Search for Annual Modulation in CDMS II

Scott Hertel SMU Physics Seminar April 9th, 2012

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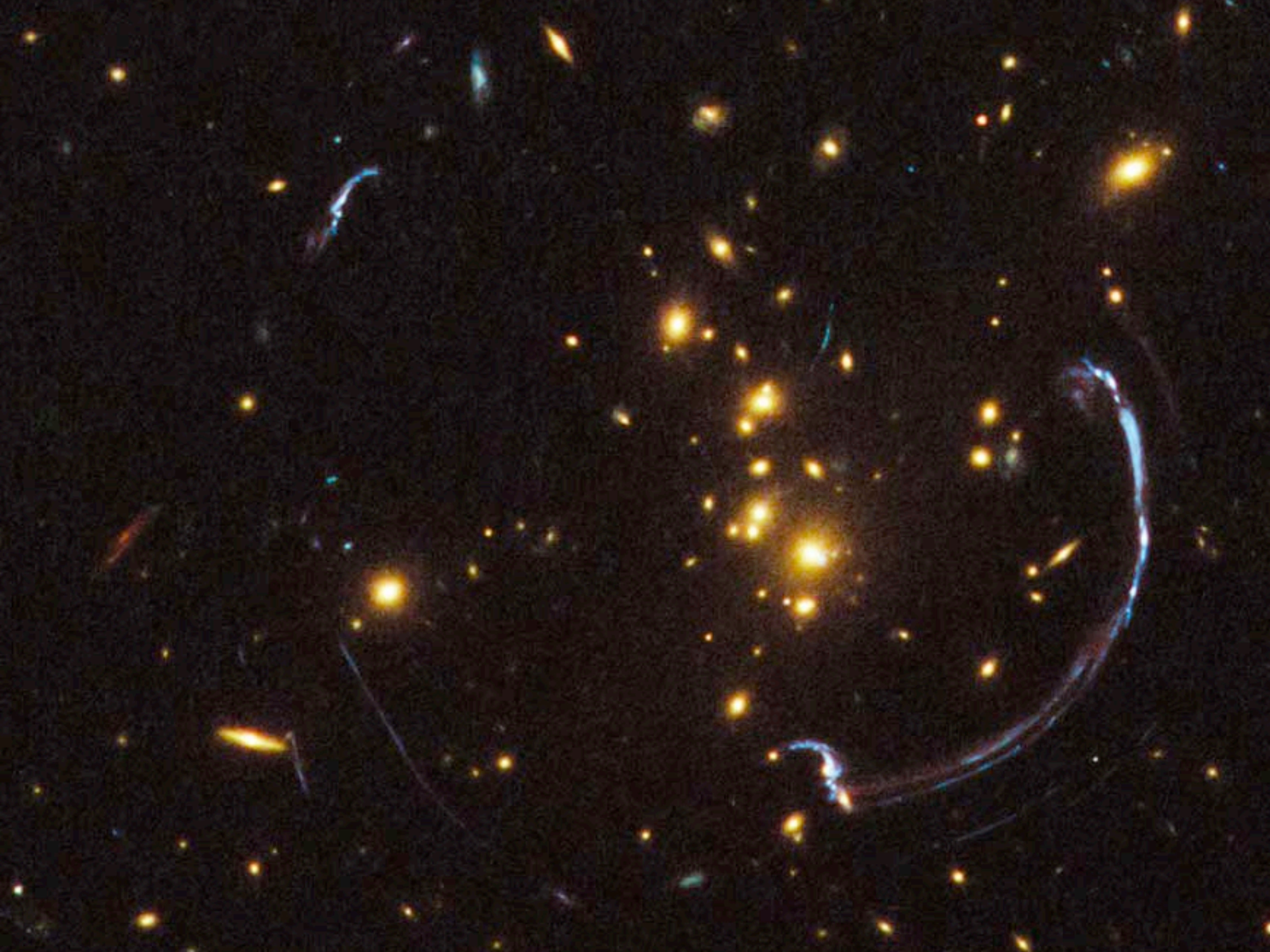
Introduction

CDMS II

CDMS II at low energies

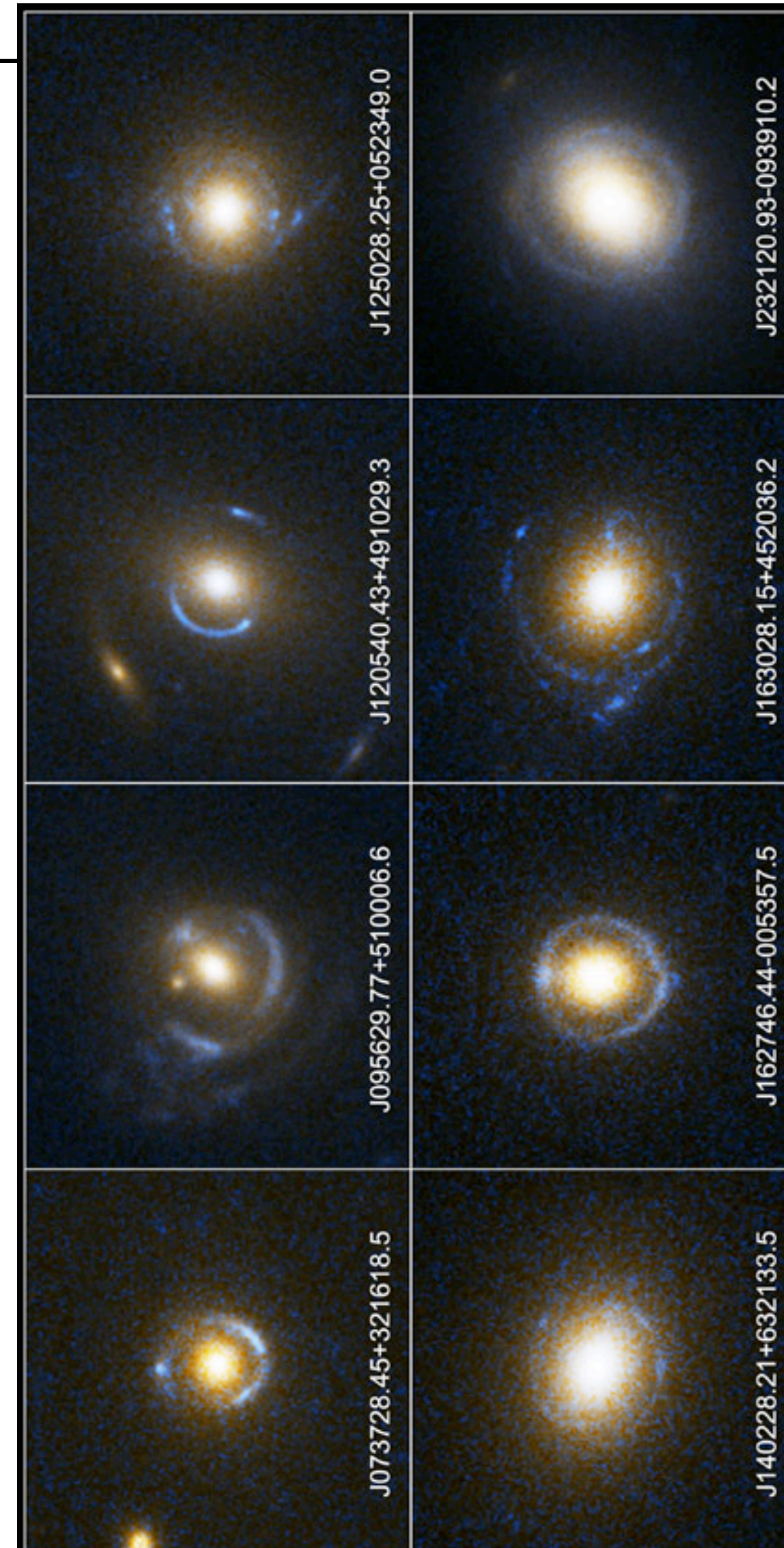
Annual Modulation

Introduction:
WIMPs and Yield-based Discrimination



Everywhere we look, we see ~5x more gravity than expected.

-galaxies
-clusters of galaxies
-the Universe as a whole



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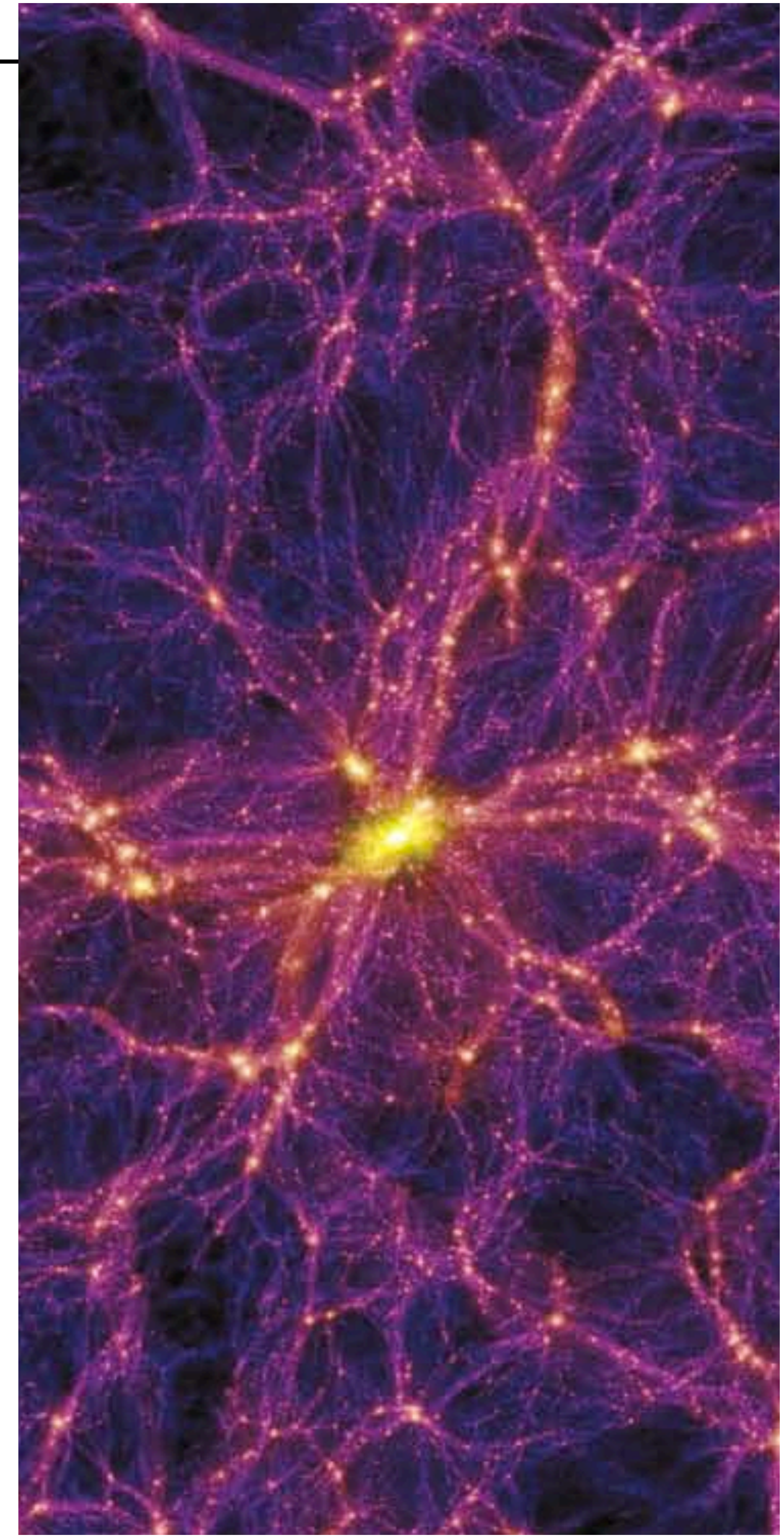
Explainable only by hypothesizing a new, nearly non-interacting type of matter.

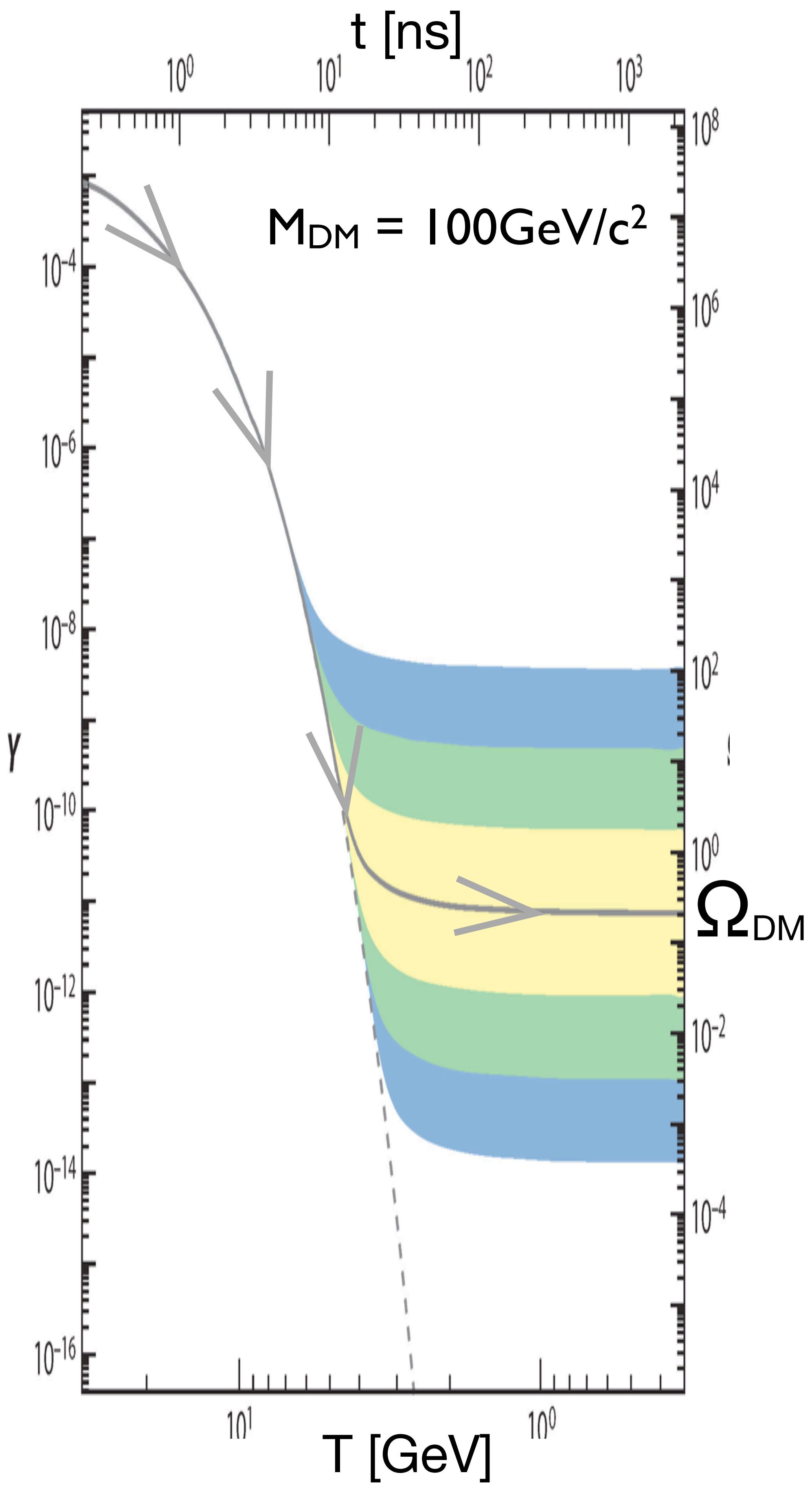


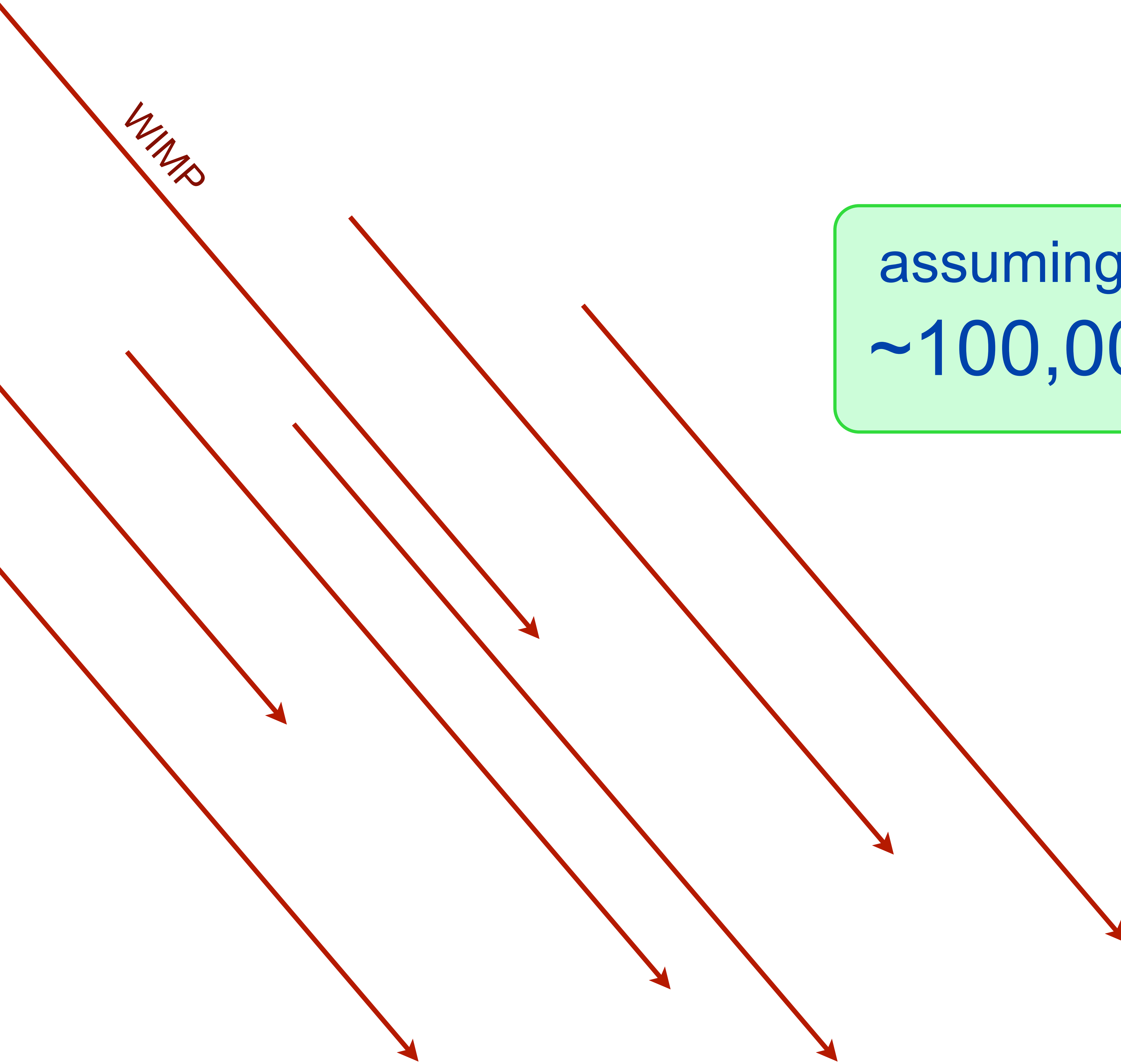
Everywhere we look, we see
~5x more gravity than expected.

-galaxies
-clusters of galaxies
-the Universe as a whole

Explainable only by
hypothesizing a new, nearly
non-interacting type of matter.

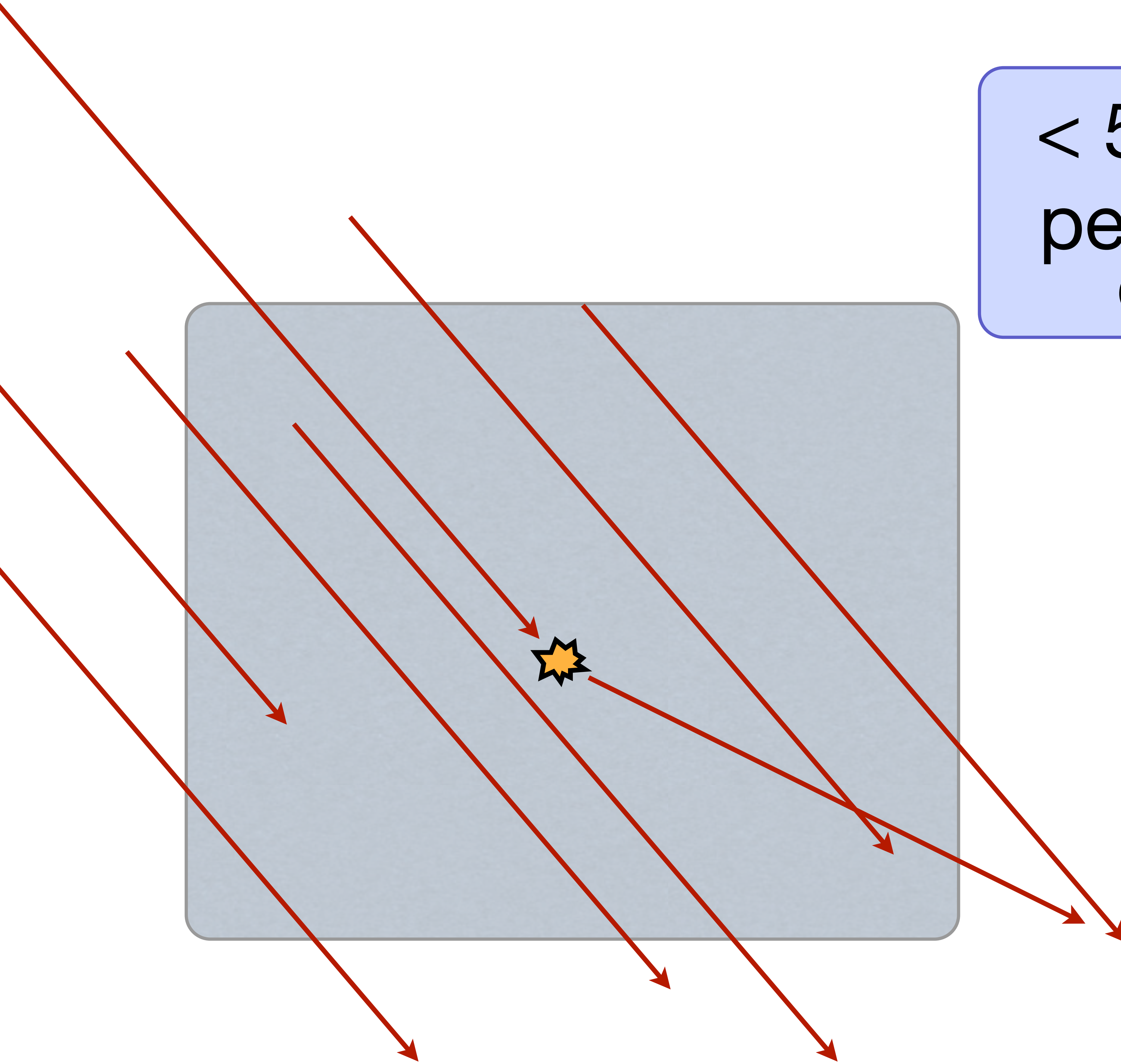
Observed cosmological density
(1.3 GeV/m^3) could result from
weak-scale interactions.





