Cryogenic Dark Matter Search

experiment status and future:
CDMS II to SuperCDMS

Tobias Bruch
RWTH-Aachen
for the CDMS Collaboration

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The CDMS Collaboration

Brown University
M.Attisha, R.Gaitskell, J.P.Thompson

Caltech
Z. Ahmed, S.Golwala

Case Western Reserve University
D.S. Akerib, C.N. Bailey, D.R. Grant,
R. Hennings-Yeomans,
M.R. Dragowsky, R.W.Schnee

Fermi National Accelerator Laboratory
D.A. Bauer, M.B. Crisler, D. Holmgren,
E.Ramberg, J.Yoo

MIT
E. Figueroa

RWTH Aachen
S. Arrenberg, L.Baudis , T.Bruch,
M.Tarka

Santa Clara University
B.A. Young

Stanford University
P.L. Brink, B.Cabrera, J.Cooley-Sekula,
W.Ogburn, M. Pyle, S. Yellin

University of California, Berekley
M. Daal, J. Filippini, N. Mirabolfathi,
B. Sadoulet, D. Seitz, B. Serfass, K. Sundqvist

University of California, Santa Barbara
R. Bunker, D. O. Caldwell, R. Mahapatra,
H. Nelson, J. Sander

University of Colorado at Denver
M. E. Huber

University of Florida
T. Saab, J. Stoerbeck

University of Minnesota
P. Cushman, L. Duong, X. Qiu,
A. Reisetter

Outline

Some WIMP direct detection physics

Introducing the experiment

Analysis chain

CDMS II to SuperCDMS

Physics potential of CDMS II and SuperCDMS

Recoil spectra of WIMP-nucleus scattering

$$\frac{dR_{(v_E, v_{esc})}}{dE_R} = \frac{R_0}{E_0 \cdot r} \cdot f(v_{0,} v_E, v_{esc}, E_{0,} r) \cdot F^2(q \cdot r_n)$$

$$R_0 = \frac{2}{\sqrt{\pi}} \cdot \frac{N_0}{A} \cdot \frac{\rho_{WIMP}}{m_{WIMP}} \cdot \sigma_0 \cdot v_0 \qquad E_0 = \frac{1}{2} \cdot m_{WIMP} \cdot v_0^2 \qquad r = \frac{4 \cdot M_T \cdot m_{WIMP}}{(m_{WIMP} + M_T)^2}$$

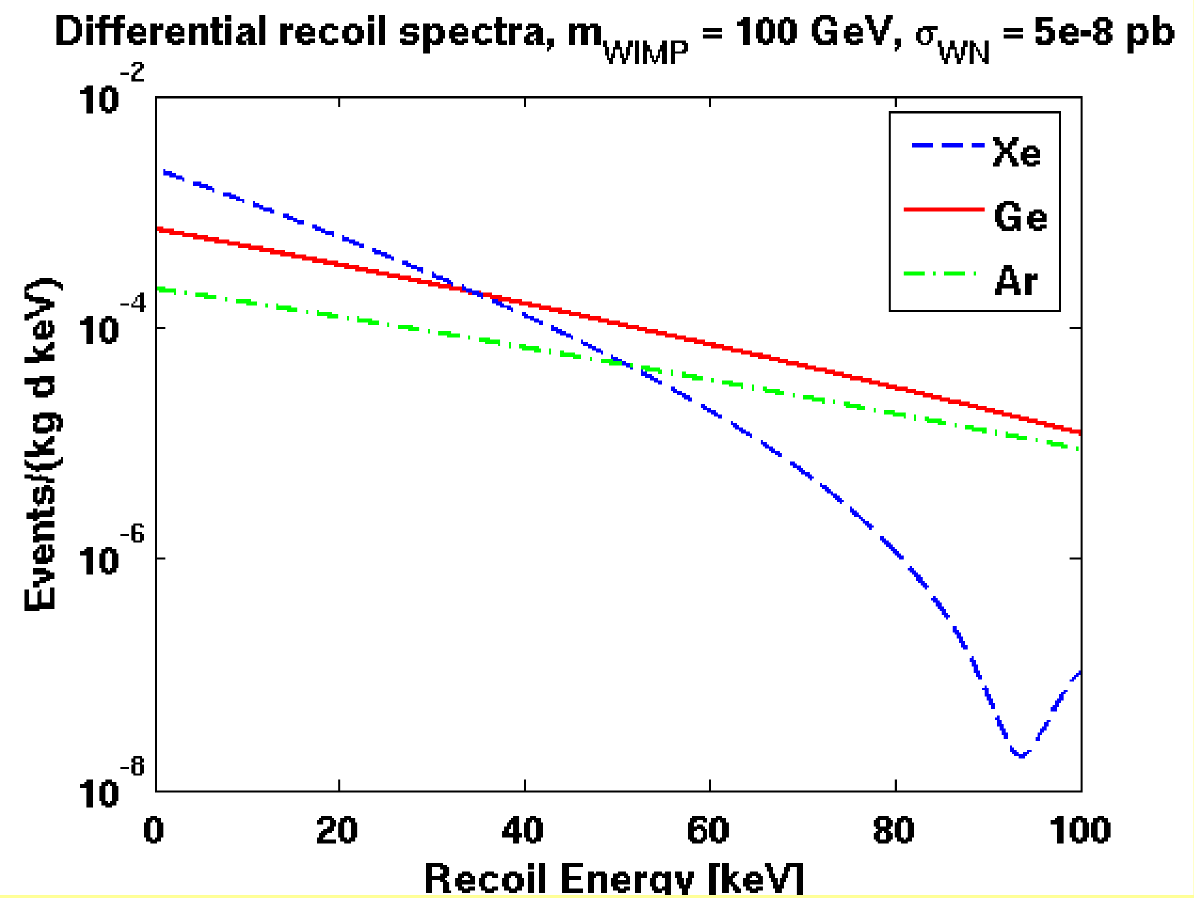
v_0 : mean velocity of WIMPs ~ 220 km/s

v_{esc} : escape velocity of WIMPs ~ 544 km/s

v_E : earth velocity ~ 232 km/s

ρ_{WIMP} : local WIMP density ~ 0.3 GeV/cm^3

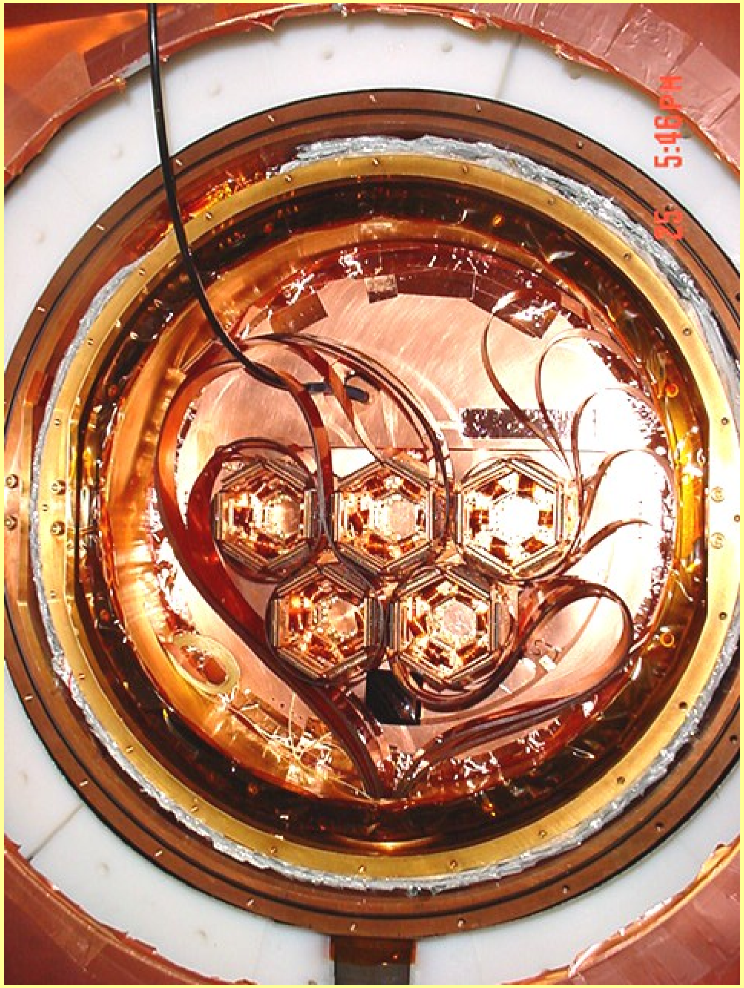
σ_0 : WIMP-nucleus scattering crossection, scales with A^2 (SI)



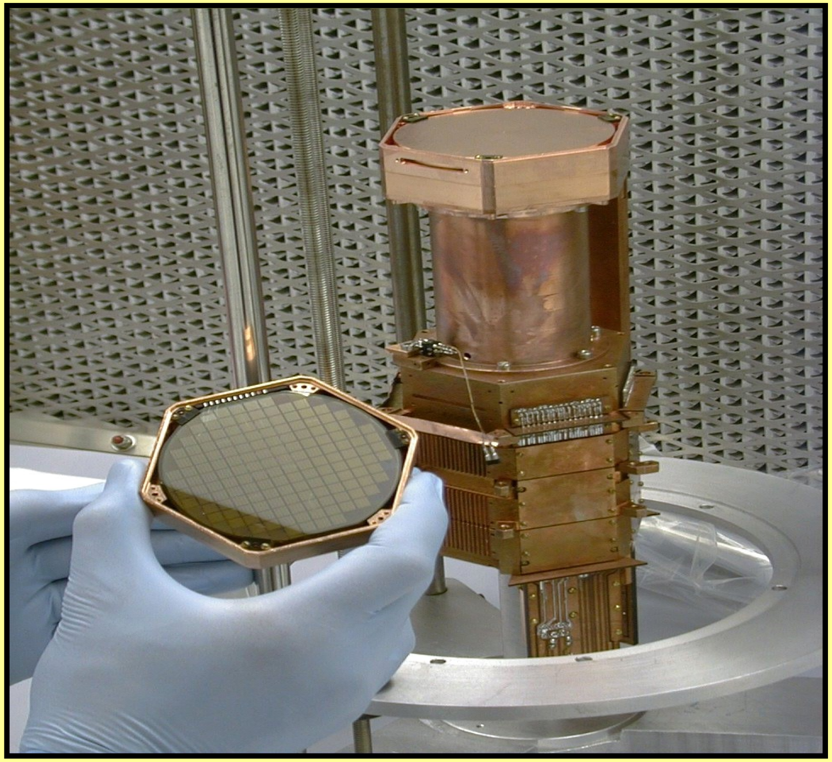
CDMS detectors

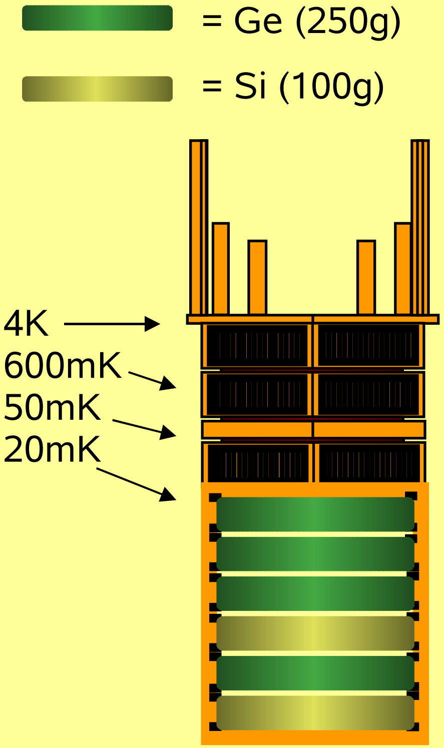
CDMS uses semiconductor (Ge; Si) detectors which measure the ionization and phonon signal of a recoil. These two signals provide an event by event discrimination between background (mainly gammas) and nuclear recoils (expected WIMP signal).

CDMS detectors are operated at cryogenic temperatures (~ 20 mK).

