New Experiments With Spheres -Gas Light Dark Matter search

NEWS-G LSM results and NEWS-G SNOlab project

Principles of gaseous spherical detector

Light Dark Matter search with SEDINE at LSM

NEWS-SNO project, future ideas

Outlook

Gilles Gerbier

Queen's University

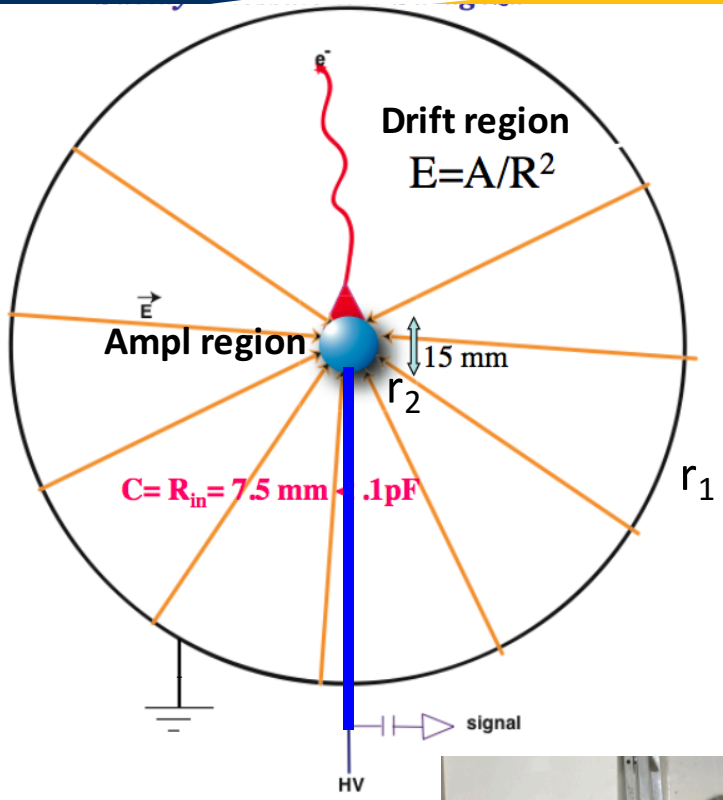
Cosmic Vision workshop

Washington– Mar 24th 2017

Canada Excellence Research Chairs

Chaires d'excellence en recherche du Canada

Spherical gas detectors
New Experiments With Spheres



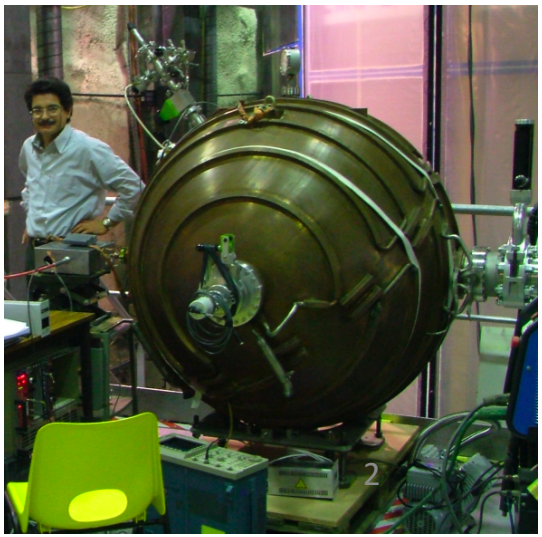
- Sphere cavity + spherical sensor + HT
- => **Low threshold (low C), does not depend on size**
- **Fiducial volume selection by risetime**
- **Flexible (P, gaz)**
- Large mass / large volume (30 kg) with single channel
- Simple, sealed mode
- 2 LEP cavity 130 cm Ø tested
- **1 low activity 60 cm Ø in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

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

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

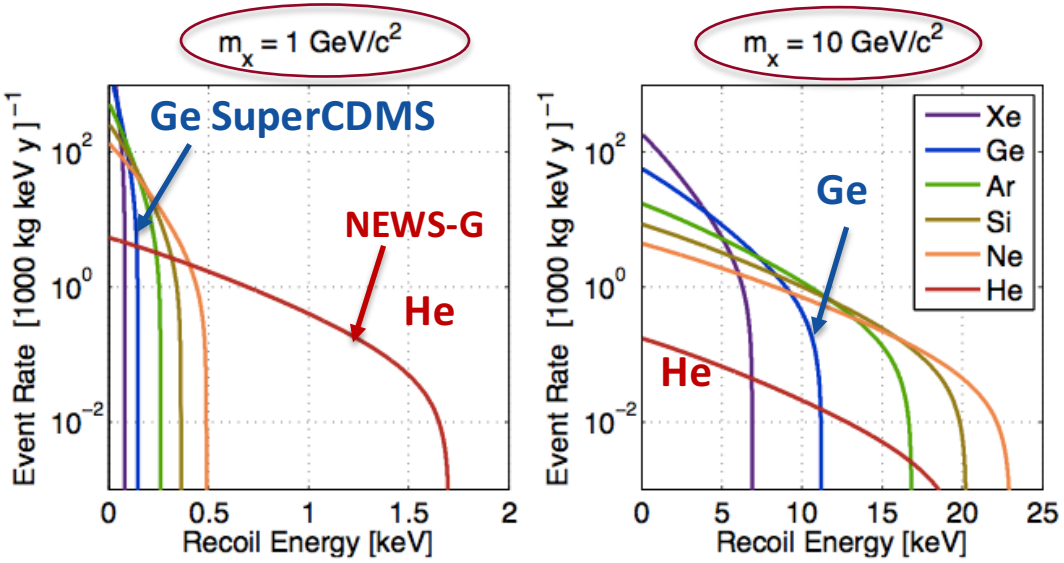
$\rho \approx r_2$

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



Detection of “low mass” flying particle

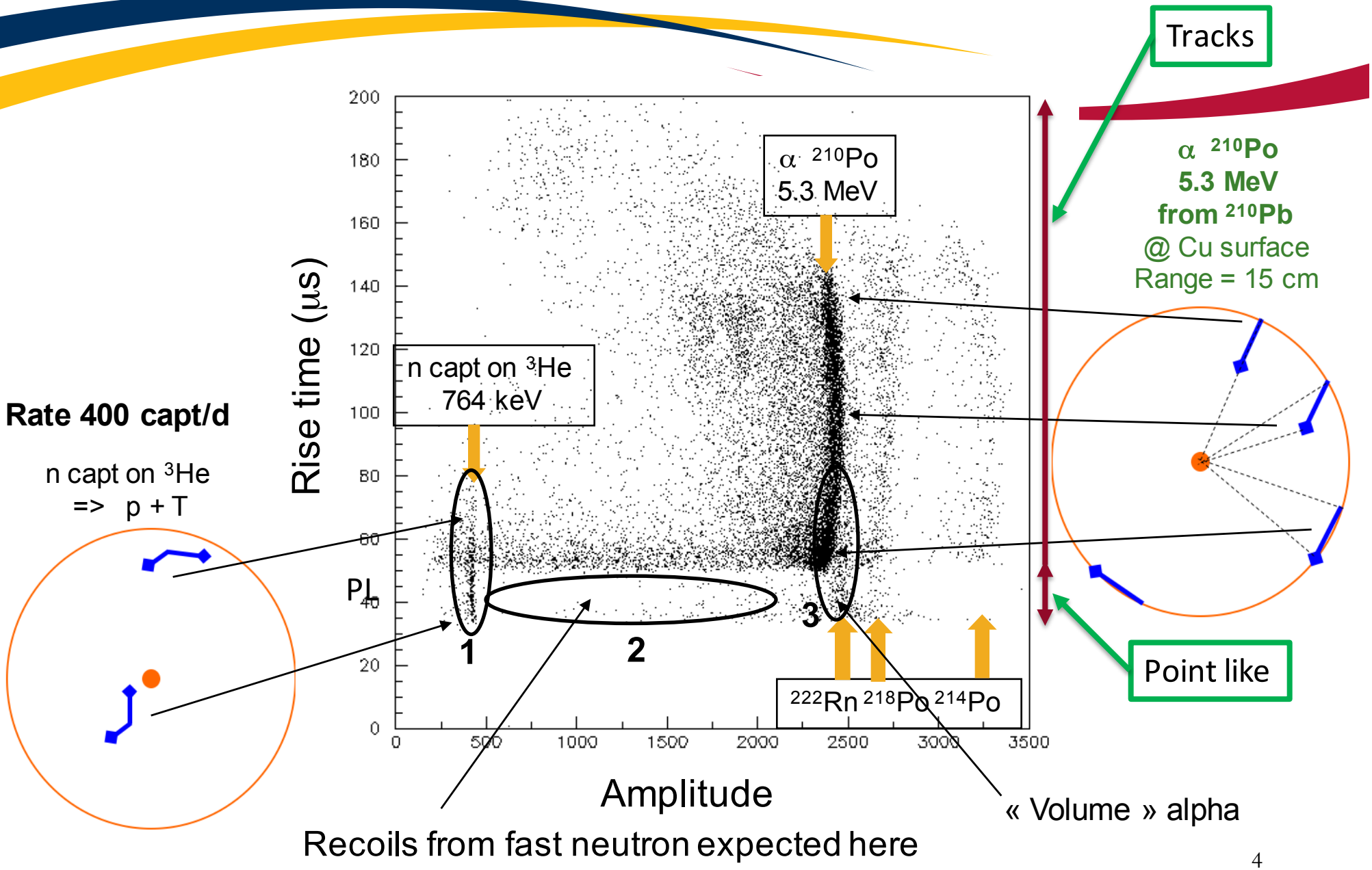
- Kinematical match
- To detect **flying ping pong balls** is it better to have as **target** :
  - **lead** “petanque” balls
  - or **ping pong** balls ?
- => use light nuclei to detect light WIMPs
- H, He, Ne lightest among noble gas



