GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

SNOLAB

DEAP-3600 updates, new physics results and prospects for exotic DM searches

Guillermo Vera Díaz
(CIEMAT)

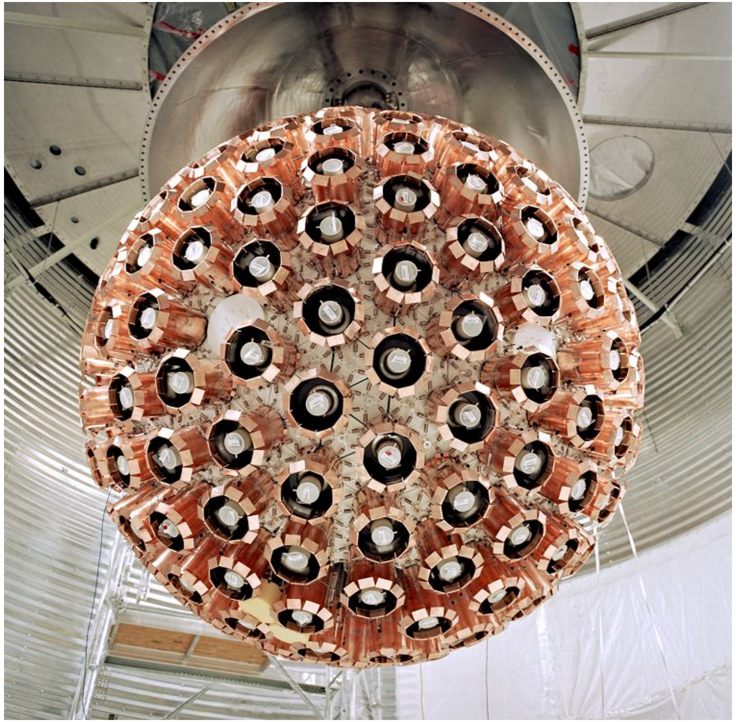
on behalf of the DEAP collaboration

16th International Workshop on the Identification of Dark Matter

Zaragoza, Spain, 1-5 June 2026

DEAP 3600

The DEAP-3600 detector

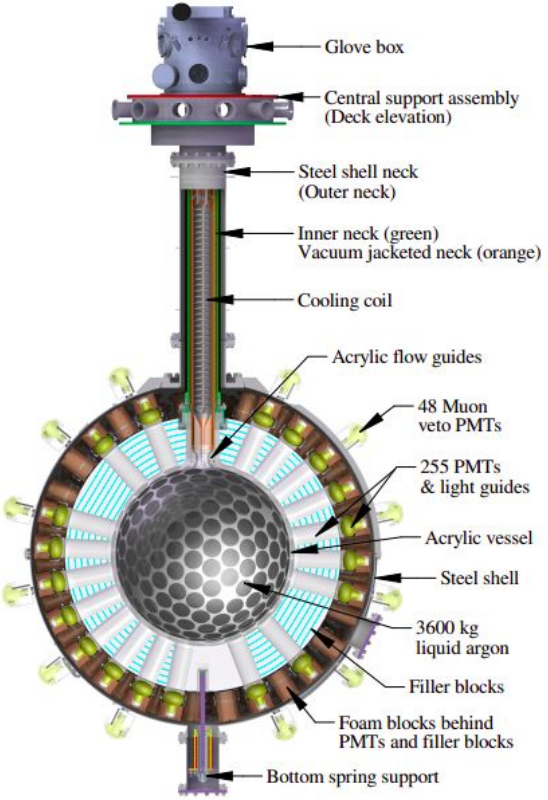


First detector for the DM direct search with more than 1 tonne of target.

So far, it has established the most stringent limits for SI WIMP-nucleon interaction using non-Xe target (LAr).

It constitutes a relevant milestone in the path for next generation Ar detectors within the GADMC.

The DEAP-3600 detector

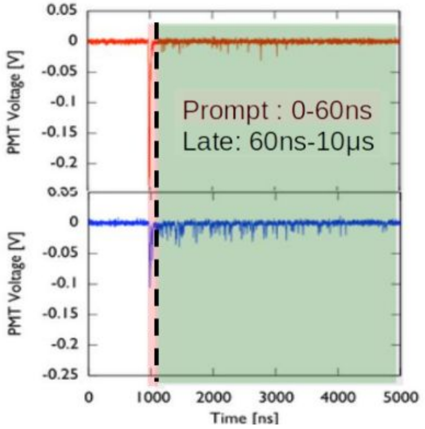


Main remarks outside to inside

- Located 2 km underground at SNOLAB, Canada: 6000 m.w.e where the muon flux is 0.03 muon/m^2/day.
- Placed inside a muon veto (water tank with 48 PMTs detecting Cherenkov light).
- 255 PMTs: 8” - 32% QE - 75% coverage.
- Ultraclean 85 cm radius acrylic vessel bonded to 50-cm-long light guides.
- In-situ vacuum evaporated TPB on inner 10 m^2 surface.
- 3.3 tonne LAr target.

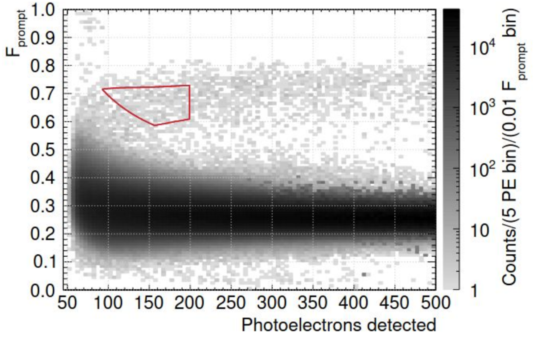
The DEAP-3600 detector: Ar scintillation

- Nuclear recoils populate mostly singlet state, which decays promptly (8 ns).
- Electronic recoils populate mostly triplet state, which has a slower decay (1.4 μs).
  Eur. Phys. J. C 80,303 (2020)

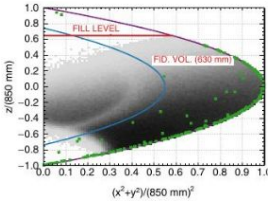


- Pulse shape discrimination provides outstanding rejection against gamma and beta backgrounds
  (^{39}Ar leakage probability is ~10^{-10} at 50% nuclear recoil acceptance)
  Eur. Phys. J. C 81,823 (2021)

Neutron calibration data



- Position reconstruction and fiducialization allow us to reduce surface and external backgrounds.
  (Resolution of ~ 50 mm)
  JINST 20 P07012 (2025)



The DEAP-3600 detector: updates and goals

★ Introducing hardware upgrades to recover WIMP sensitivity

- ^{210}Po background in the neck.
- Presence of dust in the inner volume.

