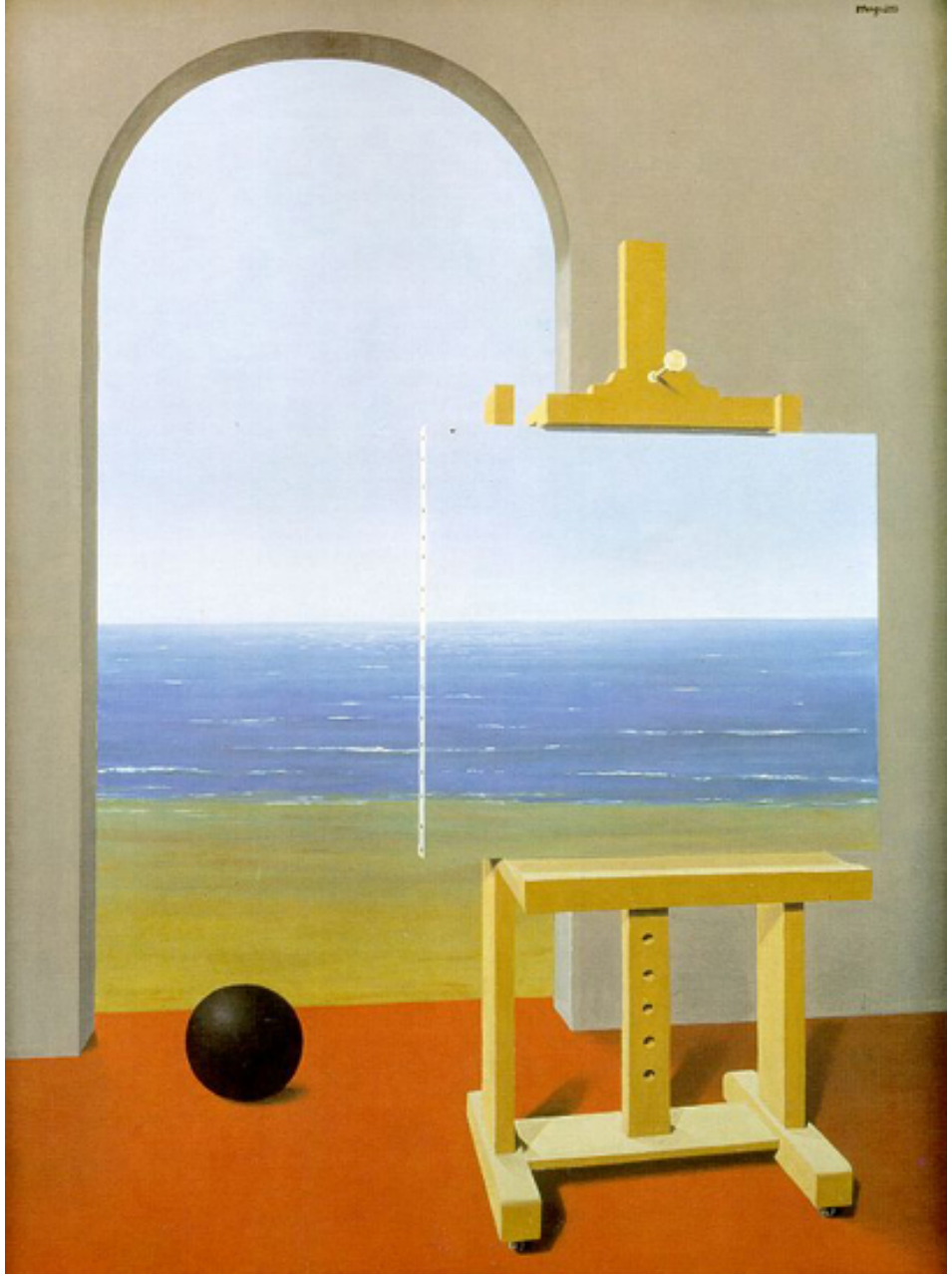


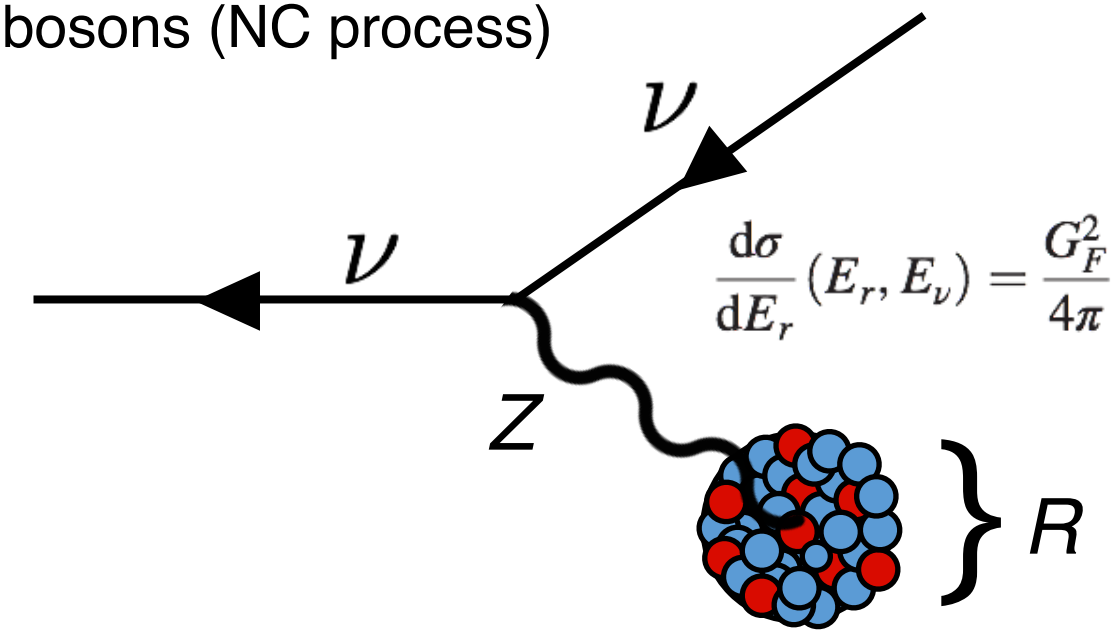
CEνNS

SM signal, DM background, BSM test

James Dent
Sam Houston State University

Partially based on Dent, Dutta, Newstead, Liao, Strigari, Walker, 1612.06350
and Dent, Dutta, Newstead, Liao, Strigari, Walker, in progress

Elastic neutrino-nucleus scattering proceeds through the exchange of Z bosons (NC process)



$$\frac{d\sigma}{dE_r}(E_r, E_\nu) = \frac{G_F^2}{4\pi} Q_W^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r),$$

The Standard Model prediction goes back to 1974, but experimental confirmation has yet to occur

D.Z. Freedman, PRD 9 (1974) 5 1389-1392

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering.

Coherence occurs due to comparing the neutrino wavelength to the nuclear size. The effect is to enhance the cross section by roughly an N^2 factor.

$$qR \lesssim 1$$

Kinematics Orientation

Momentum Exchanged

$$|\vec{q}| = \sqrt{2E_\nu m}$$

Up to 10s of MeV range

$$E_\nu \lesssim 50\text{MeV}$$

Coherent nuclear scattering

$$q < \frac{1}{R_{nucleus}}$$

Nuclear Recoil energy $O(1\text{keV})$

$$E_R = \frac{2mE_\nu^2\cos^2\theta}{(m+E_\nu)^2 - E_\nu^2\cos^2\theta}$$

$$E_{R,max} = \frac{2E_\nu^2}{m+2E_\nu}$$

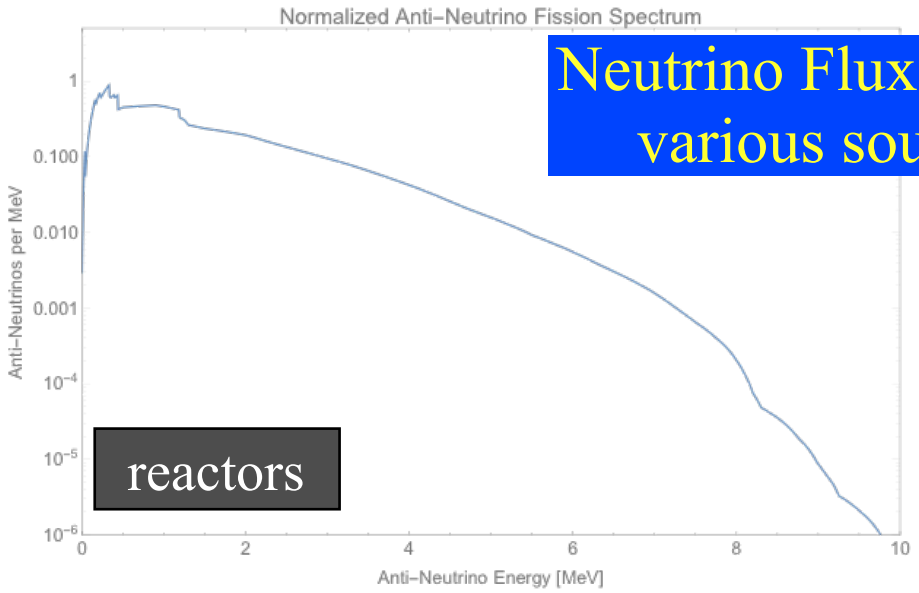
For A ~ 50

$$E_\nu \approx 5\text{MeV} \Longrightarrow E_R \approx 1\text{keV}$$

low threshold detectors needed

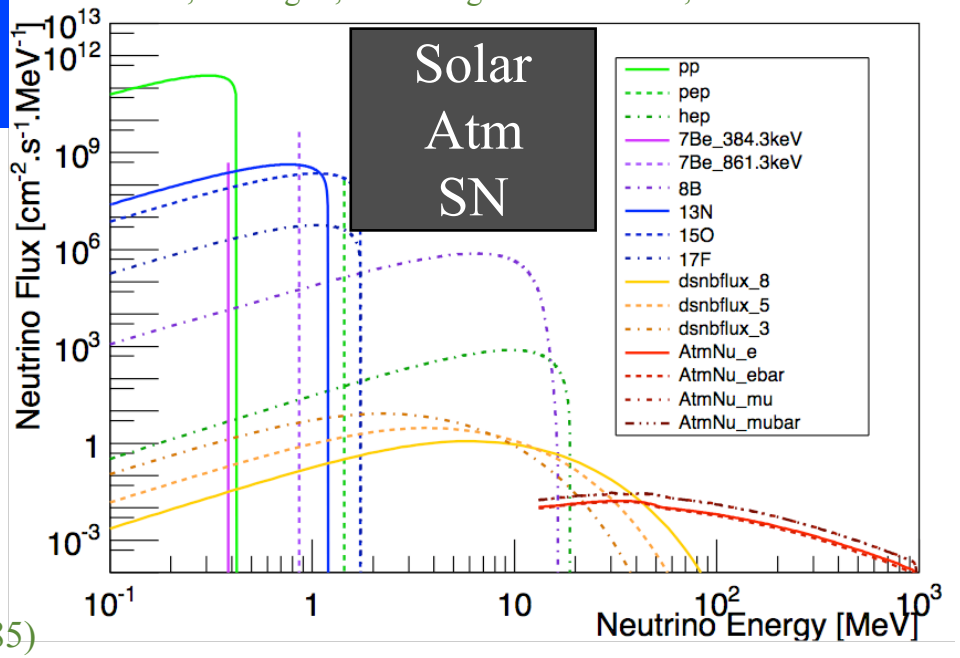
(Electron recoil energy goes much higher)

Neutrino Fluxes from various sources



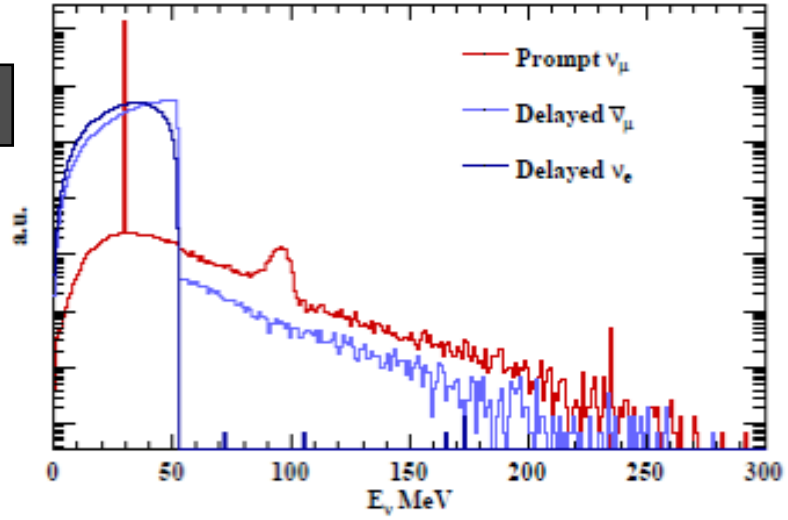
V.I. Kopeikin (2012)
K. Schreckenbah, G. Colvin, W. Gelletly, and F. Von Feilitzsch, PLB (1985)
B. Dutta, R. Mahapatra, L.E. Strigari, and J.W. Walker, 1508.07981 PRD

J. Billard, L. Strigari, and E. Figueroa-Feliciano, arXiv:1307.5458 PRD

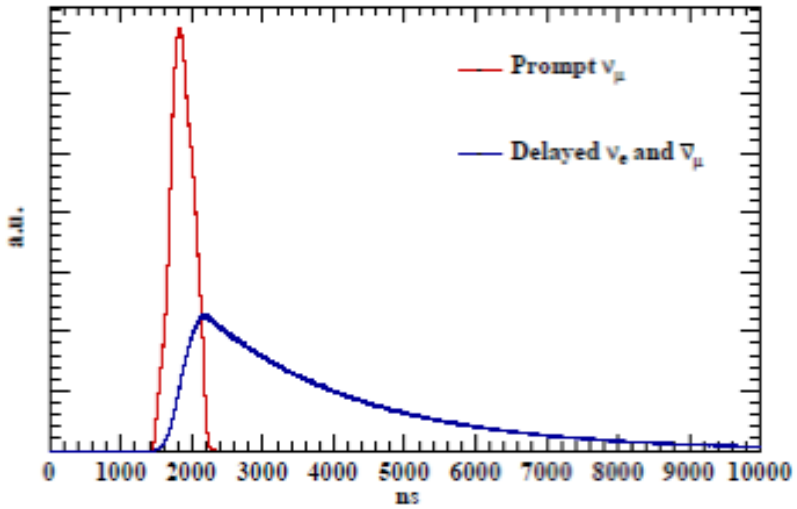


SPS

COHERENT Collaboration
1509.08702

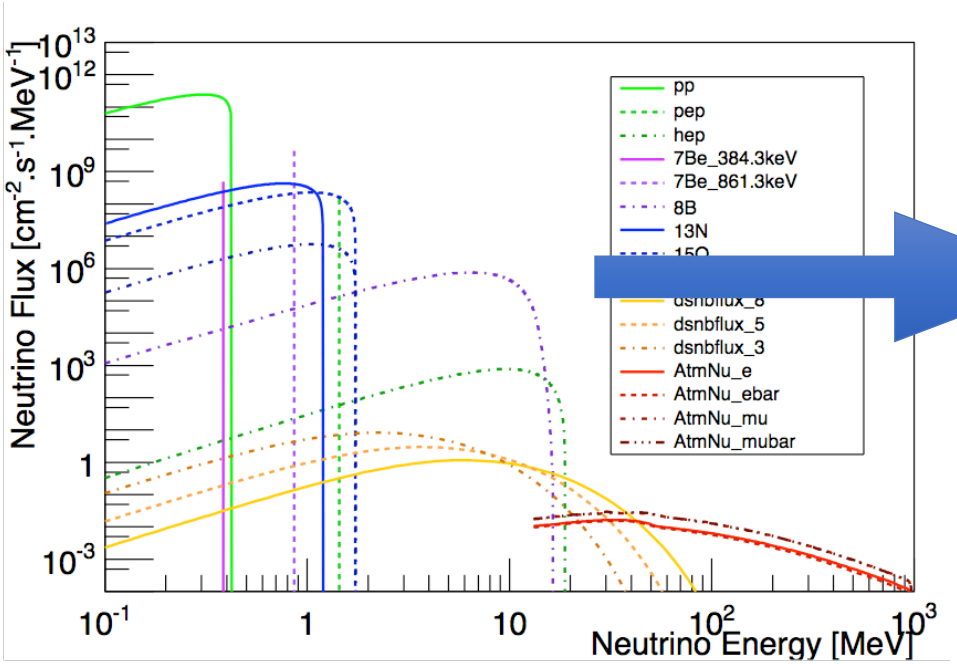


(a)SNS neutrino energy spectrum

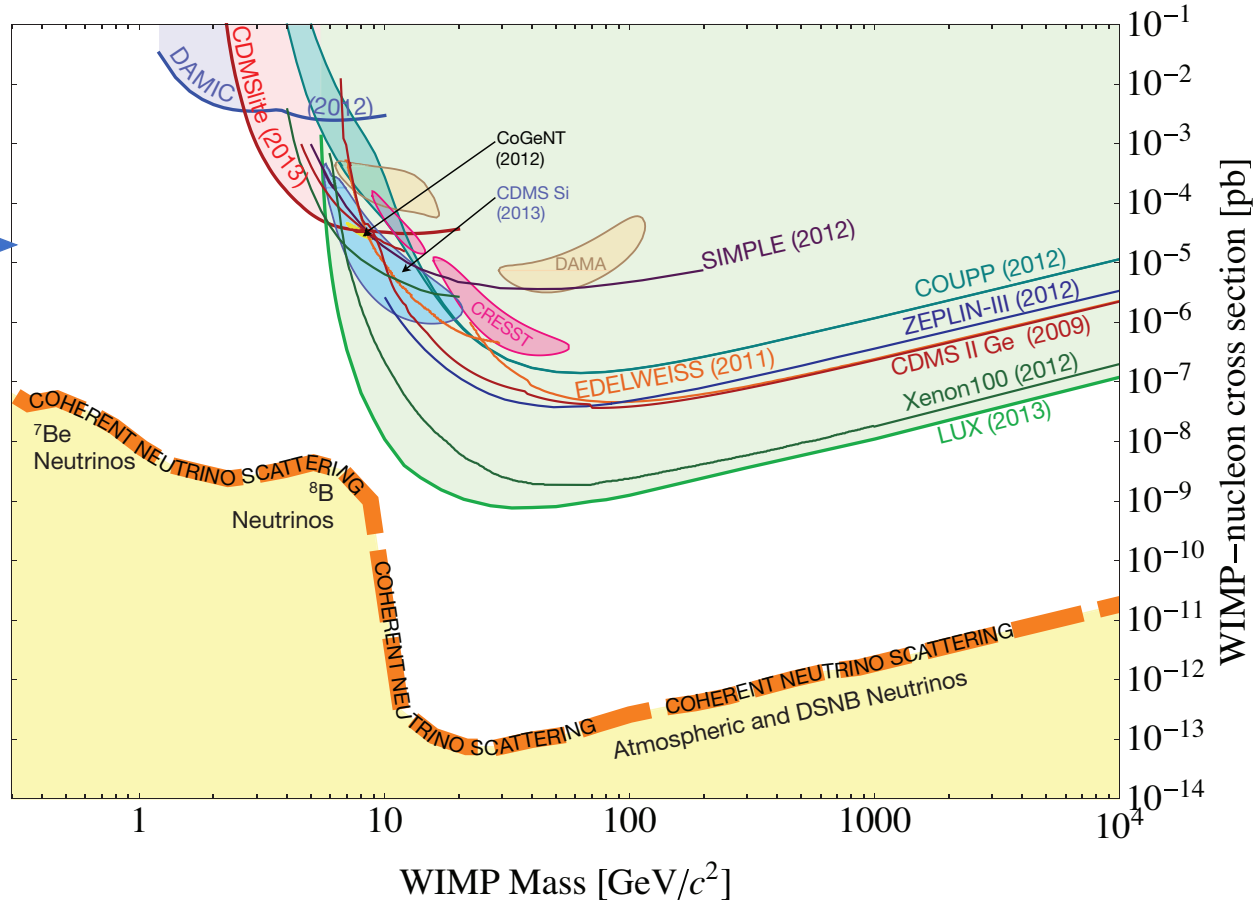


(b)SNS neutrino timing distribution

The neutrino floor: irreducible background for direct detection experiments



J. Billard, L. Strigari, and E. Figueroa-Feliciano, arXiv:1307.5458 PRD



In the Standard Model

Recoils off of target mass m

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 m}{2\pi}\left((g_v+g_a)^2 + (g_v-g_a)^2\left(1-\frac{E_R}{E_\nu}\right)^2 + (g_a^2-g_v^2)\frac{mE_R}{E_\nu^2}\right)$$

$$(g_v, g_a) = (T_3 - 2Q_{em}\sin^2\theta_W, T_3)$$

+(1,1) for e^-

g_a sign flip for $\bar{\nu}_e$

nuclear recoils

$$\frac{d\sigma_{\nu N}}{dE_R} = \frac{G_F^2}{4\pi} Q_v^2 m_N \left(1 - \frac{m_N E_R}{2E_\nu^2}\right) F^2(E_R)$$

vector coupling dominates

$$Q_v = N - (1 - 4\sin^2\theta_W)Z$$

coherency factor
(mainly neutron number sensitive)

form factor incorporates coherency loss

N^2 enhancement

Non-Standard Interactions (NSI)

