Dark Matter-Electron Scattering in the DarkSide-50 Experiment

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The DarkSide-50 Experiment

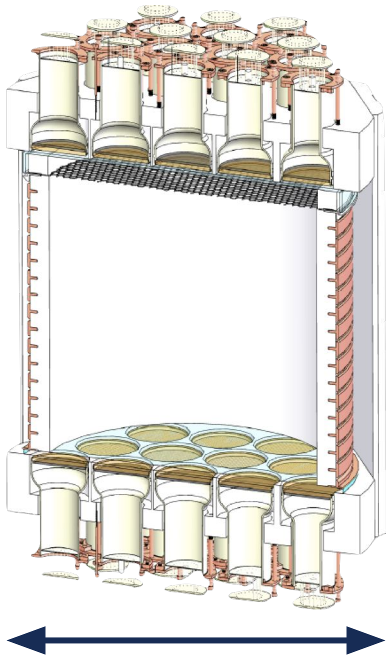
Dark matter direct detection using an Ar dual-phase TPC

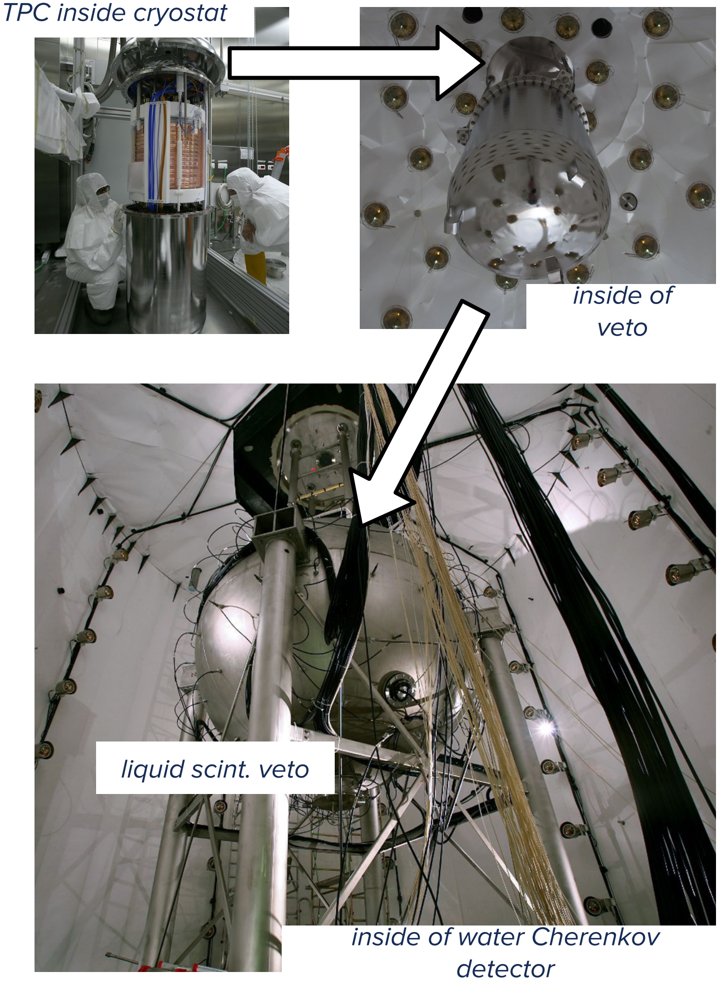
2014 - present

Gran Sasso National Laboratory (LNGS), Italy

50 kg of underground argon

TPC inside 30 t liquid scintillator veto within a 1 kt water Cherenkov detector





