# New Experiments With Spheres -Gas
# Light Dark Matter search

Introduction

NEWS-G partners contributions

Outlook

Gilles Gerbier

Queen's University

CAP 2017

Kingston– June 1st 2017

Canada Excellence Research Chairs

Chaires d'excellence en recherche du Canada

# NEWS-G Collaboration

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

# NEWS collaboration

- **Queen's University Kingston** – G Gerbier, P di Stefano, R Martin, T Noble, D Dunrford, S Crawford 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,
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  - Coordination for lead/PE shielding and copper sphere
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  - Simulations, analysis, R&D

- **Associated lab : TRIUMF** - F Retiere
  - Future R&D on light detection, sensor

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# The initiators

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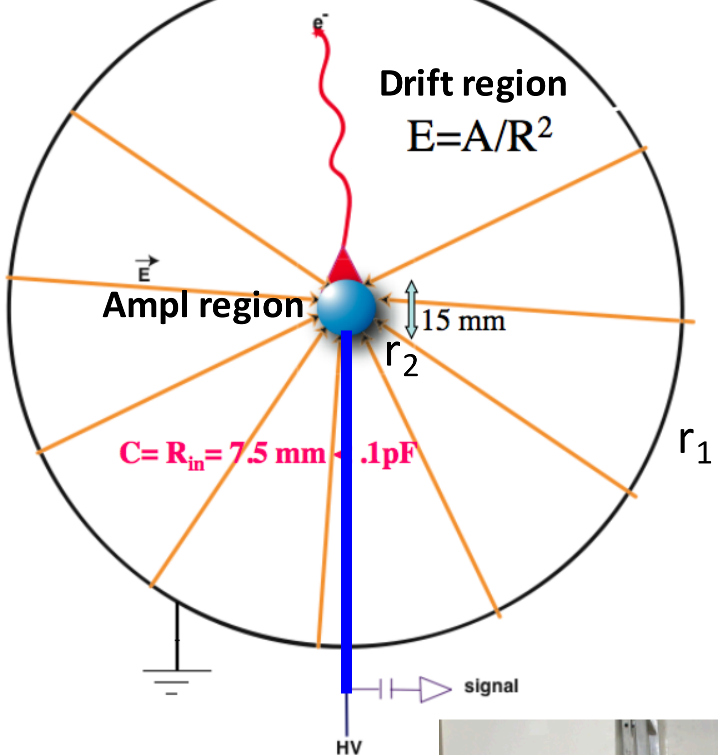
# Spherical gas detectors
## New Experiments With Spheres



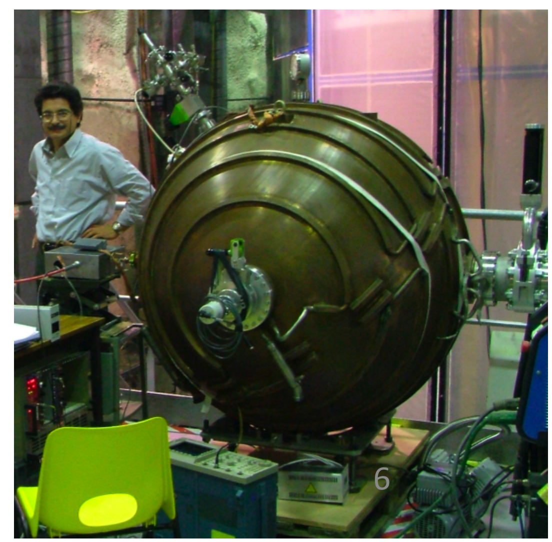

- Sphere cavity + spherical sensor + HT
- **=> Low threshold (low C), does not depend on size**
- **Fiducial volume selection by pulse risetime**
- **Flexible (P, gaz)**
- Large mass / large volume (30 kg) with single channel
- Simple, sealed mode
- 2 LEP cavity 130 cm Ø tested
- **1 low activity 60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

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

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

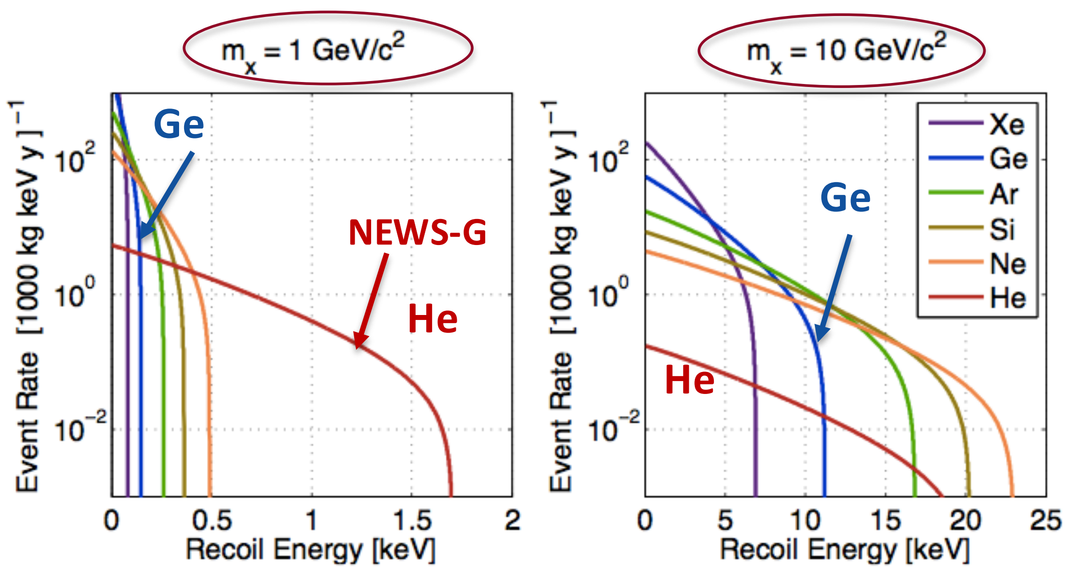
$$\rho \approx r_2$$

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



# Detection of "low mass" flying particles

- 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

# The first experiment SEDINE, data taking and analysis

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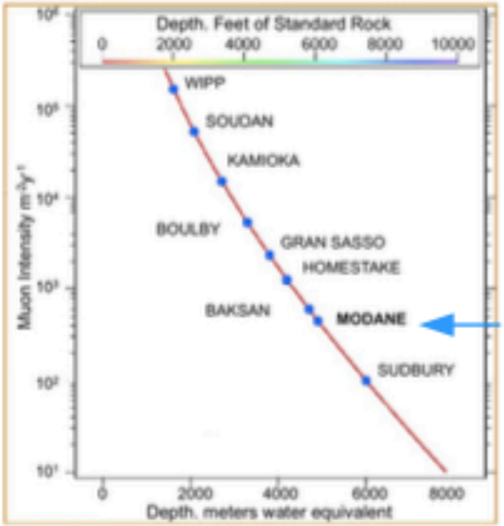
# Ne data analysis : Quentin A

