Constraints on dark matter-nucleon effective couplings with DEAP-3600 and prospects for the next campaign

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on behalf of the DEAP collaboration

International Conference on Identification of Dark Matter,
Wien, Austria, 18-22 July 2022

Outline

Context

Exploring different non-standard scenarios

Recovering sensitivity: Hardware upgrades

Prospects

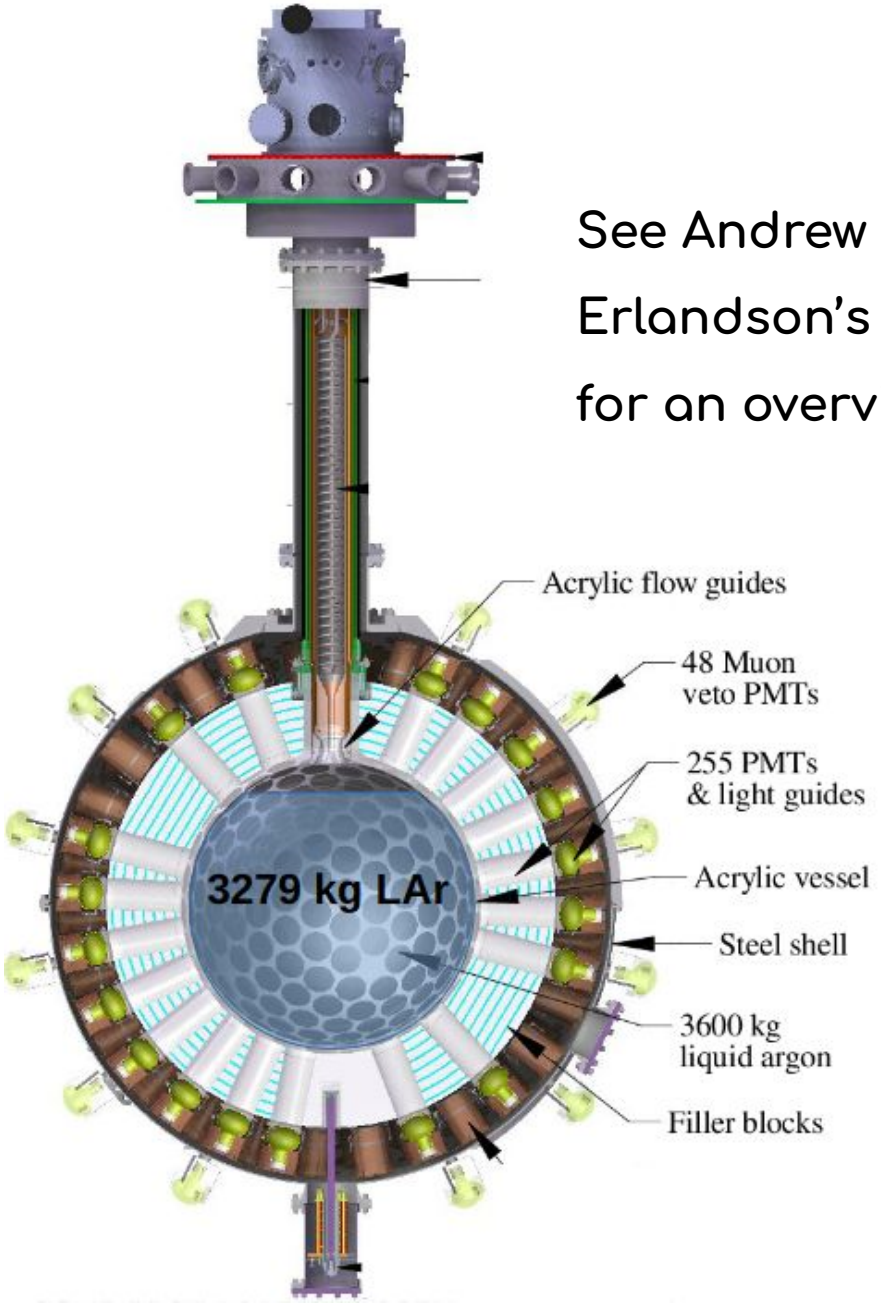
DEAP-3600

First DM detector with a target > 1 tonne

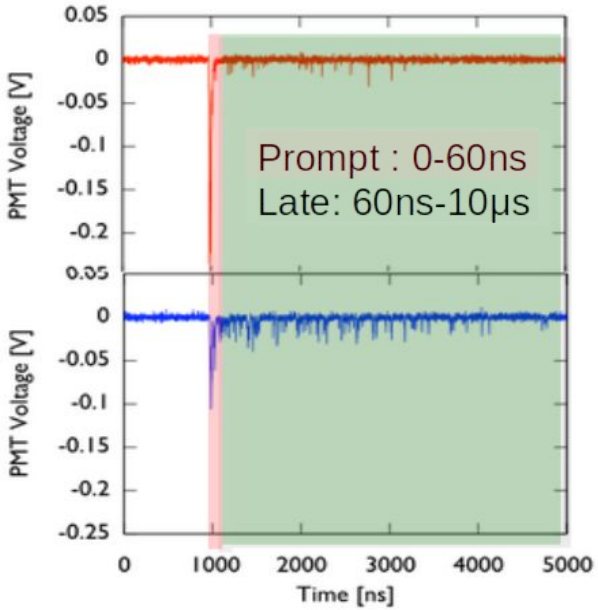
Most stringent limits for standard WIMP SI interaction with a non-Xe target

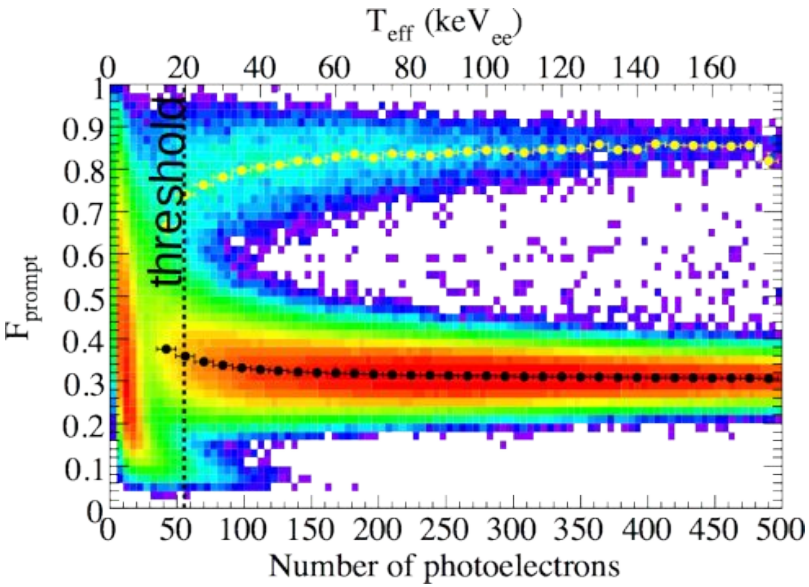
Ar allows for background rejection in single phase.