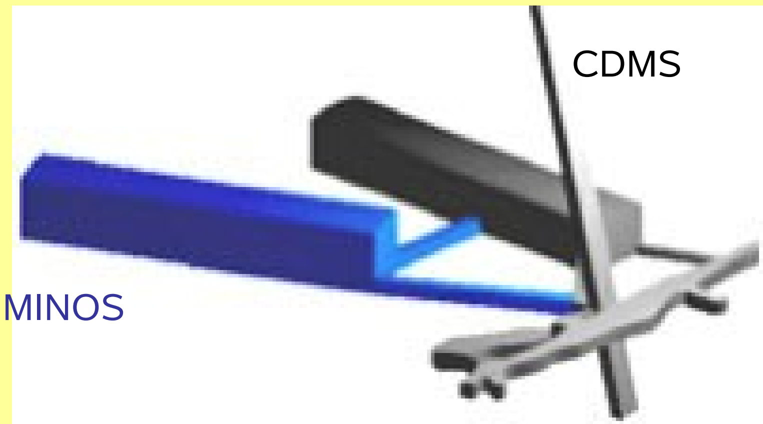


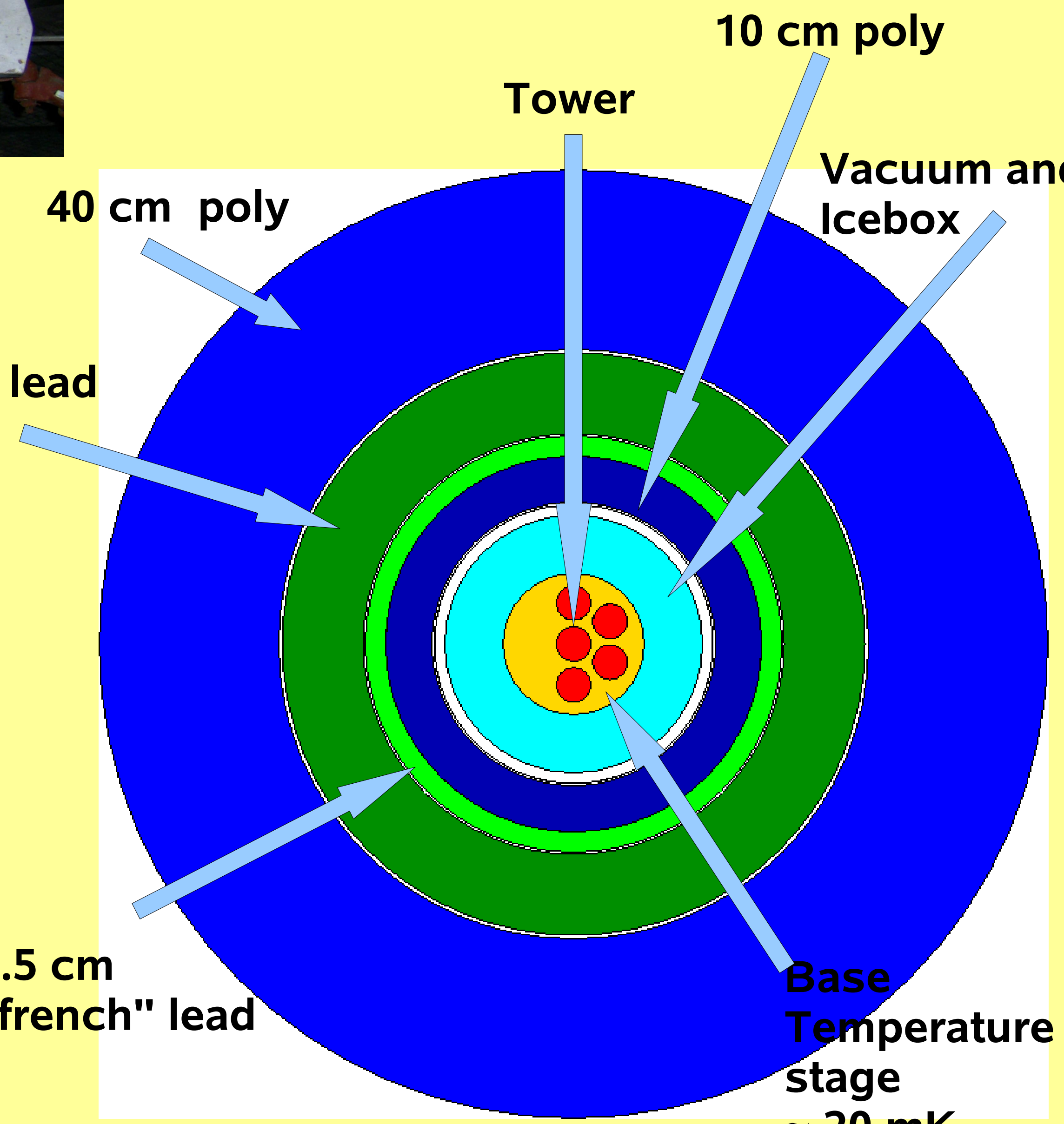
CDMS II now runs 5 towers (each containing 6 1 cm thick detectors).





Shielding of the detectors at Soudan





Experimental setup is surrouded by a scintillator veto.

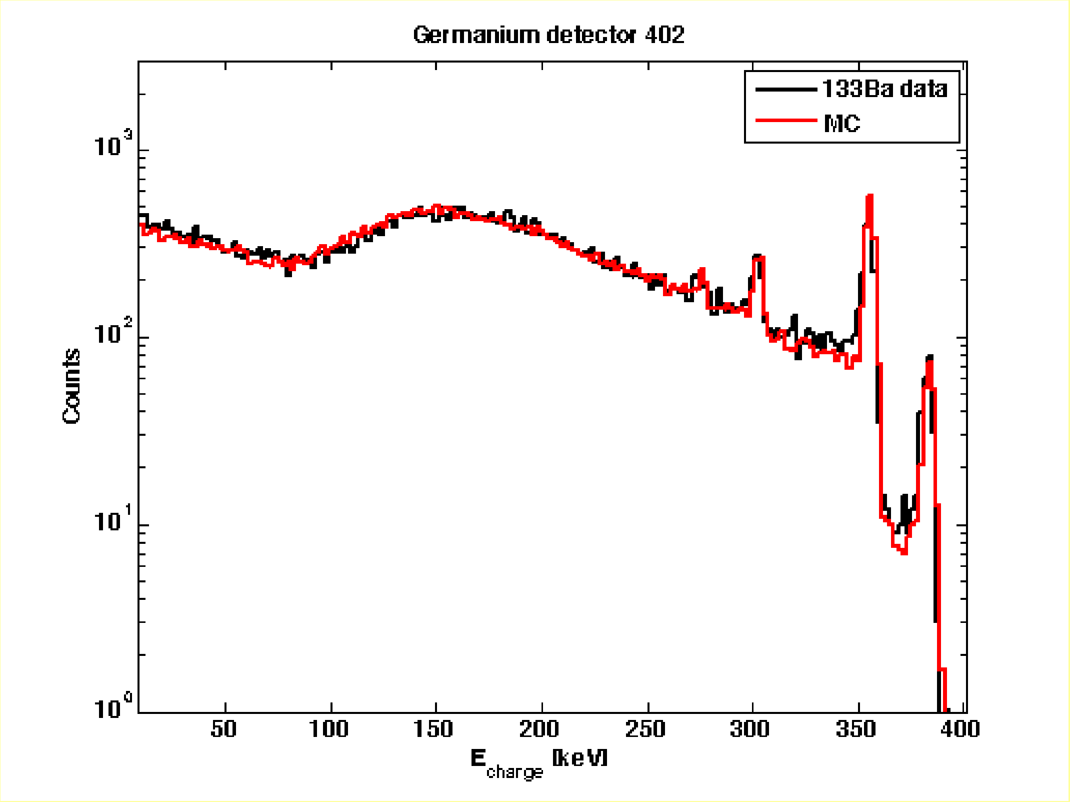
Total unvetoed myon induced and natural radioactivity neutron flux :
0.05 /kg/y .

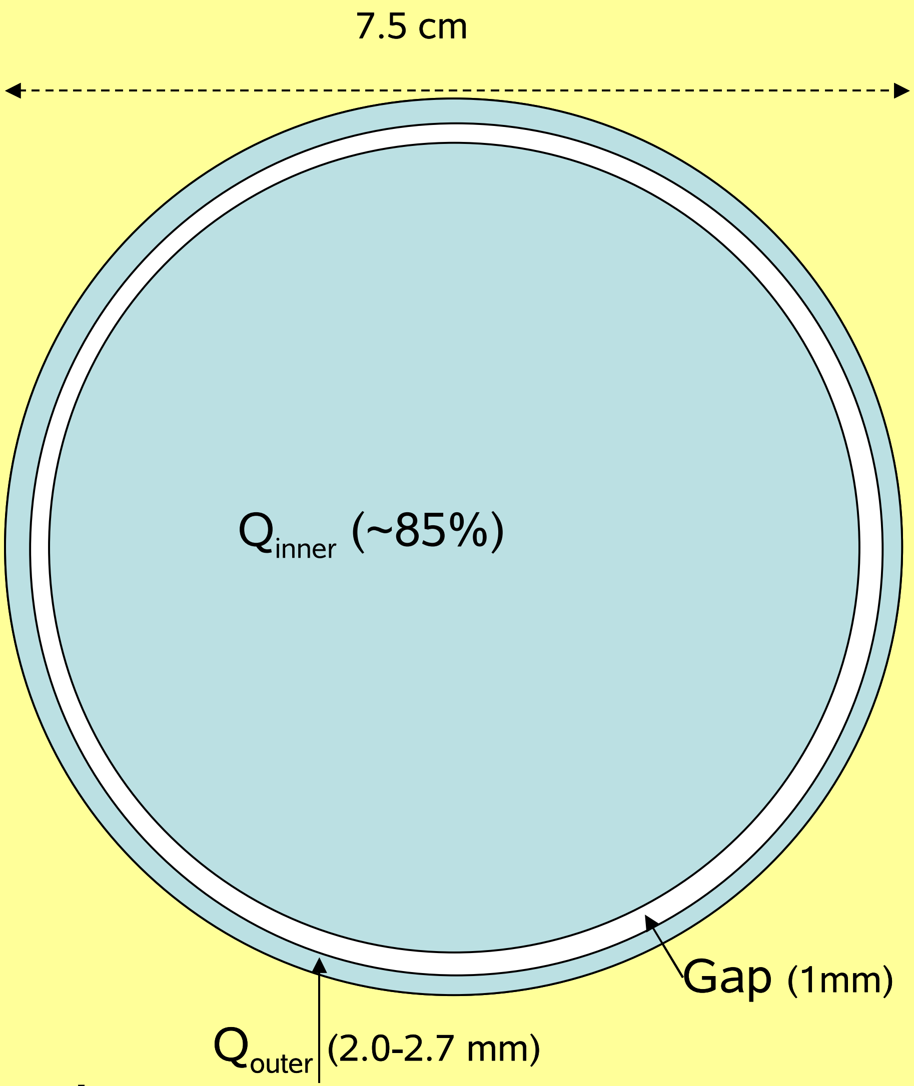
Current and future runs at Soudan are **not** limited by the neutron background.

Ionization measurement

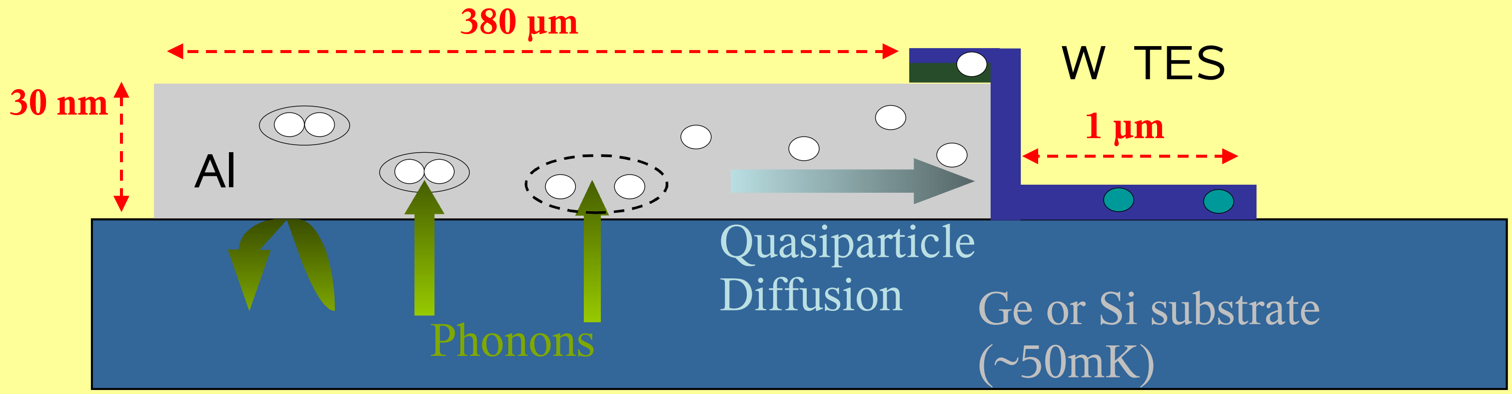
Since interactions at the crystal edges can have an incomplete charge collection, the outer electrode acts as a guard ring.

Events with a significant signal on Q_{outer} are rejected in the analysis.





Calorimetry using phonons



Phonons break Cooper-Pairs in superconducting Al film.

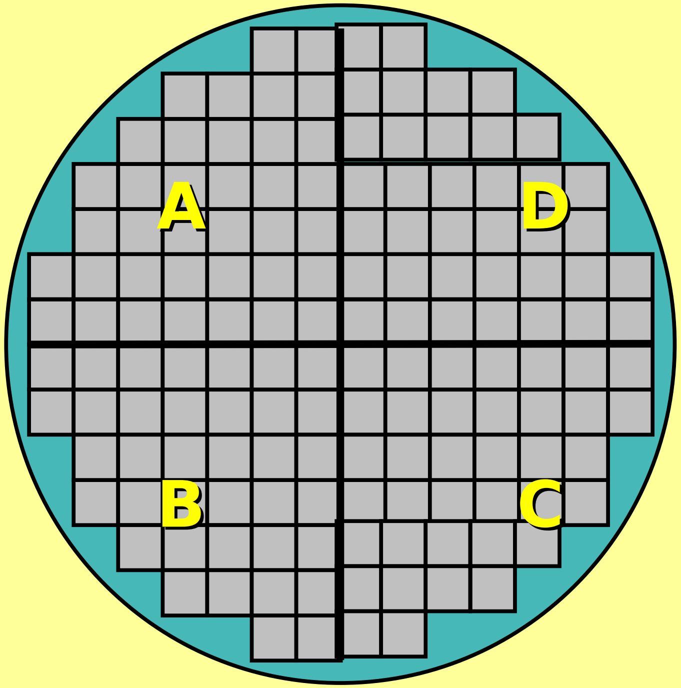
Quasiparticles (e⁻) diffuse to the W TES, and deposit their energy → Temperature rises.

W TES is voltage - biased on superconducting – normal transition;

Rising temperature → higher resistance → lower current;

Measure Phonon pulse as a change in current with DC SQUID readout.