## NEWS-G @ LSM - Experimental Setup




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

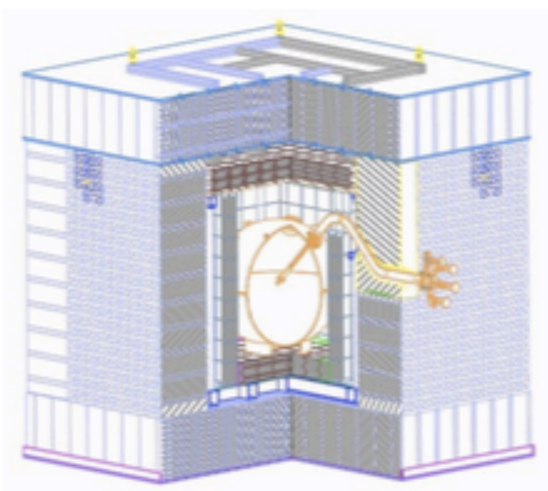
Muon flux

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

**L**aboratore **S**outerrain de **M**odane

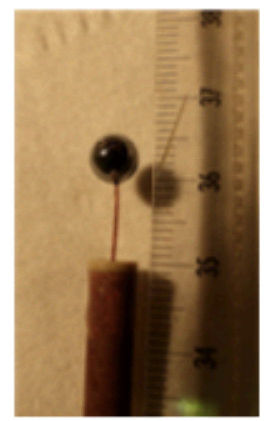

<u>**Data taking conditions**</u>

**9.7 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**



<u>Shieldings</u>
**30 cm PE, 10-15 cm Pb,** [3-8] **cm Cu**


<u>Vessel</u>
**60 cm** Ø NOSV Copper

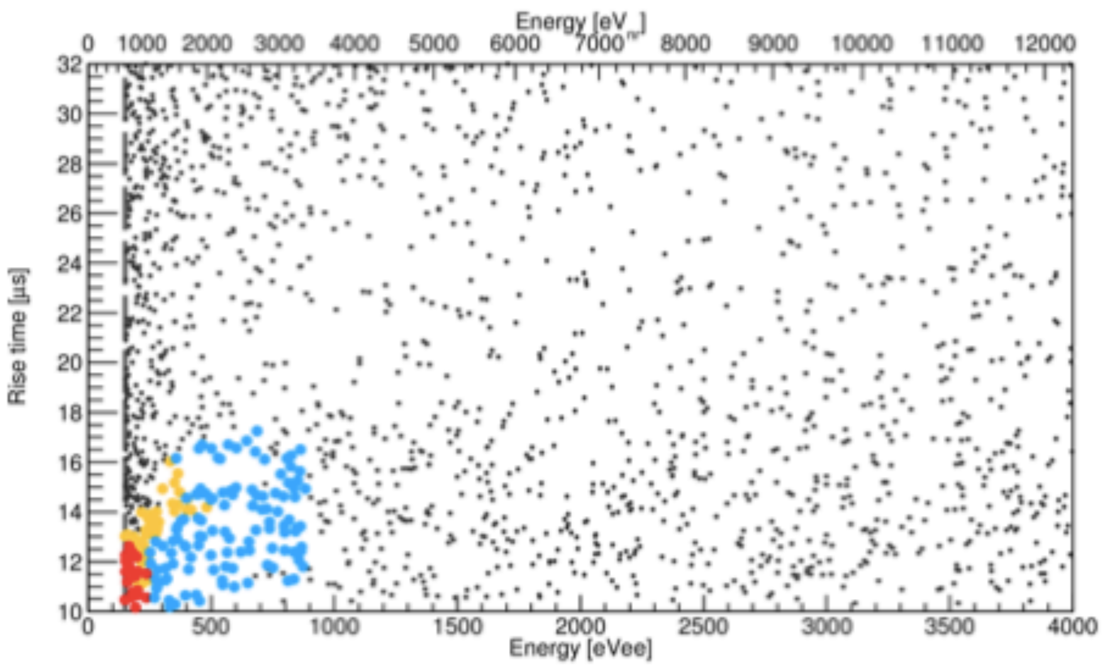


<u>Sensor</u>
**6.3 mm** Ø

# Physics-run data analysis

We make use of a Boosted Decision Tree (BDT) algorithm that we train with our signal and background models to identify the fine-tuned ROI that maximizes our expected sensitivity for 8 different WIMP masses

We end with a WIMP-mass-dependent fine-tuned ROI in the rise time vs energy plane




1715 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**

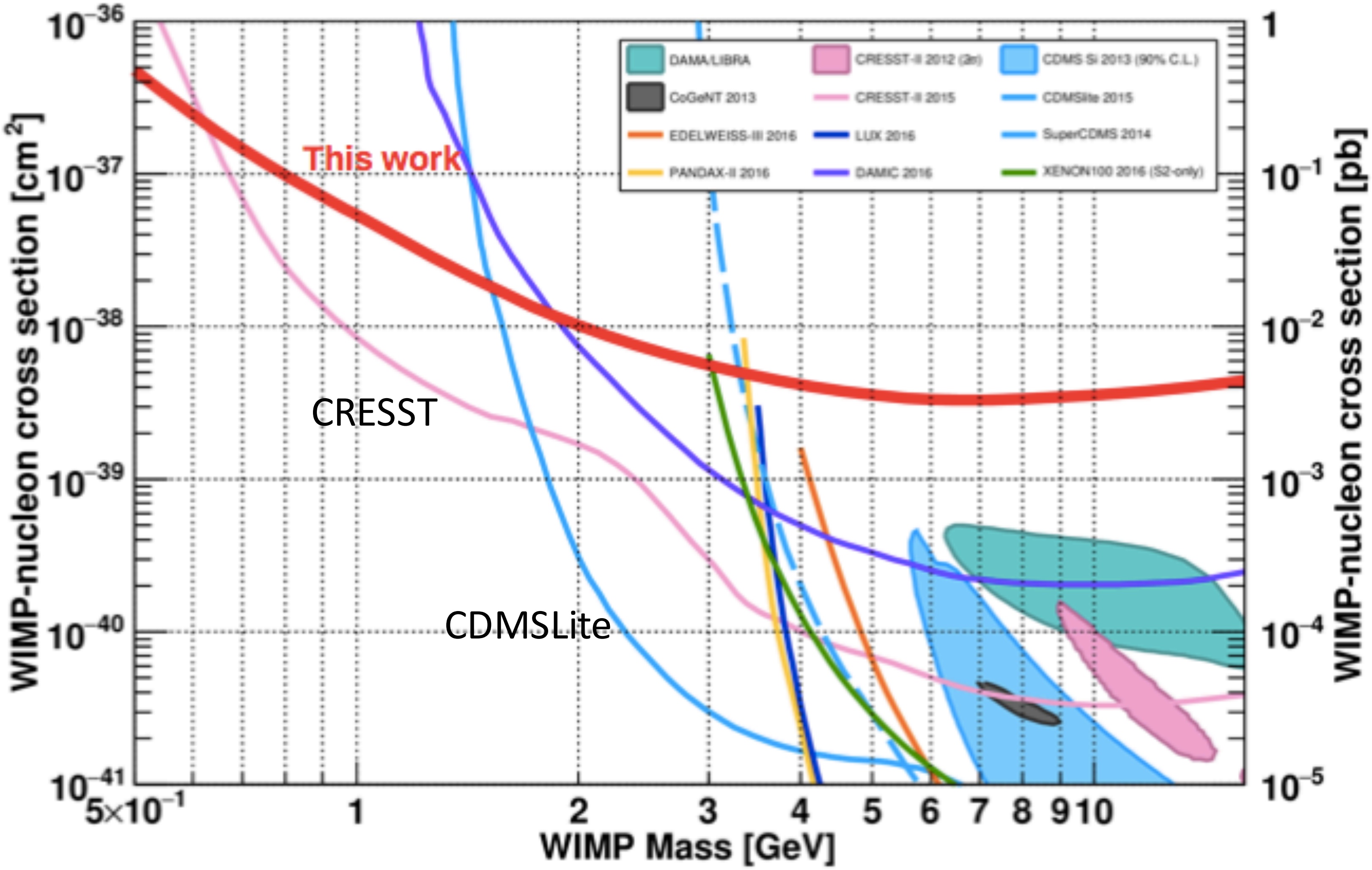
Robustness of the analysis methodology against background mis-modeling

If the BDT were to be trained with inaccurate background models, the fine-tuned ROI would just end to be non-optimized for signal/background discrimination

Still, an accurate modelisation of the signal is critical for the exclusion limit to be unbiased.

# First result

## Results

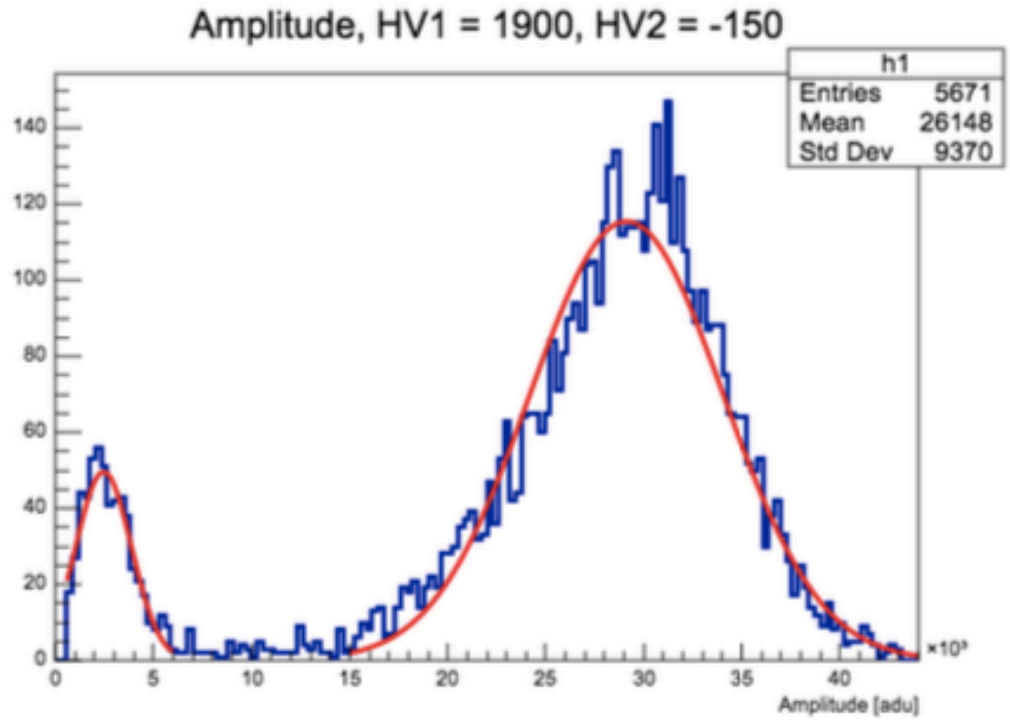


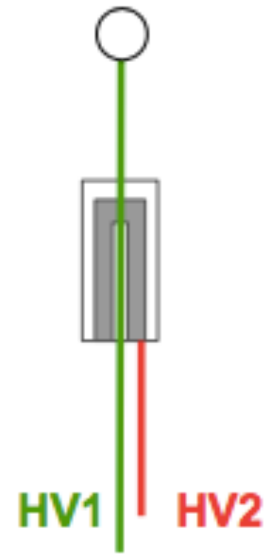

90 % (CL) upper limit derived from Poisson statistics.

