New Experiments With Spheres-Gas

Quentin ARNAUD

Past, present and future activities of NEWS-G at the LSM and SNOLAB

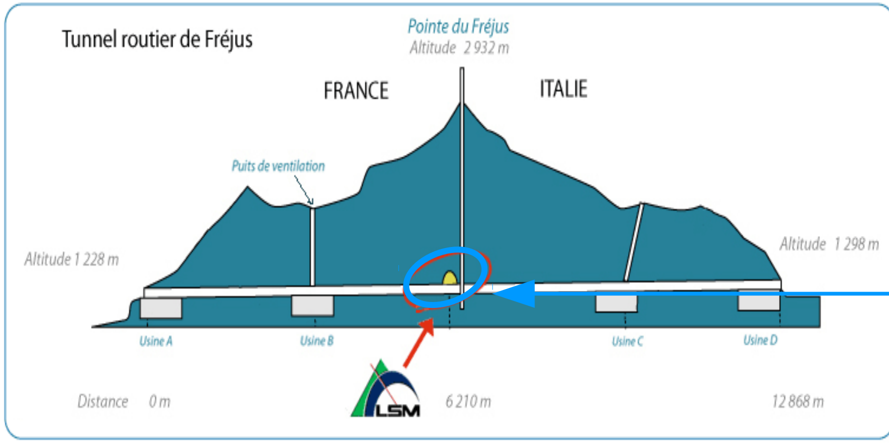
2018 CAP Congress – Dalhousie University (Halifax, NS)

Queen's University

Laboratoire Souterrain de Modane

NEWS-G @ LSM : Experimental set-up

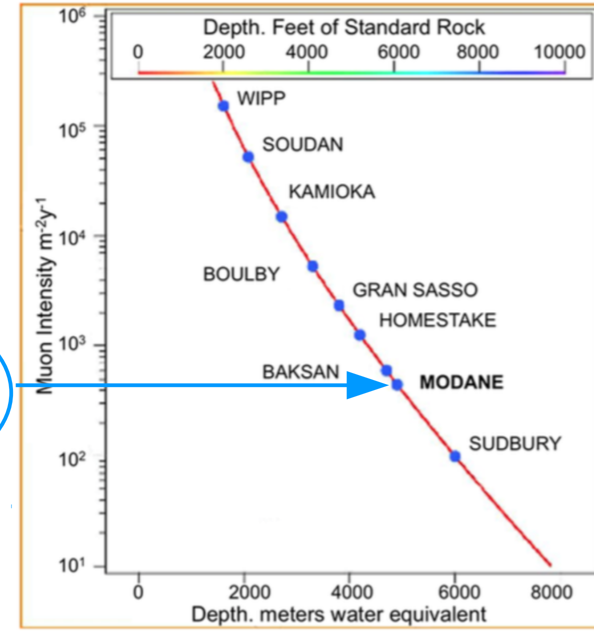
Laboratore Souterrain de Modane



surface
$10^6 \mu/m^2/day$

Muon flux

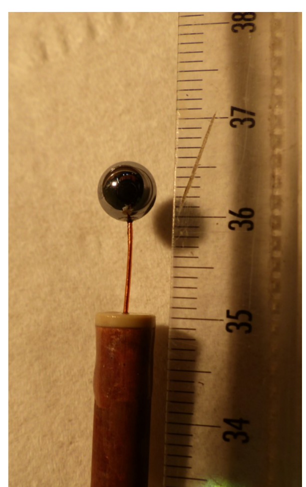
4800 mwe
$5\mu/m^2/day$



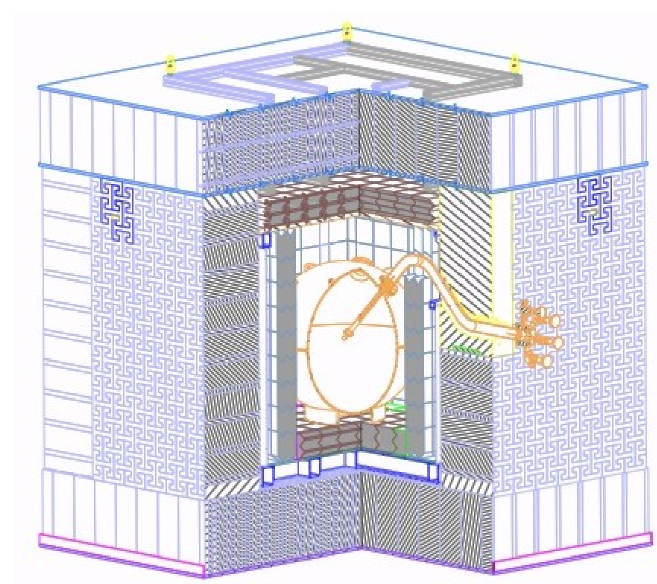
Data taking conditions

9.6 kg.days of exposure with Neon+0.7 % CH_4 @ 3.1 bars
~280 g target mass, operated for 42.7 days in sealed mode

Vessel
60 cm ∅ NOSV Copper

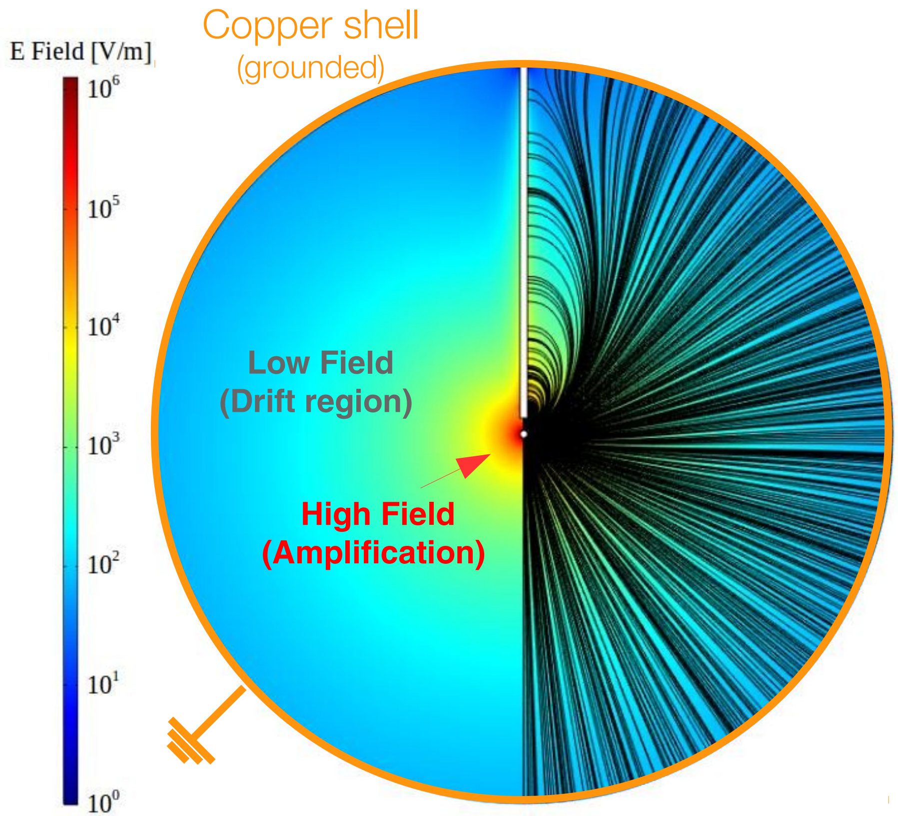


Sensor
6.3 mm ∅



Shieldings
30 cm PE, 10-15 cm Pb, [3-8] cm Cu

Light dark matter search with Spherical Proportional Counters (SPCs)



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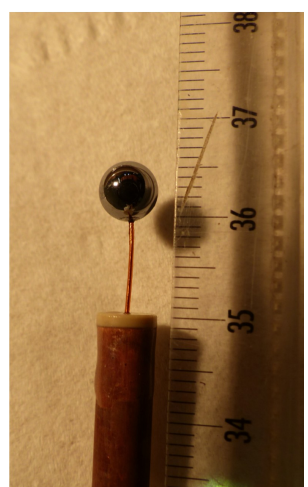


Sensor
6.3 mm ∅

Sensitivity to single electrons

Low energy thresholds of 10 - 40 eVee

High amplification gain arising from $E(r) \propto \frac{1}{r^2}$

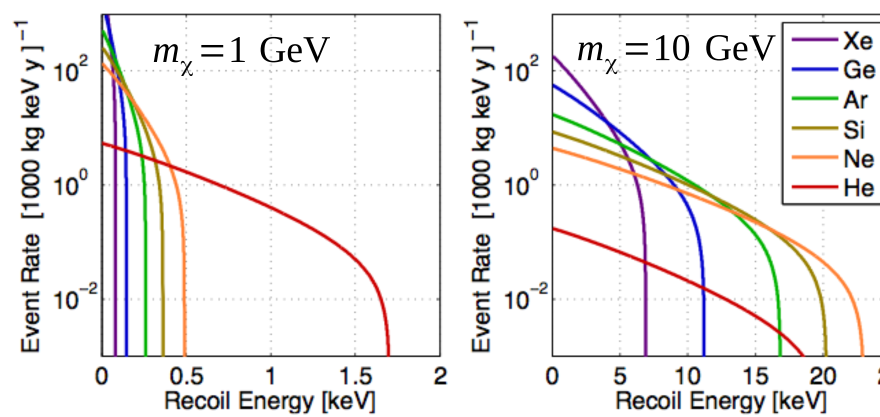
Low intrinsic capacitance (independent on the size of the sphere)

Easily scalable

$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.35\,\mathrm{pF}$$

Light Targets (H,He,Ne)

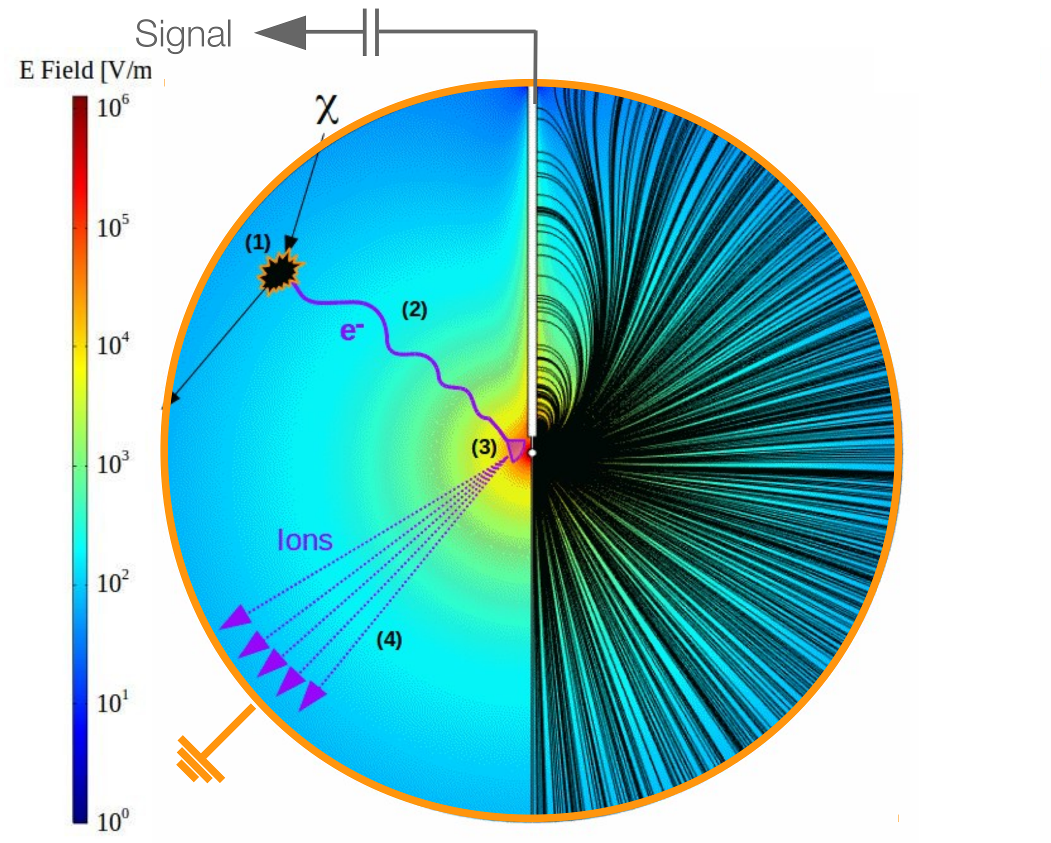
Optimization of momentum transfers for low-mass particles



Pulse shape discrimination

The rise time of pulses allows for a statistical discrimination against sub-keV surface events

SPC functioning principle in a nutshell



(1) Primary Ionization

Mean energy to create one paire in Ne :

$$\epsilon_\gamma = 36 \text{ eV} \qquad \epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$$

(2) Drift of the primary electrons towards the sensor

Typical drift time surface → sensor : ~ 500 μs

(3) Avalanche process

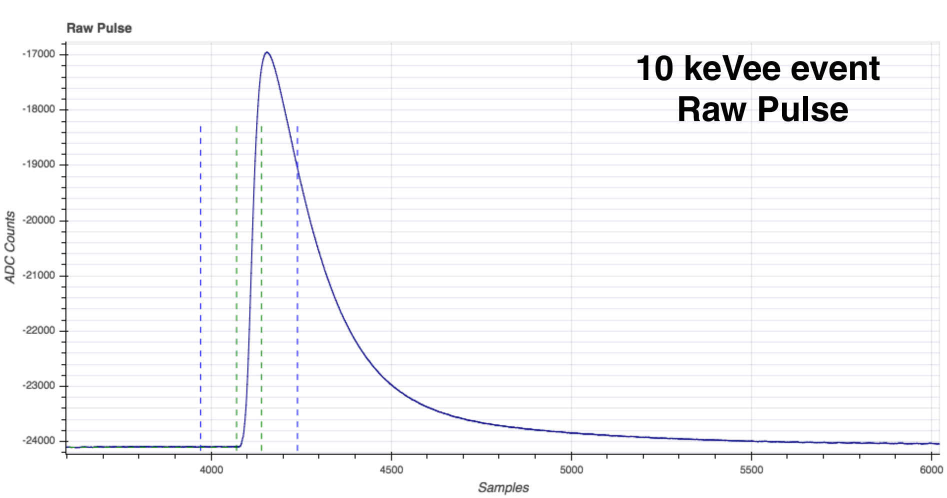
Thousands of secondary electron-Ion pairs / primary electron reaching the sensor

