CHARACTERIZATION OF LOW-ENERGY ARGON RECOILS WITH THE RED EXPERIMENT

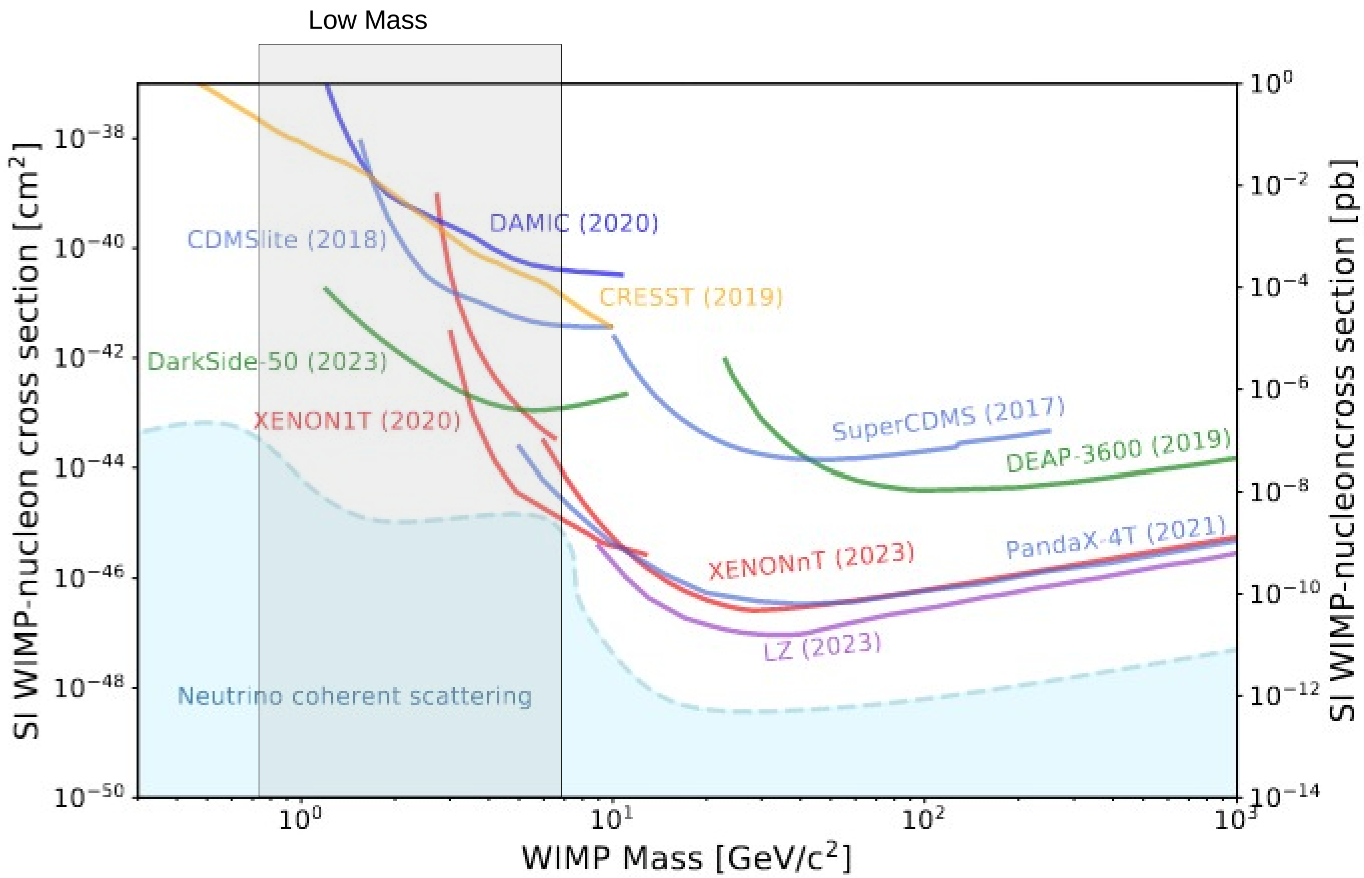
M. Ave (University of São Paulo), on behalf of the ReD working group

Funding by:

FAPESP

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | INFN

Physics Background: *Low Mass WIMP-Nucleon interaction searches*



Particle Data Group 2024

Spin independent low mass (<5 GeV)

LUX (Migdal)	Xe	118	6.9×10^{-38}	2
XENON1T (Migdal)	Xe	1042	3×10^{-40}	2
XENON1T (ionisation only)	Xe	1042	3.6×10^{-41}	3
DarkSide-50 (ionisation only)	Ar	20	1.4×10^{-42}	2
SuperCDMS (CDMSlite)	Ge	0.6	2×10^{-40}	2
SuperCDMS (CDMSlite, Migdal)	Ge	0.6	6×10^{-38}	2
CRESST	$CaWO_4$ - O	0.024	1×10^{-39}	2
CRESST	Si	0.0035	4.5×10^{-32}	0.15
DAMIC	Si	0.3	1×10^{-40}	4
NEWS-G	Ne	0.3	1×10^{-38}	2

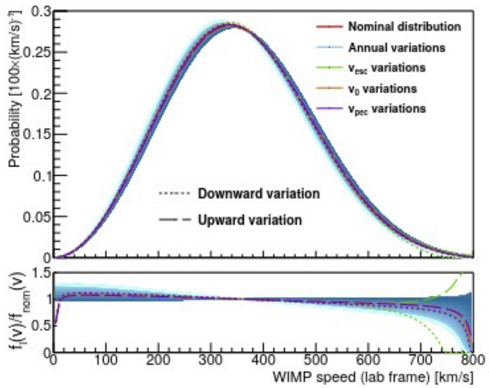
Nuclear Recoil spectrum induced by WIMP

$$\frac{dR(E_R,t)}{dE_R} = N_T \frac{\rho_0}{m_{\rm DM}} \int_{v>v_{min}} v f(\vec{v}+\vec{v}_E(t)) \frac{d\sigma(E_R,v)}{dE_R} d^3v,$$

Astrophysics (WIMP density)

0.2-0.6 GeV/cm3

Astrophysics (WIMP velocity distribution)



D. Baxter et al, The European Physical Journal C 81, 907 (2021)

Particle Physics

$$\frac{d\sigma(E_R,v)}{dE_R} = \frac{m_N}{2m_r^2 v^2}\left(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R)\right),$$

$$\frac{dR}{dE_R} = \frac{R_0}{E_0 r} e^{-\frac{E_R}{E_0 r}} \qquad < E_R > = E_0 r = \left(\frac{1}{2} m_\chi v^2\right)\left(\frac{4 m_\chi m_N}{(m_\chi + m_N)^2}\right)$$

For m_χ = 1.5 GeV

Target	***<E$_R$> [eV]***
Xenon	30
Germanium	60
Argon	100
Silicon	144
Neon	200
Oxygen	235

What is the response of Argon to low energy Nuclear Recoils ?
IONIZATION CHANNEL

$$Q_y^{NR} = \frac{N_{i.e.}}{E_{nr}} = \frac{(1-r)N_i}{E_{nr}}$$

$$N_i = \beta\,\kappa(\epsilon) \;=\; \beta\,\frac{\epsilon\, s_e(\epsilon)}{s_n(\epsilon)+s_e(\epsilon)}$$

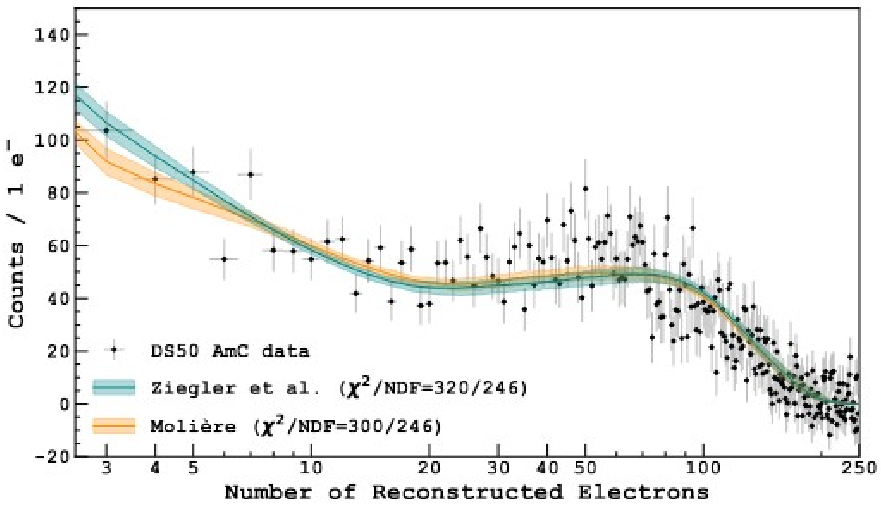
$$1 - r = \frac{1}{\gamma N_i}\,\ln(1+\gamma N_i)$$

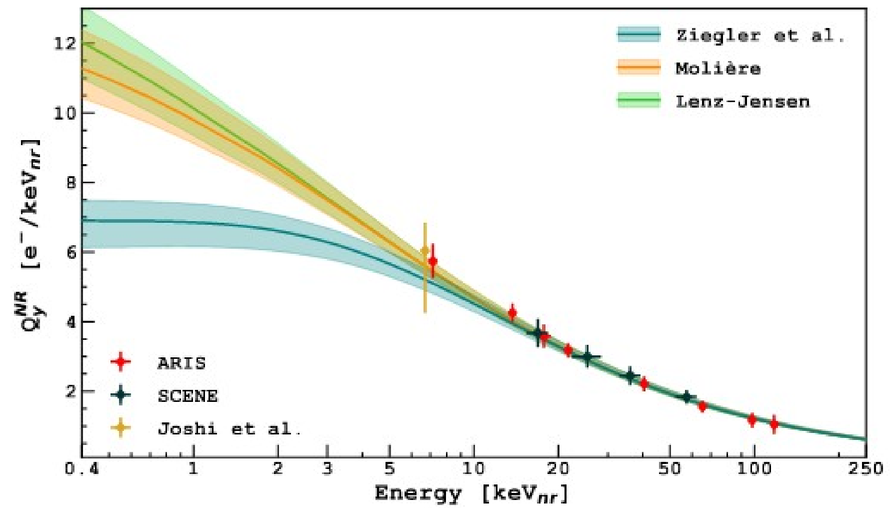
r :recombination probability
N_i : Number of ionizations
κ(ε) **:** fraction of energy lost in electronic w.r.t nuclear

The average number of electrons produced depends critically on:
- The average energy required to produce a quantum: 19.5 [eV] for Argon , 3.8 [eV] for Silicon.
- The fraction of energy lost in electronic w.r.t nuclear collisions

The fluctuations in the number of electrons depend critically on:
- The fluctuations in the energy lost in electronic w.r.t nuclear

DS-50 Collaboration, Phys. Rev. D 104, 082005 (2021)



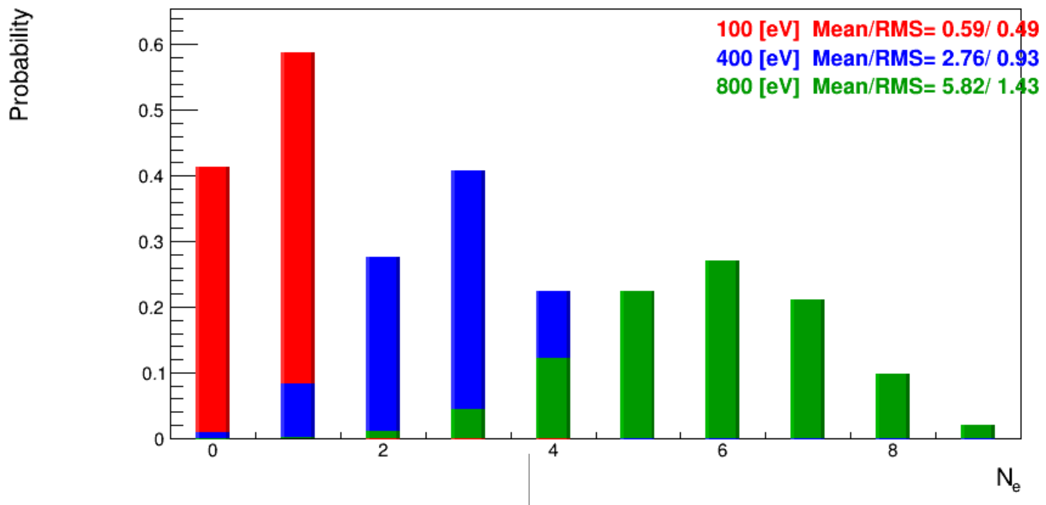


The current model used in DS-50 comes from a fit of the AmC spectrum+External Data sets. (β,γ) free parameters.

Issues:
- κ(ε) is fixed to Ziegler et al, other s_n (ε) reproduce the data as well.
- Data is insensitive to the fluctuations of the number of quanta

The current approach to overcome the second issue is to adopt two extreme models of fluctuations.

The seed functions: N_e spectra for mono-chromatic Nuclear Recoils

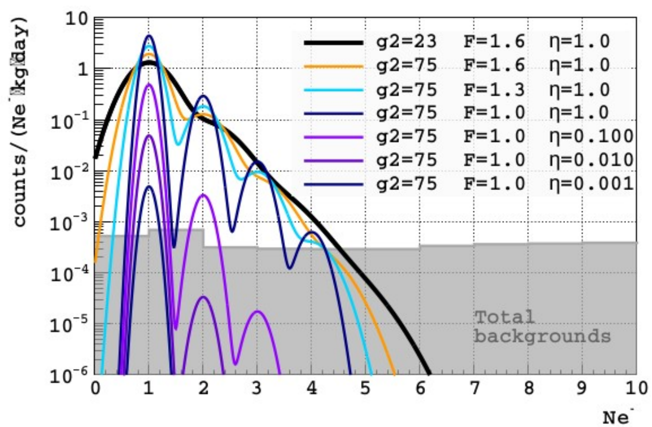


Just for illustration, simple model (not actually measured)
It is likely that 60% of the times a 100 [eV] recoil leaves a measurable signal in a Argon detector.

To predict the WIMP spectrum we need to measure these seed functions accurately.

Needs to be convolved with the experimental resolution.
This depends critically on g2 (Number of photons per extracted electron).