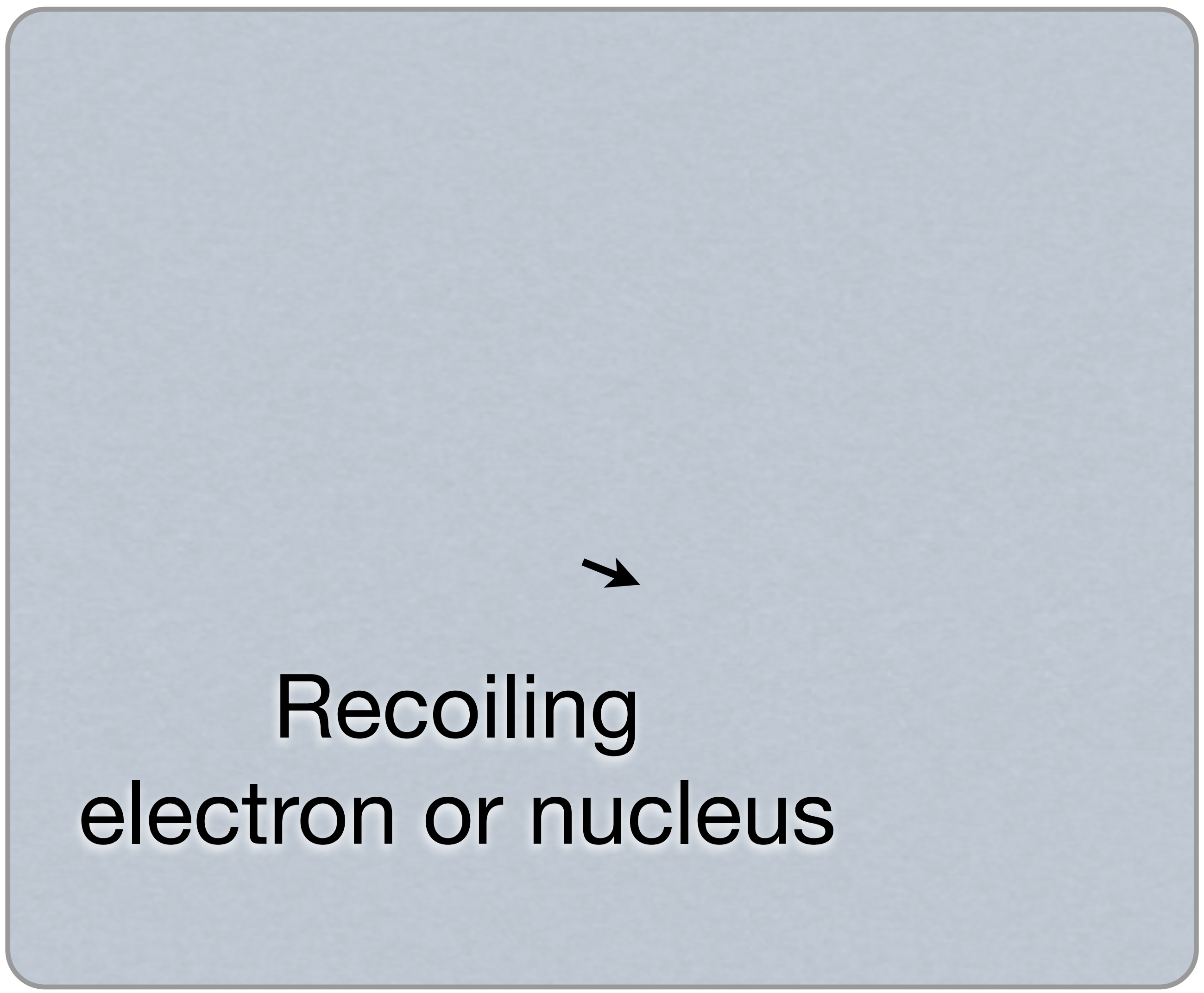
assuming $m_\chi \approx 70$ GeV ,

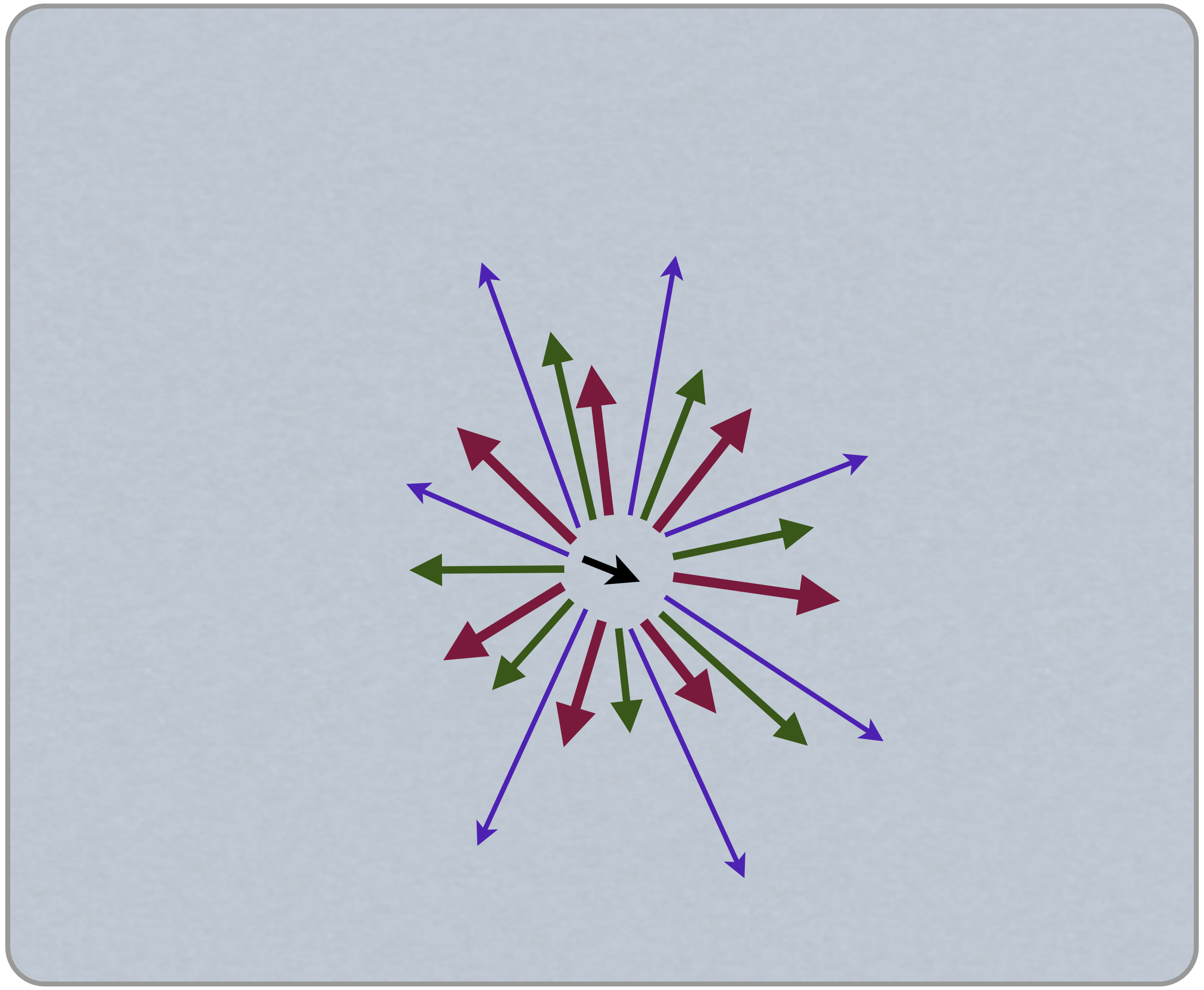
$\sim$100,000 /cm^2/sec

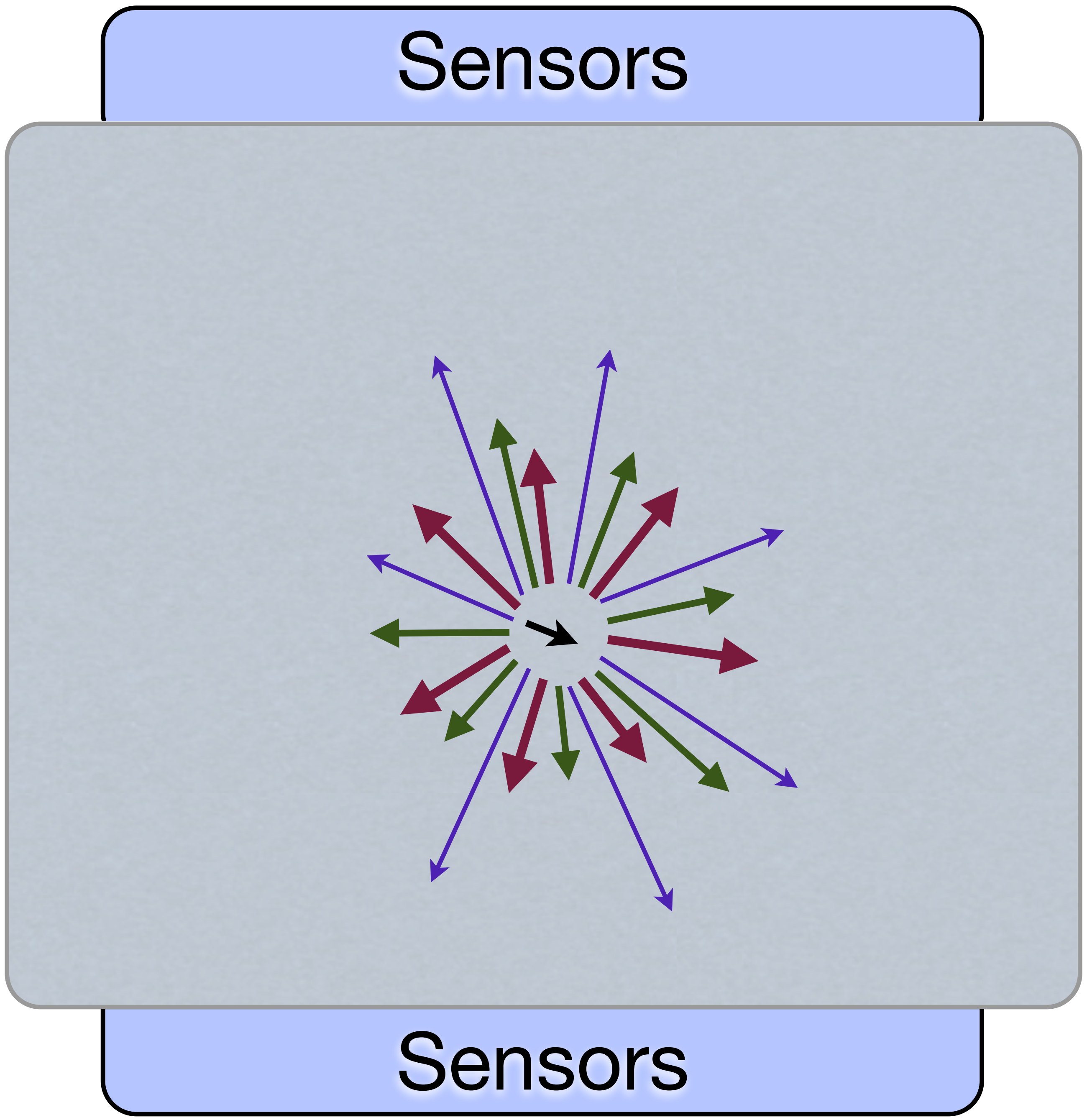


< 5 interactions per ton per day

($\sigma < 3.8 \times 10^{-44}$ cm^2)

