Dark Matter Searches with the IceCube Neutrino Observatory

Jeff Lazar on behalf of IceCube
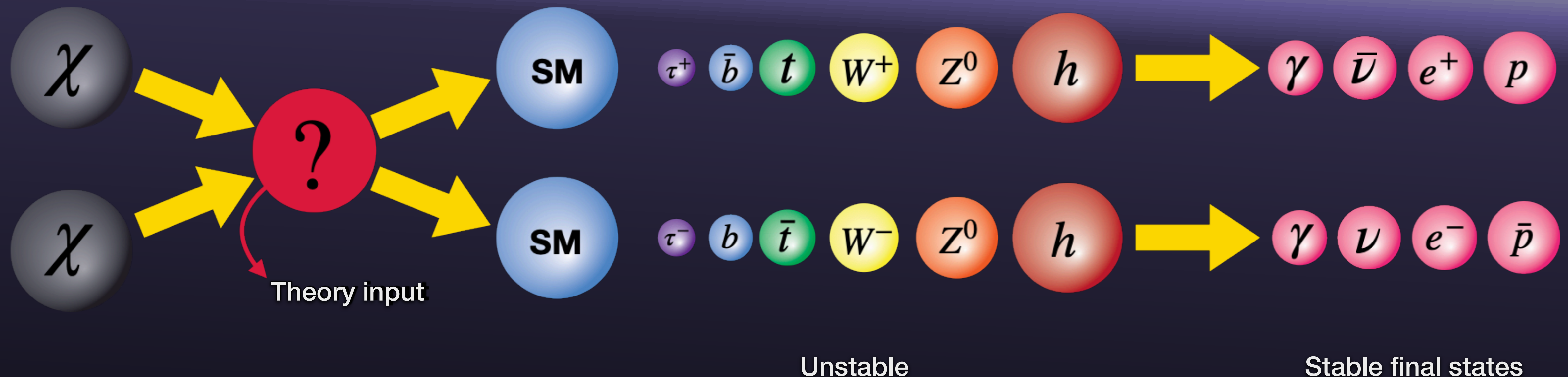European Physical Society Conference on High Energy 2021
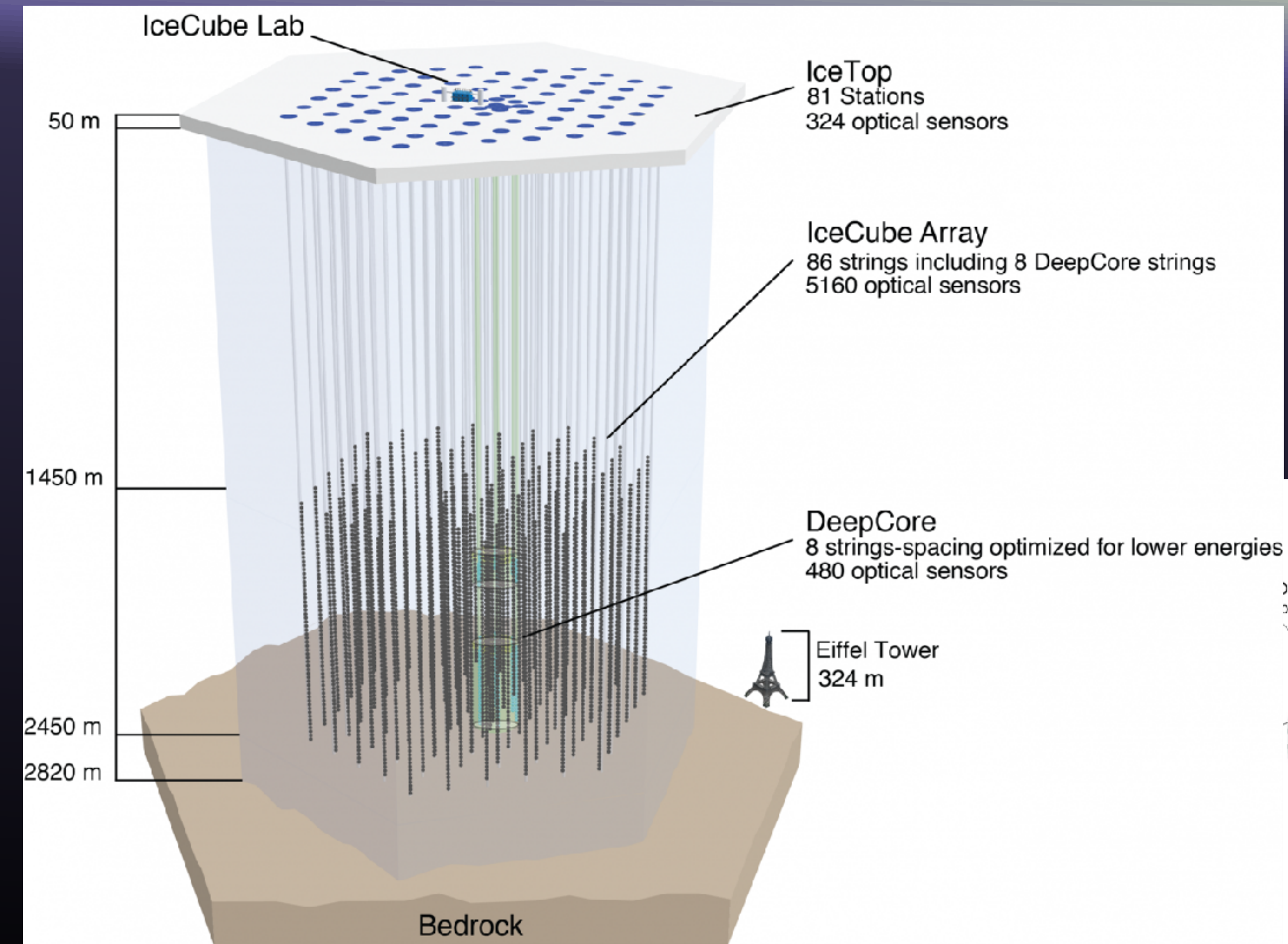28 Jul., 2021

Dark Matter Detection

- <u>Indirect detection</u>: Searches for stable SM particles as evidence of DM
- Neutrinos can escape dense astrophysical environments
- Look to places where dark matter should accumulate
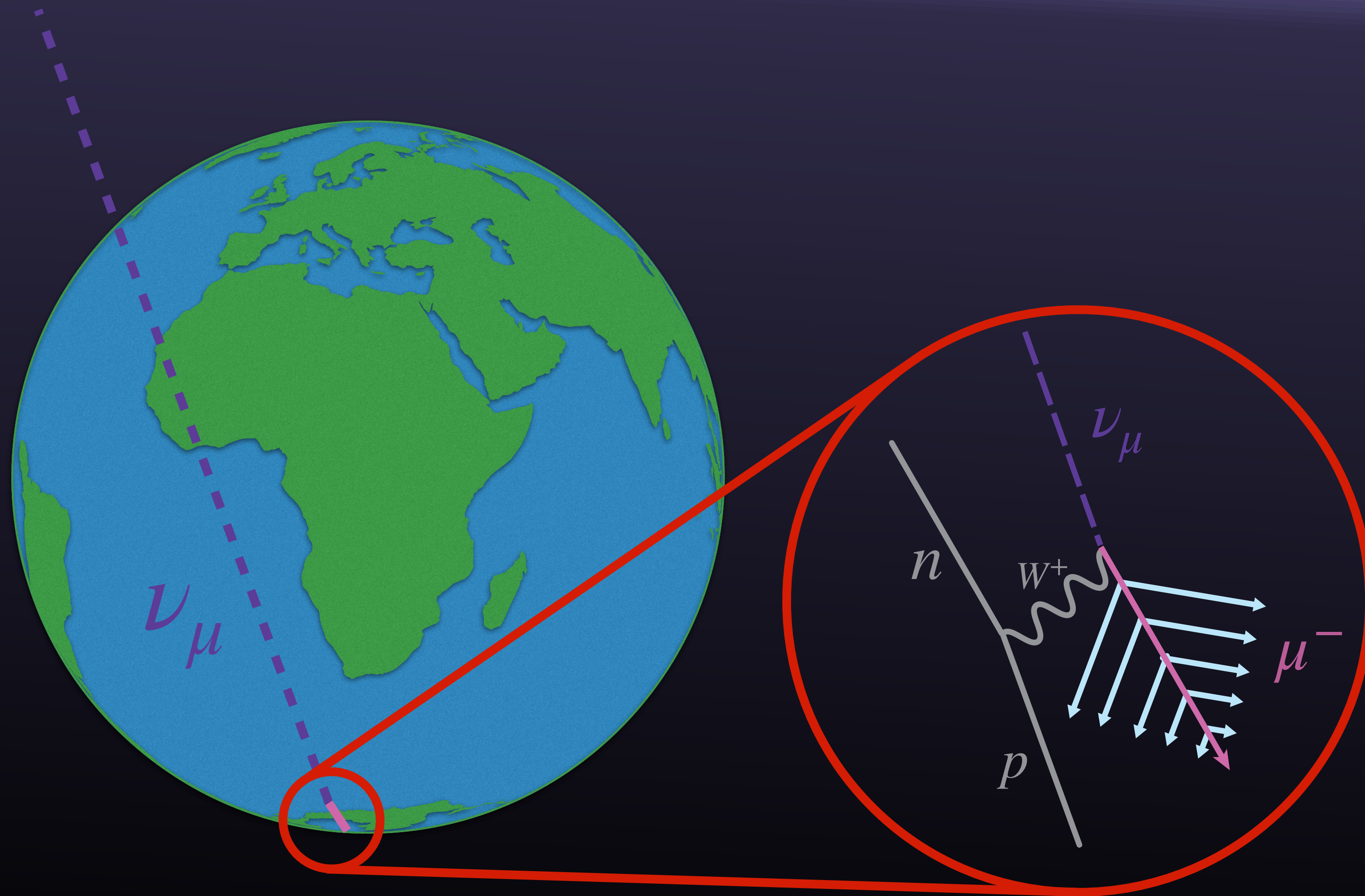
IceCube Observatory

