

# Neutrinos from Dark Matter Annihilation versus the Diffuse Supernova Neutrino Background

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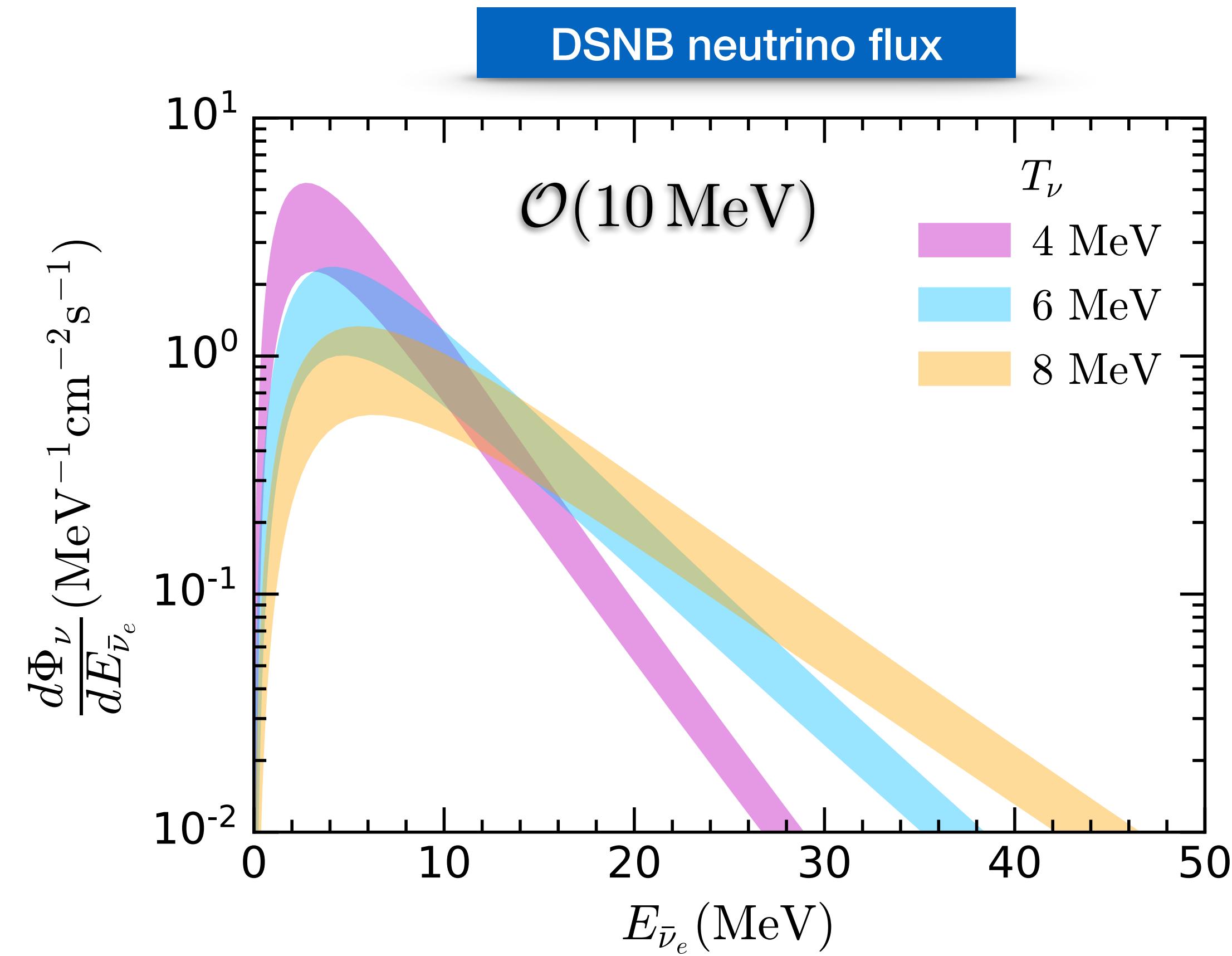
in collaboration with  
Nicole Bell & Matthew Dolan (U. Melbourne)  
[arXiv: 2205.14123](https://arxiv.org/abs/2205.14123) (JCAP 11 2022)



# Introduction

## Diffuse Supernova Neutrino Background (DSNB)

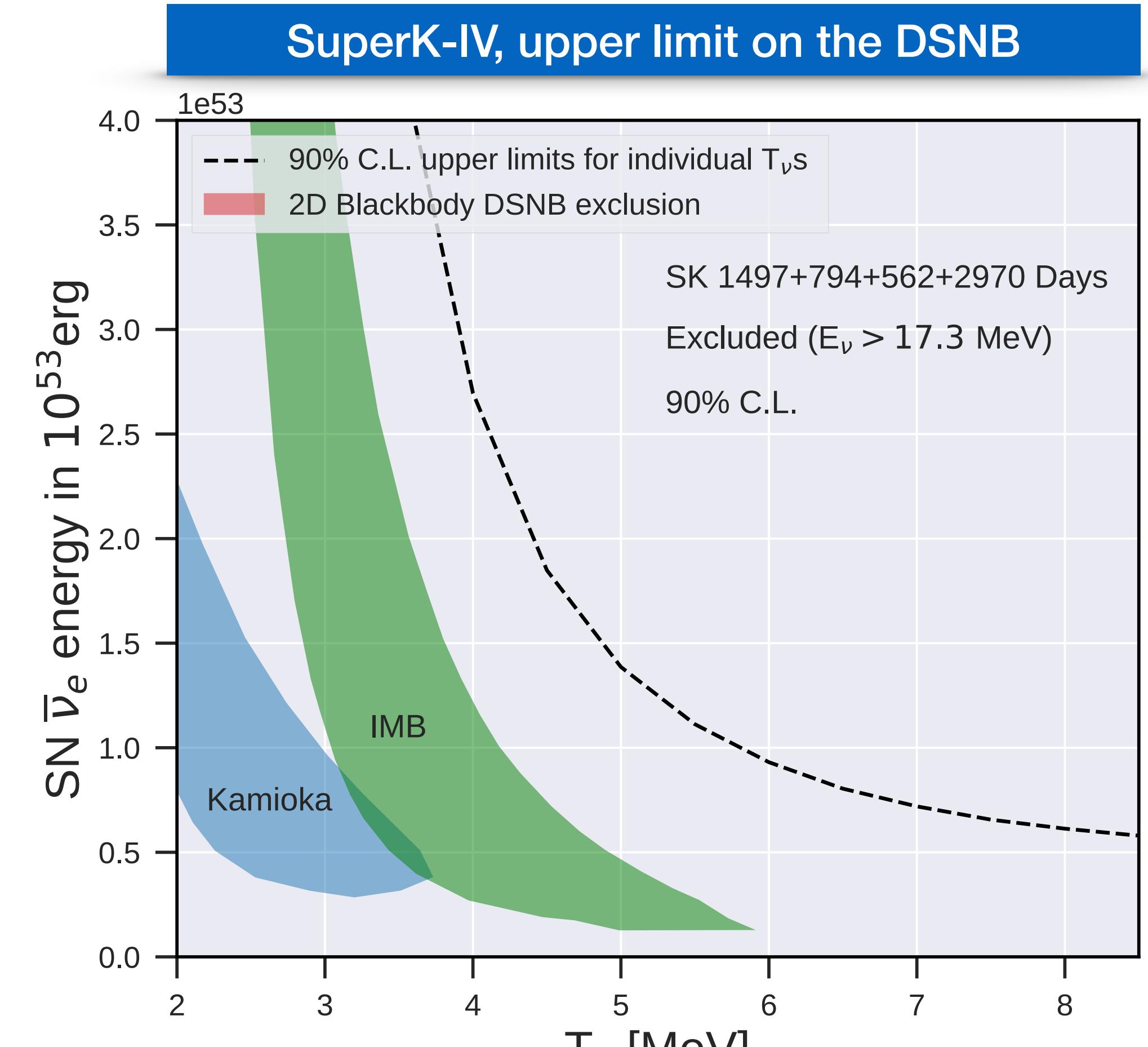
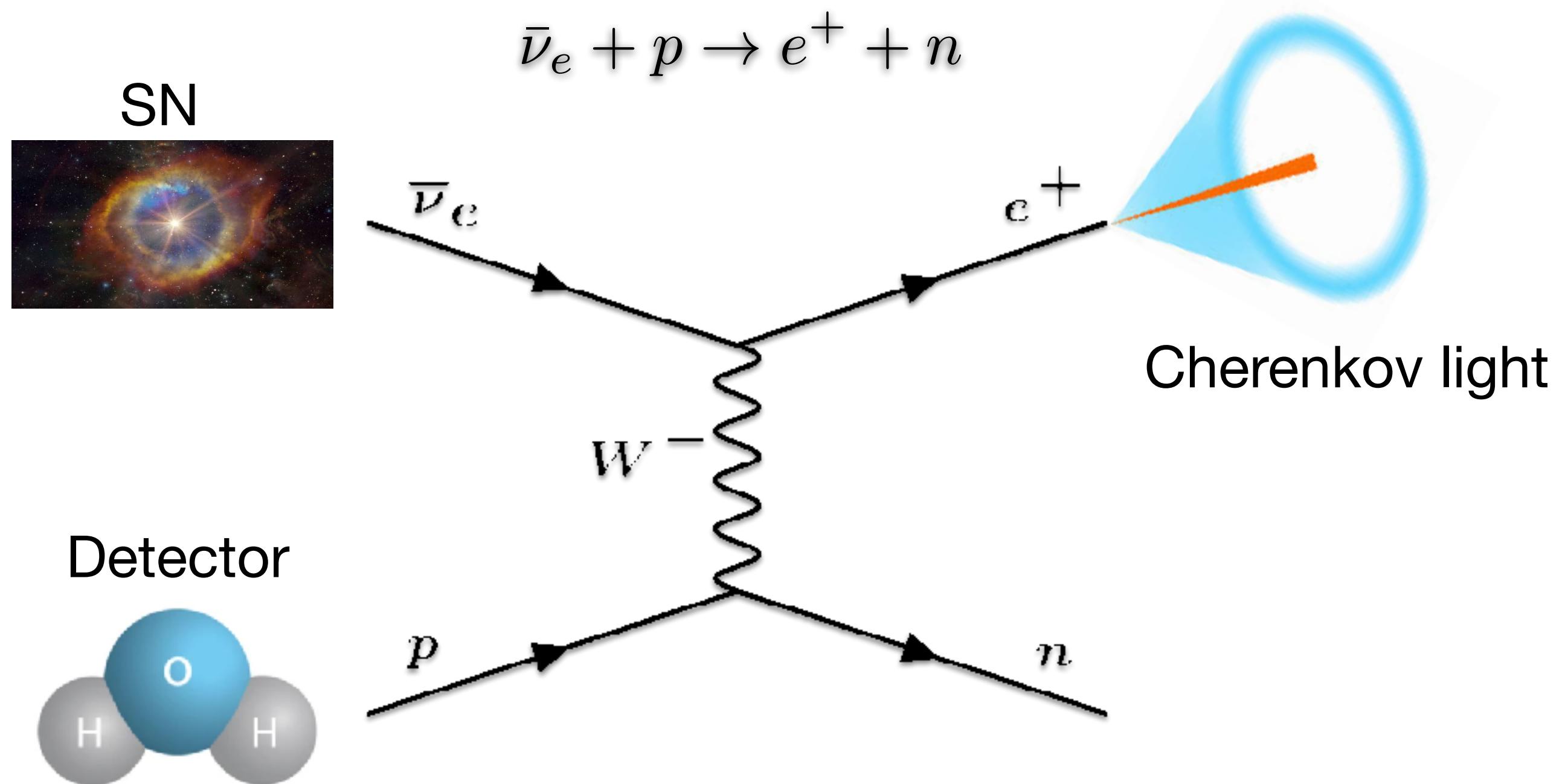
- DSNB: Neutrinos from all previous core-collapse SNe
  - ➡ Isotropic signal, quasi-thermal spectrum
- Not discovered yet, in the reach of upcoming neutrino detectors
- Galactic supernova are rare (~ few per century)
- ~99% of the energy from SN is released as neutrinos