Four-Fermi NC

$$-2\sqrt{2}G_F\epsilon^{f,X}_{\alpha\beta}(\bar{\nu}_\alpha\gamma^\mu P_L\nu_\beta)(\bar{f}\gamma_\mu P_X f)$$

$$\alpha,\beta = e,\mu,\tau \;\; ; \;\; f = e,u,d$$

Some overviews: Barranco, Miranda, Moura, Valle, hep-ph/0512195 PRD, Kopp, Lindner, Ota, Sato, 0708.0152, PRD, Ohlsson, 1209.2710, Gonzalez-Garcia, Maltoni, 1307.3092 JHEP, Wise, Zhang, 1404.4663 PRD

New physics would produce parameters of roughly along with a ratio of squared couplings

$$|\epsilon| \sim \frac{M_W^2}{M_X^2}$$

Light mediator models: Farzan&Heeck 1607.07616, Babu, Friedland, Machado, Mocioiu 1705.01822

These coefficients have been constrained by oscillation and scattering experiments

Gonzales-Garcia&Maltoni 1307.3092, Khan, 1605.09284, Coloma, Denton, Gonzalez-Garcia,Maltoni, Schwetz, 1701.04828

Non-Standard Interactions (NSI)

These NSI affect the overall rate of CEνNS

For CEνNS for neutrino flavor α the NSI (vector) parameters are

$$Q^2_{V,NSI} = 4\left(Z\left(g_p^V + 2\epsilon^{uV}_{\alpha\alpha} + \epsilon^{dV}_{\alpha\alpha}\right) + N\left(g_n^V + \epsilon^{uV}_{\alpha\alpha} + 2\epsilon^{dV}_{\alpha\alpha}\right)\right)^2 + \sum_{\alpha\neq\beta} 4\left(Z(2\epsilon^{uV}_{\alpha\beta} + \epsilon^{dV}_{\alpha\beta}) + N(2\epsilon^{dV}_{\alpha\beta} + \epsilon^{uV}_{\alpha\beta})\right)^2$$

Where the SM couplings g_p^V and g_n^V

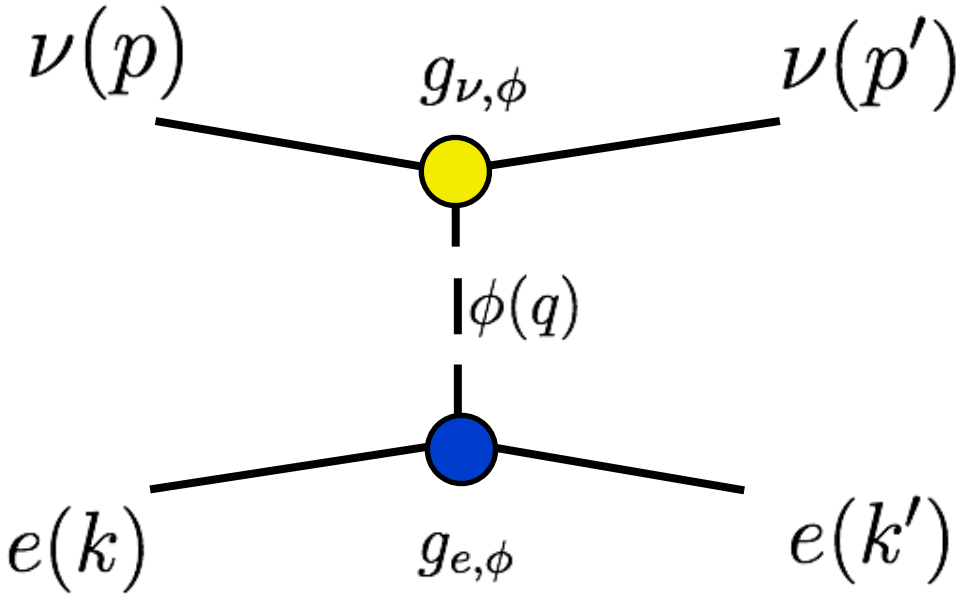
depend on electroweak parameters including their radiative corrections

Reactors can probe

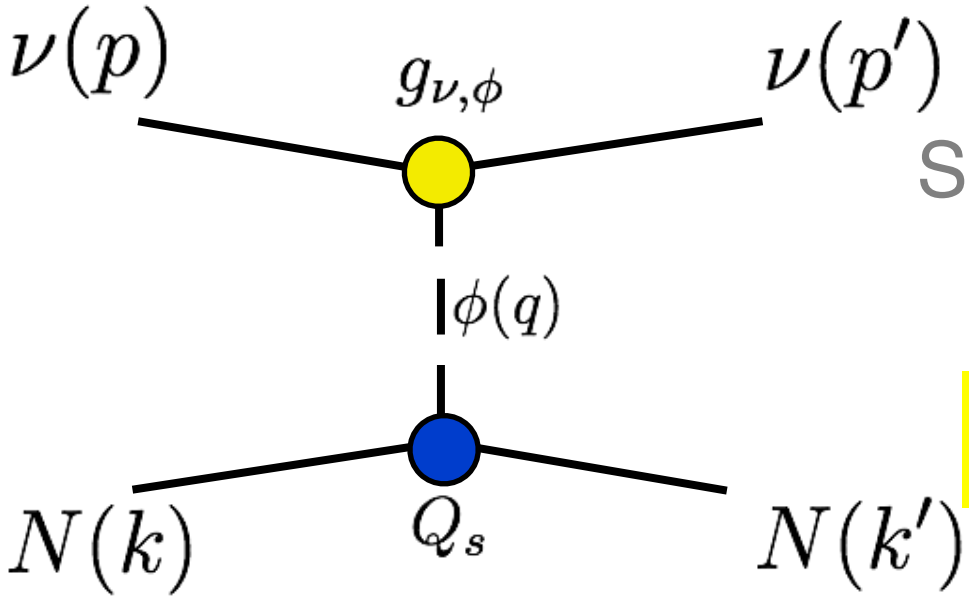
$\epsilon_{e\alpha}$

stopped pion sources can probe

$\epsilon_{e\alpha}$ $\epsilon_{\mu\alpha}$



No SM interference terms



NSI for mediator masses light compared to the momentum exchanged

Scalar or Pseudoscalar Exchange

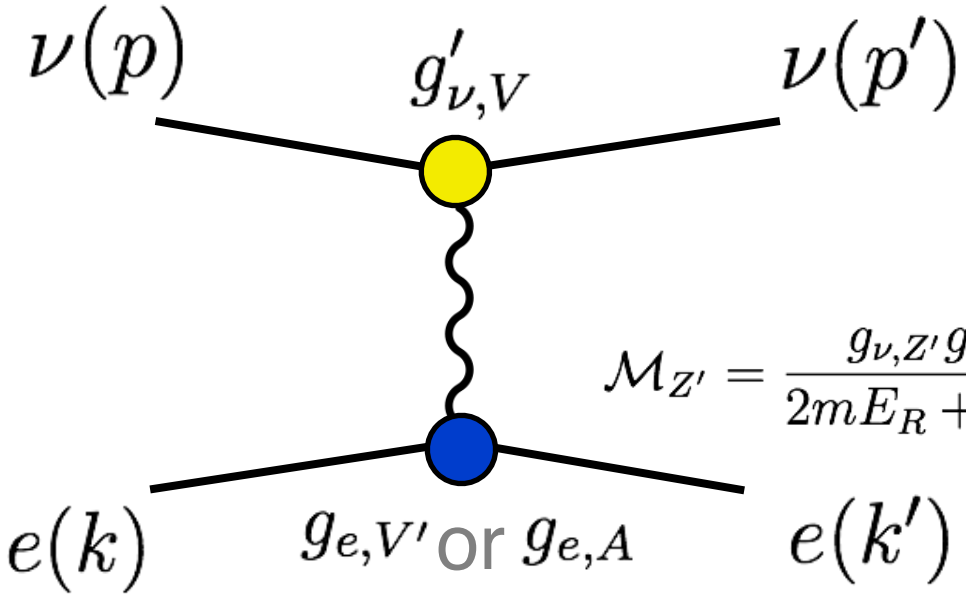
Simplified model approach

$$g_{\nu,\phi}\ g_{e,\phi}\ \ Q_s\ \ m_\phi$$

These NSI can affect the Spectrum and the overall rate of CEνNS

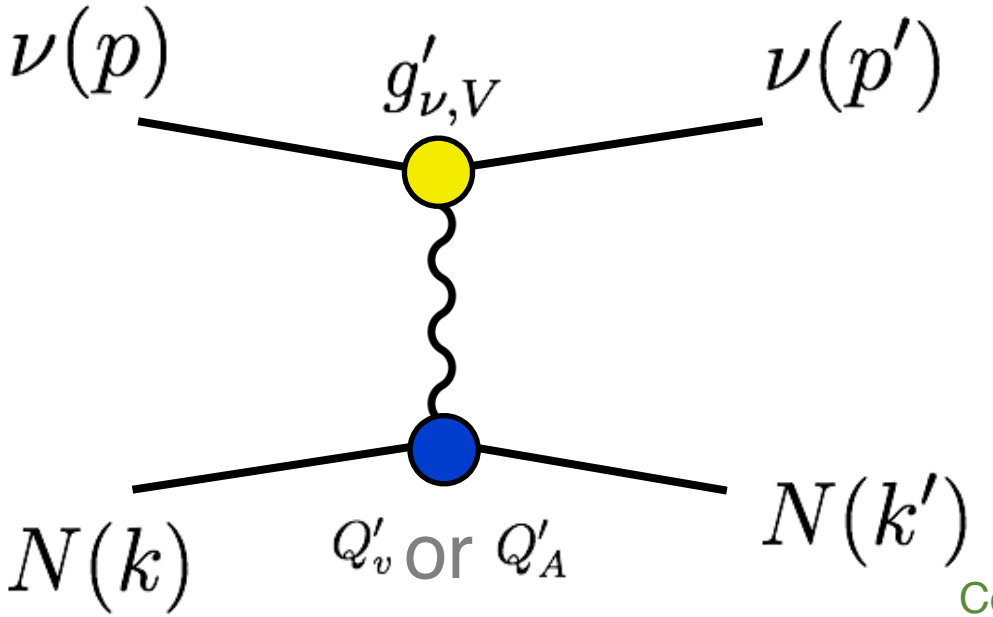
Dent, Dutta, Liao, Newstead, Strigari, Walker, 1612.06350

Vector and Axial-Vector Exchange

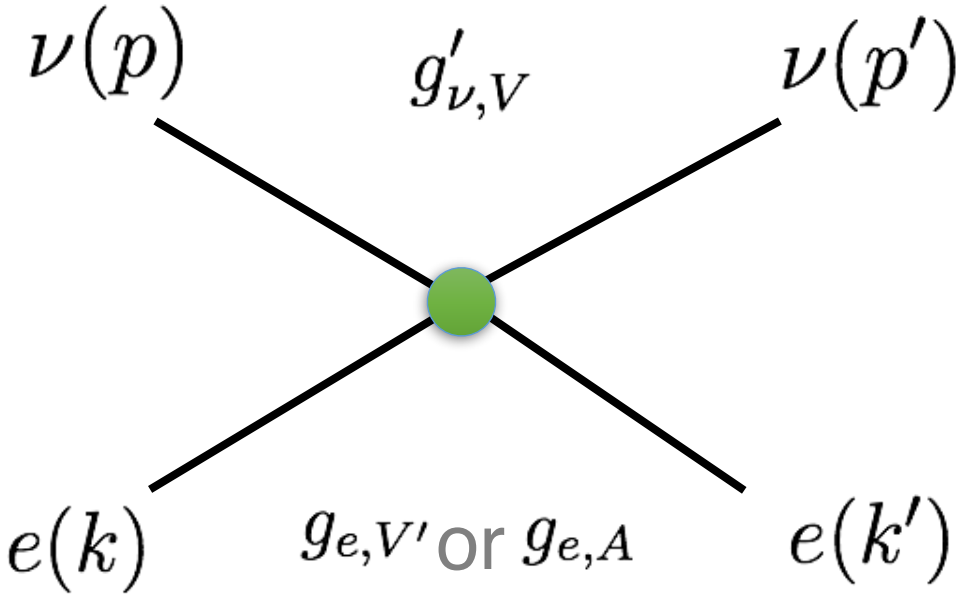


$$\mathcal{M}_{Z'} = \frac{g_{\nu,Z'} g_{q,v}}{2mE_R + m_{Z'}^2} \bar{\nu}(p')\gamma^\mu \left(\frac{1-\gamma^5}{2}\right) \nu(p)\bar{u}(q')\gamma_\mu u(q)$$

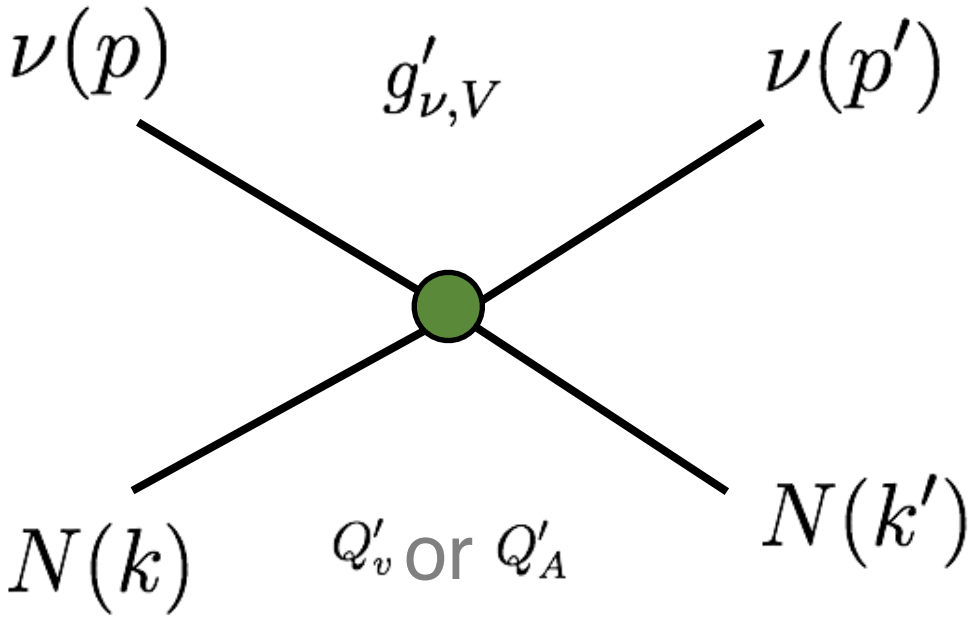
SM interference terms



for the solar case see:
Harnik, Kopp, Machado, 1202.6073
Cerdeno, Fairbairn, Jubb, Machado, Vincent, Boehm, 1604.01025

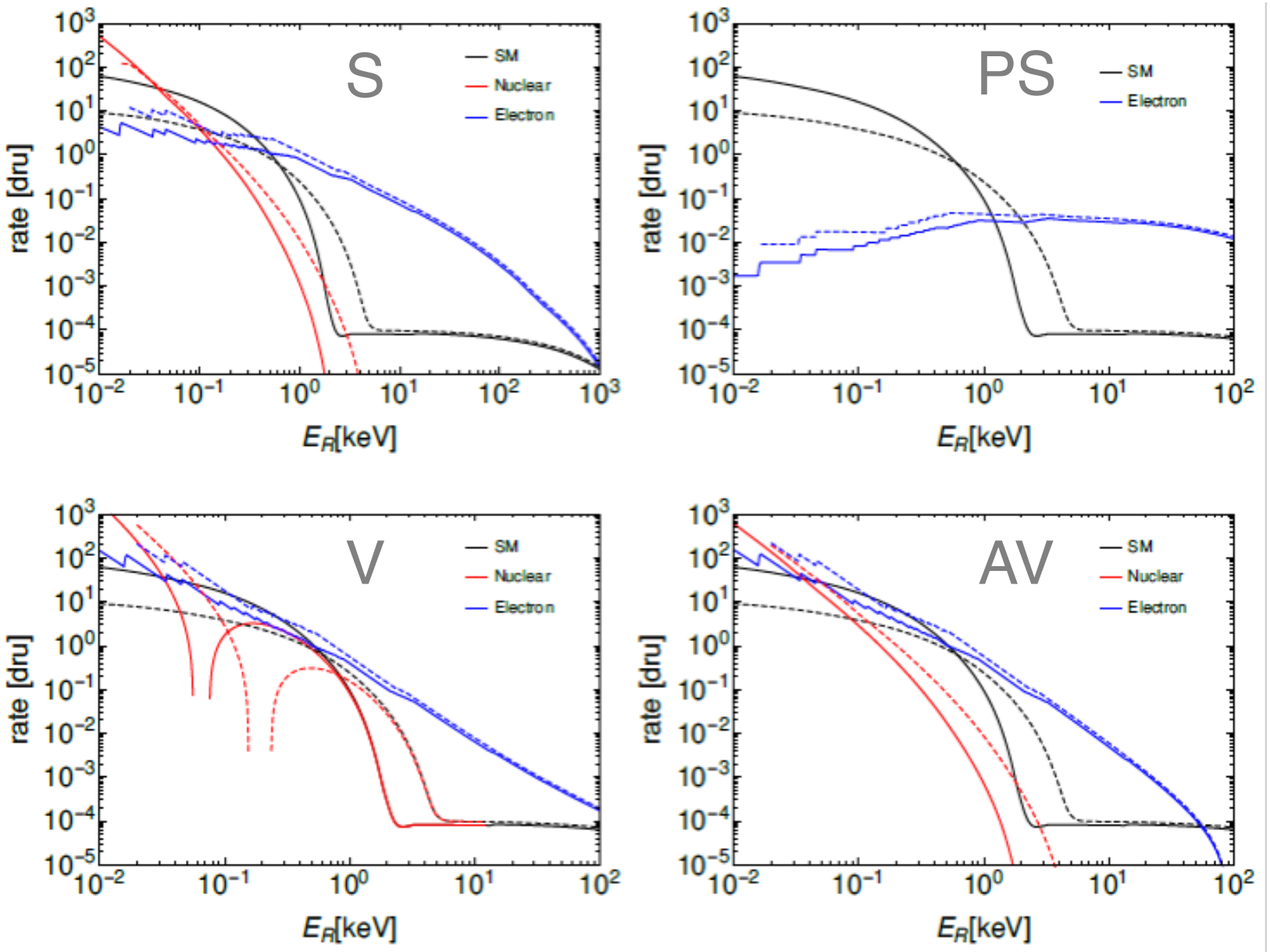


Oscillation experiments constrain light mediator scenarios since matter effects arise from forward scattering



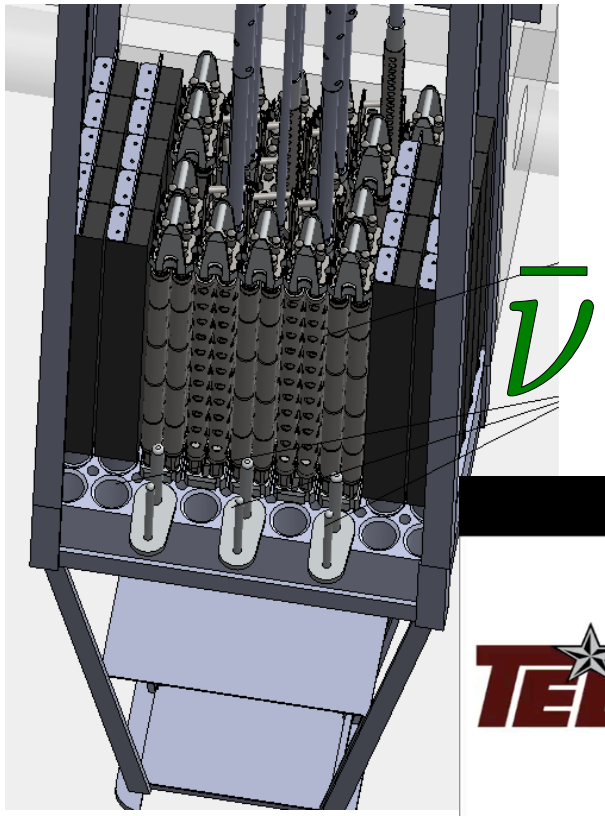
$$\epsilon^q_{\alpha\beta} = \frac{g^\nu_{\alpha\beta} g^q}{m_v^2} \frac{1}{2\sqrt{2}G_f}$$