- 1 km^3 of Antarctic ice instrumented with 5,160 light-detecting sensors (DOMs)
- Look for Cherenkov 'footprint' of neutrinos which interact in or around the detector
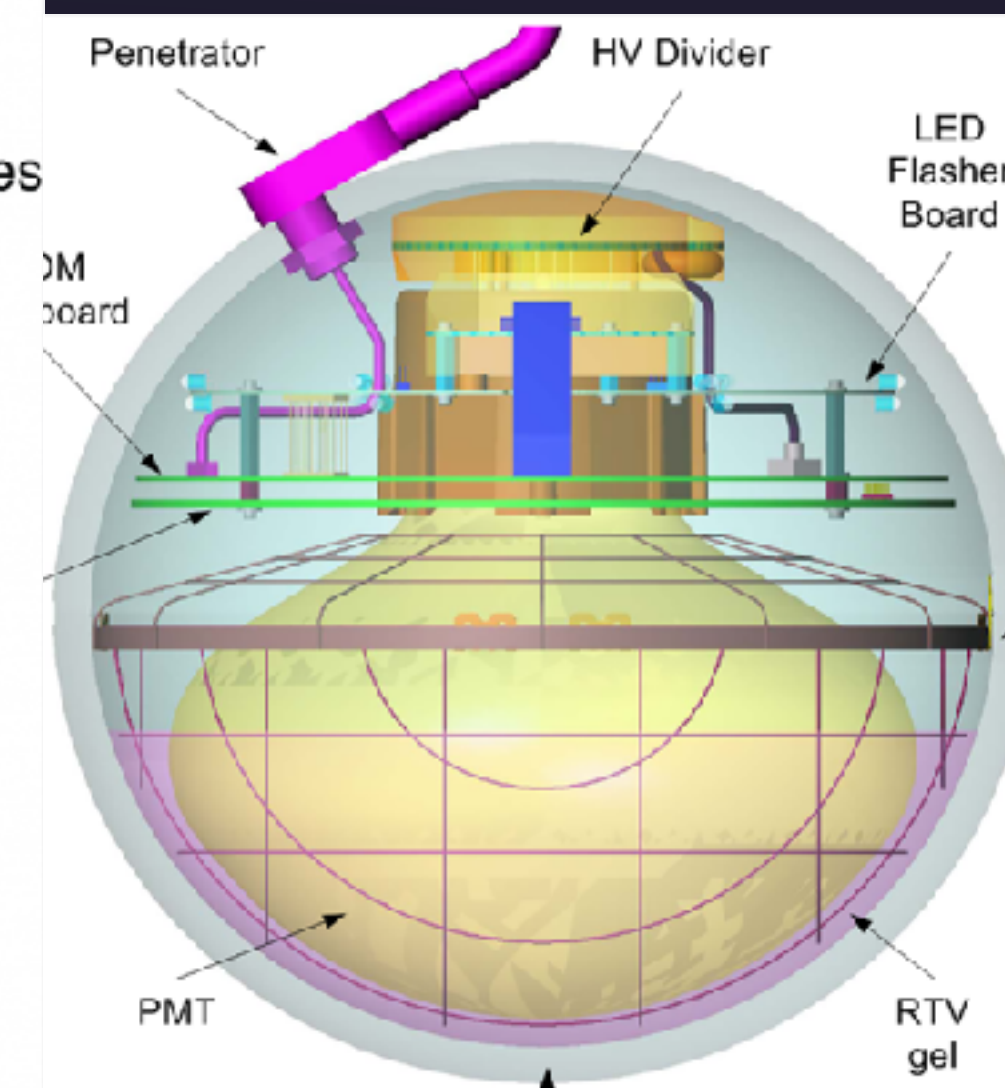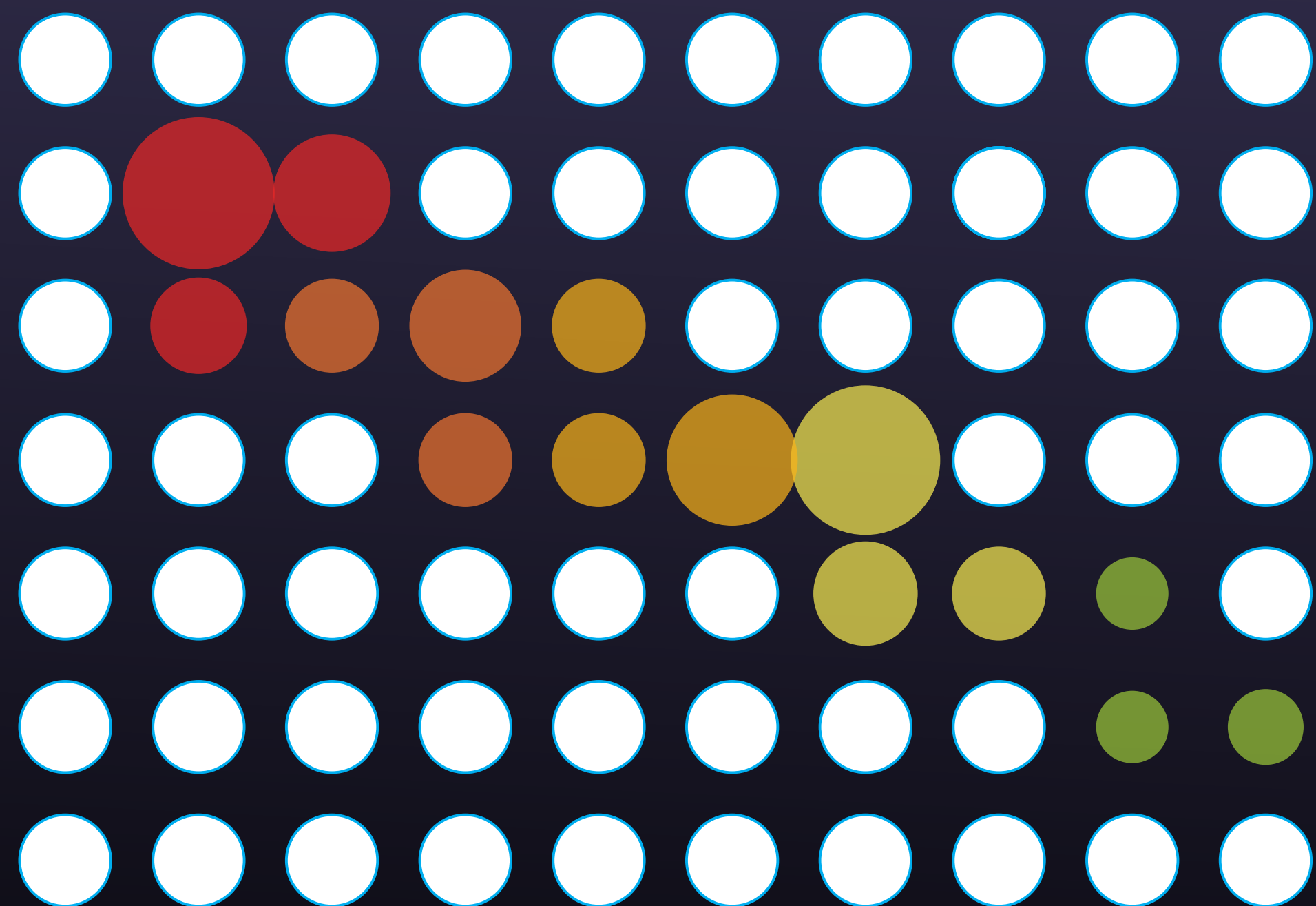
Detection Principle

- Detect Cherenkov light produced by charged byproducts of neutrino interactions
- Charged lepton nearly collinear with incident neutrino

A Bump, a Dip, or an Anisotropy

Track

Cascade

$$\nu_\mu \, \mathrm{CC}$$

<1° above 1 TeV
Factor of 2 energy resolution

$$\nu_e \, \mathrm{CC} \,|\, \nu_\ell \, \mathrm{NC}$$

~15°
15% if contained

- Reconstruct <u>direction</u> using timing information
- Reconstruct <u>energy</u> based on amount of light
- Infer <u>flavor</u> from event morphology
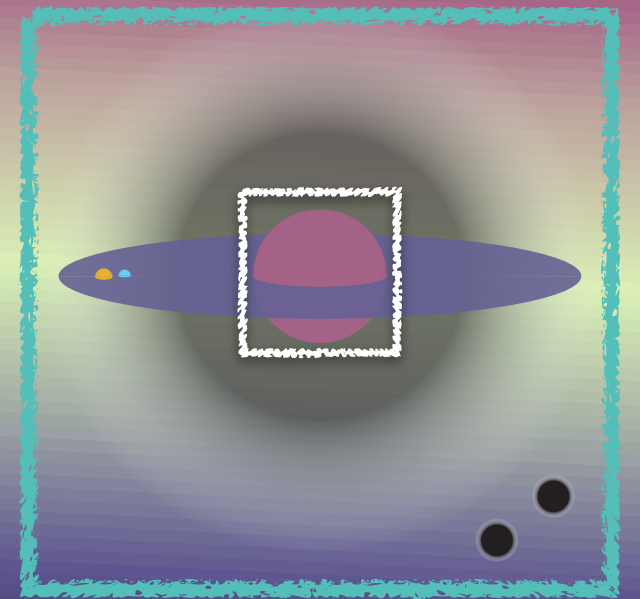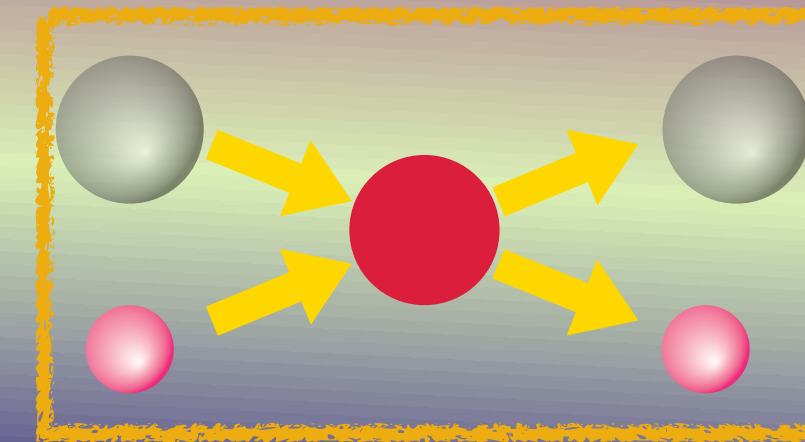- Unexpected excesses, deficits, or anisotropies may be evidence of DM

Where to Look

Solar system

Galactic Center (GC)

Nearby galaxies

Dark matter
Halo
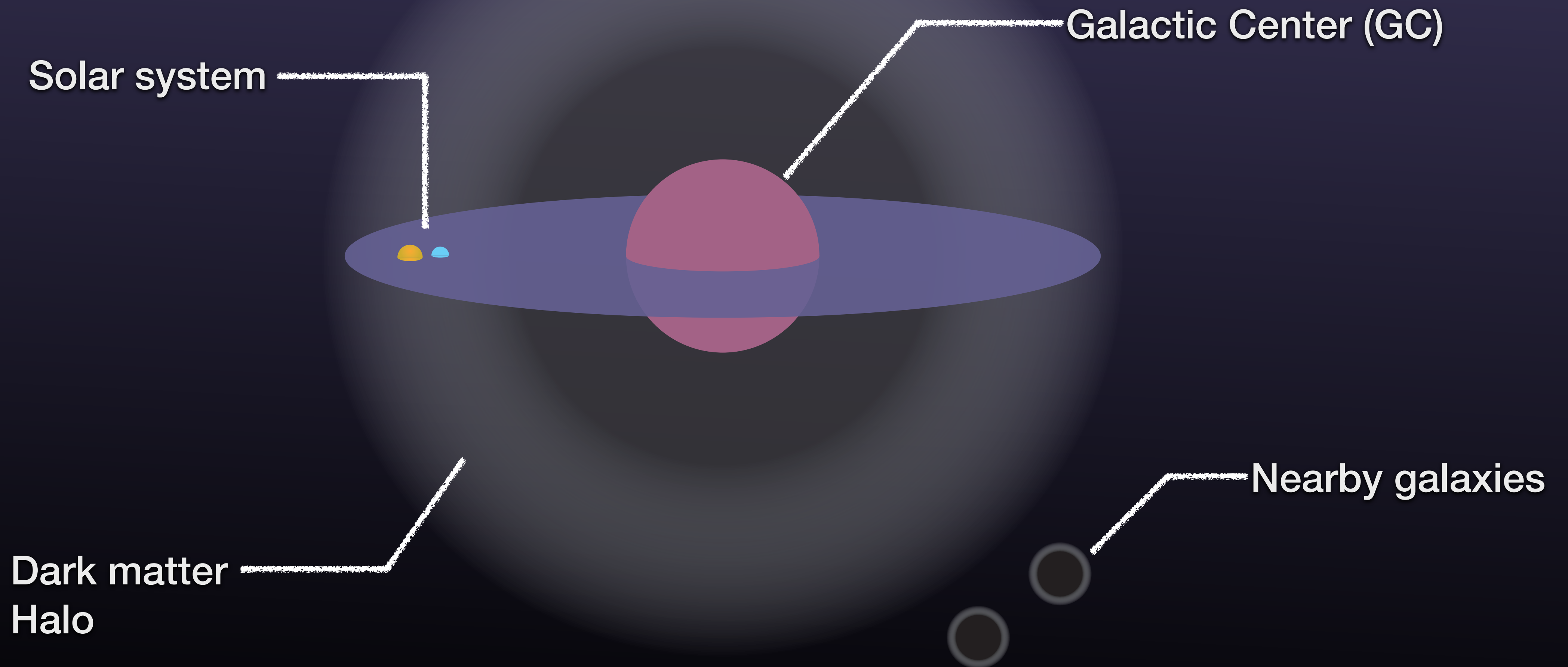
Notation for this Talk

Schematics in top-right corner tell which process gives rise to this signal and where we can look for this symbol