# Introduction

## DSNB searches

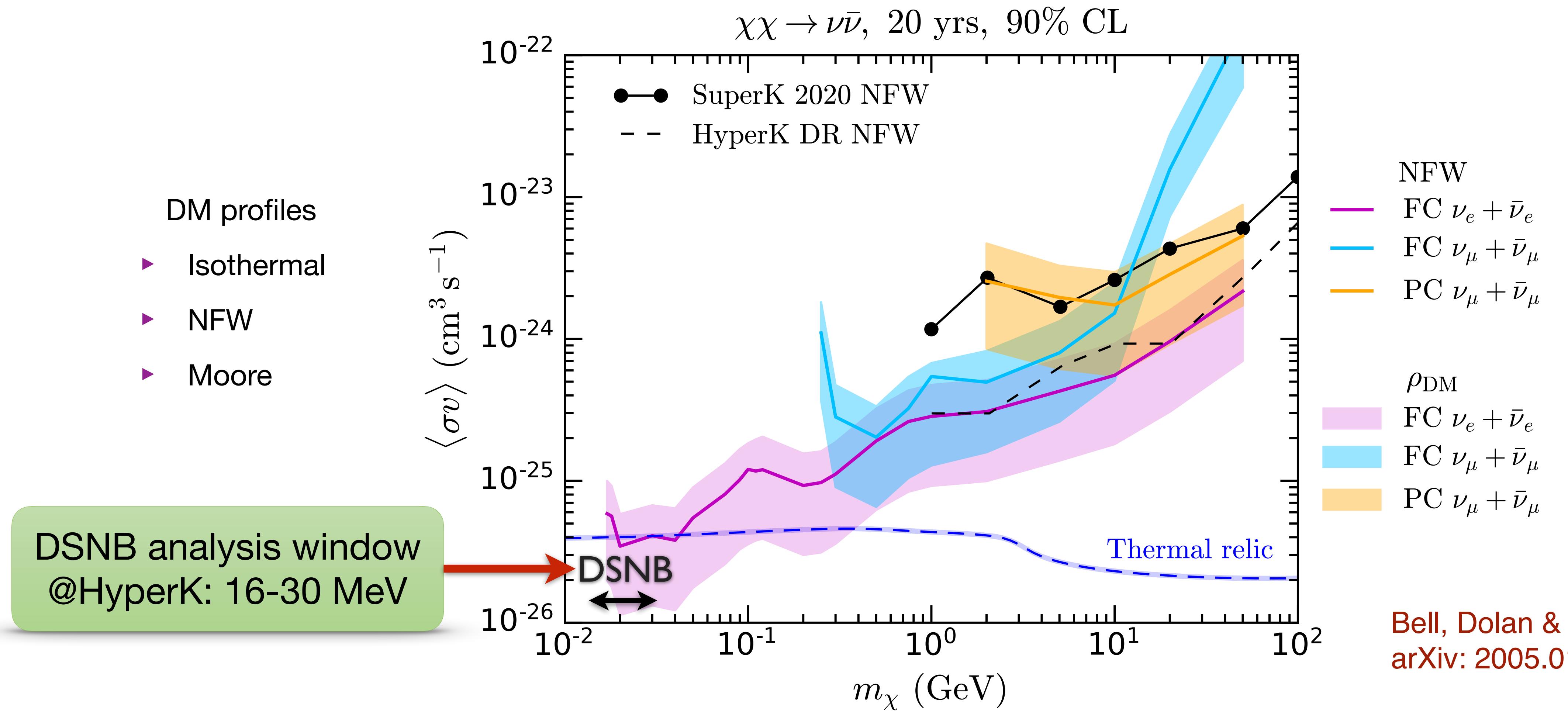
- Detection
  - ➡ Water Cherenkov detectors (SuperK, HyperK)
  - ➡ Liquid argon (DUNE) and scintillator (JUNO)
- Water Cherenkov detectors
  - ➡ Channel: Inverse beta decay (IBD)



SuperK Collaboration arXiv: 2109.11174

# Introduction

- HyperK should be able to probe **thermal annihilation cross-sections** for DM of mass  $\sim 20 - 40$  MeV for annihilation into neutrinos.



Can neutrinos from DM annihilation  
contribute a significant background  
to DSNB searches?

next

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# Background for DSNB searches



Atmospheric Neutrinos

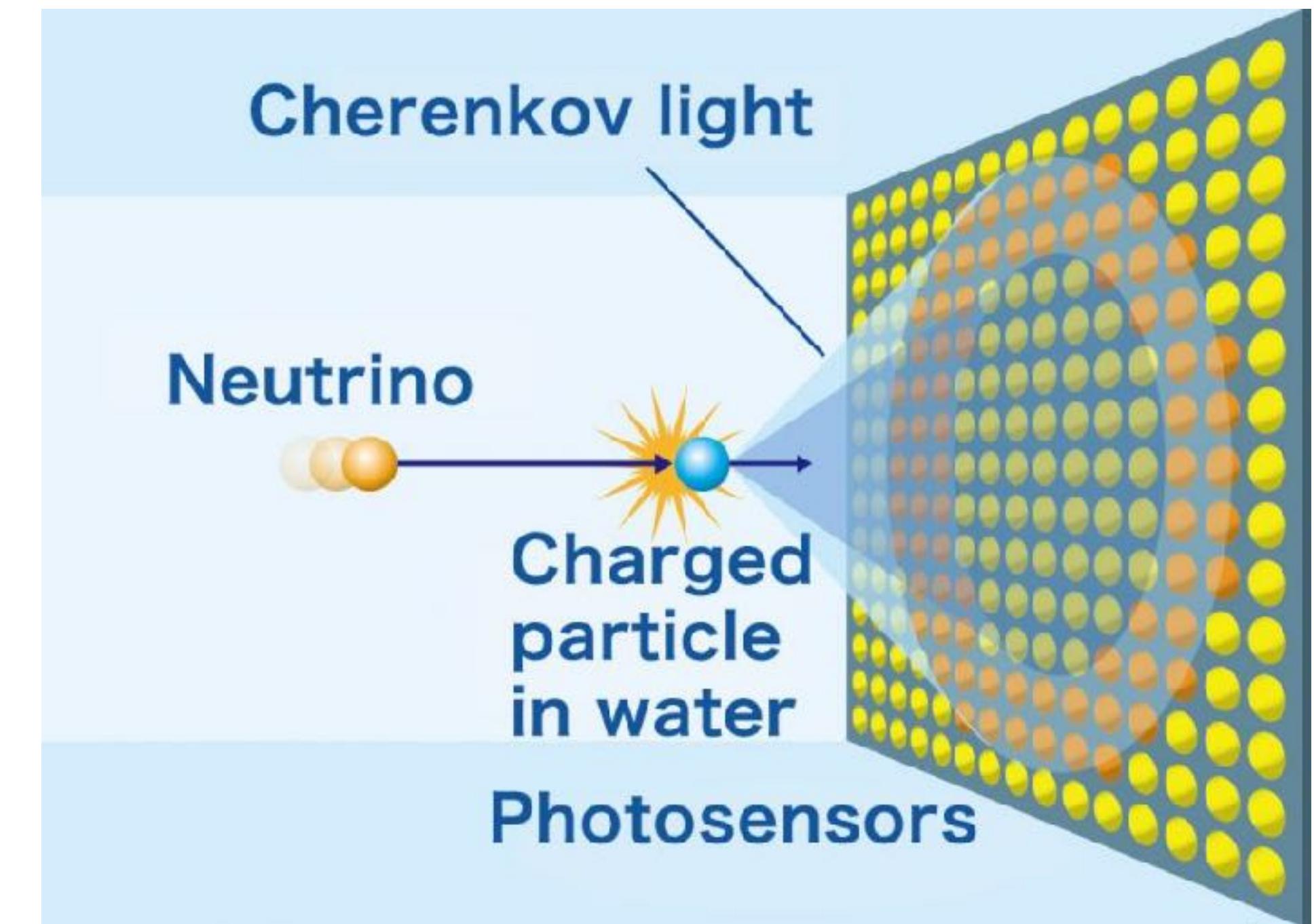
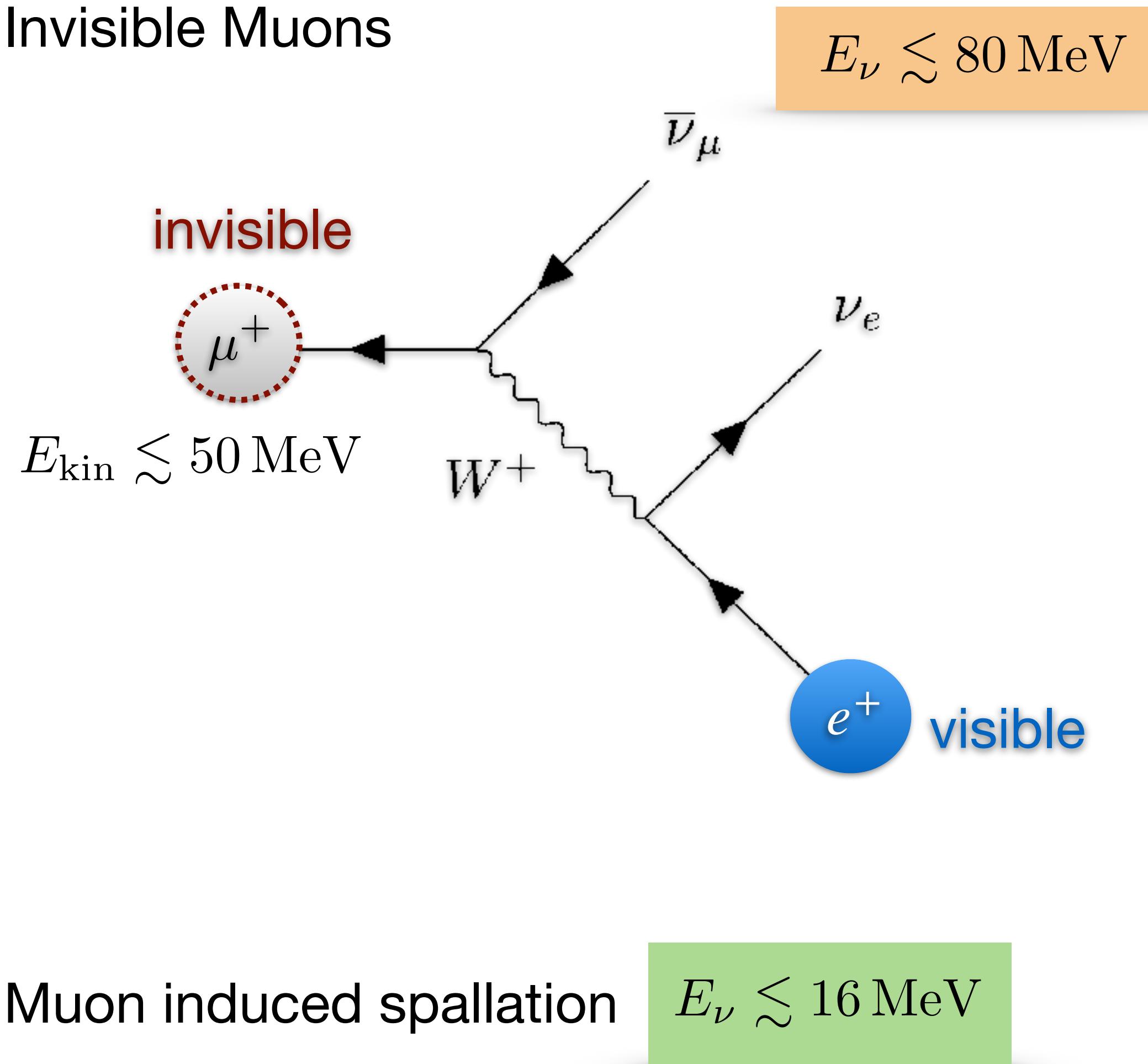


