

Measuring the gamma background at NEXUS facility

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In partnership with:

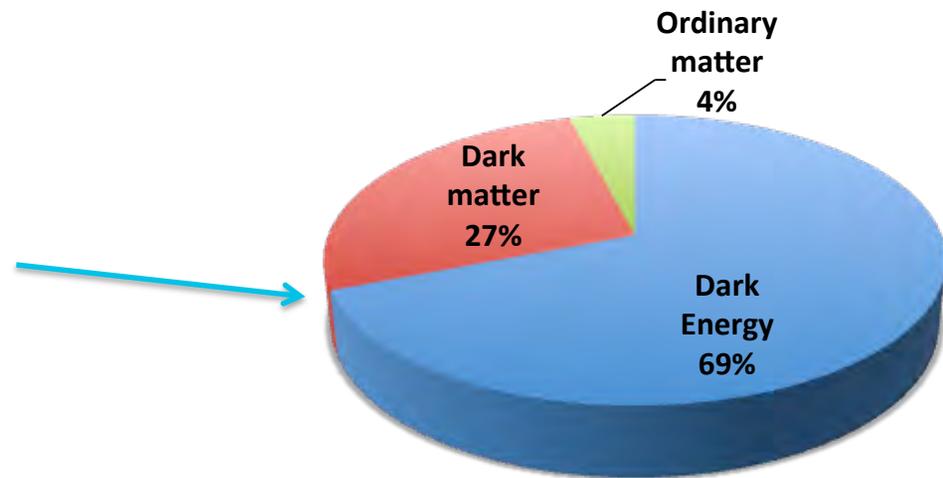


Overview

- **INTRODUCTION: DARK MATTER**
 - SuperCDMS experiment
- **SUPERCDMS CALIBRATION**
 - nuclear recoils calibration through a D-D generator
 - NEXUS facility at NuMI tunnel
- **MY PROJECT: MEASURING AND MODELLING THE BACKGROUND AT NEXUS SITE**
 - measurement of the gamma background
 - Geant4 simulation of the fridge
 - Estimate of the background rate
- **CONCLUSION AND FUTURE PERSPECTIVES**

Dark matter (DM)

- much more abundant than ordinary matter
- effectively neutral (no interaction with light)
- weakly interacting



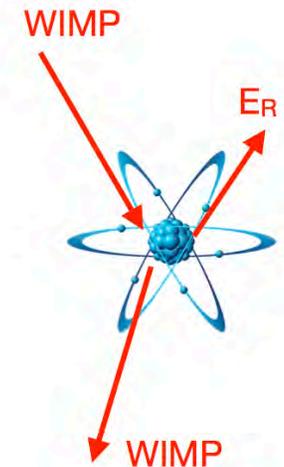
WIMP
(Weakly Interacting Massive Particle)

① Indirect detection

② Production at colliders

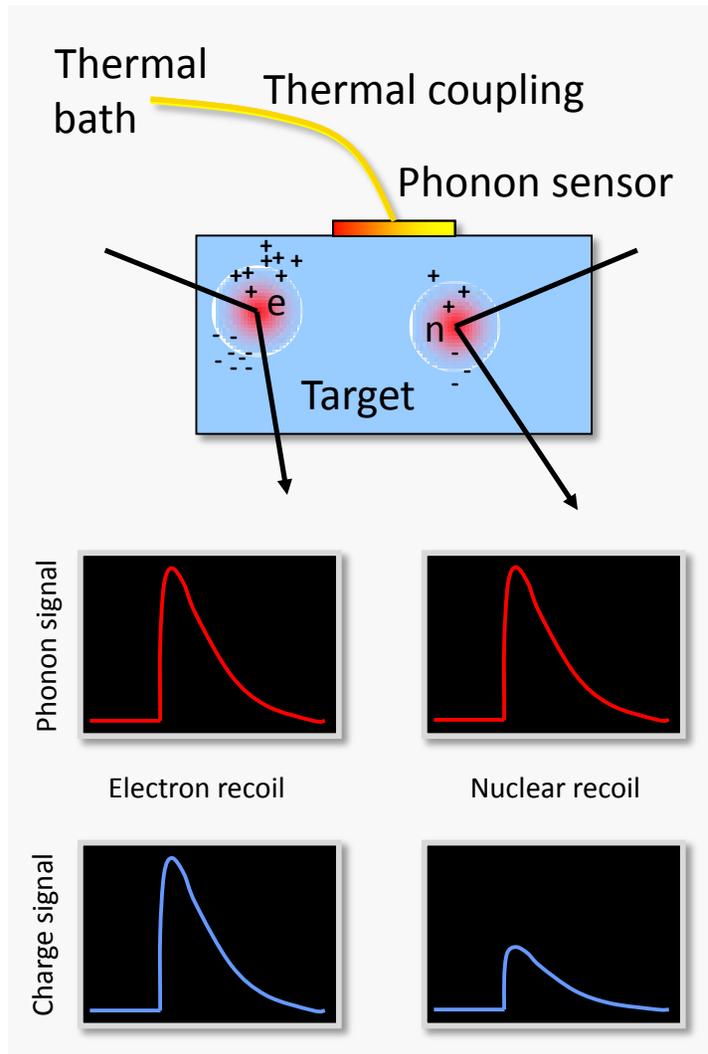
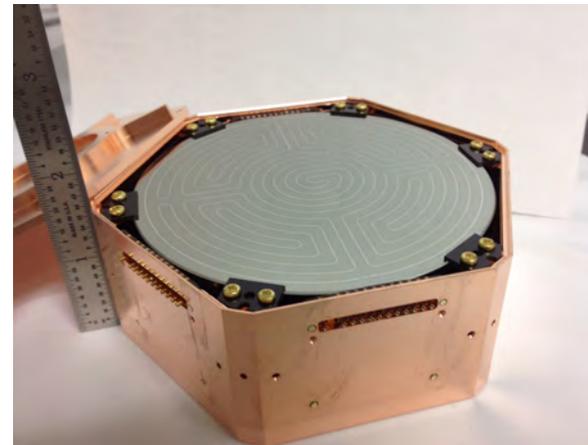
③ **DIRECT DETECTION**

- earth is surrounded by a halo of WIMPs
- measure the recoil of nuclei colliding elastically with them



SuperCDMS experiment

Cryogenic
Dark
Matter
Search



- direct detection experiment
- Ge/Si crystals
 - 10 cm \varnothing , 3.3 cm height
 - $T < 50$ mK
- **phonon signal**: measures the energy deposition
- **ionization signal**: quenched for neutrons/WIMPs wrt γ , e^+
 - allows us to distinguish potential signal from background

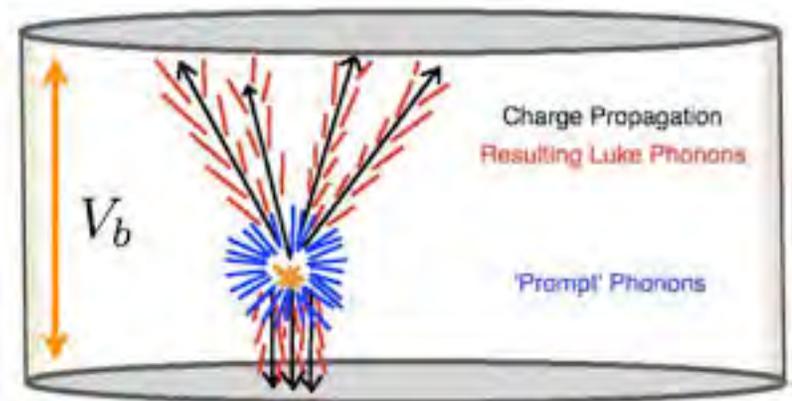
Measuring low mass WIMPs

- low mass means also low recoil energy
- WIMPs with $1 \text{ GeV} < m < 10 \text{ GeV}$ produce recoils as low as **100 eV**, very difficult to distinguish from electronic noise...
- some amplification of the signal is required

