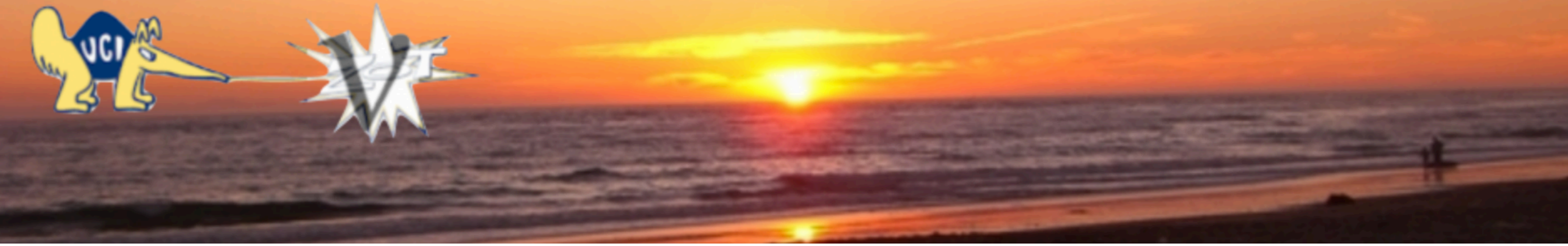


The 26th International Workshop on
Weak Interactions and Neutrinos
(WIN 2017)

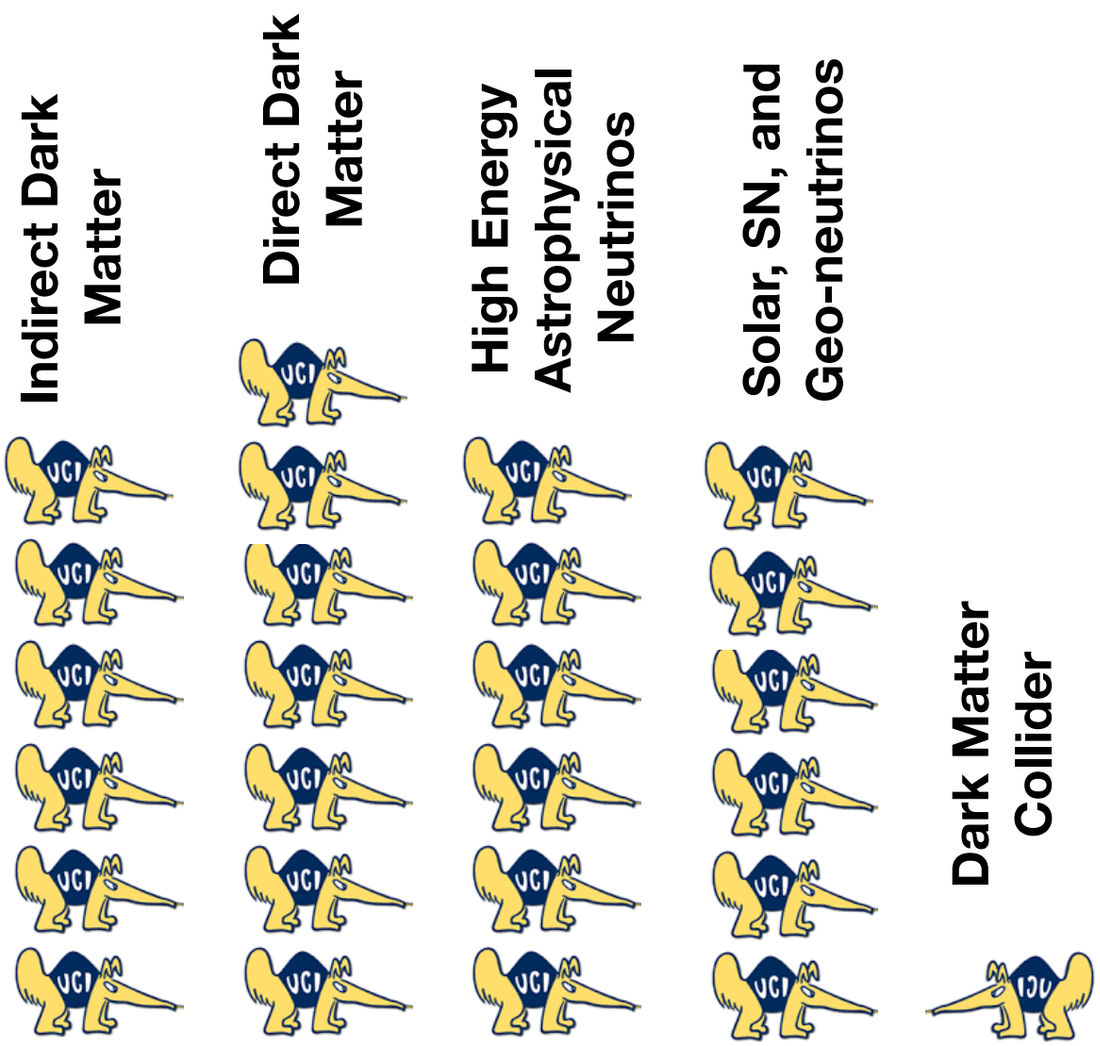
Summary of Astroparticle Physics

Carsten Rott
rott@skku.edu
Sungkyunkwan University, Korea

on the summary …

I will summarize the astroparticle physics part of the cosmology and astroparticle physics sessions. See Jan Hamann's talk for the cosmology part

26 talks distributed over 5 sessions + 1 joint astro/neutrino exp session



- Strategy
  - One slide per talk
    - Hope this can serves as reference for the future
    - Connect them in consistent story

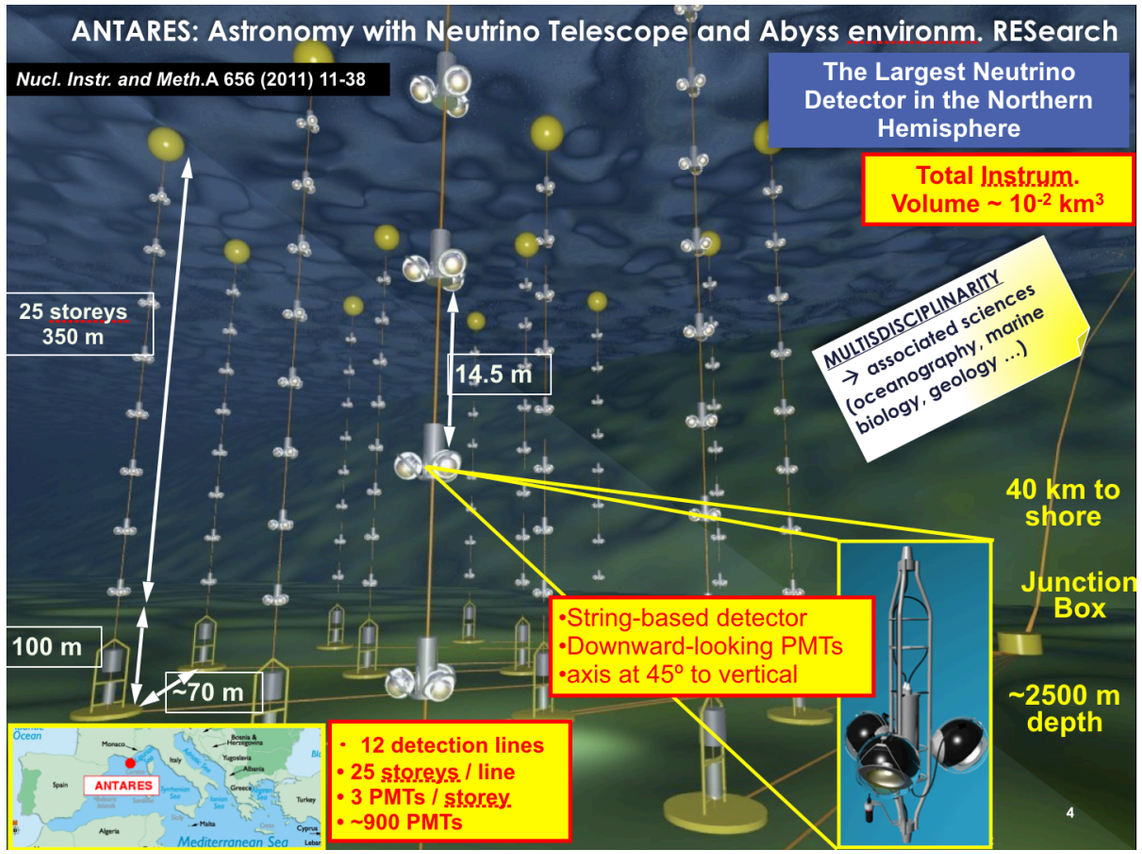
    …
- Some of the materials presented in the parallel session have already been highlighted in other plenary talks
  - I will focus on those results that have not been shown

Thanks for chairing some of the sessions: Jodi Cooley, Spencer Klein, Dinesh Loomba, Makoto Miura

Astrophysical Neutrinos

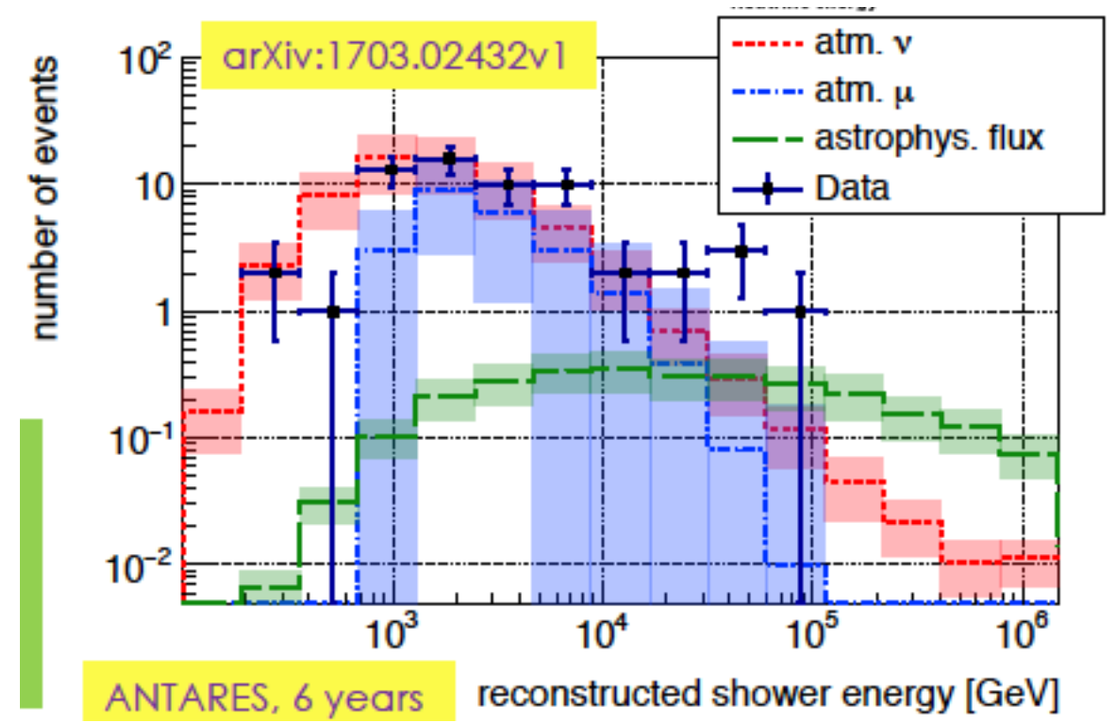
Recent Results from ANTARES and KM3NeT-ARCA Status report

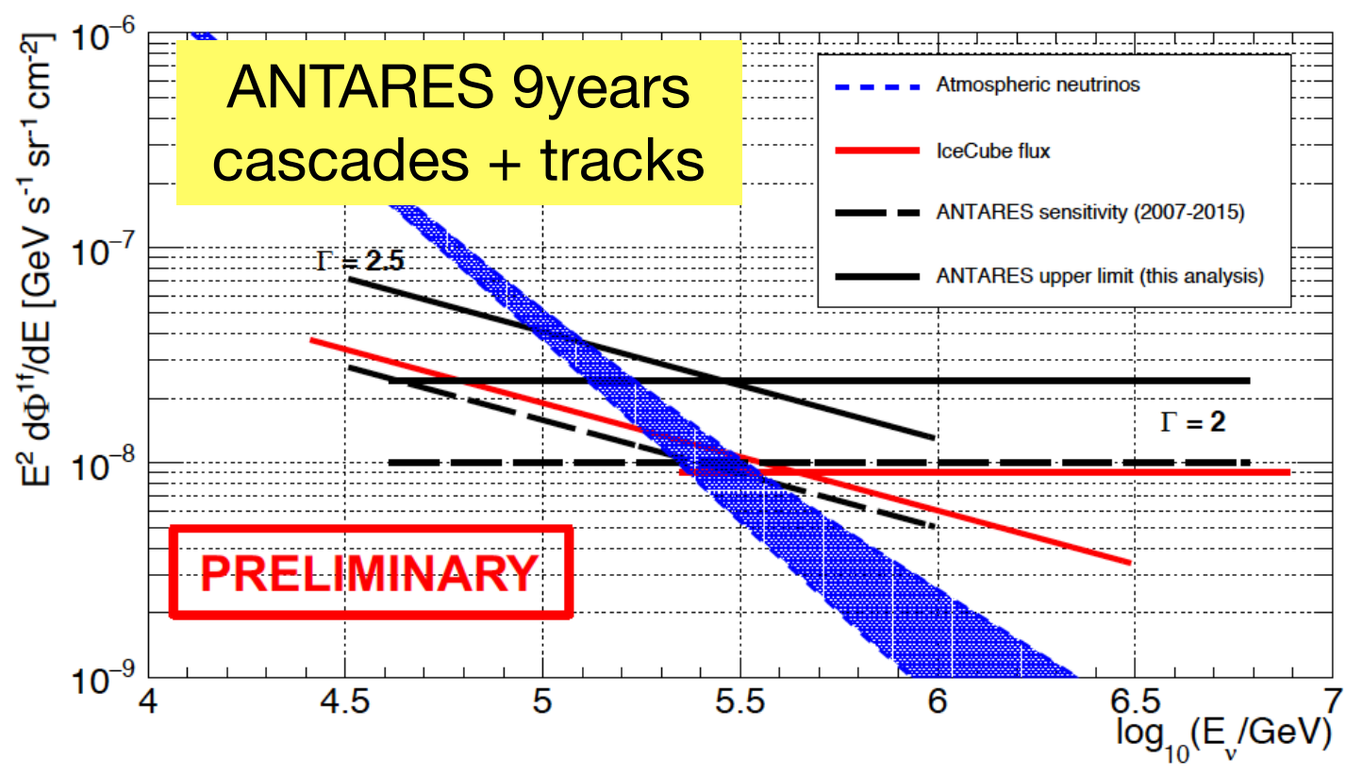
Antonio Capone



- ANTARES studied the **Southern sky** with ν_μ competitive sensitivities and excellent angular resolution for both ***tracks*** and ***cascades***;
- Detailed study of **extended** regions (Galactic plane, Fermi Bubbles)
- A large **multi-messenger** effort
  - EM radiation: radio (MWA), optical, X-ray, γ-rays (LAT,IACTs)
  - Gravitational Wave observatories and IceCube
- ANTARES contribute to the indirect searches for **Dark Matter**
  - Most competitive limits for spin-dependent cross-section
  - Competitive $\langle\sigma v\rangle$ limits from the Galactic centre
- **KM3NeT-Arca** Neutrino Telescope under construction will soon be able to observe the neutrino sky with unprecedented sensitivities.

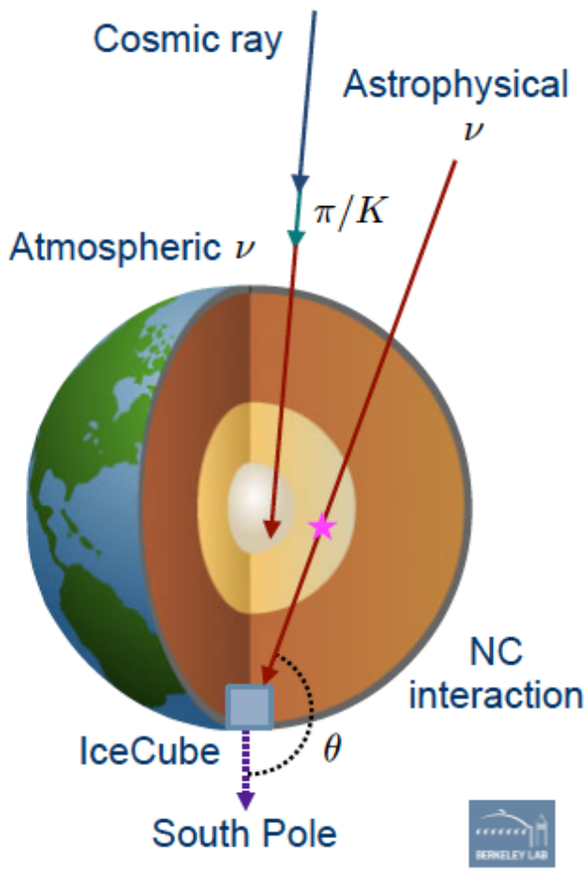
Astrophysical Neutrino Search

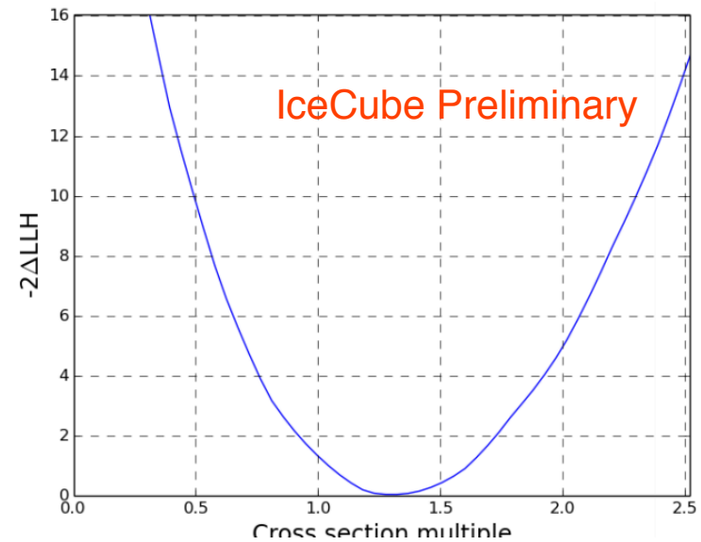




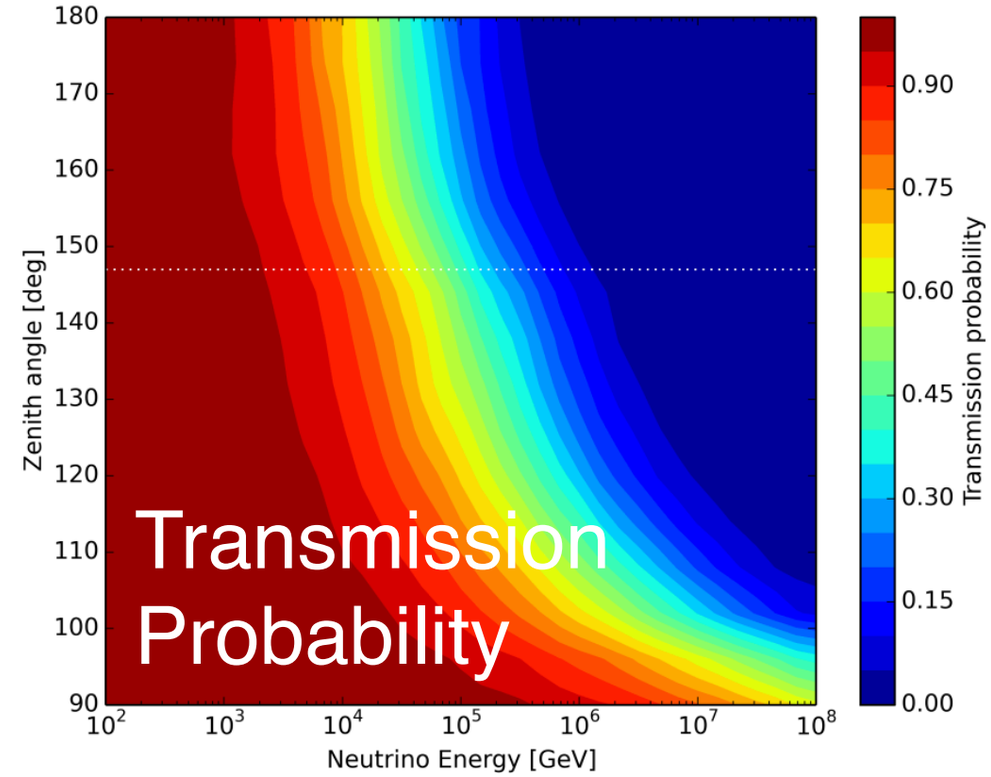
Neutrino absorption in the Earth and measurement of the neutrino-nucleon cross-section at multi-TeV energies with IceCube

Gary Binder

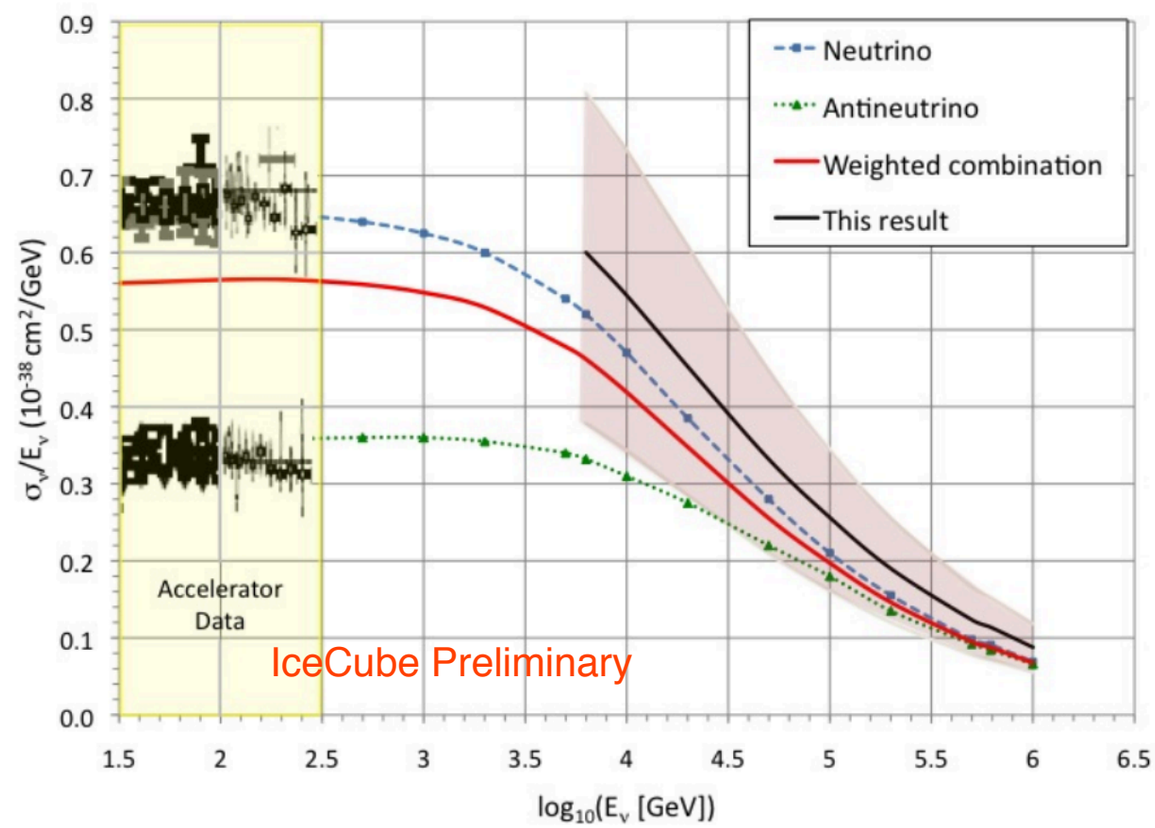




$$\frac{\sigma_{\text{meas.}}}{\sigma_{SM}} = 1.30^{+0.21}_{-0.19}\,(\text{stat.})\,^{+0.39}_{-0.43}\,(\text{syst.})$$



- 2 orders of magnitude higher in energy than previous accelerator based measurements
- Measurement reflects a flux-weighted sum of neutrinos and antineutrinos
- First measurement where the DIS cross section is no longer linear in energy
- Consistent with current Standard Model calculations
- 6 more years of data are available and could reduce uncertainties below 20% and enable a binned measurement across energy



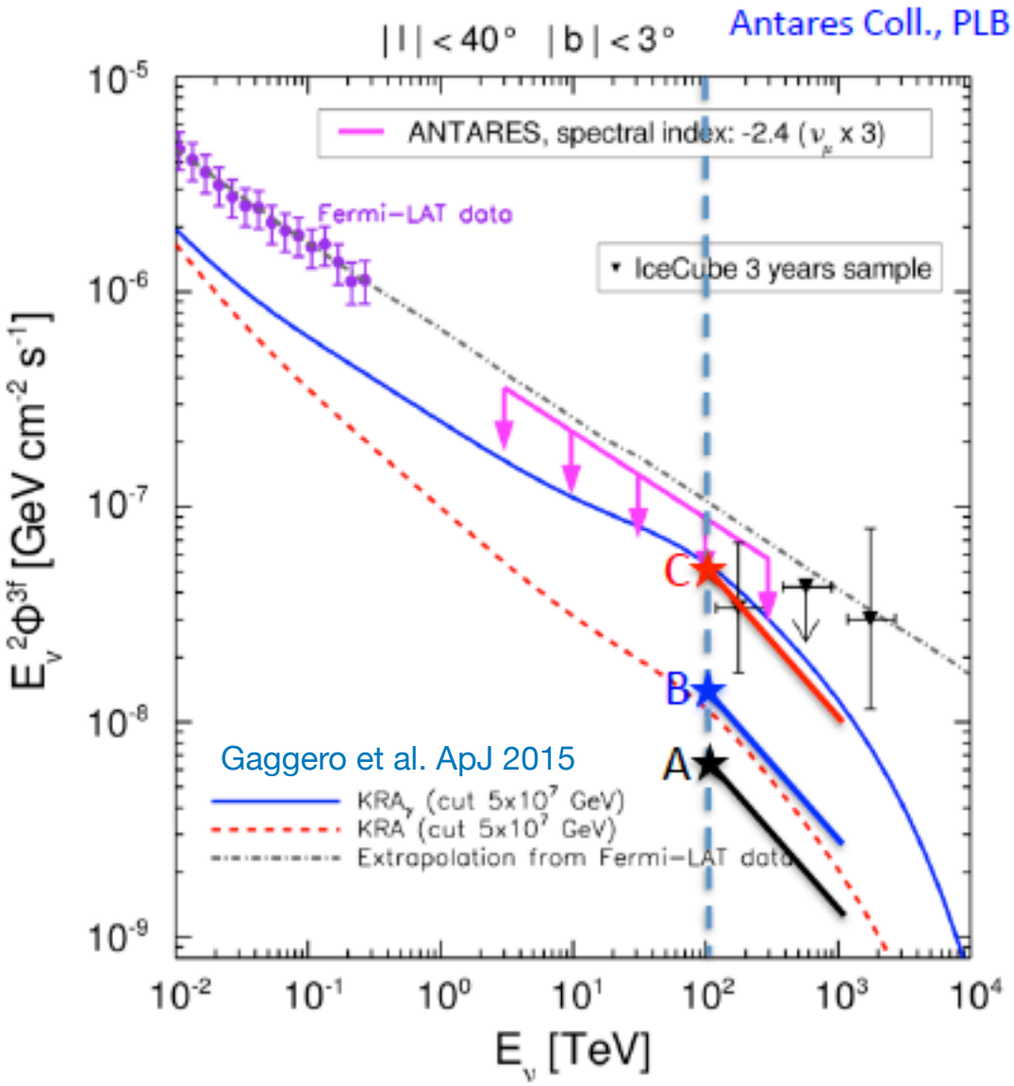
New Result !

High energy diffuse galactic neutrinos for different cosmic ray distributions

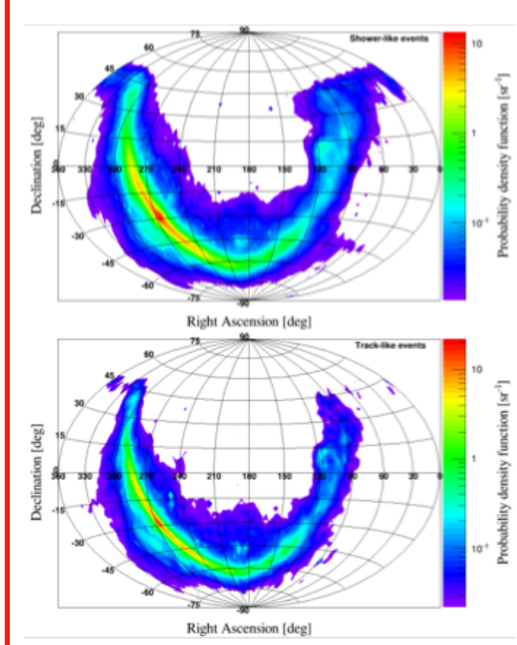
F.L.Villante

Consider 3 cases:

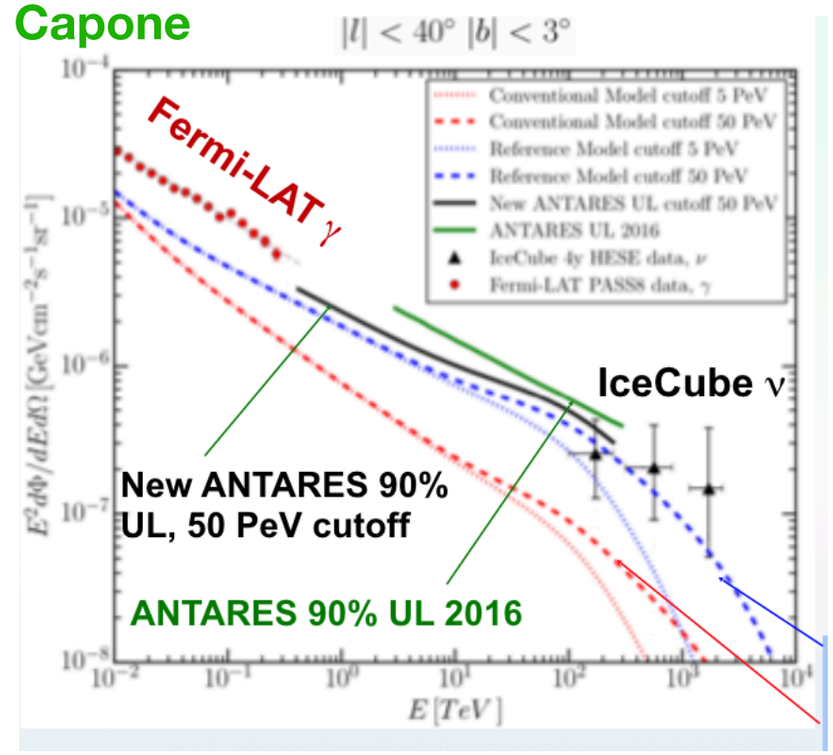
- **Case A**: CR flux is homogenous in the Galaxy
- **Case B**: CR flux follows the distribution of Galactic CR sources (SNRs,PWNe)
- **Case C**: CR flux has a spectral index that depends on the galactocentric distance.



see also … **Antonio Capone**



ANTARES arXiv:1705.00497v1
1 May 2017



KRA$_\gamma$ 50PeV cut-off for CR
KRA$_\gamma$ 5PeV cut-off for CR

KRA$_\gamma$ a new model to describe the CR transport in our Galaxy (see Gaggero et al. ApJ 2015) In agreement with CR measurements (KASCADE, PAMELA, AMS, Fermi-LAT, H.E.S.S.). Fermi-LAT diffuse γ flux from along the Galactic plane ($\pi^0 \rightarrow \gamma\gamma$) well explained above a few GeV.

