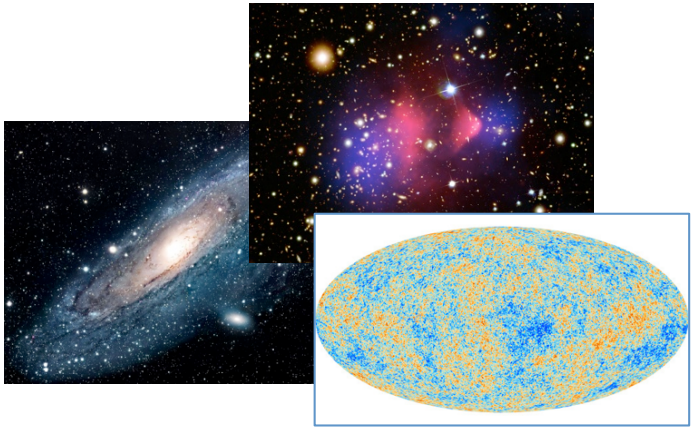
# The CRESST Experiment

## Status and Prospects of Low-Mass Dark Matter Search


**Raimund Strauss**
Max-Planck-Institut für Physik
München,

Project Review
14.12.2015

# Dark Matter

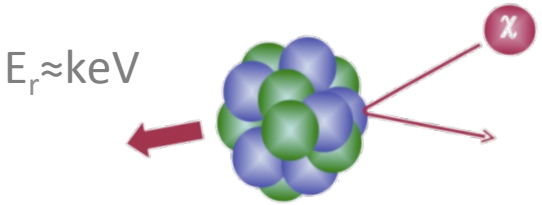


Dark Matter exists in the Universe!

## WIMPs

Weakly Interacting Massive Particles

Particles are a well-motivated interpretation




Elastic WIMP-nucleus scattering

Direct detection with Earth-bound experiments

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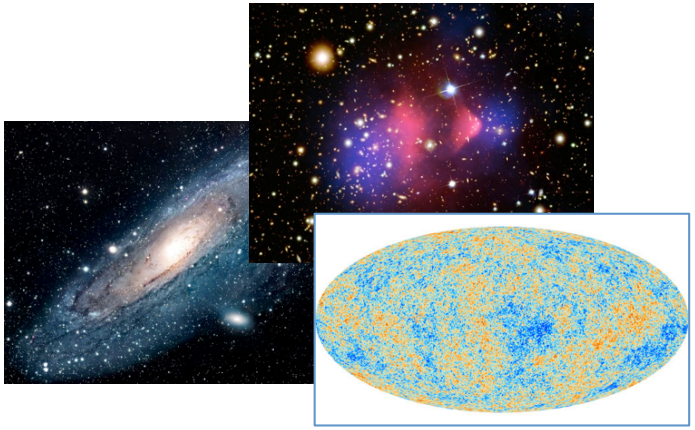

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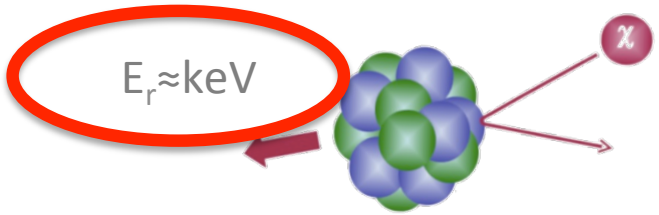
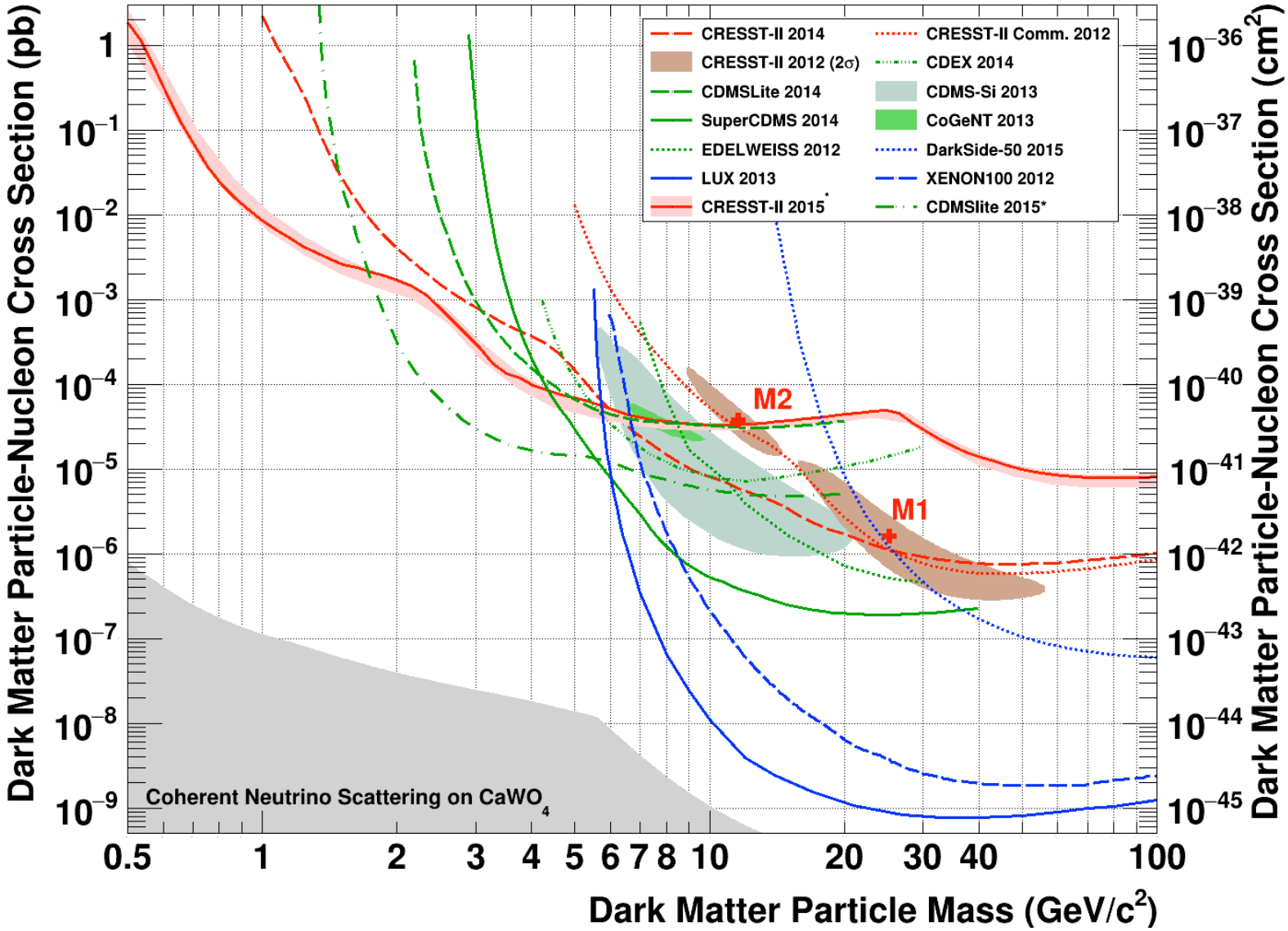



