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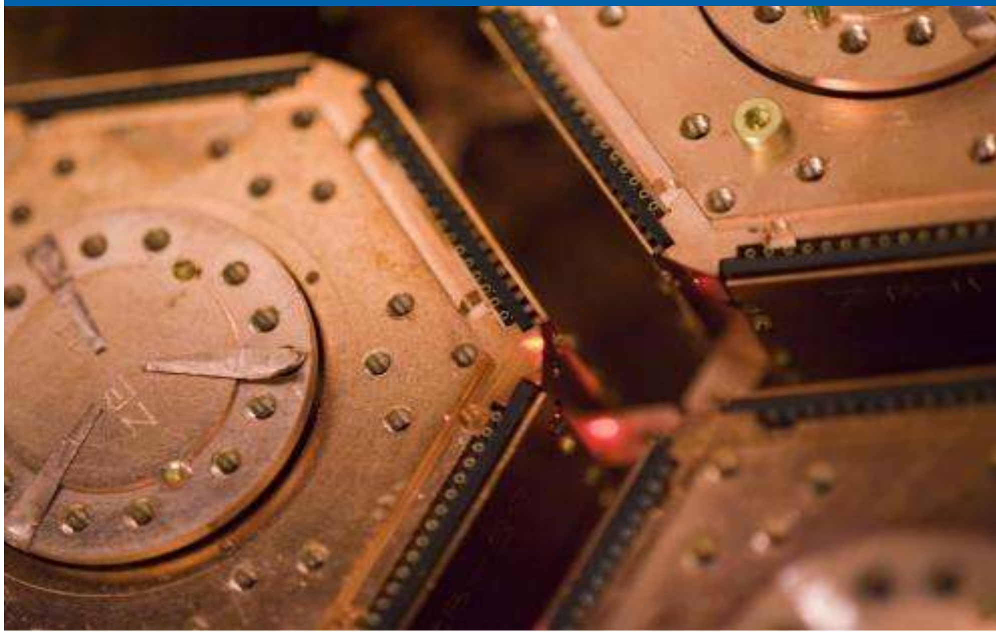

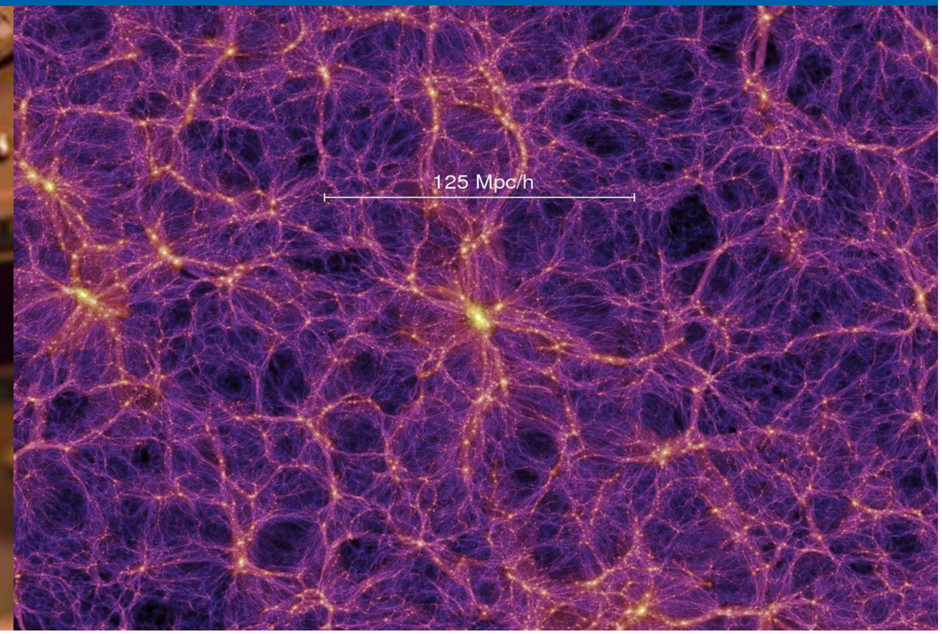

Measuring the gamma background at NEXUS facility

Tommaso Pajero *(University of Pisa & Scuola Normale Superiore)*

Mentor: **Ziqing Hong** *(Northwestern University)*

Lauren Hsu *(FNAL)*

Enectali Figueroa-Feliciano *(Northwestern University)*

Final presentation, Summer Students 2016

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In partnership with:

SCUOLA NORMALE SUPERIORE

NORTHWESTERN UNIVERSITY

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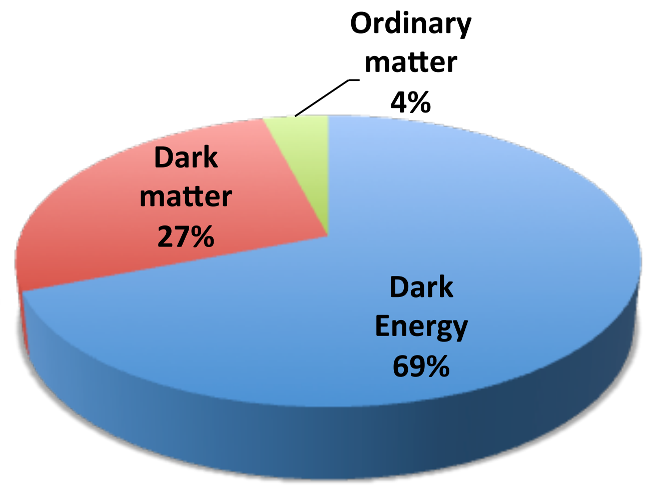
Overview

- **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

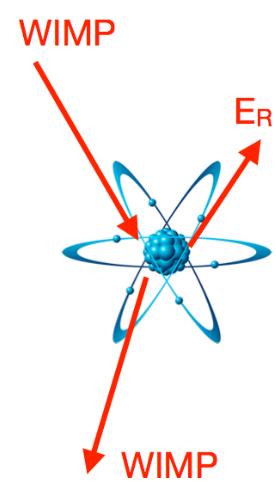
WIMP
(Weakly Interacting Massive Particle)

① **Indirect detection**

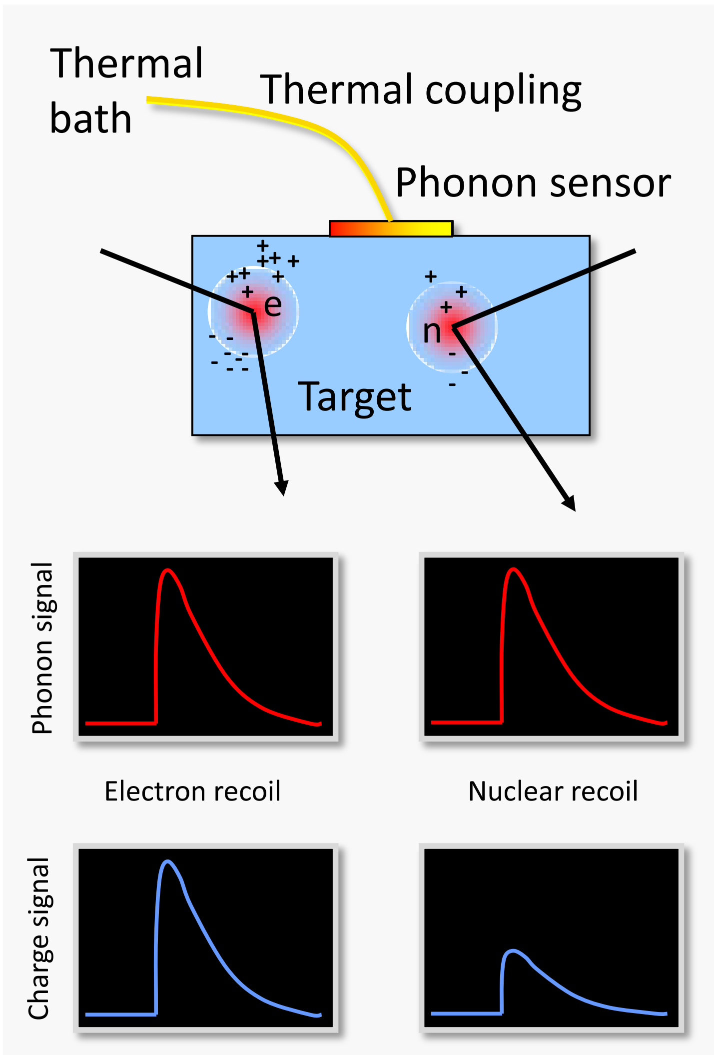
② **Production at colliders**

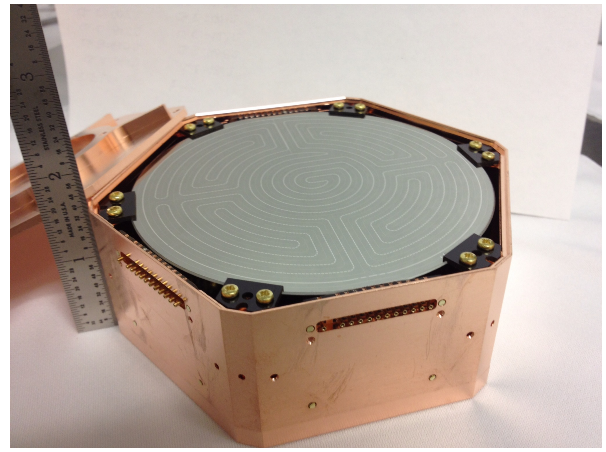
③ **DIRECT DETECTION**

- 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 Ø, 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

