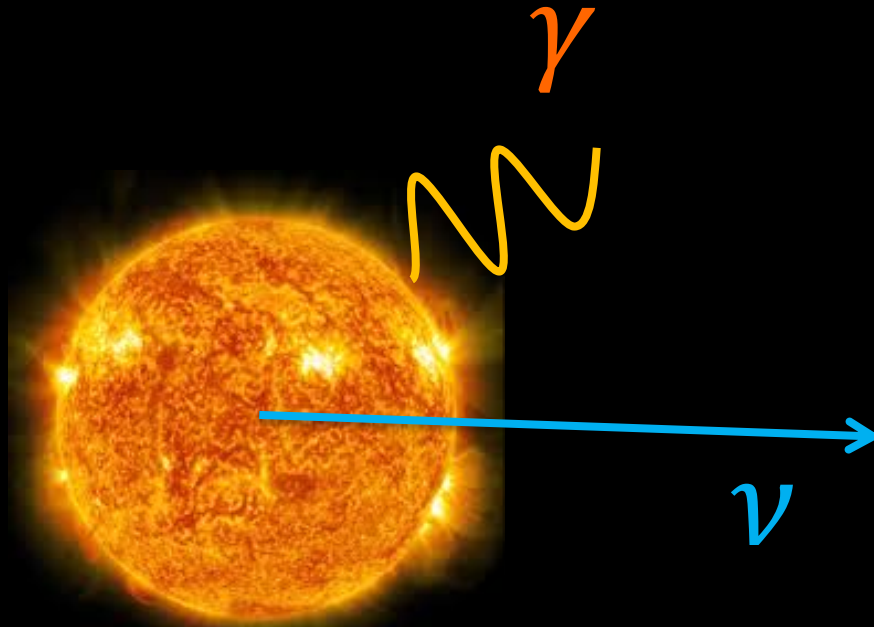


Solar Atmospheric Gamma Rays and Neutrinos



Kenny, Chun Yu Ng (吳震宇)

Marie Curie fellow

GRAPPA, University of Amsterdam

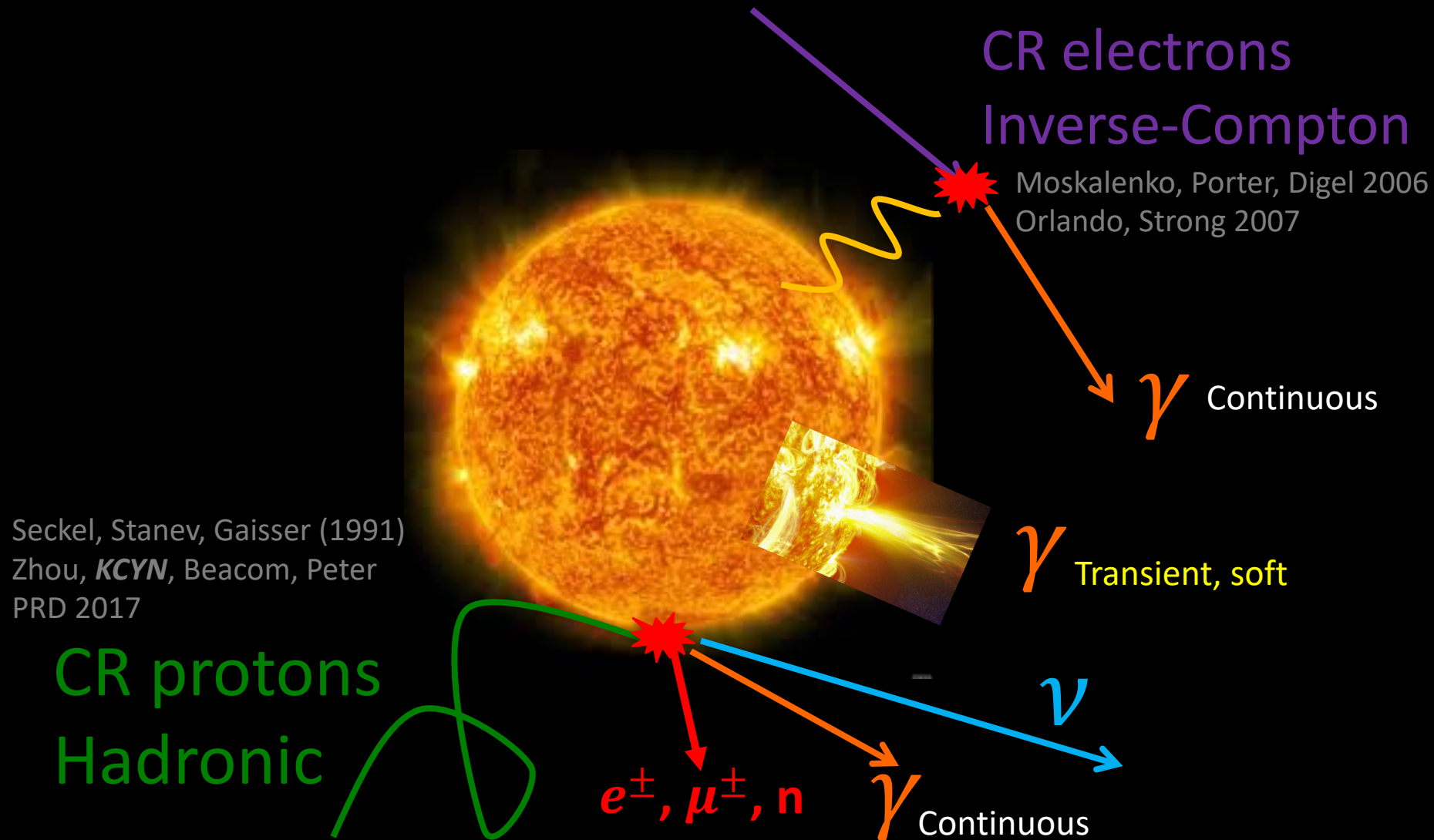
TeVPA 2019



Related works

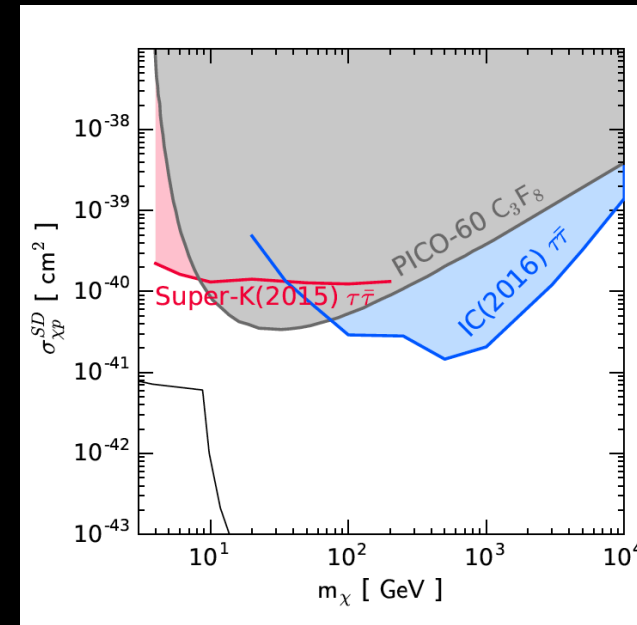
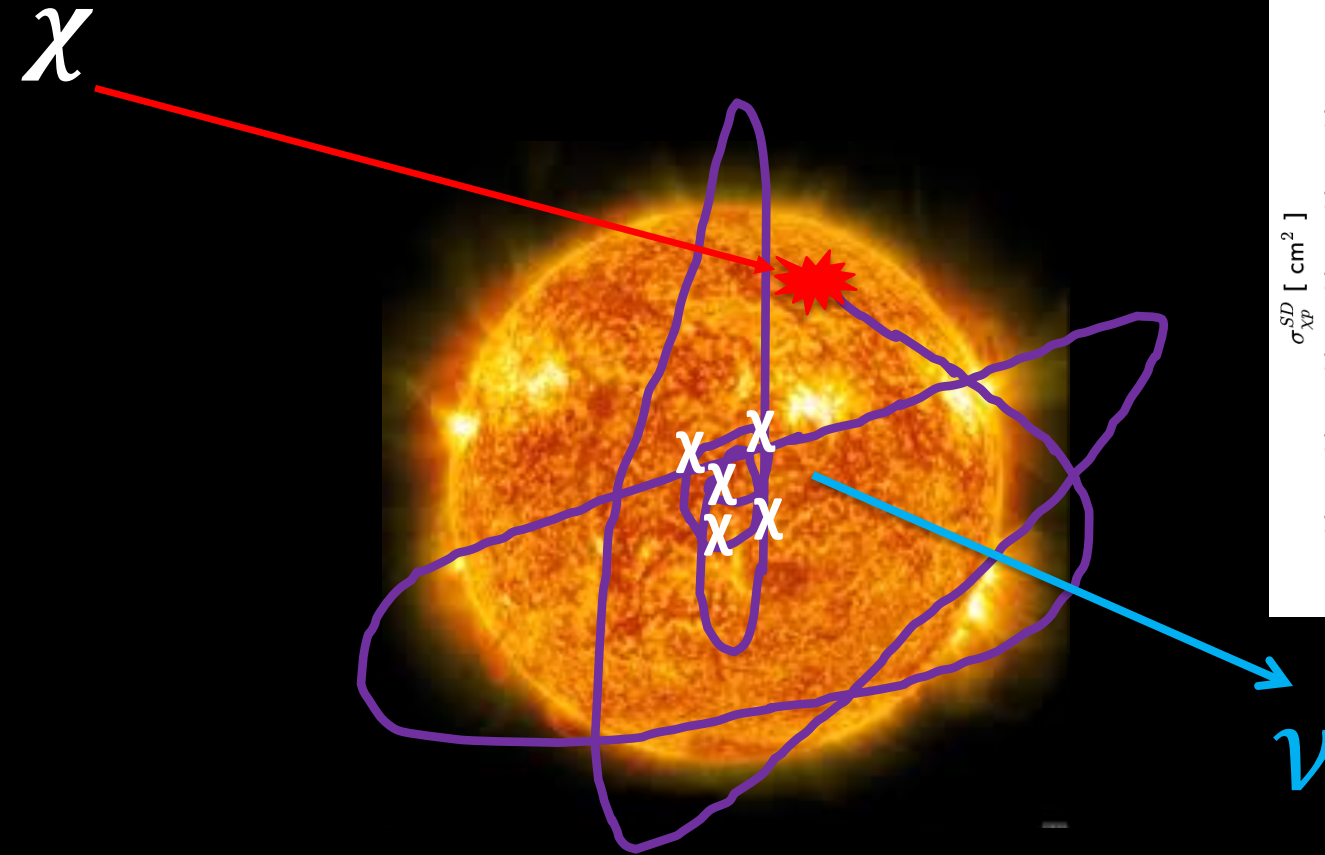
- Gamma-ray analysis
 - **KCYN**, Beacom, Peter, Rott, 1508.06276 PRD
 - Linden, Zhou, Beacom, Peter, **KCYN**, Tang, 1803.05436 PRL
 - Tang, **KCYN**, Linden, Zhou, Beacom, Peter, 1804.06846 PRD
 - HAWC col. + **KCYN**, 1808.05620 PRD
- Dark Matter
 - Leane, **KCYN**, Beacom, 1703.04629 PRD
 - HAWC col. + **KCYN**, 1808.05624 PRD
- Solar atmospheric neutrinos
 - **KCYN**, Beacom, Peter, Rott, 1703.10280 PRD
- Solar gamma-ray estimations
 - Zhou, **KCYN**, Beacom, Peter 1612.02420 PRD
- *2020 Science White paper*
- *The Sun at GeV-TeV Energies: A New Laboratory for Astroparticle Physics*
 - Nisa, Beacom, BenZvi, Leane, Linden, **KCYN**, Peter, Zhou 1903.06349

