New Experiments With Spheres
Light Dark Matter search
NEWS_LSM results and NEWS_SNO project

Principles of gaseous spherical detector

Light Dark Matter search with SEDINE at LSM

NEWS-SNO project

Outlook

Gilles Gerbier
Queen's University

Large TPC symposium Paris– Dec 6th 2016

Canada Excellence Research Chairs
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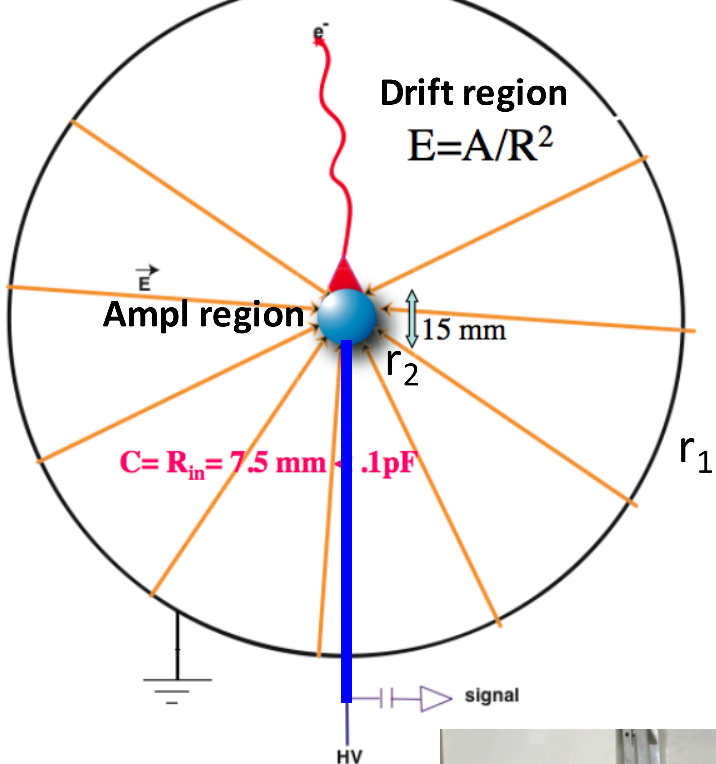
Spherical gas detectors
New Experiments With Spheres



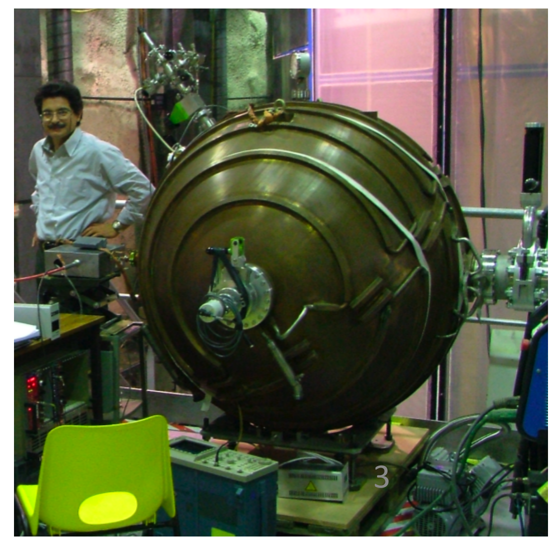
- Sphere cavity + spherical sensor + HT
- => **Low threshold (low C), does not depend on size**
- **Fiducial volume selection by risetime**
- **Flexible (P, gaz)**
- Large mass / large volume (30 kg) with single channel
- Simple, sealed mode
- 2 LEP cavity 130 cm Ø tested
- **1 low activity 60 cm Ø in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

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

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

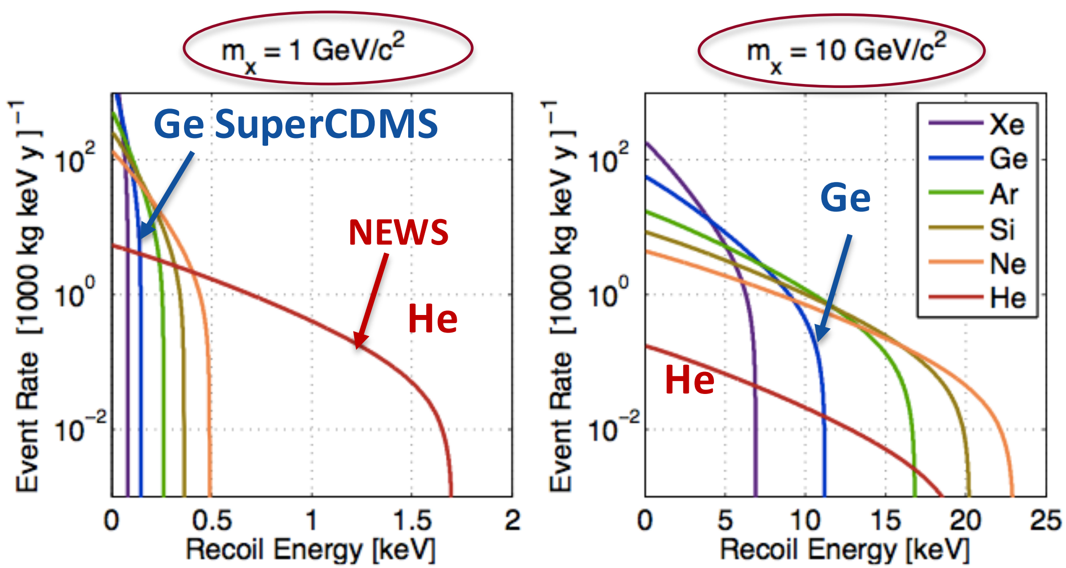
$$\rho \approx r_2$$

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



Detection of “low mass” flying particle

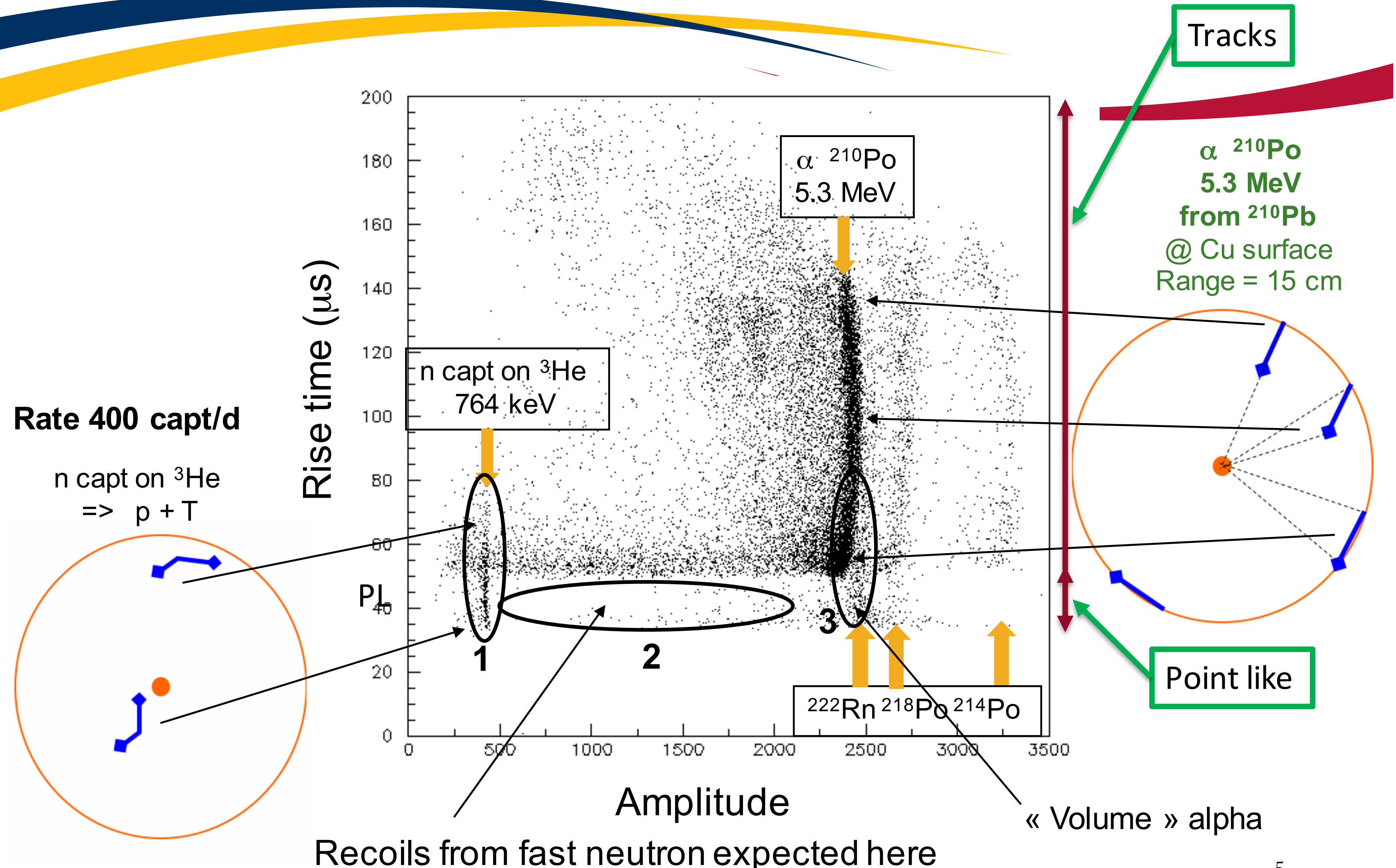
- Kinematical match
- To detect **flying ping pong balls** is it better to have as **target** :
  - **lead** “petanque” balls
  - or **ping pong** balls ?
- => use light nuclei to detect light WIMPs
- H, He, Ne lightest among noble gas



Recoil distributions with various targets

Illustration of particle identification at MeV energy

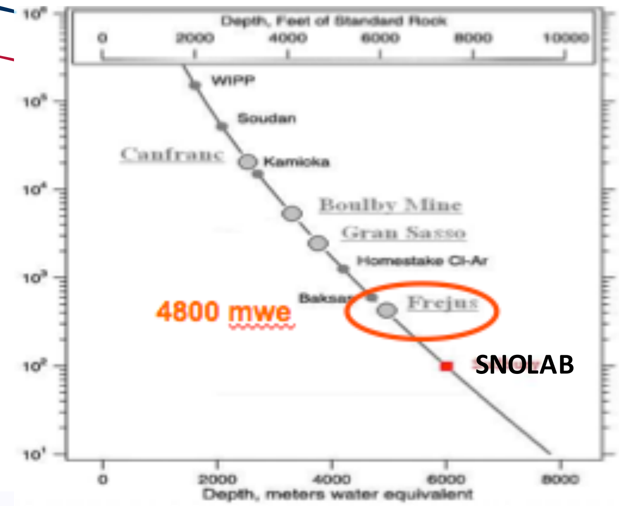
Ar/CH_4 + 3g ^{3}He @ 200 mb SPC 130cm Ø @ LSM



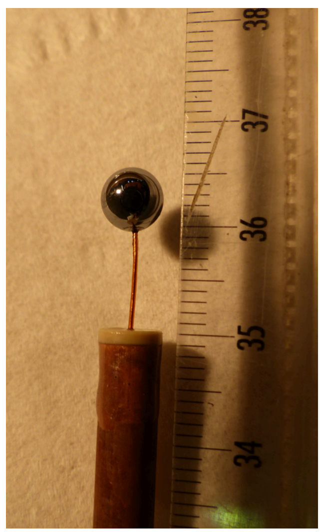
Light WIMP (WINSMP) search NEWS-LSM
Low activity 60 cm Ø prototype @ LSM : SeDiNe

