Neutrino Scattering Backgrounds To Dark Matter Searches

Jocelyn Monroe, 7.23.07
Cygnus Workshop

1. Neutrino Fluxes
2. Coherent Scattering Cross Section
3. Event Rates

`Monroe, Fisher, arXiv:0706.3019; accepted to Phys. Rev. D`

Motivation: $\sigma(\chi A)$ may be 10^{-48} cm^2

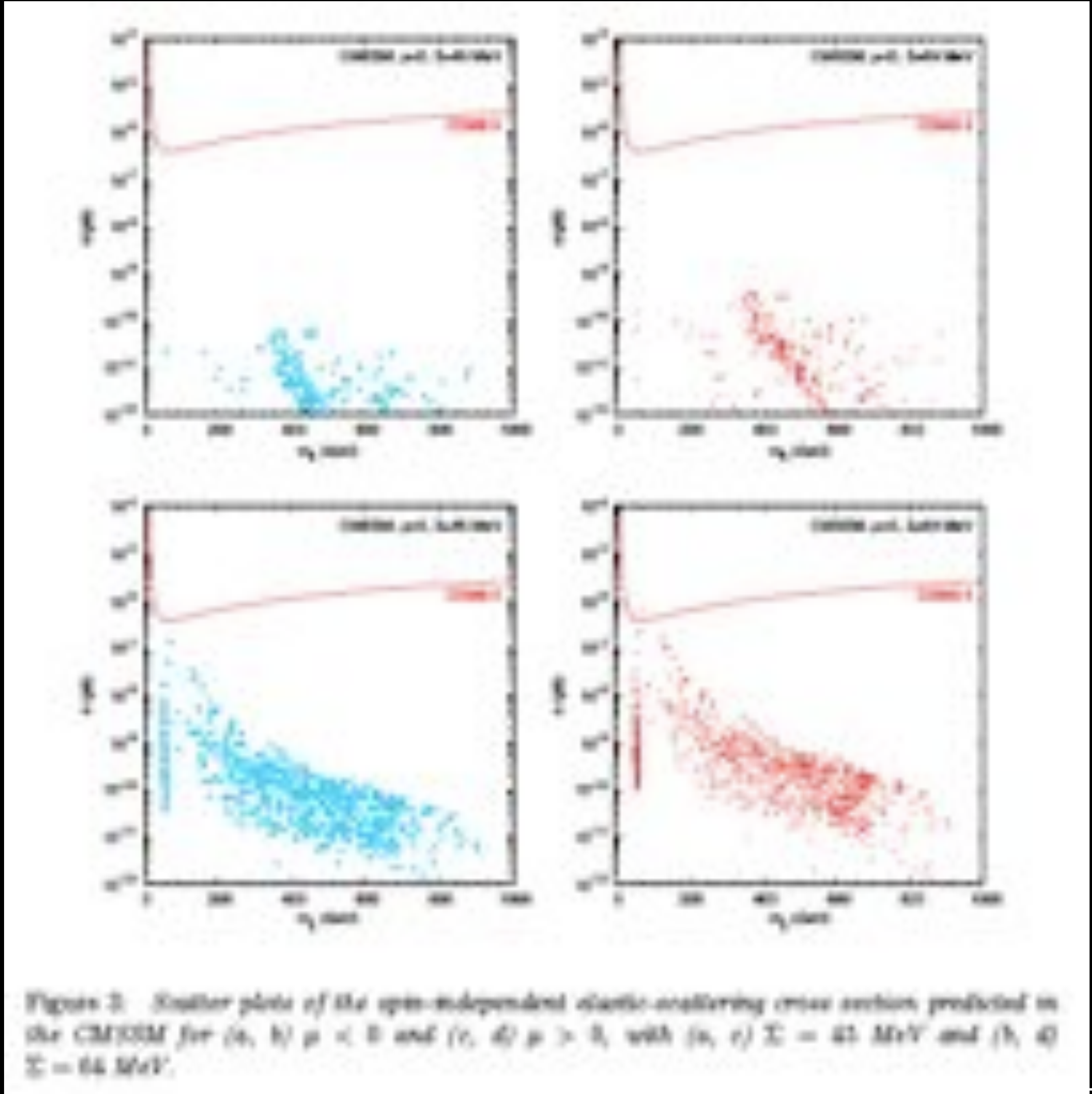
SUSY collider limits:

J. R. Ellis, et al.,
PRD **71**, 095007 (2005)
arXiv:hep-ph/0502001

Shrimps, not WIMPS:

1 pb $= 10^{-36}$ cm^2
σ(weak) ~ 10^{-3} pb
σ(DM el) ~ 10^{-10} pb

~10^4 below current expt'l sensitivity



Motivation: 10^4 is a lot of σ

Not to Scale

10^{-28} cm^2: σ(total inelastic pp at TeVatron)

10^{-34} cm^2: $\sigma(pp \rightarrow W^+W^-)$ at TeVatron

10^{-39} cm^2: $\sigma(\nu$ coherent) at SNS (E_ν = 10 MeV)

10^{-39} cm^2: σ(single top) at TeVatron

10^{-40} cm^2: $\sigma(\nu$ QE) at MiniBooNE (E_ν = 1 GeV)

10^{-43} cm^2: $\sigma(\nu$ NC Elastic) for geo-ν (E_ν = 2 MeV)

10^{-45} cm^2: $\sigma(\nu$-e Elastic) for solar ν

σ(DM elastic scattering)? 10^{-48} cm^2

Are weak interactions of SM particles a background to DM searches at 10^{-48} cm^2?

ν Fluxes ($cm^{-2}\ s^{-1}$)

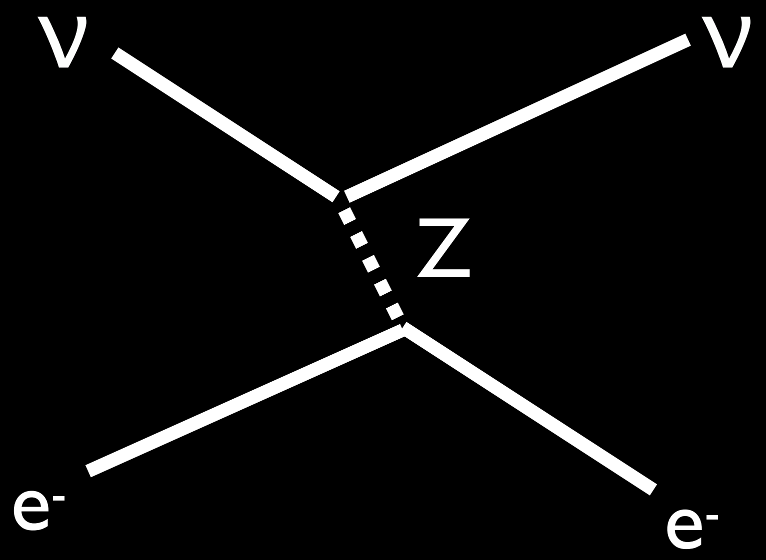
Considered here

Source	Predicted	E_ν Range
Solar Total	O(1E13)	<18 MeV
pp	5.99E10	<0.4 MeV
CNO	5.46E8	<2 MeV
7Be	4.84E9	0.3 /0.8 MeV
8B	5.69E6	<12 MeV
hep	7.93E3	<18 MeV
Geo Total	O(1E7)	<5 MeV
238U	2.34E6	<5 MeV
232Th	1.99E6	<2.5 MeV
235U	~4E3	<2 MeV
40K	~1E7	<2 MeV
Atmospheric	O(1/E(GeV)$^{2.7}$)	0 to multi-GeV
Reactor	O(1E20/d^2)	<10 MeV
Supernova Relic	O(10)	<60 MeV