Sun – Cosmic-Ray Beam Dump



Kenny C.Y. NG, TeVPA 2019

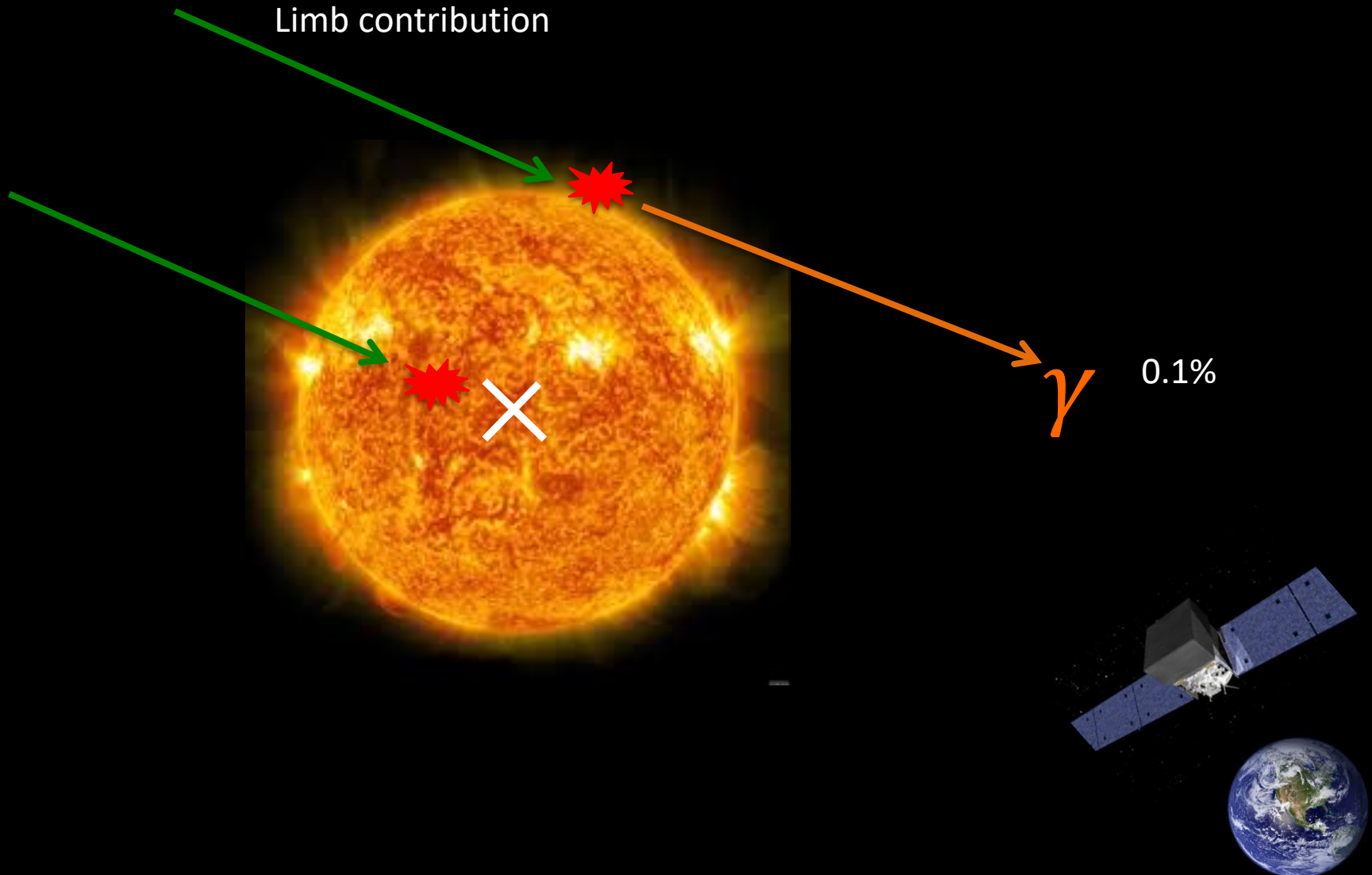
Sun – Dark Matter detector



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

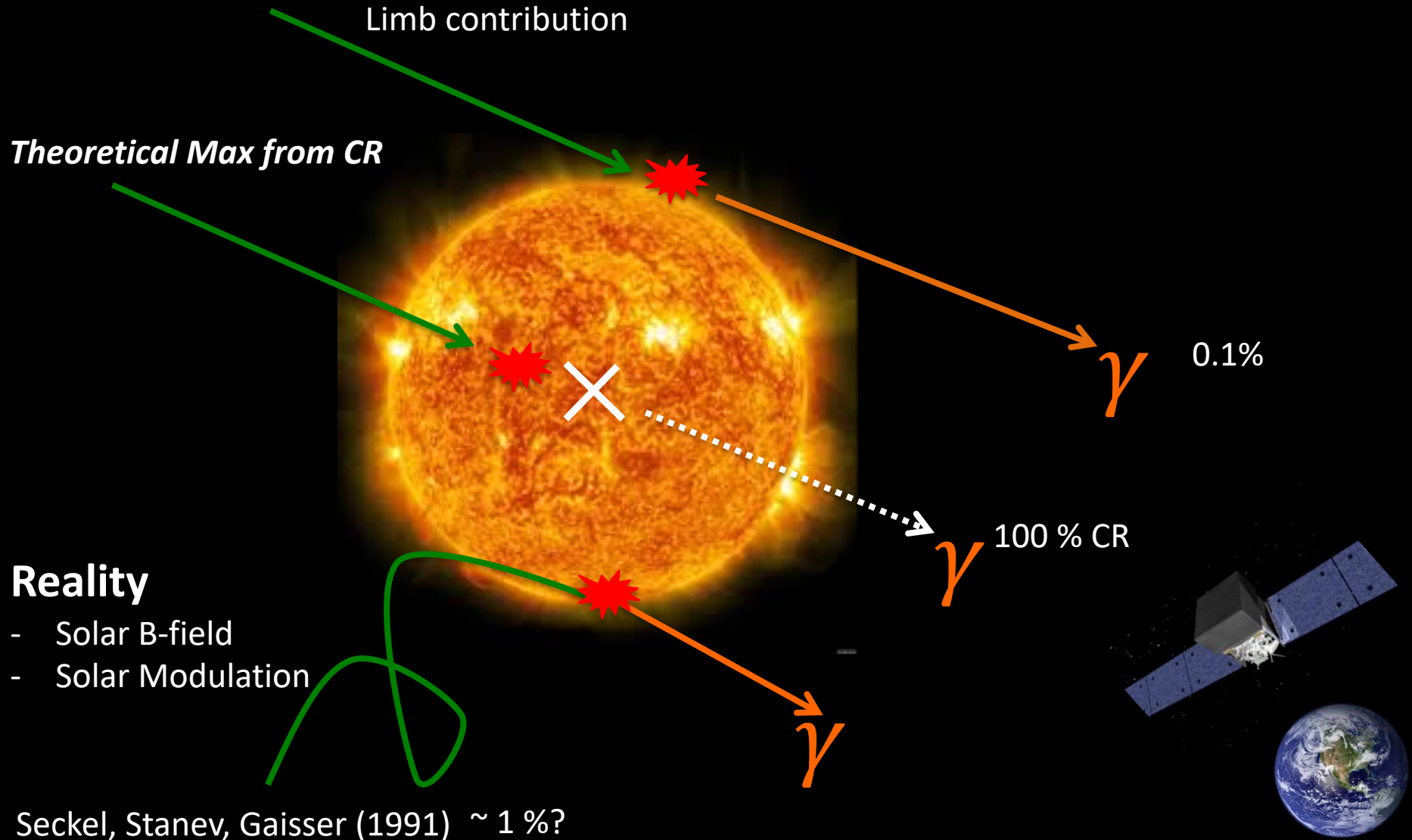
Solar atmospheric gamma rays

Zhou, *KCYN*, Beacom, Peter PRD 2017

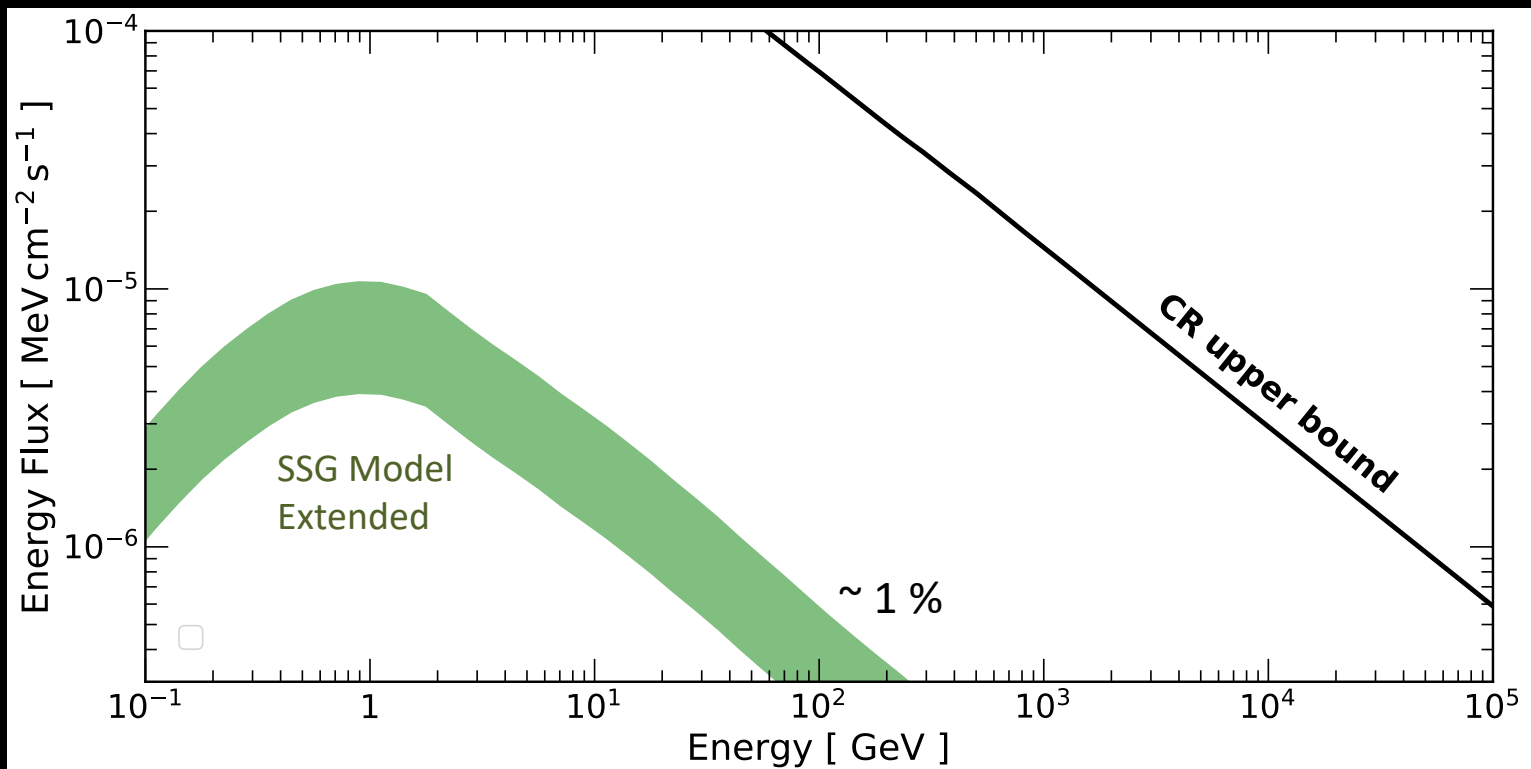


Solar atmospheric gamma rays

Zhou, *KCYN*, Beacom, Peter PRD 2017

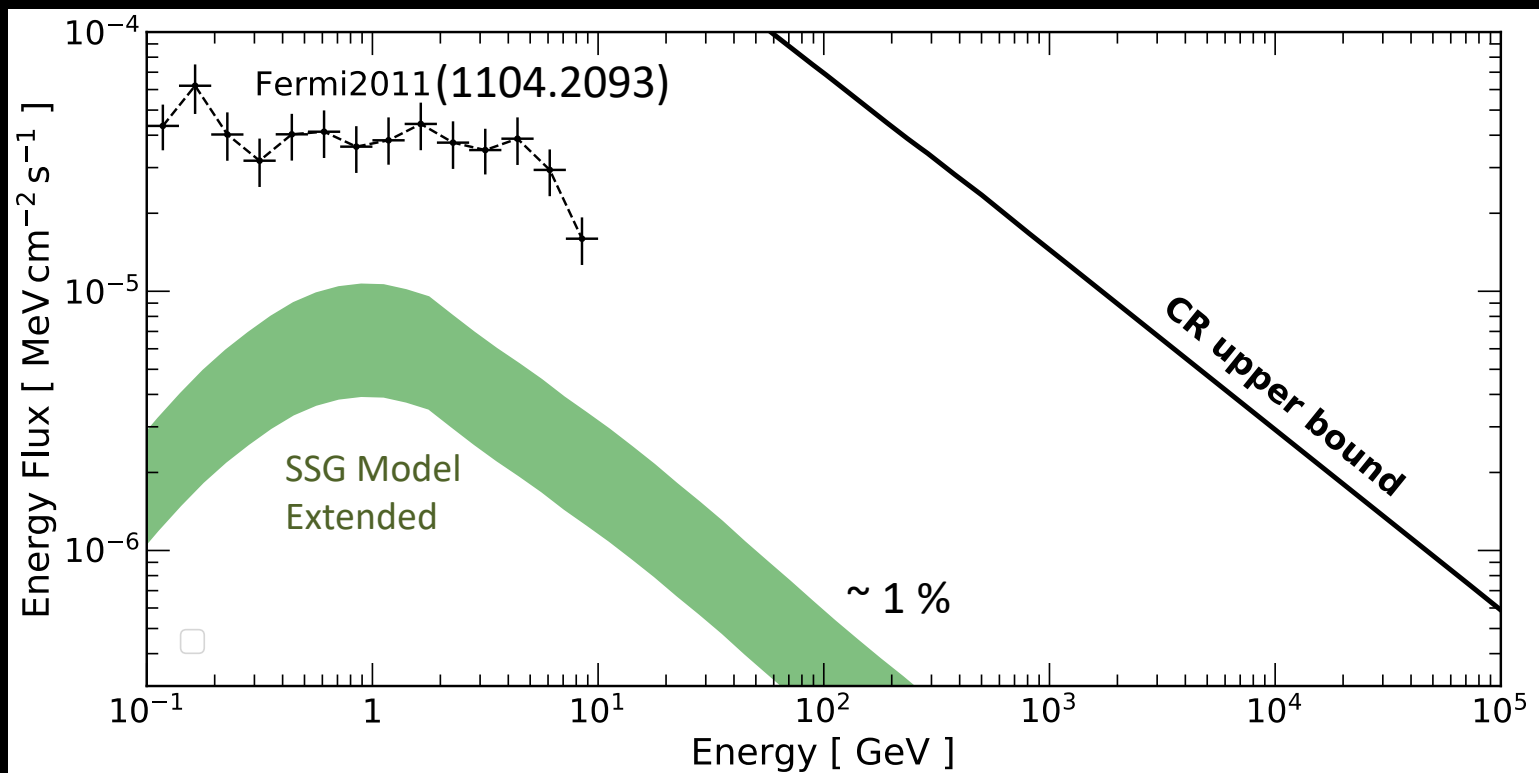


The overall picture



Fermi Detection (18 months)

- First detection was EGRET (Orlando, Strong 2008)
- Model prediction too small
- Satisfy cosmic-ray bound \leftrightarrow CR model with large B-field enhancement

