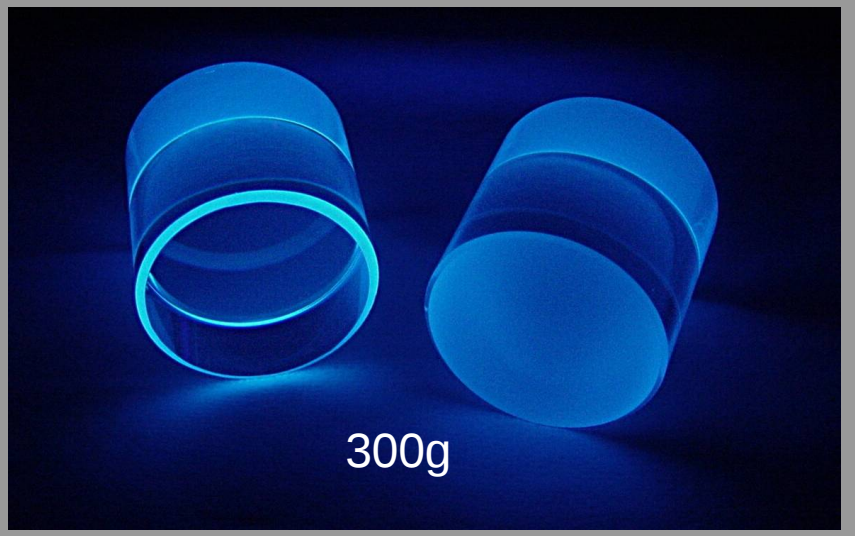
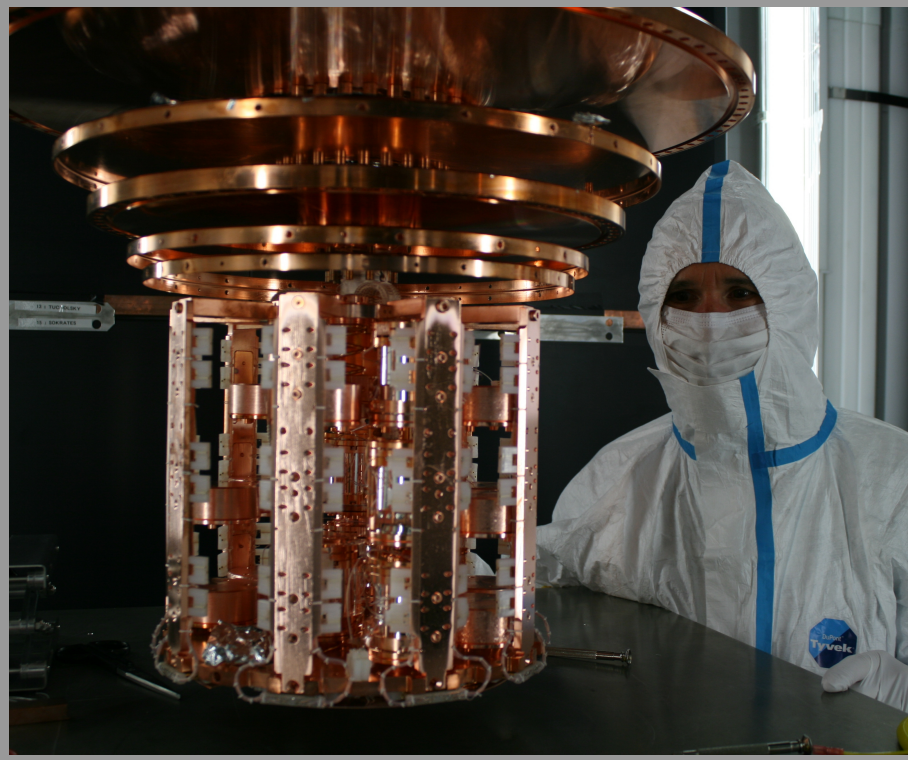
Search for low mass WIMPs with CRESST

Collaboration

MPI für Physik, TU München
Institut für Hochenergiephysik Wien
University of Oxford, Universität Tübingen
Laboratori Nazionali del Gran Sasso



- Scintillating $CaWO_4$ target crystals
- Cryogenic detectors @T≈15 mK
- Nuclear recoil discrimination via measurement of phonons and scintillation light
- Located in hall A of LNGS



Franz Pröbst, MPI Munich, for the CRESST collaboration

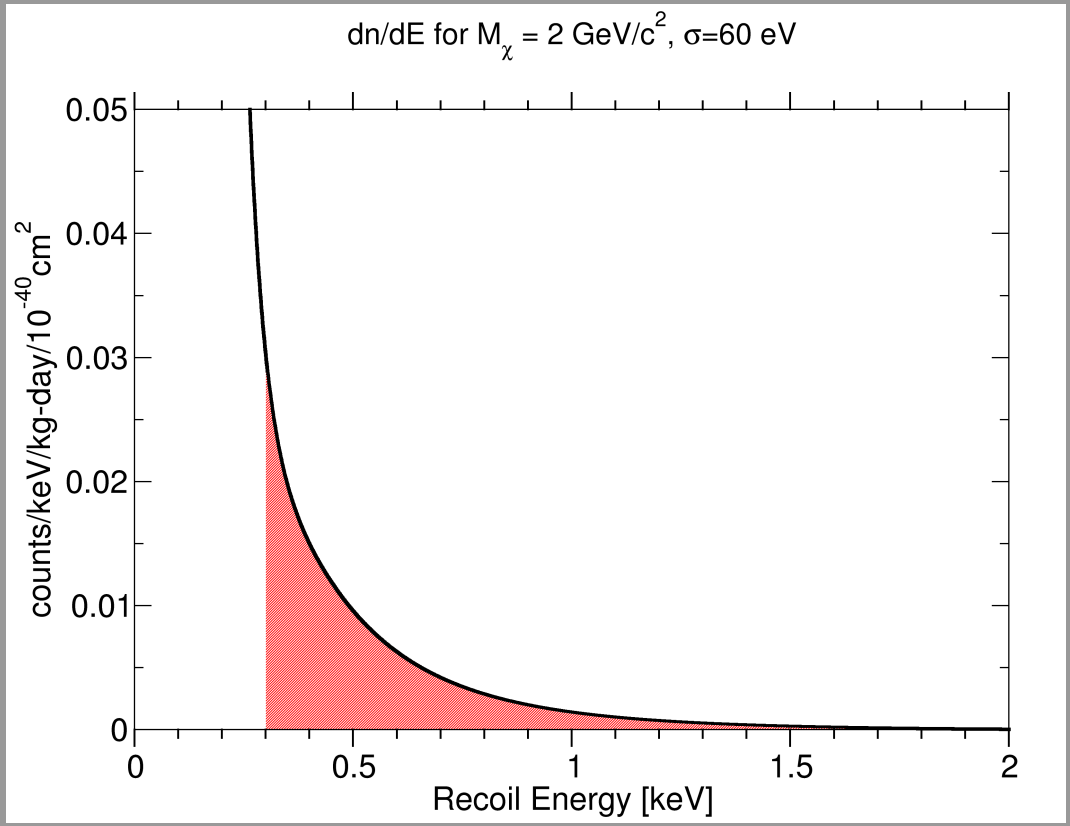
Outline

- Introduction (low mass challenge, CRESST detectors)
- Recent low mass results from CRESST-II phase 2
- Upcoming phase CRESST-III

The low mass challenge

- Recoil energy goes quadratically with M_χ (linearly with $1/M_N$)

$$E_{recoil} = \frac{2M_\chi^2 M_N}{(M_\chi + M_N)^2} v^2 (1-\cos\theta) \approx \frac{2M_\chi^2}{M_N} v^2 (1-\cos\theta) \quad \text{for } M_\chi \ll M_N$$



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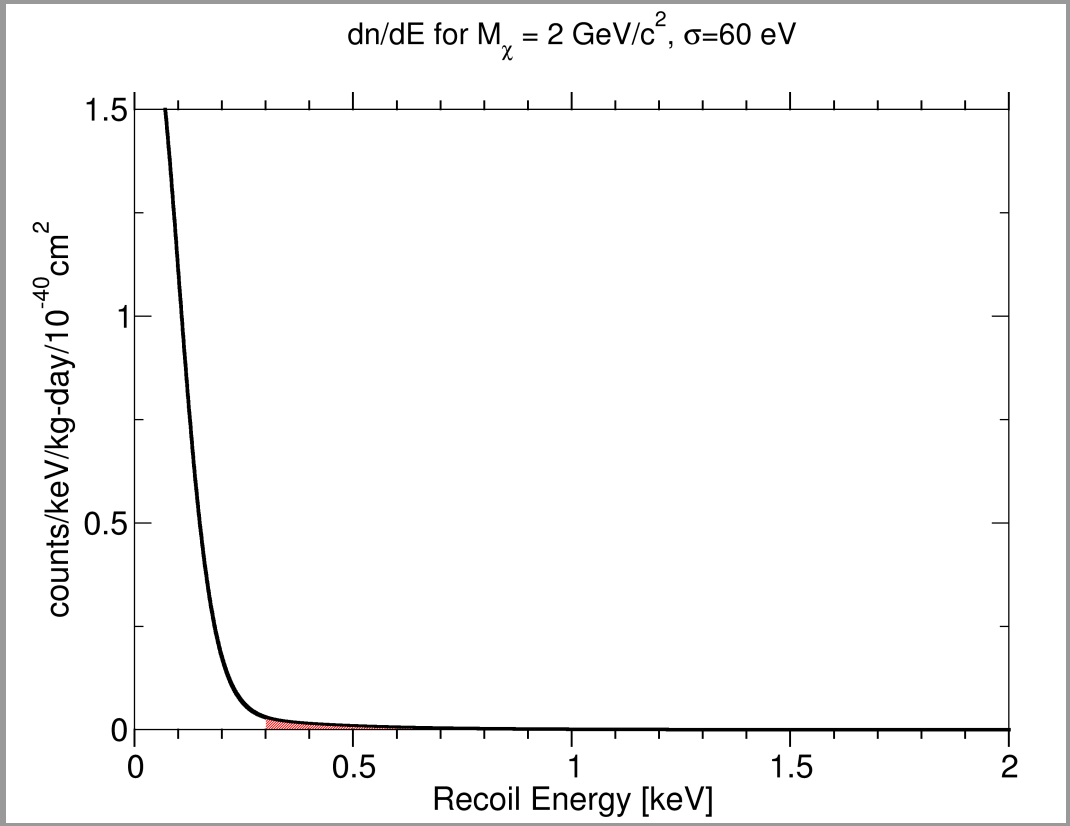
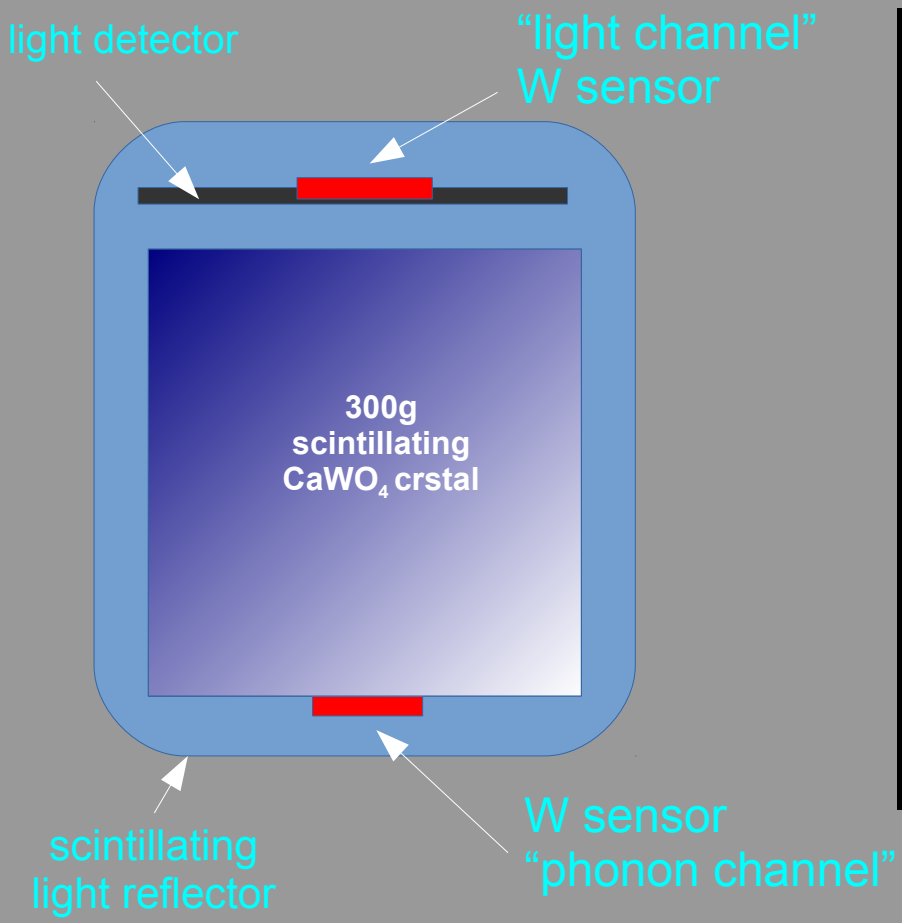
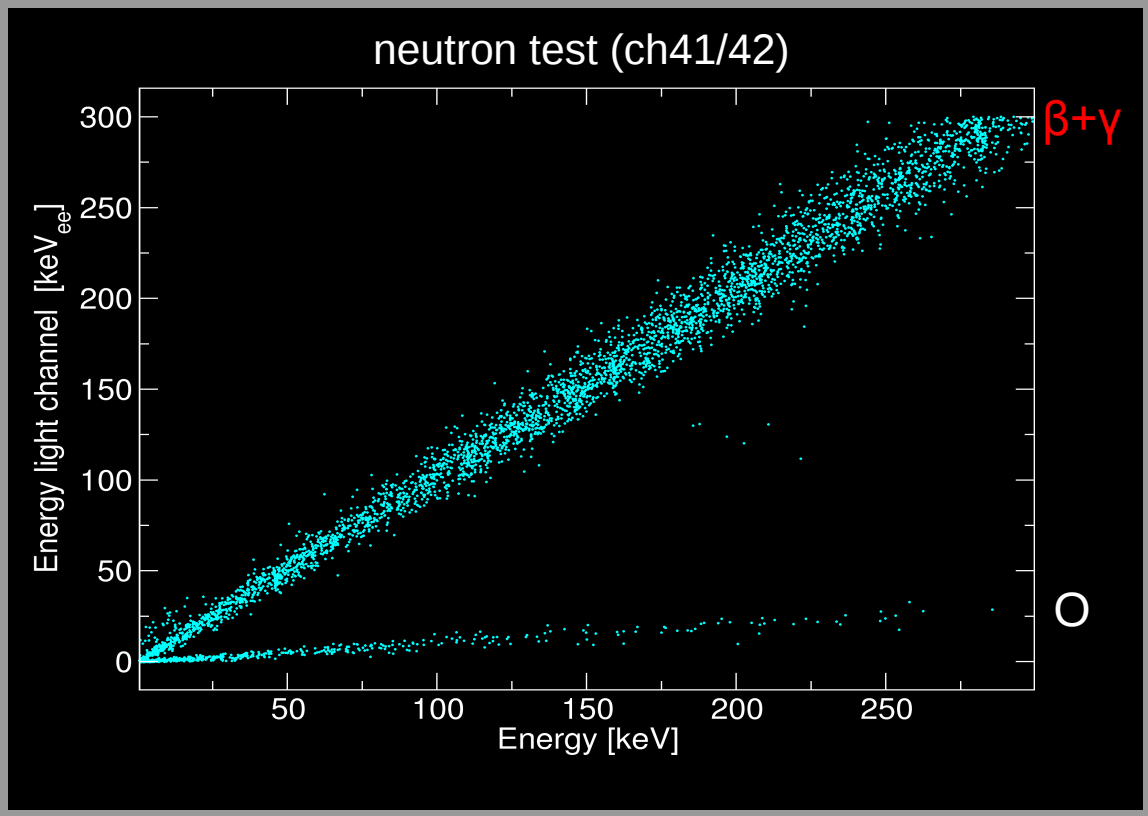


