



Vrije Universiteit Brussel



IceCube Gen2

Krijn D. de Vries
IIHE/VUB

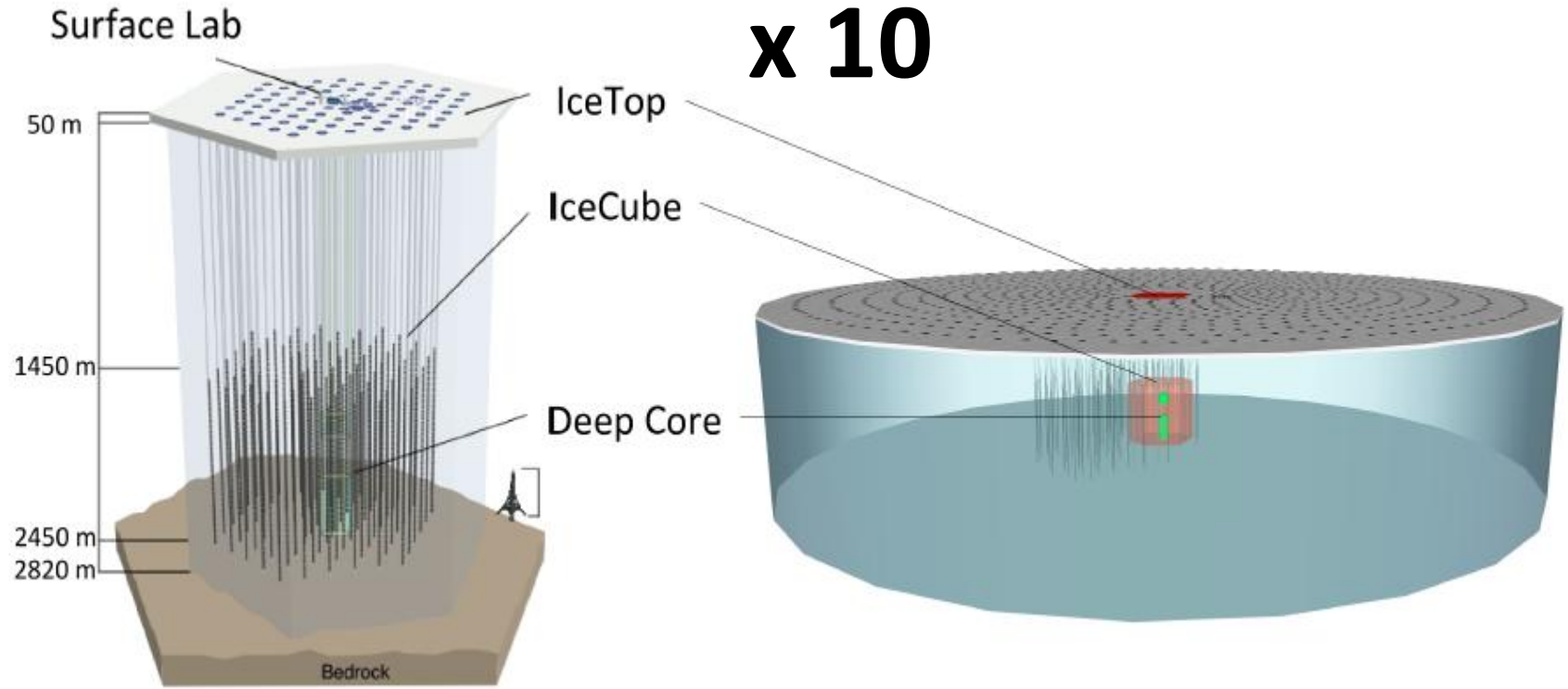


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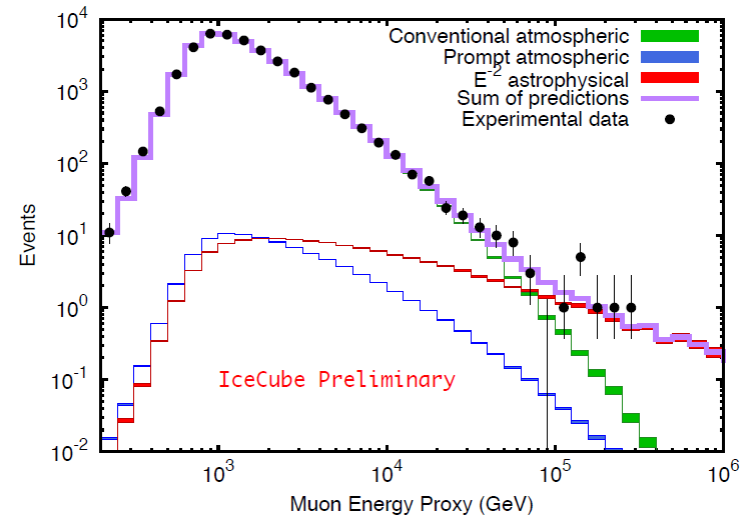
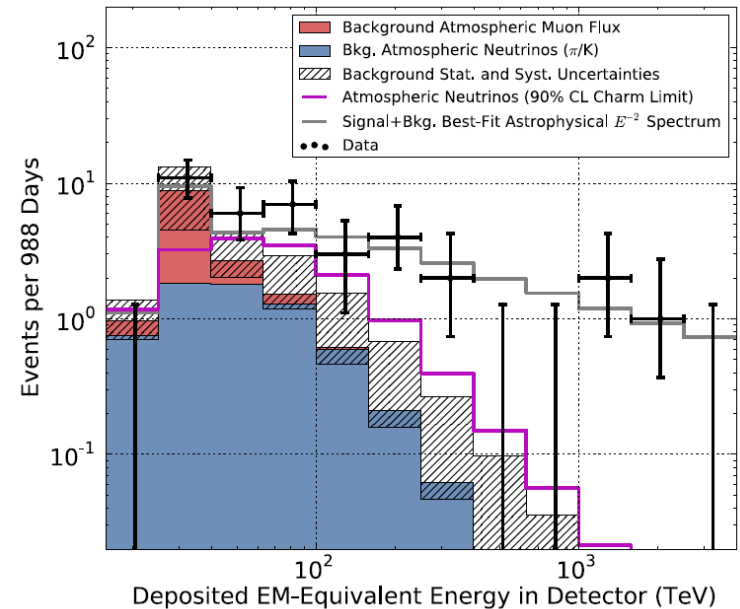


IceCube: Astrophysics

- Diffuse astrophysical neutrino flux has been detected.
- 10-20 events per year with $E > 30$ TeV
- Measured flux exceptionally high \rightarrow Large hadronic component in HE universe.
- Close to the Waxman-Bahcall bound:

$$E_\nu^2 \frac{dN}{dE_\nu} = 2.9 \times 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