(4) Signal formation

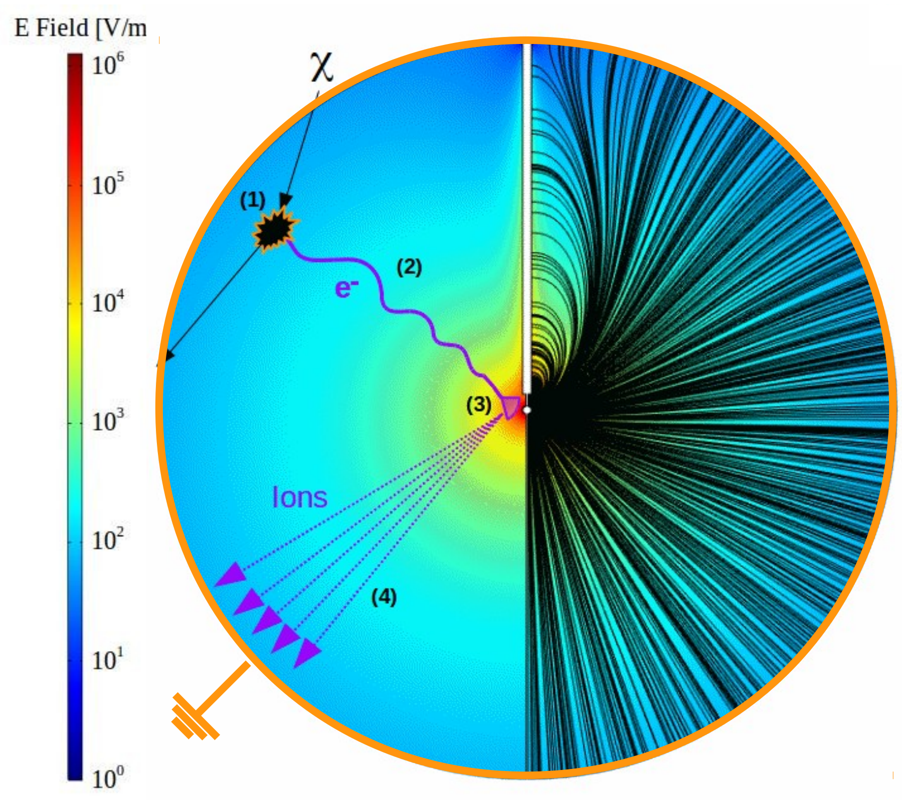
Current induced by the ions as they drift back towards the copper shell at ground

(5) Read out

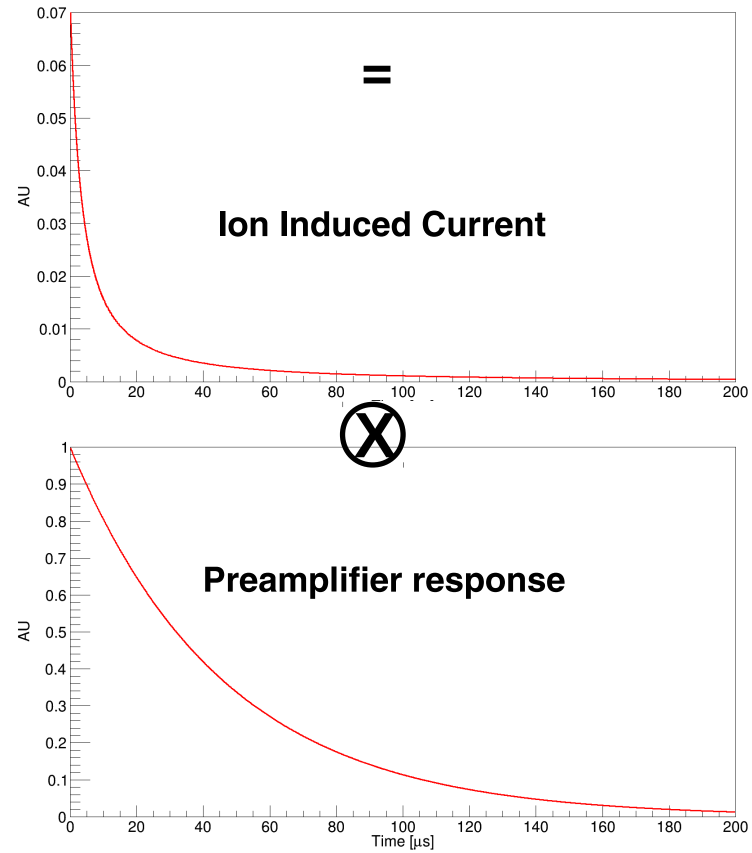
Induced current integrated by a resistive feedback charge sensitive pre-amplifier CAMBERRA (RC=50 μs) and digitized at 2.08 MHz

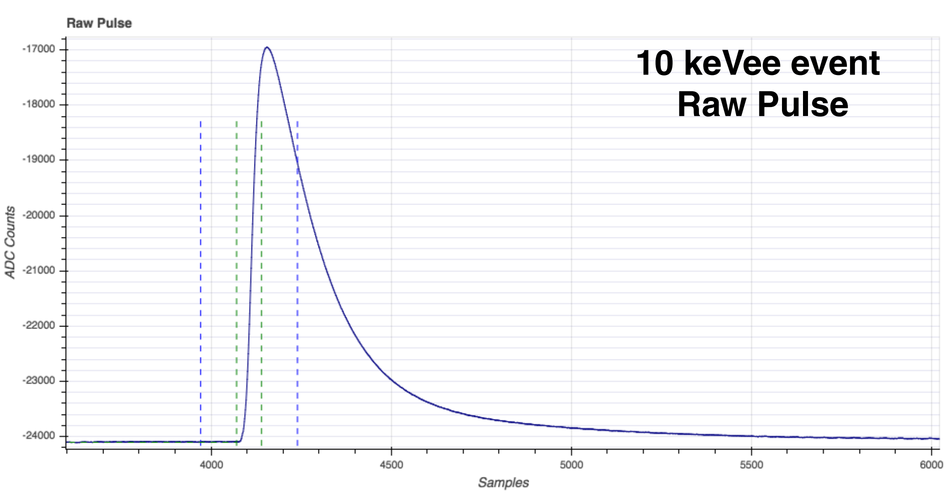


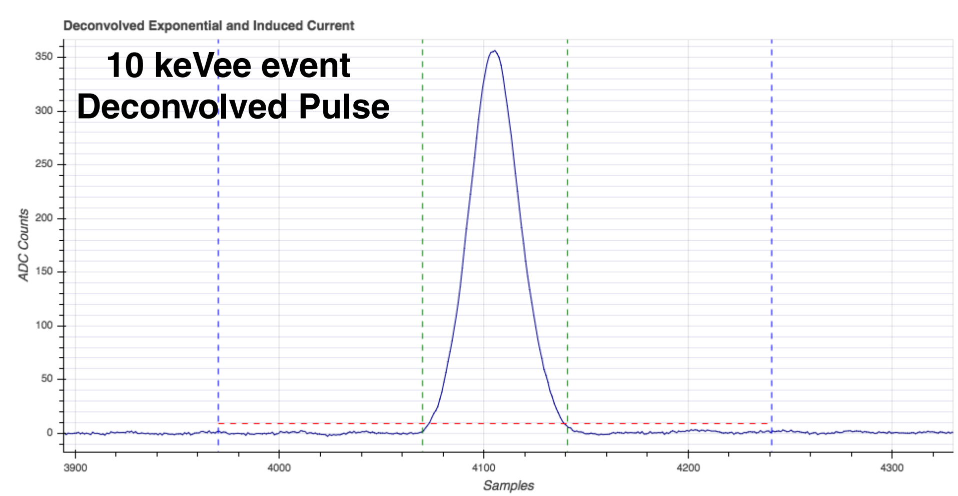
SPC functioning principle and pulse treatment



Detector Response







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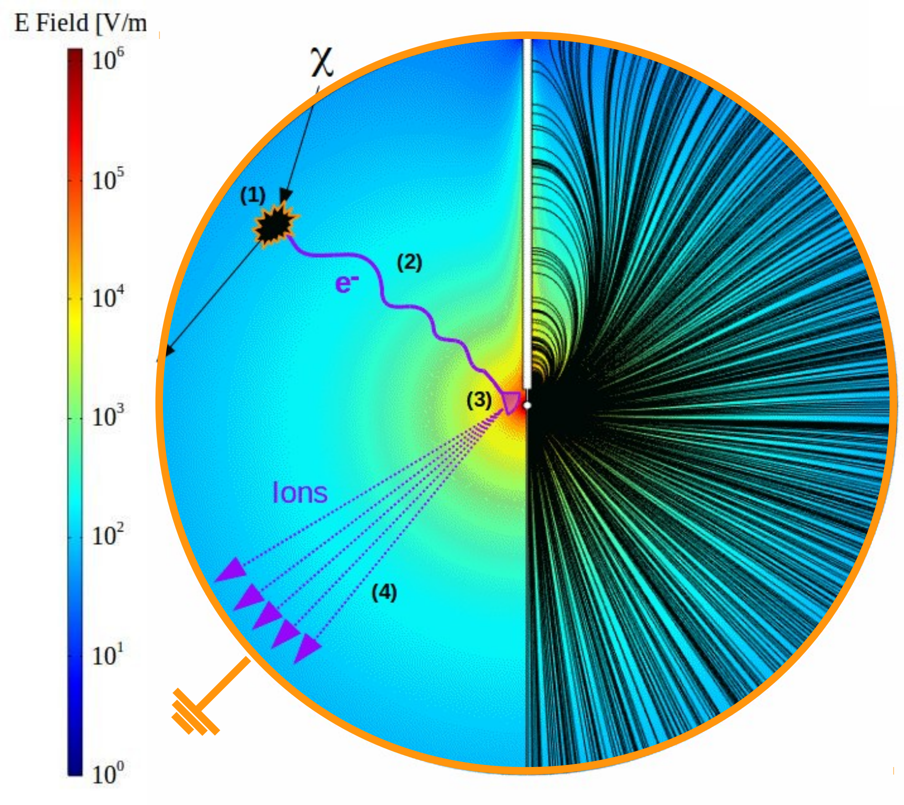
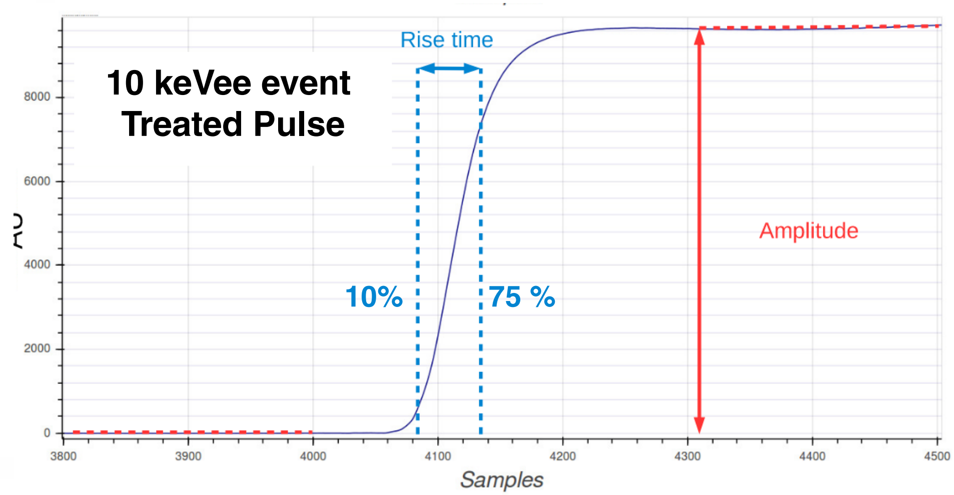


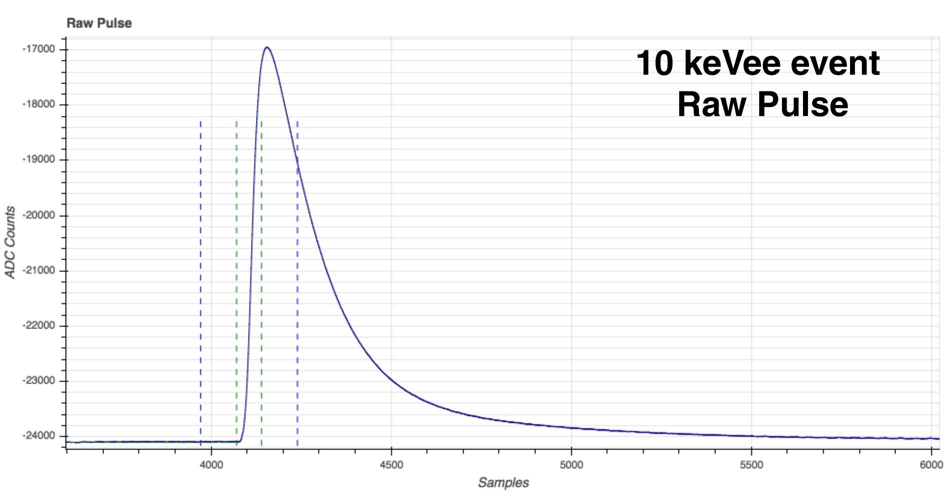
Surface event discrimination

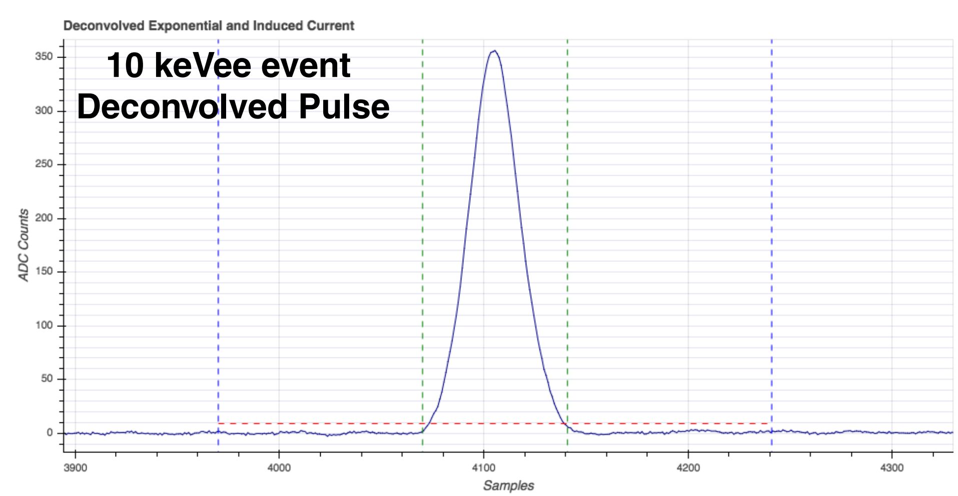
Typical drift time surface → sensor **(500 ± 20) μs**