4 quadrants per detector.



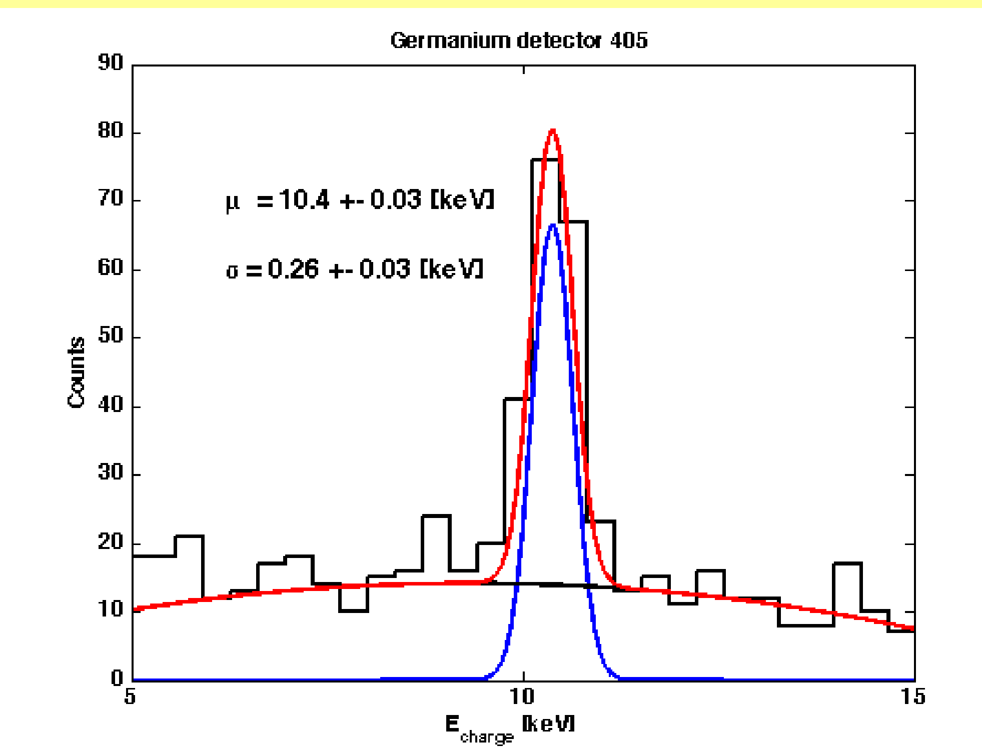
Energy calibration for low energetic recoils

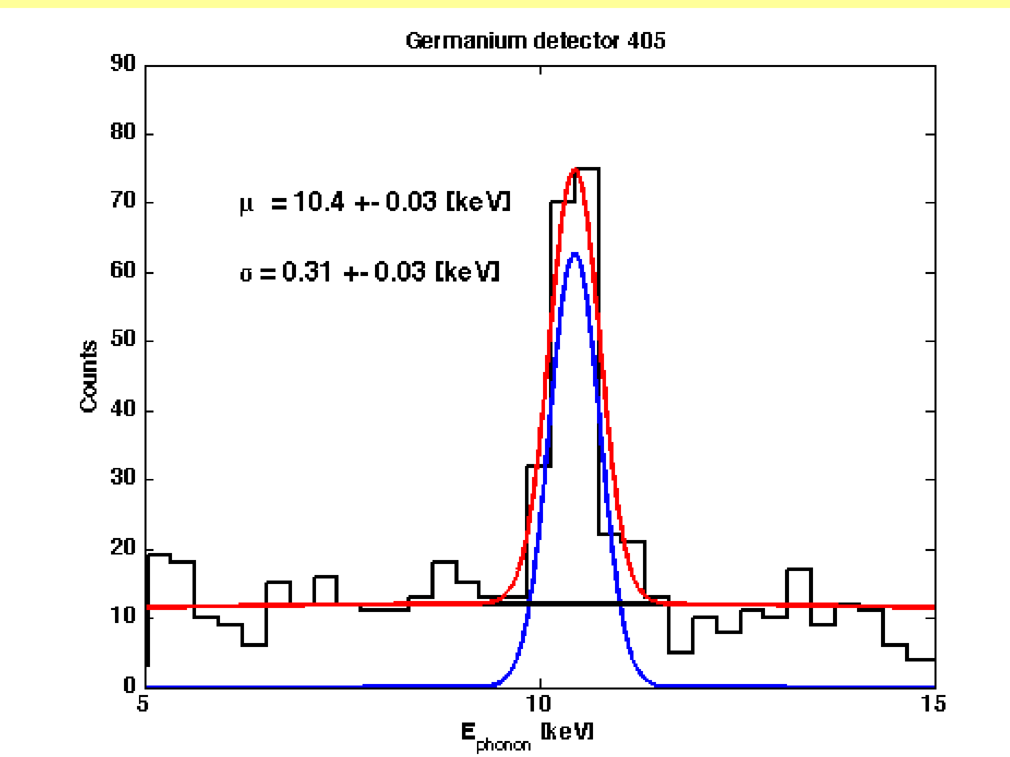
We are using the 10.4 keV line of the neutron activated Ge isotope:

$$^{70}\mathrm{Ge} + n \rightarrow {}^{71}\mathrm{Ge} \rightarrow {}^{71}\mathrm{Ga} + \gamma(10.36\,keV),\ \tau_{1/2} = 11.4\,days$$

to determine the energy resolution of the charge and phonon channel for low energetic recoils.

In both channels we achieve an energy resoultion of: ~3 %





Signal and background interactions

Suppressed ionization signal for nuclear recoils.

True recoil energy of an event:

$$E_{phonon}$$

Yield defined as:

$$y=\frac{E_{charge}}{E_{phonon}}$$

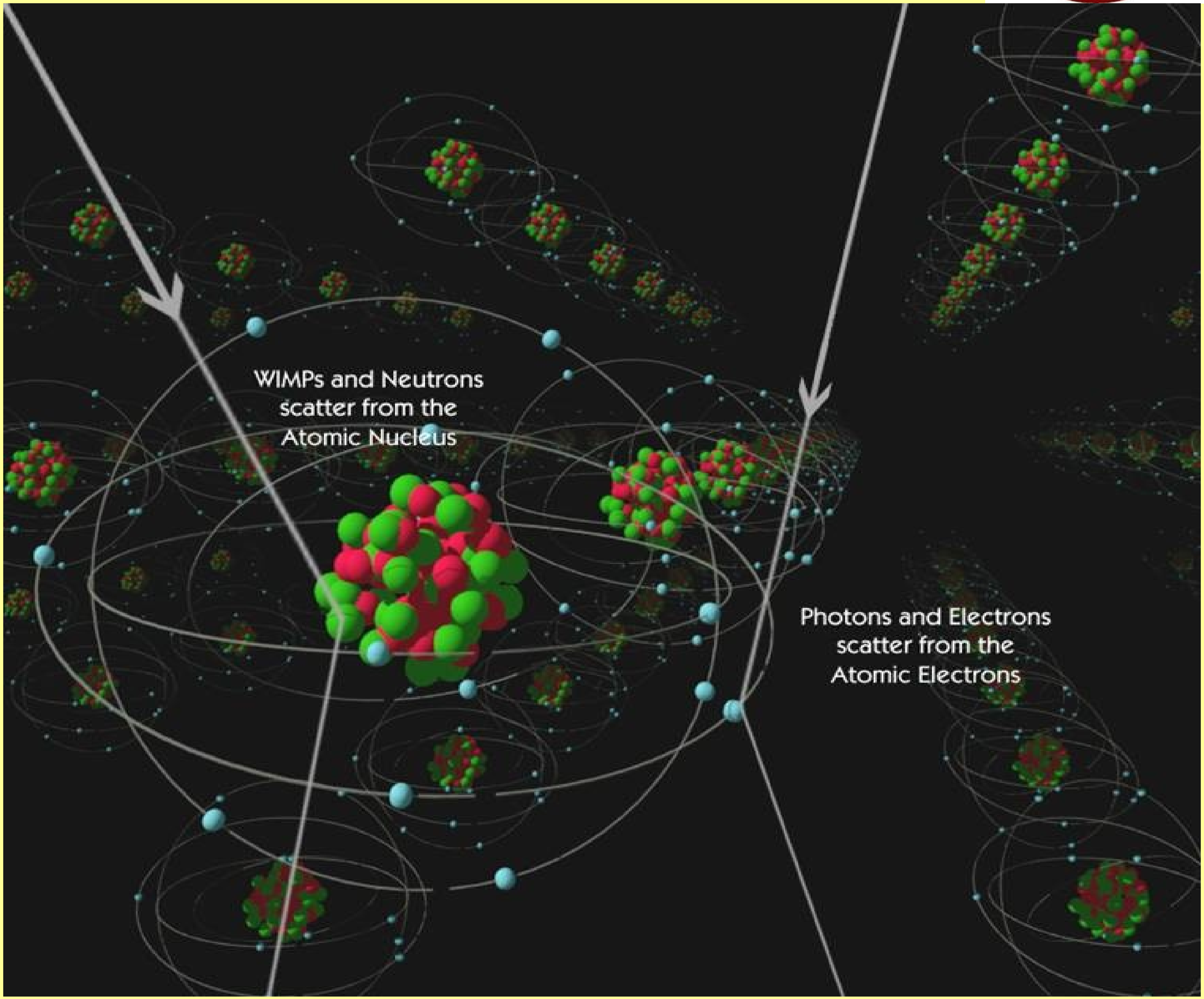
Electron recoil:

$$y=1$$

Nuclear recoil:

$$y\approx 1/3$$

Yield is our main discrimination quantity.



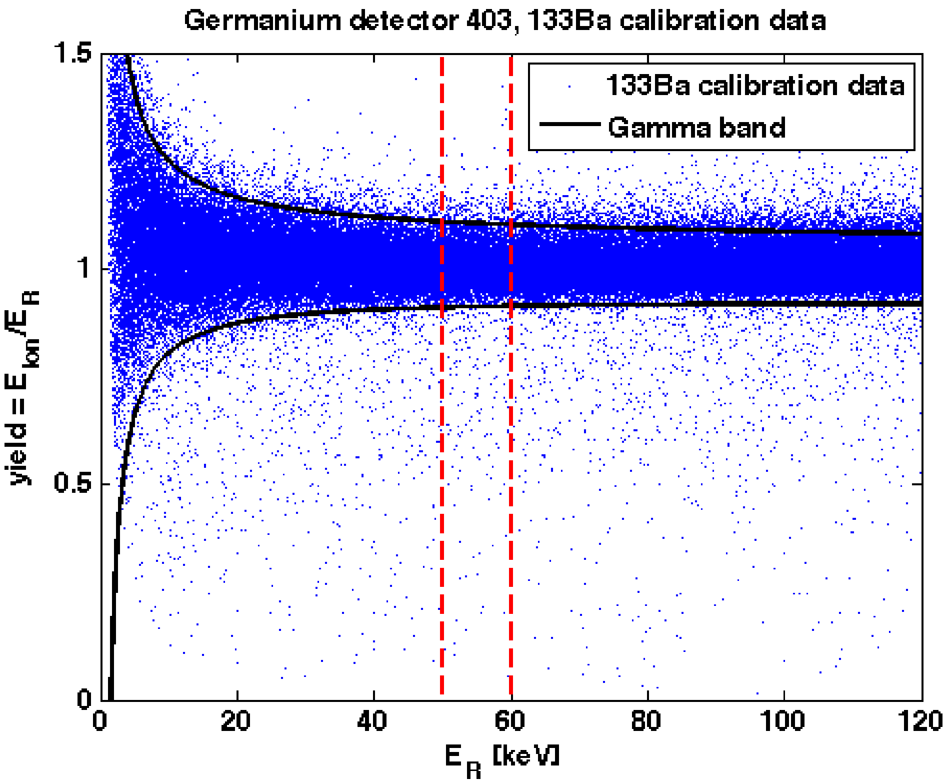
thanks to M. Attisha

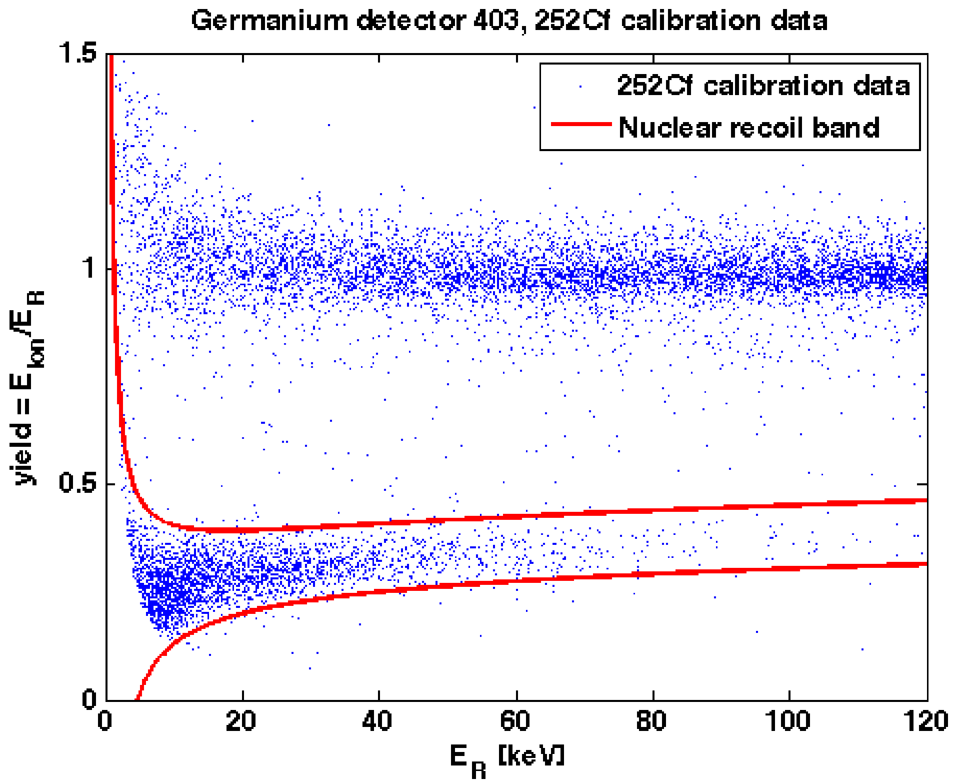
Primary discrimination through yield

Ionization yield bands: functional form fitted to 133Ba and 252Cf calibration data is based on Lindhard model.