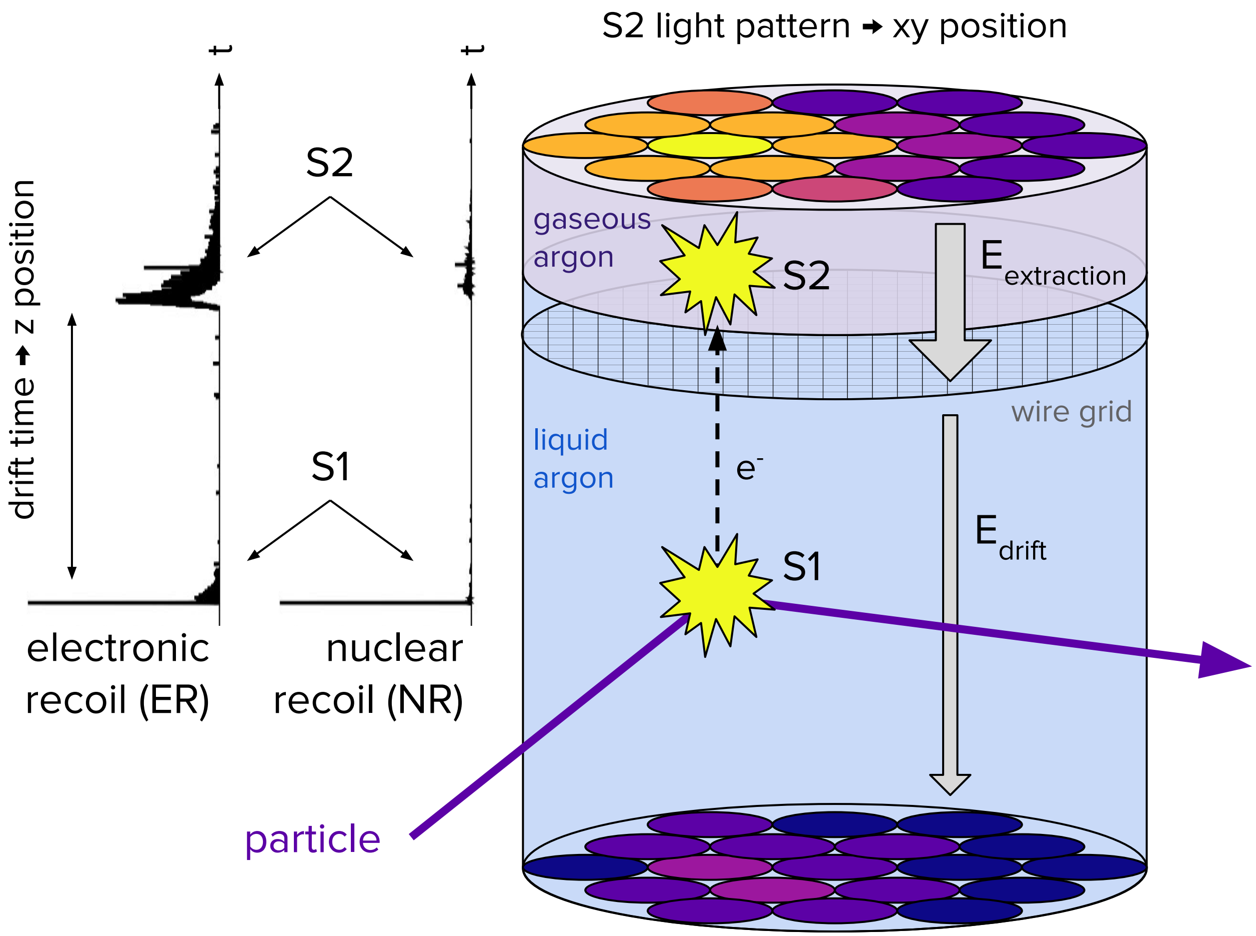
Phys. Lett. B 743, 456-466 (2015)

Dual-phase Ar Time Projection Chamber (TPC)

Calorimetry + 3D position

Energy deposition in LAr produces scintillation photons and free electrons

- S1: primary scintillation in LAr (typically used as energy estimator)
- S2: secondary scintillation from electroluminescence of electrons in gas pocket



