Latest data analysis results from DEAP-3600

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On behalf of the DEAP-3600 Collaboration
June 8th, CAP 2020

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Layout of DEAP-3600 detector

Single phase liquid argon detector

Detects light from recoiling argon nucleus after collision with WIMP

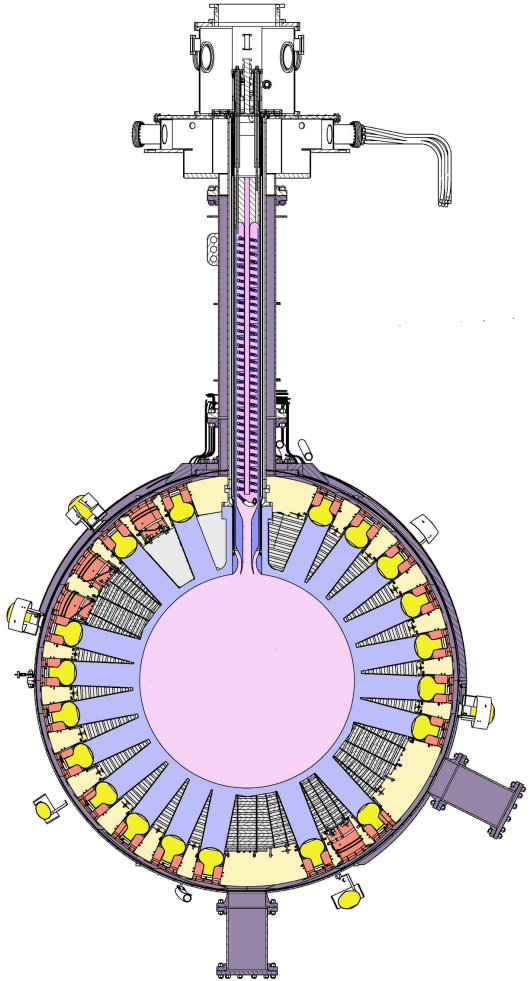
1.7m diameter acrylic vessel holds 3300 kg of ultra-pure liquid argon target

