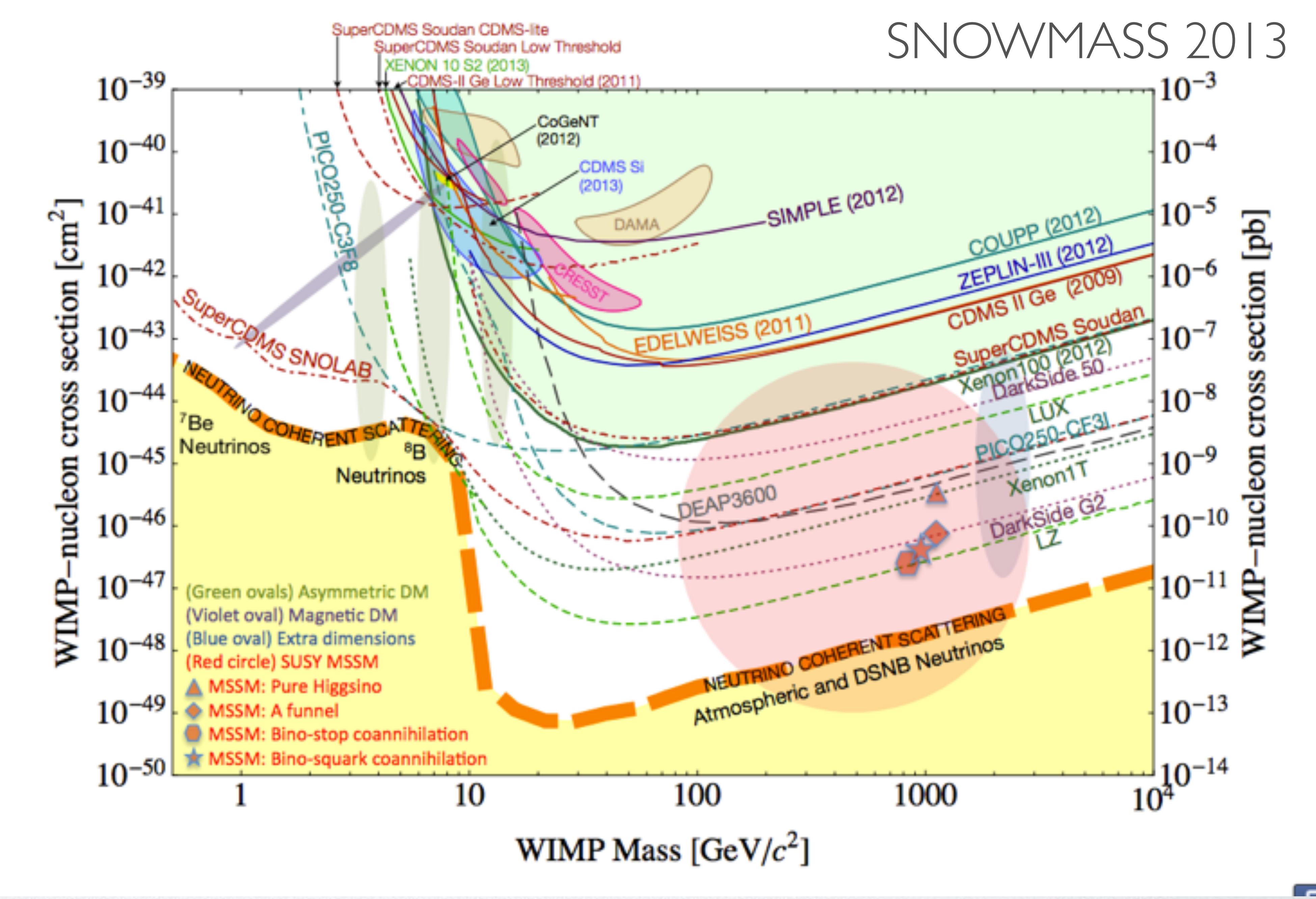
Sub-GeV Dark Matter: Direct Detection Prospects