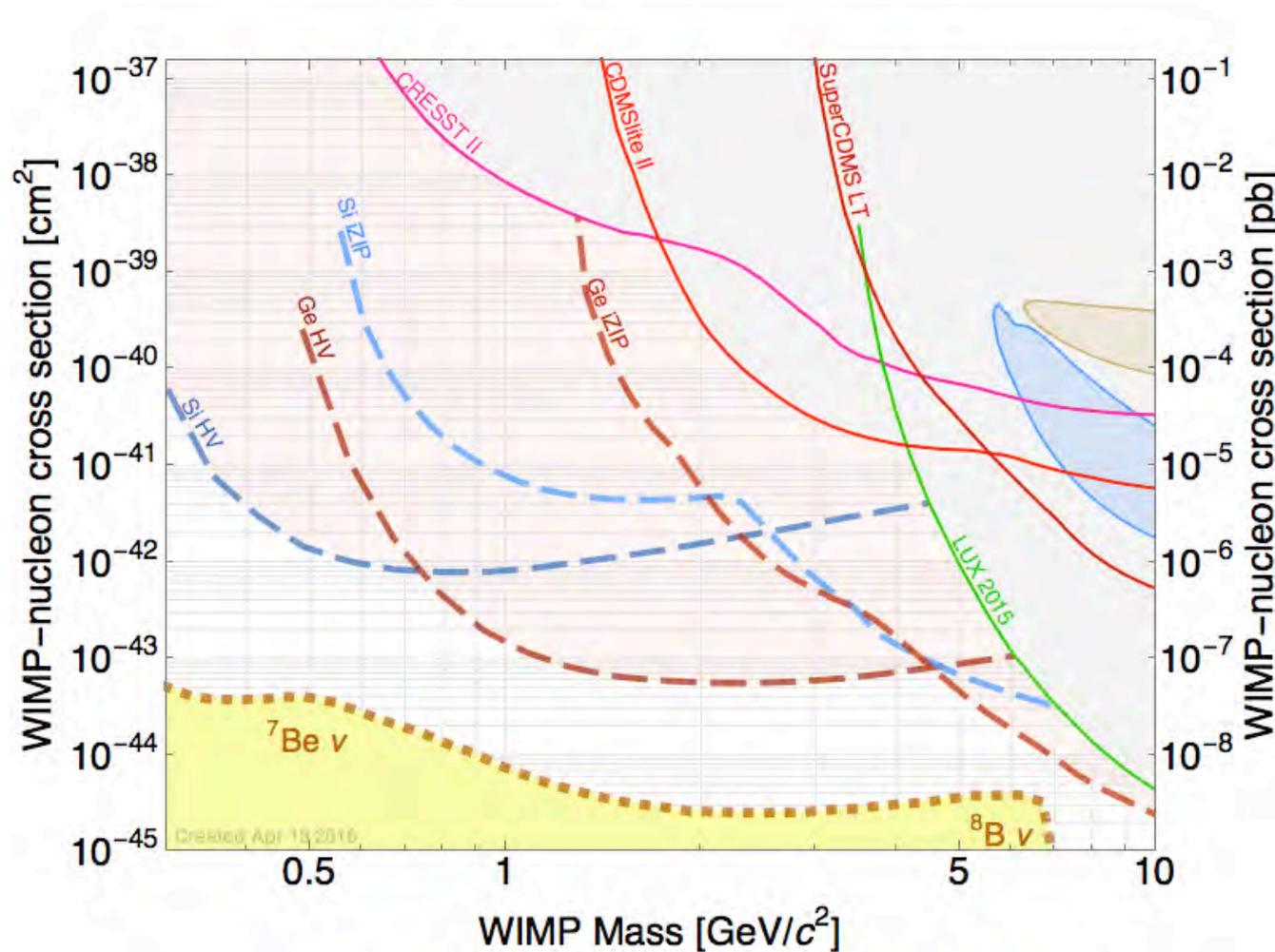
SuperCDMS HV (old CDMSlite)

- Idea: accelerate the ionization electrons (and holes) in a strong electric field (~ 30 V/cm)
 - the work done on the charges by the electric field is nearly entirely converted into acoustic phonons (**Neganov – Luke effect**)
 - phonon energy is proportional to the primary ionization energy...
 - ...but we need to know the relationship between the recoil energy and the ionization yield!

CDMS
Low
Ionization
Threshold
Experiment



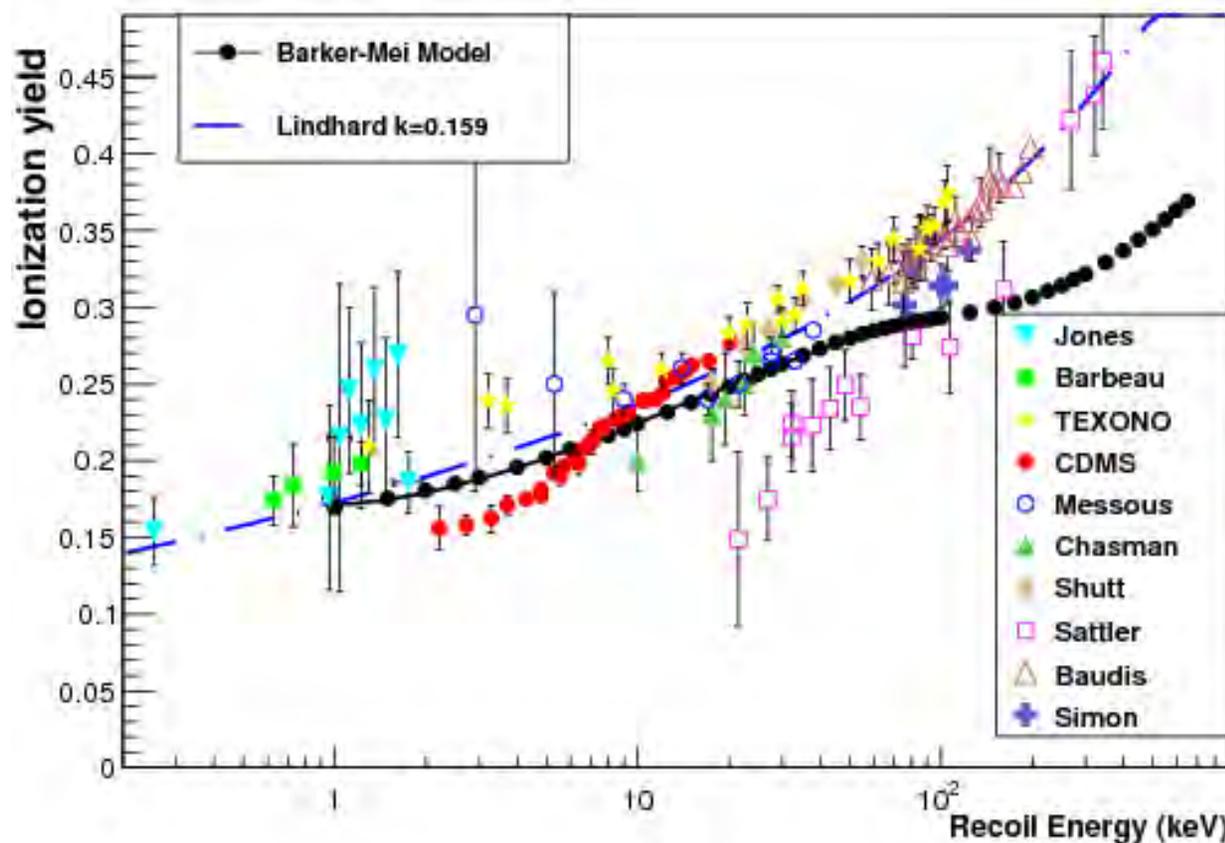
SuperCDMS discovery potential



great sensitivity to low mass WIMPs ($m < 10 \text{ GeV}$)!

Ionization calibration

- Problem: there are very few experimental points under 1 keV (no-one under 250 eV) and the theoretical models may fail under that value...

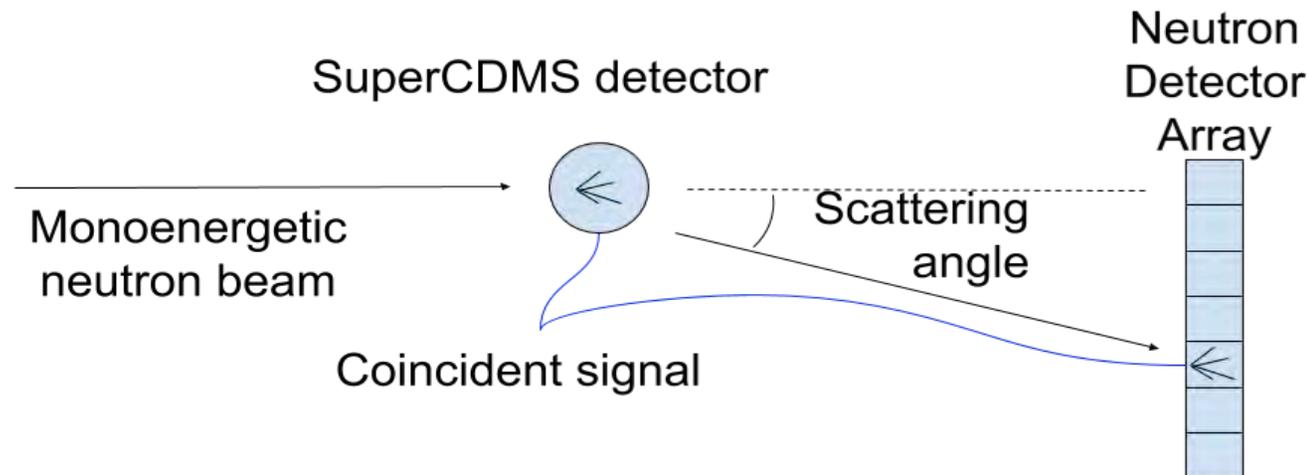


Besides, response depends on:

- crystal purity
- field strength
- ...

Moral: perform the calibration by yourself (possibly with the same detectors used in the experiment!)

Ionization calibration: experimental apparatus



1. measure the neutron scattering angle
2. calculate the recoil energy from kinematics
3. compare it with the phonon energy measured by SuperCDMS detector

Background problem: SuperCDMS detectors are sensitive to both cosmic rays and radioactive decay products, with dead time ~ 50 ms
→ underground laboratory additionally shielded from natural radioactive sources needed to perform both the experiment and the calibration...