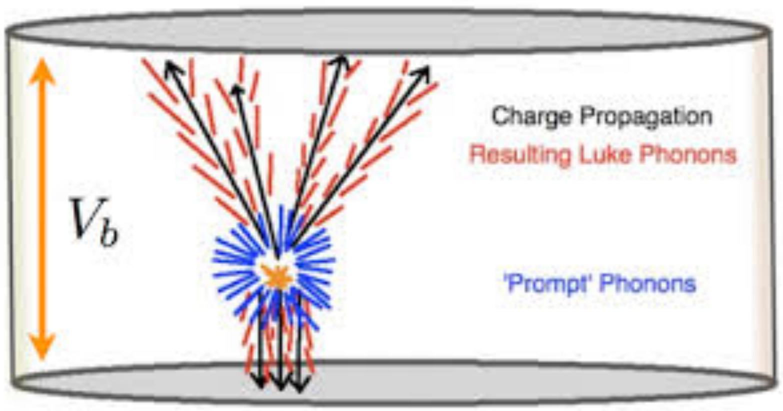
Measuring low mass WIMPs

- low mass means also low recoil energy
- WIMPS with 1 GeV < m < 10 GeV produce recoils as low as **100 eV**, very difficult to distinguish from electronic noise…
- some amplification of the signal is required

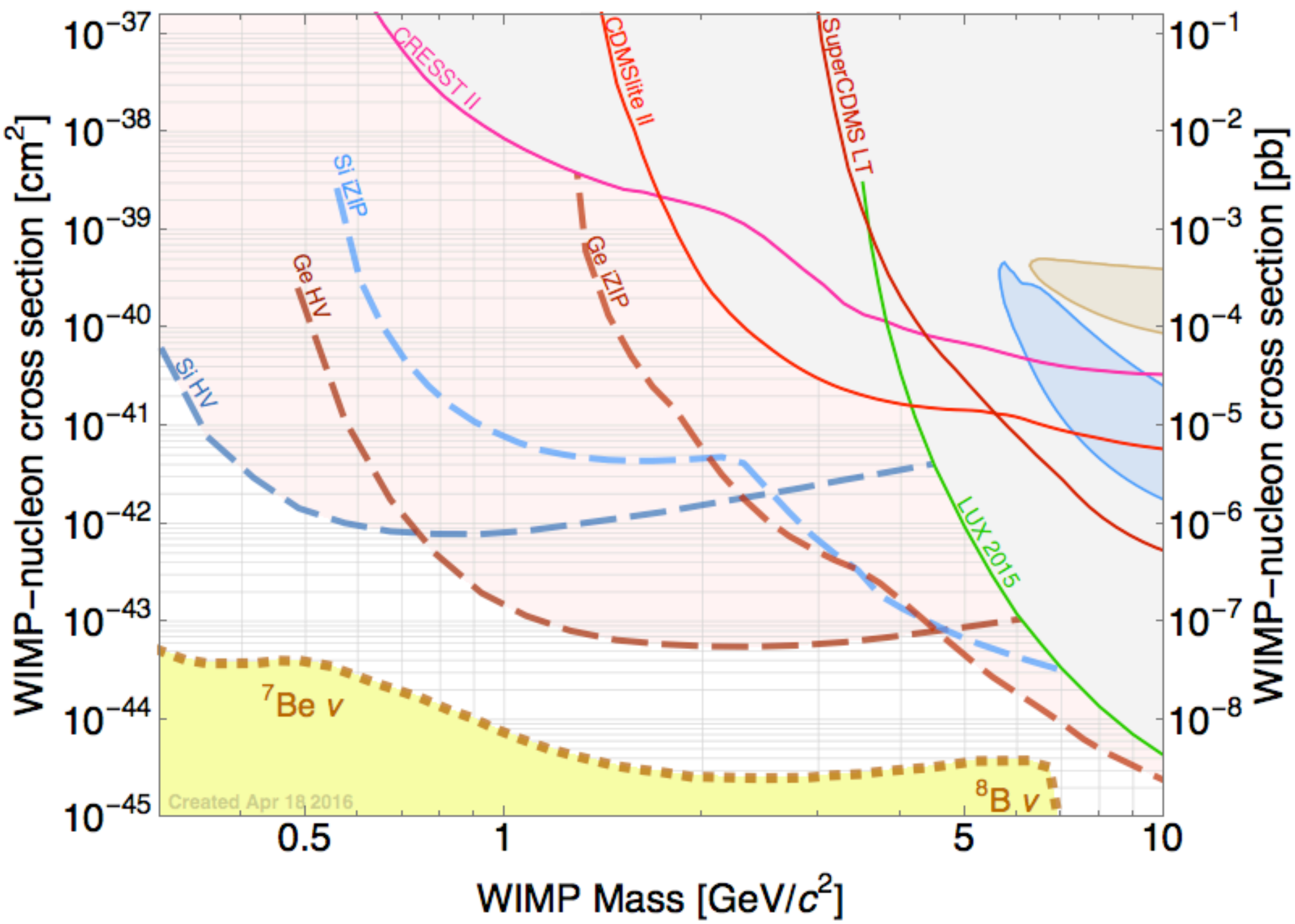
SuperCDMS HV (old CDMSlite)

- 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



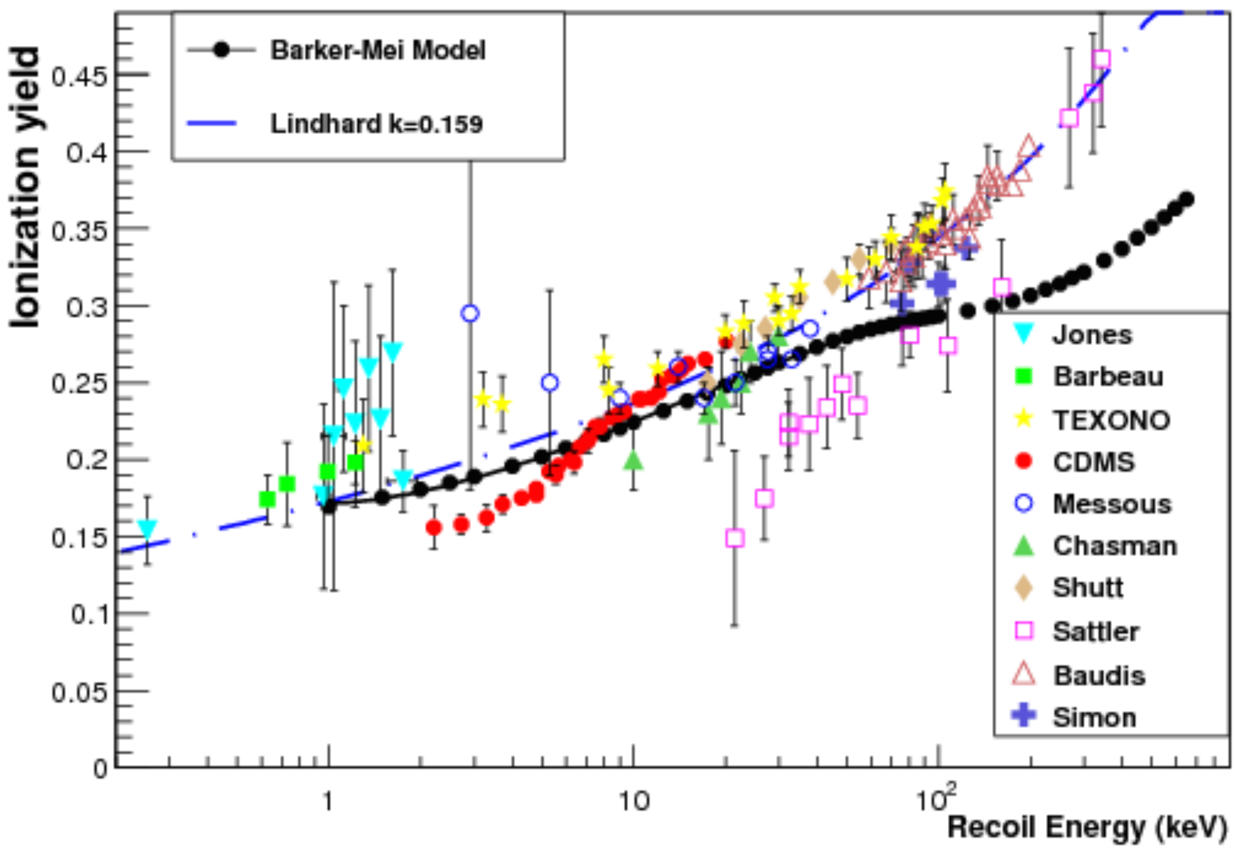
SuperCDMS discovery potential



great sensitivity to low mass WIMPs (m < 10 GeV)!