Gaussian dispersion in the arrival time of the PEs due to diffusion

$$\sigma(\boldsymbol{r}) = \left(\frac{\boldsymbol{r}}{r_{sphere}}\right)^3 \times\ 20\mu s$$



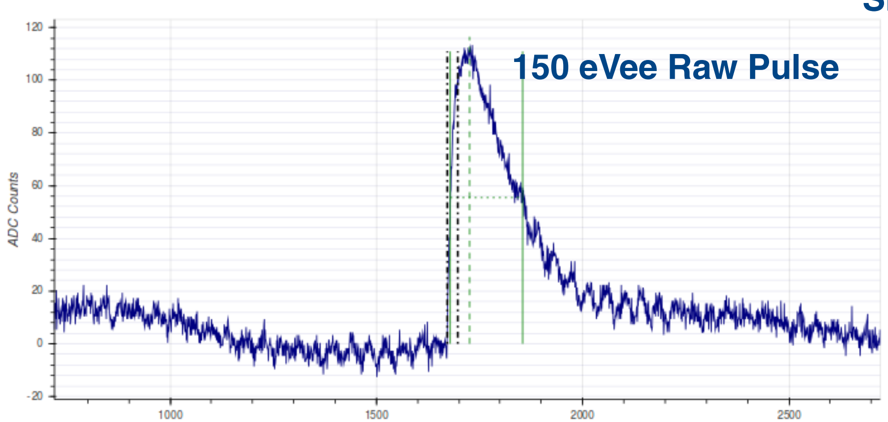


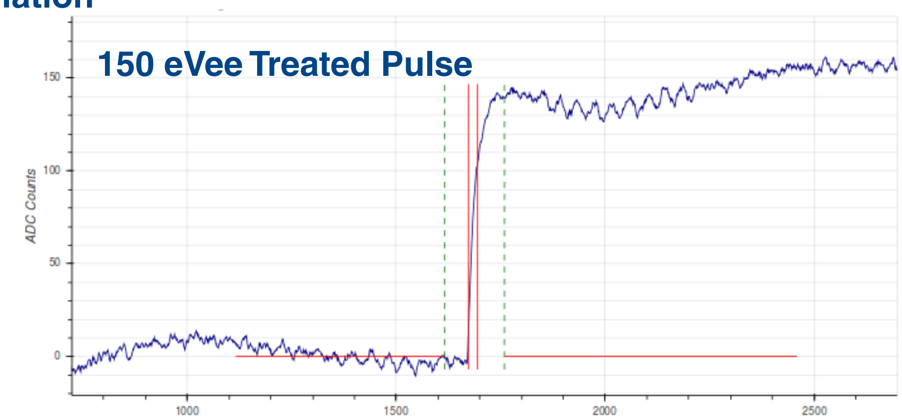


Simulations

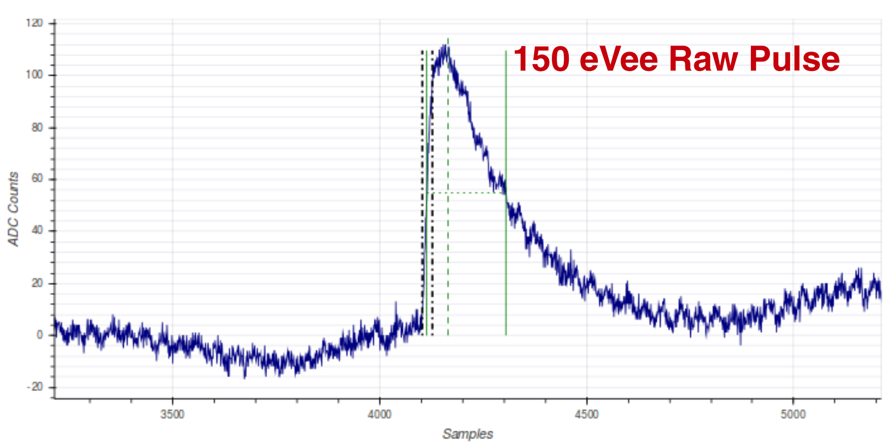
- **Drift of individual electrons** : Field map from COMSOL, drift parameters from Magboltz
- **Quenching** $Q(E_R)=0.216\,E_R^{\,0.163}$ parametrization derived from SRIM (Stopping and Range of Ions in Matter)
- **Avalanche** : Number of secondary ionizations drawn from the Polya distribution (parametrized with Garfield)
- **Simulated pulses** : (Ion Induced current X preamplifier response)
- **Noise templates** taken from the pretraces of real pulses
- **Same trigger algorithm and processing than for real pulses**

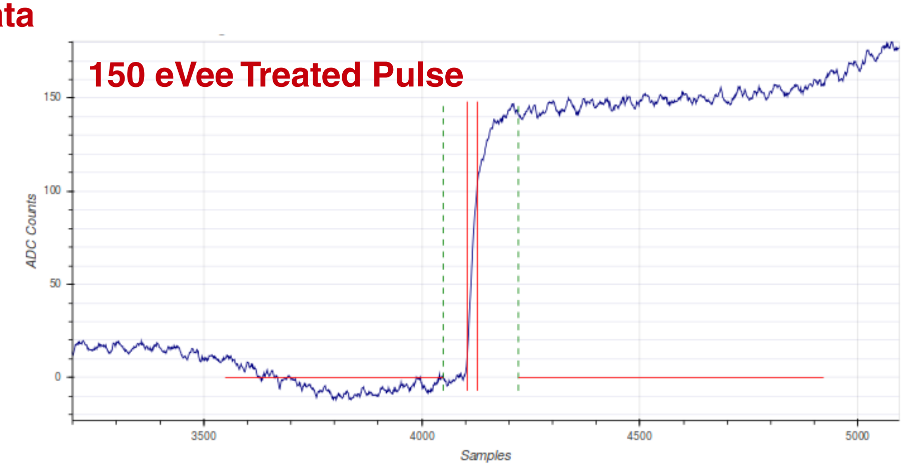
Simulation





Data

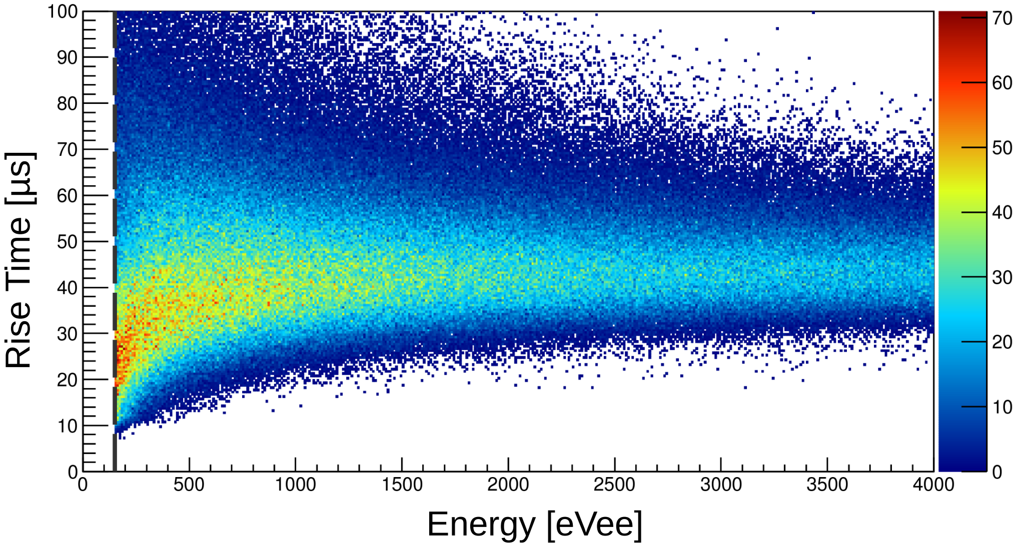




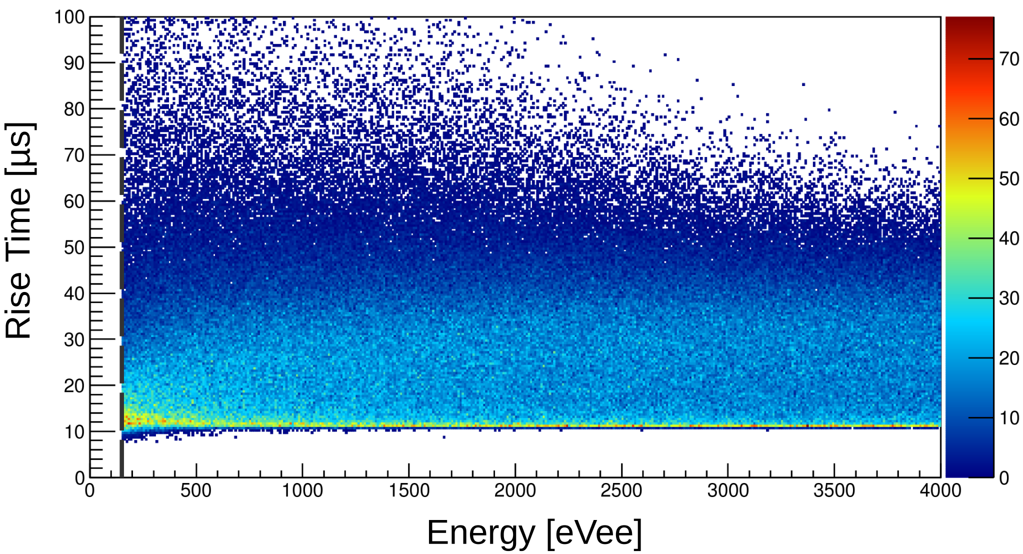
Physics-run data analysis

Simulations

Surface events



Volume events



Physics-run Data

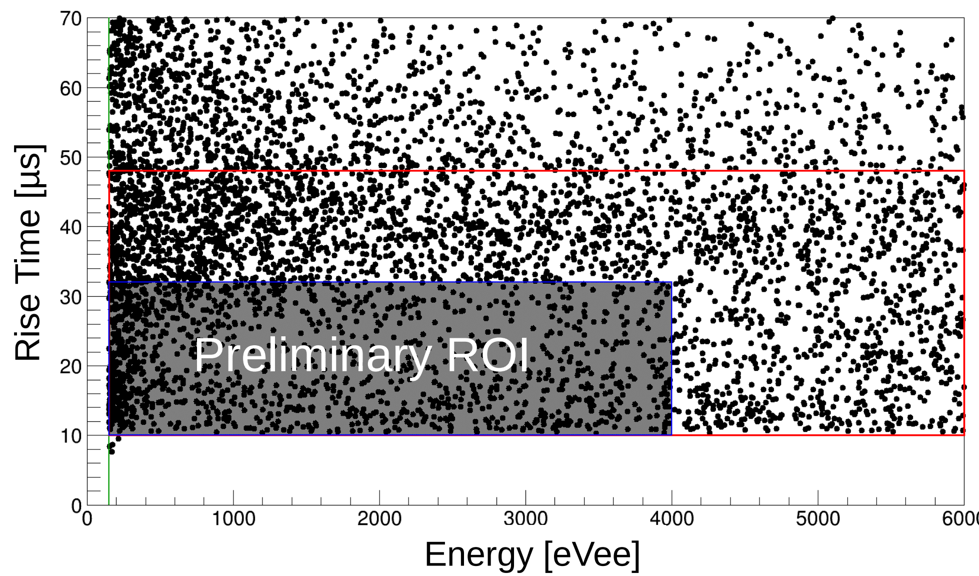
Quality cuts : 20.1 % dead time

Total exposure : 34.1 live-days x 0.28 kg = **9.6 kg.days**

Analysis threshold : 150 eVee (~720 eVnr)

Trigger threshold : 35 eVee (~100% efficiency @ 150 eVee)

WIMP search run

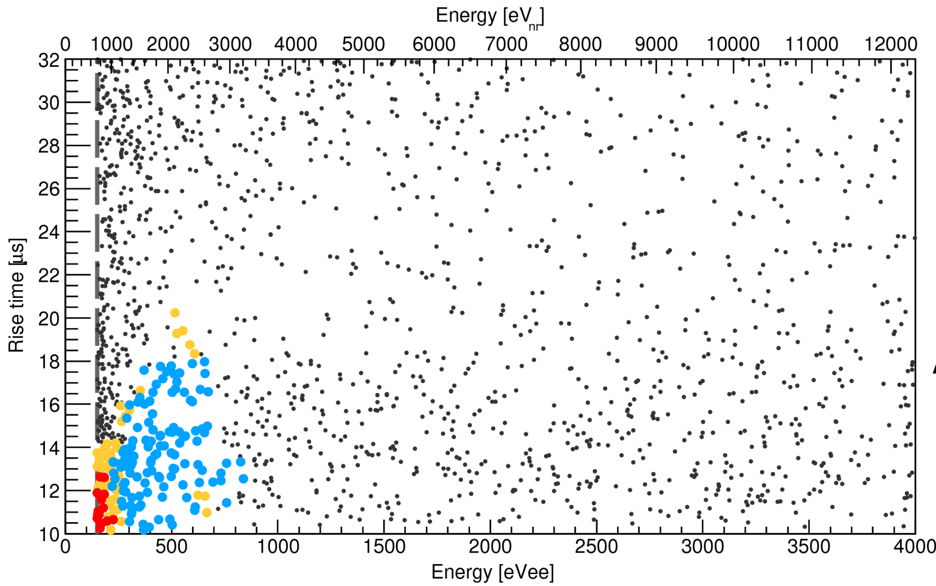


Side Band region and simulations used to determine the expected background in the **preliminary ROI**

Further tuning of the ROI performed with a Boosted Decision Tree (BDT)

Physics-run data analysis

WIMP mass dependent ROI for 8 WIMP masses



1620 events recorded in the preliminary ROI :

Fail any of the BDT cuts
pass the BDT cut for 0.5 GeV/c2 : 15 events
pass the BDT cut fot 16 GeV/c2 : 123 events
pass the BDT cut for other masses

