New Experiments With Spheres -Gas
Light Dark Matter search
NEWS-G LSM results and SNOlab project

Principles of gaseous spherical detector

Light Dark Matter search with SEDINE at LSM

NEWS-SNO project, future ideas

Outlook

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Queen's University

EDU 2017

Qui Nhon-ICISE– July 27th 2017

Canada Excellence Research Chairs

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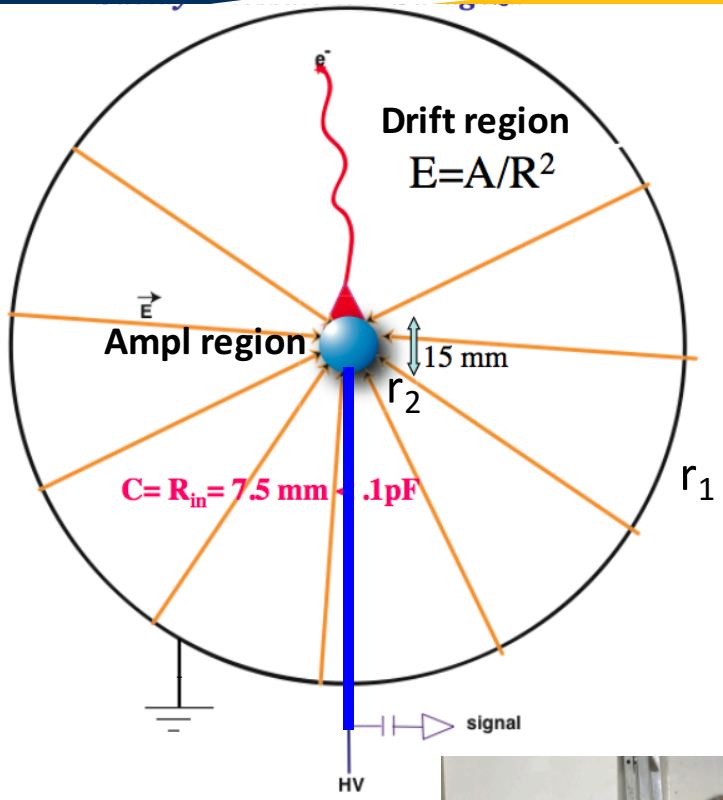
Spherical gas detectors
New Experiments With Spheres



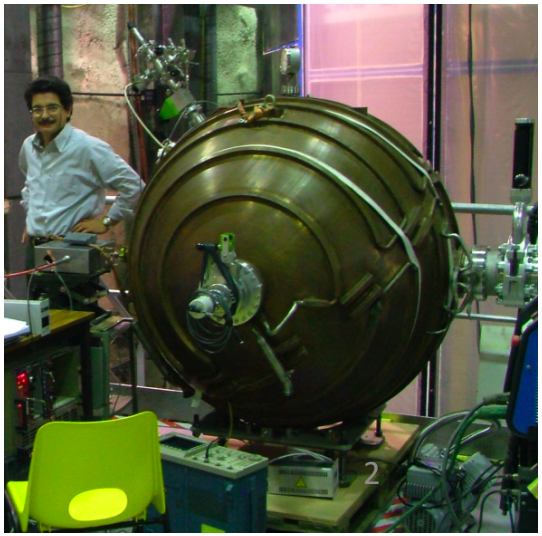
- Sphere cavity + spherical sensor + HT
- => **Low threshold (low C), does not depend on size**
- **Fiducial volume selection by risetime**
- **Flexible (P, gaz)**
- Large mass / large volume (30 kg) with single channel
- Simple, sealed mode
- 2 LEP cavity 130 cm Ø tested
- **1 low activity 60 cm Ø in operation @ LSM**

$$C = 4\pi\epsilon\rho$$

$$1/\rho = 1/r_2 - 1/r_1$$

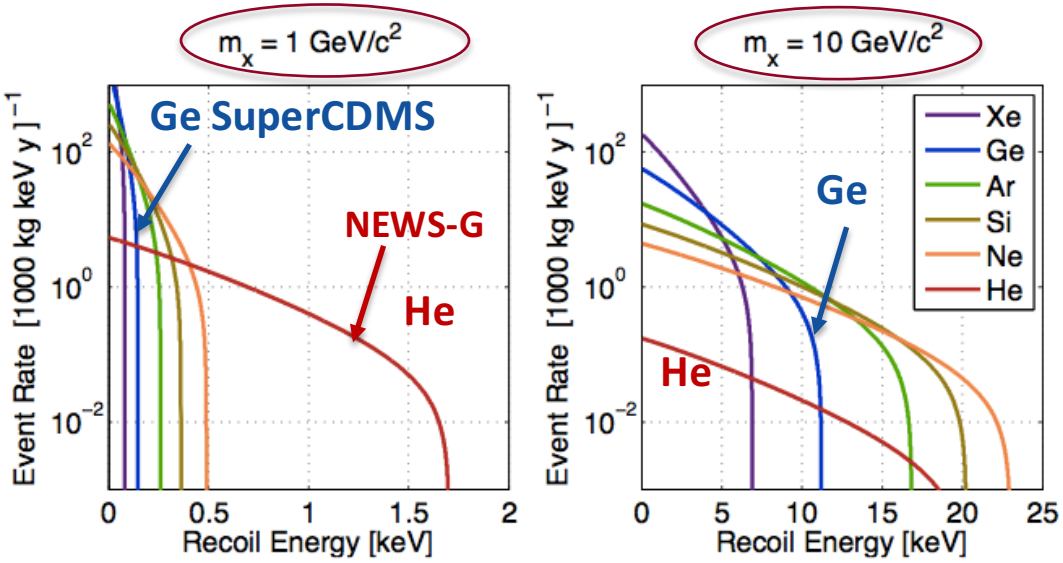
$\rho \approx r_2$

$$E(r) = \frac{V_0}{r^2}\rho$$



Detection of “low mass” flying particle

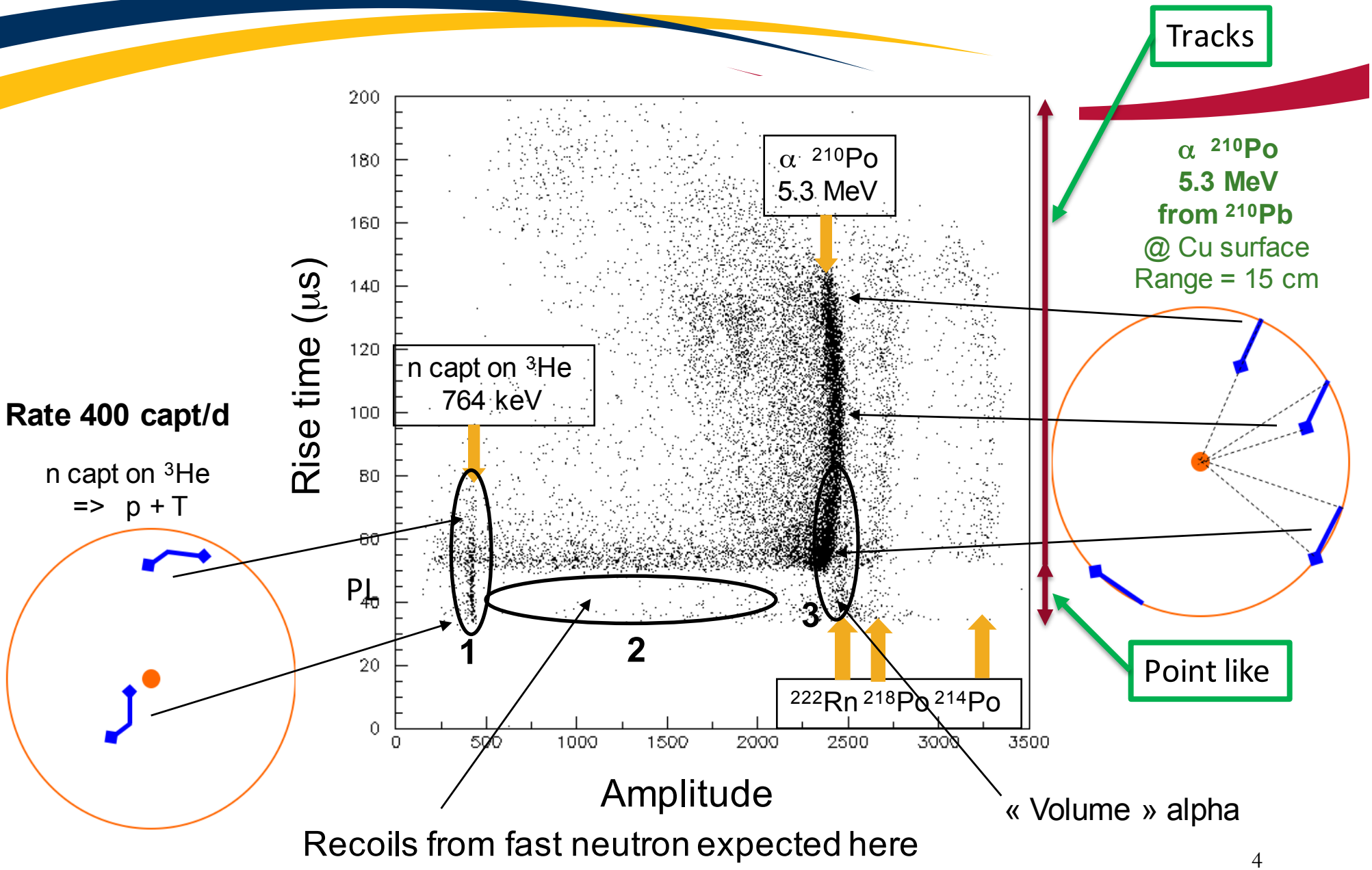
- Kinematical match
- To detect **flying ping pong balls** is it better to have as **target** :
  - **lead** “petanque” balls
  - or **ping pong** balls ?
- => use light nuclei to detect light WIMPs
- H, He, Ne lightest among noble gas



Recoil distributions with various targets

Illustration of particle identification at MeV energy

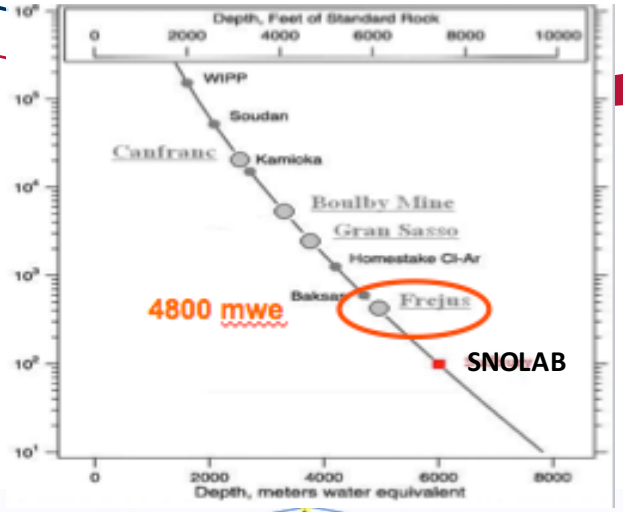
Ar/CH_4 + 3g ^3He @ 200 mb SPC 130cm Ø @ LSM

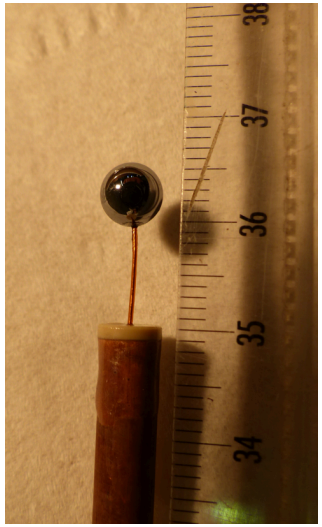


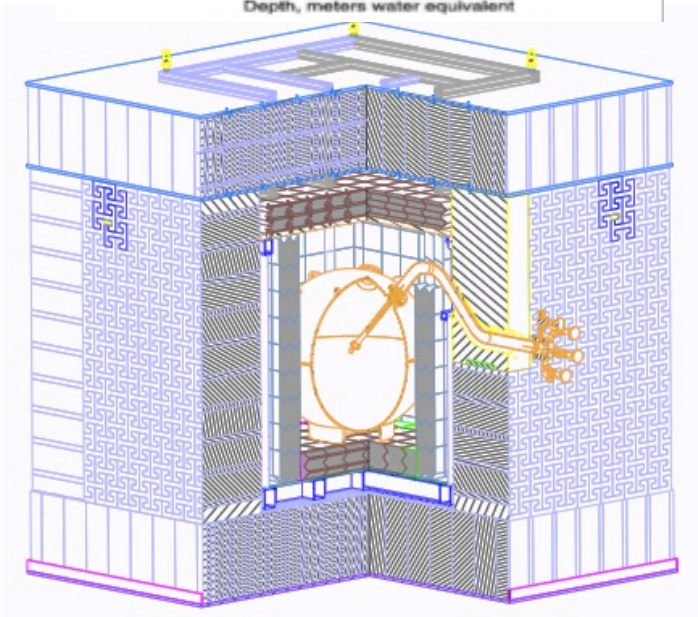
Light WIMP search NEWS-G @LSM
Low activity 60 cm Ø prototype : SeDiNe

