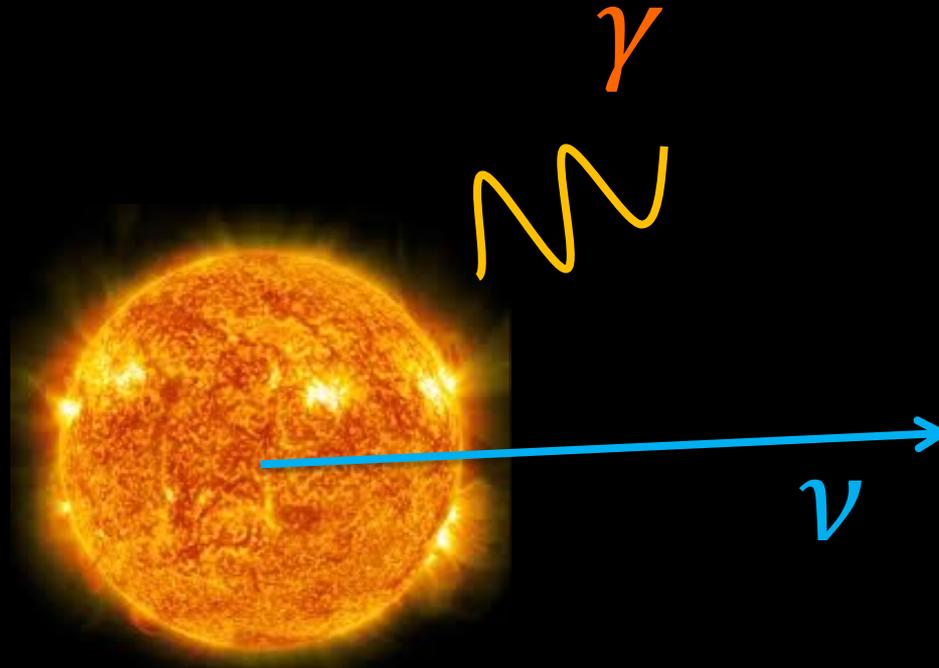


Solar Atmospheric Neutrinos and Dark Matter



Kenny, Chun Yu Ng (吳震宇)

Marie Curie fellow

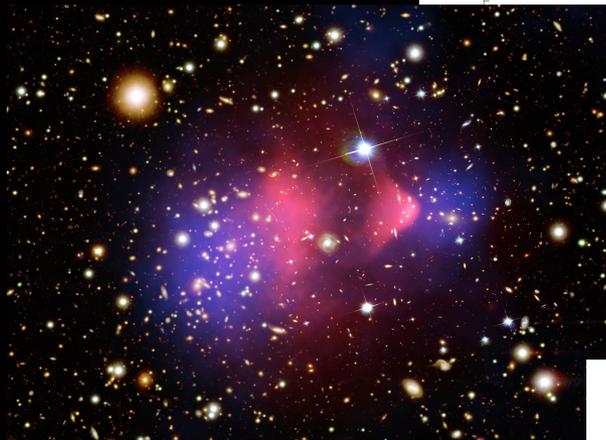
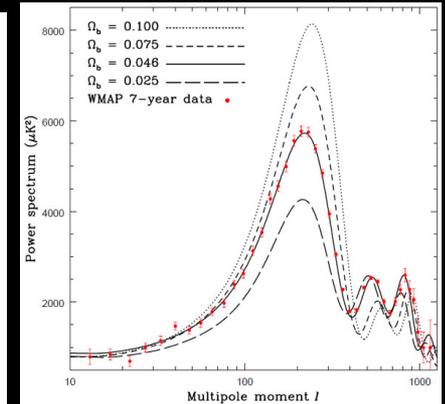
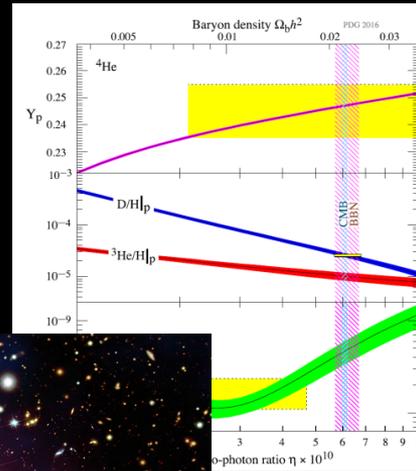
GRAPPA, University of Amsterdam



UNIVERSITY
OF AMSTERDAM

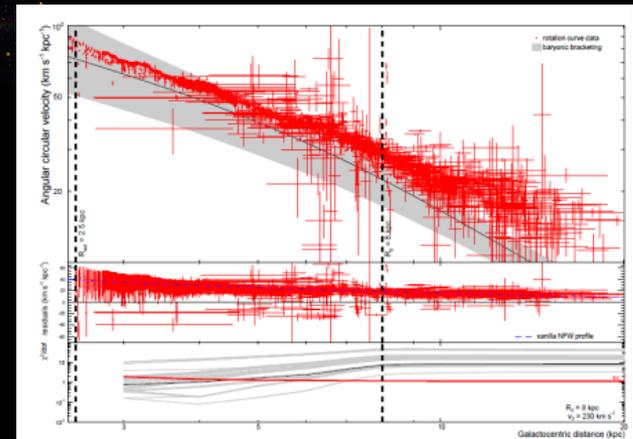
Dark Matter/Gravity problem

- Big Bang Nucleosynthesis
 \backslash CMB



- Clusters

- Galaxies/Local

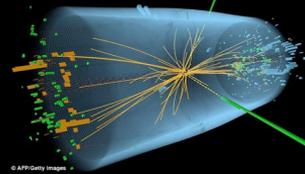
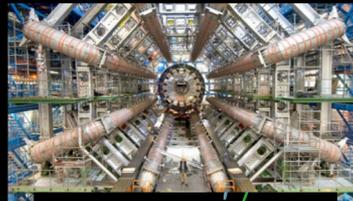


Weakly interacting massive particles

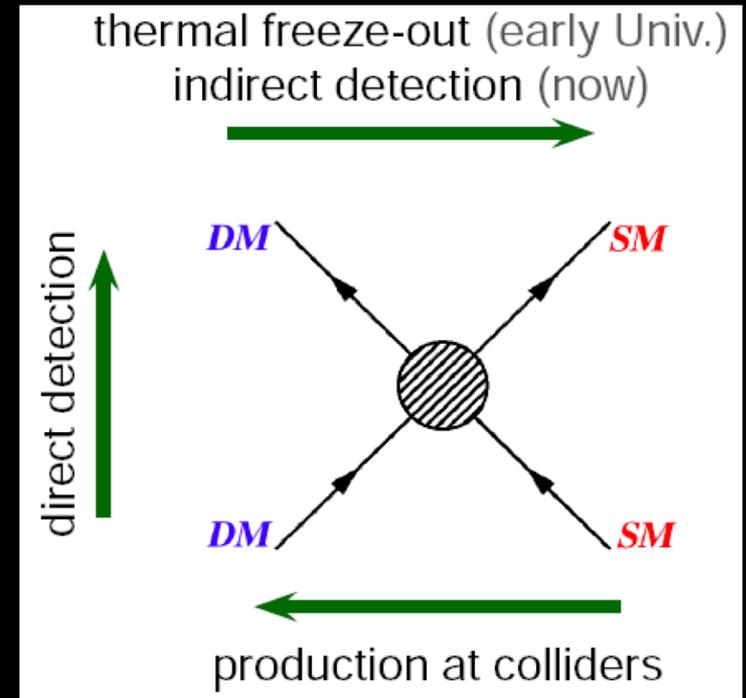
- Direct Detection



- Collider Search



- *Indirect Detection*

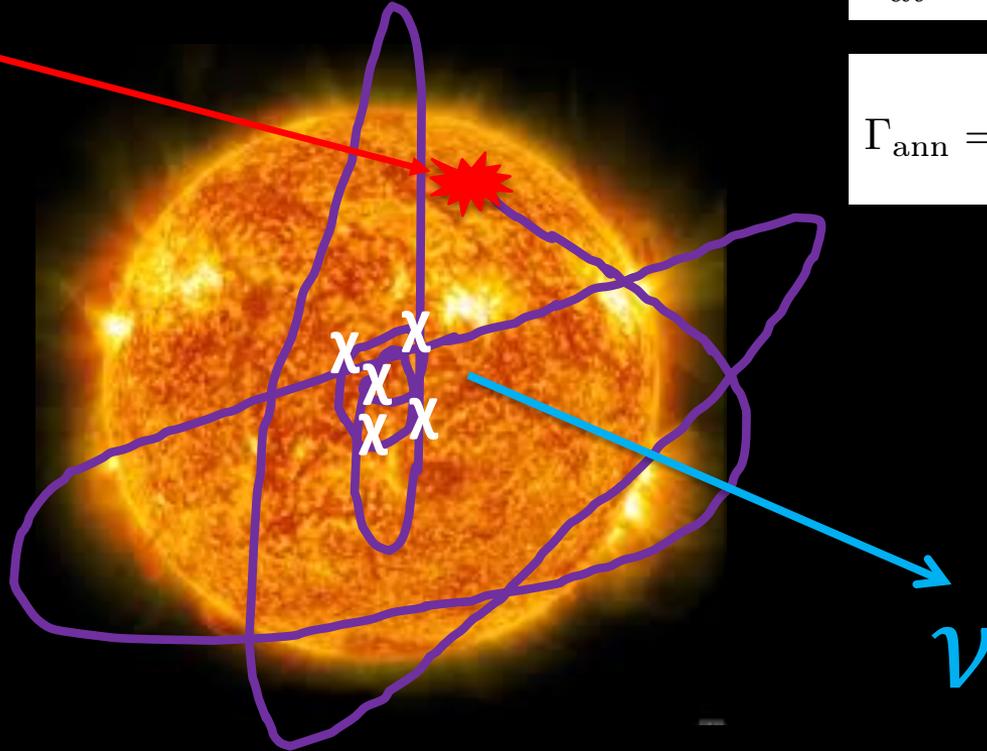
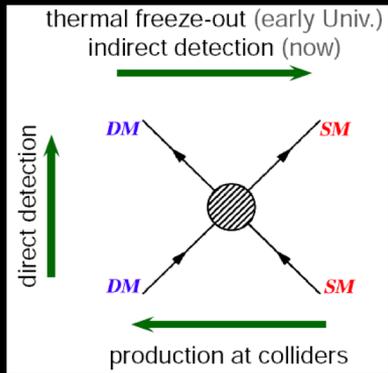


Sun – Dark Matter detector

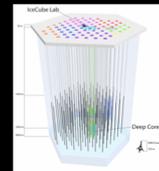
χ

$$\frac{dN}{dt} = \Gamma_{\text{cap}} - C_{\text{ann}} N^2$$

$$\Gamma_{\text{ann}} = \frac{1}{2} C_{\text{ann}} N^2 = \frac{1}{2} \Gamma_{\text{cap}}$$