Ionization calibration

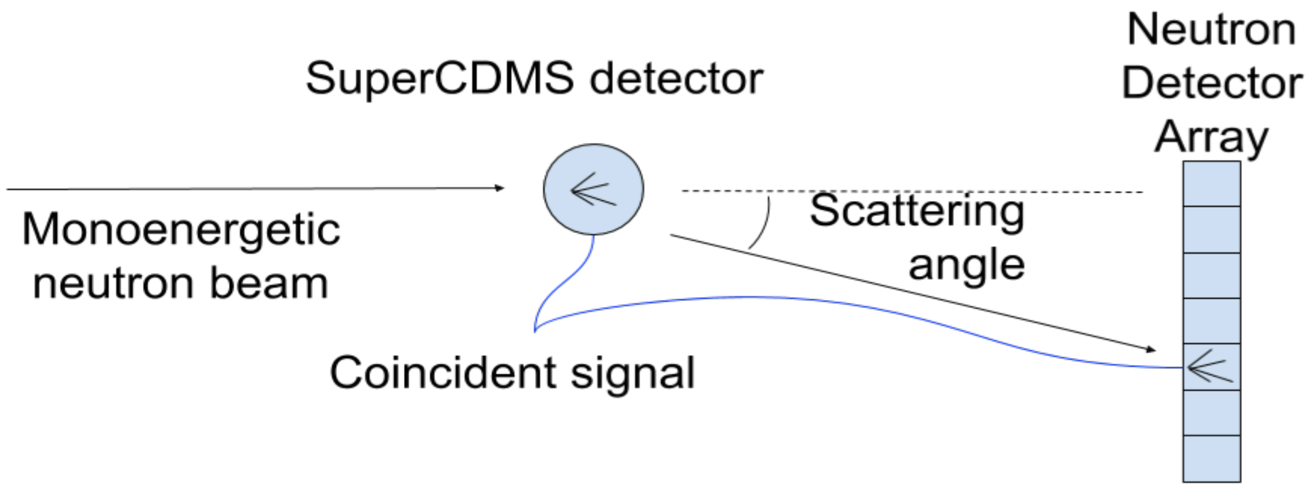
- Problem: there are very few experimental points under 1 keV (no-one under 250 eV) and the theoretical models may fail under that value…



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

Northwestern
EXperimental
Underground
Site

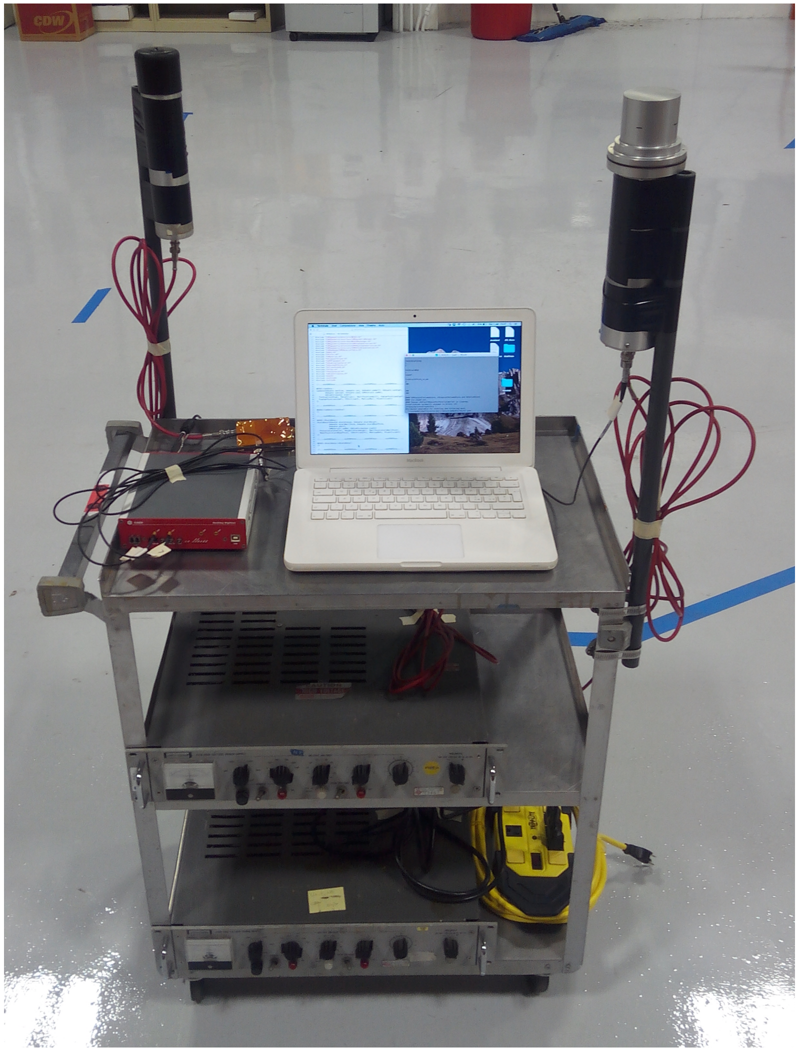
- **low background** underground facility for **ultrasensitive detectors calibration**
- located in NuMI tunnel (MINOS hall) at FNAL
- cryogenic dry fridge: T down to ~ **20 mK**
- neutron source (D-D generator)
  - ~ 2.45 MeV monochromatic neutrons
- facility available also for other experiments (e.g.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

