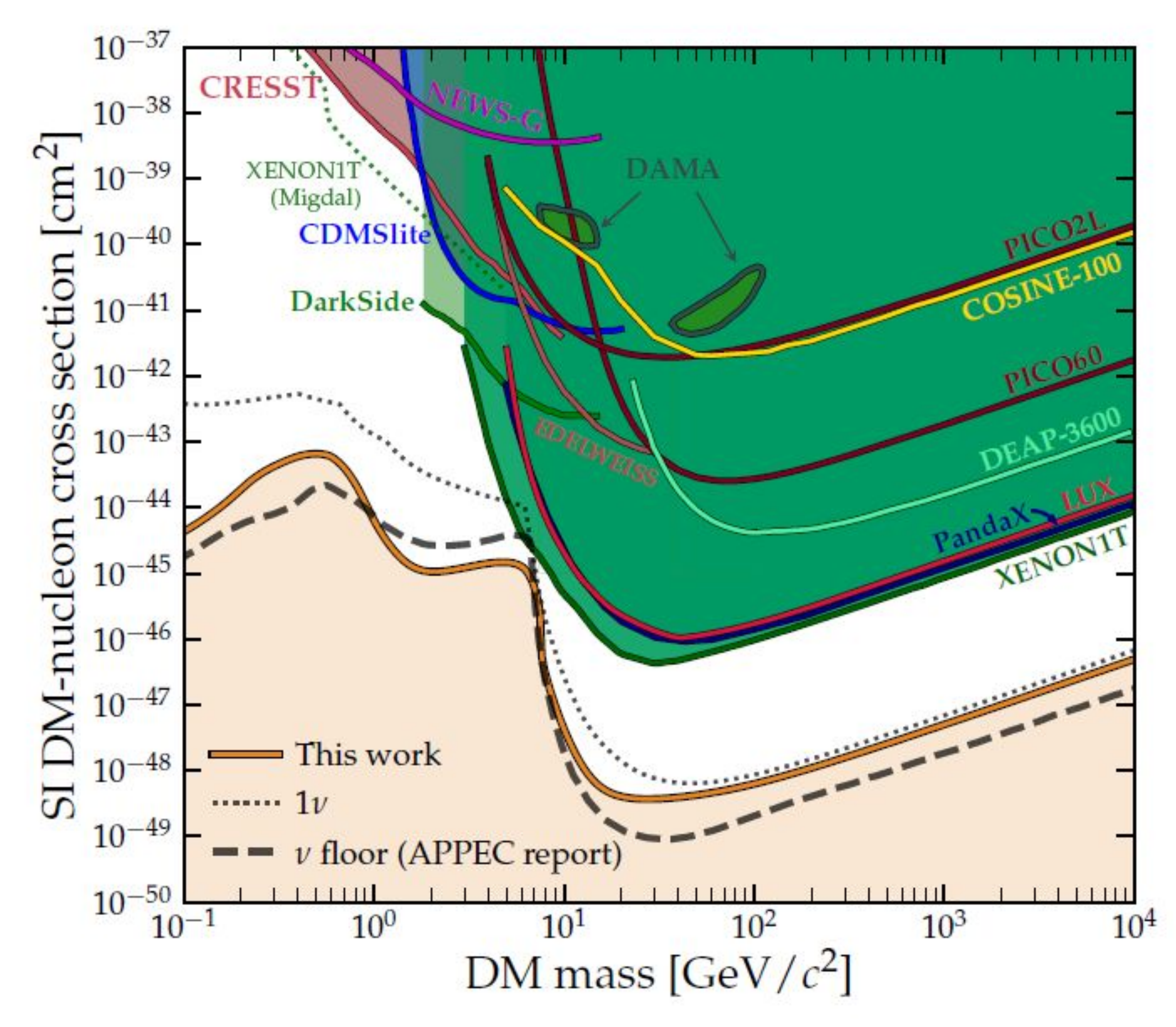
SOLAR NEUTRINO DETECTION AT DARK MATTER DETECTORS

Solar neutrinos with CEvNS and flavor-dependent radiative correction

arxiv: 2305.17827

Nityasa Mishra and Louis E. Strigari

NEUTRINO FLOOR



Plot credit:
arXiv: 2109.03116v2
Ciaran A. J. O'Hare

- arXiv:1712.06522
  David G. Cerdeno, Jonathan H. Davis, Malcolm Fairbairn, Aaron C. Vincent
- arXiv:1910.12437
  D. Aristizabal Sierra, Bhaskar Dutta, Shu Liao, Louis E. Strigari

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Outline

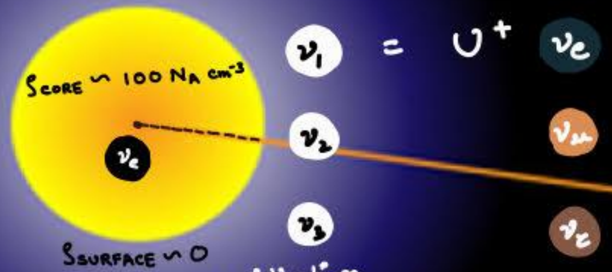
- Solar neutrinos
- Neutrino Oscillation
- CEνNS
- Radiative Correction
- Results

NEUTRINO SOURCE:

SOLAR NEUTRINOS AND NEUTRINO OSCILLATIONS

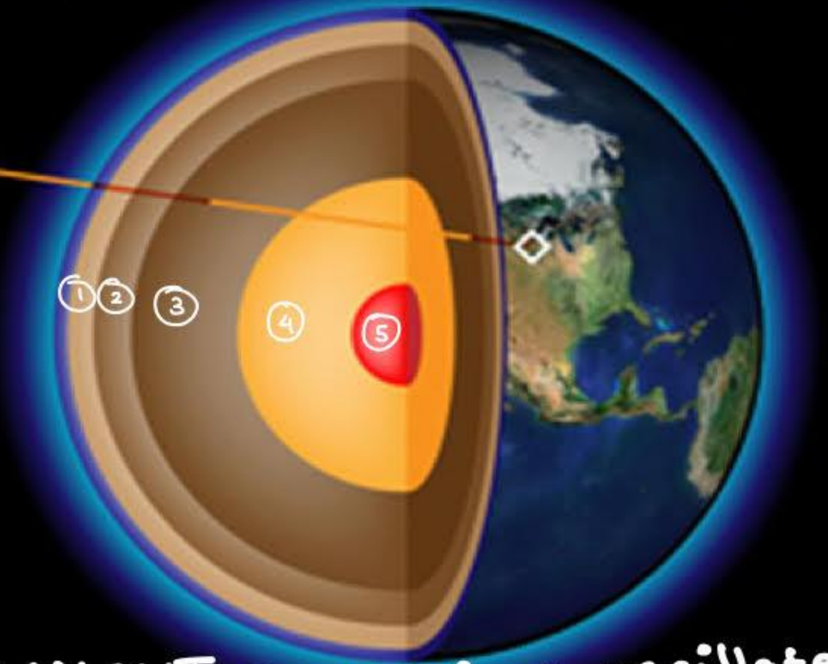
NEUTRINO PROPAGATION TROUGH EARTH

ρ variation "slow"