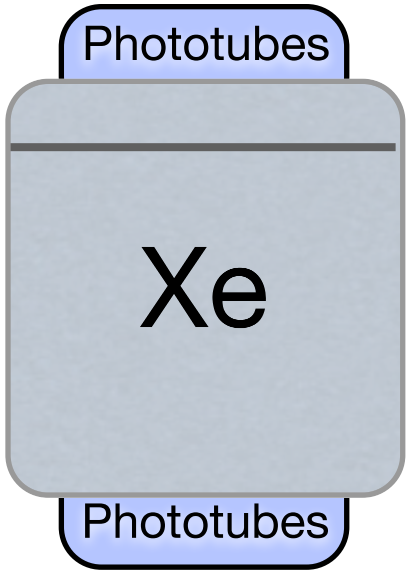

Recoiling
electron or nucleus



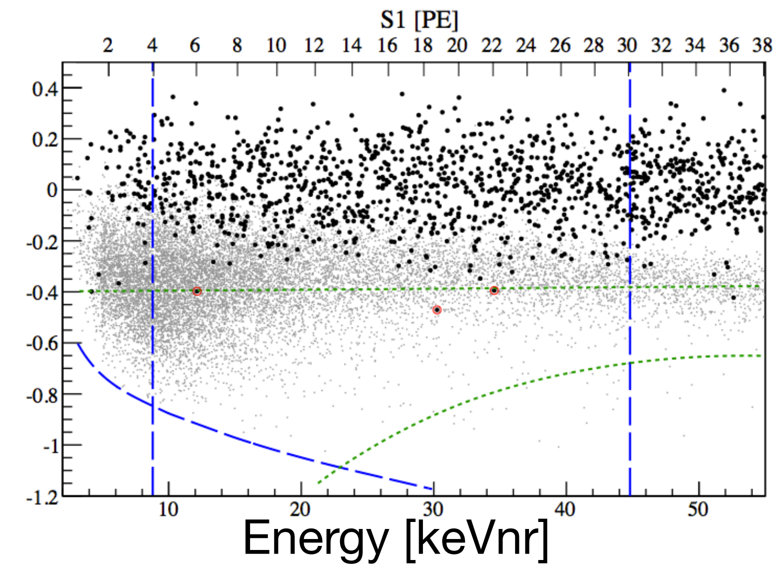


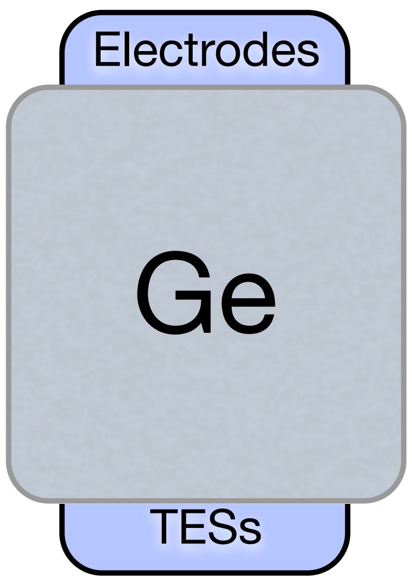
Phonons
Charge Carriers
Photons

Relative fractions depend on dE/dx

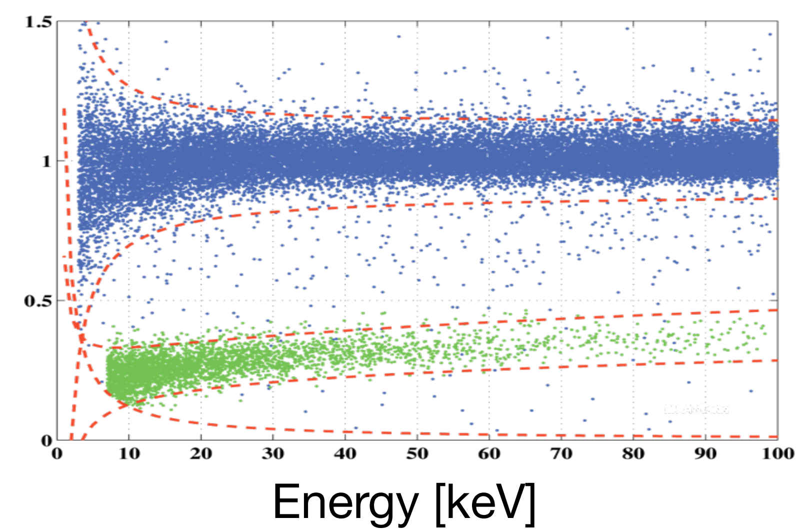


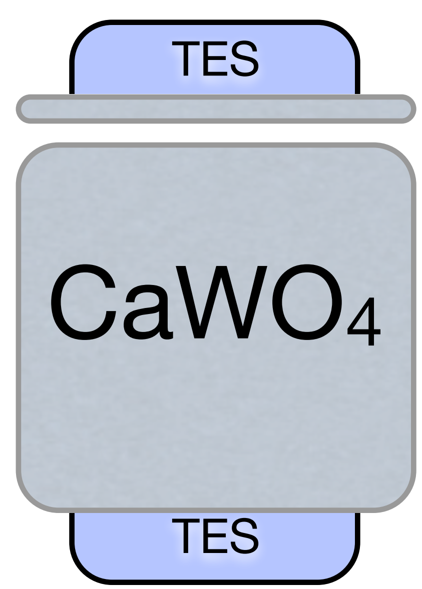
charge
photons



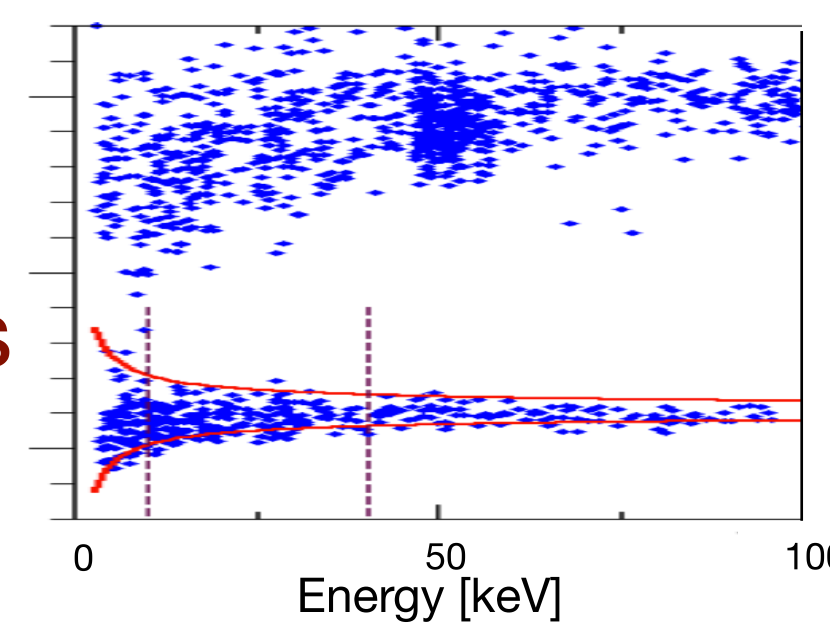


charge
phonons



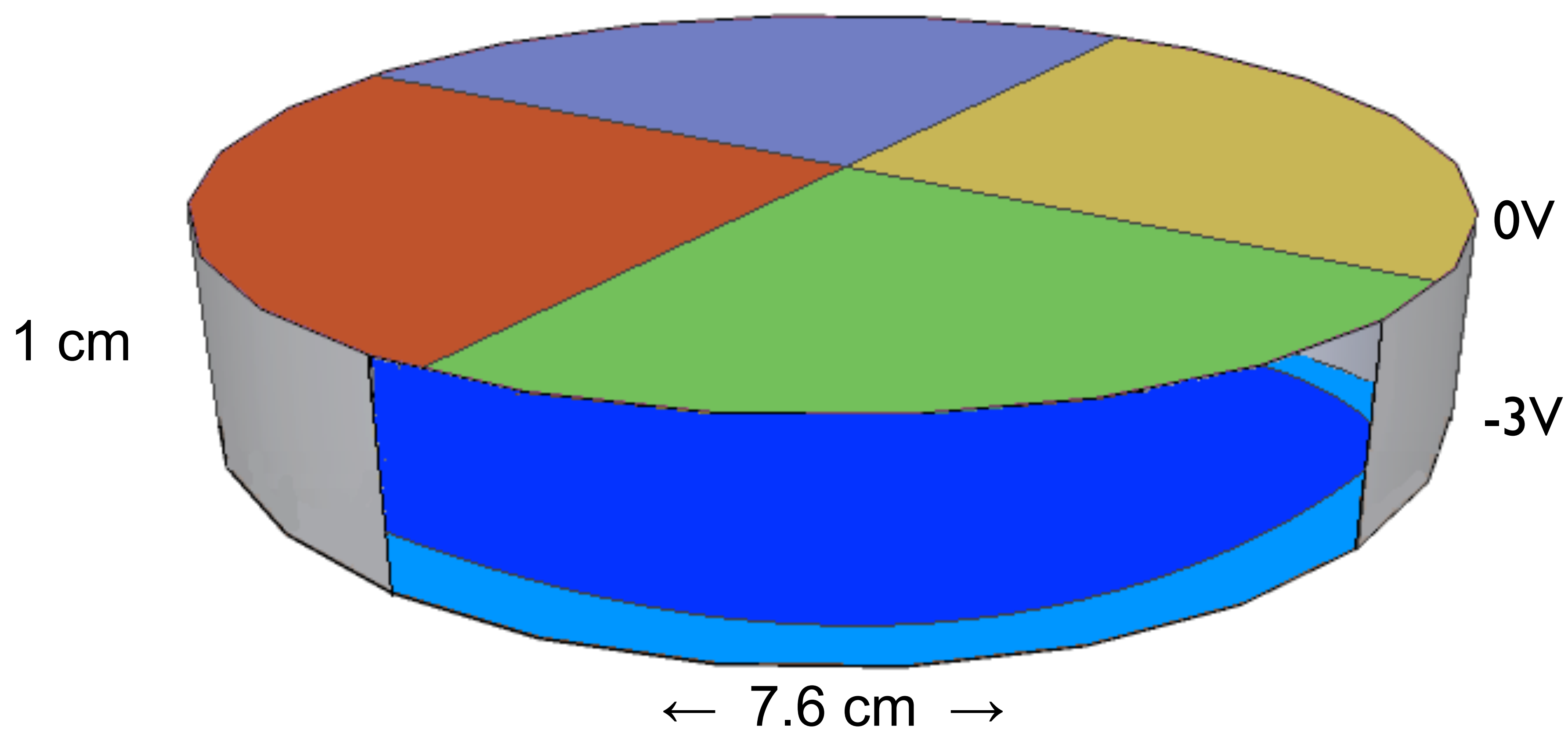


photons
phonons



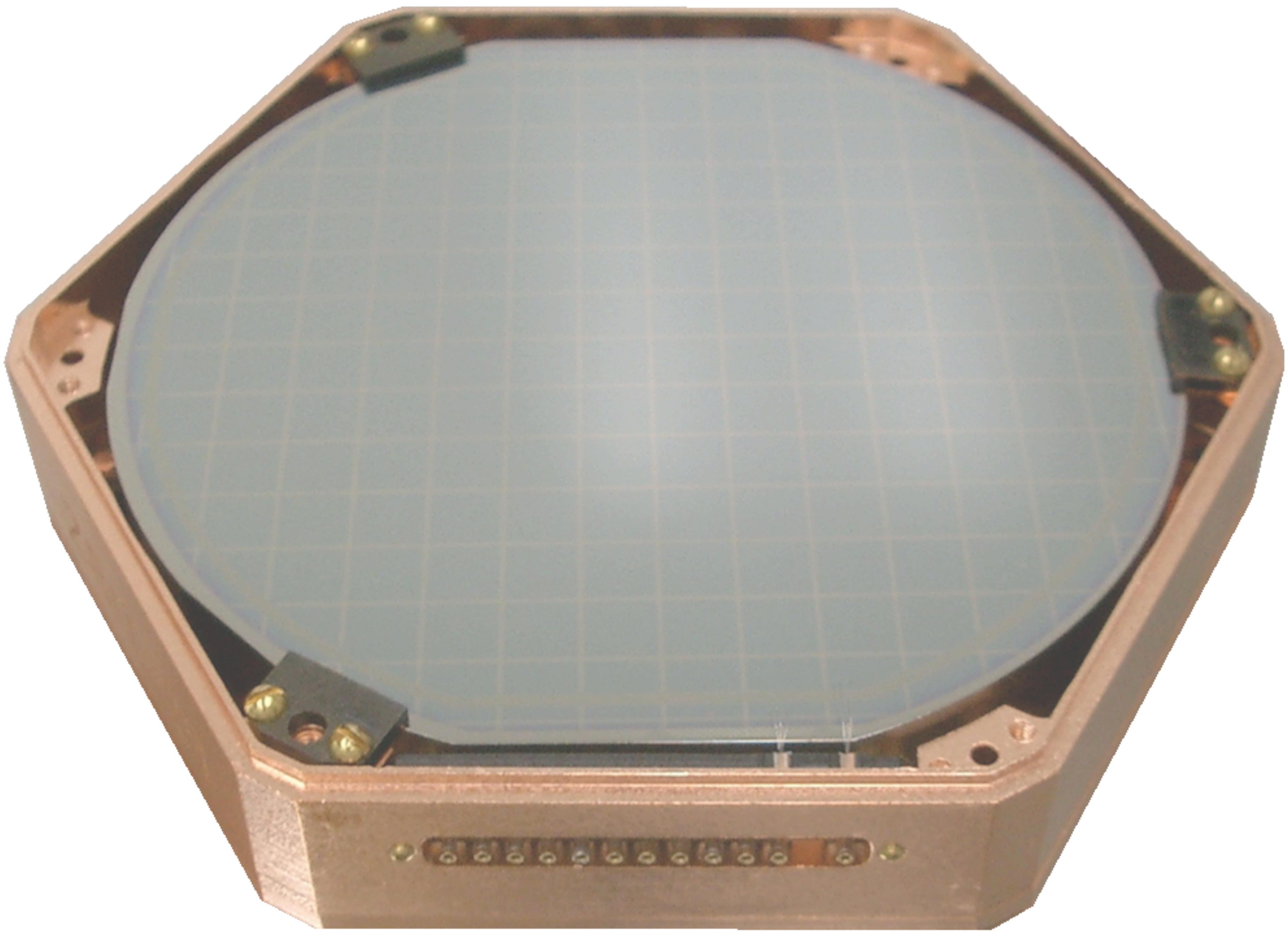
1. CDMS II

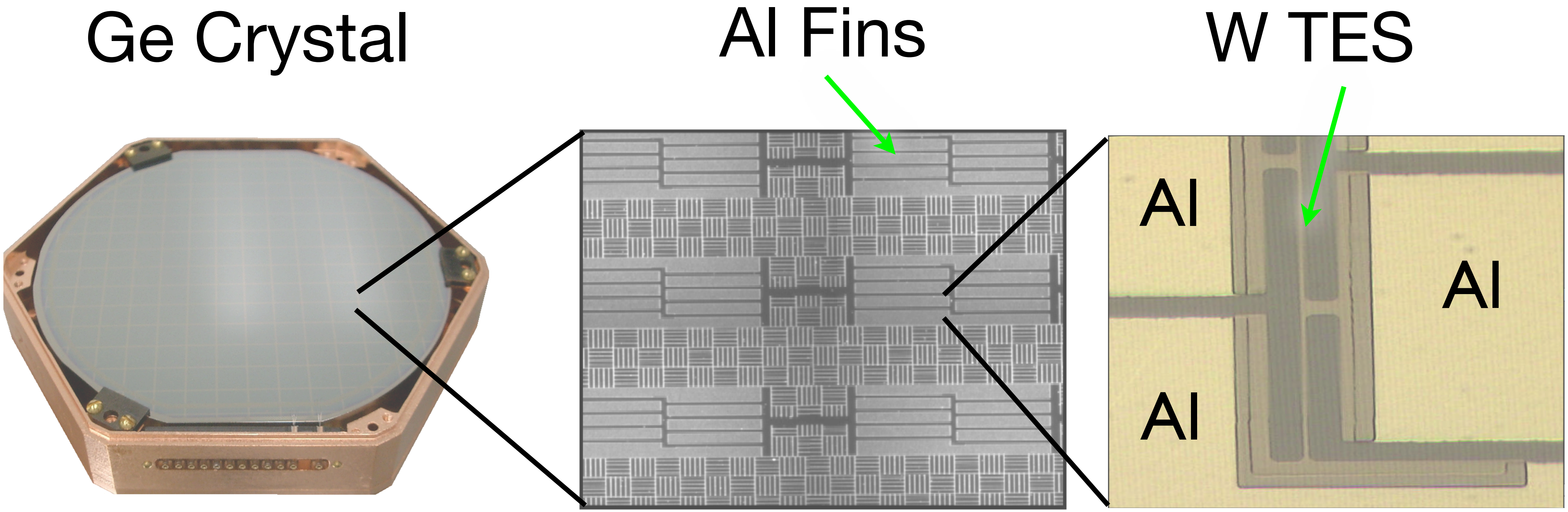
4 Phonon Channels

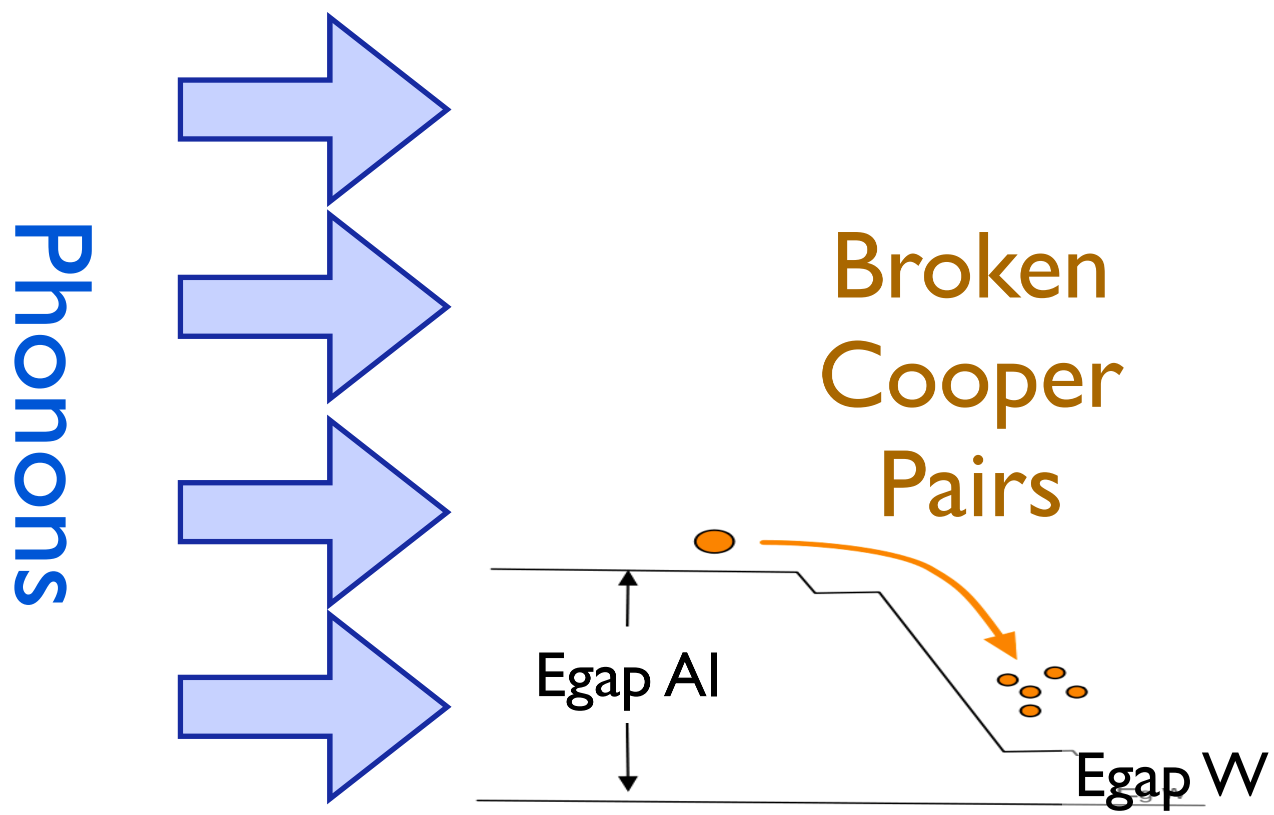


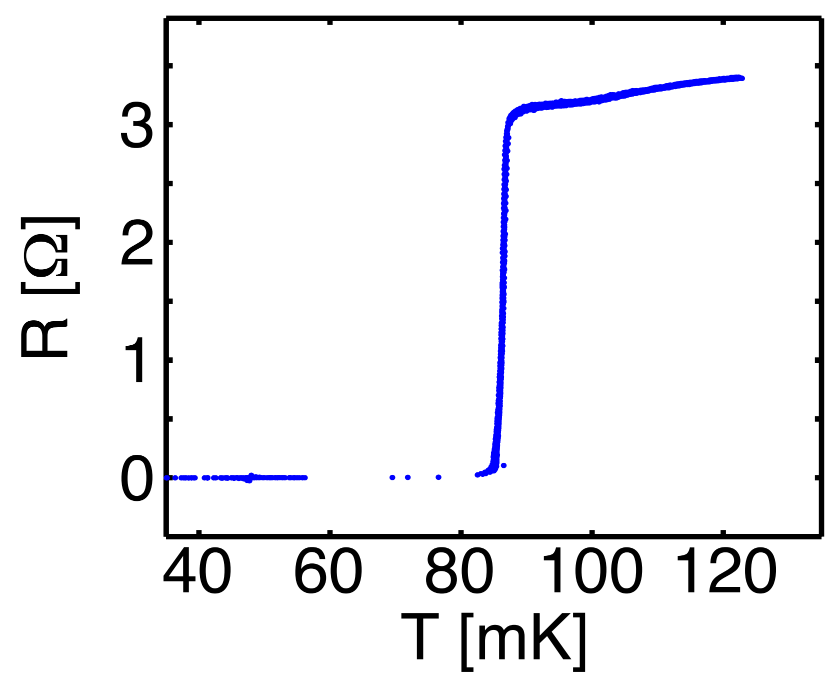
2 Charge Channels

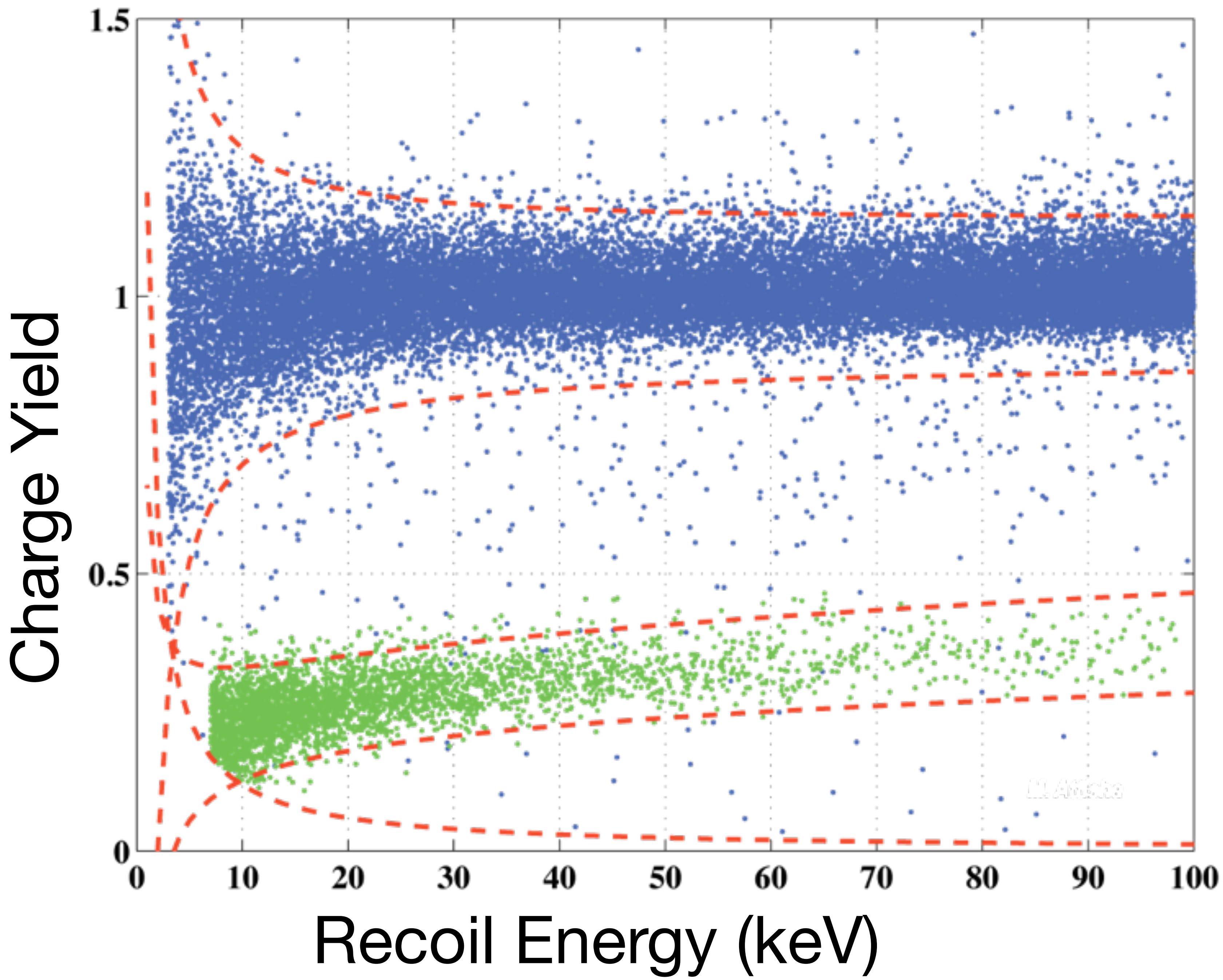
1. CDMS II




Ge Crystal
Al Fins
W TES
Al
Al
Al

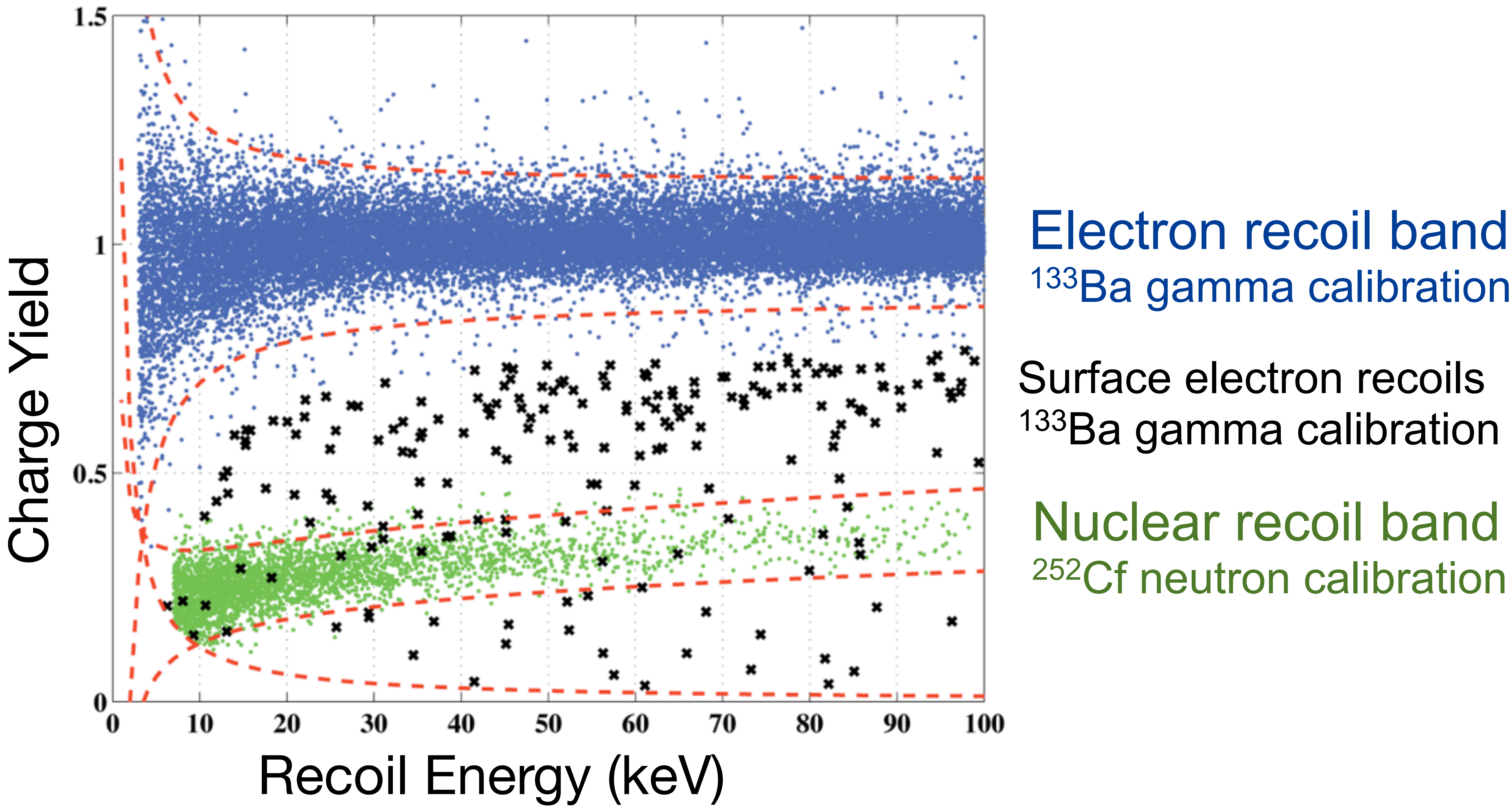

Phonons
Broken
Cooper
Pairs
Egap Al
Egap W


R [Ω]
3
2
1
0
40
60
80
100
120
T [mK]

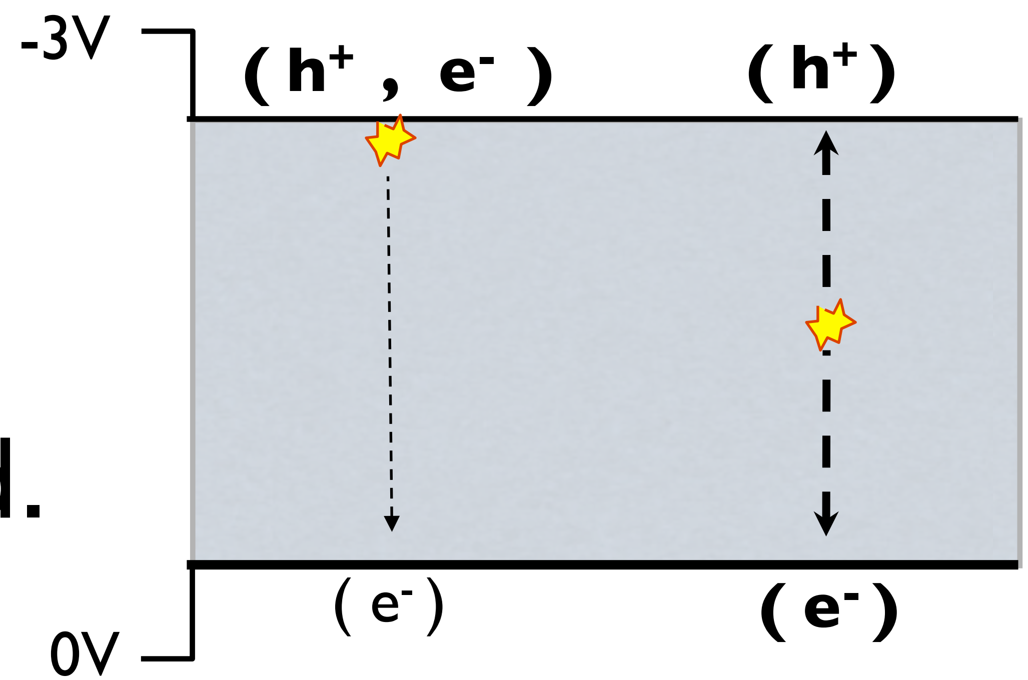


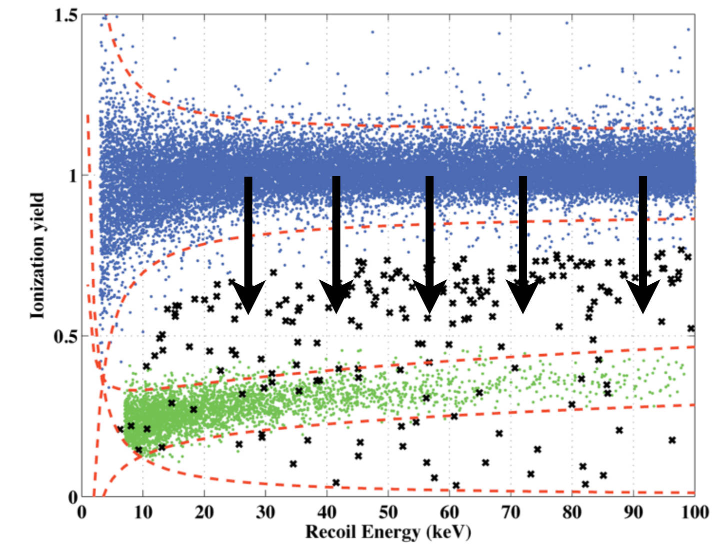
Electron recoil band
^{133}Ba gamma calibration

Nuclear recoil band
^{252}Cf neutron calibration

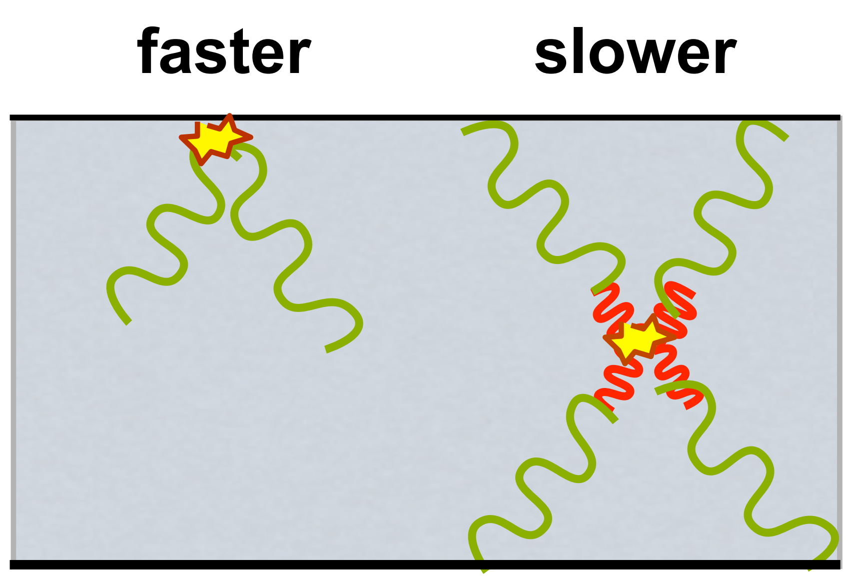

1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
90
100
Charge Yield
Recoil Energy (keV)
Electron recoil band
^{133}Ba gamma calibration
Surface electron recoils
^{133}Ba gamma calibration
Nuclear recoil band
^{252}Cf neutron calibration

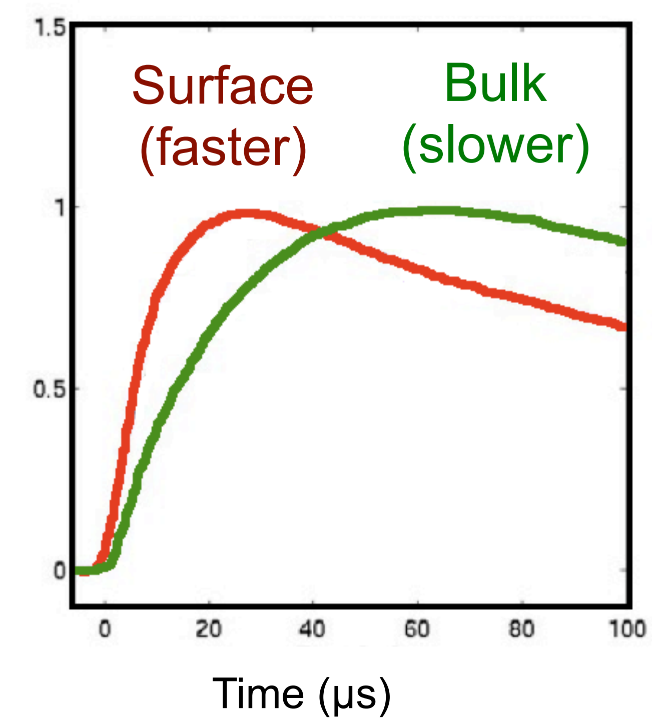
Surface events can exhibit suppressed yield.



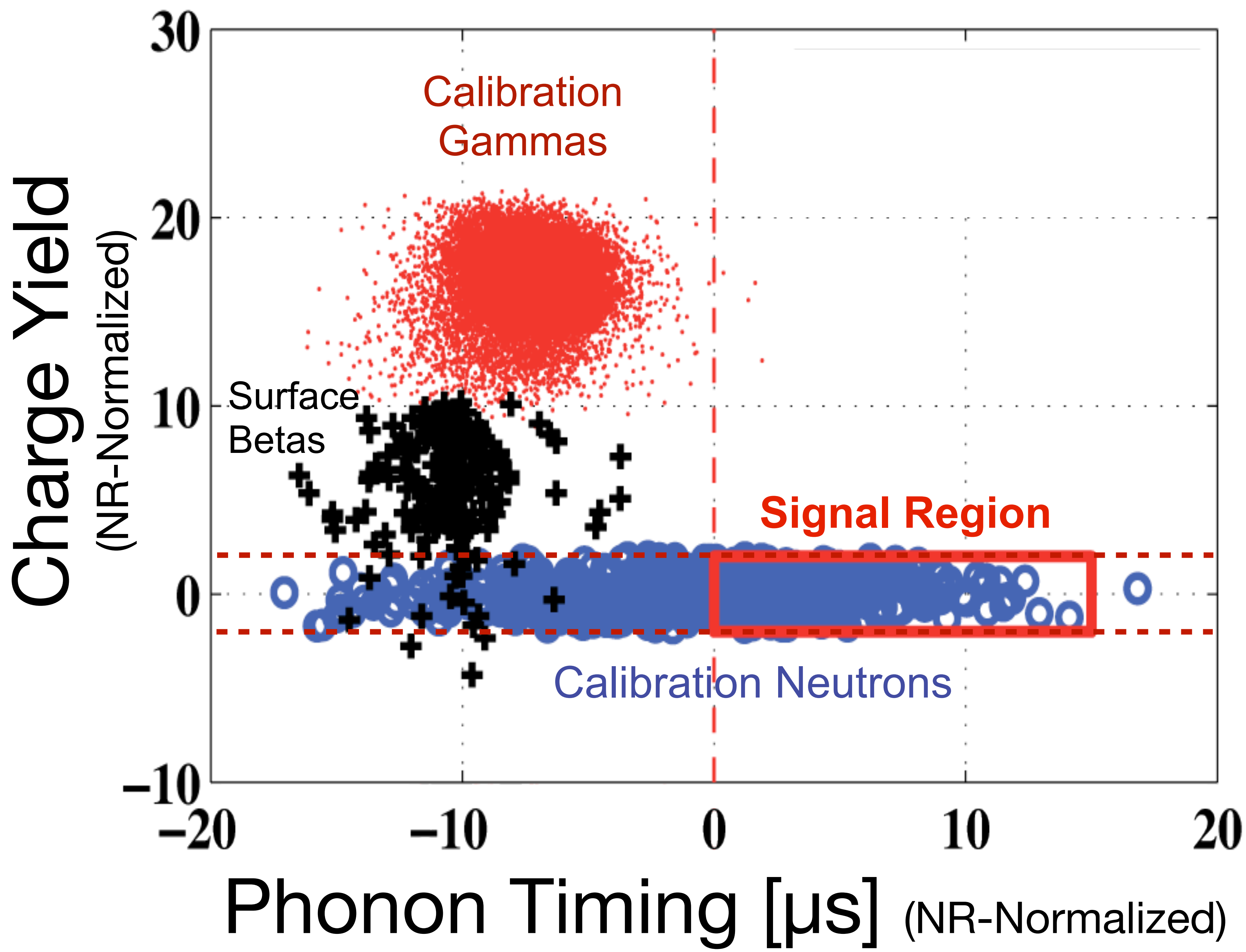


CDMS II strategy: phonon timing



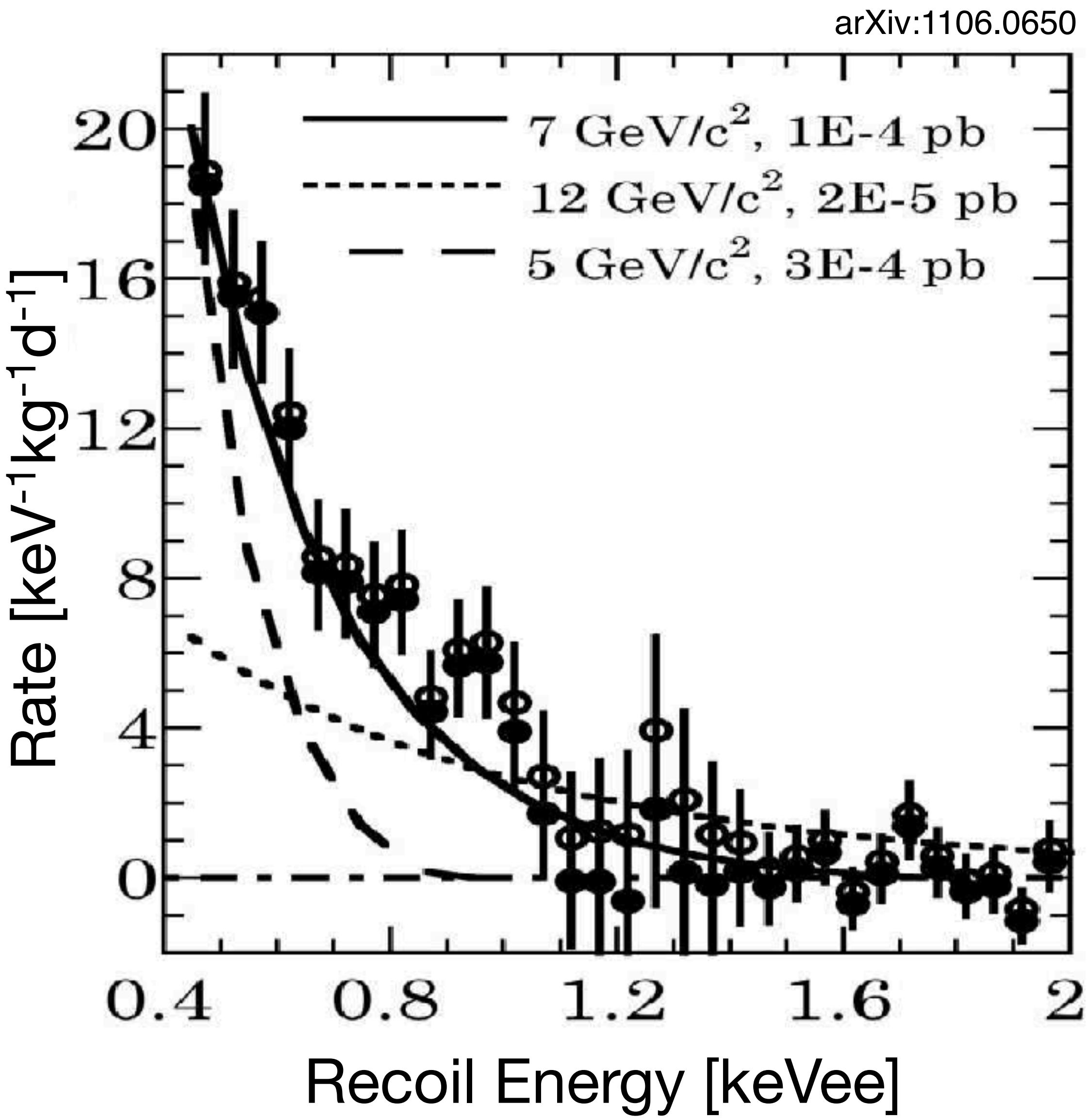


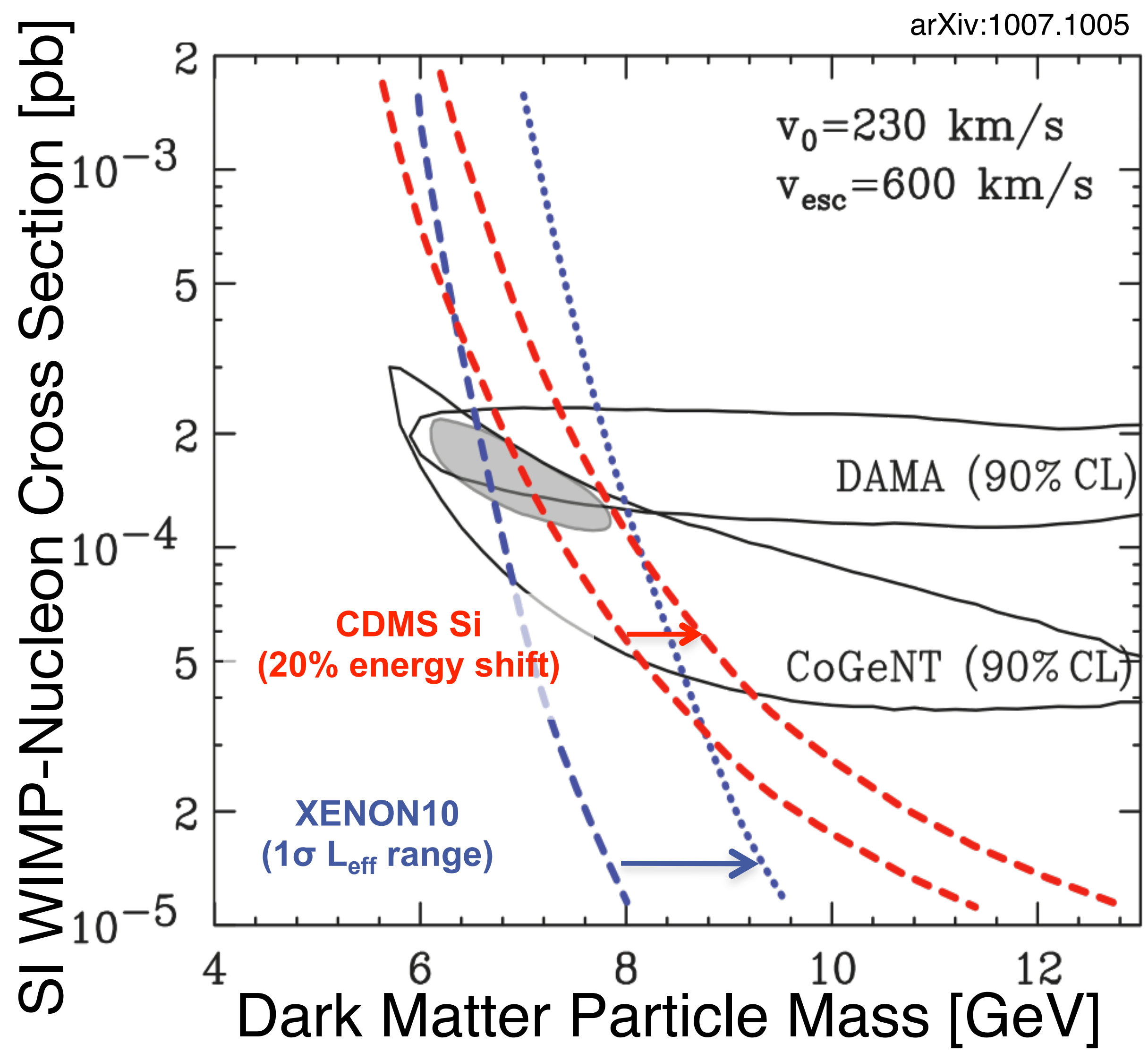
Yield vs Timing Space:



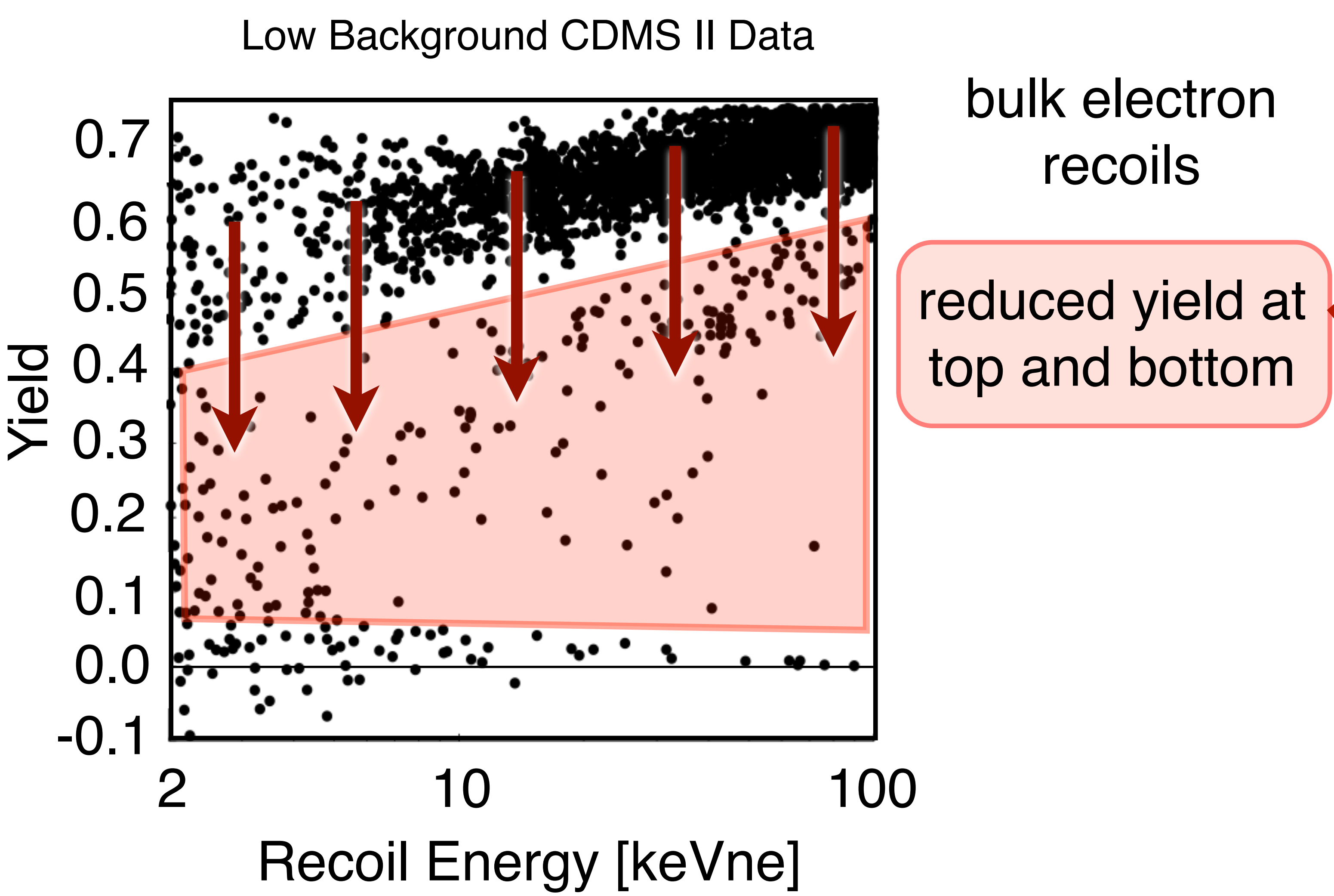
2. CDMS II at Low Energies

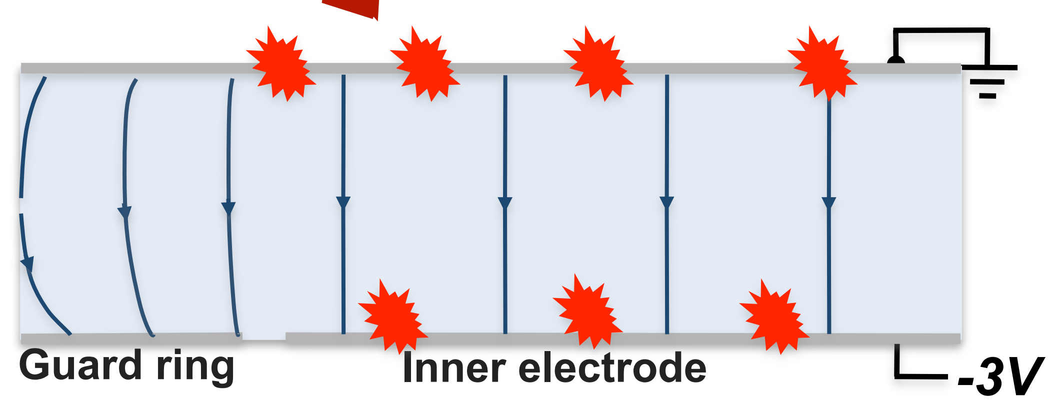
Motivation: DAMA, CoGeNT, CRESST





2. CDMS II at low energies





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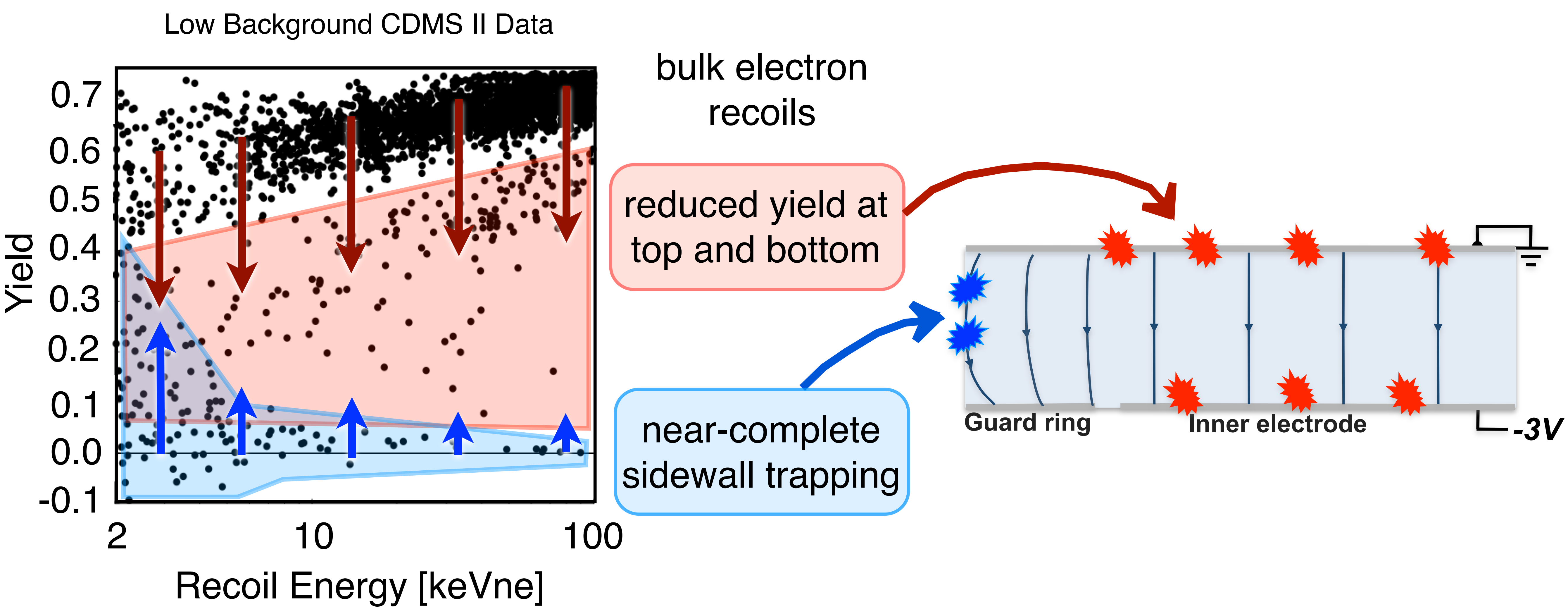