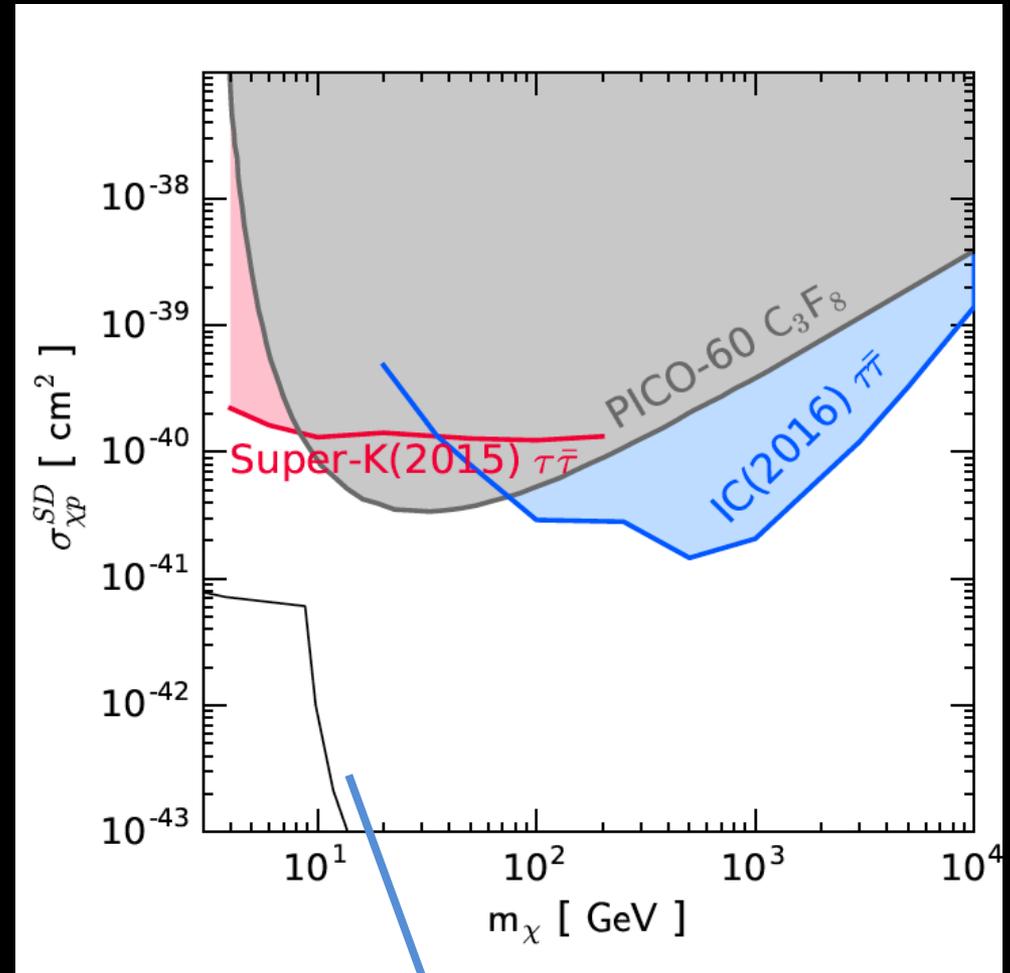


- Press, Spergel (1985)
- Krauss, Freese, Press, Spergel (1985)
- Silk, Olive, Srednicki (1985)



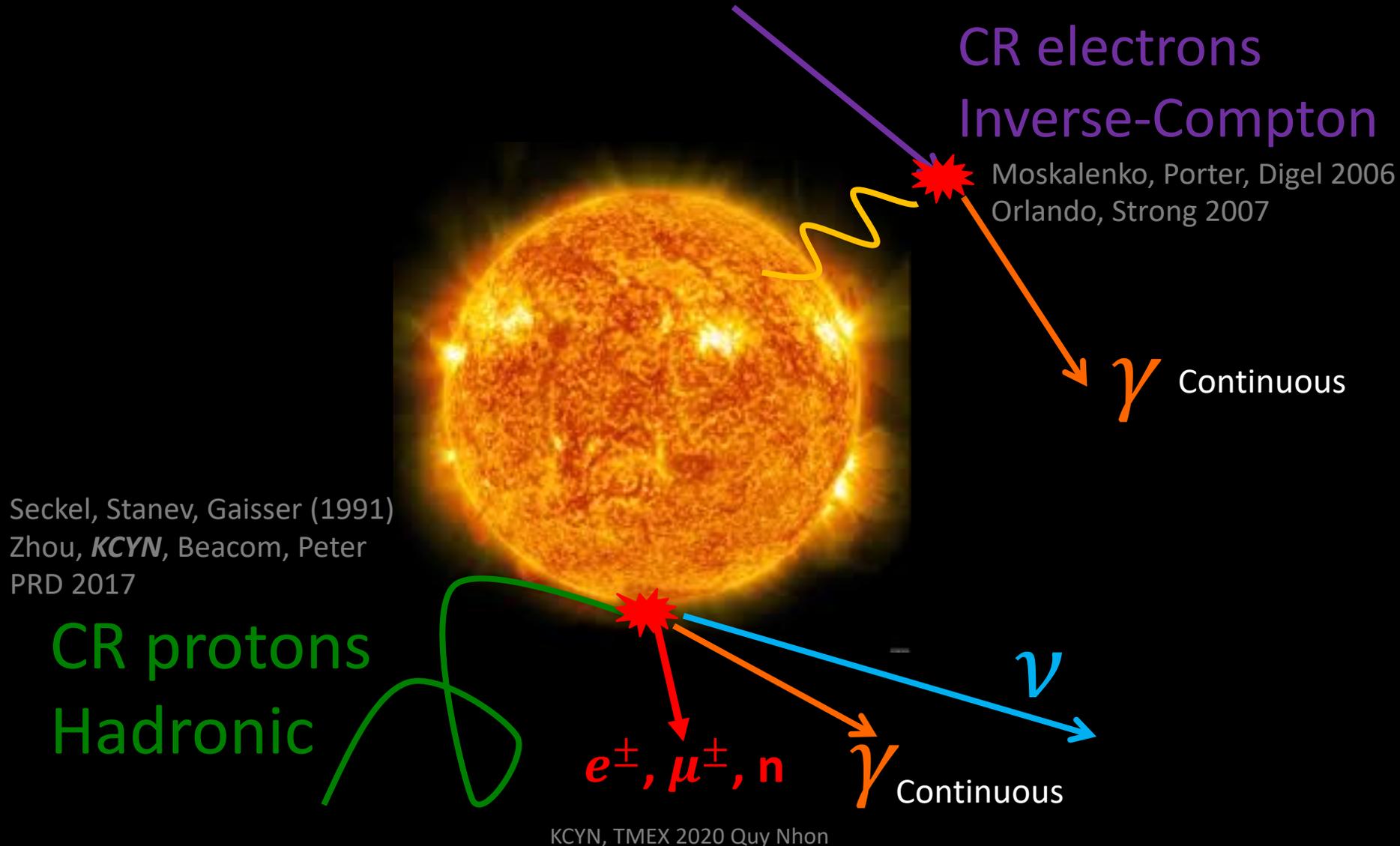
Solar WIMP Search

- Best limit on SD cross sections
 - Hard Channels
- Both scattering and Annihilation!
- How far can neutrino telescopes reach?



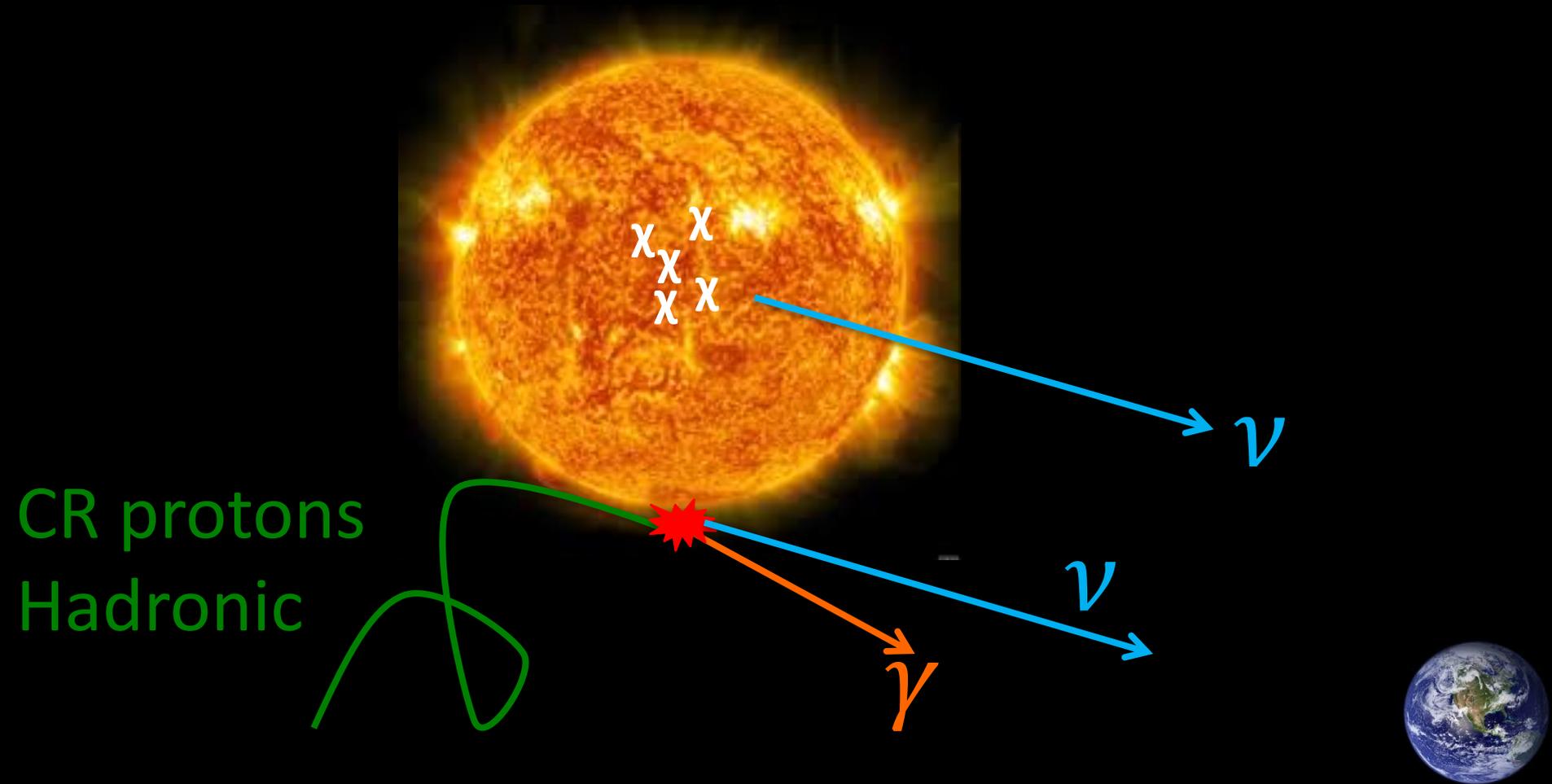
C₃F₈ Direct Detection
Neutrino floor
Ruppin et al. 2014

Sun – Cosmic-Ray Beam Dump



KCYN, TMEX 2020 Quy Nhon

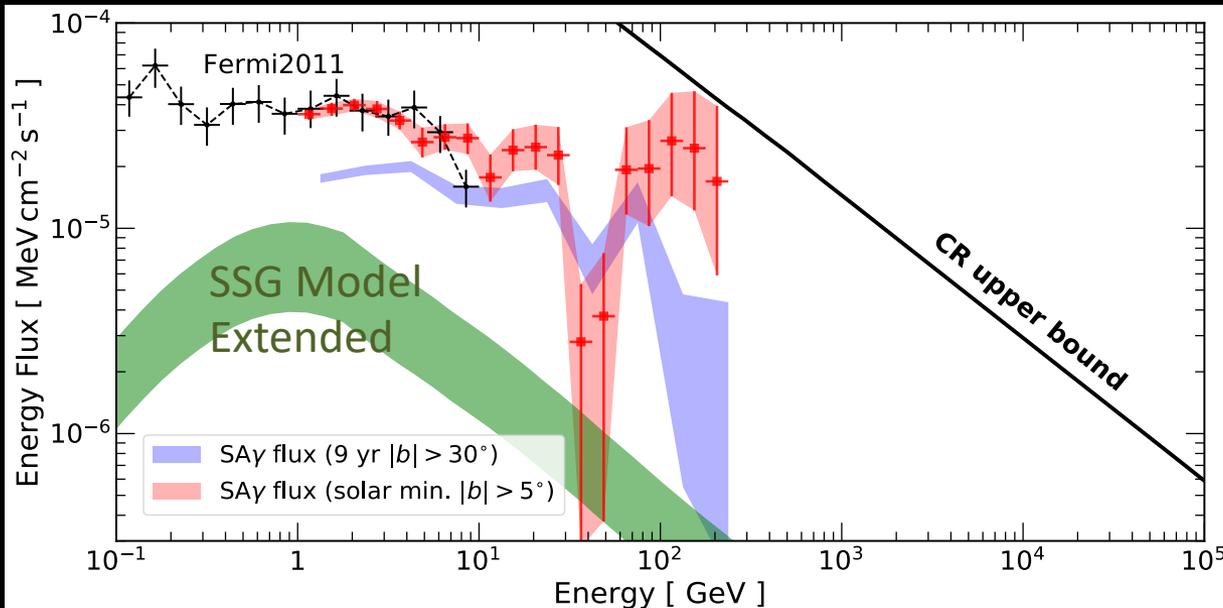
HE Gamma-ray & Neutrino Source Dark Matter Detector