- **Threshold is the key parameter**
- **Target with light nuclei important**

- Majority of counts for M_χ=2 GeV below 300 eV

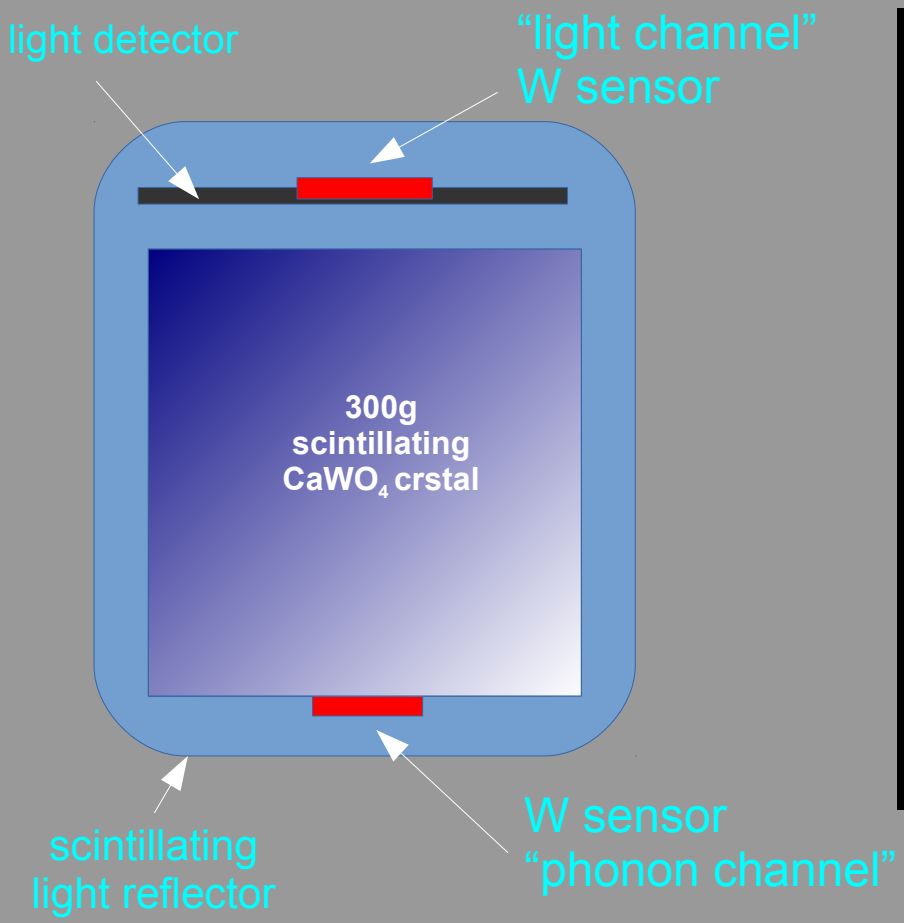
CRESST Detectors

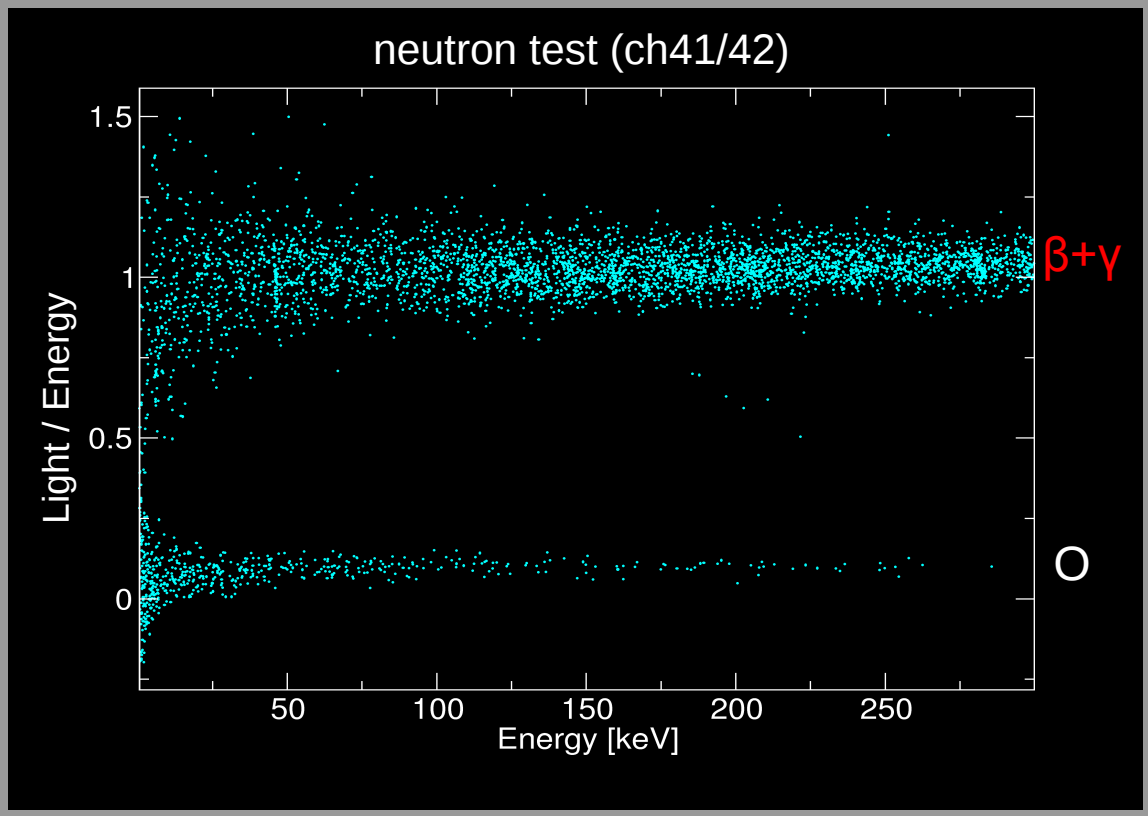




- Phonon and light signals: W -TES (~15 mK) and SQUID readout
- Phonon signal allows energy measurement with < 100 eV resolution and accuracy
- Light signal distinguishes types of interaction
- Types of recoiling nuclei have slightly different slopes in energy-light plane

CRESST Detectors





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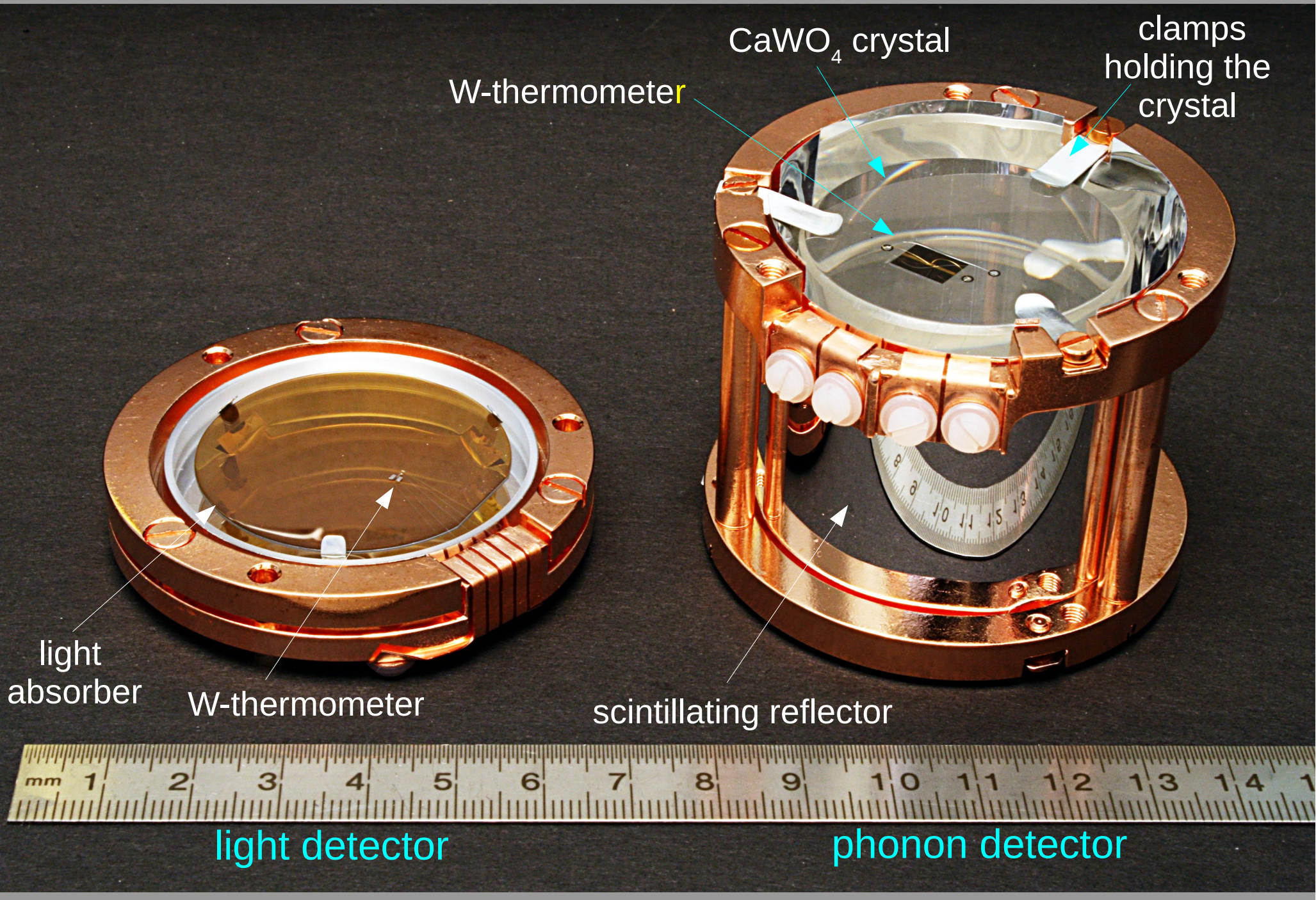
300 g Detector Module



CRESST II Phase 2

Data taking: July 2013 – August 2015

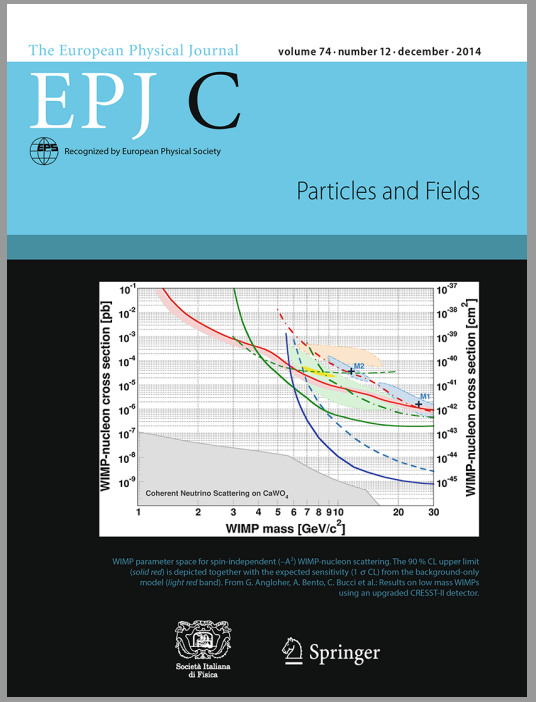
Results from low mass analysis of CRESST-II phase 2

CRESST II Phase 2

Data taking: July 2013 – August 2015

First Phase 2 analysis on low mass dark matter particles:

- Single module, fully scintillating design
- Self grown crystal (TUM40), lowest intrinsic background
- 2013 data set, 29 kg days of exposure, 600 eV threshold
- Non-blind analysis
- Paper submitted in July 2014



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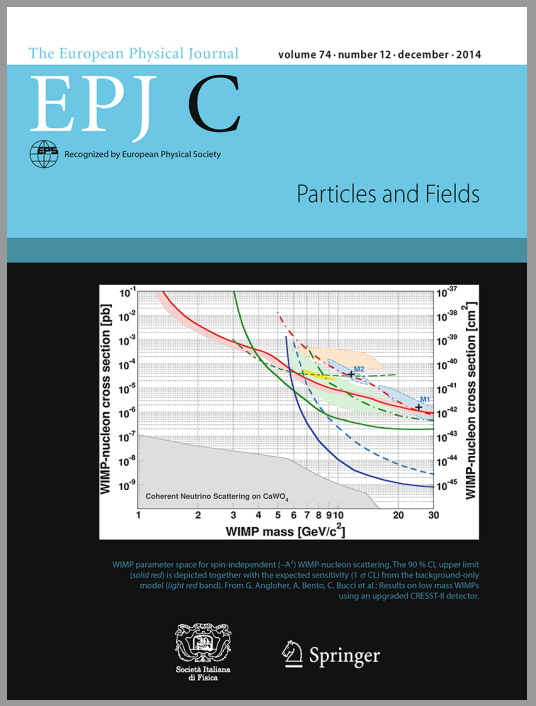


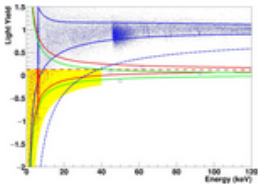
Trigger thresholds of several modules lowered

Final Phase 2 results on low mass dark matter particles:

- Single module Lise
- Commercial crystal, higher intrinsic background
- Lowest threshold
- 52 kg days of exposure
- Blind analysis
- Paper submitted in September 2015

EPJ C Highlight - Bright sparks shed new light on the dark matter riddle

Published on Wednesday, 27 January 2016 18:04



Data gathered by the detector module Lise depicted in the light yield energy plane.

Highest sensitivity detector ever used for very light dark matter elementary particles

The origin of matter in the universe has puzzled physicists for generations. Today, we know that matter only accounts for 5% of our universe; another 25% is constituted of dark matter. And the remaining 70% is made up of dark energy. Dark matter itself represents an unsolved riddle

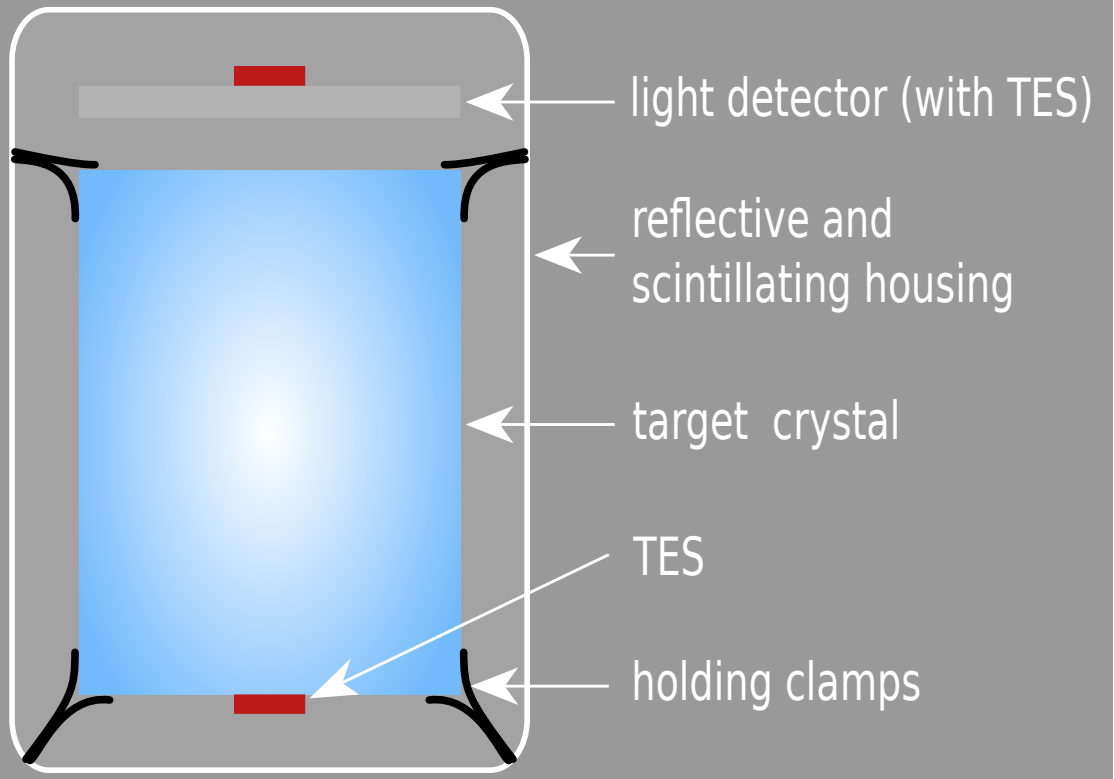
Detector Lise

"Conventional" design
- metallic holding clamps → No fully efficient veto for surface alpha decays

Crystal: commercial
- Higher background ~8.5 counts/(keV kg day)