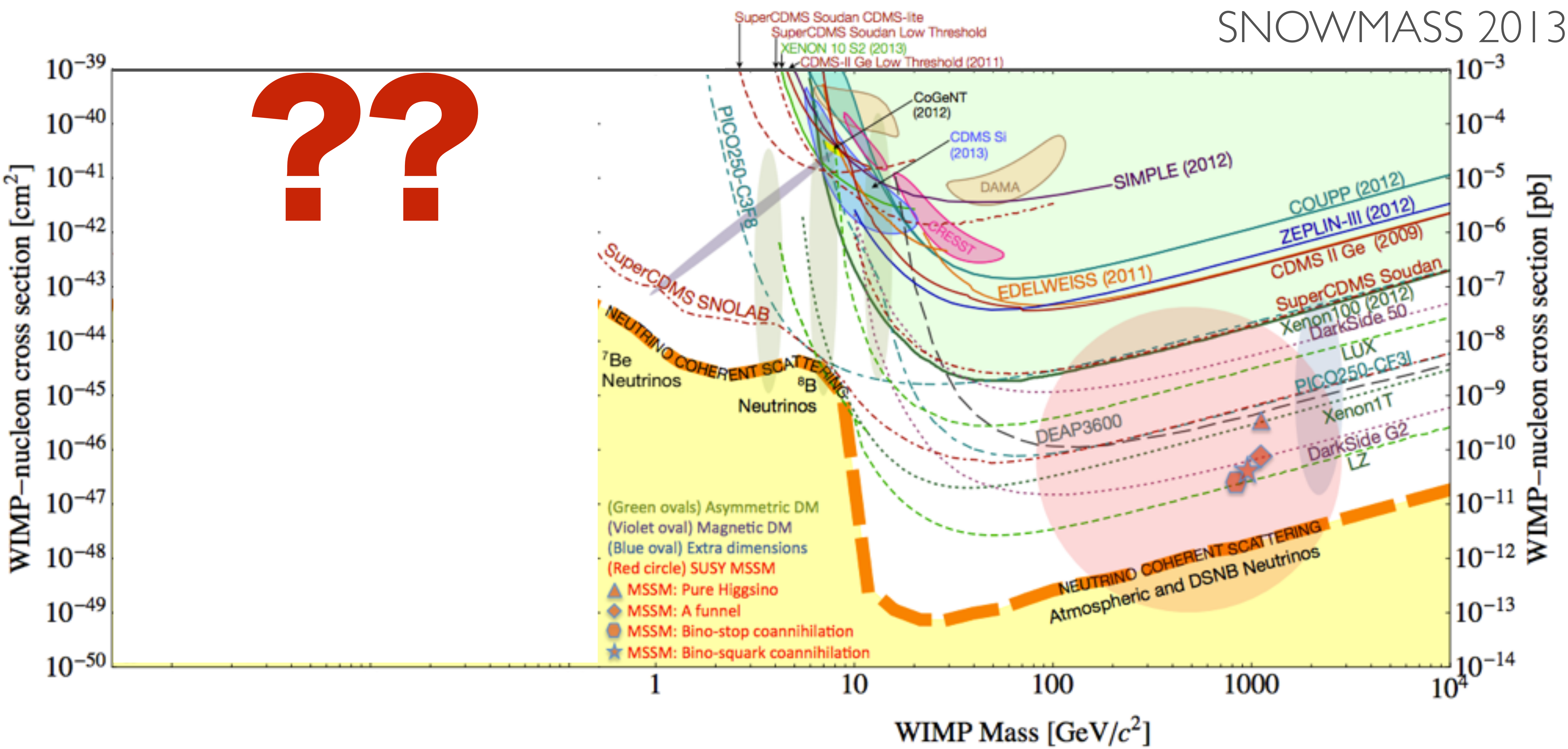
Jeremy Mardon, SITP, Stanford

Direct detection below 1 GeV?



Jeremy Mardon, SITP, Stanford

DIRECT DETECTION BELOW 1 GEV?