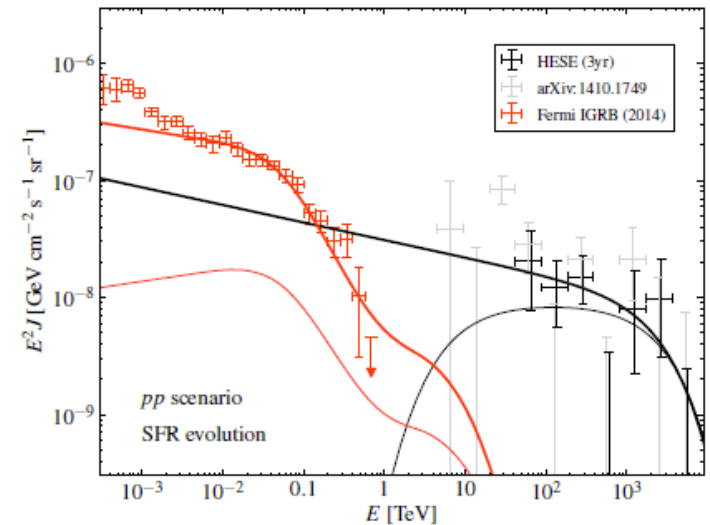
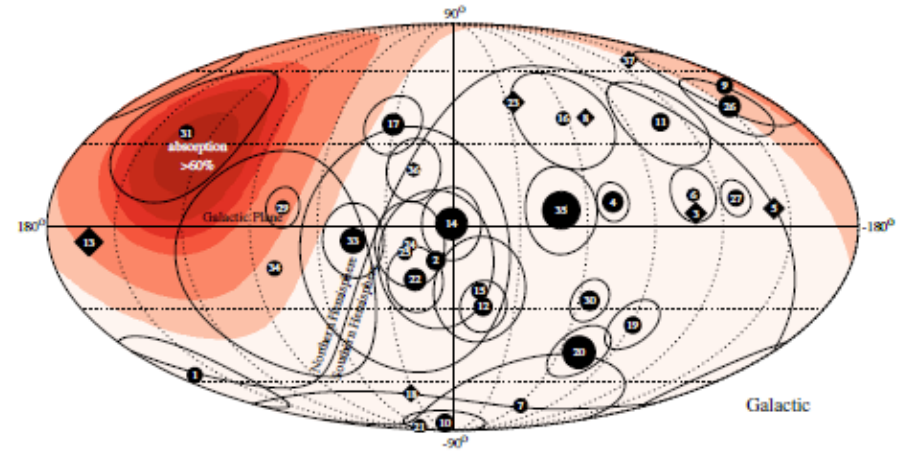
- Spectral index (single power law): 2.0-2.6
> 10 TeV best fit: 2.43
- Consistent with 1:1:1 flavor ratio.
- No events > 3 PeV (no GZK events seen yet, several expected)





IceCube: Astrophysics

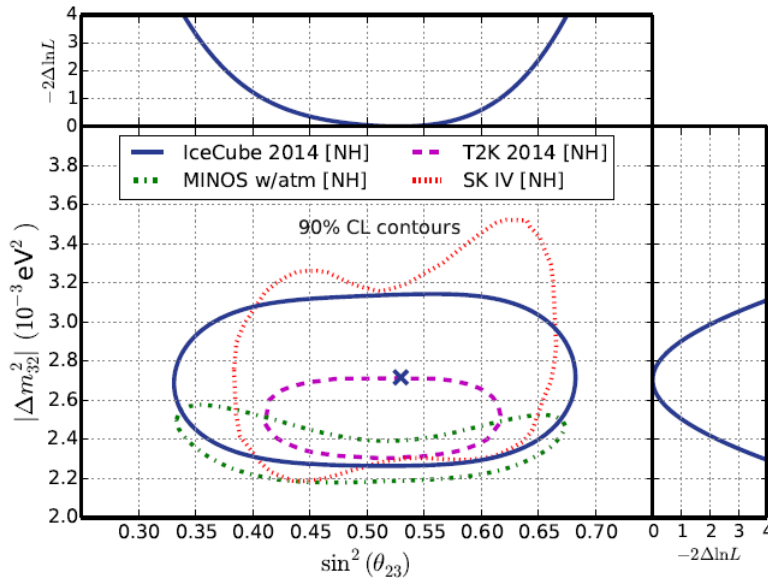
- No point-source detected yet.
- Correlation with galactic center not significant. Best fit at 7.5 degrees around galactic center gives post-trial chance probability 2.8%.
- GRB's highly constrained as only sources of UHECRs.
- Single source hypothesis highly disfavored.
- Flux consistent with Fermi Gamma-Ray flux.



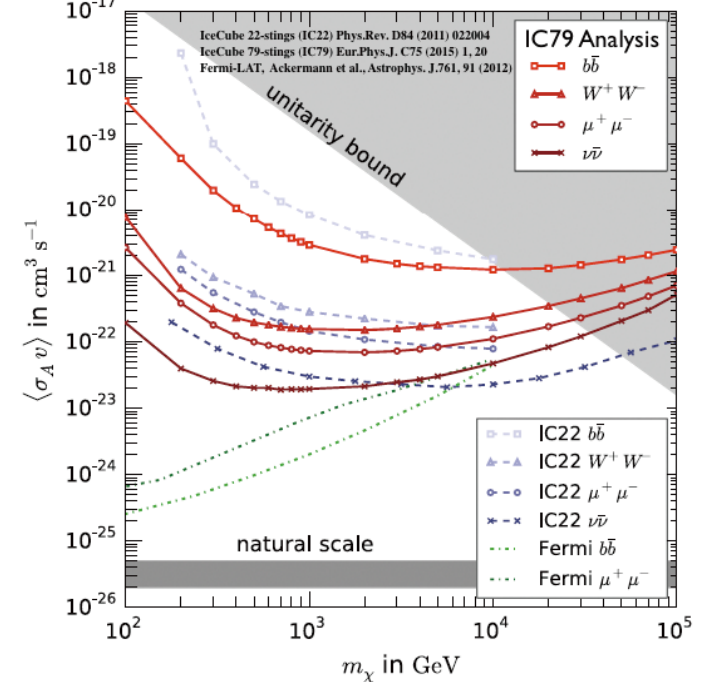


IceCube: DM + Neutrino physics

- Using the Deep Core extension, strong limits on the spin-(in)elastic WIMP cross-sections and annihilation rates have been set.



C. Rott AAPPs Vol 25 No 3



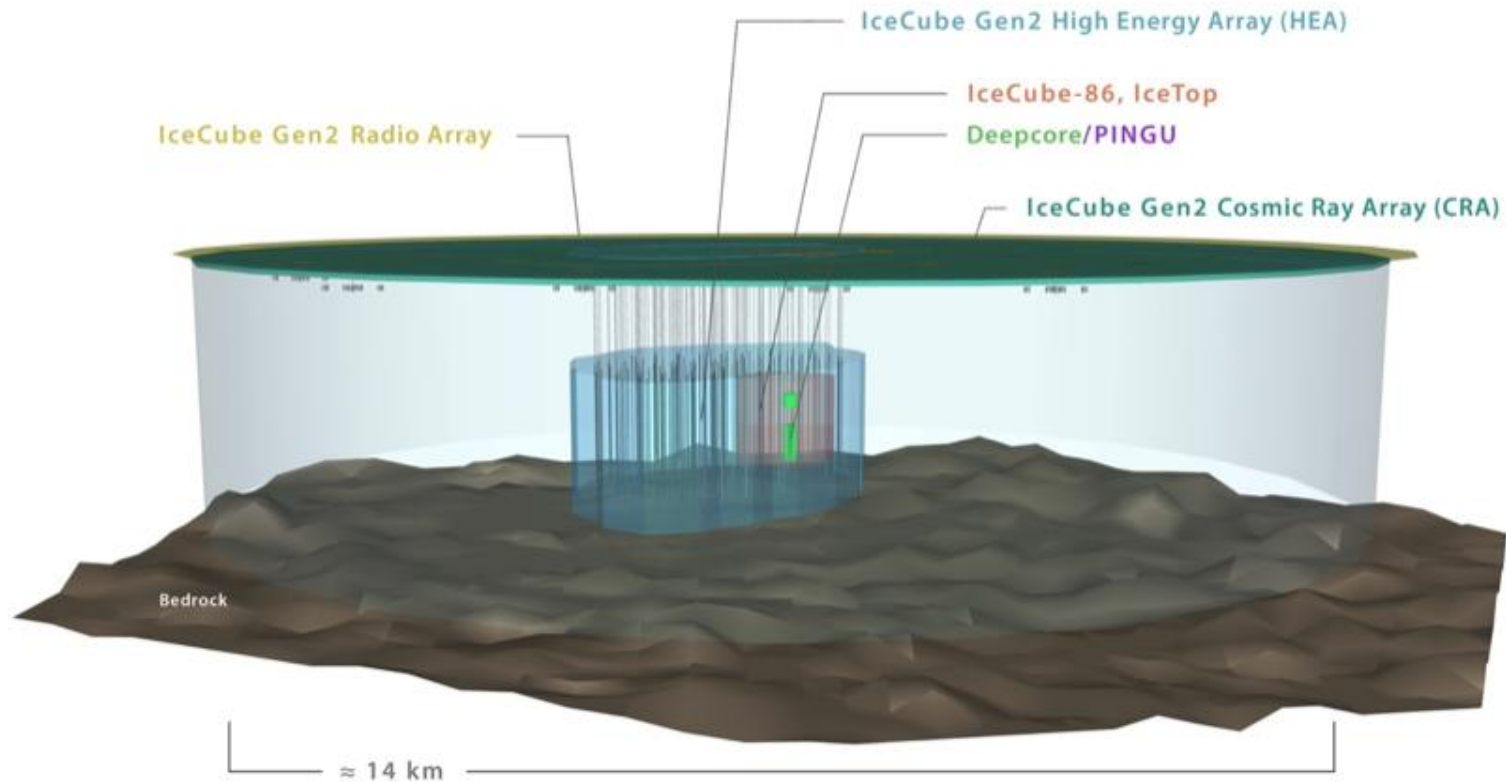
- Oscillation parameters have been determined with high precision

