DIRECT SEARCH FOR LIGHT DARK MATTER WITH THE CRESST-III EXPERIMENT

L. SCIENTIFIC COMMITTEE MEETING, OPEN SESSION, LNGS

Florian Reindl
HEPHY & TU Vienna

for the CRESST collaboration

THE CRESST COLLABORATION

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

TECHNISCHE UNIVERSITÄT MÜNCHEN

HEPHY Institut für Hochenergiephysik

UNIVERSITY OF OXFORD

INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso

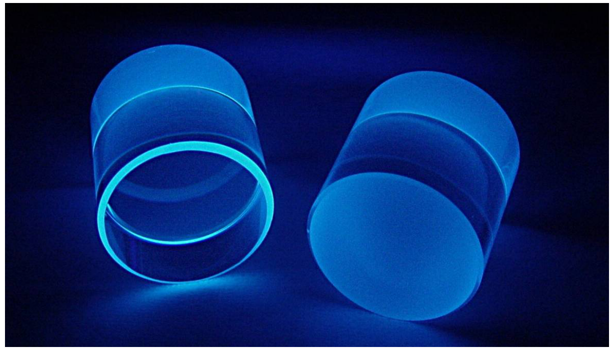
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

THE CRESST EXPERIMENT

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

Direct detection of dark matter particles via their scattering off target nuclei

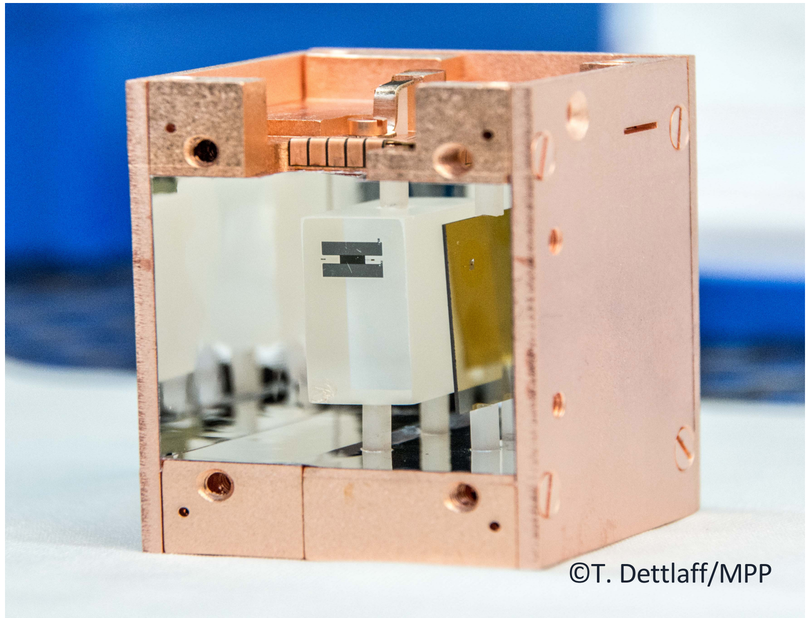
Scintillating $CaWO_4$ crystals as target



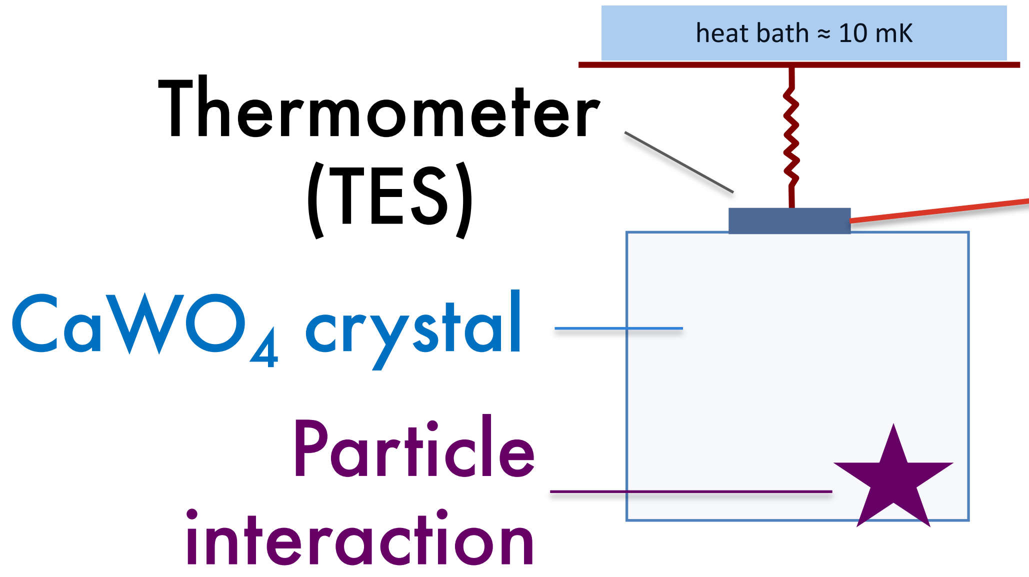
Target crystals operated as

cryogenic calorimeters (~15mK)

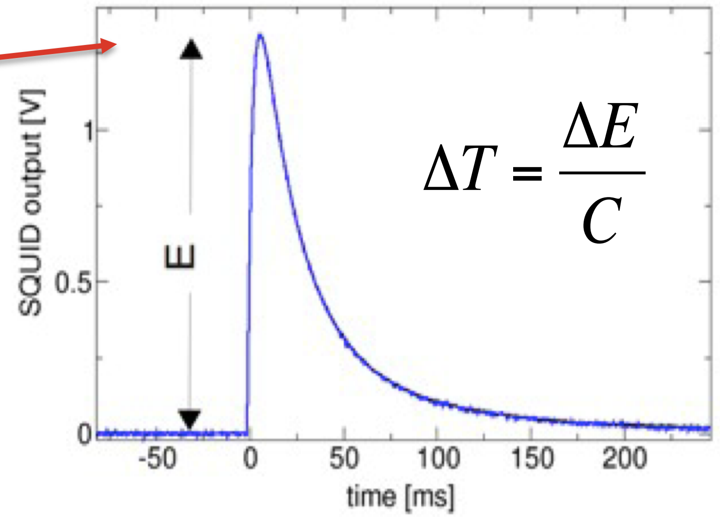
Separate **cryogenic light detector** to detect the scintillation light signal



CRYOGENIC DETECTOR



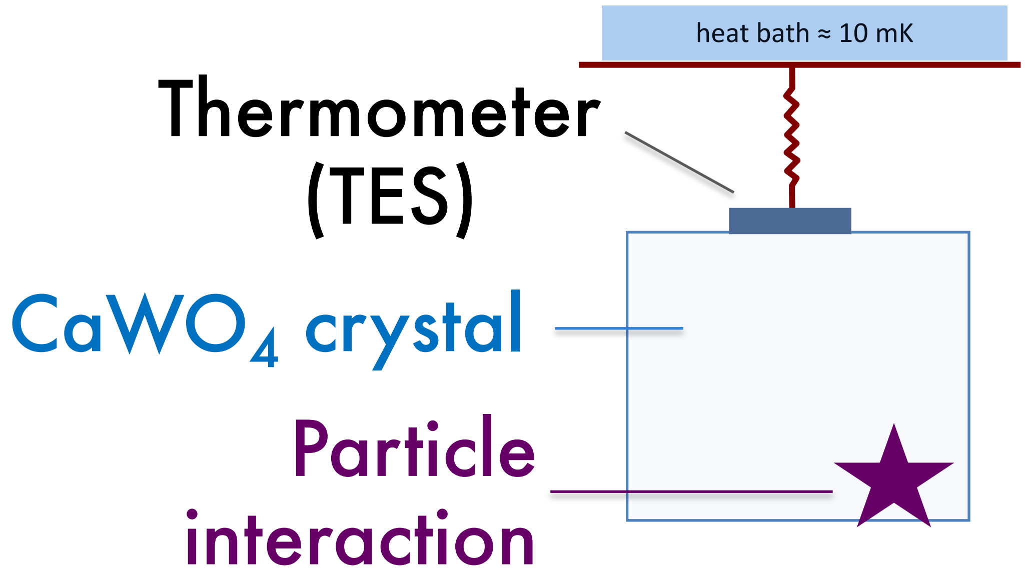
Temperature pulse



Low temperature
Low heat capacity

High sensitivity

CRYOGENIC DETECTOR

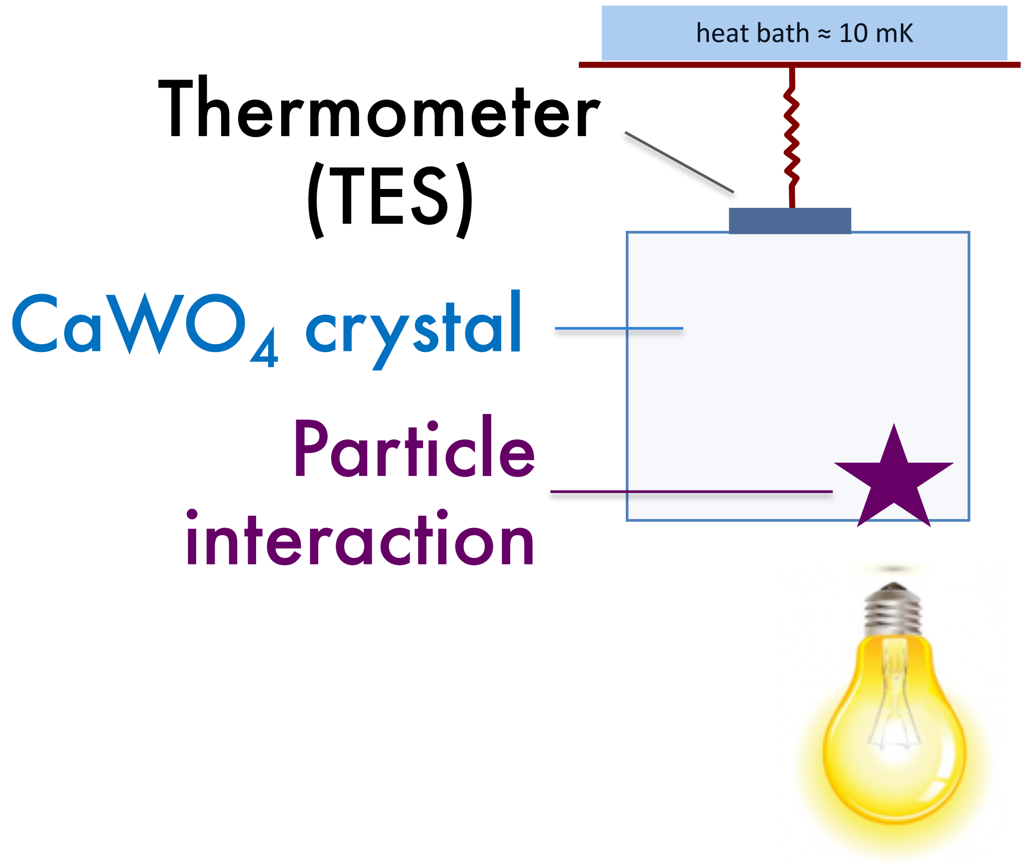


Phonon signal (≳90 %)

(Almost) Independent of particle type

Precise measurement of the deposited energy

SCINTILLATING CALORIMETER



Phonon signal (≳90 %)

(Almost) Independent of particle type

Precise measurement of the deposited energy

Scintillation light (few %)

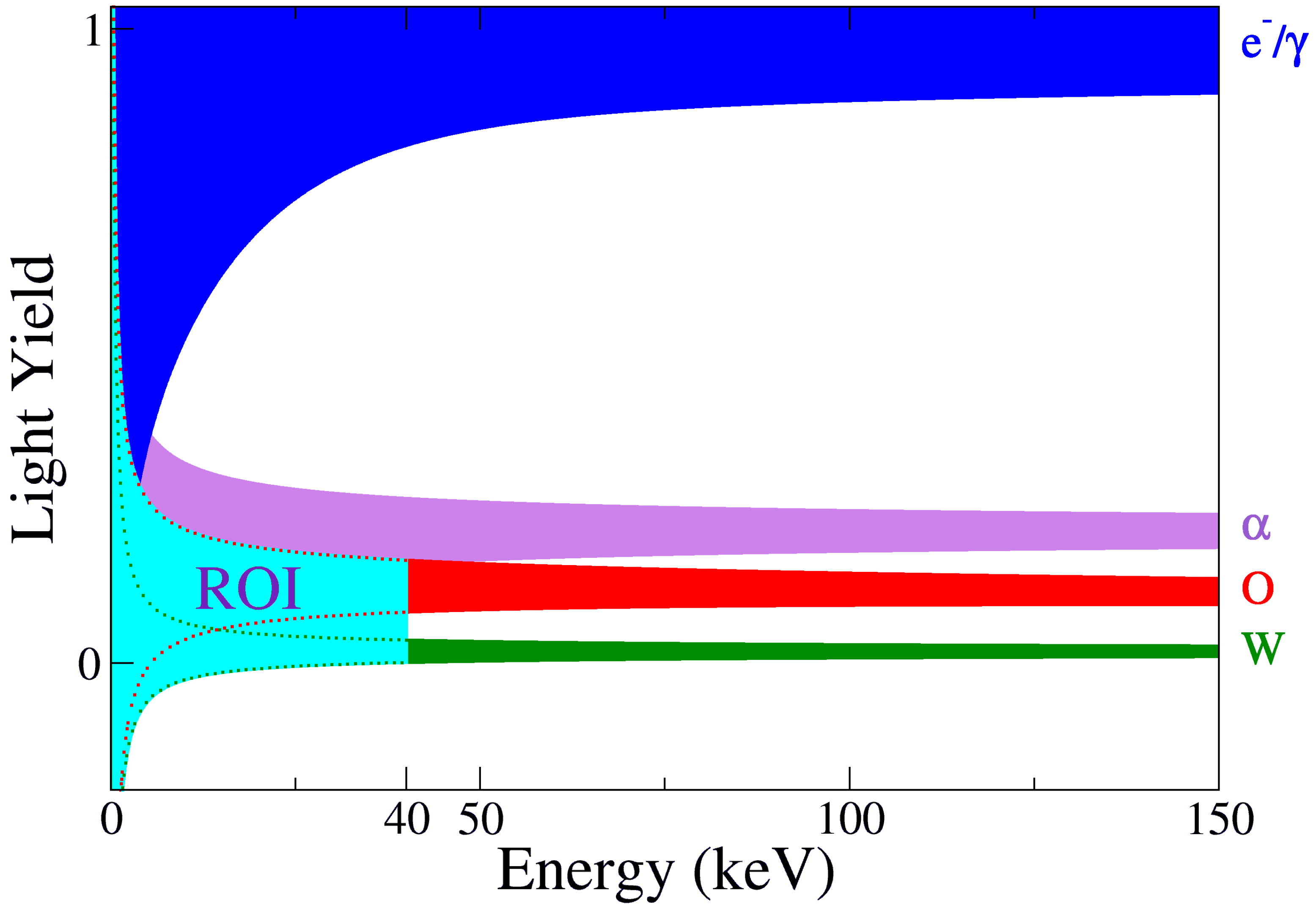
Particle-type dependent
→ LIGHT QUENCHING

EVENT DISCRIMINATION

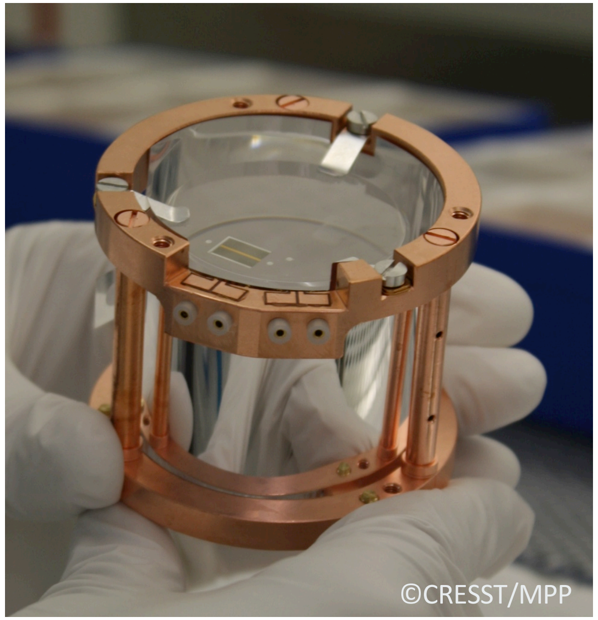
Light Yield= $\frac{\text{Light signal}}{\text{Phonon signal}}$

Characteristic of the event type

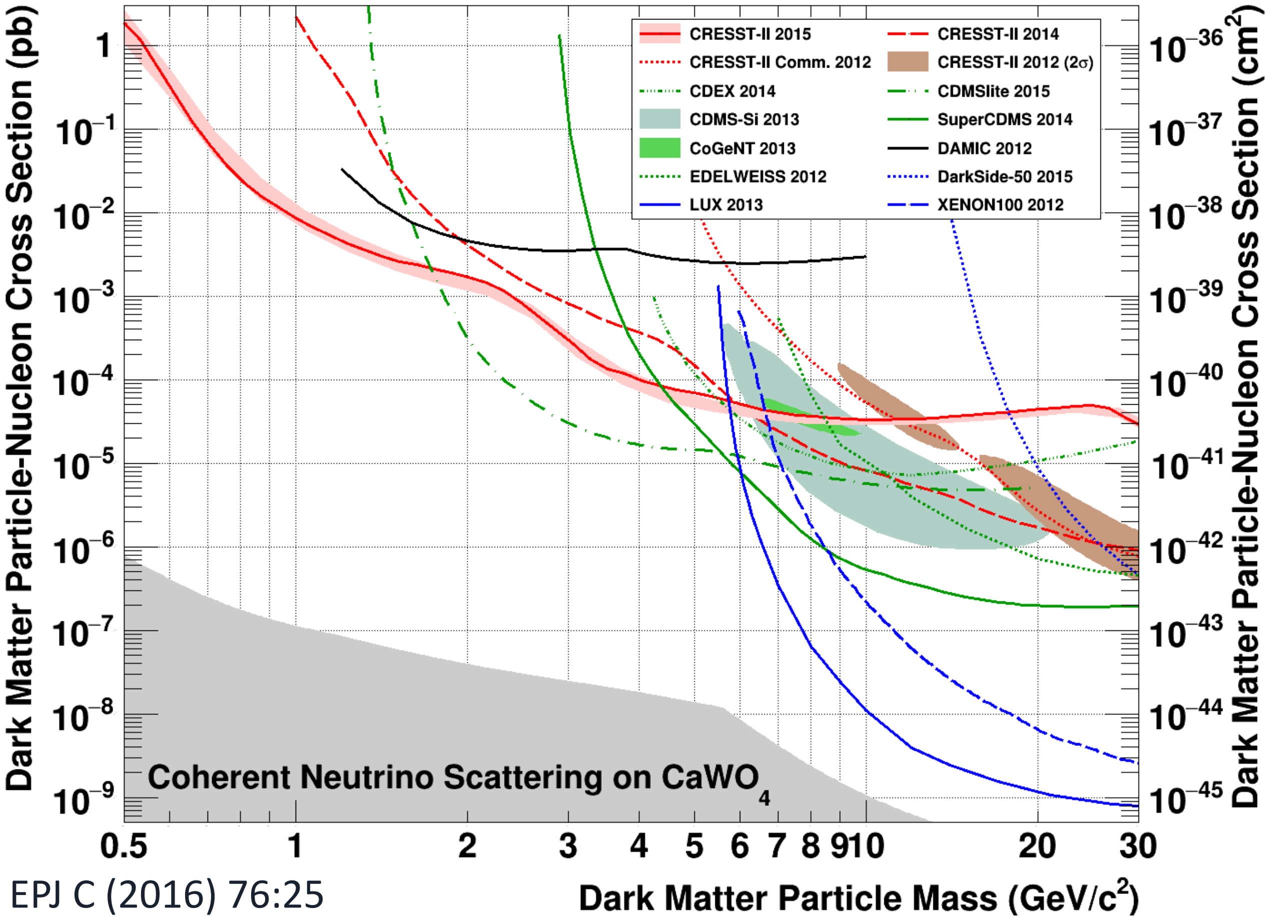
ROI : region of interest
for dark matter search



CRESST-II RESULTS - 2015



Lise: Background level ≈8.5 counts/(keV kg day)
Threshold: 307eV



EPJ C (2016) 76:25

Until 2017 world-leading below 1.7GeV/c^2

Opened up sub-GeV/c^2 regime

Hunting light dark matter requires a low threshold!

