Solar Dark Matter Search with the IceCube Neutrino Observatory

Jeffrey Lazar for the IceCube Collaboration

34th Rencontres de Blois

Blois, France

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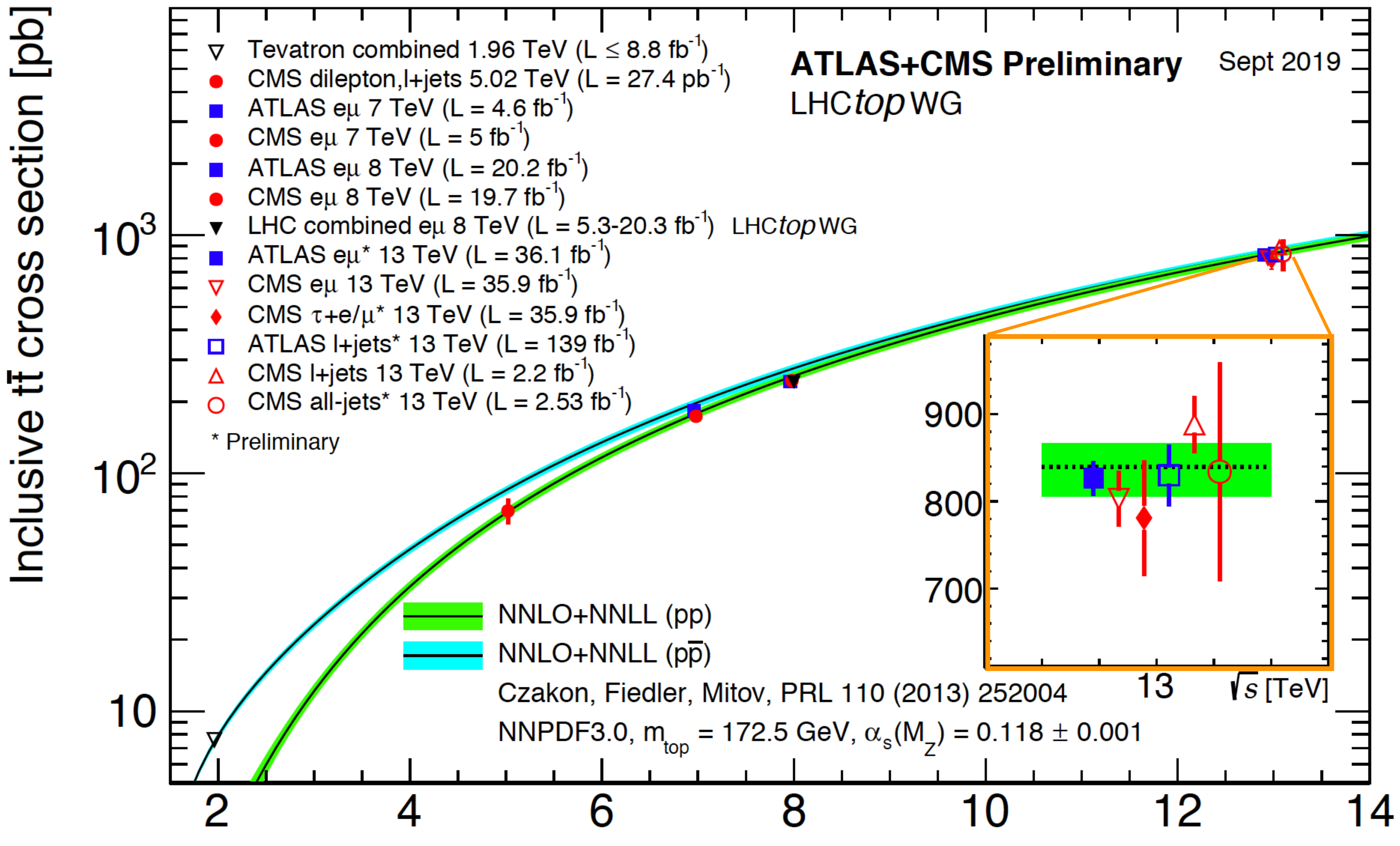
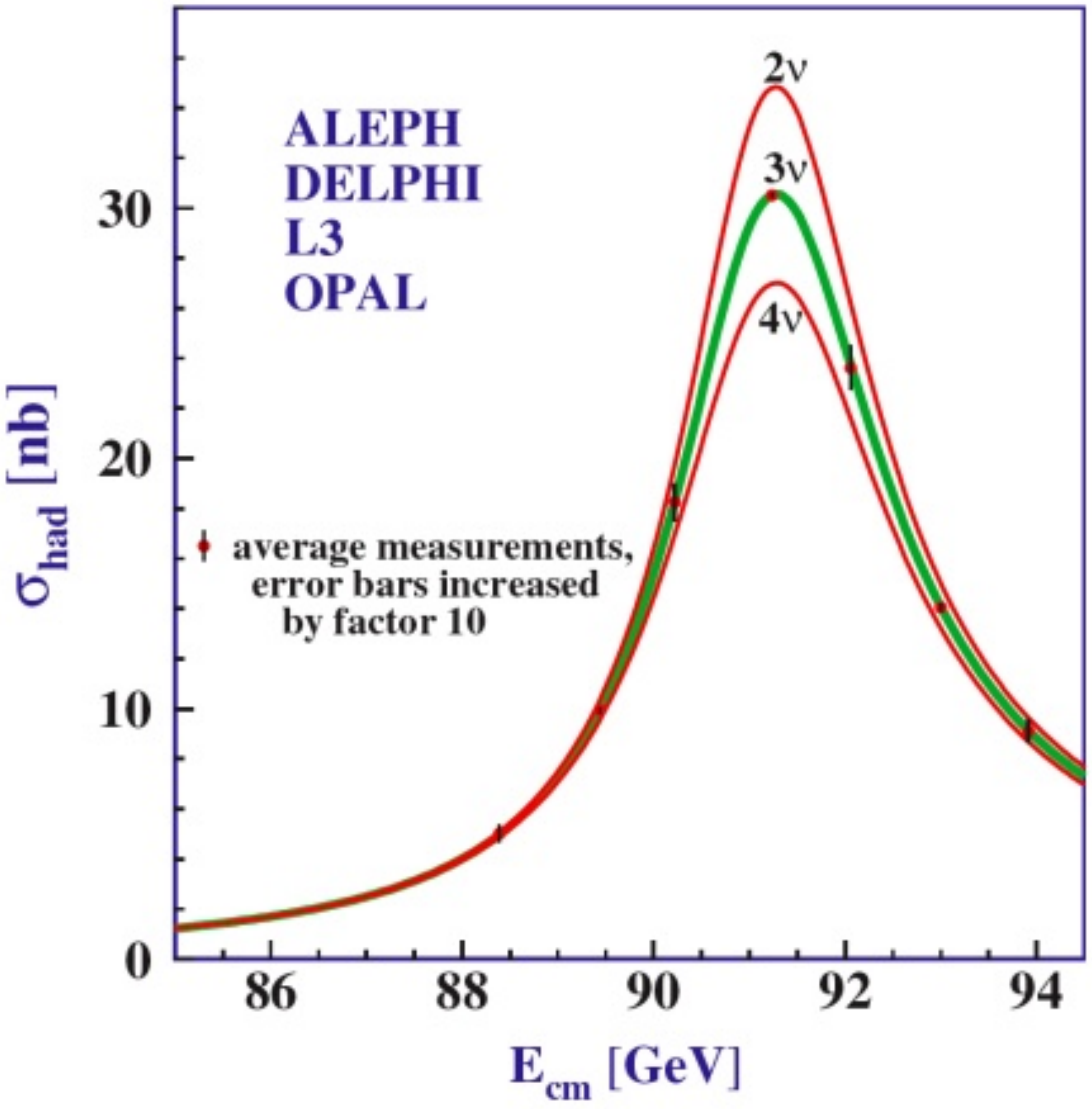
Triumphs of the Standard Model

The Standard Model (SM) has proved an incredibly powerful theory



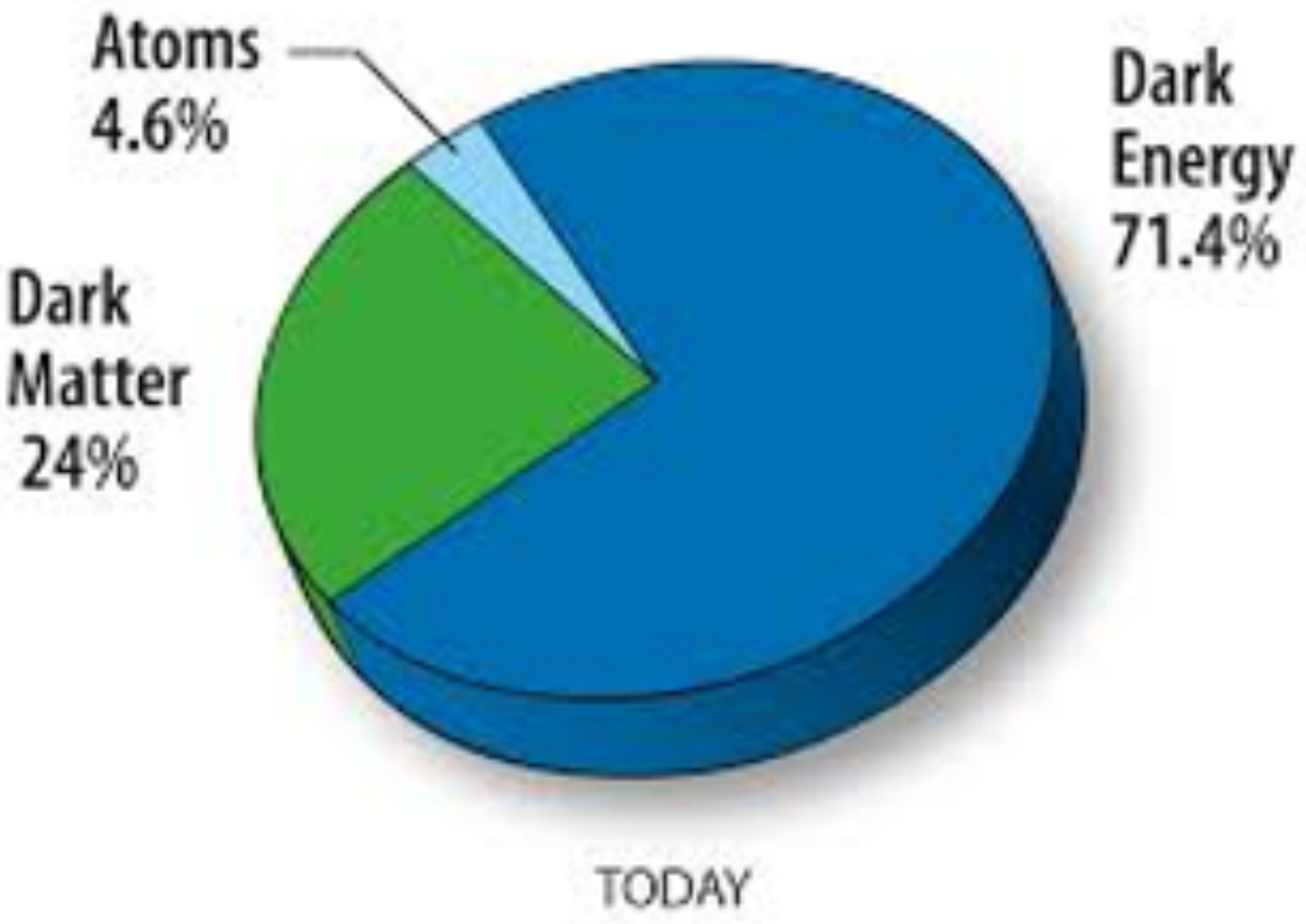
S. Amoroso (2020): Proceedings of Science

