New Results from the CDMS-II experiment

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for the CDMS Collaboration
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Outline

Introducing the experiment

Detection principle

Low – yield events

EM backgrounds

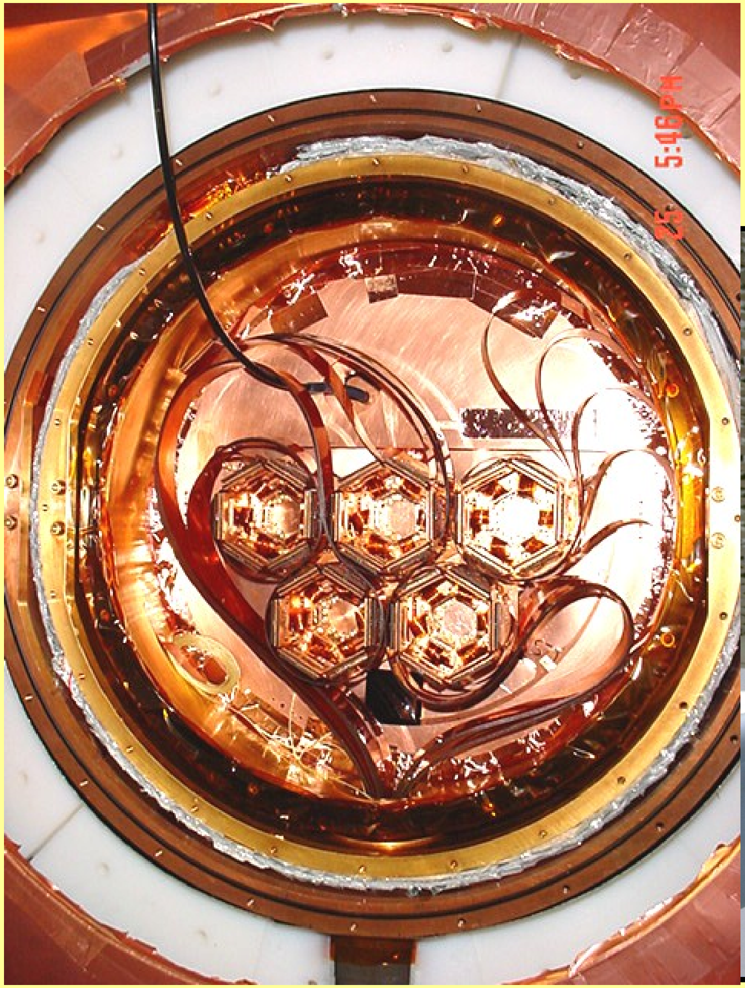
Physics potential of CDMS

Conclusions

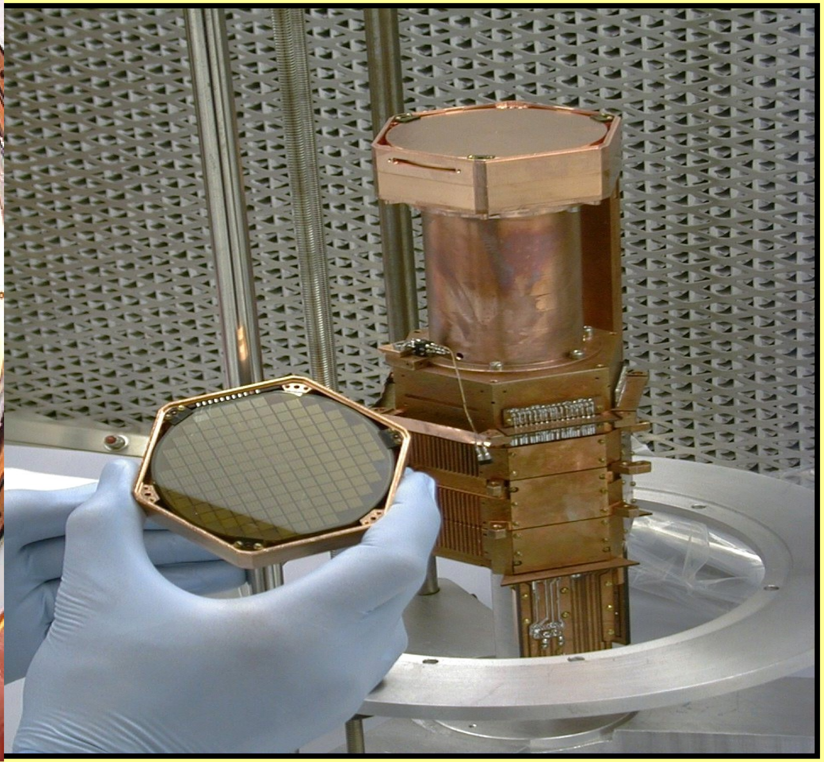
CDMS detectors

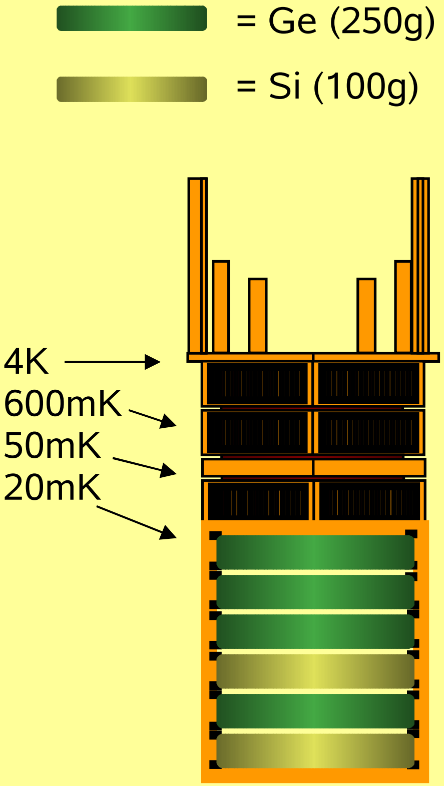
CDMS uses semiconductor (Ge; Si) detectors which measure the ionization and phonon signal of a recoil. These two signals provide an event by event discrimination between background (mainly gammas) and nuclear recoils (expected WIMP signal).

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



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





Ionization Signal

A drift field of -3V/cm (-4V/cm) is applied to the Ge (Si) detectors.

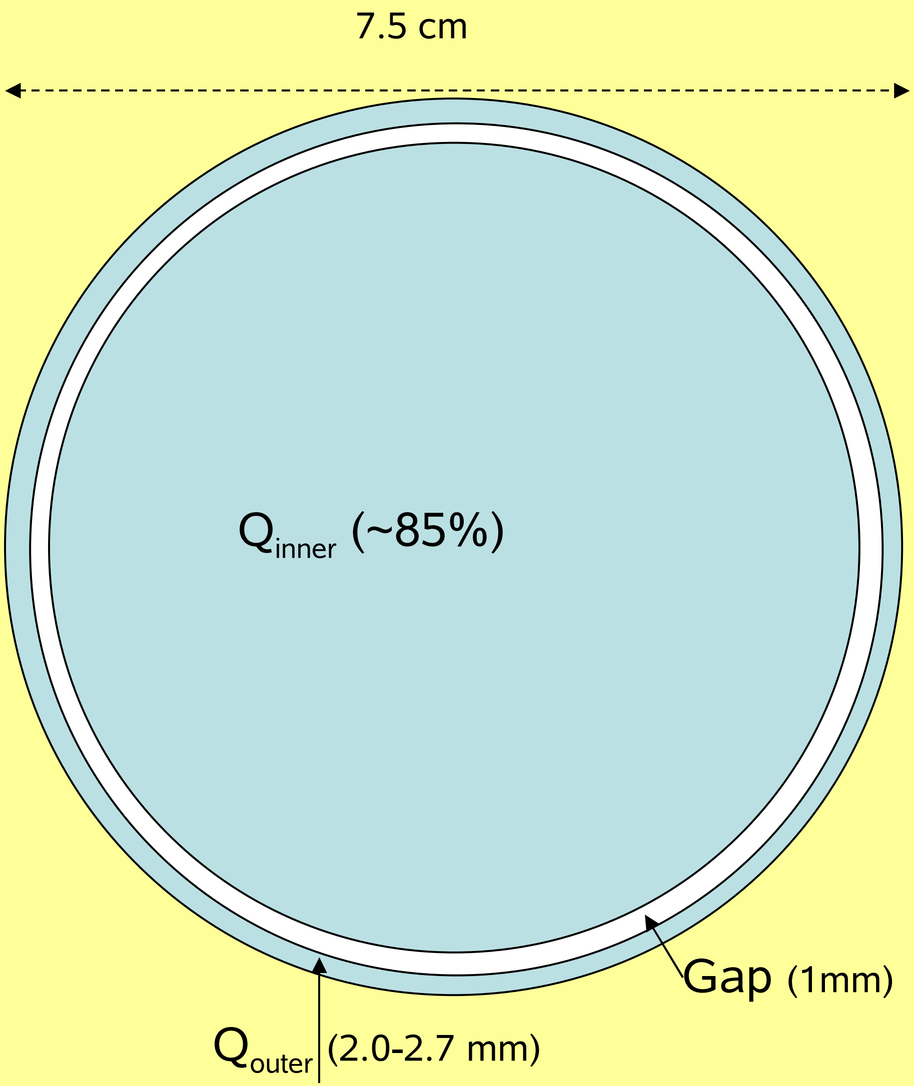
Electron – Hole pairs created by an interaction drift towards the electrodes, inducing charge on the inner (Q_{inner}) and outer (Q_{outer}) electrode.

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

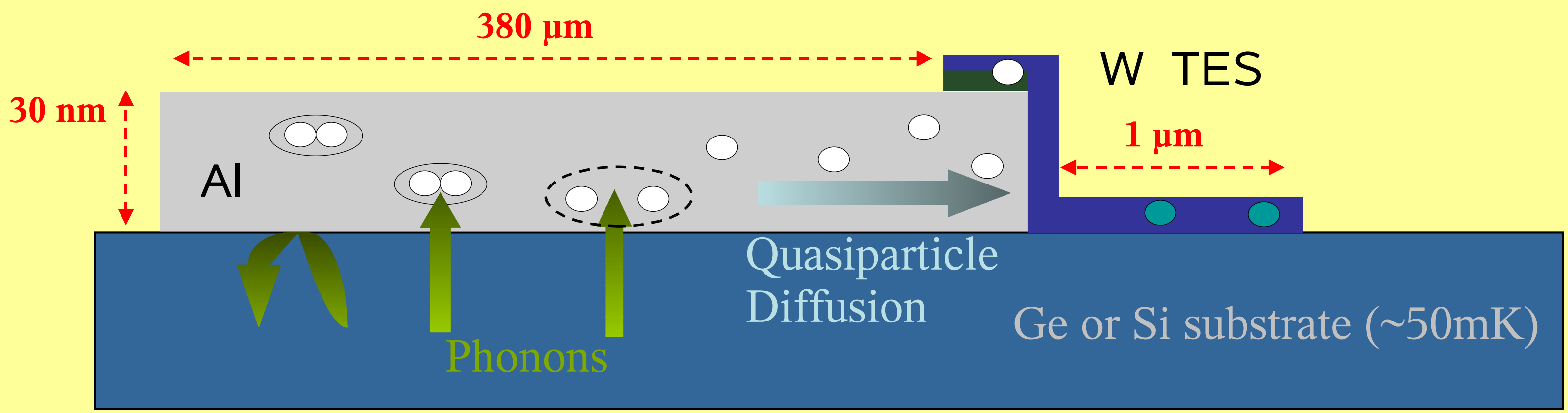
Events with a significant signal on Q_{outer} are rejected in the analysis.

Q_{outer} constrains our fiducial volume.

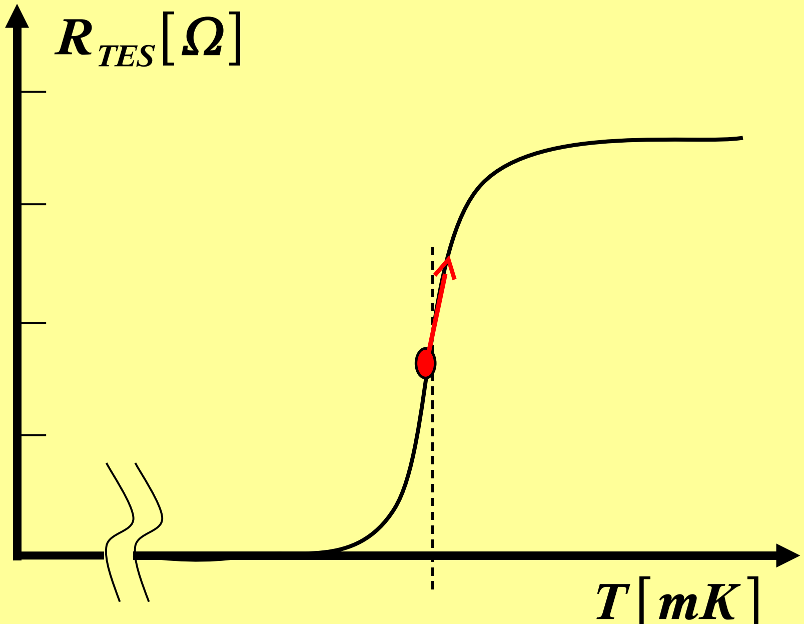
Capacitive readout of the signal.



Calorimetry using phonons



Phonons break Cooper-Pairs in super conducting Al film.



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

Rising temperature → higher resistance → lower current;

Signal is a dropdown in current, which is readout by a SQUID.

4 Phonon channels per ZIP → Segmented phonon readout useful for localisation of an event in x-y plane, and timing parameters in the primary quadrant are used to discriminate surface events.

Signal and background interactions

Suppressed ionization signal for nuclear recoils.

