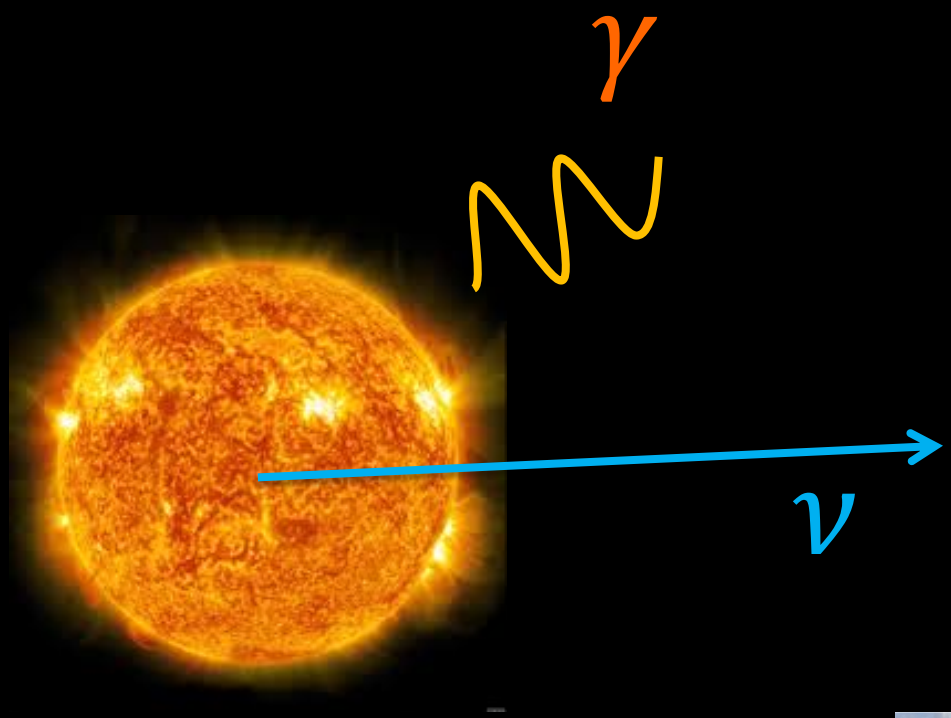
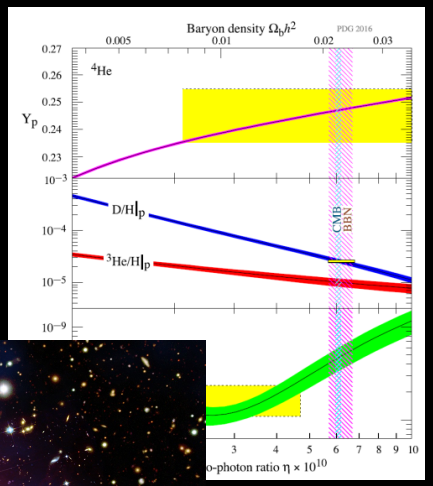
Solar Atmospheric Neutrinos and Dark Matter

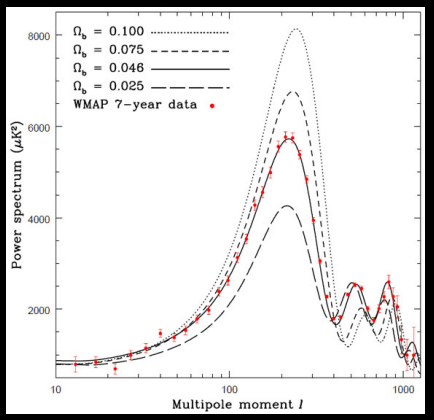


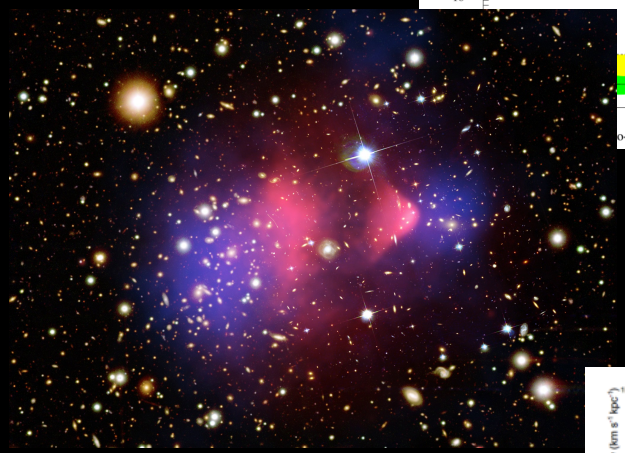
Kenny, Chun Yu Ng (吳震宇)
Marie Curie fellow
GRAPPA, University of Amsterdam

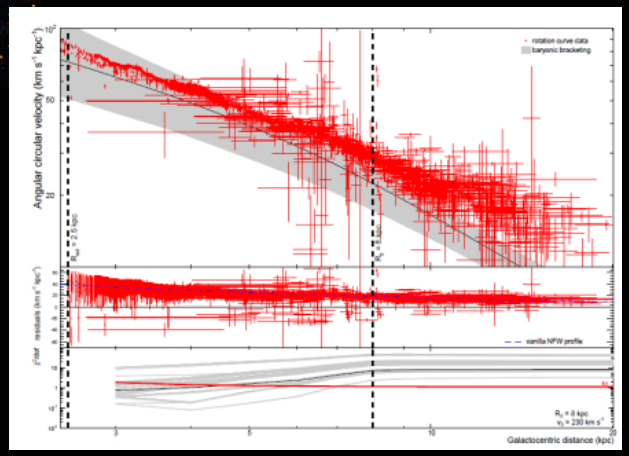
Dark Matter/Gravity problem

- Big Bang Nucleosynthesis \CMB
- Clusters
- Galaxies/Local



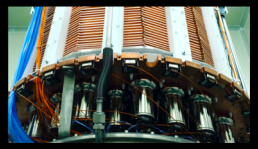




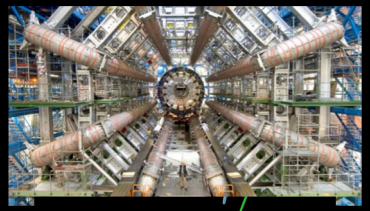


Weakly interacting massive particles

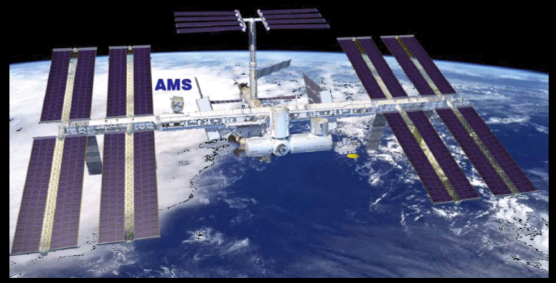
- Direct Detection

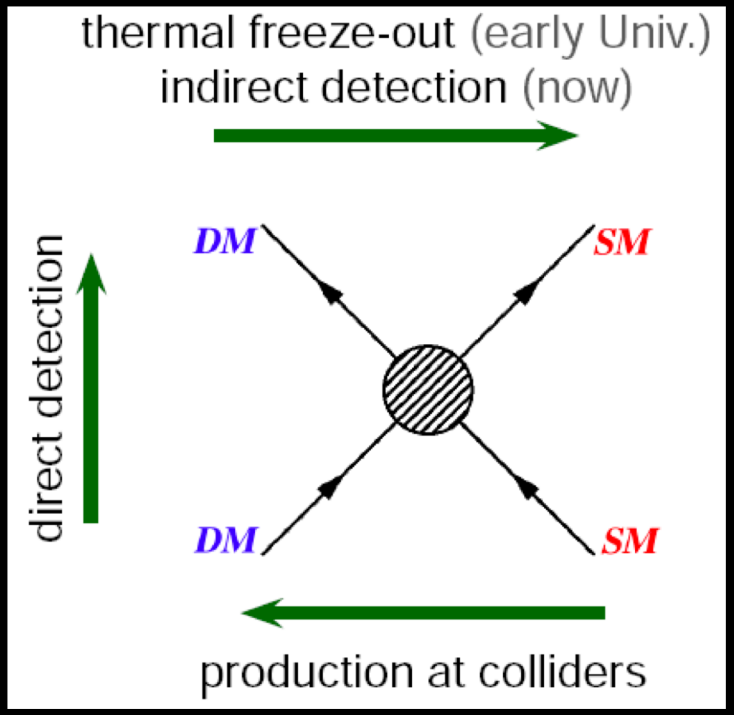


- Collider Search



- *Indirect Detection*



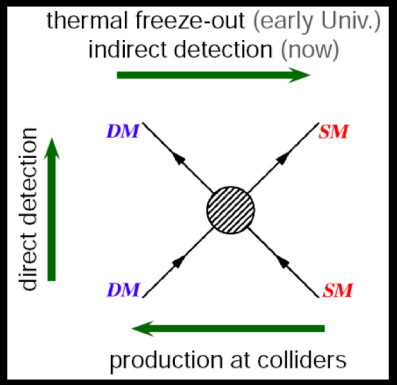


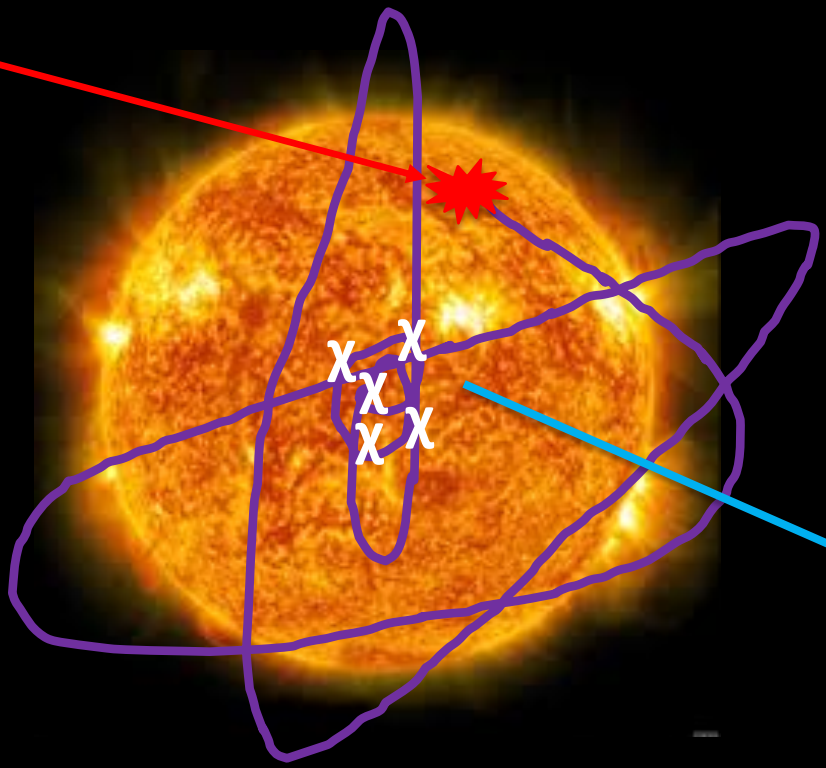
Sun – Dark Matter detector

χ

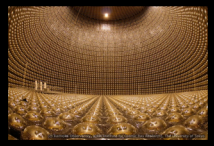
$$\frac{dN}{dt} = \Gamma_{\rm cap} - C_{\rm ann} N^2$$