Top 30cm filled with gaseous argon

Inner edge of vessel coated in TPB wavelength shifter

255 PMTs connected to sphere via acrylic light guides

Located 2km underground at SNOLAB, Sudbury, Ontario

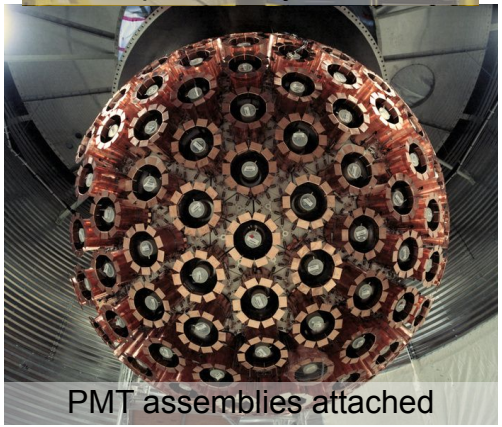


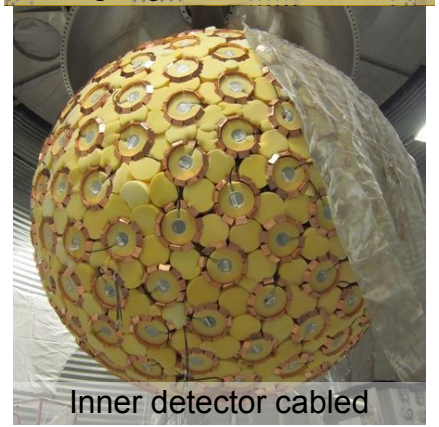
Construction of DEAP

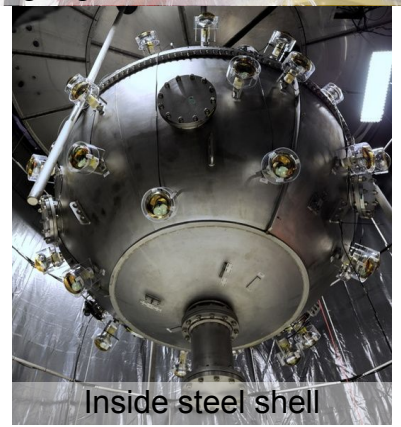

Completed acrylic vessel


Light guides attached


Light guides dressed in reflectors


PMT assemblies attached


Inner detector cabled


Inside steel shell

Dark Matter interaction in DEAP

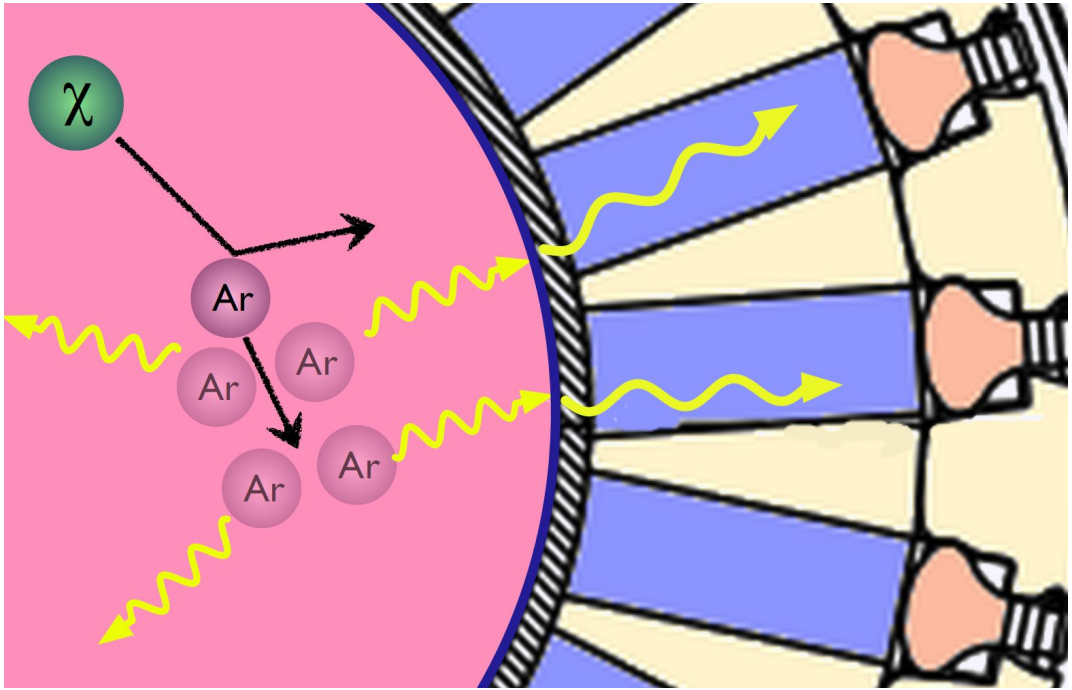
WIMP scatters off argon nucleus

Recoiling nucleus ionises argon

Argon atoms form dimers

Dimers decay radiatively at 128nm

TPB wavelength shifter on inner surface re-emits in visible wavelength

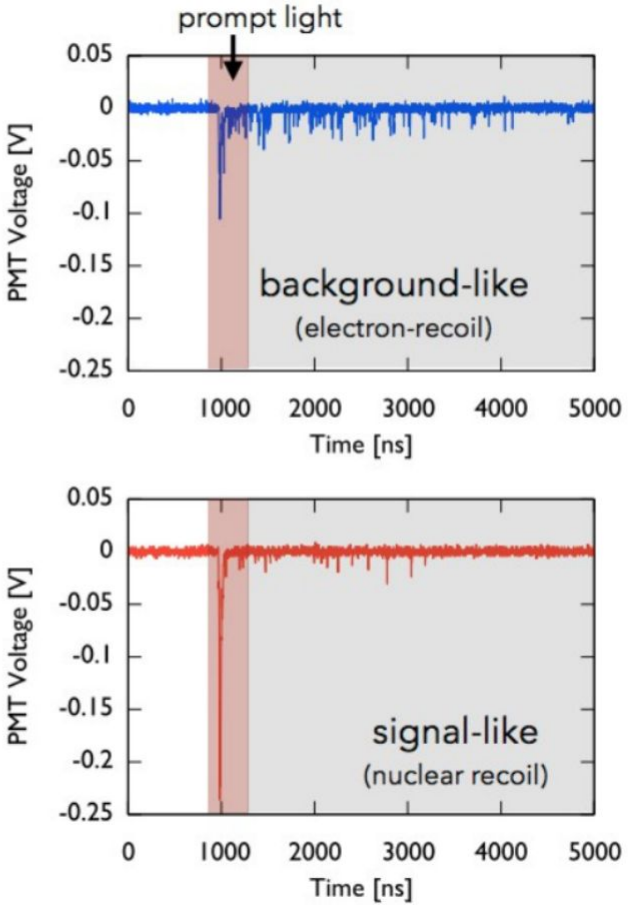


Pulse Shape Discrimination

Argon dimers form in two states:
- Singlet
  τ_S = 6 ns in liquid
- Triplet
  τ_L = 1.3 μs in liquid