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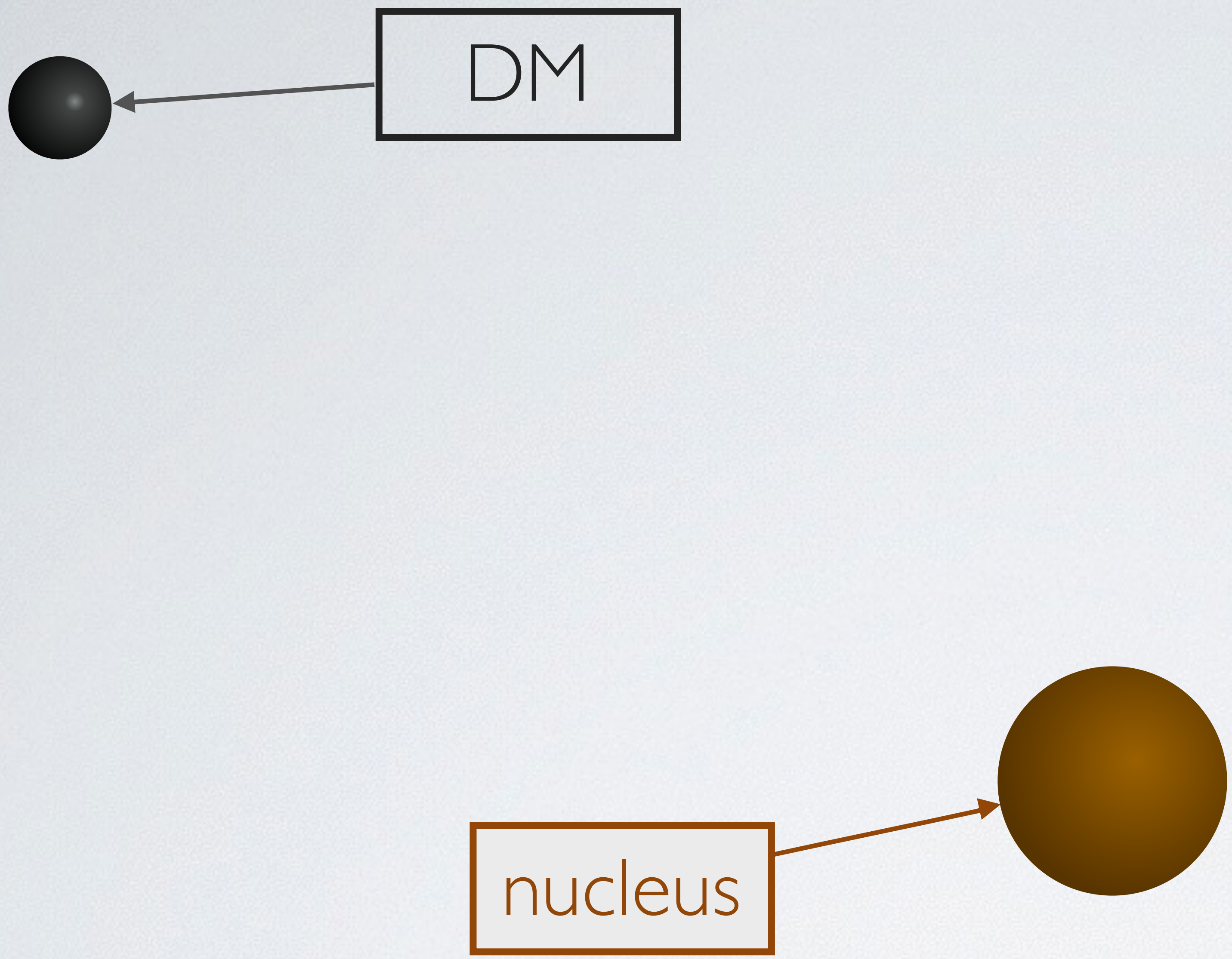
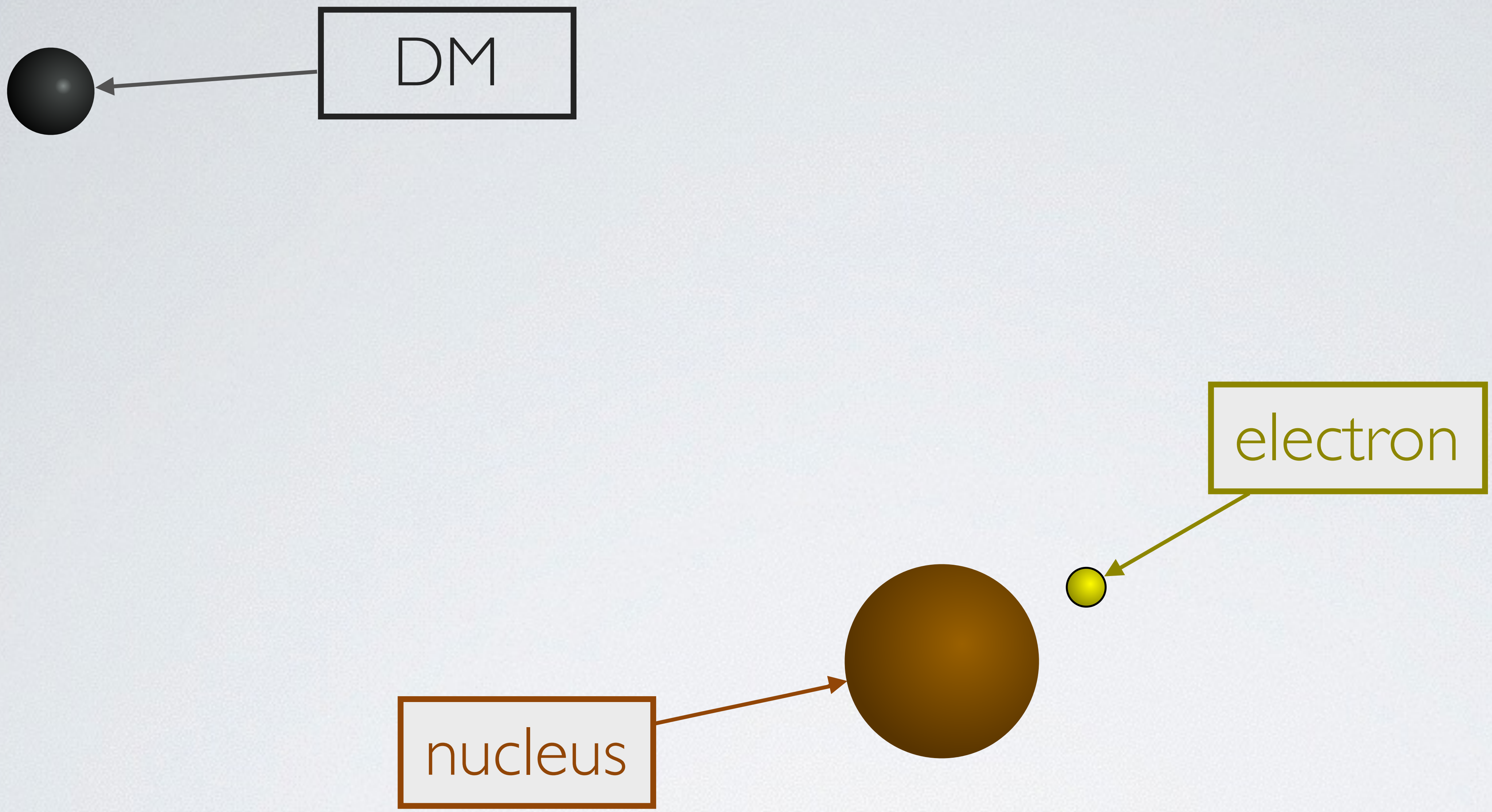


