Limit on sub-GeV dark matter from PROSPECT experiment

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On behalf of the PROSPECT Collaboration

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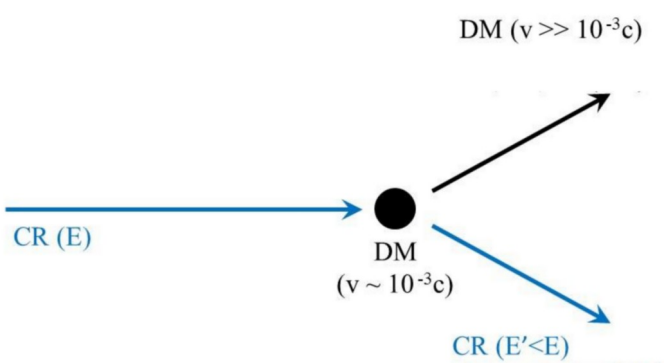
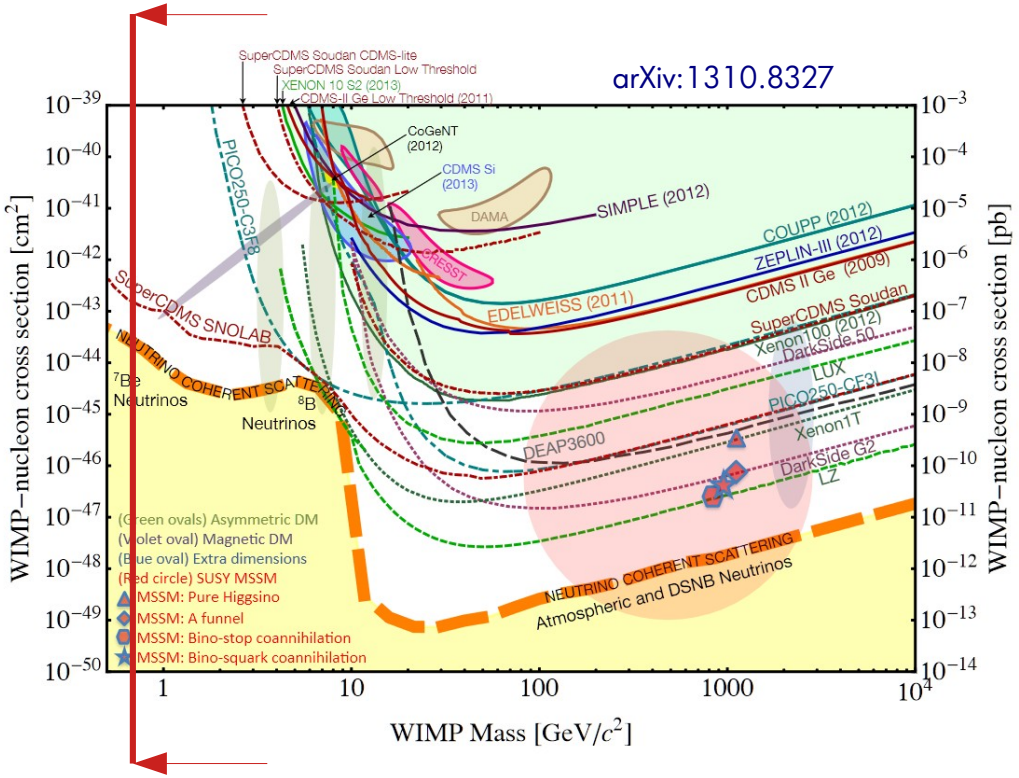
Dark-Matter direct detection

- DM direct detection focuses on GeV-scale.
- Light DM does not have enough momentum to trigger detector.
- DM can gain energy through DM-cosmic rays scattering.
- In higher cross-section space, overburden will actively block DM signals!