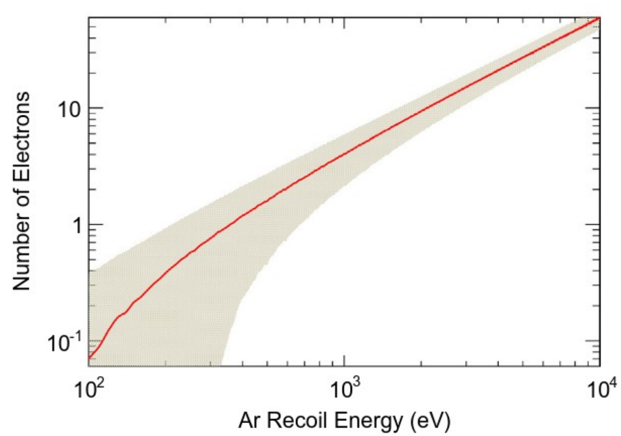
g2=23 [pe/e-] in DS-50, it can be improved tuning the Amplification field or the Gas Pocket Height.



GADM Collaboration, Phys. Rev. D 107, 112006 (2023)

Nuclear recoils with energies 20-100 [eV] might have a finite probability to leave a signal in the detector.

Since ionization threshold is ~20 [eV], the detectability of the signal depends on the fluctuations, i.e. the competition between Nuclear and Electronic scatterings.

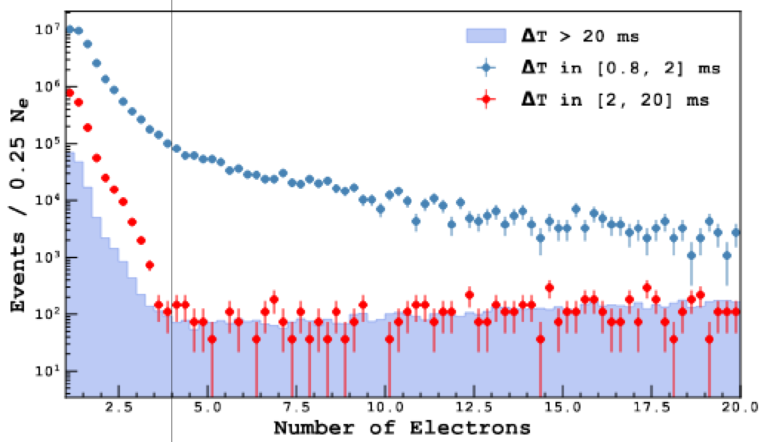


M. Foxe et al, Astroparticle Physics 69, (2015), p 24-29

Atomistic Monte Carlo to model the number of ionizations and its fluctuations

What is the actual threshold in Argon based detectors?

DS-50 Collaboration, Physical Review D, 107 (2023) 6: 063001



Analysis Threshold N_e=4 (~500 eV^{nr})

There is a sudden rise in DS-50 background for N_e<4: this is the so called *Spurious Electron Background (SE)*.

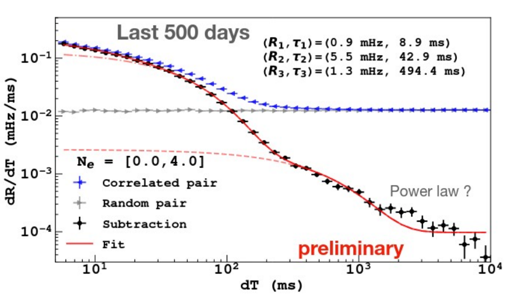
SE happens more frequently after a high energy event.

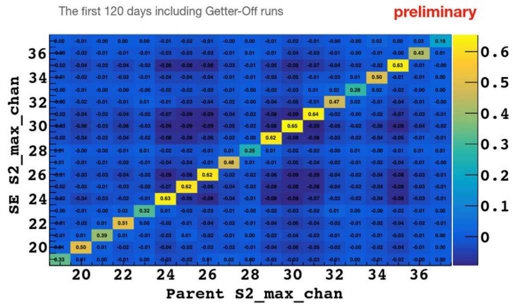
(1) A great fraction of those events are correlated in time with previous high energy events.

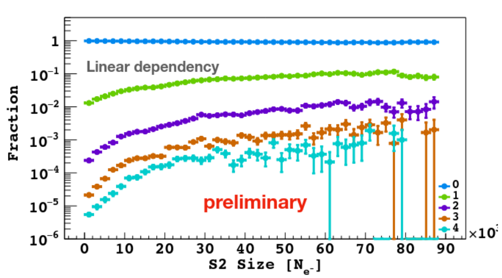
(2) Also they appear at the same (x,y)

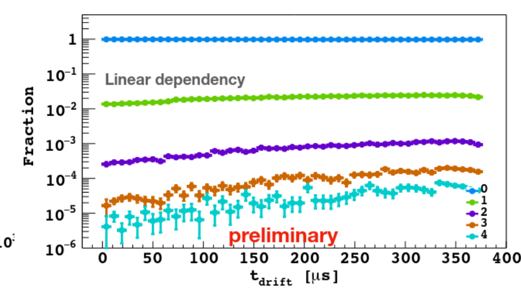
(3) SE production is larger when parent has larger size.

(4) SE production is larger when parent had to travel longer distances in LAr



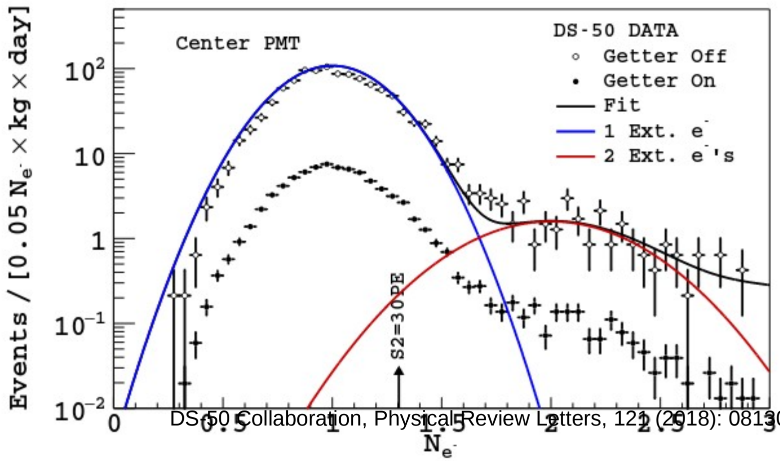






N_e=(0,4)

More importantly, most of the obvious mechanisms considered produce a background for N_e =1, so why we see it for N_e =2,3 and 4?



DS-50 Collaboration, Physical Review Letters, 121 (2018): 081307

R_2 : Rate for N_e =2
R_1 : Rate for N_e =1

PRELIMINARY: R_2/R_1 ~0.03 and does not depend on ΔT or t_{drift} .

This suggest that overlaps might not be the cause of the SE for N_e >1.

A mechanism that duplicate electrons when reaching the top of the TPC?

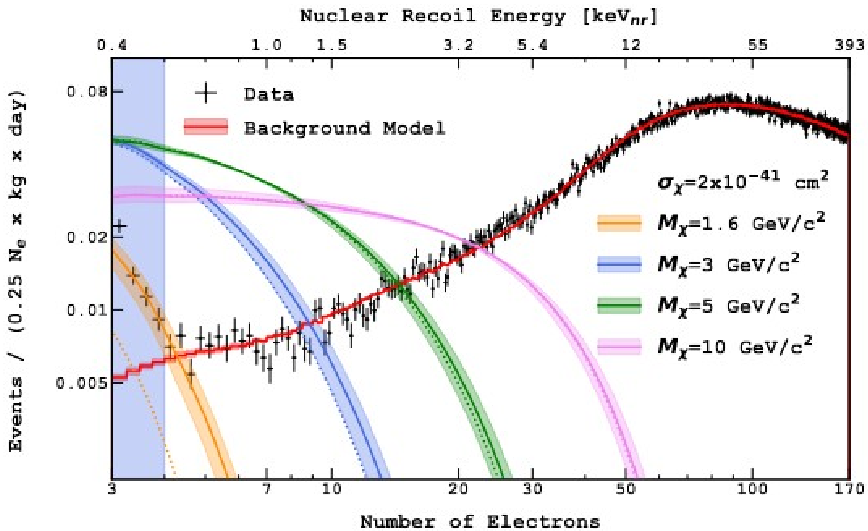
DS-50 data is compatible with a model in which SE spectrum is a Poisson Distribution (convolved with experimental resolution). The overall normalization depends of the impurity level.

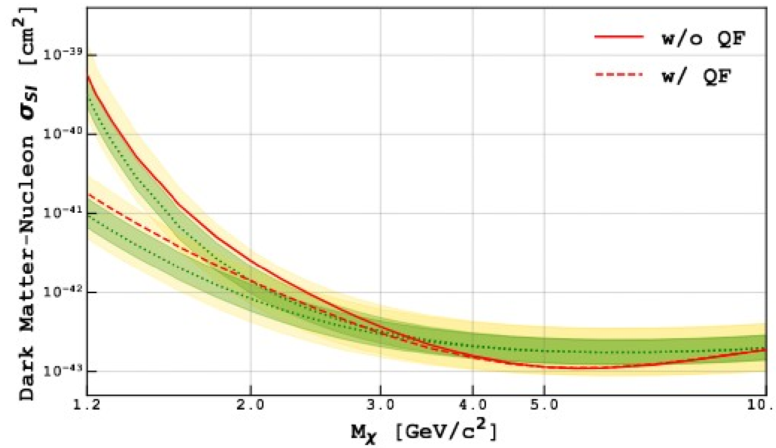
See **arXiv:2407.05813,** such model is used in Profile Likelihood sensitivity estimates for DS-20k.

See back up slide 22 for the current plans for future Argon detectors
See back up slide 23 for seasonal modulations (that can potentially be used to set limits with N_e <4)
See back up slide 24 for R&D on Spurious Electron Background

Uncertainties in cross section limits

DS-50 Collaboration, Physical Review D, 107 (2023) 6: 063001





Solid/Dashed lines correspond to two extreme models of fluctuations. Differences for M_{WIMP} =1.6 [GeV] are noticable.

→ >x10 uncertainty at 1.2 GeV

With the current threshold of N_e =4 and for M_{WIMP} <2 GeV, we have systematics due to the shape of the seed functions.

Note: Phonon based detectors are more suitable for M_{WIMP}<1 GeV : lower energy threshold and narrower seed functions.

Migdal effect helps Xenon and Argon searches in the sub-GeV range, but we need experimental evidence of such effect.

See back up slides 25 and 26

ReD goals in the Low Mass range

ReD is a subgroup of the GADM collaboration formed with the initial goal to investigate the directionality sensitivity of the Argon target for High Masses.
The current goal is Low Energy NR characterization.

DS-20k Collaboration
Eur. Phys. J. C 84:24 (2024)

1) Phase I : measure ionization yield in the 1-10 [keV] range.

Data already taken at INFN Sezione di Catania, preliminary results presented in this talk.

2) Phase II : measure the seed functions in the 0.2-1 [keV] range

Ongoing at IFUSP and INFN LNS

3) Phase III: R&D in spurious electron background (Mitigation and Characterization)

Funding is being requested within the DRD2 collaboration

Additionally:

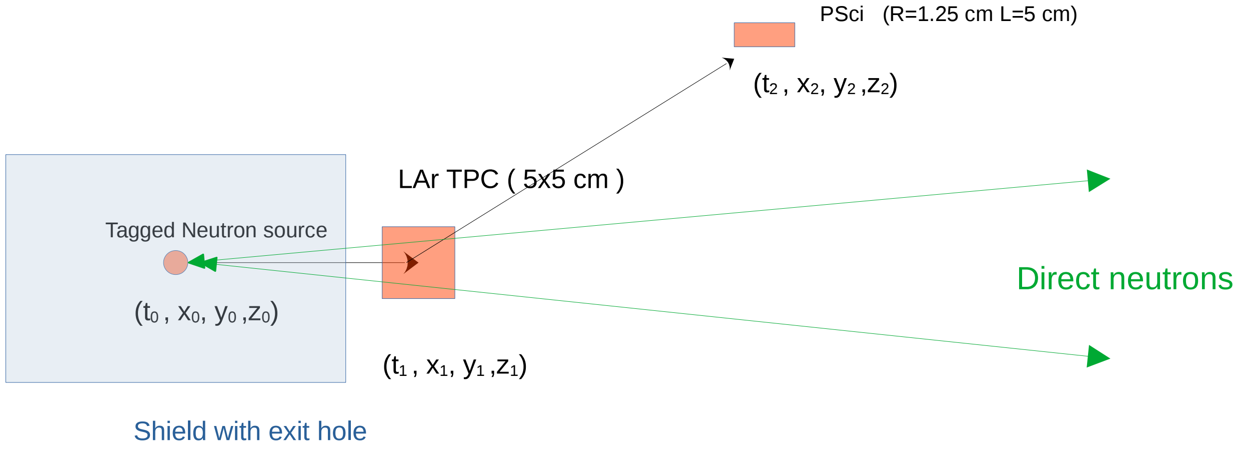
- Feasibility studies to measure the Migdal effect in Argon
- Apply calibration methodology to other targets: Silicon (CCDs) and $CaWO_4$ (CRESST)

Brazilian FAPESP funding : new neutron source
Italian PRIN funding : new TPC

Sub-keV NR energy calibrations are actively pursued by other collaborations. Some of the methods could be adopted for Argon; see back up slide 27

For phase III see back up slide 24 and 26

Phase I *(at INFN Sezione di Catania, Italy)*



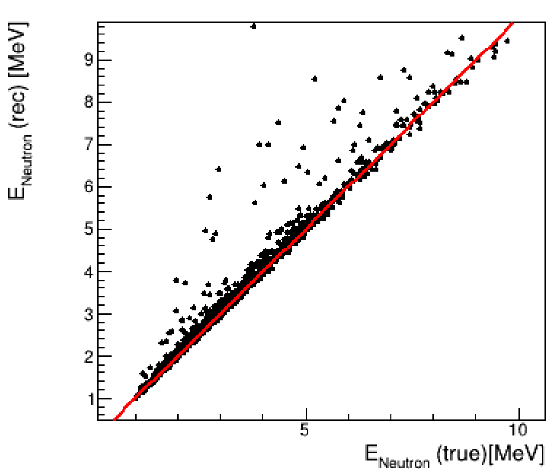
$$E_{NR} = 2KE_{neutron}\frac{m_n m_{Ar}}{(m_n + m_{Ar})^2}(1 - cos\theta_{scatt})$$