Standard halo model parameters : $\rho_{DM}=0.3\ \mathrm{GeV/c^2/cm^3}$ $v_{esc}=544\ \mathrm{km/s}$ $v_0=220\ \mathrm{km/s}$

# Developments at Queen's, Alexis B, Dan & al

## Calibration at low energy


$\mu_1 = 2467$
$\sigma_1/\mu_1 = 57$ %
$R_1 = 3$ Hz

L capture:
0.2702 keV
BR = 0.0890

$\mu_2 = 29125$
$\sigma_2/\mu_2 = 17$ %
$R_2 = 28$ Hz

K capture
2.8224 keV
BR = 0.9017

NB
Analysis threshold = 50 eV

Online trigger ⇔ 10 eV
ie 0.3 electron

Ar + 2% $CH_4$ @ 500 mbar

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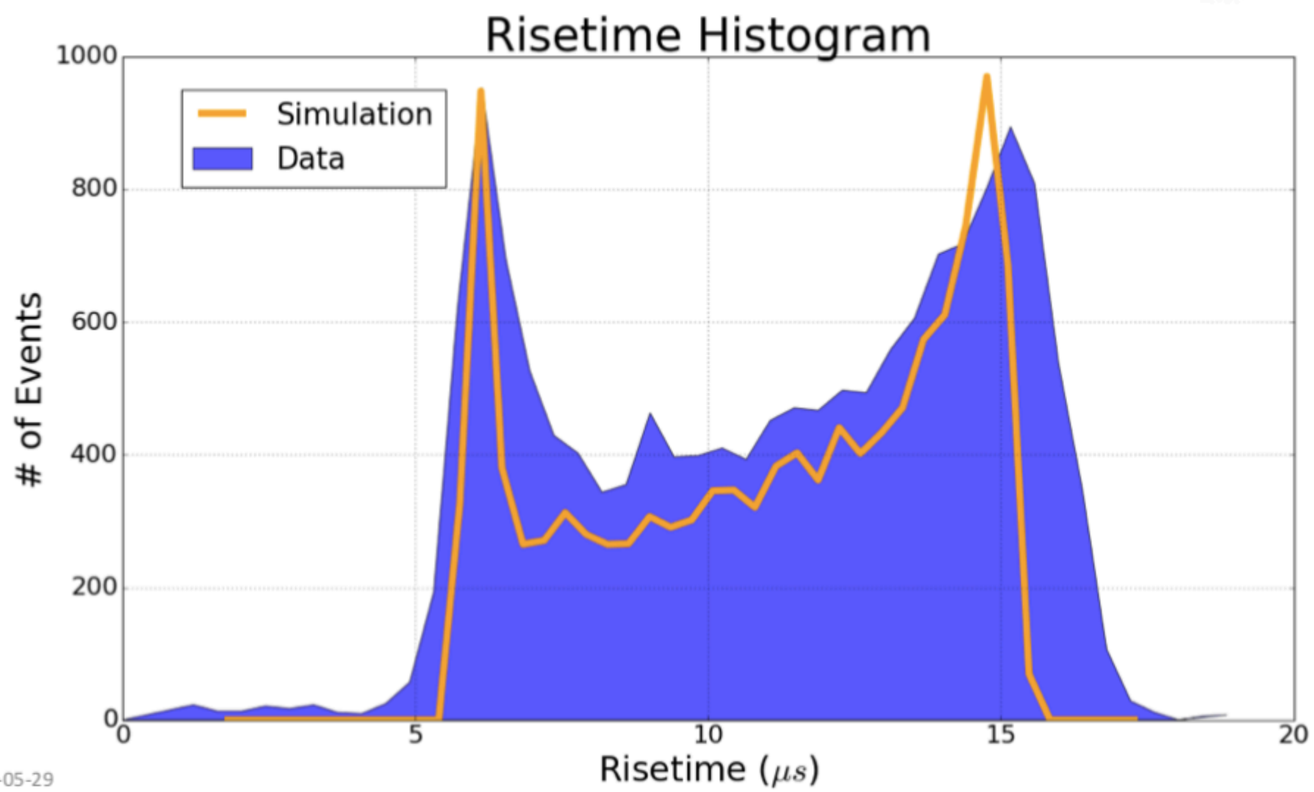
## Alpha Particle Calibration



# New skills, ideas

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# RMCC

Production of $^{37}Ar$ at the RMCC

David Kelly, Andrew Faurschou & Emily Corcoran

NEWS-G 3rd Collaboration Meeting
Kingston
Tuesday 25th of April 2017

- $^{37}Ar$ production from CaO
  - $^{40}Ca + n \rightarrow {}^{37}Ar + \alpha$
- Production parameters
  - $^{37}Ar$ at $< 10^{-5}$ Torr
  - Absence of other radionuclides
  - 'Cold' container
  - Simple production process ($t_{1/2}$ = 35.1 d)
  - Known activities

## Production Challenges

- Size: 7 mL vial
- Transfer: Compatibility
- Materials: Vacuum and activation
- Liberation: CaO matrix
- Quantification: Can't measure $^{37}Ar$

First delivery may 2017 = complete success !!

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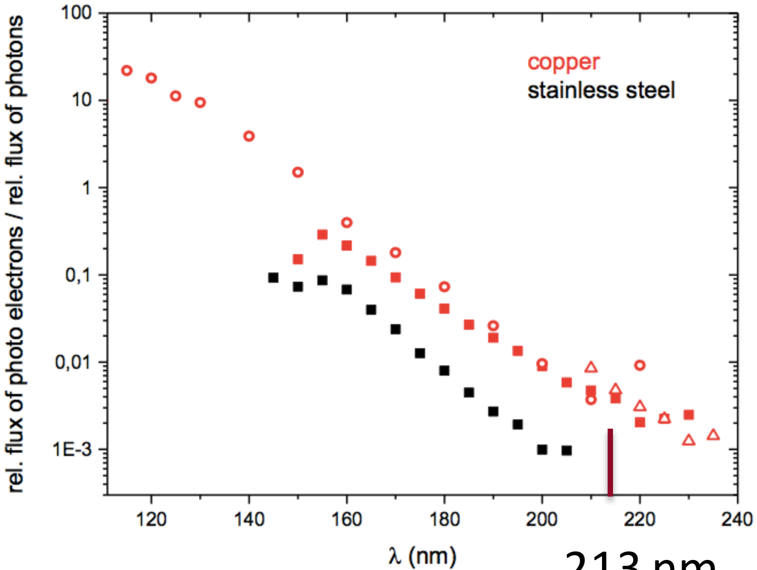
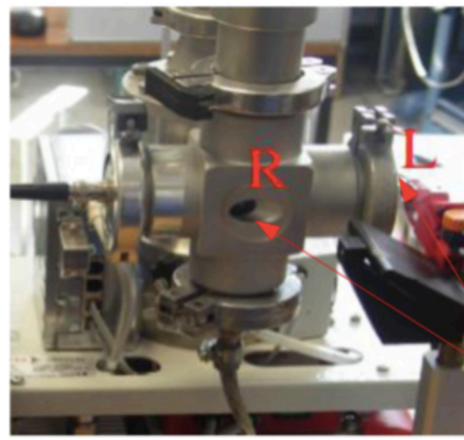
# Technical Uinversity Munich : A Ulrich

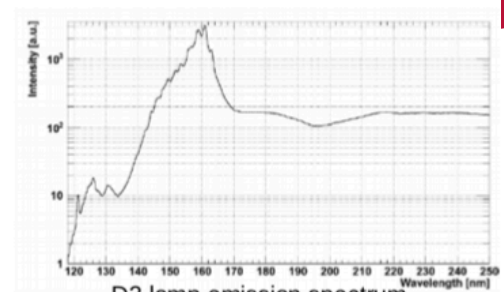
Measurements of work function in Copper/Steel as function of UV wavelength




213 nm




Test cell under vacuum (E-06 Pa)