Bands are constructed by a gaussian fit in several energy bins.

Cut at 2 sigma of the nuclear recoil band defines our signal region.



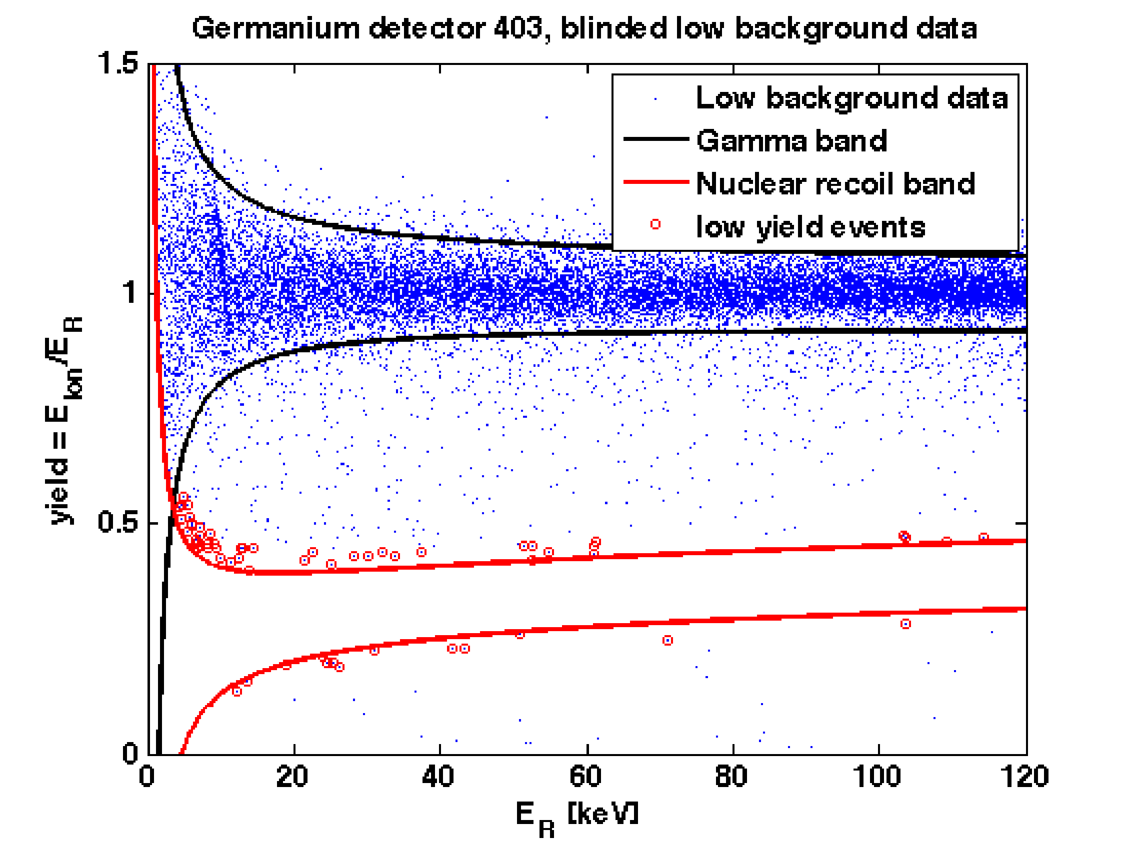


First look at blinded low background WIMP-Search data

The analysis of the WIMP search data is performed „blind“ (there are no events in the Signal region during the analysis). This ensures a non biased definition of selection cuts.

Since surface events suffer from back – diffusion of the charge carriers, they do have an incomplete charge collection.

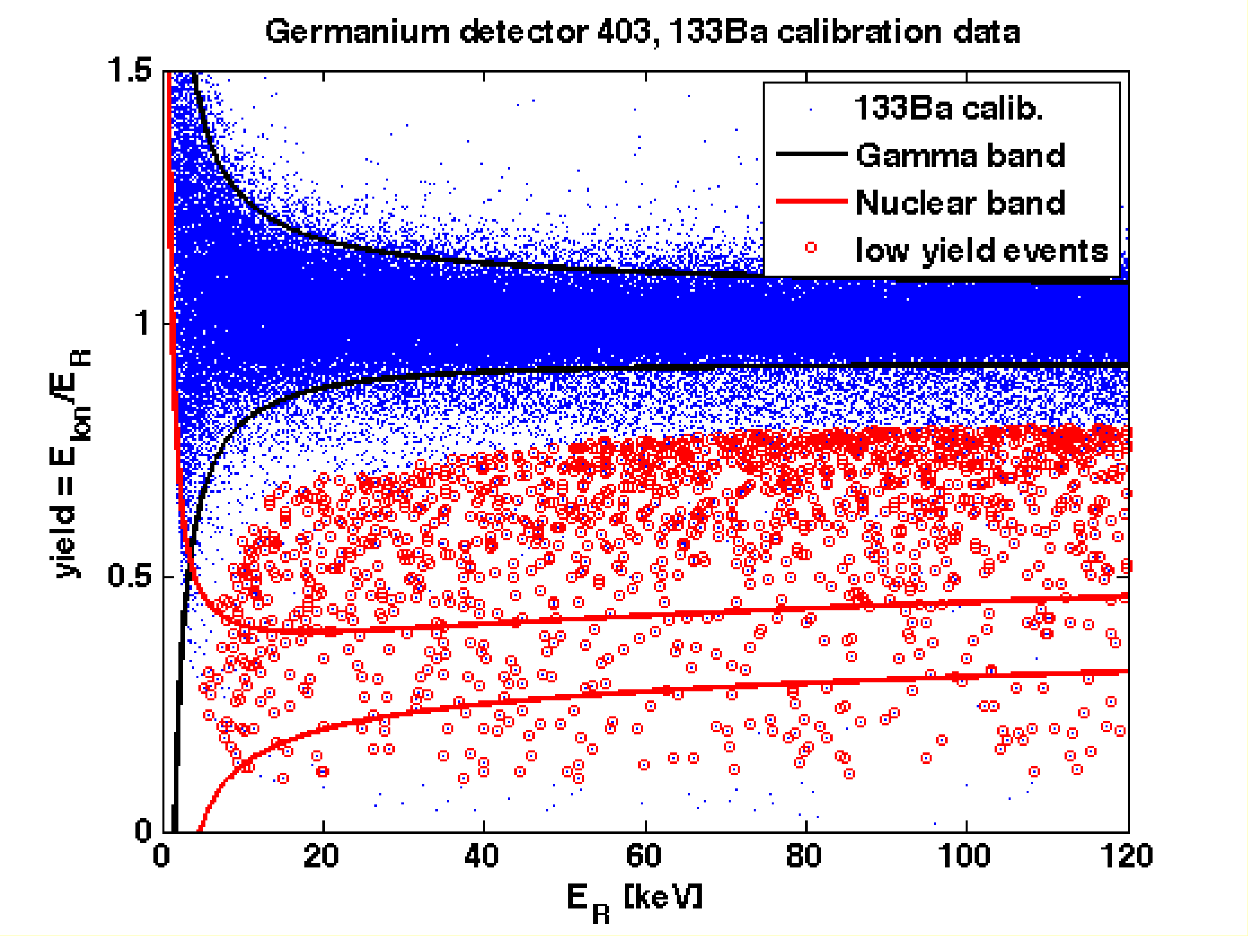
Incomplete charge collection lowers the yield discriminator of these events. They leak into the signal region, and mimic nuclear recoils.



Low yield events are our main and most dangerous background.

Discrimination of these events is achieved by using timing information of the phonon signals.

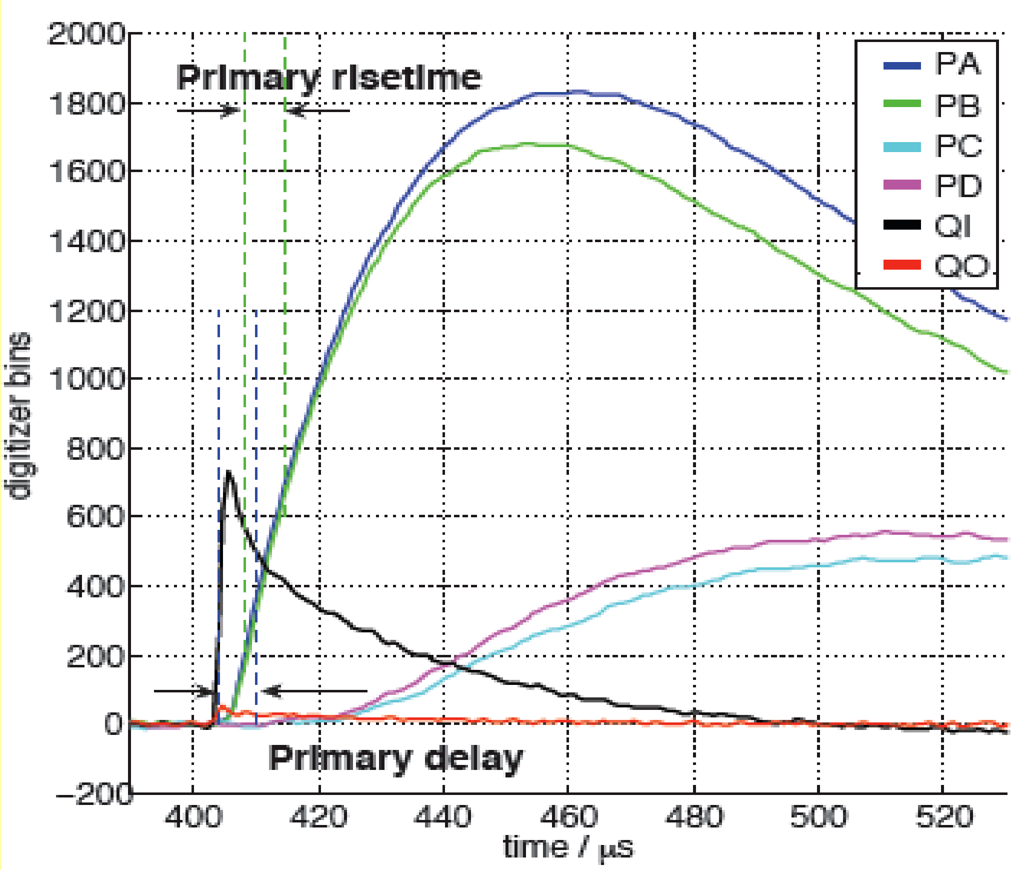
Being more conservative



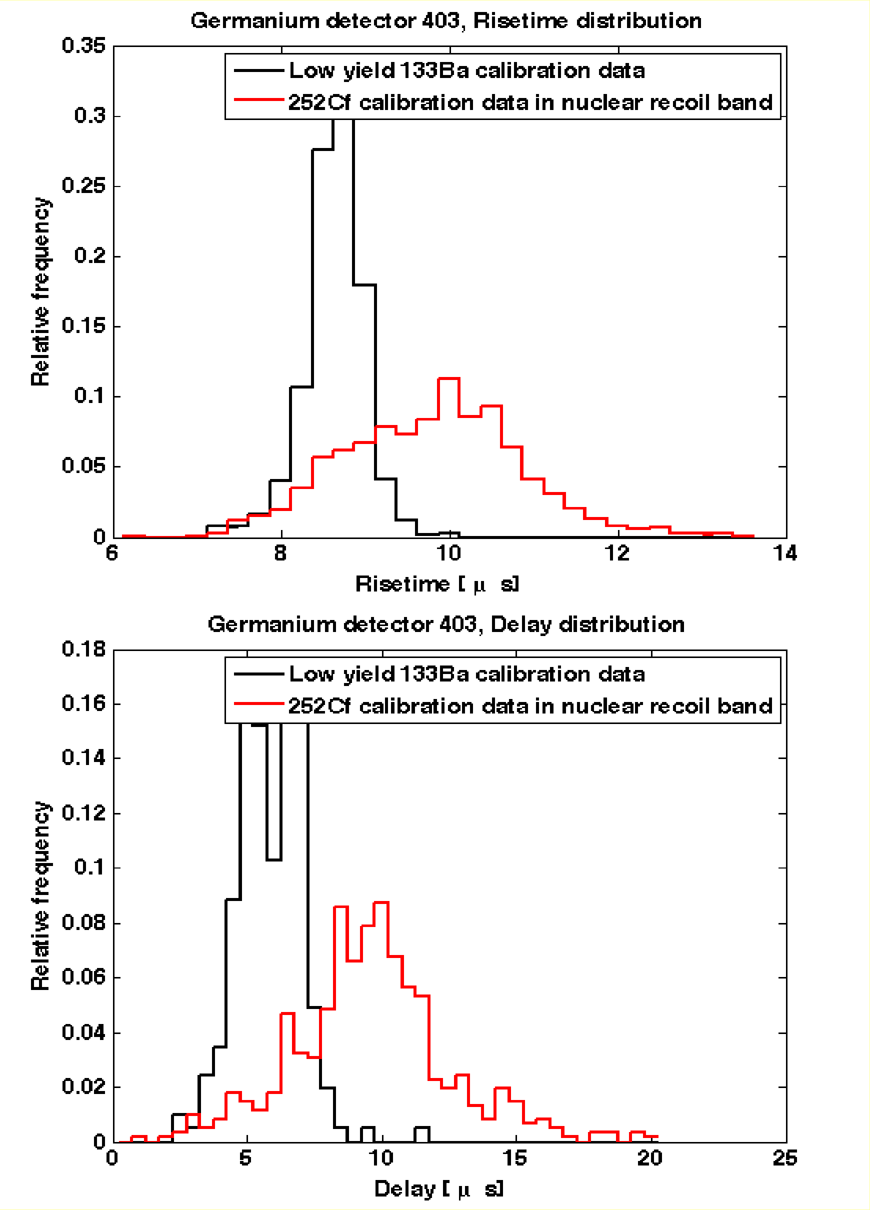
Definition of timing cuts is done on low yield Ba data and Cf data in the 2σ nuclear recoil band.

