CRESST Dark Matter Search

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Bethe Forum 2011

CRESST Collaboration
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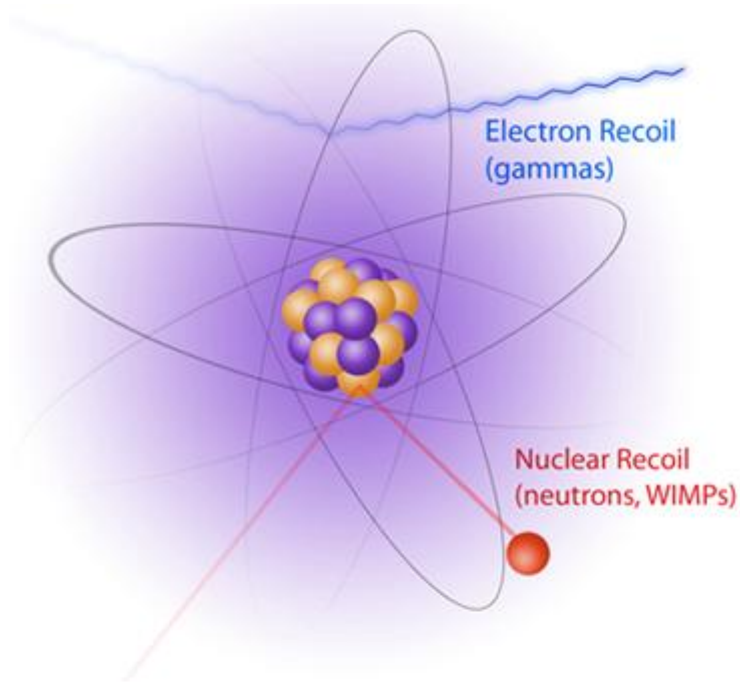
TU München, Universitat Tübingen
Laboratori Nazionali del Gran Sasso

Outline

- WIMP Search with CRESST
- Background Estimation
- Full Analysis Procedure and Results

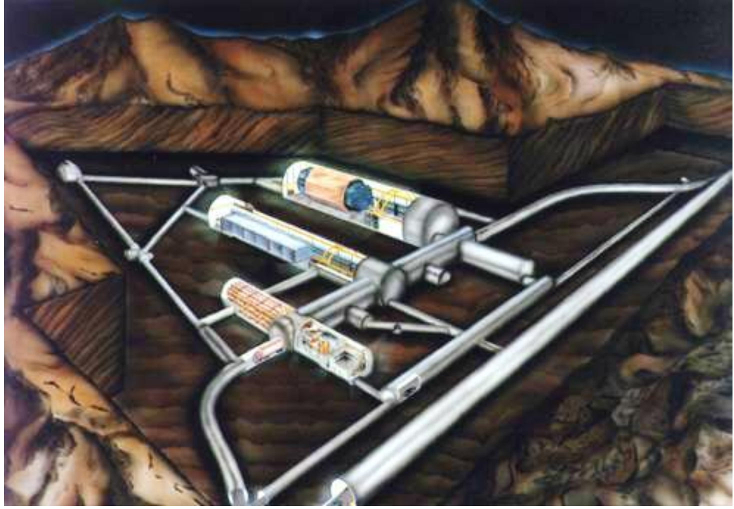
WIMP Detection

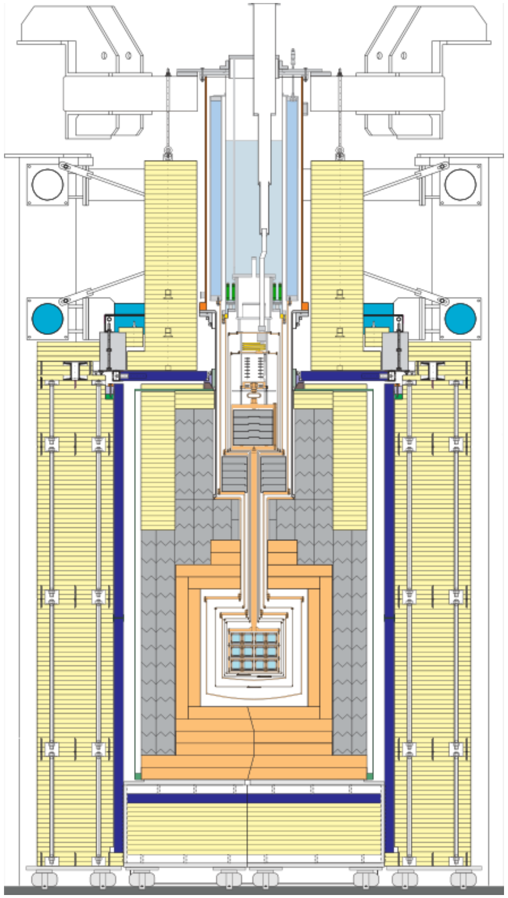
- Expected WIMP mass: GeV – TeV range
- Expected WIMP-nucleon cross section: < 10^{-5} pb
- Coherent scattering off nuclei, $\sigma \sim A^2$
- Signal: nuclear recoils
- Challenges:
  - low rate (few counts per kg year)
  - Small energy transfer (few keV)

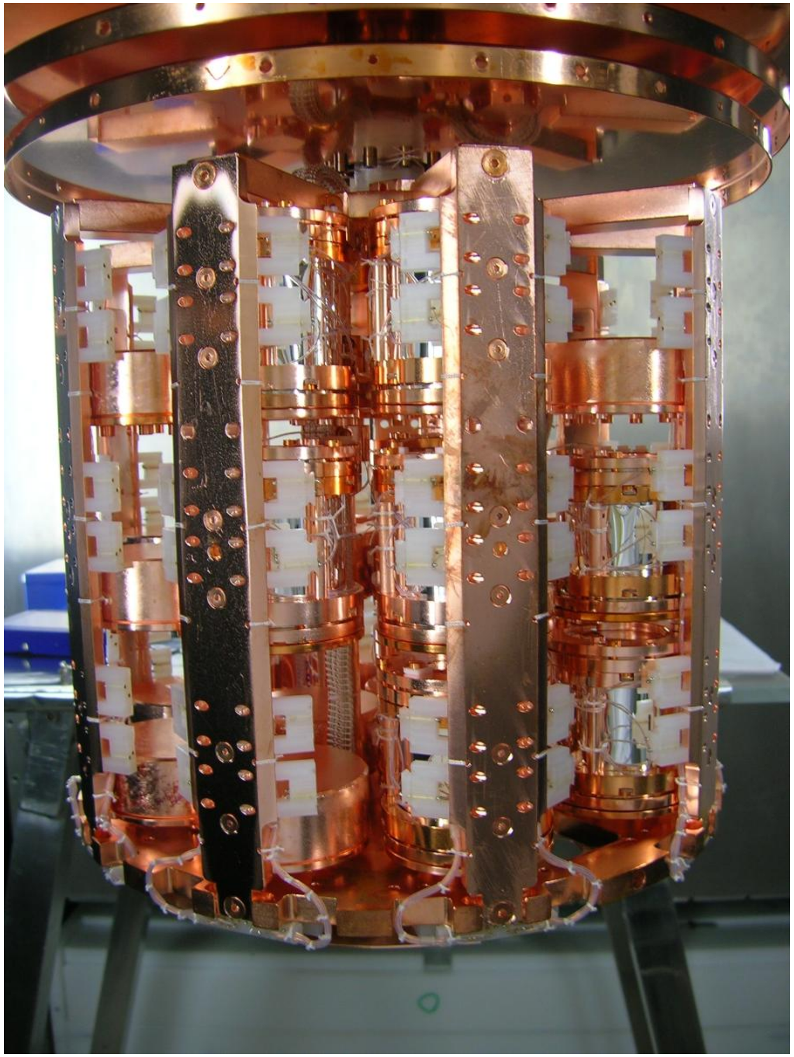


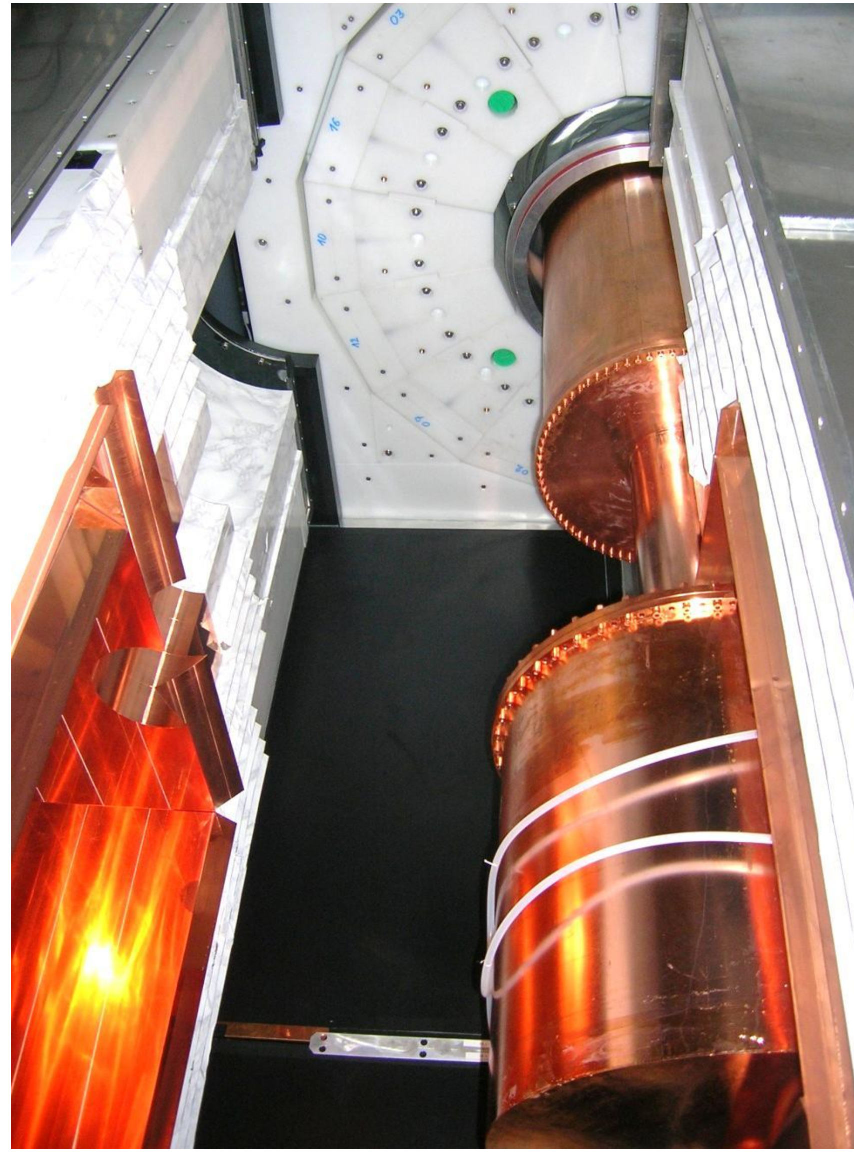
CRESST at LNGS

- Located in Hall A of the LNGS deep underground laboratory
- Shielding of setup:
  - PE (12 tons)
  - Active muon veto
  - Radon box
  - Lead shielding (24 tons)
  - Copper (10 tons)
- Detector carrousel
  - Can currently house up to 33 detector modules at ~10 mK (total target mass for $CaWO_4$: ~10 kg)

