Boosted Dark Matter

Exploring sensitivity in the DarkSide detectors

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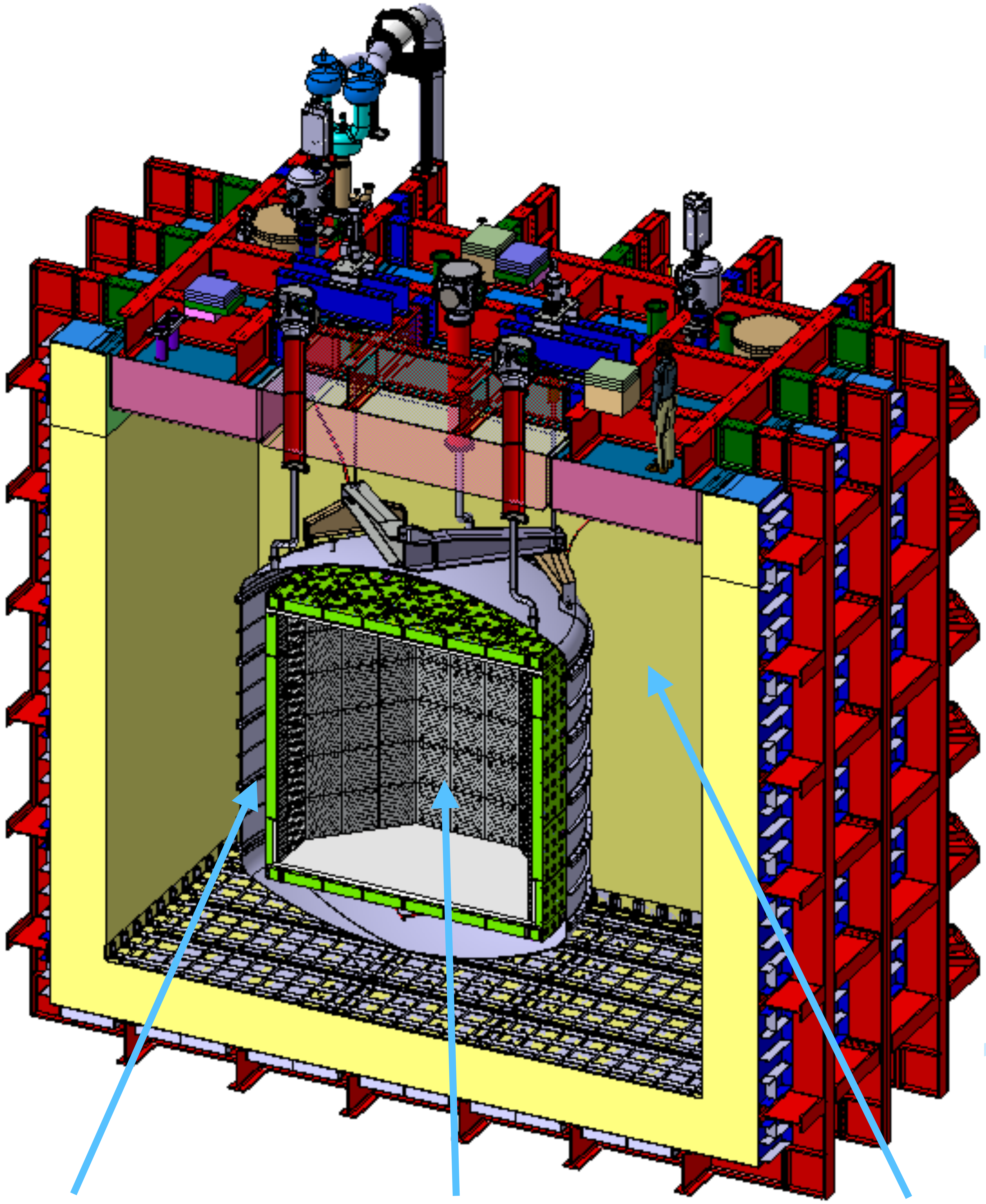
DARKSIDE

ROYAL HOLLOWAY UNIVERSITY OF LONDON

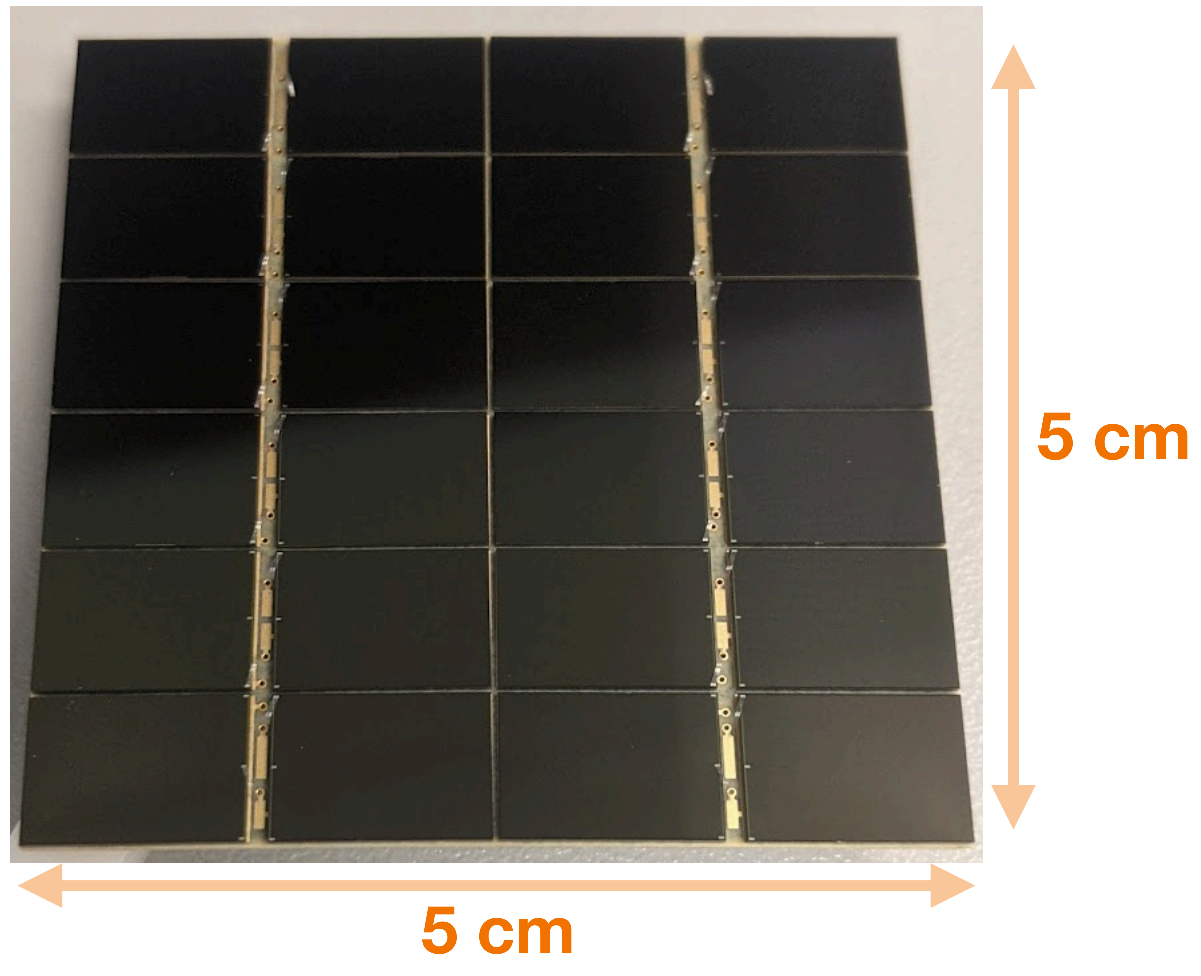
The DarkSide-20k detector: a dual-phase argon direct detection experiment