Threshold: 307eV

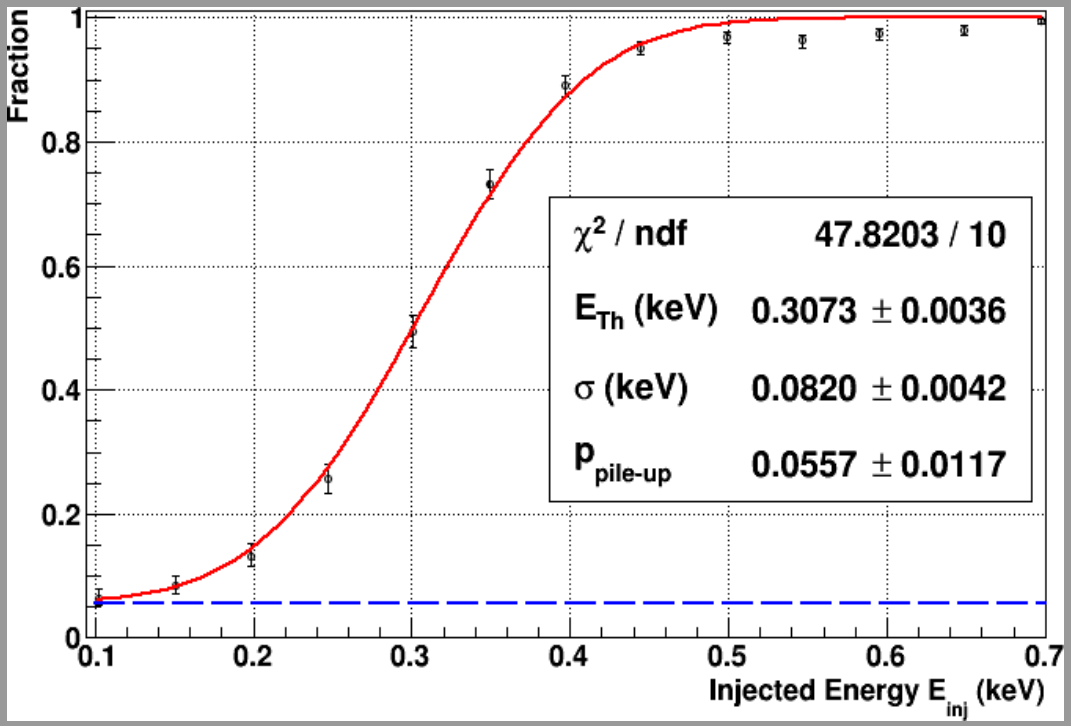
Resolution: 62eV at low energies



- **Average overall performance**
- **Lowest threshold**

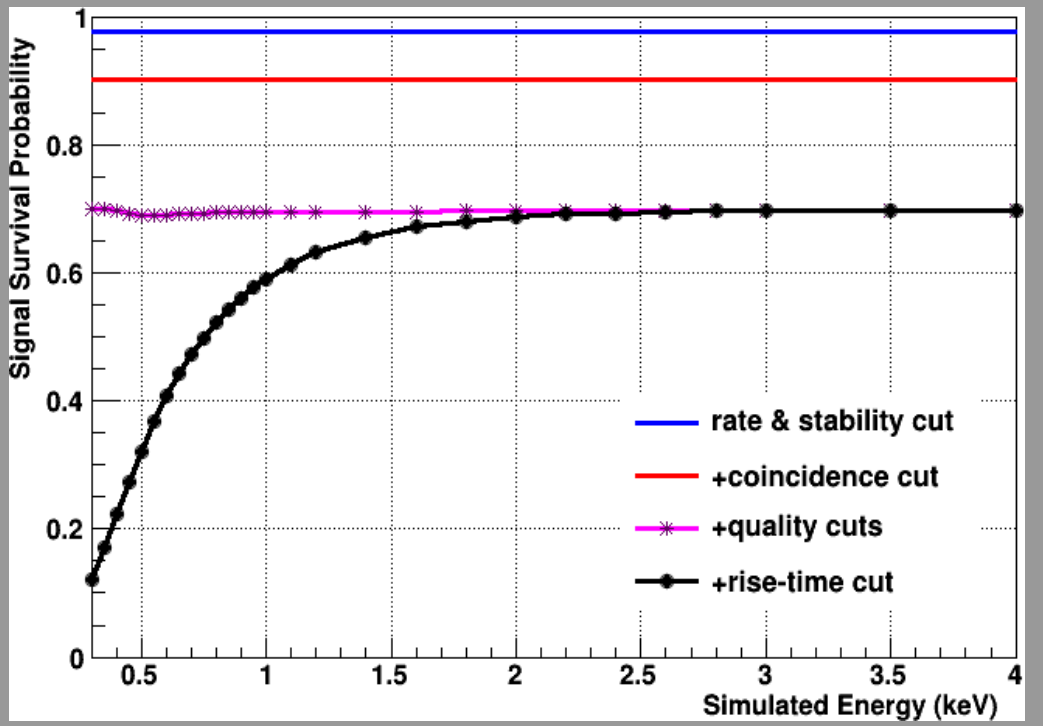
Detector Lise

Trigger threshold



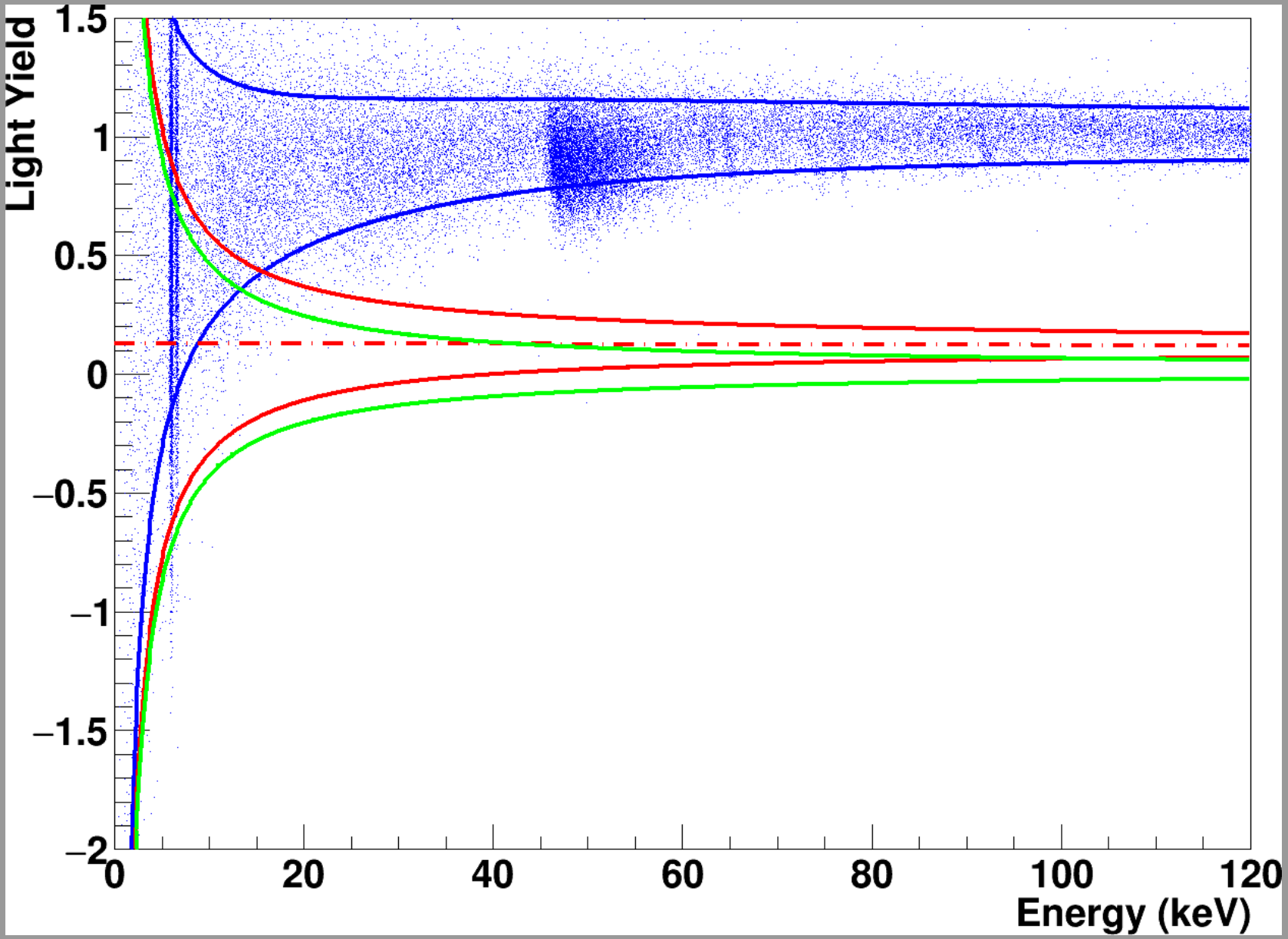
- **Lowest threshold: 307eV**
  Measured with injected heater pulses

Signal survival probability

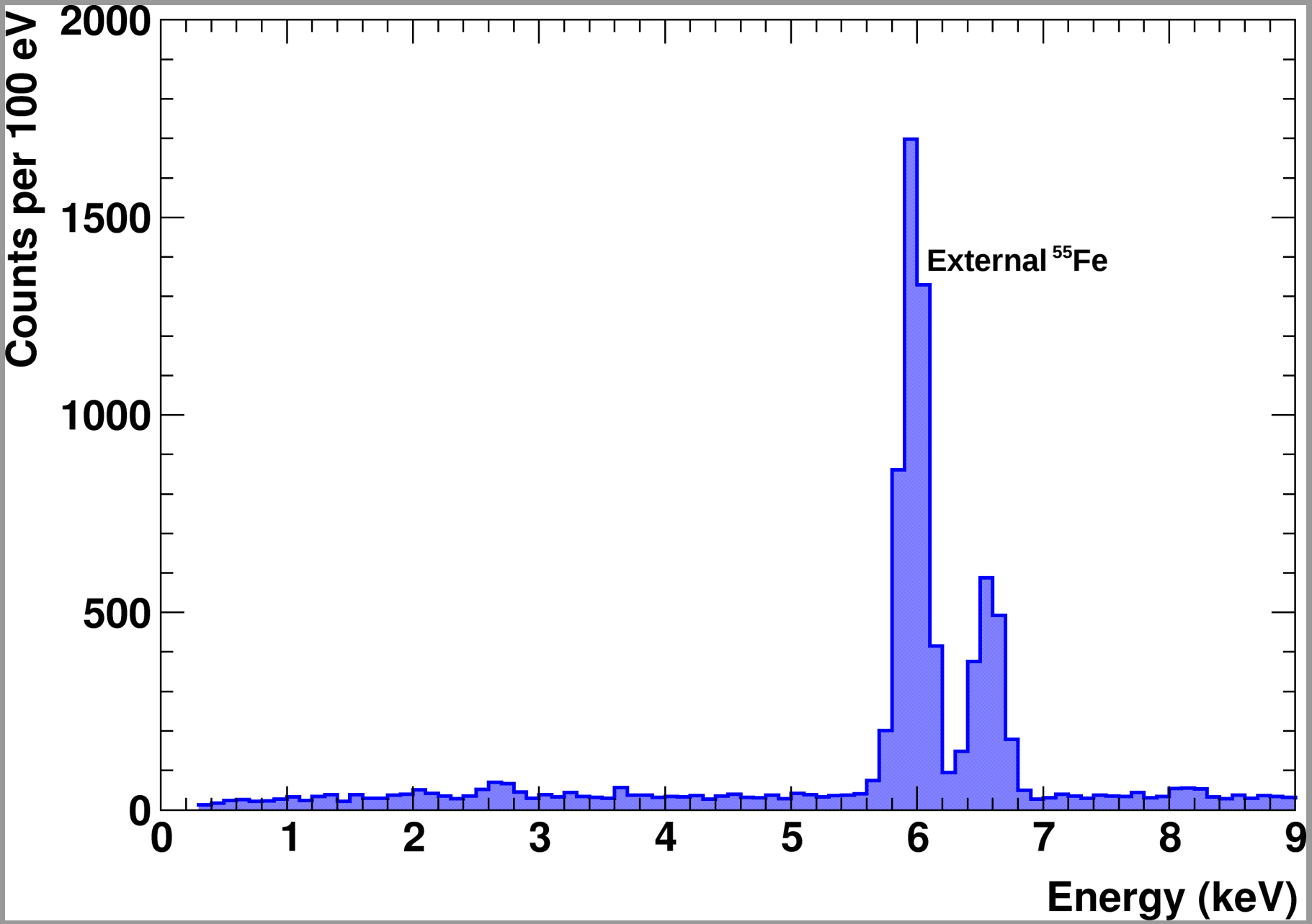


- **Survival: 12% at threshold**
  Determined via superimposed pulse templates on randomly sampled empty baselines

Data

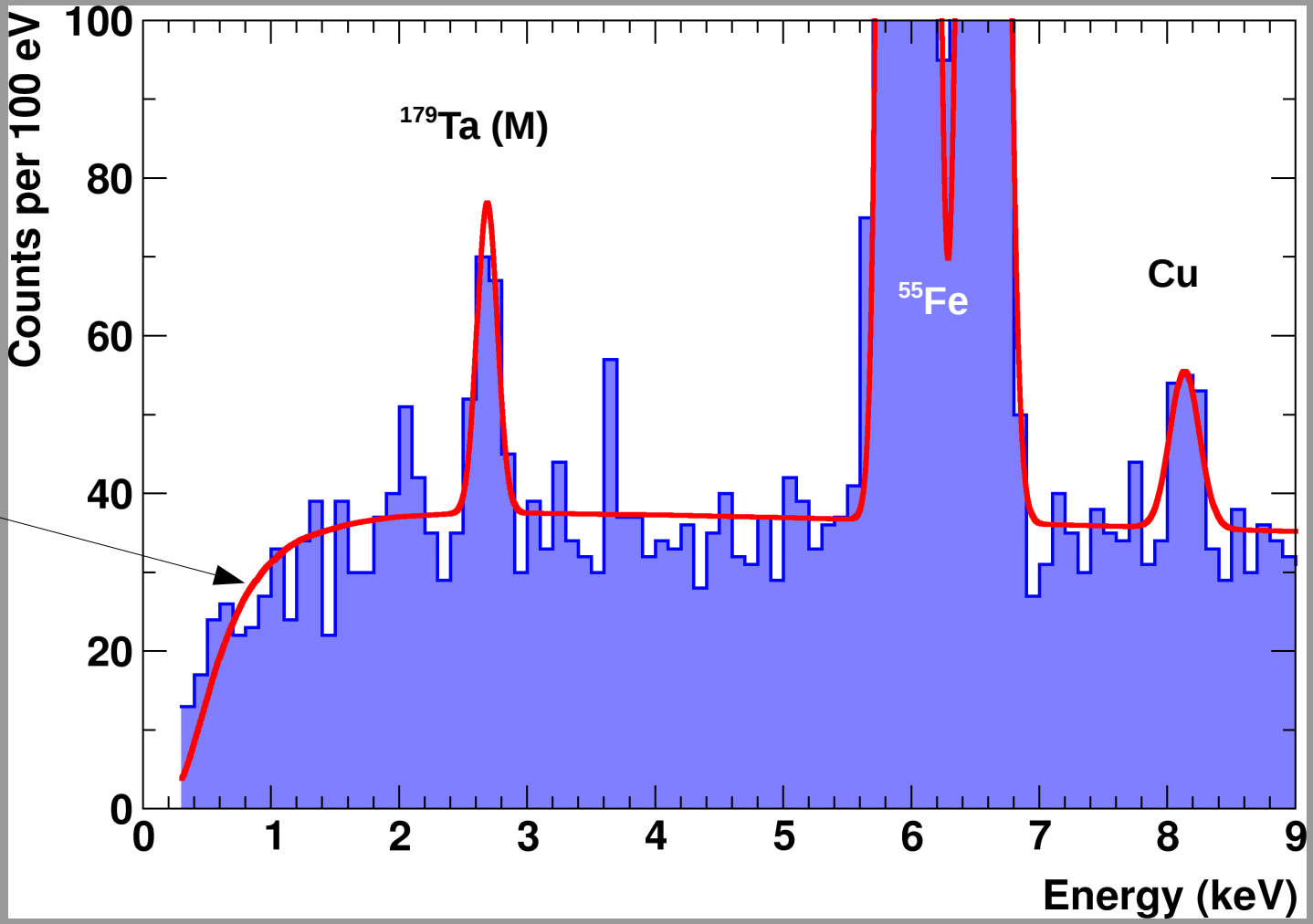

Light Yield
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
20
40
60
80
100
120
Energy (keV)
e-/γ
O
W

e/γ Background



e/γ Background

Flat background down to hardware threshold @ 307 eV
~8.5 counts per (kg keV day)