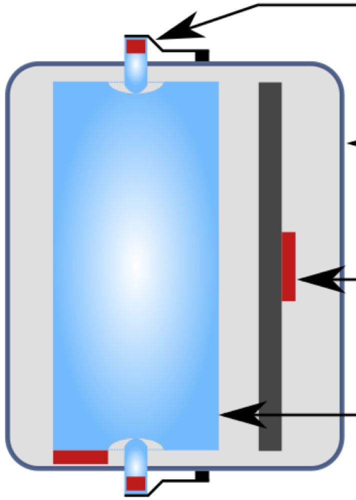
CRESST-III LOW-THRESHOLD DETECTORS

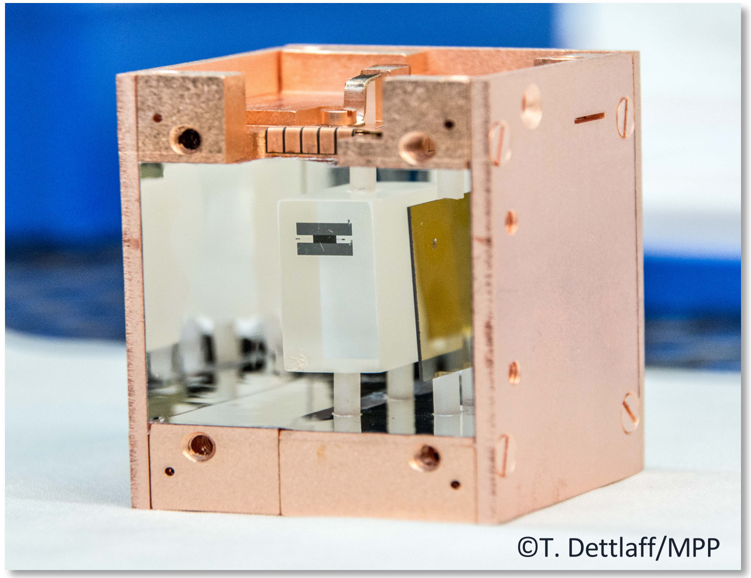
Detector layout optimized for low-mass dark matter
Radical reduction of dimension (250g → 24g)

- Cuboid crystals of (20×20×10)mm^3 (≈**24g**)
- Design goal: **100 eV threshold**

- Fully scintillating housing
- Instrumented sticks

} Veto surface-related background





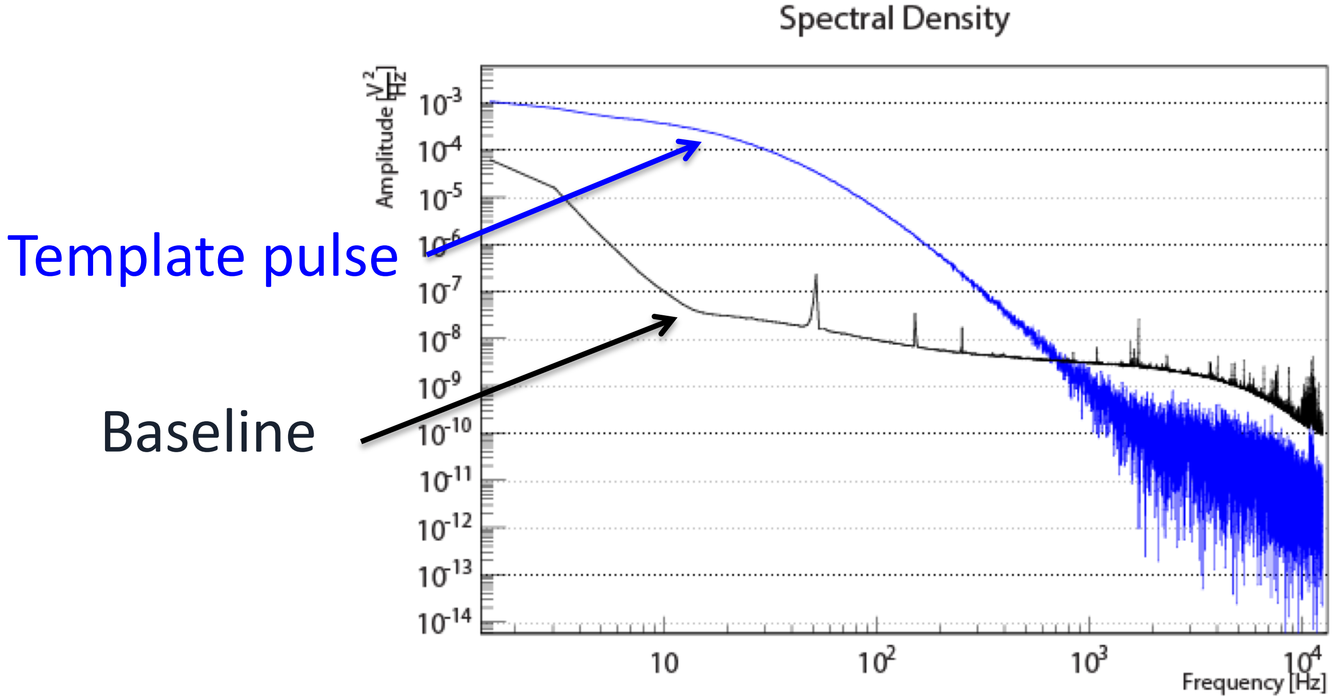
CRESST-III phase 1

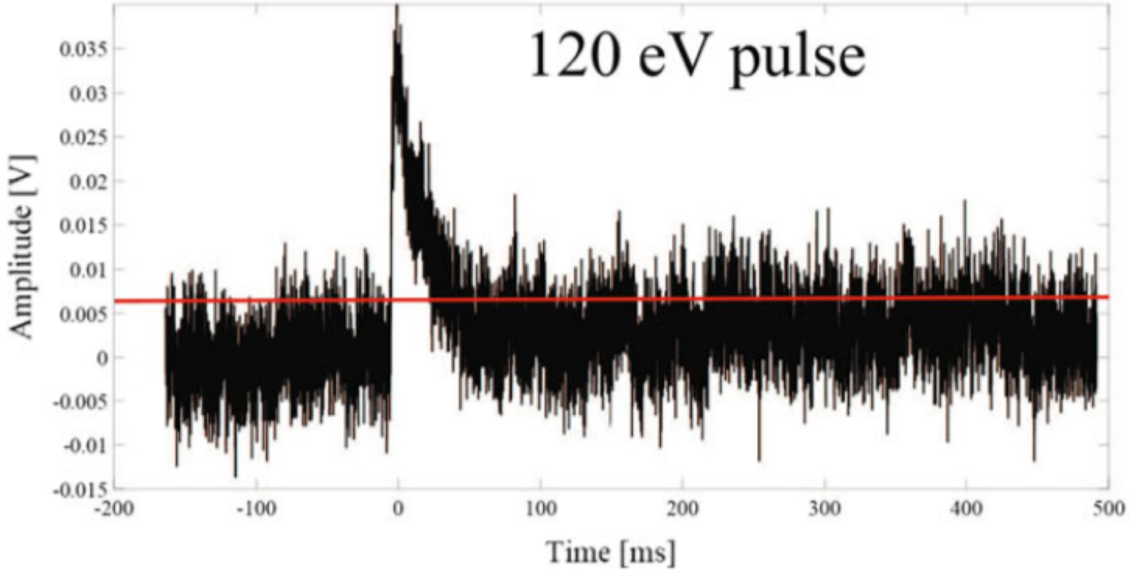
Data taking from July 2016 to February 2018

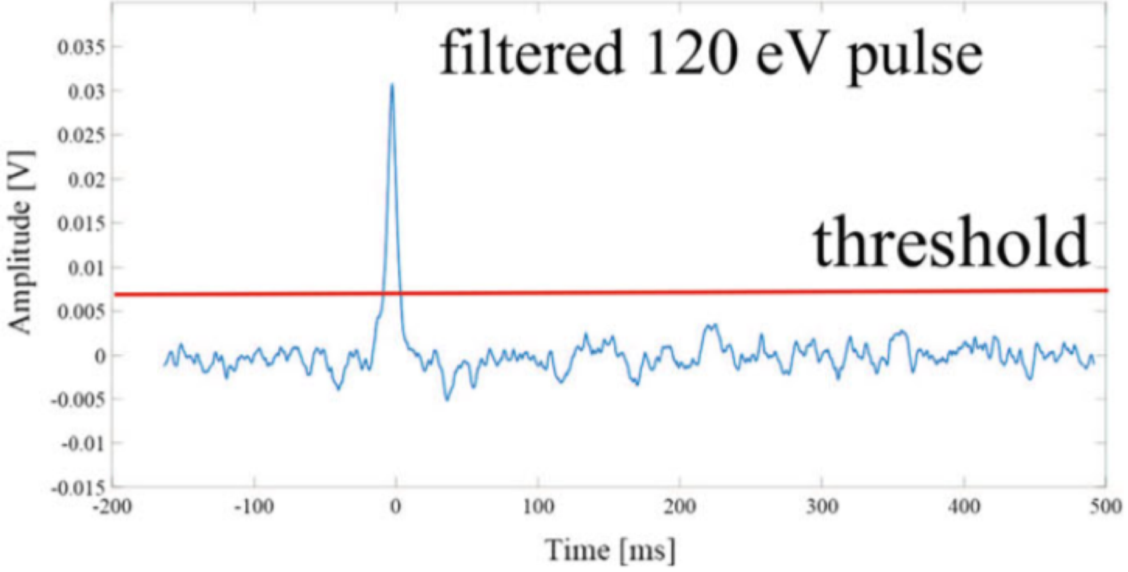
OPTIMUM FILTER

Maximizes signal-to-noise ratio (in frequency space)

Factor 2-3 typical improvement in resolution

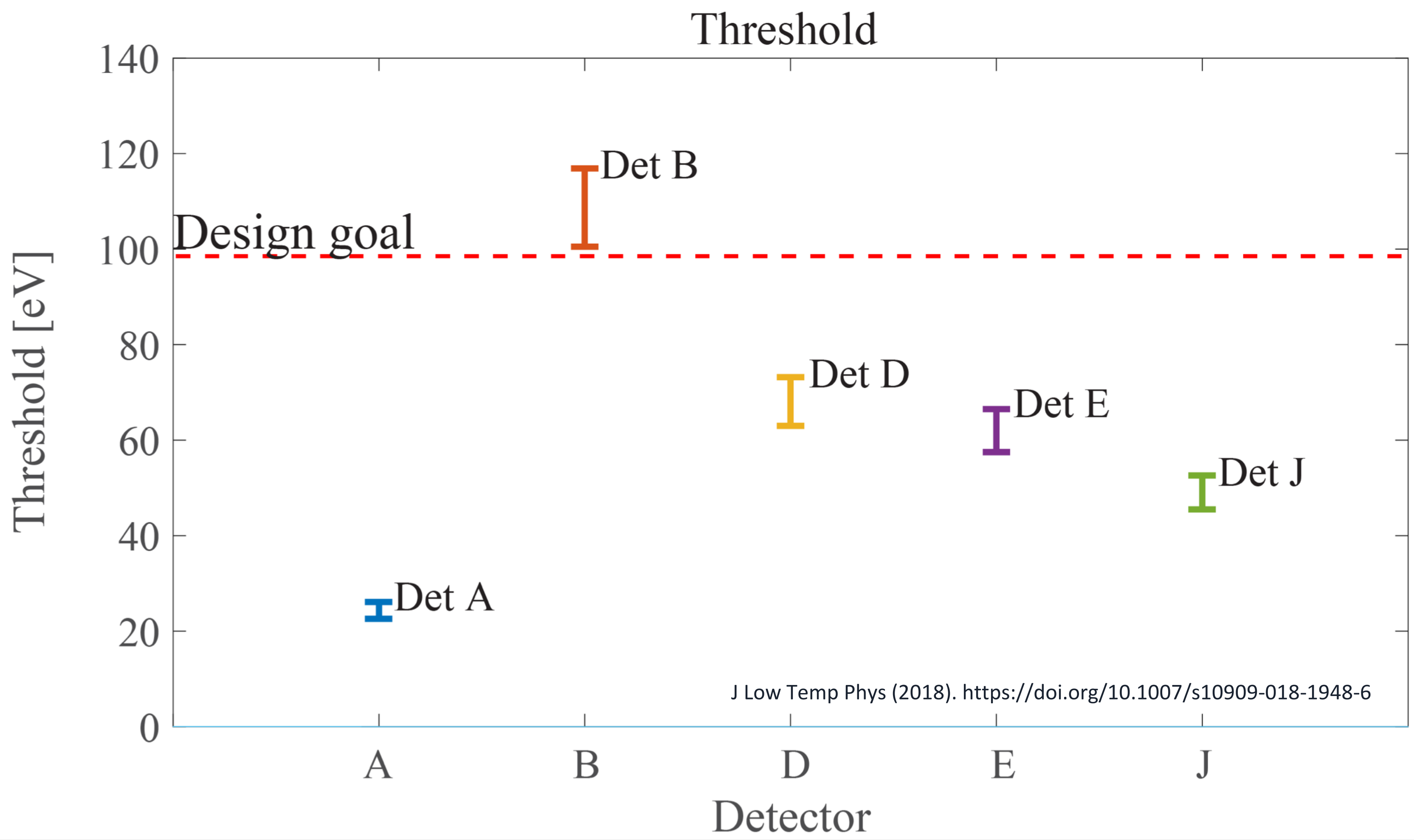






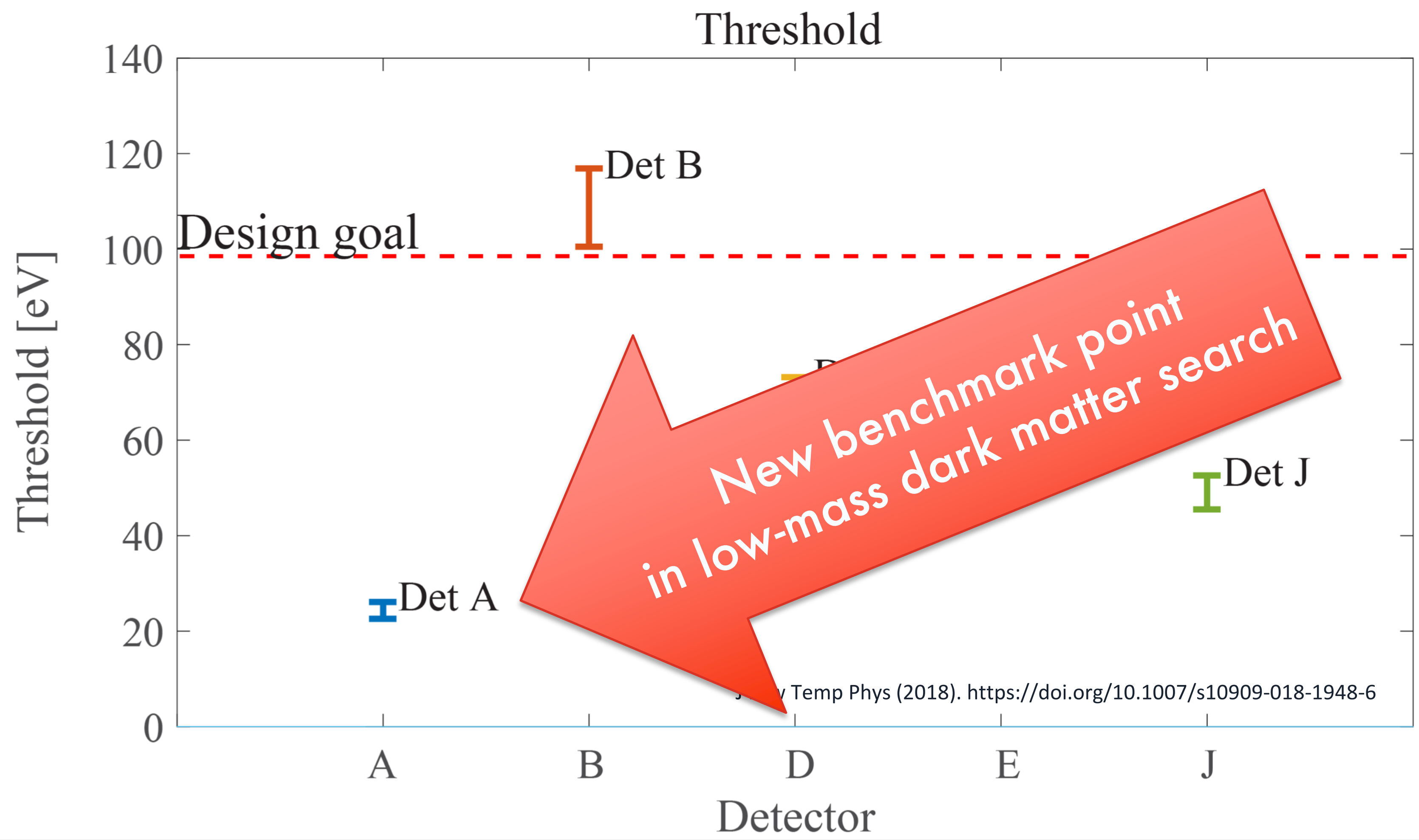
J Low Temp Phys (2019)
doi.org/10.1007/s10909-018-1948-6