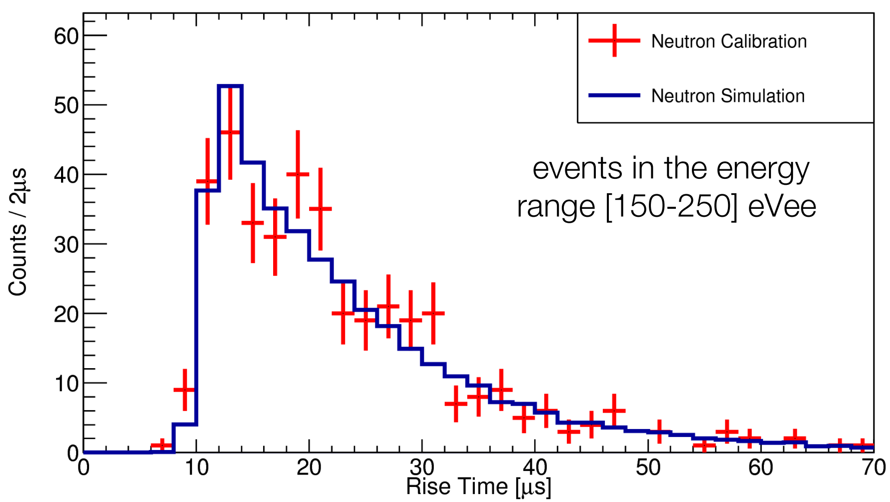
Analysis methodology robust against background mis-modeling

If the BDT were to be trained with inaccurate bkg models,
the ROI would simply not be optimized for signal/bkg discrimination

Validation of the modeling of the detector response in energy and rise time

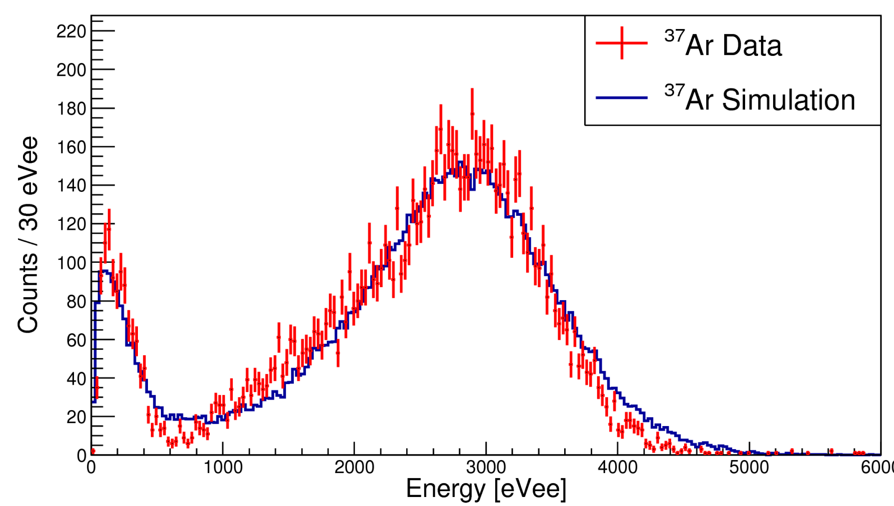
Am-Be neutron source

Nuclear recoils
homogeneously distributed in the volume



^{37}Ar gas added to the mixture

2.82 keV and 270 eV X-rays from
the electron capture in the K- and L-shells respectively



The overall agreement allows us to confidently derive our sensitivity from simulated WIMP events

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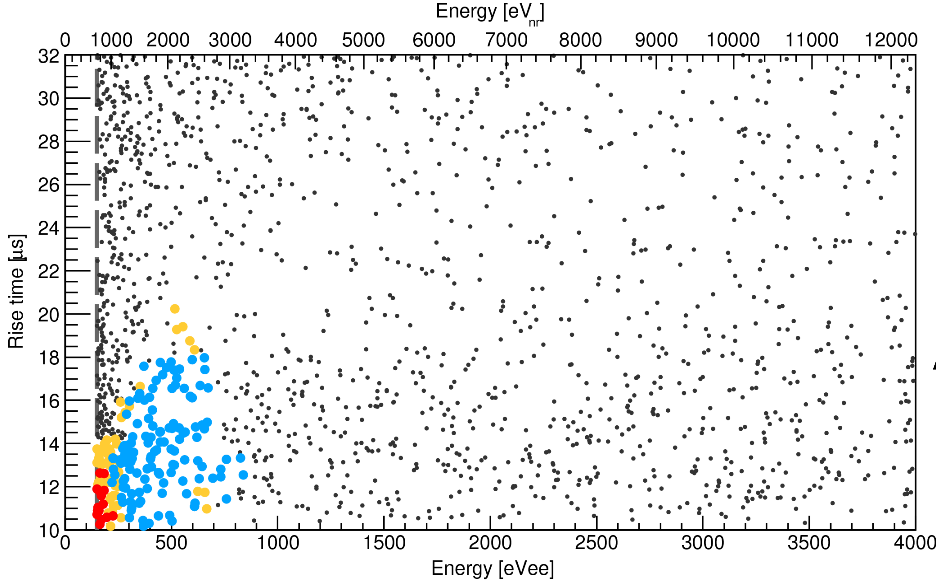

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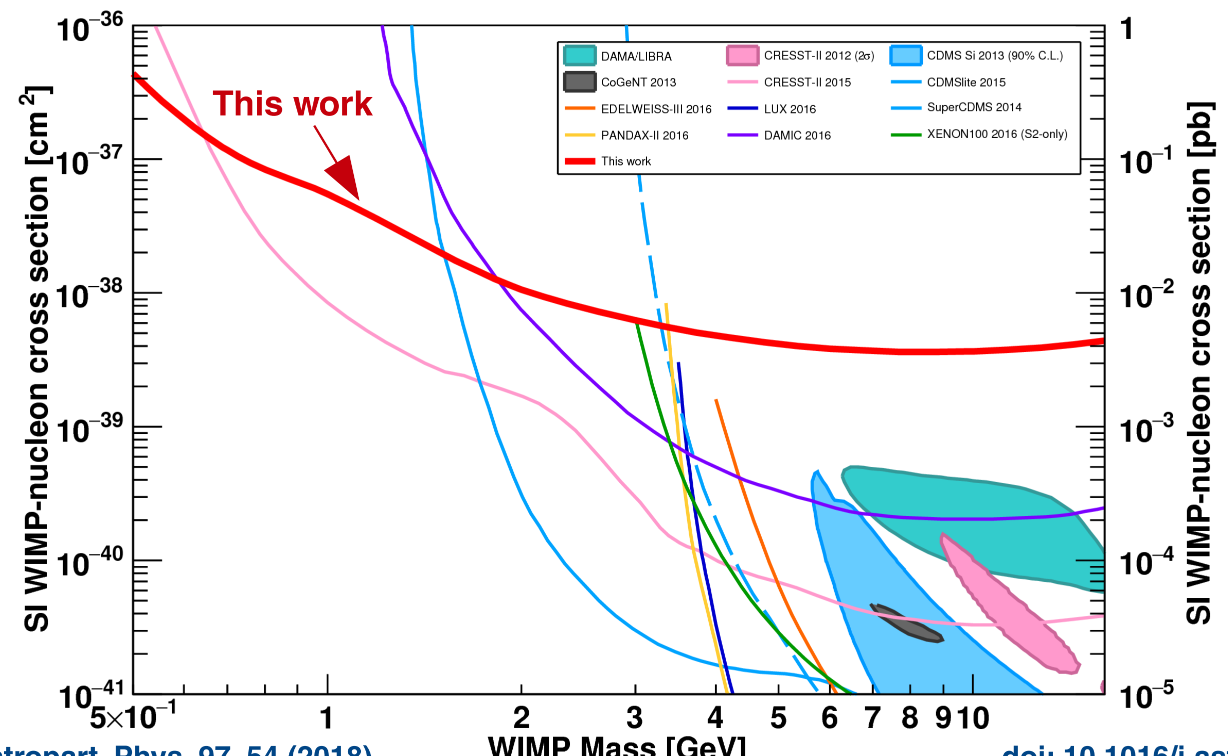

Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018)

doi: 10.1016/j.astropartphys.2017.10.009

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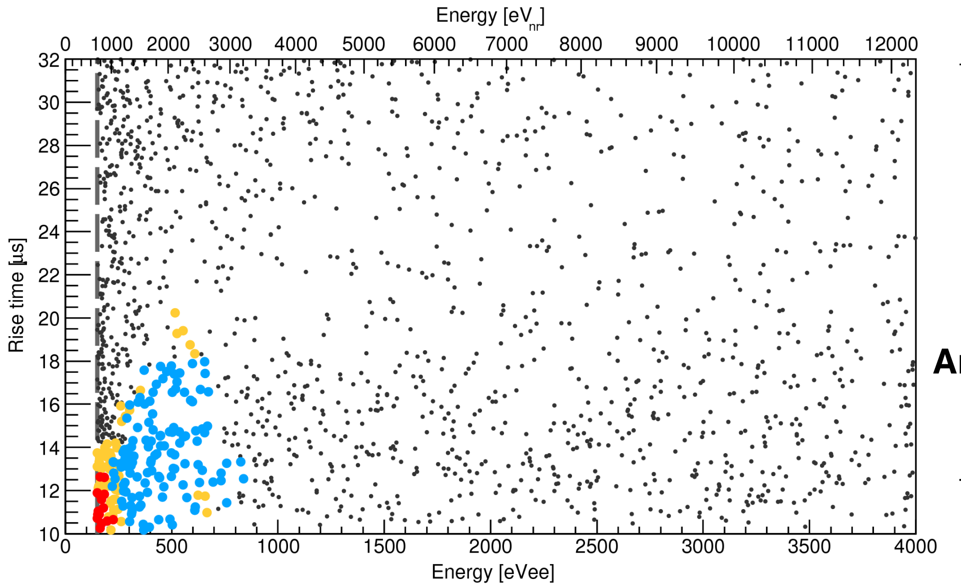

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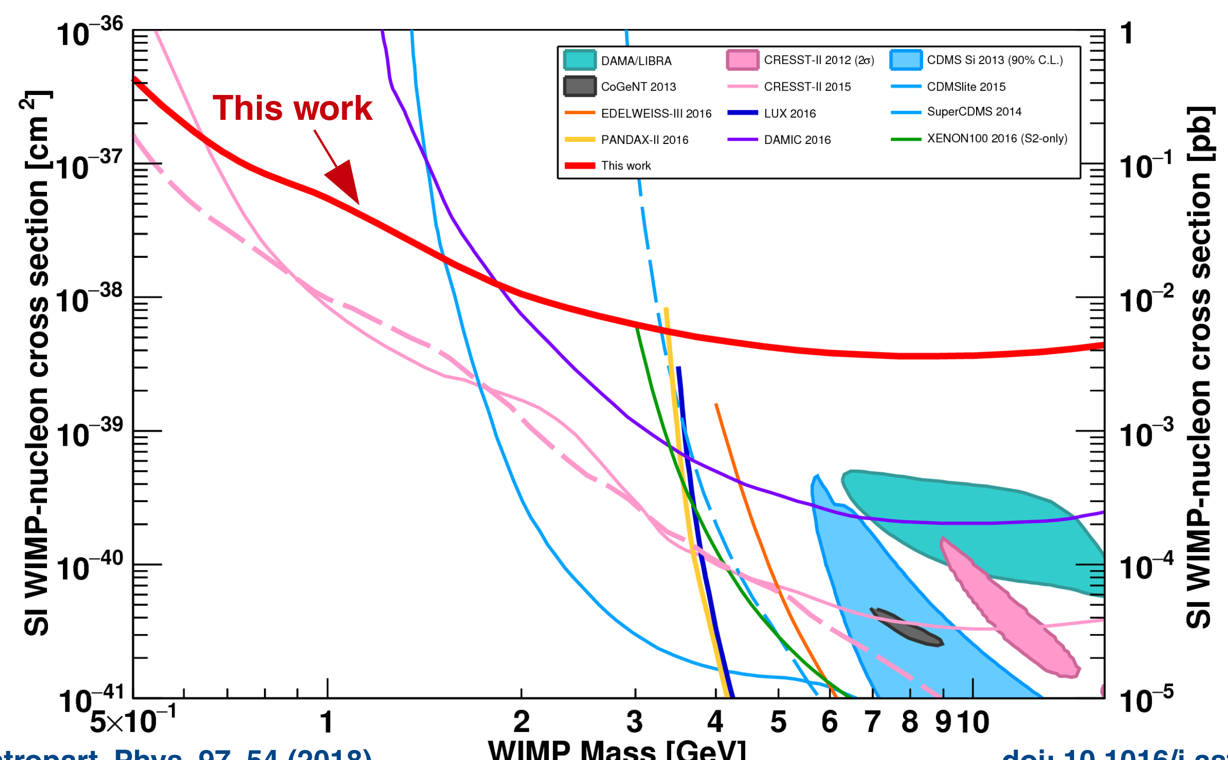

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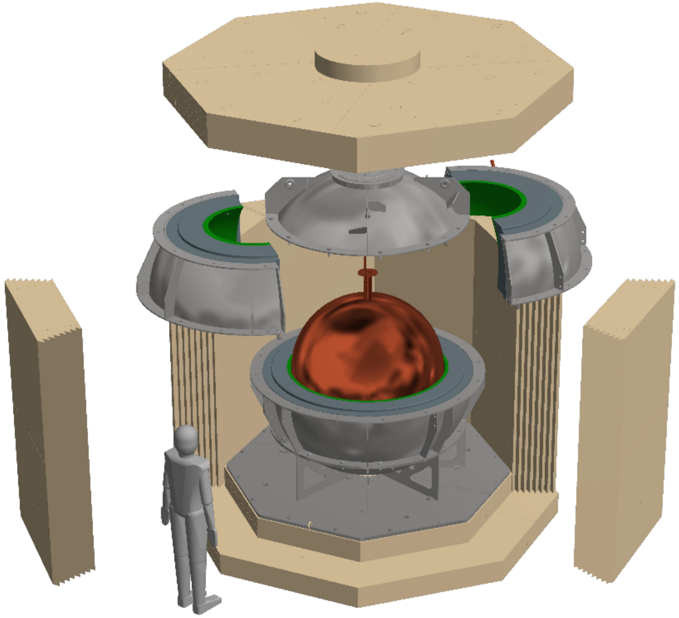
NEWS-G @ SNOLAB

SNOLAB : 6000 mwe (0.27 μ /m²/day)

Copper vessel (140 cm ∅, 12 mm thick)
- Low activity copper (C10100)
  - 7 - 25 μBq/kg ^{232}Th } measurements from PNNL
  - 1 - 5 μBq/kg ^{238}U
- Electropolishing cleaning & electroplating