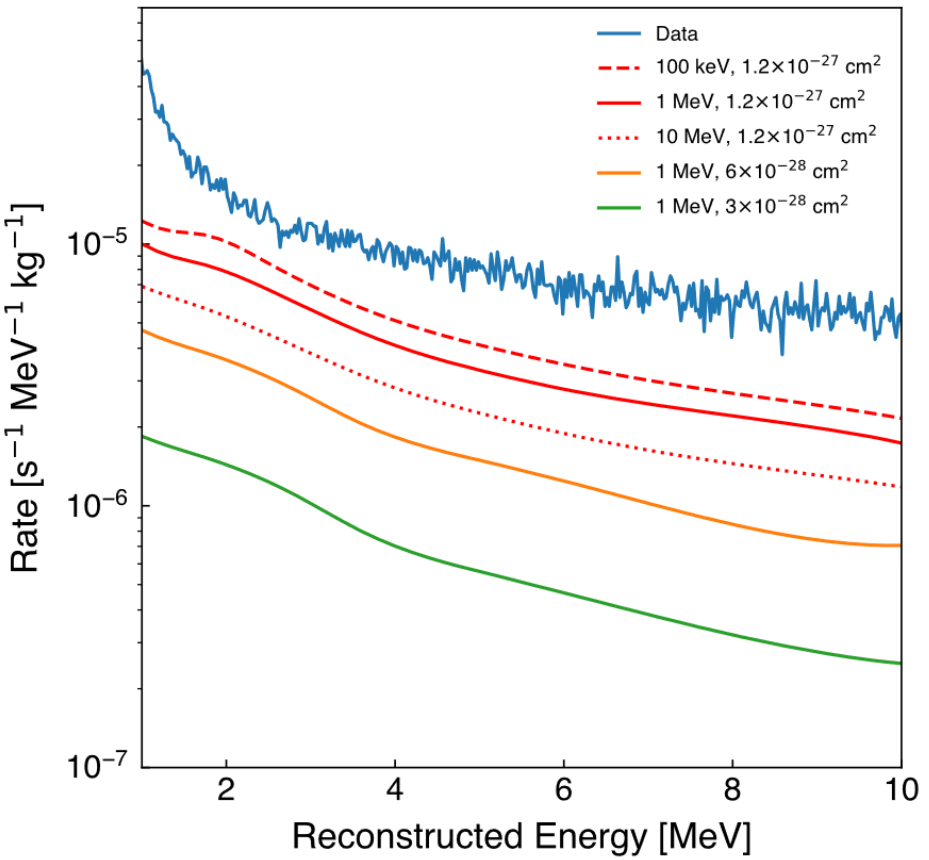


What about here?