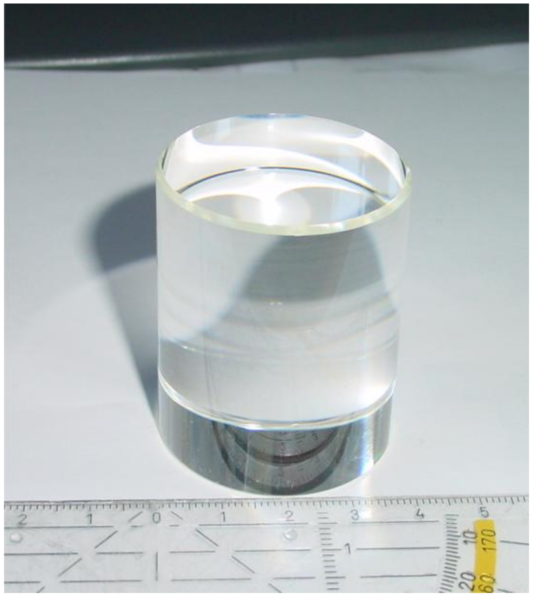




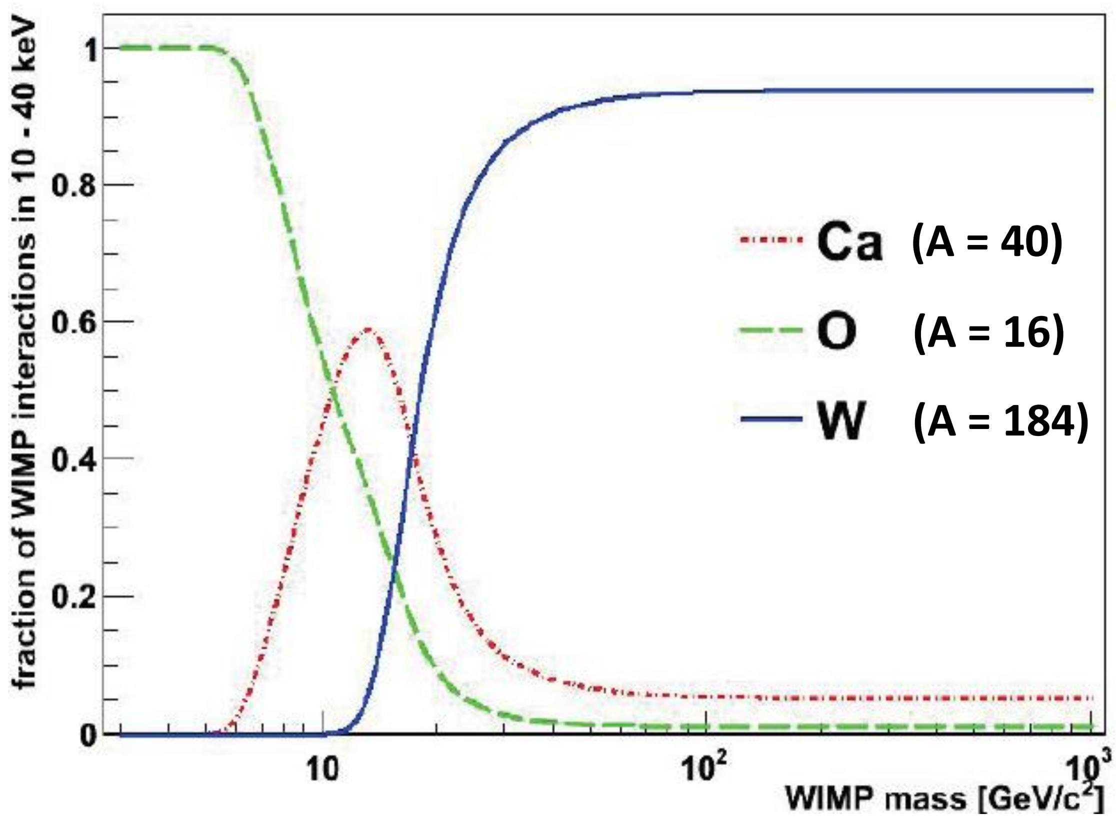




$CaWO_4$ Single Crystals as Target Material



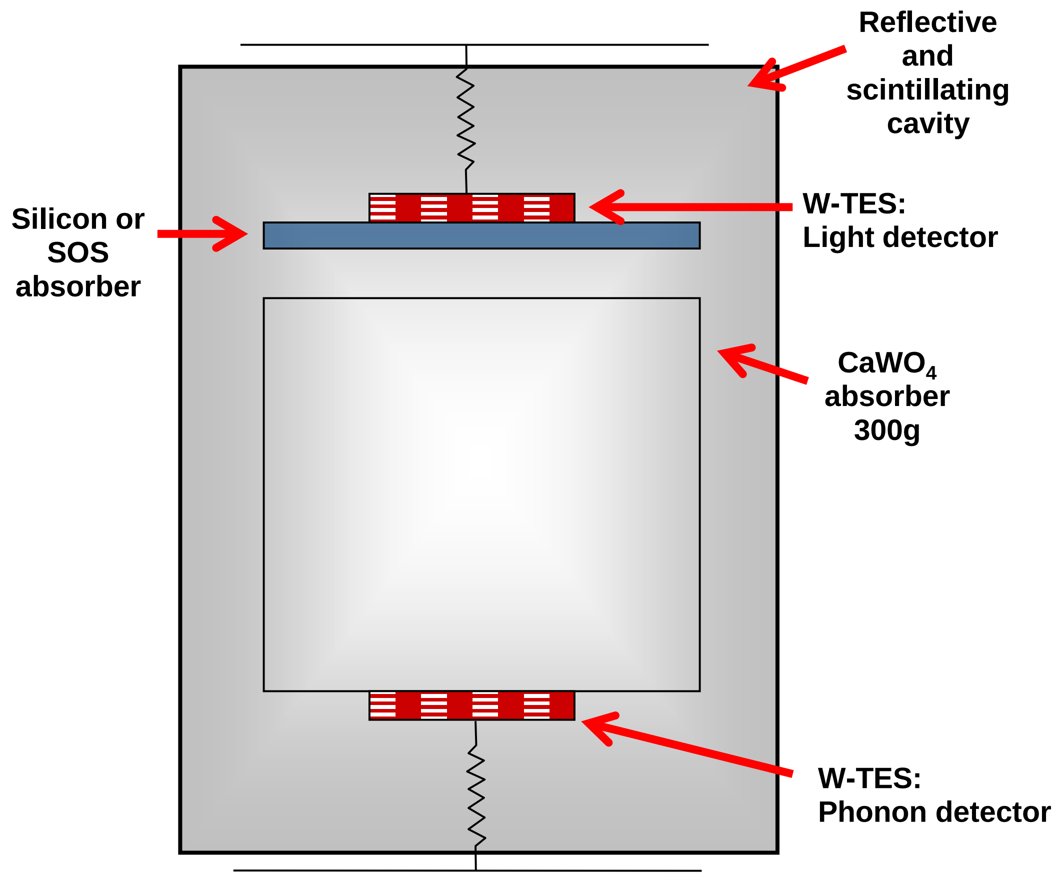
300 g $CaWO_4$ crystal
Diameter: 40 mm
Height: 40 mm

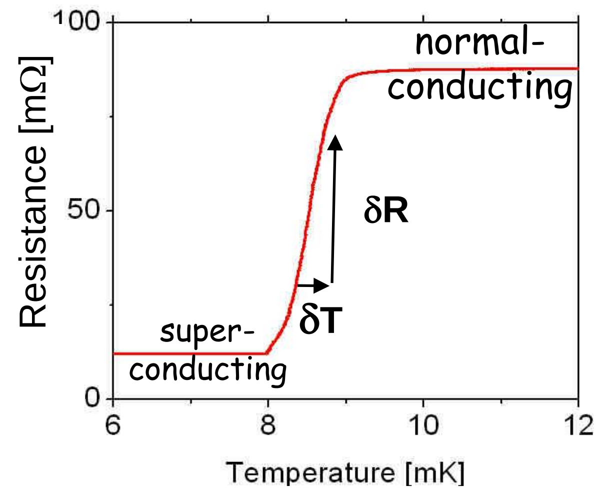


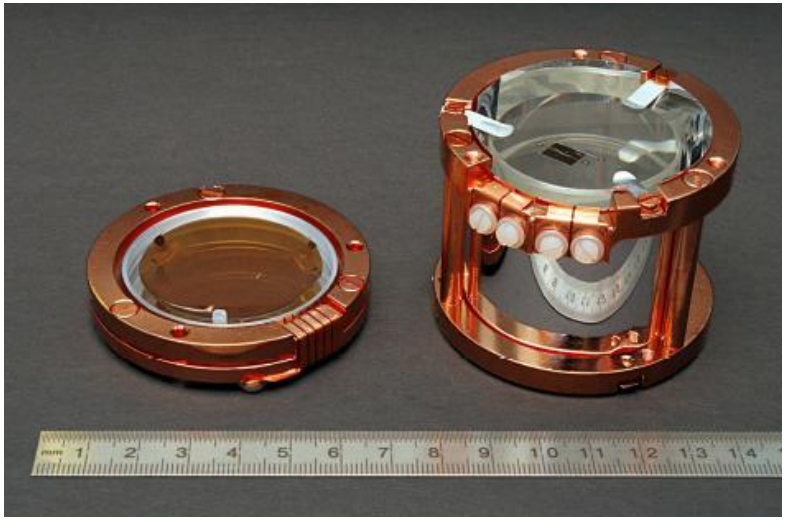
- multi-material target $CaWO_4$: **unique feature of CRESST**