Phys. Rev. D 91, 072004 (2015)



IceCube: Gen2

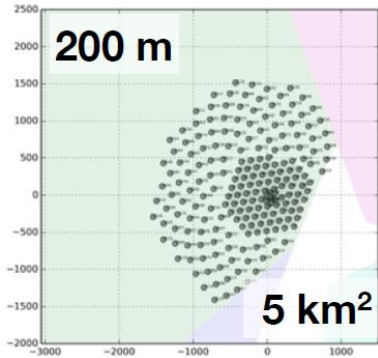
The IceCube Gen2 Facility





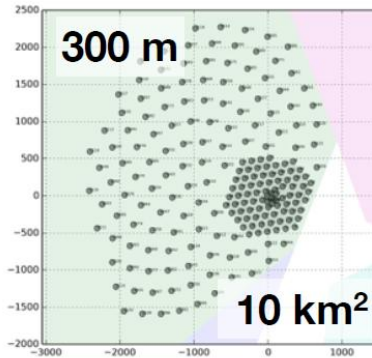
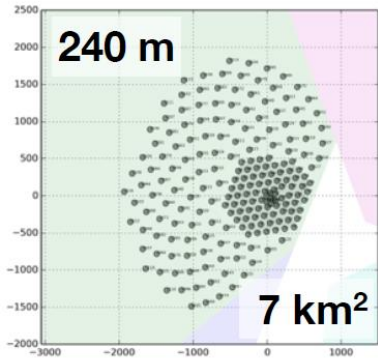
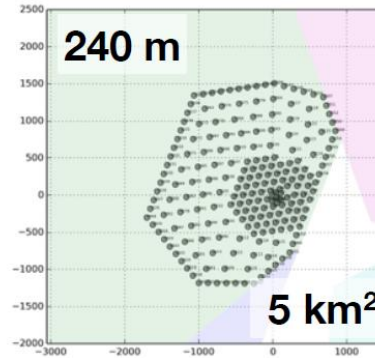
IceCube: Gen2

Sunflower

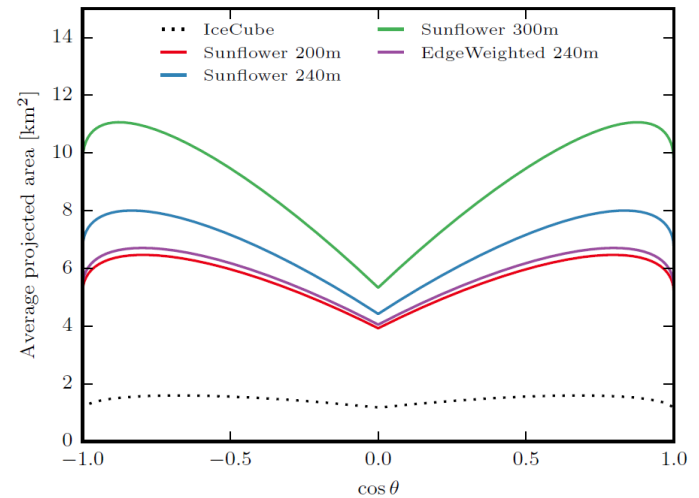


- ▶ 122-125 strings
- ▶ 80 DOMs per string

Edge-weighted



$$A_{\text{eff}}(E_{\mu}, \theta) = A_{\text{geo}}(\theta) \cdot \epsilon(E_{\mu}, \theta)$$



Jakob van Santen - Gen2 sensitivity

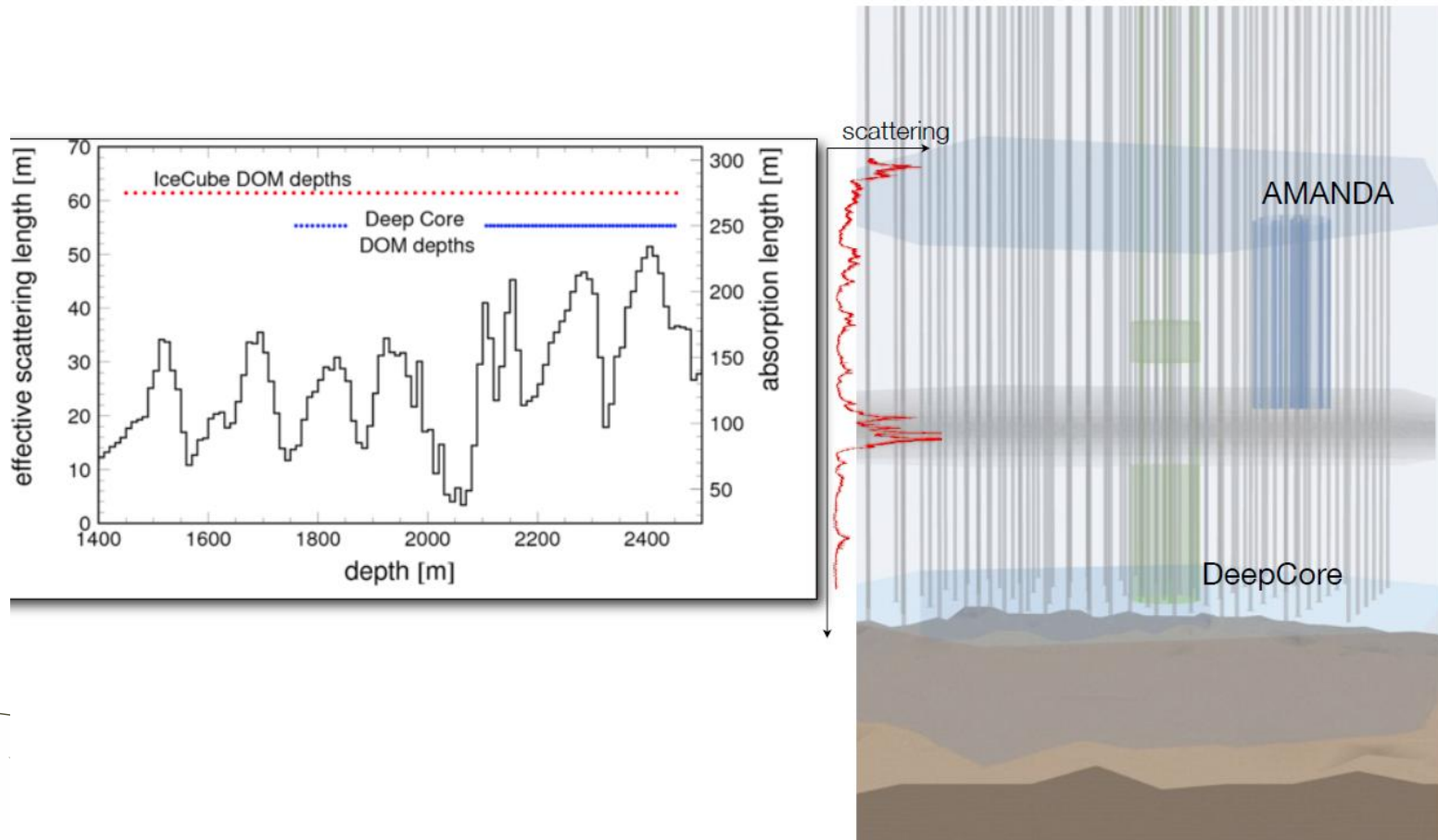


IceCube: Gen2 proposal

What makes Gen2 possible?