NEXUS facility

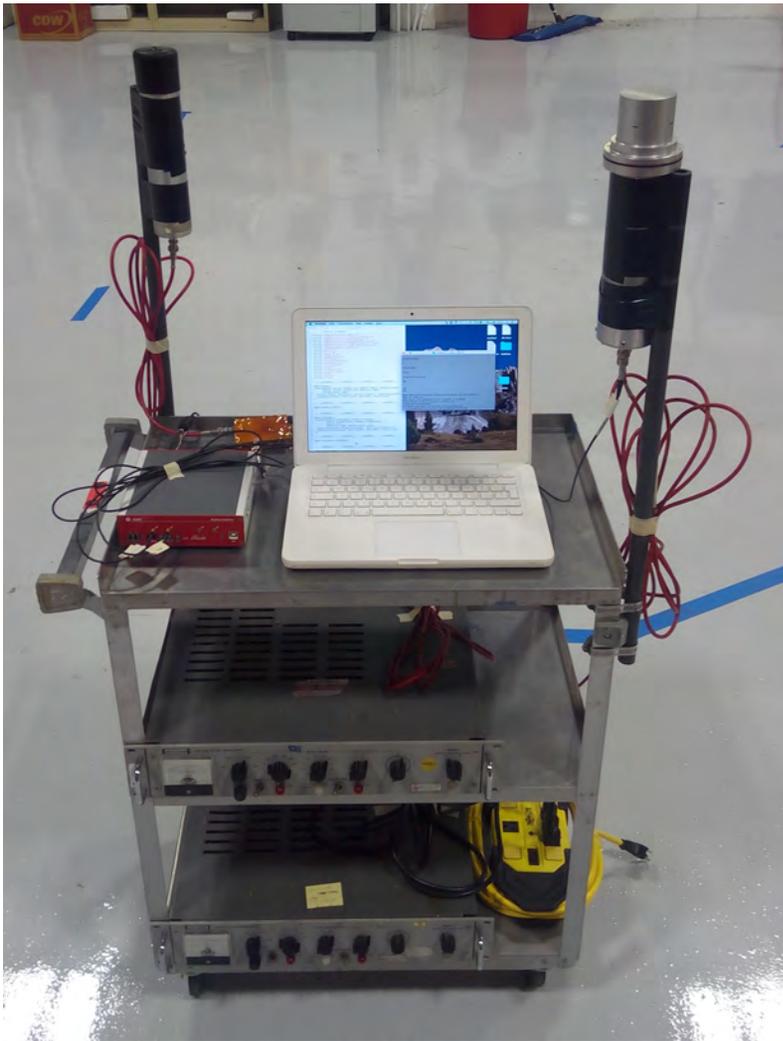
- **low background** underground facility for **ultrasensitive detectors calibration**
- located in NuMI tunnel (MINOS hall) at FNAL
- cryogenic dry fridge: T down to ~ **20 mK**
- neutron source (D-D generator)
 - ~ 2.45 MeV monochromatic neutrons
- facility available also for other experiments (e.g. DAMIC)

Northwestern
EXperimental
Underground
Site

NEXUS facility: background shielding

- 300 m water equivalent of rock overburden
 - no need for muon active vetoes
- **main background: radioactive decays from unstable isotopes in the surrounding rock**
 - must be reduced by further shielding!
- **MY PROJECT:**
 1. **measure the γ background** in the NuMI tunnel
 2. develop a **GEANT4 simulation** of the NEXUS facility
 3. input the measured backgrounds in the simulation
 4. **determine the amount of extra shielding needed**

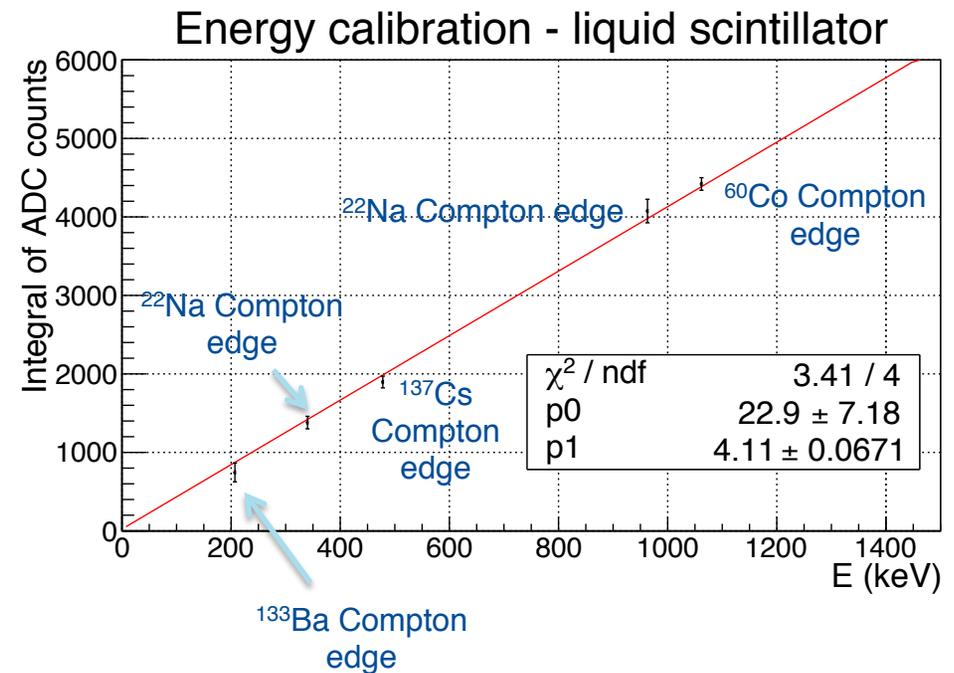
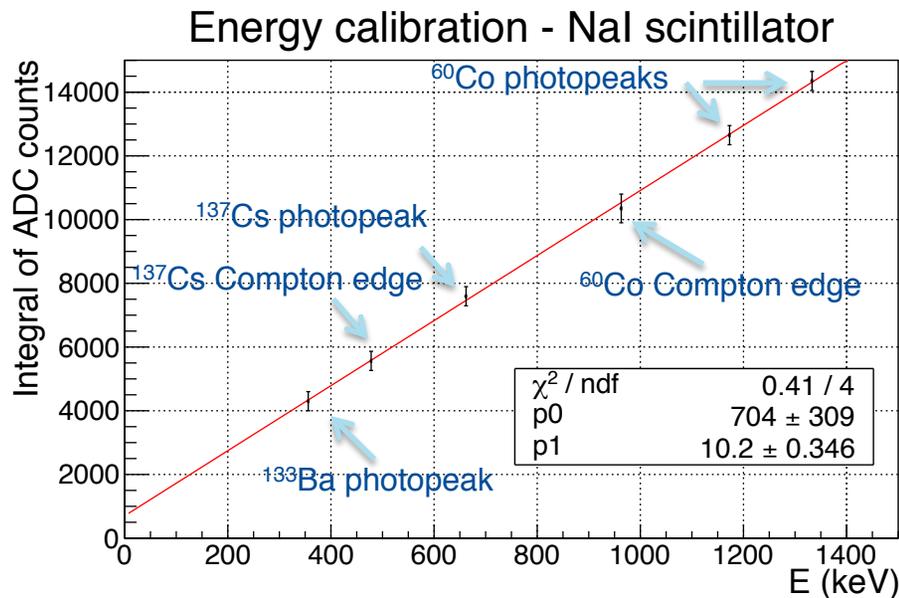
Experimental apparatus



- **Eljen 301** liquid scintillator
- **Victoreen 490 Thyac NaI** scintillator
- **Caen DT5720** ADC
- **FLUKE 408B** HV supply