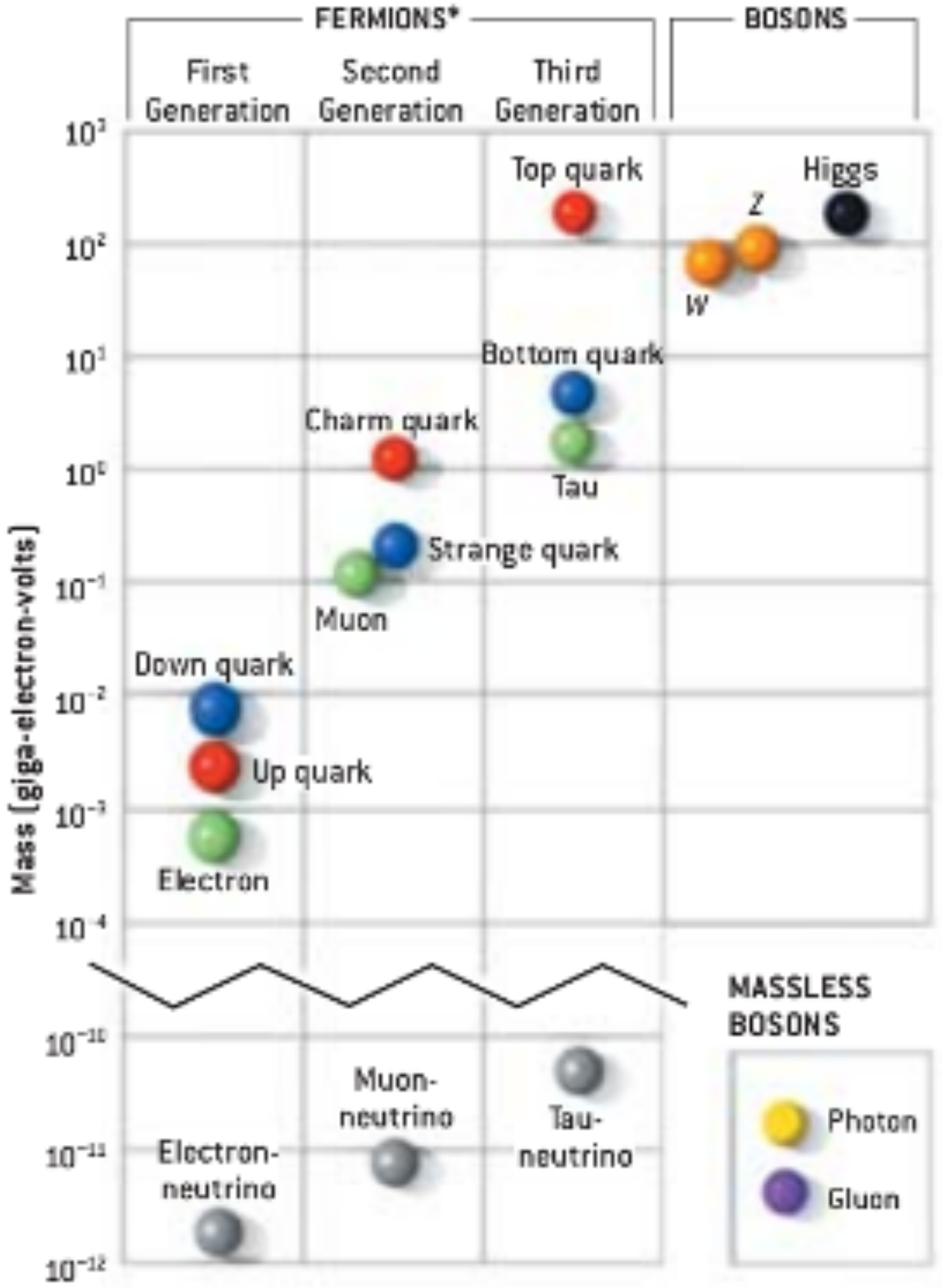


DELPHI (1989): Physical Letters B, **OPAL**: (1989): Physical Letters B
ALEPH: (1989): Physical Letters B, **L3**: (1990): Physical Letters B

But Something is Off

On large and small scales, something is amiss





Hints of Particle Dark Matter

- Observations hint that DM may be corpuscular in nature
- Bullet cluster suggests two populations of matter: one more strongly interacting than the other
- Blue is where matter is from lensing data, red from X-ray

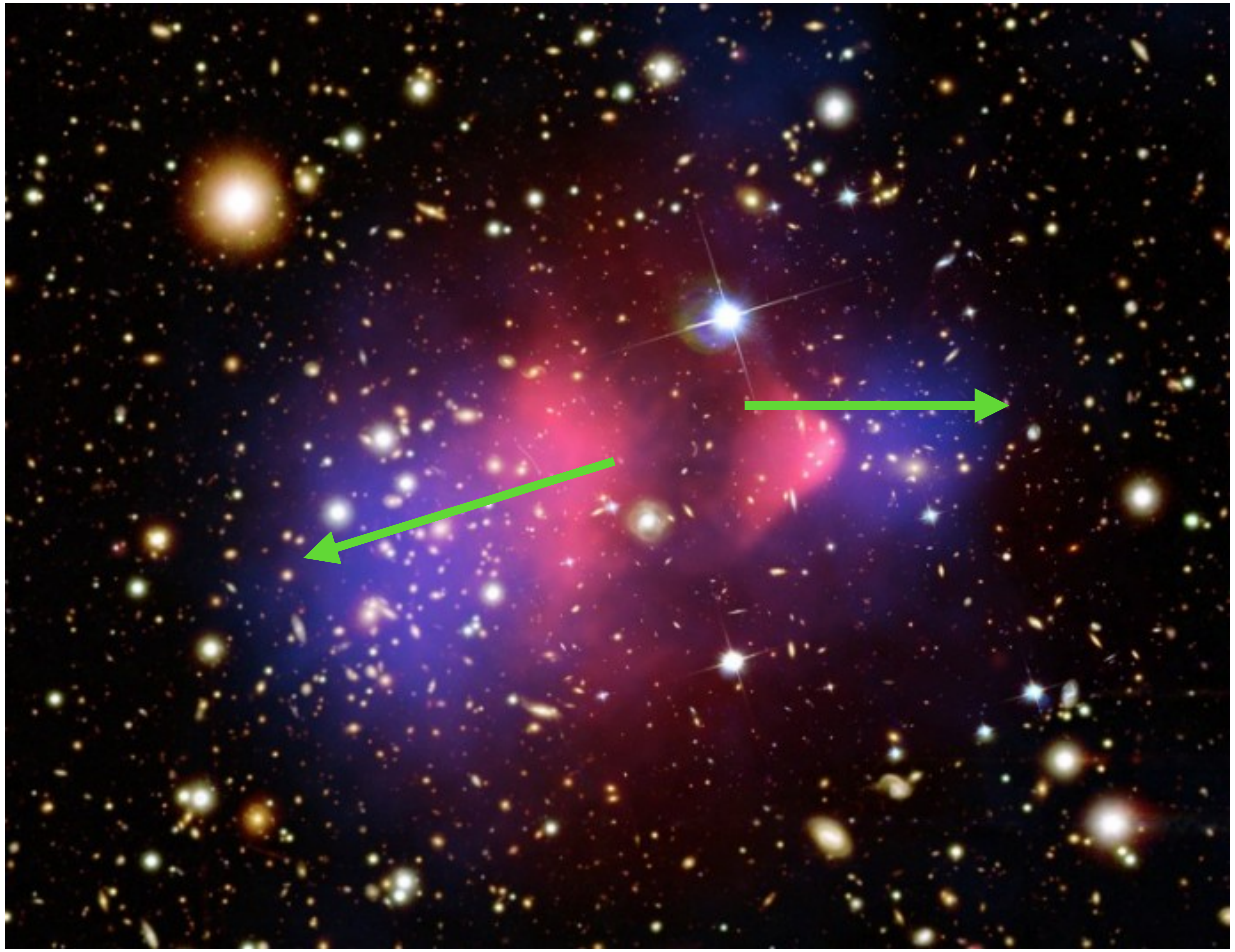
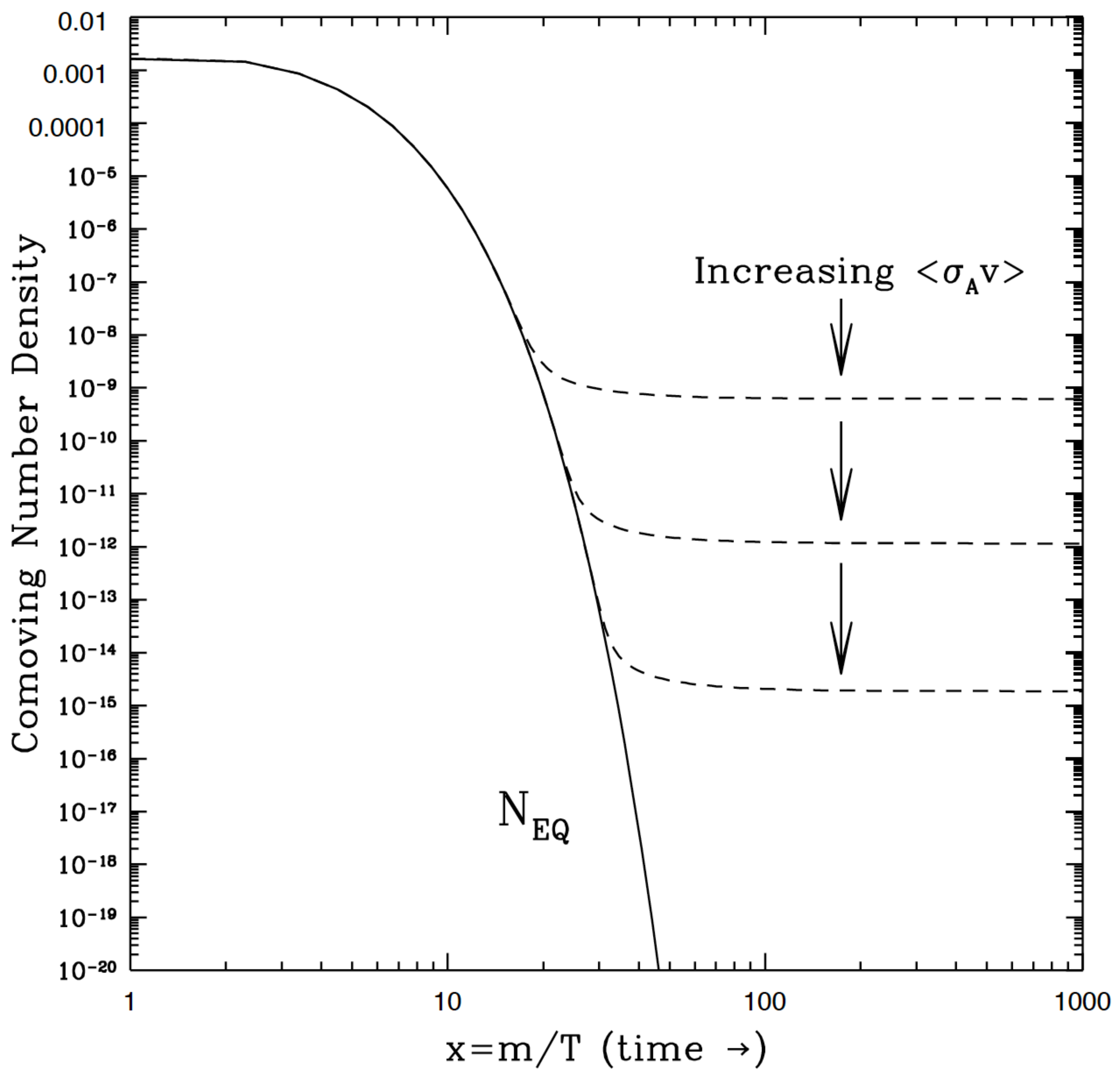


Image credit: X-ray: M.Markevitch et al.; Lensing Map/Optical: Magellan/U.Arizona/D.Clowe et al.