S2-Only Analysis

S1 for a low-energy event may not be detectable

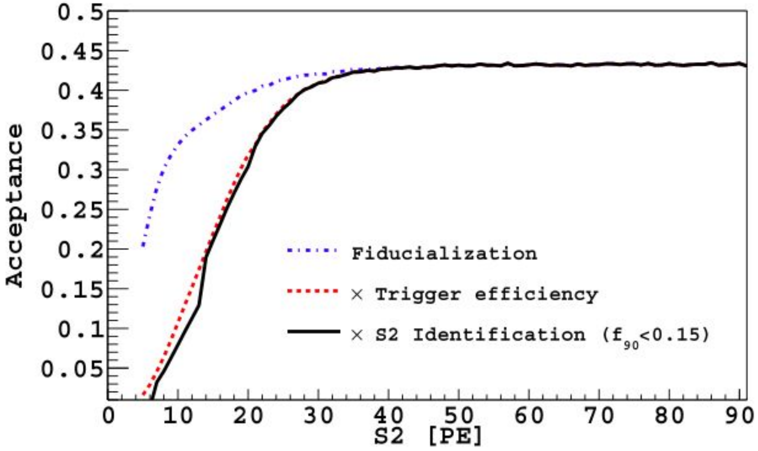
- no *z* position
- no NR/ER discrimination
- S2 is now energy estimator

S2 yield = 23±1 PE/e-

100% trigger efficiency at 1.3 e^-

- trigger: 2 PMTs firing within 100 ns

energy deposited ⟷ extracted electrons (N_{e-}) ⟷ PE detected



Recent improvements:

- increased statistics (+1.5x 2018 dataset)
- improved data selection

Phys. Rev. Lett. 121, 081307 (2018)

DarkSide-50 Calibrations

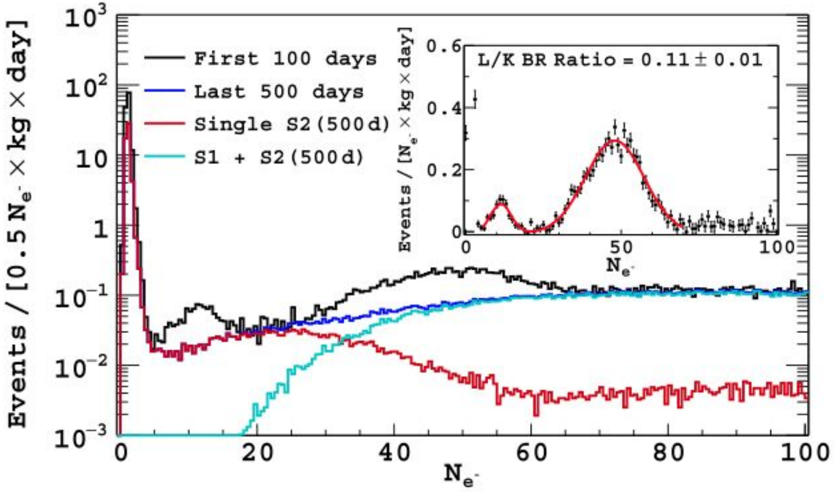
ER energy scale:
^{37}Ar decays throughout TPC ($\tau_{1/2}$ ~ 35 days)

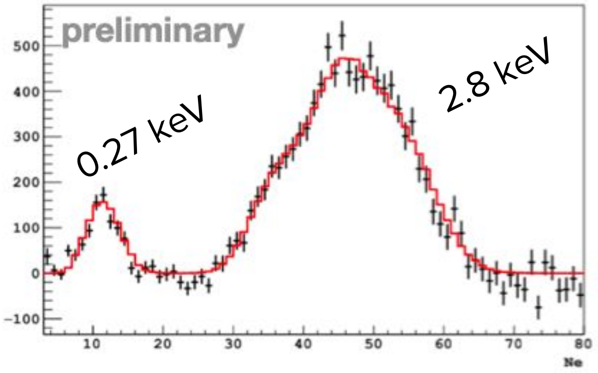
NR energy scale:
$^{241}Am^{13}C$ and $^{241}AmBe$ sources

Recent improvements:

- detector effects (radial dependency, geometry)
- reduction of the overall systematic uncertainties