neutrino-oscillation in the sun

- **DAY** ~ same as surface of the sun



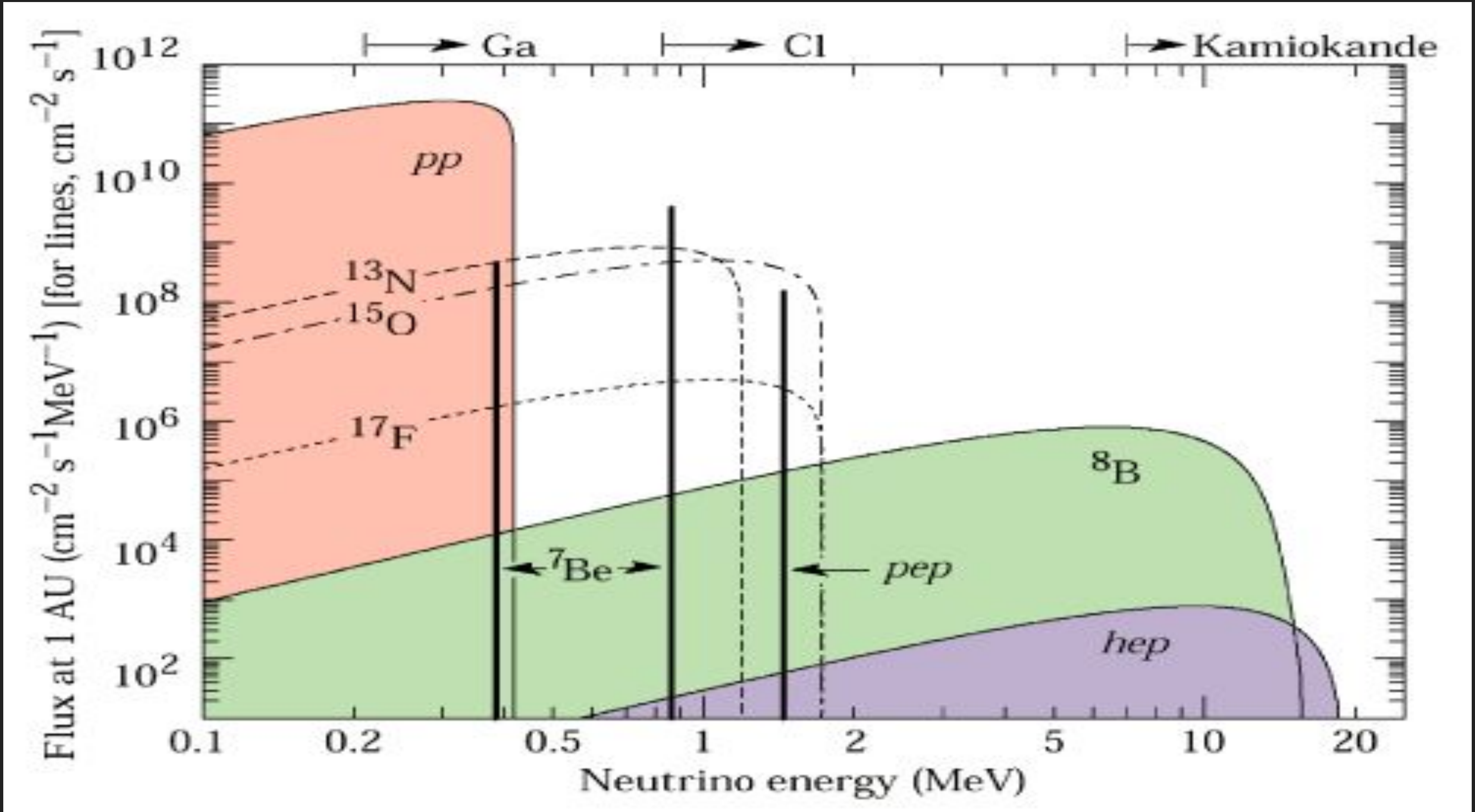
SOLAR NEUTRINOS

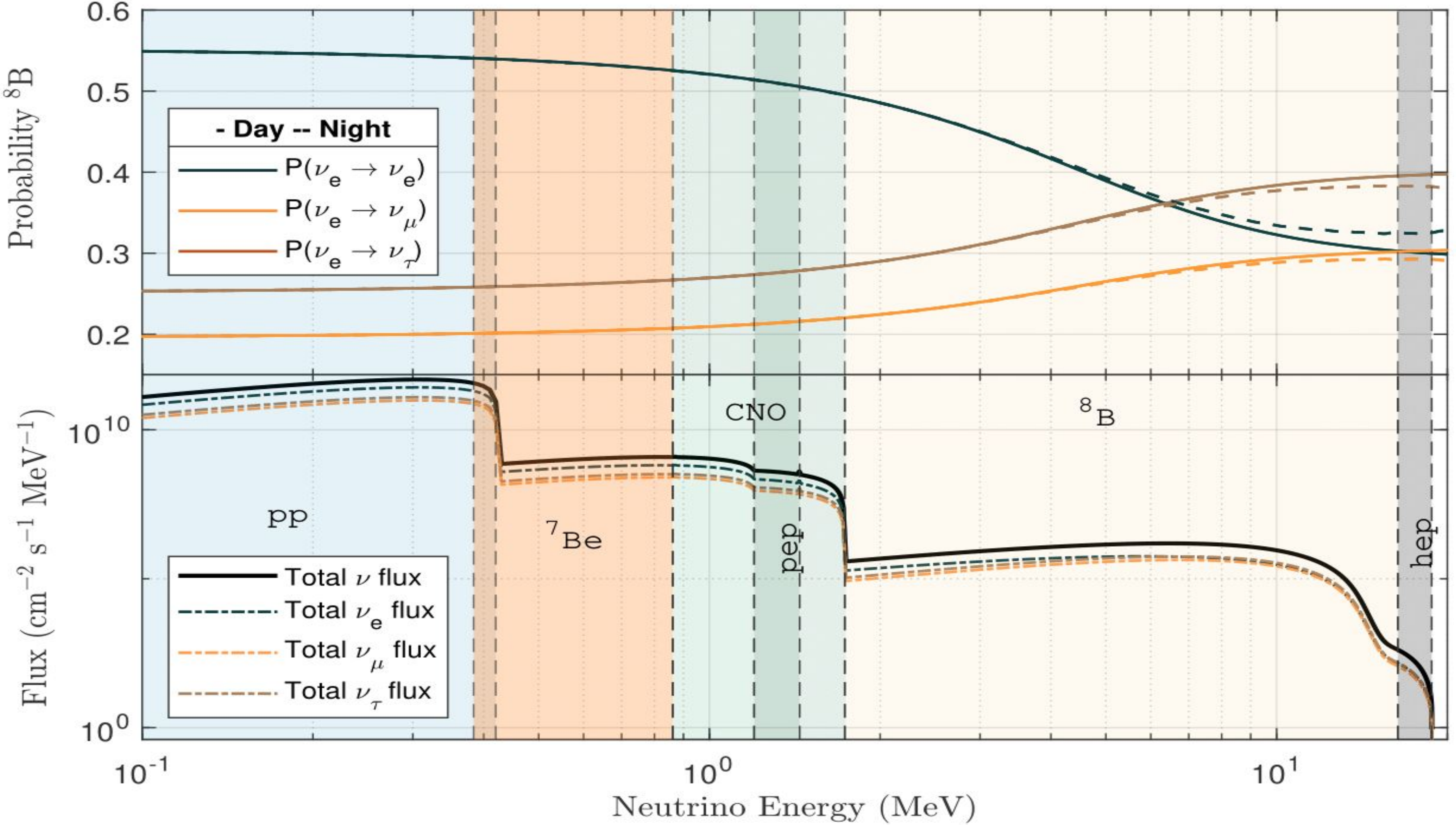
- pp chain
- CNO cycle

} produce ν_e

- Adiabatic propagation
- $\nu_e \rightarrow \nu_1, \nu_2, \nu_3$

- **NIGHT** ~ neutrinos oscillate through layers of Earth
  - Probability changes with Zenith angle


Ga
Cl
Kamiokande
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
Flux at 1 AU (cm^{-2}s^{-1}MeV^{-1}) [for lines, cm^{-2}s^{-1}]
pp
^{13}N
^{15}O
^{17}F
^{8}B
^{7}Be
pep
hep
0.1
0.2
0.5
1
2
5
10
20
Neutrino energy (MeV)



Probability ^{8}B
0.6
0.5
0.4
0.3
0.2
- Day -- Night
$P(\nu_e \to \nu_e)$
$P(\nu_e \to \nu_\mu)$
$P(\nu_e \to \nu_\tau)$
Flux ($cm^{-2}\ s^{-1}\ MeV^{-1}$)
10^{10}
10^0
pp
^{7}Be
CNO
pep
^{8}B
hep
Total ν flux
Total ν_e flux
Total ν_μ flux
Total ν_τ flux
10^{-1}
10^0
10^1
Neutrino Energy (MeV)

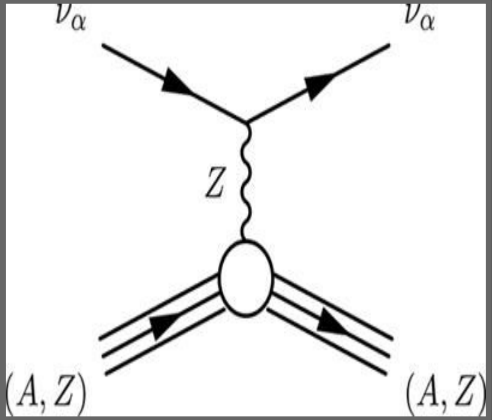
NEUTRINO DETECTION:

CEνNS AND FLAVOR-DEPENDENT RADIATIVE CORRECTIONS

arXiv:2011.05960 :
Oleksandr Tomalak, Pedro Machado,
Vishvas Pandey, Ryan Plestid

CEνNS

Coherent Elastic Neutrino Nucleus Scattering



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

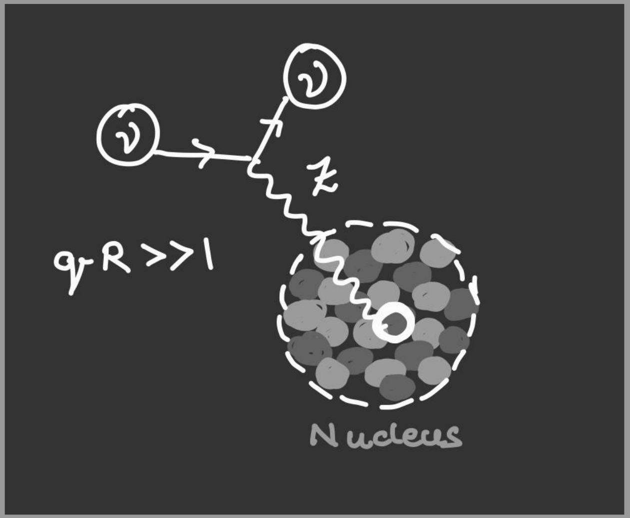
Coherent effects of a weak neutral current

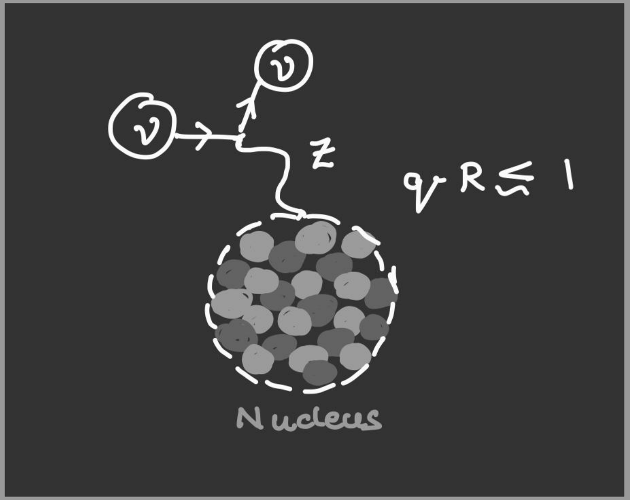
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

