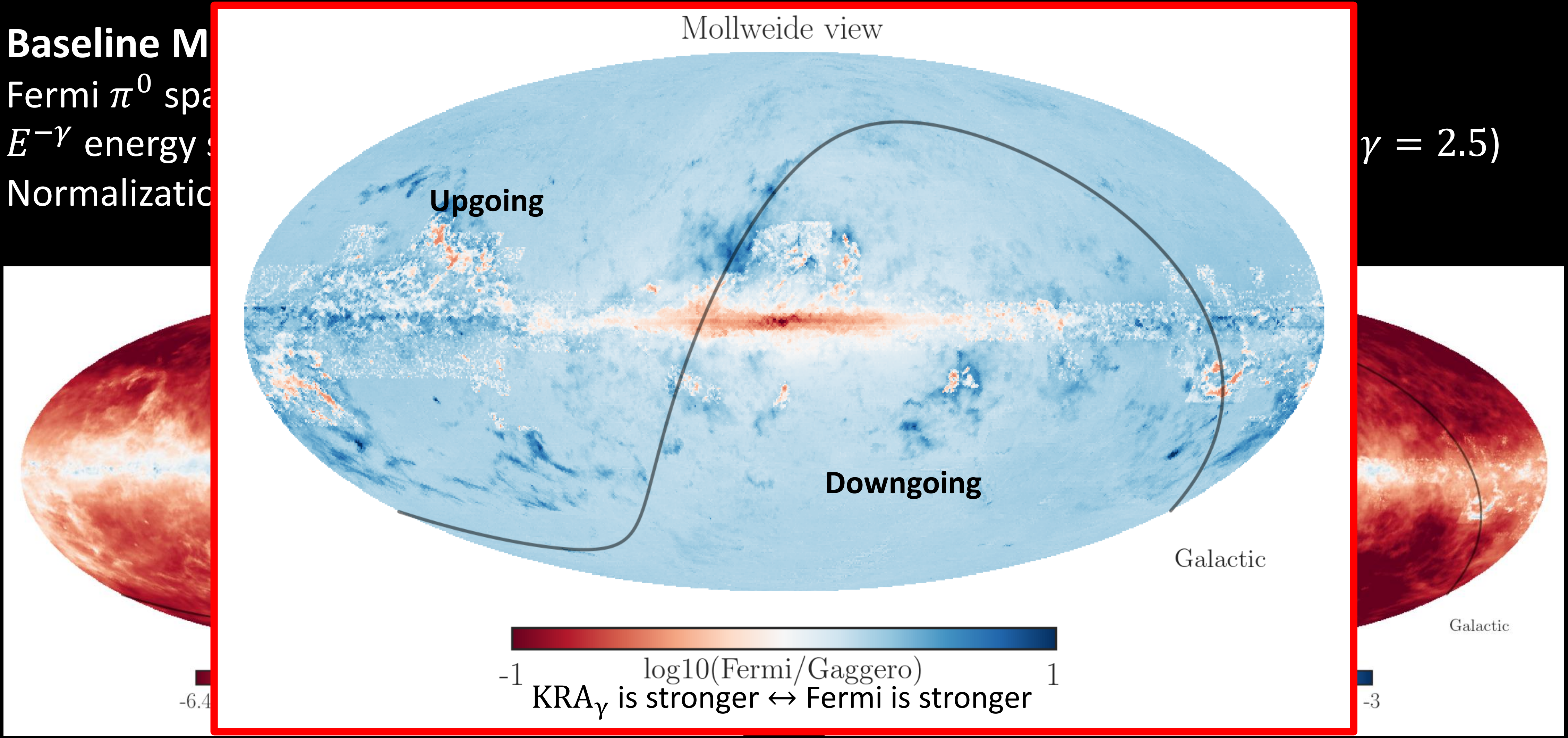