^{37}Ar calibration





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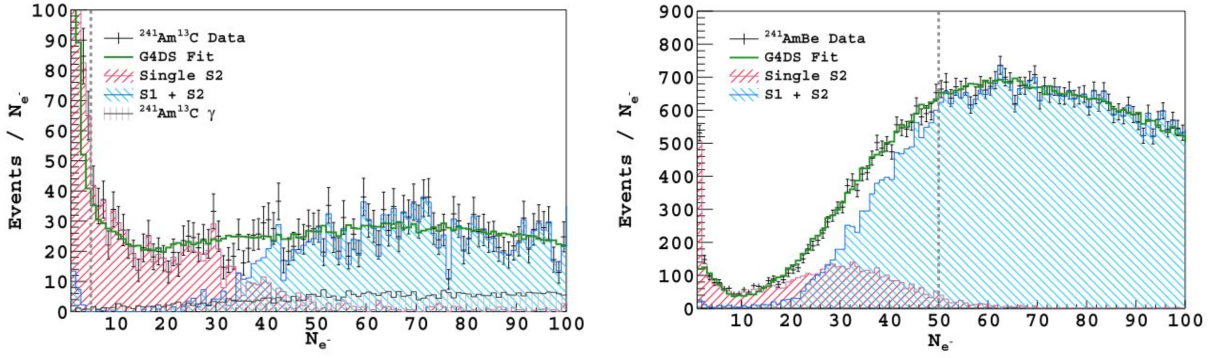
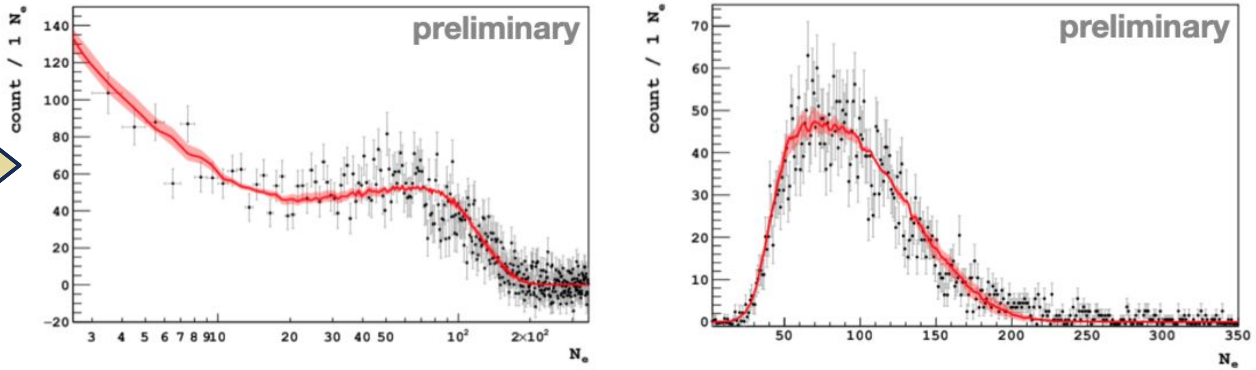
$^{241}Am^{13}C$ calibration   *$^{241}AmBe$ calibration*





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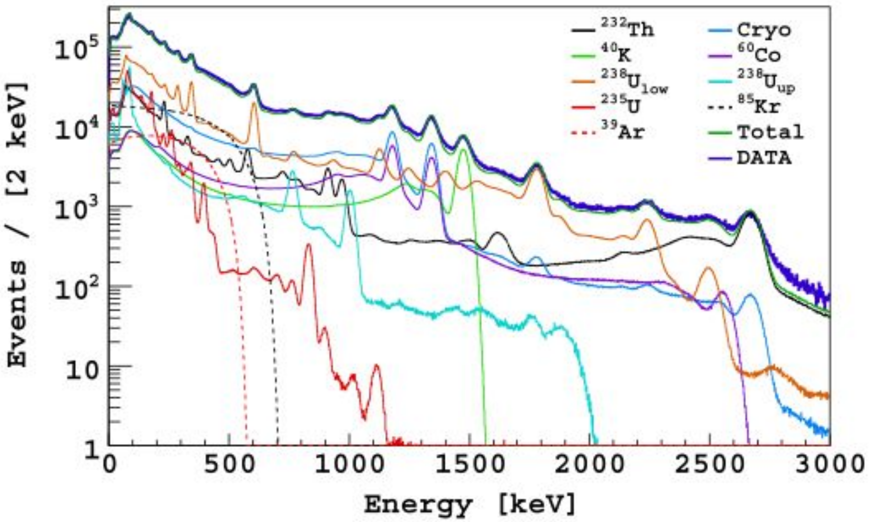
DarkSide-50 Backgrounds