Elastic WIMP-nucleus scattering

Direct detection with Earth-bound experiments

challenging!

# Current Status of Direct Dark Matter Searches



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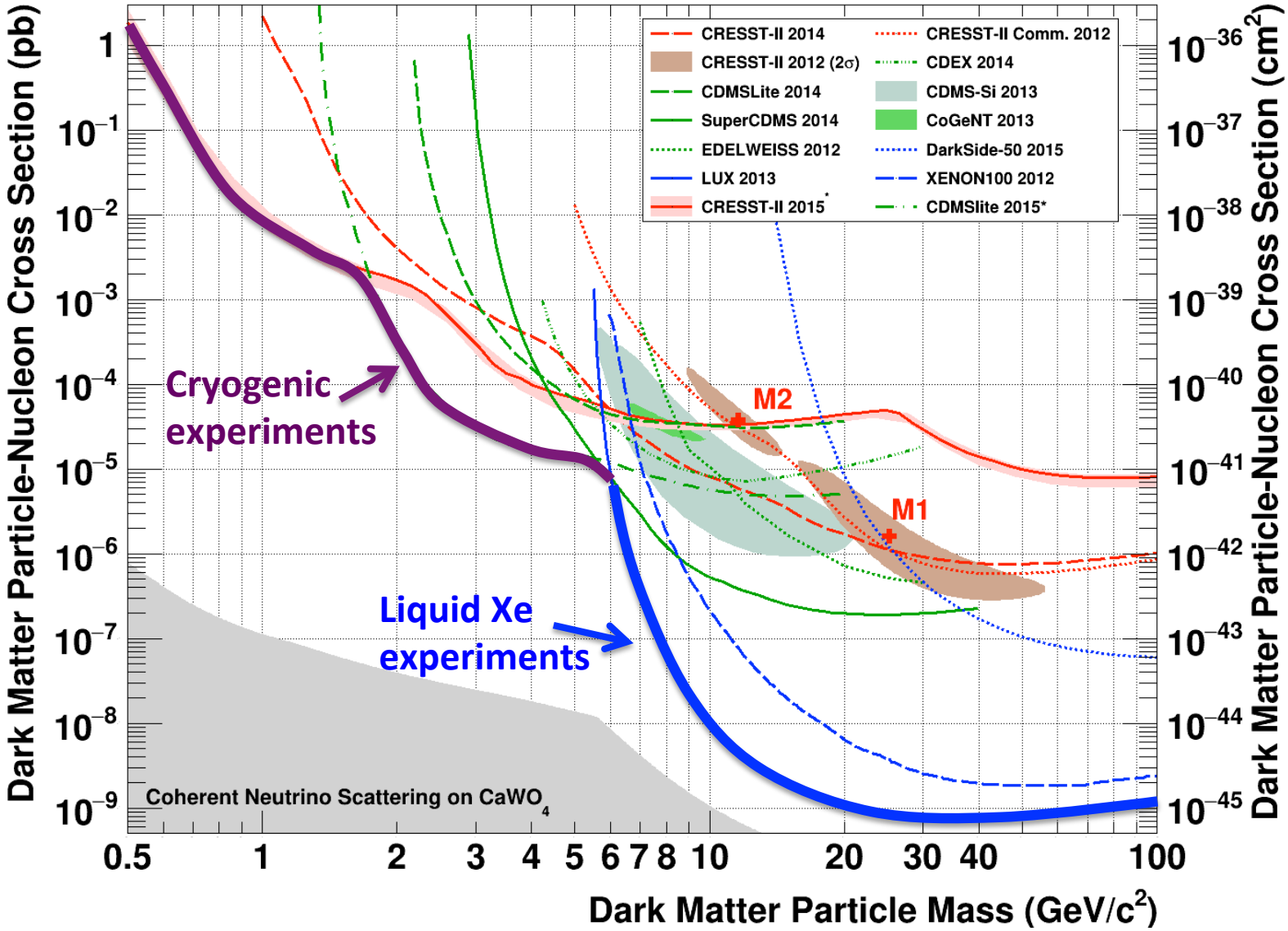
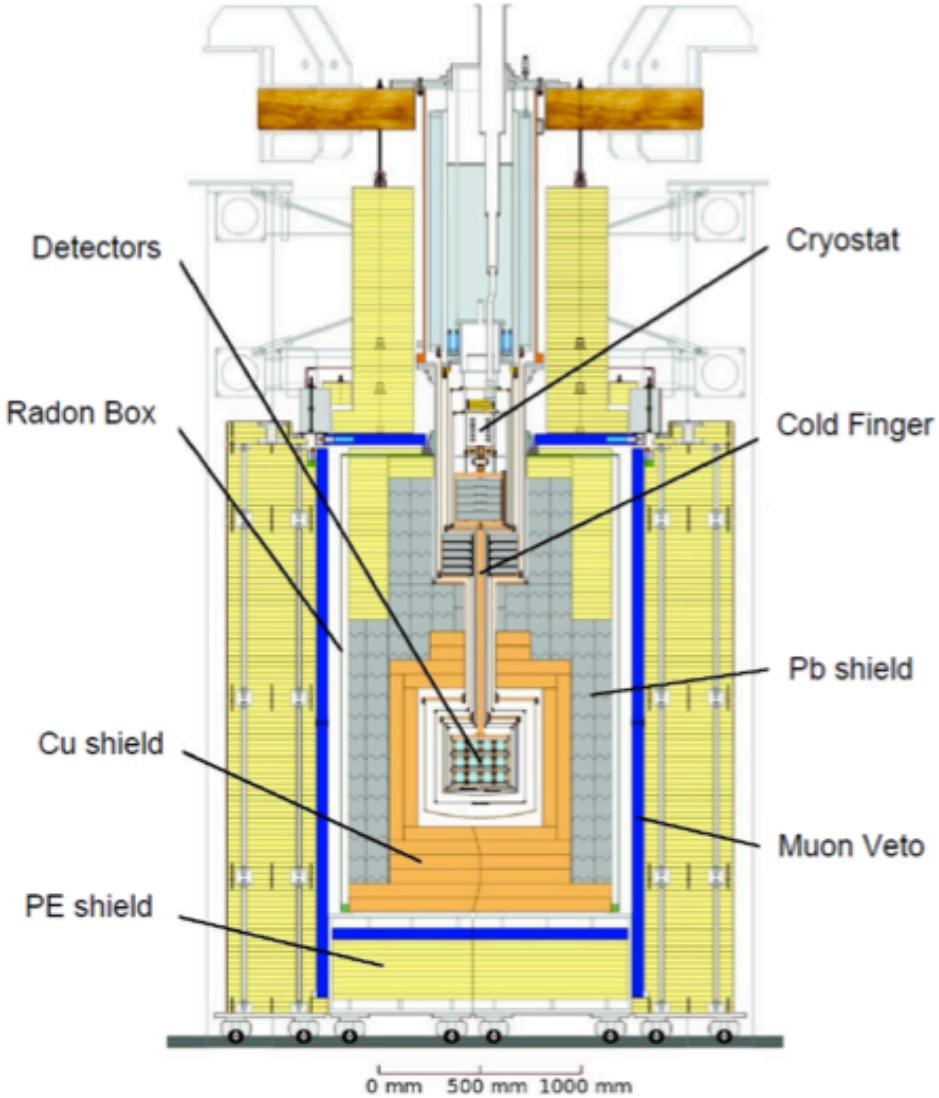
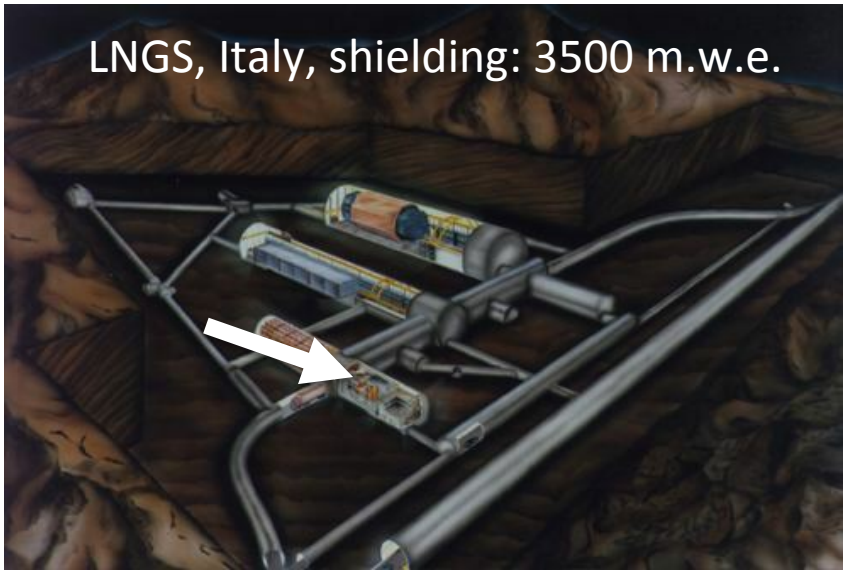