D2 lamp emission spectrum

Optical ports for light injection

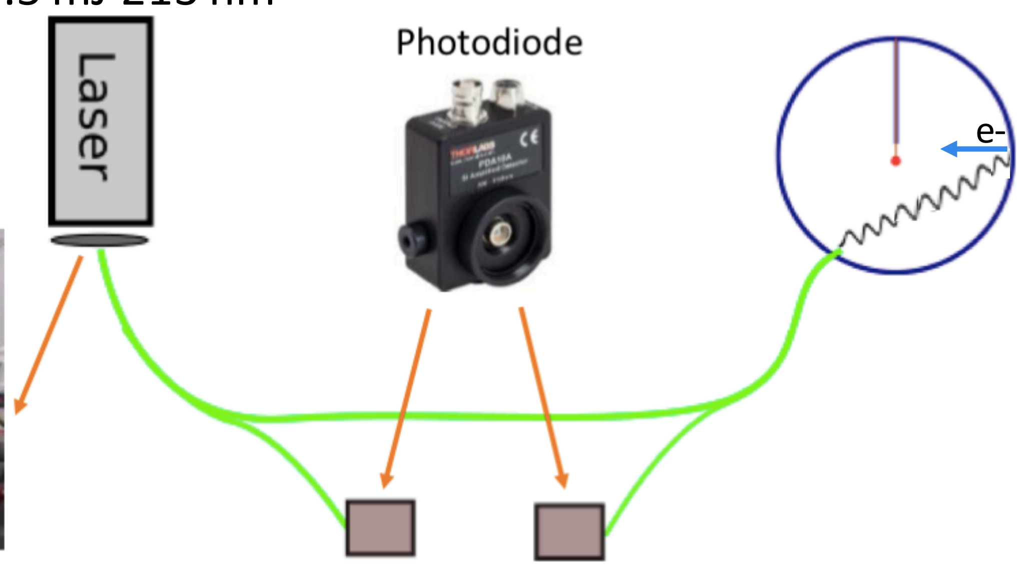
0.5 mJ 213 nm

- Allowed to size the power and wavelength of laser
- Principles of control of input light and aging of fibers with photodiodes

Changeable neutral density filters

A Kamaha

Photodiode



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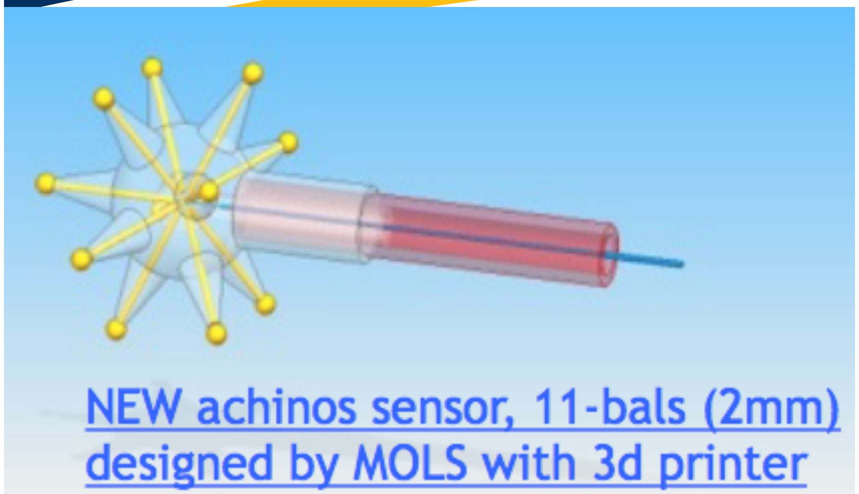
# R&D Saclay : Achinos

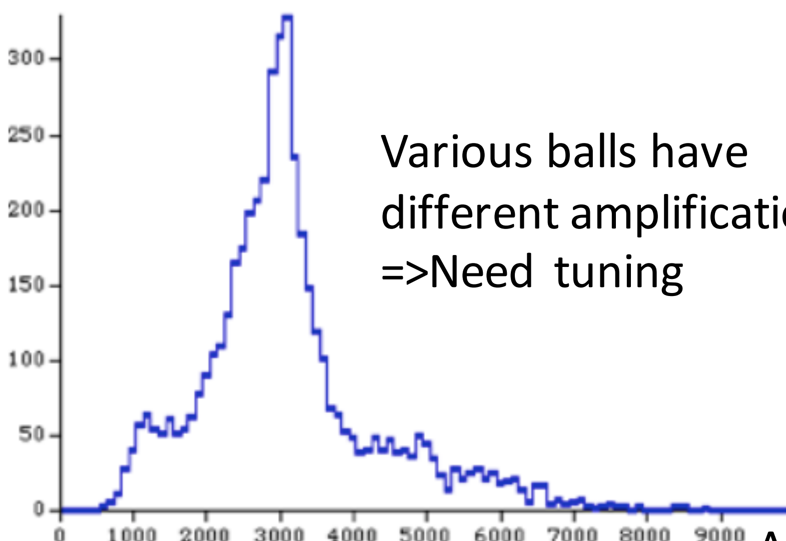



**Advantages**

- **Amplification tuned by the ball size: 1-2mm diameter for high pressure**
- **Volume electric field tuned by the size of the ACHINOS structure**
- **Detector segmentation**

**ACHINOS-11balls phi=2mm,phi bakelite=25mm,ball distance=7.5mm**

Gas filling: p=330mbar He+10%CH4
RUN :ra09e000 180 deg, HV1=1450, HV=-50V , T=5720, N=61k