Nuclear recoils (e.g. WIMPs, neutrons, alpha particles) produce higher proportion of singlet states
- Light is more prompt

Electron recoils (e.g Ar_{39} beta particles, gamma particles) produce higher proportion of triplet states
- Light is less prompt



The liquid-argon scintillation pulseshape in DEAP-3600

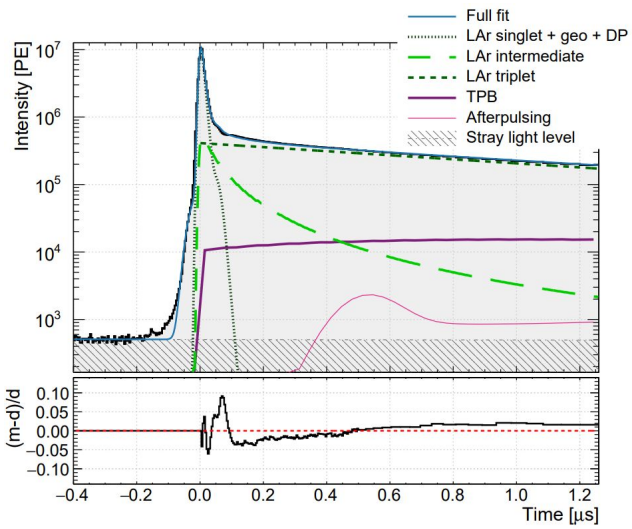
Eur. Phys. J. C 80, 303 (2020)

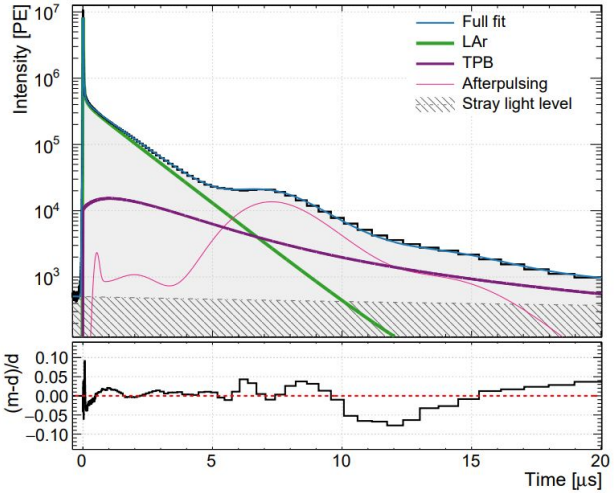
Presented complete model for features observed in large liquid argon based detectors using TPB and PMTs including:

- TPB effects
- stray light and dark noise
- PMT afterpulsing
- Intermediate argon electron recombination component

Corroborated intermediate component to liquid argon pulseshape first identified in Eur. Phys. J. C 73:2618 (2013)

Identified and measured delayed TPB emission in a large detector for the first time





F_{prompt}

$$F_{prompt} = \frac{\Sigma_{t=-28\ ns}^{60\ ns} PE(t)}{\Sigma_{t=-28\ ns}^{10\ \mu s} PE(t)}$$