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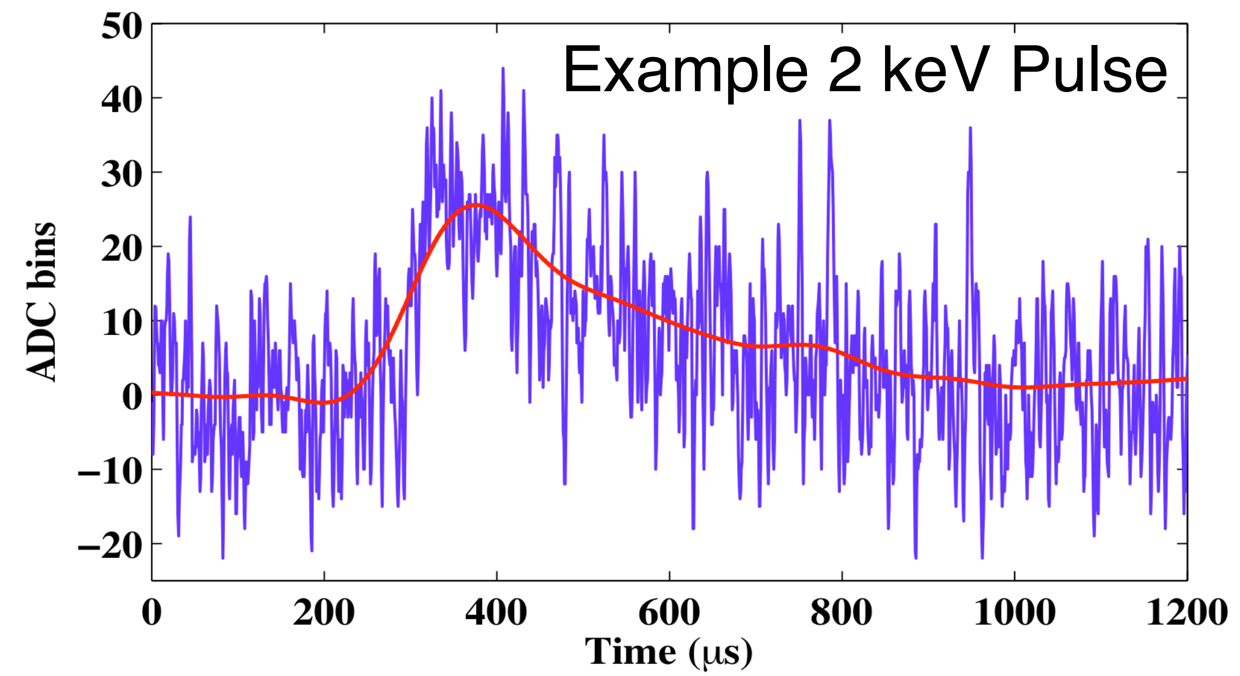
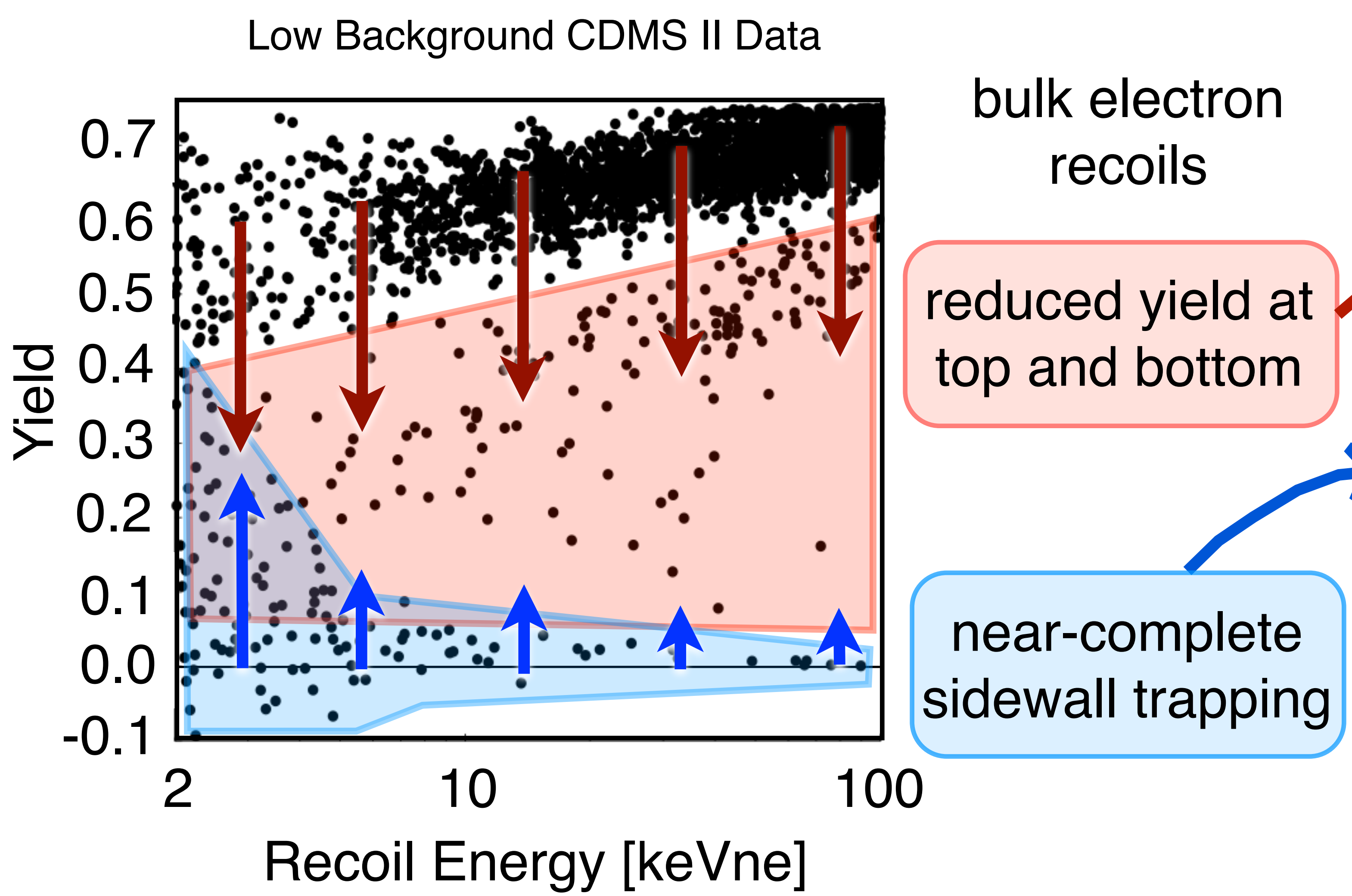
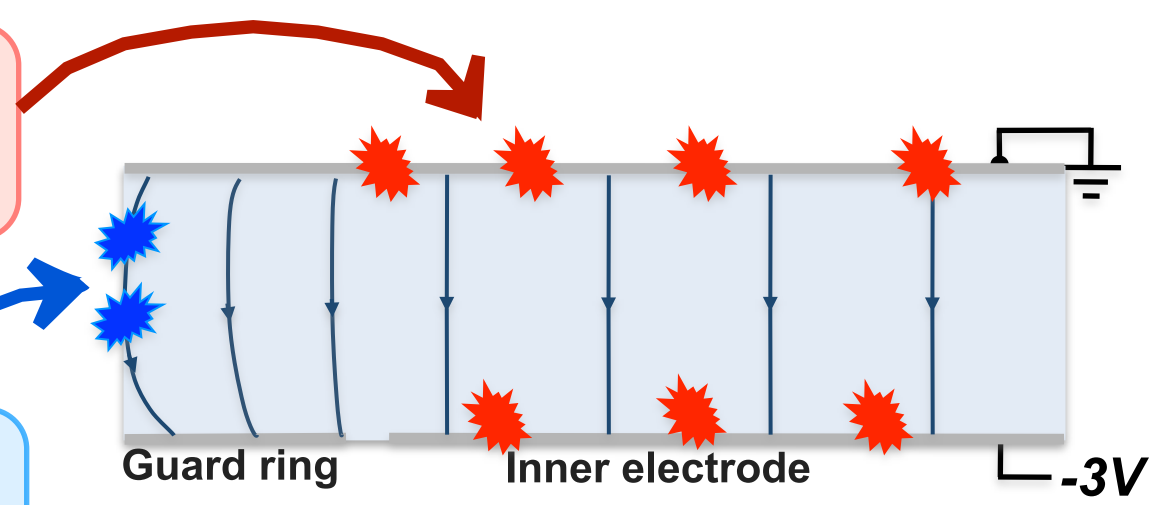
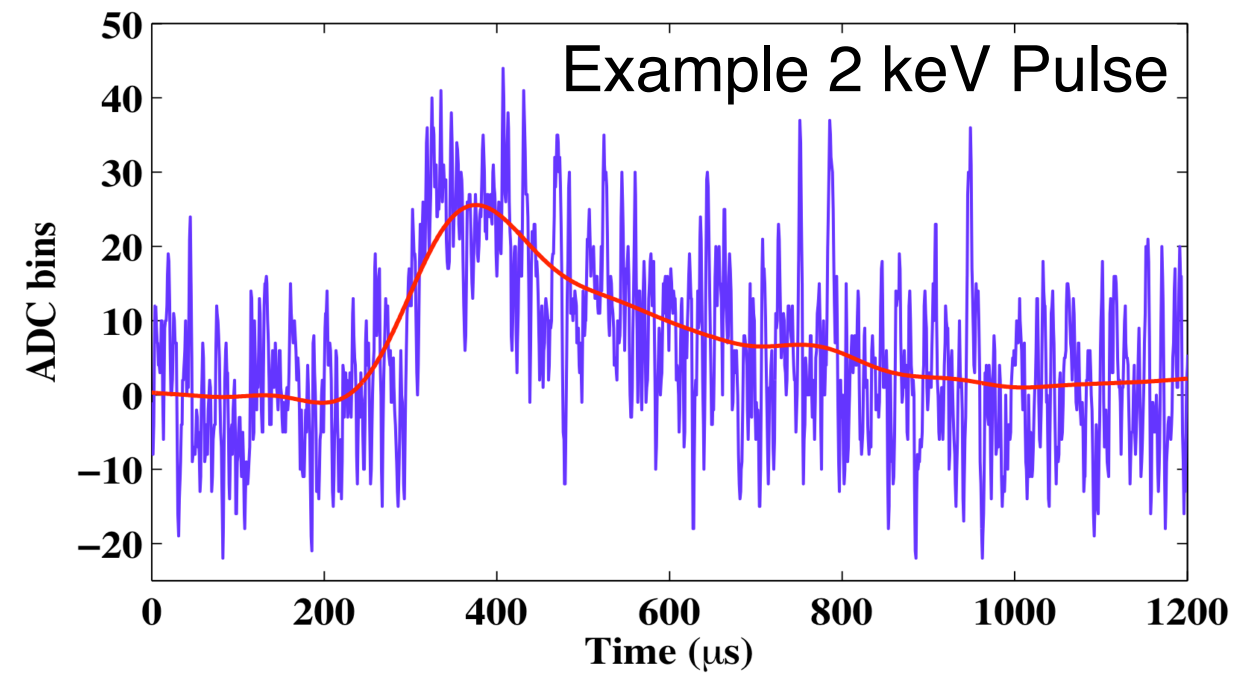


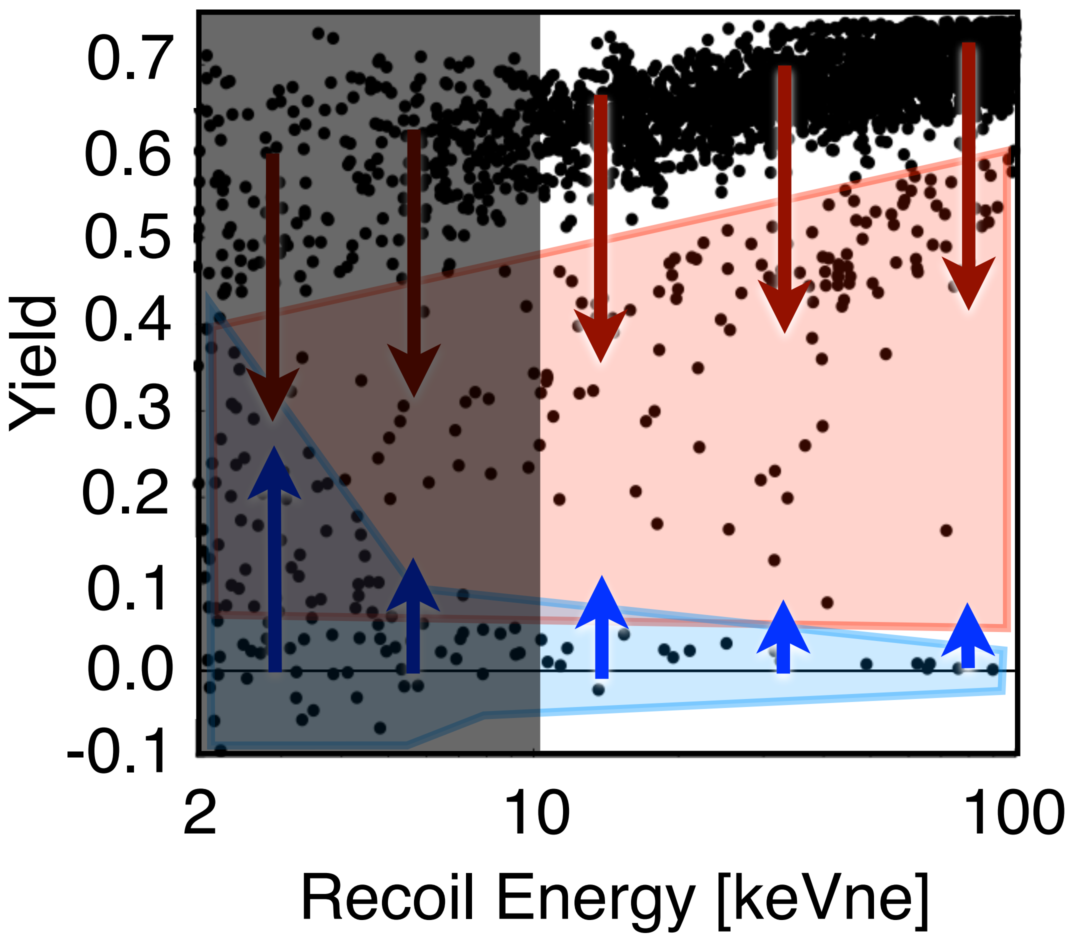






CDMS timing rejection
fails below ~10 keV...

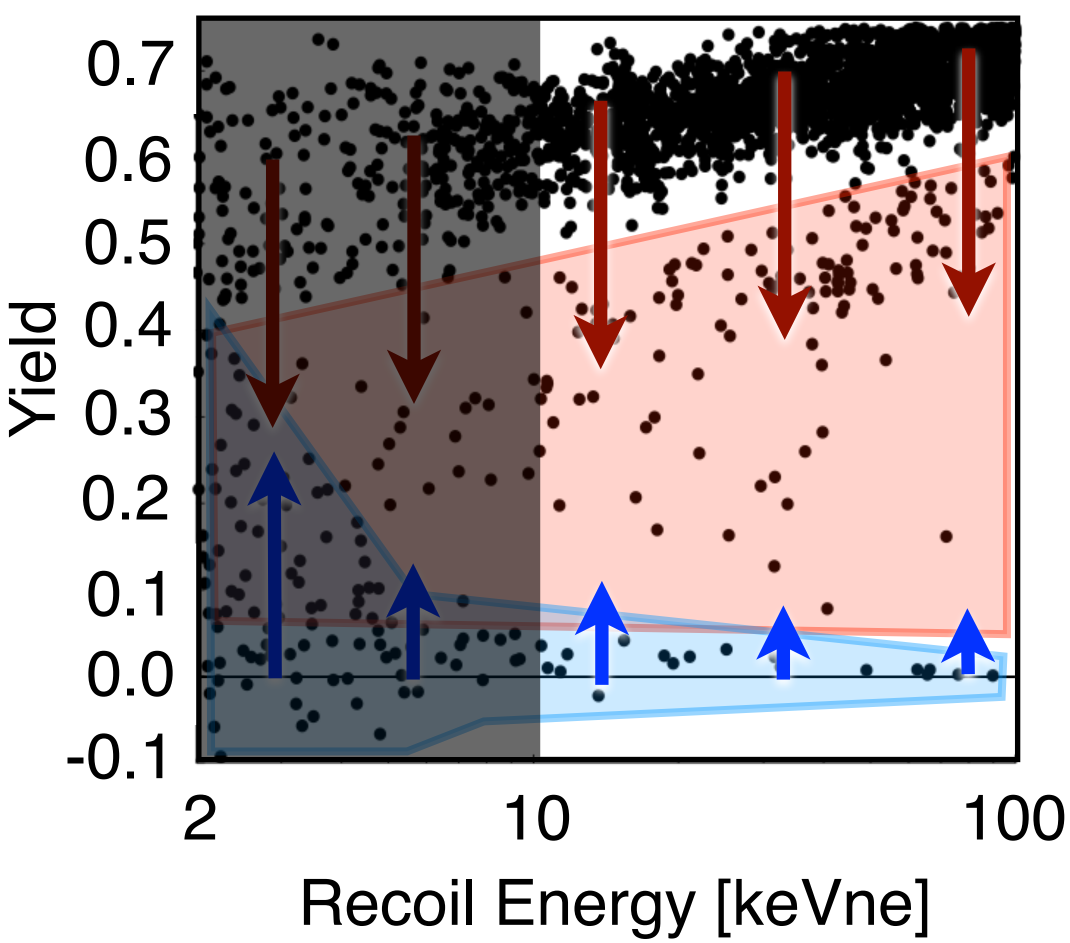
Low Background CDMS II Data



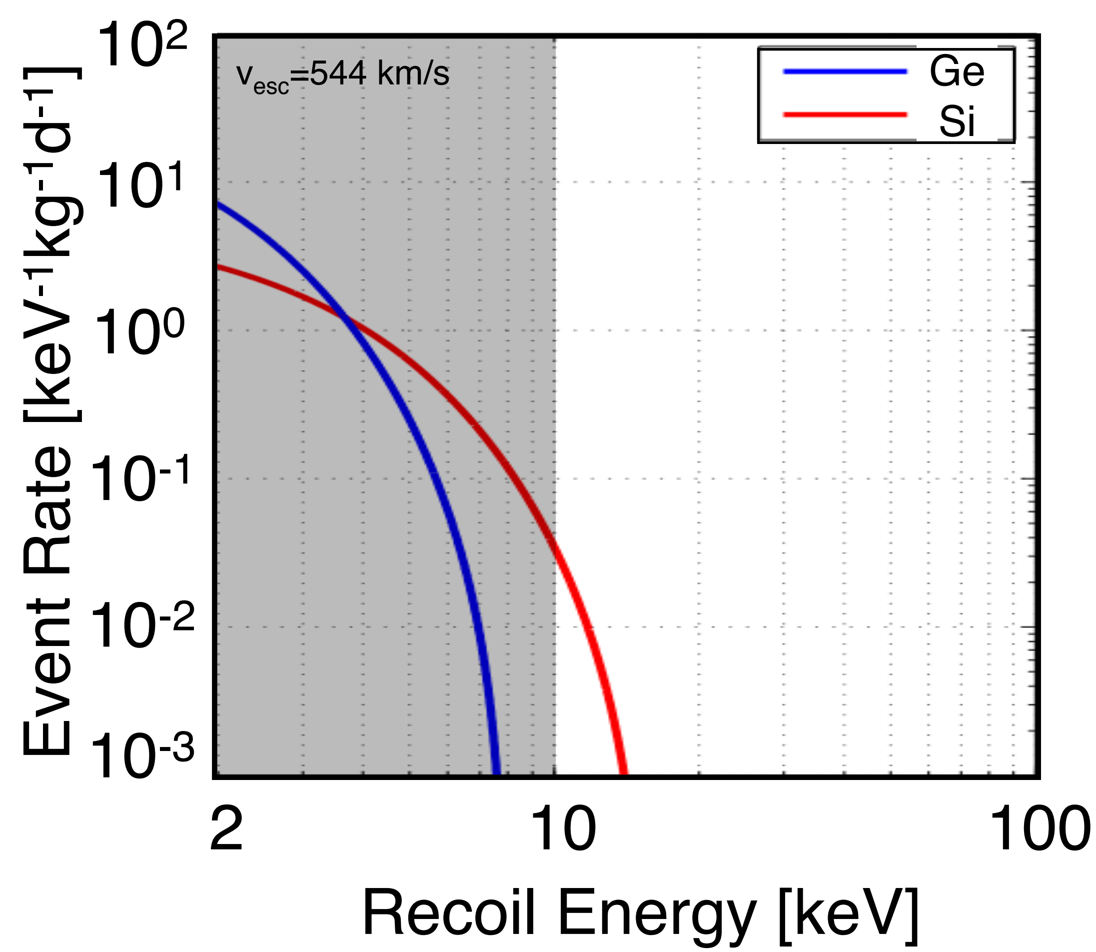
CDMS timing rejection fails below ~10 keV...

... where a 7 GeV WIMP would appear.

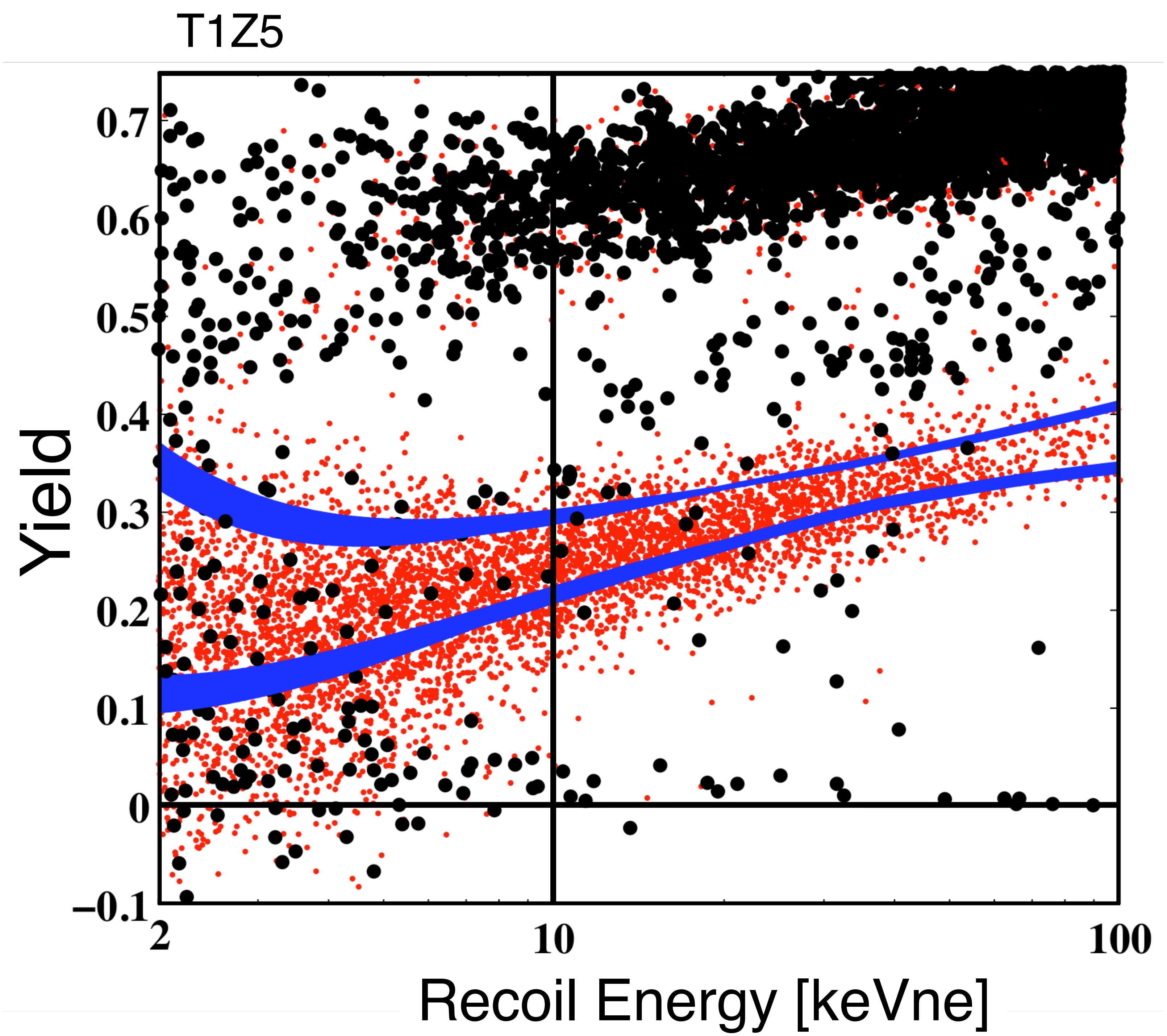
Low Background CDMS II Data



Predicted WIMP Recoil Spectrum
M = 7 GeV/c² , σ=1.5x10⁻⁴⁰ cm²

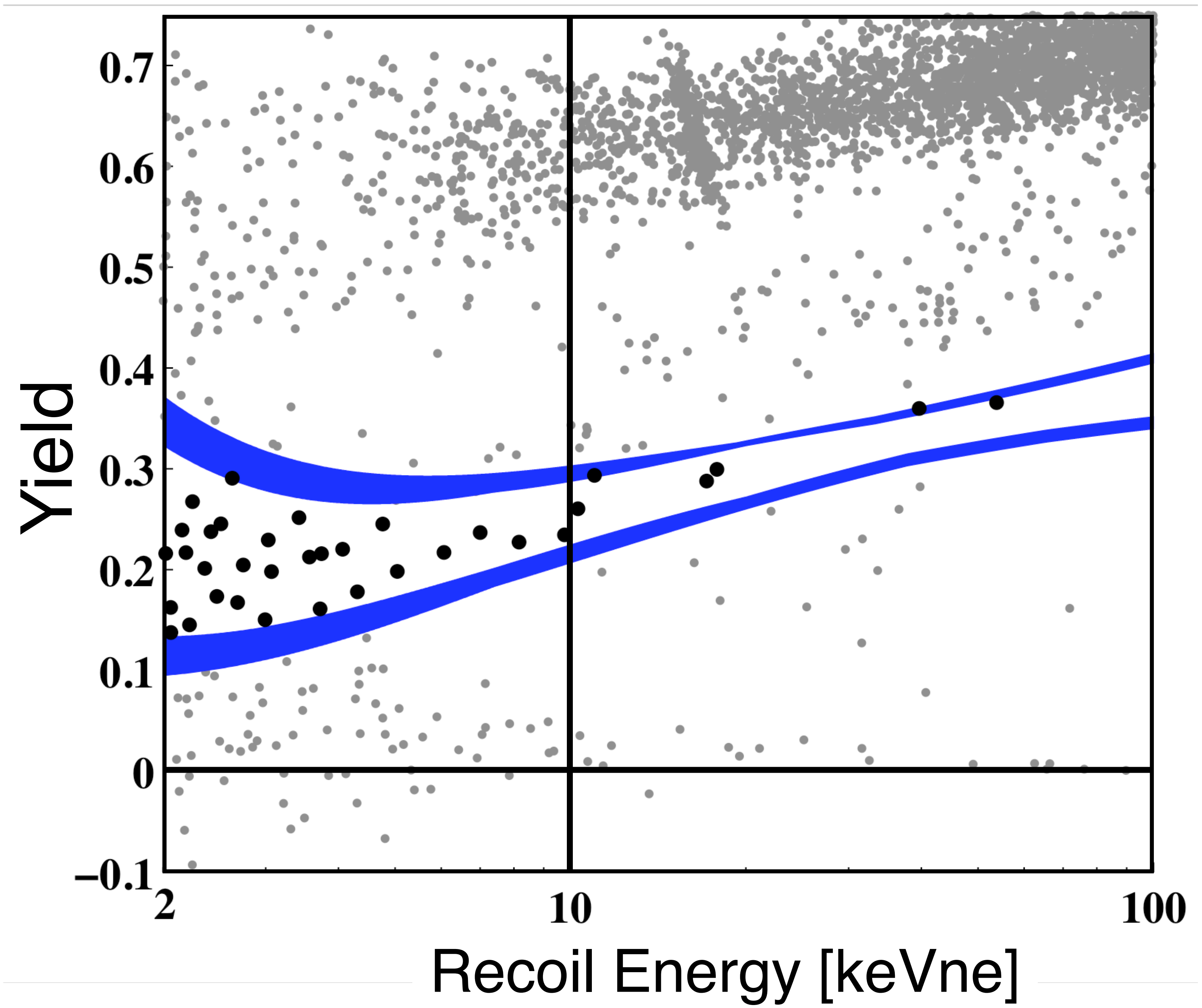


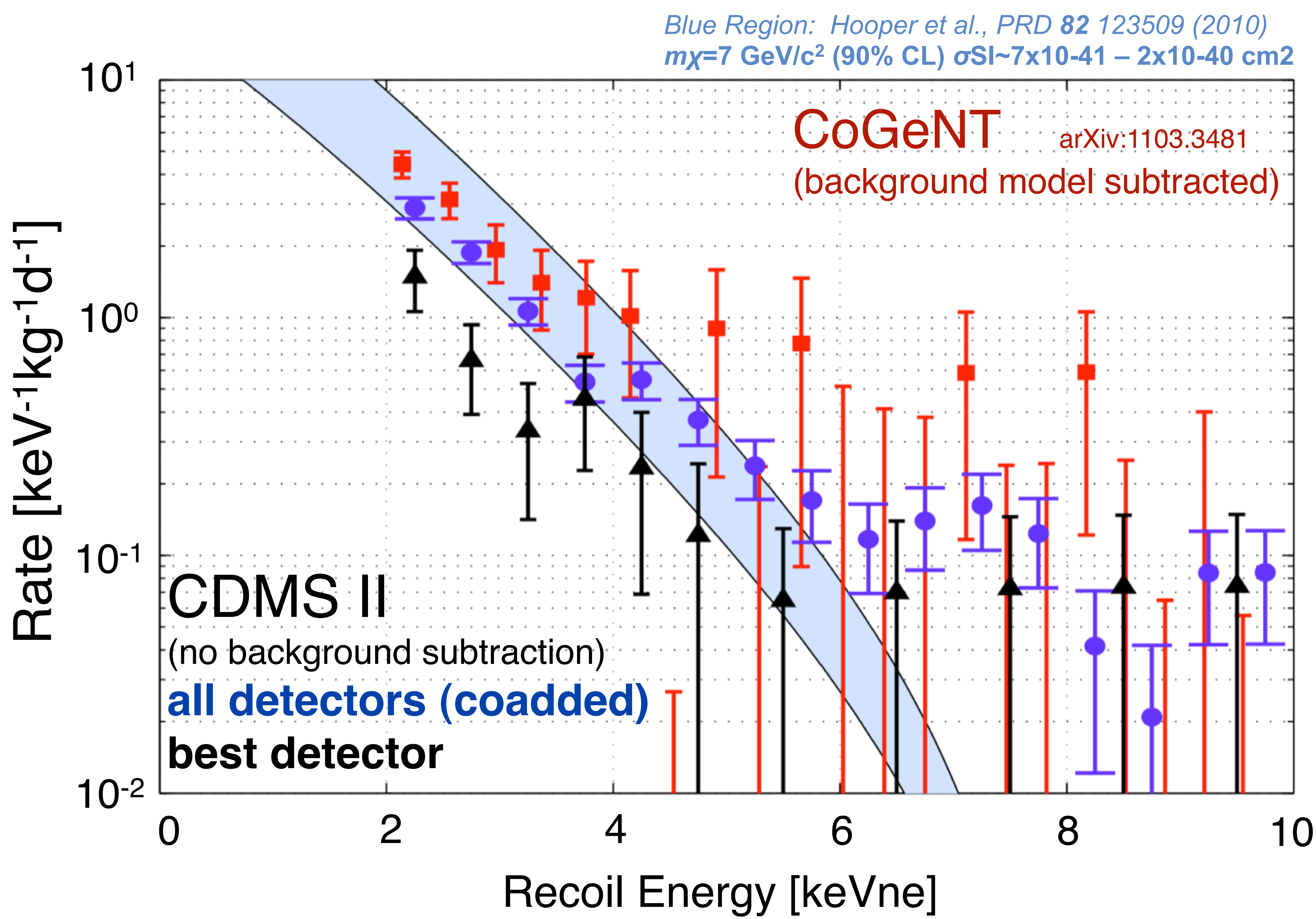
A Nuclear Recoil Yield band is defined, using the **-0.5σ to +1.25σ** range to maximize reach.