True recoil energy of an event:

$$E_{phonon}$$

Ionization yield defined as:

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

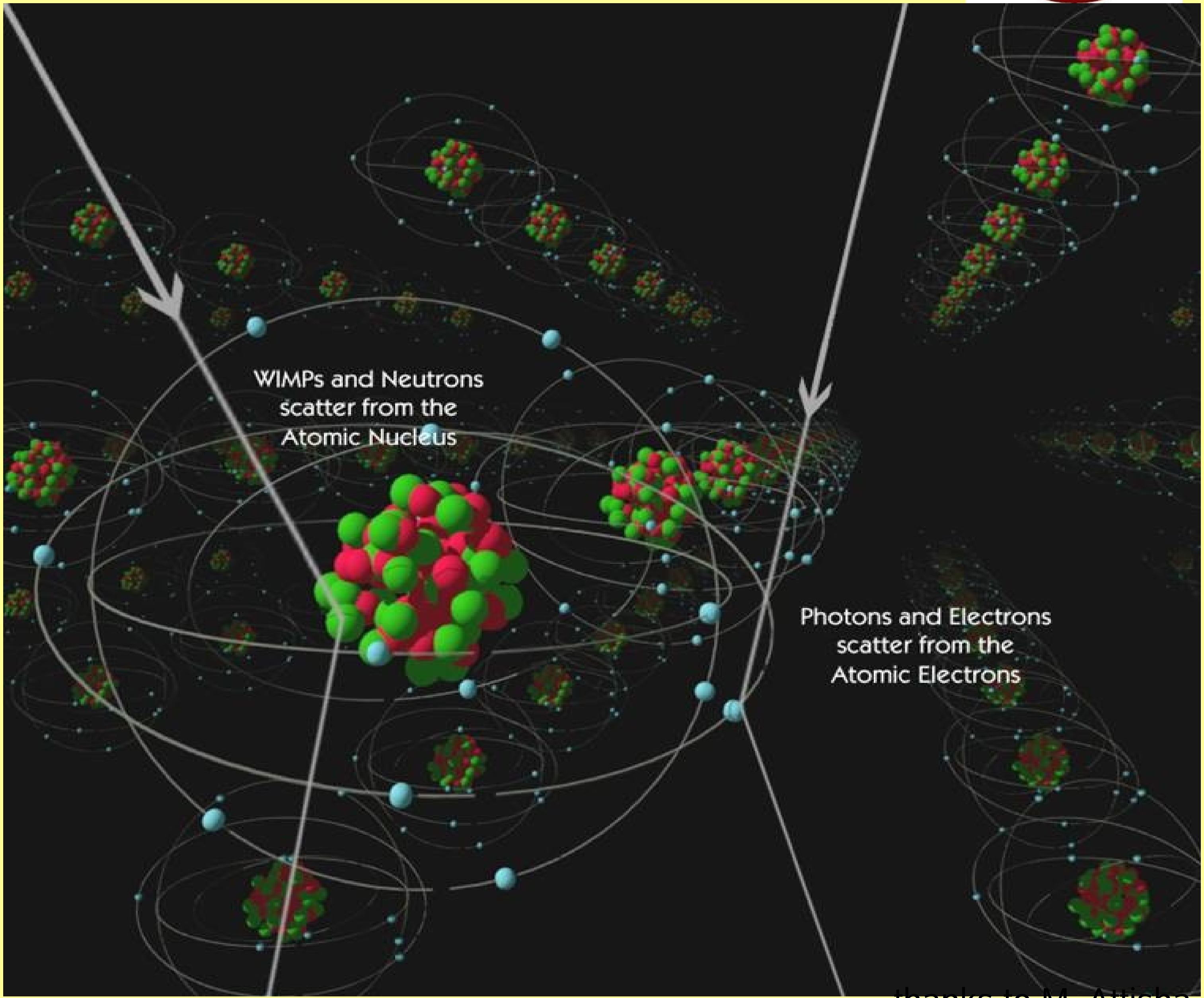
Electron recoil:

$$y = 1$$

Nuclear recoil:

$$y \approx 1/3$$

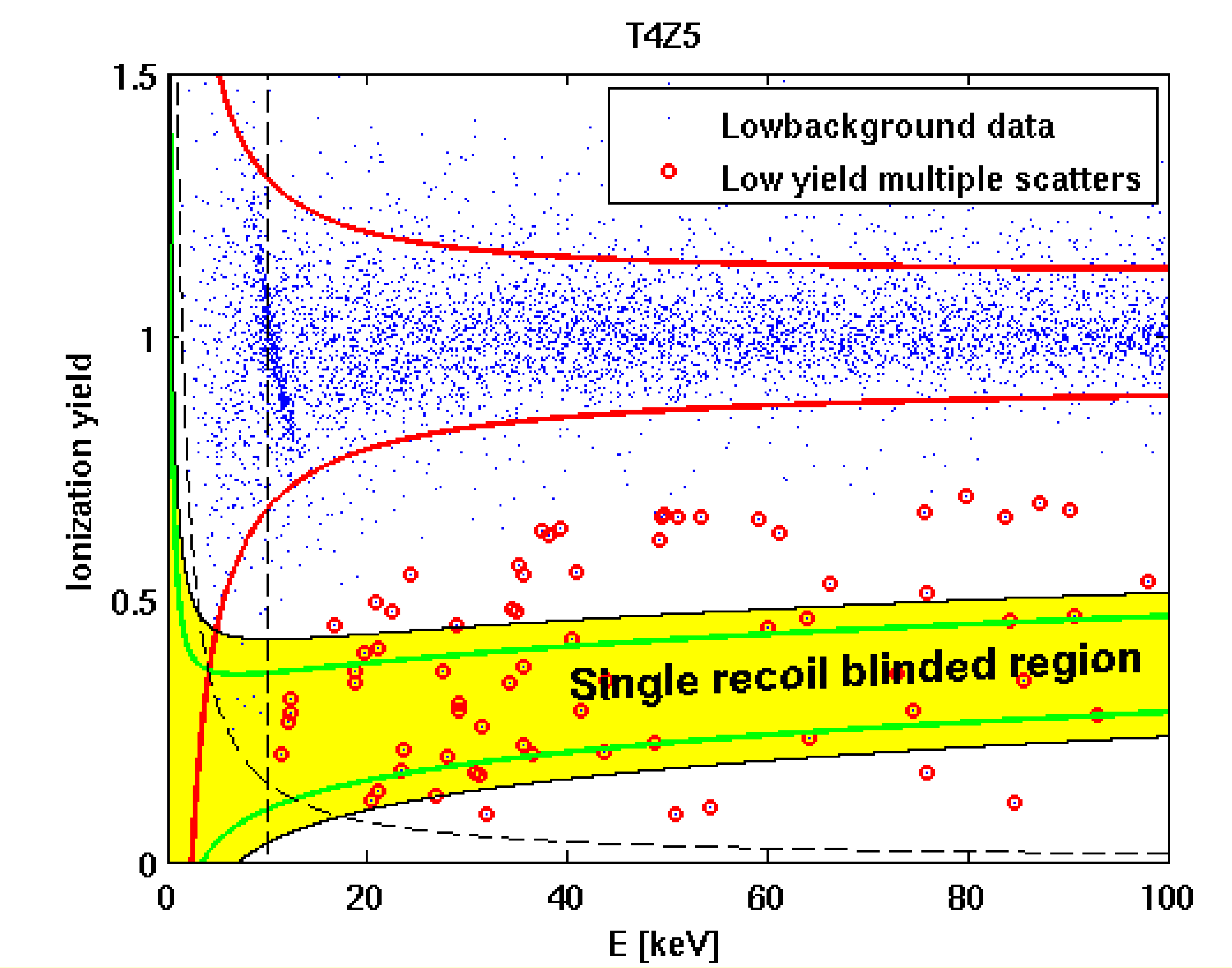
Yield is our main discrimination quantity.



thanks to M. Attisha

First look at blinded low background WIMP-Search data

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



Surface events suffer from 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.

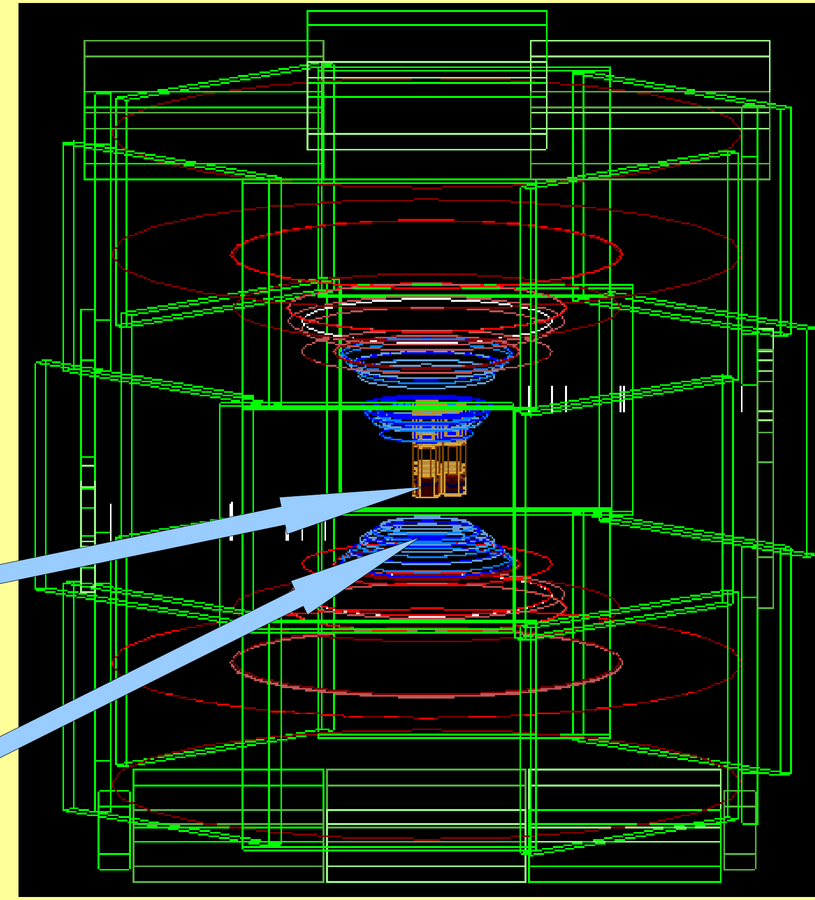
Discrimination of these events is achieved by using the timing information of the phonon signal.

Use GEANT4 Toolkit for background model

Full GEANT4 geometry of the experimental setup.

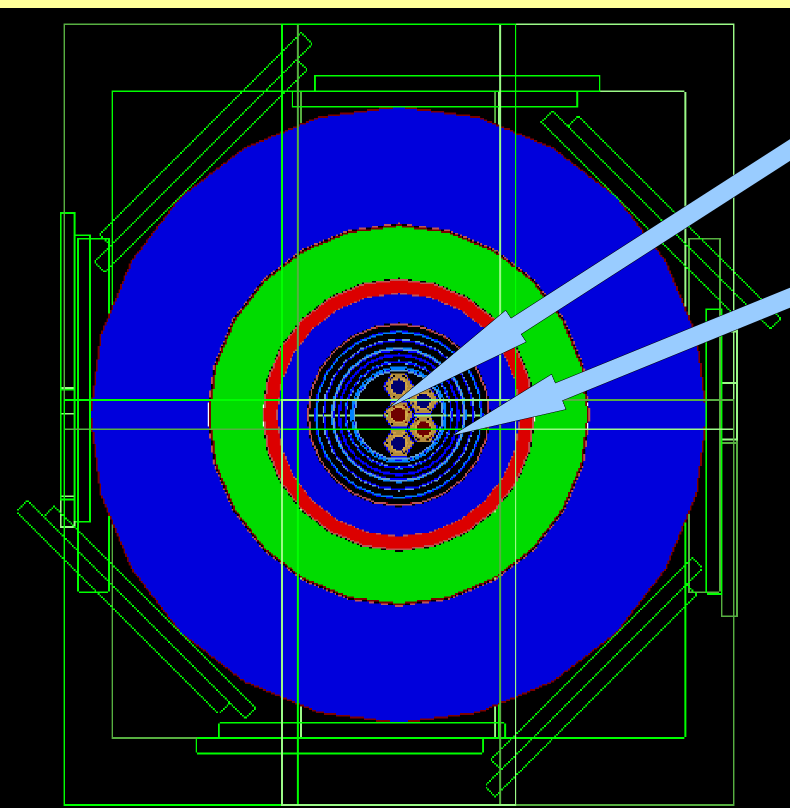
Use G4RadioactiveDecay module to simulate the decay of several isotopes.

Especially in components which are close to the detectors.
No shielding material (polyethylene, lead)in between.



Towers

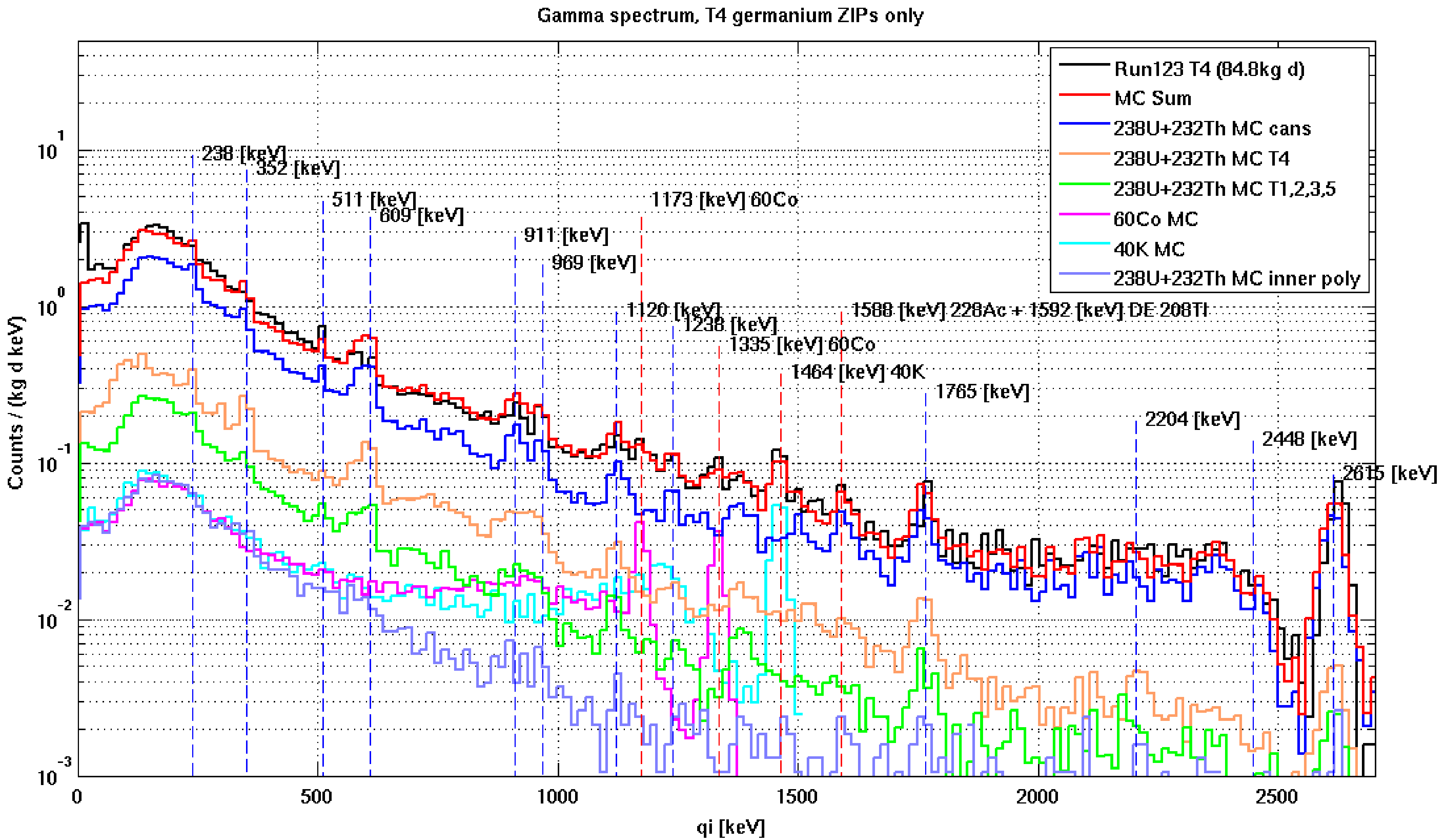
Vacuum cans



Simulate decays of isotopes from the 232Th and 238U chain.