INNER VETO
32 tonnes UAr

TPC
51.1 tonnes UAr

OUTER VETO
600 tonnes AAr

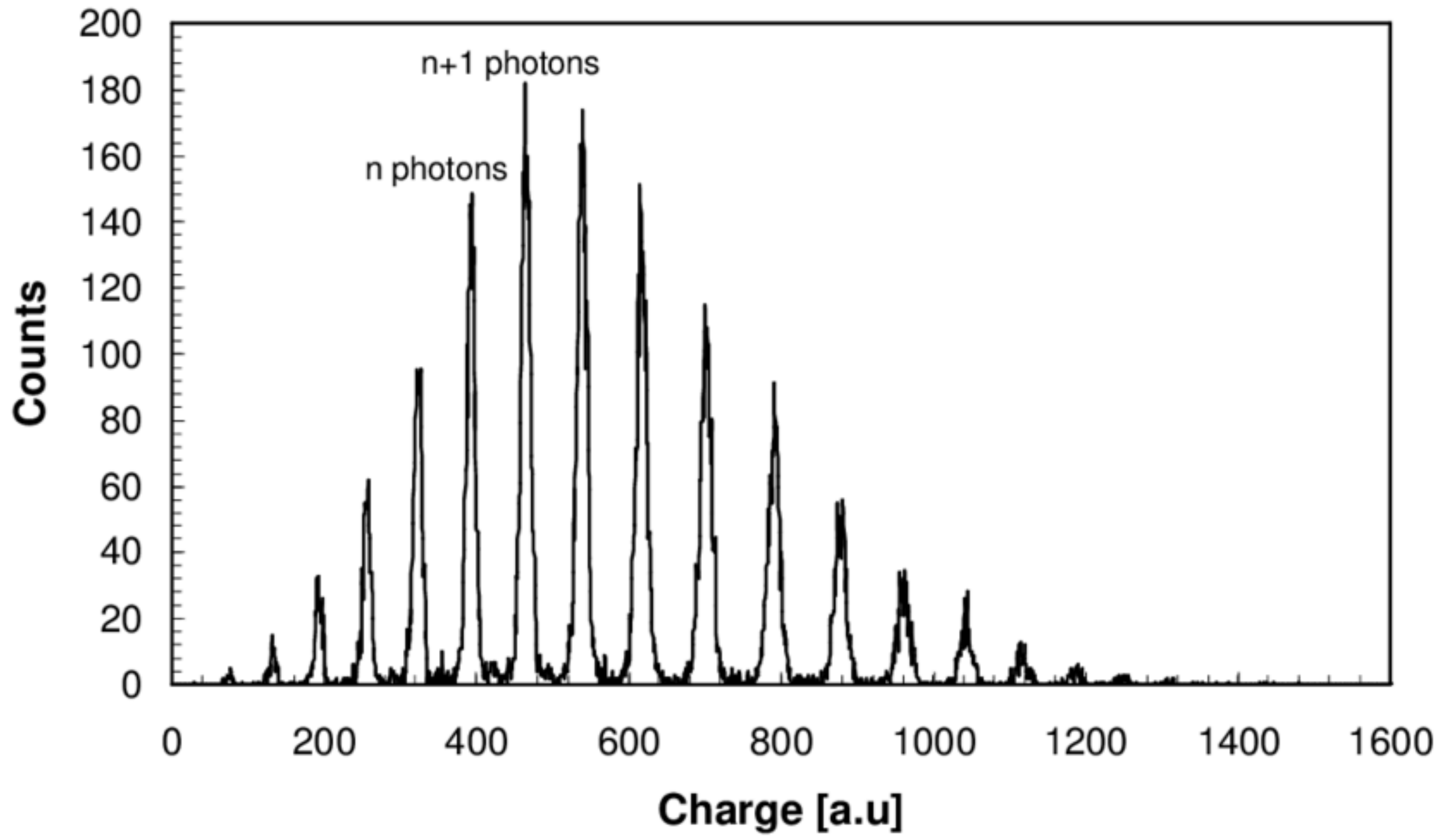


~26 m^2 photosensor coverage → SiPM sensors

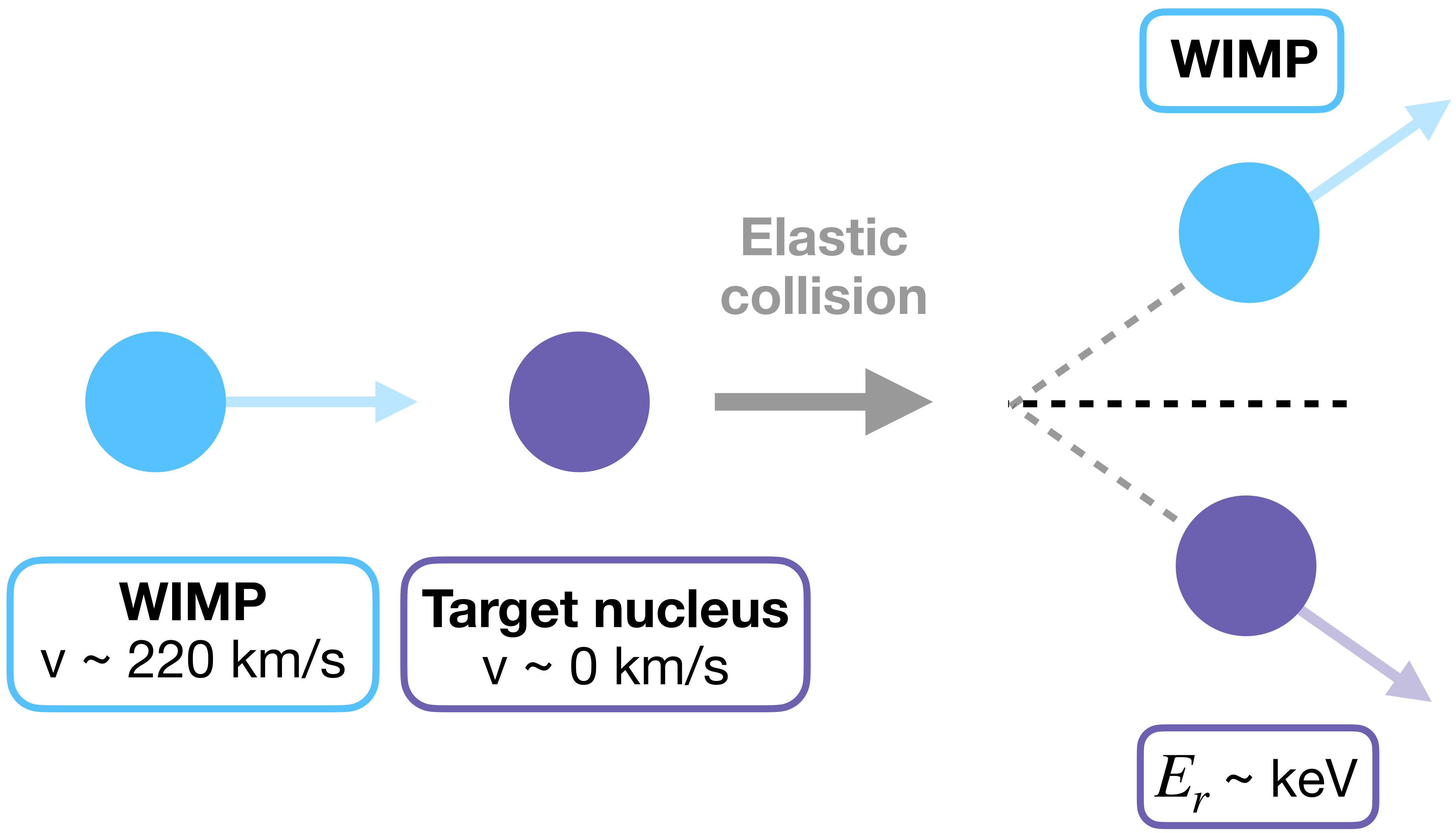
- 21 m^2 in TPC
- 5 m^2 in vetoes

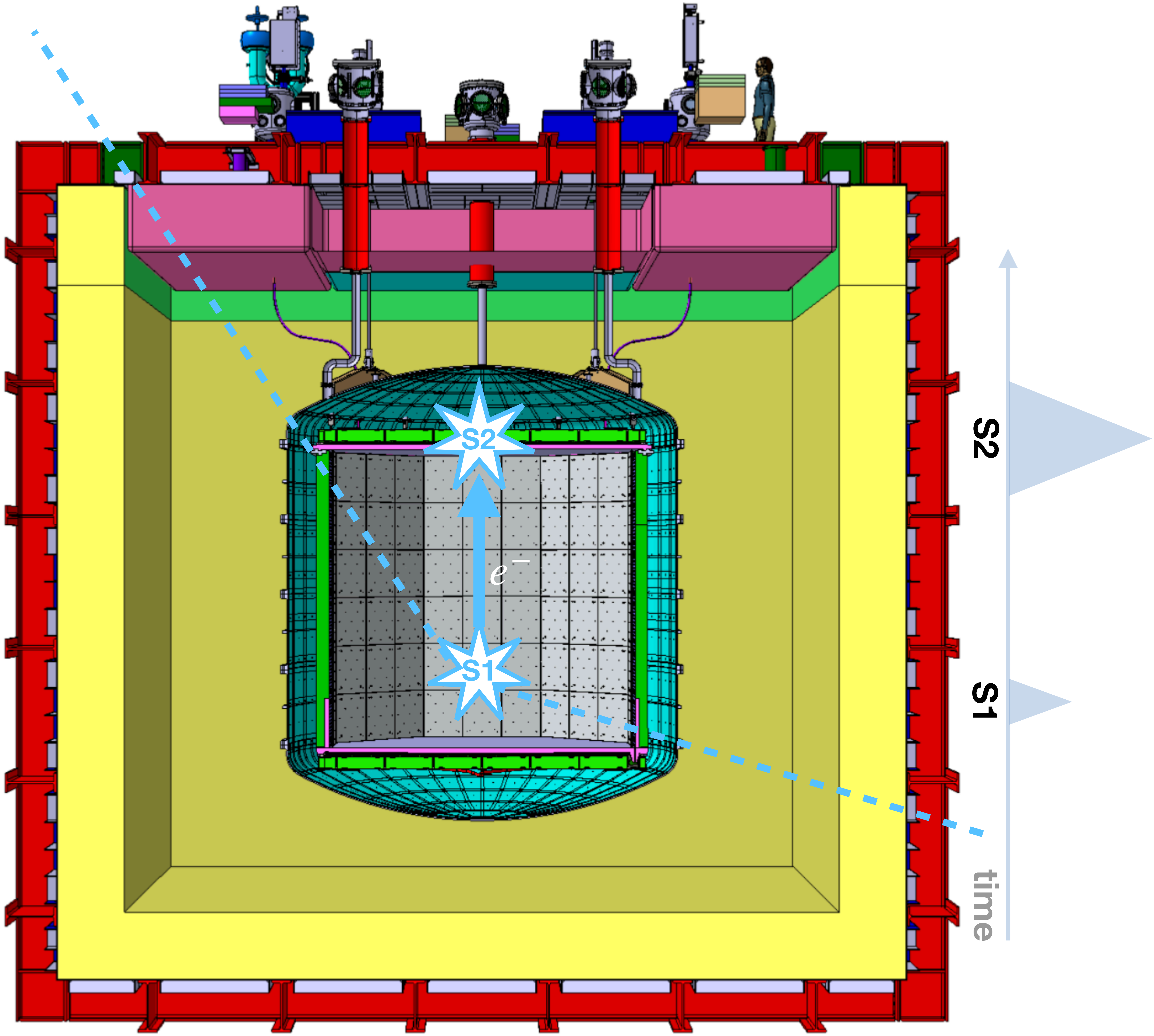
Compared to PMTs…

- 3 x PDE
- 10 x lower noise
- > 10 x lower radiogenic background
- Excellent SPE resolution