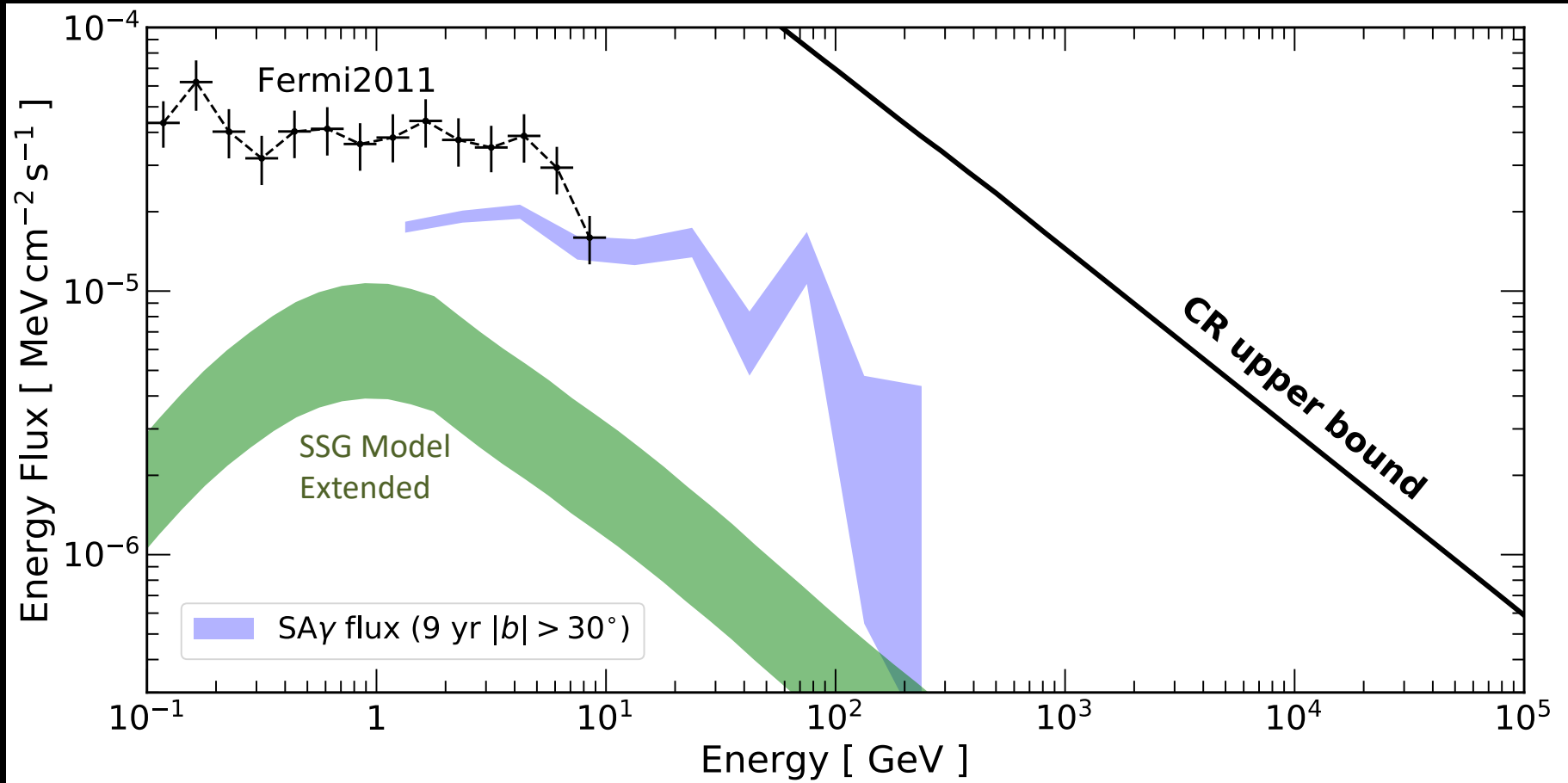


Observation: 9-year averaged spectrum

- 2008 – 2017 (9 years)

KCYN, Beacom, Peter, Rott PRD 2016

Tang, KCYN, Linden, Zhou, Beacom, Peter PRD 2018

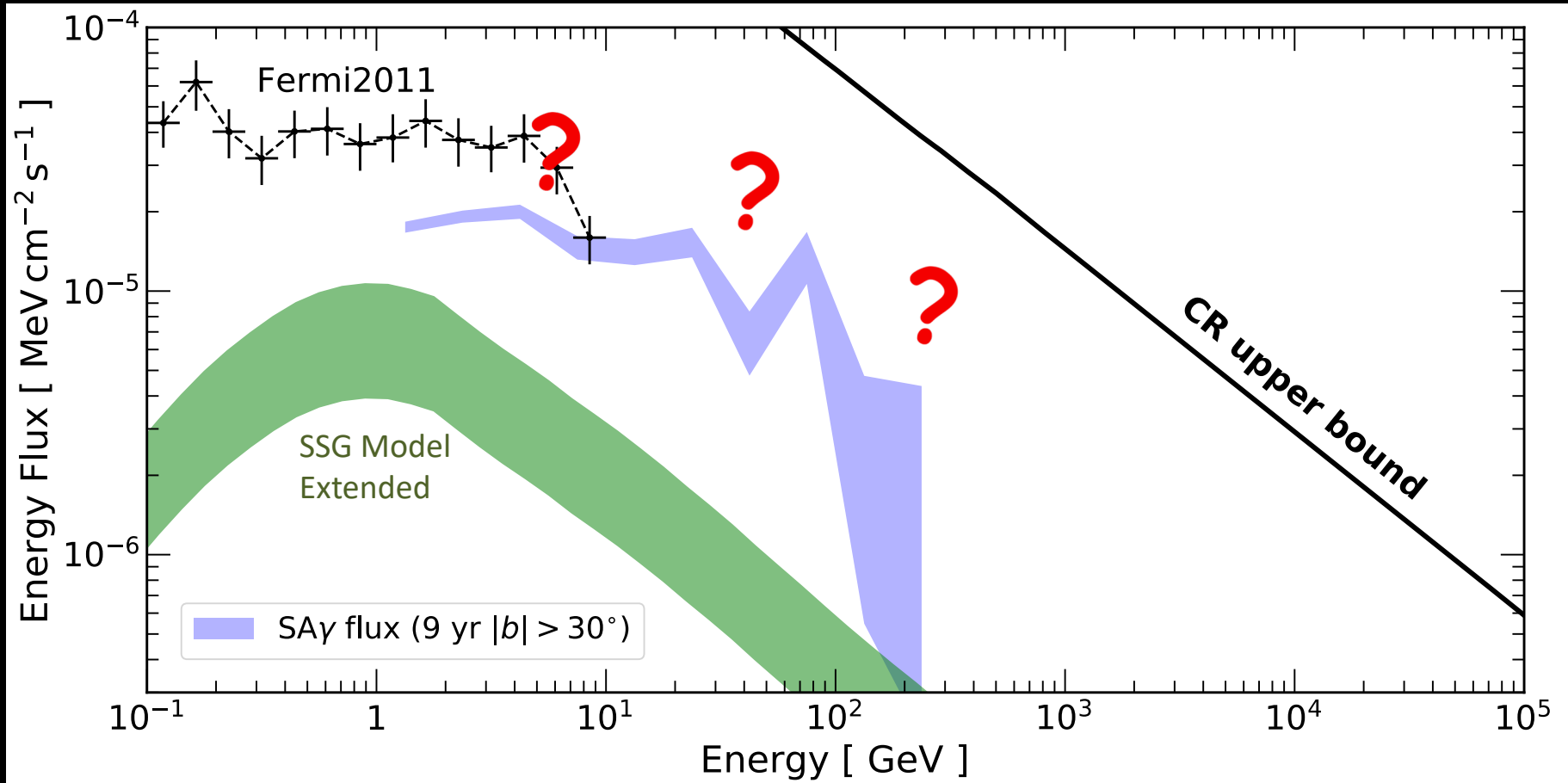


Observation: 9-year averaged spectrum

- 2008 – 2017 (9 years)

KCYN, Beacom, Peter, Rott PRD 2016

Tang, KCYN, Linden, Zhou, Beacom, Peter PRD 2018

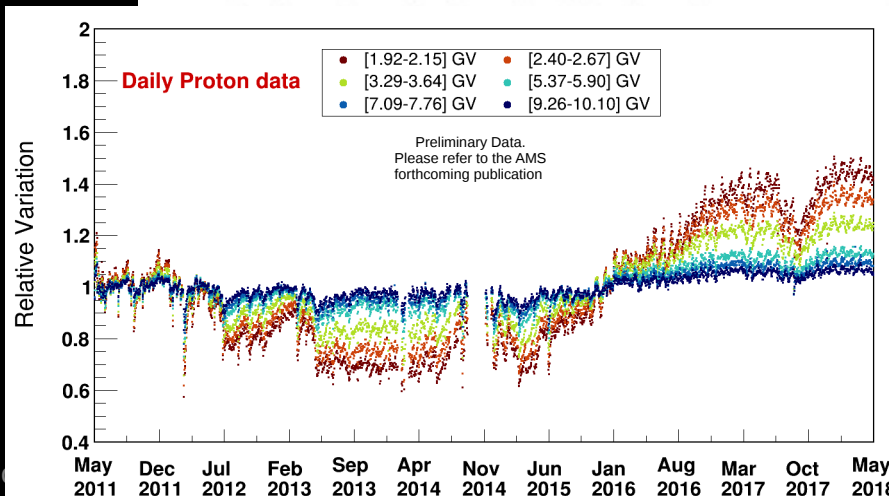
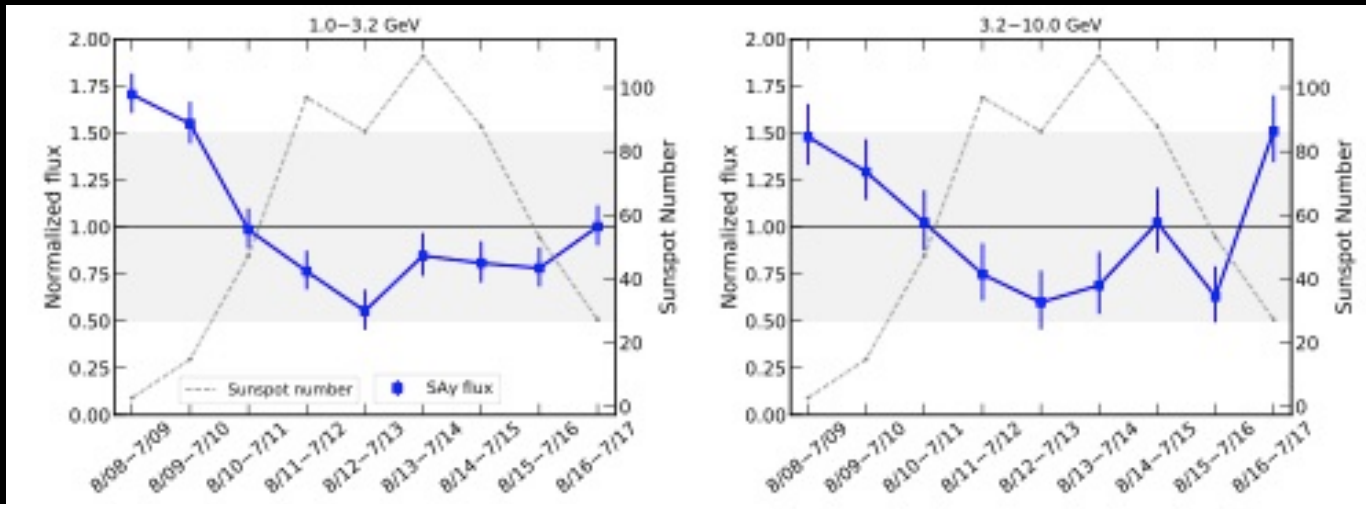


Time variation

KCYN, Beacom, Peter, Rott PRD 2016

Tang, KCYN, Linden, Zhou, Beacom, Peter PRD 2018

- Clear anticorrelation with solar activity from 1-10 GeV
- Less clear in 10-100 GeV (less variation or insufficient statistics)

