New Experiment With Spheres - Gas

Light Dark Matter Search with NEWS-G

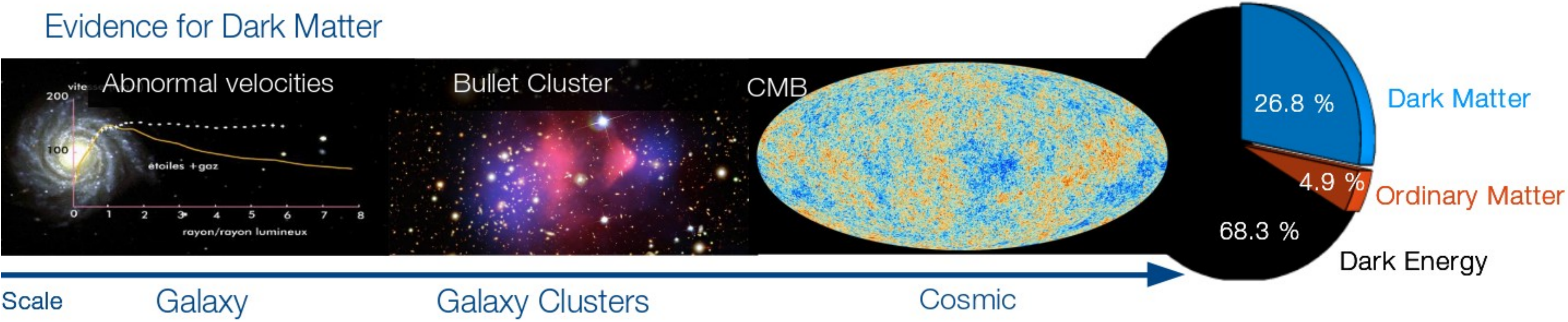
First Results and Outlook

Daniel Durnford

Supervisor: Gilles Gerbier

WNPPC 2018

Evidence for Dark Matter



Direct search for WIMPs (**W**eakly **I**nteracting **M**assive **P**articles)... Extremely Challenging!

Low event rate (<<1 evt/kg/year):

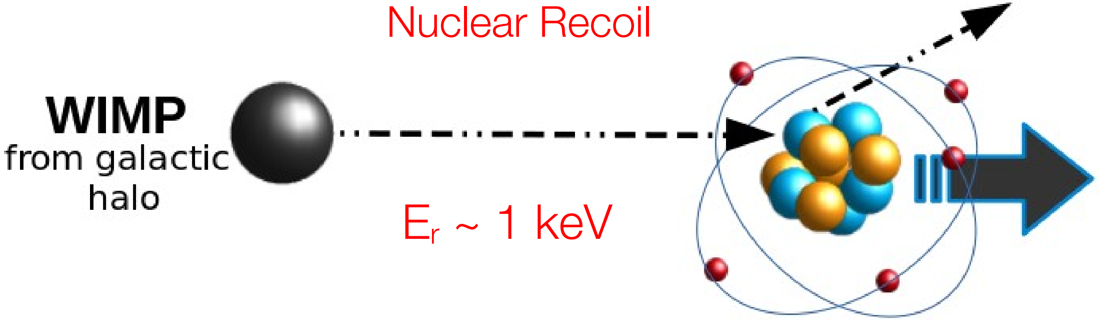
- Large exposures

Background Events:

- Clean materials and construction
- Background discrimination
- Shielding
- Underground labs

Small energy depositions:

- Low energy thresholds



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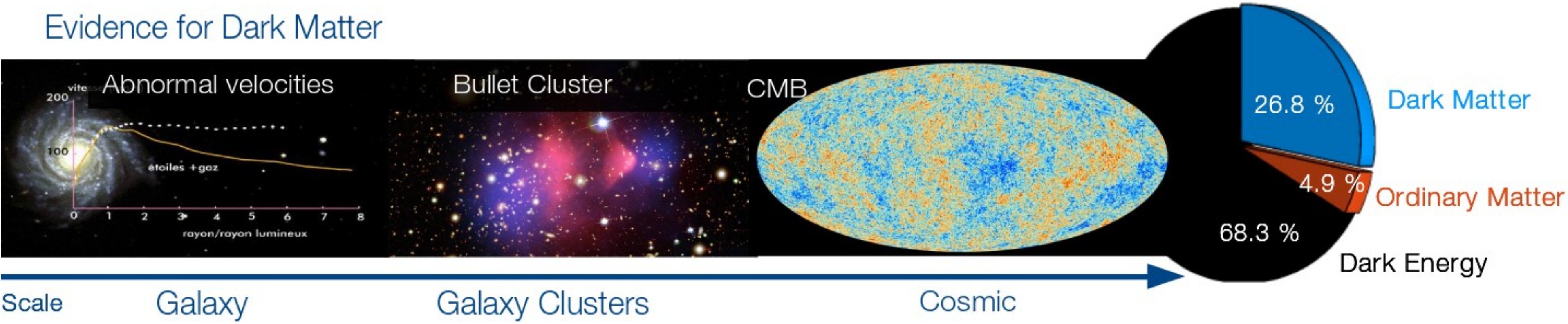

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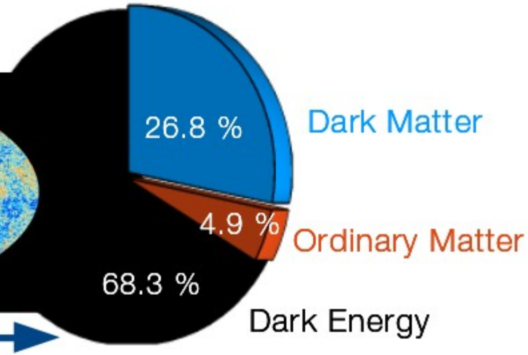

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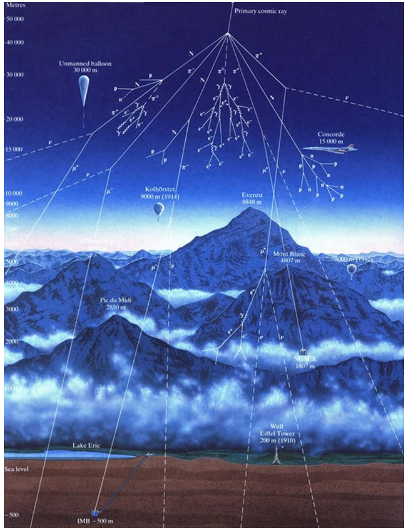

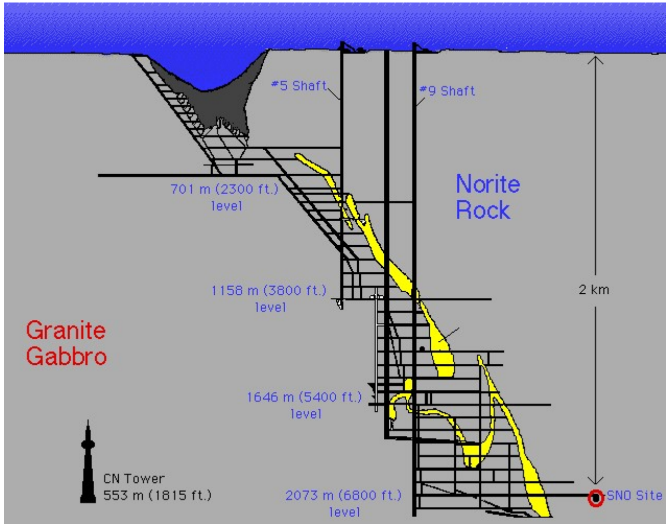

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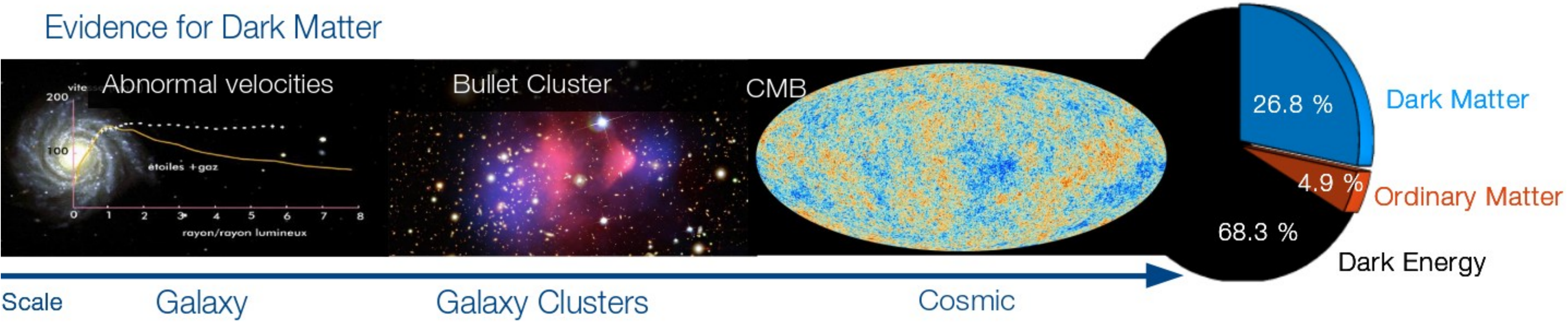

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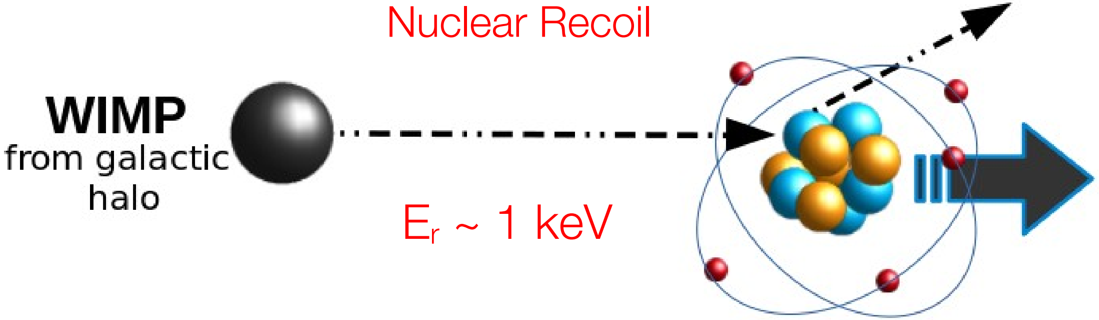

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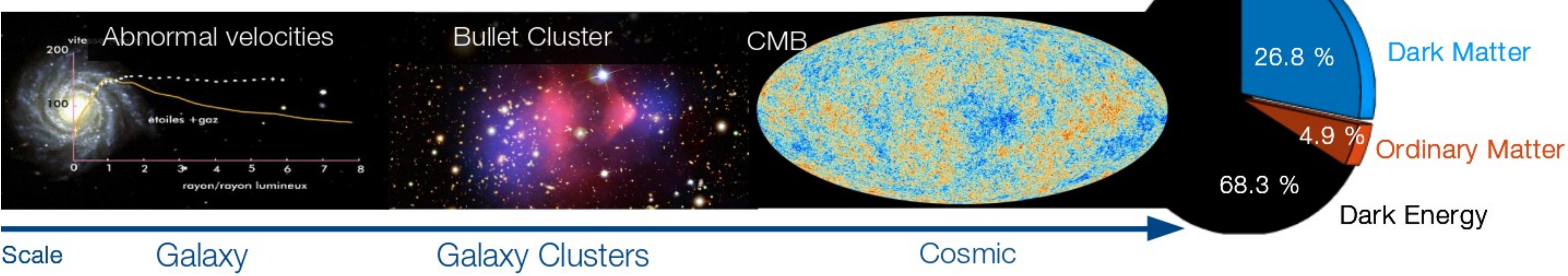

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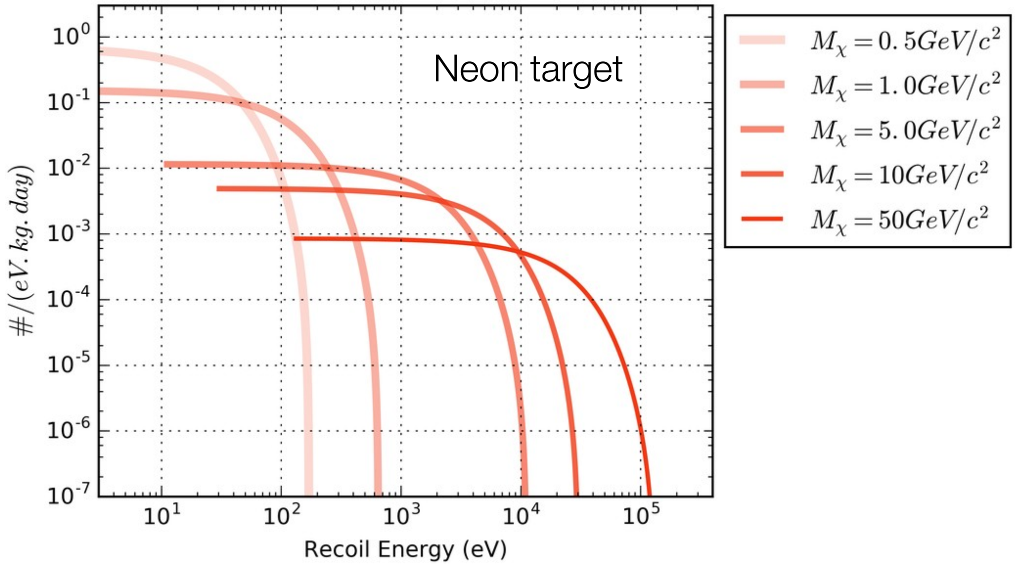