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**

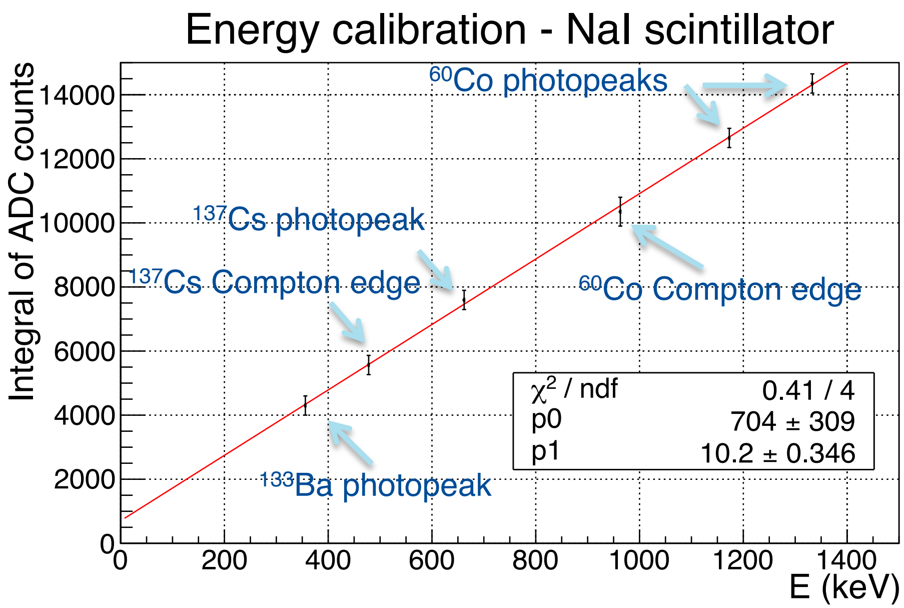
Experimental apparatus

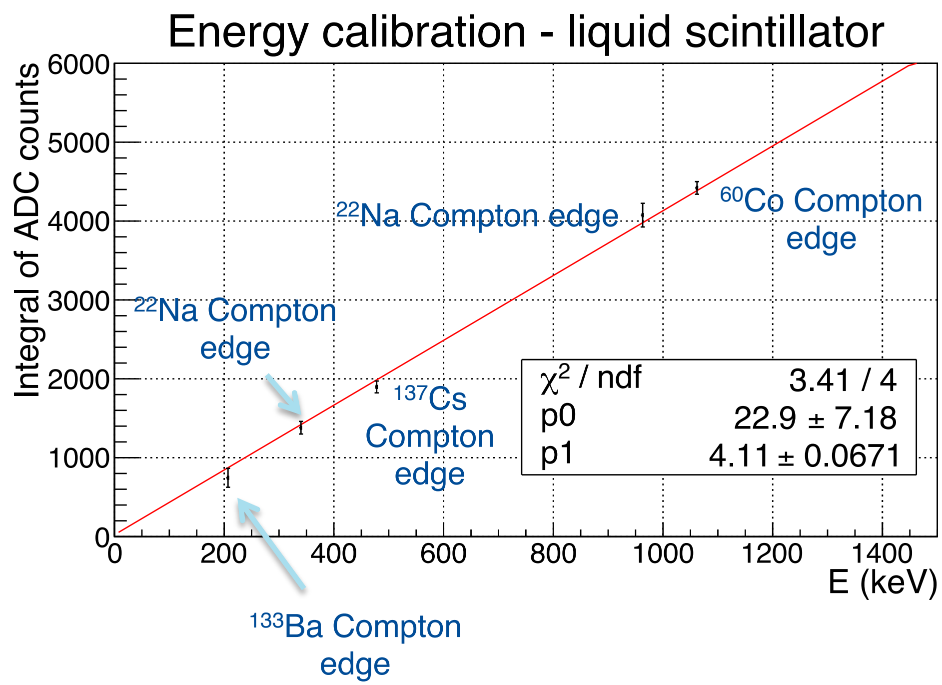


- **Eljen 301** liquid scintillator
- **Victoreen 490 Thyac** NaI scintillator
- **Caen DT5720** ADC
- **FLUKE 408B** HV supply

Calibration

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

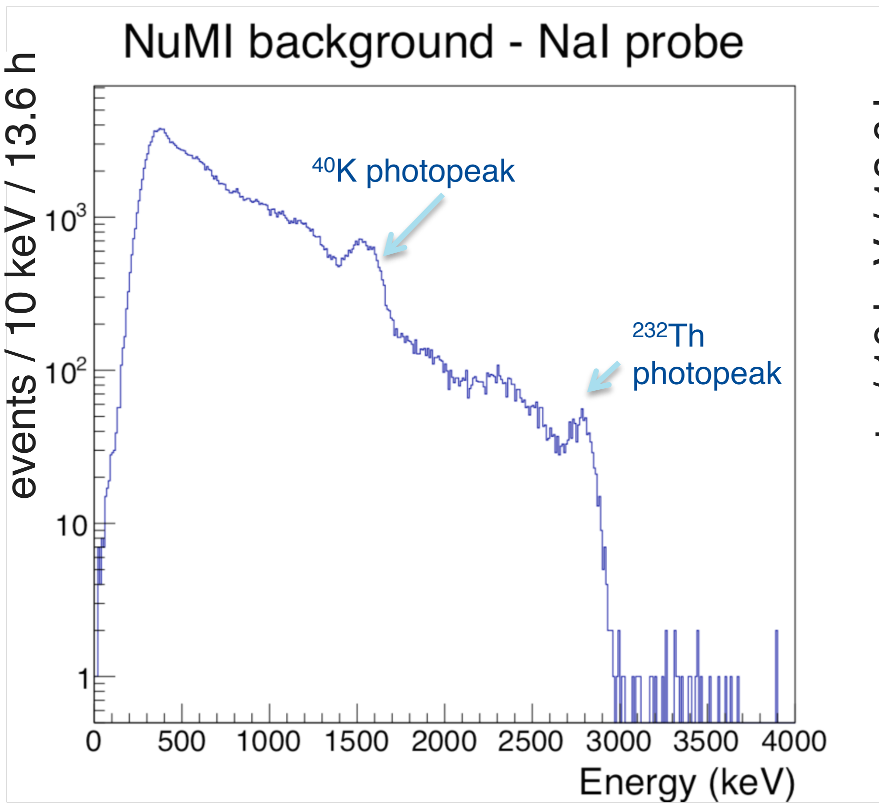


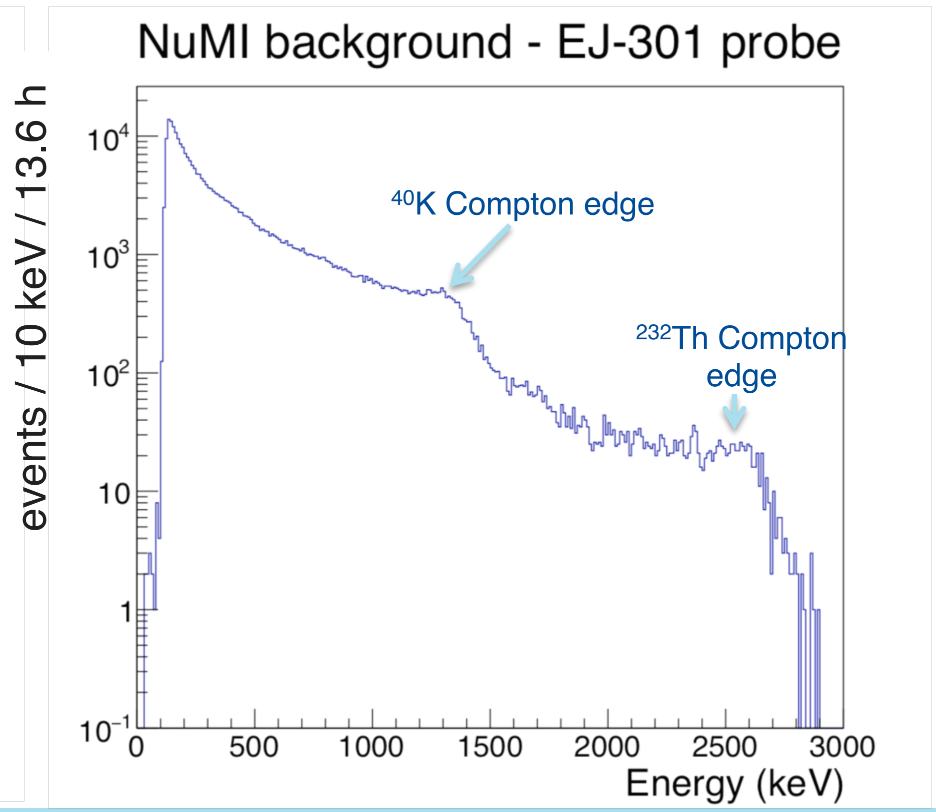


- Efficiency measurement: known source at fixed distance
  - NaI probe: $\varepsilon = 0.33 \pm 0.08$
  - liquid probe: $\varepsilon = 0.16 \pm 0.03$