Recoil distributions with various targets

Illustration of particle identification at MeV energy

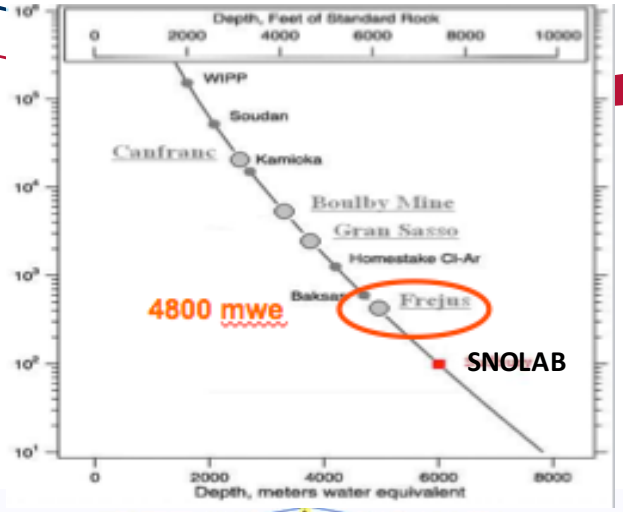
Ar/CH_4 + 3g ^3He @ 200 mb SPC 130cm Ø @ LSM

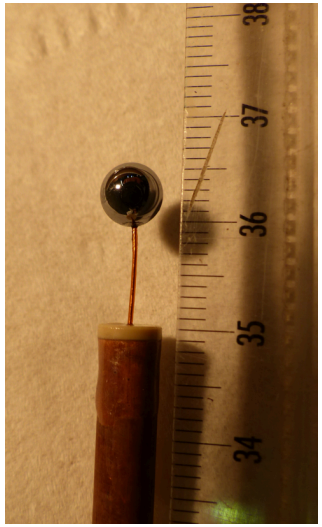


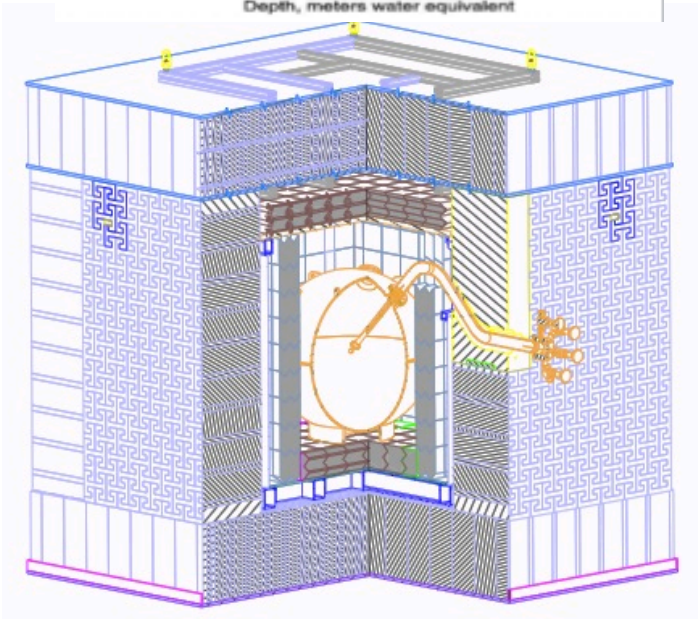
Light WIMP search NEWS-G @LSM
Low activity 60 cm Ø prototype : SeDiNe

- 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

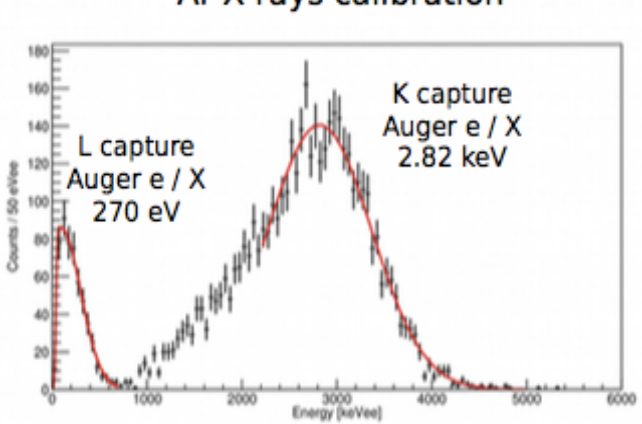
6.3 mm sensor

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

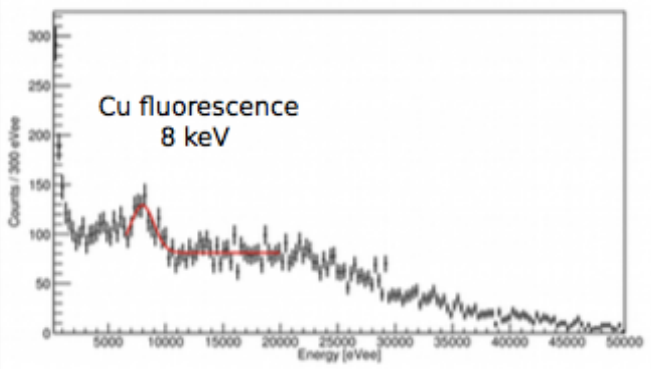
Operation and data taking conditions

- **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

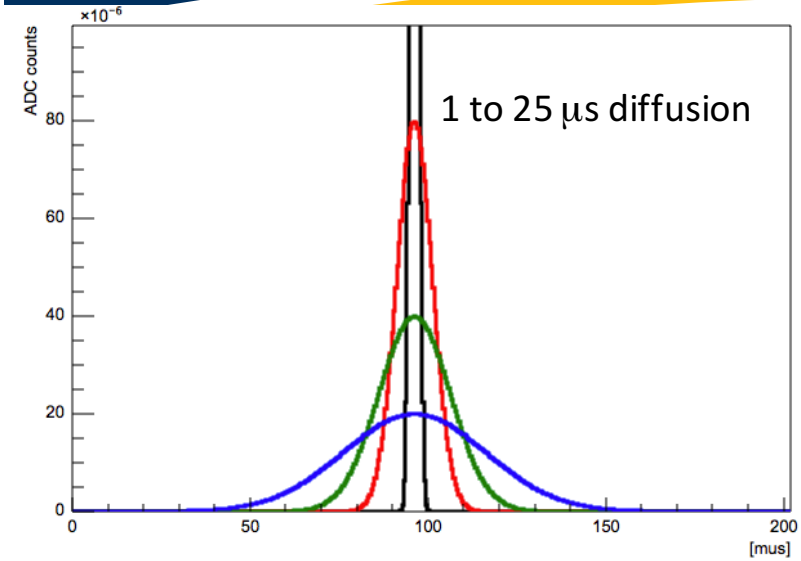
^{37}Ar X rays calibration



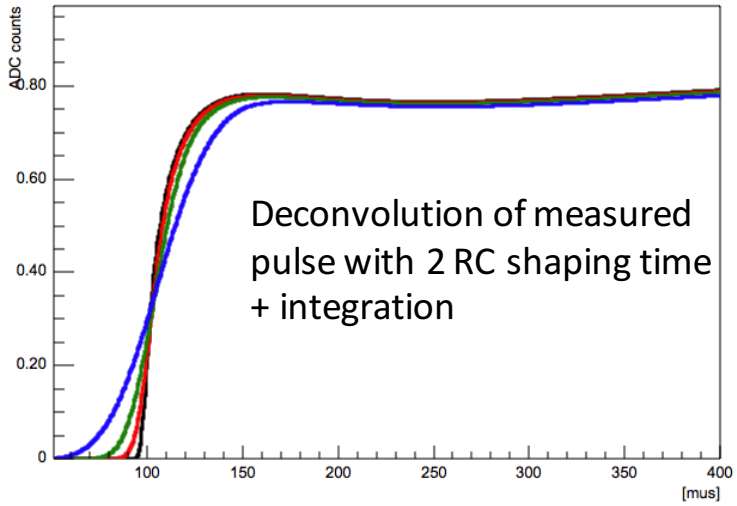
WIMP search data



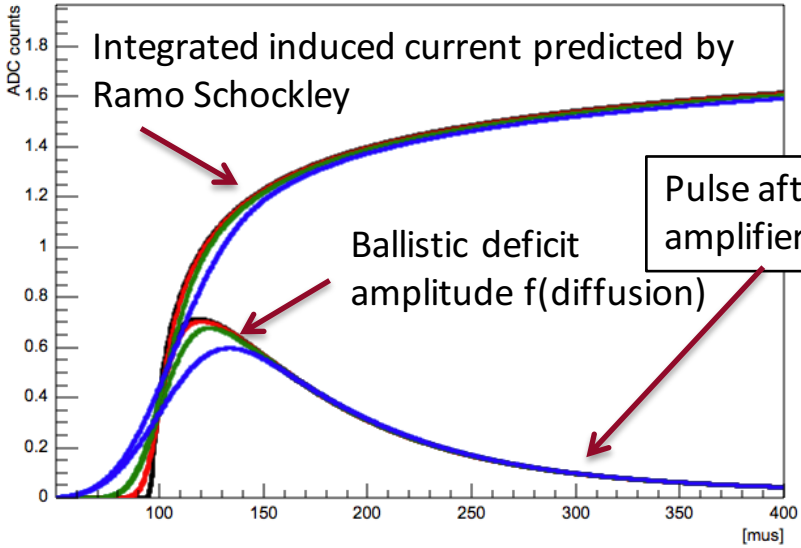
Pulse formation and simulation

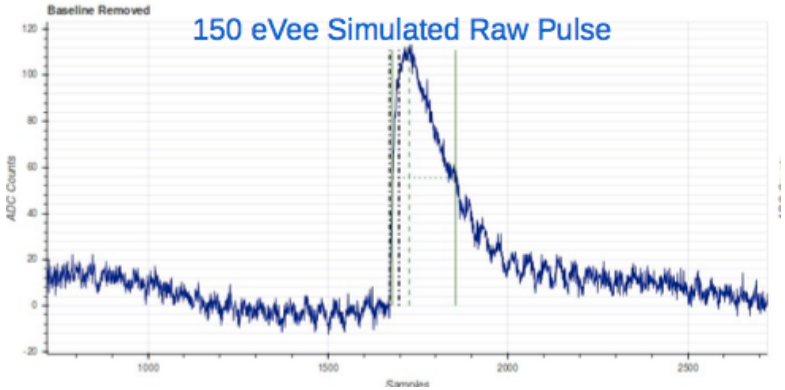


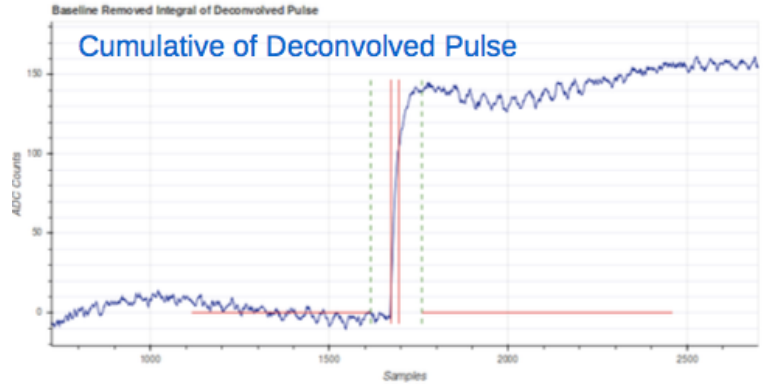
Primary pulse : arrival times of primary electrons