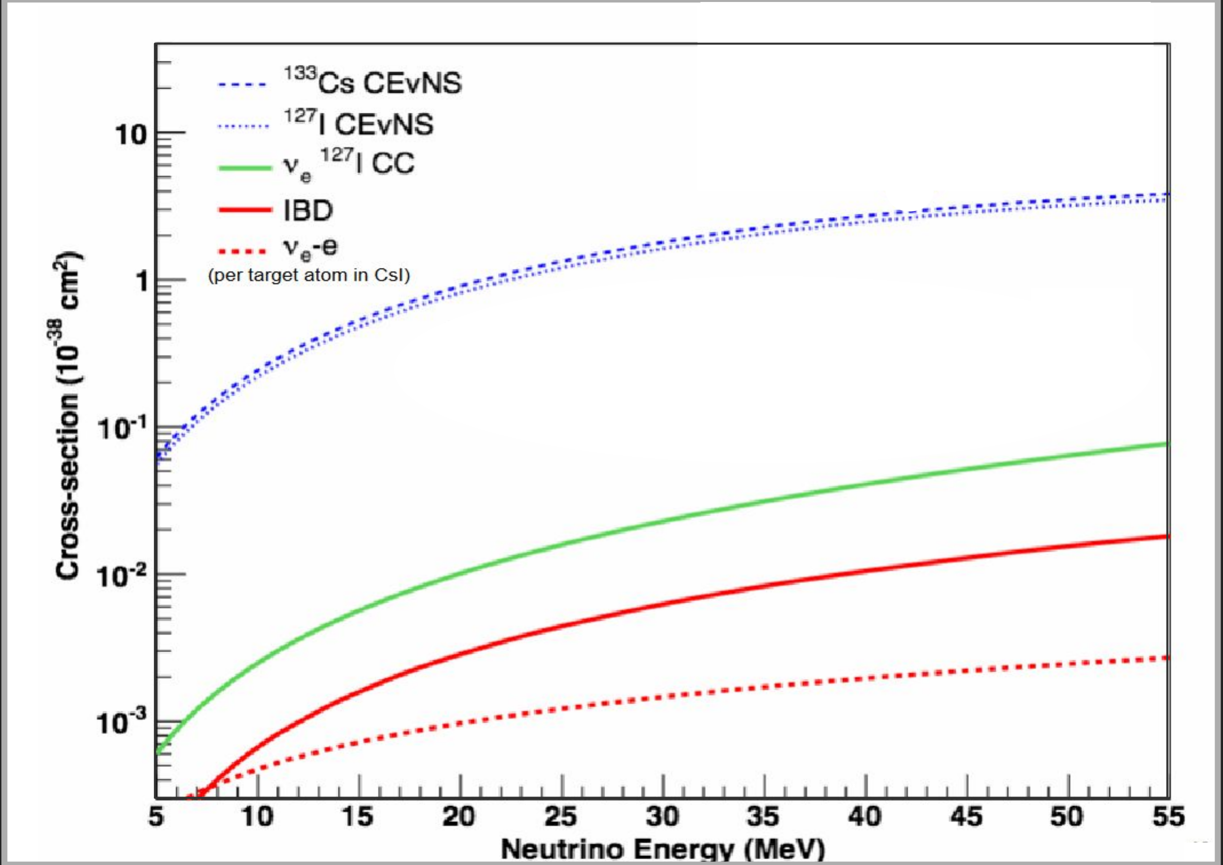
(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

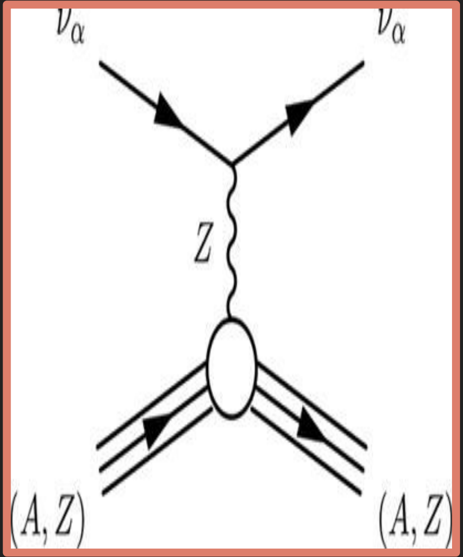
CEνNS → coherent enhancement ⟶ $\sigma \sim N^2$



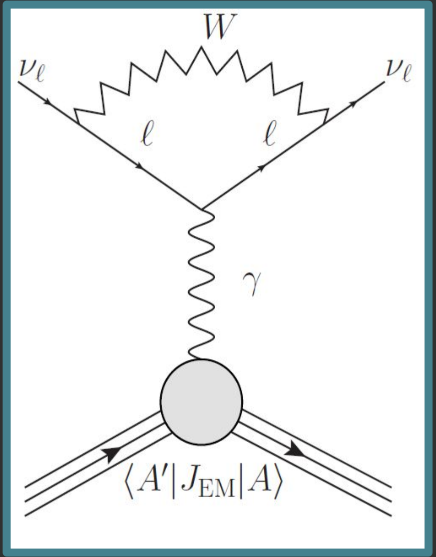


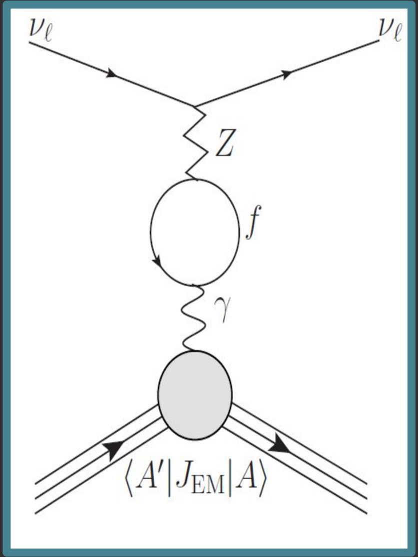


TREE-LEVEL



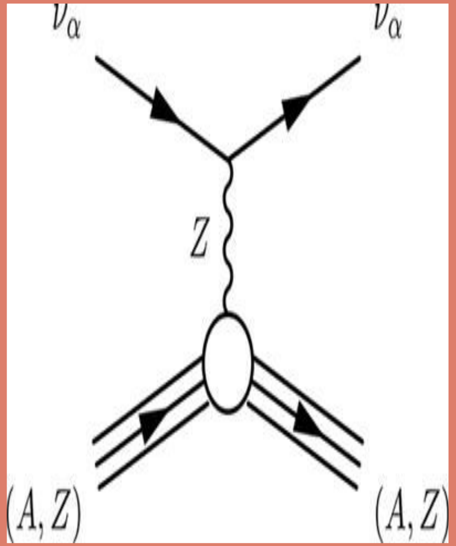
WITH RADIATIVE CORRECTION





arXiv:2011.05960 :
Oleksandr Tomalak, Pedro Machado,
Vishvas Pandey, Ryan Plestid

TREE-LEVEL

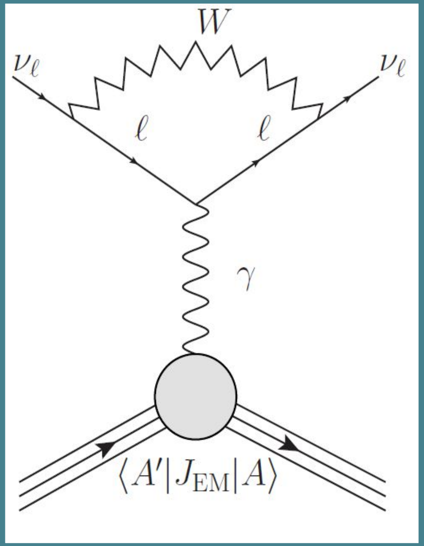


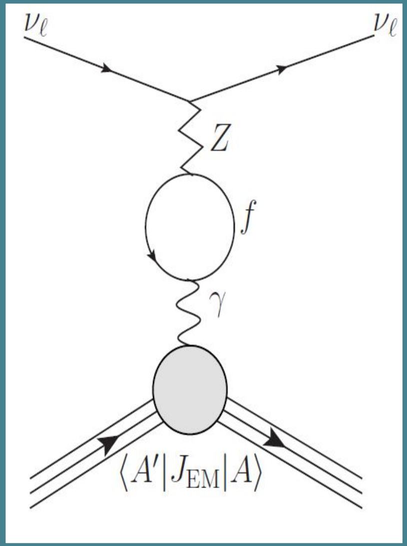
$$\frac{d\sigma_\nu}{dT} = \frac{G_F^2 M_A}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) Q_W^2 F_W^2(Q^2)$$

Weak charge:

$$Q_W = N - (1 - 4\sin^2\theta_w)Z$$

WITH RADIATIVE CORRECTION





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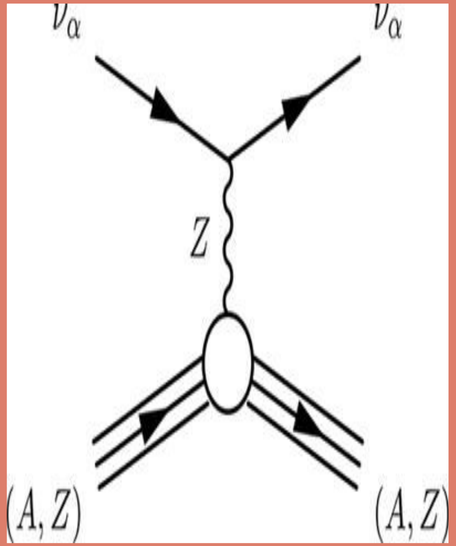
TREE-LEVEL



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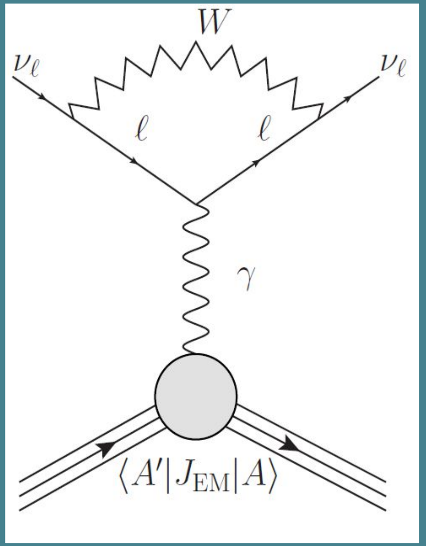
Weak charge:

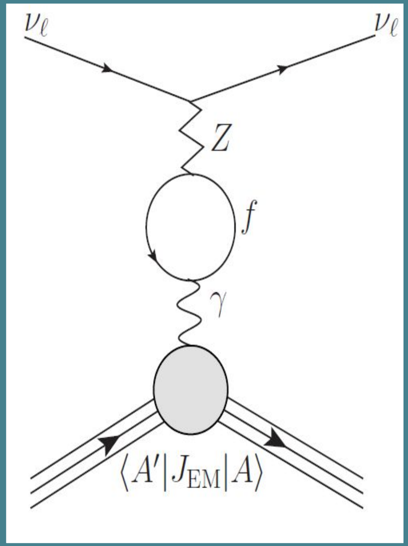
$$Q_W = N - (1 - 4\sin^2\theta_w)Z$$

Weak Form Factor:

$$F_W = \frac{1}{Q_W}[NF_n(Q^2) - (1 - 4\sin^2\theta_w)ZF_p(Q^2)]$$

WITH RADIATIVE CORRECTION





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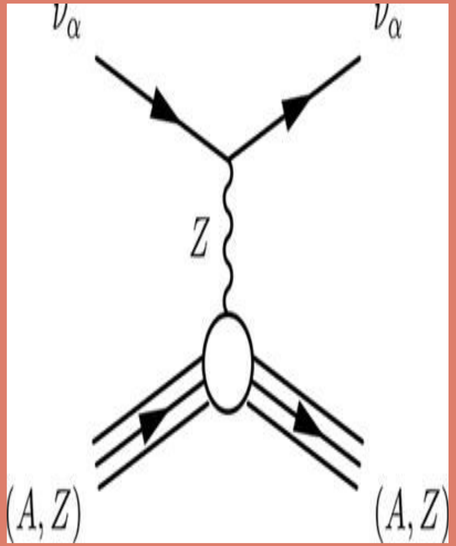
Oleksandr Tomalak, Pedro Machado, Vishvas Pandey, Ryan Plestid

