

Status of Sensitivity Projections

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NEWS-G Collaboration Meeting
Grenoble, France



We have our nominal WIMP sensitivity projections for Ne + 10% CH4 at SNOLAB

Our limits are produced with the Optimum Interval method

A possible paper on this was in preparation (>50% written)

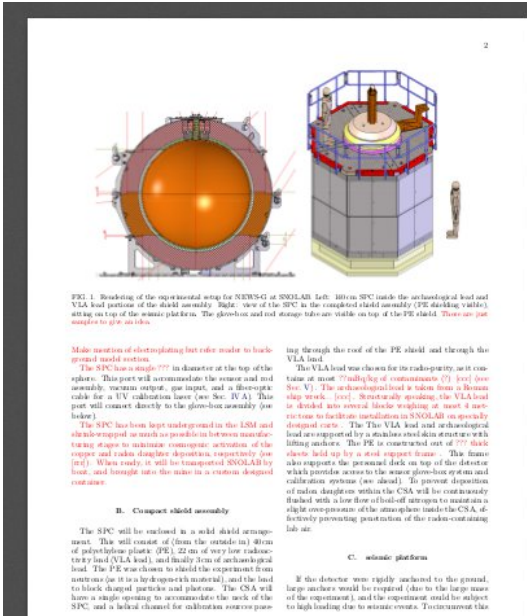


FIG. 1. Schematic of the experimental setup for NEWS-G at SNOLAB. Left: 180cm SPC inside the architecture of lead and VLA lead portion of the shield assembly. Right: view of the SPC in the completed shield assembly (SPC drawing visible) sitting on top of the main platform. The glowtube and lead storage tubules visible on top of the PE shield. There are not enough to go on this.

Make mention of electroplating lead rate made to handle ground isolation. The SPC is a single 77° in diameter at the top of the sphere. This part will accommodate the cover and assembly vacuum outlet, gas input, and a diagnostic cable for a TV calibration laser (see Sec. IV). This part will connect directly to the glass-bowl assembly (see below).

The SPC has been kept underground in the LSM and shielded as much as possible in between manufacturing stages to minimize cosmogenic activation of the copper and carbon daughter deposition, respectively (see [18]). When ready, it will be transported SNOLAB by road, and brought into the main assembly area.

B. Compact shield assembly

The SPC will be enclosed in a solid shield arrangement. This will consist of (from the outside in) 40cm of polyethylene plastic (PE), 22cm of very low radioactivity lead (VLA lead), and finally 3cm of archaeological lead. The PE was chosen to shield the experimental from neutrons (as is a by-product of materials), and the lead to block charged particles and photons. The CSA will have a single opening to accommodate the neck of the SPC, and a helix channel for calibration source pass-

ing through the roof of the PE shield and through the VLA lead.

The VLA lead was chosen for the radioactivity self-corrects at most 70% (due to cosmogenic ^{210}Pb (see Sec. VI). The archaeological lead is taken from a British ship wreck [19]. Historically speaking, the VLA lead is divided into several thin segments of most 4 meters to facilitate installation in SNOLAB in specially designed carts. The VLA lead and archaeological lead are supported by a stainless steel skin structure with lifting mechanisms. The PE is constructed out of 100 thick elastic held up by a steel support frame. This frame also supports the personal dark on top of the detector which provides access to the sensor globe and cryo and calibration systems (see above). In present disposition of radio daughter within the CSA will be continuously flushed with a low flow of alcohol to maintain a slight overpressure on the atmosphere inside the CSA, effectively preventing penetration of the radiocontaminating air.

C. Winch platform

If the detector were rapidly moved to the ground, the winch and cable would be required (due to the large mass of the equipment), and the equipment would be subject to high loading due to seismic events. Truncation of the

Projected WIMP sensitivity of the NEWS-G low-mass dark matter search experiment

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I. INTRODUCTION

Astronomical and cosmological evidence for the existence of dark matter has been mounting for almost a century [1, 2], constituting the greatest of its nature as a principal challenge of modern physics. A final class of dark matter candidates from beyond the Standard Model is Weakly Interacting Massive Particles (WIMPs), which have been the focus of many experimental efforts to directly observe such particles over the past few decades. Such particles are well motivated by various theoretical models such as supersymmetry, with the relic abundance of dark matter in the Universe being a particle mass in the 10 GeV/c² to 10² GeV/c² range [3]. However, the lack of definitive observation of WIMPs in this mass range thus far, and the absence of independent support for supersymmetry at the Large Hadron Collider, has prompted consideration of alternative candidates for particle dark matter [1, 2]. Appealing theories such as axion-like particles [4, 5], and dark sector models [4, 6] possible dark matter masses on the order of 1 GeV/c² or less. Growing interest in these models has motivated various experimental efforts to explore this new region of WIMP parameter space, including efforts by the NEWS-G, CRESST, Edelweiss, SuperCDM, DAMIC, and SENSE collaborations [3–12].

II. PLANNED WIMP SEARCH

This section will briefly introduce the NEWS-G experiment, reference our first results from the LSM, and outline the planned WIMP search run (i.e., define the gas mixture, expected exposure). Finally, we include this in the introduction section.

III. EXPERIMENTAL SETUP

The next generation of NEWS-G detector will be located at the SNOLAB facility near Sudbury, Canada. Roughly 20m of rock over-burden provides 60 t/m of water-equivalent shielding against cosmic rays [13]. The detector will be located on the ‘‘Cave Hall’’ next to the DEAP-F300 experiment. It will consist of a 1.8-ton detector SPC (see Sec. III A) housed in a compact shield assembly (CSA) including low activity lead, archaeological lead, and polyethylene shielding (see Sec. III B). The following sub-sections, the setup depicted in Fig. 1 and planned hardware improvements are described in more detail.

A. The 1.8-ton SPC

The 1.8-ton ultra-diameter SPC is constructed of CERN copper from 77° on alloy drawn for its low concentrations of potentially radioactive trace contaminants. Two separate hemispheres are created by ‘‘splitting’’ that disk of copper around a cylindrical metal tool, resulting in uniform pieces with thicknesses of 77°. The process has already been completed.

Details of the rest of the SPC assembly process, i.e., electroplating, electron beam welding, final cleaning—

problem, the detector and CSA will sit on a winch platform using ball bearings, coil springs, and laser dark-spot dampers to isolate the detector from vertical and horizontal ground motion. The winch platform is currently being fabricated in Sudbury, and designed to limit acceleration of the experiment to less than 0.1 g horizontally and 0.5 g vertically.

D. Sensor globe and electronics

Description of the globe and analog tube: Also details identification of electronics.

E. Gas and handling system

Description of the gas mixture (purity, manufacturing, mixing procedure). Description of gas filtration equipment that will be used to maintain purity. Details of the vacuum ‘‘single-chamber’’ filtration problem, or otherwise circulation system(s).

F. Sensor design

Details of ‘‘neutron-like’’ sensor with a glass window. Details of the detector window with the ultra-thin SPC and its distance to the possibility of using an scintillator. Anticipation that the gas will be at atmospheric level (so will not be 100% of the volume of the detector).

IV. CALIBRATION SYSTEMS

A. UV laser

UV laser system will serve as a principal calibration for NEWS-G at SNOLAB. A 100-mW, diode-pumped solid-state pulsed laser will be used in combination with a 100-mm diameter, windowless resonator to produce a beam with a $\lambda = 213\text{nm}$. Illuminating the inner surface of the detector vessel with this beam produces photoelectrons for calibration. This method of source production is similar with a variable attenuator, allowing for the production of signals to many hundreds of photoelectrons. Additionally, the beam is split before reaching the detector, with the secondary beam directed to a silicon based ThermoFisher DET100 photodiode. This allows laser counts in the SPC to be tracked by looking for correlations in the photodiode circuit. The calibration scheme has already been demonstrated with SPC in [14] (see later), where a more detailed description of the setup can be found in [14].

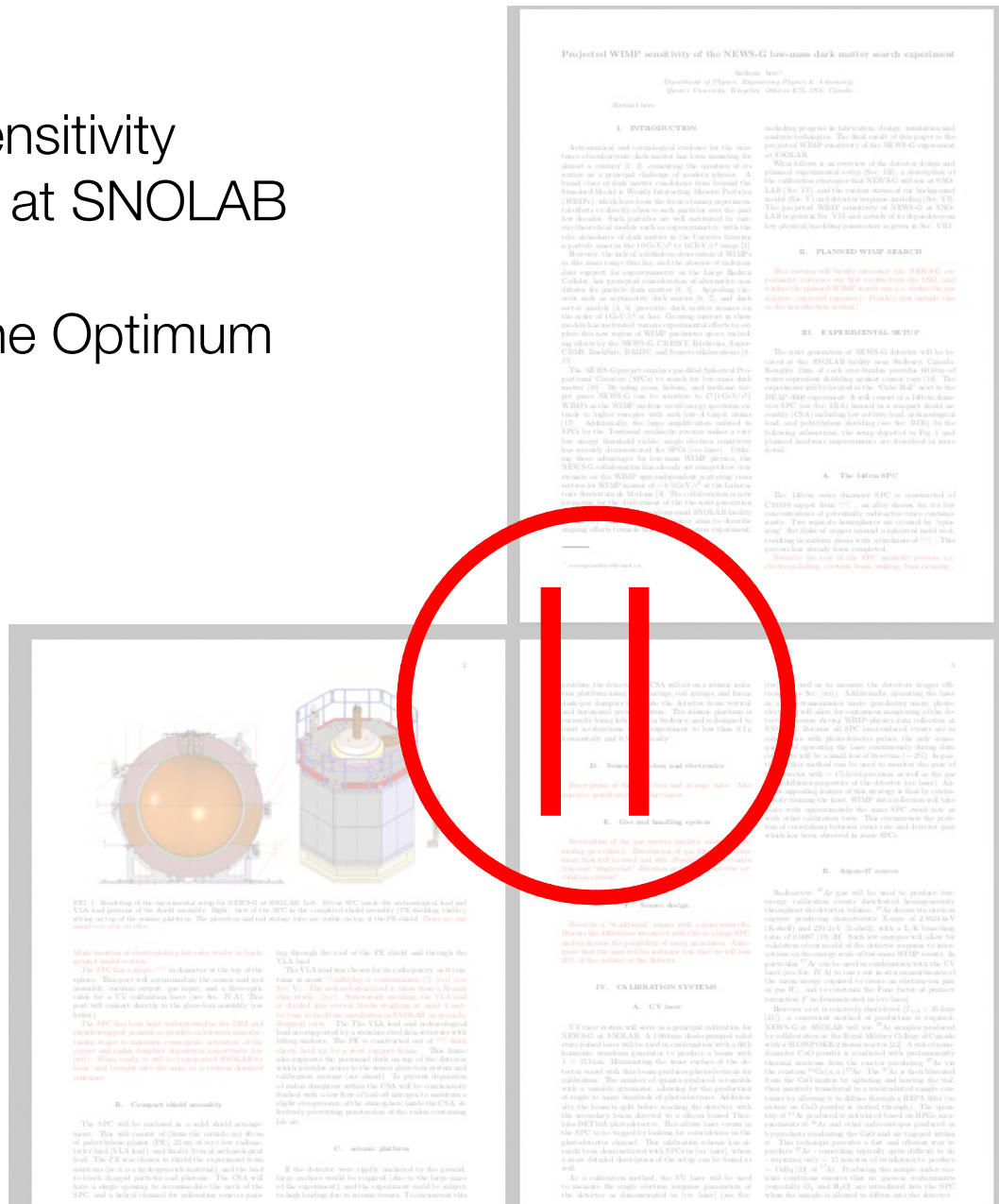
As a calibration method, the UV laser will be used to measure the single electron response parameters of the detector as demonstrated in [14] (see [14]).



We have our nominal WIMP sensitivity projections for Ne + 10% CH4 at SNOLAB

Our limits are produced with the Optimum Interval method

Put on hold over concerns about our ill-understood low-energy background, proximity to physics results...