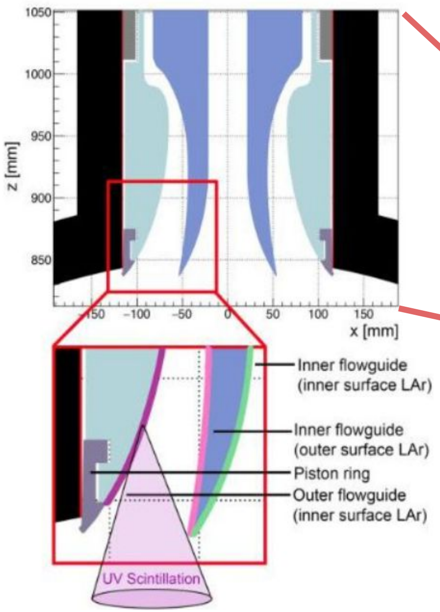
★ WIMP searches analysis: **new sensitivity!** arXiv:2603.13965

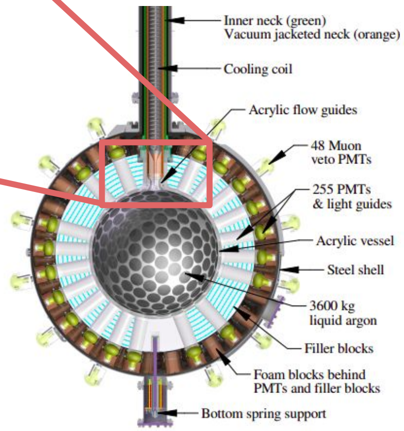
★ Learning for future LAr detectors (Darkside-20k, ARGO)

★ More physics with DEAP: first ^{39}Ar activity measurement, solar neutrinos, exotic DM candidates, ...

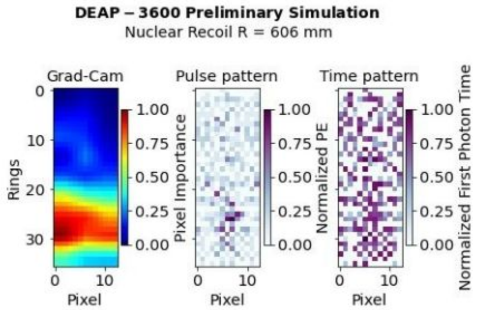
Recovering WIMP sensitivity: α from the neck

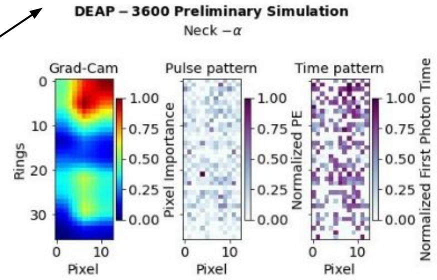
Condensation in the neck + ^{210}**Po in the neck** producing **α** particles: shadowing of scintillation light





Previously these events were tagged by a **CNN** specifically trained to tag these events giving very good results!





NOW FIXED via hardware upgrade including WLS to the surface so that neck events will have:

- different time profile
- distinct PSD pattern
- more light collected
- Out of the ROI

Recovering WIMP sensitivity: α from dust

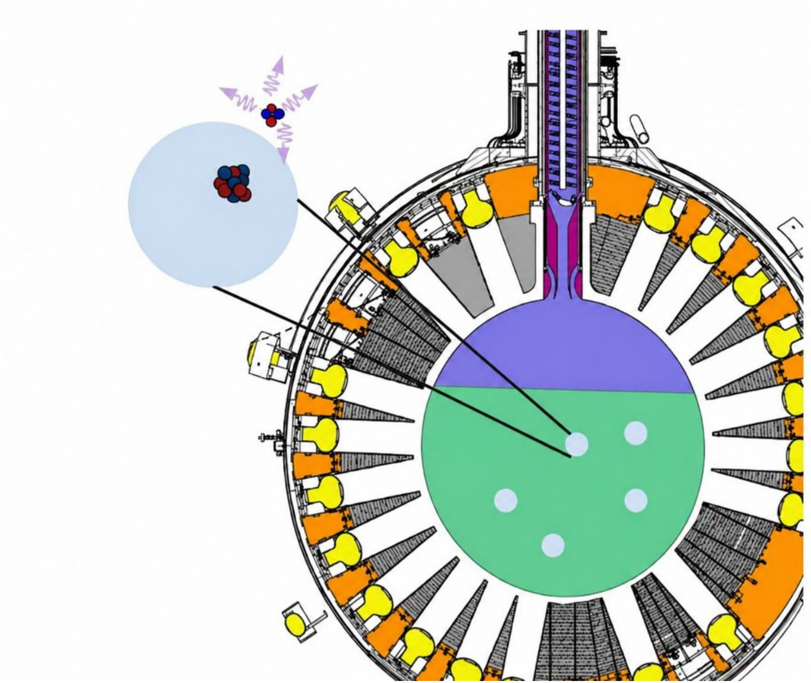
No recirculation system present in the detector caused tiny dust particles to be present within LAr volume.

This dust introduced degraded **α**, constituting a source of background

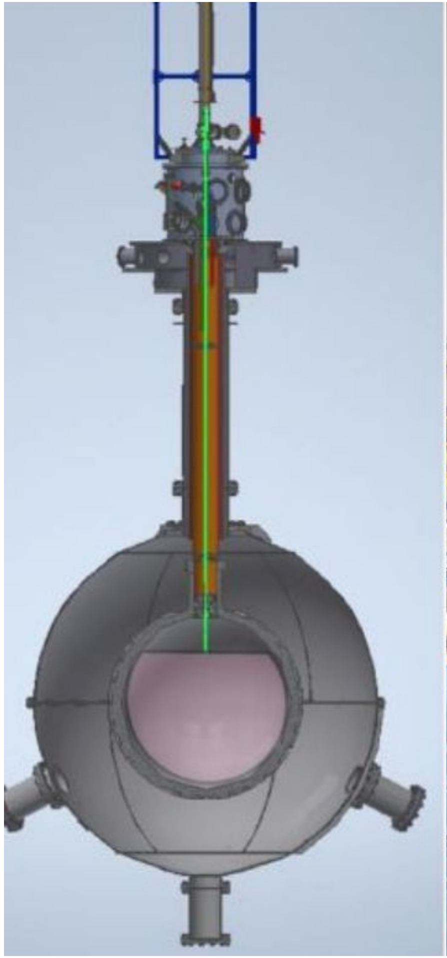
Fixed:

Installation of a filtration + recirculation system which removes the dust from the target

The external cooling also helps preventing condensation in the neck!