Also take into account 60Co and 40K contaminations.

Understanding the origin of our gamma background



MC simulations of known background sources match the observed spectra very well.
There are **no** hints for additional contaminations from unexplained spectral lines.

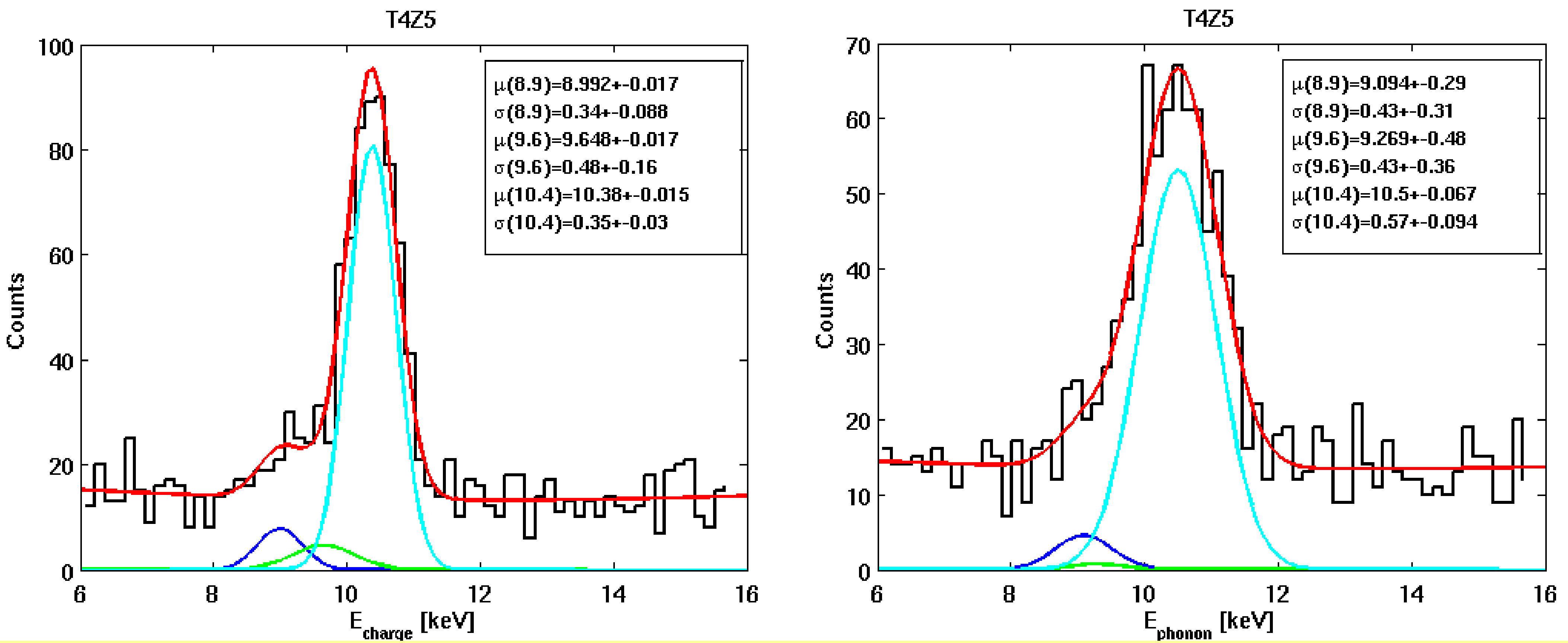
Energy calibration for low energetic events

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 ionization and phonon channel for low energetic recoils.

Additional cosmogenic contibution: 68Ga (9.66 keV) and 65Zn (8.98 keV).



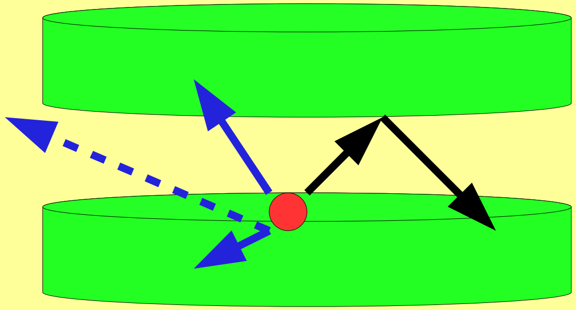
Surface contaminations of the ZIPs

Although taking much efford to keep detectors clean, they are exposed to radon (air) during fabrication, testing, ...

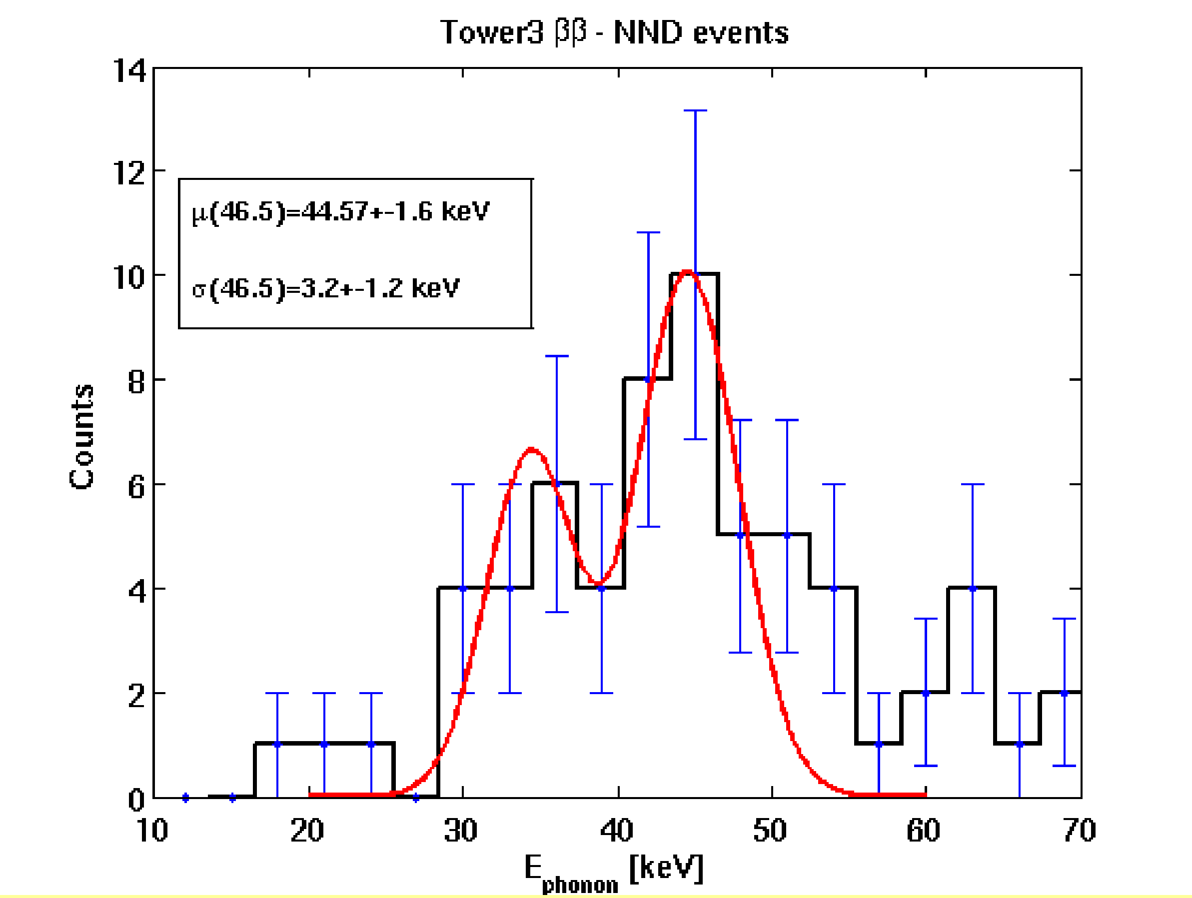
→ 210Pb a decay product of 222Rn can be deposited on the detector surfaces.

$$^{210}\mathrm{Pb} \rightarrow {}^{210}\mathrm{Bi} + (46.54\, keV), \tau_{1/2} = 22.3\, years$$

Decay can be identified by studying NND events.



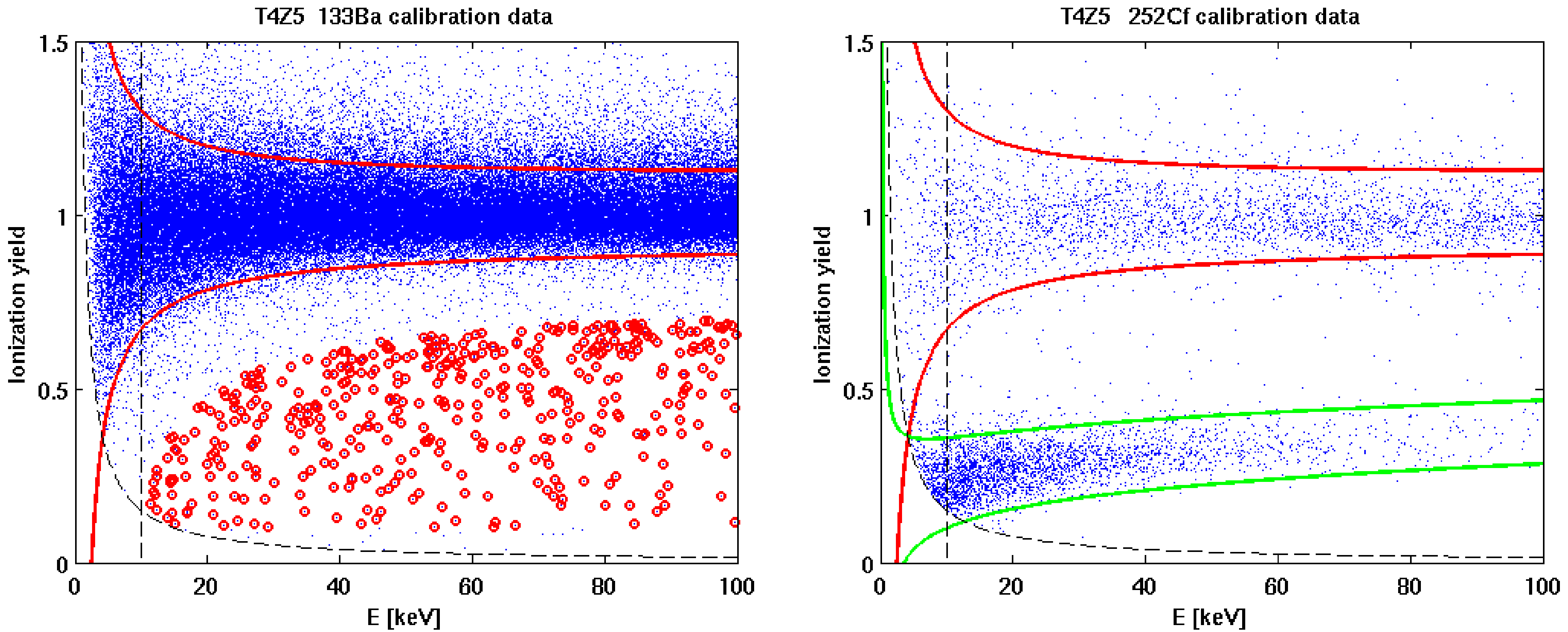
The low energetic gammas and electrons involved in this decay, are a major contribution to the low yield event population.



Work by R. Mahapatra, J. Cooley and S. Golwala

Ionization yield based discrimination

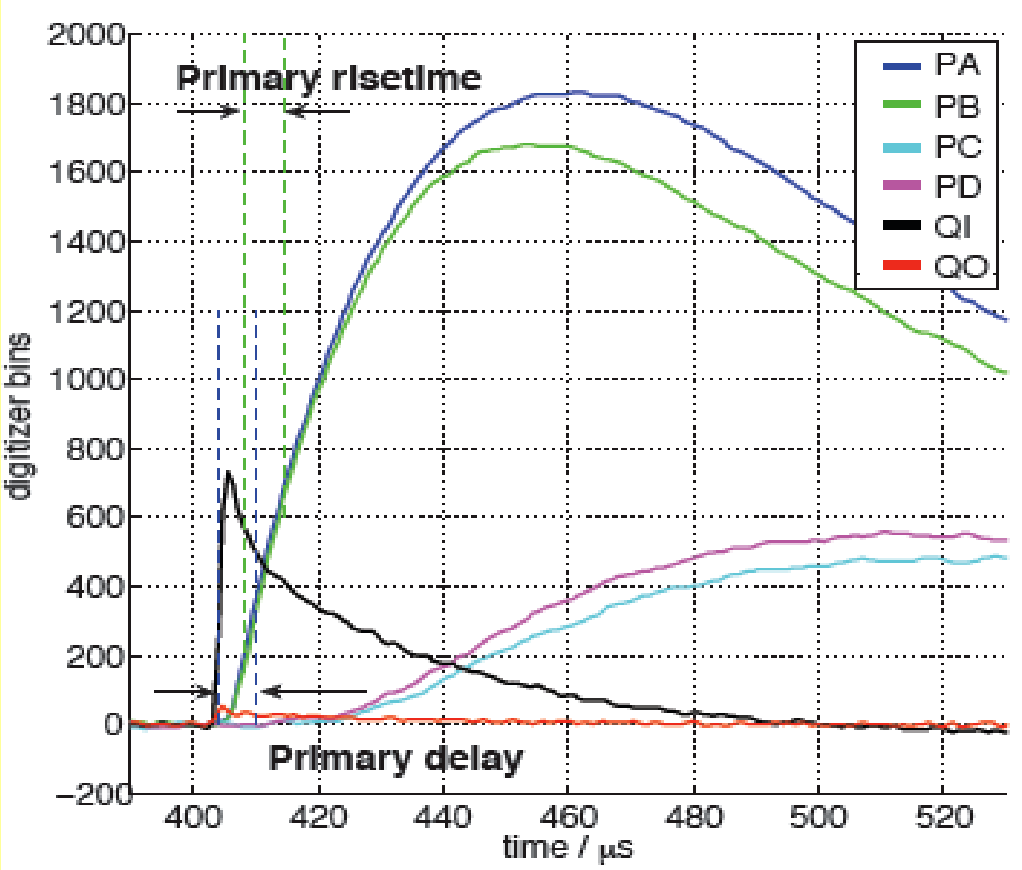
Main discrimination is achieved by the ionization yield parameter.
Ionization yield bands are defined by 133Ba and 252Cf calibrations.
The 2σ NR band defines our expected signal region.