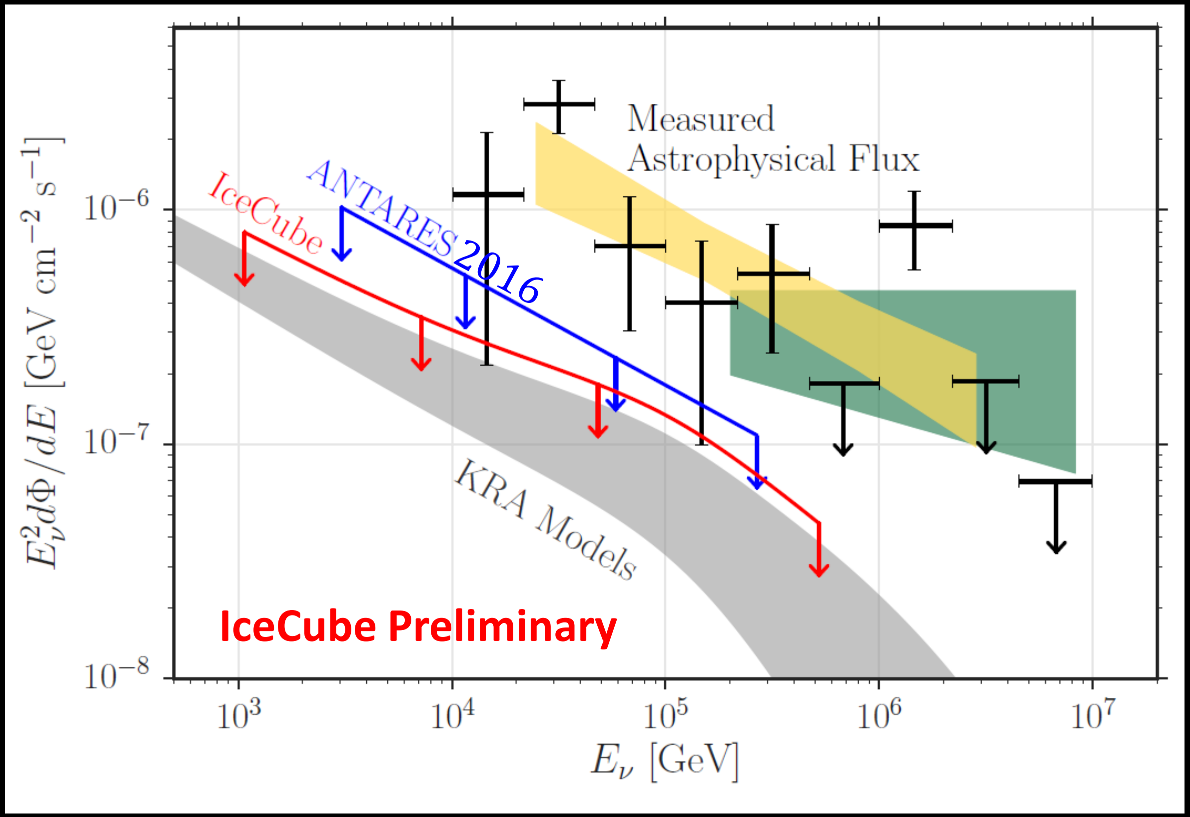