TREE-LEVEL

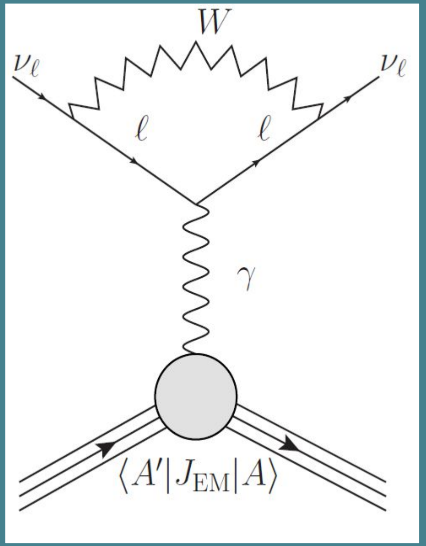


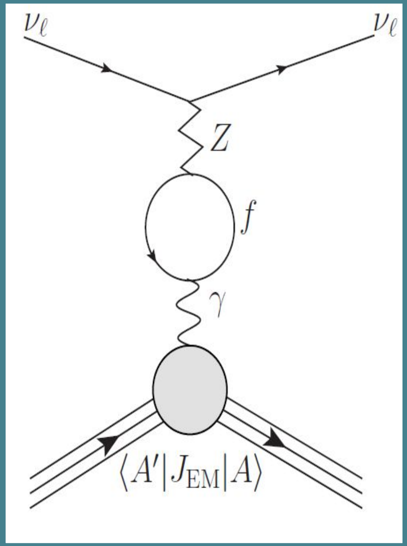
$$\frac{d\sigma_\nu}{dT} = \frac{G_F^2 M_A}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) Q_W^2 F_W^2(Q^2)$$

Weak Form Factor:

$$F_W = \frac{1}{Q_W}[N F_n(Q^2) - (1 - 4\sin^2\theta_w) Z F_p(Q^2)]$$

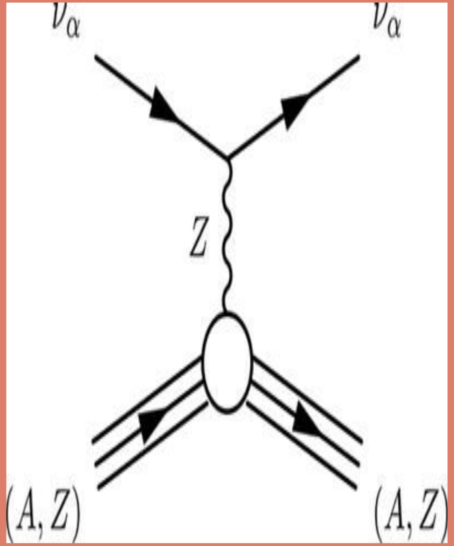
WITH RADIATIVE CORRECTION





$$\frac{d\sigma_{\nu l}}{dT} = \frac{G_F^2 M_A}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) \mathcal{F}_{\nu l}^2(Q^2)$$

TREE-LEVEL

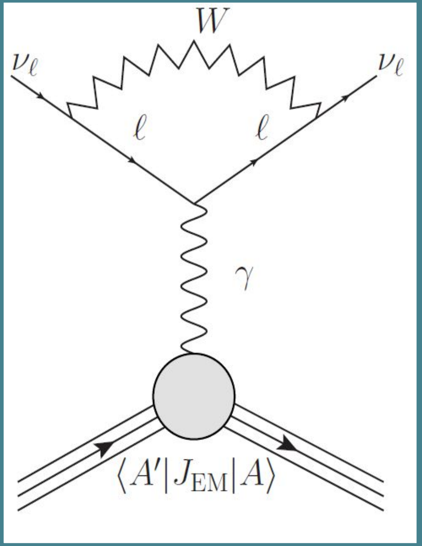


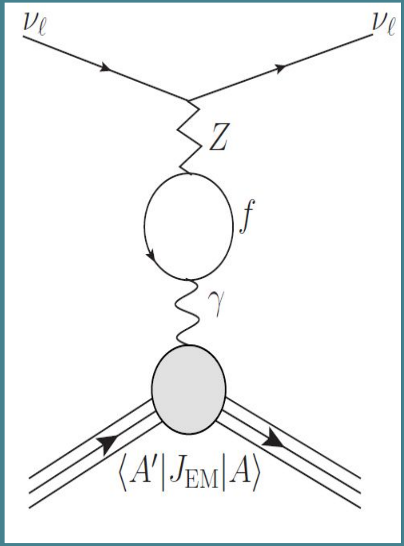
$$\frac{d\sigma_\nu}{dT} = \frac{G_F^2 M_A}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) Q_W^2 F_W^2(Q^2)$$

Weak Form Factor:

$$F_W = \frac{1}{Q_W}[N F_n(Q^2) - (1 - 4\sin^2\theta_w) Z F_p(Q^2)]$$

WITH RADIATIVE CORRECTION

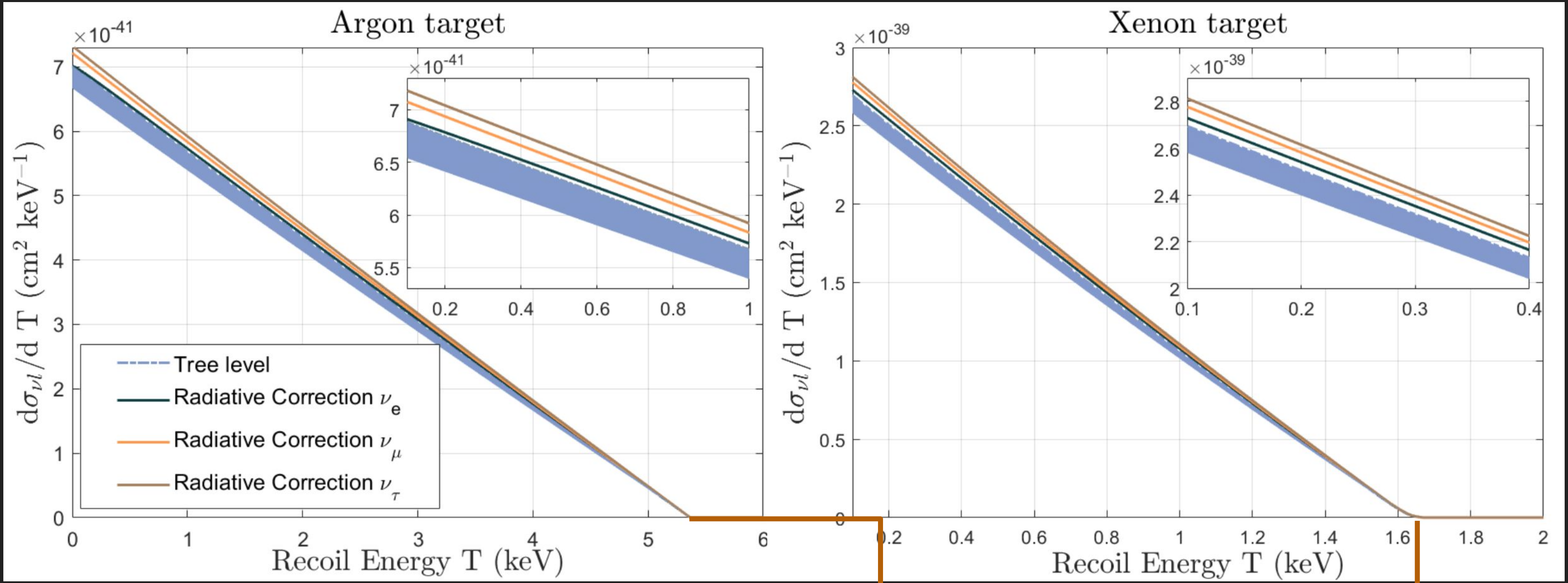




$$\frac{d\sigma_{\nu l}}{dT} = \frac{G_F^2 M_A}{4\pi}\left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) \mathcal{F}_{\nu l}^2(Q^2)$$

$$\mathcal{F}_{\nu l}(Q^2) = (\mathcal{F}_W(Q^2) + \frac{\alpha}{\pi}[\delta^{\nu l} + \delta^{QCD}]\mathcal{F}_{ch}(Q^2))$$

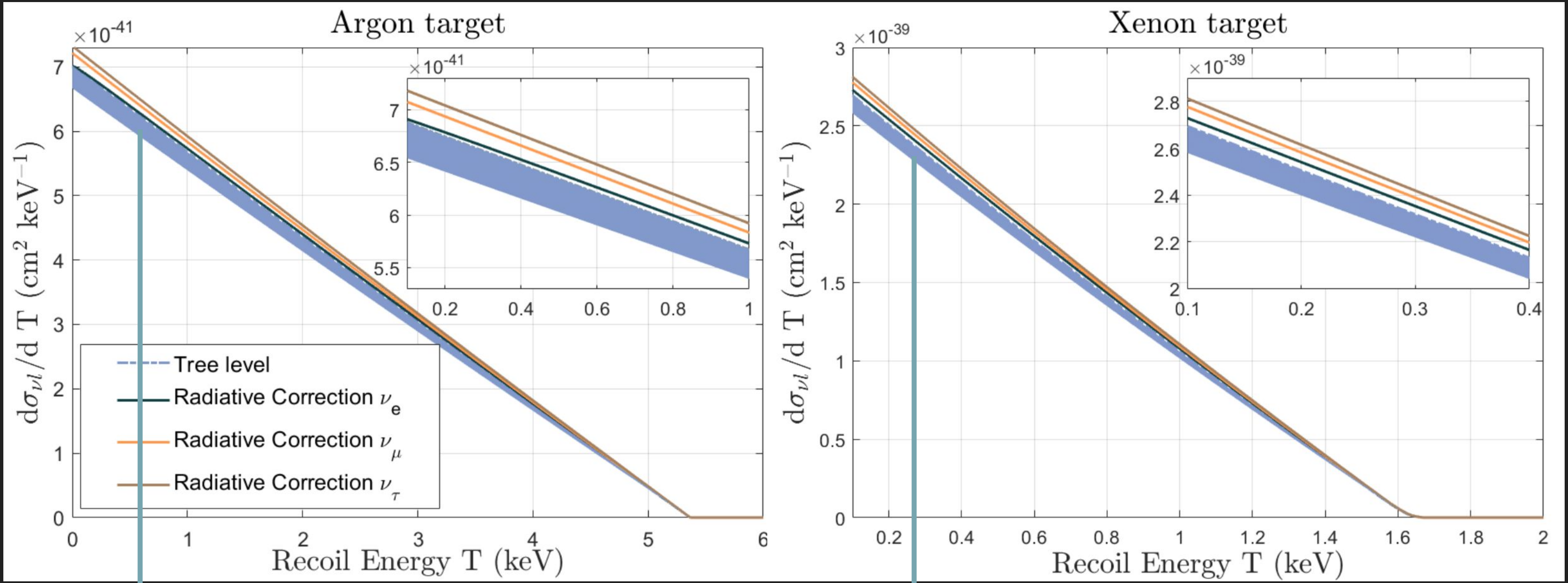
CEνNS DIFFERENTIAL CROSS-SECTION



$$F_W = \frac{1}{Q_W}[NF_n(Q^2) - (1 - 4\sin^2\theta_w)ZF_p(Q^2)]$$

$$T_{max} = \frac{2E_\nu^2}{M_A + 2E_\nu}.$$

Cross-section for $\nu_\tau > \nu_\mu > \nu_e$ radiative corrections > Cross-section for tree-level ($\nu_\tau = \nu_\mu = \nu_e$)



