Gen2 diffuse

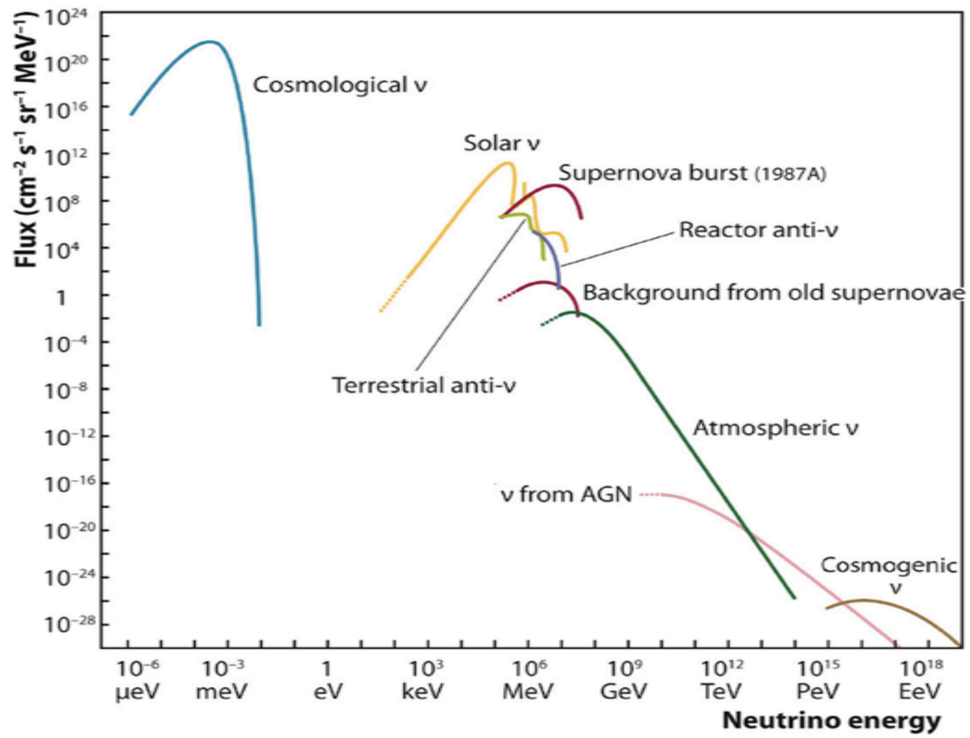
Brainstorming

Albrecht Karle
and Lu Lu

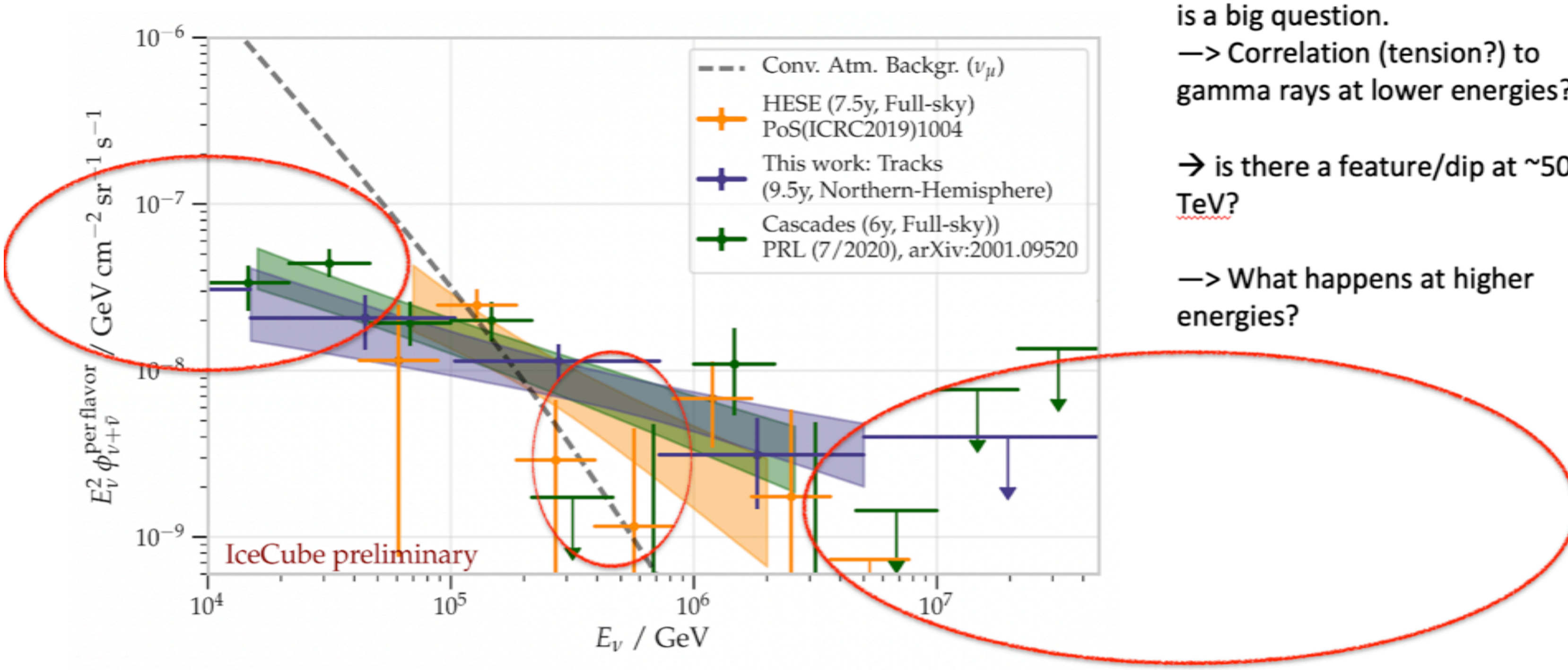
- Atmospheric nu
  - Unfolding
  - Seasonal variation
  - **Prompt flux**
  - Earth core
- Astrophysical nu
  - **Flux - bump? Power law?**
  - **Flavour**
- Cosmogenic nu
  - **Direct measurement**
  - Indirect (tau secondaries)

- Inelasticity
- Cross-section
- nu/nubar (with inelasticity or Glashow)

Galactic



Exposure needed



The extension to lower energies is a big question.
—> Correlation (tension?) to gamma rays at lower energies?

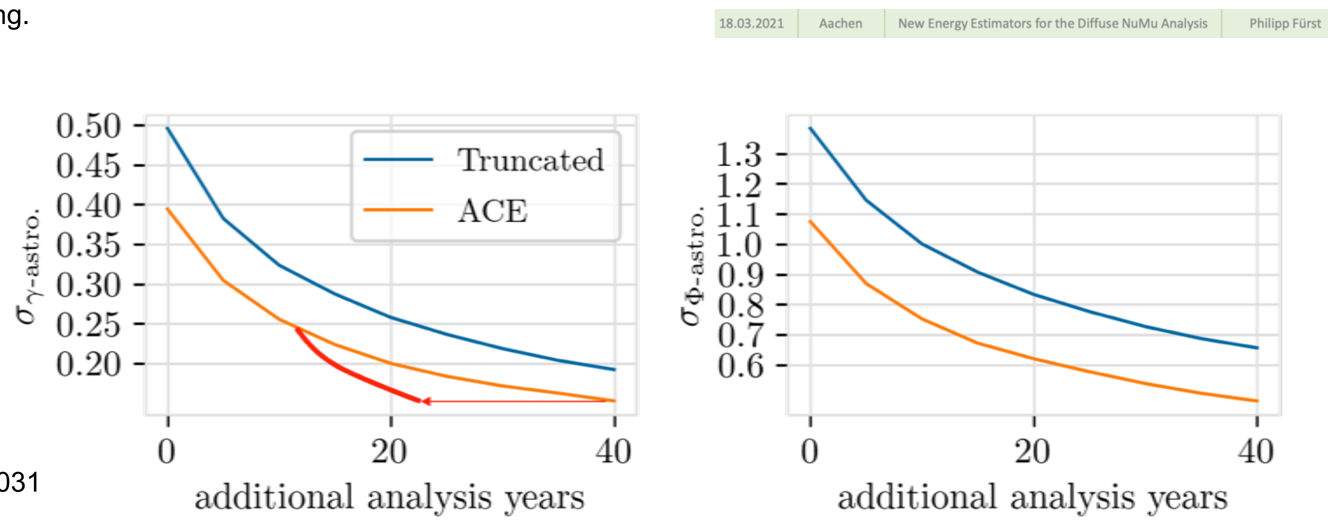
→ is there a feature/dip at ~500 TeV?