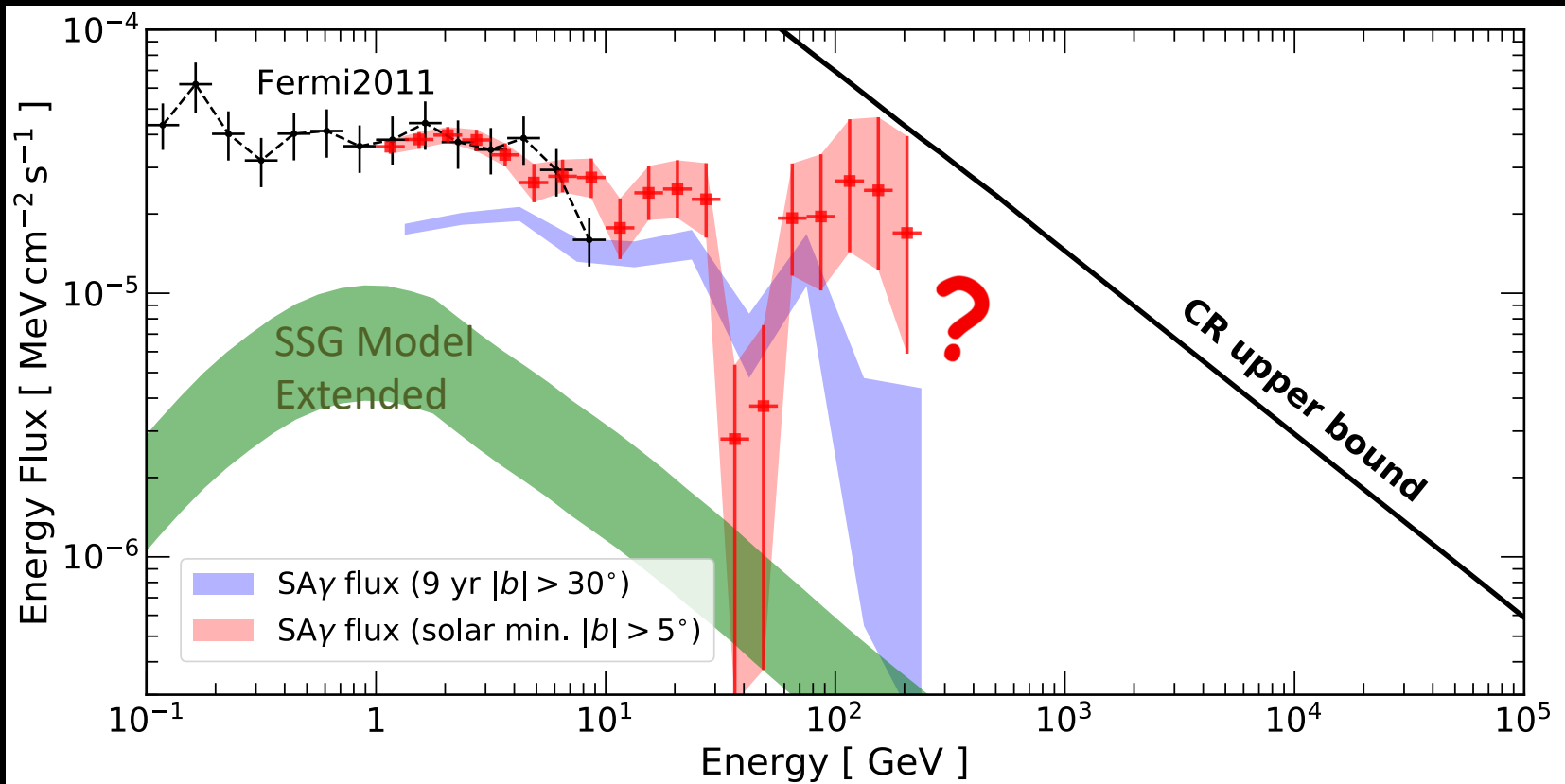


Small modulation amplitude
 -> extra modulation needed near the Sun

C. Consolandi ICRC-CRD8c

Observation: 9-year averaged spectrum

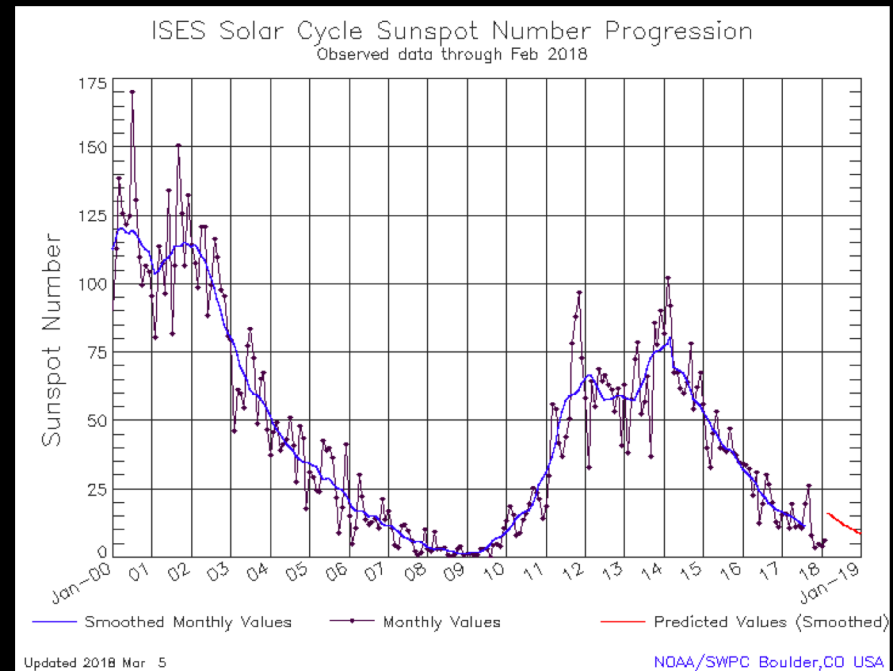
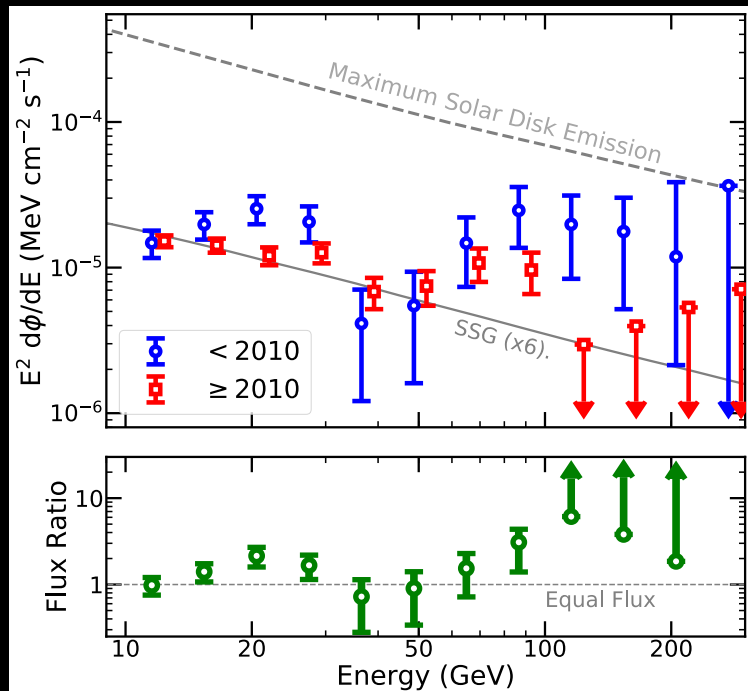
- Aug 2008 – Jan 2010 (solar min. 76 weeks)
- 2008 – 2017 (9 years)



High energy photon/Time variation, *Surprise (1)*

- **>100 GeV events**
- **6 events** from AUG 2008 to Jan 2010 (quiet Sun)
- **0 events** for the next 7.8 years (active Sun) +1 Feb 2018 !

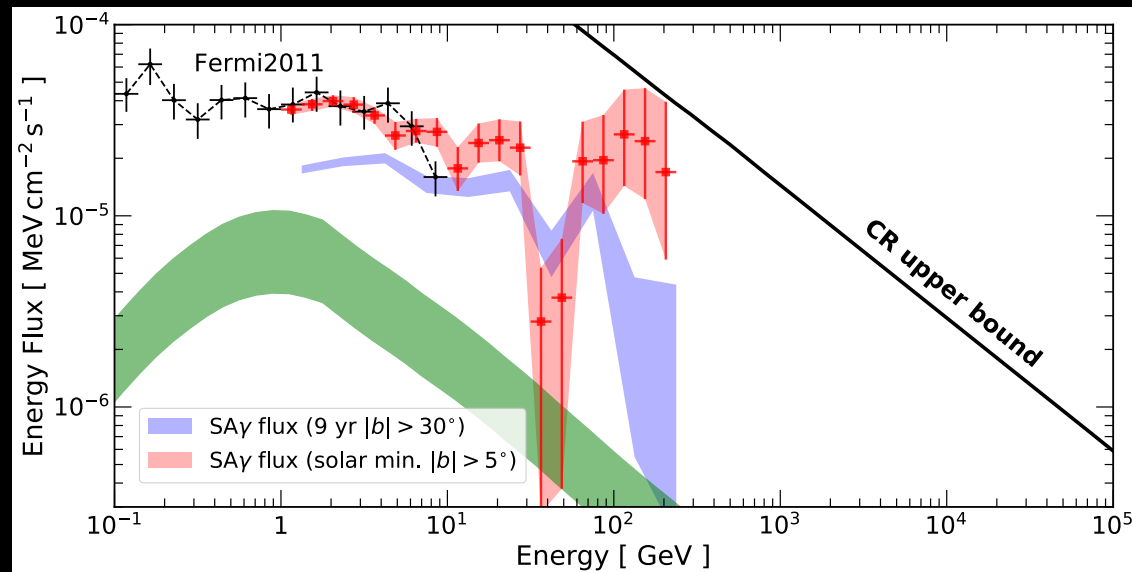
Linden, Zhou, Beacom, Peter, KCYN, Tang
PRL 2018



The high-energy photon production are very sensitive to the solar condition
Effect stronger than at lower energies!

Spectrum, *surprise* (2)

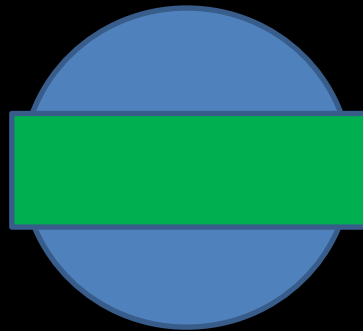
- Hard spectrum till ~ 100 GeV at *solar minimum*
 - Magnetic enhancement works for protons \sim TeV
 - Enhancement increasingly efficient! Close to upper bound at HE



$$\text{FLUX}(E) \propto \sigma_{pp} \times \Phi_p(E) \times \epsilon(E)$$

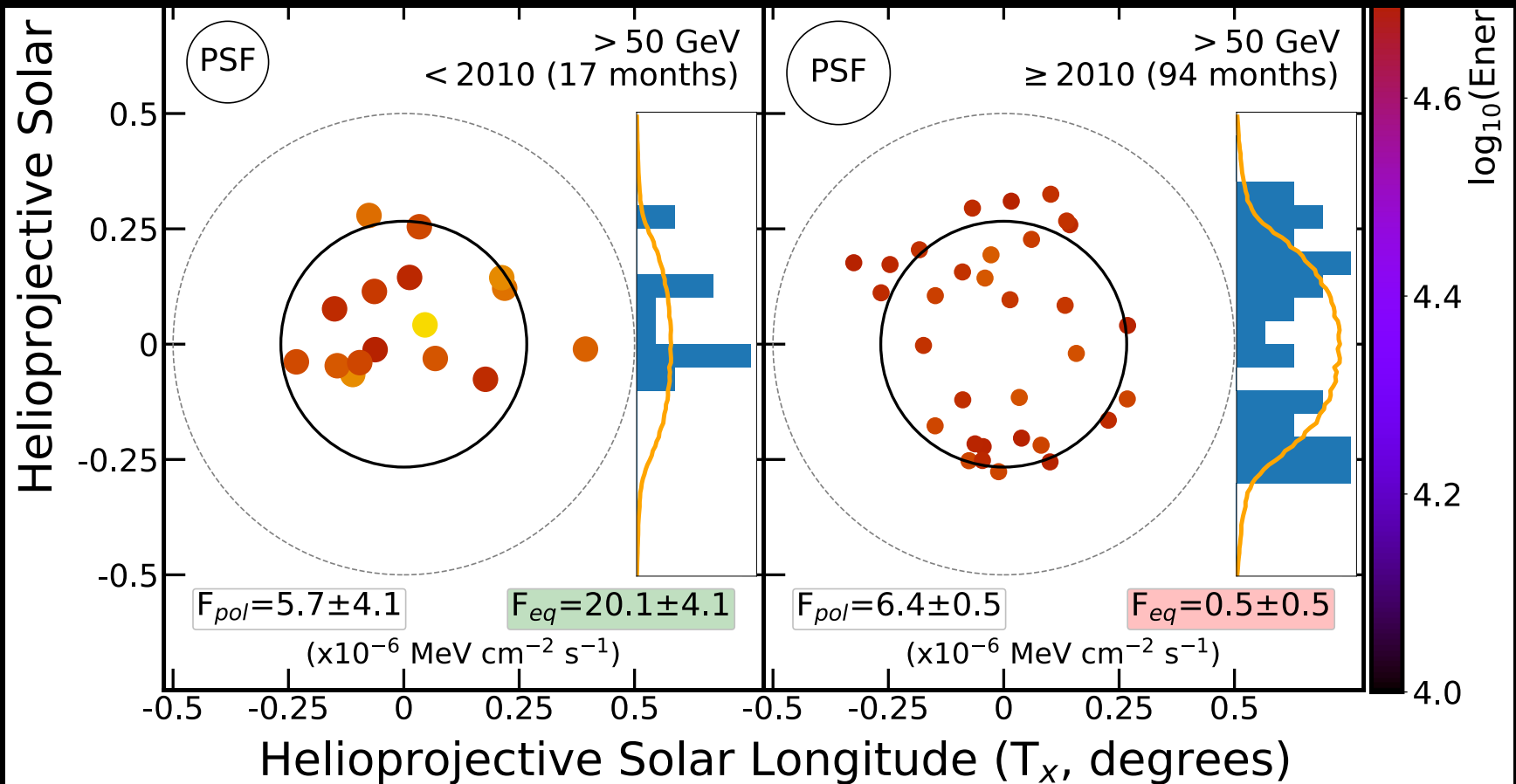
$$\sim E^{-2.2} \quad \sim E^{-0} \quad \sim E^{-2.7} \quad \sim E^{+0.5}$$

Morphology, *surprise* (3)