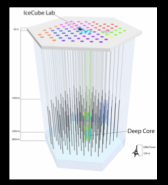
$$\Gamma_{\rm ann} = \frac{1}{2} C_{\rm ann} N^2 = \frac{1}{2} \Gamma_{\rm cap}$$





ν

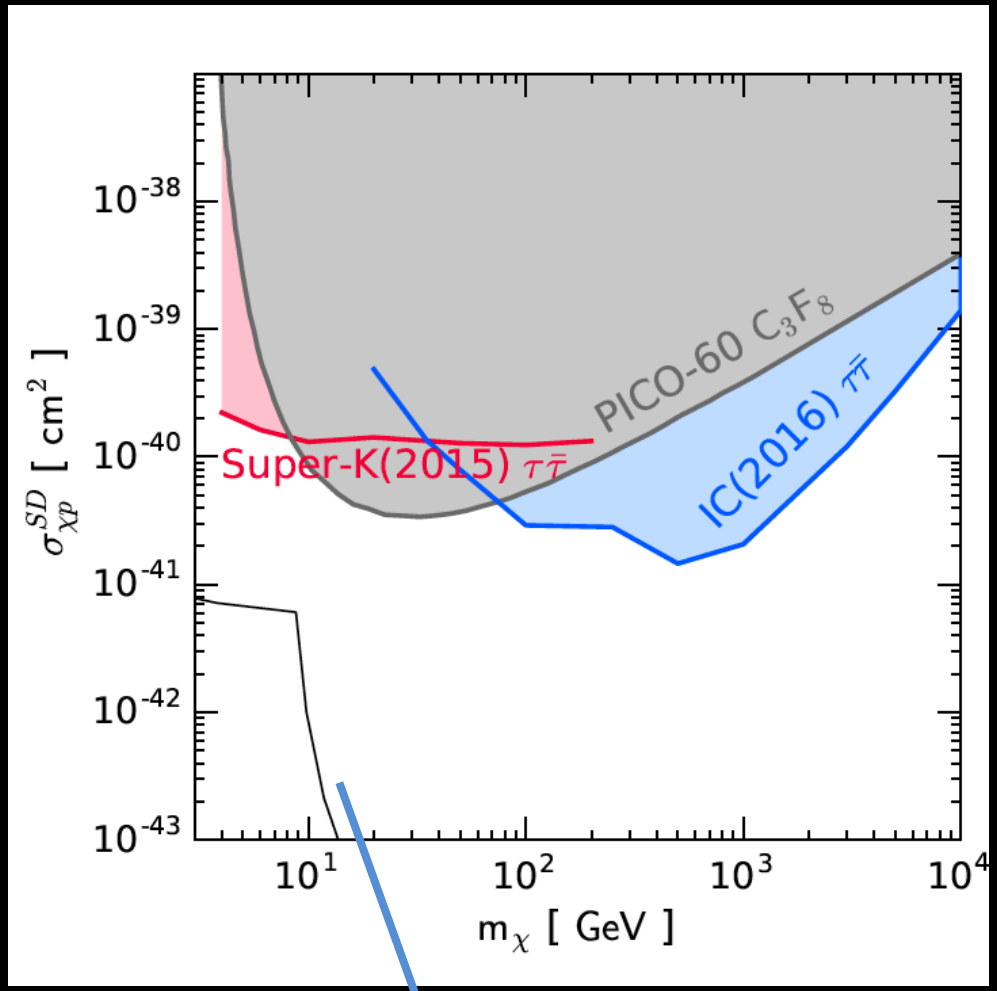




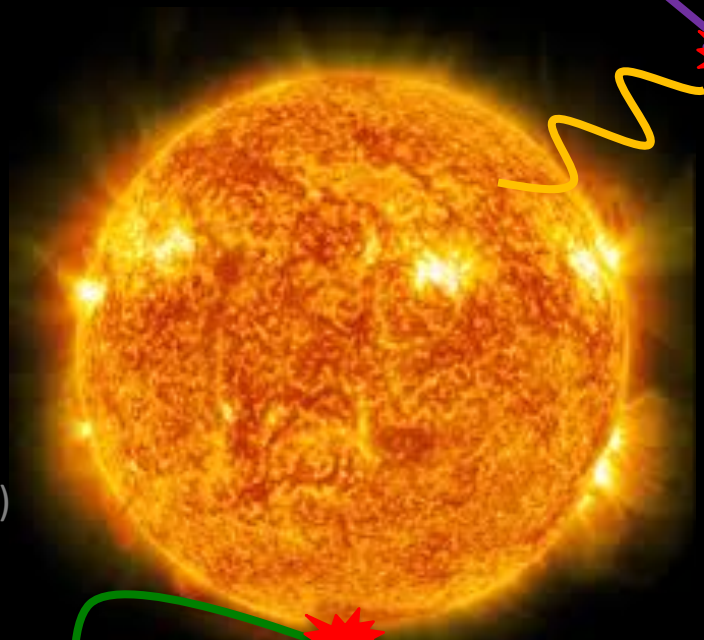
Press, Spergel (1985)
Krauss, Freese, Press, Spergel (1985)
Silk, Olive, Srednicki (1985)