Conclusion: The diffuse HE galactic neutrino flux is expected to be subdominant but not necessarily negligible (up to 13% of the total astrophysical signal in our calculations)

High energy diffuse galactic neutrinos for different cosmic ray distributions

F.L.Villante

Consider 3 cases:

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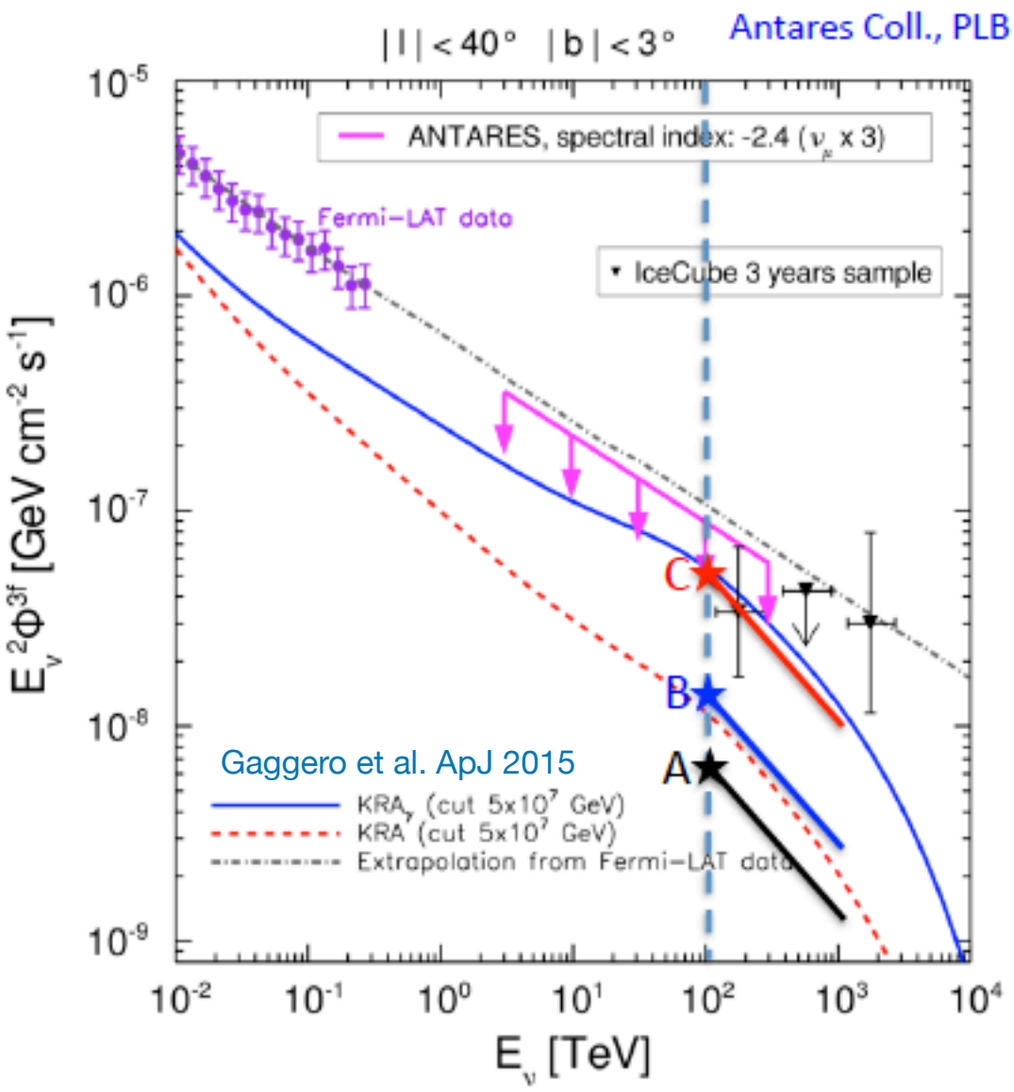
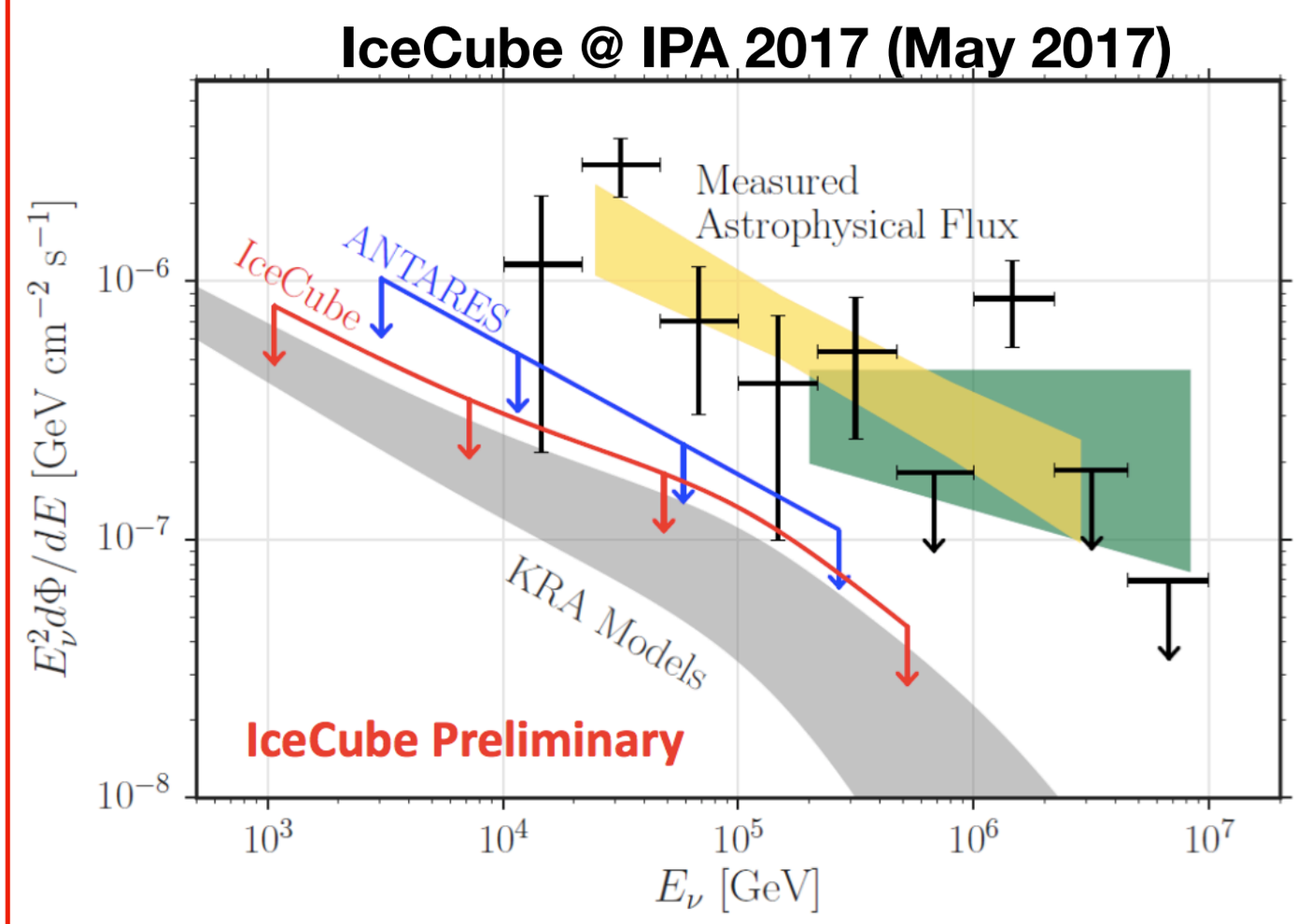


see also …



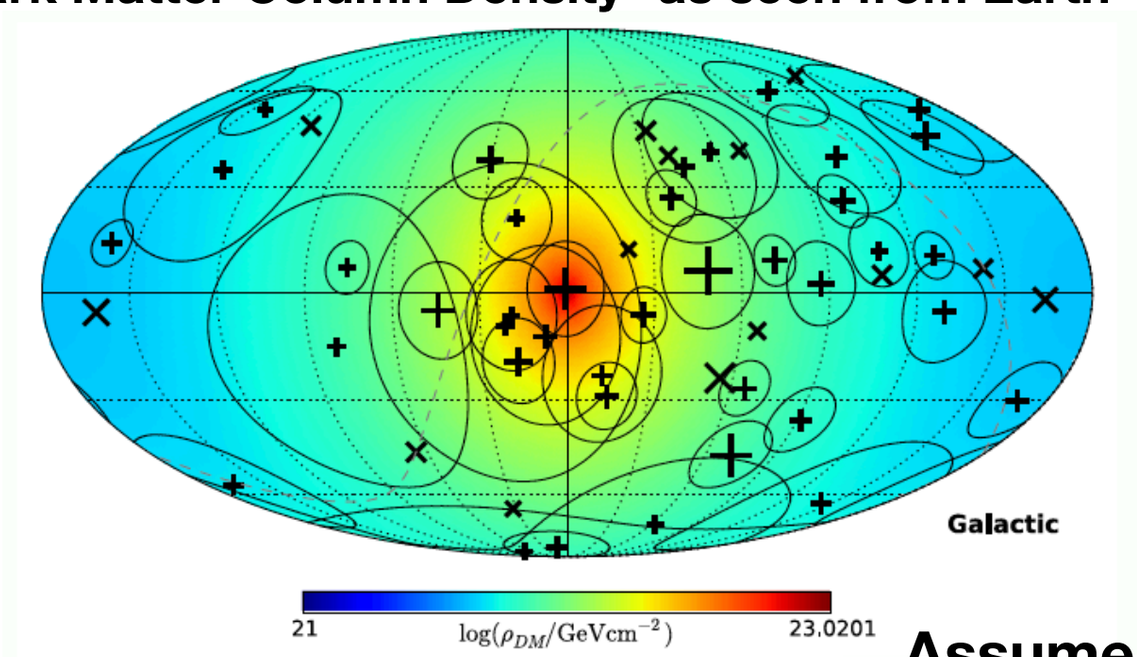
Conclusion: The diffuse HE galactic neutrino flux is expected to be subdominant but not necessarily negligible (up to 13% of the total astrophysical signal in our calculations)

[arXiv:1703.00451]

Ali Kheirandish

Imaging Galactic Dark Matter with IceCube's High-Energy Cosmic Neutrinos

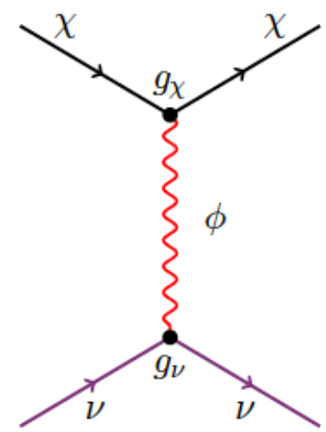
Dark Matter Column Density* as seen from Earth



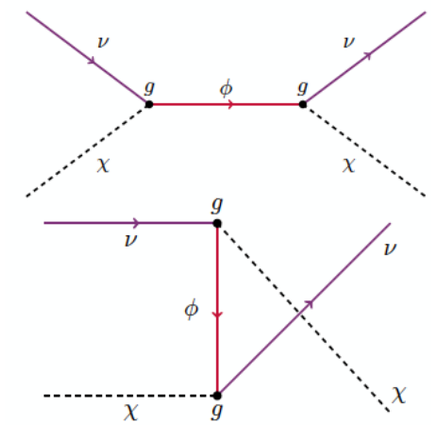
***Einasto Profile**

Dark Matter - Neutrino Interaction

(1) Fermion DM, vector mediator

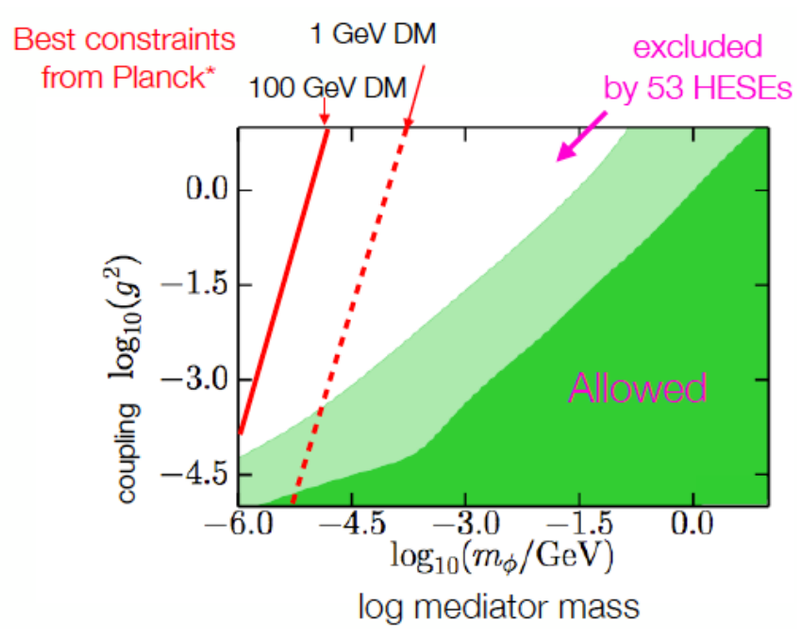


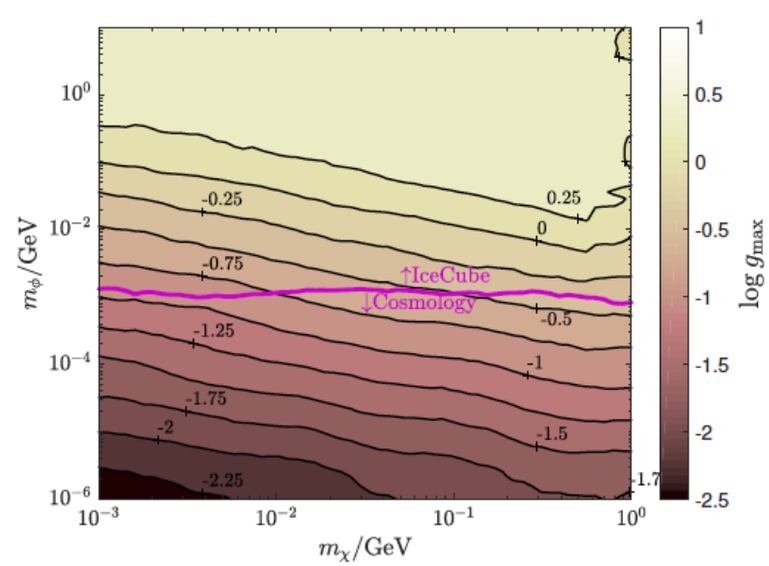
(2) Scale DM, ferminonic mediator

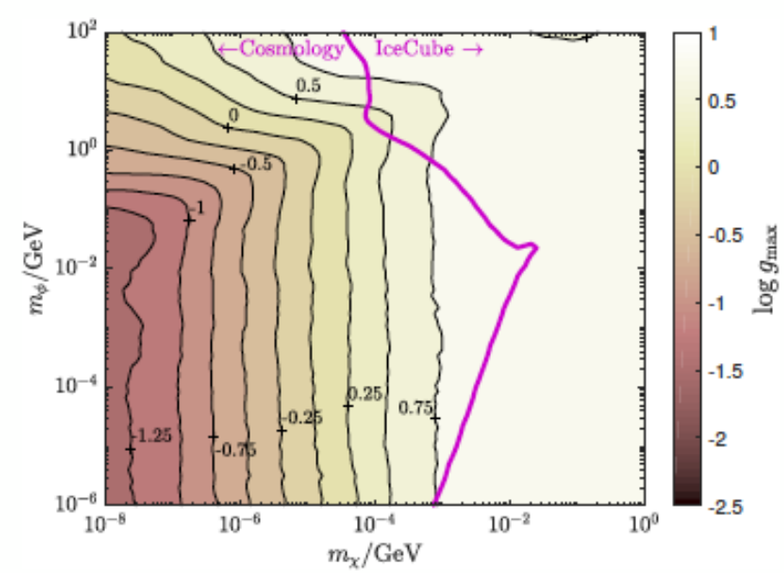


Assume:

$$\sigma_{DM-\nu} \propto E_\nu^2$$







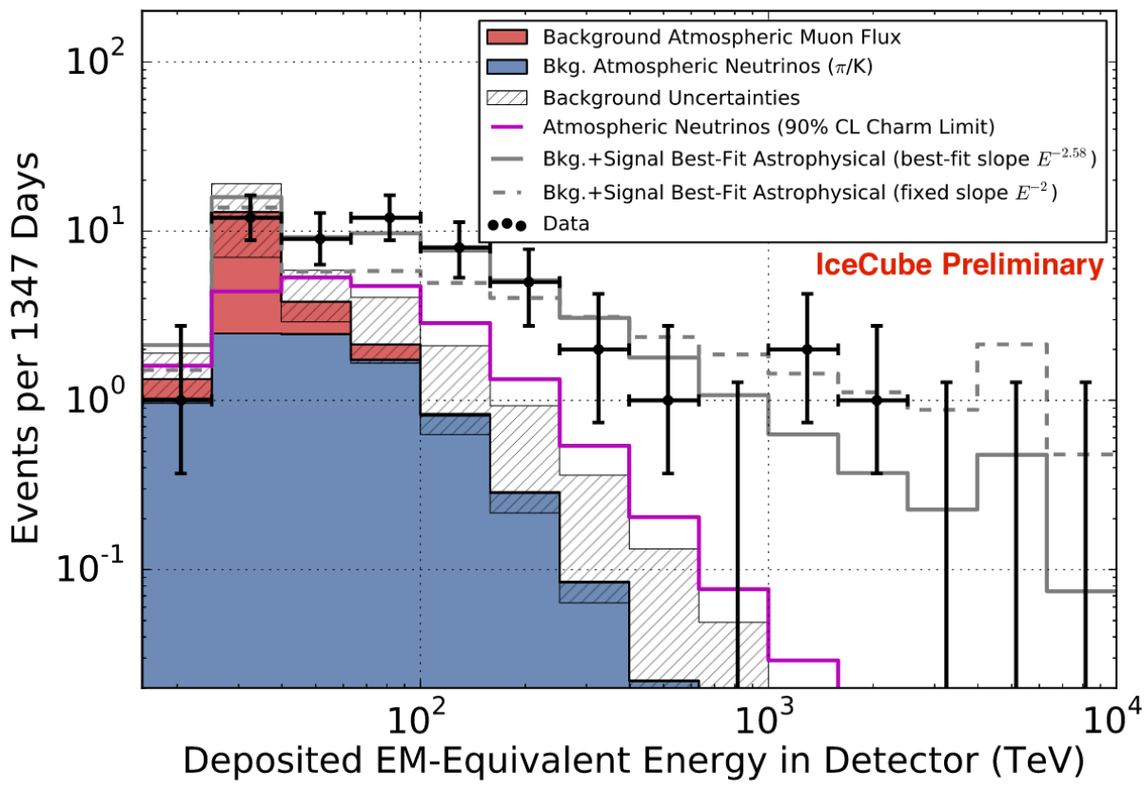
Indirect Dark Matter

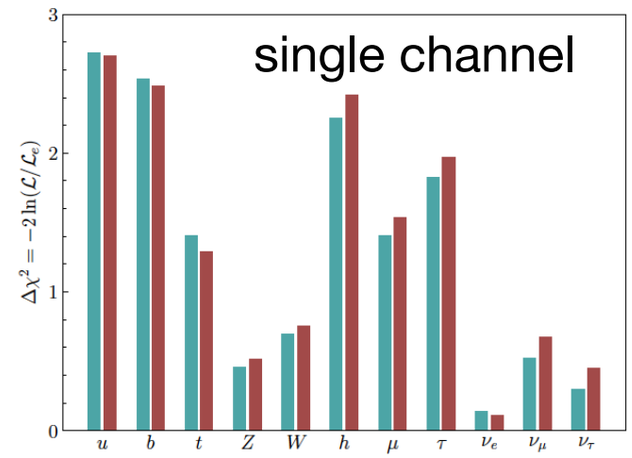
Atri Bhattacharya, Arman Esmaili, Sergio Palomares-Ruiz and Ina Sarcevic, arXiv: 1706.05746

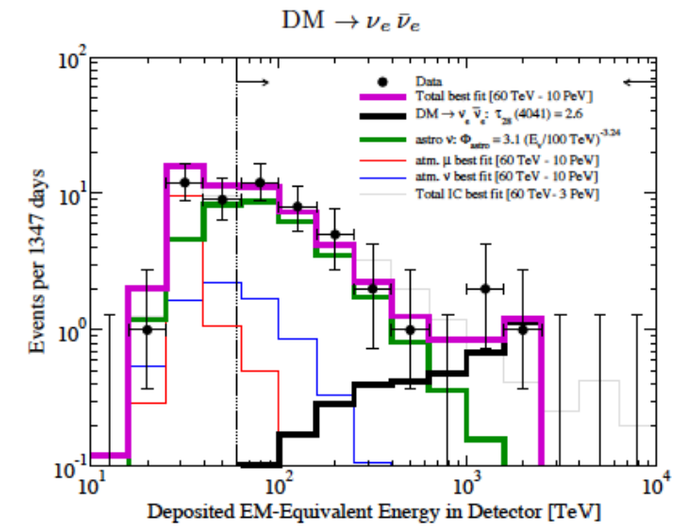
Probing Decaying Heavy Dark Matter with 4-year IceCube HESE data

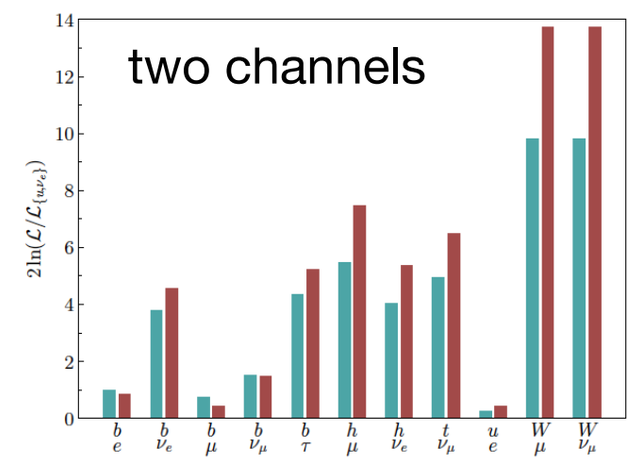
Ina Sarcevic

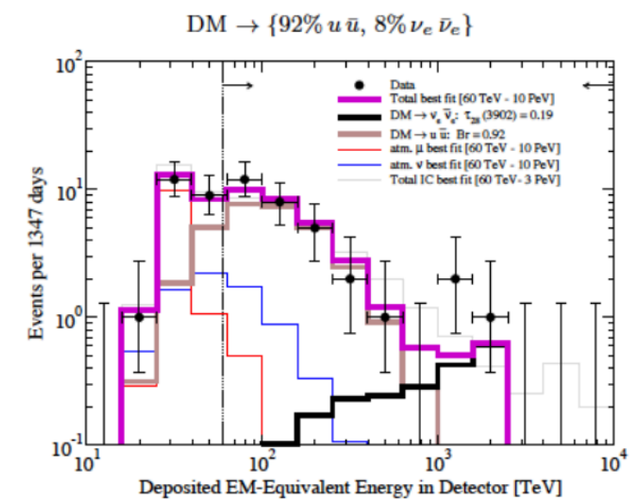
(see also talk by Kohta Murase)











Could the observed neutrino flux be due to only dark matter decaying into multiple channels?

$$\frac{d\Phi_{\mathrm{DM},\nu_\alpha}}{dE_\nu} = \frac{d\Phi_{\mathrm{G},\nu_\alpha}}{dE_\nu} + \frac{d\Phi_{\mathrm{EG},\nu_\alpha}}{dE_\nu}$$

Take Galactic and Extra galactic contributions into account

- Consider DM decay into two channels, one that would describe low energy data and the other high energy (PeV) events
- We find that HESE data can be best described with the combination of the astrophysical neutrino flux and the dark matter decay
- Best fit values for DM mass and lifetime depend on the channel, for DM decay into leptons, DM mass is of the order of several PeV, describing PeV events, while astrophysical flux describes lower energy flux
- DM decay into bb is disfavored

INDIRECT DARK MATTER SEARCHES IN ICECUBE

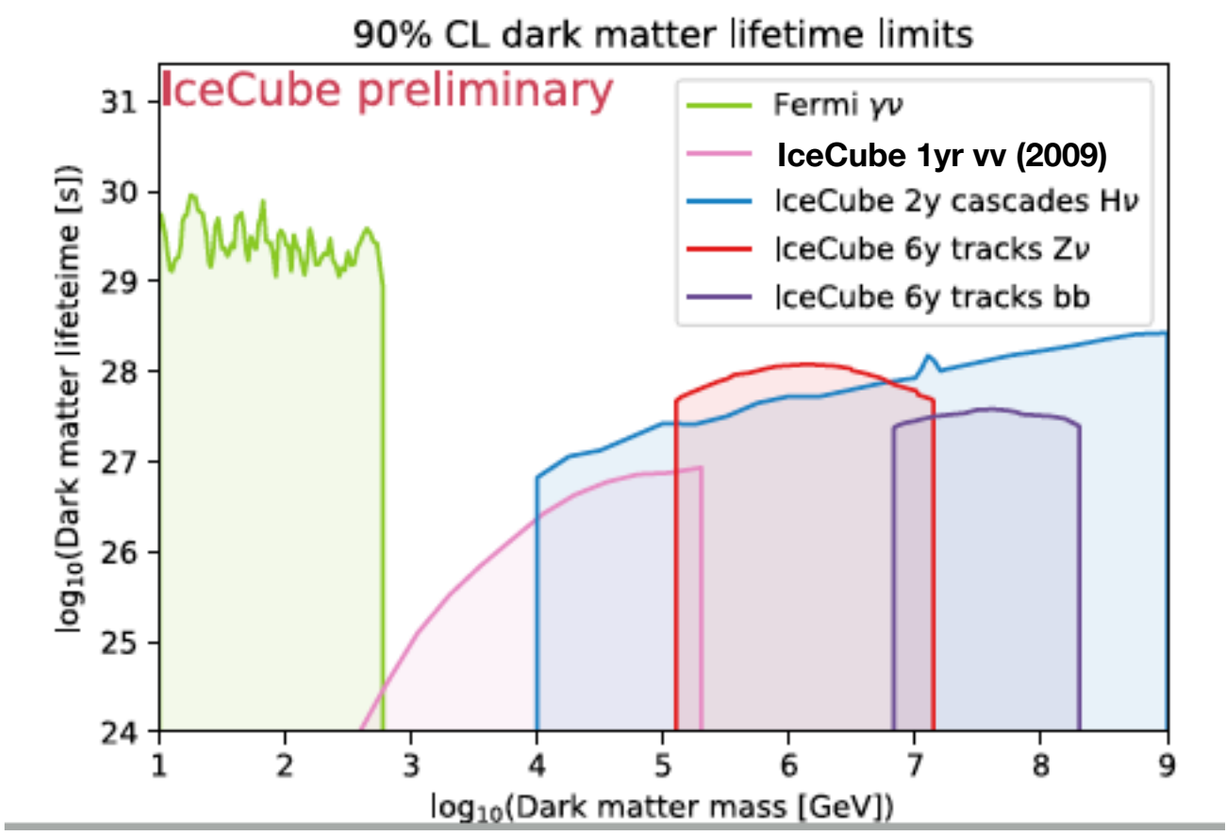
Morten Medici

Two independent analyses using event selections designed for unfolding the neutrino spectrum:

(1) Using dataset with 6 years of northern hemisphere tracks

(2) Using dataset with 2 years of full sky cascades

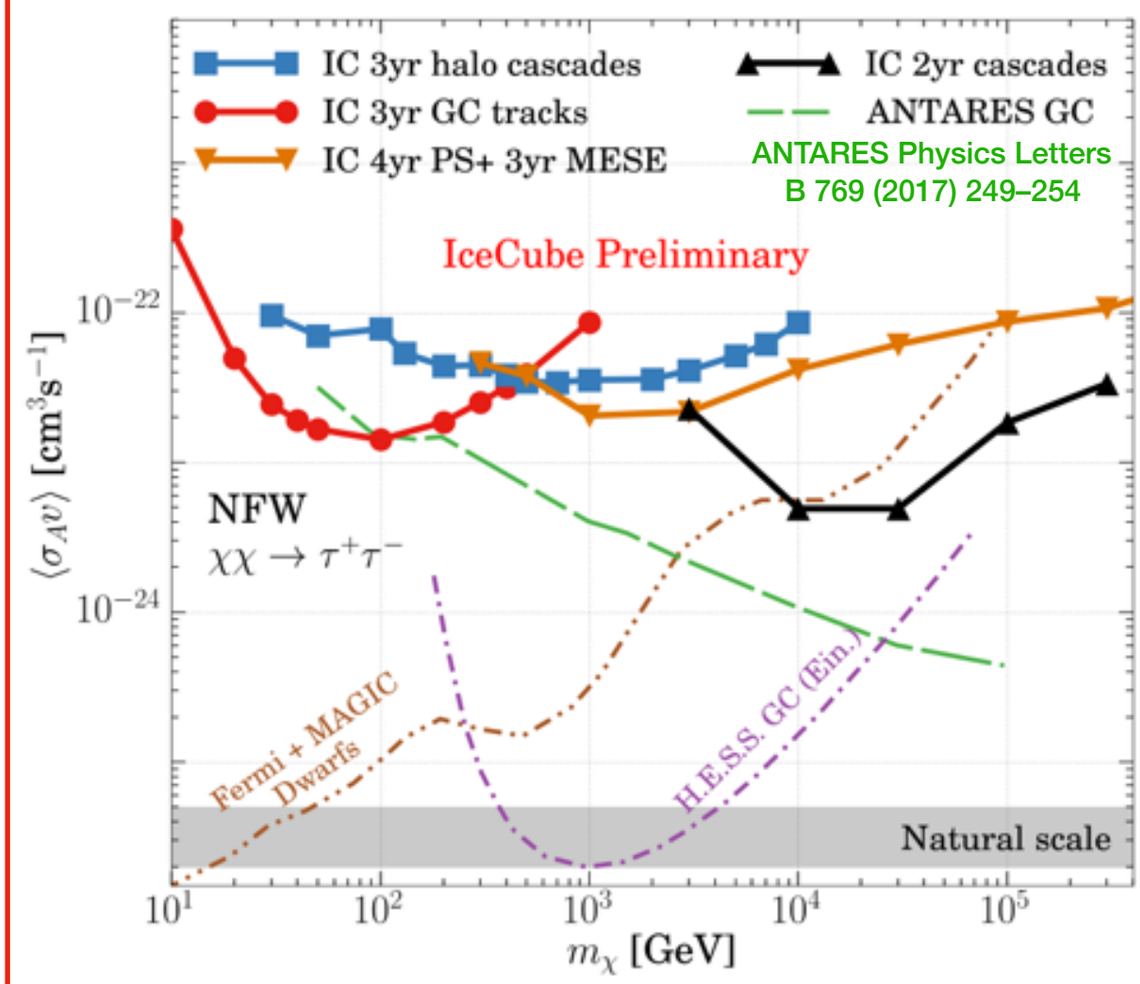
- Focusing on the **Xv-channel** which has a significant peak in energy from the neutrino line spectrum
- Dark matter signal is composed of galactic halo and isotropic extragalactic component



New Result !