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

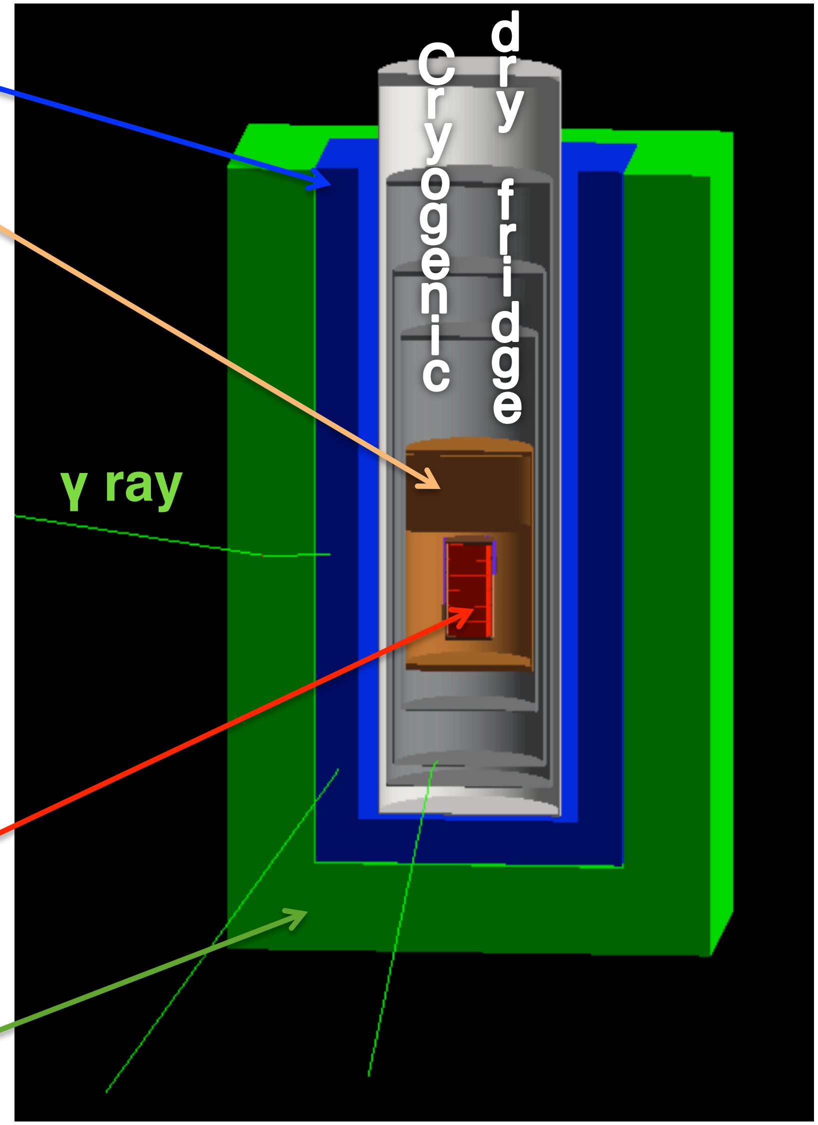
Outer lead γ-shielding

Internal metal γ-shielding

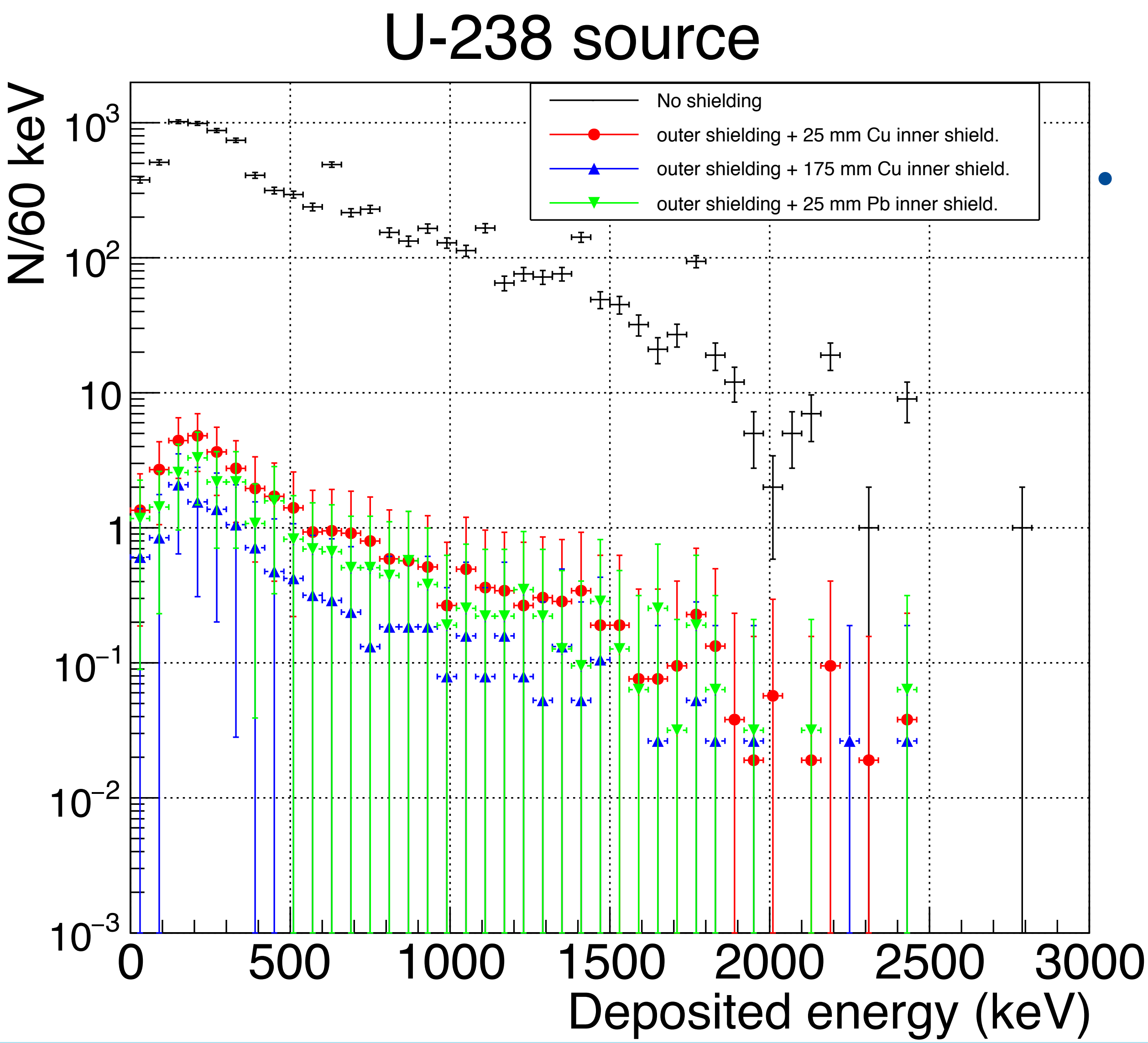
- **User interface developed allows to:**
  - build the facility with or without shielding
  - add an additional metal shielding within the fridge
  - change its material (copper/lead)
  - change its thickness

SuperCDMS detector

Polyethylene n-shielding

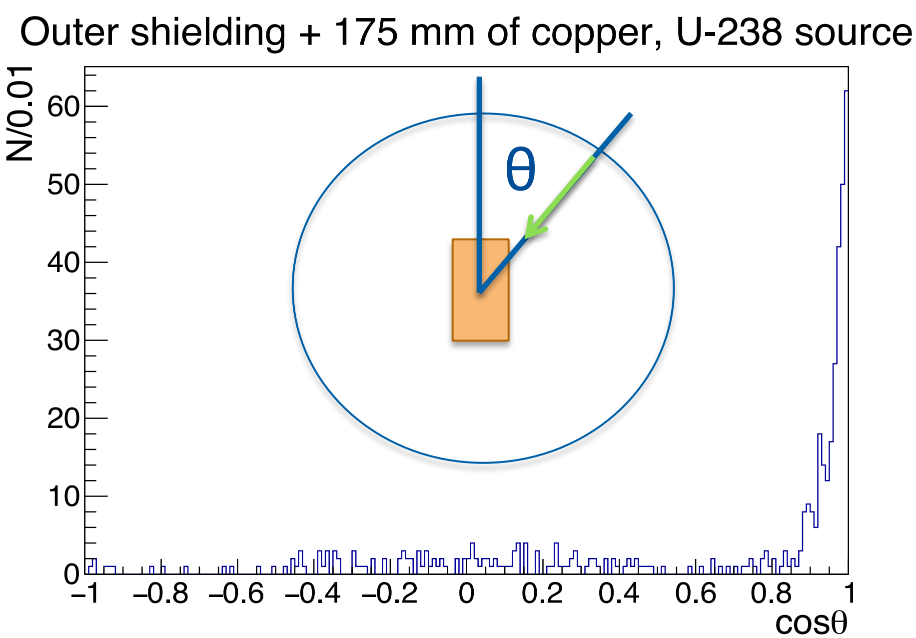


Results from the first simulations…

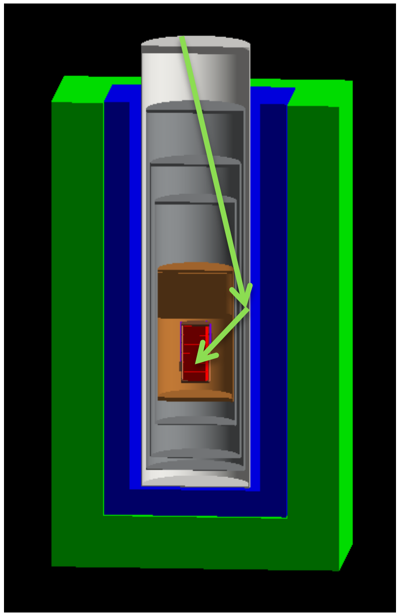


- Conclusions about the inner shielding:
  - lead is not necessary (it becomes a superconducor at 7 K ⟶ poor heat conductor)
  - outer shielding + 175 mm of copper inner shielding give more than **500 rejection**…
  - …but the improvement from 25 mm of copper to 175 mm is not as good as we would have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

Angular distribution of the primaries



- 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)

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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

