DISCOVERING NONSTANDARD DARK MATTER

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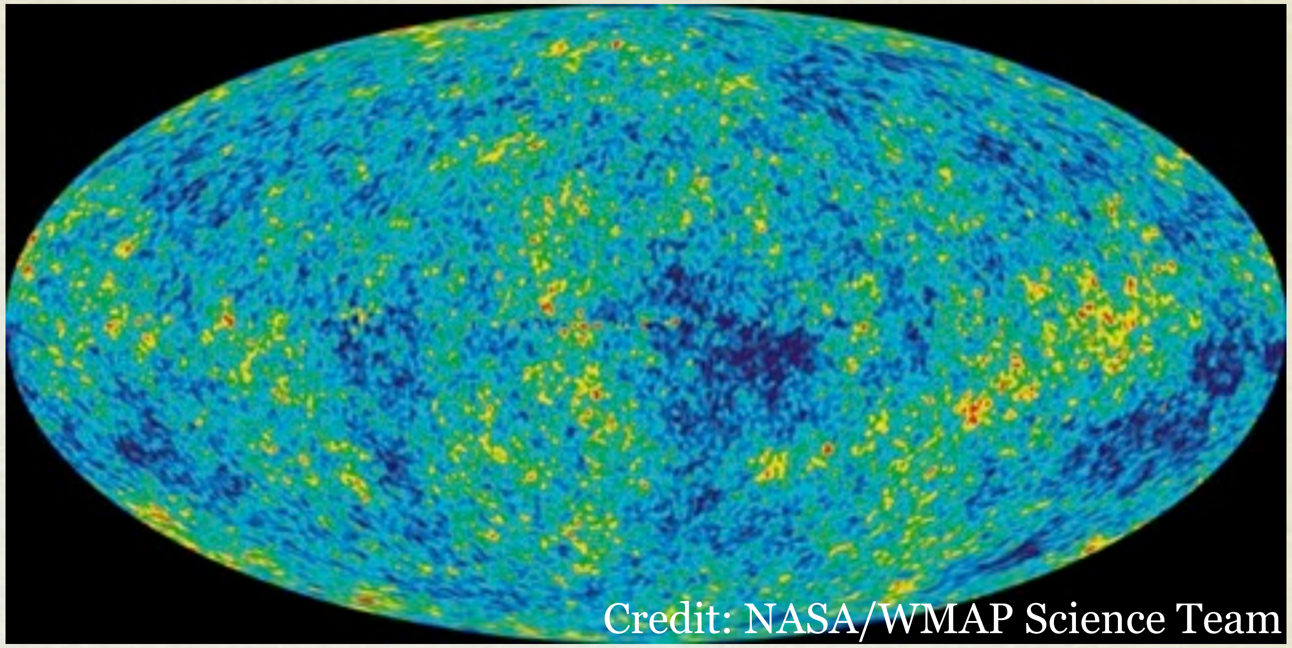
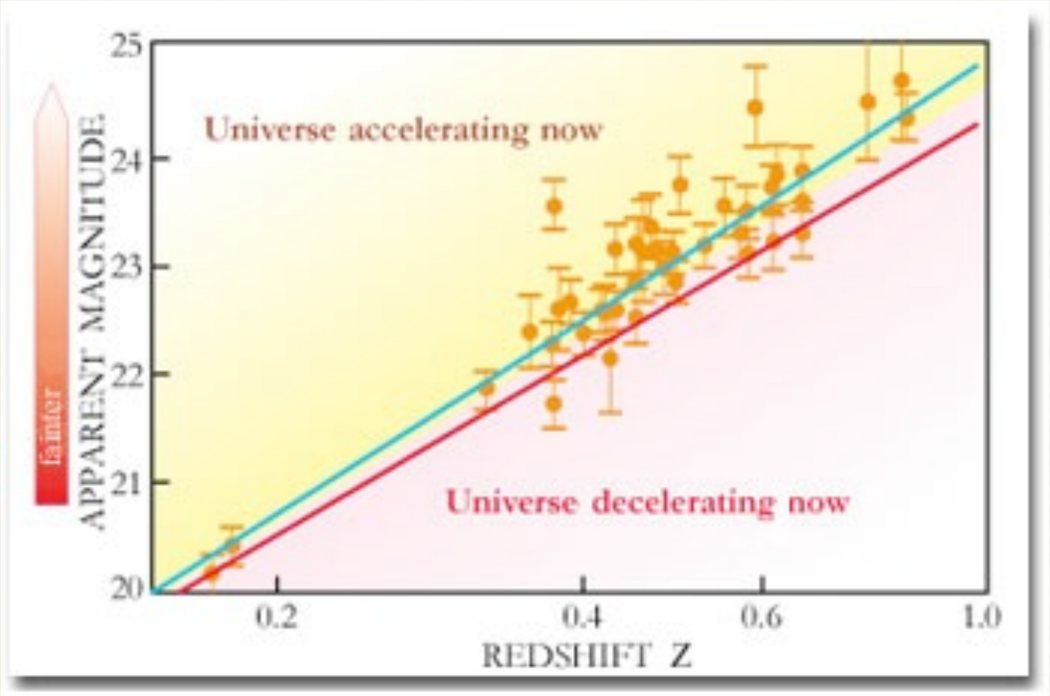
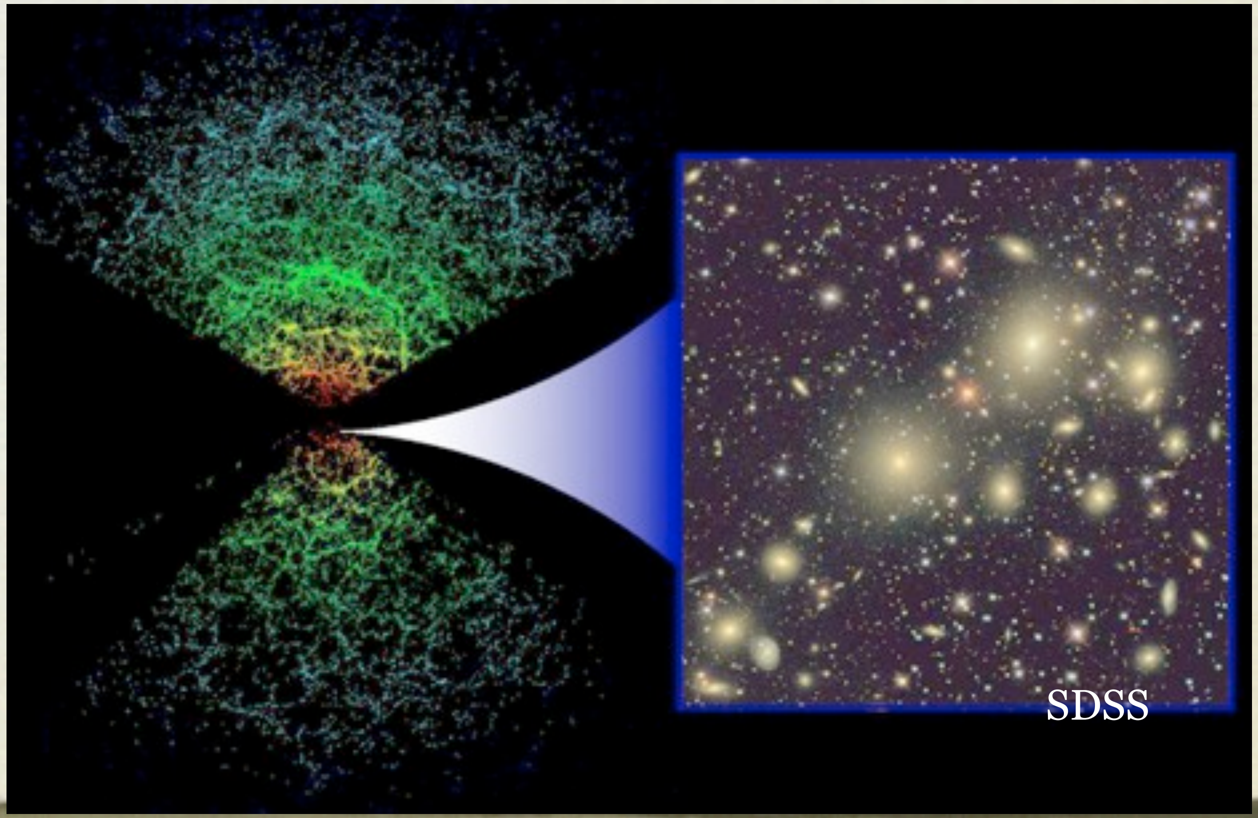
Fermilab Theory Seminar 3/5/09

EVIDENCE FOR DARK MATTER

Cosmic Microwave Background, Galaxy, and Supernovae Surveys







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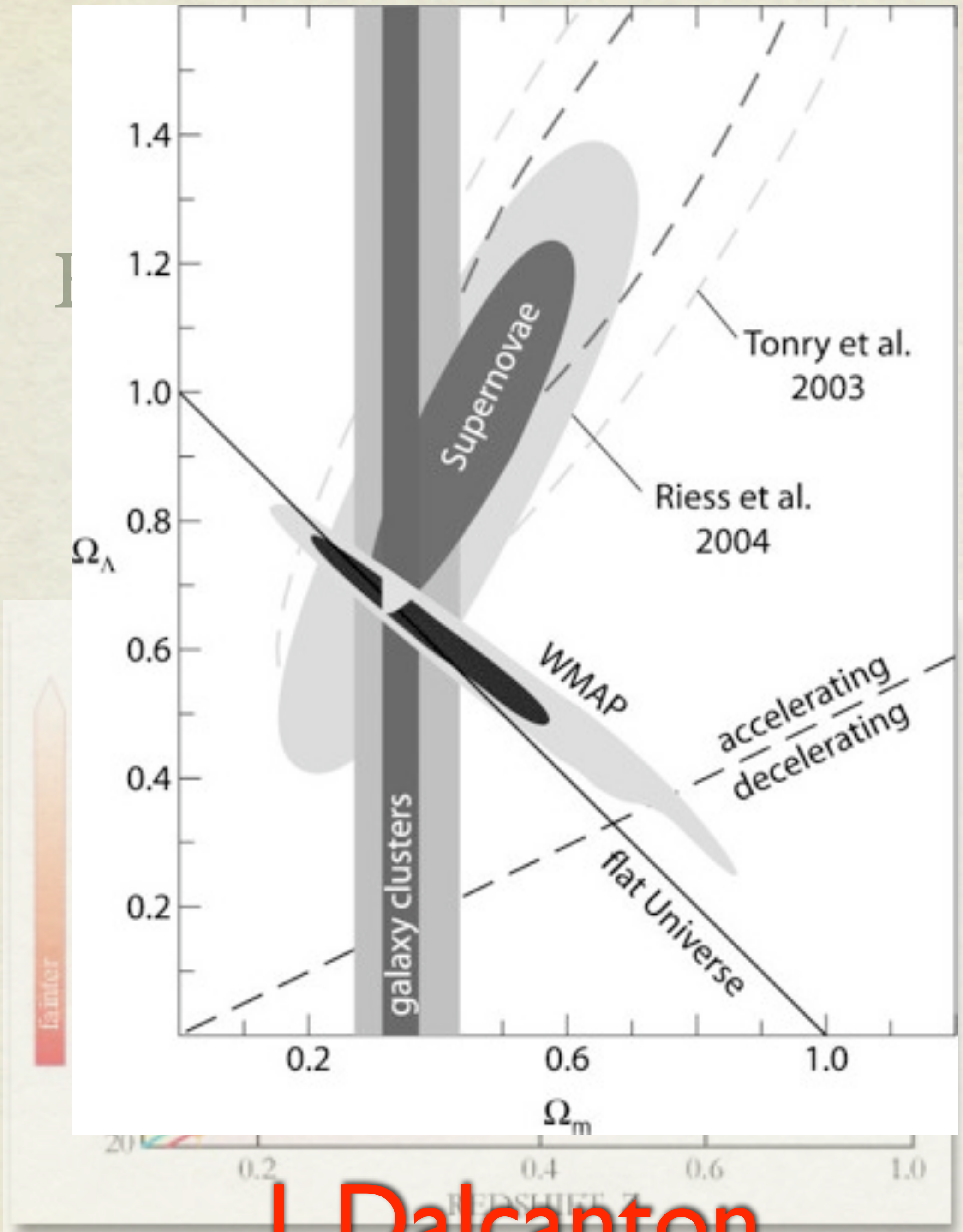
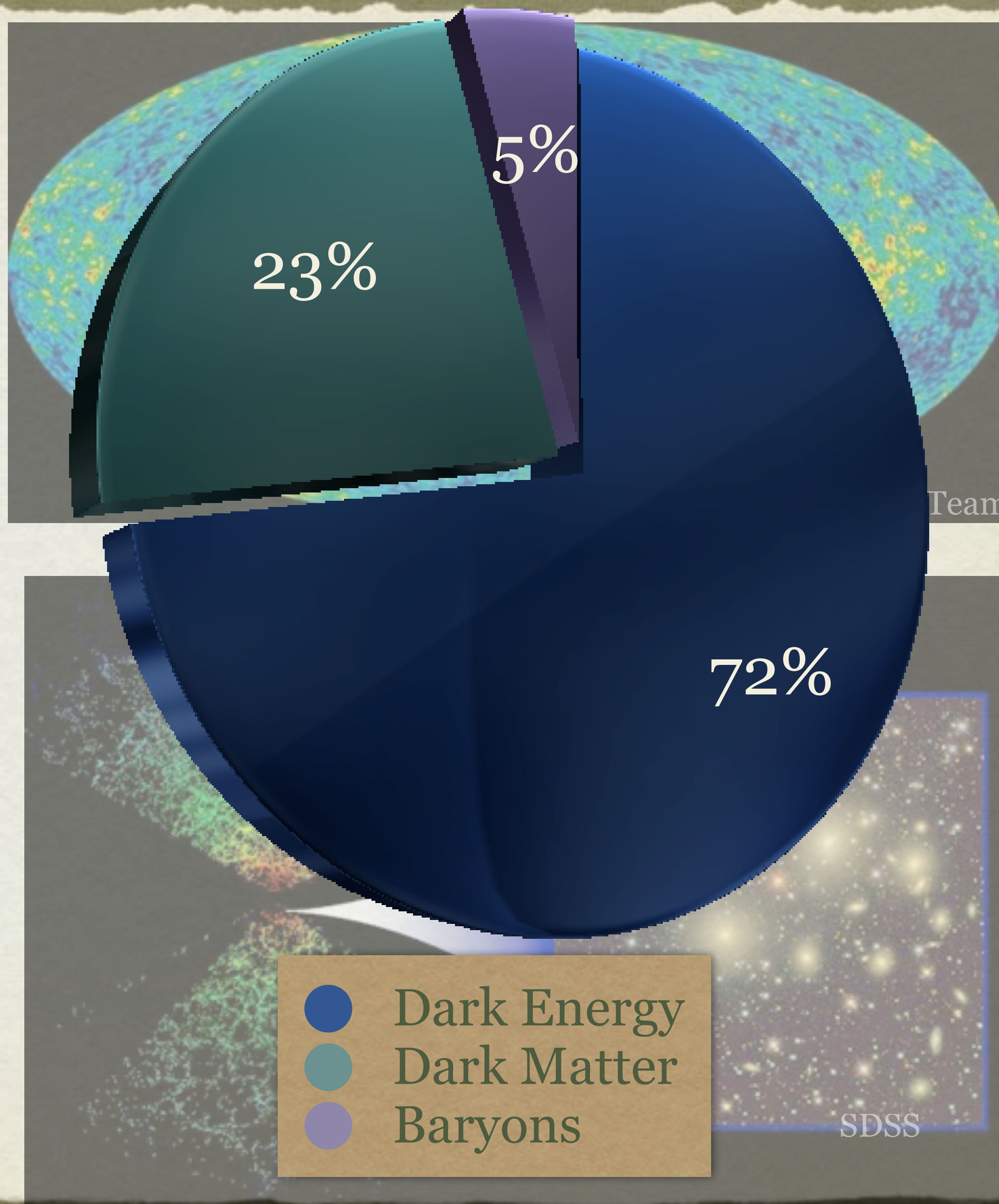
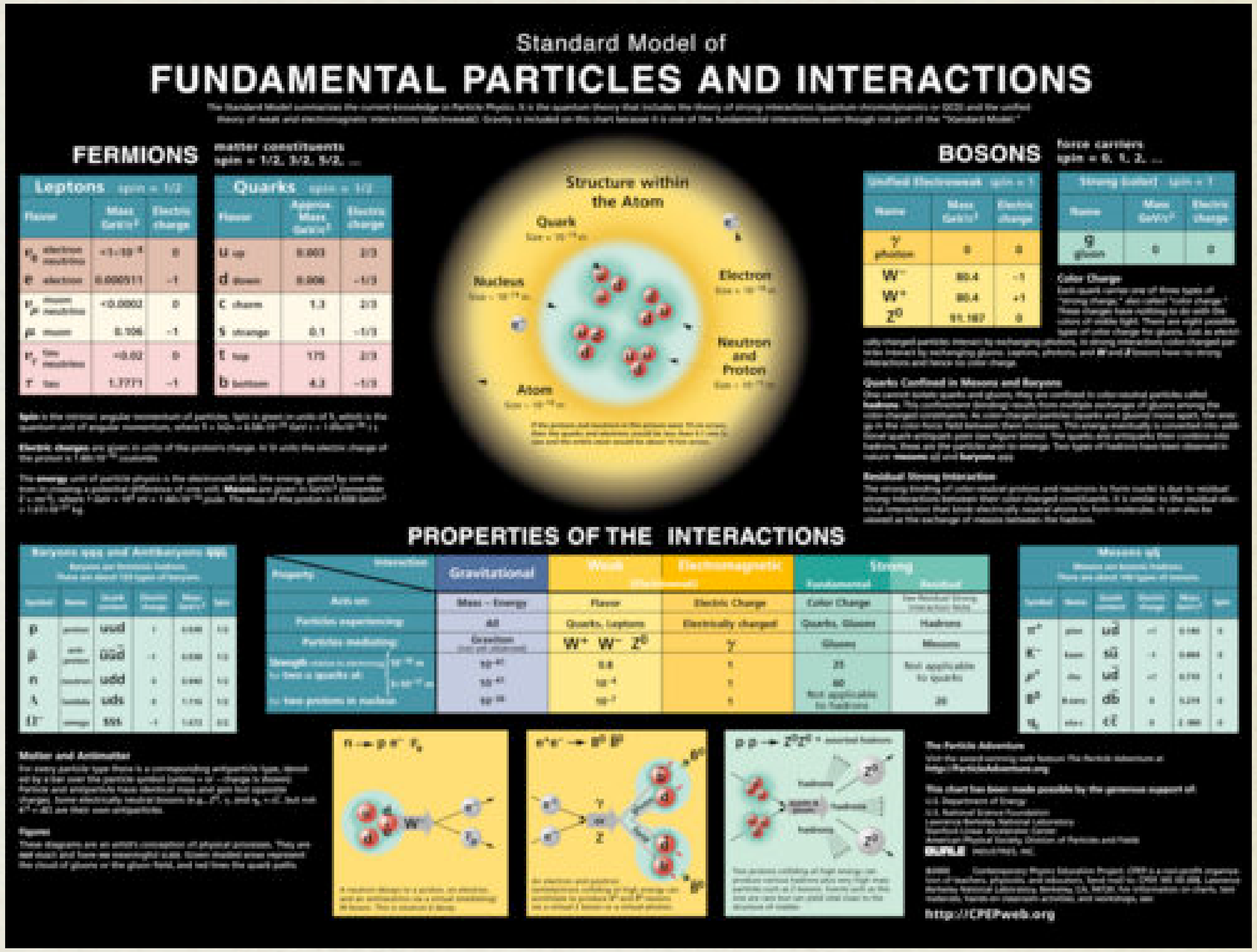


J. Dalcanton



BUT WHAT IS IT?