Full simulation of radioactive components

- detector materials (^{238}U, ^{232}Th, ^{40}K, ^{60}Co)
- intrinsic to target (^{39}Ar, ^{85}Kr)

Multivariate approach fits background components to data

- S1 single scatters, S1 multiple scatters, drift time

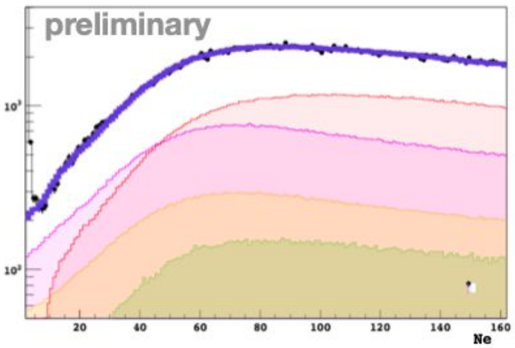


Phys. Rev. D 98, 102006 (2018)

Improved background model:

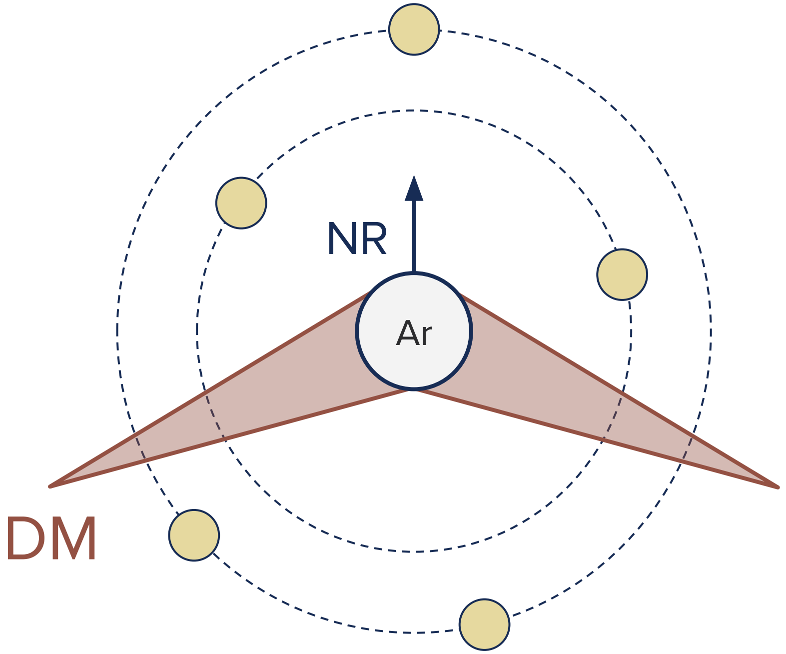
- extended above 50 N_{e-}
- more accurate pdfs, improved constraints on internals,new calibration