To gain more statistics and spread in the timing parameters distributions, we do not only select events which are close to the nuclear recoil band in the definition of the timing cuts.

Using more information to select nuclear recoils



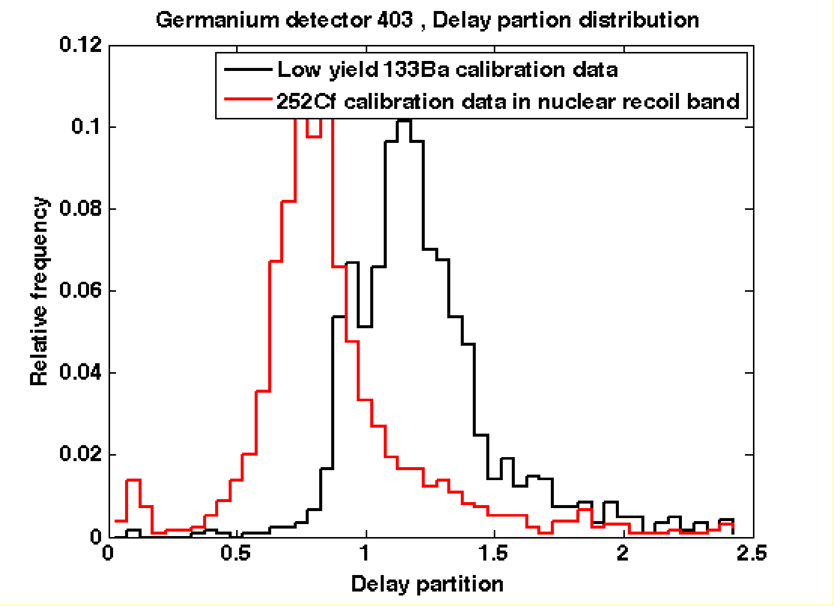
thanks to J. Filippini



Surface events are faster in timing than bulk nuclear recoils.

Timing is a powerful discriminator, used to get rid of low yield events, providing a **background free** signal region.

Additional timing parameters and surface event discrimination

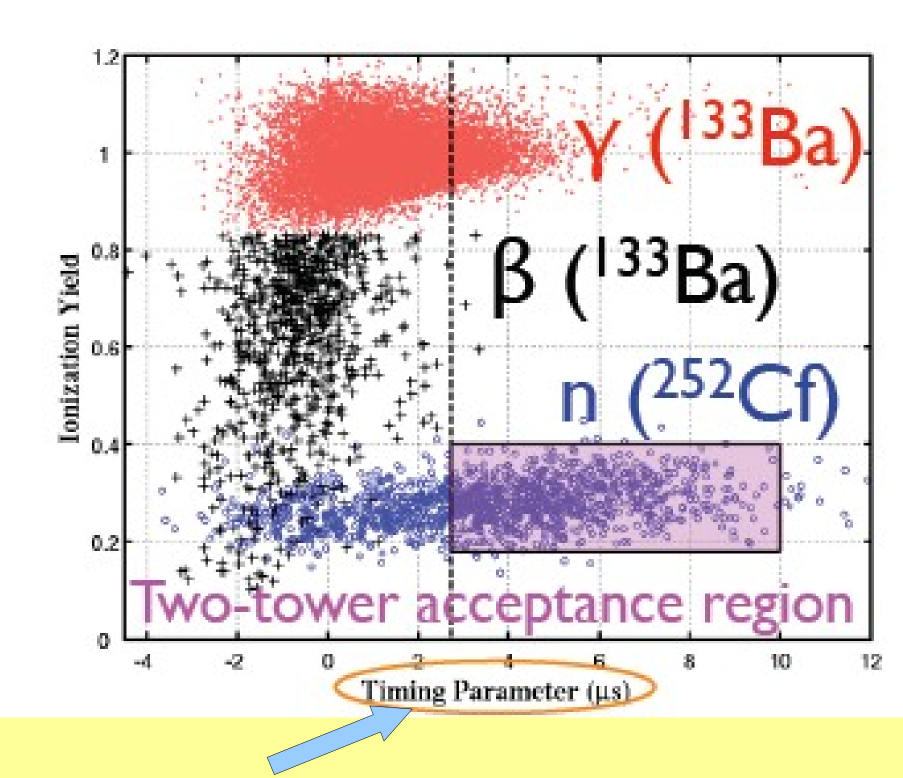


4 parameter is the ratio of the phonon amplitudes in the leading and opposing quadrant.

Parameters have not been used in past analysis (Run 118 + Run 119).

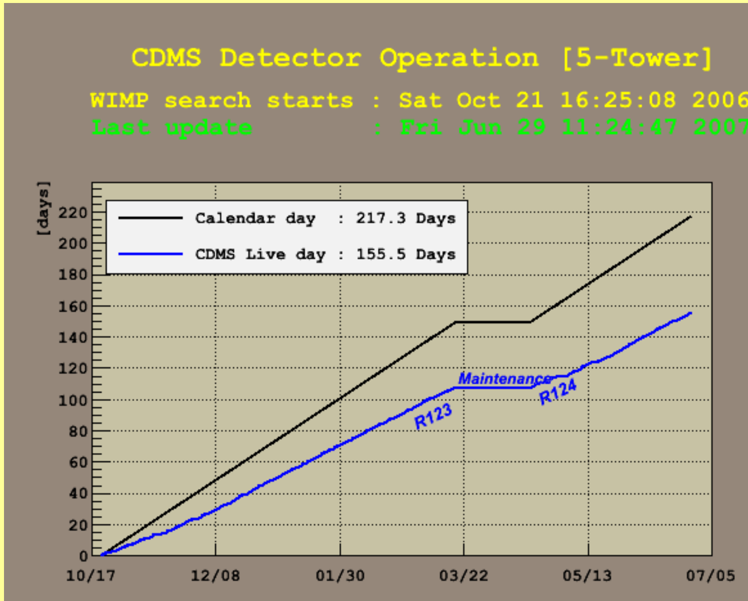
Discrimination capability will be evaluated in the Run c89 analysis (combined dataset of Run118 and Run119), which will be done soon.

Timing cut used in the Run 119 analysis.



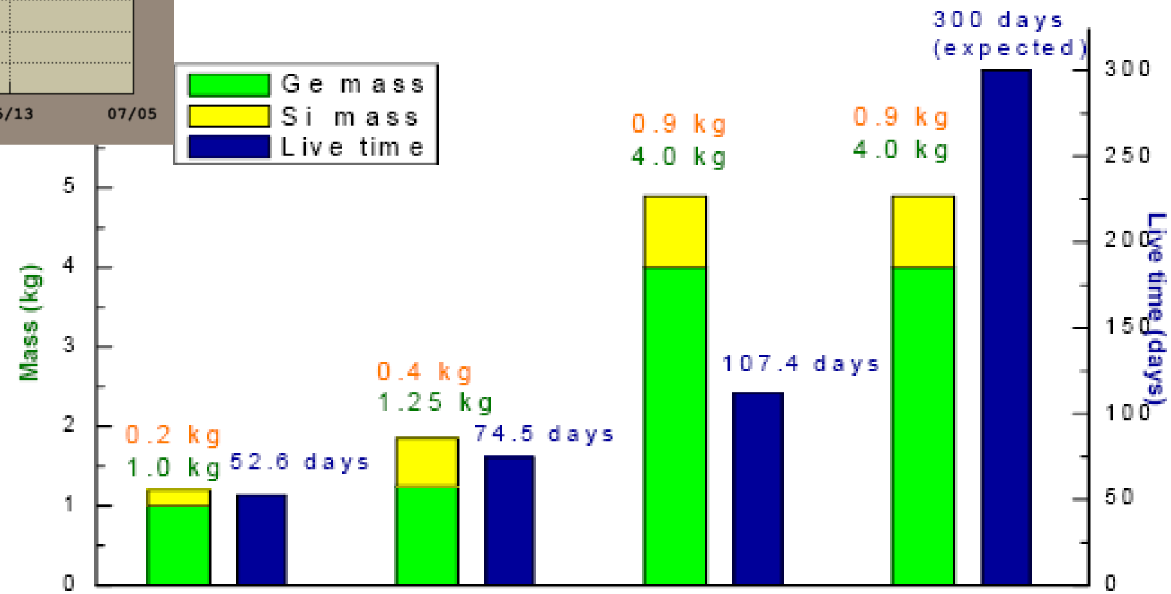
Linear combination of risetime and delay:
A.Reisetter, PRL 96, 011302 (2006).

Status and plans for current setup at Soudan



Stable running for Run123 ended in March after 107.4 Live days.

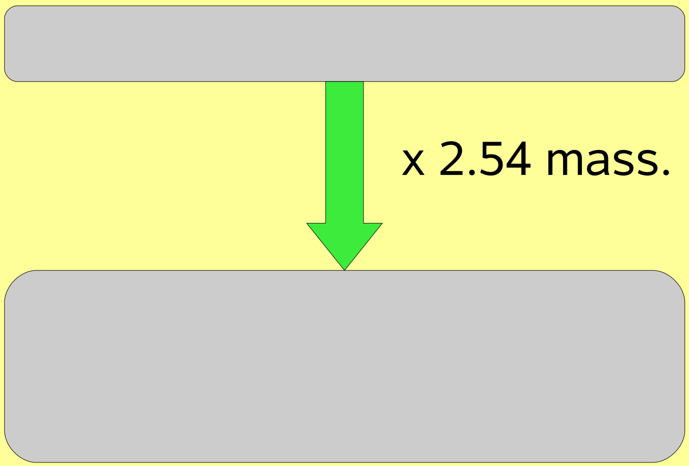
After short maintenance period, cooldown for Run124. Stable running and data aqusition since May.



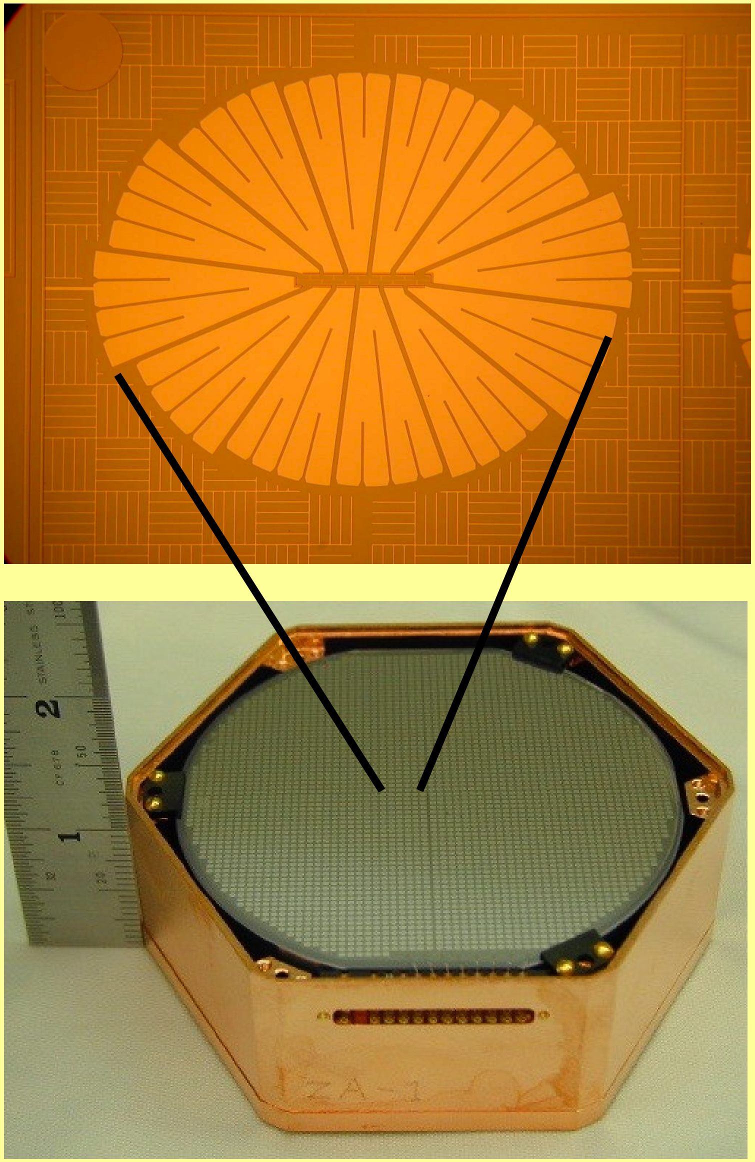
SuperCDMS at Soudan

New 1 inch thick ZIP detectors with an improved phonon readout.