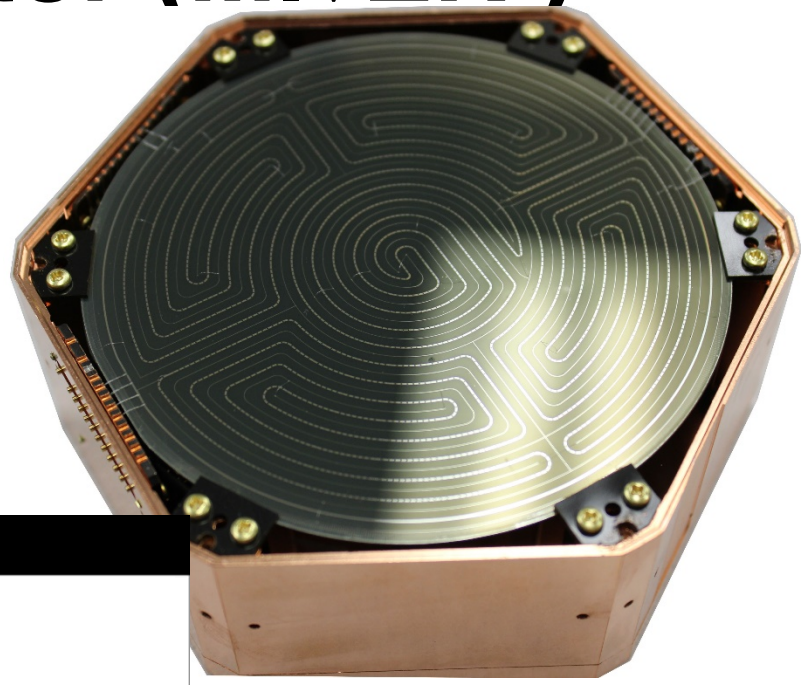
Sample recoil rates for 1keV mediators



JBD, Dutta, Liao, Newstead, Strigari, Walker, 1612.06350

Mitchell Institute Neutrino Experiment at Reactor (MIνER)





1609.02066

MIνER – 4 Countries, ~50 collaborators

Texas A&M University, Physics &
R. Mahapatra
R. Mahapatra, *G. Agnolet*, *B. Dutta*, *R. Harris*, *N. Mirabolfathi* , *L. Strigari*, *W. Teizer*, *B. Webb*, Y. Gao, C. Hays, A. Jastram, A. Kubik, W. Baker, R. Beck, Z. Wetzel, F. Kadribasic

Fruit of TAMU faculty synergy

Cyclotron Institute - *G. Rogchev*, *J. Hooke*,
Nuclear Engineering - C. Marianno, *Danie*

TEES Nuclear Science Center (NSC)
S. McDeavitt, J. Newhouse, J. Vermaak

University of Minnesota
V. Mandic, P. Cushman, M. Fritts, A. Kennedy, N. Mast, A. Villano, D. Barker

University of South Dakota
J. Sander, A. Roberts

Arizona State Univ
J. Newstead

University Texas Austin
Karol Lang, *Will Flanagan*, *Marek Proga*, *John Cesar*, *Dung Phan*, *Tom Carroll*, *Simon De Rijick*, *Ramon Salazar*, *Shiv Yadavalli*, *Kayla Leonard*, *Adam Rouhiainen*

National Institute of Science Education and Research (NISER), India
B. Mohanty, *K. Senapati*, V. Iyer

Queen's University, Canada
R. Martin

Fukui University, Japan
Y. Tamagawa, *I. Ogawa*, *K. Nakajima*, *M. Shimada*

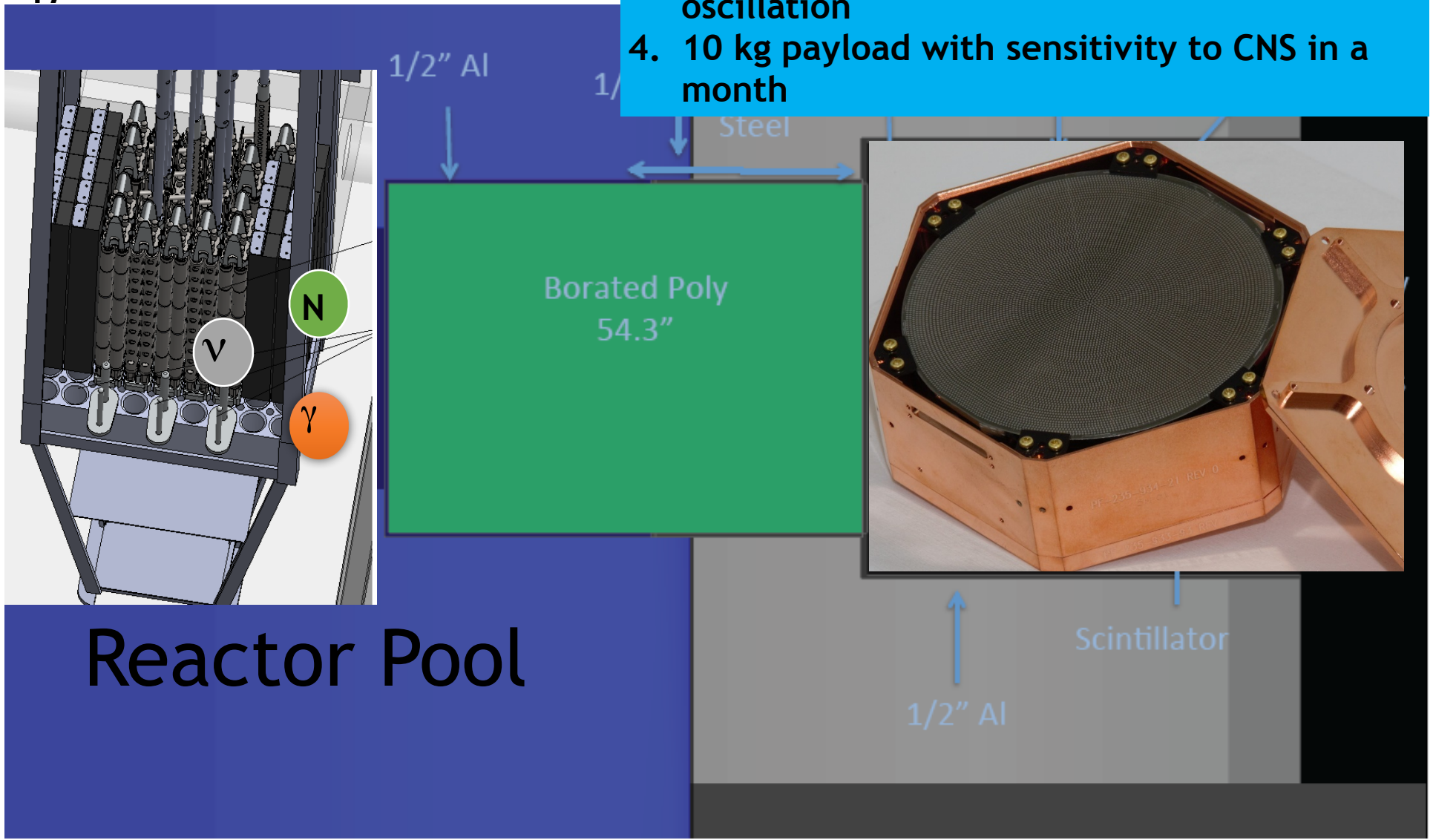
Sam Houston State Univ
J. Walker, *J. Dent*

MIνER with Ge/Si

Dilution fridge being commissioned
Shielding construction in progress
Expect engineering data by end of '17

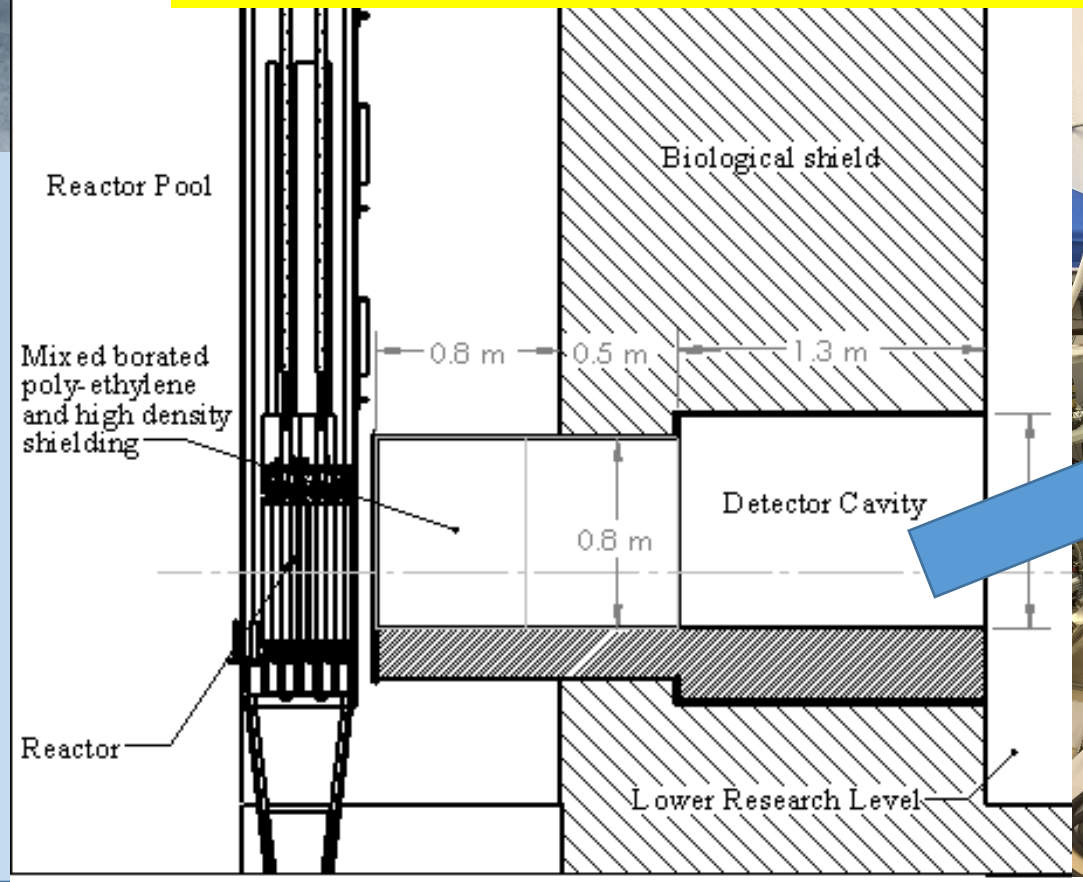
Key Features

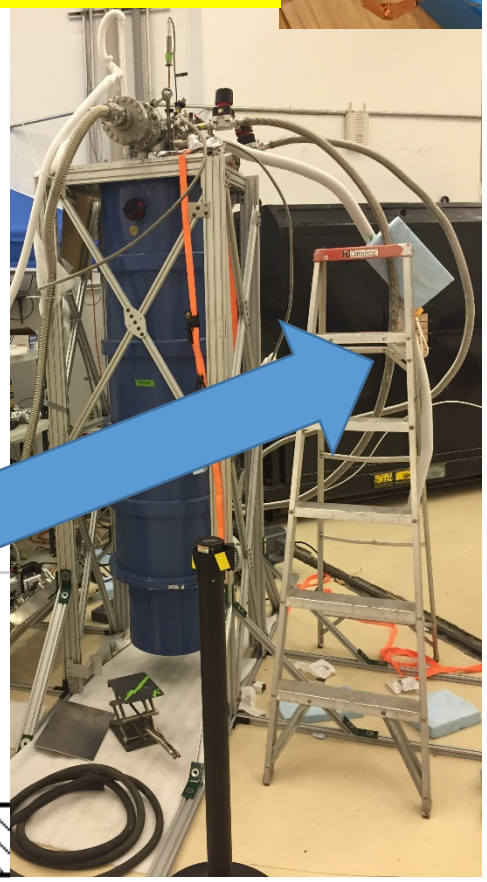
1. **Low-threshold (<100 eV) with sensitivity to CNS**
2. **2m proximity to core (rate enhancement)**
3. **Moveable Core tests short baseline oscillation**
4. **10 kg payload with sensitivity to CNS in a month**



First run may happen outside of thermal cavern with straight hanging detector tower. Distance from core is higher (~4m), but quicker engineering run

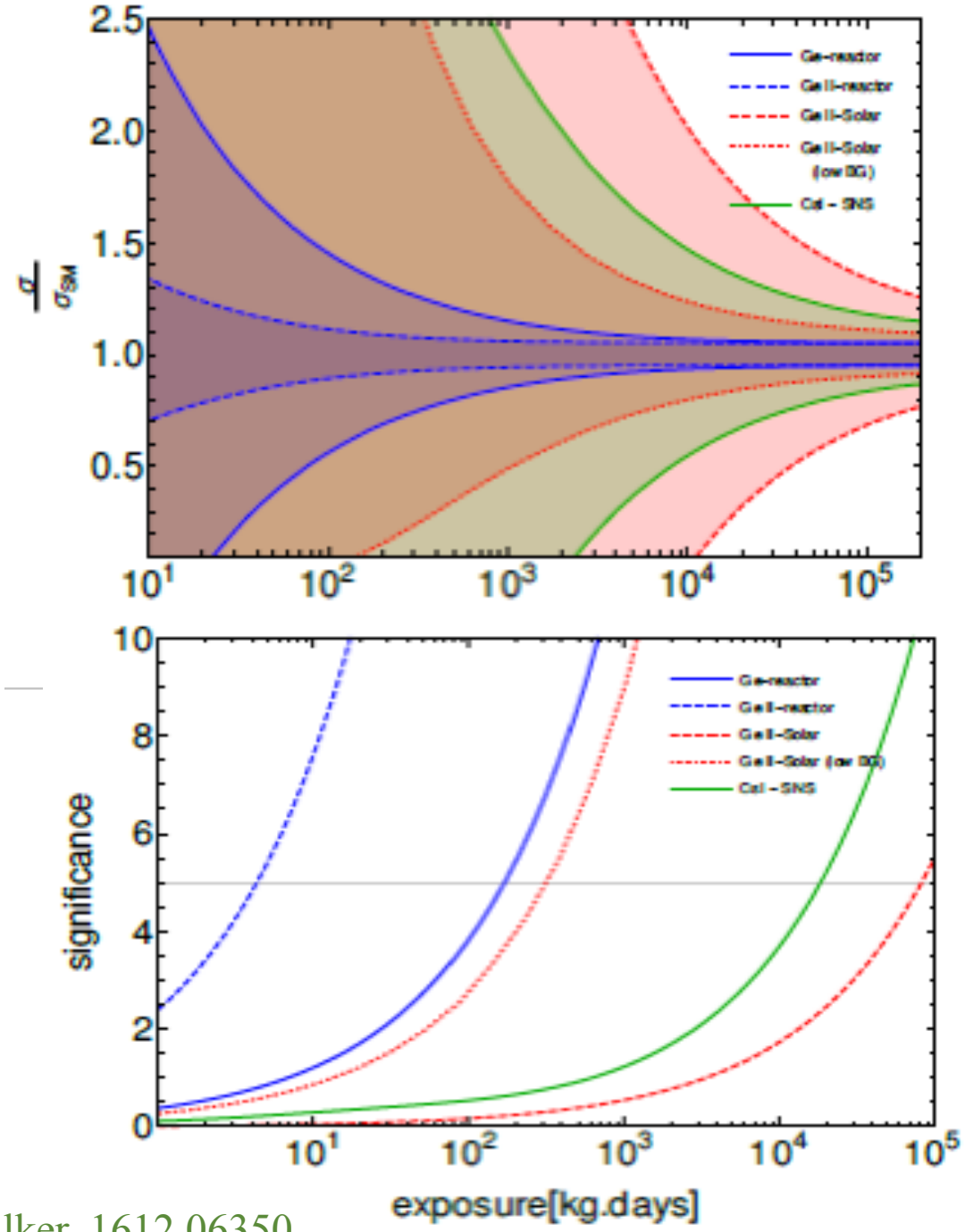
Full run will occur with detectors in Icebox (adapted from SuperCDMS Soudan design) that will reside inside thermal cavern with ~2m proximity and overburden.





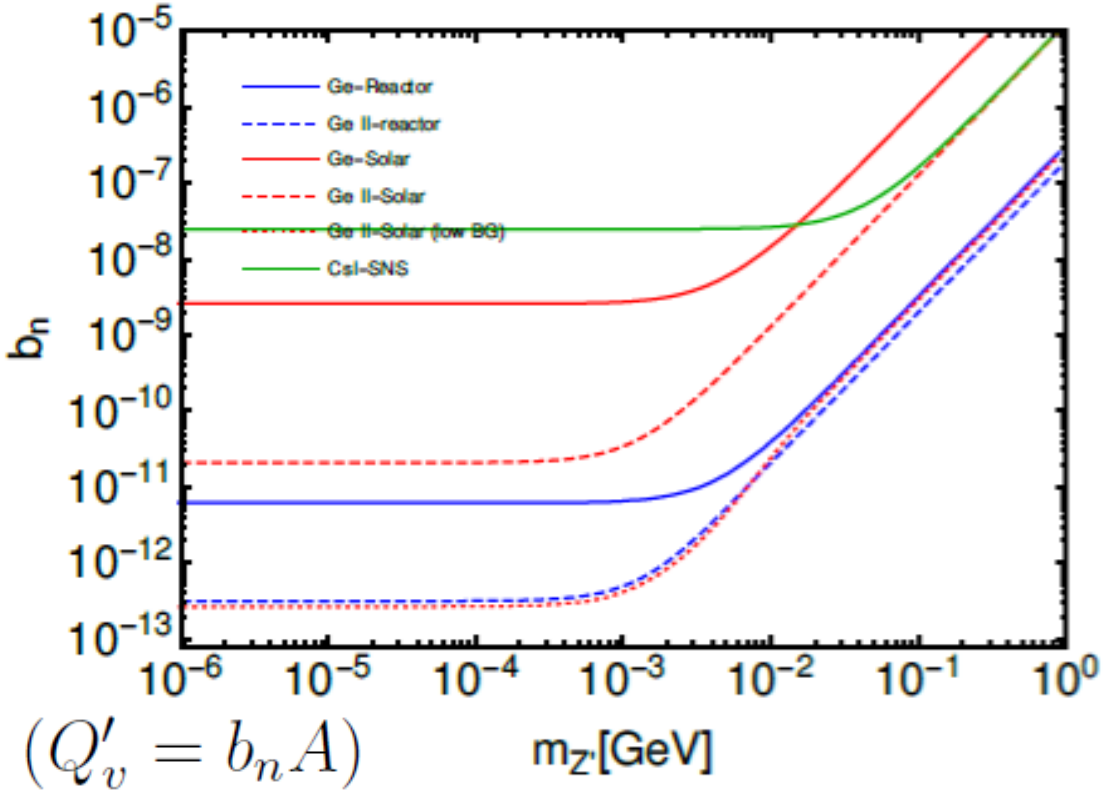
Reactor, SNS, Solar comparison

component	ν flux ($cm^{-2}s^{-1}$)
TAMU reactor (at 1m)	$1.50(1 \pm 0.02) \times 10^{12}$
SNS (at 20m)	
ν_μ (prompt)	$4.30(1 \pm 0.1) \times 10^{7}$
ν_e (delayed)	$4.30(1 \pm 0.1) \times 10^{7}$
$\bar{\nu}_\mu$ (delayed)	$4.30(1 \pm 0.1) \times 10^{7}$
Solar	
pp	$5.98(1 \pm 0.006) \times 10^{10}$
^{7}Be	$5.00(1 \pm 0.07) \times 10^{9}$
^{8}B	$5.58(1 \pm 0.14) \times 10^{6}$
pep	$1.44(1 \pm 0.012) \times 10^{8}$