Background ionization spectra

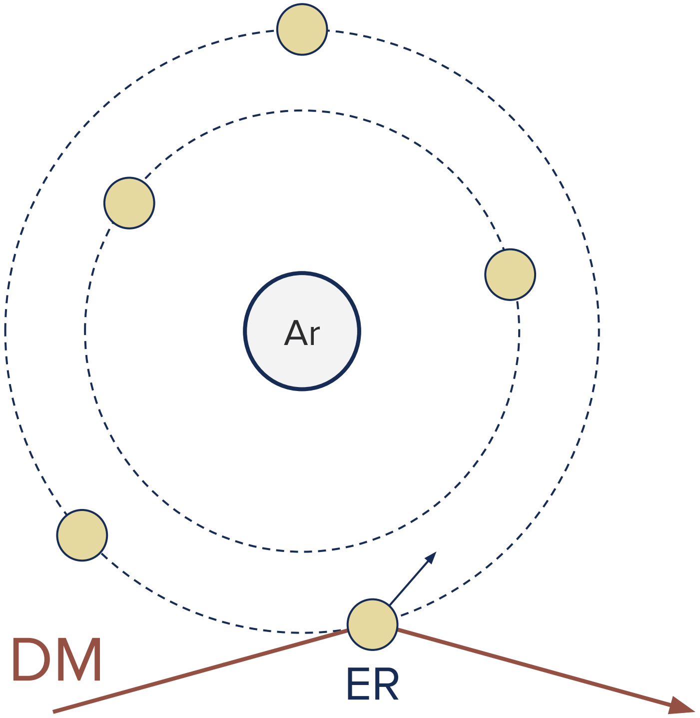


Dark Matter-Argon Interactions

DM-nucleon scattering



DM-electron scattering

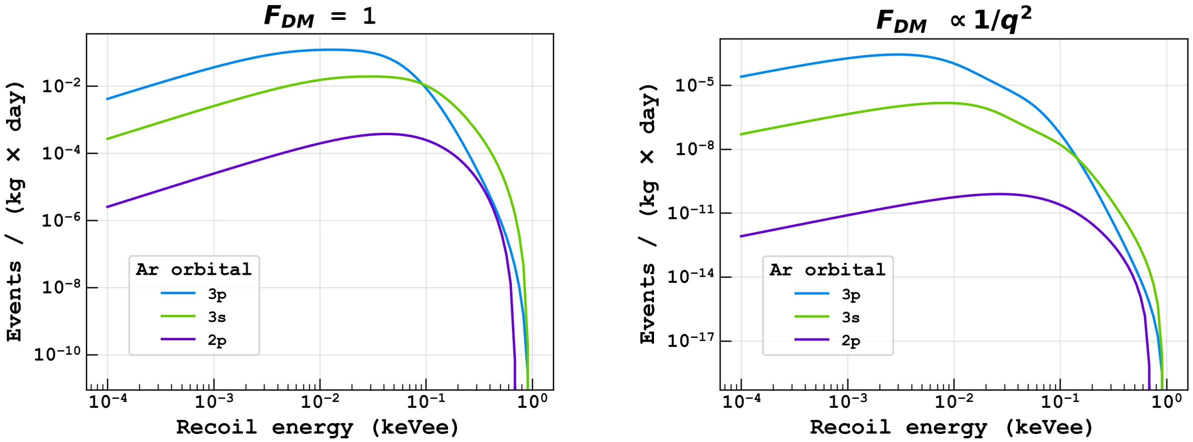


DM-Electron Scattering

Model observable: differential ionization rate

- events / target mass / exposure time
- argon ionization form-factor
- dark matter velocity distribution
- dark matter form-factor (F_{DM})

Predicted DM-electron scattering rates



m_{DM} = 100 MeV/c^2
σ_e = 1e-36 cm^2

- depends on momentum transfer of interaction (q)
- heavy mediator case: $F_{DM}(q) \simeq 1$
- light mediator case: $F_{DM}(q) \sim 1/q^2$

Phys. Rev. Lett. 121, 111303 (2018)

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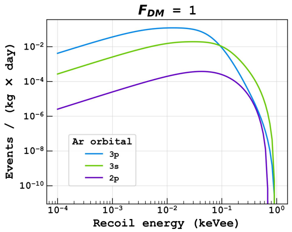
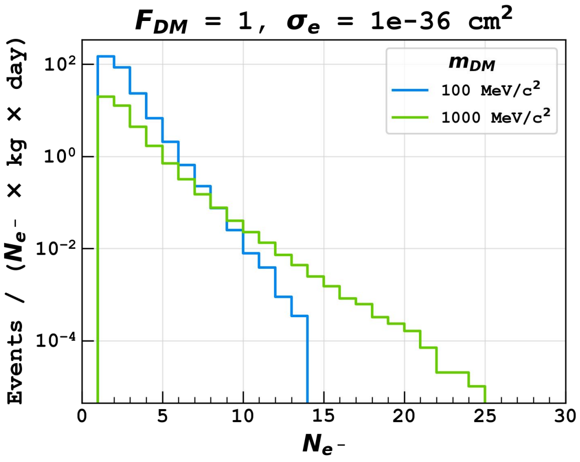
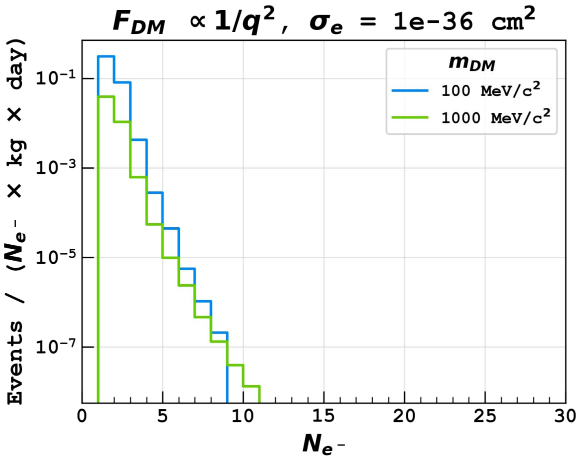