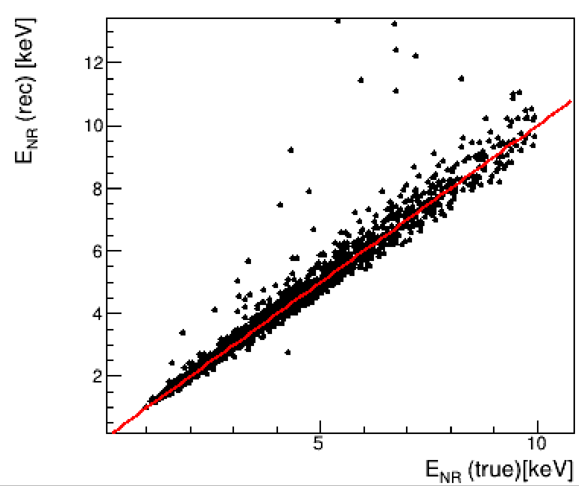
Time of flight (→ $E_{neutron}$) — Fixed by geometry (→ θ_{scatt})

Design settings:
- ^{252}Cf source : 26 [kBq] SF
- Scattering angle of 15.25 [deg]
- 92.1 [cm] source → TPC
- 103.4 [cm] TPC → Psci
- 1 [cm] accuracy in TPC position reconstruction
- 1 [cm] accuracy in placement of the different detectors
- <1 [ns] accuracy in Psci/Tagger TOF

Time of Flight → Neutron Energy
Vertex reconstruction → Scattering Angle → E_{NR}

Full MC simulations (Geant4+Detector Response+Reconstruction)

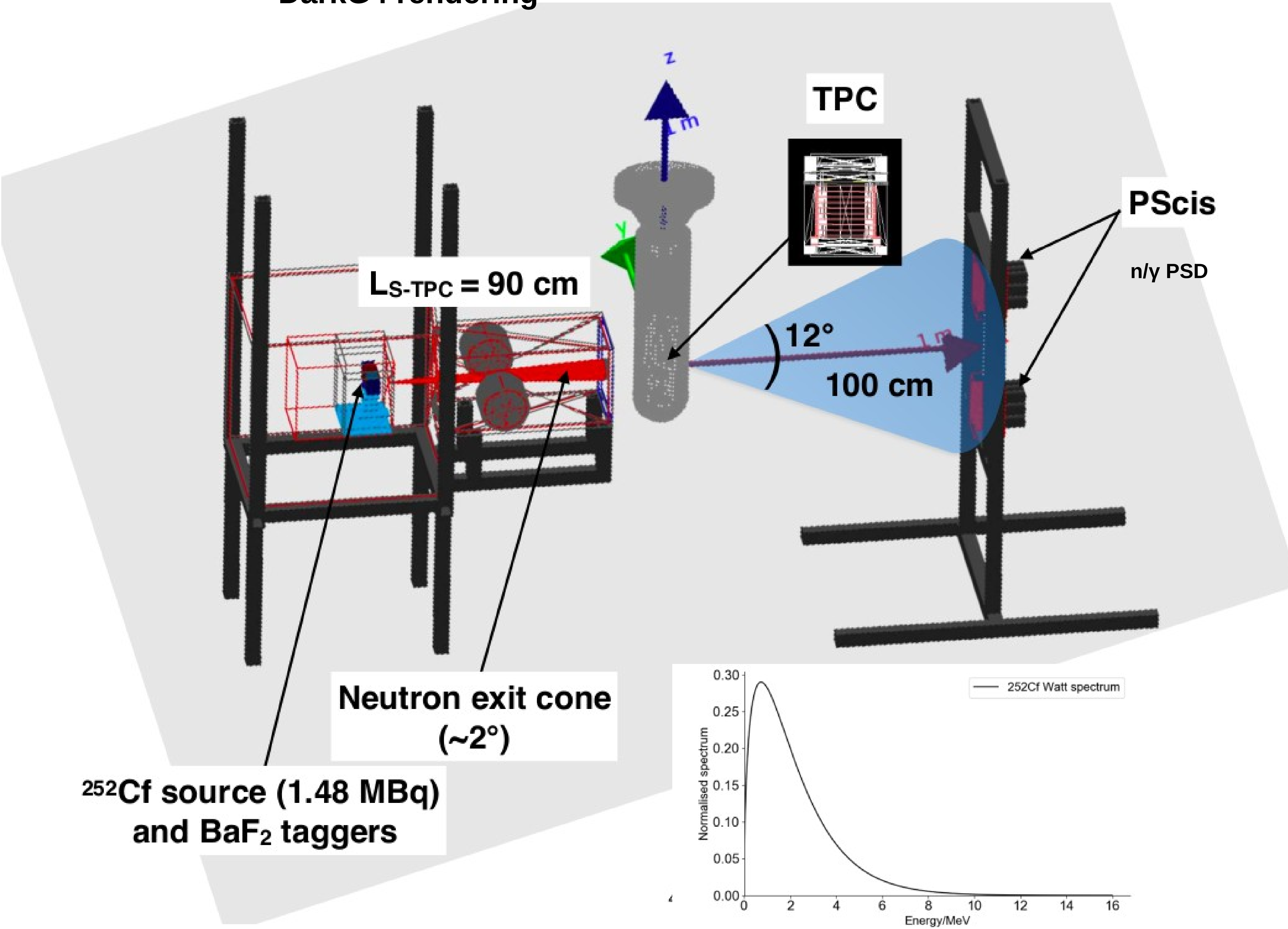




<u>Only good topology events.</u>
BaF0 && PSci coincidences.

~6% accuracy in $E_{neutron}$
~7% accuracy in E_{NR} reconstruction.

DarkG4 rendering



The components

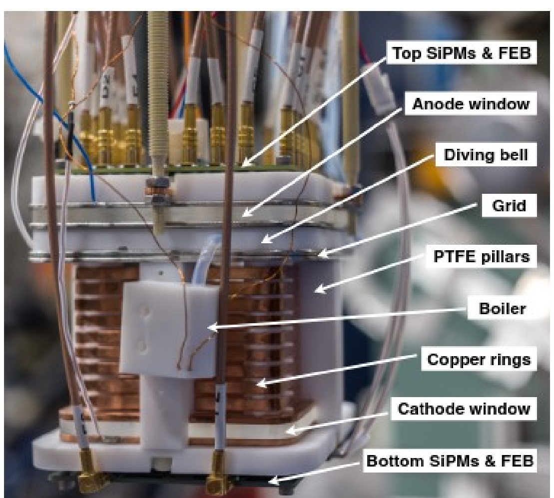
The shield/collimator made of Boron Loaded HDPE and Lead. The collimator is conical with 2.6 [deg] aperture.

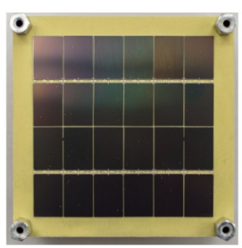
- ^{252}Cf source : 26 kBq Fission
- Two BaF taggers: fast detectors that providing the **start tag:**
  - Trigger Logic: OR with ~100-200 [keV] threshold. ~40% SF tagging efficiency.
  - Trigger rate for each BaF ~10 [kHz]

Two cameras with 9 1" Plastic Scintillator.

EJ-276: good PSD and <0.5 [ns] Time Resolution

~10 [Hz] trigger rate each





5x5x5 cm TPC

24 Top SiPM
4 Bottom SiPM
NUV-HD-Cryo from FBK

SiPM channels work in the high occupancy regime.

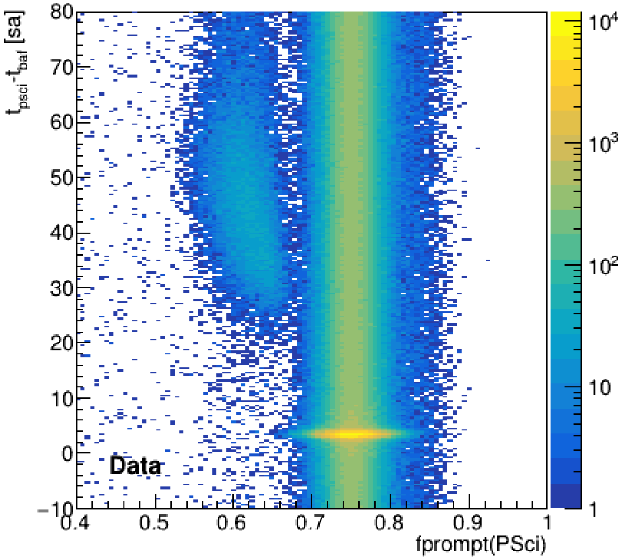
See back up slides 28-31 for details on the TPC analysis

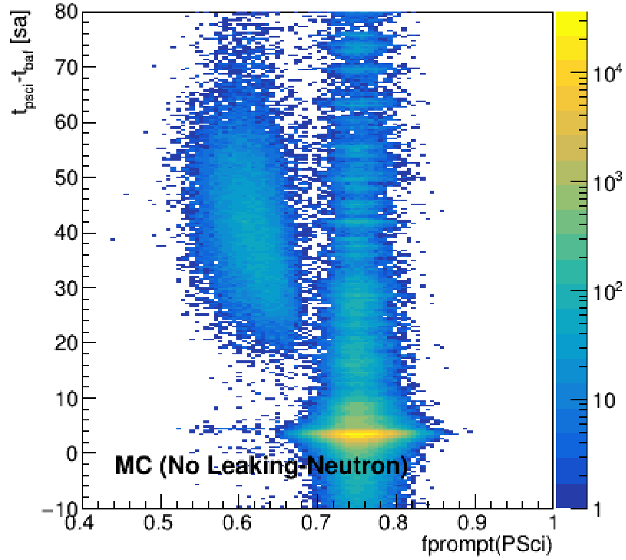
Trigger logic:
Any BaF && Any Psci
~[Hz] rate

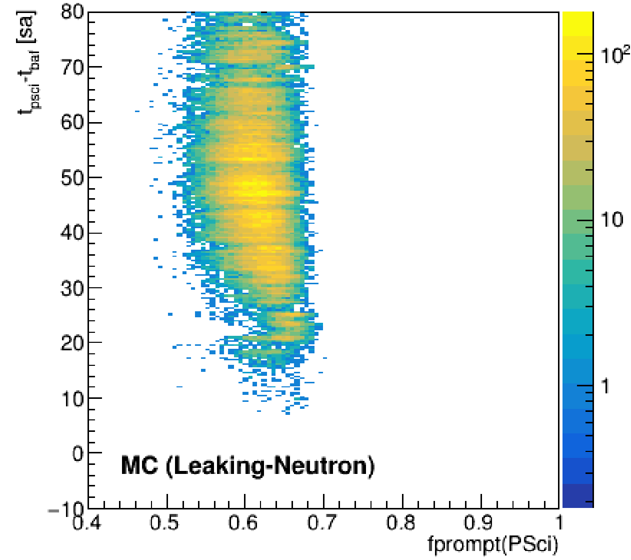
PRELIMINARY:
- *Data and MC:* PSci energy calibrated with ^{241}Am, Electronic Quenching was ignored (it is being measured for EJ-276 at USP)
- *MC :*
  - ^{252}Cf spectrum uses FREYA model, Mannhart et al is our default now.
  - EJ-309 nuclear quenching.

BaF0-Psci coincidences

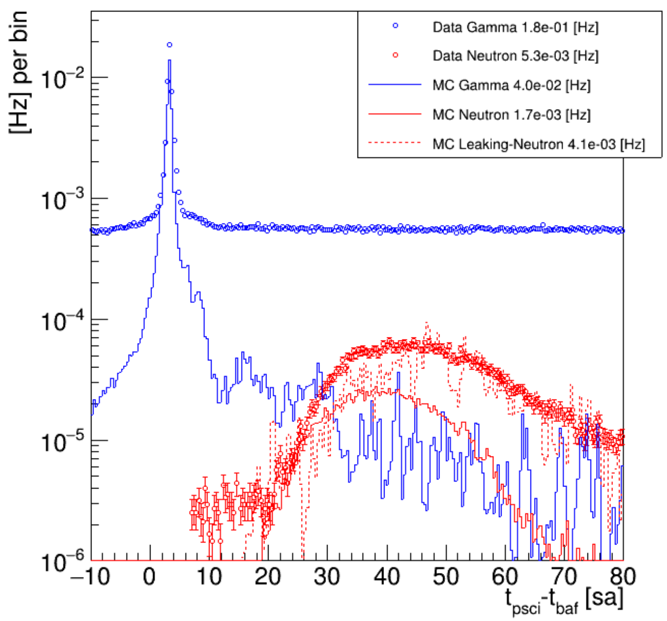
Leaking neutrons refer to neutrons that exit the shield from the front without going through the TPC. The shield needs to be reinforced.

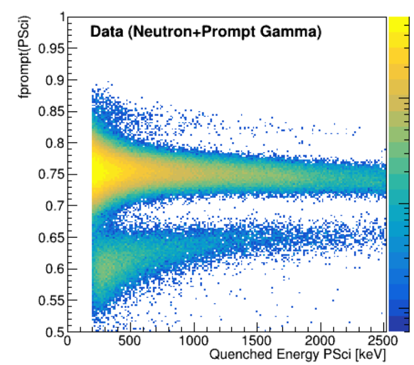






- **Gamma Flash:** rate well reproduced and TOF resolution ~0.7 [ns] (6% $E_{neutron}$, slide 11)
- **Accidental Gammas** missing in the simulations.
- **Leaking neutrons** are the dominant population for tof>40 [sa] . When TPC coincidence is required, they disappear.





This data set is not optimum to tune the BaF/PSci MC due leaking neutrons.

In Nov 2023 we took runs with one camera exposed to the beam.

This data set is being analyzed and will be presented in the near future.