Extremely clear ice gives very long absorption length and little scattering.
String spacing can be enlarged -> IceCube x 10 for the same price!

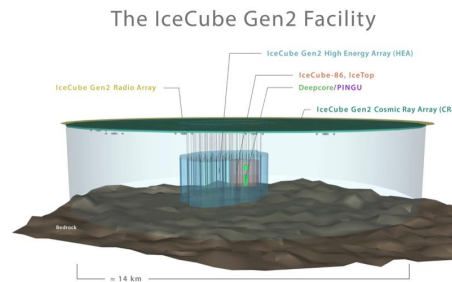
Plot from D.Jason Kosinen



IceCube: Gen2

What will the LE extension give us:

- High sensitivity to physics associated with the neutrino mass
- High sensitivity to physics associated with the nature of dark matter
 - “Dream signal” -> Galactic Supernova



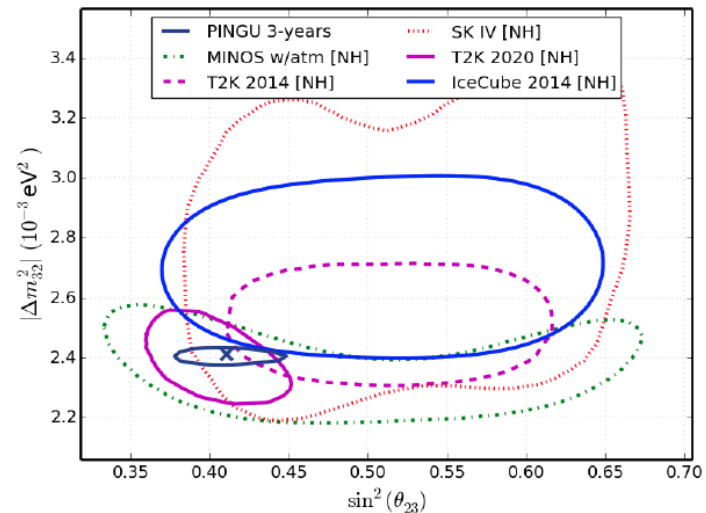
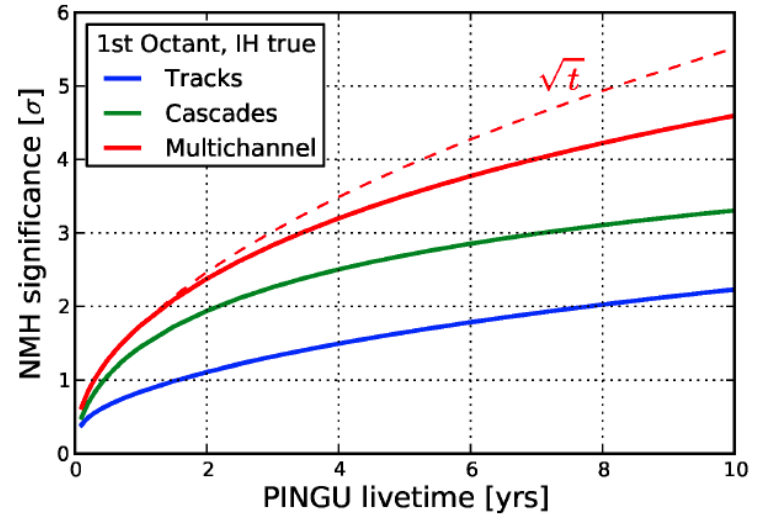
What will Gen2 HE extension give us:

- Sensitivity to astrophysical neutrinos at extreme energies $> \text{PeV}$
 - High statistics of astrophysical neutrinos of all flavors.
 - Detailed spectral studies
 - Significant point-source discoveries
 - New discoveries
- Detailed Cosmic ray composition at the ankle through surface array



IceCube: Gen2 LE extension

- Detailed simulations show a sensitivity to the neutrino mass hierarchy of 3 sigma in 5 years.
- Sensitivity to make a world-class measurement of neutrino oscillation parameters.





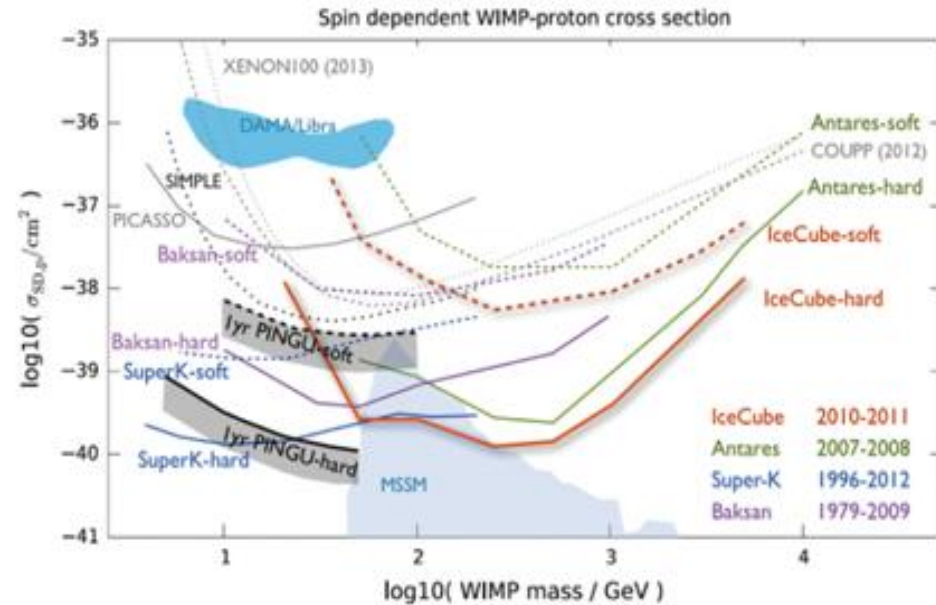
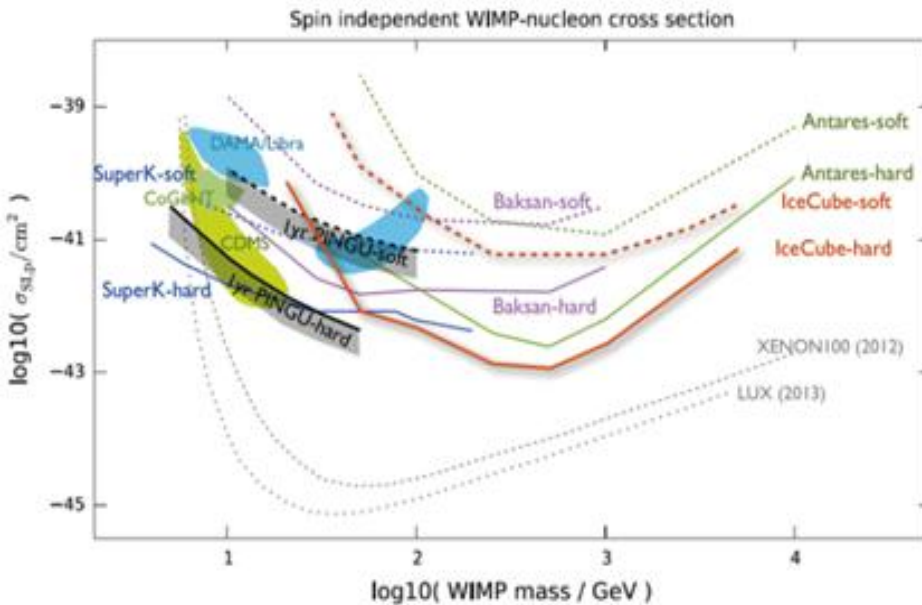
IceCube: Gen2 LE extension