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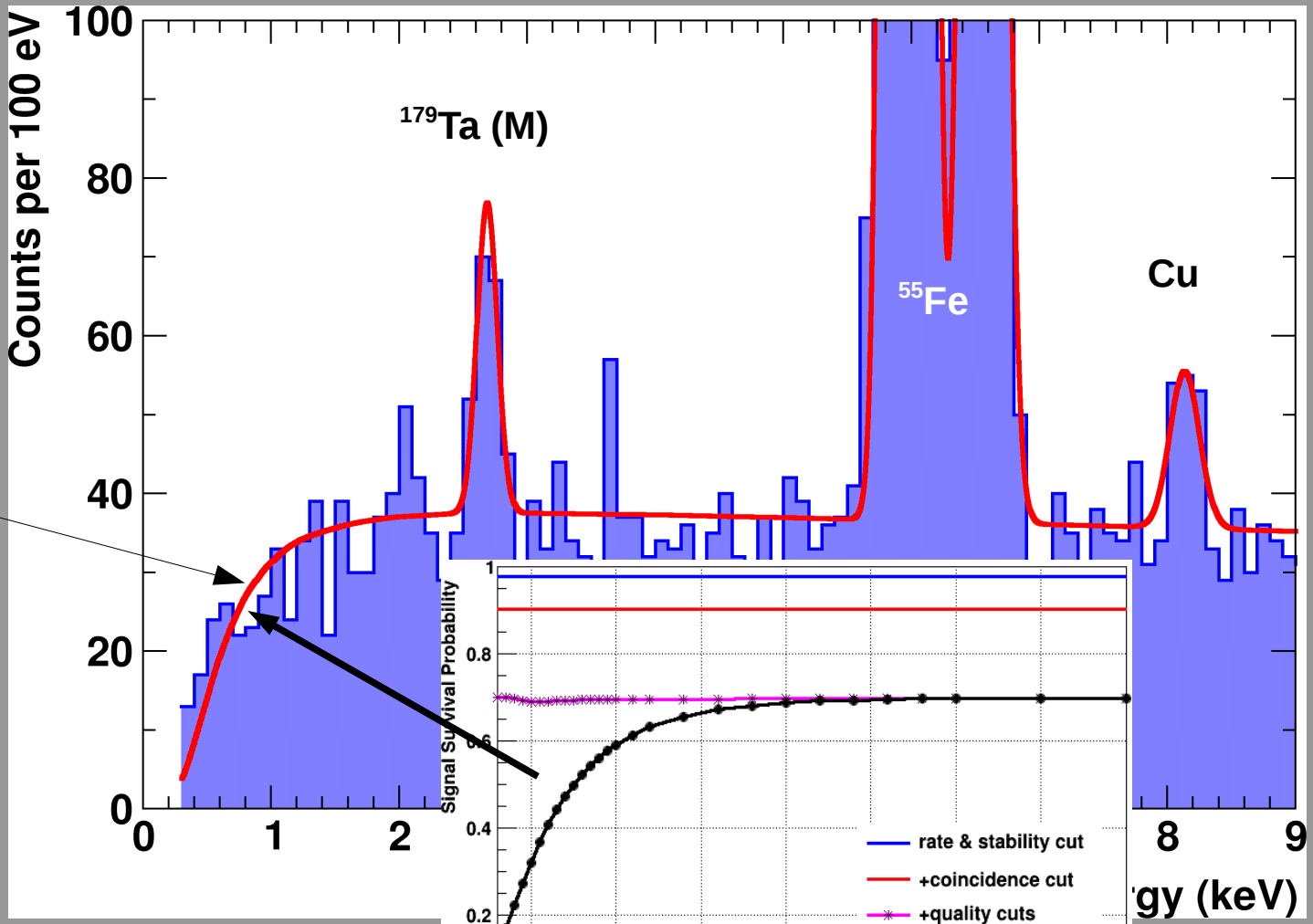
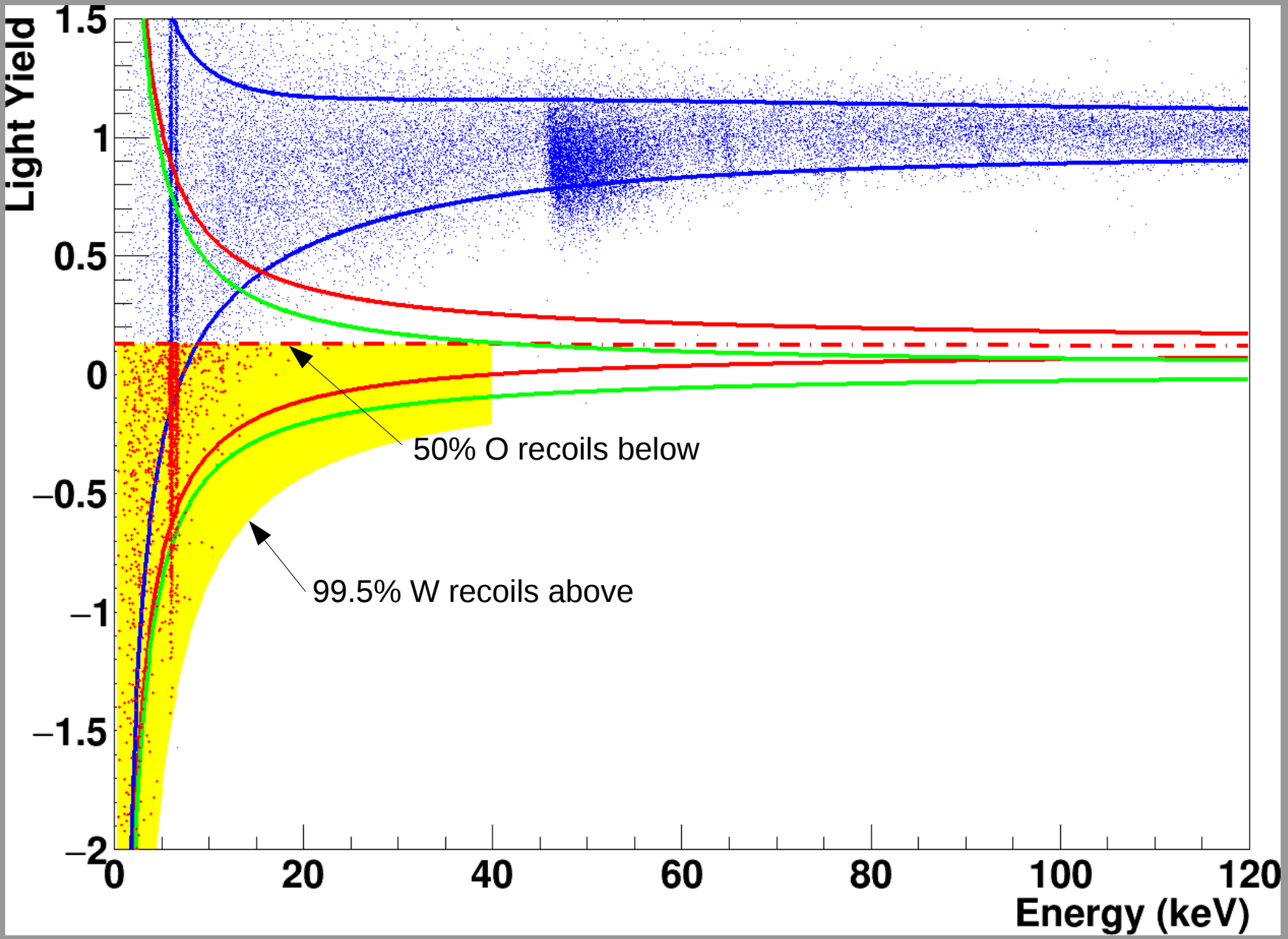
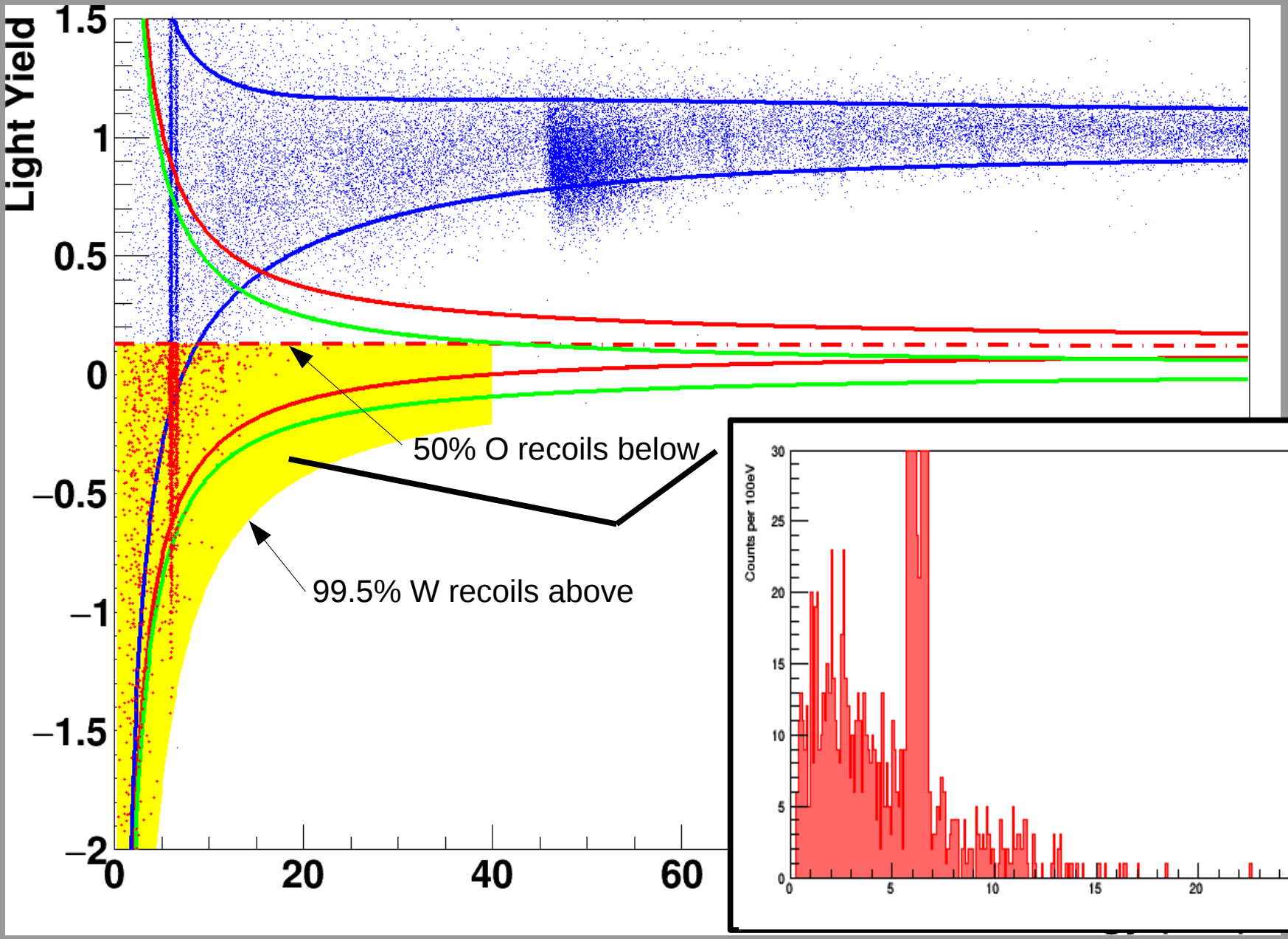
Background model



Data


Light Yield
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
20
40
60
80
100
120
Energy (keV)
50% O recoils below
99.5% W recoils above
e-/γ
O
W

Data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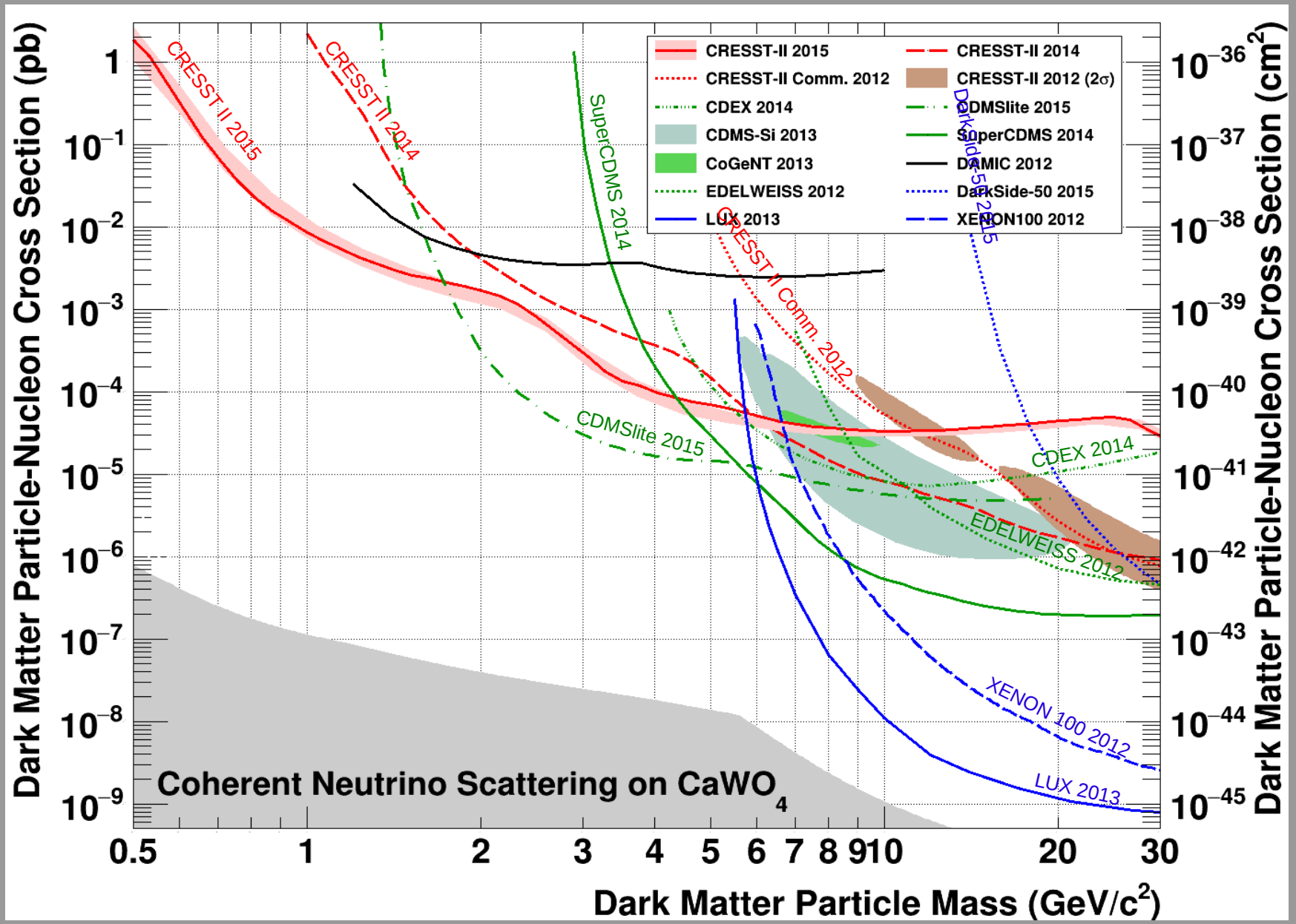
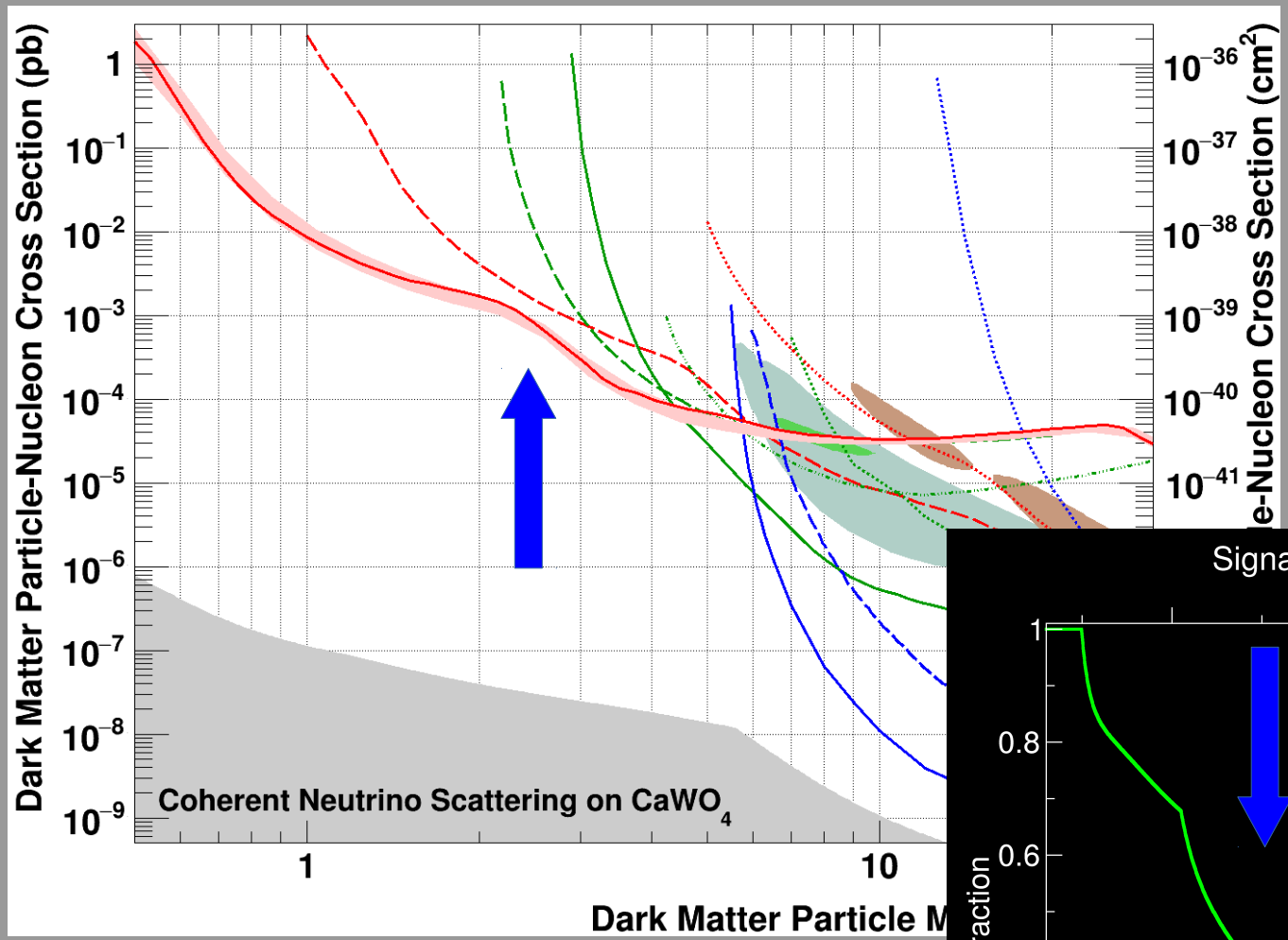
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
20
40
60
50% O recoils below
99.5% W recoils above
e⁻/γ
O
W
Counts per 100eV
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Energy (keV)