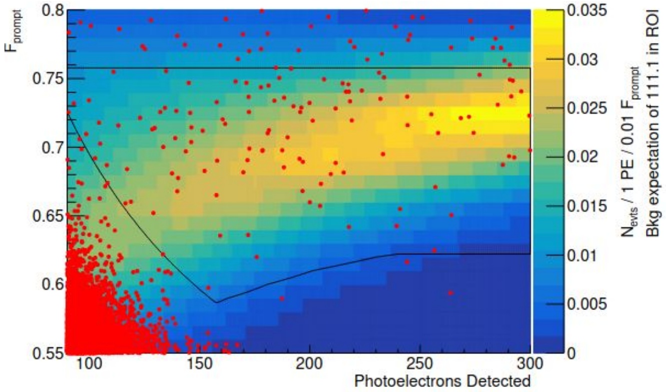
Some pictures of the hardware work



WIMP searches: a new milestone

Dark Matter Search with the DEAP-3600 Detector using the Profile Likelihood Ratio Method

arXiv:2603.13965



Source	Prior	Best-fit (bkg-only)	Best-fit (sig+bkg)
Radiogenic n	$1.2^{+1.0}_{-1.0}$	$1.2^{+0.9}_{-0.9}$	$1.2^{+0.9}_{-0.9}$
Surface α	$7.4^{+15.2}_{-15.4}$	$0.0^{+3.1}_{-3.1}$	$0.0^{+1.8}_{-1.8}$
Shadowed α	$15.2^{+12.3}_{-10.3}$	$18.3^{+8.9}_{-7.4}$	$16.5^{+8.2}_{-6.9}$
Dust α	$44.2^{+39.9}_{-40.4}$	$91.6^{+10.6}_{-11.9}$	$64.1^{+15.9}_{-16.2}$
Total Bkg	$68.0^{+49.9}_{-45.2}$	$111.1^{+16.3}_{-15.2}$	$81.7^{+20.3}_{-18.0}$
$M_\chi = 1$ TeV$/c^2$	–	–	$32.0^{+23.9}_{-22.4}$

New SI WIMP-nucleon cross section derived from DEAP-3600 data analysis using PLR:

★ Less restrictive background cuts: higher acceptance (76% rel. increase)

★ 115 events observed in the ROI vs $111^{+16.3}_{-15.2}$ expected background events

★ Identification of dominant source of background: dust particles within the target. **Fixed for the future runs via hardware upgrades.**

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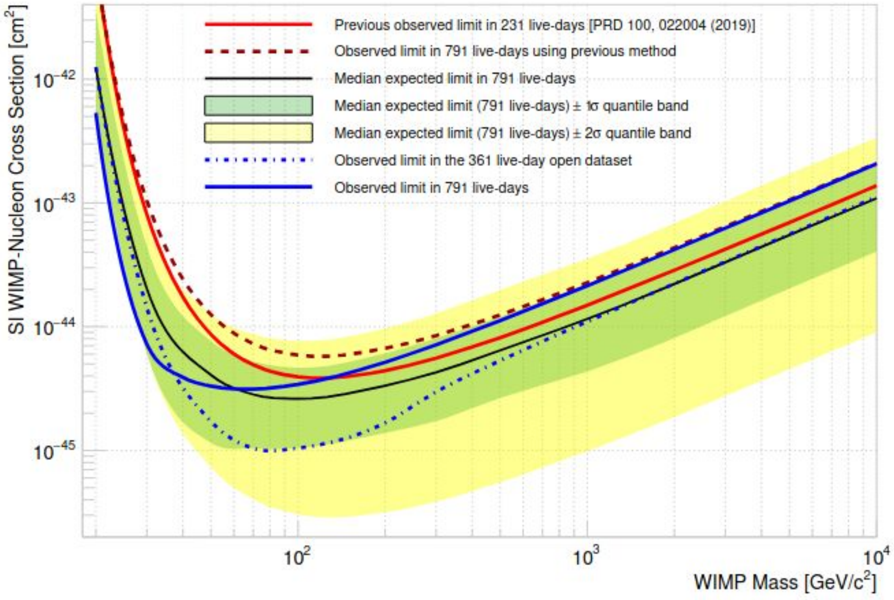

New SI WIMP-nucleon cross section derived from DEAP-3600 data analysis using PLR:

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★ 115 events observed in the ROI vs $111^{+16.3}_{-15.2}$ expected background events

★ Identification of dominant source of background: dust particles within the target. **Fixed for the future runs via hardware upgrades.**

★ $\sigma_X \leq 3.4 \times 10^{-45}$ at 100 GeV/c^2

$\sigma_X \leq 3.2 \times 10^{-45}$ at 60 GeV/c^2

More physics with DEAP

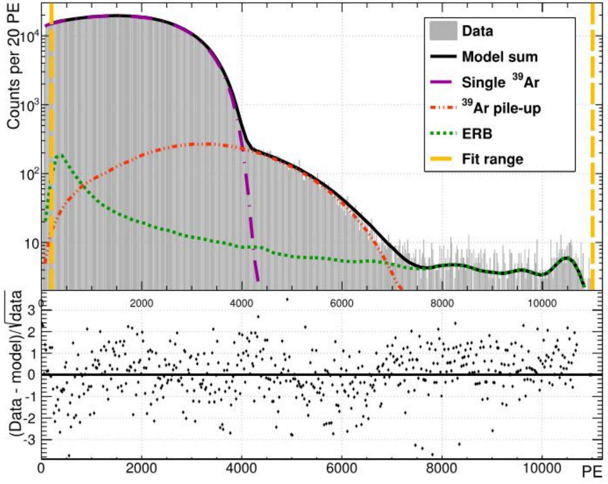
- ★ **^{39}Ar activity in atmospheric Ar precision measurement** Eur. Phys. J. C 83, 642 (2023)
- ★ **^{39}Ar half life first direct measurement** Eur.Phys.J.C 85 (2025) 7, 728
- ★ Alpha quenching in LAr Eur.Phys.J.C 85 (2025) 1, 87