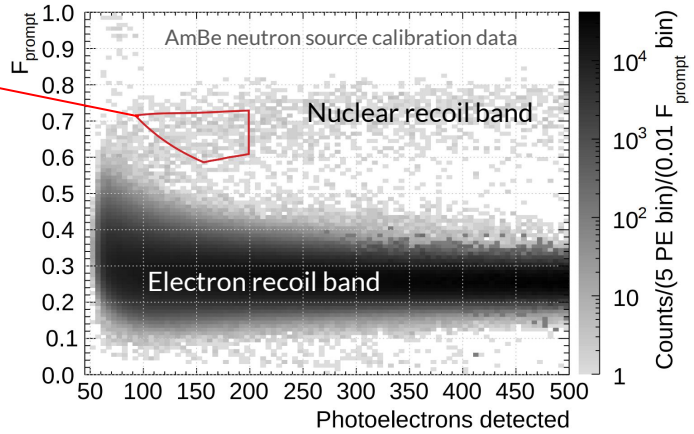
F_{prompt} is our PSD variable

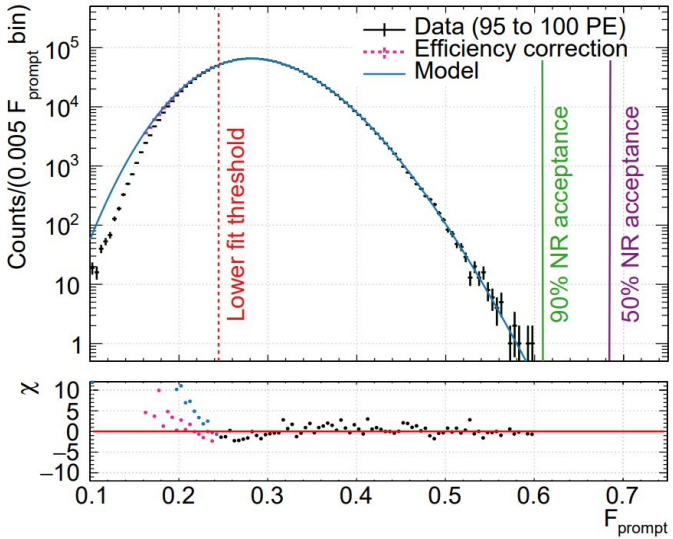
Quantifies proportion of light from an event in the prompt (60ns) window

Reduces 2.44×10^9 Ar_{39} backgrounds to 0.03±0.01 in the WIMP ROI

Bayesian algorithm used to remove afterpulsing

WIMP region of interest



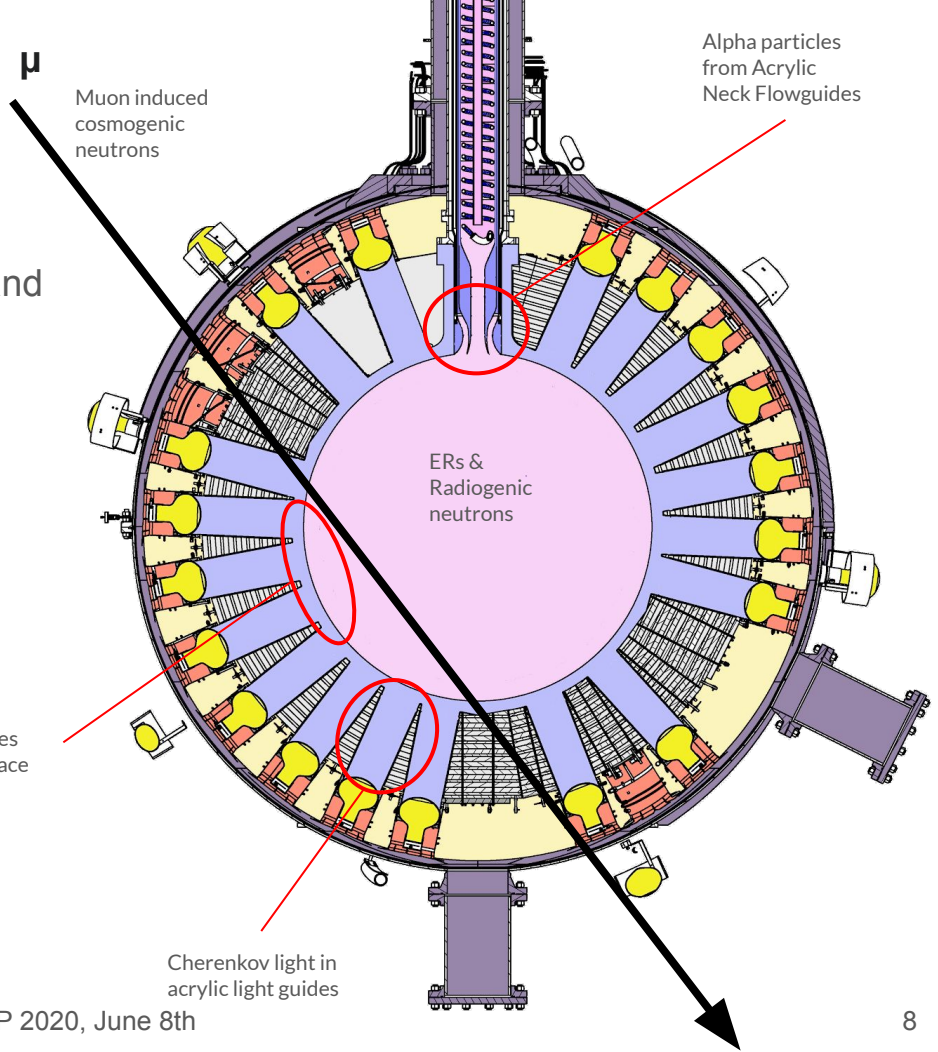


Phys. Rev. D 100, 022004 (2019)