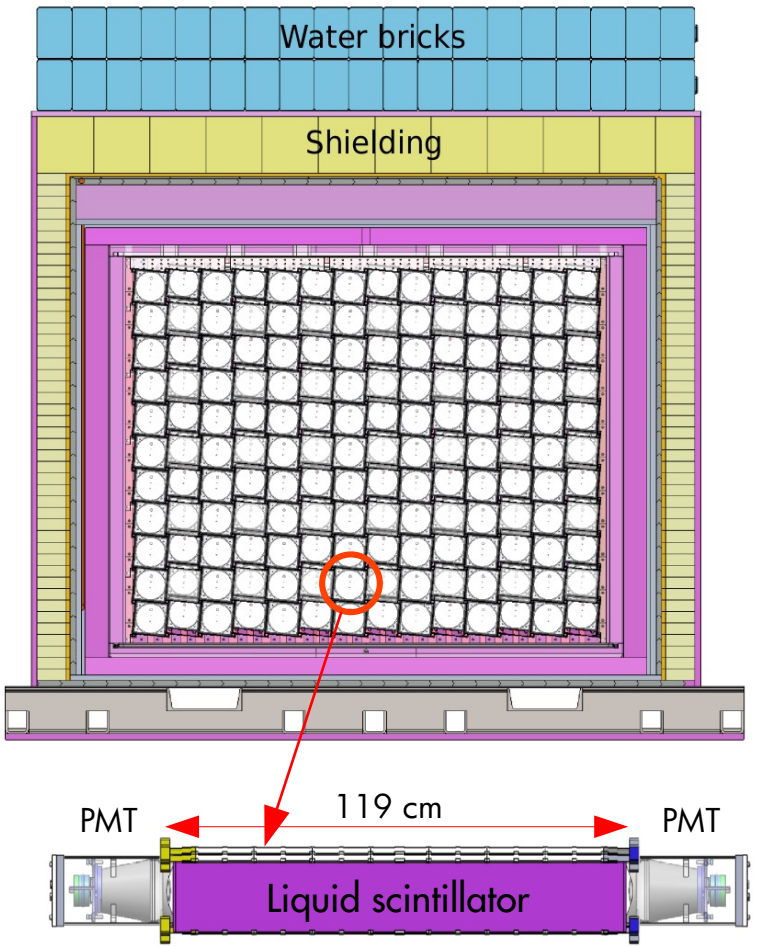
Dark-Matter propagation

- Assume Navarro-Frenk-White DM profile.
- Cosmic-rays halo is modeled as a cylinder with R = 25 kpc and h = 4 kpc.
- Use Local Interstellar spectrum for the CR energy distribution.
- Propagate through atmosphere and detector shielding.
- DM flux in the detector vary as the earth rotate:
  - High signal period
  - Low signal period



The PROSPECT Experiment & Detector

- Designed to measure ^{235}U spectrum and search for sterile neutrino oscillations.
- Deployed on surface with minimal overburden by the High Flux Isotope Reactor at Oak Ridge National Laboratory.
- The detector consists of 11x14 optically isolated segments filled with ^{6}Li-doped liquid scintillator (LiLS).
- Double ended PMTs for each segment.



Physical quantities reconstruction

- The EJ-309 used as base for PROSPECT LiLS has Pulse Shape Discrimination (PSD) capabilities.
- Combine a segment's 2 PMT waveforms into a **pulse** with reconstructed variables: Energy (electron-equivalent), z-position, segment, PSD, …
- Reconstructed energy is determined by combining charge from both PMTs.
- Heavy particles' energy depositions are modeled using Birks quenching parameters validated with n-Li capture data and fast neutron calibration sources.