OPTIMUM THRESHOLDS
NEW FRONTIER IN DIRECT DM DETECTION



5 detectors reach/exceed the CRESST-III design goal

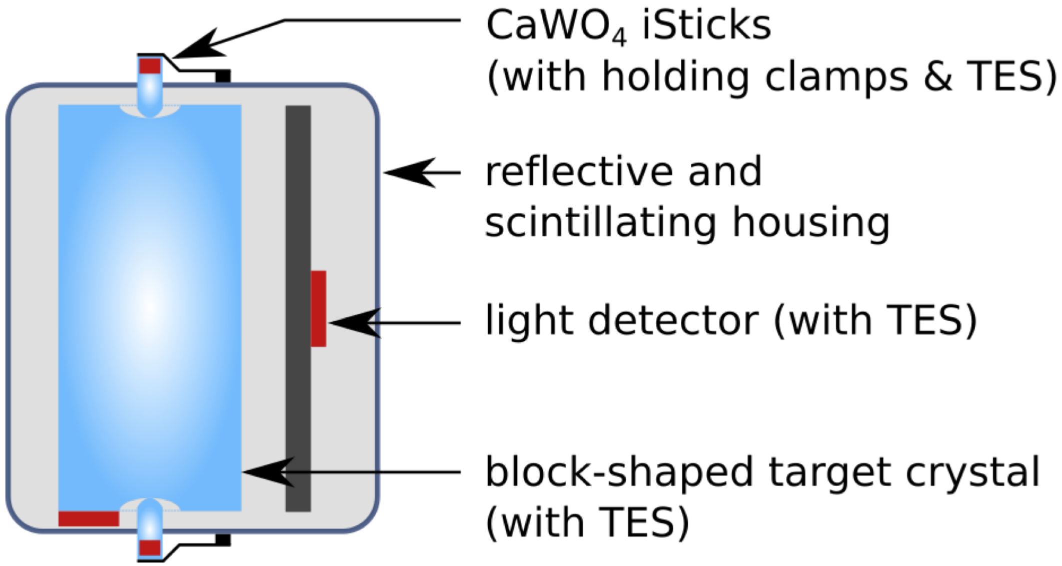
OPTIMUM THRESHOLDS
NEW FRONTIER IN DIRECT DM DETECTION

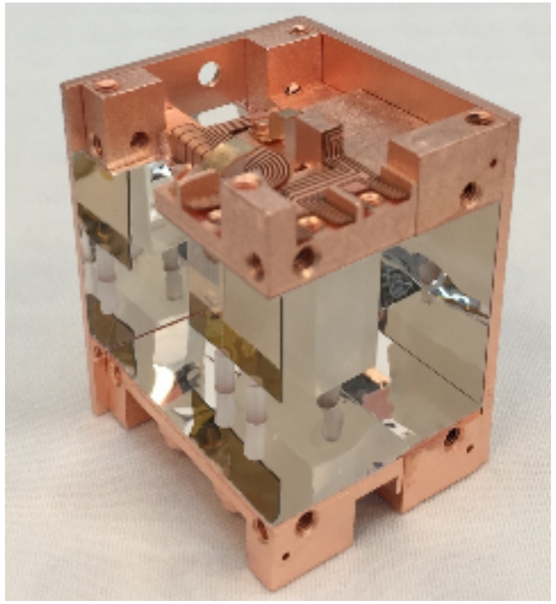


5 detectors reach/exceed the CRESST-III design goal

DETECTOR A

= LOWEST THRESHOLD IN CRESST-III PHASE 1





Data taking period:	10/2016 – 01/2018
Non-blind data (dynamically growing):	20% randomly selected
Target crystal mass:	23.6g
Gross exposure (before cuts):	5.7 kg days
Nuclear recoil threshold:	30.1 eV
Resolution at zero energy:	σ = 4.5eV

SELECTION CRITERIA (AKA "CUTS")

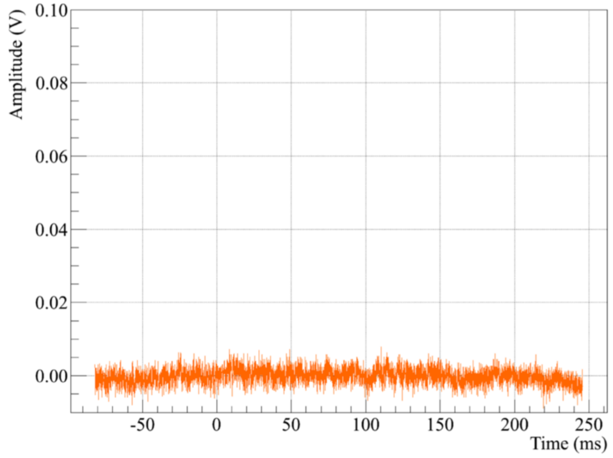
Objective

Keep only events where a correct determination of the amplitude (→energy) is guaranteed

Unbiased analysis

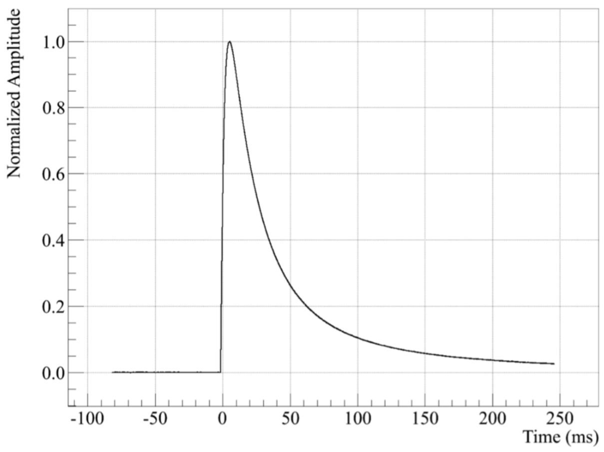
1. Design cuts on non-blind training set (≦20%, excluded from DM data set)
2. Apply without change to blind DM data set

EFFICIENCY DETERMINATION



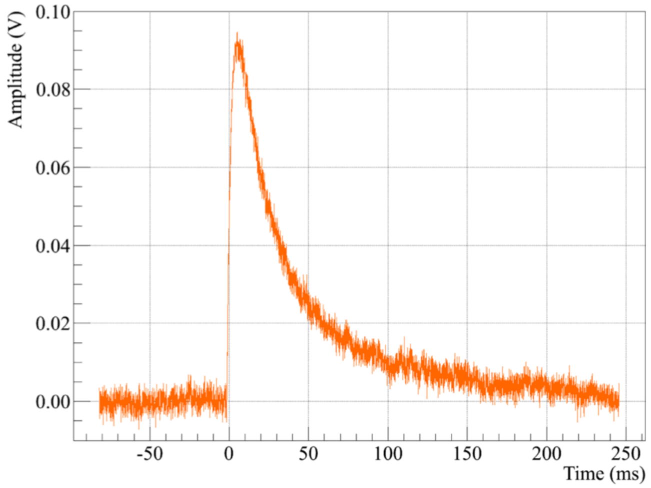
Empty baseline

+



Averaged pulse

=



Simulated pulse

Simulated pulses (of desired energies) passed through analysis chain

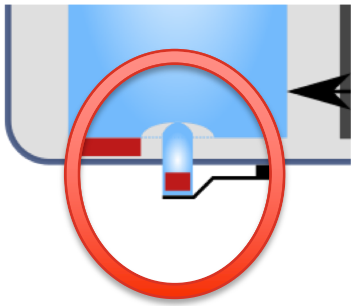
SELECTION CRITERIA (AKA "CUTS")

Rate: Noise conditions

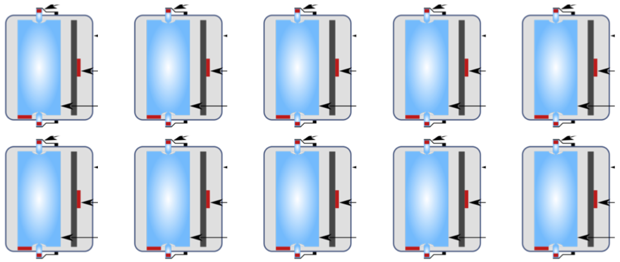
Stability: Detector(s) in operating point

Data quality: Non-standard pulse shapes (in particular iStick events and pileup)