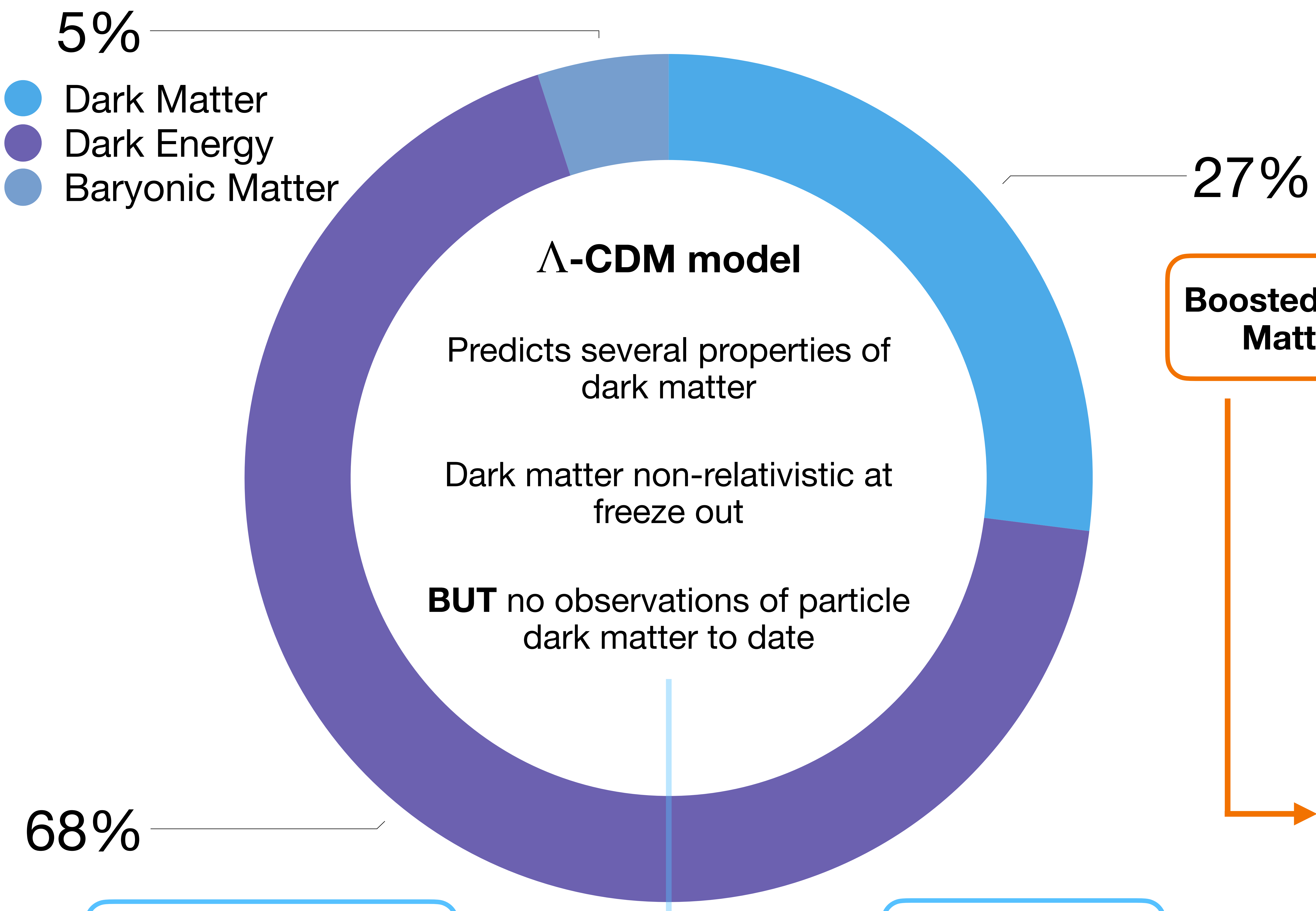


Dark matter direct detection: what are we looking for?





Motivating boosted dark matter: looking beyond the Λ-CDM model



Increase sensitivity of detectors

Consider other DM models

Boosted Dark Matter

- DM produced at late times can be relativistic
- BDM exists as subdominant DM component within SHM
- Cold DM component is dominant: accounts for most of DM energy density

Can be searched for using existing detectors and technologies

BDM remains consistent with Λ-CDM model

https://doi.org/10.1016/j.physletb.2018.03.043

Boosted dark matter: a two component model

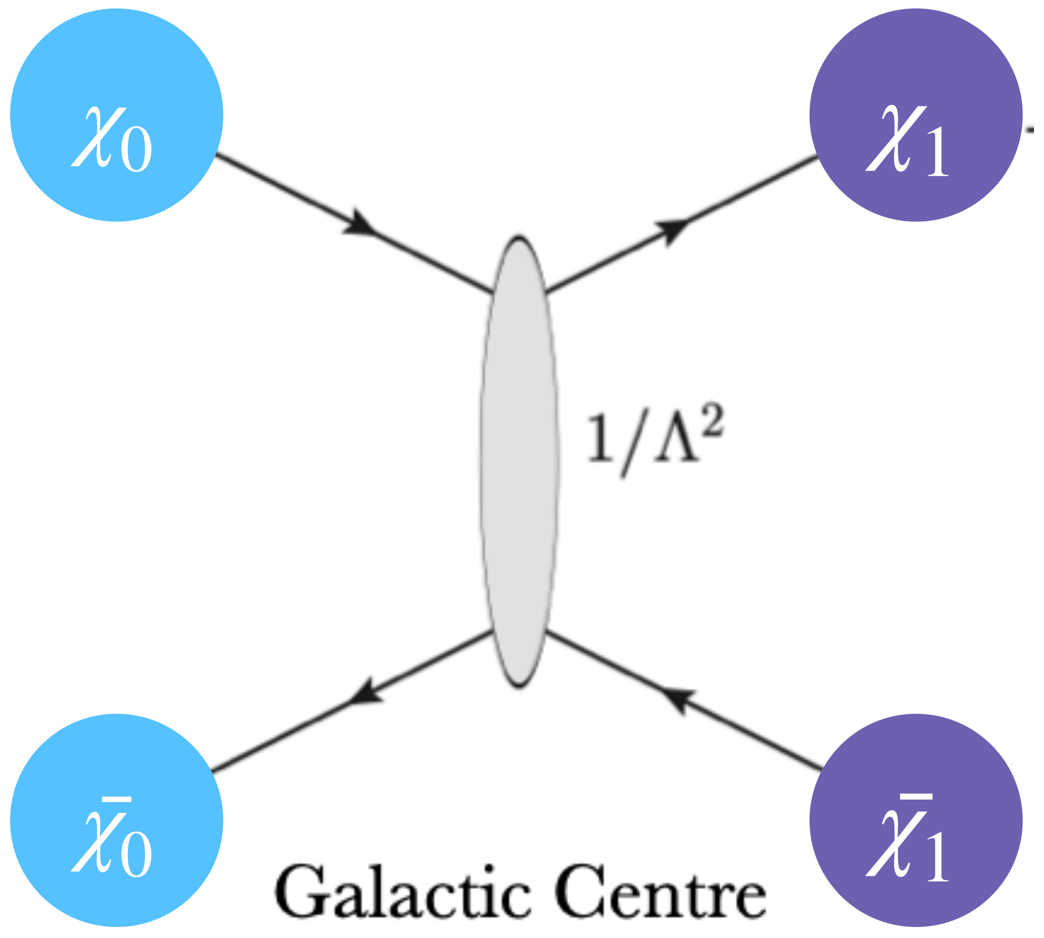
Two component model

2 dark matter components: χ_0 & χ_1 ($m_0 > m_1$)

χ_1 created by χ_0 self-annihilation: $\chi_0\overline{\chi_0} \rightarrow \chi_1\overline{\chi_1}$

Dominant χ_0 , subdominant χ_1, only χ_1 couples to SM

Boosted dark matter can then be detected via e^- or nuclei scattering in terrestrial detectors



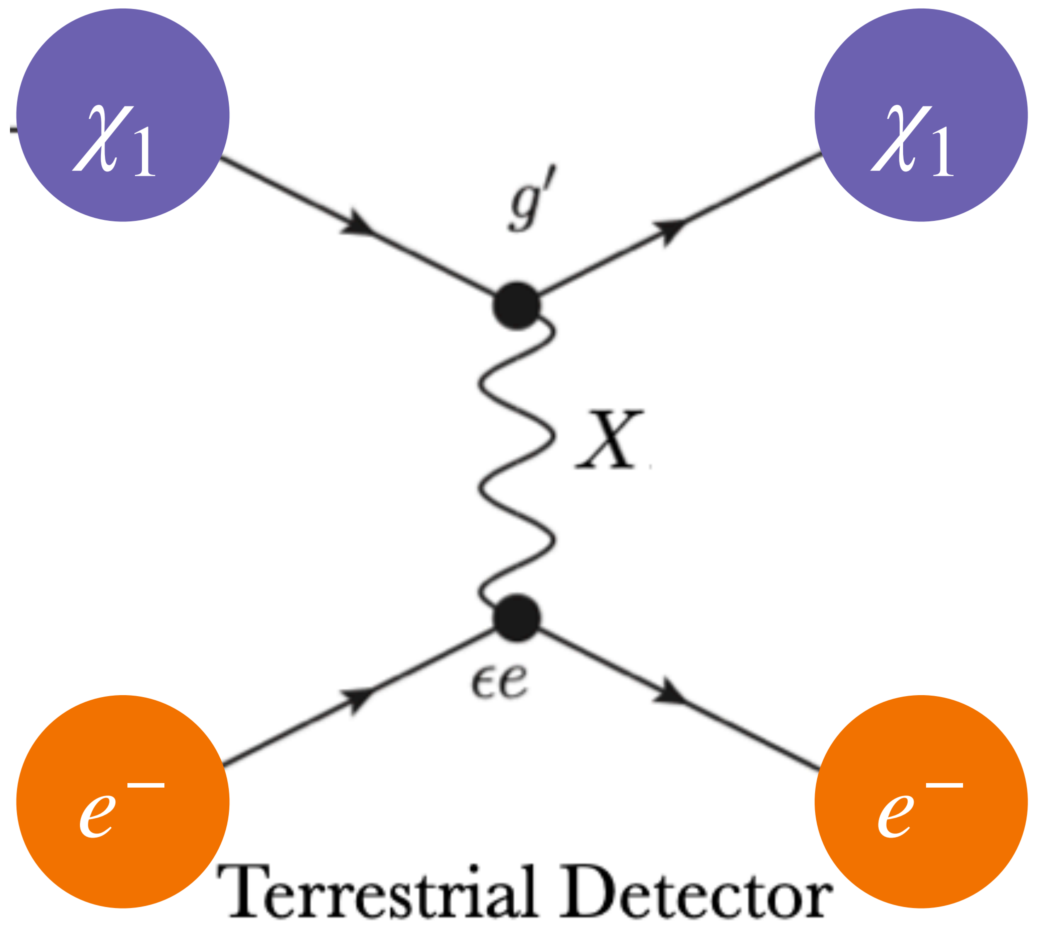
χ_1 kinematically boosted due to mass difference by a factor $\gamma = \dfrac{m_0}{m_1}$