Results

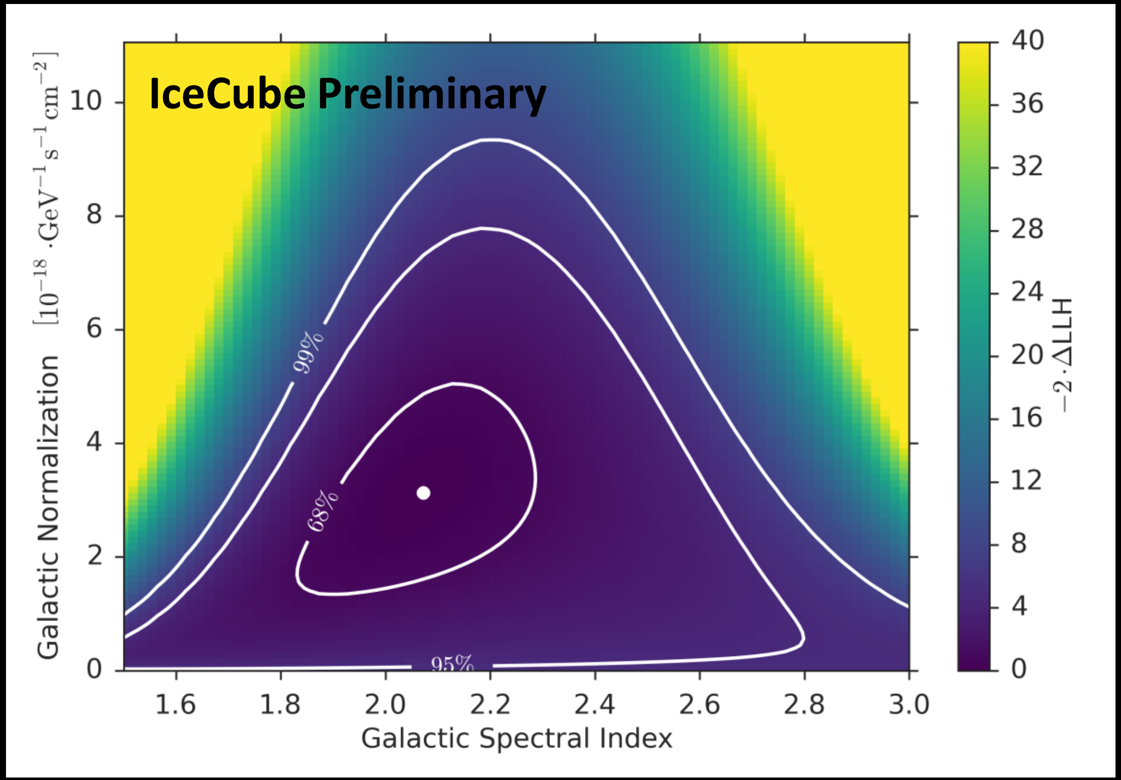
Results #1: Data Background

- Using the data-background method, we set an upper limit of:
  1.2 x $\mathbf{KRA_\gamma}$ (50PeV cutoff)
- For the Fermi π^0 model:
  $$\Phi_{90} = 1.2 \cdot 10^{-5} \left(\frac{E}{GeV}\right)^{-2.5} \mathrm{GeV^{-1}cm^{-2}s^{-1}}$$
- Not more than **16%** of the isotropic diffuse flux @ $\gamma = 2.5$ from the galactic plane
- New ANTARES (arXiv: 1705.00497) limit: **1.25 x $\mathbf{KRA_\gamma}$** (50PeV cutoff)



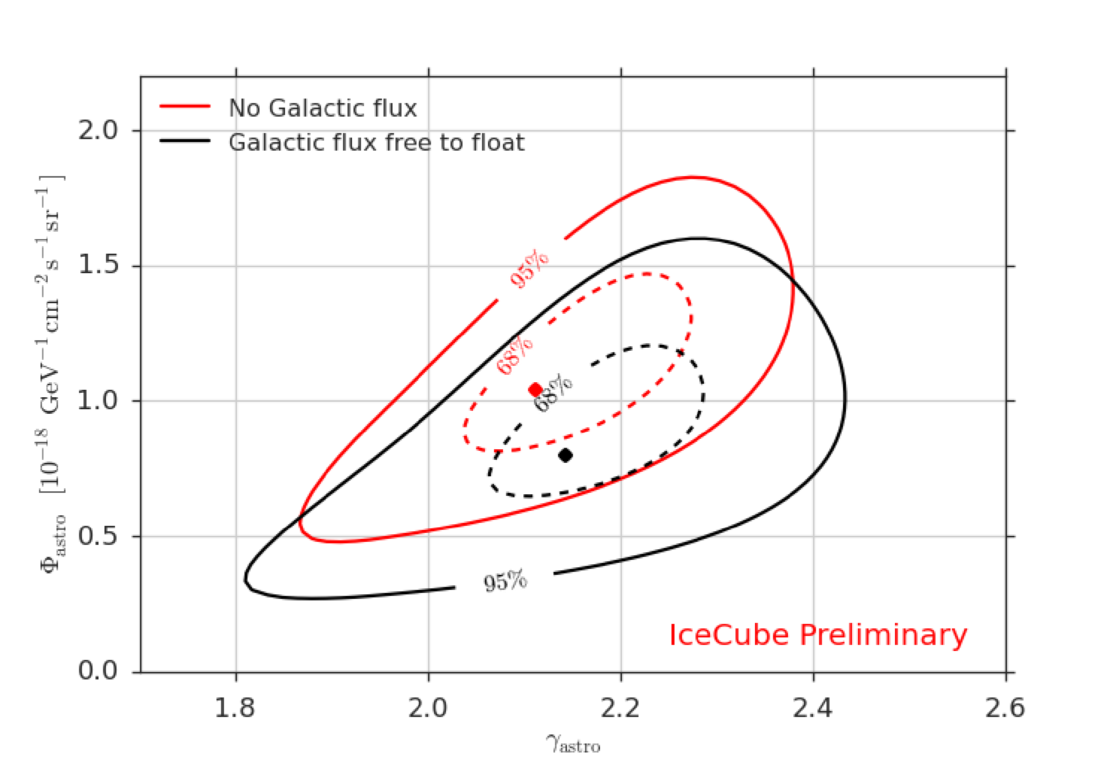
Results #2: Simulation Background

- Using the simulation-background method and the Fermi π^0 model, we obtain an insignificant best fit:
- $\Phi_0 = 0.98 \pm^{0.66}_{0.58}, \gamma = 2.07 \pm^{0.22}_{0.25}$
  $\Phi = \Phi_0 \cdot 10^{-5} \left(\frac{E}{GeV}\right)^{-\gamma} \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- P-Value of no galactic flux: 7%
- Consistent with data-background method