CR protons
Hadronic

Solar Atmospheric Gamma Rays

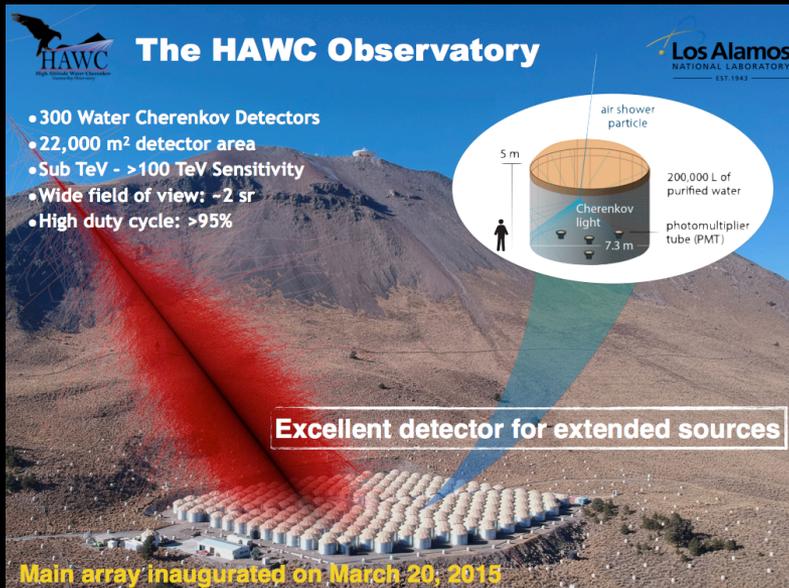
- **High Flux**, O(10)% efficiency at 100 GeV
- **Time variation** solar Min-Max
 - (2x @1 GeV, 10x @ 100 GeV)
- **Morphology** changes
- **Dip** at ~ 30 GeV, mostly at solar min.
- **Hard Spectrum**, $\sim E^{-2.2}$



- Abdo+ Apj, 2011
- KCYN+ PRD, 2016
- Linden+ PRL, 2018
- Tang+ PRD, 2018

Air-shower Arrays

HAWC



The HAWC Observatory

- 300 Water Cherenkov Detectors
- 22,000 m² detector area
- Sub TeV - >100 TeV Sensitivity
- Wide field of view: ~2 sr
- High duty cycle: >95%

Excellent detector for extended sources

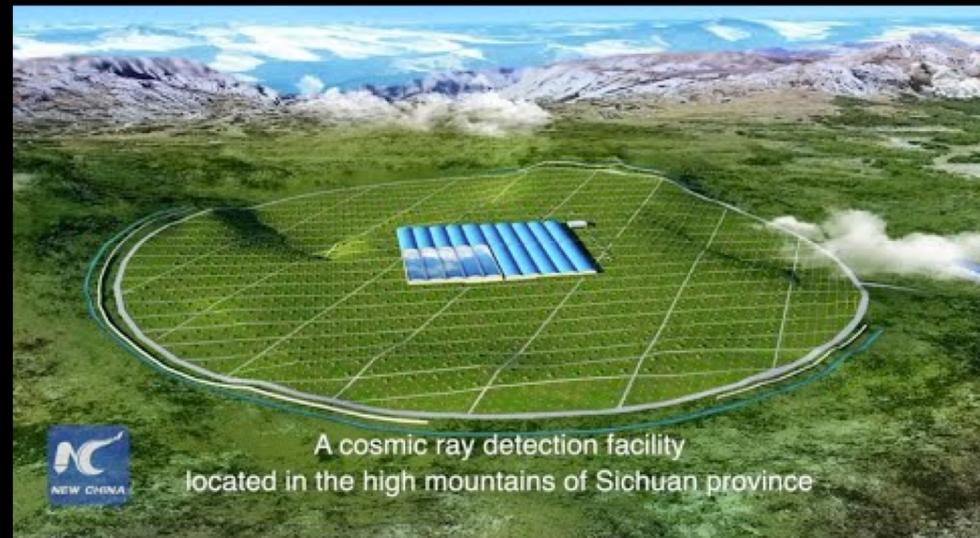
Main array inaugurated on March 20, 2015

Los Alamos NATIONAL LABORATORY EST. 1948

Diagram labels: air shower particle, 5 m, 200,000 L of purified water, Cherenkov light, 7.3 m, photomultiplier tube (PMT)

The slide features a photograph of the HAWC observatory on a mountain ridge. A red cone represents the wide field of view of the detectors. An inset diagram shows a cross-section of a detector: a cylindrical tank 5 meters high and 7.3 meters in diameter, filled with 200,000 liters of purified water. An air shower particle enters from the top, creating Cherenkov light that is detected by a photomultiplier tube (PMT) at the bottom.

LHAASO (25% +)



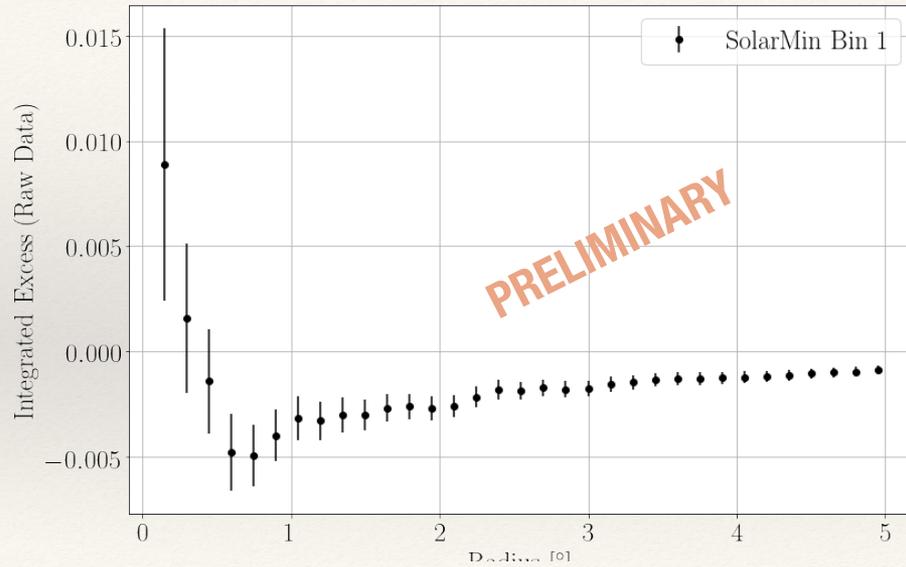
A cosmic ray detection facility located in the high mountains of Sichuan province

NEW CHINA

The slide shows an aerial view of the LHAASO facility, a large circular array of detectors on a high-altitude mountain plateau. A blue-roofed building is visible in the center of the array. The background shows rugged mountains under a blue sky with some clouds.

Friday PS#13
Prof. Huihai He

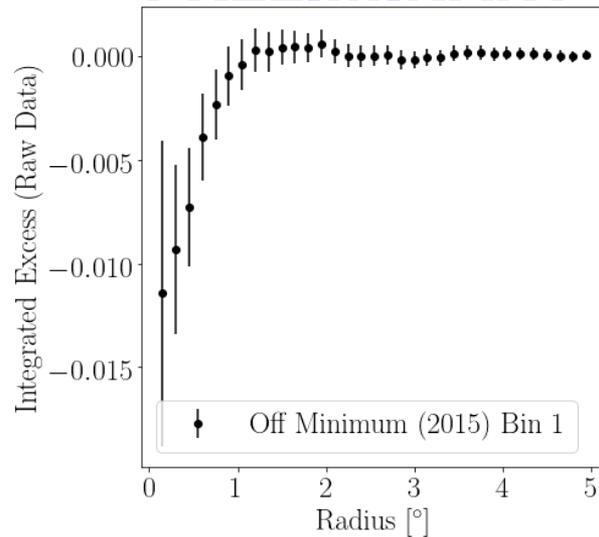
2018 Data: Onwards to the Solar Minimum



Mehr Un Nisa CRI13c

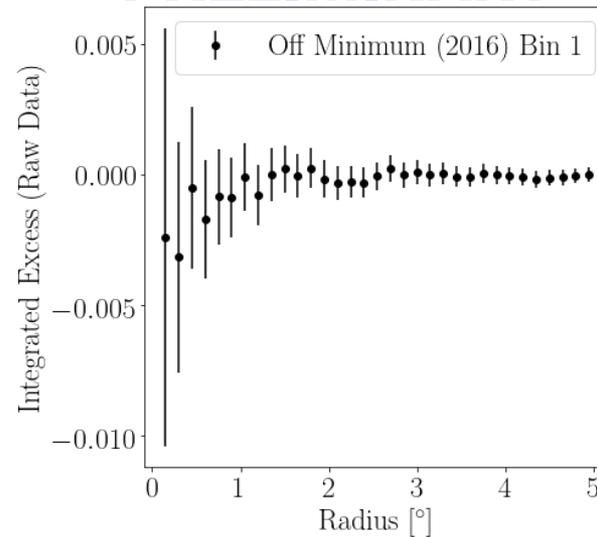
Probing the Anomalous Flux of Very-high-energy Gamma rays from the Sun with HAWC