- DM sensitivity expected down to

$$M_{\chi} = 5 \text{ GeV}$$

- Expected upper limit on annihilation rate at 5 GeV:

$$\langle \sigma_A v \rangle = 10^{-23} \text{ cm}^3 \text{ s}^{-1}$$

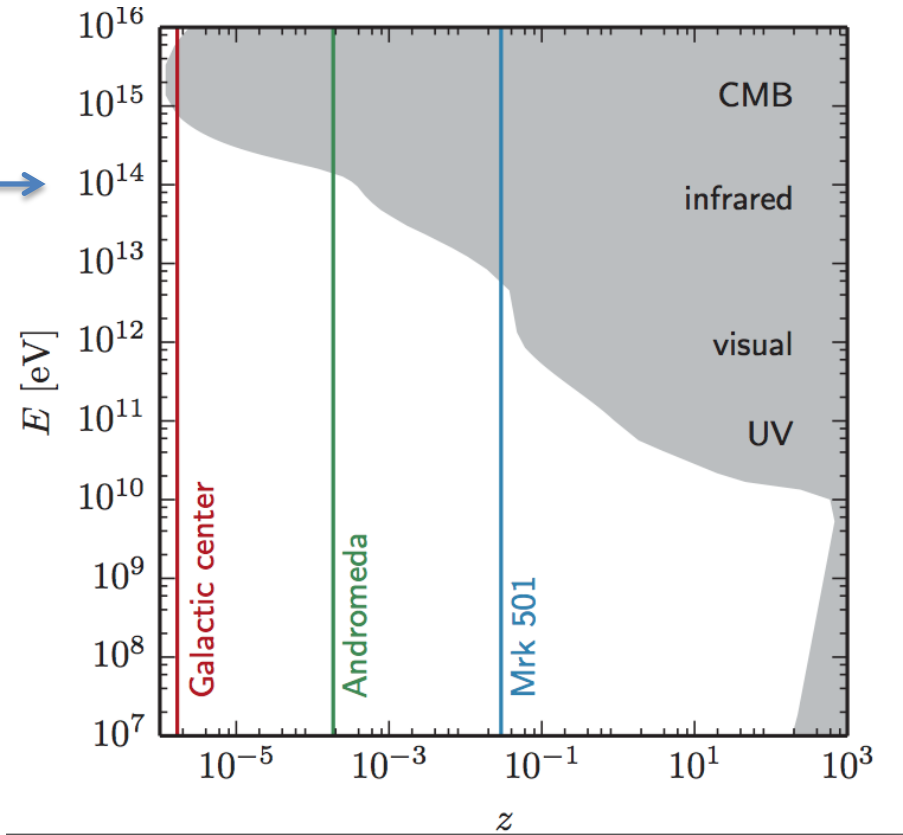
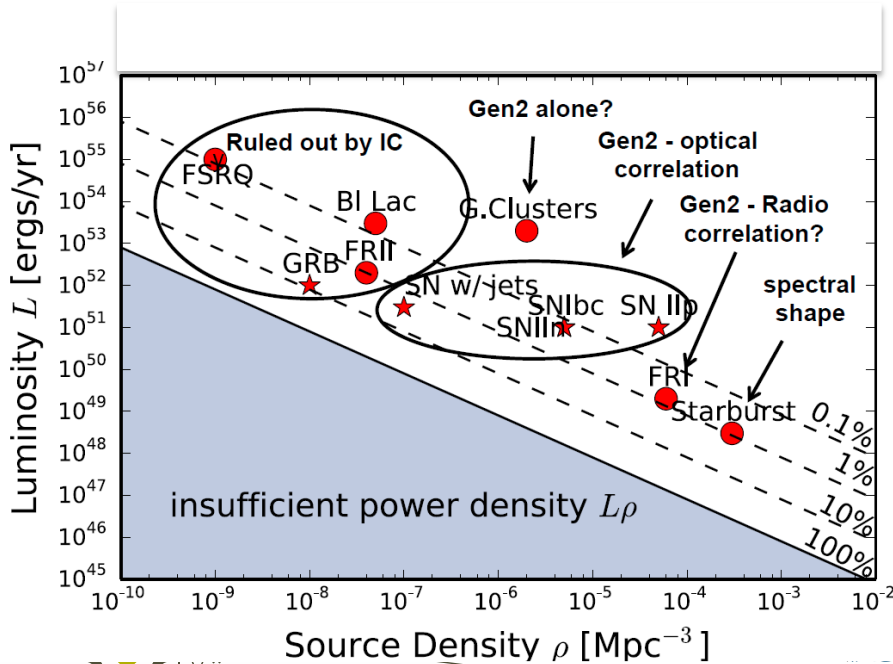


C. Rott, AAPPS Vol 25 No 3



IceCube: Gen2 HE extension

- Neutrino astronomy is the window to extragalactic astronomy above 100 TeV!
- What are the sources of our cosmic neutrinos?

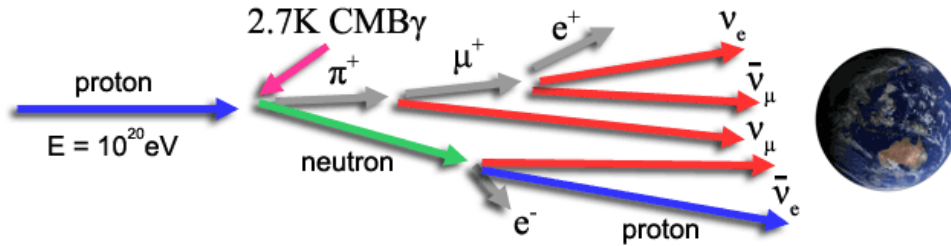


Multi-messenger era has started!!



IceCube: Gen2 HE extension

- GZK physics

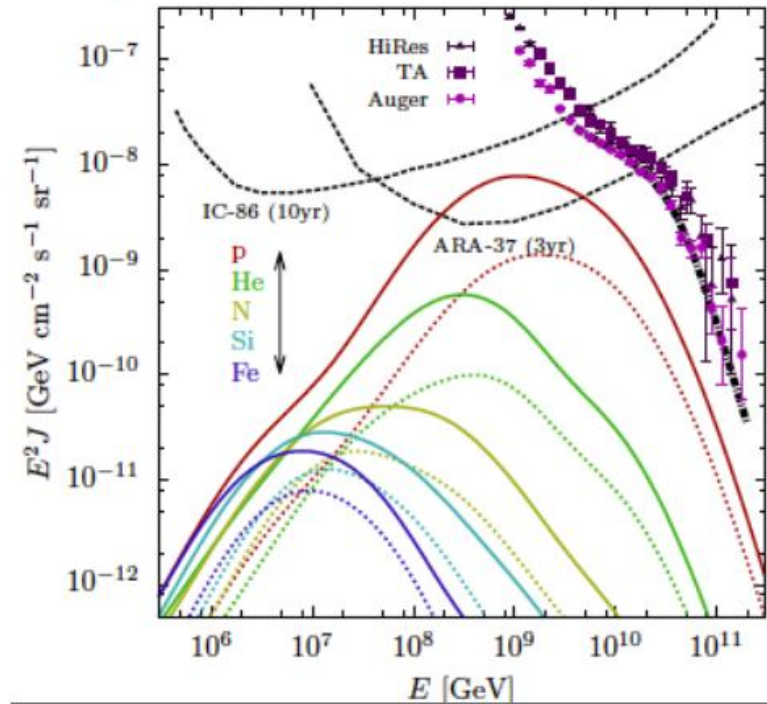


www.astroblogs.nl

- Cut-off observed by Auger & TA
Composition unclear. Do we see the GZK effect, or photodisintegration?