Results #2: Simulation Background

- The simulation background method delivers consistent picture of isotropic & astrophysical galactic fluxes
- Check the influence of inclusion of galactic component on isotropic flux measurement
- Scan isotropic flux parameters with galactic plane parameters (norm. + spectral index) free to float



-> Inclusion of galactic component in fit does not strongly affect ability to constrain isotropic astrophysical flux.

Summary & Conclusions

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- A measurement of a diffuse galactic neutrino emission can provide valuable insight into CR propagation mechanisms
- IceCube is already able to probe models for diffuse ν_μ emission
  90% UL: 1.2 x KRA_γ (50PeV)
  For Fermi π^0 model: $\Phi_{90} = 1.2 \cdot 10^{-5} \left(\frac{E}{GeV}\right)^{-2.5} \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Simulation background analysis results in an overfluctuation (~7% p-value)
- The best-fit galactic spectral index is suprisingly hard ($2.07 \pm^{0.22}_{0.25}$)
  → But no conclusions can be drawn yet

Outlook: Global analysis combining multiple detection channels

Thank You!

DIVERSITY IN ICECUBE

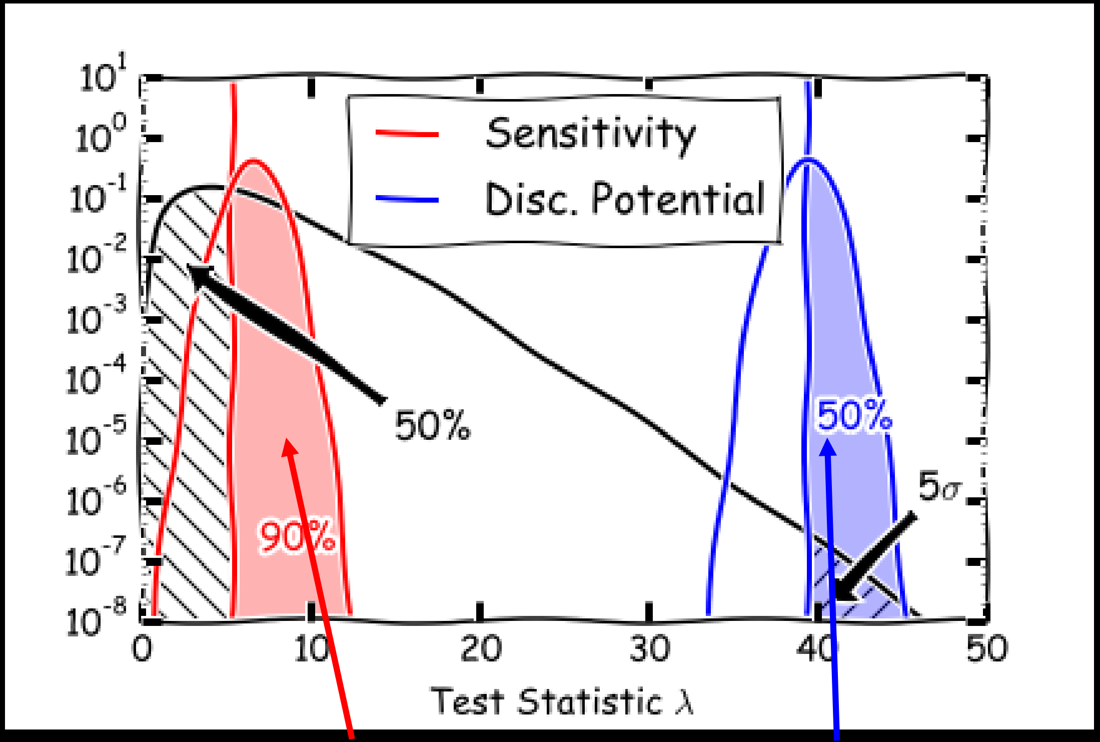
WHERE WE COME FROM

Algeria
Argentina
Australia
Austria
Belgium
Brazil
Canada
Chile
China
Colombia
Croatia
Denmark
Egypt
France
Germany
Greece
India
Iran
Ireland
Israel
Italy
Japan
Mexico
Nepal
New Zealand
Peru
Poland
Romania
Russia
Serbia
South Korea
Spain
Sweden
Switzerland
Syria
Taiwan
The Netherlands
The UK
Trinidad and Tobago
Turkey
Ukraine
USA
Venezuela