Calibration

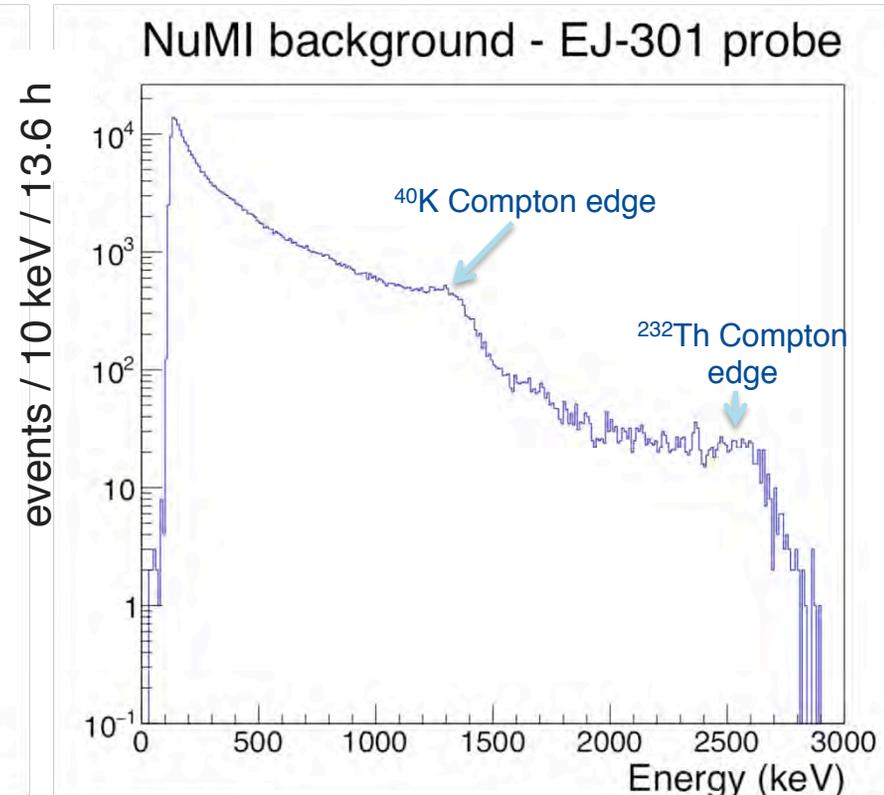
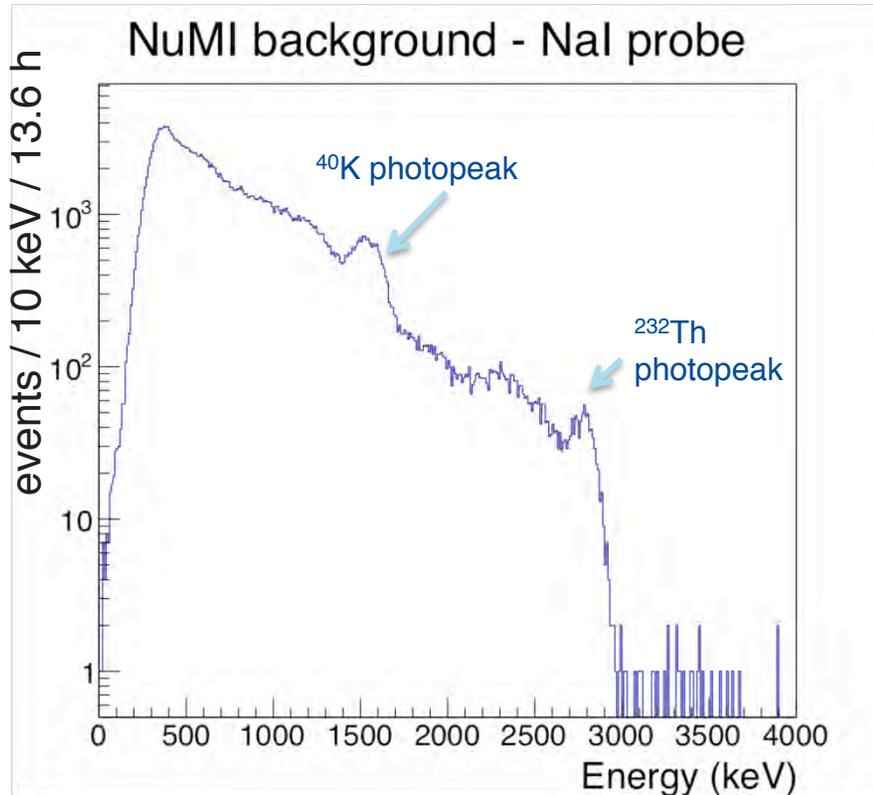
- ^{22}Na , ^{60}Co , ^{133}Ba , ^{137}Cs sources



- Efficiency measurement: known source at fixed distance
 - NaI probe: $\varepsilon = 0.33 \pm 0.08$
 - liquid probe: $\varepsilon = 0.16 \pm 0.03$

Measured spectrum at NuMI

- ~ 13 h of DAQ
- data acquired on Monday, precise measurement of the rate and of the relative weight of ^{40}K , ^{238}U and ^{232}Th chains still to be done (and a good measurement probably requires more DAQ time...)



GEANT4 application for NEXUS

- **SuperSIM**: GEANT4 application for CDMS simulations
 - entirely developed by Michael Kelsey at SLAC
 - detectors geometry and rock isotopic composition for all the past CDMS experiments
- My task:
 - draw the cryogenic fridge and shielding geometry of NEXUS in GEANT4 and integrate it into SuperSIM
 - implement some simple commands to allow to perform simulations of the background changing the main parameters of the shielding from a **user interface**
 - final goal: **decide the shielding configuration for NEXUS**

A simulation example

Outer lead γ -shielding

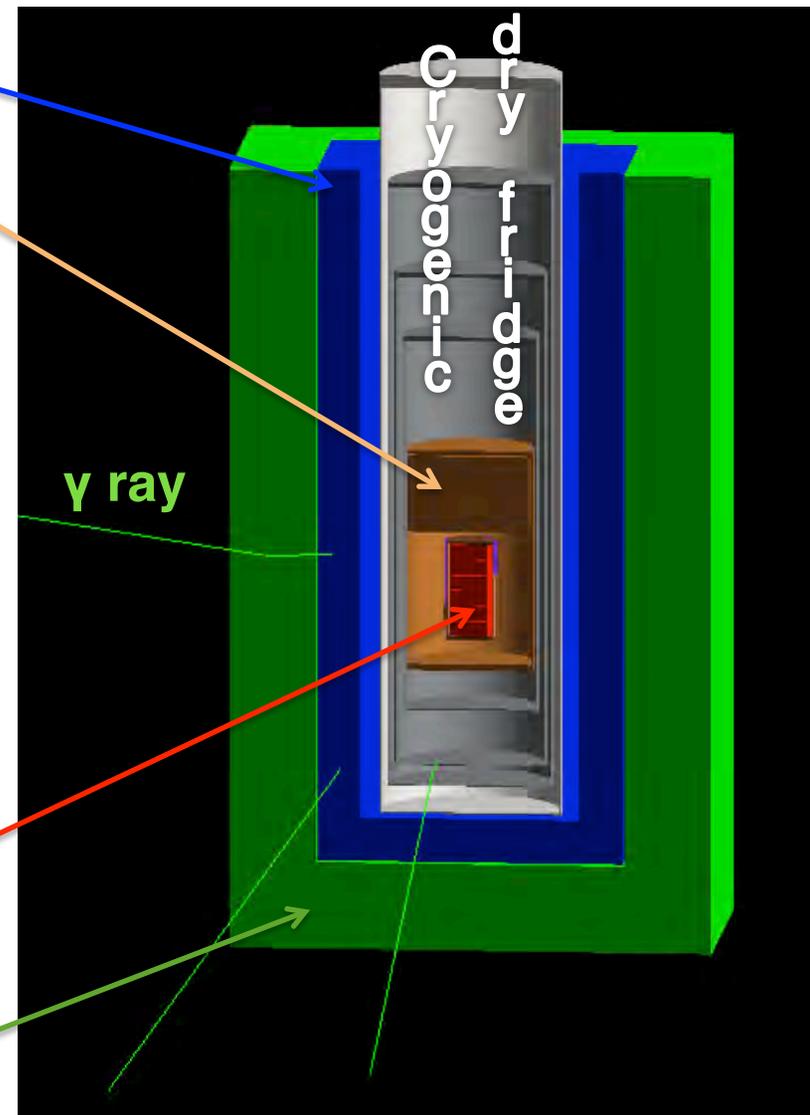
Internal metal γ -shielding

- User interface developed allows to:

- build the facility with or without shielding
- add an additional metal shielding within the fridge
- change its material (copper/lead)
- change its thickness