Work by J. Filippini

Low yield events also show up in 133Ba calibration. This is **good**, since we can study their timing properties and compare them to those of nuclear recoils.

A closer look at low yield events and differences to nuclear recoils



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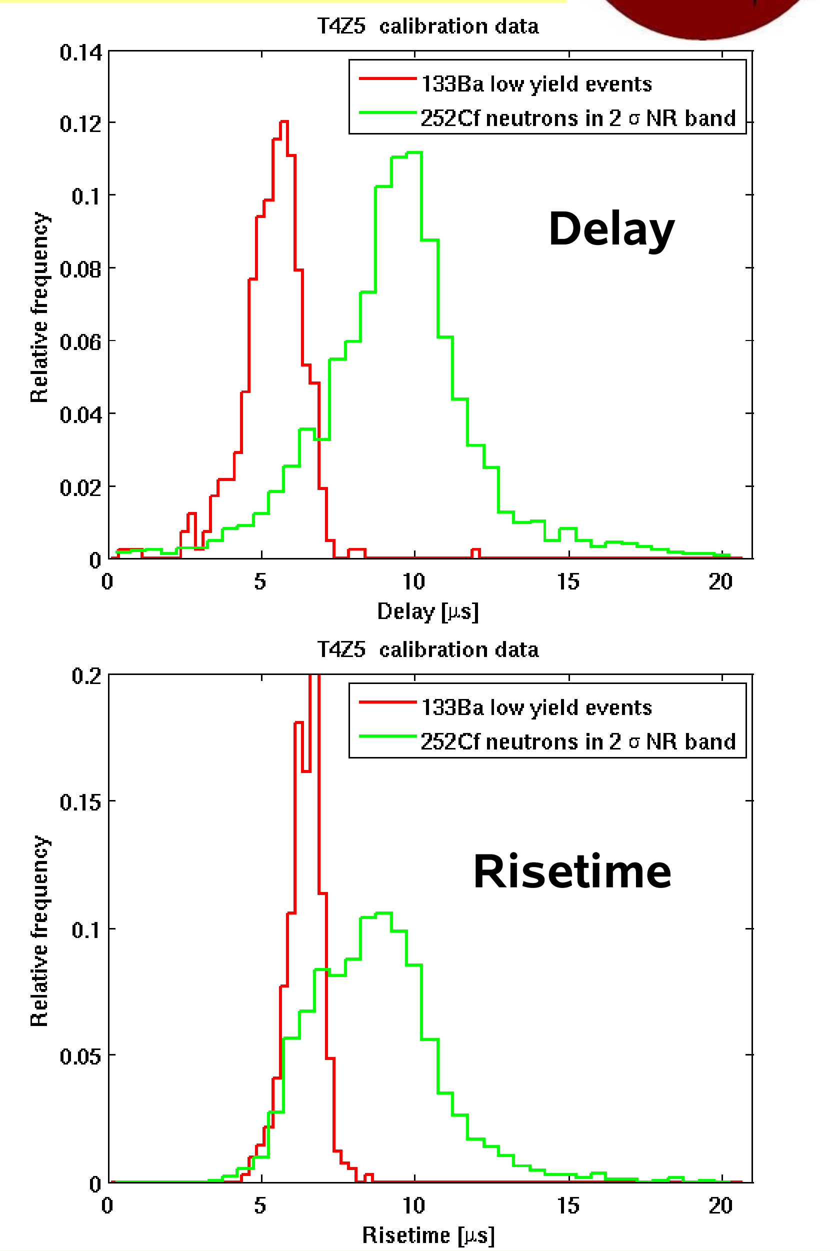
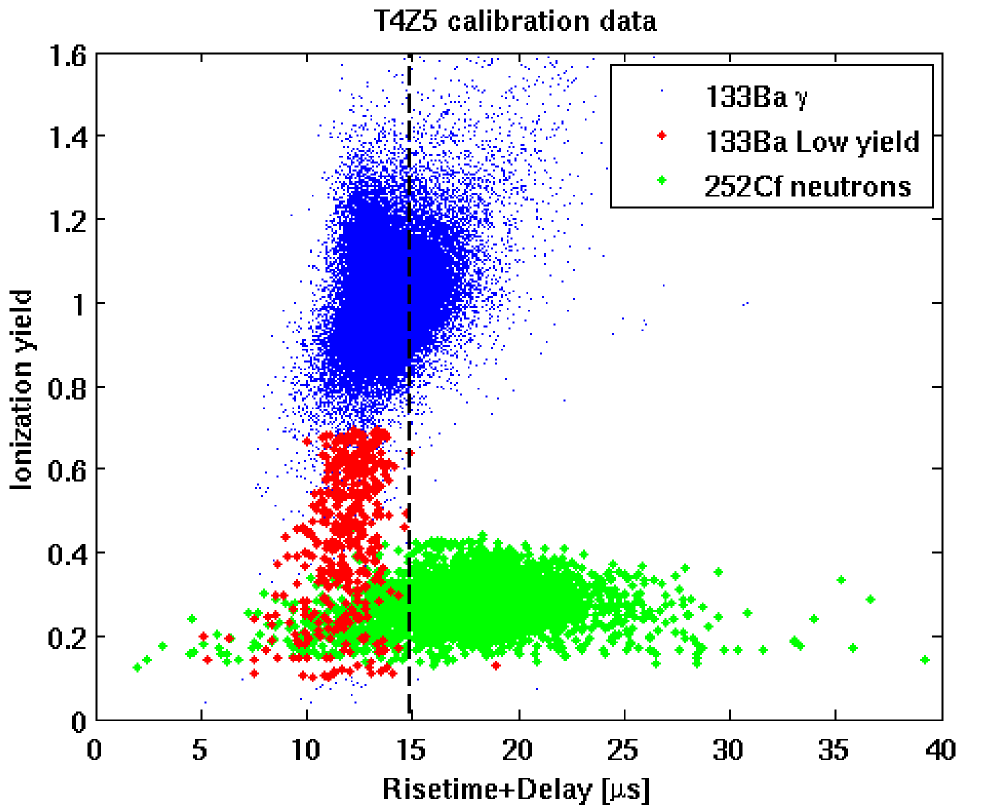


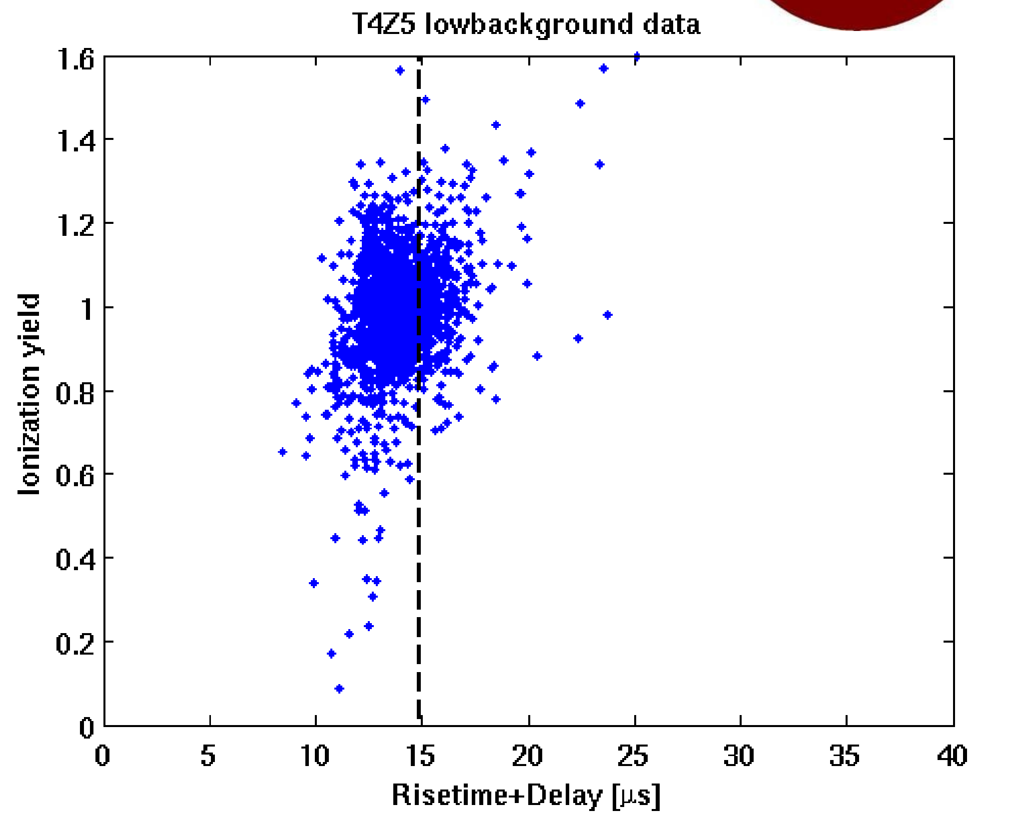
Low yield surface events are faster in timing than bulk nuclear recoils.

Timing is a powerful discriminator, used to get rid of low yield events.

Defining the surface event cut

Surface cut is defined on calibration data only and freezed before unblinding.





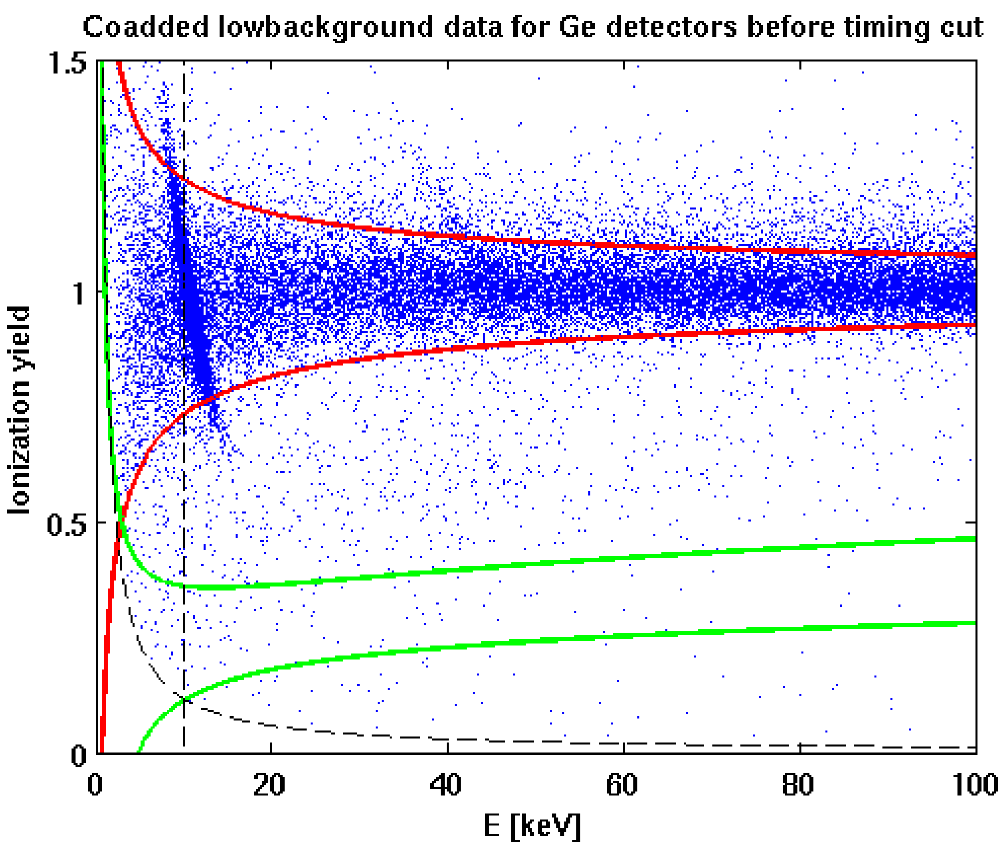
Work by X. Qui

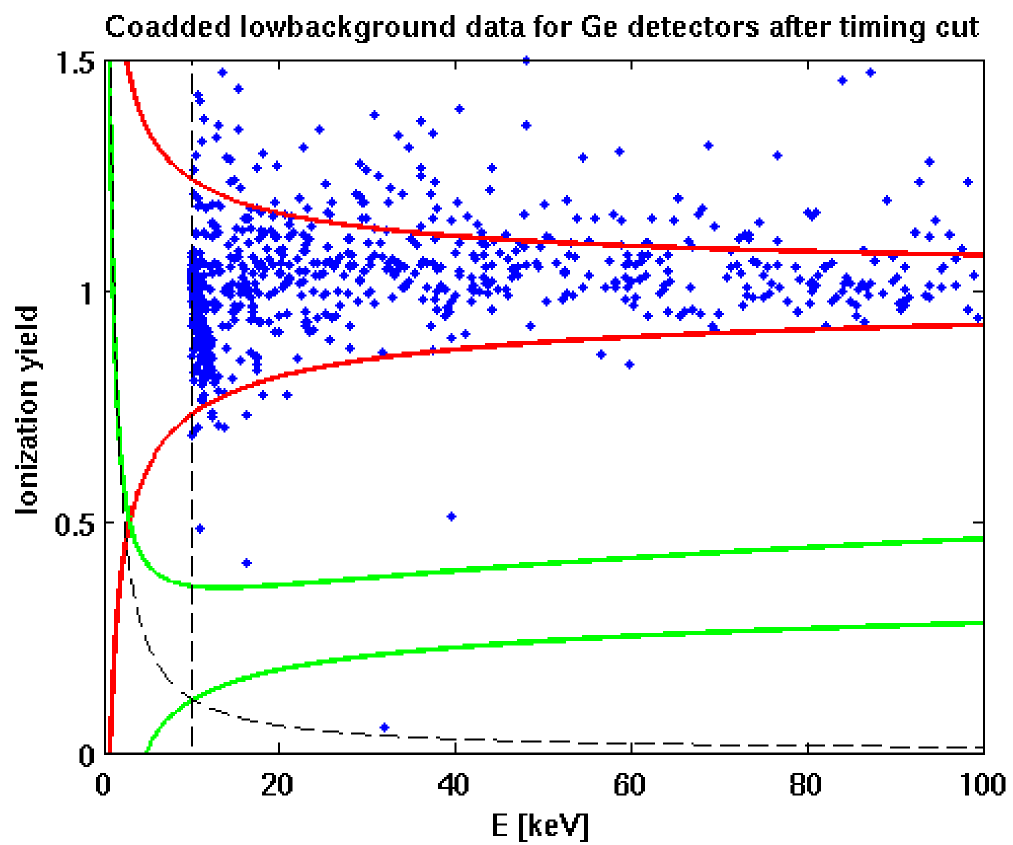
Timing cut **chosen** at a level to contribute ~0.5 events total leakage to WIMP candidates.