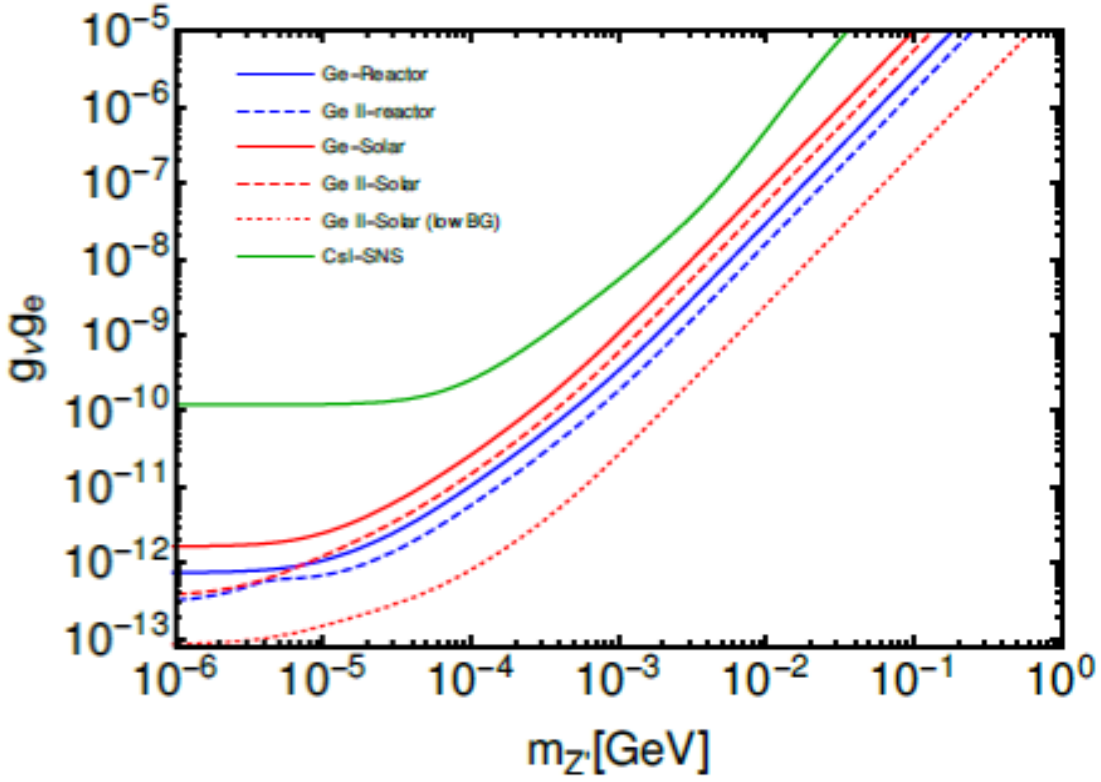


Dent, Dutta, Liao, Newstead, Strigari, Walker, 1612.06350

Comparative discovery reach for a new, light Vector mediator



$(Q'_v = b_n A)$

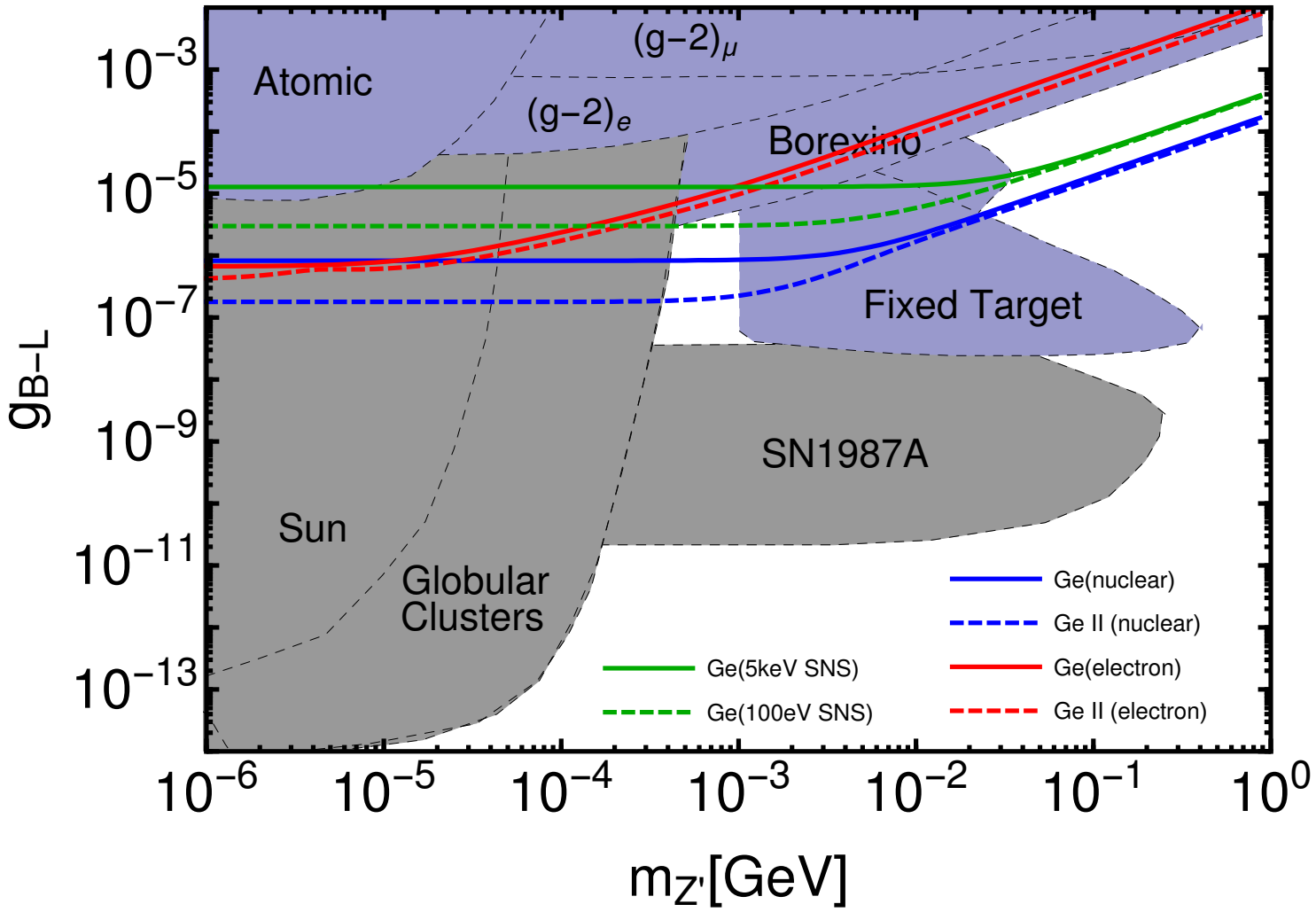


Dent, Dutta, Liao, Newstead, Strigari, Walker, 1612.06350

comparing with SNS and the solar case of:
Cerdeno, Fairbairn, Jubb, Machado, Vincent, Boehm, 1604.01025

Reactor reach for $U(1)_{B-L}$

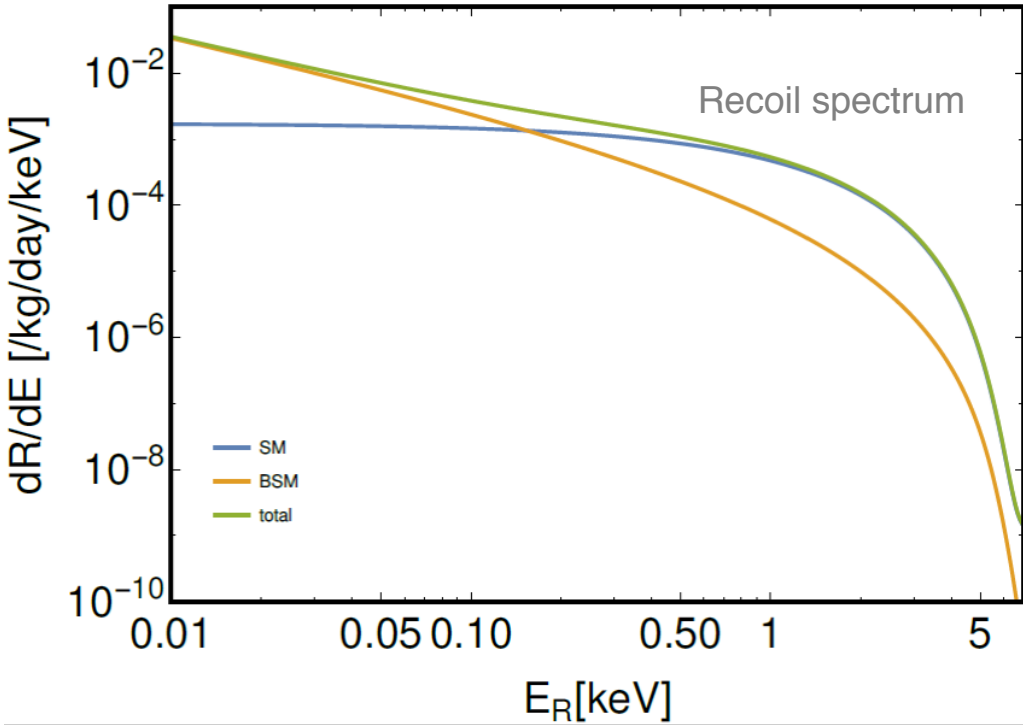
$$\mathcal{L}_{B-L} \supset g_{B-L} Z'_\mu \left(\frac{1}{3}\bar{q}\gamma^\mu q - \bar{\nu}\gamma^\mu \nu - \bar{e}\gamma^\mu e \right)$$

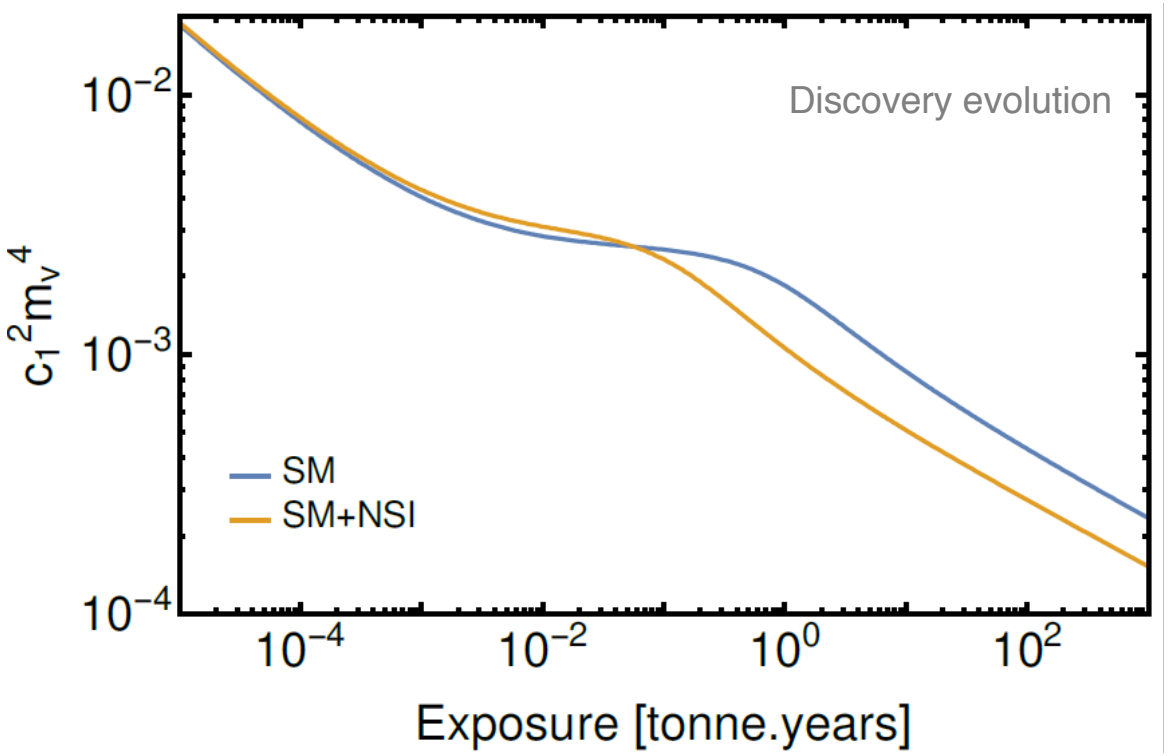


Dent, Dutta, Liao, Newstead, Strigari, Walker
Comparison with Ge at SNS `Shoemaker 1703.05774

Light mediator NSI effect on the Neutrino Floor

(preliminary work in preparation
Dent,Dutta,Newstead,Liao.Strigari,Walker)





1keV scalar mediator
6GeV WIMP SI interaction
100eVnr Ge threshold

(idealized situation of perfectly known NSI coupling)

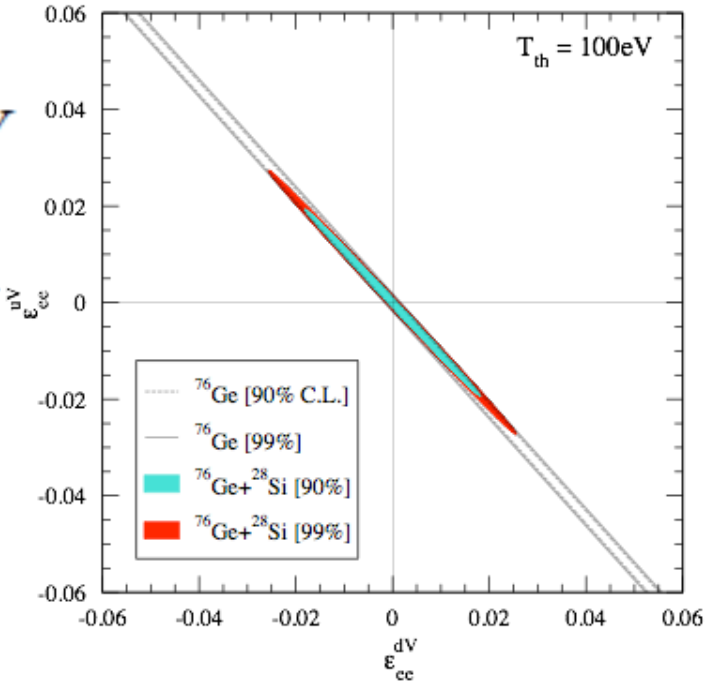
also see work from E. Bertuzzo, F.F. Deppisch, S. Kulmaki, Yuber F. Perez G., R.Z. Funchal, 1701.07443

Degeneracies

$$Q^2_{V,NSI} = 4\left(Z\left(g_p^V + 2\epsilon^{uV}_{\alpha\alpha} + \epsilon^{dV}_{\alpha\alpha}\right) + N\left(g_n^V + \epsilon^{uV}_{\alpha\alpha} + 2\epsilon^{dV}_{\alpha\alpha}\right)\right)^2 + \sum_{\alpha\neq\beta} 4\left(Z(2\epsilon^{uV}_{\alpha\beta} + \epsilon^{dV}_{\alpha\beta}) + N(2\epsilon^{dV}_{\alpha\beta} + \epsilon^{uV}_{\alpha\beta})\right)^2$$

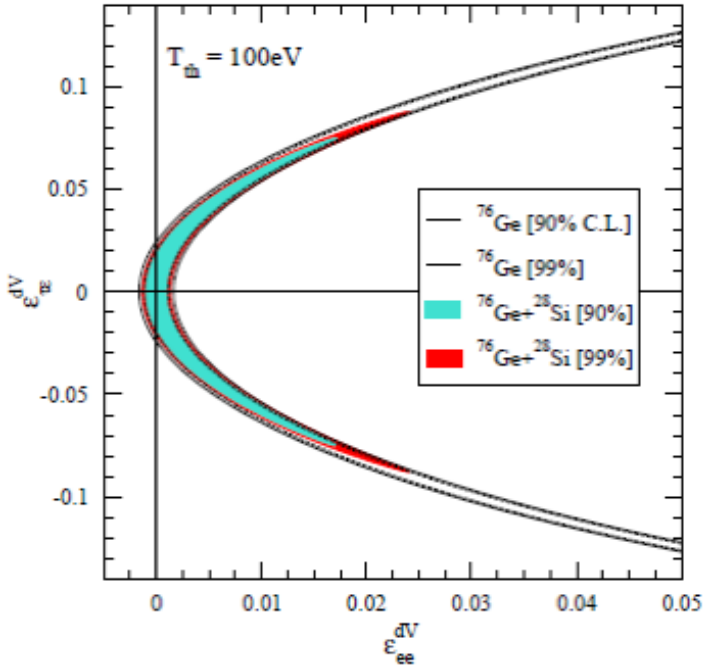
ϵ^{uV}_{ee}

ϵ^{dV}_{ee}



ϵ^{dV}_{ee}

$\epsilon^{dV}_{\tau e}$



Reactors: J. Barranco, O.G. Miranda, and T.I. Rashba, JHEP (2005) hep-ph/0508299
also see M.Lindner, W. Rodejohann, .X.-J. Xu 1612.04150. SPS: COHERENT 1509.08702

Degeneracy from CPT

Gonzales-Garcia&Maltoni 1307.3092

$$\Delta m^2_{31} \to -\Delta m^2_{31} + \Delta m^2_{21} = -\Delta m^2_{32}\,,$$
$$\sin\theta_{12} \to \cos\theta_{12}\,,$$
$$\delta \to \pi - \delta\,,$$

as in LMA-Dark

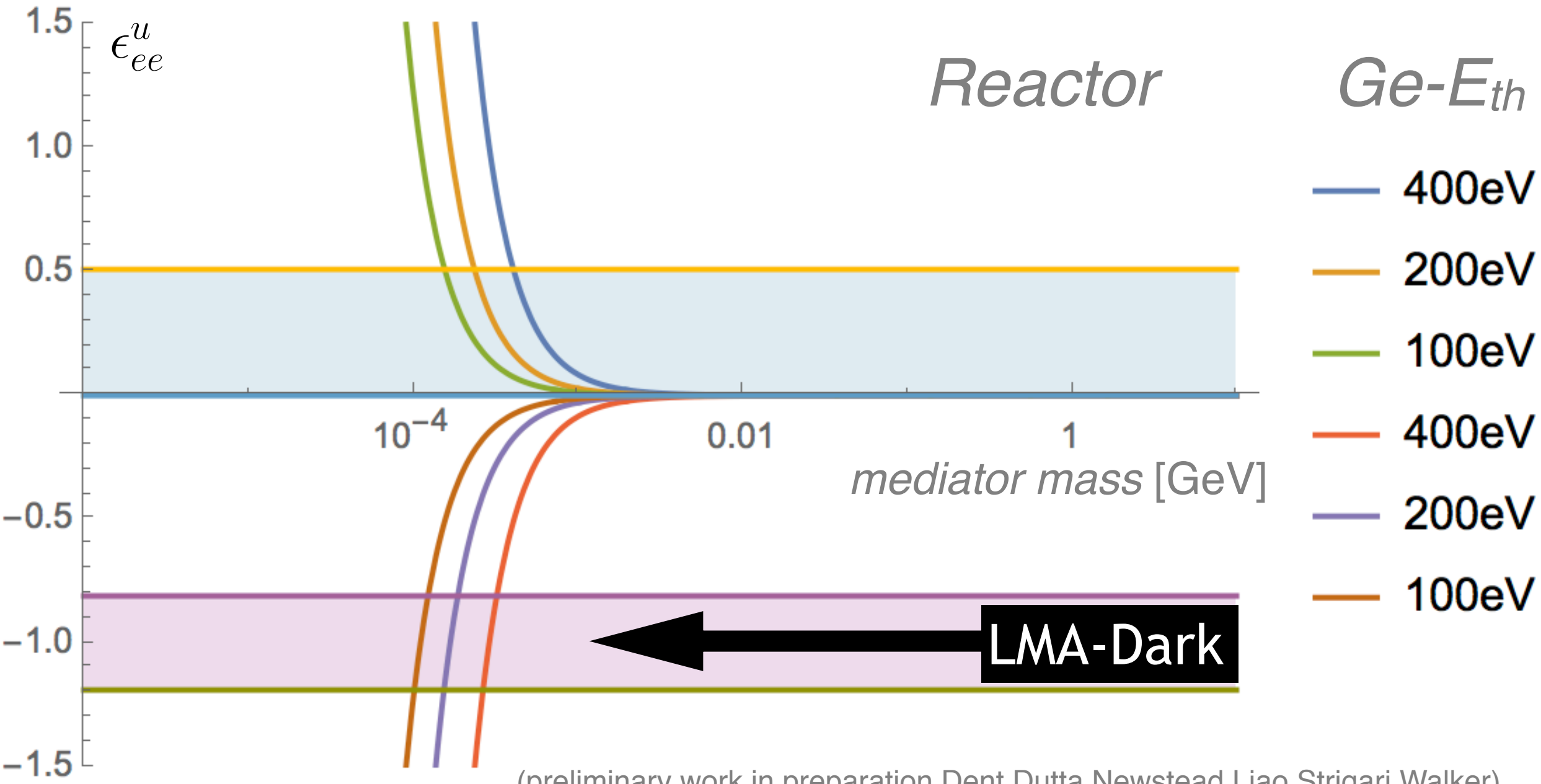
effective NSI parameters

(for NSI/CP:
Liao, Marfatia, Whisnant 1601.00927
Forero&Huber 1601.03736
Masud&Mehta 1606.05662 …)

$$(\epsilon_{ee} - \epsilon_{\mu\mu}) \to -(\epsilon_{ee} - \epsilon_{\mu\mu}) - 2\,,$$
$$(\epsilon_{\tau\tau} - \epsilon_{\mu\mu}) \to -(\epsilon_{\tau\tau} - \epsilon_{\mu\mu})\,,$$
$$\epsilon_{\alpha\beta} \to -\epsilon^*_{\alpha\beta} \quad (\alpha \neq \beta)\,,$$

$$\epsilon^{u,V}_{ee} - \epsilon^{u,V}_{\mu\mu} \quad \Big| \quad [-1.19, -0.81] \oplus [0.00, 0.51]$$