modeled detector response

Predicted ionization spectra





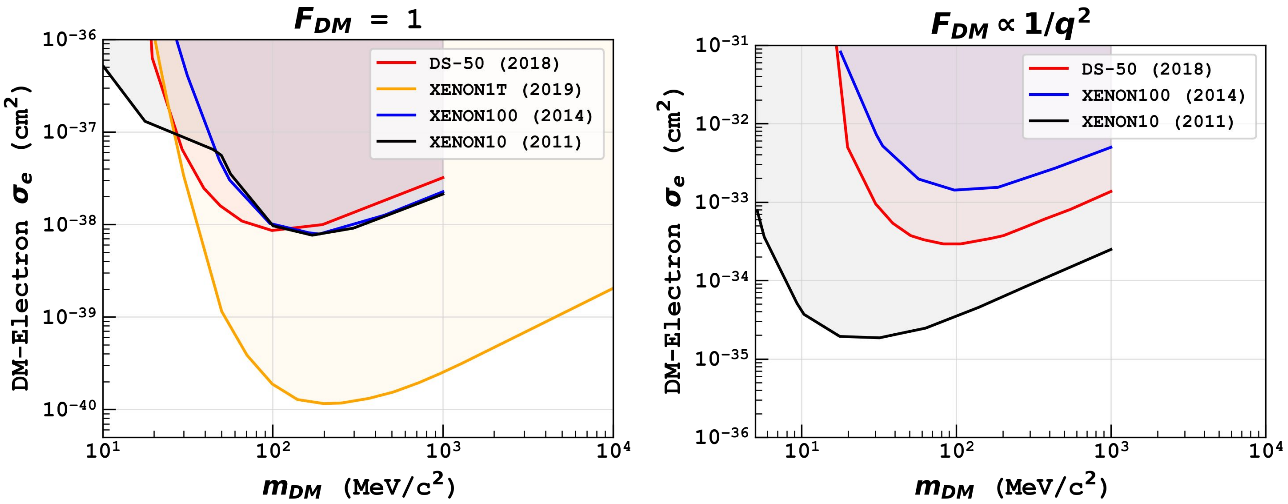
Phys. Rev. Lett. 121, 111303 (2018)

90% CL Exclusion Limits

Significant improvements expected

Binned profile likelihood method used to set upper limit on DM cross-section

Significant improvements over 2018 DS-50 limits expected… stay tuned!



DarkSide: Phys. Rev. Lett. 121, 111303 (2018)
XENON: Phys. Rev. Lett. 123, 251801 (2019)

Questions?

Backup Slides

DM-Electron Scattering

$$\frac{dR}{d\ln E_{\mathrm{er}}} = N_T \frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}} \sum_{nl} \frac{d\langle \sigma_{\mathrm{ion}}^{nl} v \rangle}{d\ln E_{\mathrm{er}}}$$

target atoms per unit mass

local DM density

Ar electronic orbitals

velocity-averaged differential ionization cross section

DM-Electron Scattering

$$\frac{d\langle\sigma_{\text{ion}}^{nl} v\rangle}{d\ln E_{\text{er}}} = \frac{\overline{\sigma}_e}{8\,\mu_{\chi e}^2} \times \int dq\, q\, |f_{\text{ion}}^{nl}(k', q)|^2\, |F_{\text{DM}}(q)|^2\, \eta(v_{\text{min}}),$$

$$F_{\text{DM}}(q) = \frac{{m_{A'}}^2 + \alpha^2 {m_e}^2}{{m_{A'}}^2 + q^2} \simeq \begin{cases} 1, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 {m_e}^2}{q^2}, & m_{A'} \ll \alpha m_e \,, \end{cases}$$

$$v_{\text{min}}(q, E_b^{nl}, E_{\text{er}}) = \frac{|E_b^{nl}| + E_{\text{er}}}{q} + \frac{q}{2m_\chi}$$

Why liquid argon?