➢ probe for light and heavy WIMPs

CRESST Detector Design





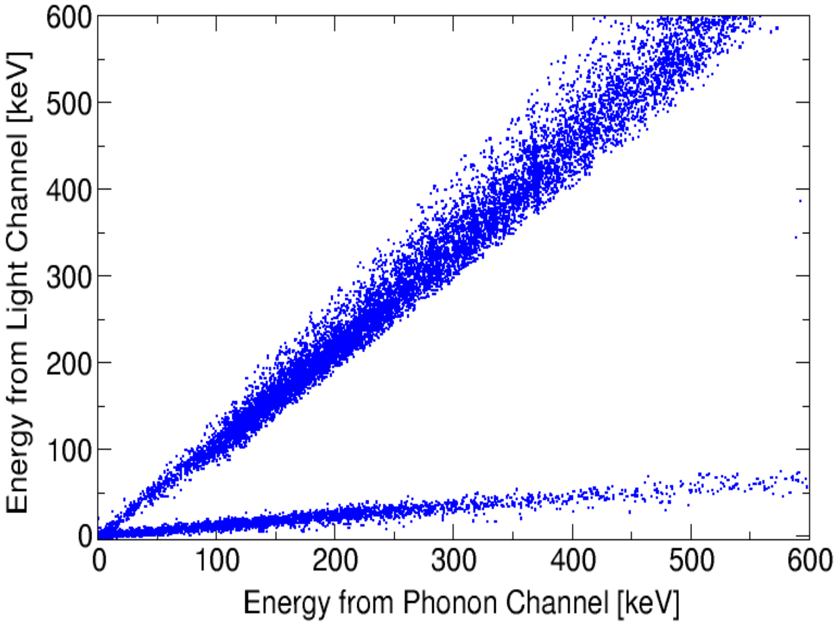


Independent measurement of two signals of a particle interaction:

- Phonon signal (≈ complete energy deposition)
- Scintillation light signal

Detector Response

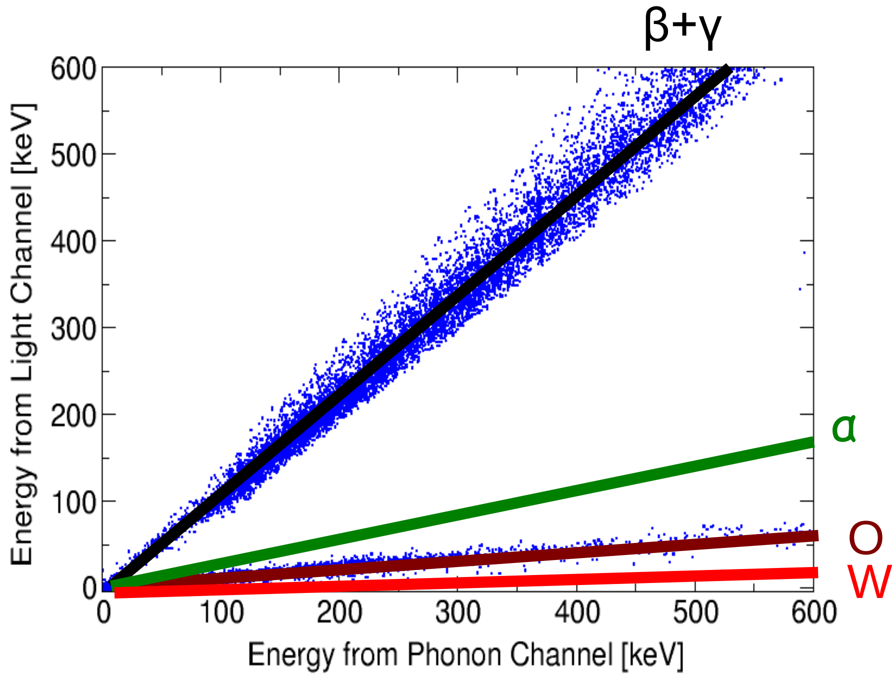
- Energy deposition of a particle interaction visible in both channels:
  - Phonon channel (>95% of total energy)
  - Light channel (~5% for electron recoils)
- Scintillation light output for nuclear recoils quenched compared to electron recoils (er)



Calibration measurement with neutron source

Detector Response

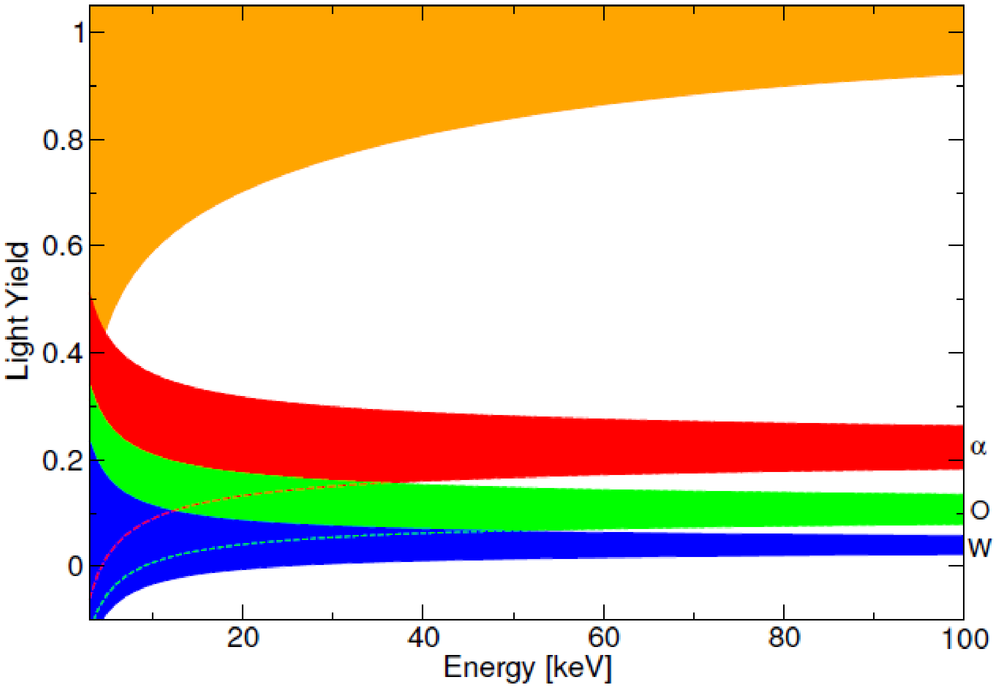
- Energy deposition of a particle interaction visible in both channels:
  - Phonon channel (>95% of total energy)
  - Light channel (~5% for electron recoils)
- Scintillation light output for nuclear recoils quenched compared to electron recoils (er)
- *Quenching Factors*: QF(W) < QF(Ca) < QF(O) < QF(alphas) < QF(er) = 1



Calibration measurement with neutron source

Event Type Discrimination

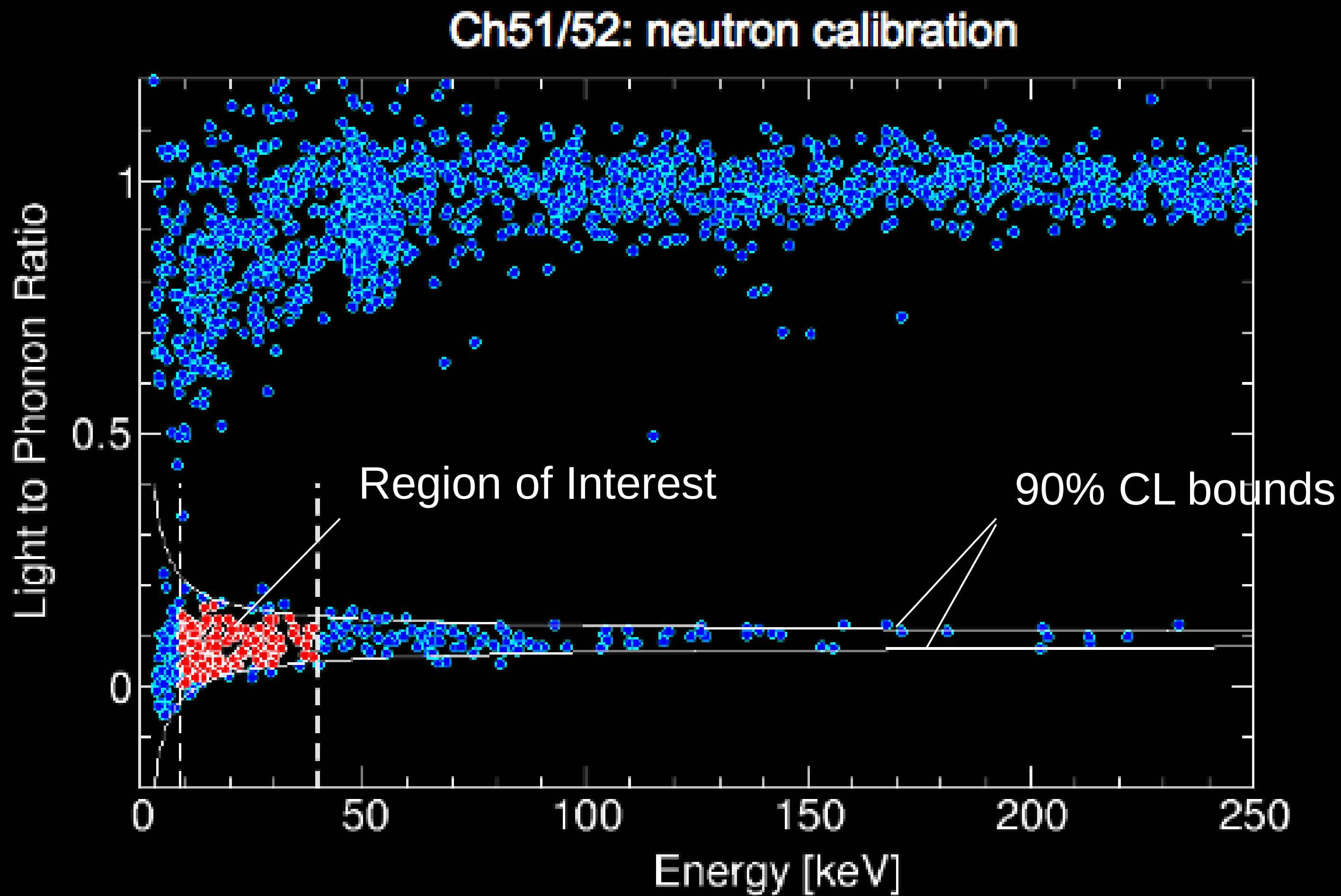
- Light yield defined as E_{light} / E_{phonon}
- QF(er) = 1 (by def)
- QF(alpha) ≈ 0.22
- QF(O) ≈ 0.1
- QF(Ca) ≈ 0.06
- QF(W) ≈ 0.04
- In the signal region, the nuclear recoil bands overlap due to the finite resolution of the light detector



Excellent rejection of electron recoils

Neutron Calibration

Calibration campaign with neutron source (Am-Be)