BaF-Psci neutron coincidences with TPC signal

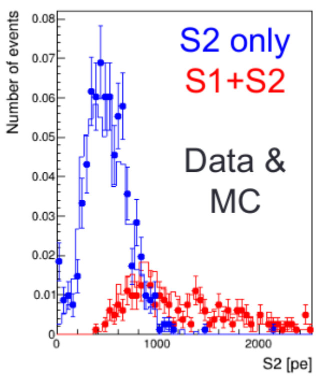
TPC cuts

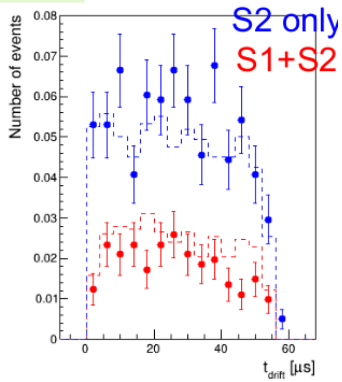
- S1+S2 → (f100>0.5 || S1<100) && (t_{TPC} -$t_{TPC}^{expected}$)<15 [ns]
  S2only → T_{start} >2500 [sa] && T_{stop} <39000 [sa]
- BG before 1st pulse and after last pulse < 1.5 [spe/us]
- (x,y) in the central 4x4 cm region
- S2 (XYT corrected) < 3000 [spe]

Total number of events (S2 or S1+S2) : 2606
Total selected : 649 (S2 only) 224 (S1+S2)

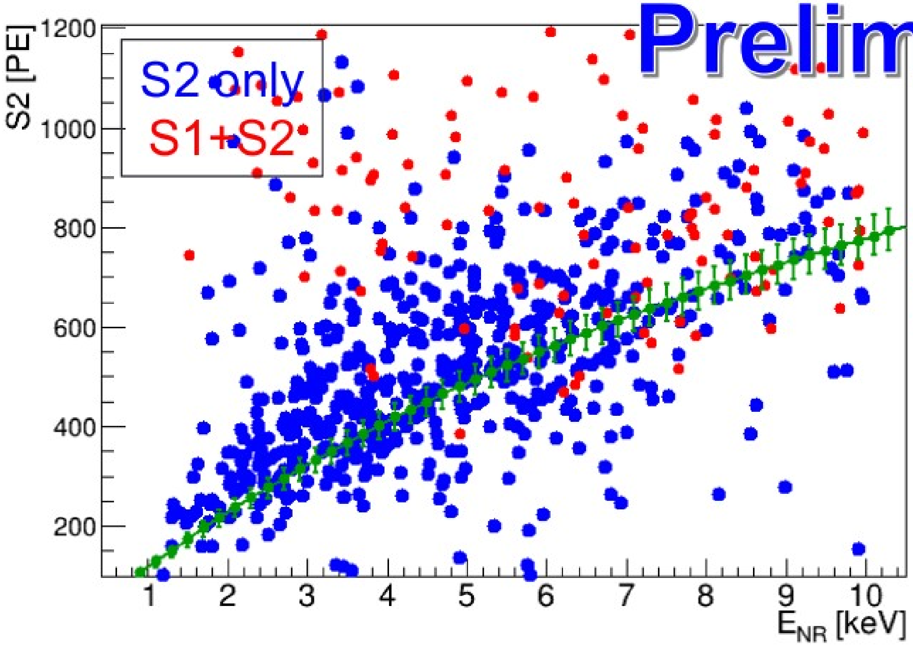
Data taking: From Jan 10th to Mar 16th, 2023
~2.5 Hz, 80 μs waveforms (600 GB/day)

- Good agrement with DS-50 model
- Work in progress to pin down g2 and set the absolute scale.
- Work in progress to clean the data set due to BaF1 tag timing tails.
- See back slides for benchmarks of the reconstruction chain.



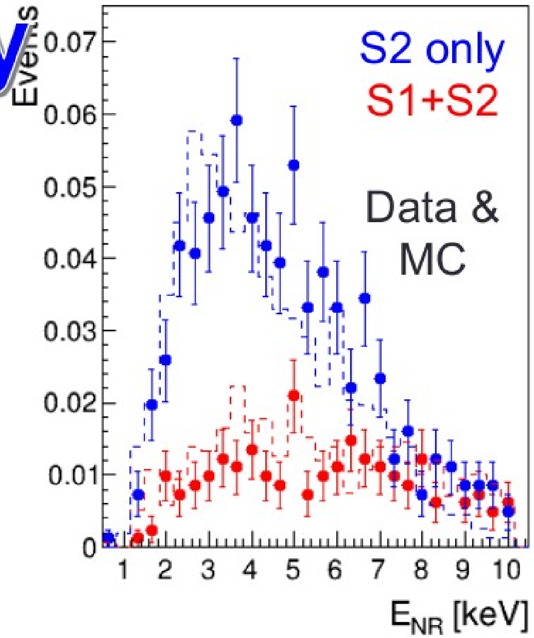


Preliminary



DS-50 model

WORK IN PROGRESS



Phase II *(at IFUSP, Brazil and INFN LNS, Italy)*

Physics goal: Nuclear Recoil Energies 0.2-1 [keV]

Funding already secured.

Ingredients:
- Neutron source : DD generator
  ^{252}Cf with higher activity and new taggers (better timing and higher SF tagging eff.)
- New TPC : larger, less passive materials, better field configuration and larger g2.
- Spectrometer : 36 PSci (x2) with better camera design (avoid neutron reflections)
- DAQ : new DAQ that allows triggering on Single Electrons using top multiplicity

Technical goals:
- Boost signal rate by a factor 10
- Decrease bad topologies by a factor of 2

See back up slide 32 for possible set-ups

Why a DD Generator?

- *Large flux:* adjustable 3e5-1e7 n/s
- *Mono-energetic neutrons*

Generator chosen: Adelphi DD-107 API with a home made conical flange that host a Silicon Detector to detect ^{3}He

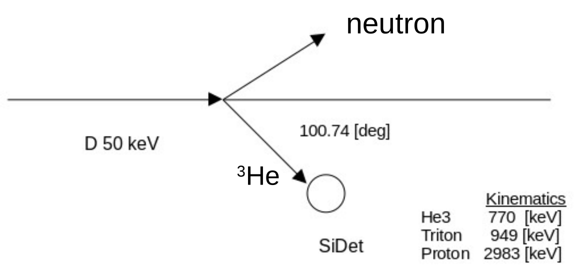
Requirements

- Low X-ray flux
- Efficient Trigger on ^{3}He with the SiDet.
- Good timing accuracy of SiDet (TOF measurements).
- Narrow neutron cone beam formed when triggering in the SiDet
- SiDet can be operated in long campaigns (radiation damage).

After preliminary measurements at Adelphi, the generator is at USP for characterization.

It will be sent to INFN LNS for Physics Campaign after characterization.

The tagged neutron cone shape: the key issue

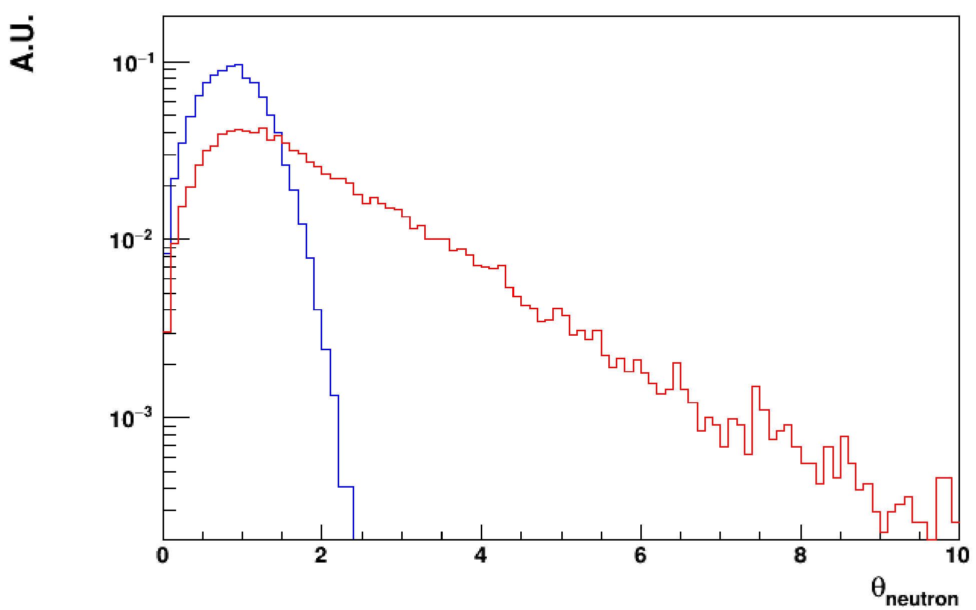


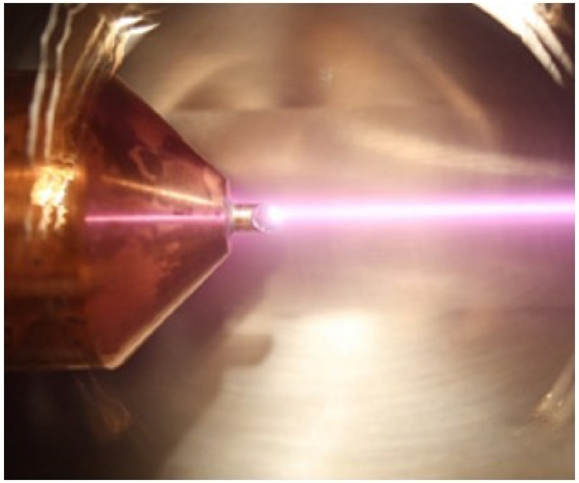
Deuterons incident on the target loose energy and suffer deflections. Simple kinematics does not hold.

SRIM is used to evaluate this extra source of spread:
50 keV deuterons incident on a 45 [deg] inclided target
Two layers: 1 um Titanium Deuterated (1:1) , 2 um Copper

Spatial extent of a tagged neutron beam

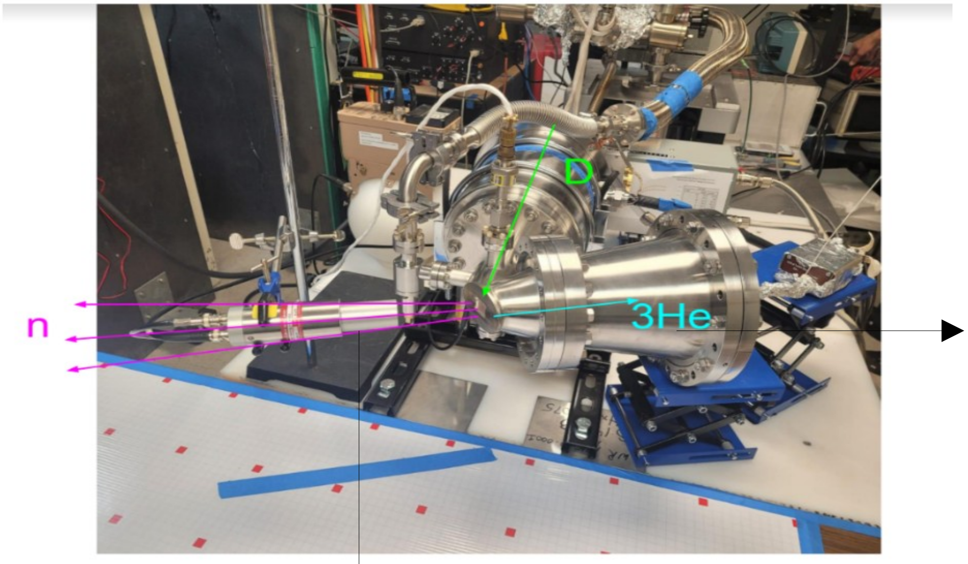
Simple Kinematics
SRIM





Deuterium-Tritium beam striking small target on a sub 2mm spot.

Preliminary measurements at Adelphi



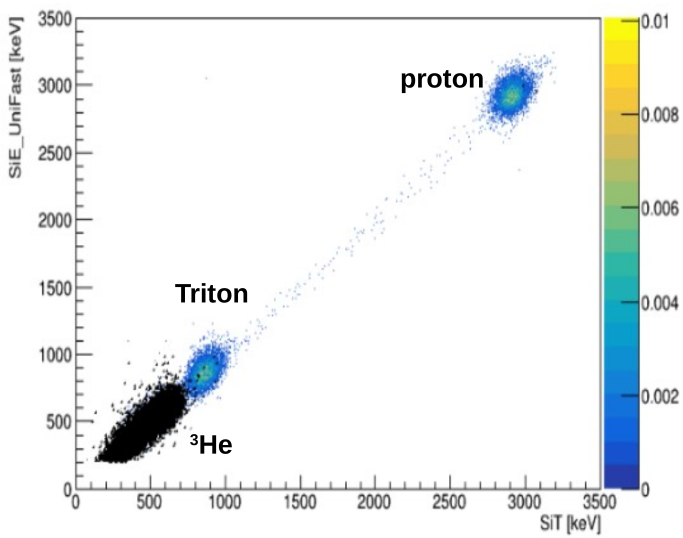
Home made Conical flange hosting the SiDet

1” PSci

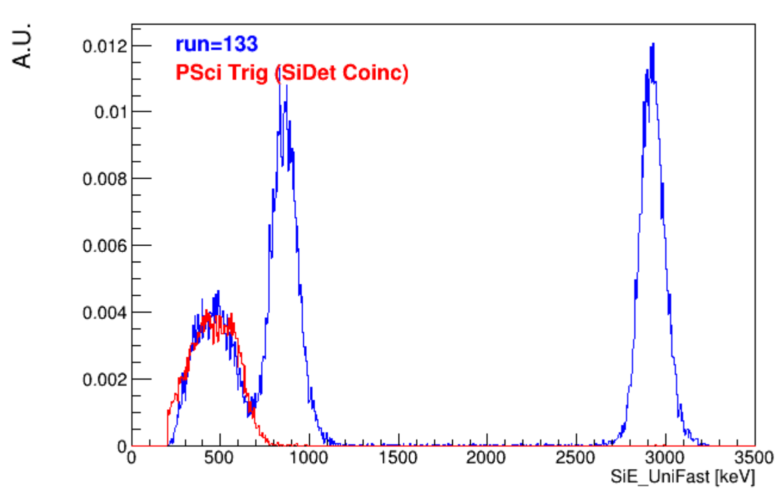
The generator head that we tested at Adelphi was a spare that did not go through factory testing.

The neutron flux was measured with a calibrated Bonner Sphere, ~3e5 n/s.