Potential path for next generation

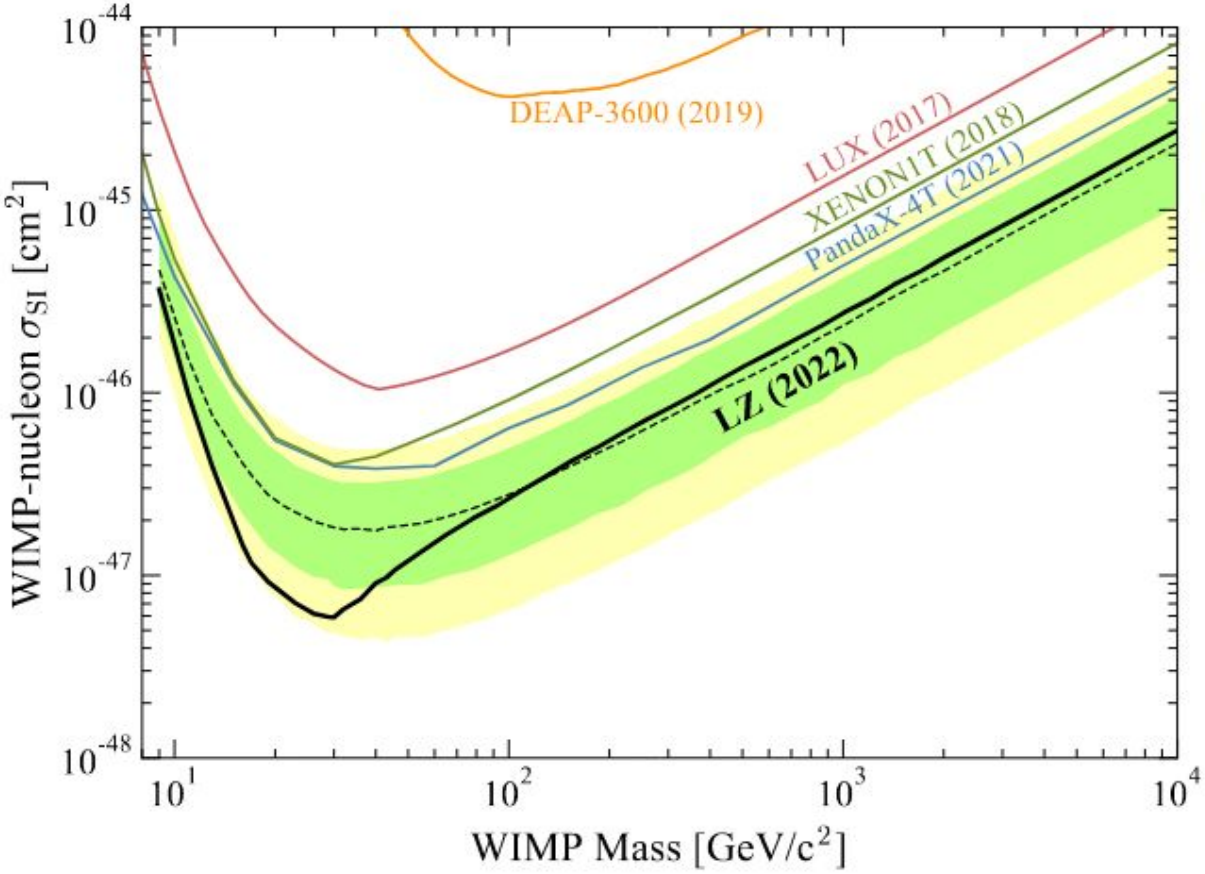


See Andrew Erlandson's slides for an overview



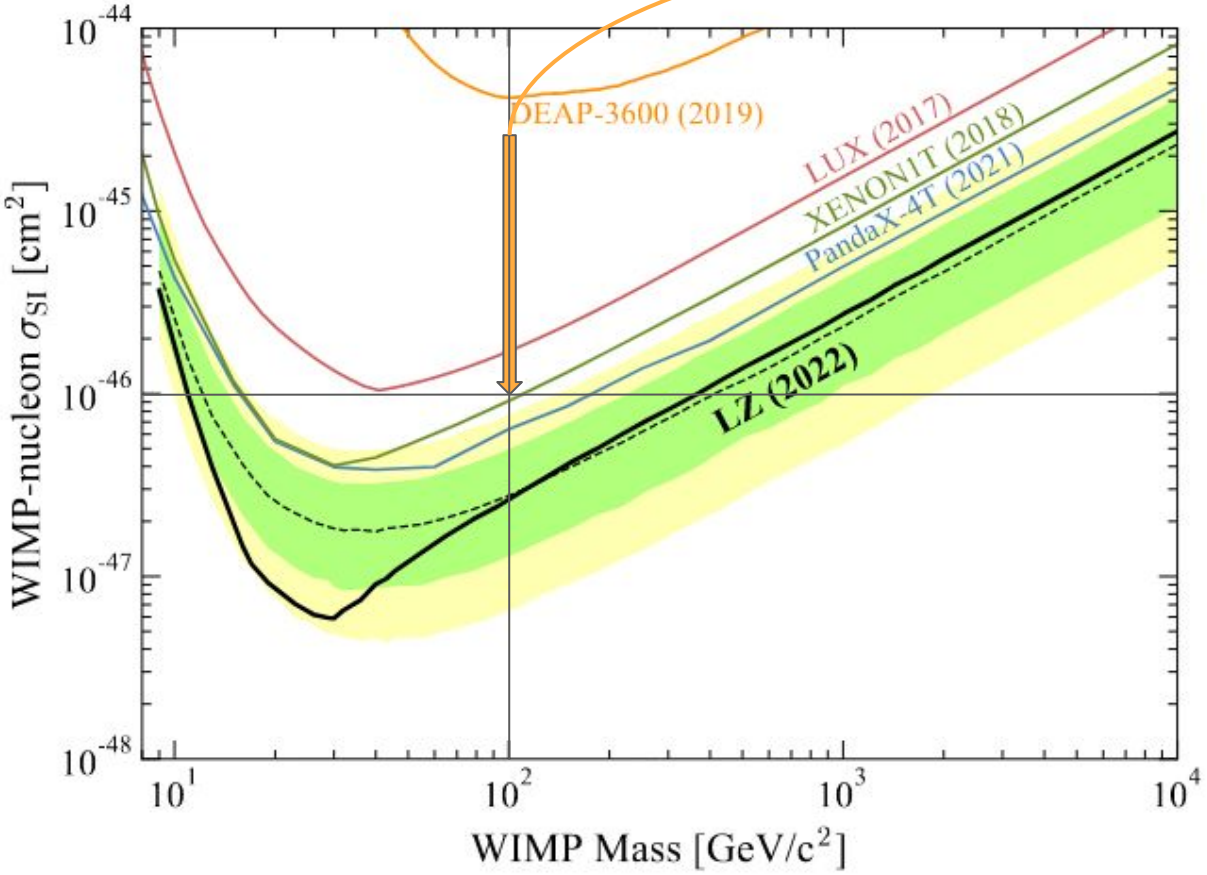


Current picture



Broadly accepted picture...