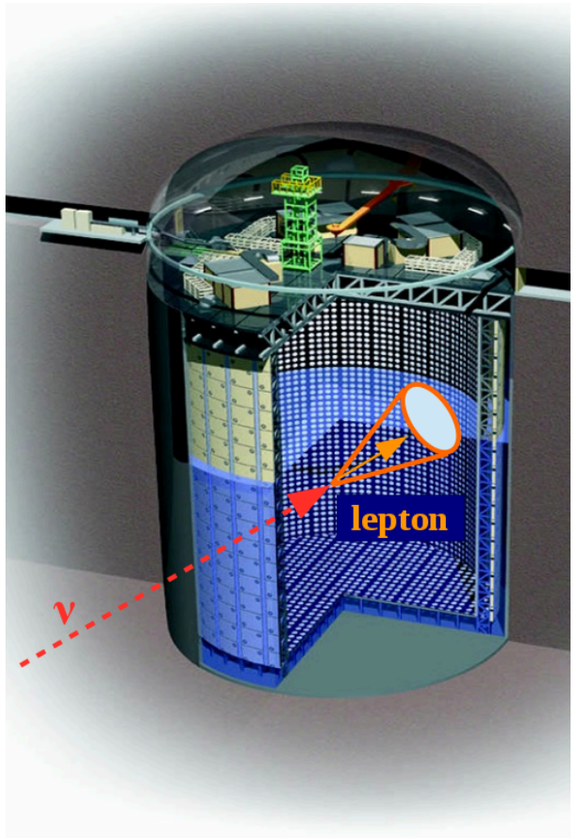
Galactic Halo DM annihilation searches cover 10 GeV - 300 TeV Dark Matter masses with 3 analyses:

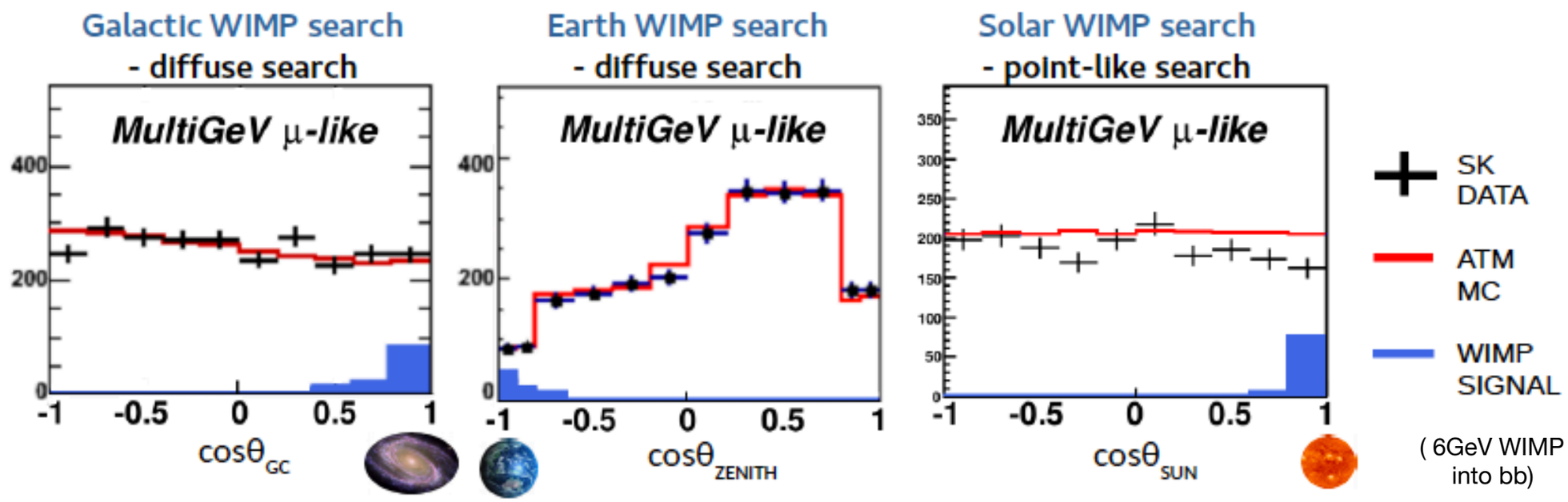
- Galactic Halo Cascades 2yrs
- Galactic Center Tracks 7yrs
- Galactic Center Track 3yrs (low-energy)
  - IceCube [arXiv:1705.08103]



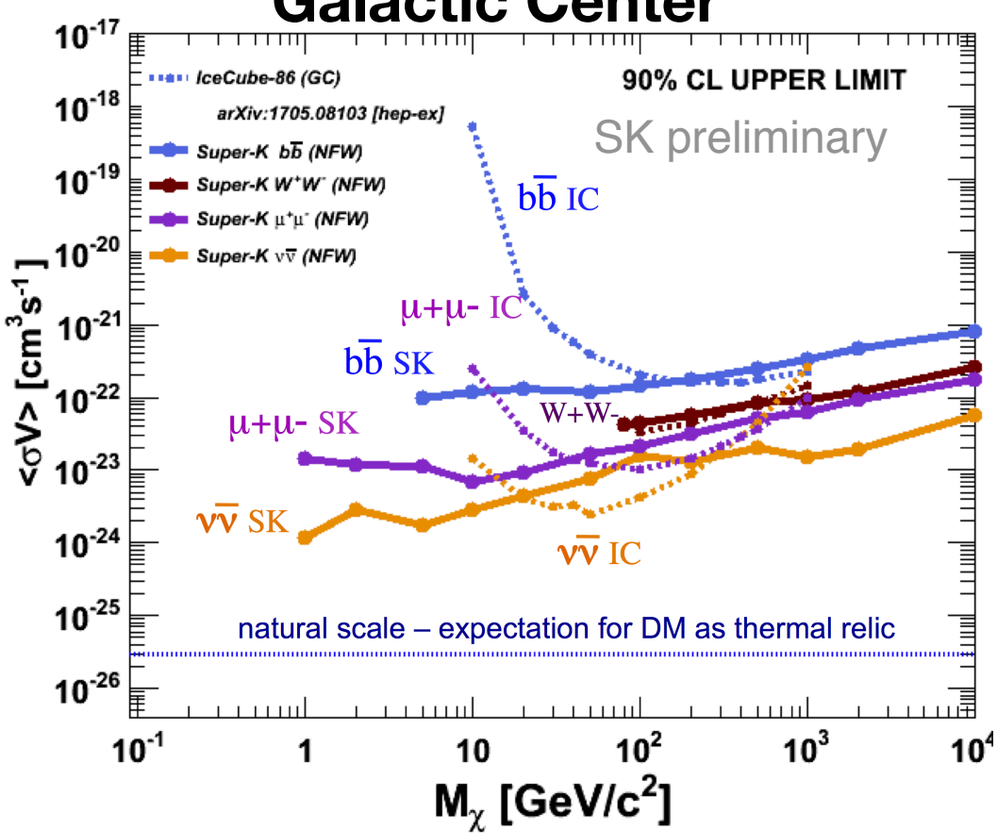
Dark matter searches with the Super-Kamiokande detector

K. Frankiewicz

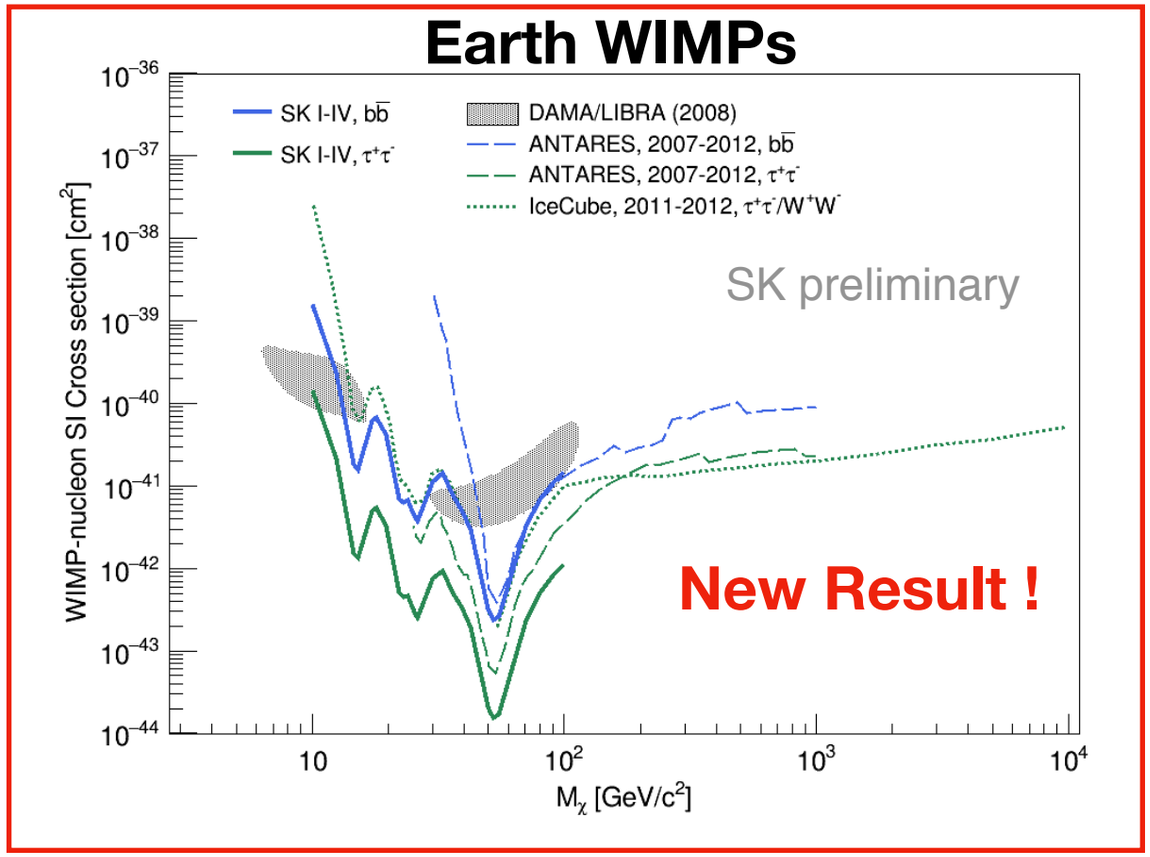




Galactic Center



Earth WIMPs

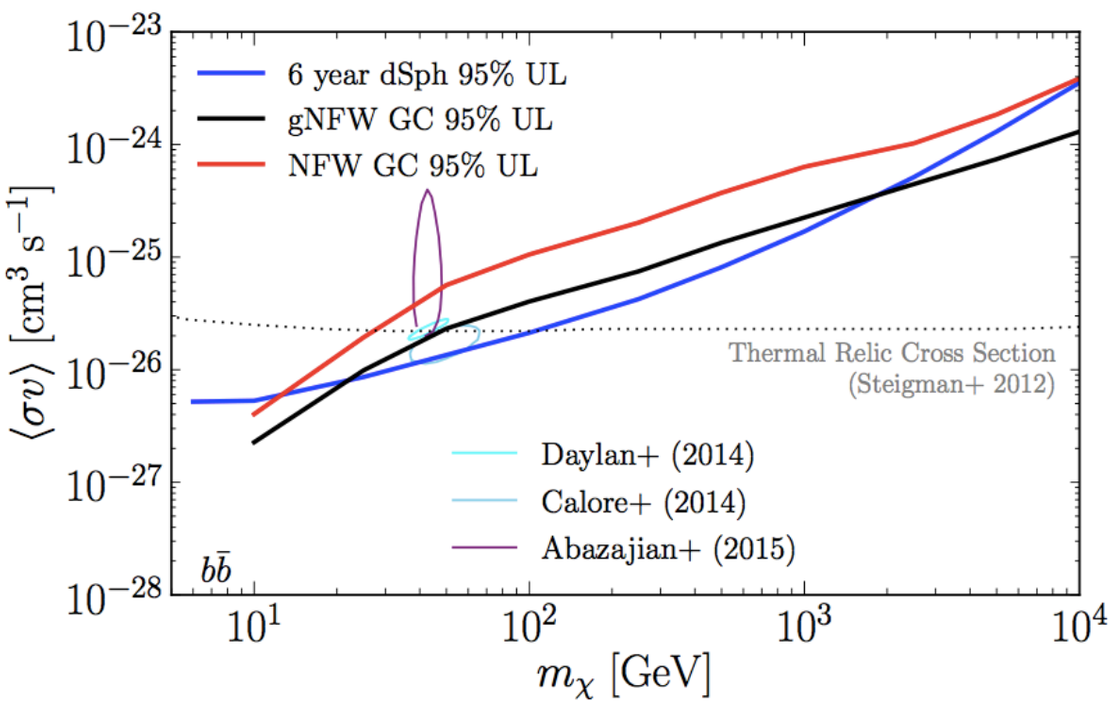


… see backup/talk for new boosted DM result

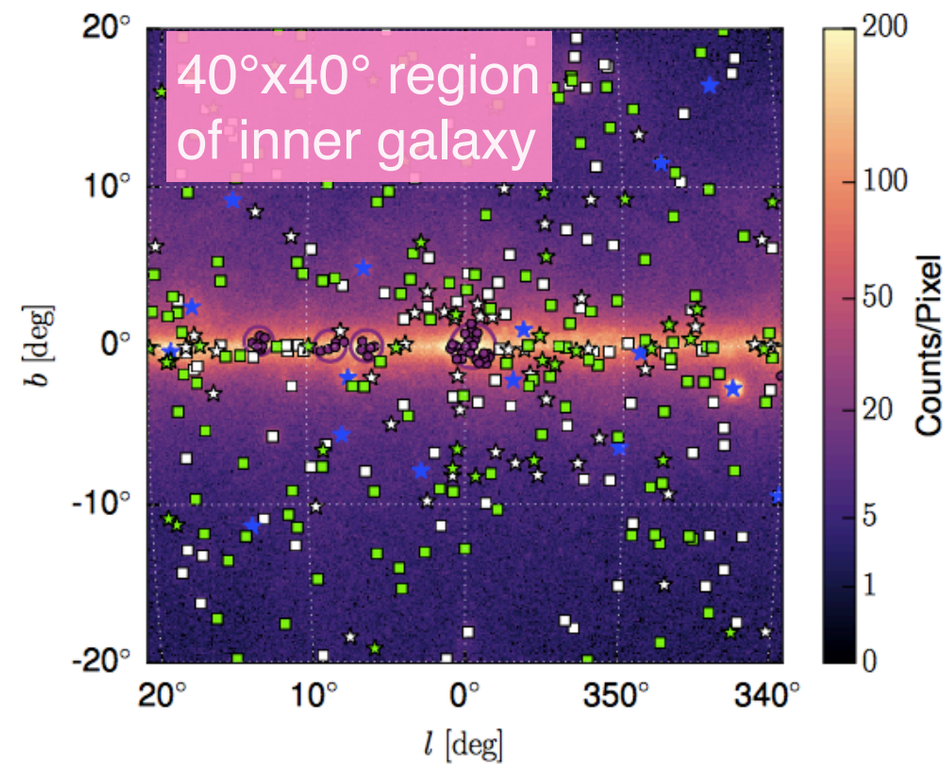
Dark Matter Searches with Fermi-LAT

Regina Caputo

What's going on in the Galactic Center?

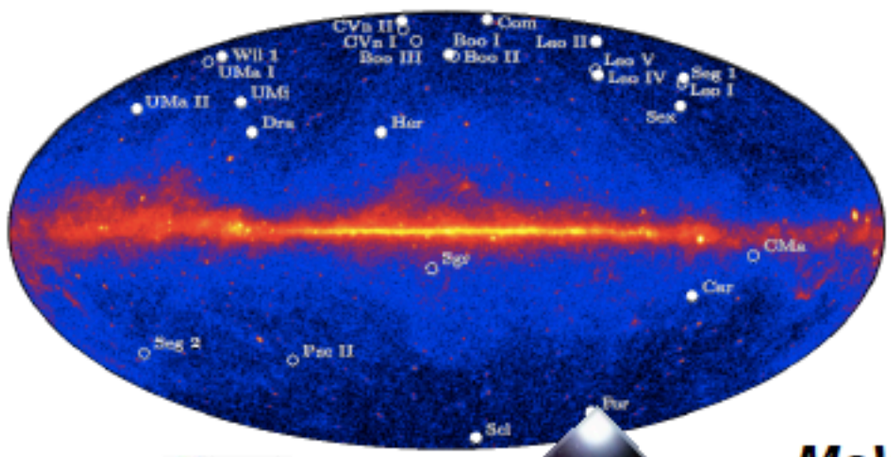


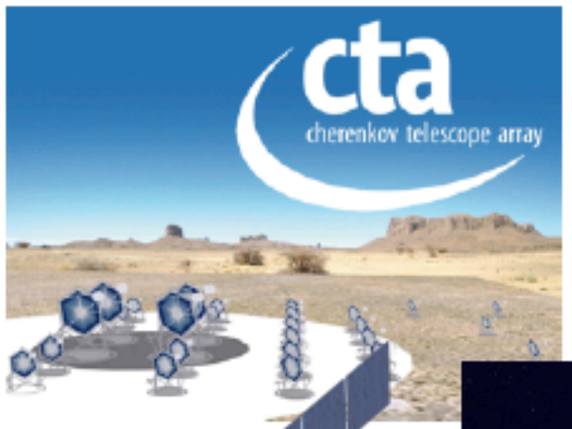
Current campaigns to identify pulsars near the Galactic Center



Mounting evidence of large contribution from pulsars

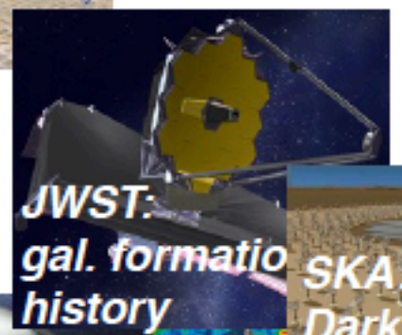
The Next Generation…





Astrophysics of Dark Matter (Special Dark)

Not to mention…



MeV mission

33% of Fermi Sources are unassociated

Fermi	DES		LSST	CTA	AMEGO
Today		2018	2020	2023	2025

R. Caputo, UMD/NASA/GSFC I WIN2017

22

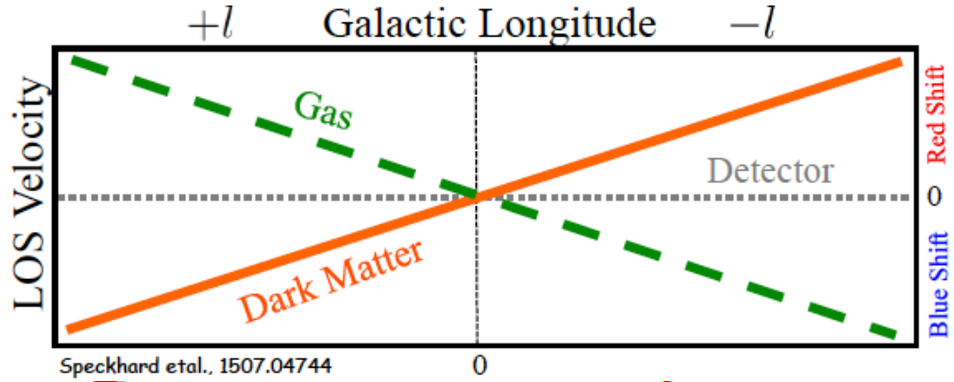
arXiv 1507.04744 Phys. Rev. Lett. 116 (2016) 031301 (Editors' Suggestion)

Ranjan Laha

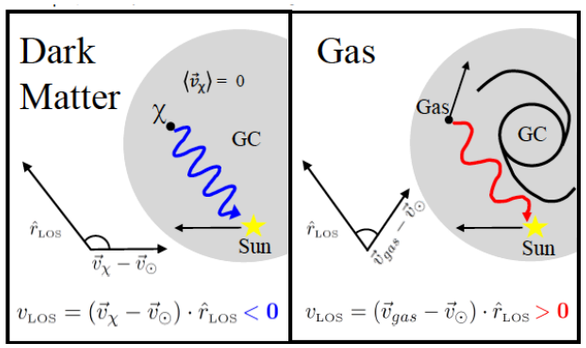
Dark matter velocity spectroscopy

- Dark matter halo has little angular momentum

Bett, Eke, etal., "The angular momentum of cold dark matter haloes with and without baryons"; Kimm etal., "The angular momentum of baryons and dark matter revisited"



Speckhard etal., 1507.04744



- Sun moves at ~220 km/s

Instruments with $\sim \mathcal{O}(0.1)\%$ energy resolution

- Distinct longitudinal dependence of signal

Past

Hitomi/ Astro-H

$$\frac{\sigma_E}{E} \approx \frac{1.7\,\text{eV}}{3.5\,\text{keV}}$$

Present

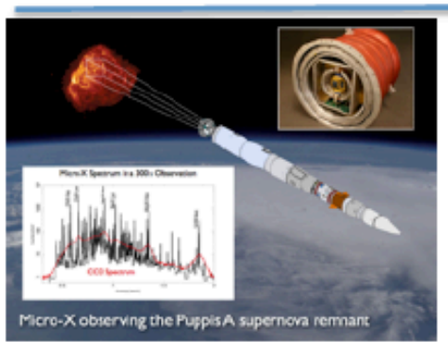
INTEGRAL/ SPI

2.2 keV (FWHM) at 1.33 MeV

http://www.cosmos.esa.int/web/integral/instruments-spi

- Doppler effect

Future



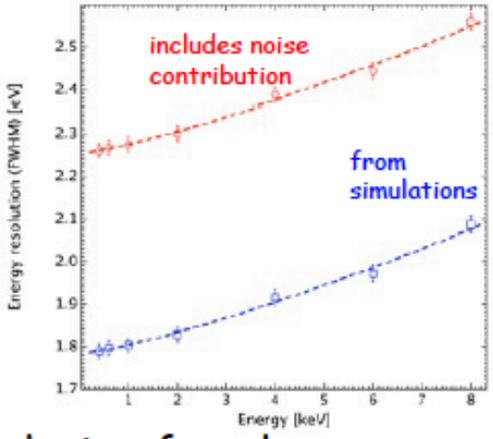
Micro-X

FWHM of 3 eV at 3.5 keV

Figueroa-Feliciano etal. 2015

ATHENA

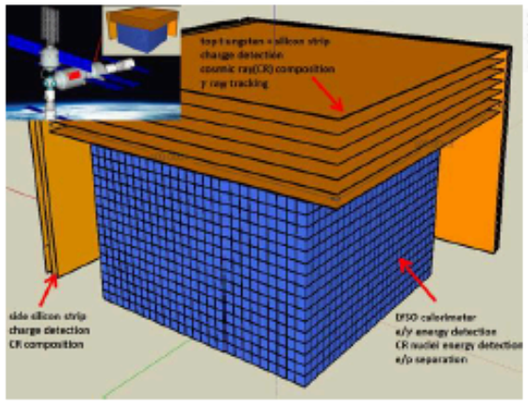
ATHENA X-IFU 1608.08105

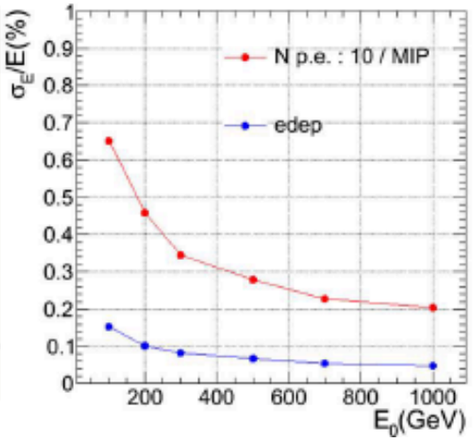


Energy resolution for electrons and gamma will be < 1% at 200 GeV

Wang & Xu Progress of the HERD detector

HERD: High Energy Cosmic Radiation Detection





Dark matter velocity spectroscopy is a promising tool to distinguish signal and background in dark matter indirect detection

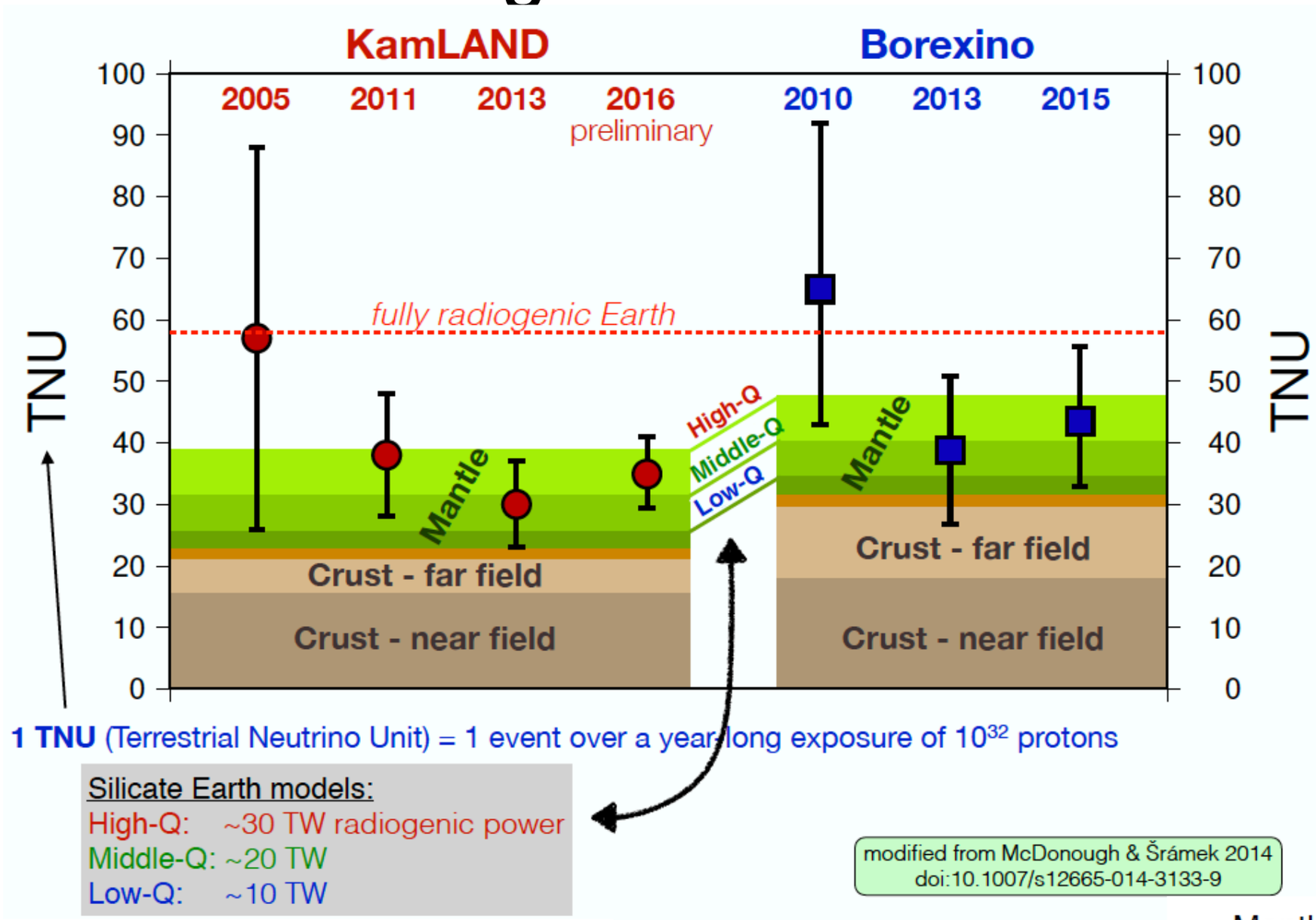
- We see a smoking gun in motion
- Immediate application to the 3.5 keV line
- Future improvements in the energy resolution of telescopes at various energies will result in this technique being widely adopted

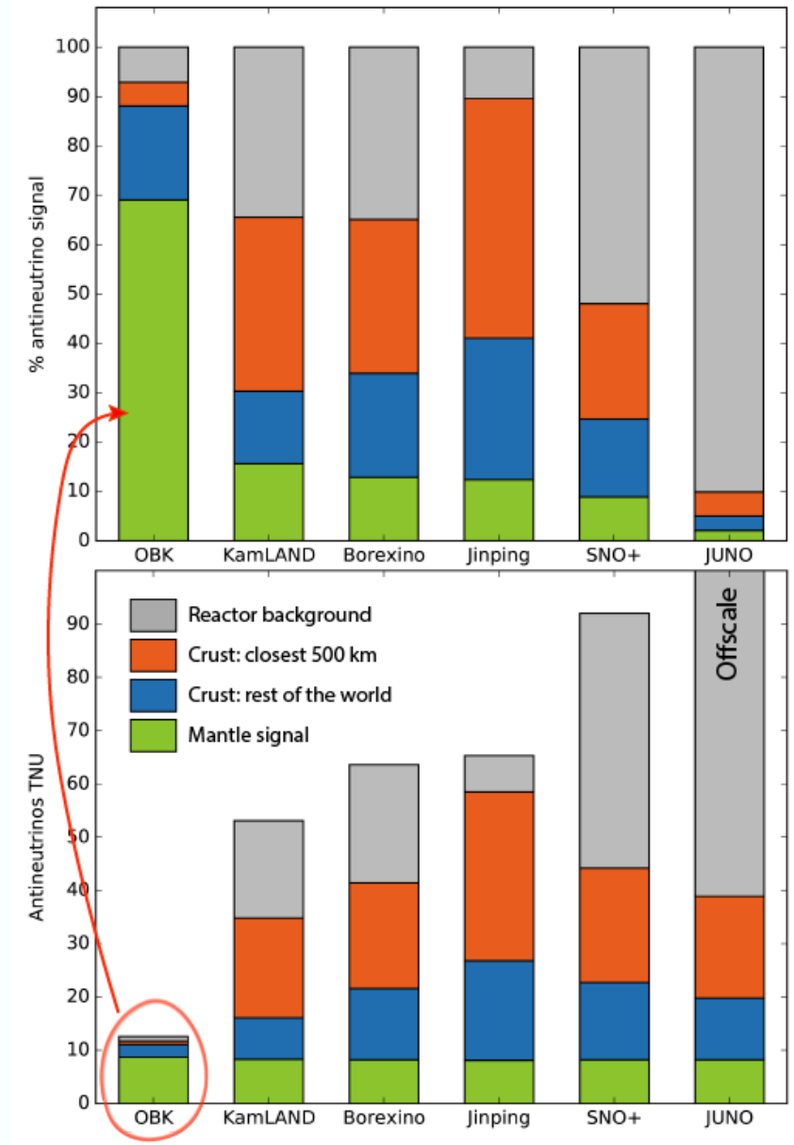
Geo and Solar Neutrinos

OBK

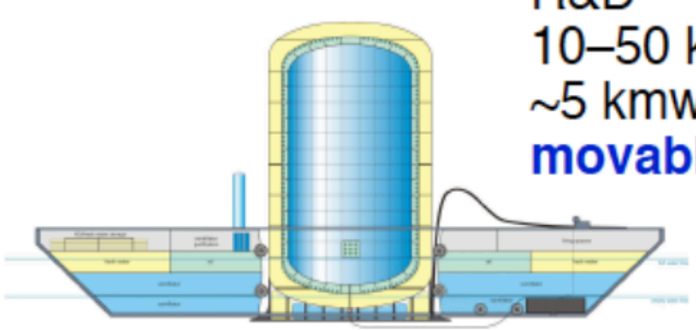
Looking Inward with Neutrinos

John Learned





Ocean Bottom KamLAND

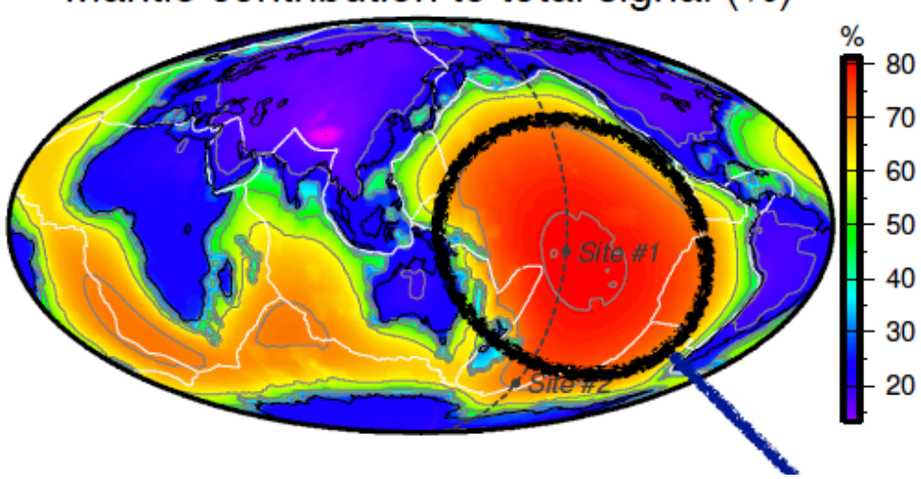


R&D
10–50 kt
~5 kmwe
movable

Requirements:

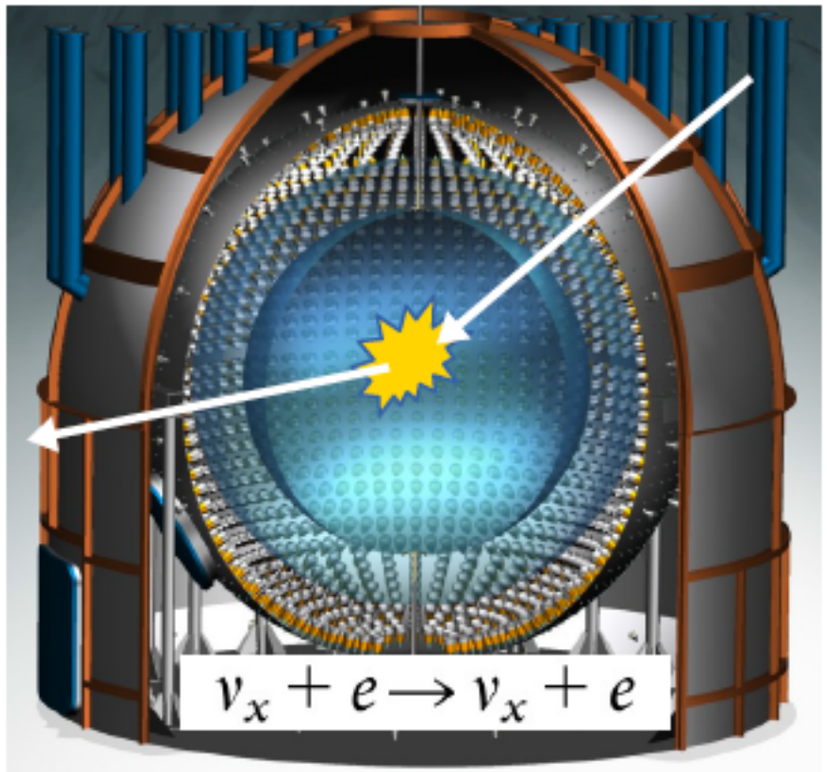
- Deep ocean neutrino detector 10-50 kT
- Filled with ultra pure liquid scintillator
- Viewed by many photodetectors (~10,000)
- Moveable to various ~5km deep locations
- Service-able
- Shore cable for power & communications

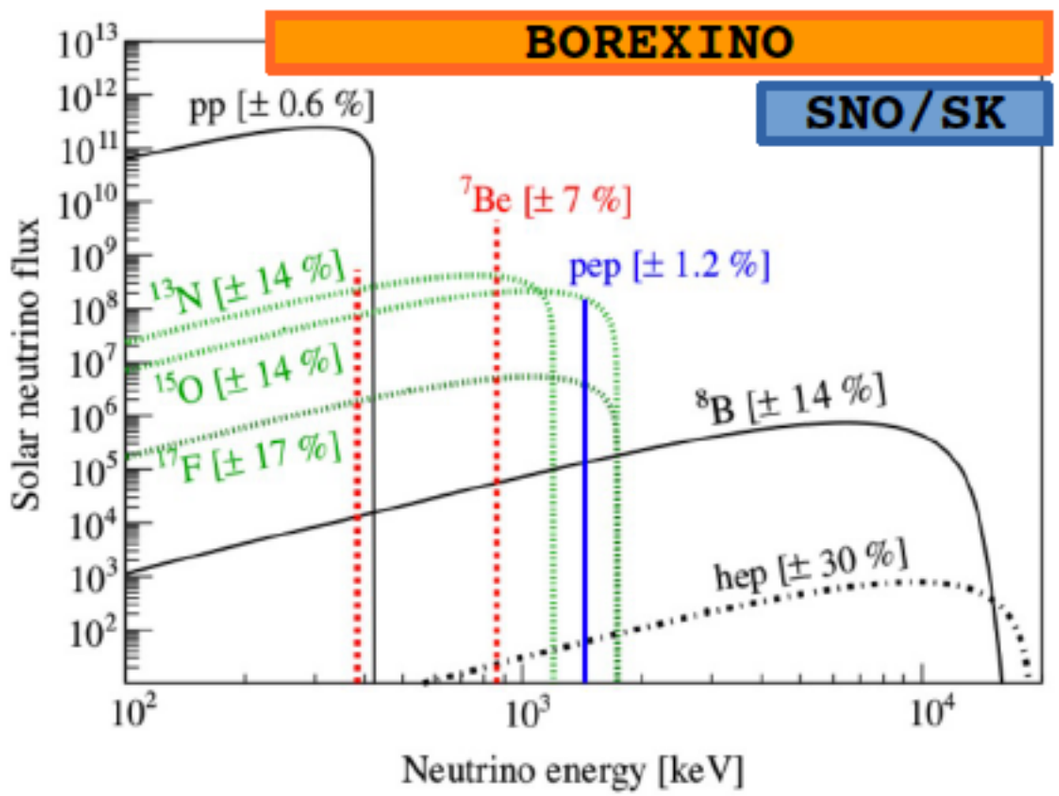
Mantle contribution to total signal (%)



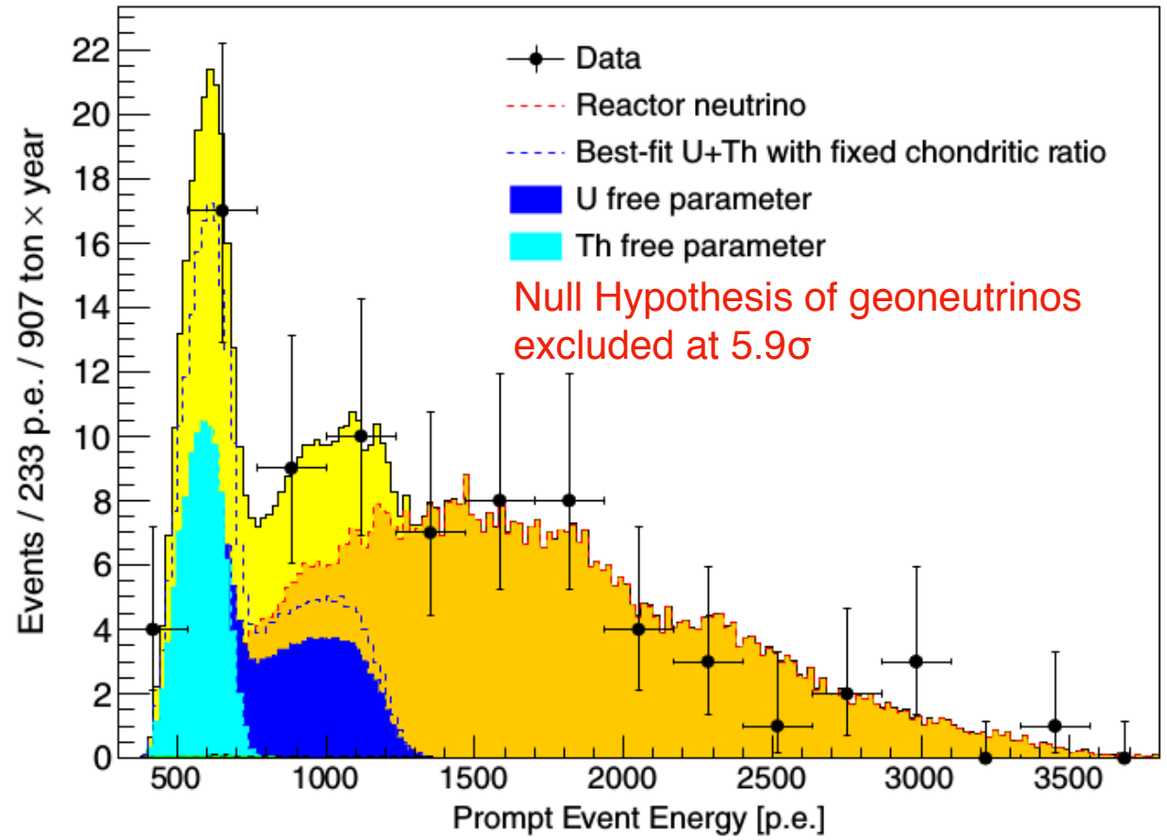
Results from Borexino on Solar and Geo-Neutrino

Francesco Lombardi





Geo-Neutrino

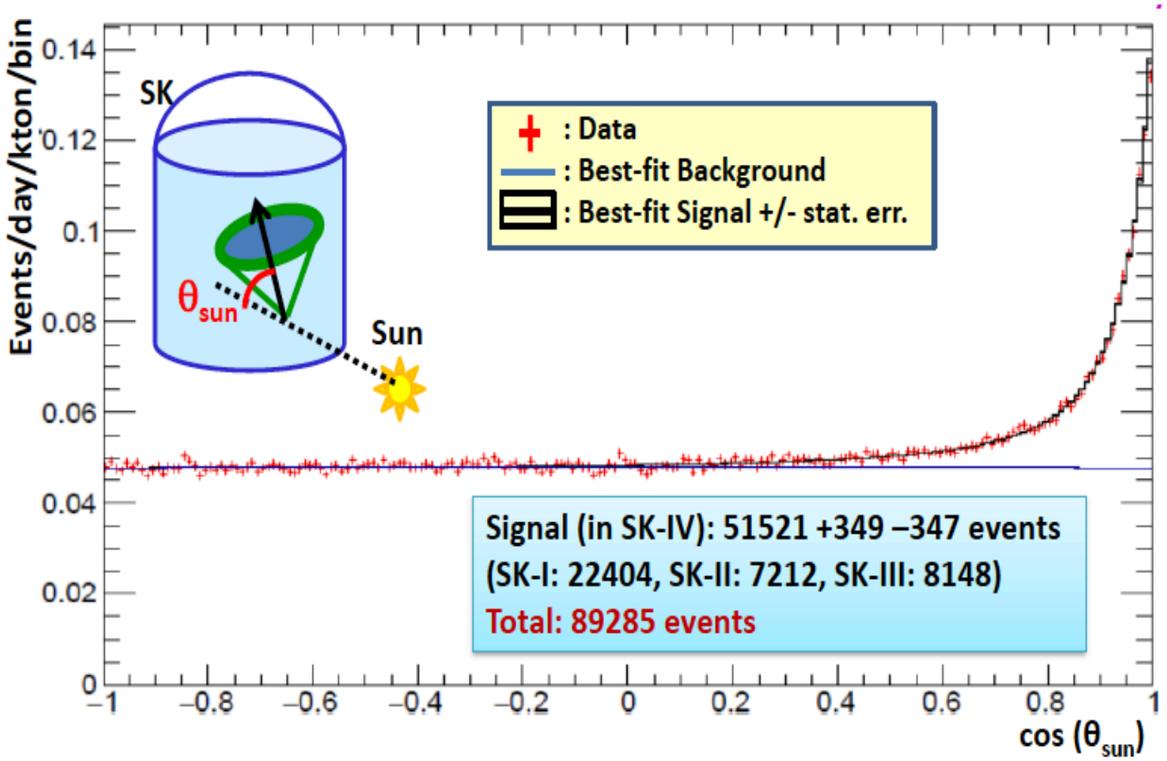


Neutrinos $R(\nu)$ [cpd/100 ton]		
^7Be	46.0	± 1.5 (stat) $^{+1.5}_{-1.6}$(sys)
^8B(3 -16 MeV)	0.22	± 0.04(stat)± 0.01(sys)
pep	3.1	± 0.6(stat)± 0.3(sys)
$CNO(limit)$	< 7.9	–
pp	144	± 13(stat)± 10(sys)

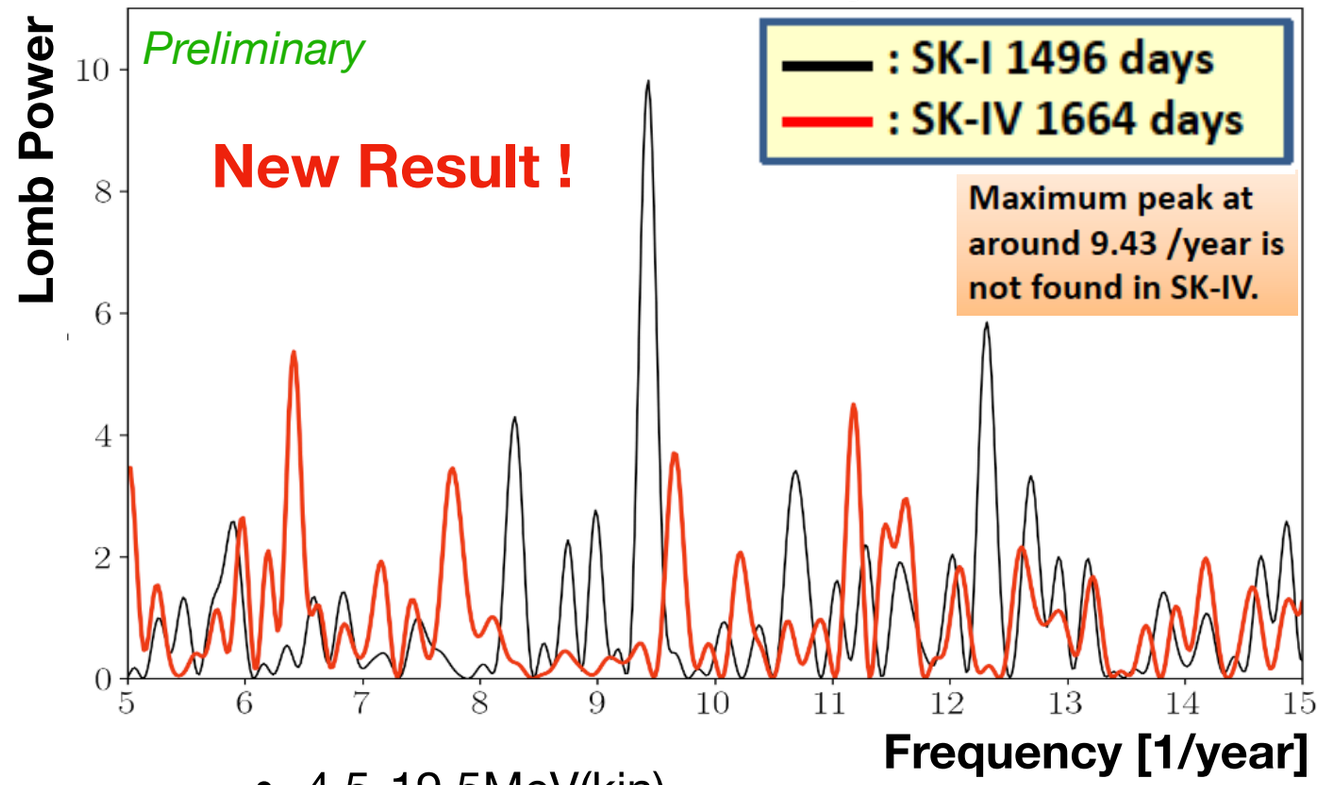
Neutrinos $\Phi(\nu)$ $[cm^{-2}s^{-1}]$		
^7Be $(\times 10^9)$	2.79	± 0.13
^8B $(\times 10^6)$	2.4	± 0.4(stat)± 0.1(sys)
pep $(\times 10^8)$	1.6	± 0.3
CNO $(\times 10^8)$	< 7.7	95% C.L.
pp $(\times 10^{10})$	6.6	± 0.7

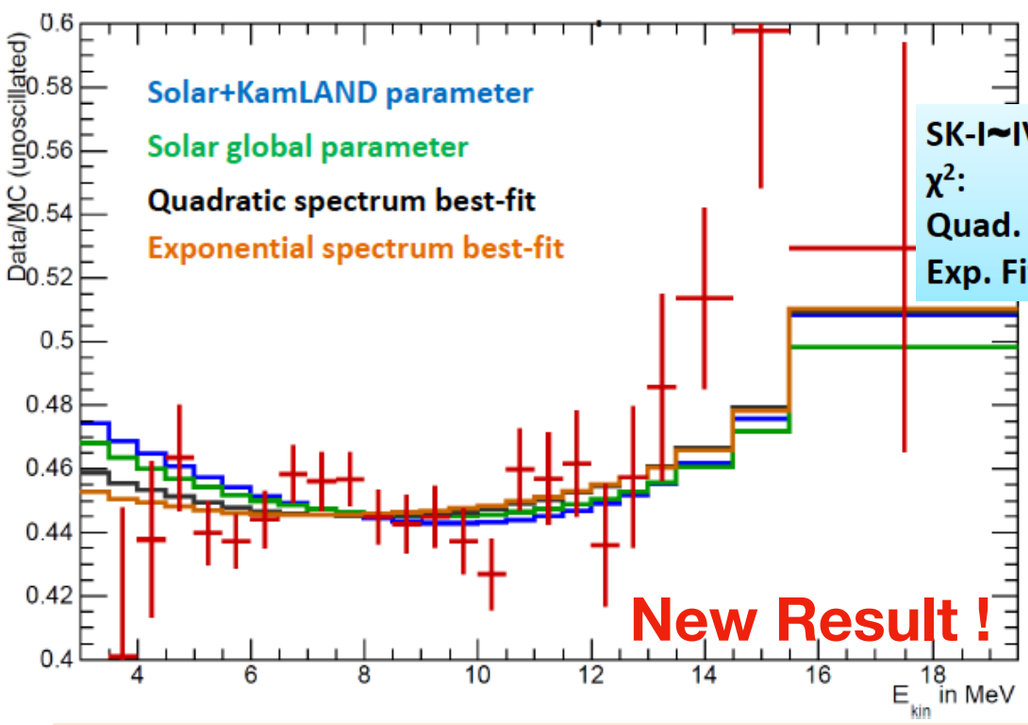
Astrophysical Neutrinos at Super-Kamiokande

Yasuo Takeuchi



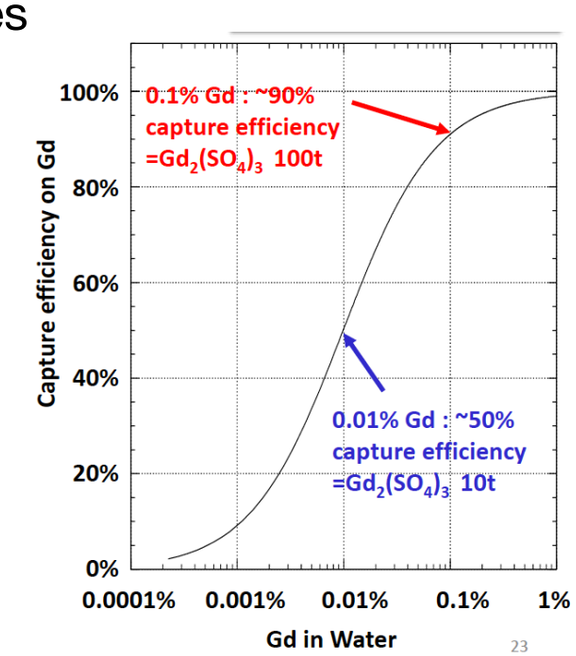
Periodic Modulation Analysis in SK-IV





- 4.5-19.5MeV(kin)
- 5-day long samples

- Next detector upgrade for SK-Gd is expected to start in 2018



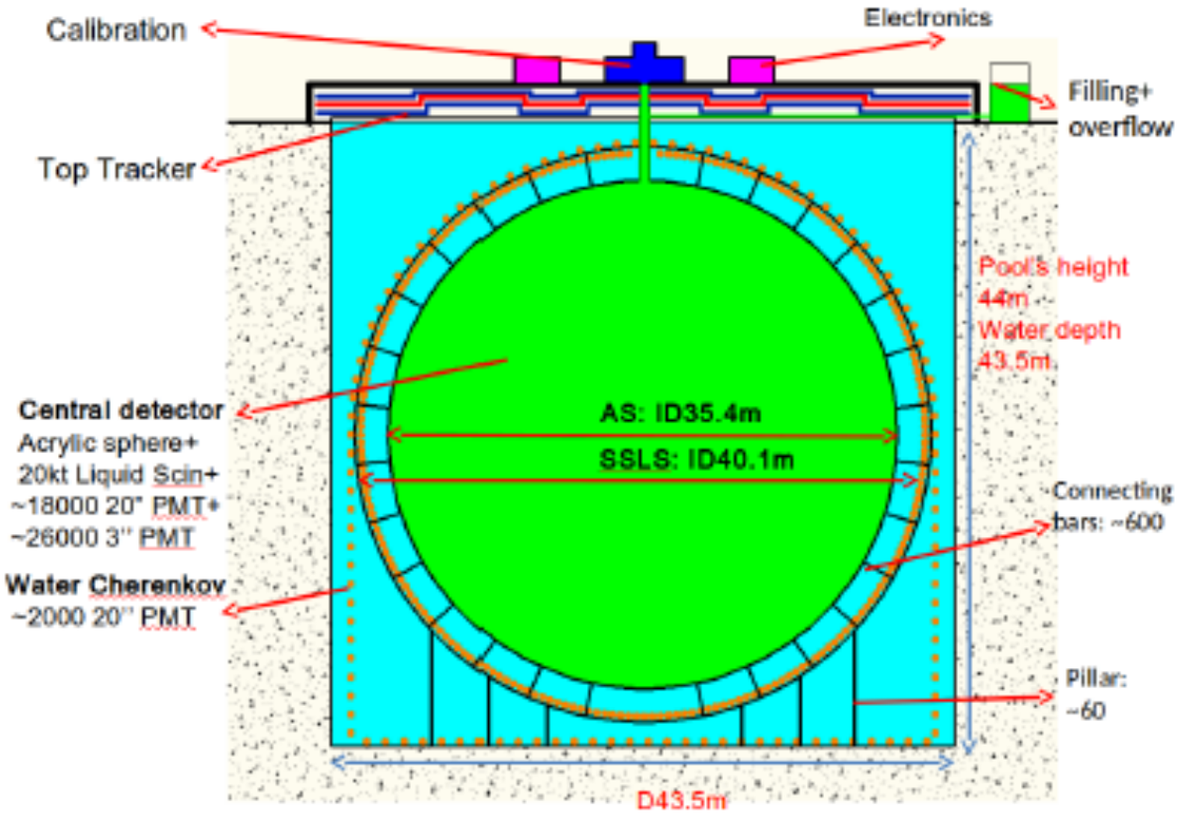
SK spectrum is consistent within ~1 sigma with the MSW upturn for the solar best fit parameters, and marginally consistent within ~2 sigma with the MSW upturn for the solar+KamLAND best fit parameters.

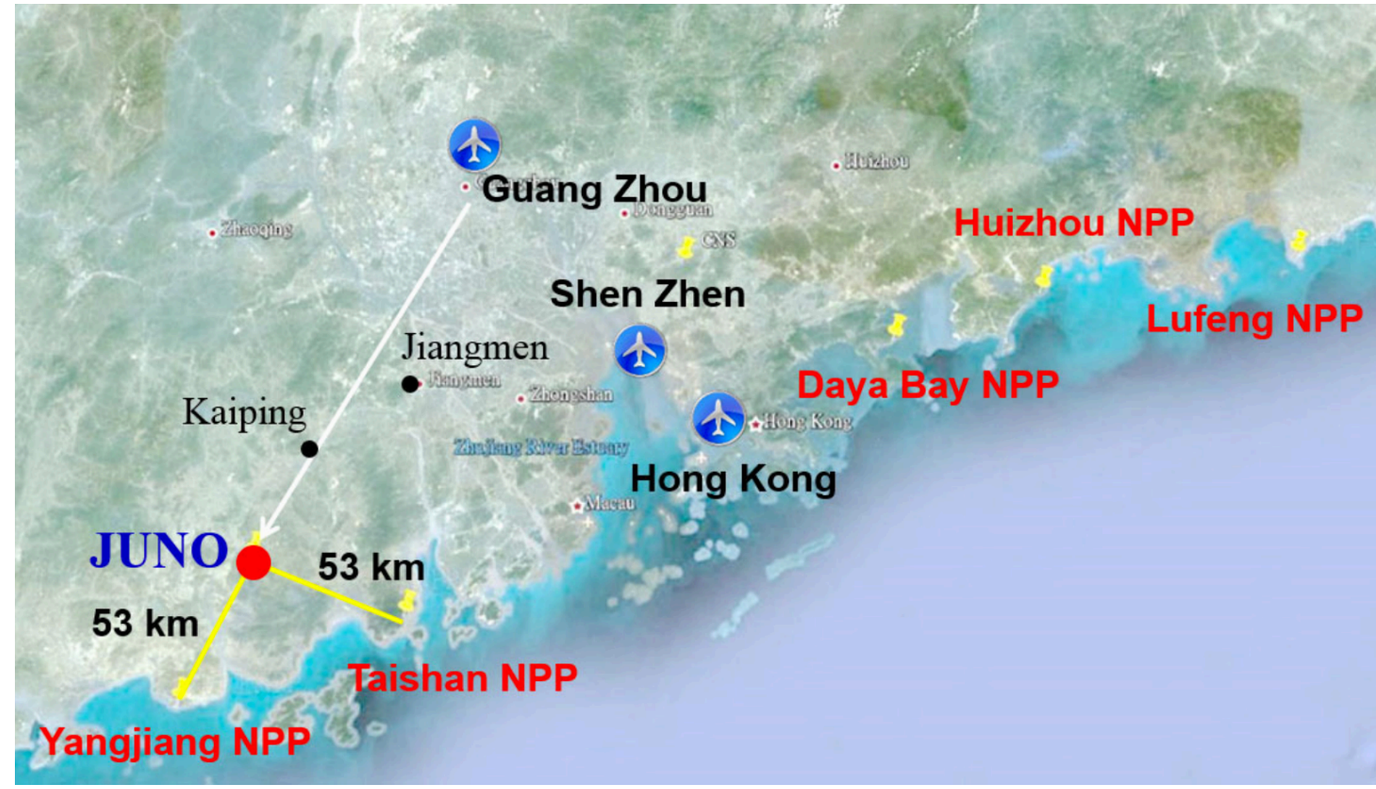
see talk by Nakahata

Supernova Neutrinos

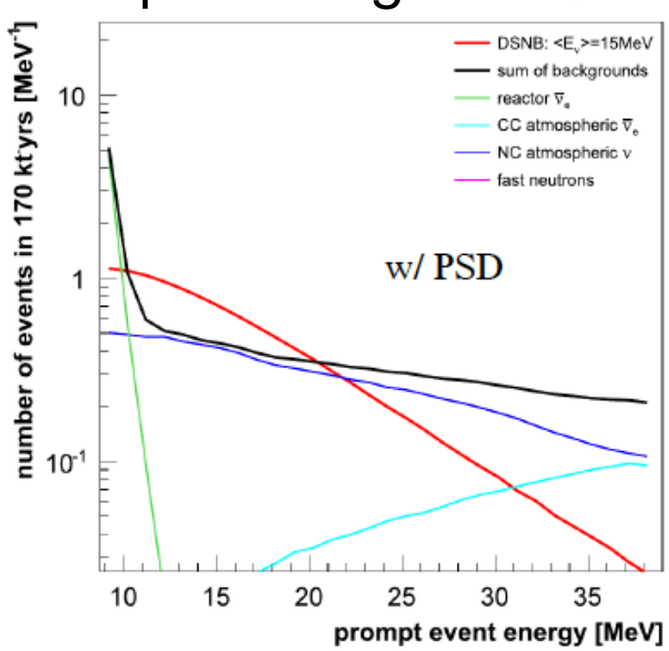
Supernova Neutrinos with the JUNO Experiment

Huiling Li

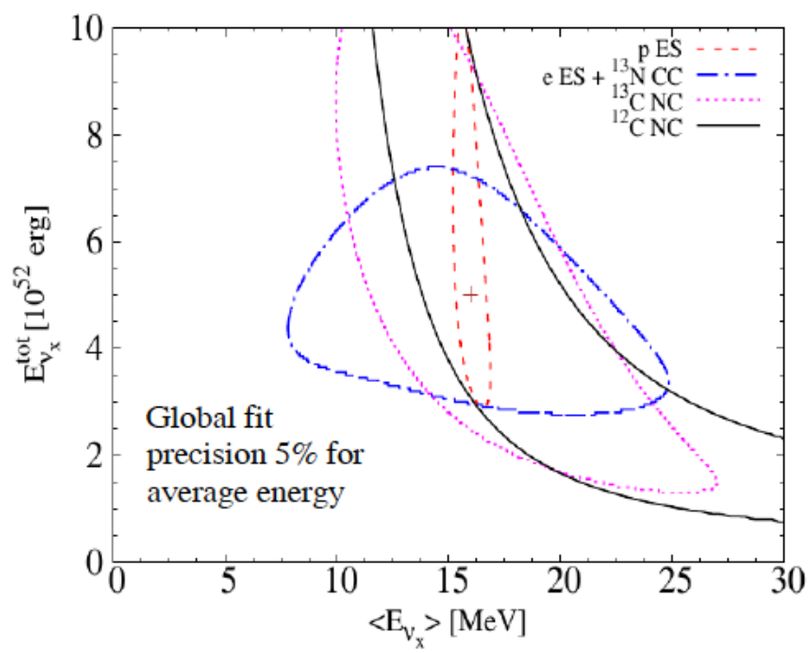




Also promising for DSNB



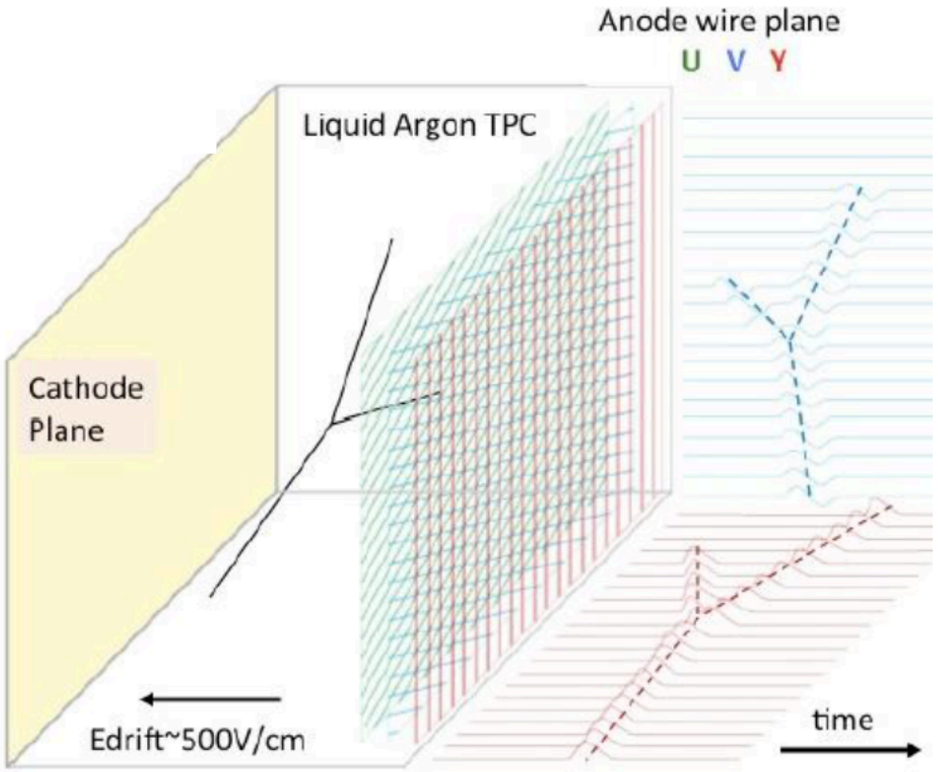
J.S Lu et al. Phys. Rev. D 94, 023006

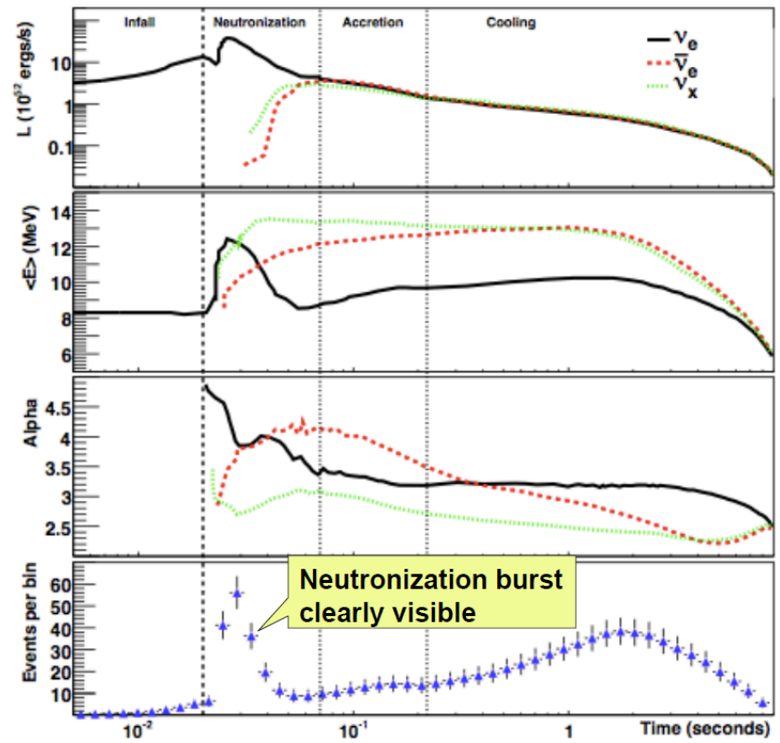


- 700m underground
- 20kt LS
- plan to start data taking in 2020
- Sensitivity to $\bar{\nu}_e$, ν_e, ν_x