PRELIMINARY



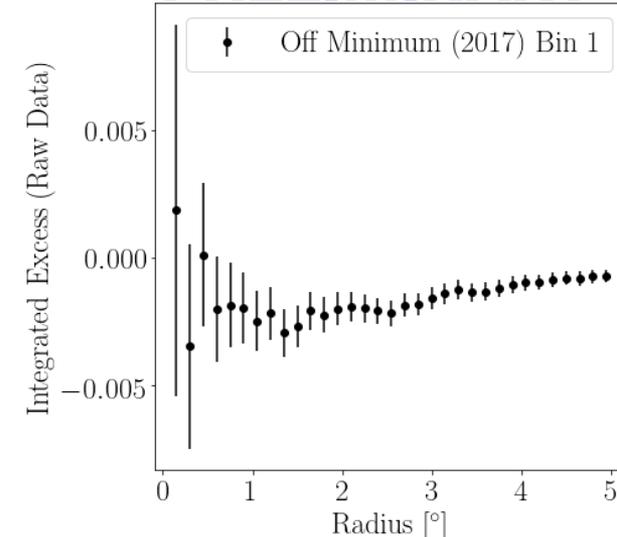
2015

PRELIMINARY



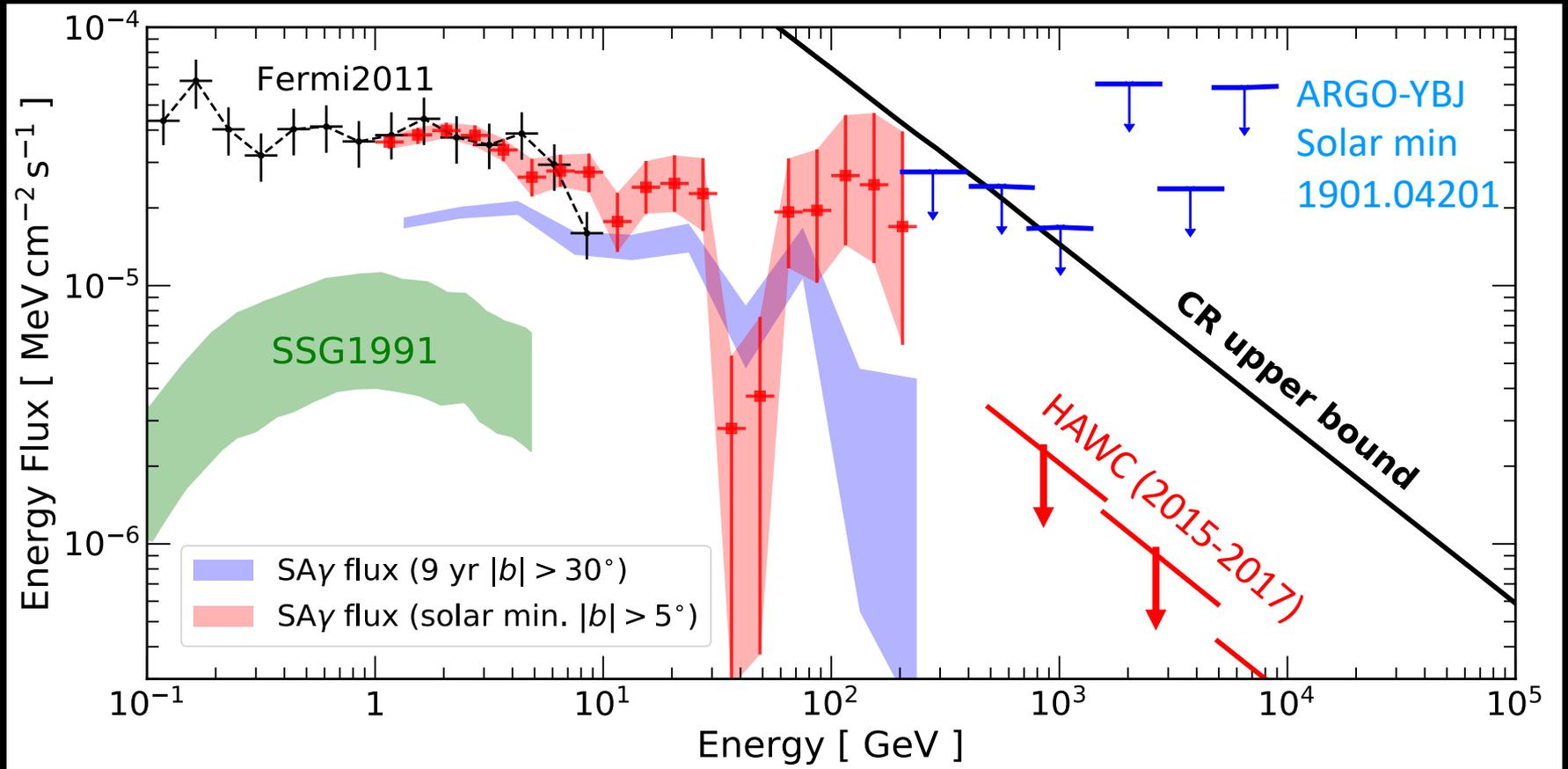
2016

PRELIMINARY



2017

The Sun as a TeV source?!



Solar Atmospheric Gamma rays

Complicated.....

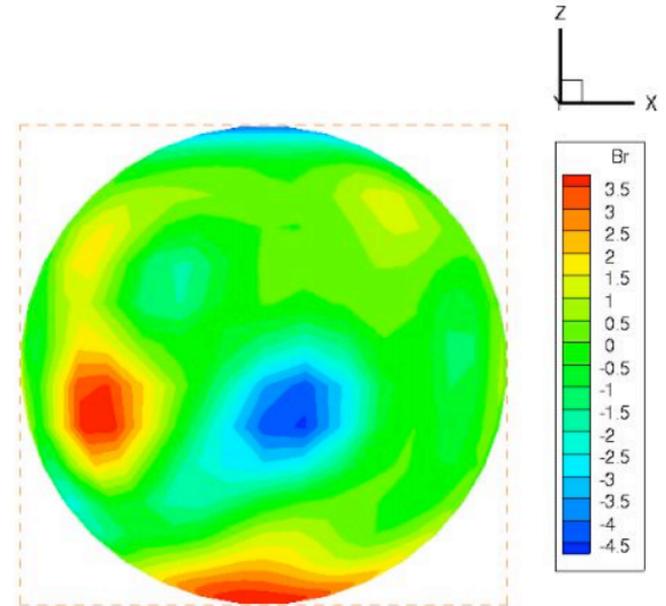
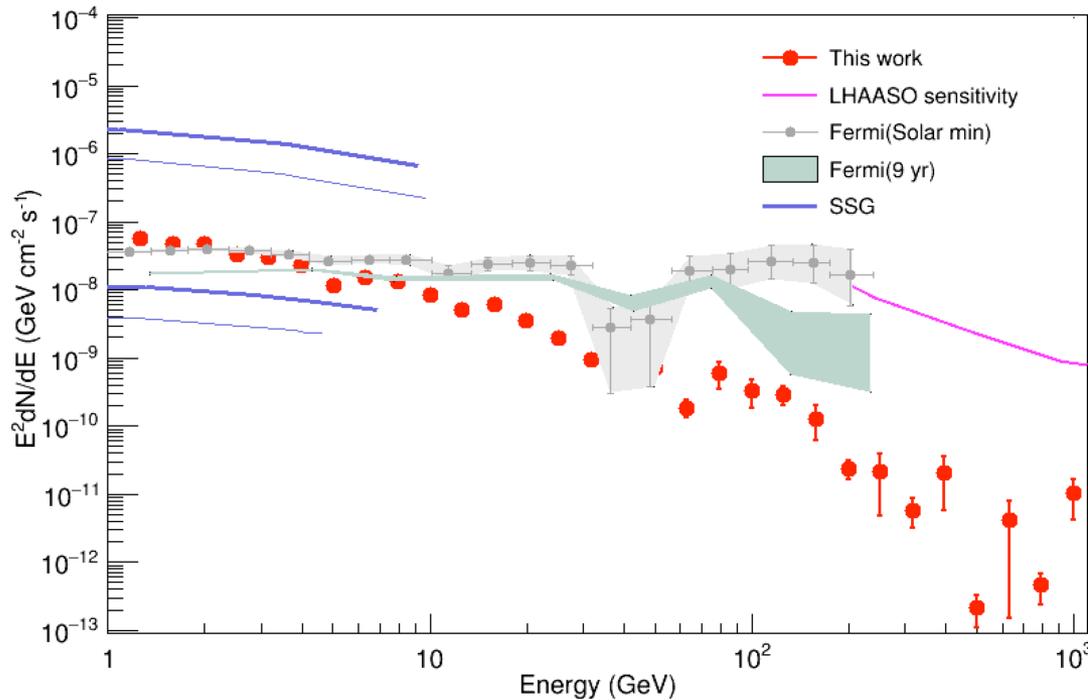
But could be a new probe for solar physics!

Necessary for robust prediction on neutrinos

First Solar gamma simulation w/ B-field



3. Solar disk simulation result



PFSS model for "quiet" Sun

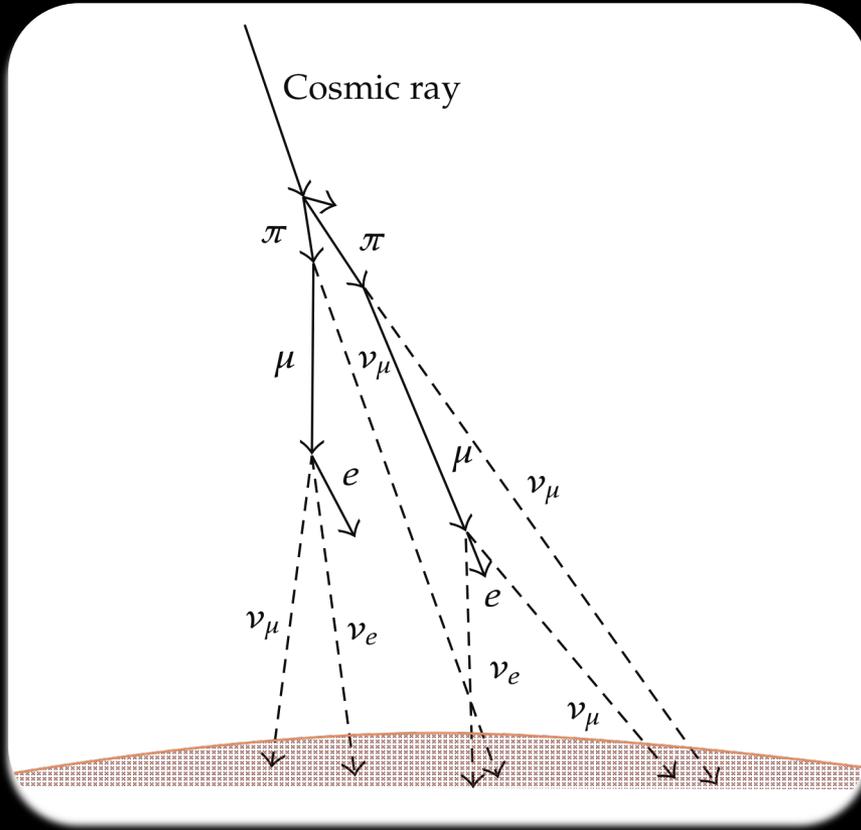
2019-7-29

Zhe Li (IHEP)

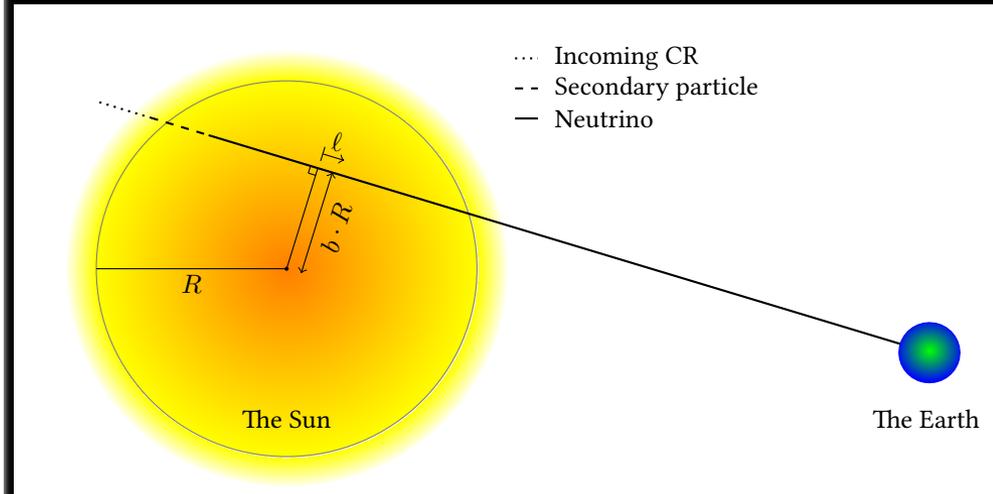
SH5e: Estimation of Solar Disk Gamma-ray Emission Based on Geant4

17

Solar Atmospheric Neutrinos



Zero Magnetic Fields!