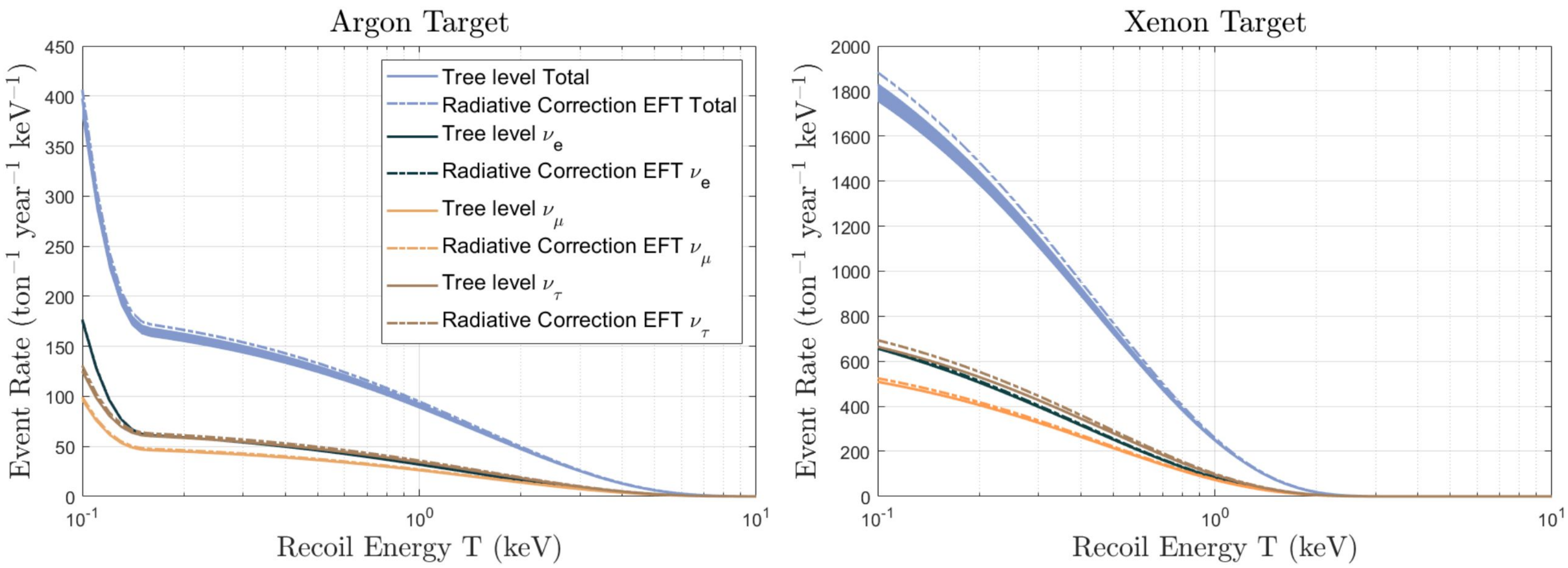
$$F_W = \frac{1}{Q_W}[NF_n(Q^2) - (1 - 4\sin^2\theta_w)ZF_p(Q^2)]$$

$$T_{max} = \frac{2E_\nu^2}{M_A + 2E_\nu}.$$

RESULTS:

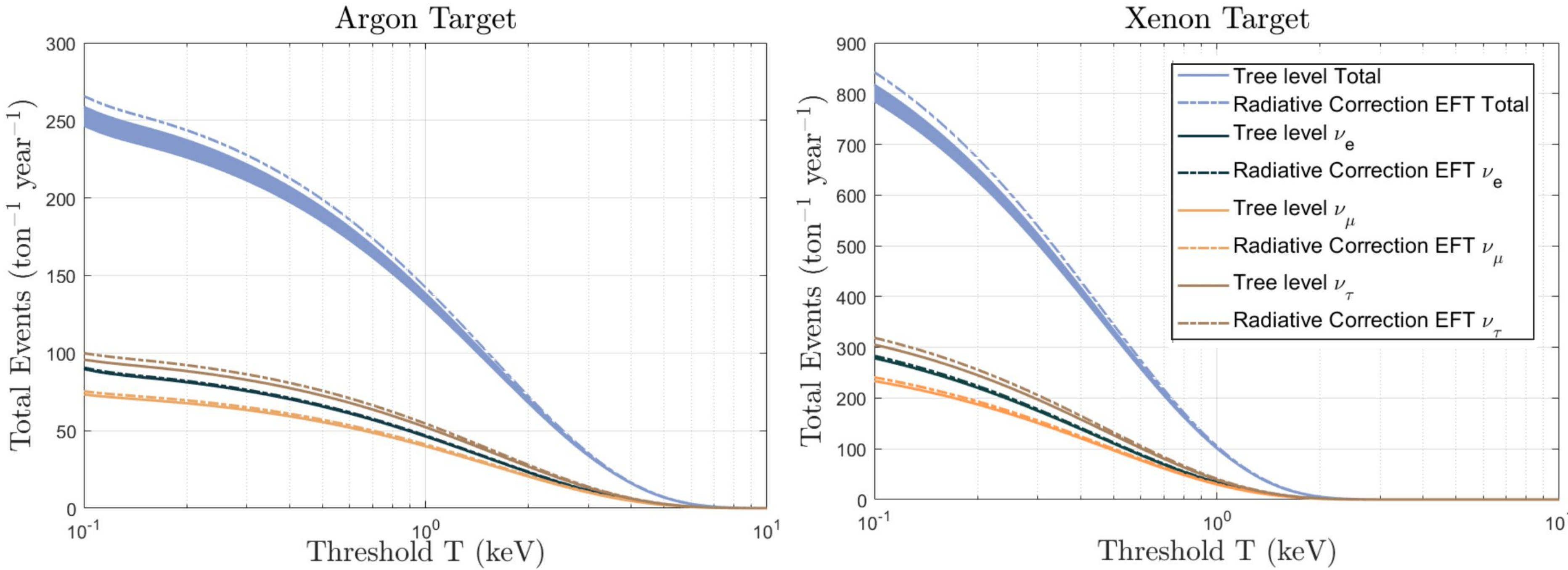
FOR ARGON AND XENON TARGETS

EVENT RATE:



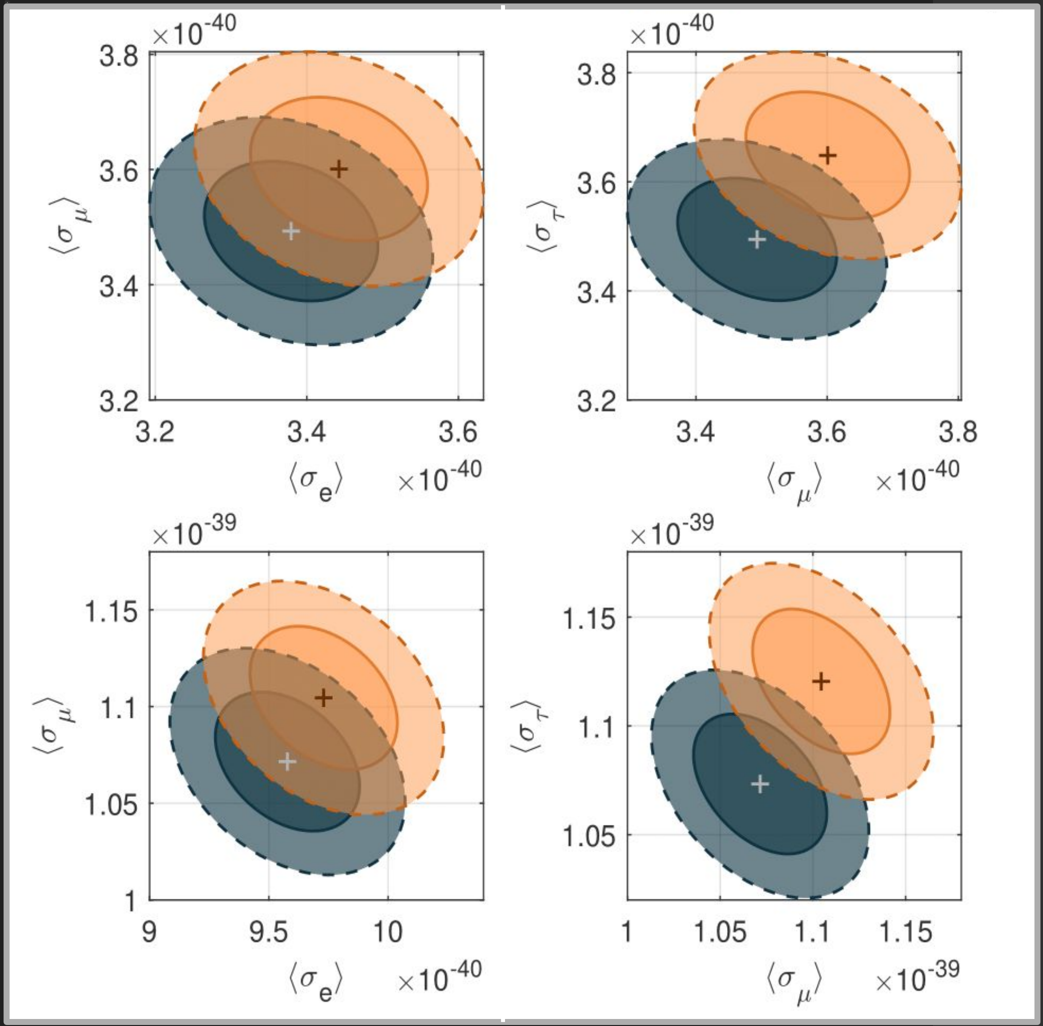
$$\frac{dN_\alpha}{dT} = \int_{E_{\nu,min}} \frac{d\phi(E_\nu)}{dE_\nu} \frac{d\sigma_\alpha(E_\nu, T)}{dT} P(\nu_e \to \nu_\alpha) dE_\nu$$