Expected leakage from lowbackground data 0.6 ± 0.5 events. (Preliminary uncertainty).

Unblinding of germanium detectors

After applying the timing cut, **0** events are observed in the signal region.





Expected background: 0.6 ± 0.5 leakage events
< 0.2 Neutrons (< 0.1 Cosmogenic + < 0.1 Fissions)

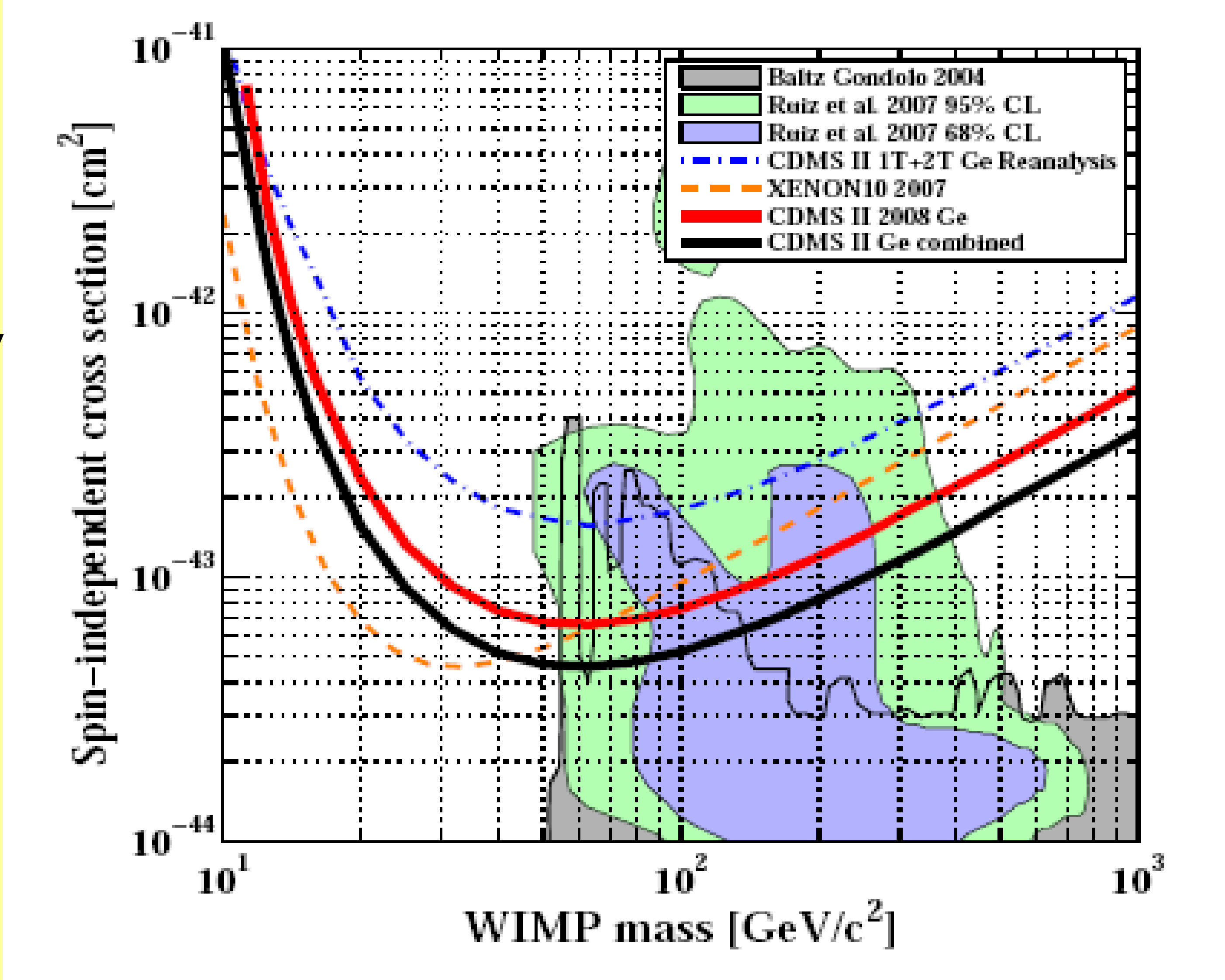
What can we study if no candidate events are observed?

If no valid candidate events are detected, upper limits can be set on the WIMP nucleon scattering cross-section.

This mass dependent limits are independent of the nature of Dark Matter

Best SI- cross section limit for WIMP masses > 40 GeV

Starting to probe favored parameterspace for WIMP masses > 50 GeV.



What can we study if candidate events are observed?

If candidate events are detected we want to determine the mass and cross-section of the Dark Matter particles.

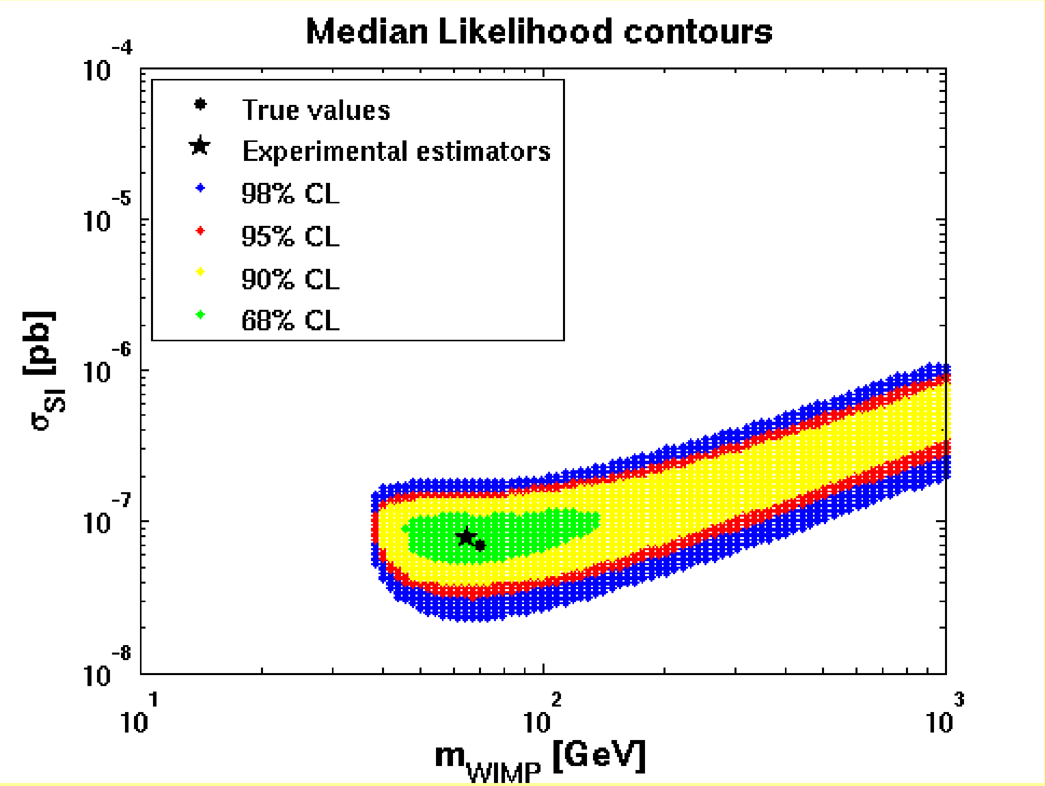
Simpelst approch would be a Likelihood estimation of confidencelevels.

Log of the likelihood function is not χ^2 distributed for low statistics. $\chi^2 \,!= -2\ln(L(\theta))$

Confidence level determination by $\ln L(\theta) = \ln L_{max} - Q/2$ (Q=4.61 for 90% CL and 2 dof) questionable.

Possible improvement by Bayesian analysis.

Bayesian analysis needs prior, a certain parameter set for the true parameters has to be choosen which is a priori unknown.



Feldmann - Cousins Likelihood ratios

Use Likelihood ratio to determine propability of a parameter point.

$$\chi(\theta_{point}) = \frac{L(n|\theta_{point})}{L(n|\theta_{best})}$$

disfavoured $0 \leq \chi \leq 1$ favoured

G.J. Feldman, R.D. Cousins, Phys Rev. D 57 (1998), 3873-3889

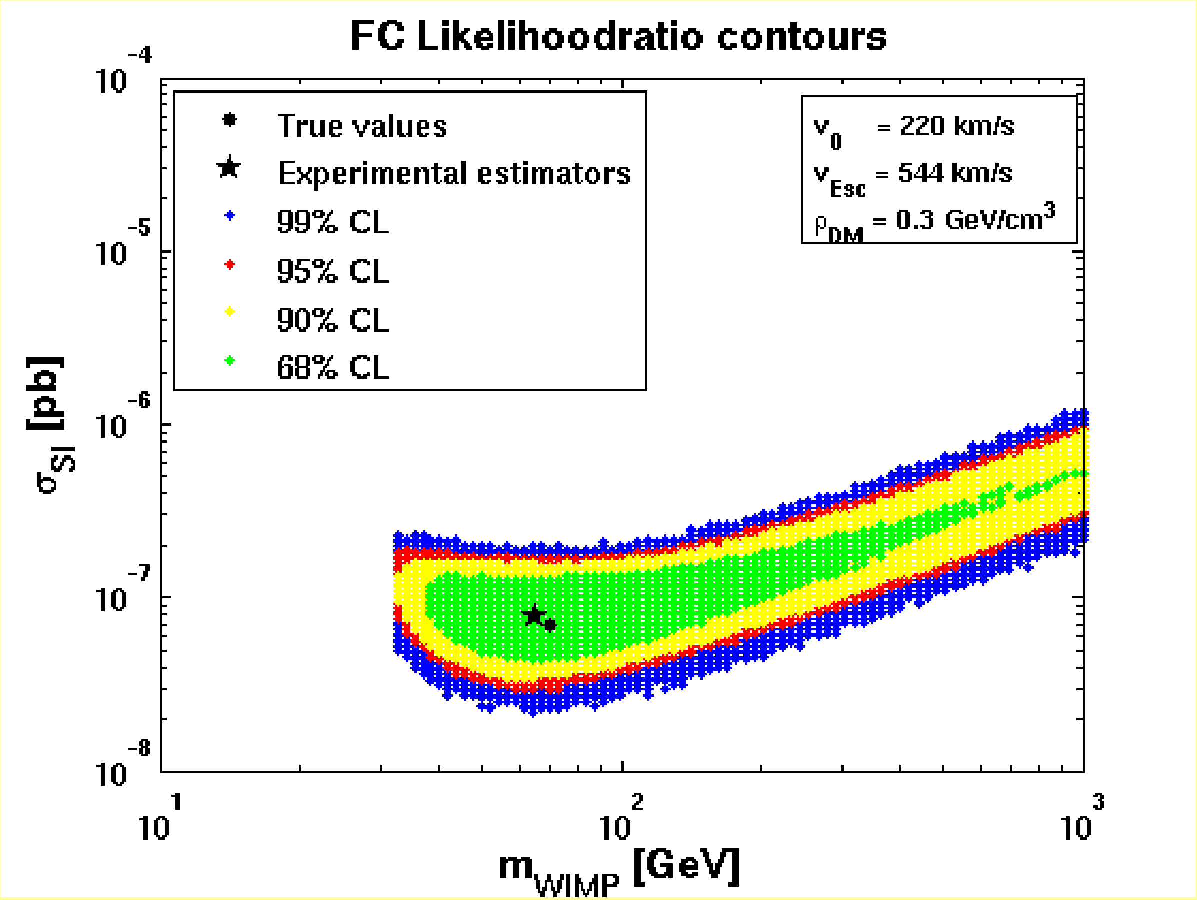
Likelihood ratio accurate for low statistics (n ≤ 10).

For each parameter point run a lot of MC experiments and define χ_c such that α (CL)of these experiments have $\chi \geq \chi_c$.

For the „real“ data calculate χ_{test} for each parameterpoint. Find confidence levels by Likelihood ratio test. ($\chi_{test} \geq \chi_c$).

No need of prior, confidence levels determined by Likelihood ratio test with „real“ data.

Needs a lot of computation time.

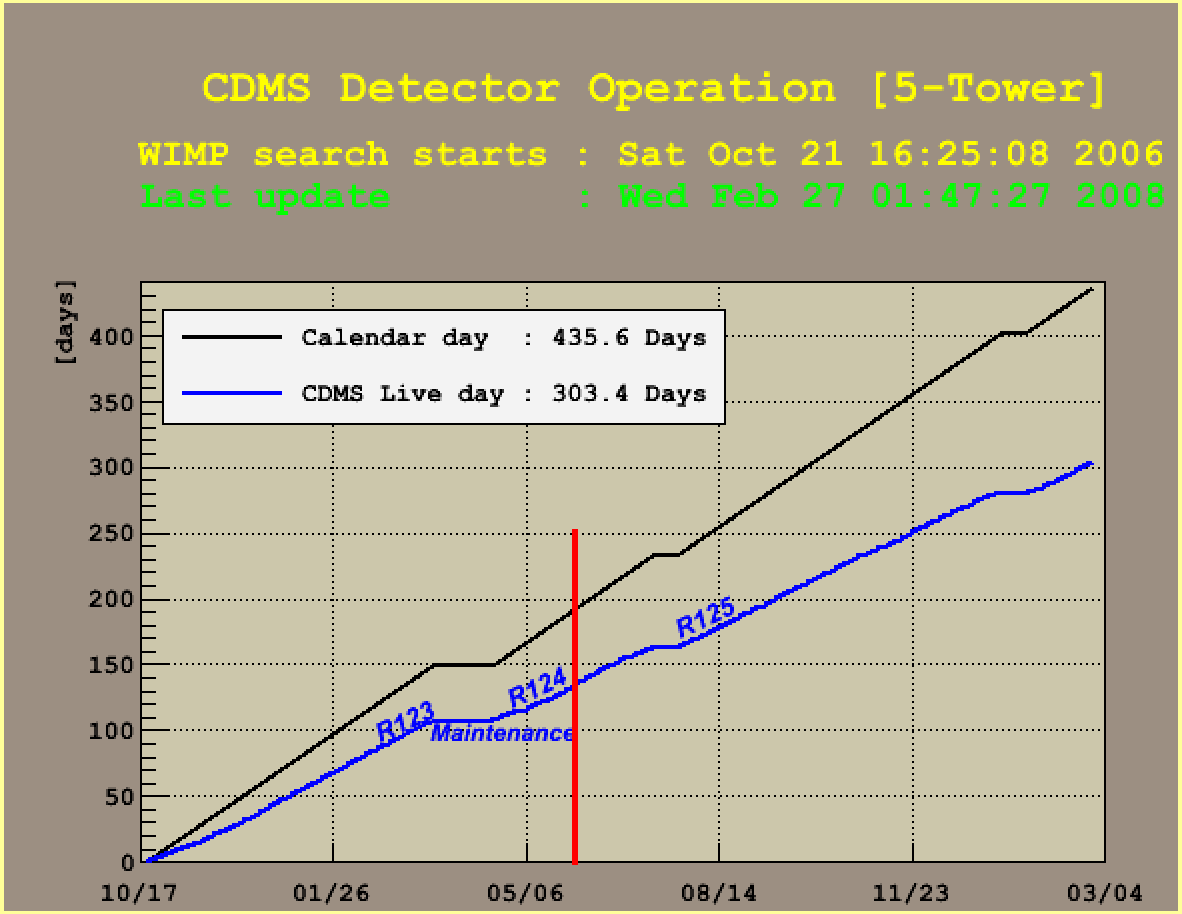


Conclusions

The CDMS experiment has an event by event discrimination between background and expected signal, resulting in an expected background of 0.6 ± 0.5 events.