Supernova Neutrinos, Proton Decay and Atmospheric Neutrinos at DUNE

Juergen Reichenbacher



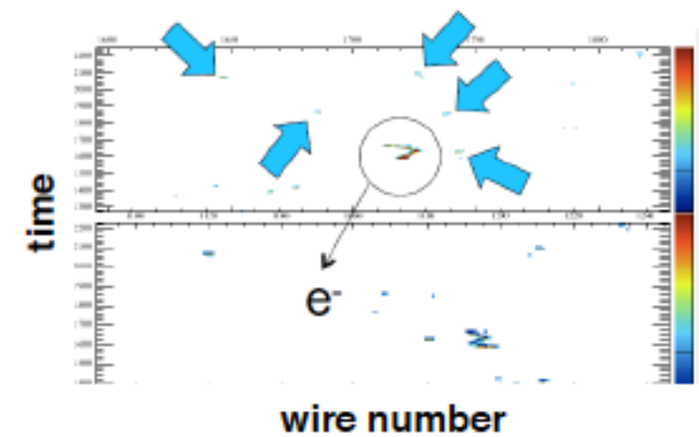


Flux from Huedepohl et. al, PRL 104 (2010) 251101 @ 10 kpc

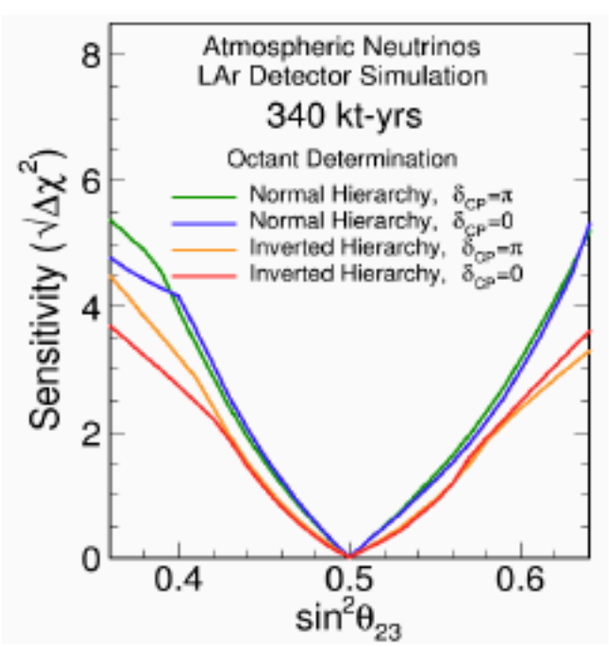
Charged-current absorption:

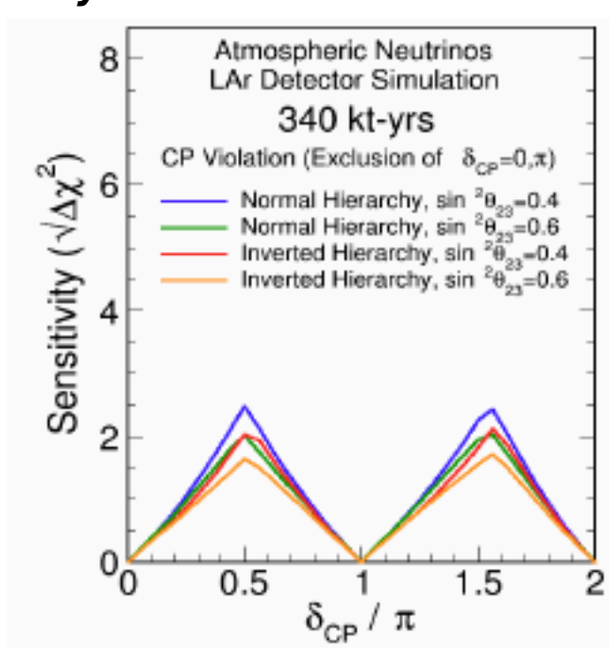
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$

Can we tag ν_e CC interactions in argon using nuclear deexcitation γ's?

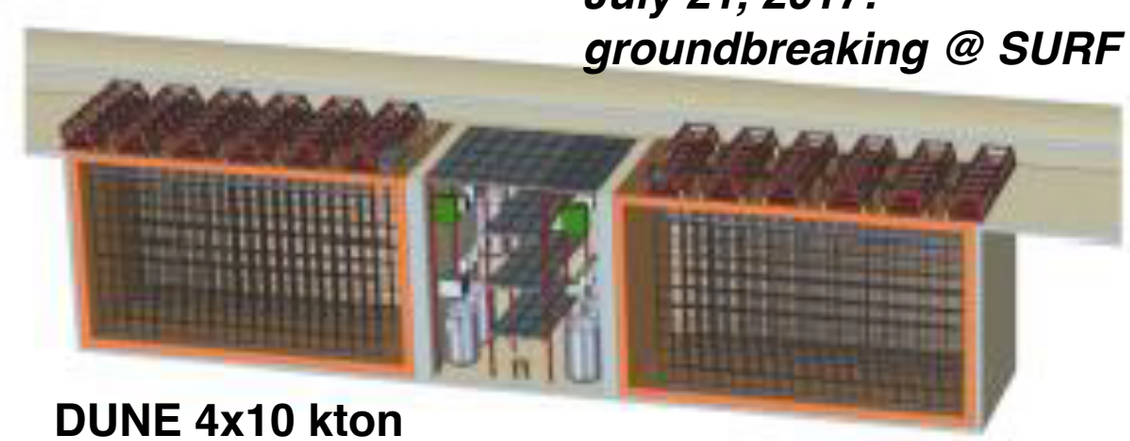


Moderate sensitivity to octant and dCP





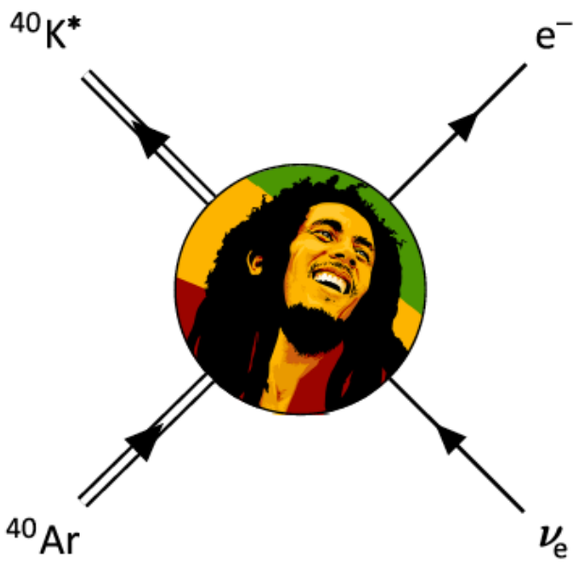
July 21, 2017: groundbreaking @ SURF



DUNE 4x10 kton

An event generator for supernova neutrinos in argon

Steven Gardiner



Model of Argon Reaction Low Energy Yields

Bob Marley illustration by Zero Anixter

Reconstructing true neutrino energy:

Q is determined by measuring de-excitation gammas and nucleons

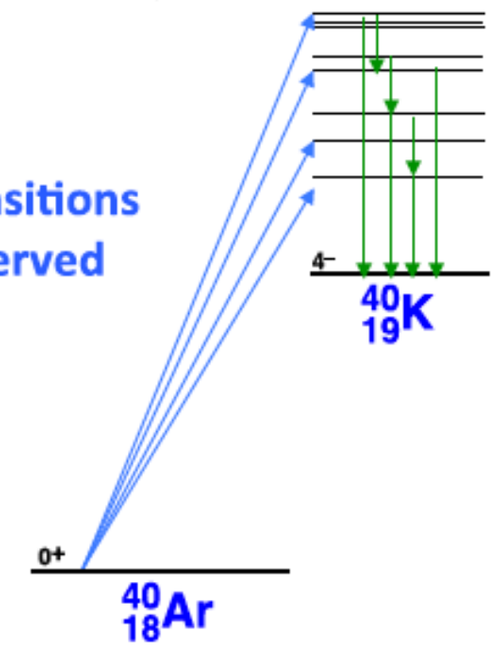
Outgoing e⁻ Energy — Energy donated to transition — Recoil Energy of Nucleus (negligible)

$$E_\nu = E_e + Q + K_{\text{recoil}}$$

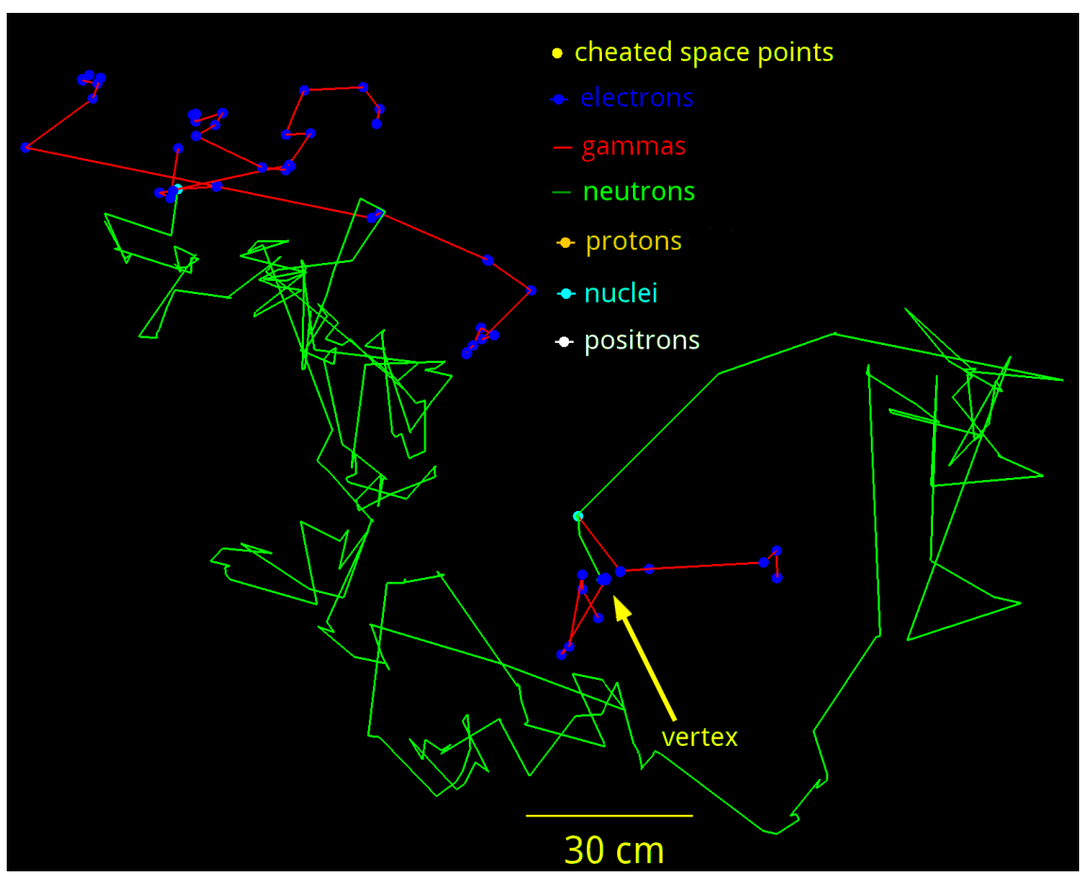
Charged-current absorption:

$$\nu_e + {}^{40}\text{Ar} \rightarrow {}^{40}\text{K}^* + e^-$$

At least 25 transitions have been observed indirectly



Transition levels are determined by observing de-excitations (γ's and nucleons)



Nuclear effects greatly complicate supernova neutrino event reconstruction in argon

- MARLEY is a new generator specifically targeting supernova neutrinos in ^{40}Ar
- Studies are underway to learn how to reconstruct these events in DUNE

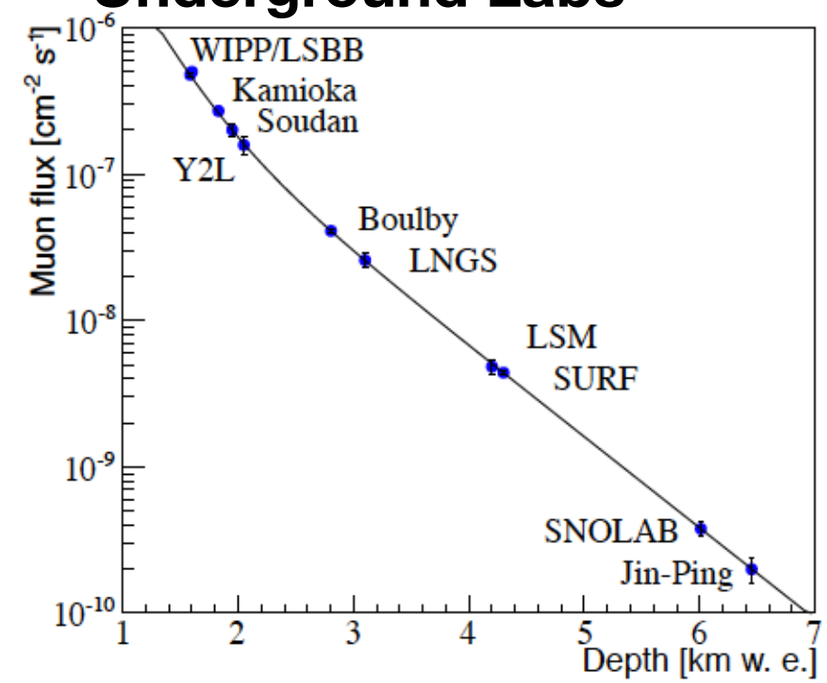
Dark Matter Direct

many details in talk by Jodi Cooley

Dark Matter Direct Detection

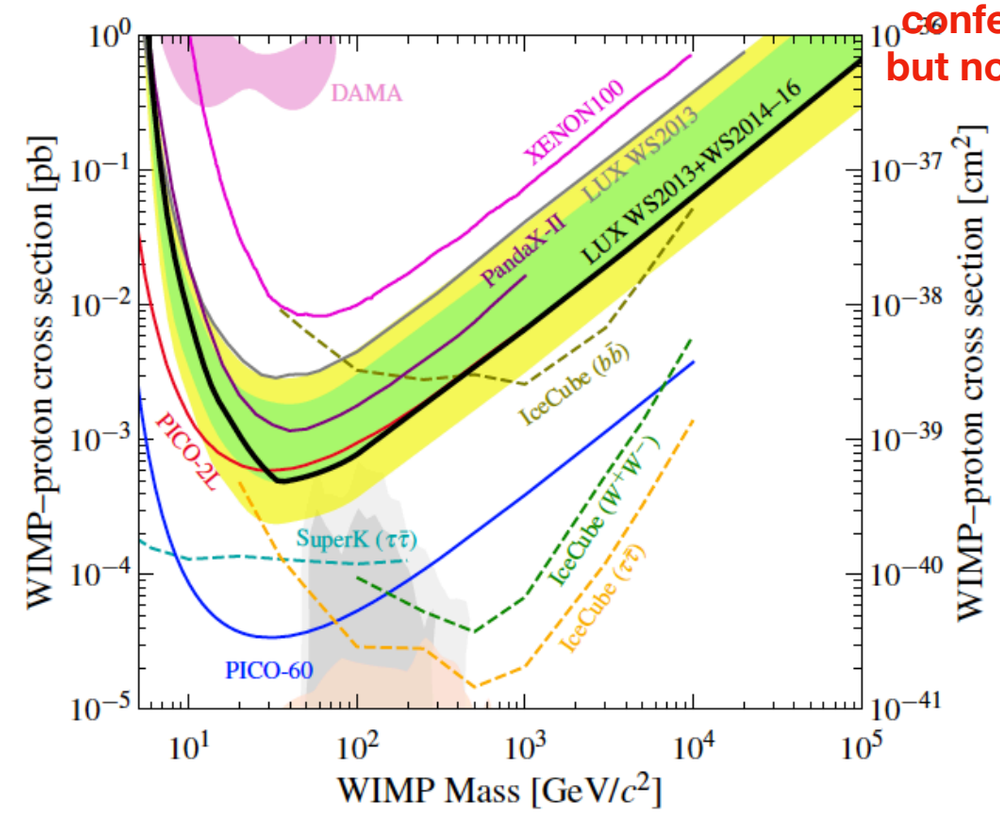
- Liquid Nobel Gases making rapid progress
  - Moving towards multi ton scales
  - Neutrino Floor in reach
- Bubble Chambers proves to be extremely competitive for SD searches (PICO, …)
- Impressive progress in exploring light DM region with cryogenic detectors (CRESST-III, CDMSLite, …)
- DAMA Anomaly to be resolved in the near future
- Directional DM to go below the neutrino floor

Underground Labs



LUX Collaboration 1705.03380

Not at this conference but note also

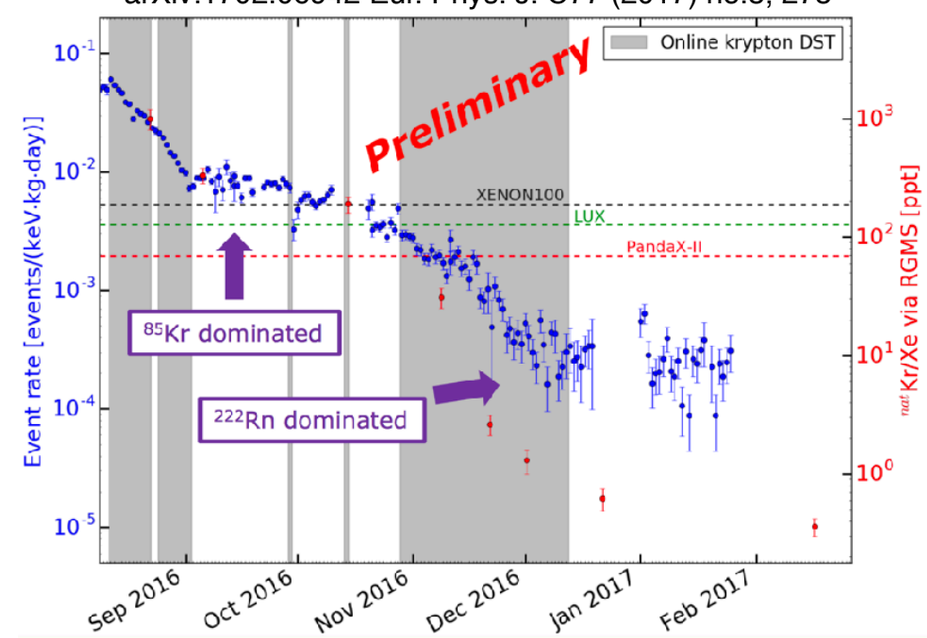


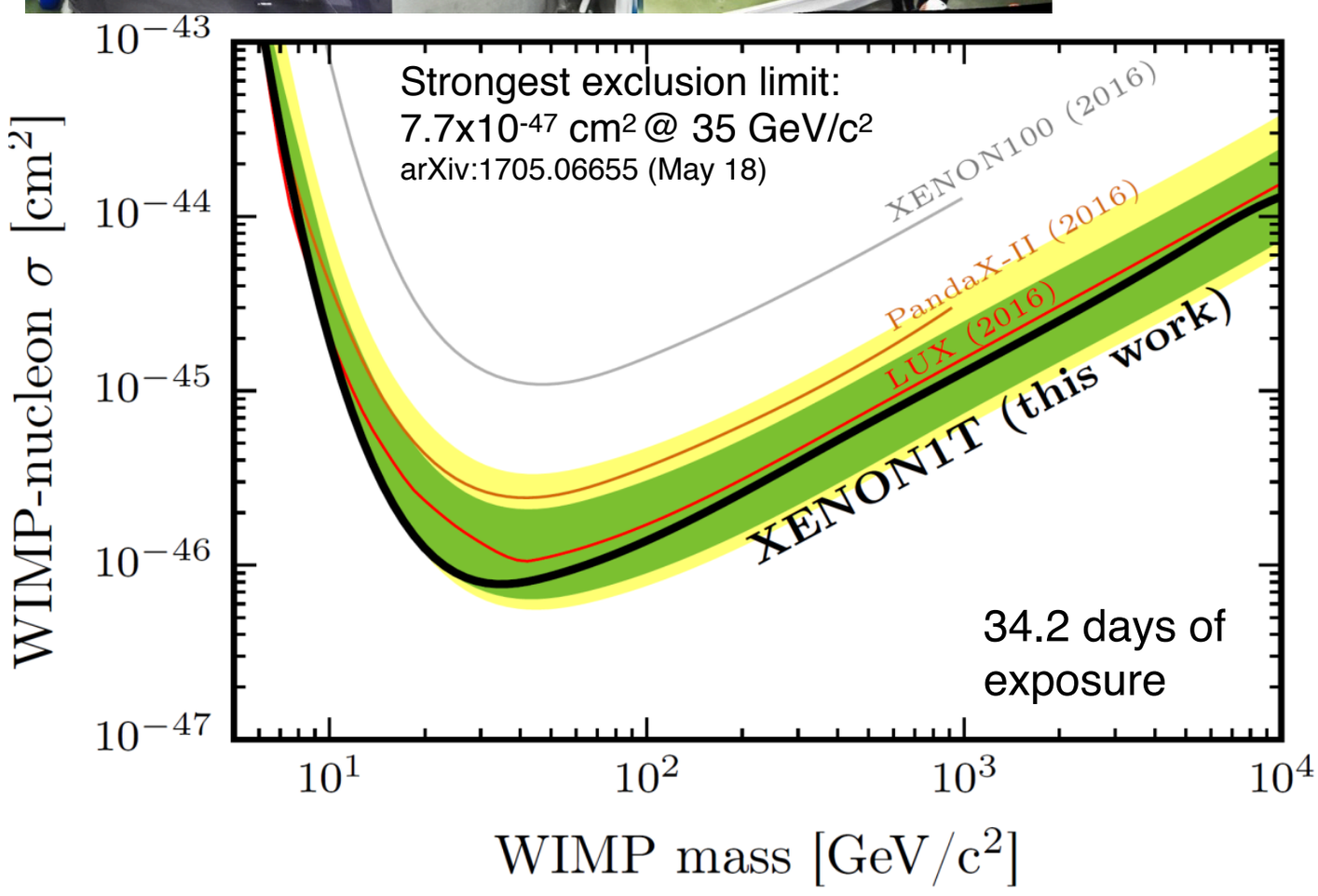
FIRST RESULTS FROM THE XENON1T EXPERIMENT

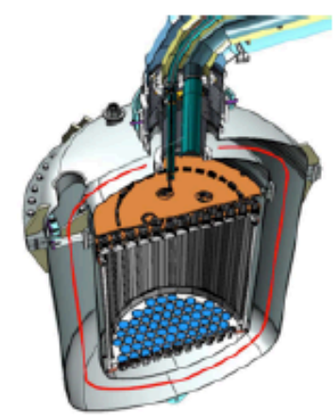
Sara Diglio

Active removal of Kr contamination in Xe

arXiv:1702.06942 Eur. Phys. J. C77 (2017) no.5, 275





XENON1T 2012 – 2019	XENONnT 2017 – 2023	DARWIN ~2023 –
		
Total mass : 3.2 t	Total mass : ~8 t	Total mass : ~50 t
Target mass: 2 t	Target mass: ~6 t	Target mass: ~40 t
Drift TPC: 96 cm	Drift TPC: 144 cm	Drift TPC: 260 cm
Sensitivity ~ 10^{-47}cm^2	Sensitivity ~ 10^{-48}cm^2	Sensitivity ~ 10^{-49}cm^2

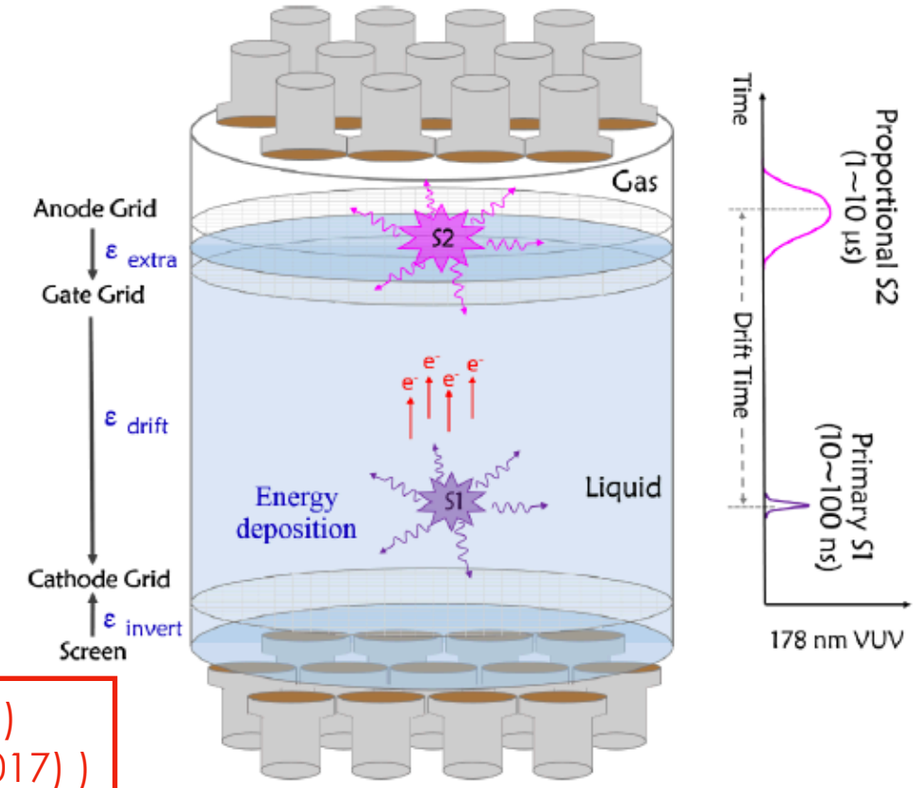
PANDA X

Particle and Astrophysical Xenon Experiments

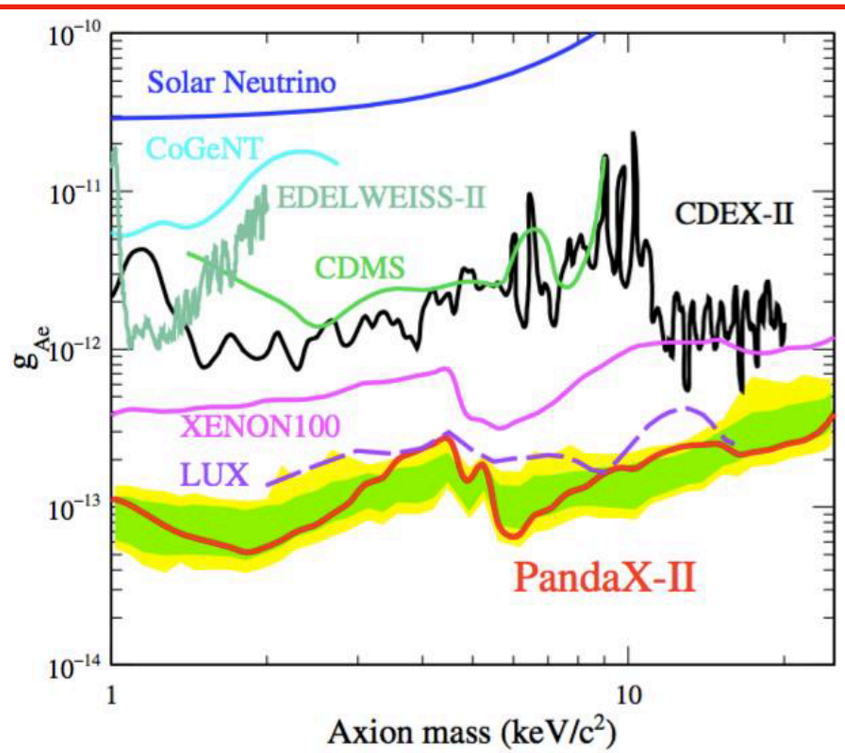
Dark matter search results from the PandaX-II experiment

Mengjiao Xiao

- **H=60 cm, ∅ = 60 cm**
- **More than Larger Volume:**
  - New IV: inner vessel with clean low radioactive Stainless steel
  - New PMTs: 55+55, 3-inch high QE (R11410) and improved base with split ±HV power.
  - New Veto: PMTs in skin region
  - Better Reflector: improved reflectivity of PTFE, etc.