↓

BDM has higher energy than equivalent 'normal' WIMP DM with mass m_1

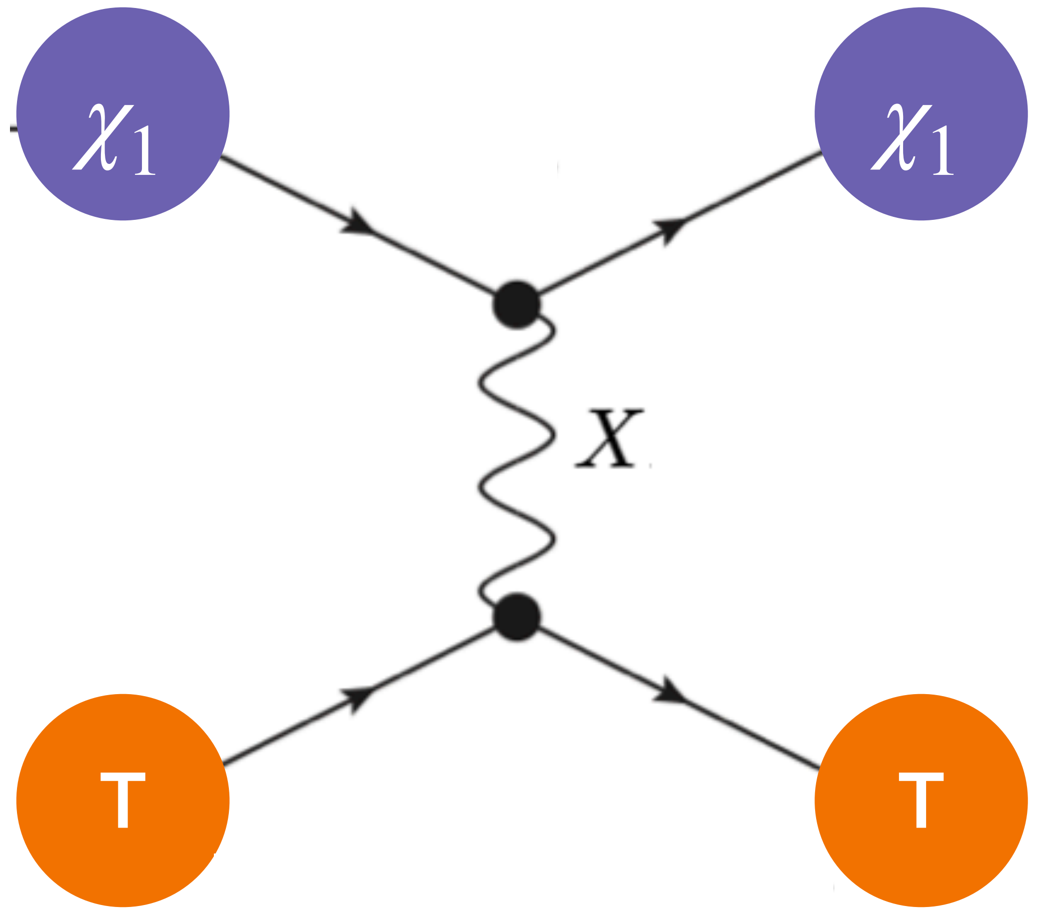
↓

Can probe lower masses



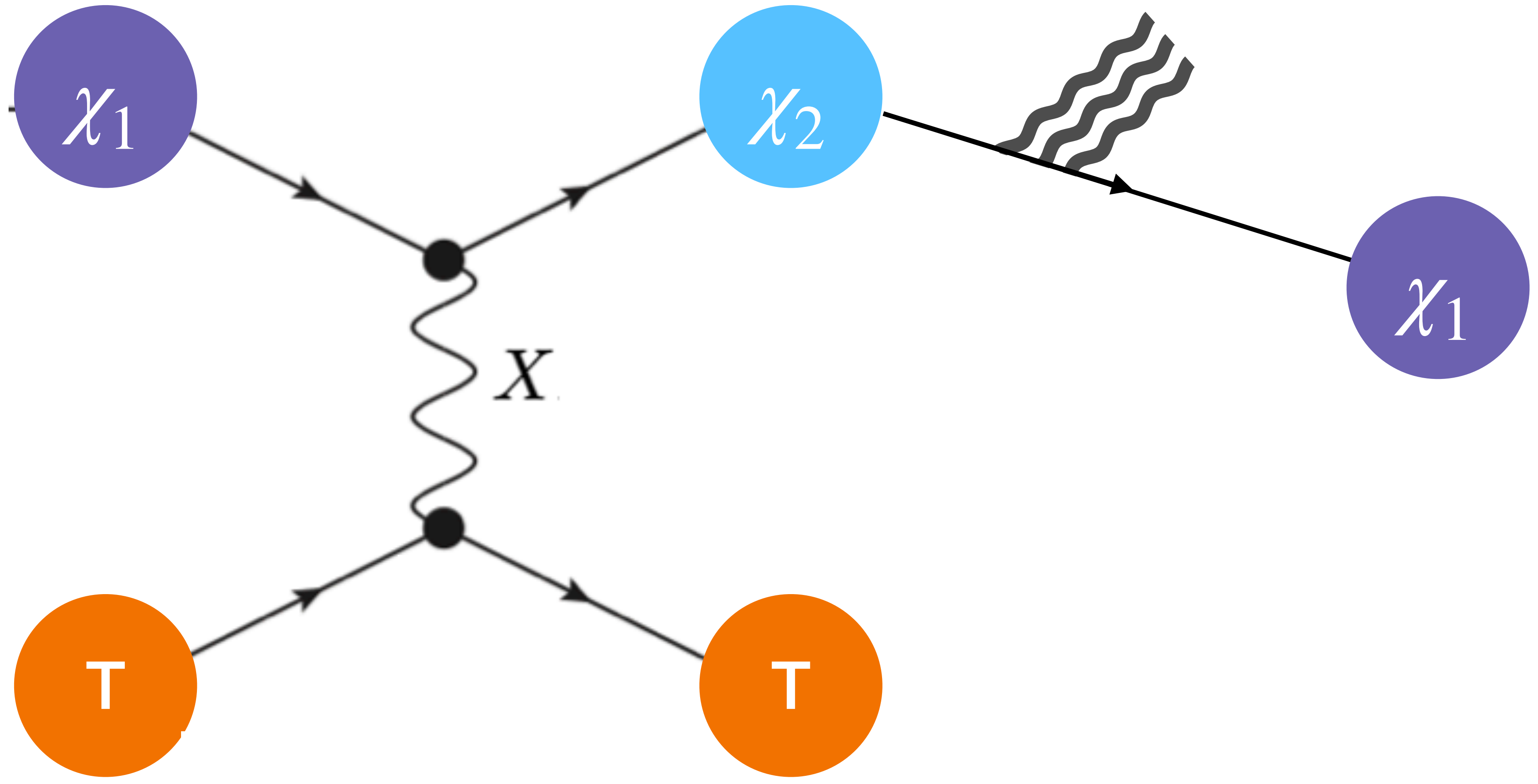
Boosted dark matter: expected interactions