- ★ **Detecting ^{8}B solar neutrinos** arXiv:2605.12769
- ★ Solar axion search
- ★ Muon flux and instrumentation
- ★ Neutrinoless double electron capture in ^{36}Ar
- ★ Search for neutrinos in coincidence with GW

- ★ Exotic DM searches
  - Best limits for xenon-phobic DM Phys. Rev. D 102, 082001 (2020).
  - Prospection of unpopulated regions of the parameter space at Planck-scale masses (ultra heavy) Phys. Rev. D, 100, 072009 (2019).
  - **Inelastic boosted dark matter**

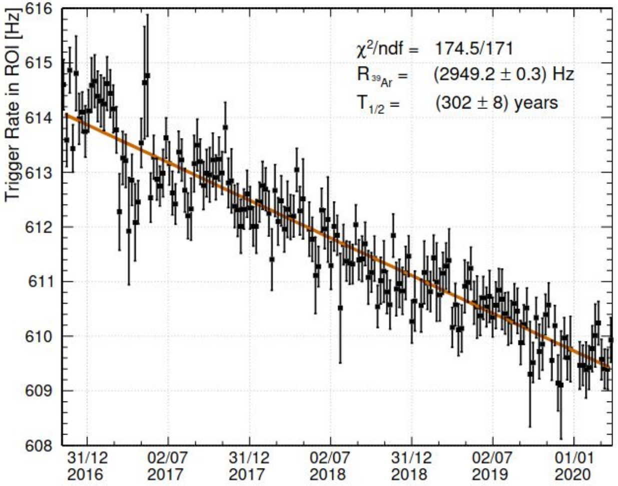
More physics with DEAP

★ ^{39}**Ar activity in atmospheric Ar precision measurement** Eur. Phys. J. C 83, 642 (2023)



Measurement	Specific activity [Bq/kg$_{atmAr}$]
WARP [15]	$1.01 \pm 0.02_{stat} \pm 0.08_{sys}$
ArDM [16]	0.95 ± 0.05
DEAP-3600 (this work)	$0.964 \pm 0.001_{stat} \pm 0.024_{sys}$

★ ^{39}**Ar half life first direct measurement** Eur.Phys.J.C 85 (2025) 7, 728



$$T_{1/2} = (302 \pm 8_{\rm stat} \pm 6_{\rm sys})\ \text{years.}$$

Most widely referenced value → $(269 \pm 3_{\rm stat} \pm 8_{\rm sys})$ years

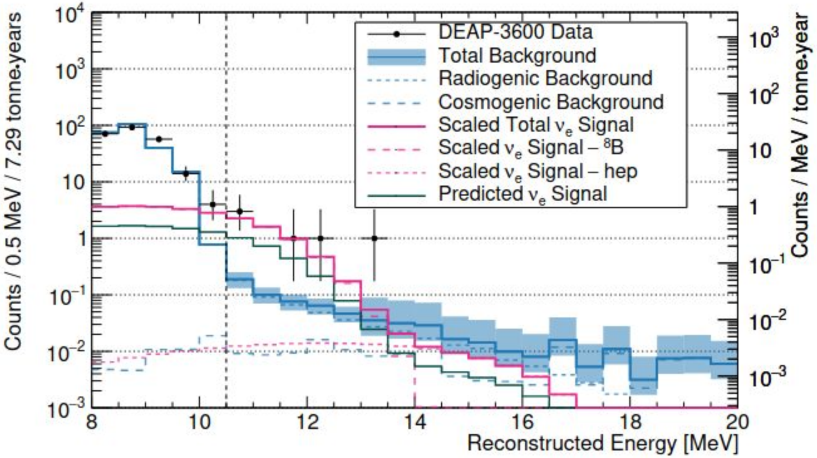
More physics with DEAP

★ **First evidence of neutrino absorption on argon using ^{8}B solar neutrinos in DEAP-3600** arXiv:2605.12769

Experimental evidence for neutrino absorption of ^{8}B solar neutrinos on ^{40}Ar.

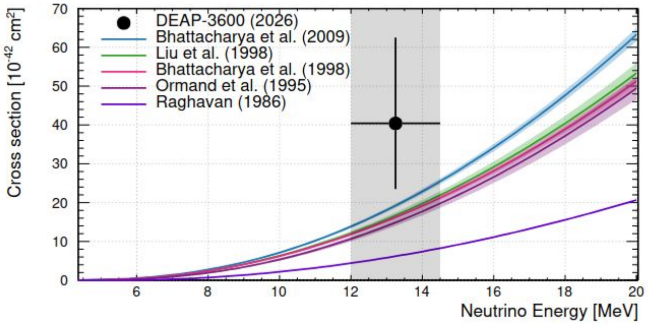
6 events in the ROI vs $0.48^{+0.16}_{-0.15}$ background.
4.0σ signal over background.

$$\nu_e + {}^{40}\mathrm{Ar} \longrightarrow {}^{40}\mathrm{K}^* + e^-$$



Data analysed in the high-energy region [10.5, 13.0] MeV.

Main backgrounds in this region:
- Radiogenic (n, γ):
  - Neutrons coming from (α, n) reactions thermalise and are captured, producing (n, γ) cascades.
  - Estimated via calibration with AmBe source
- Cosmogenic:
  - Residual muons producing electronic showers surviving the veto cut & muon spallation isotopes
  - Estimated via FLUKA simulations.



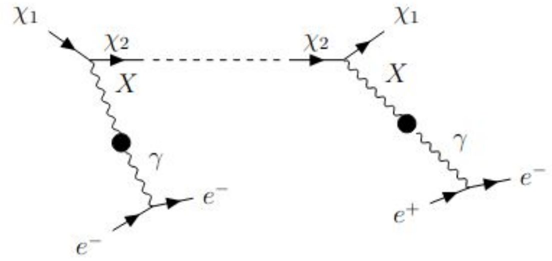
Cross section measurement limited by statistics (~ 50 %)
Next measurement needs higher exposure

Inelastic Boosted Dark Matter in DEAP-3600

iBDM is a multiparticle Dark Matter model consisting on two particles with a clear difference in mass (χ_0, χ_1) and an unstable excited state (χ_2).

$$\mathcal{L} = -\frac{\epsilon}{2} F_{\mu\nu} X^{\mu\nu} + \sum g_{ii} \bar{\chi}_i \gamma^\mu \chi_i X_\mu + (g_{12} \bar{\chi}_2 \gamma^\mu \chi_1 X_\mu + h.c.)$$