—> What happens at higher energies?

Projections of diffuse sensitivity with Gen2

Plots that could be useful for the proposal:

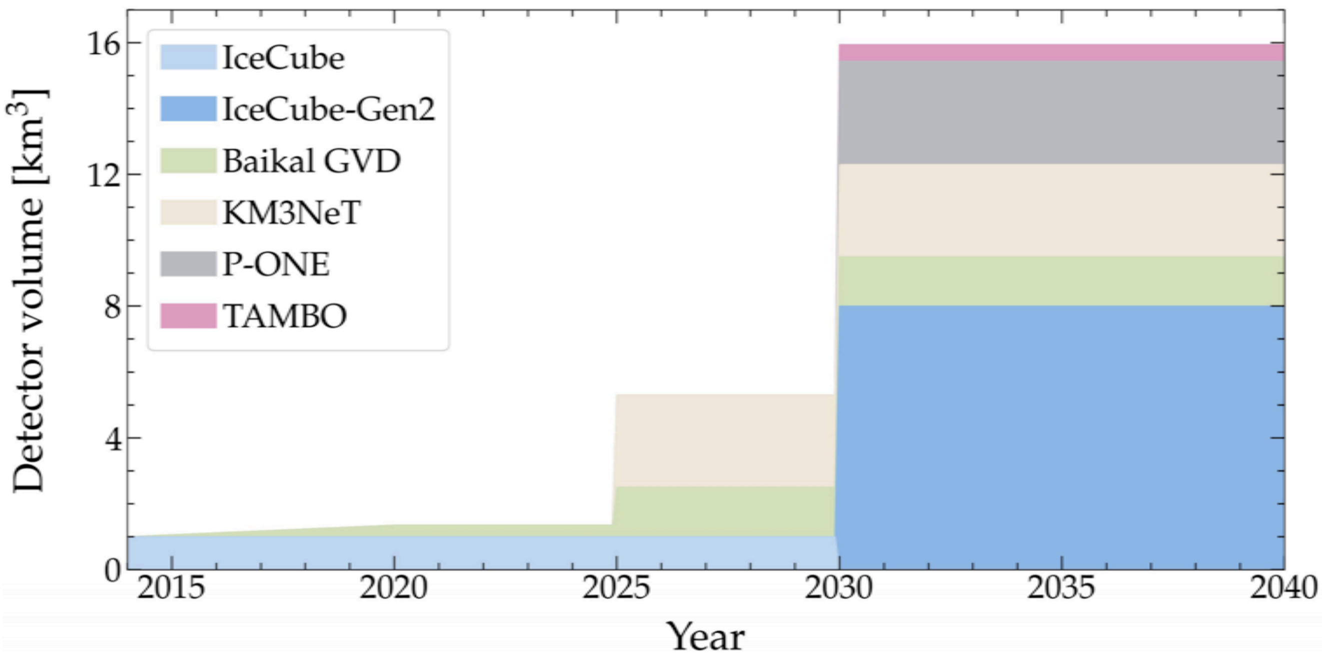
This is just a sketch based on scaling.



- Phase 2 online in January 2028
- Gen2 switched on in January 2031 (mid point of construction).

The landscape of the future?

(global fit at some point really global)



Song, Li, Argüelles, MB, Vincent, *JCAP* 2021

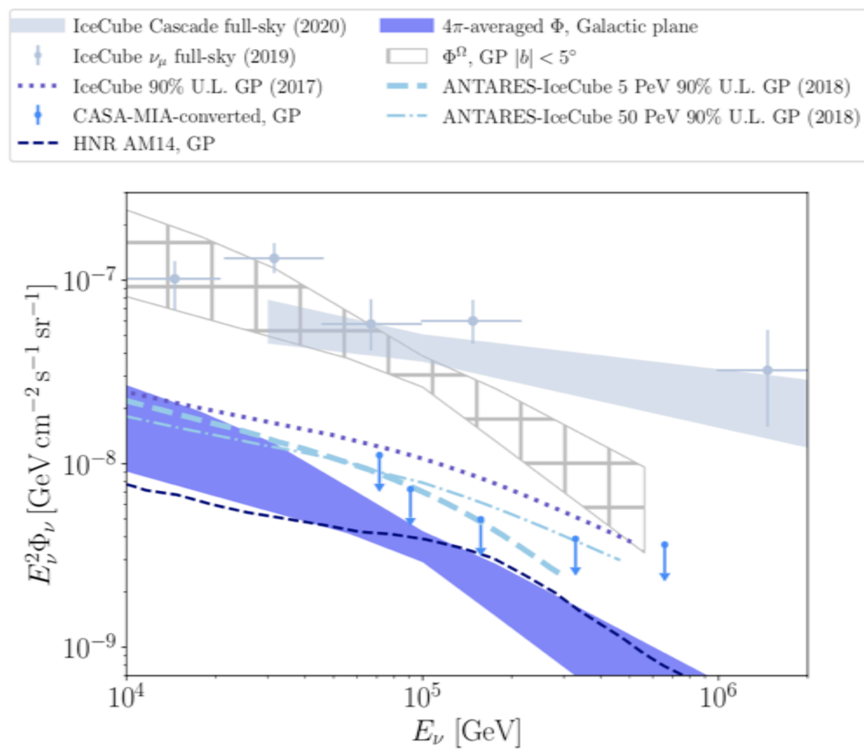
Galactic plane, low energy

Fang, Murase 2021

Can Gen2 help in the threshold region,
Eg galactic plane, below 60 TeV.

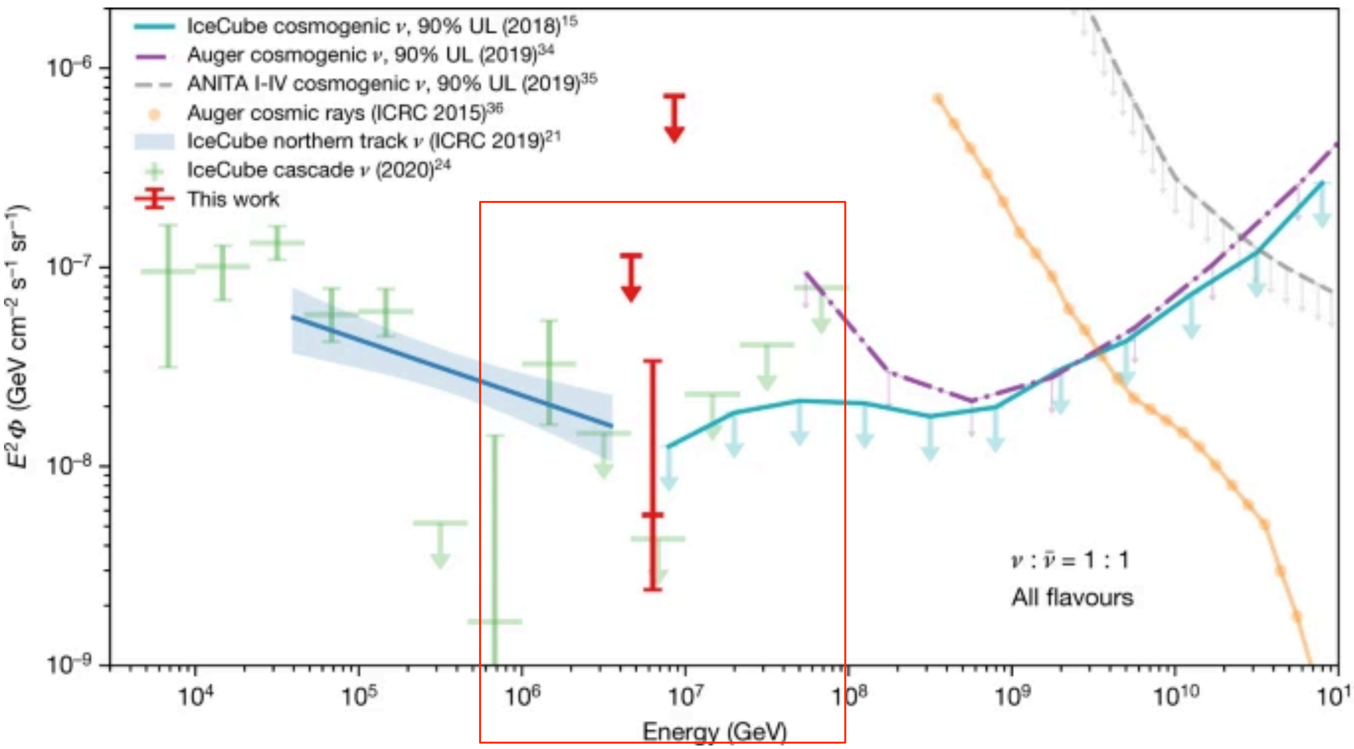
Probably not much.