Elastic scattering



Target: e^- or nucleus

Inelastic scattering

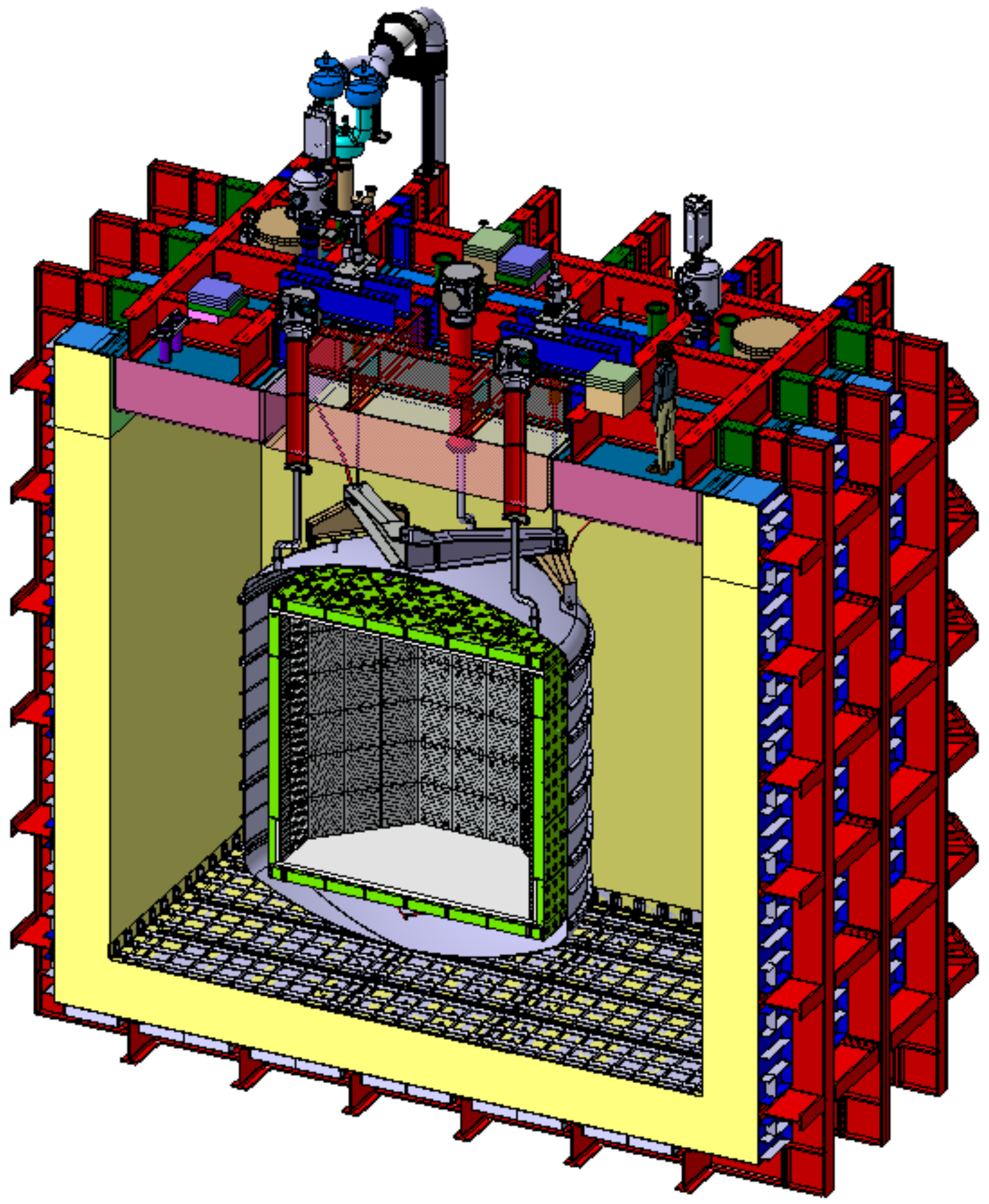


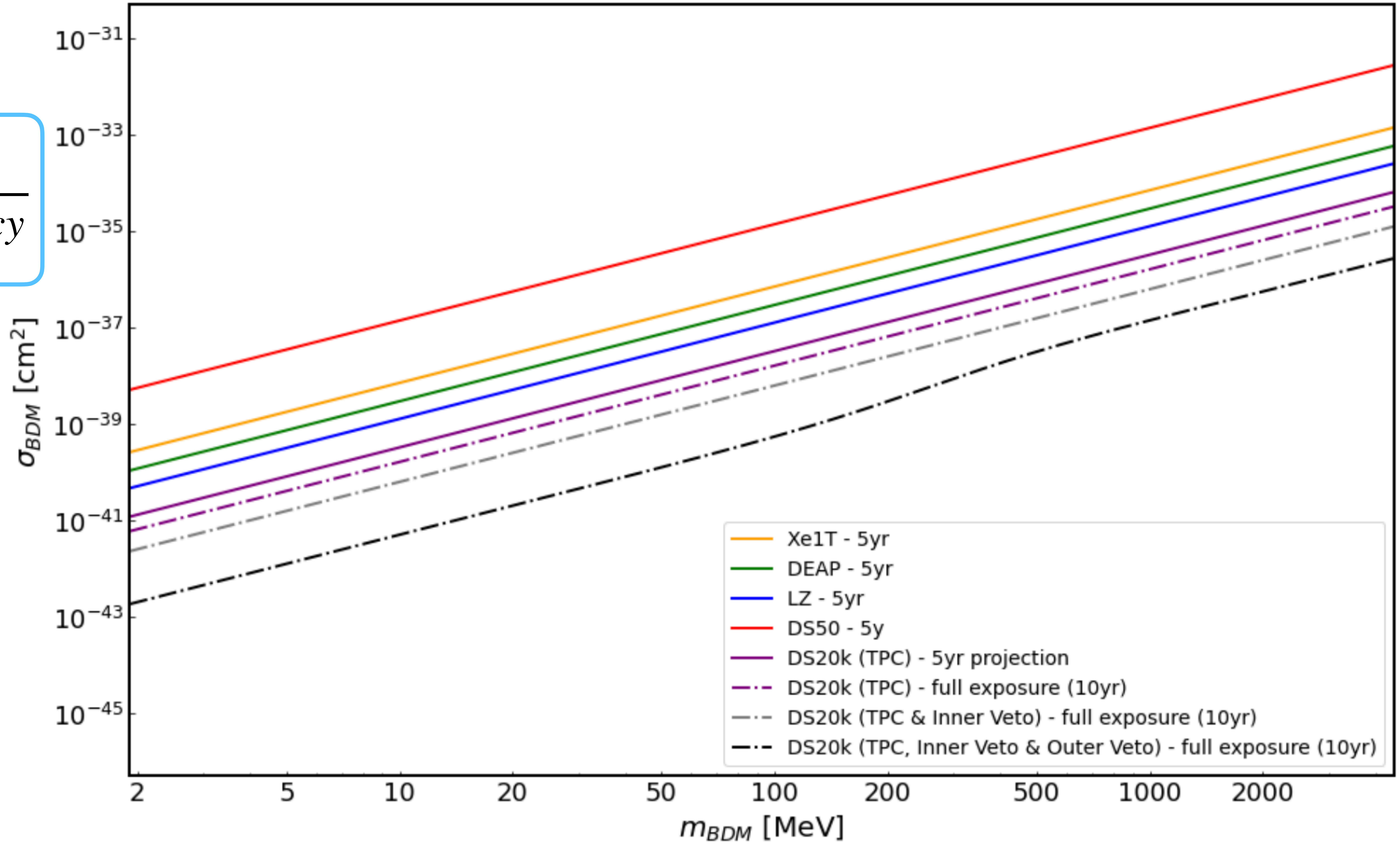
χ_1 scatters to an unstable particle (χ_2) following interaction in detector

χ_2 decays back to χ_1 —> detector resolution limits if this is detectable or merged with primary interaction

Poisson counting limit: zero background 90% CL

$$\sigma > \frac{2.3}{t_{exp} \times N_T \times Flux \times Efficiency}$$

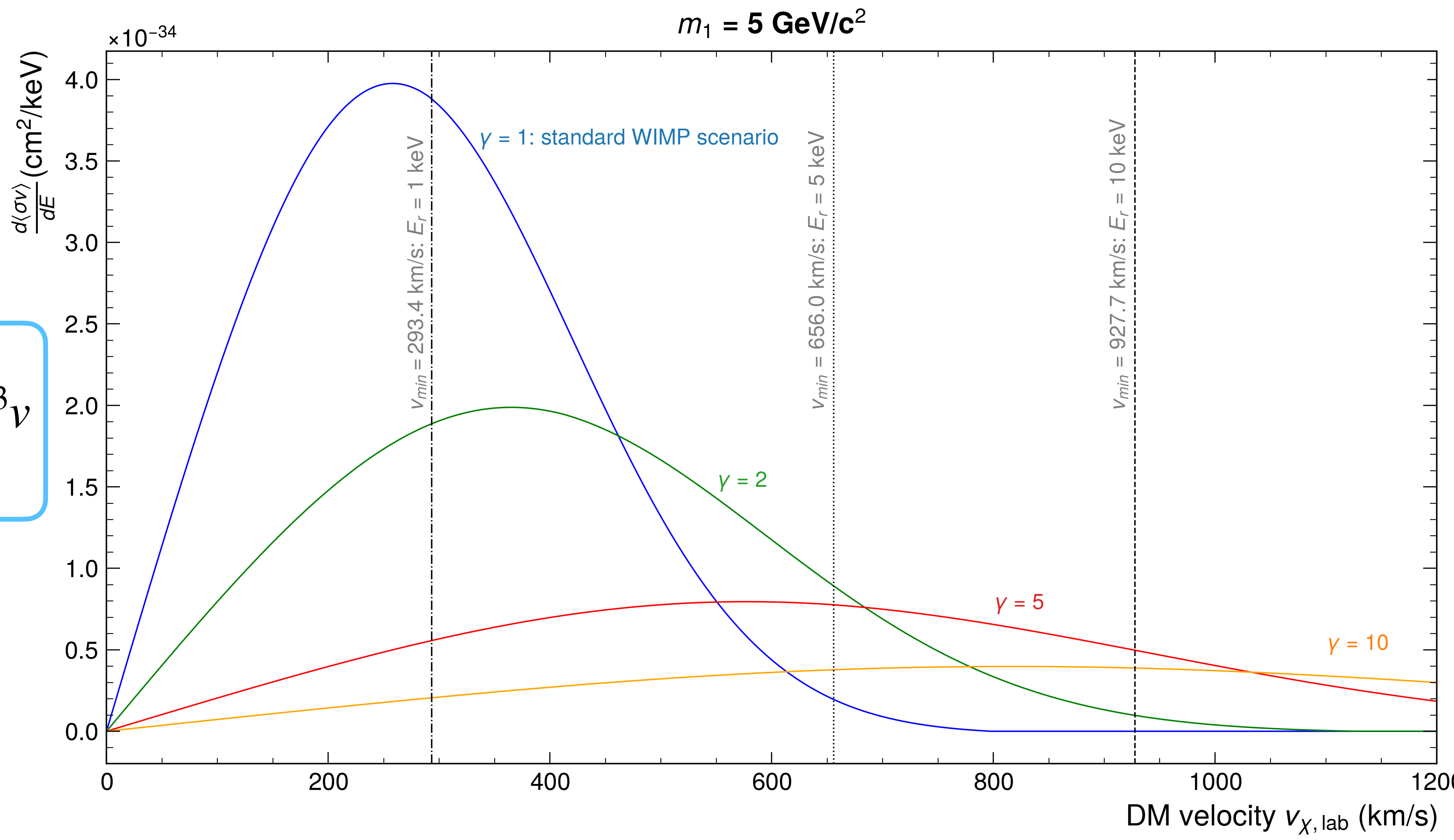




Elastic nuclear recoils: expected BDM event rate

$$\frac{dR}{dE_r} = \frac{1}{m_T}\frac{\rho_\chi}{m_\chi}\int_{|v|>v_{\min}}^{\infty}\frac{d\sigma}{dE_r}f(v;v_E)\,|v|\,d^3v$$

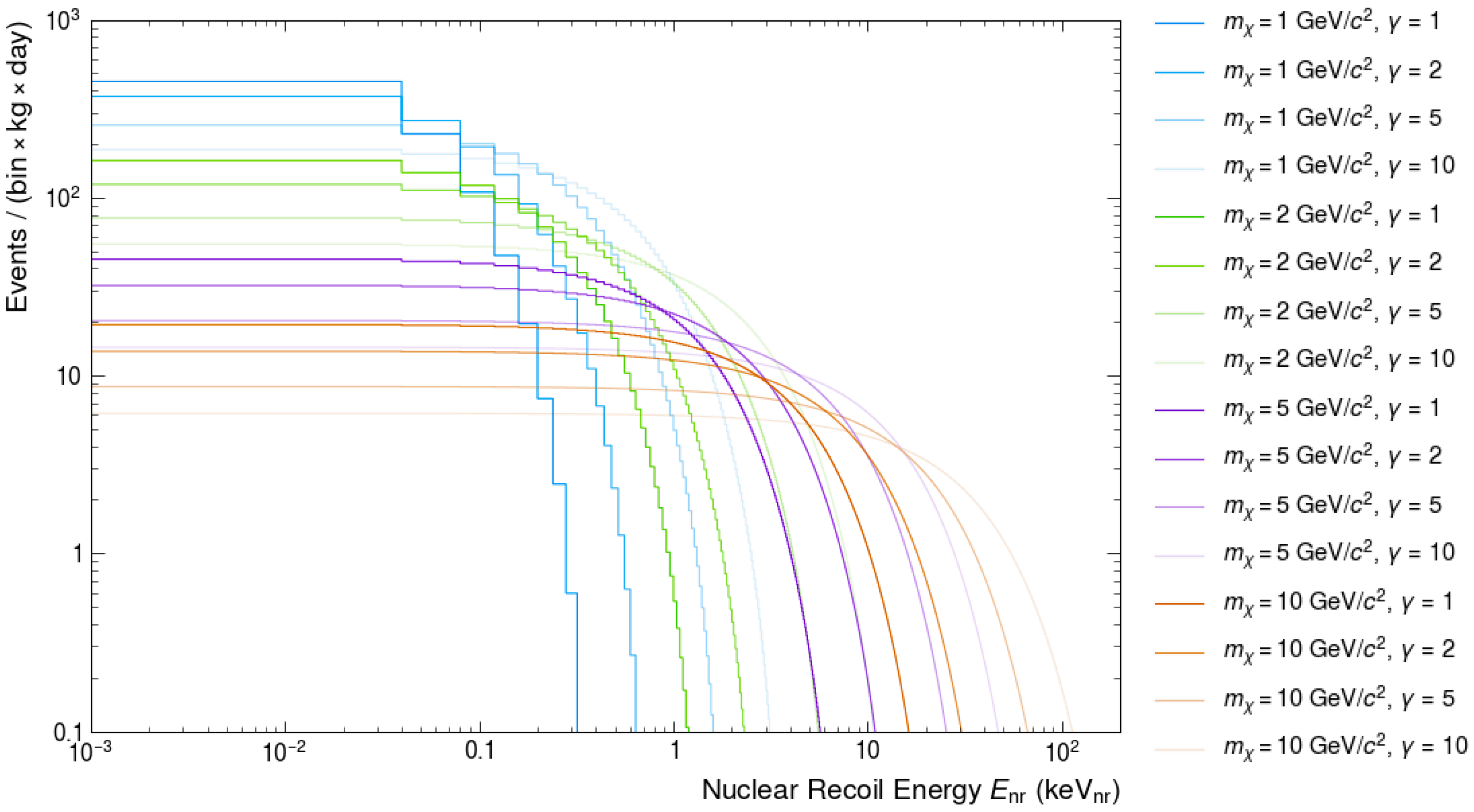
Assume:
$m_T = m_{\text{Argon}}$
$\rho_\chi = 0.3$ GeV/cm^3