Scalable

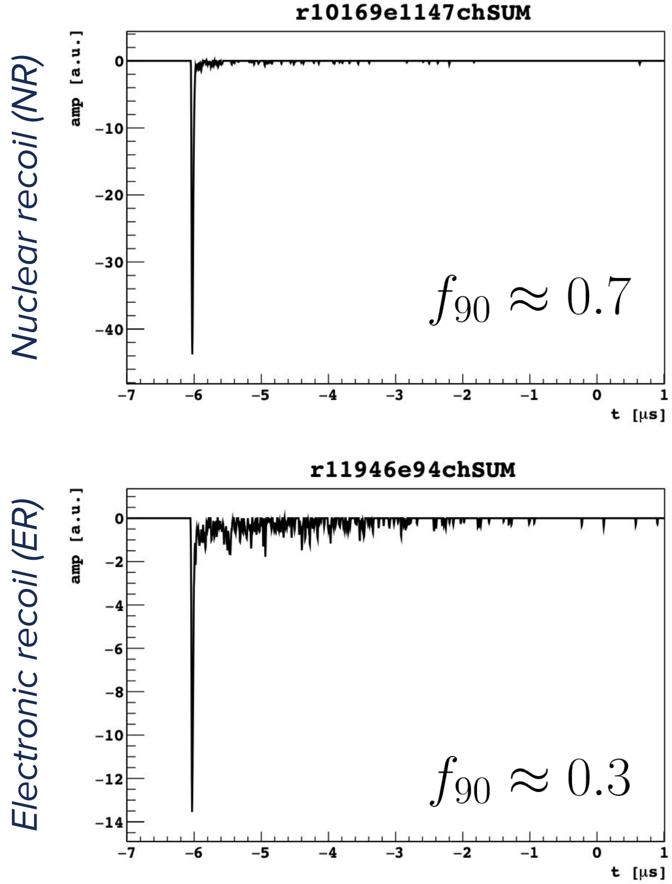
Efficient scintillator

Sensitive to WIMPs over large mass range

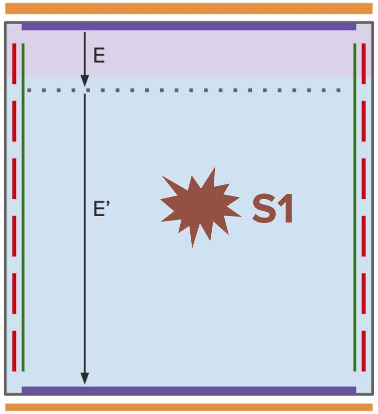
Pulse shape discrimination (PSD)

- f_{90}
- S2 / S1

f_{90}



$$f_{90} = \frac{\text{S1 light in first 90 ns}}{\text{Total S1 light}}$$



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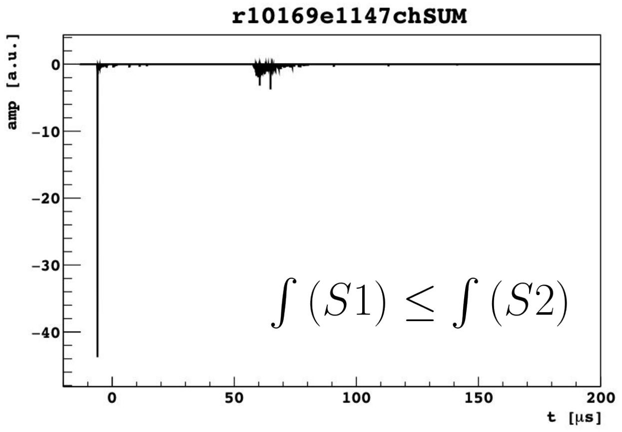
Nuclear recoil (NR)



Electronic recoil (ER)