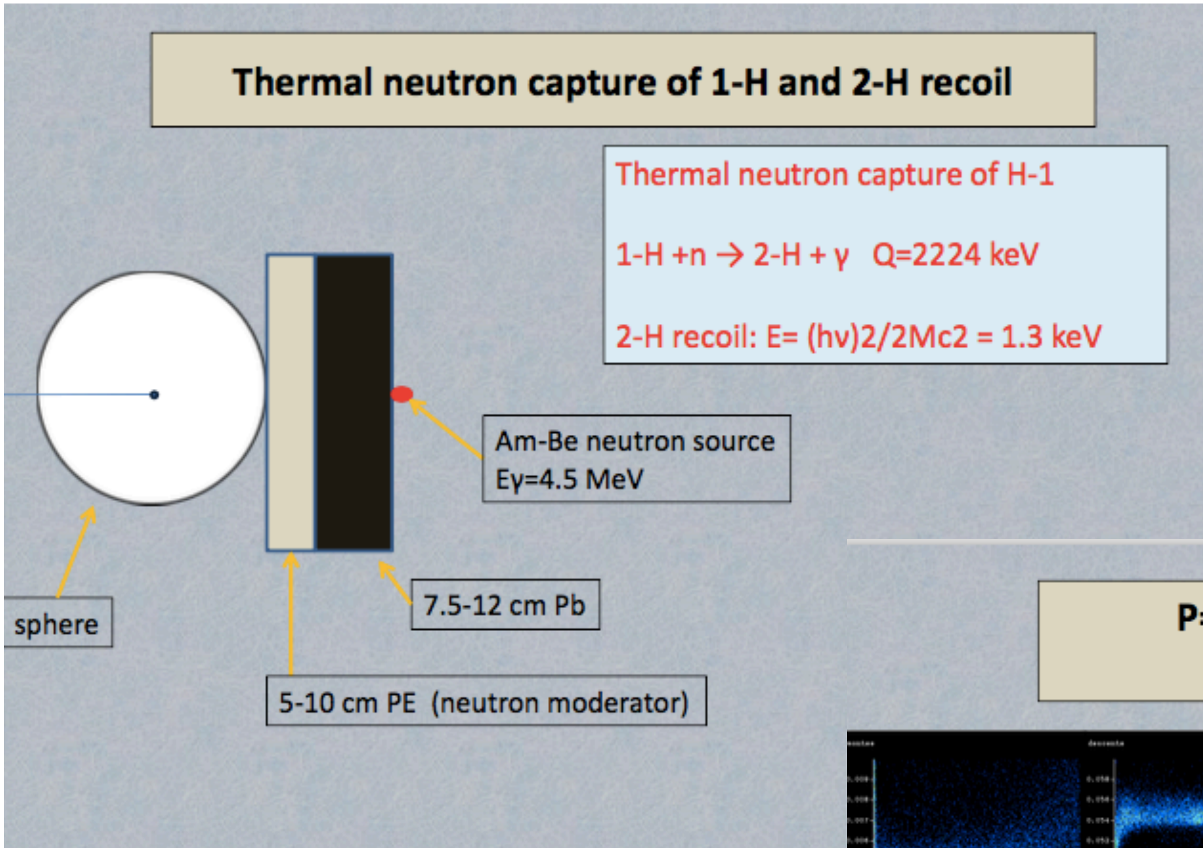


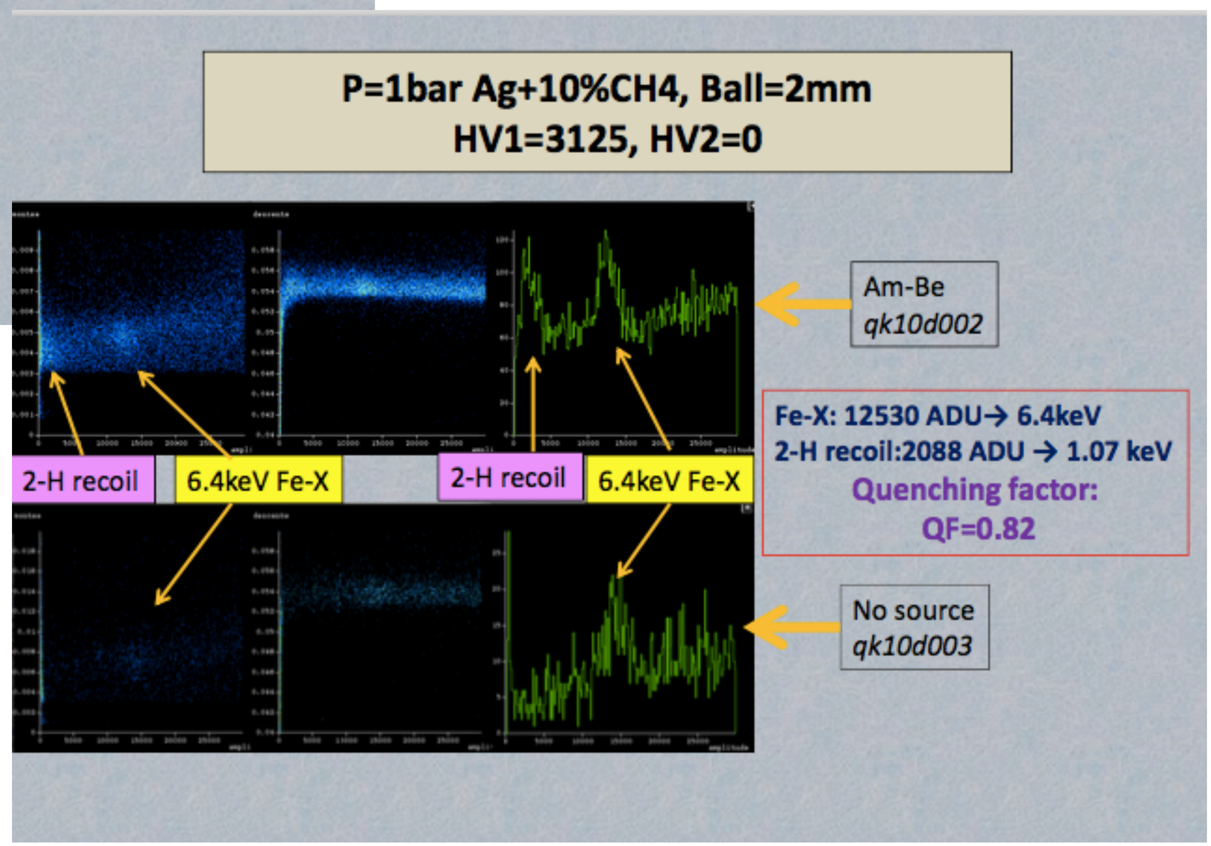

Various balls have different amplifications =>Need tuning

Diffusion time indeed reduced from 40 to 4 mics

Amplitude 5.9 keV from $^{55}Fe$

# R&D Thessaloniki : Neutron capture calibration




Measurement of quenching of
H2 recoil of 1.3 keV   in Argon

# Preparing the 140cm project @ SNOLAB

# NewS collaboration

## NEWS-G SNOLAB project

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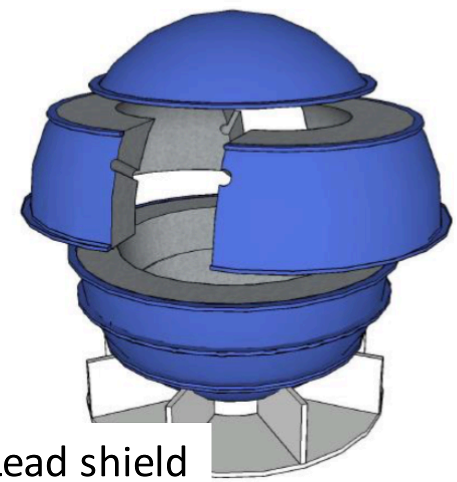
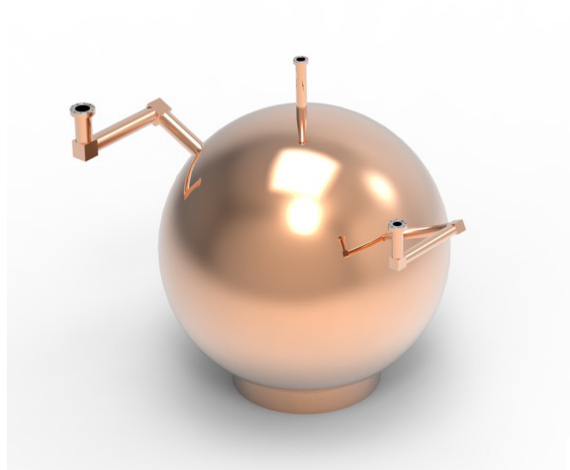
# 140 cm diameter project with compact shield option

## implementation at SNOLAB by 2018

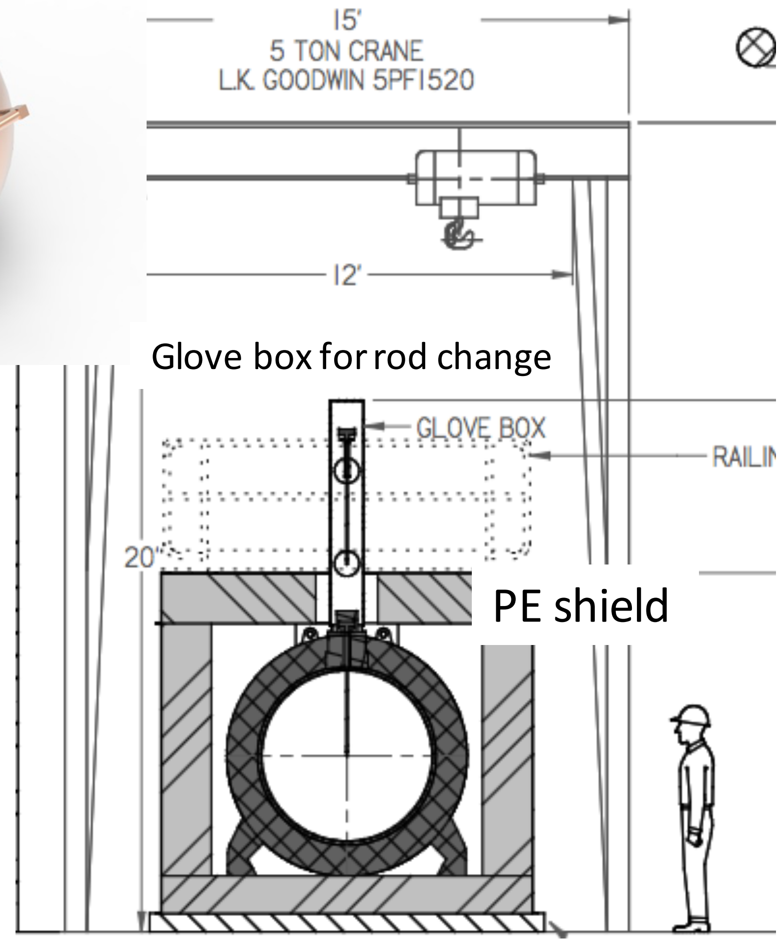
- 140 cm Ø detector, 10 bars, Ne, He, $CH_4$
- 25 cm compact lead –3cm ancient - LSM
- 40 cm PE + Boron sheet