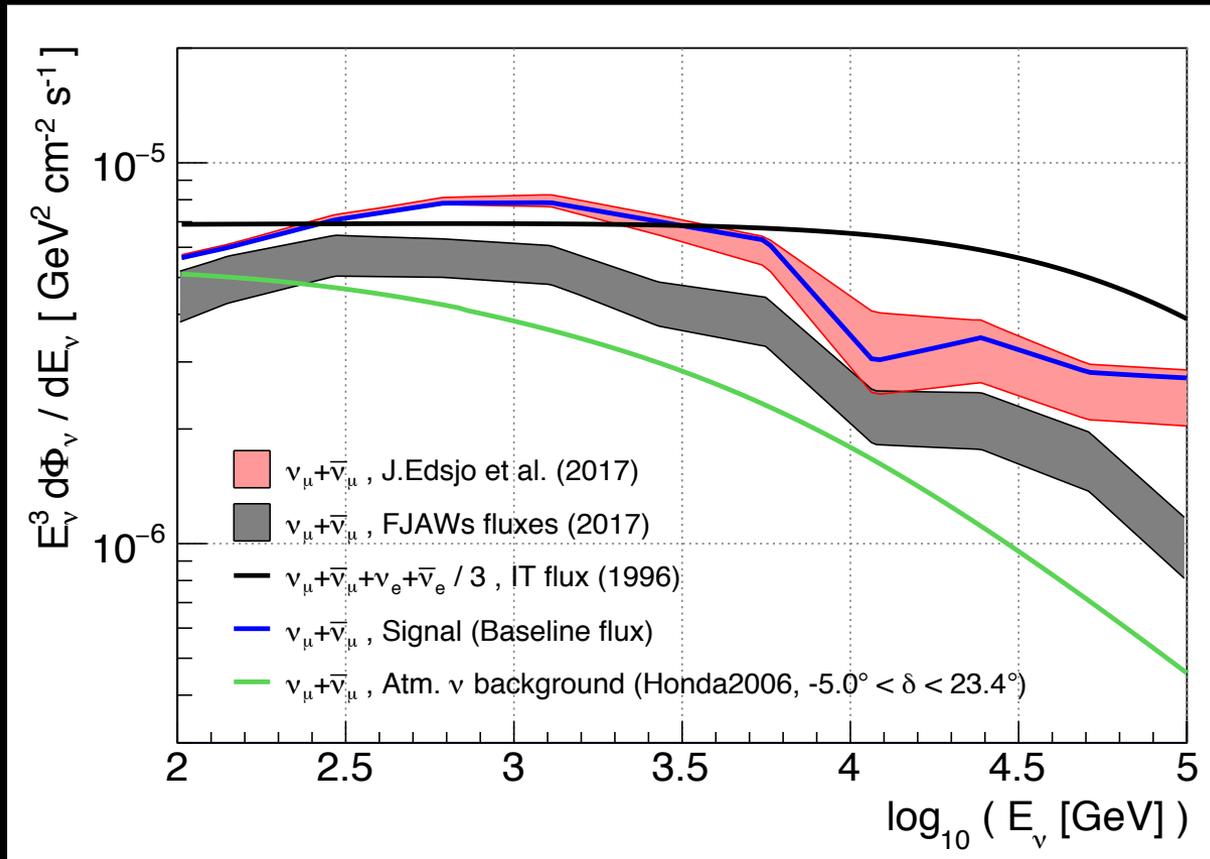


- Dilute atmosphere, larger neutrino flux

Seckel+ 1991, Moskalenko+, 1993, Ingelman+ 1996,
Hettlage+ 2000, Fogli+ 2003

C.A. Argüelles+ 1703.07798
Joakim Edsjo+ 1704.02892

Solar Atmospheric Neutrinos



IceCube, 1912.13135

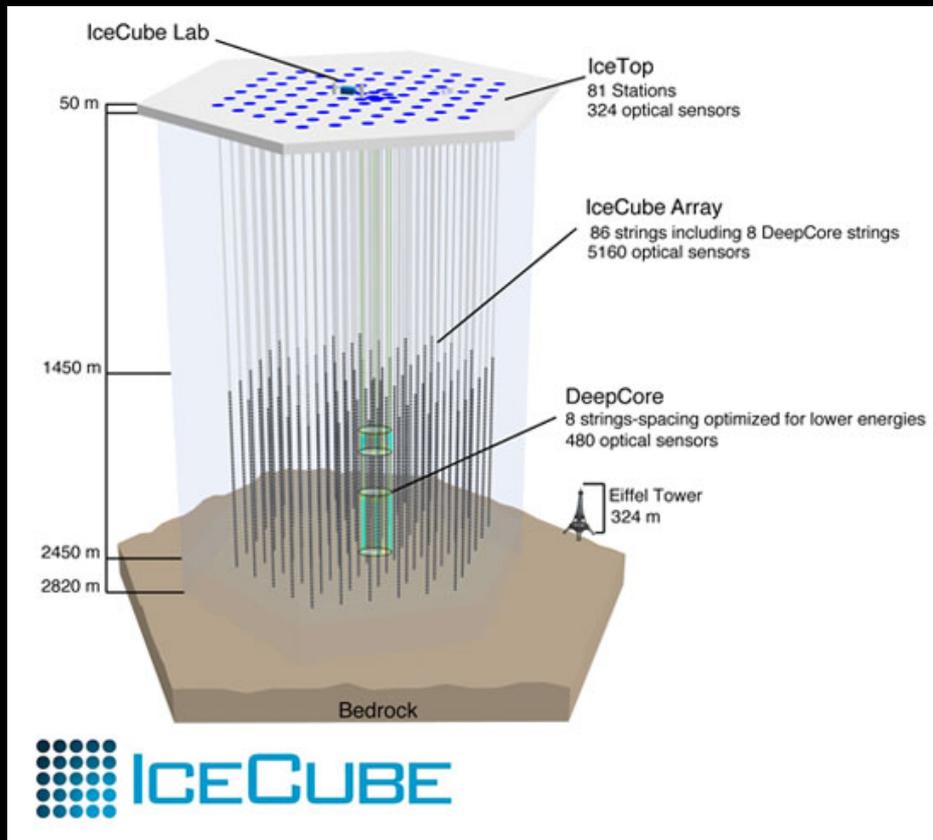
- Dilute atmosphere, larger neutrino flux

Seckel+ 1991, Moskalenko+, 1993, Ingelman+ 1996,
Hettlage+ 2000, Fogli+ 2003

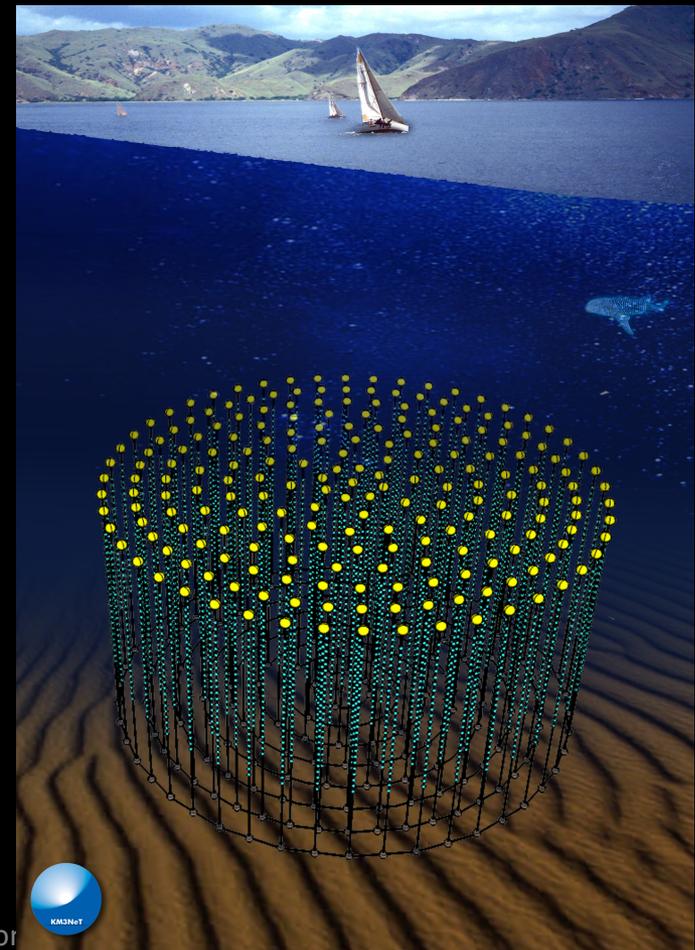
C.A. Argüelles+ 1703.07798
Joakim Edsjo+ 1704.02892

Gigaton Neutrino Detectors

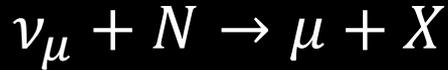
IceCube Southpole



KM3NeT (future) Mediterranean



Neutrino point source detection



- ν_μ CC events

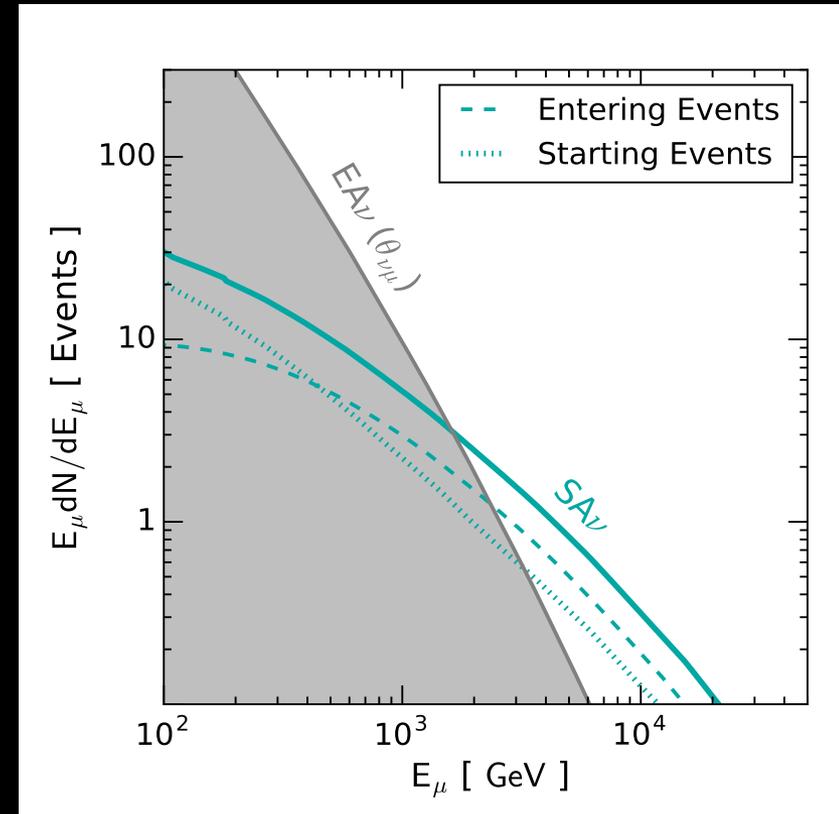
– Starting events

$$\frac{dN^{\text{sta}}}{dE_\mu} \simeq N_A \rho V T \frac{1}{1-y} \left[\frac{d\Phi}{dE_\nu}(E_\nu) \sigma(E_\nu) \right]_{E_\nu = \frac{E_\mu}{(1-y)}}$$