Generator operated at 100 [kV]



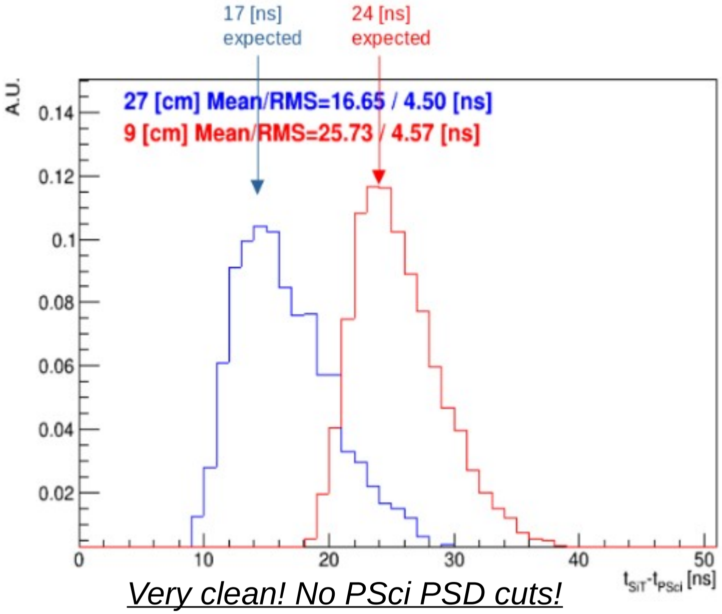
Projection in the Y-Axis



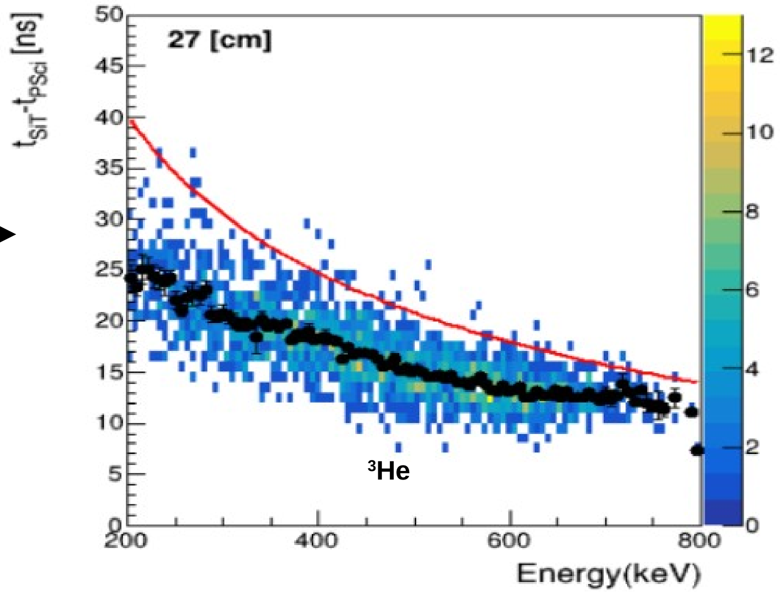
- The 3 peaks are clearly seen.
- Only ^{3}He peak have associated neutrons
- ^{3}He energy is much lower than expected; very likely the SiDet has a 0.5 [um] dead layer.
- The ^{3}He peak rate is ~10 [Hz] for 3e5 n/s. Lower than we expected.

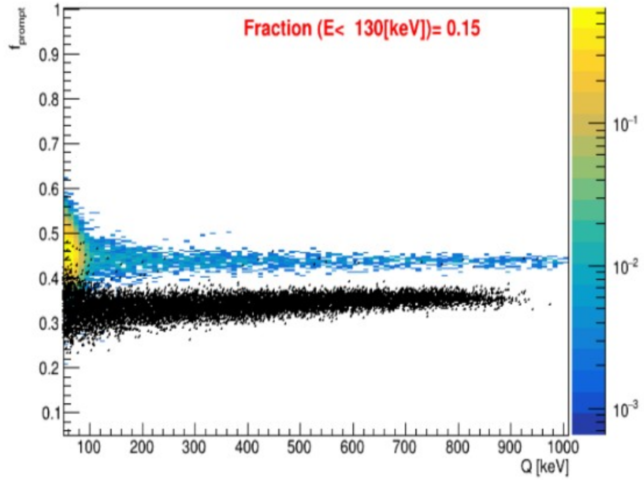
SiDet energy measured with pre-amp (timing) and amp (energy) outputs
Color Histogram: one run with SiDet trigger
Black dots: PSci-SiDet time coincidences in all runs with PSci trigger.

Time of Flight distributions



Very clean! No PSci PSD cuts!
But the PSD is compatible with neutrons



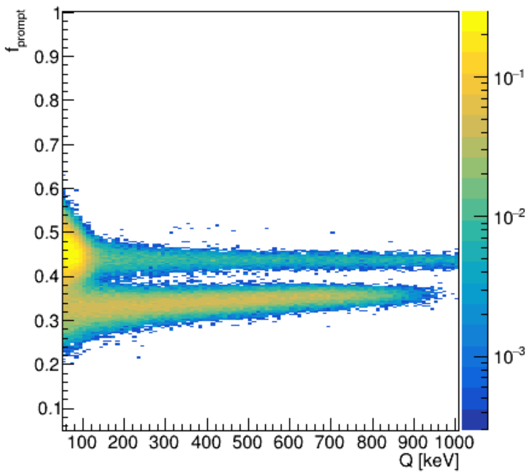


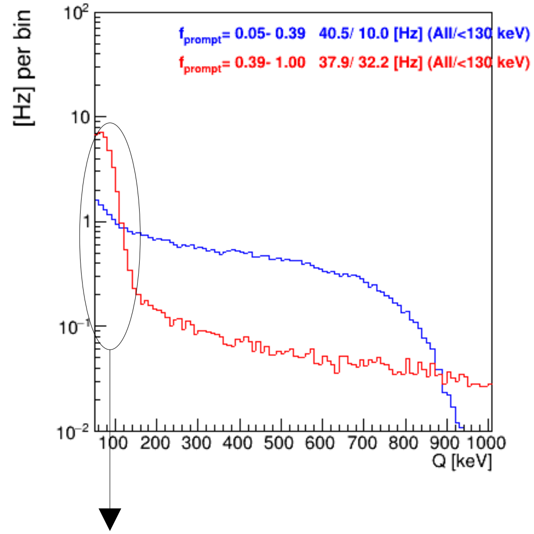
- *Mean TOF* compatible with expectations.
- *RMS of TOF* is ~4.5 [ns]; part of the spread is due to ^{3}He Time of Flight from target to SiDet (non-monochromatic ^{3}He)

Color Histogram: ^{241}Am run
Black dots: PSci-SiDet time coincidences

X-Ray Background

PSD plot
PSci trigger
PSci at 30 [cm] from target.





X-rays with end point 100 [keV]

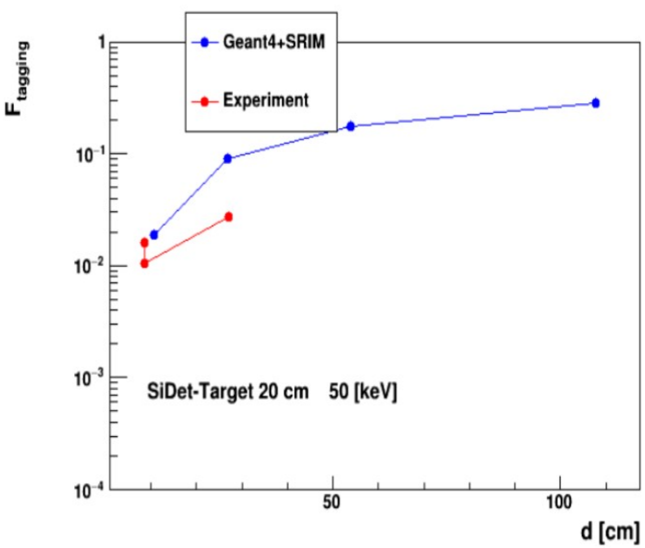
X-Ray and Neutron rate are both ~40 [Hz]

Very good news!!

The PSci has no shielding so is seeing all X-ray flux produced in the generator body.

For physics runs we will collimate the beam and only X-rays produced in the target will contribute (very likely much smaller, X-rays are produced by back electrons entering in the body of the generator).

Neutron Beam shape



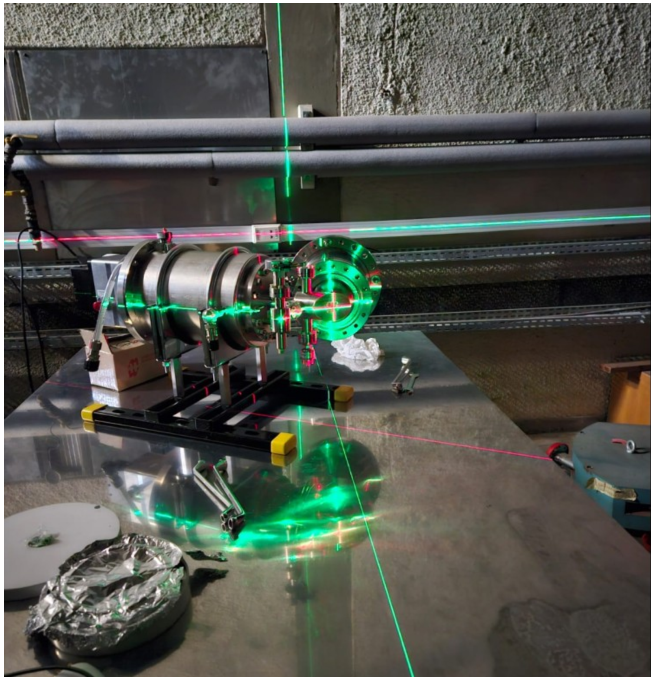
$F_{tagging}$: the fraction of neutrons passing through the PSci that are tagged.

Geant4+SRIM → The assyptotic value of ***$F_{tagging}$*** is 20% (40%) for SiDet-Target distance 20 (10) [cm].

If ^{3}He and neutron direction are not correlated, then ***$F_{tagging}$ =1e-4***

Very good news! We have a beam!

Deviations in that plot are probably due to the crude alignment we were able to do at Adelphi.



The generator at IFUSP
Characterizing the beam and put it in a small collimator hole will be the next challenge.

Conclusions

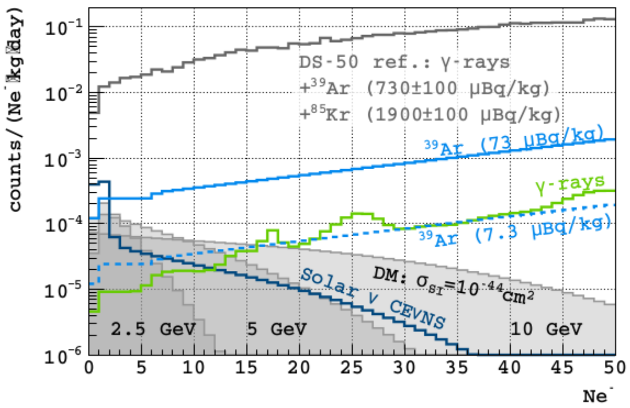
- Argon is an attractive target for direct DM searches in the 1.5-5 [GeV] mass range.
- Sub-GeV sensitivity with Migdal effect; but Migdal needs to be measured in similar conditions.
- Very few measurements of the ionization yield response functions. ReD performed the first (based on Kinematics) in the 2-5 [keV] range.
- Very good prospects to constrain the fluctuations of the ionization yield.
- Phase II targeting the 0.2-1 [keV] region is funded and on going
- The DD Neutron Generator provides a high intensity neutron beam that opens the possibility for Migdal detection in Phase III.
- Abatement of Spurious Electron Background is possible through R&D in Phase III.

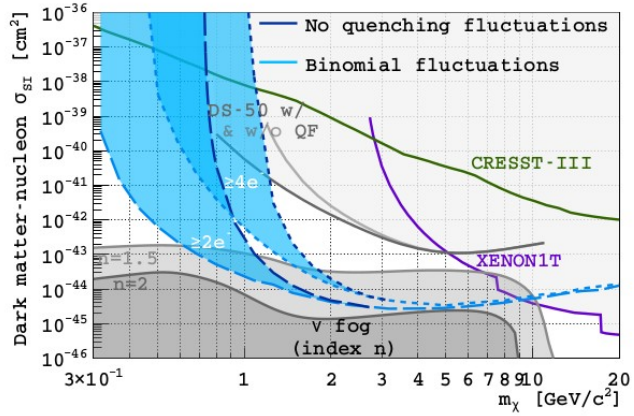
Other exciting possibilities with small (~10 [kg]) Argon Double Phase TPCs:
CEνNS in Nuclear Reactor , slide 33
CEνNS in Spallation source, slide 34

Back Up slides

Future Low Mass searches with Argon

Two approaches : High Luminosity (DS-20K) and Low Background (DS-LM)

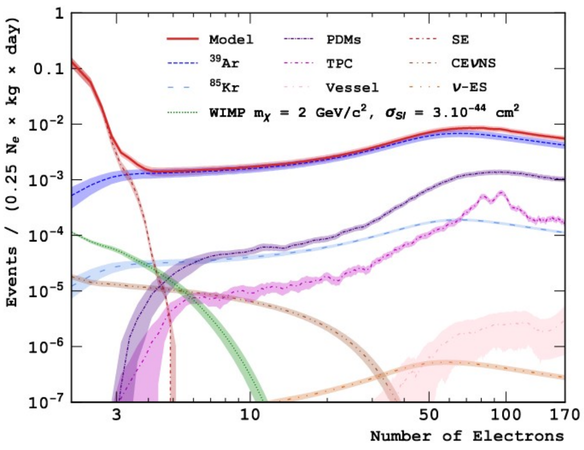


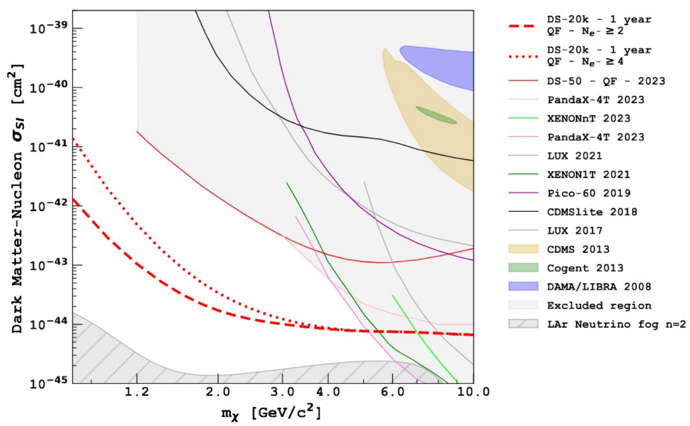


DS-LM

1 Ton-Year
^{39}Ar 73 [μBq/kg]

Phys. Rev. D 107, 112006 (2023)





DS 20k

17 Ton-Year
^{39}Ar 730 [μBq/kg]

arXiv:2407.05813

High Luminosity approach will be likely limited by SE background and ^{39}Ar modelling systematics, S2 performance is not optimized for low charges.
Low Background approach needs a dedicated experiment and further ^{39}Ar purification; but it has a lot of flexibility for improvements since its design is not bounded to the design requirements of a High Mass experiment.