- ★ **Heavier χ_0** (GeV scale) annihilates in the G.C. producing a flux of **boosted χ_1** (MeV scale) coming towards the Earth.
- ★ χ_1 can interact with S.M particles via kinetic mixing of a dark photon *X*. In the inelastic case, χ_1 transitions into χ_2
- ★ χ_2 can then decay visibly ($e^+ + e^-$) or invisibly ($\chi_1 + \chi_1$)



The whole process is characterized by high energy deposition (MeV up to GeV) collimated tracks with certain vertex displacement, which can range from *O*(mm)-*O*(km)

Based on: *Physics Letters B, 780*, 543-552 (2018)

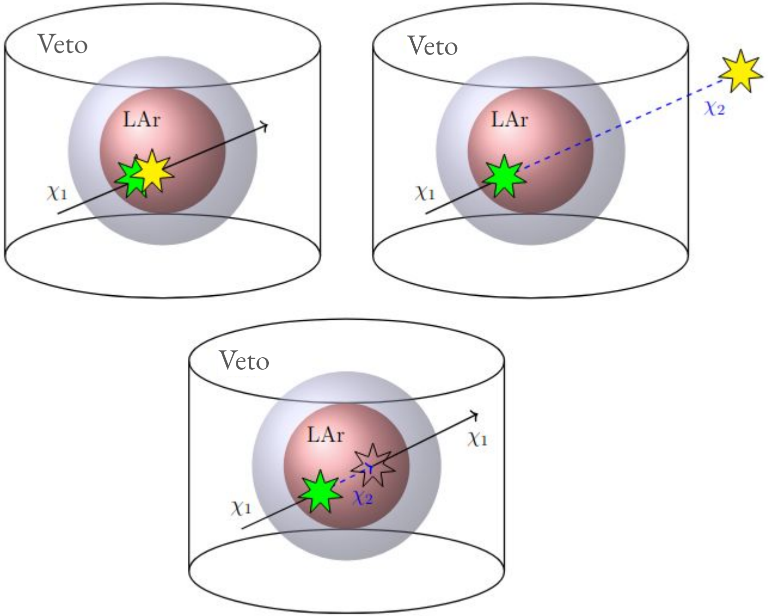
Inelastic Boosted Dark Matter in DEAP-3600

Three different scenarios with the same signature (**one collimated, highly energetic track** in the target with **no signal in the veto**) are considered.

Representative set of parameters which produce these scenarios are under study to determine the acceptance.

After defining the set of cuts 3 year dataset of DEAP-3600 will be analysed, looking for iBDM events.

In addition, we are refining a generator which can help simulate detector response to this kind of events.



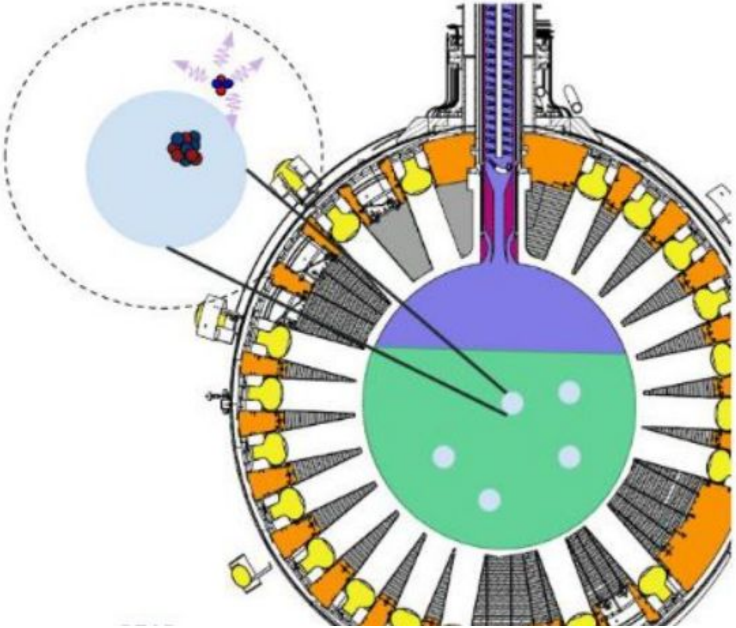
Summary

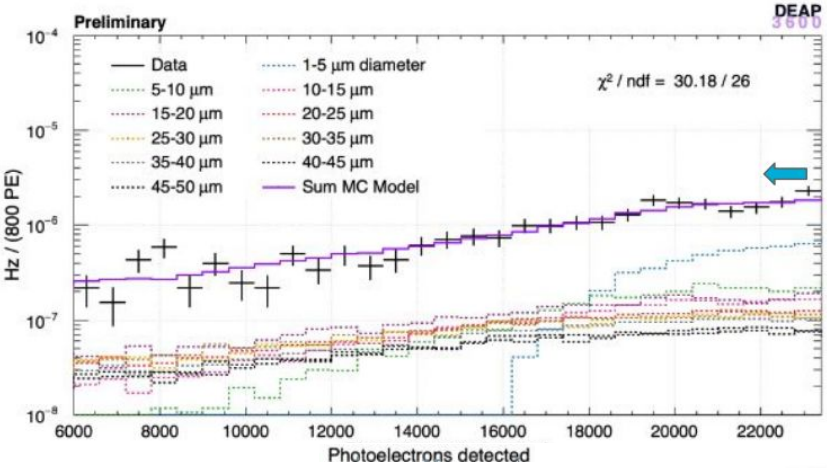
- DEAP-3600 is the largest running LAr experiment dedicated for WIMP searches and has achieved a **world-leading sensitivity with this target**.
- DEAP-3600 has a strong programme beyond the WIMP analysis, due to its **ultra-low background** being an ideal frame for physics analysis such as solar neutrinos and exotic DM candidates.
- Identification of a relevant source of background in the WIMP ROI: **α**-induced backgrounds (neck-**α** induced events and dust-**α**).
    - Hardware upgrades have been implemented: WLS coating in the neck (preliminary data indicates promising results), dust pipe for volume dust mitigation recently deployed
    - Main contributions to this background are now included in PLR WIMP analysis.
- Learning for future LAr experiments (DarkSide-20k, ARGO, ...).
- **Next steps:** analysis of data of the upgraded detector after one more year of data taking.

BACKUP

Recovering WIMP sensitivity

No recirculation system present in the detector caused tiny dust particles to be present within LAr volume.