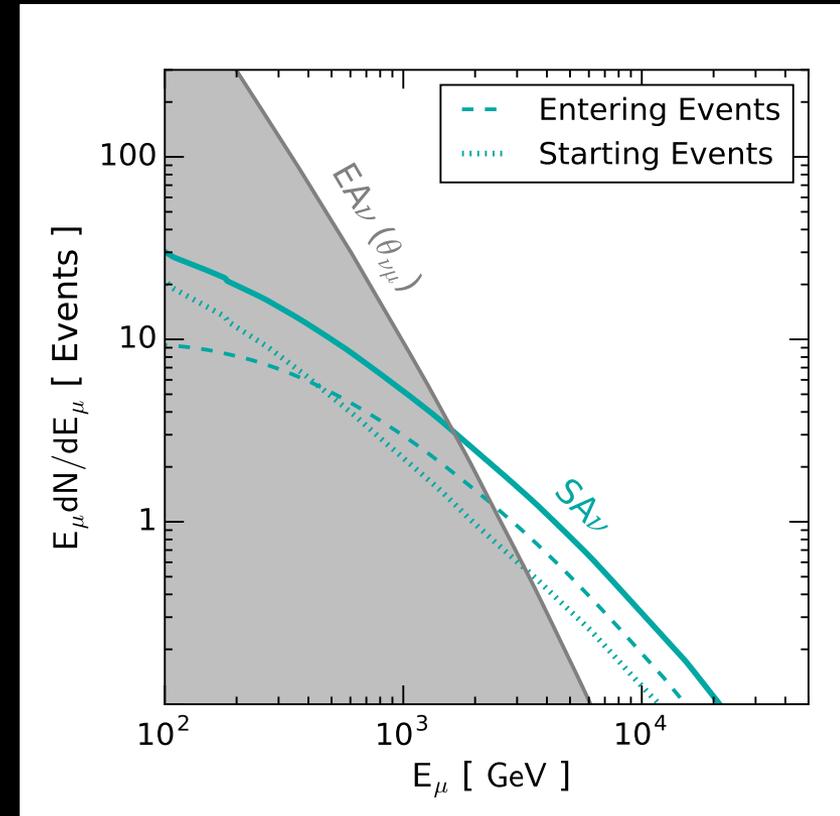
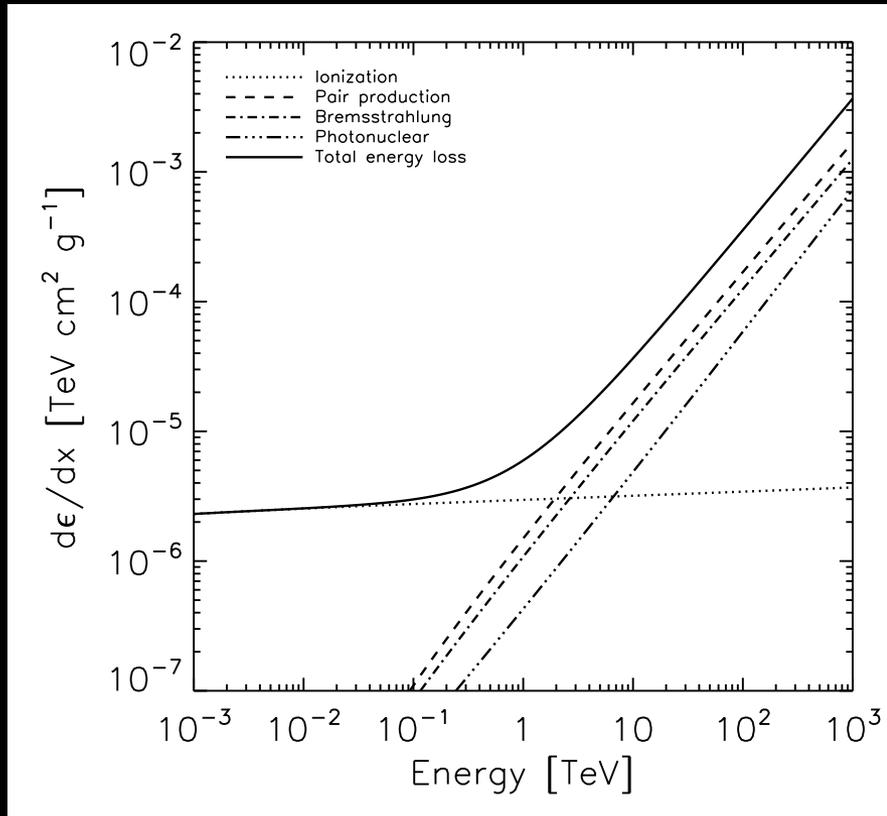
– Entering events

$$\frac{dN^{\text{ent}}}{dE_\mu} \simeq \frac{N_A \rho A T}{\rho(\alpha + \beta E_\mu)} \int_{\frac{E_\mu}{1-y}}^{\infty} dE_\nu \frac{d\Phi}{dE_\nu}(E_\nu) \sigma(E_\nu)$$

Muon range



Energy information - Muon energy loss

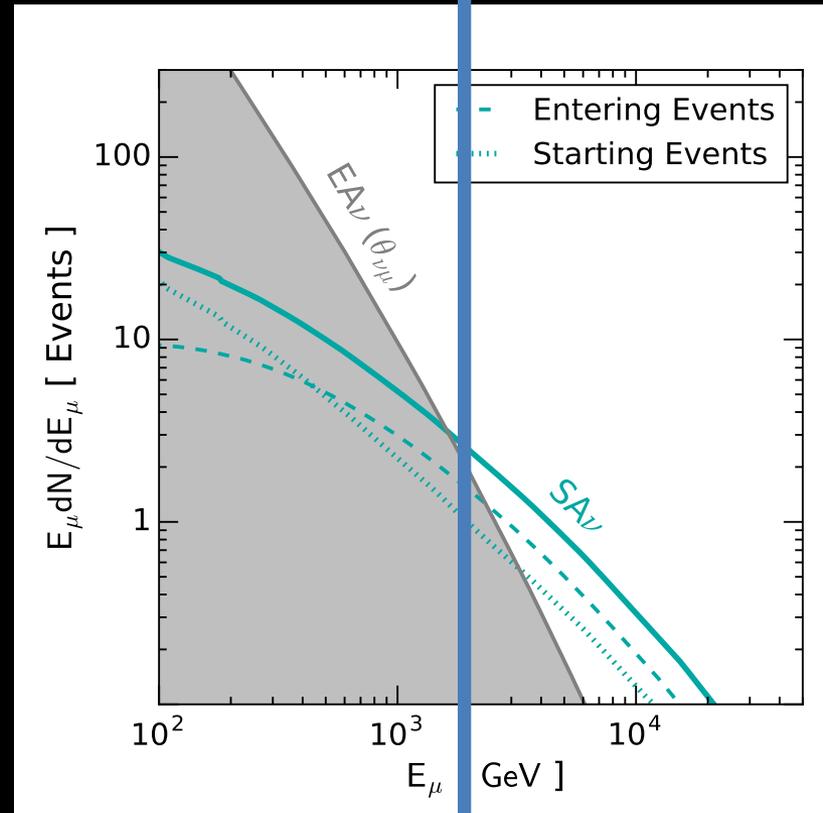
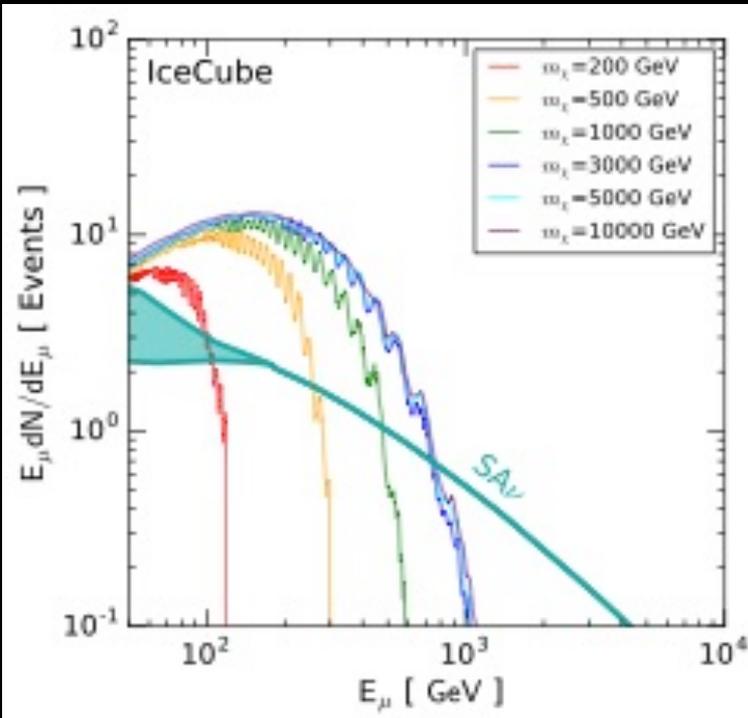


Astraatmadja 2011

- Energy resolution from muon radiative energy loss?

Background or Signal? (Both!)

Theorist Expectation



BAD energy-resolution
Difficult to distinguish from DM signal
Background!

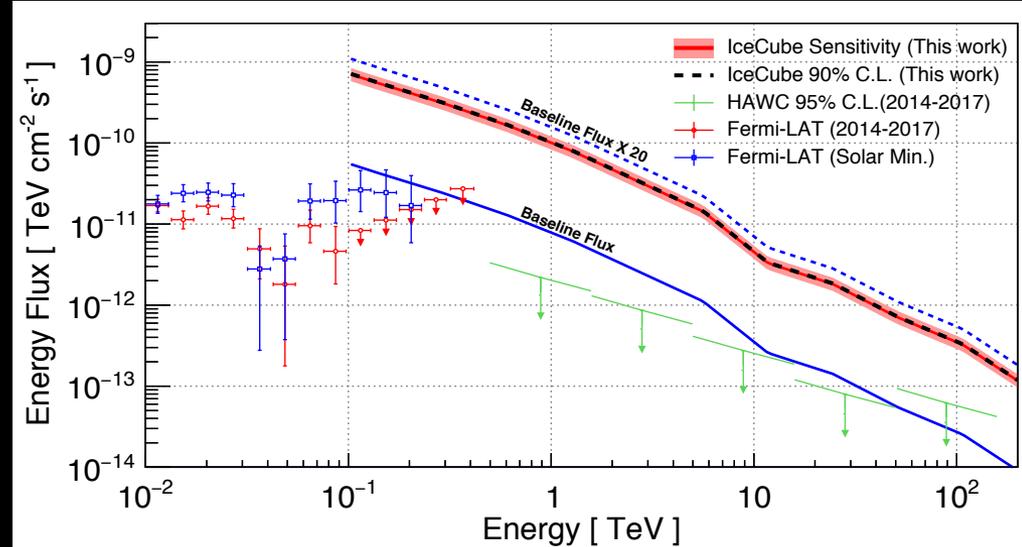
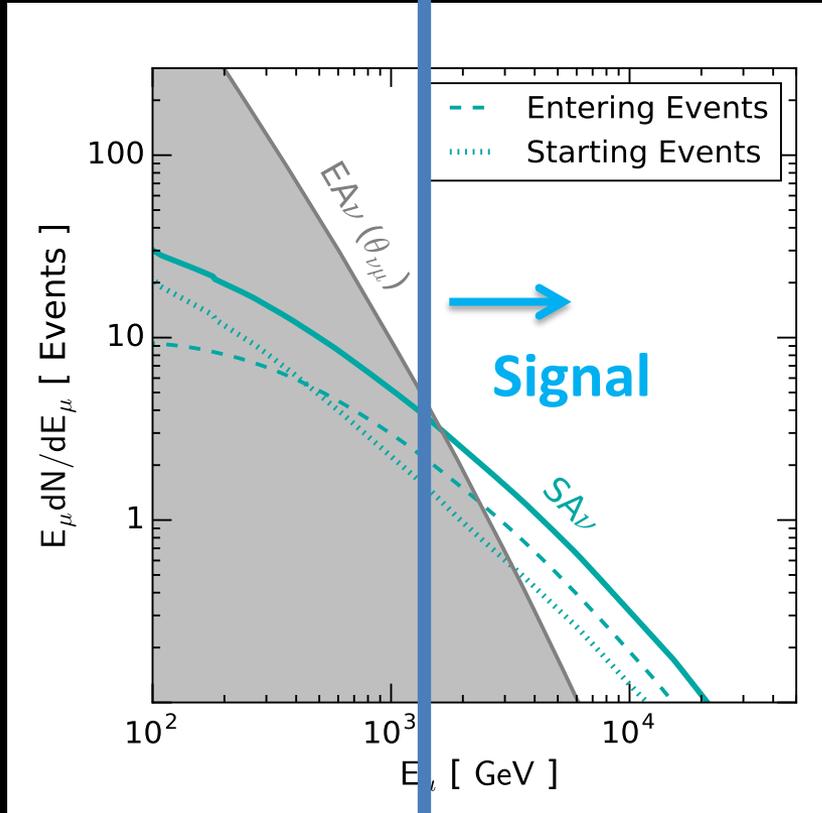


Some energy-resolution
No DM signal*
Astrophysical signal!