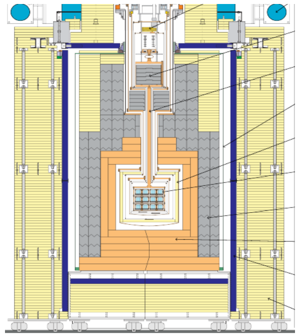
Coincidences: iSticks



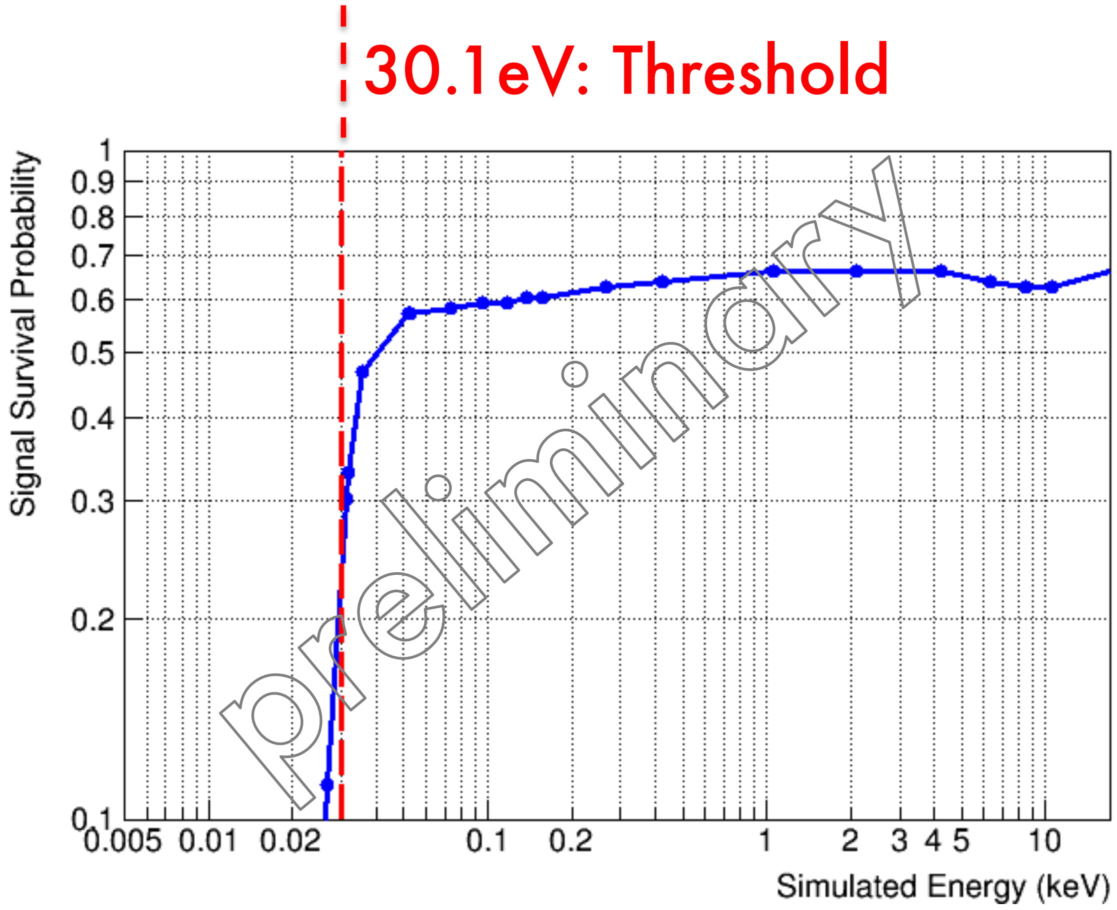
multi-hit events



muon veto



EFFICIENCY

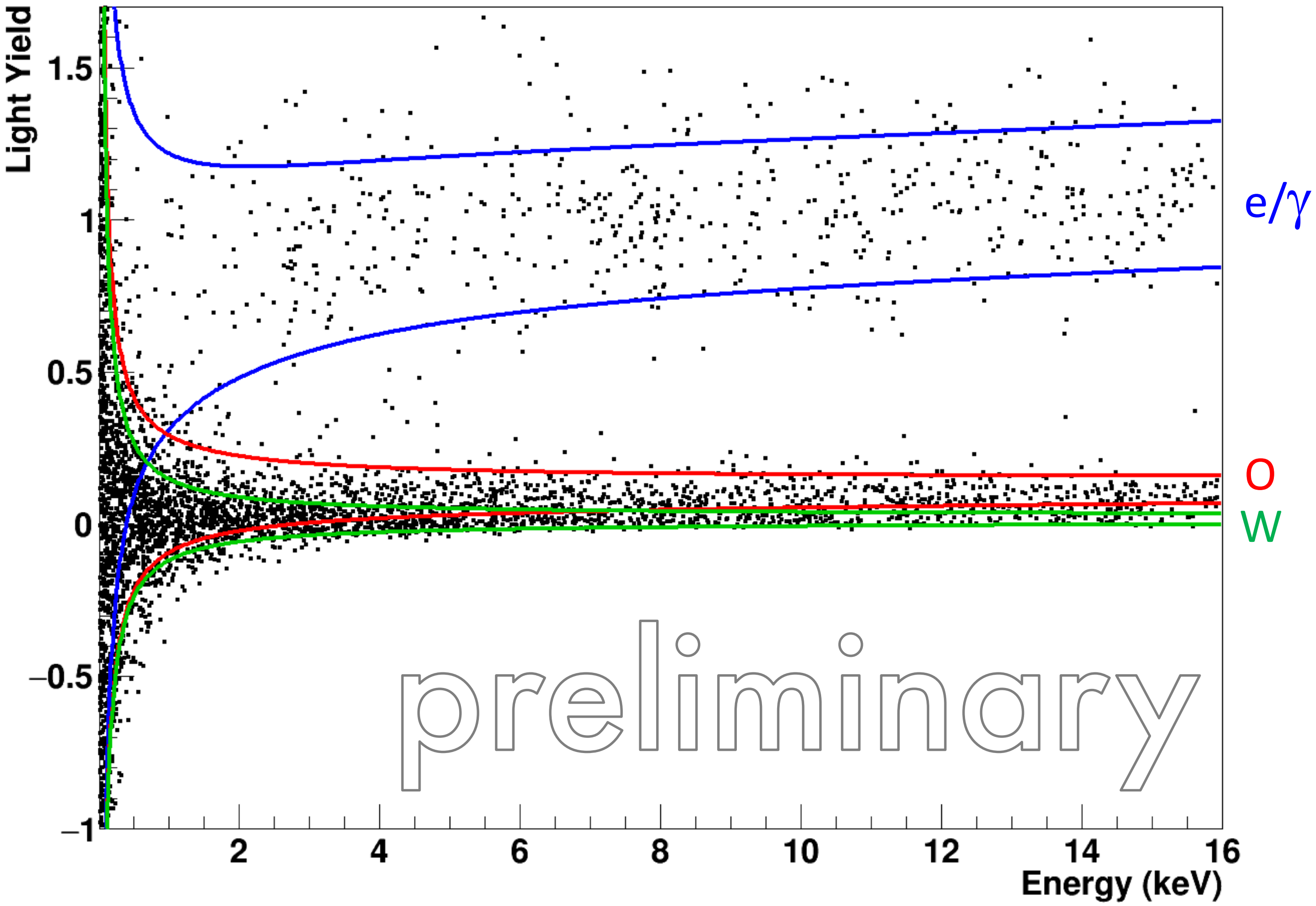


Simulated by artificial pulses placed at random positions in the data stream

Includes trigger and cuts

≳60% efficiency over broad energy range

NEUTRON CALIBRATION DATA

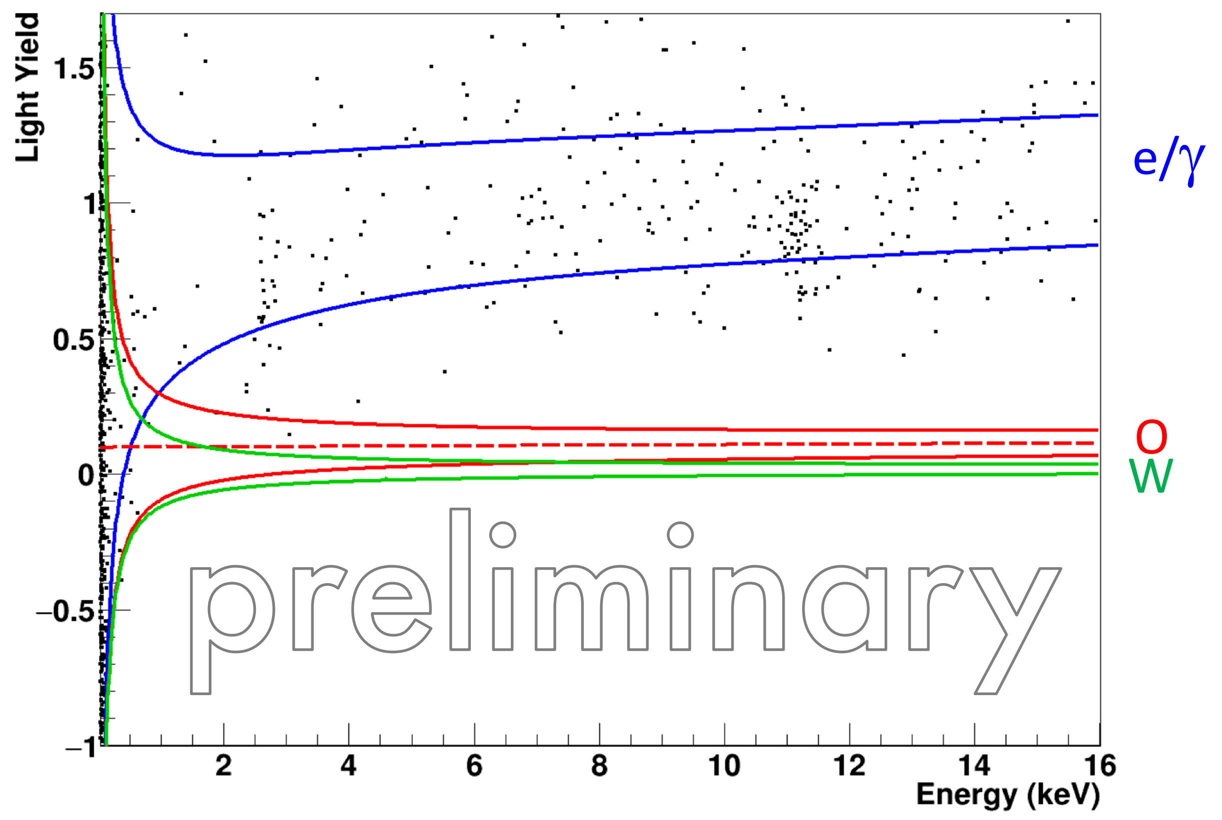


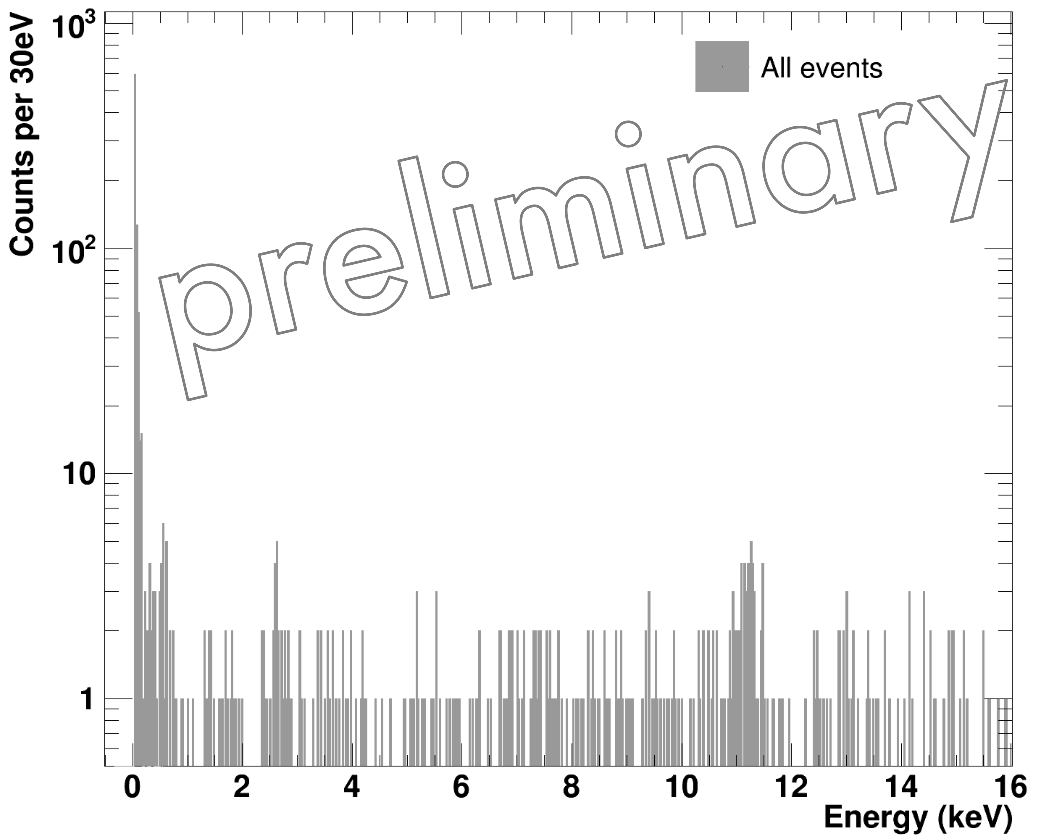
Unbinned maximum likelihood fit

Quenching factors measured with neutron beam

DARK MATTER DATA

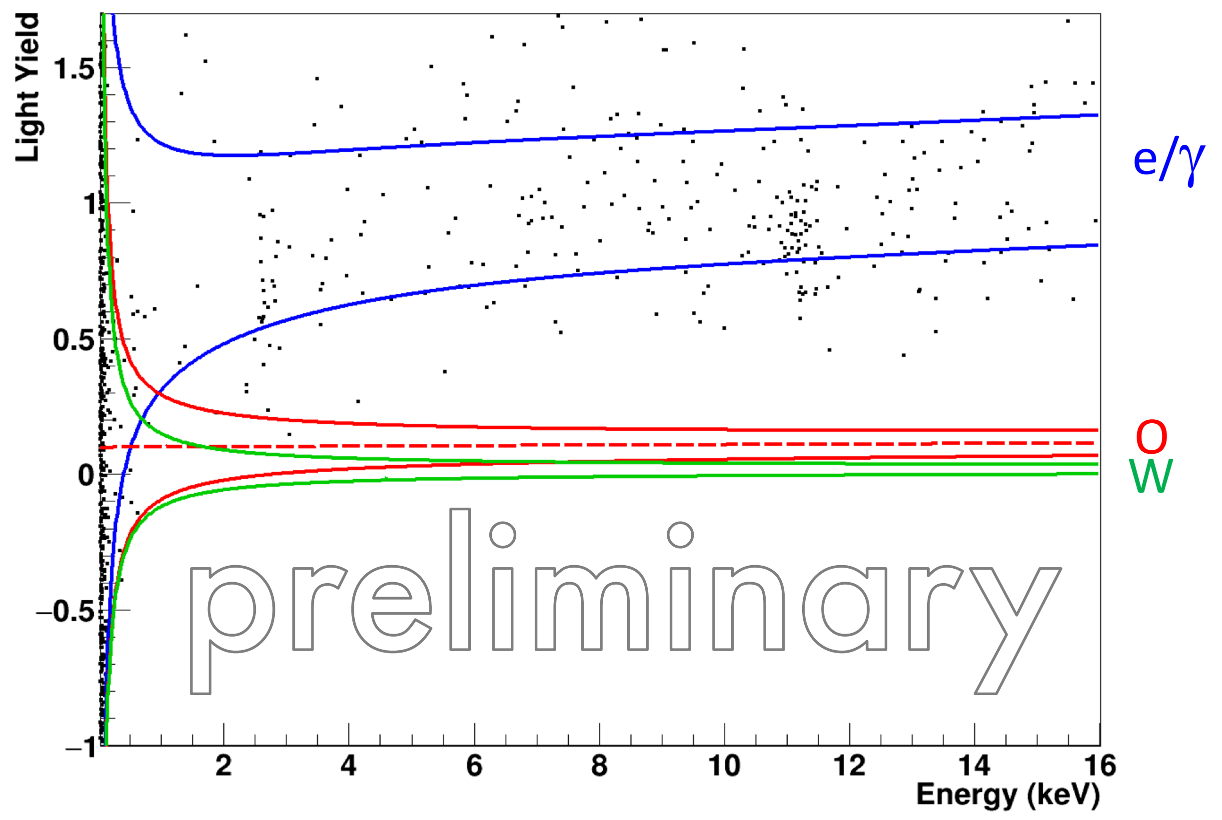
Analysis optimized for very low energies: 30eV → 16keV

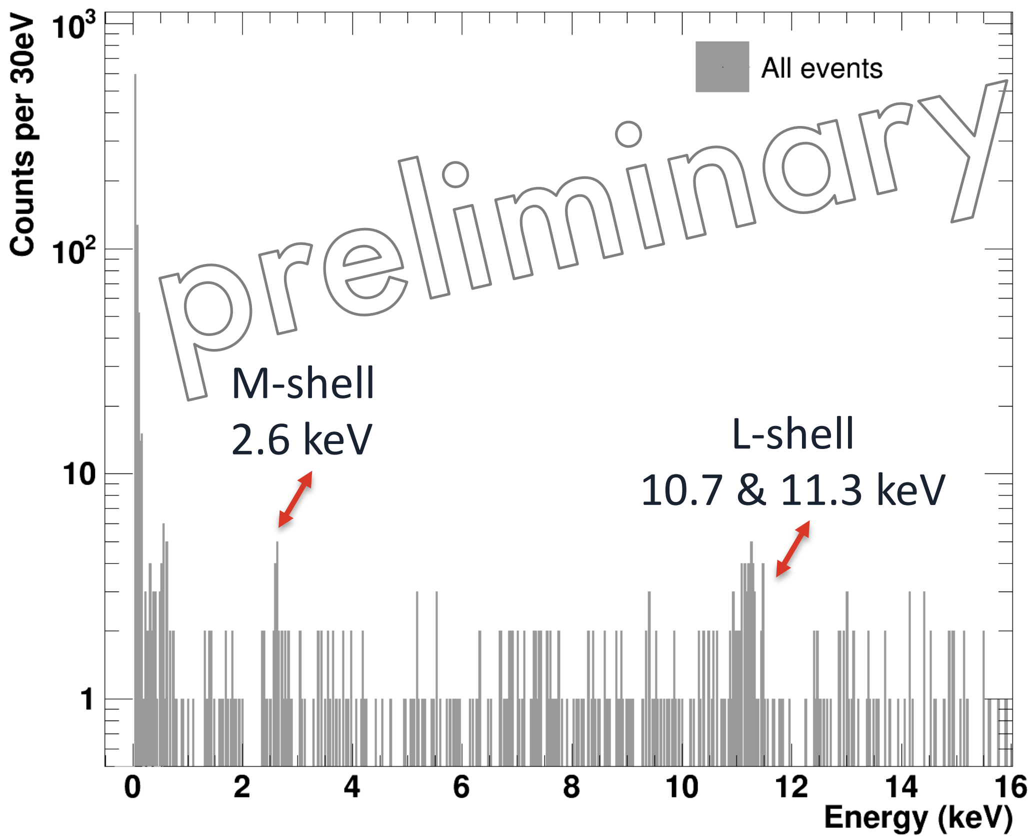




DARK MATTER DATA

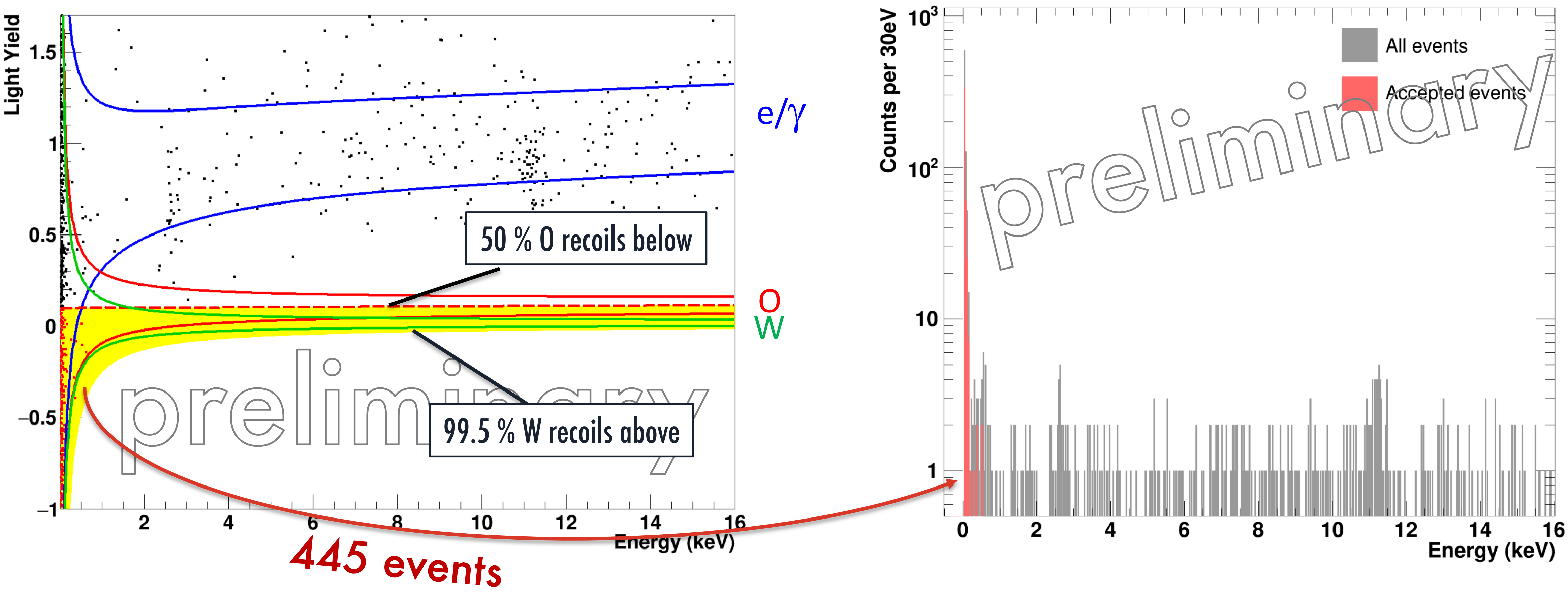
Cosmogenic activation → $^{179}Ta + e^{-} \rightarrow {}^{179}Hf + \nu_e$ (1.8y)