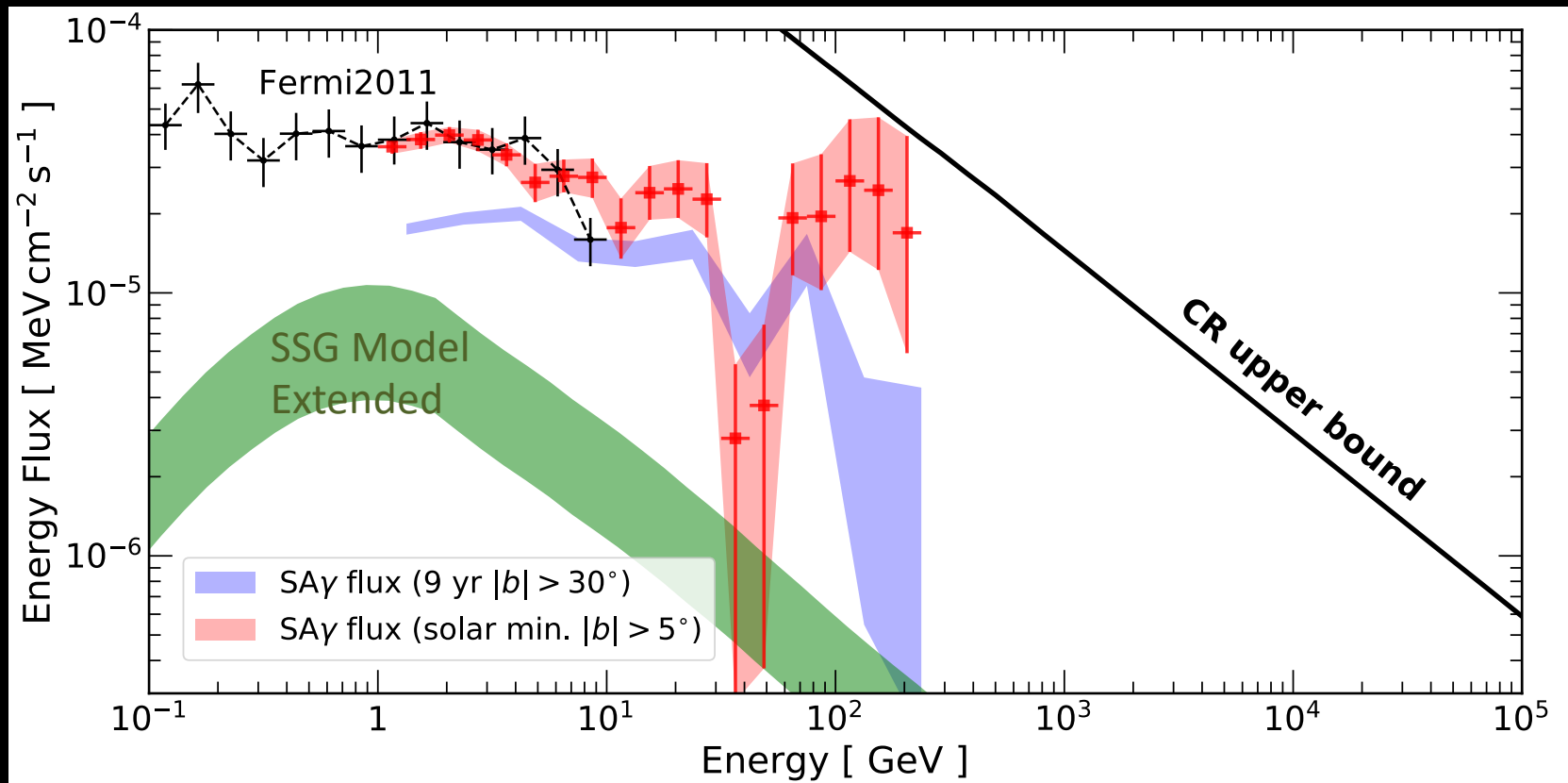
Linden, Zhou, Beacom, Peter, KCYN, Tang
PRL 2018

- High Energy Bin
– (> 50 GeV)

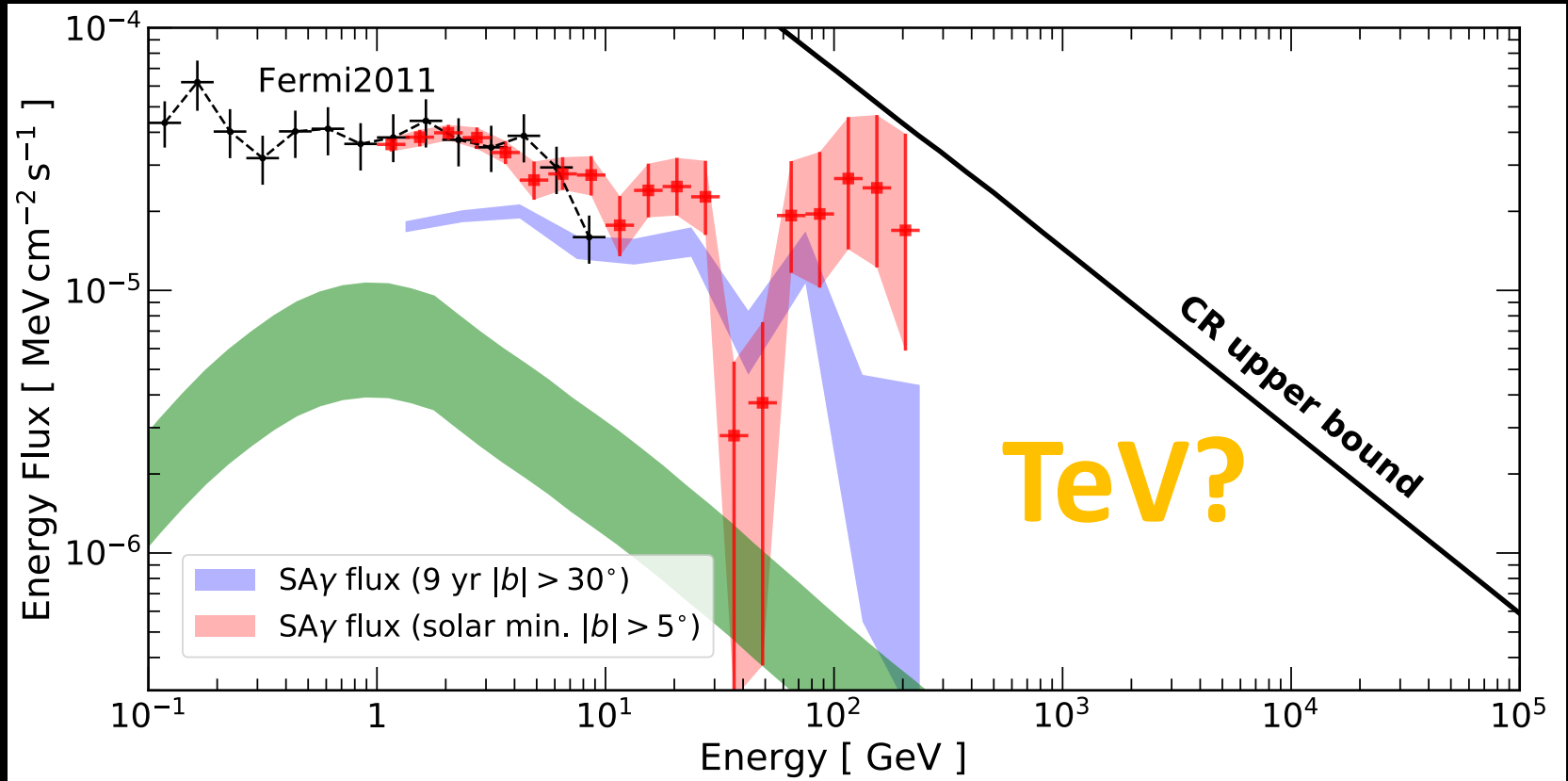


Spectrum, *surprise* (4)

- Strange “dip” between 30-50 GeV
 - Naively, two components, but not easy
 - No obvious instrumental explanation
 - Seems shallower outside solar minimum
 - Statistical fluke? Time-dependent feature/systematics? Will know soon

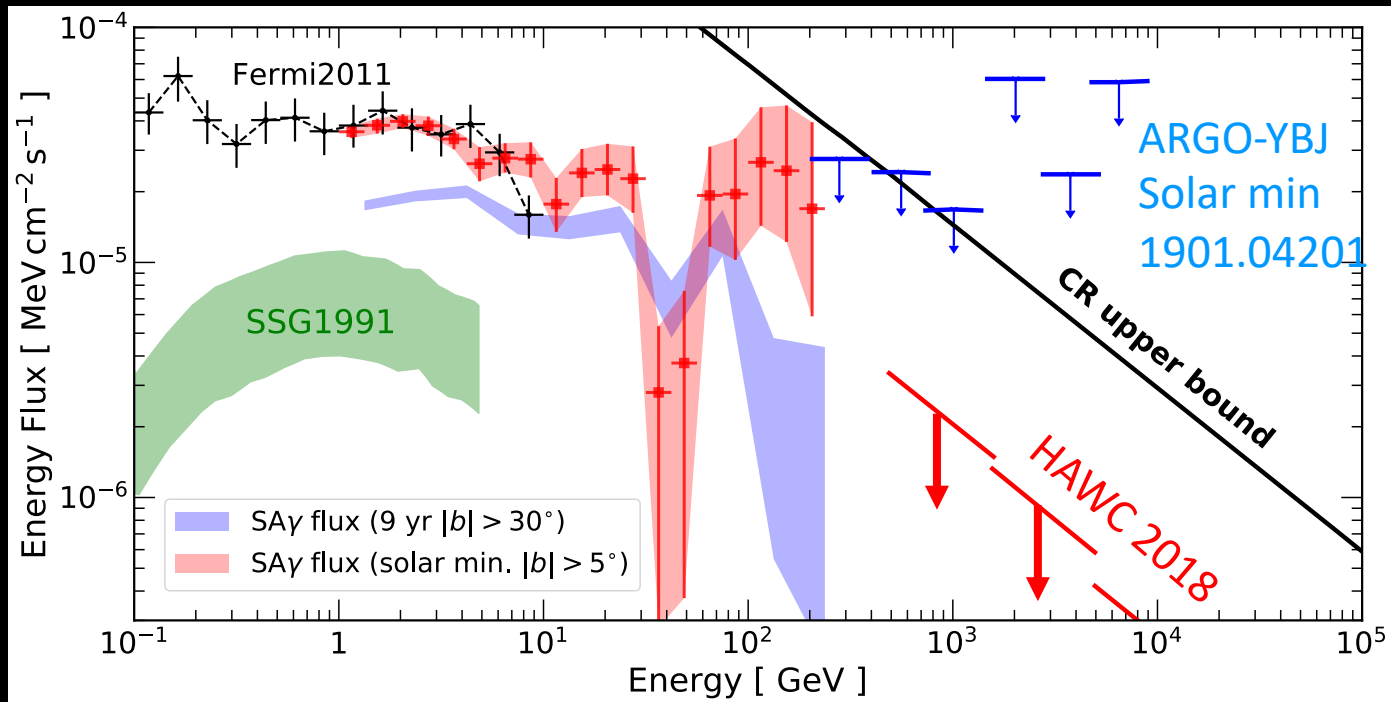


Solar Gamma Spectrum

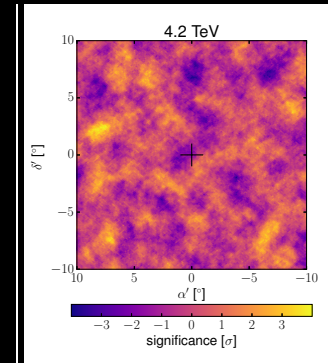


HAWC analysis of the Sun (2014-2017)

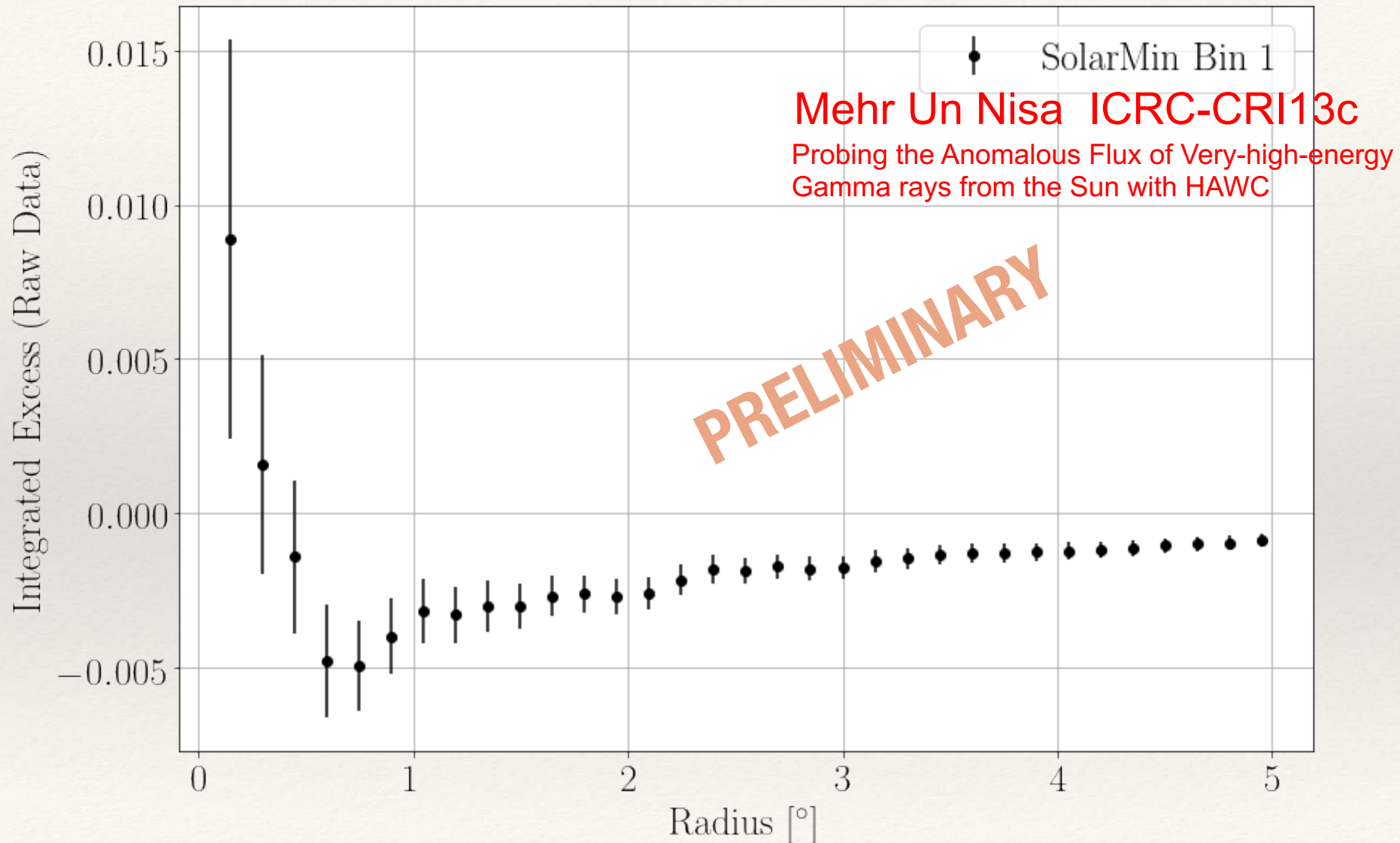
- Constrain $\sim 10\%$ of CR upper bound (active phase)
- Exciting prospect for current solar min (2018 -)