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

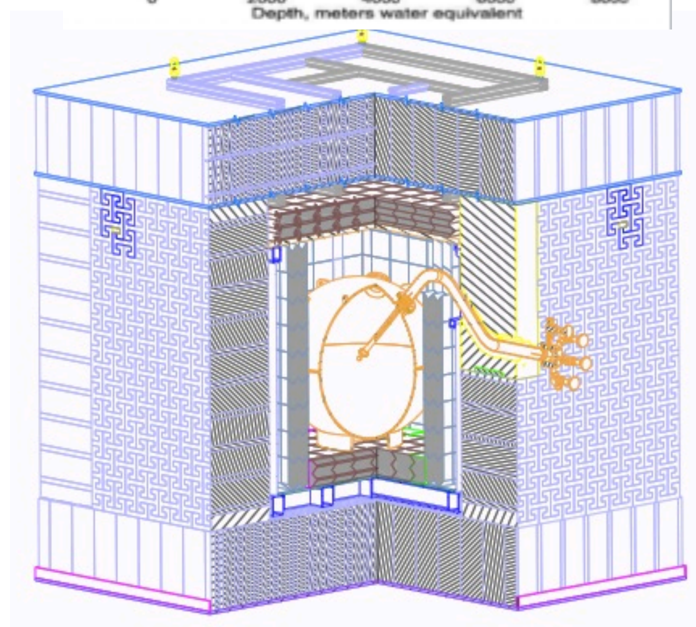
- Copper vessel equipped with 6 mm Ø sensor
- Runs with **Neon**+0.7%CH_4 @ 3.1 bars
- => 310 g sensitive mass
- Several internal cleanings for radon deposit removal
- 42 days run for WIMP search



60 cm NOSV copper vessel



6.3 mm sensor

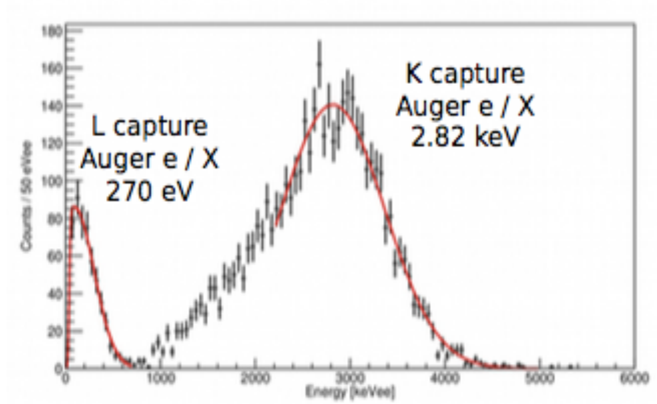


Shields 4 to 7 cm Cu, 10 cm Pb, 30 cm PE

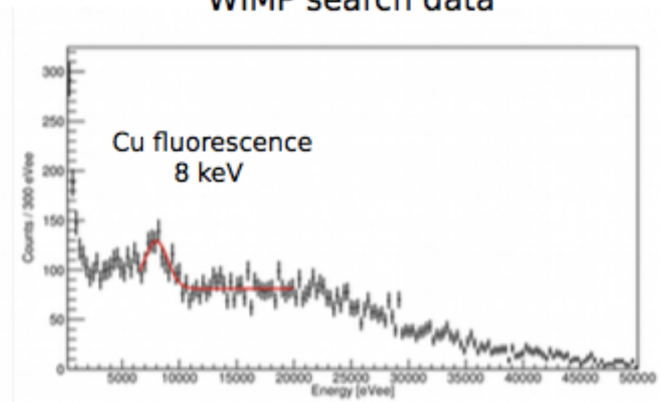
Operation and data taking conditions

- **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**
- **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

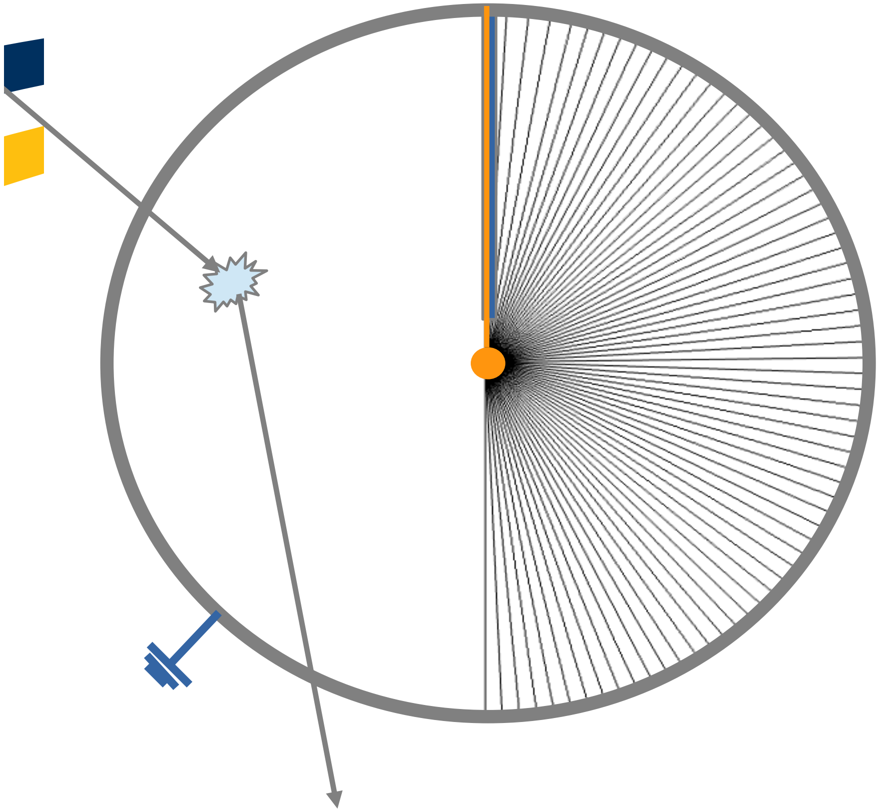


WIMP search data



Pulse formation

Following an energy deposit within the target gas :



Primary Ionisation

Mean number of primary electrons created :

$$\langle N \rangle = \frac{E_R}{\epsilon_j}$$

With Neon : $\epsilon_\gamma = 36$ eV

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

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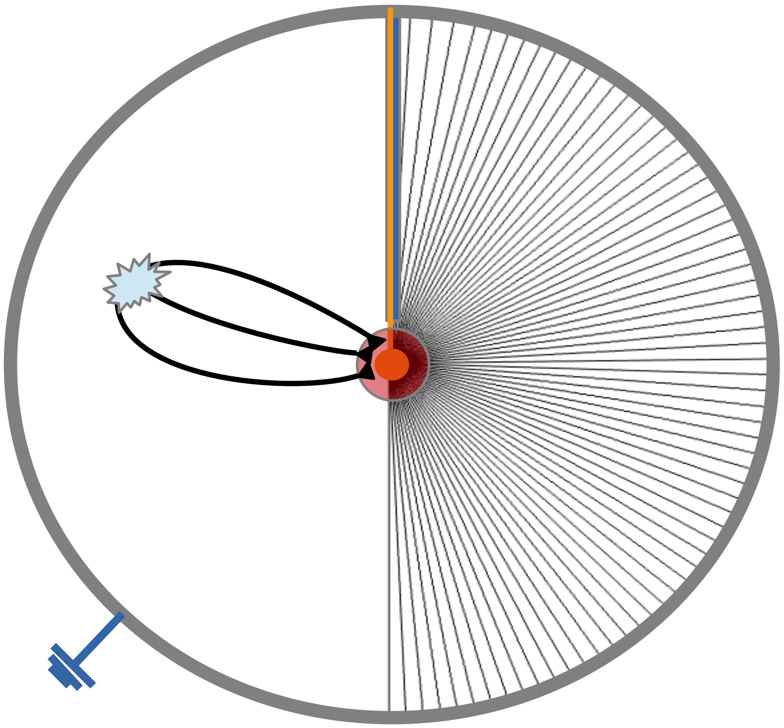

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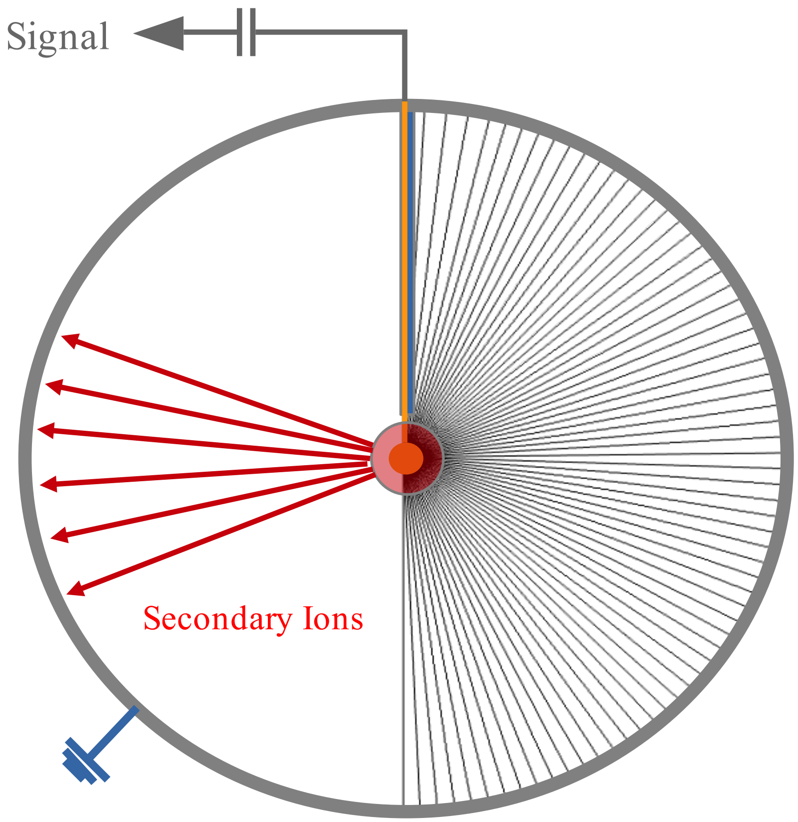
<u>Drift of the electrons toward the sensor</u>

Typical drift time surface → sensor : ~500 µs

Pulse formation



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[Drift of the electrons toward the sensor]

Typical drift time surface → sensor : ~500 μs

[Avalanche Process]

Each primary electron leads in average to 3000 secondary ionisations

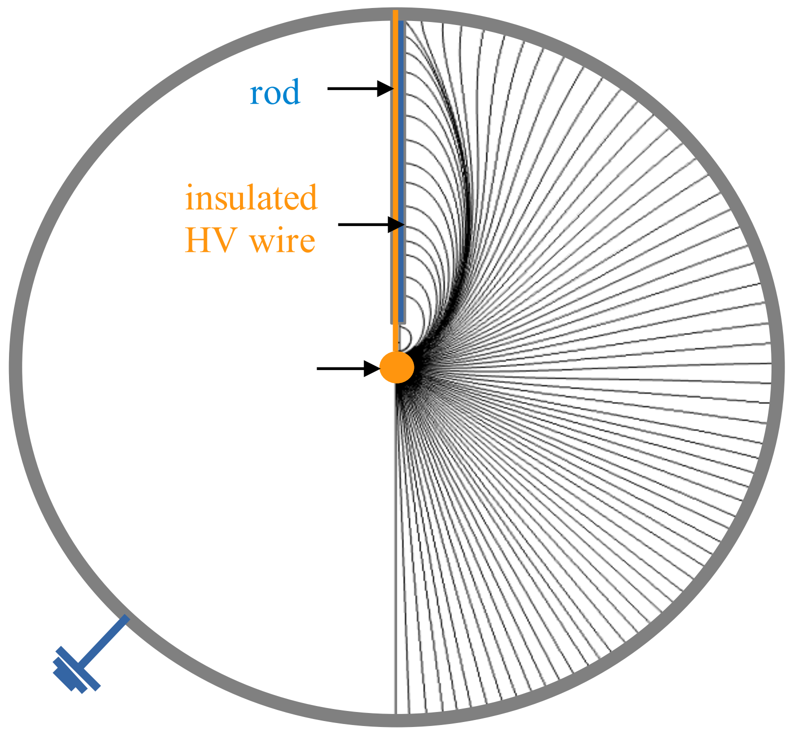
[Signal Formation]