(That energy range is, even below 30TeV remains important for point sources.(



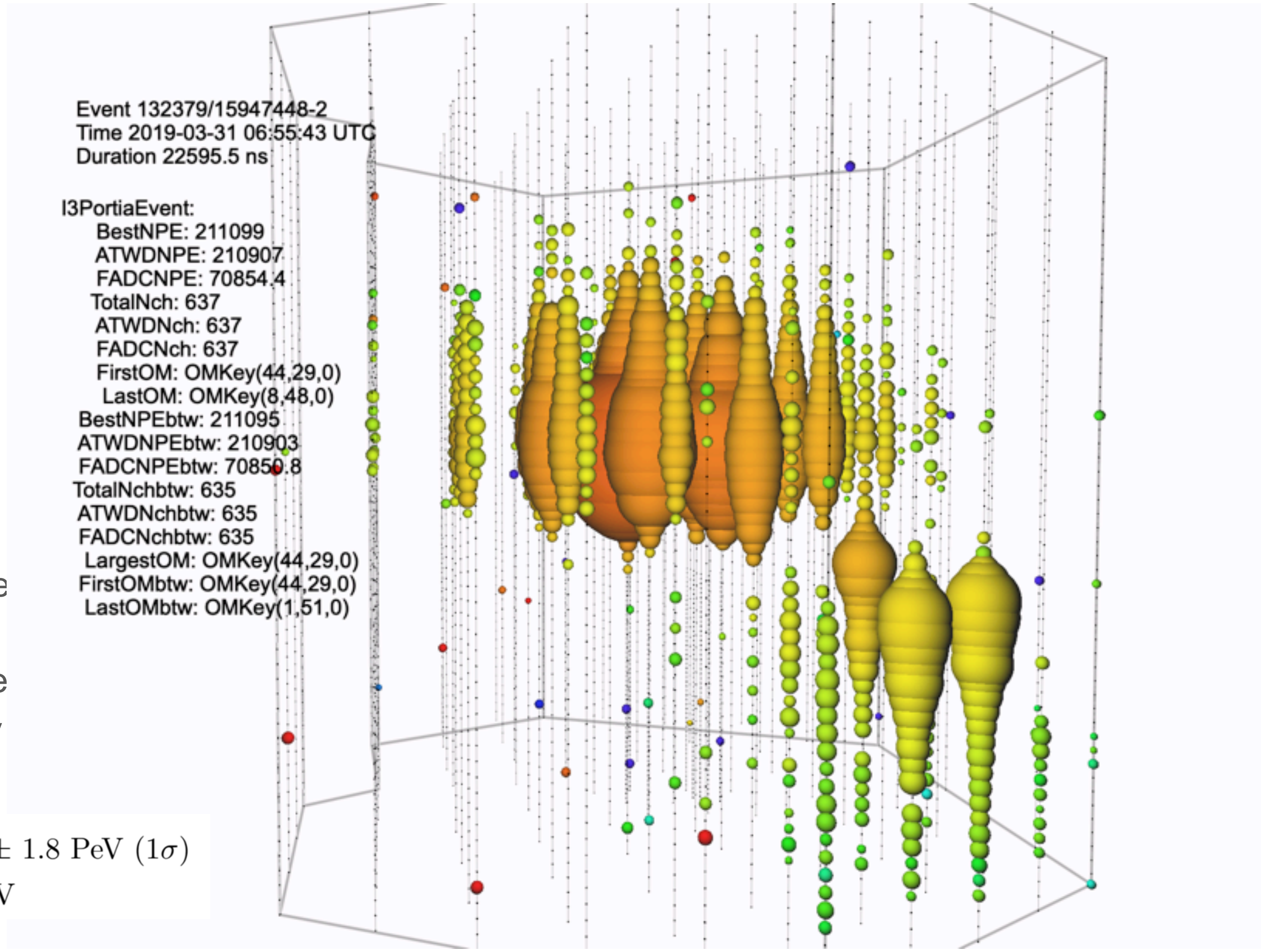
Flux beyond 10 pev

Do PeV neutrinos share the same origin with UHECR?



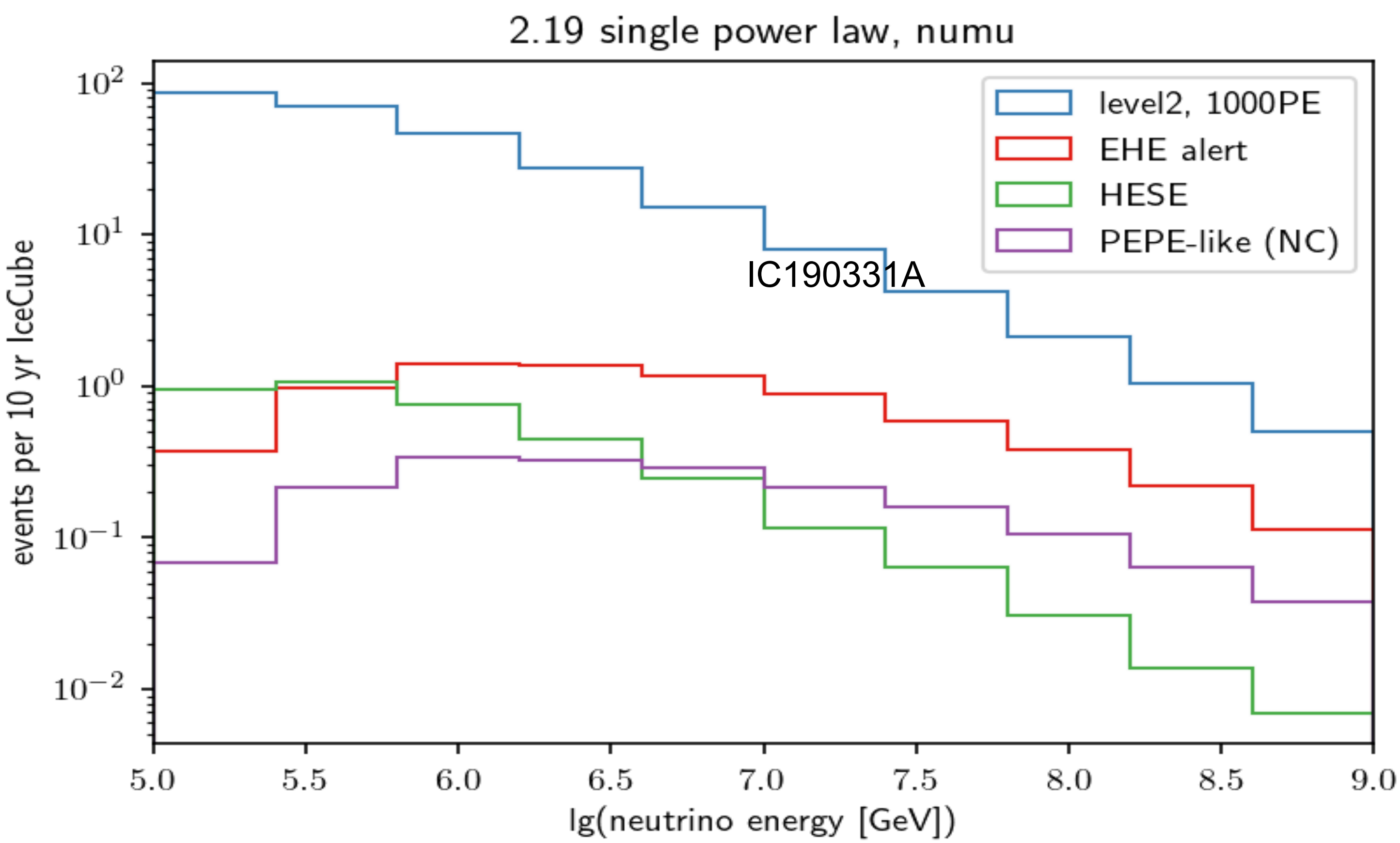
The highest neutrino energy event

- Starting track
- ~10PeV (5 PeV deposited)
- We know the spectrum continue over 10 PeV but they will mostly be from southern sky