Backup

Sensitivity Calculation

- Sensitivity is defined as median upper limit, when no signal is present
- Neyman construction:
  - Generate BG & Signal pseudoexperiments
  - 90% UL is found when $Q_{50}(TS_{BG}) \mathrel{\hat{=}} Q_{10}(TS_{Signal})$



Signal distribution $n_{inj} = n_{UL}$

Signal distribution $n_{inj} = n_{DiscPot}$

Event Selection

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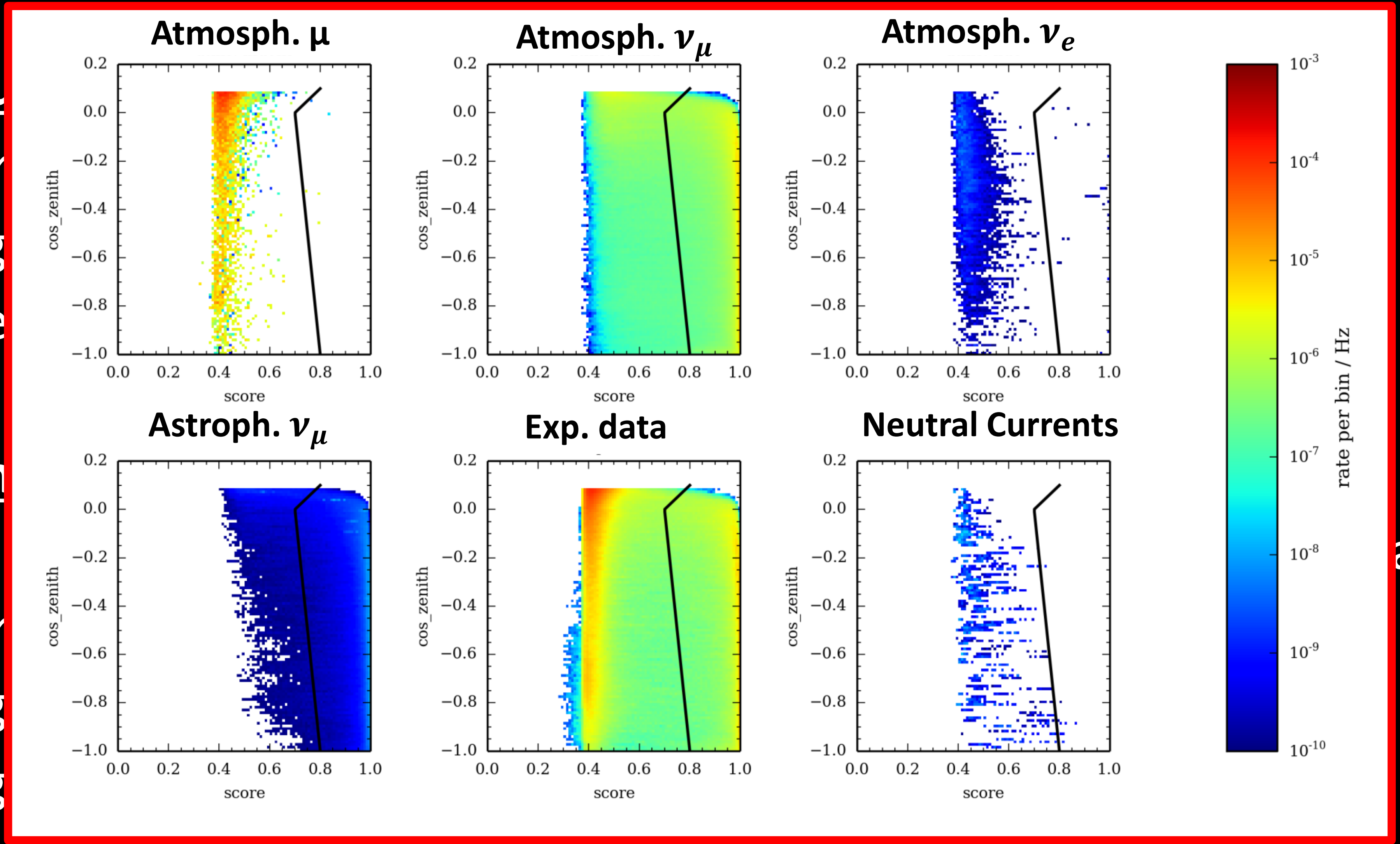