- Gen2 will provide a guaranteed observation if UHECRs are protons \rightarrow CR composition.

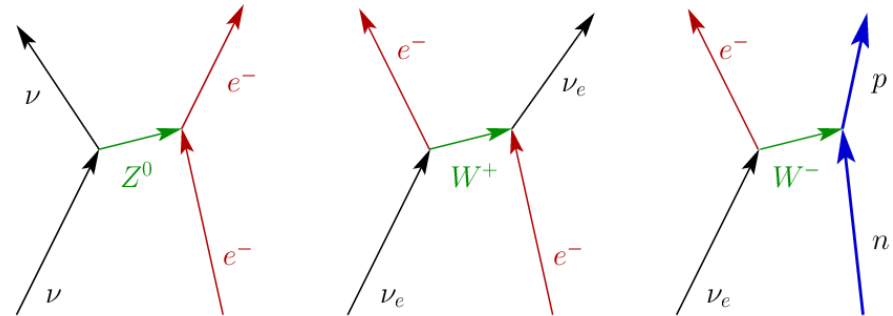
[Ahlers et al. Phys. Rev. D 86, 083010 (2012)]





IceCube: Gen2 HE extension

- Neutrino cross-section at ~ 100 TeV c.m.s. Testing the weak interaction at scales out of reach for terrestrial accelerators.



Neutral current

Charged current

- Glashow resonance \rightarrow Distinguish between photo- or hadro-production channel

$$\bar{\nu}_e e^- \rightarrow W^- \text{ (6.3 PeV resonance)}$$

$$pp \rightarrow \pi^+ \pi^- \text{ pairs} \rightarrow \bar{\nu}_e \nu_e 2\bar{\nu}_\mu 2\nu_\mu$$

$$p\gamma \rightarrow \pi^+ \text{ only} \rightarrow \nu_e \bar{\nu}_\mu \nu_\mu$$



IceCube: Gen2 status

Gen2 White Paper published on the arXiv: 1412.5106

Pingu Lol published on the arXiv: 1401.2046

NSF Major Research Equipment and Facilities Construction Proposal is aimed for.

Construction funding start in FY2017 or FY2018 is aimed for.

Funding applied for equivalent to IceCube funding.

Significant contribution from European IceCube partners expected.

Very tentative timeline:

FY	Strings installed	What?
2018		Construction starts. Instrumentation Procurement, Drill Design
2019		Instrumentation Production, Drill finishes design
2020	8	Full production
2021	16	Full production - PINGU Operations start
2022	18	Full production - PINGU Complete
2023	20	Full production
2024	20	Full production
2025	20	Instrumentation production finishes. Last Pole shipments.
2026	20	Marching Deploy army
2027	14	Marching Deploy army. Shutdown.



IceCube: Gen2 Belgium

Until funding is applied by NSF the contribution of Belgium groups to the IceCube Gen2 project is restricted.

Current involvement of Belgium groups in Gen2:

Sander Vanheule (Gent)

(Communications Firmware)

Simona Toscana (VUB)

(Gen 2 simulations, layout, optical, link optical to radio)

Krijn De Vries (VUB), Nick van Eindhoven (VUB), Simona Toscana (VUB) Kael Hanson (UW,ULB), Thomas Meures (UW,ULB), Aongus O'Murchadha(ULB)

(Radio simulations, new detection techniques)

Aongus O'Murchadha (ULB)

(ARA monitoring and detector developmen/deployment)

Juan Antonio Aguilar Sánchez (ULB) +Christopher Raab (ULB)

(DOM upgrade, Pingu DM analysis)

Gwenhaelle de Wasseige (VUB), Nick van Eindhoven (VUB)

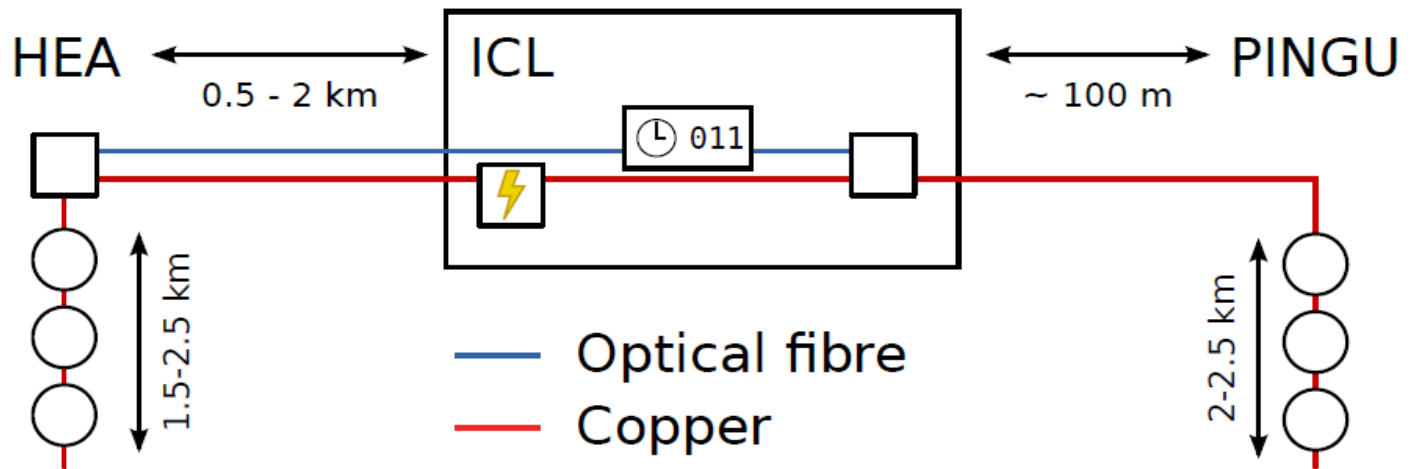
(Pingu Solar flare analysis)



IceCube: Gen2 Belgium

Sander Vanheule: Gen2 Firmware development

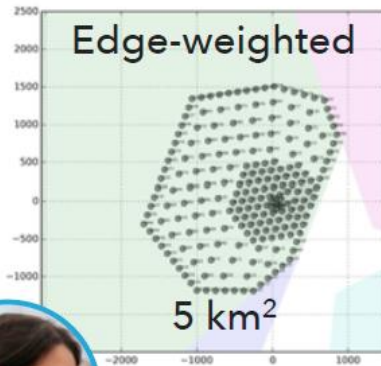
- Split data/timing and power between ICL and top of string
- ICL to top of string
 - Optical fibre: data + timing (White Rabbit)
 - Copper: power
- Downhole cable: copper quad for data + timing + power



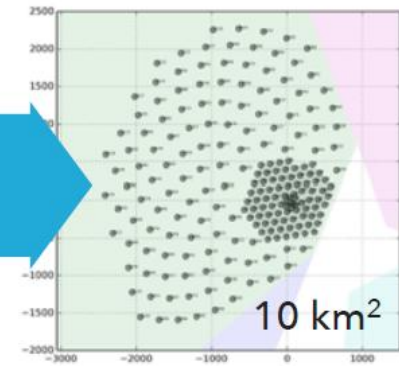
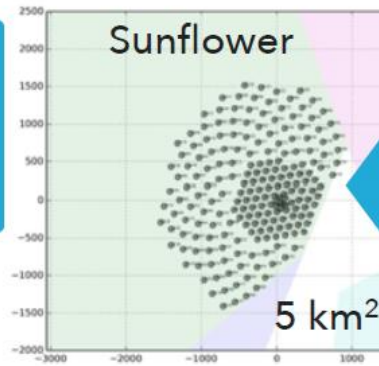


IceCube: Gen2 Belgium

$$\frac{\text{IceCube-Gen2}}{\text{IceCube}} \approx 2 \times (1 + \delta_{\text{geo}}) \times (1 + \delta_{\text{reco}}) \times (1 + \delta_{\text{veto}}) \times (1 + \delta_{\text{tech}})$$