Spectrum	% of spectrum above threshold $v_{min} = 293$ km/s	$v_{min} = 656$ km/s	$v_{min} = 927$ km/s
$\gamma = 1$ (blue)	86.47	32.36	0
$\gamma = 2$ (green)	96.62	83.09	66.18
$\gamma = 5$ (red)	99.46	97.29	94.59
$\gamma = 10$ (yellow)	99.86	99.32	98.65

Energy spectra: boosted dark matter signal

$\gamma = 1$ corresponds to standard WIMP scenario



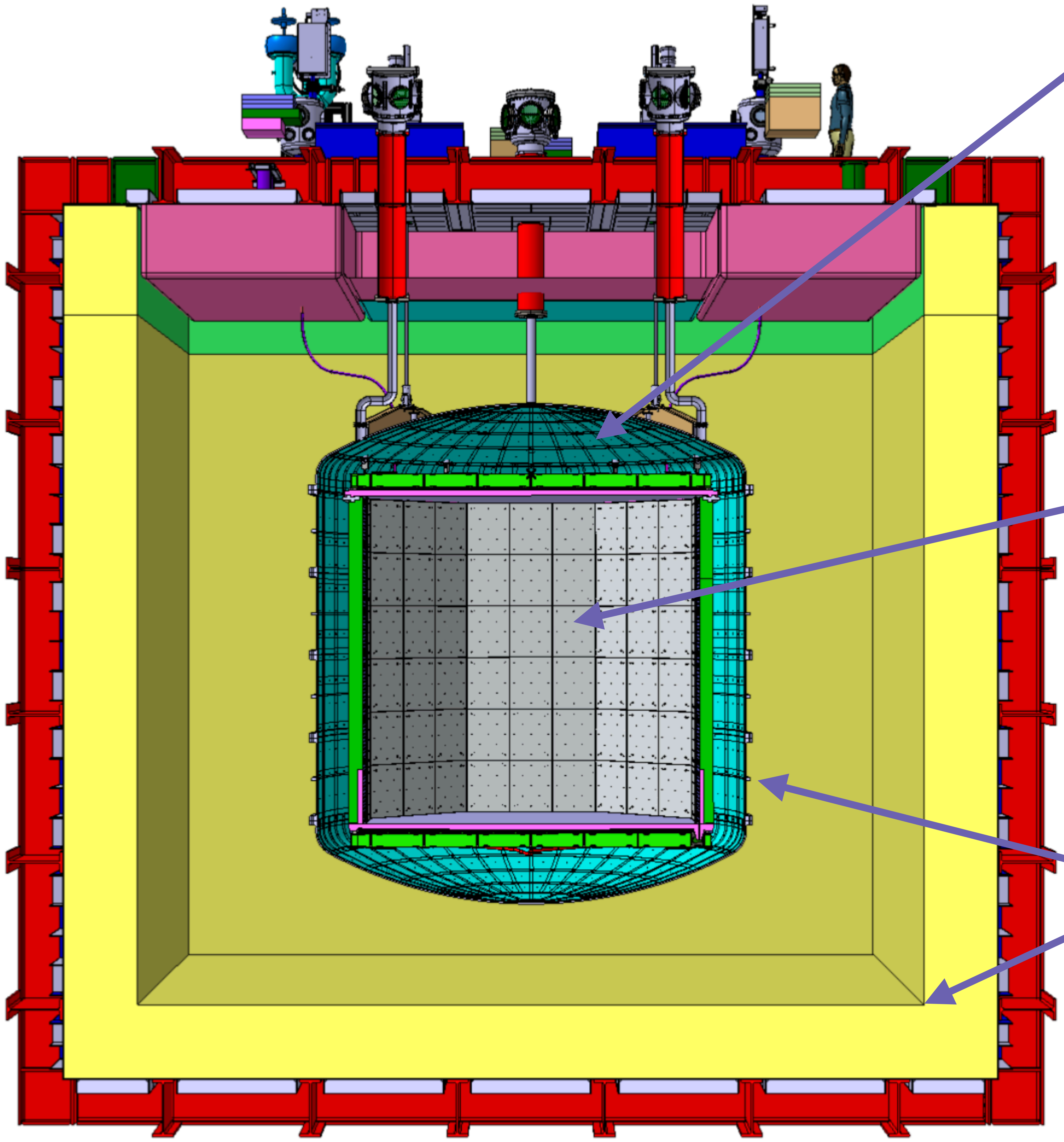
Backgrounds: sources and mitigations

Cosmogenic muons

→ Underground detectors and instrumented muon veto

Radiogenic neutrons

→ Instrumented neutron veto



Radioactive contaminants from photosensors

→ Radio assay photosensor materials

^{39}Ar & ^{85}Kr β decays from LAr bulk

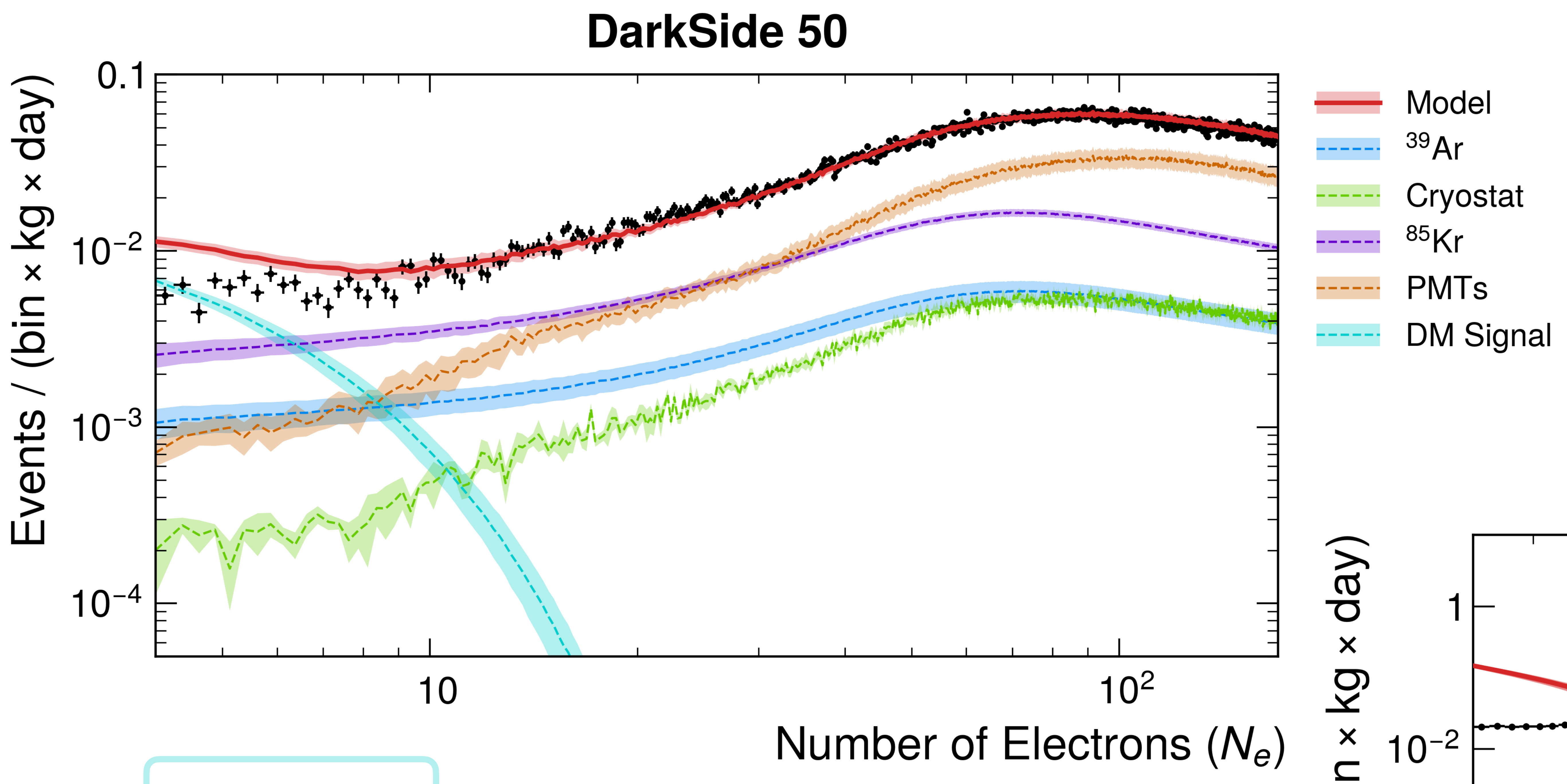
→ Purified UAr

Radioactive contaminants from detector materials

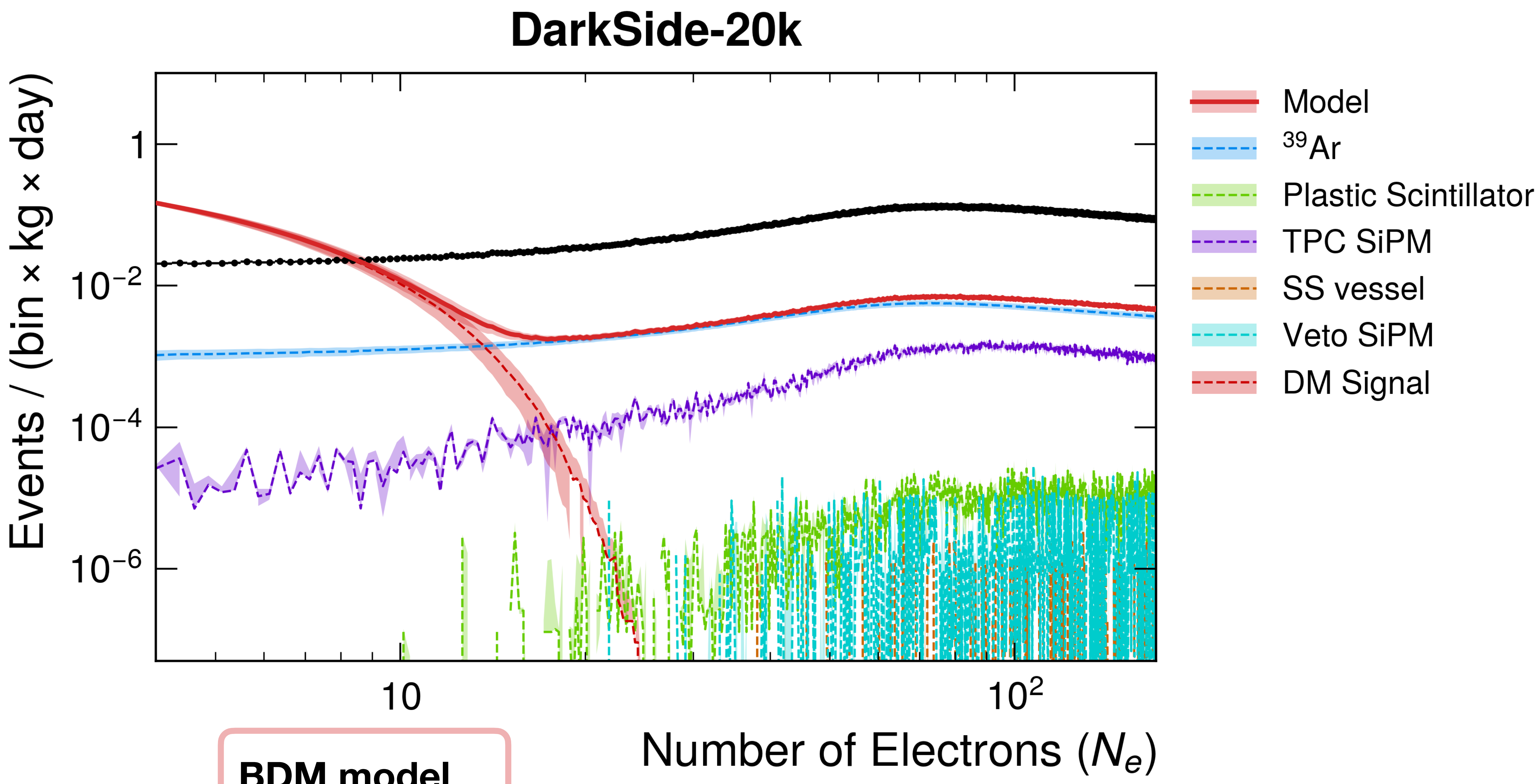
→ Radio assay materials