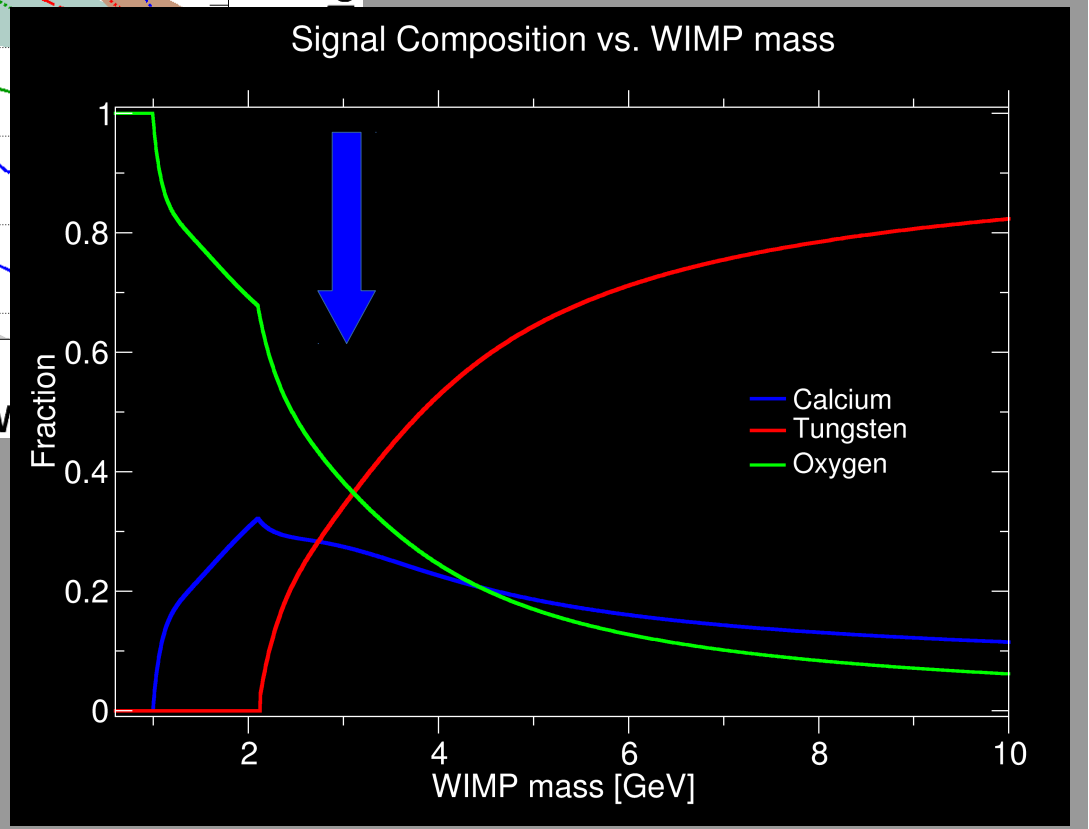
Exclusion limit

Extends searches to sub-GeV/c^2 range



Exclusion limit

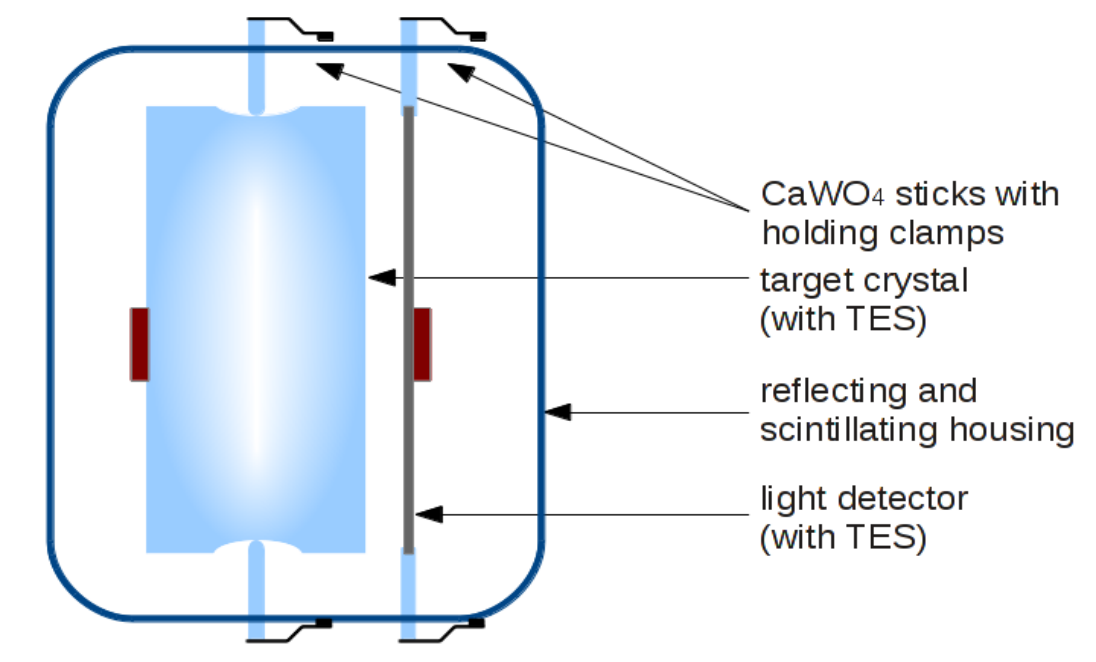




Modules for CRESST III

Detector layout optimized for low mass dark matter

- Reduced crystal size (20×20×10)mm^3 (~ 24 g)
- light detector 20x20 mm^2
- **100 eV threshold**
- available self grown crystals, background level ~3 counts/(keV kg day)
- 3 crystals grown from chemically purified powders
- $CaWO_4$ sticks holding crystal → fully scintillating housing (surface α veto)
- Instrumented $CaWO_4$ sticks to tag any holder related events



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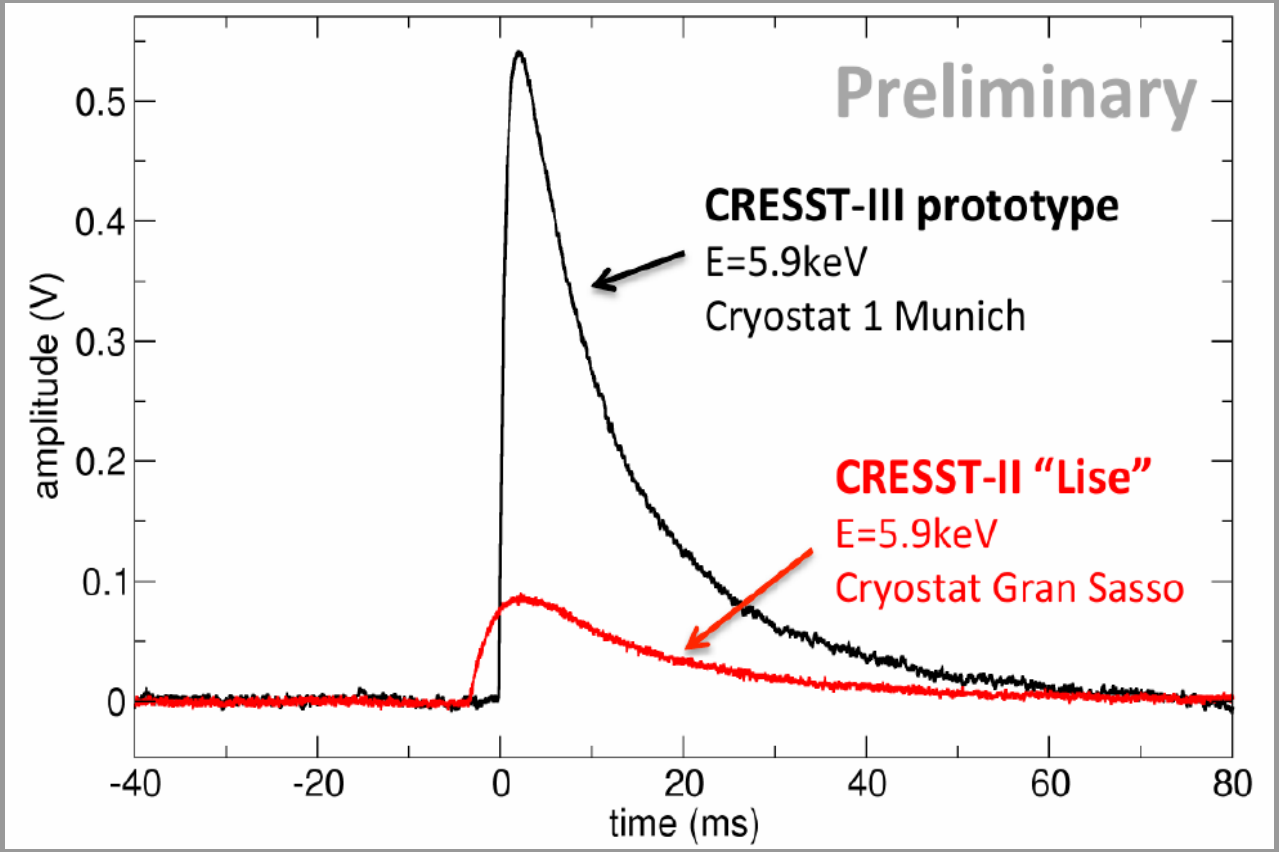
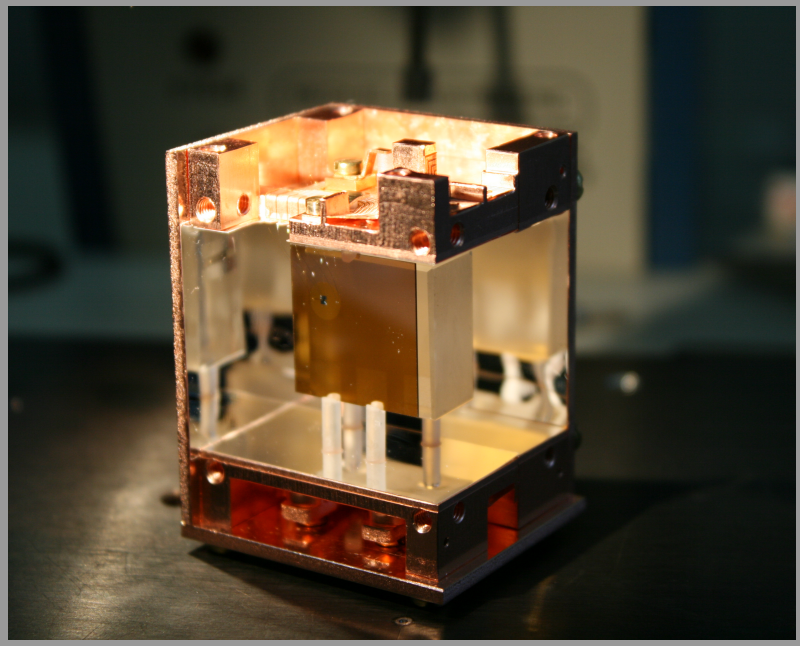
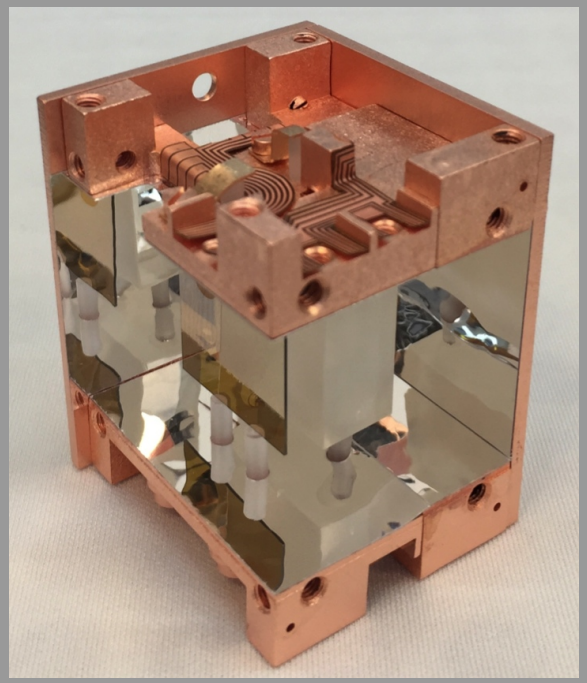


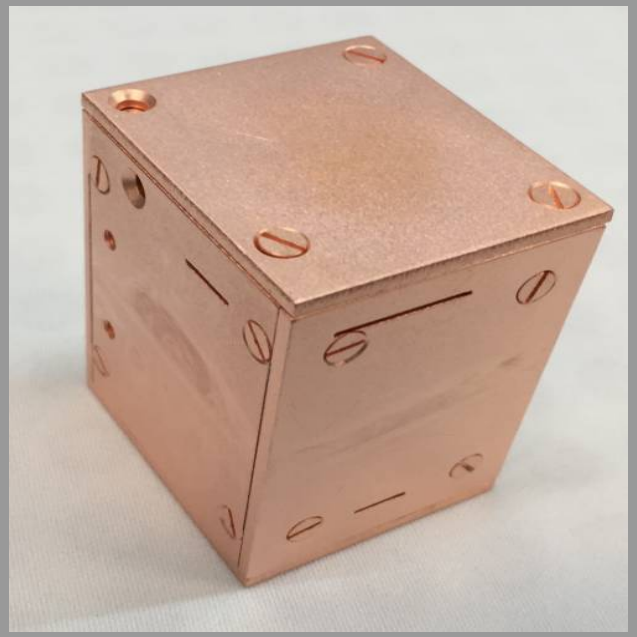


- First tests in Munich: Signal/Noise improved by a factor of ~6
- Threshold of ~50eV

Design goal (100eV) exceeded at first try

Towards CRESST III





- 10 modules mounted last week in Gran Sasso

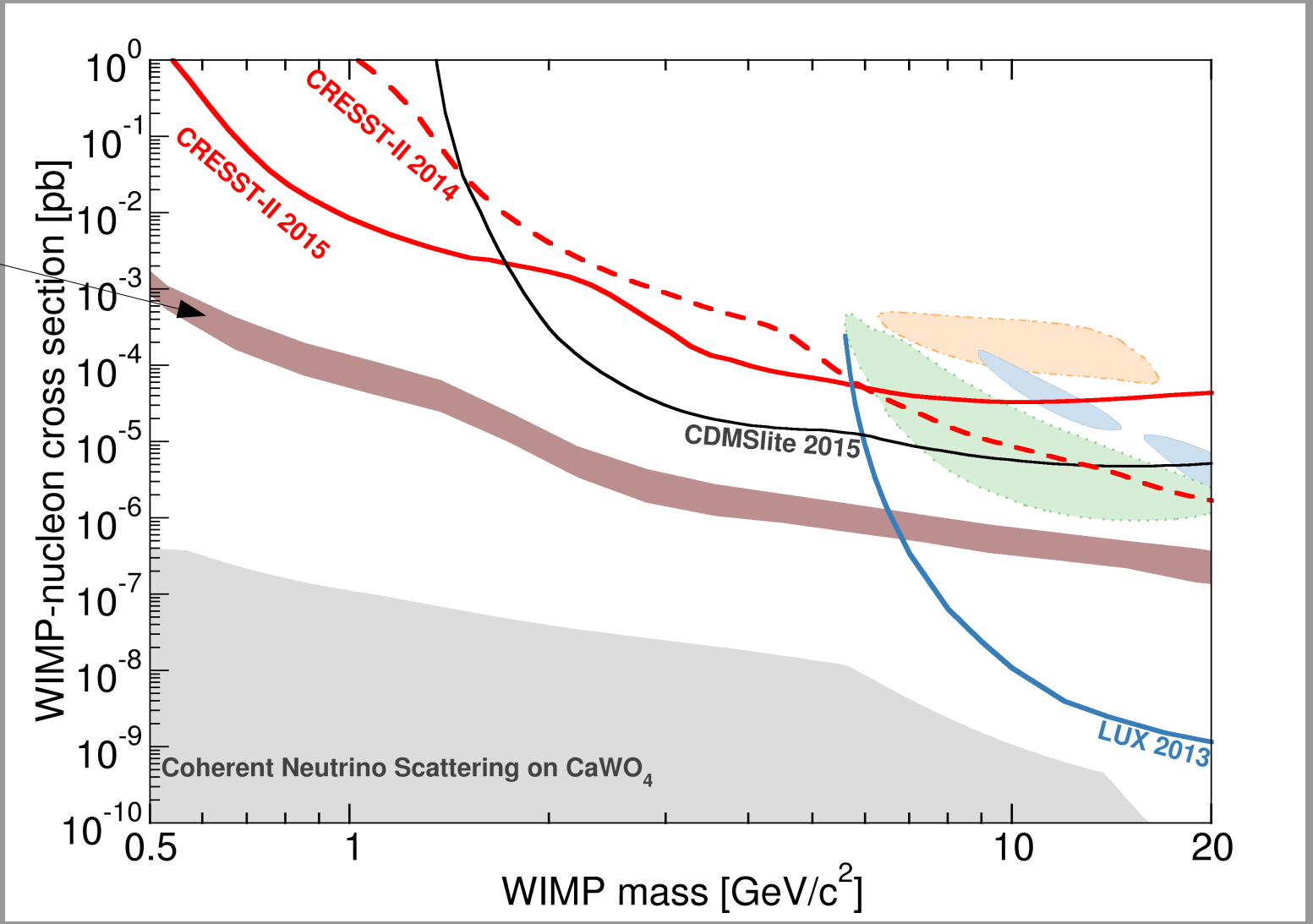
Start of CRESST III in April

CRESST III projection

arXiv:1503.08065 [astro-ph.IM]