Paco Vasquez de Sola PhD







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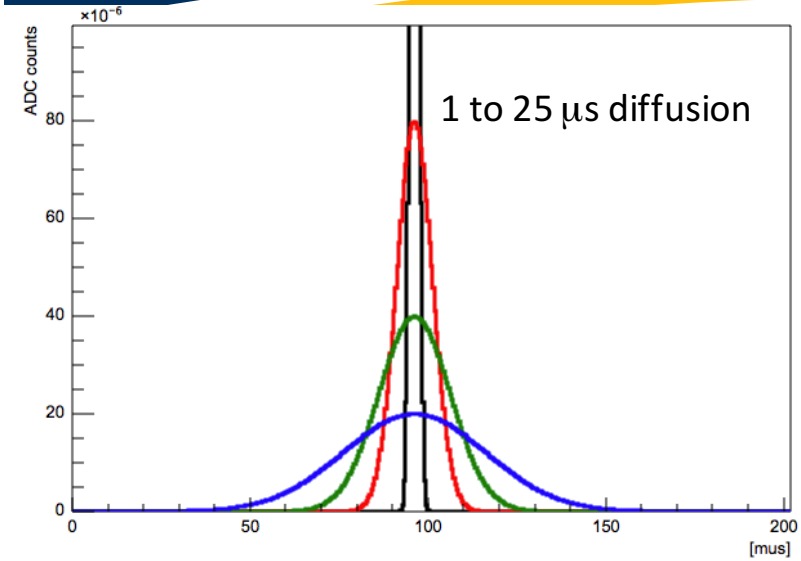

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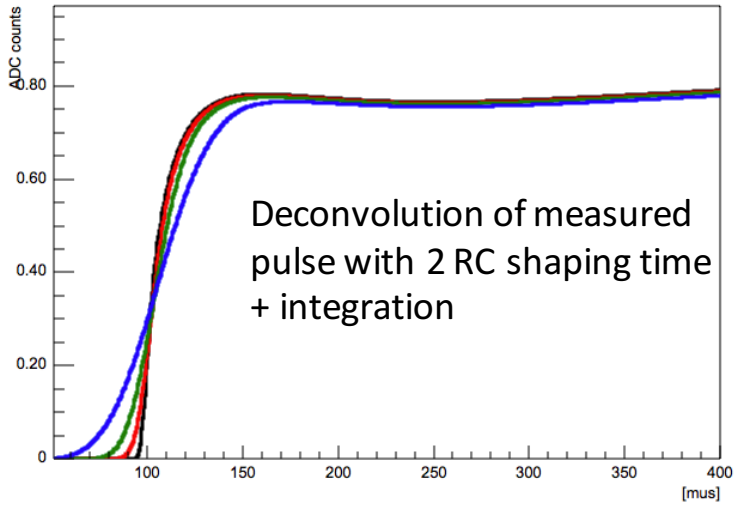
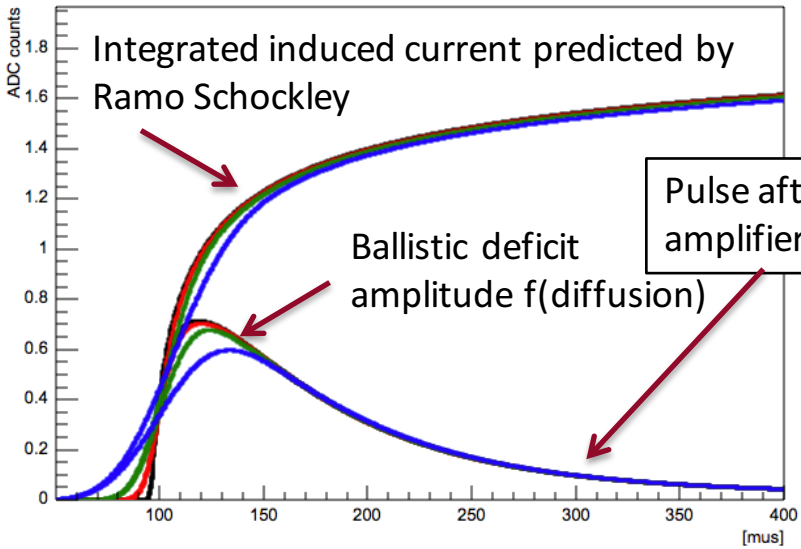
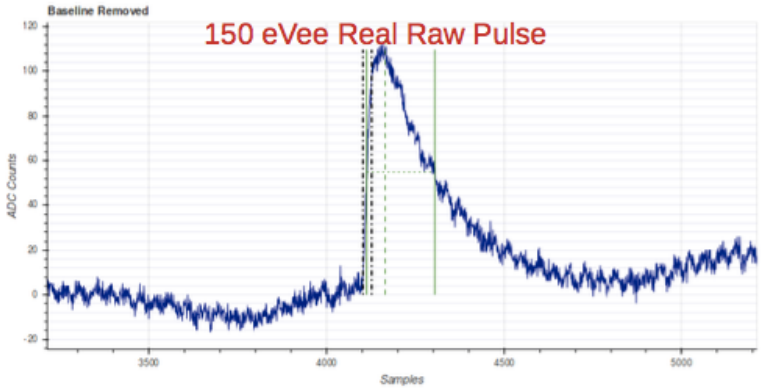
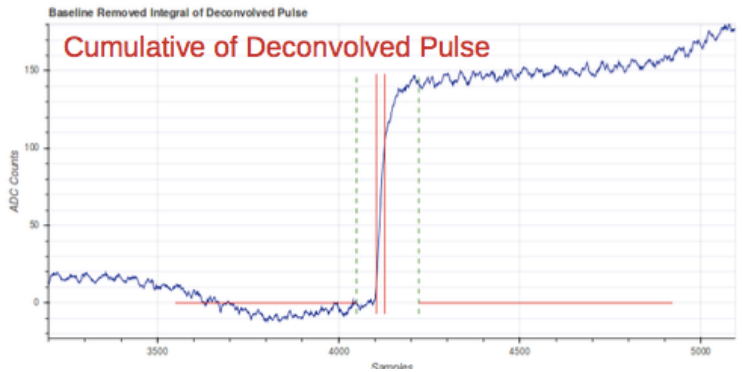
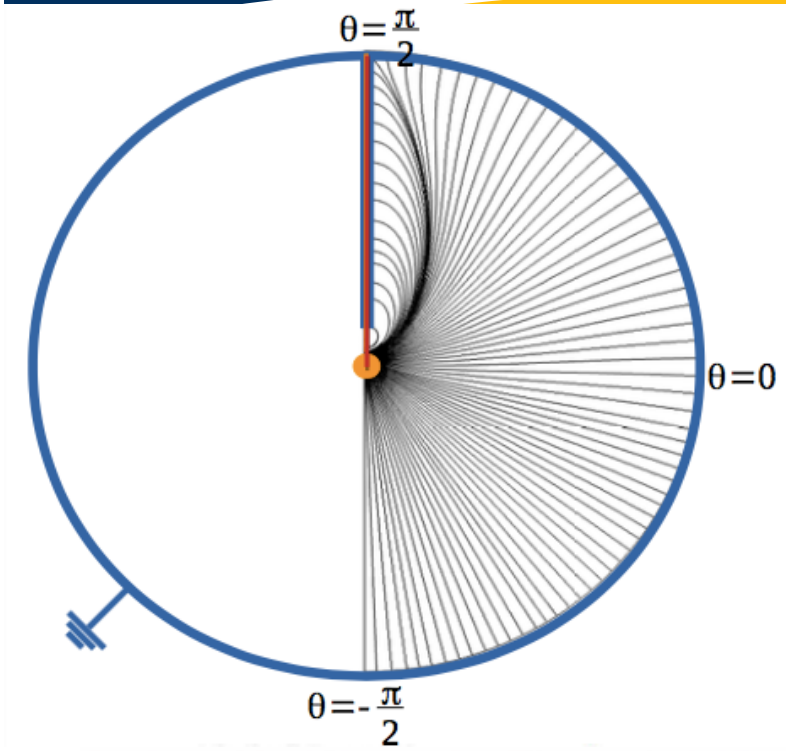








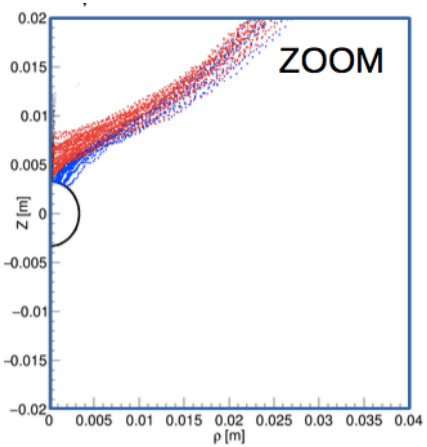
Detailed simulation of electric field and transport