Solar WIMP Search

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



Sun – Cosmic-Ray Beam Dump



CR electrons
Inverse-Compton

Moskalenko, Porter, Digel 2006
Orlando, Strong 2007

γ Continuous

Seckel, Stanev, Gaisser (1991)
Zhou, ***KCYN***, Beacom, Peter
PRD 2017

CR protons
Hadronic

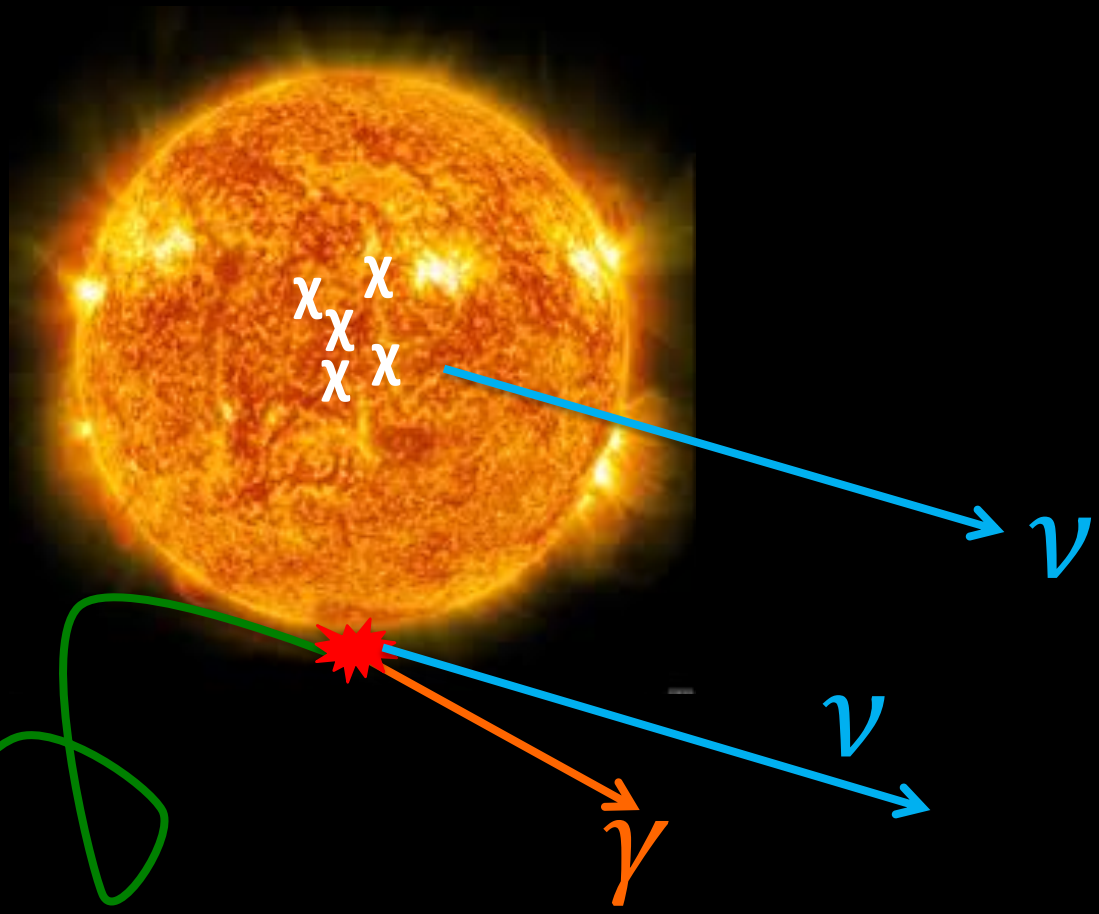
ν

$e^{\pm}, \mu^{\pm}, \mathrm{n}$

γ Continuous

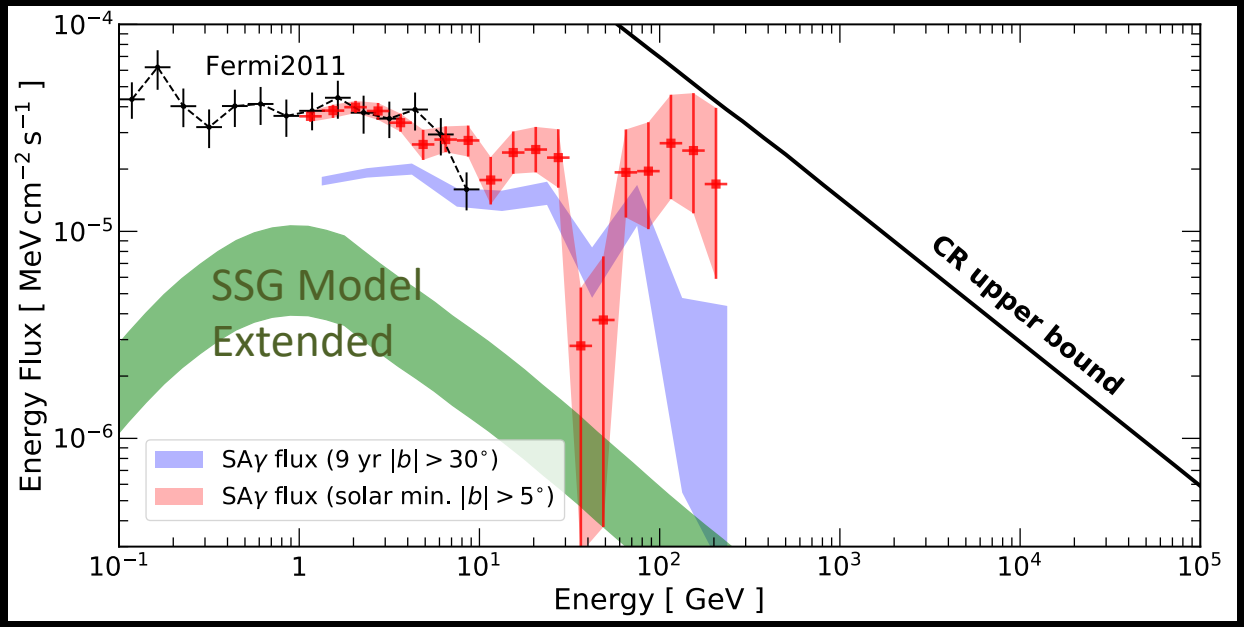
KCYN, TMEX 2020 Quy Nhon

HE Gamma-ray & Neutrino Source Dark Matter Detector



Solar Atmospheric Gamma Rays

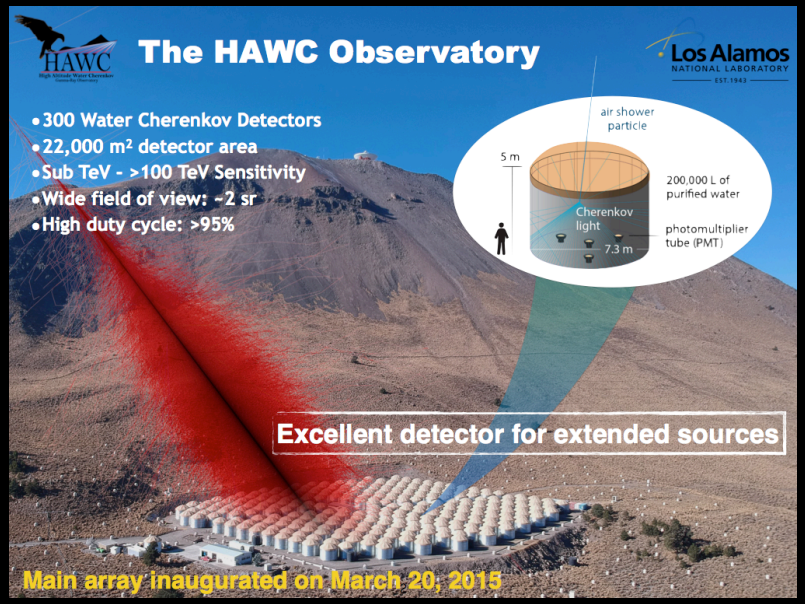
- High Flux, O(10)% efficiency at 100 GeV
- Time variation solar Min-Max
  - (2x @1 GeV, 10x @ 100 GeV)
- Morphology changes
- Dip at ~ 30 GeV, mostly at solar min.
- Hard Spectrum, $\sim E^{-2.2}$



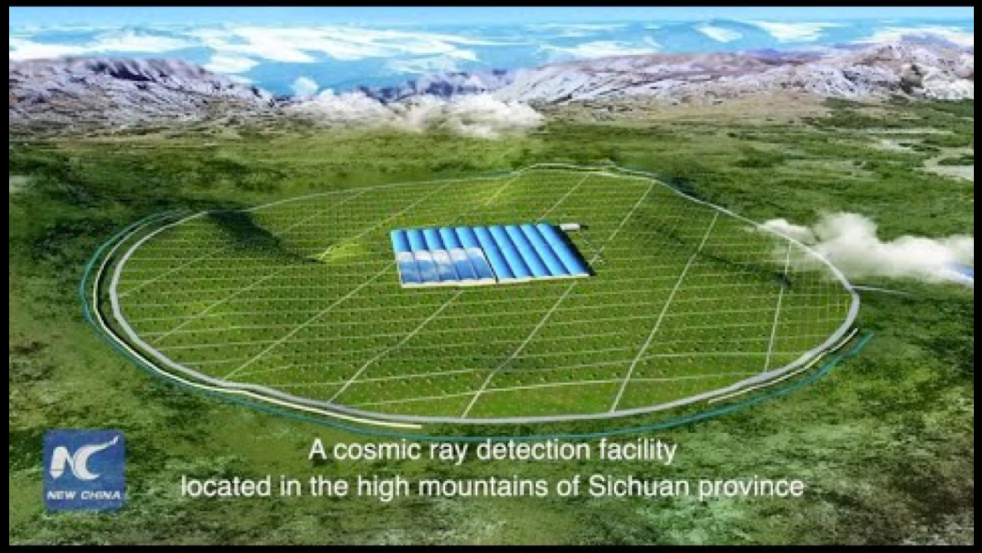
- Abdo+ Apj, 2011
- KCYN+ PRD, 2016
- Linden+ PRL. 2018
- Tang+ PRD, 2018

Air-shower Arrays

HAWC

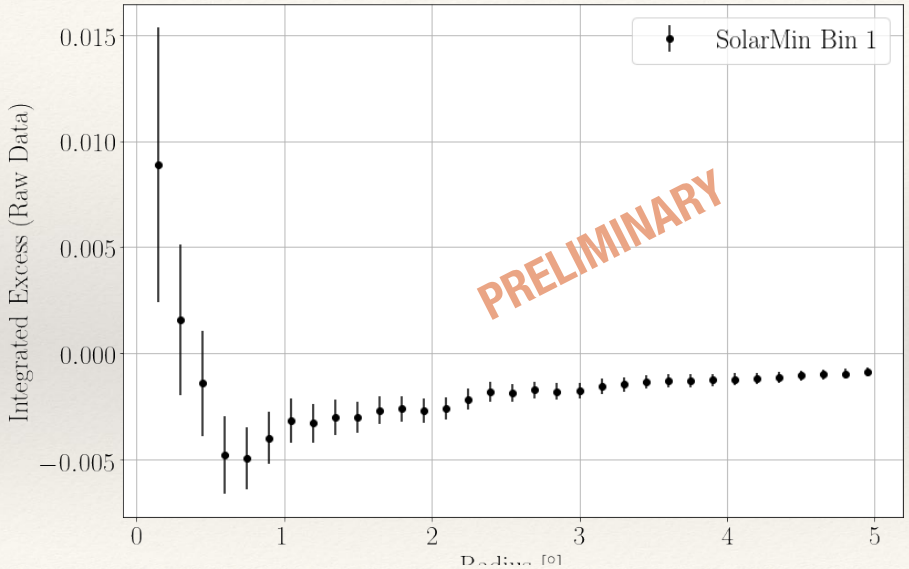


LHAASO (25% +)



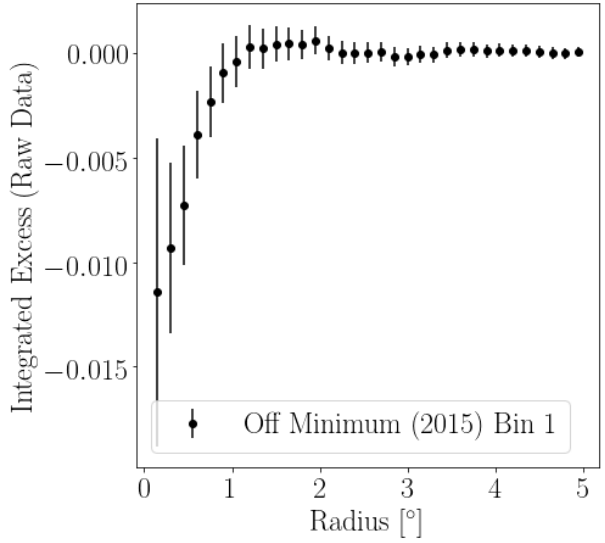
Friday PS#13
Prof. Huihai He

2018 Data: Onwards to the Solar Minimum

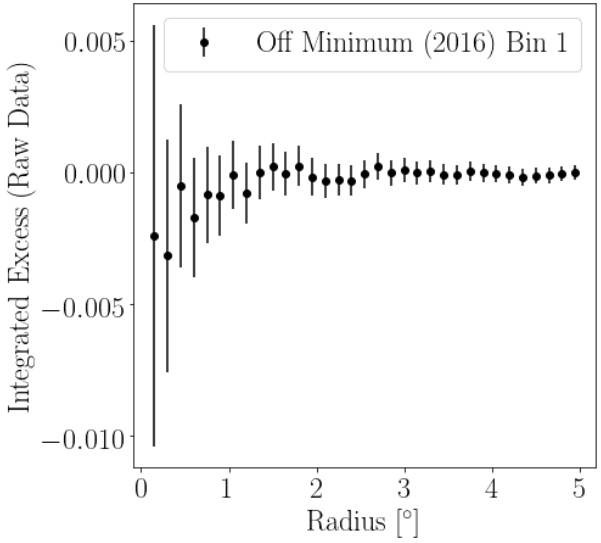


Mehr Un Nisa CRI13c

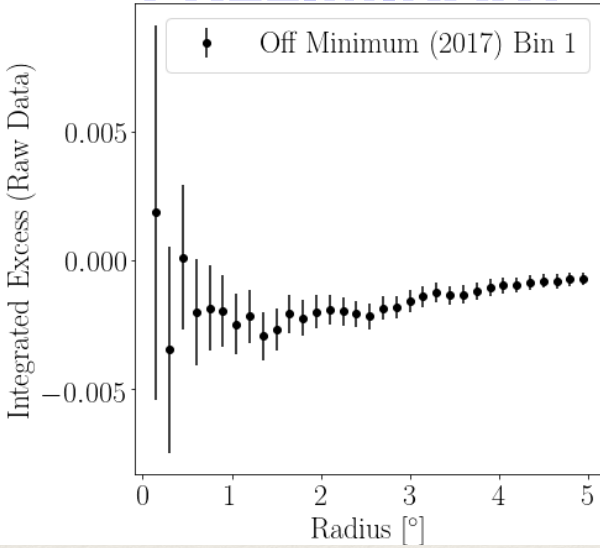
Probing the Anomalous Flux of Very-high-energy Gamma rays from the Sun with HAWC



2015

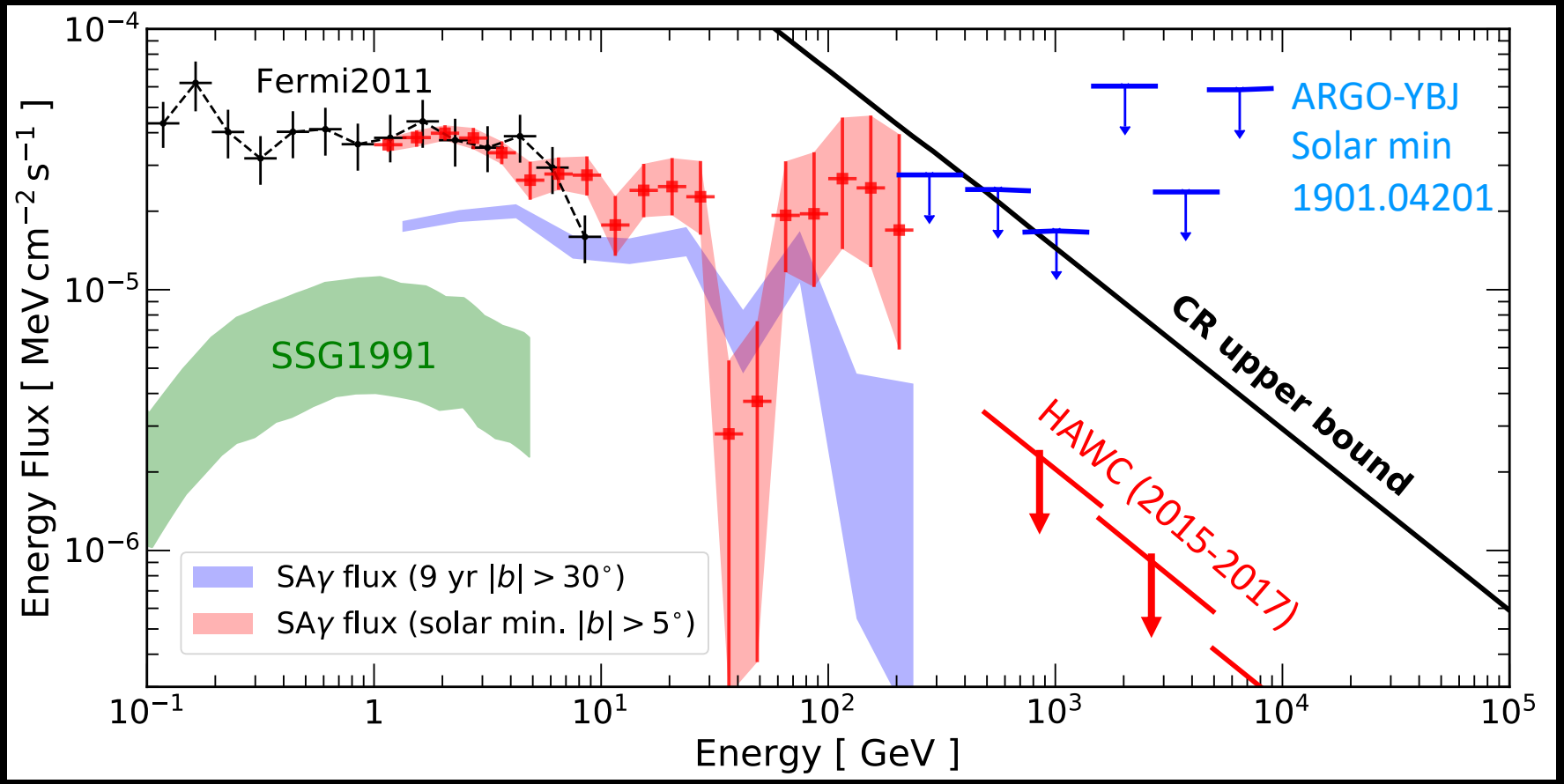


2016



2017

The Sun as a TeV source?!