- Copper vessel equipped with 6 mm Ø sensor
- Runs with **Neon**+0.7%CH_4 @ 3.1 bars
- => 310 g sensitive mass
- Several internal cleanings for radon deposit removal
- 42 days run for WIMP search

Laboratoire **S**outerrain de **M**odane







60 cm NOSV copper vessel

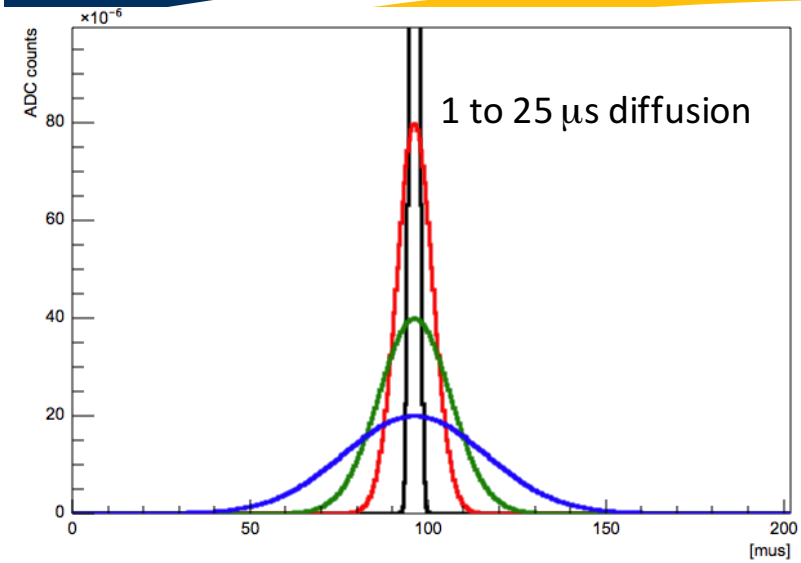
6.3 mm sensor

Shields 4 to 7 cm Cu, 10 cm Pb, 30 cm PE

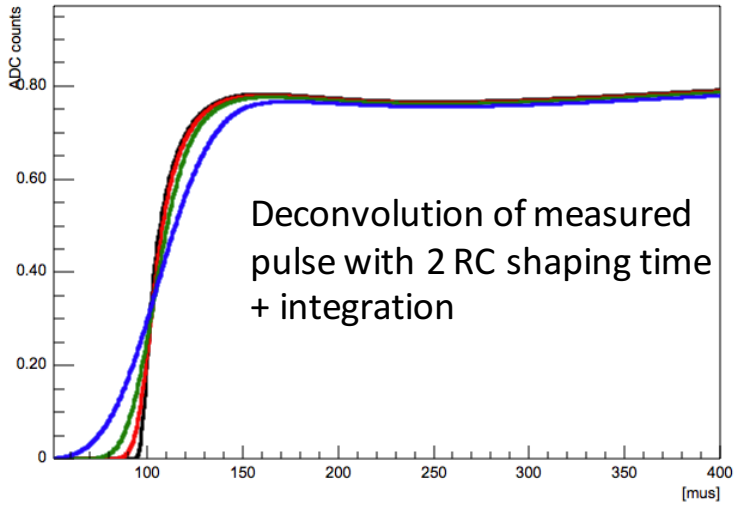
Operation and data taking conditions

- **Use of 3100 mb Ne/CH4 mixture with 0.7 % CH4 (penning effect expected)**
- 6N Ne, 5.5 N CH_4
- Energy to ionize a single electron in Neon w= 36 eV
- High Voltage on sensor set to **2520 V**, no sparks
- **Gain around 3000**
- **Sealed mode, no recirculation**
- Amplifier Canberra 2006 with 50 μs RC decay constant
- Analog signal digitized at 2 MHz, stream fed into DAQ which operates soft trigger after filtering
- **Data taking continuously during 42 days => 9.7 kg.d**
- **Acquisition threshold**
  - **set at 30 ADU, around 50 eV**
  - set not to keep any noise in stable conditions
- **Loss of gain 3 % along 42 days monitored with ^{210}Po line** + variation on days scale of +- 4%
- Calibrations in energy with ^{37}Ar gazeous source (from n,α reaction on ^{40}Ca) and with 8 keV line from Cu fluoresence duriing data taking

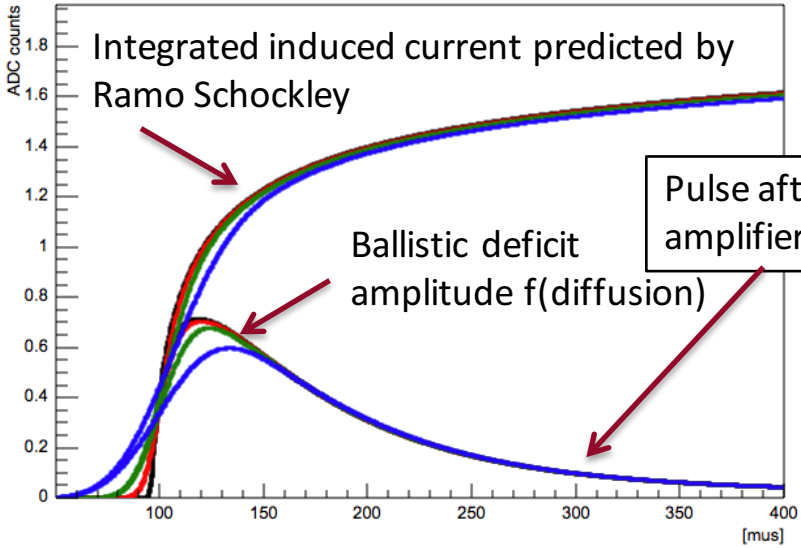
Pulse formation and simulation

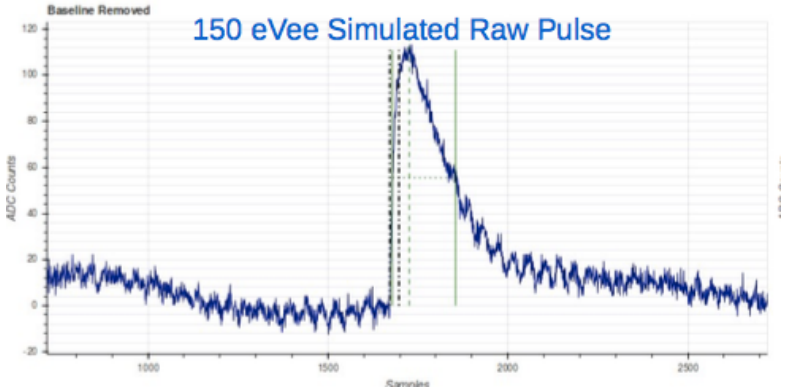


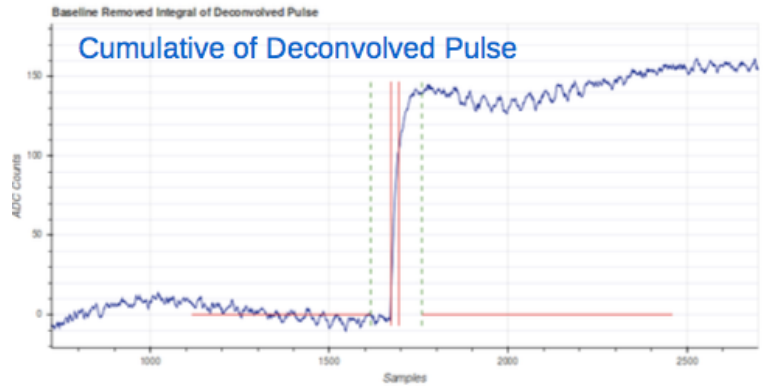
Primary pulse : arrival times of primary electrons



Paco Vasquez de Sola PhD







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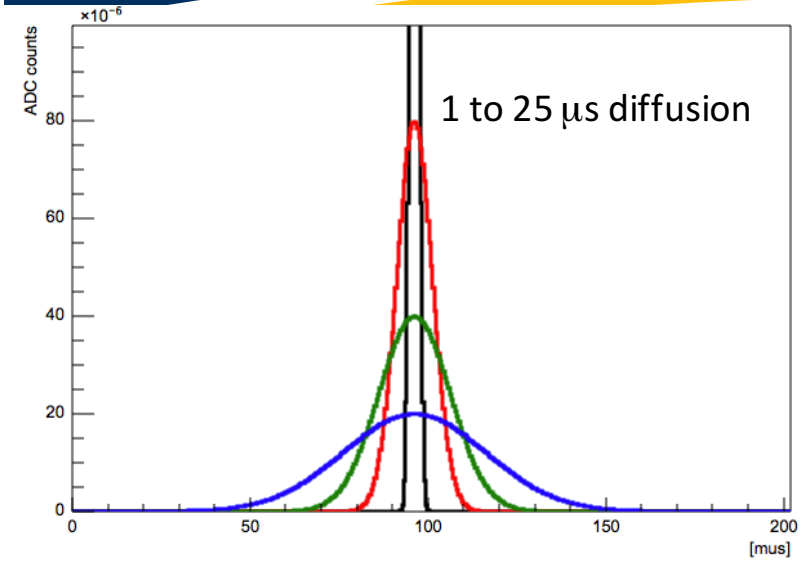