# The CRESST Experiment

Cryogenic Rare Event Search with Superconducting Thermometers




- Underground installation
- Ultra-low background environment
- Cryogenic detectors (10-15mK)



# The CRESST Detector Module

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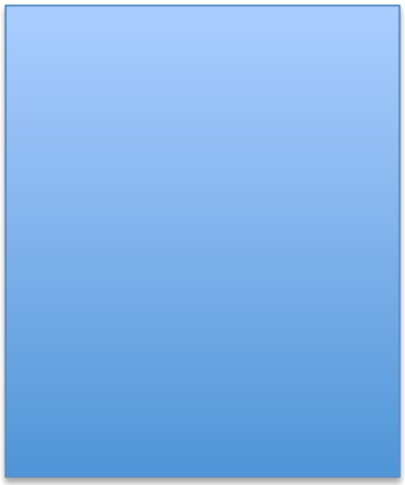
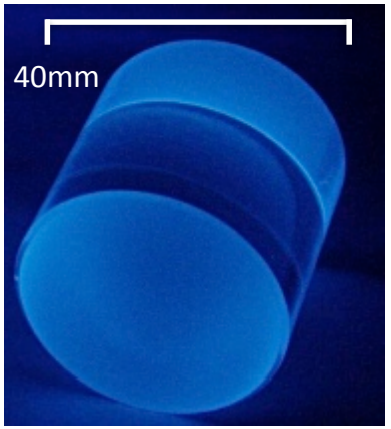