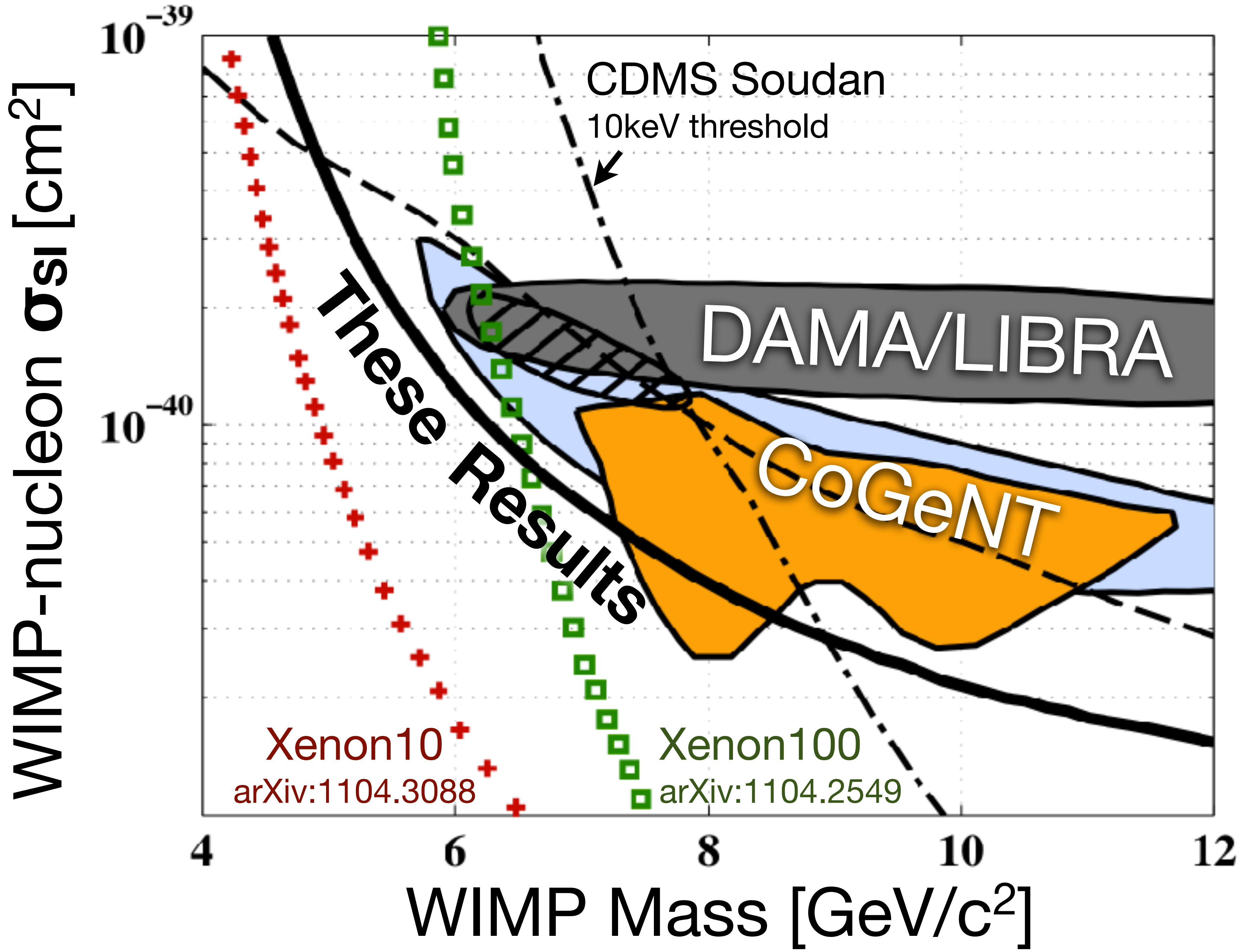


The ‘candidate’ events were selected from WIMP-search data, ignoring pulse shape.

T1Z5



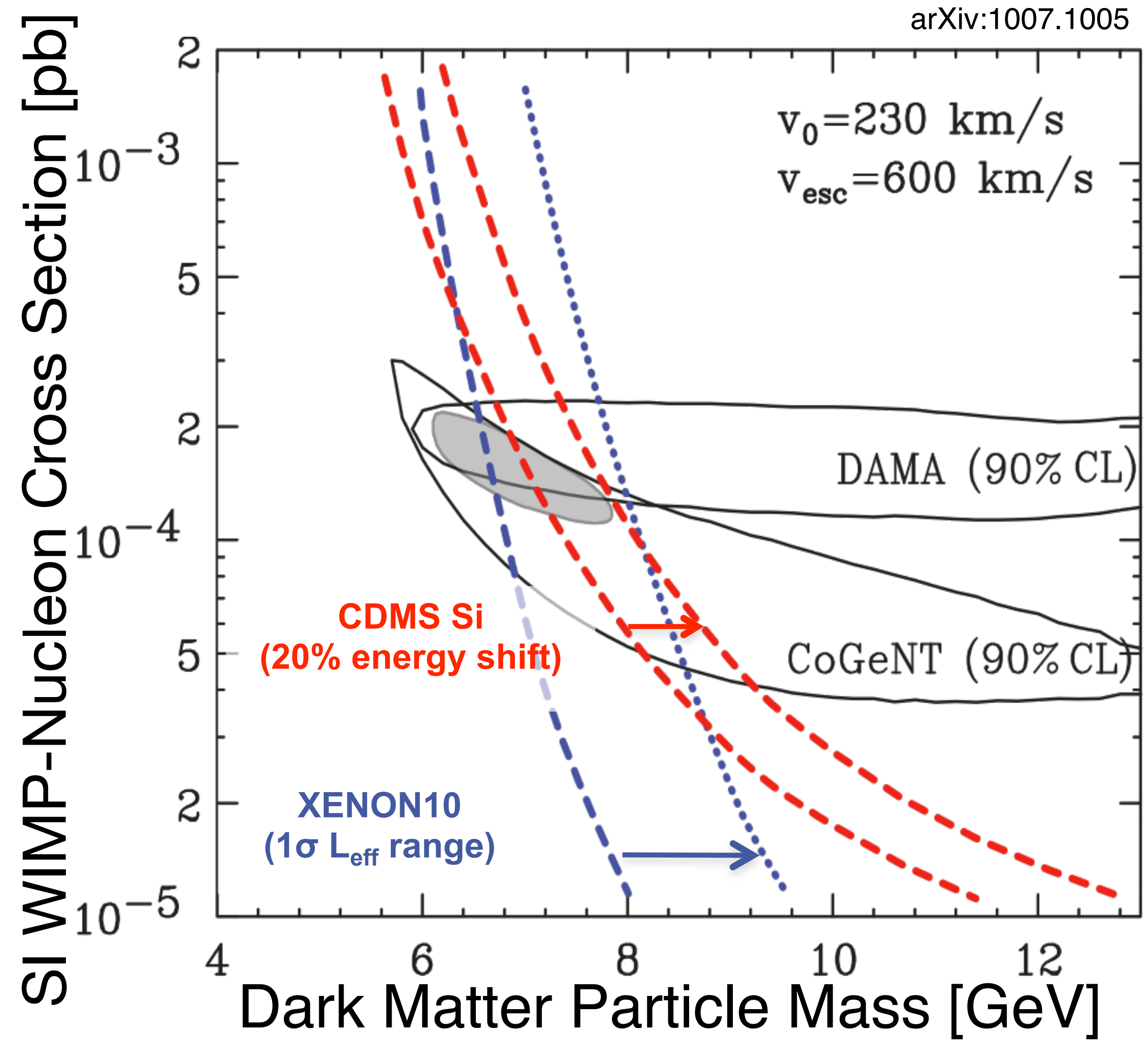

Blue Region: Hooper et al., PRD 82 123509 (2010)
mχ=7 GeV/c² (90% CL) σSI~7x10-41 – 2x10-40 cm2
CoGeNT
arXiv:1103.3481
(background model subtracted)
CDMS II
(no background subtraction)
all detectors (coadded)
best detector
Rate [keV-1kg-1d-1]
Recoil Energy [keVne]
10¹
10⁰
10⁻¹
10⁻²
0
2
4
6
8
10



DAMA/LIBRA, light blue CoGeNT region, and combined region:
*Hooper et al., PRD **82** 123509 (2010)*

Question:
Are we sure of
the energy scale?

arXiv:1007.1005



Two types of phonons

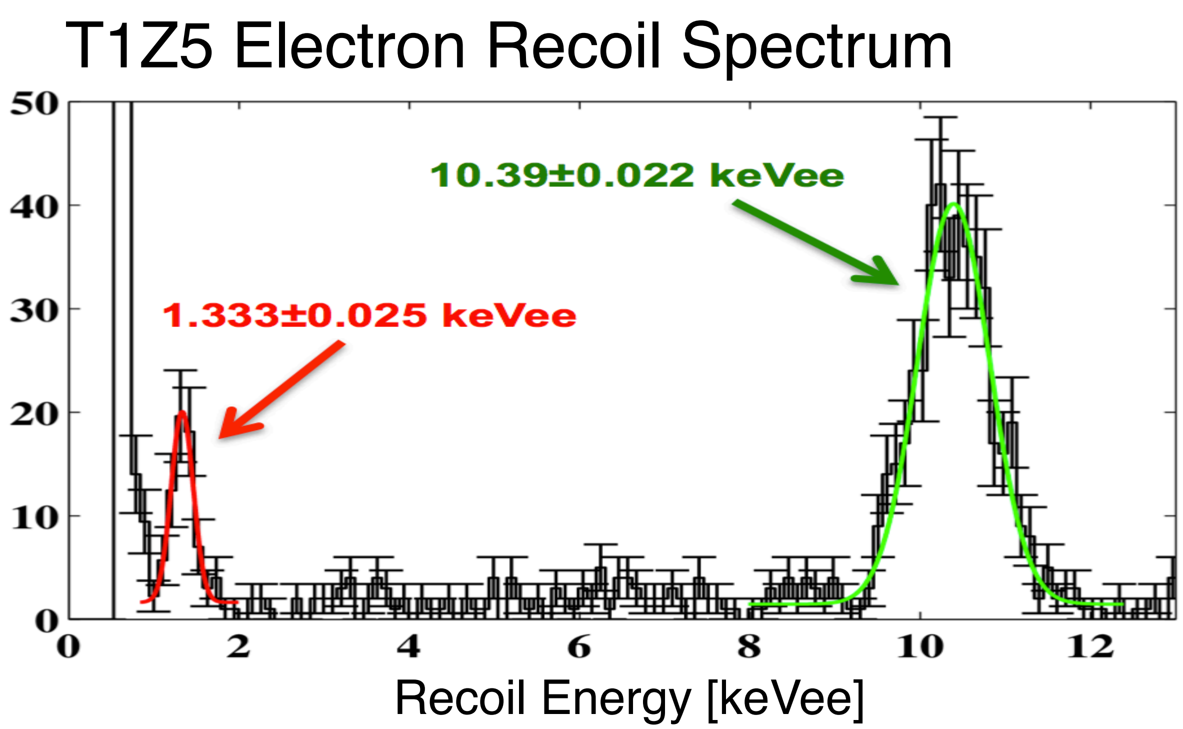
Total Phonon Signal = **Recoil + Luke**

At 3V running...