We look for this process from the GC

DM scattering off SM particles gives rise to this process

Neutrino-DM Scattering

- Neutrino-DM scattering present in scotogenic neutrino mass models

- These scatterings create a deficit of neutrinos from the direction of the GC predicted in [1]

- First analysis of this kind showed sensitivities at ICRC 2021

Equatorial — $E_\nu = 10^5$ GeV — Galactic Center — Survival Probability
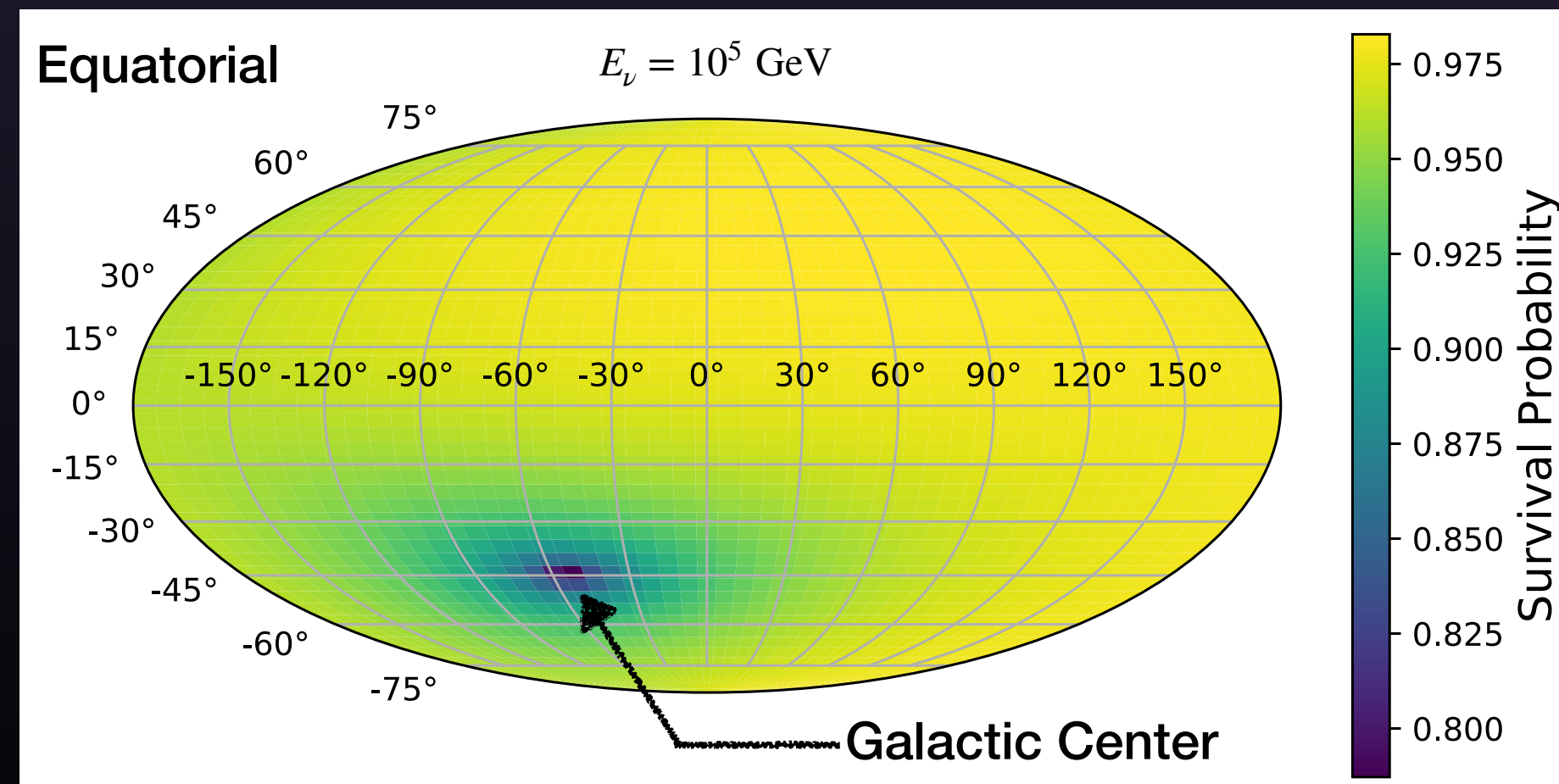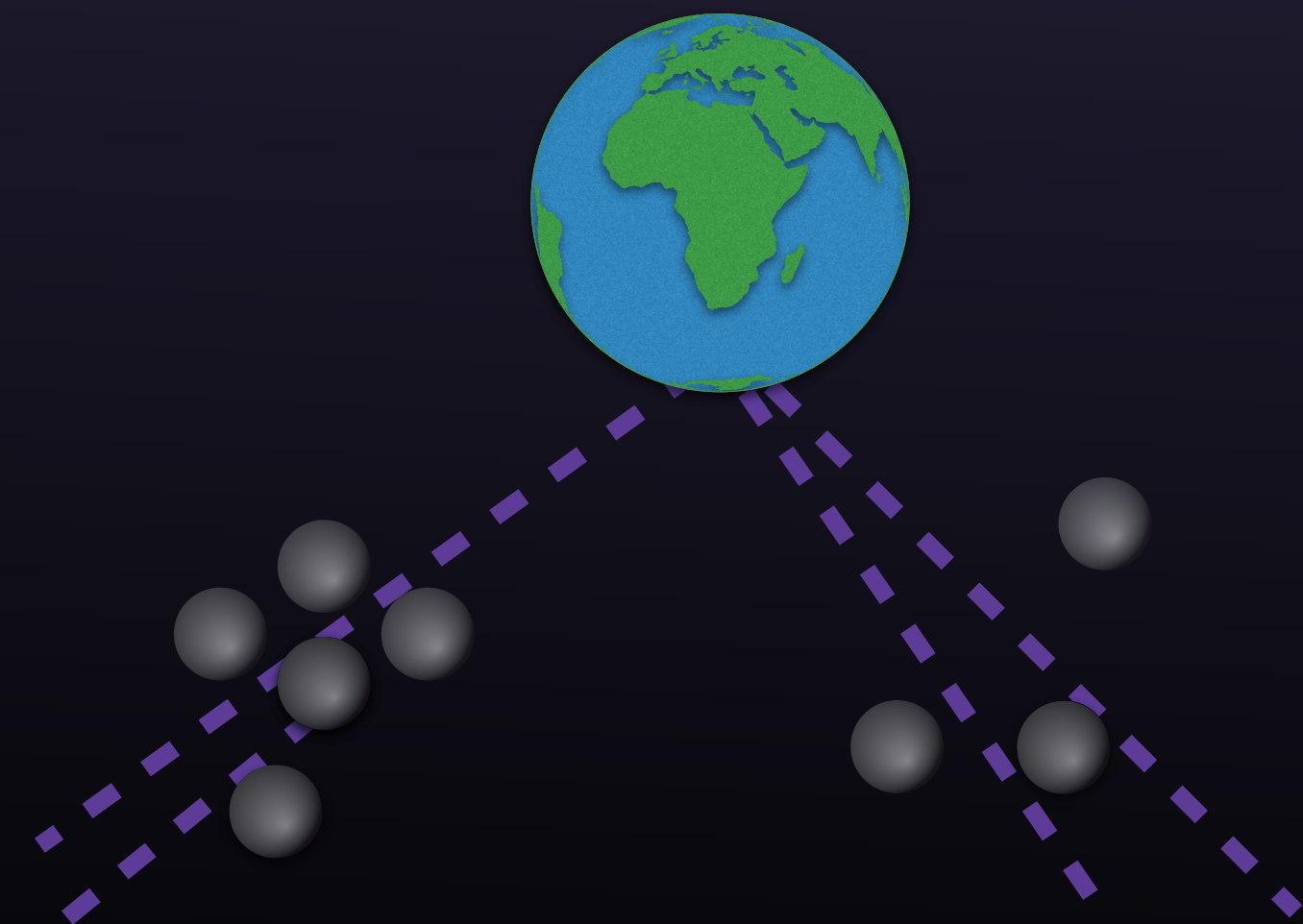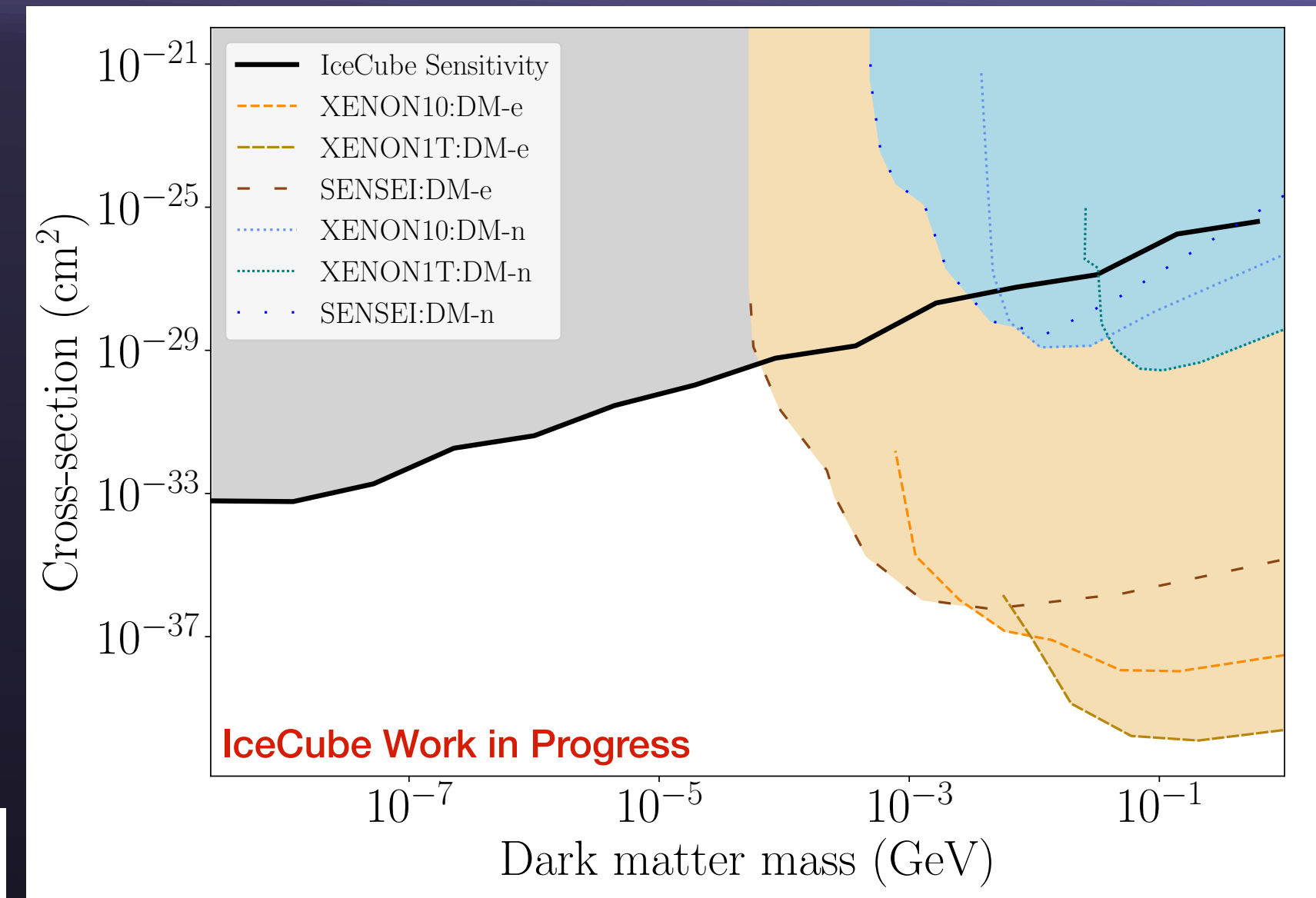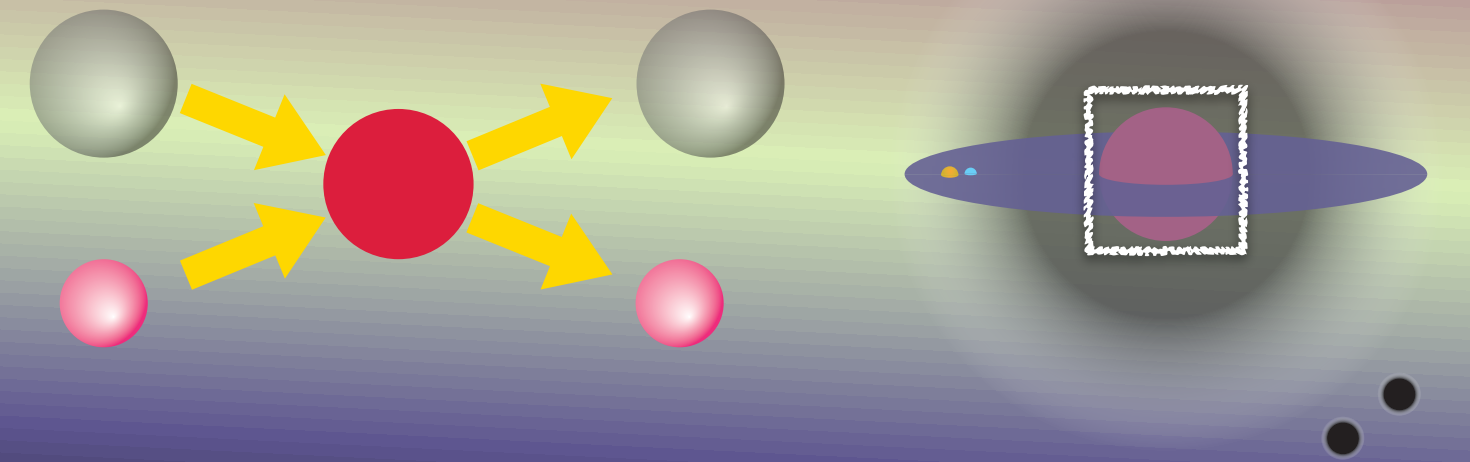
[1] C. A. Argüelles, A. Kheirandish, and A. C. Vincent:
DOI 10.1103/PhysRevLett.119.201801