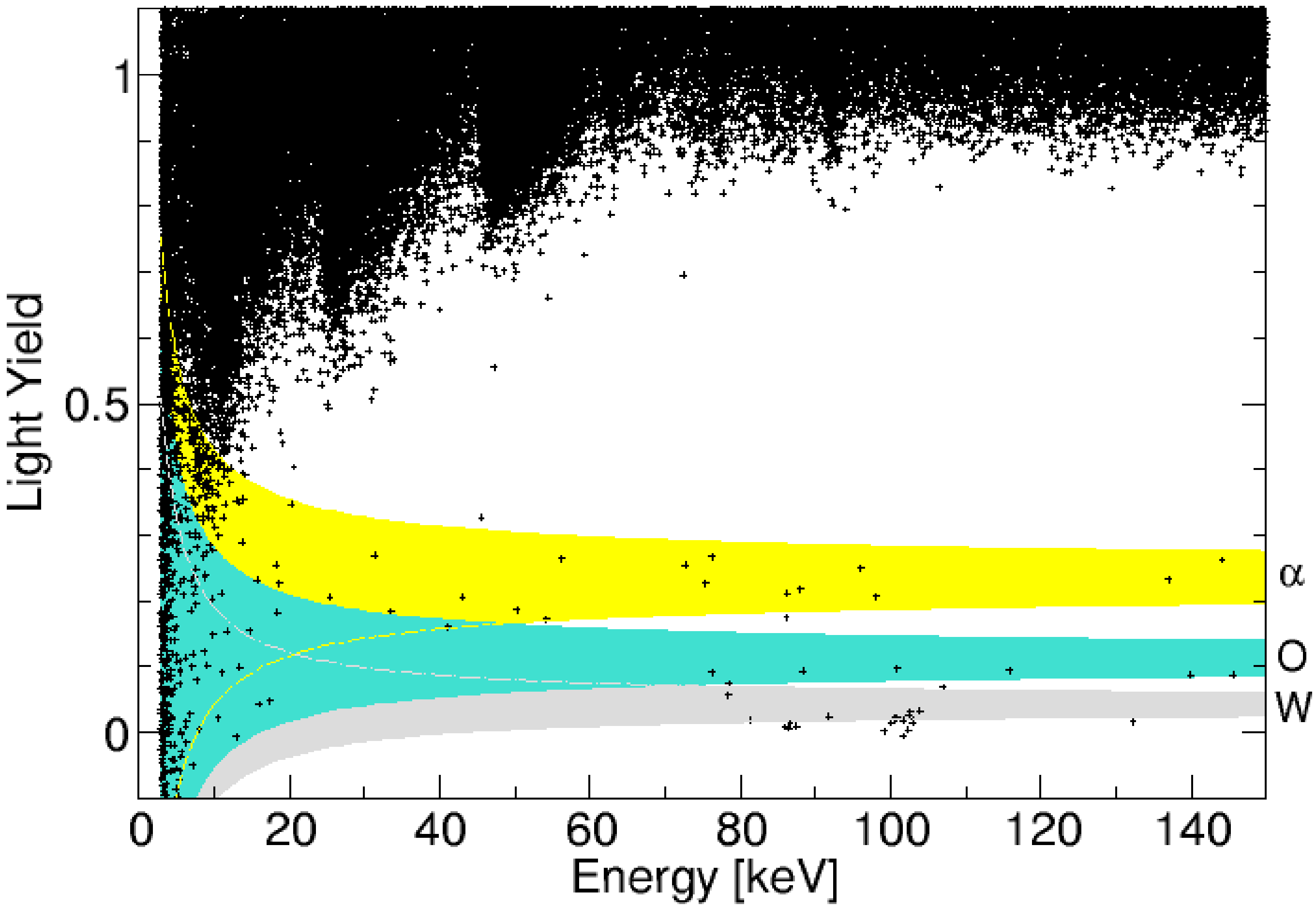


Excellent nuclear recoil discrimination seen in calibration run

The Latest CRESST Run

- June 2009 to April 2011
- 18 detector modules installed
  - 10 complete detector modules (9 $CaWO_4$ and 1 $ZnWO_4$)
  - 8 modules used for analysis
  - 7 additional modules for vetoing of coincident events (i.e. events with multiplicity > 1)
- Total exposure after cuts: 730 kg d

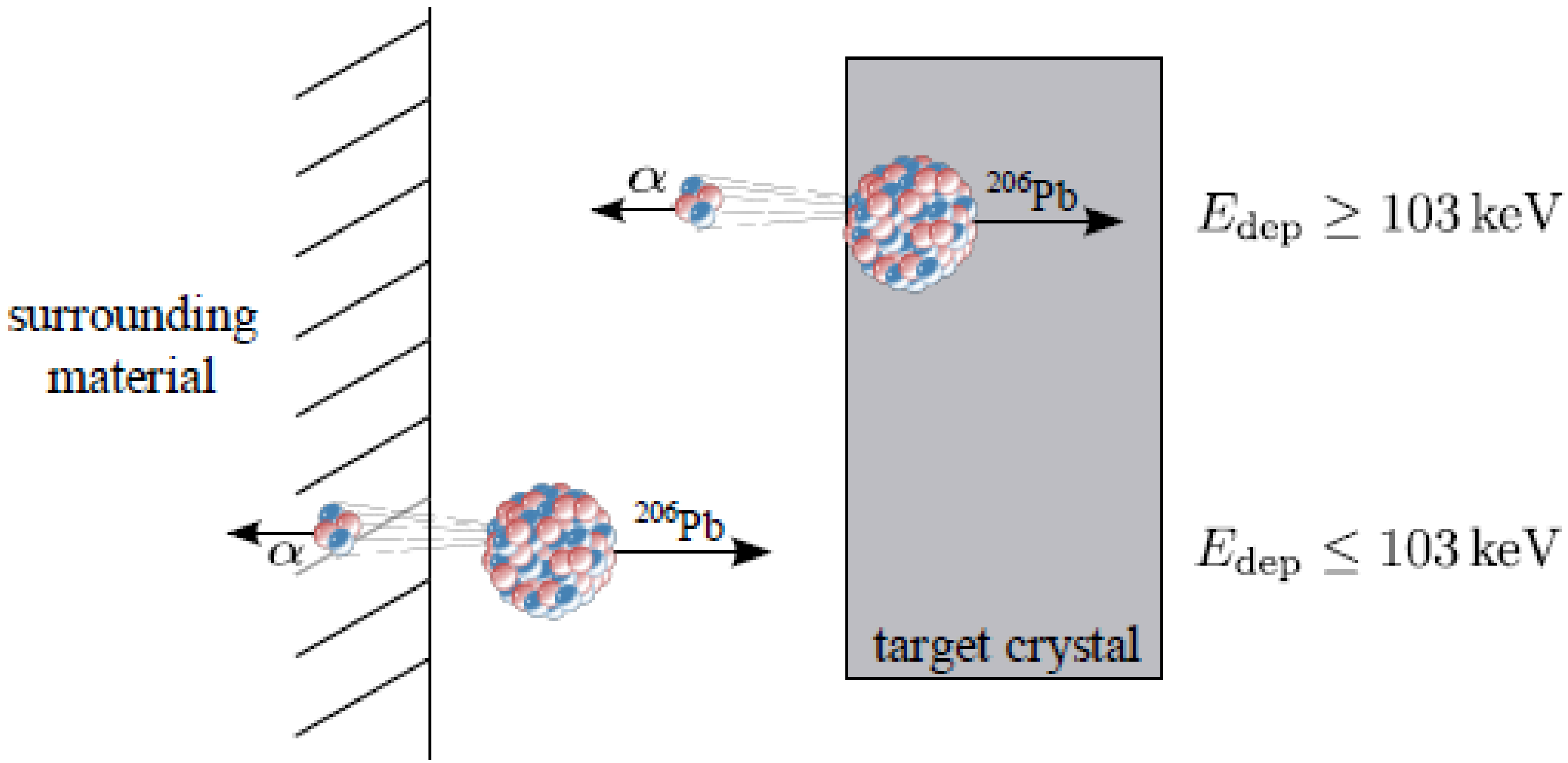
Background Run Example



Possible Background in Signal Region

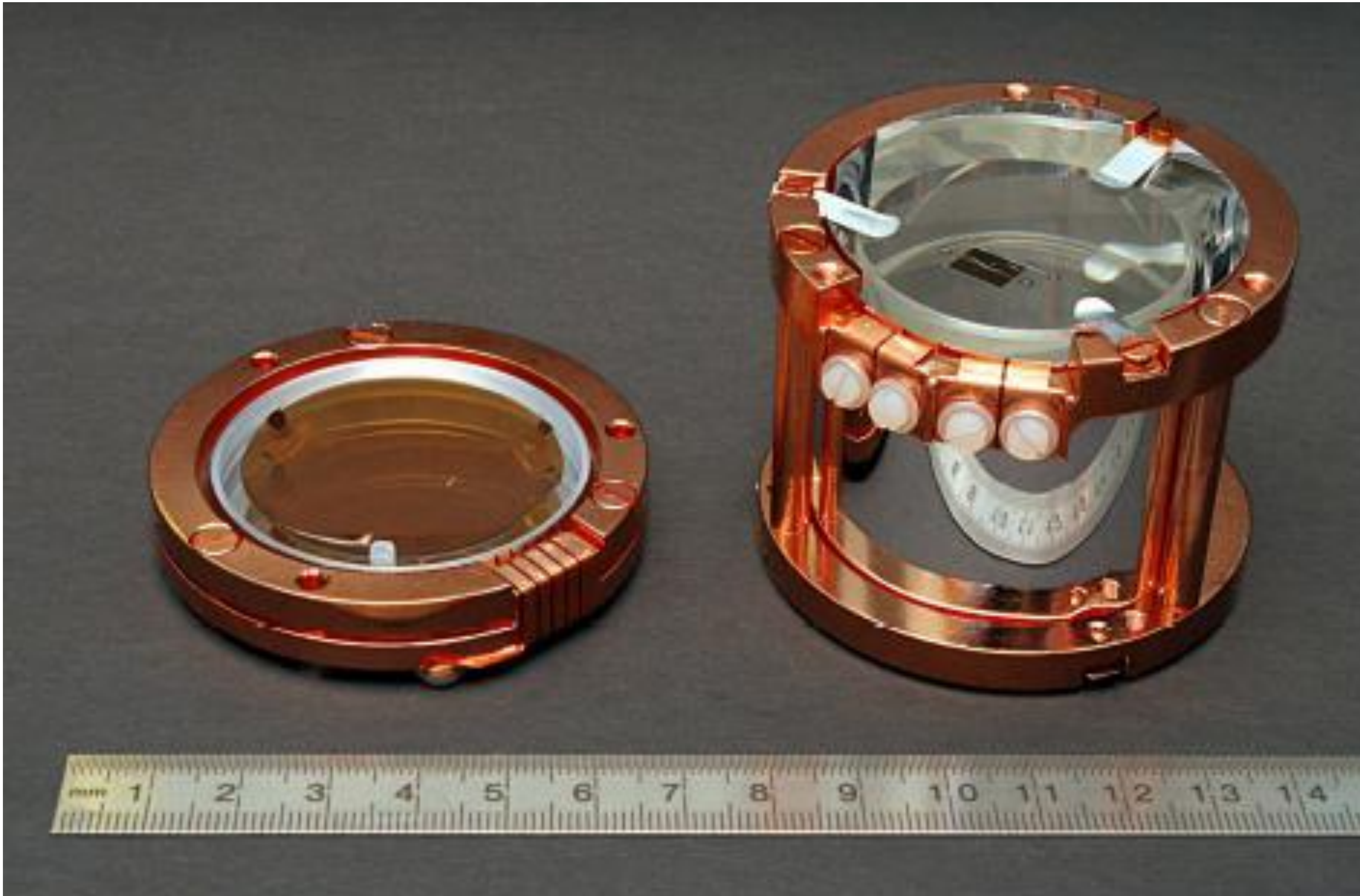
- Gamma leakage (definition of analysis threshold: 1 leaked event per detector module in whole data set)
- Alpha decays (detailed in next slides)
  - Alpha particle interacts with target crystal
  - Heavy nucleus (Pb) interacts with target crystal
- Neutron Background
  - Neutrons produced by natural radioactivity
  - Muon induced neutrons (can be estimated by multiplicity of muon induced events, see below)