Analysis of the Run 123/124 data (398 kg d of germanium raw exposure) revealed **0** candidate events.   preprint availible at arxiv.org: astro-ph 0802.3530v1

Additional data already taken, and acquisition of new data is ongoing, right now!



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Backup Slides

Recoil spectra of WIMP-nucleus scattering

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

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

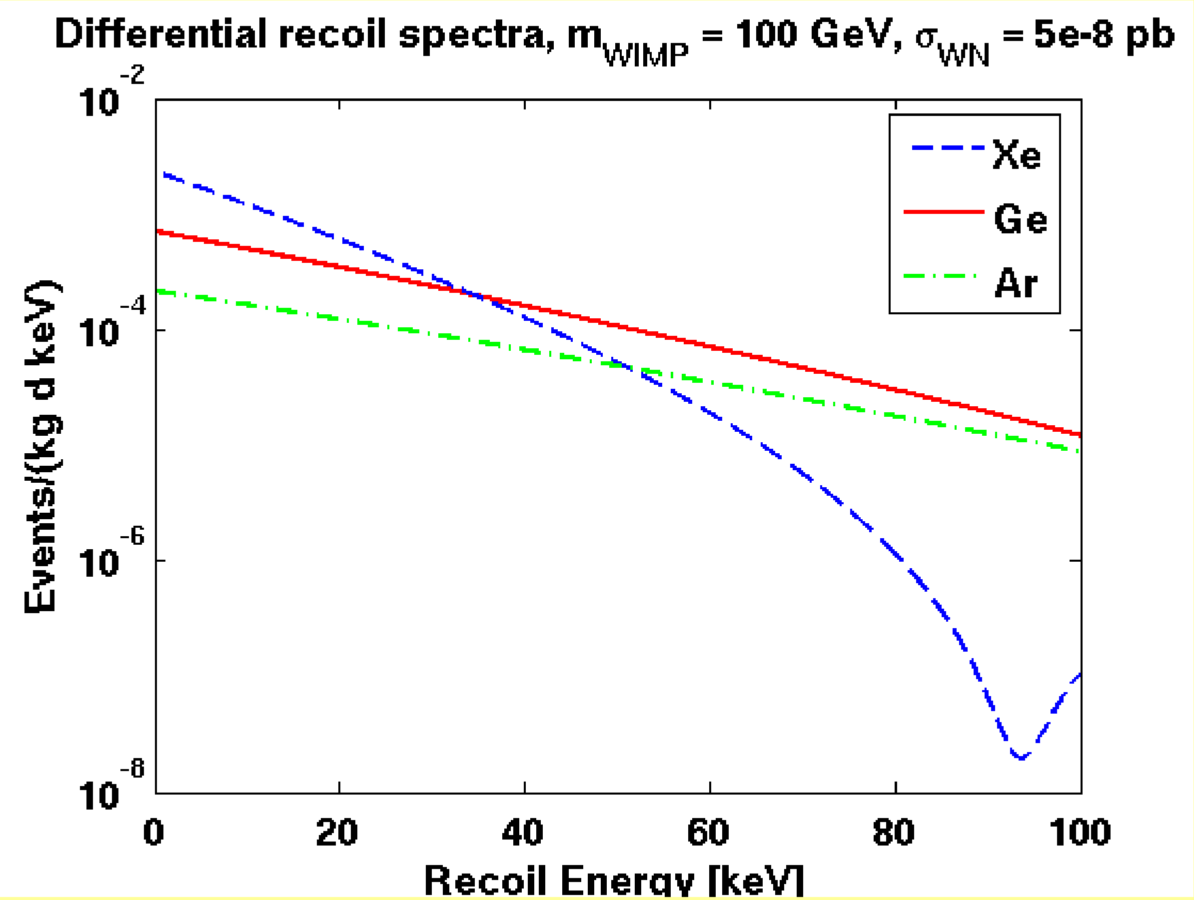
v_0 : mean velocity of WIMPs
~ 220 km/s

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

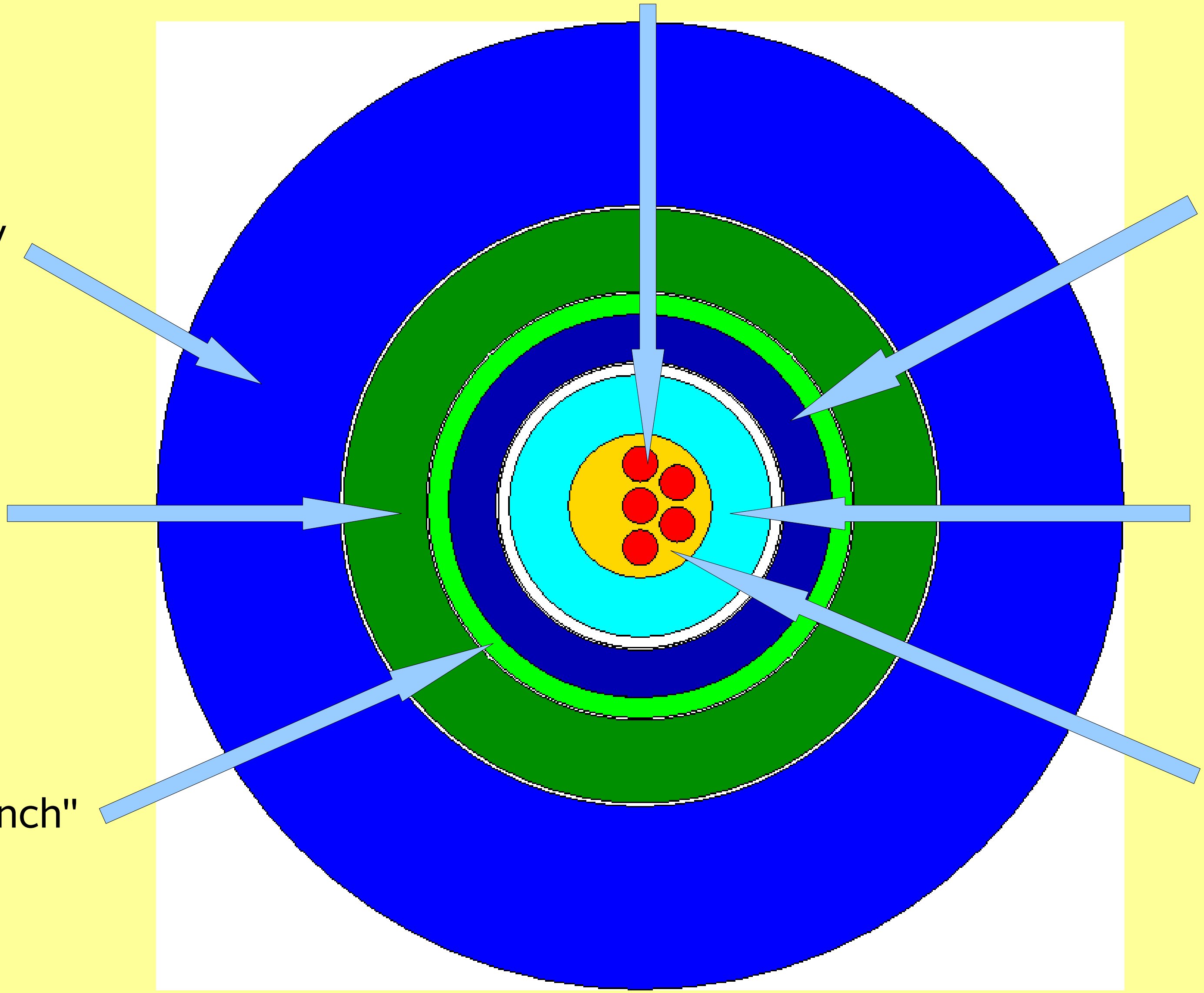
v_E : earth velocity ~ 232 km/s

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

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

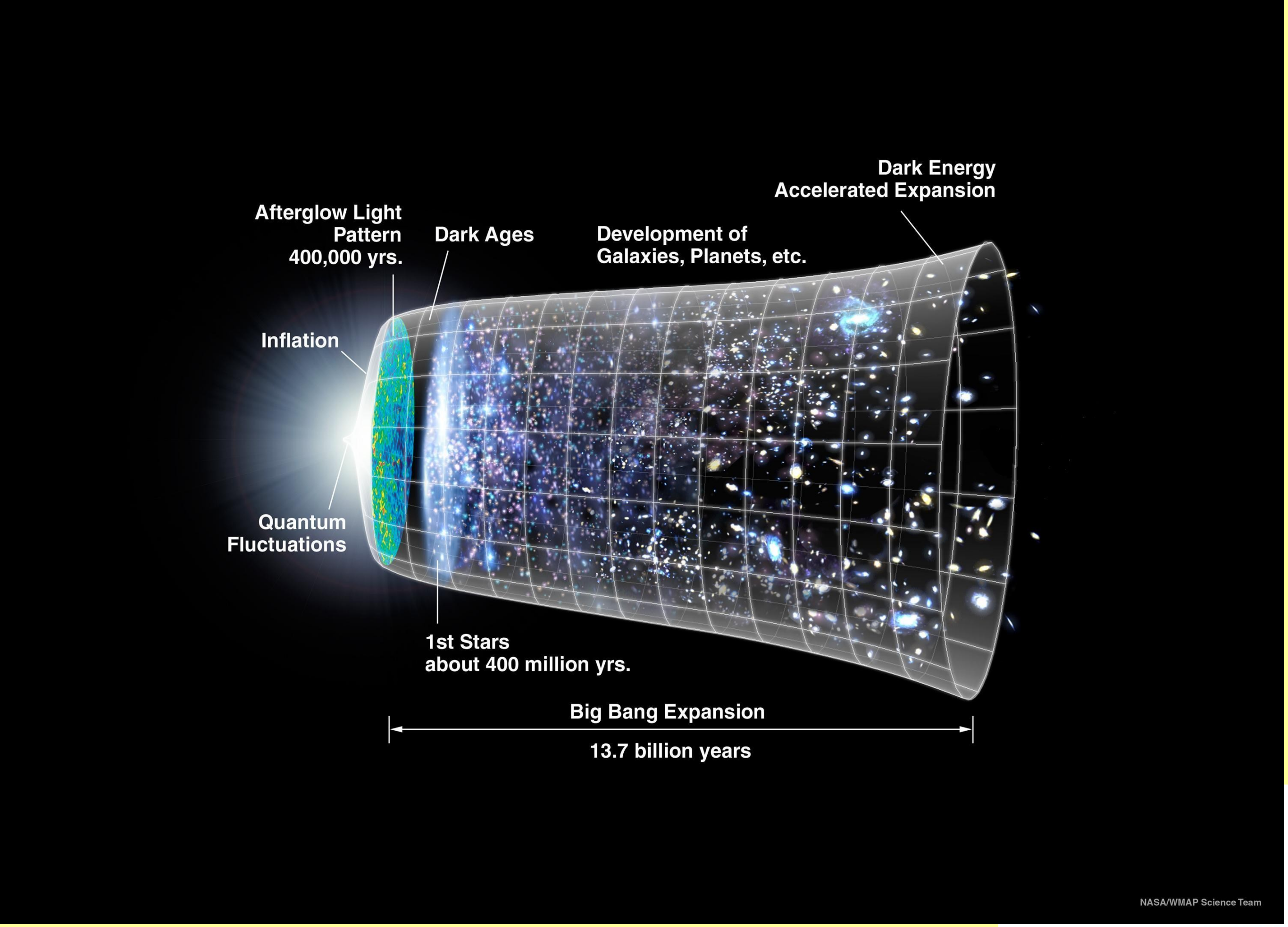


Shielding of the detectors



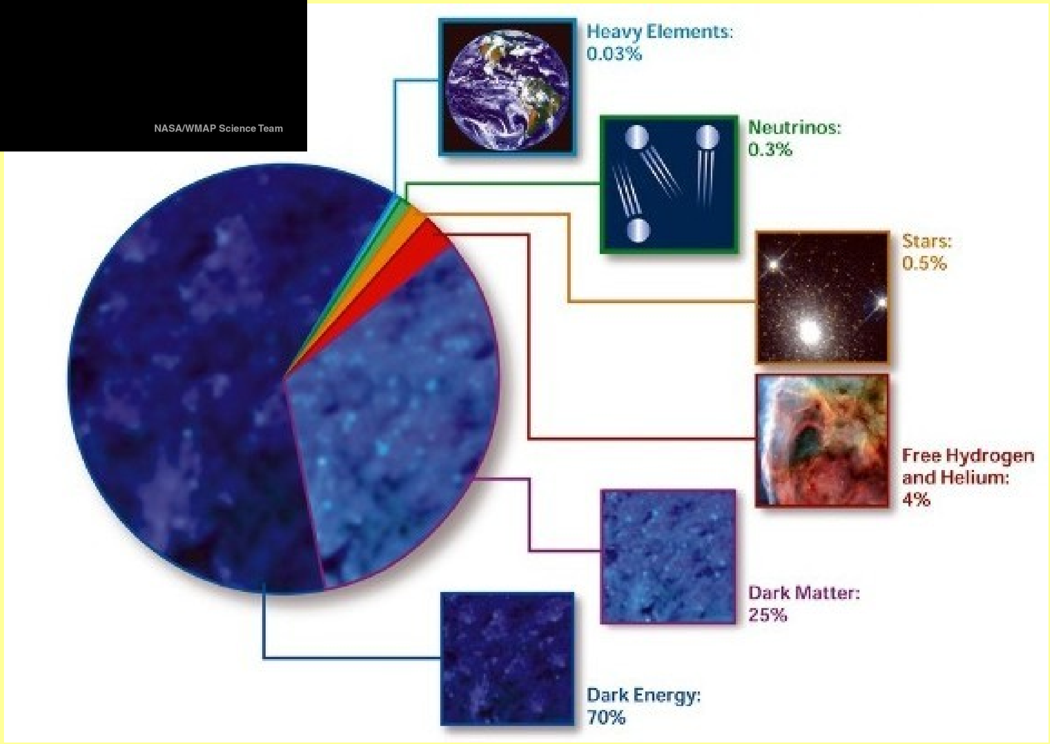
Excellent shielding necessary to suppress external neutron and gamma background.