ν Cross Sections: ν-e$^-$ Elastic Scattering

ν scatters off atomic e$^-$

proposed detection mechanism for solar pp, ^{7}Be νs (XMASS, CLEAN, GENIUS,..)



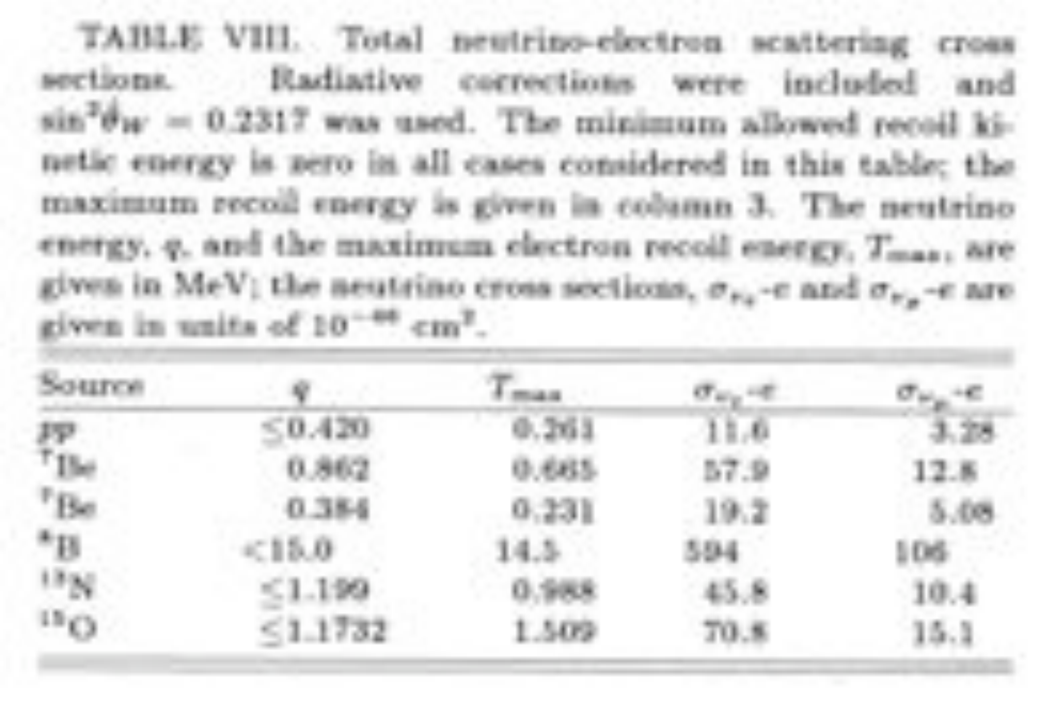


TABLE VIII. Total neutrino-electron scattering cross sections. Radiative corrections were included and $\sin^2\theta_W = 0.2317$ was used. The minimum allowed recoil kinetic energy is zero in all cases considered in this table; the maximum recoil energy is given in column 3. The neutrino energy, q, and the maximum electron recoil energy, T_{max}, are given in MeV; the neutrino cross sections, σ_{ν_e}-e and σ_{ν_μ}-e are given in units of 10^{-46} cm^2.

Source	q	T_{max}	σ_{ν_e}-e	σ_{ν_μ}-e
pp	$\leq$0.420	0.261	11.6	3.28
^{7}Be	0.862	0.665	57.9	12.8
^{7}Be	0.384	0.231	19.2	5.08
^{8}B	<15.0	14.3	594	106
^{13}N	$\leq$1.199	0.988	45.8	10.4
^{15}O	$\leq$1.1732	1.509	70.8	15.1

Cross sections are small

~ (Eν/10 MeV) x 10^{-44} cm^2

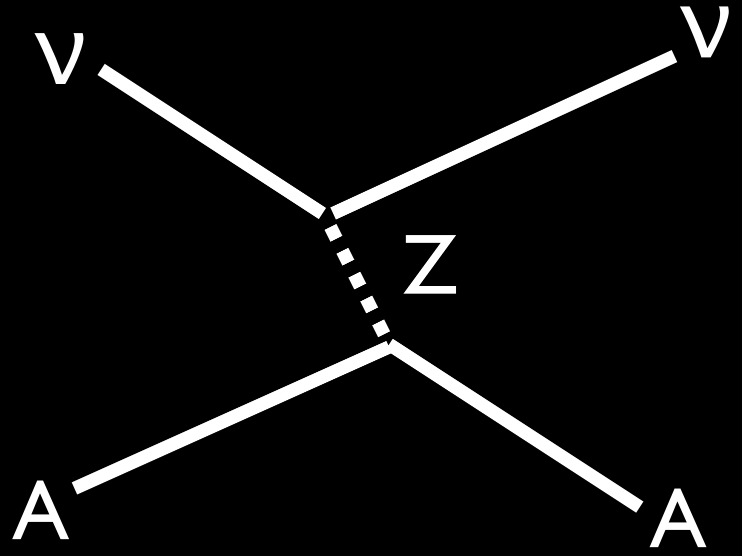
Recoils are O(10^2 KeV)

`J. Bahcall, M. Kamionkowski, A. Sirlin, PRD 51, 6146 (1995)`

ν Cross Sections: ν-N Coherent Scattering

ν scatters coherently
off of the entire nucleus A

≡ low Q^2



coherence condition:
$Q^2 (r_A)^2 \sim 1$

coherent scattering produces
very low recoil kinetic energies

$$T_{max} = \frac{2E_\nu^2}{m_{nucleus} + 2E_\nu}$$

= 0.6 KeV for ^{12}C, E_ν=2 MeV

proposed mechanism for
solar pp ν, supernova ν
detection (CLEAN)