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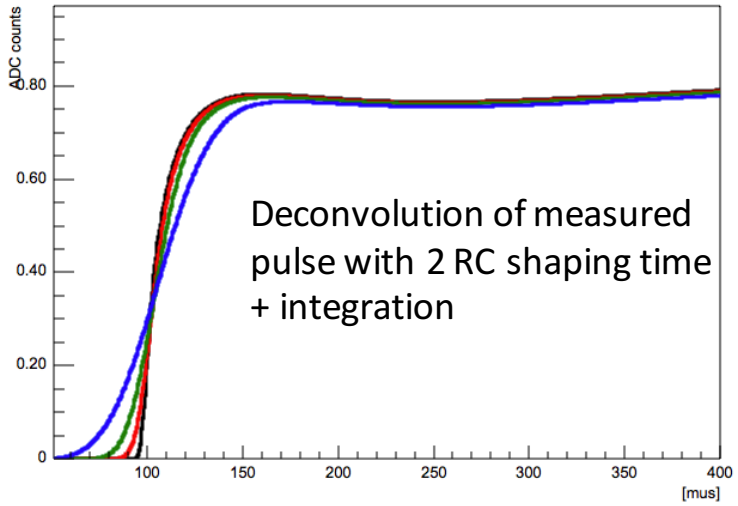
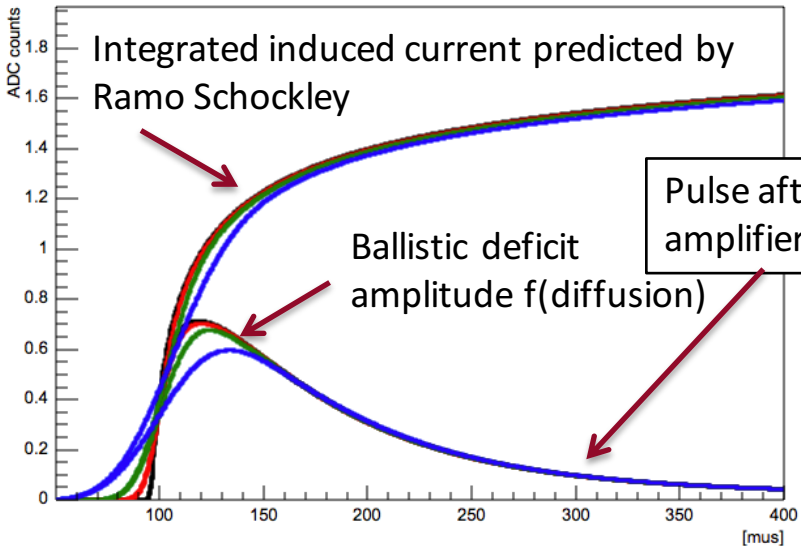
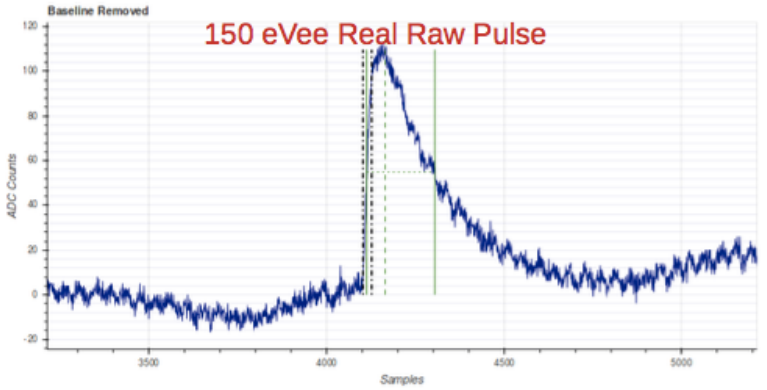
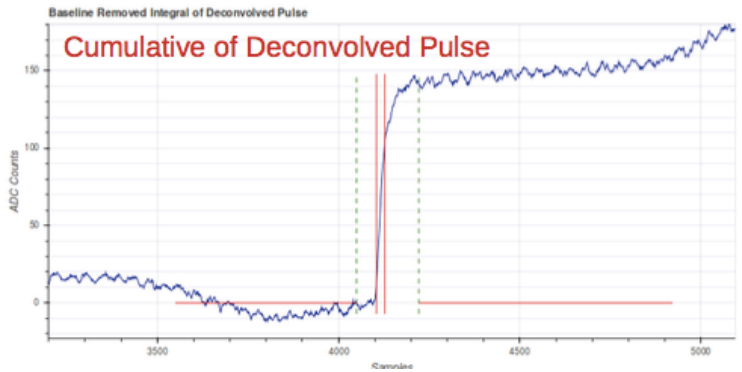
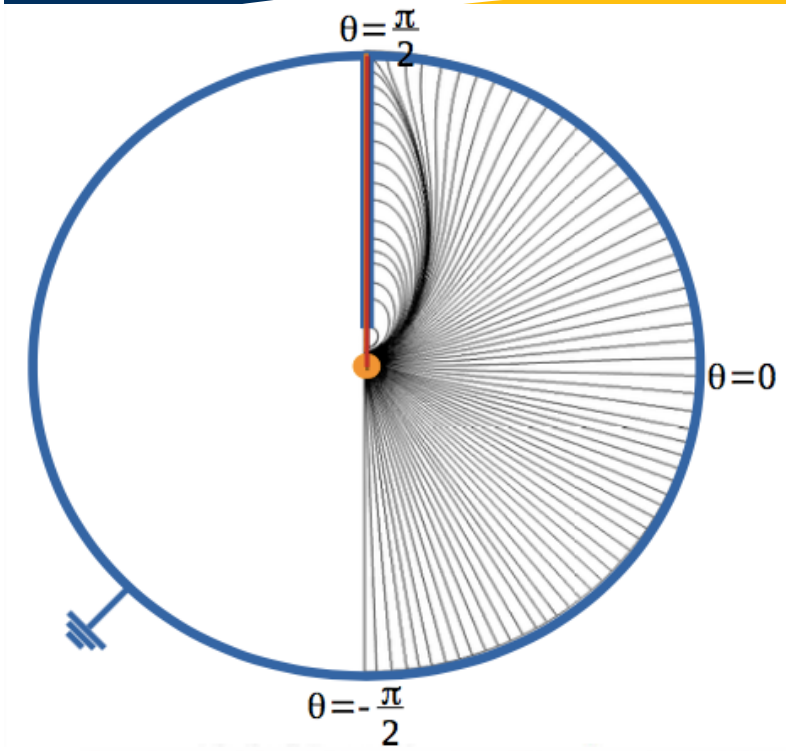








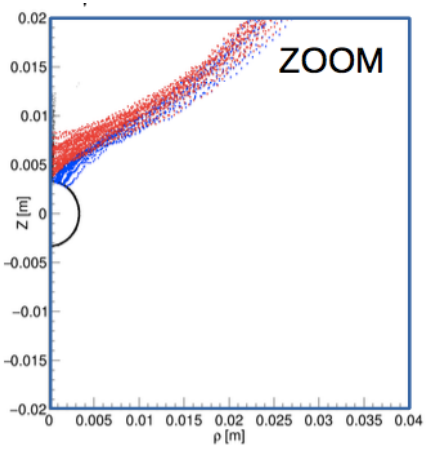
Detailed simulation of electric field and transport



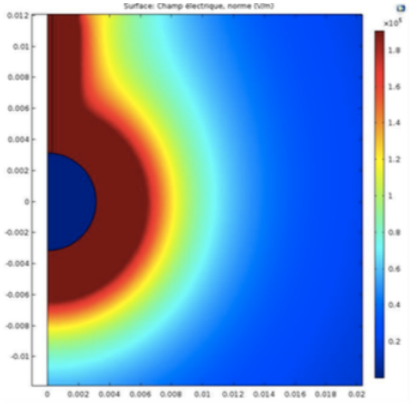
Non fully radial field => dependance on teta of

- drift velocities / diffusion
- avalanche gain

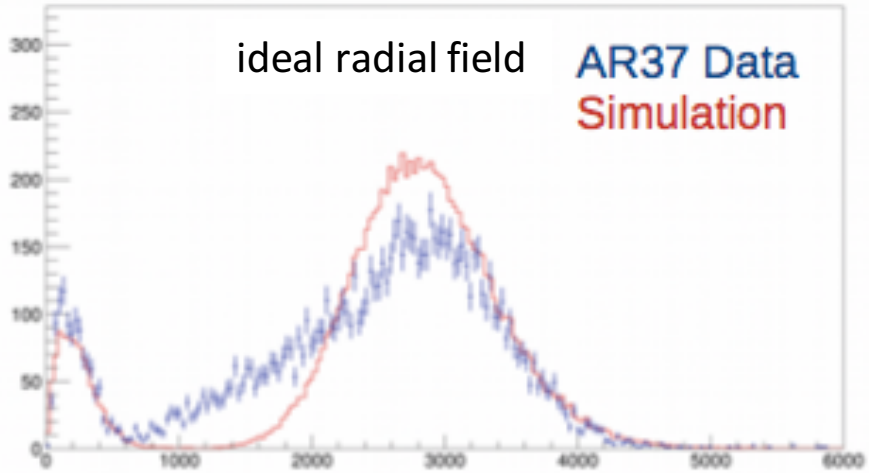
Simulated/parametrised through Comsol/Magboltz

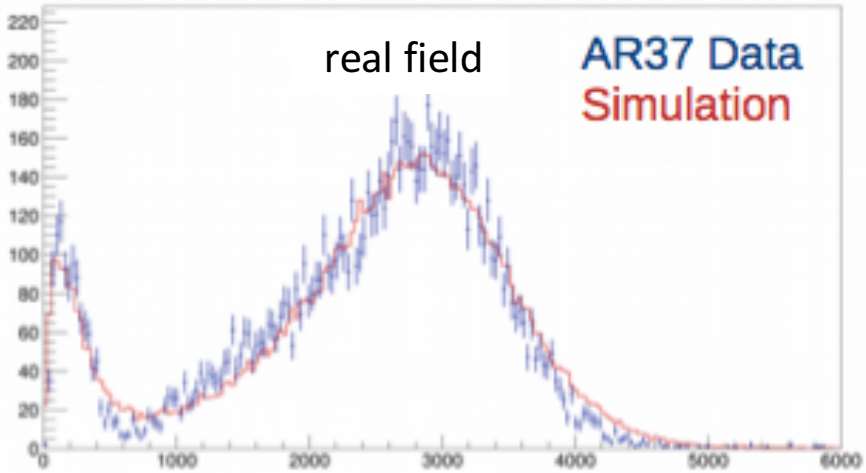


Drift at high teta



Field near sensor

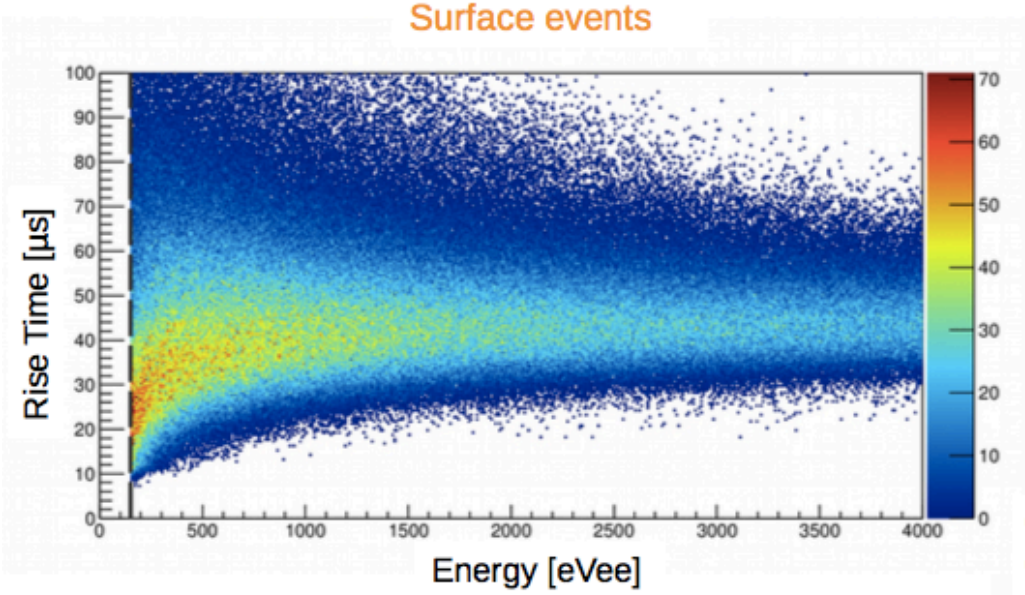




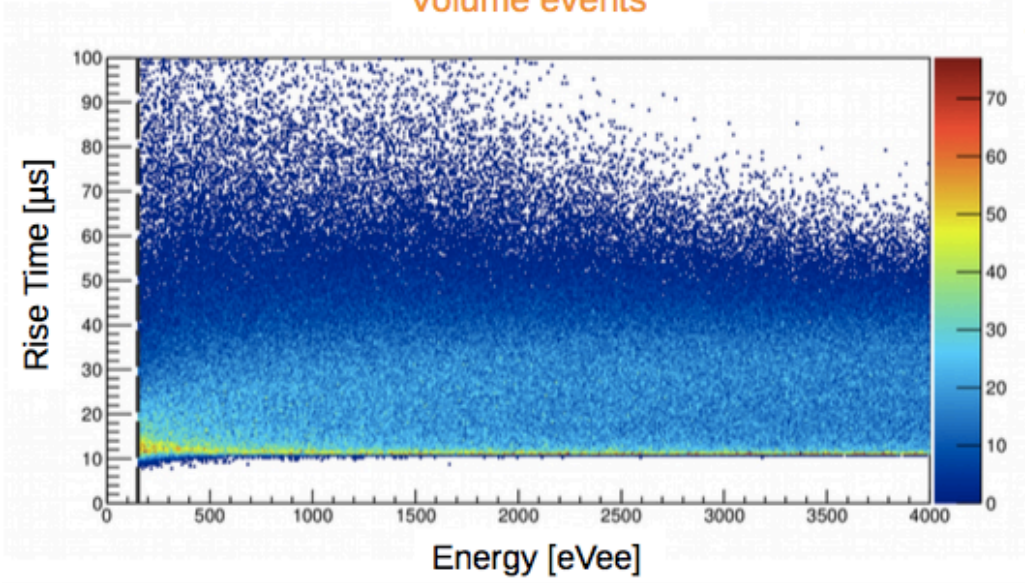
Data and simulations of two main expected populations