Image credit: ICRR (Institute for Cosmic Ray Research), The University of Tokyo

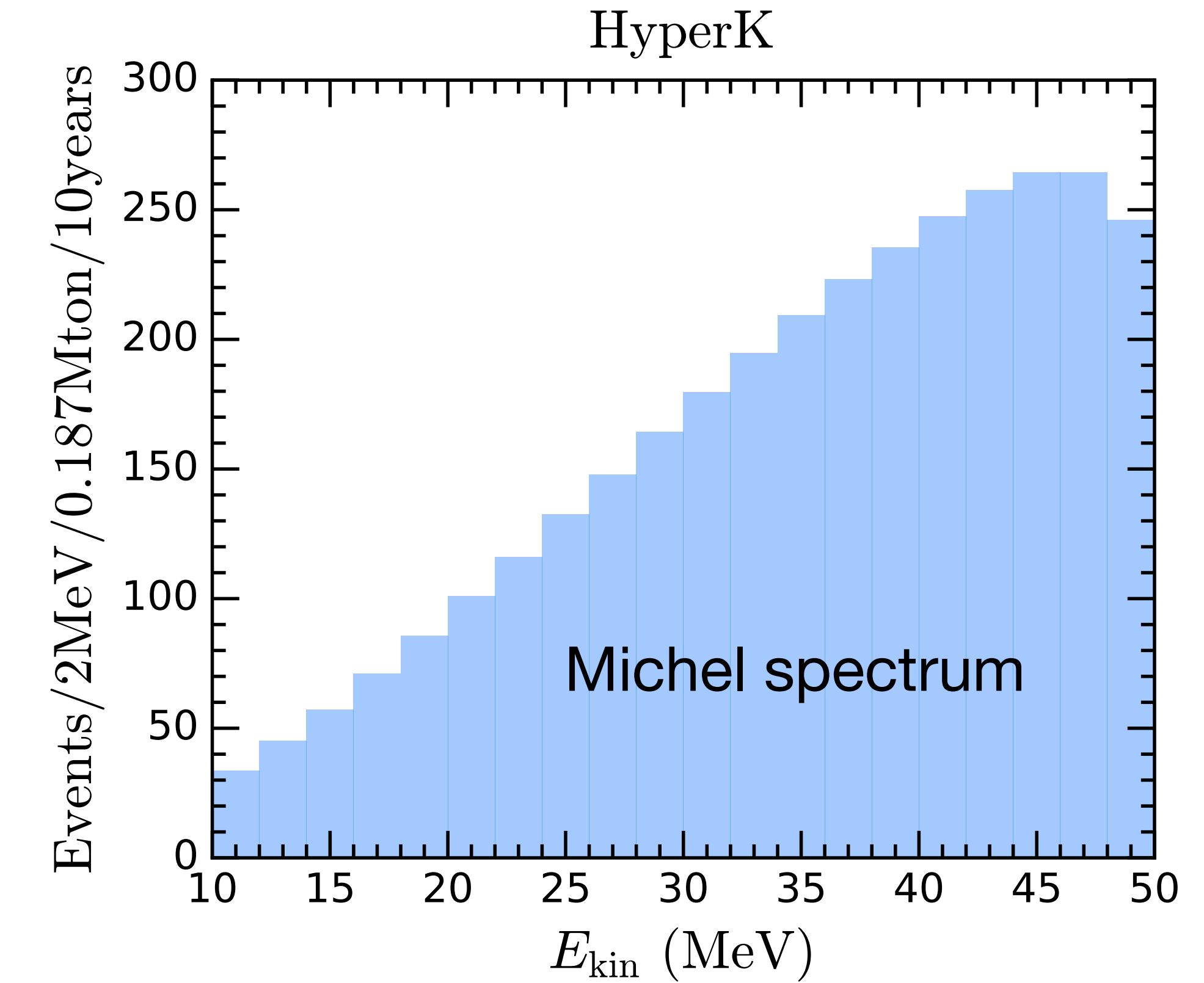
- Flux predictions at Kamioka site
  - HKKM11: 100 MeV - 10TeV      Honda et al. arXiv:1102.2688
  - FLUKA: 13 MeV – 100 MeV      Battistoni et al.,  
Astropart. Phys. 23 (2005) 526
- Charged current interactions  
 $\nu_\ell + N \rightarrow \ell + N'$