C. J. Horowitz, K. J. Coakley,
D. N. McKinsey, PRD 68, 023005 (2003)

ν Coherent Scattering

$Q^2 = 2mT$, low Q^2 simplifies nuclear description
(to 1st order no Q^2 dependence except in form factor)

$$\frac{d\sigma}{dT} = \frac{G_F^2(\hbar c)^2 m_{nucleus}}{4\pi}\left(N-(1-4sin^2\theta_W)Z\right)^2\left(1-\frac{m_{nucleus}T_{nucleus}}{2E_\nu^2}\right)F(Q^2)^2$$

N = number of target nucleons
Z = number of protons
$F(Q^2)$ = nuclear form factor

- cross section ~ N^2, heavier nucleus = more events
- as $T_{nucleus}$ increases, cross section decreases

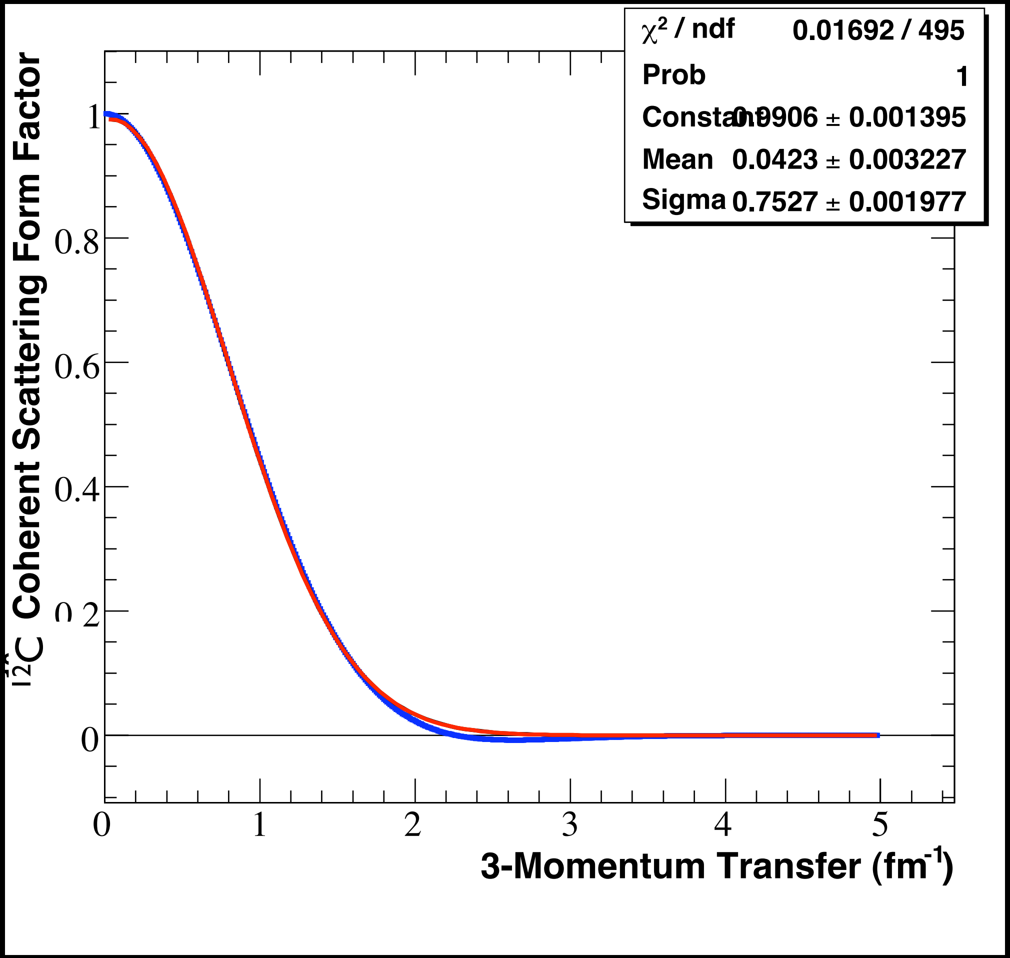
D. Z. Freedman, PRD 9, 1389 (1974);
H. T. Wong, et al., J. Phys. Conf. Ser. 39, 266 (2006);
K. Scholberg, PRD 73, 033005 (2006)

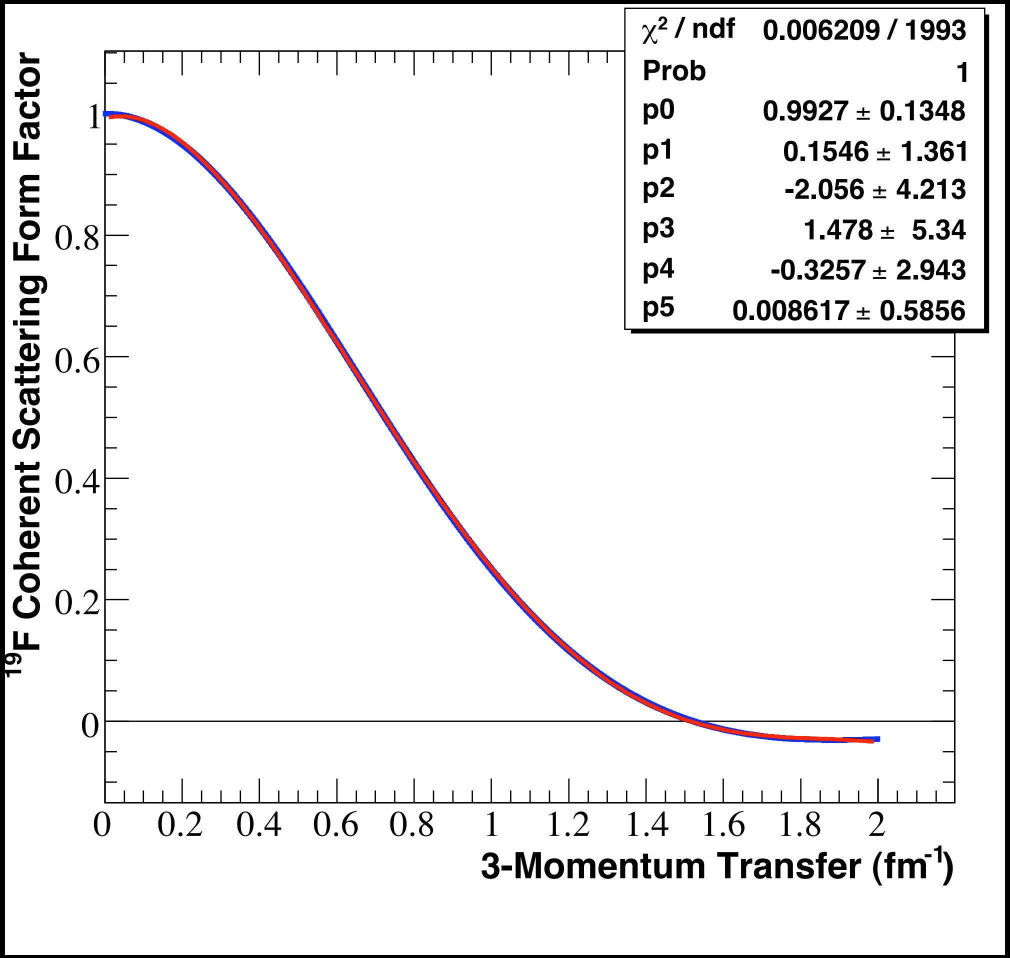
ν Scattering Form Factors

F(q) vs. q (3-momentum) (fm^{-1})