Solar Atmospheric Gamma rays

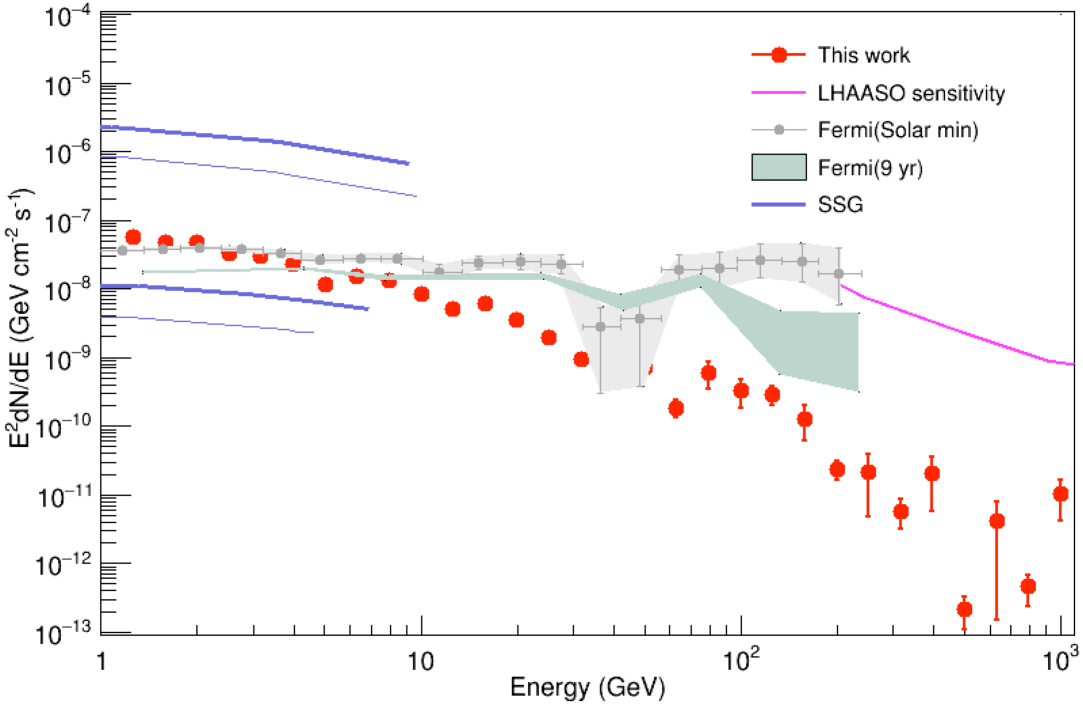
Complicated……

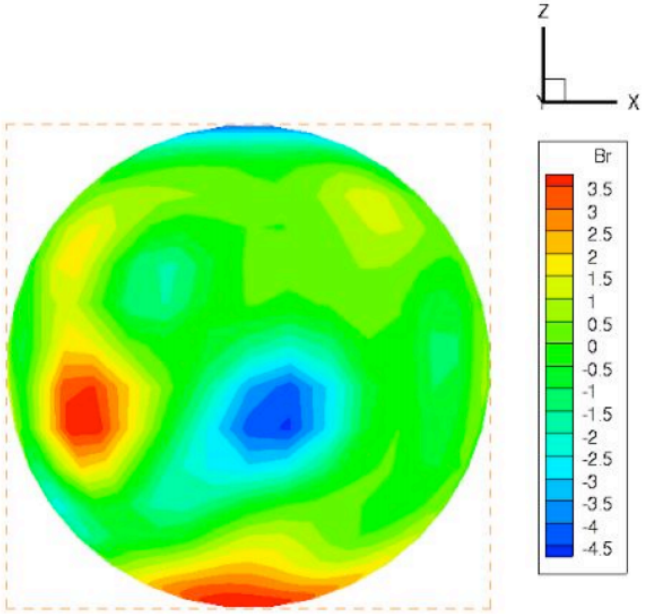
But could be a new probe for solar physics!

Necessary for robust prediction on neutrinos

First Solar gamma simulation w/ B-field

3. Solar disk simulation result



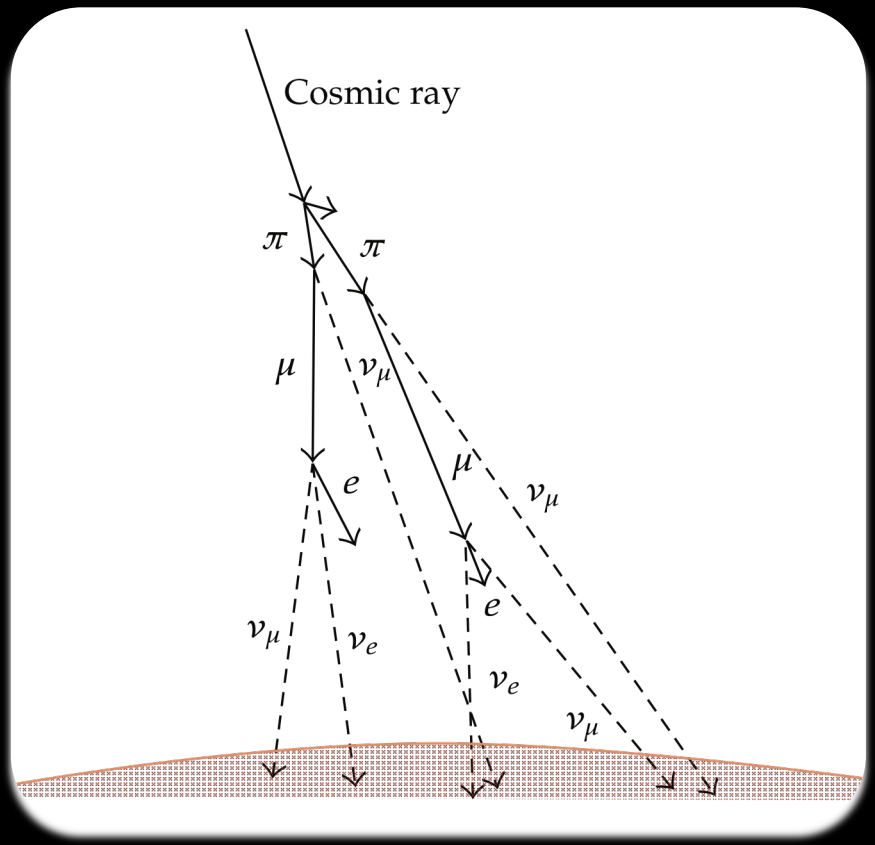


PFSS model for "quiet" Sun

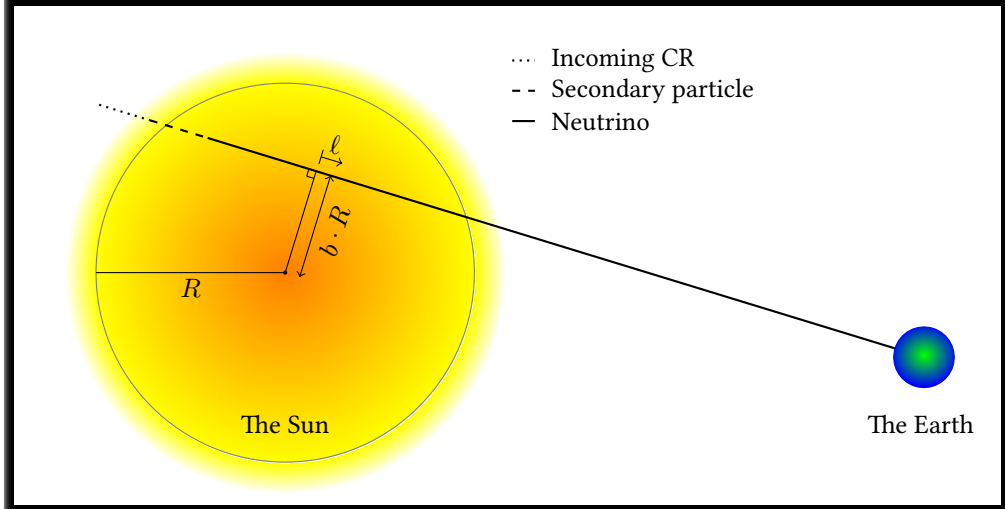
Zhe Li (IHEP)

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

Solar Atmospheric Neutrinos



Zero Magnetic Fields!