# Background for DSNB searches

- Invisible Muons

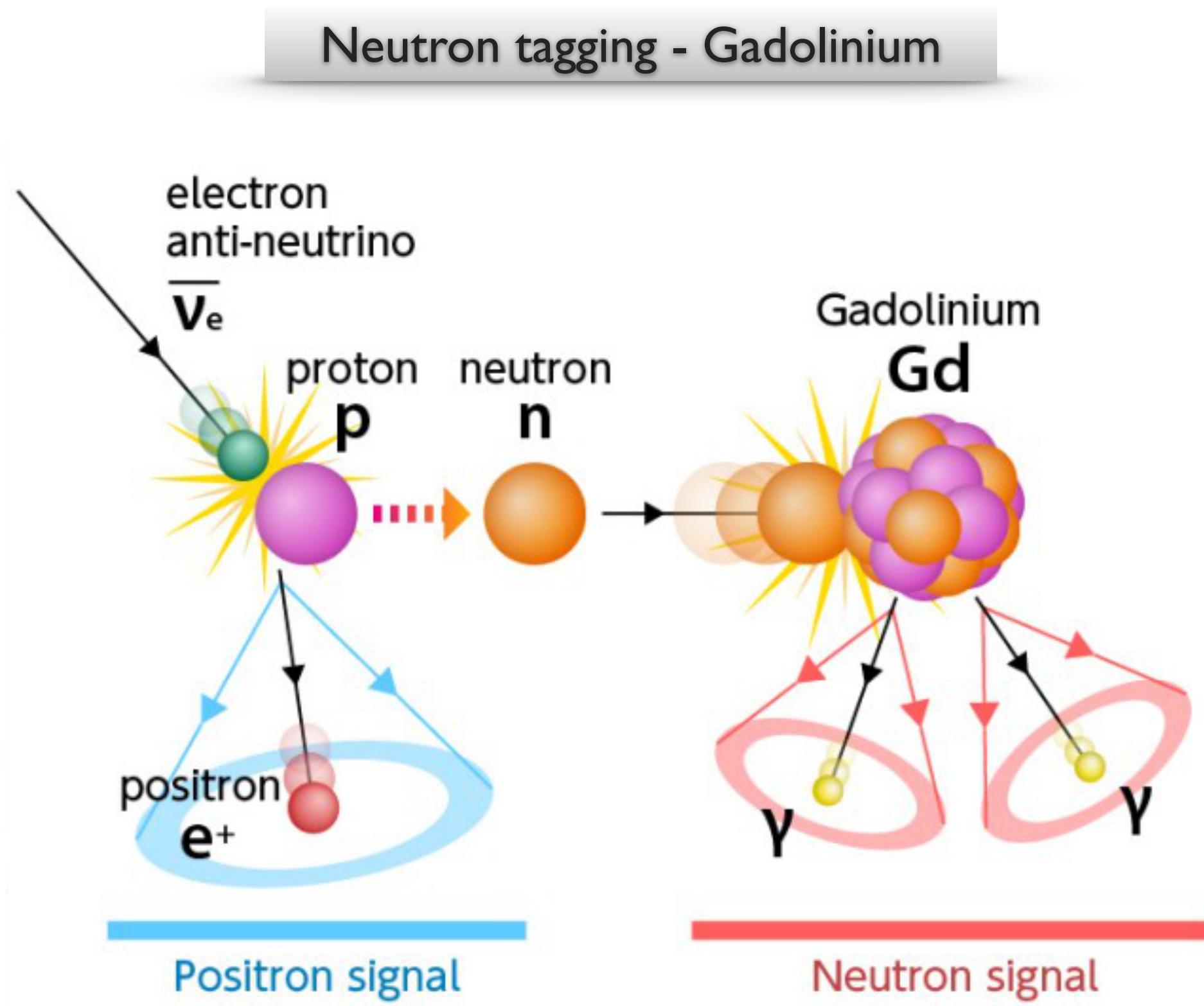


- Muon induced spallation

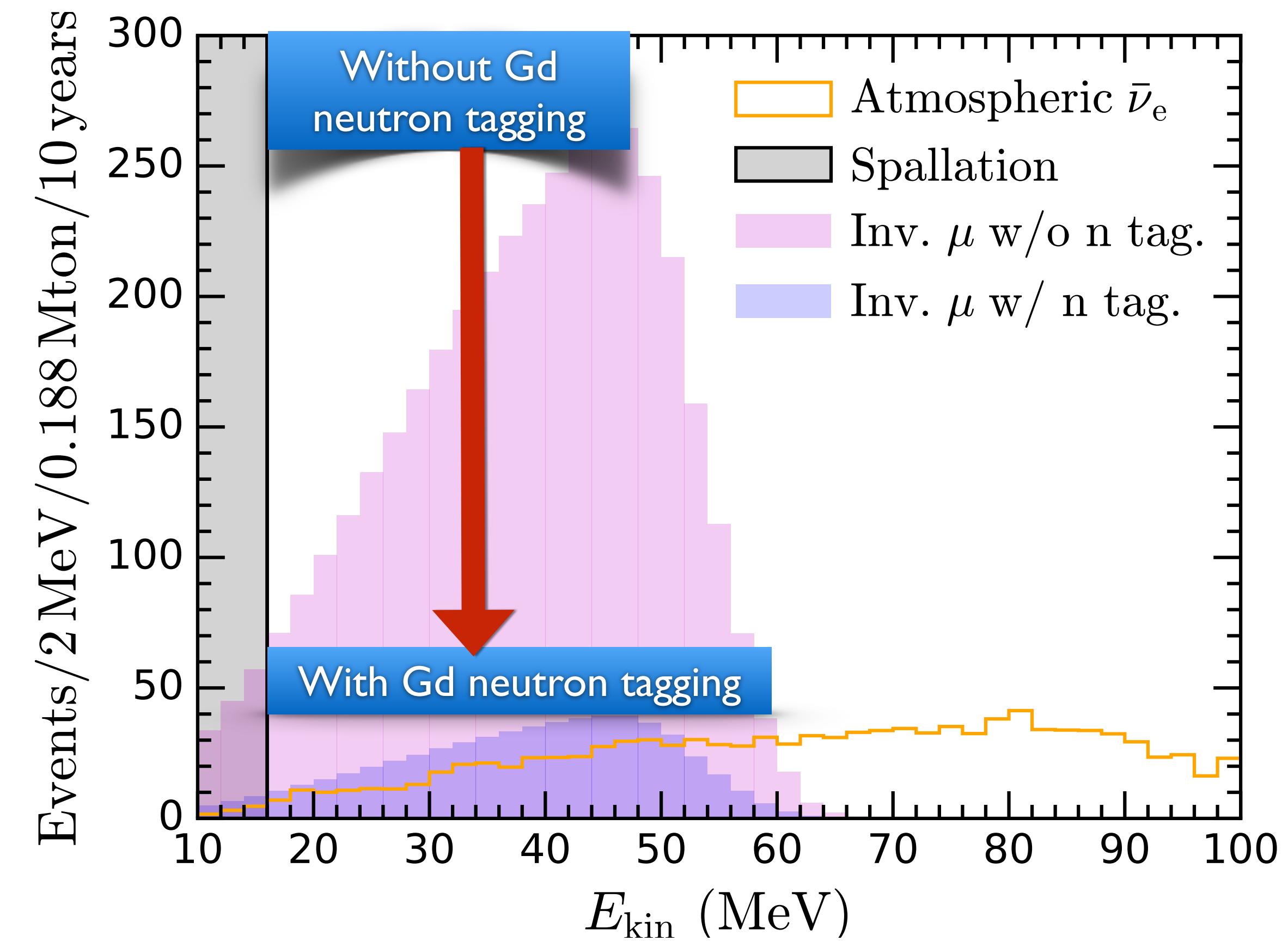


# Background for DSNB searches

- Invisible muons from HyperK design report

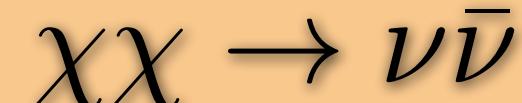


- Background at HyperK



# DM Signal

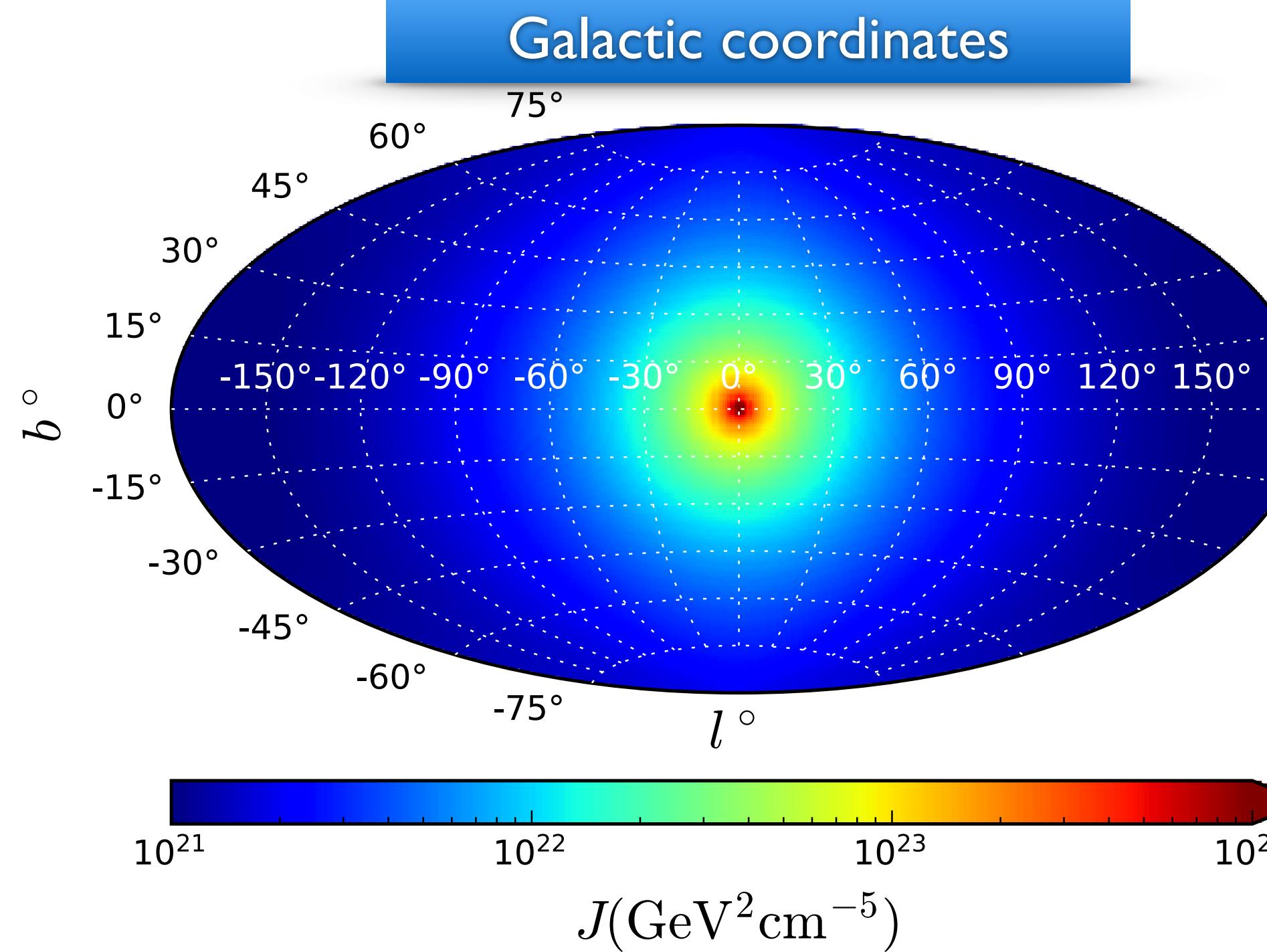
Primary contribution: Neutrinos from DM annihilation in the Galactic halo



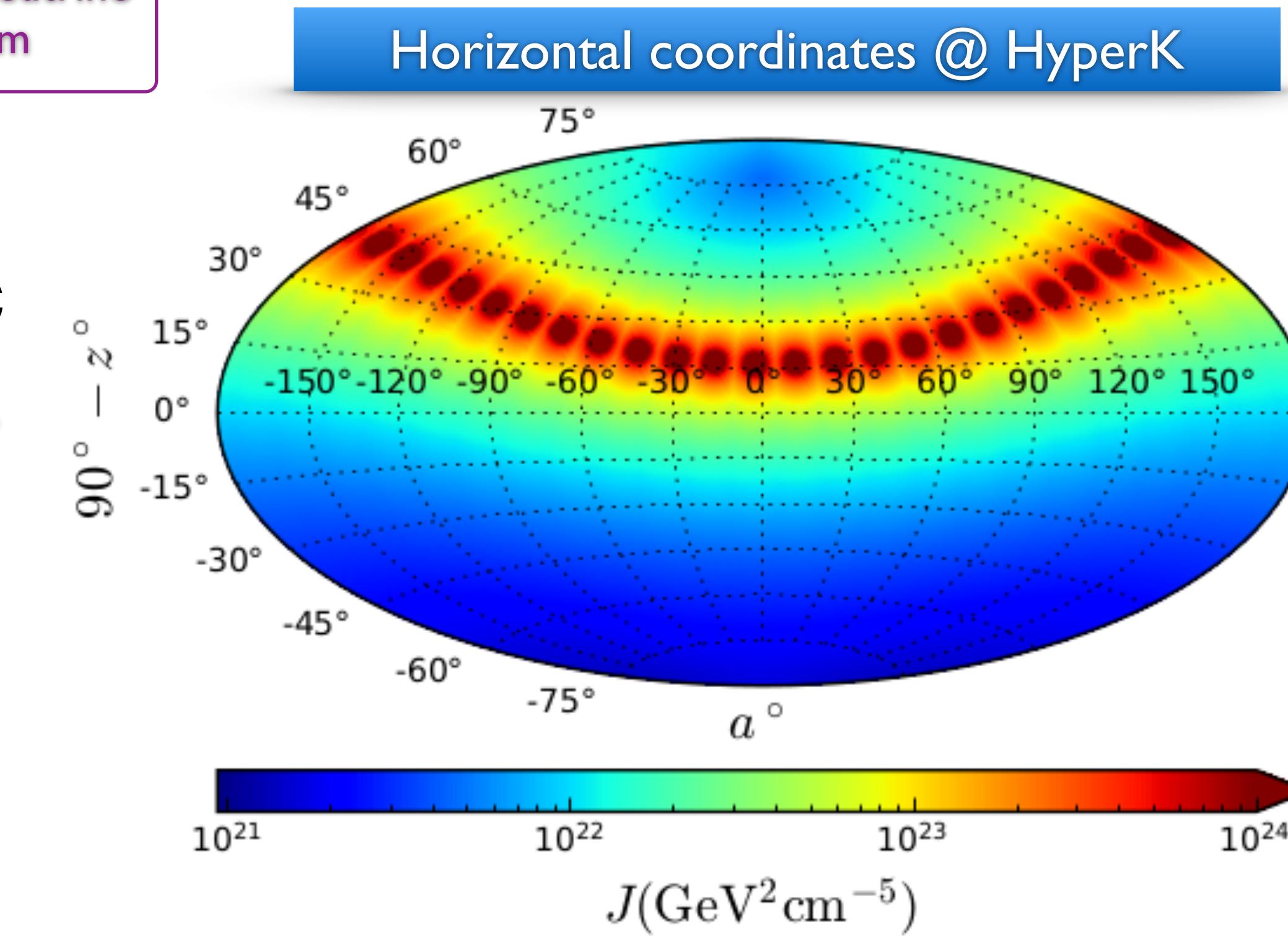
$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu, b, l) = \frac{\langle\sigma v\rangle}{8\pi m_\chi^2} \frac{dN_\nu}{dE_\nu} J(b, l)$$

DM particles producing  
vs along the l.o.s.