Random forest result: 12.7 ± 1.8 PeV (1σ)

Agrees with Mirco's 13.6 PeV


2.19 single power law, numu
level2, 1000PE
EHE alert
HESE
PEPE-like (NC)
IC190331A
events per 10 yr IceCube
10^2
10^1
10^0
10^{-1}
10^{-2}
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
lg(neutrino energy [GeV])

Zen 69-90

Dummy estimate of event rate (CC numu)

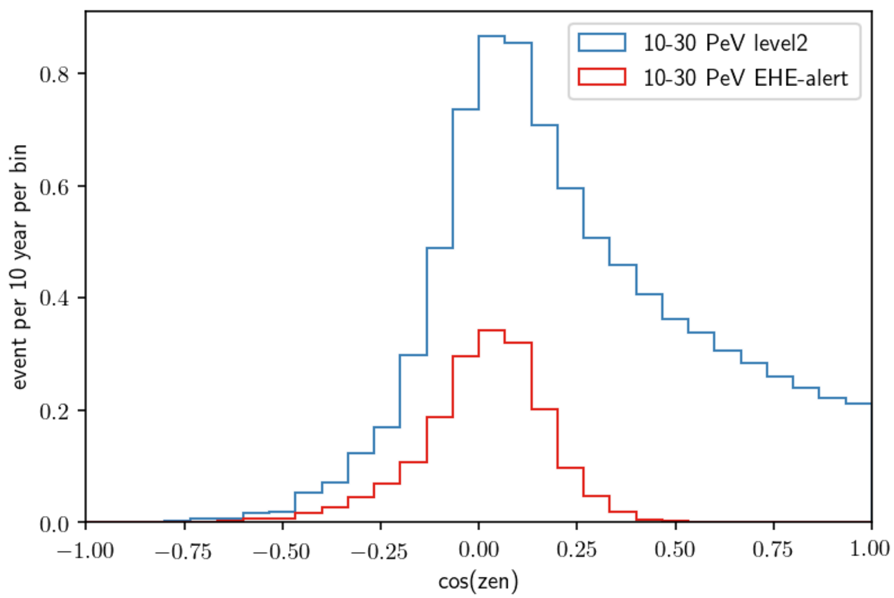


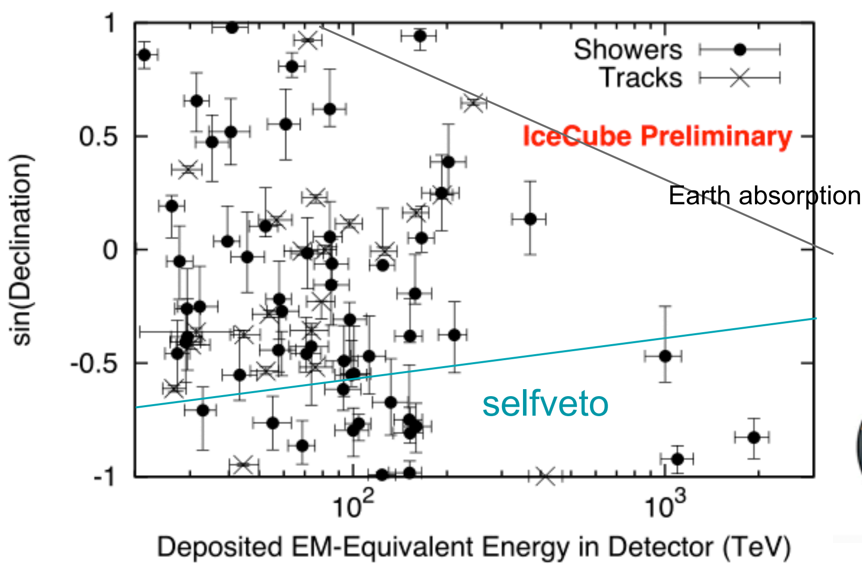
Table below shows 10 yrs expected in IceCube at the final event selection level

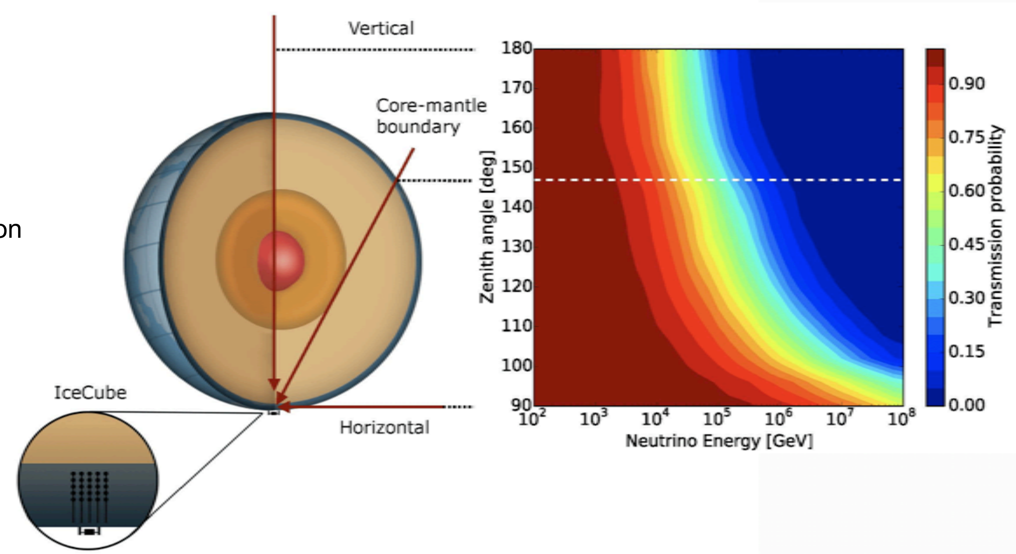
10yrs IceCube 10-30 PeV	EHE alert (2.89)	EHE alert (2.49)	EHE alert (2.19)
Vertical (0-48 deg)	0	0	0.0004
Middle (48-70 deg)	0.002	0.01	0.03
Horizontal (70-90 deg)	0.06	0.5	1
sum	0.06	0.51	1.03

If CR background-> CR energy ~100 x mu at EeVs

Rate is low if assuming continued powerlaw. But any knowledge of beyond 10 PeV would be new and connecting to UHE

Earth absorption for the highest energy
Self-veto boosts signal purity from southern sky

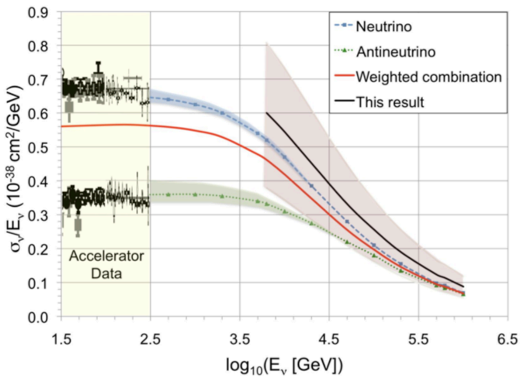




Neutrino physics, cross section

Slide from A. Connolly
(Gen2 radio review in Feb.)