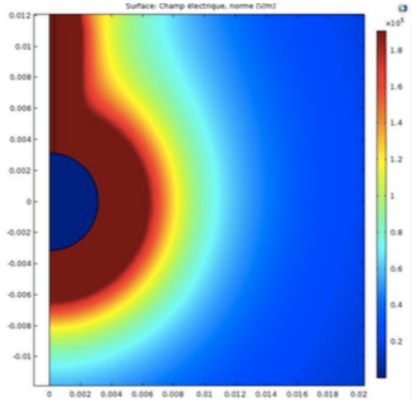
Non fully radial field => dependance on teta of

- drift velocities / diffusion
- avalanche gain

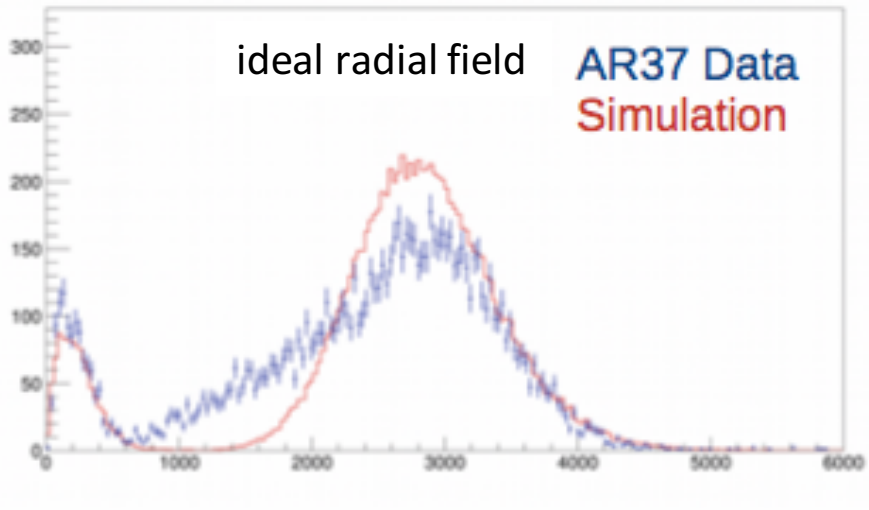
Simulated/parametrised through Comsol/Magboltz

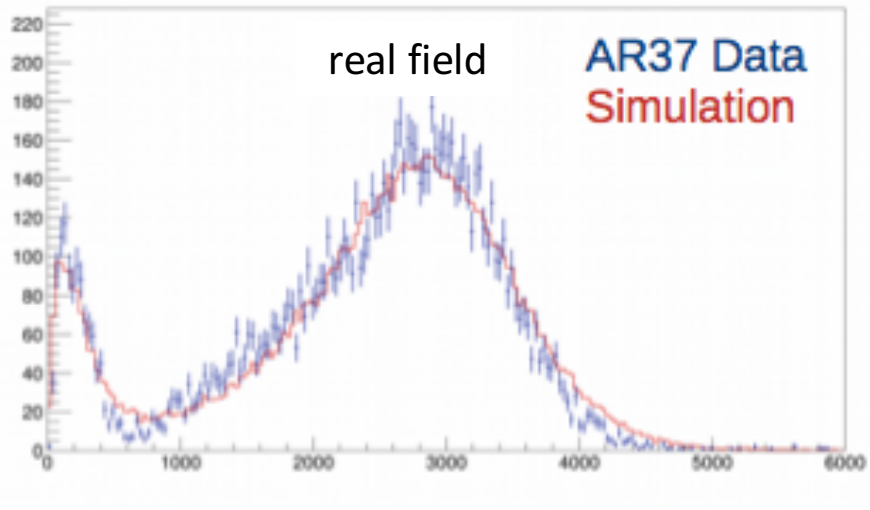


Drift at high teta



Field near sensor

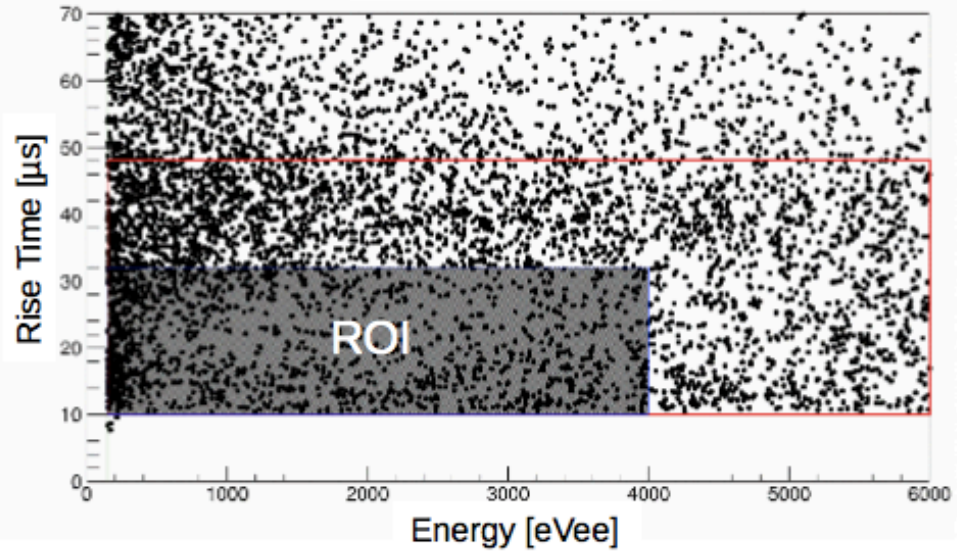




Data and simulations of two main expected populations

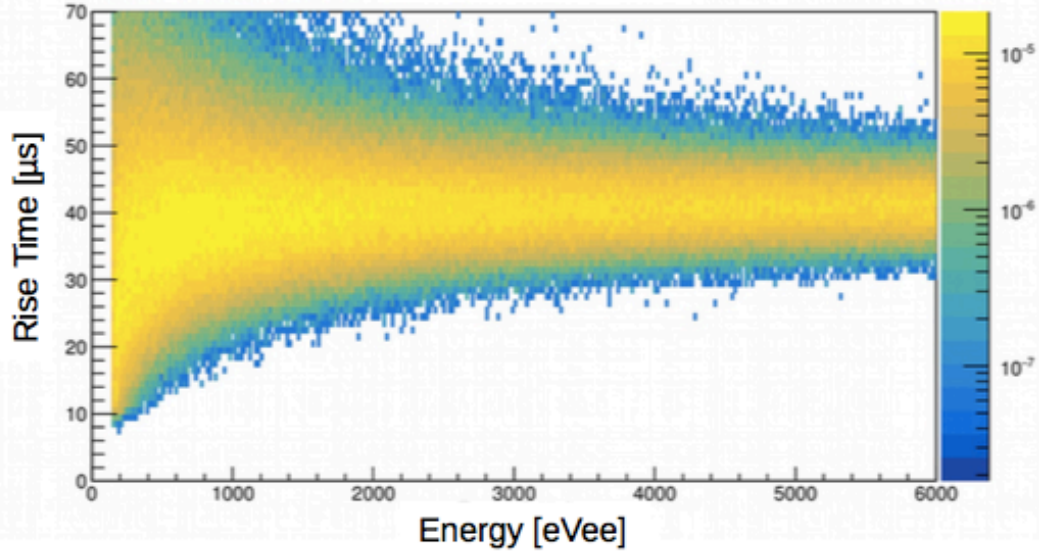
Sedine data

WIMP search run



Background PDFs

Surface events



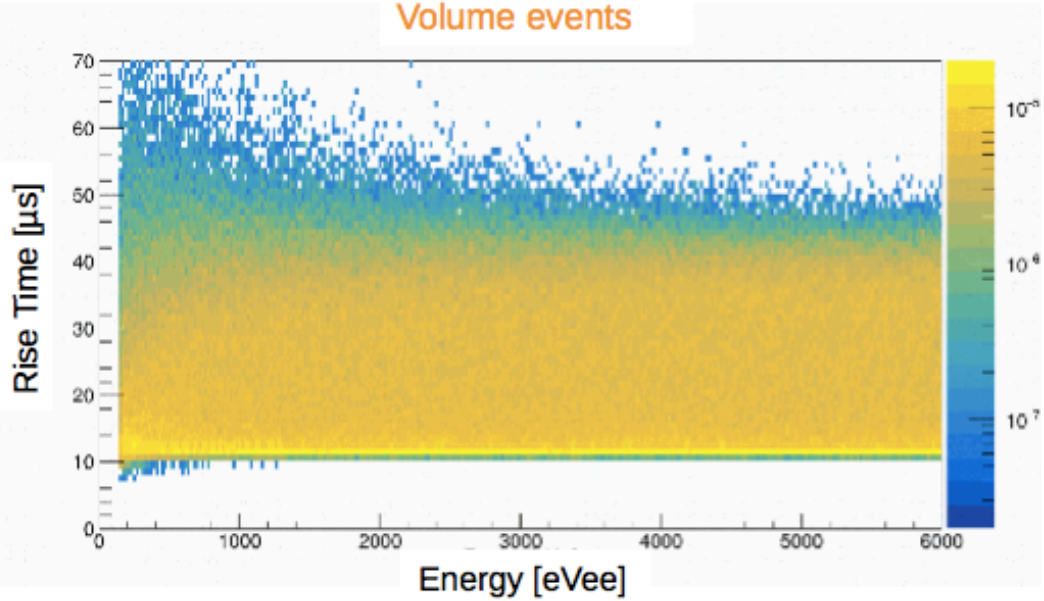
Analysis threshold set at **150 eVee**
(100% trigger efficiency)

Side Band region used to determine
The number of background events
expected in the **ROI**