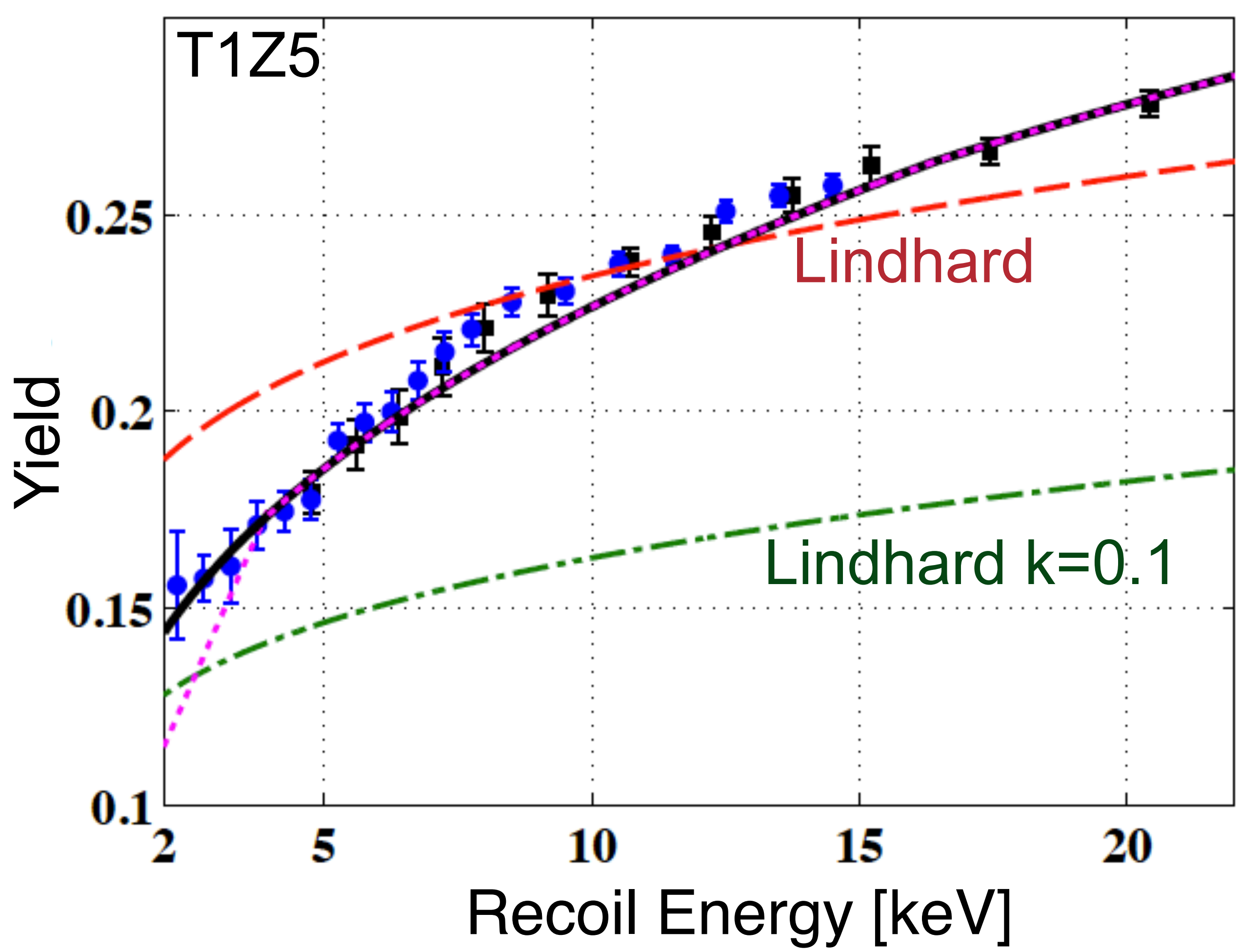
Electron Recoils: Recoil | Luke

Nuclear Recoils: Recoil | Luke

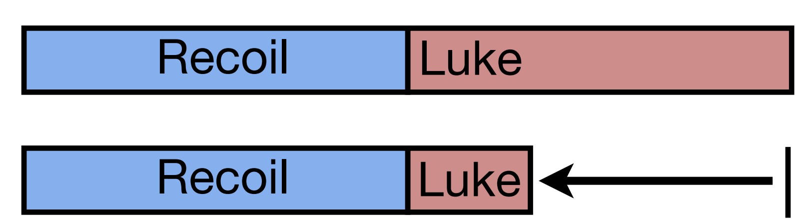
2. CDMS II at low energies



STEP 1:
Calibrate Using ER

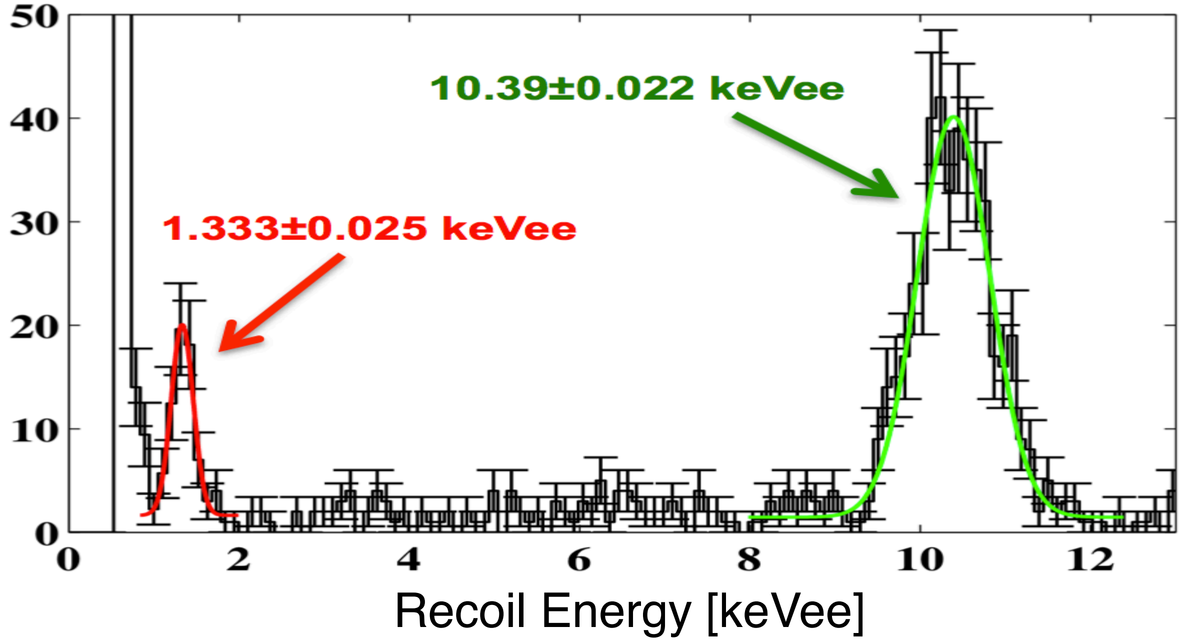


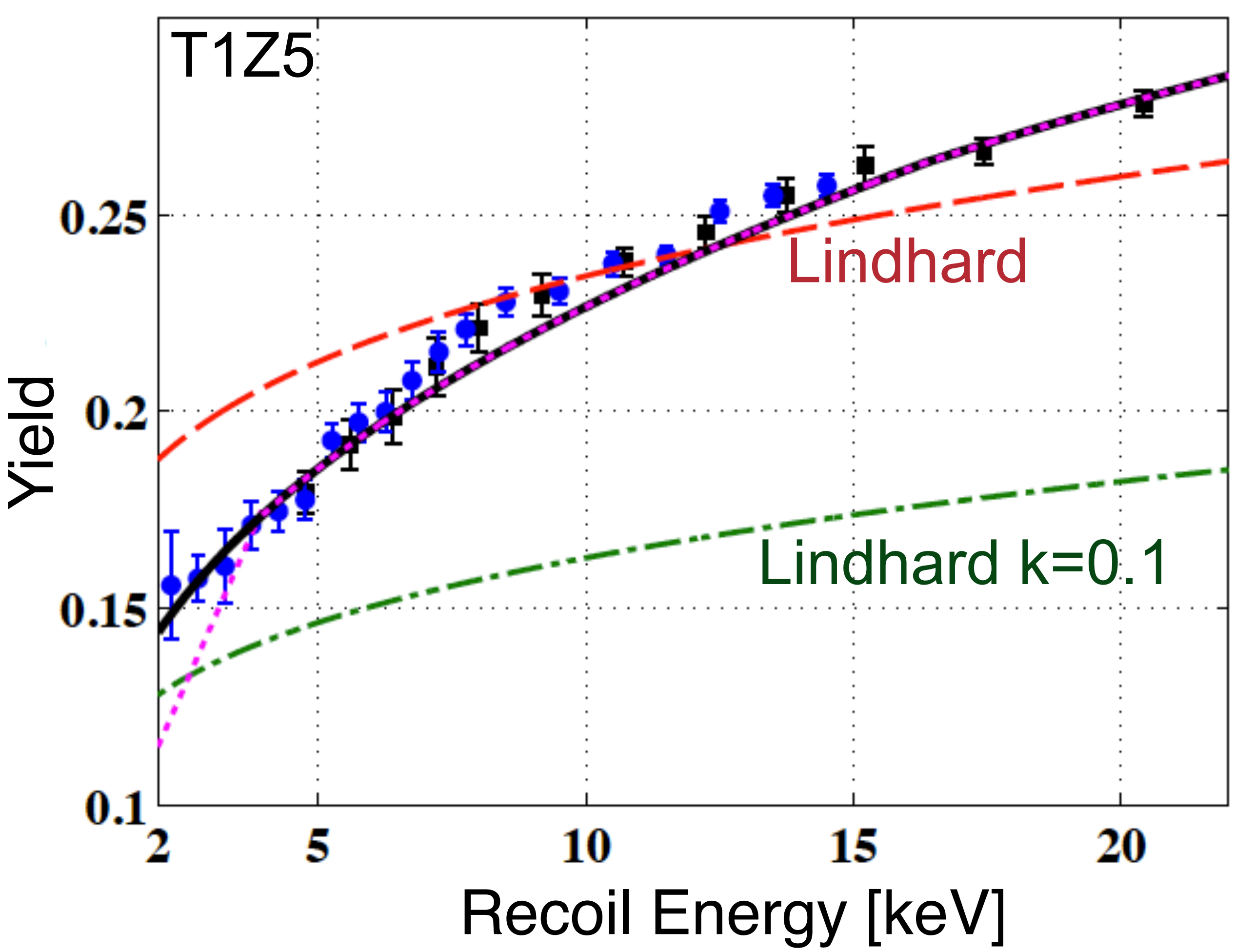
STEP 2:
Scale from ER to NR

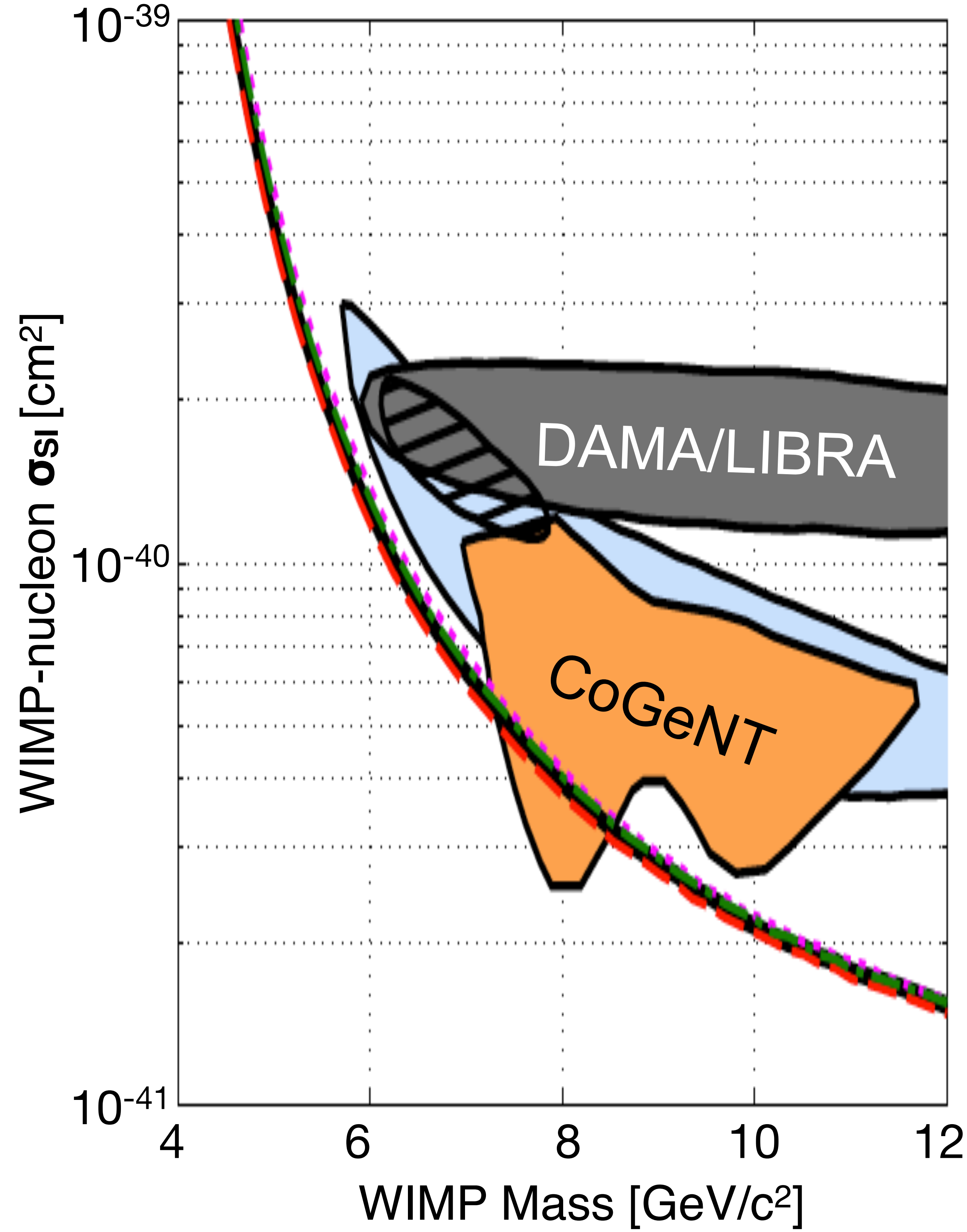


2. CDMS II at low energies

T1Z5 Electron Recoil Spectrum



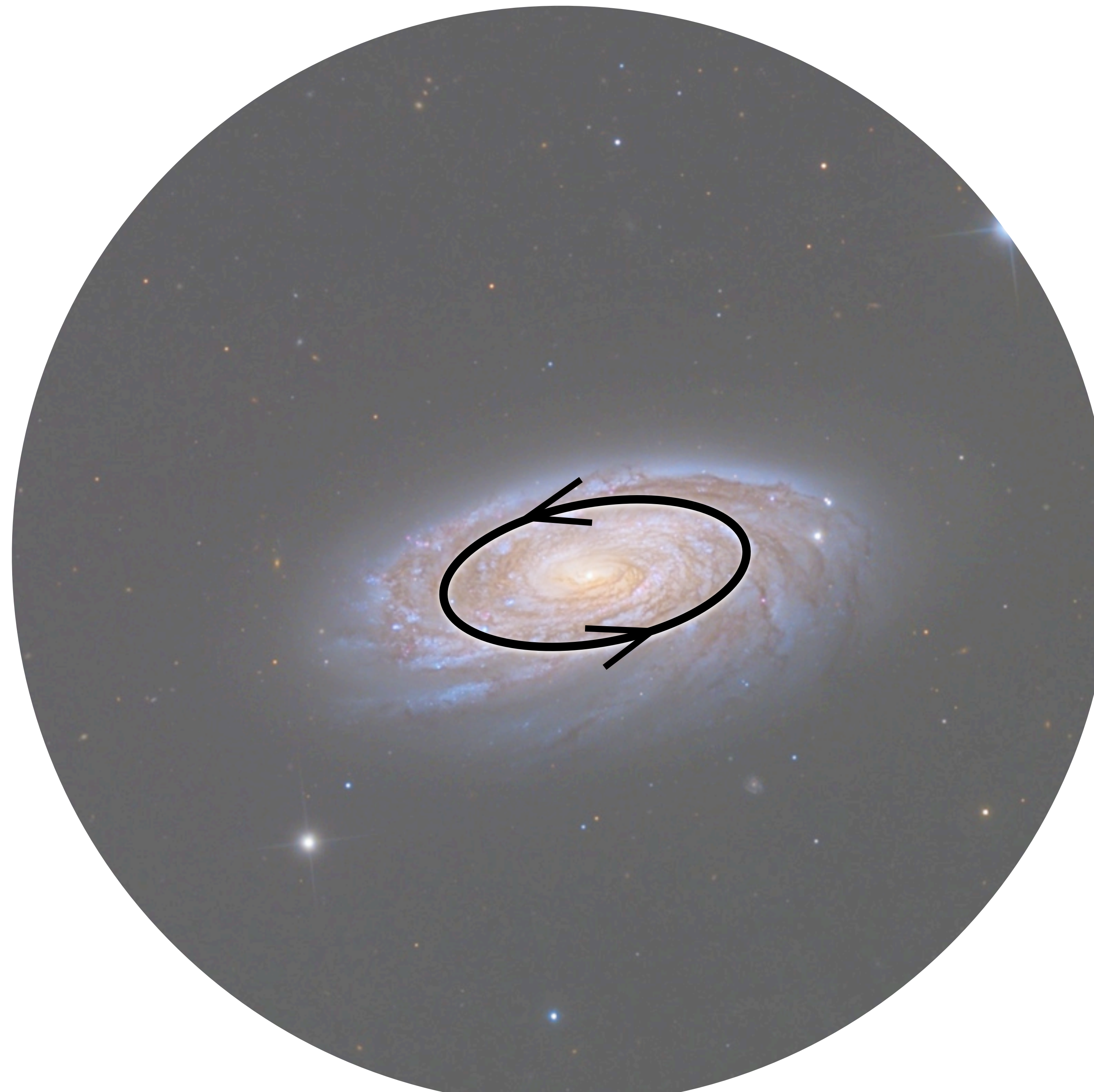




3. Annual Modulation

Baryons
orbit ‘together’
roughly circular orbits
small velocity dispersion

Halo DM
orbit ‘individually’
no circular preference
large velocity dispersion



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orbit ‘together’
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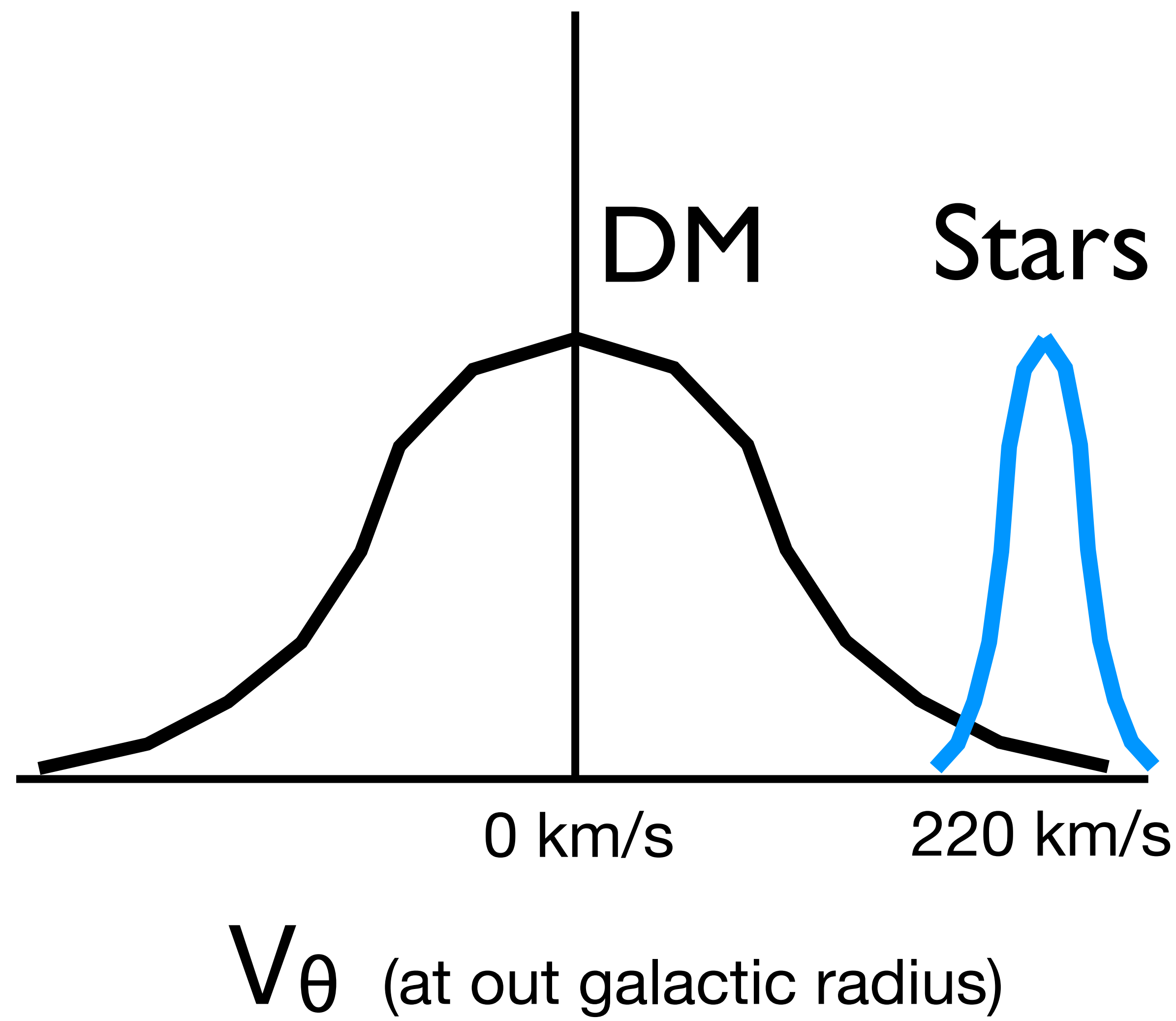
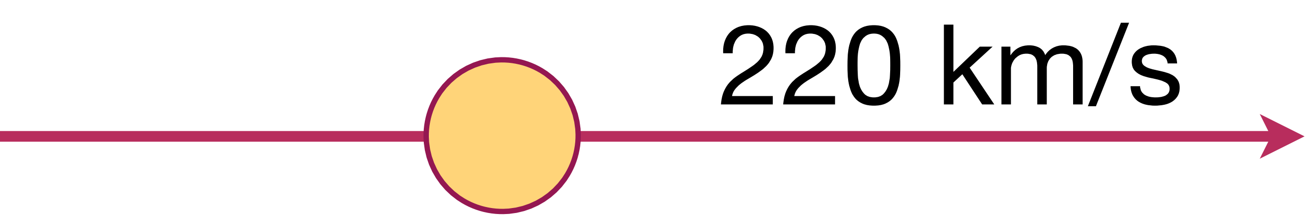
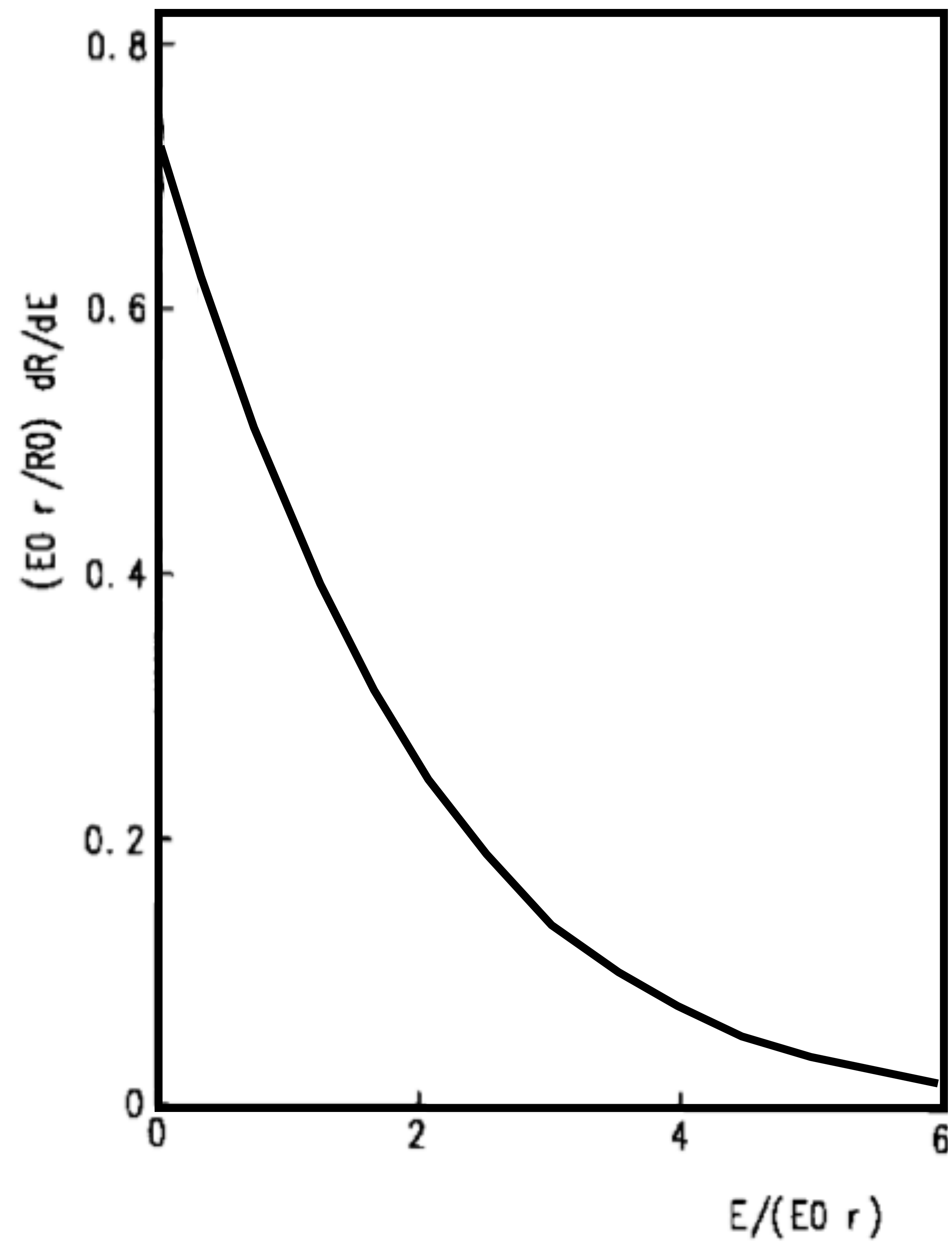
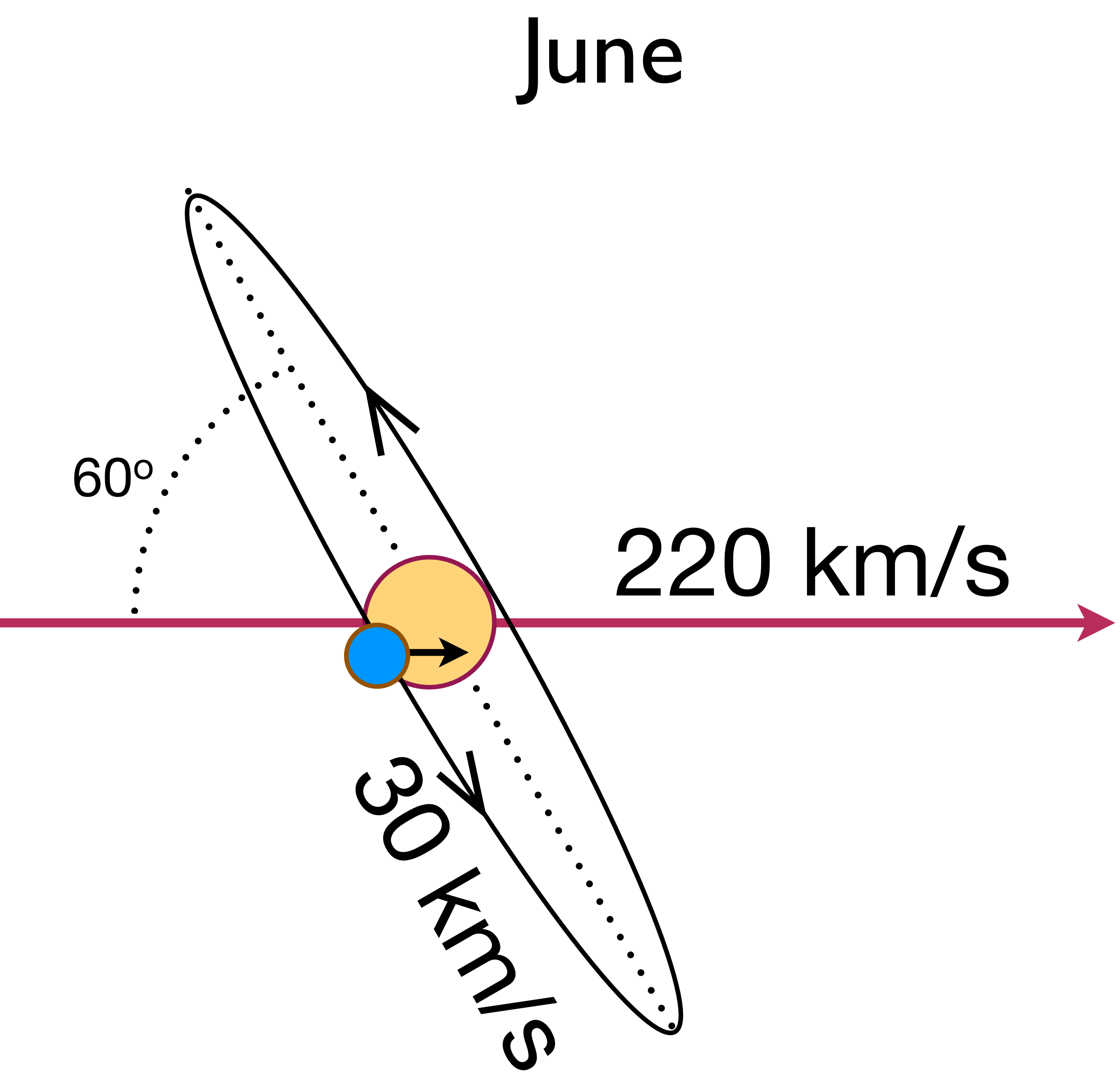
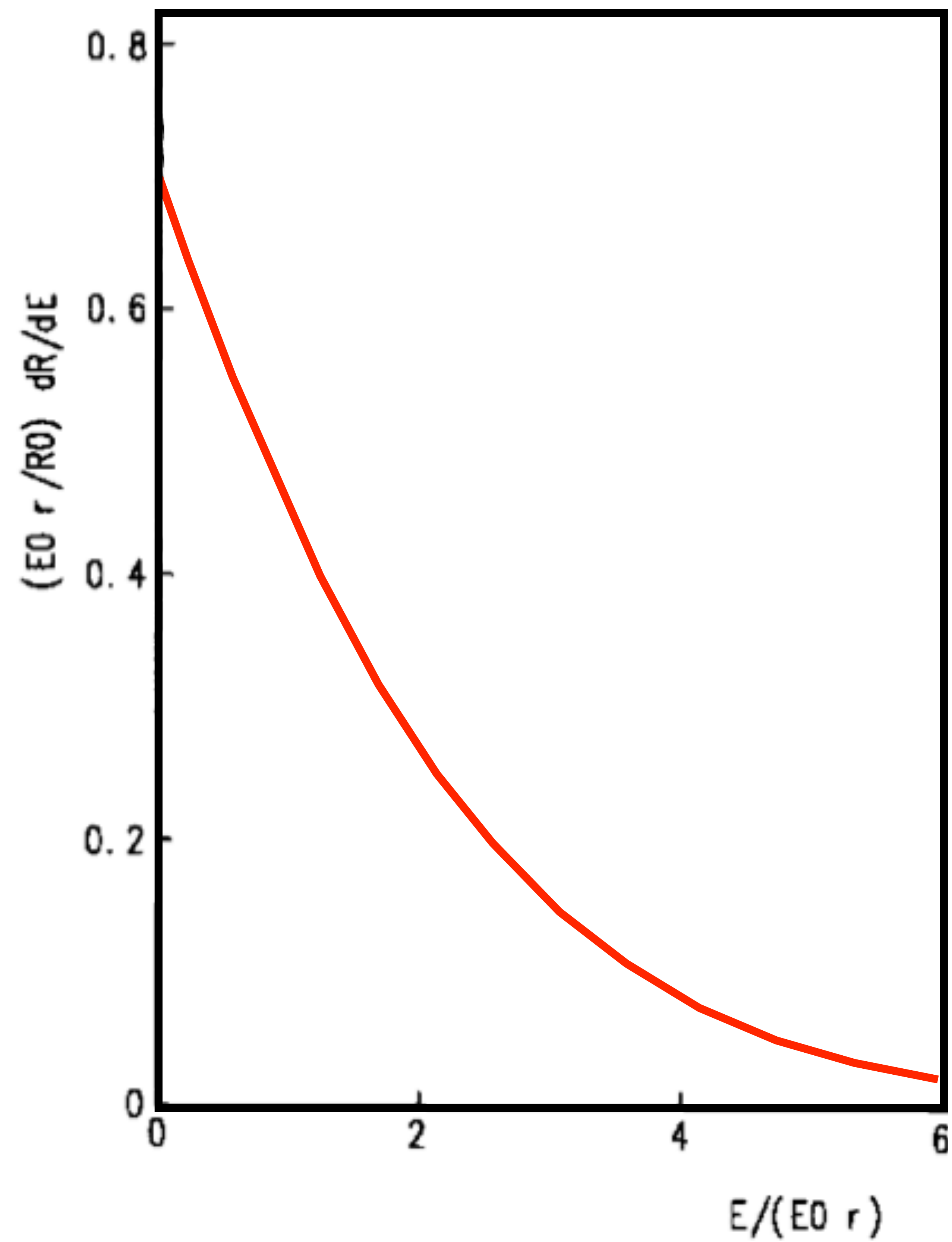


3. Annual Modulation

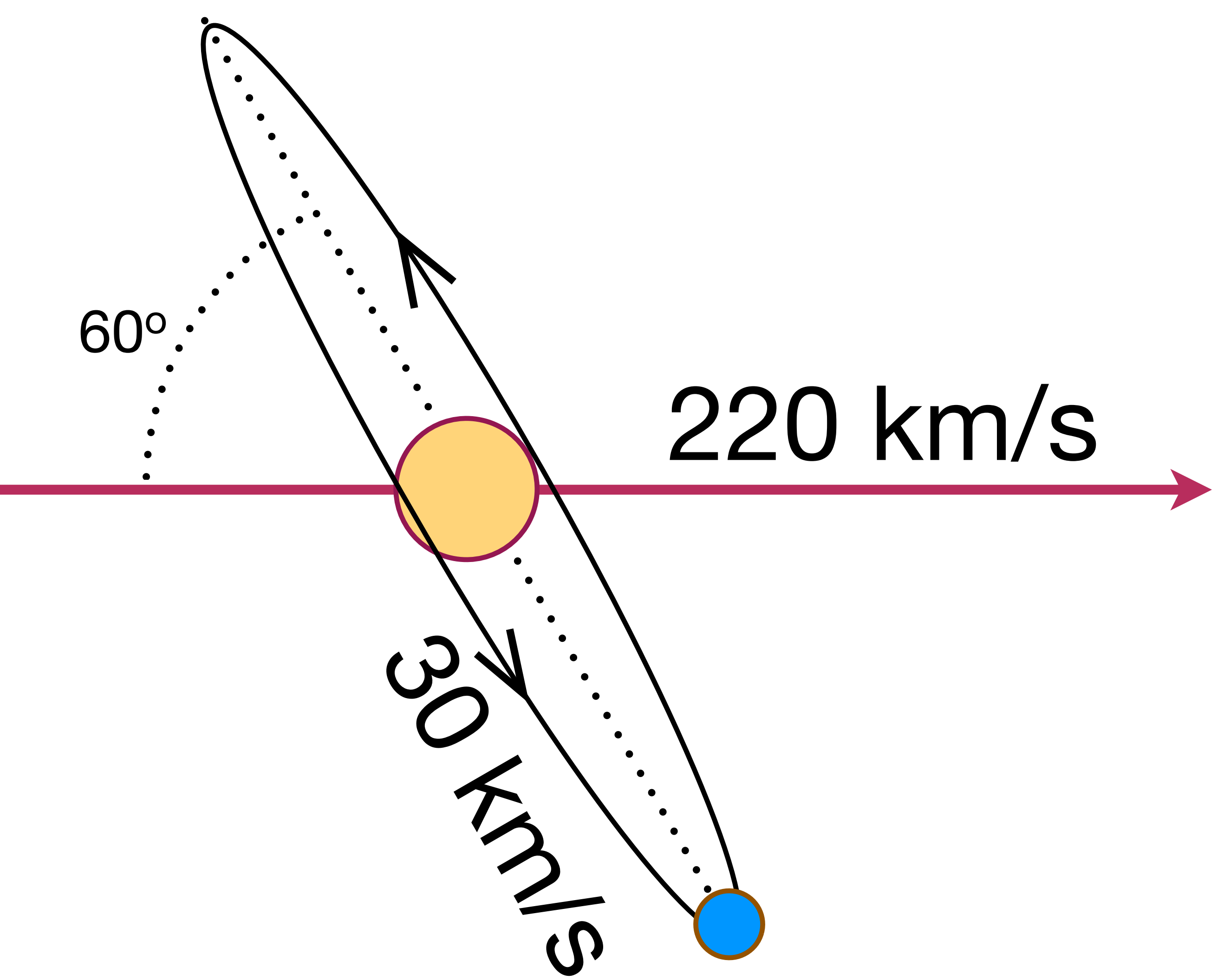


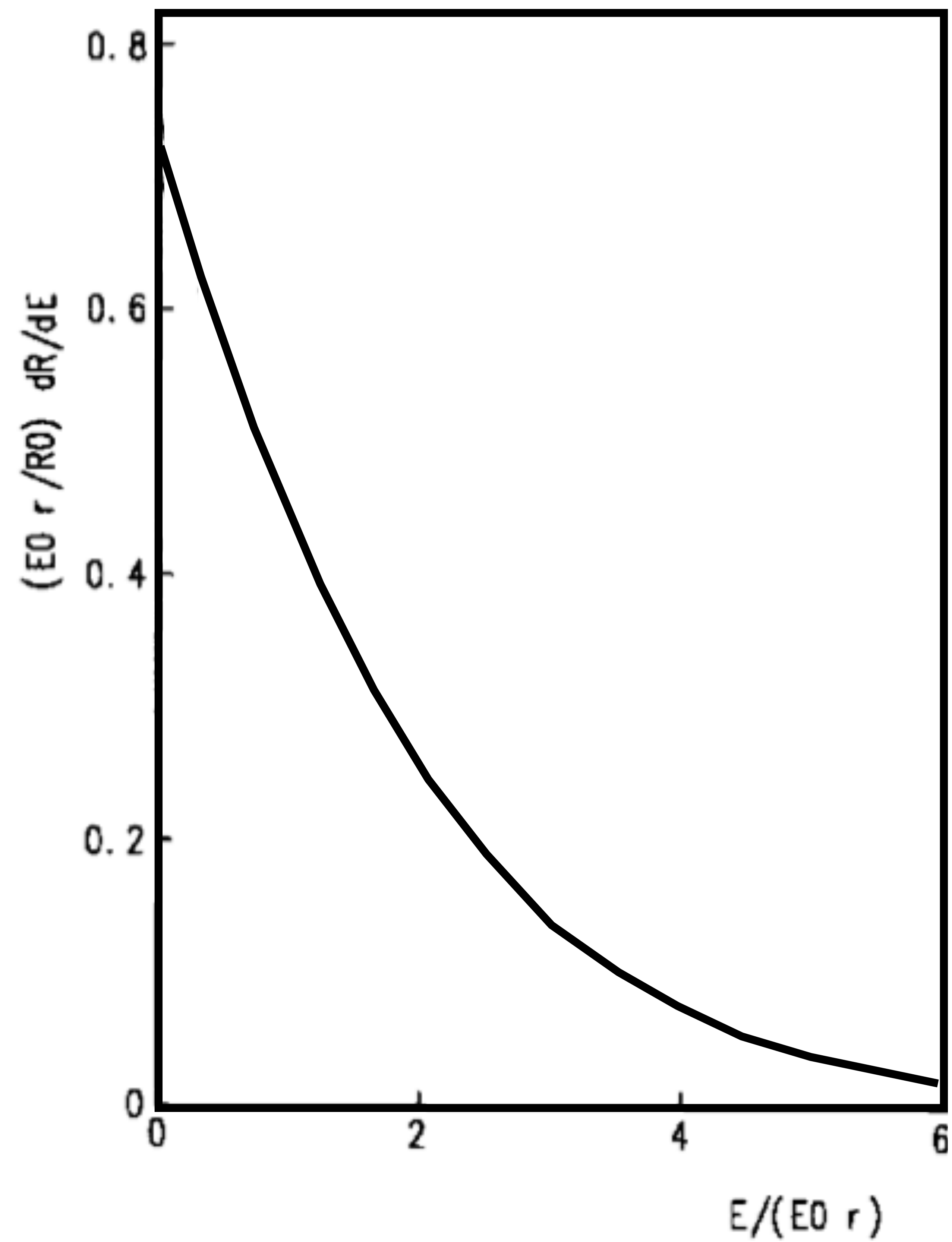



June
60°
220 km/s
30 km/s

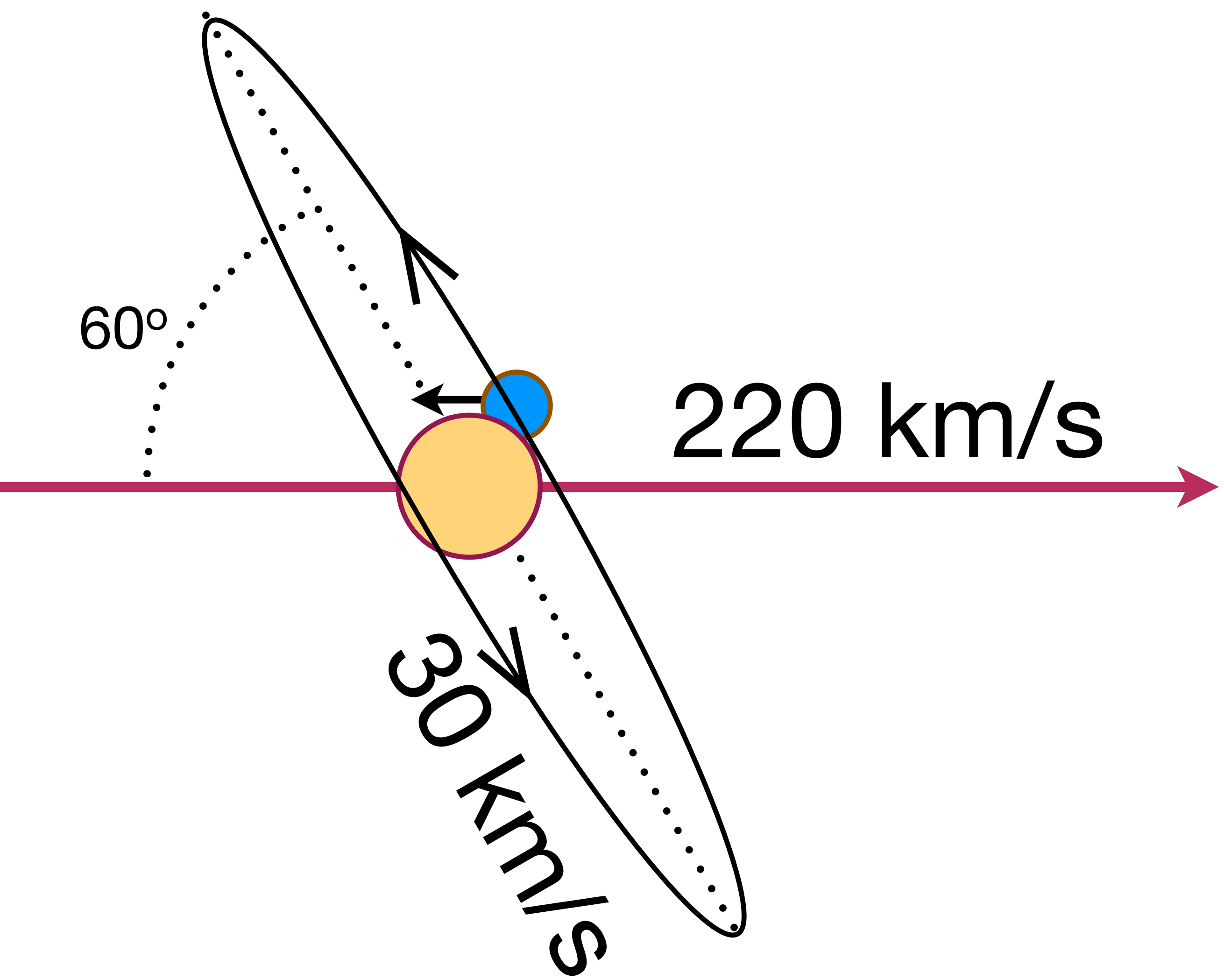

0.8
0.6
0.4
0.2
0
(E0 r /R0) dR/dE
0
2
4
6
E/(E0 r)