DARK MATTER DATA

Acceptance region fixed before unblinding

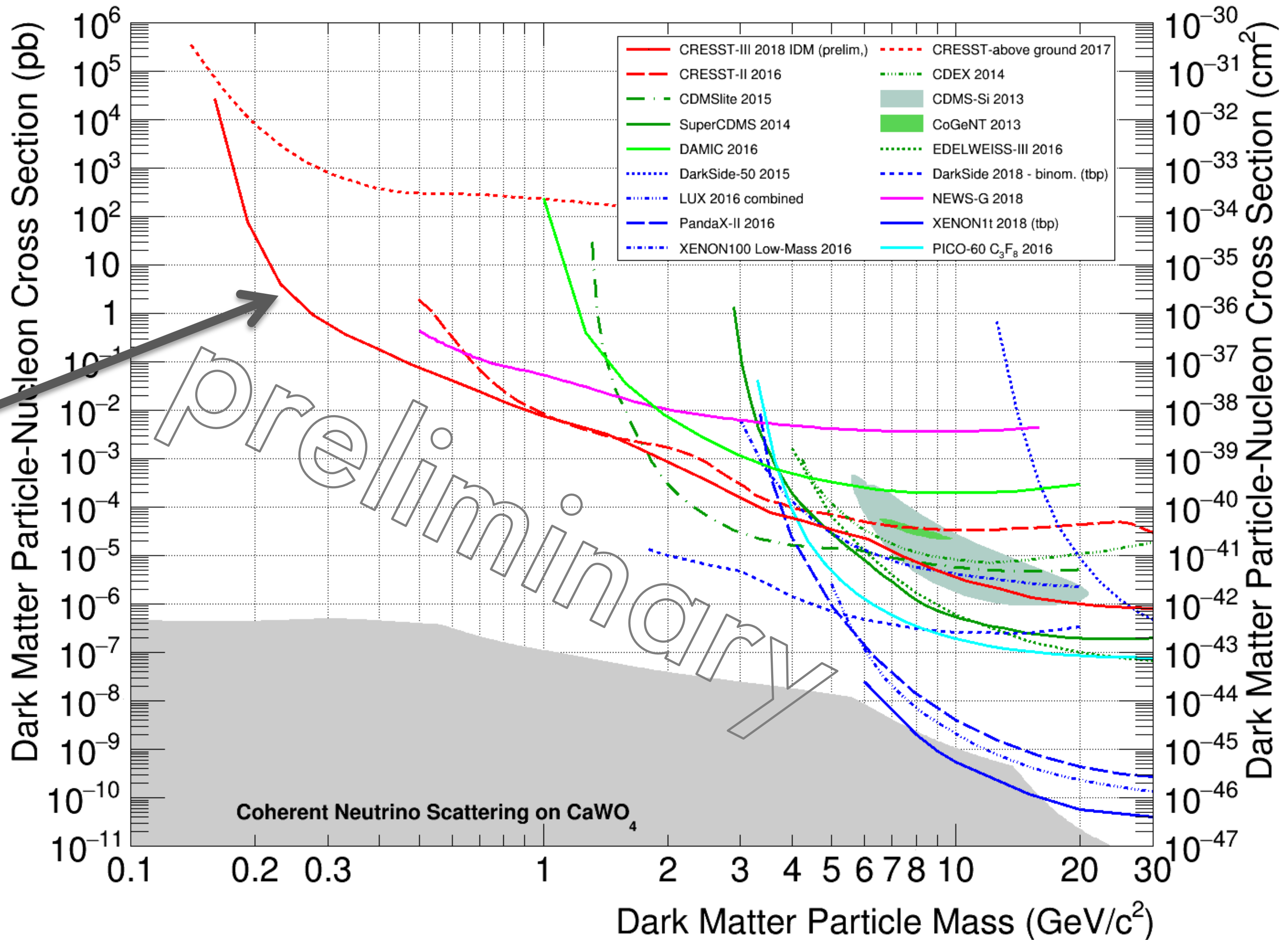


(PRELIMINARY) RESULT

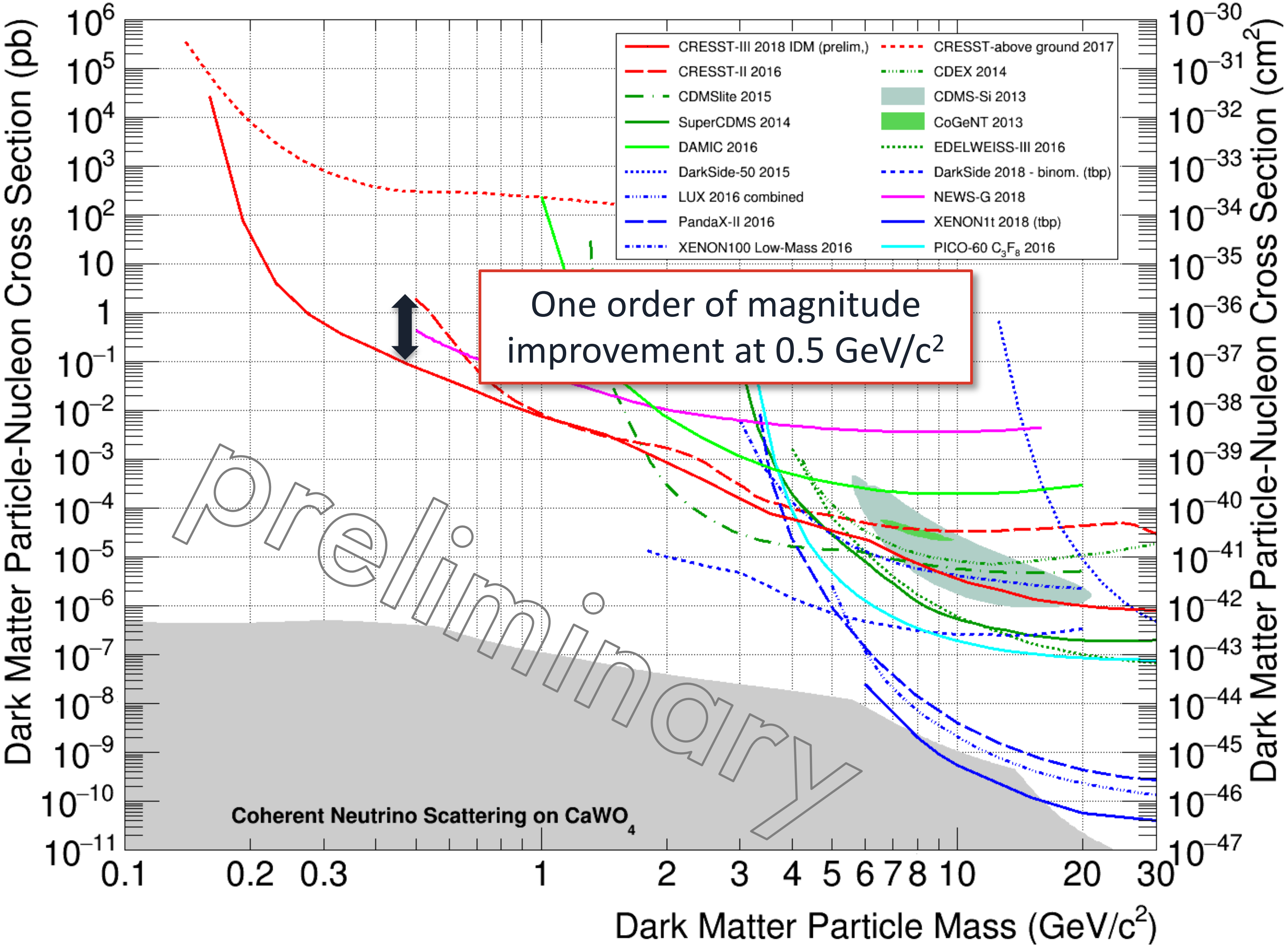
Energy spectrum of accepted events

Yellin 1D optimum interval method

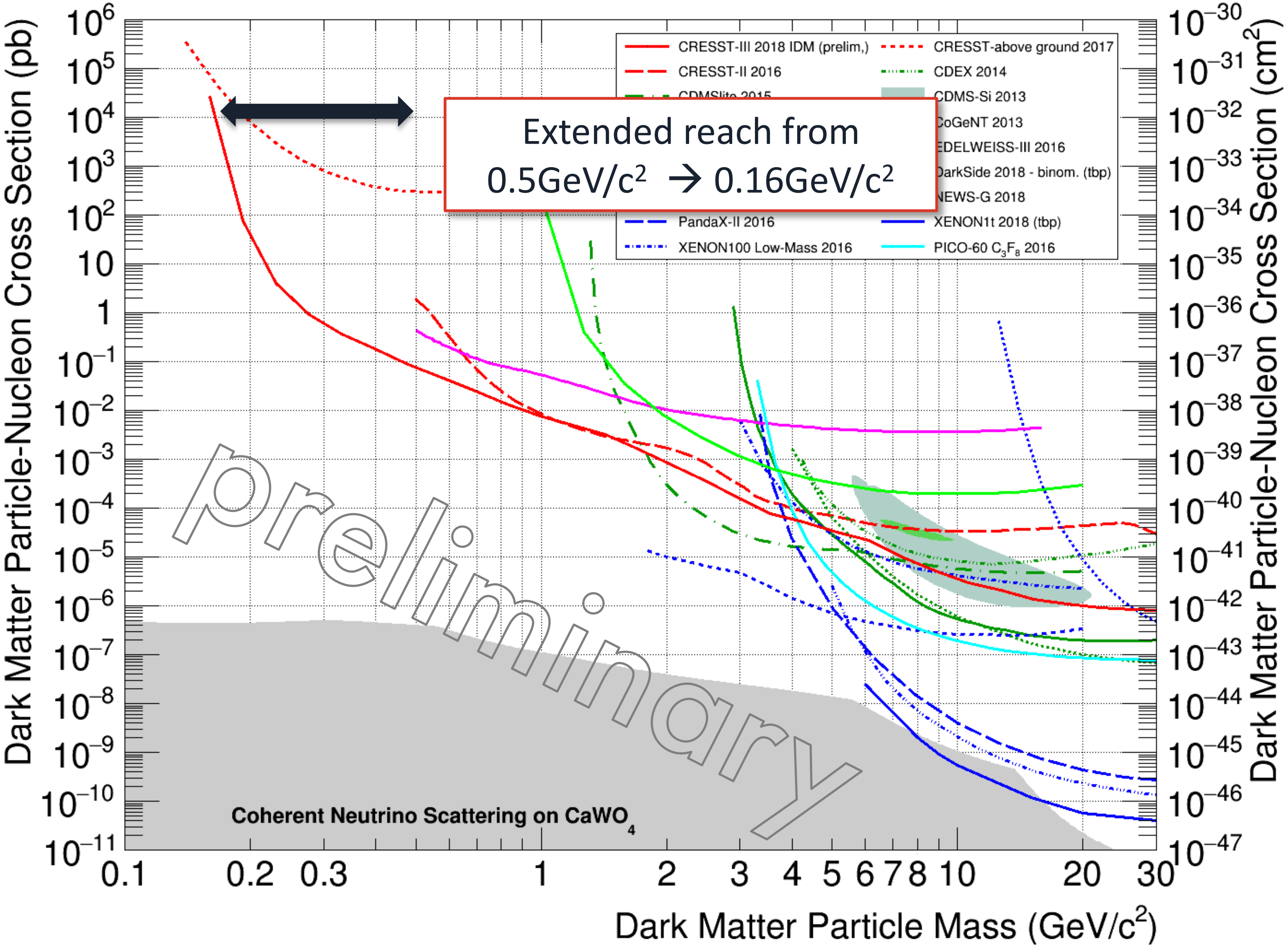
Energy spectrum expected for DM



(PRELIMINARY) RESULT



(PRELIMINARY) RESULT



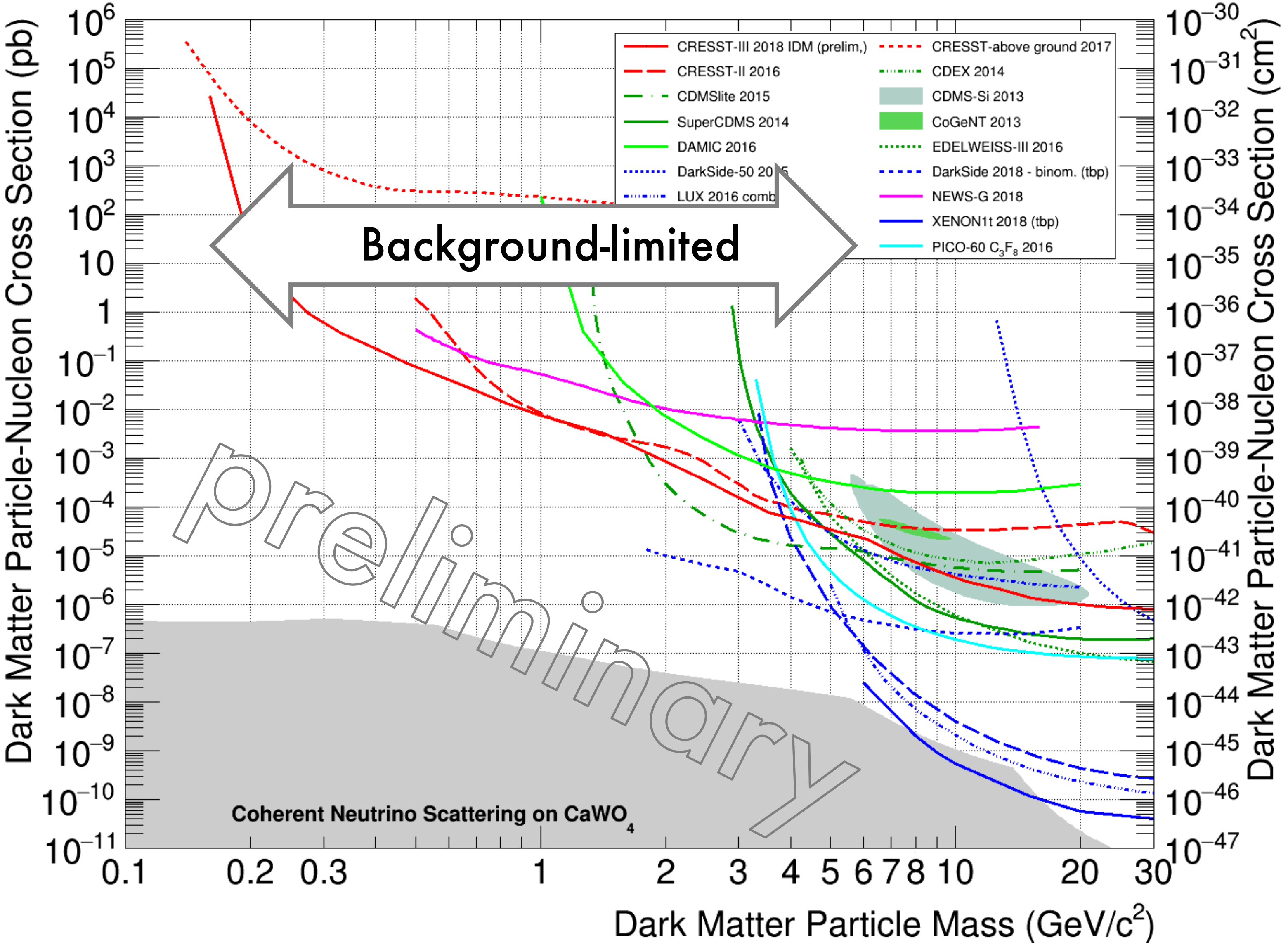
CONCLUSIONS

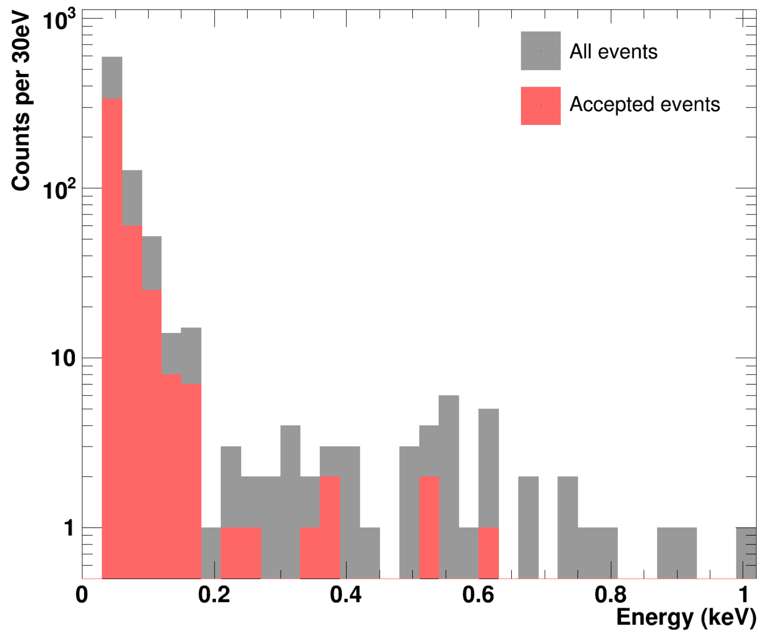
First CRESST-III run 07/2016 - 02/2018

Unprecedented low nuclear recoil thresholds of 30.1eV

Leading sensitivity over one order of magnitude: $160MeV/c^2 \rightarrow 1.8GeV/c^2$

(PRELIMINARY) RESULT



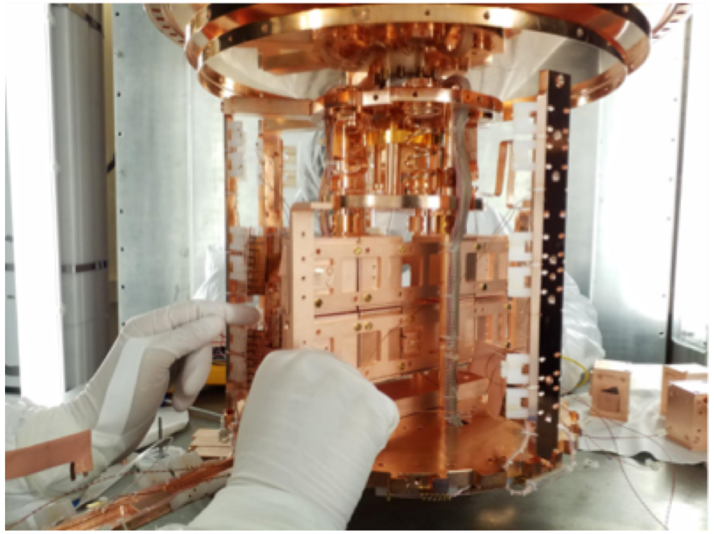


Unexpected rise of event rate < 200eV

SECOND CRESST-III RUN: JUST STARTING

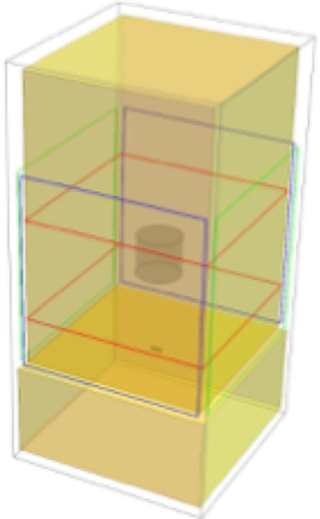
Key innovation

Upgraded detector modules with dedicated hardware changes to understand backgrounds