EVENTS:



$$N_\alpha = \int_{T_{th}} \frac{dN_\alpha}{dT} dT.$$

XENON TARGET
ERROR ELLIPSES



$$\mu_i = \sum_\alpha f_\alpha \mu_{i\alpha} = f_e \mu_{ie} + f_\mu \mu_{i\mu} + f_\tau \mu_{i\tau}$$

$$= f_e N_{ie} + f_\mu N_{i\mu} + f_\tau N_{i\tau}$$

$$f_\alpha = \frac{\langle\phi_\alpha\rangle}{\langle\phi_\alpha\rangle_{SSM}}.$$

$$\phi_\alpha \sim \langle \phi P_{e\alpha} \rangle$$

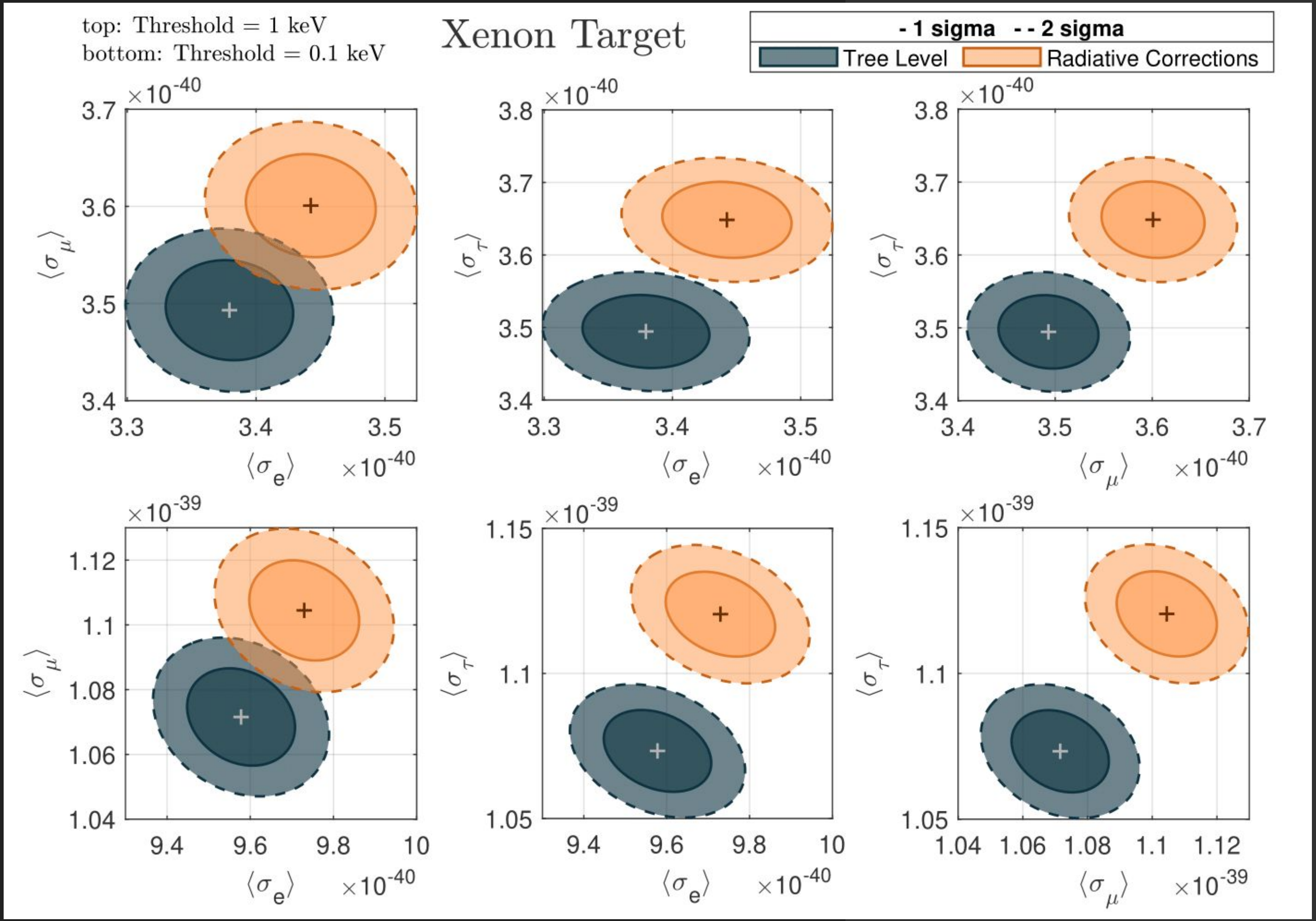
$\sin^2\theta_w = 0.2385$

flux prior:2.5%
Exp:100 ton-yr

top: Threshold = 1 keV
bottom: Threshold = 0.1 keV

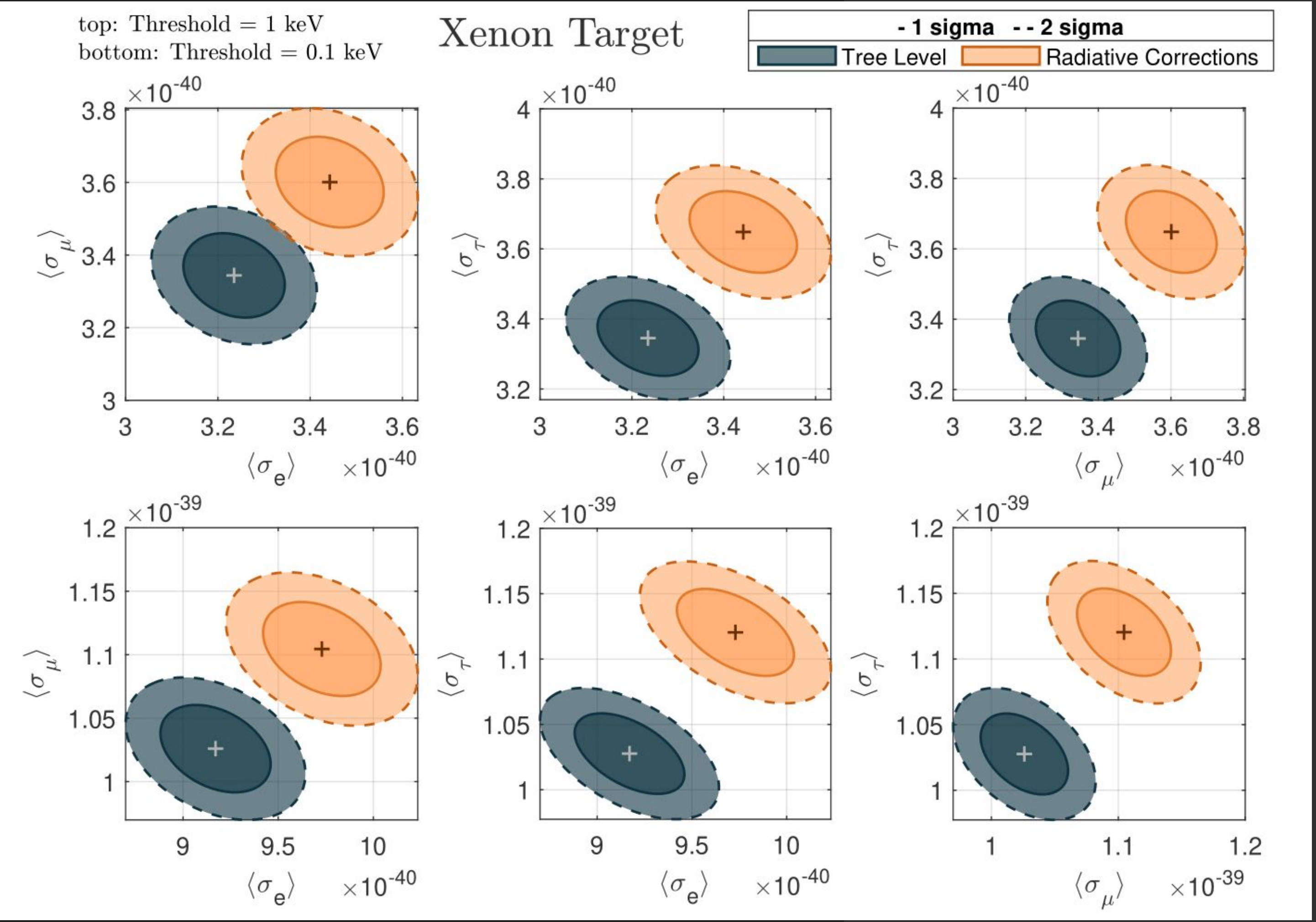
- 1 sigma - - 2 sigma

Tree Level | Radiative Corrections



$\sin^2 \theta_w = 0.2385$

Flux prior: 1%



$\sin^2\theta_w = 0.23112$

Flux prior: 2.5%

EFFECTIVE 2-FLAVOR MODEL FOR DETECTION OF ν_τ