But contaminations of our internal materials are a source of gamma backgrounds.



Structure forming needs initial, gravitational seeds.

Strong evidences for Dark Matter from astronomy.



The nature of the dominating part of matter in the universe is unknown.

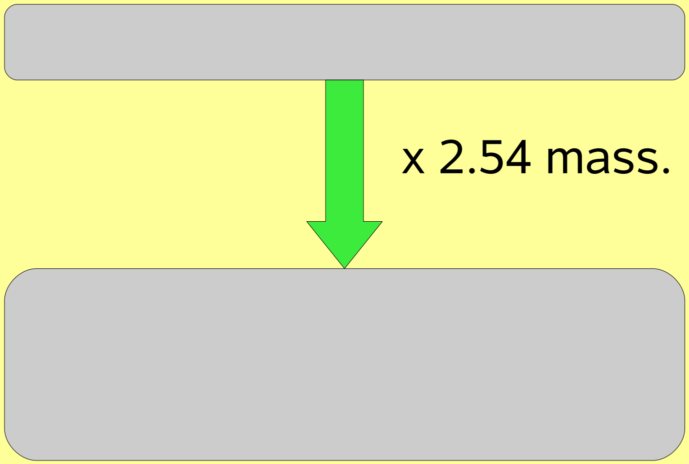
Extensions of the SM give good candidates for WIMPs.

Maybe something completely different.

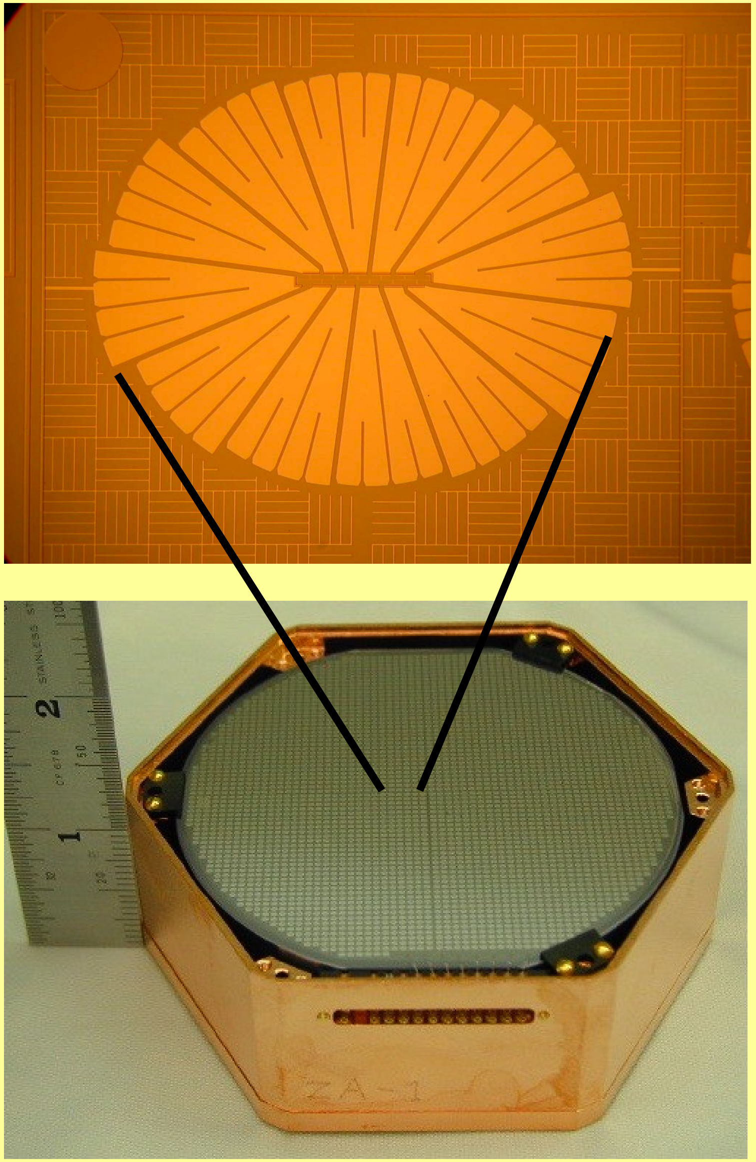
SuperCDMS at Soudan

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.

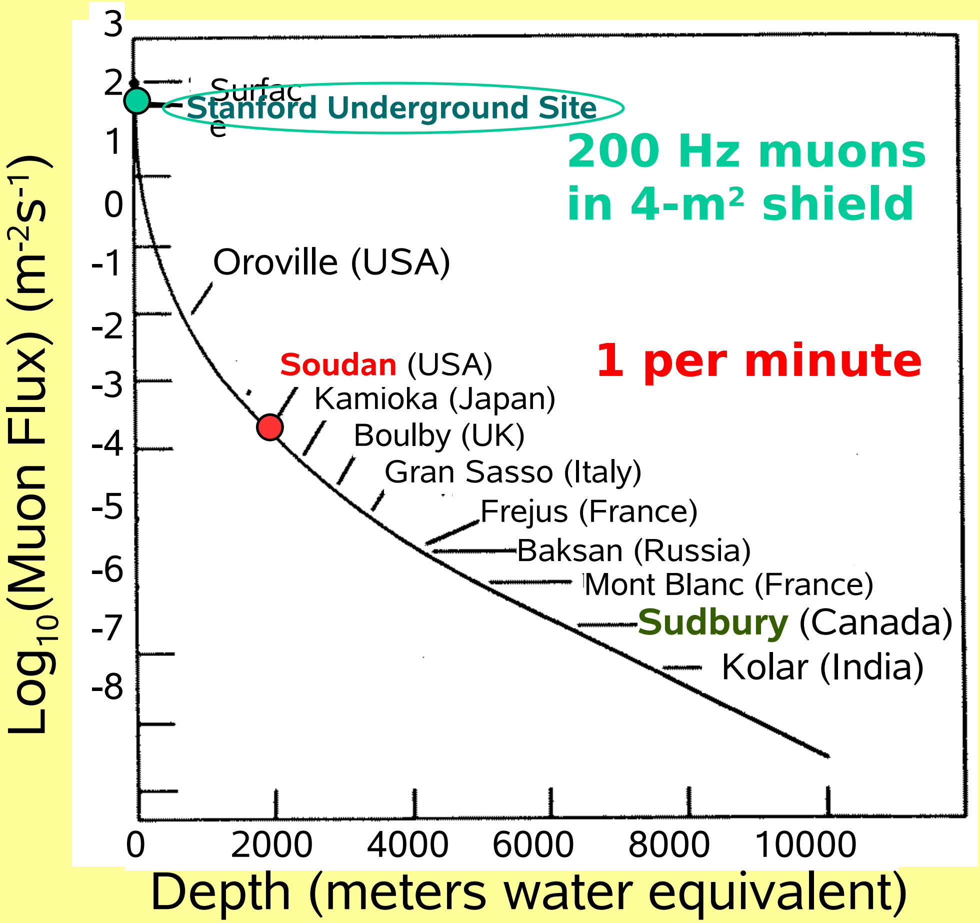
Phase A :

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.

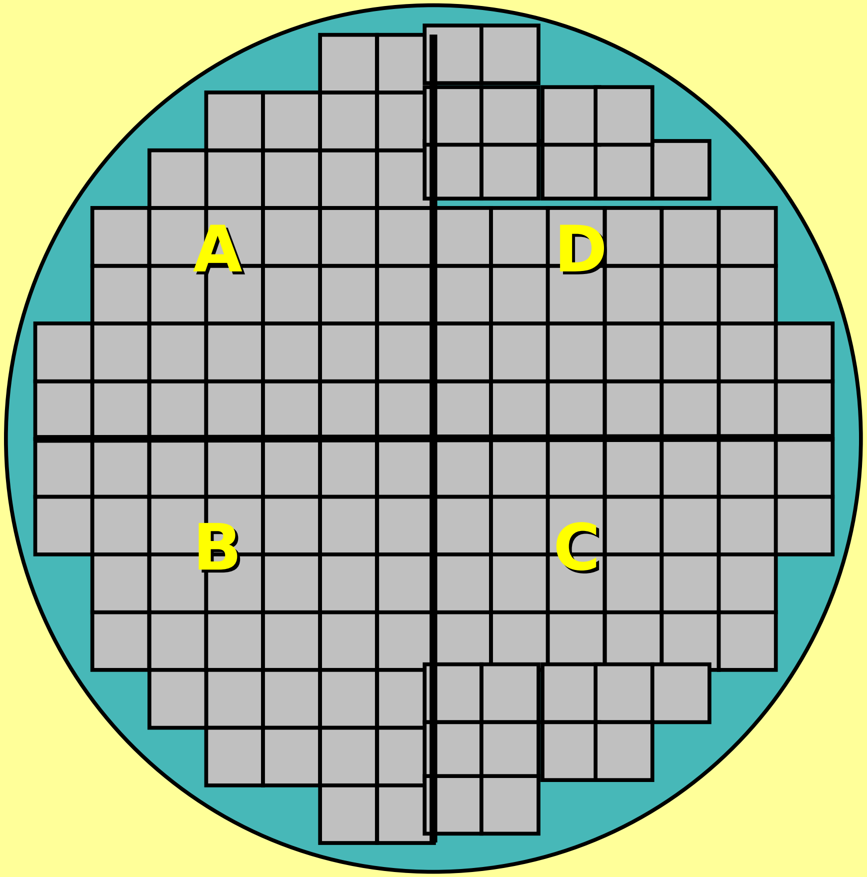
Getting more discrimination power for low yield events by segmented phonon readout

Each quadrant consists of 37 cells with 28 TESs per cell.

Segmented phonon readout useful for localization of an event in x-y plane.

Event location in the x-y plane can be reconstructed in two ways:

- Partition of energy among the four quadrants.
- Relative delay of phonon pulses in four quadrants.



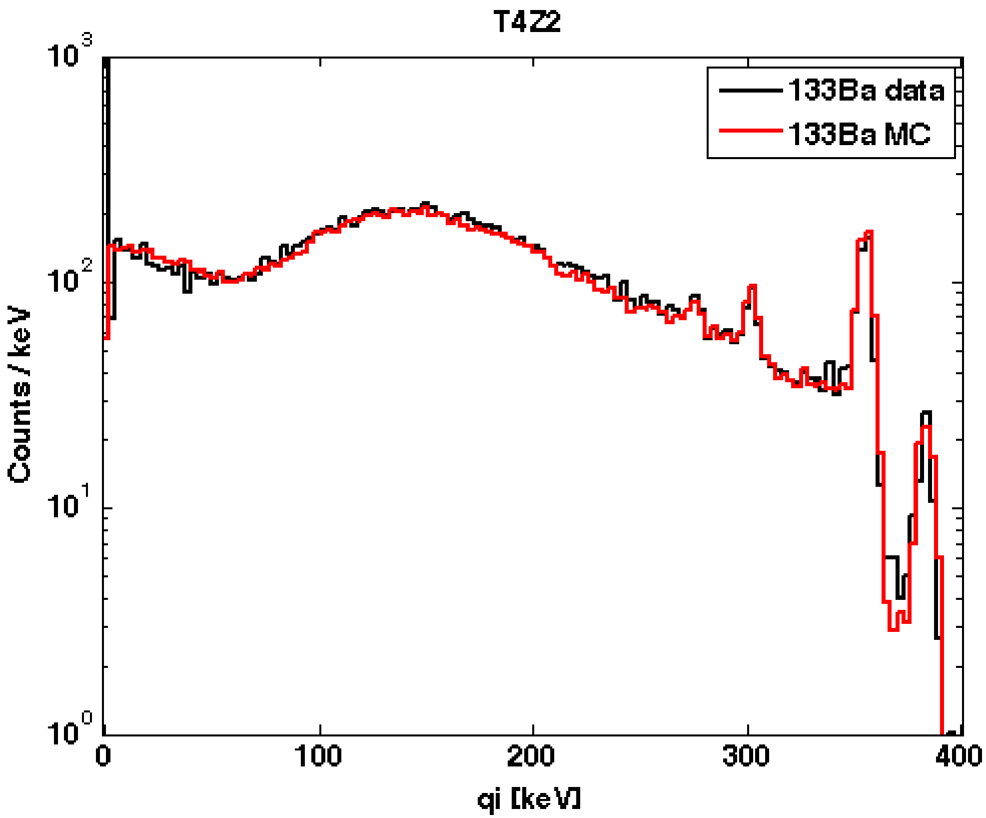
Differences in the timing parameters in severeal quadrants can be used to disrciminate surface events.

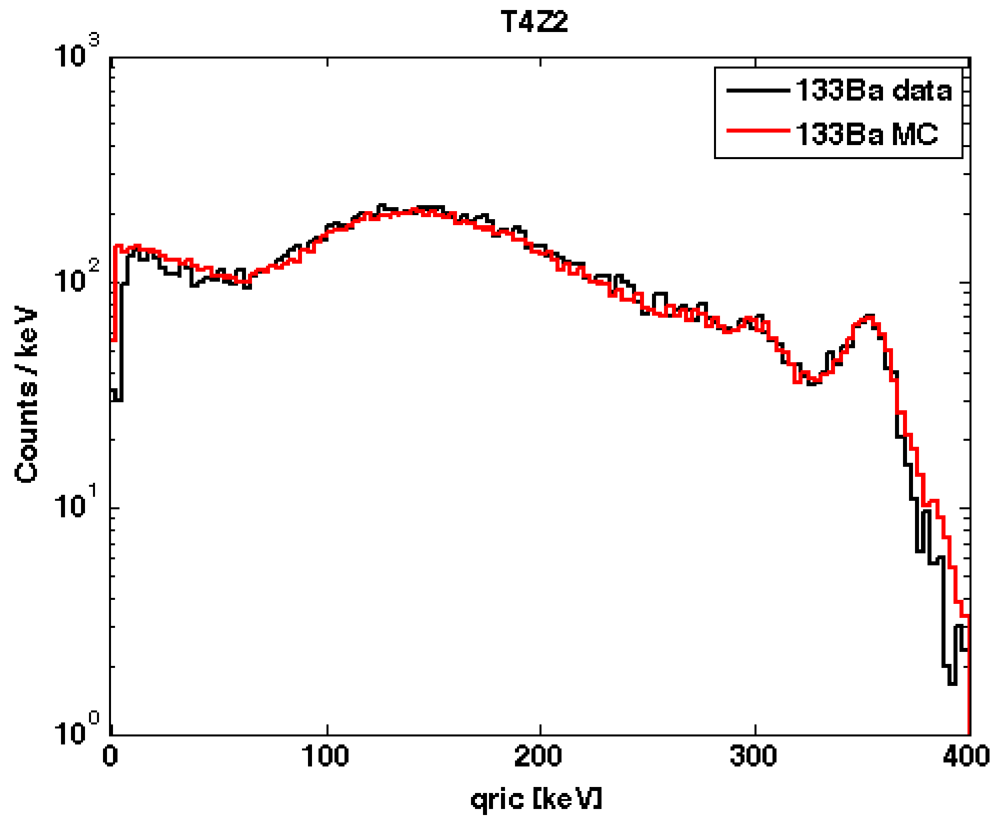
Energy calibration of the detectors

We are using the 133Ba calibration runs to calibrate our detectors :

Four lines in ionization channel: 276keV 302 keV 356keV and 384 keV

One (Two) lines in phonon channel: 356 keV (302keV) due to a bad resolution at high energys.