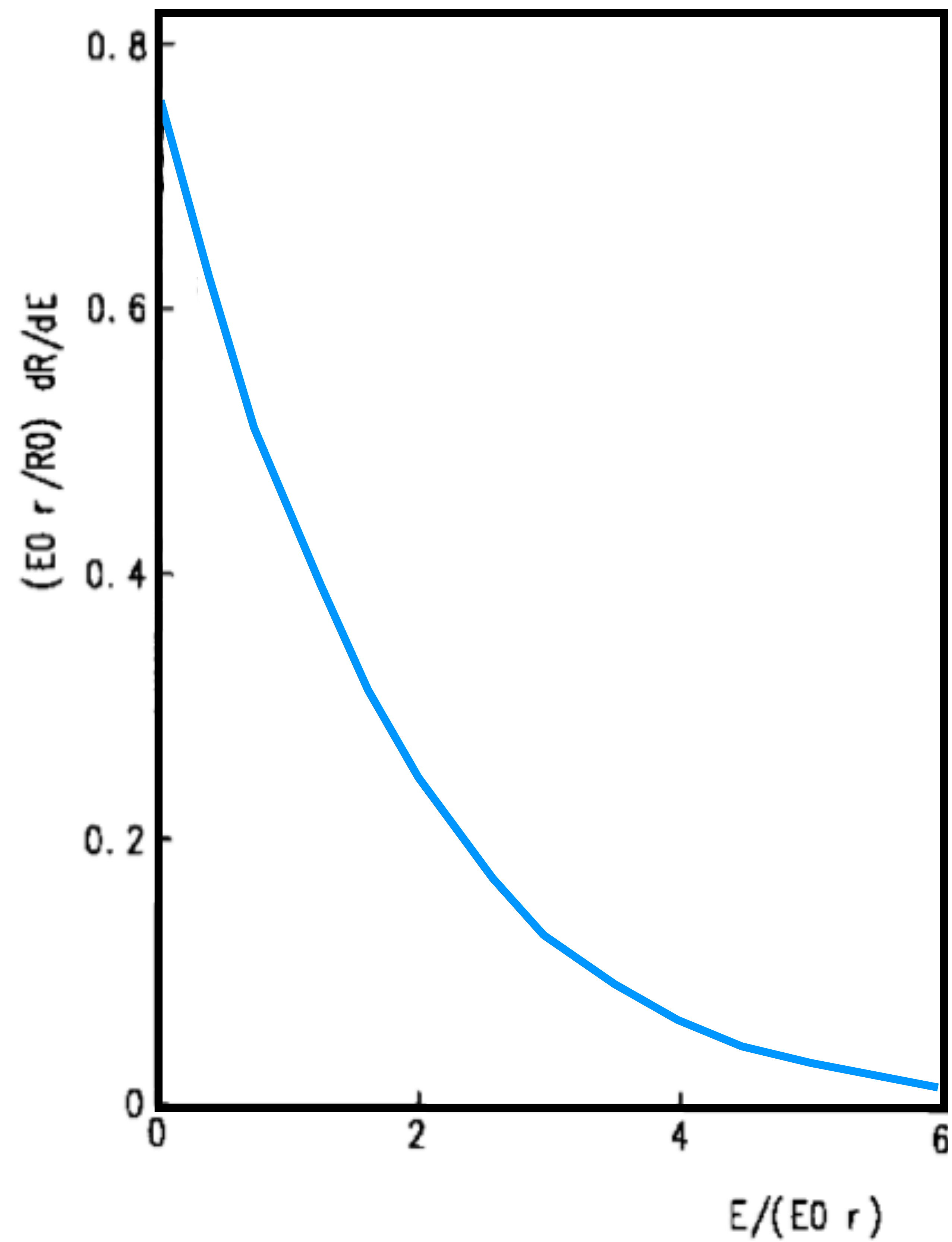
September

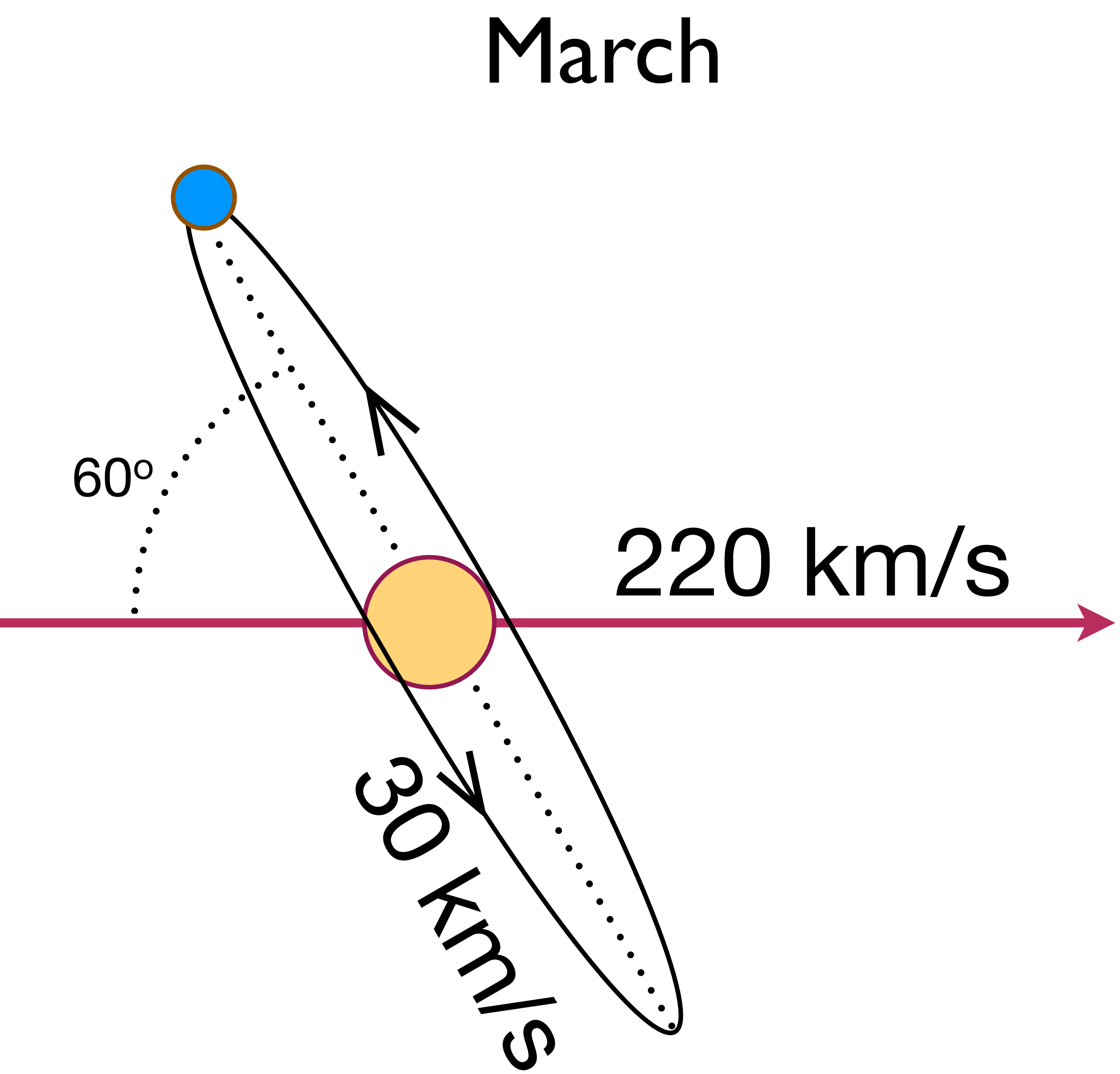


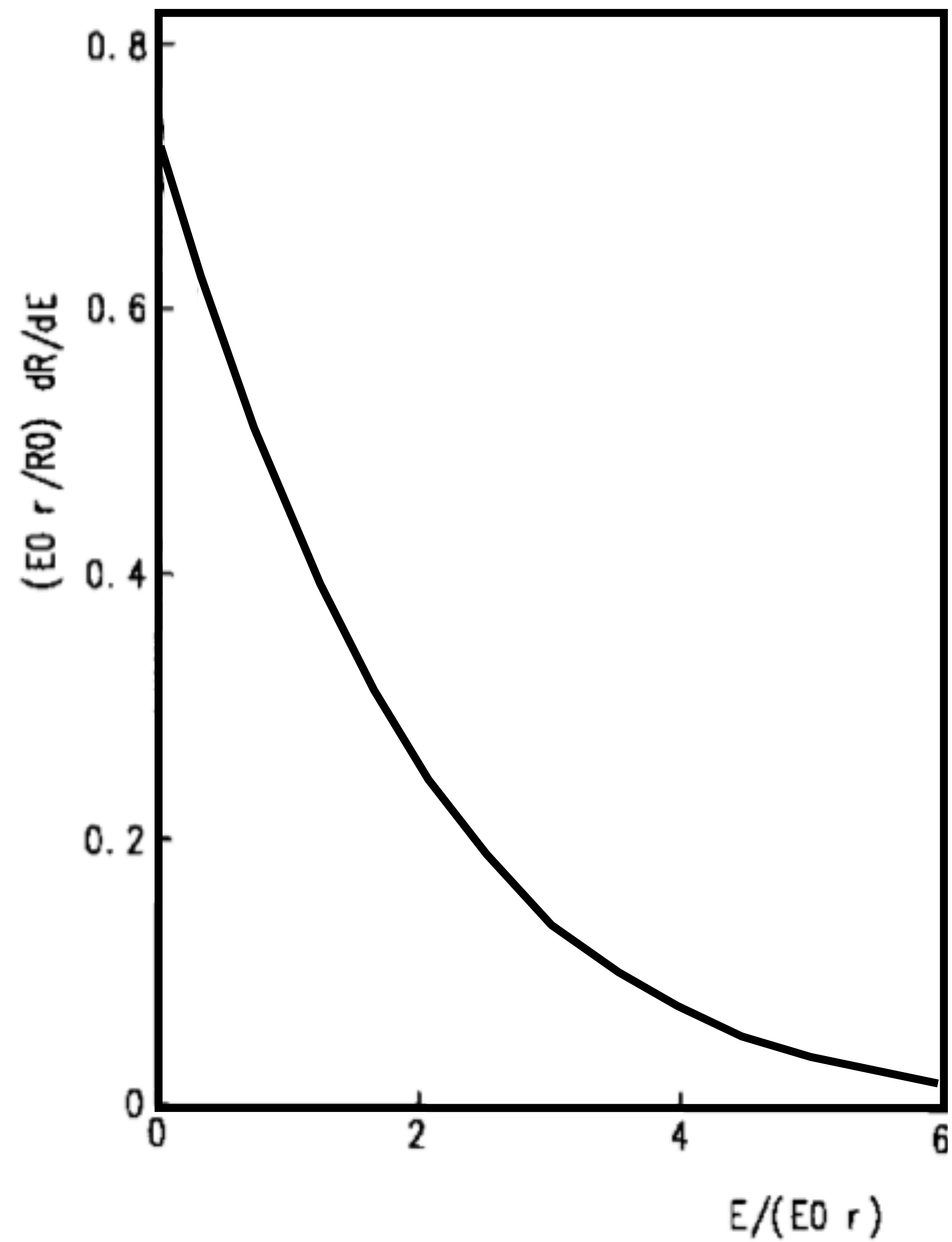


December

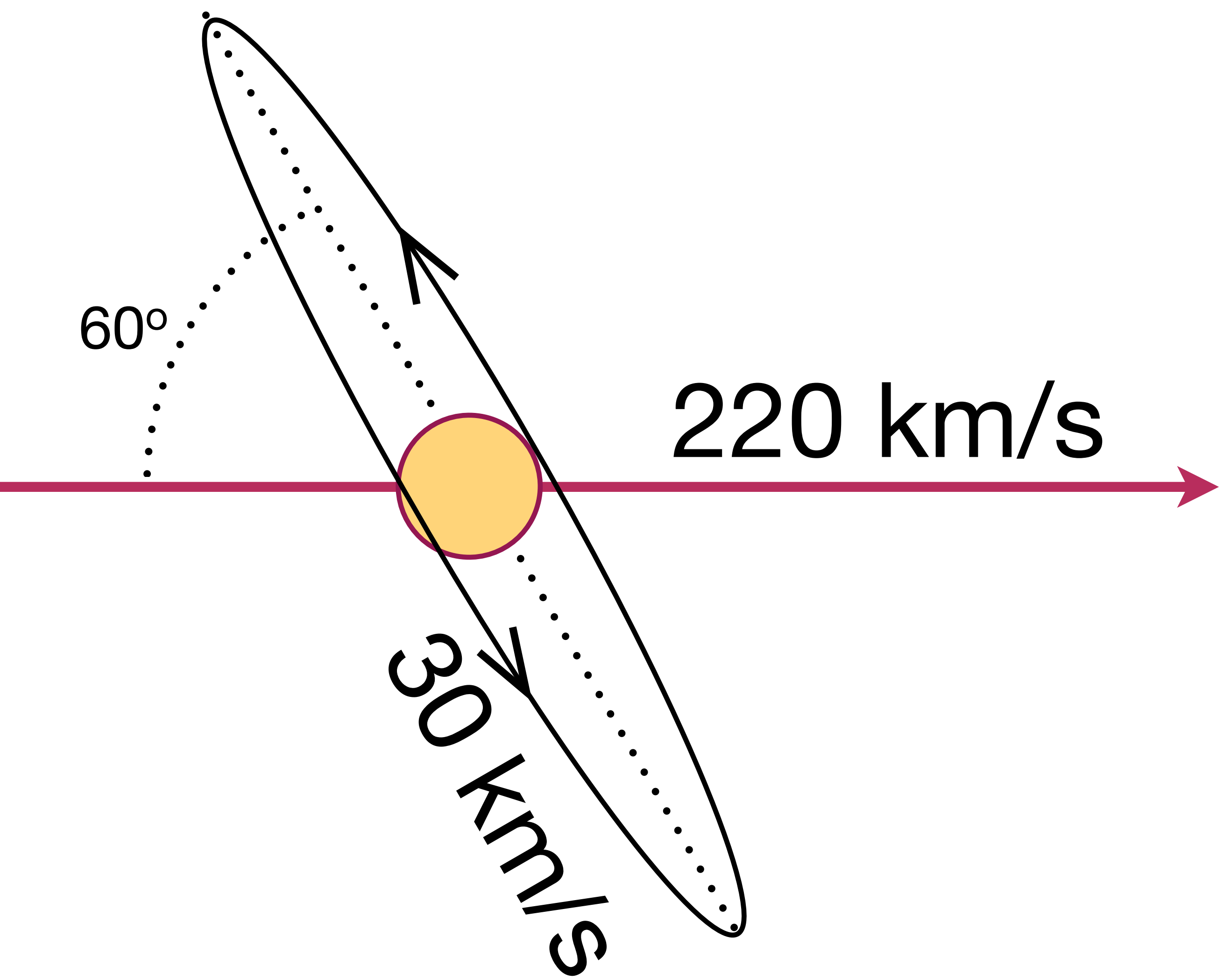


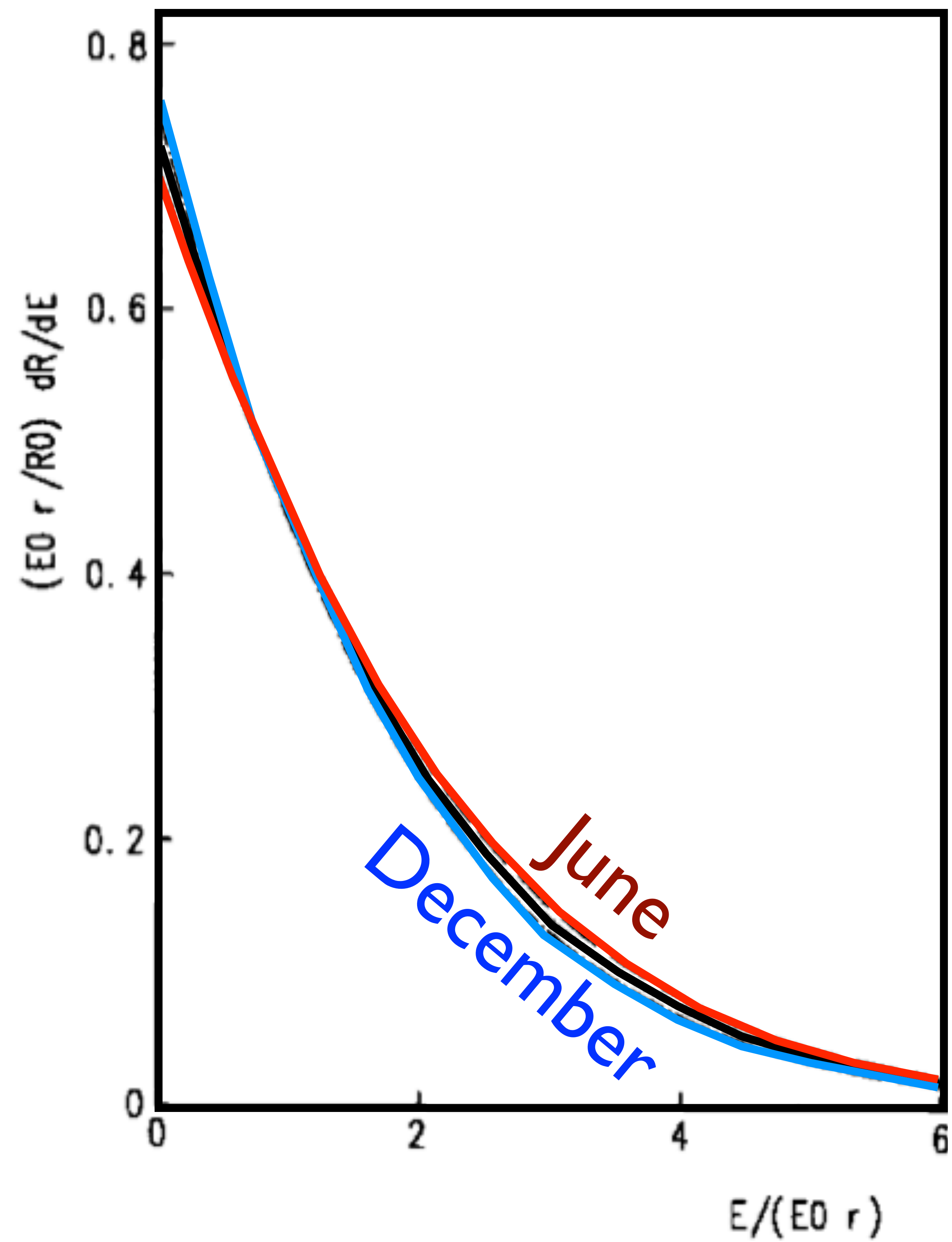



March
60°
220 km/s
30 km/s

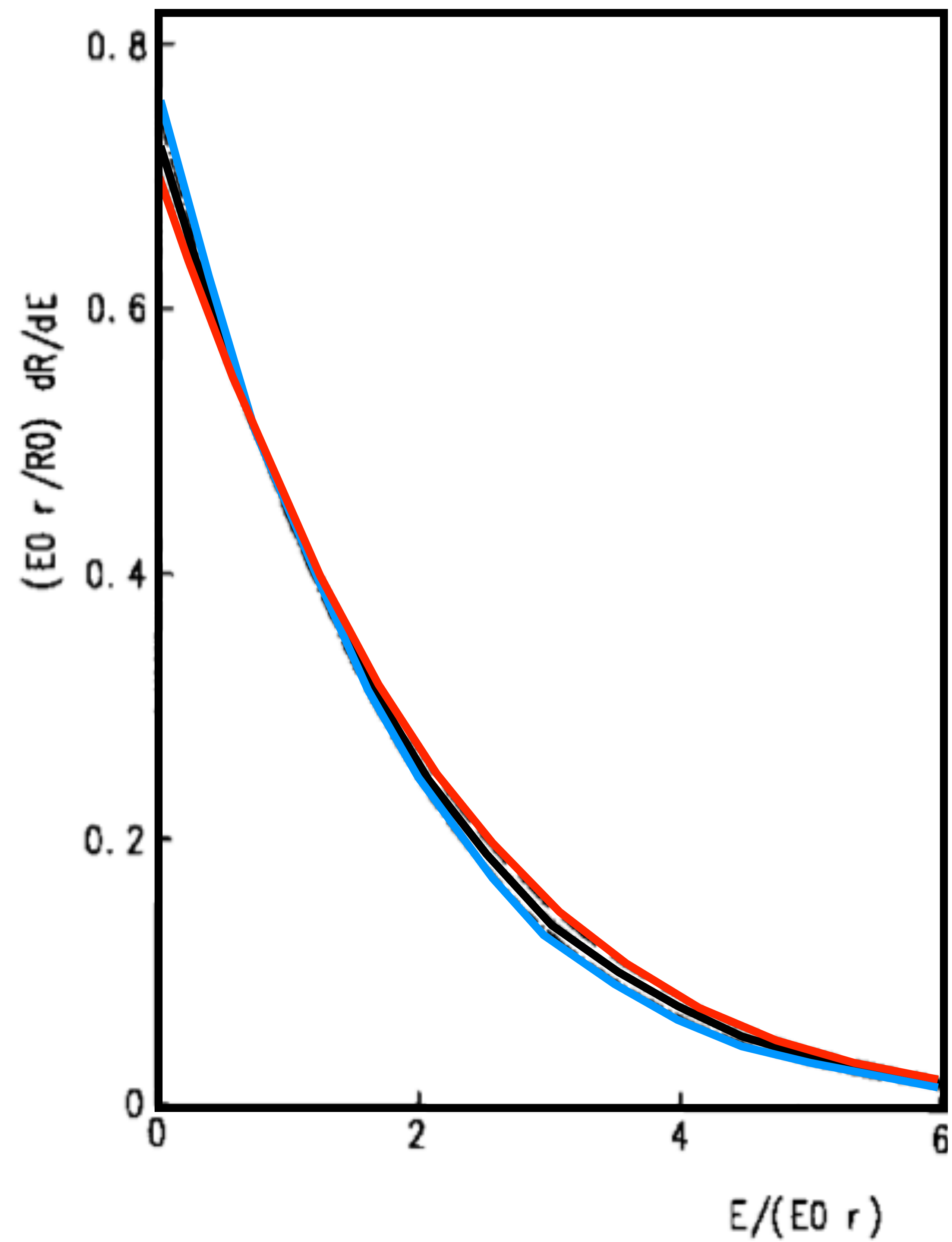

0.8
0.6
0.4
0.2
0
(E0 r /R0) dR/dE
0
2
4
6
E/(E0 r)

3. Annual Modulation



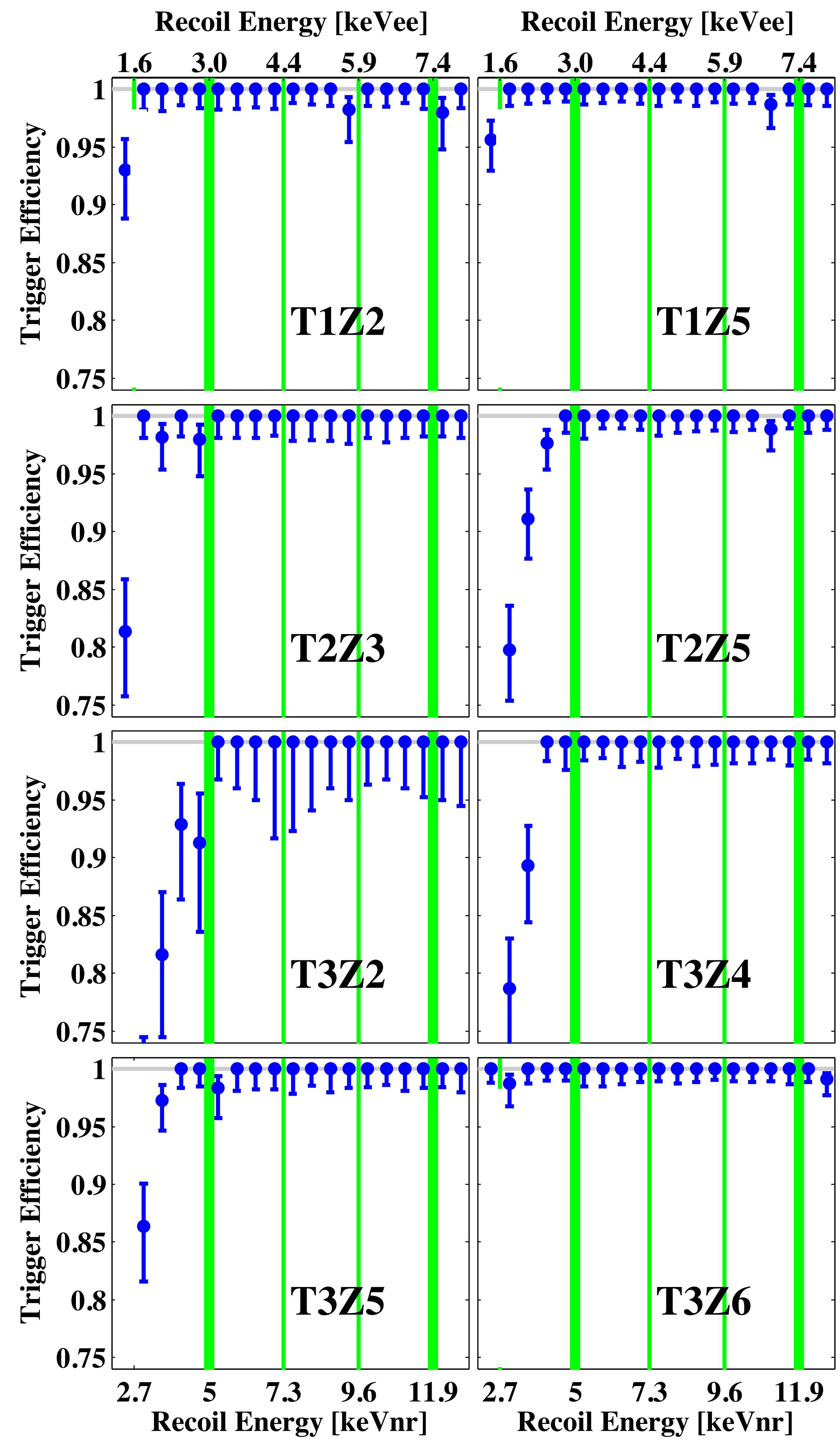


Must understand efficiency vs time



Must understand efficiency vs time

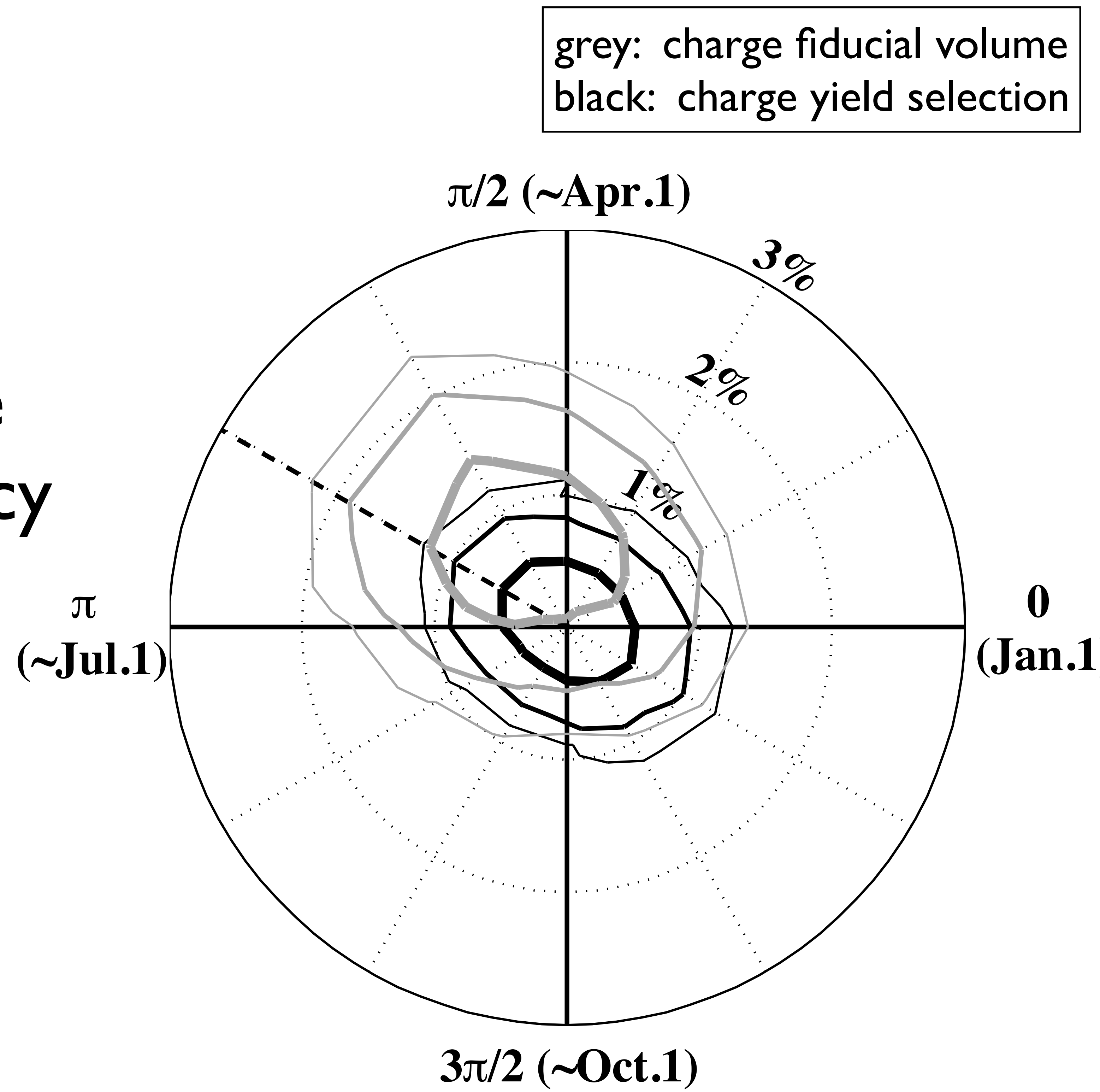
1: constrain energy range, to safely assume constant trigger-efficiency