Phase 1

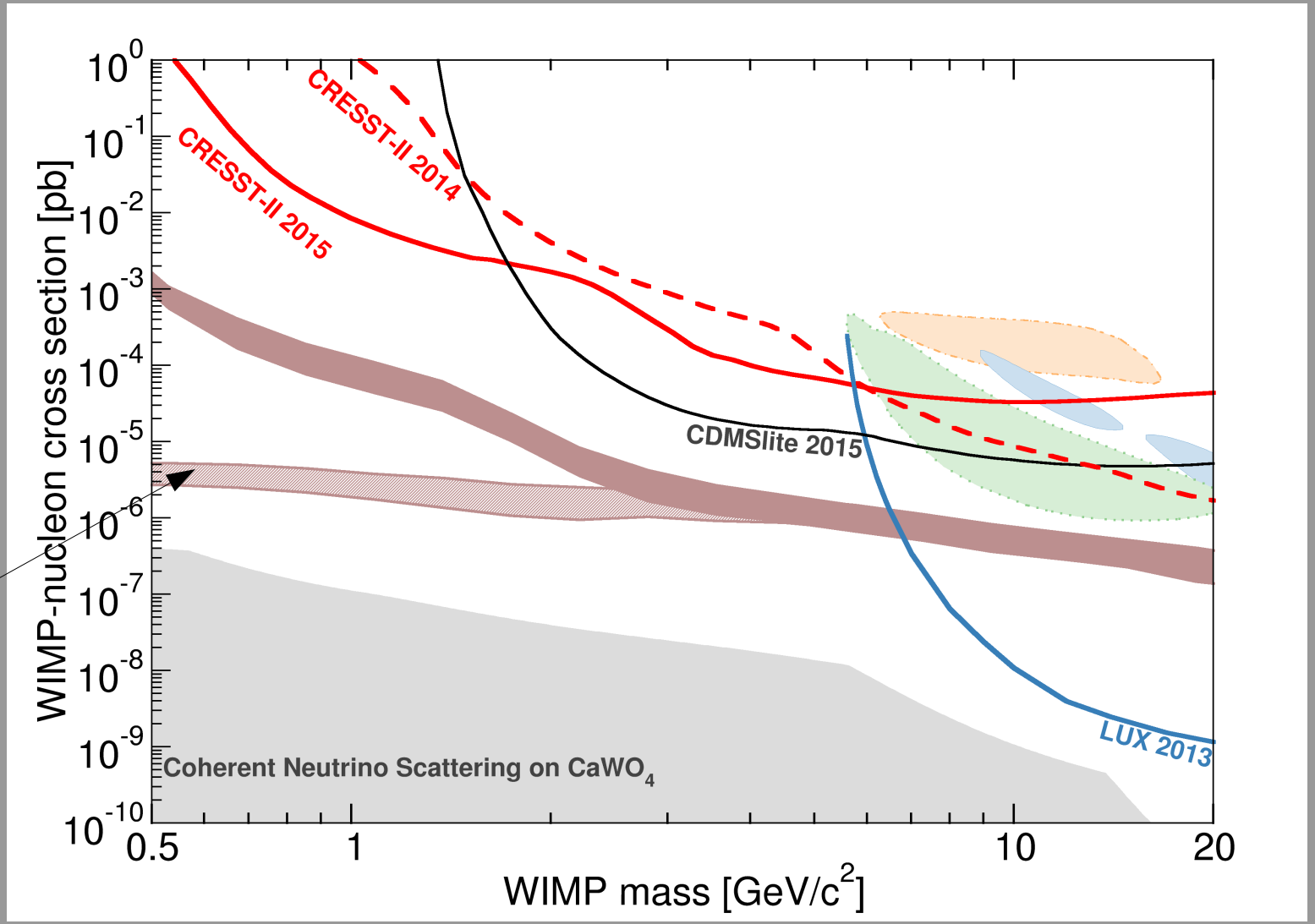
- 50 kg-days
  <1 year of running with 10 small modules
- Background of existing self grown crystals
- **100 eV threshold**



CRESST III projections

Phase 1

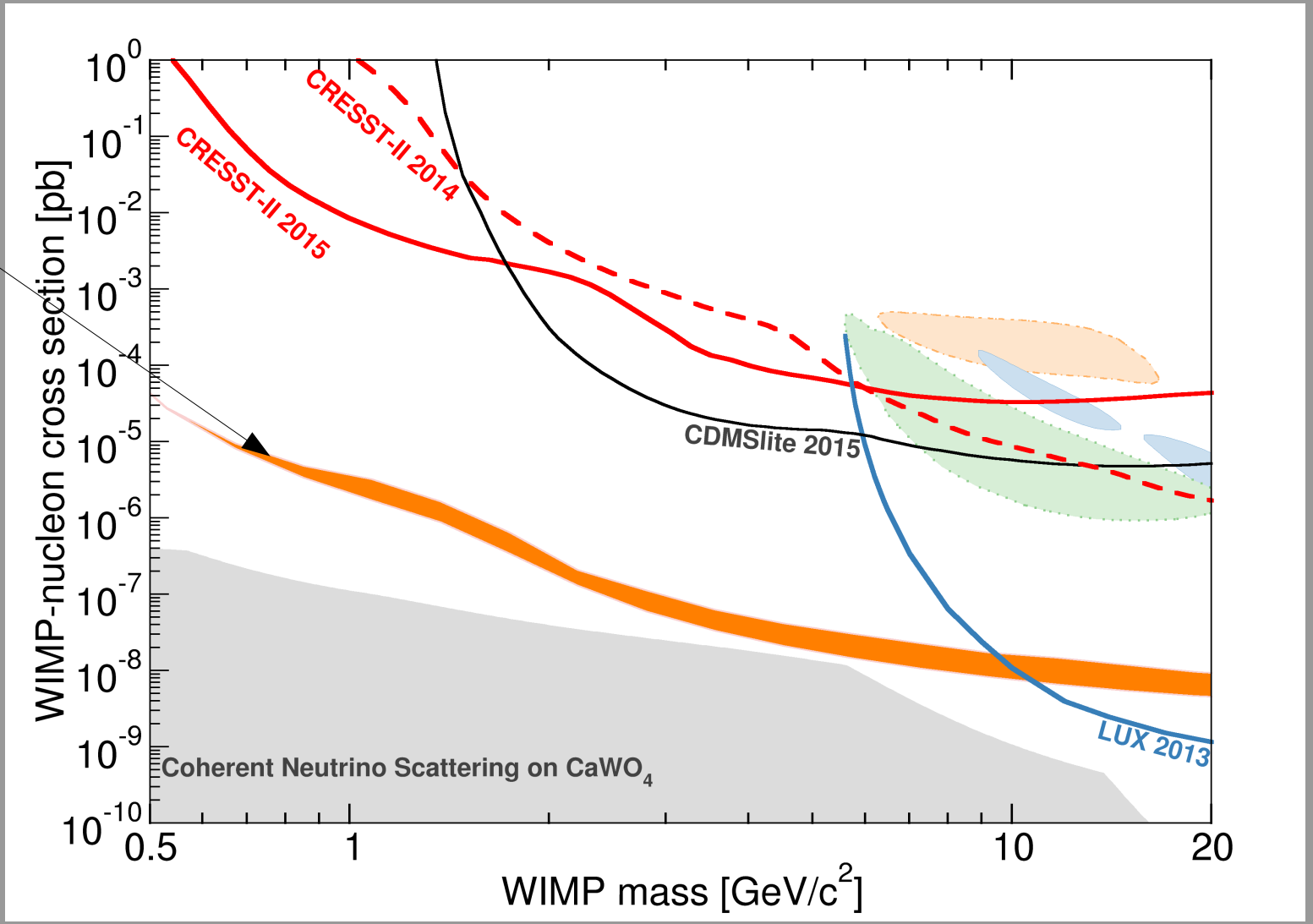
- 50 kg-days
  1 year of running with 10 small modules
- Background of existing self grown crystals
- **20 eV threshold**



CRESST III phase 2 projection

Plans for Phase 2

- 1000 kg-days
  2 years of running with 100 small modules
- **factor 100 reduced background**
- **100 eV threshold**



CRESST III phase 2 projection

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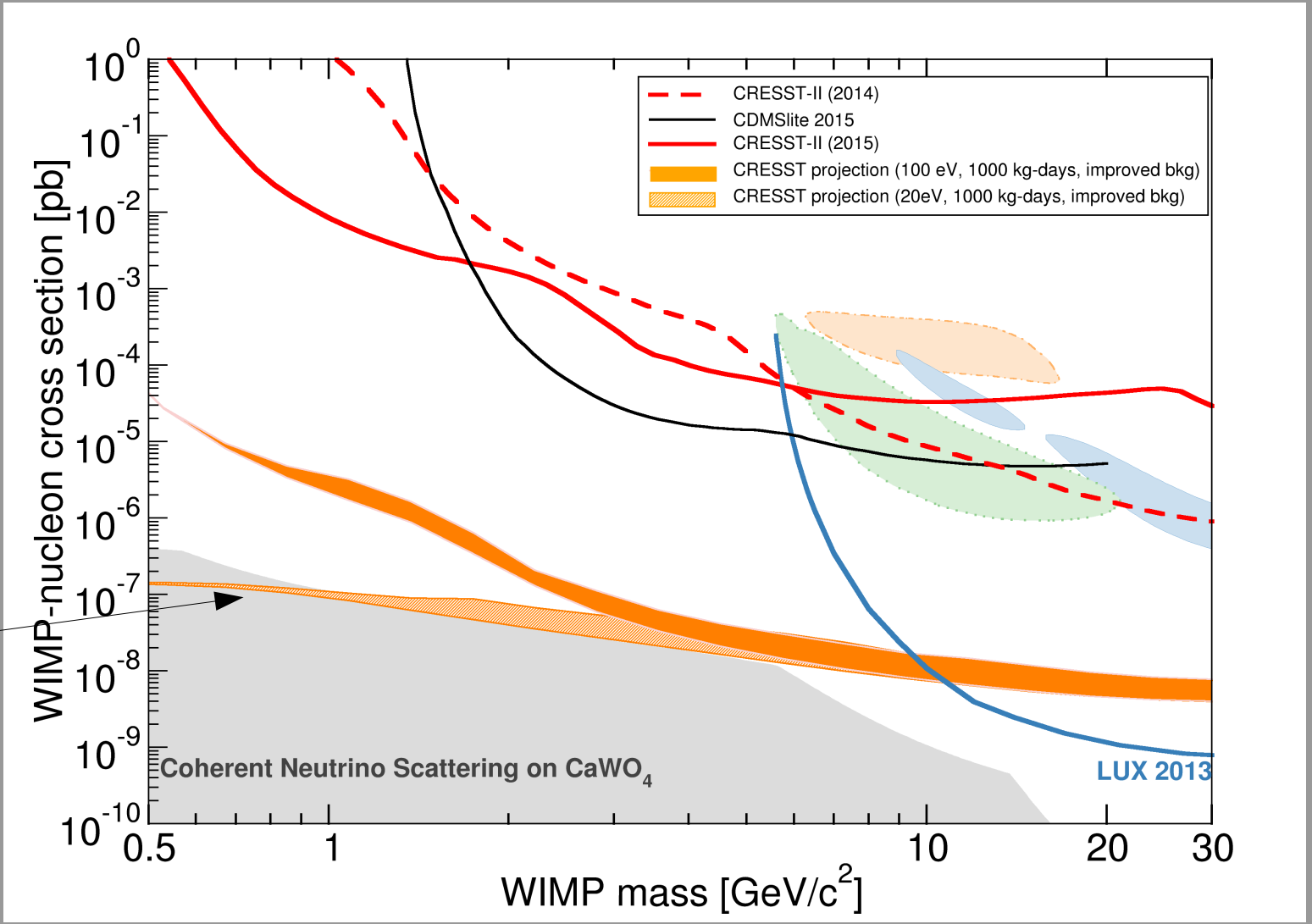


Summary

- **CRESST-II demonstrated potential of CRESST technology for low-mass WIMP search**
  - ✓ Very low threshold for recoil energies: ~300eV
  - ✓ Nuclear-recoil energy scale precisely known
  - ✓ Background discrimination down to low energies
  - ✓ Efficient rejection of surface backgrounds
  - ✓ Multi-element target with low mass nuclei

- **CRESST-III** has unique potential to explore low-mass WIMP region, sensitivity may allow to see first solar neutrinos
  - ✓ Threshold of ~50 eV demonstrated with prototype detector in Munich
  - ✓ Start in April

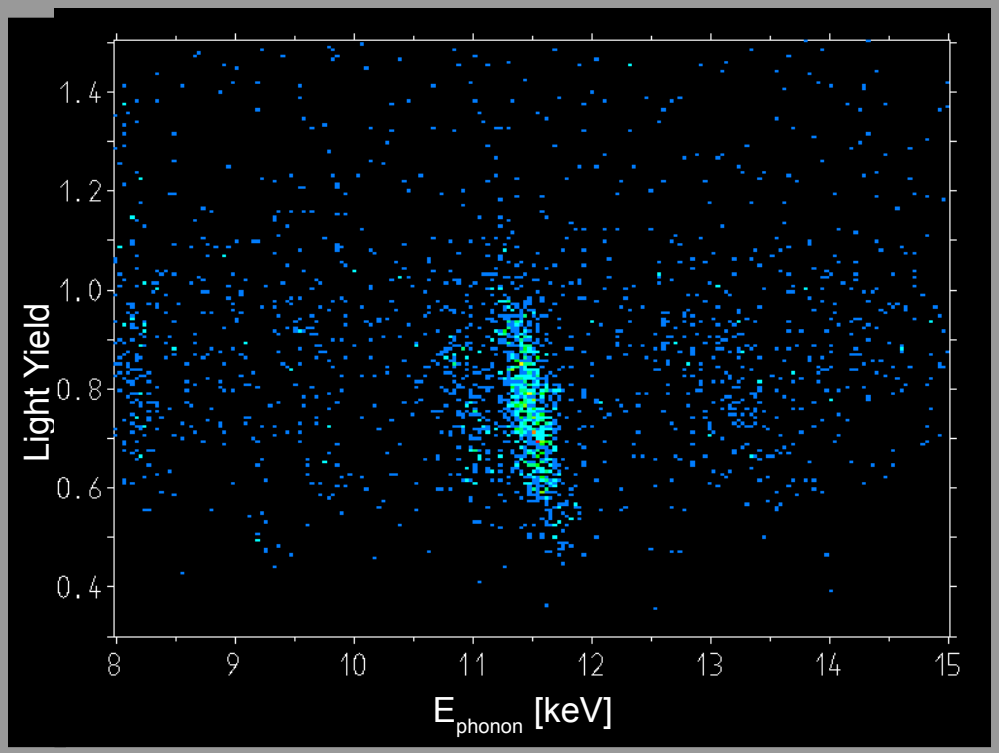
Backup slides

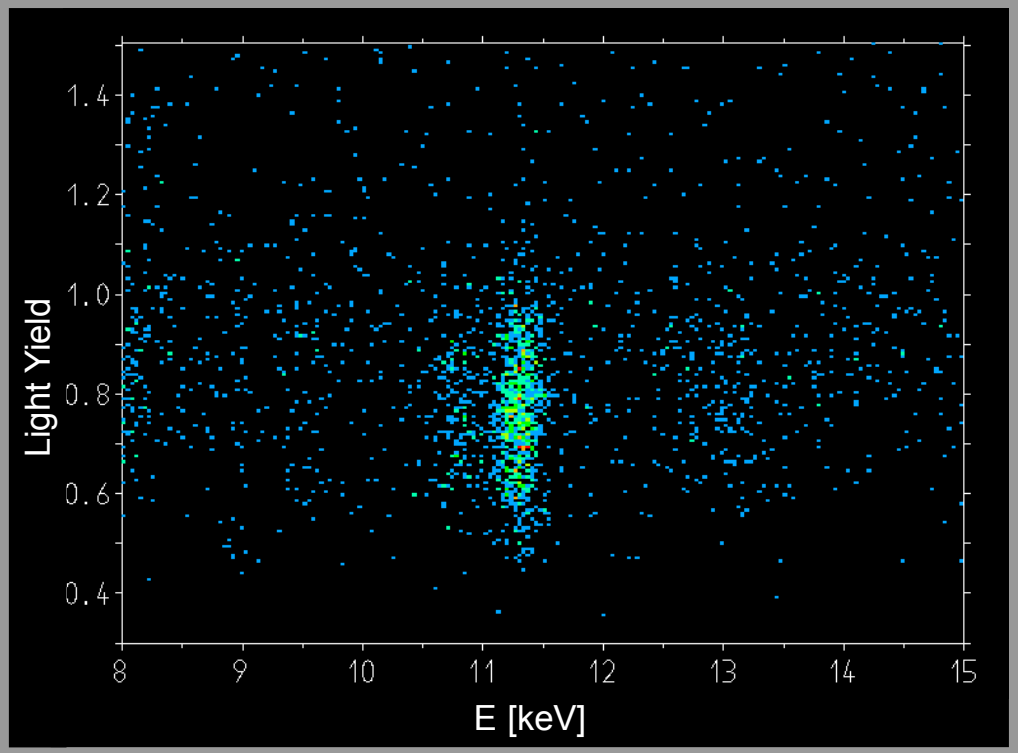
Extraction of Total Deposited Energy E

- Energy of phonon channel gives deposited energy for events with light yield 1
- Deposited energy spent in phonons + scintillation light escaping crystal