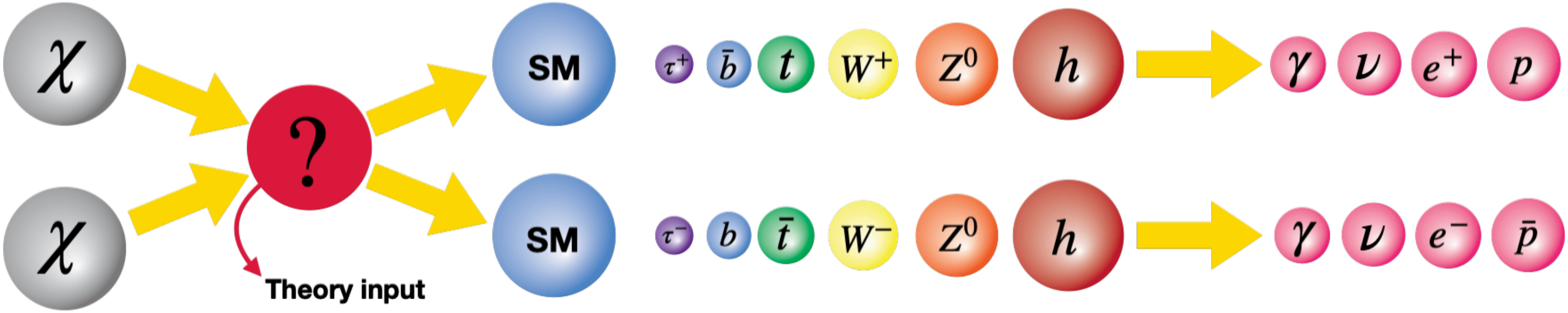
Theoretically Motivated Dark Matter

- Particle DM arises naturally in many theoretical frameworks meant to address other issues
- 100 GeV-scale DM with weak-scale interactions produces the right relic abundance: WIMP miracle
- WIMPs also occur in scotogenic neutrino mass models



G. Jungman, M. Kamionkowski, and K. Griest: Physics Reports (1995)

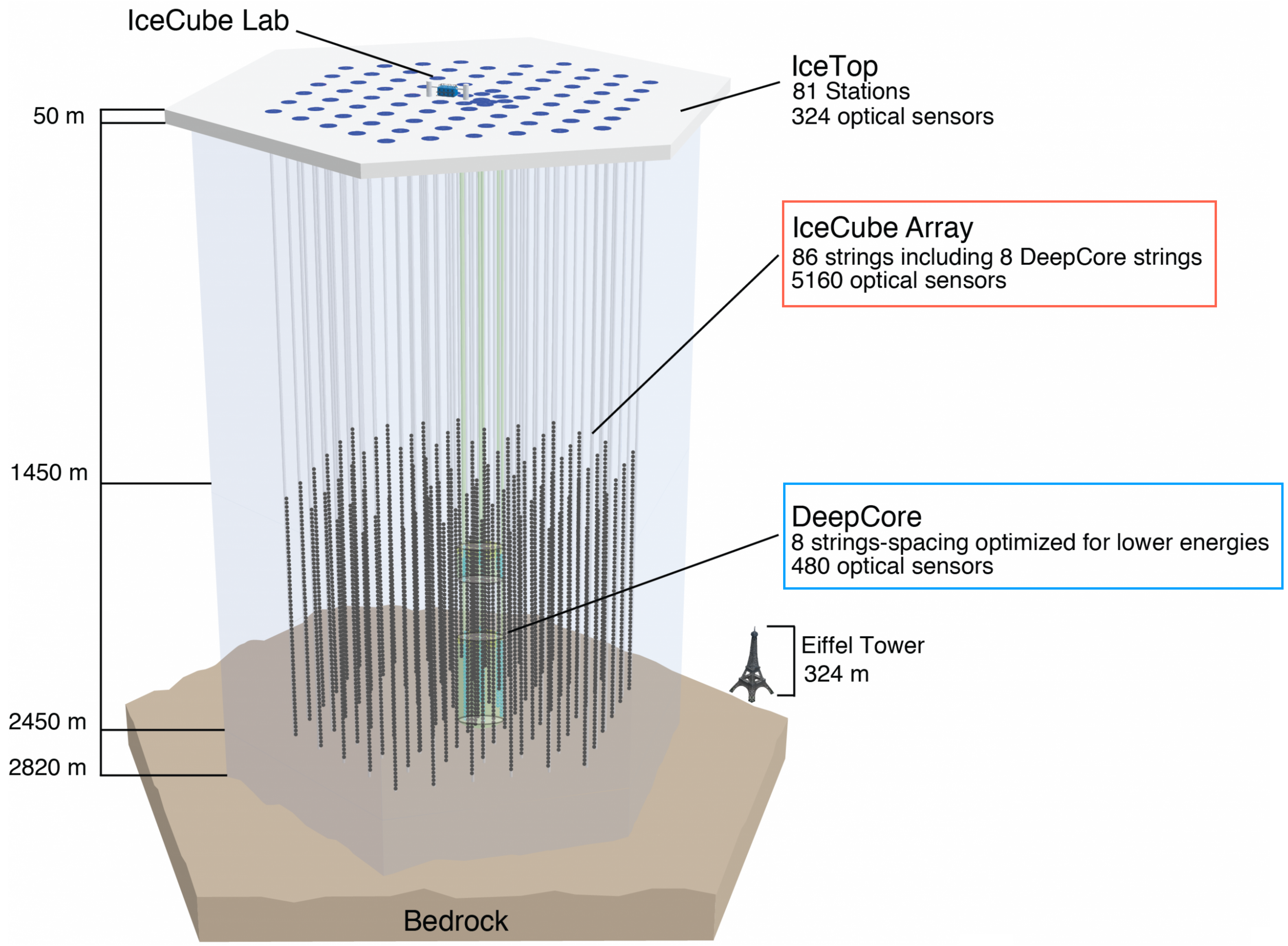
WIMPs' Astrophysical Signatures



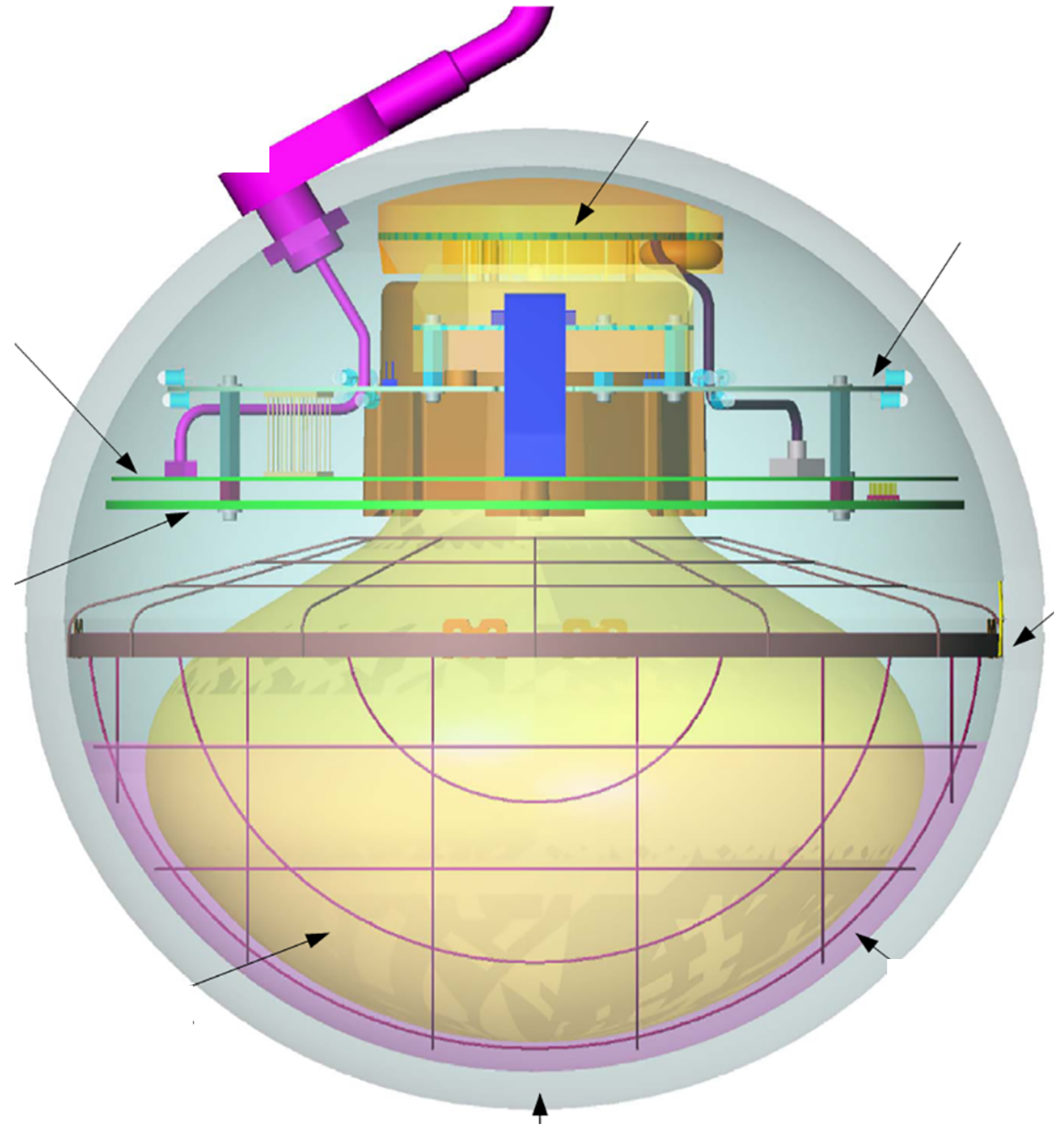
- Look for stable SM byproducts of WIMP annihilation or decay
- Neutrinos can escape dense astrophysical environments
- Look towards places where WIMPs are expected to accumulate