ZIP used in the CDMS II setup.



ZIPs used in the first phase of SuperCDMS.



Improvement in phonon readout by new geometry of TESs, which maximizes the active Al coverage.

First results show an improved yield discriminator for 1 inch detectors.

Installation of the first two SuperTowers at Soudan at the end of 2008.

SuperCDMS at SNO-LAB

SuperCDMS will be split in four phases, with an increased mass at each phase reaching for a ton scale experiment.

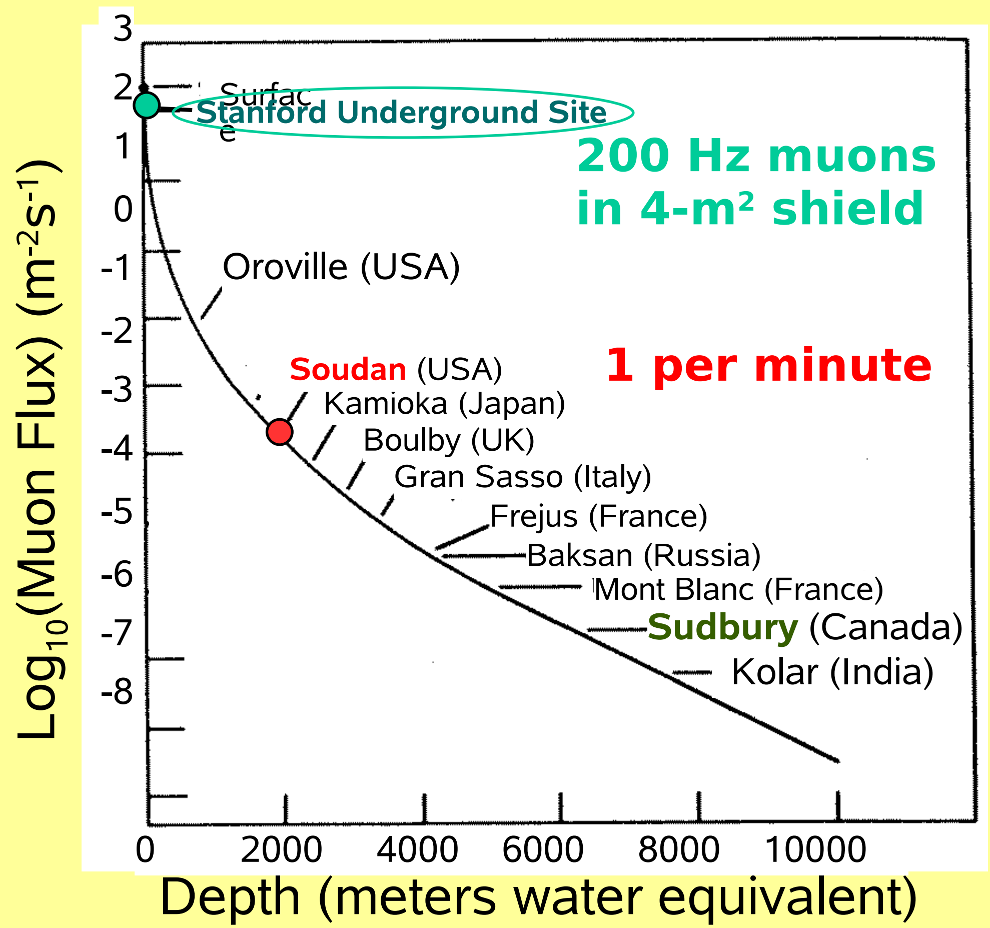
Phase A :

Operation of 7 SuperTowers with a total mass of 25kg at SNO-LAB.

Retaining zero background for SuperCDMS:

Background rejection	×4
Analysis discrimination	×2
Background reduction	×5
Total Improvement	**= ×40**
Production rate per kg	×5

Table 2: Targeted improvement factors over CDMS II advanced analysis levels (see Section 3.2) to achieve SuperCDMS 25 kg sensitivities with zero background from internal sources. The cosmogenic fast-neutron background is eliminated by the SNO-LAB overburden of 6000 mwe.



Muon induced neutron flux negligible at SNO - LAB.

Current and projected sensitivity

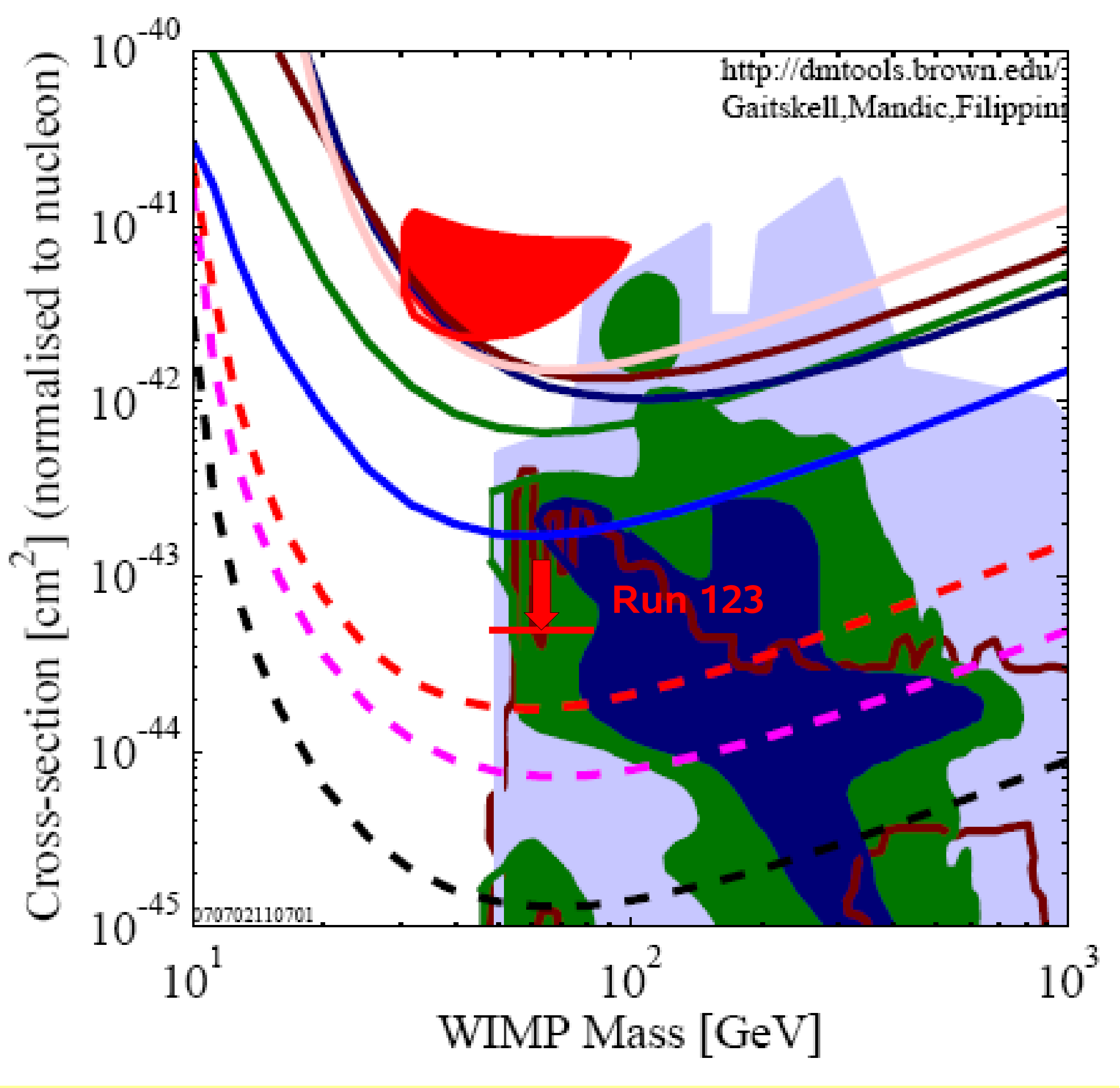
In the Run 118 and Run 119 analysis no valid candidate events were obseverd, hence an upper limit could be set on the WIMP - nucleon scattering cross-section.

CDMS combined (2004+2005) 90% CL (SI) limit:
σ = 1.6 e-43 cm² @ 60 GeV

CDMS II 5 Towers at Soudan projected sensitivity (2008).

CDMS II 2 SuperTowers at Soudan projected sensitivity (start 2009).

CDMS 25kg at SNO-LAB projected sensitivity.



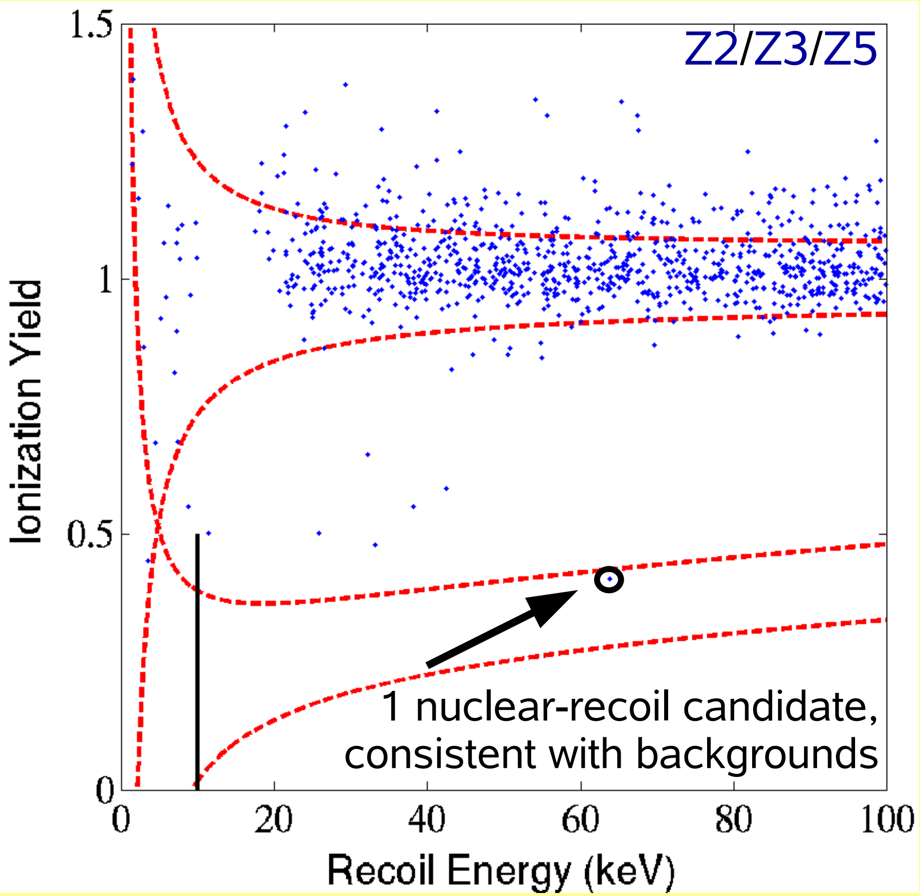
Analysis of the first 5-Tower exposure (Run123) in progress.

New analysis parameters and discriminants promise a **background-free** operation for current runs → **maximal discovery potential**.

Backup Slides

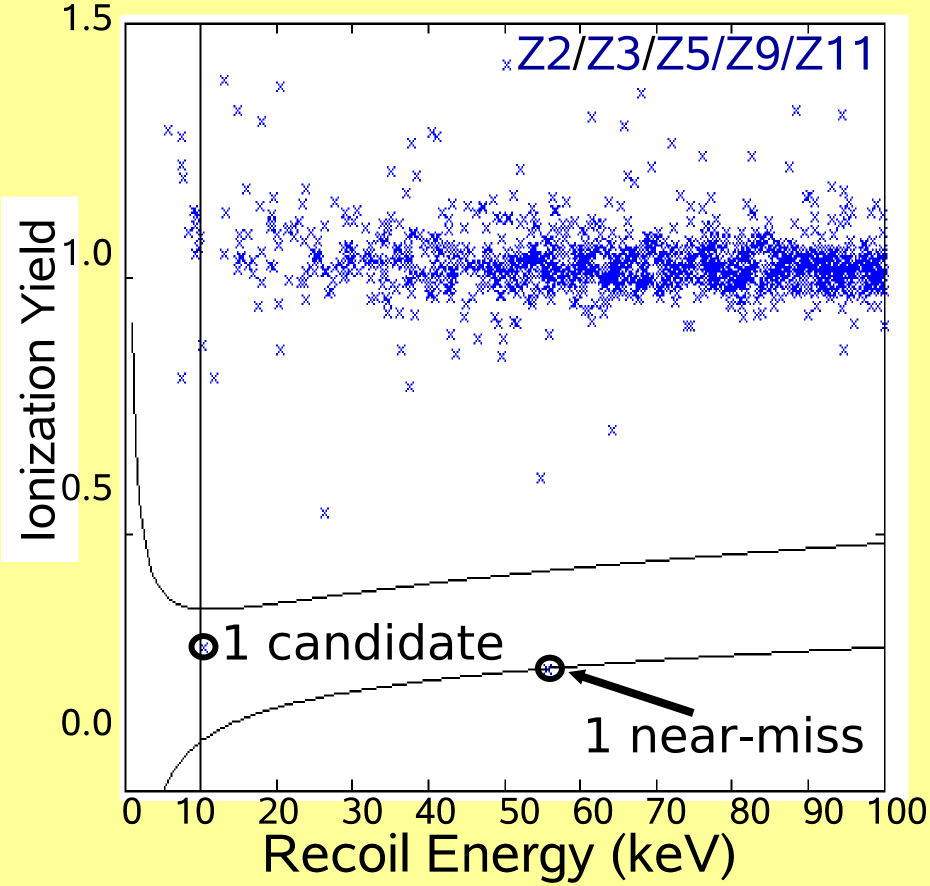
Results from Run 118 and Run 119

Run 118 WIMP-Search data after timing cuts, which reject most of electron recoils.