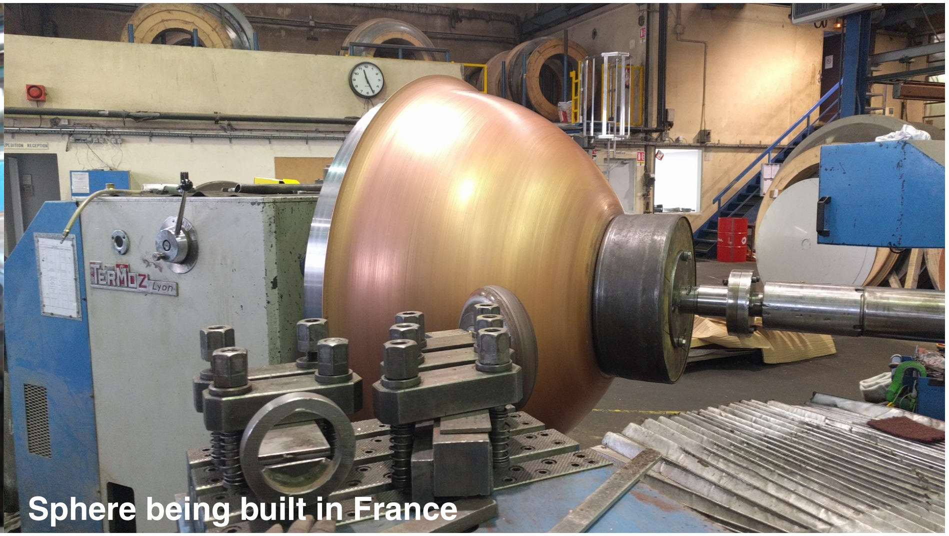
Compact shielding (35 t)
- 40 cm PE + Boron sheet
- 22 cm Low Activity lead
- 3 cm archeological lead
- Air tight SS envelope to flush pure N (against radon)

Installation in Cube Hall at SNOLAB in spring 2019

Sphere already built and currently stored at the LSM

Spinning + electron beam welding

Copper spinning test



Sphere being built in France

Glove box ready

Change of rod without introducing radon

NEWS-G @ SNOLAB

Improved sensitivity to low-mass WIMPs

- lighter targets (H,He), lower backgrounds, lower threshold

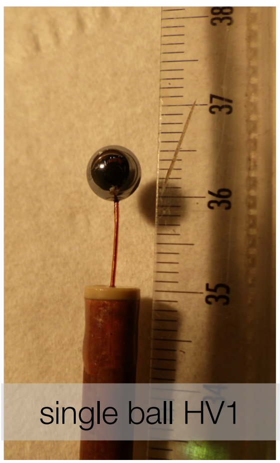
Improved Gas quality and monitoring

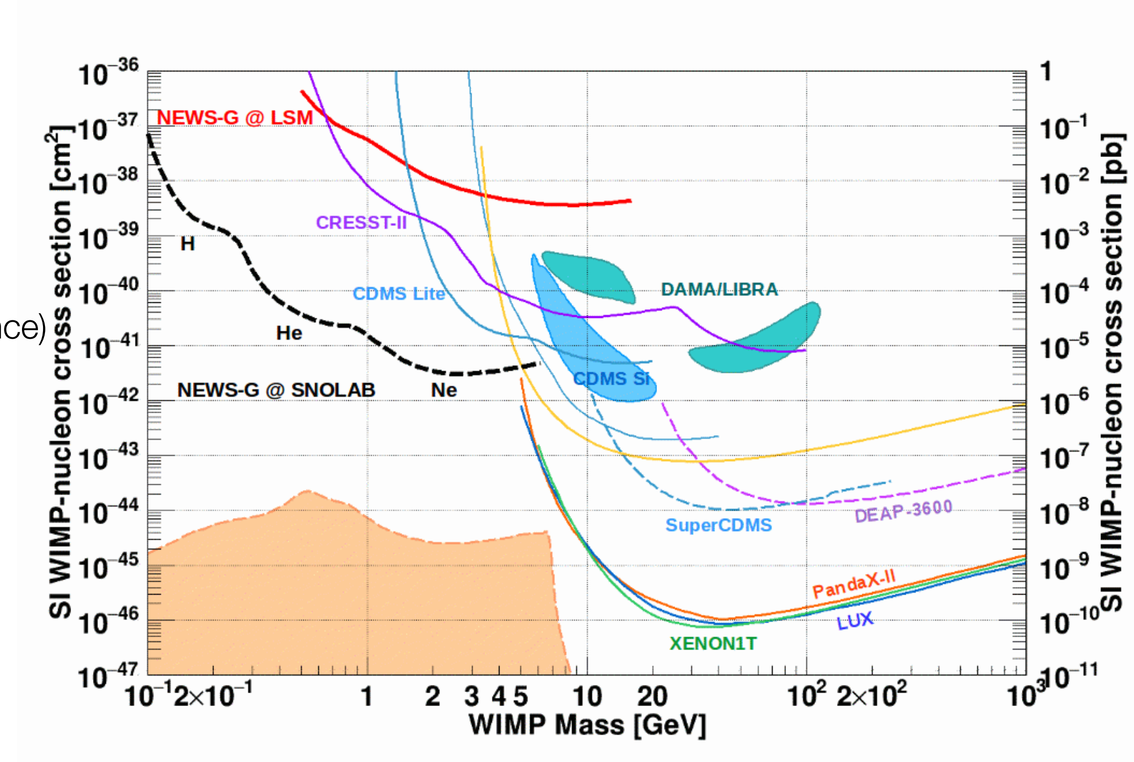
- Recirculation system, Getter, RGA

Quenching factor measurements

- Neutron beam (TUNL, US) & Ion / electron beam (LPSC, France)

Sensor development

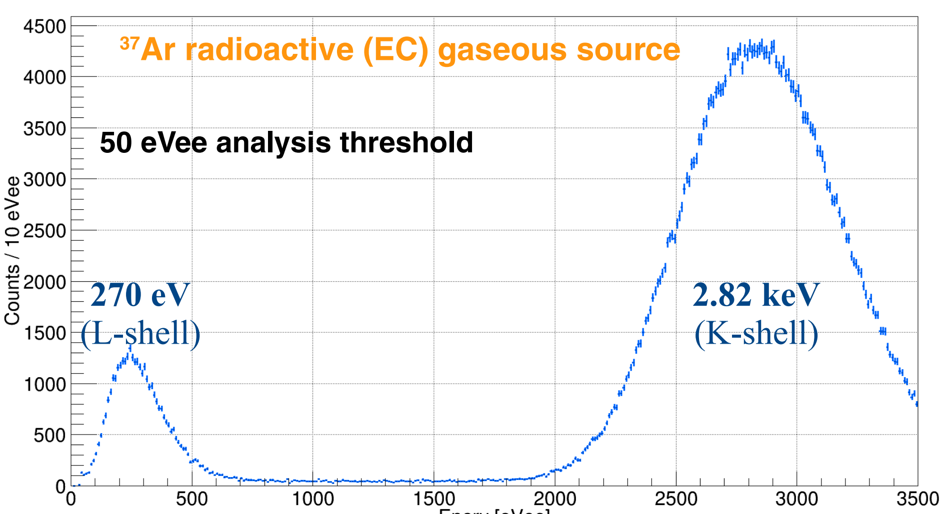


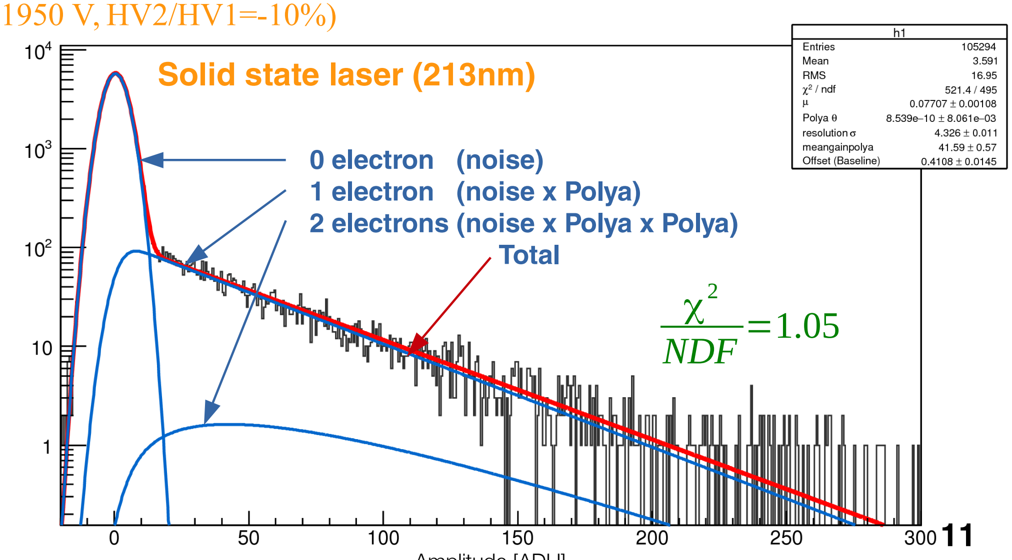


100 kg.days, 200eVee ROI above threshold @ 1 electron

Calibration measurements with a 30 cm SPC & new Bakelyte sensor

98% Ar + 2% CH_4 (500 mbar, HV1=1950 V, HV2/HV1=-10%)





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See Marie Vidal talk on Wednesday (09:15 – 09:30) (SUB 224, cap 50)

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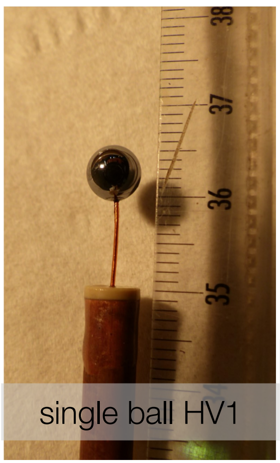

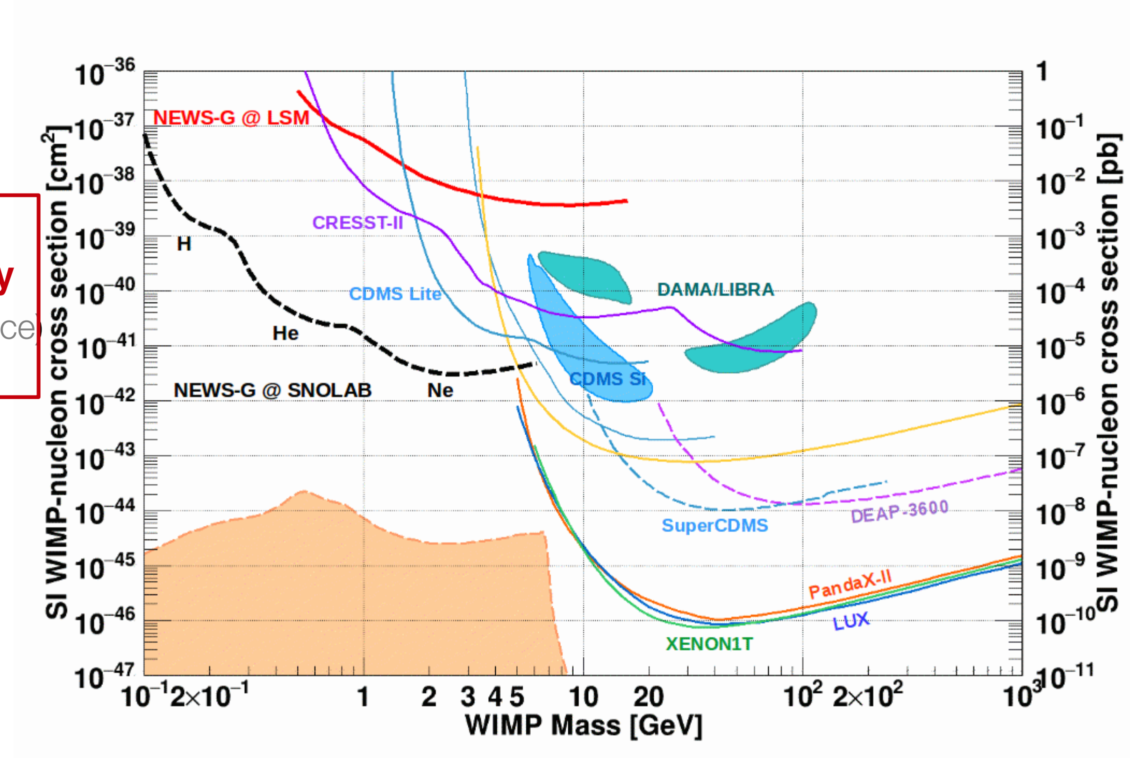

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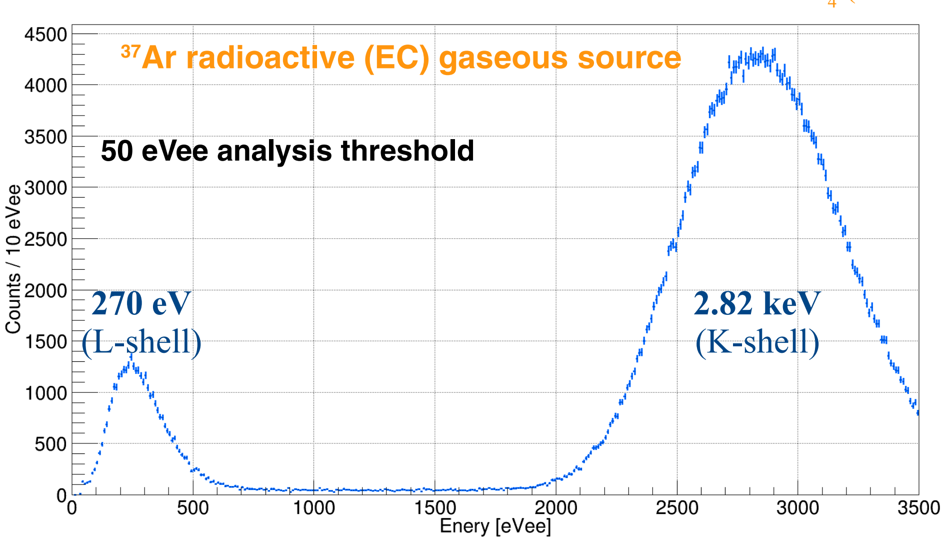