Detector response: ionisation spectra

Shaded bands represent systematic errors

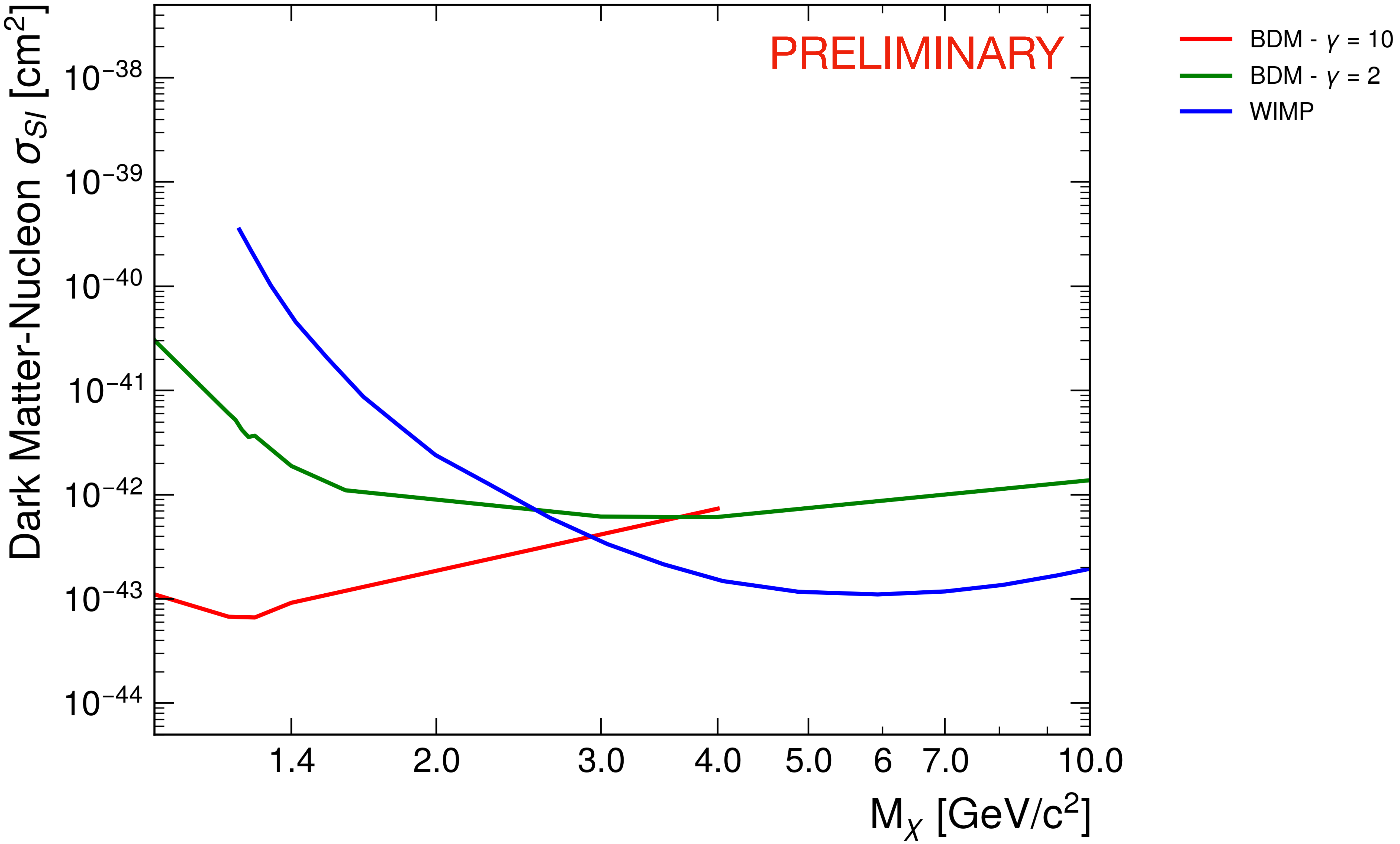


BDM model
$m_\chi = 2$ GeV
$\gamma = 2$



BDM model
$m_\chi = 2$ GeV
$\gamma = 2$

Projected sensitivity: DarkSide-50



DS-20k sensitivity in progress

Conclusions & future work

- DarkSide-50 and DarkSide-20k: both use LAr to search for GeV - TeV scale WIMPs

- Two-component boosted dark matter model presented

    —> dark matter velocity boosted, generates higher energy recoils, allowing lower DM masses to be probed in existing detectors

- Projected sensitivity presented for DarkSide-50

    —> Sensitivity gained at lower masses

- Zero background sensitivity in DarkSide-20k shows promising potential

    —> 2 - 4 orders of magnitude increased sensitivity compared to DarkSide-50

    —> PLR in progress

Back up

What is Boosted Dark Matter?