- Missing the Particle Physics story
- Want to observe it directly in the lab
- Can produce it directly at colliders (LHC)
- Look for interactions with dark matter in our halo



ENDGOAL (WIMP)

- Observe it at colliders, direct, indirect experiments
- Measure its mass, couplings (and potentially for its interacting partners)
- Compute relic density and compare to WMAP
- Celebrate!

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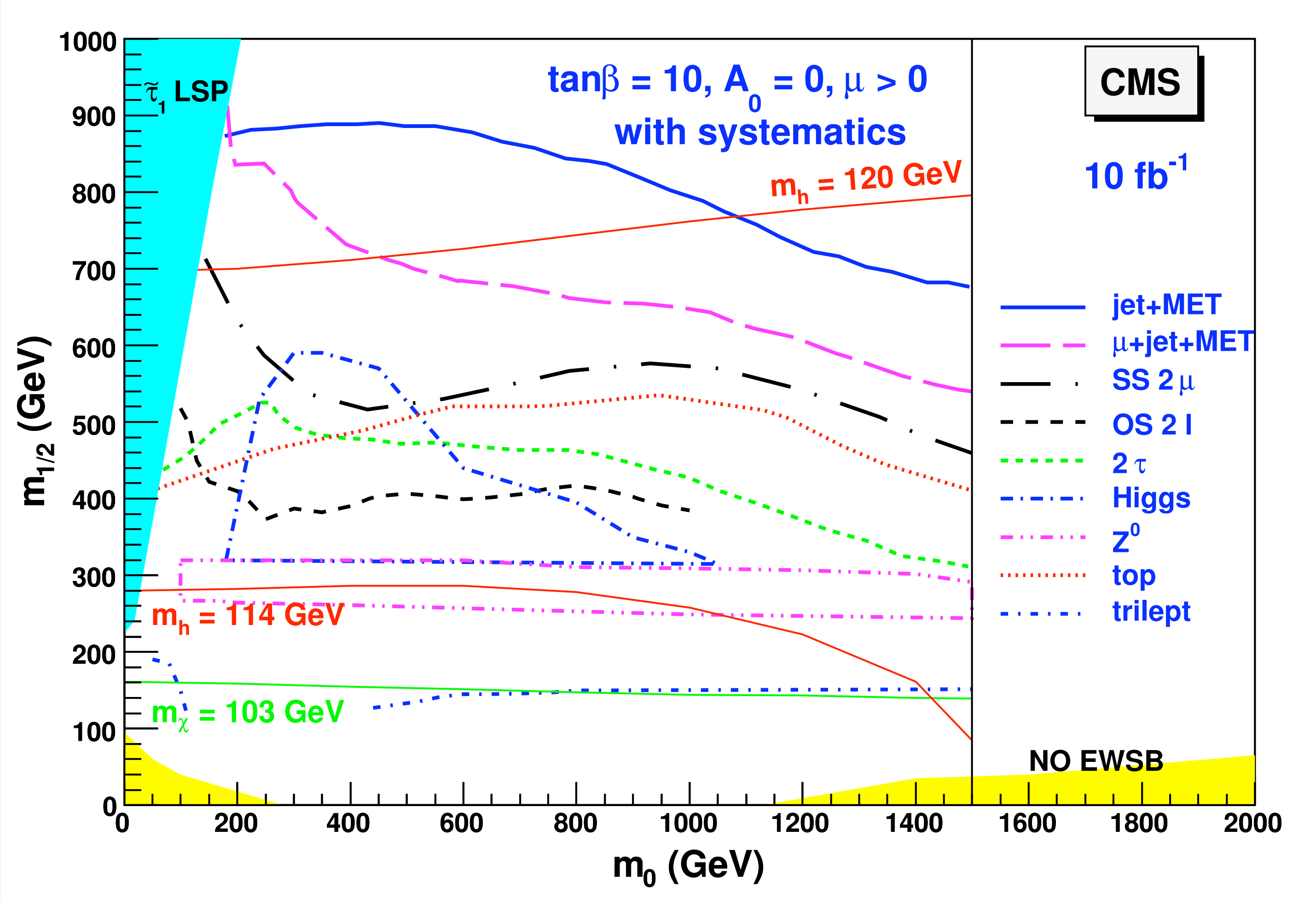

Discover SUSY at the LHC

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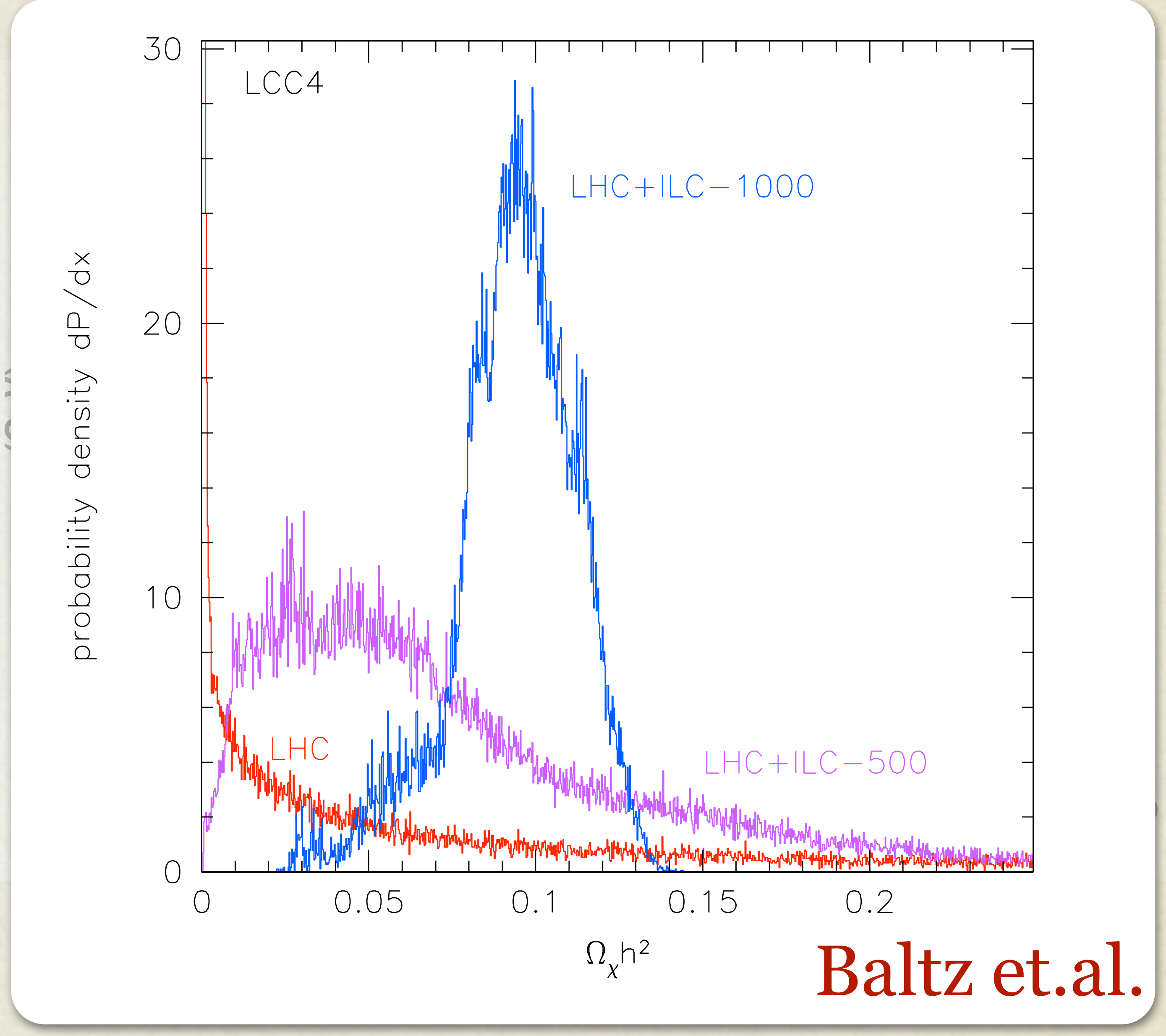
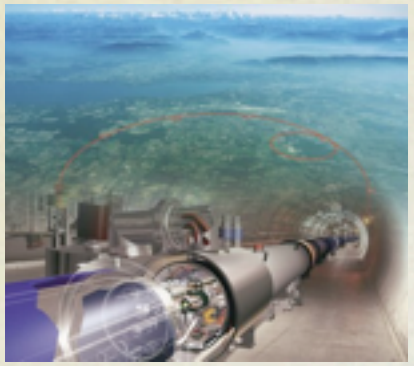
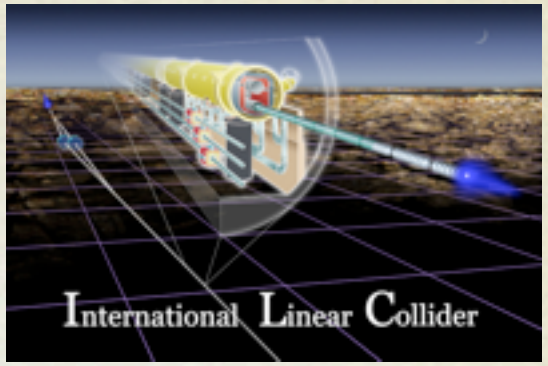


Baltz et.al.



Timeline



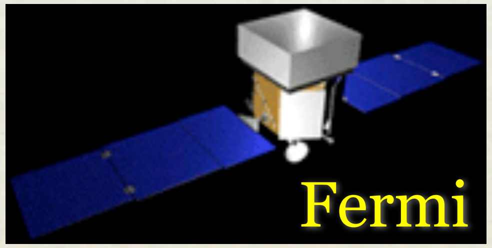
LHC	LHC	LHC	SLHC	
10 TeV	14 TeV	14 TeV	14 TeV	ILC
10^{31}	10^{32-33}	10^{34}	10^{35}	

~ 3-5 yrs

Indirect
& Direct
Current Gen

~ 1-3 yrs

Next Gen



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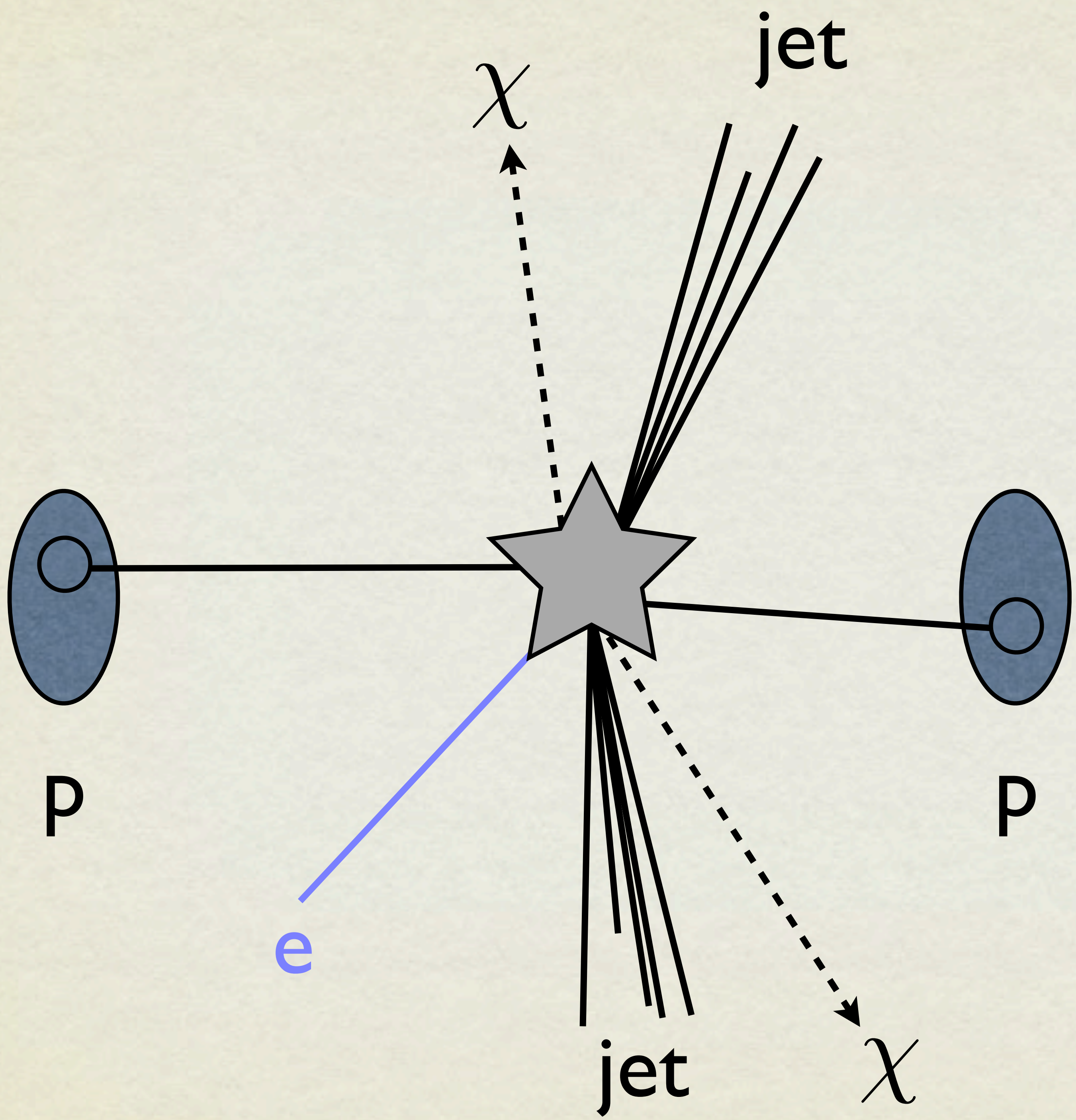
EARLY STEPS IN A LONG JOURNEY

- Avoid theoretical prejudice, get the complete picture
- Look for new signals of DM, don't miss a discovery
- Test signals of DM, don't make any mistakes

OUTLINE

- Dark matter searches: Need for nonstandard searches
- Colliders: Fake dark matter
- Direct detection: Inelastic & other nonstandard dark matter interactions
- Conclusions

DM COLLIDER SIGNAL



Dark matter escapes detector

Imbalance in transverse energy-momentum

Jets+leptons+MET

STEPPING BACK

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- Does this signal (MET events) truly indicate a new stable particle?

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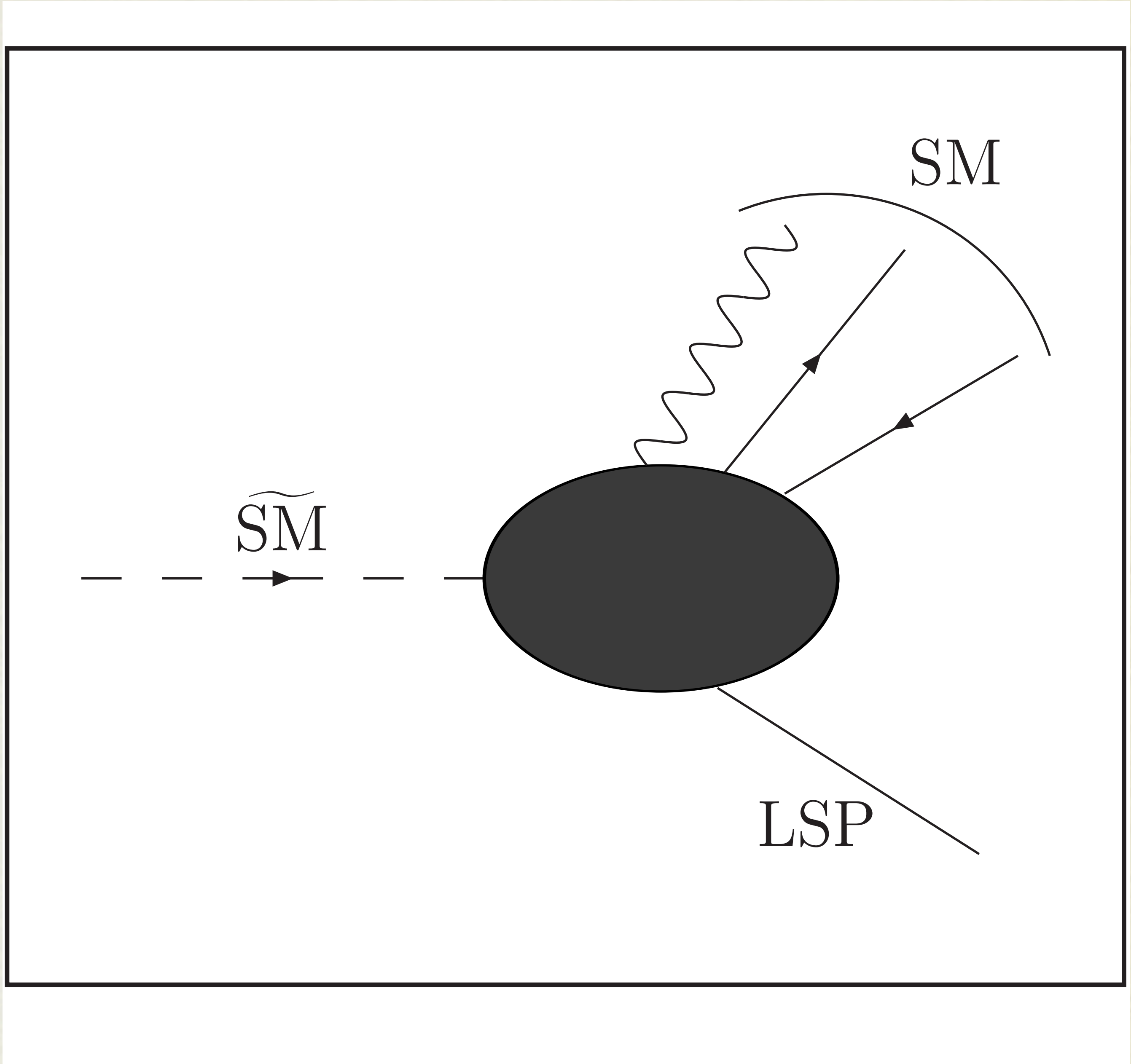
- Are there alternative explanations with no WIMP-like particle?
- If so, how can we tell these scenarios apart?