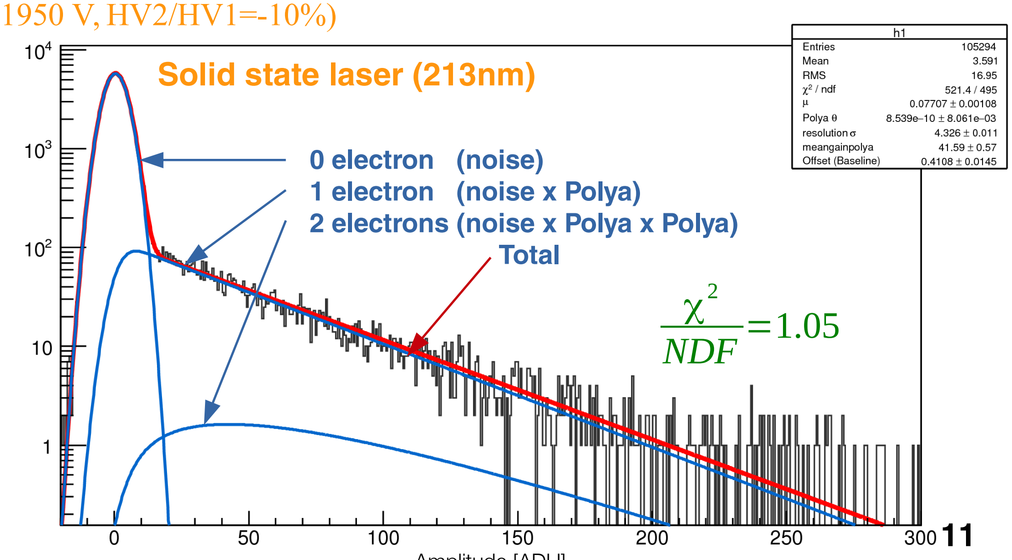

THANK YOU for your attention

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- Copper vessel and gas set-up specifications, calibration, project management
- Gas characterization, laser calibration, on smaller scale prototype
- Simulations/Data analysis

IRFU (**I**nstitut de **R**echerches sur les Lois **F**ondamentales de l'**U**nivers) **/ CEA Saclay -** I. Giomataris, M. Gros, C. Nones, I. Katsioulas, T. Papaevangelou, J.P. Bard, J.P. Mols, X-F Navick,

- Sensor/rod (low activity, optimization with 2 electrodes)
- Electronics (low noise preamps, digitization, stream mode)
- DAQ/soft

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- Low activity archeological lead
- Coordination for lead/PE shielding and copper sphere

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- Studies on sensor

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- Quenching factor measurements at low energy with ion beams

PNNL (**P**acific **N**ational **N**orthwest **L**ab) - E. Hoppe, R. Bunker

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RMCC (**R**oyal **M**ilitary **C**ollege **C**anada), **Kingston** - D. Kelly, E. Corcoran

- ^{37}Ar source production, sample analysis

SNOLAB, Sudbury - P. Gorel

- Calibration system/slow control

University of Birmingham - K. Nikolopoulos, P. Knight

- Simulation and R&D

Associated lab: TRIUMF - F. Retiere

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Other talks from NEWS-G collaboration members

"Research and Development for the NEWS-G Dark Matter experiment"
Philippe Gros **Today (right now) (here)**

"Quenching factor measurement for NEWS-G"
Marie Vidal **Wednesday (09;15 – 09:30) (SUB 224, cap 50)**

"A Novel Approach to Account for the Fano Factor"
Daniel Durnford **Tuesday (14:00 – 14:15) (Dunn 135, cap 82)**

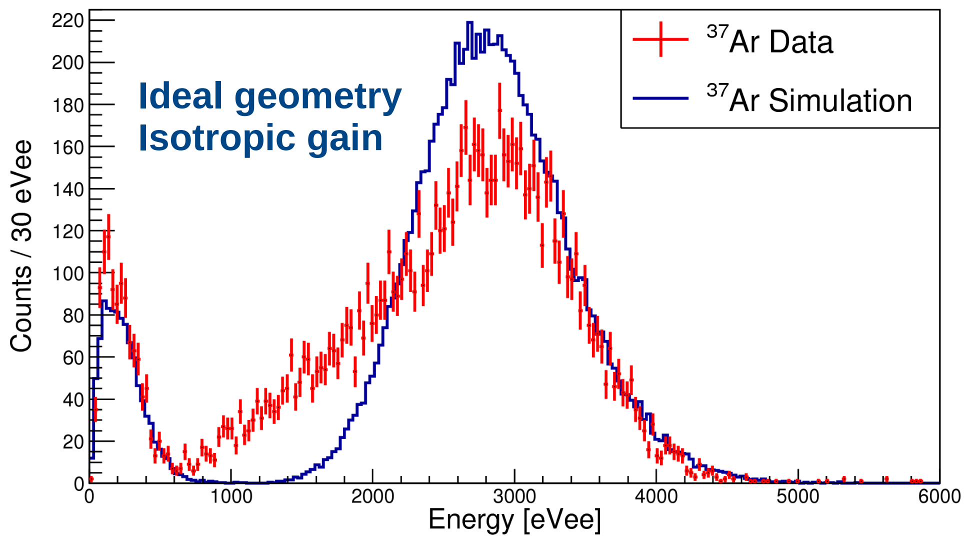
Back-up Slides

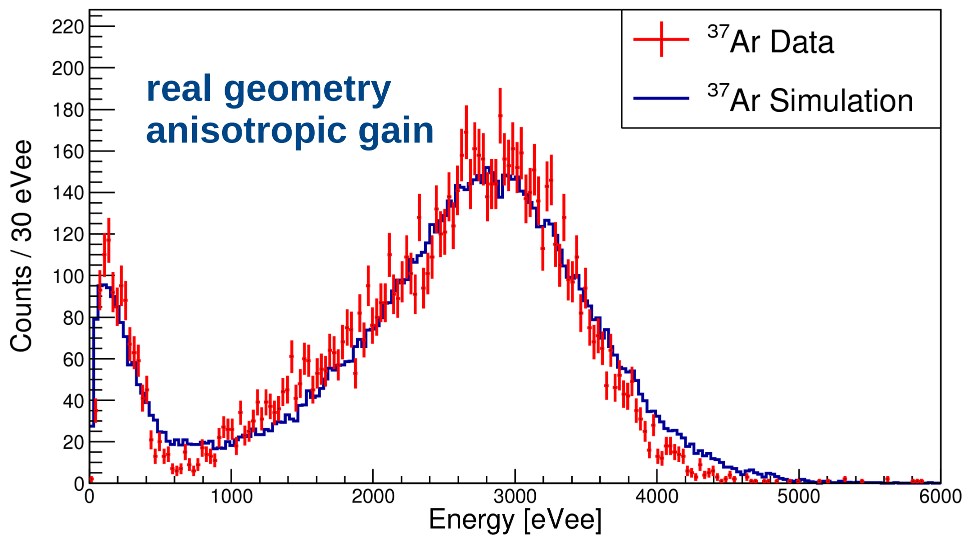
NEWS-G @ SNOLAB : Background budget

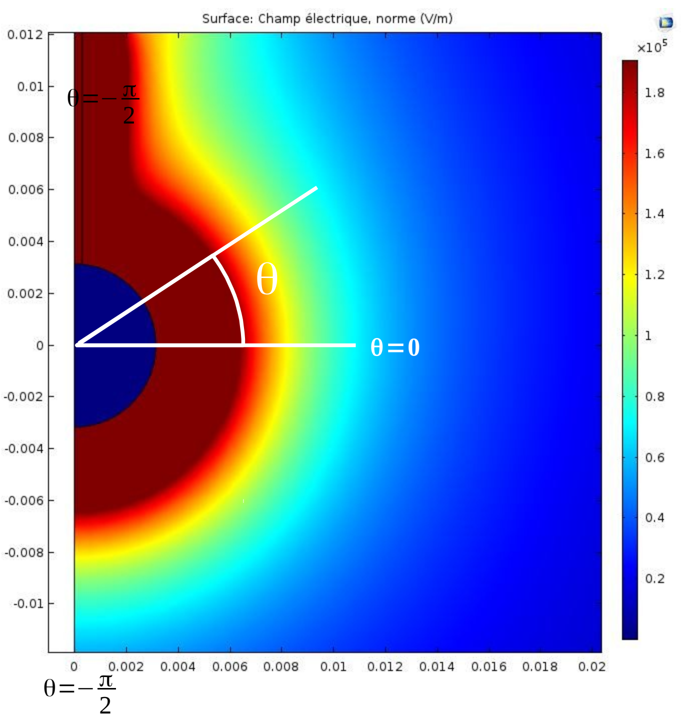
Source Position	Qty	Source	Contamination	Units	Evt/kg/day <1keV
Copper	627.83 kg	^{60}Co	30	µBq/kg	0.054
Copper	627.83 kg	^{238}U	3	µBq/kg	0.011
Copper	627.83 kg	^{232}Th	12.9	µBq/kg	0.063
Inner surface	57255 cm^2	^{210}Pb	0.16	nBq/cm^2	0.002
Arch Lead	2108.95 kg	^{238}U	61.8	µBq/kg	0.062
Arch Lead	2108.95 kg	^{232}Th	9.13	µBq/kg	0.010
Rod	0.0932 kg	^{60}Co	30	µBq/kg	0.000
Rod	0.0932 kg	^{238}U	3	µBq/kg	0.000
Rod	0.0932 kg	^{232}Th	12.9	µBq/kg	0.000
Wire	2.66×10^{-5} kg	^{60}Co	31000	µBq/kg	0.000
Wire	2.66×10^{-5} kg	^{238}U	3×10^5	µBq/kg	0.001
Wire	2.66×10^{-5} kg	^{232}U	5×10^4	µBq/kg	0.000
Wire	2.66×10^{-5} kg	^{40}K	166×10^4	µBq/kg	0.001
Lab		$^{208}Tl/^{40}K$			0.076

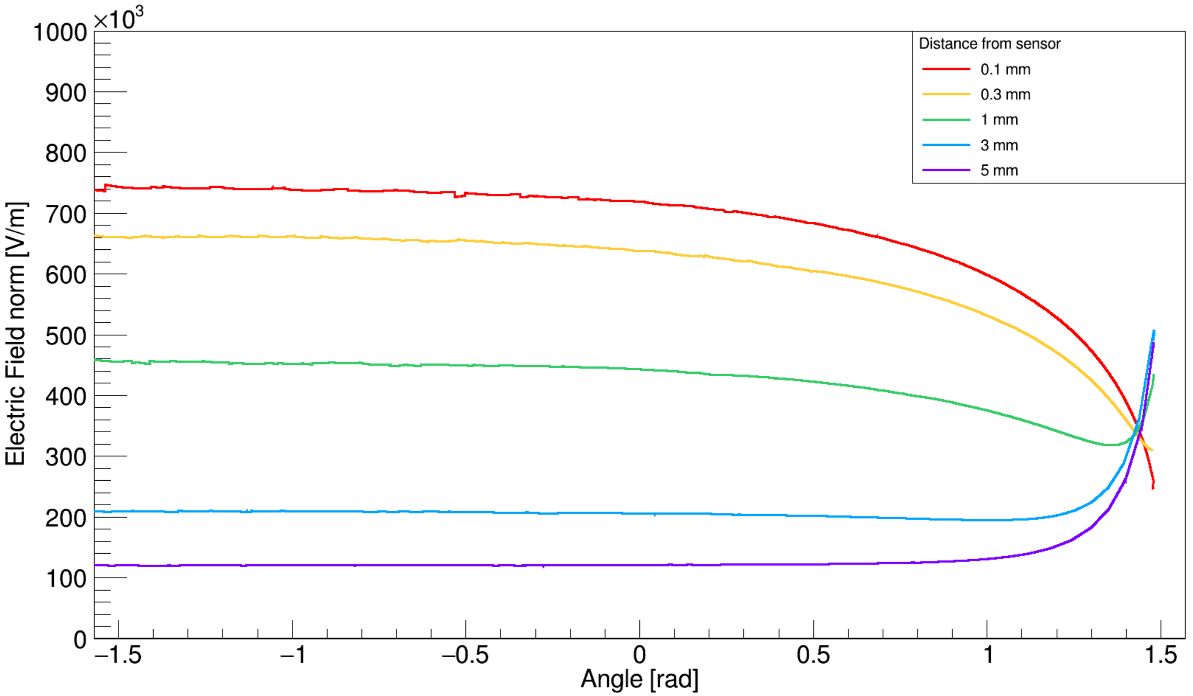
Total: 0.279 evts/kg/day < 1keV

Anisotropies of the avalanche gain





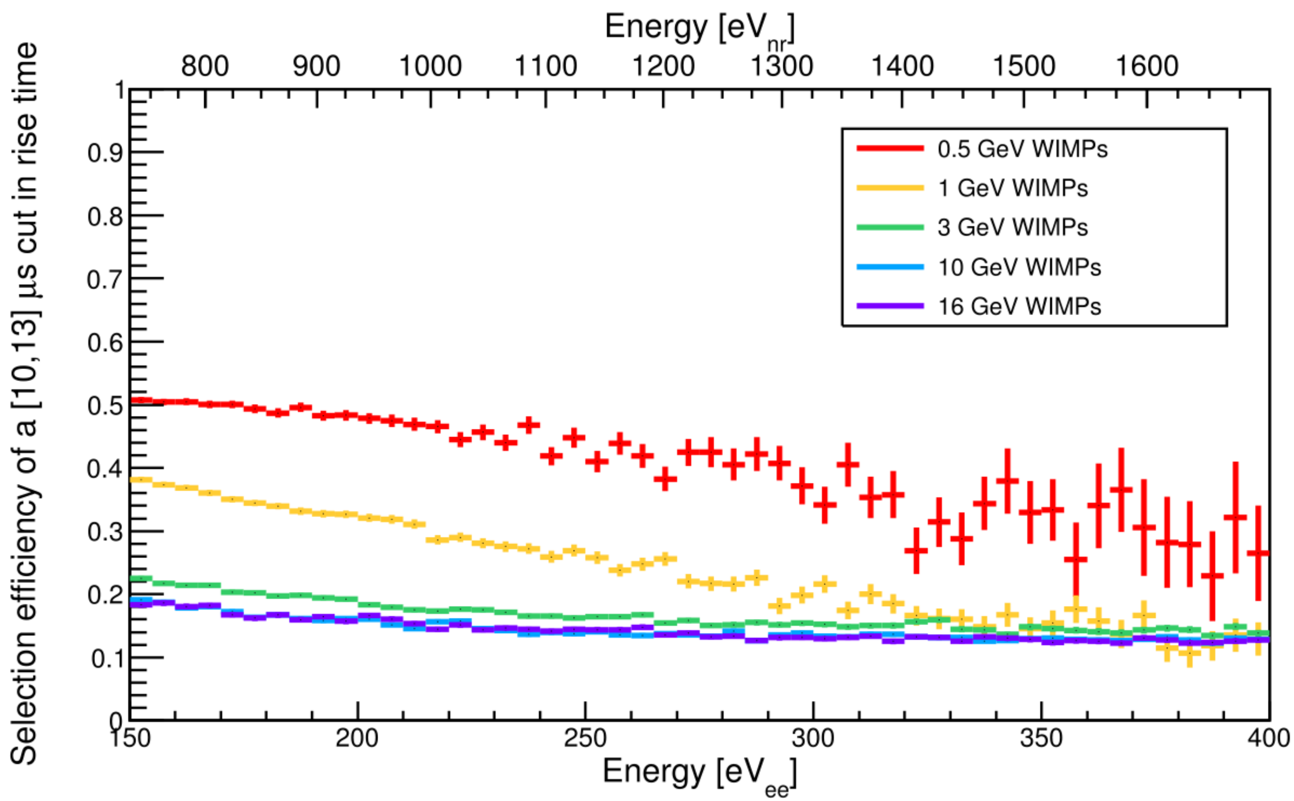




Signal efficiency of cuts in rise time & Recoil energy spectrum

(Proportion of simulated WIMPs that pass a cut in rise time [10,13] us) vs. (energy)