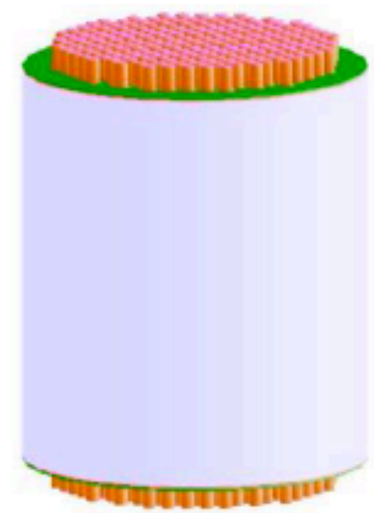


Current SI bound **2.5×10^{-46}cm^2** @ 40 GeV/c^2 (Phys. Rev. Lett. 117, 121303 (2016))
SD bound / χ-n limit: **4.1×10^{-41}cm^2** @ 40 GeV/c^2 (Phys. Rev. Lett. 118, 071301 (2017))

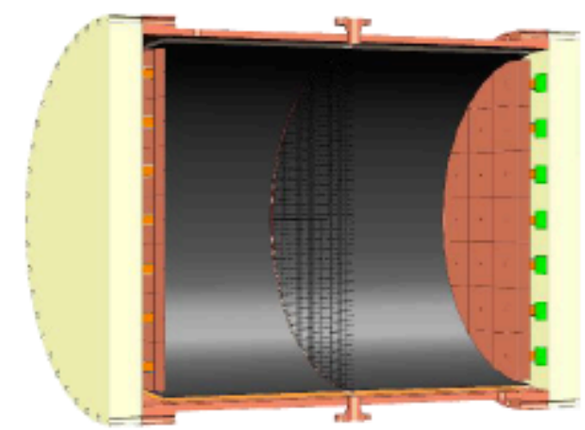


upper limits are set to Solar and Galactic ALP, paper is coming soon

PandaX-II: 500 kg DM experiment
2014-2018



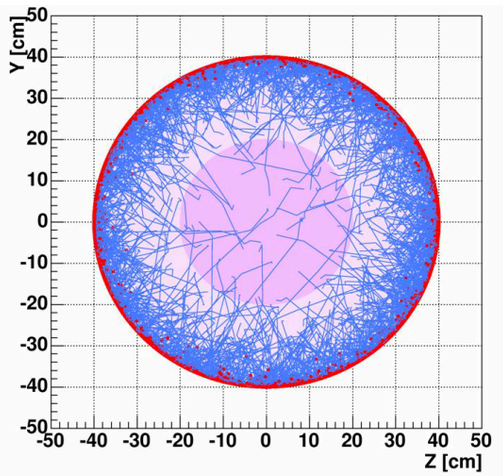
PandaX-xT: multi-ton (~4-T) DM experiment
future



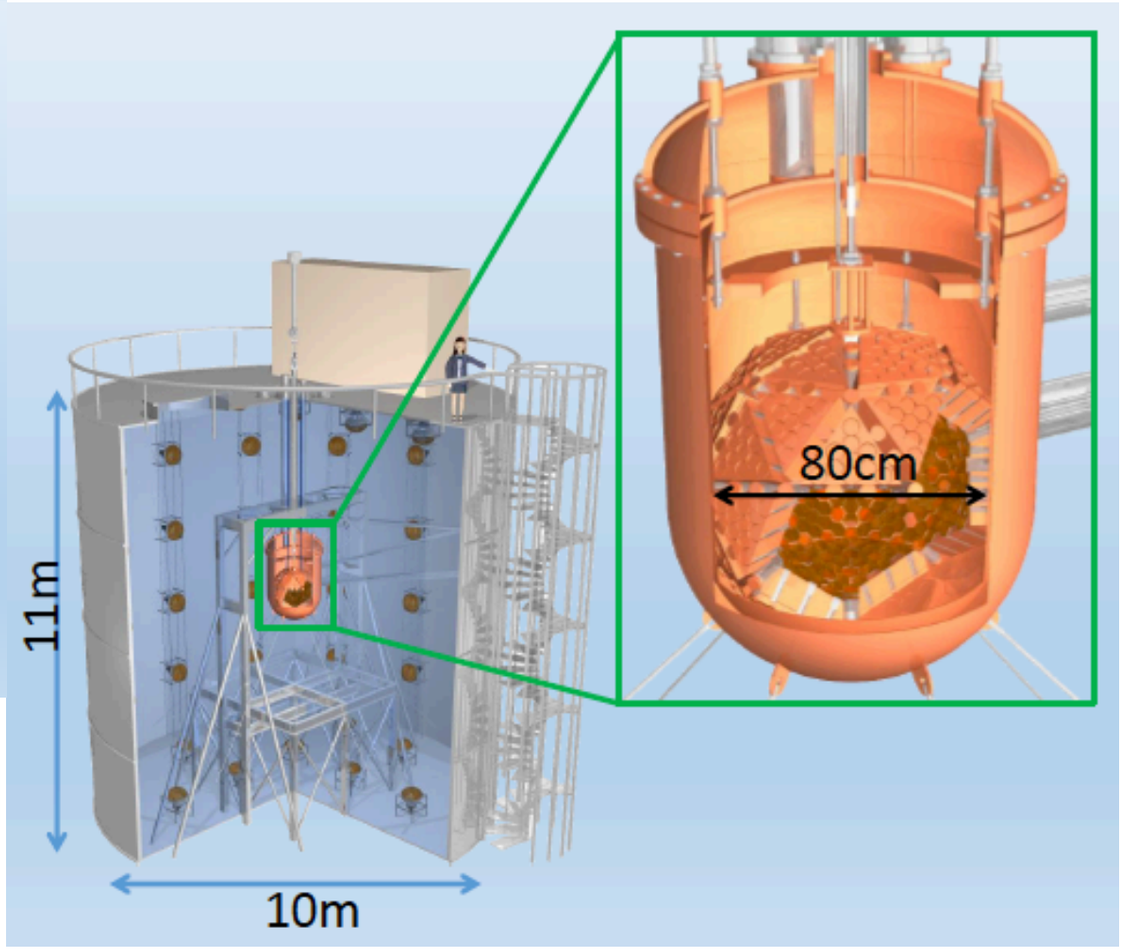
PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0νDBD experiment
future

Recent results from XMASS

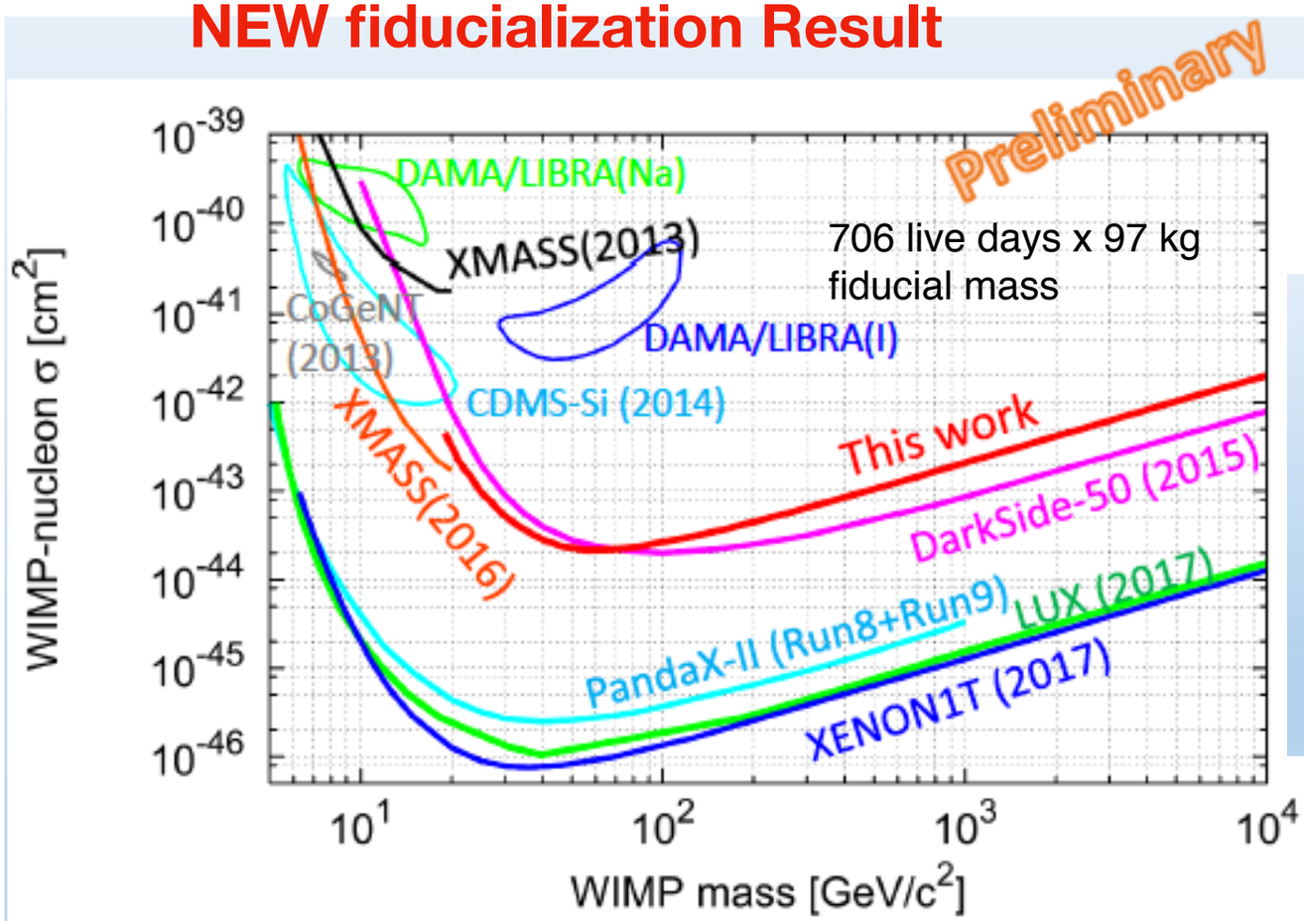
Katsuki Hiraide



- Liquid xenon detector
  - 832 kg of liquid xenon (-100 °C)
  - 642 2-inch PMTs (Photocathode coverage >62%)
  - Each PMT signal is recorded by 10-bit 1GS/s waveform digitizers
- Water Cherenkov detector
  - 10m diameter, 11m high
  - 72 20-inch PMTs
  - Active shield for cosmic-ray muons
  - Passive shield for n/γ



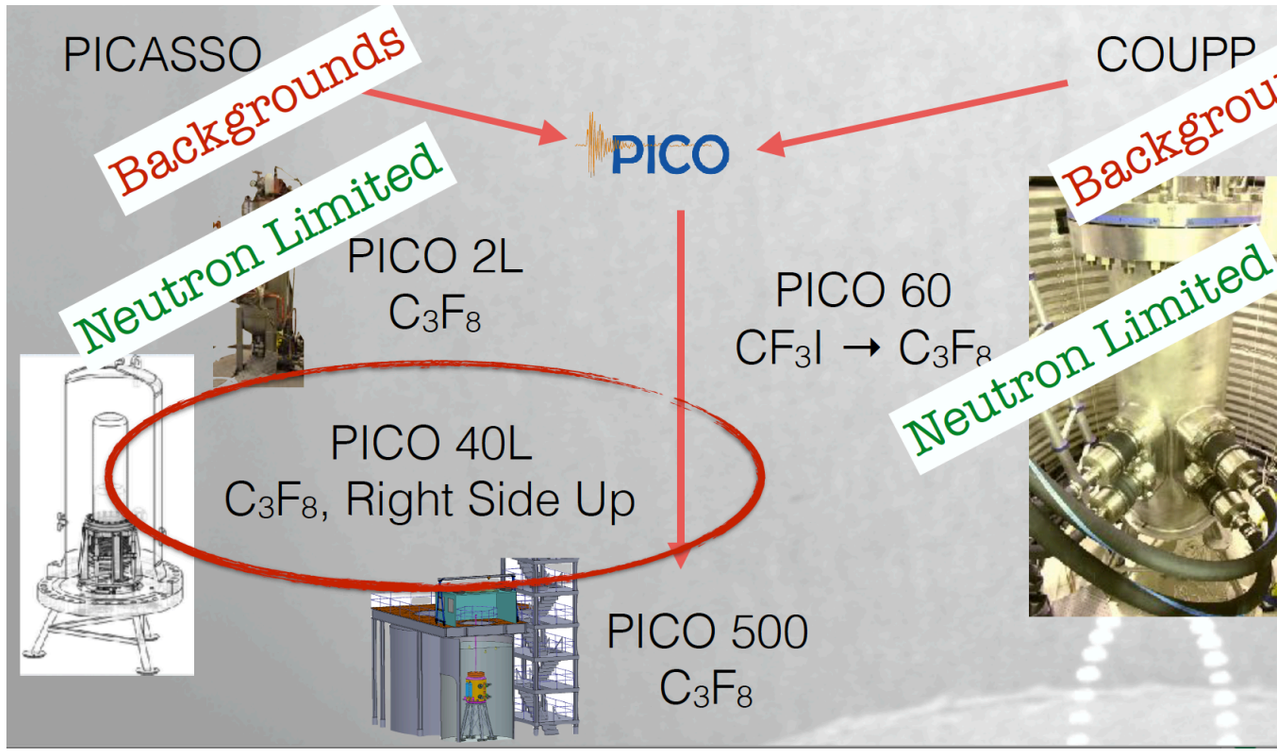
NEW fiducialization Result

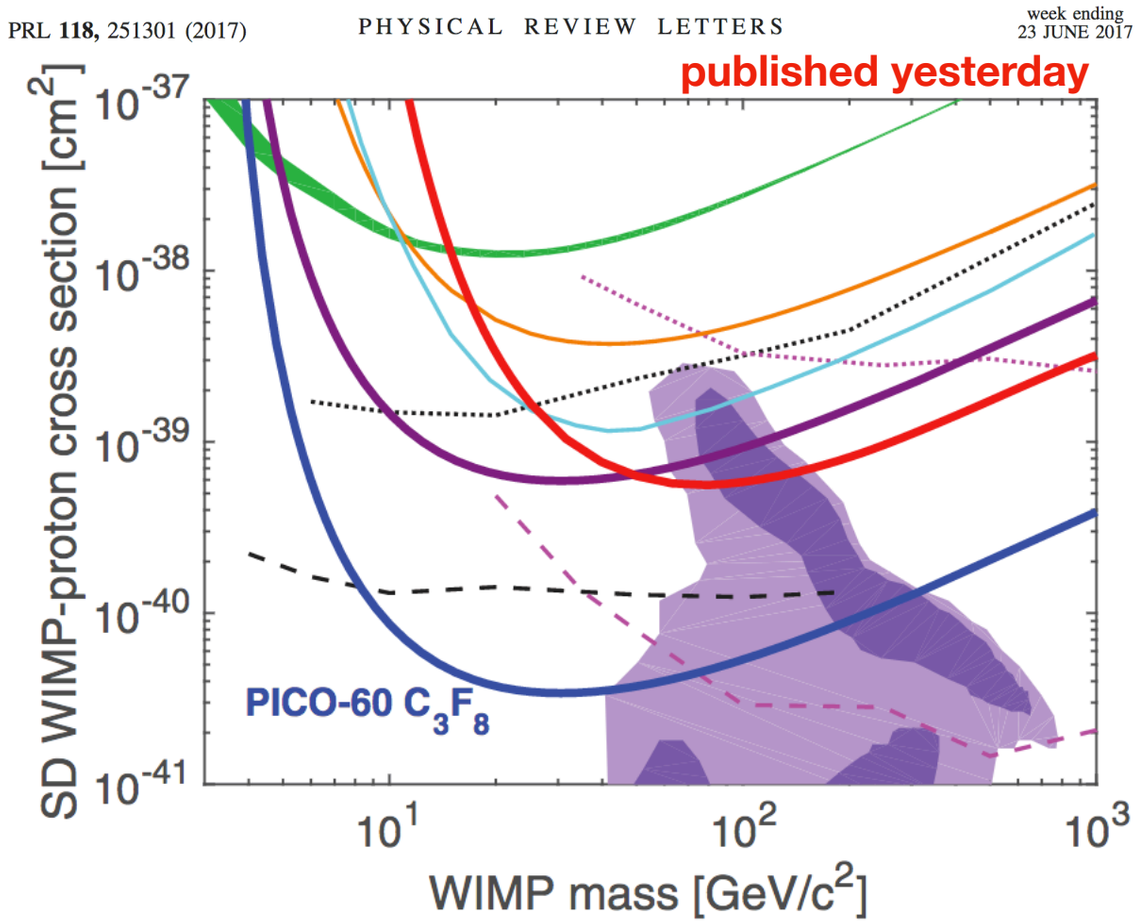


- XMASS is a multi-purpose experiment using liquid xenon.
- Annual modulation search
  - With 1-year of data, no significant modulation was observed.
  - Results from 2.7 years of data will come soon.
- WIMP search by fiducialization
  - 706 live days x 97 kg fiducial mass
  - Limit on SI WIMP-nucleon cross section $\sigma<2.2\times10^{-44}$ cm² for 60 GeV/c²
- XMASS is waiting for neutrinos from galactic supernovae
- More physics results will be presented at coming summer conferences.

Bubble Chambers for Dark Matter Searches and Recent PICO 60 Results

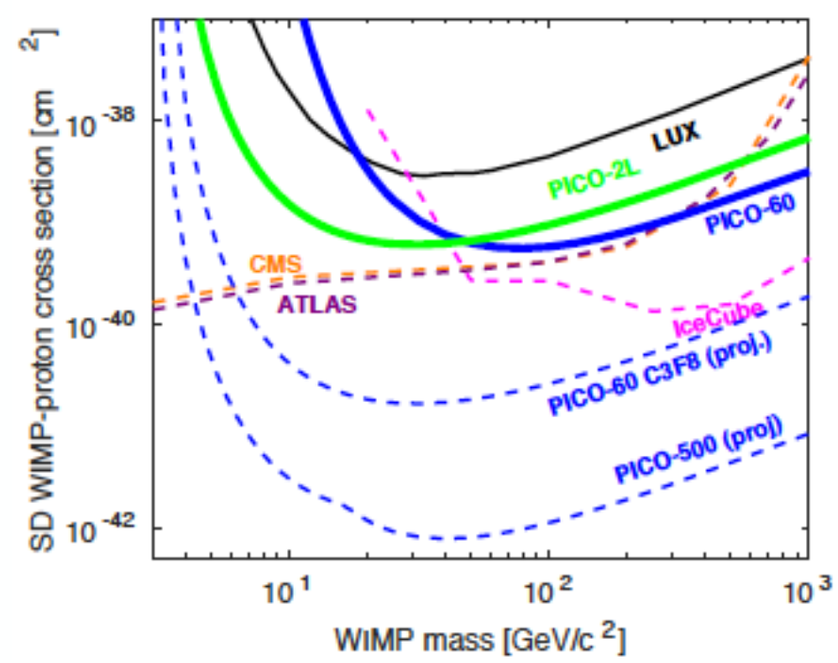
Carsten Krauss





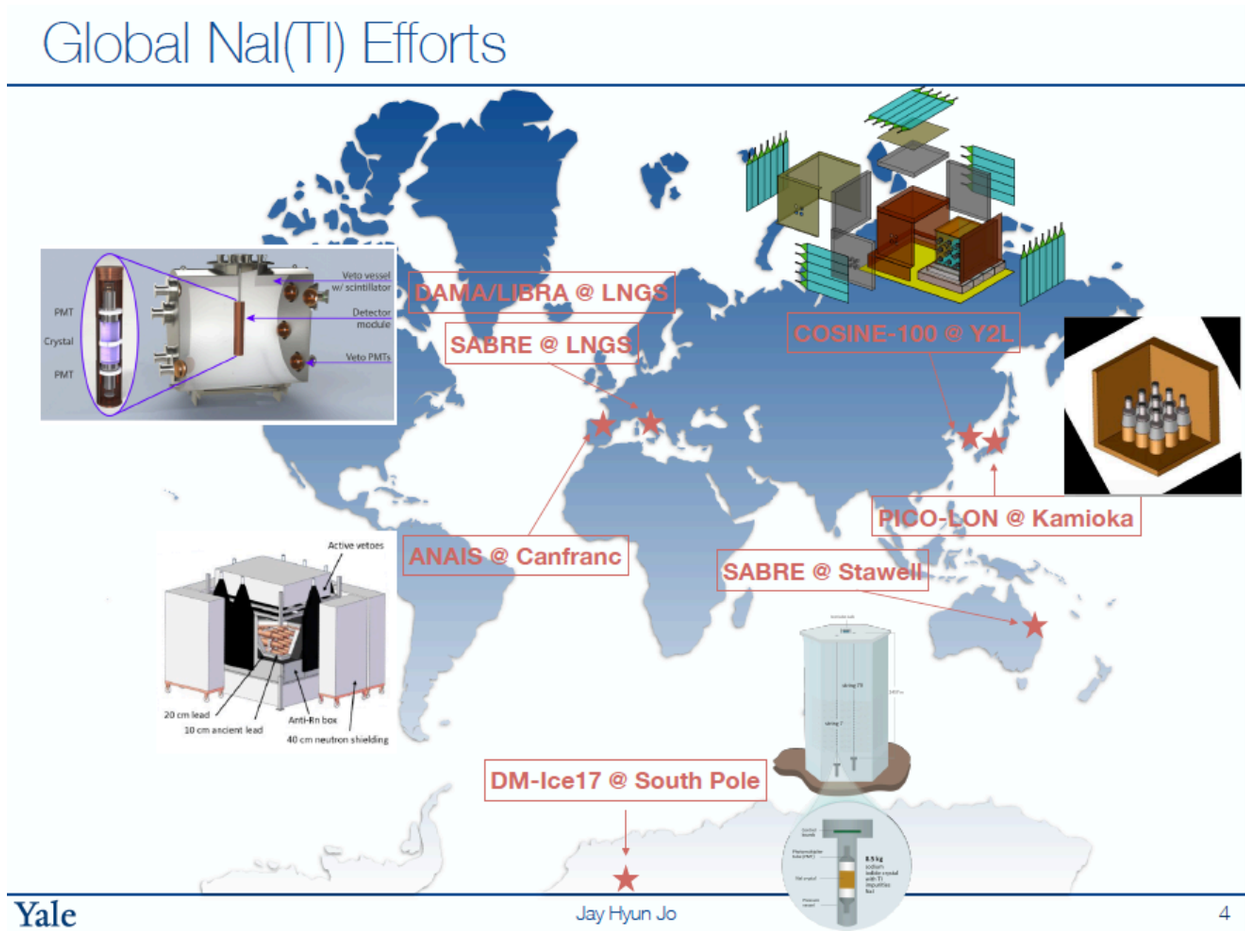
PICO 40L is expected to be operational by the end of the year 2017

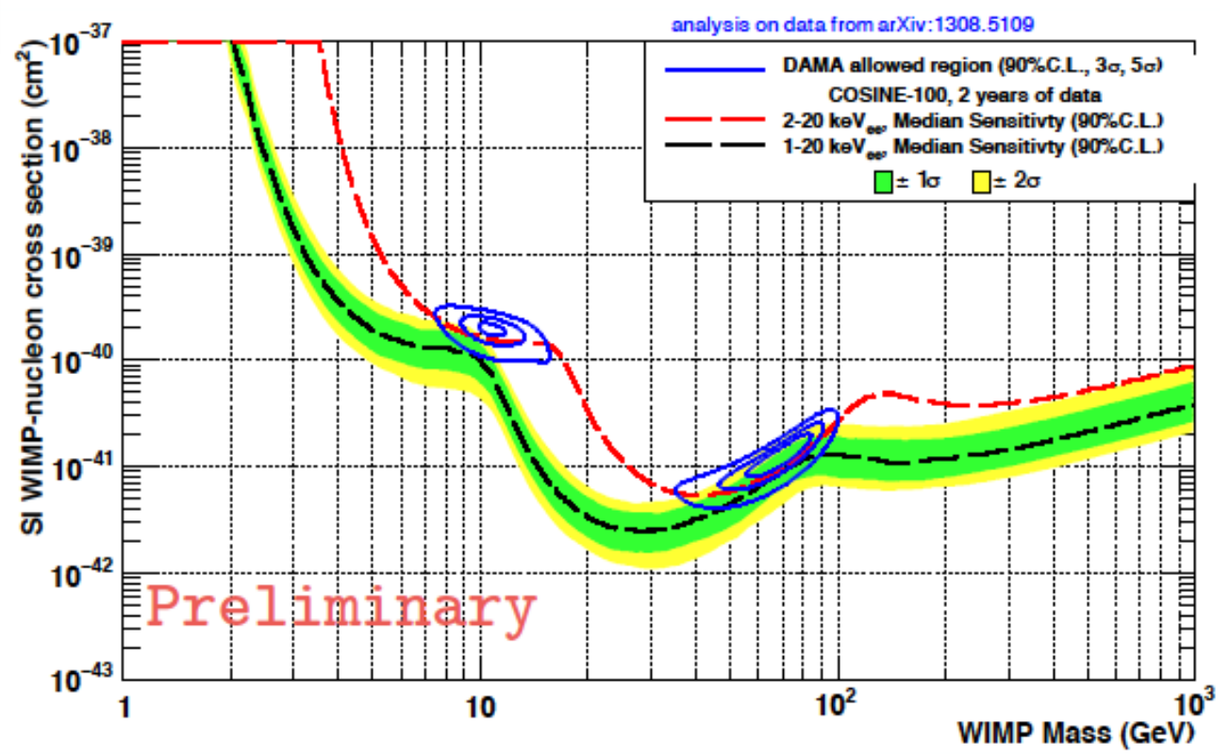
PICO 500 will explore the ultimate sensitivity of a low background bubble chamber



Status of the COSINE-100 Dark Matter Experiment

Jay Hyun Jo



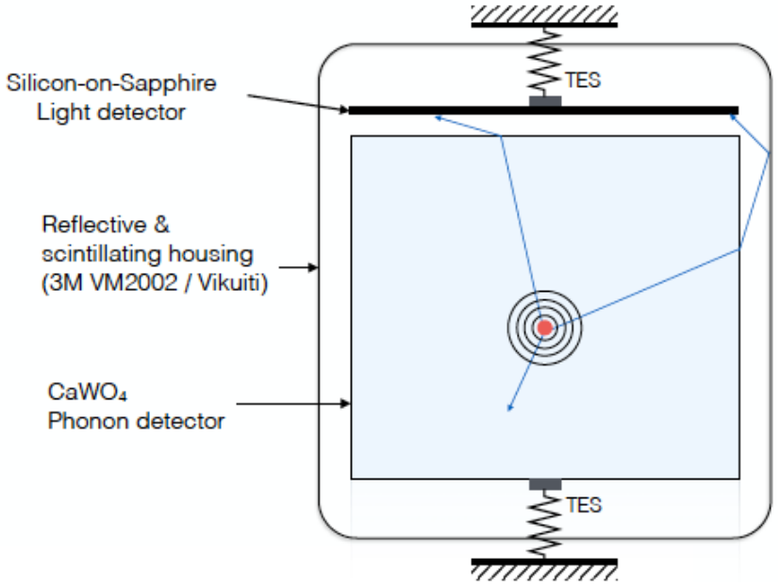


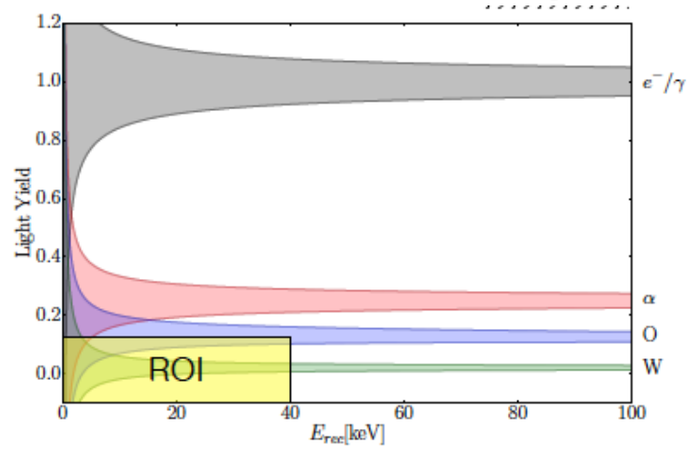
- Detector construction started Dec 2016
  - COSINE-100 is running with 106 kg of NaI(Tl) crystals
- Data taking since Sep 2016
- Expect first results ~1year
- ~2 years of data with 1 keV analysis threshold will give comparable sensitivity to DAMA's 90% C.L. allowed region
- Continued R&D for higher purity crystals

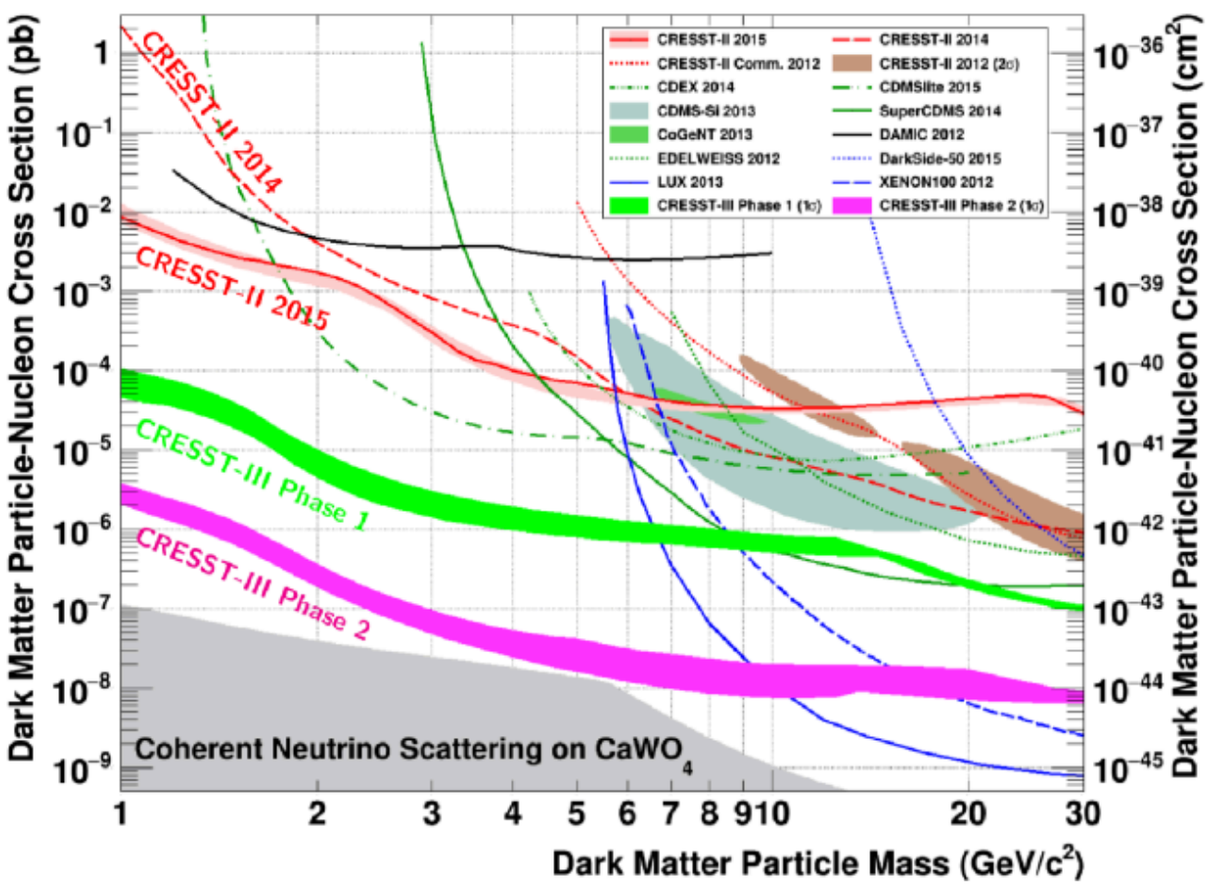
Search for low-mass Dark Matter with CRESST-III