Projected WIMP sensitivity of the NEWS-G low-mass dark matter search experiment

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I. INTRODUCTION
Astrophysical and cosmological evidence for the existence of a dark matter particle has been mounting for almost a century [1]. ...

II. PLANNED WIMP SEARCH
This section will briefly summarize the NEWS-G component objectives ...

III. EXPERIMENTAL SETUP
The main generation of NEWS-G detectors will be located at the SNOLAB facility ...

A. The UltraSPC
The Ultra-scale detector SPC is constructed of CRH100 support from ^{70}Ti ...

B. Argon-OT system
Radon-free ^{40}Ar gas will be used to produce low-energy calibration events ...

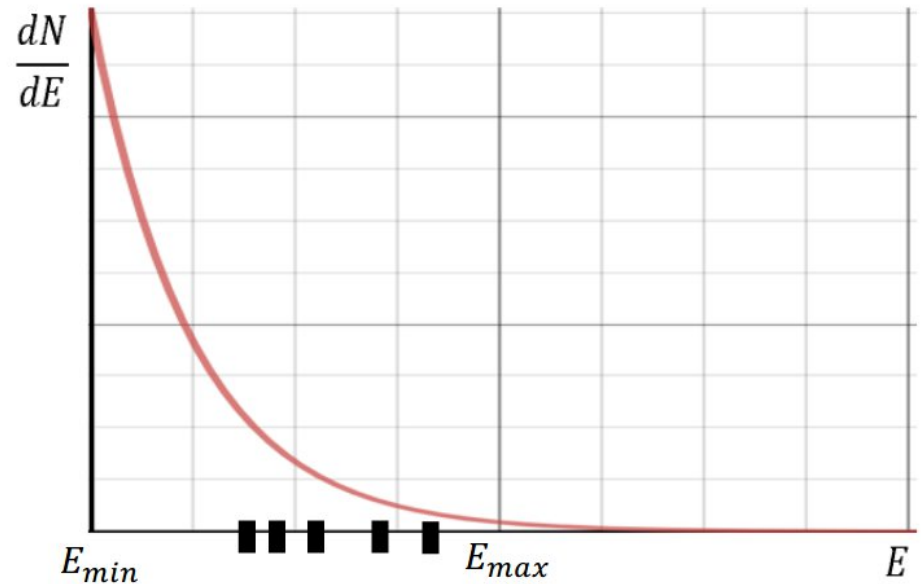
IV. CALIBRATION SYSTEMS
A. UV beam
Between 200 and 250 nm, a broad calibration for NEWS-G at SNOLAB ...

FIG. 1. Schematic of the experimental setup for the NEWS-G at SNOLAB. Left: Ultra SPC inside the cryostat shield and VAA lead portion of the shield assembly. Right: view of the SPC in the completed shield assembly (SPC shielding visible) sitting on top of the main platform. The photostat and stage transfer table is on top of the PE shield.

III. CALIBRATION SYSTEMS
A. UV beam
UV laser system will serve as a primary calibration for NEWS-G at SNOLAB. A 100-mW, diode-pumped solid state pumped laser will be used in combination with a high-resolution monochromator to produce a beam with $\lambda = 213\text{nm}$

Yellin’s method ([thanks Alan](#)) uses the shape of the expected signal to find the sub-range of parameter space that allows for the best sensitivity

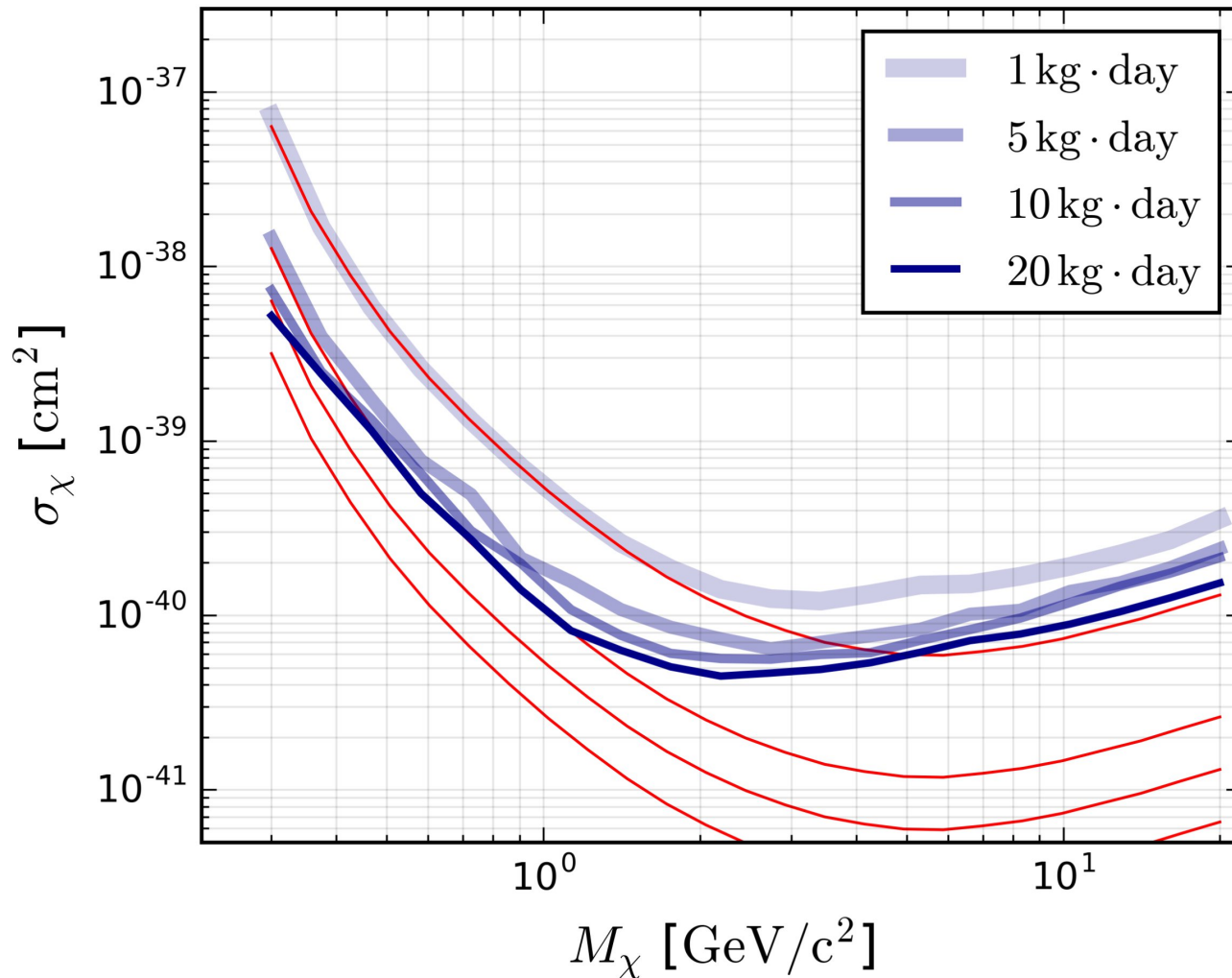
“Looking” at the data incurs a statistical penalty



	Poisson	Optimum Interval	Profile \mathcal{L} Ratio
Uses background information	✗	✗	✓
Uses Signal information	✗	✓	✓

(We don’t yet understand our background well enough to use a likelihood analysis)

The Optimum Interval method allows us to recover much of our sensitivity, especially at low WIMP masses

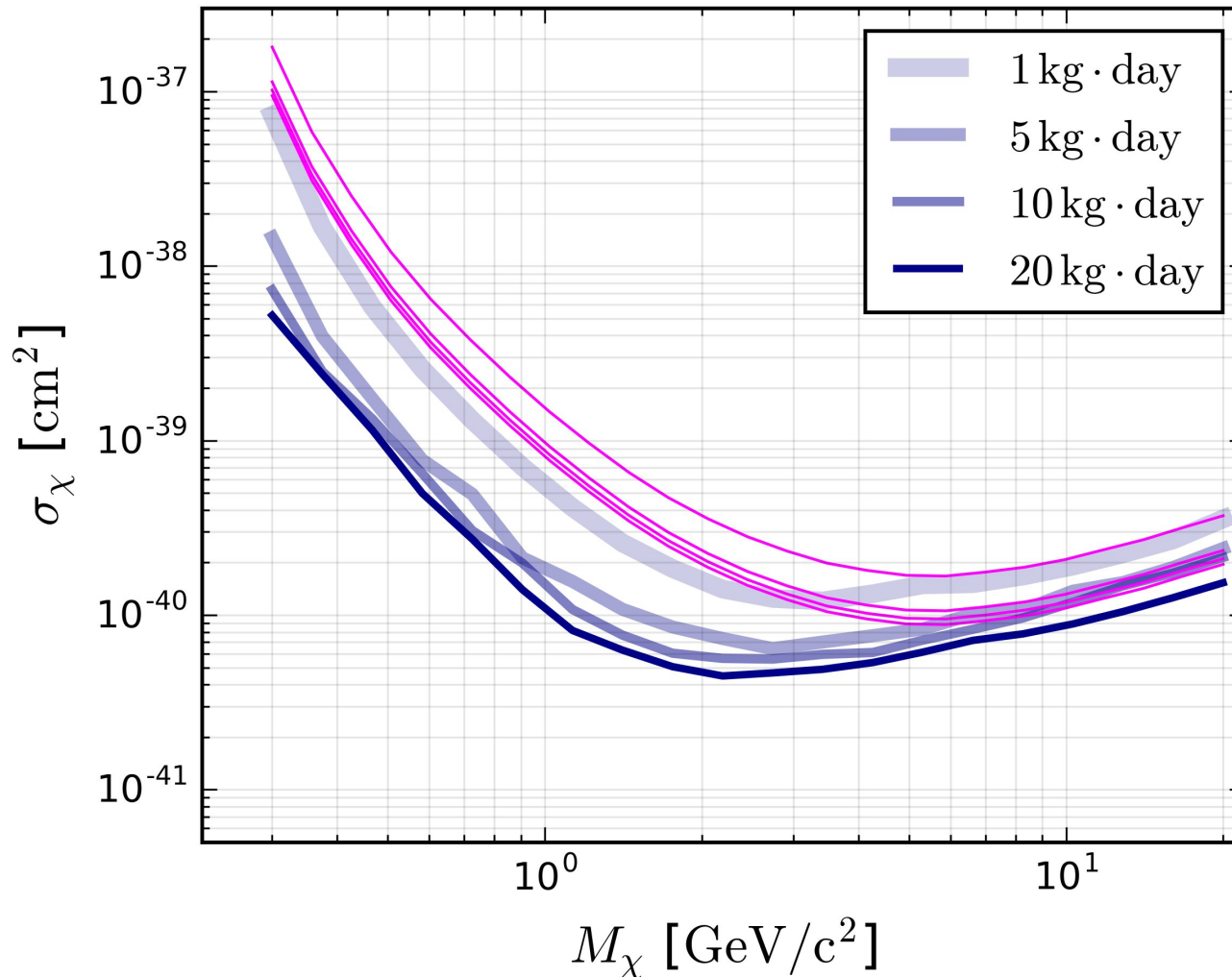


OI Limits

Corresponding Background Free Limits

- Neon, 1 kg.day
- Flat background (3 dru_{ee})
- $F = 0.2, \theta=0, \text{SRIM Q}$
- 100 trials
- ROI of 36 eV_{ee} - 1 keV_{ee}

The Optimum Interval method allows us to recover much of our sensitivity, especially at low WIMP masses