(cut that optimizes our sensitivity to sub-GeV WIPS)



The selection efficiency of a cut in rise time at a given energy depends on the WIMP mass

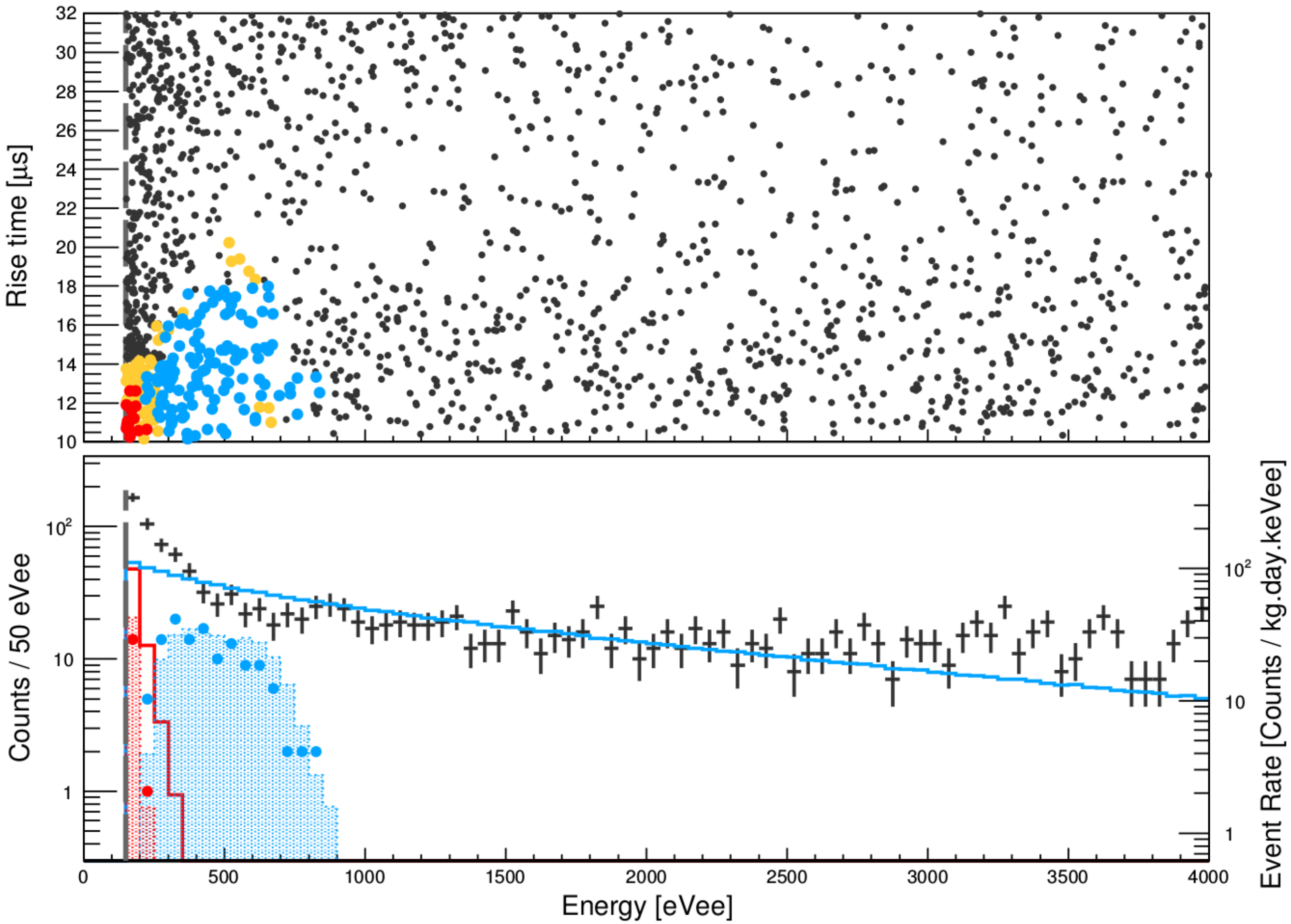
<u>Illustrative explanation : let's consider an event reconstructed @ 150 eVee</u>

For 16 GeV WIMPs the event is most likely to be a 4 PE + mean gain <G> from the avalanche

For 0.5 GeV WIMPs the event is most likely to be a 1 PE event + large overfluctuation of the gain

Single PEs : artificially reconstructed around 10 us VS multiple PEs : rise time depends on the location of the event

Preliminary ROI and WIMP candidates



Scatter plot in rise time vs energy

1620 Events recorded in the preliminary ROI :

- **Fail any of the BDT cuts**
- **pass the BDT cut for 0.5 GeV/c2**
- **pass the BDT cut fot 16 GeV/c2**
- **pass the BDT cut for other masses**

Energy spectrum

- **All the events**
- **pass the BDT cut for 16 GeV/c2**
- **pass the BDT cut for 0.5 GeV/c2**

Energy specta from simulated WIMPs of 16 GeV mass with σ_{excl} = 4.4x10^{-39} cm^2

Before BDT cut

After BDT cut

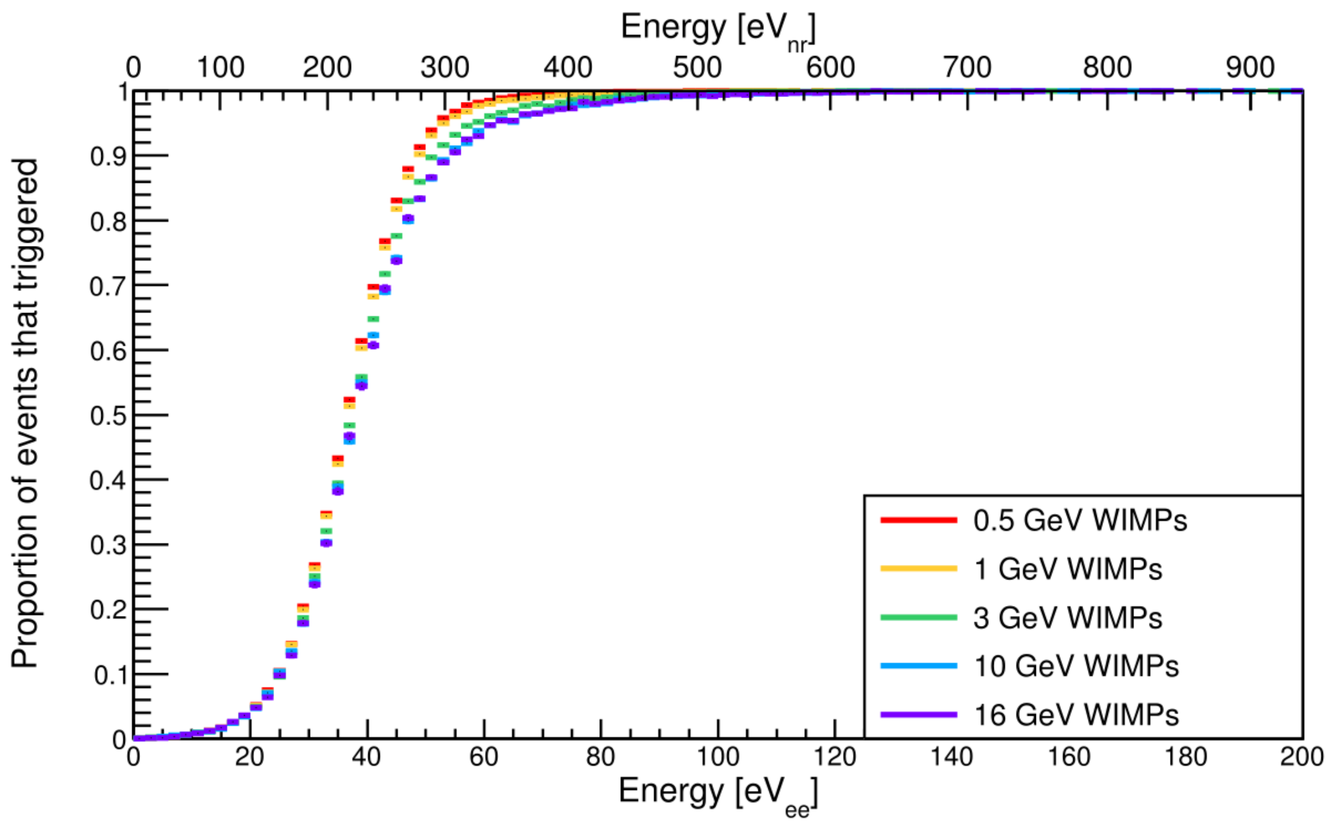
Energy specta from simulated WIMPs of 0.5 GeV mass with σ_{excl} = 4.4x10^{-37} cm^2

Before BDT cut

After BDT cut

Trigger threshold efficiency curve

Analysis threshold set @ 150 eVee far above the trigger threshold of ~35 eVee (100% trigger efficiency @ 150 eVee)



Proportion of events that trigger when pulses are added on top of a baseline vs the energy of the pulse alone

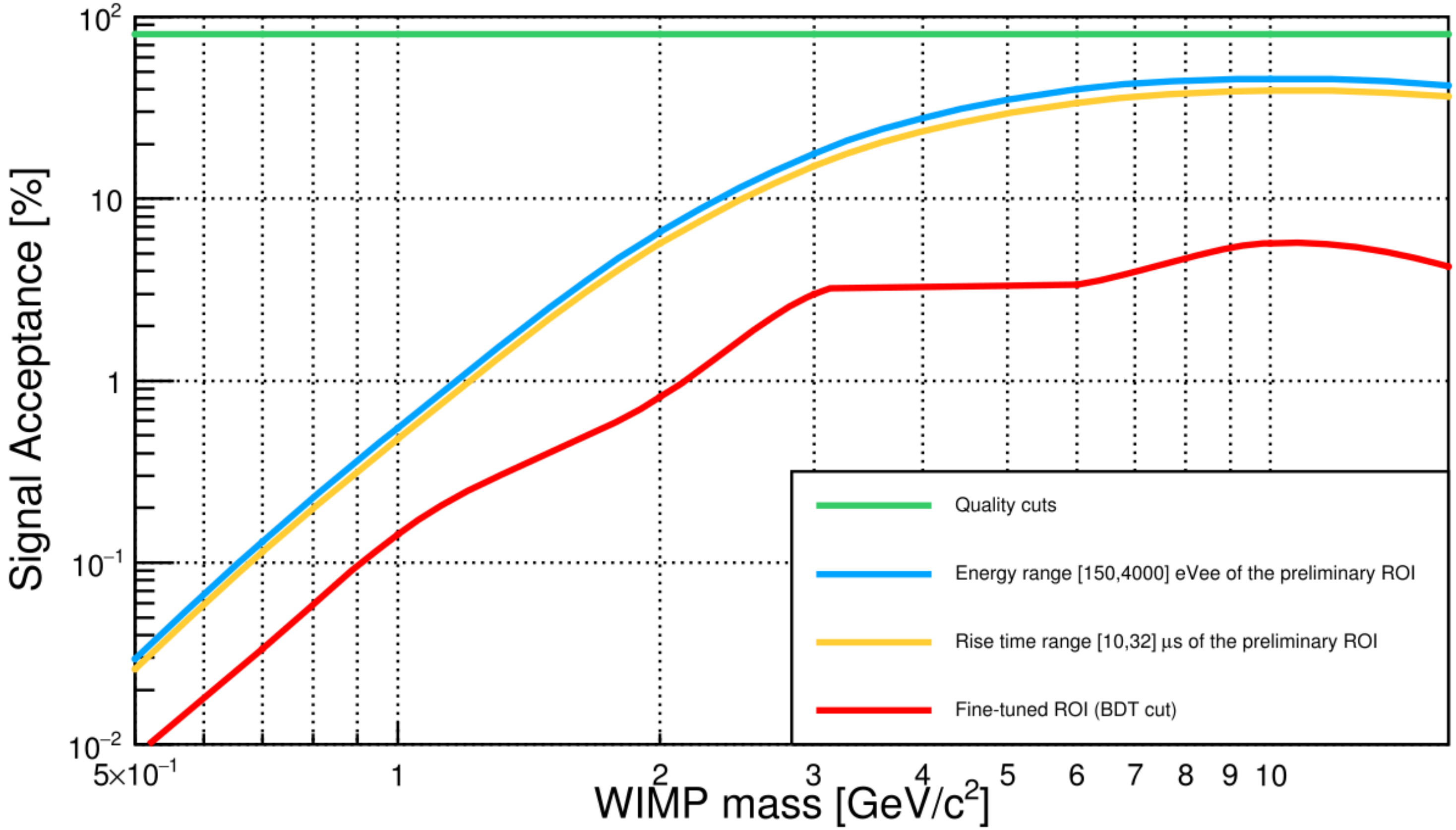
Trigger efficiency derived from simulated WIMP events of various masses to point out its dependence with the WIMP mass.