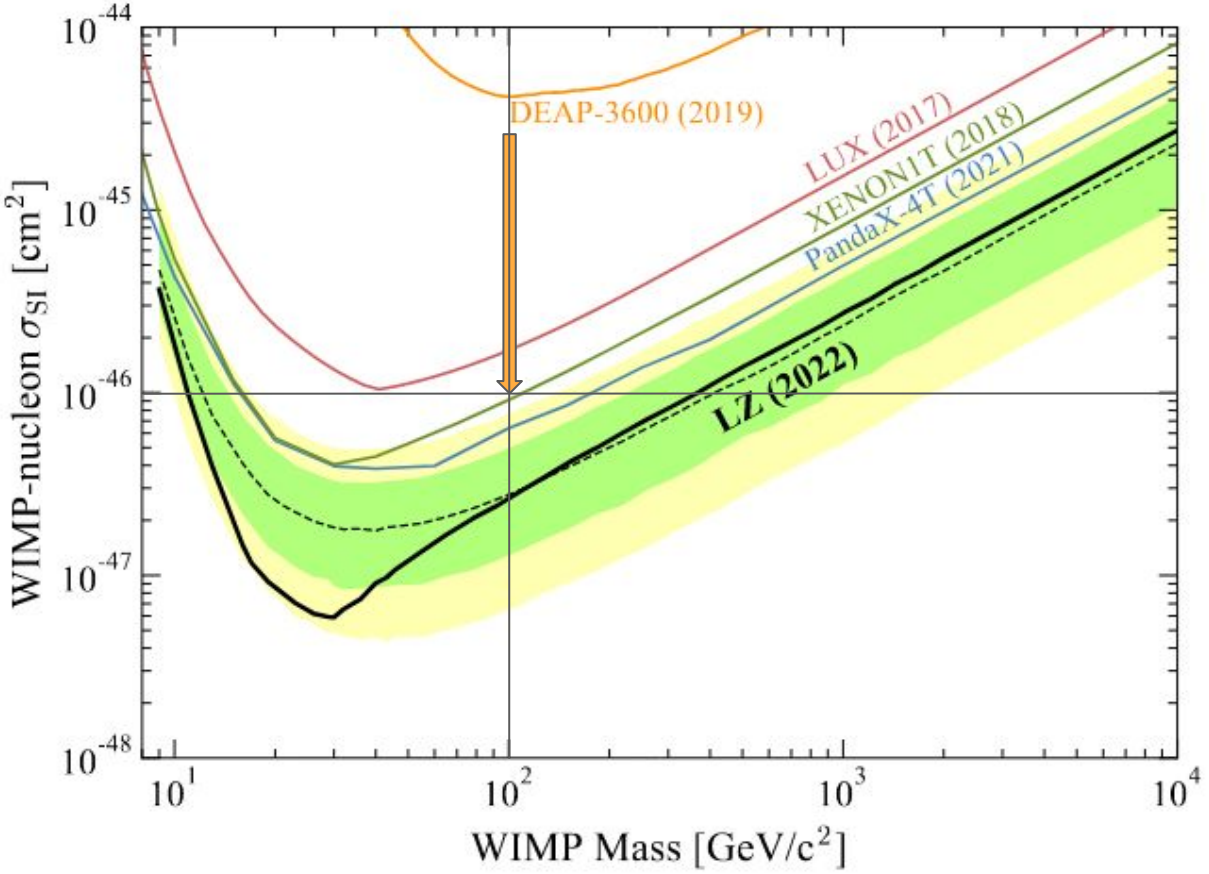
Current picture



Our goal

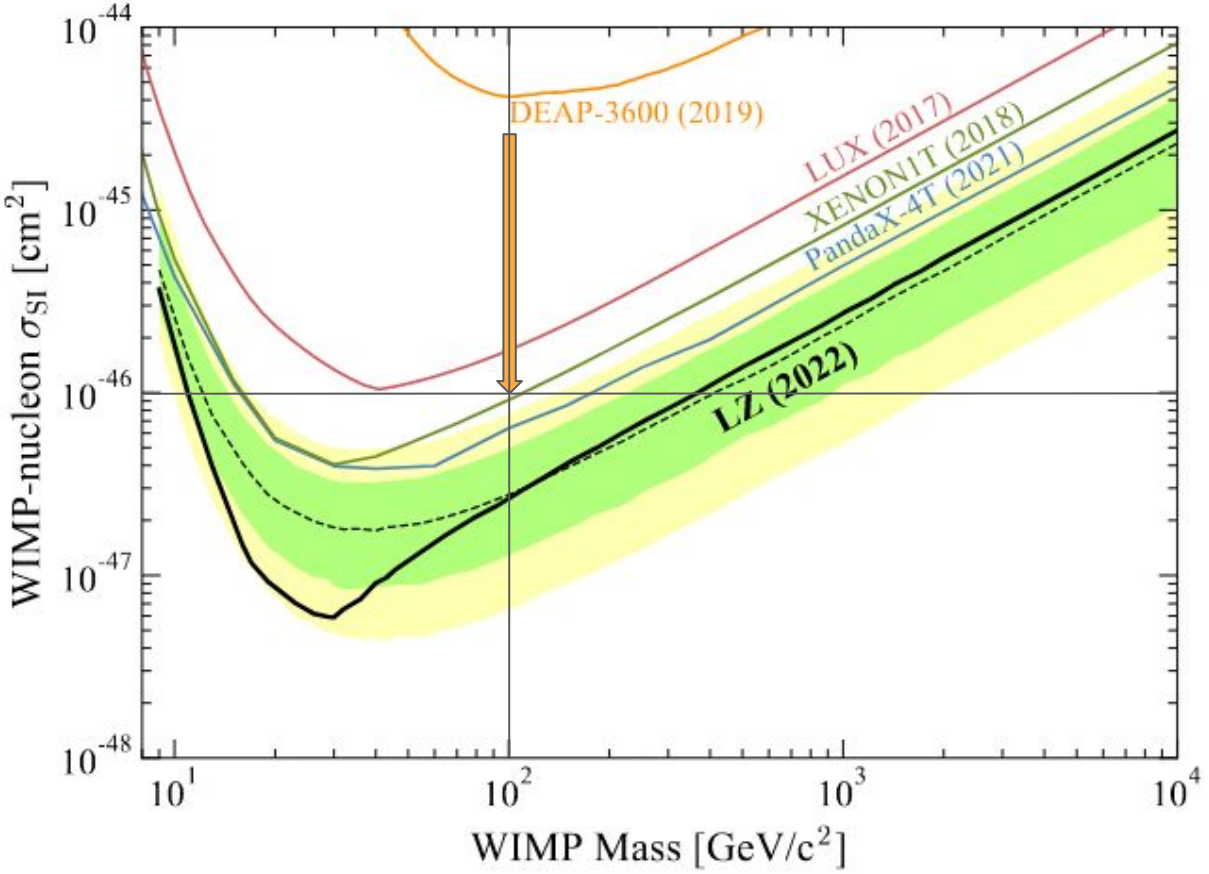
Broadly accepted picture...

Current picture



Broadly accepted picture... which relies on two unknowns:

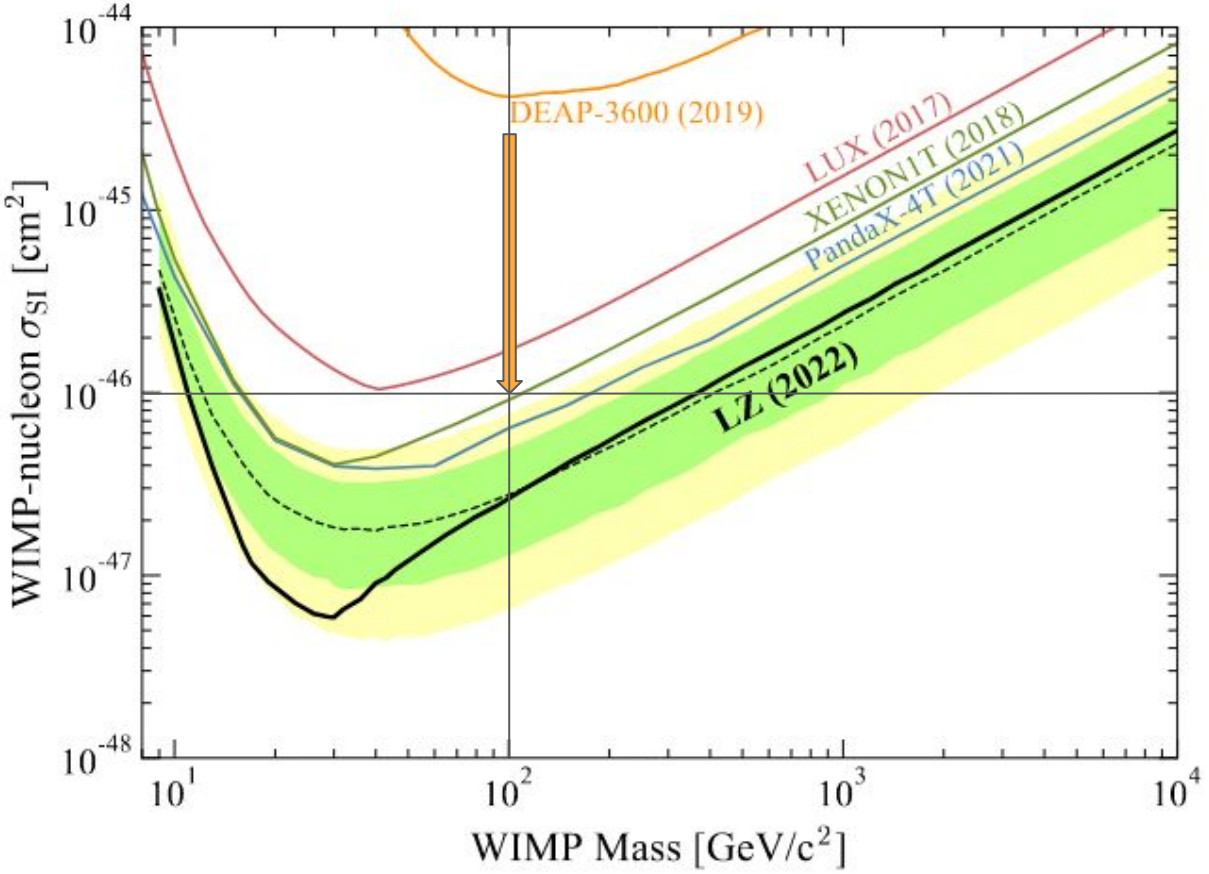
Current picture



Broadly accepted picture... which relies on two unknowns:

- Standard Halo Model
- DM-nucleon coupling

Current picture



Broadly accepted picture... which relies on two unknowns:

- Standard Halo Model
- DM-nucleon coupling

which is not essentially bad, but worth keeping an eye on

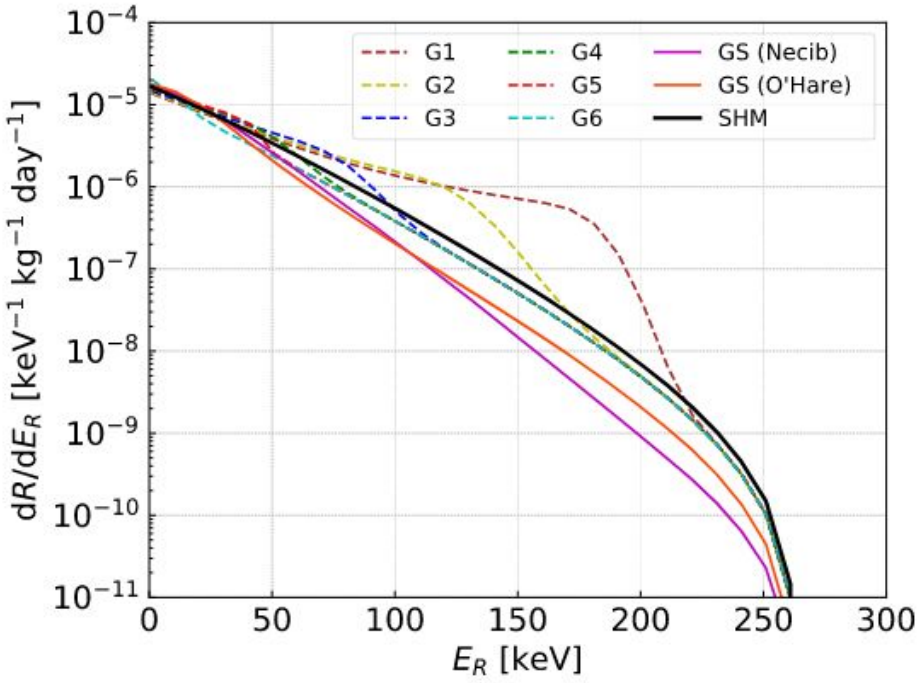
Exploring different scenarios

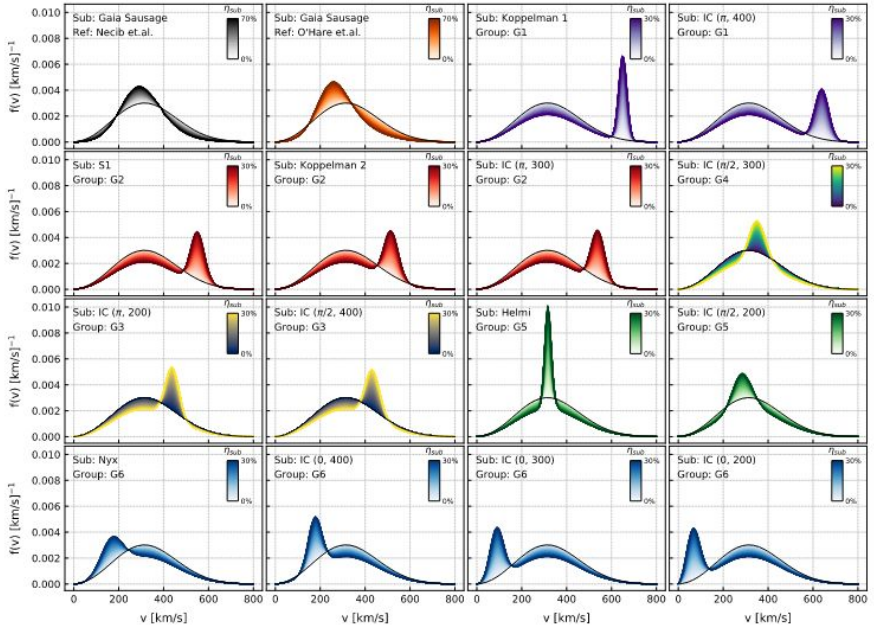
$$\frac{dR}{dE_R} = \frac{\rho_T}{m_T}\frac{\rho_\chi}{m_\chi}\varepsilon(E_R)\int_{v_{\min}}^{\infty} v f_\chi^{\oplus}(\vec{v})\frac{d\sigma}{dE_R}d^3\vec{v}$$