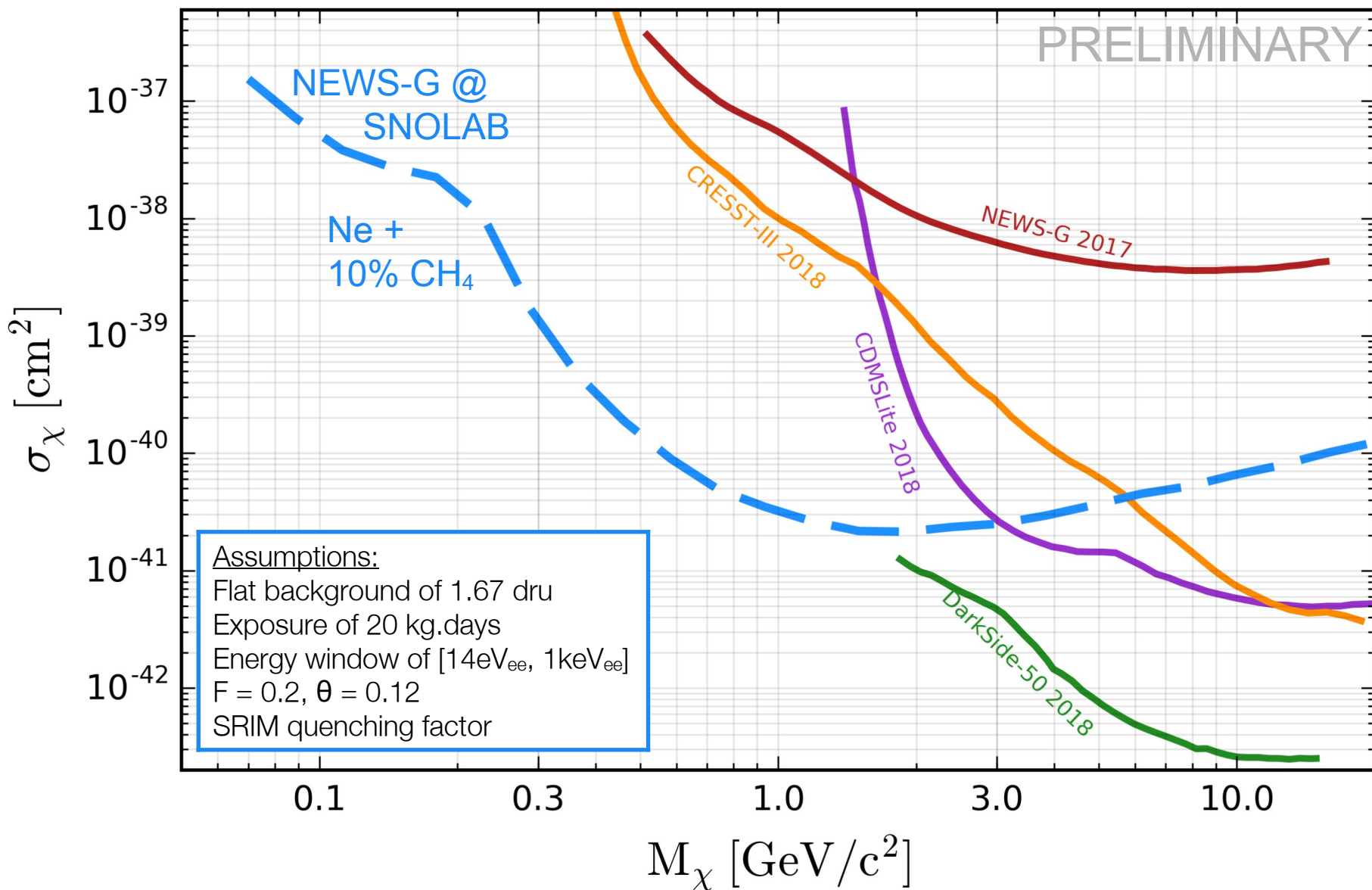
OI Limits

Corresponding
Poisson Limits

- Neon, 1 kg.day
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- ROI of $36 \text{ eV}_{ee} - 1 \text{ keV}_{ee}$



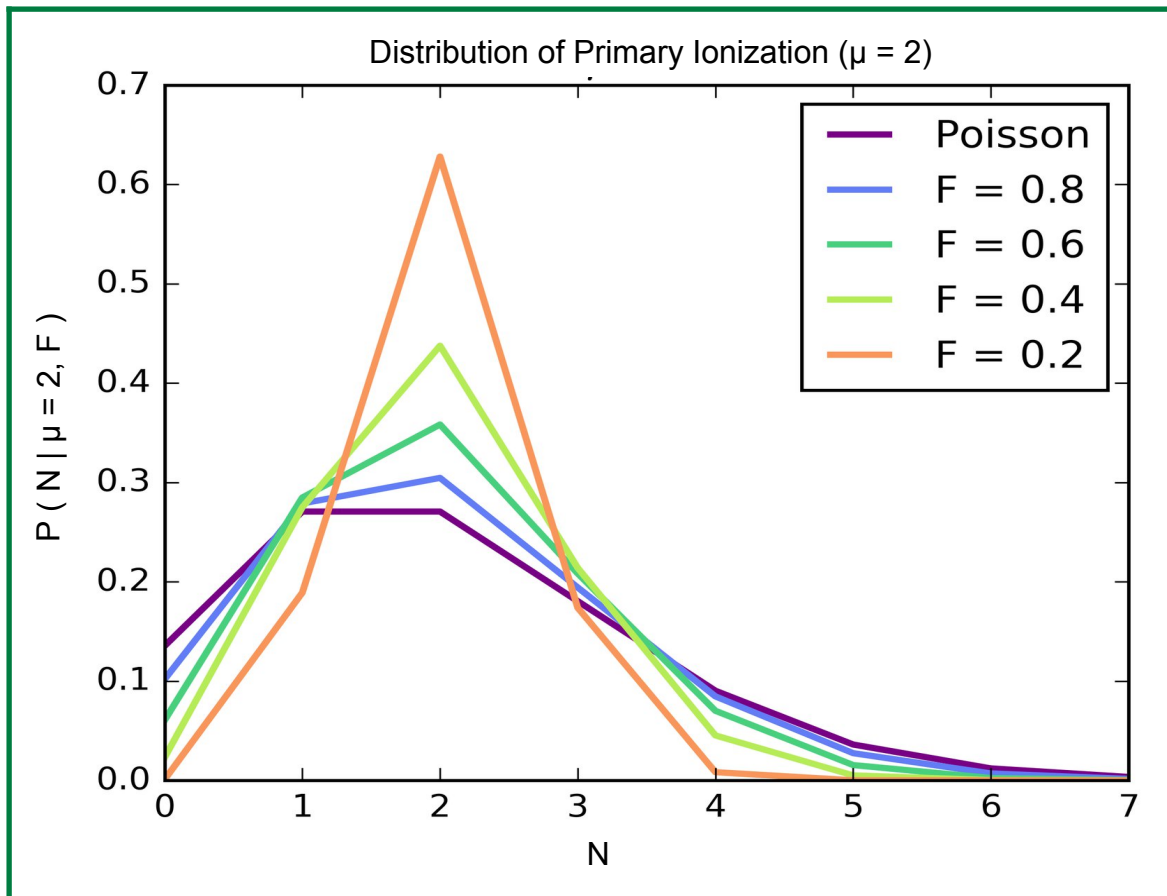
Our nominal projection for NEWS-G @ SNOLAB





Our detector response model assumes:

» COM-Poisson for primary ionization





Our detector response model assumes:

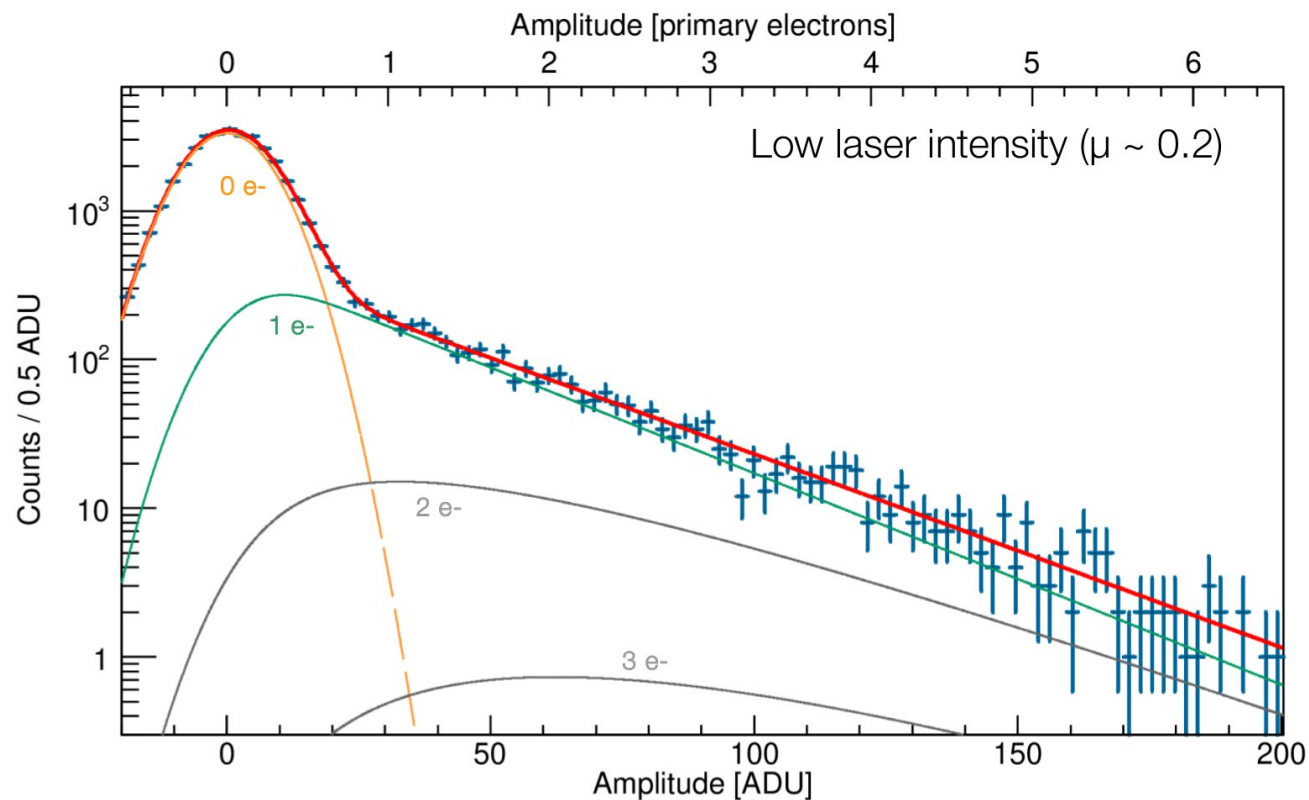
- » COM-Poisson for primary ionization
- » SRIM quenching factor





Our detector response model assumes:

- » COM-Poisson for primary ionization
- » SRIM quenching factor
- » Nth Polya for avalanche response





Our detector response model assumes:

» COM-Poisson for primary ionization

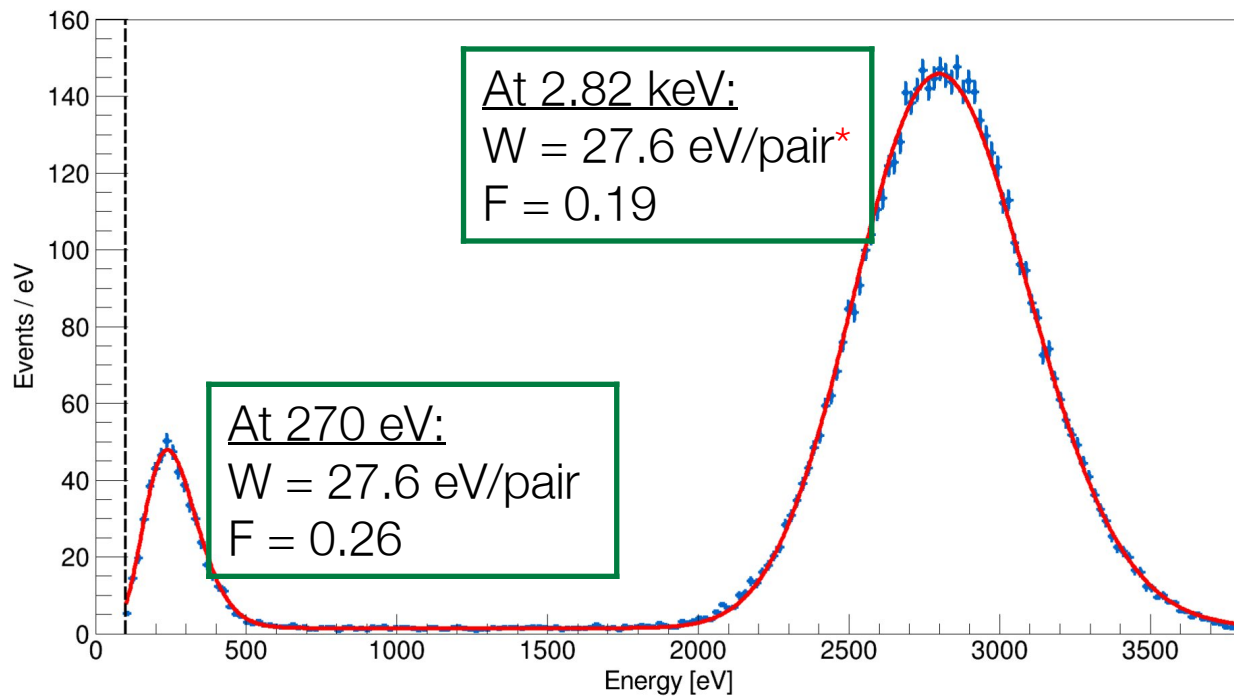
$$f(E') = \sum_{N=1}^{N_{\max}} P_{\text{CMP}}(N|\mu, F) \times P_{\text{Polya}}^{(N)}(E' | \langle G \rangle, \theta)$$

» SRIM quenching factor

» Nth Polya for avalanche response

» Laser or Laser + ^{37}Ar measurements of θ , $\langle G \rangle$, W-value, F

Best-fit values

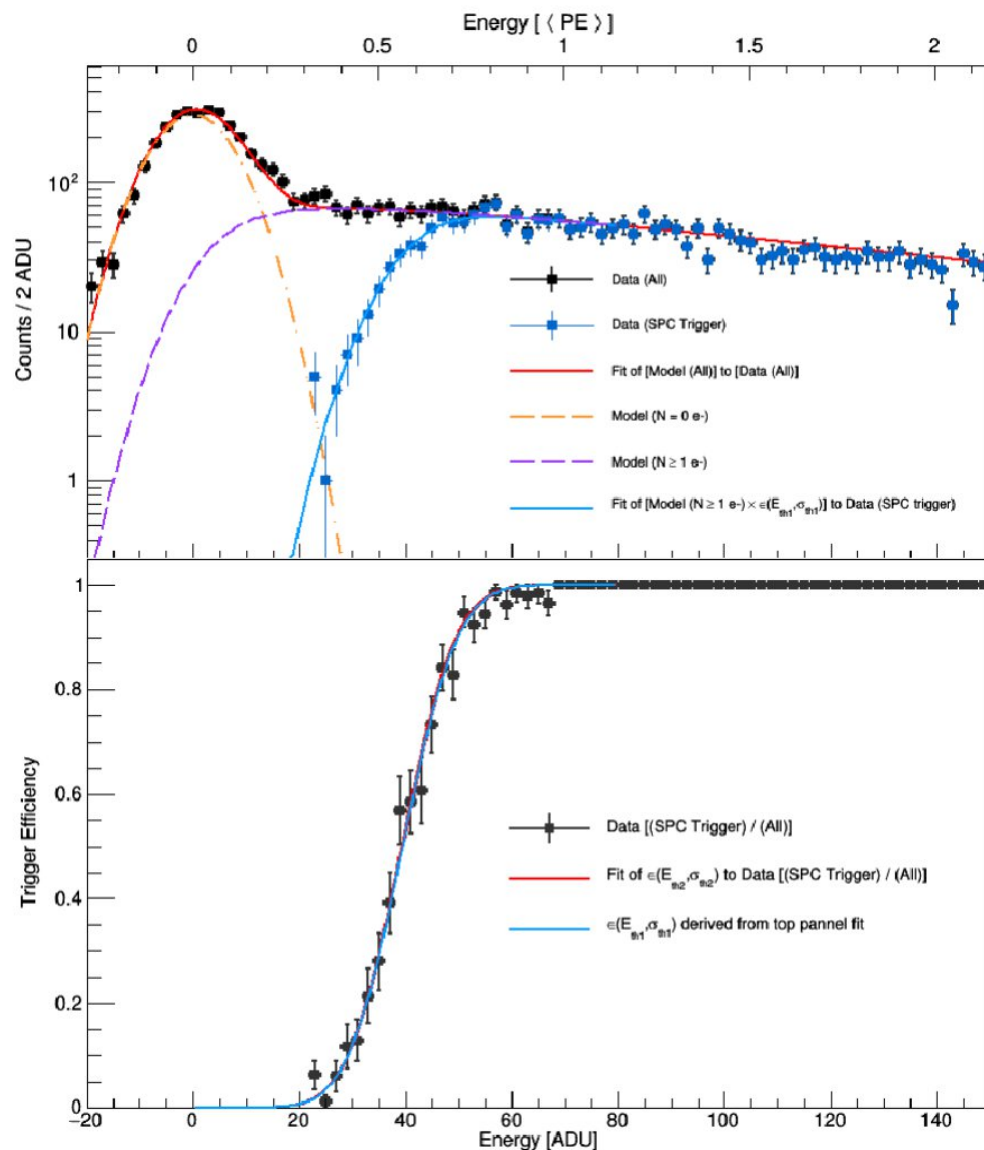


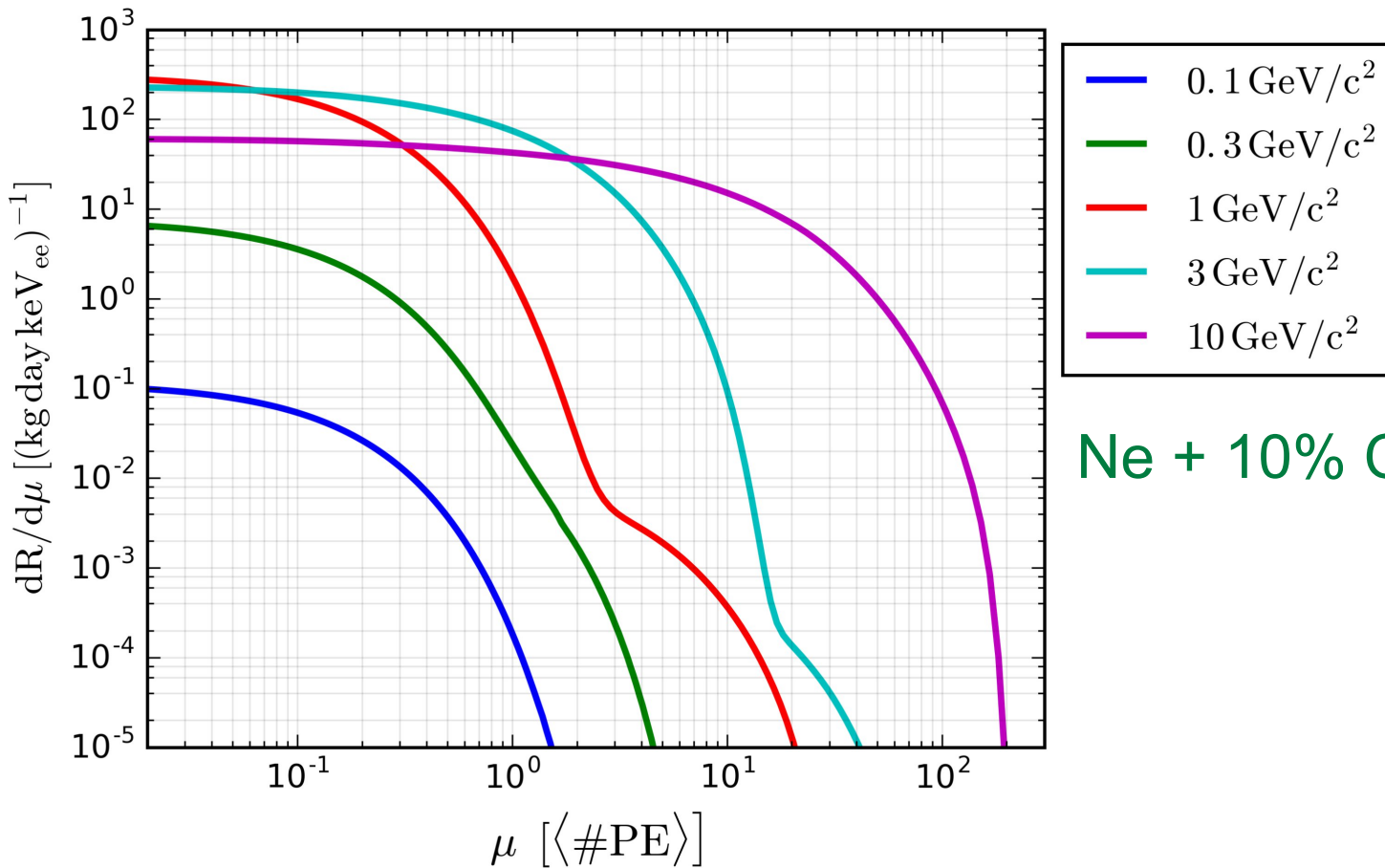
*The W-value at 2.82 keV was calculated directly from $\langle G \rangle$ and fixed for this fit



Our detector response model assumes:

- » COM-Poisson for primary ionization
- » SRIM quenching factor
- » Nth Polya for avalanche response
- » Laser or Laser + ^{37}Ar measurements of θ , $\langle G \rangle$, W -value, F
- » Trigger efficiency energy threshold driven by laser measurements





$$\frac{dR}{dE}(E_{ee}) = \int_0^{E_{\max}} \frac{dR}{dE}(E_{nr}) \times \sum_{N=0}^{N_{\max}} \left[P_{\text{COM}}(N|\mu, F) \times P_{\text{Polya}}(E_{ee}|\theta, \langle G \rangle) \right] dE_{nr}$$

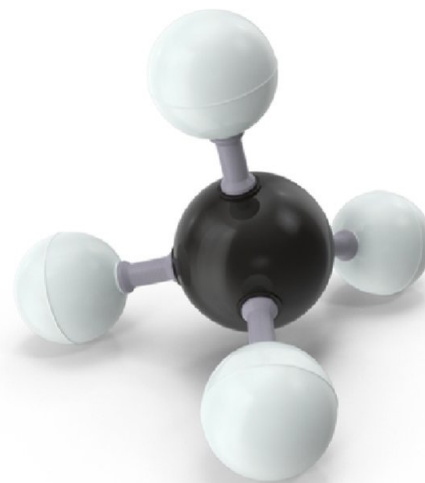
$$\mu = E_{nr} \times \left(\frac{Q(E_{nr})}{W(E_{nr})} \right) \quad N_{\max} = \left\lfloor \frac{E_{nr}}{I} \right\rfloor$$



What is the physics advantage of a pure 200 mbar CH₄ run?