Nuclear scattering transfers very little energy!



Energy available ≈ eV (m_{DM}/MeV)
Electron scattering can transfer most of energy

Program

— Search for **DM—electron scattering**

— Signal: **single/few ionized electrons**

Reach

Noble liquid target	**Semiconductor target**
$E_{\text{thresh}} \sim 10$ eV	$E_{\text{thresh}} \sim 1$ eV
$m_{\text{DM,min}} \sim 10$ MeV	$m_{\text{DM,min}} \sim 1$ MeV

Challenges

Experimental

— Achieving low thresholds

— Totally new backgrounds

Theoretical

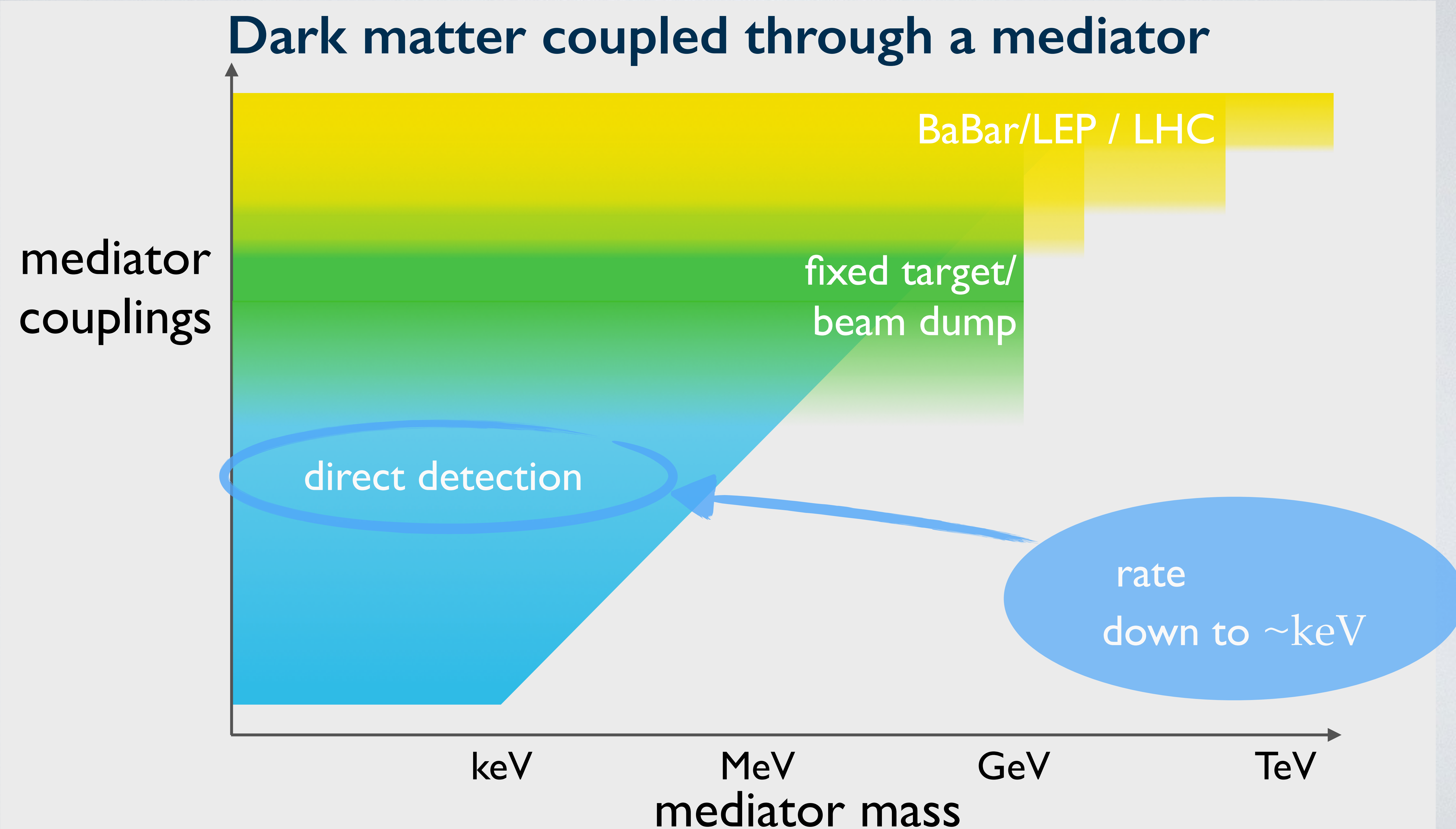
— Calculating form-factor

"Direct Detection of Sub-GeV Dark Matter" R. Essig, J. M. & T. Volansky arXiv:1108.5383

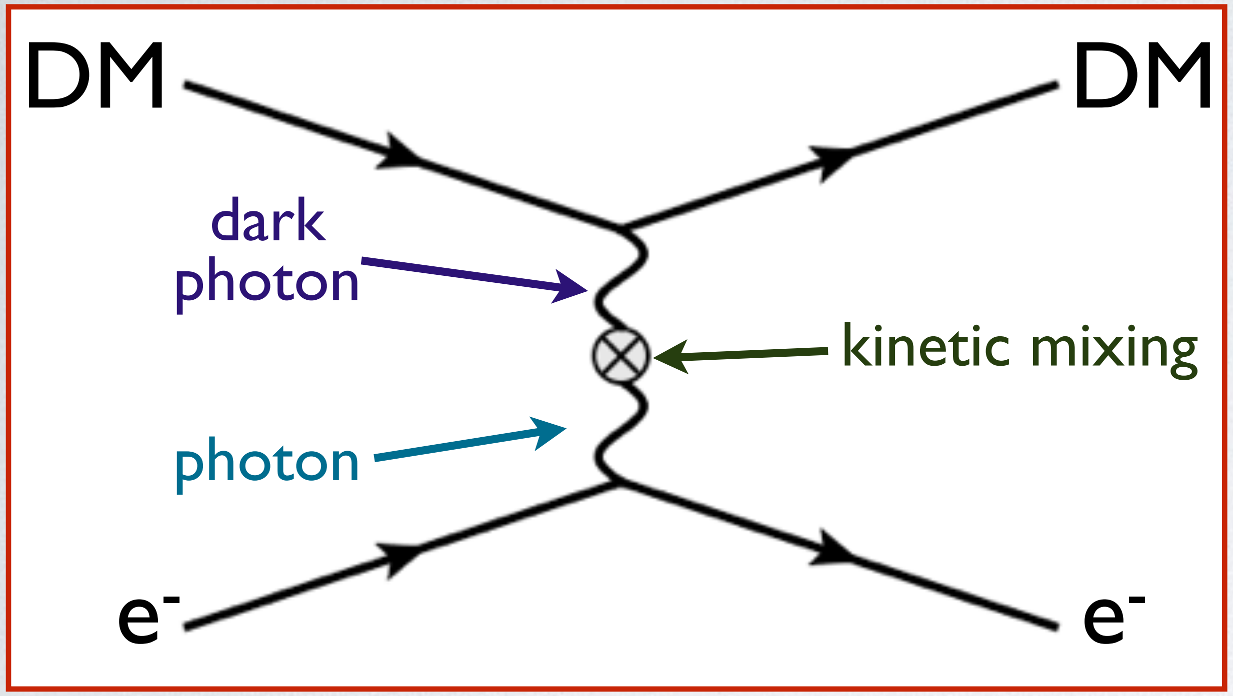
see also: Graham, Kaplan, Rajendran & Walters arXiv:1203.2531

DIRECT DETECTION VS COLLIDERS

(SCHEMATIC)