Alpha Background



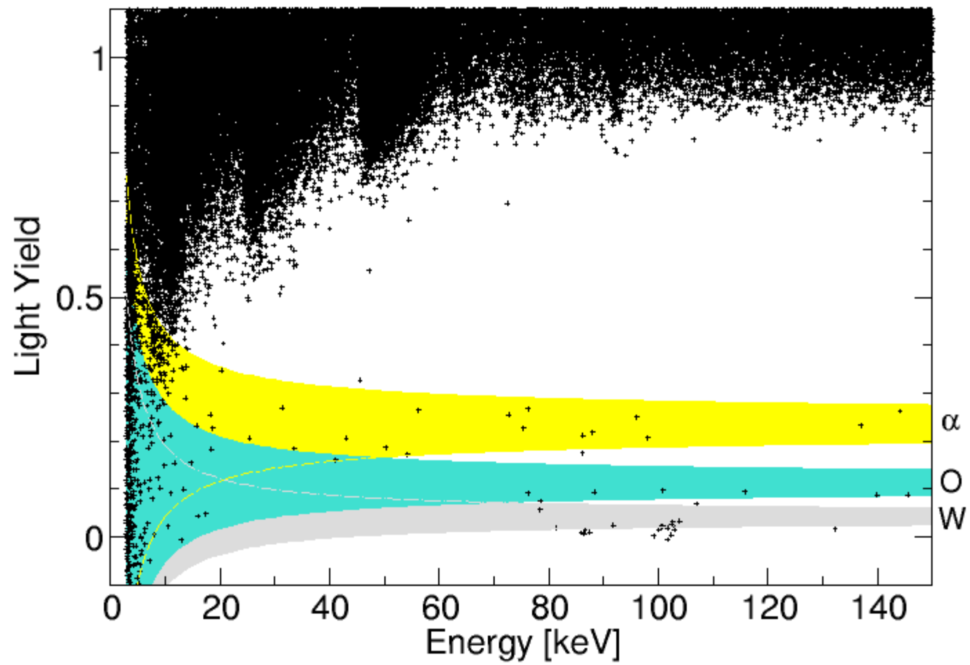
Alpha Background

- Possible alpha decay scenarios:
  - Internal alpha decay
    → several MeV energy deposition in target crystal, no leakage in signal region
  - Surface alpha decay
    - alpha hits crystal, heavy nucleus (Pb) hits scintillating /reflective foil
      →several MeV energy deposition in target crystal
    - Heavy nucleus hits crystal, alpha hits scintillating/reflective foil
      →high light yield due to scintillating foil
    - Heavy nucleus hits crystal, alpha hits passive detector material (i.e. clamp)
      → ≈ 100 keV deposited in crystal by heavy nucleus (signal region: up to 40 keV)
  - Nucleus implanted in passive detector material (i.e. clamps)
    - Alpha hits target crystal, previous loss of arbitrary amount of energy in clamp
      → degenerated alpha
    - Heavy nucleus hits target crystal
      →leakage of lead recoils in signal region


mm 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Overview: Observed Event Classes

- Bulk of events are electron recoils
- Degenerated alphas
- Pb recoils at 103 keV and lower
- Nuclear recoil events on O, Ca and W



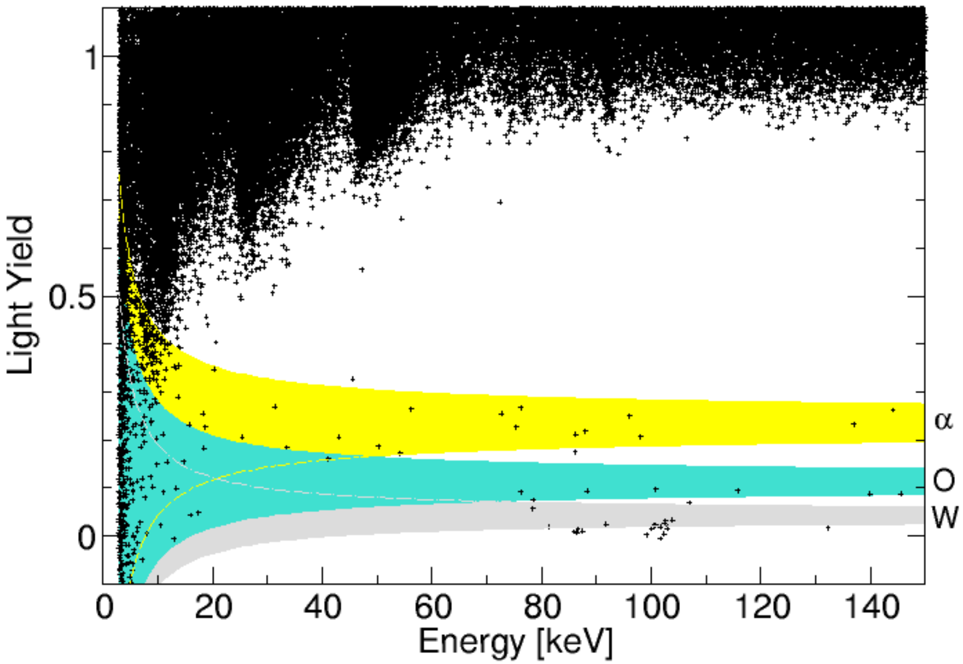
Complete data for whole run of one exemplary module

Parametrization of Background Events I – Electron Recoils

- Leakage expected at **high light yield** and **low energy threshold**
- Over complete run: High statistics of electron recoils
  - → very good description of electron recoil band at all energies
  - → definition of signal region:
    - E_{min} : 1 leakage event for whole run and detector module. E_{min} thus individual for each detector
    - E_{max} = 40 keV (contribution of WIMP signal above 40 keV negligible.)

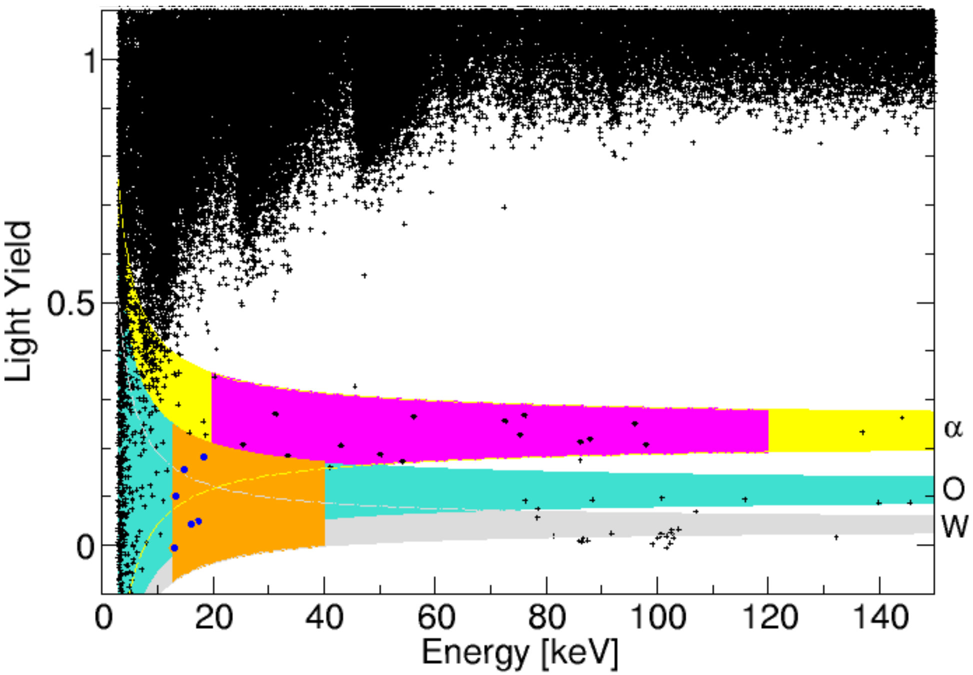
Parametrization of Background Events II – Alpha Recoils

- Degenerated alphas observed at all energies



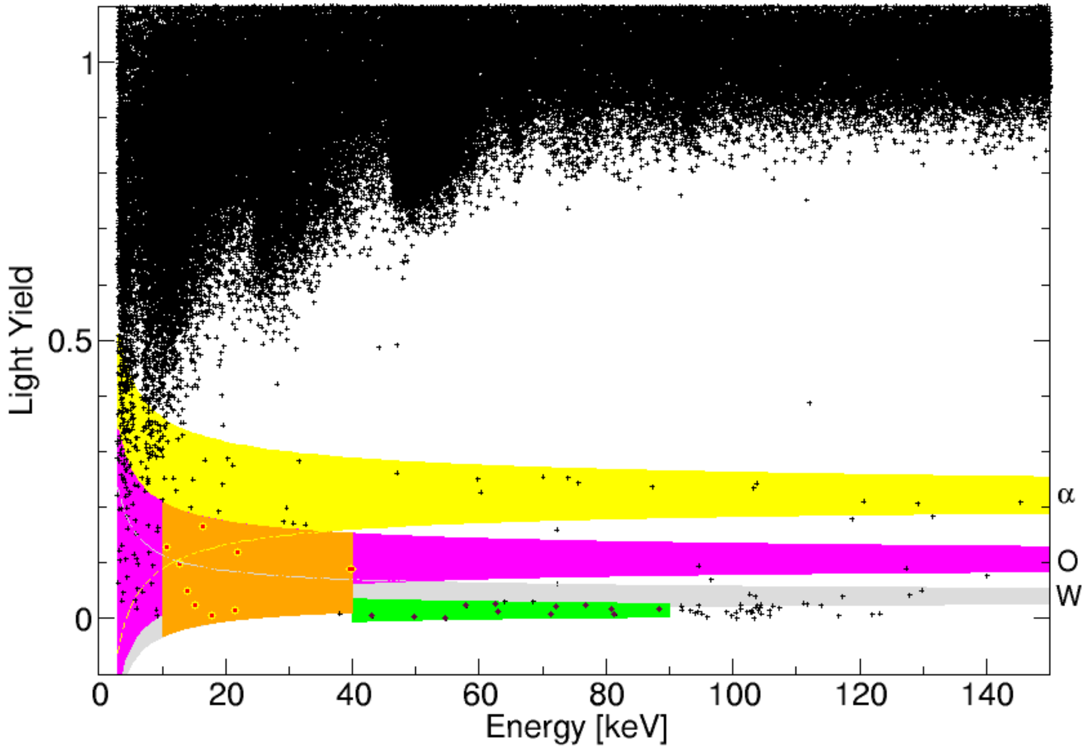
Parametrization of Background Events II – Alpha Recoils