while (1/q) is < nuclear size (~3-5 fm), ν scatters coherently

$$Q^2 = \vec{q}^2 - \nu^2, \quad |\vec{q}| = \sqrt{Q^2+\nu^2} = \sqrt{Q\left(1+\left(\frac{1}{2m}\right)^2\right)}$$





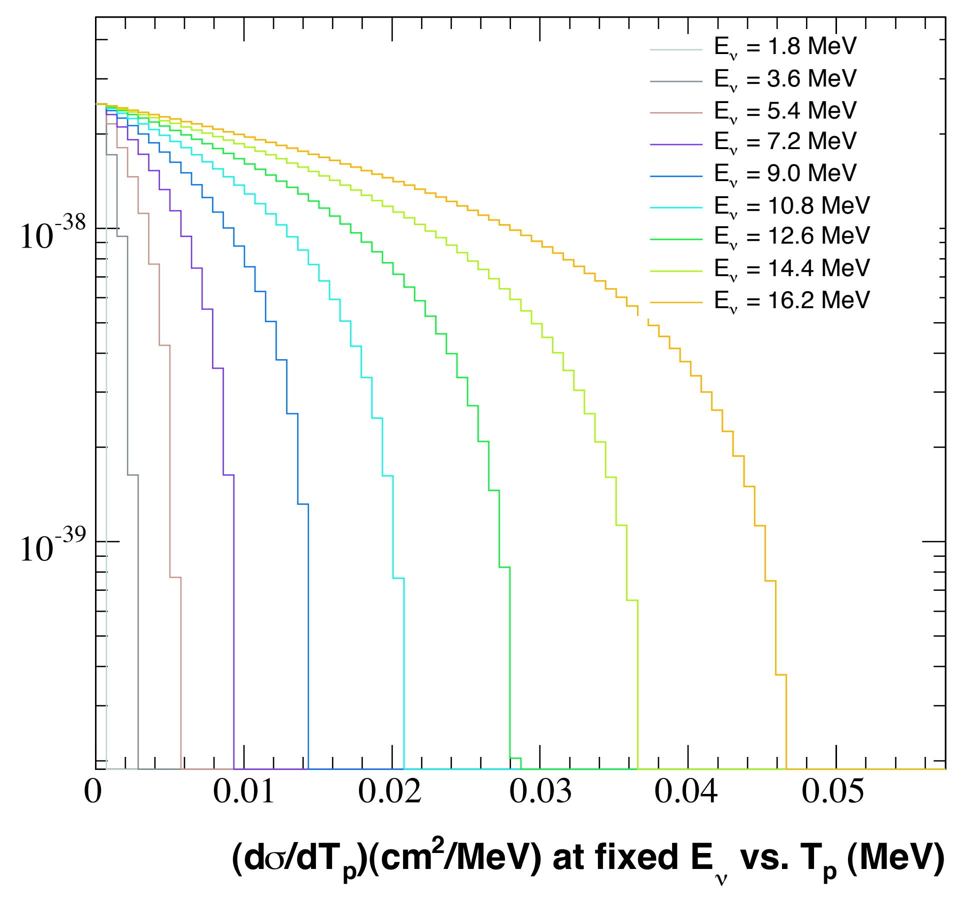
ν Coherent Scattering Cross Section

calculated on ^{12}C for geo-ν
through solar-ν energies

–σ suppressed by $F(Q^2)^2$
(nuclear effects)

`C. J. Horowitz et al, PRD68 (2003) 023005`
`C. J. Horowitz et al., NPA368 (1981) 503`

-suppression is 5-10%
at these ($E\nu$,Q^2)



Cross sections are large!
But. recoil energies are small, O(10 KeV).

Prediction vs. Measurement

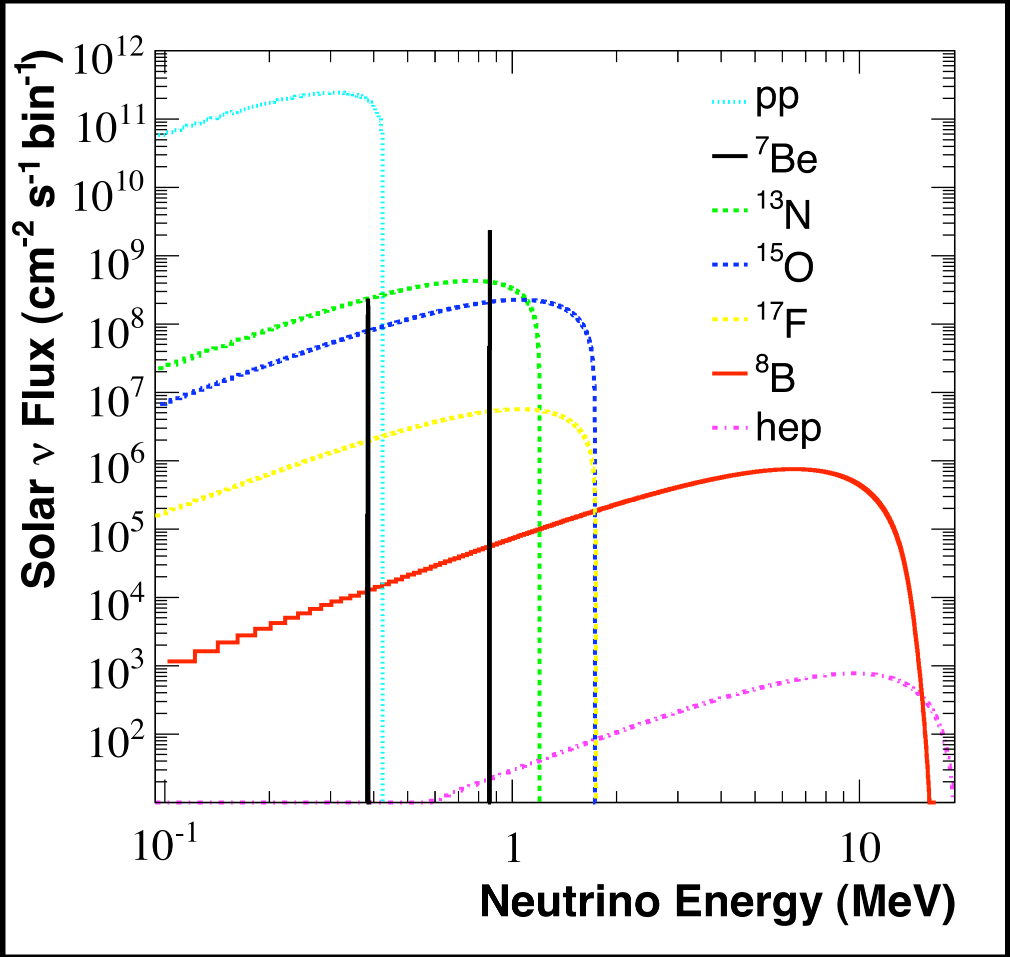
	Predicted	Measured
Solar ν:	$\Phi(B^8) = 5.86$ x 10^6 cm^{-2} s^{-1} 16% normalization uncertainty http://www.sns.ias.edu/~jnb/SNdata/sndata.html	SNO: 1.09 x predicted (10%) SK: $\Phi(B^8)$ uncertainty = 3.5%
Geo ν:	$\Phi(U^{238}) = 2.34$ x 10^6 cm^{-2} s^{-1} $\Phi(Th^{232}) = 1.98$ x 10^6 cm^{-2} s^{-1} *http://www.awa.tohoku.ac.jp/~sanshiro/geoneutrino/spectrum/index.html*	KamLAND: ~4 x predicted, 76% measurement uncertainty
Atm ν:	$\Phi(U^{238}) = 9.6$ x 10^{-1} cm^{-2} s^{-1} (geomagnetic cutoff important) 20% normalization uncertainty	SuperK: normalization within 10% of prediction (+ osc.) for $E\nu < 100$ MeV
ν–N σ:	uncertainty from approximations in form factor calculation: 5-10%	**never measured!** (historically, surprises at low Q^2)