The trigger algorithm performs slighlty better for single PE events

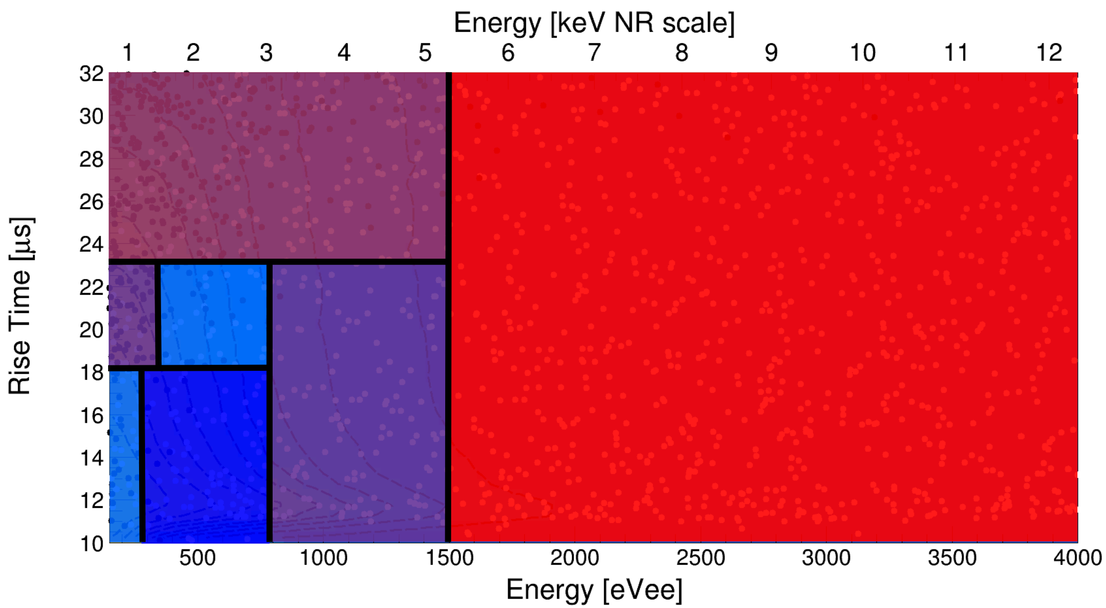
For 0.5 GeV WIMPs : mostly single PE events VS For higher WIMP masses : single & multiple PE events

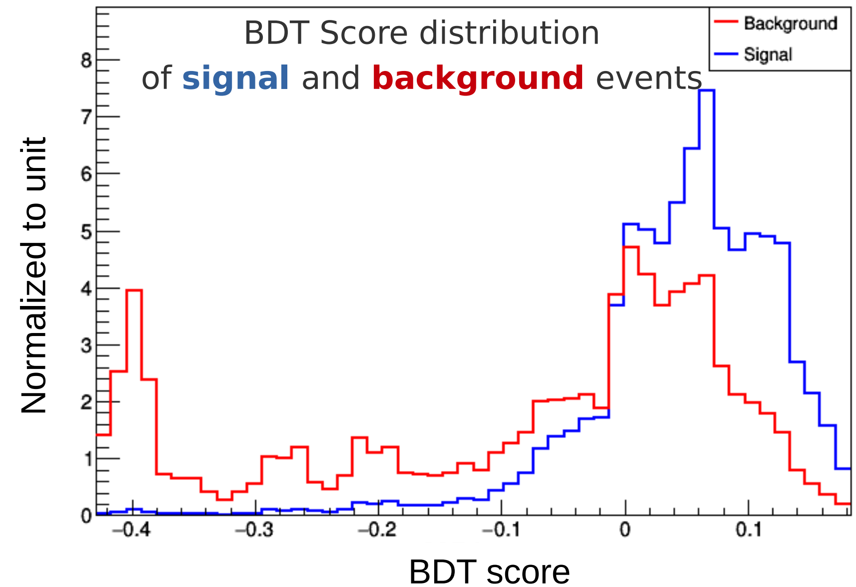
Signal acceptance vs. WIMP mass

Proportion of simulated WIMPs that pass a successive set of cuts vs the WIMP mass



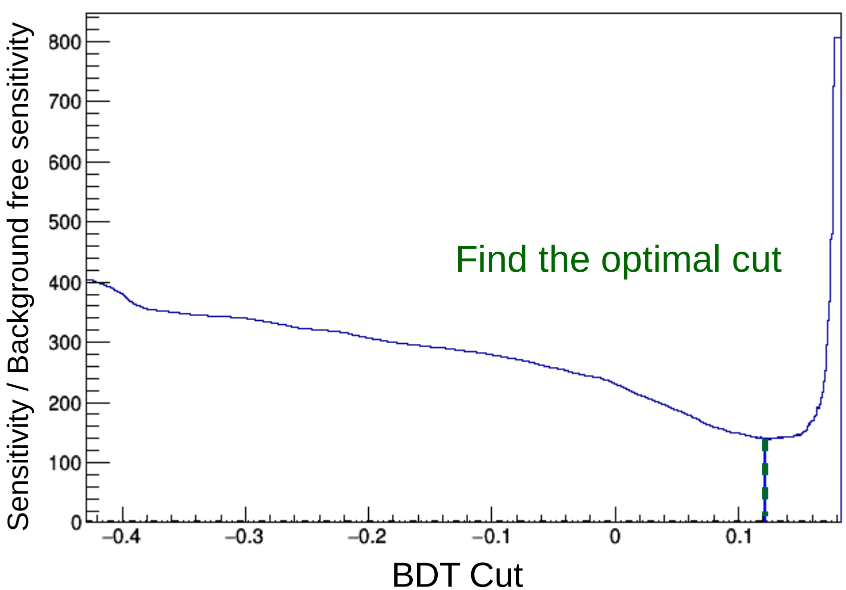
Boosted Decision Tree (BDT) : how it works

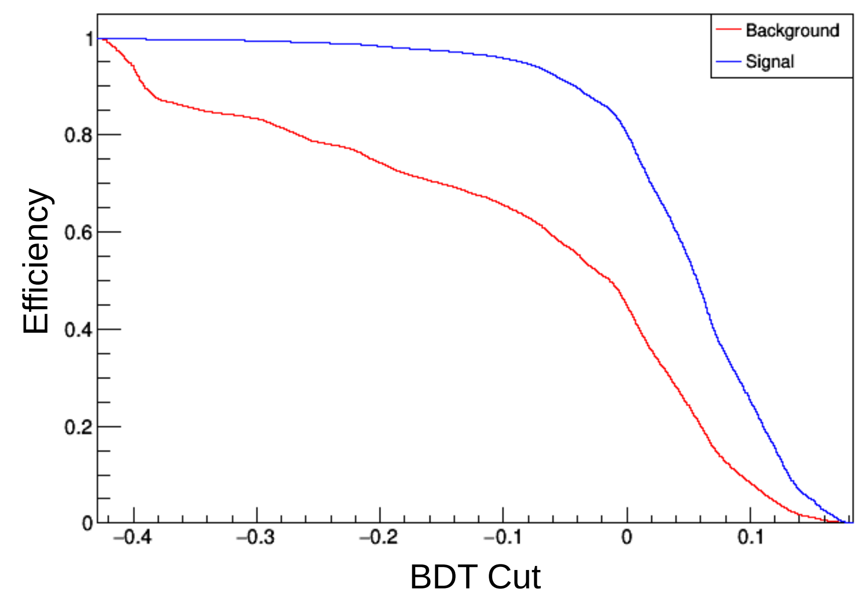




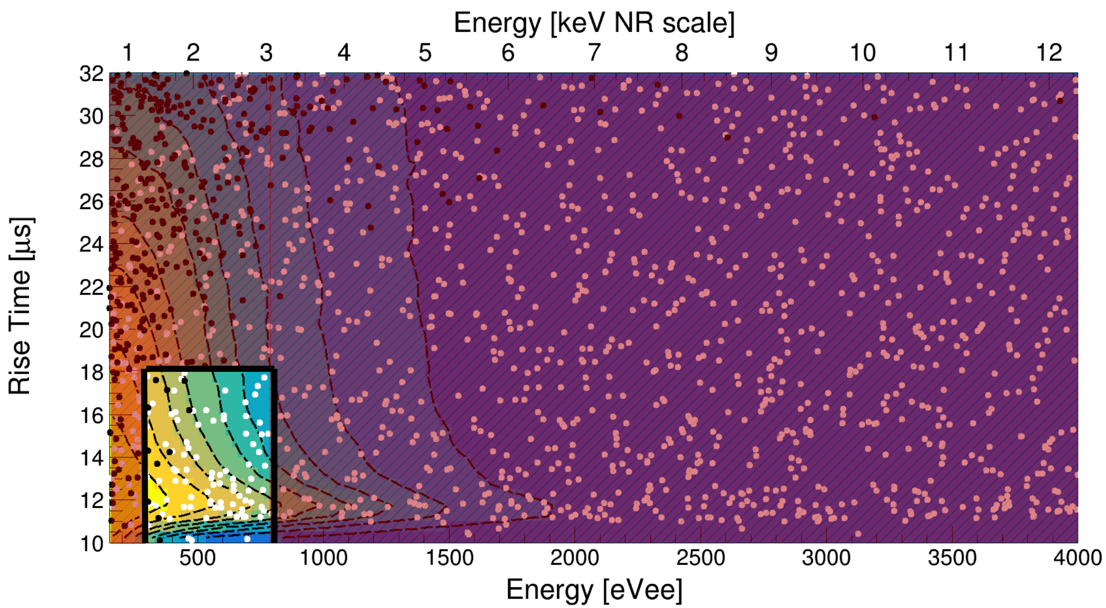
Background like
low BDT Score

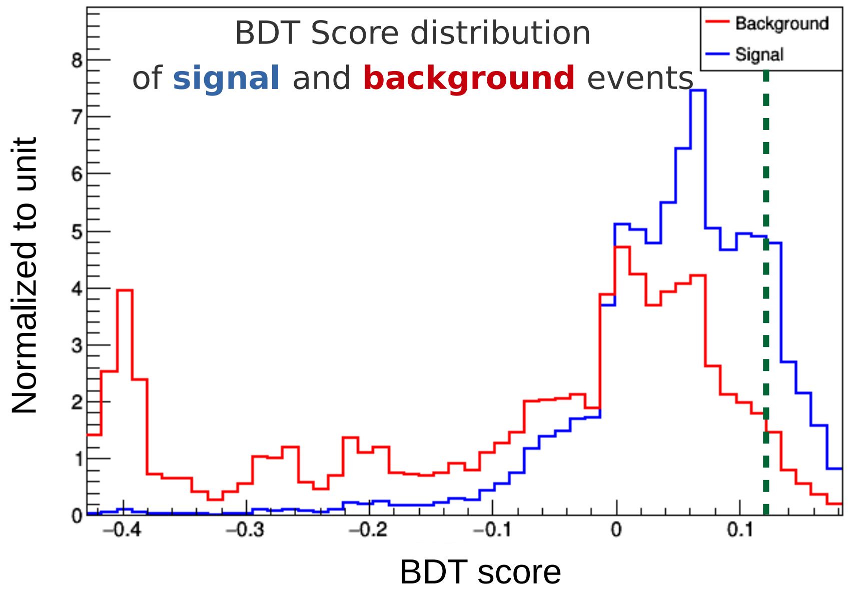
Signal like
high BDT Score



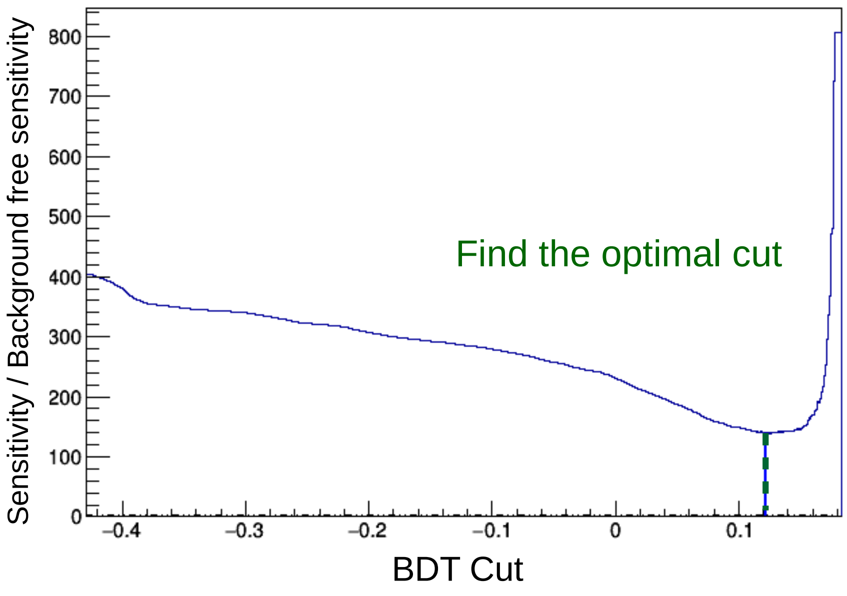


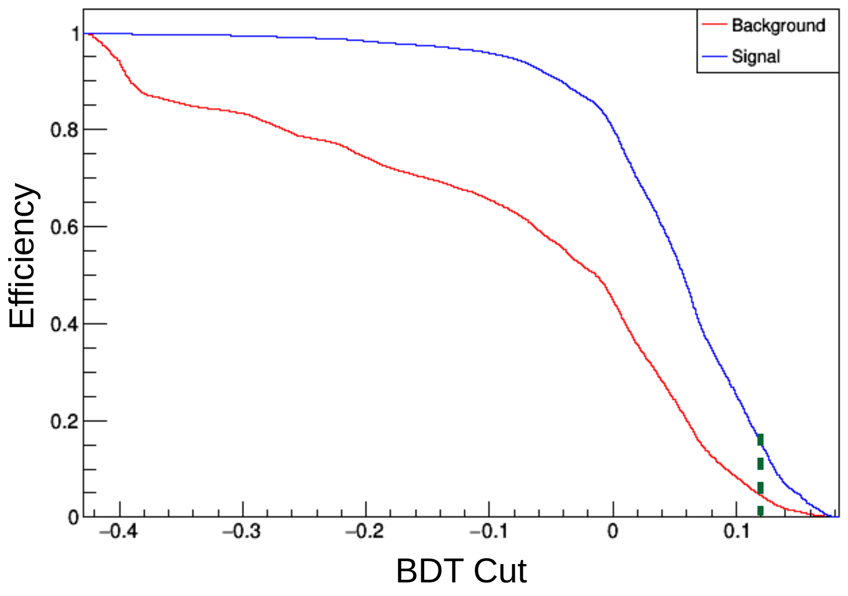
Boosted Decision Tree (BDT) : how it works





We can then perform the cut on the BDT score that optimizes the **signal** / **background** discrimination





Exclusion limit + Background-only expected sensitivity