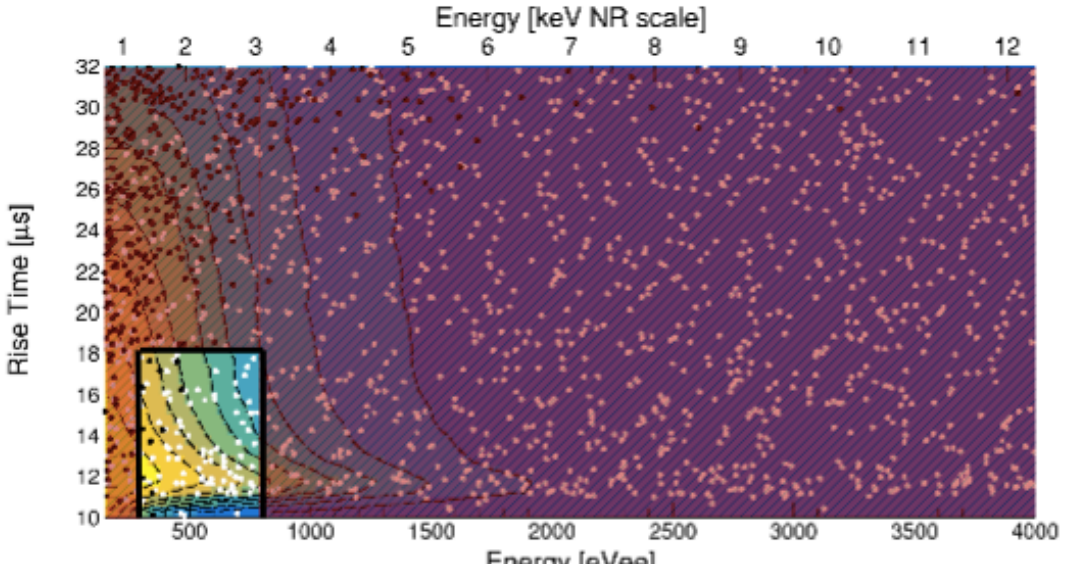
~1600 events expected in the ROI ...

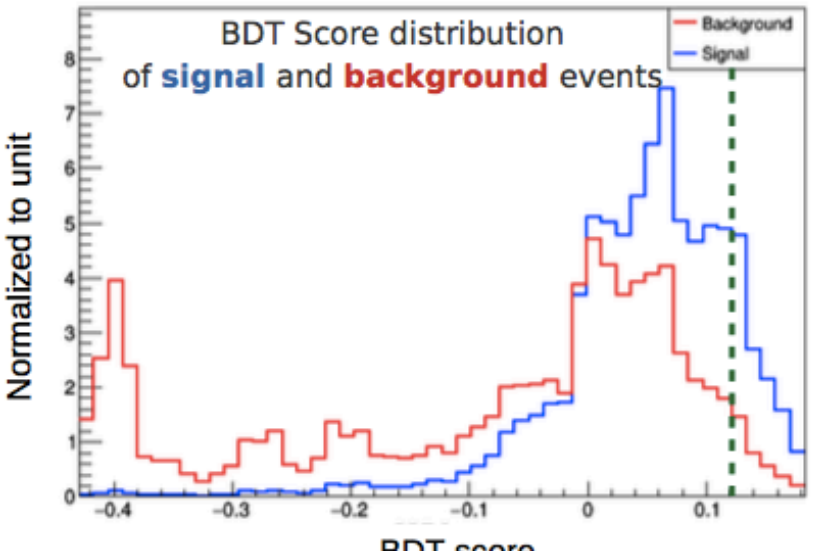
Need to determine a fine-tuned ROI optimized for signal/background discrimination

Volume events

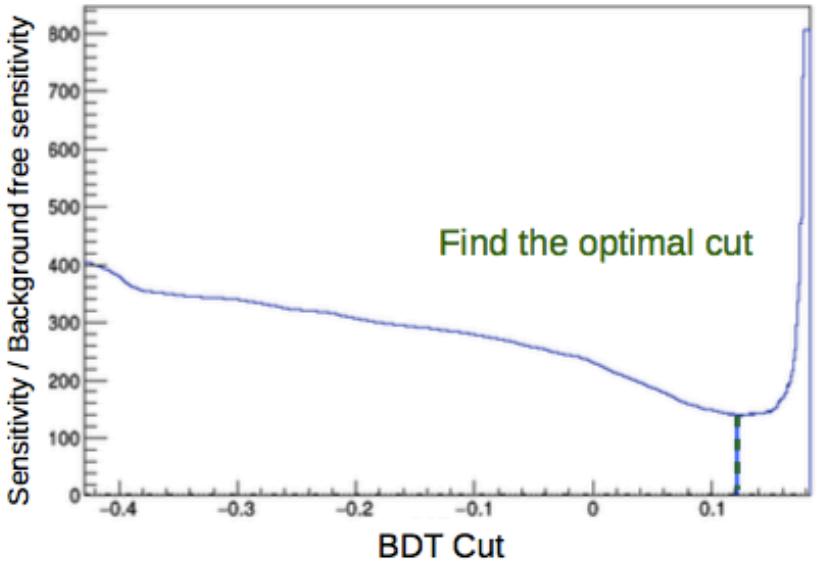


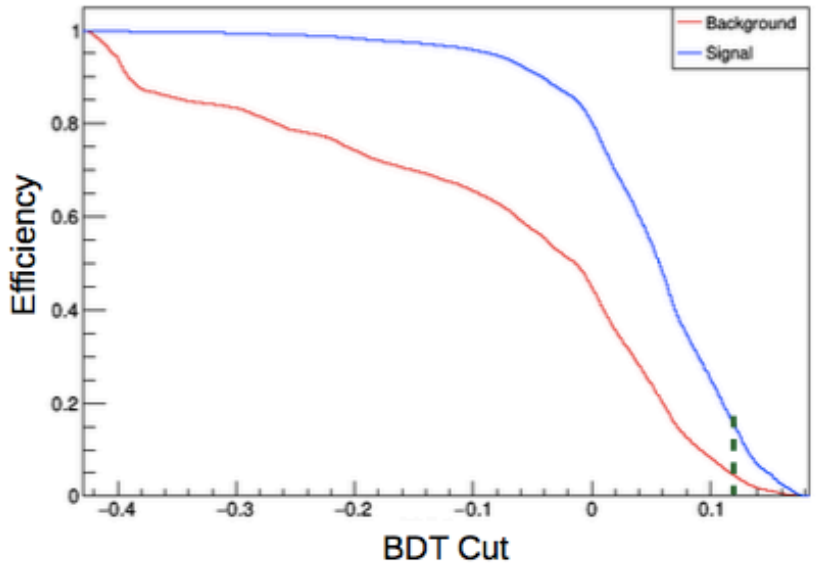
Boosted Decision Tree method



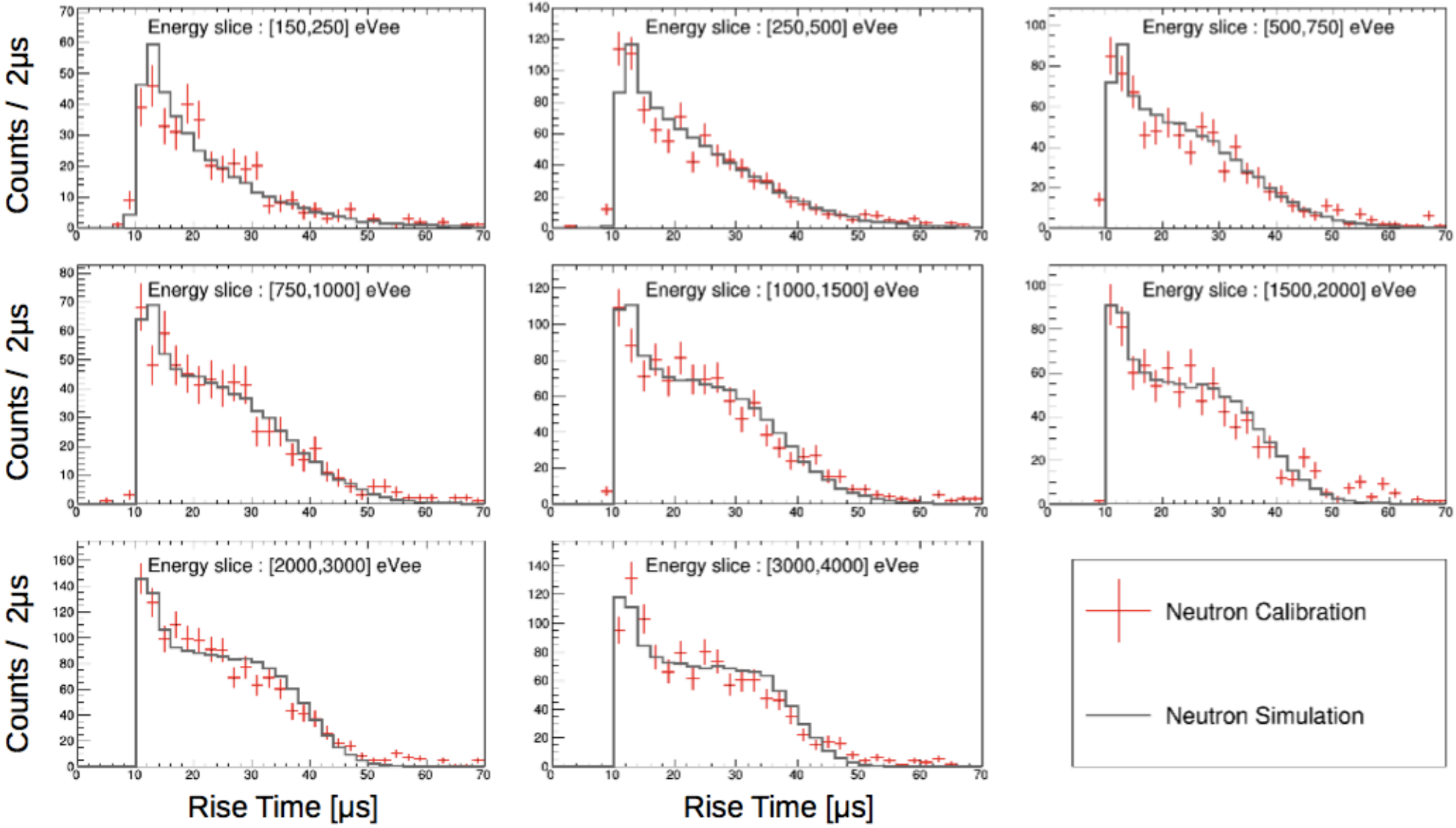


While this method gives conservative limits if inaccurate background models were to be used for the training of the BDT, it assumes we know very well the response to signal (volume/compton/NR recoil), ie behaviour of RiseTime vs Energy for WIMP's