Differential neutrino  
spectrum



Tracking the GC



# DM Signal

Secondary contribution: Neutrinos from extragalactic DM annihilation

- Isotropic signal

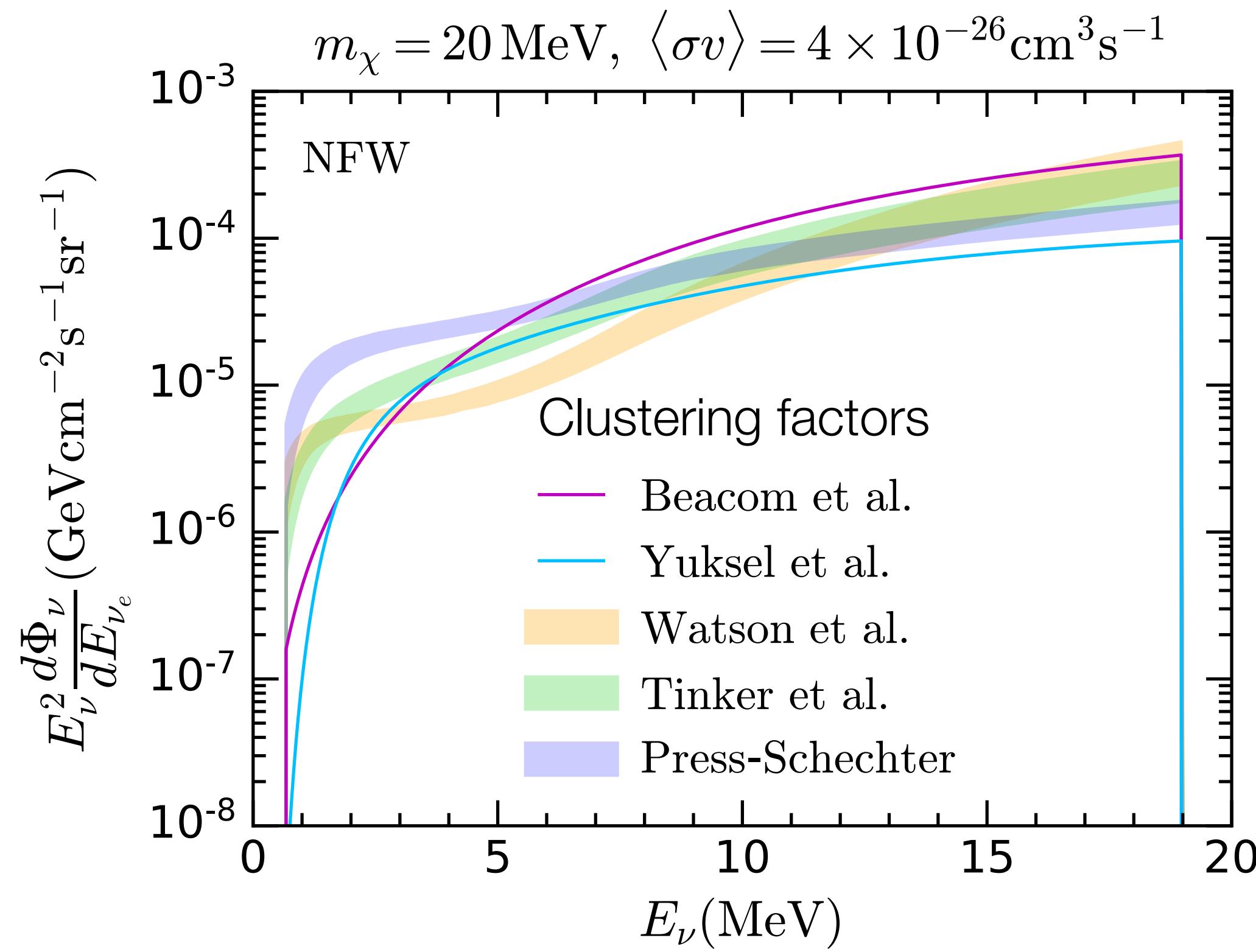
$$\frac{d\Phi_\nu}{dE_\nu} = \frac{\langle\sigma v\rangle}{2} \frac{c}{4\pi H_0} \frac{\Omega_{\text{DM},0}^2 \rho_{c,0}^2}{m_\chi^2} \int_0^{z_{up}} dz \frac{\Delta^2(z)}{\sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0}}} \frac{dN_\nu(E'_\nu)}{dE'_\nu}$$

Enhancement due to DM clustering

Differential neutrino spectrum

Beacom, Bell & Mack astro-ph/0608090

- Assumptions
  - DM density profile
  - DM clustering factor (halo mass function)

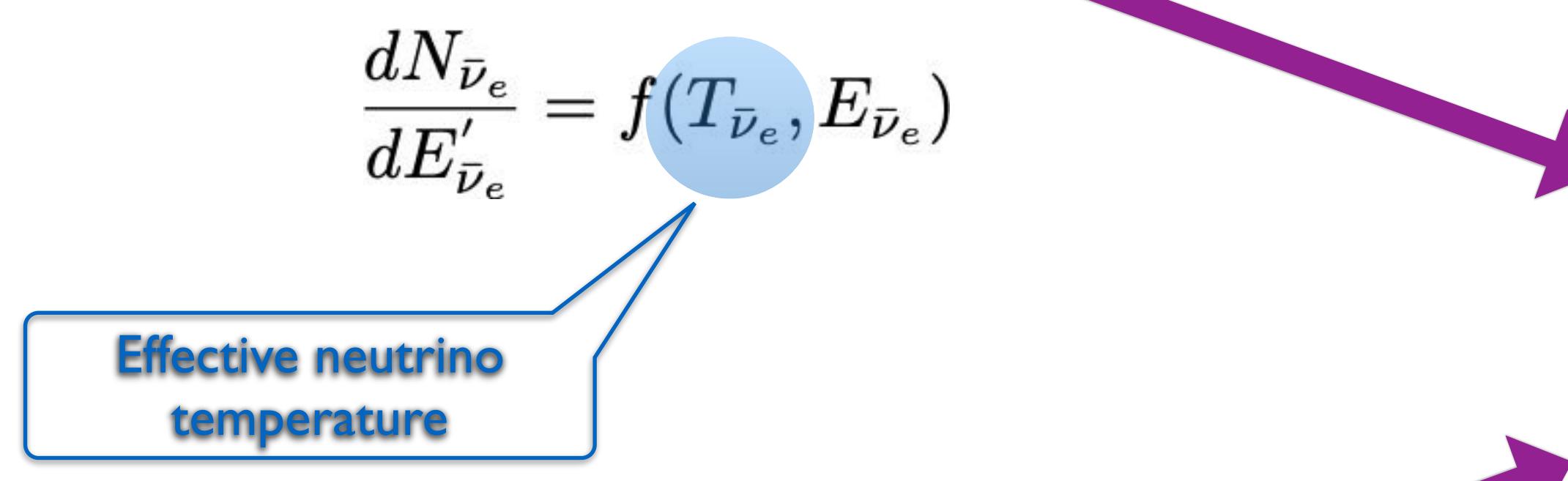


# DSNB flux

- DSNB flux
  - ➡ obtained by redshifting neutrino spectrum from single SN according to the SN rate
- Neutrino spectrum per SN

$$\frac{dN_{\bar{\nu}_e}}{dE'_{\bar{\nu}_e}} = f(T_{\bar{\nu}_e}, E_{\bar{\nu}_e})$$

Effective neutrino temperature



$$\frac{d\Phi_{\bar{\nu}_e}}{dE_{\bar{\nu}_e}} = \frac{c}{H_0} \int_0^{z_{\max}} \frac{R_{CCSN}(z)}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}} \frac{dN_{\bar{\nu}_e}}{dE'_{\bar{\nu}_e}}(E'_{\bar{\nu}_e}) dz$$

- Core-collapse SN rate

$$R_{CCSN}(z) = \text{SFR}(z) \times \text{NS fraction}$$

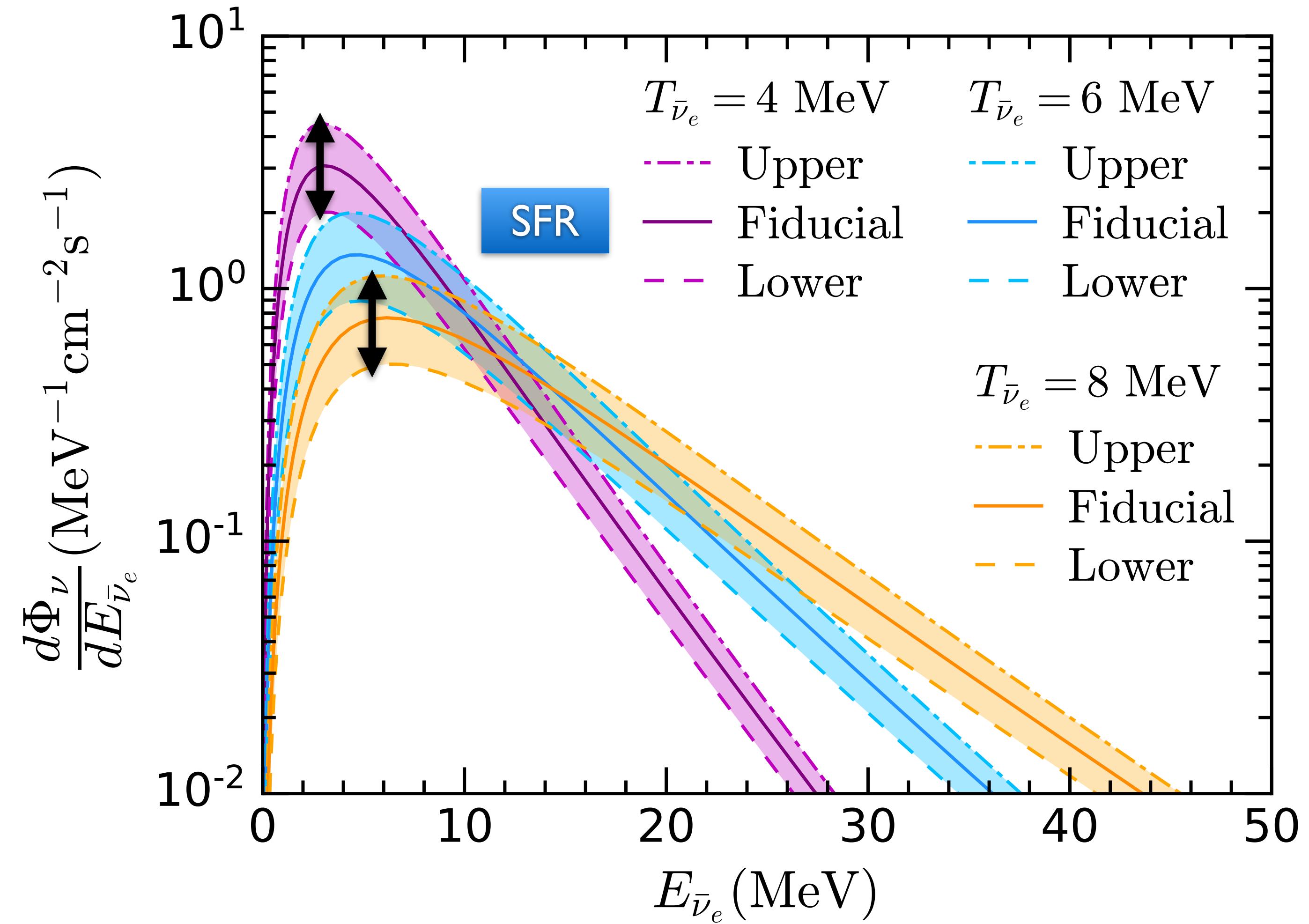
- Main assumptions
  - ➡ Star Formation Rate (SFR)
  - ➡ Effective neutrino temperature