Backgrounds in DEAP

Detailed background model constructed using sideband analysis and Monte Carlo

	Source	N^{ROI}
β/γ's	ERs	0.03 ± 0.01
	Cherenkov	< 0.14
n's	Radiogenic	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	<0.11
α's	AV surface	< 0.08
	AV Neck FG	$0.49^{+0.27}_{-0.26}$
	Total	$0.62^{+0.31}_{-0.28}$

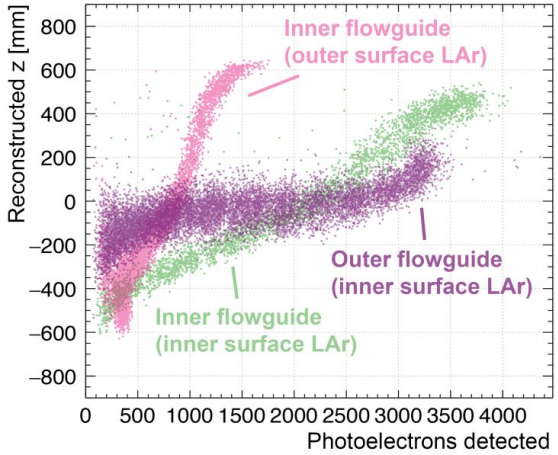


Neck Alphas

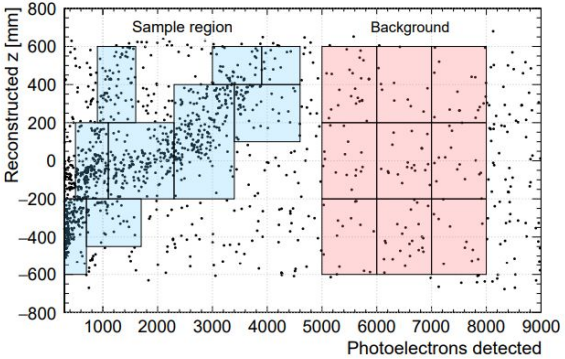
Alpha events originating in the acrylic neck flow guides are shadowed by the neck

Position reconstruction is difficult due to shadowing

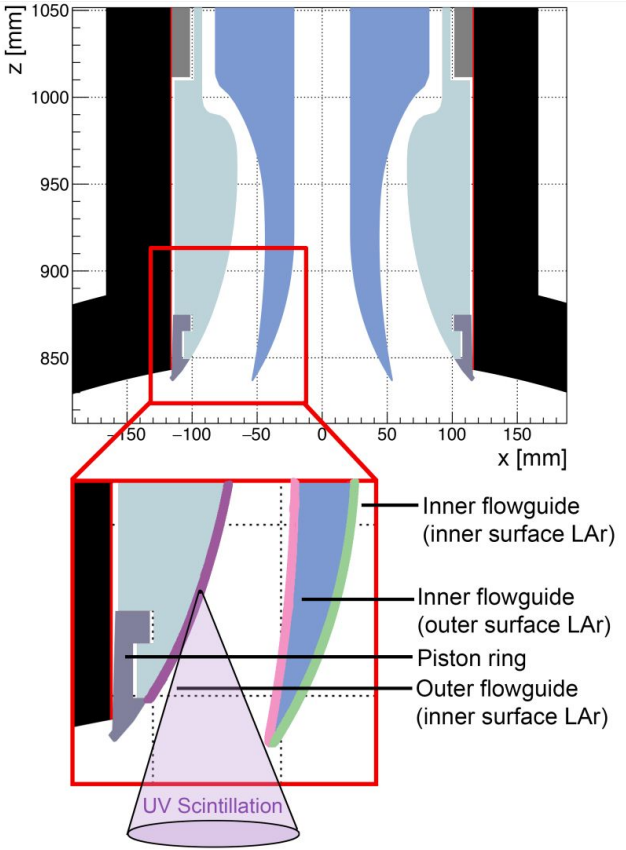
Liquid argon film on guides assumed to explain experimental results



Simulated neck events



Arm structures in data



231 day DM search results

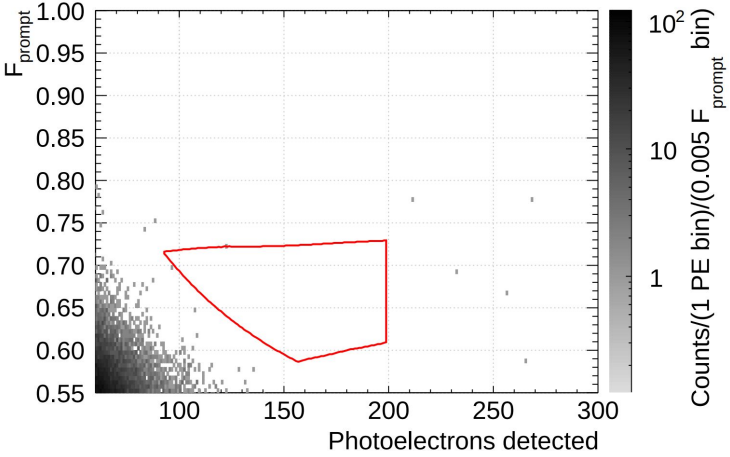
WIMP region of interest tuned on MC models to reduce expected background count to < 1