Fake Dark Matter

SC, de Gouvea

- Neutrinos are a known source of missing energy, new physics w/ neutrinos can fake the DM signal
- Look for “SUSY” lookalikes, cascades that produce neutrinos
- Assume no visible decays or displaced vertices



Fake Dark Matter phenomenology

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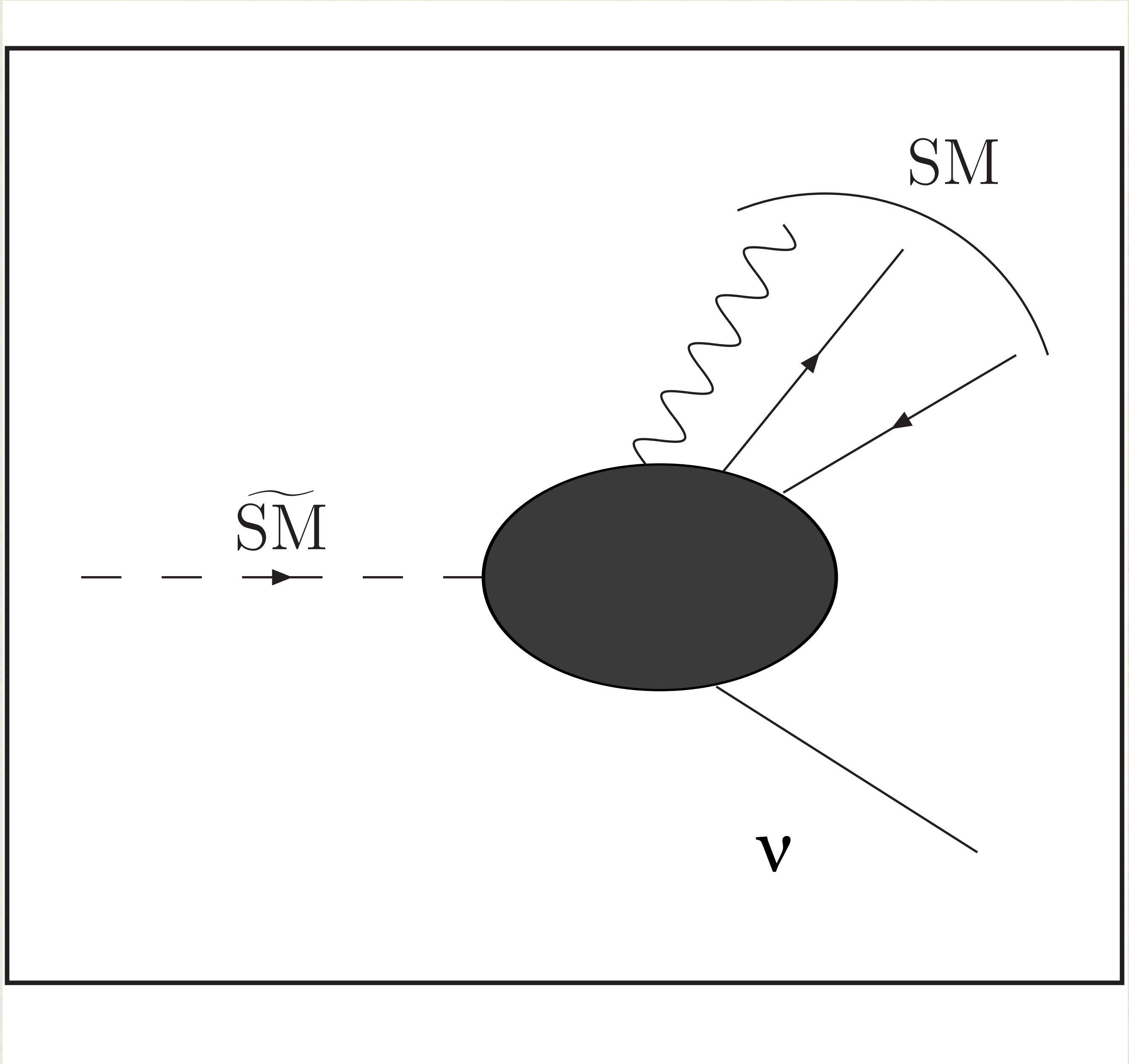


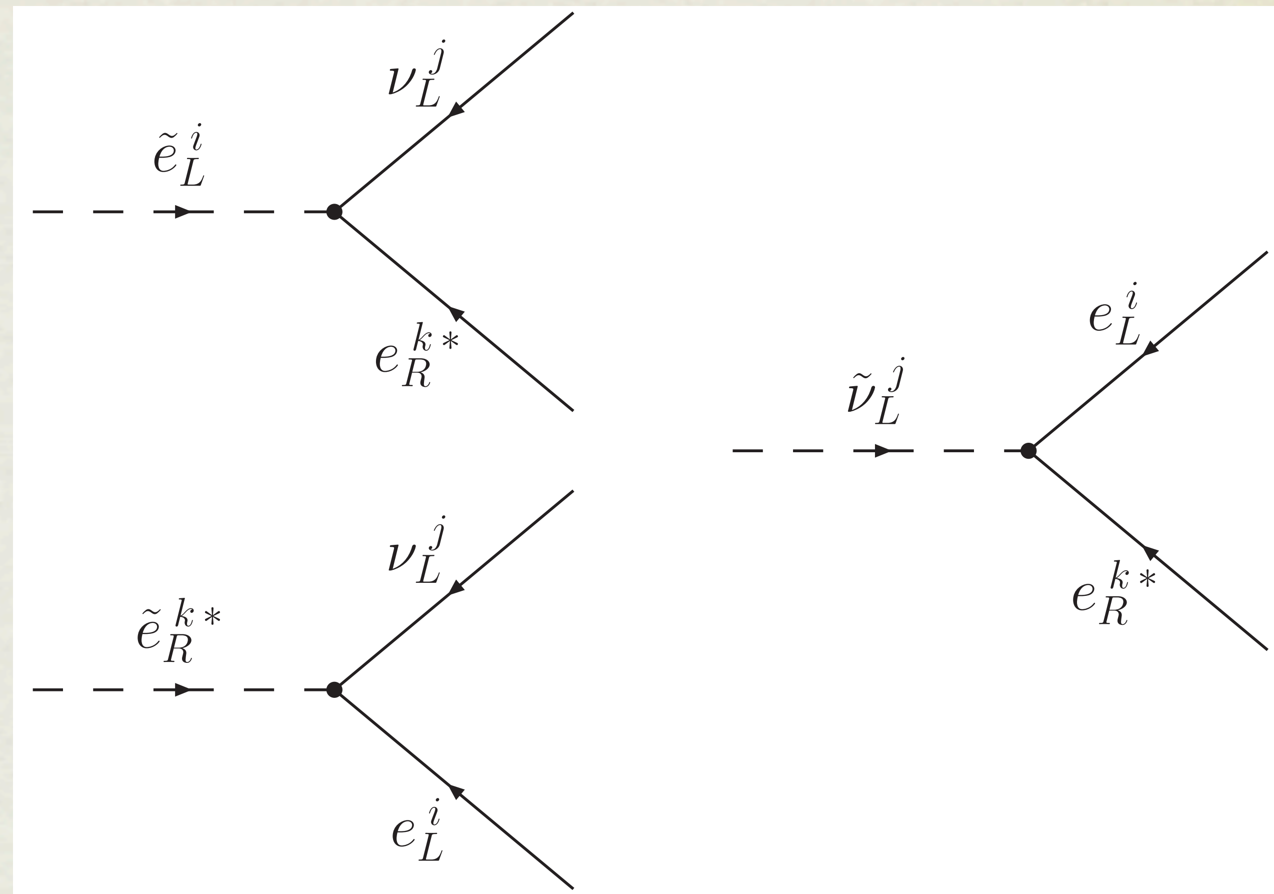
Fake Dark Matter phenomenology

RPV IN THE MSSM

- Examples of fake dark matter exist within the best known BSM theory
- R-parity violation with neutrinos must involve L superfield
- LLE and LQD couplings (considered one at a time) lead to different phenomenologies

LLE

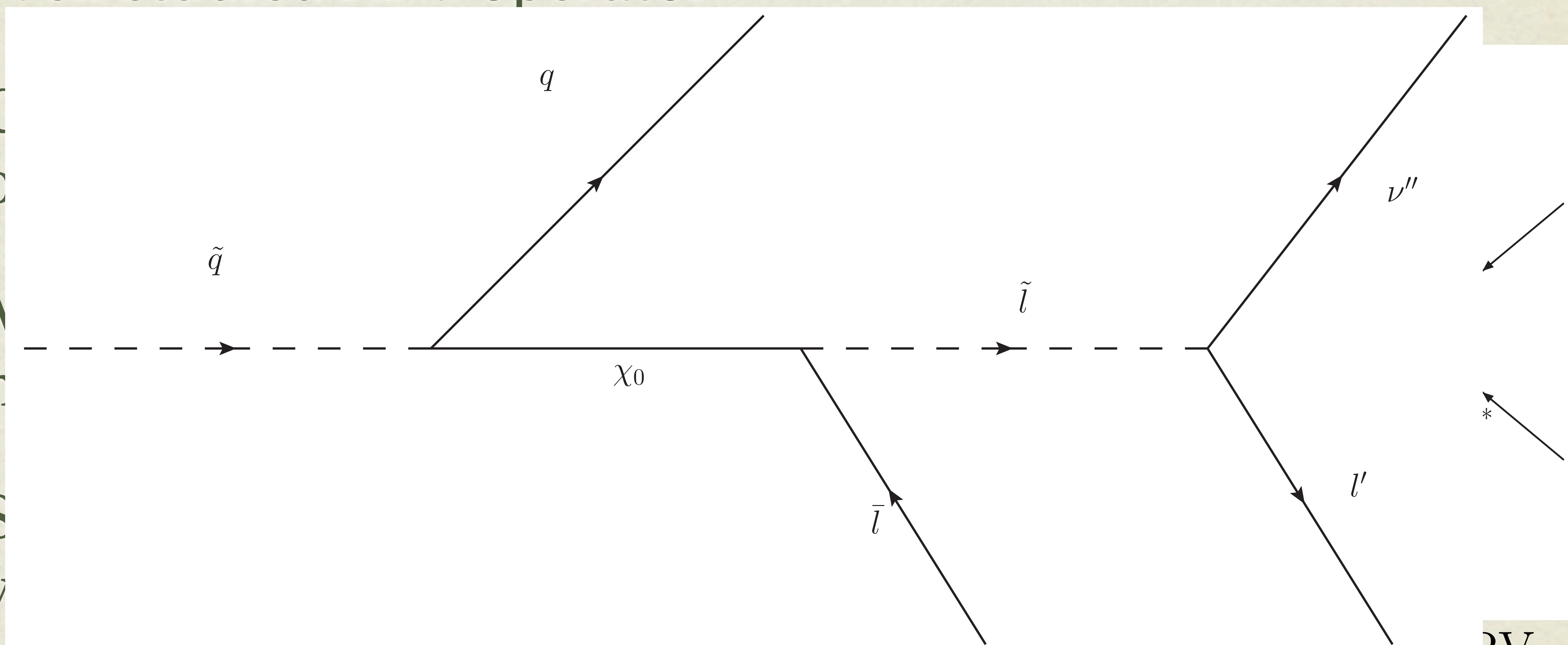
- Well studied RPV operator
- Collider pheno emphasis is on leptons
- MET still appears from neutrinos
- Sneutrinos could lead to visible events, except usually produced with neutrinos



Invisible RPV Visible RPV

LLE

- Well studied RPV operator



- C
  o
- M
  n
- S
  v
  usually produced with
  neutrinos

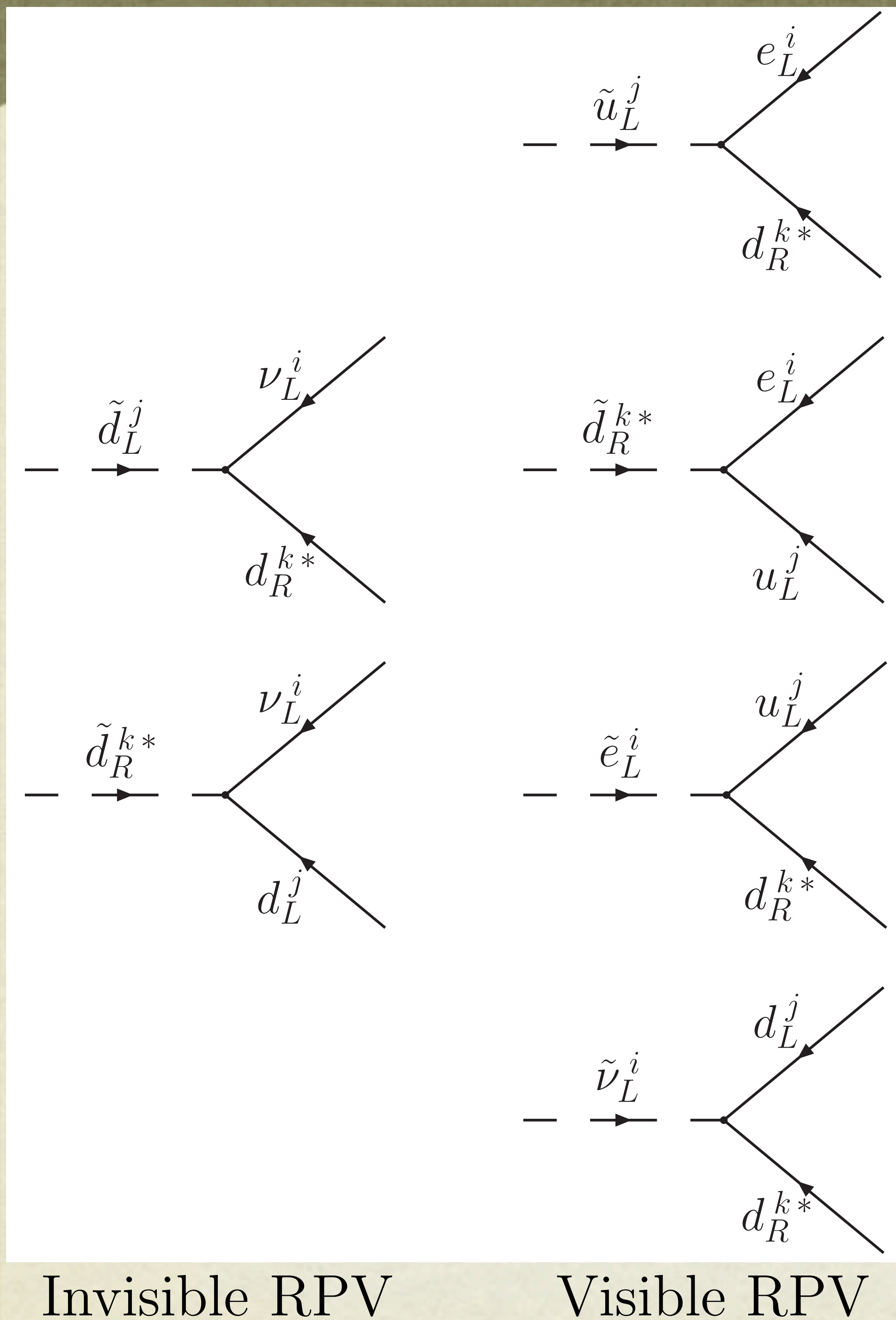
Invisible RPV

Visible RPV

LLE CONSEQUENCES

- Many charged leptons appear in each event
- LLE operator violates lepton flavor, so lepton flavor counts will show asymmetry
- Can look for sneutrino mass peaks in lepton pairs, potentially of different flavors

LQD



- Less well known
- Fake dark matter realization is more nontrivial
- Many visible decays, preventing RPV coupling from being O(1) and restricting LSP to not have visible decay