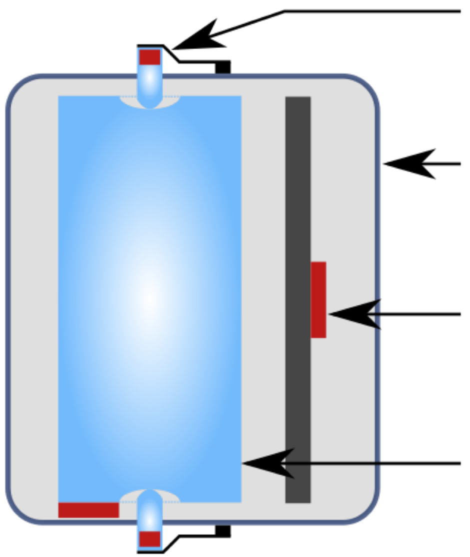


New feature

Active magnetic field compensation with three air coils for x,y & z-axes

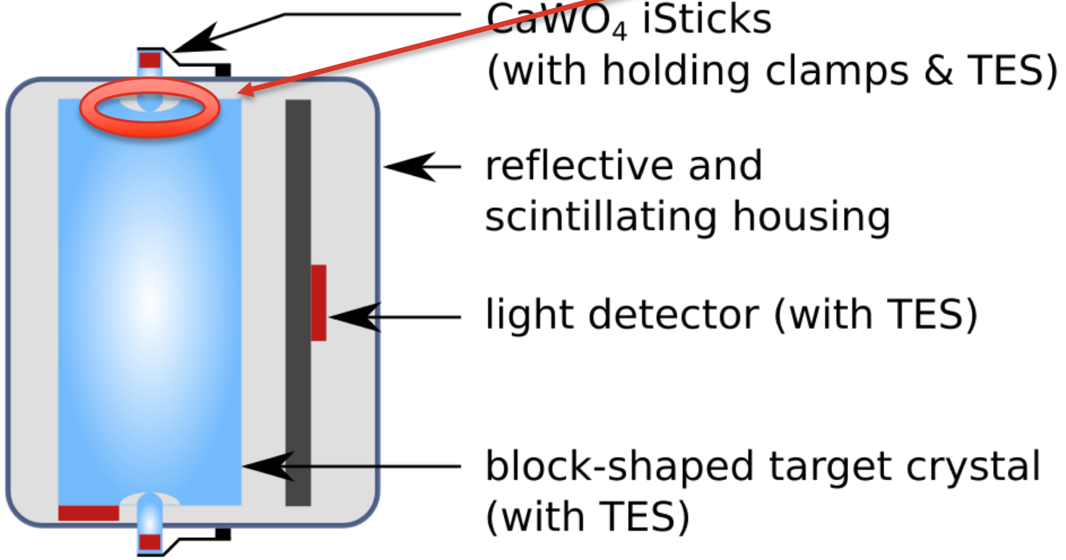


BACKGROUND HYPOTHESES



BACKGROUND HYPOTHESES

Holding with $CaWO_4$ sticks



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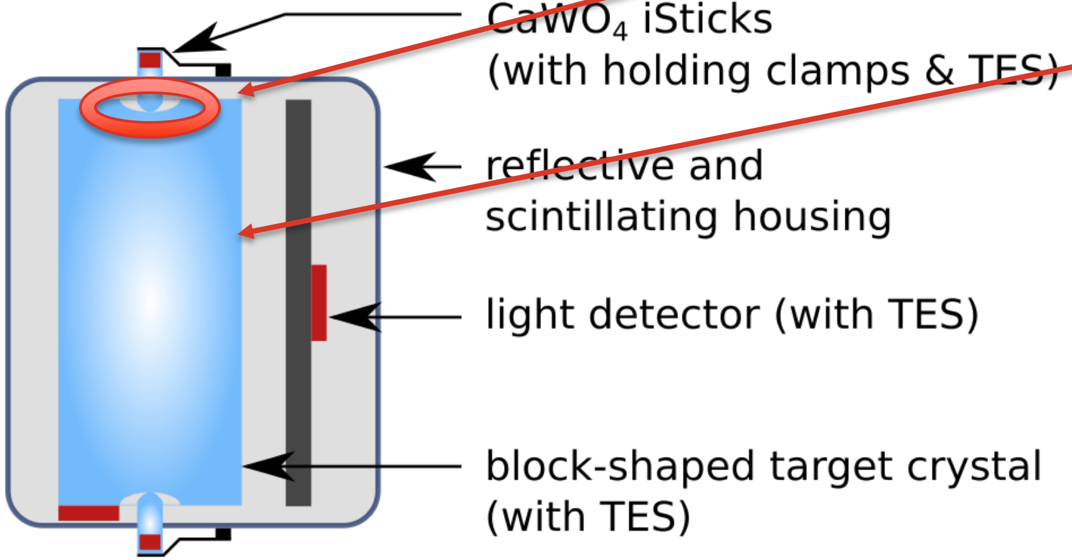
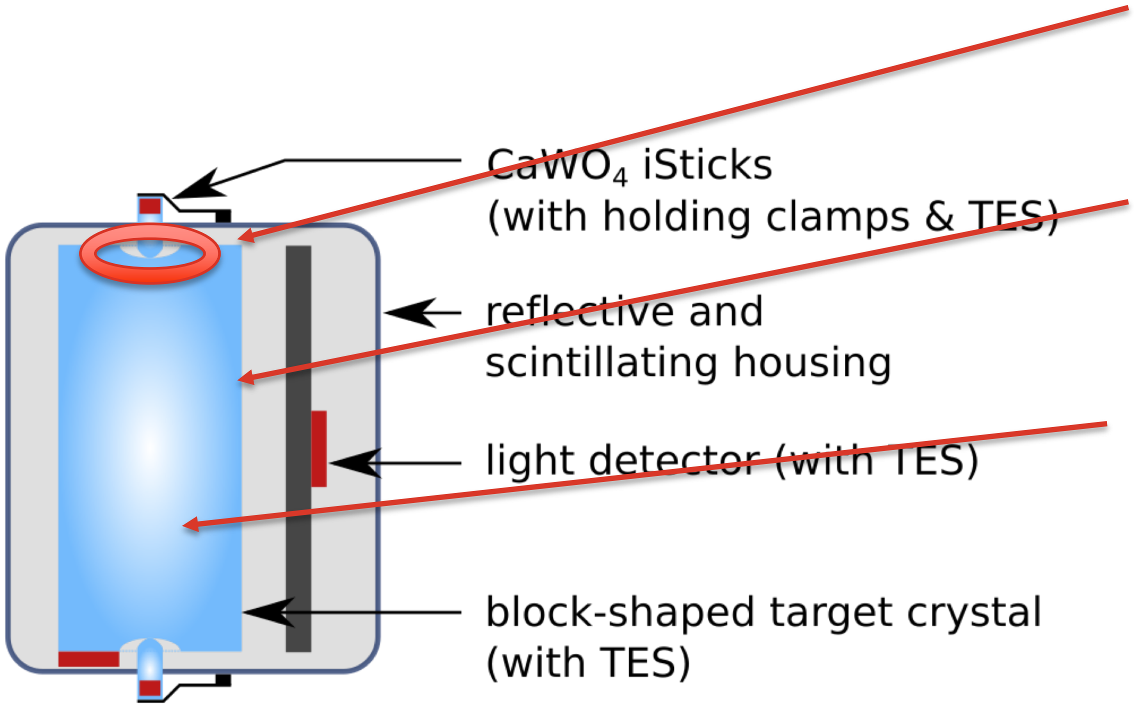


Holding with $CaWO_4$ sticks

Surface effects

BACKGROUND HYPOTHESES

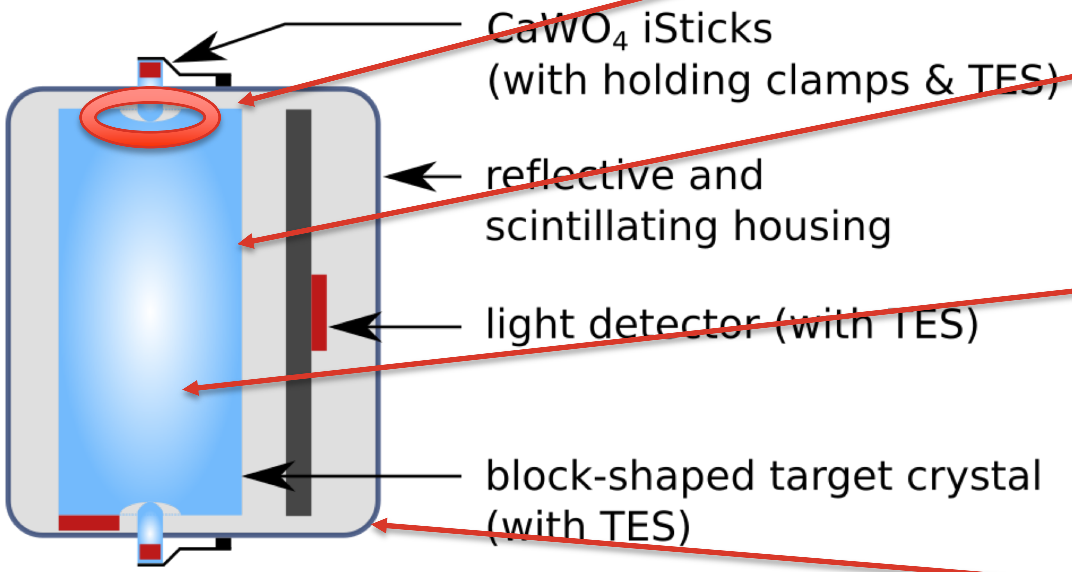


Holding with $CaWO_4$ sticks

Surface effects

Crystal (internal stress, material)

BACKGROUND HYPOTHESES



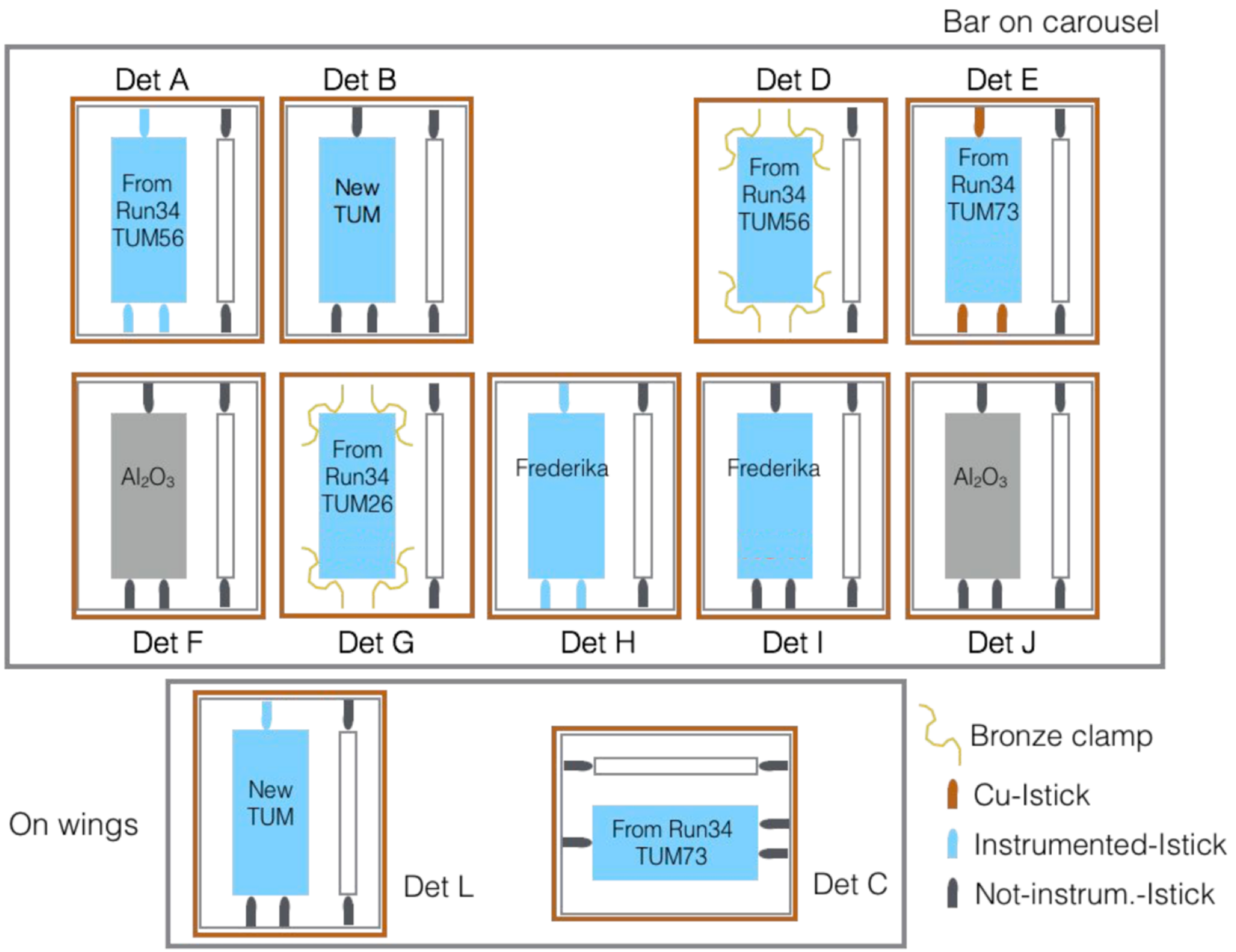
Holding with $CaWO_4$ sticks

Surface effects

Crystal (internal stress, material)

Passive scintillator

BACKGROUND HYPOTHESES



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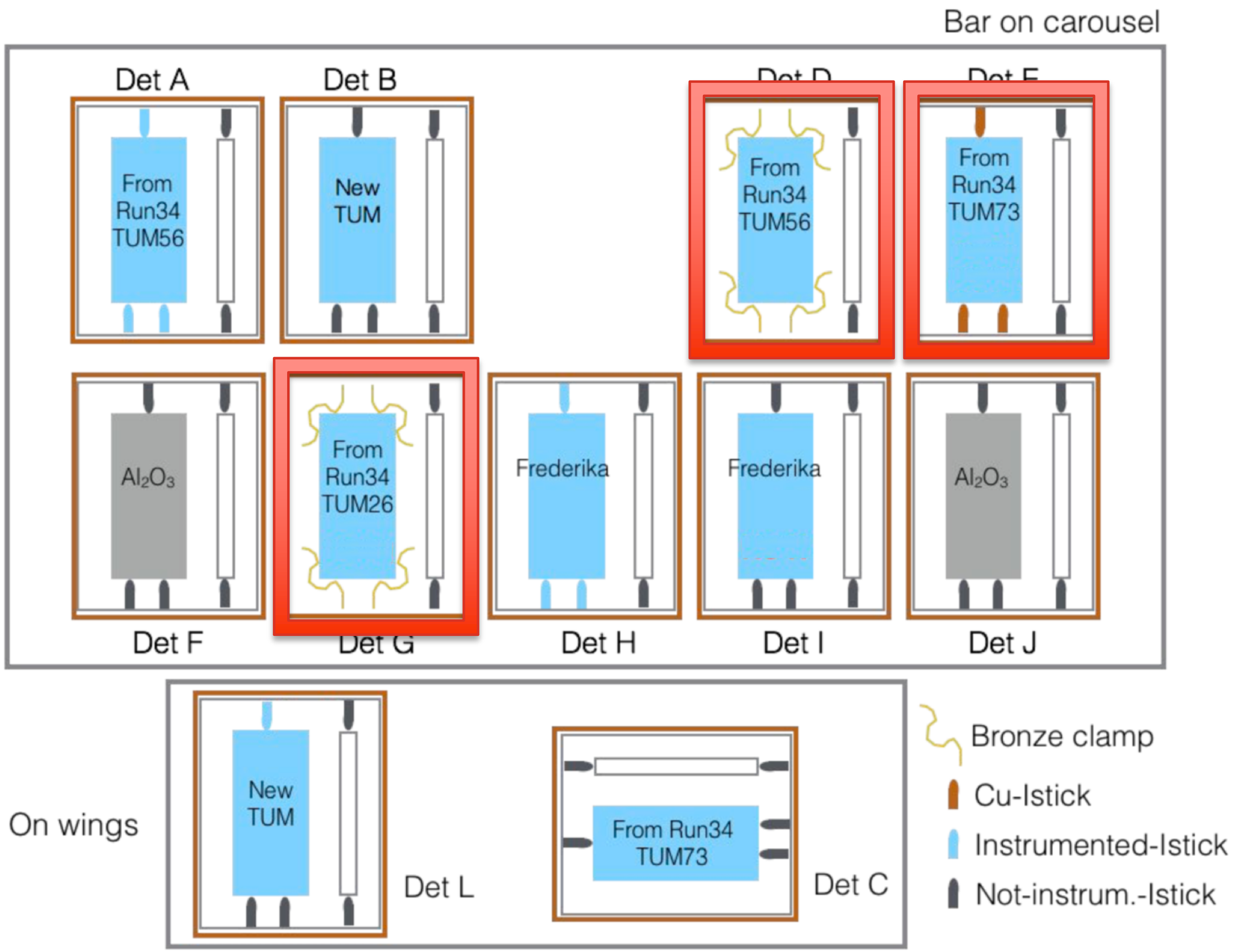

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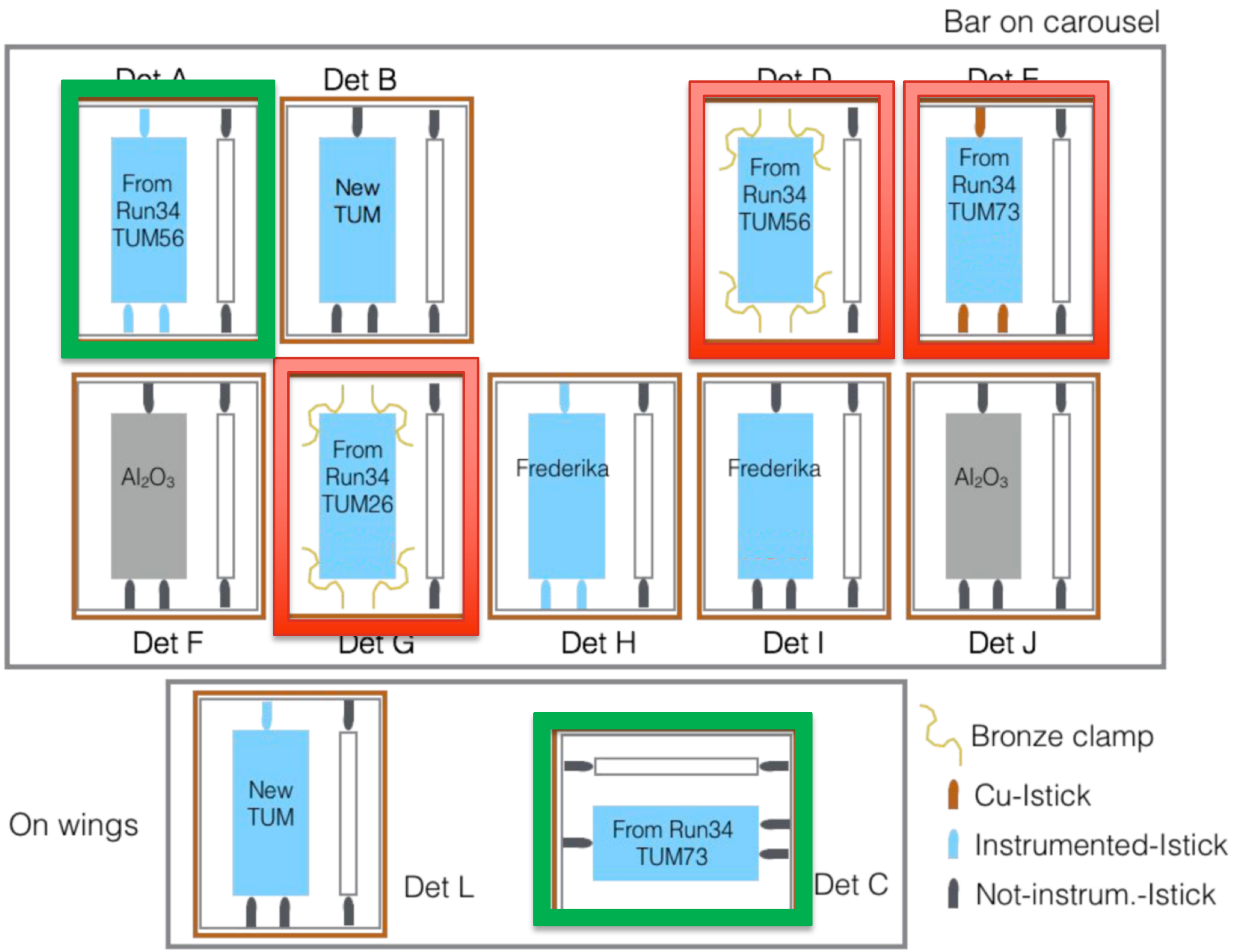