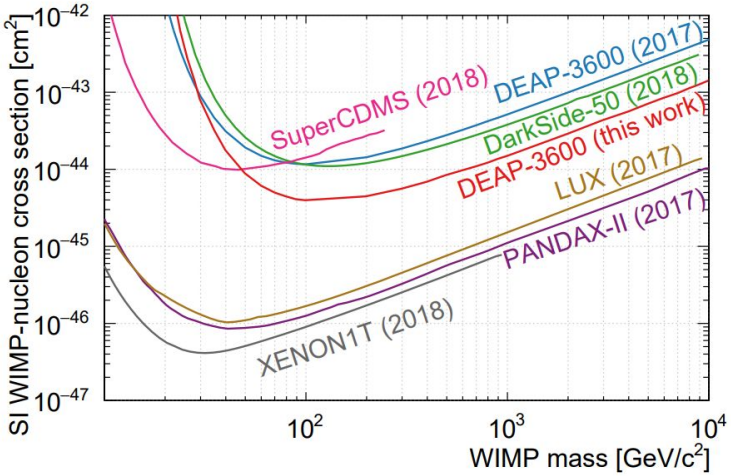
After all cuts, 0 events in ROI

Background model predicts 0.46 events (+0.13,−0.18) between ROI and F_{prompt}<0.75

1.25 events (+0.26, −0.42) predicted between 200-300 PE above 0.55 F_{prompt}

excludes spin-independent WIMP nucleon cross sections above 3.9×10^{-45} cm^2 for 100 GeV/c^2 mass WIMP





We re-interpreted our data in the context of NR Effective Field Theory and recent survey data of the Milky Way

arXiv:2005.14667

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

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

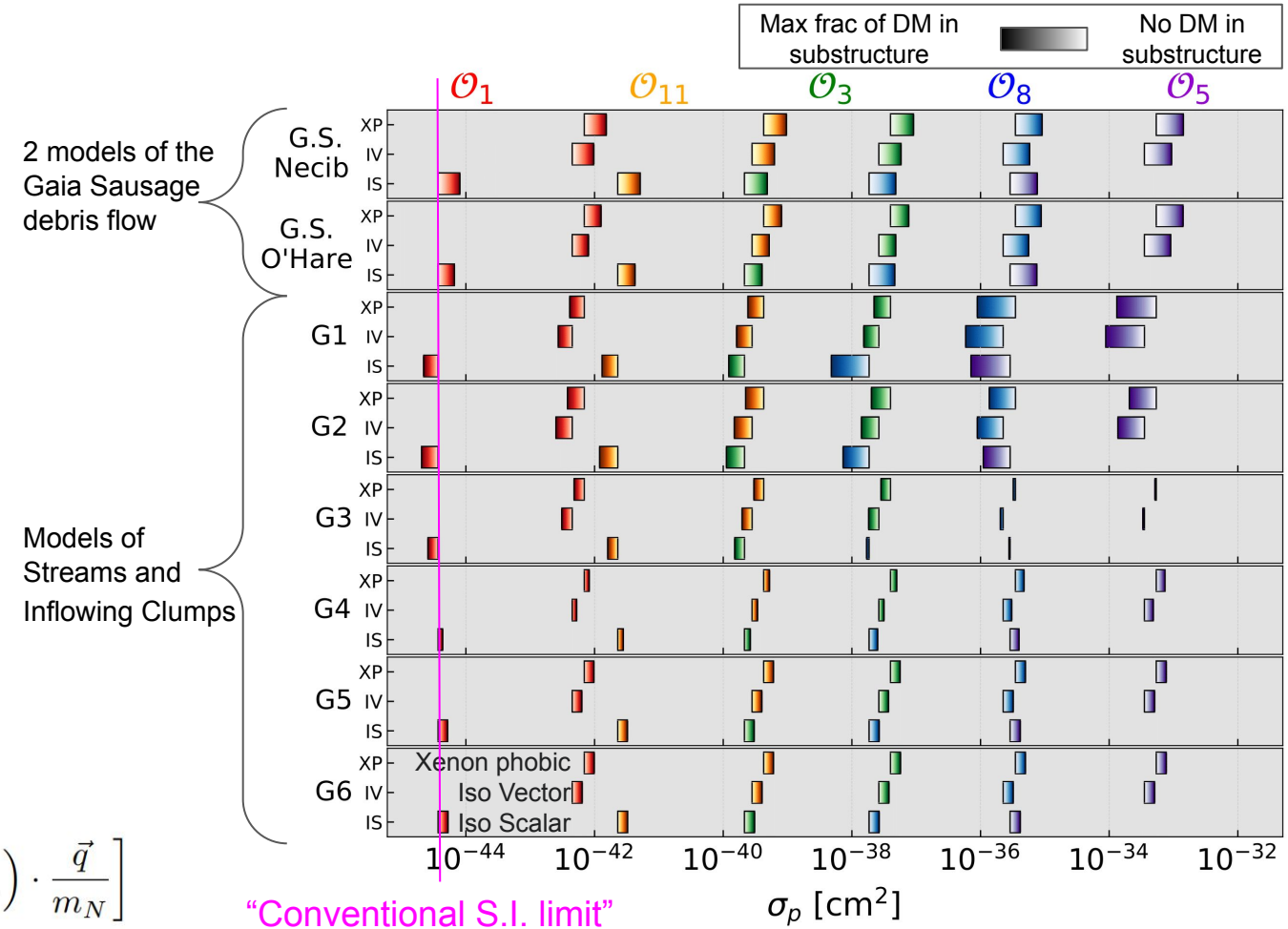
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$$