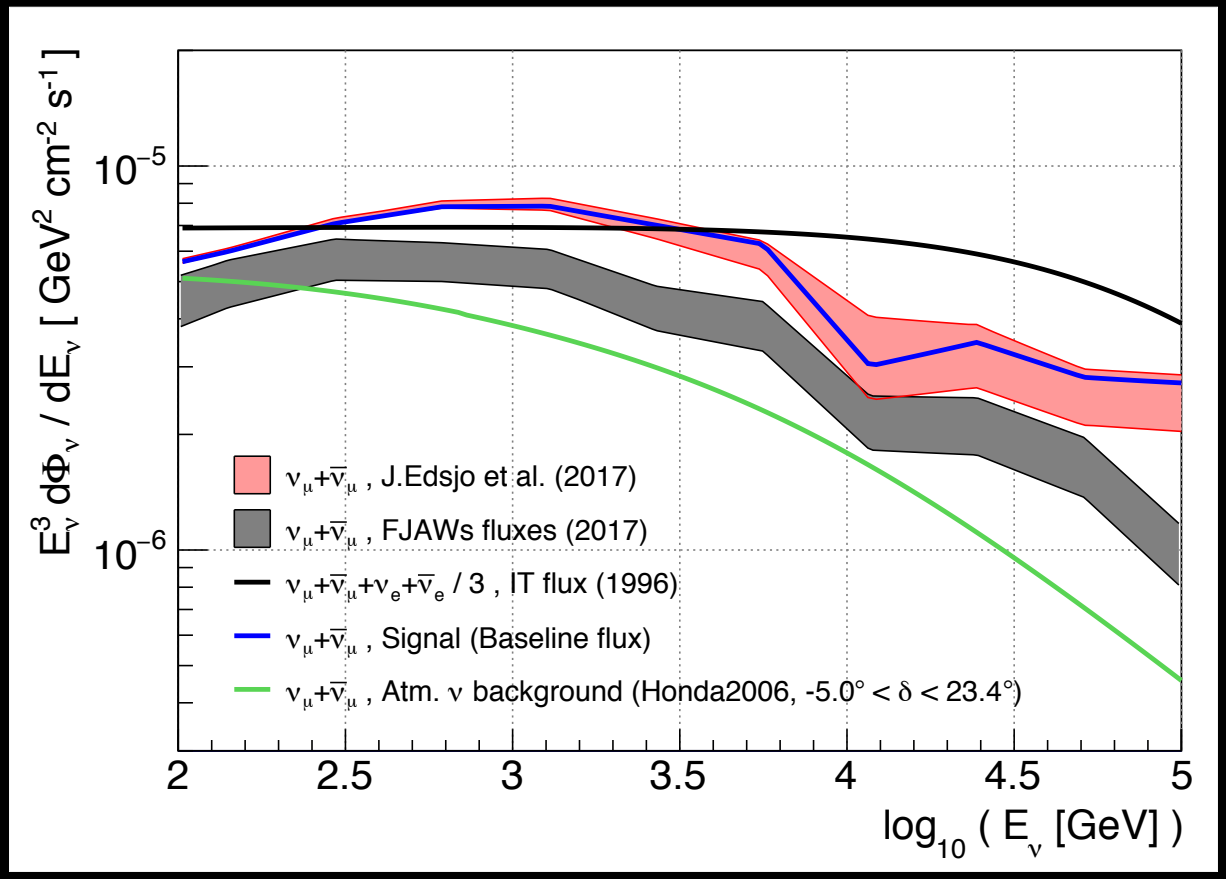


- Dilute atmosphere, larger neutrino flux

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

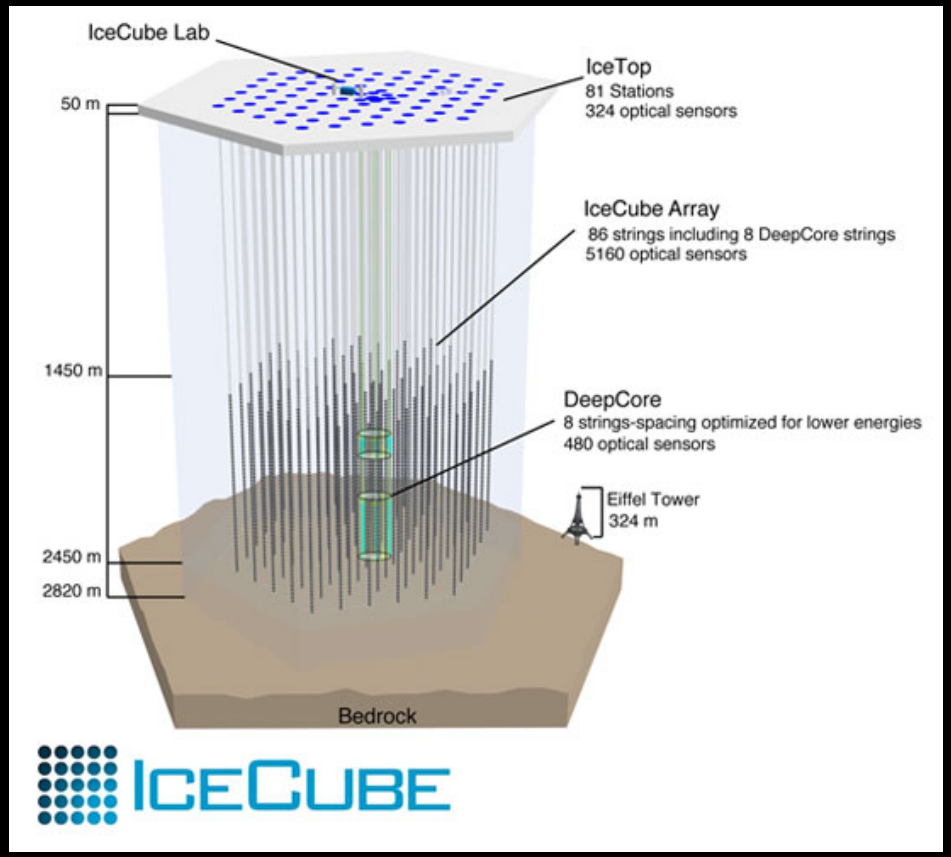
- Dilute atmosphere, larger neutrino flux

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

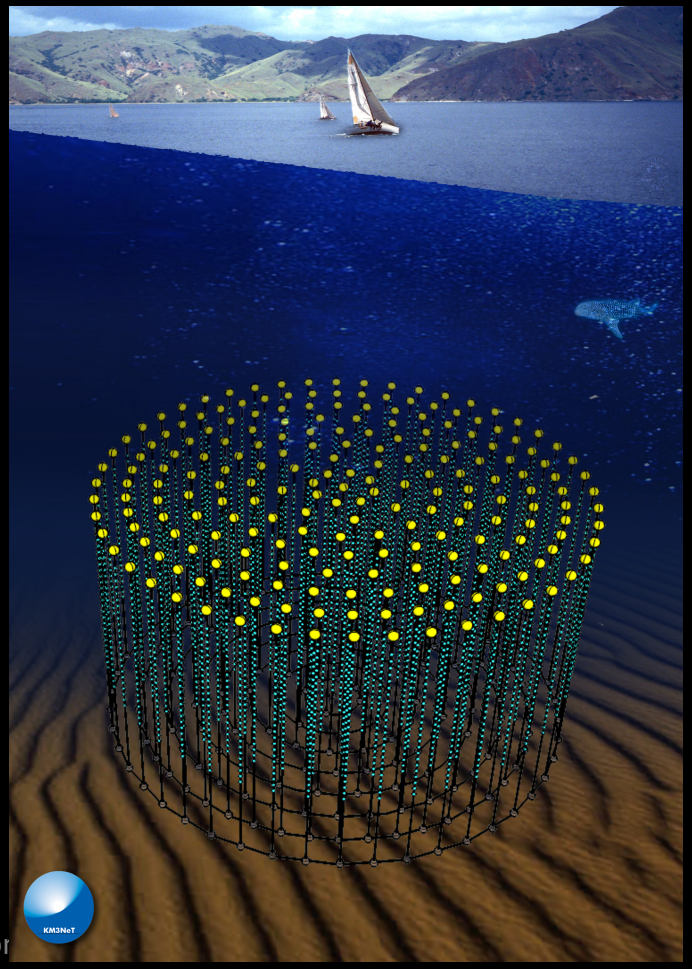
C.A. Argüelles+ 1703.07798
Joakim Edsjo+ 1704.02892