Dark Matter Decay

- DM may decay if it's lifetime is greater than the age of the Universe

- Decay to SM particles will generically create an excess of neutrinos and gamma rays

- Complementary channels: good angular resolution from tracks and energy resolution from cascades

Tracks: 2,060 days
Cascades: 278 days
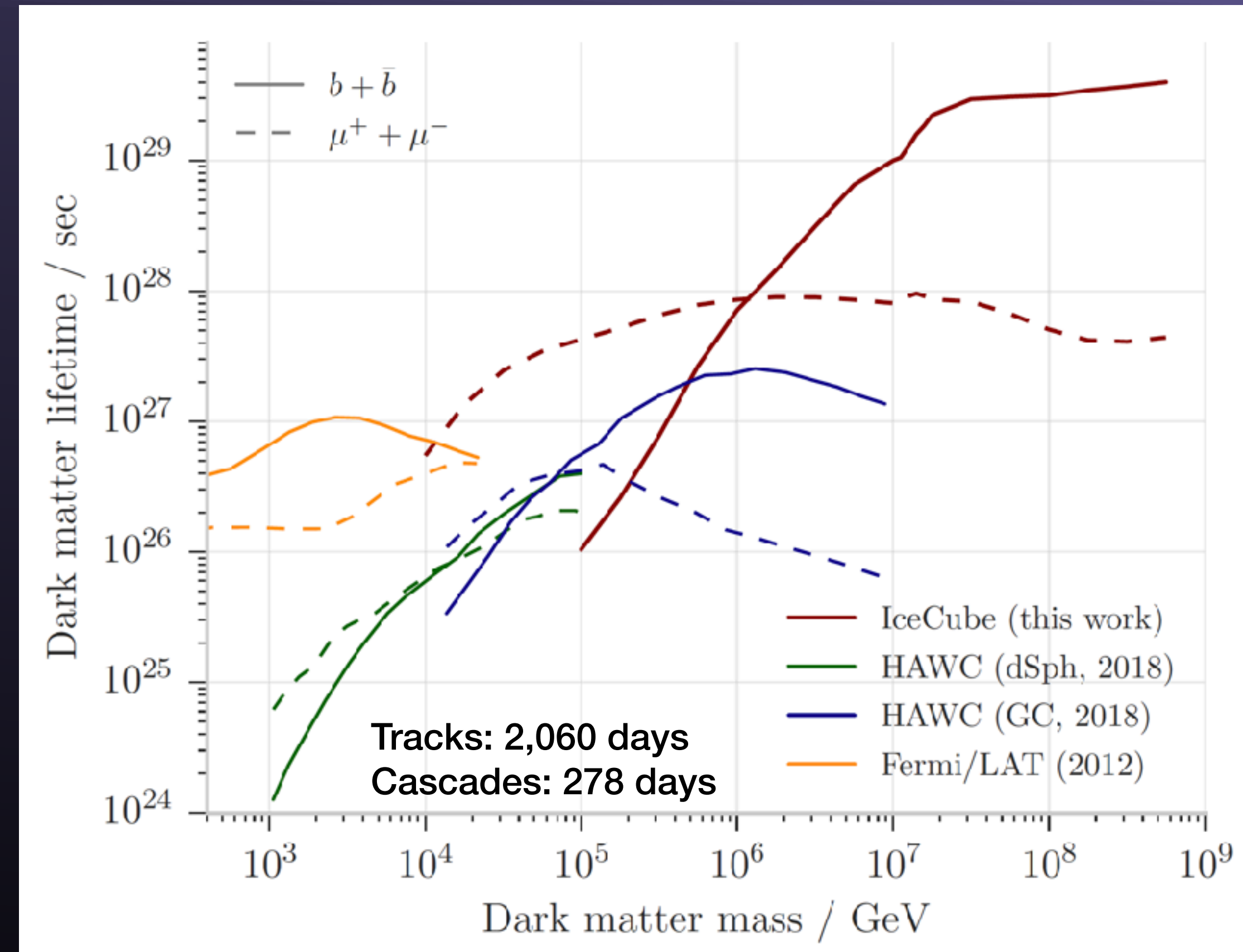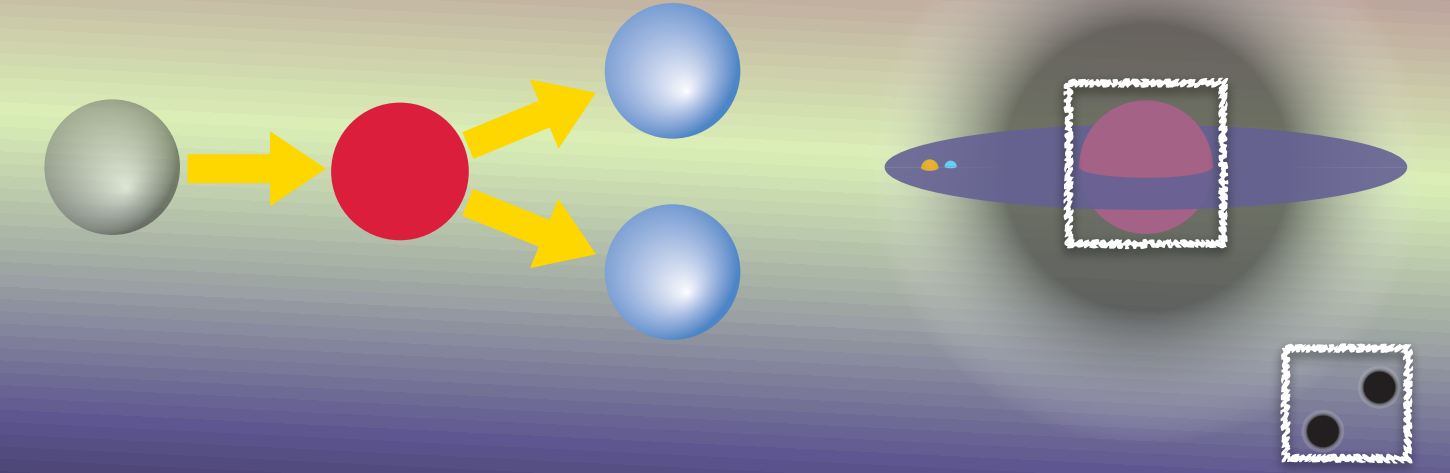
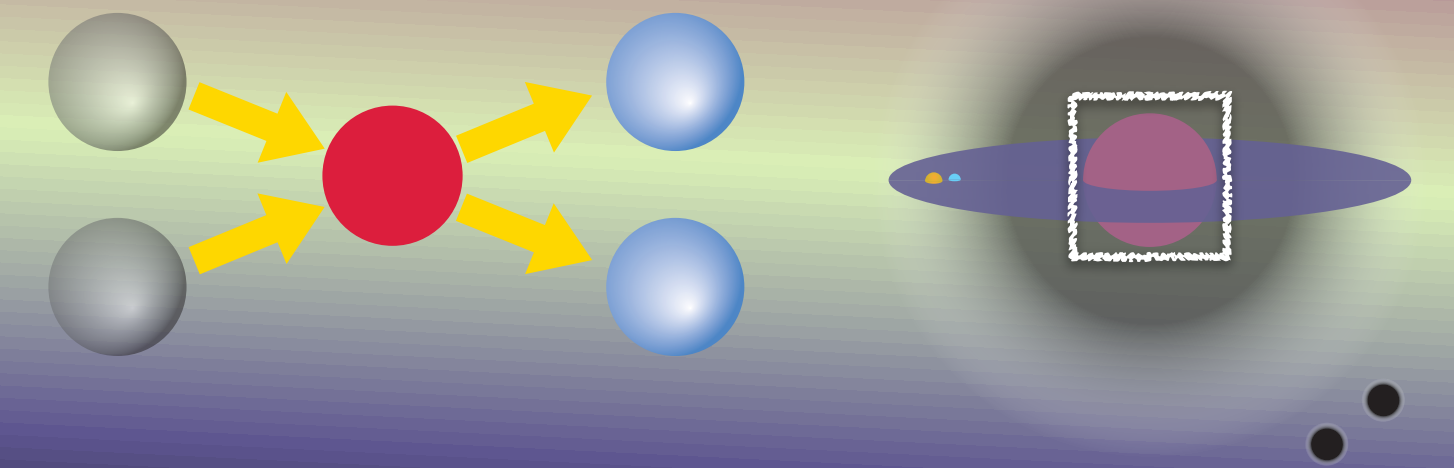M. G. Aarsten, *et al*.: DOI 10.1140/epjc/s10052-018-6273-3