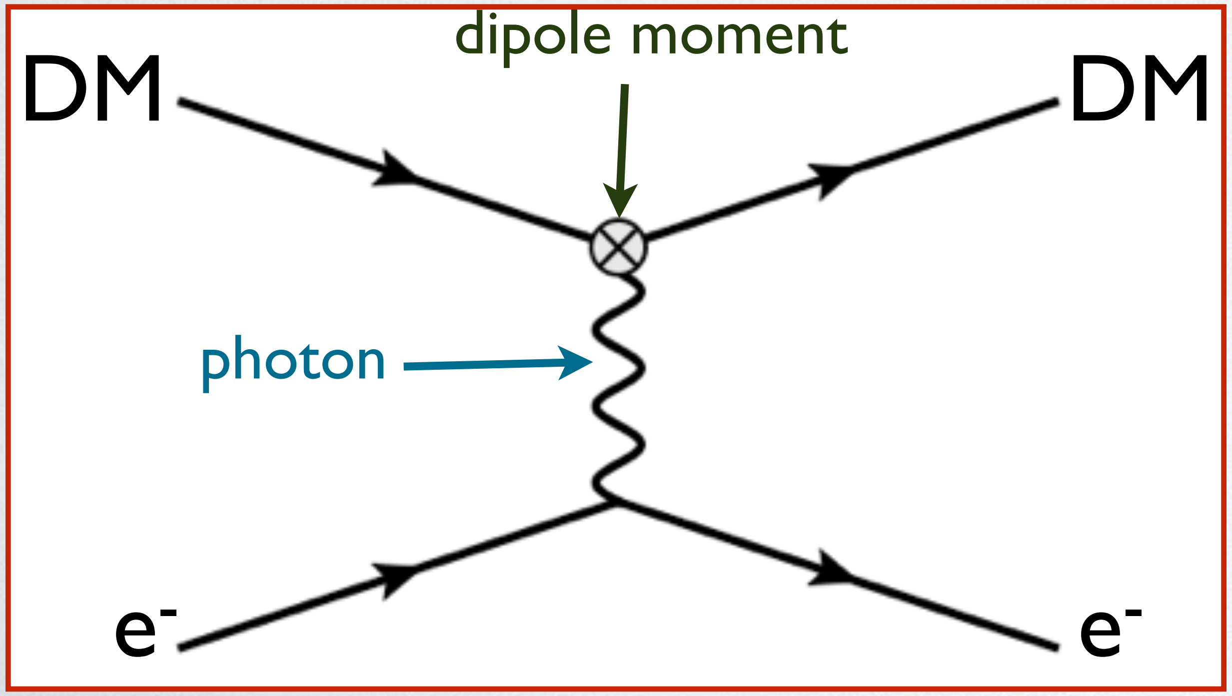
BENCHMARK MODELS



dark photon mediator:

- — light (~10 MeV)
- — massless (or << keV)

e.g. Essig et al 1108.5383, Lin et al 1111.0293, Chu et al 1112.0493
Hall et al 0911.1120



dipole moment:

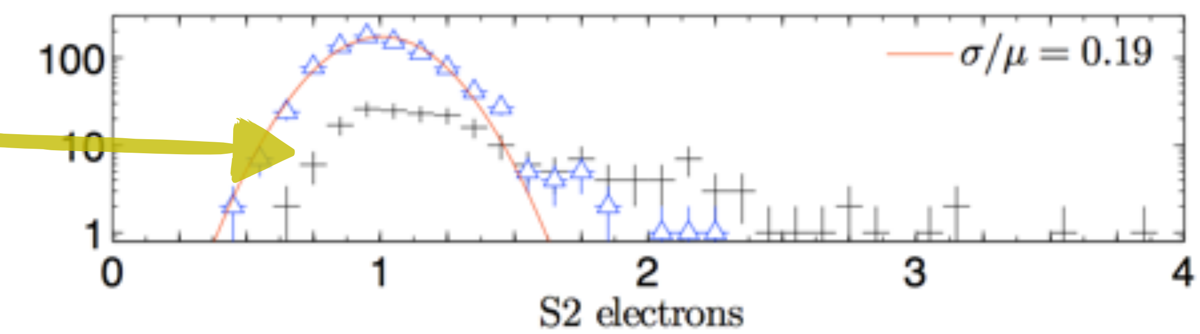
- — MDM
- — EDM

Sigurdson et al Phys.Rev. D70 (2004) 083501 + Erratum-ibid.
Graham et al 1203.2531