DM Capture and Indirect Detection

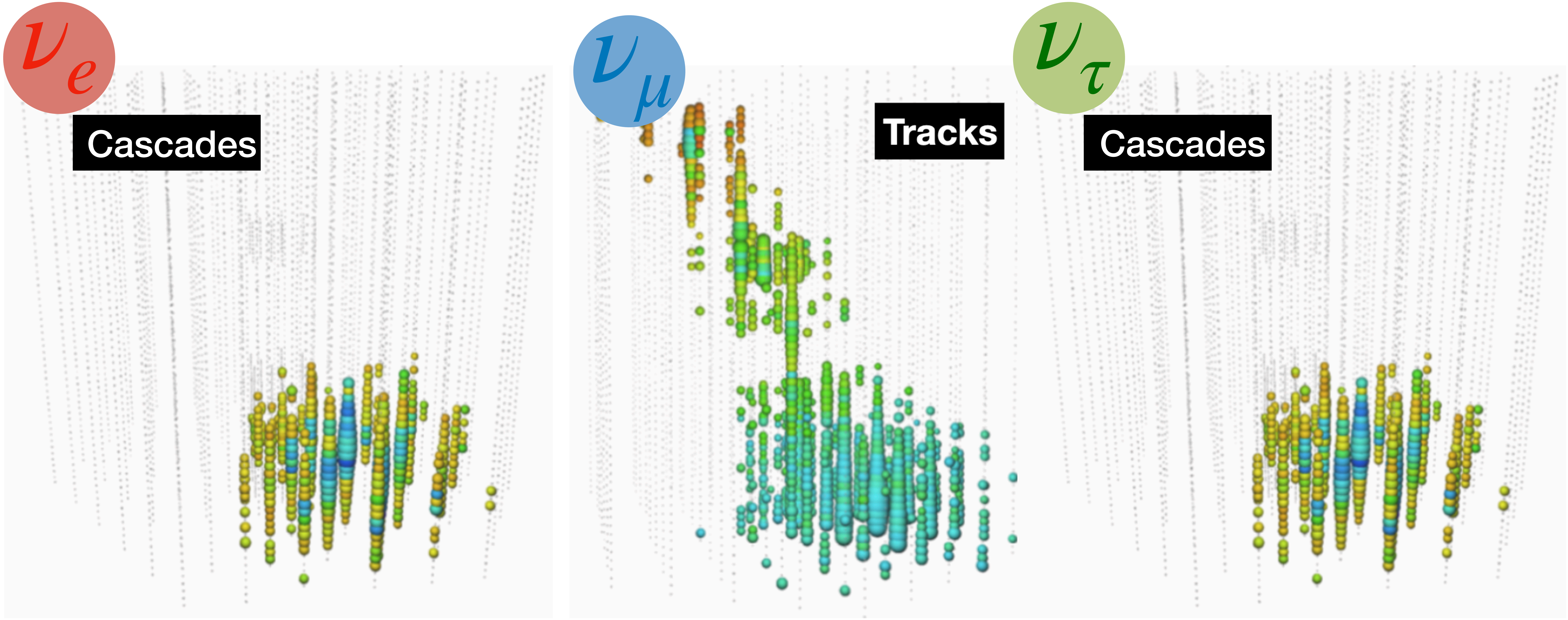
The IceCube Neutrino Observatory



- Gigaton-scale neutrino observatory beneath the ice at the geographic South Pole
- IceCube and DeepCore sensitive to high- and low-energy neutrinos



How Do Neutrino Telescopes See ?



Solar Dark Matter Limits

$$\dot{N} = C_C - C_A N^2 - C_E N$$

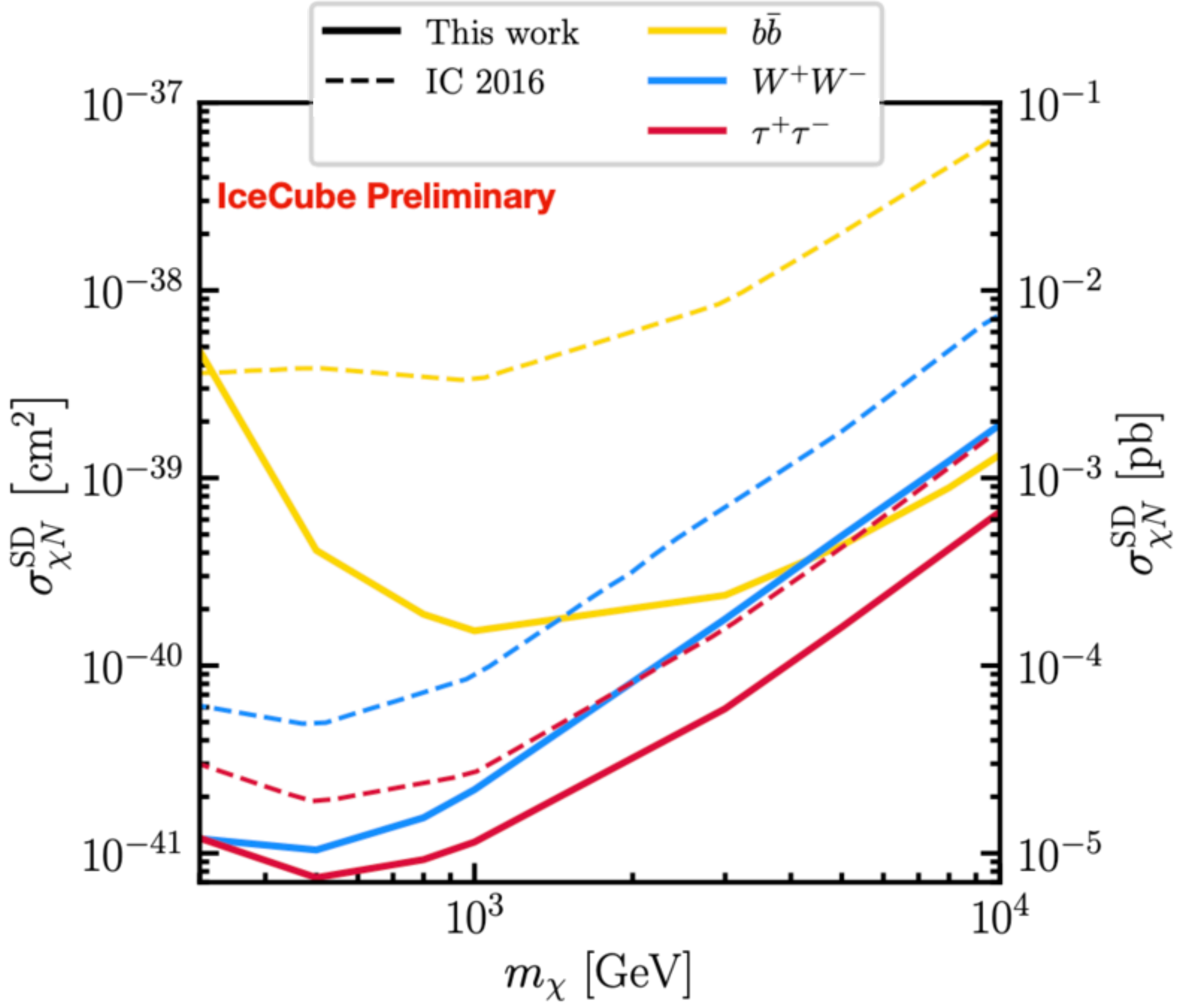
($\dot{N} = 0$, $C_E N = 0$)