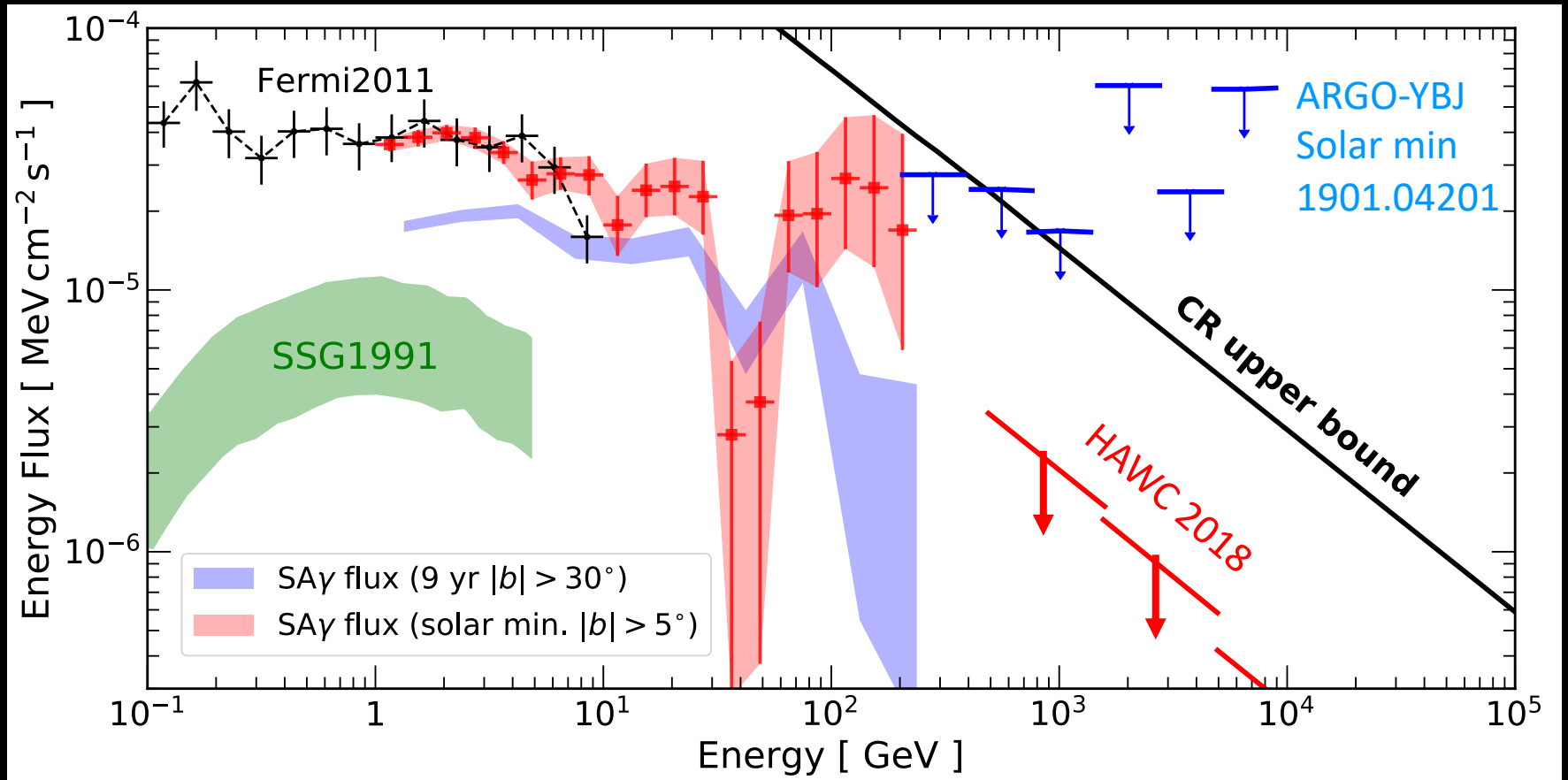
HAWC 1808.05620



2018 Data: Onwards to the Solar Minimum

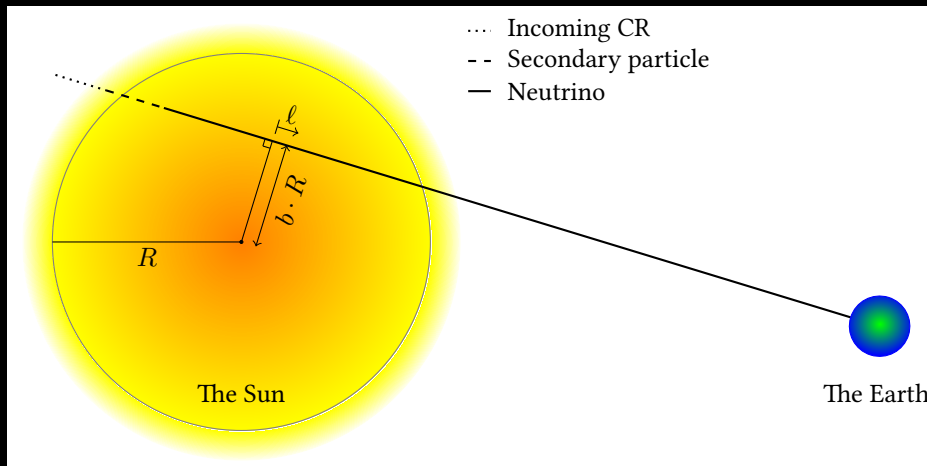


The Sun as a TeV source?!



Solar Atmospheric Neutrinos (signal)

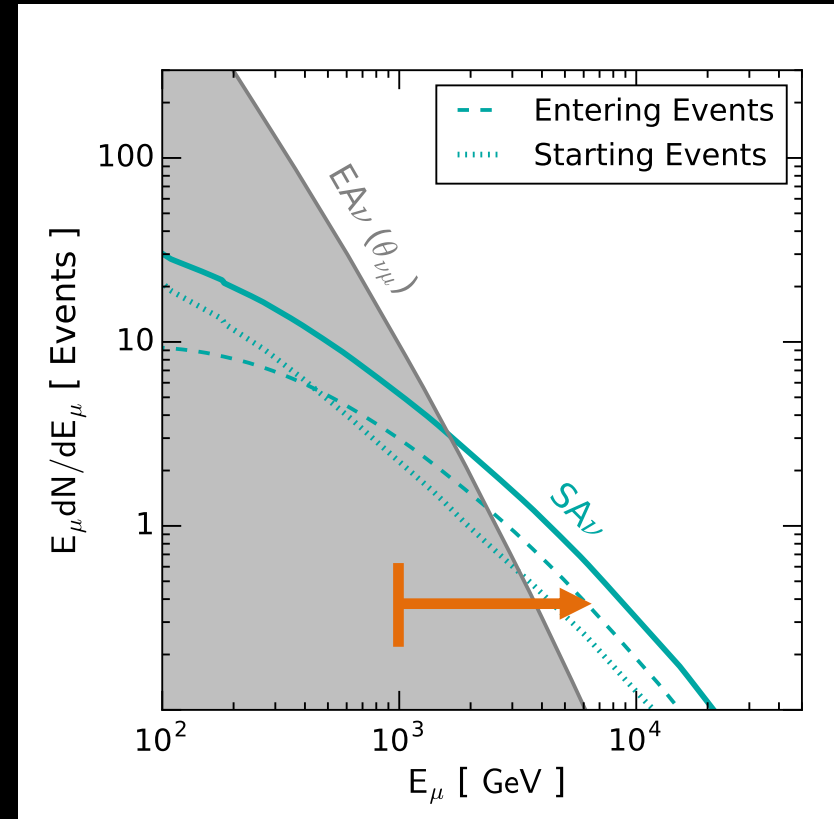
KCYN, Beacom, Peter, Rott 2017



Ingelman+1996

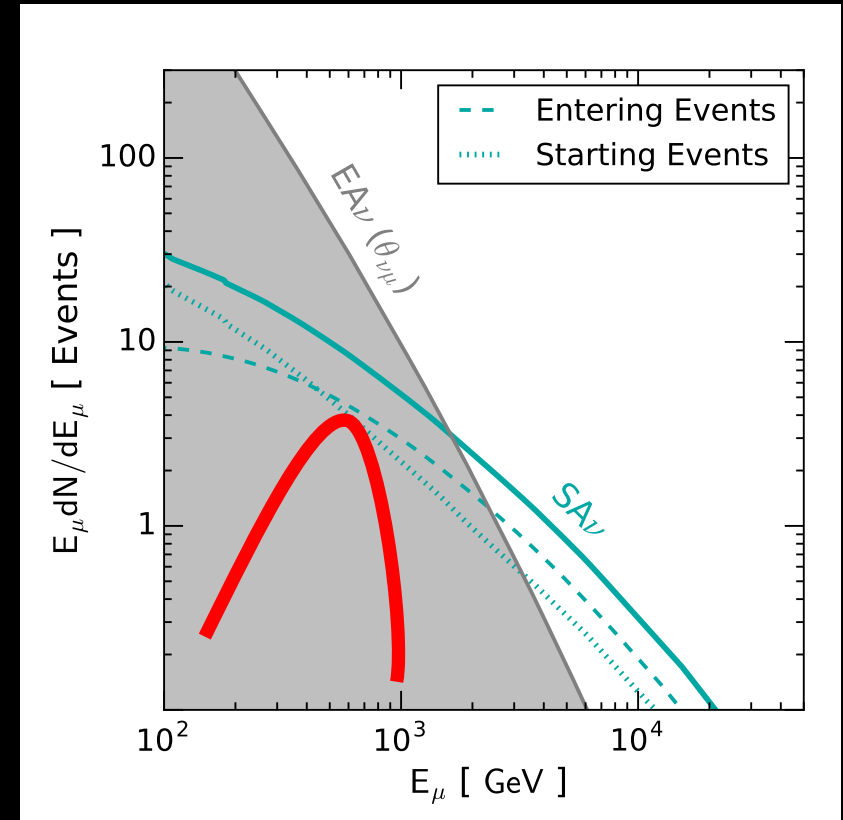
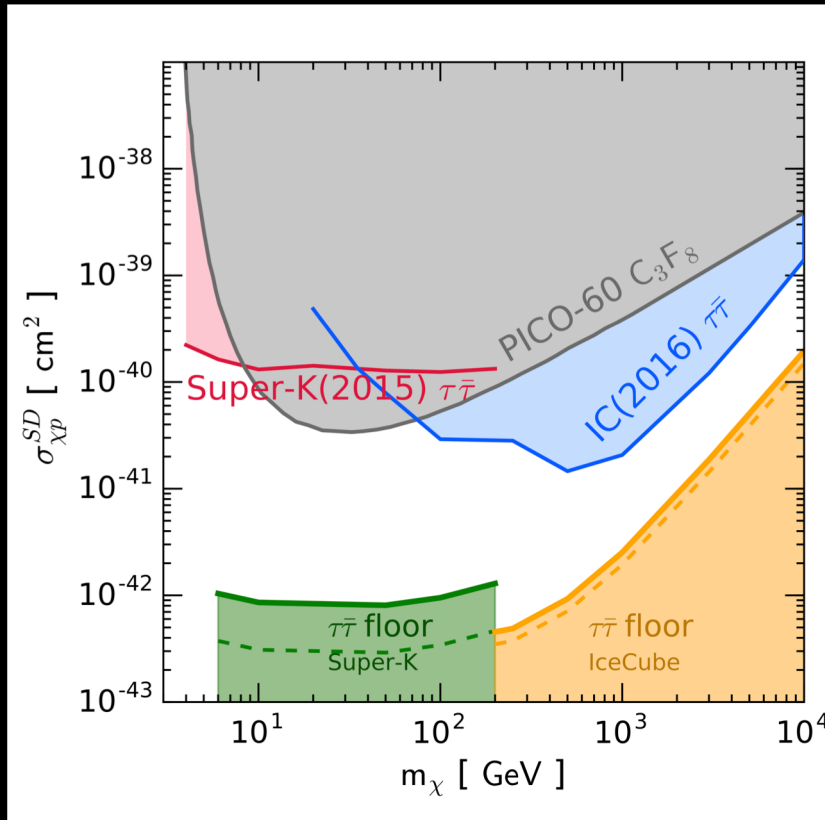
Arguelles+2017 **No Magnetic Fields!**

Edsjo+2017



Dark Matter Neutrino Floor

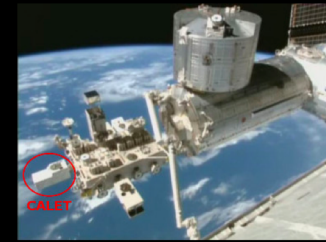
KCYN, Beacom, Peter, Rott 2017



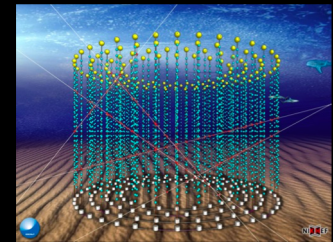
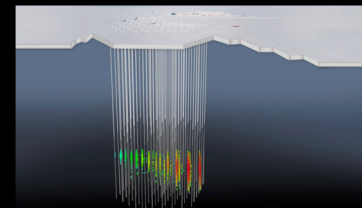
DM events < 1TeV due to absorption

Summary

- Solar gamma rays
 - *Complicated -> solar physics*
 - *TeV (HAWC-operating, LHAASO-soon)*
 - *CALET- preliminary detection*
 - *More time (solar minimum starting 2018)*



- Solar atmospheric neutrinos
 - *Signal at $> \text{TeV}$*
 - *IceCube, KM3NeT (future)*



- ***Anomalous Signals from the Sun -> New Physics!***

Thanks!