Recoil rate in Ar for

different WIMP distributions

	Substructure	Type	Reference
	Gaia Sausage (Necib *et al.*)	Debris flow	[60]
	Gaia Sausage (O'Hare *et al.*)	Debris flow	[17]
G1	Koppelman 1[a]	Stream	[19]
	IC (π, 400 km/s)	IC	···
G2	S1[a]	Stream	[17]
	Koppelman 2	Stream	[19]
	IC (π, 300 km/s)	IC	···
G3	IC (π, 200 km/s)[a]	IC	···
	IC ($\frac{\pi}{2}$, 400 km/s)	IC	···
G4	IC ($\frac{\pi}{2}$, 300 km/s)[a]	IC	···
G5	Helmi[a]	Stream	[19]
	IC ($\frac{\pi}{2}$, 200 km/s)	IC	···
G6	Nyx[a]	Stream	[18]
	IC (0, 400 km/s)	IC	···
	IC (0, 300 km/s)	IC	···
	IC (0, 200 km/s)	IC	···





Phys. Rev. D 102, 082001 – Published 22 October 2020; Erratum Phys. Rev. D 105, 029901 (2022)'

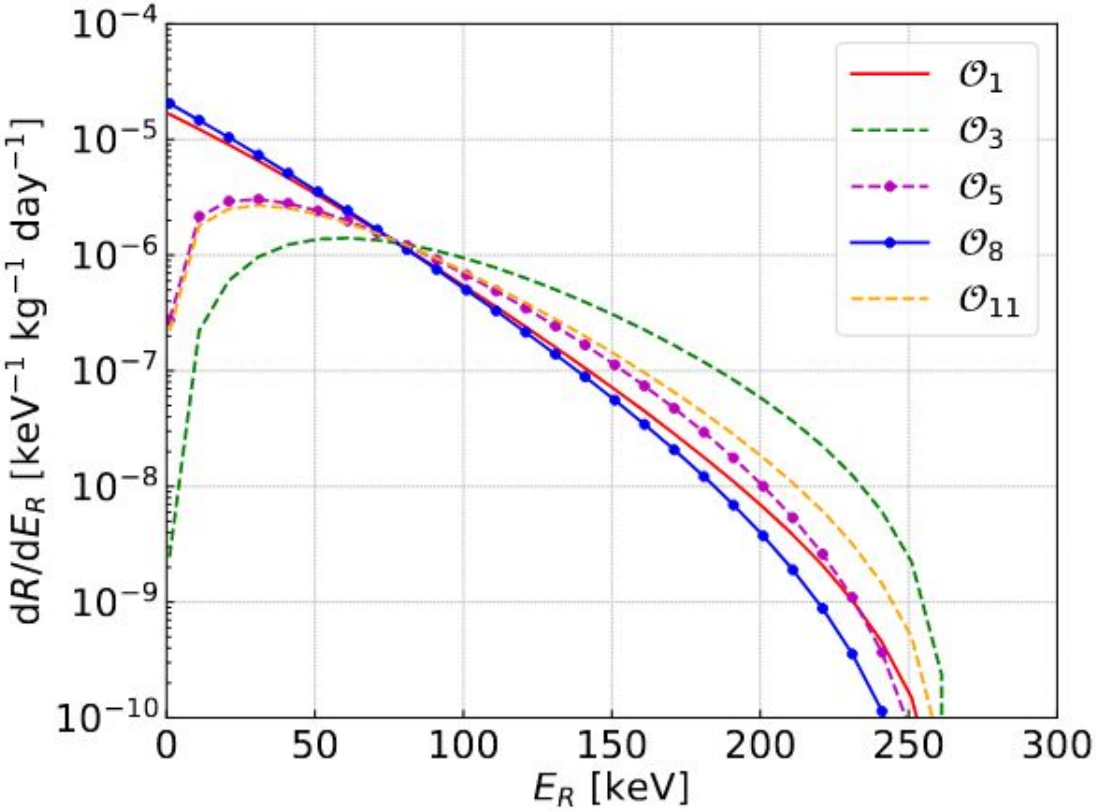
Exploring different scenarios

Recoil rate in Ar for

$$\mathcal{L}_{\rm int} = \sum_{N=n,p} \sum_i c_i^{(N)} \mathcal{O}_i \chi^+ \chi^- N^+ N^-$$

different non-relativistic effective operators

Phys. Rev. D 102, 082001 – Published 22 October 2020; Erratum Phys. Rev. D 105, 029901 (2022)'



$$\mathcal{O}_1 = 1_\chi 1_N,$$

$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp \right),$$

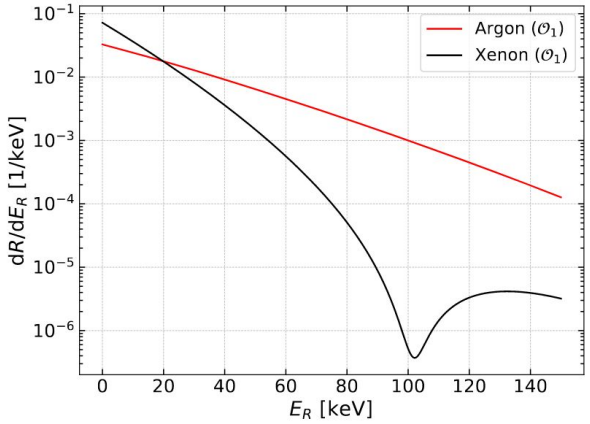
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp \right),$$

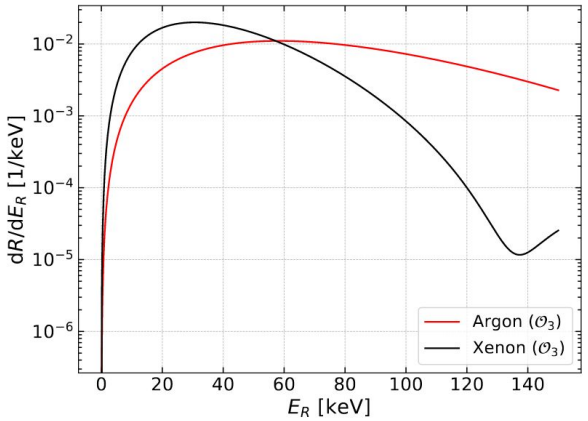
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}_\perp,$$

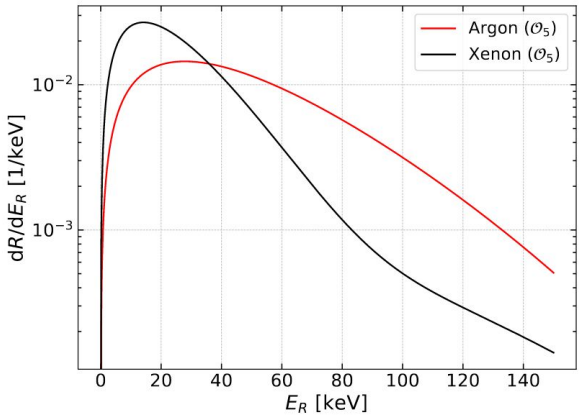
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N},$$

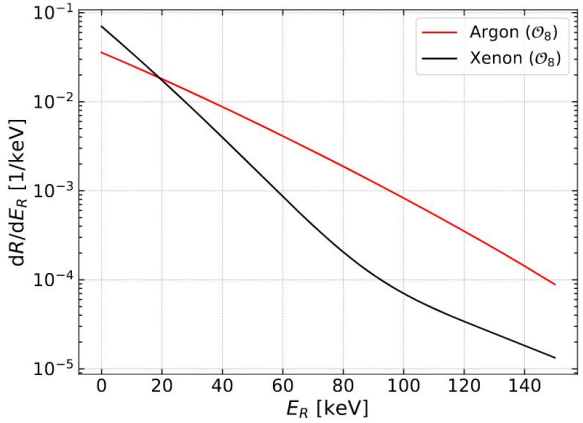
Exploring different scenarios

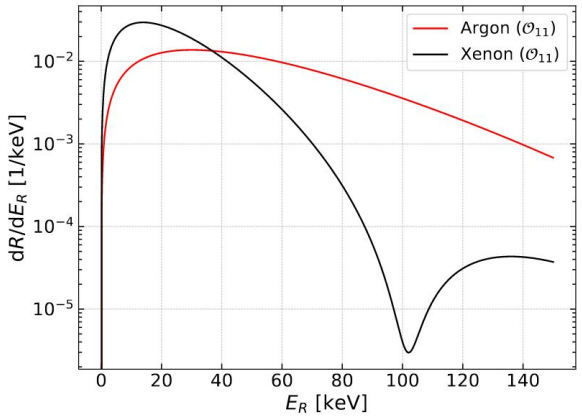
- Mχ = 100 GeV/c^2.
- Isoscalar coupling (cp = cn).
- Arbitrary cross section considered, just for comparison of shapes.