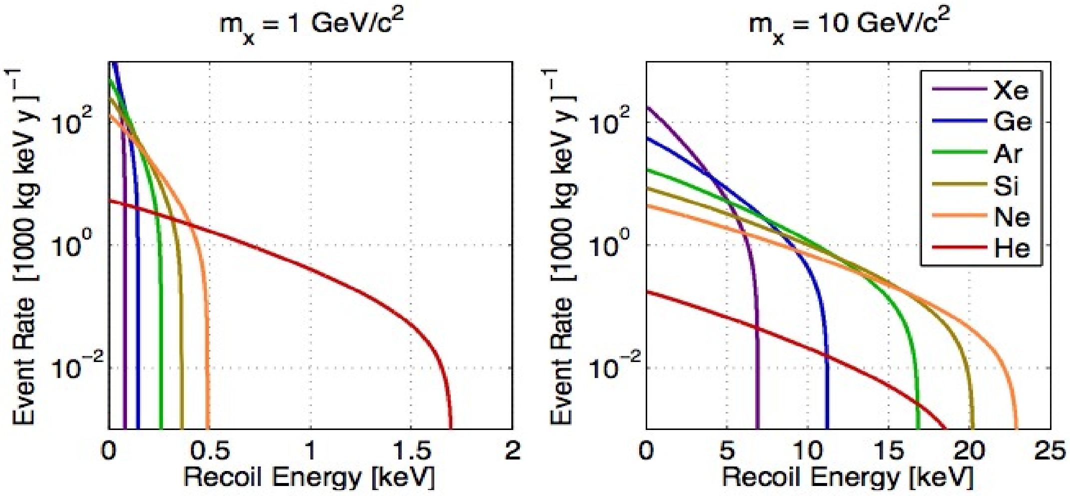
Spherical Proportional Counter (SPC)

Simple design, single sensor

Gas target, easily changeable

High gain, low energy threshold

Low A target → Good for low mass WIMPs



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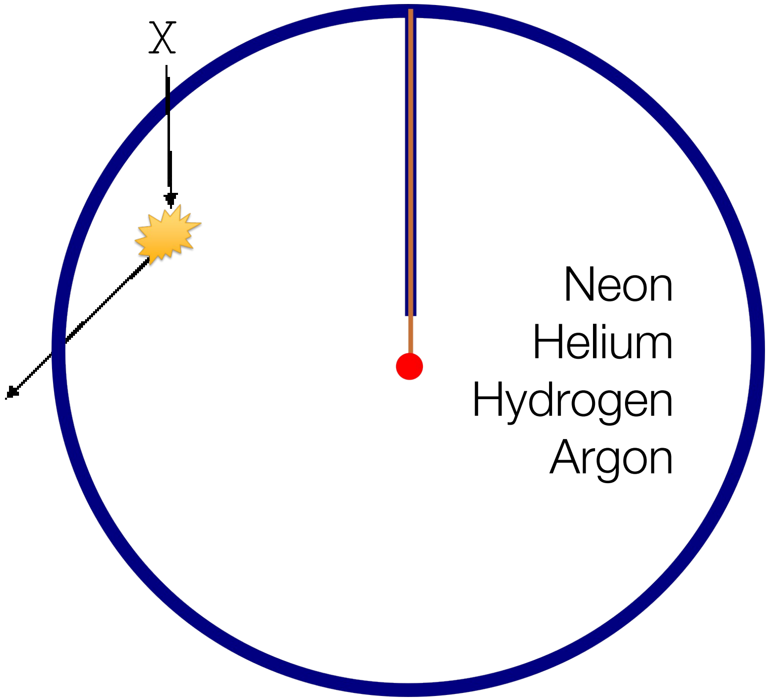

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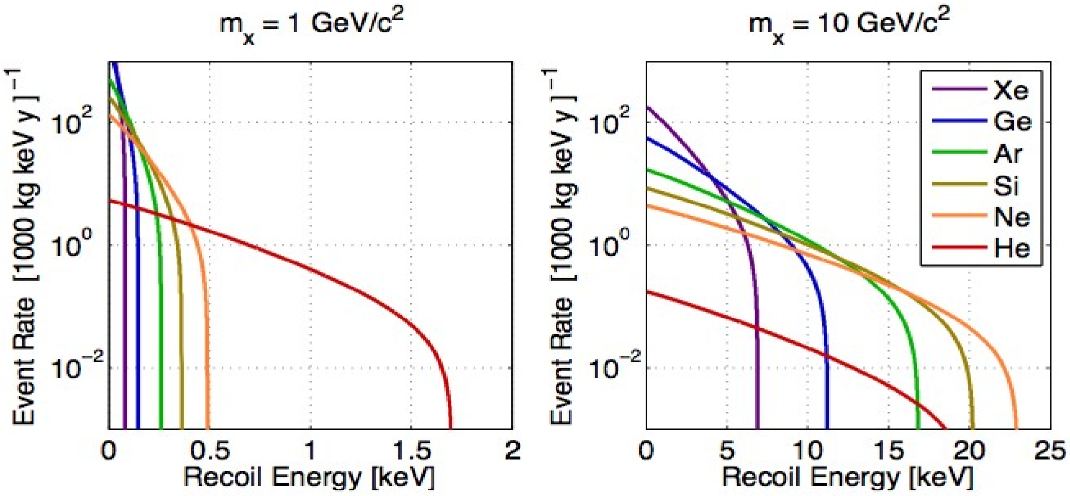
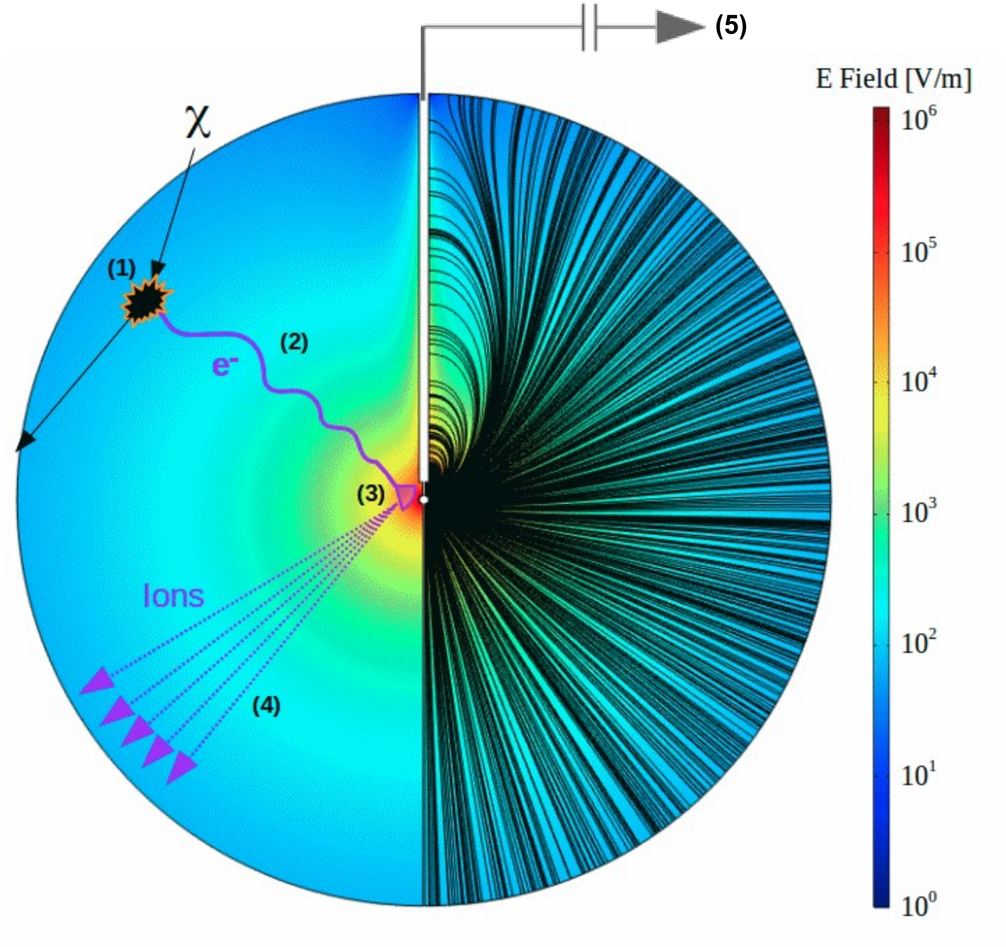


Detector Principle



(1) Primary Ionization

Mean energy to create one pair in Ne :

$$w_e = 36eV/pair \quad w_n = \frac{w_e}{Q(E_r)} \approx 5w_e$$

(2) Drift of charges

Typical drift time surface → sensor : ~ 500 μs

(3) Avalanche of secondary e-/ion pairs

Amplification of signal through Townsend avalanche

(4) Signal formation

Current induced by the ions drifting away from anode

(5) Signal readout

Induced current integrated by a charge sensitive pre-amplifier and digitized at 2.08 MHz

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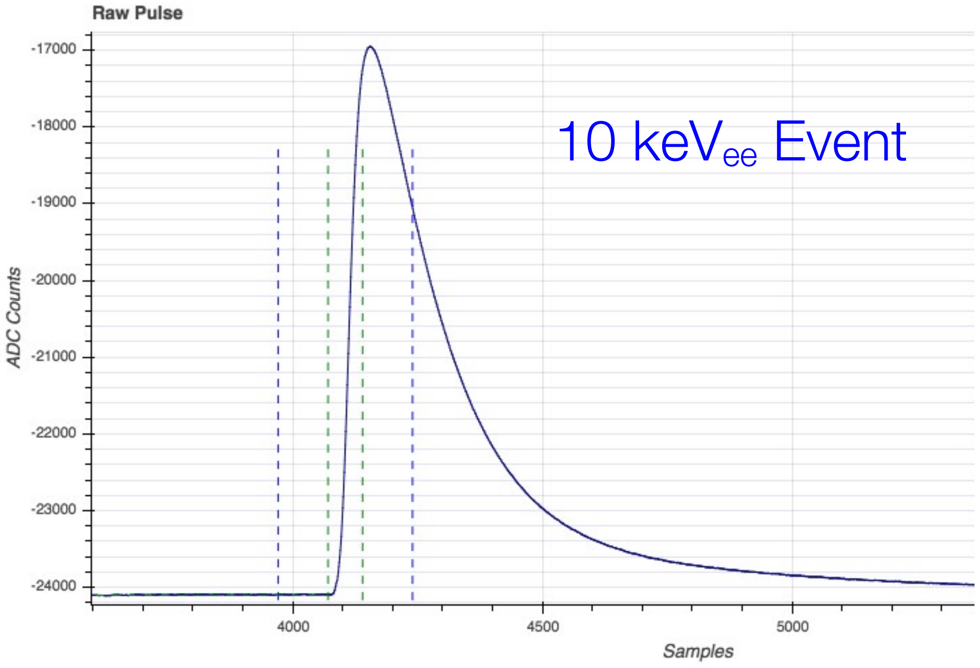