Current induced by secondary Ions drifting toward the ground ~ few seconds

Signal readout with a charge amplifier

(RC=46 μs)

Pulse formation



In real life

Primary Ionisation

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With Neon : $\epsilon_\gamma = 36$ eV $\quad \epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$

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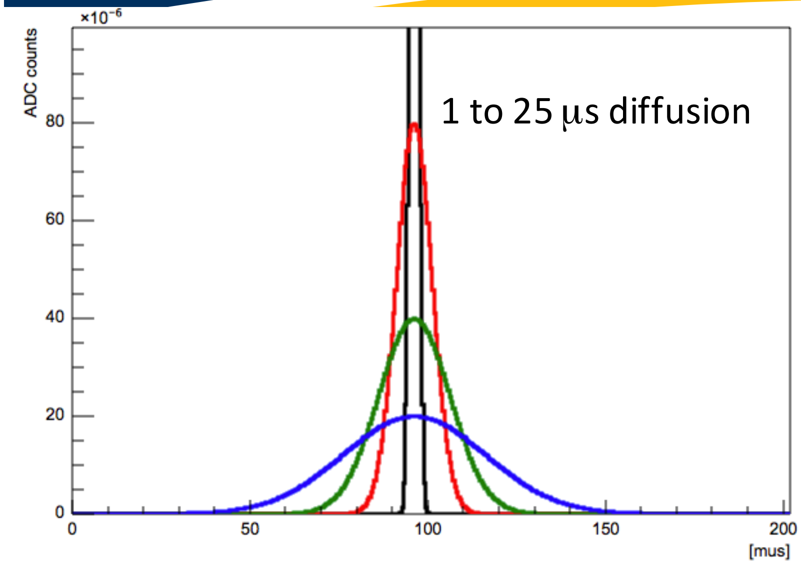
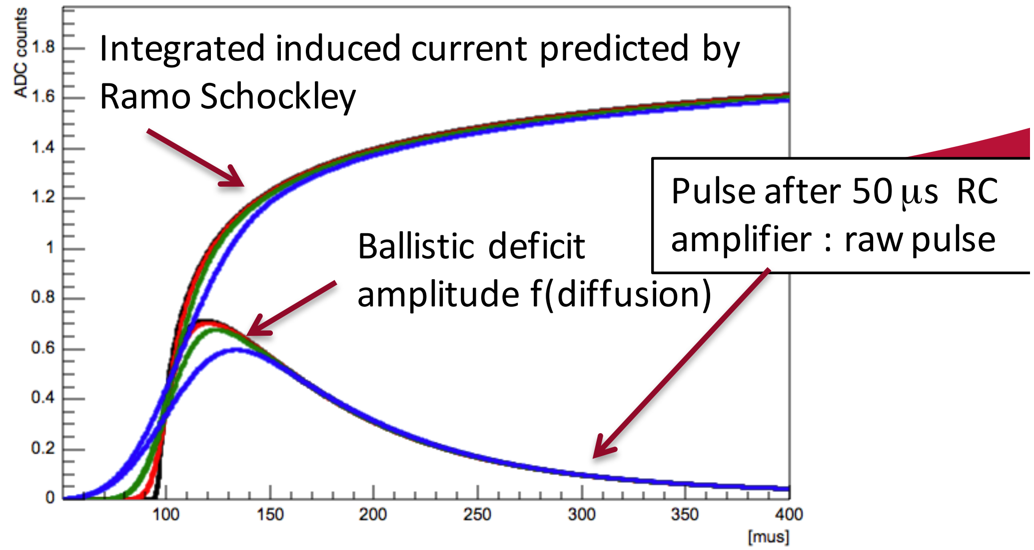
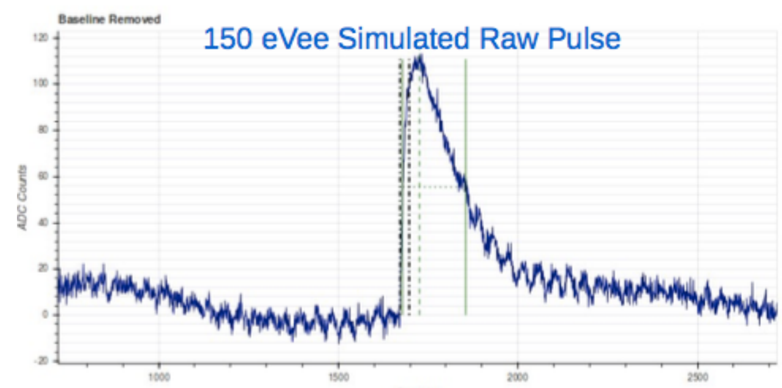
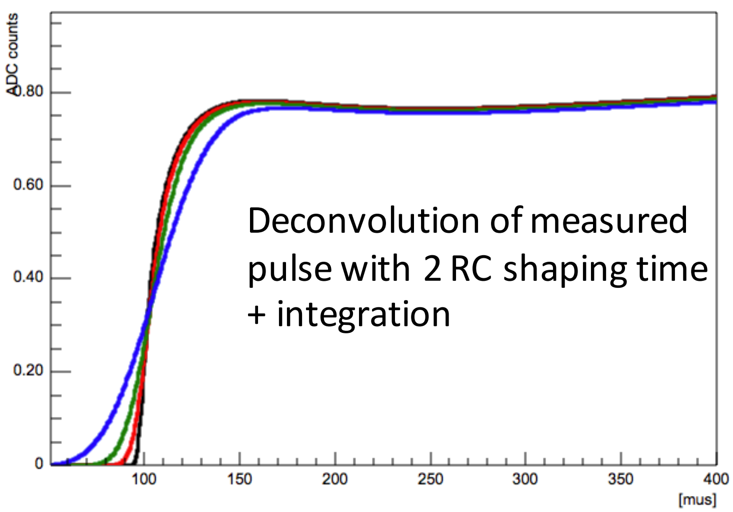
Pulse formation and simulation

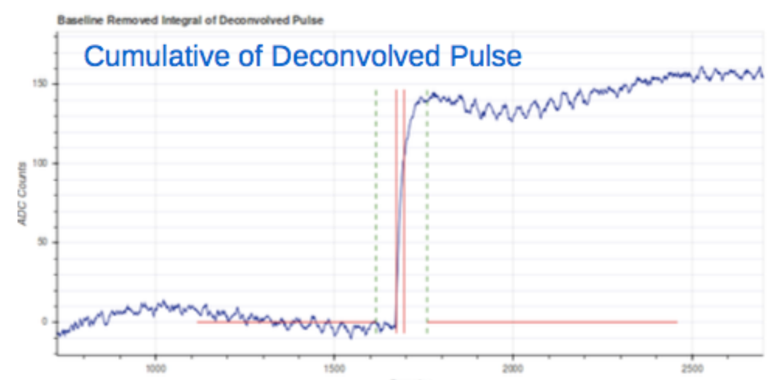


Primary pulse : arrival times of primary electrons



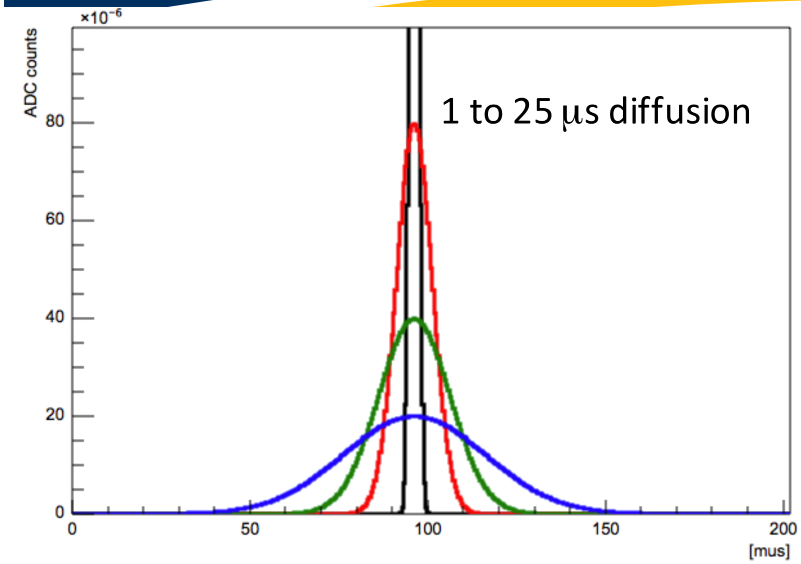






Paco Vasquez de Sola PhD

Pulse formation and simulation



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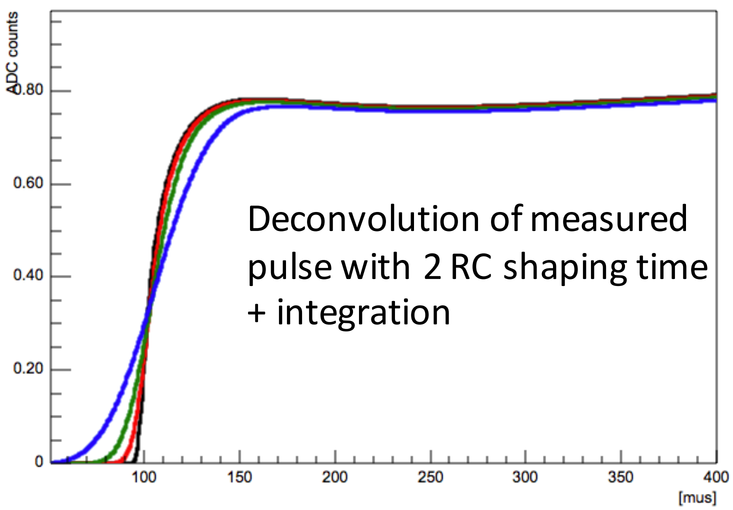
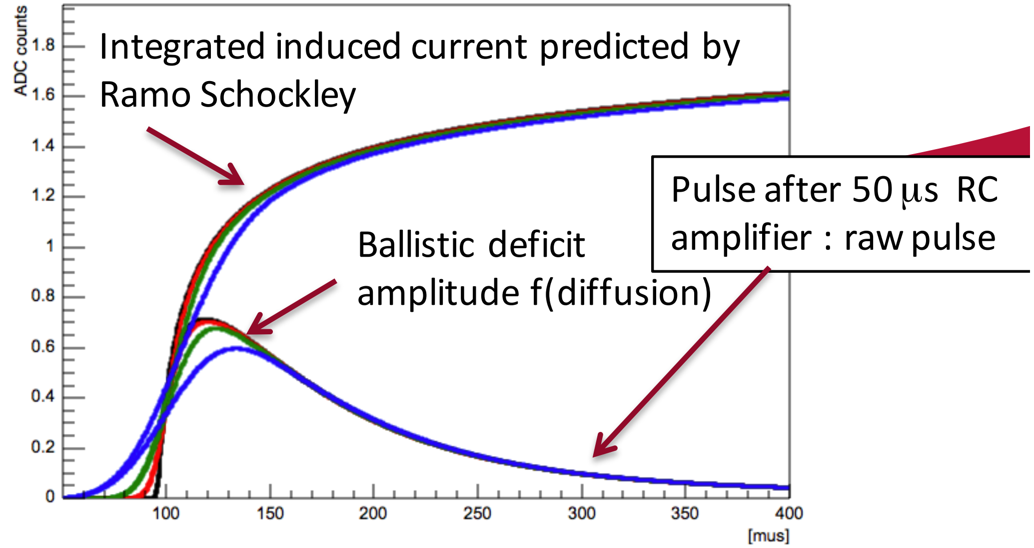
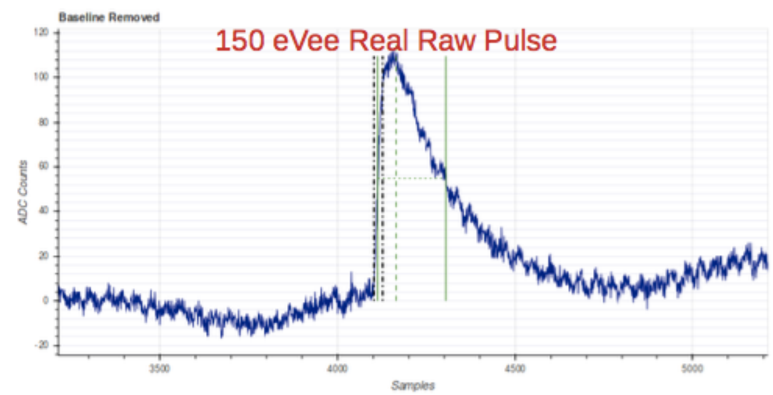
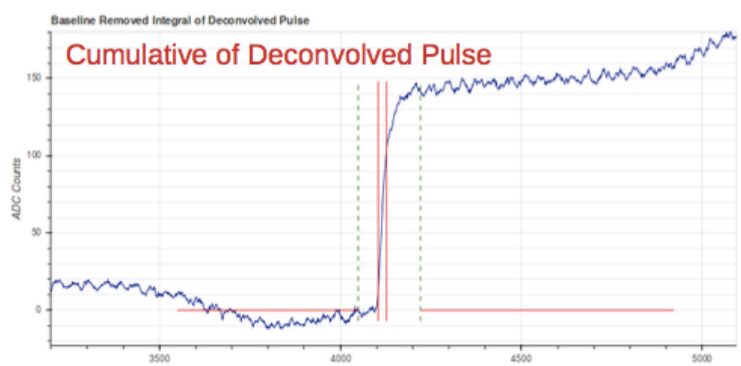