LQD CONSEQUENCES

Only down-type squarks have neutrino decays

1) $\tilde{d}_L \longrightarrow d_R \nu$

For tan β > 1, d_L squark is heavier than u_L partner from D-term splitting

Exception is 3rd-gen squarks, since top quark is heavier than bottom

Flavor alignment means d_R is b-quark

2) $\tilde{d}_R \longrightarrow u_L e$ or $d_L \nu$

First decay is closed if u_L is top, so again d_L is a b-quark

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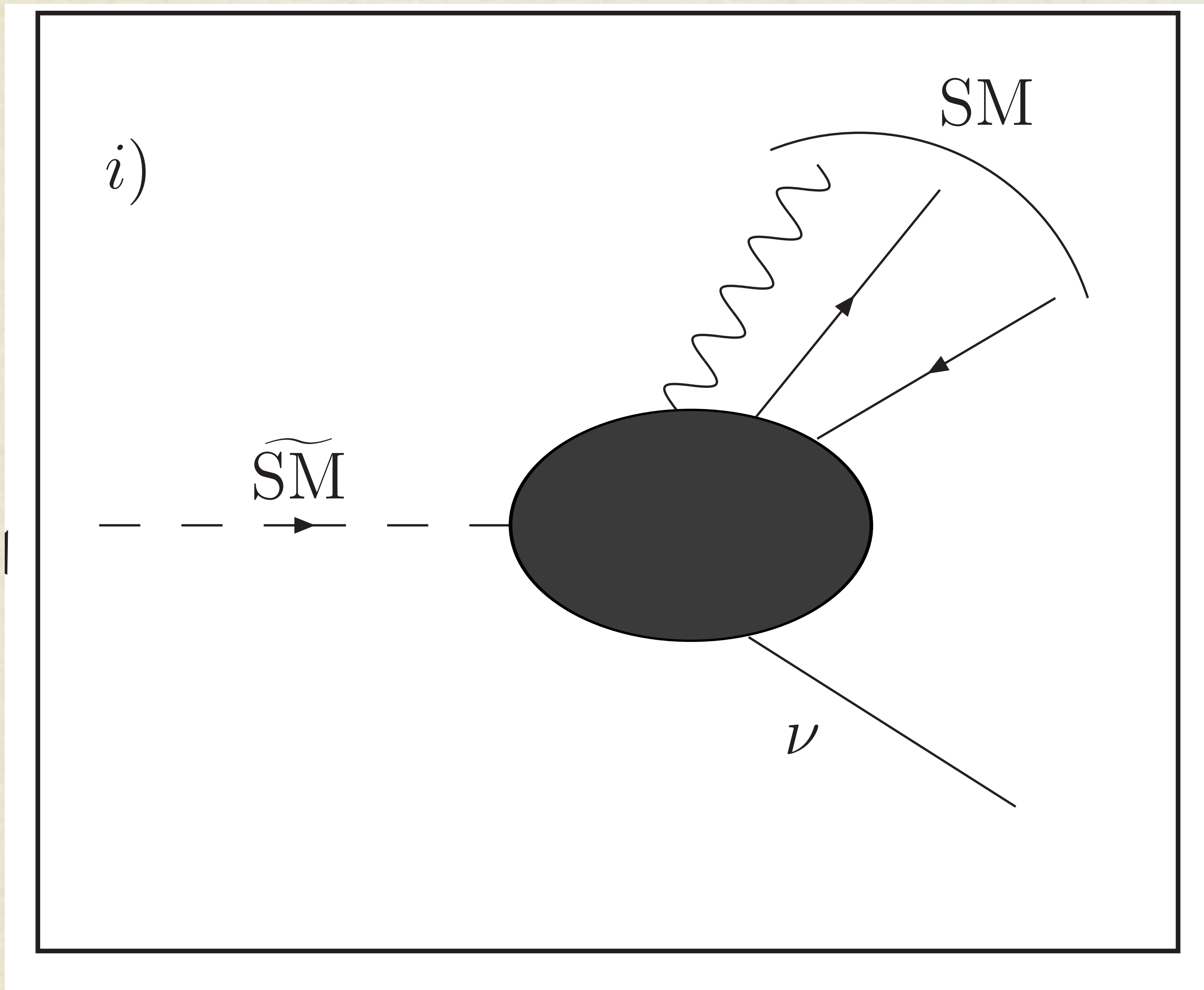
LQD is bottom heavy and LSP has mass $O(m_{top})$

MASS MEASUREMENTS



Model independent test: measure missing mass

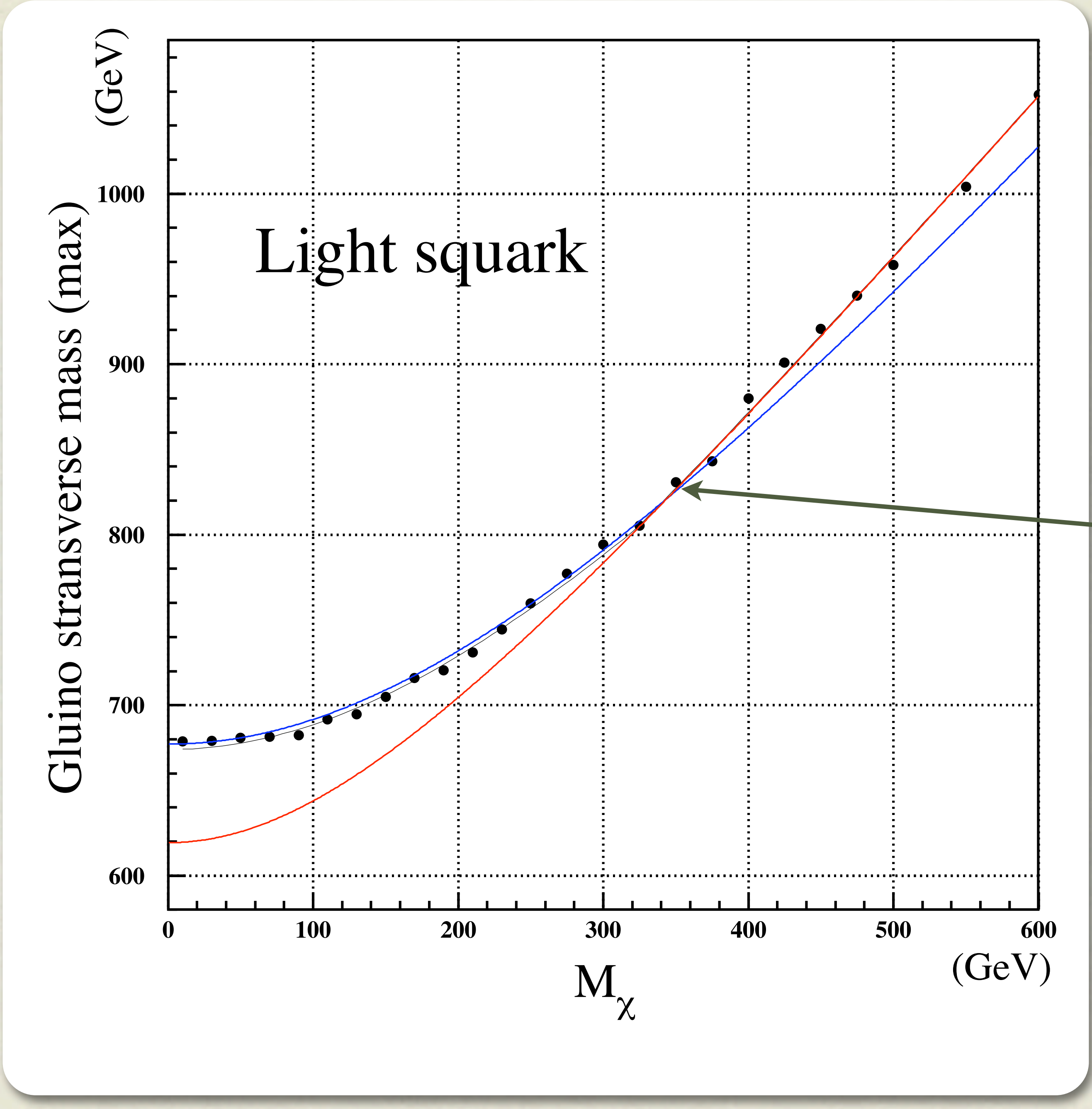
A lot of work recently in terms of mass measurements

Depending on cascade topology,

1) Long cascade: can solve 4-momenta and mass,

2) Short cascade: can look at max $m_{T}2$ and find kink at true mass m_{ν}

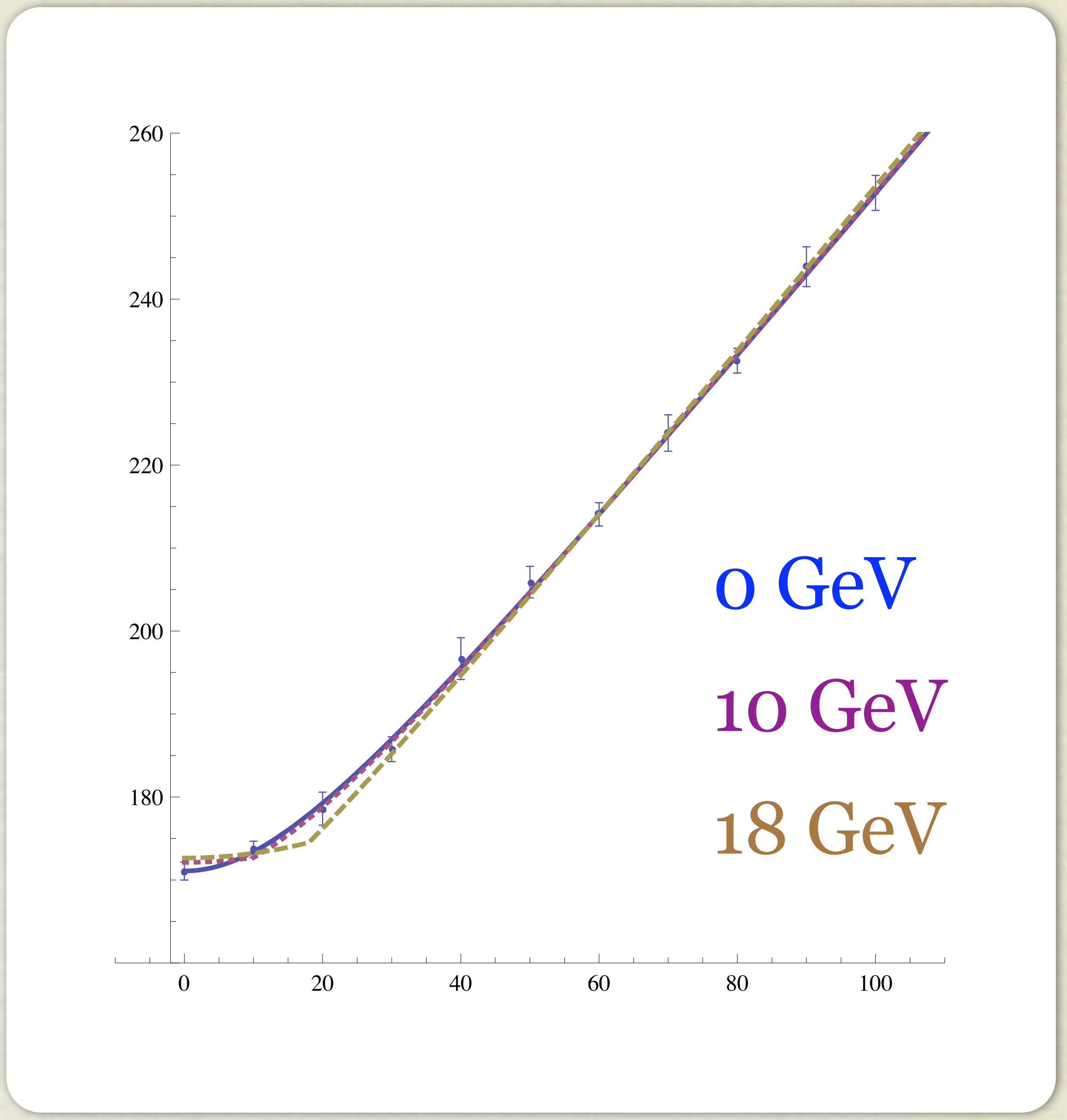
E.G. GLUINO DECAYS (CHO 0709.0288)



Kink is close to true mass of 350 GeV

TOP ALL LEPTONIC "DATA" TAKEN FROM CHO 0804.2185

- For massless particles, there is no kink
- Difficult to measure no kink, χ^2 fit gives $m_{inv} < 18$ GeV (95% CL)
- Mass resolution can be expected to be O(10) GeV



max M_T2 (m_ν) for $t \to b\, l\, \nu$

FAKE DARK MATTER SUMMARY

- Missing energy events are not always tied to new stable particles
- Should know what possibilities exist
- RPV leads to events with leptons and b-jets, can tag MSSM fake dark matter
- Further predictions, flavor violation, mass of NLSP, and massless final state, can provide further evidence
- Mass resolution is estimated to be O(10) GeV

OUTLINE

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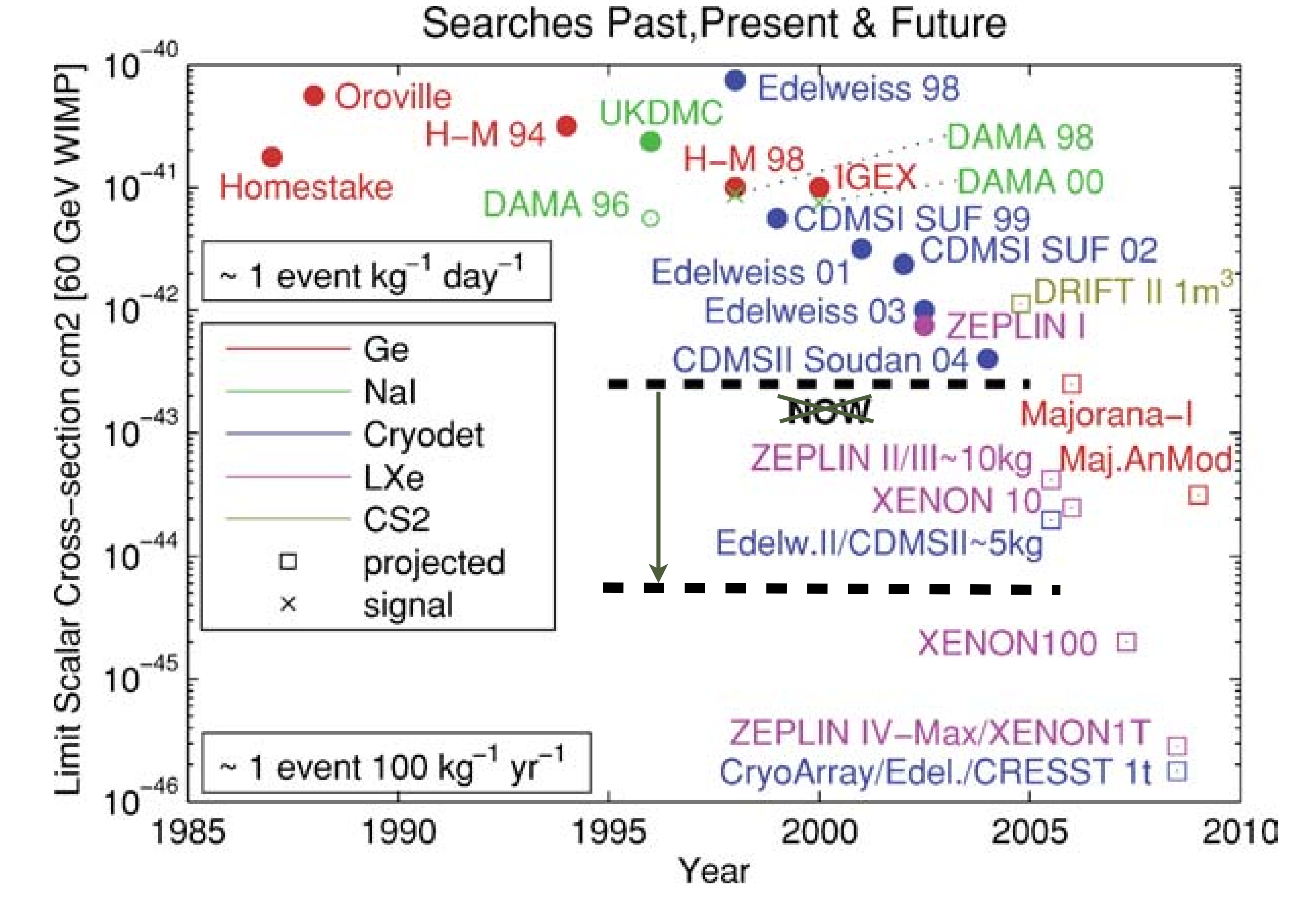
DIRECT DETECTION EXPERIMENTS