Phys. Rev. Lett. 93, 211301 (2004)

Run 119 WIMP-Search data after timing cuts, which reject most of electron recoils.



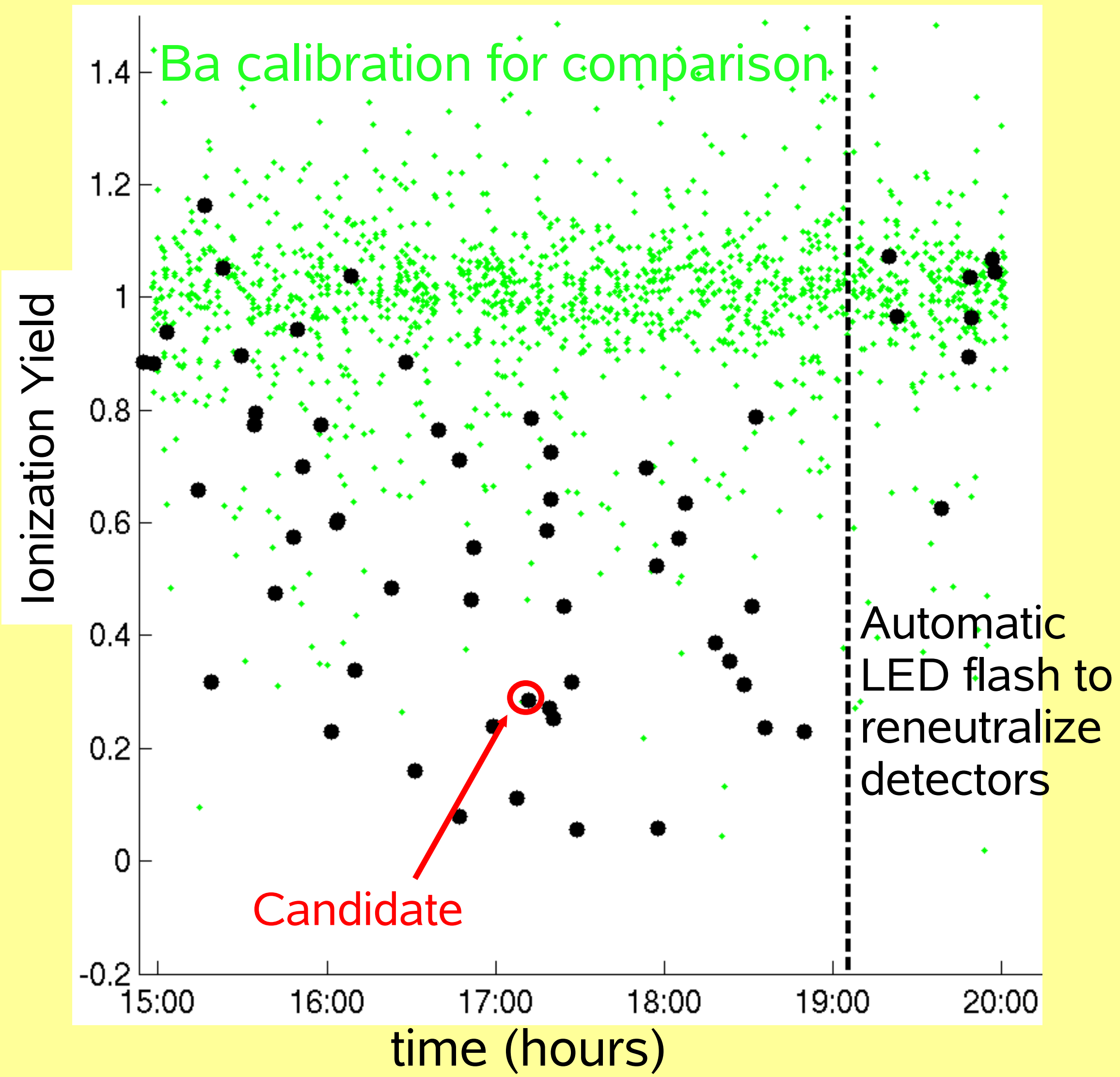
Phys. Rev. Lett. 96, 011302 (2005)

Candidate event in Run 119 WIMP-Search data

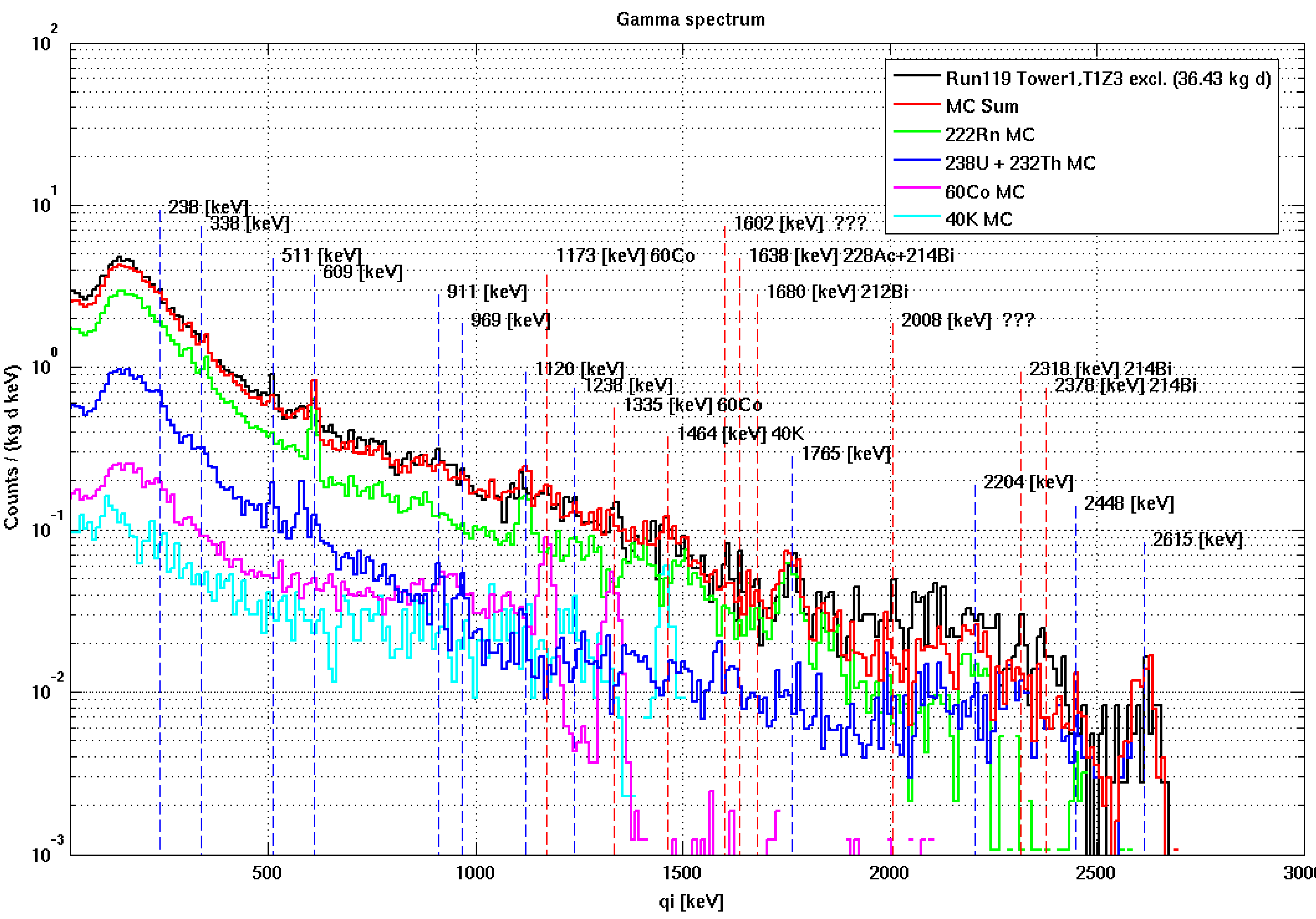
Data set containing the candidate event was taken immediately after extended exposure to strong 60Co source.

After many interactions, charge build up in crystal: **deneutralization**.

Ionization collection is suppressed until the crystal is **reneutralized** by LED flashing.

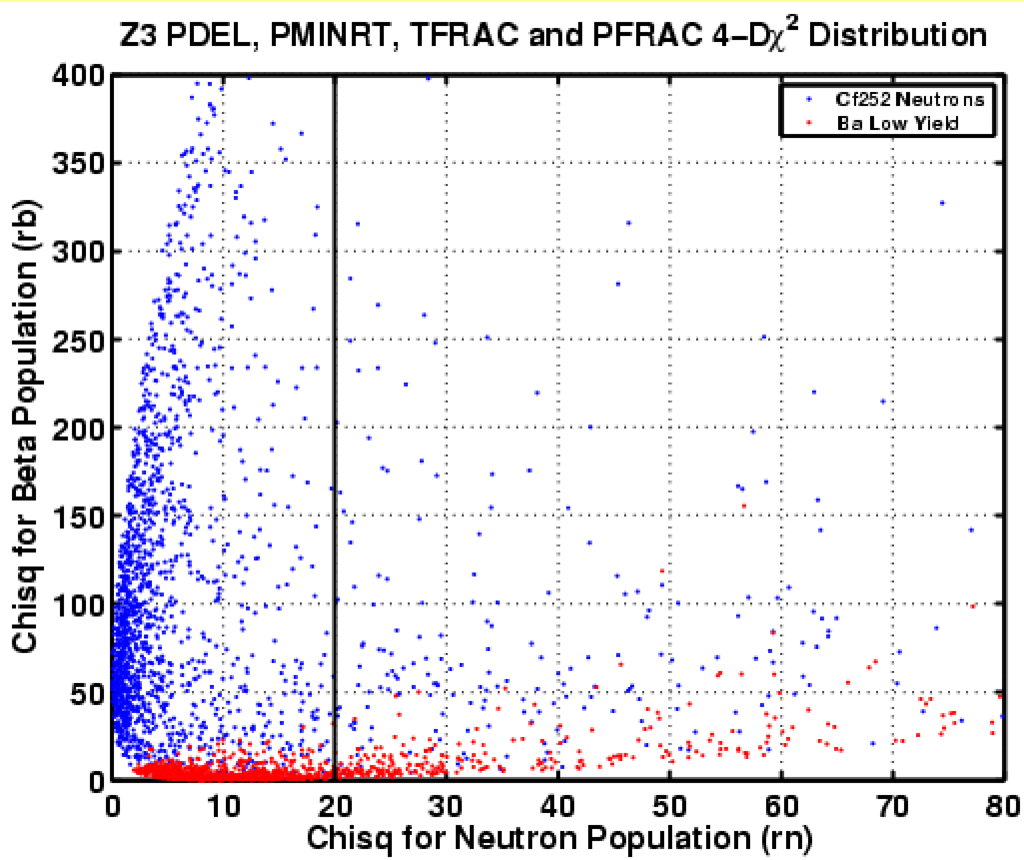


Understanding the origin of our Background

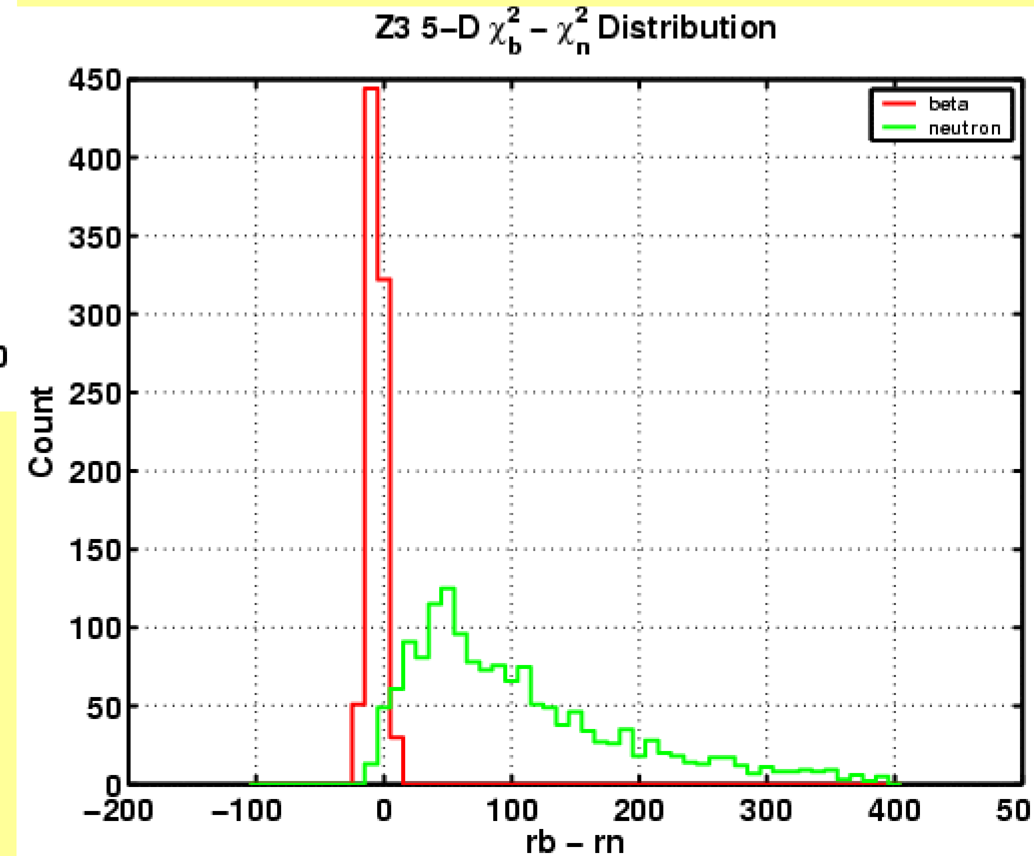


Natural radioactivity of our materials is causing our gamma background. MC simulations of known background sources matches the observed spectra very well.