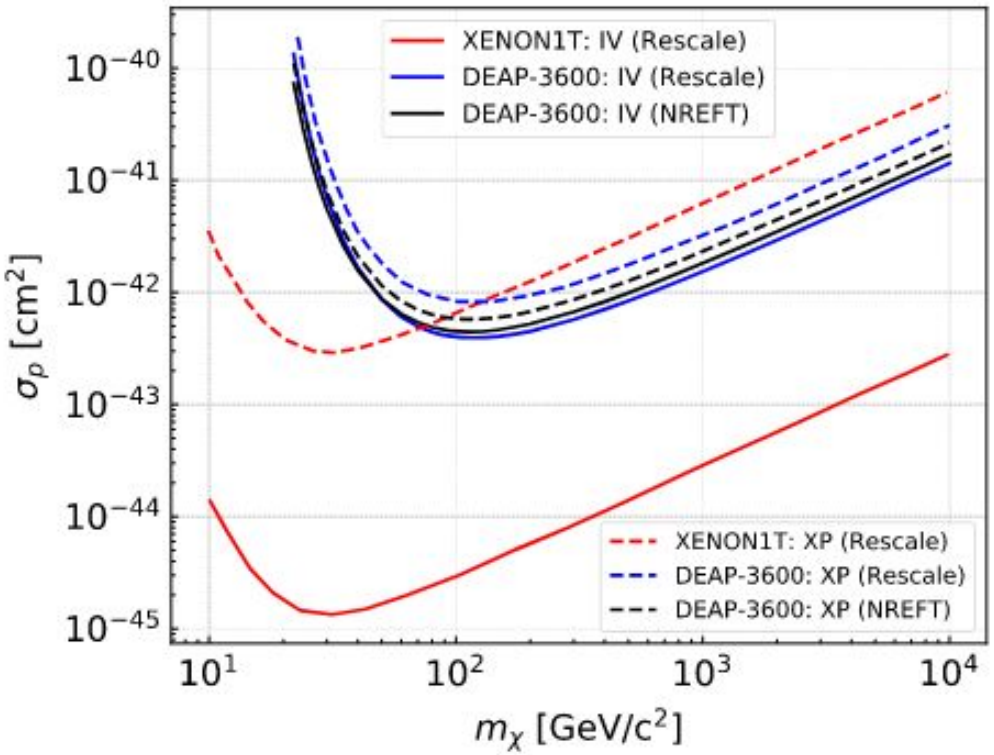


Exploring different scenarios

Recoil rate in Ar for

different c_i^0 / c_i^1 escenarios

Phys. Rev. D 102, 082001 – Published 22 October 2020; Erratum Phys. Rev. D 105, 029901 (2022)'



$$c_i^p \equiv (c_i^0 + c_i^1)/2$$

$$c_i^n \equiv (c_i^0 - c_i^1)/2$$

IS $c_i^n = c_i^p$

IV $c_i^n = -c_i^p$

XP $c_i^n / c_i^p = -0.7$

Prospects in a nutshell

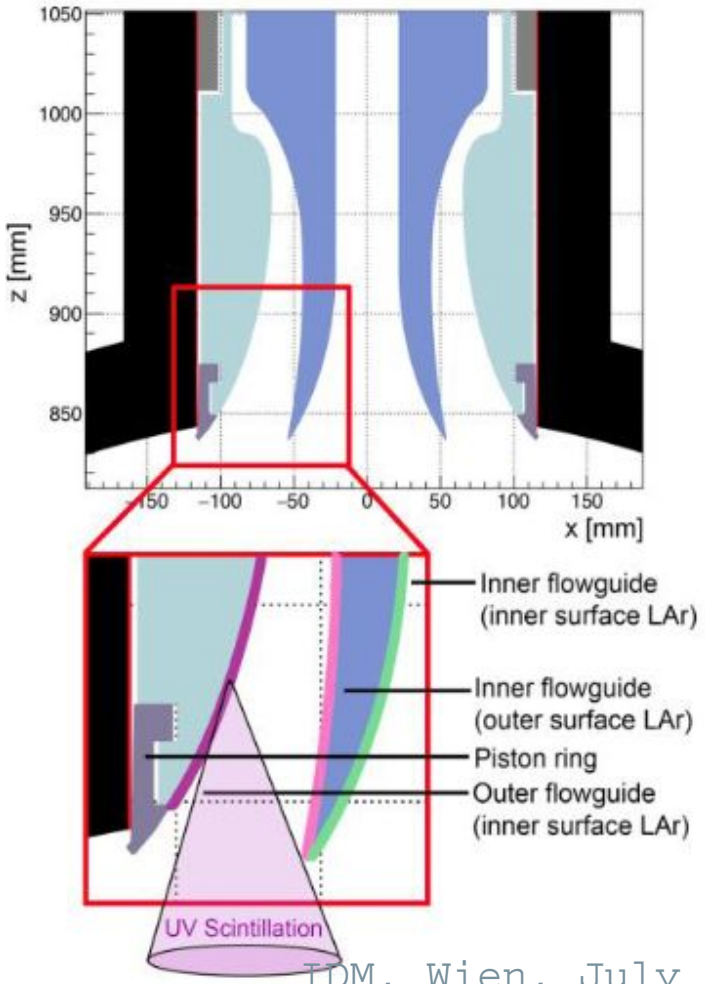
1. Tackle limiting factors to WIMP sensitivity (hardware upgrades)

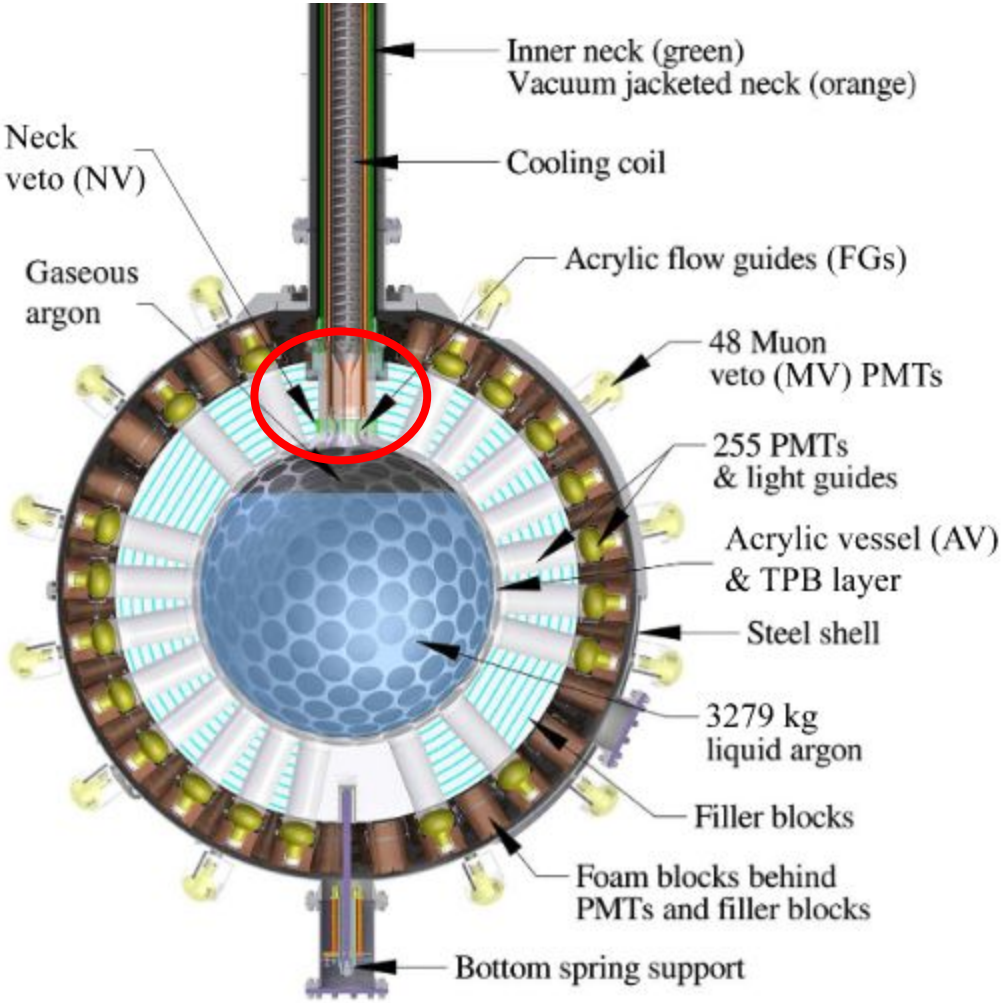
2. Finalize refined analyses (better detector model + Profile likelihood + machine learning) and unblind

3. Exploit this science machine and learn for DarkSide-20k and ARGO

Recovering sensitivity

Bkg 1: surface ^{210}Po on the neck (above target)