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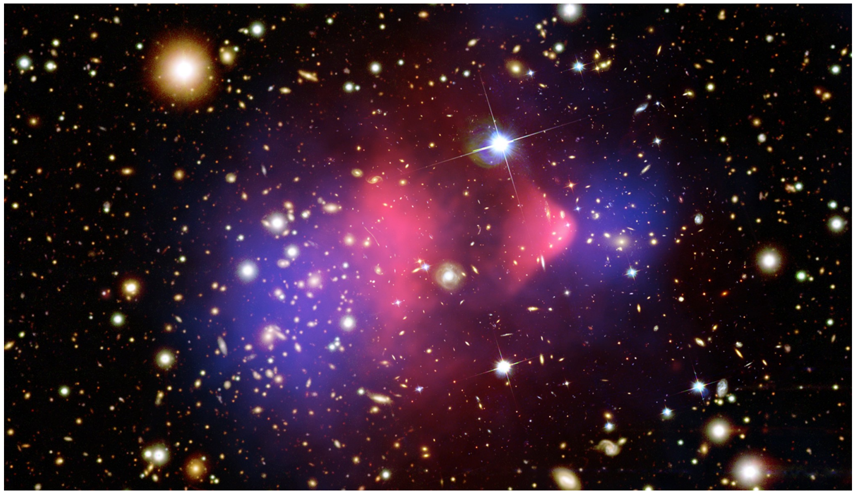
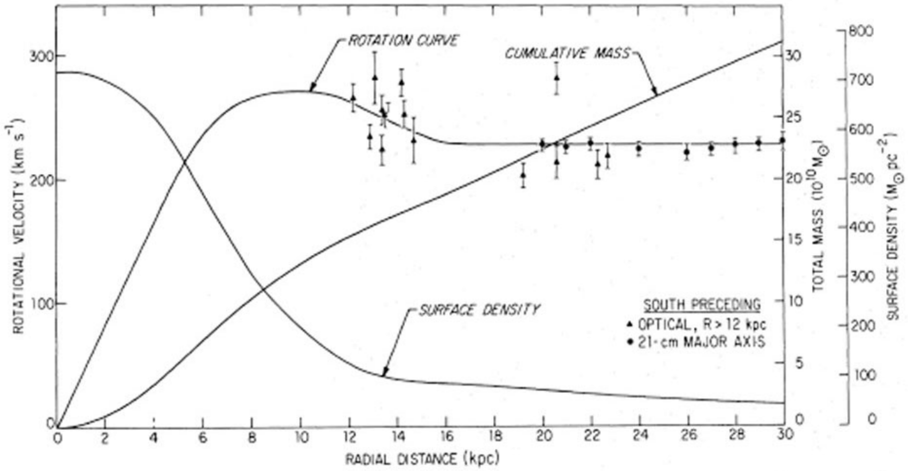
Thank you for your attention…

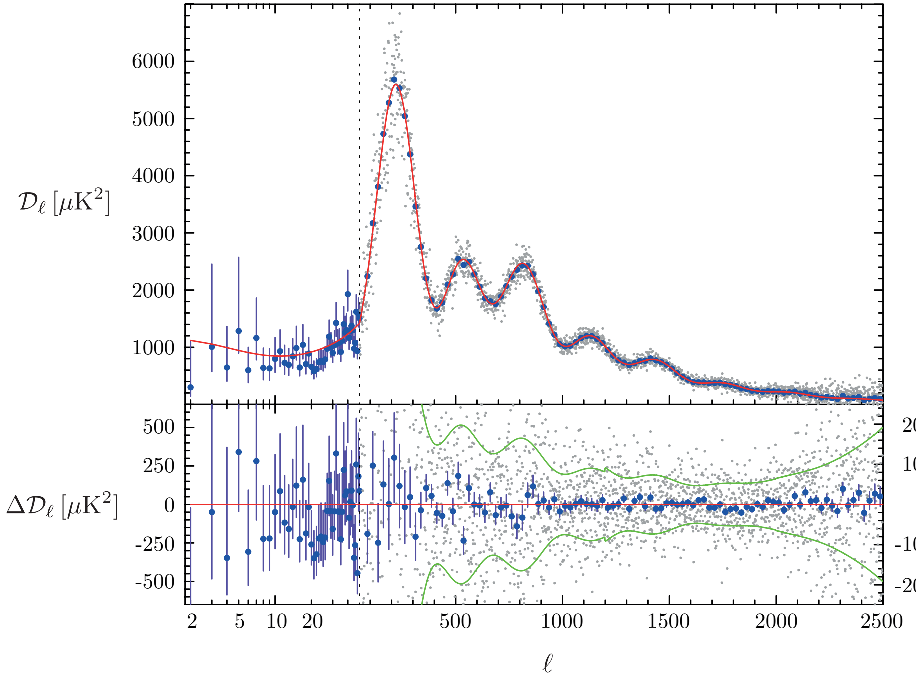
Any questions?