Experimental strategies are evolving, sensitivities are close to expected range



Gaitskell

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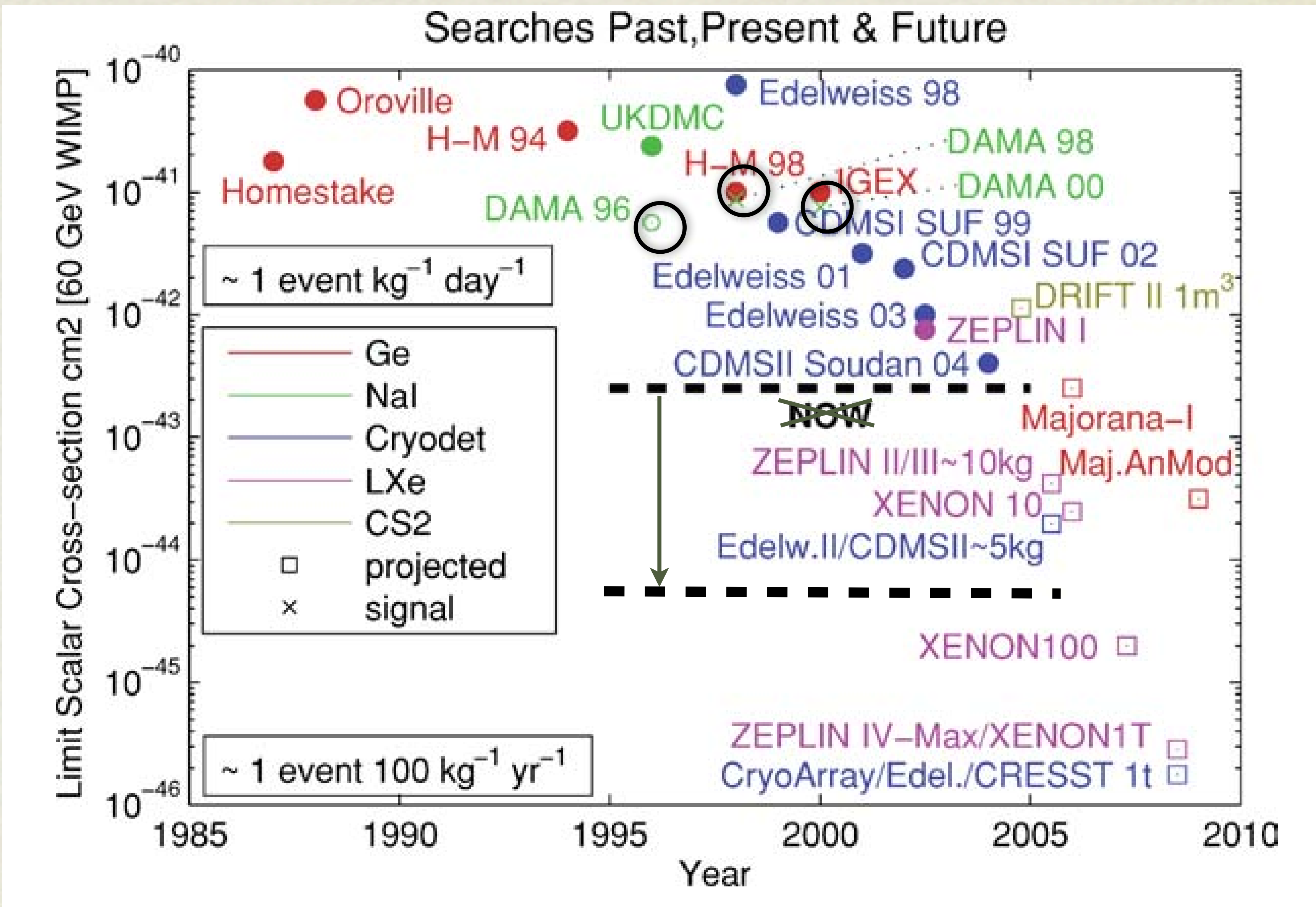
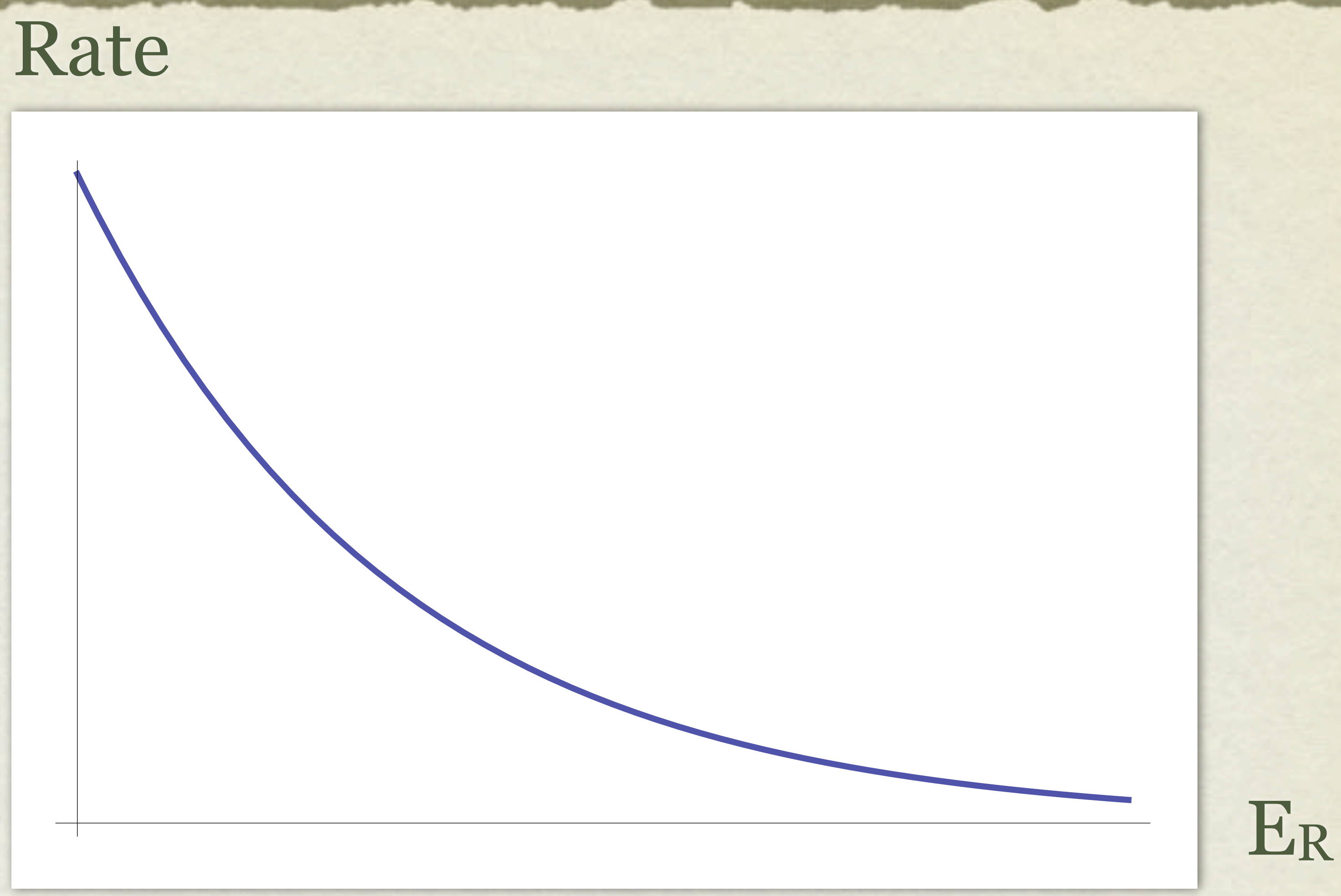


Gaitskell

DM SCATTERING

For nuclei, $E_R \sim 10$ keV

Also, for given E_R, DM with $v > v_{min} = \sqrt{2m E_R/\mu^2}$ give contribution



Example plot of scattering rate

Exponential falloff, due to exponential tail of velocity distribution

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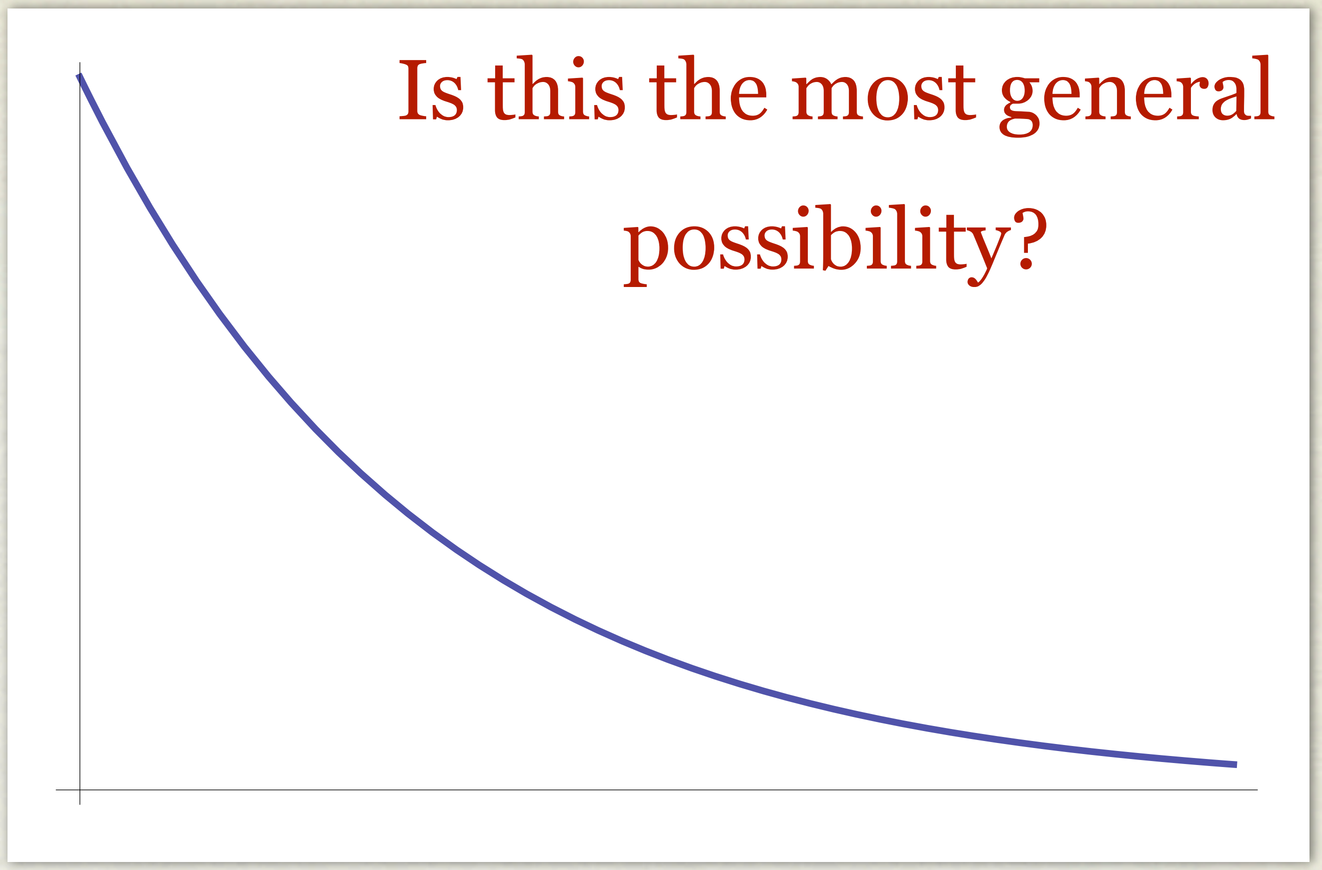
Rate



E_R

Example plot of scattering rate

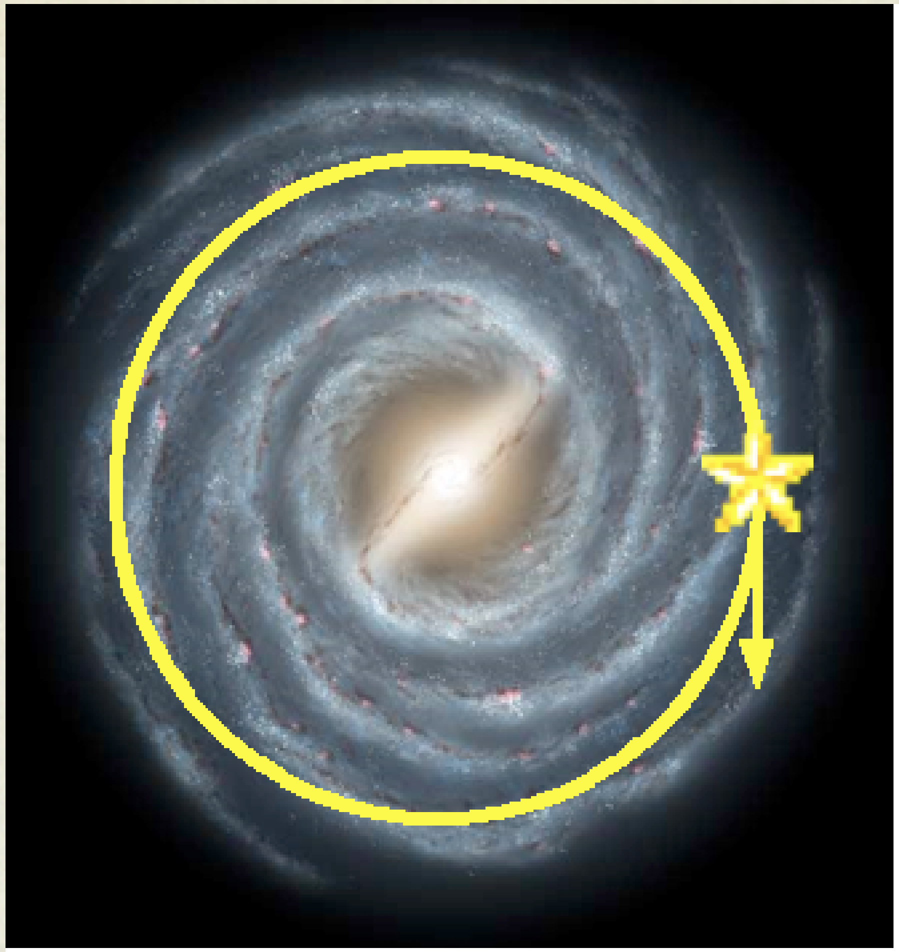
Exponential falloff, due to exponential tail of velocity distribution

DAMA

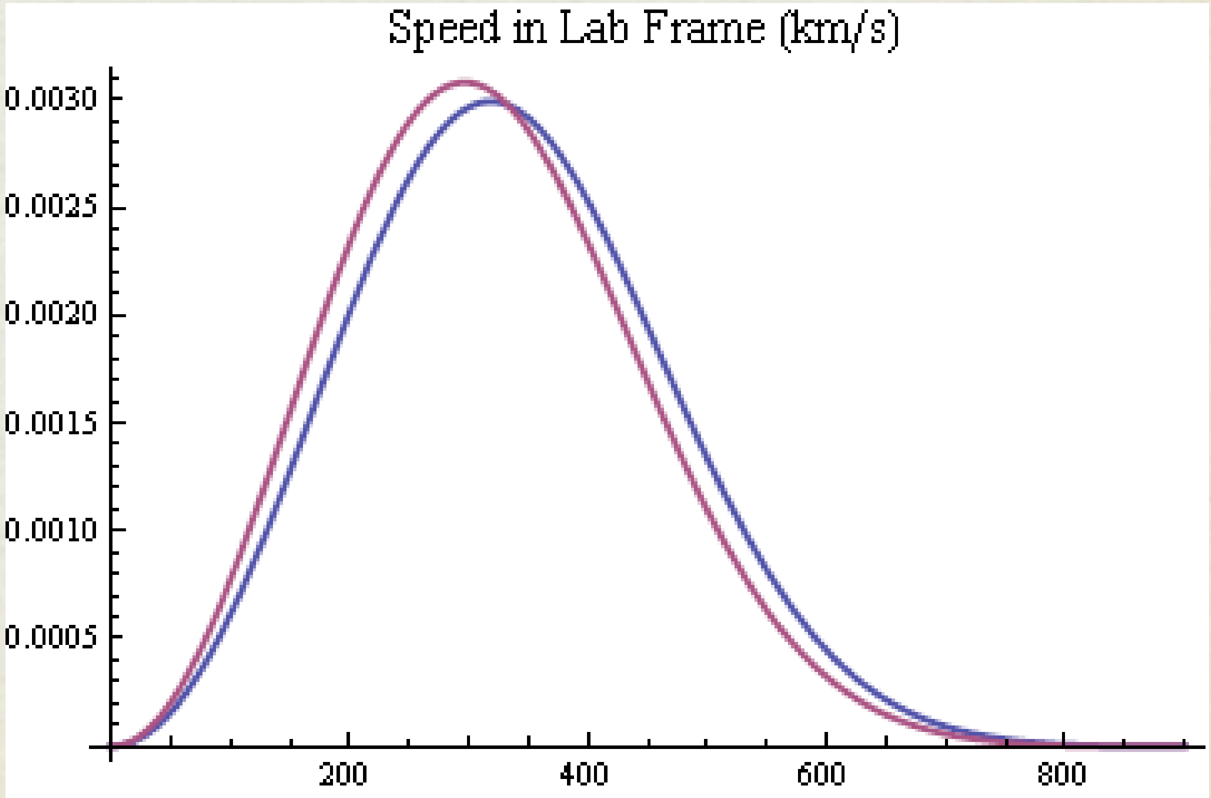
- Strategy is different from other experiments
- Does not try to distinguish nuclear from electron recoils
- Instead it tries to detect a yearly variation in the rate (modulation)
- Claims a consistent effect which persists in new data

MODULATION

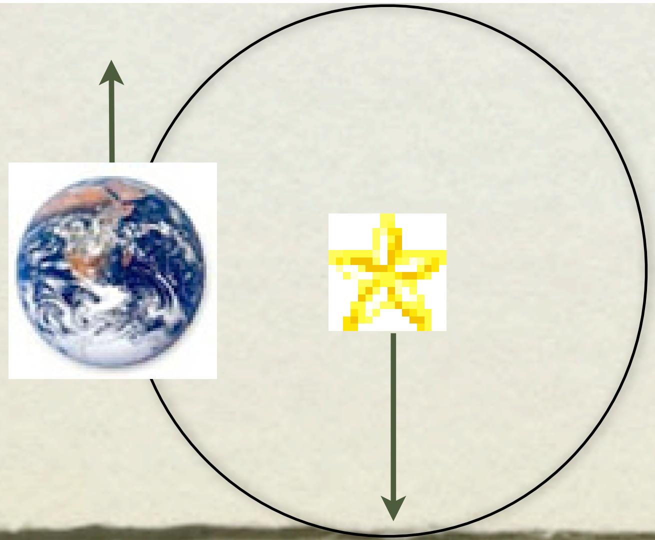
Drukier, Freese, Spergel



Dark Matter Speed Distribution changes annually due to Earth's motion around the sun



Dec
2nd
min



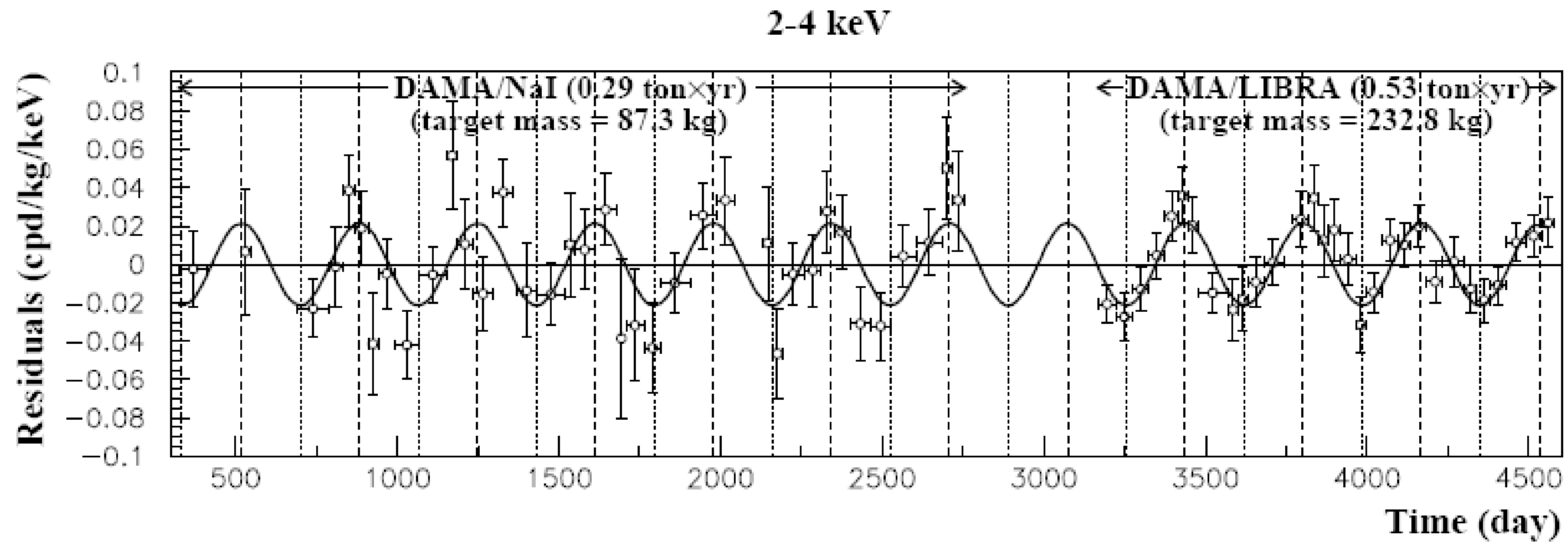
June
2nd
max

MODULATION PREDICTION

$$\frac{dR}{dE_R} = S_0 + S_m \cos\frac{2\pi(t - t_0)}{T}$$

- t_0 = June 2nd, T = 1 year
- S_m can be positive or negative, starts negative at low E_R and becomes positive at high E_R