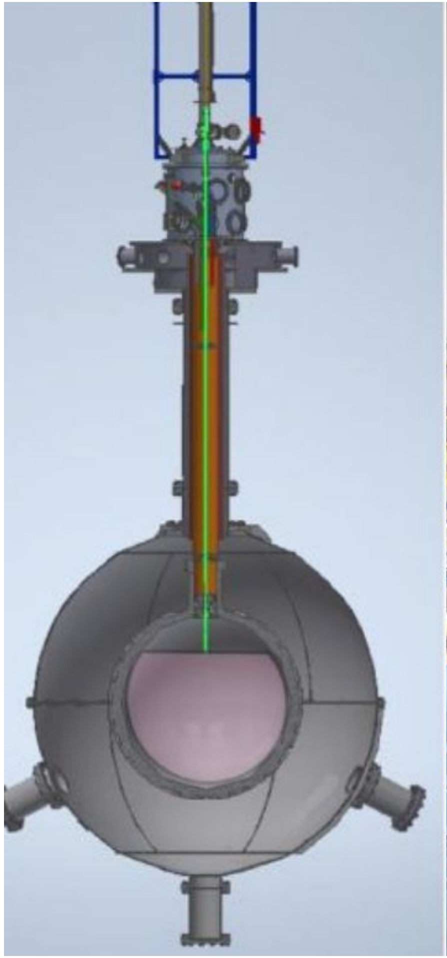
This dust introduced degraded **α**, constituting a source of background

Recovering WIMP sensitivity

Fixed:

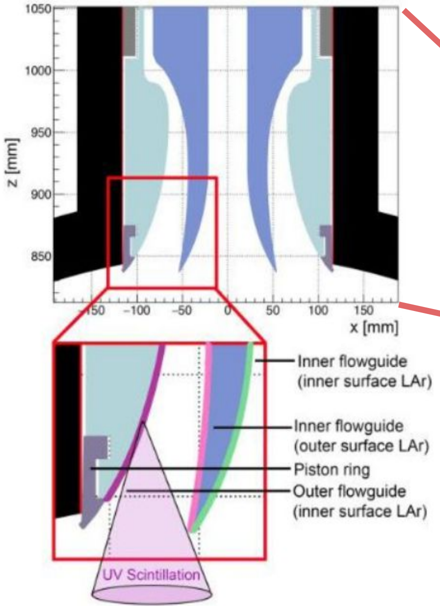
Installation of a filtration + recirculation system which removes the dust from the target

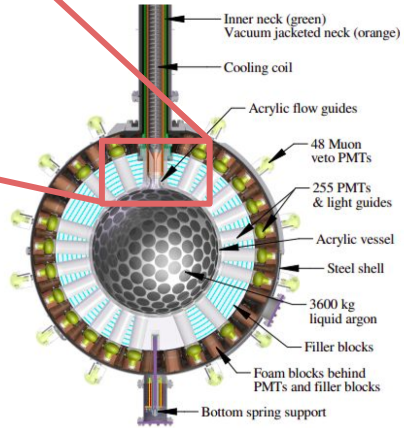
The external cooling also helps preventing condensation in the neck!



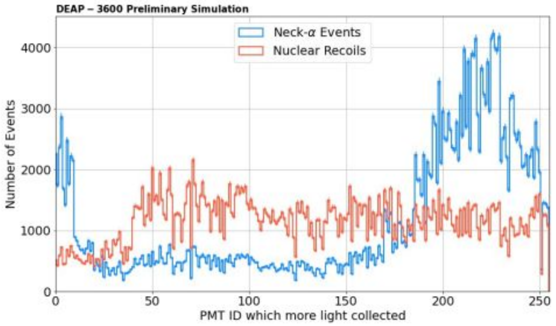
Recovering WIMP sensitivity

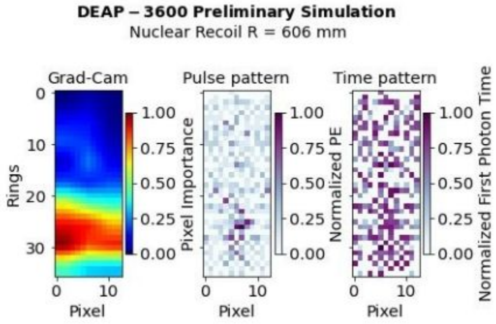
^{210}**Po in the neck** produces **α** particles very hard to identify

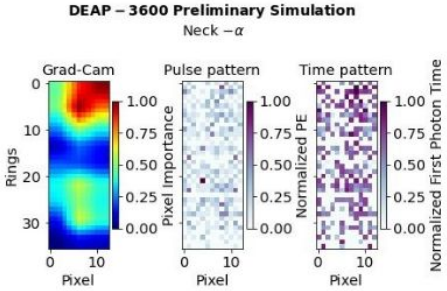




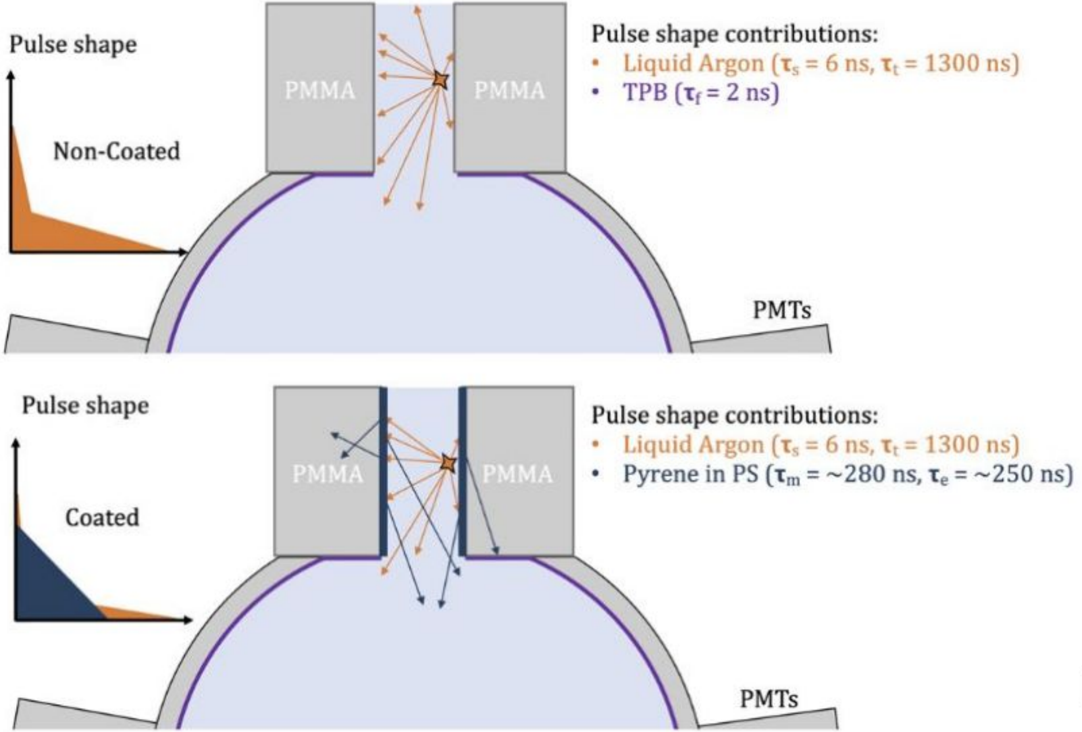
CNN specifically trained to tag these events gives very good results!