Back-up slides

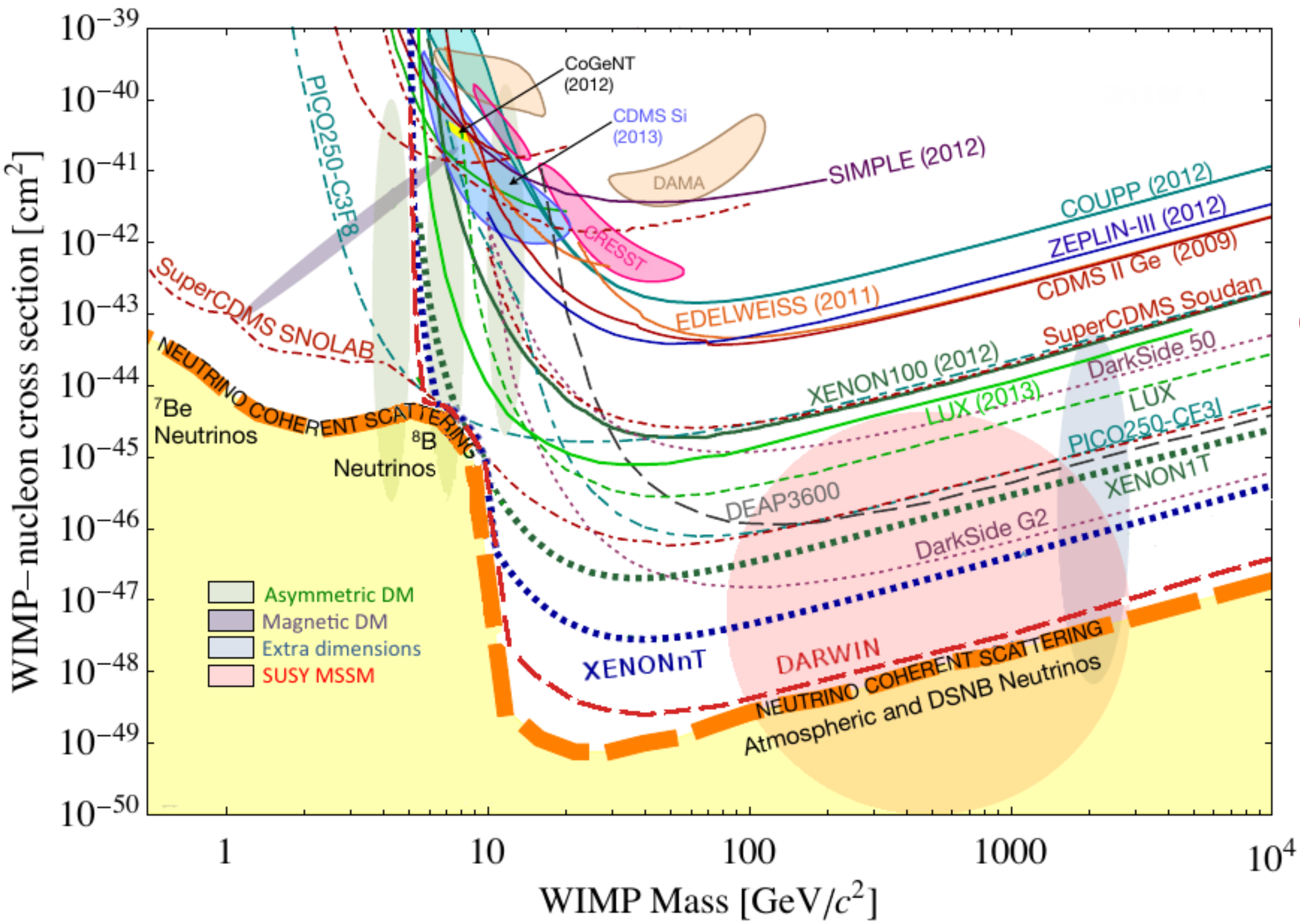
Dark matter experimental evidence





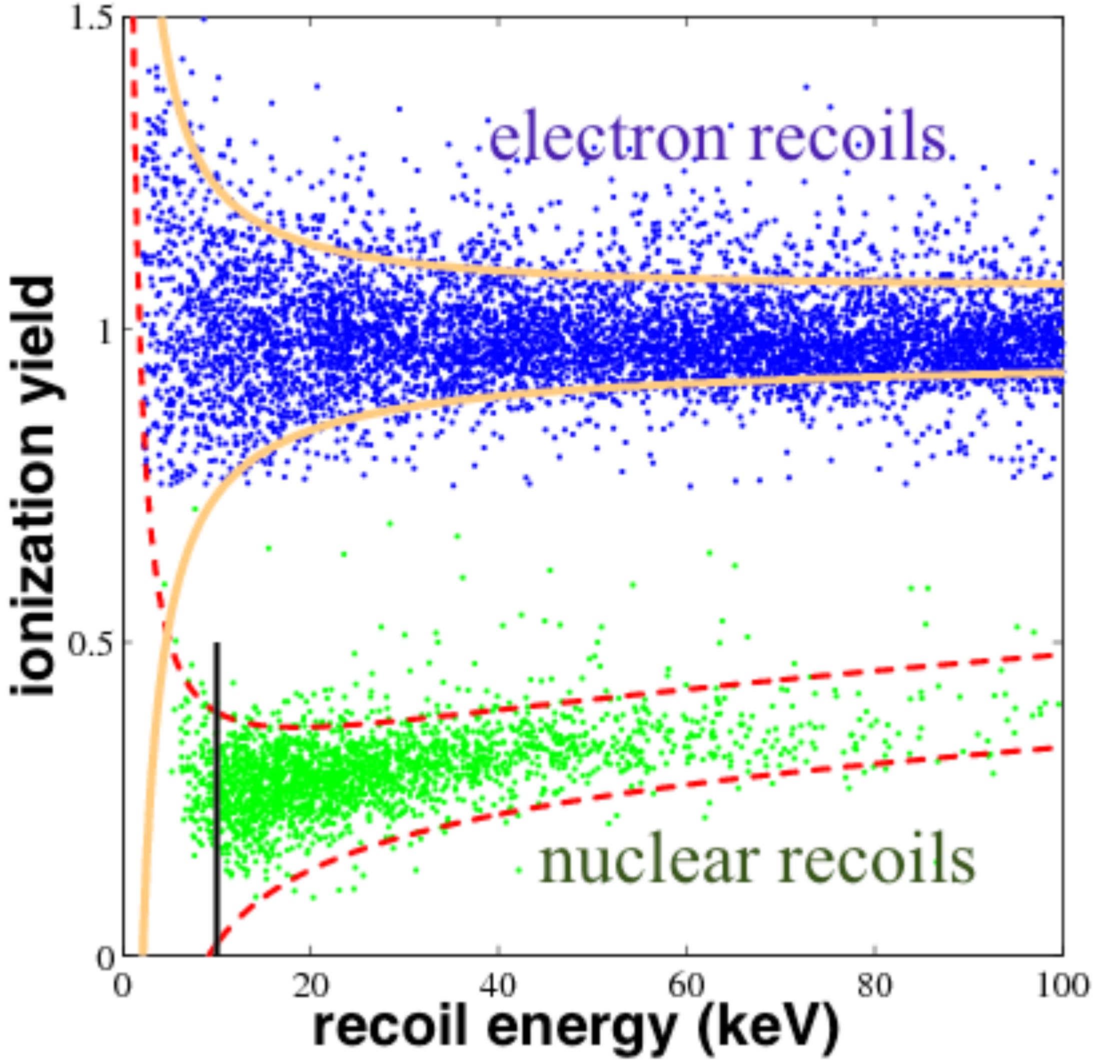


SuperCDMS discovery potential – a broader view



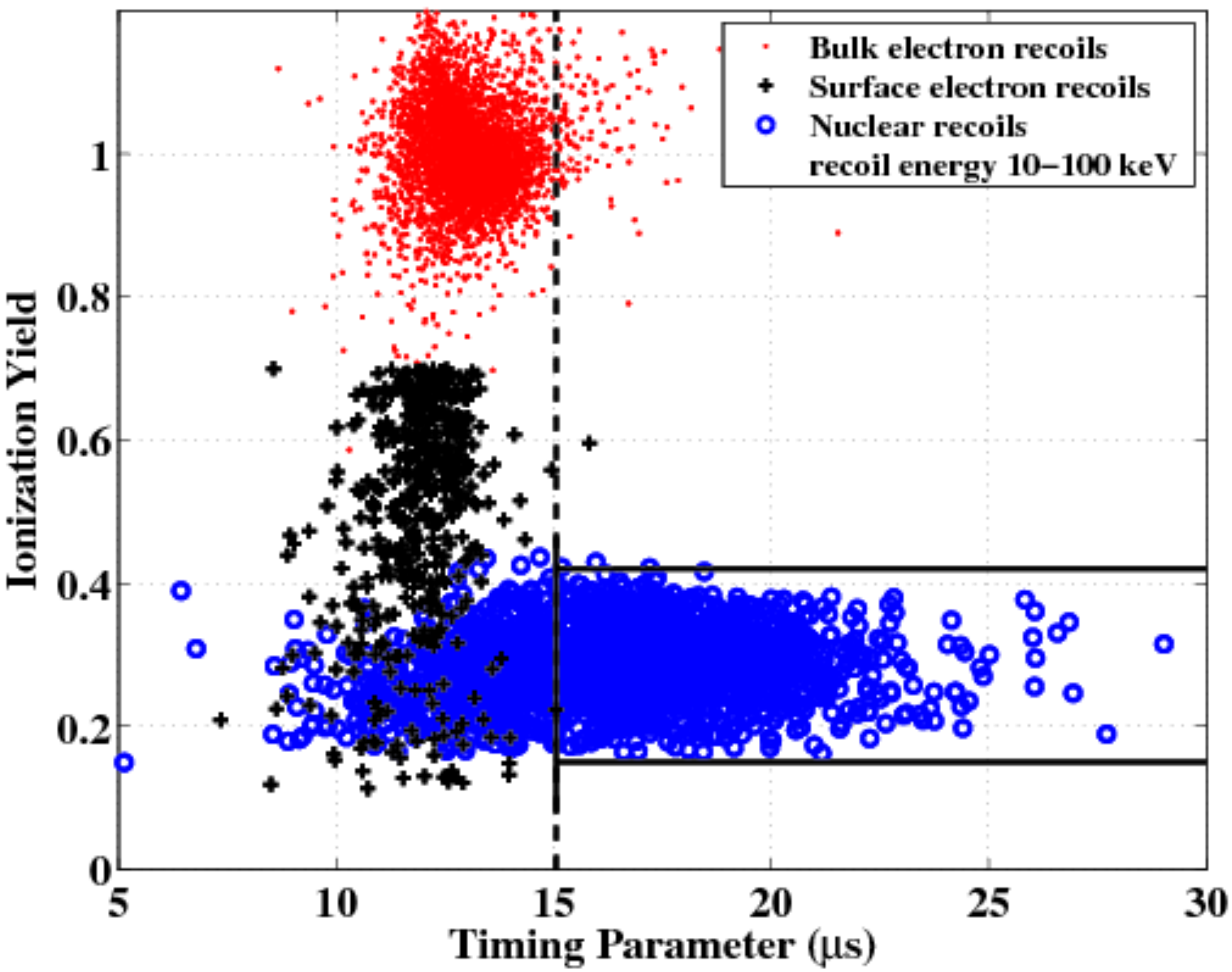
great sensitivity to low mass WIMPs (m < 10 GeV)!