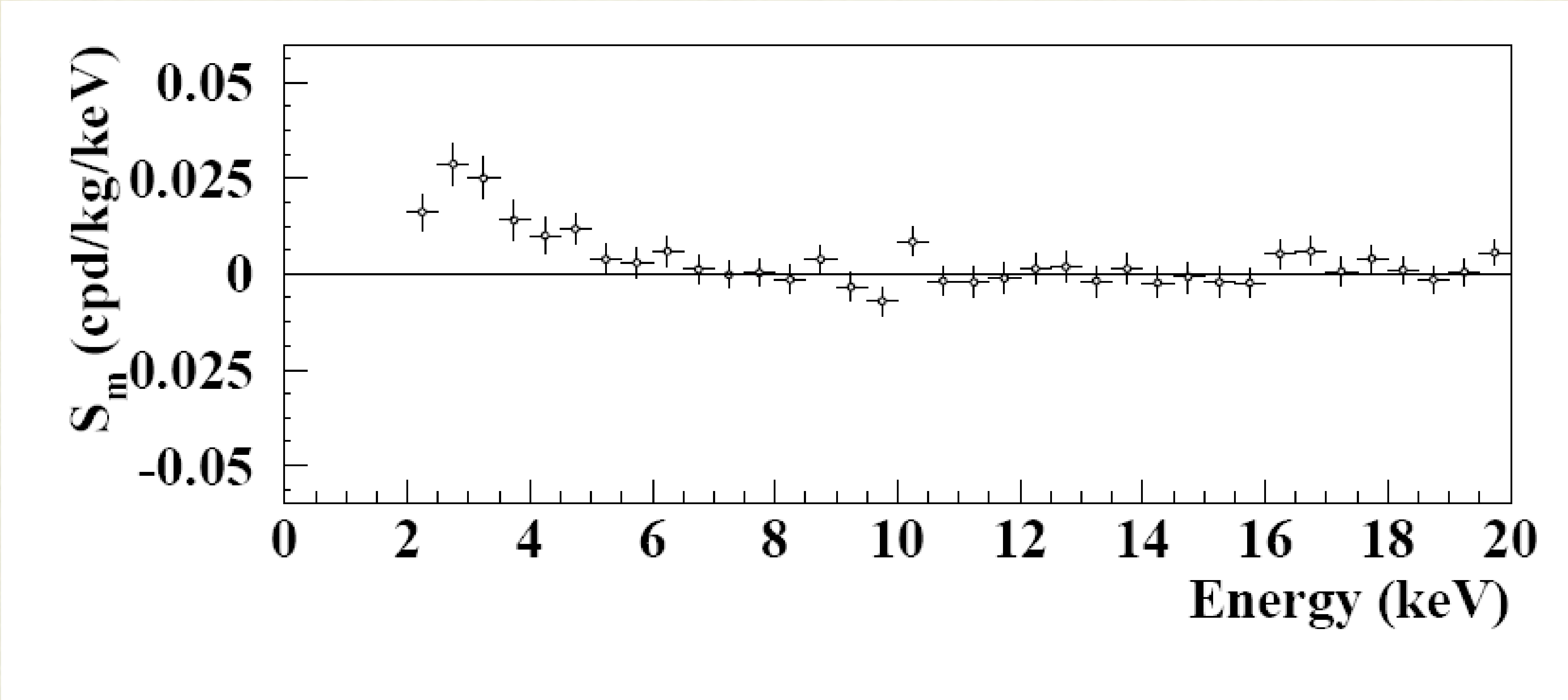
DAMA new data



	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (day)	C.L.
DAMA/NaI				
(2–4) keV	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0σ
(2–5) keV	0.0215 ± 0.0039	1.01 ± 0.02	140 ± 30	5.5σ
(2–6) keV	0.0200 ± 0.0032	1.00 ± 0.01	140 ± 22	6.3σ
DAMA/LIBRA				
(2–4) keV	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7σ
(2–5) keV	0.0165 ± 0.0024	0.998 ± 0.002	143 ± 9	6.9σ
(2–6) keV	0.0107 ± 0.0019	0.998 ± 0.003	144 ± 11	5.6σ
DAMA/NaI+ DAMA/LIBRA				
(2–4) keV	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3σ
(2–5) keV	0.0178 ± 0.0020	0.998 ± 0.002	145 ± 7	8.9σ
(2–6) keV	0.0131 ± 0.0016	0.998 ± 0.003	144 ± 8	8.2σ

Predictions 1 152

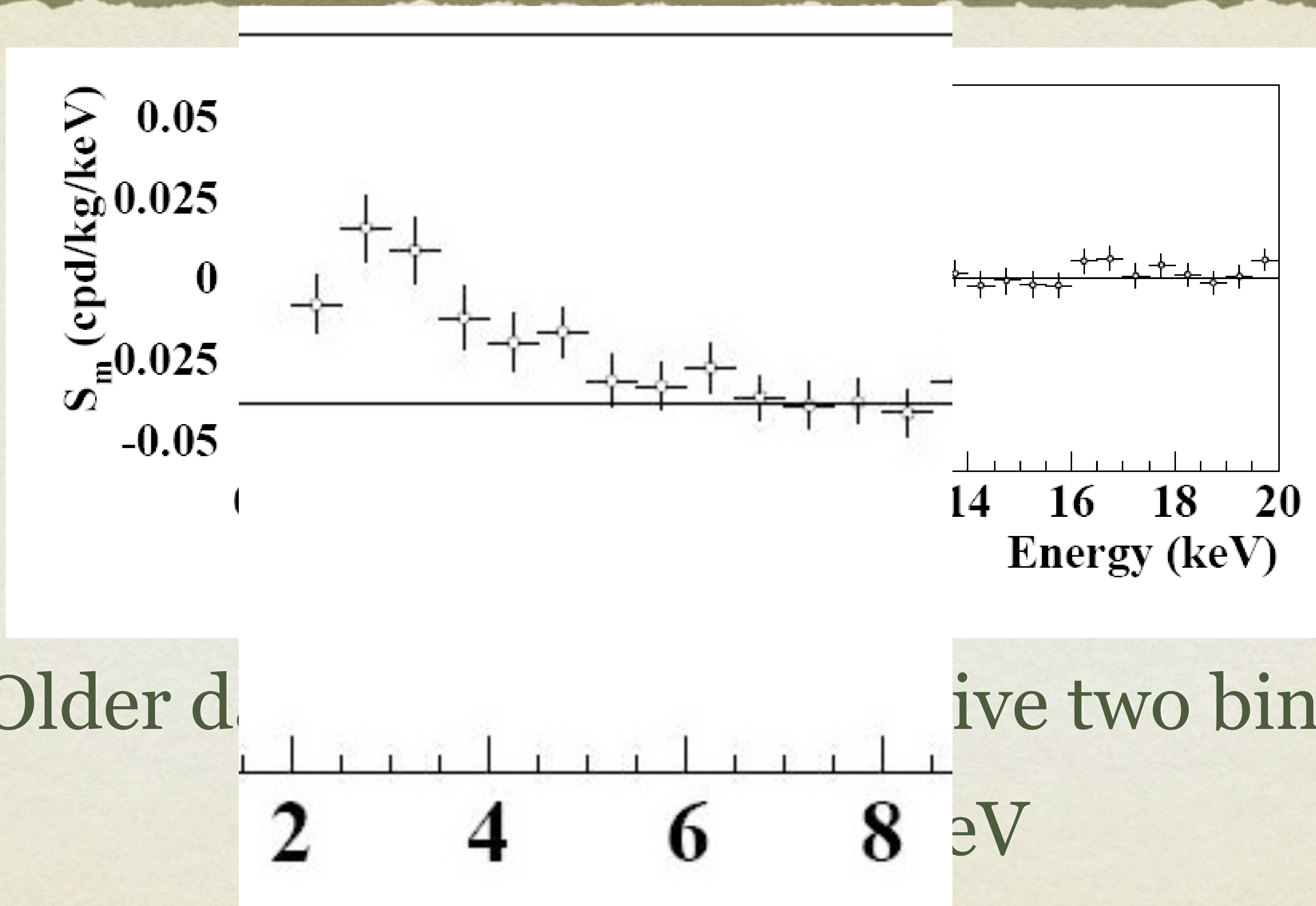
MORE INFO FROM DAMA



Older data was only able to give two bins

2-6 keV and 6-14 keV

MORE INFO FROM DAMA



Older d… ive two bins

…eV

CONSISTENT DM MODELS

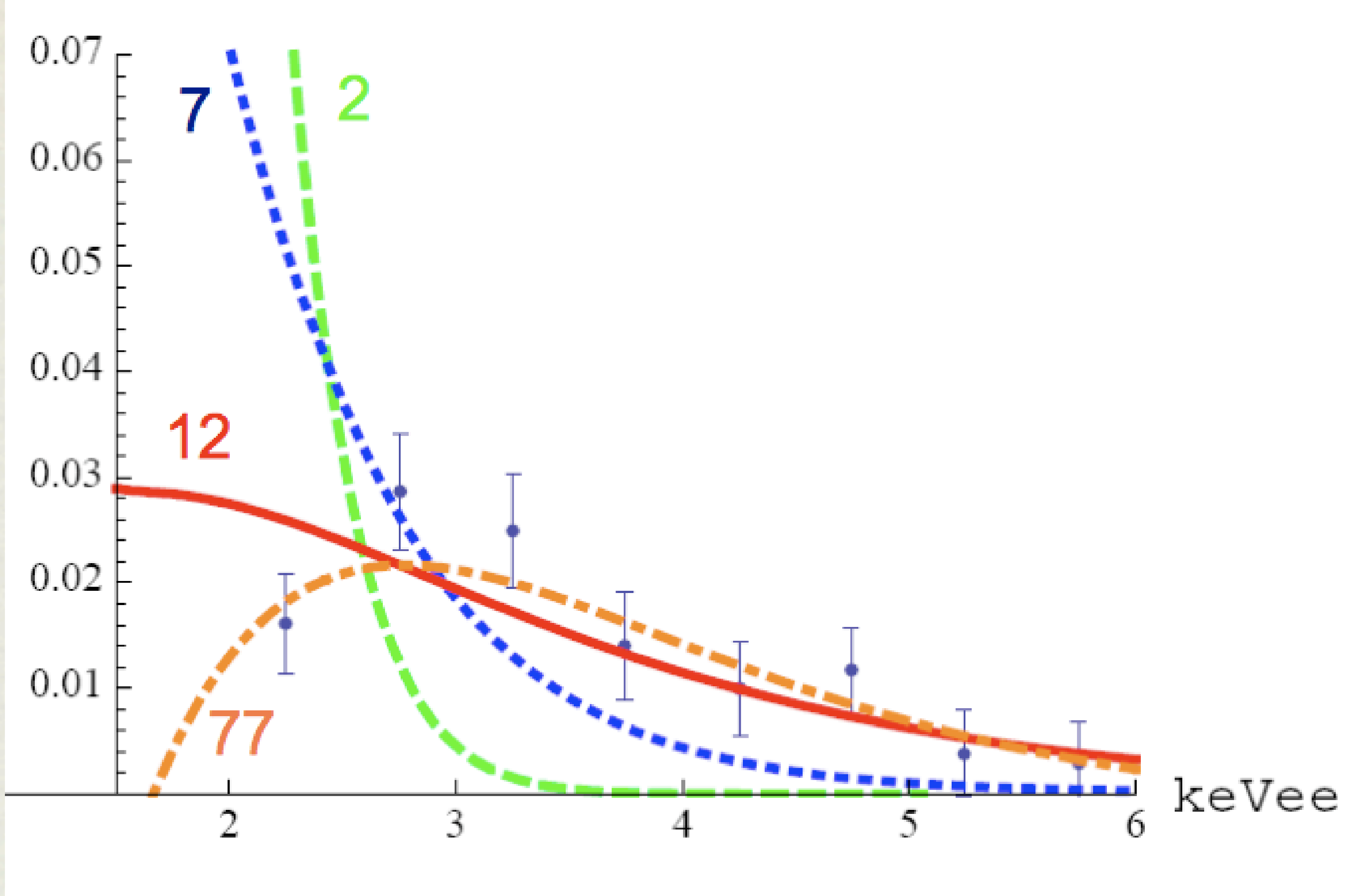
- DAMA/LIBRA signal data is specific enough to pin down parameters of dark matter
- Gives a precise target to compare with exclusion limits from other experiments
- Use its signal as inspiration for new DM properties

MODELS

- Will cover some simple examples
- SI Elastic (SC, Pierce, Weiner)
- SI Inelastic (SC, Kribs, Smith, Weiner)
- Also considering SI, SD Q^2 suppressed (SC, Pierce, Weiner still in progress)

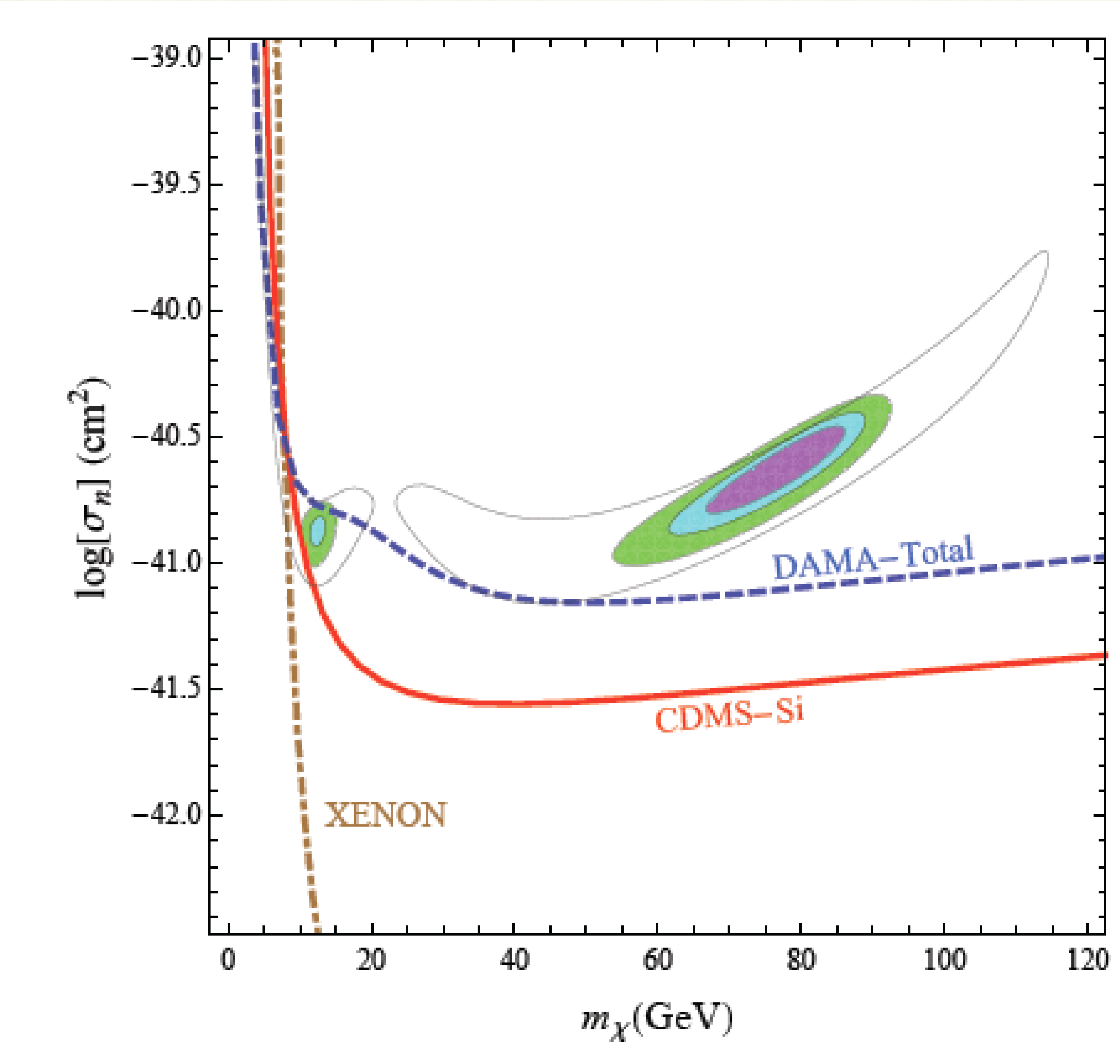
ELASTIC DARK MATTER

Only two parameters, mass and overall rate σ gives a very simple fit to DAMA data