Simulations

Surface events



Volume events



Physics-run Data

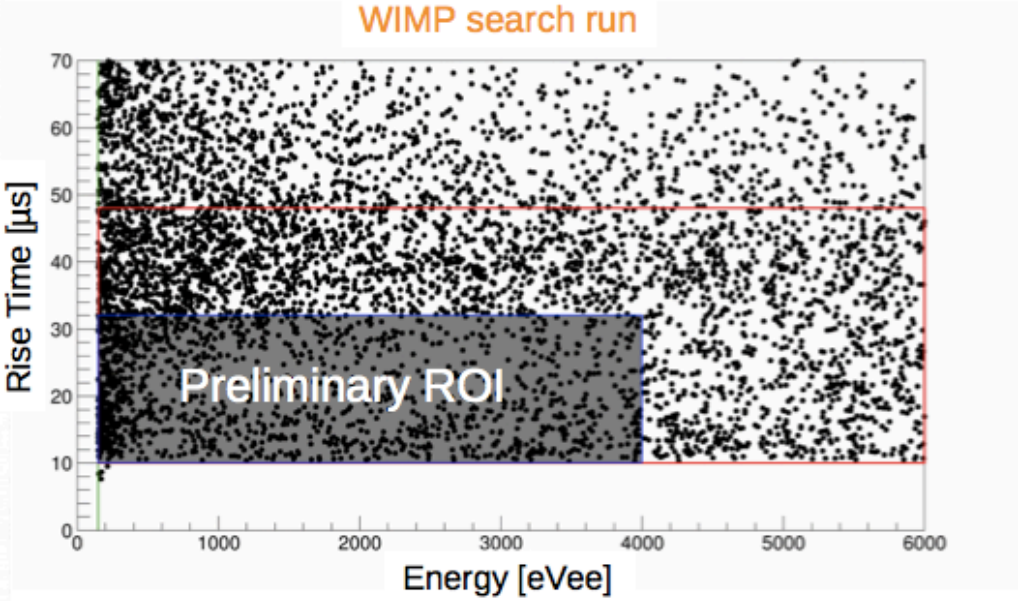
Quality cuts responsible for 20.1 % dead time

Total exposure = 34.1 live-days x 0.28 kg = **9.7 kg.days**

Analysis threshold : 150 eVee (~720 eVnr)

100% trigger efficiency (trigger threshold @ ~35 eVee)

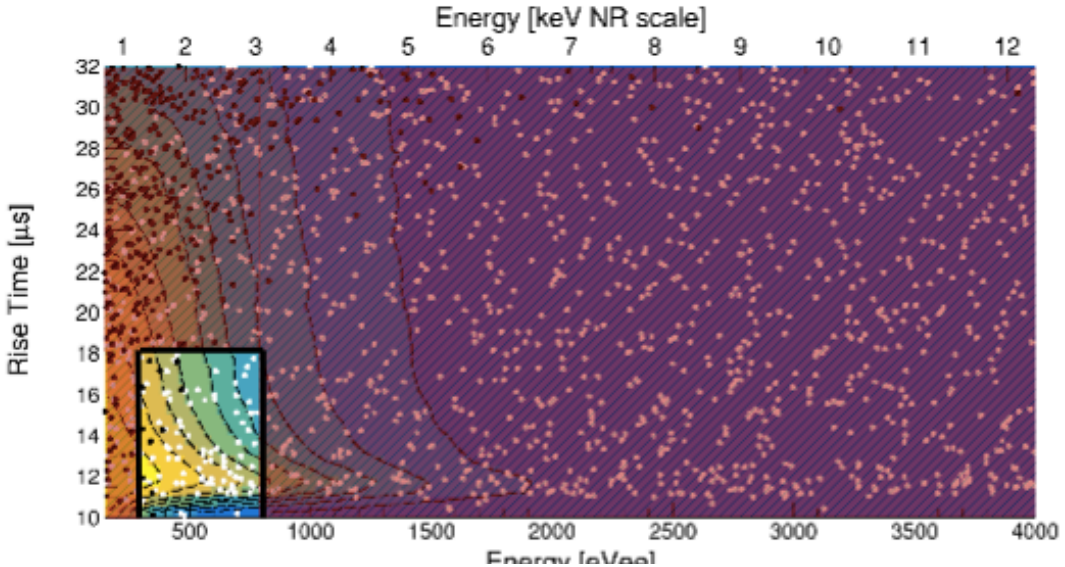
WIMP search run

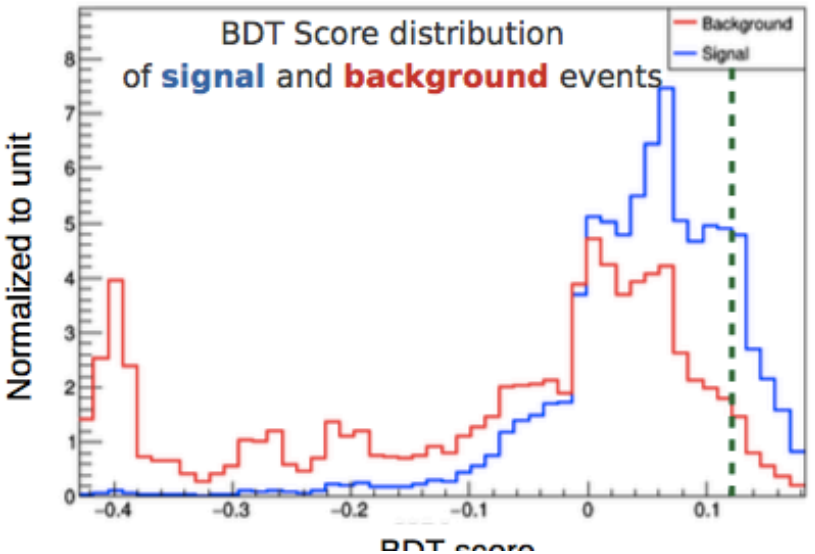


Side Band region used together with simulations to determine the number and distribution of background events expected in the **preliminary ROI**

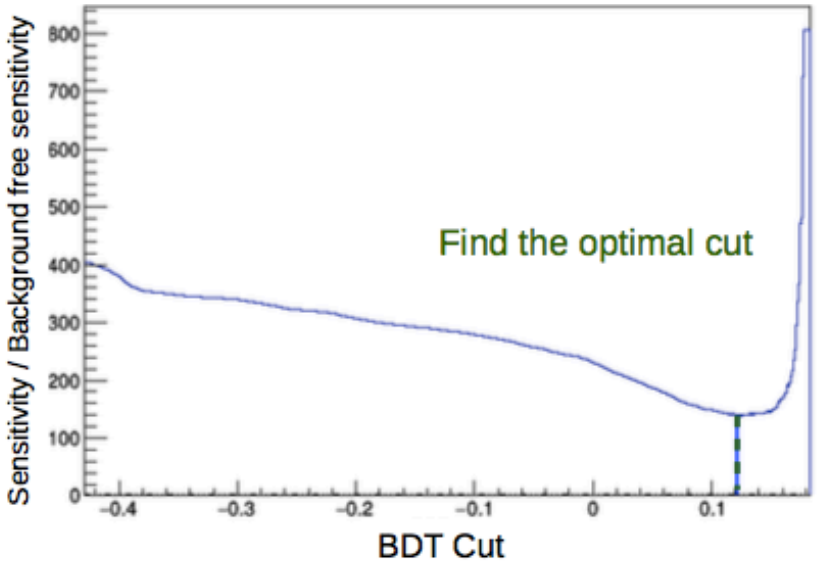
Further tuning of the ROI performed with a Boosted Decision Tree (BDT)

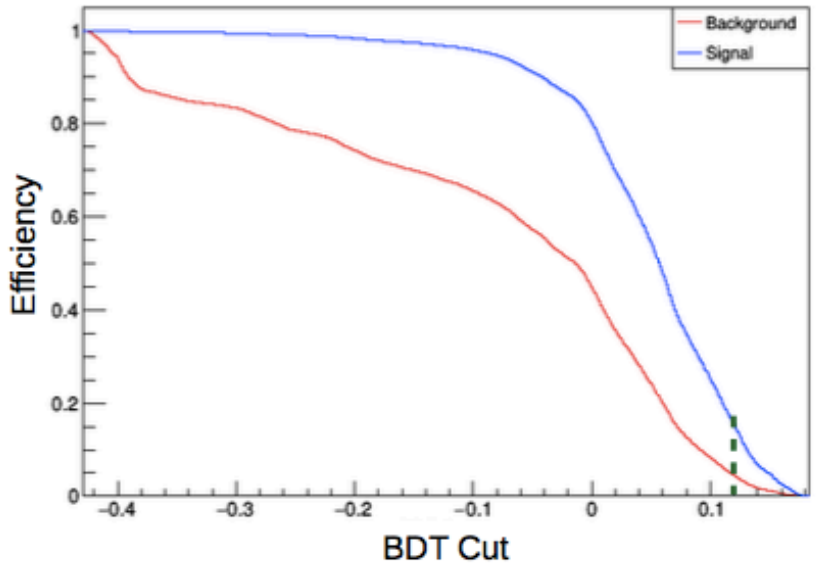
Boosted Decision Tree method



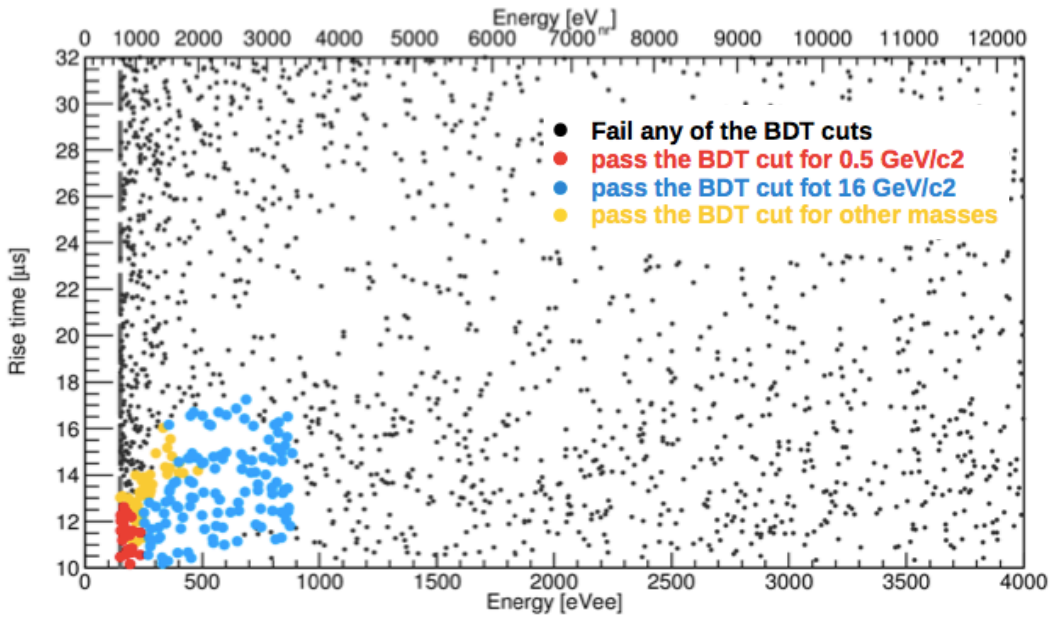


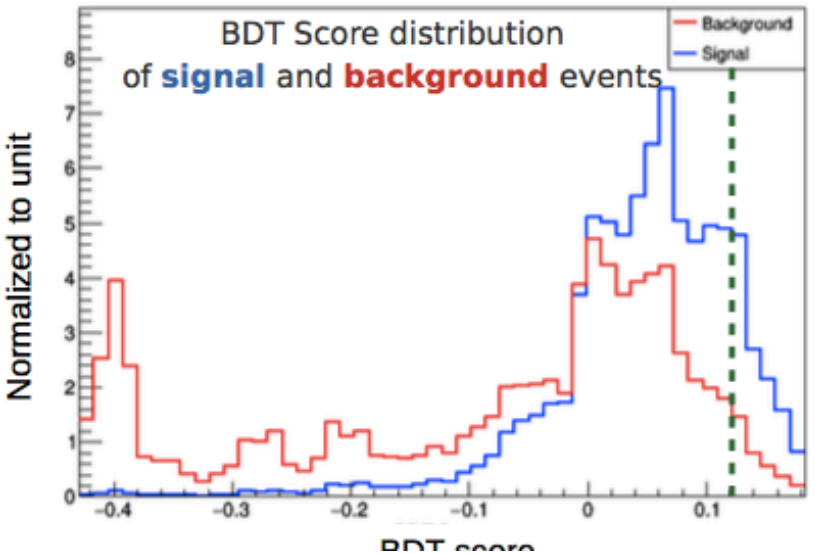
While this method gives conservative limits if inaccurate background models were to be used for the training of the BDT, it assumes we know very well the response to signal (volume/compton/NR recoil), ie behaviour of RiseTime vs Energy for WIMP's