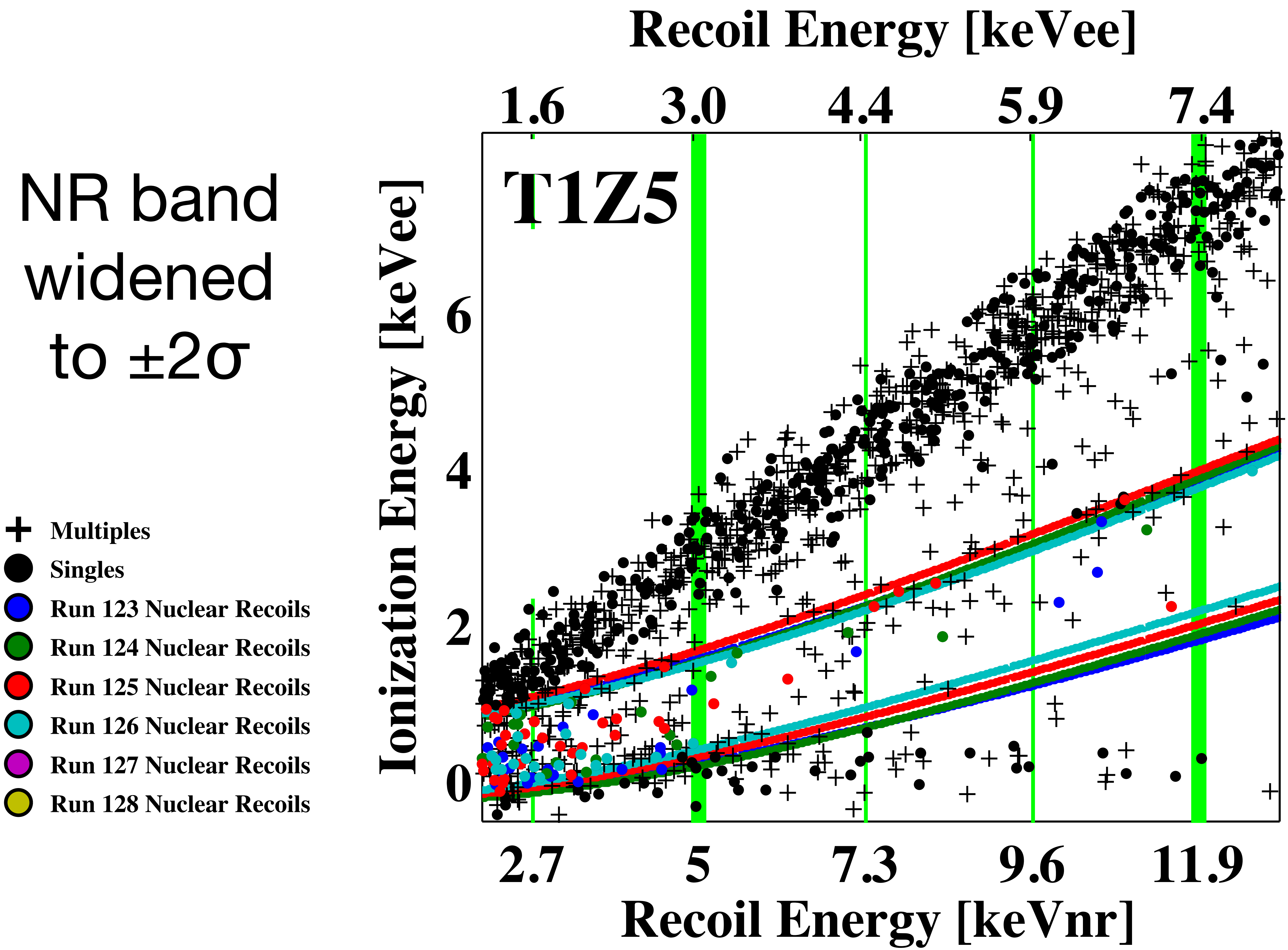
Must understand efficiency vs time

1: constrain energy range, to safely assume constant trigger-efficiency

2: place limits on cut efficiencies, given this energy range

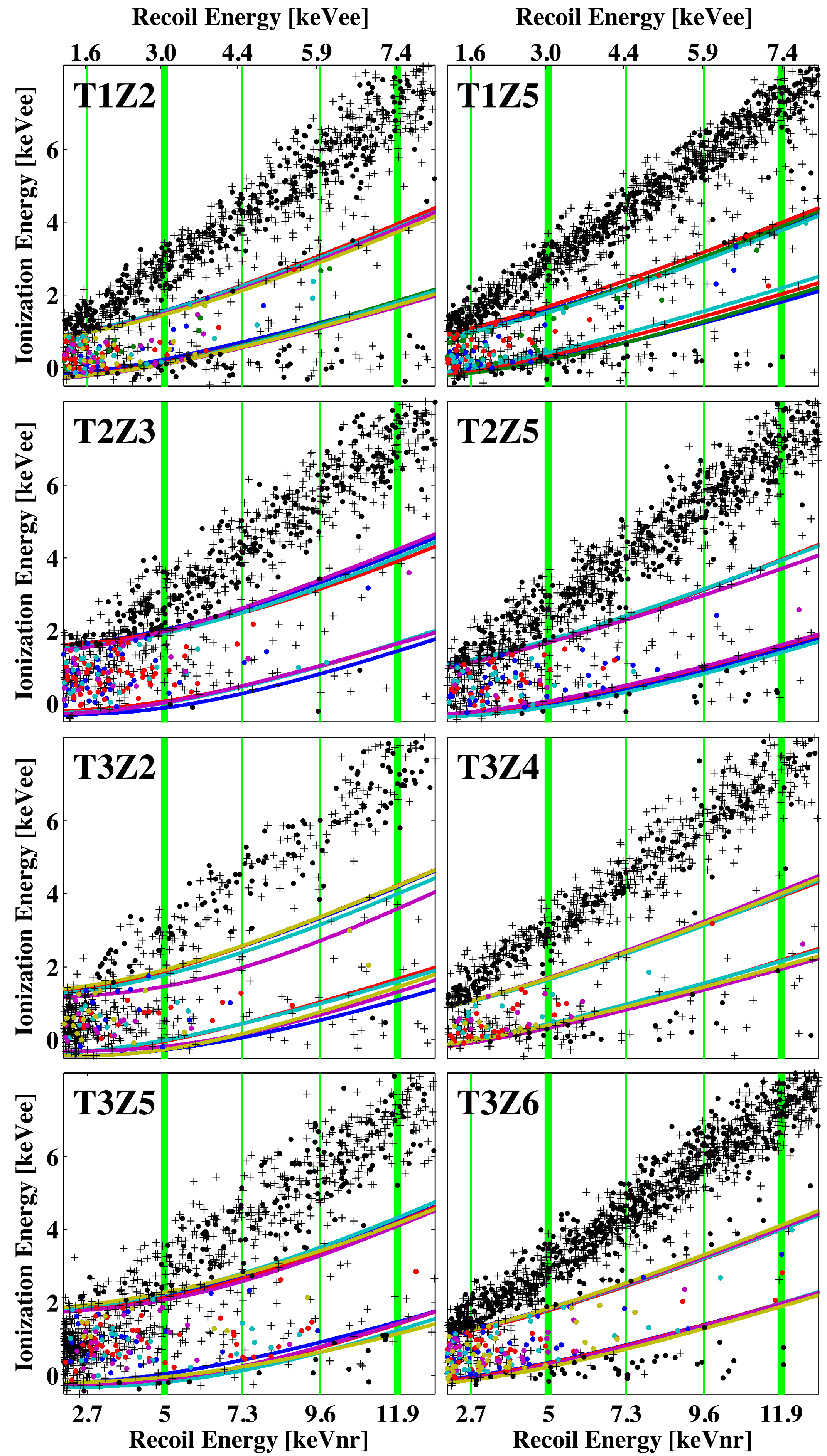


NR band widened to ±2σ

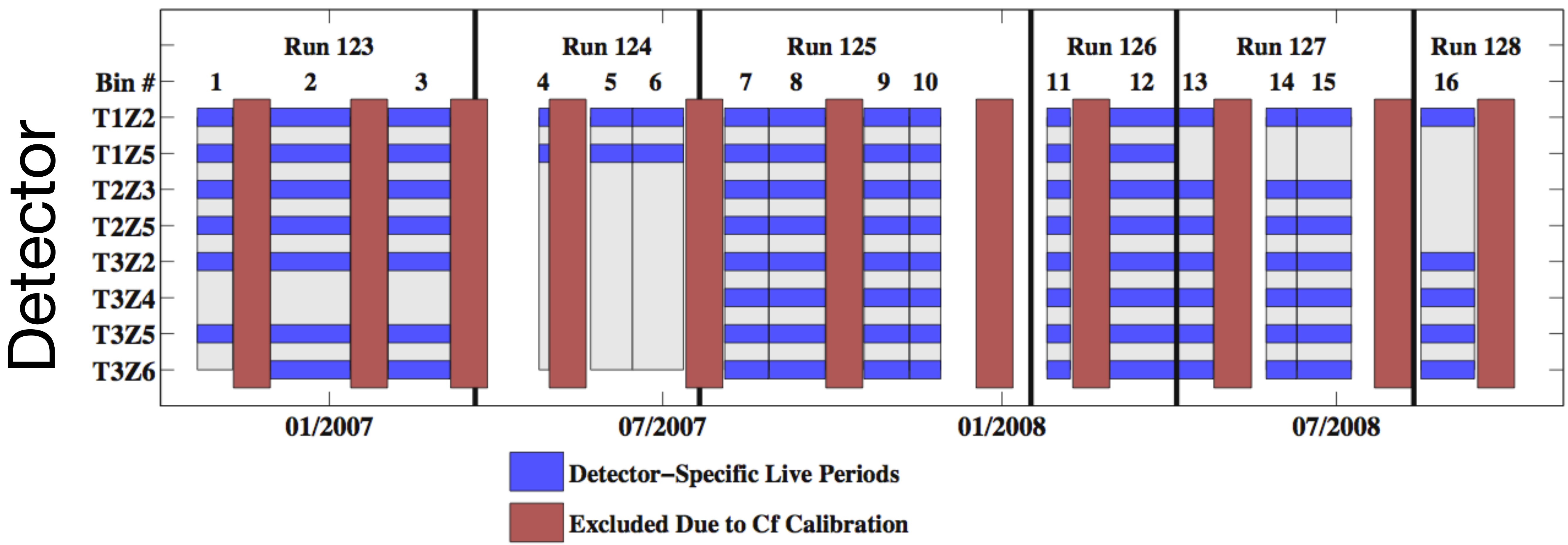


3. Annual Modulation

NR band widened to ±2σ

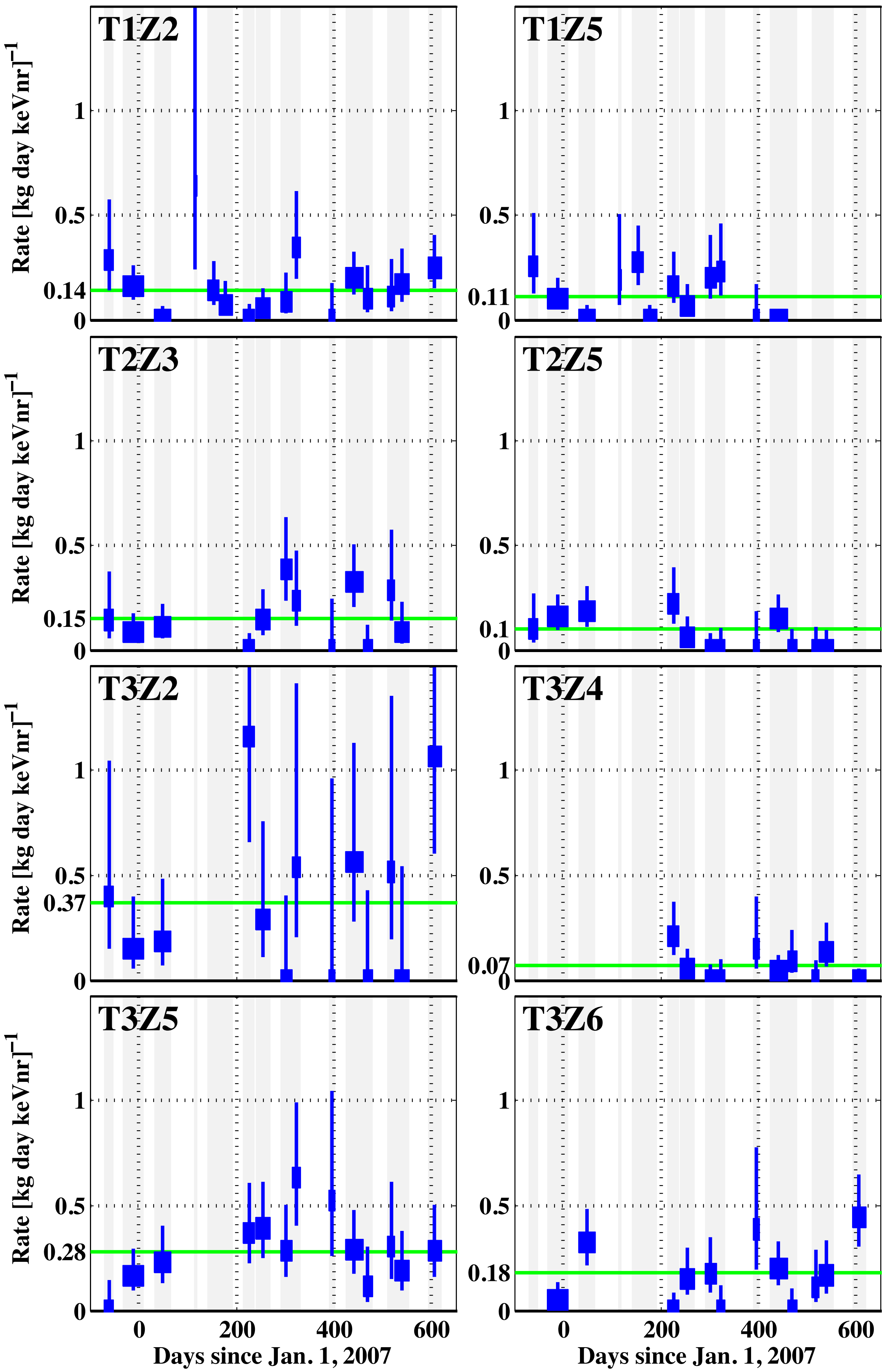


Binning the exposure in time...



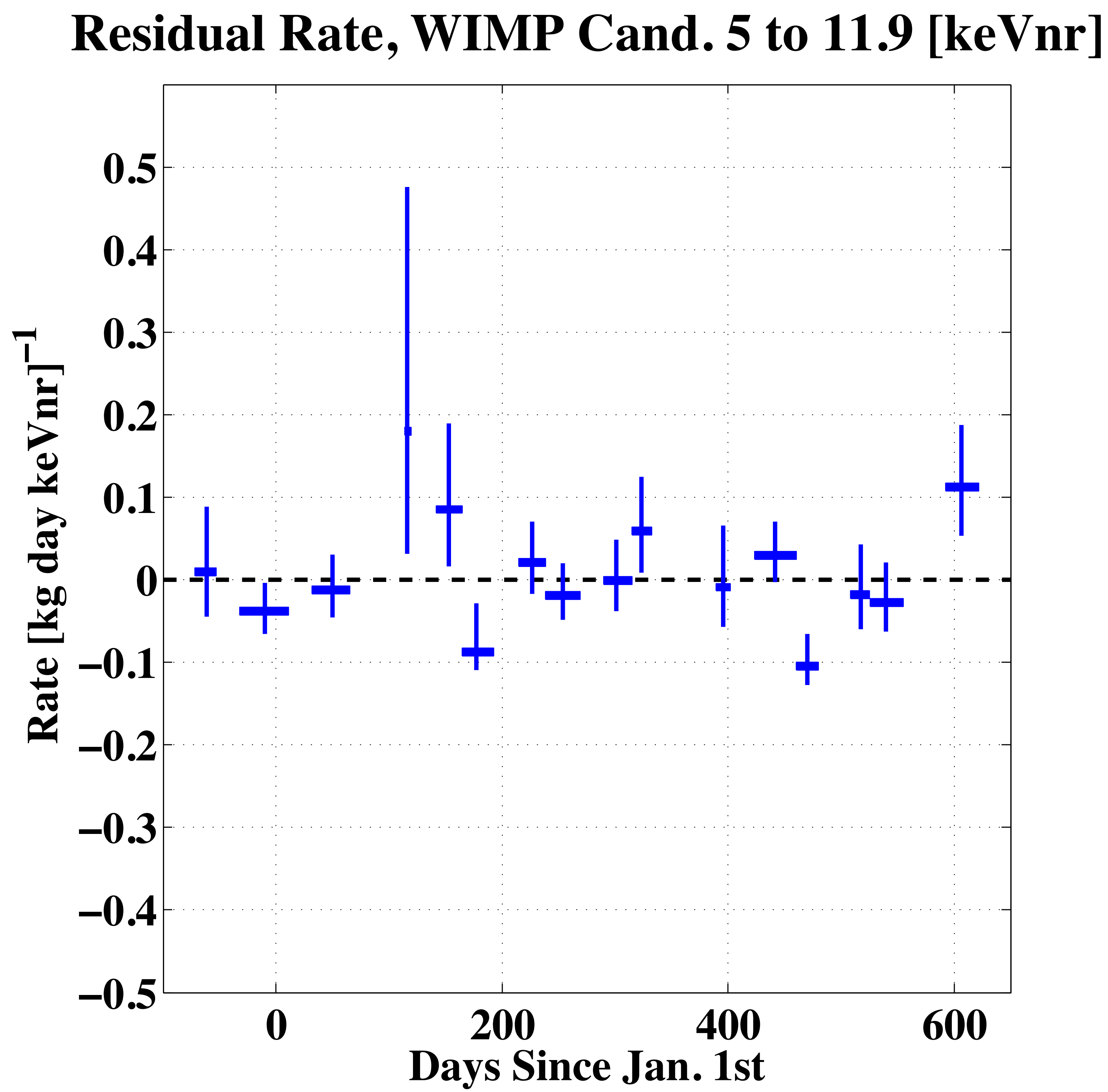
Candidate Event Rate vs. Time

(each detector)



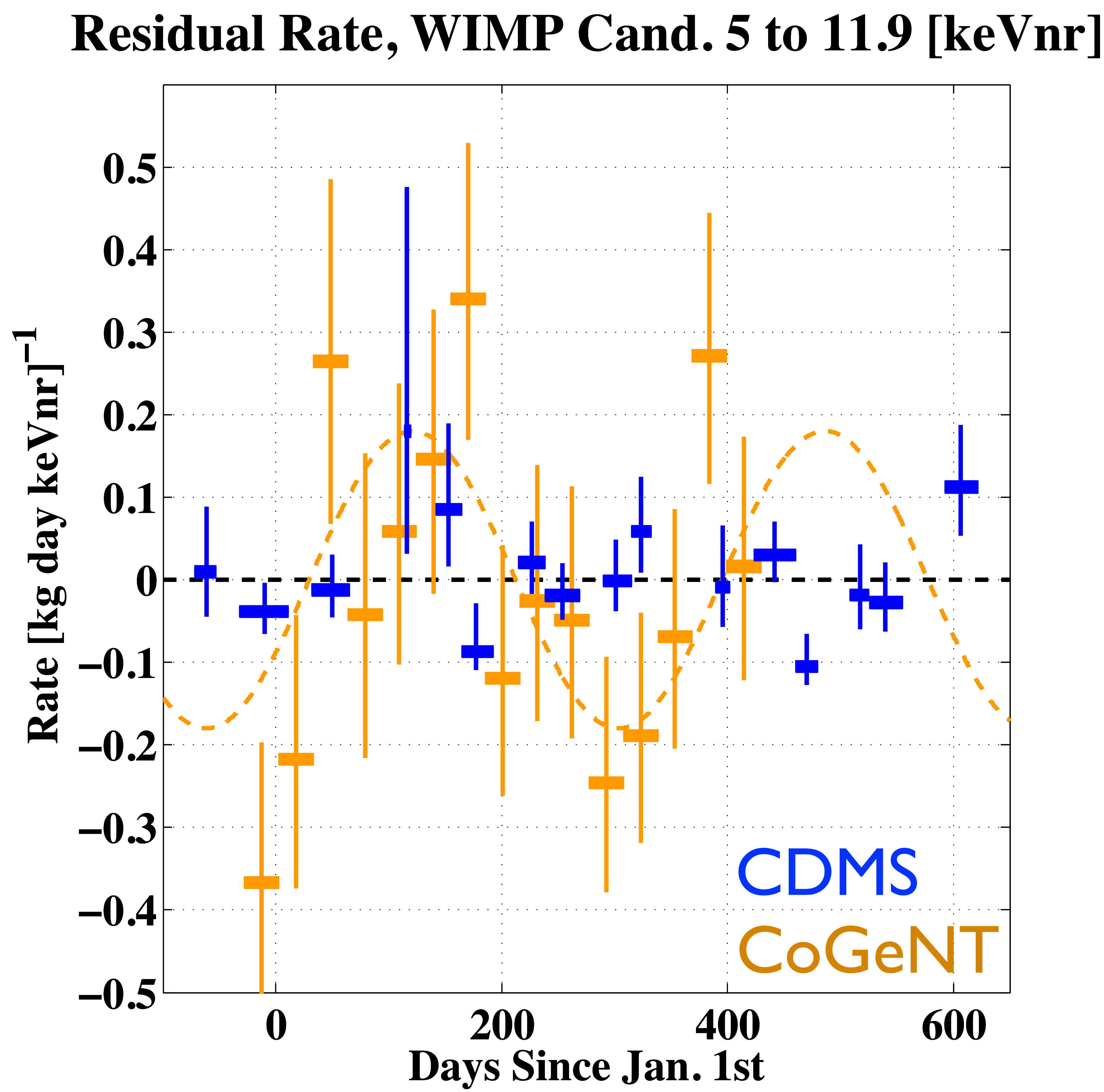
Candidate Event Rate vs. Time

(detectors DC-subtracted, then combined)



Candidate Event Rate vs. Time

(detectors DC-subtracted, then combined)



combined likelihood of data, for all time bins (β), and all dets (d)

$$\ell = \prod_{\beta,d} e^{-\mu_{\beta d}} \left(\mu_{\beta d}\right)^{n_{\beta d}}$$

where $\mu_{\beta d}$ is the model prediction for det d, bin β

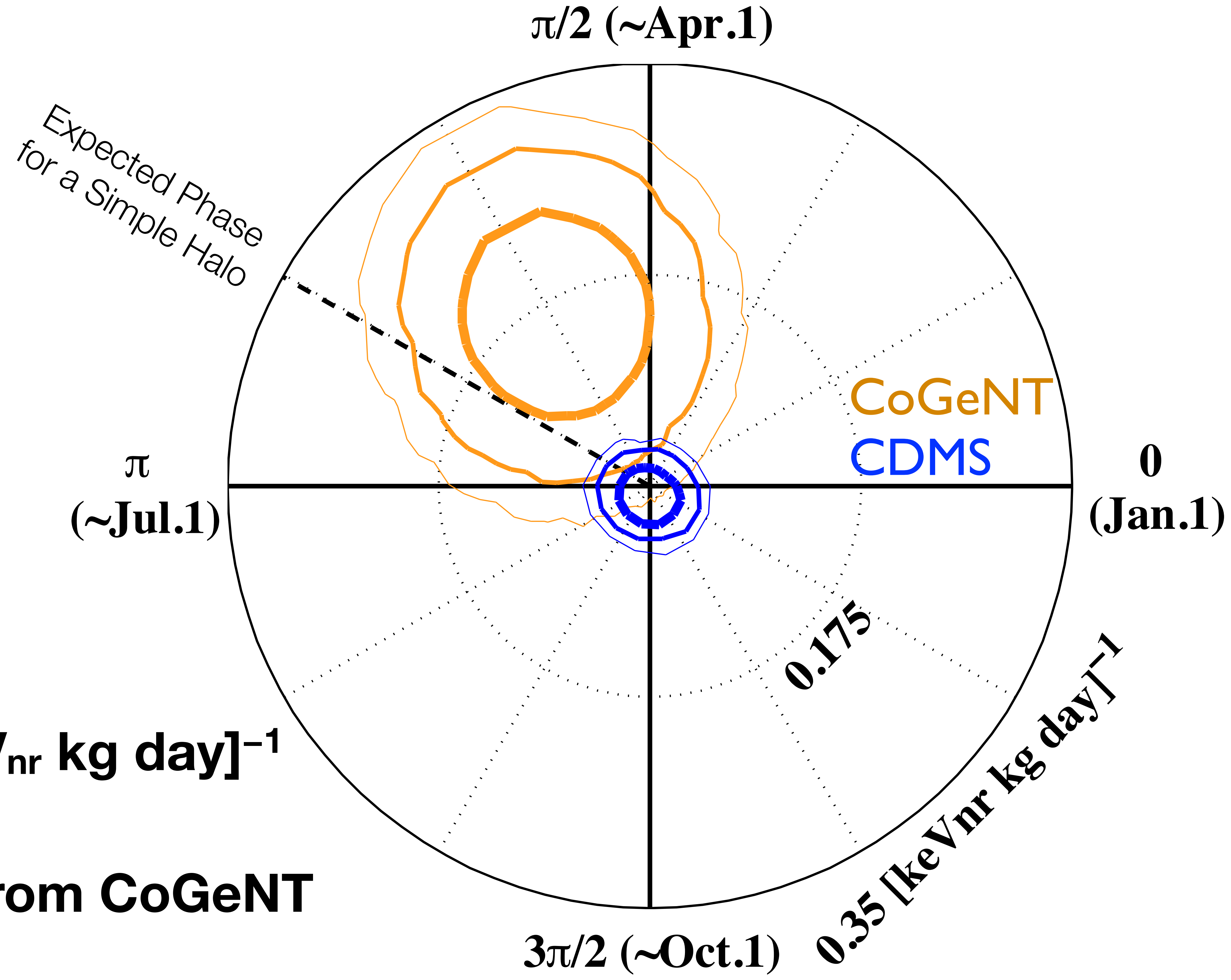
$$\mu_{\beta d} = \{\Gamma_d + M \cos\left[\omega\left(t_\beta - \phi\right)\right]\} m_d \varepsilon_{\beta d} f_{\beta d} \Delta t_\beta \Delta E$$

DC Rate

Mod. Rate

Mod. Phase

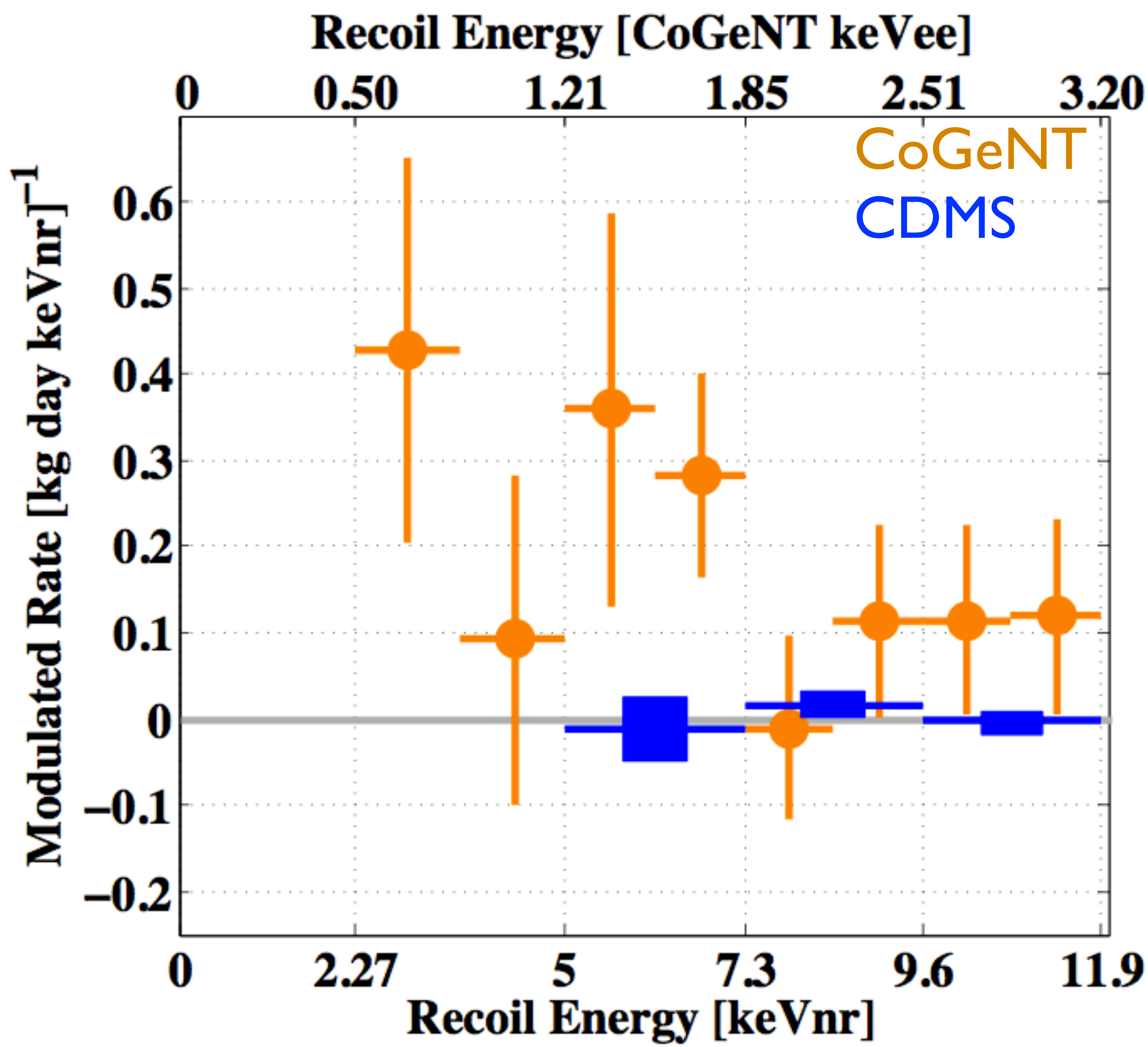
exposure



<0.06 [keV$_{nr}$ kg day]$^{-1}$
(99% CL)

different from CoGeNT
(>98% CL)

106-day phase
(CoGeNT Best-Fit)



152.5-day phase
(Simple Halo Model)