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

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

$$\mathcal{O}_{12} = \vec{v}_\perp \cdot (\vec{S}_\chi \times \vec{S}_N)$$

$$\mathcal{O}_{15} = -\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left[\left(\vec{S}_N \times \vec{v}_\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$



Future of DEAP

DM Search paper later this year covering:

- ~ 3 years of live time (November 2016 - March 2020)
- 80% of data taken since January 2018 is blinded
- Improved background analysis
- Machine learning techniques to cut down neck alpha background

DEAP-3600 began draining April 3rd, complete April 20th

- Safety due to ongoing COVID-19 crisis
- Allows analysis of backgrounds in gas argon state

DEAP-3600 currently warm, stable and sealed with access available for maintenance

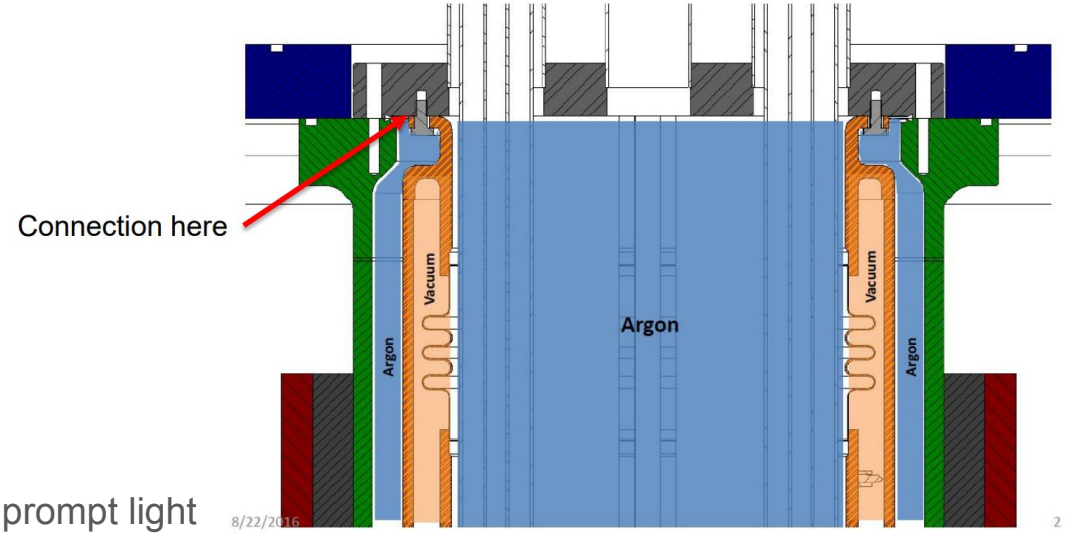
Begin hardware upgrades to DEAP later this year