Boosted Decision Tree method





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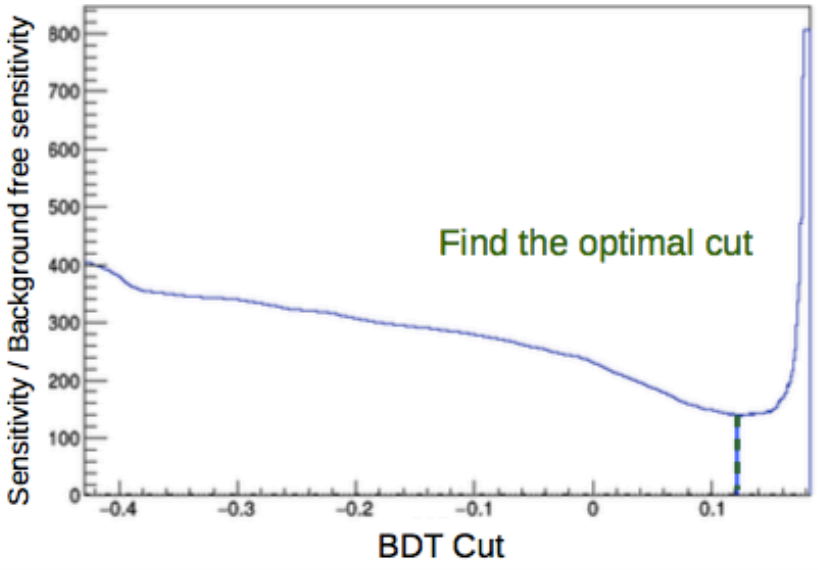
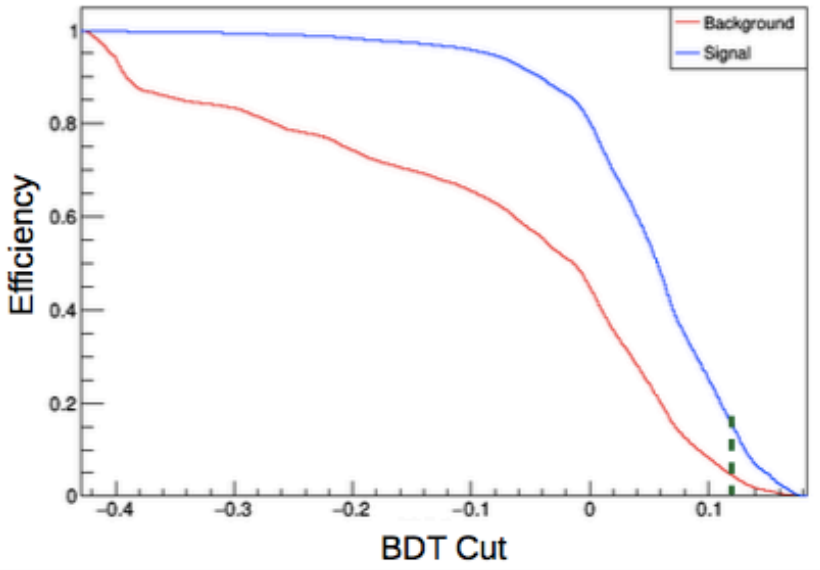
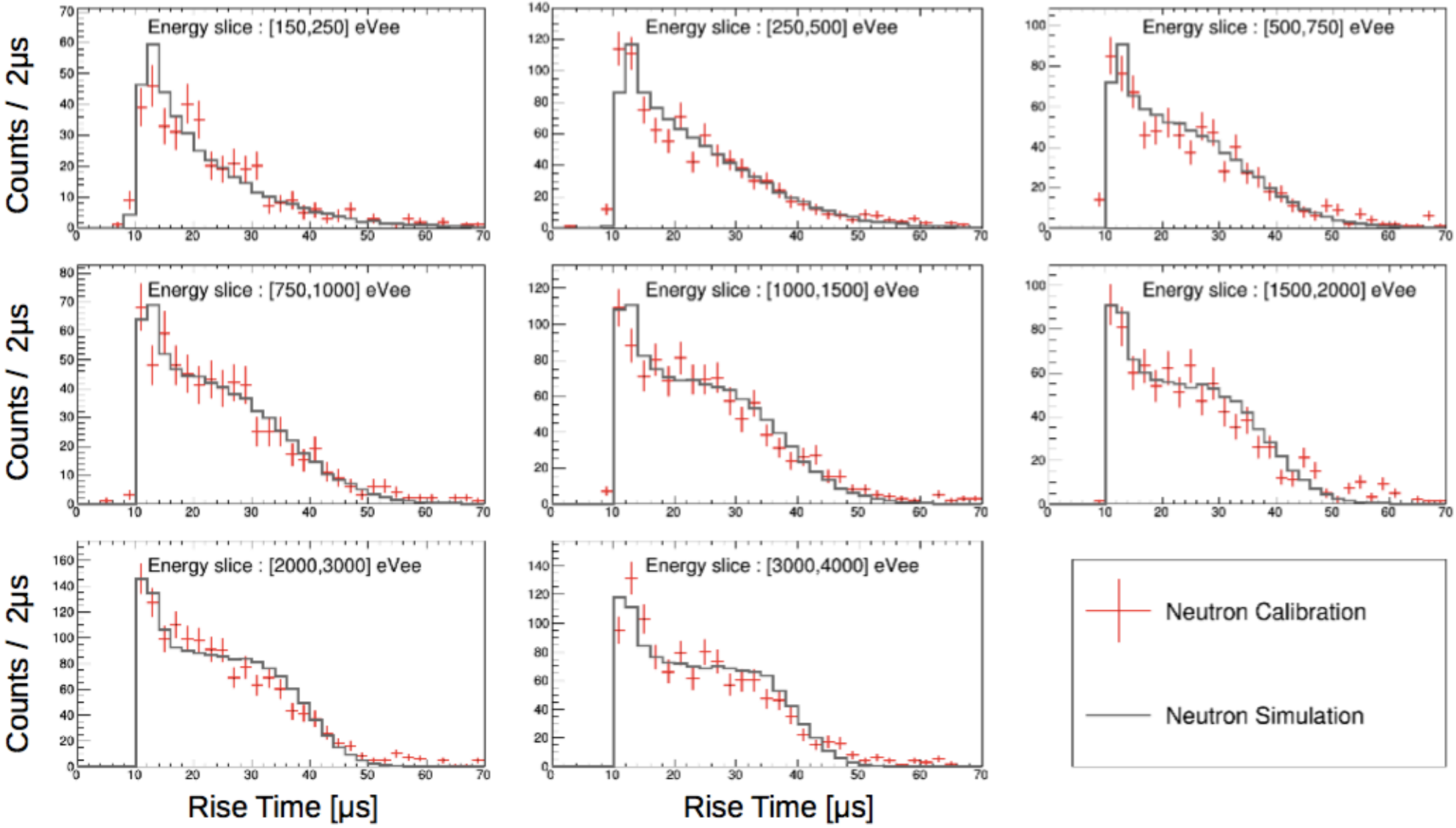


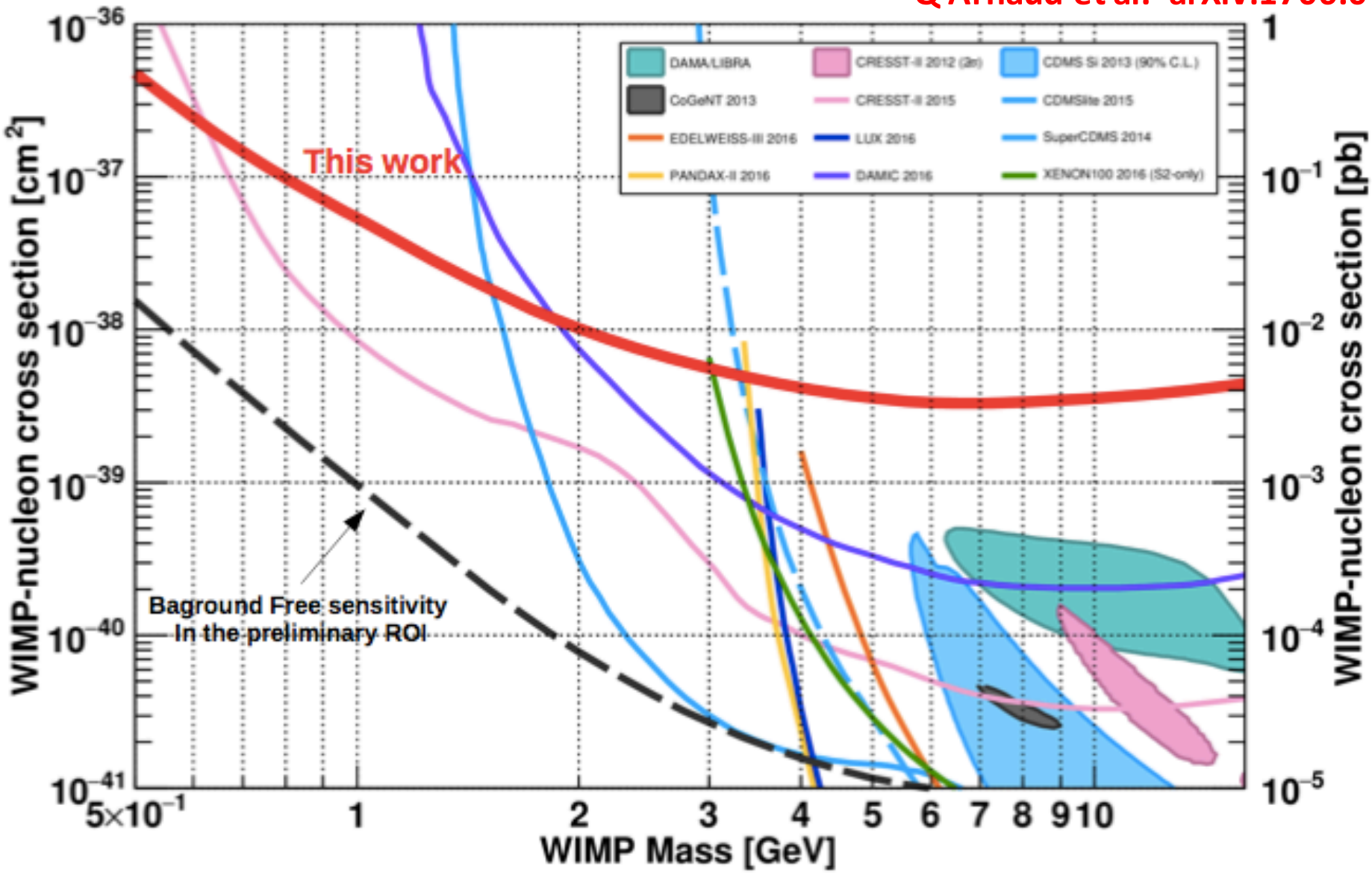


Volume events : comparison of simulation with neutron calibration data with Am-Be source



Sensitivity of NEWS-G -LSM to Spin Independent couplings WIMPS

Q Arnaud et al. arXiv:1706.04934



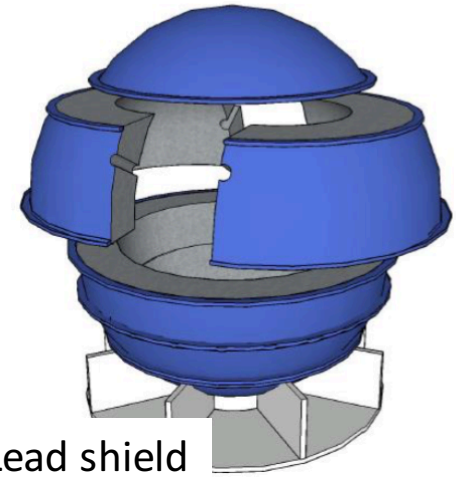
Limit set on spin independent coupling WIMPs with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

Systematics on energy calibration / quenching factor / polya parameter / fiducial mass <30 % at lowest energy