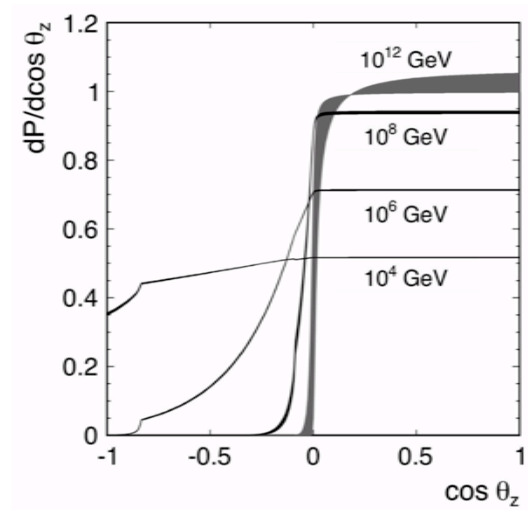
Nature 551 (2017) 596-600



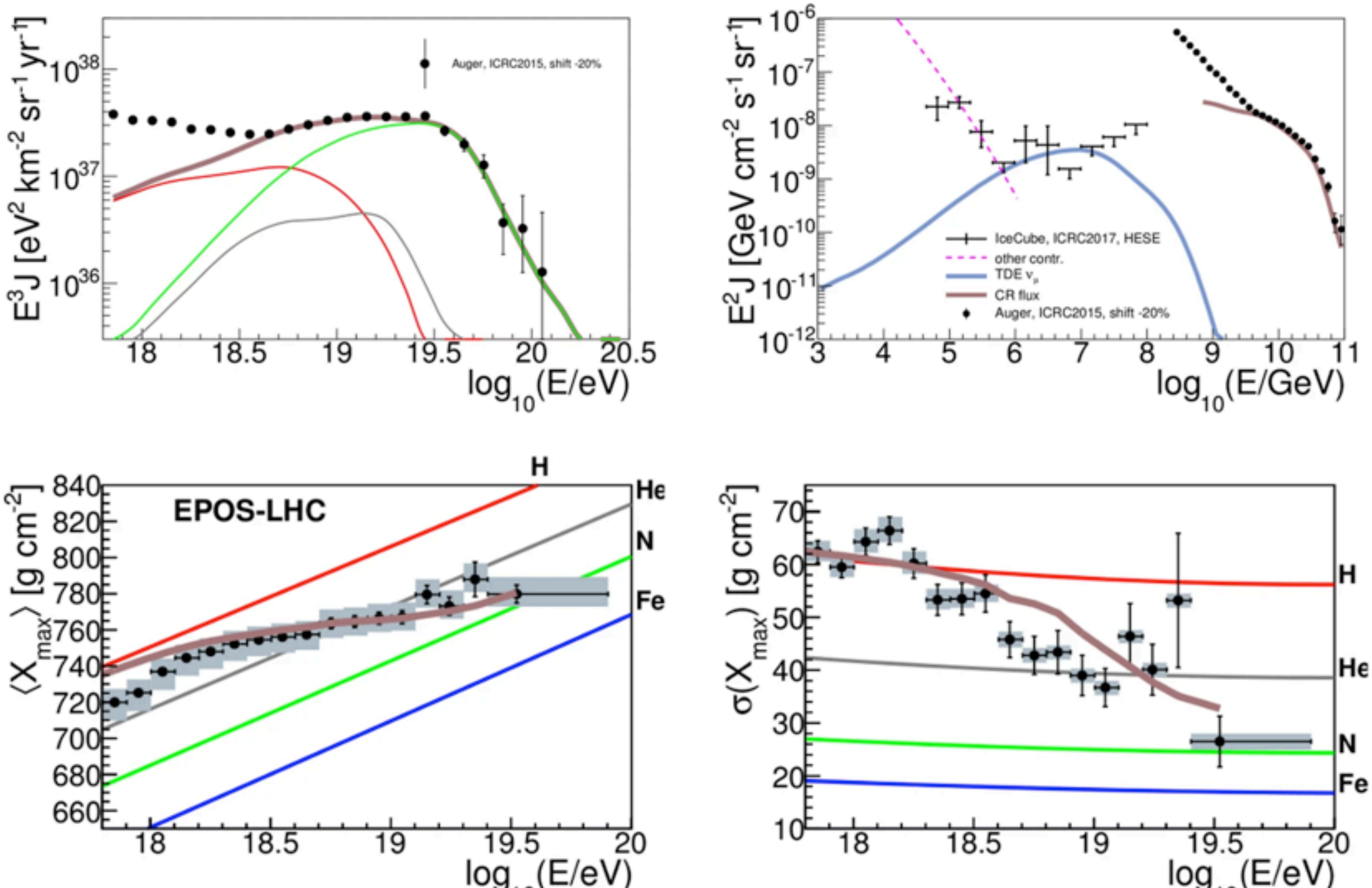
νN cross sections

- Statistics-dominated uncertainties on cross sections until we have ~50 UHE neutrino events
- Even for a detector at our target sensitivity, we don't expect to reach this regime.
- Until then, measurements will improve by ~√N

ICECUBE GEN2



Phys.Rev.D 83 (2011) 113009



TDE as common origin of UHECR and nu

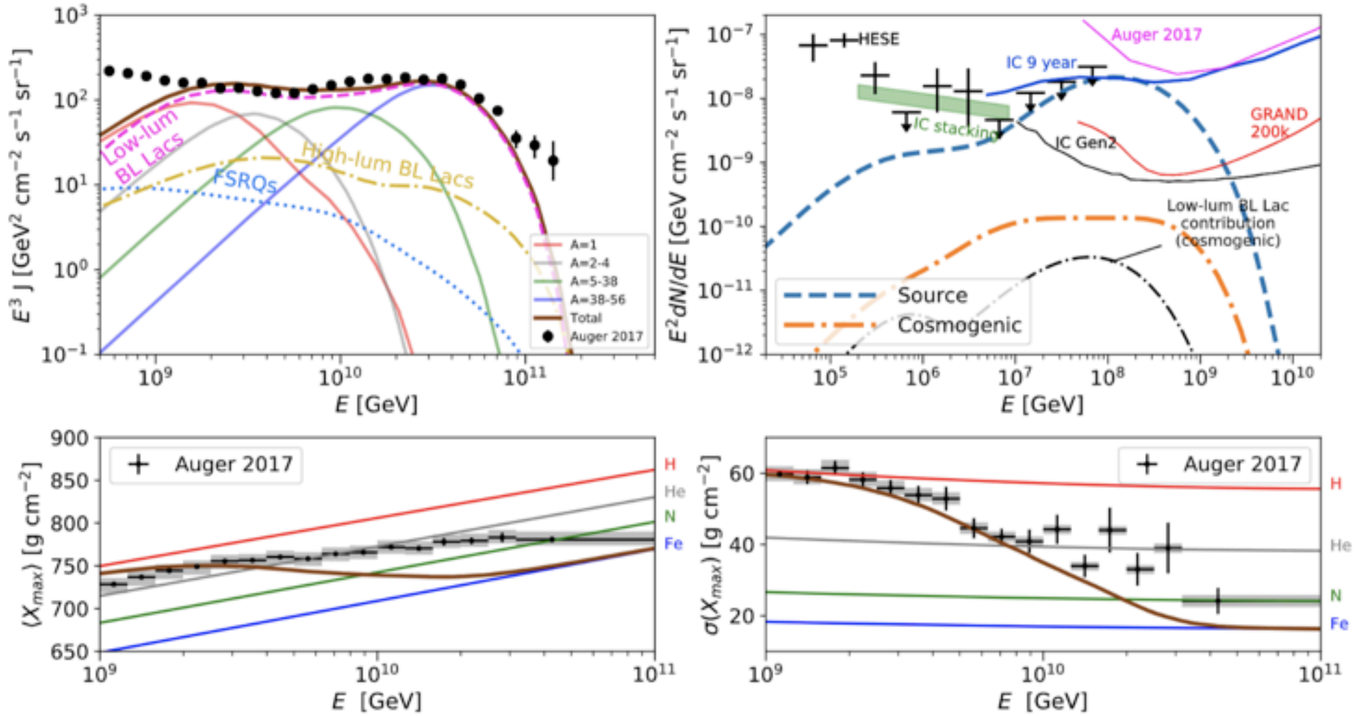
Winter et.al., Tidally disrupted stars as a possible origin of both cosmic rays and neutrinos at the highest energies. *Sci Rep* 8, 10828 (2018).