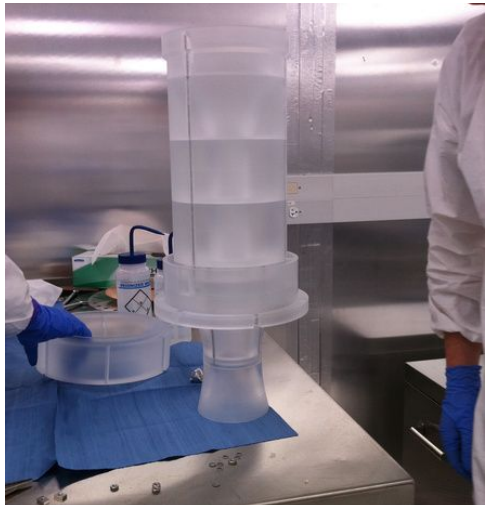
Hardware upgrades

Neck seal fix
- Will allow filling to full design mass

Flow guide wavelength-shifter coating
- Decrease shadowing of neck events
- Use slow wavelength shifter to reduce prompt light
- Significantly reduce backgrounds with PSD

External cooling system with argon return pipe
- Keep neck flow guides dry
- eliminate liquid argon scintillation of neck events
- Allows argon extraction while cool for dust filtration





Conclusion

DEAP-3600 stable in warm state

Awaiting hardware upgrades to reach design sensitivity

Recently published on DEAP pulseshape and DM coupling constraints in context of NR Effective Field Theory and recent survey data of the Milky Way

Working on ~3.5 year run time DM search paper with part blind analysis

DEAP-3600 Collaboration

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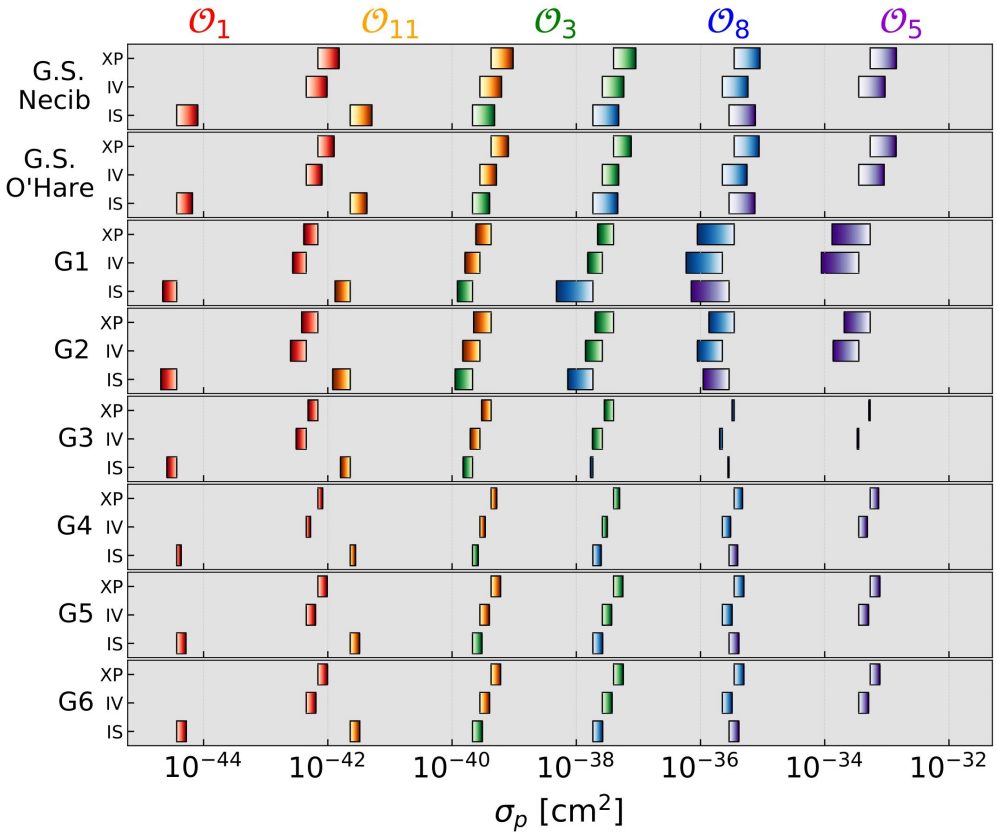
Y-axis shows various galactic DM substructure models

Sub-Y-axis shows xemophobic, isovector and isoscalar DM interactions

Top X-axis & colour show selection of considered DM-nucleon vector operators

Shading indicates proportion of DM in considered substructure, darker denotes greater

O_1 isospin with minimum shading corresponds to standard spin-independent interaction with standard halo model



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