IceCube Search (Signal)

IceCube, 1912.13135

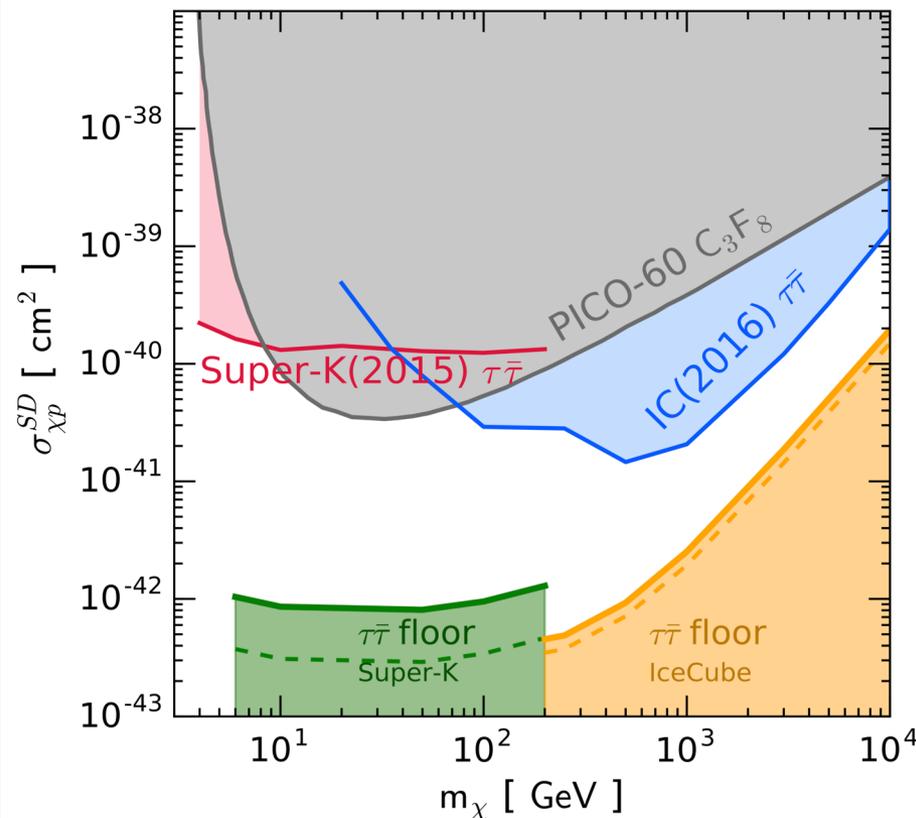
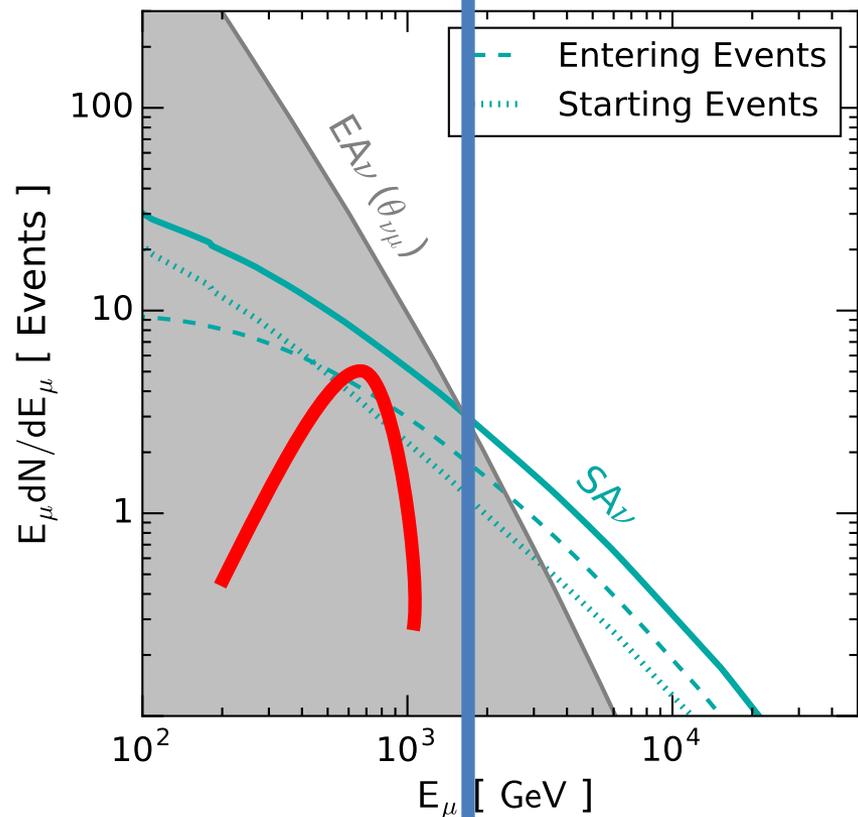
Theorist Expectation



Seems difficult.....

- Improve analysis?
- IceCube-gen 2/ KM3NeT

Solar ATM neutrino – indirect detection Neutrino Floor (Background)



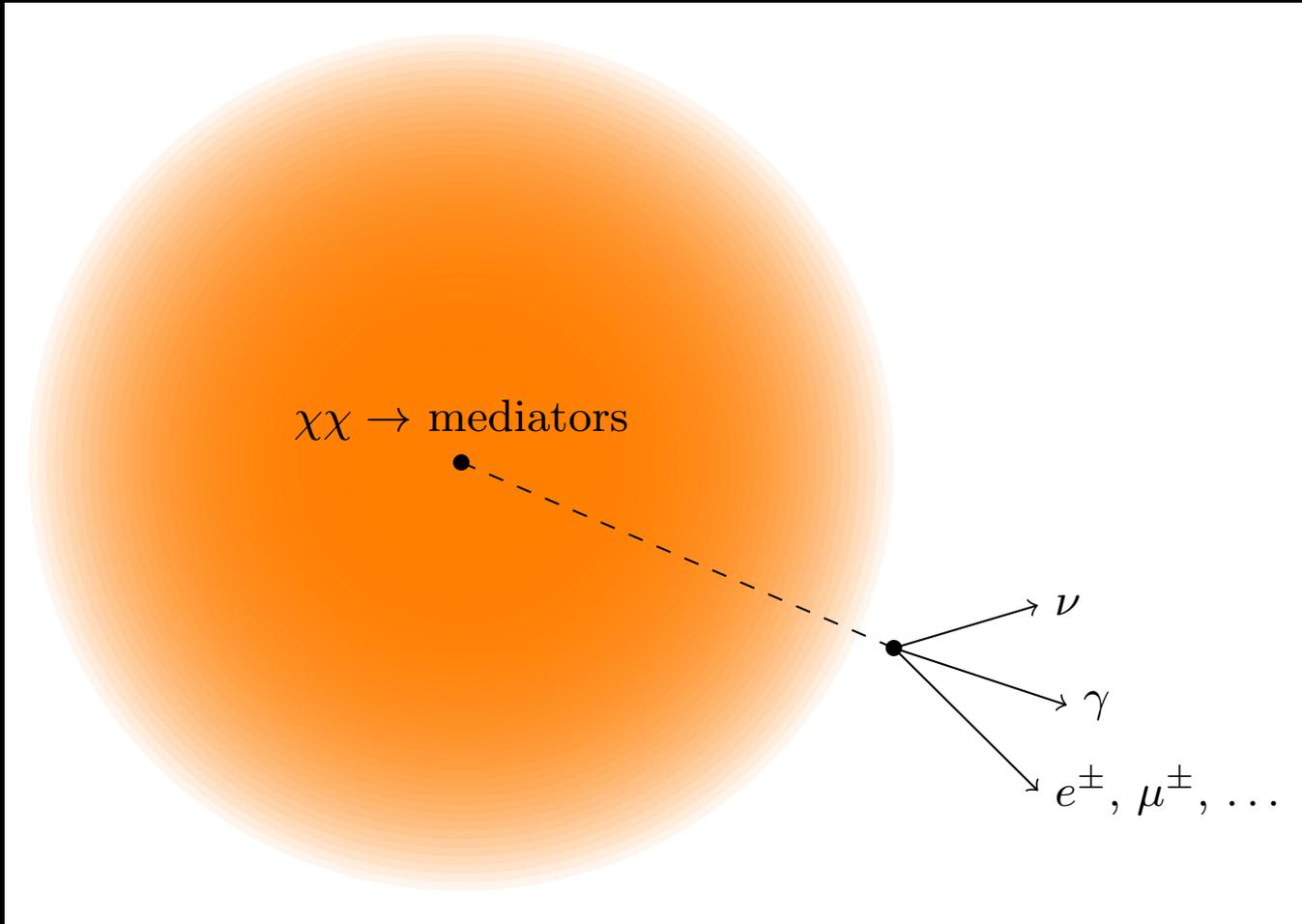
KCYN, Beacom, Peter, Rott, PRD 2017

See also

Arguelles+ 1703.07798

Edsjo+ 1704.02892

Beyond WIMPs

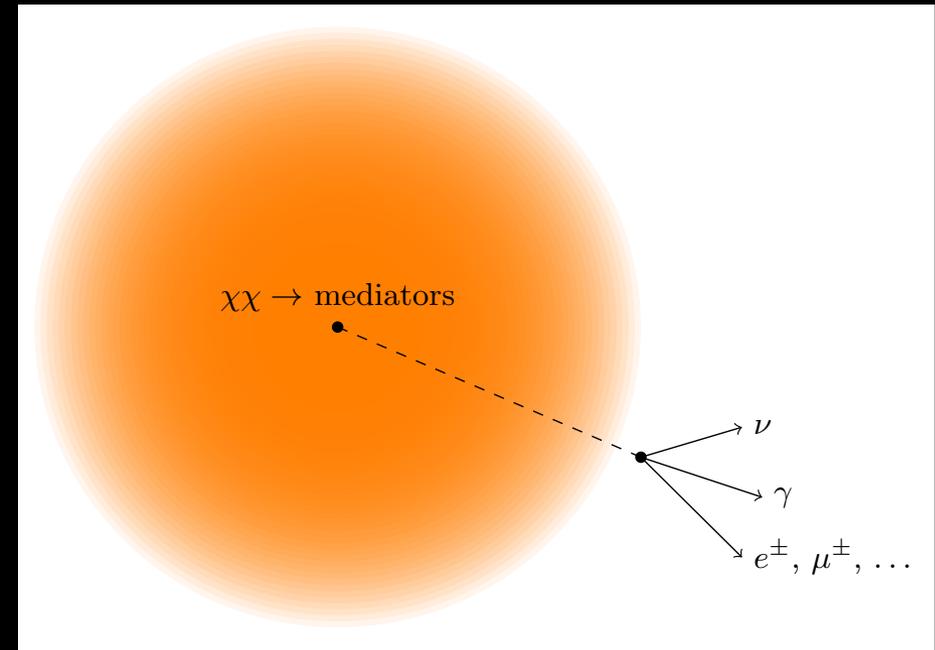


Leane, KCYN, Beacom 1703.04629

Dark Matter with long-lived mediators

Leane, KCYN, Beacom 1703.04629

- Unlock
 - Gamma rays
 - Electrons, muon, etc
- Unsuppressed
 - Neutrinos!
- Less absorption (ν)
- Lower density (ν)
- Decay tail (ν, γ)