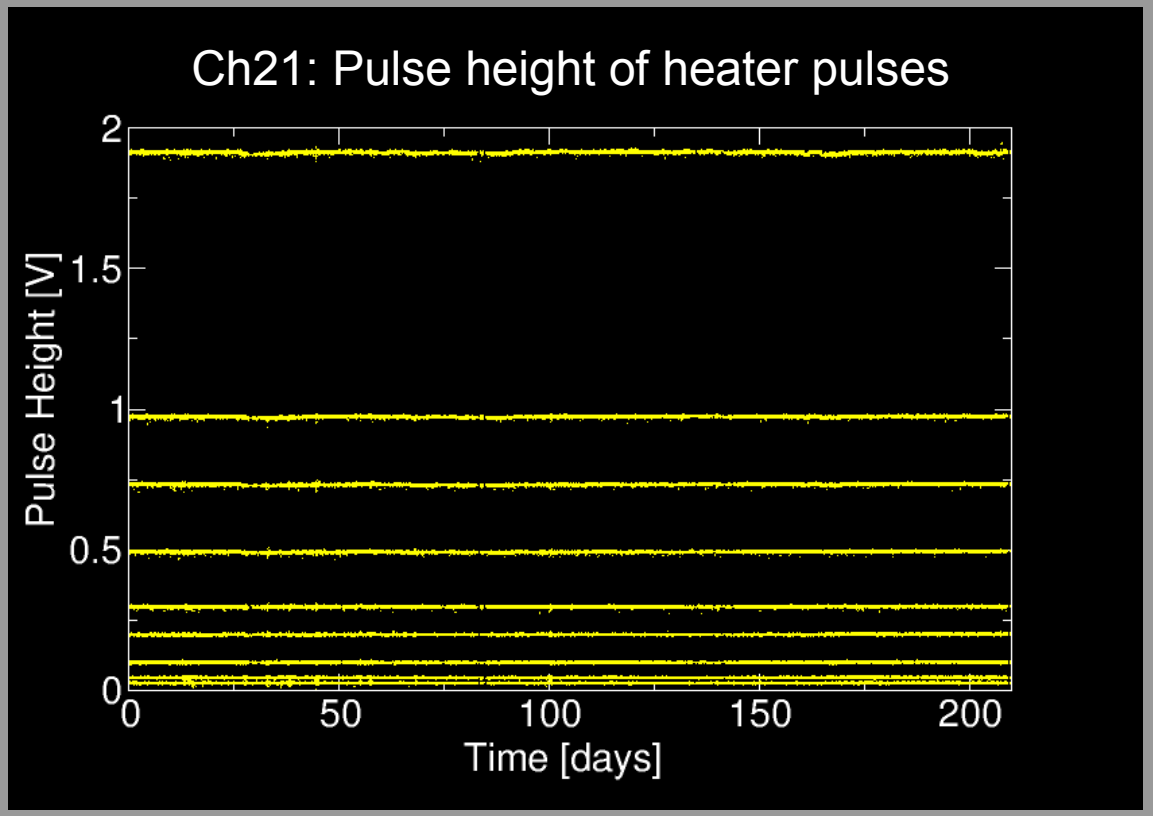
$$E=(1-f)\,E_{phonon} + f\,E_{light} = [1 - f(1-LY)]\,E_{phonon}$$

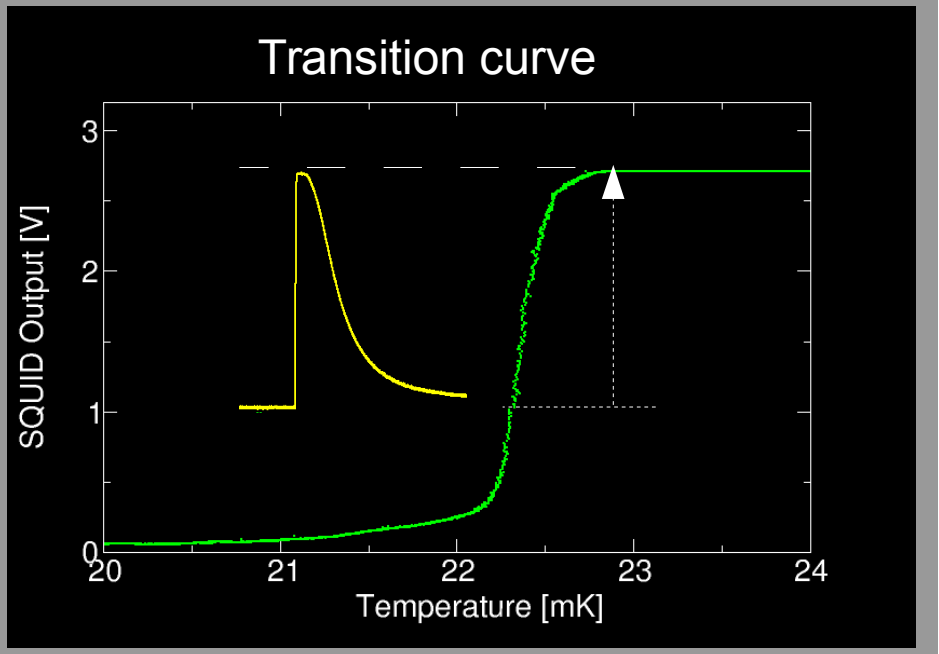
- f from tilt of γ lines in E_{phonon} Light Yield plane





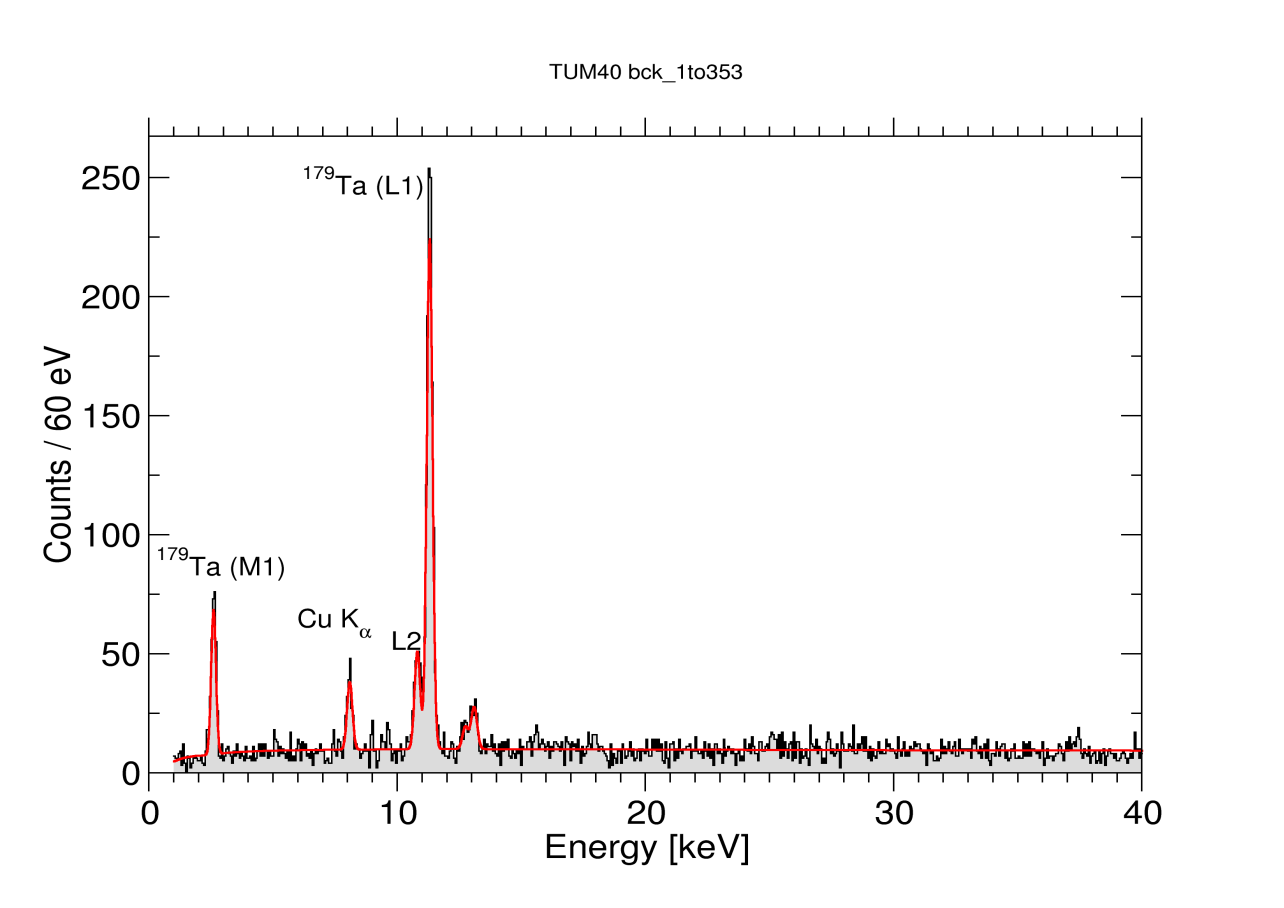
Calibration and Stabilization of Energy Response





- Each channel of module equipped with electrical heater
- Operating temperature controlled with large heater pulses
- Injected heater pulse energy calibrated with 122 keV γ's
- Set of heater pulses with lower energy extrapolates calibration to low energies

Energy spectrum of events in e/γ-band



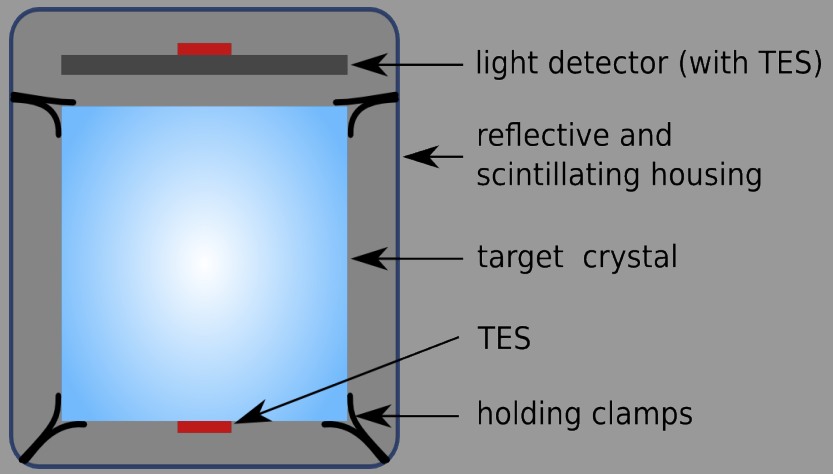
Check of Energy calibration via heater pulses:

EC decay of ^{179}Ta (cosmogenic activation of ^{182}W)

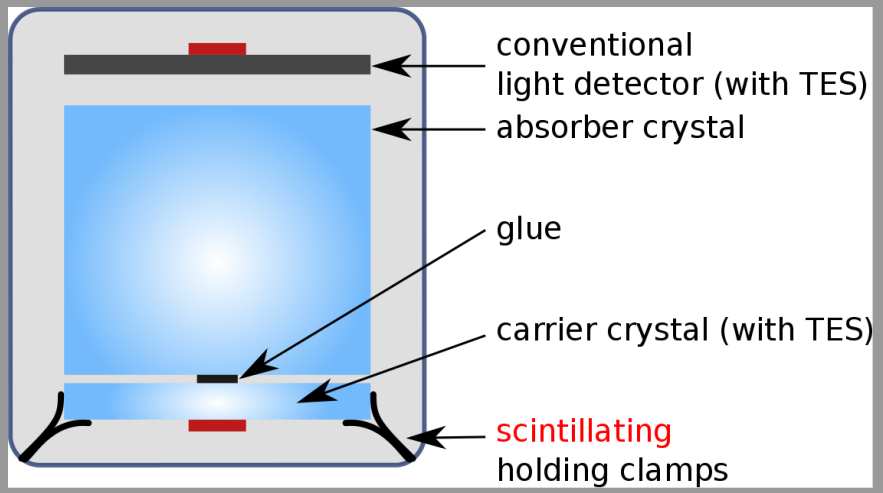
- Peaks at 2.601 keV, 11.273 keV argee within < 3 eV with tabulated values.
- Peaks at higher energies also agree within statistical errors
- Energy resolution: σ=90 eV at 2.6 keV peak