Horiuchi, Beacom & Dwek, arXiv: 0812.3157

# DSNB flux

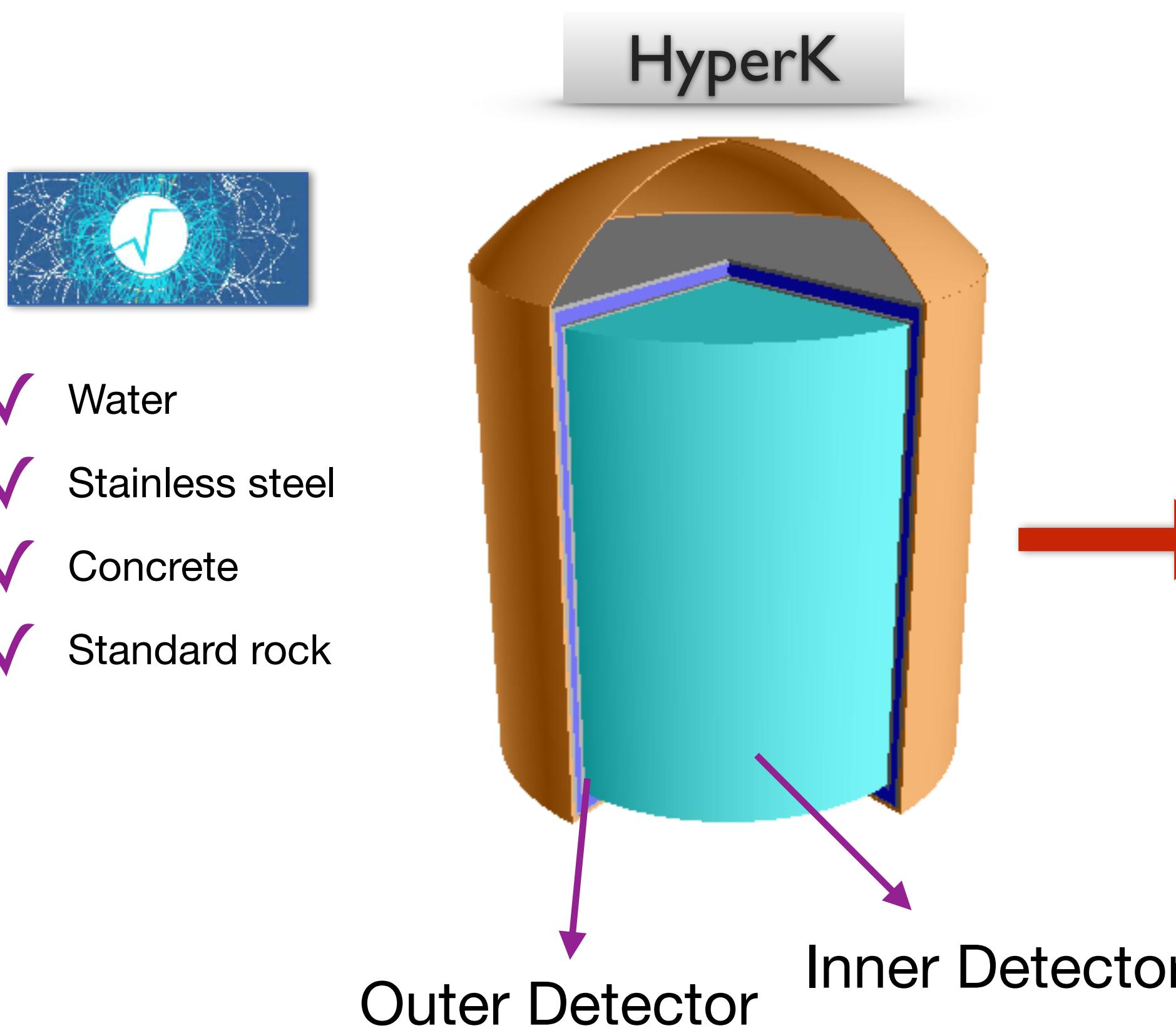
$$\frac{d\Phi_{\bar{\nu}_e}}{dE_{\bar{\nu}_e}} = f(\text{SFR}, T_{\bar{\nu}_e})$$

- Parameters for DSNB physics
  - SFR: continuous broken power law
  - Effective temperature for emission: Fermi-Dirac distribution



# Detector simulation

- GENIE neutrino Monte Carlo event generator  
[Andreopoulos et al. arXiv:1510.05494](#)
- ROOT geometry package - detector geometry

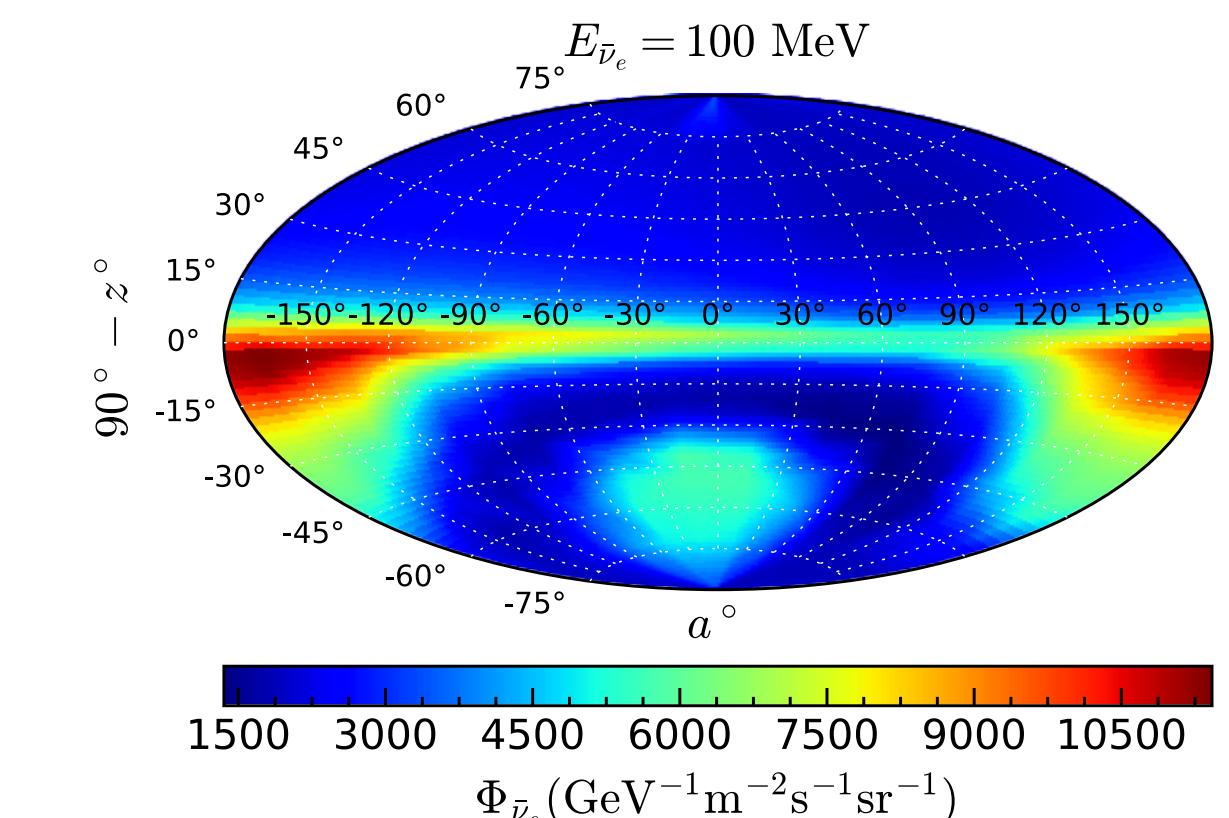
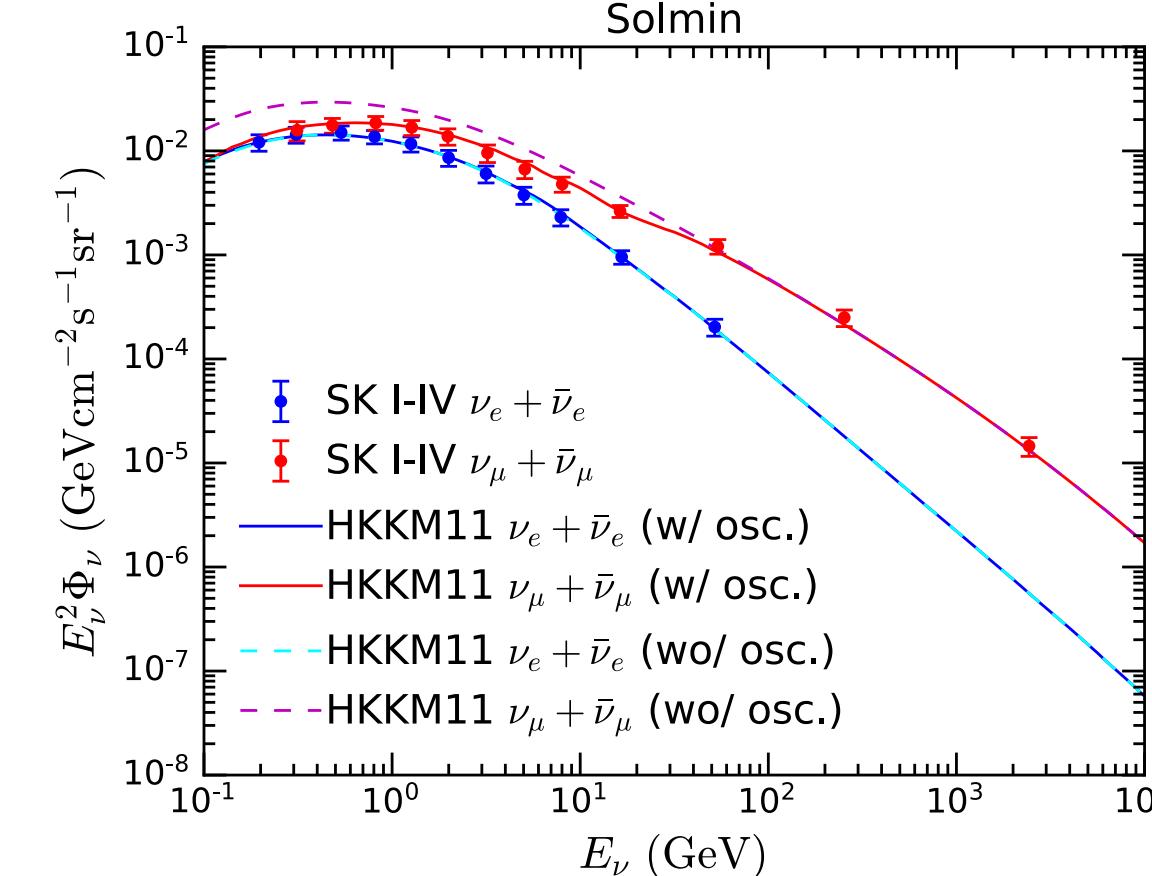