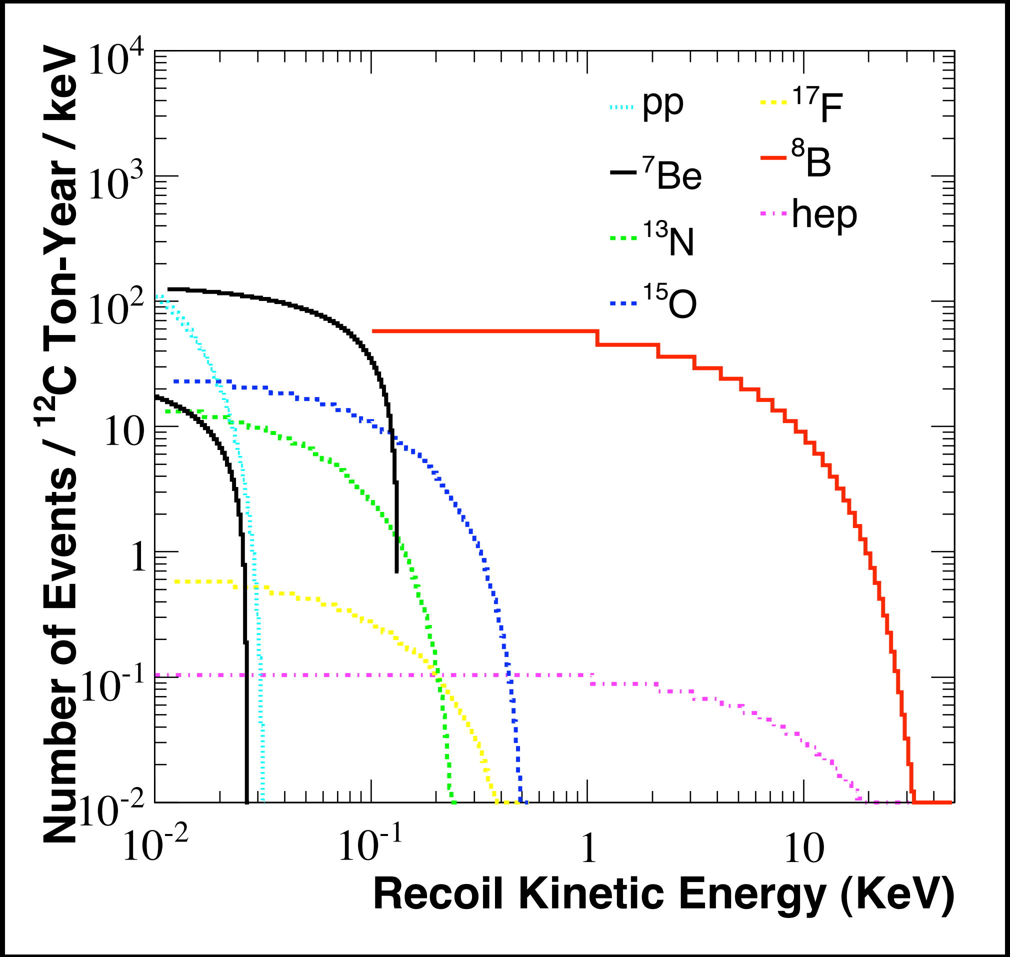
Solar ν Event Rates

1. calculated σ vs E$_\nu$
2. flux = Bahcall predicted
3. 1 ton of ^{12}C, 1 year