- Degenerated alphas observed at all energies
- Define **overlap free reference region** for alpha recoils: Observed energy spectrum of these events: flat $dN_{alpha}/dE = const$ (but individual for each detector)
- Based on the resolution of the light detector, the total background contribution of alpha recoils can be estimated for all detectors

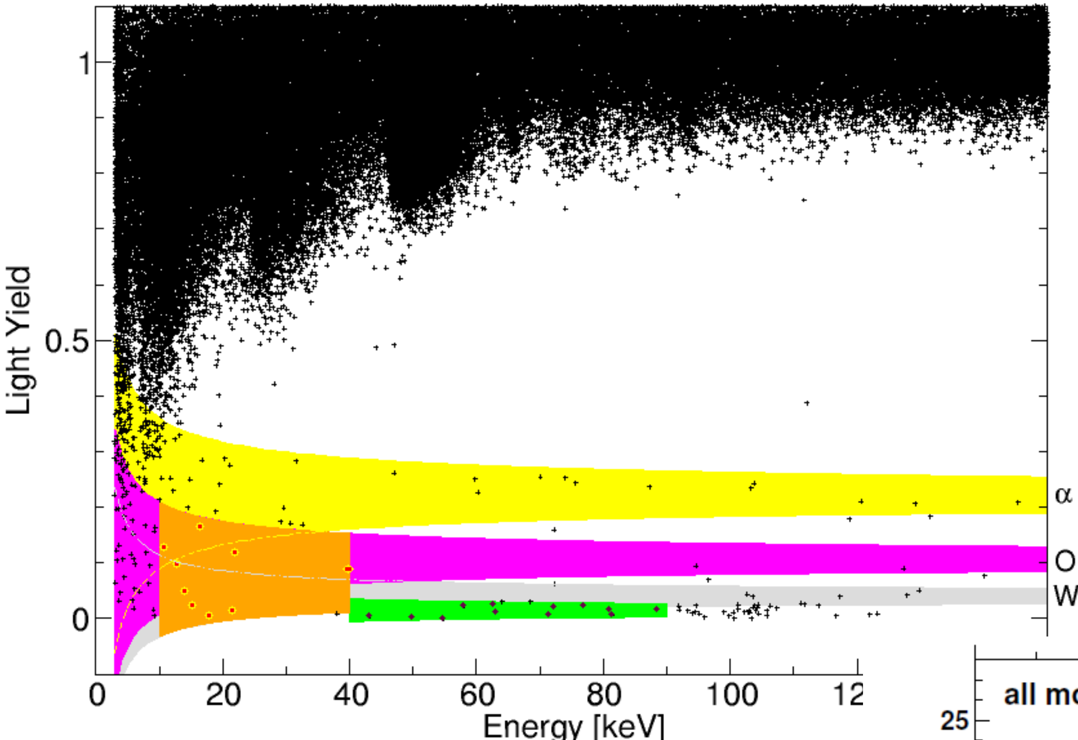


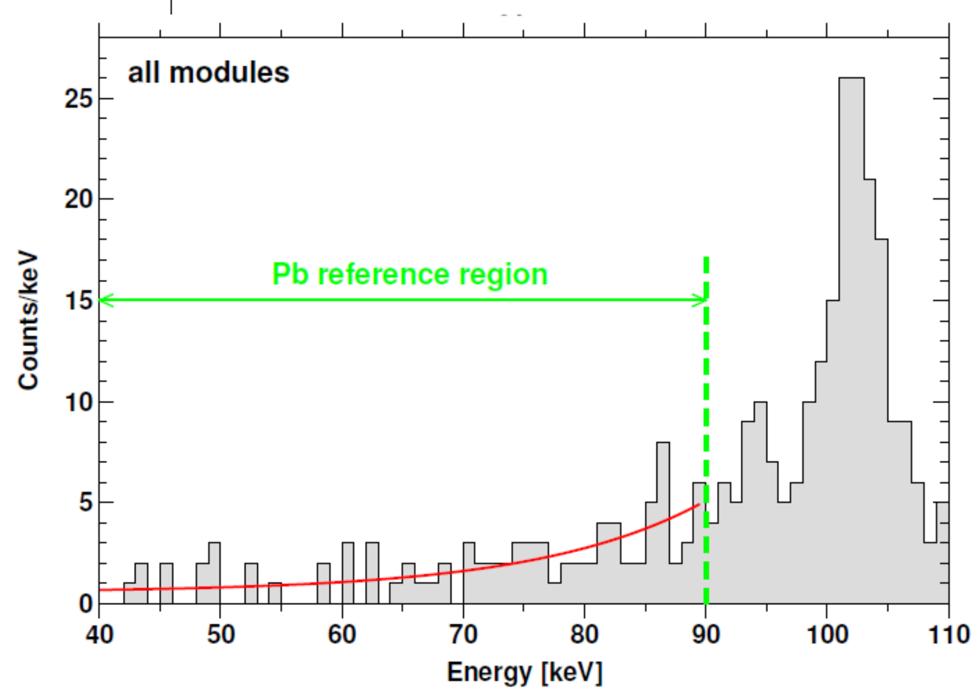
→ Simple estimate:
9.2 events for all detectors and complete run

Parametrization of Background Events III – Lead Recoils



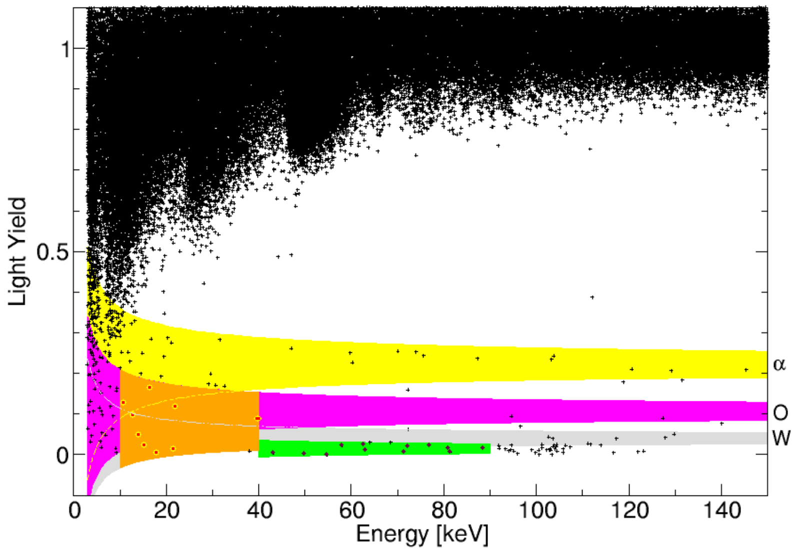
ckground Events
ecoils

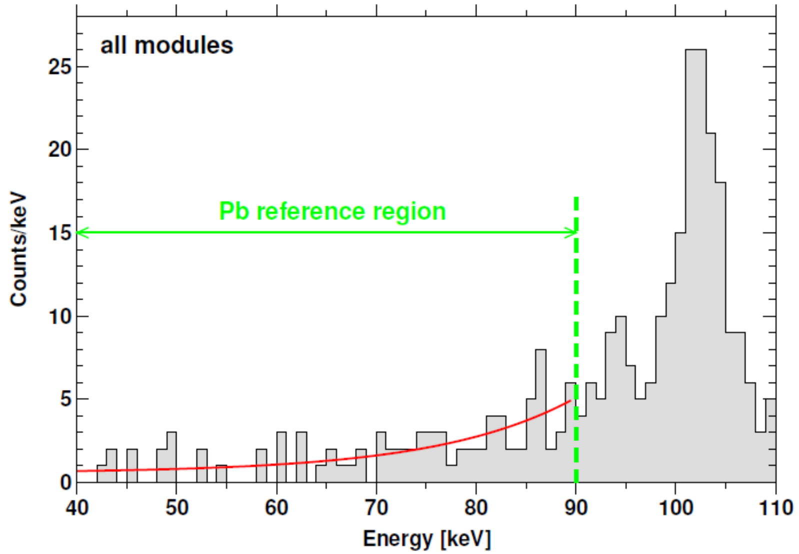




Parametrization of Background Events III – Pb Recoils

- Distribution of Pb recoils can have tail to low energies, they behave similar to W-recoils
- Define **overlap free reference region**
- Parametrize observed spectrum
- Extrapolate to signal region
- Simple estimate:
  17 events for all detectors and complete run