30%



Simona Toscano

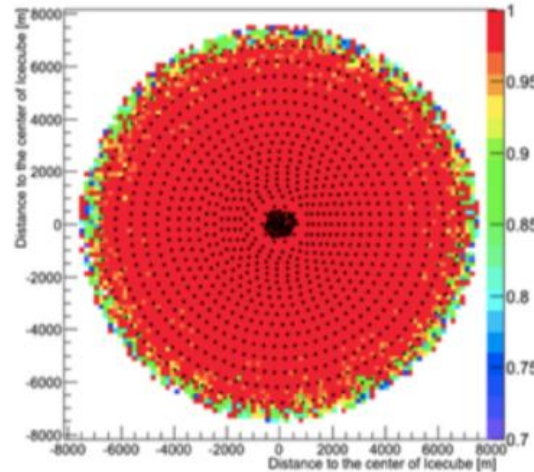
122-125 additional strings w/ 80 DOMs per string.
Different geometries might improve different analysis



IceCube: Gen2 Belgium

$$\frac{\text{IceCube-Gen2}}{\text{IceCube}} \approx 2 \times (1 + \delta_{\text{geo}}) \times (1 + \delta_{\text{reco}}) \times (1 + \delta_{\text{veto}}) \times (1 + \delta_{\text{tech}})$$

Cosmic-ray showers can be vetoed with a dedicated surface array. Improving sensitivity in the Southern Sky



50%



IceCube: Gen2 Belgium

Dedicated reconstructions for IceCube-Gen2 might improve the performance.



Kevin Meagher

50%

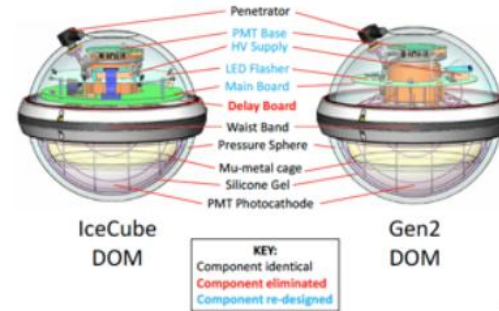
$$\frac{\text{IceCube-Gen2}}{\text{IceCube}} \approx 2 \times (1 + \delta_{\text{geo}}) \times (1 + \delta_{\text{reco}}) \times (1 + \delta_{\text{veto}}) \times (1 + \delta_{\text{tech}})$$



IceCube: Gen2 Belgium

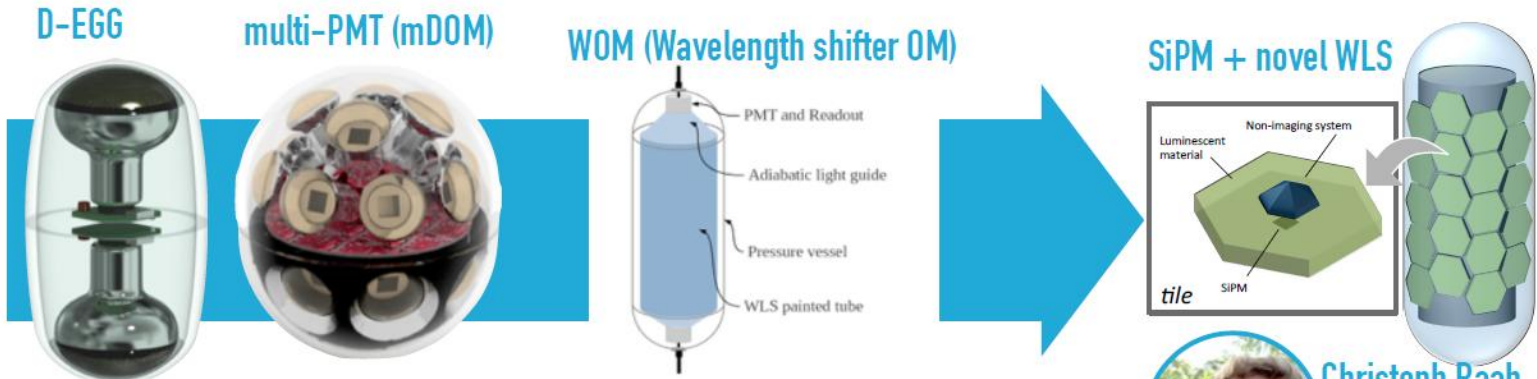
Baseline Design:

Improved design of the IceCube DOM
Robust approach and known technology



50%

$$\frac{\text{IceCube-Gen2}}{\text{IceCube}} \approx 2 \times (1 + \delta_{\text{geo}}) \times (1 + \delta_{\text{reco}}) \times (1 + \delta_{\text{veto}}) \times (1 + \delta_{\text{tech}})$$



Christoph Raab

J.A. Aguilar

Slides from J.A. Aguilar Sanchez



IceCube: Gen2 Belgium

$$\frac{\text{IceCube-Gen2}}{\text{IceCube}} \approx 2 \times (1 + \delta_{\text{geo}}) \times (1 + \delta_{\text{reco}}) \times (1 + \delta_{\text{veto}}) \times (1 + \delta_{\text{tech}})$$

Diagram illustrating the components of the IceCube-Gen2 performance ratio relative to IceCube. The ratio is approximately 2, multiplied by four factors: δ_{geo} (30%), δ_{reco} (50%), δ_{veto} (50%), and δ_{tech} (50%).

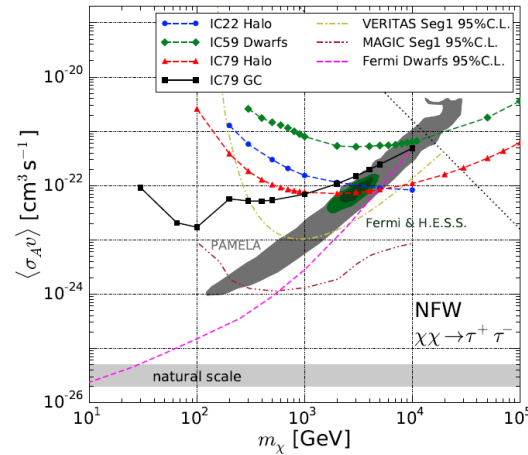
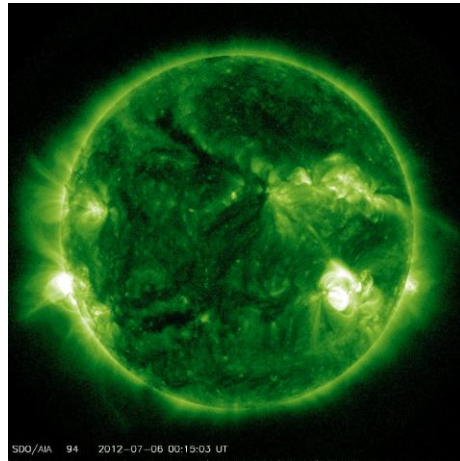
IceCube-Gen2 could outperform IceCube by a factor of 8
More work is needed