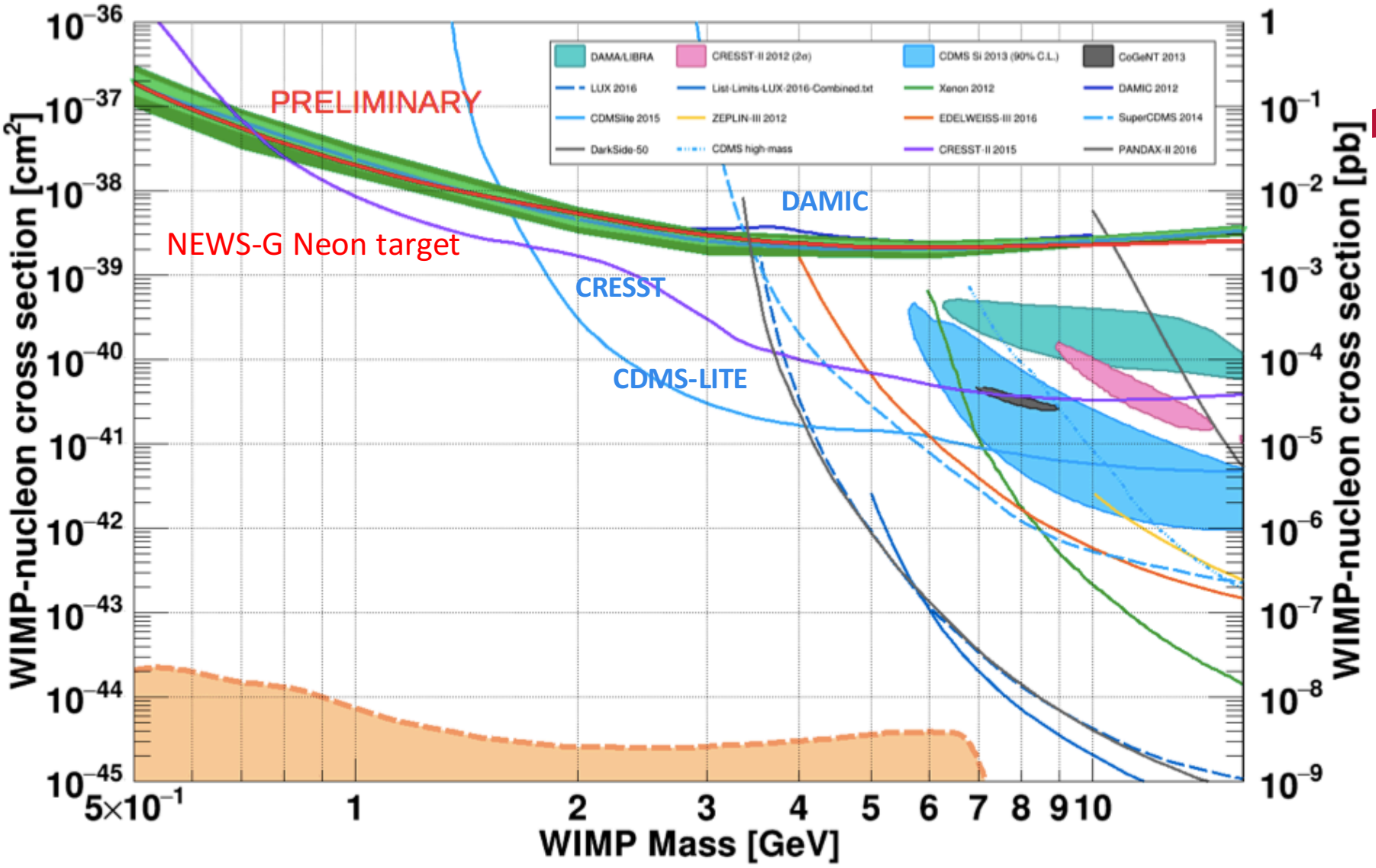




Volume events : comparison of simulation with neutron calibration data with Am-Be source



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

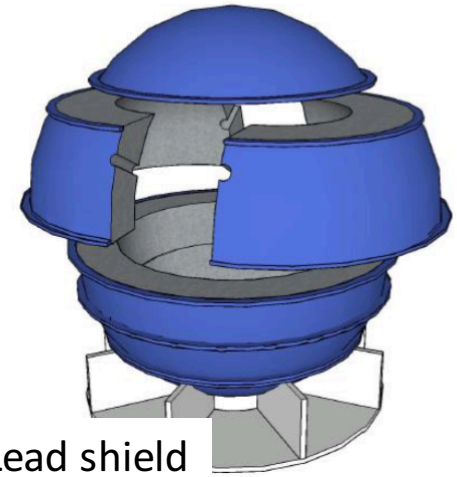


Limit set on spin independent coupling WIMPs with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM
Systematics on energy calibration / quenching factor / polya parameter / fiducial mass <30 % at lowest energy

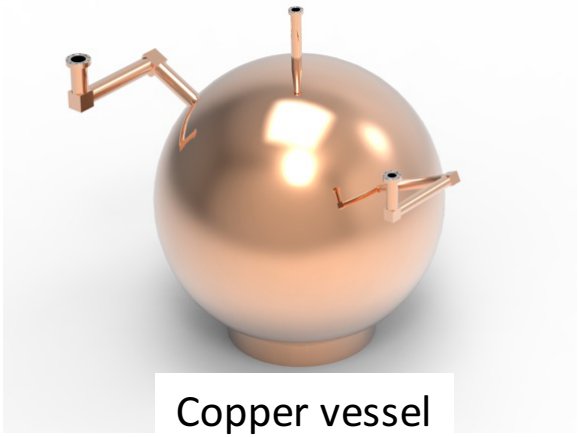
140 cm diameter project with compact shield option

implementation at SNOLAB by 2018

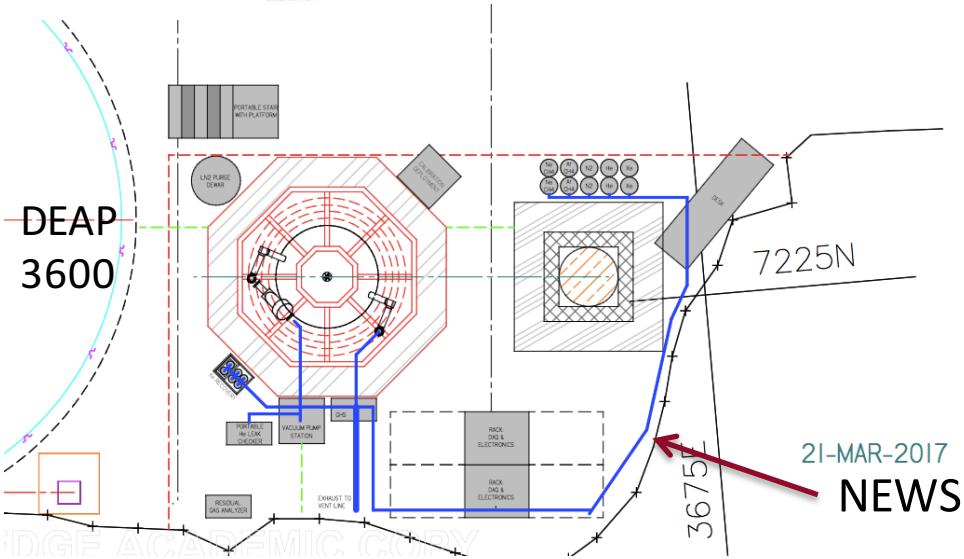
- 140 cm Ø detector, 10 bars, Ne, He, CH_4
- 25 cm compact lead –3cm ancient - LSM
- 40 cm PE + Boron sheet