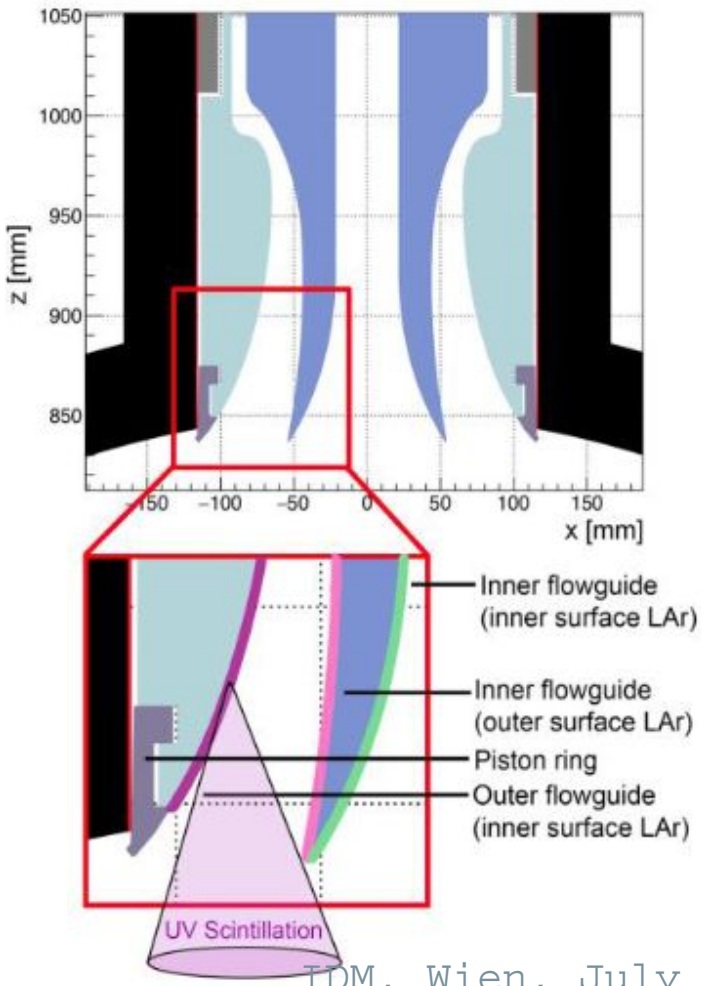


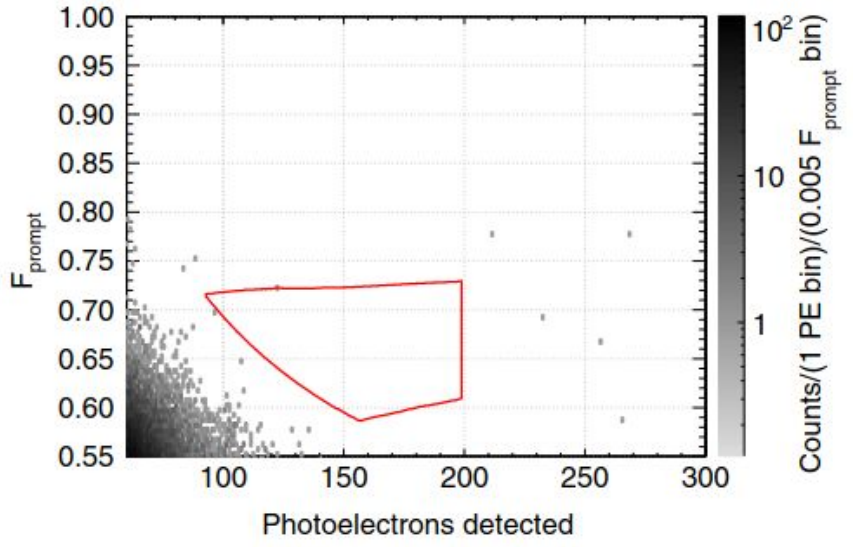


PRD, 100 (2019), p 022004

Recovering sensitivity

Bkg 1: surface ^{210}Po on the neck (above target)





Unfortunate combination of:

· Surface activity

· Condensation on neck surf. ⬆

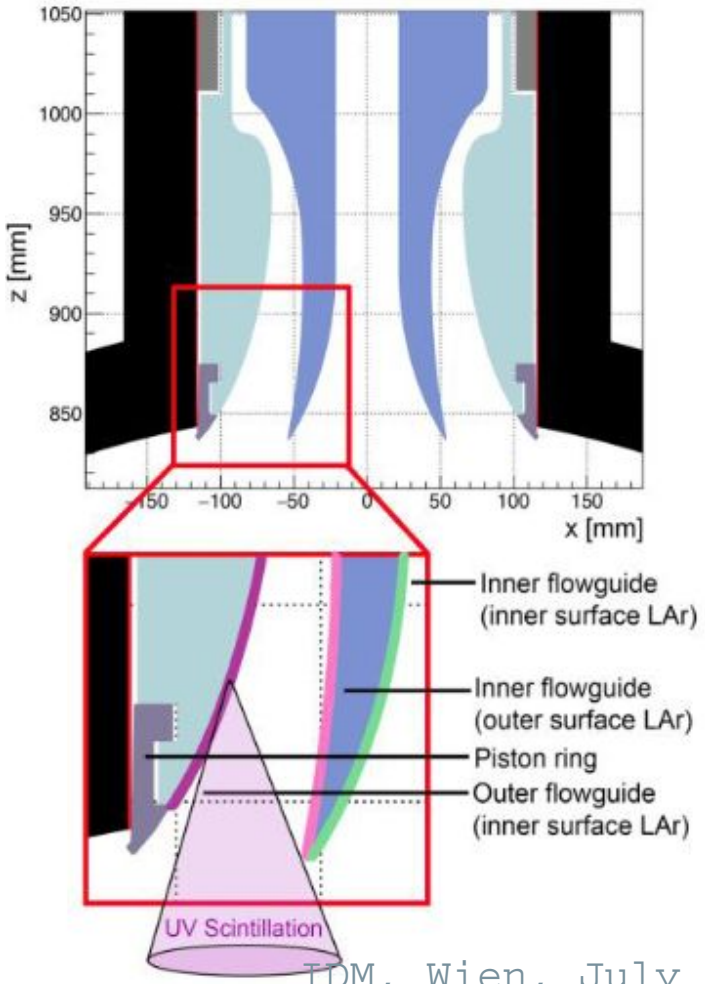
· Many photons not detected ⬅

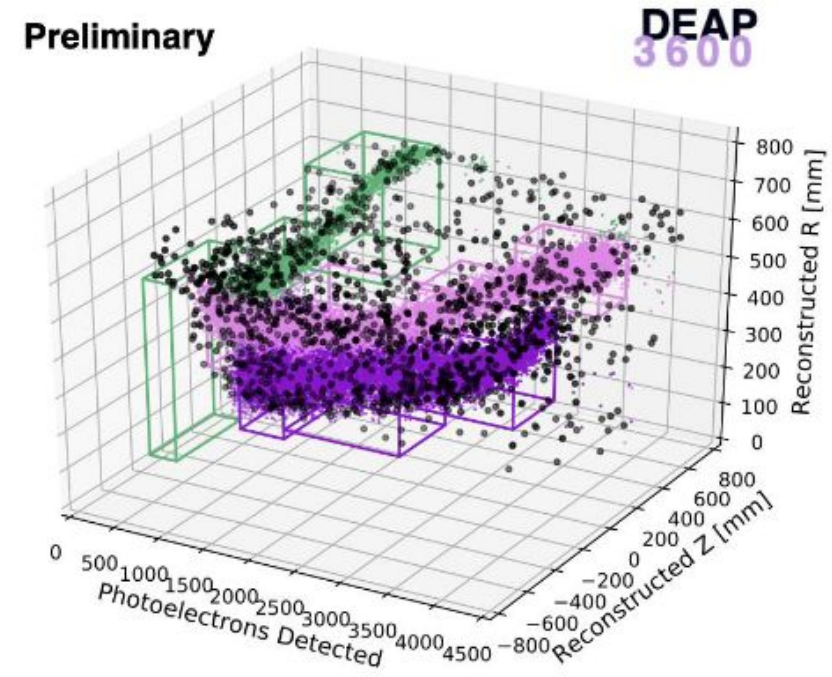
· Topologic pattern mimicking good NR events

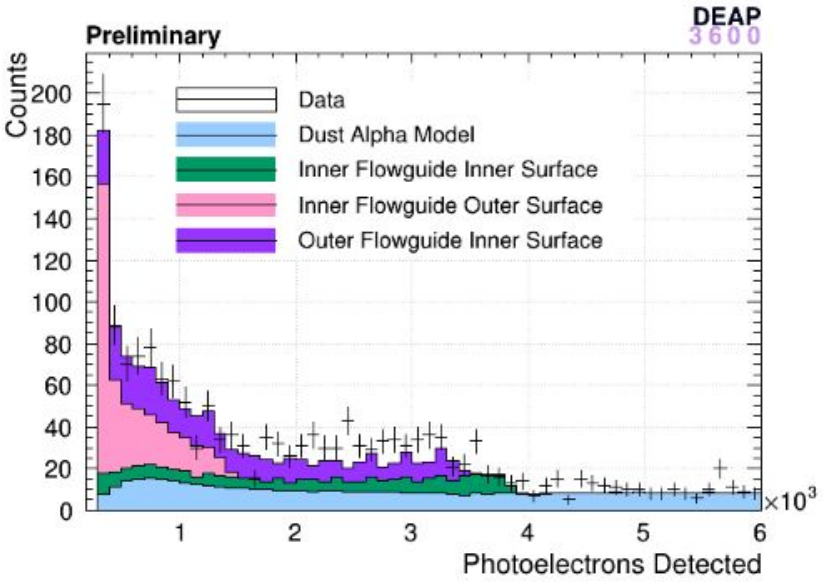
PRD, 100 (2019), p 022004

Recovering sensitivity

Bkg 1: surface ^{210}Po on the neck (above target)