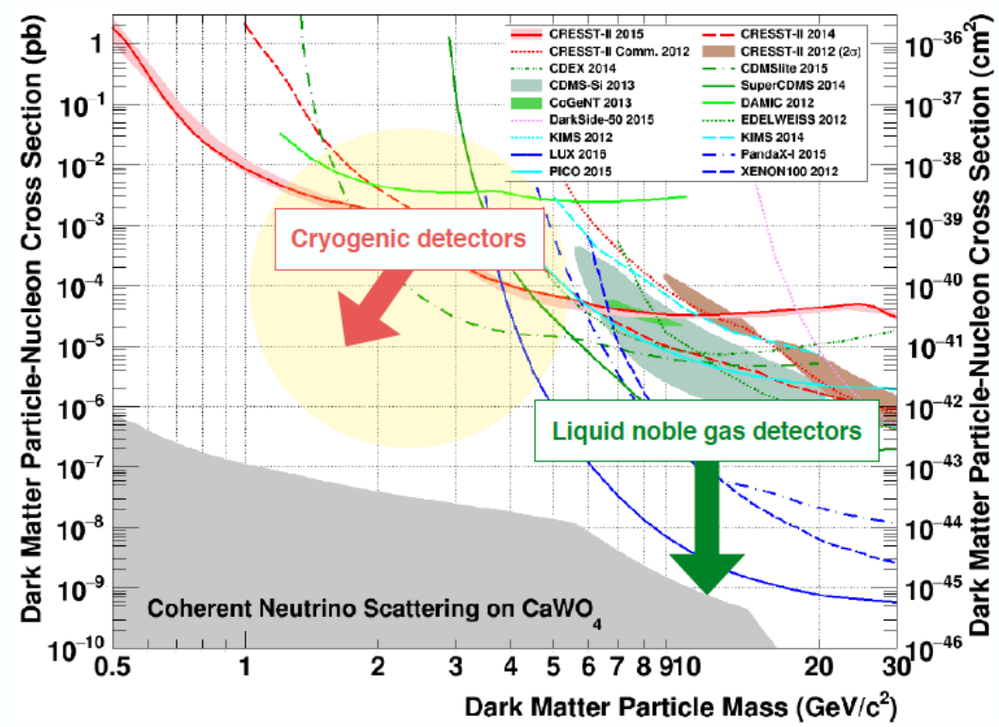
Michael Willers

Cryogenic Rare Event Search with Superconducting Thermometers









CRESST → World leading DM limit below ~ 1.7 GeV / c^2

CRESST-III detector technology:

- Precise measurement of low-energetic nuclear recoils
- Very low threshold: E_{thr} < 100 eV
- Fully scintillating detector housing & rejection of holding structure related backgrounds
- TUM-grown crystals provide improved radiopurity

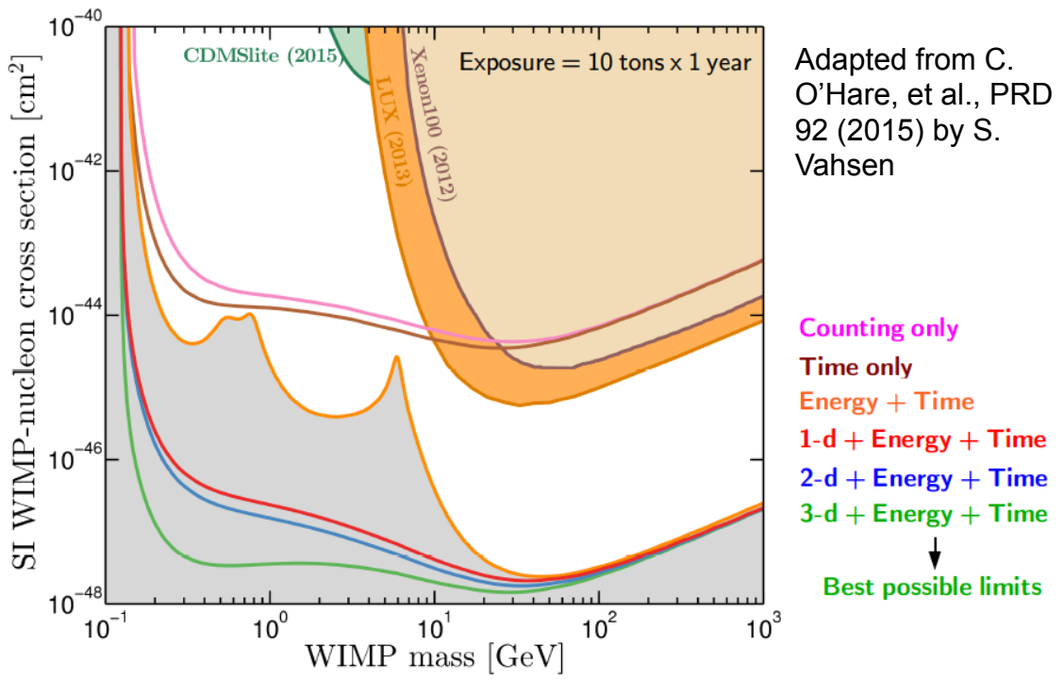
→ CRESST III has high potential to explore low-mass dark matter parameter space below ~ 3 GeV / c^2

arXiv:1503.08065 & Journal of Physics: Conference Series **718** (2016) 042048

An Overview of Directional Dark Matter Experiments: Current Status and Future Prospects

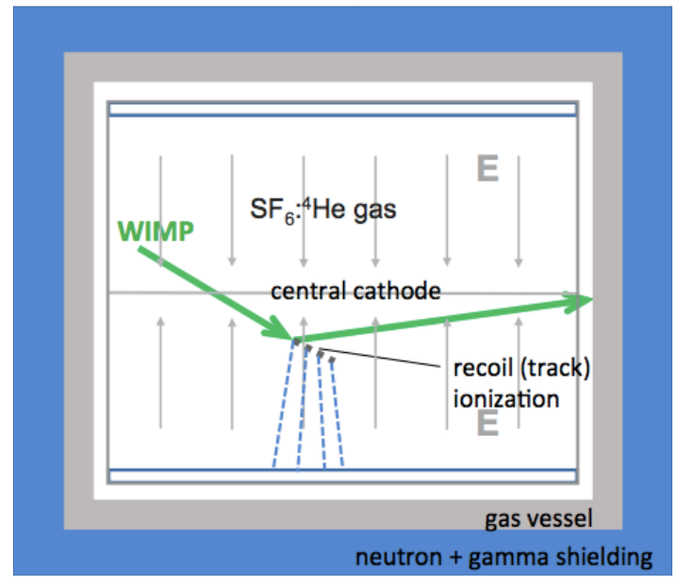
Dinesh Loomba

…directional experiments critical for going below the neutrino floor:



Adapted from C. O'Hare, et al., PRD 92 (2015) by S. Vahsen

CYGNUS HD10*

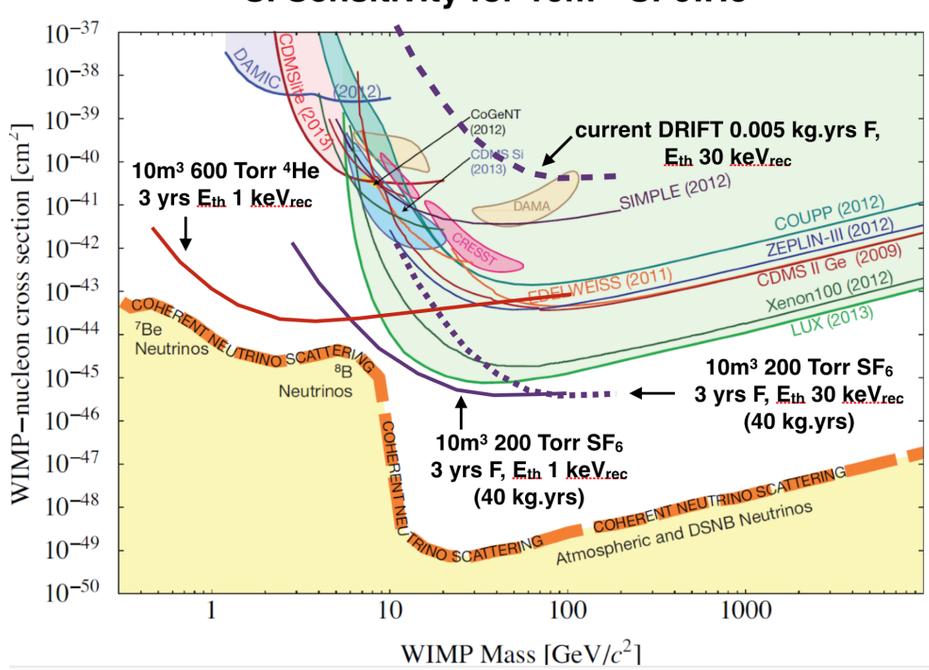


Presented by S. Vahsen at the "U.S. Cosmic Visions: New Ideas in Dark Matter" workshop as a strawman proposal to the DoE

On-going efforts

- DRIFT
  - operating for >10years
- NEWAGE
- Cygnus Newage 1m^3
  - Funded, ready by 2018
- DMTPC
- MIMAC

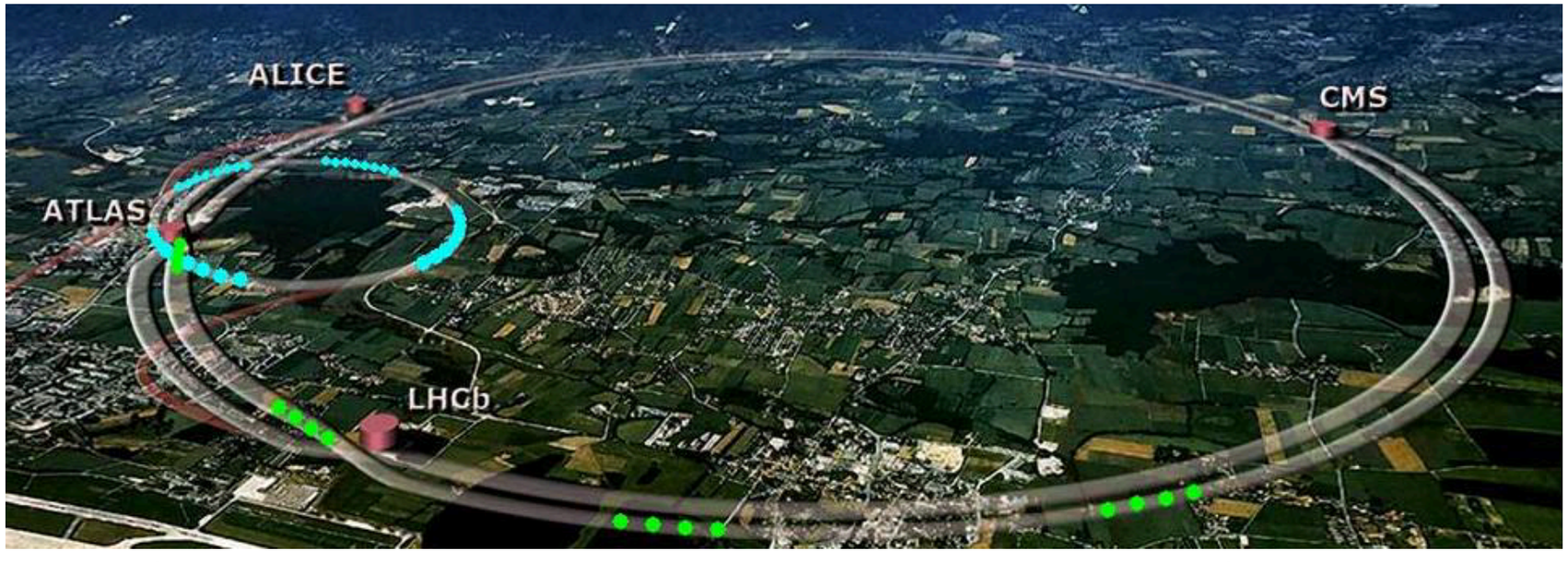
SI Sensitivity for 10m³ SF6:He



- Experimental effort have demonstrated and improved their directionality. We are approaching the simulated predictions on strength of signature.
- Discrimination with range vs energy is excellent. But good signal-to-noise and resolution will be needed as we push to lower thresholds.
- Demonstrated ZERO background operation
- Flexibility of technology enables numerous approaches for probing a wide range of WIMP parameters, e.g. low mass WIMPs
- Experiments are all getting larger, but we are volume limited and need to scale up.
- Many new groups entering field, some with novel ideas in solids-state and high pressure gas

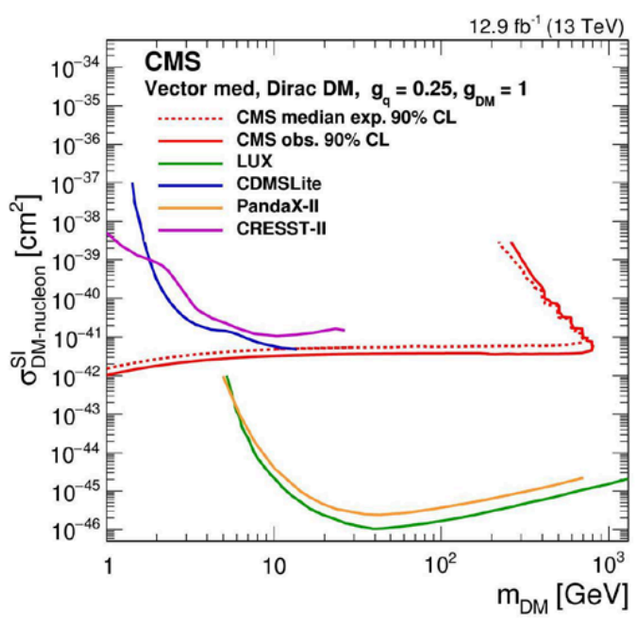
DM at the LHC

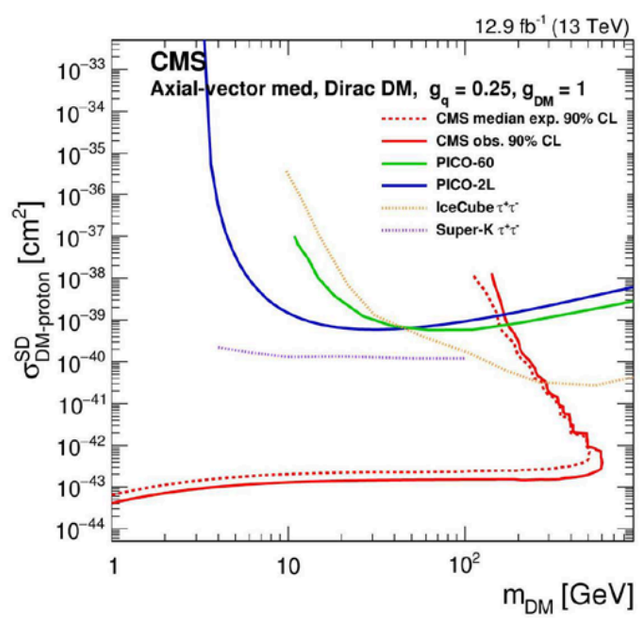
Bhaskar Dutta



Larger/ smaller <σv> : Non thermal dark matter, e.g., due to moduli decay Prior to BBN

Non standard cosmology: Expansion rate is different [Dark Matter is thermal]





Comparing only the EFT limit with direct searches is misleading and can lead to incorrect conclusions about the relative sensitivity of the two search approaches."

Buechmueller, Dolan, Mccabe, '13

$\Delta\phi(l_1, l_2), \Delta\phi(l_{1,2}$, missing-$E_T$$), \Delta\phi(j$, missing–ET$)$ are very useful

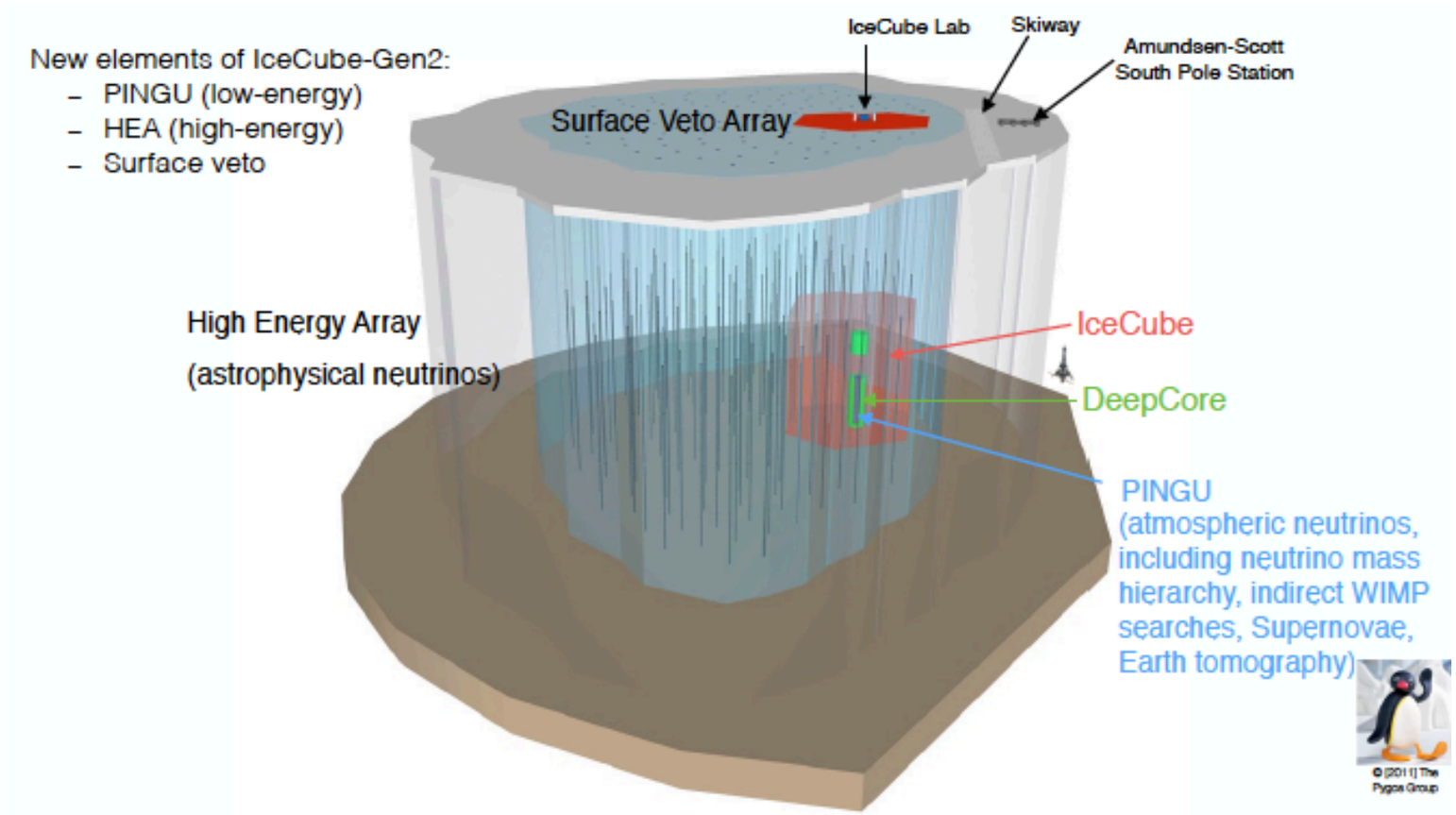
Selection	$t\bar{t}jj$	$ZZjj$	$WZjj$	$WWjj$	S^{110}_{20}	S^{110}_{30}	S^{110}_{40}	S^{110}_{50}	S^{110}_{55}	S^{110}_{60}
Small Mass Gap Optimization										
$1.0 < P_T^{l_1} + \not{E}_T < 1.3$	4.5×10^{-1}	2.7×10^{-3}	6.2×10^{-2}	6.6×10^{-1}	4.2×10^{-1}	3.0×10^{-1}	2.4×10^{-1}	1.8×10^{-1}	1.6×10^{-1}	1.4×10^{-1}
$\Delta\phi(\not{E}_T, j) \div \pi > 0.95$	1.8×10^{-1}	2.2×10^{-3}	2.7×10^{-2}	3.8×10^{-1}	4.0×10^{-1}	2.3×10^{-1}	1.7×10^{-1}	9.6×10^{-2}	7.7×10^{-2}	6.2×10^{-2}
Events at $\mathcal{L} = 300$ fb^{-1}	52.7	0.7	8.1	113.6	120.0	69.0	51.0	28.8	23.1	18.6
$S \div (1 + B)$	-	-	-	-	0.68	0.39	0.29	0.16	0.13	0.11
$S \div \sqrt{1 + B}$	-	-	-	-	9.0	5.2	[illegible]	2.2	1.7	1.4
Intermediate Mass Gap Optimization										
$\Delta\phi(l_1, l_2) \div \pi > 0.5$	1.1×10^{0}	7.7×10^{-3}	1.2×10^{-1}	1.3×10^{0}	4.0×10^{-1}	1.0×10^{-1}	4.4×10^{-1}	4.1×10^{-1}	3.7×10^{-1}	3.9×10^{-1}
$\Delta\phi(\not{E}_T, l_1) \div \pi < 0.6$	4.8×10^{-1}	5.5×10^{-3}	7.9×10^{-2}	9.0×10^{-1}	3.7×10^{-1}	3.3×10^{-1}	3.3×10^{-1}	3.0×10^{-1}	2.4×10^{-1}	2.1×10^{-1}
$\Delta\phi(\not{E}_T, l_2) \div \pi < 0.6$	4.8×10^{-1}	4.4×10^{-3}	4.8×10^{-2}	5.1×10^{-1}	2.7×10^{-1}	2.3×10^{-1}	2.2×10^{-1}	2.0×10^{-1}	1.6×10^{-1}	1.4×10^{-1}
Events at $\mathcal{L} = 300$ fb^{-1}	52.8	1.3	14.5	151.7	81.0	69.0	66.0	60.0	48.0	42.0
$S \div (1 + B)$	-	-	-	-	0.37	0.34	0.30	0.27	0.22	0.19
$S \div \sqrt{1 + B}$	-	-	-	-	5.4	4.6	4.4	4.0	[illegible]	2.8
Large Mass Gap Optimization										
$\Delta\phi(\not{E}_T, l_1) \div \pi > 0.25$	8.5×10^{-1}	6.6×10^{-3}	1.0×10^{-1}	9.5×10^{-1}	2.4×10^{-1}	2.7×10^{-1}	3.3×10^{-1}	2.9×10^{-1}	3.0×10^{-1}	3.3×10^{-1}
$P_T^{j2} > 40$ GeV	3.4×10^{-1}	5.6×10^{-4}	3.7×10^{-2}	4.1×10^{-1}	1.1×10^{-2}	7.3×10^{-2}	1.4×10^{-1}	1.5×10^{-1}	2.1×10^{-1}	2.4×10^{-1}
Events at $\mathcal{L} = 300$ fb^{-1}	102.2	0.2	11.0	124.3	3.3	21.9	42.0	45.0	63.0	72.0
$S \div (1 + B)$	-	-	-	-	0.01	0.09	0.18	0.19	0.26	0.30
$S \div \sqrt{1 + B}$	-	-	-	-	0.2	1.4	2.7	2.9	4.1	4.7

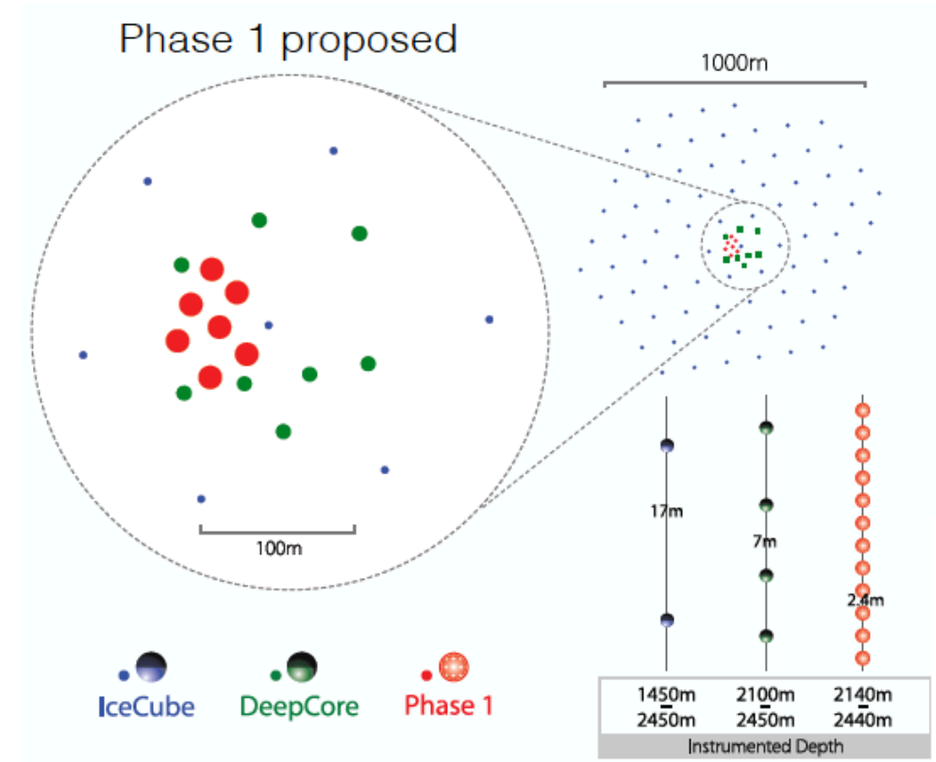
Dutta, Fantahun, Fernando, Ghosh, Kumar, Sandick, Stengel, Walker, arXiv:1706.05339

Next-generation neutrino telescopes

IceCube-Gen2

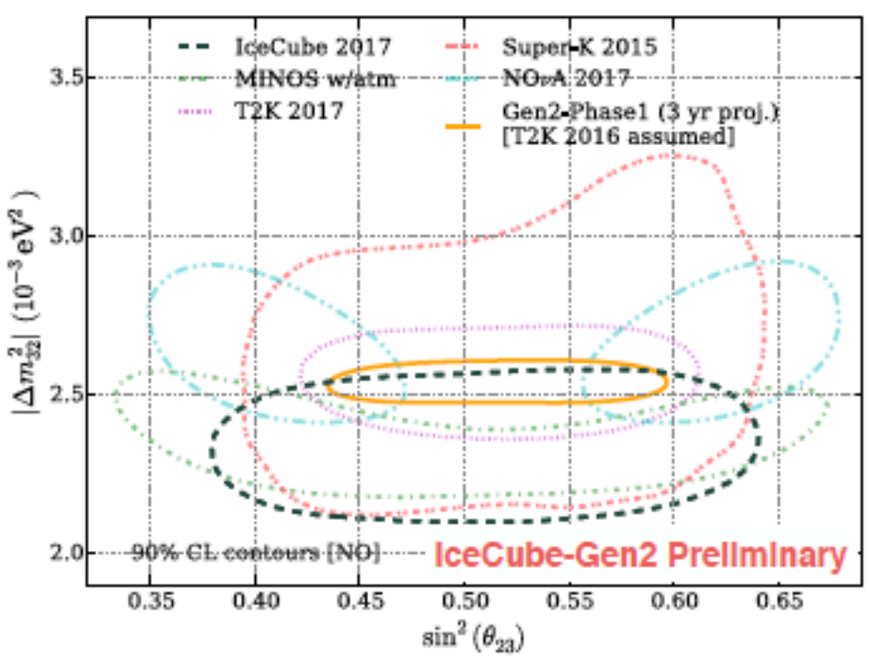
see talk by Darren Grant



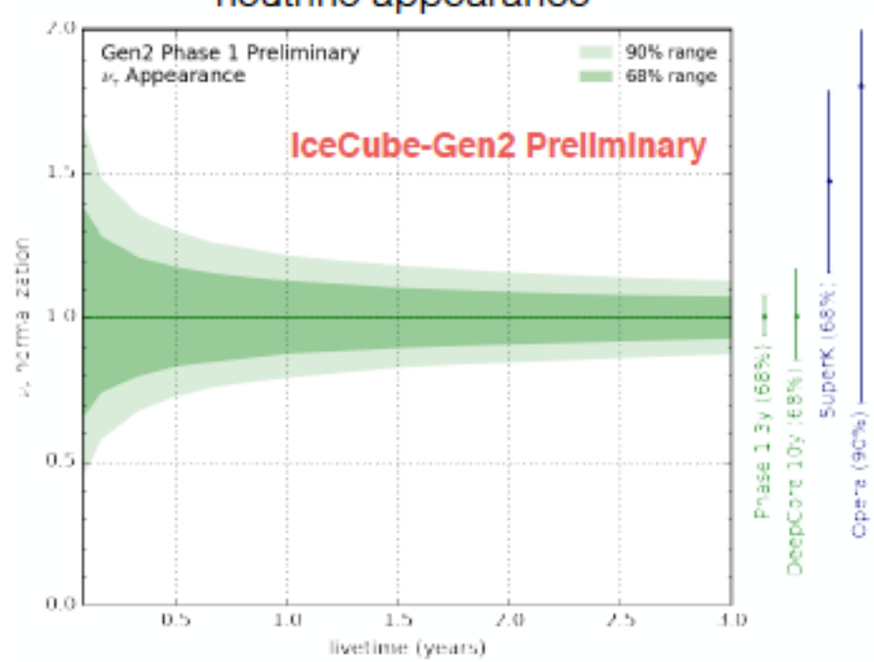


Total IceCube-Gen2 value O(IceCube w/inflation)