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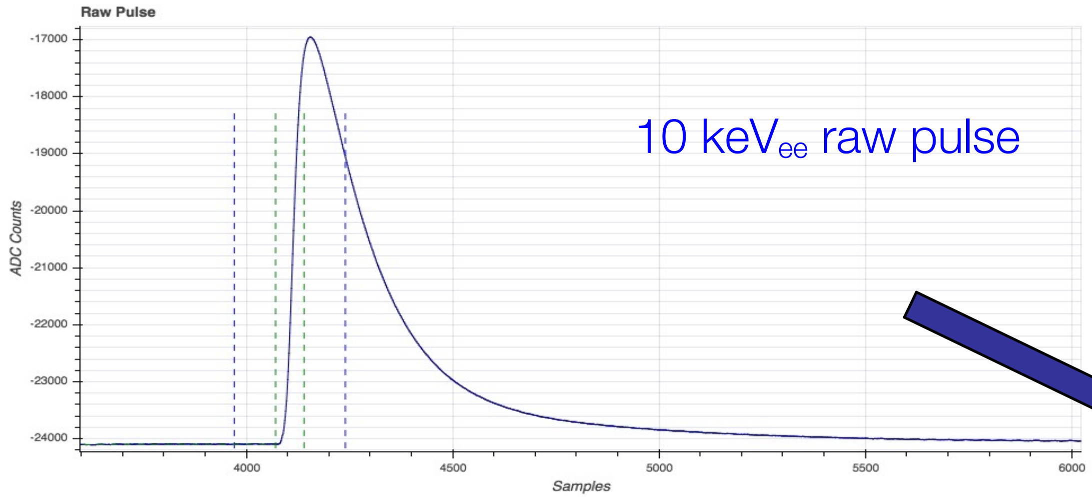
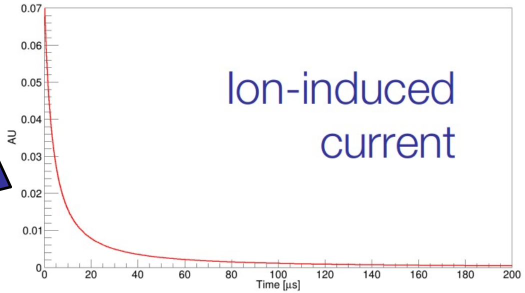
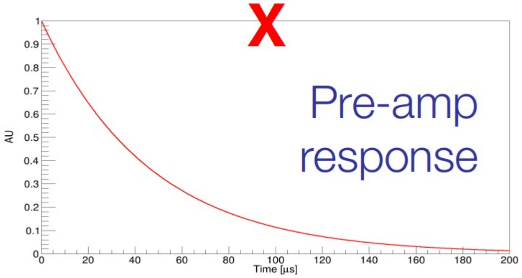
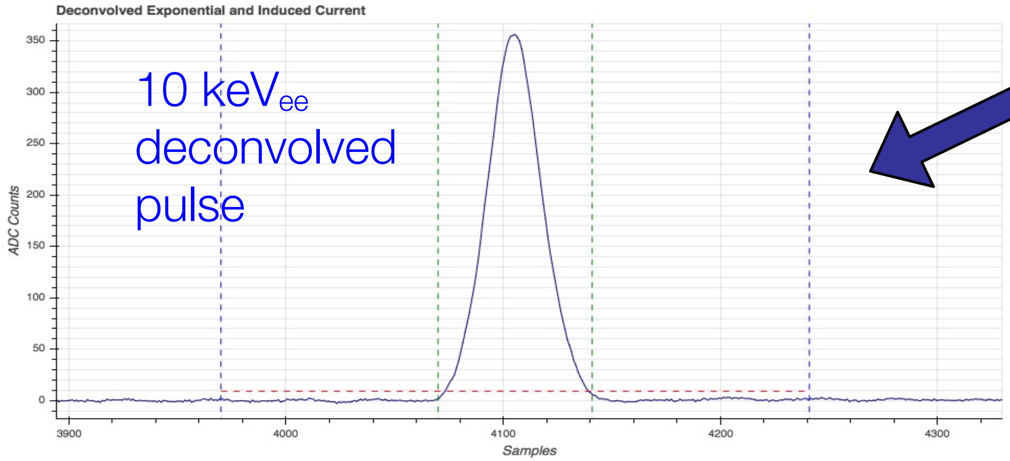
Pulse Treatment



Deconvolve for amplifier response and ion-induced current





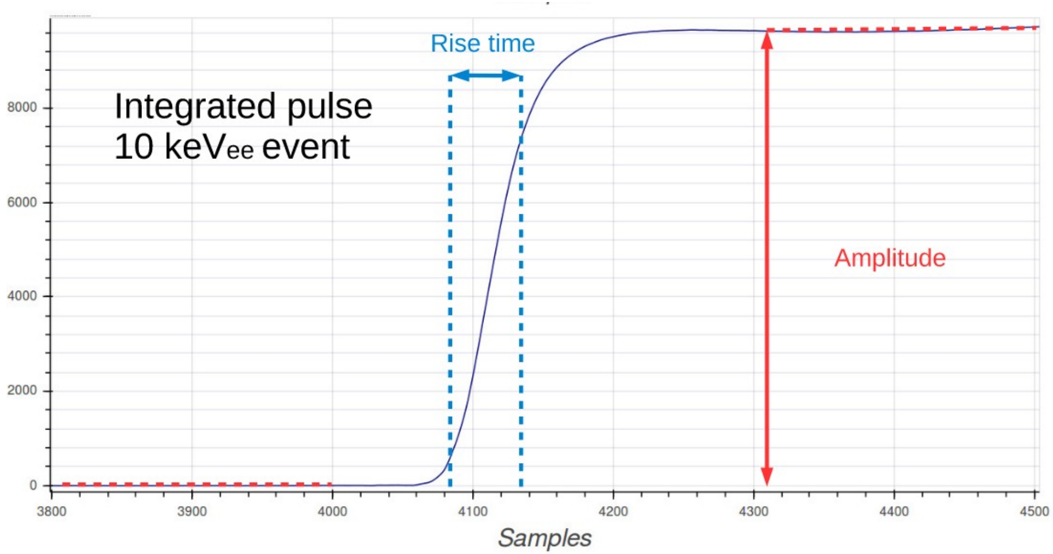


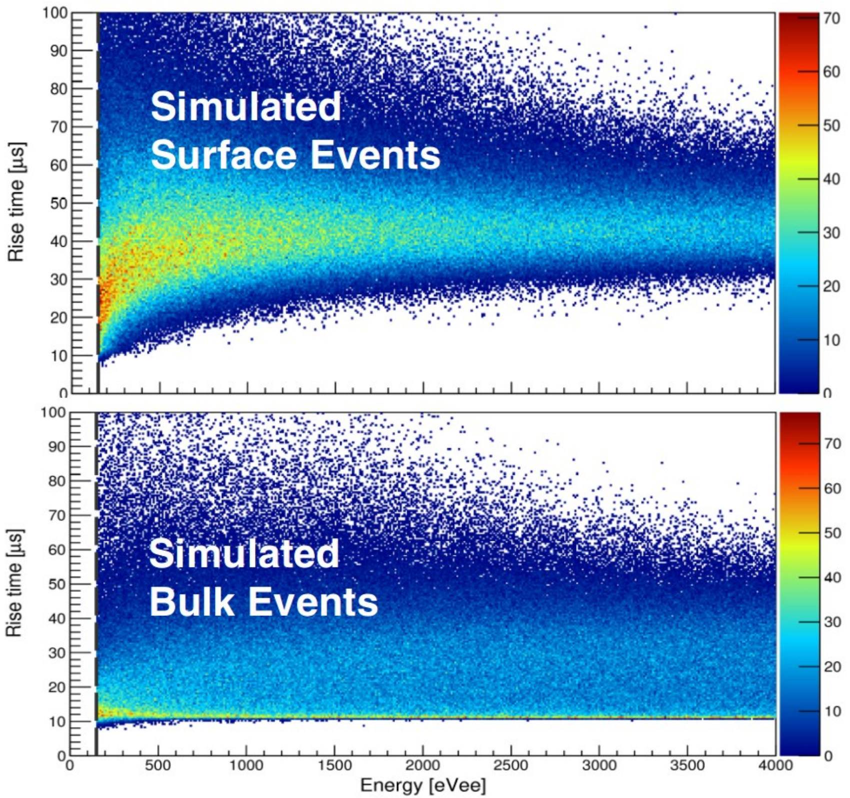
Rise time

Gaussian dispersion in arrival time due to diffusion of charges:

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

Rise time used for surface event discrimination





Simulation

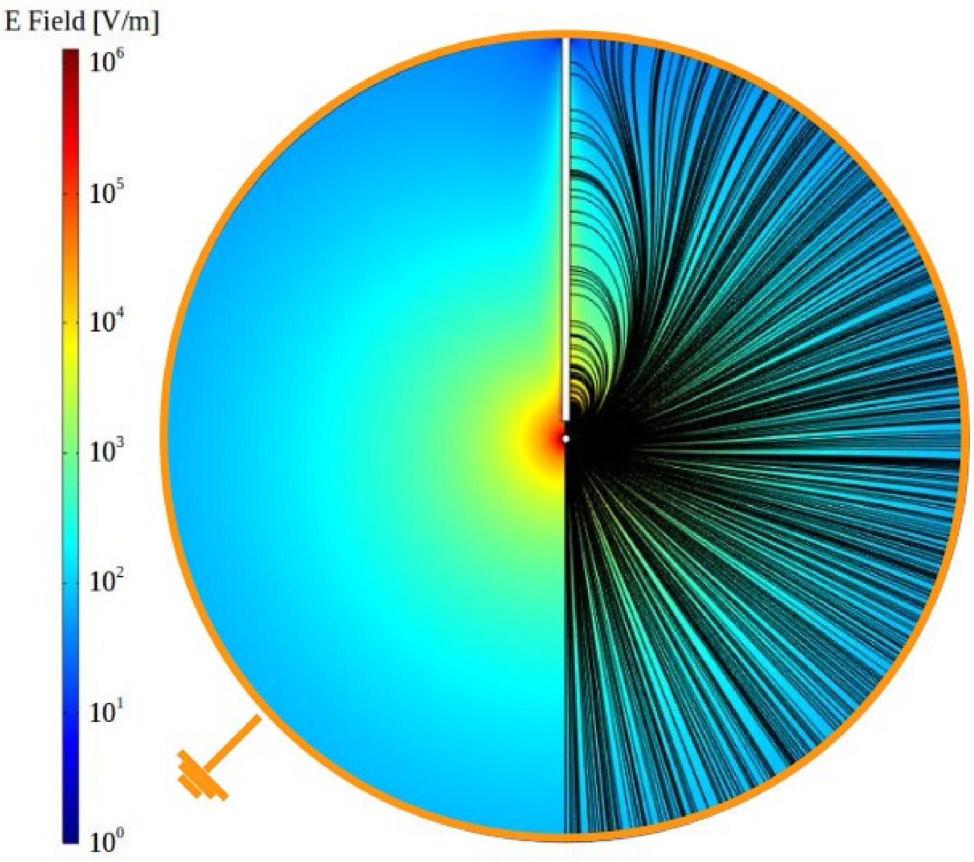
1) Electric field model

2) Drift of charges simulated

3) Energy response simulated

4) Pulses simulated: pre-amp response, ion current, noise

5) Same treatment as real data



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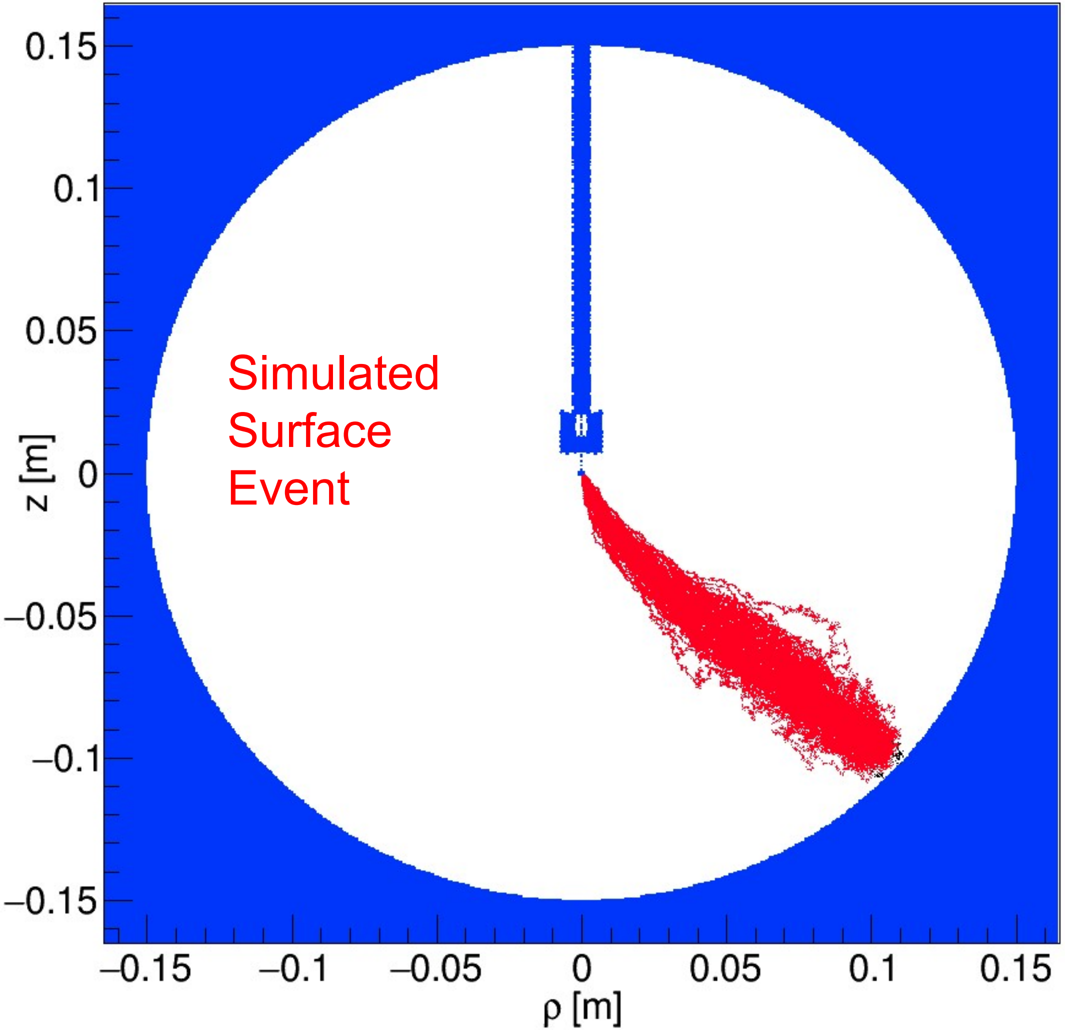