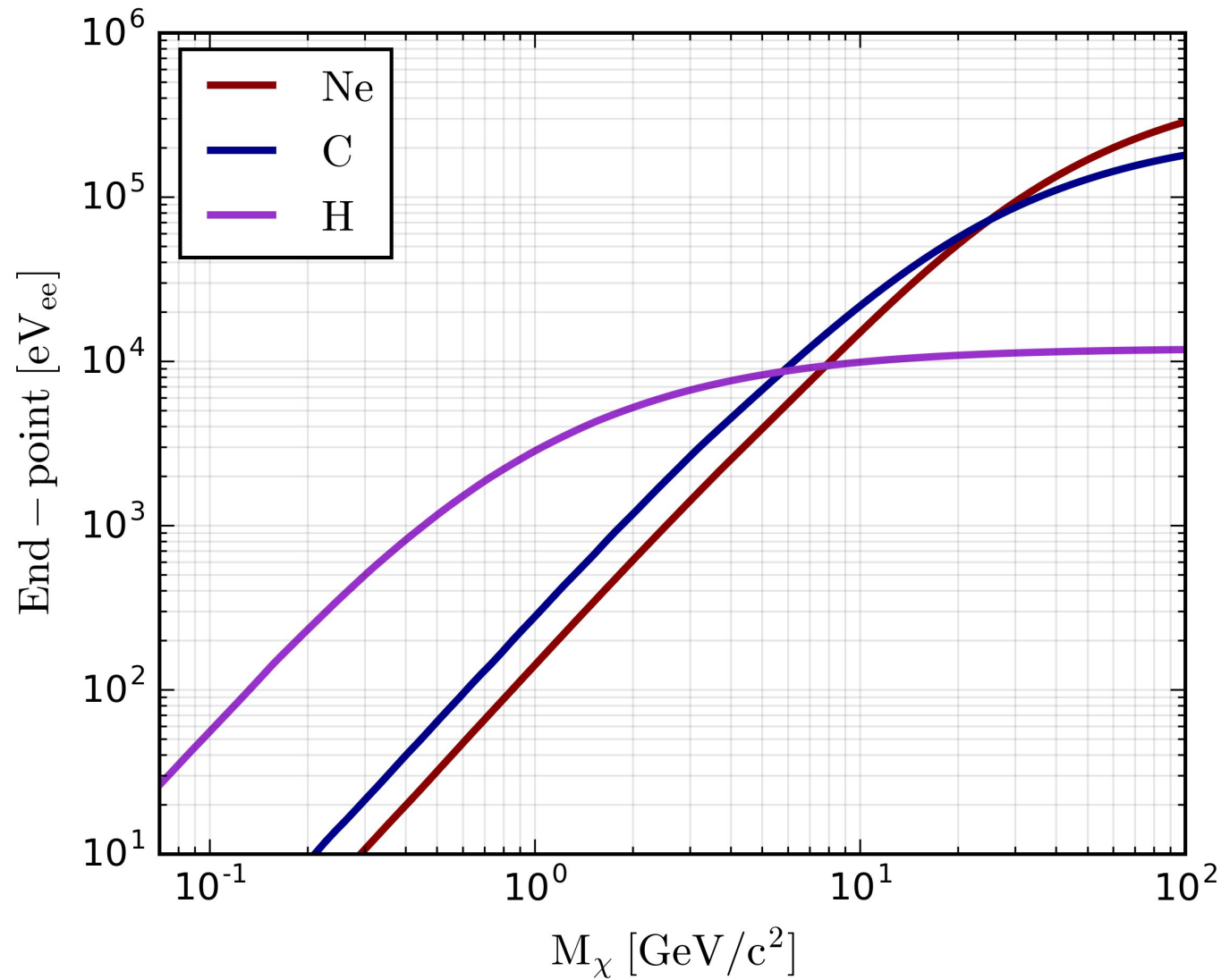
Given time constraints at the LSM, it might be advantageous:

- » The proportion of hydrogen is greater per unit mass of gas
- » Slightly higher background $\text{kg}^{-1}\text{day}^{-1}$ (ask Alexis), but lower background rate $\text{kg}^{-1}\text{day}^{-1}$ of H than 2 bar of Ne + 10% CH₄
- » Greater sensitivity to low-mass WIMPs for given exposure
- » Quenching factor measurements from Grenoble t.b.p. soon?
- » W-value known for pure methane, no need to worry about characterizing Penning transfers in gas mixtures





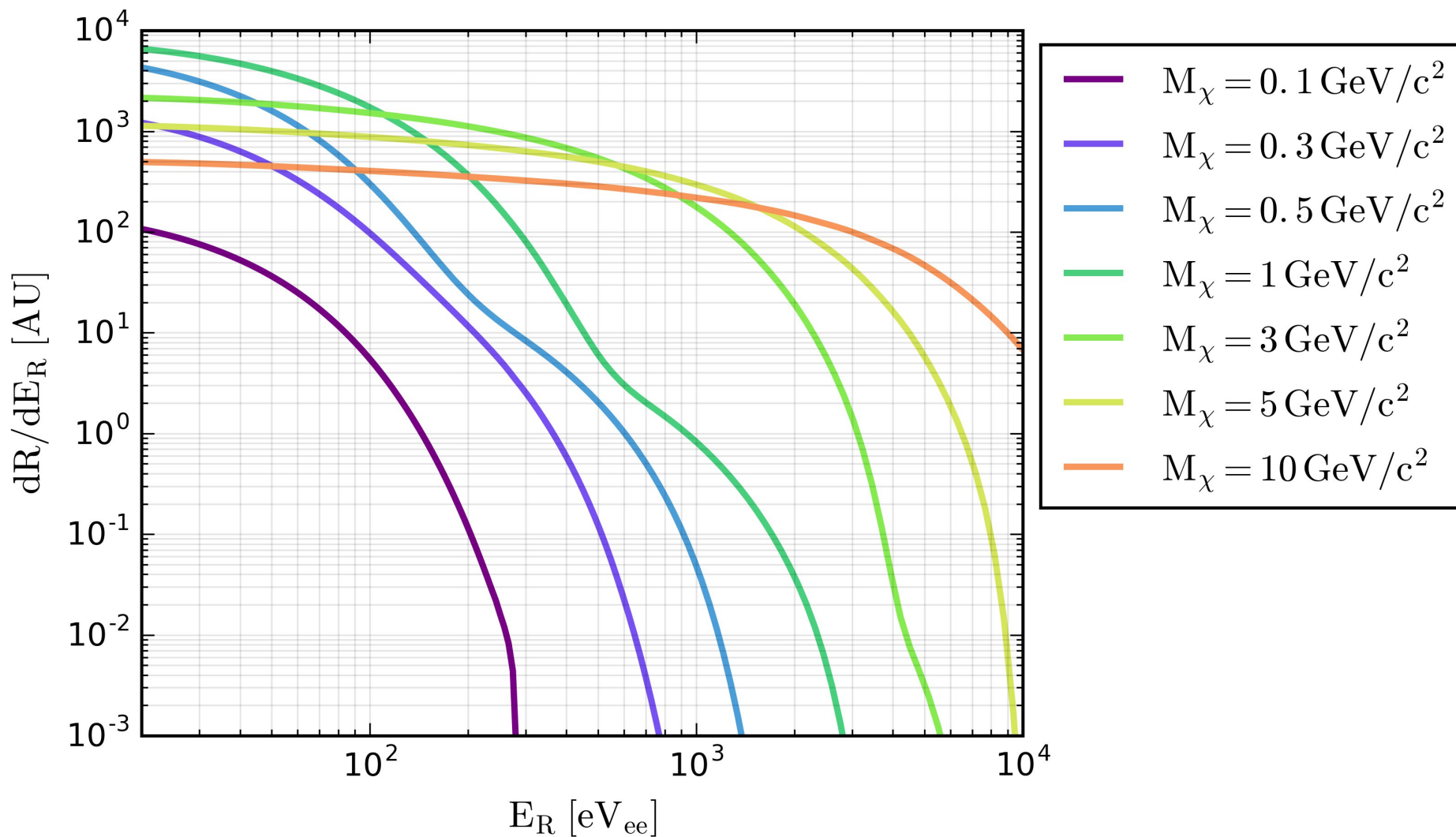
I haven't had a chance yet to write code include carbon in the Ne + CH₄ limit code
(it is not super easy)



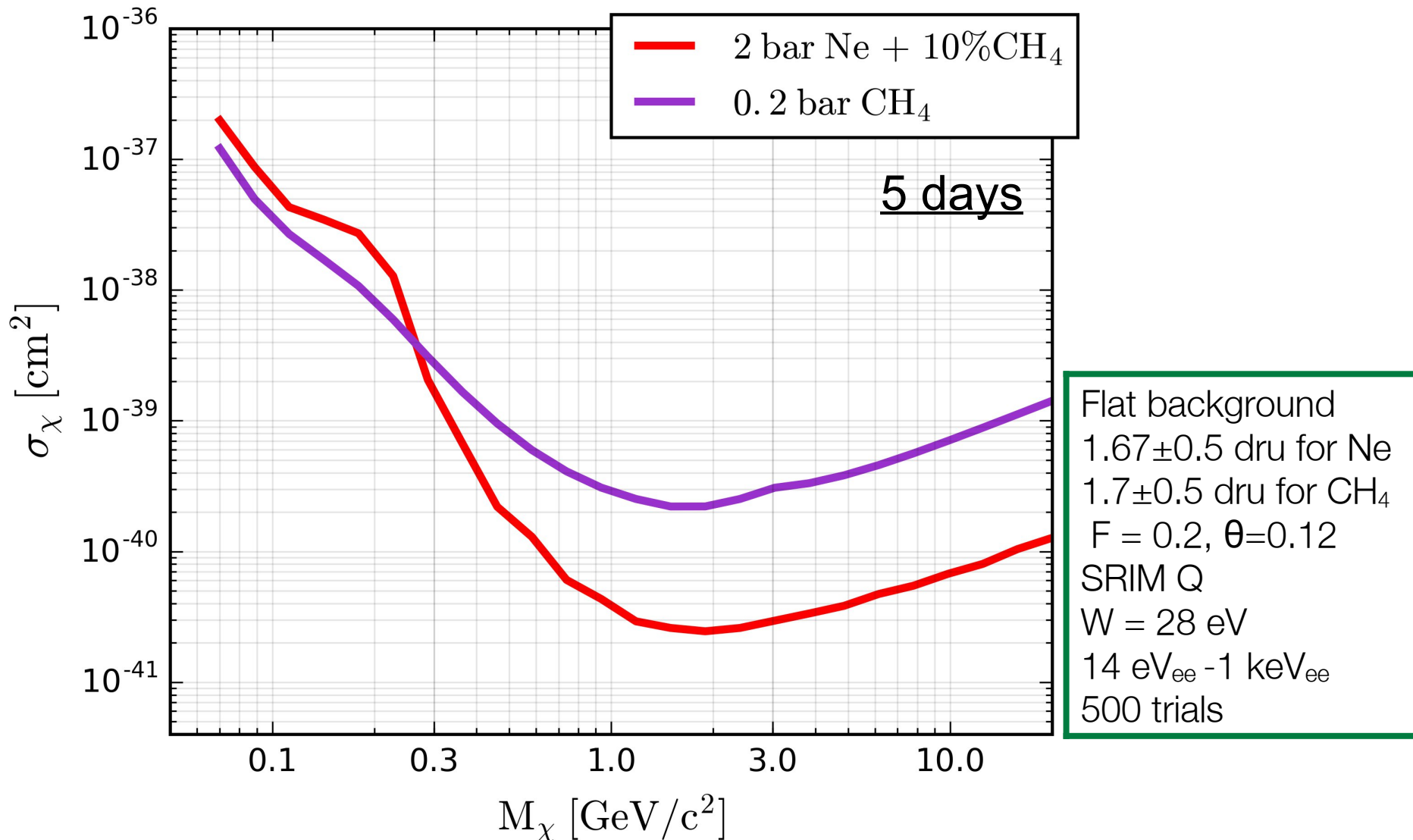
In any case, the impact of carbon in this limit will be very small (possibly completely invisible)