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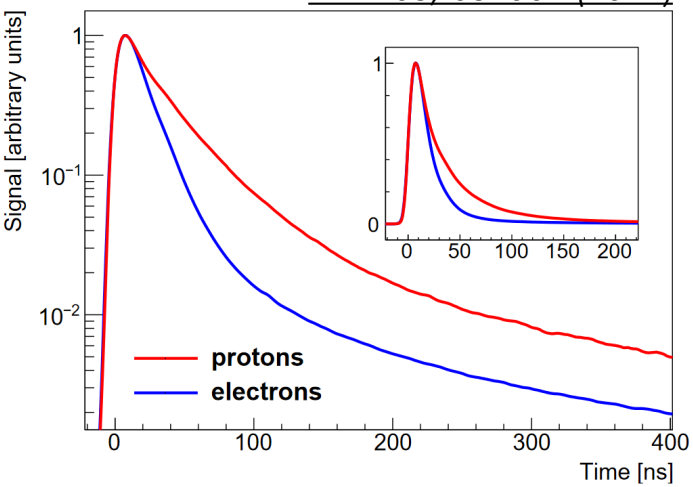
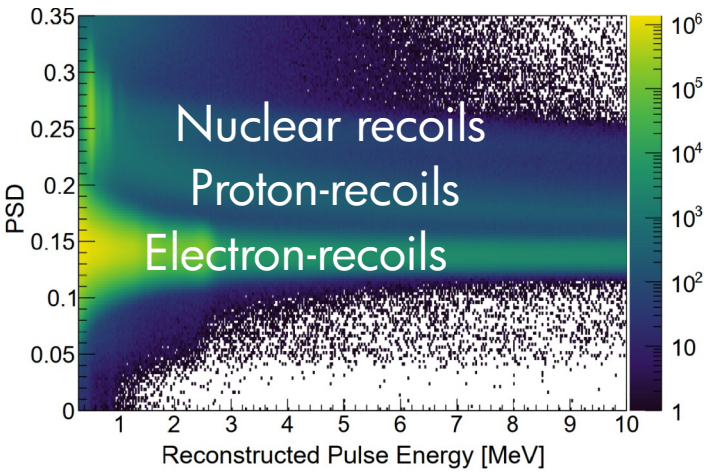
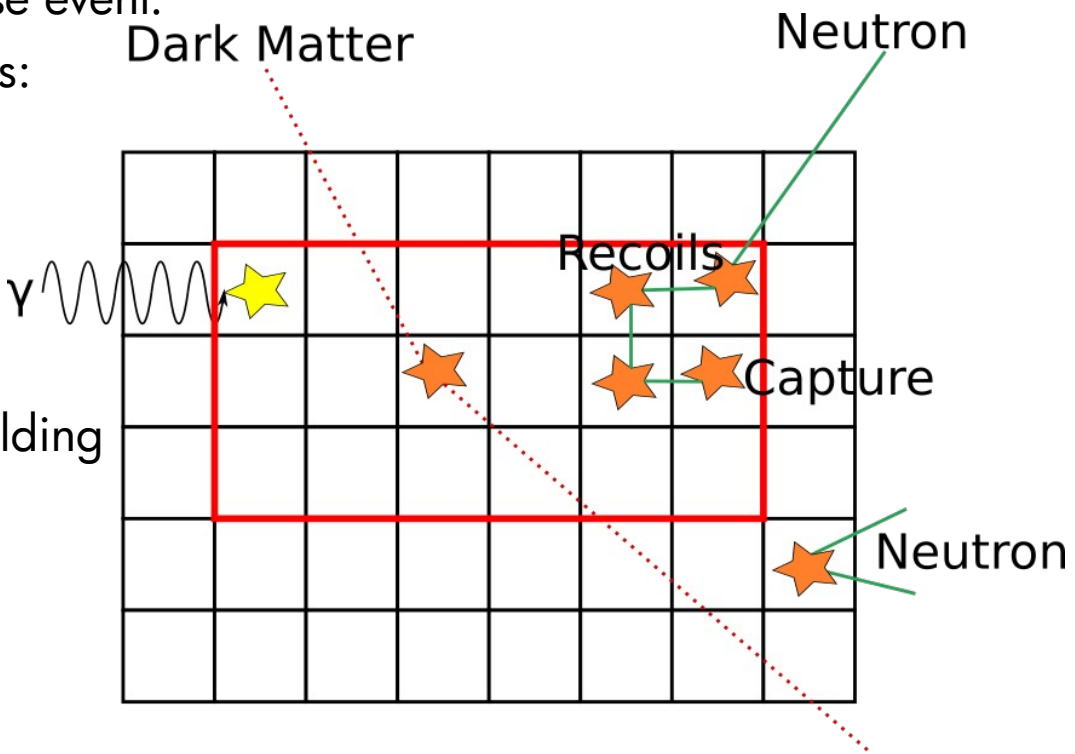