Gigaton Neutrino Detectors

IceCube
Southpole



KM3NeT (future)
Mediterranean



Neutrino point source detection

$\nu_\mu + N \rightarrow \mu + X$

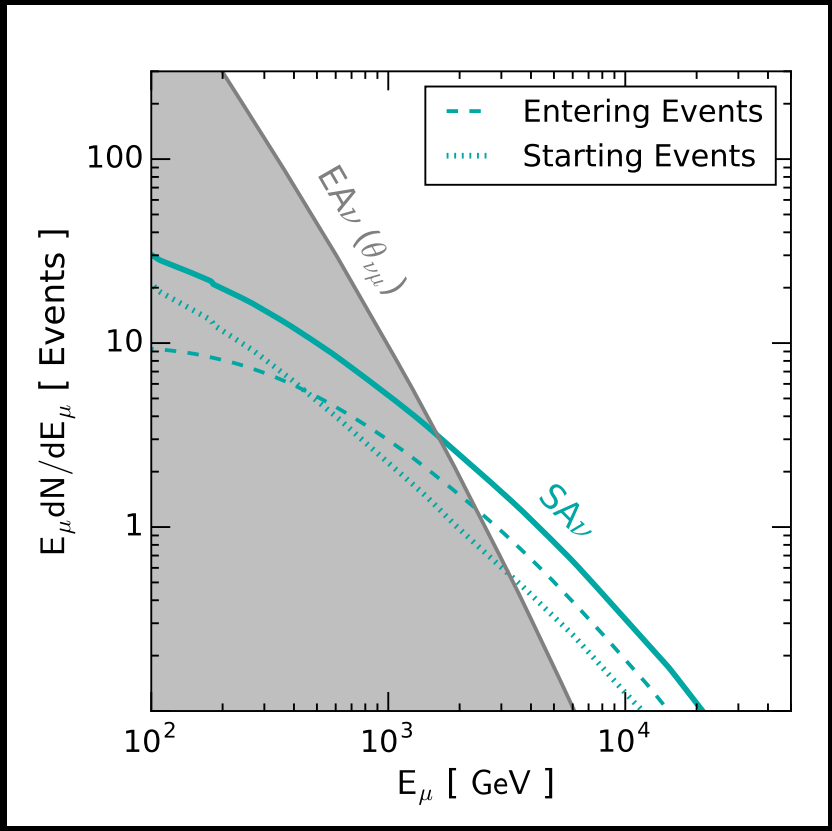
- ν_μ CC events
  - Starting events

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

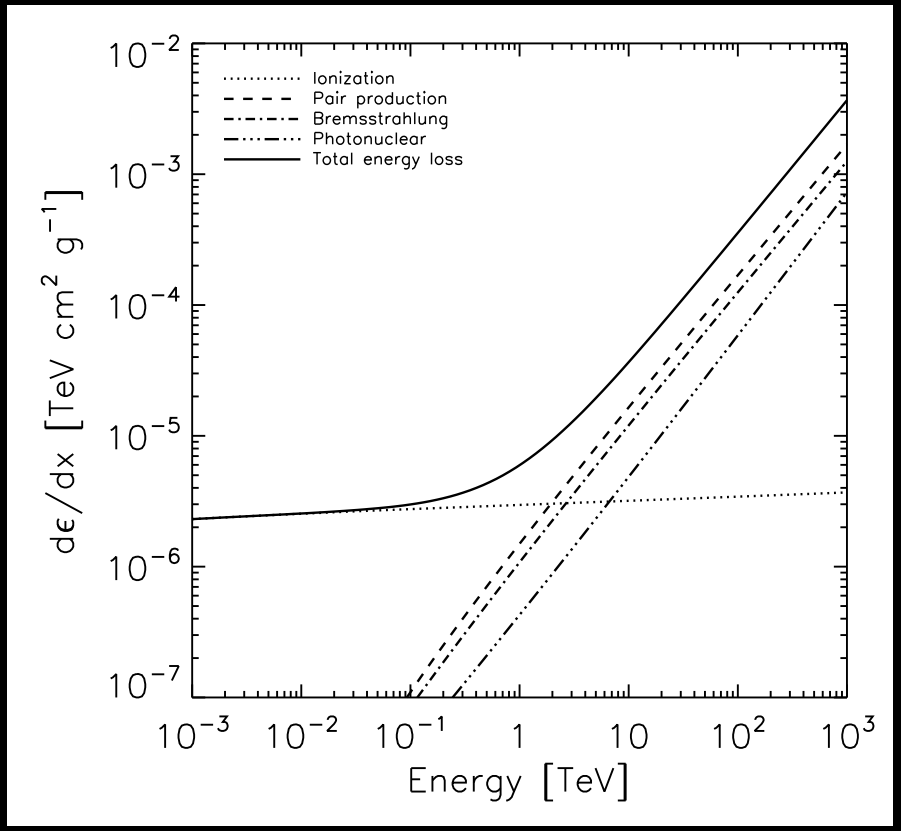
  - Entering events

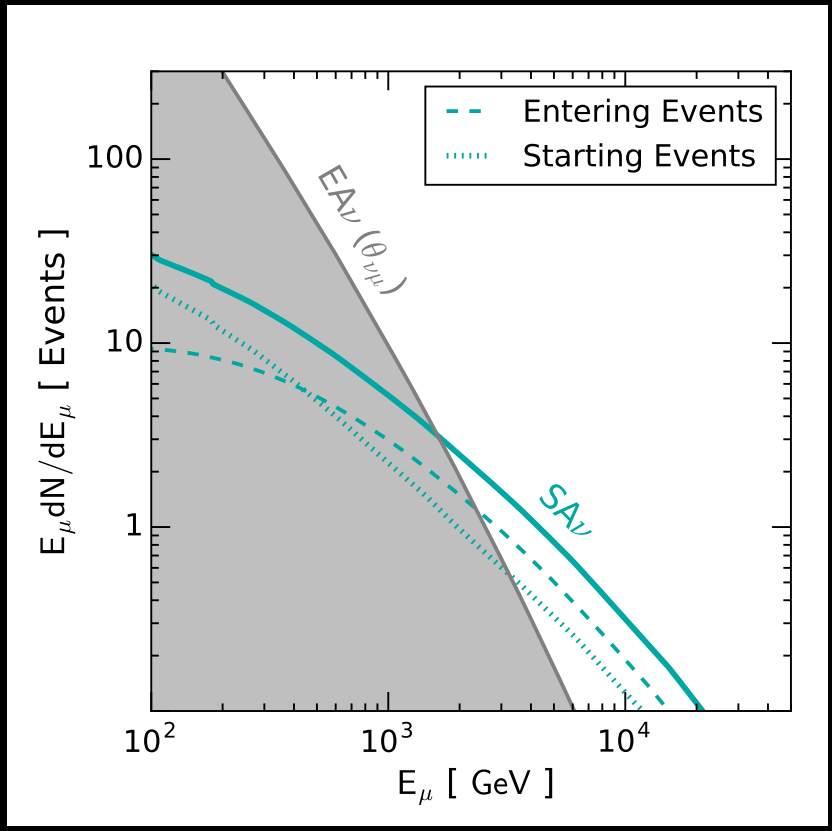
$$\frac{dN^{\mathrm{ent}}}{dE_\mu} \simeq \frac{N_A \rho A T}{\rho\,(\alpha + \beta E_\mu)} \int_{\frac{E_\mu}{1-y}}^{\infty} dE_\nu \frac{d\Phi}{dE_\nu}(E_\nu)\sigma(E_\nu)$$

Muon range



Energy information - Muon energy loss



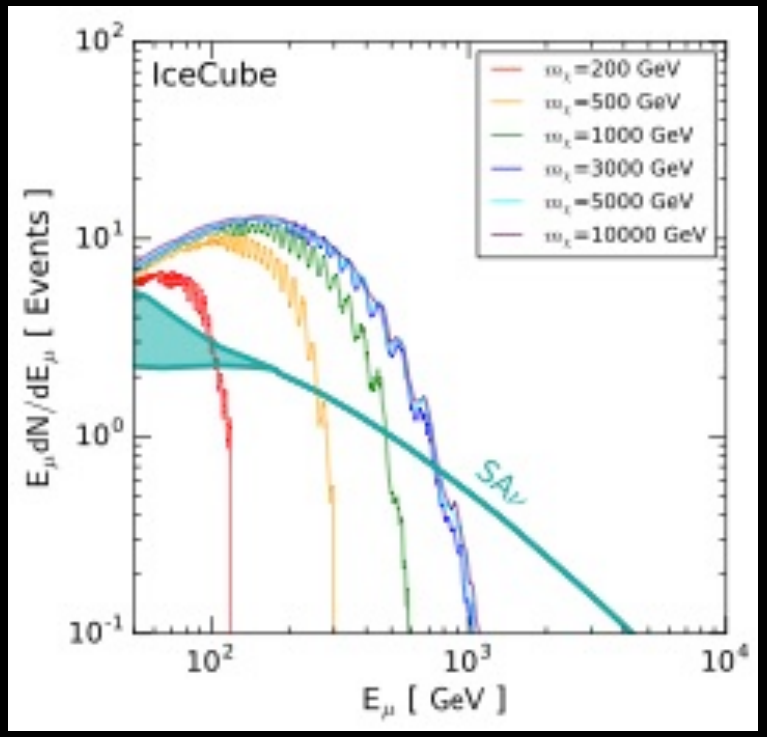


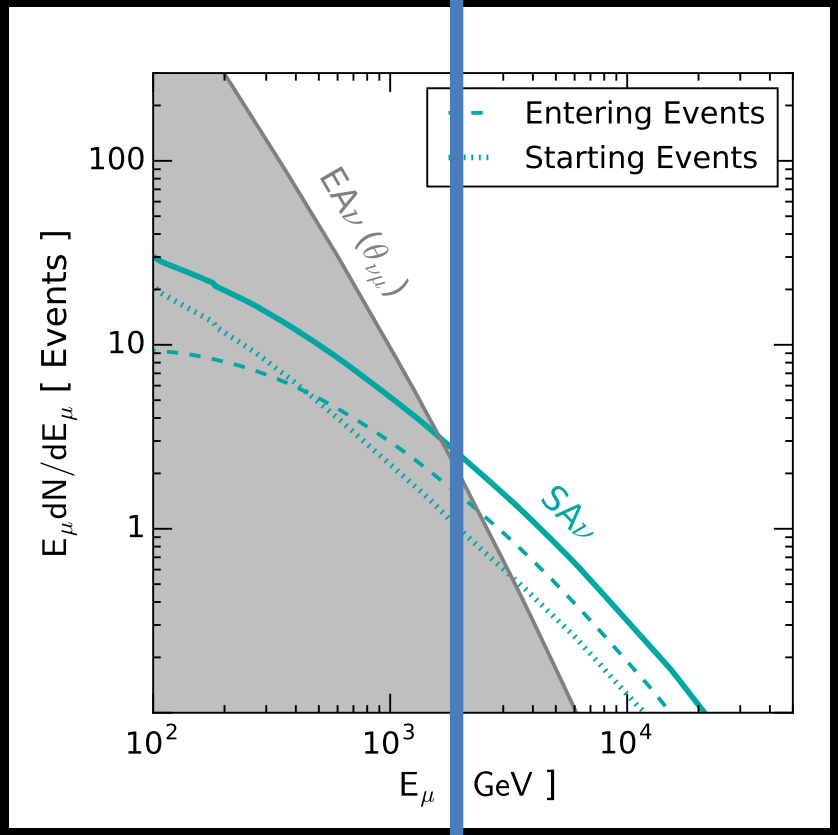
Astraatmadja 2011

- Energy resolution from muon radiative energy loss?

Background or Signal? (Both!)

Theorist Expectation



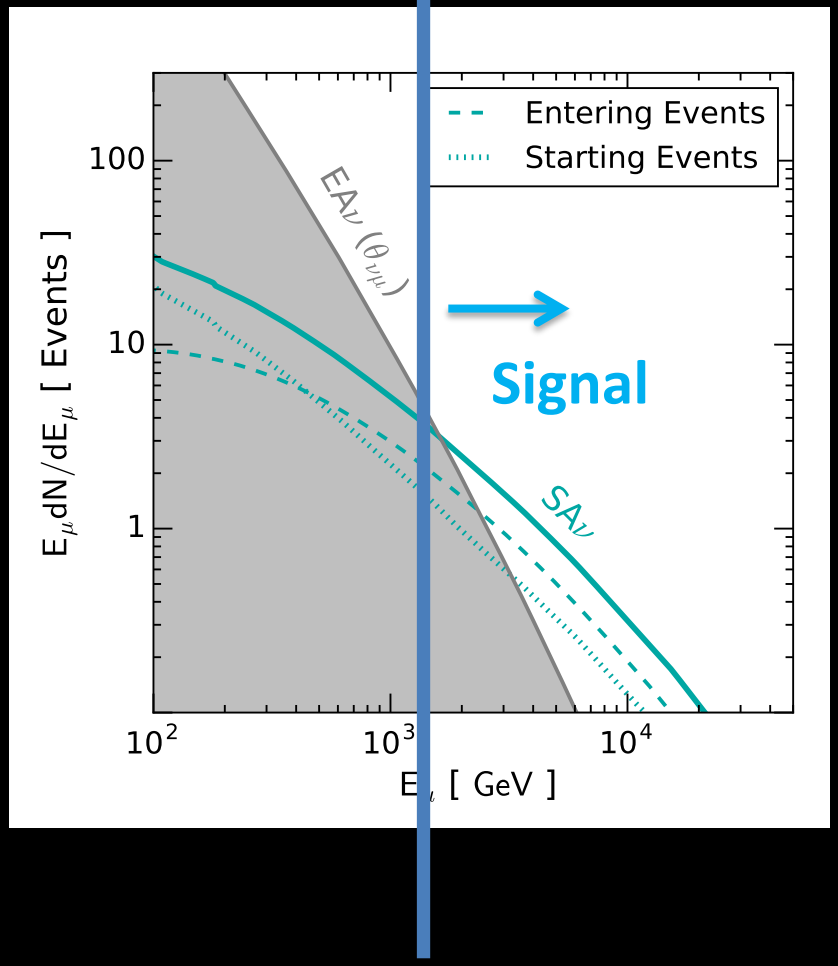


BAD energy-resolution
Difficult to distinguish from DM signal
Background!

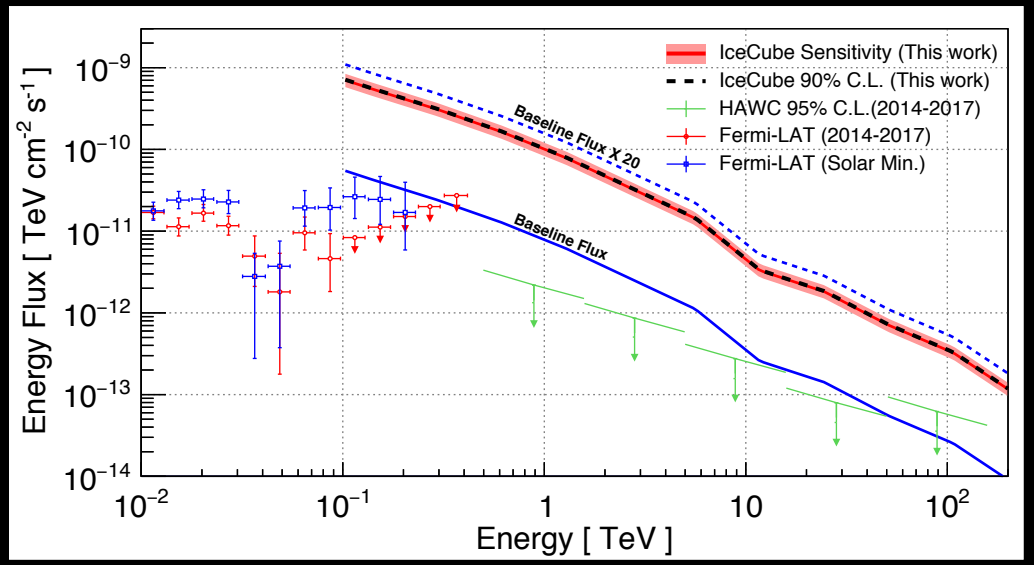
Some energy-resolution
No DM signal*
Astrophysical signal!