Coloma, Denton, Gonzalez-Garcia, Maltoni, Schwetz, 1701.04828



(preliminary work in preparation Dent,Dutta,Newstead,Liao.Strigari,Walker)

LMA-Dark degeneracy

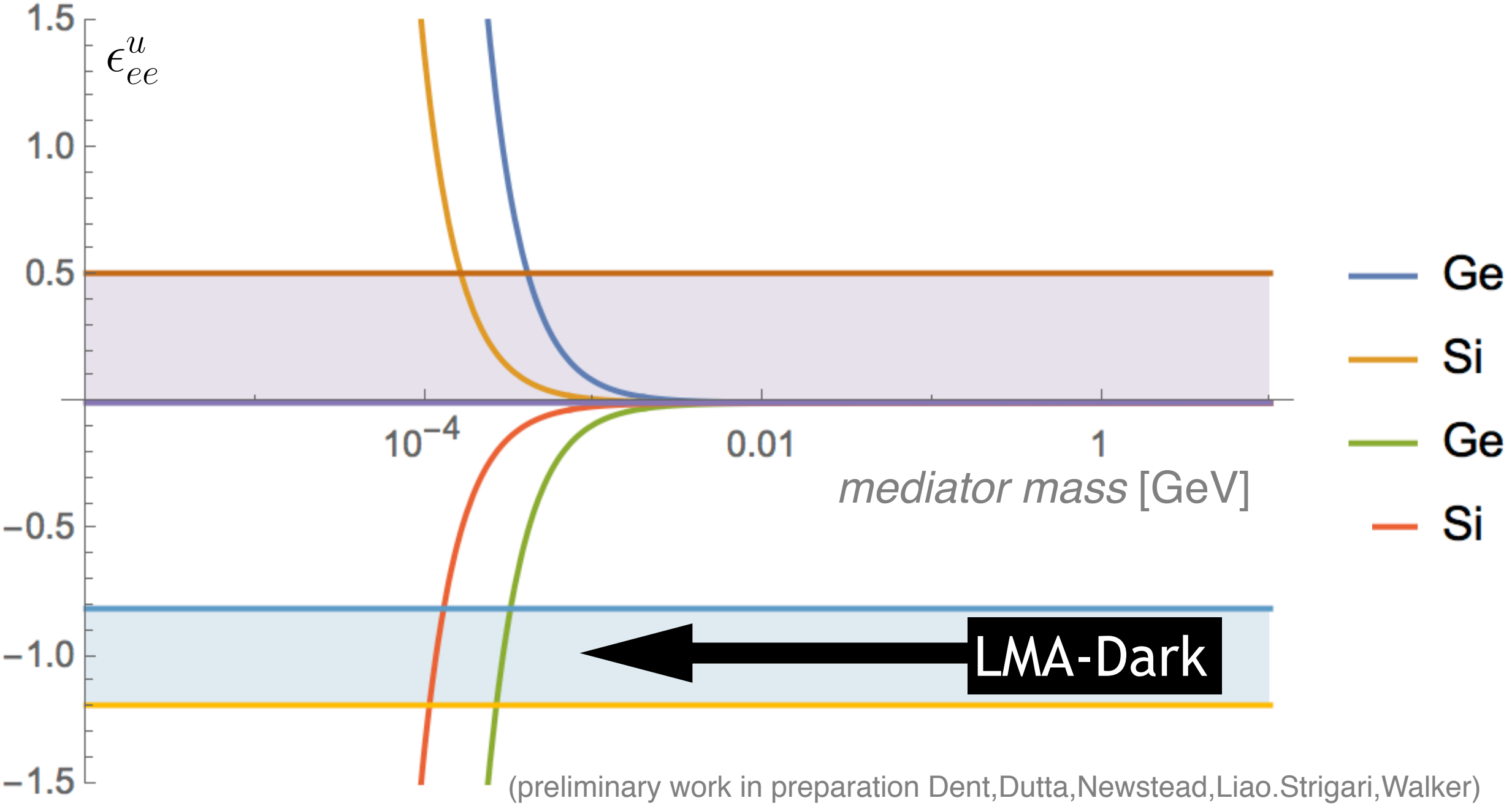
Coherent scattering depends on:

$$[Zg_p + Ng_n + \epsilon^u_{ee}(2Z+N)]^2 \to [Zg_p + Ng_n + (\epsilon^u_{ee})'(2Z+N)]^2$$

$$\epsilon^u_{ee} = (\epsilon^u_{ee})'$$

$$\epsilon^u_{ee} = -2\left(\frac{Zg_p + Ng_n}{2Z+N}\right) - (\epsilon^u_{ee})'$$

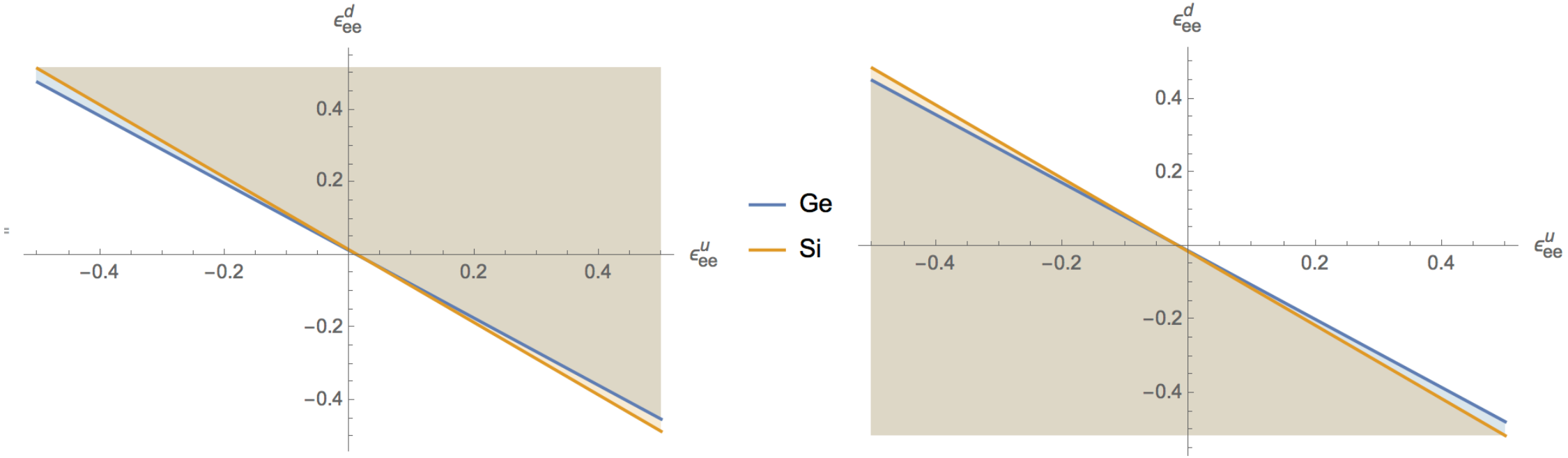
target dependence



(preliminary work in preparation Dent,Dutta,Newstead,Liao.Strigari,Walker)

LMA-Dark degeneracy

1MeV vector mediator
100eVnr threshold



Dent,Dutta,Newstead,Liao.Strigari,Walker

Summary

Coherent elastic neutrino-nucleus scattering has the opportunity in the near future to provide a test of a wide variety of physics including NSI, the weak mixing angle, sterile neutrinos, electromagnetic form factors, new dark sectors, etc…

Coherent elastic neutrino-nucleus scattering also plays an important role as a background for upcoming direct detection of dark matter experiments.

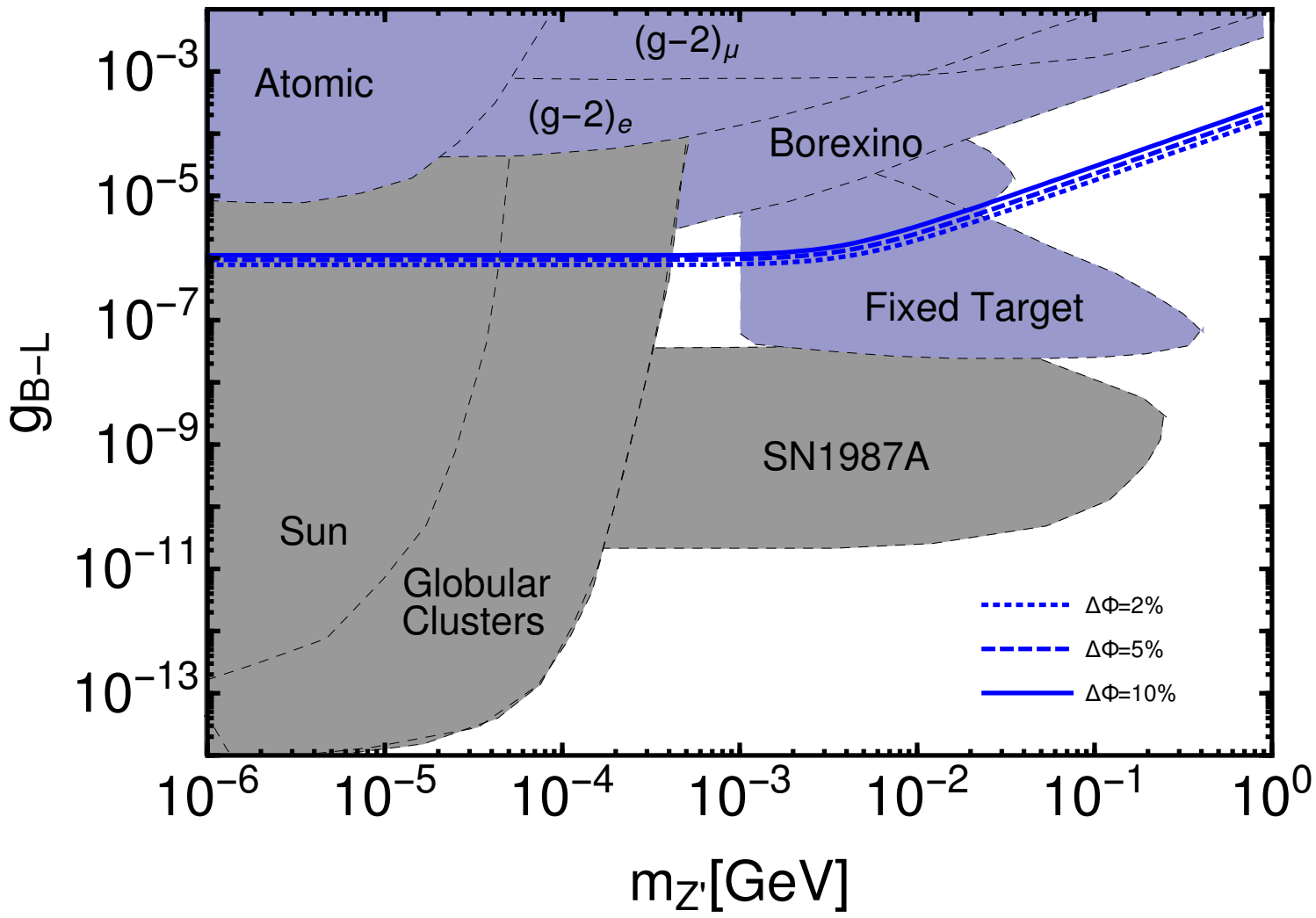
There is great physics potential with several projects projected to provide measurements in the very near future, providing complementary probes (to each other and to other experiments such as upcoming oscillation experiments) of physics of and beyond the Standard Model.

Extra Slides

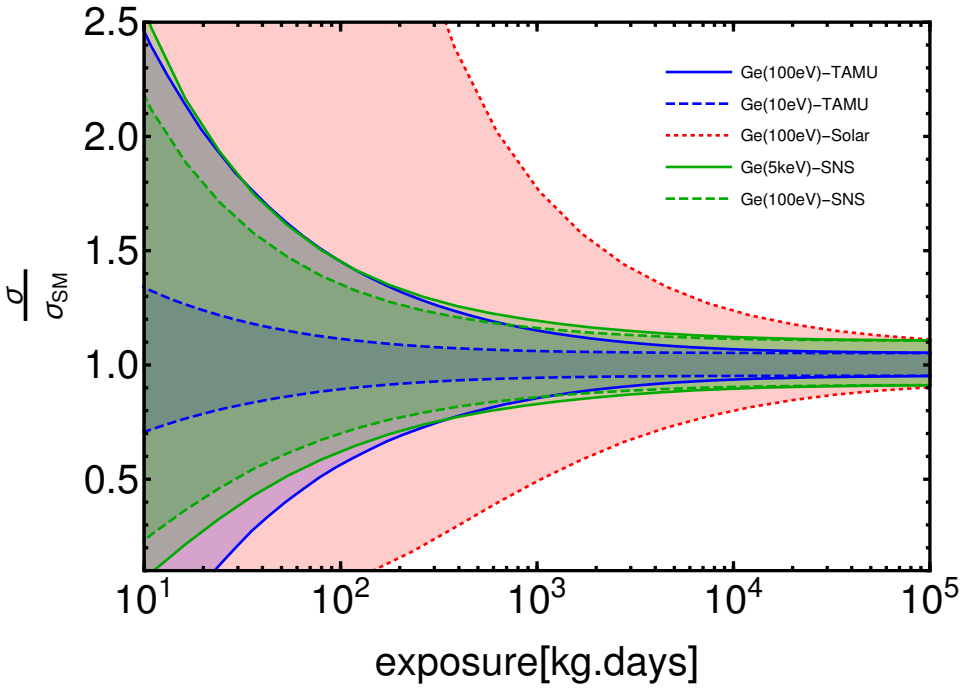
Flux uncertainty effect of reach

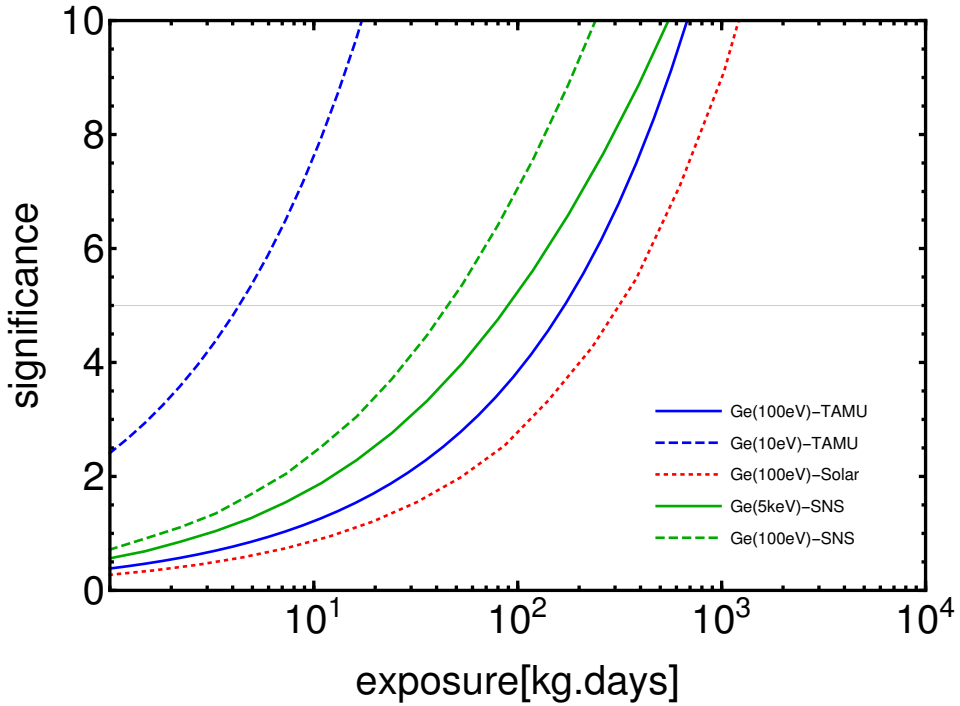
Reactor reach for a $U(1)_{B-L}$ model

$$\mathcal{L}_{B-L} \supset g_{B-L} Z'_\mu \left(\frac{1}{3}\bar{q}\gamma^\mu q - \bar{\nu}\gamma^\mu \nu - \bar{e}\gamma^\mu e \right)$$



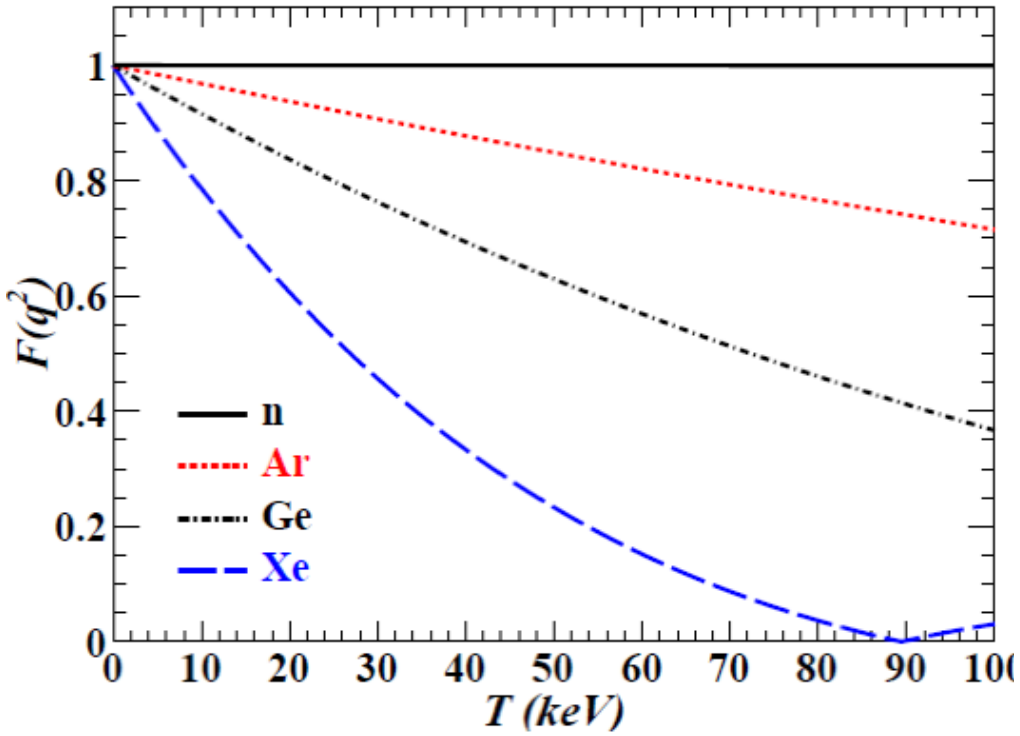
Comparison with Ge at SNS

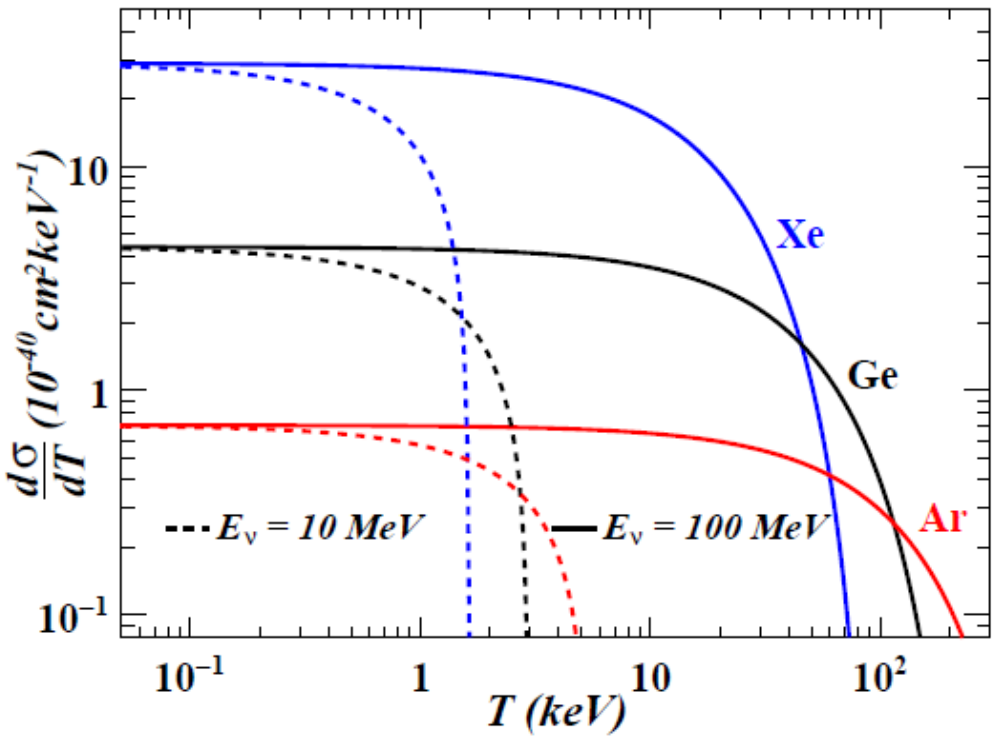

Ge(100eV)−TAMU
Ge(10eV)−TAMU
Ge(100eV)−Solar
Ge(5keV)−SNS
Ge(100eV)−SNS
$\frac{\sigma}{\sigma_{SM}}$
exposure[kg.days]