J. B. Birks, International series of Monographs on Electronics and Instrumentation , v. 27 Macmillan, New York (1964)

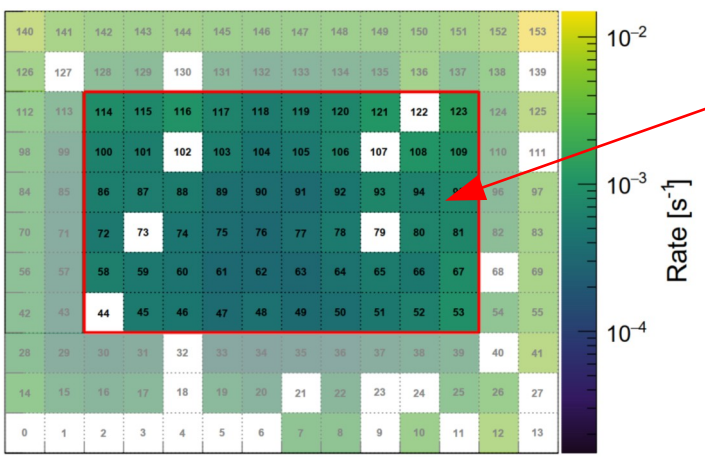
Signal and Backgrounds

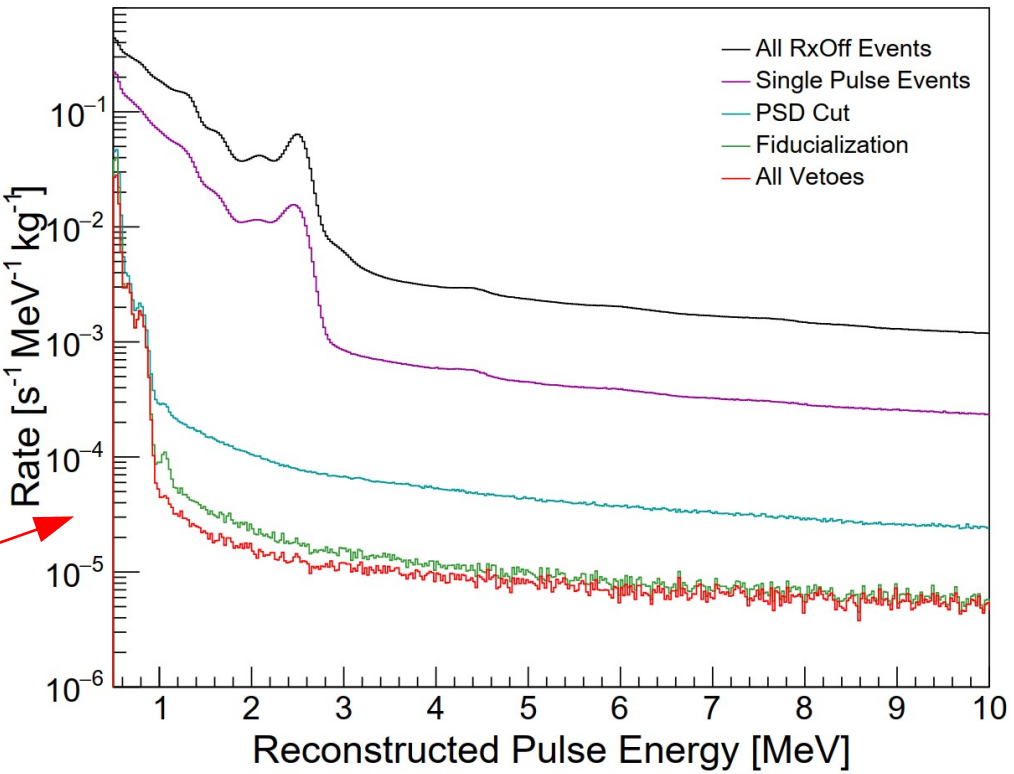
- Boosted Dark Matters (BDM) scatter with free proton in the LS producing a high PSD single pulse event.
- Detector subjected to multiple backgrounds:
  - PSD rejects environmental gamma backgrounds.
  - Single-pulse requirement rejects cosmic events producing multiple scatters.
  - Fiducialization enables detector self-shielding for cosmic neutrons.
  - Additional time-based cosmic veto cuts also applied.



Signal selection

- 14.6 days of Rx-Off dataset from March 16th 2018.
- Set of cuts/vetoes applied to remove backgrounds.
- Background rate decreases by ~2.5 – 3.5 order of magnitude.