The Chinese University of Hong Kong



Photo credit: Longzijun



2020 --

- Postdoc
- PhD students

Theoretical Astro-particle physics

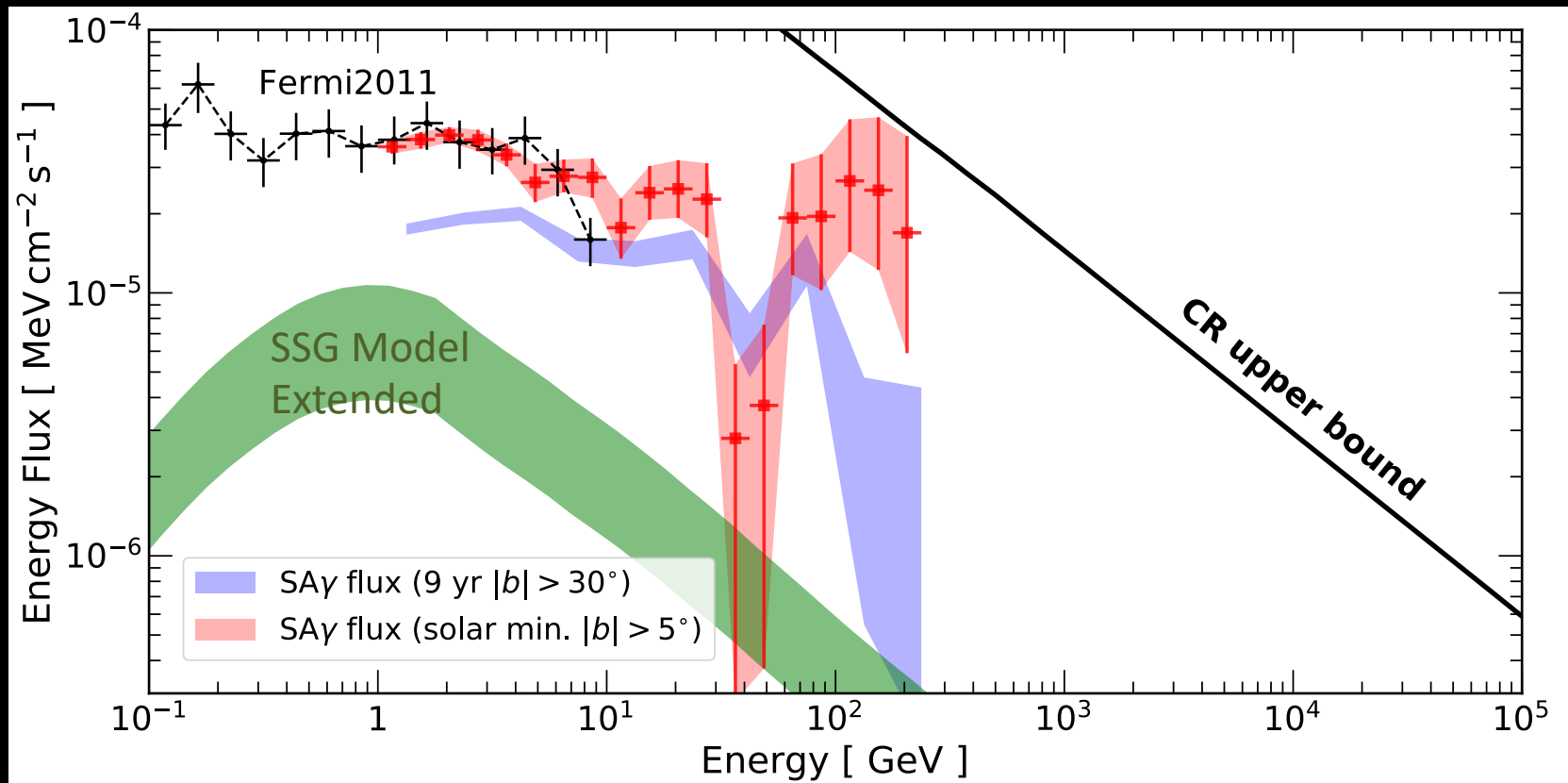
- Dark Matter
- Multi-messenger Astrophysics
- Cosmology

Contact:

Kenny CY NG
c.y.ng@uva.nl

CALET

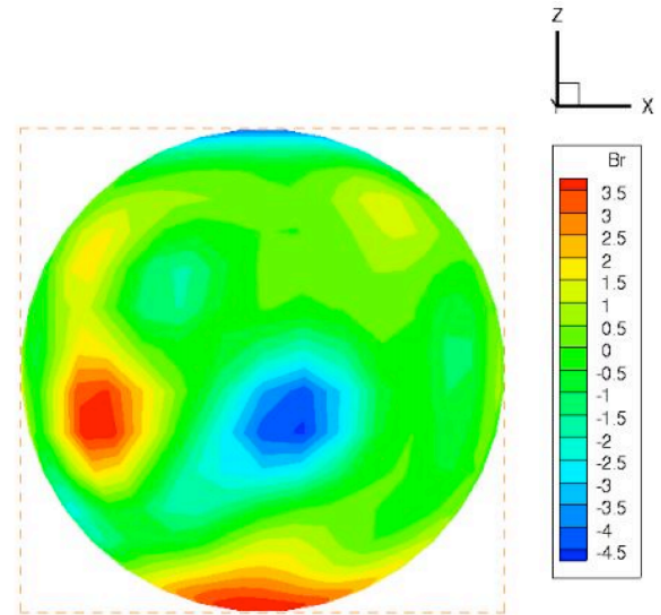
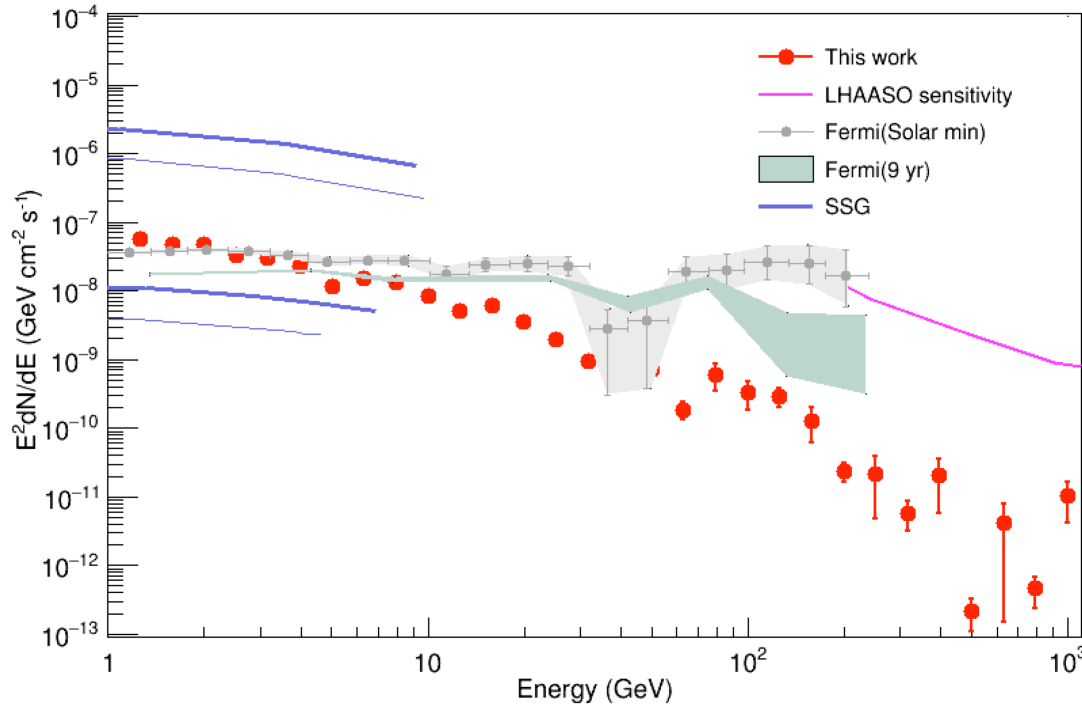
- Observations of the Sun in GeV Gamma Rays by CALET on the ISS
- Nicholas Cannady, APS April Meeting 2019
 - 3 years
 - Consistent with hard spectrum
 - 3 photons above 10GeV, 1 at 30-50GeV ?!



First Solar gamma simulation w/ B-field



3. Solar disk simulation result



PFSS model for "quiet" Sun

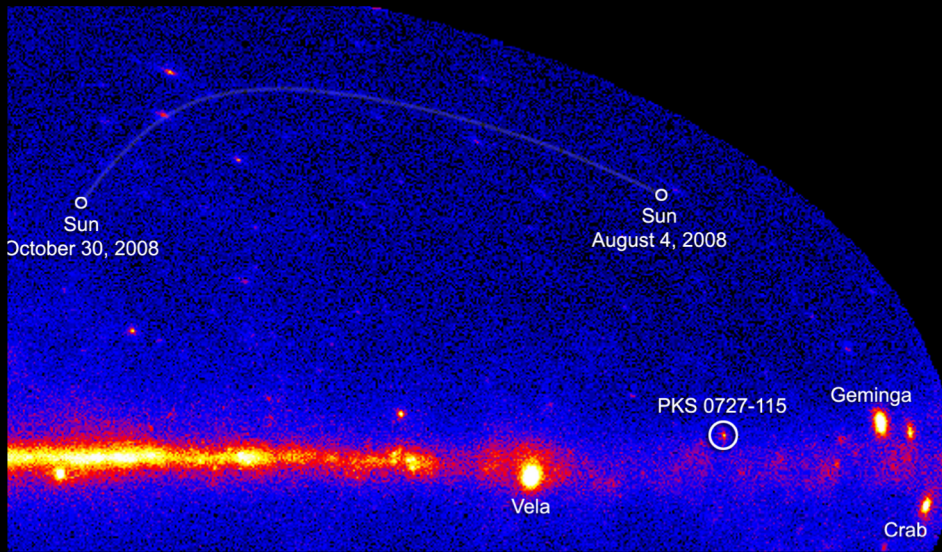
2019-7-29

Zhe Li (IHEP)

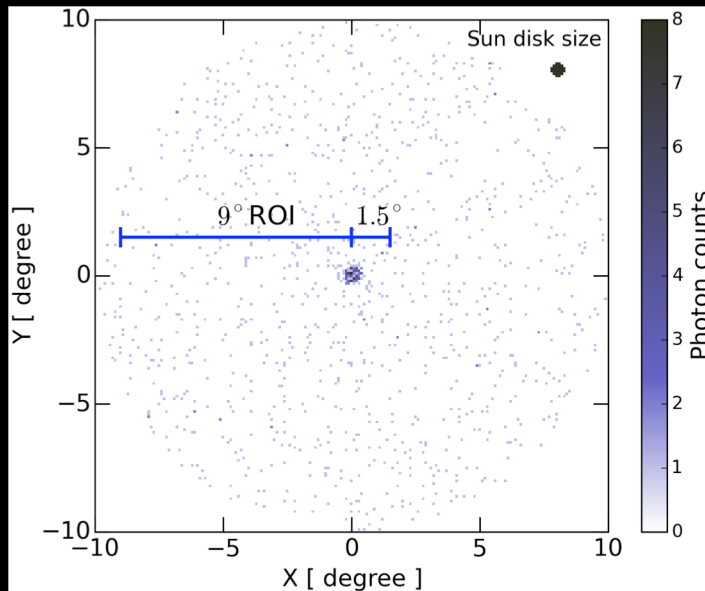
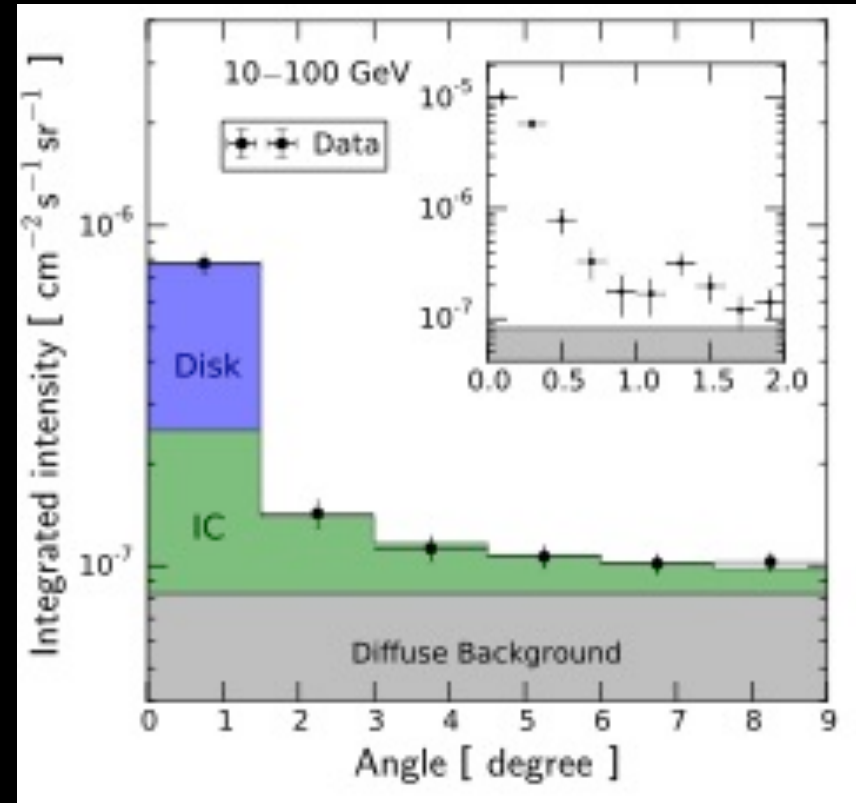
SH5e: Estimation of Solar Disk Gamma-ray
Emission Based on Geant4