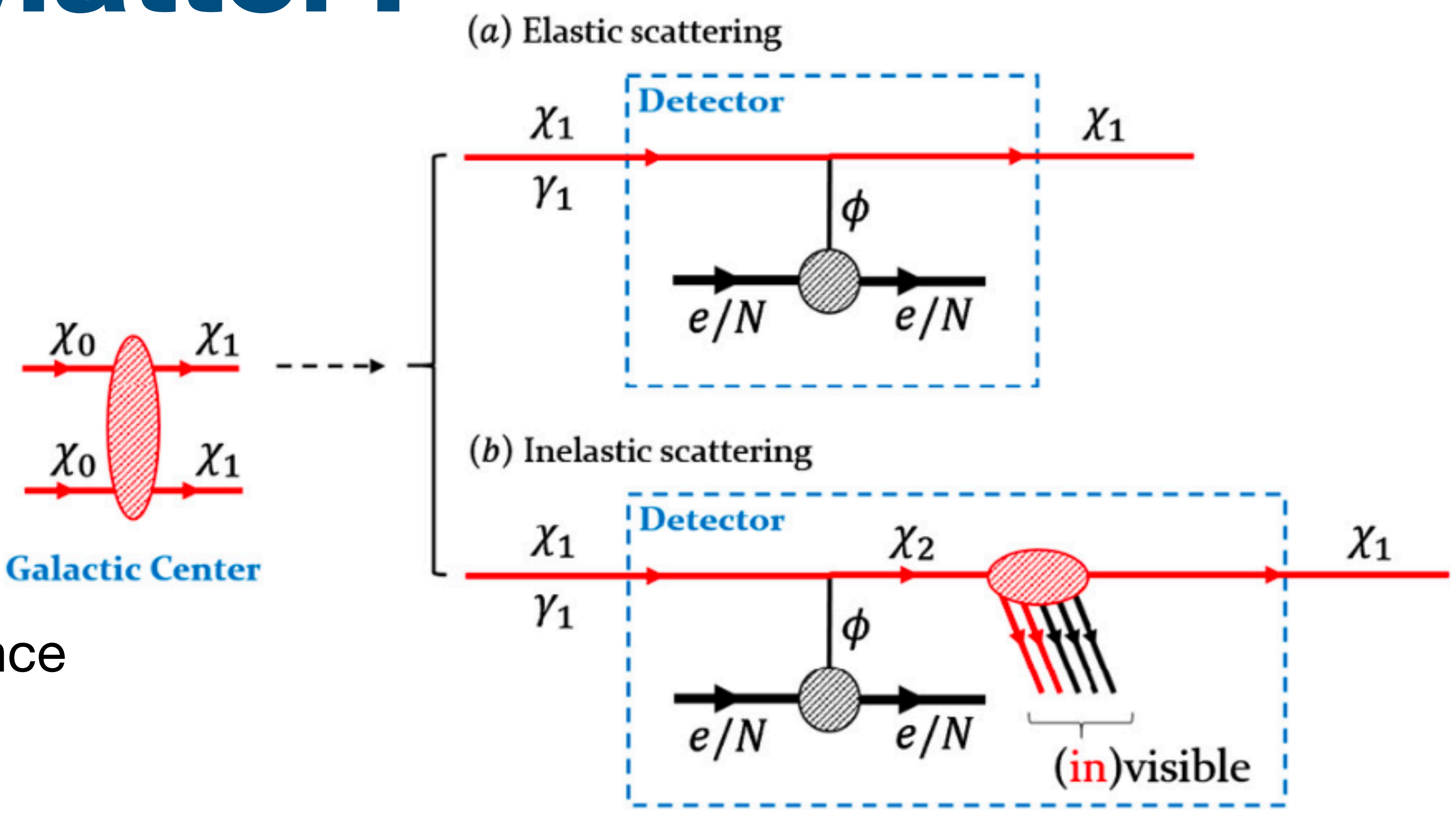
BDM formation and properties

- 2 DM components: dominant χ_0 and subdominant χ_1
  $m_0 > m_1$

- χ_1 forms by self-annihilation of χ_0 in galactic centre:
  $\chi_0\overline{\chi_0} \rightarrow \chi_1\overline{\chi_1}$

- χ_1 is kinematically Lorentz boosted (γ_1) due to mass difference between 2 components
  - higher energy ($E_1 = \gamma_1 m_1$) compared to equivalent 'normal' DM with mass m_1, allowing lower masses to be probed

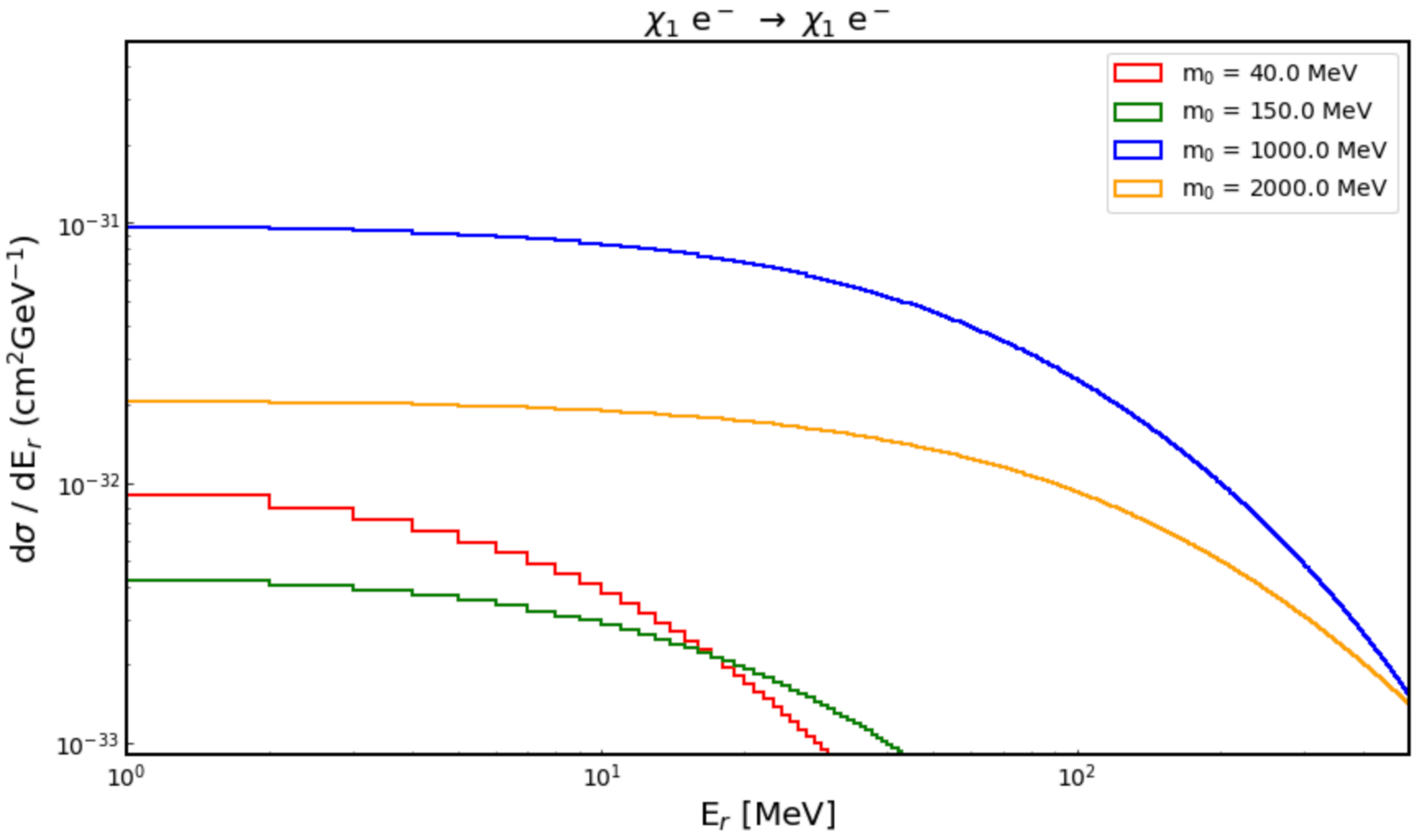
- Only χ_1 couples to SM
  - BDM could then be detected via e^- or nuclei scattering in terrestrial detectors
  - Paper refs



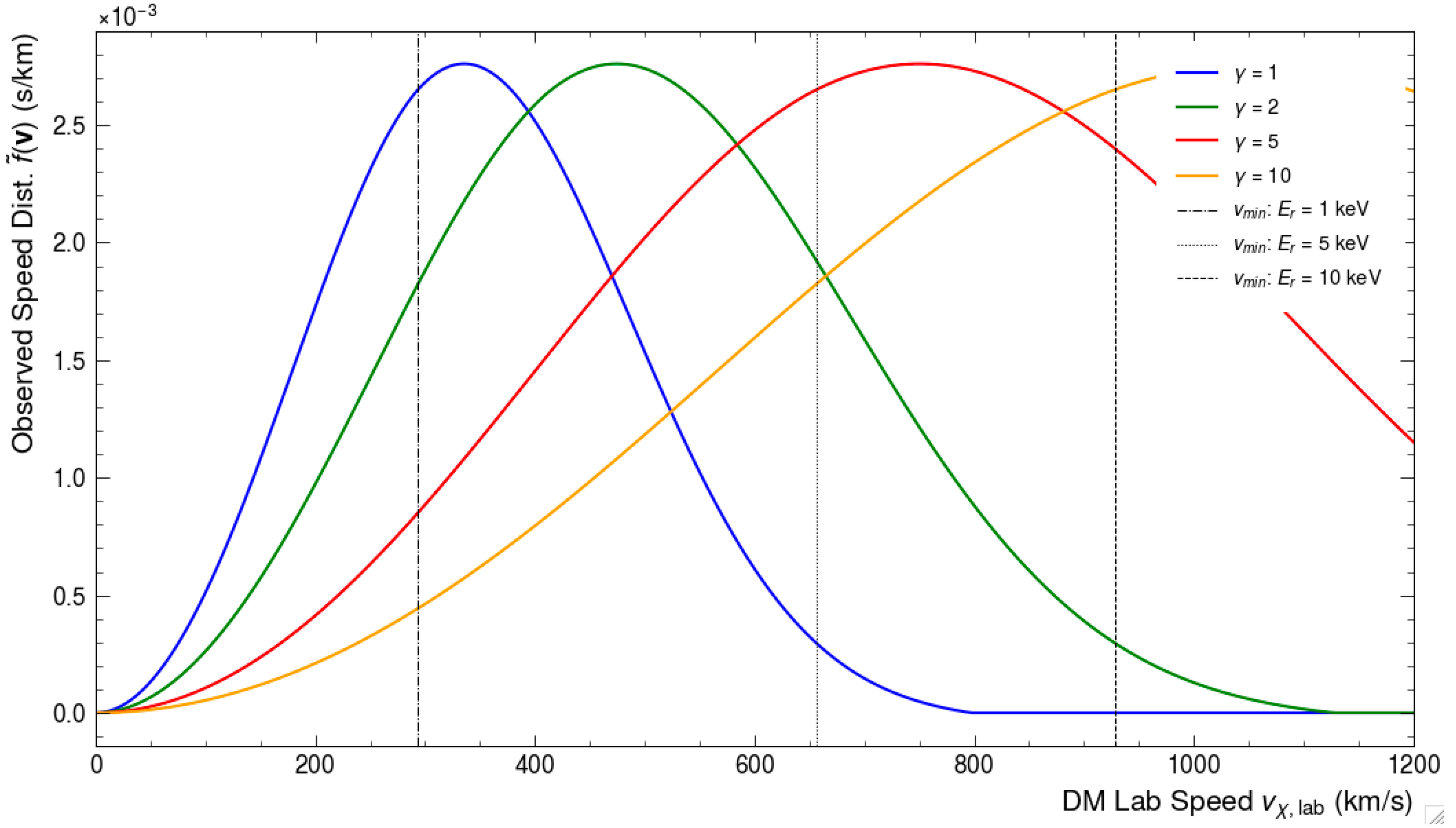
Expected event rate

$$\frac{dR}{dE_r} = \frac{1}{m_T}\frac{\rho_\chi}{m_\chi}\int_{|v|>v_{\min}}^{\infty}\frac{d\sigma}{dE_r}f\left(v;v_E\right)|v|\,d^3v$$

Differential cross-section



Velocity distribution



Expected flux