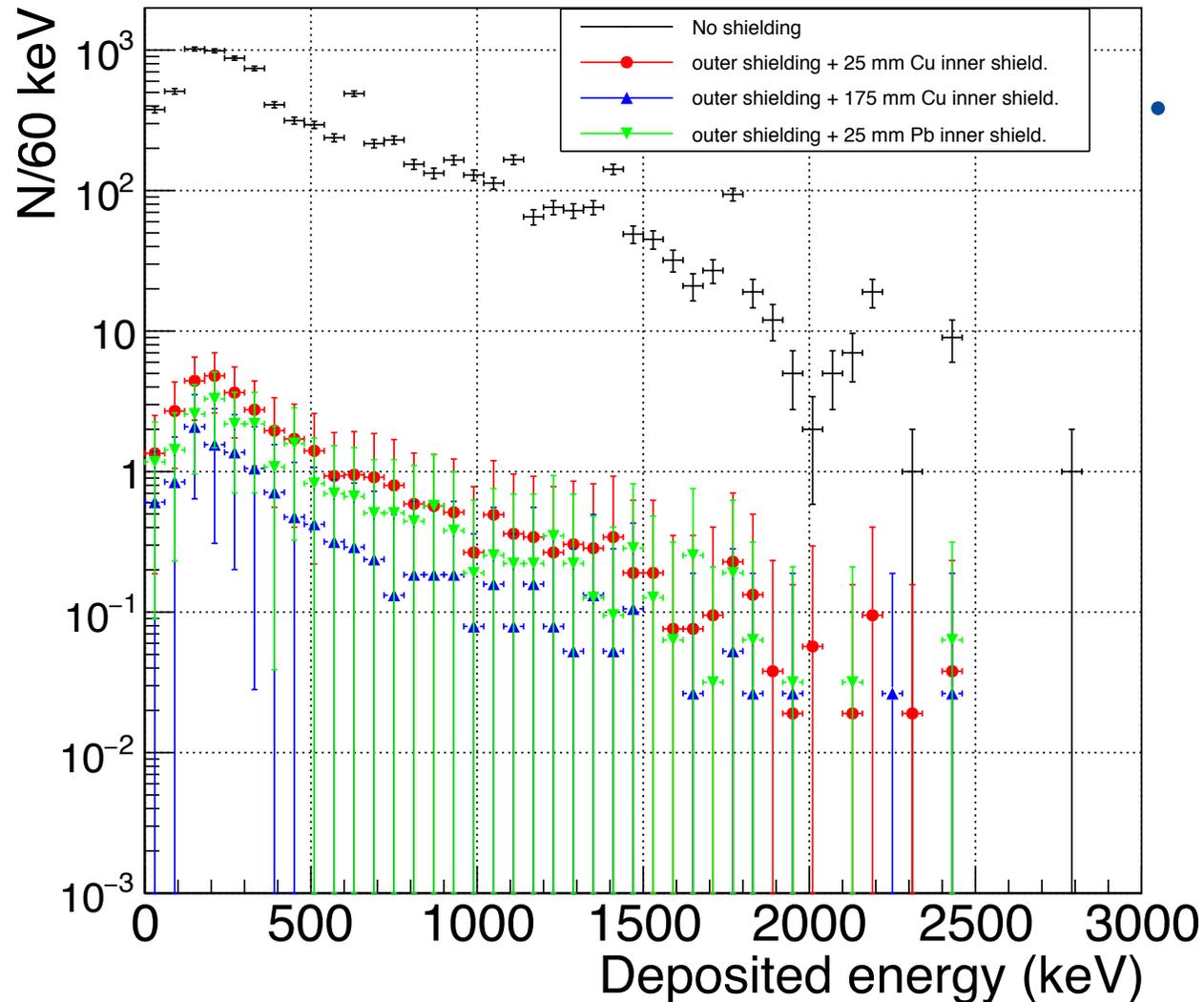
SuperCDMS detector

Polyethylene
n-shielding



Results from the first simulations...

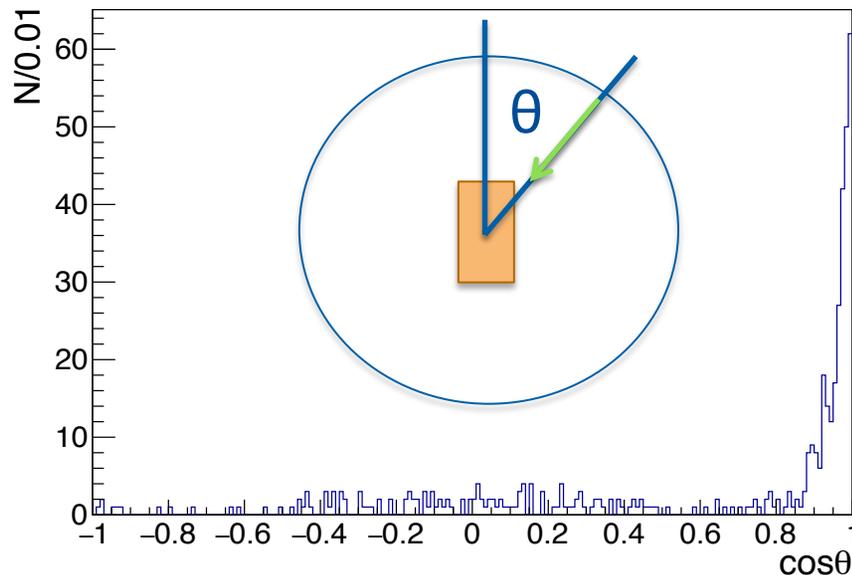
U-238 source



- **Conclusions about the inner shielding:**
 - lead is not necessary (it becomes a superconductor at 7 K → poor heat conductor)
 - **outer shielding + 175 mm of copper inner shielding give more than 500 rejection...**
 - ...but the improvement from 25 mm of copper to 175 mm is not as good as we would have expected. Why?

Angular distribution of the primaries

Outer shielding + 175 mm of copper, U-238 source



- About 2/3 of the events still come from the top of the experimental apparatus
- Inner shielding is critical, but the increase in its thickness gives worse results than expected

- Probably there is some scattering on the walls of the cans
- The simulation dates back to this morning, hypothesis still to be confirmed...



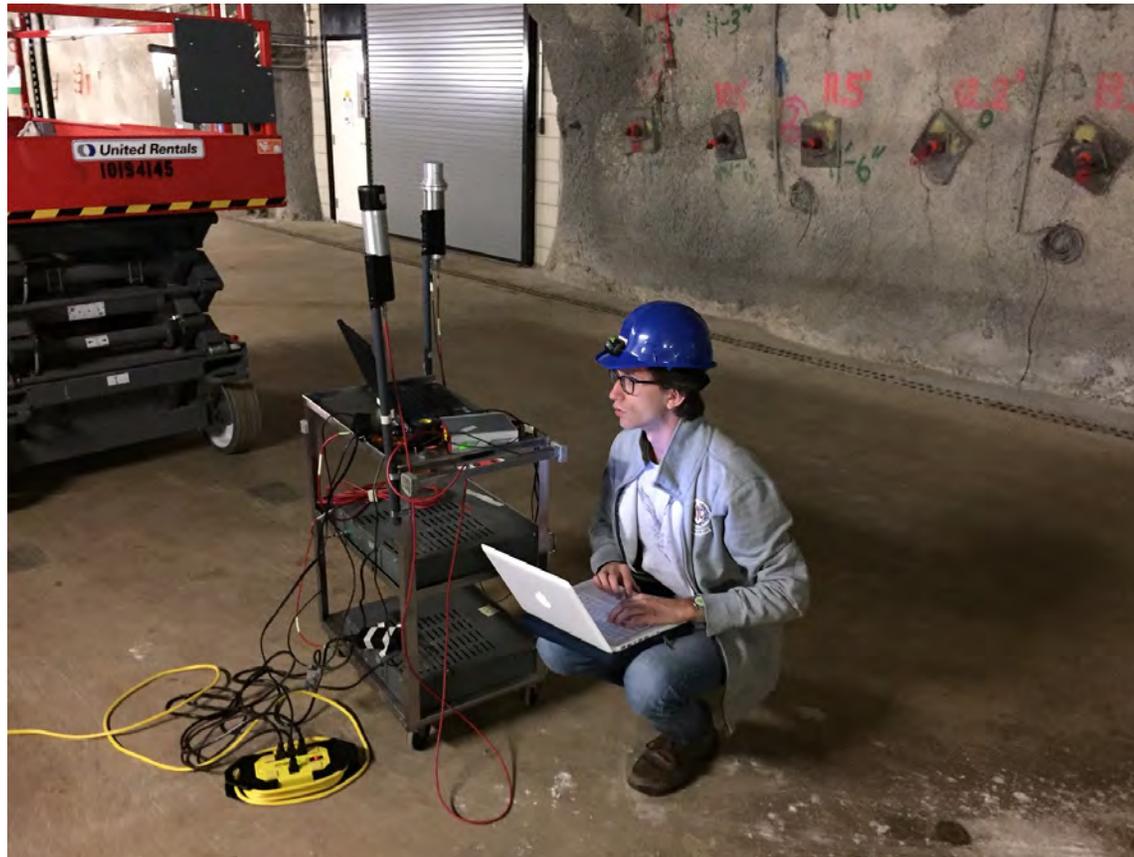
Preliminary estimate of the background

- Start from the background rate observed at NuMI at 1 MeV
- Multiply the spectrum by the rejection ratio obtained in the simulation with the outer shield + 175 mm of inner copper (for ^{238}U)
- Result: background of ~ 100 dru (events / keV / kg / day)
- NEXUS shoots for a background < 100 dru
 - we are just within the desired performance
 - further simulations needed to confirm the estimate
 - a little change of the geometry can help to further reduce the background rate (e.g. some bricks on the top to block the line of sight around the inner shielding)