- ✓ Water
- ✓ Stainless steel
- ✓ Concrete
- ✓ Standard rock

$\Phi_\nu(E_\nu, z, a)$



✓ Validated against atmo.  $\nu$  events @ SuperK



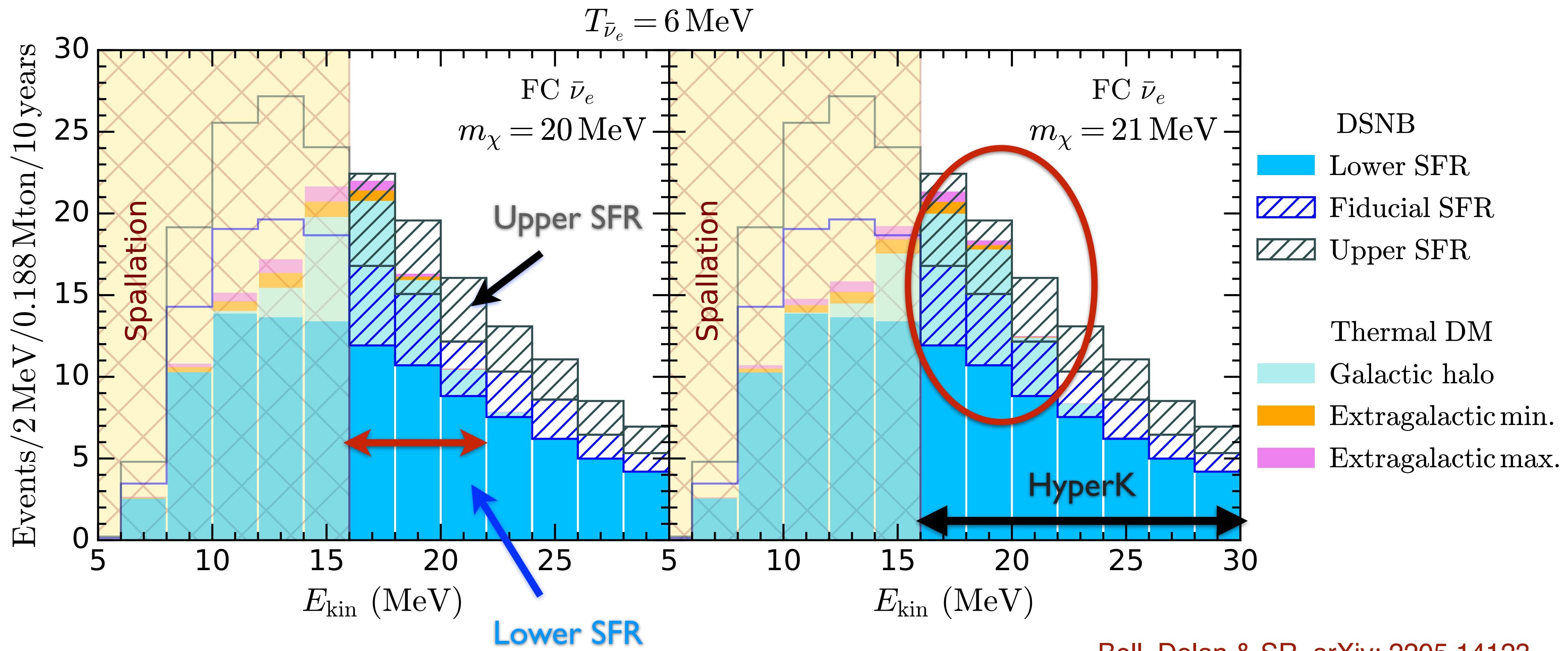
Atmospheric  $\nu$  4D flux  
HKKM11: arXiv:1102.2688

Bell, Dolan & SR  
arXiv: 2005.01950

- ✓ Kinematics
- ✓ Vertex of the interaction
- ✓ Tracking leptons & pions
- ✓ Smearing