Lead shield



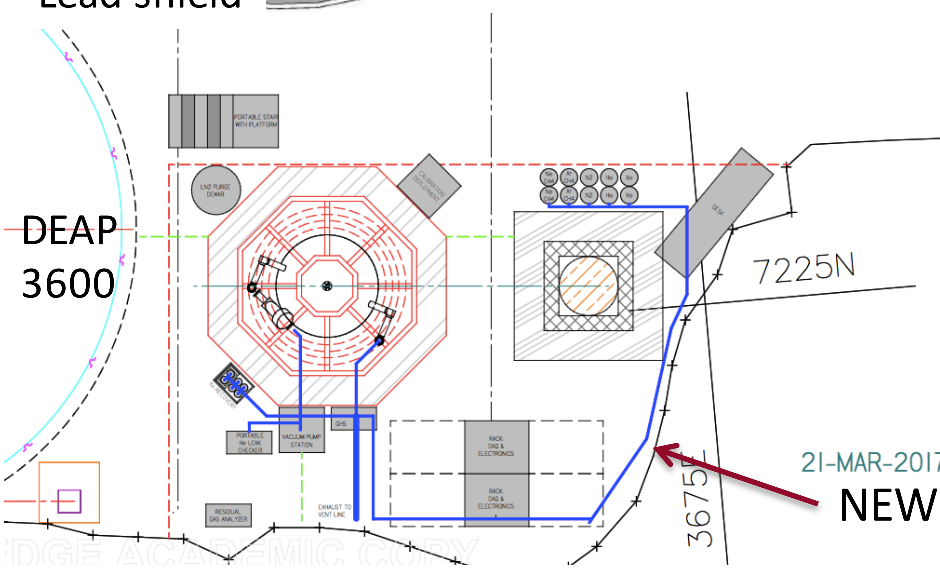
Copper vessel




Glove box for rod change

PE shield

35 t shields



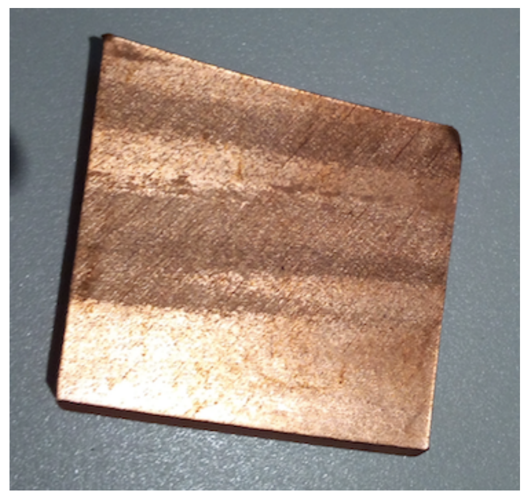

NEWS-G in Cube Hall

# Hemisphere spinning test and clean up

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

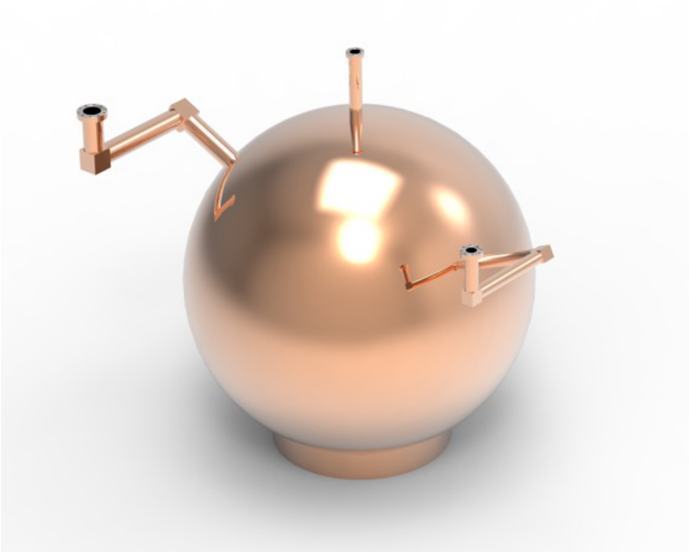
- PNNL measurements of bulk and surface
⇒ 7 to 25 μBq/kg of Th
⇒ 1 to 5 μBq/kg of U
Ok for goals fixed of first expt

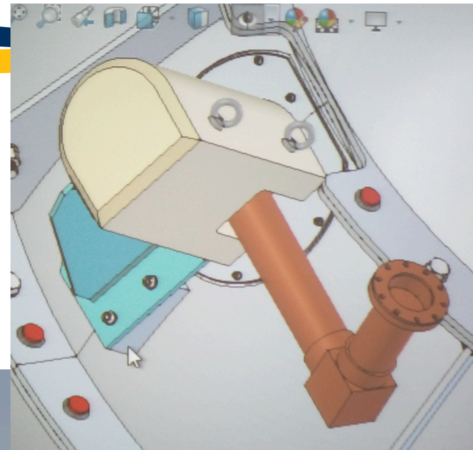
- Test of surface cleaning with HP water jet tests
  - 3000b water jet => 30 μ removal
  - Possible but -too- expensive



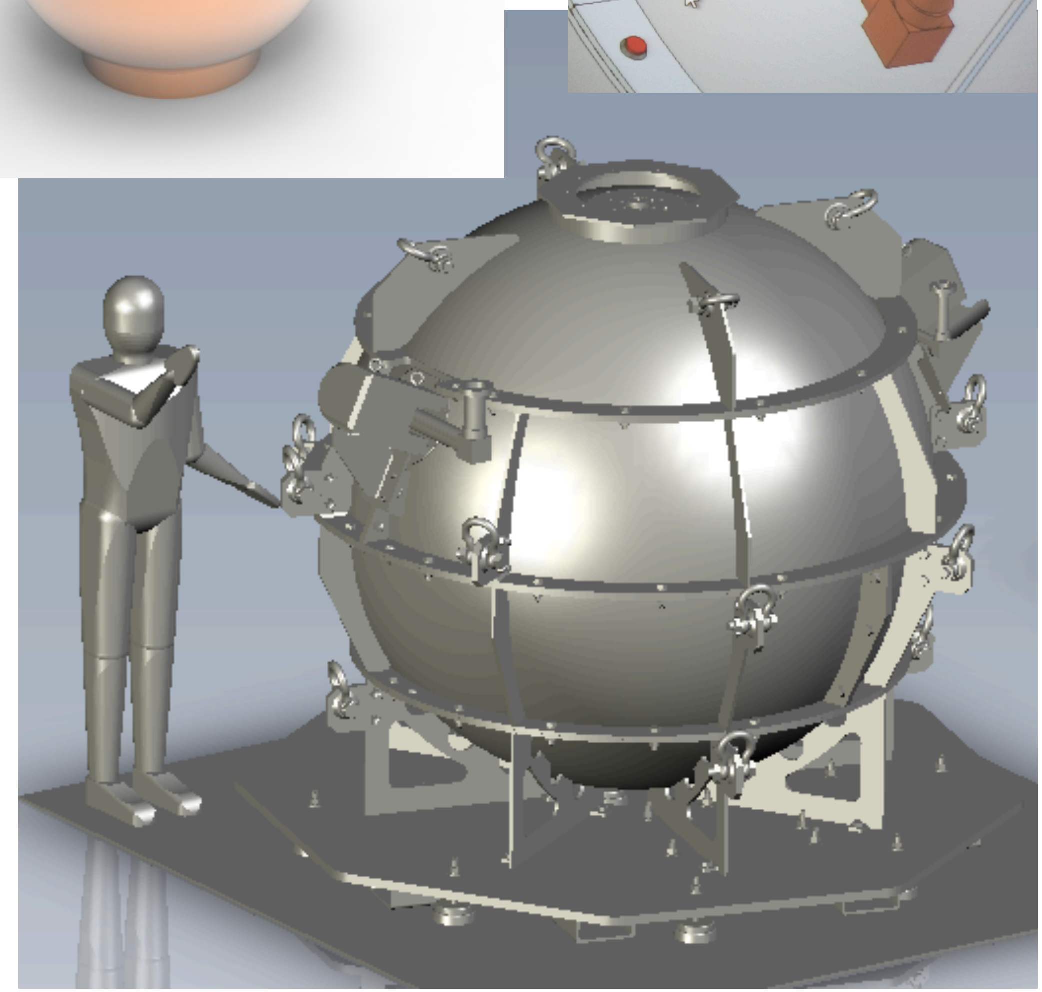
- Electron welding of hemispheres and piping