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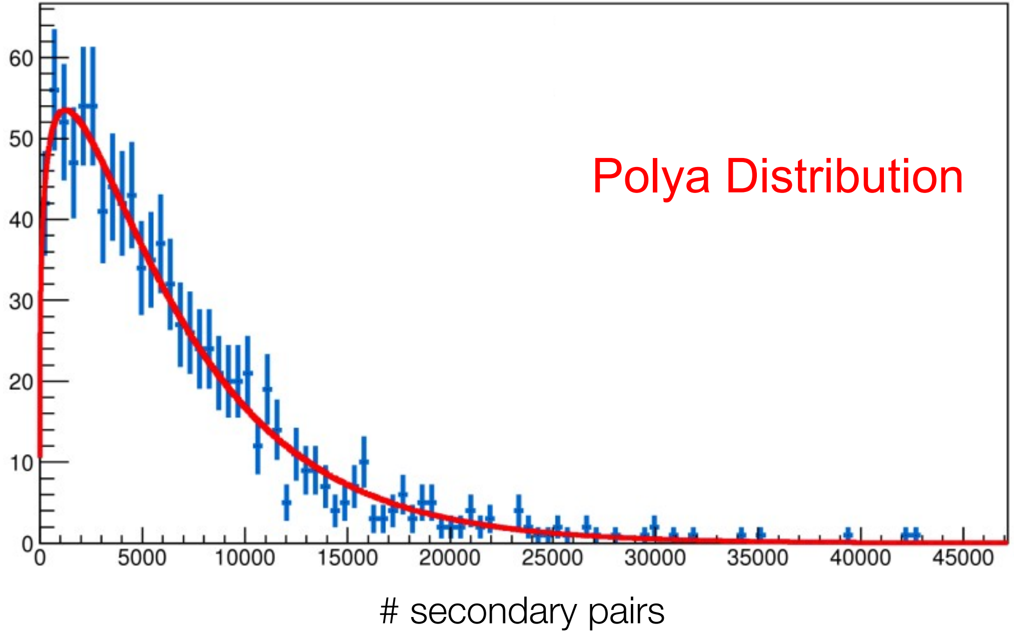
Polya distribution for # of secondary pairs
Modeled with Garfield++

~ 7000 secondary pairs / PE



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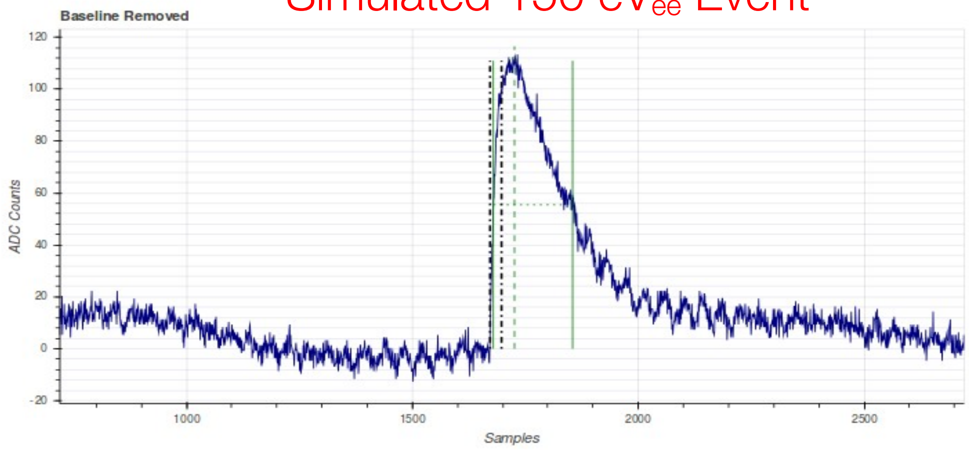
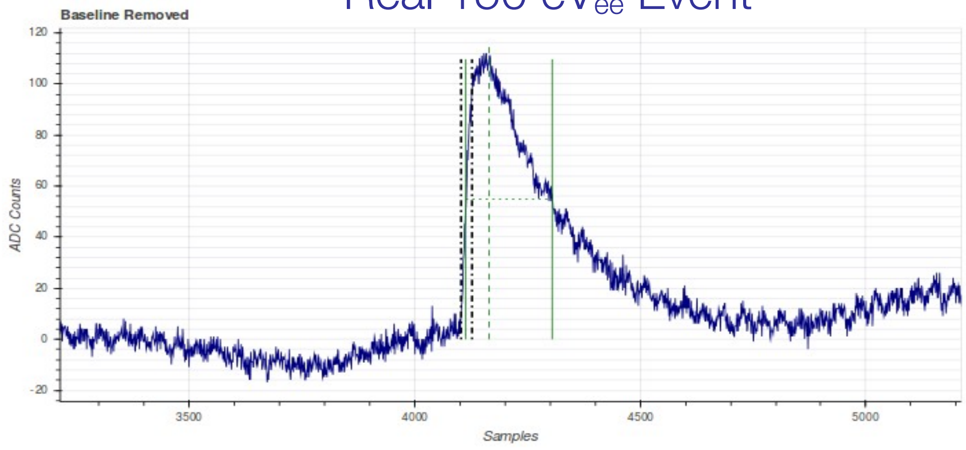
Simulated 150 eV_{ee} Event



Real 150 eV_{ee} Event



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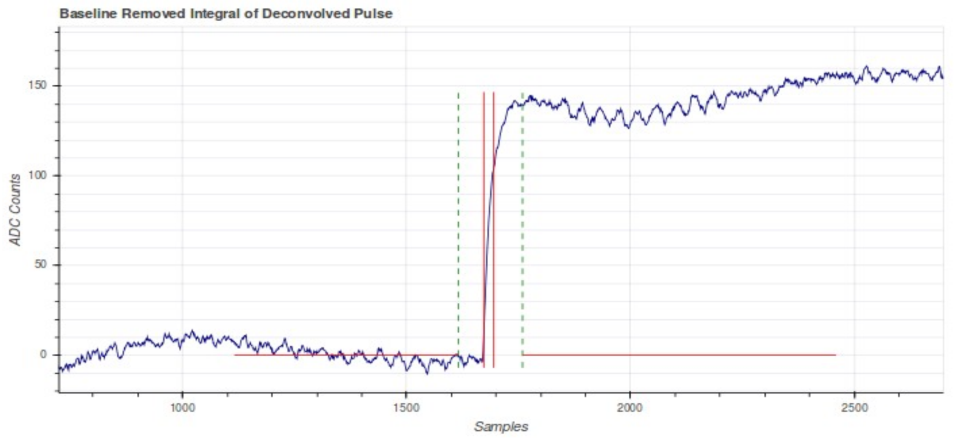

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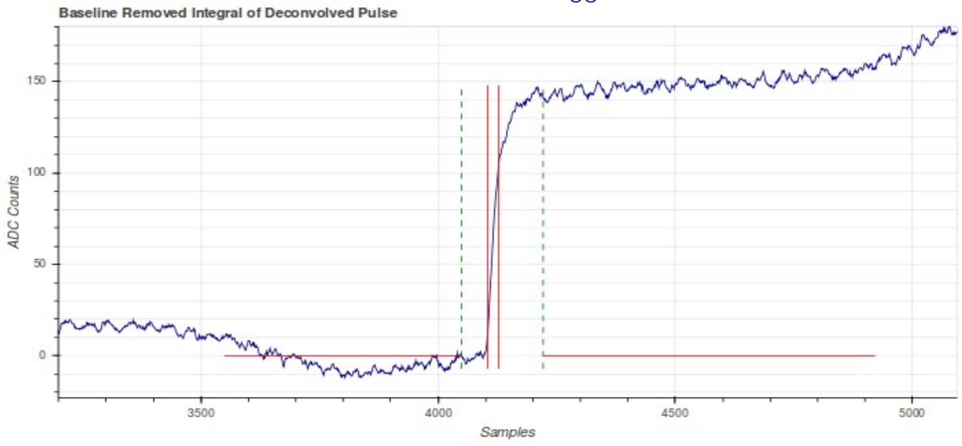
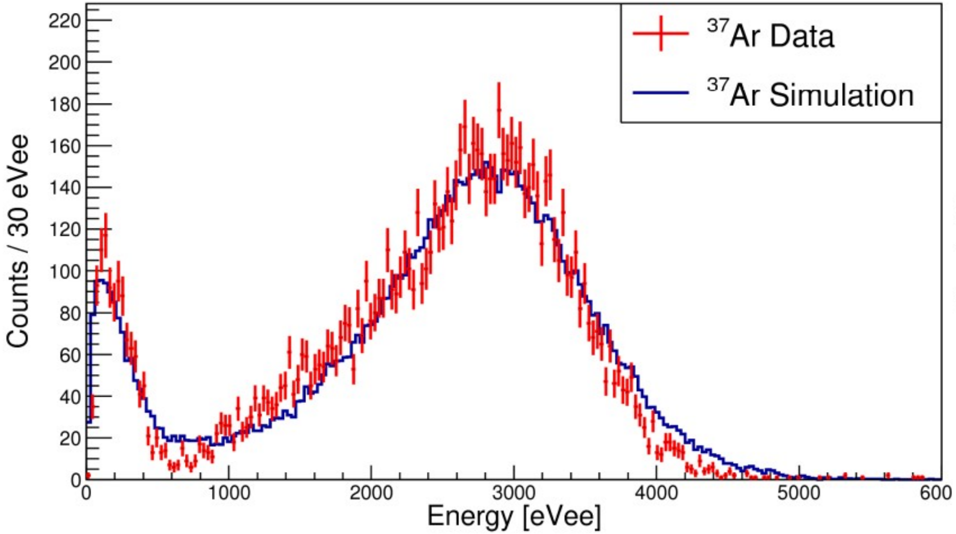


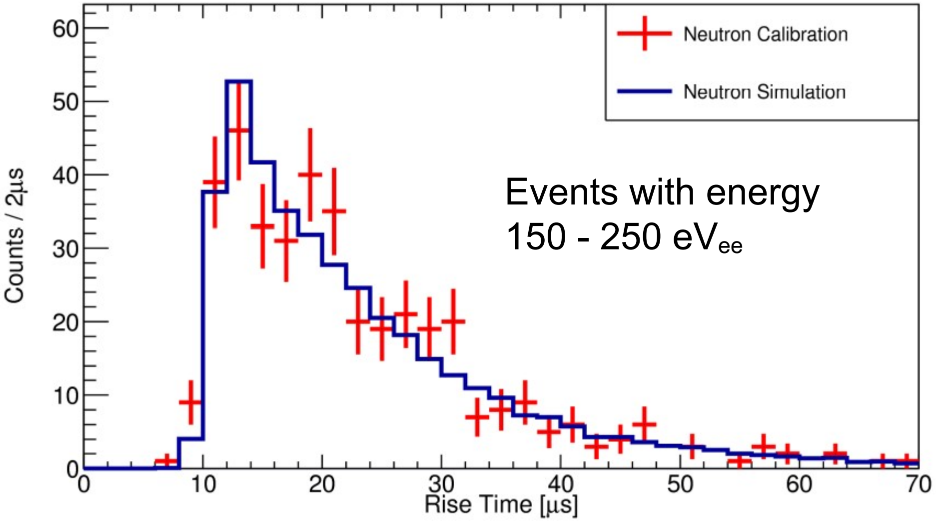
Simulation

- Am/Be neutron source

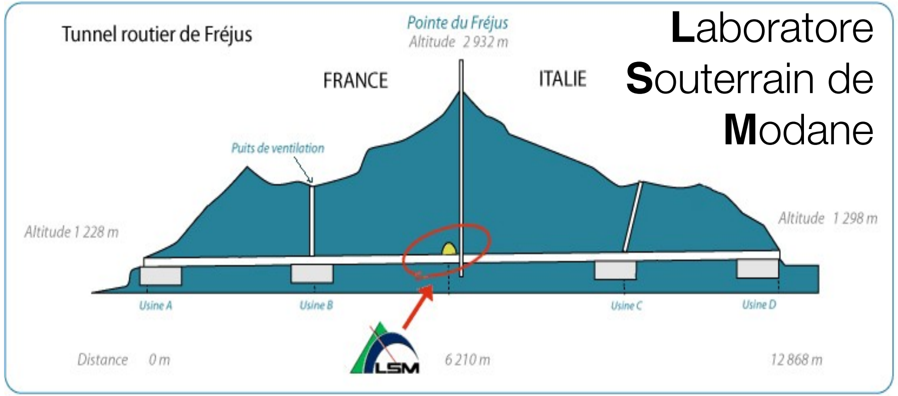
- 2.82 keV and 0.27 keV X-rays from gaseous ^{37}Ar