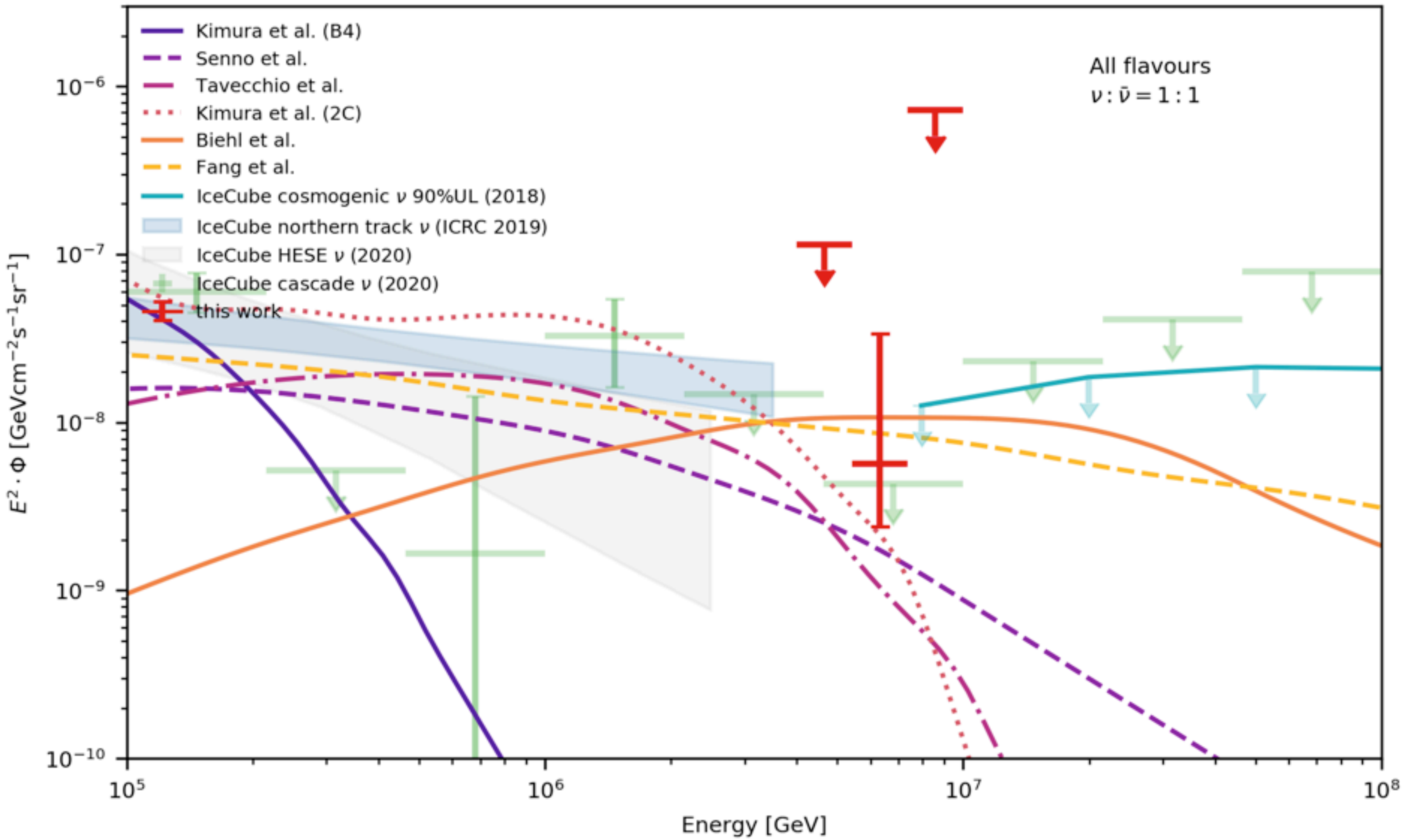
UHECRs and neutrinos from AGN

Results

- Low-lum. BL Lacs dominate the UHECR spectrum
- Light UHECRs from FSRQs improve composition
- FSRQ source neutrinos dominate neutrino flux
- **Source neutrinos can outshine cosmogenic neutrinos**

X. Rodrigues, J. Heinze, A. Palladino, AvV and W. Winter, arXiv:2003.08392, accepted for publication in PRL





Kimura et al. (B4)
Senno et al.
Tavecchio et al.
Kimura et al. (2C)
Biehl et al.
Fang et al.
IceCube cosmogenic ν 90%UL (2018)
IceCube northern track ν (ICRC 2019)
IceCube HESE ν (2020)
IceCube cascade ν (2020)
this work
All flavours
ν : ν̄ = 1 : 1
$E^2 \cdot \Phi$ [GeVcm^{-2}s^{-1}sr^{-1}]
Energy [GeV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^5
10^6
10^7
10^8

Using high-energy neutrinos as magnetometers

If sources have strong magnetic fields, charged particles cool via synchrotron:

Proton cooling

Induce a high-energy cut-off in the emitted ν spectrum:

$$E_\nu'^2 \frac{dN_\nu}{dE_\nu'} \propto E_\nu'^{2-\alpha_\nu} e^{-E_\nu'/E_\nu'^{\max}}$$

$$E_\nu^{\max} \approx \frac{10^{10}\Gamma \text{ GeV}}{\sqrt{B'/\text{G}}}$$

Muon cooling

Change flavor composition:

$$(f_{e,\text{S}}, f_{\mu,\text{S}}, f_{\tau,\text{S}}) = \begin{cases} (\frac{1}{3}, \frac{2}{3}, 0), & \text{if } E_\nu < E_{\nu,\mu}^{\text{sync}} \\ (0, 1, 0), & \text{if } E_\nu \geq E_{\nu,\mu}^{\text{sync}} \end{cases}$$

$$E_{\nu,\mu}^{\text{sync}} \approx 10^9 \Gamma \frac{\text{G}}{B'} \text{ GeV}$$

$$p + \gamma(p) \rightarrow \pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \hookrightarrow \bar{\nu}_\mu + e^+ + \nu_e$$

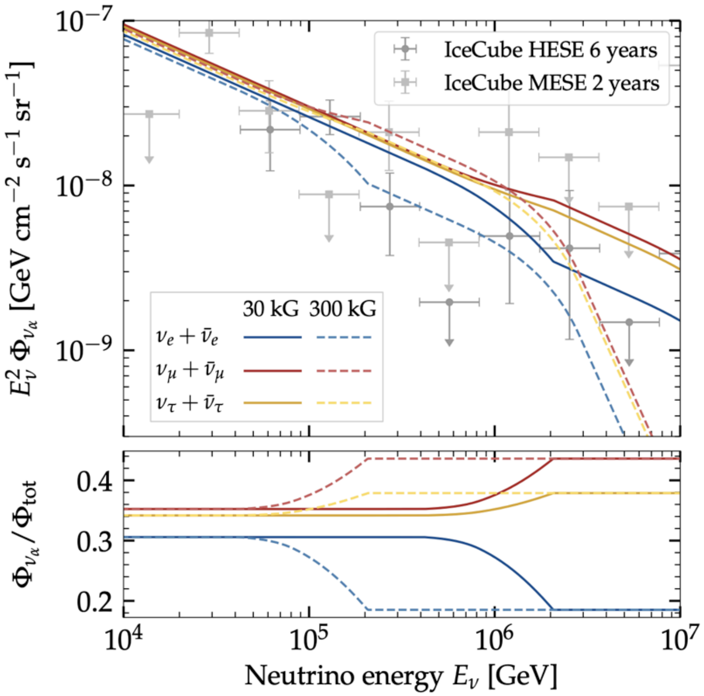
Pion cooling

Steepen the ν spectrum: $\alpha_\nu = \begin{cases} \gamma, & \text{if } E_\nu < E_{\nu,\pi}^{\text{sync}} \\ \gamma + 2, & \text{if } E_\nu \geq E_{\nu,\pi}^{\text{sync}} \end{cases}$

$$E_{\nu,\pi}^{\text{sync}} \approx 10^{10} \Gamma \frac{\text{G}}{B'} \text{ GeV}$$