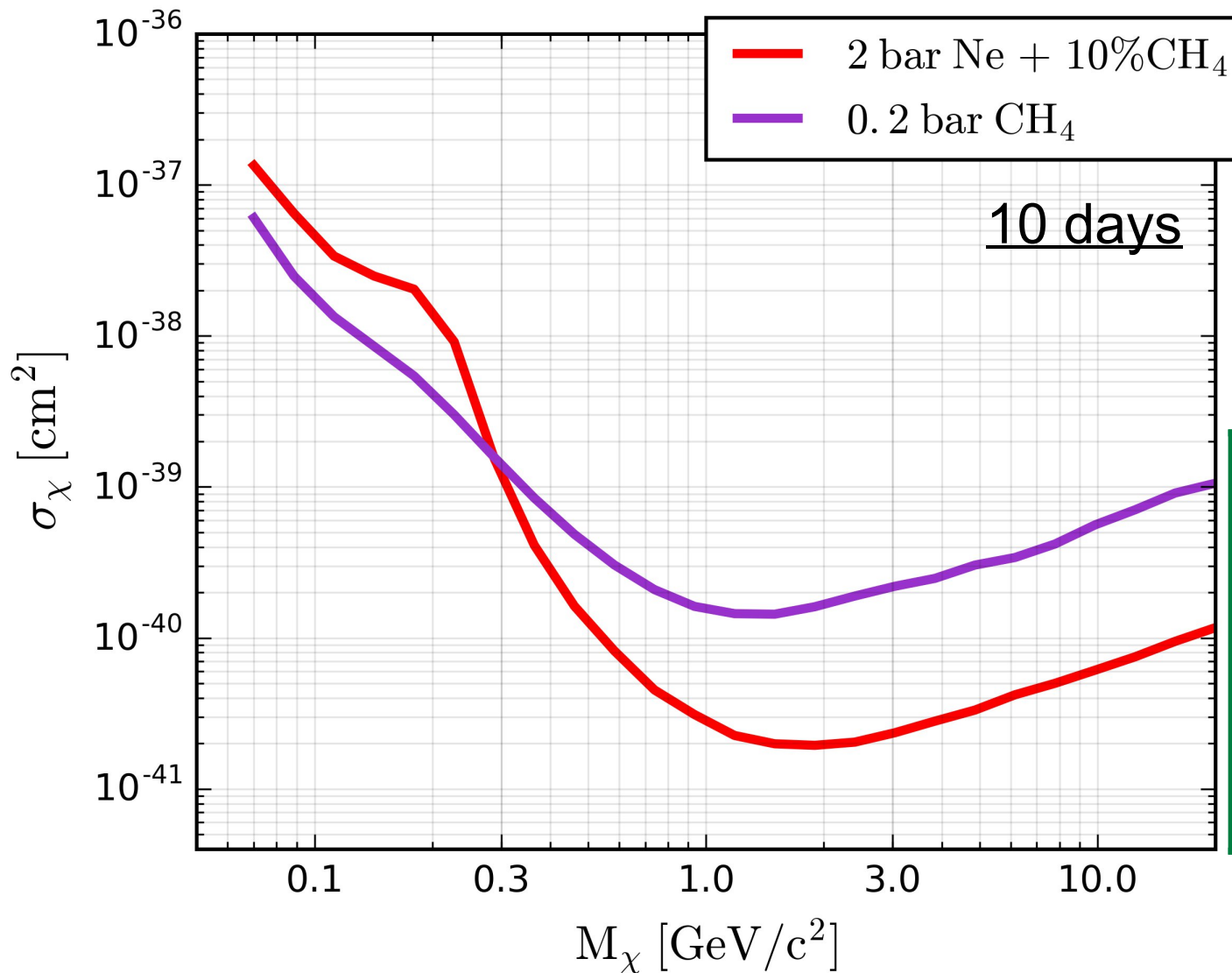
The code for pure CH₄ works! Carbon almost replaces Neon in this case



The Neon limit is immediately background-limited, but the CH₄ limit is not

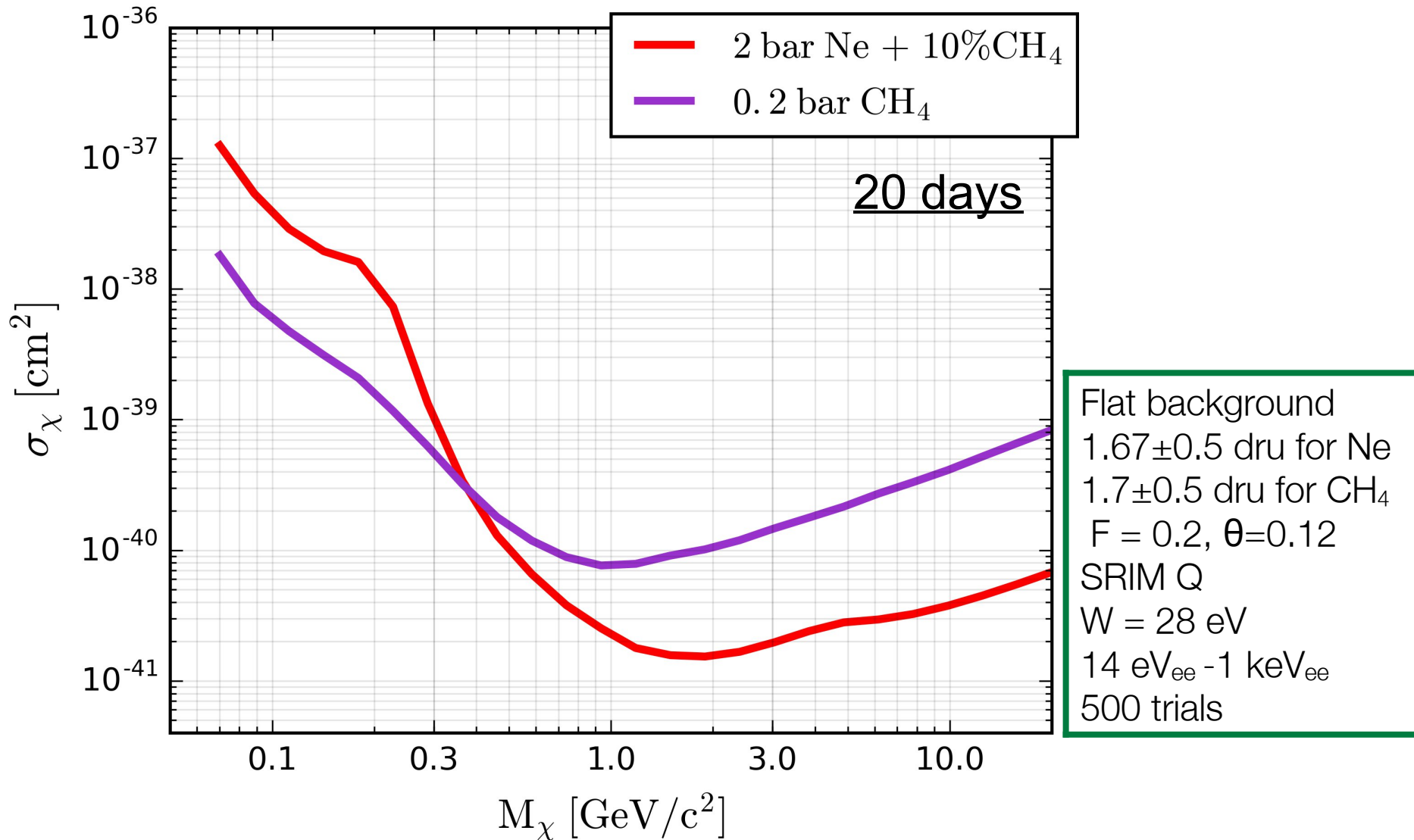


The Neon limit is immediately background-limited, but the CH₄ limit is not



Flat background
 1.67±0.5 dru for Ne
 1.7±0.5 dru for CH₄
 F = 0.2, $\theta=0.12$
 SRIM Q
 W = 28 eV
 14 eV_{ee} - 1 keV_{ee}
 500 trials

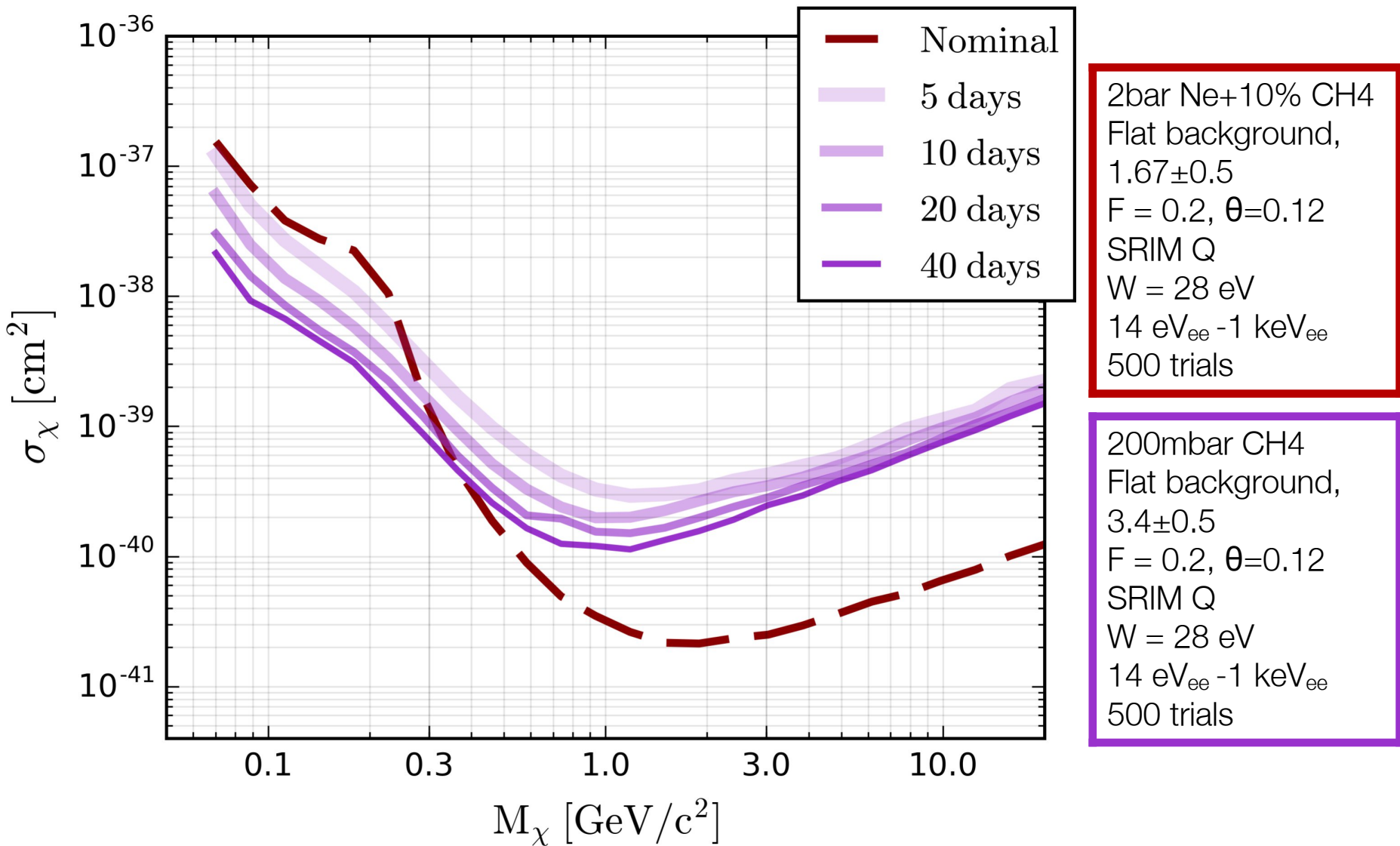
The Neon limit is immediately background-limited, but the CH₄ limit is not



The Neon limit is immediately background-limited, but the CH₄ limit is not

Data taking [days]	2 bar Ne+10% CH ₄		200 mbar CH ₄	
	Exposure [kg.days]	<#BE>	Exposure [kg.days]	<#BE>
5	11.5	18.9	0.93	3.16
10	22.9	37.7	1.86	6.32
20	45.8	75.4	3.72	12.6
40	91.6	151	7.44	25.3