Flux Templates

Atmospheri
- Prompt (
- Conventi

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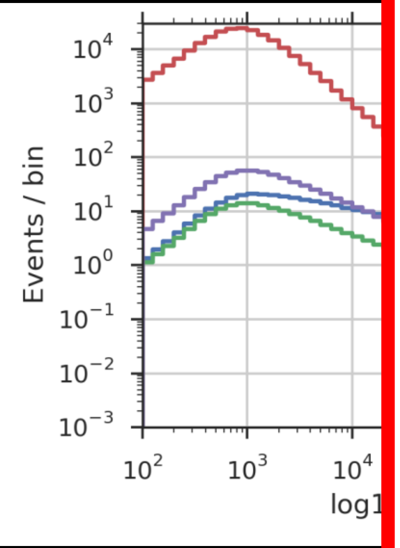
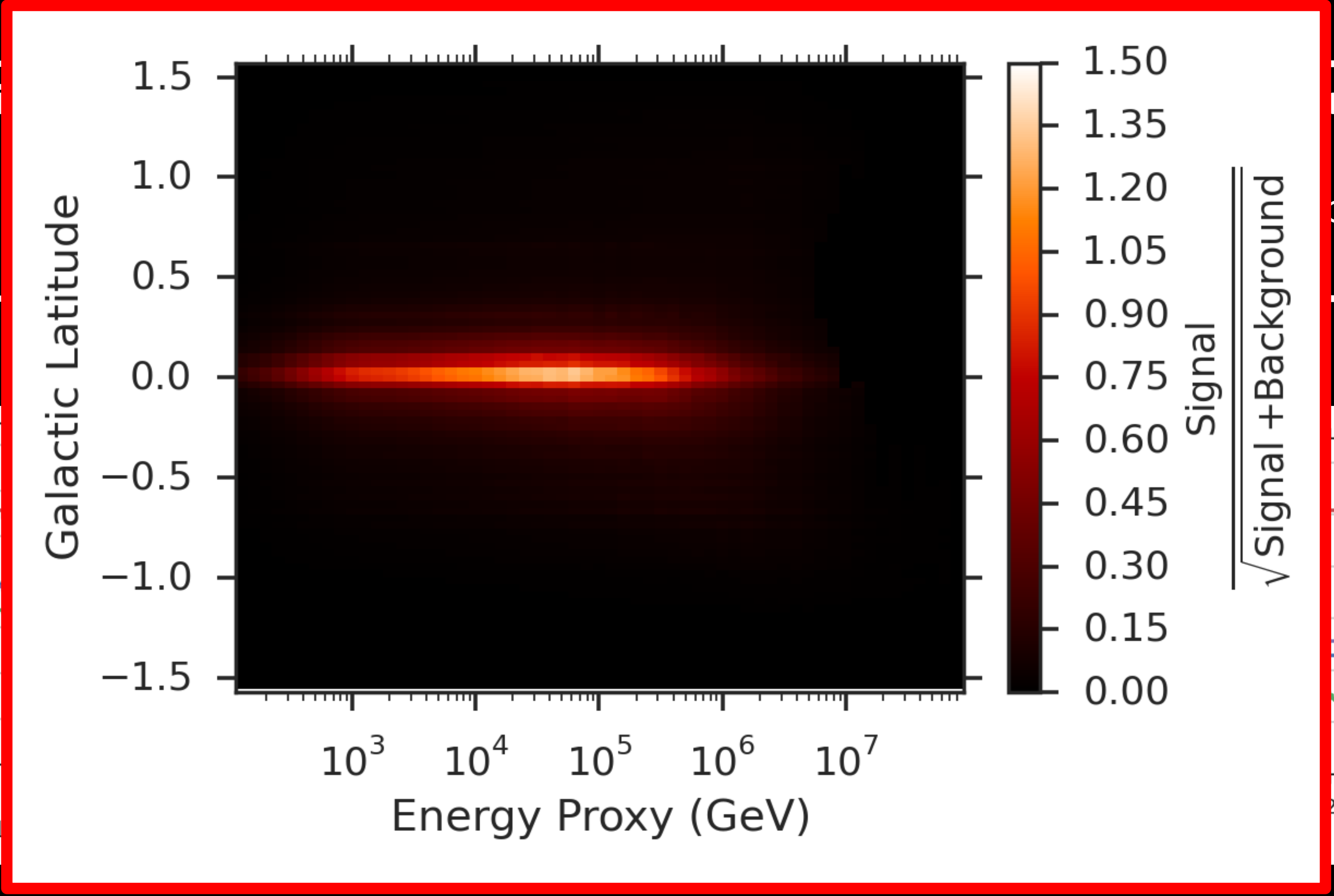
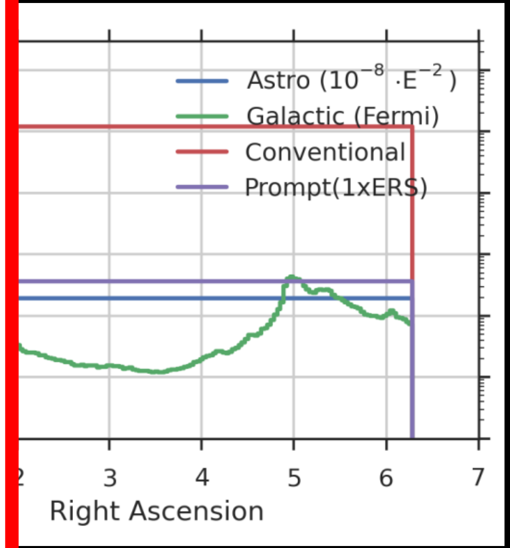
powerlaw)