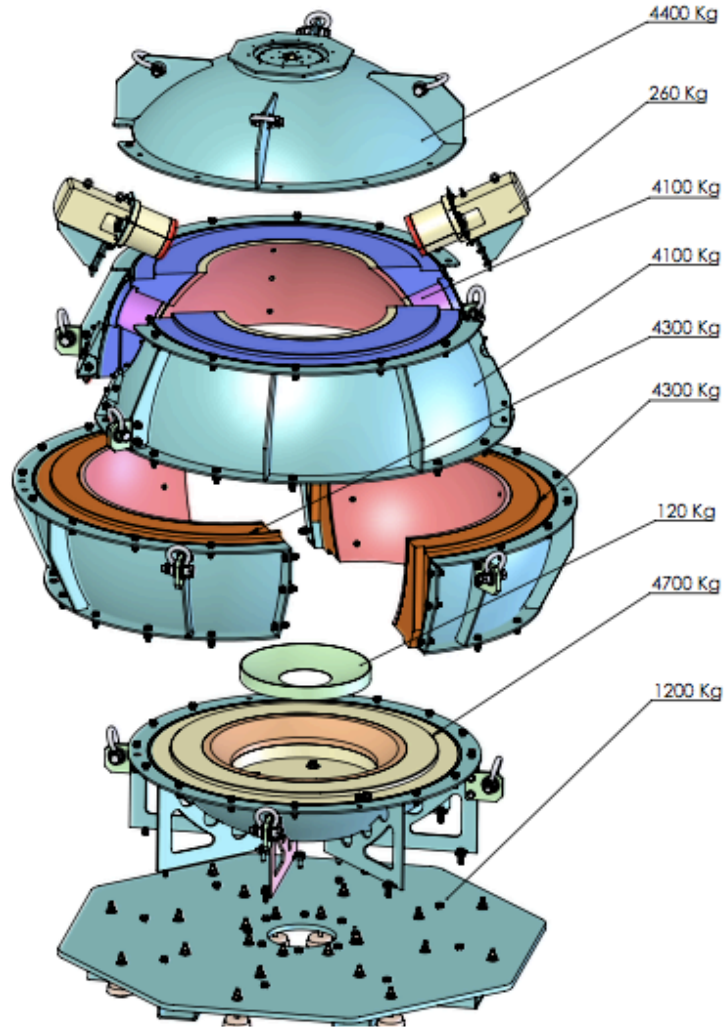
# TDR – construction phase





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 |

Copper

Internal surface

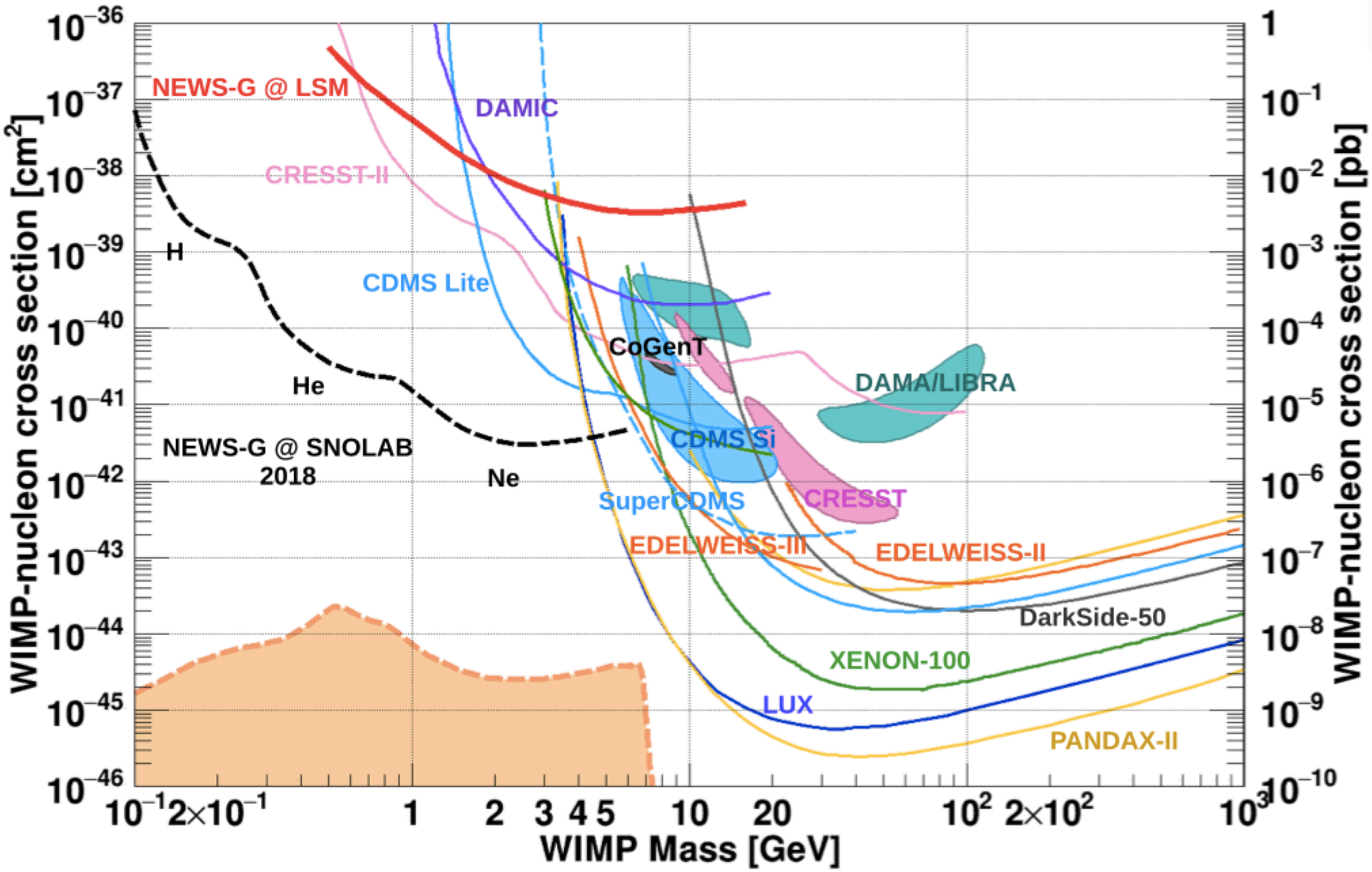
Lead shield

External bckg with SNOLAB flux

| | |
|---|---|
| **Total** | **0.279** |

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

# Projections for NEWS-G wrt current situation (2016)



## Beyond : lowering background

# NEWS-G collaboration

- **Queen's University Kingston** – G Gerbier, P di Stefano, R Martin, T Noble, D Dunrford , S Crawford 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
- **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

*April 2017*

# Electroforming spherical prototype

## Electroforming the NEWS spheres

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

R&D funding now in place at PNNL to electroform a small (30 cm? diameter) prototype sphere

- Plate onto a mandrel made of material which is dissolved when completed-intact sphere
- Center ball and vessel spheres could be a wide range of diameters electroformed as single unit or hemispheres with flange
- Collaboration can decide on specific dimensions limited by PNNL LDRD budget
    - Wall thickness or alloy to meet engineering requirements for 10-50 (?) atm pressure vessel

- Electroforming underground would significantly reduce cosmogenic $^{60}$Co ingrowth
- Growth rate ~ 1mm/month
- 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

2

Decrease of $^{60}$Co by >10

Decrease of U/Th by >10

Funding from
Prototype of 30 cm sphere being designed

# Quenching factor measurements : the ultimate tool

# NewS collaboration

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cf Philippe di Stefano talk

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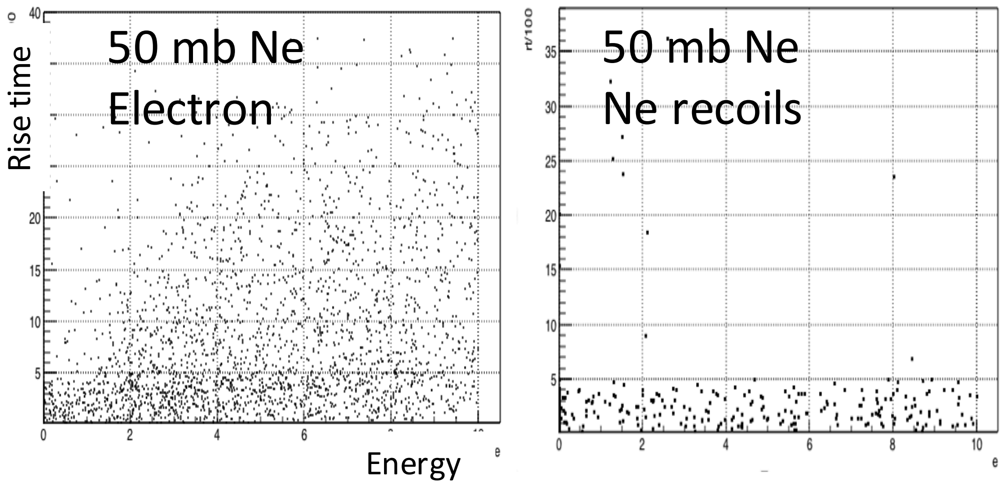
# Longer term ideas