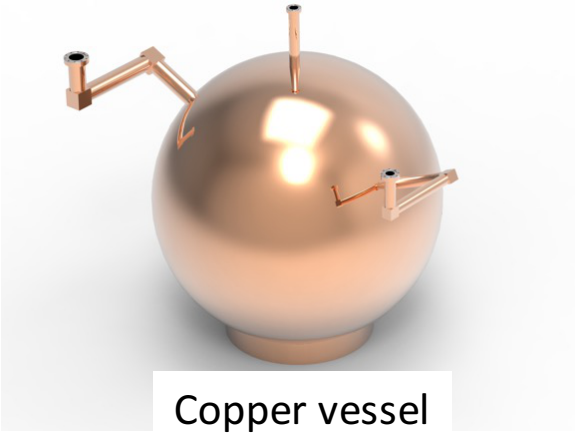
140 cm diameter project with compact shield option

implementation at SNOLAB by 2018

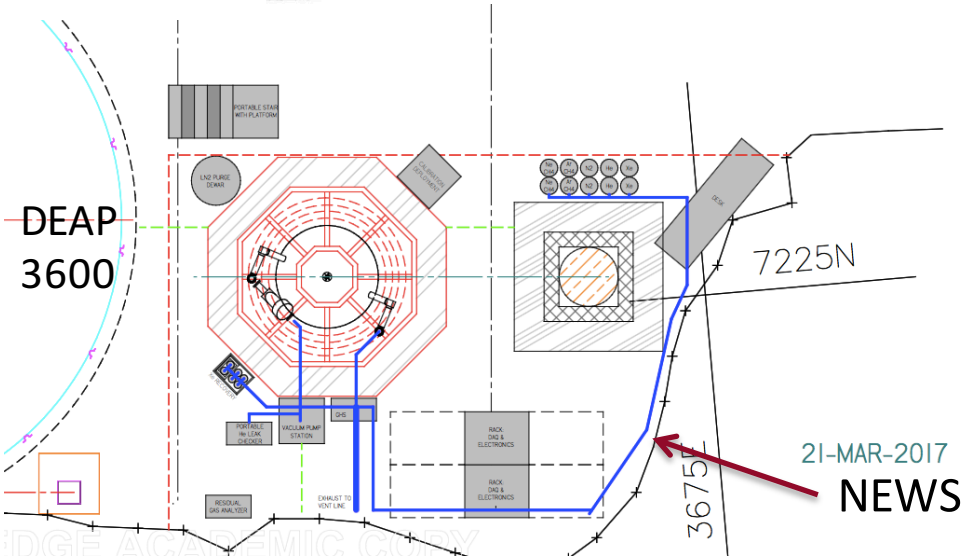
- 140 cm Ø detector, 10 bars, Ne, He, CH_4
- 25 cm compact lead –3cm ancient - LSM
- 40 cm PE + Boron sheet



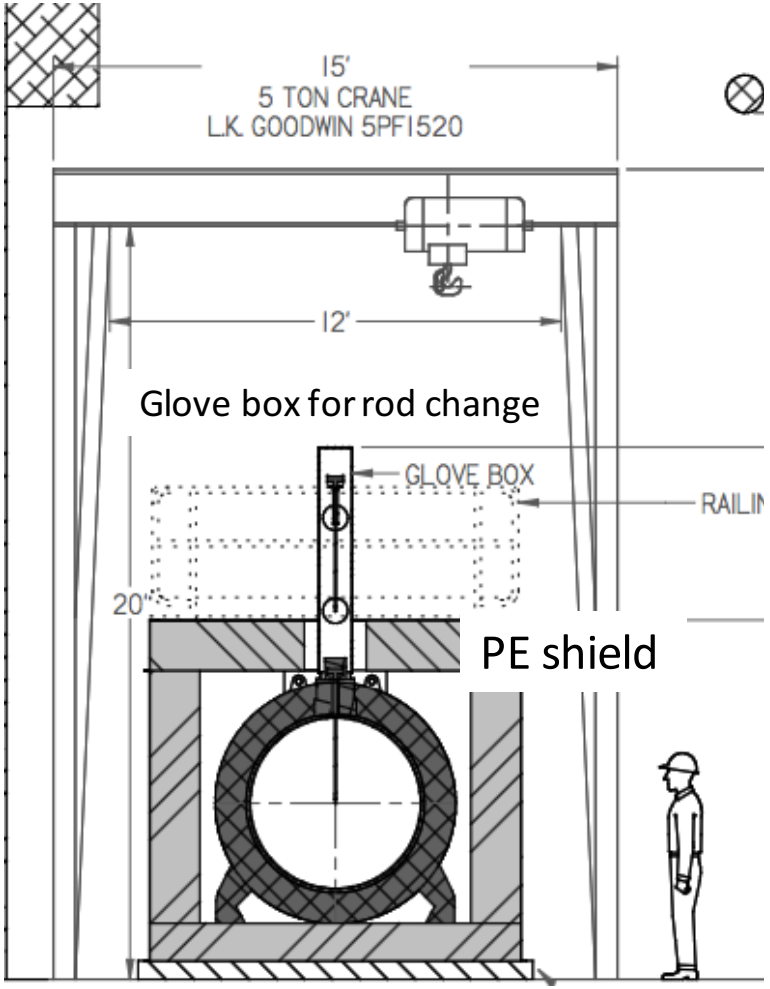
Lead shield



Copper vessel



NEWS-G in Cube Hall



35 t shields

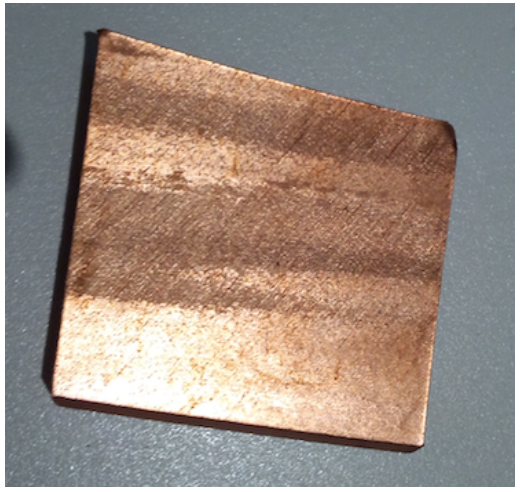
EDGE ACADEMIC COPY

Hemisphere spinning test and clean up

Plate of C10100 15 mm thick was spinned
Samples from spinned hemisphere

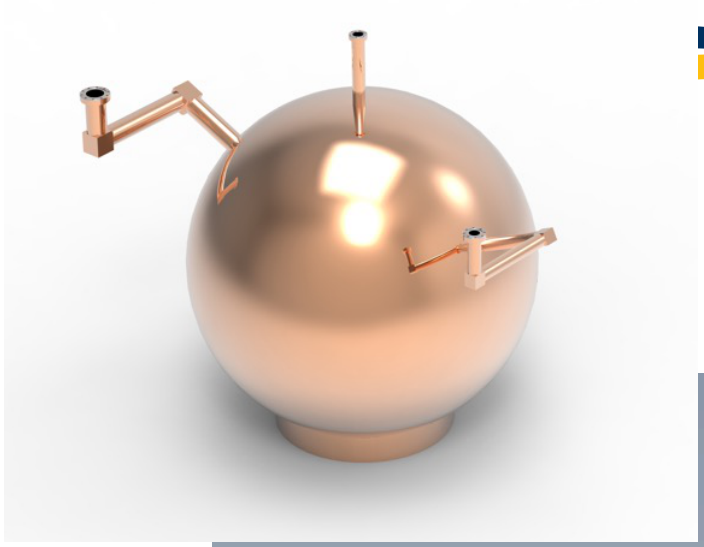
- PNNL measurements of bulk and surface
⇒ 7 to 25 μBq/kg of Th
⇒ 1 to 5 μBq/kg of U
Ok for goals fixed of first expt

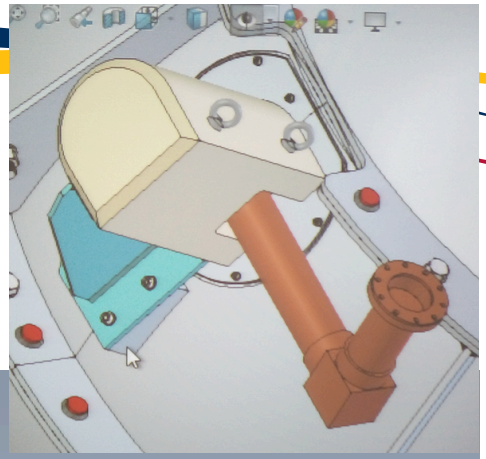
- Test of **surface cleaning** with HP water jet tests
  - -3000b water jet => 30 μ removal
  - -Possible but -too- expensive
- Going to electropolishing/electroplating

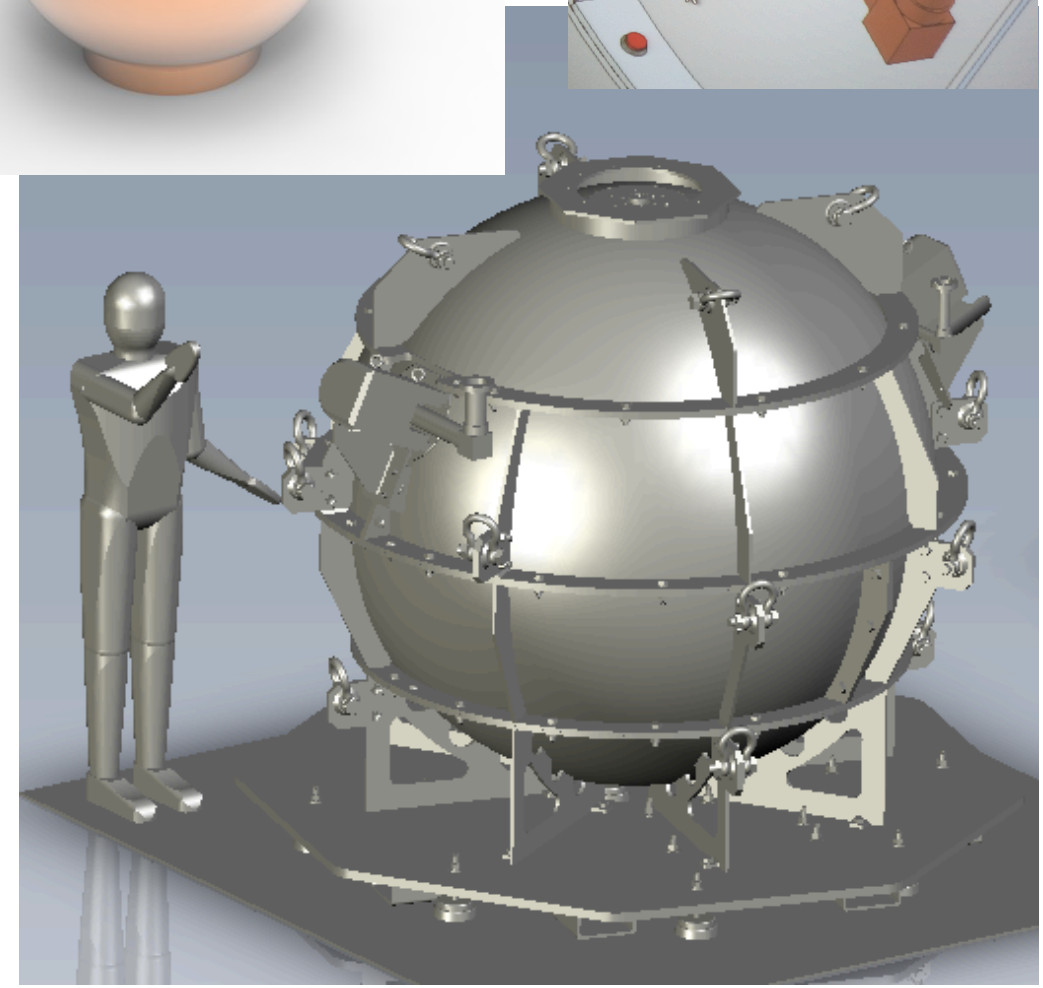


- Electron welding of hemispheres and piping

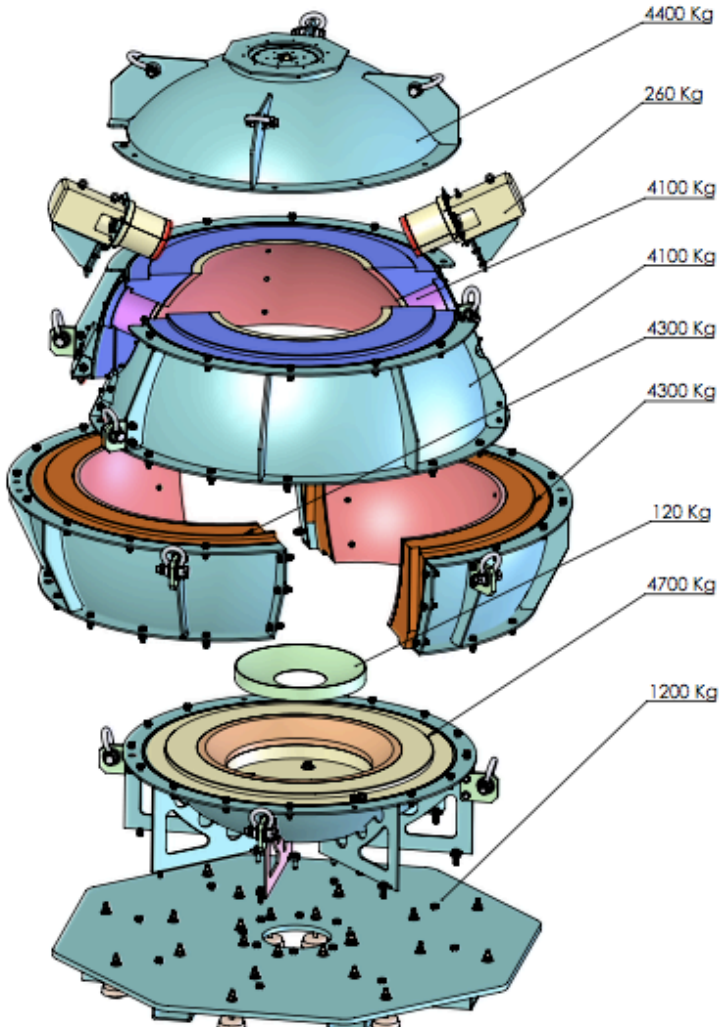
TDR – construction phase







Optimised part splitting for transport/mount at SNOLAB



Background budget (simulation)