$$N = \Phi(E_\nu) \times \sigma(E_\nu) \times N_{targets}$$

$$N_{targets} = \frac{Detector\ Mass}{A} \times N_A$$



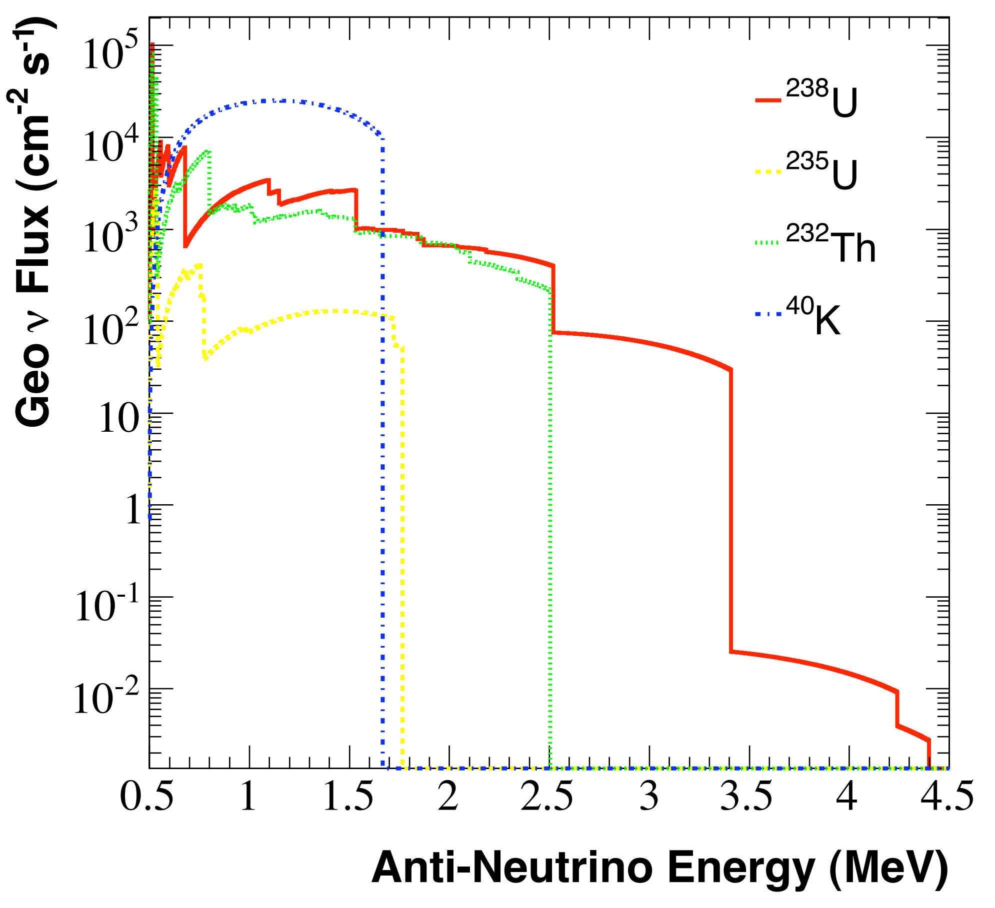


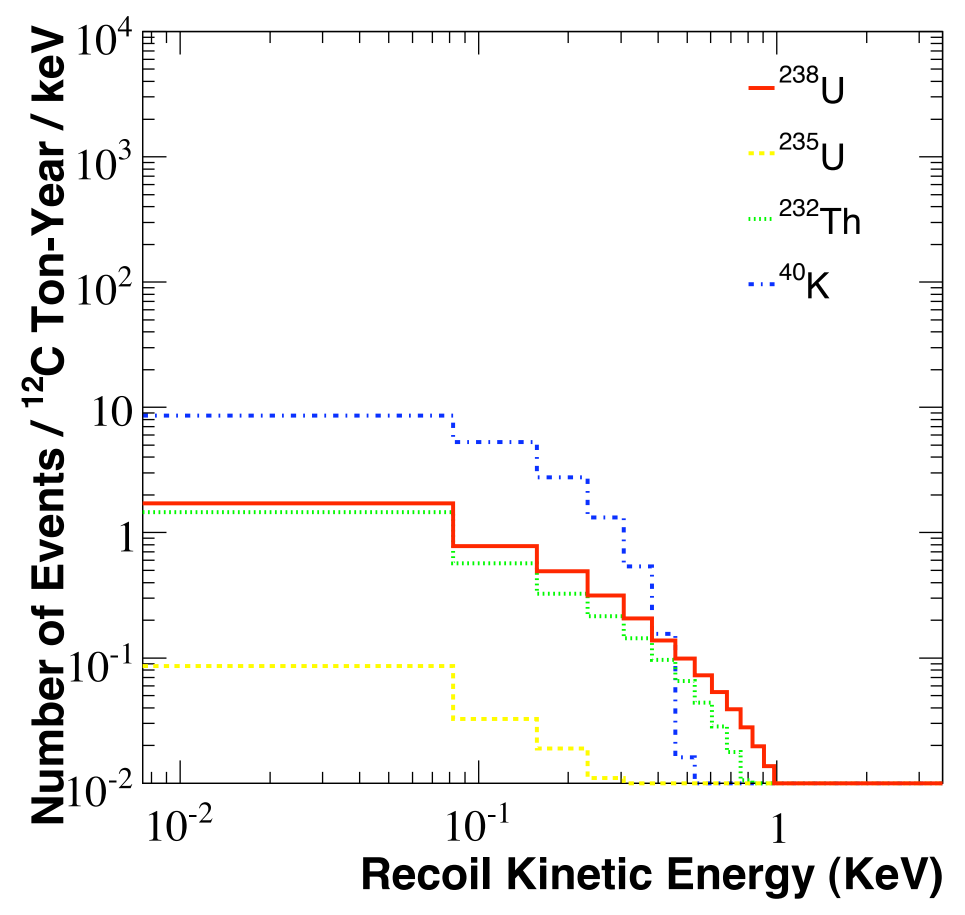
Geo ν Event Rates

1. calculated σ vs E_ν
2. flux = Sanshiro predicted (0.25xKamLAND)
3. 1 ton of ^{12}C, 1 year