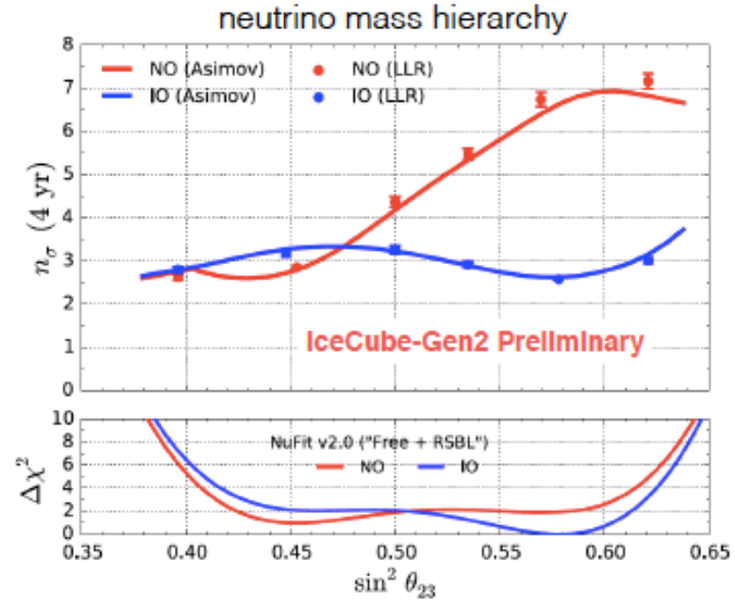
precision measurements of muon neutrino disappearance



precision measurements of tau neutrino appearance

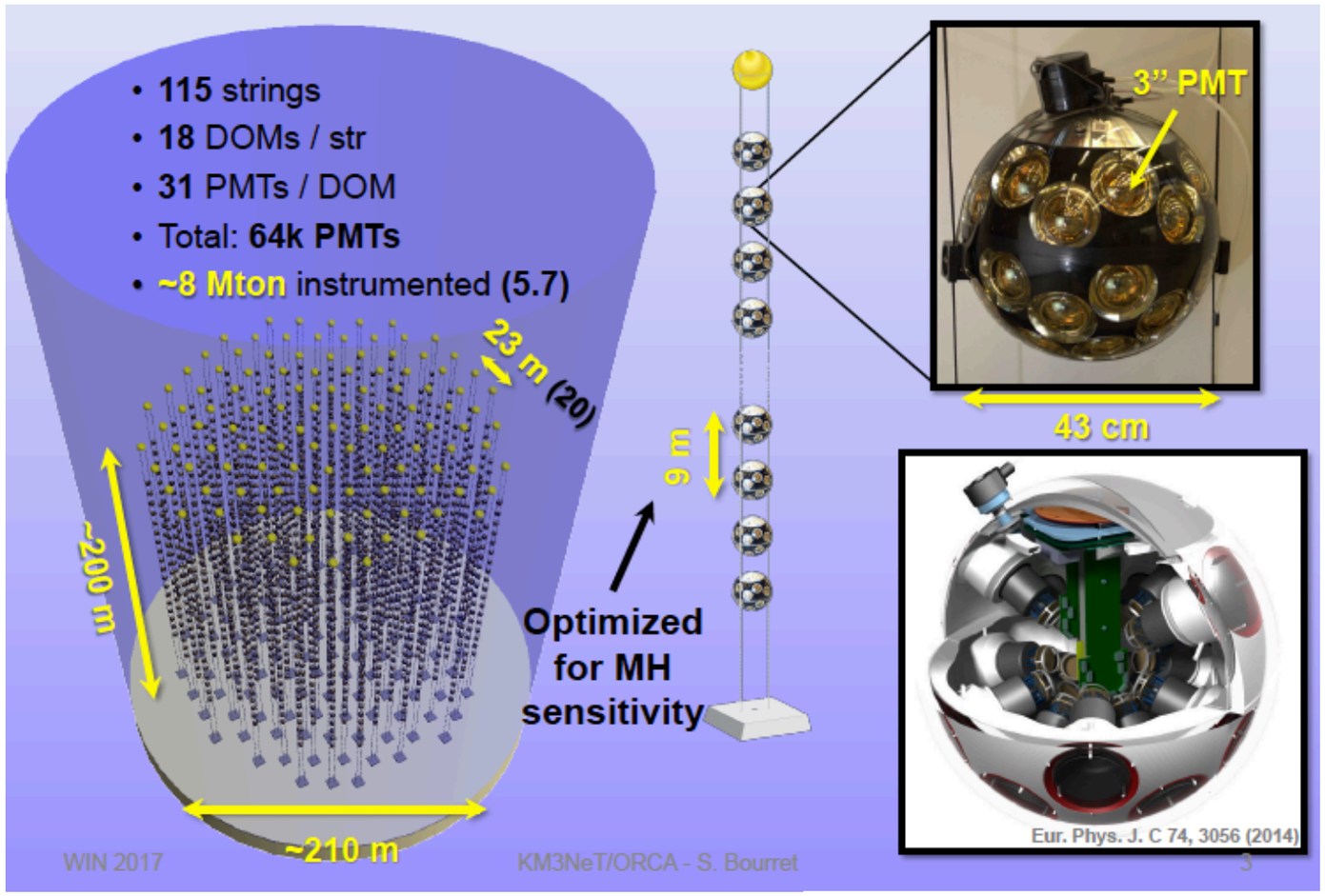


PINGU sensitivity to the neutrino mass hierarchy

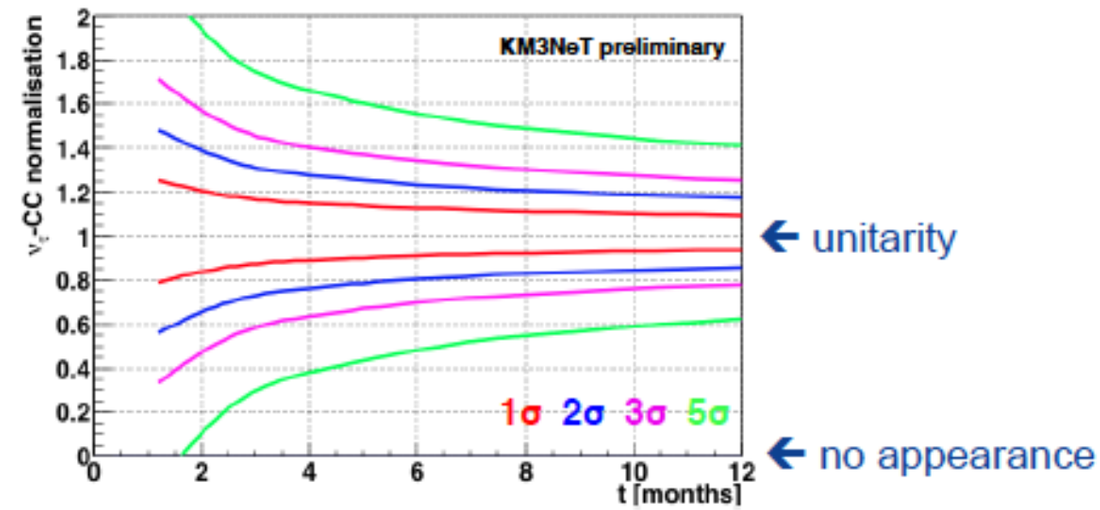


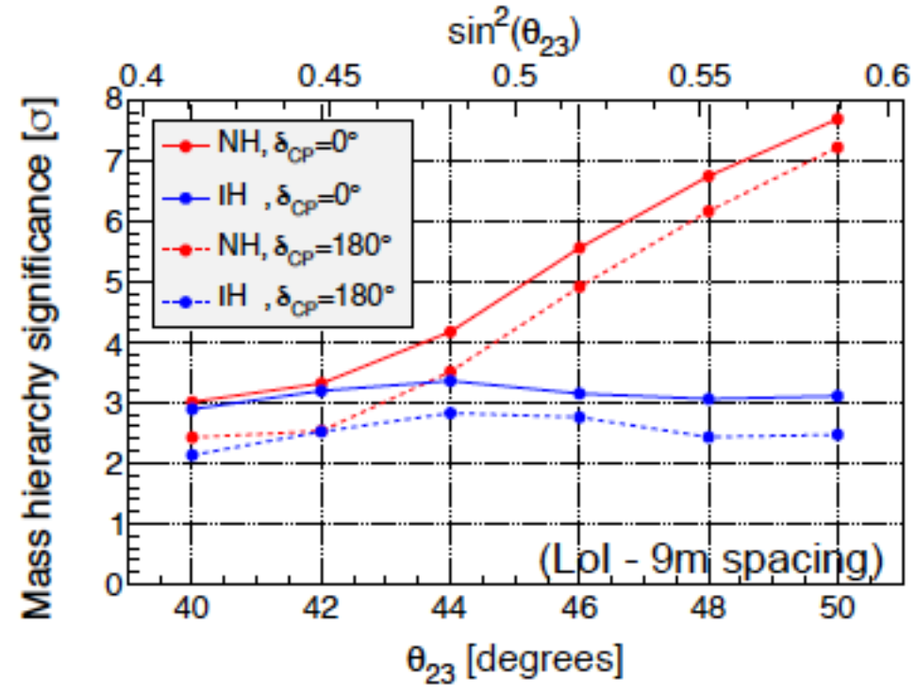
KM3NeT/ORCA: Measuring neutrino oscillations and the mass hierarchy in the Mediterranean

Simon BOURRET

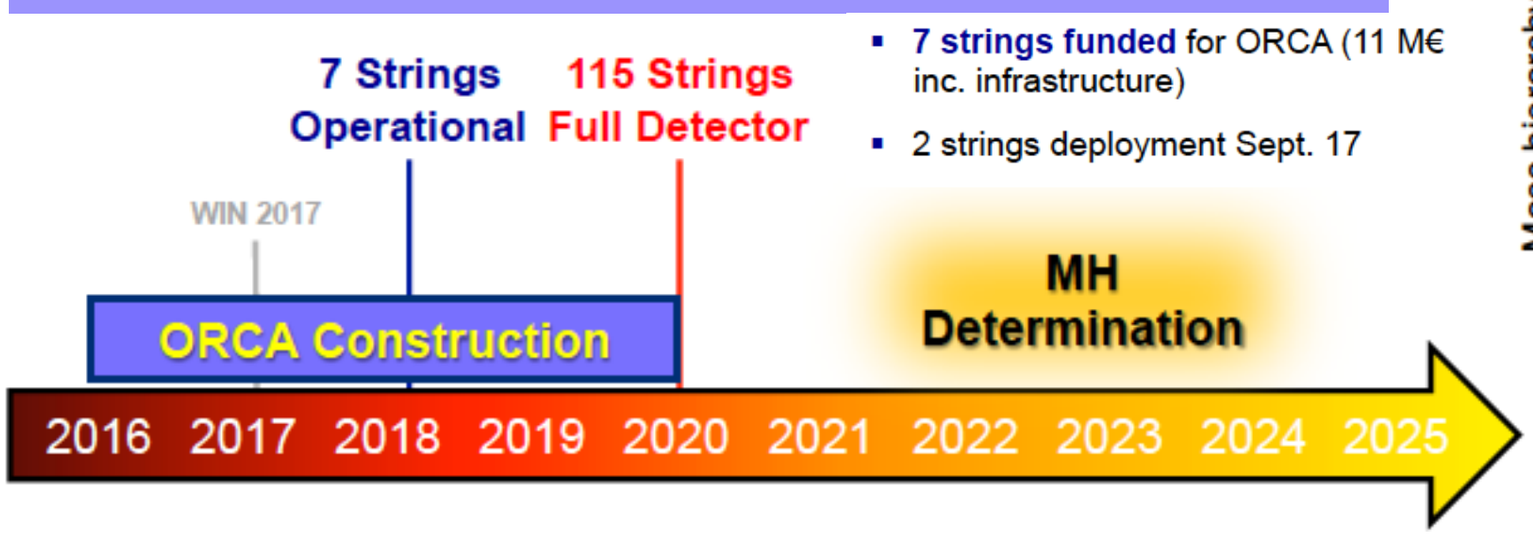


J. Phys. G 43 (2016) 0840





- ~ 3σ MH sensitivity in 3 years



- **7 strings funded** for ORCA (11 M€ inc. infrastructure)
- 2 strings deployment Sept. 17

(see also Antonio Capone)

Radiodetection of ultra-high energy neutrinos

Spencer Klein

Different techniques for different ν energies

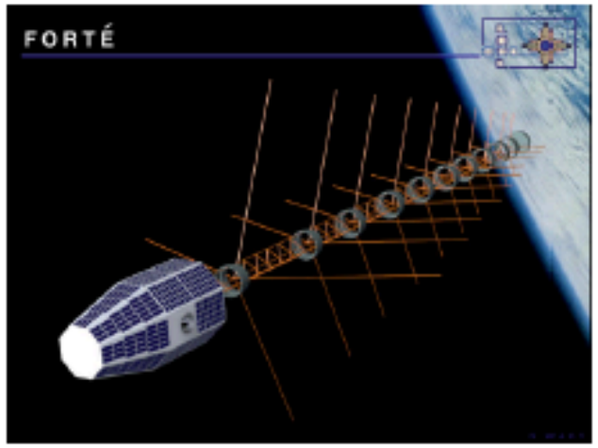
Larger target- antenna separations
Higher $E_{threshold}$
Larger targets

- The Moon -> radiotelescopes
- Greenland -> Satellite
  - FORTE
- Antarctica -> high altitude balloon
  - ANITA
- Antarctica/Greenland-> embedded antennas
  - RICE/ARA/ARIANNA
- Embedded antennas w/ interferometric triggers

New Physics

GZK neutrinos

> PeV ν spectrum



Overall Energy Dynamic range > 10^5

Conclusions

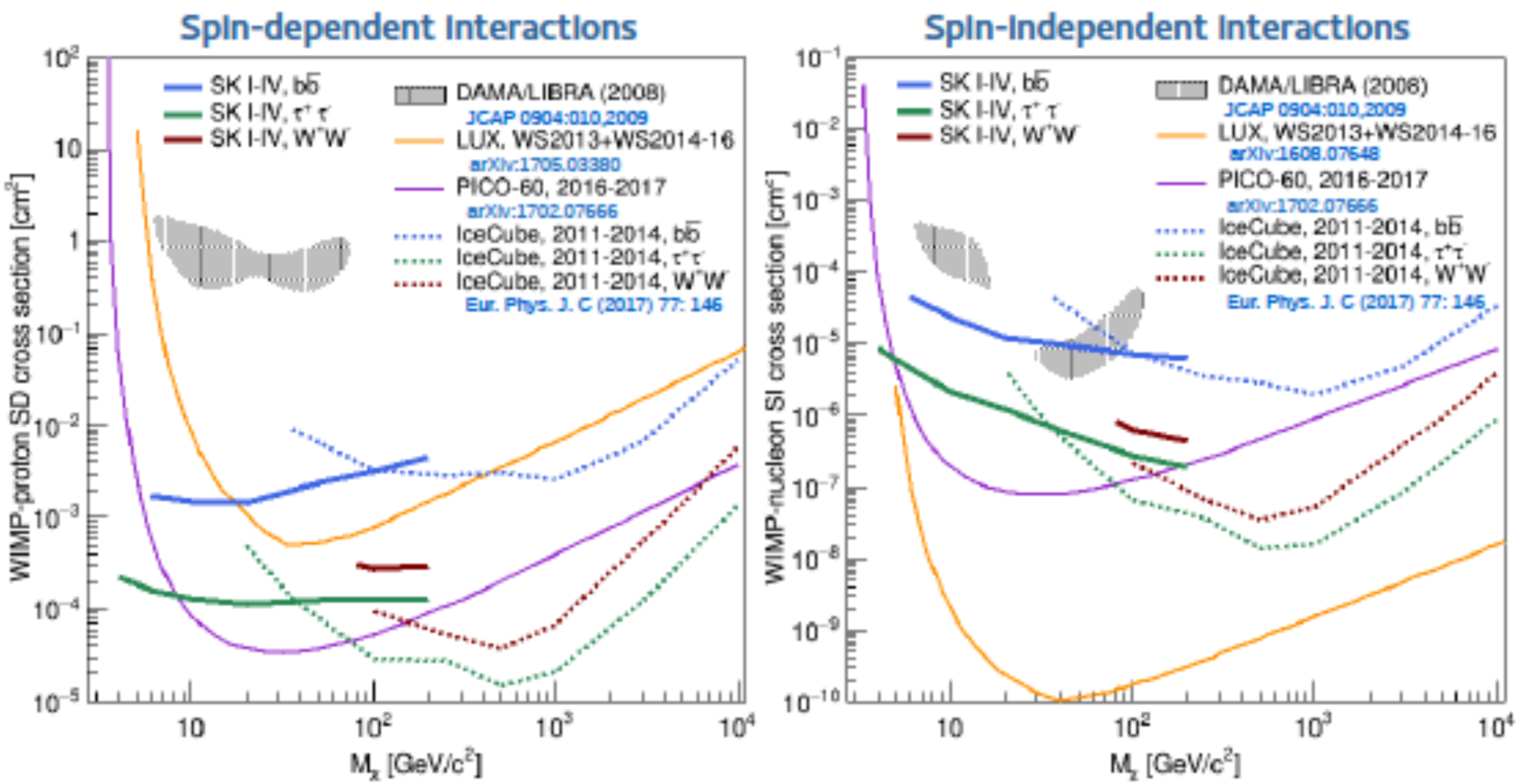
- Many exciting results & New detectors on the horizon
  - Bright outlook for astroparticle physics
- Intense efforts to identify the sources of the high-energy astrophysical neutrinos
- Direct Detection is approaching neutrino floor
- Hope for hint for new physics at LHC
- Interesting dark matter anomalies (3.5 keV Line, GeV excess @ Galactic Center, AMS positrons, DAMA?)

Backup slides

Dark matter searches with the Super-Kamiokande detector

K. Frankiewicz

Solar WIMP search – WIMP-nucleon SD & SI cross-section limit

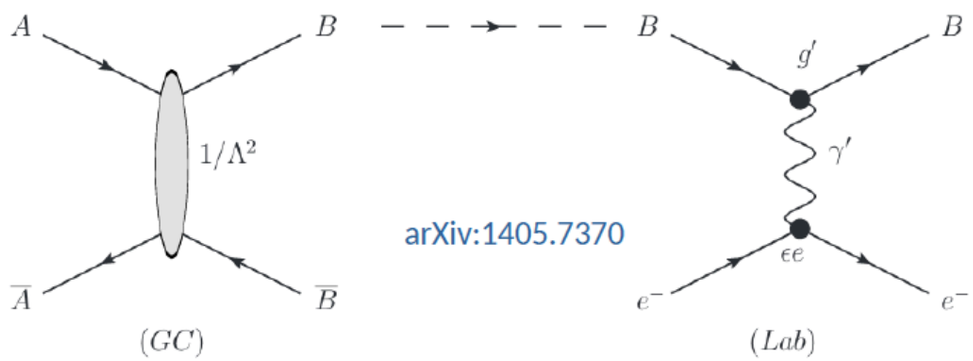


Published analysis: K.Choi et al., Phys. Rev. Lett. 114, 141301 (2015)

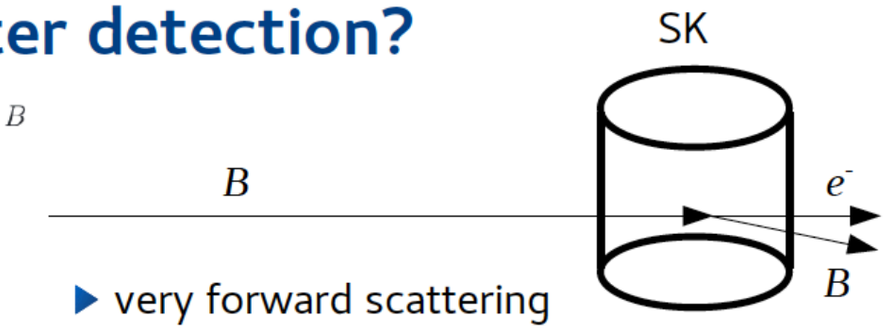
more New Results …

Super-K Boosted Dark Matter Search

(In)direct dark matter detection?



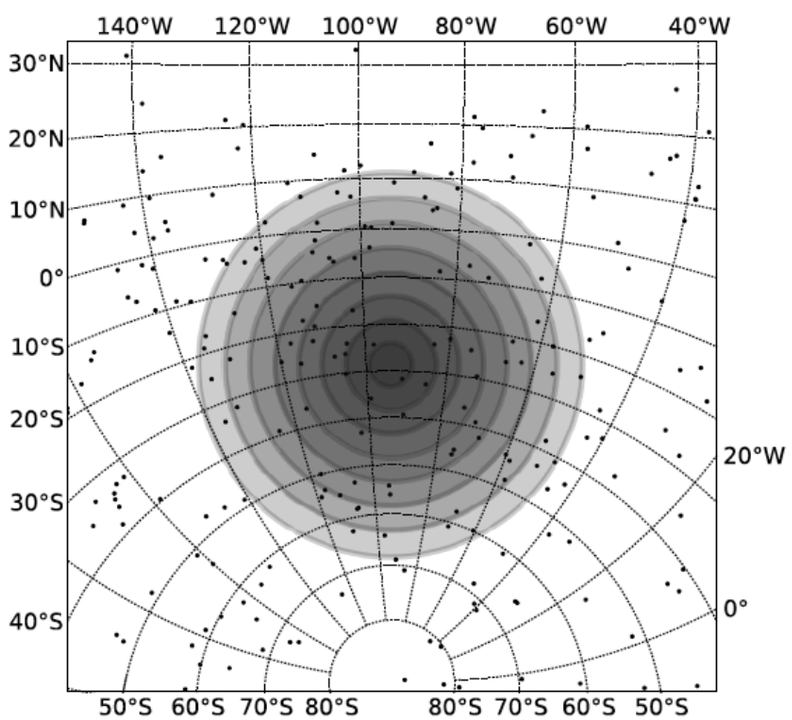
arXiv:1405.7370



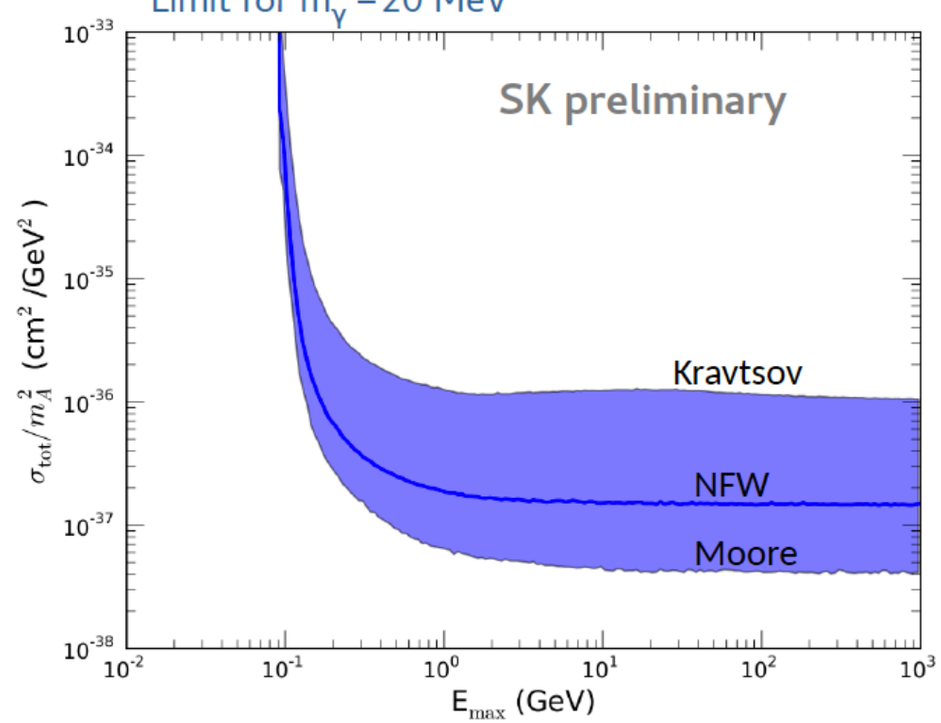
- very forward scattering
- electromagnetic shower
- no hadrons → no decay e, no neutrons

Cone search: 8 cones from 5° to 40° around GC

→ No clusters visible



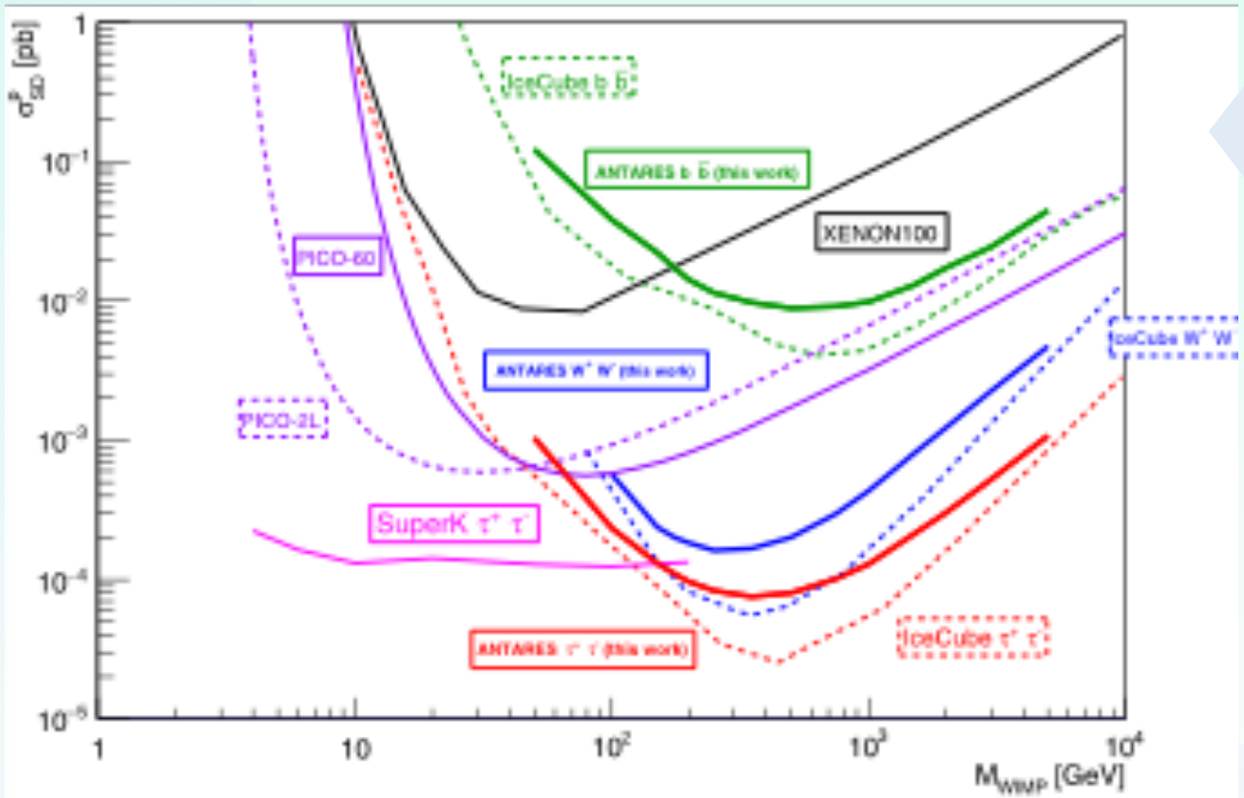
Limit for $m_{\gamma'}$=20 MeV



K. Frankiewicz WIN 2017, 2017/06/21 18

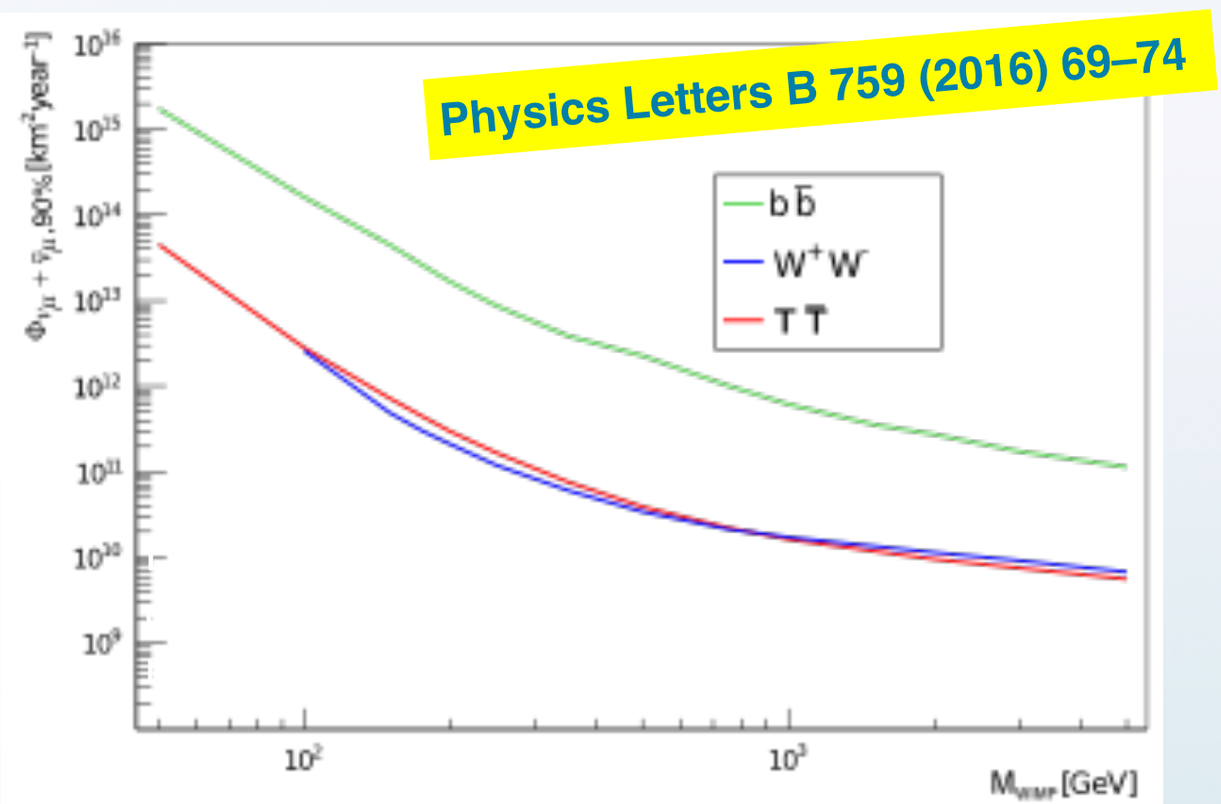
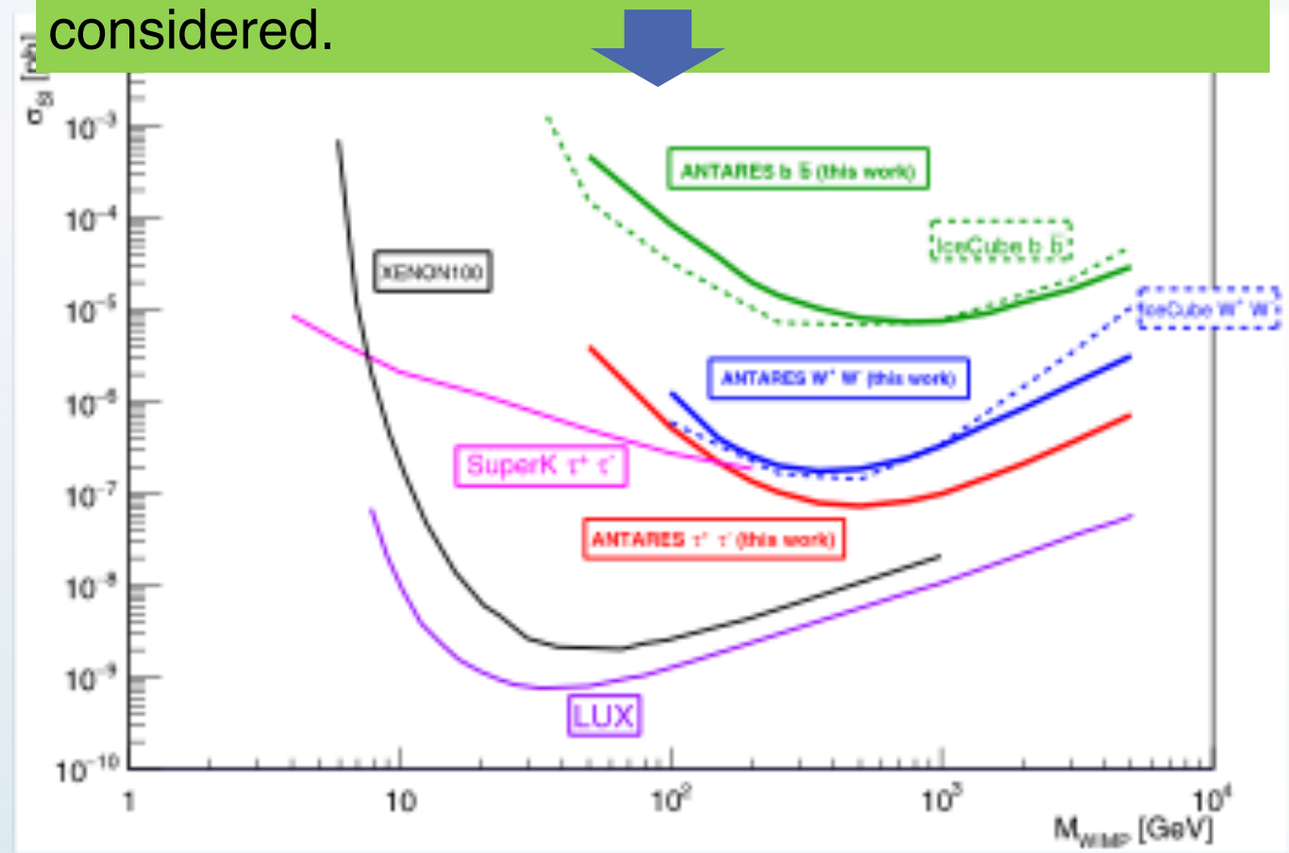
Indirect search for Dark Matter in the Sun

No excess observed over the expected background: evaluate 90% C.L. upper limits for expected signal



Limits on the **spin-dependent** WIMP-nucleon scattering cross-section as a function of WIMP mass for the $b\bar{b}$, $\tau^+\tau^-$ and W^+W^- channels.

assumptions:

- **capture and annihilations in equilibrium**
- local D.M. density =0.4 GeV cm^{-3}
- v_{SUN}^{DM} according to Maxwell distr. 270 km s^{-1} r,m.s.

Limits on the **spin-independent** WIMP-nucleon scattering cross-section as a function of WIMP mass for the different channels considered.