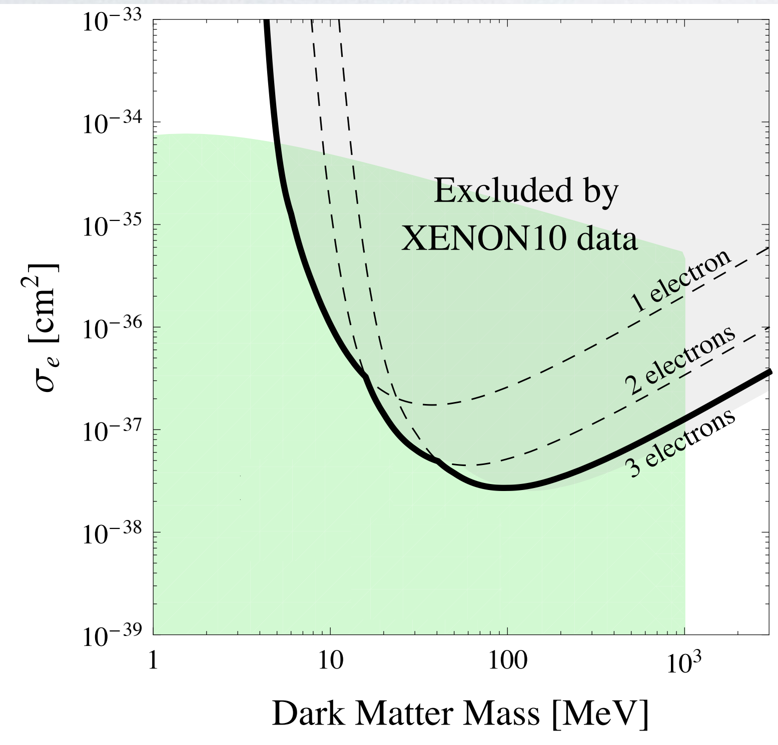
FIRST BOUNDS FROM XENON10

single-electron
events observed from
15 kg-day run in 2006

"*A search for light dark matter in XENON10 data*" 1104.3088

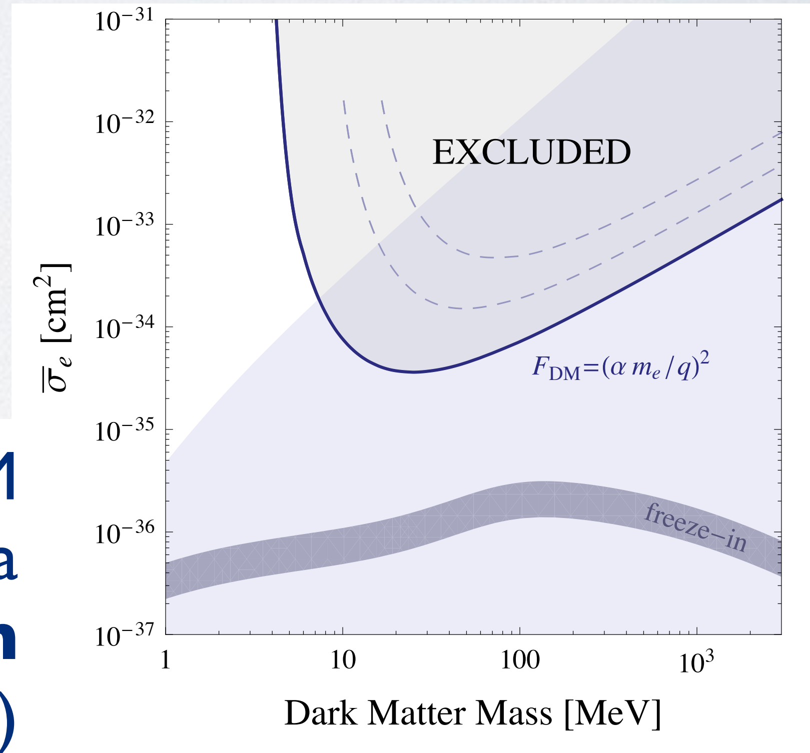


Observed ionization rate $\Longrightarrow$ upper limit on DM—electron scattering rate



DM
coupled via a
light dark photon
(mass~10 MeV)

DM
coupled via a
massless dark photon
(mass<< keV)

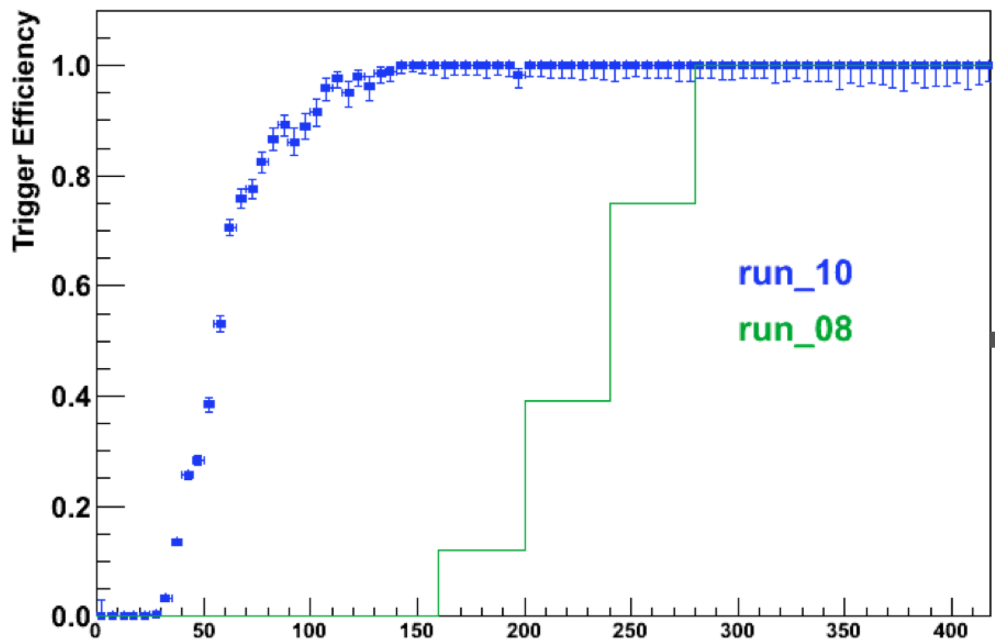


"First Direct Detection Limits on Sub-GeV Dark Matter from XENON10"
R. Essig, A. Manalaysay, J. M., P. Sorensen & T. Volansky arXiv:1206.2644