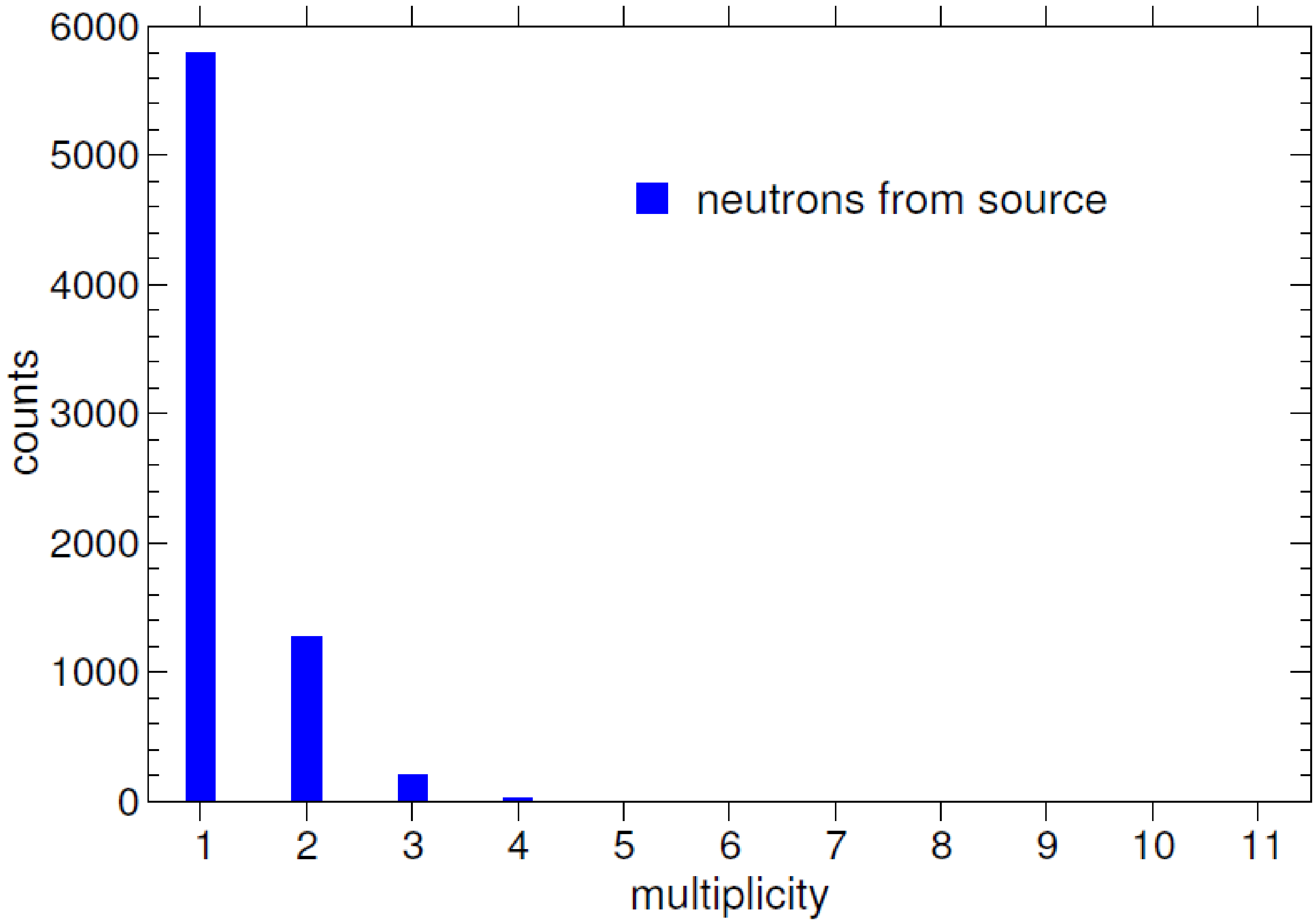




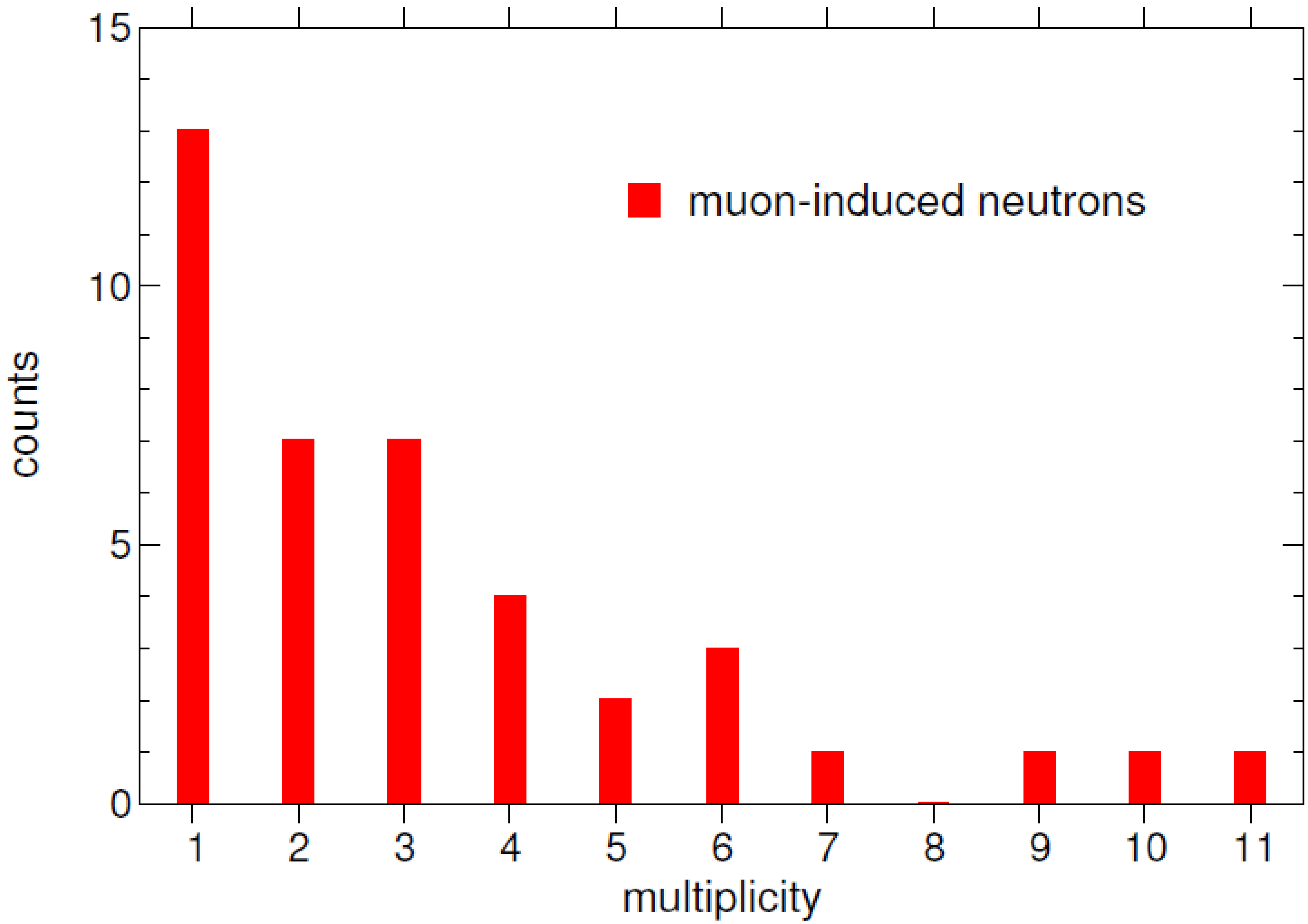
Parametrization of Background Events IV – Neutrons

- Based on stoichiometric and kinematic arguments, neutrons are mainly visible as oxygen recoils (similar to light WIMPs)
- Event multiplicity: neutrons can interact in more than one detector module, leading to coincident events in the detector array
- In the data set, 3 coincident events were observed in the acceptance region:
  - Two with multiplicity 3
  - One with multiplicity 5
- Causes: a) radioactive processes inside neutron shielding
  b) neutrons are muon induced
- To estimate neutron background: Calculate the expected number of events with multiplicity = 1, if 3 events with multiplicity > 1 were observed in the signal region

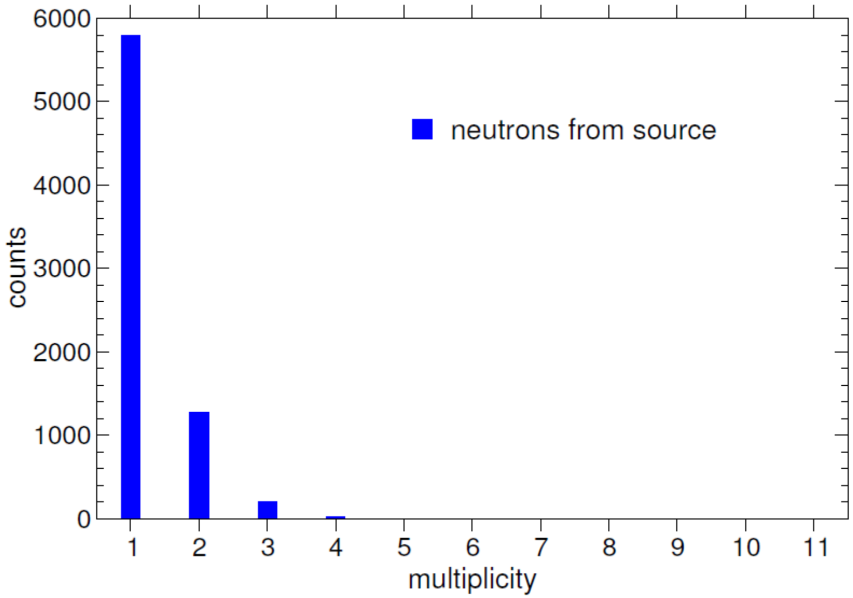
Observed Event Multiplicity Neutron Calibration AmBe source

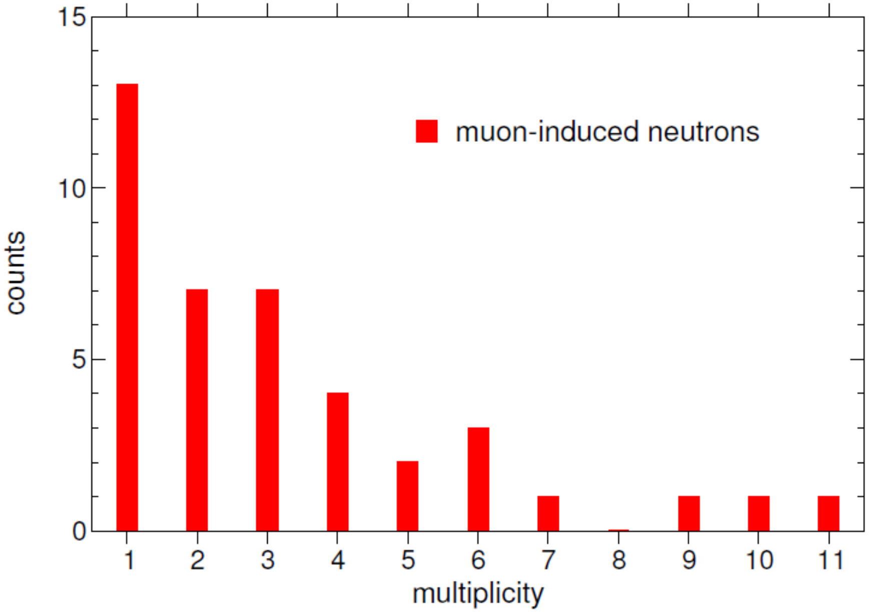


Observed Event Multiplicity
Muon Coincident Neutrons



Parametrization of Background Events IV – Neutrons





- Neutron source: single/coincident ≈ 3.8
  - → if 3 coincident events are observed, 11.4 single events are estimated
- Muon coincident: single/coincident ≈ 0.5
  - → if 3 (unvetod by the muon veto) coincident events are observed, 1.5 single events are estimated

Simple Estimates Summary

- Electron Recoils: 8 events
- Degenerated alphas: 9.2 events
- Pb recoils: 17 events
- Neutron background: 1.5 - 11.4 events
- Total: 35.7 – 45.6 events
- Total observed events: 67