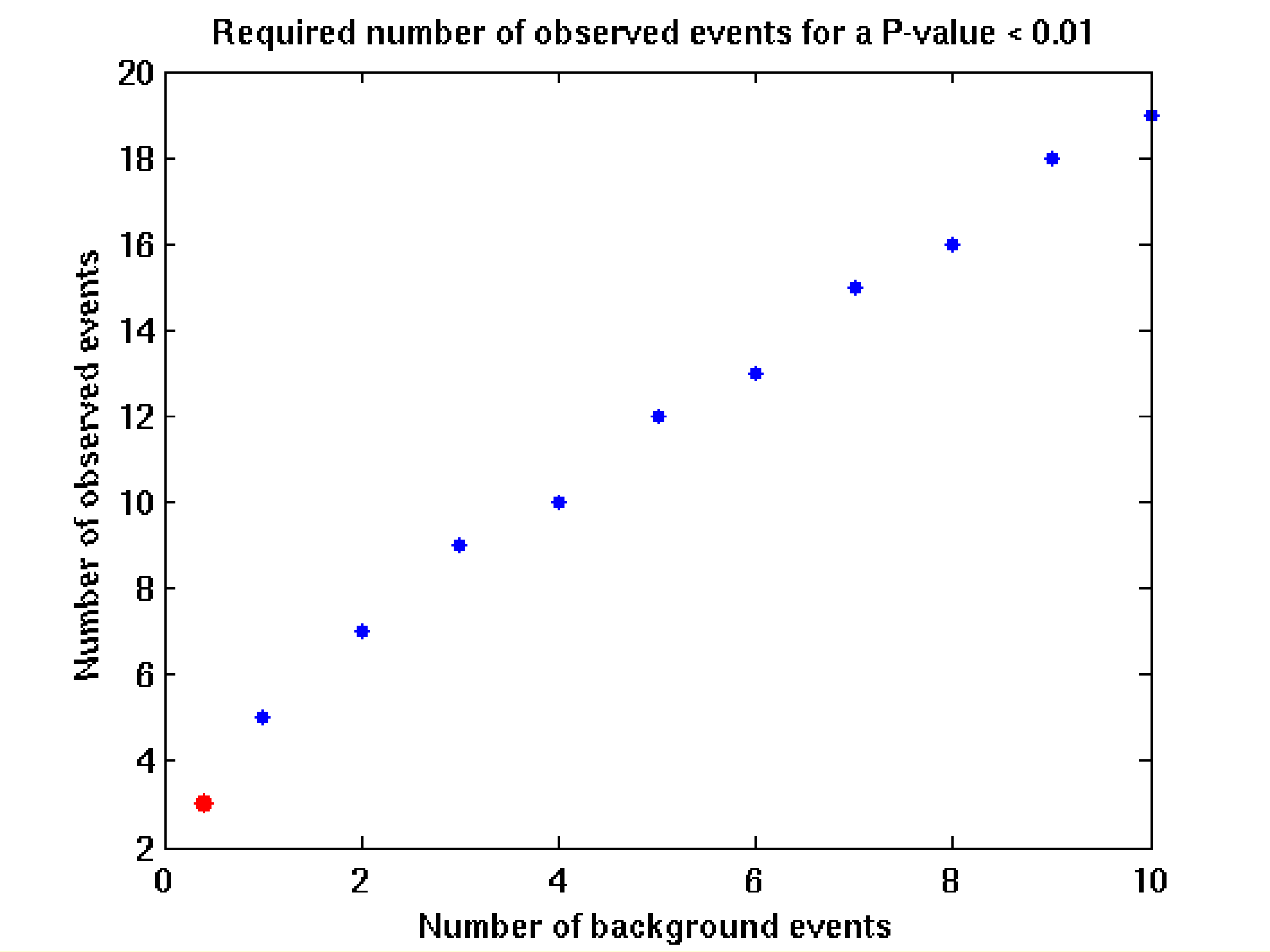


Significance of a signal

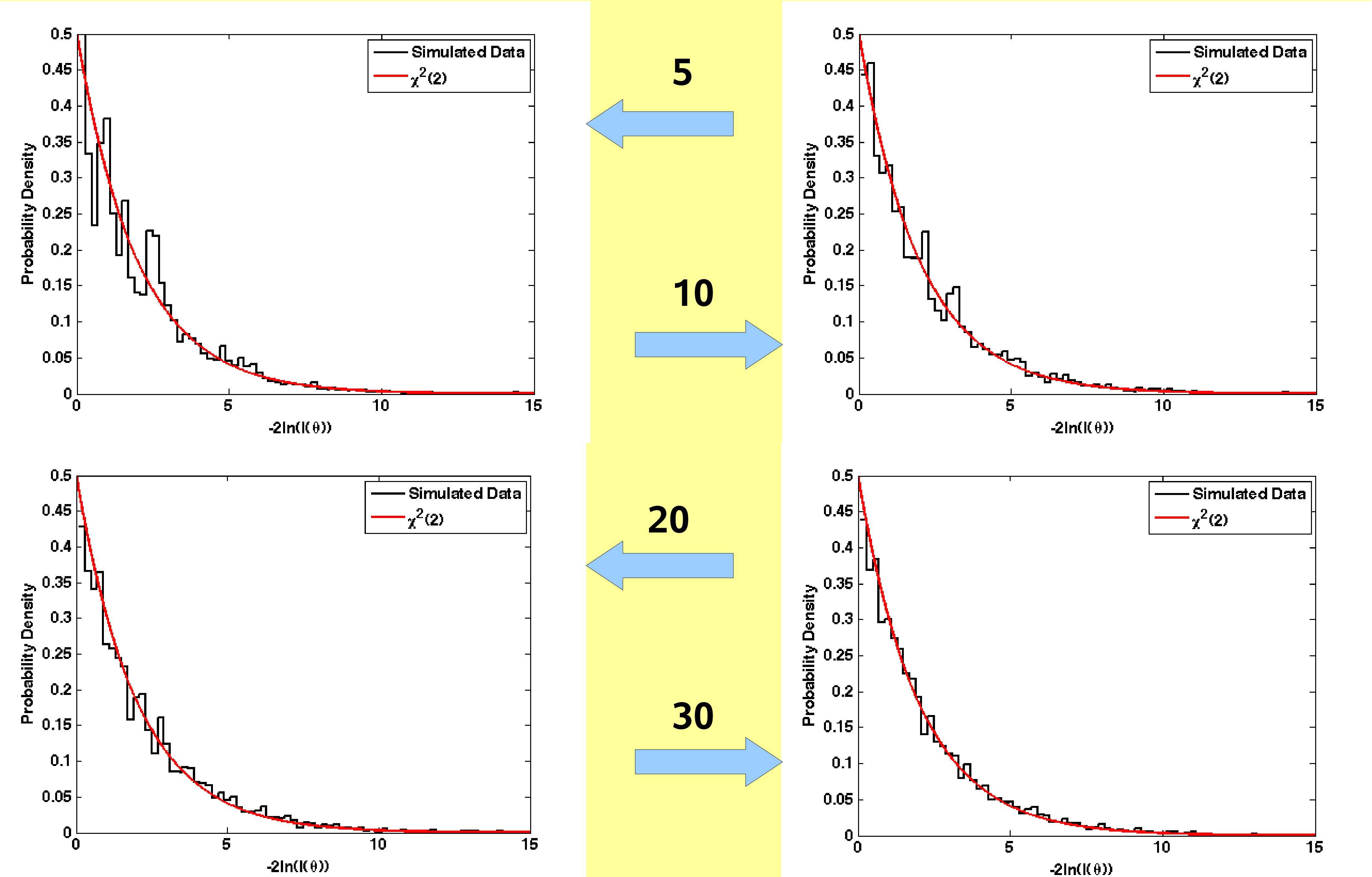
P-value determines the propability that the amount of observed events is caused by a statistical fluctuation of the background.

$$P(n \geq n_{obs}) = 1 - \sum_{n=0}^{n_{obs}-1} \frac{n_b^n}{n!} \cdot e^{-n_b}$$

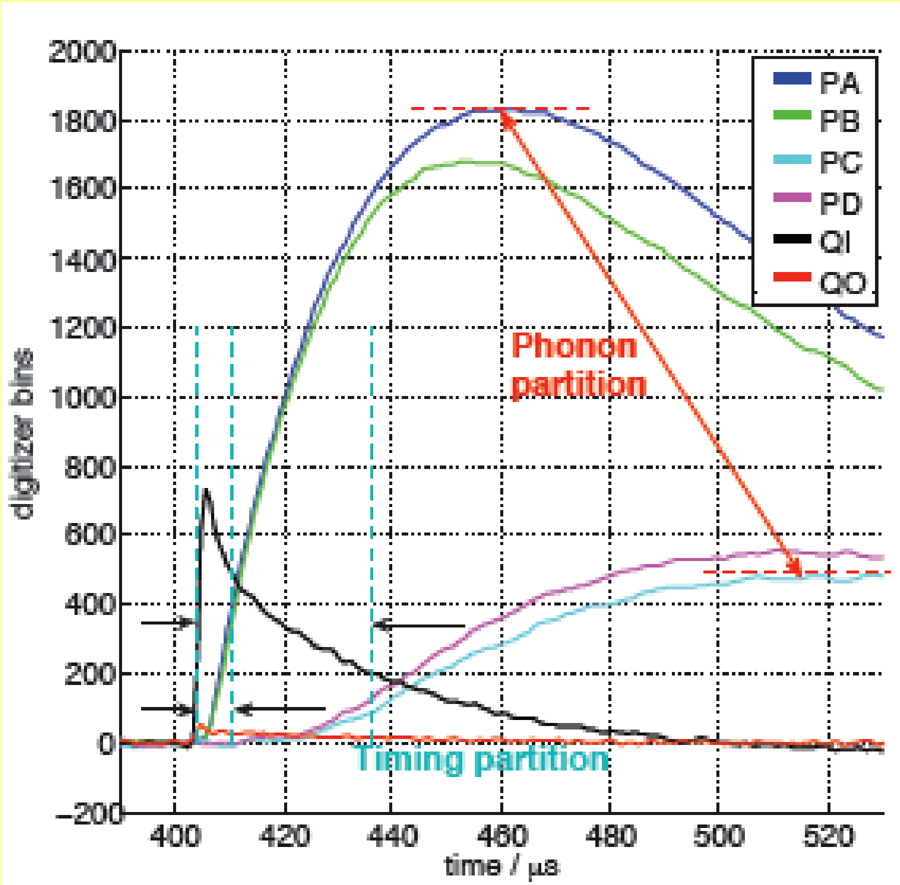
With a low background, the amount of candidate events decreases to reach the same P-value.



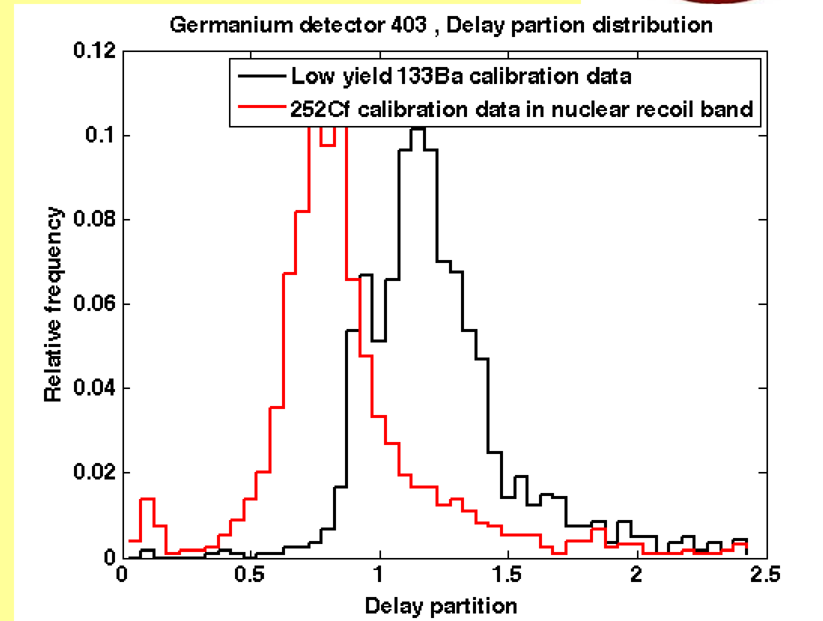
-2ln(L(Θ)) distributions for different numbers of detected events

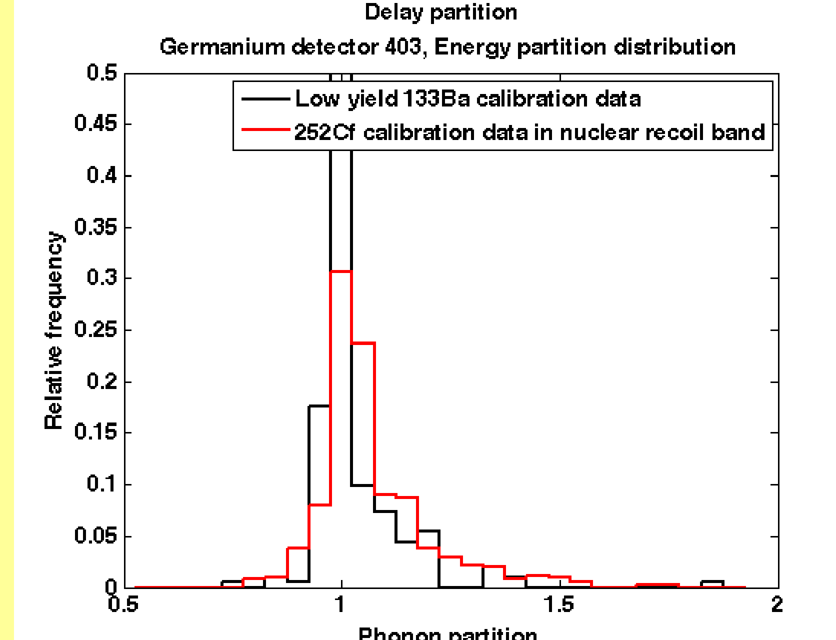


Using more information to select nuclear recoils



thanks to J. Filippini





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

Parameters can be used in a extended timing analysis, to achieve better discrimination.