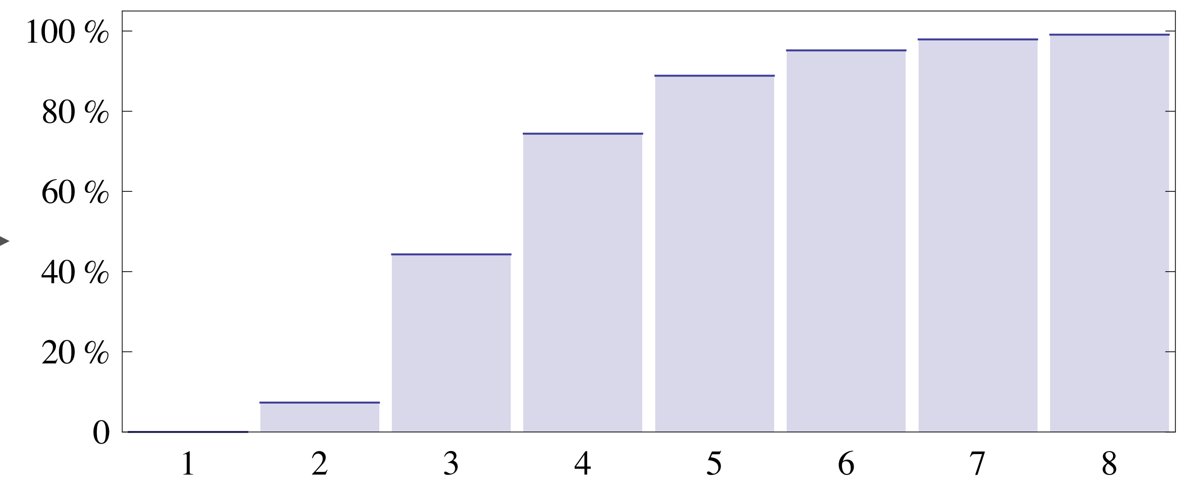
WORK CURRENTLY UNDERWAY

ELECTRON SCATTERING IN XENON100

Run10 trigger efficiency



observed photoelectrons



ionized electrons

Electron scattering analysis currently underway

— expect to be competitive with Xenon10

— will learn a lot about backgrounds & how to reduce them

XENON100 collaboration, with R. Essig, J. M. & T. Volansky
this year

— **LUX** analysis in near future too

SILICON TARGET WITH DAMIC

DAMIC uses thick silicon CCDs as targets

— ionization threshold ~1eV

— new readout system under development

— could have single-electron sensitivity in ~1 year

— best mass reach yet (down to MeV)

— **CDMS** has a pathway to single electron sensitivity with germanium detectors over next few years

CALCULATING RATES

Scattering rate

$$\frac{d\langle\sigma^{nl}v\rangle}{d\ln E_R} = \overline{\sigma}_e \int \frac{q\,dq}{8\mu_{\chi e}^2}\left|f^{nl}(E_R,q)\right|^2\left|F_{\rm DM}(q)\right|^2\eta(v_{\rm min}(q))$$

$$v_{\rm min} = \frac{|E_{\rm binding}^{nl}| + E_R}{q} + \frac{q}{2m_{\rm DM}}$$

R. Essig, J. M. & T. Volansky 1108.5383

Calculating rates

Scattering rate

Underlying DM model

Halo model

$$\frac{d\langle\sigma^{nl}v\rangle}{d\ln E_R} = \overline{\sigma}_e \int \frac{q\,dq}{8\mu_{\chi e}^2} \left|f^{nl}(E_R,q)\right|^2 \left|F_{\rm DM}(q)\right|^2 \eta(v_{\rm min}(q))$$

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Simple kinematics

R. Essig, J. M. & T. Volansky 1108.5383

Calculating rates

Scattering rate

Underlying DM model

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Simple kinematics

Ionization form factor

R. Essig, J. M. & T. Volansky 1108.5383

CALCULATING RATES

— A complicated quantum mechanics calculation

$$|f(q)|^2 \approx \sum_{\text{degeneracies}} \left| \langle \psi_{\text{ionized}} | e^{i\vec{q}\cdot\vec{r}} | \psi_{\text{bound}} \rangle \right|^2$$

— A (hopefully) reasonable treatment already done for Noble liquids:

R. Essig, J. M. & T. Volansky 1108.5383

R. Essig, A. Manalaysay, J. M., P. Sorensen & T. Volansky 1206.2644

— Semiconductors:

- — hard many-body quantum problem
- — accurate numerical treatment possible by adapting solid state codes
- — currently underway by Tien-Tien Yu & Adrian Soto at Stonybrook

OTHER DIRECTIONS

Molecular breakup by DM—nucleus scattering

— threshold ~eV

— DM masses down to ~30 MeV

— Theory work underway by Tomer Volansky & Oren Slone

Use DAMIC's CCDs as low-noise photon detectors for larger target?

New ideas?

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work underway on all fronts

Thank you