Summary and next to do

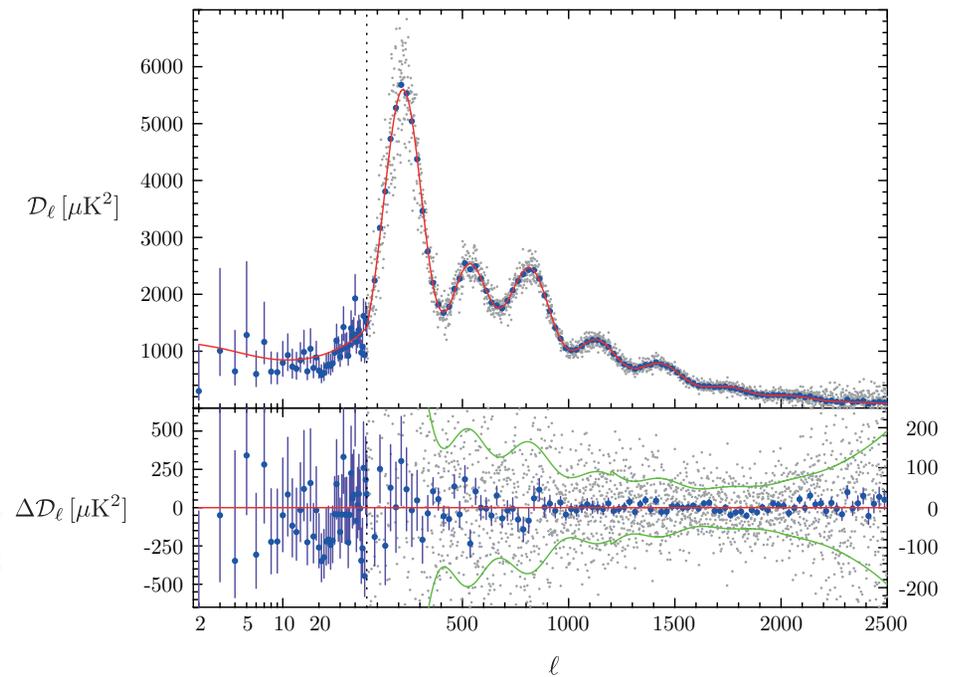
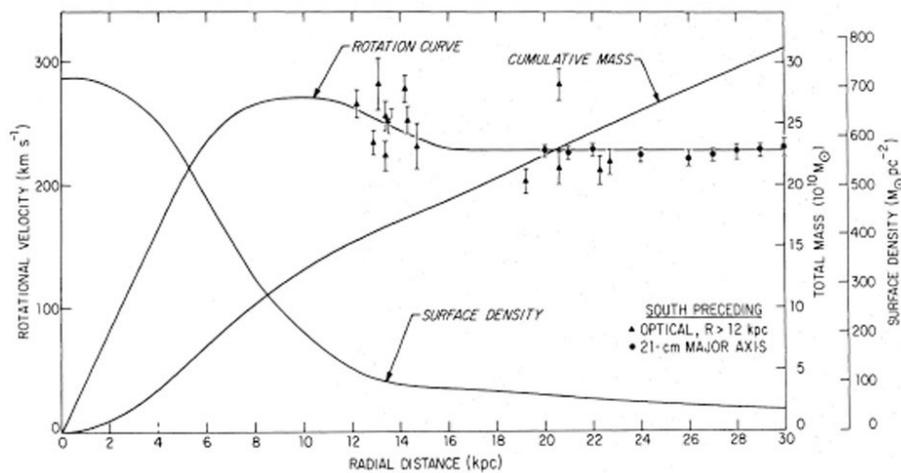
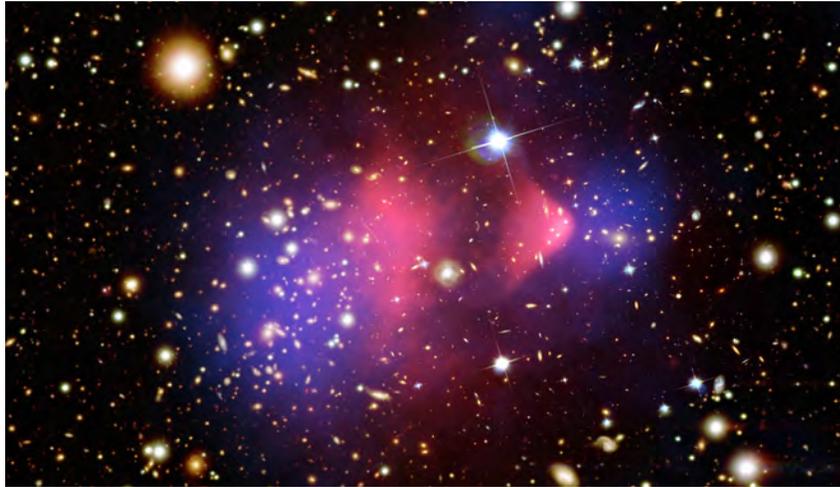
- rough measurement of the gamma spectrum in NuMI tunnel has been performed
- the GEANT4 NEXUS model has been used to make a first estimate of the expected background rate and is ready to perform many more simulations
- **but** many things are still to be done:
 - a longer DAQ in NuMI tunnel to better determine the shape of the spectrum and the weights of the various sources
 - some more simulations to confirm the required dimensions for the inner shielding/the need for a further upper shielding
 - is the background mainly due to scattering on the walls of the cans?
 - is the background with 175 mm of copper already saturated by the previous effect? → try different thicknesses...
 - different sources (^{40}K , ^{232}Th , ...) to see if the rejection rate stays stable at higher energies

Thank you for your attention...
Any questions?