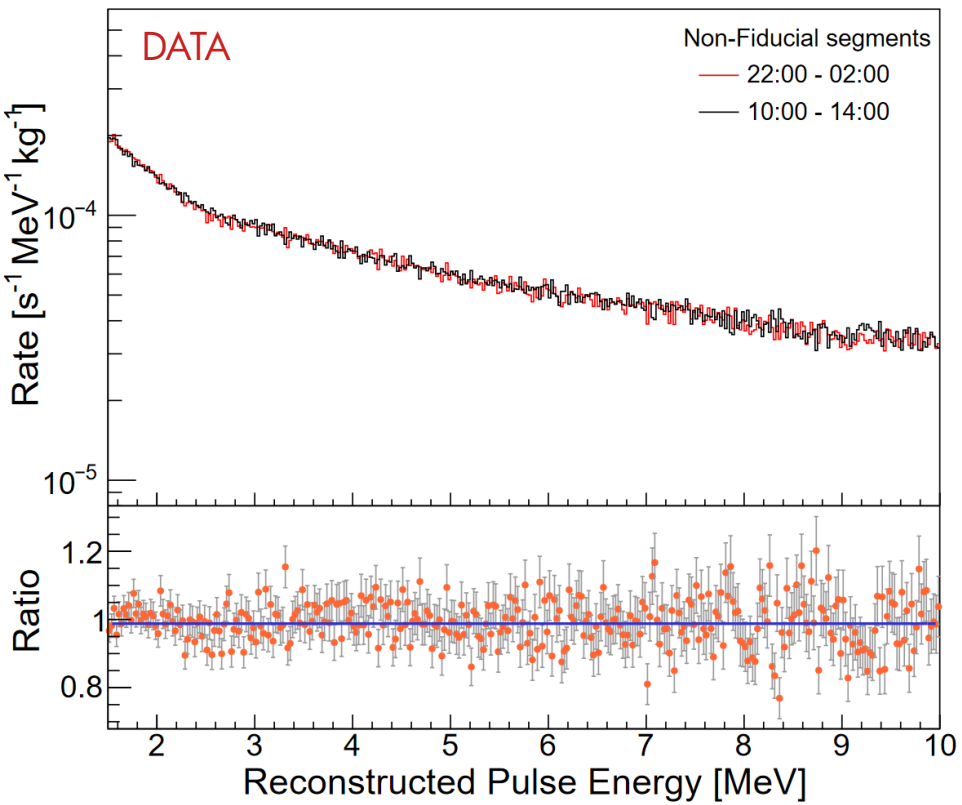




- 38k signal candidates out of 2.8B of clusters.

Expected vs Measured background variation

- How do we know cosmogenic backgrounds are not time-varying ?
- Neutron capture event rate is ~10 Hz.
- Comparing two time periods of DM flux,
  - High expected flux: 22:00 – 02:00 GMST
  - Low expected flux: 10:00 – 14:00 GMST
- Expected level of modulation is: 0.988
- Flat-line fit to ratio shows no modulation: 0.987±0.003
- Hourly DM prediction must account for the expected variations in cosmogenic backgrounds.

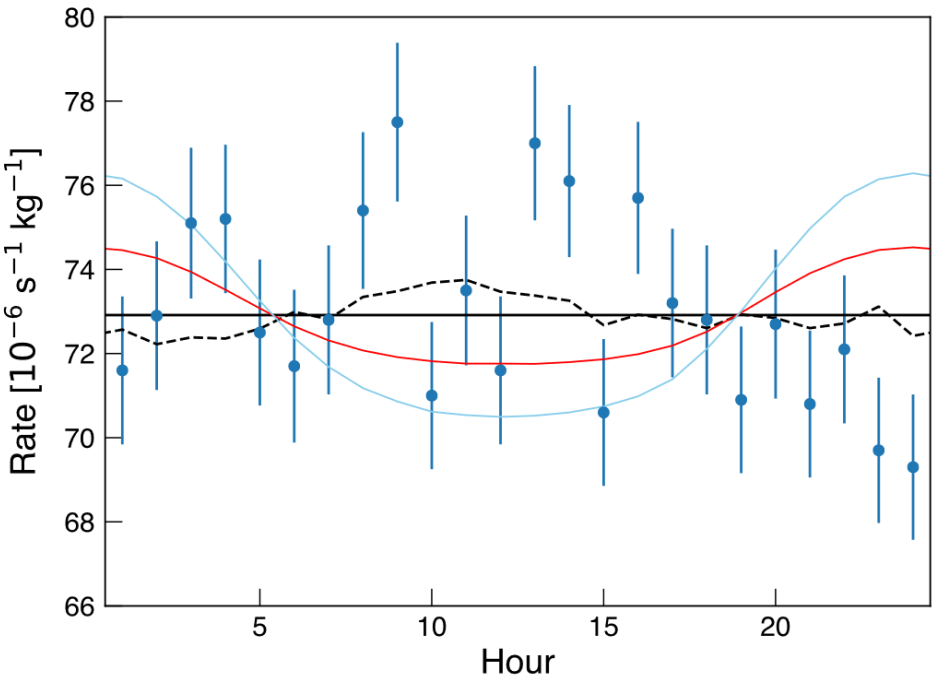


Time modulation of signal

- How about time modulation of signal ?
  - Divide the signal spectrum into hour-bin rate.
  - No obvious diurnal sidereal modulation.
- Estimate sensitivity/identify excluded space using following chi-square-based test statistic