Example fits to DAMA spectra for different masses

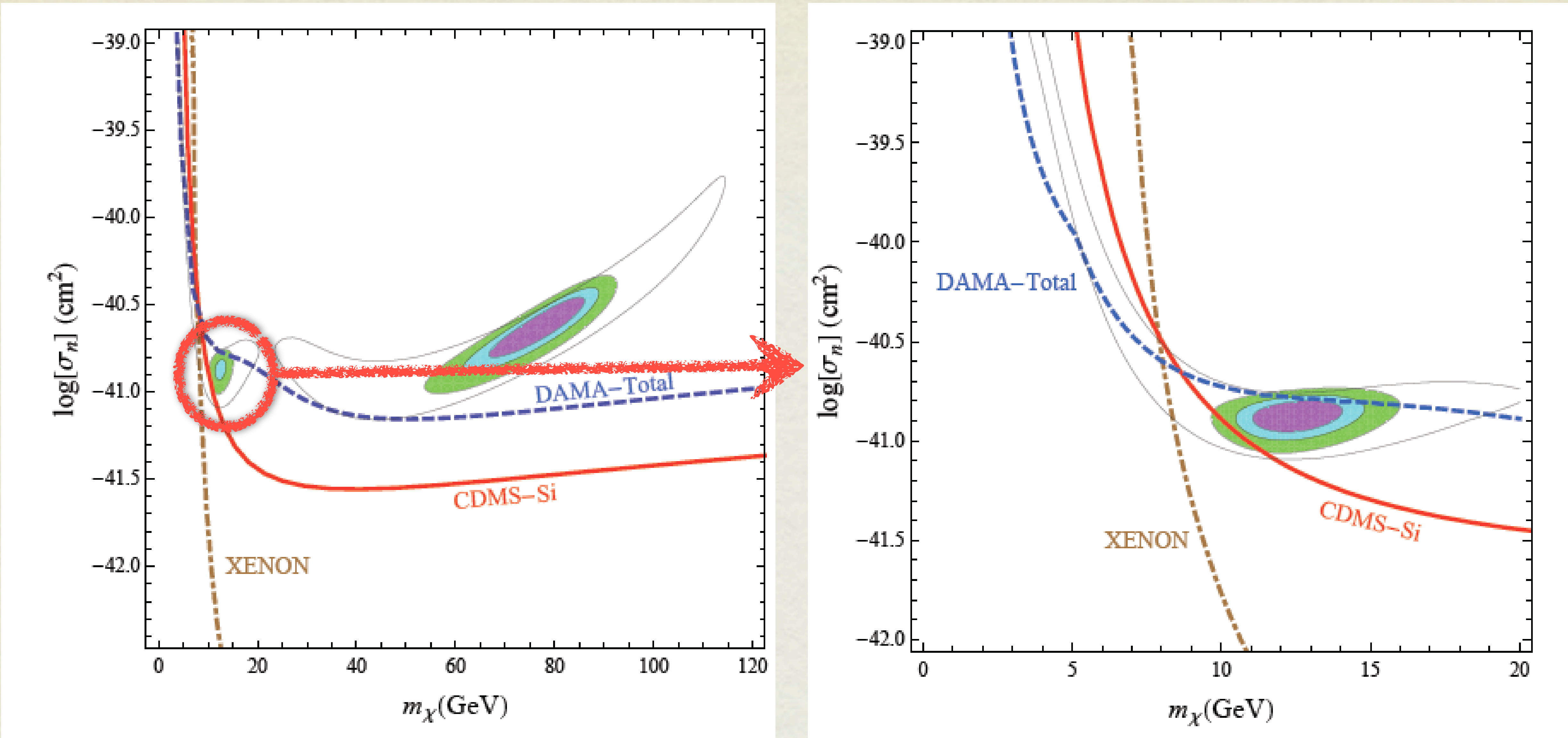
FITS TO THE DATA



Old two bin contours are shown in empty white contour

New spectral information says that consistent story is constrained

FITS TO THE DATA



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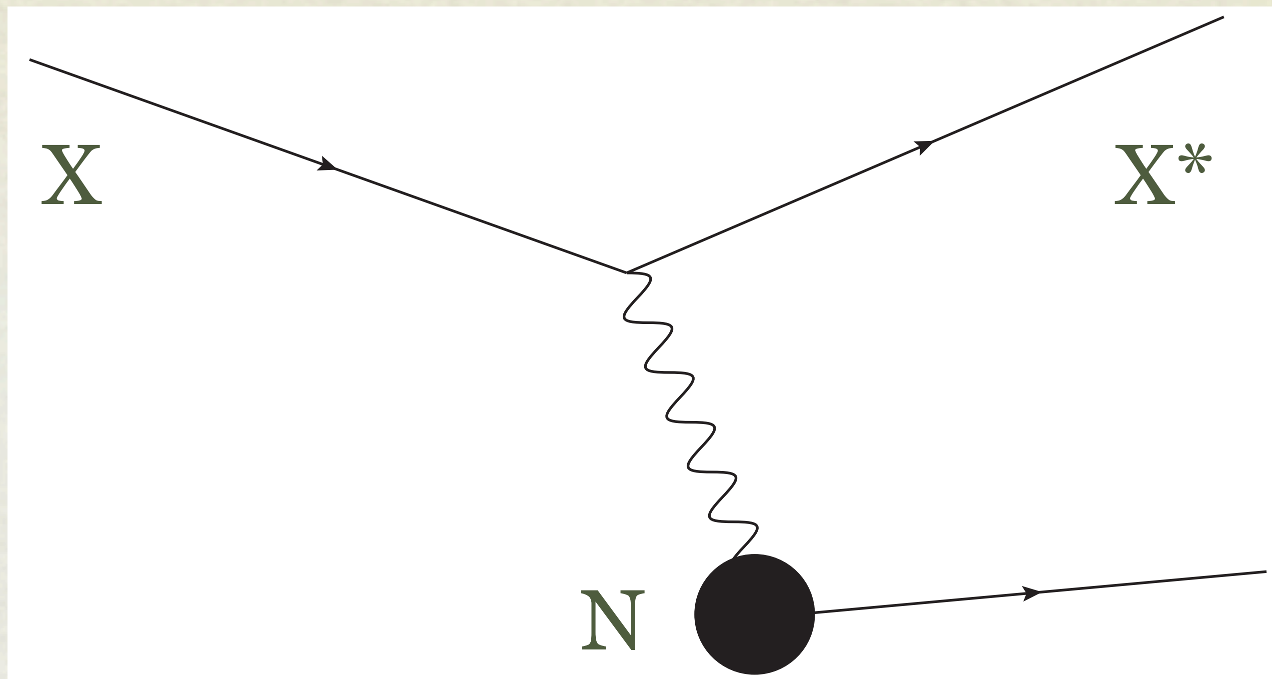
HOW TO TEST ELASTIC DARK MATTER

- Low mass dark matter means that it is best probed at low threshold experiments
- CoGeNT, low threshold runs at CDMS (Si or Ge), more running at XENON, future Argon experiments

INELASTIC DARK MATTER

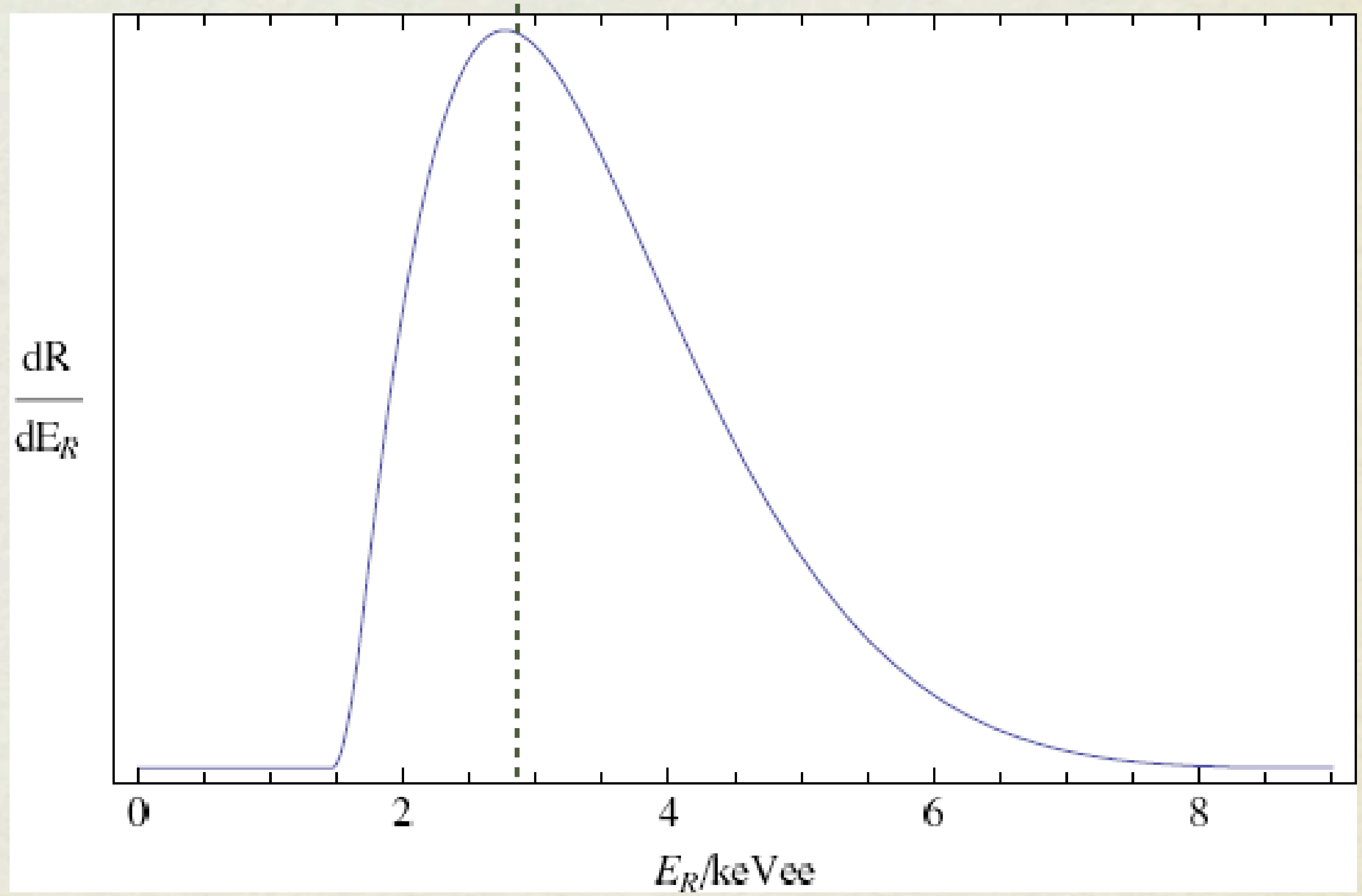


- Simple modification originally proposed to explain older DAMA, CDMS conflict (Smith, Weiner)
- One new parameter, mass splitting $\delta = m_{X^*} - m_X$
- Change in kinematics has profound effect that can fit spectrum

IDM SPECTRUM

$$v_{min} = \sqrt{\frac{1}{2m_N E_R}}\left(\frac{m_N E_R}{\mu} + \delta\right)$$

Threshold E_R



Inelastic nature changes spectrum

No longer exponential at low energies

Shape is suggestive of DAMA spectrum

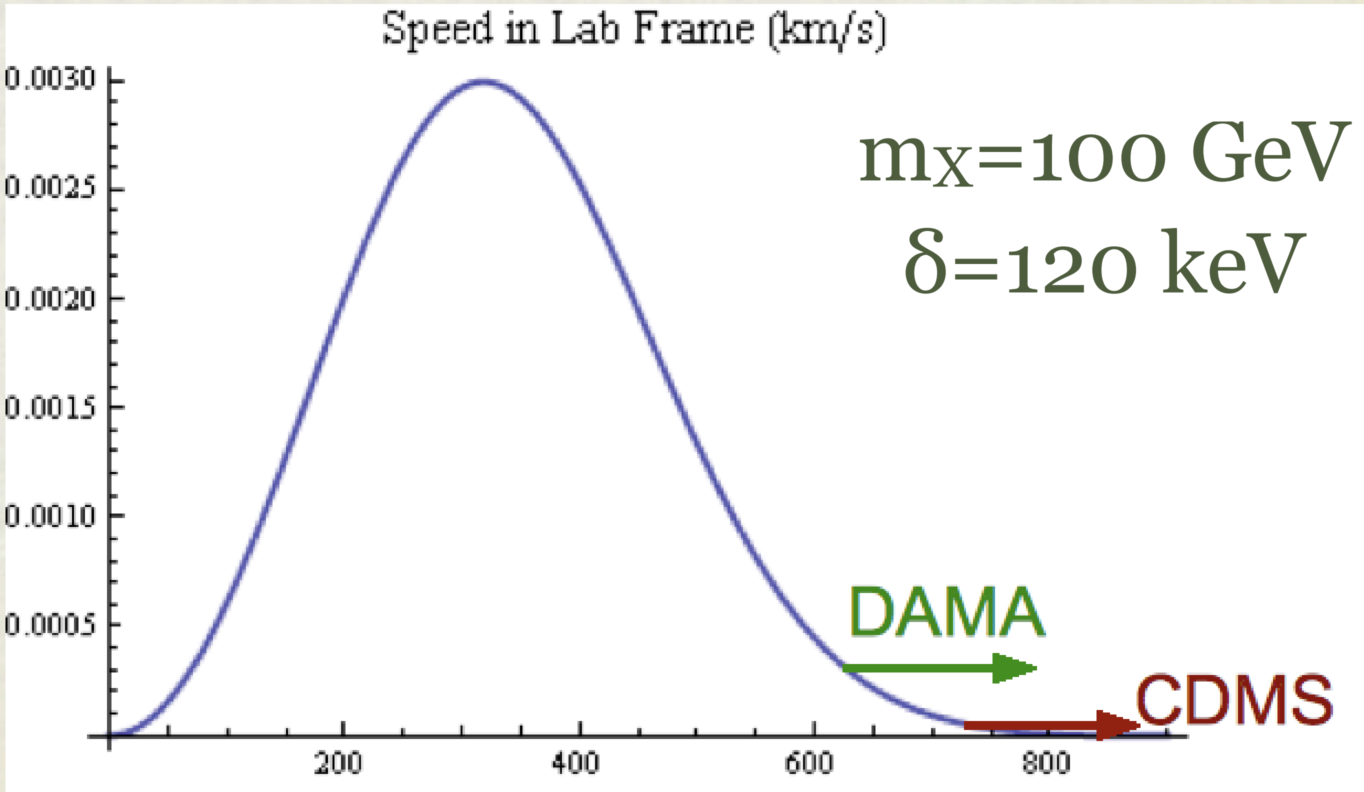
Example inelastic scattering spectrum

SUPPRESSED RATES

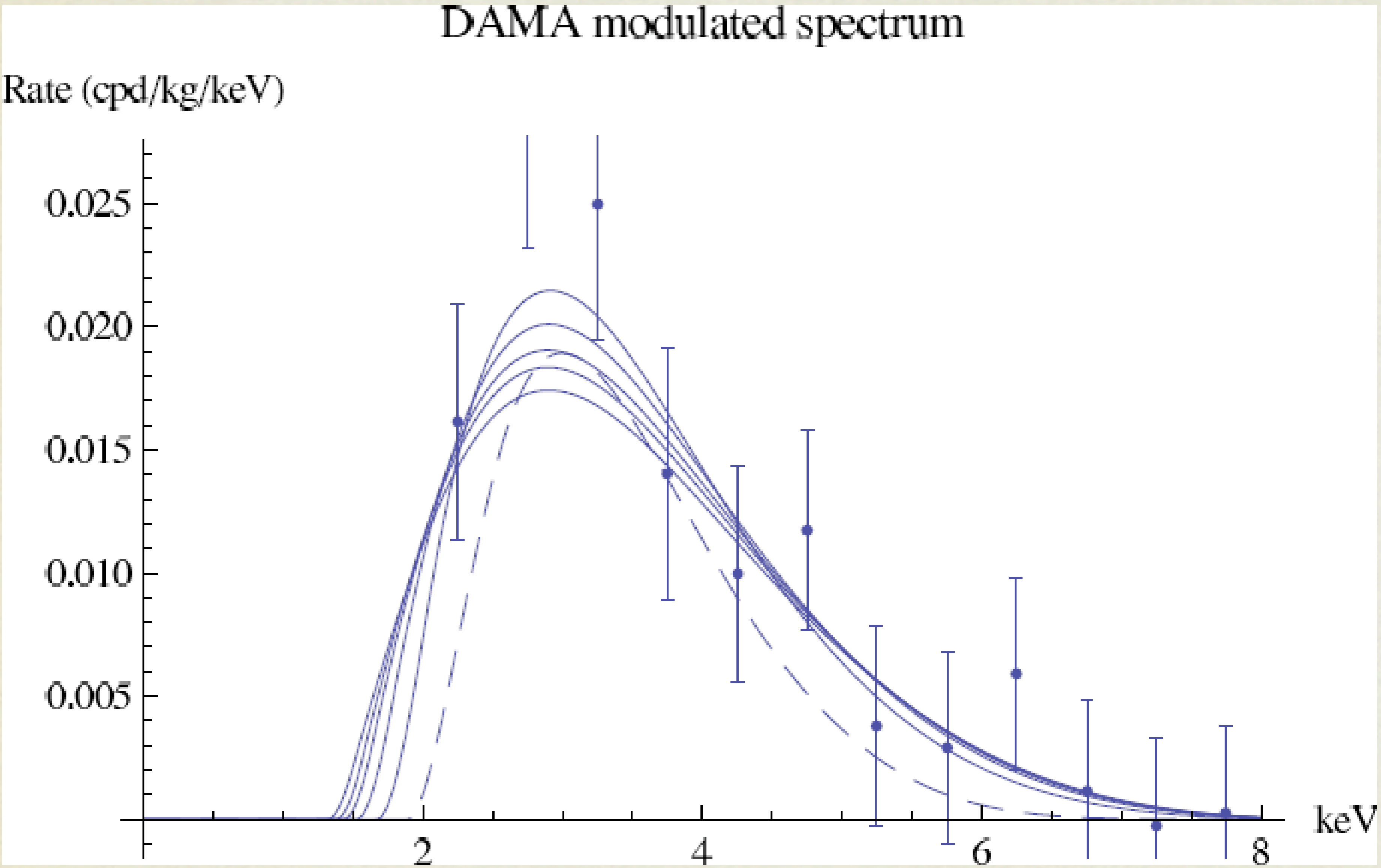
$$v_{th}^2 = \frac{2\delta}{m_X}\left(1 + \frac{m_X}{m_N}\right)$$

Threshold velocity is lower for heavier targets, so light targets have suppressed rates

(^{127}I in DAMA versus ^{73}Ge in CDMS)