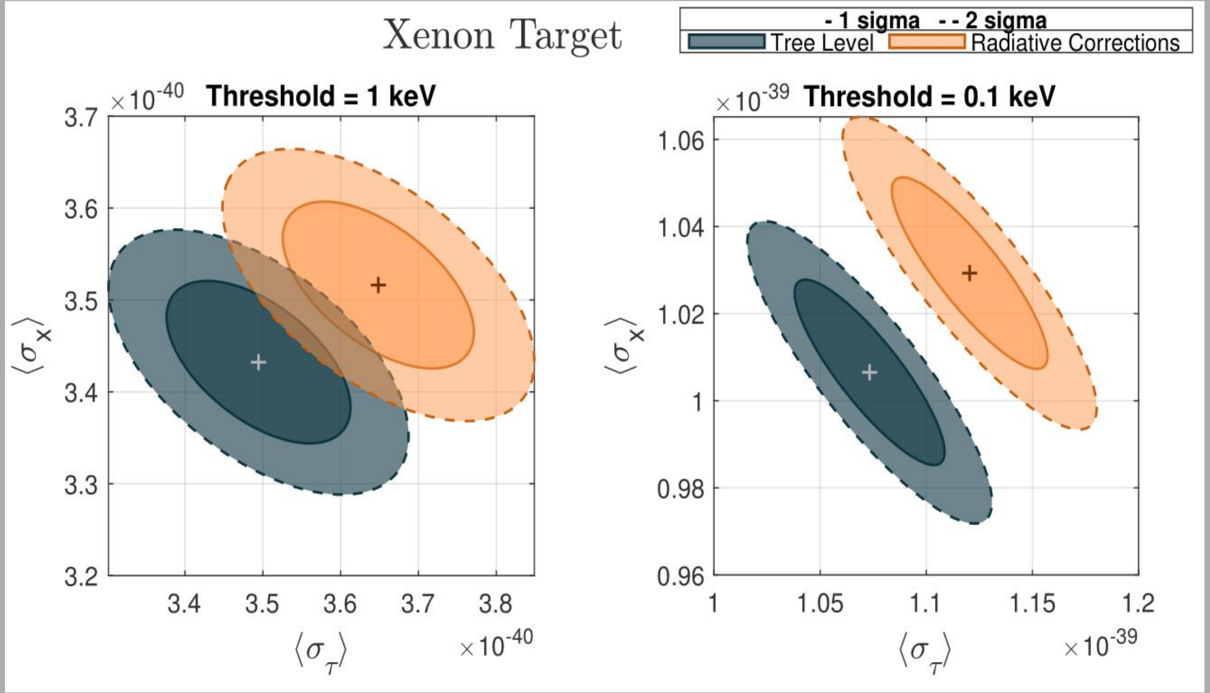
$$\mu_i = f_\tau N_{i\tau} + f_x(N_{i\mu} + f_\tau N_{ie})$$

$$\langle\sigma_x\rangle = \frac{N_e + N_\mu}{T_{exp}\langle\phi_x\rangle}$$

$$\langle\phi_x\rangle = \langle\phi_e\rangle + \langle\phi_\mu\rangle$$

Flux prior: 2.5%

$\sin^2\theta_w = 0.2385$



DAY-NIGHT ASYMMETRY

$$A = 2\frac{N_N - N_D}{N_N + N_D}$$

$$A \simeq -2.5 \times 10^{-4}$$

*requires $O(10^5)$ tonne - years

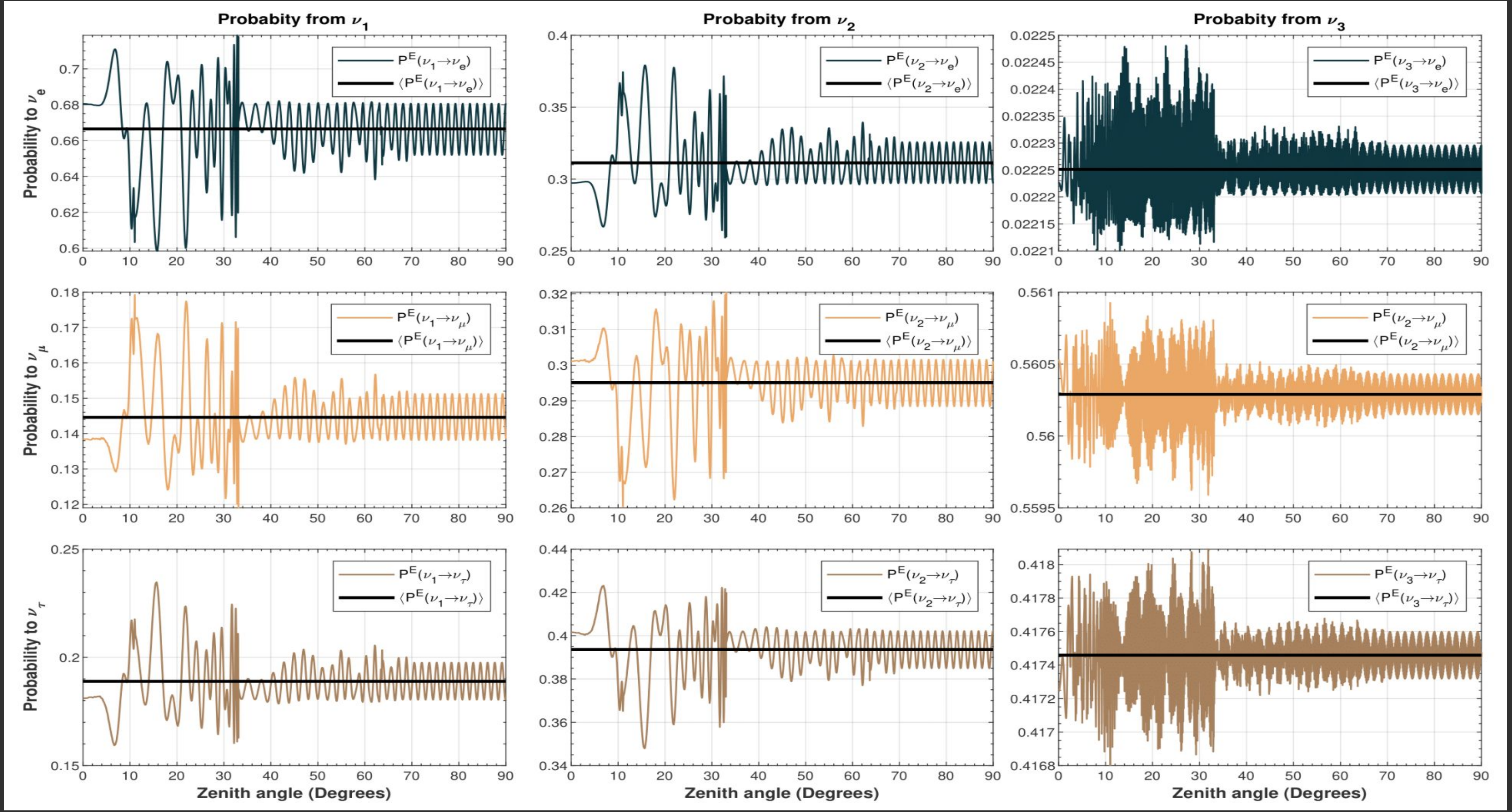
CONCLUSION:

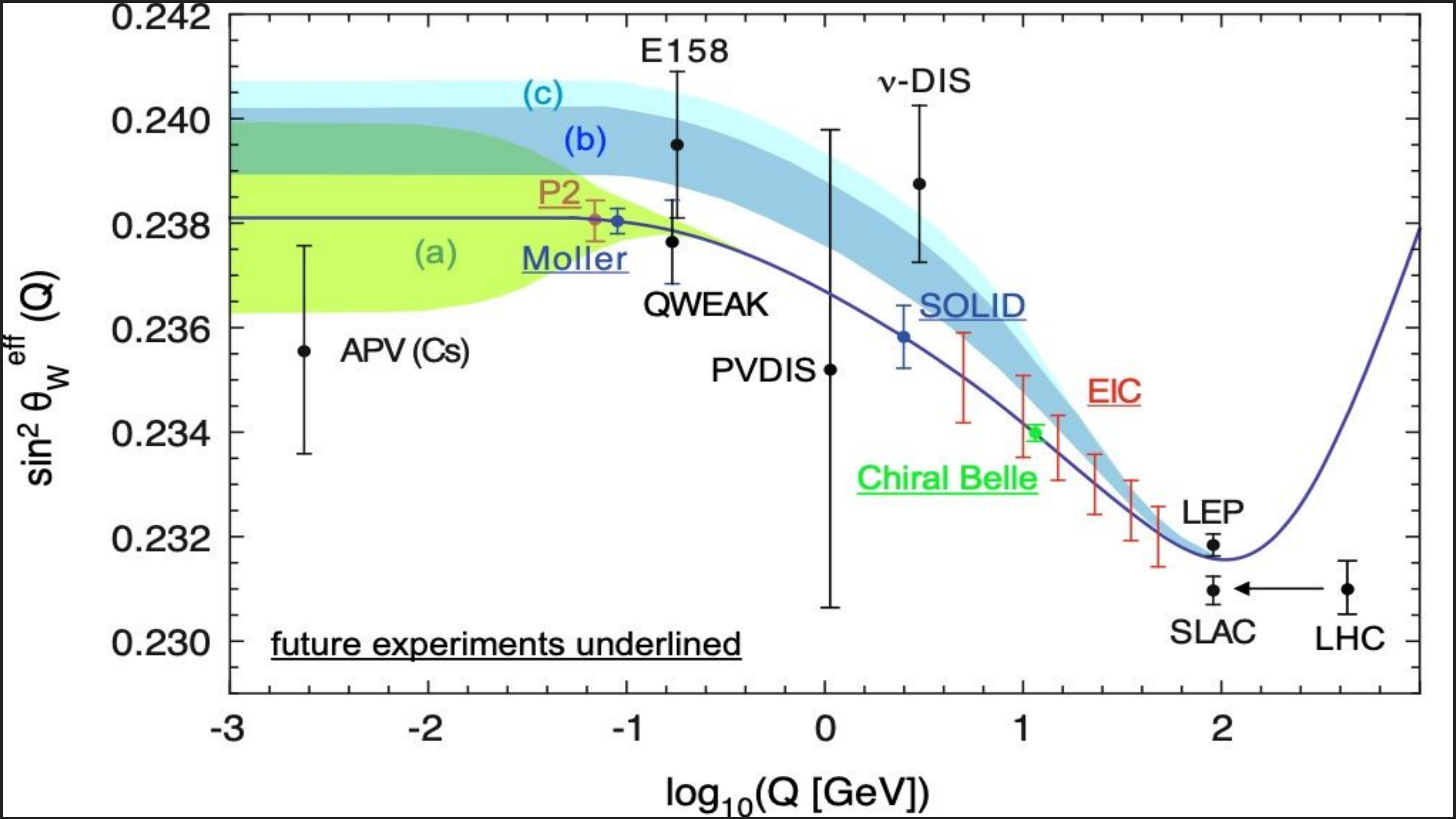
Within the context of a full three-flavor analysis that includes the
effects of matter oscillations in the Sun and the Earth, we find that detectors with exposure ~ 100 ton-year would be able to
measure a cross section value that deviates from the tree-level prediction.