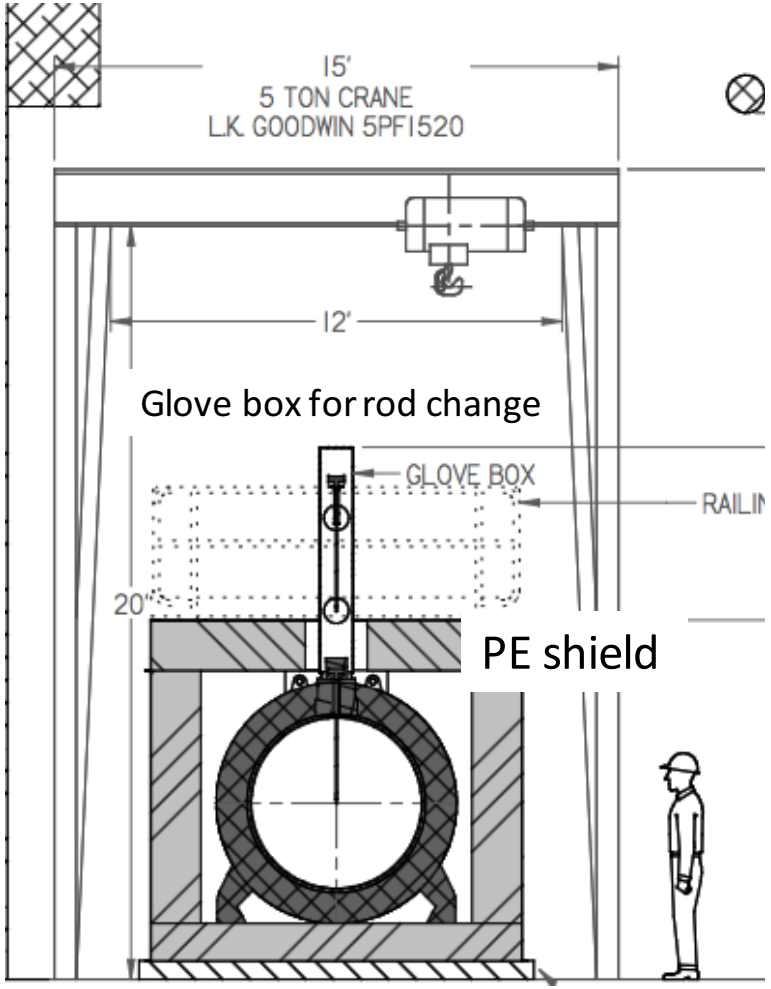
Lead shield



Copper vessel



NEWS-G in Cube Hall



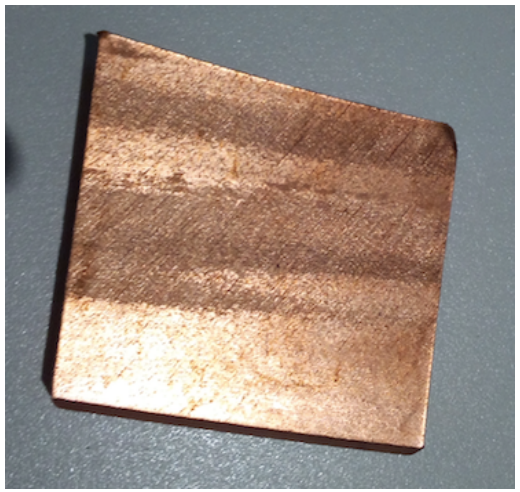
35 t shields

Hemisphere spinning test and clean up

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

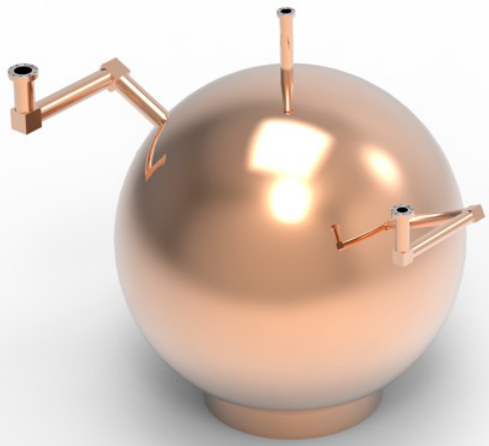
- PNNL measurements of bulk and surface
⇒ 7 to 25 μBq/kg of Th
⇒ 1 to 5 μBq/kg of U
Ok for goals fixed of first expt

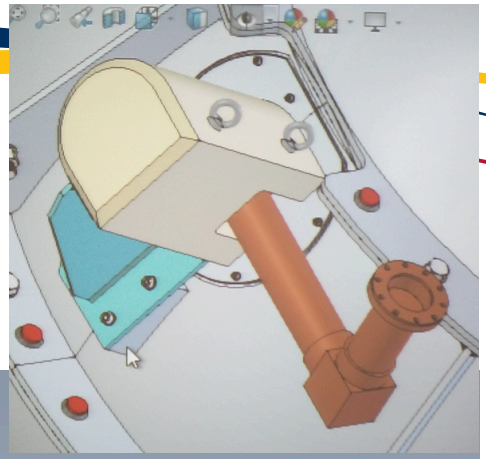
- Test of surface cleaning with HP water jet tests
  - -3000b water jet => 30 μ removal
  - -Possible but -too- expensive