$$N = \Phi(E_\nu) \times \sigma(E_\nu) \times N_{targets}$$

$$N_{targets} = \frac{Detector\ Mass}{A} \times N_A$$



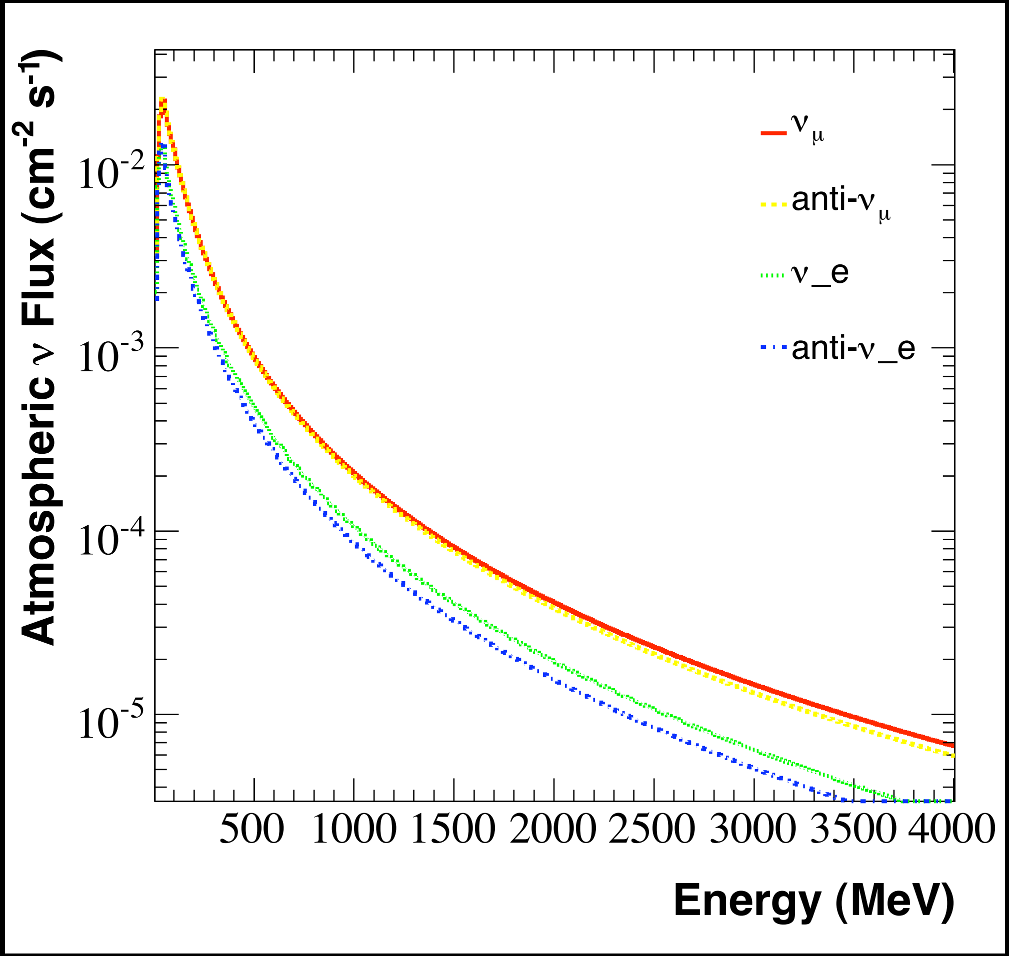


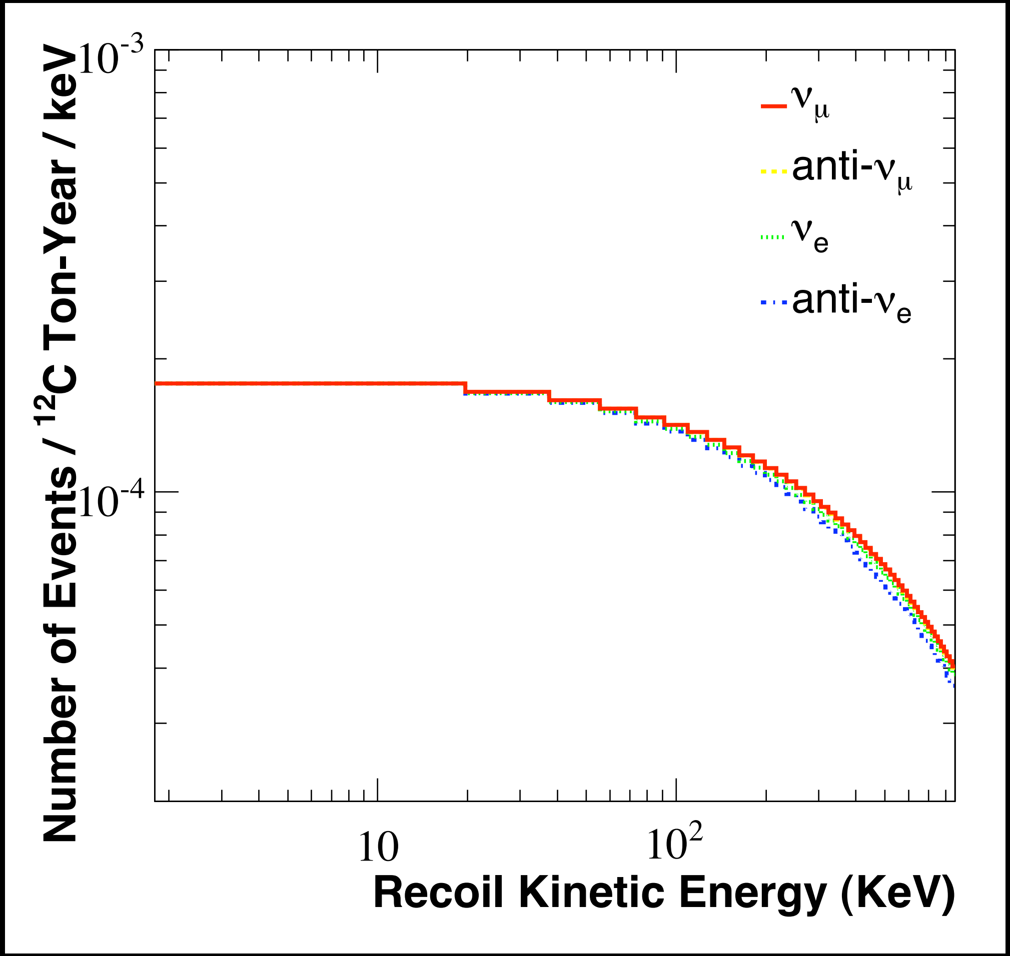
Atmospheric ν Event Rates

1. calculated σ vs E_ν
2. flux = Honda predicted
3. 1 ton of ^{12}C, 1 year

$$N = \Phi(E_\nu) \times \sigma(E_\nu) \times N_{targets}$$

$$N_{targets} = \frac{Detector\ Mass}{A} \times N_A$$



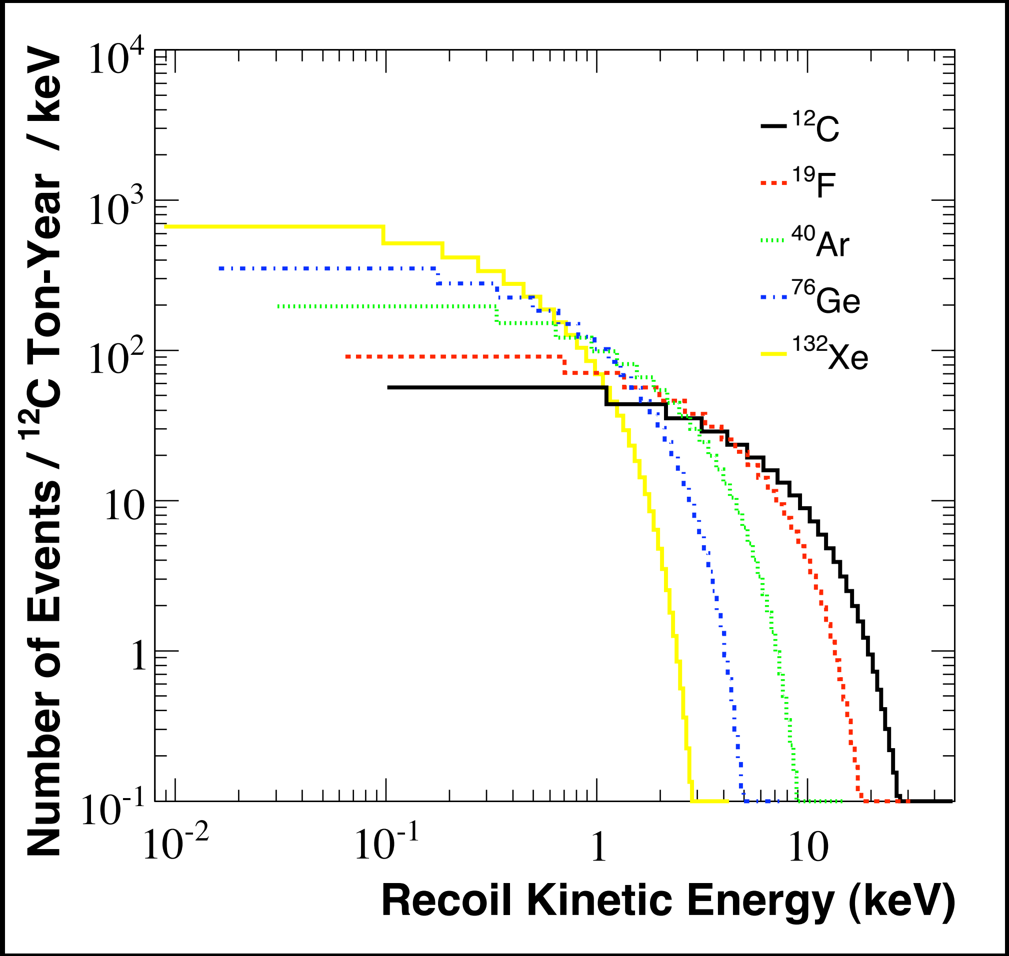


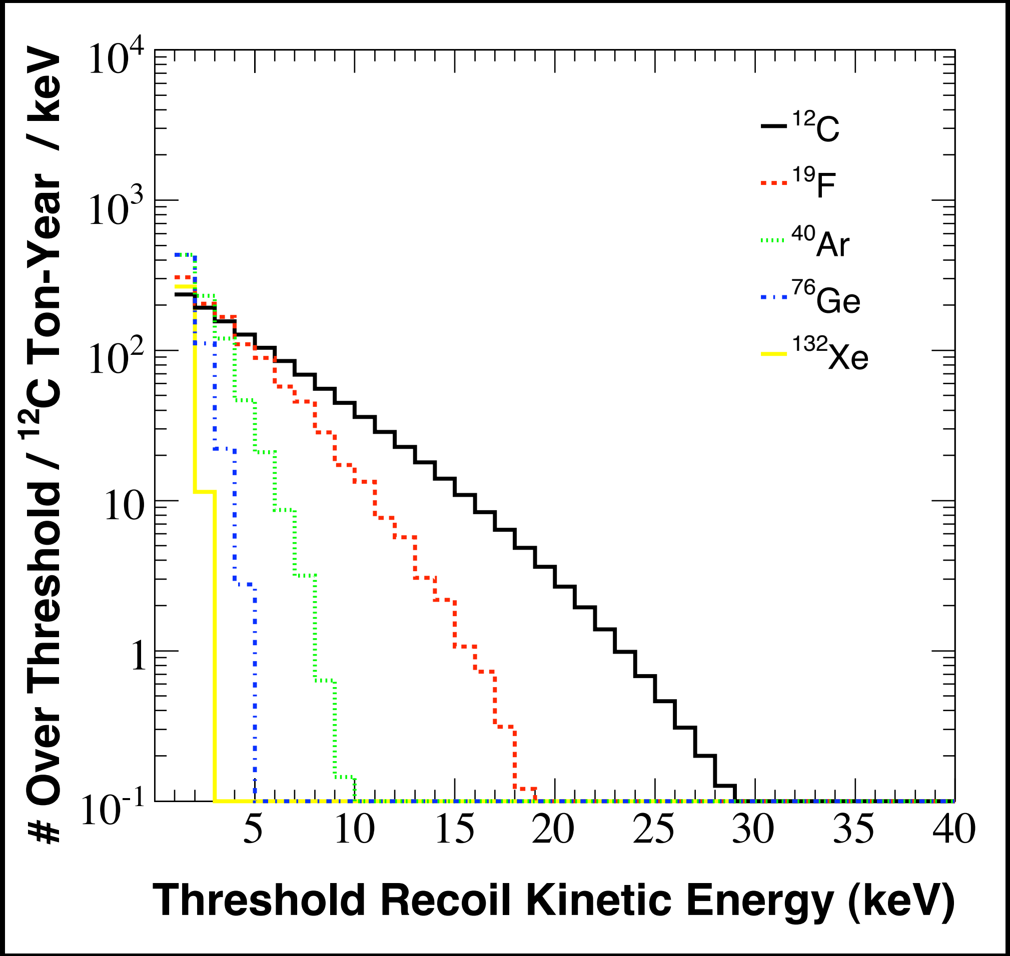
^{8}B ν Event Rates on Materials of Interest

1. calculated σ vs E_ν
2. flux = predicted
3. 1 ton of detector, 1 year

$$N = \Phi(E_\nu) \times \sigma(E_\nu) \times N_{targets}$$

$$N_{targets} = \frac{Detector\ Mass}{A} \times N_A$$





Summary of Event Rates

solar ^{8}B coherent neutrino scattering events per ton-year:

nucleus	total	T>2 KeV	T>5 KeV	T>10 KeV
^{12}C	235.7	191.8	104.1	36.0
^{19}F	378.0	204.1	88.8	13.3
^{40}Ar	804.8	231.4	21.0	<1.0
^{76}Ge	1495.0	111.5	<1.0	<1.0
^{132}Xe	2616.9	14.7	<1.0	<1.0

* current experimental recoil energy thresholds

No such thing as a low-threshold zero-background experiment!

Implications

1. can easily cut these events by raising the energy threshold

   -e.g. raise threshold from 5 to 30 keV, *but*, factor of ~6 reduction in sensitivity in ^{12}C

2. or, if choose to live with these events

   -expect 5-25 signal events (depending on material) for true dark matter cross section of 10^{-46} cm^2, therefore, ν background is ~same size as signal (for this signal cross section)

   -with background, sensitivity increases as sqrt(time), not (time)

   -background has angular distribution: $\frac{d\sigma}{d(cos\theta)} \propto (1 + cos\theta_{sun})$

Conclusions

Coherent scattering of solar νs is an unavoidable background to ton-scale, O(keV) threshold dark matter searches.

10-100 events/ton-year =
~ 10^{-46} cm^2 limit

Difficult to discriminate against this background since recoil spectrum looks ~like an exponential WIMP recoil spectrum

Coherent NC ν-N scattering has not yet been observed... dark matter detectors have ν discovery potential!

directional dark matter detection is the *only* unambiguous way to distinguish this background from signal!