MB, Tamborra, *PRD* 2020
See also: Winter, *PRD* 2013

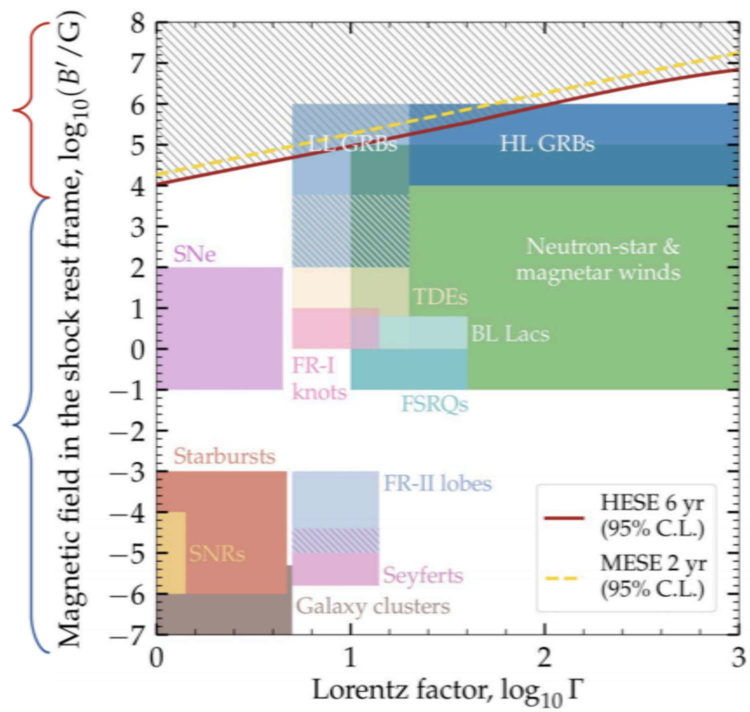
https://arxiv.org/pdf/2009.01306.pdf



MB, Tamborra, *PRD* 2020
See also: Winter, *PRD* 2013

ν sources with strong B' are likely not dominant

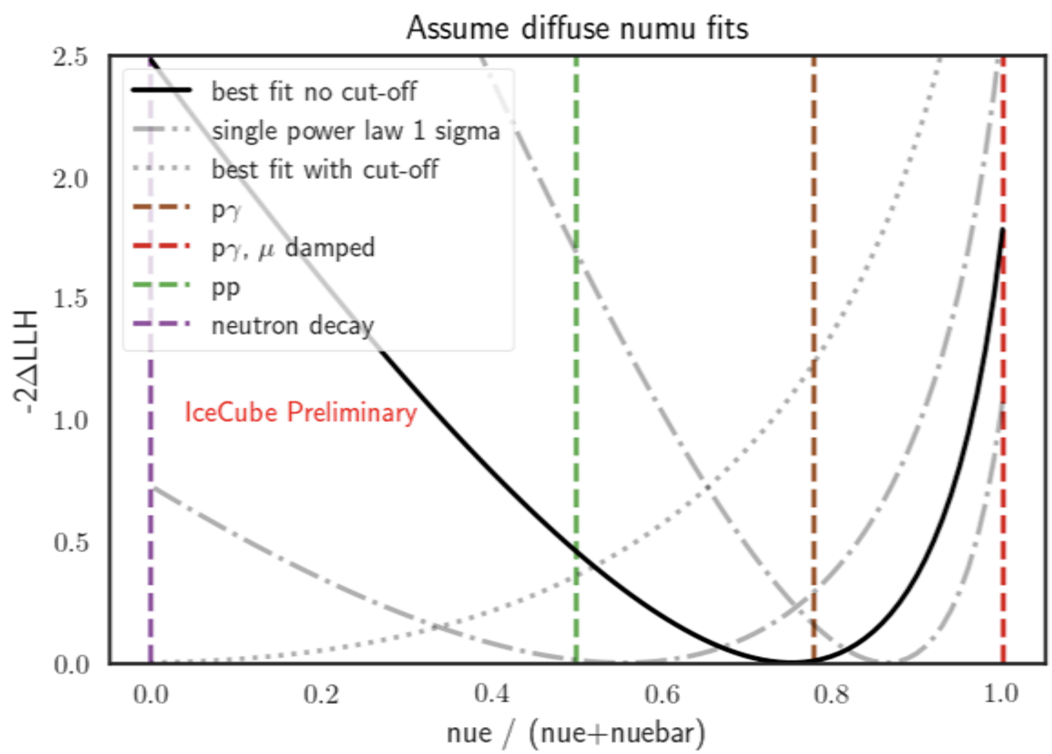
Average B' must be < 10kG–10 MG



Pp:pgamma via the Glashow resonance

γ_{astro}	2.28	2.49	2.89
Φ_{astro}	4.32	7.0	6.45
PEPE *pp*	2.27	1.55	0.28
HESE *pp*	1.15	0.79	0.14
PEPE *pγ*	1.01	0.69	0.12
HESE *pγ*	0.51	0.35	0.06

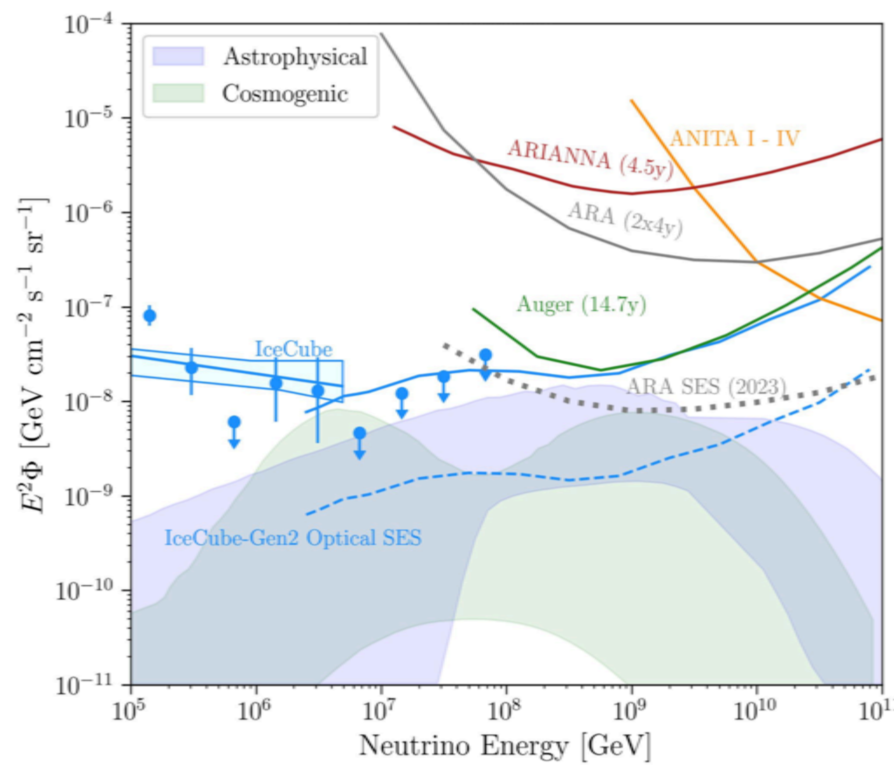
Need to have good knowledge on astro gamma and norm



Gen2 requirements

Gen2 optical and radio

Note:
Sensititivity shown is “Single Event Sensitivity”.
It is basically the sensitivity where in 50% of the cases one event would be seen.
A conventional sensitivity, or upper limit would be a factor of ~4 higher.