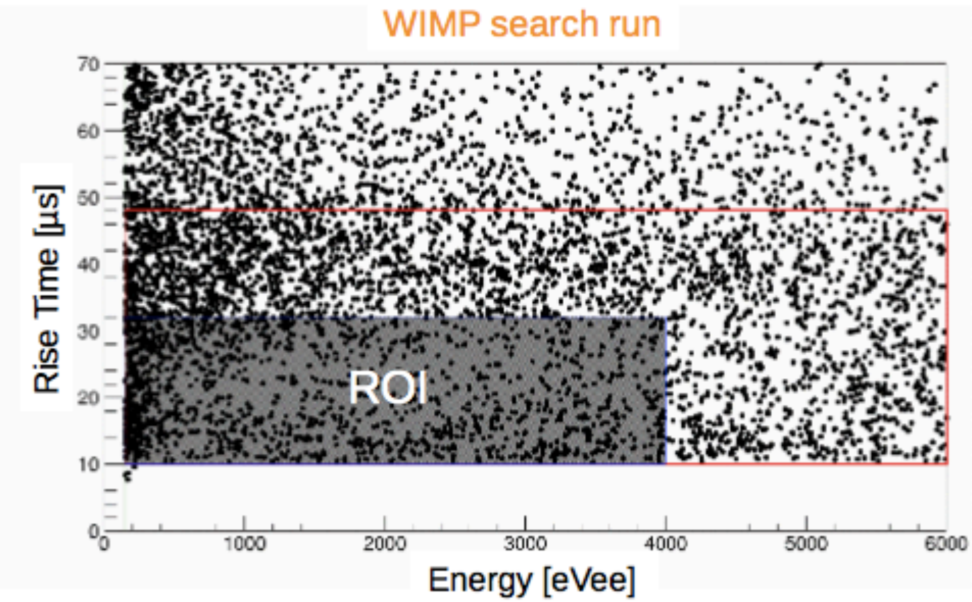




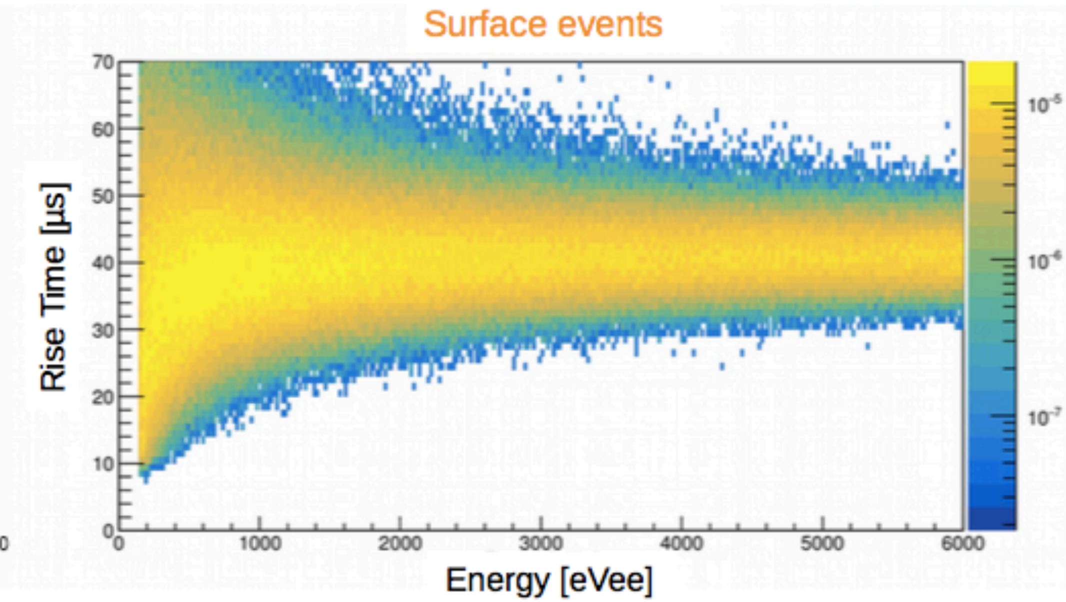


Data and simulations of two main expected populations

Sedine data



Background PDFs

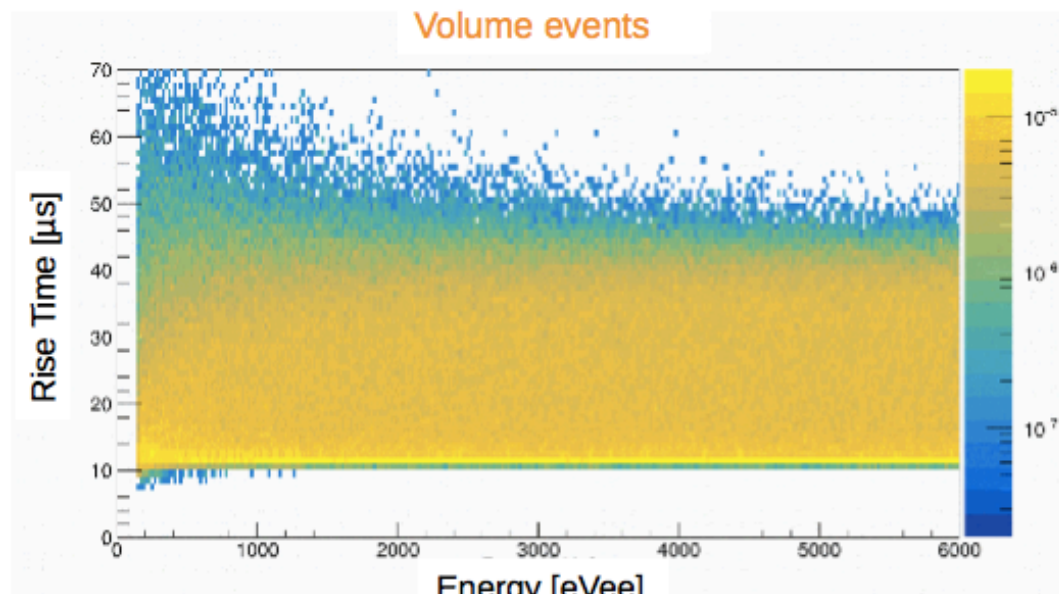


Analysis threshold set at **150 eVee**
(100% trigger efficiency)

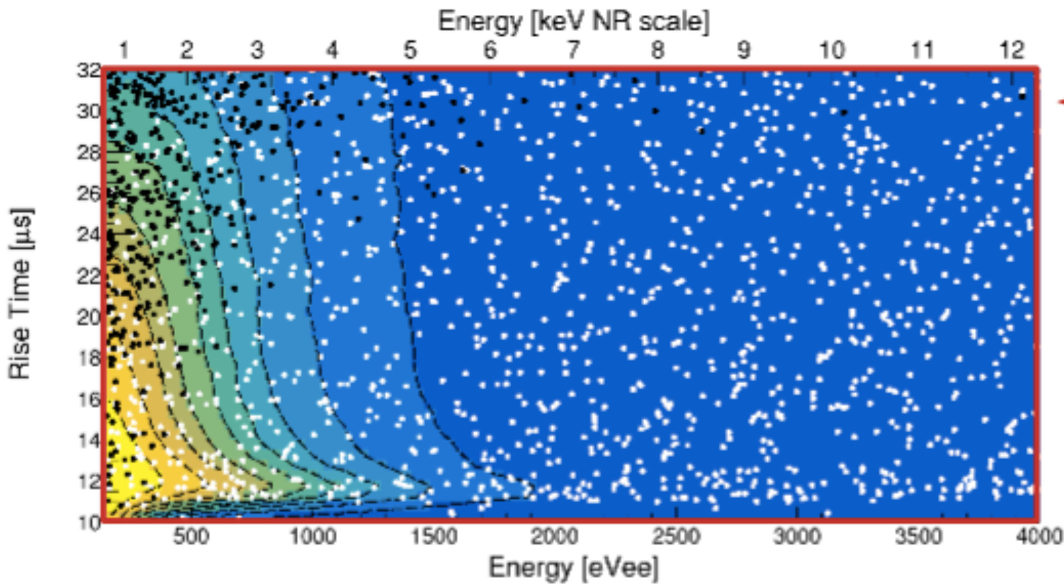
Side Band region used to determine
The number of background events
expected in the **ROI**

~1600 events expected in the ROI …

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



Some words about Boosted Decision Tree method



Preliminary ROI to be fine-tuned

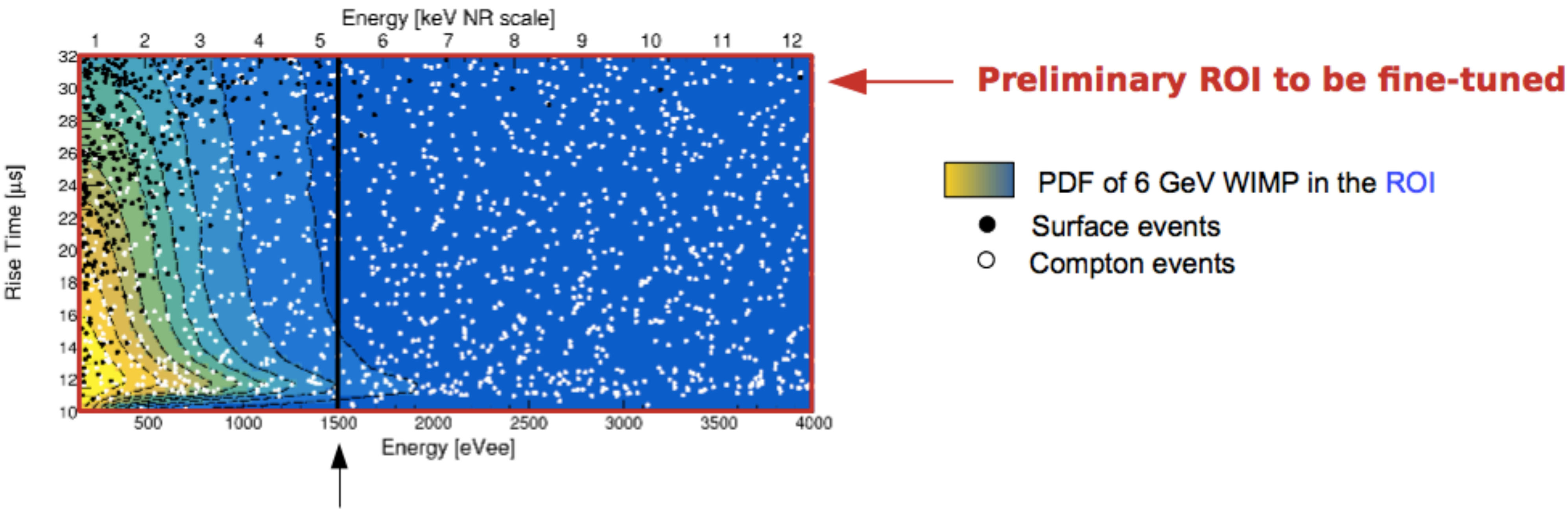
PDF of 6 GeV WIMP in the ROI

● Surface events

○ Compton events

Quentin Arnaud PostDoc

Some words about Boosted Decision Tree method



With a simple cut (Energy < 1500eVee), we could get rid of a large part of the Compton background for a small price to pay of 10% signal efficiency loss