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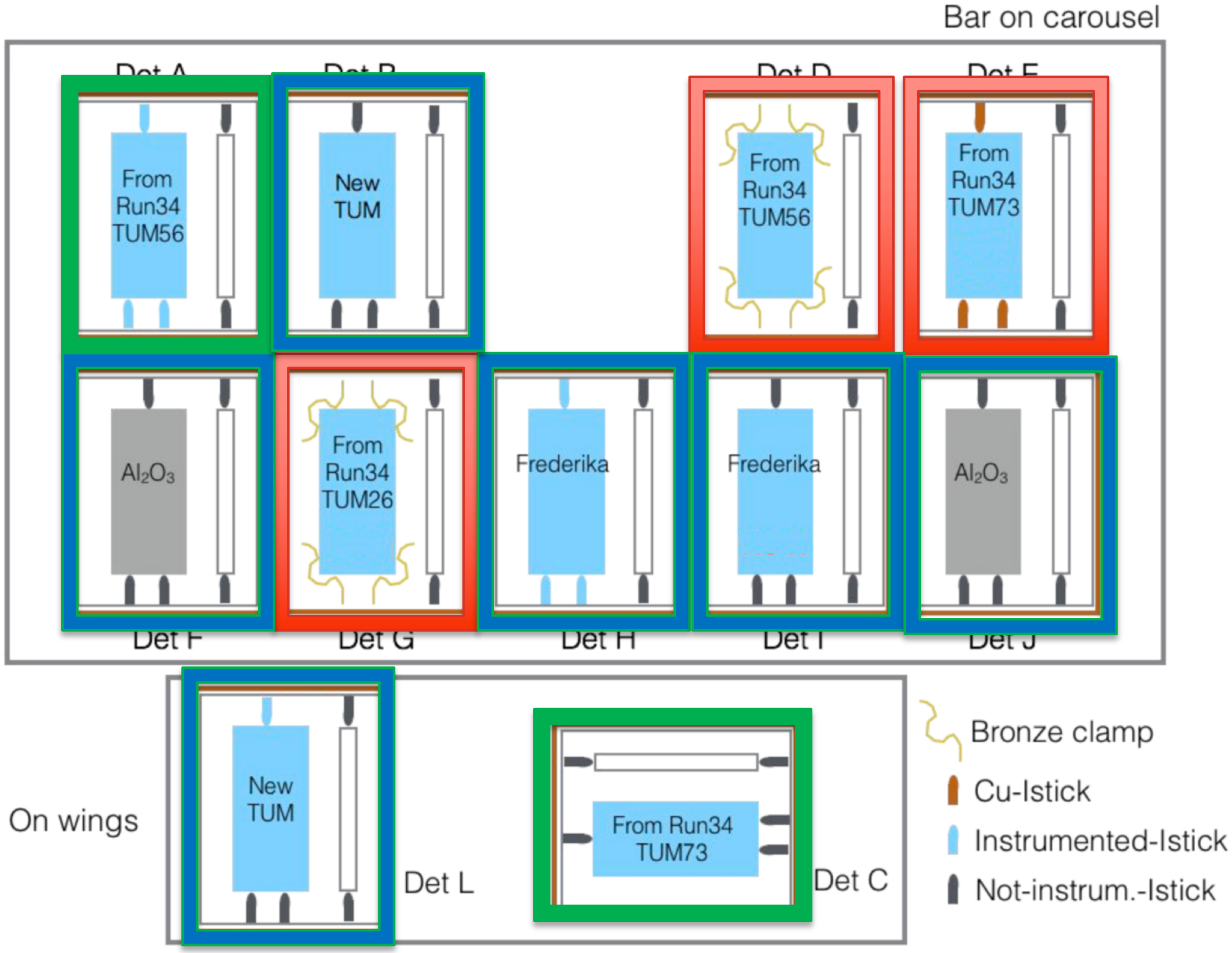

Holding with $CaWO_4$ sticks

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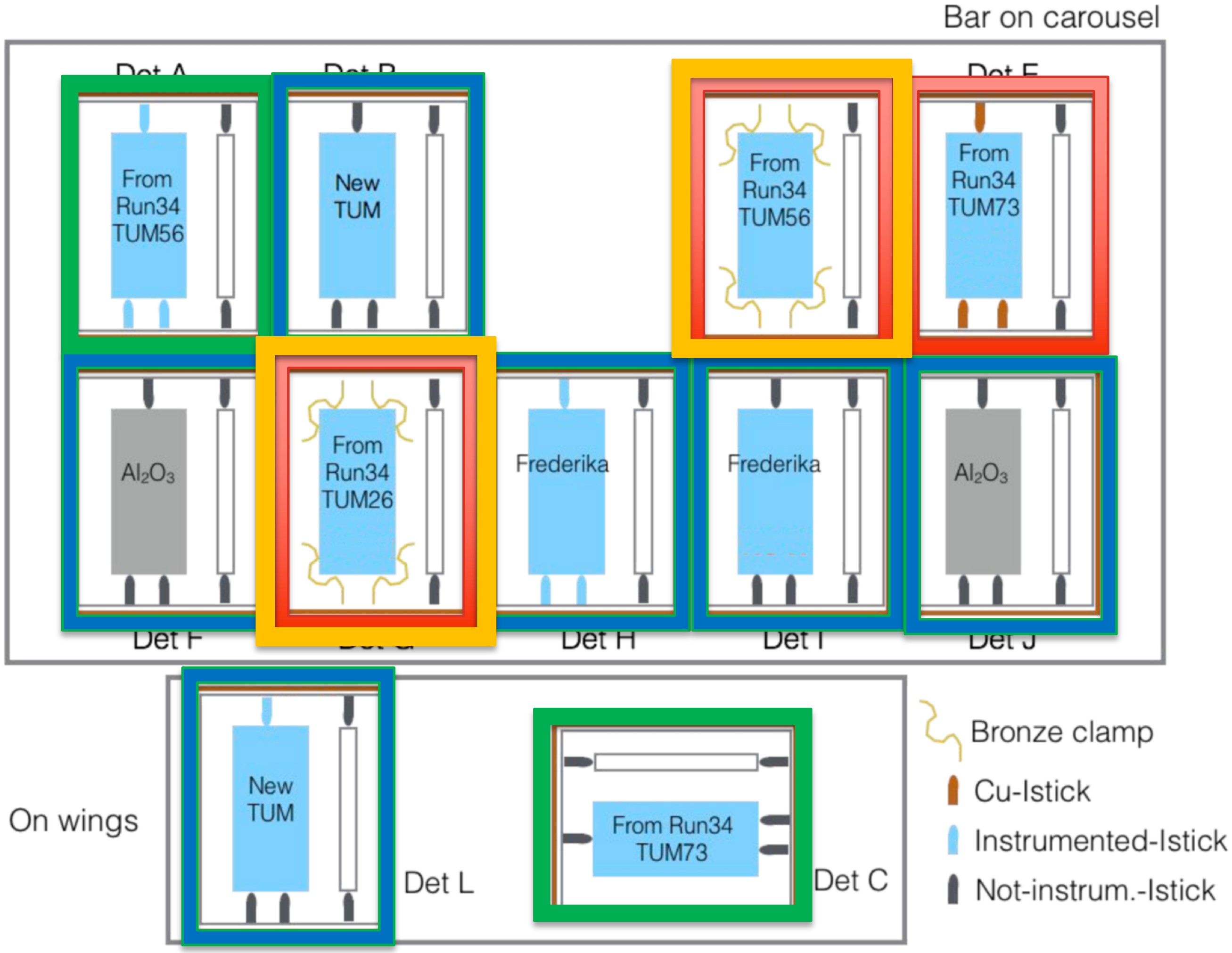

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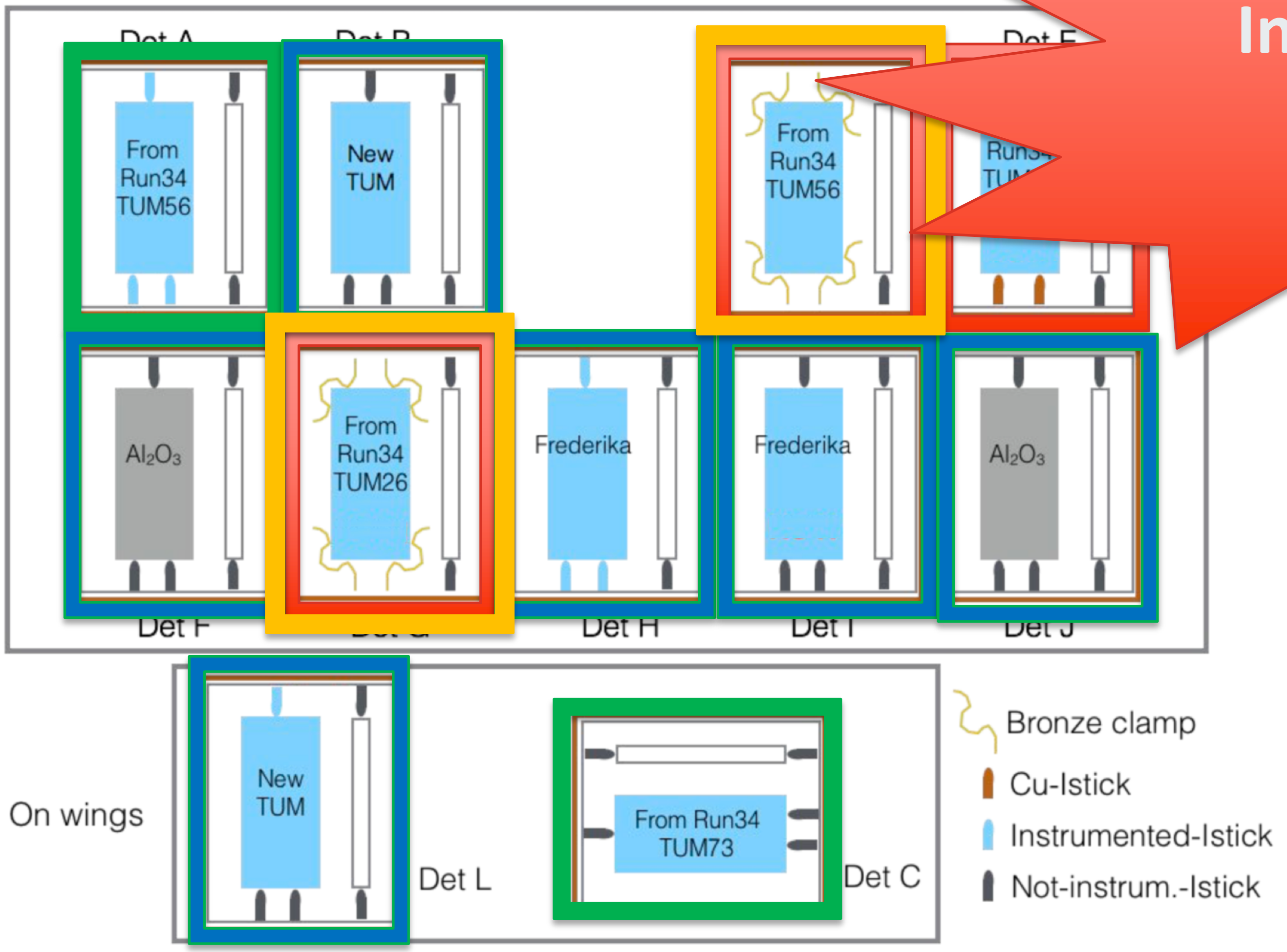


In addition: Increased simulation effort

O_4 sticks

rface effects

Crystal (internal stress, material)

Passive scintillator

CURRENT STATUS

Detectors installed in May 2018

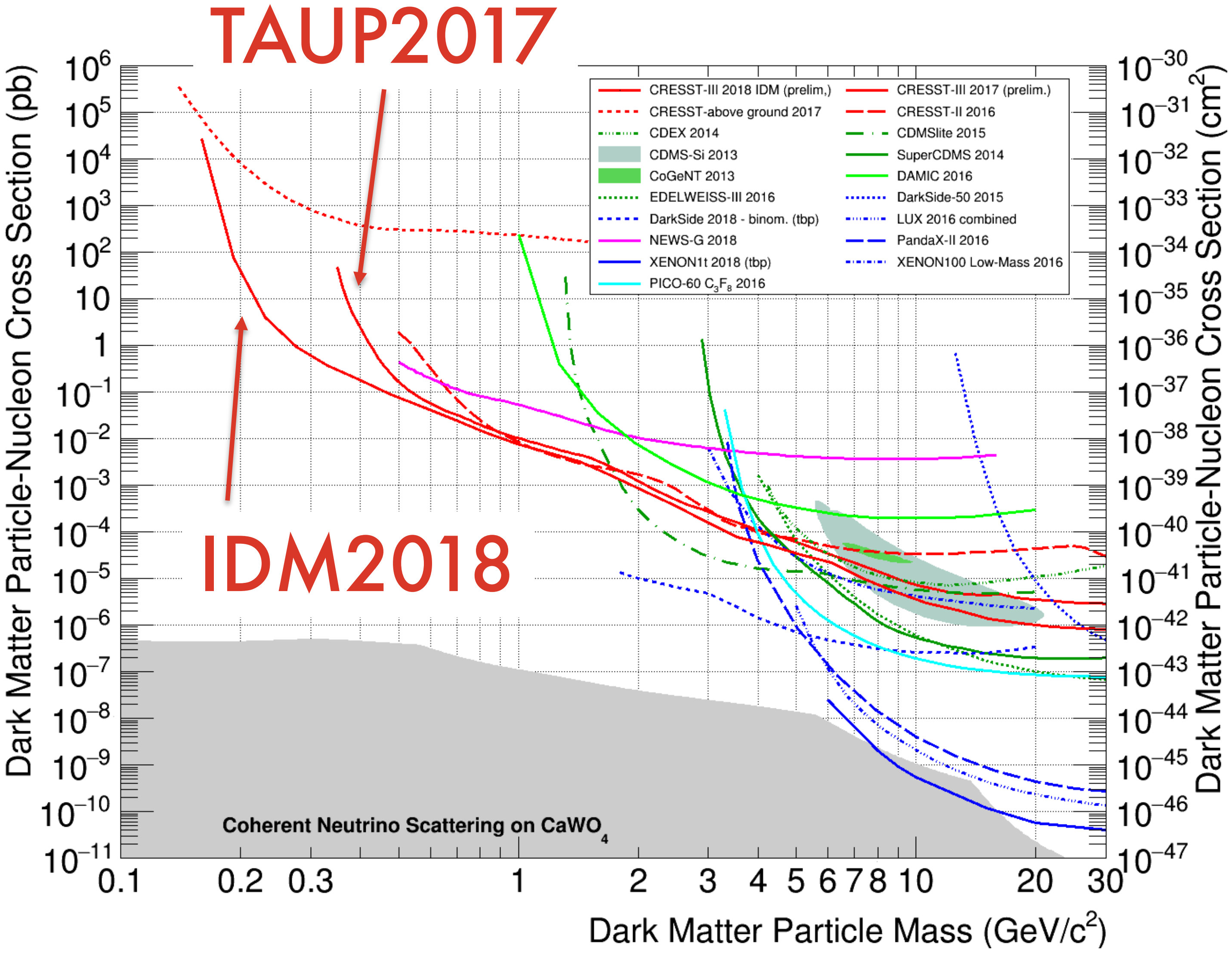
Cryogenics can be hard:
Three successful cool-downs, but warm-up after ~2weeks

Tests ongoing!

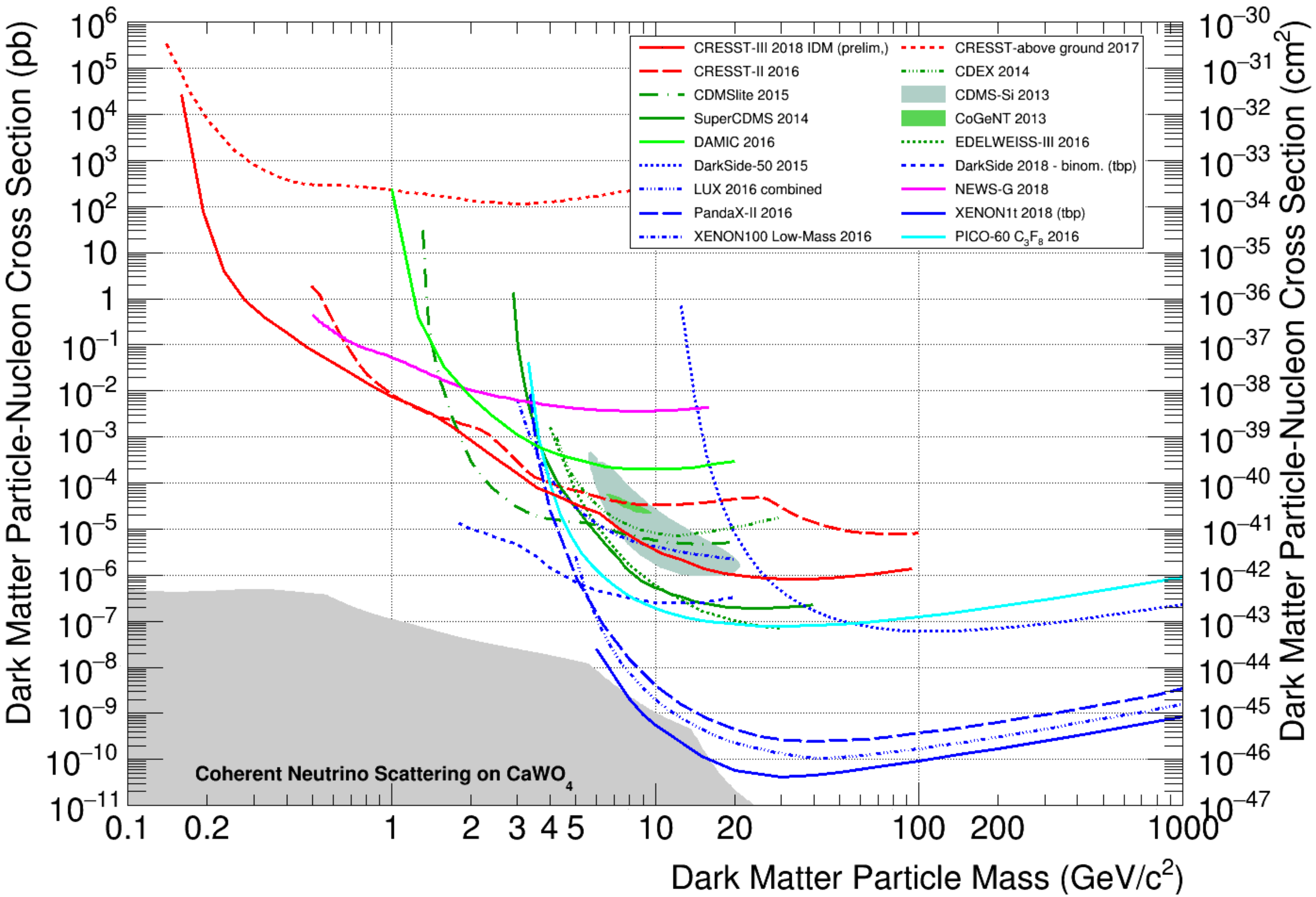

New frontiers ...
... new potentials ...
... new challenges!