Detector designs

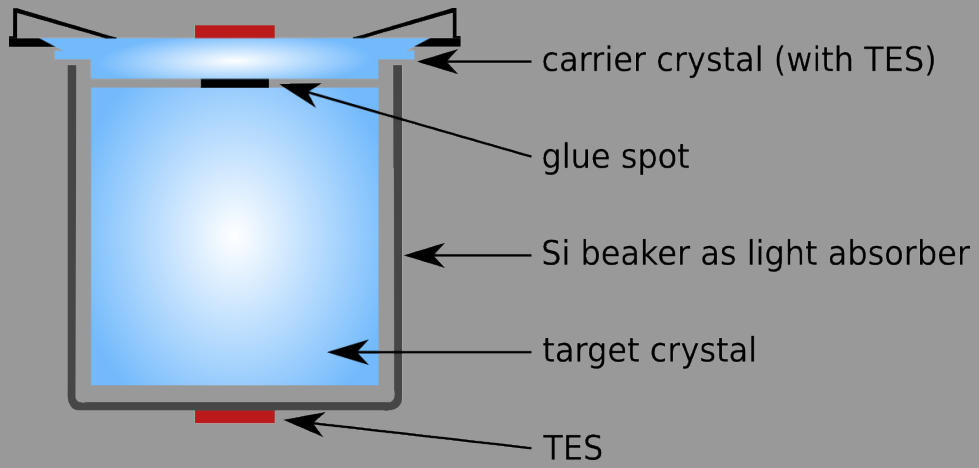
Conventional



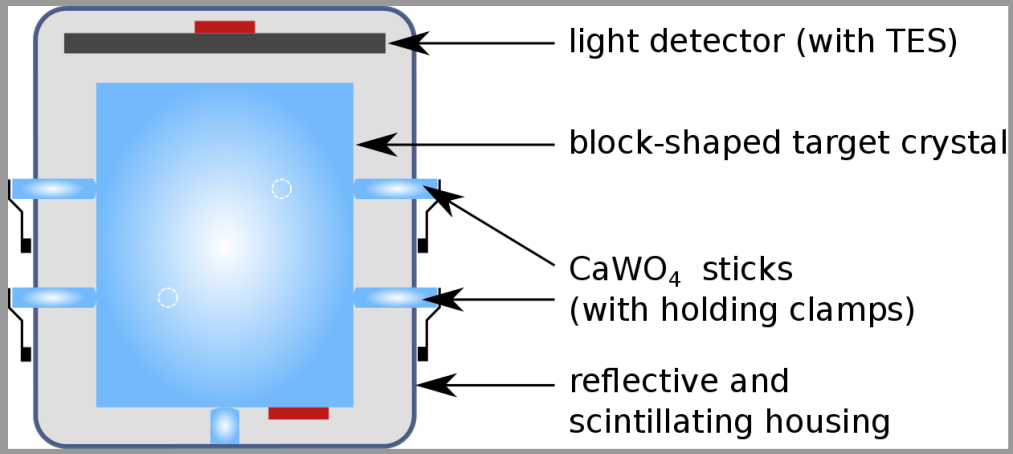
Crystal Clamped on Carrier



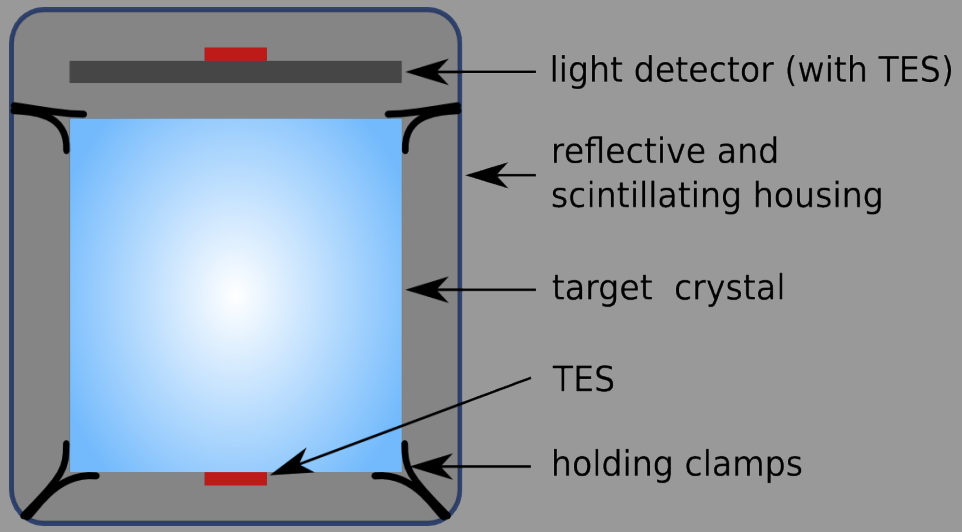
Silicon Beaker Light Detector

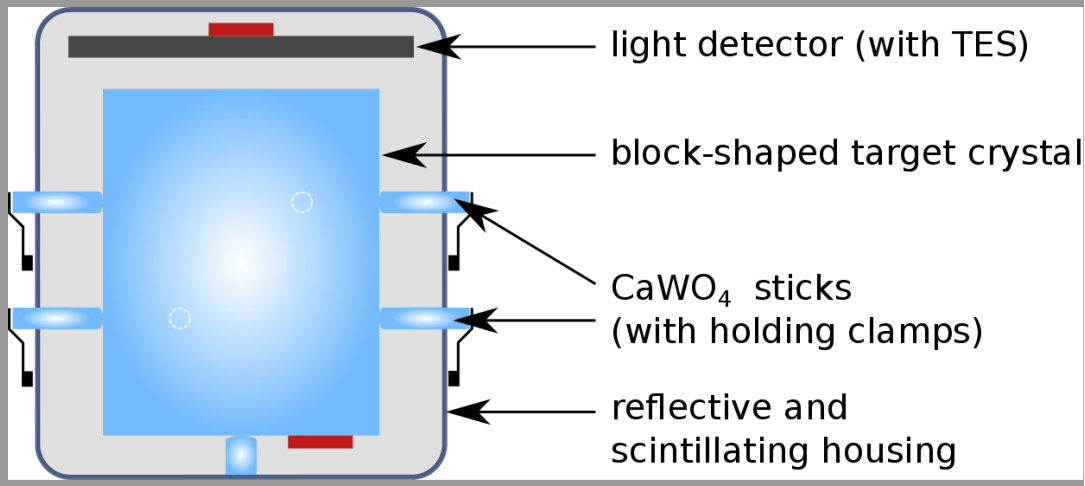


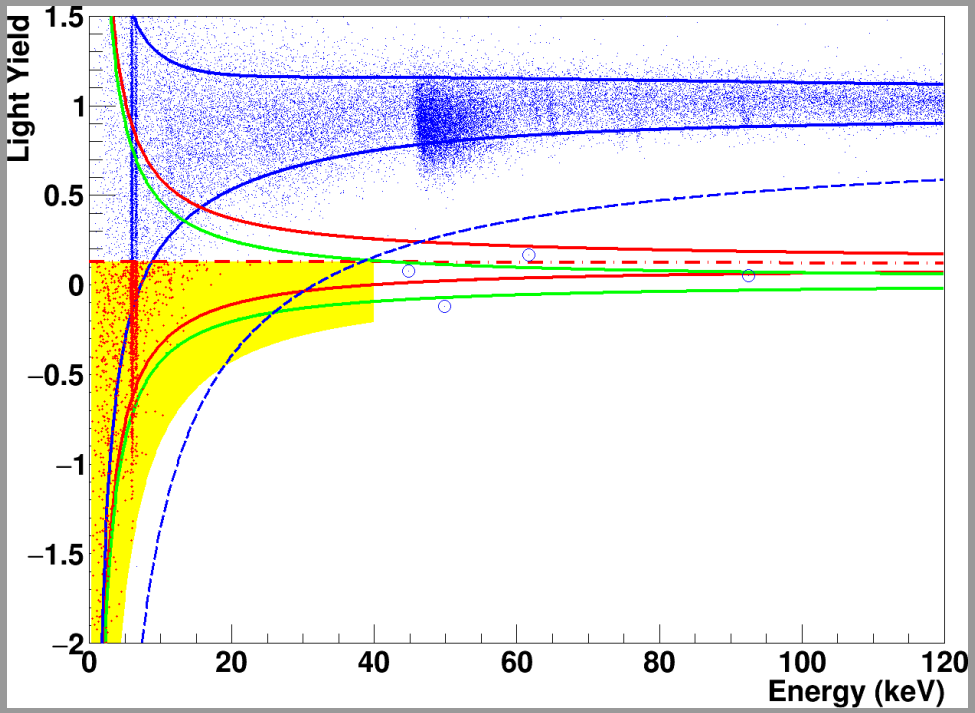
Crystal Held by Sticks

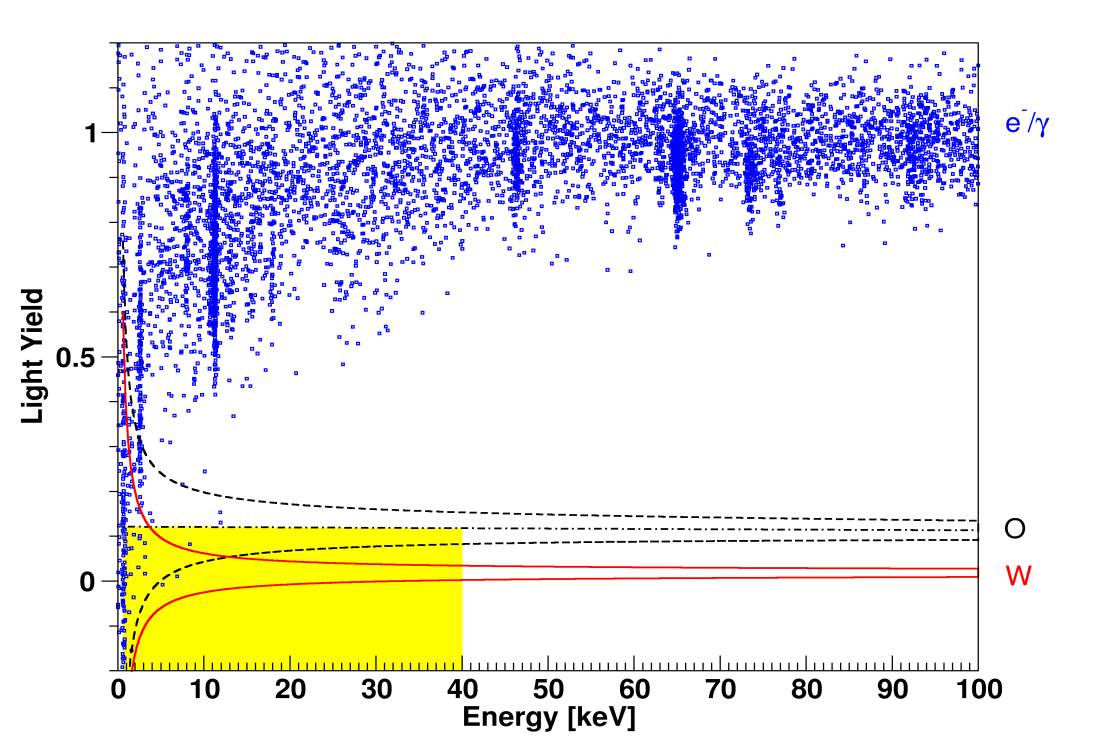


Lise vs. TUM40

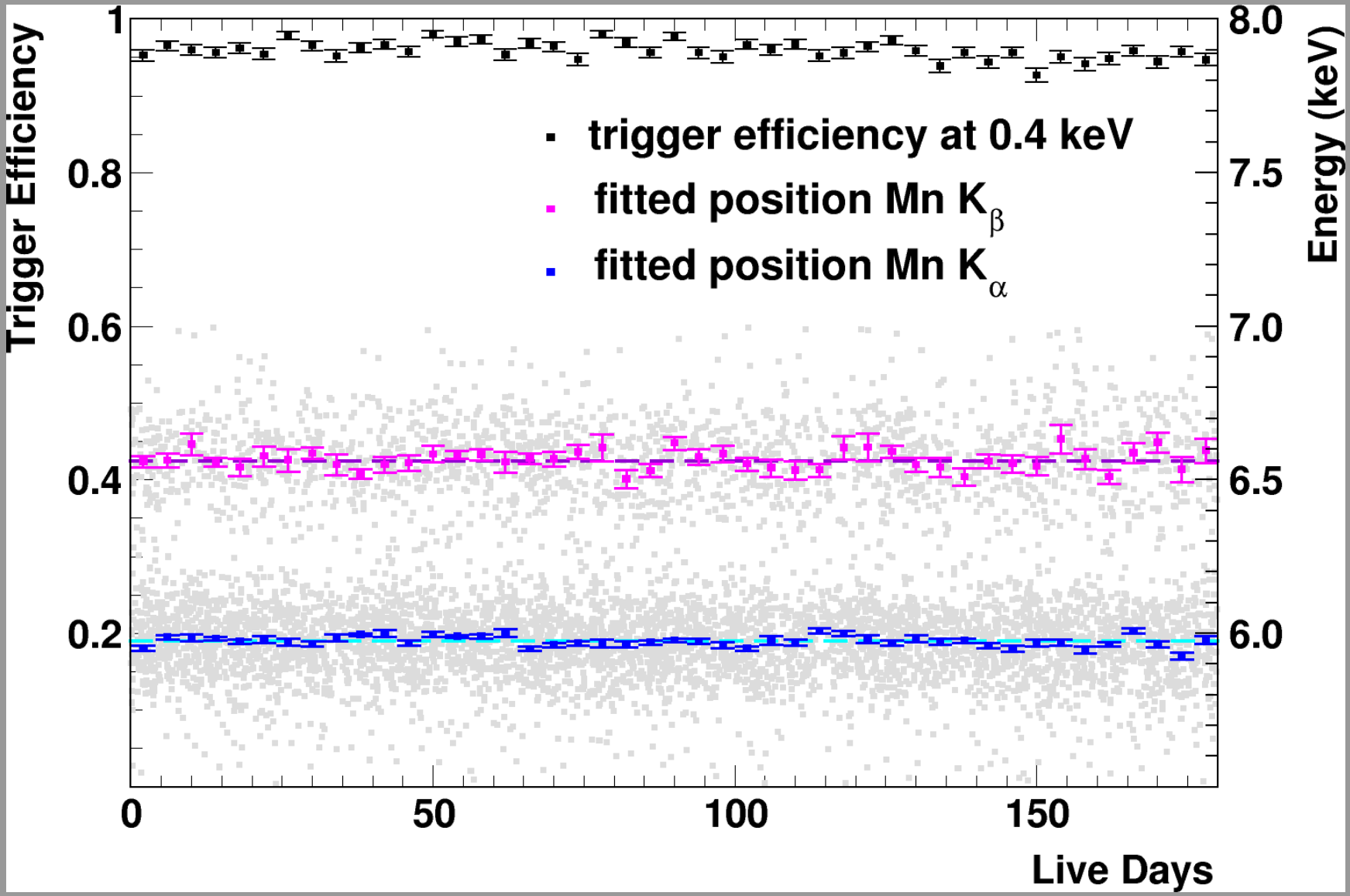






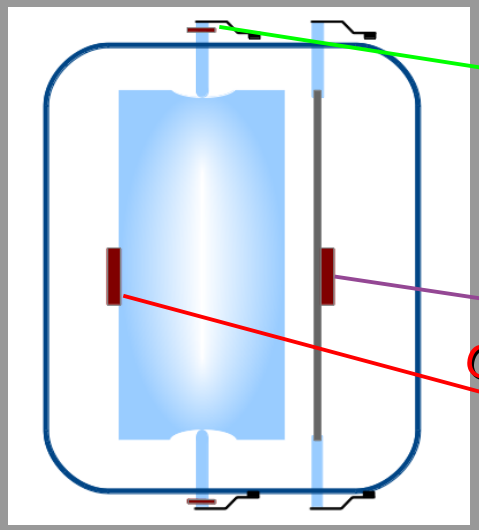


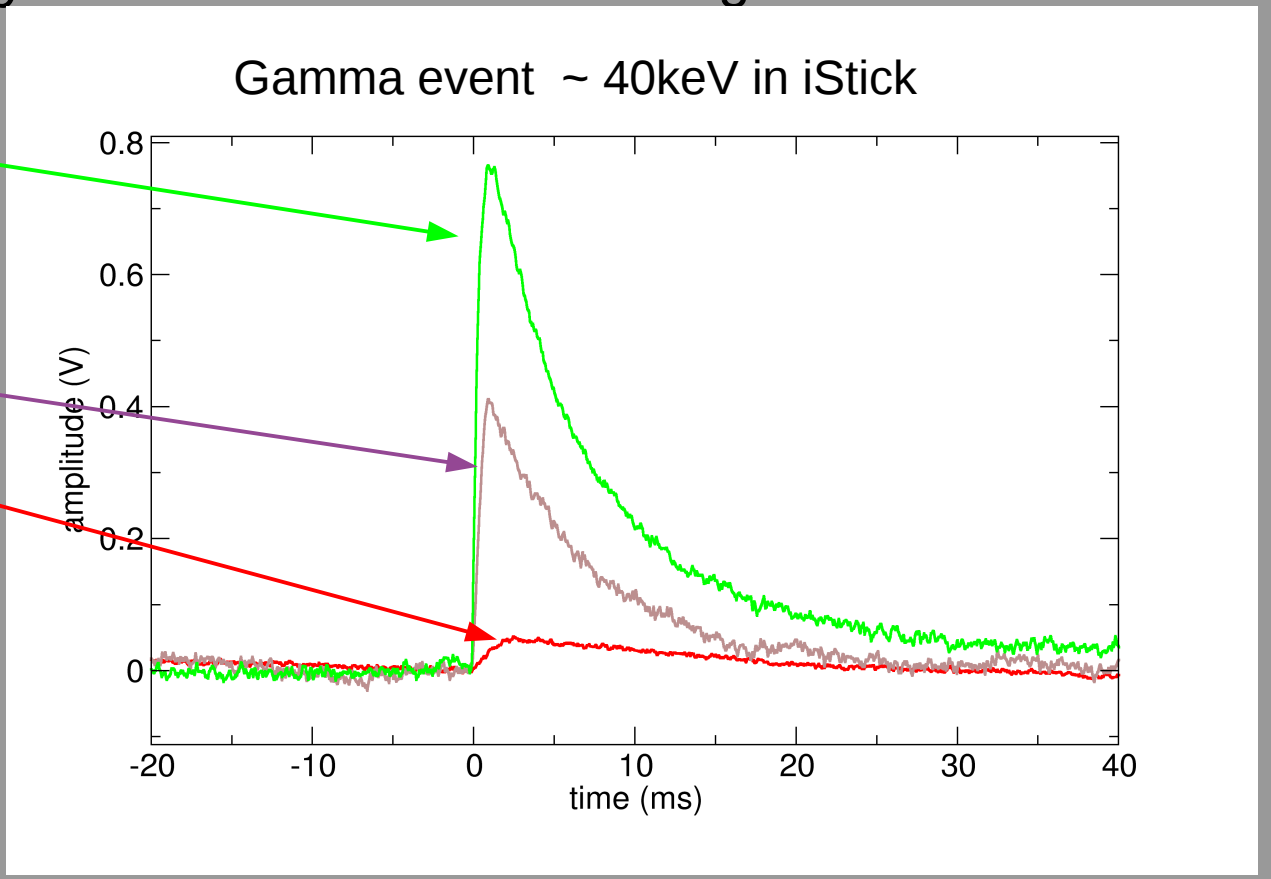
Long term stability

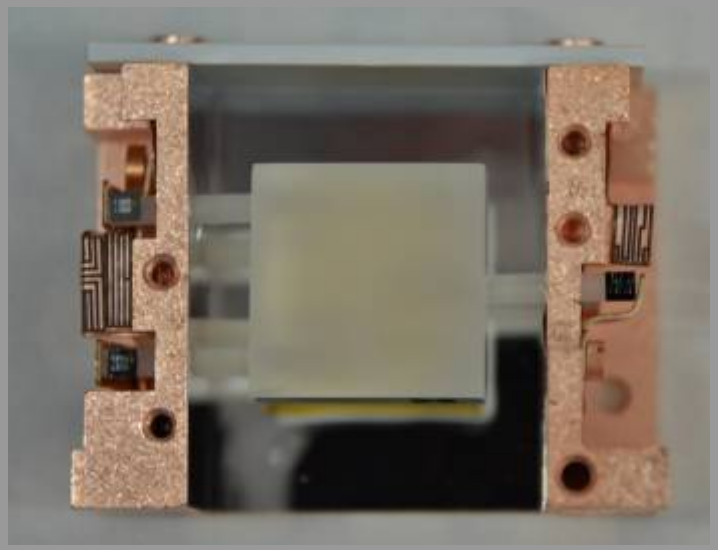


iSticks

Powerful discrimination of any effect related to the holding





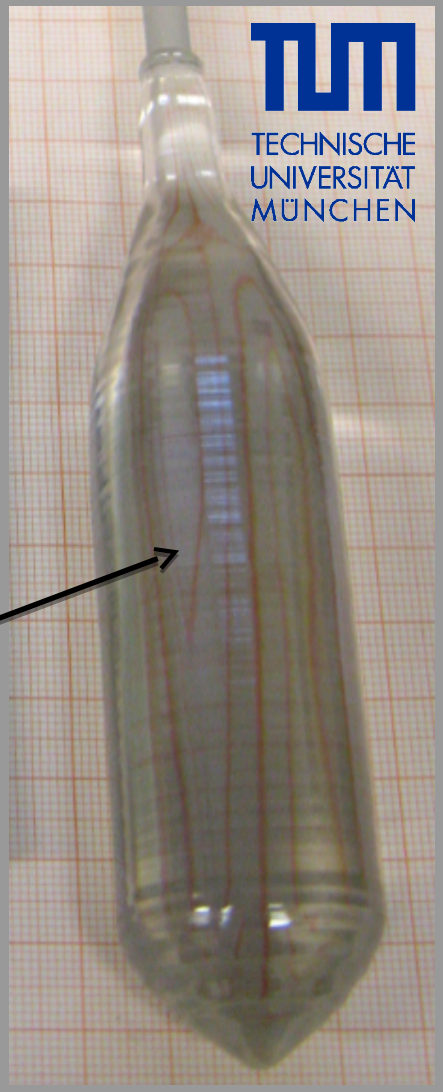


Recent Exciting Progress

Chemical purification of $CaCO_3$ powder:

- Measurements indicate purification
  - **Th** contamination decreased by factor 2-7
  - **U** contamination decreased by factor 15-35
- Crystal growth with cleaned powder successful

Ingot for 3-4 CRESST-III



- Two such crystals will be already implemented in CRESST-III phase 1

work by H.H. Trinh Thi, A. Münster, A. Erb