Agreement with simulation allows us to derive our WIMP sensitivity from simulated WIMPs

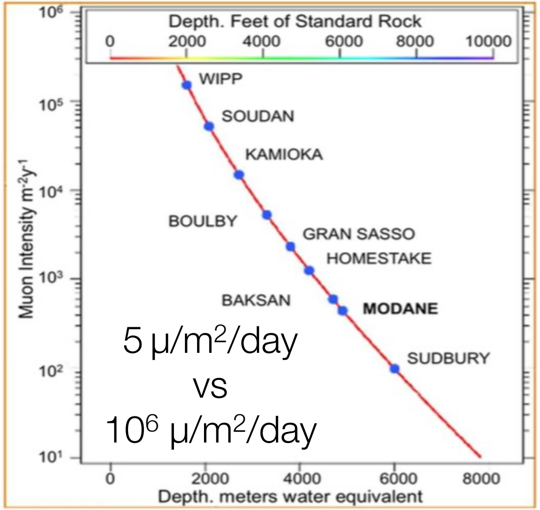




NEWS-G @ LSM

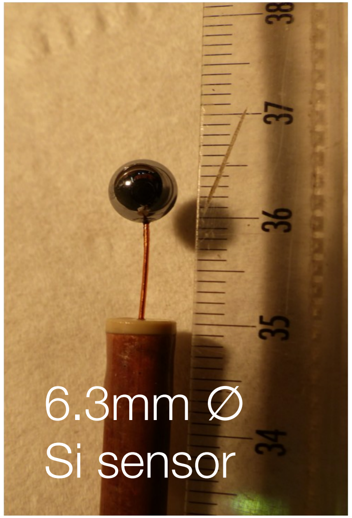


Laboratore **S**outerrain de **M**odane

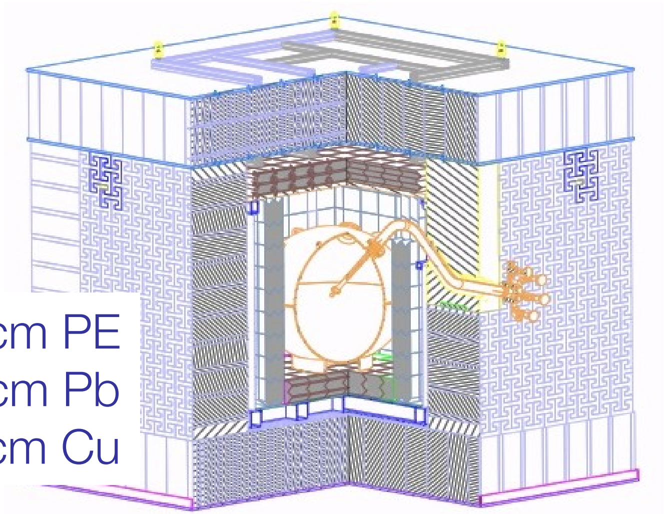


5 μ/m²/day
vs
10^6 μ/m²/day

SEDINE
60cm Ø
NOSV copper vessel



6.3mm Ø
Si sensor



30cm PE
10-15cm Pb
3-8cm Cu

Physics Data

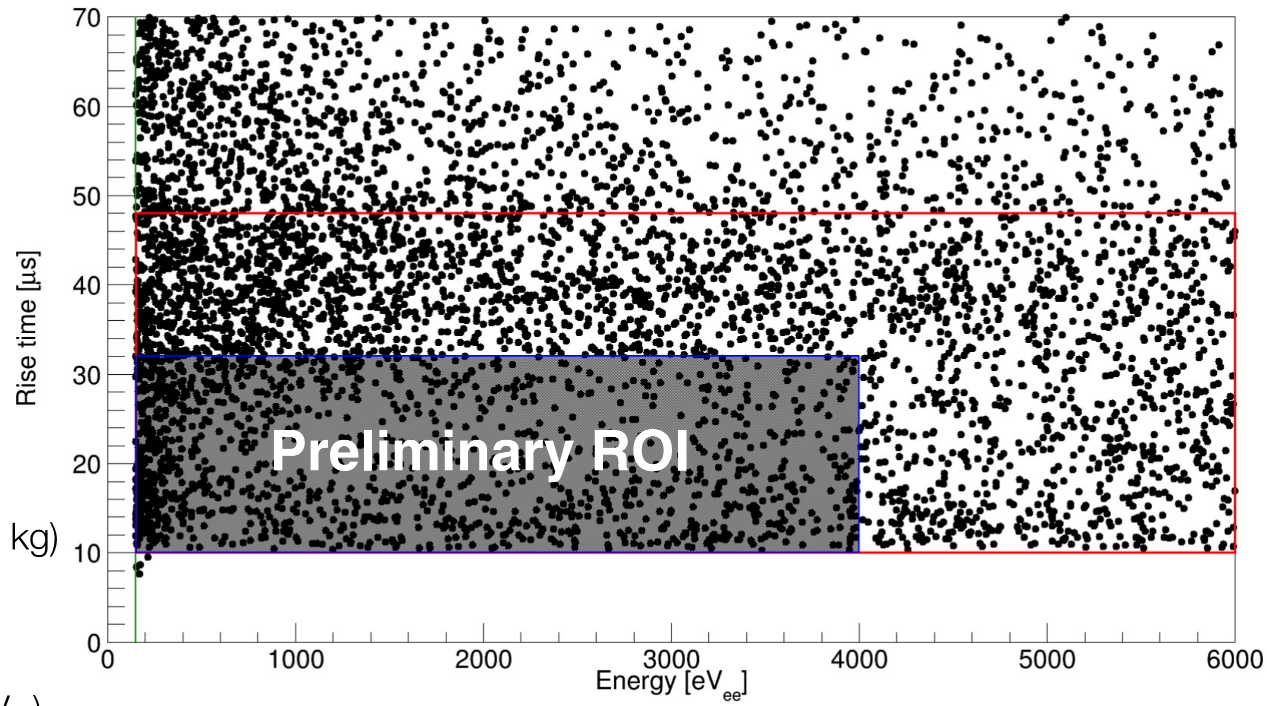
Target:
Neon + 0.7% CH_4
@ 3.1 bars

Quality cuts:
20.1 % dead time

Exposure:
9.6 kg·days (34.1 live-days x 0.28 kg)

Trigger threshold:
35 eV_{ee} (~100% efficient at 150 eV_{ee})

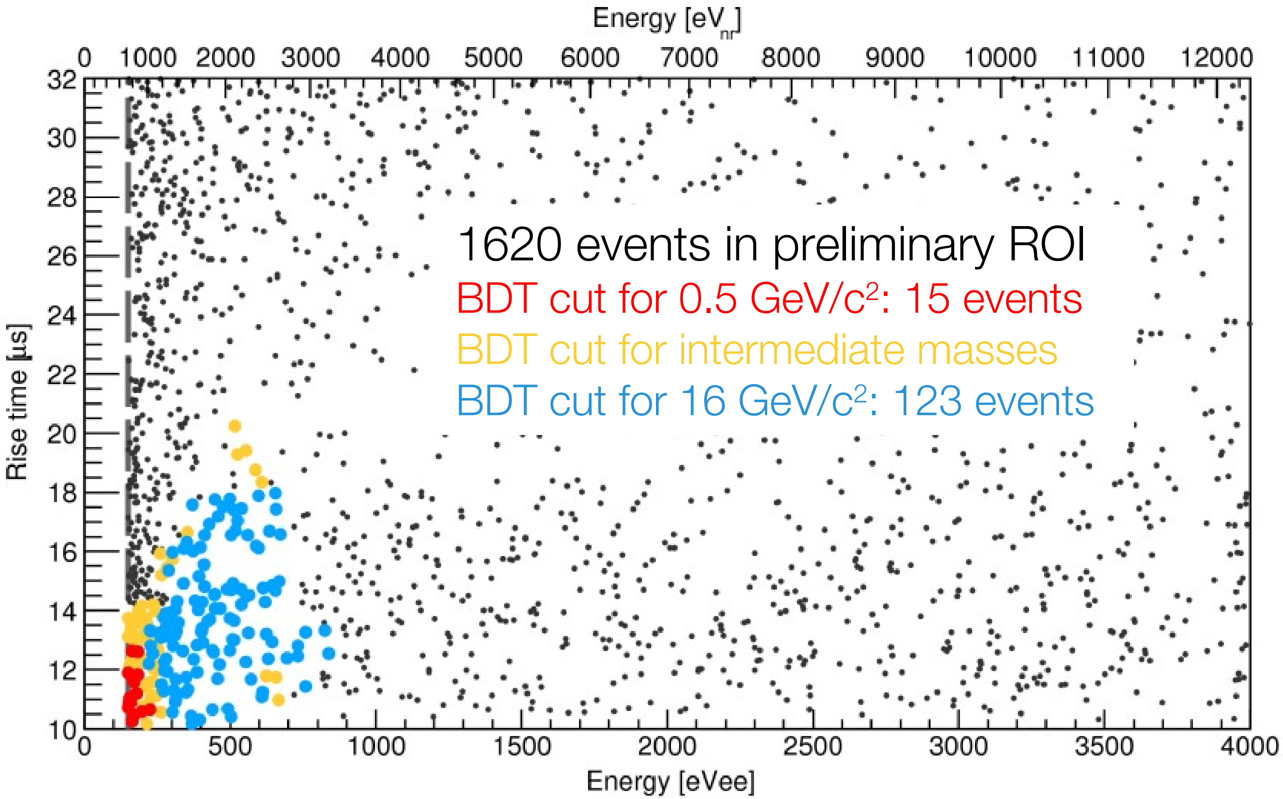
Analysis threshold:
150 eV_{ee} (~720 eV_{nr})



Sideband region used to determine # of expected events in preliminary ROI

Data Analysis

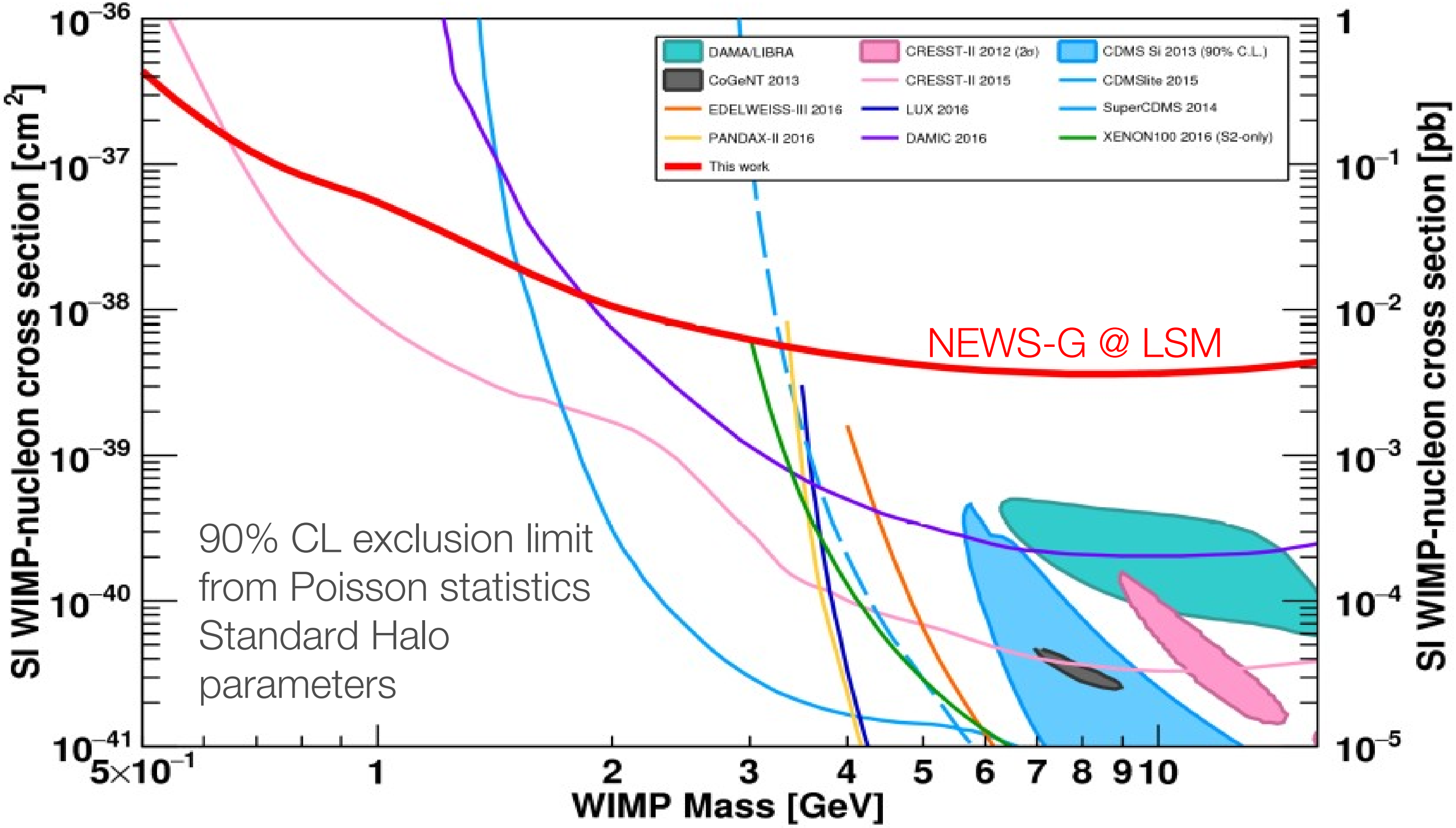
We use a Boosted Decision Tree (machine learning algorithm)
Optimized cuts for 8 different WIMP masses



Trained with simulated WIMPs and background events

Mis-modeling of backgrounds would lead to non-optimal cuts (underestimating our sensitivity)

First results from NEWS-G @ LSM!