A. U. Abeysekara, *et al*.: DOI 10.1088/1475-7516/2018/02/049
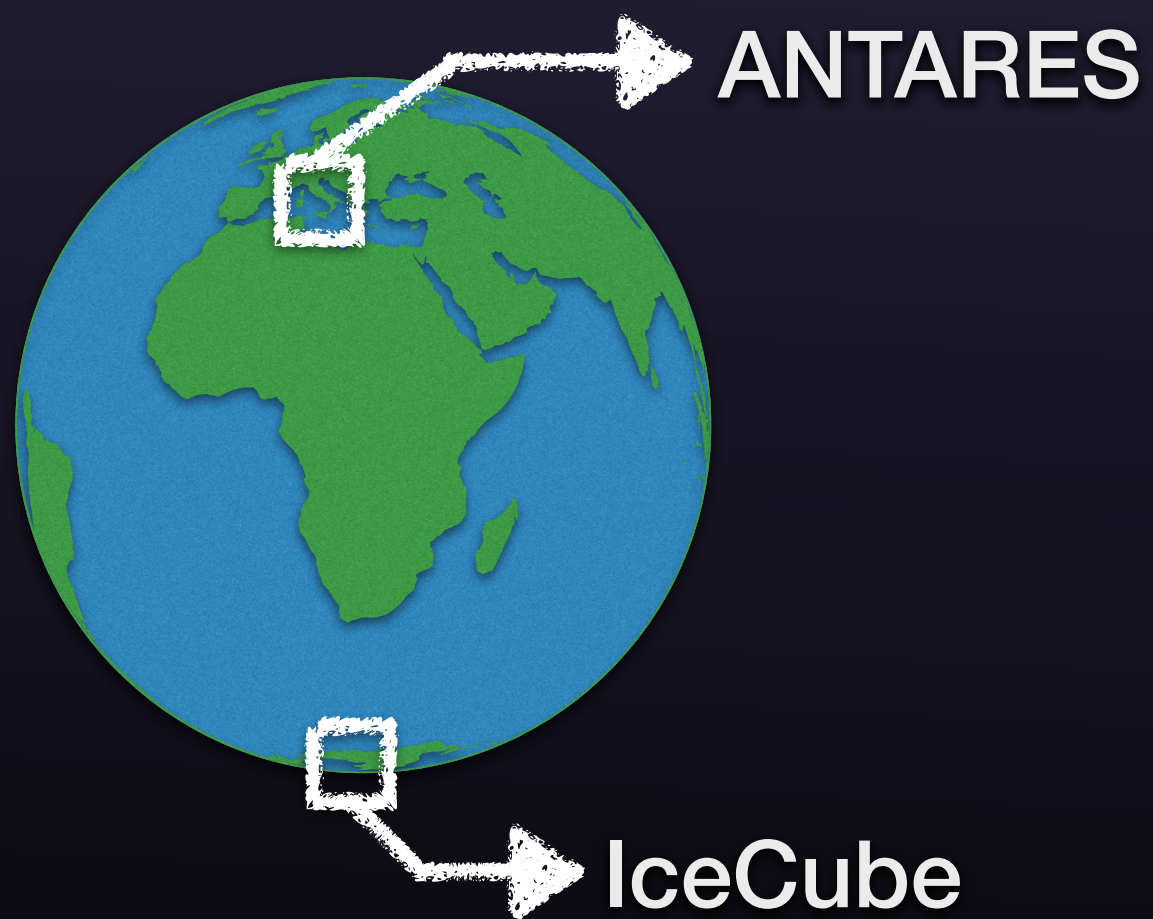A. Albert, *et al*.: DOI 10.3847/1538-4357/aaa6d8
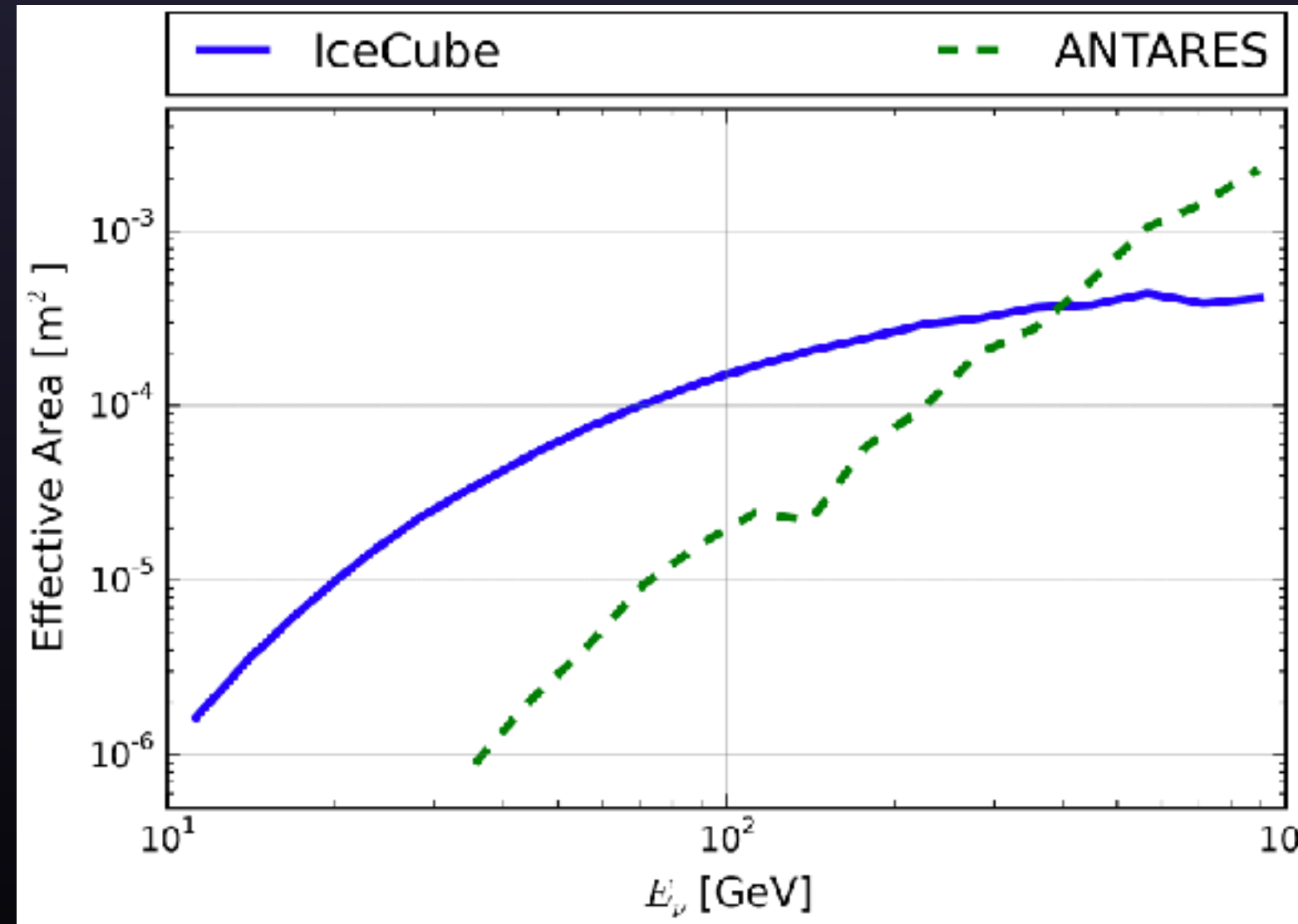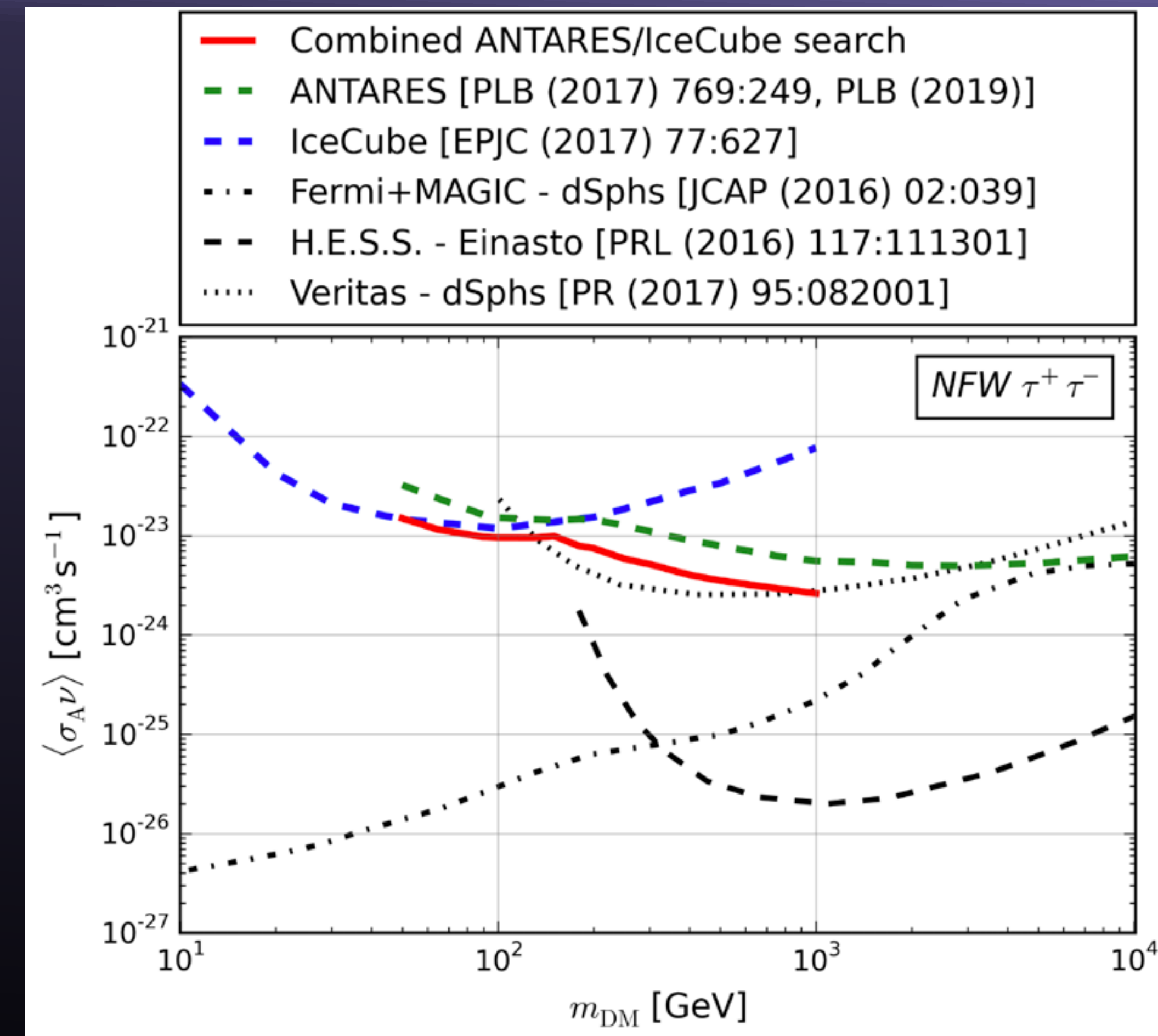M. Ackermann, *et al*.: DOI 10.1088/0004-637X/761/2/91

ANTARES Combined Analysis

- Southern sky is muon dominated for IceCube→outer detector used as a veto, smaller fiducial volume