Recovering WIMP sensitivity



Fixed including WLS to the surface so that neck events will have:

- different time profile
- distinct PSD pattern
- more light collected
- Out of the ROI

NIM A 1034 (2022) p 166683

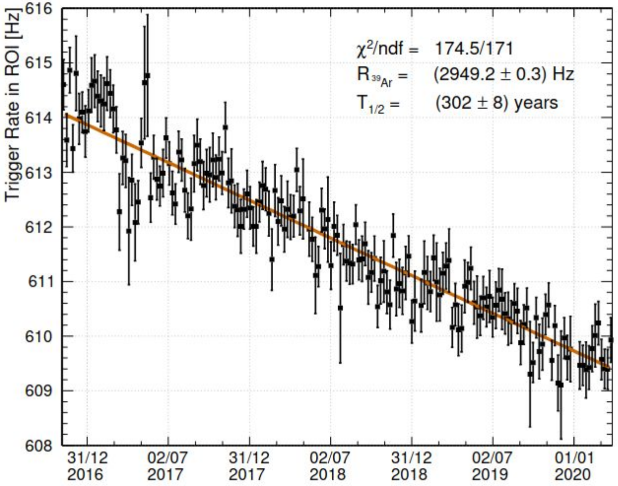
More physics with DEAP

Measurement	Half-life [years]	Method
Zeldes et al. (1952)	265 ± 30	Isotopic ratios of argon samples using mass spectrometry
Stoenner et al. (1960)	$325 \pm 16^{\dagger}_{\text{stat}}$	Activity ratios of ^{39}Ar to ^{37}Ar
Stoenner et al. (1965)	$269 \pm 3_{\text{stat}} \pm 8_{\text{sys}}$	Activity ratios of ^{39}Ar to ^{37}Ar
Baksi et al. (1996)	$276 \pm 3_{\text{sys}}$	Isotopic ratios of ^{39}Ar to ^{38}Ar in a double-spike using mass spectrometry
NDS (2018)	$268 \pm 8_{\text{sys}}$	Re-evaluation of the Stoenner et al. (1965) result with an updated ^{37}Ar half-life
DEAP-3600 (2025)	$302 \pm 8_{\text{stat}} \pm 6_{\text{sys}}$	Direct observation of the decay curve

†Estimated from uncertainty on the measured count rates.

★ **^{39}Ar half life first direct measurement**

Eur.Phys.J.C 85 (2025) 7, 728



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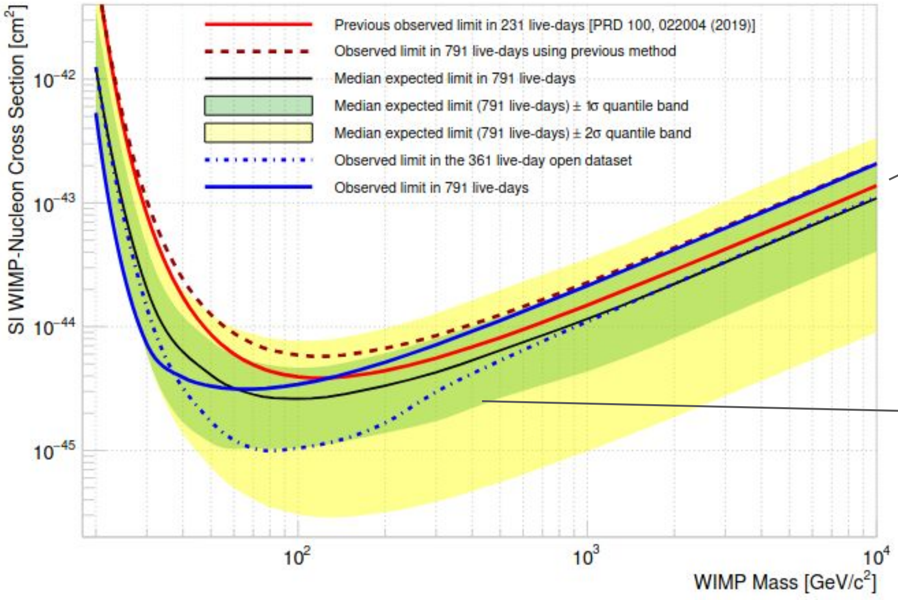
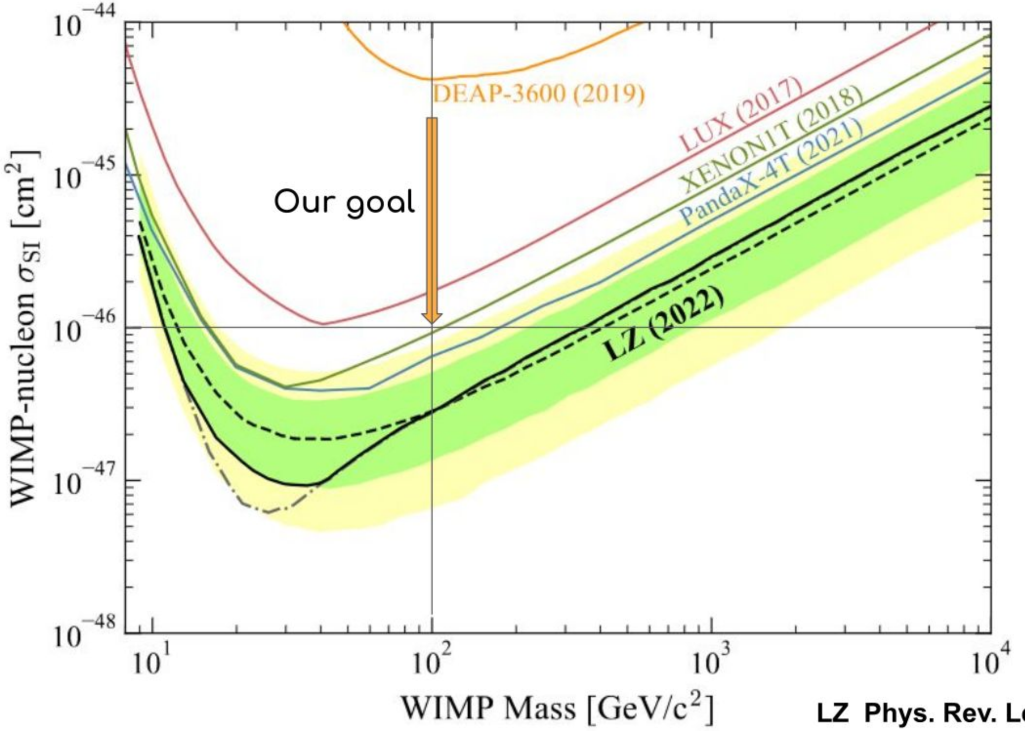