IceCube: Gen2 Belgium

Pingu analysis

Solar flare physics



Dark matter searches using Pingu



Gwenhaël De Wasseige + Nick van Eindhoven + Kael Hanson



Christoph Raab



IceCube: Radio Belgium

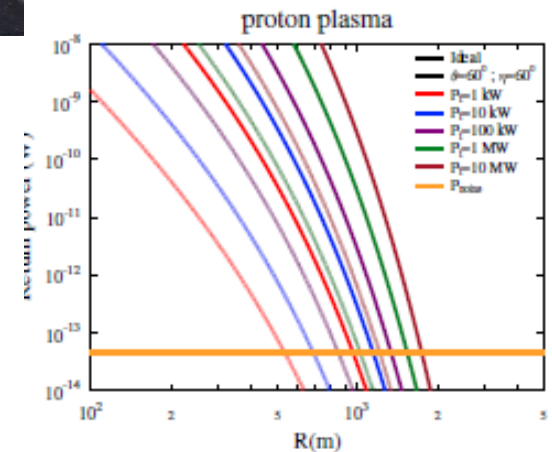
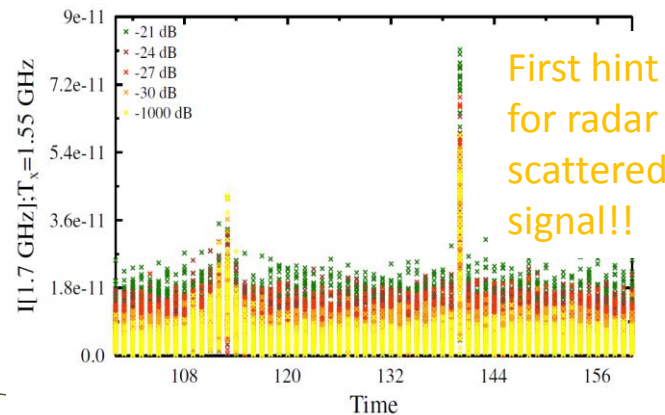
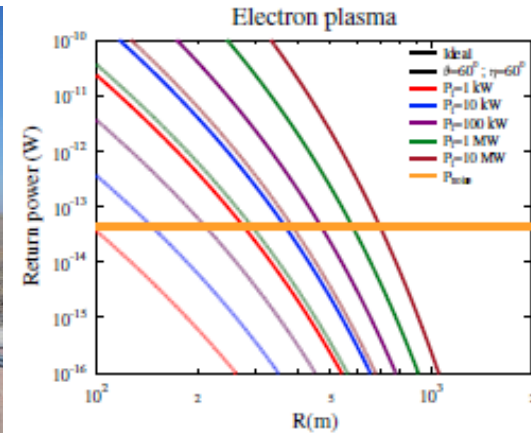
On the feasibility of RADAR detection of high-energy neutrino-induced showers in ice

Krijn D. de Vries^a, Kael Hanson^b, Thomas Meures^b

^aVrije Universiteit Brussel, Dienst ELEM, B-1050 Brussels, Belgium

^bUniversité Libre de Bruxelles, Department of Physics, B-1050 Brussels, Belgium

- First estimations are very promising for this method.
- Energy threshold > few PeV
- Plasma properties are crucial for the method to work.
 - First feasibility test performed, possible scatter observed.
- Background measurements currently performed at the South Pole by Aongus O'Murchadha





ICECUBE

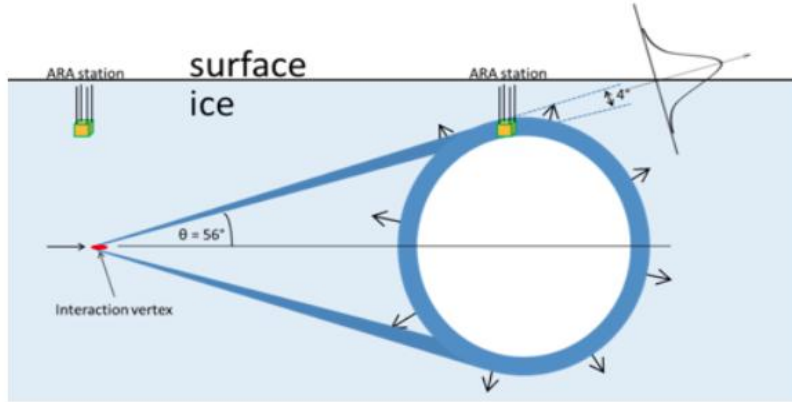
IceCube: Radio Belgium

ARA ASKARYAN RADIO ARRAY



Slides from J.A. Aguilar Sanchez

15



- ▶ Radio detection of ultrahigh-energy neutrinos in ice via the **Askaryan effect**
- ▶ Goal of $\sim 100 \text{ km}^2$ to detect **GZK neutrinos**

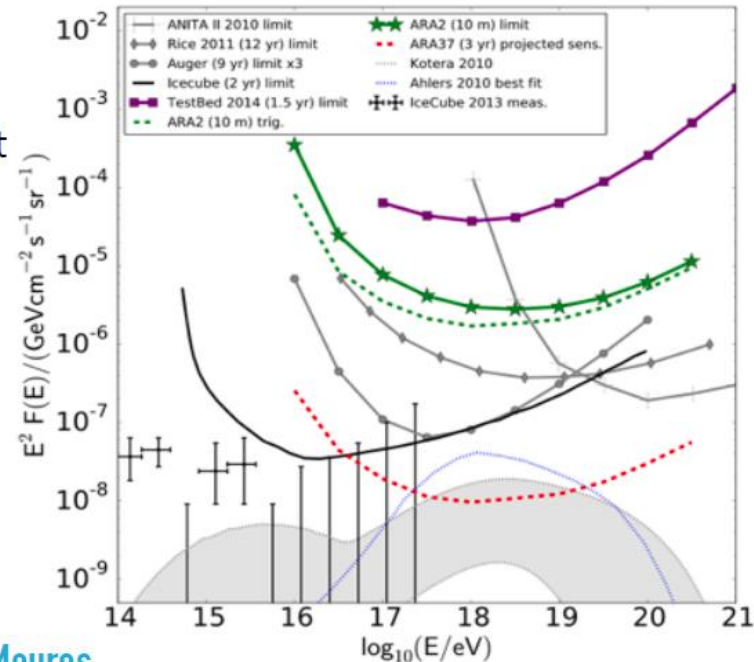
- ▶ 3 stations at South Pole, at least 2 more planned for 2016/17 or 2017/18 (subject to operational support review)
- ▶ 2015: First paper giving limits from full design stations submitted to PRD (**T. Meures**), 2 papers giving limits from TestBed prototype



Aongus O'Murchadha



Thomas Meures



Brussel

The cosmic-ray air-shower signal in Askaryan radio detectors

Krijn D. de Vries^a, Stijn Buitink^a, Nick van Eijndhoven^a, Thomas Meures^b, Aongus Ó Murchadha^b, Olaf Scholten^{a,c}

^aVrije Universiteit Brussel, Dienst ELEM, B-1050 Brussels, Belgium

^bUniversité Libre de Bruxelles, Department of Physics, B-1050 Brussels, Belgium

^cUniversity Groningen, KVI Center for Advanced Radiation Technology, Groningen, The Netherlands



IceCube: Gen2 Costs

Pingu ~\$65 M US + ~\$25 M non US (marginal to Gen2)
 Surface array ~\$45 M

# of strings	PDOMs / string	Total PDOMs	Drill / Deploy Seasons	TPC w/o contingency	Instrumentation cost only
H80/P40	60/60	7200	7+	\$268M	\$126M (47%)
H96/P24	80/80	9600	7+	\$283M	\$142M(50%)
H96/P24	80/96	9984	7+	\$285.5M	\$145(51%)
H96/P40	80/60	10080	8+	\$302M	
H96/P40	80/96	11520	8+	\$311.1M	
H96/P40	80/120	12480	8+	\$317M	\$171M(54%)
H120/P40	80/60	12000	9+	\$332M	\$171M(54%)
H120/P40	80/96	13440	9+	\$341M	



Summary

IceCube Gen2 has a very broad physics potential

What can the LE extension give us:

- Mass hierarchy
- DM physics
- Supernova + Solar flare physics

What will Gen2 HE extension give us:

- Detailed understanding of Source distributions, spectrum and flavor composition for the astrophysical neutrinos detected.
 - Multimessenger astronomy.
- GZK neutrino detection (in case UHECRs are protons)
 - Neutrino cross-section at extreme energies.
 - Glashow resonance p-p/p-gamma distinction.
- Precision physics of cosmic rays at the knee of the spectrum.
- Belgium involved through simulation / analysis studies. Further involvement on hardware development strongly depend on obtained NSF funding.