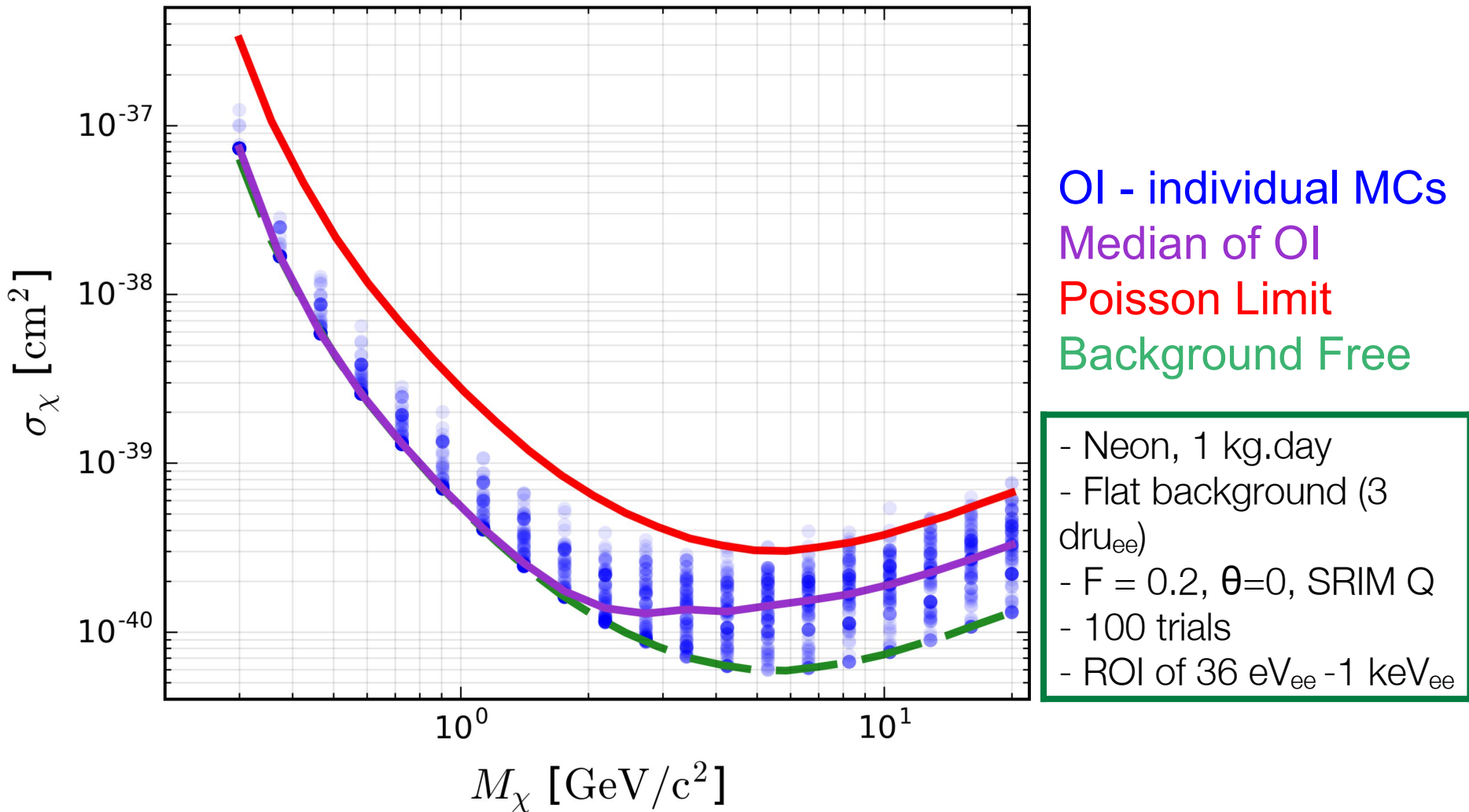
But something else to keep in mind: Higher background from cosmogenics while at the LSM (~3.4 dru, ask Alexis)



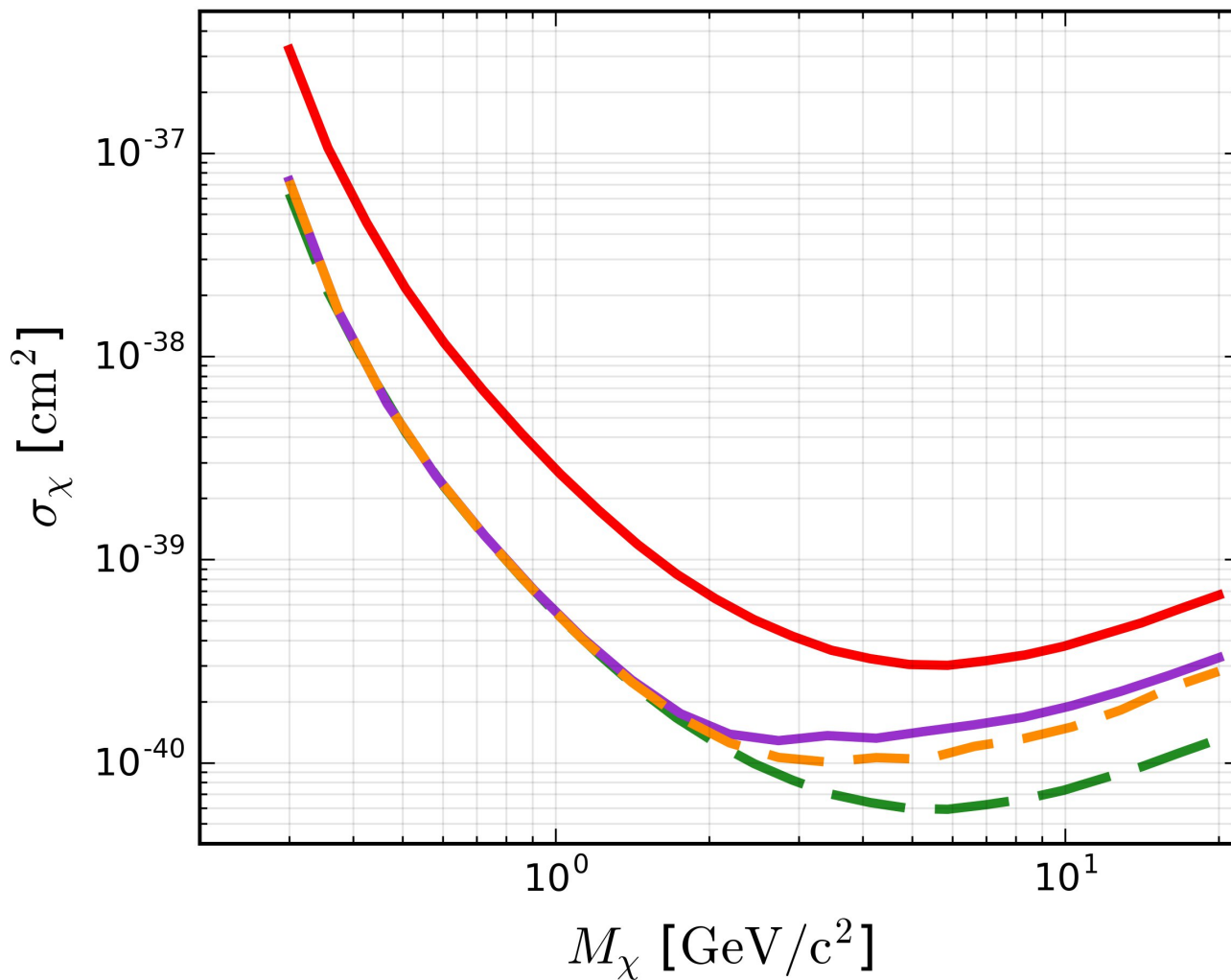
Thank you!

Extra Slides

The Optimum Interval method allows us to recover much of our sensitivity, especially at low WIMP masses



The Optimum Interval method allows us to recover much of our sensitivity, especially at low WIMP masses

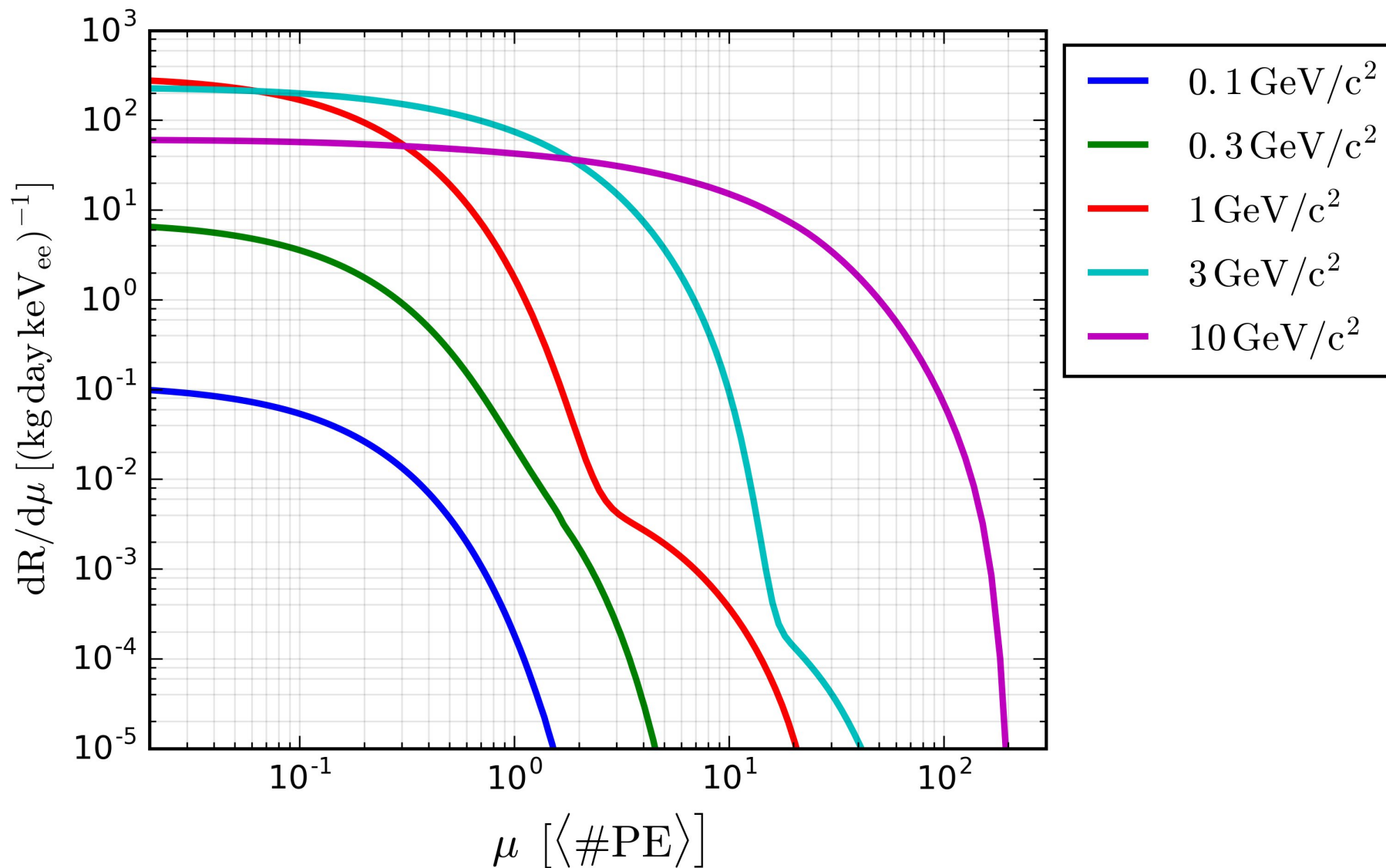


Median Poisson on Optimum Interval
 Median of OI
 Poisson Limit
 Background Free

- Neon, 1 kg.day
- Flat background (3 dru_{ee})
- $F = 0.2, \theta=0, \text{SRIM Q}$
- 100 trials
- ROI of $36 \text{ eV}_{ee} - 1 \text{ keV}_{ee}$