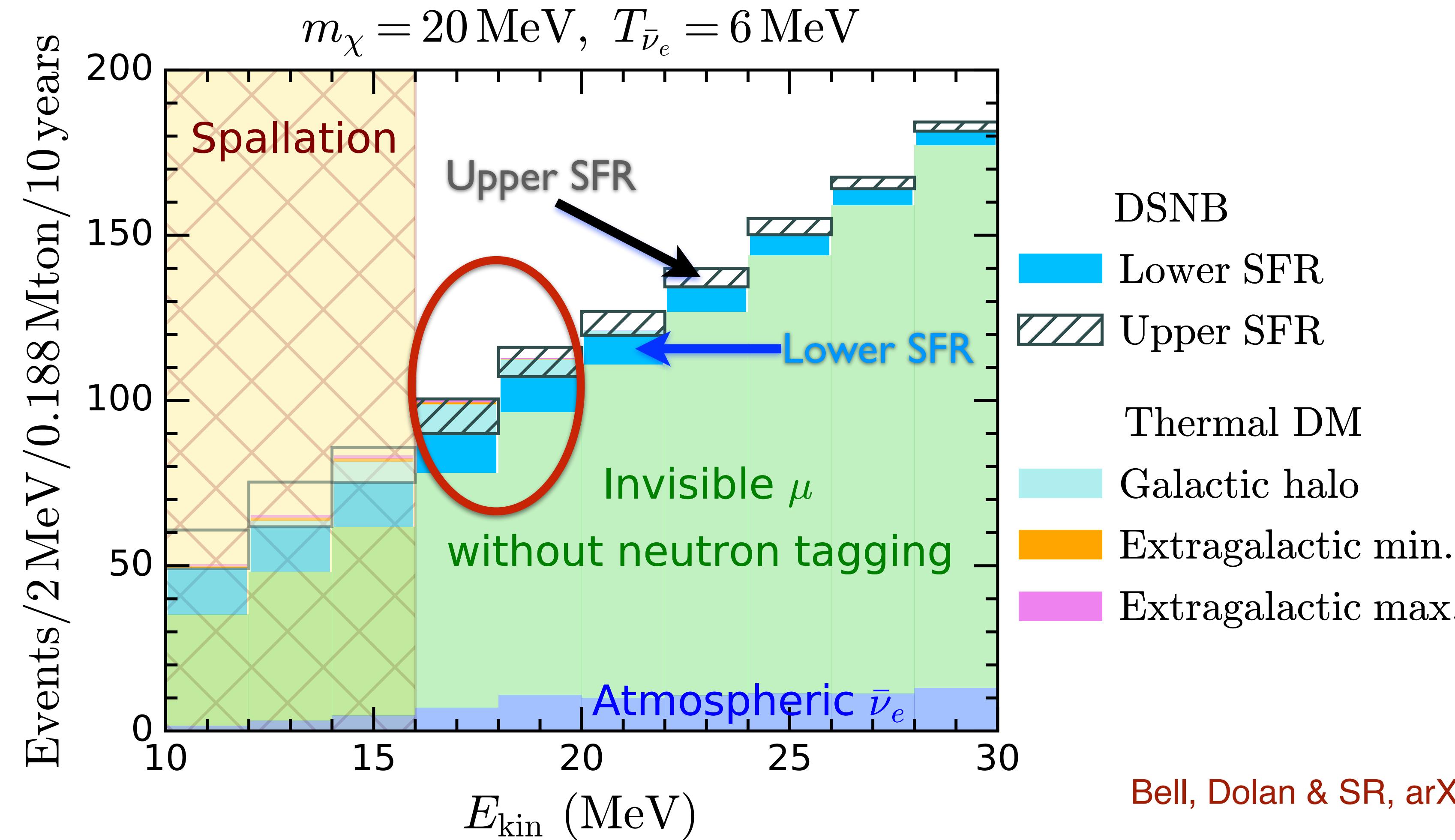
# DSNB and DM events @ HyperK

Analysis window: 16 - 30 MeV



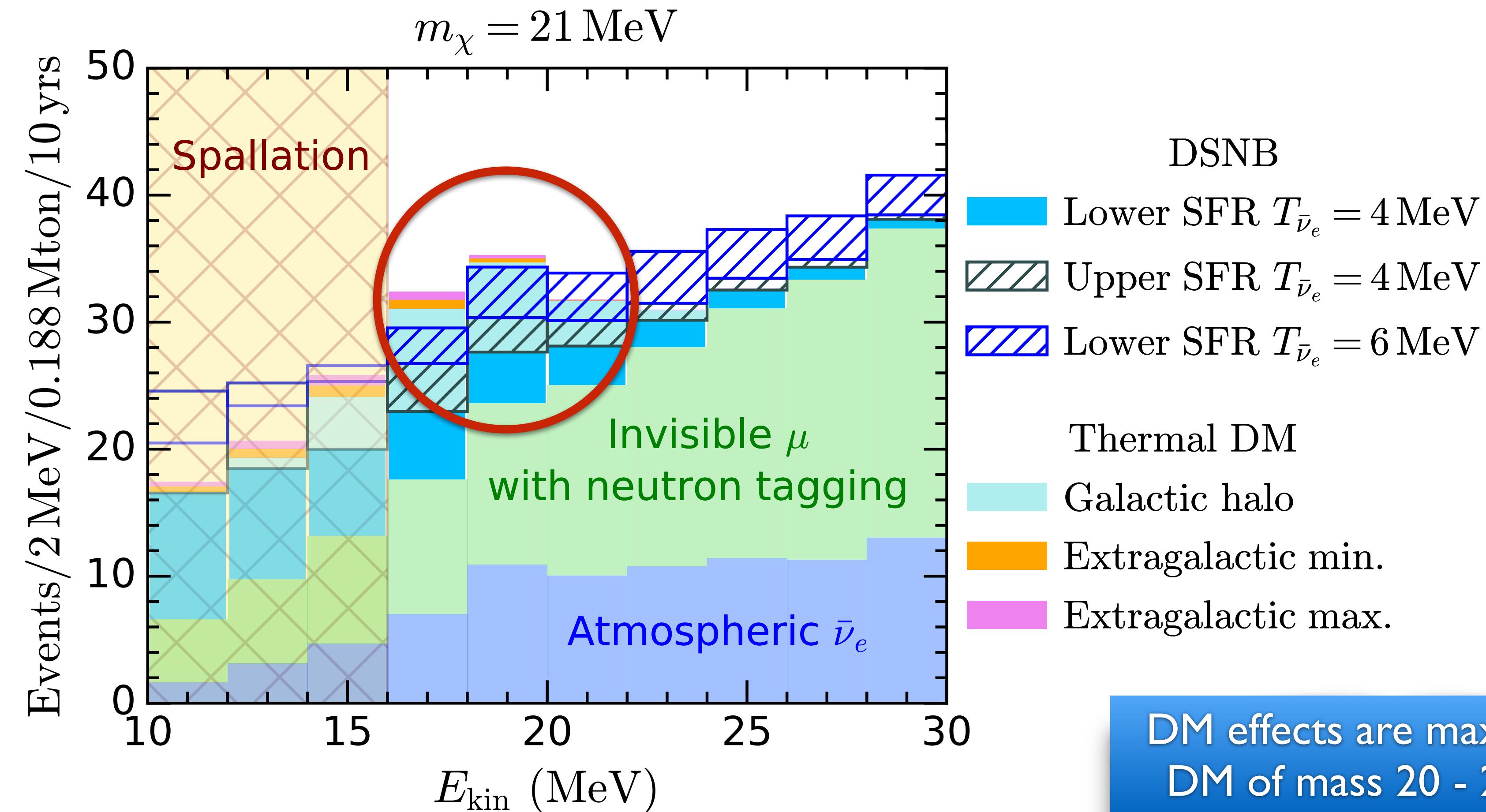
# Expected signal and background @ HyperK

DSNB + DM without neutron tagging → right model ruled out at 90%



# Expected signal and background @ HyperK

DSNB + DM with Gd n-tagging → wrong SFR or wrong  $T_\nu$  at 95% CL



Bell, Dolan & SR, arXiv: 2205.14123

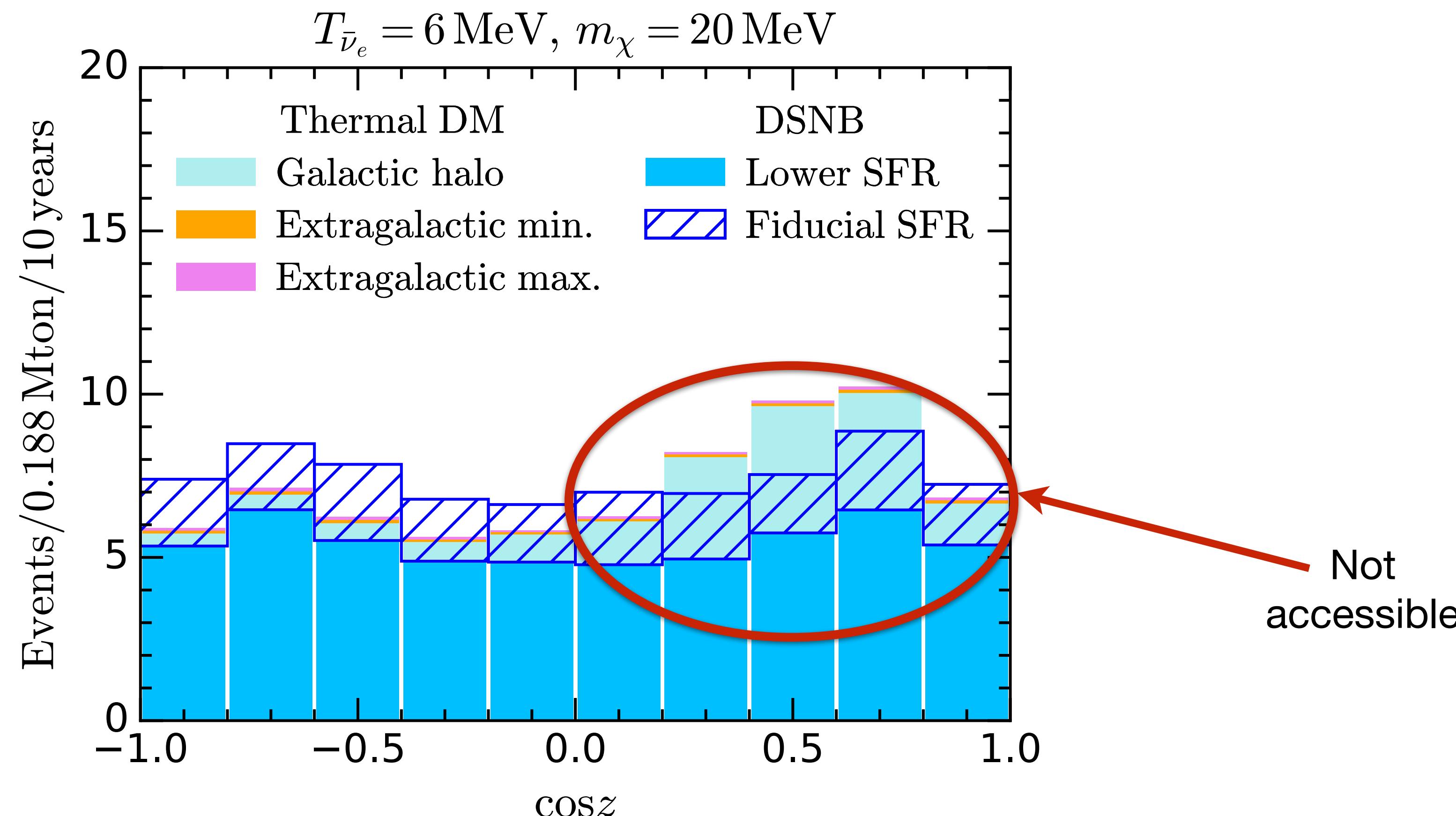
Is there a way to reliably  
disentangle DSNB and DM signals?



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# On-off analysis @ HyperK?

- IBD offers weak directionality, nearly isotropic positron-neutron offset  
➡ Reconstruction of the anti-neutrino direction is not possible.



# Summary

- Pollution from neutrinos from light DM annihilation
  - ➡ could lead to incorrect inferences about the astrophysics behind the DSNB and potentially missing a DM signal.
- Using a dedicated simulation of the HyperK detector, we have shown that this could occur.
- Unfortunately, it will be hard to discriminate between both signals due to the lack of angular information.
- Conclusions should hold for other experiments sensitive to the DSNB (JUNO and DUNE).

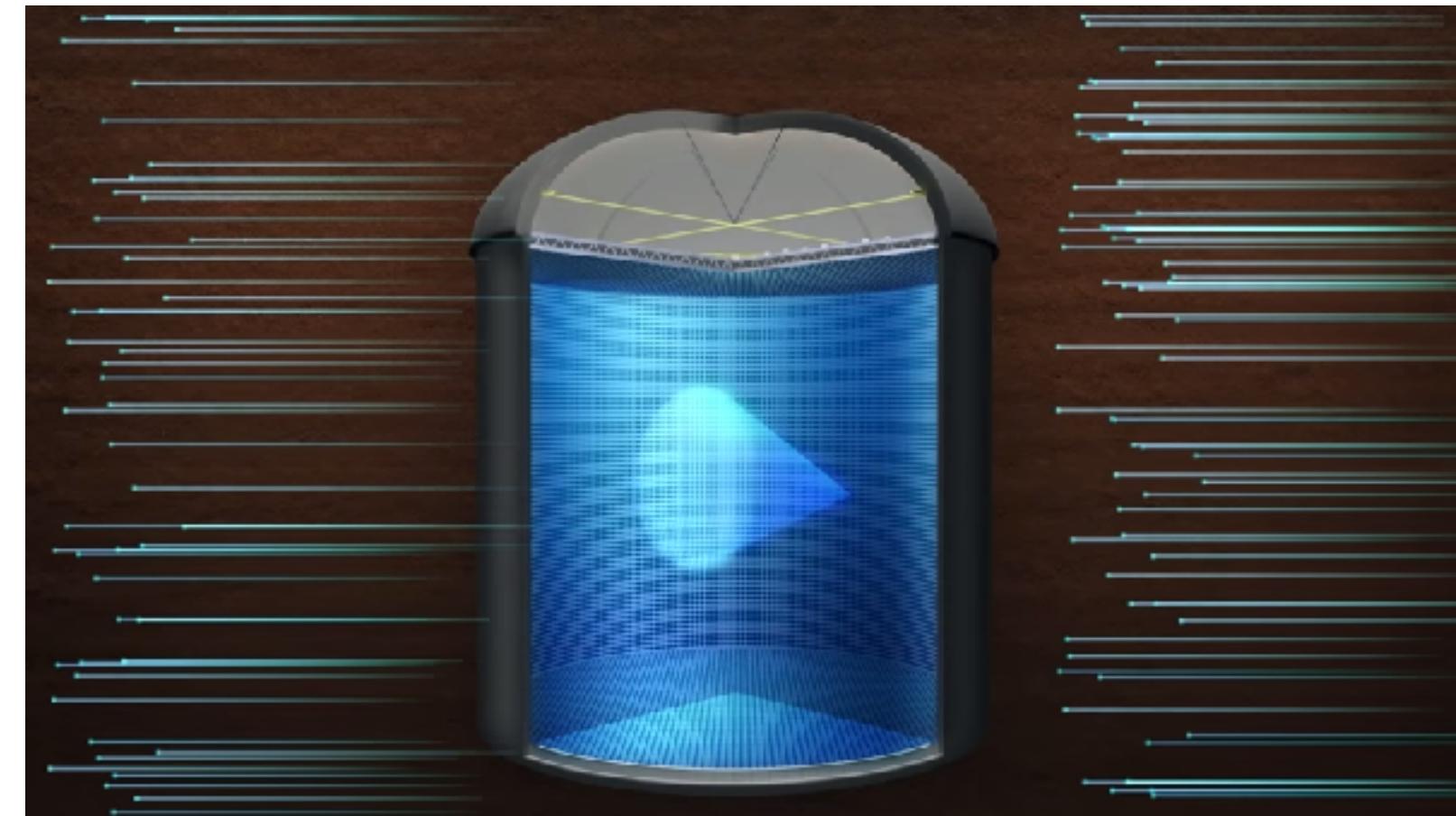


Image credit: ICRR (Institute for Cosmic Ray Research), The University of Tokyo

Thank you!