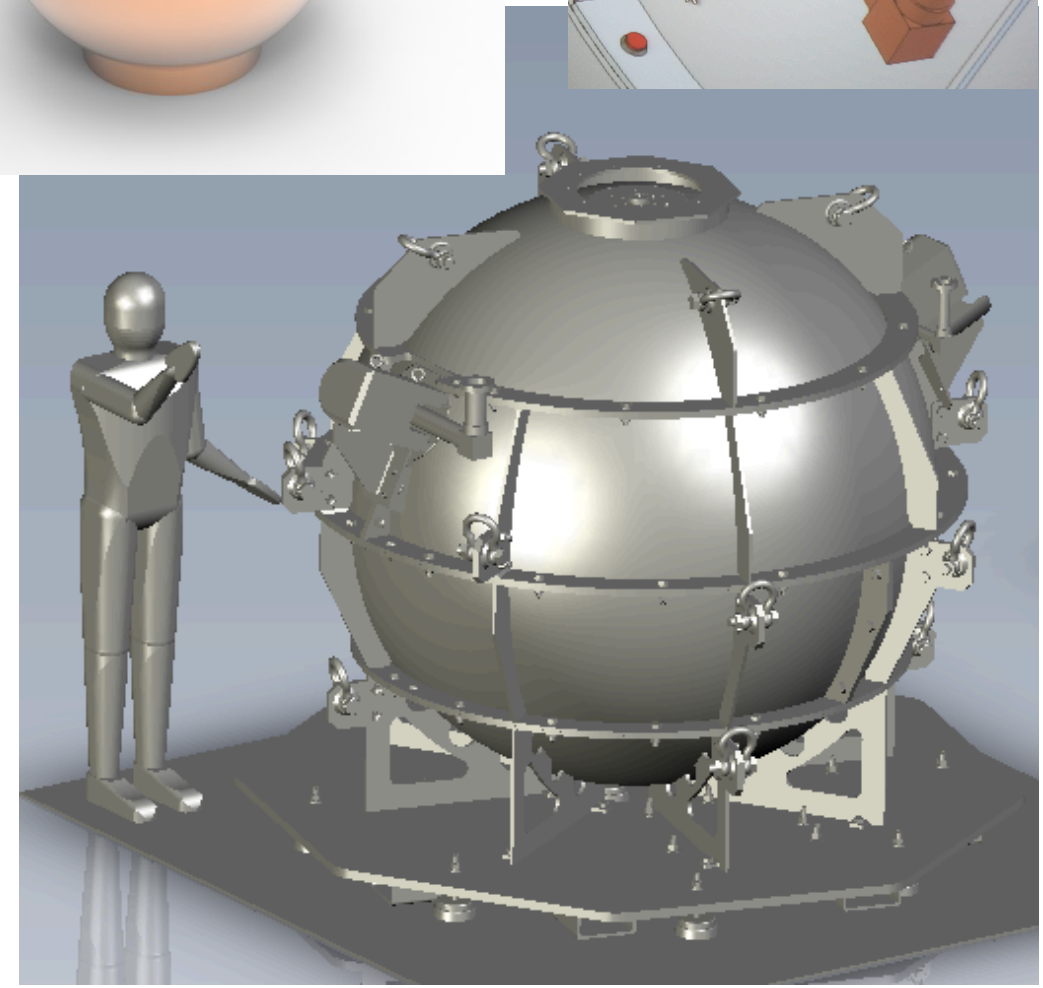


- Electron welding of hemispheres and piping

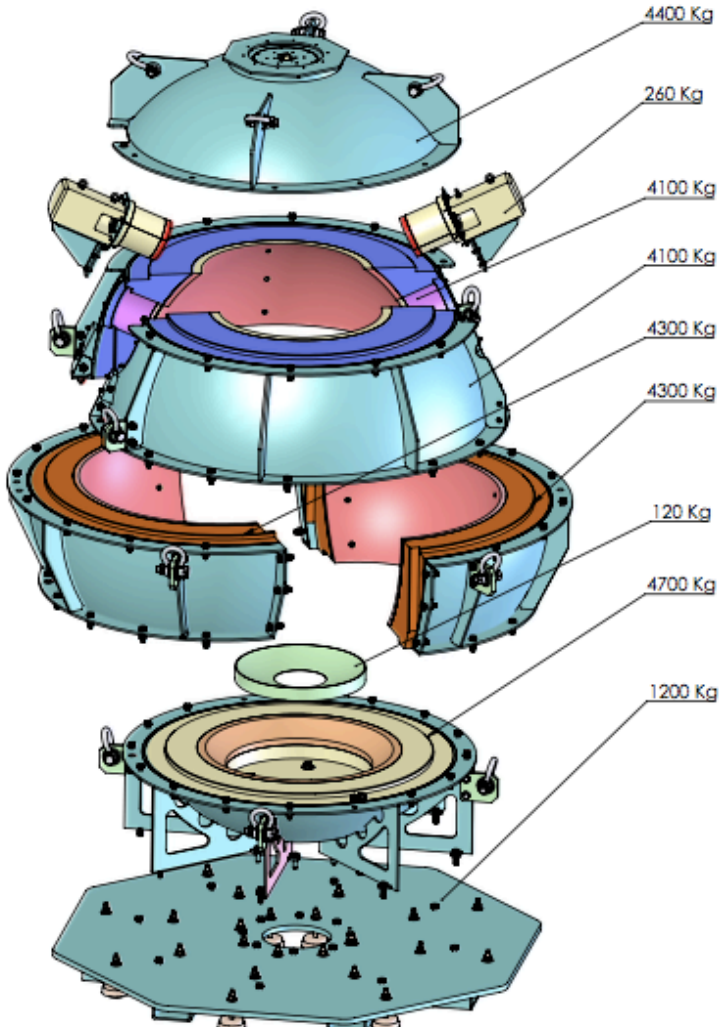
TDR – construction phase







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

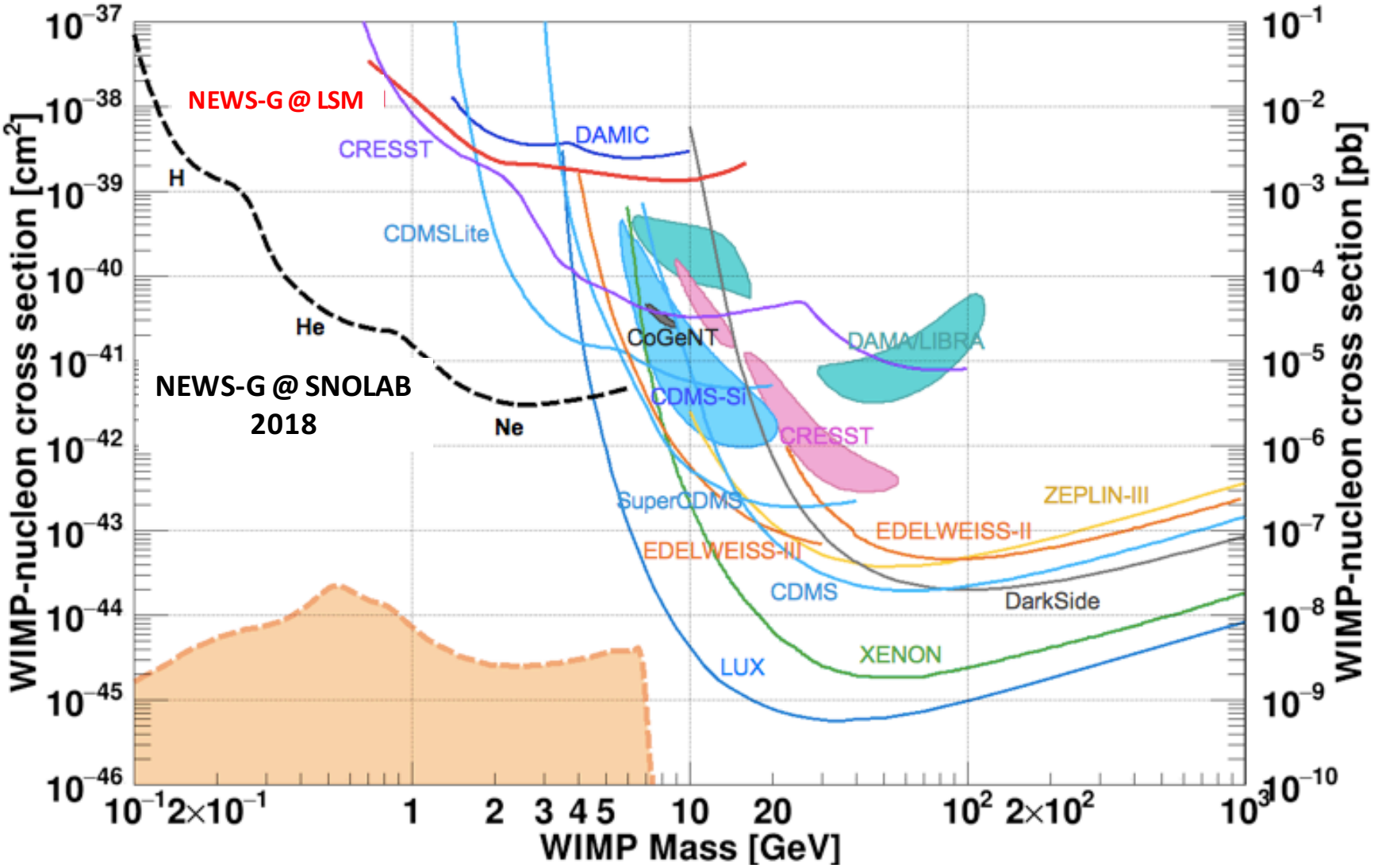
Internal surface

Lead shield

External bckg with SNOLAB flux

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

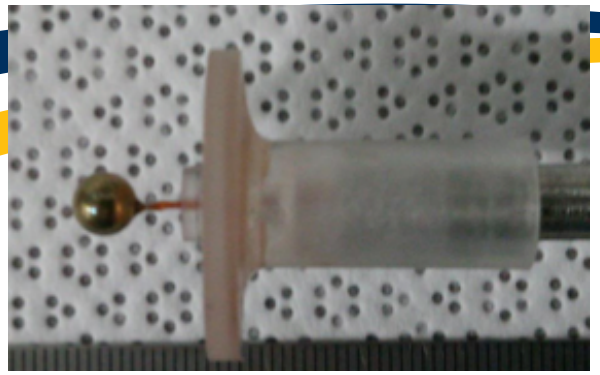
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 19

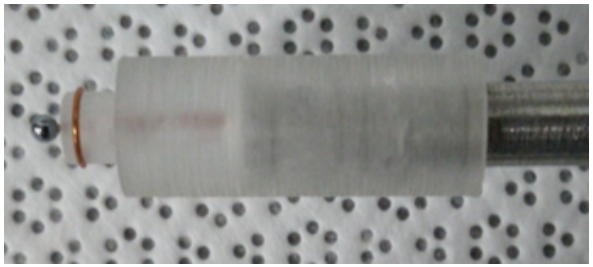
60 cm NEWS prototype

- 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

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

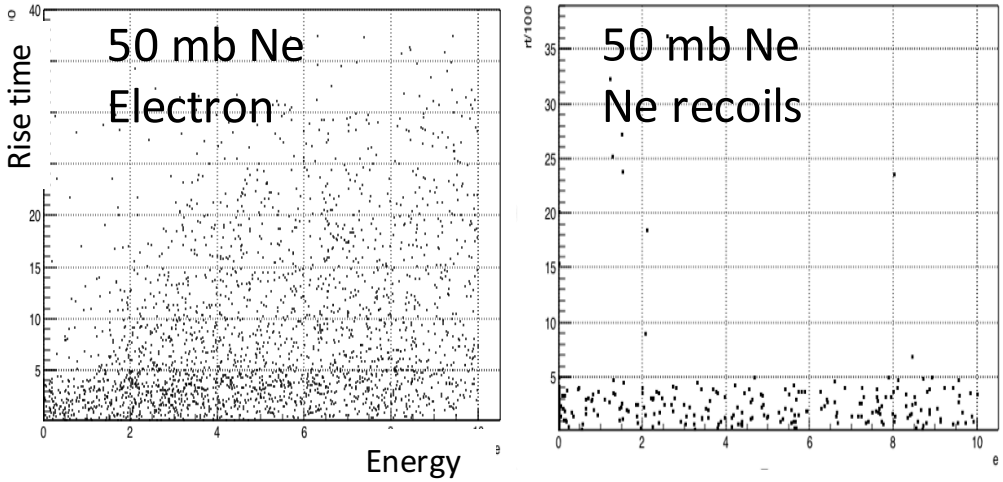
Suited for

- very large sphere > 2m

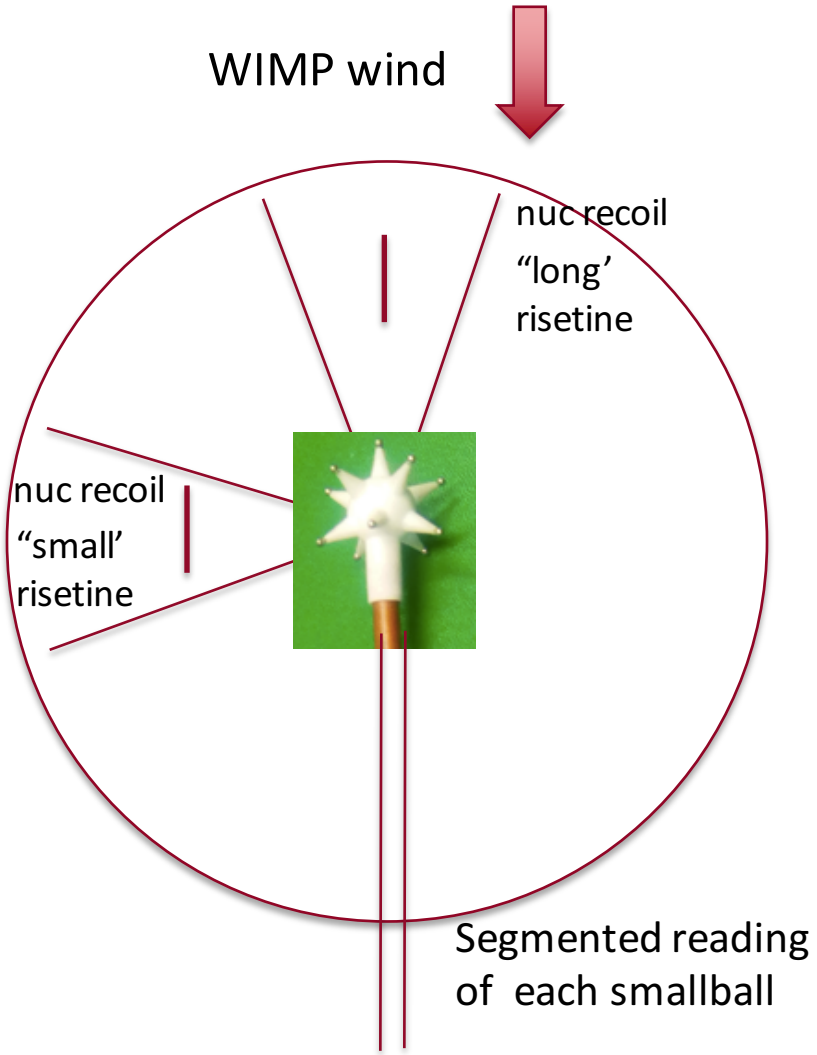
$E \sim V r_s / r^2$

Operation at low pressure 50 mb

- e/Nr discrimination by range



- Possible directionality with segmented sensor
  - Feasibility tbc

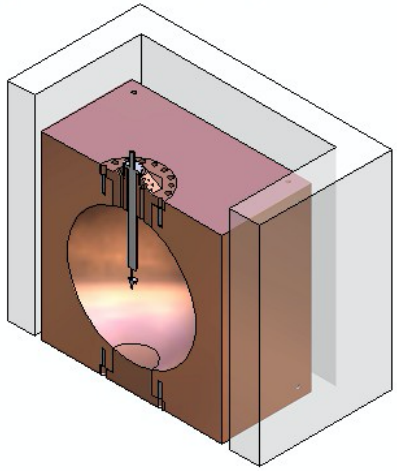


Conclusion and outlook

- 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,
  - cubic sphere …



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

collaboration

- **Queen's University Kingston** – G Gerbier, P di Stefano, R Martin, T Noble, D Dunford A Brossard, A Kamaha, P Vasquez dS, 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)**/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
  - 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 Nicolopoulos
  - Simulations, analysis, R&D
- **Associated lab : TRIUMF** - F Retiere
  - Future R&D on light detection, sensor

March 2017

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