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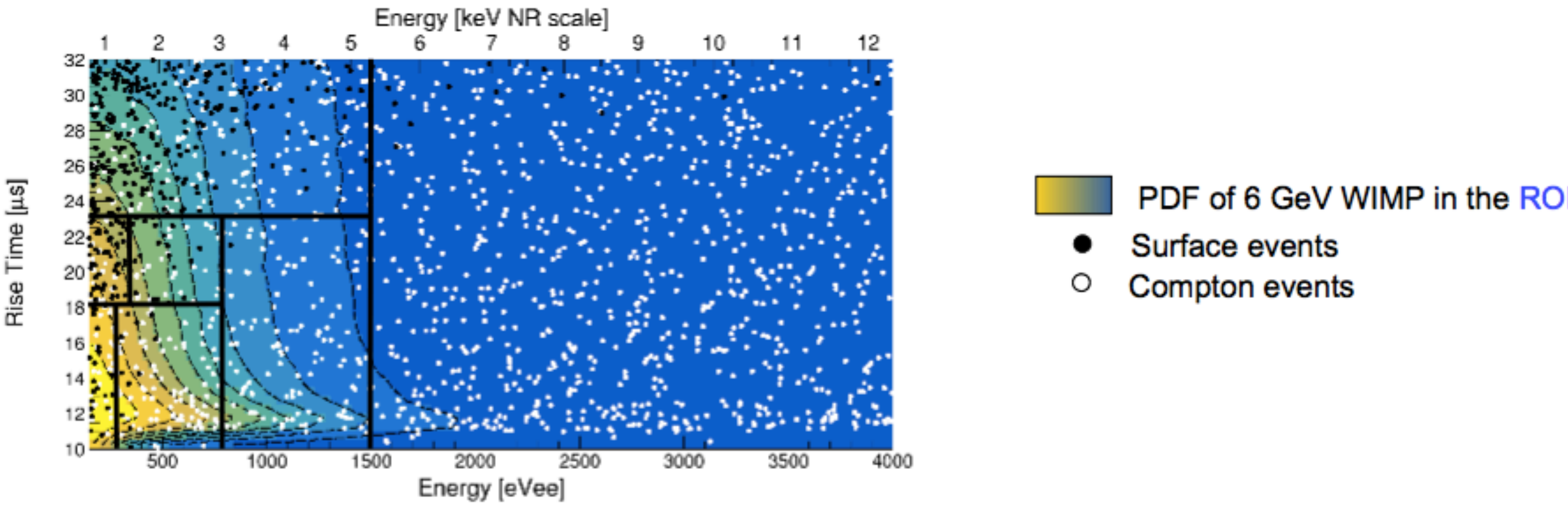


With a simple cut (Energy < 1500eVee), we could get rid of a large part of the Compton background for a small price to pay of 10% signal efficiency loss

To determine the optimal set of cuts that will maximize our sensitivity

we use a **B**oosted **D**ecision **T**ree

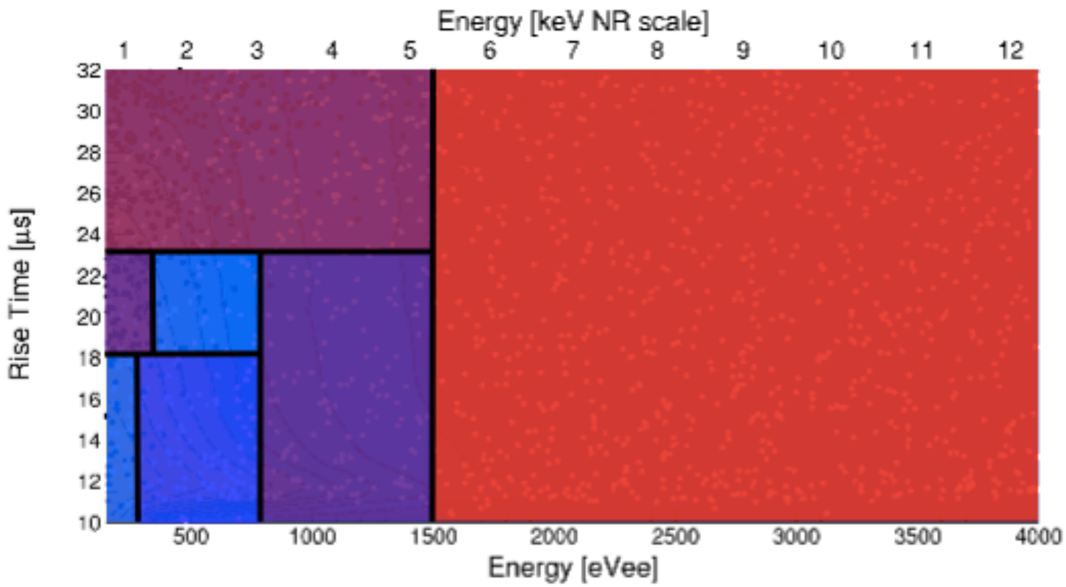
The **BDT** is trained with simulated events from our **signal** and **background** models

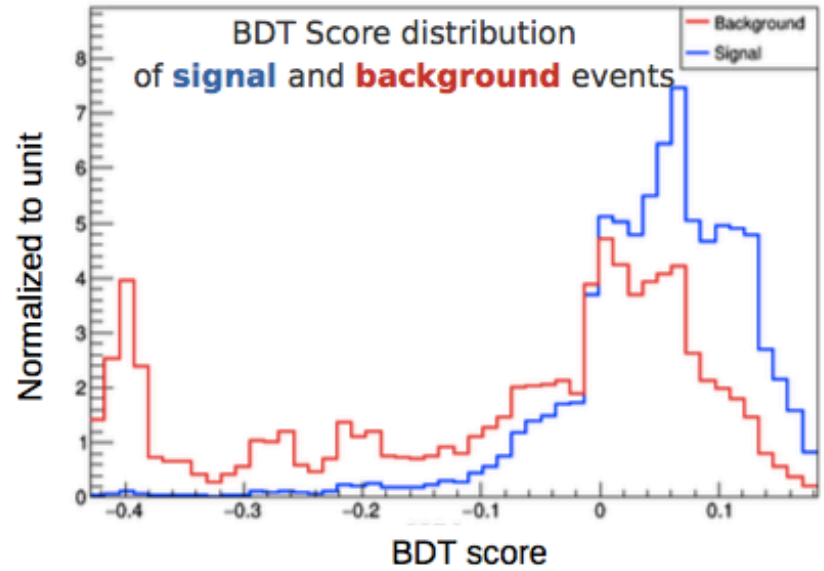
to classify events weither they are **signal-like** or **background-like**

by applying different cuts in the **Rise Time vs Energy** plane

Reduces the parameter space to only one variable : the BDT score

Some words about Boosted Decision Tree method





Background like
low BDT Score

Signal like
high BDT Score

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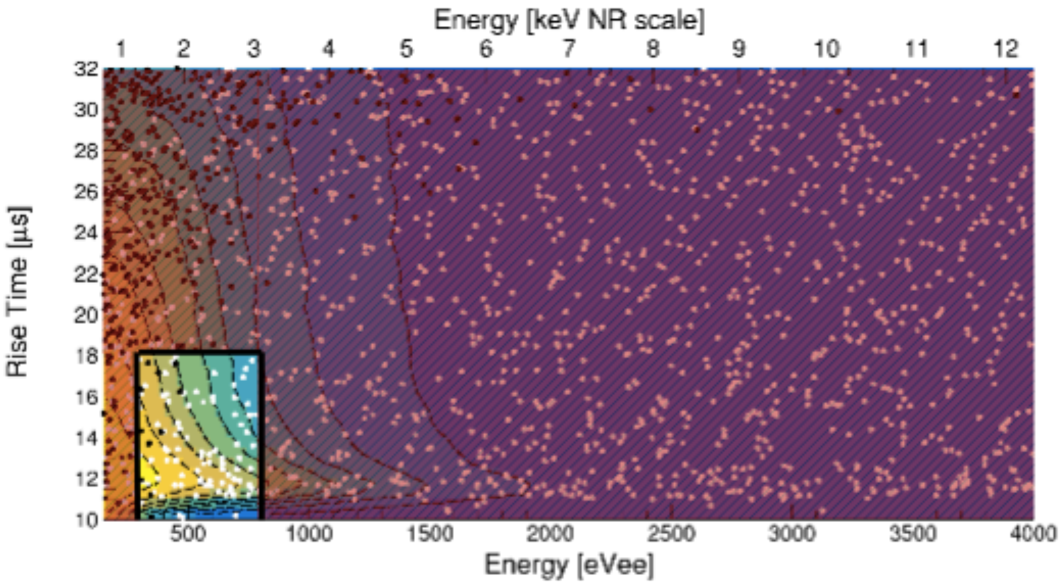
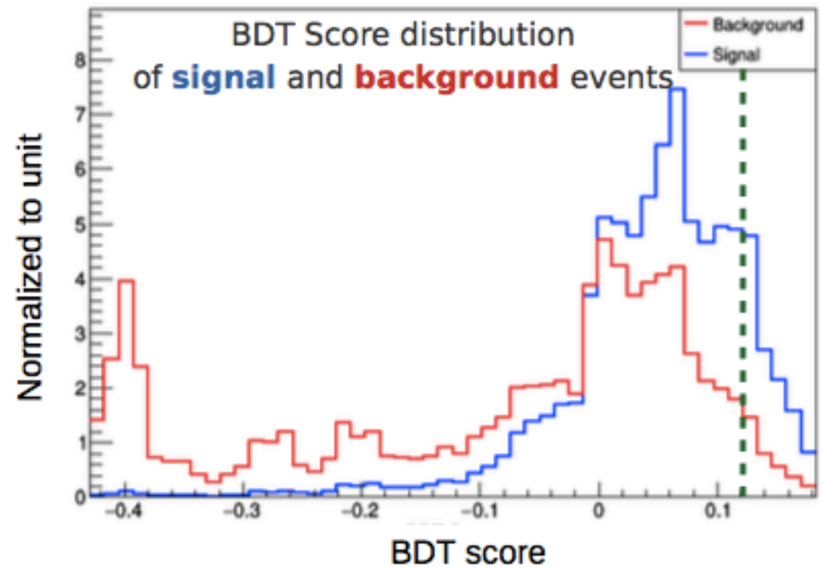
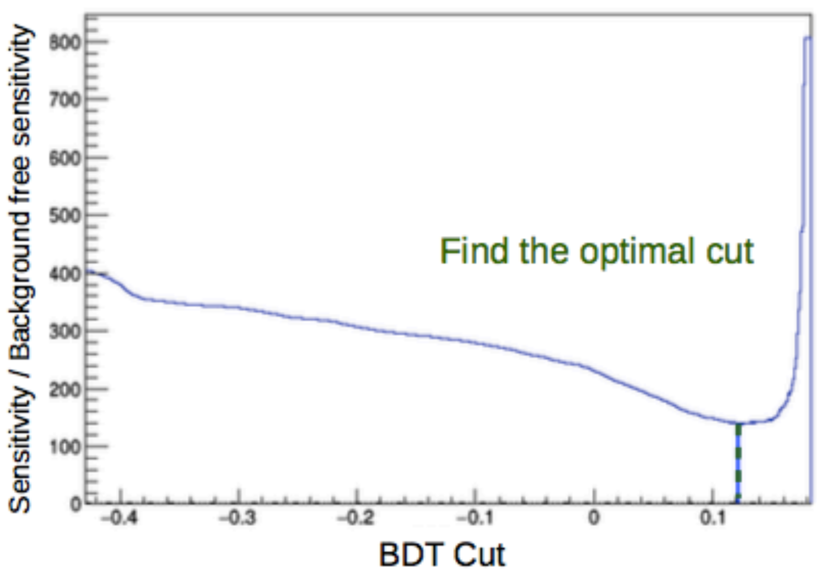
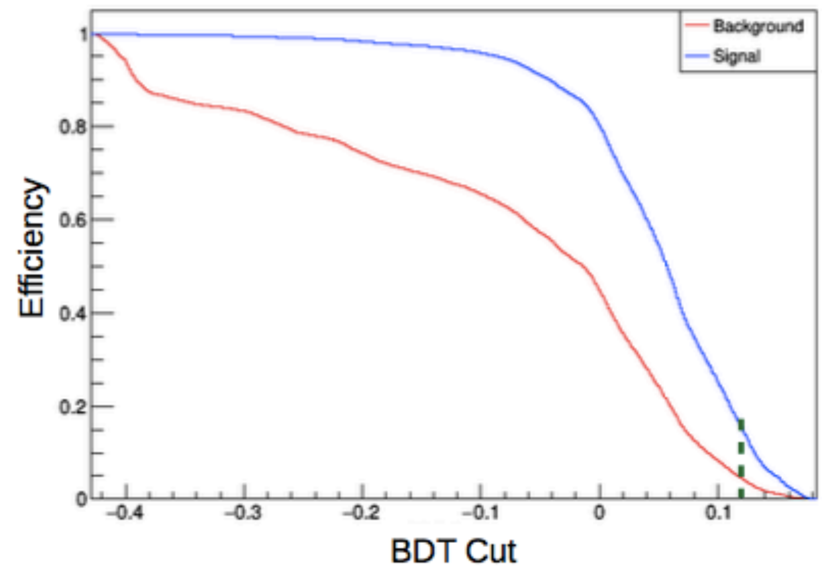