Systematic Uncertainties

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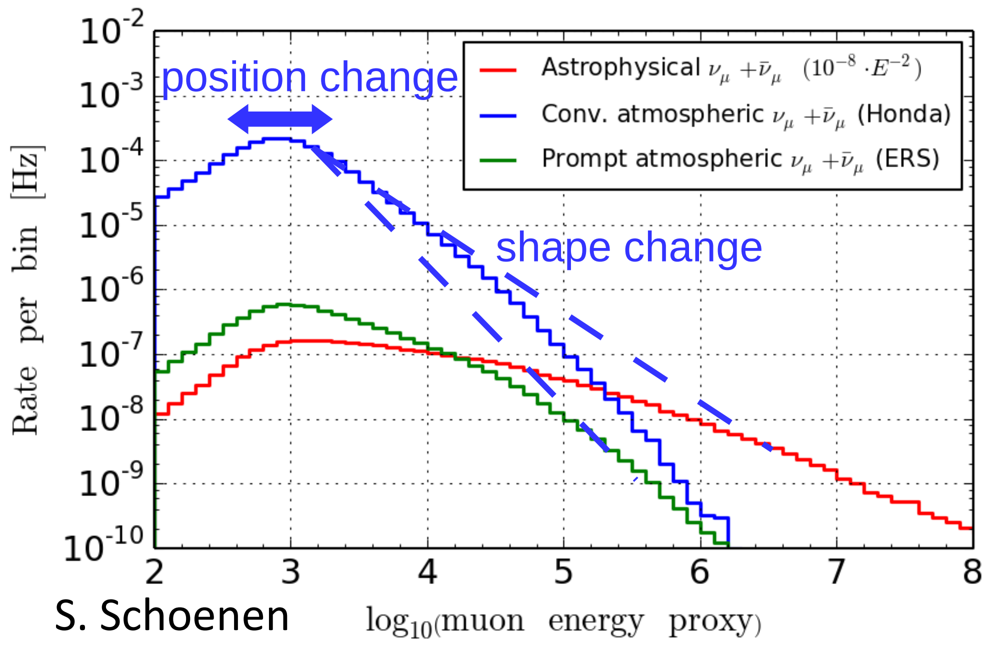
Detector Effects:

Ice properties, optical sensor efficiency

Flux Uncertainties:

Rate, shape and composition of the CR flux, rate of pion-to-kaon decay in air showers, neutrino cross sections