Capture rate: Proportional to $\sigma_{\chi N}$

Annihilation rate: Sets rate of WIMP conversion to neutrinos

Evaporation rate: Negligible for WIMP masses above a few GeV

$$\implies \frac{\Gamma_A}{2} = C_C \propto \sigma_{\chi N}$$



Limits on WIMP-nucleon cross-section using a high-energy track analysis

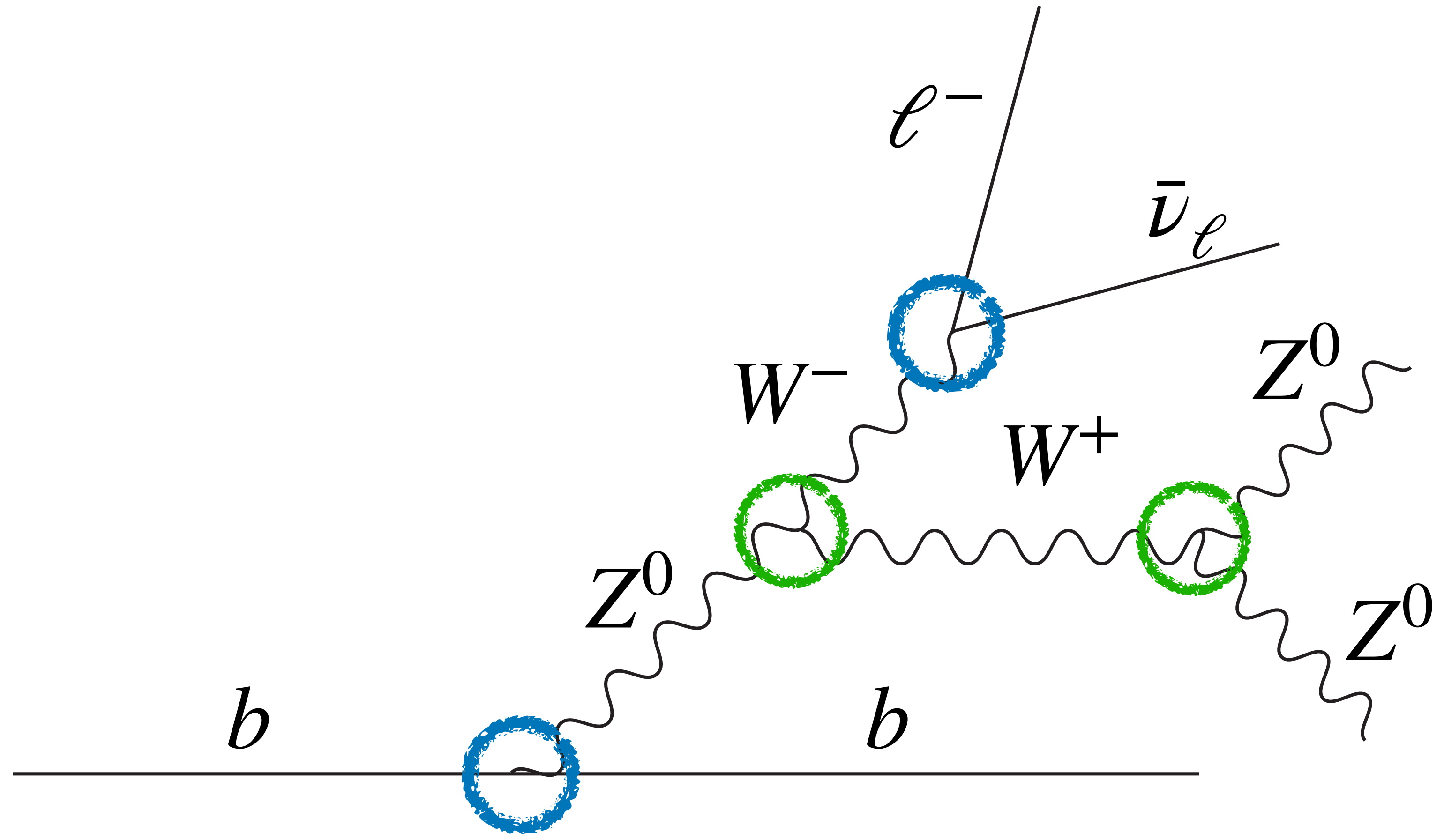
χaroν

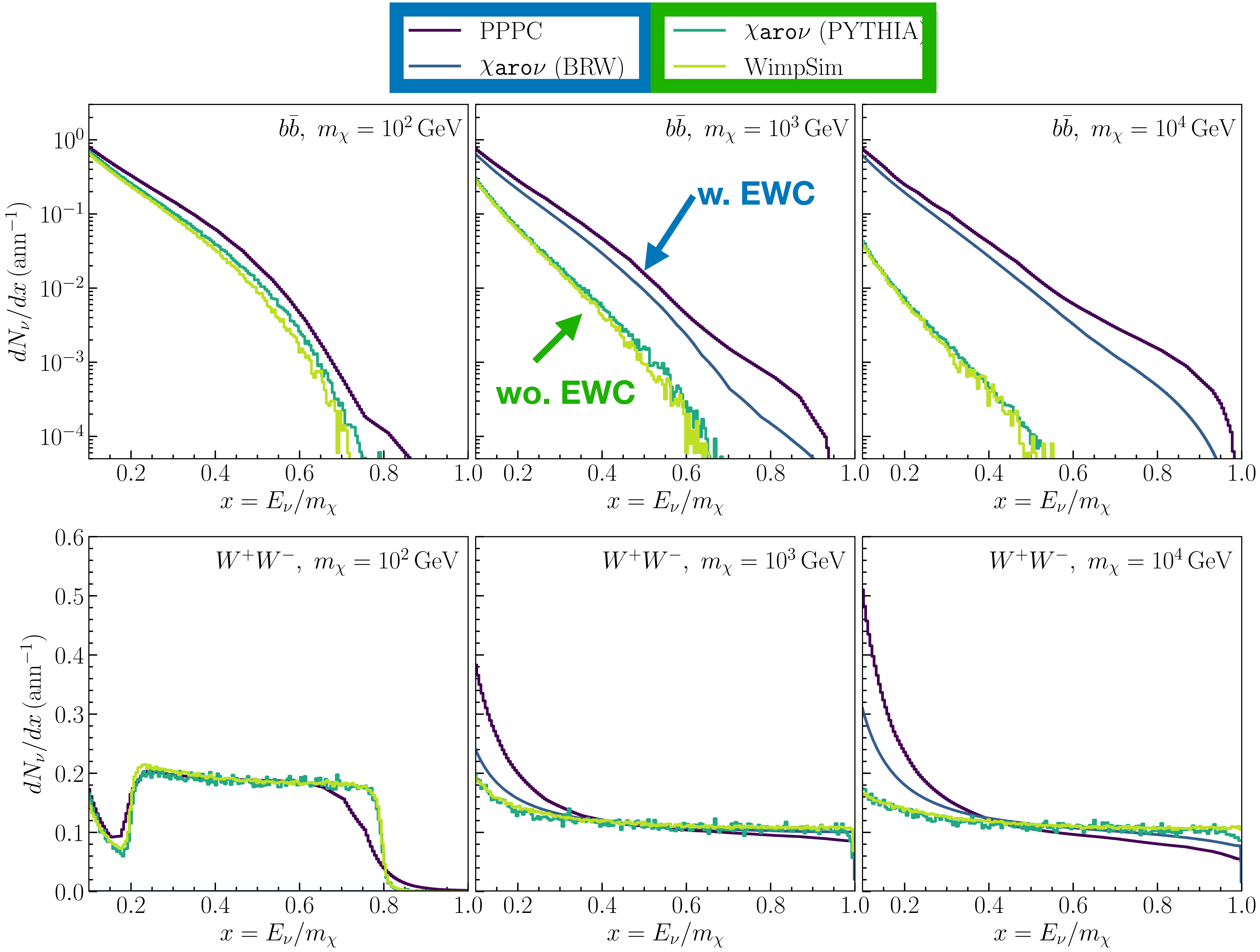
- Software package for calculating neutrino yields from DM annihilation/decay [1]
- Couples PYTHIA8 to an updated calculation of EW correction (BRW calculation) [2]
- Flexible python-based package allows for easy implementation of systematics and new fluxes
- Source code at https://github.com/icecube/charon

[1] **Q. Liu, JL, C. A. Argüelles, A. Kheirandish**: JCAP (2020)
[2] C. W. Bauer, N. L. Rodd, B. R. Webber: JHEP (2020)

New Spectra

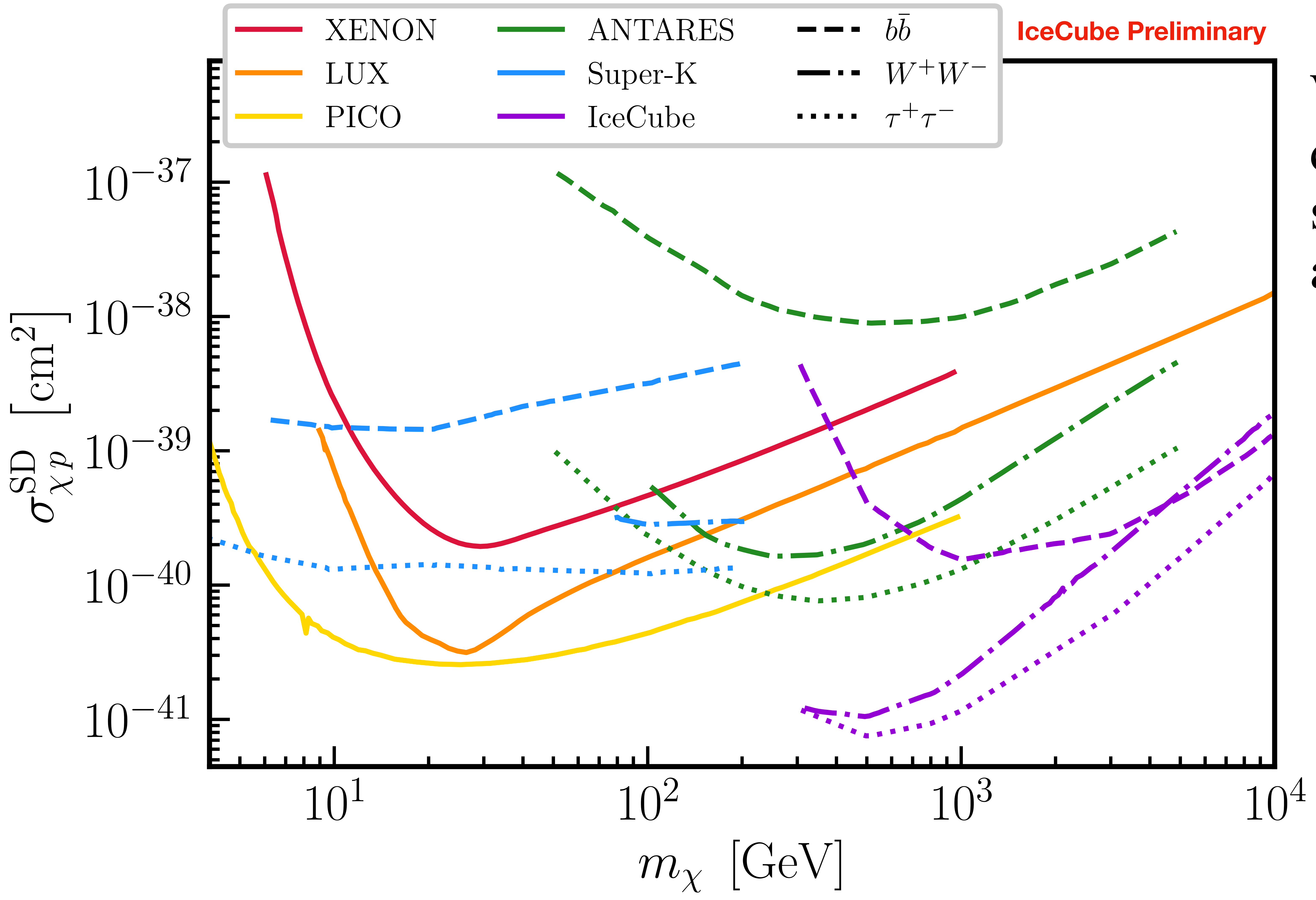
- New calculation of EW correction increases initial flux by $\mathcal{O}(10)$
- Included in χaroν package, an open-source package for calculating fluxes