Ge(100eV)−TAMU
Ge(10eV)−TAMU
Ge(100eV)−Solar
Ge(5keV)−SNS
Ge(100eV)−SNS
significance
exposure[kg.days]

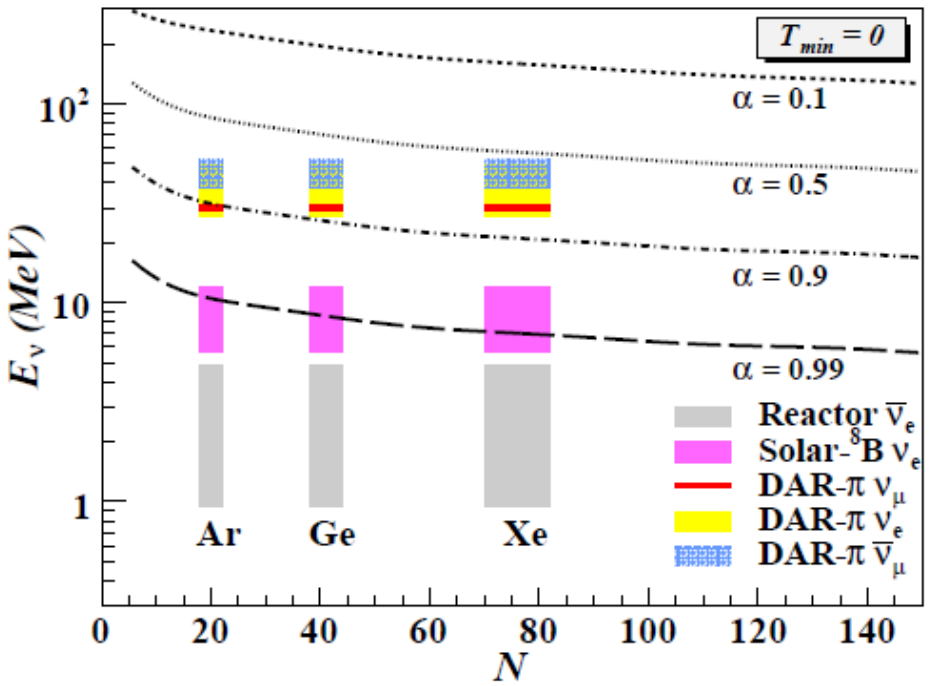
Loss of Coherency

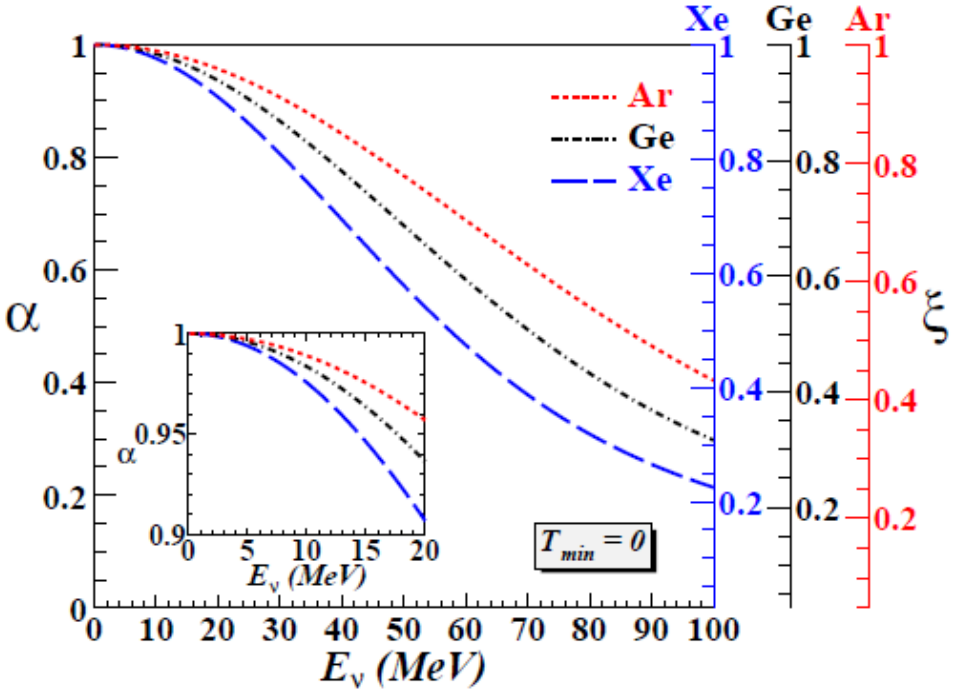
$$F(q^2) = [\frac{3}{qR_0}]\ J_1(qR_0)\ \exp[-\frac{1}{2}q^2 s^2]$$





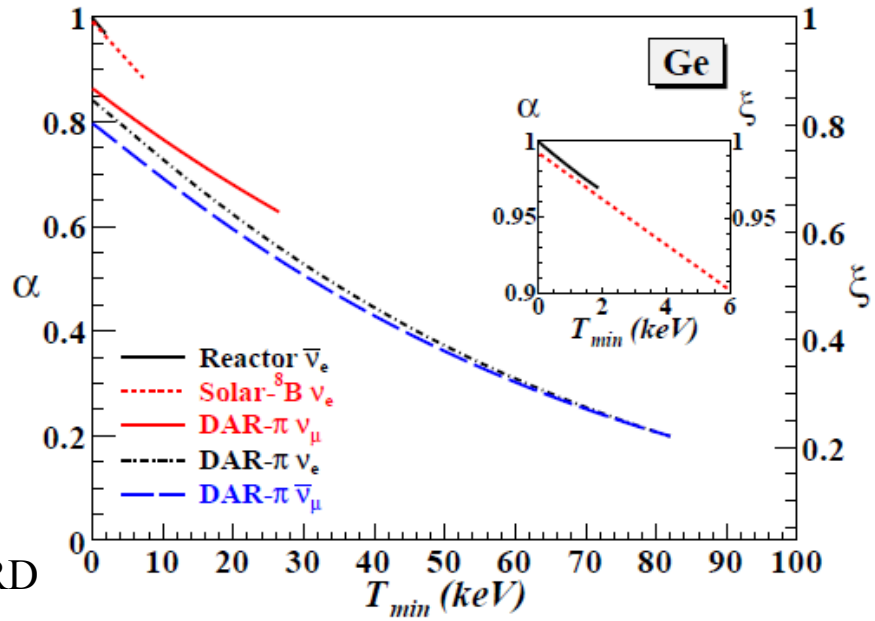
S. Kerman et al., TEXONO Collaboration, 1603.08786





$$\frac{\sigma_{\nu A_{el}}(Z,N)}{\sigma_{\nu A_{el}}(0,1)} \tag{11}$$
$$= \{\ \varepsilon^2 Z + N + \varepsilon^2 Z(Z-1)\alpha + N(N-1)\alpha - 2\varepsilon Z N \alpha\ \}$$
$$= \{\ Z\varepsilon^2[1+\alpha(Z-1)] + N[1+\alpha(N-1)] - 2\alpha\varepsilon Z N\ \}\ .$$

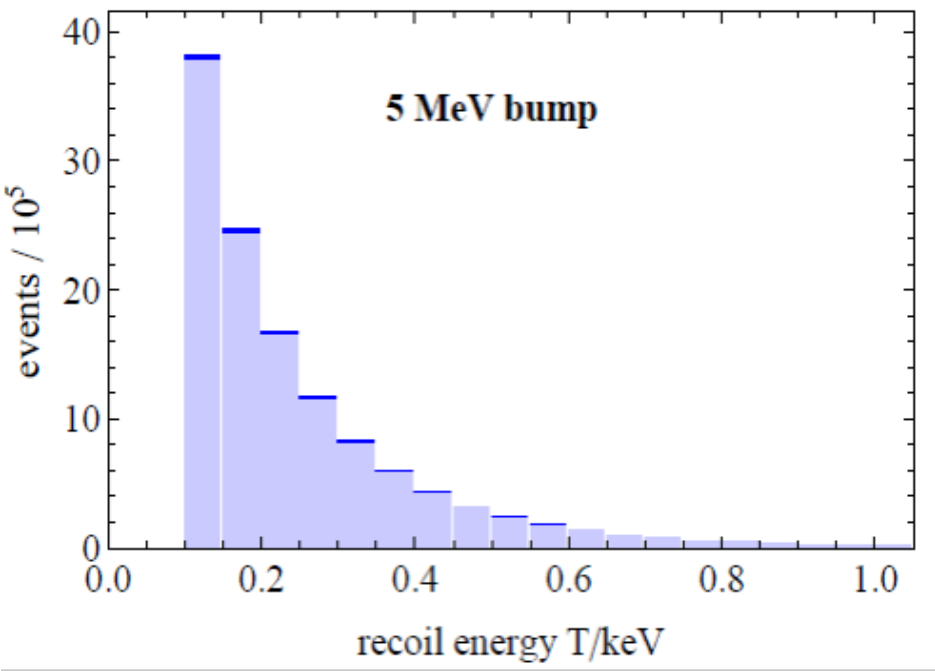
$$\xi \equiv \frac{\sigma_{\nu A_{el}}(\alpha)}{\sigma_{\nu A_{el}}(\alpha=1)} = \alpha + (1-\alpha)\left[\frac{(\varepsilon^2 Z + N)}{(\varepsilon Z - N)^2}\right]$$

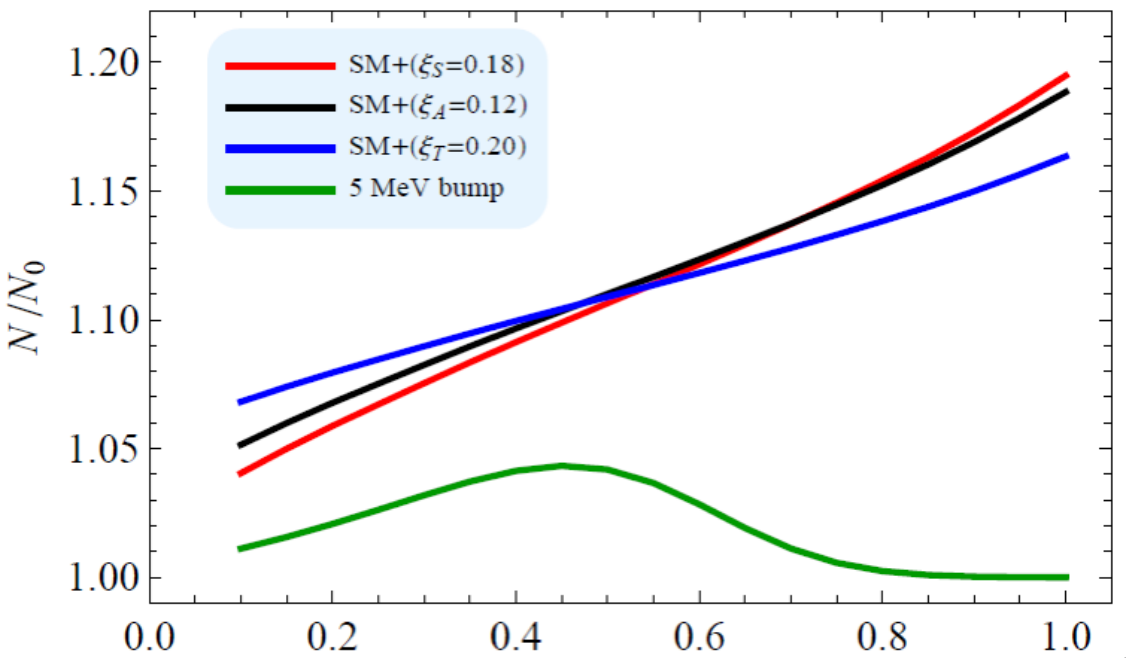


S. Kerman et al., TEXONO Collaboration, 1603.08786 PRD

Reactor Anomalies

Reactor Anomaly: 5MeV bump effect on coherent scattering





M. Lindner, W. Rodejohann, and X.-J. Xu, 1612.04150

Confidence Intervals
Discovery Evolution

Profile Likelihood Test statistic

$$t_\mu = -2\log\frac{\mathcal{L}(\mu,\hat{\theta})}{\mathcal{L}(\hat{\mu},\hat{\theta})}$$

Binned Likelihood

$$\mathcal{L} = \prod_i \frac{\nu_i^{n_i} e^{-\nu_i}}{n_i!} \prod_j e^{-\frac{1}{2\delta_j^2}(1-N_j)^2}$$

Discovery Evolution: smallest signal to produce a 3σ fluctuation 90% of the time

$$q_0 = \begin{cases} -2\log\frac{\mathcal{L}(\mu=0,\hat{\theta})}{\mathcal{L}(\hat{\mu},\hat{\hat{\theta}})} & \sigma \geq \hat{\sigma} \\ 0 & \sigma < \hat{\sigma} \end{cases}$$

$$p_0 = \int_{q_0^{\mathrm{obs}}}^{\infty} f(q_0|H_0)dq_0$$

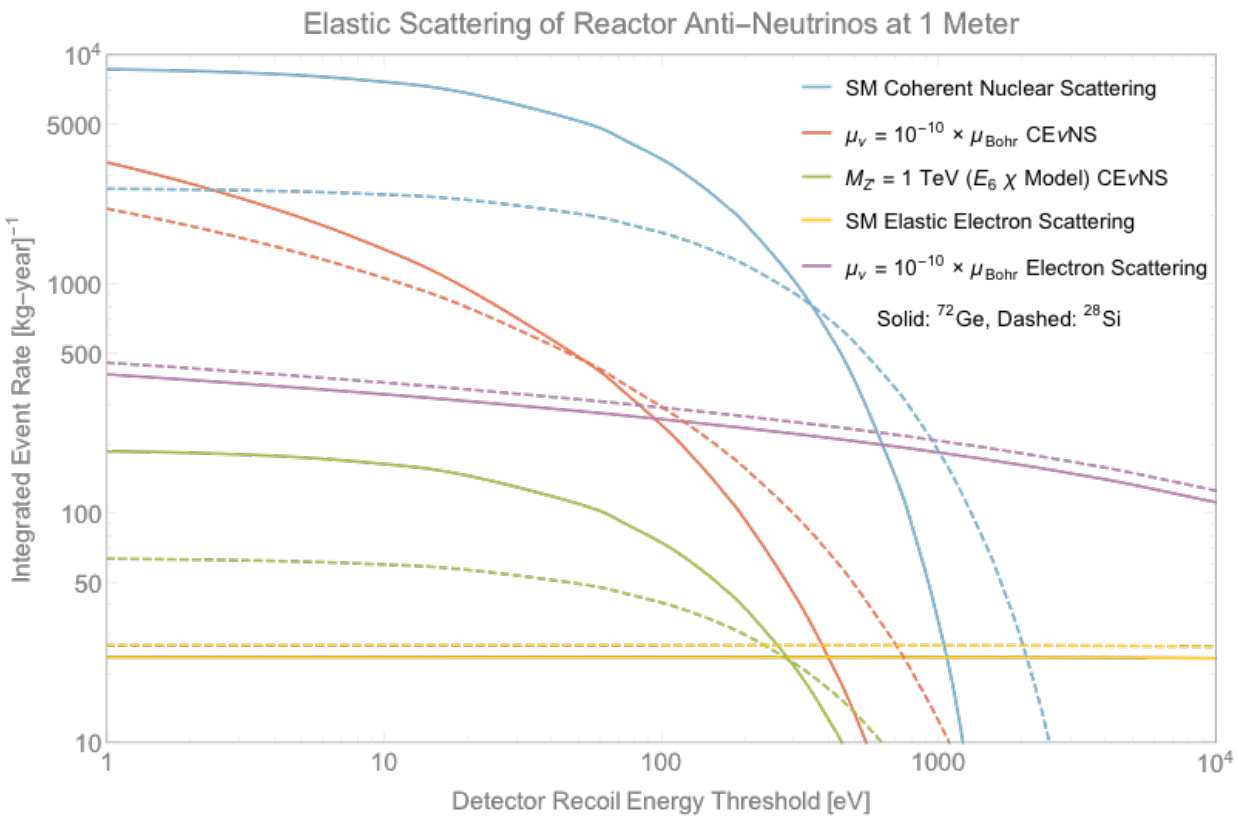
$$Z = \sqrt{q_0^{\mathrm{obs}}}$$

Z units of σ

G. Cowan, K. Cranmer, E. Gross, O. Vitells, 1007.1727 Eur.Phys.J. C
J. Billard, F. Mayet, and D. Santos, 1110.6079 PRD
J. Billard, L. Strigari, and E. Figueroa-Feliciano, arXiv:1307.5458 PRD

Magnetic Moment

A neutrino magnetic moment can also alter the recoil spectrum



$$\left.\frac{d\sigma}{dT_{\rm R}}\right|_{\mu_\nu} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left[\frac{1-T_{\rm R}/E_\nu}{T_{\rm R}} + \frac{T_{\rm R}}{4E_\nu^2}\right]$$

B. Dutta, R. Mahapatra, L.E. Strigari, and J.W. Walker, Phys.Rev. D**93** (2016) 013015, arXiv:1508.07981

Experimental constraints

Experiment	Bounds
Reactors	[Expression in Eqs.(12)-(13)]
KRASNOYARSK [33]	$\mu_{\bar{\nu}_e} \leq 2.7 \times 10^{-10} \mu_B$
ROVNO [34]	$\mu_{\bar{\nu}_e} \leq 1.9 \times 10^{-10} \mu_B$
MUNU [35]	$\mu_{\bar{\nu}_e} \leq 1.2 \times 10^{-10} \mu_B$
TEXONO [23]	$\mu_{\bar{\nu}_e} \leq 2.0 \times 10^{-10} \mu_B$
Accelerators	[Expression in Eqs. (14)-(15)-(16)]
LAMPF [36]	$\mu_{\nu_e} \leq 7.3 \times 10^{-10} \mu_B$
LAMPF [36]	$\mu_{\nu_\mu} \leq 5.1 \times 10^{-10} \mu_B$
LSND [37]	$\mu_{\nu_e} \leq 1.0 \times 10^{-9} \mu_B$
LSND [37]	$\mu_{\nu_\mu} \leq 6.5 \times 10^{-10} \mu_B$

Experiment	Previous limit [52]	This work	Full expression
Borexino	$\mu_\nu \leq 5 \times 10^{-11} \mu_B$	$\mu_\nu \leq 3.1 \times 10^{-11} \mu_B$	Eq. (18)

B.C. Canas, O.G. Miranda, A. Parada, M. Tortola, and J.W.F. Valle 1510.01684 PLB

Solar neutrino projections

Solar neutrino measurement projections

Experiment	ϵ (ton-year)	$E_{th,n}$ (keV)	$E_{th,o}$ (keV)	E_{max} (keV)	$R(pp)$	$R(^8\mathrm{B})$	$R(\mathrm{CNO})$
G2-Ge	0.25	0.35	0.05	50	–	[62 – 85]	[0 – 3]
G2-Si	0.025	0.35	0.05	50	–	[3 – 3]	0
G2-Xe	25	3.0	2.0	30	[2104 – 2167]	[0 – 64]	0
Future-Xe	200	2.0	1.0	30	[17339 – 17846]	[520 – 10094]	0
Future-Ar	150	2.0	1.0	30	[14232 – 14649]	[6638 – 12354]	0
Future-Ne	10	0.15	0.1	30	[1141 – 1143]	[898 – 910]	[21 – 63]