Simulation done with 12mm thick 140cm diam copper sphere full with 99% Ne 1%CH4, 11.43 kg of gas

Source Position	Mass (kg) or Surface (cn		Source	evts/kg/day/[(µBq/kg) or (nBq/cm2)]	contamination	units	evts/kg/day < 1ke
CopperSphere	627.83 kg		Co60	0.0018	30	µBq/kg	0.054
CopperSphere	627.83 kg		U238	0.0036	3	µBq/kg	0.011
CopperSphere	627.83 kg		Th232	0.0049	12.9	µBq/kg	0.063
InnerSurface	57255 cm^2		Pb210	0.012	0.16	nBq/cm2	0.002
ArchLead	2108.95 kg		U238	0.001	61.8	µBq/kg	0.062
ArchLead	2108.95 kg		Th232	0.0011	9.13	µBq/kg	0.010
Rod	0.0931721 kg		Co60	2.95E-007	30	µBq/kg	0.000
Rod	0.0931721 kg		U238	1.81E-006	3	µBq/kg	0.000
Rod	0.0931721 kg		Th232	2.11E-006	12.9	µBq/kg	0.000
Wire	2.66005e-05	kg	Co60	1.48E-010	31000	µBq/kg	0.000
Wire	2.66005e-05	kg	U238	2.12E-009	300000	µBq/kg	0.001
Wire	2.66005e-05	kg	Th232	1.42E-009	50000	µBq/kg	0.000
Wire	2.66005e-05	kg	K40	5.41E-010	1660000	µBq/kg	0.001
LabArea			**Tl208/K40**				0.076
						Total	**0.279**

Copper

Internal surface

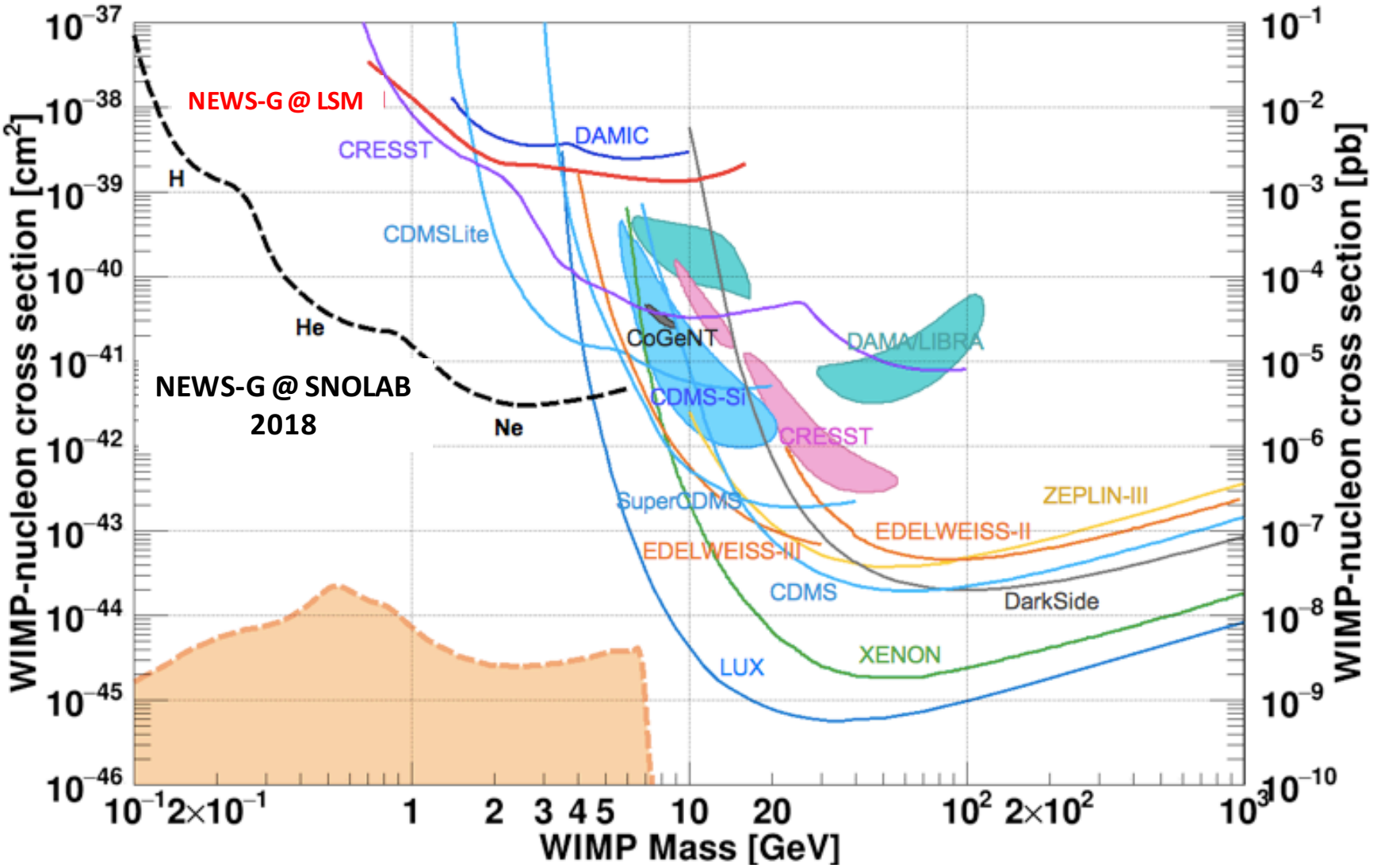
Lead shield

External bckg with SNOLAB flux

Currently investigating impact of ^{210}Pb in bulk of copper and mitigation

Hypothesis for WIMP sensitivity limit calculation : 100 kg.d, 1 electron threshold

Projections for NEWS-G wrt current situation



Upgrades : copper electroformed sphere

Electroforming the NEWS spheres

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 19

60 cm NEWS prototype

- Center ball and vessel spheres could be a wide range of diameters electroformed as single unit or hemispheres with flange
- 140 cm diameter sphere could be electroformed as a single unit
- Electroforming underground would eliminate cosmogenic ^{60}Co ingrowth
- Plate onto a mandrel made of material which is dissolved when completed
- Growth rate ~ 1mm/month
- Wall thickness of 1 cm grown in 10 months would significantly exceed engineering requirements for 10 atm pressure vessel
- Flanges could be electroformed into place
- Electroformed copper purity:
  - <0.01 pg/g ^{238}U and ^{232}Th, <1.0 ng ^{39}K/g Cu approximately <0.1 μBq/kg Cu
  - <10^{-4} alphas/cm^2/hr after surface etching and passivation

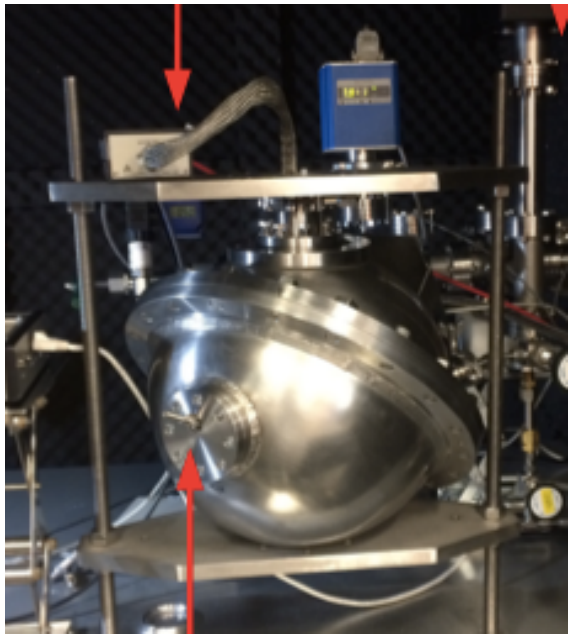
10^{-4} alpha/cm^2/h = 3 10^{-8} decay/cm^2/s= 30 nBq/cm^2 ⇔ few nBq/cm^2

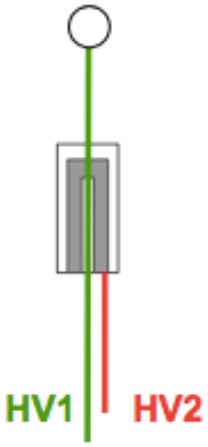
Developments at Queen's

- Use 2mm ball + umbrella sensor in S30
- Tune HV2 to optimise resolution, HV1 =1950 V
- Ar/CH4 (98/2) @ 500 mb

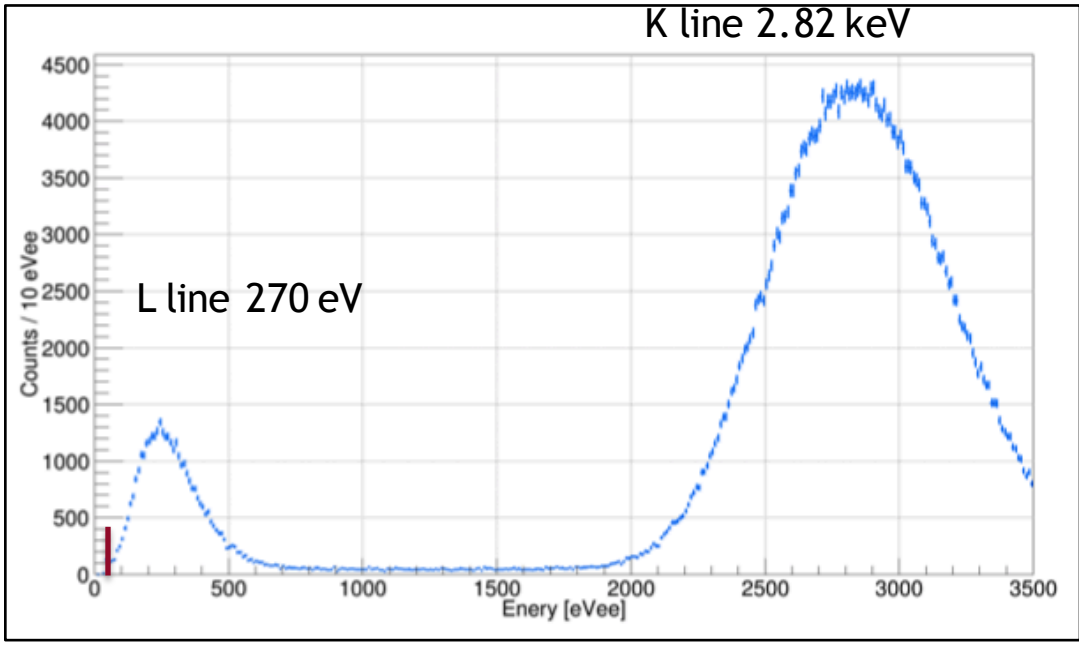
Online trigger ⇔ 10 eV
ie 0.3 electron

30 cm diameter High Pressure



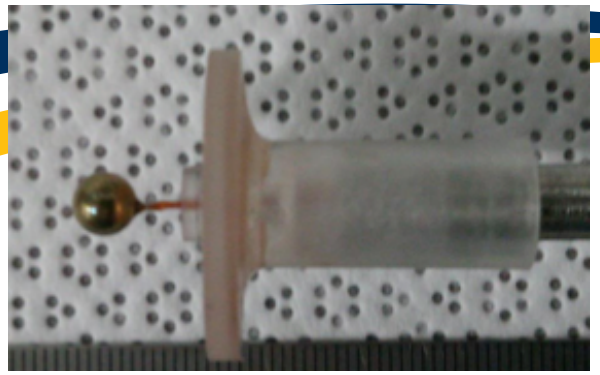


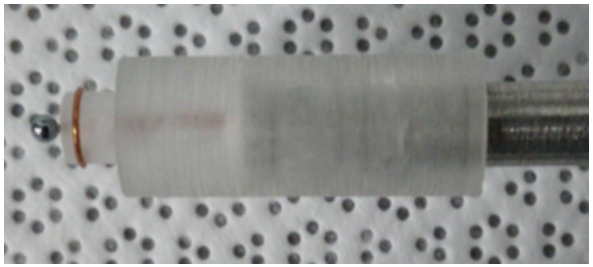
^{37}Ar source



40 eV threshold analysis

New sensor with resistive insulators and “achinos”