Q. Liu, JL, C. A. Argüelles, A. Kheirandish: JCAP (2020)

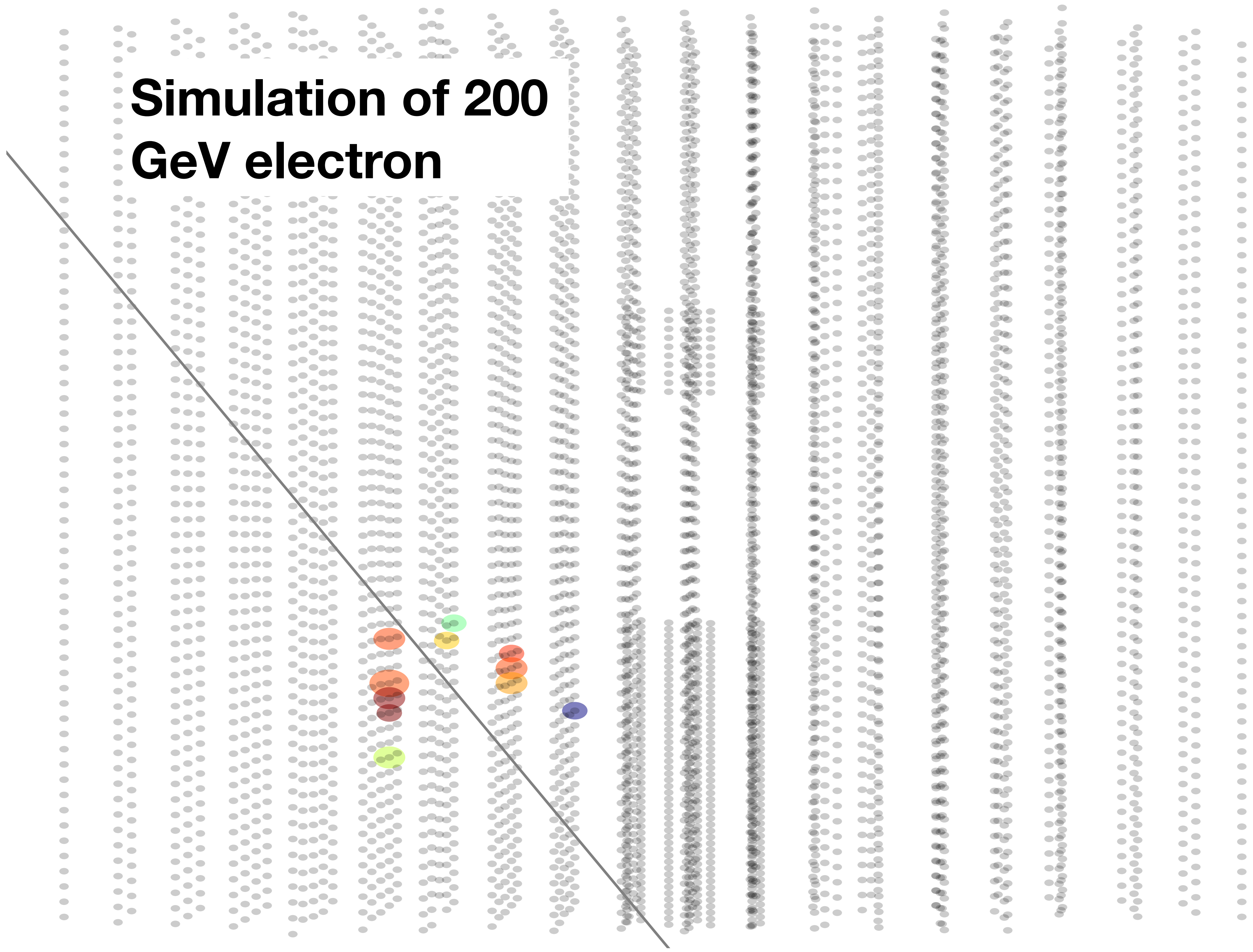
Global picture

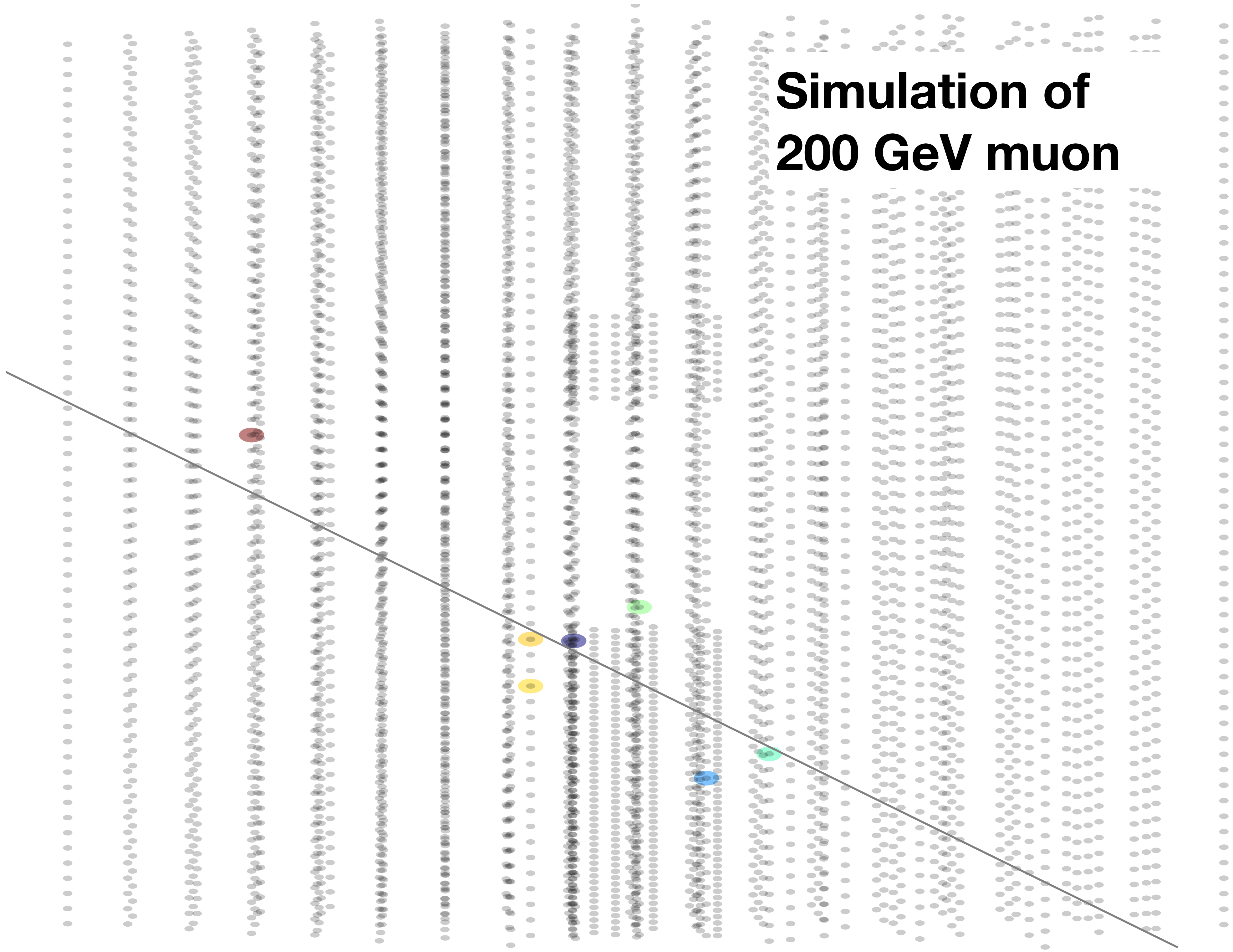


World leading limits on spin-dependent WIMP-proton cross section for WIMPs with masses above 300 GeV

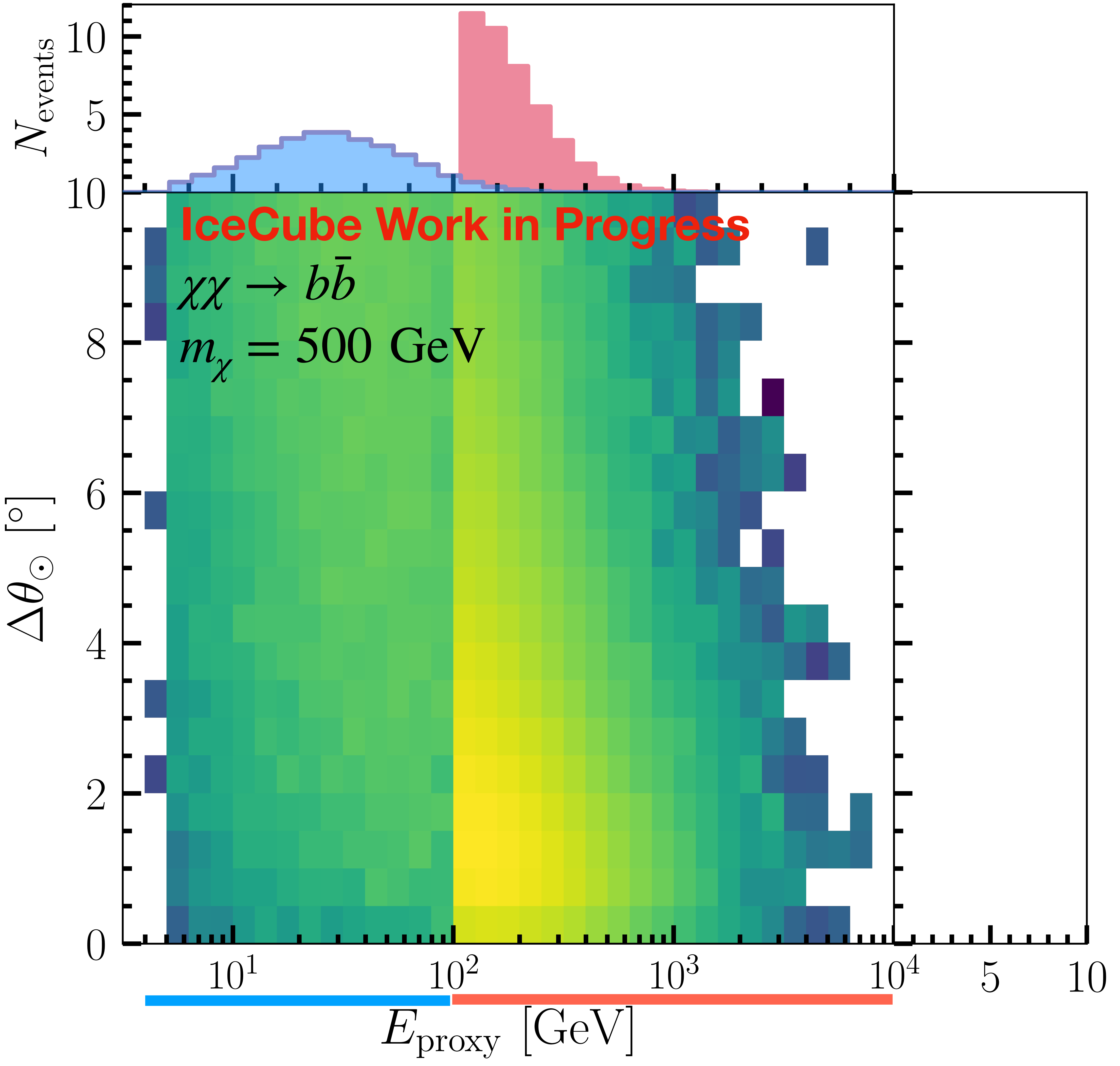
All-Energy, All-Flavor

- IceCube + DeepCore to cover WIMP mass range from 10 GeV to 10 TeV
- Directional reconstruction challenging at lower-energies
- Cascade channel signal-backgrounds ~10x better→ Include all flavors in analysis





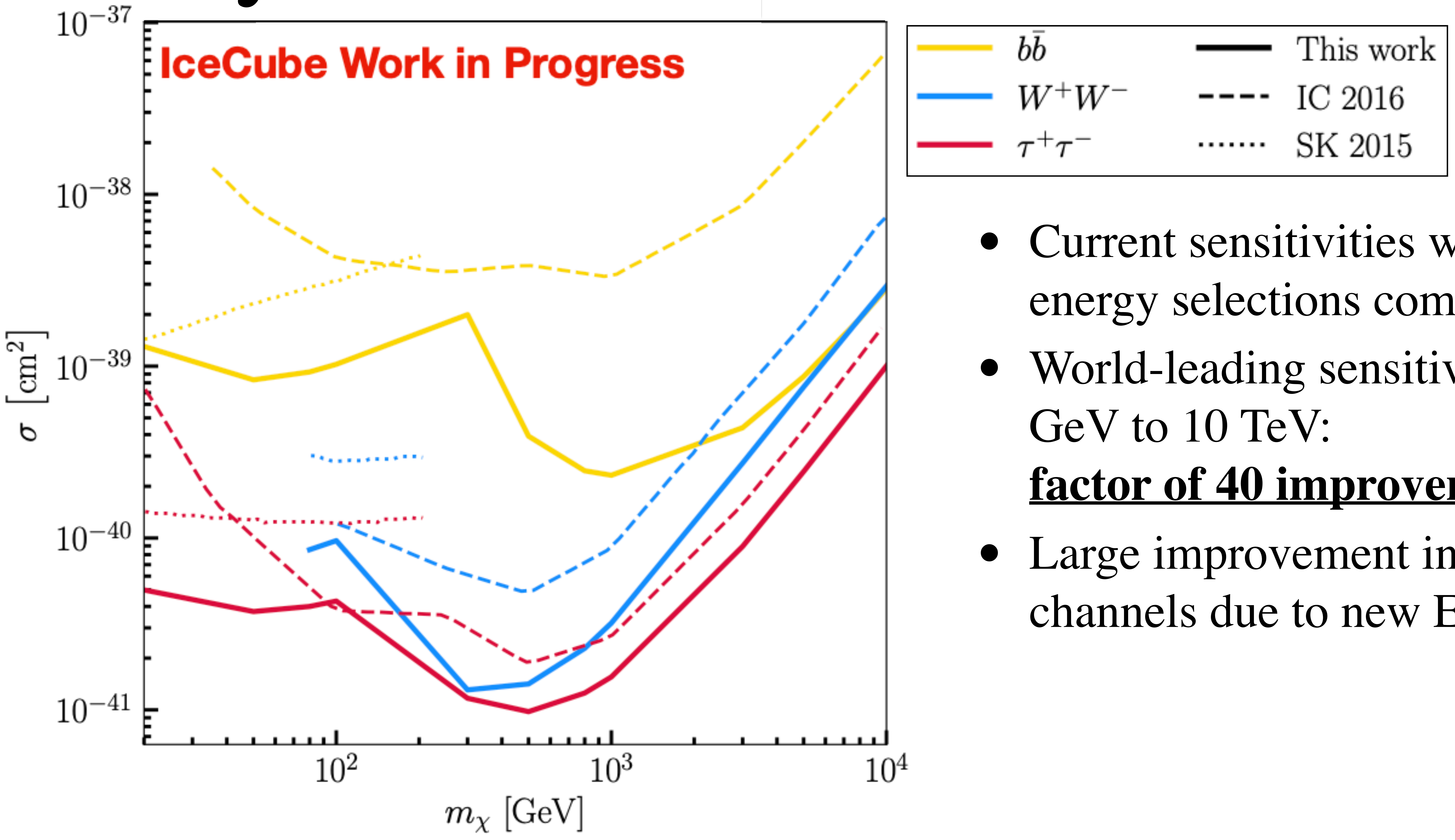
Analysis Event Distributions



- Combine low- and high-energy selections
- Expected event distribution for an example DM hypothesis
- HE events clustered towards the Sun
- LE events more spread due to worse angular resolution