## $CaWO_4$ Target Crystal

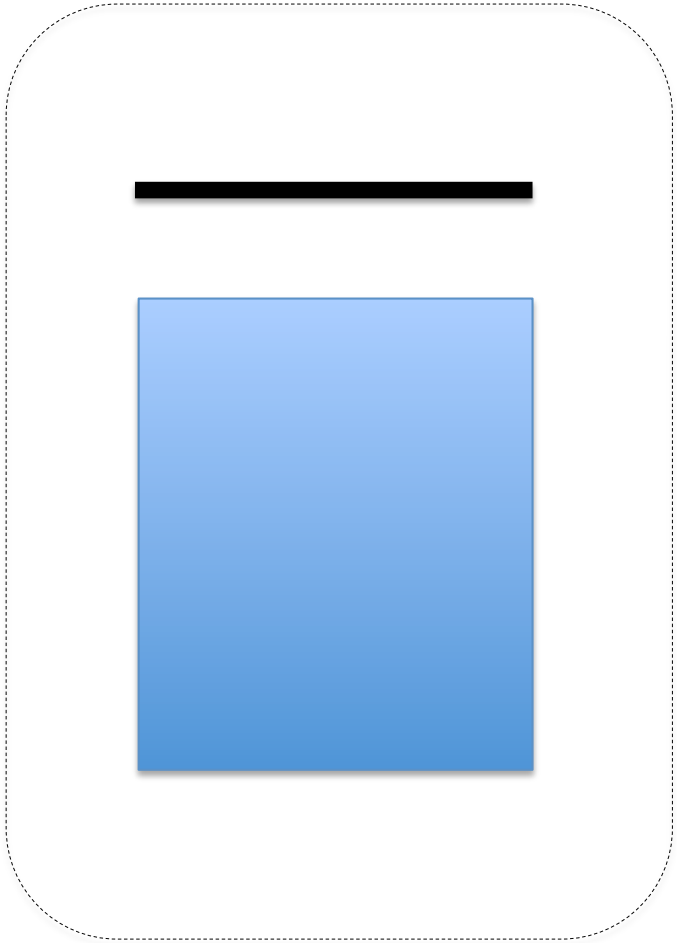



- scintillating
- multi-element target
- mass: 200 – 300 g

**$^{16}O$ $^{40}Ca$ $^{184}W$**

In-house production and processing at our institutes

# The CRESST Detector Module

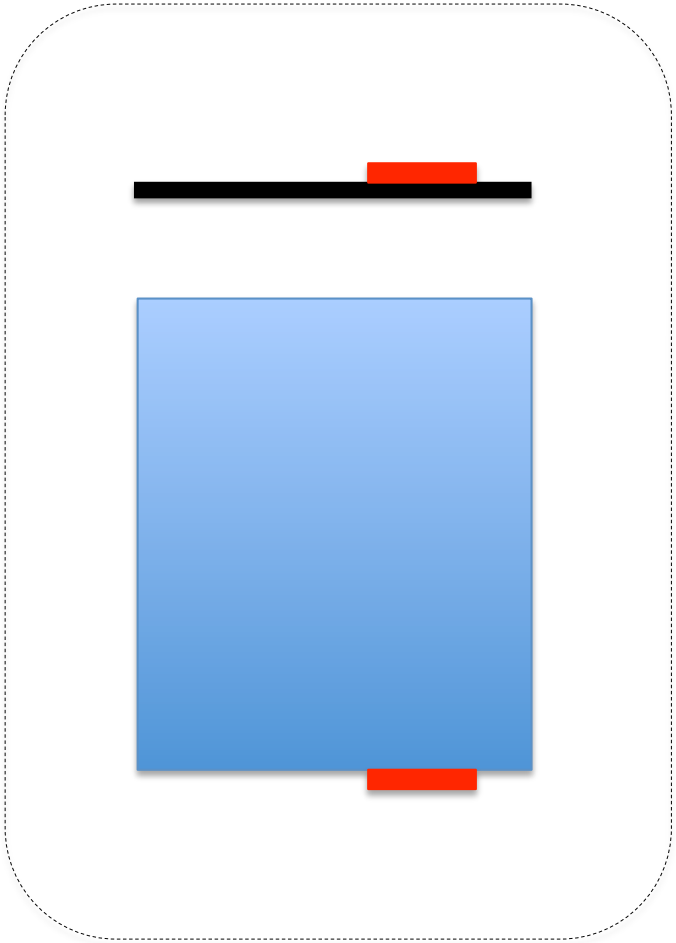


## Light Absorber

for scintillation-light detection

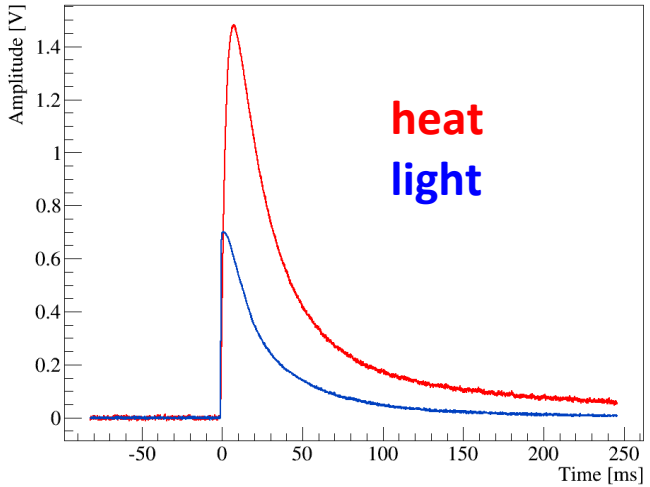
- silicon-on-sapphire disc
- diameter: 40mm
- thickness: 500µm