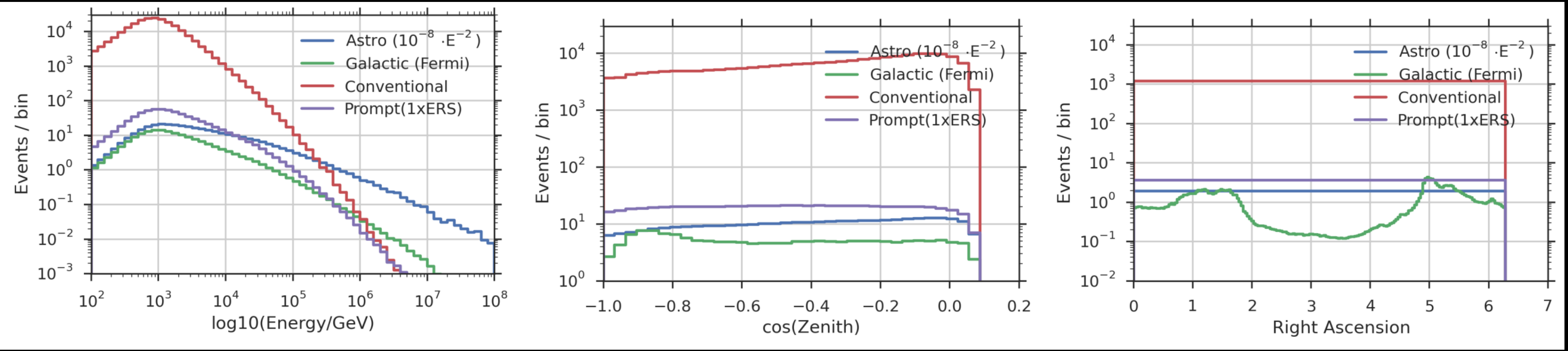
Influence of every sys. effect on analysis variables is parametrized continously and implemented as *nuisance parameters*

Detector is symmetric in azimuth (and located at South Pole)
→ RA not influenced by sys. Effects

Flux Templates

Atmospheric Neutrinos
- Conventional (pion / kaon decay)
- Prompt (heavy meson decay)

Astrophysical Neutrinos
- Diffuse Galactic (powerlaw)
- Diffuse isotropic (powerlaw)



Analysis Methods

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Q: Does the data include a contribution of galactic neutrinos?

- 3D histogram of observables: zenith angle, right ascension, energy
- Forward-folding template fit using poissonian likelihood:

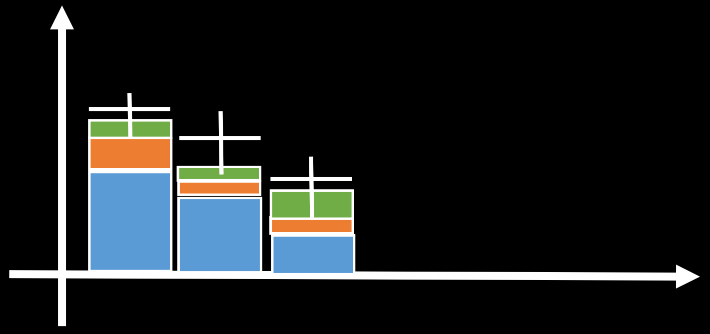
MC-expectation

Signal & Nuisance Parameters

$$L(\boldsymbol{\mu}(\boldsymbol{\theta},\boldsymbol{\xi})|\boldsymbol{n}) = \prod_{i=1}^{N} \frac{(\boldsymbol{\mu_i}(\boldsymbol{\theta},\boldsymbol{\xi}))^{n_i}}{n_i!} \exp(-\boldsymbol{\mu_i}(\boldsymbol{\theta},\boldsymbol{\xi}))$$

Bin number

data events



- Likelihood ratio test: $\mathrm{TS} = \dfrac{\mathcal{L}(\hat{n}_{galactic}, \hat{n}_{astro} \,|\, \hat{\theta}_{nuisance})}{\mathcal{L}(n_{galactic}=0, \hat{\hat{n}}_{astro} \,|\, \hat{\hat{\theta}}_{nuisance})}$

Event Selections

High Purity Sample („Diffuse")

- Upgoing track-like events
- Six years of data combining multiple detector configurations
- Purity: >99.7%
- ~350,000 events
- Allows measurement of spectral properties of astrophysical ν_μ-flux

High Statistics Sample („Point Source")

- Upgoing, downgoing and starting track-like events
- Seven years of data combining multiple detector configurations
- Contamination from atmos. Muons and neutral current ($+\nu_e$) interactions
- ~700,000 events

Good pointing (<0.5° @ PeV)