Signal event distribution in reconstructed quantities. Expected number of events in low- and high-energy selections for $\chi\chi \rightarrow b\bar{b}, m_\chi = 500$ GeV

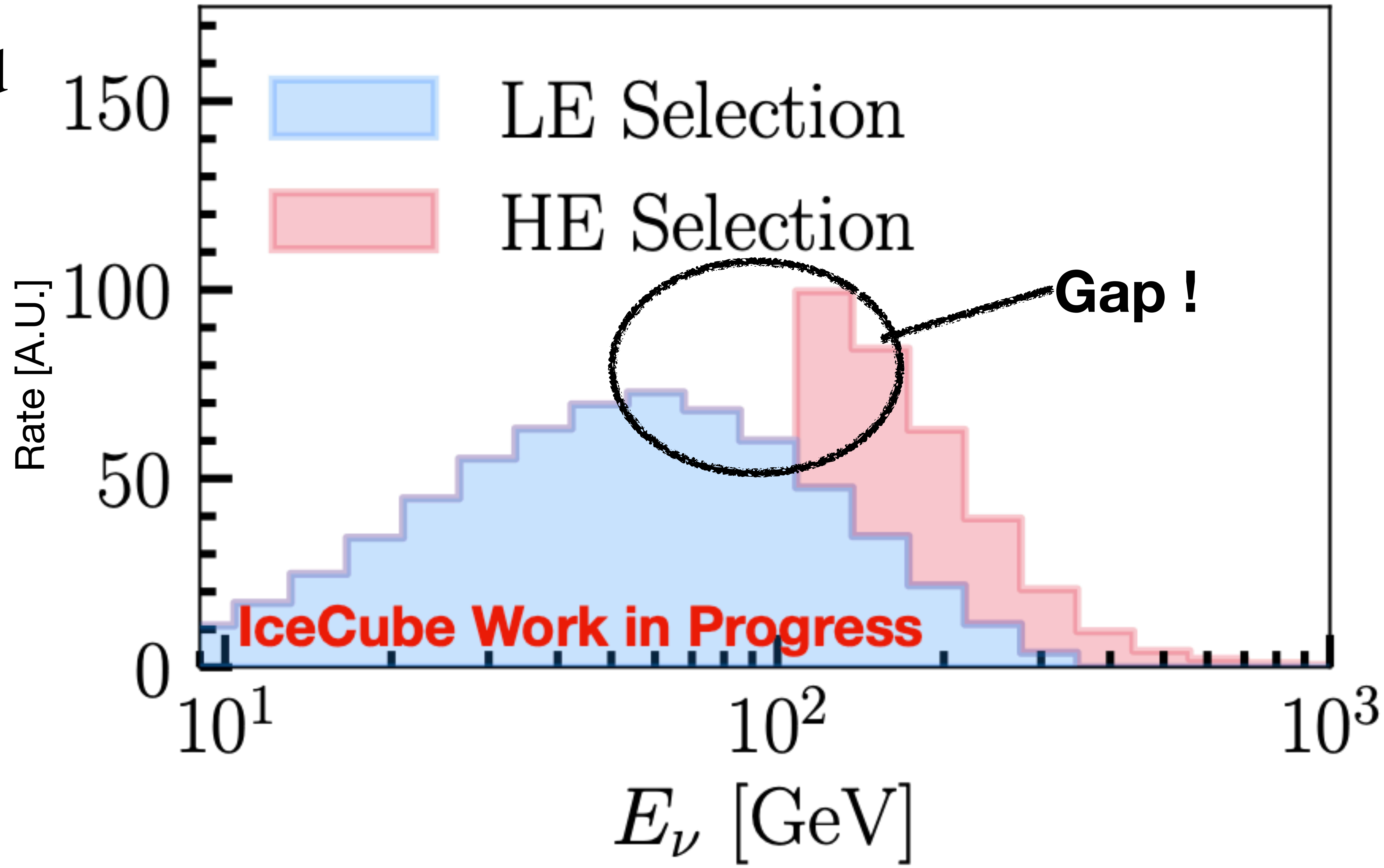
Analysis Sensitivities



- Current sensitivities with low- and high-energy selections compared to current limits
- World-leading sensitivities over range from 10 GeV to 10 TeV: **<u>factor of 40 improvement in $b\bar{b}$</u>**
- Large improvement in high-mass hadronic channels due to new EW calculation

Augmented Selection

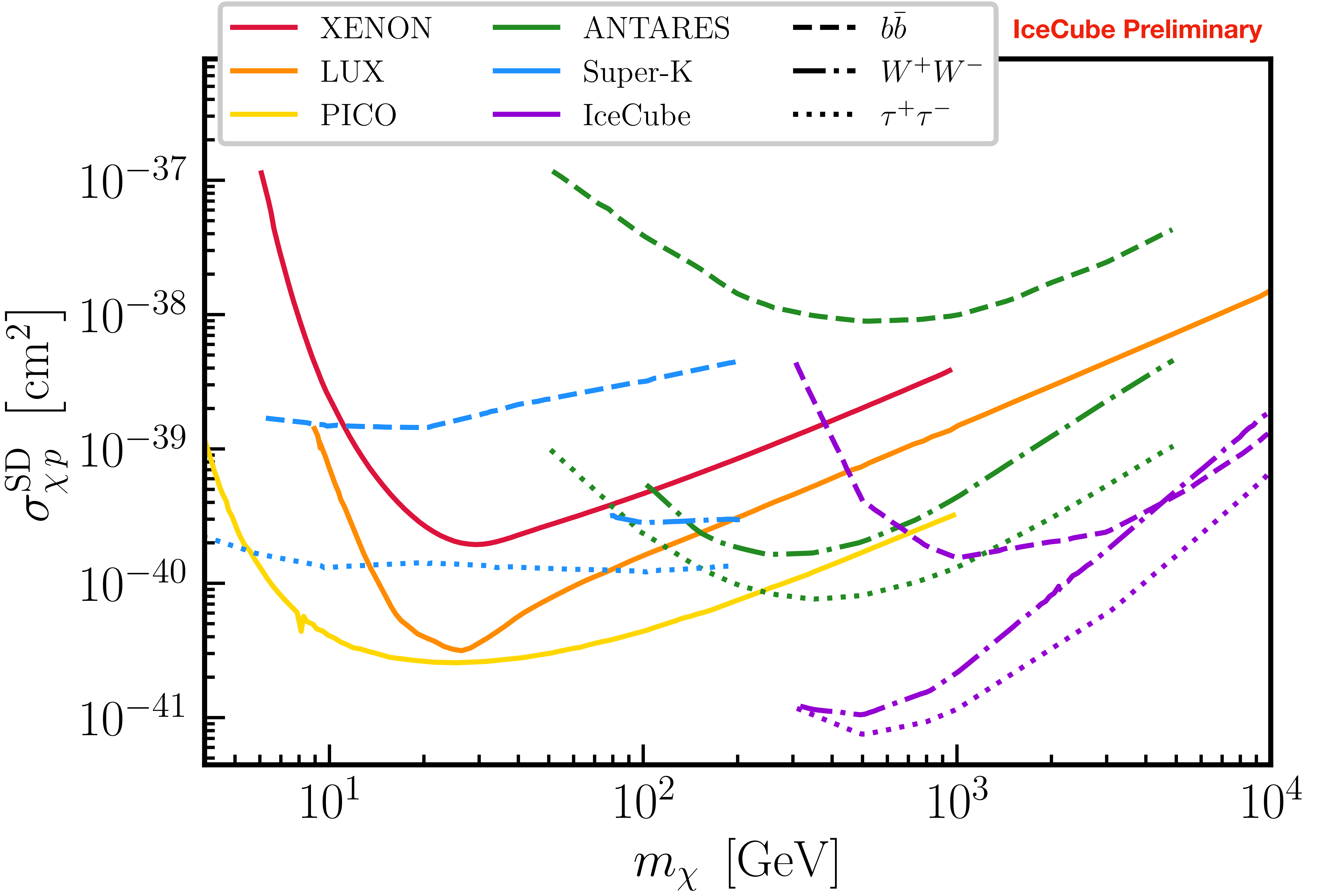
- Improve on current analysis by developing selection to target gap around 100 GeV
- Expected to fix loss of sensitivity around $m_\chi = 100$ GeV



Event rate vs. true neutrino energy. Event rate in arbitrary units in low- and high-energy selections for $\chi\chi \rightarrow b\bar{b}$, $m_\chi = 500$ GeV

Summary

- New solar WIMP analysis has:
  - World-leading limits above 300 GeV
  - World-leading sensitivities over 3 order of magnitude
- Improved sensitivity to ~100 GeV region in progress
- Results coming very soon



Thank you for listening

Questions ?