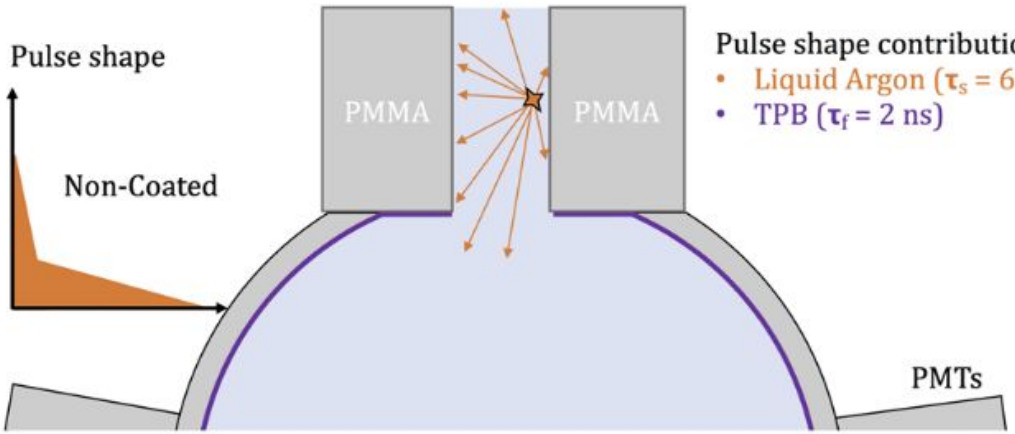


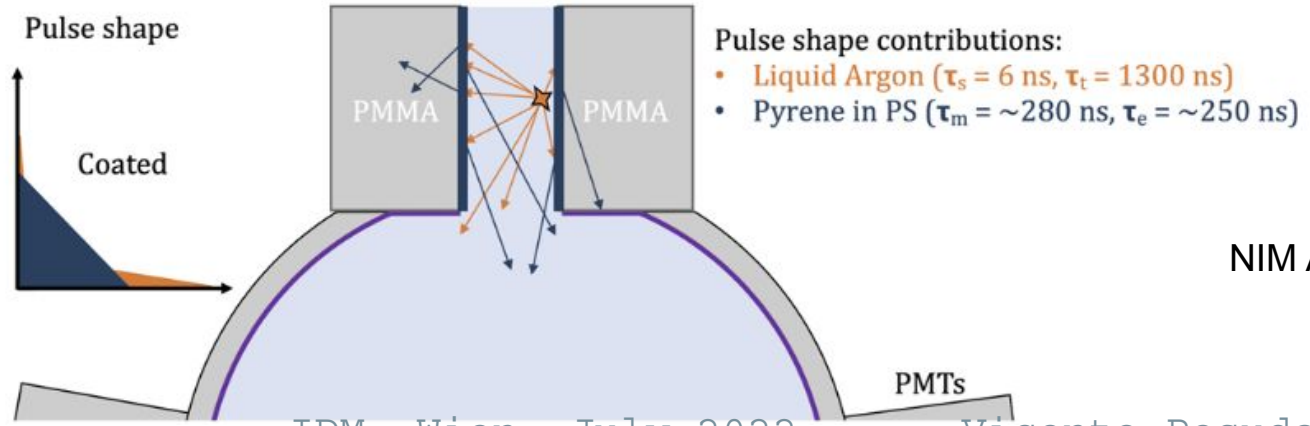




Recovering sensitivity

Fix 1: WLS modifying the time profile of alpha scintillation



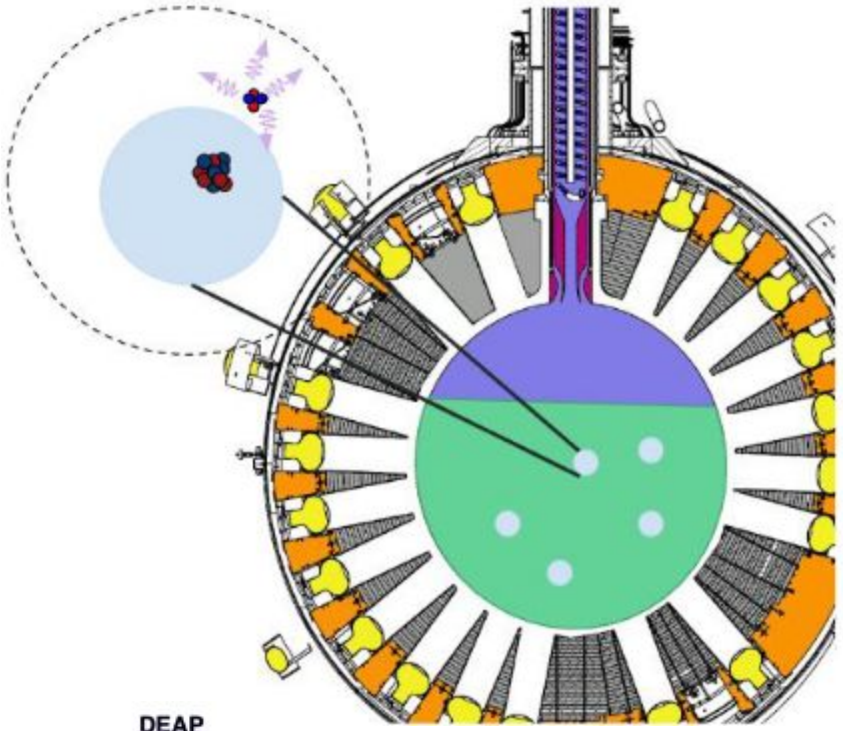


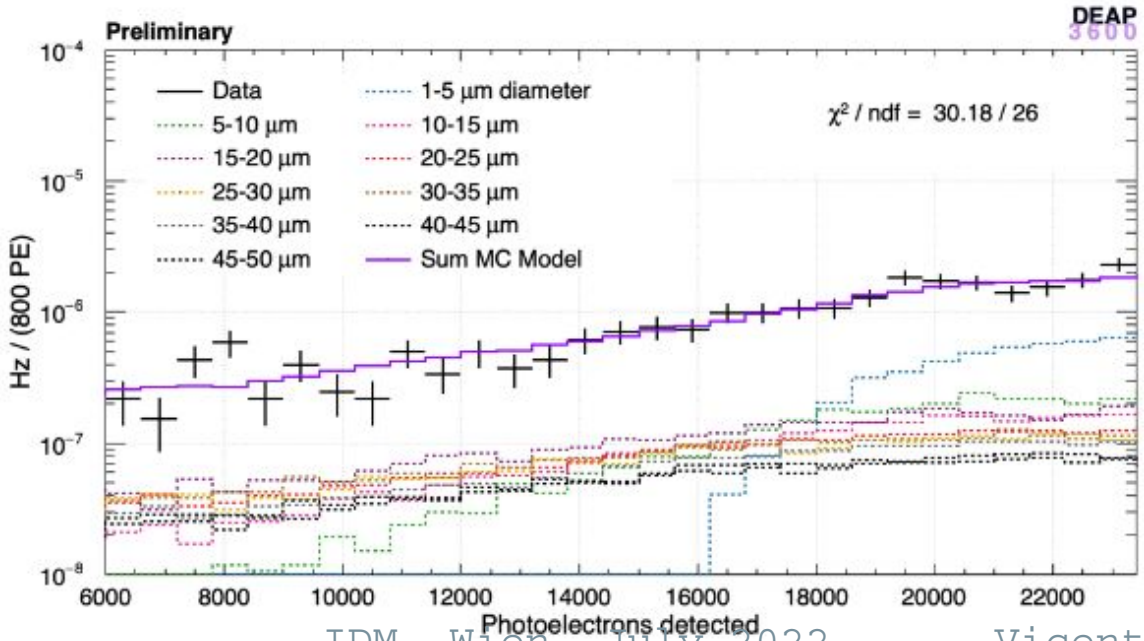
Already @ SNOLAB

NIM A 1034 (2022) p 166683

Recovering sensitivity

Bkg 2: degraded alphas from dust particulates in suspension

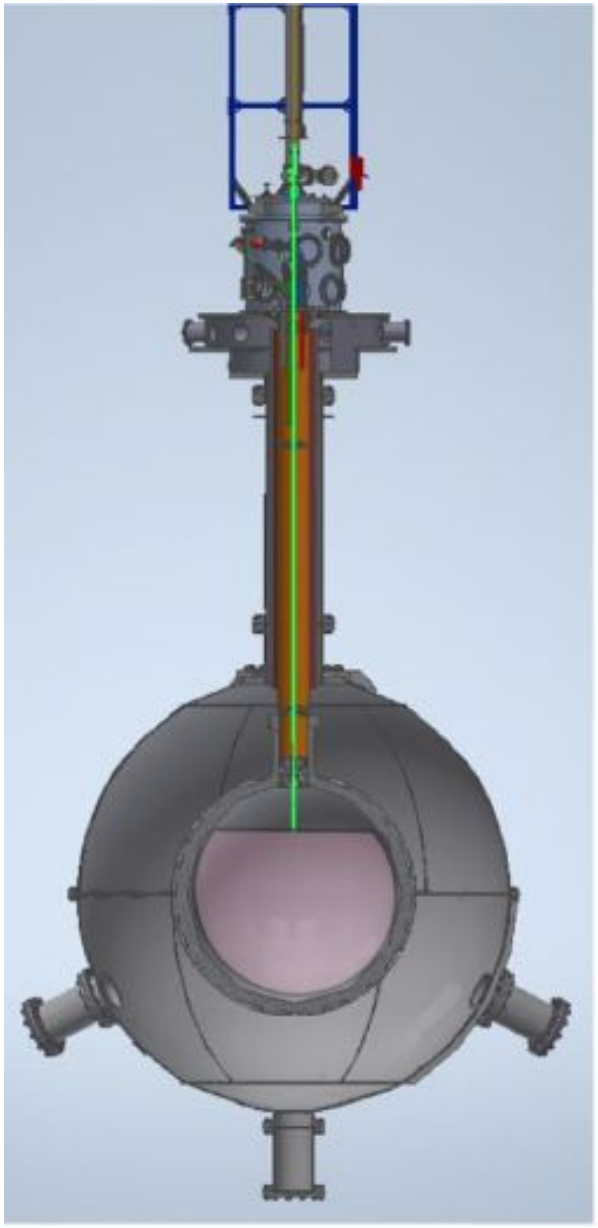




E lost in the dust itself does not produce photons

Recovering sensitivity

Fix 2: New recirculation+filtration system to remove dust from target



External cooling also prevents condensation in the neck!