- Excess above considered background events observed

Full Likelihood Analysis

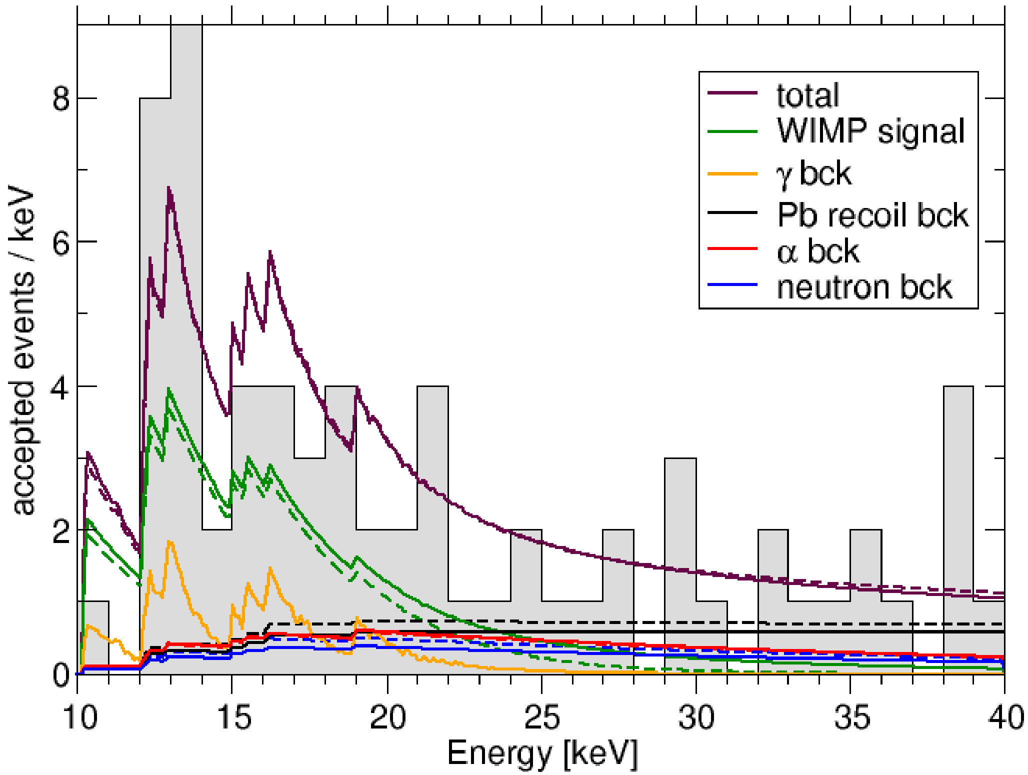
- The full analysis takes into account
  - All spectra in the reference regions
  - The light yield of each event
  - Spectral distribution of neutron calibration
  - Observed and expected multiplicities
  - the individual resolution and signal region of each detector module
  - A possible WIMP signal to explain the excess events
- Full likelihood analysis yields similar results to simple estimates (as is expected)

Full Likelihood Analysis Results

- Likelihood function shows two maxima for the WIMP parameters (M1 and M2)
  - M1 is the global maximum
  - M2 only slightly disfavoured with respect to M1
- Best fit values:

	M1	M2
e/γ-events	8.00 ± 0.05	8.00 ± 0.05
α-events	$11.5^{+2.6}_{-2.3}$	$11.2^{+2.5}_{-2.3}$
neutron events	$7.5^{+6.3}_{-5.5}$	$9.7^{+6.1}_{-5.1}$
Pb recoils	$15.0^{+5.2}_{-5.1}$	$18.7^{+4.9}_{-4.7}$
signal events	$29.4^{+8.6}_{-7.7}$	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

The Two Maxima: Phonon Channel

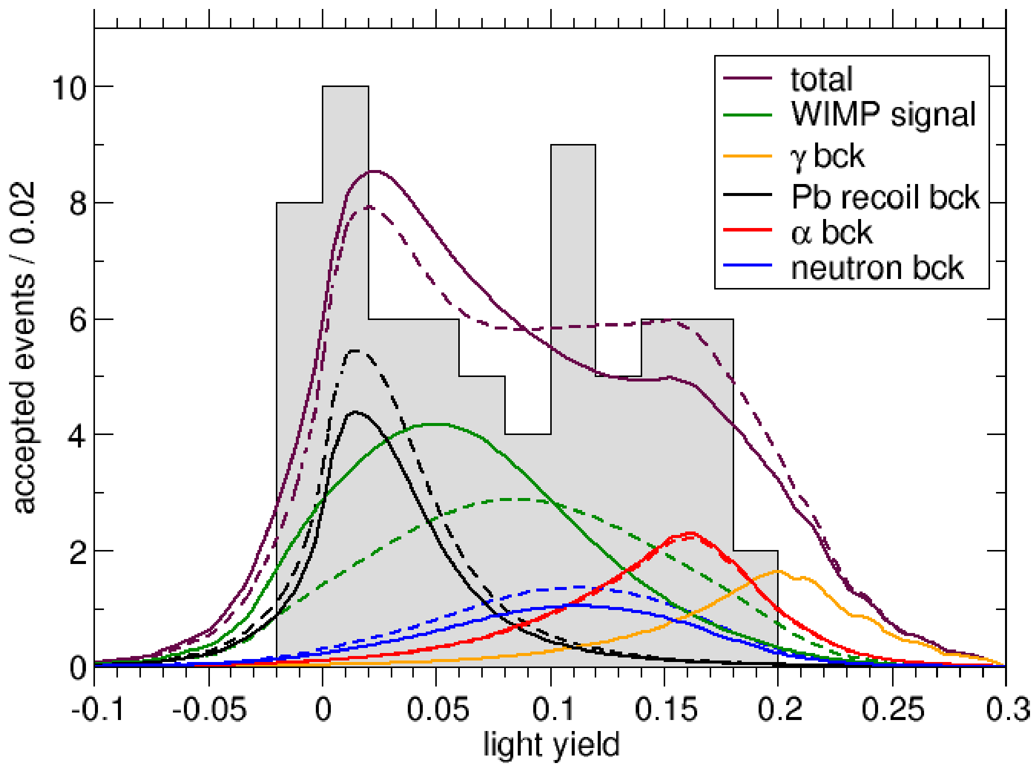


Solid lines: M1
Dashed lines: M2

Spectral shape: Pb recoils and alpha background **do not** reproduce observed excess events.

Gamma events?

The Two Maxima: Light Channel



Solid lines: M1

Dashed lines: M2

Gamma events?

Gamma events are at high light yield compared to excess events.

The Two Maxima: Composition

- M1 and M2 give nearly identical spectra in the phonon channel
- Composition of recoiling nuclei is different, thus leading to a different light yield distribution of the signal events:
  - M1: Mass ≈ 25.3 GeV
    7% oxygen, 25% calcium, 69% tungsten
  - M2: Mass ≈ 11.6 GeV
    52% oxygen, 48% calcium, 0% tungsten

Significance

- Fitting the observed events once with a WIMP contribution and once without
- Calculate the likelihood ratio for both maxima:

  M1: 4.7 σ
  M2: 4.2 σ
- Interpretation: Considered background is not sufficient to explain observation

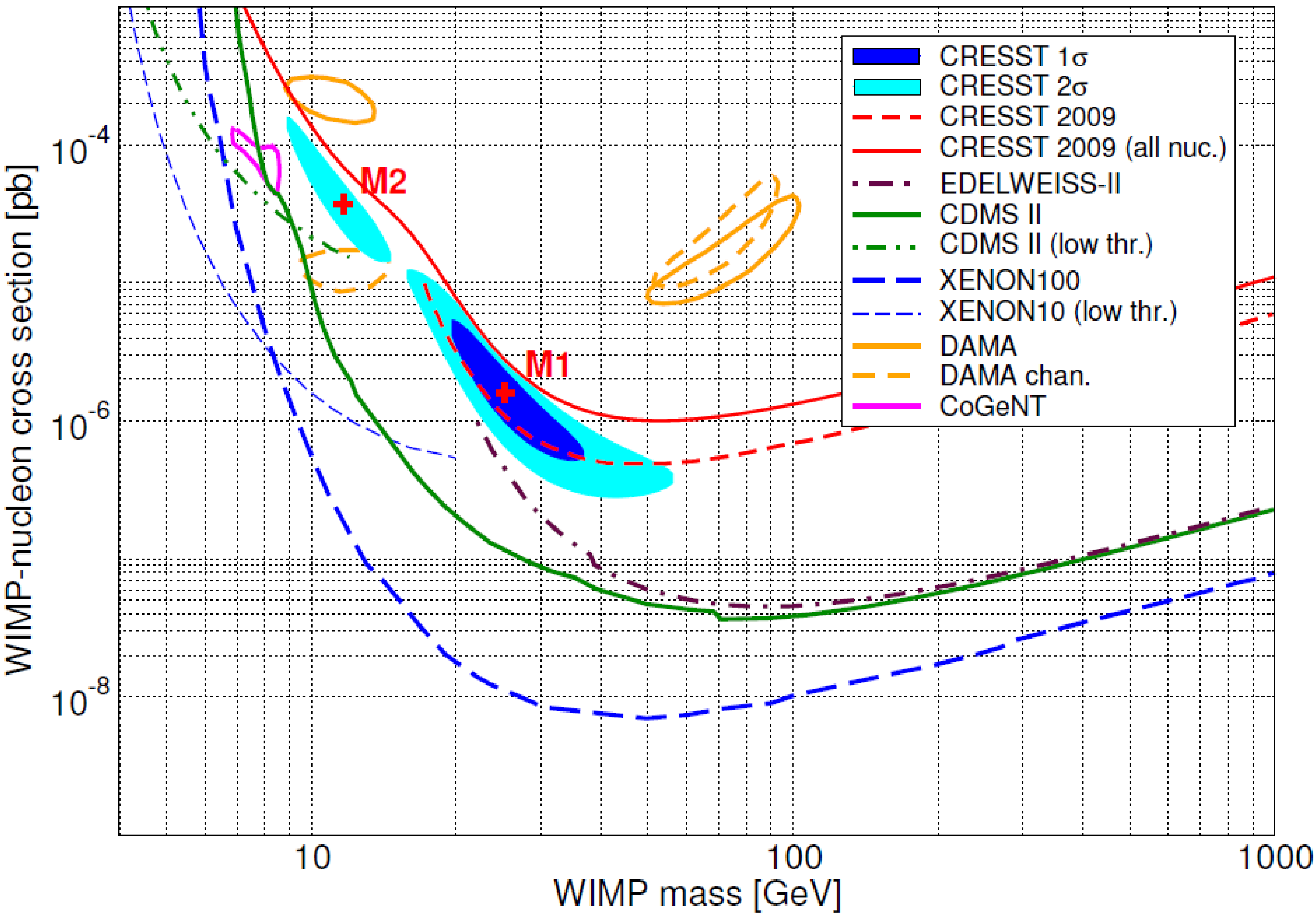
  → **additional source of events needed**

  → WIMPs are a **possible** source for the excess events

- However: Background is still relatively large
  - Main background source coming from non-scintillating clamps

    → goal for next run: clarify possible signal by reducing the observed background

WIMP Parameter Space



Concluding Remarks

- Successful physics run of CRESST:
  - Total exposure after cuts: 730 kg days
  - 67 events observed in signal region
- Detailed background analysis does not explain the observed events. An additional source for events is needed.

  → The expected properties of WIMPs can explain the signal excess
- Paper submitted to European Physical Journal C, arXiv: 1109.0702
- Outlook:
  - New clamps to reduce alpha and Pb background significantly currently in production
  - Additional shielding currently under discussion
  - Increase of target mass planned
  - Next run scheduled to start early next year