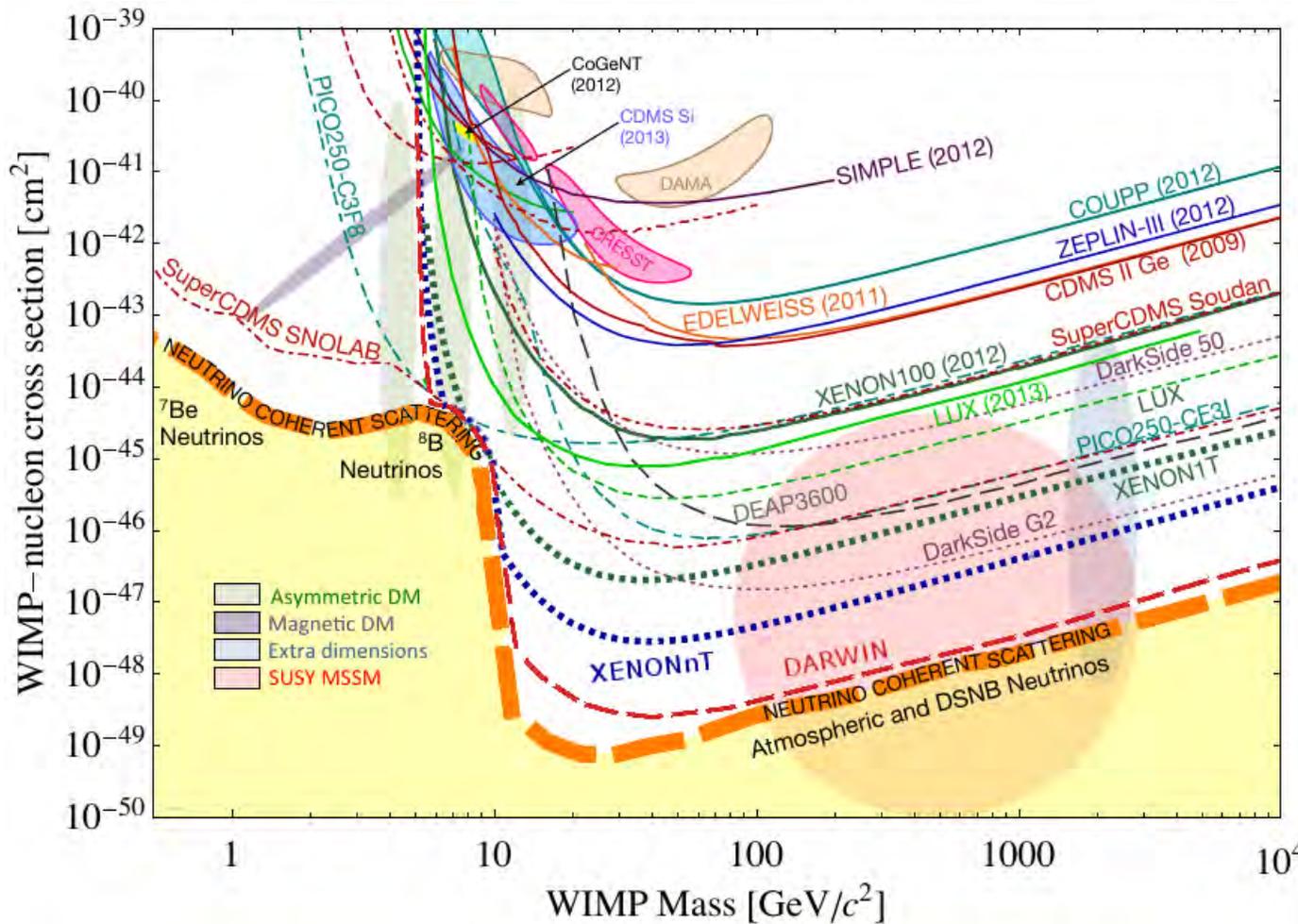


Back-up slides

Dark matter experimental evidence

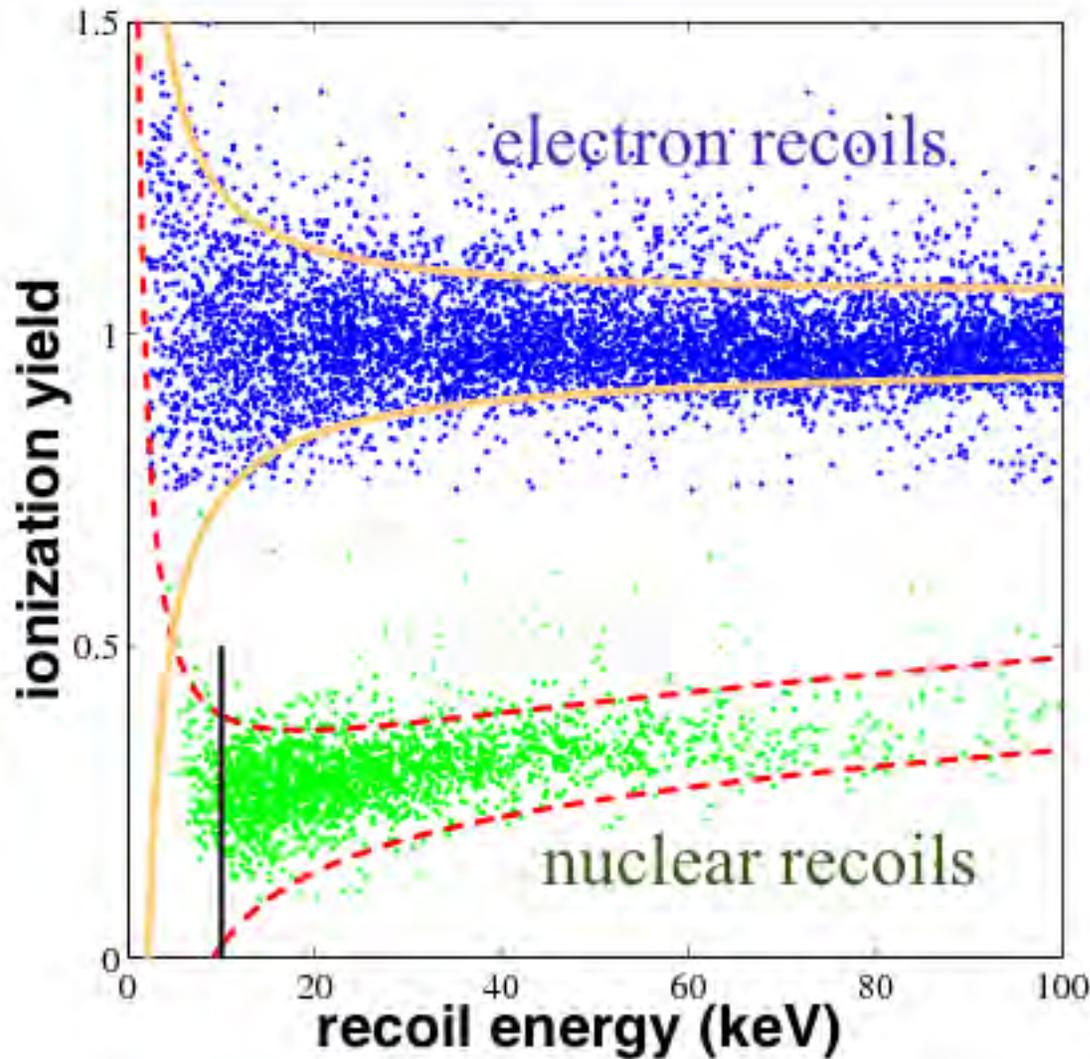


SuperCDMS discovery potential – a broader view



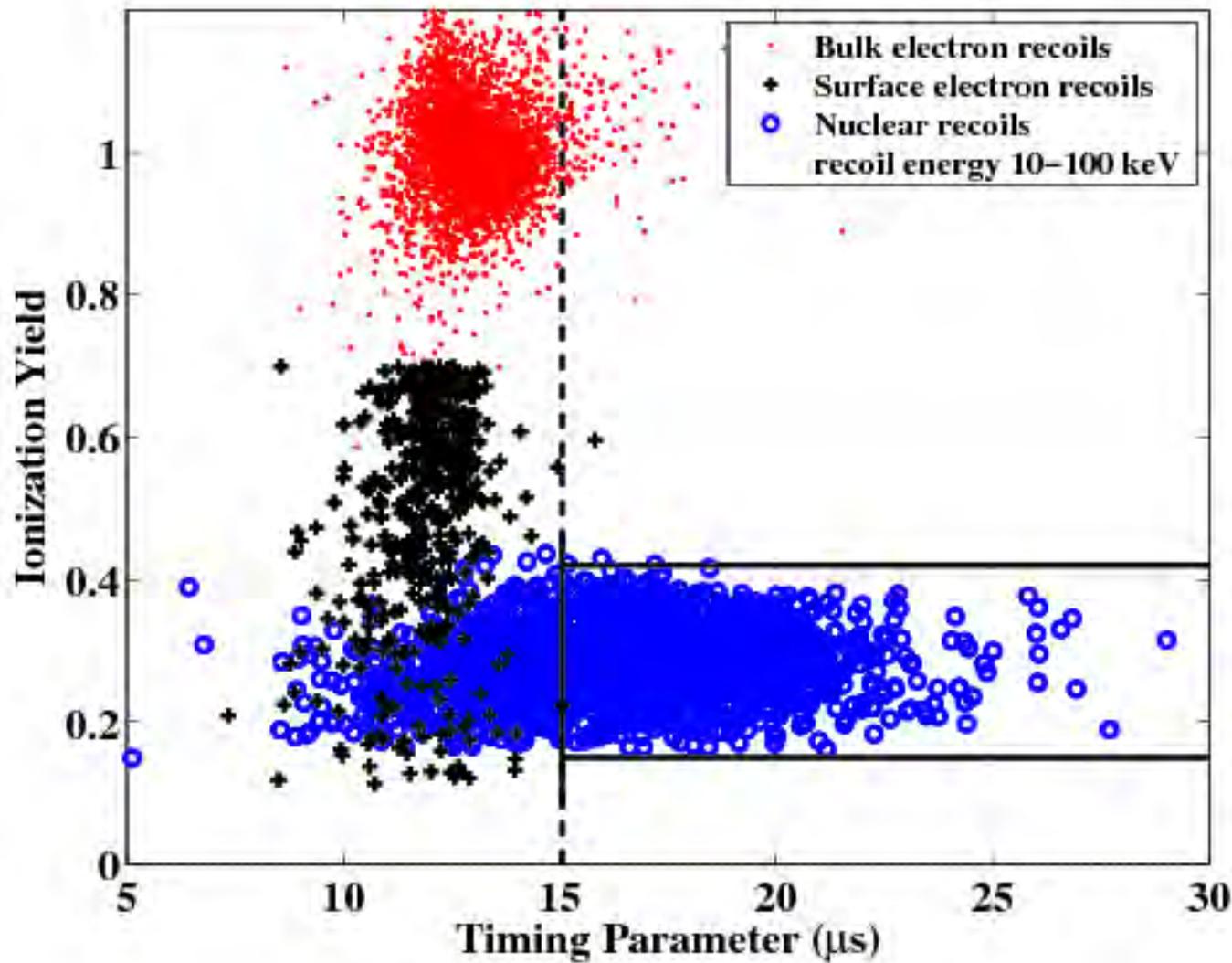
great sensitivity to low mass WIMPs ($m < 10 \text{ GeV}$)!

Ionization calibration at SuperCDMS



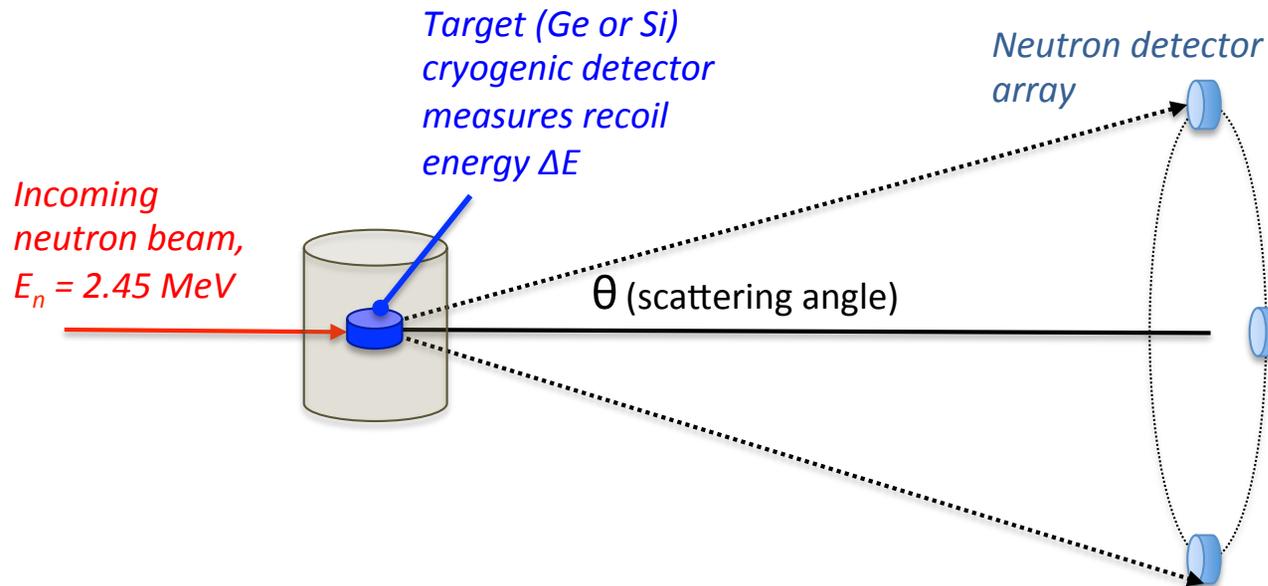
misidentification rate
 $< 1 \text{ in } 10^4$