Restoration of radial field

-with 2 electrodes

-conical resistive

Decoupling of

- need for low sensor radius for high amplification
- need for large sensor radius for not too low field at high shpere radii

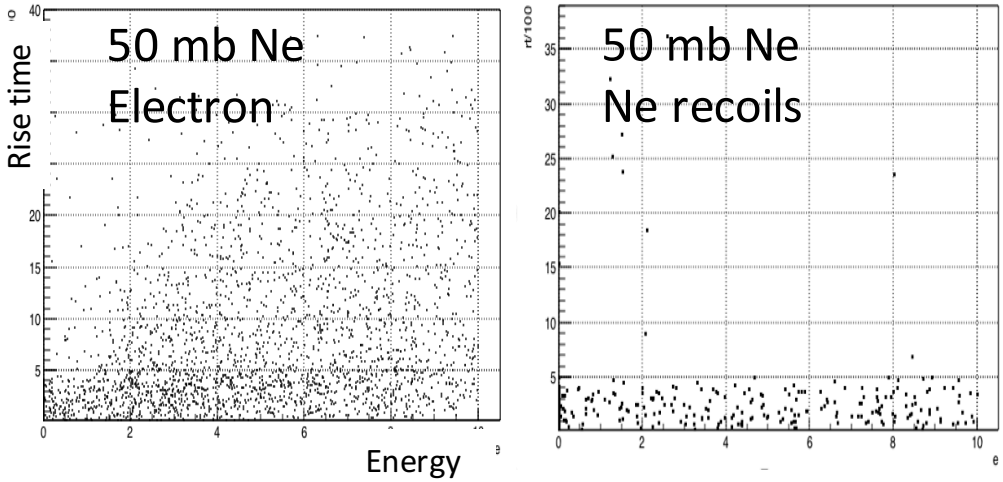
Suited for

- very large sphere > 2m

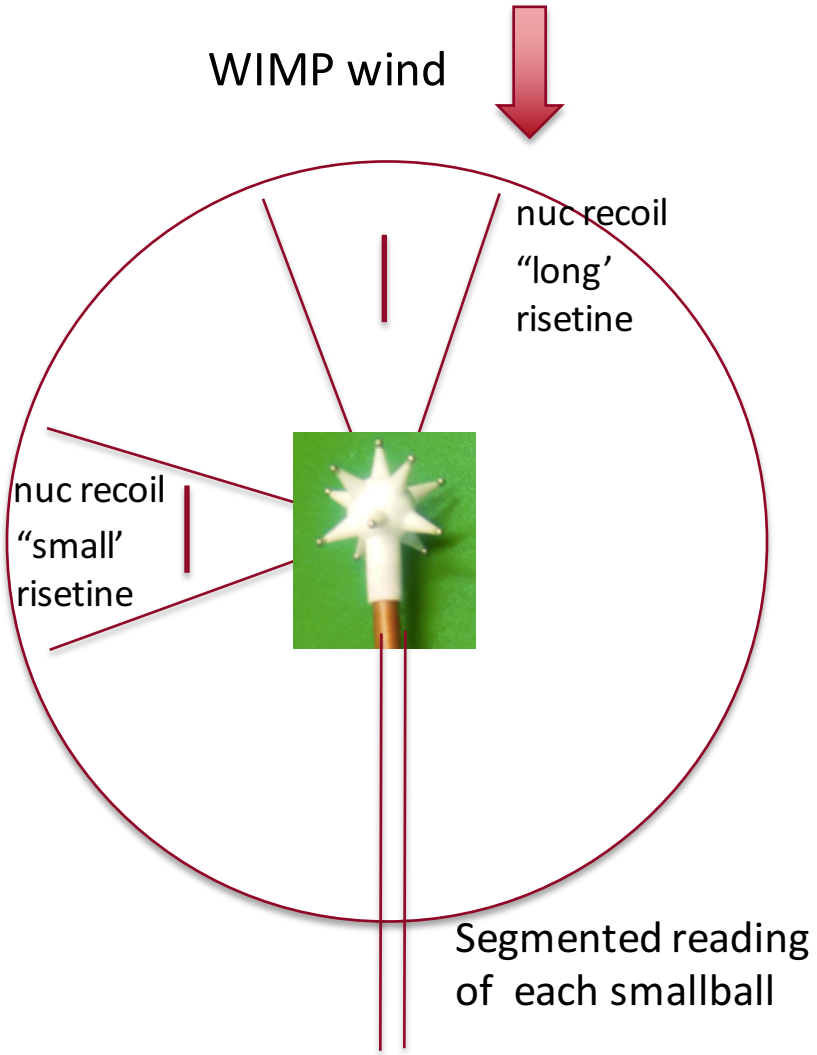
$E \sim V r_s / r^2$

Operation at low pressure 50 mb

- e/Nr discrimination by range



- Possible directionality with segmented sensor
  - Feasibility tbc



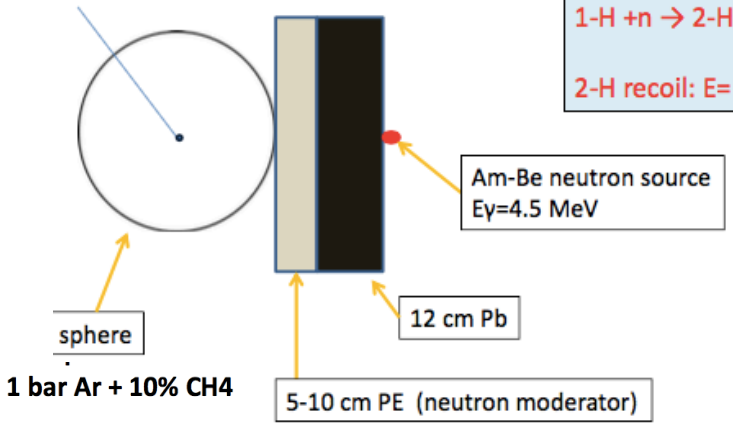
n capture for LE QF
Hydrogen (I Savvidis – Thessaloniki)

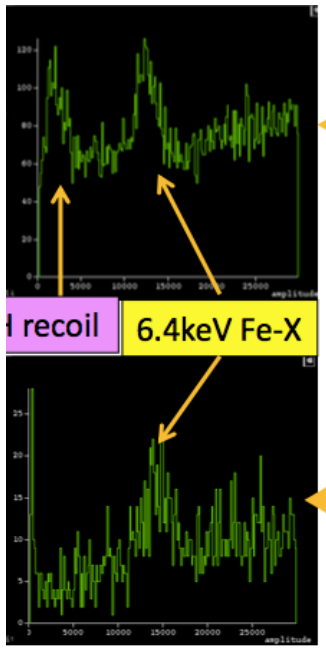
Thermal neutron capture of 1-H and 2-H recoil

Thermal neutron capture of H-1

1-H +n → 2-H + γ Q=2224 keV

2-H recoil: E= (hν)2/2Mc2 = 1.3 keV





Am-Be
qk10d002

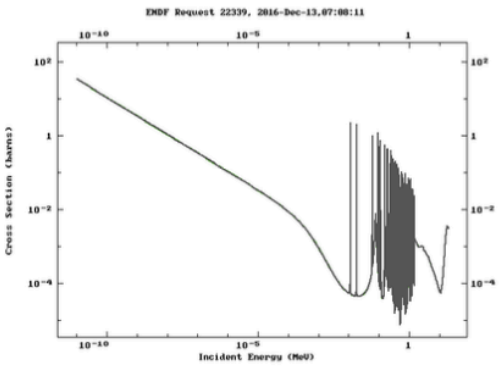
Fe-X: 12530 ADU→ 6.4keV
2-H recoil:2088 ADU → 1.07 keV
Quenching factor:
QF=0.82

No source
qk10d003

+ Neon
+ He

Next step with Ar-41 recoils

Cross section

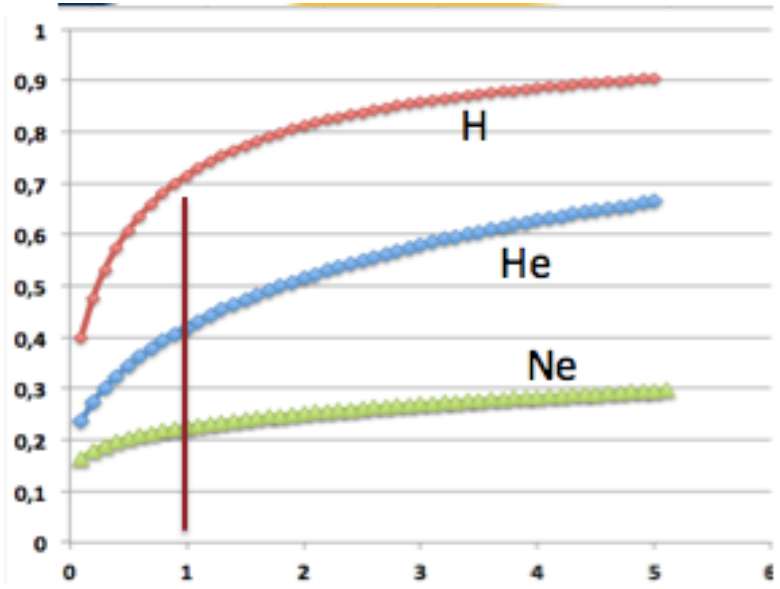


Thermal neutron capture
40-Ar + n → 41-Ar + γ

Main γ ray emission:
E1=4743 keV
E2=5582 keV

41-Ar recoil energy, E= (hν)2/2Mc2
Er≈ 450 eV

With a quenching factor ≈ 0.2 the detecting energy is only **90eV**



NEWS-G Collaboration

3rd meeting in Isabel Bader Center for Performing Arts/Kingston on april 25-27th 2017

collaboration

- **Queen's University Kingston –** G Gerbier, P di Stefano, R Martin, T Noble, D Dunrford, S Crawford, G Giroux A Brossard, A Kamaha, P Vasquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis

  2017 Summer : + Laetitia, Jonathan, Hadiya, Florentin, Ian
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay** -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**), IN2P3, U of 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, D 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–** K Nicolopoulos, P Knights
  - Simulations, analysis, R&D
- **Associated lab : TRIUMF** - F Retiere
  - Future R&D on light detection, sensor

July 2017

Conclusion and outlook

- First competitive results with gas detector in DM search
- Planned runs with He and H nuclei in coming months @ LSM
- 60 cm SEDINE detector essential to optimise project @ SNOLAB

- NEWS-G @SNOLAB will have better shield /materials/procedure
- Project at TDR step, construction to start fall 2017, installation at SNOLAB by 2018

- R&D under way on
  - cleaning methods underground electroformed sphere (PNNL)
  - “achinos” type sensor
  - multi channels sensor
  - low pressure operation…

- + investigation of
  - Low mass spin dependent coupling with H
  - KK solar axions through 2 photon decay
  - Dark photon (arXiv:1507.07531)
- Coherent Neutrino Scattering, SuperNovae…