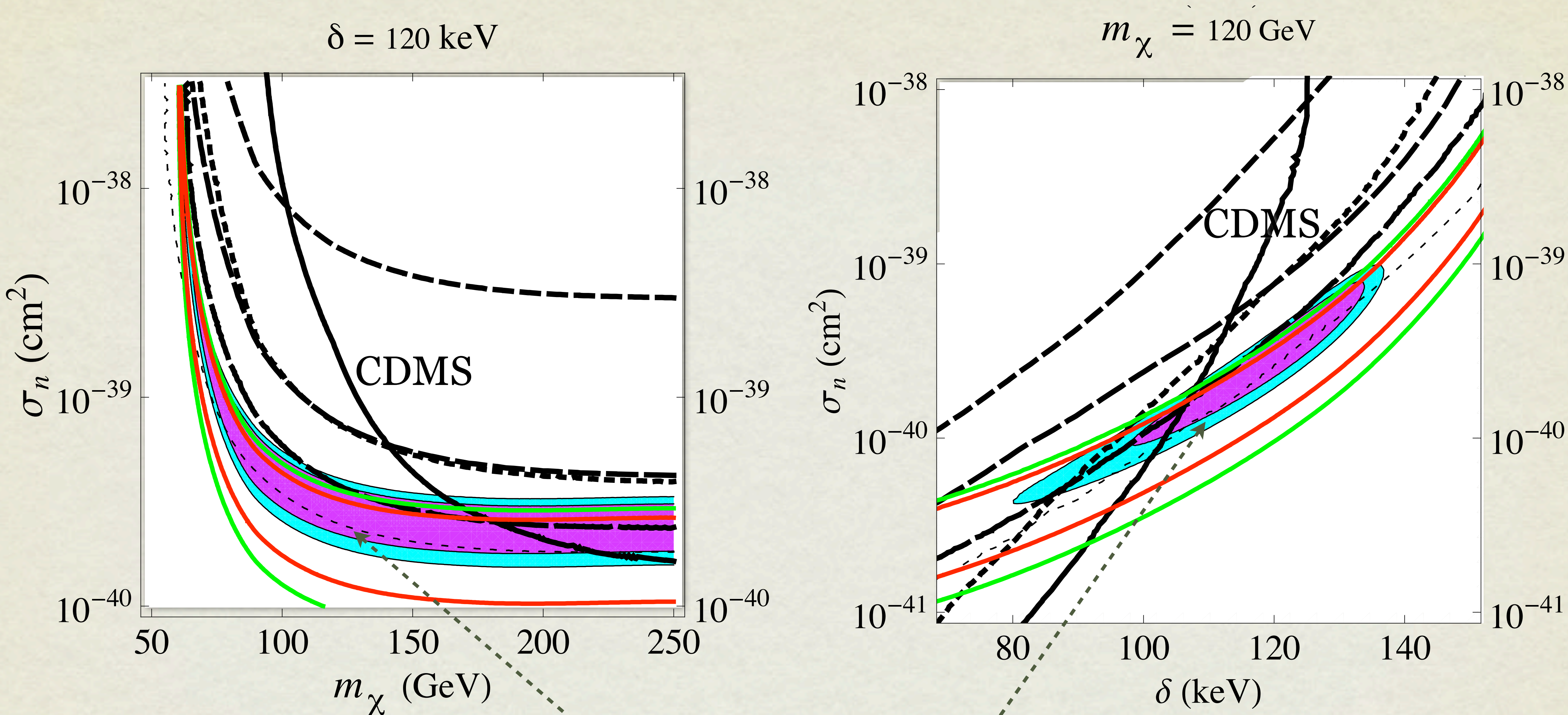
IDM FIT



Dark matter mass ranges from 70 to 250 GeV

Mass splitting changes to fit peak

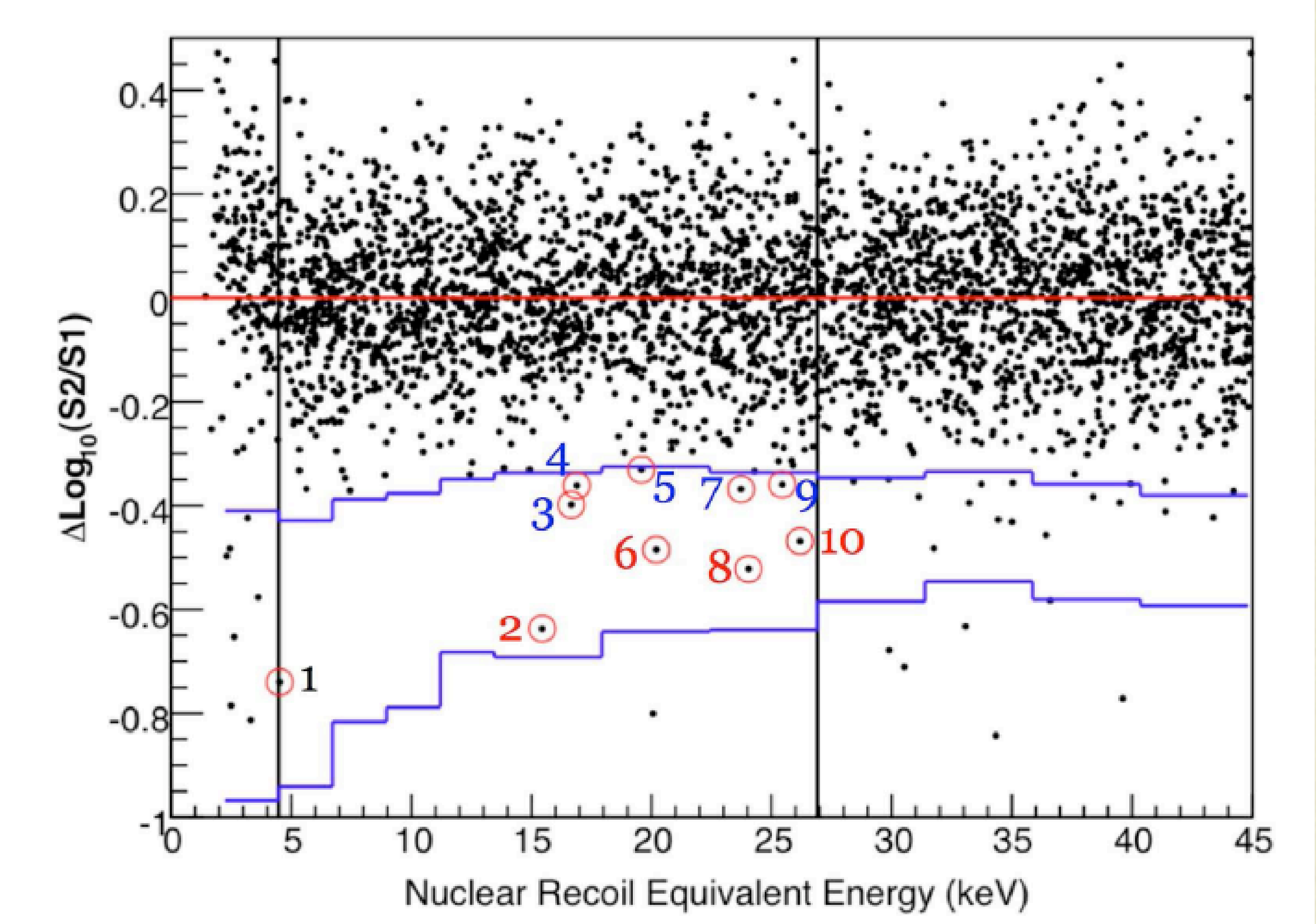
IDM CONSTRAINTS



CRESST (W)

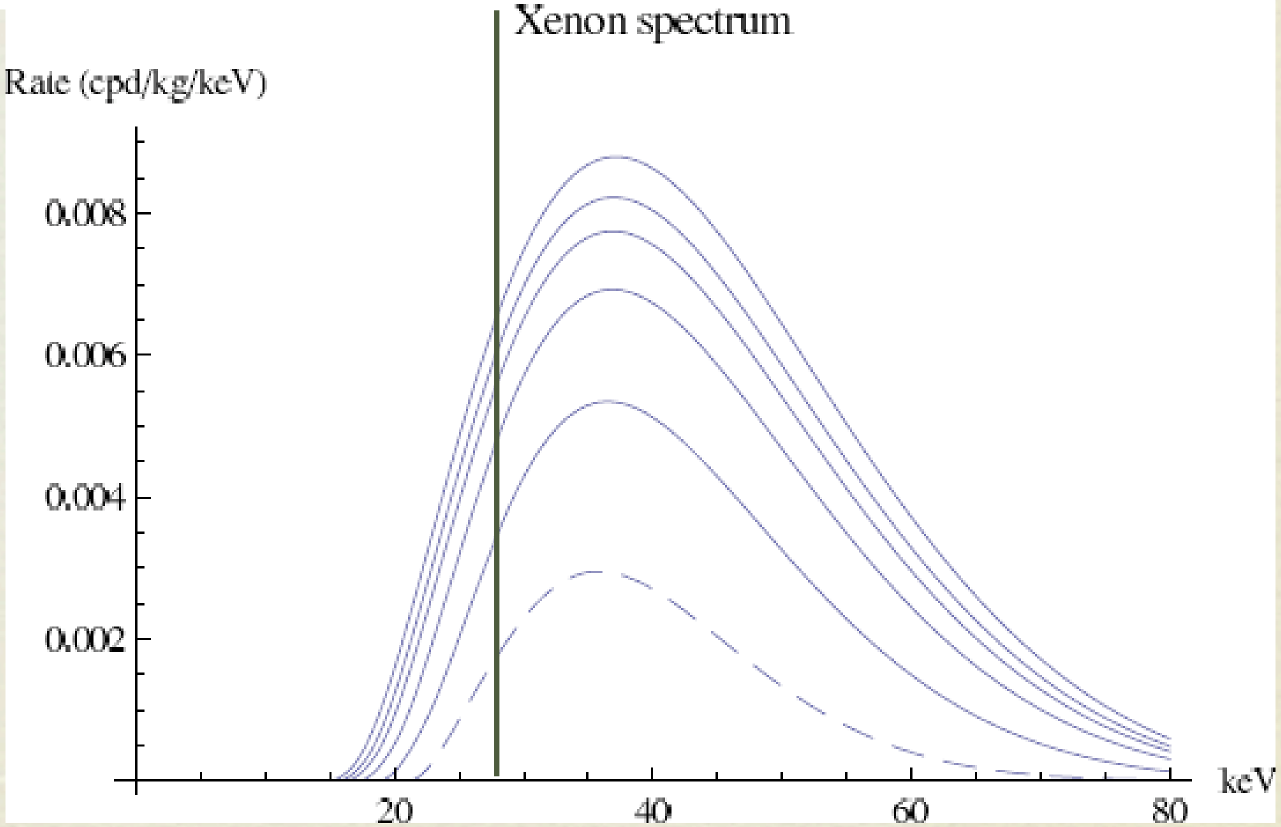
There are constraints, but model is still okay at 90%CL

Xenon 10 limits are weaker for a different reason

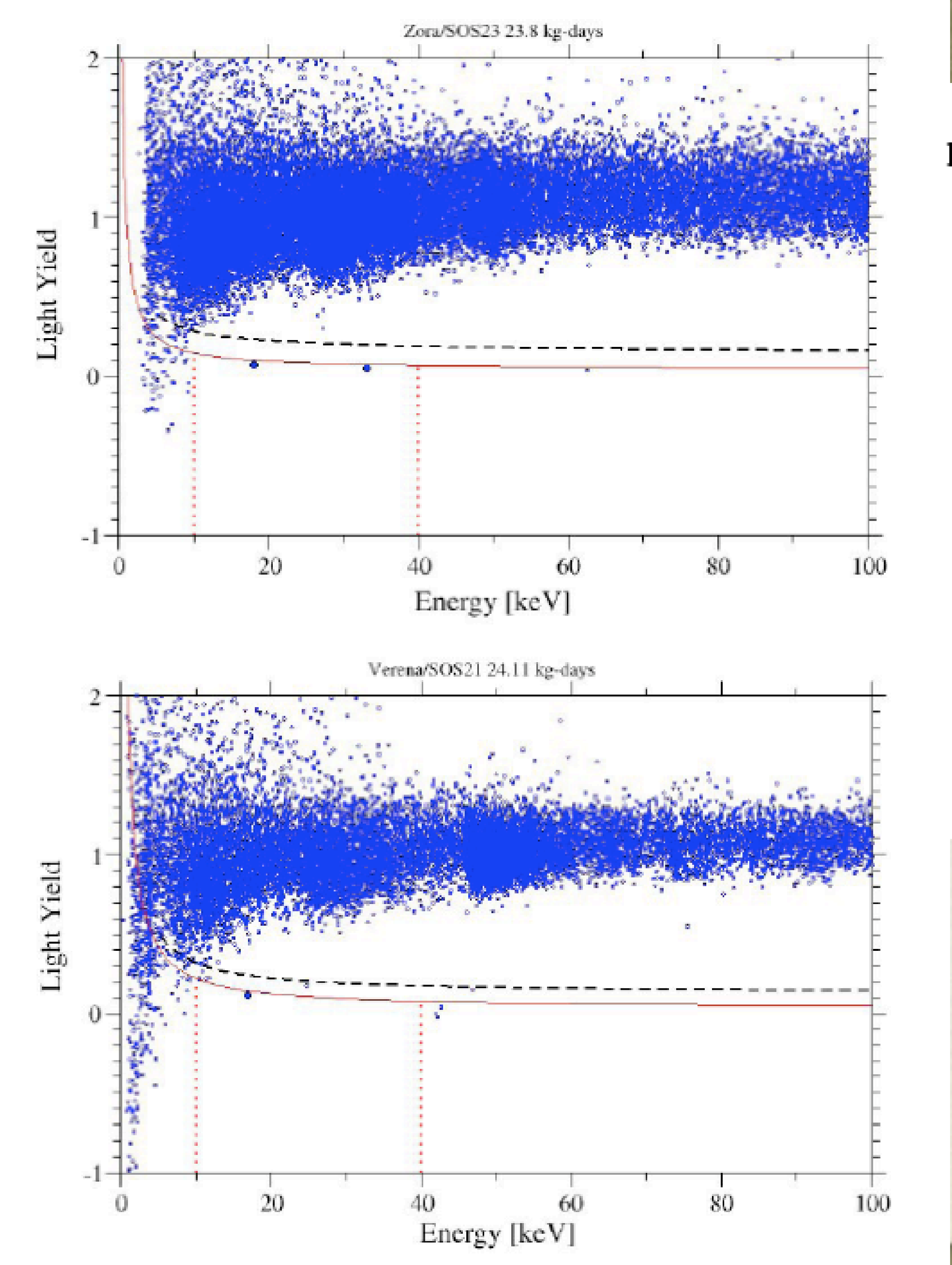


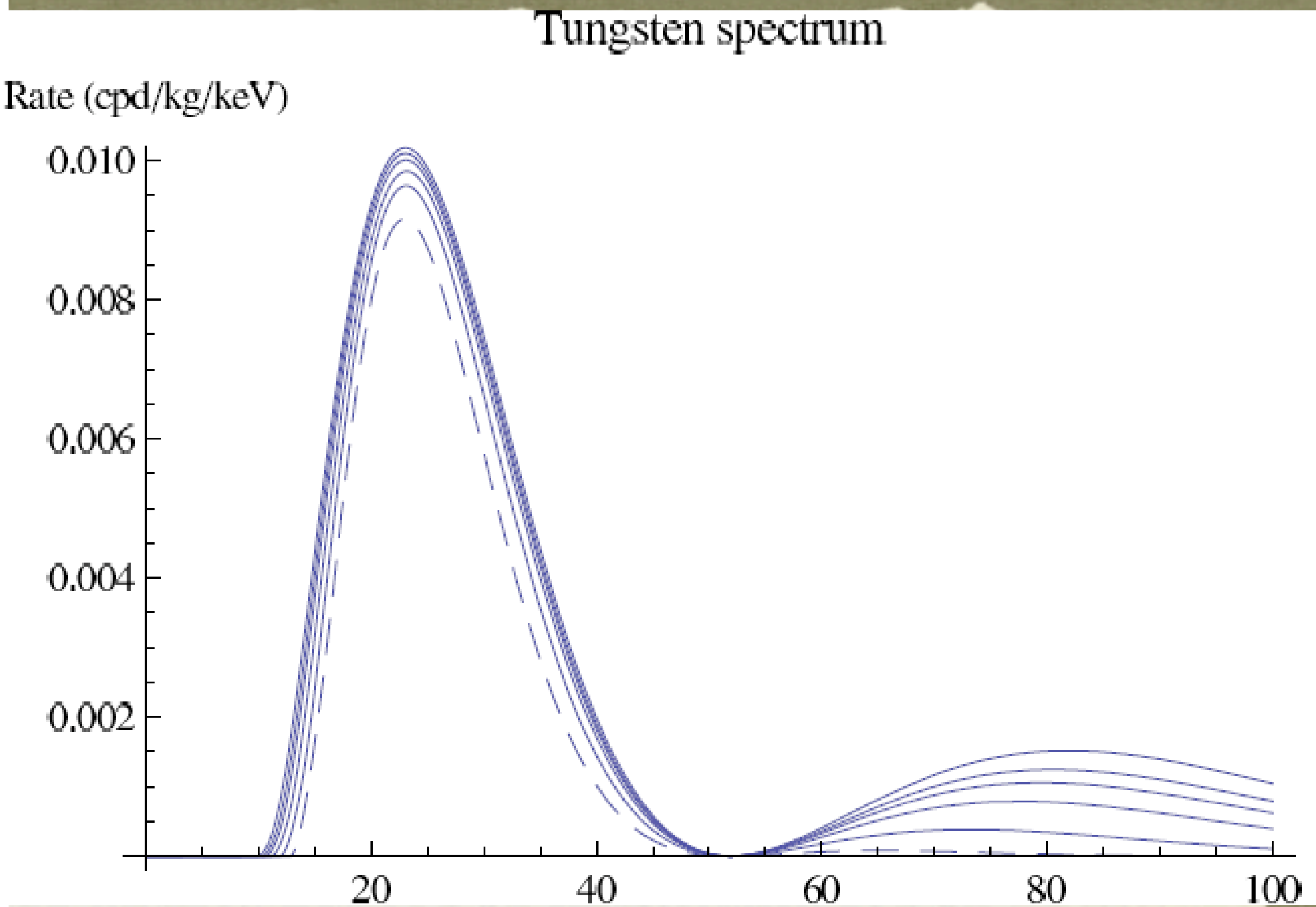
Spectrum is of the right shape, event rate is similar, so limit is weaker

There is an ongoing reanalysis of high energy region



CRESST CONSTRAINT





Strongest constraint due to heavy Tungsten target, however observed events are not background like

HOW TO TEST INELASTIC DARK MATTER

- Heavy targets are preferred, so Xenon, Iodine, and Tungsten targets can probe all regions
- CDMS can detect it at heavy enough dark matter mass or small mass splitting
- Most importantly, spectrum is not peaked at low energy, but instead at intermediate energy region
- Experiments should work on backgrounds and analyses for this sometimes neglected region

CONCLUSIONS

- Dark matter will be directly tested in the near future
- Journey with many steps, should do as much as possible with the data
- Should be suspicious of signal, motivates thinking about fake dark matter signals involving neutrinos

CONCLUSIONS (CONT.)

- Direct detection has many possible signals (used DAMA signal as inspiration)
- Elastic dark matter (w/ or w/o q^2 effects), can get low energy suppression through matrix element
- Inelastic dark matter, get low energy suppression through kinematic requirement on velocity
- Such low energy suppressions could reappear at future direct detection experiments