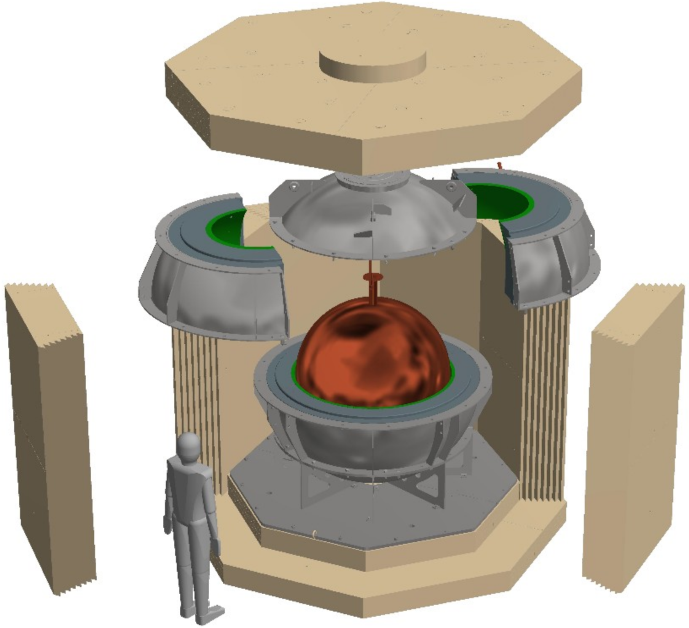


Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018) doi: 10.1016/j.astropartphys.2017.10.009

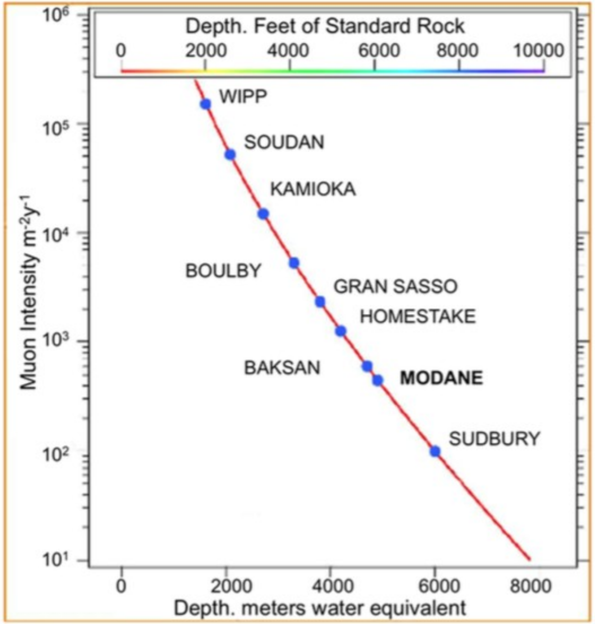
Looking forward... SNOLAB Many improvements:

Lighter targets, larger exposure, pure materials

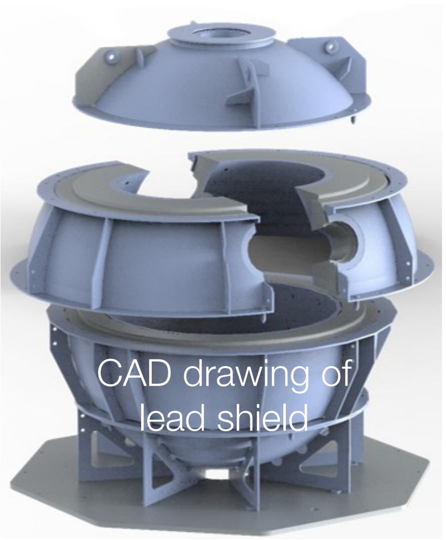
Better shielding
- 40 cm PE + Boron sheet
- 22 cm VLA Pb (1 Bq/kg ^{210}Pb)
- 3 cm archaeological lead

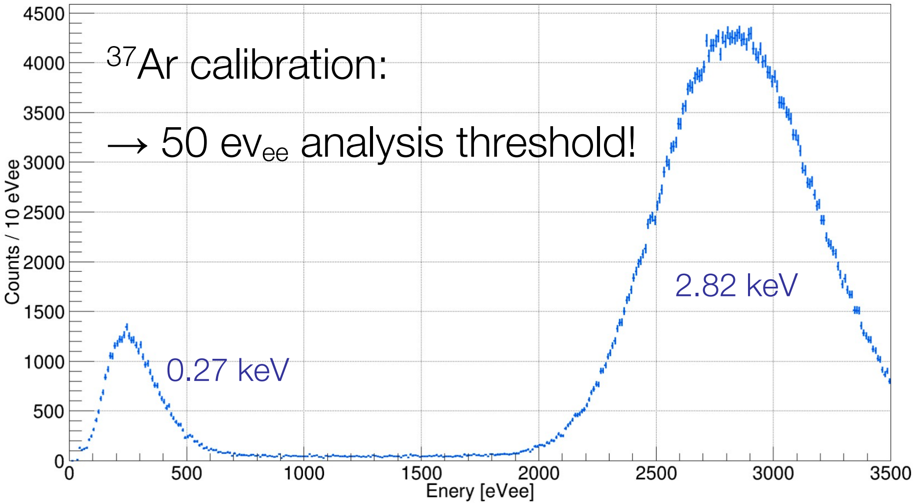


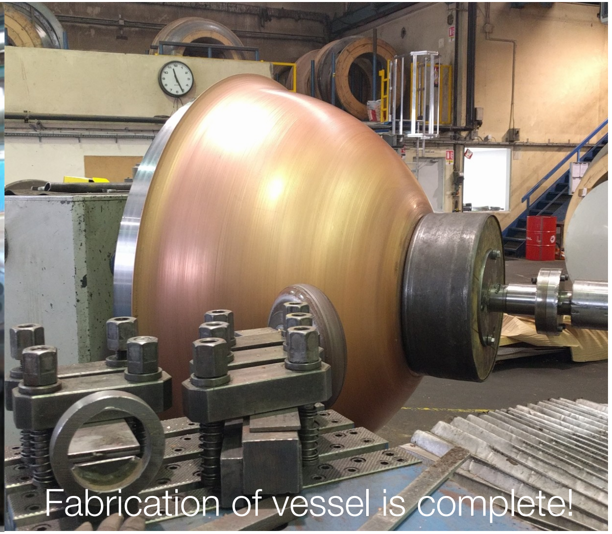
Deeper underground, ~4x lower μ flux



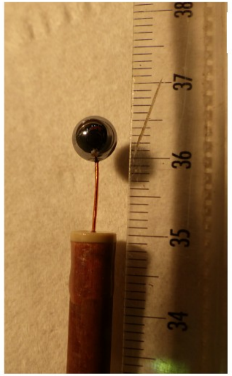
In progress!







Sensor Development →

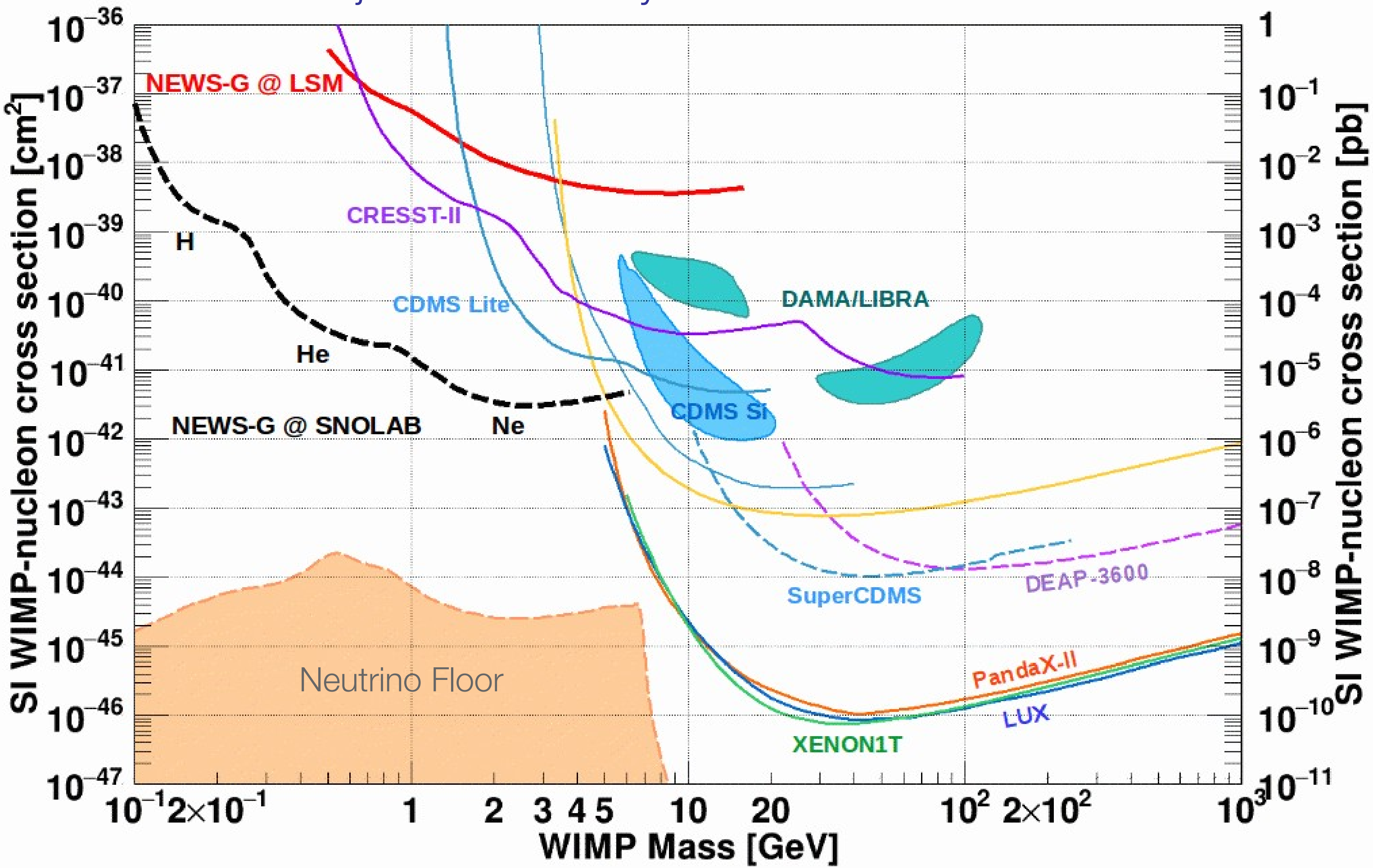


single ball

single ball umbrella

multi-ball umbrella

Projected sensitivity to WIMPs @ SNOLAB



Thank you!