Exp.	$\phi_\nu^{^8\mathrm{B}}$	ϕ_ν^{pp}	$\sin^2\theta_W$
Measured	2.0% [a]	10.6 %[b]	
G2	1.9% (1.9%)	2.5 % (2.5%)	4.6% (4.5%)
Future-Xe	1.8% (0.9%)	0.7% (0.7%)	1.7% (1.7%)
Future-Ar	1.0% (0.6%)	0.6% (0.5%)	1.5% (1.4%)
HyperK[c]	1.43%	–	–

[a] Global fit [44] $\phi_\nu^{^8\mathrm{B}} = (5.1 \pm 0.1) \times 10^6$ cm^{-2} s^{-1}

[b] Borexino [19] measurement $\phi_\nu^{pp} = (6.6 \pm 0.7) \times 10^{10}$ cm^{-2} s^{-1}

[c] Based on 1 year projected data [43]

D.G. Cerdeno, M. Fairbairn, T. Jubb, P.A.N. Machado, A.C. Vincent, and C. Boehm, JHEP (2016), 1604.01025

NSI parameterization for coherent scattering

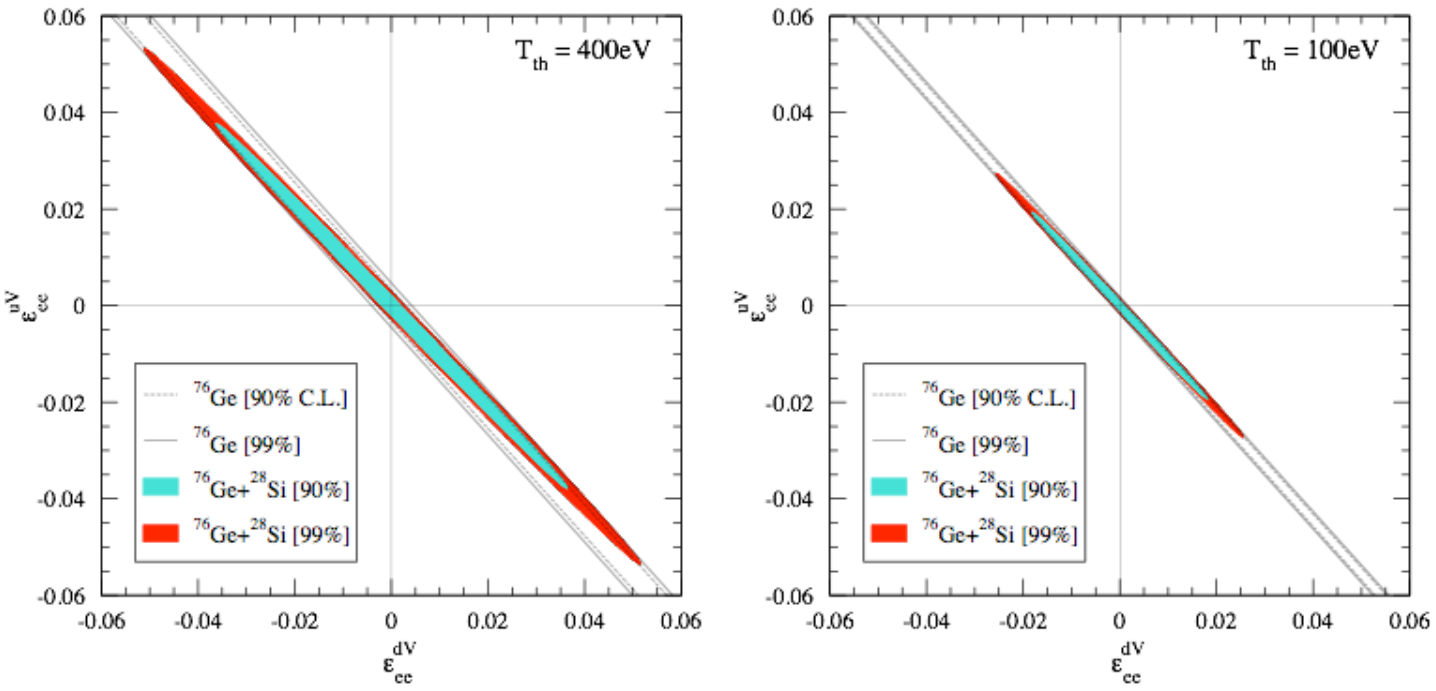
$$G_V = \left[\left(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}\right) Z + \left(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV}\right) N\right] F_{nucl}^V(Q^2)\,,$$

$$G_A = \left[\left(g_A^p + 2\varepsilon_{ee}^{uA} + \varepsilon_{ee}^{dA}\right)(Z_+ - Z_-) + \left(g_A^n + \varepsilon_{ee}^{uA} + 2\varepsilon_{ee}^{dA}\right)(N_+ - N_-)\right] F_{nucl}^A($$

$$g_V^p = \rho_{\nu N}^{NC}\left(\frac{1}{2} - 2\hat{\kappa}_{\nu N}\hat{s}_Z^2\right) + 2\lambda^{uL} + 2\lambda^{uR} + \lambda^{dL} + \lambda^{dR},$$

$$g_V^n = -\frac{1}{2}\rho_{\nu N}^{NC} + \lambda^{uL} + \lambda^{uR} + 2\lambda^{dL} + 2\lambda^{dR}\,.$$

J. Barranco, O.G. Miranda, and T.I. Rashba, JHEP (2005) hep-ph/0508299



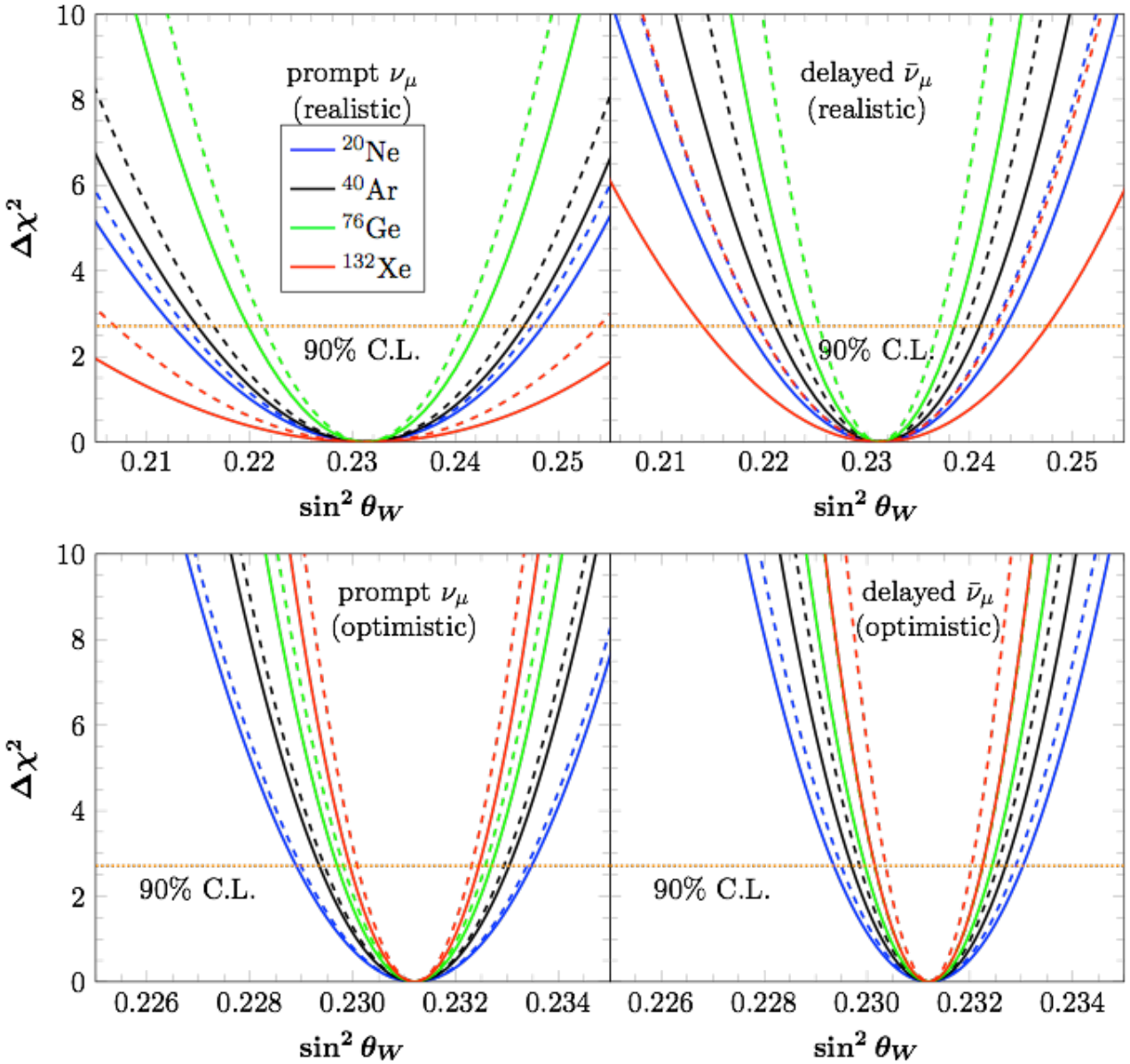
example for non-universal NSI

J. Barranco, O.G. Miranda, and T.I. Rashba, JHEP (2005) hep-ph/0508299

Weak mixing angle

Projection for COHERENT

$$\chi^2 = \left(\frac{N_{SM}^{events} - N_{\rm SNS}^{events}(\sin^2\theta_W)}{\delta N_{SM}^{events}} \right)^2$$



currently 2.4MeV is the lowest measurement

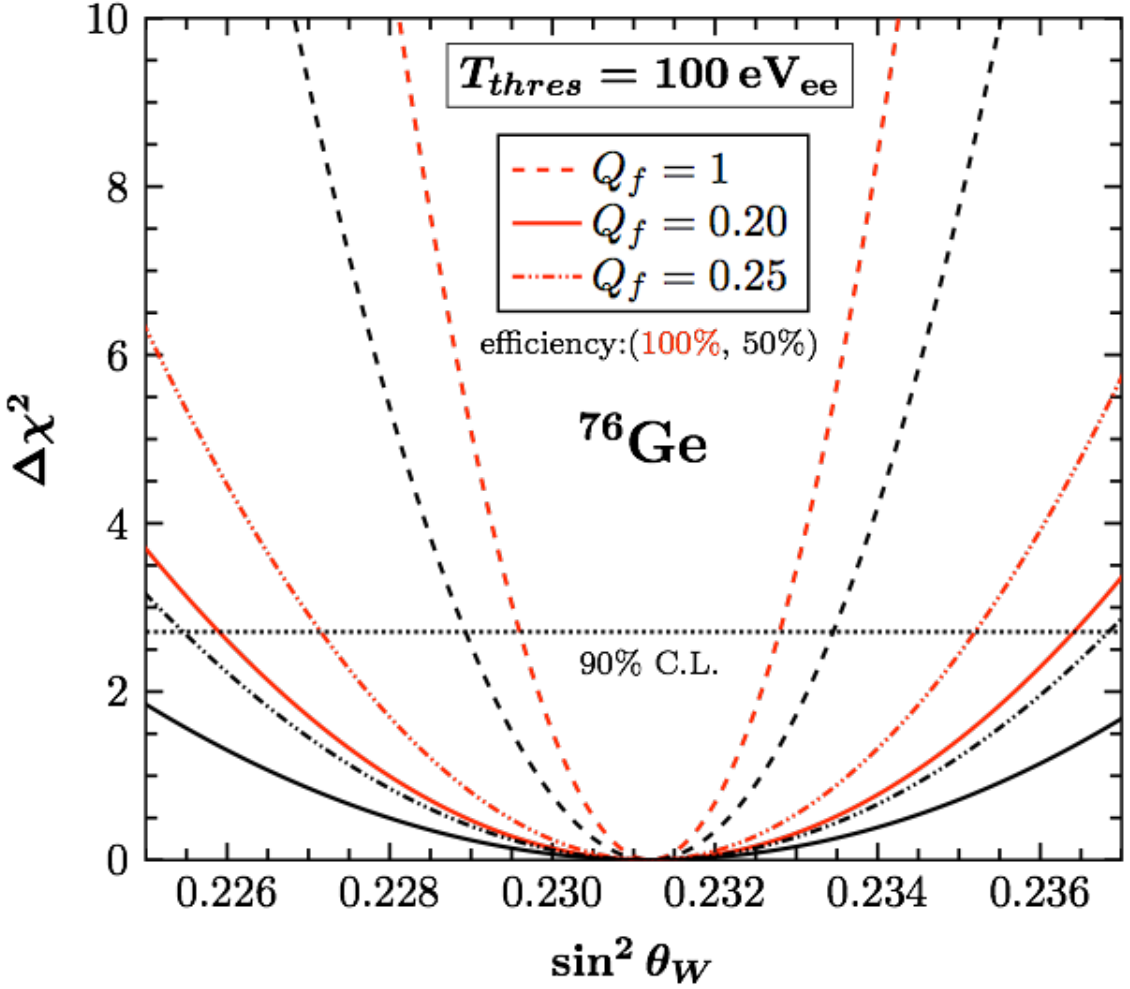
S.G. Porsev, K. Beloy, and A. Derevianko, PRL 102 (2009) arXiv:0902.0335

T.S. Kosmas, O.G. Miranda, D.K. Papoulias, M. Tortola, and J.W.F. Valle, PRD 92 (2015) arXiv:1505.03202

Projection for TEXONO

$$\chi^2 = \left(\frac{N_{SM}^{events} - N_{\rm SNS}^{events}(\sin^2\theta_W)}{\delta N_{SM}^{events}} \right)^2$$

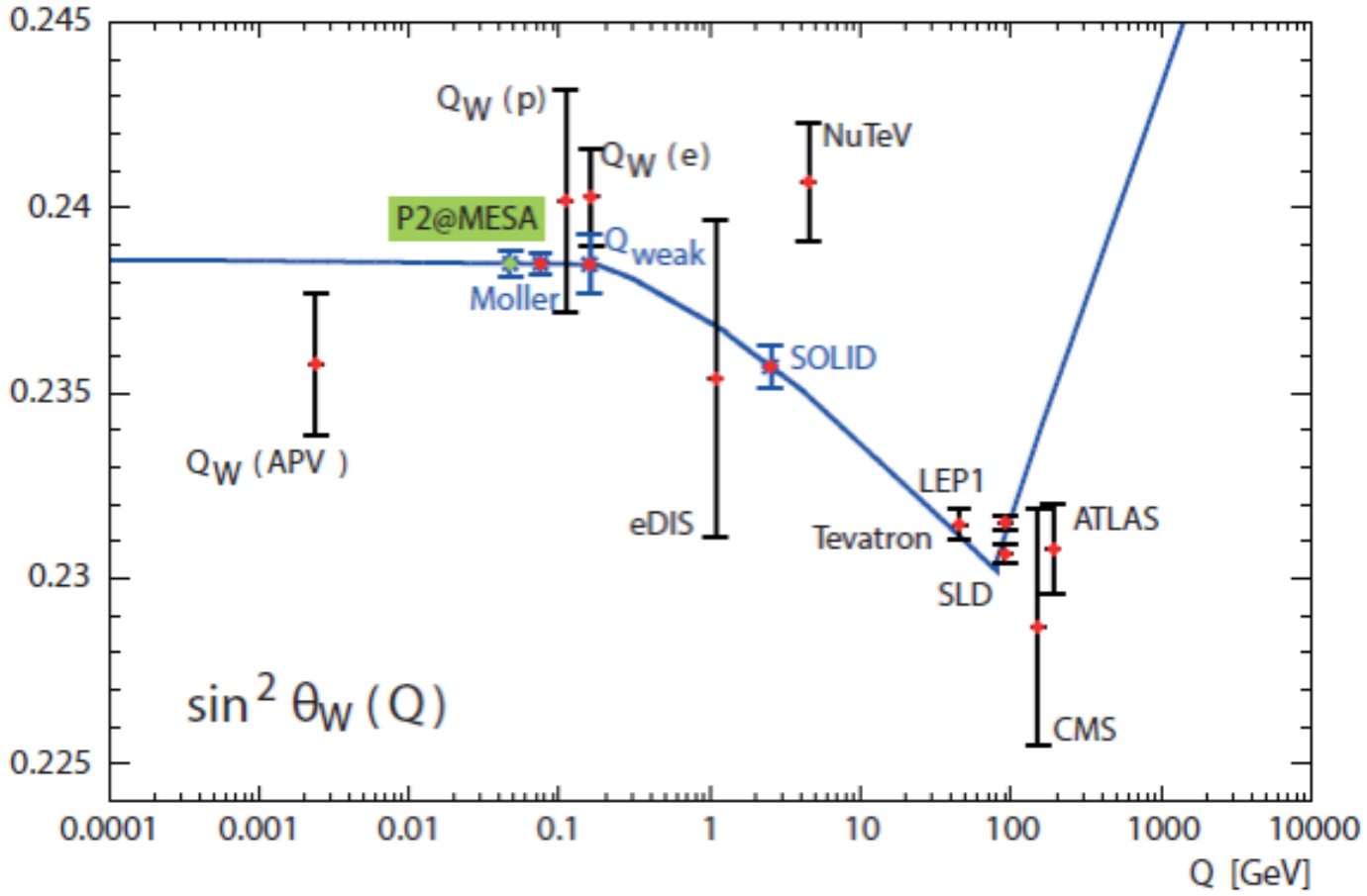
currently 2.4MeV is the lowest measurement



S.G. Porsev, K. Beloy, and A. Derevianko, PRL 102 (2009) arXiv:0902.0335

T.S. Kosmas, O.G. Miranda, D.K. Papoulias, M. Tortola, and J.W.F. Valle, PLB 750 (2015) arXiv:1506.08377

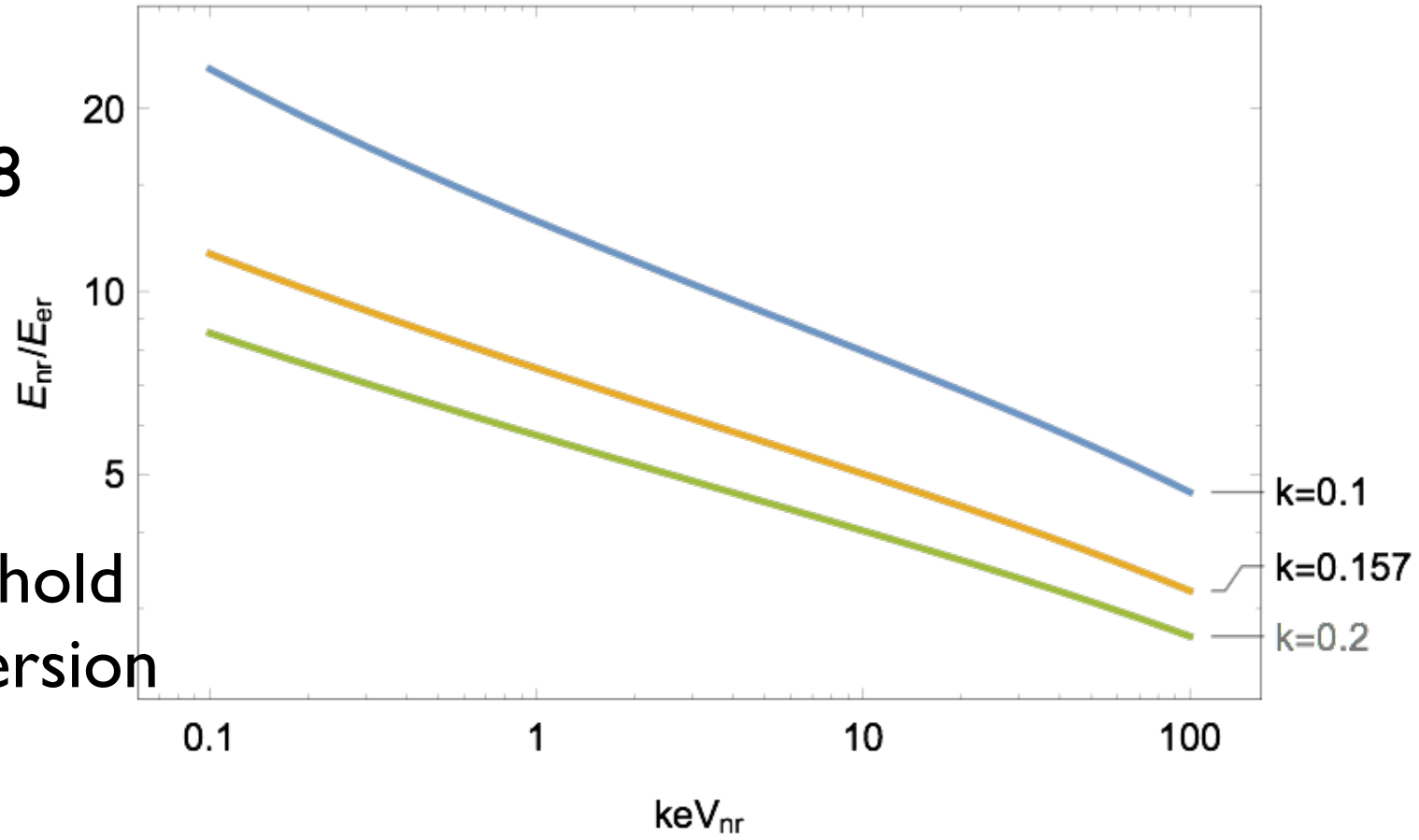
Projections for upcoming experiments



N. Berger et al., 1511.03934, JUSTC

CDMSlite
1509.02448

56eVee threshold
ee to nr conversion



$$E_{\rm nr} = E_{\rm ee}\left(\frac{1+eV_b/\epsilon_\gamma}{1+Y(E_{\rm nr})eV_b/\epsilon_\gamma}\right) \qquad Y(E_{nr}) = \frac{k\cdot g(\varepsilon)}{1+k\cdot g(\varepsilon)}$$

$$g(\varepsilon) = 3\varepsilon^{0.15}+0.7\varepsilon^{0.6}+\varepsilon,\ \varepsilon = 11.5E_{\rm nr}({\rm keV})Z^{-7/3}$$