Evolution of WIMP recoil spectrum for Ne + 10% CH₄



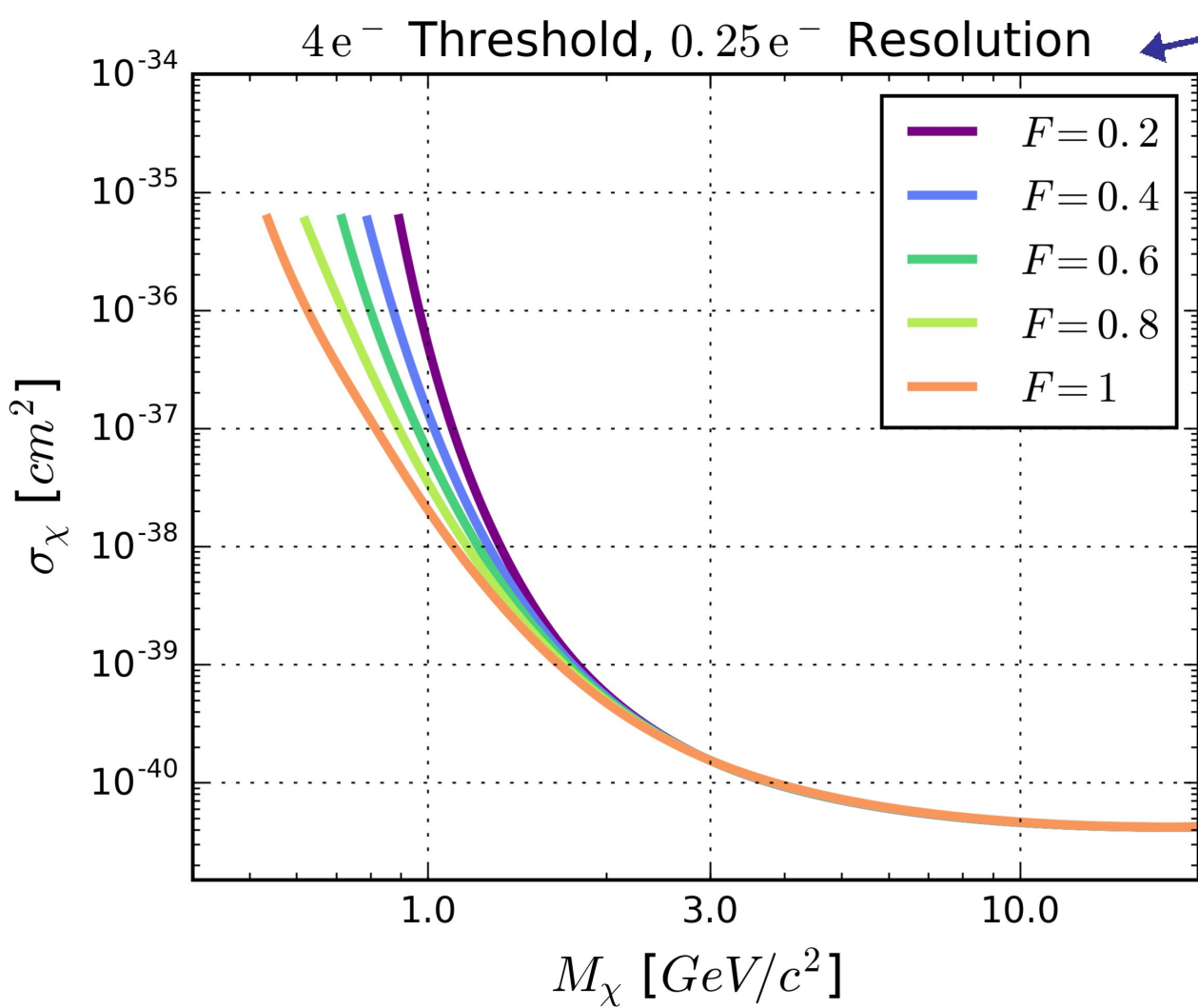
The (proposed) main elements/sections for the sensitivity projections paper, based on similar papers from other experiments (SuperCDMS: [cdms arXiv 1610.00001](#), LUX: [arXiv 1802.06039](#)):

1. Experimental setup
2. Sources and simulation of backgrounds
3. Detector simulation
4. Calculation of sensitivity
5. Impact of experimental parameters



Accounting for the Fano factor

We can use this tool to assess the impact on low-mass DM experiments



(i.e. CCD detectors like DAMIC)

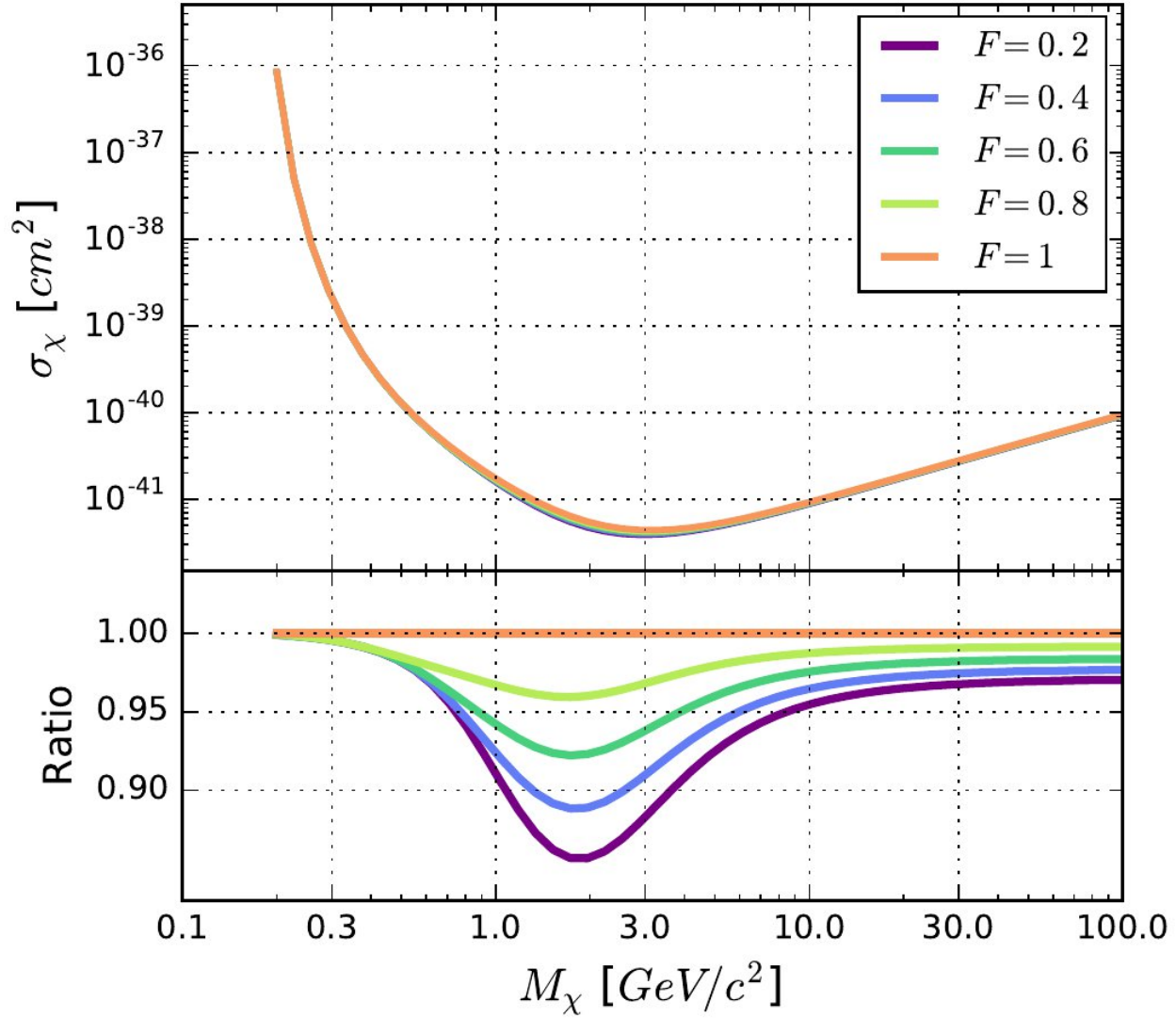
F can have a big impact!

Neon experiment modelled with COM-Poisson + Gaussian resolution



Accounting for the Fano factor

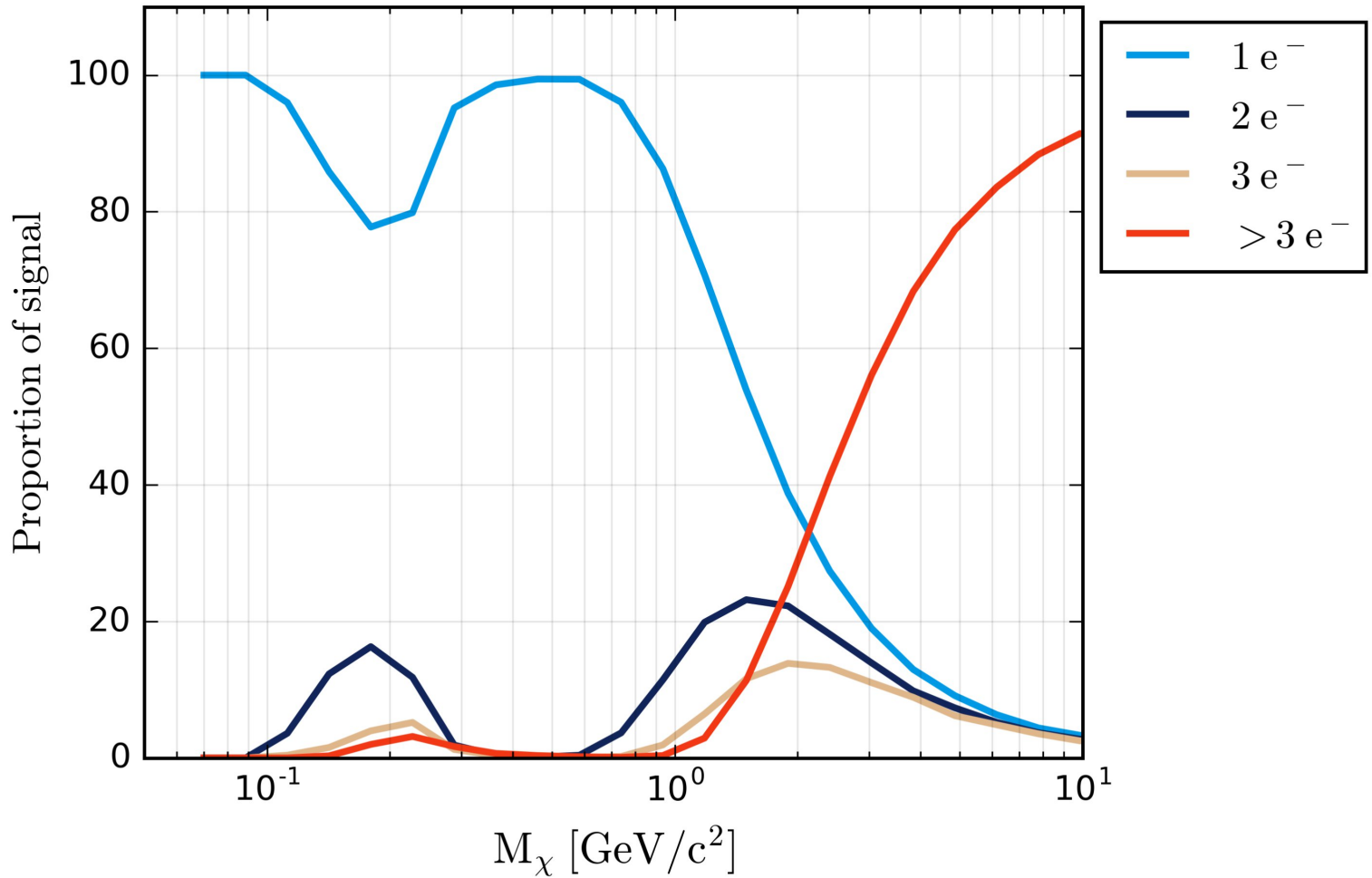
We can use this tool to assess the impact on low-mass DM experiments



...but probably won't for NEWS-G

Neon experiment modelled with COM-Poisson + Polya, $1e^-$ to 1 keV_{nr} energy window

Much of our sensitivity at these WIMP masses derives from $1e^-$ events:



Therefore characterization of our single electron response is essential!