FUTURE ASPECTS

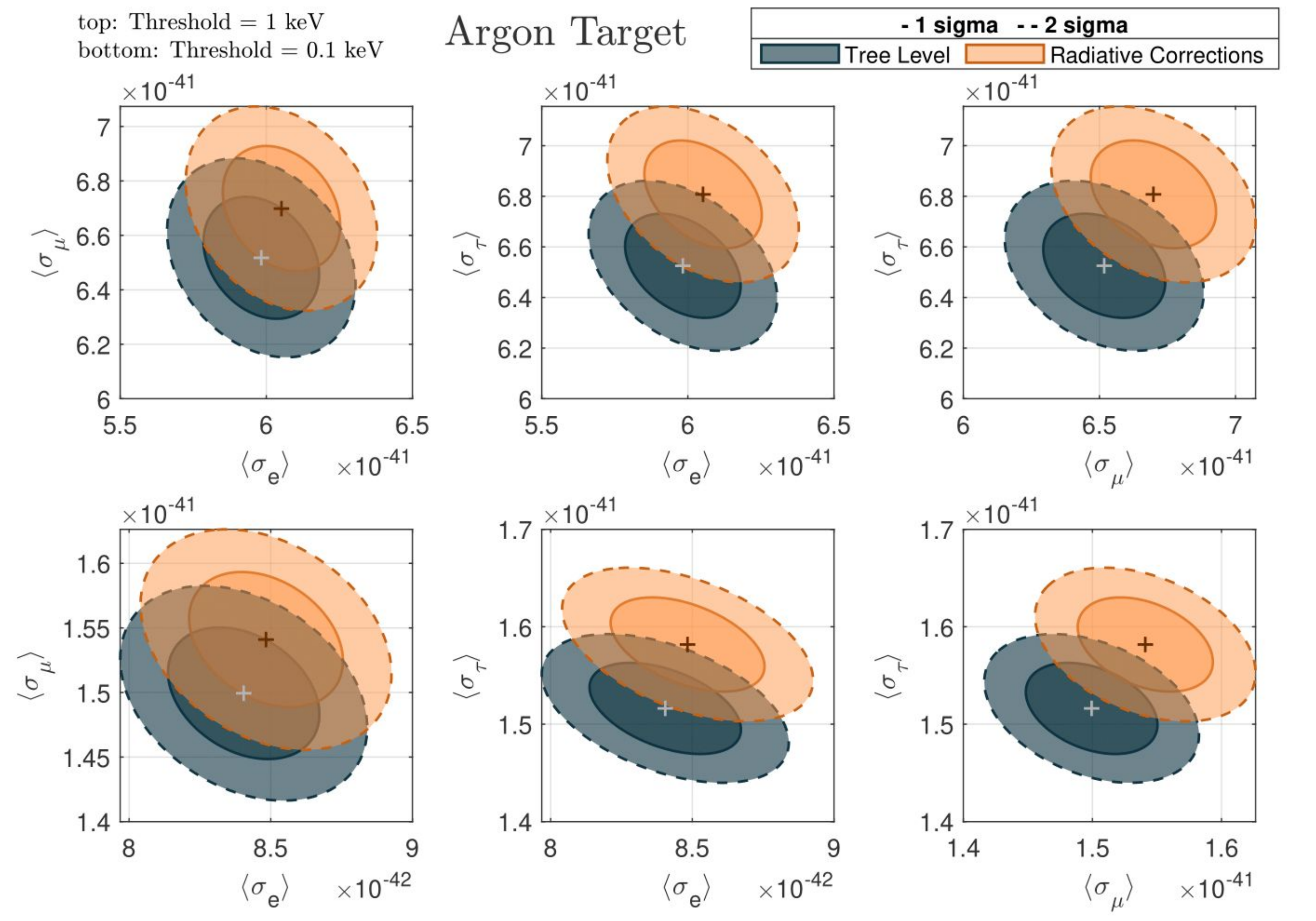
- Rigorous monte-carlo based simulation analysis with backgrounds
- Analysis with other neutral current channels arXiv:2306.03160 Vedran Brdar, Xun-Jie Xu
- BSM physics

BACKUP SLIDES

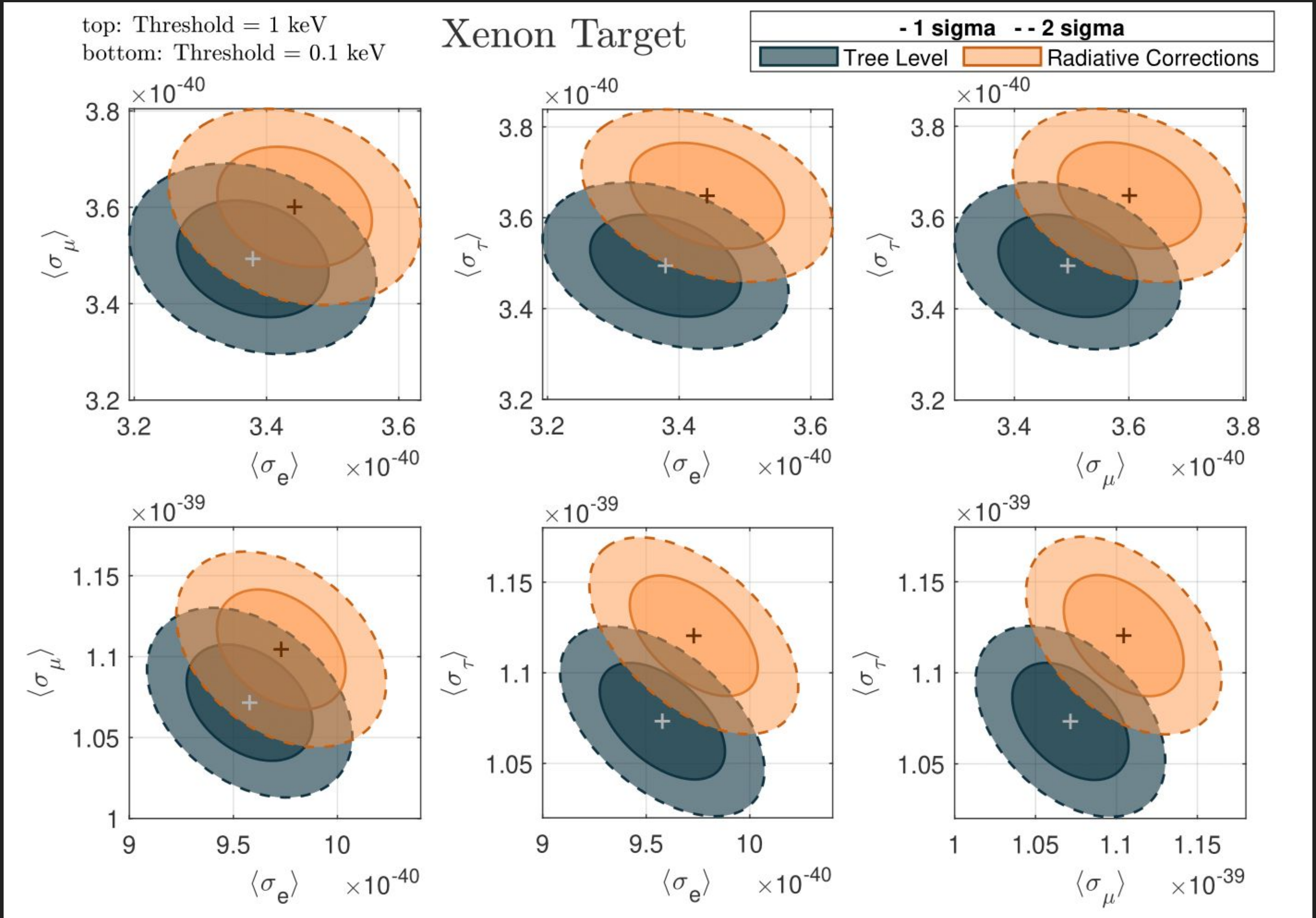

Probabity from ν_1
Probabity from ν_2
Probabity from ν_3
Probability to ν_e
Probability to ν_μ
Probability to ν_τ
$P^E(\nu_1\to\nu_e)$
$\langle P^E(\nu_1\to\nu_e)\rangle$
$P^E(\nu_2\to\nu_e)$
$\langle P^E(\nu_2\to\nu_e)\rangle$
$P^E(\nu_3\to\nu_e)$
$\langle P^E(\nu_3\to\nu_e)\rangle$
$P^E(\nu_1\to\nu_\mu)$
$\langle P^E(\nu_1\to\nu_\mu)\rangle$
$P^E(\nu_2\to\nu_\mu)$
$\langle P^E(\nu_2\to\nu_\mu)\rangle$
$P^E(\nu_2\to\nu_\mu)$
$\langle P^E(\nu_2\to\nu_\mu)\rangle$
$P^E(\nu_1\to\nu_\tau)$
$\langle P^E(\nu_1\to\nu_\tau)\rangle$
$P^E(\nu_2\to\nu_\tau)$
$\langle P^E(\nu_2\to\nu_\tau)\rangle$
$P^E(\nu_3\to\nu_\tau)$
$\langle P^E(\nu_3\to\nu_\tau)\rangle$
Zenith angle (Degrees)
Zenith angle (Degrees)
Zenith angle (Degrees)



E158
ν-DIS
(c)
(b)
(a)
P2
Moller
QWEAK
APV (Cs)
PVDIS
SOLID
EIC
Chiral Belle
LEP
SLAC
LHC
future experiments underlined
0.242
0.240
0.238
0.236
0.234
0.232
0.230
-3
-2
-1
0
1
2
sin² θ_W^eff (Q)
log₁₀(Q [GeV])



top: Threshold = 1 keV
bottom: Threshold = 0.1 keV
Argon Target
- 1 sigma - - 2 sigma
Tree Level
Radiative Corrections
⟨σ_e⟩
⟨σ_μ⟩
⟨σ_τ⟩
×10^-41
×10^-42


top: Threshold = 1 keV
bottom: Threshold = 0.1 keV
Xenon Target
- 1 sigma - - 2 sigma
Tree Level
Radiative Corrections
$\langle\sigma_\mu\rangle$
$\langle\sigma_e\rangle$
$\langle\sigma_\tau\rangle$
$\times 10^{-40}$
$\times 10^{-39}$