We can then perform the cut on the BDT score that optimizes the **signal** / **background** discrimination





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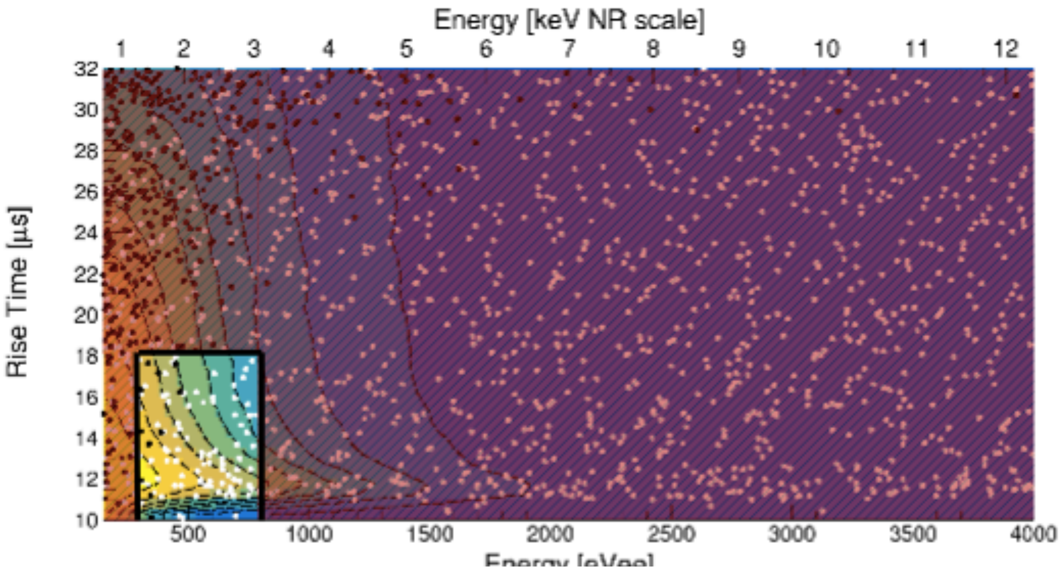
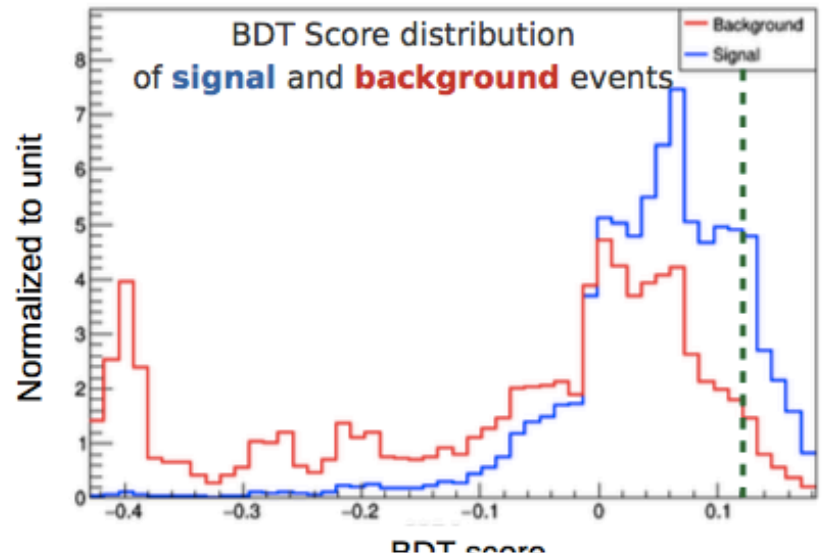
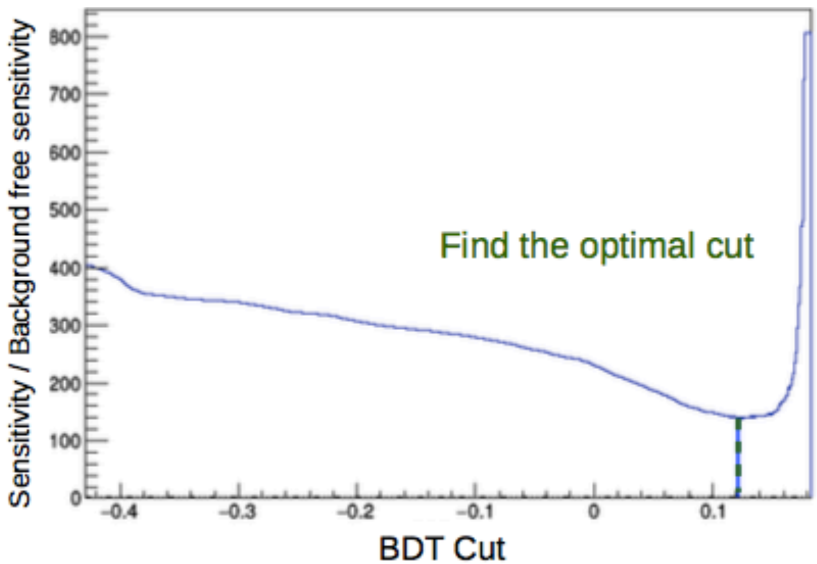
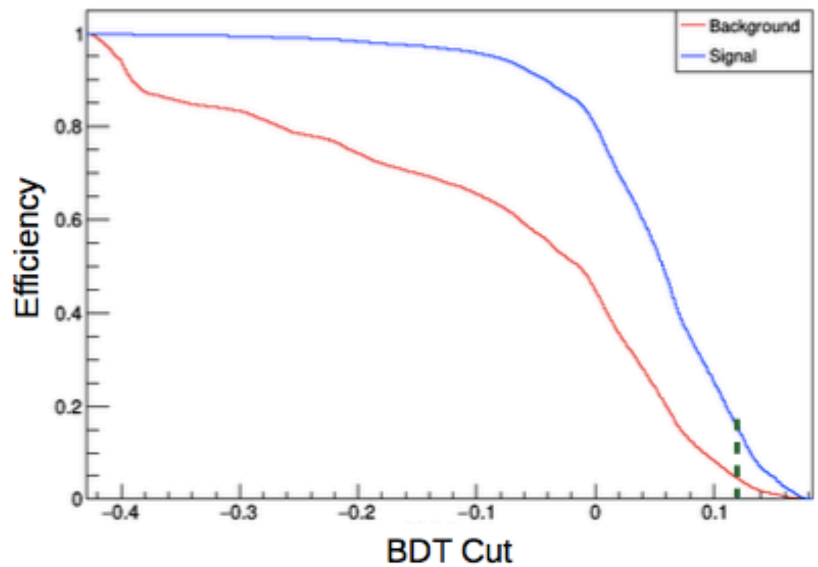


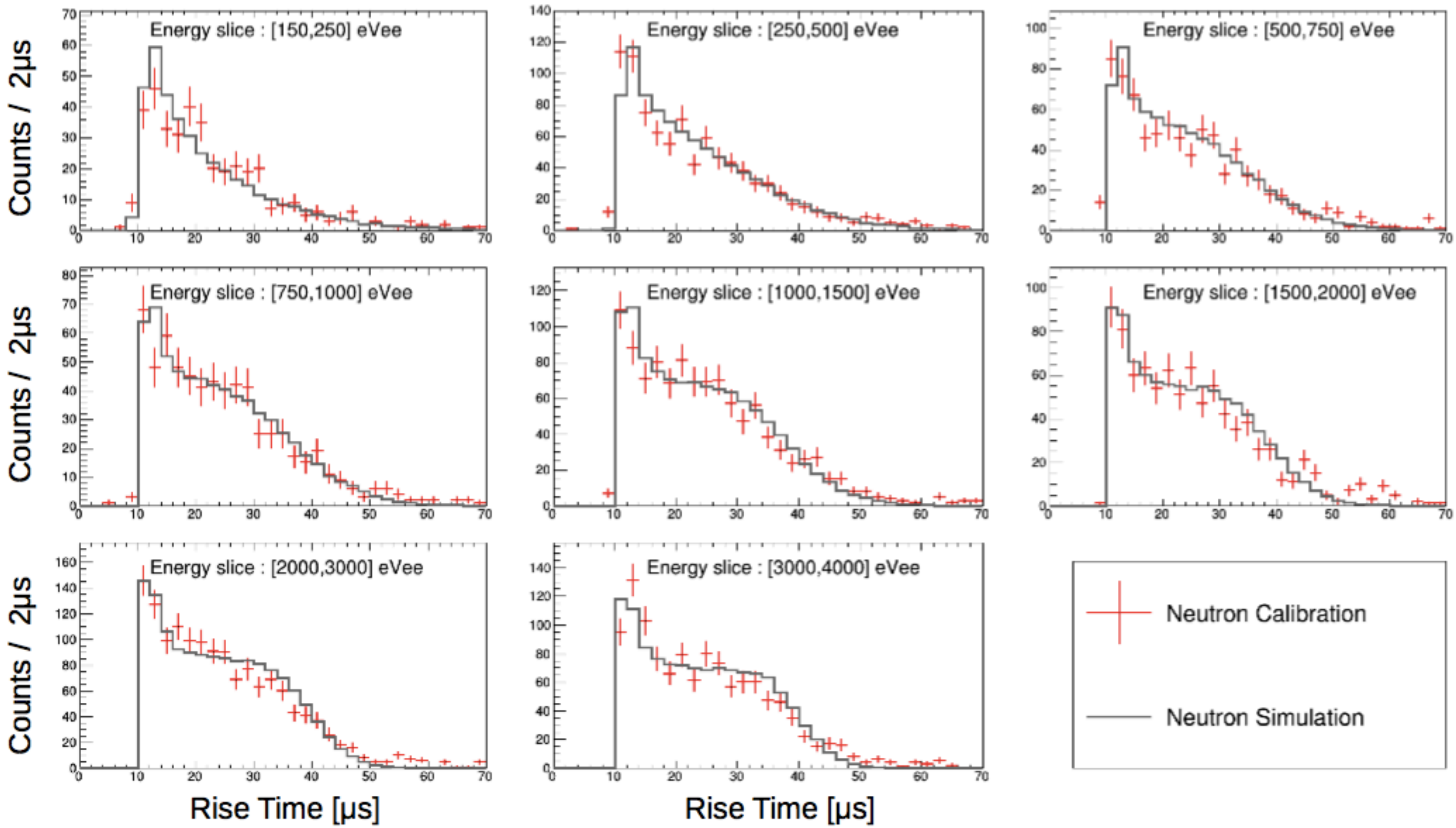


While this method gives conservative limits if inaccurate background models were to be used for the training of the BDT, it assumes we know very well the response to signal (volume/compton/NR recoil), ie behaviour of RiseTime vs Energy for WIMP's