Backups

Bullet Cluster Information

CREDIT:	X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.
RELEASED:	August 21, 2006
SCALE:	Image is about 7.5 x 5.4 arcmin
COORDINATES (J2000):	RA 06h 58m 37.9s Dec -55° 57' 00.00"
CONSTELLATIONS:	Carina
OBSERVATION DATE:	2004: Aug 10, 11, 14, 15, 17, 19, 24, 25
OBSERVATION TIME:	140 hours (5 days 20 hours)
COLOR CODE:	X-ray (Pink); Optical (White/Orange); Lensing Map: (Blue)
DISTANCE ESTIMATE:	About 3.8 billion light years

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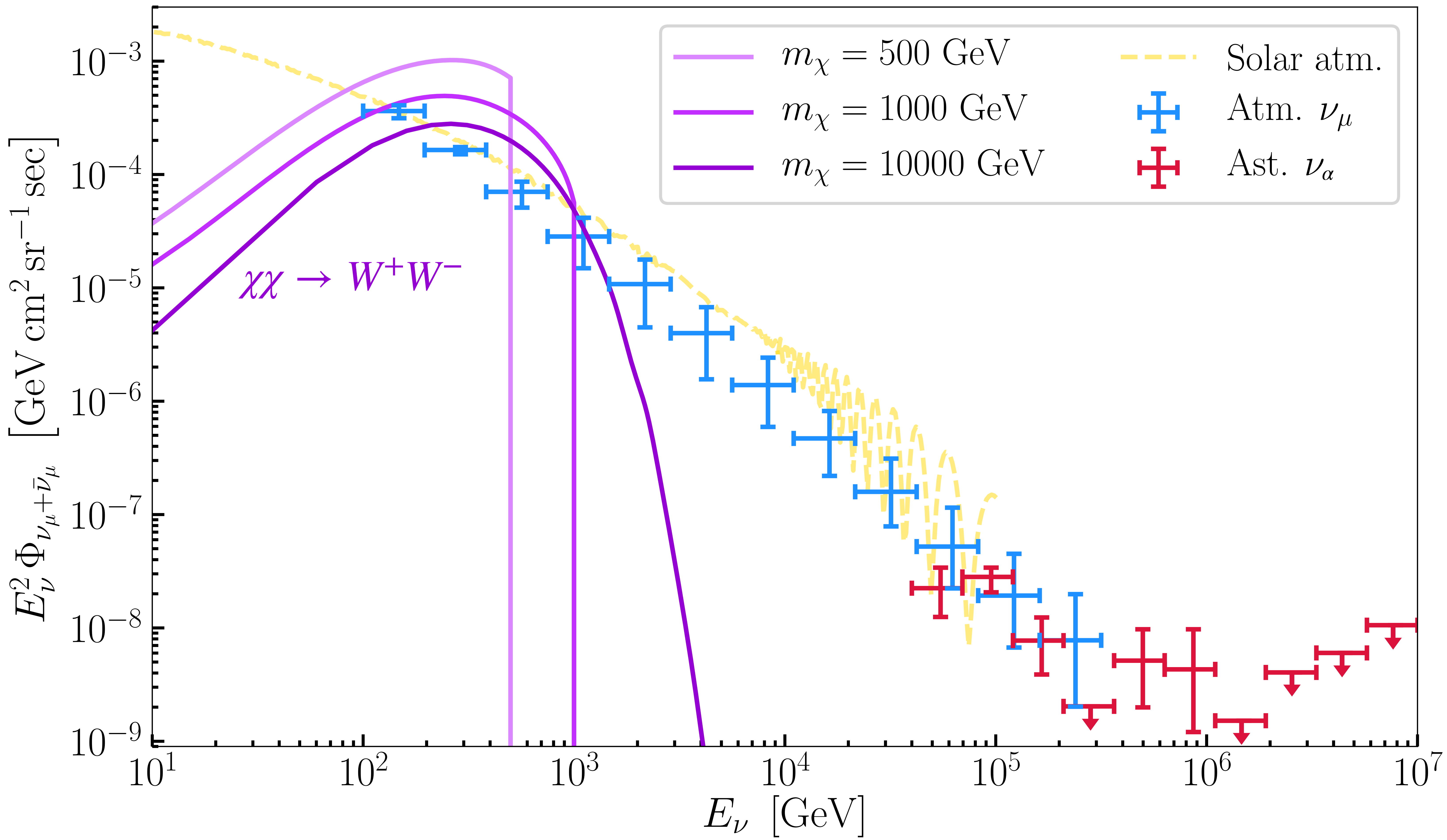
$\chi aro\nu$

- Software package for calculating neutrino yields from DM annihilation/decay [1]
- Couples PYTHIA8 to an updated calculation of EW correction (BRW calculation) [2]
- Flexible python-based package allows for easy implementation of systematics and new fluxes
- See contribution 1141 for by Qinrui Liu more details on this work
- Source code at https://github.com/icecube/charon

[1] **Q. Liu, JL, C. A. Argüelles, A. Kheirandish**: JCAP (2020)
[2] C. W. Bauer, N. L. Rodd, B. R. Webber: JHEP (2020)

Backgrounds to this Analysis

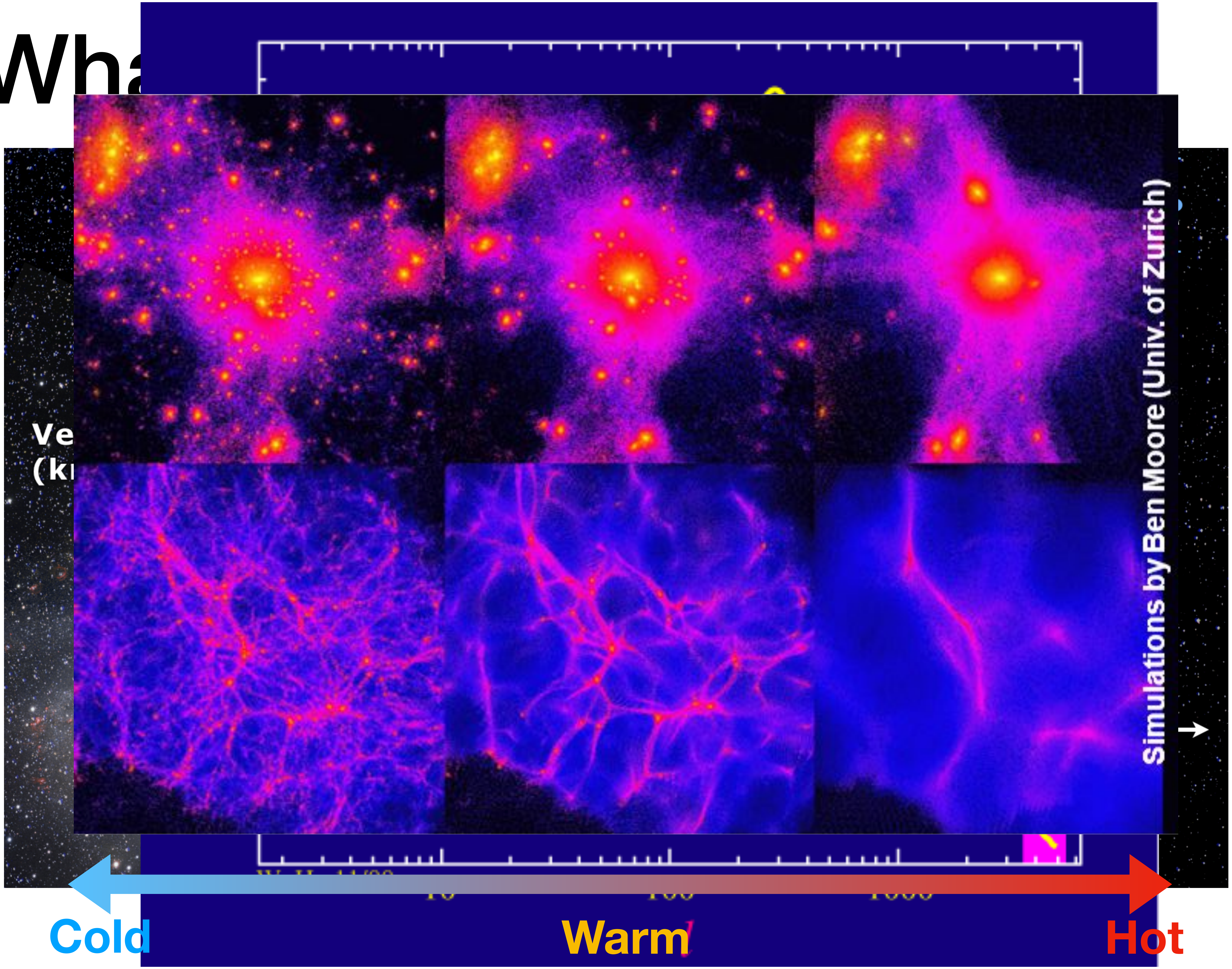


R. Abbasi, *et al.*: PRD (2020)
T. Kajita: Adv. High Energy Phys. (2012)

- Backgrounds well-understood in direction of Sun
- Sun opaque to neutrinos above $E_\nu = 3$ TeV.
- Relevant backgrounds:
  - Atmospheric neutrinos
  - Atmospheric muons
  - Solar atmospheric neutrinos

Dark Matter: Wha

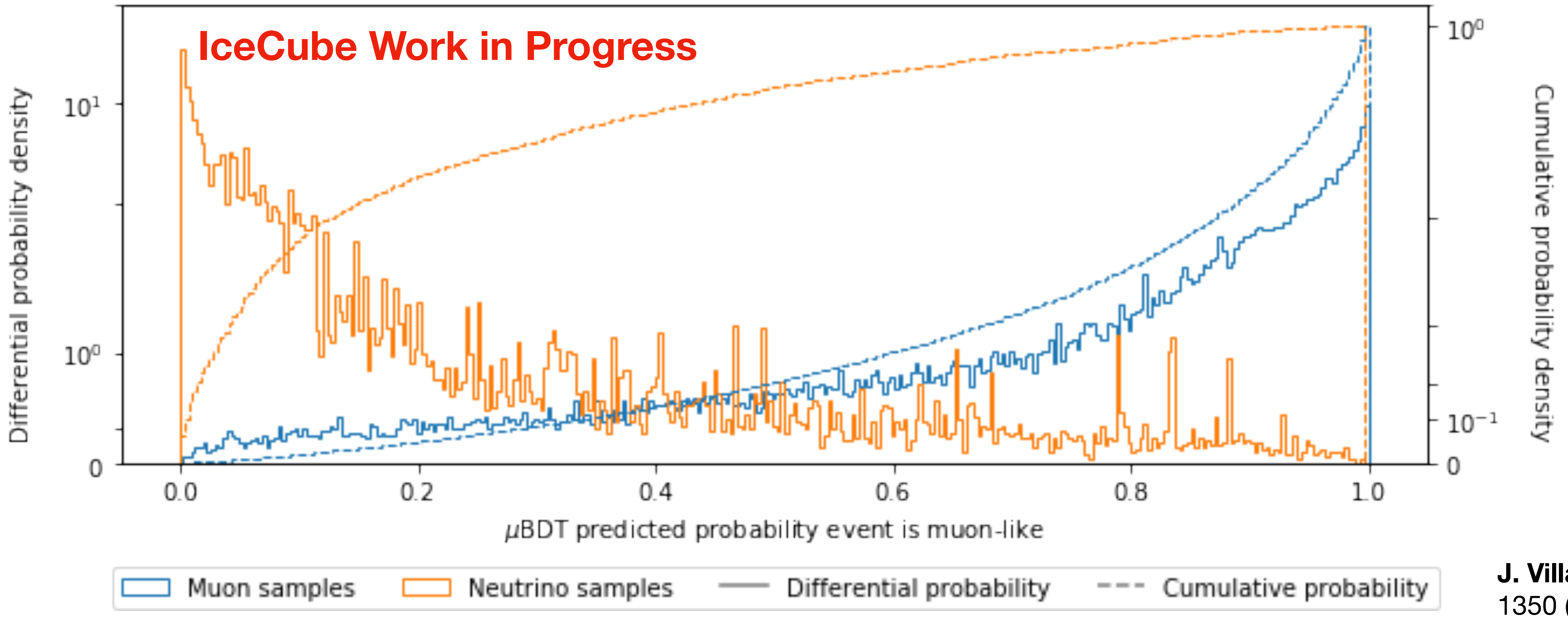
- Evidence from numerous length scales
- Must be ‘cold,’ *i.e.* non-relativistic
- Many candidates put forward but no evidence yet



Gif courtesy of Wayne Hu

Towards a Medium-Energy Selection

- Developing an event selection to bridge low- and high-energy regimes
- Three-stage approach:
  ✓ Target mid-energy events with filter designed for previous solar WIMP search
  ✓ Filter out atmospheric muons with a branched decision tree (BDT)
  ➡ Differentiate signal and background neutrinos with another BDT



J. Villarreal, G. Roellinghoff, JL: ICRC PoS 1350 (2021)