Ionization calibration at SuperCDMS



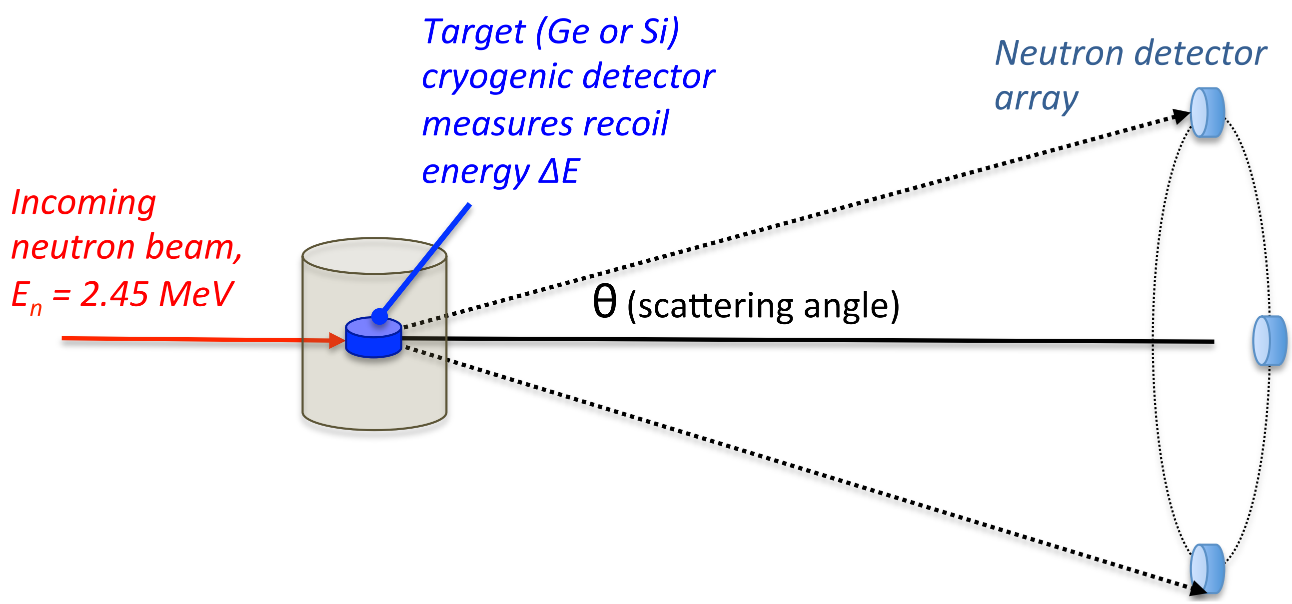
misidentification rate
< 1 in 10^4

CDMS timing calibration



misidentification rate < 1 in 10^6

Calibration kinematics

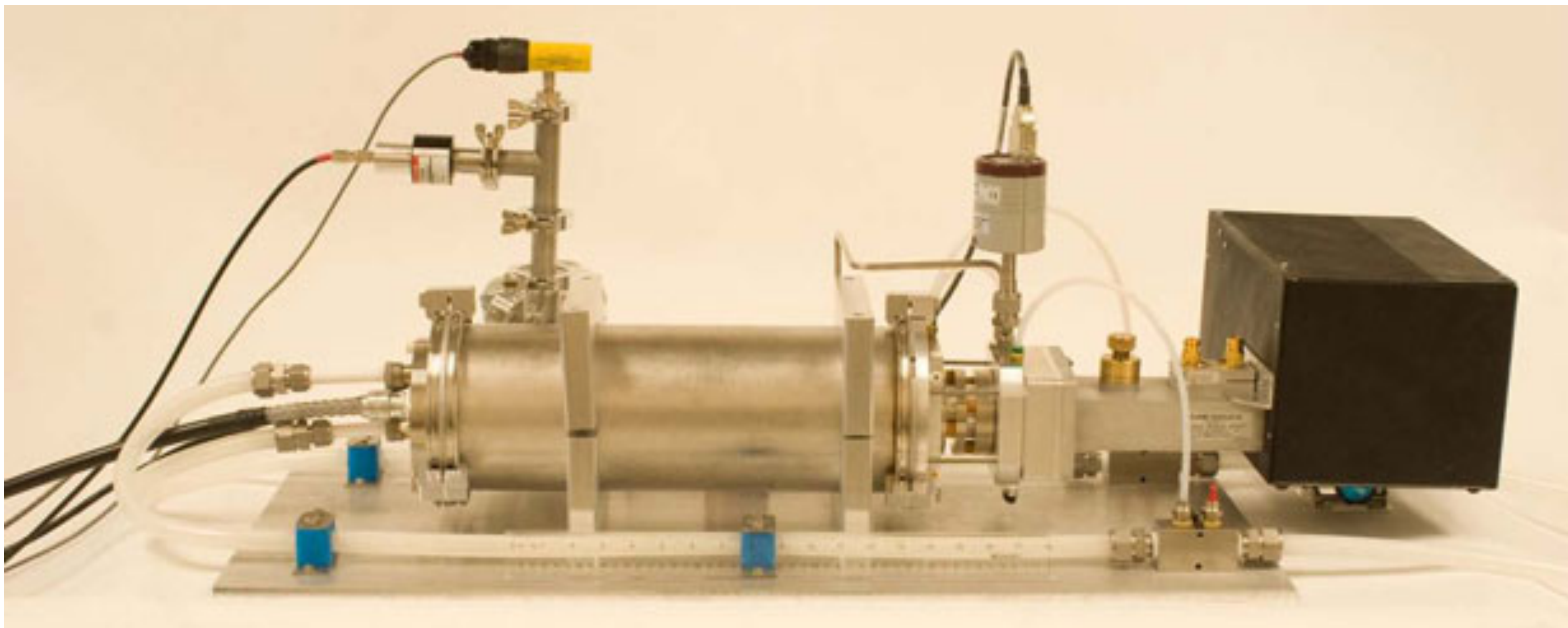


$$\Delta E = 2E_{\mathrm{n}} \frac{M_{\mathrm{n}}^2}{(M_{\mathrm{n}} + M_{\mathrm{T}})^2} \left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}} + \sin^2\theta - (\cos\theta)\sqrt{\left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}}\right)^2 - \sin^2\theta} \right)$$

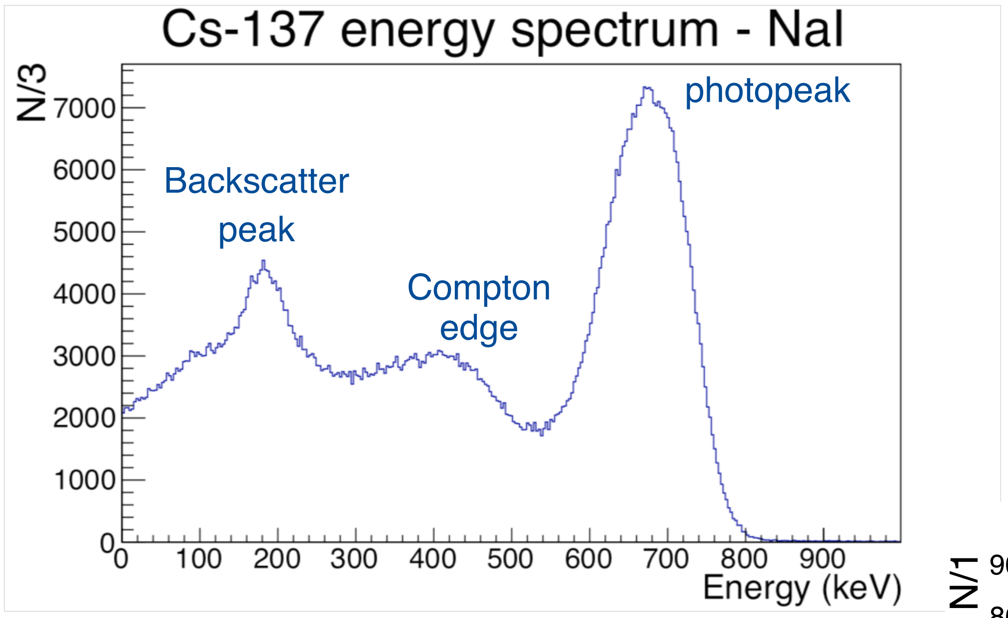
Precise knowledge of the scattering angle and incident (monoenergetic) neutron beam will yield the recoil energy in the calibration detector

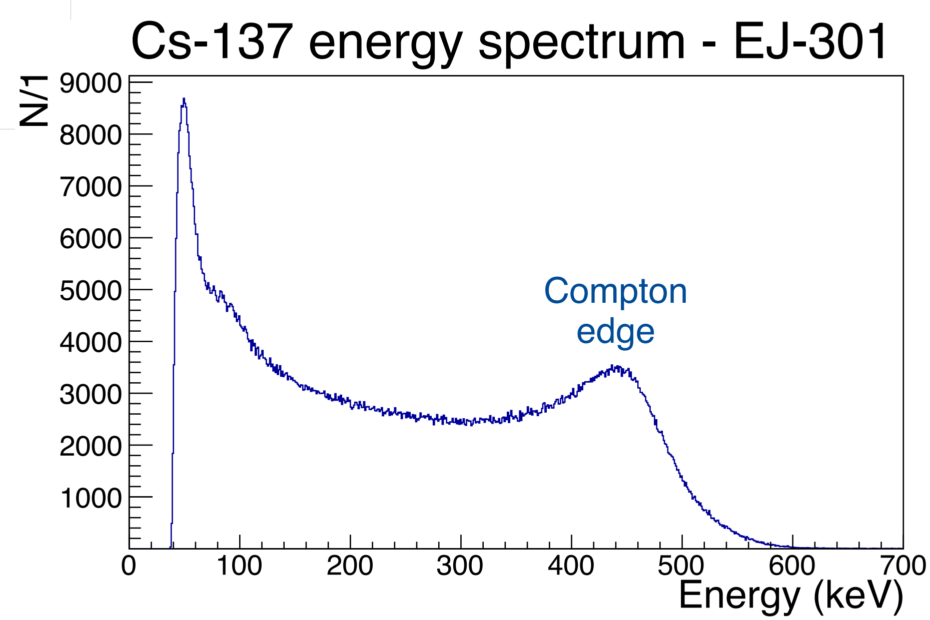
D-D neutron generator

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



Example: ^{137}Cs spectrum





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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/fluo true
/process/em/auger true
/process/em/pixe true

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