New SI WIMP-nucleon cross section derived from DEAP-3600 data analysis using PLR:

- 231 day dataset expected 1.5 events with the new background model but 0 events were observed (p value of 22%), resulting in a better limit.
- Using cut and count on the 791 day dataset yields a worse limit since 11 events survive the cuts while 5 events are expected (p value of 1.3%).
- Excess of data over the predicted background in the blind part explains this discrepancy.

The DEAP-3600 detector: sensitivity prospects



LZ Phys. Rev. Lett. 131, 041002 (2023)

World-leading sensitivity for WIMP searches in LAr experiments

2. Model and calculations

E_T: energy of the target after the scattering

$$\frac{d\sigma}{dE_T} = \frac{m_T}{8\pi\lambda^2(s, m_T^2, m_{\chi_1}^2)}|\overline{M}|^2 \tag{4.7}$$

with the matrix element squared,

$$\begin{aligned} |\overline{M}|^2 = & \frac{8m_T(\epsilon e g_{12})^2}{[2m_T(E_{\chi_2} - E_{\chi_1}) - m_X^2]^2} \\ & \times \left[M_0(F_1 + \kappa F_2)^2 + M_1\left[-(F_1 + \kappa F_2)\kappa F_2 + (\kappa F_2)^2 \frac{E_{\chi_1} - E_{\chi_2} + 2m_T}{4m_T}\right]\right]. \end{aligned} \tag{4.8}$$

M_0 and M_1 are:

$$M_0 = \left[m_T(E_{\chi_1}^2 + E_{\chi_2}^2) + (\delta m)^2 \tfrac{E_{\chi_2} - E_{\chi_1} + m_T}{2} + m_T^2(E_{\chi_1} + E_{\chi_2}) + m_{\chi_1}^2 E_{\chi_2} - m_{\chi_2}^2 E_{\chi_1}\right] \tag{4.9}$$

$$M_1 = m_T\left[\left(E_{\chi_1} + E_{\chi_2} - \tfrac{m_{\chi_2}^2 - m_{\chi_1}^2}{2m_T}\right) + (E_{\chi_1} - E_{\chi_2} + 2m_T)\left(E_{\chi_2} - E_{\chi_1} - \tfrac{\delta m^2}{2m_T}\right)\right], \tag{4.10}$$

[1] Search for Dark Matter with Liquid Argon Detectors, Théo Hugues' thesis

2. Model and calculations

SCATTERING OFF ELECTRONS: $F_2 = 0$

E_T: energy of the **electrons** after the scattering

$$\frac{d\sigma}{dE_T} = \frac{m_T}{8\pi\lambda^2(s, m_T^2, m_{\chi_1}^2)}|\overline{M}|^2 \tag{4.7}$$

with the matrix element squared,

$$|\overline{M}|^2 = \frac{8m_T(\epsilon e g_{12})^2}{[2m_T(E_{\chi_2} - E_{\chi_1}) - m_X^2]^2} \times \left[M_0(F_1 + \cancel{\kappa F_2})^2 + \cancel{M_1\left[-(F_1 + \kappa F_2)m_T E + (\kappa F_2)^2 \frac{E_{\chi_1} - E_{\chi_2} + 2m_T}{4m_T}\right]}\right]. \tag{4.8}$$

M_0 and M_1 are:

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$$M_1 = m_T\left[\left(E_{\chi_1} + E_{\chi_2} - \frac{m_{\chi_2}^2 - m_{\chi_1}^2}{2m_T}\right) + (E_{\chi_1} - E_{\chi_2} + 2m_T)\left(E_{\chi_2} - E_{\chi_1} - \frac{\delta m^2}{2m_T}\right)\right], \tag{4.10}$$

[1] Search for Dark Matter with Liquid Argon Detectors, Théo Hugues' thesis

2. Model and calculations

Second ingredient: incoming flux of interacting particles

$$\mathcal{F} = 6.1 \times 1.6 \times 10^{-4}\text{cm}^{-2}\text{s}^{-1} \left(\frac{\langle \sigma v \rangle_{0\to 1}}{5 \times 10^{-26}\text{cm}^3\text{s}^{-1}}\right) \left(\frac{\text{GeV}}{m_{\chi_0}}\right)^2$$

Third ingredient: volume of interaction – DEAP!

$V_{eff} = 4/3\pi R^3$

Fourth ingredient: mean free path of the primary interaction.

$$L_{int} = \frac{1}{\rho_{LAr} \mathcal{N}_A \frac{Z}{A} \sigma}$$

$$\ell_{2,lab} = \frac{c\gamma_2}{\Gamma_2} \sim 16\text{cm} \left(\frac{10^{-3}}{\epsilon g_{12}}\right)^2 \left(\frac{m_X}{30\text{ MeV}}\right)^4 \left(\frac{10\text{ MeV}}{\delta m}\right)^5 \frac{\gamma_2}{10}.$$

$$l_{X.lab} = \frac{c\gamma_X}{\Gamma_X} \sim 0.4\text{cm} \left(\frac{10^{-4}}{\epsilon}\right)^2 \left(\frac{20\text{ MeV}}{m_X}\right) \frac{\gamma_X}{10}$$