IceCube Search (Signal)

Theorist Expectation



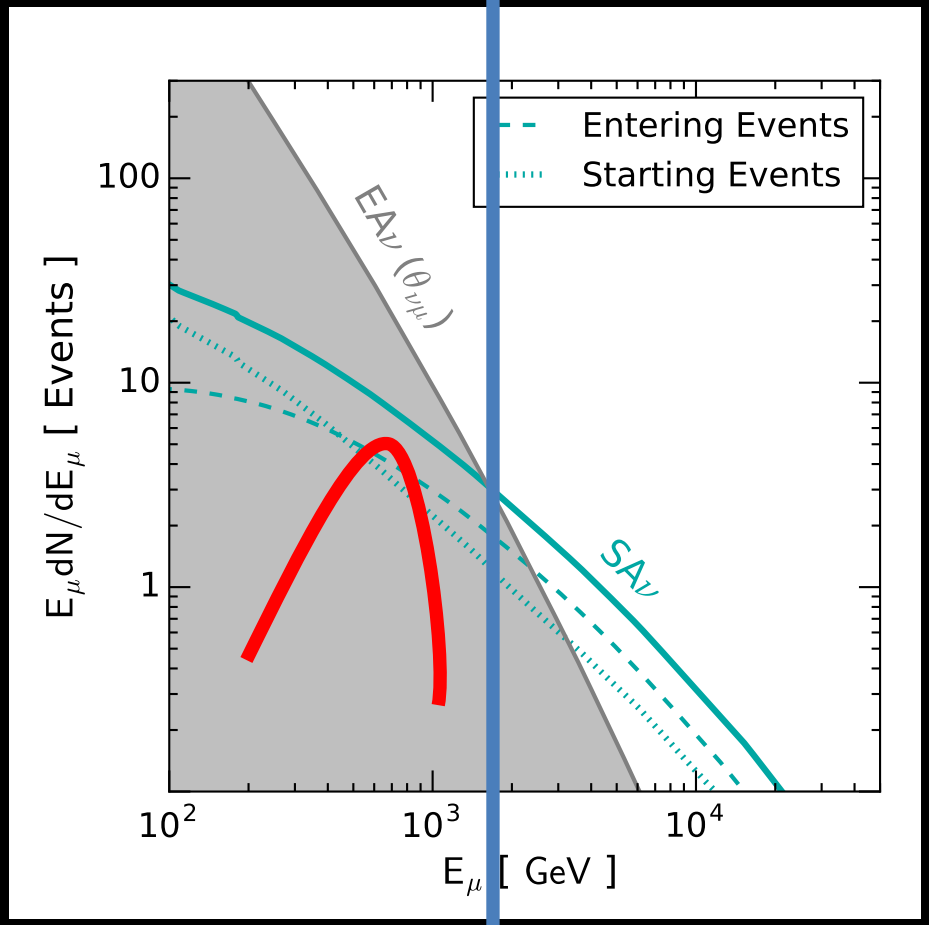
IceCube, 1912.13135

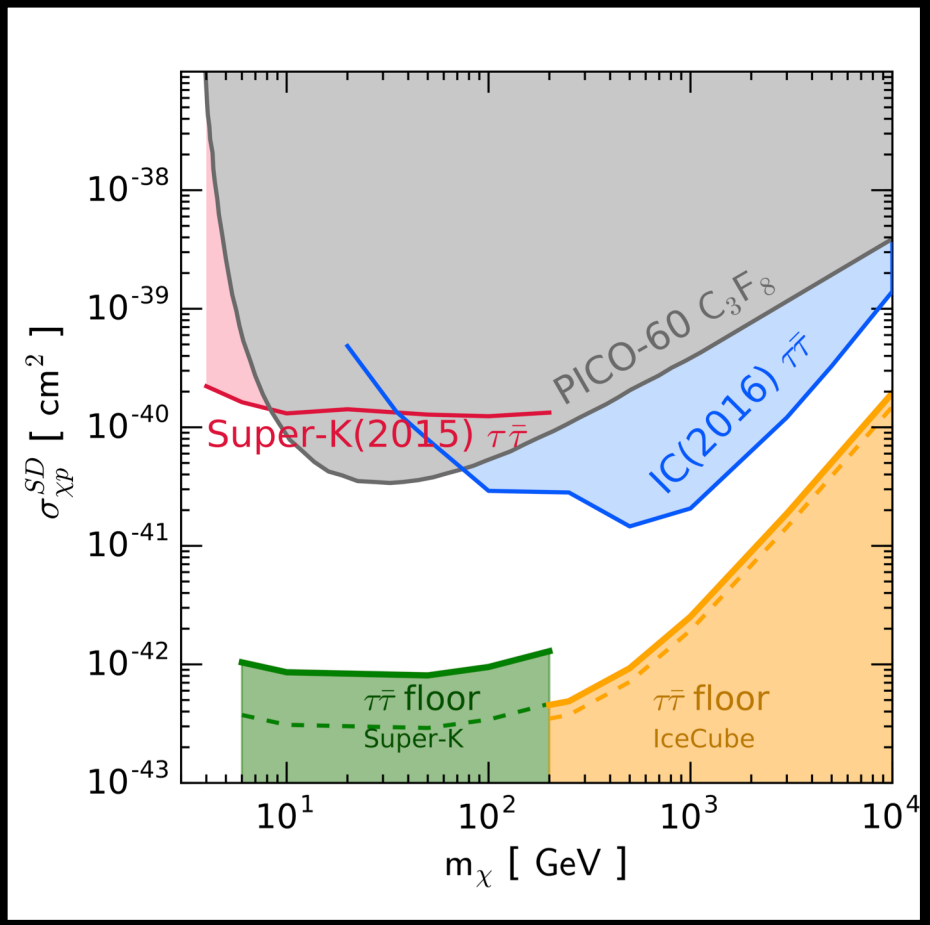


Seems difficult……

- Improve analysis?
- IceCube-gen 2/ KM3NeT

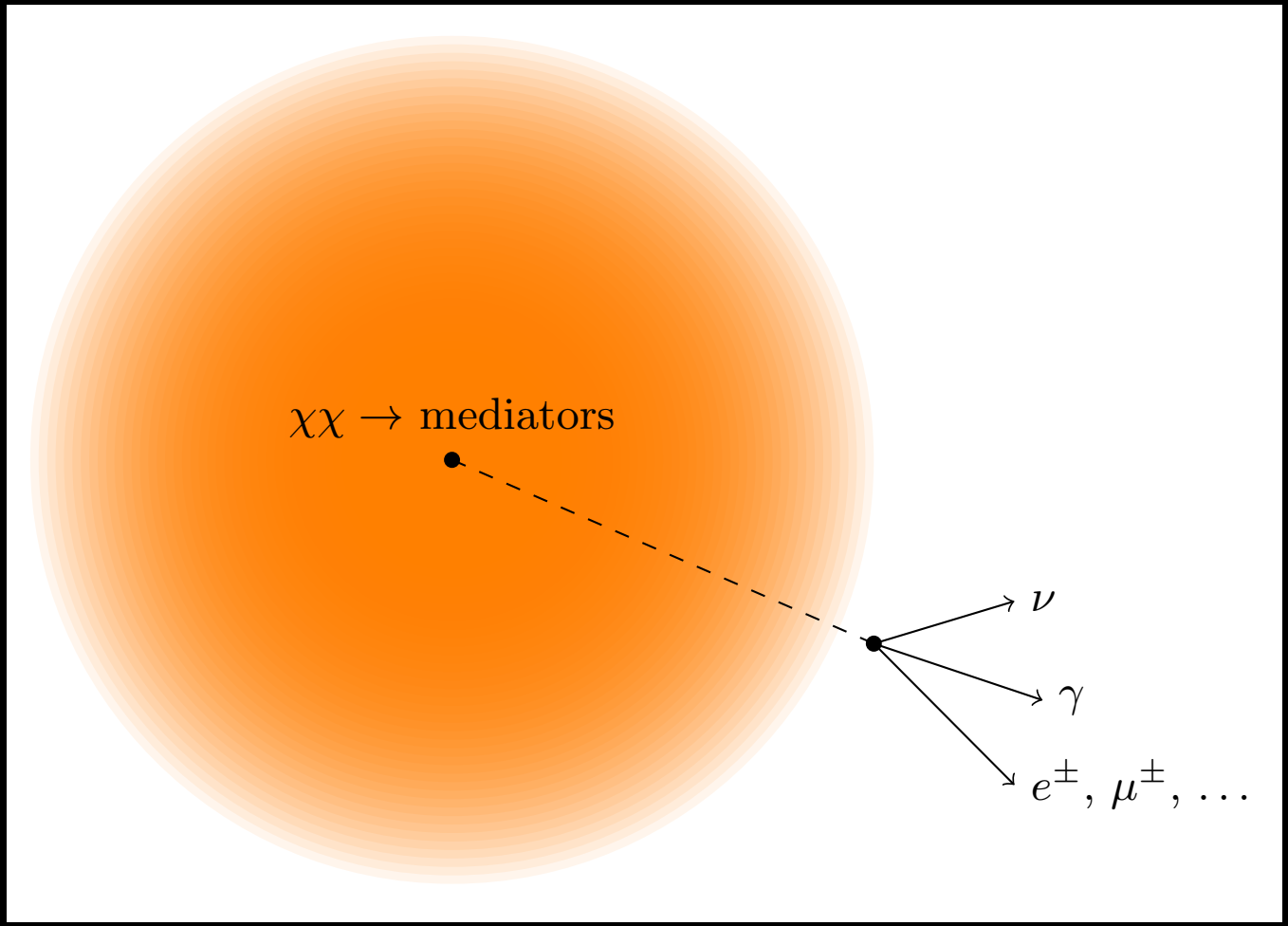
Solar ATM neutrino – indirect detection Neutrino Floor (Background)





KCYN, Beacom, Peter, Rott, PRD 2017
See also
Arguelles+ 1703.07798
Edsjo+ 1704.02892

Beyond WIMPs

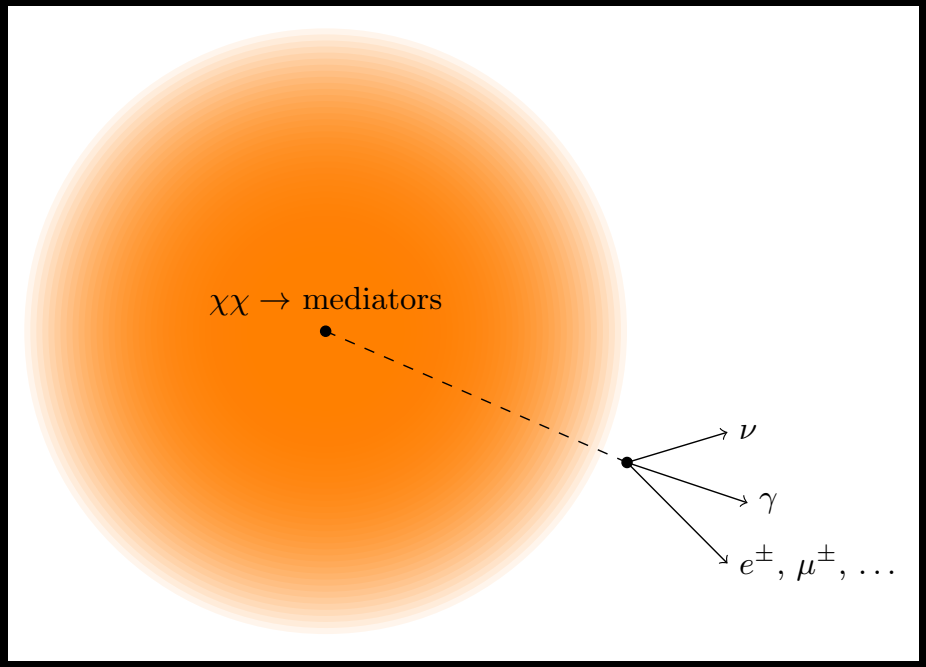


Leane, KCYN, Beacom 1703.04629

Dark Matter with long-lived mediators

Leane, KCYN, Beacom 1703.04629

- Unlock
  - Gamma rays
  - Electrons, muon, etc
- Unsuppressed
  - Neutrinos!