# The CRESST Detector Module



**T**ransition-**E**dge-**S**ensors

→ 2 independent calorimeters



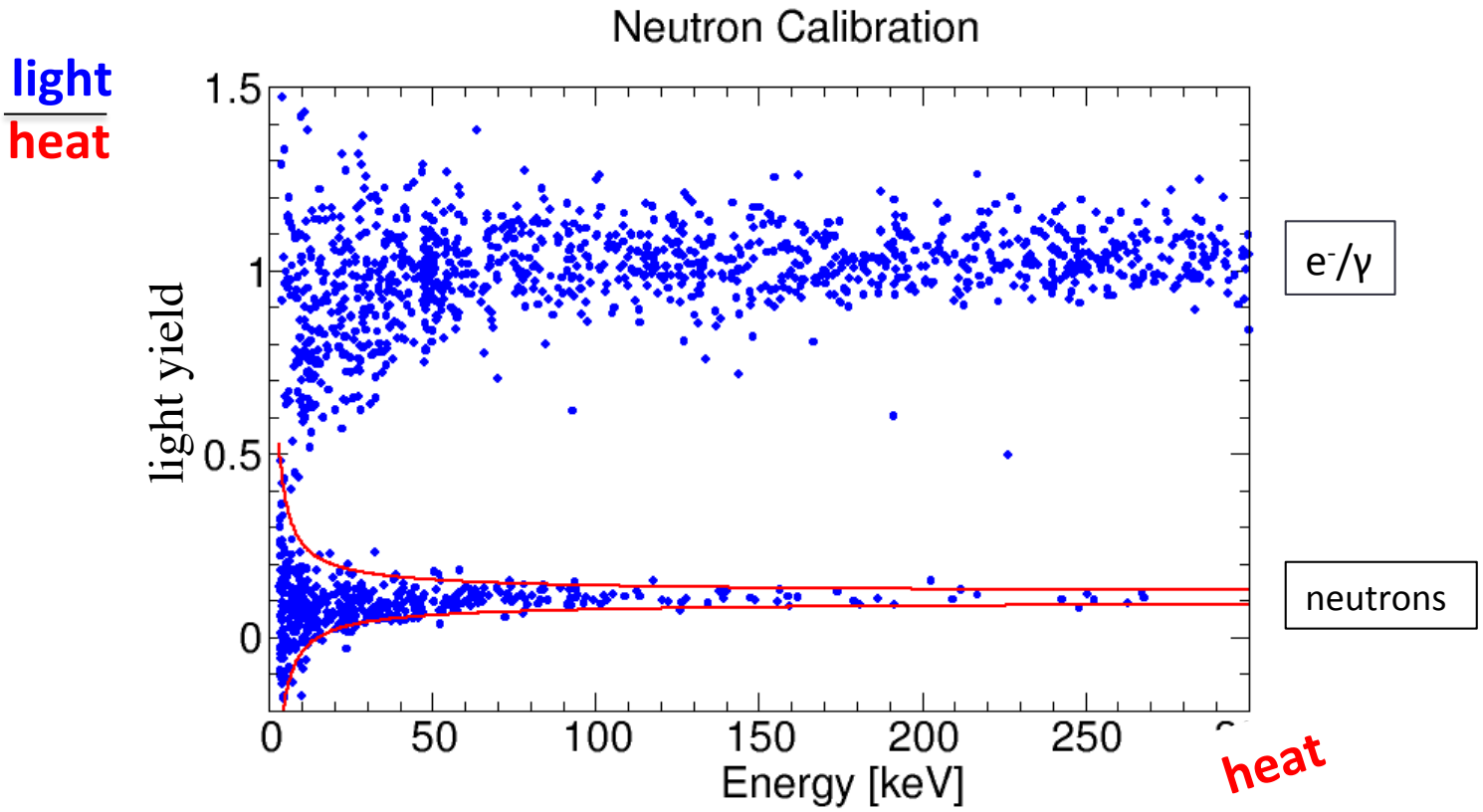

**Phonon** detector ($CaWO_4$)

- Threshold: $E_{th} \geq 300$ eV
- Resolution: $\sigma \approx$ 60-200 eV

**Light** detector (SOS)

- Resolution : $\sigma \approx$ 5eV

# Phonon-Light Technique




Reduced light output for highly-ionizing particles ⟹ Quenching

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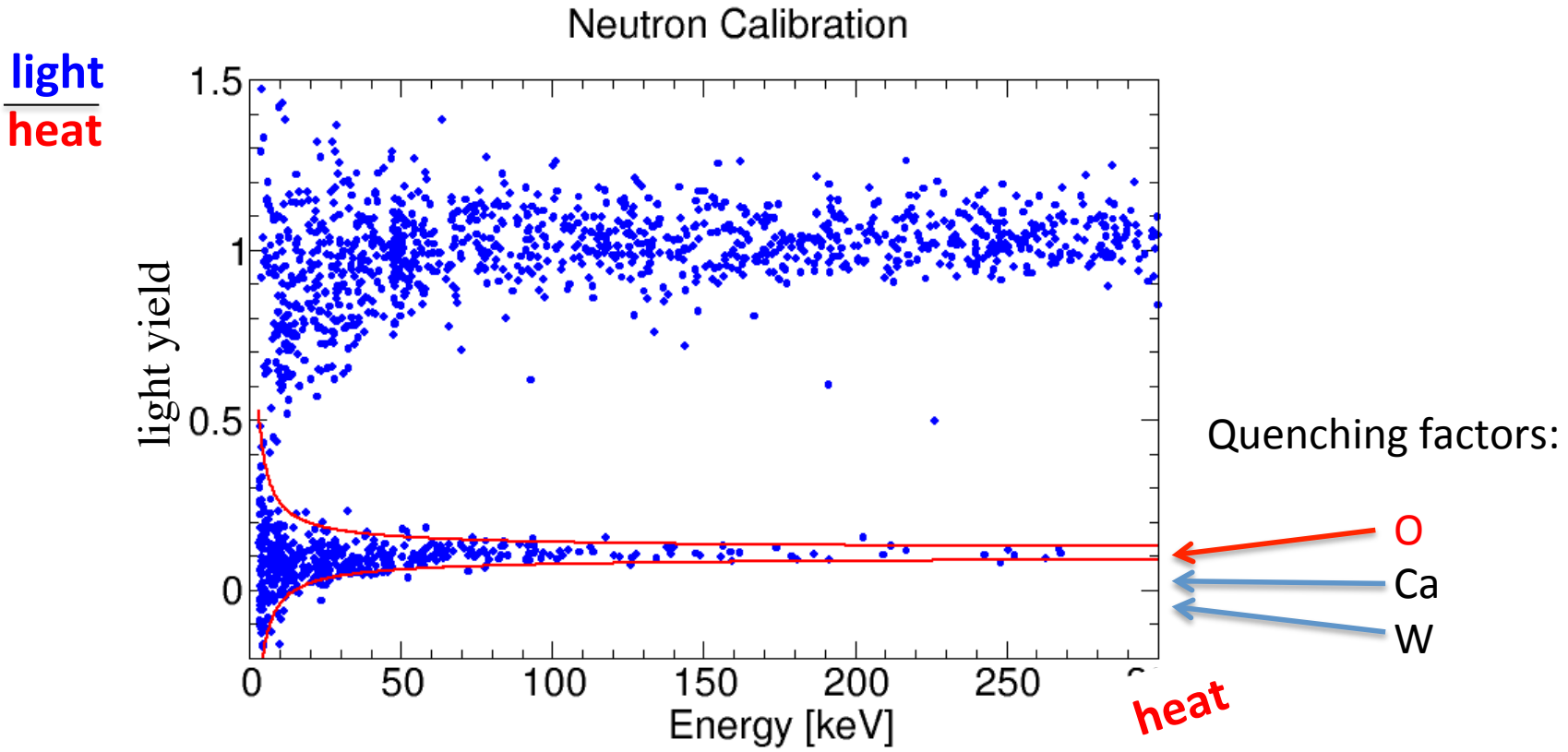