BACKUP

COMPARISON TO TAUP2017

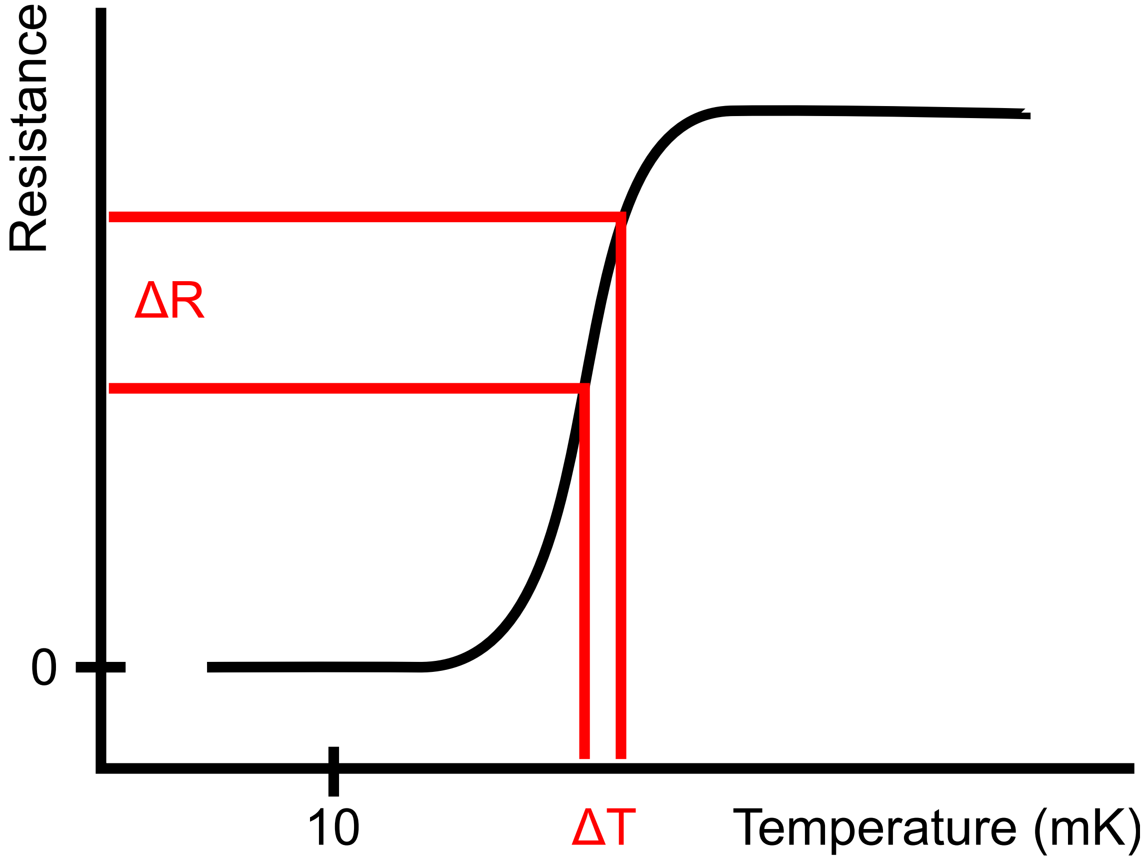


EXTENDED MASS RANGE



TRANSITION EDGE SENSOR (TES)

WORKING PRINCIPLE



Energy deposition

~keV

↓

Temperature rise

~μK

↓

Resistance change

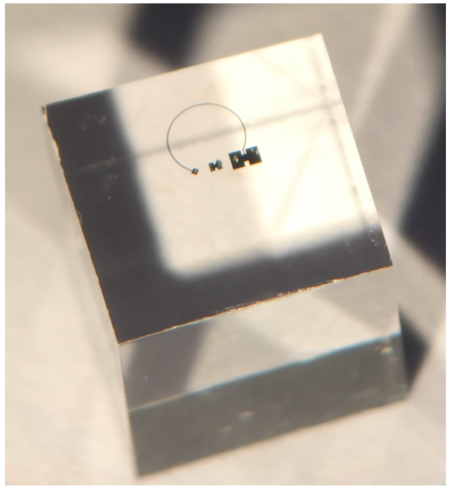
~mΩ

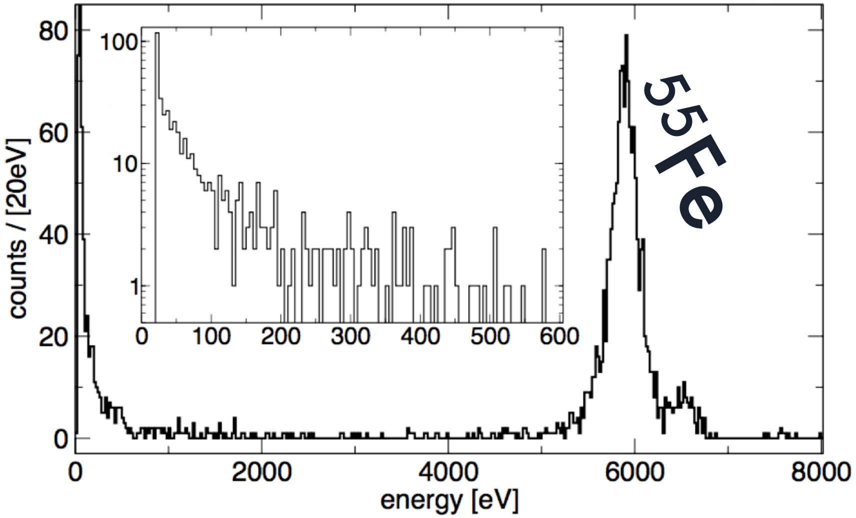
GRAM-SCALE DETECTOR

Al_2O_3 0.49g 5x5x5mm^3

E_{th} = (19.7 ± 0.9) eV

Measured above ground





Measuring time 5.3h

No data quality cuts

EPJ C (2017) 77:637

GRAM-SCALE DETECTOR: THEORISTS LOVE IT😻

ABOVE GROUND: SENSITIVITY FOR STRONGLY INTERACTING DM

1) Search for a Non-Relativistic Component in the Spectrum of Cosmic Rays at Earth. By J.I. Collar., [arXiv:1805.02646 [astro-ph.CO]].

2) Constraints on Dark Matter with a moderately large and velocity-dependent DM-nucleon cross-section. By M. Shafi Mahdawi, Glennys R. Farrar., [arXiv:1804.03073 [hep-ph]].

3) SENSEI: First Direct-Detection Constraints on sub-GeV Dark Matter from a Surface Run. By SENSEI Collaboration (Michael Crisler et al.)., [arXiv:1804.00088 [hep-ex]].

4) Mapping The Neutrino Floor For Dark Matter-Electron Direct Detection Experiments. By Jason Wyenberg, Ian M. Shoemaker., [arXiv:1803.08146 [hep-ph]].

5) Supernova 1987A Constraints on Sub-GeV Dark Sectors, Millicharged Particles, the QCD Axion, and an Axion-like Particle. By Jae Hyeok Chang, Rouven Essig, Samuel D. McDermott., [arXiv:1803.00993 [hep-ph]].

6) Probing sub-GeV Dark Matter-Baryon Scattering with Cosmological Observables. By Weishuang Linda Xu, Cora Dvorkin, Andrew Chael., Phys.Rev. D97 (2018) no.10, 103530.

7) How blind are underground and surface detectors to strongly interacting Dark Matter?. By Timon Emken, Chris Kouvaris., [arXiv:1802.04764 [hep-ph]].

8) Robust Constraints and Novel Gamma-Ray Signatures of Dark Matter That Interacts Strongly With Nucleons. By Dan Hooper, Samuel D. McDermott., Phys.Rev. D97 (2018) 115006.

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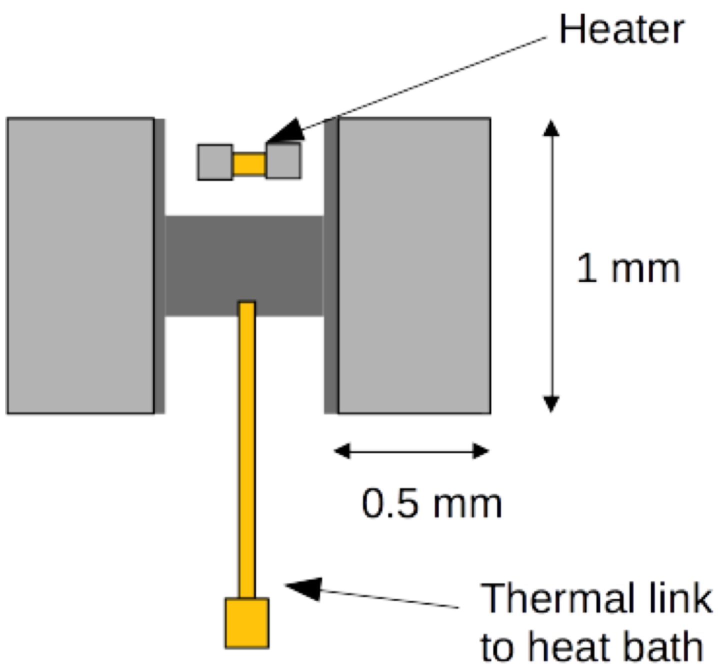
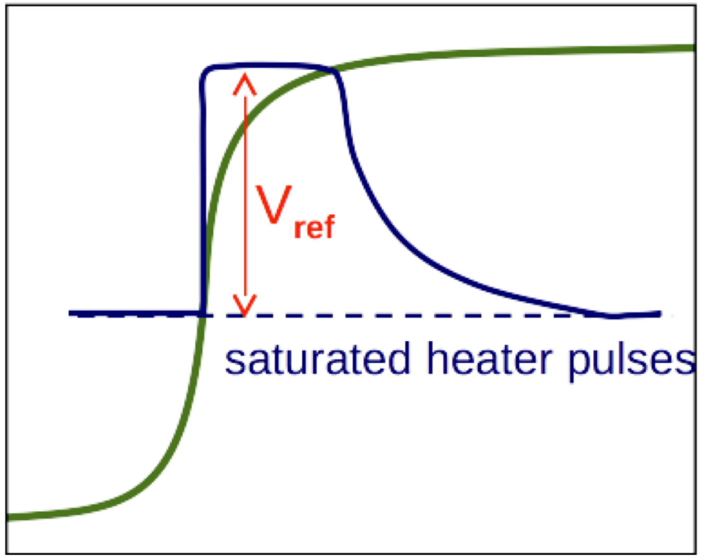
Source: inspire-hep (11/06/2018), paper on arXiv since 07/2017

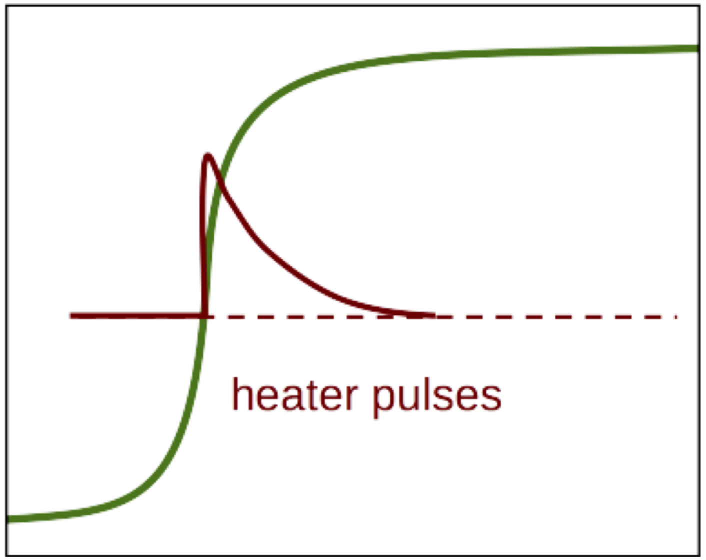
DETECTOR STABILITY

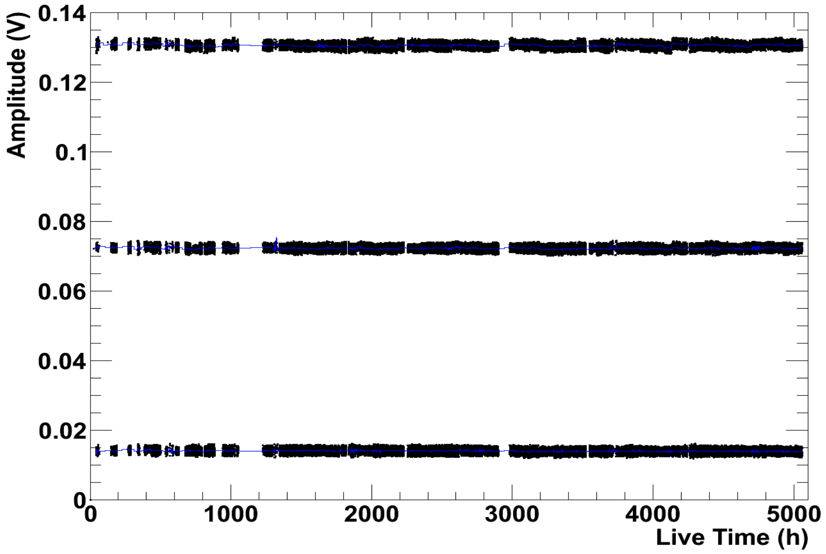
W-TES equipped with heaters

- Stabilization of detectors in the operating point
- Injection of heat pulses for calibration and determination of trigger threshold



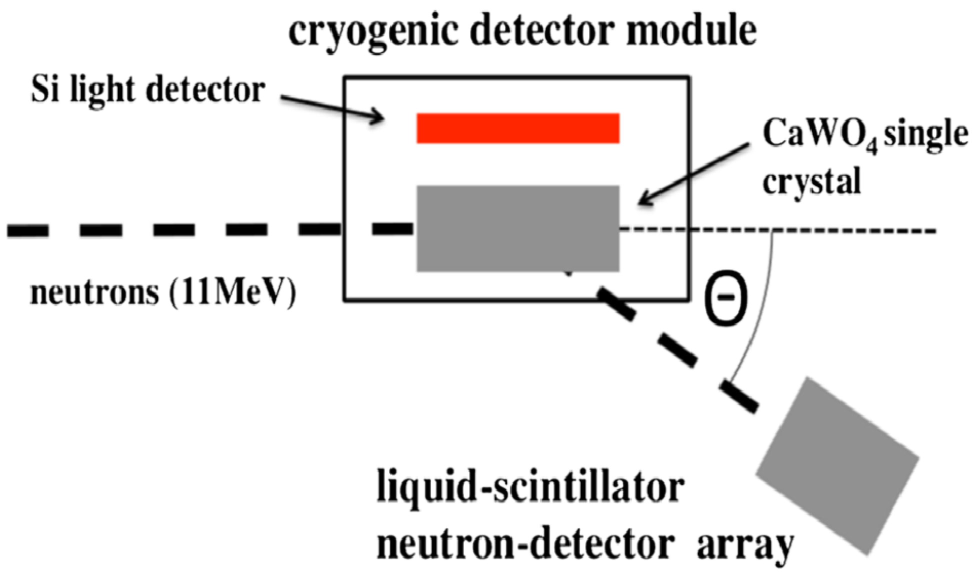


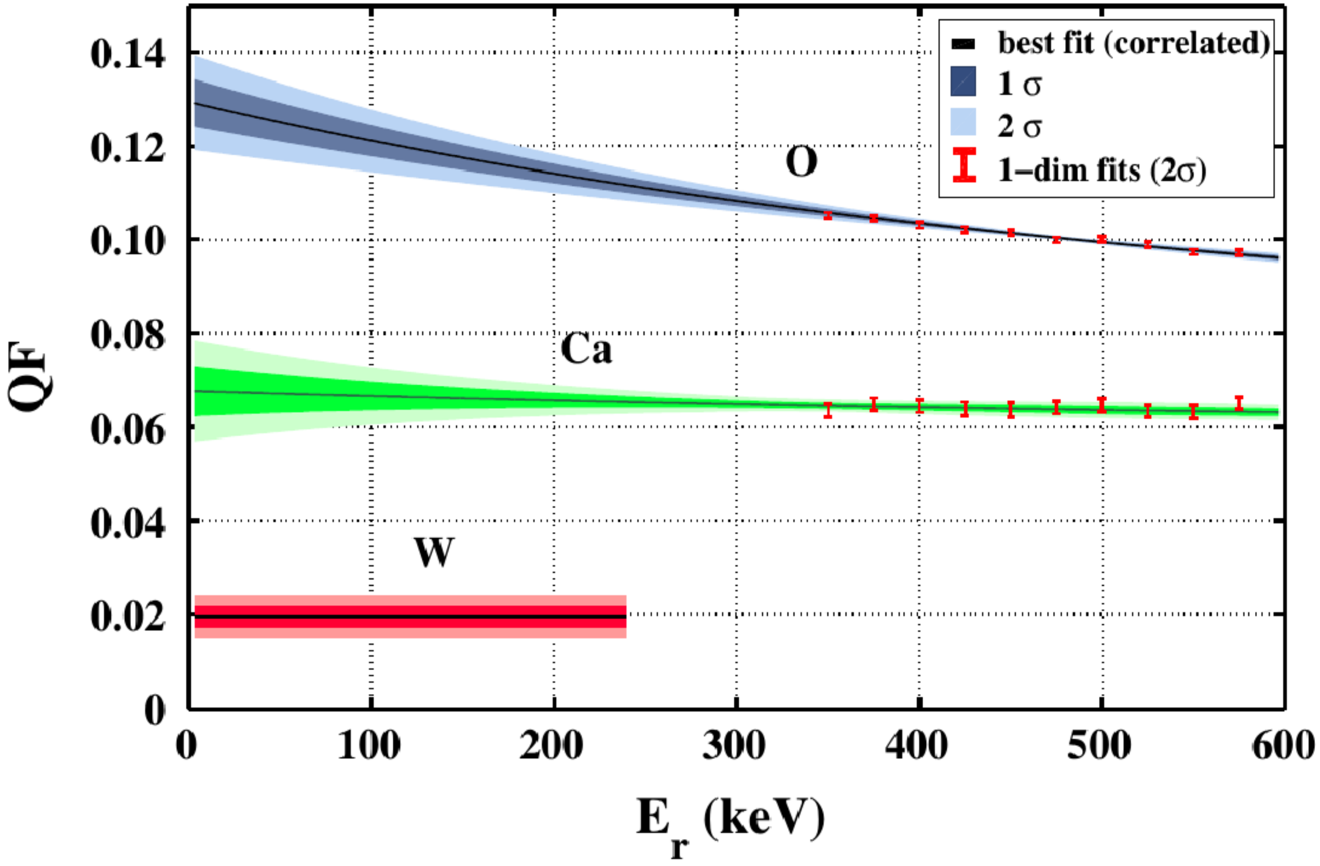




QUENCHING FACTOR MEASUREMENT

@ accelerator of Maier-Leibnitz-Laboratorium





Precise determination of QFs for O, Ca & W **@mK temperatures**

O: (11.2 ± 0.5)% Ca: (5.94 ± 0.49)% W: (1.72 ± 0.21)%

DET. A – 100eV EVENT EXAMPLES

Raw signals: no filtering, fitting etc.