Seasonal Modulations in DS-50

arXiv:2311.18647

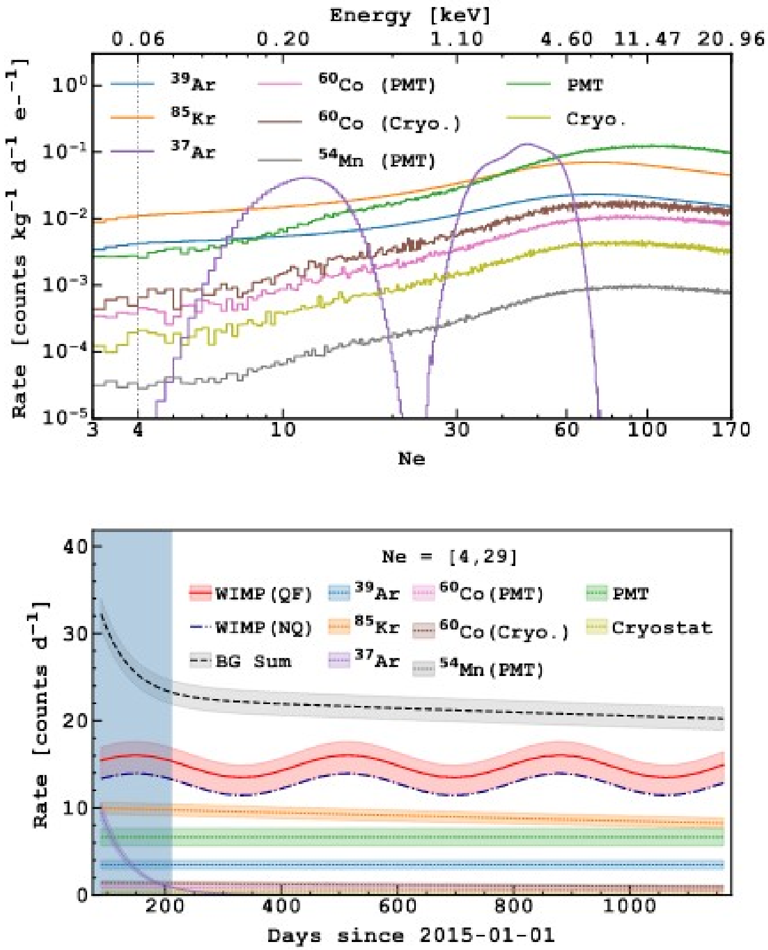


Figure 3. Top: background model of each component with their total uncertainties including both shape and amplitude systematics. The amplitude of each component shown here is normalized at 123 d passed since the reference day. Bottom: temporal evolution of the expected rate from each background source within 4–29 e^-. Also shown are that of WIMP with 3 GeV/c^2 assuming WIMP-nucleon cross-section equal to 3×10^{-41} cm^2 with (QF) and without (NQ) quenching fluctuations (see text for more detail). The blue-shaded period is same as in figure 2.

If temporal stability in future detectors is good enough, seasonal modulations might be another way of using the N_e <4.

R&D to mitigate Spurious Electron Background

What can be done to reduce the role of the SE background in Future Argon Low Mass DM Detectors?

1) Investigate the origin of this background using dedicated experiments:
   - Measures to alleviate it.
   - Characterize it: build a model and estimate the model uncertainties.
2) Reduce the rate per [kg day]: further ^{39}Ar purification.
3) Reduce the rate in [Hz]: stricter ΔT cuts wihout loss of exposure.
4) For $N_e > 1$: minimize the spillover from $N_e=1$ (e.g. increase g2 and reduce g2(x,y) dependences)

Spurious Electron Background R&D in ReD+ Phase III

A TPC with low rate (~10 [Hz]) would be optimum to characterize impurities. The TPC would need to be shielded.

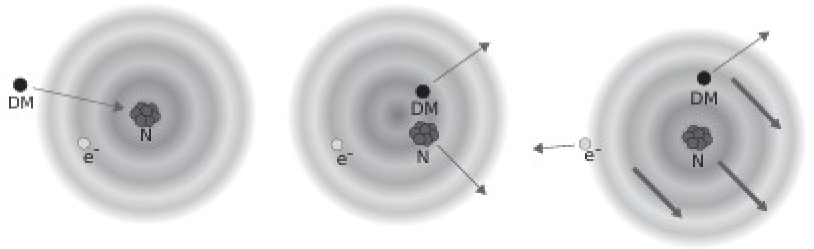
<u>Action items:</u>

- *Purification schemes*: to decrease the N_e =1 rate.
- *Scan in Amplification Field and Gas Pocket thickness:* to characterize R_2 / R_1
- *Measure Quantum efficiency of steel grid.*
- *Grid coating.*
- *The role of delayed electrons*

Synergy: Brazilian researchers at UNICAMP working in purification schemes of LAr for DUNE.

Oxygen: see talk by A. M. Caffer
Nitrogen: see talk by Dirceu Noriler

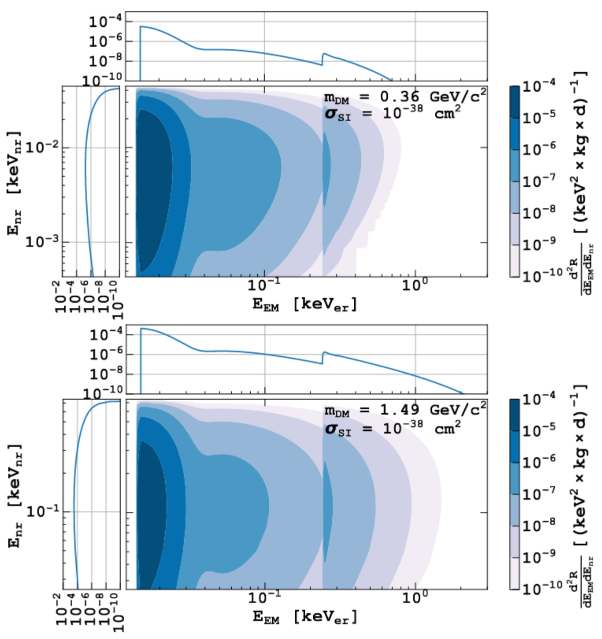
Sub-GeV DM detection using Argon through the Migdal Effect



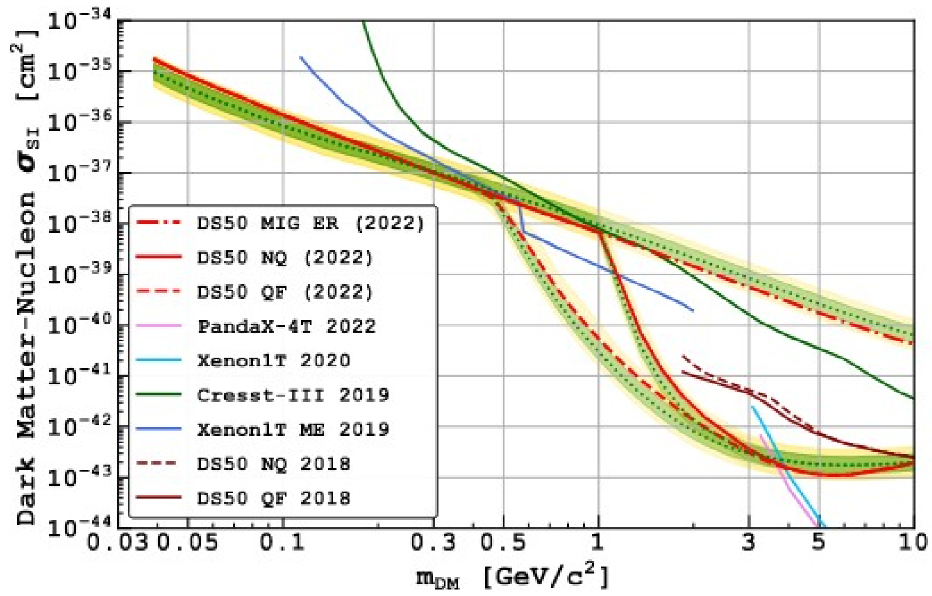
After DM scattering, the nucleus moves and the electron cloud needs to catch up. There is a finite probability that an electron is ejected.

For a 100 [eV] Argon recoil, this probability is ~10^{-3}

The maximum detectable energy for the same M_{WIMP} is enhanced.



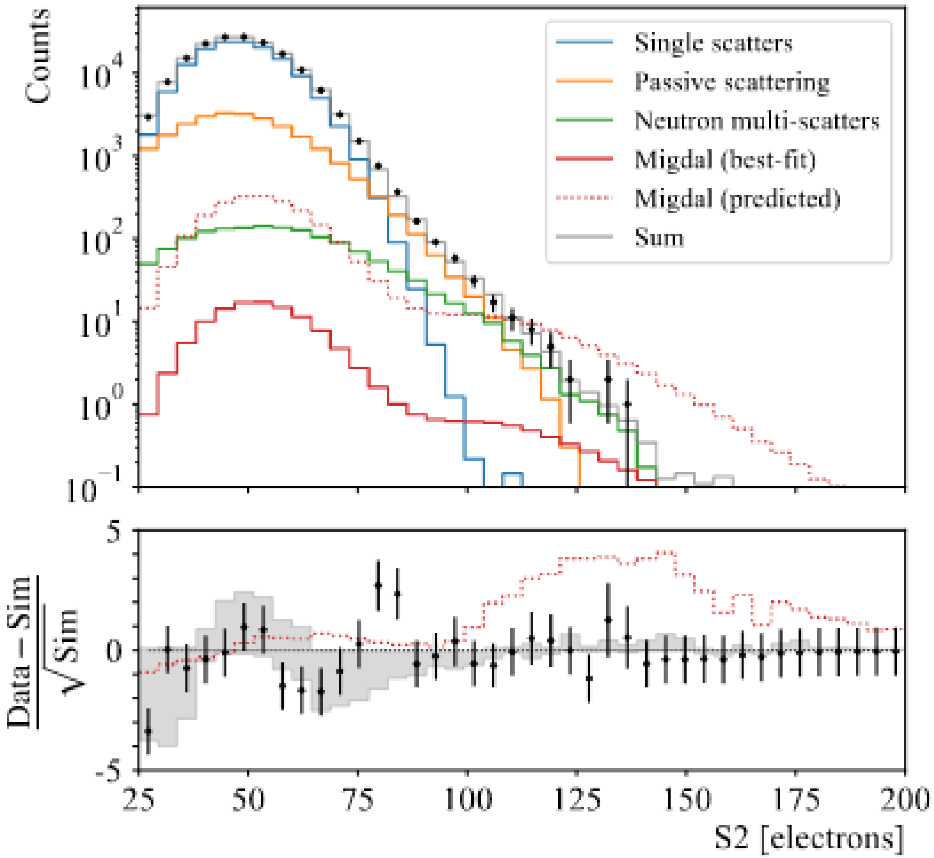
DarkSide Collaboration, Phys.Rev.Lett. 130 (2023) 10, 101001



As expected, for M_{wimp} = 3 [GeV] a Migdal EM Based limit is 10^{-3} weaker than the standard case.

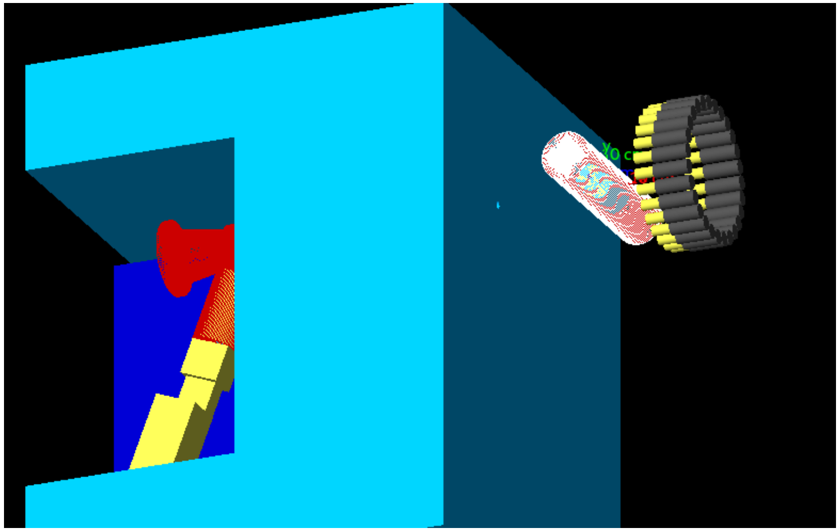
The Migdal effect is challenging to measure

Xenon Migdal constrains using a DT generator



J Xu et al, Phys. Rev. D 109, L051101 (2024)

Argon feasibility studies using a DD generator



MIGDAL with the DD Generator

High Rate Set Up >1000 [evt/h]

Qualifies in terms of rate for Migdal searches with 30 [keV] recoils. Needs to be optimized for BG. Under investigation.

- DD generator operated at 1e7 n/s
- Collimator hole 1 [deg]
- One ring of 1” Psci centered at 42 [deg]
- TPC d=10 cm h=10 cm
- 1 [m] NG-TPC | 0.2 [m] TPC-Camera

Other monochromanic low energy recoil sources

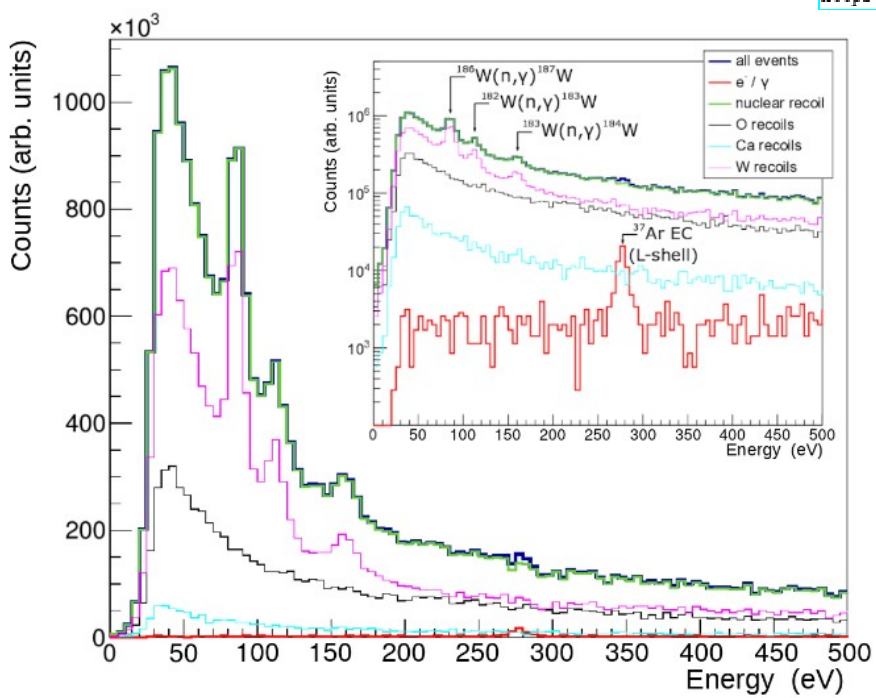
The nuclear recoil caused by radiative capture of thermal neutrons can have sub-keV energies.