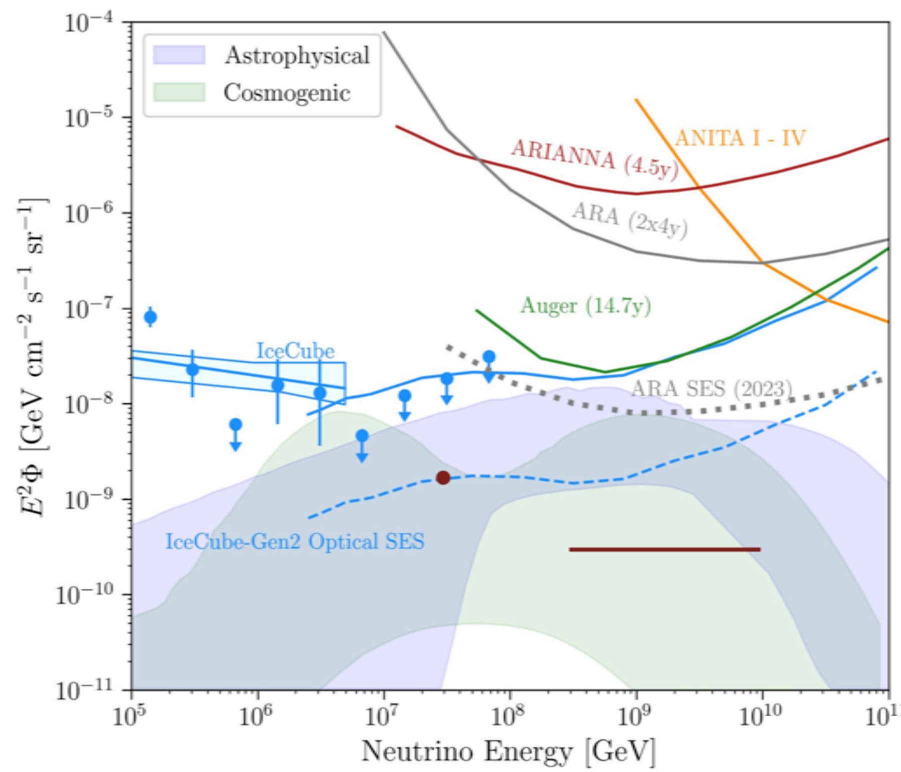


Gen2 capabilities

Radio:

Gen2 optical

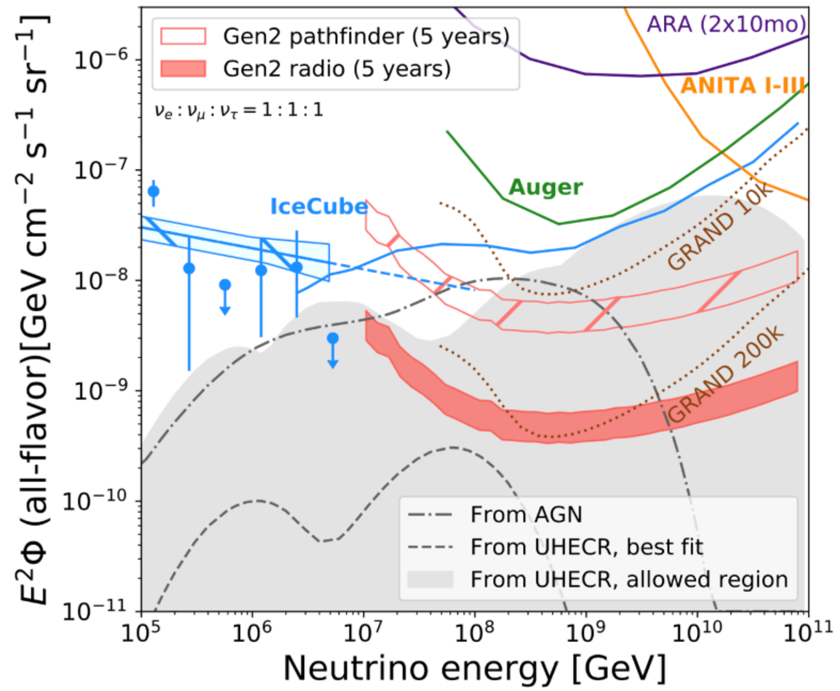
- Requirements:
  - $E^2\Phi = 3\times10^{-10}$ GeV/cm^2/s/str from $10^{17.5}$ to 10^{19} eV
  - Discovery phase: <0.1 background in optimized search
  - Once flux is established: 90% purity
  - Neutrino energies to factor of 3



Gen2 capabilities

Radio:

Gen2 optical



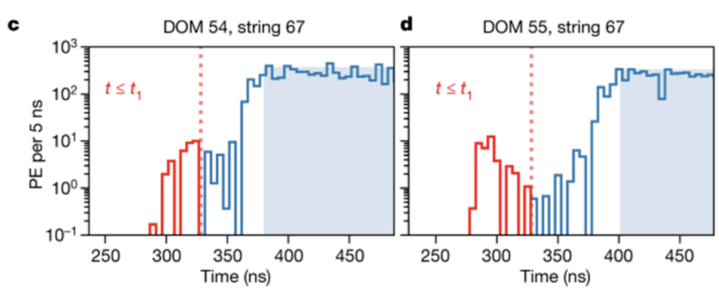
Hadronic cascade and multi-sensor pmt

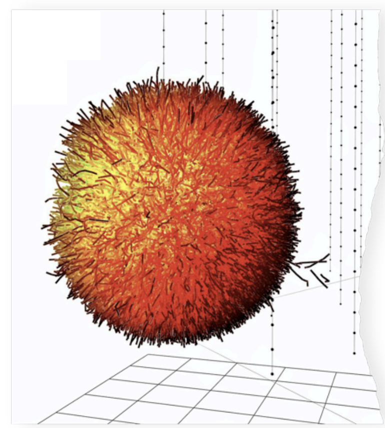
Large string spacing -> do we still see early muon pulses from hadronic cascades?

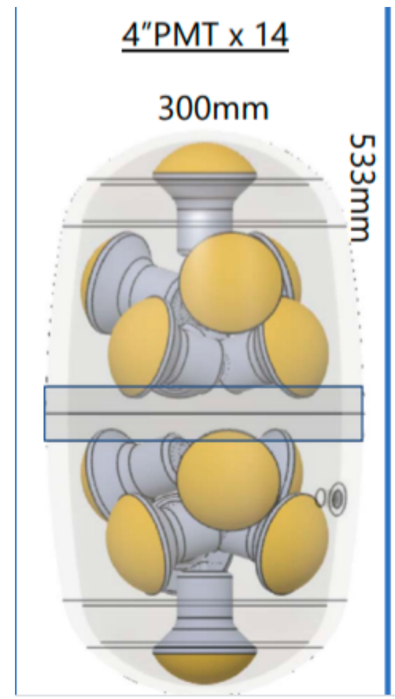
Does multipmt improve muon bundle/leading muon reconstruction?

Much higher dynamic range

(small PMTs with dynode readout added)!







Do we need optimisation for

- Cascade energy resolution
- Veto
- Cascade direction resolution?
- Tau double pulse
- Hadronic cascade early muon
- 10 pev+ flux (southern muon? Partially contained cascades? Contained should be fine)

Specific questions near term:

Thanks to Markus Ackermann for input.

- - calibration / calibration devices needs:
  - What is the energy and angular resolution needed for cascades/taus for diffuse analysis (and related bsm work) ? How does this break down into requirements on position/ orientation/light yield/ice model calibration ?
  - Do we need specific light sources/calibration modules for diffuse analysis ?
- - Reconstruction:
  - influence of mDOMs on cascade reconstruction (angular resolution/vertex/energy) and tau identification.
  - For tau: should be benefitial both double bang and double pulse reco
- - physics: flavor constraints based on realistic estimate of tau identification efficiency, energy thresholds (for tau/cascades).

Diffuse simulation needs:

For proposal preparations and preliminary design review and such.

- Assume Phase 2 can be retriggered Gen2
- What configuration, etc,
  - How does string spacing and DOM density affect diffuse science goals?
  - How to deal with systematics of hole ice. Related: do we need the degassing? (point sources may be the driver on these questions.
  - Do we need to decide on a Gen2 reference design for simulations?
- Requirements (simulation group has started), here question on what needs for diffuse
  - Background, how much life time
    - need also Corsika at least in the threshold region (which is big) for trigger studies
    - For background rejection studies, mu-gun probably the choice?
  - Signal
  - Do we need to bother with systematics for diffuse at this stage?