- ANTARES can use Earth as a shield

ANTARES

IceCube

GC

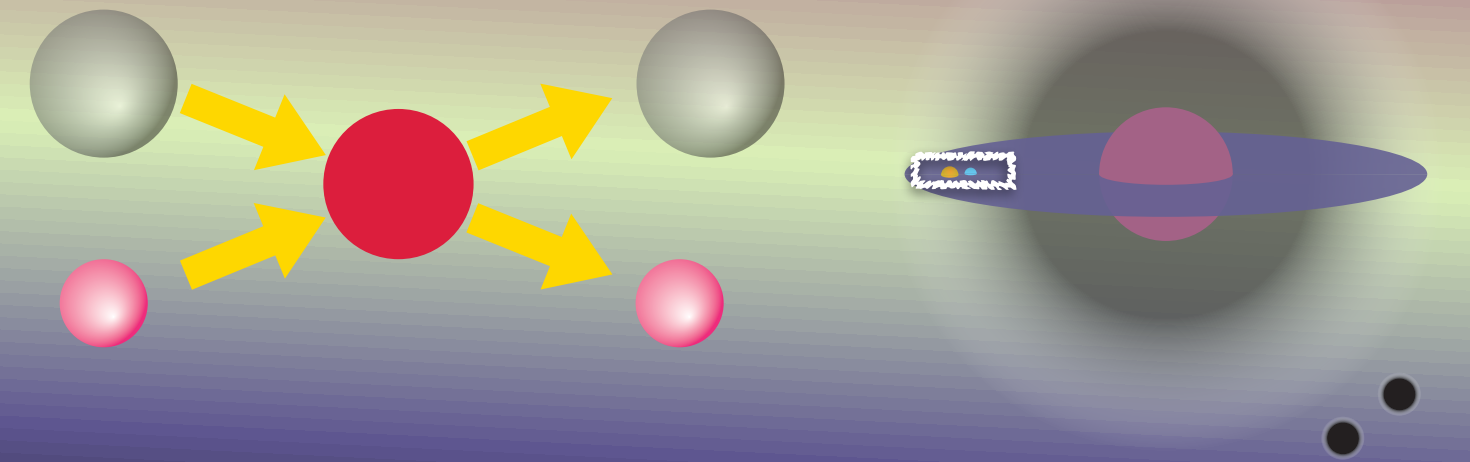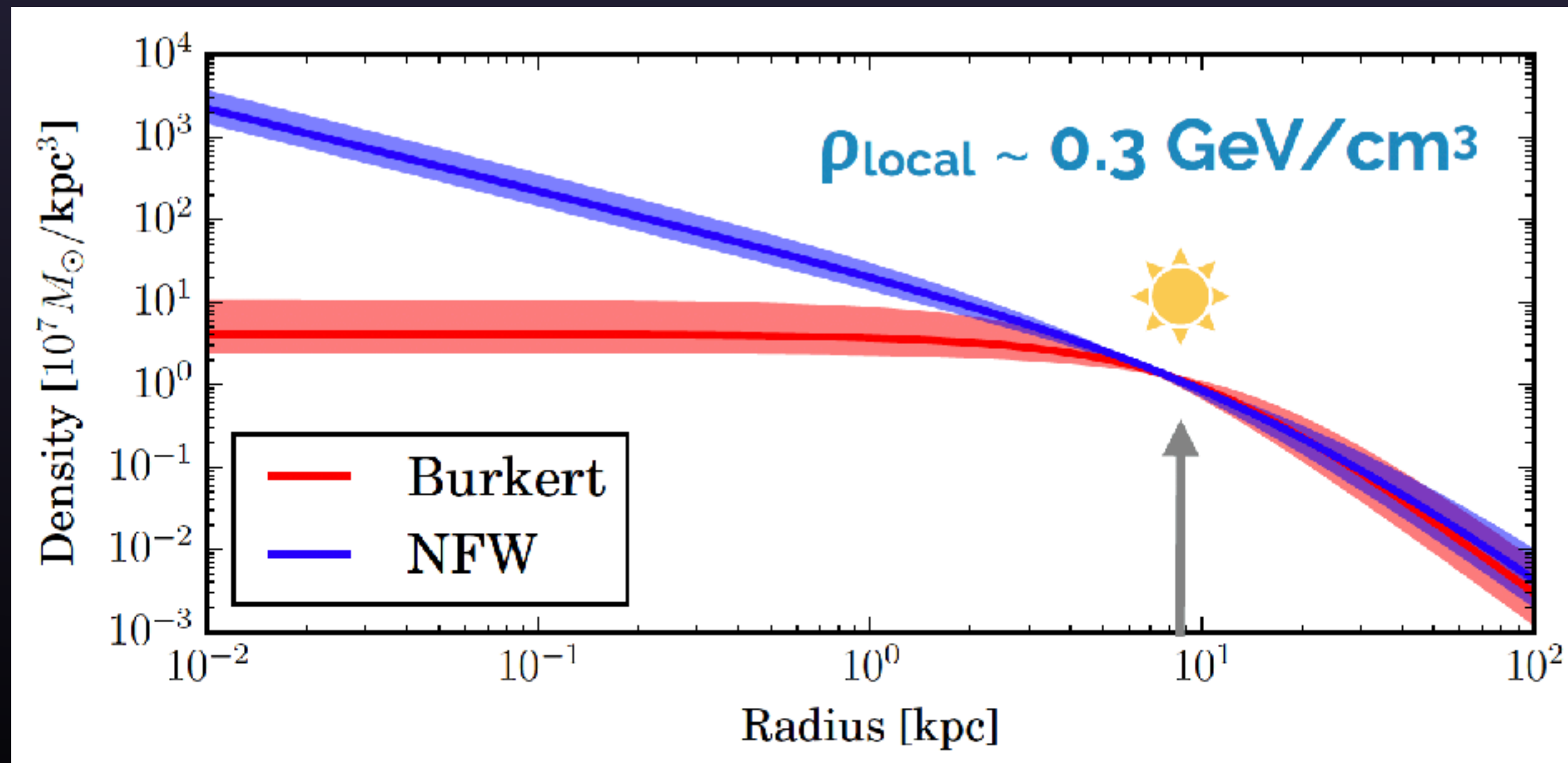A. Albert, et al.: DOI 10.1103/PhysRevD.102.082002