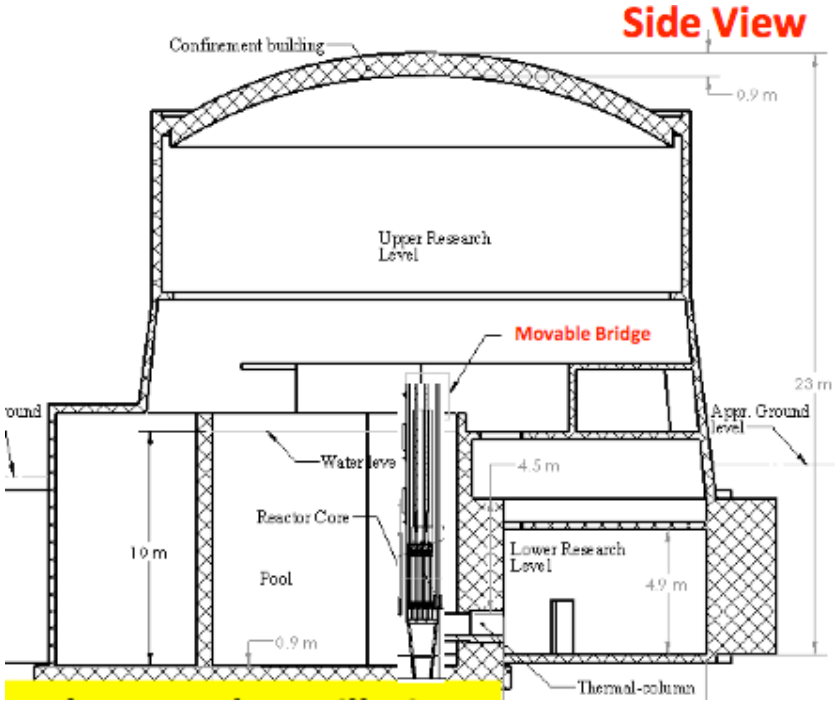
MINER experiment at Texas A&M

Mitchell Institute Neutrino Experiment at Reactor

Currently participating institutions are:
Texas A&M, University of Texas at Austin, University of Minnesota, NISER (India), Queen's University (Canada), Fukui University (Japan), University of South Dakota, and Sam Houston State University

Texas A&M has a MW research reactor with a rail mounted and moveable reactor core. There exists an experimental cavern where (Ge/Si) detectors can be placed ~1m from the core.

It provides an anti-neutrino flux of $\Phi_{\bar{\nu}}^{f} = 1.5 \times 10^{12}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



Tentatively the first run will be with 1 iZIP detector and 5HV detectors, and will commence soon.

Research efforts are ongoing to reduce thresholds and increase resolution of the detectors (see for example: N. Mirabolfathi, H.R. Harris, R. Mahapatra, K. Sundqvist, A. Jastram, B. Serfass, D. Faiez, and B. Sadoulet, arXiv:1510.00999)

number of events...

$$N_{\text{events}} = t\phi_0 \frac{M_{\text{detector}}}{M} \int_{E_{min}}^{E_{max}} dE_\nu \int_{T_{th}}^{T_{max}(E_\nu)} dT \lambda(E_\nu) \frac{d\sigma}{dT}(E_\nu, T)$$

J. Barranco, O.G. Miranda, and T.I. Rashba, JHEP (2005) hep-ph/0508299

number of events...

$$N_{\text{events}} = t\phi_0 \frac{M_{\text{detector}}}{M} \int_{E_{min}}^{E_{max}} dE_\nu \int_{T_{th}}^{T_{max}(E_\nu)} dT \lambda(E_\nu) \frac{d\sigma}{dT}(E_\nu, T)$$

exposure

neutrino flux

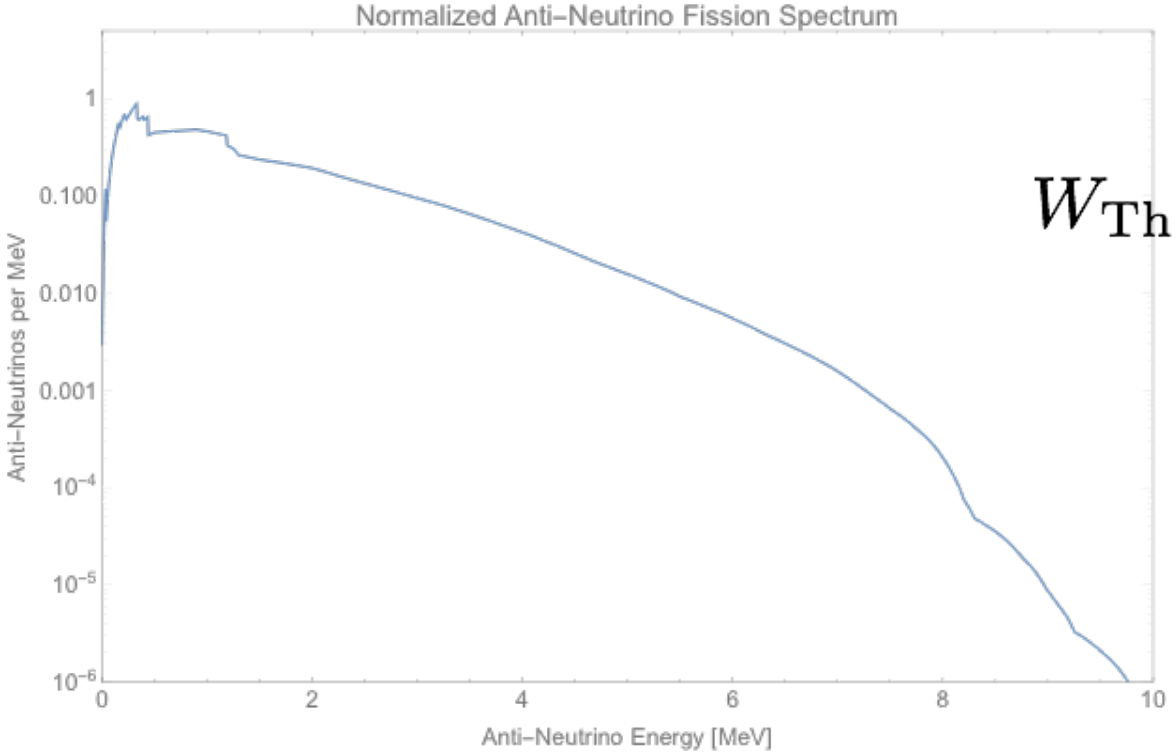
neutrino spectrum

differential cross section

single target mass

...or other quantities such as differential recoil rate $\frac{dR}{dE_r}$

J. Barranco, O.G. Miranda, and T.I. Rashba, JHEP (2005) hep-ph/0508299



TAMU reactor

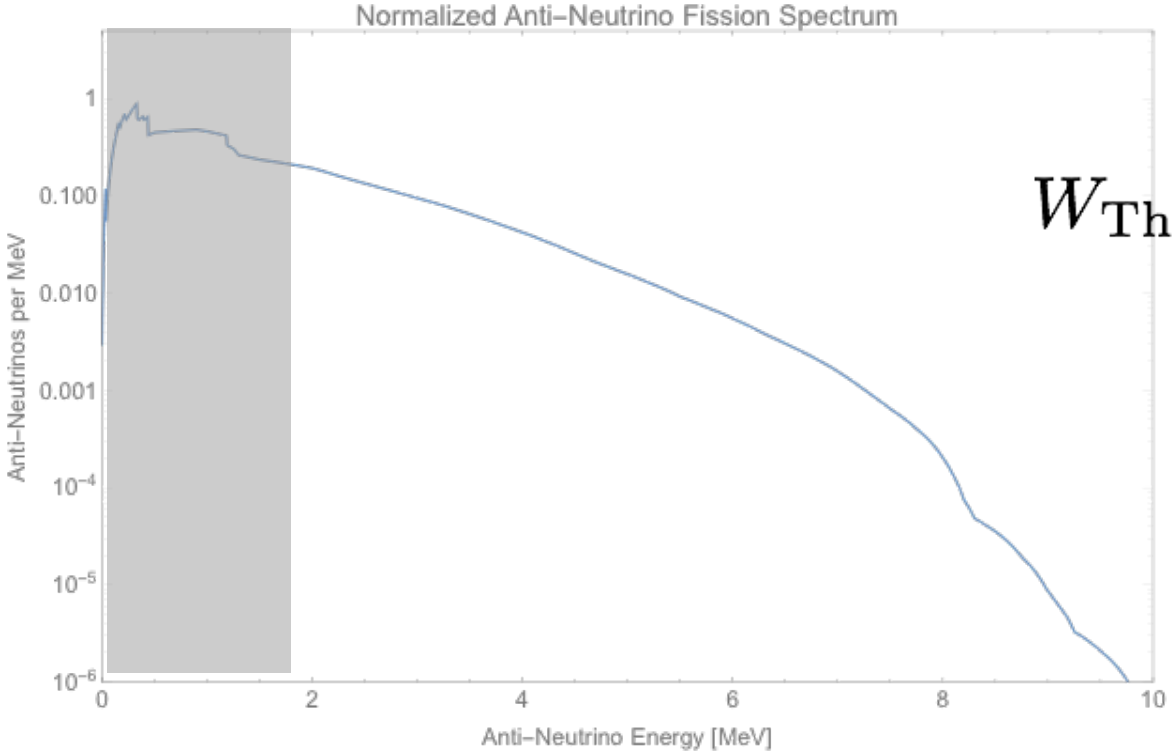
$$W_{\mathrm{Th}} = 1.00 \pm 0.02 \ \mathrm{MW}$$

B. Dutta, R. Mahapatra, L.E. Strigari, and J.W. Walker, PRD (2016) arXiv: 1508.07981

B. Dutta, Y. Gao, R. Mahapatra, N. Mirabolfathi, L.E. Strigari, and J.W. Walker, arXiv:1511.02834

Nucleus	E_{Th}	$\langle E_\nu \rangle$	$\langle N_\nu \rangle$	f_i/F
^{235}U	201.92 ± 0.46	9.07 ± 0.32	6.14	0.967
^{238}U	205.52 ± 0.96	11.00 ± 0.80	7.08	0.013
^{239}Pu	209.99 ± 0.60	7.22 ± 0.27	5.58	0.020
^{241}Pu	213.60 ± 0.65	8.71 ± 0.30	6.42	< 0.001
$^{238}\mathrm{U} \rightarrow {}^{239}\mathrm{Pu}$	1.95	1.2	2.0	0.16

examples of other reactor measurements:
K. Schreckenbach, G. Colvin, W. Gelletly, and F. Von Feilitzsch, PLB **160** (1985)
V.I. Kopeikin, Phys.Atom.Nucl. **75**, 143 (2012)
recent Daya Bay flux measurement: Feng Peng An *et al.*, arXiv:1607.05378



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B. Dutta, Y. Gao, R. Mahapatra, N. Mirabolfathi, L.E. Strigari, and J.W. Walker, arXiv:1511.02834

opportunity for measuring the anti-neutrino flux at low energy

Nucleus	E_{Th}	$\langle E_\nu \rangle$	$\langle N_\nu \rangle$	f_i/F
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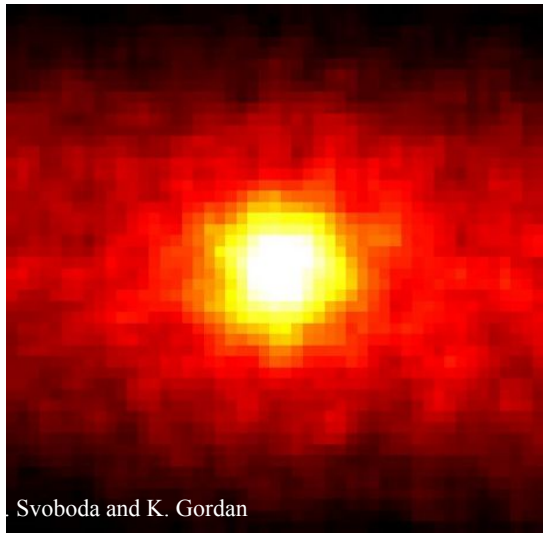
$^{238}\mathrm{U} \rightarrow {}^{239}\mathrm{Pu}$	1.95	1.2	2.0	0.16

A 1.8MeV antineutrino will produce about a 90eV max recoil energy for ^{72}Ge

examples of other reactor measurements:
K. Schreckenbach, G. Colvin, W. Gelletly, and F. Von Feilitzsch, PLB **160** (1985)
V.I. Kopeikin, Phys.Atom.Nucl. **75**, 143 (2012)
recent Daya Bay flux measurement: Feng Peng An *et al.*, arXiv:1607.05378



Solar neutrinos

$$^{8}\mathrm{B} \rightarrow {}^{7}\mathrm{Be}^{*} + e^{+} + \nu_e$$

$$^{3}\mathrm{He} + \mathrm{p} \rightarrow {}^{4}\mathrm{He} + e^{+} + \nu_e$$

hep

electron capture on $^{7}\mathrm{Be}$

pp

$$p + p \rightarrow {}^{2}\mathrm{H} + e^{+} + \nu_e$$

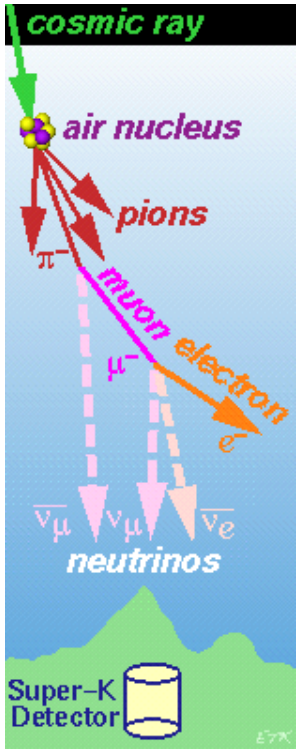
$$p + e^{-} + p \rightarrow {}^{2}\mathrm{H} + \nu_e$$

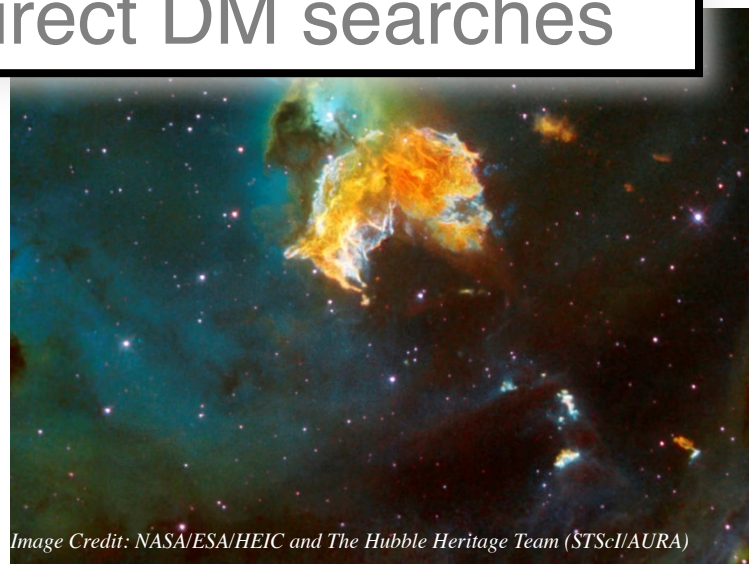
pep

neutrinos from the CNO cycle

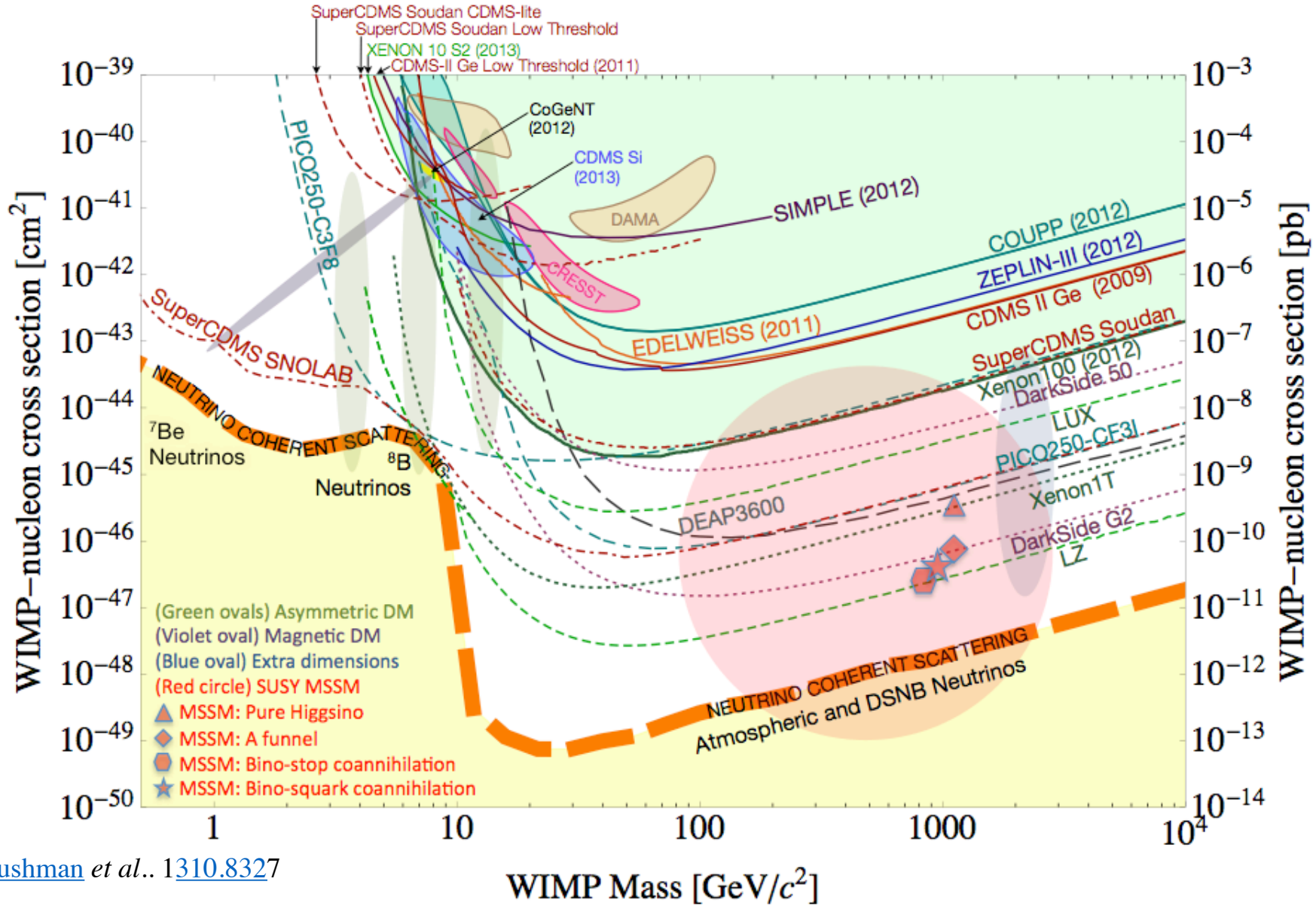
An irreducible background for direct DM searches

Atmospheric neutrinos





Diffuse SN background



P. Cushman *et al*.. 1310.8327