Queen's University Kingston – G Gerbier, P di Stefano, R Martin, T Noble, D. Durnford, G. Giroux, A Brossard, F Vazquez de Sola, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier

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

IRFU (Institut de Recherches sur les Lois fondamentales de l'Univers) - I Giomataris, M Gros, C Nones, I Katsioulas, T. Papaevangelou, JP Bard, JP Mols, XF Navick,

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

LSM (Laboratoire Souterrain de Modane) / Université de Chambéry - F Piquemal, M Zampaolo, A DastgheibiFard

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

Thessaloniki University – I Savvidis, A Leisos, S Tzamarias, C Elefteriadis, L Anastasios

- Simulations, neutron calibration
- Studies on sensor

LPSC (Laboratoire de Physique Subatomique et Cosmologie), Grenoble - D Santos, JF Muraz, O Guillaudin

- Quenching factor measurements at low energy with ion beams

Technical University Munich – A Ulrich, T Dandl

- Gas properties, ionization and scintillation process in gaz

Pacific National Northwest Lab – E Hoppe, DM Asner, R Bunker

- Low activity measurements, Copper electroforming

RMCC (Royal Military College Canada), Kingston – D Kelly, E Corcoran

- ^{37}Ar source production, sample analysis

SNOLAB, Sudbury – P Gorel

- Calibration system/slow control

University of Birmingham – Kostas Nikolopoulos, P. Knight

- Simulation and R&D

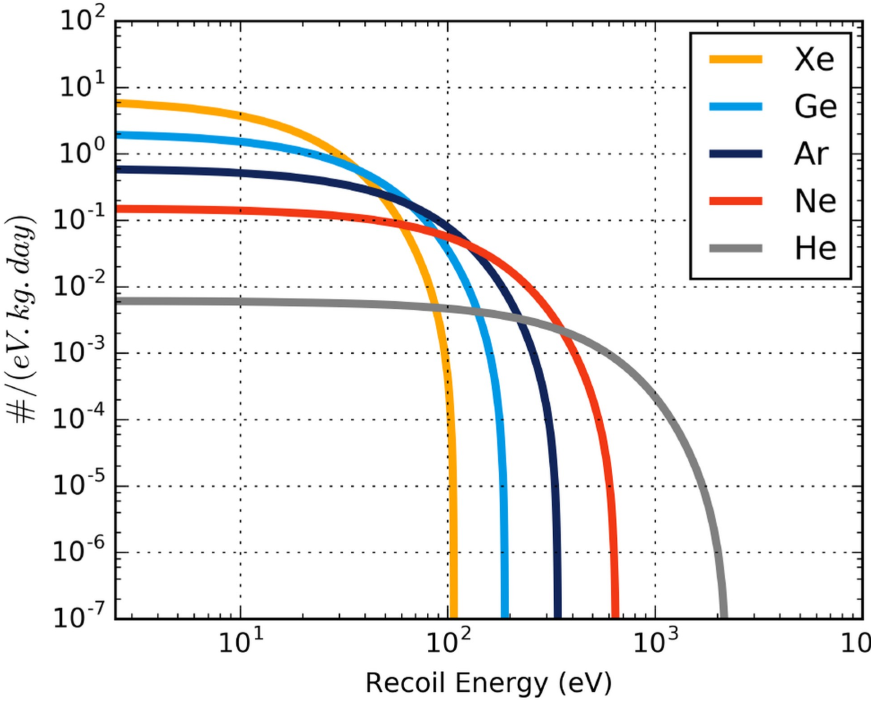
Associated lab : **TRIUMF** - F Retiere

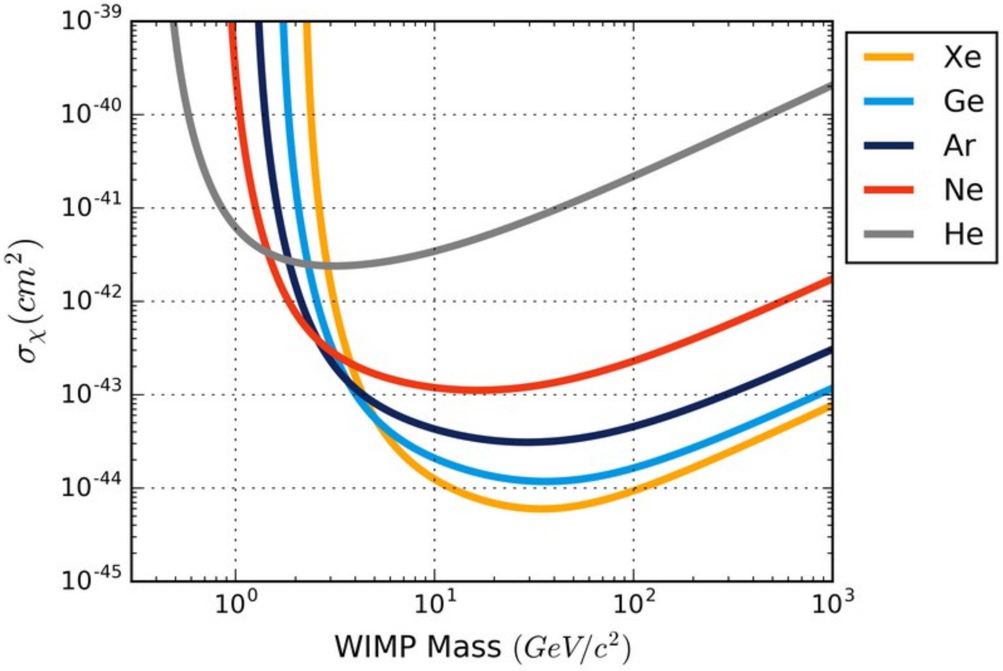
- Future R&D on light detection, sensor

Extra Slides

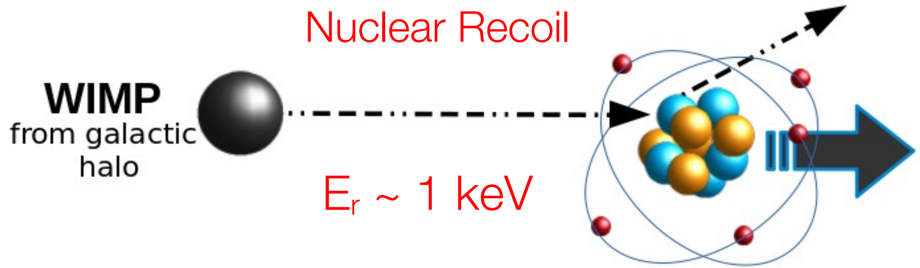
Effect of Different Targets

1 GeV WIMP, 1 kg.year, 100eV threshold

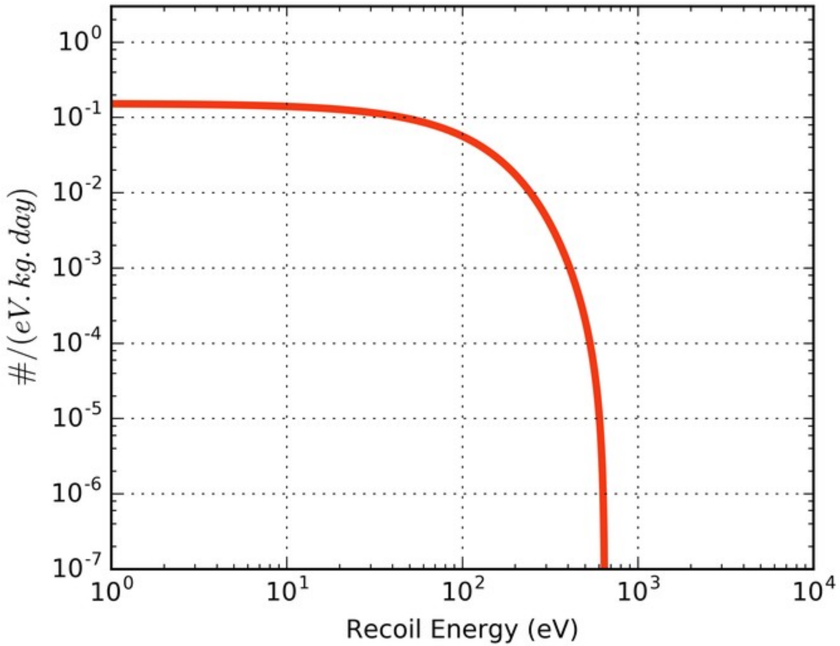




WIMP Recoil Spectrum



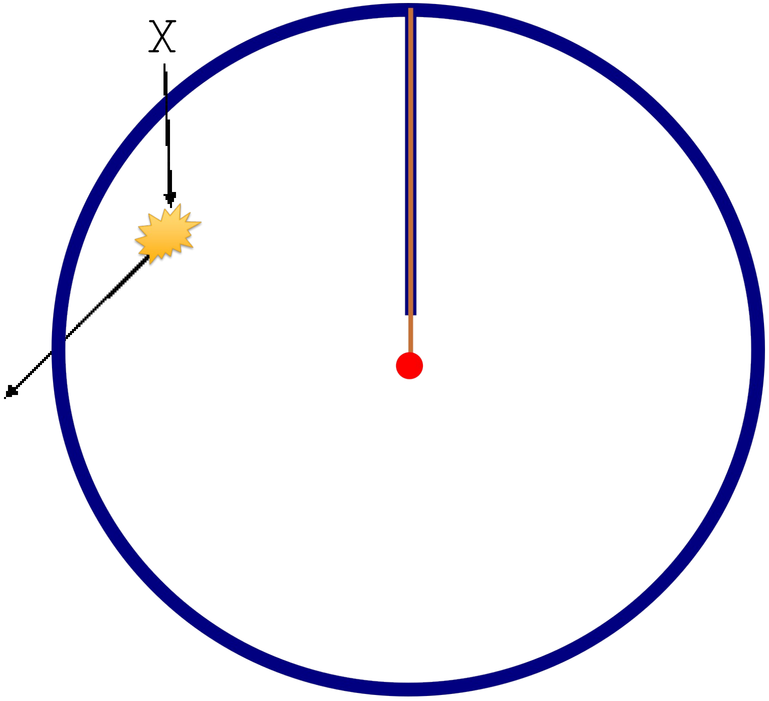
Neon, 1 kg.year, 1pb, 1 GeV WIMP



$$\frac{dR}{dE_r} = M_T \frac{\rho_0 \sigma_0}{2 m_\chi m_r^2} F^2(E_r) \int_{v_{min}} \frac{f(\vec{v})}{v} d^3v$$

Schnee, R. W. (2009). Introduction to Dark Matter Experiments. In Theoretical Advanced Study Institute in Elementary Particle Physics. Boulder, Colorado, USA.

Spherical Proportional Counter (SPC)

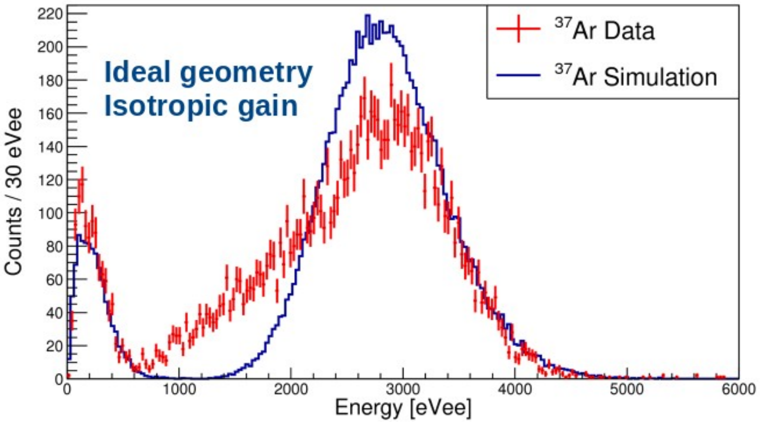


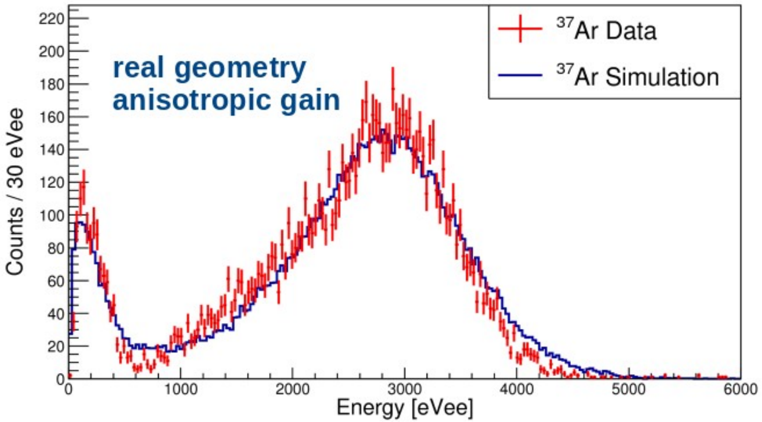
Low intrinsic capacitance → Low noise → Low energy threshold (10 - 40 eV_{ee})