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Local Sources

- DM may be captured after scattering off nuclei

- Local backgrounds very well known→smoking gun signature

- Halo models agree on DM density locally

- Sensitive to DM-nucleon cross section, not $\langle v\sigma \rangle$

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

Capture rate $\propto \sigma_{\chi N}$

Annihilation rate sets signal rate

Evaporation rate should be negligible

$\rho_{local} \sim$ **0.3 GeV/cm³**

Terrestrial Capture

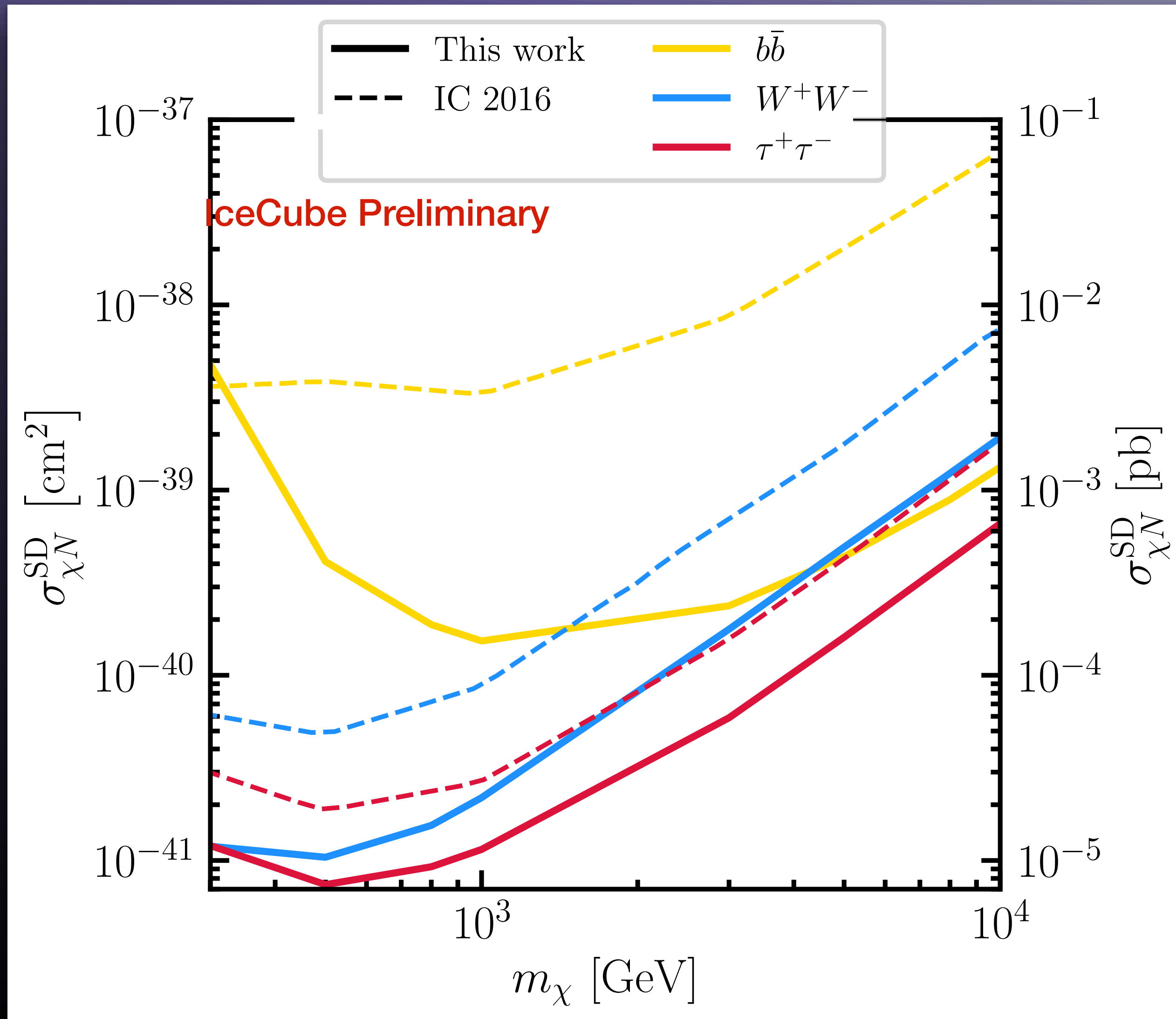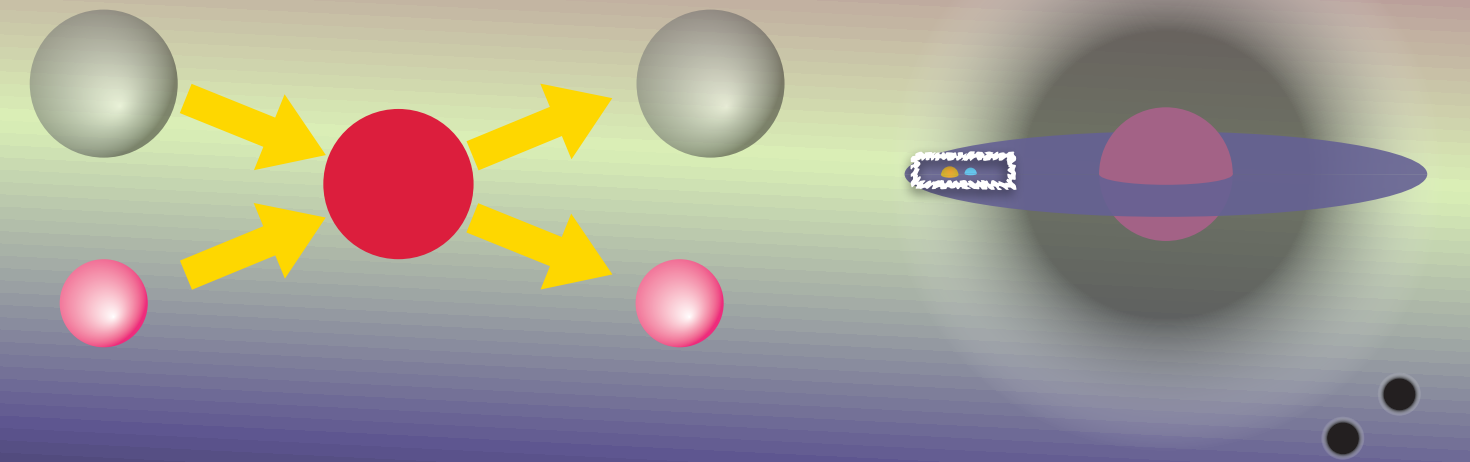- Not in equilibrium→set $\langle v\sigma \rangle$ to that predicted by thermal relic abundance
- Especially sensitive to spin-dependent cross section
- New analysis currently extending these results with more data and improved techniques—cite Giovanni's contribution
- Current sensitivities predict order of magnitude improvement in for certain regions
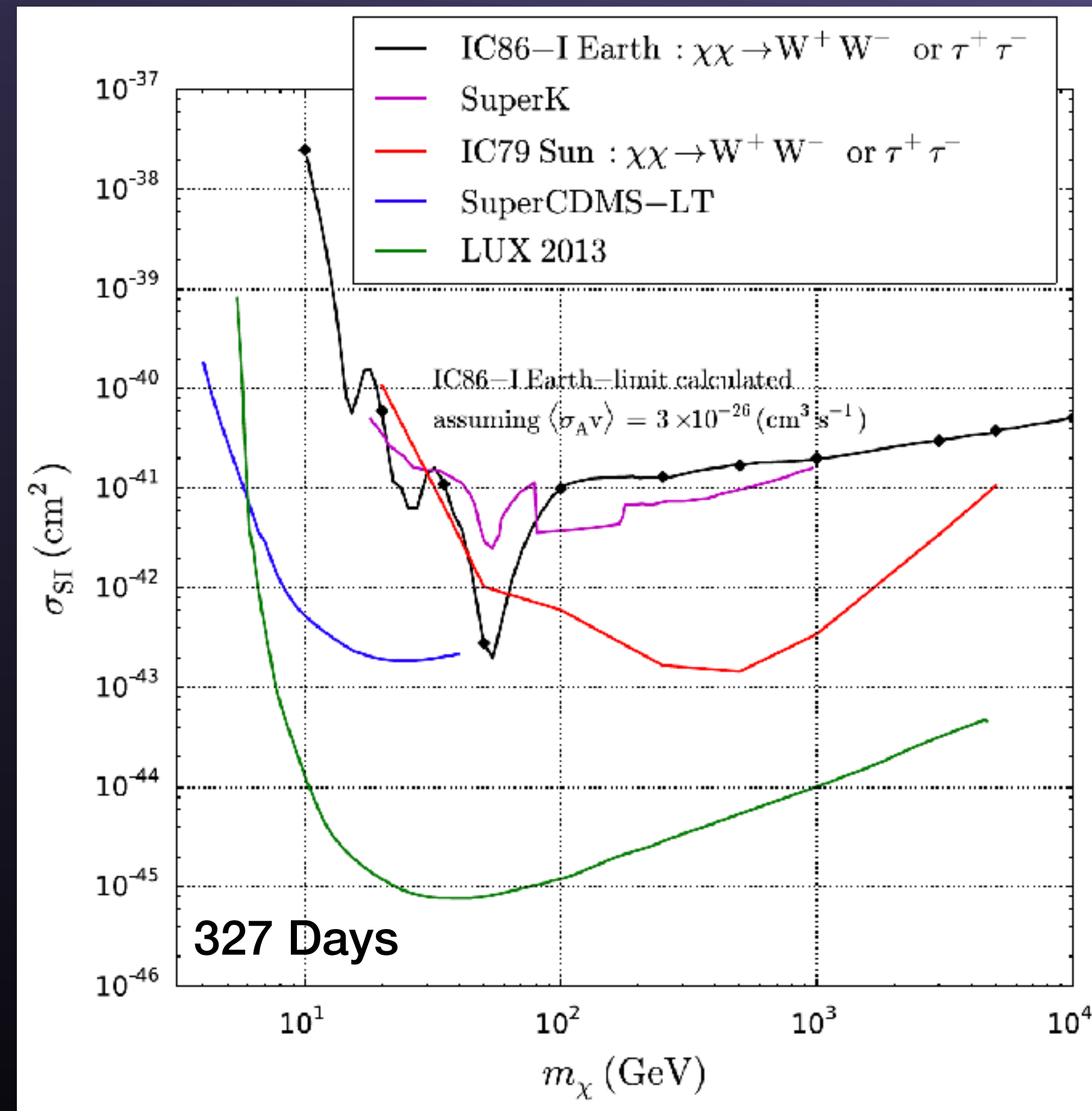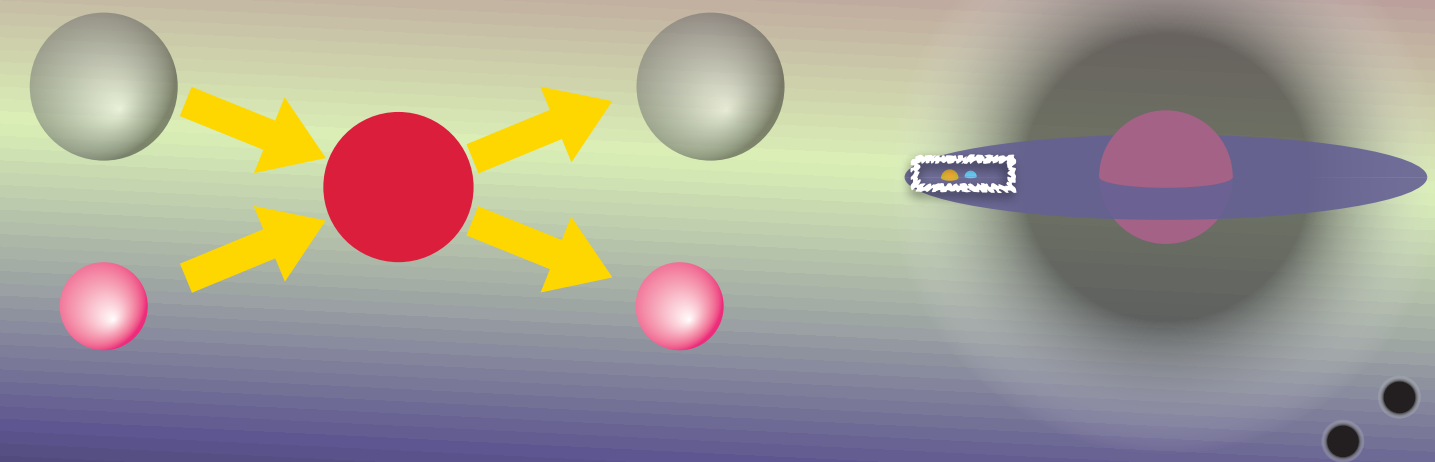
M. G. Aarsten, et al.: DOI 10.1140/epjc/s10052-016-4582-y

Solar Capture: New Result !

IceCube Preliminary

Legend:
- **This work** (solid line)
- **IC 2016** (dashed line)
- $b\bar{b}$ (yellow)
- W^+W^- (blue)
- $\tau^+\tau^-$ (red)

Axes: $\sigma^{\mathrm{SD}}_{\chi N}$ [cm^2] (left), $\sigma^{\mathrm{SD}}_{\chi N}$ [pb] (right), m_χ [GeV] (bottom)

- Ensemble in equilibrium→no assumption on annihilation cross section needed
- Especially sensitive to spin-dependent cross section
- *Limits improved by 4-50x depending on DM mass and annihilation channel*