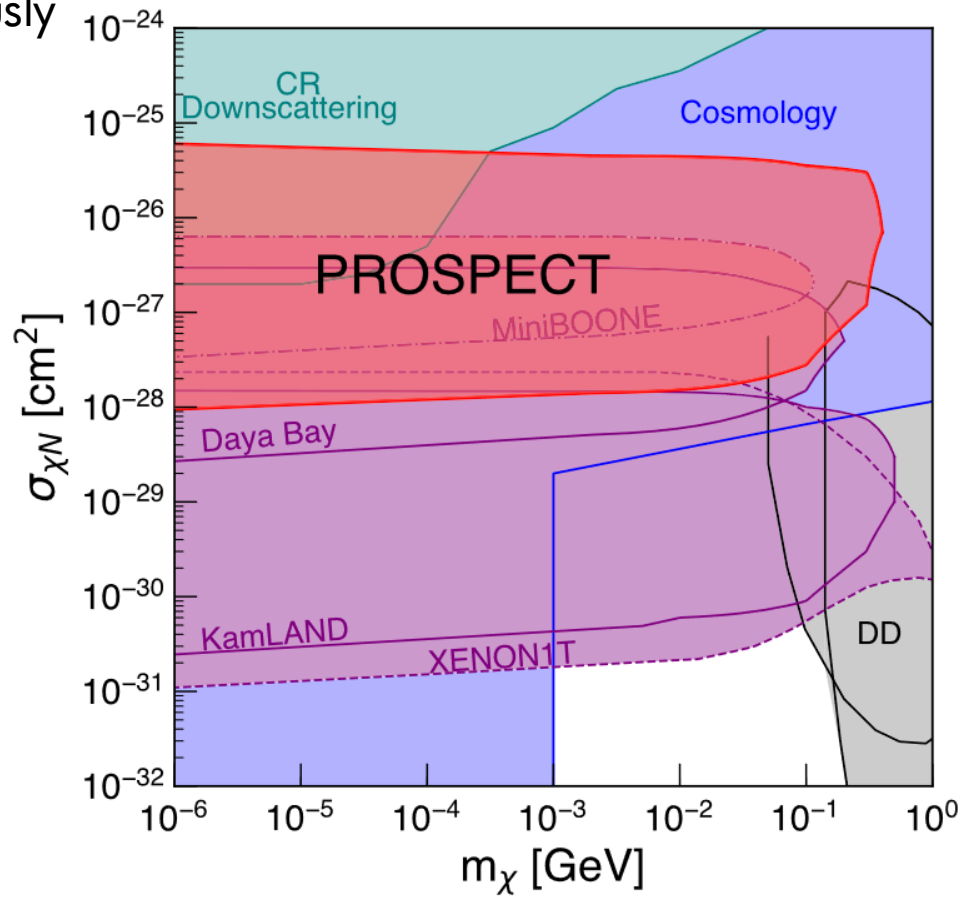
$$\Delta\chi^2 = \chi^2_{DM} - \chi^2_{const}$$

  - χ^2_{const} : flat-line fit to the data.
  - χ^2_{DM} : flat-line fit + modulation of DM (m_χ, $\sigma_{\chi N}$) at a time t.



Exclusion region

- PROSPECT's result covers new space previously un-probed by other terrestrial experiments.
  - Upper limit of exclusion is limited by DM attenuation in the atmosphere.
  - Lower limit is limited by the fraction of DM interacting with the detector.



Summary

- PROSPECT's minimal overburden and events discrimination capabilities allow to probe hard-to-reach Dark Matter phase space.
- In two weeks of data, identified 37,522 candidate events matching the signature of DM-proton scattering.
- True presence of a DM signal is expected to produce diurnal modulation in this candidate event rates, while other cosmic backgrounds are expected to produce largely constant event rates
- Our dedicated analysis probes regions of dark matter phase space unaddressed by previous terrestrial experiments.
- Complimentary to cosmological DM limits:
  - Other experiments are based on indirect constraint on scattering in the early universe.
  - PROPSECT sets limit based on direct detection on scattering in the present day.

PROSPECT Collaboration Meeting Photo – April 2020

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