χ^2 analysis of timing parameters



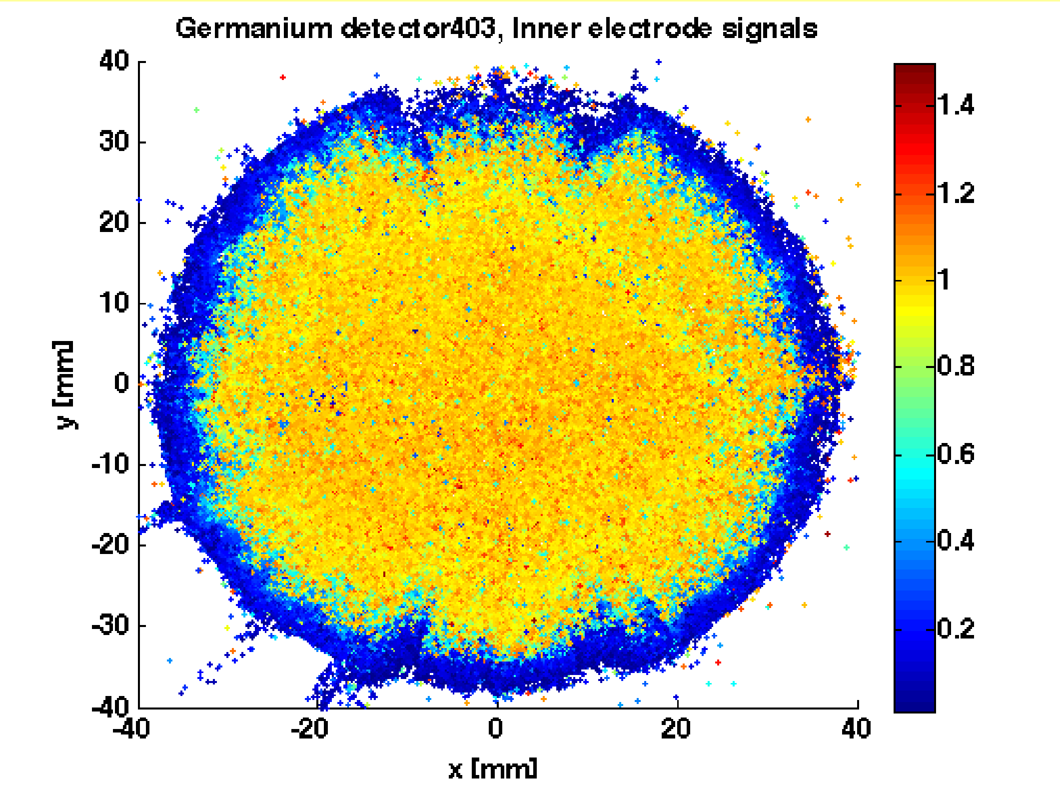
In a χ^2 analysis the distance of each event from the neutron distribution (rn) and beta distribution (rb) is determined.



Cut can be set to exlude all betas while maximizing the neutron acceptance.

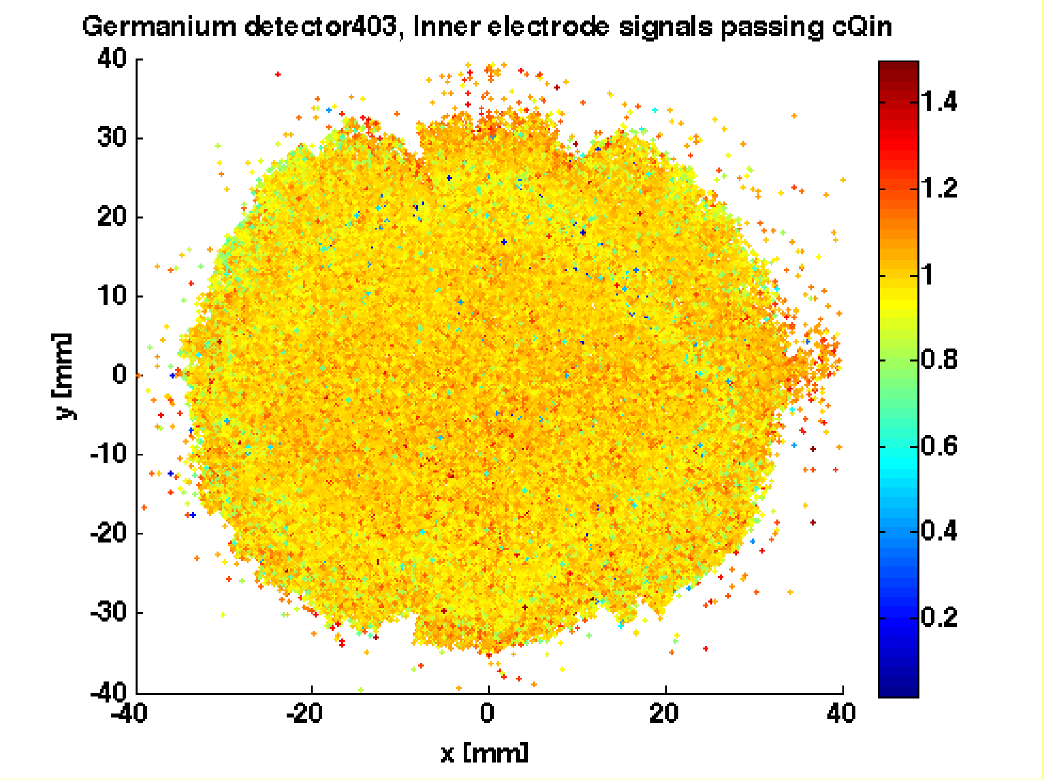
thanks to R. Mahapatra

Inner-electrode cut



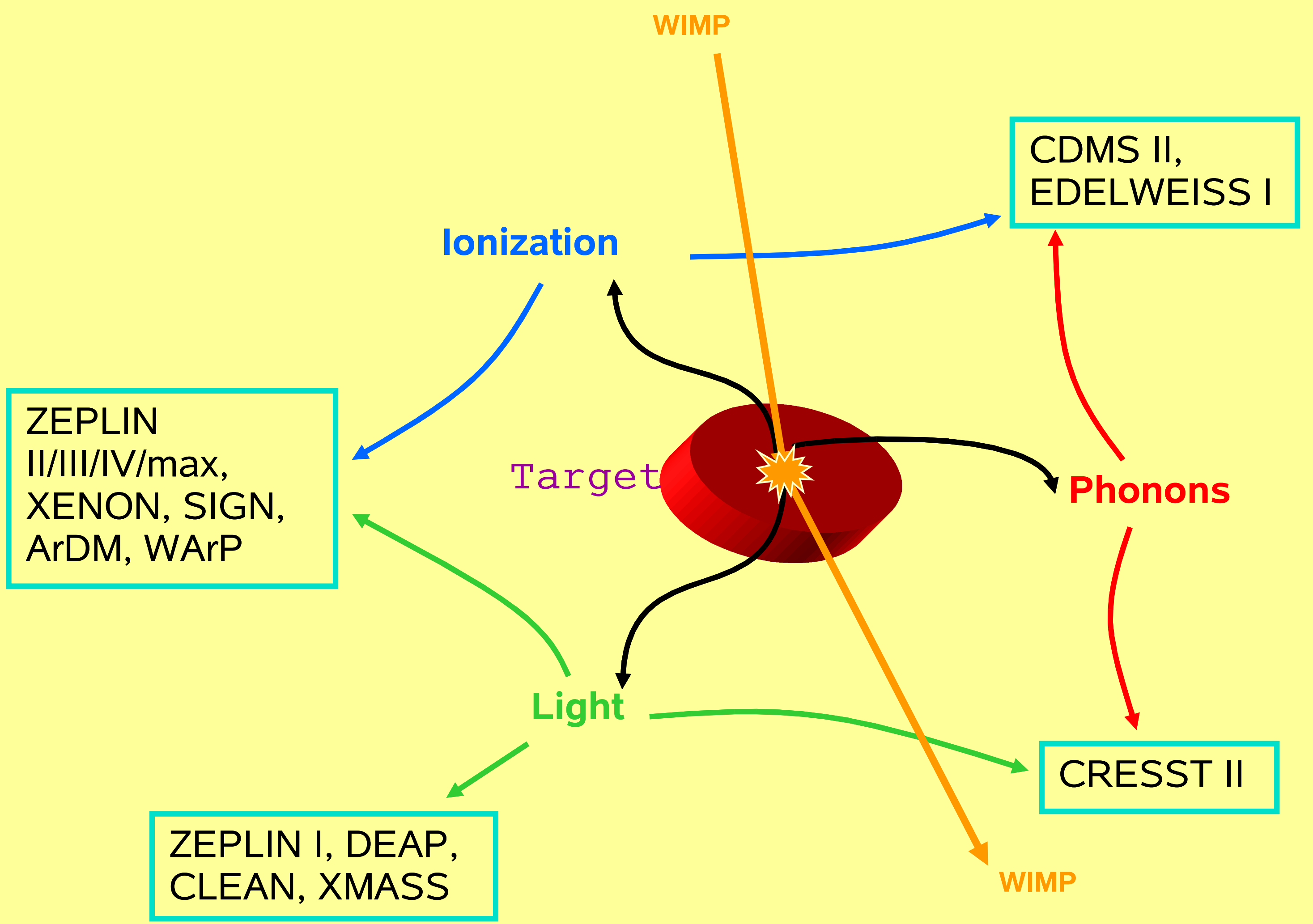
The outer electrode signals can be used to select events which are in the bulk region of our detectors.

Incomplete charge collection for events at the crystal edges, could mimic nuclear recoils.



Complete charge collection for the majority of bulk events.

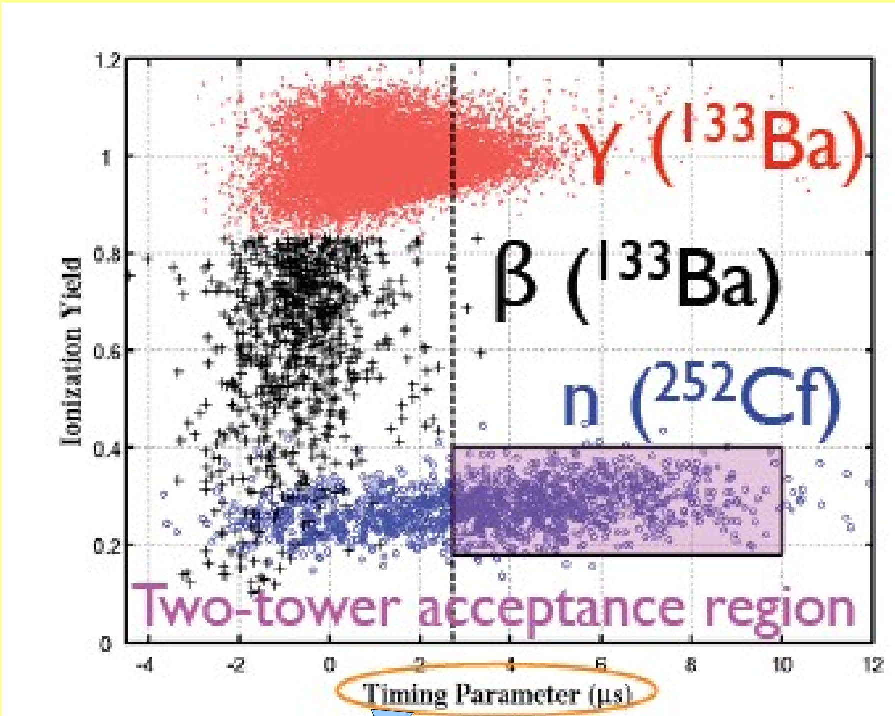
Detection and background rejection techniques



Several channels can be used to disriminate background from signal for low energetic recoils (~ < 100 keV).

Apart from background discrimination , the minimization of all possible background sources (natural radioactivity, cosmic rays ...) is necessary.

Using Phonon timing to discriminate surface events



Linear combination of risetime and delay: A.Reisetter, PRL 96, 011302 (2006).

χ^2 – Analyses:J.Filippini,R. Mahapatra, J. Sander

$$\chi^2_{\beta(n)} = (\vec{x}-\vec{\mu}_{\beta(n)})^T \cdot C^{-1}_{\beta(n)} \cdot (\vec{x}-\vec{\mu}_{\beta(n)})$$

3D (4D) space: risetime delay, phonon partition (delay partition).

Neural Networks: M.Attisha

Risetime, delay, phonon partition, wavelet components.

Train to distinguish nuclear recoils from surface events.

Likelihood Analyses: V.Mandic et al. NIM A 553 (2005)

Cut-free estimate of signal and background populations.

Position Reconstruction: R.W. Ogburn, G.Wang

Vary cut with position, tag surface events by face.