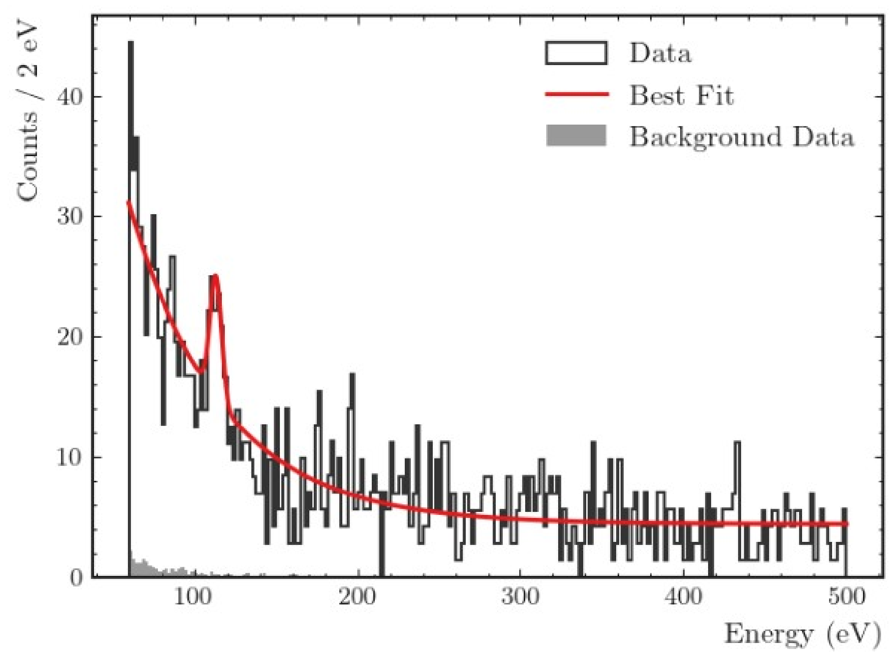
TABLE I. Properties of the potential calibration signals and the associated thermal neutron capturing on tungsten isotopes with subsequent single γ-emission: Q-value Q, recoil energy E_R, natural abundance Y, thermal neutron capture cross section $\sigma_{n,\gamma}$, branching ratio for single γ-emission $BR_{1\gamma}$, and figure of merit FOM.

	^{182}W	^{183}W	^{184}W	^{186}W
Q (keV) [12][a]	6190.7	7411.2	5794.1	5467.0
E_R (eV)	112.4	160.2	96.1	85.8
Y (%) [12][a]	26.50	14.31	30.64	28.42
$\sigma_{n,\gamma}$ (barn) [13]	20.31	9.87	1.63	37.88
$BR_{1\gamma}$ (%) [12][a]	13.936	5.829	1.477	0.263
FOM	7500.6	823.3	73.8	283.1

[a] https://www-nds.iaea.org/pgaa/egaf.html

Is there any similar channel for Argon?





CRESST Phys. Rev. D 108, 022005 (2023)Using a AmBe source 50 [Hz].

The ReD TPC Analysis flowchart

Calibration

Using laser runs (2 [ksa] 4 [us]) derive:

- SPE average shape
- SER : [adc] to [spe]
- DiCT: P_{vino}
- DeCT+AP
- DCR

Red Level Analysis

- FADC Trace Deconvolution: FFT method
- Peak Finder and Charge Integration

Output: TTree of packets
in the low occupancy regime 1 packet is 1 SPE

Blue Level Analysis

- Pulse Finder: S1 and S2 clusters and related variables.
- XY reconstruction
- XYZ corrections of S1 and S2
- S1 and S2 pulse shape fits
- SER charge distributions (Calibration cross check)
- S1 time variable for TOF (weighted average of first SPE of all channels within the tile, within a 20 [sa] window)

Output: TTree of Clusters and Pulse Shape fits

User analysis

- Echo Probability and time distribution
- External Cross Talk from S1 tails
- Delayed Electron Probability from S2 tail fluctuations

Geant4

DarkG4: a local project

- DarkEvent TTree : collection of deposits
- BlueMC TTree : collection of physical clusters

MCGenerator

Given (E_{dep} , t , type) of Physical Clusters generate Raw FADC traces:

- Using ER/NR model → time collection of photon
- Photon share among SiPM: using XYZ corrections for S1 and S2 inferred from data.
- Using calibration : time collection of SPE (DiCT+DeCT+AP and DCR)
- Using user analysis: xCT and Delayed Electrons.
- Using user analysis: Echo (S3) generation

FADC generation: SPE shape of each SiPM + Baseline Fluctuations

Trigger Logic implemented by Masato

69 TB (FADC traces)
↓
1 TB (Packet collection)

~2.4 [evt/s/CPU]
1 evt → 28 FADC traces 40 [ksa]

ONLY ONCE

All data can be reanalyzed overnight

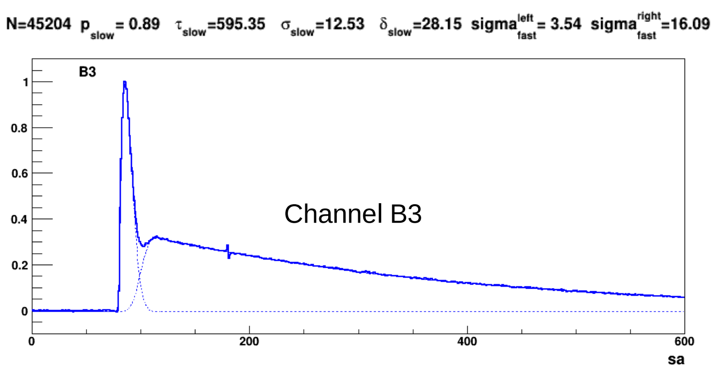
ER/NR Model

- S1(E) S2(E) and fluctuations
- S1 pulse shape
- S2 pulse shape
(with xyz dependence)

g1 from Am241
g2 from Echo

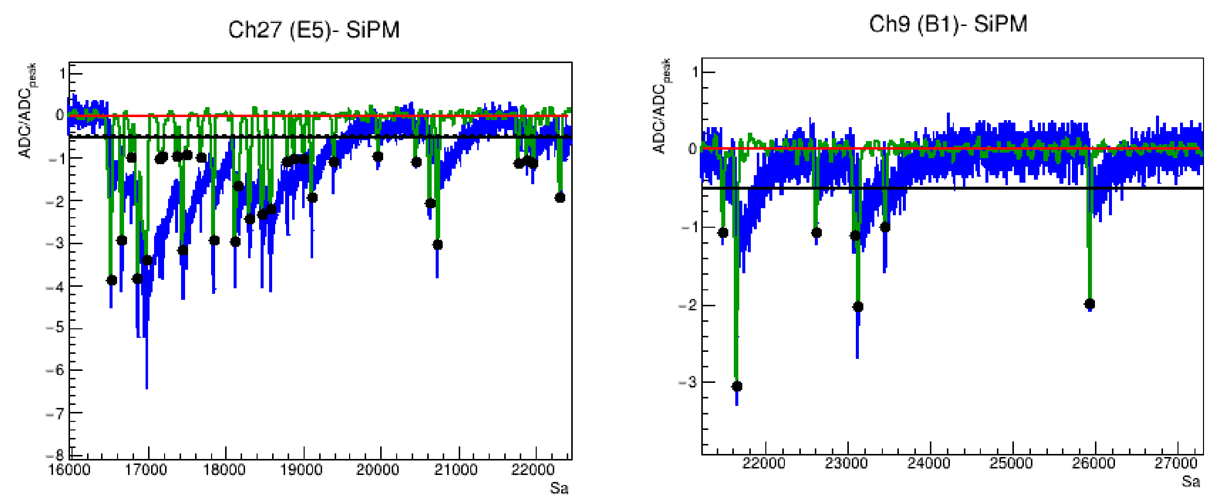
The framework has been upgraded to read native MIDAS files (ReD+ DAQ based on MIDAS).
Appliable to Proto-0 given manpower is available.

Deconvolution Method



$$\mathrm{spe}(t;\tau_s,p_s,\sigma_s,\sigma_{f,lr}) = (1-p_s)\frac{e^{-x_0^2/2\sigma_{f,lr}^2}}{\sqrt{2\pi}\sigma_{f,lr}}\frac{A}{1+e^{-(x_0+\sigma_{f,l})/\sigma_{f,l}}} + p_s\frac{e^{-x_1/\tau_s}e^{\sigma_s^2/2\tau_s^2}}{2\tau_s}\mathrm{erfc}\left(\frac{\sigma_s^2-x_1\tau_s}{\sqrt{2}\sigma_s\tau_s}\right),$$

SPE time profile from Laser Runs



Raw trace
Deconv trace 30 [ns]
Black points: packets

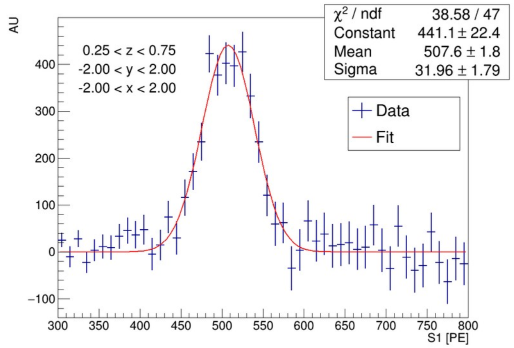
Red Files contain:

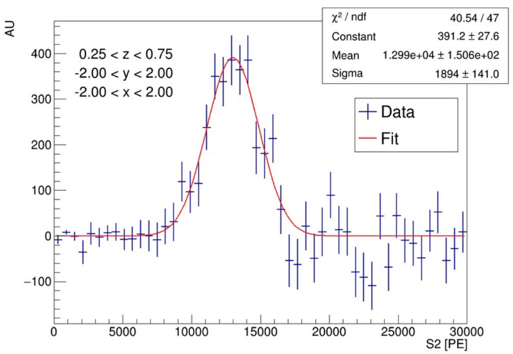
All maximum of the deconvoluted trace above 0.5 [spe_{peak}]. Each maximum is assigned:

- Time: interpolated with a 2^{nd} degree polynomial
- Charge: integrated in between valleys. If possible the integration range is extended to +-N_{user} [sa].

This method preserves charge. No distortion of the time information available.

Benchmarks of the reconstruction chain (Using only the Packet Information)

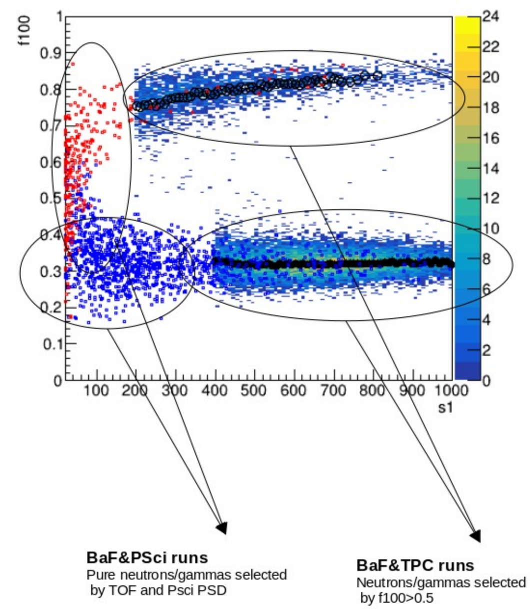




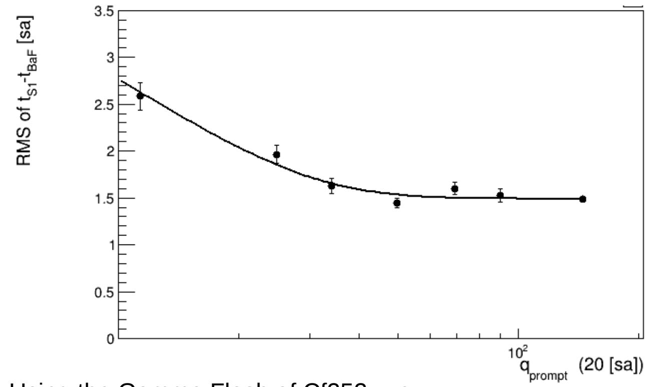
Am241 Peak Width: 6% (S1) 14%(S2) From R. Ravona

Charge Resolution

Non-Linearity induced by the method ~1%



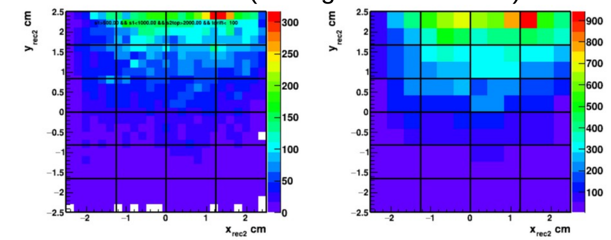
PSD



Using the Gamma Flash of Cf252, we measured the S1 time accuracy to be 3-5 [ns]

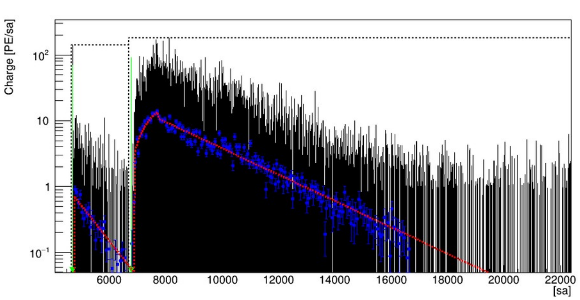
S1 timing for TOF

Run 1230 (Strong Am241 source)