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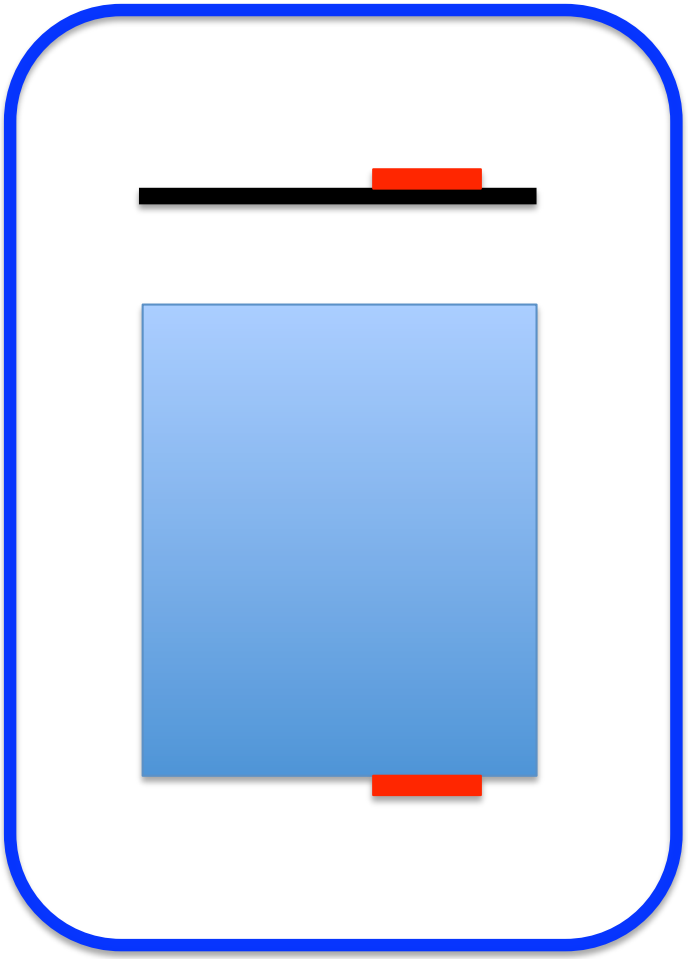

Polymeric Foil

① Highly reflective

- ➢ light collection

② Scintillating

- ➢ rejection of surface events

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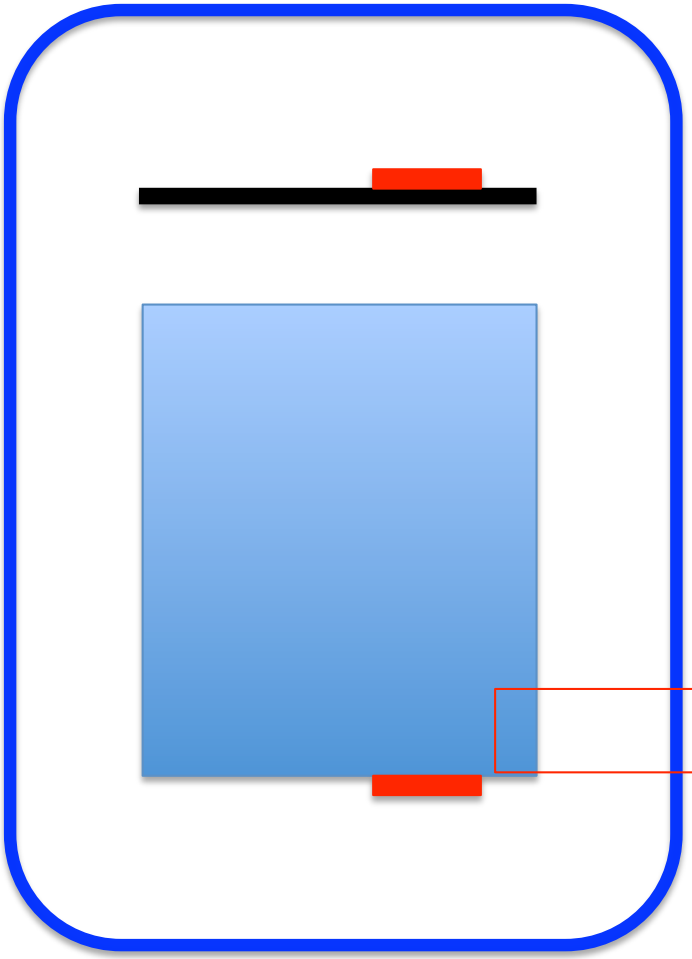

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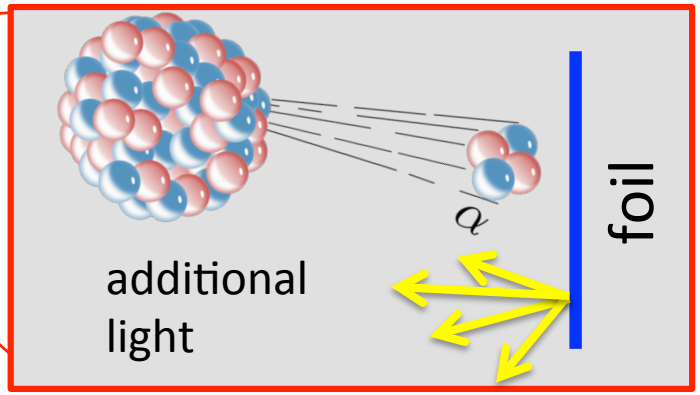