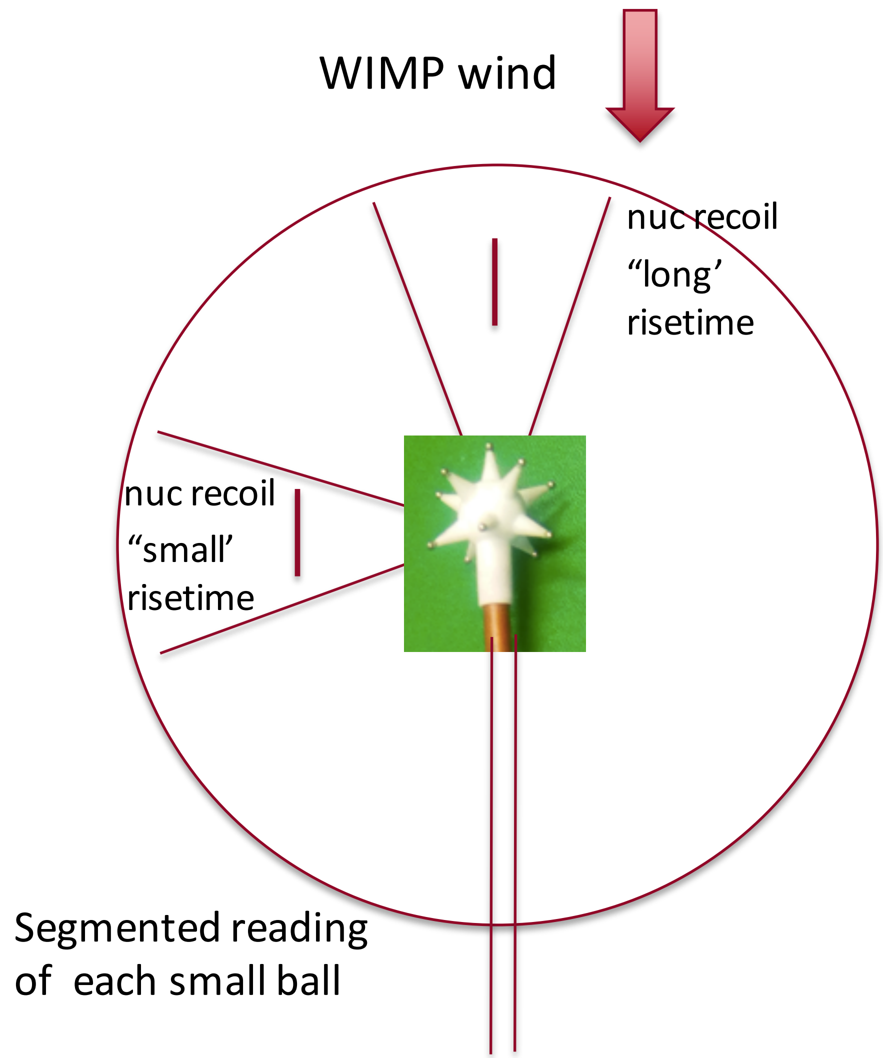
# Operation at low pressure ie 50 mb

- e/NR discrimination by range




- Possible directionality with segmented achinos sensor

- Feasibilities tbc



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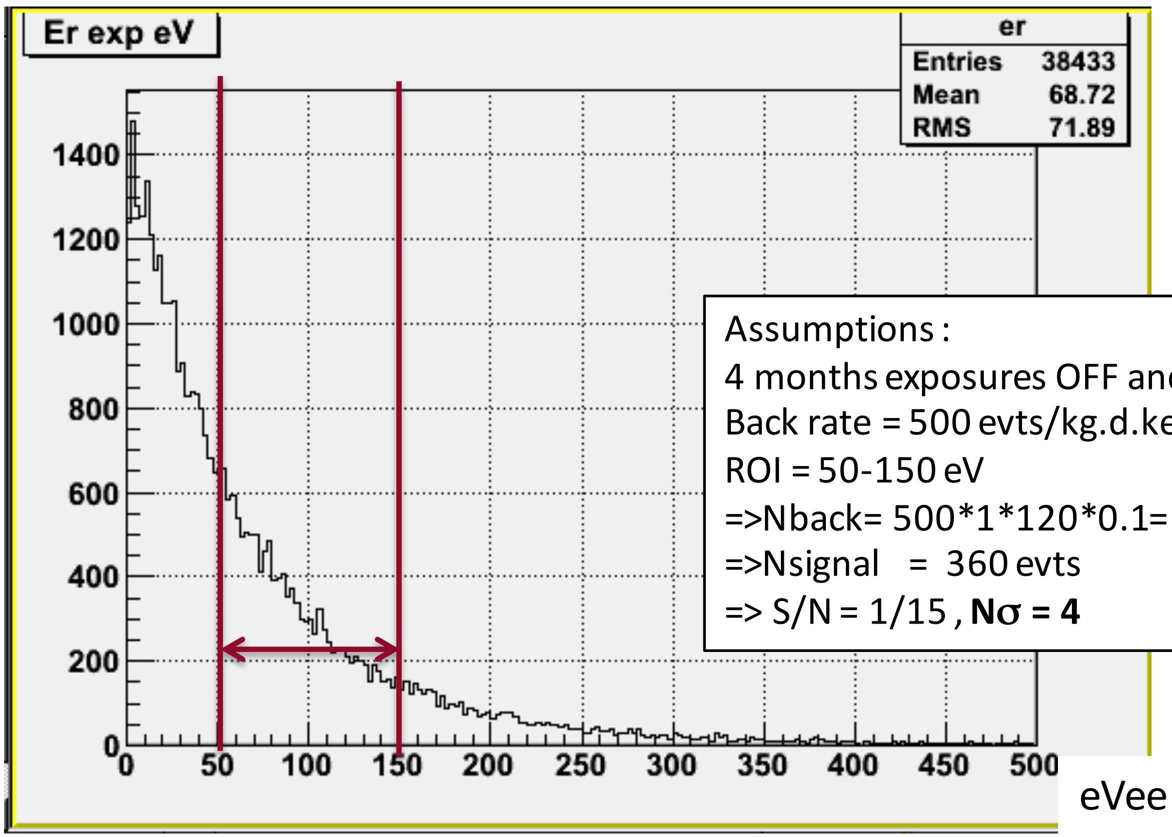
*April 2017*

# Coherent nuclear neutrino scattering at nuclear reactor within reach

- Simulation of expected spectrum from nuclear reactor, on Ar, with quenching factor and instrumental response to single electron
- Normalisation to nuclear plant of 1 GW
- Sphere of 80 cm diam, 2 bars

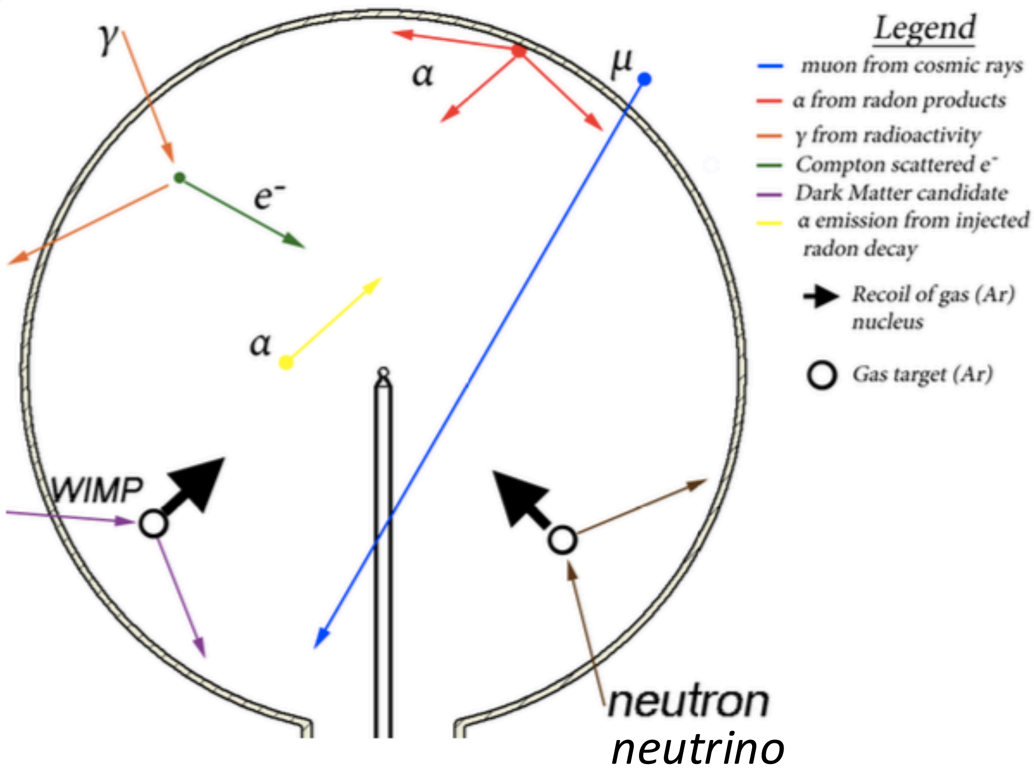
| Parameters | | | |
|---|---|---|---|
| Power of reactor | | 1 | GW |
| Distance to core | | 10 | m |
| Radius of sphere | | 0.4 | m |
| Pressure | | 2 | atm |
| Gaz | argon | 0.96 | kg |
| **Signal nucoh** | | **3** | **evts/day** |
| Delta E : 2-6e | | 0.1 | keV |

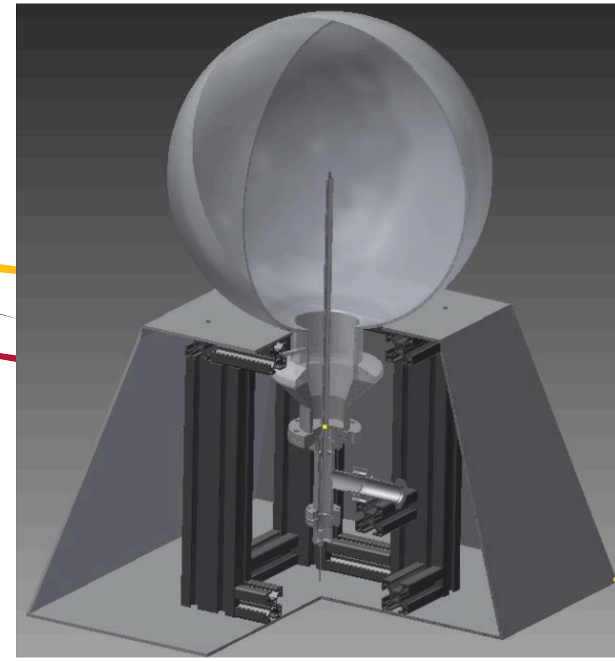
**Evis >52 eV**




Assumptions :
4 months exposures OFF and ON
Back rate = 500 evts/kg.d.keV
ROI = 50-150 eV
=>Nback= 500*1*120*0.1=6 000 evts
=>Nsignal = 360 evts
=> S/N = 1/15 , **Nσ = 4**

# Outreach / lab project : Sean C, Queen's



Build " portable " detector with integrated electronics => USB
Adapt treatment of information to "target"

- students : raw data
- secondary : description of radioactivity / cosmic rays / DM
- general : sounds and visual effects

# Conclusion and outlook

- First competitive results with gas detector in DM search
- Planned runs with He and H nuclei @ LSM
- 60 cm SEDINE detector essential to optimize 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
  - "achinos" type sensor
  - multi channels sensor
  - low pressure operation
  - …

- DM Physics : 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…