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

Large gain from charge avalanche in high electric field

$$E(r) \propto \frac{1}{r^2}$$


Ideal geometry
Isotropic gain
37Ar Data
37Ar Simulation
Counts / 30 eVee
Energy [eVee]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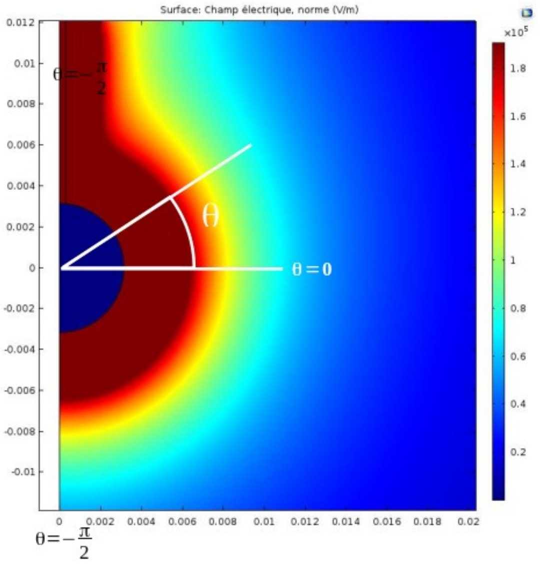
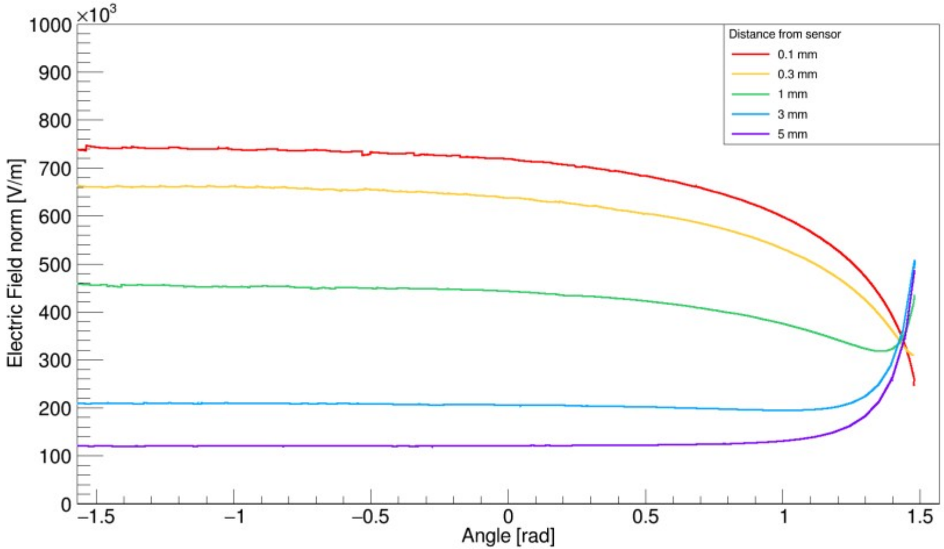
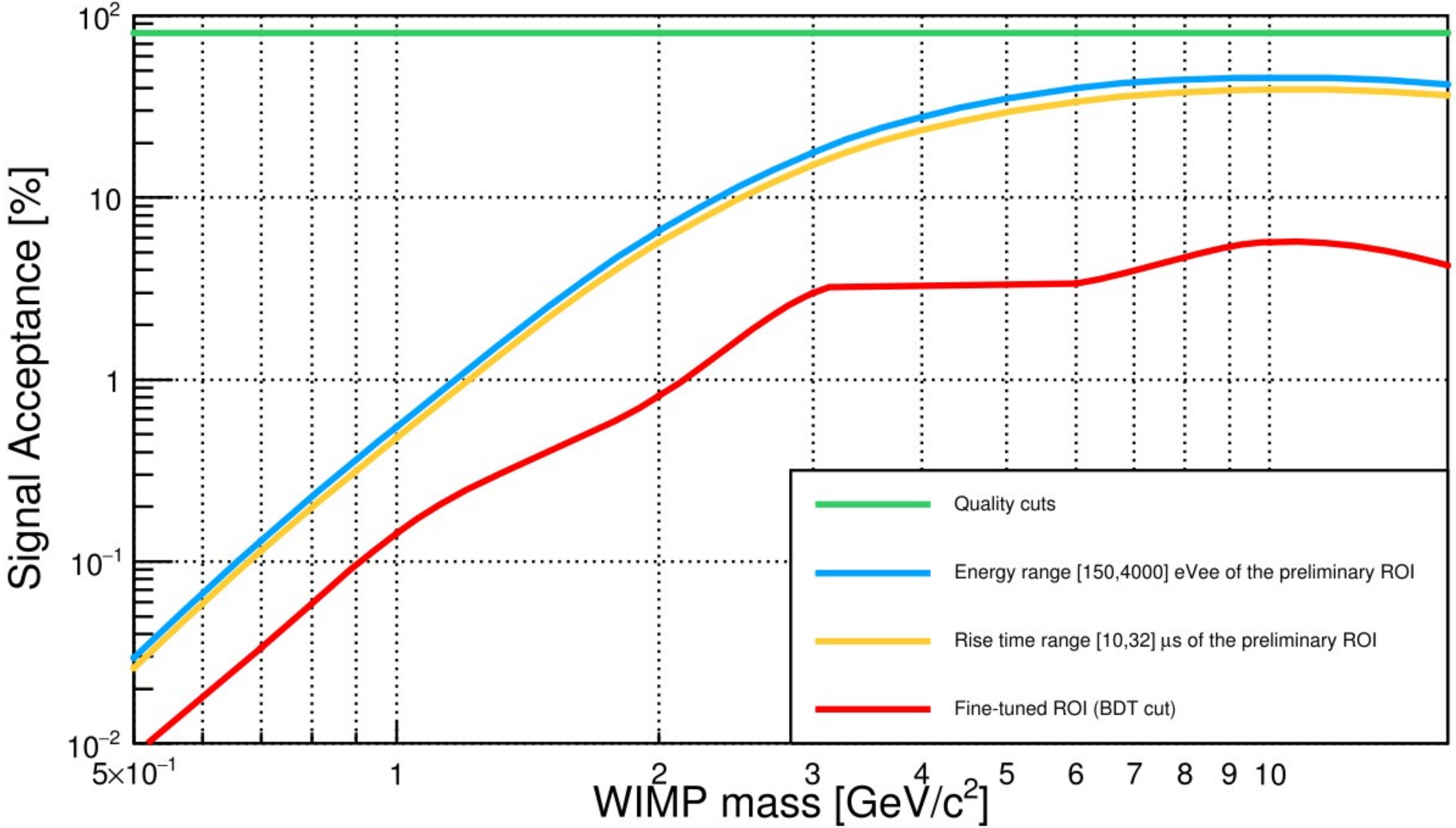
Energy [eVee]

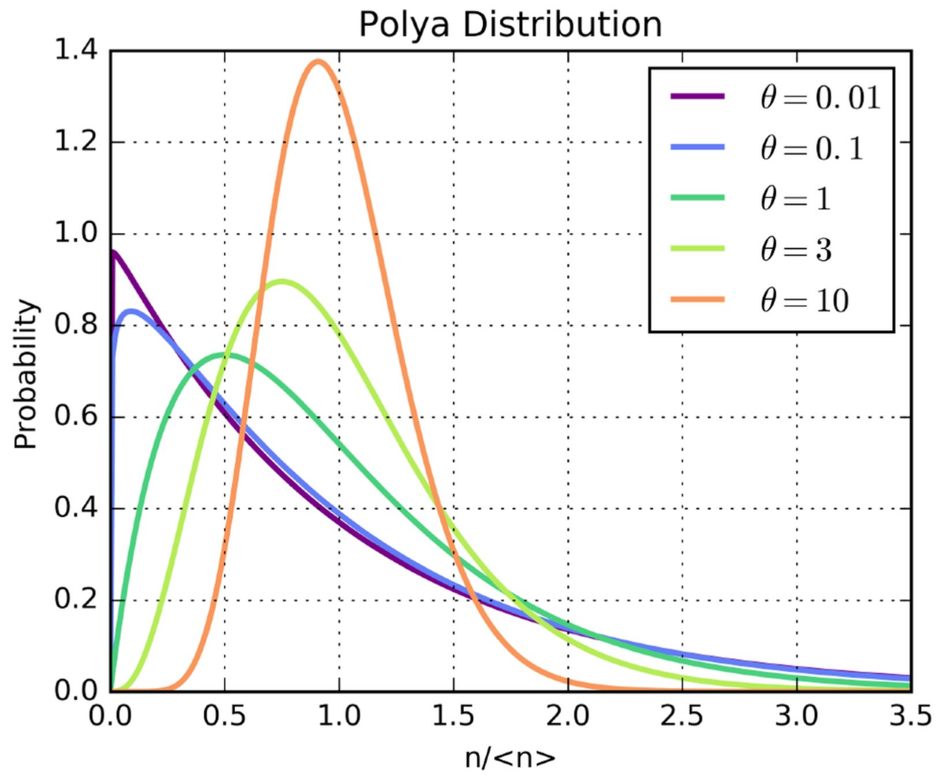

Surface: Champ électrique, norme (V/m)
θ = 0
θ
×10^5


Distance from sensor
0.1 mm
0.3 mm
1 mm
3 mm
5 mm
Electric Field norm [V/m]
×10^3
Angle [rad]

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

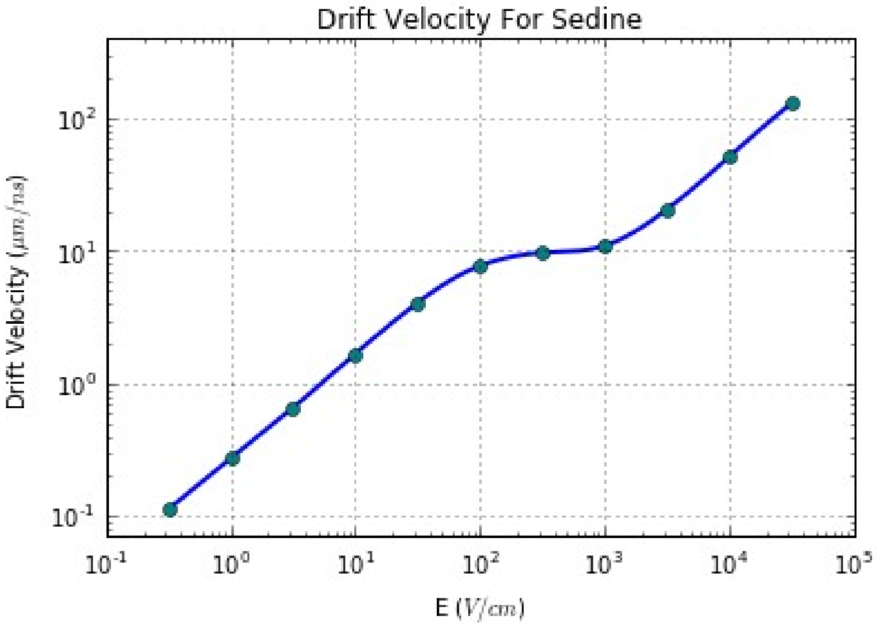


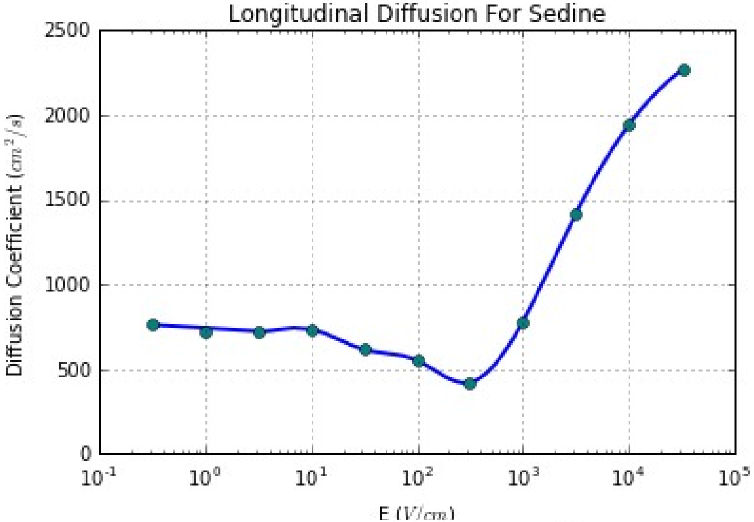
Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018) doi: 10.1016/j.astropartphys.2017.10.009

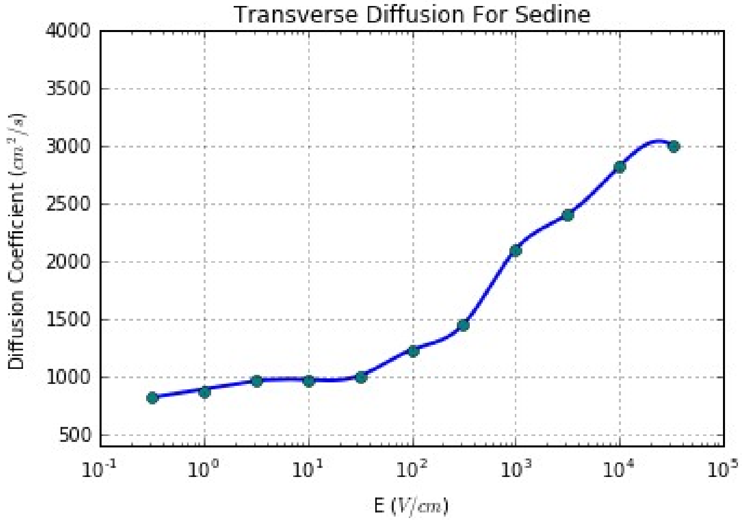


$$P\left(\frac{n}{\langle n\rangle}\middle|\theta\right) = \frac{(1+\theta)^{(1+\theta)}}{\Gamma(1+\theta)}\left(\frac{n}{\langle n\rangle}\right)^{\theta} e^{-(1+\theta)\frac{n}{\langle n\rangle}}$$

Drift Parameters from MAGBOLTZ







Effect of Energy Resolution

Neon target, Gaussian smearing, 100 eV threshold