CDMS timing calibration



misidentification
rate < 1 in 10^6

Calibration kinematics

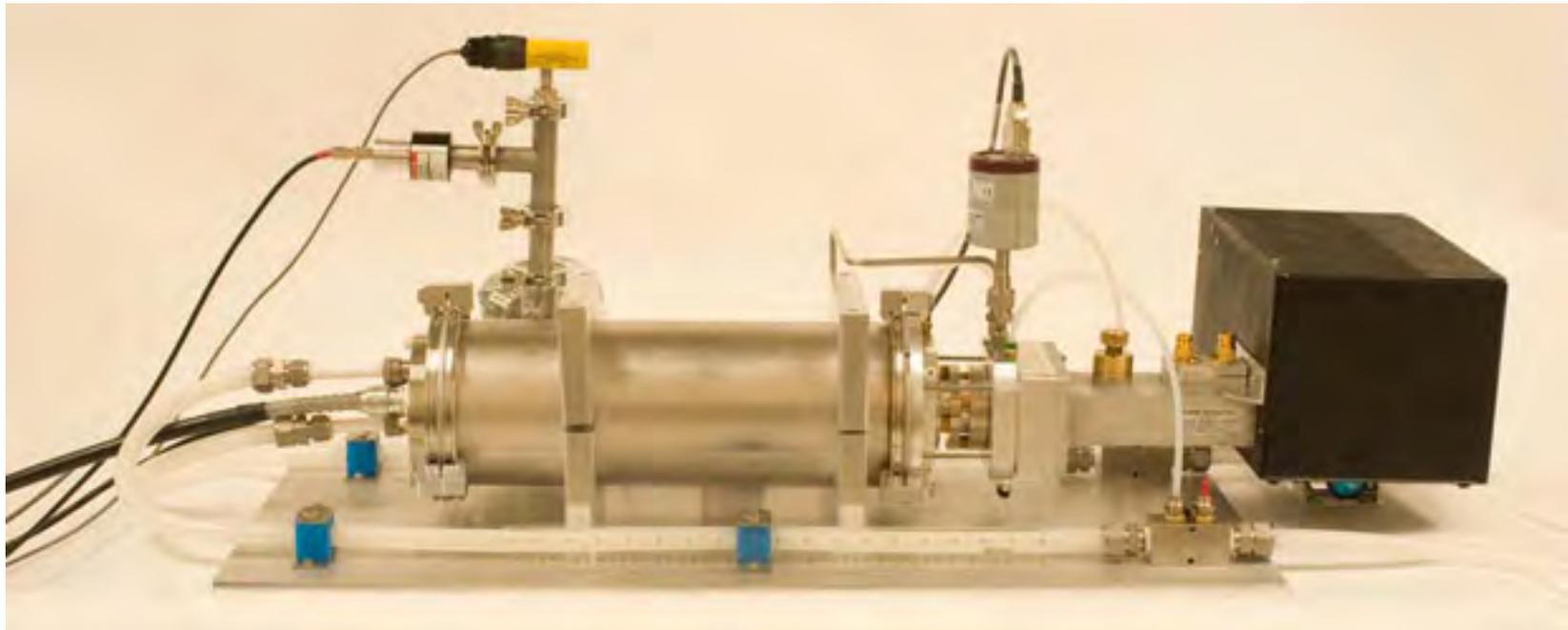


$$\Delta E = 2E_n \frac{M_n^2}{(M_n + M_T)^2} \left(\frac{M_T}{M_n} + \sin^2 \theta - (\cos \theta) \sqrt{\left(\frac{M_T}{M_n} \right)^2 - \sin^2 \theta} \right)$$

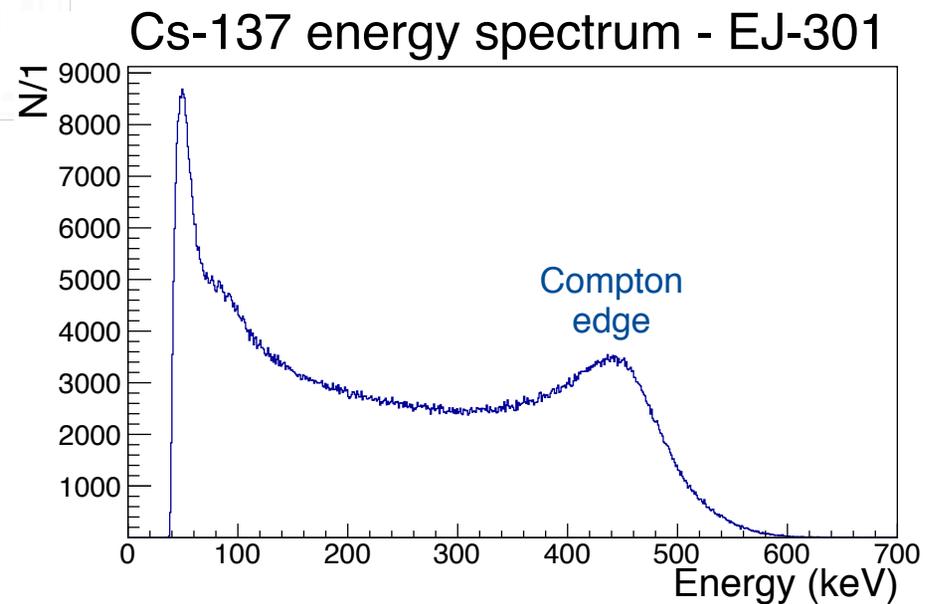
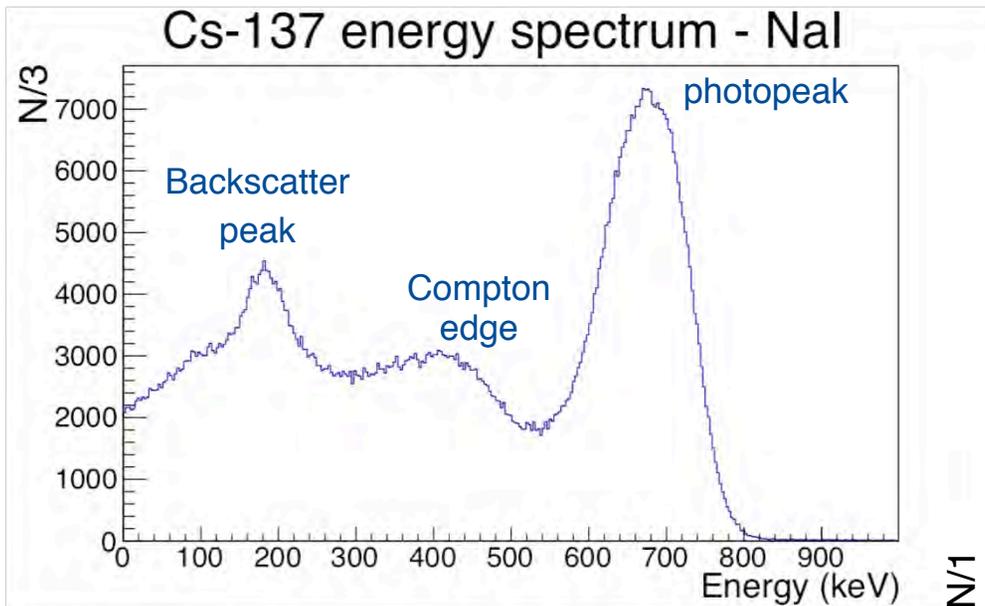
Precise knowledge of the scattering angle and incident (monoenergetic) neutron beam will yield the recoil energy in the calibration detector

D-D neutron generator

- $d+d \rightarrow {}^3\text{He}+n$ on a target
- 2.45 MeV monochromatic neutrons
- energy can be reduced by backscattering the neutrons
- very portable (can be hand-carried by a strong person)
- up to 10^{10} n/s
- pulsed operation available



Example: ^{137}Cs spectrum



User Interface: an example

- Build the NEXUS standard geometry and simulate an homogeneous and isotropic ^{238}U background (1000 events):

```
/CDMS/Lab NoLab  
/CDMS/Detector NEXUS  
/CDMS/NEXUS/verbose 0  
/CDMS/NEXUS/Shielding 1  
/CDMS/NEXUS/InnerShielding 1  
/CDMS/NEXUS/InnShieldMat copper  
/CDMS/NEXUS/InnShieldThick_in_mm 175.
```

```
/CDMS/Source sphere  
/CDMS/Sphere/Radius 2.3 m  
/CDMS/Sphere/Inward true  
/CDMS/Sphere/Lambertian true  
/CDMS/Sphere/AddIsotope 92 238  
/run/initialize  
/CDMS/setMaxDecayTime 1 second  
/process/em/fluor true  
/process/em/augetrue true  
/process/em/pixetrue true
```

```
/CDMS/updateGeom  
/run/beamOn 1000
```