χaroν

- PPPC
- χaroν (BRW)
- χaroν (PYTHIA)
- WimpSim
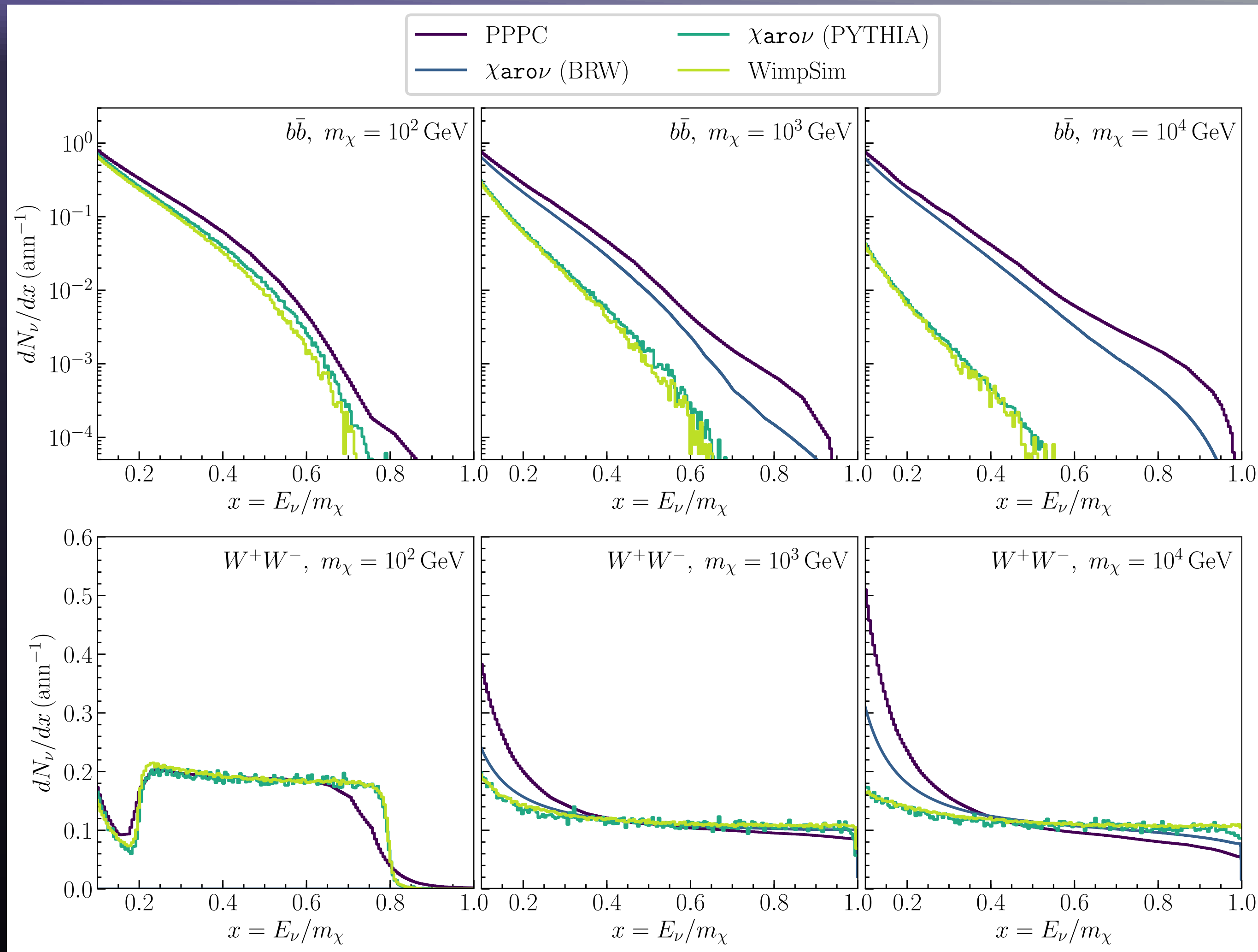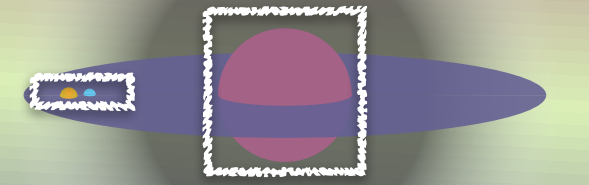
- **New software for calculating the neutrino yield from DM annihilation and decay available through IceCubeOpenSource**
- **Couples to new calculation of electroweak correction**
- **Order of magnitude increases in flux for some channels→significantly stronger limits**
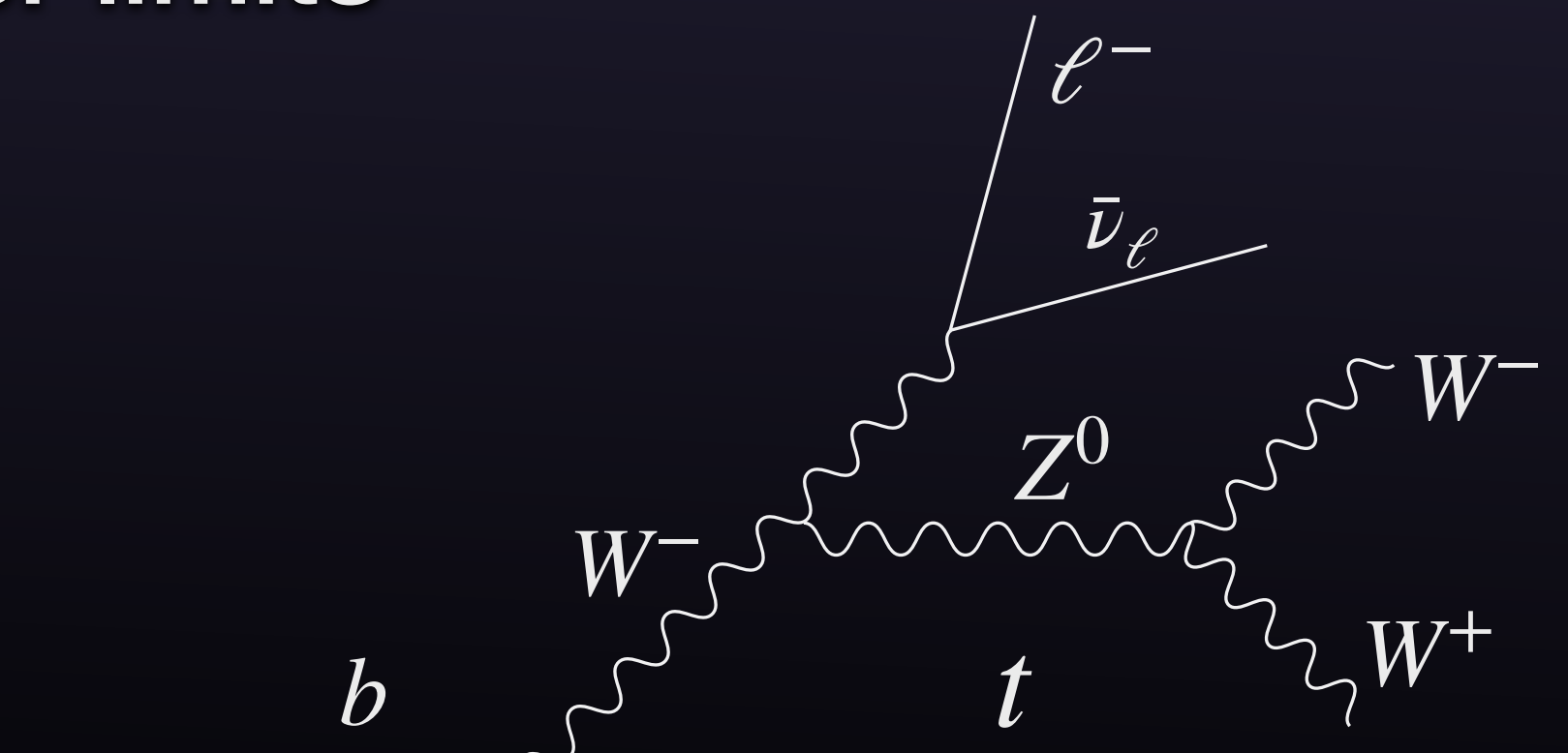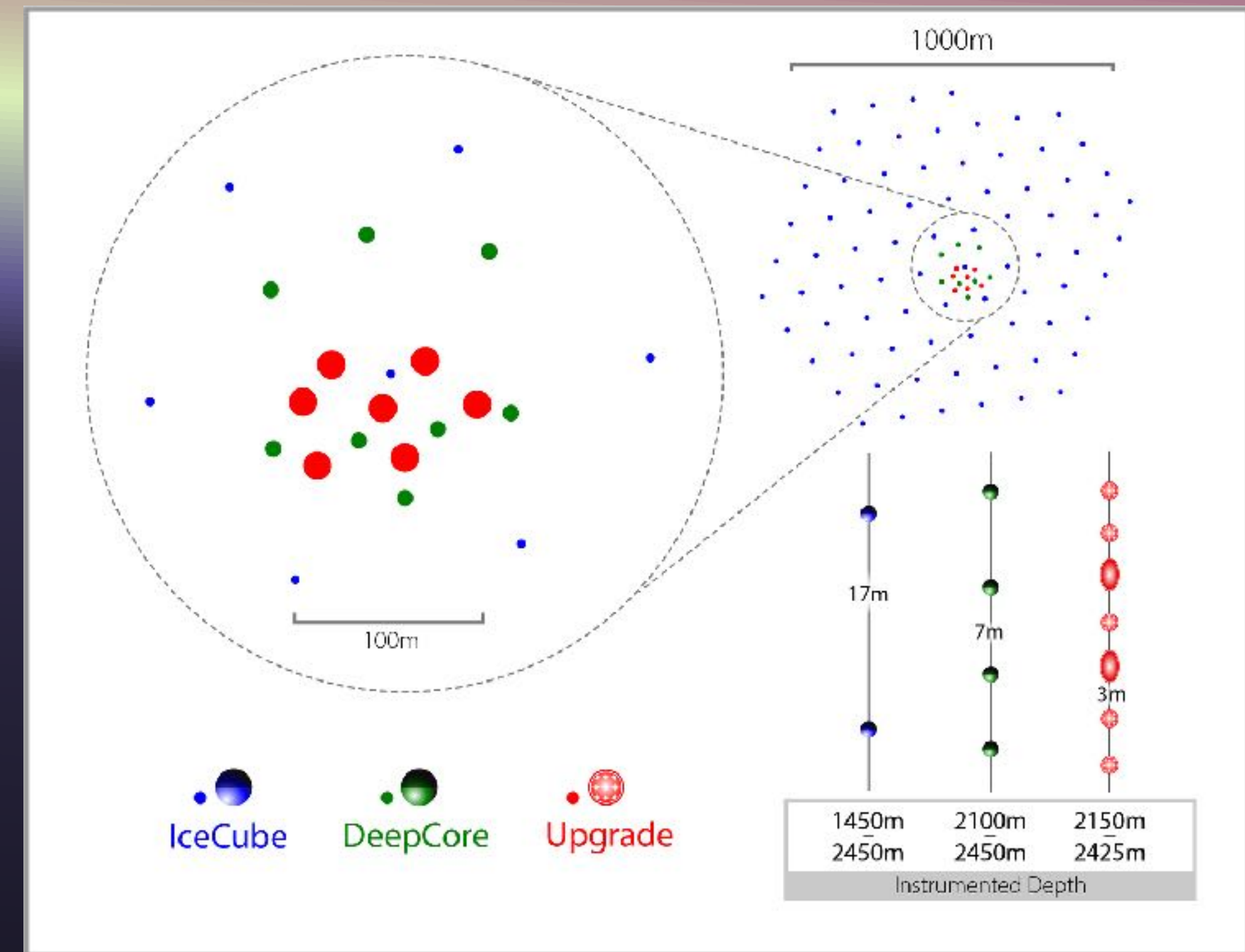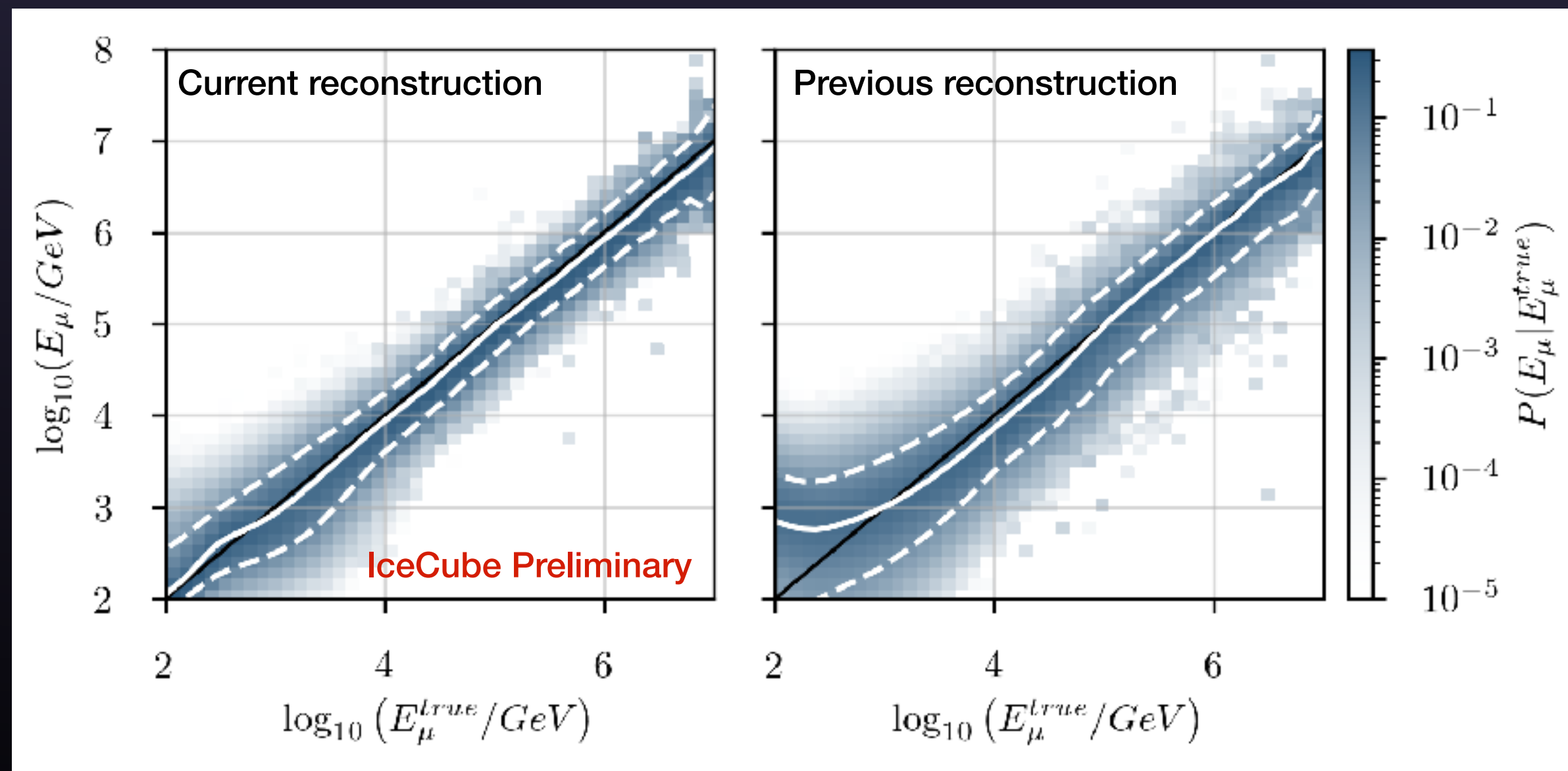
Q. Liu, JL, C. A. Argüelles, A. Kheirandish: DOI 10.1088/1475-7516/2020/10/043

C. W. Bauer, N. L. Rodd, B. R. Webber: DOI 10.1007/JHEP06(2021)121

Continued Excellence

- **IceCube Upgrade will improve sensitivity to low-energy neutrinos, further expanding DM program**

- **Continuing efforts to improve reconstruction will further these results**

Take Home Messages

- We are pushing ahead in DM searches
  - New ways to probe DM with astrophysical neutrinos
  - Probing terrain suggested by scotogenic models
  - World leading constraints on dark matter lifetime and ***DM-nucleon cross section***
- We are connecting theory and computation to develop new software which informs current and future indirect searches

Thank you very much

And may you live in exciting times

Backups

Other profile for combined analysis

- ANTARES better at higher energies where angular resolution is better

- More sensitive to cusp-y profiles / able to set better limits