Batell, Pospelov, Ritz, Shang, 0910.1567

Bell, Petraki, 1102.2958

Feng, Smolinsky, Tanedo, 1602.01465

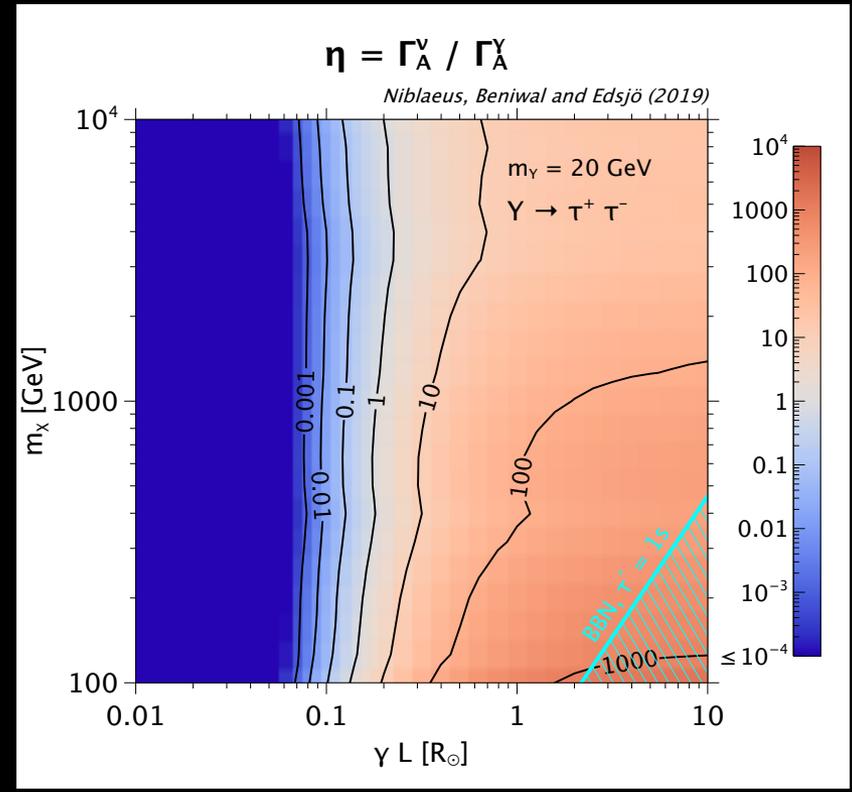
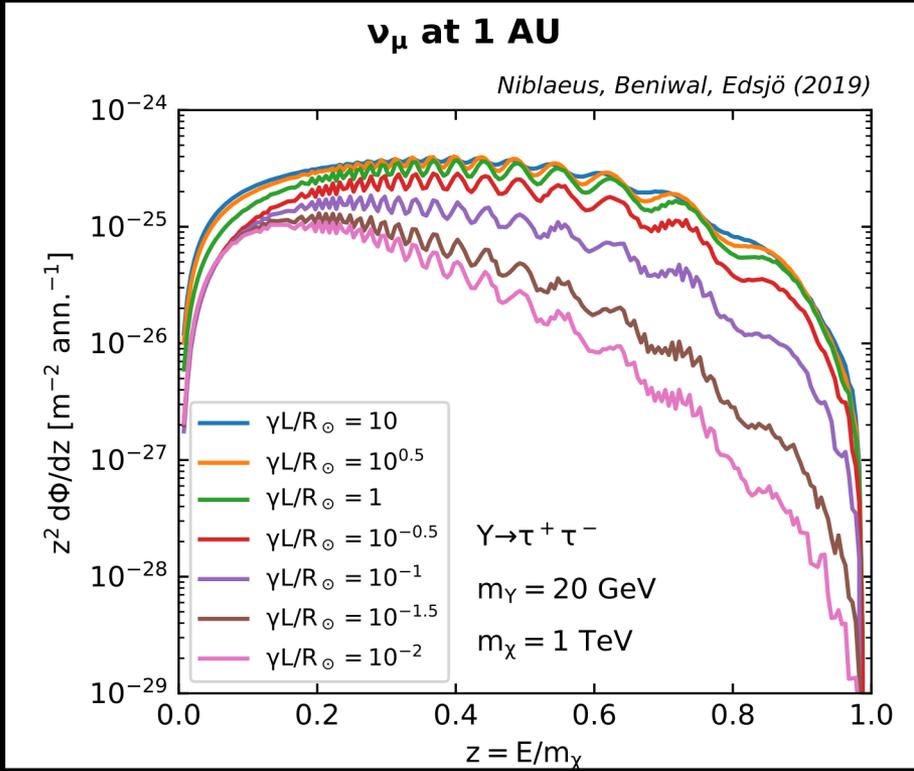
Arina, Backovic, Heisig, Lucente, 1703.08087

Niblaeus, Beniwal, Edsjo, 1903.11363

etc

Enhanced Gamma-Ray & Neutrino Spectra

γL = boosted decay length of the mediator



Neutrino <-----> Gamma rays

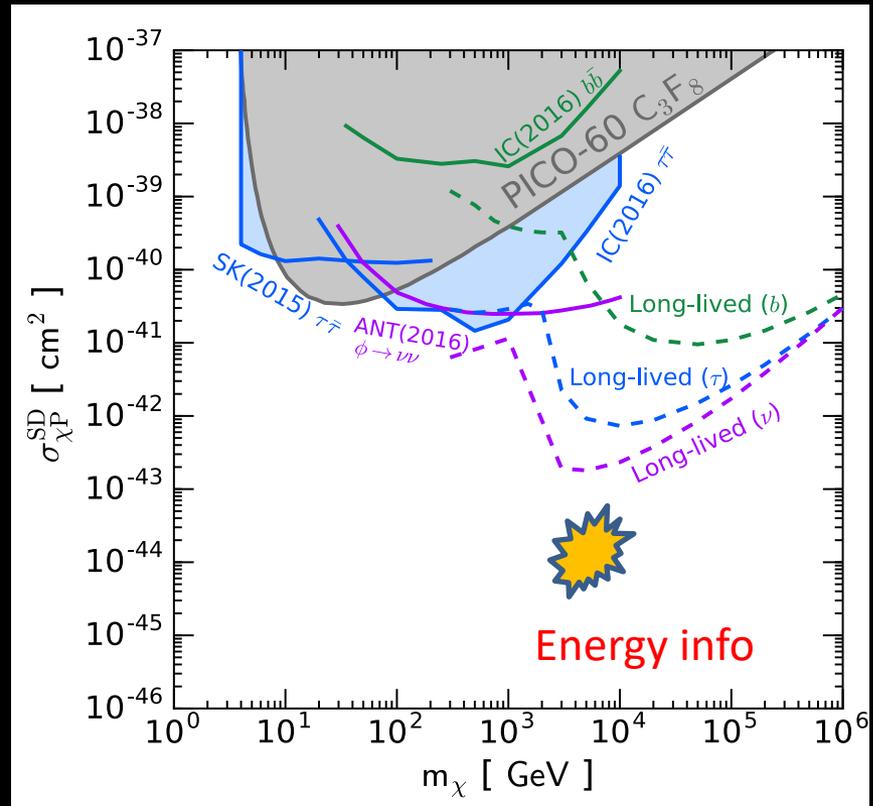
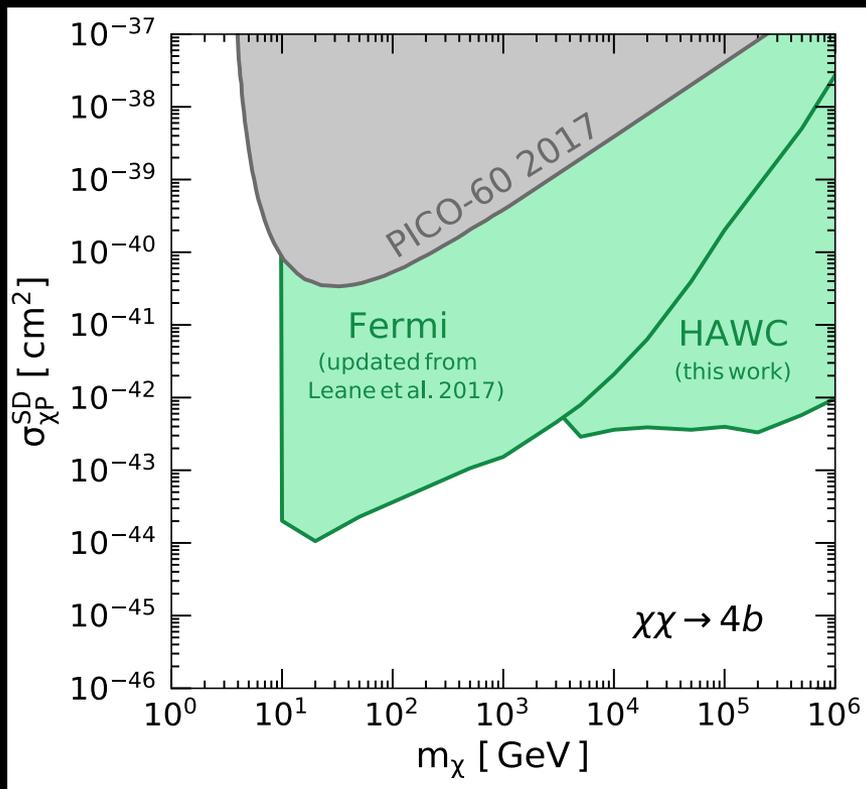
Niblaeus, Beniwal, Edsjo, 1903.11363

Dark Matter with long-lived mediators

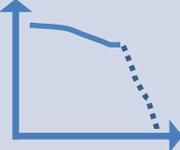
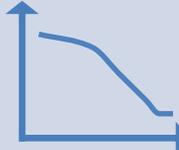
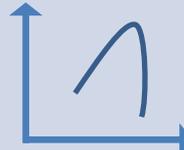
HAWC+KCYN 1808.05624

Also Leane, KCYN, Beacom 1703.04629

- Gamma Rays & Neutrinos are complementary



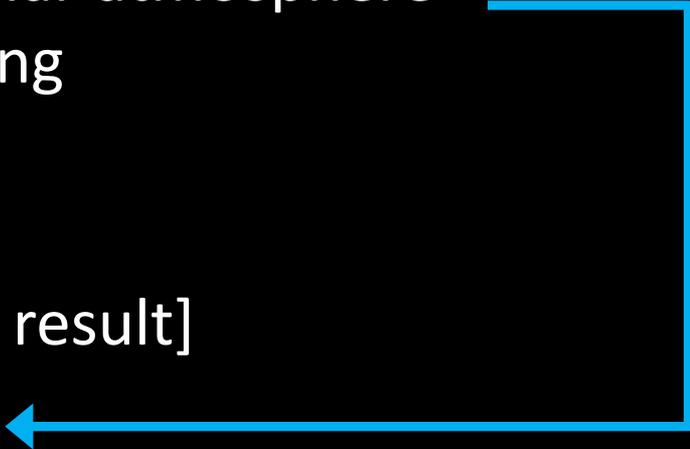
High-energy Solar Messengers

	Gamma Rays	Neutrinos (< TeV)	Neutrinos (> TeV)
Cosmic rays + Solar Atmosphere			
WIMP Dark Matter			
Dark Matter + Mediators			

No spec. info ?

Maybe **electrons/positrons** or **neutrons** can also be seen from space?

Summary

- Sun
 - Dark Matter detector/ CR beam dump experiment
 - *Solar atm gamma rays*
 - Info on how CR interact with solar atmosphere
 - TeV observation seems promising
 - *Solar atm neutrinos*
 - First IceCube search is out [null result]
 - Complete model with B-field
 - *Anomalous Signals from the Sun -> New Physics!*
- 

Thanks!