17

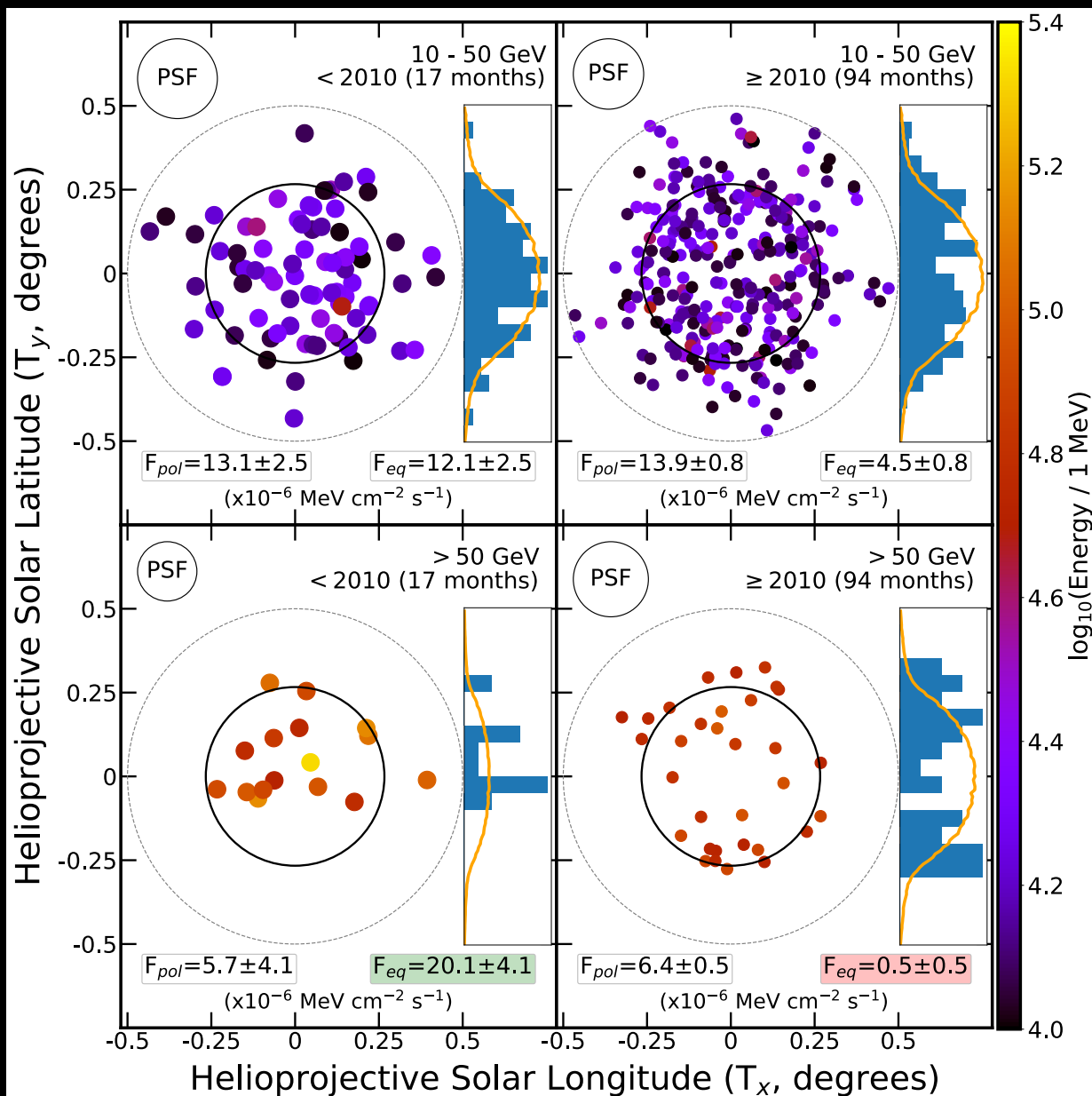
Finding the Sun with Fermi



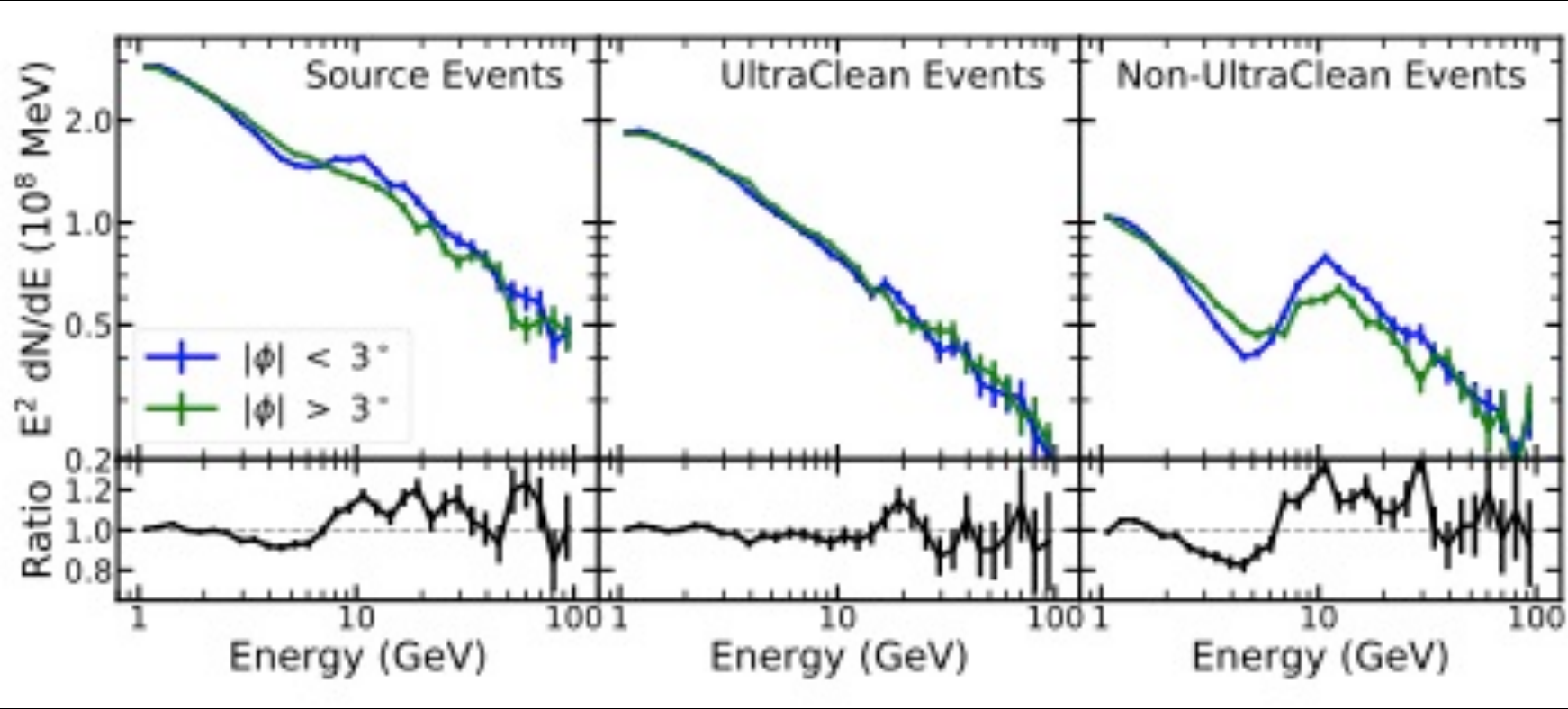
Angular distribution












KCYN+ 2015



- Background distribution
 - Test for energy features



HE Solar Messengers

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

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

Seckel Stanev Gaisser 1991

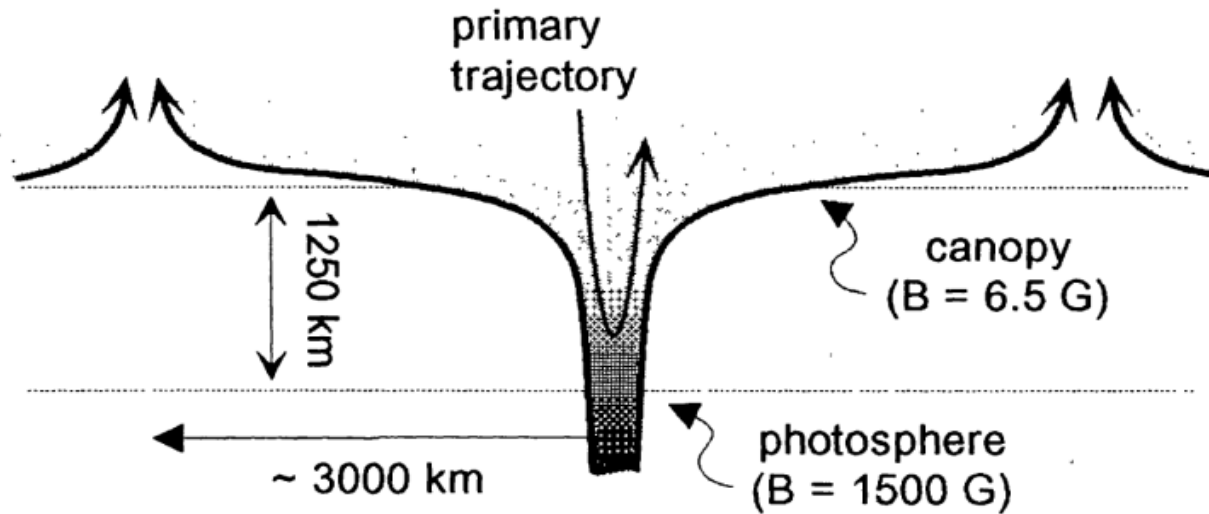
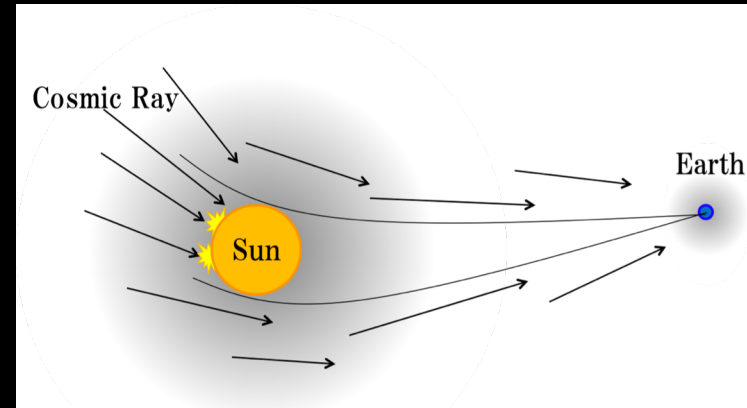


Figure 1: Model of magnetic fields near the photosphere. Shading increases with magnetic field intensity.

- Follow the field line
- Gas-B-field pressure equilibrium
- Magnetic field gradient \rightarrow mirroring
- Trajectory \rightarrow **interaction probability $\rightarrow \sim 1\%$** **Boost gamma-ray production**

Sun shadow observations

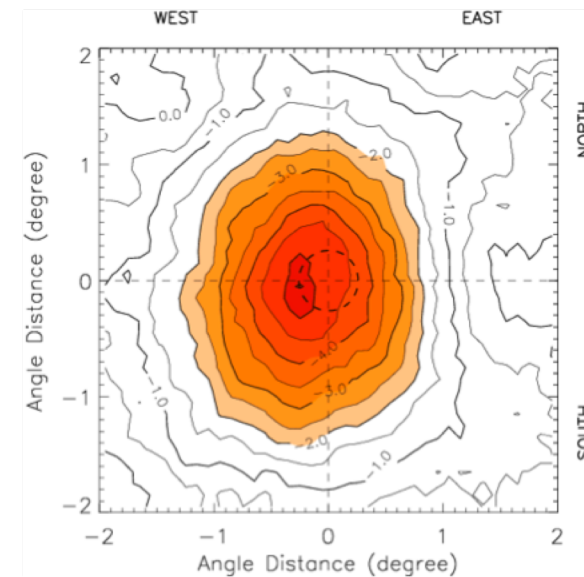
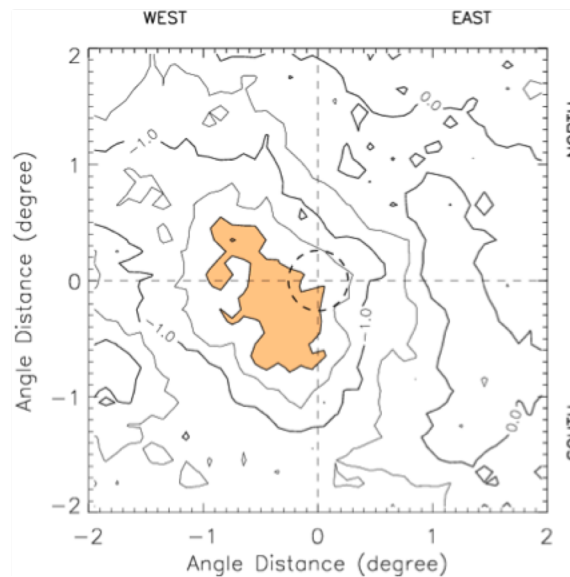
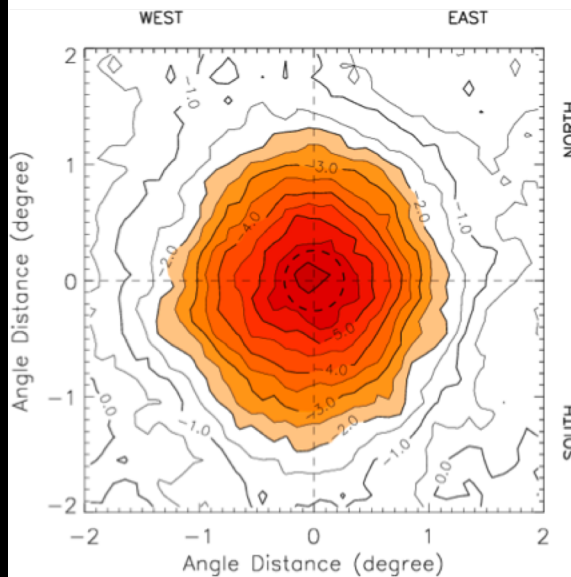
- **TeV** cosmic-ray Sun shadows (near Sun-trajectory)



1996

2000

2008



ICRR, Tibet AS-gamma PRL

2013

2nd Dec 2019

Kenny C.Y. NG, TeVPA 2019

32