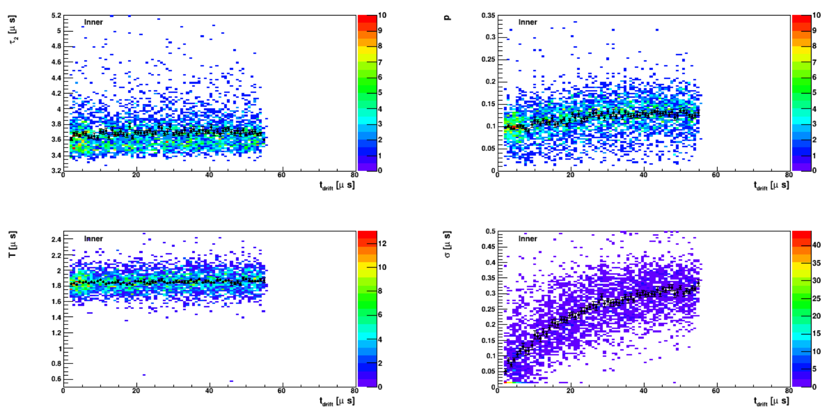


XY reconstruction

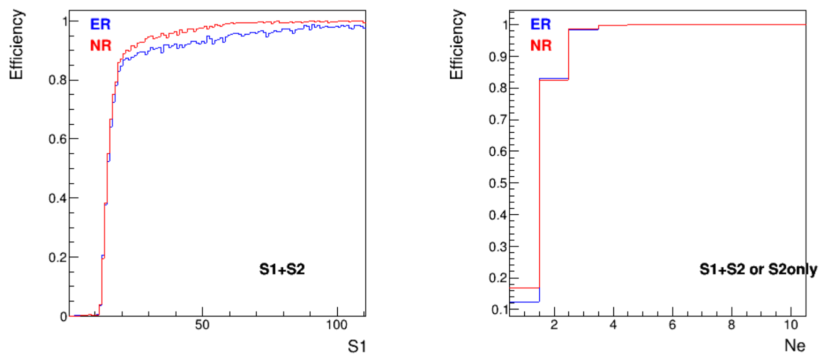
S2 Pulse Shape Fits (event by event)



Run 2299 Cf252+Am241 (Inner Pixels)

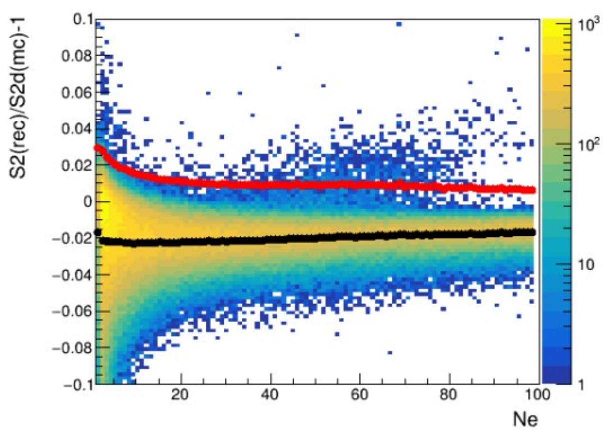


Pulse Finder Efficiency



G2~15 [pe/e-]

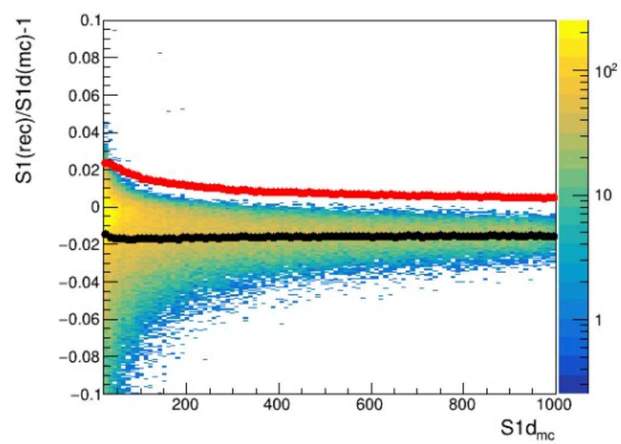
S2 charge reconstruction accuracy



t_{drift} >20 us

Black : mean
Red : rms

S1 charge reconstruction accuracy

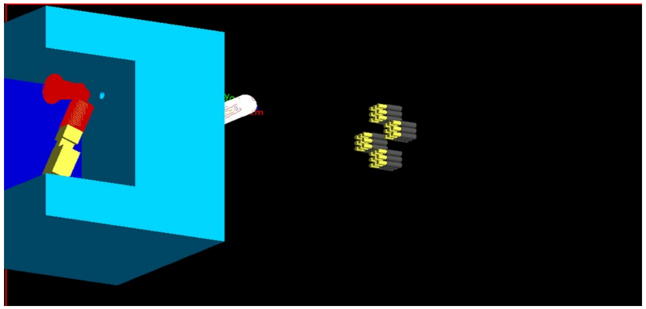


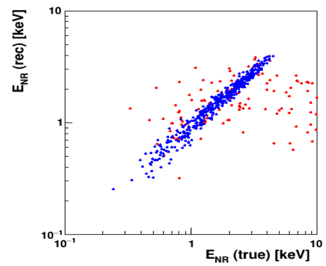
Possible setups for Phase II

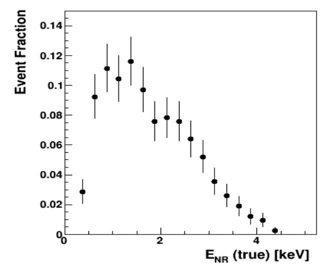
Set Up A

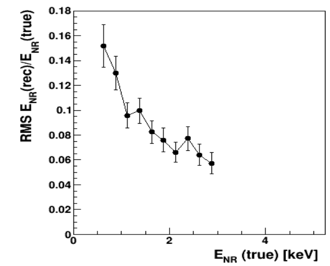
- DD generator operated at 3e5 n/s
- Collimator hole 2.5 [deg]
- 4 cameras at scattering angle 9 [deg]
- TPC d=10 cm h=10 cm
- 1 [m] NG-TPC | 1 [m] TPC-Camera

- Signal rate : 32 [evt/h]
- Tagged Neutron rate (no TPC): 23 [evt/h]
- Good topology fraction : 70%







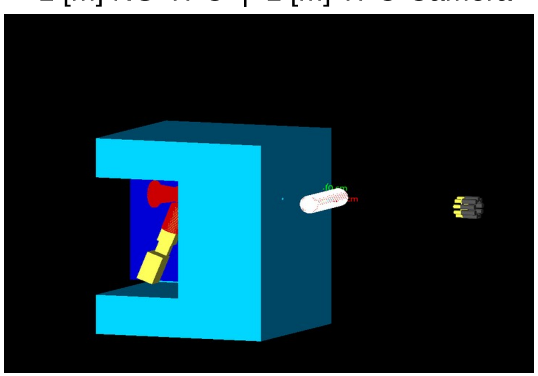


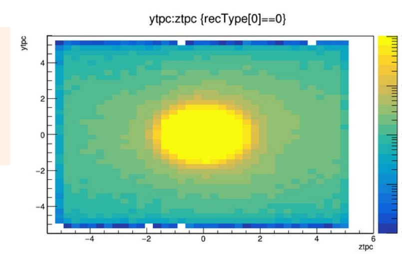
Bad topology
Good topology

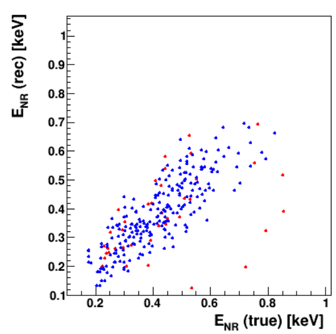
Set Up B

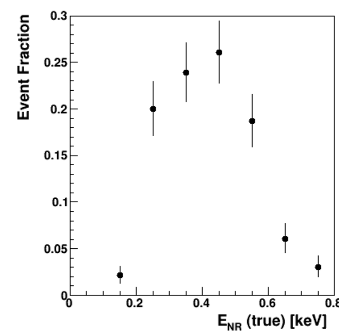
- DD generator operated at 1e7 n/s
- Collimator hole 1 [deg]
- One ring of 1" Psci centered at 3.8 [deg]
- TPC d=10 cm h=10 cm
- 1 [m] NG-TPC | 1 [m] TPC-Camera

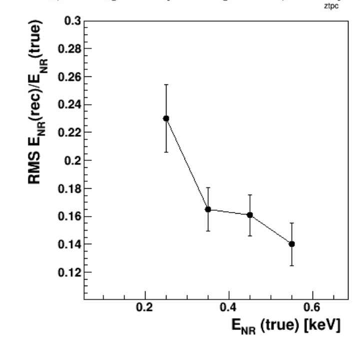
- Signal rate : 60 [evt/h]
- $<E_{NR}>$=300 [eV]
- Good topology fraction : 70%
- Direct neutron fraction still tolerable.







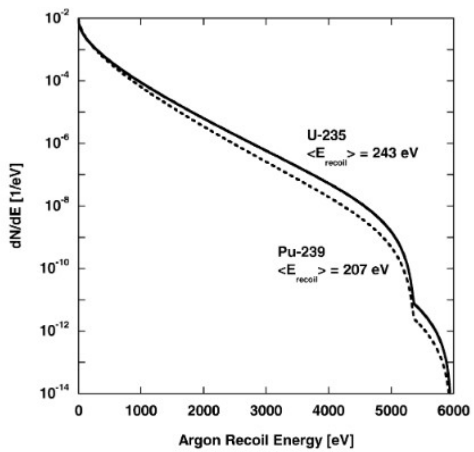




Bad topology
Good topology

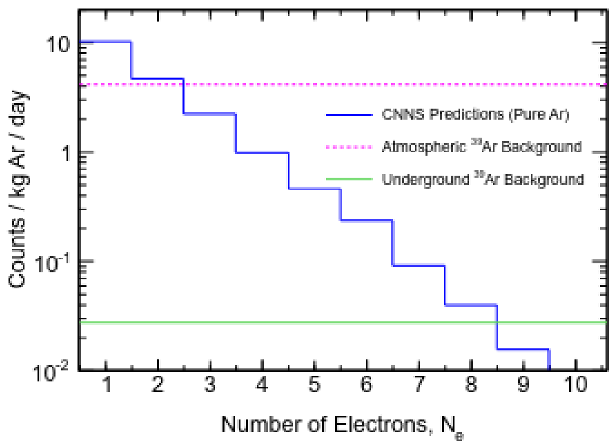
CEνNS in Nuclear Reactor

Reactor neutrinos provide a good source of ~200 [eV] nuclear recoils, which can also test neutrino interactions in a kinematic region not observed before.



Recoil energy spectra from Nuclear Reactor neutrinos via CEνNS
25 [m] from 3 GWt Reactor
~50 [evt/kg/day]

IEEE Transactions on Nuclear Science (Volume: 51, Issue: 5, 2004)

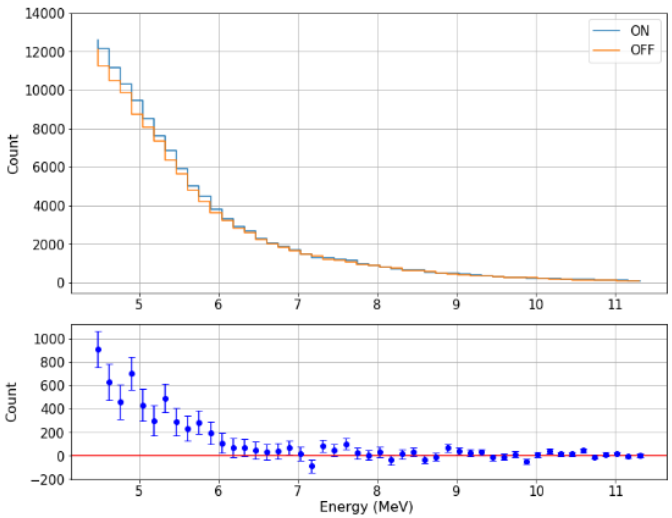


Astroparticle Physics 69, (2015), p 24-29

If we target a high S/N measurement:

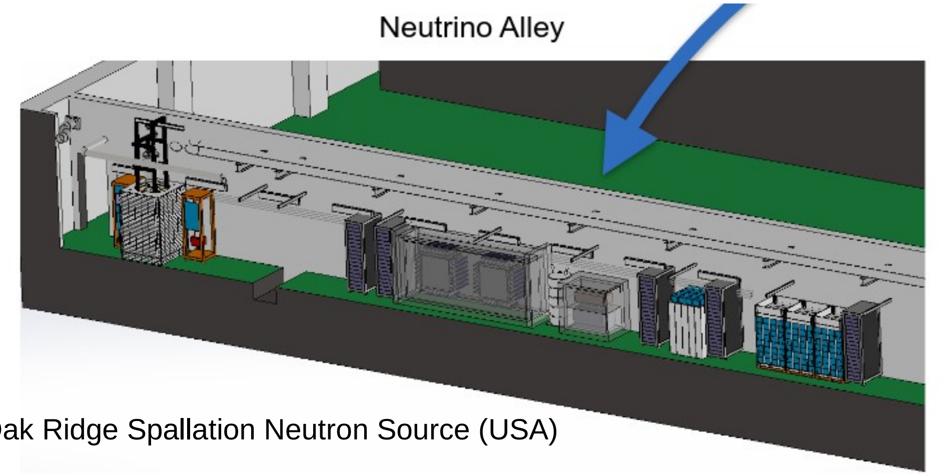
- It requires the use of UAr.
- It requires suppressing the Spurious Electron Background
- It requires a shallow depth location to avoid Cosmogenics and ^{39}Ar activation
- It requires abatement of neutron and gamma backgrounds

Otherwise, find a optimum background for Reactor On/Off measurement

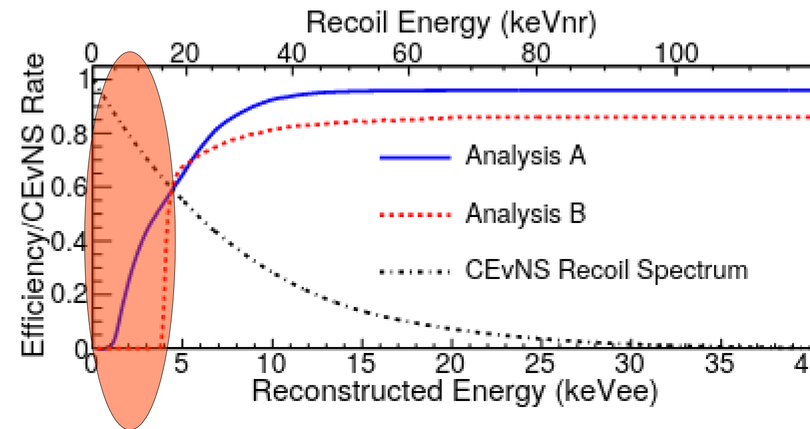


1.3 kL of water doped with 0.2% gadolinium chloride (GdCl3) by mass
Angra dos Reis Reactor, Brazil
arXiv:2407.20397v2

Other places where to measure Nuclear Recoils



Oak Ridge Spallation Neutron Source (USA)



CEvNS in Argon measured already for E_{nr} >15 [keV]

Kinematic region only accesible with Double Phase TPC.

CENNS-10 detector.
Single Phase, 24 kg AAr

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ON-OFF analysis with f_{90} ER/NR discrimination

5