Already @ SNOLAB

Recovering sensitivity

Upgrade to be finished this year

Ar fill scheduled for winter 2022

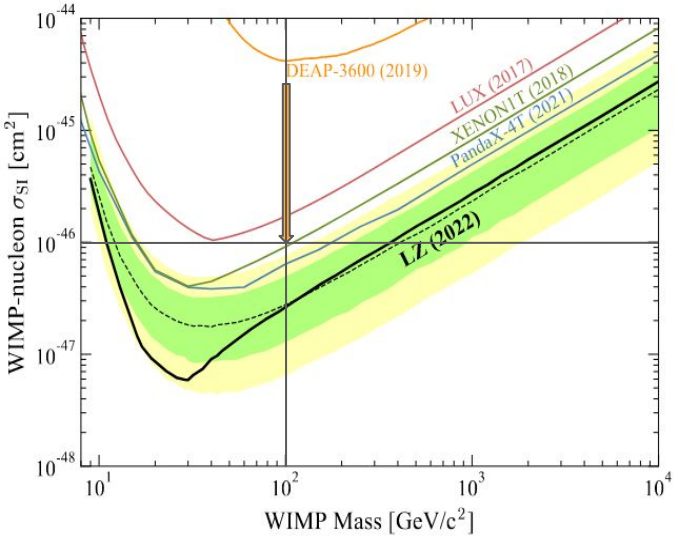
Data taking scheduled to resume in Spring 2023

Prospects

Taking data with upgraded detector for >2 years

Finalize refined analysis and unblind

Recover design sensitivity



More physics:

Solar axion search

Planck scale DM

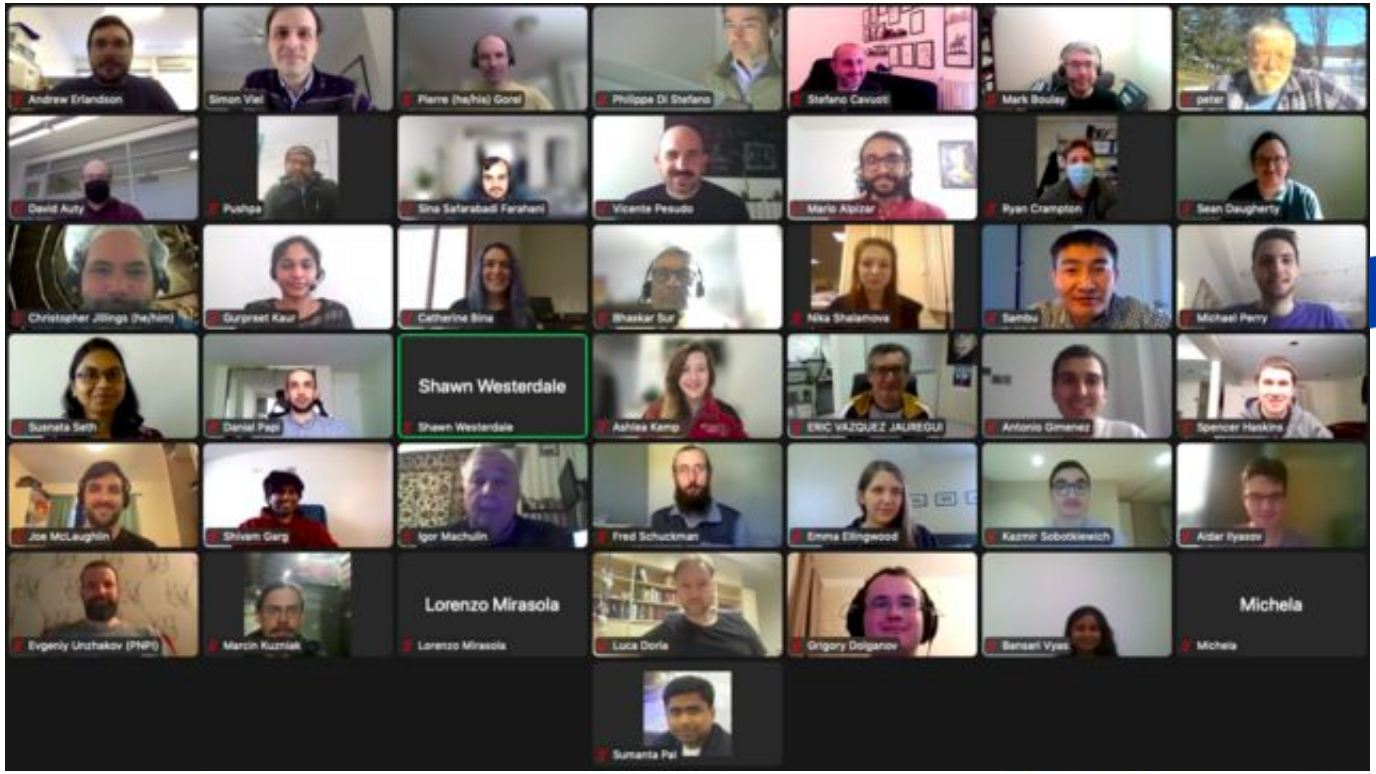
39Ar activity and half life

SuperNova neutrinos

Boosted DM

muon flux

Acknowledgements



Backup

Exploring different scenarios

[17] C. A. J. O'Hare, N. W. Evans, C. McCabe, G. C. Myeong, and V. Belokurov, Velocity substructure from *Gaia* and direct searches for dark matter, Phys. Rev. D **101**, 023006 (2020).

[18] L. Necib *et al.*, Evidence for a vast prograde stellar stream in the solar vicinity, arXiv:1907.07190.

[19] L. Necib *et al.*, Chasing accreted structures within Gaia DR2 using deep learning, arXiv:1907.07681.

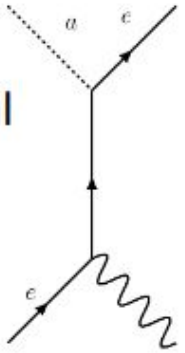
[60] L. Necib, M. Lisanti, and V. Belokurov, Inferred evidence for Dark Matter Kinematic Substructure with SDSS–*Gaia*, Astrophys. J. **874**, 3 (2019).

	Substructure	Type	Reference	v_r (km/s)	v_θ (km/s)	v_ϕ (km/s)	$\lvert\sigma_{rr}\rvert$ (km/s)	$\lvert\sigma_{\theta\theta}\rvert$ (km/s)	$\lvert\sigma_{\phi\phi}\rvert$ (km/s)	$\eta_{\rm sub}$
	Gaia Sausage (Necib *et al.*)	Debris flow	[60]	$\pm 147^{+7.2}_{-6.4}$	$-2.8^{+1.5}_{-1.6}$	$27.9^{+2.8}_{-2.9}$	$113.6^{+3.1}_{-3.0}$	$65.2^{+1.1}_{-1.2}$	$61.9^{+2.6}_{-2.9}$	0–0.70
	Gaia Sausage (O'Hare *et al.*)	Debris flow	[17]	−8.2	0.99	25.7	158.9	80.9	61.5	0–0.70
G1	Koppelman 1[a]	Stream	[19]	−169	−59	−375	11–37	3–16	6–28	0–0.30
	IC (π, 400 km/s)	IC	···	0	0	−400	35.4	35.4	30	0–0.30
G2	S1[a]	Stream	[17]	−29.6	−72.8	−297.4	82.6	58.5	26.9	0–0.30
	Koppelman 2	Stream	[19]	213	161	−226	52	18	29	0–0.30
	IC (π, 300 km/s)	IC	···	0	0	−300	35.4	35.4	30	0–0.30
G3	IC (π, 200 km/s)[a]	IC	···	0	0	200	35.4	35.4	30	0–0.30
	IC ($\frac{\pi}{2}$, 400 km/s)	IC	···	282.8	282.8	0	21.2	21.2	50	0–0.30
G4	IC ($\frac{\pi}{2}$, 300 km/s)[a]	IC	···	212.1	212.1	0	21.2	21.2	50	0–0.30
G5	Helmi[a]	Stream	[19]	29	−287	141	37–83	6–21	4–15	0–0.30
	IC ($\frac{\pi}{2}$, 200 km/s)	IC	···	141.4	141.4	0	21.2	21.2	50	
G6	Nyx[a]	Stream	[18]	$156.8^{+2.1}_{-2.2}$	$-1.4^{+3.1}_{-3.0}$	$141.0^{+2.5}_{-2.6}$	$46.9^{+1.7}_{-1.6}$	$70.9^{+2.4}_{-2.2}$	$52.5^{+1.8}_{-1.8}$	0–0.30
	IC (0, 400 km/s)	IC	···	0	0	−400	35.4	35.4	30	0–0.30
	IC (0, 300 km/s)	IC	···	0	0	−300	35.4	35.4	30	0–0.30
	IC (0, 200 km/s)	IC	···	0	0	−200	35.4	35.4	30	0–0.30

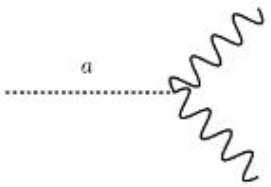
Axion interactions in DEAP-3600 produce EM events

- **Compton conversion**
  - Get 1 gamma and 1 electron, with 5.5 MeV total kinetic energy
- **Inverse Primakov**
  - Get 1 gamma with 5.5 MeV energy
- **Axio-electric effect**
  - Get 1 electron with 5.5 MeV kinetic energy
- **Axion decay into 2 gammas**
  - Get 2 gammas with 5.5 MeV total energy

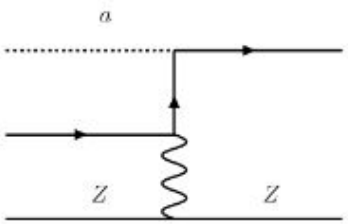
Compton Conversion



Decay to 2γ



Inverse Primakov



Axio-Electric Effect