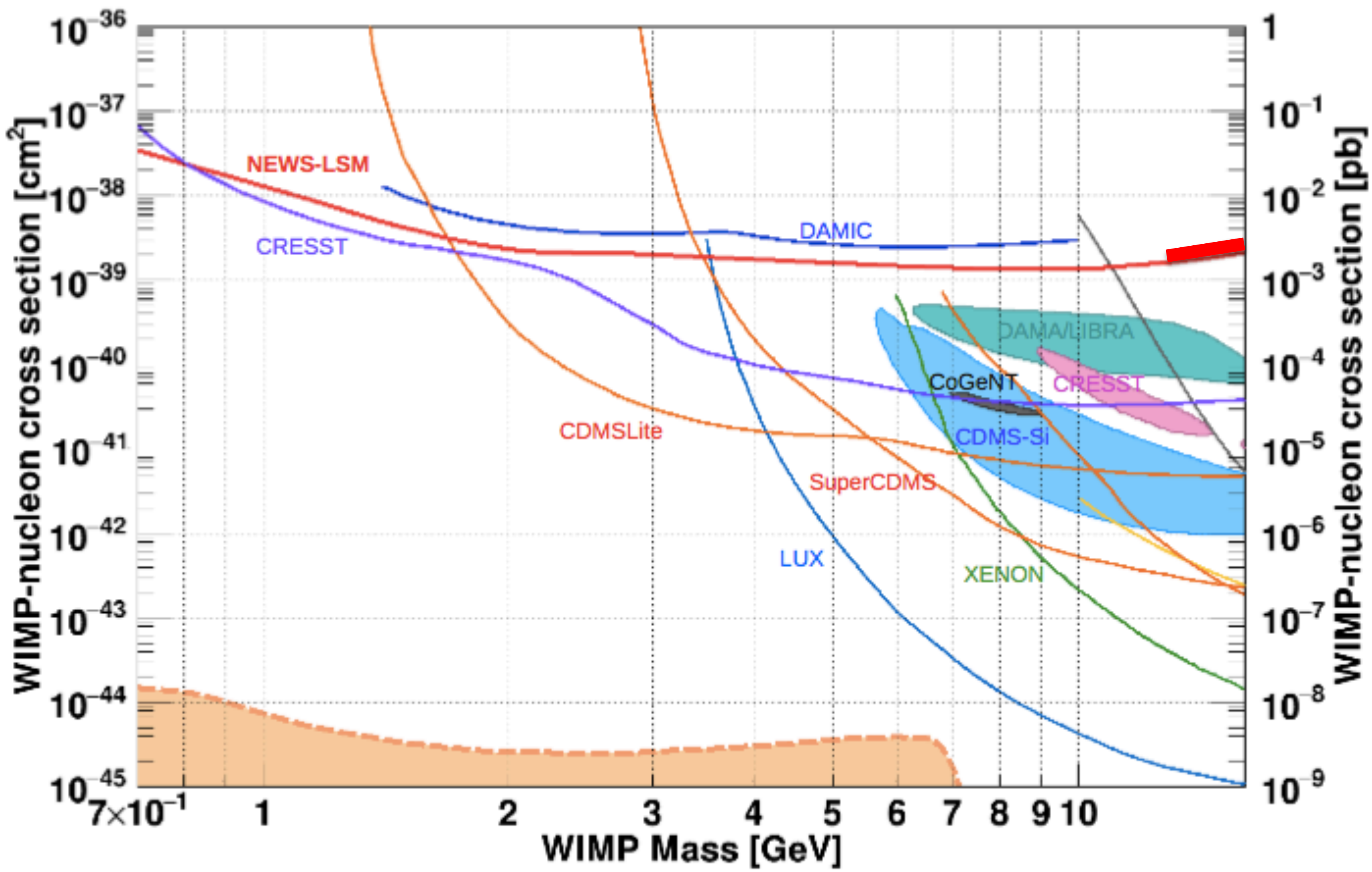




Volume events : comparison of simulation with neutron calibration data with Am-Be source



Sensitivity of NEWS-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

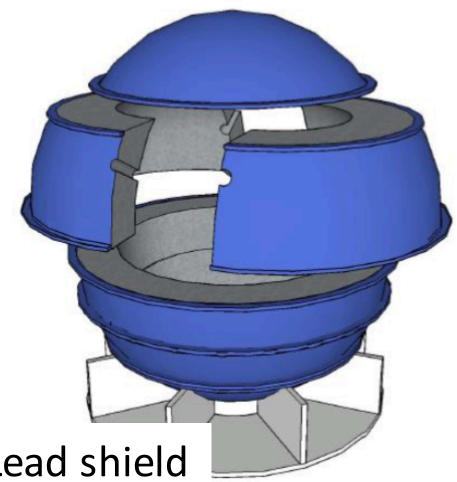
What next

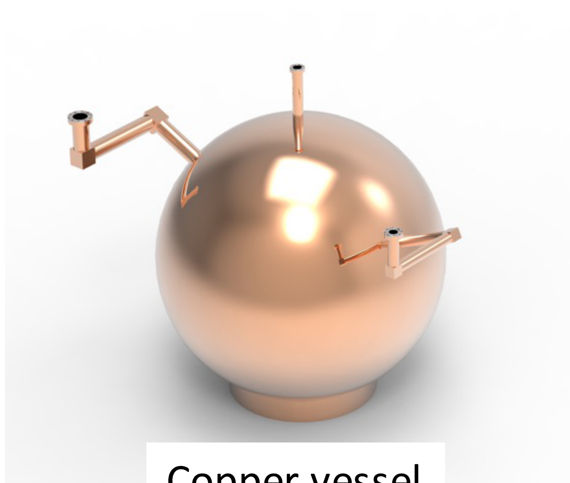
- Refine field simulation and full pulse simulation
- Check if possible to go to lower analysis threshold/lower WIMP mass
- Investigate background subtraction
- Background simulation (*Alexis Brossard PhD*)
- Improve shielding of Modane set-up (some « holes ») *See Ali DastGheibi talk*
- Set up HP water jet cleaning of internal surface (studies ongoing)
- Run with He and He/CH4 (90/10, non flammable) mixtures
- Quenching factor measurements on going at Grenoble with ion source at CoMimac (D Santos, P di Stefano)

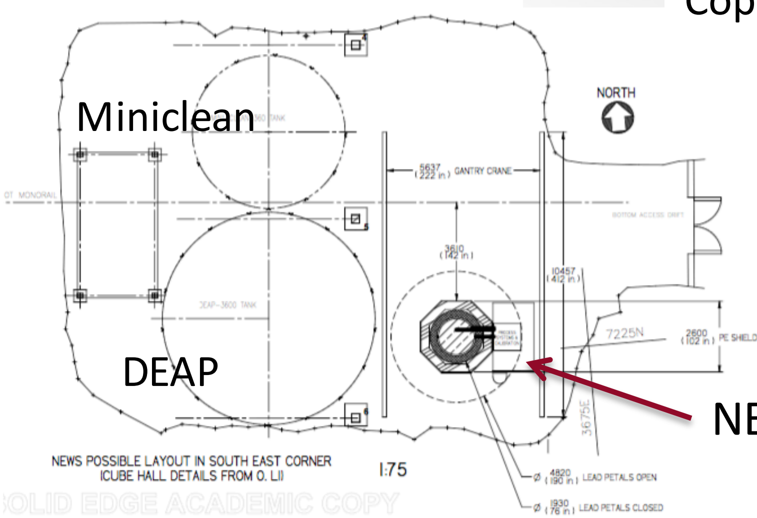
- Go to bigger sphere and optimised management of radioactive contaminants => NEWS-SNOLAB project

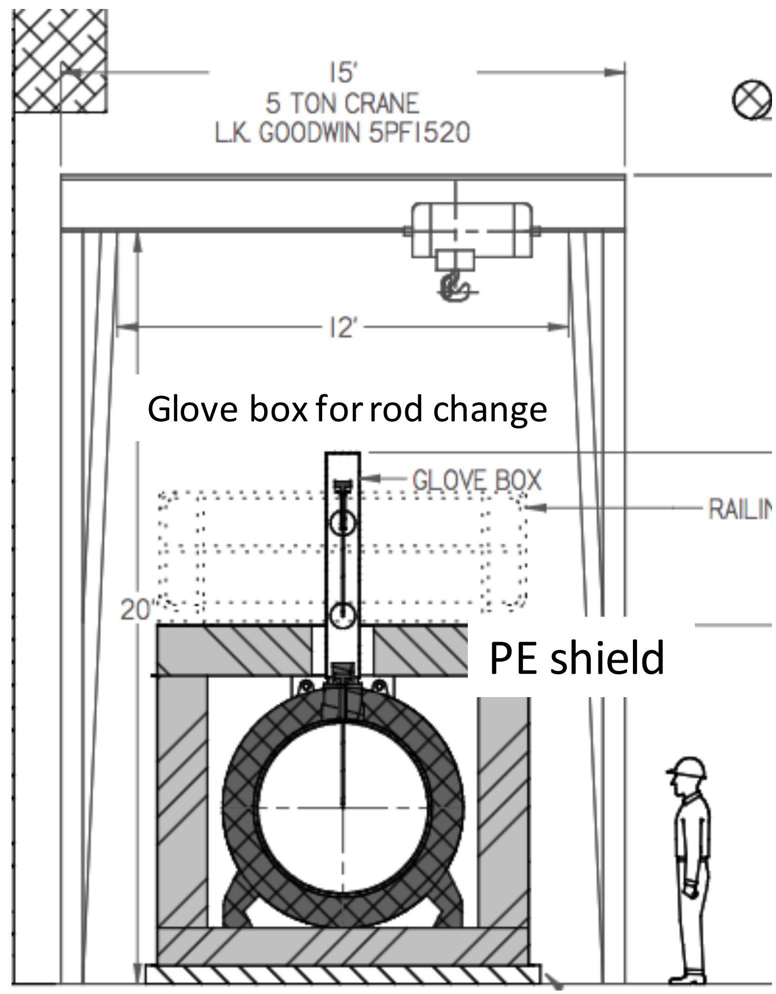
Compact shield option : implementation at SNOLAB by fall 2017