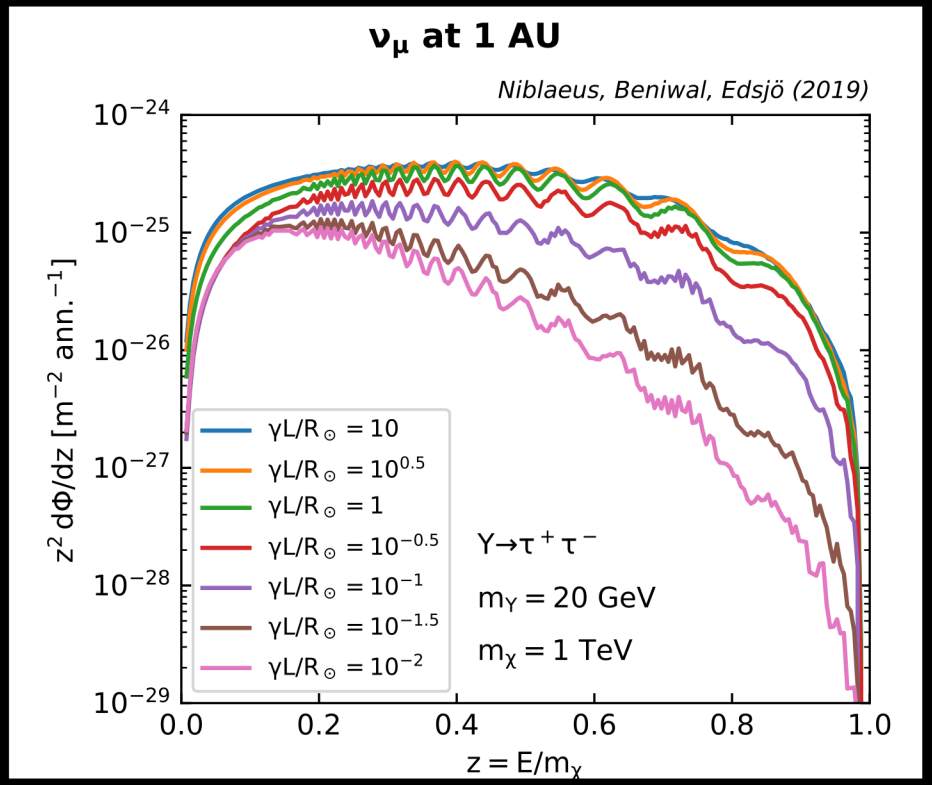
- Less absorption (ν)
- Lower density (ν)
- Decay tail (ν, γ)

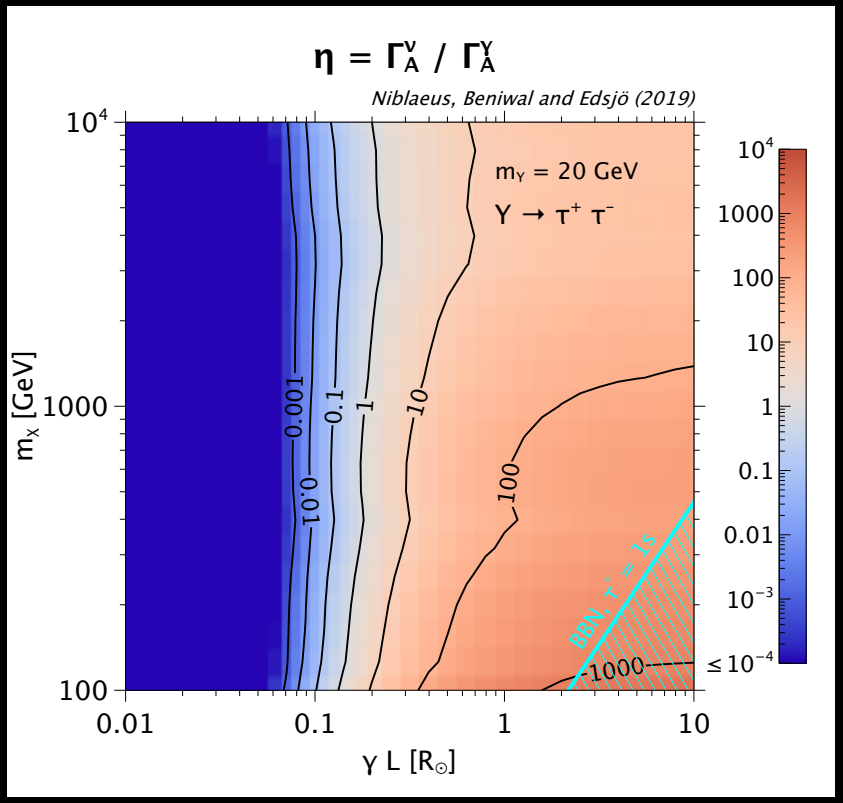
Batell, Pospelov, Ritz, Shang, 0910.1567
Bell, Petraki, 1102.2958
Feng, Smolinsky, Tanedo, 1602.01465
Arina, Backovic, Heisig, Lucente, 1703.08087

Niblaeus, Beniwal, Edsjo, 1903.11363
etc

Enhanced Gamma-Ray & Neutrino Spectra

γL = boosted decay length of the mediator





Neutrino <------ > Gamma rays

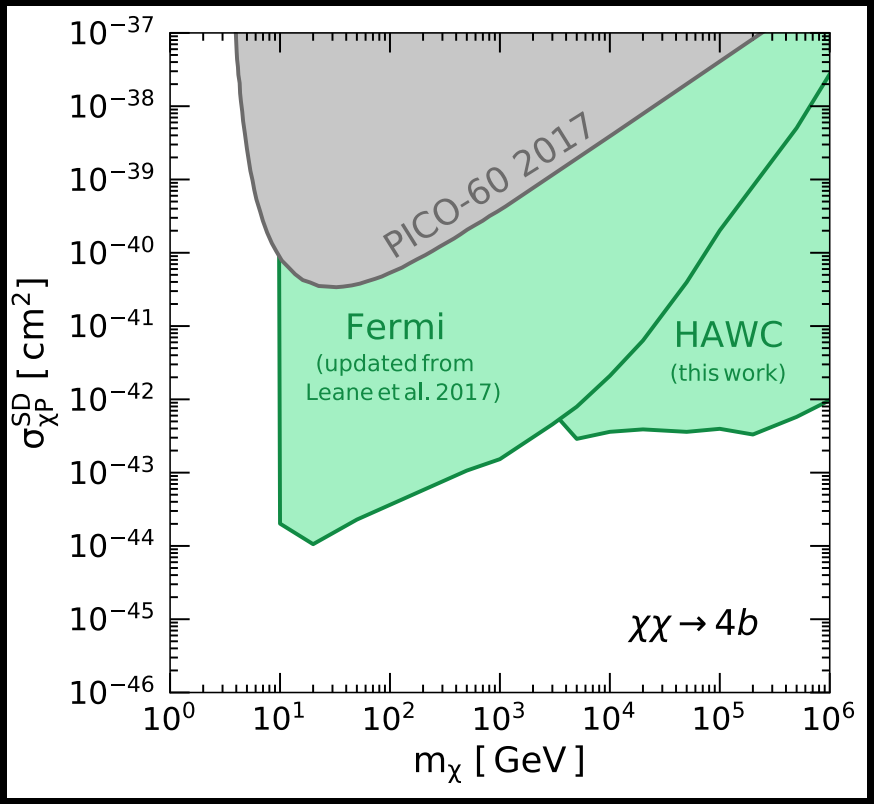
Niblaeus, Beniwal, Edsjo, 1903.11363

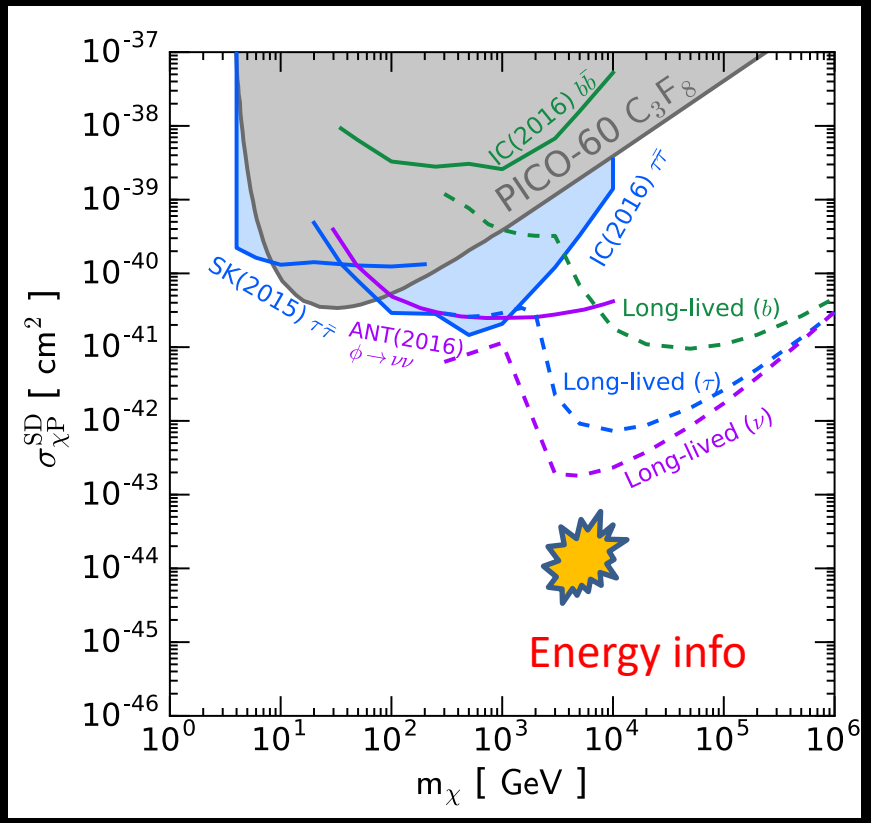
Dark Matter with long-lived mediators

HAWC+KCYN 1808.05624

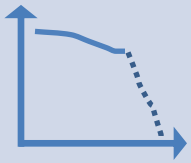
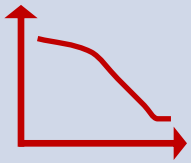
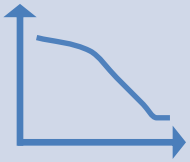
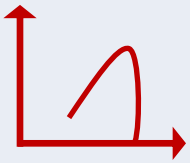
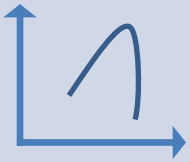
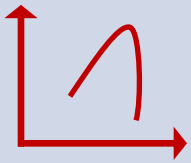
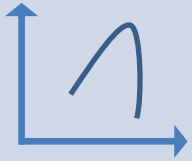
Also Leane, KCYN, Beacom 1703.04629

- 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 been 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!