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


Lead shield


Copper vessel





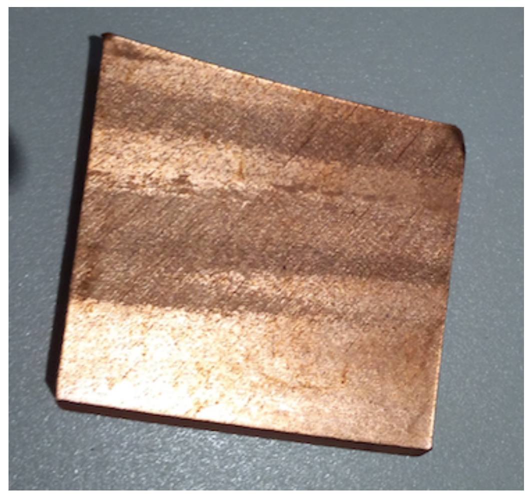
35 t shields

Hemisphere spinning test and clean up

Plate of C101000 of 15 mm thick

Samples from spinned hemisphere

- sent to PNNL for ICPMS measurements
- cut for HP water jet tests



Background budget (simulation)

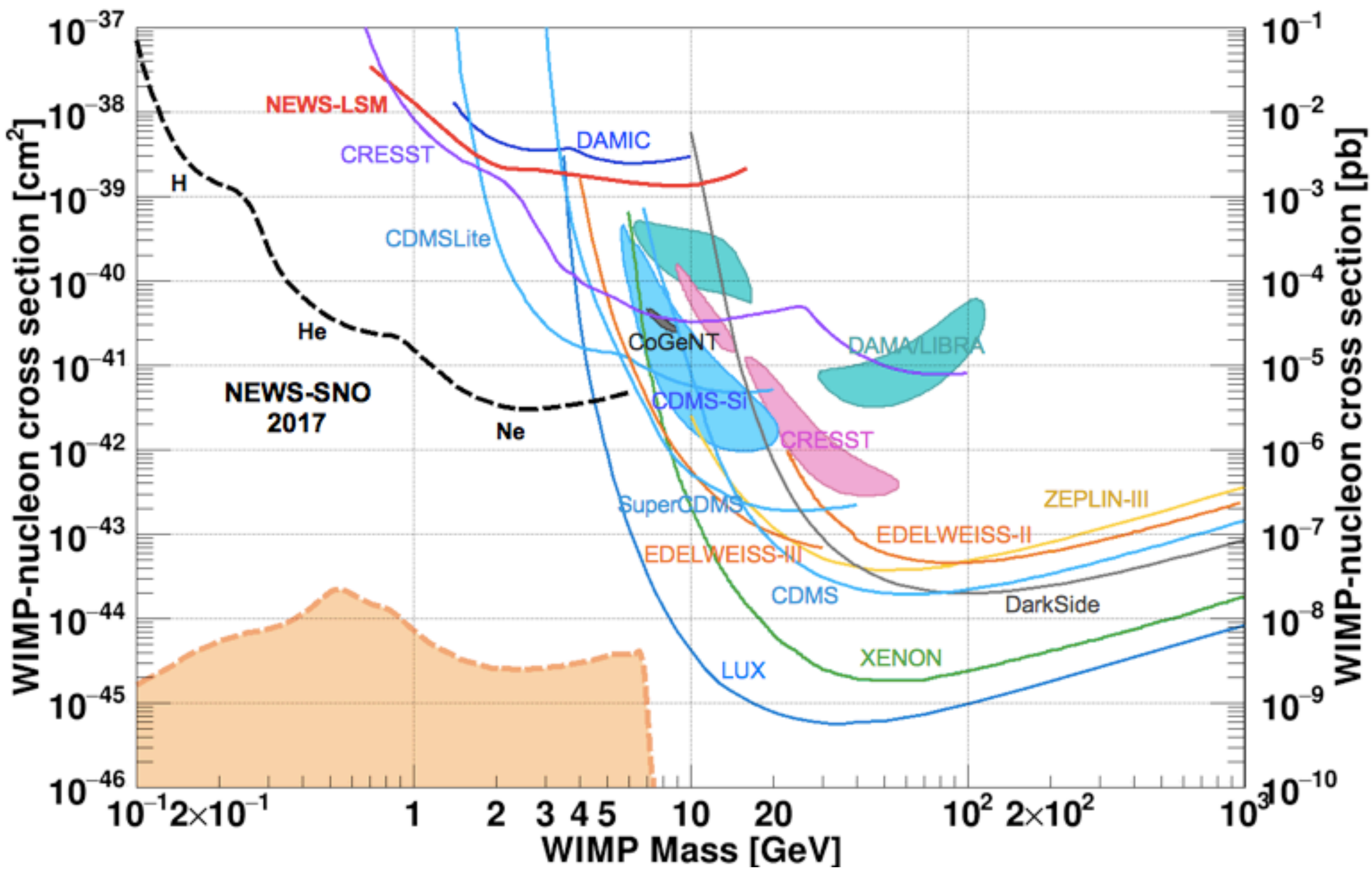
Radioactive background budget	Goal / estimation / measurement	Rate Ne ev/kg.keV.d in 0-1 keV in Neon 10b	Relative weight %	Rate He ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %	Rate H ev/kg.keV.d in 0-1 keV for He/CH4-90/10	Relative weight %
U Copper	3 µBq/kg	0.017	8.2	0.006	4.0	0.055	4.0
Th Copper	13 µBq/kg	0.053	26.4	0.004	3.0	0.041	3.0
Co60 Copper	30 µBq/kg integrated exposure to CR	0.046	22.8	0.046	33.2	0.460	33.2
External radiation from rock	208Tl and 40K flux underground	0.006	3.0	0.002	1.4	0.020	1.4
U/Th from shield	U/Th in Pb shield	0.050	24.8	0.001	0.7	0.010	0.7
Radon in gas	Rn emanation within sphere/pipes/ valve (0.3 mBq)	0.005	2.5	0.005	3.6	0.050	3.6
Rod/sensor	Max 0.01 mBq	0.005	2.5	0.005	3.6	0.050	3.6
Bi210 external Surface	Assuming exposure of 4 weeks to 30 Bq/m3 Radon in air	0.001	0.5				
Pb210 internal Surface	Max exposure= 17 Bq/m3*h (100 Bq/m3 10 mins)	0.014	6.9	0.070	50.5	0.700	50.5
Pb210 in bulk from spinning inclusion	Assuming exposure of 4 weeks to 30 Bq/m3 Radon in air all going in bulk	0.005	2.5				
Total	dru	**0.202**	100.0	0.139	100.0	**1.386**	100.0
Nb evts in 0.2 keV	in 100 kg.d	**4.039**		**2.772**		**27.724**	

Ne He H

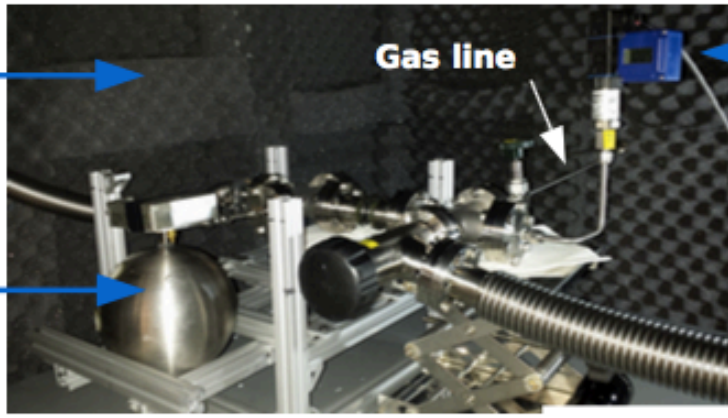
- U/Th from Lead and Copper samples samples from spinned hemisphere measured by ICPMS at PNNL
- Electron Beam Welding of all parts
- Internal cleaning of copper vessel with HP water jet in radon free gas

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

Projections for NEWS wrt current situation

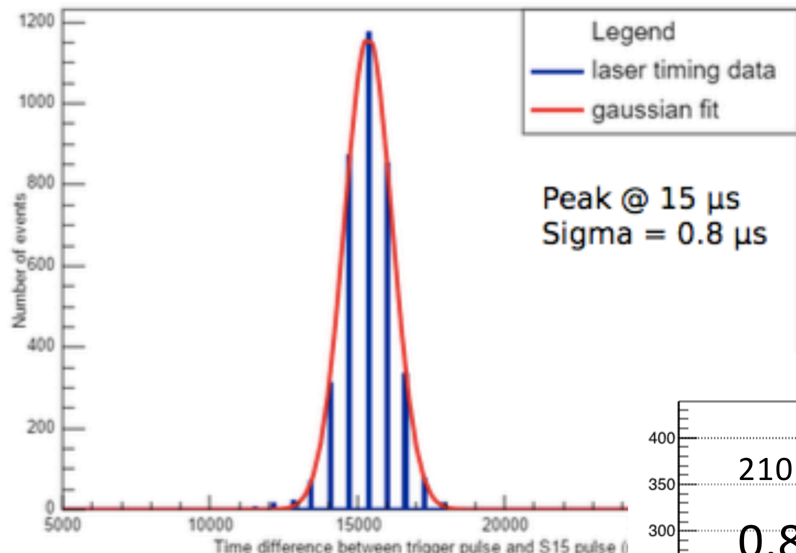


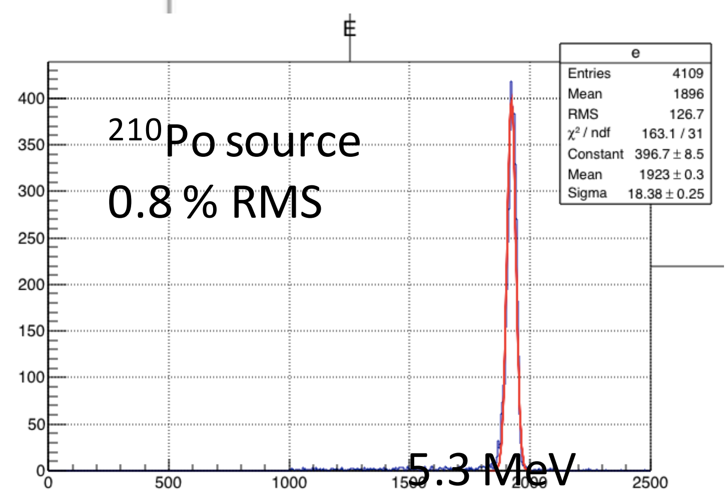
R&D @ Queens



<u>electron drift time</u>
Time difference between laser trigger pulse and gas detector signal

<u>electron diffusion time</u>
given by the width of the distribution



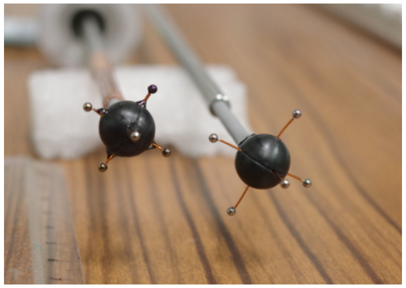


Setting up of laser calibration system with fiber to monitor gain
Penning mixtures studies with 30 and 50 cm spheres
Alvine Kamaha, Mike Clark et al

Conclusion and outlook

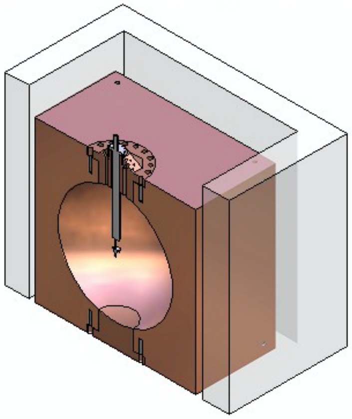
- First competitive results with gas detector in DM search
- Planned measurements with He and H nuclei in coming months @ LSM
- 60 cm SEDINE detector essential to optimise NEWS-SNO

- NEWS-SNO project will have better shield /materials/procedure
- Project at TDR step, construction to start spring 2017, installation at SNOLAB by end 2017



see Ilias Savvidis talk

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



see XF Navick talk

- Investigation also of spin independent coupling with H and KK solar axions through 2 photon decay
- Coherent Neutrino Scattering, SuperNovae…

NewS collaboration

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

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

Nov 2016

VewS Collaboration

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