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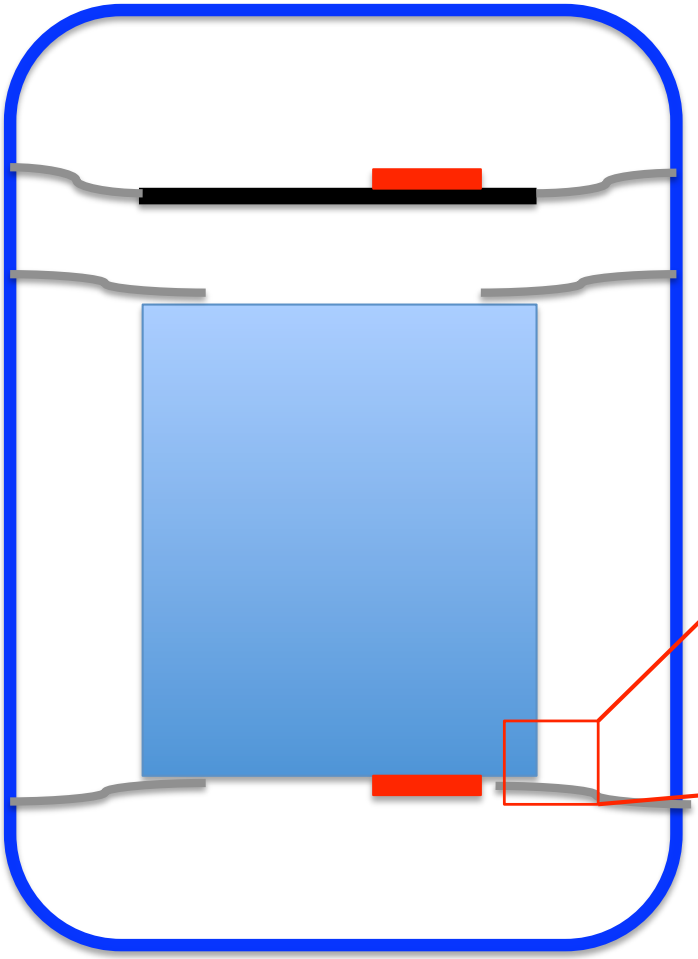
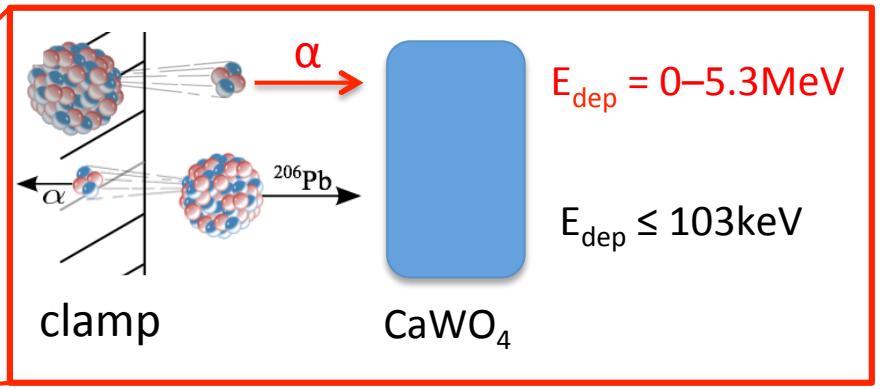


## Dangerous Surface Backgrounds

$^{210}Po \rightarrow {}^{206}Pb\ (103keV) + \alpha\ (5.3MeV)$




→ Lead/alpha recoils can mimic WIMPs

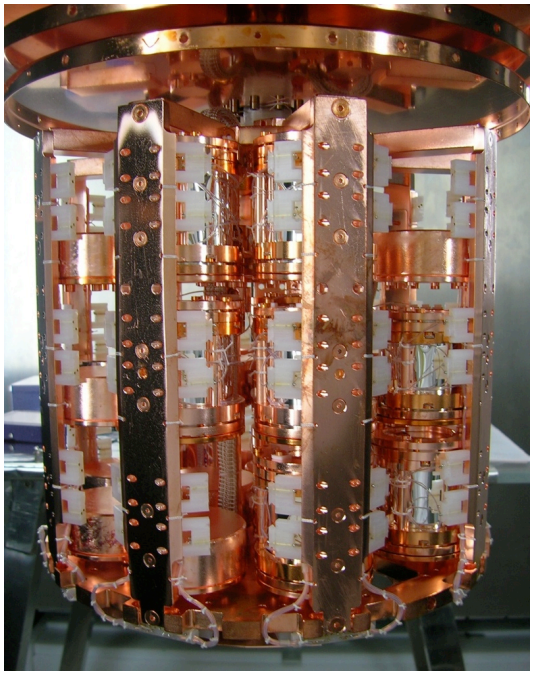
→ Avoid non-scintillating materials!

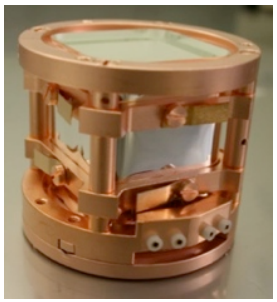
STATE-OF-THE-ART

# CRESST II

# Recently Finished – CRESST-II Phase 2

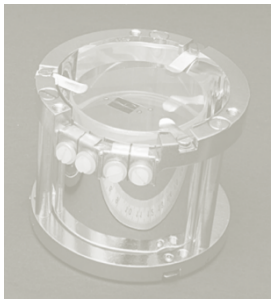
Data-taking from July 2013 to August 2015





**2014 Results: "TUM-40"**

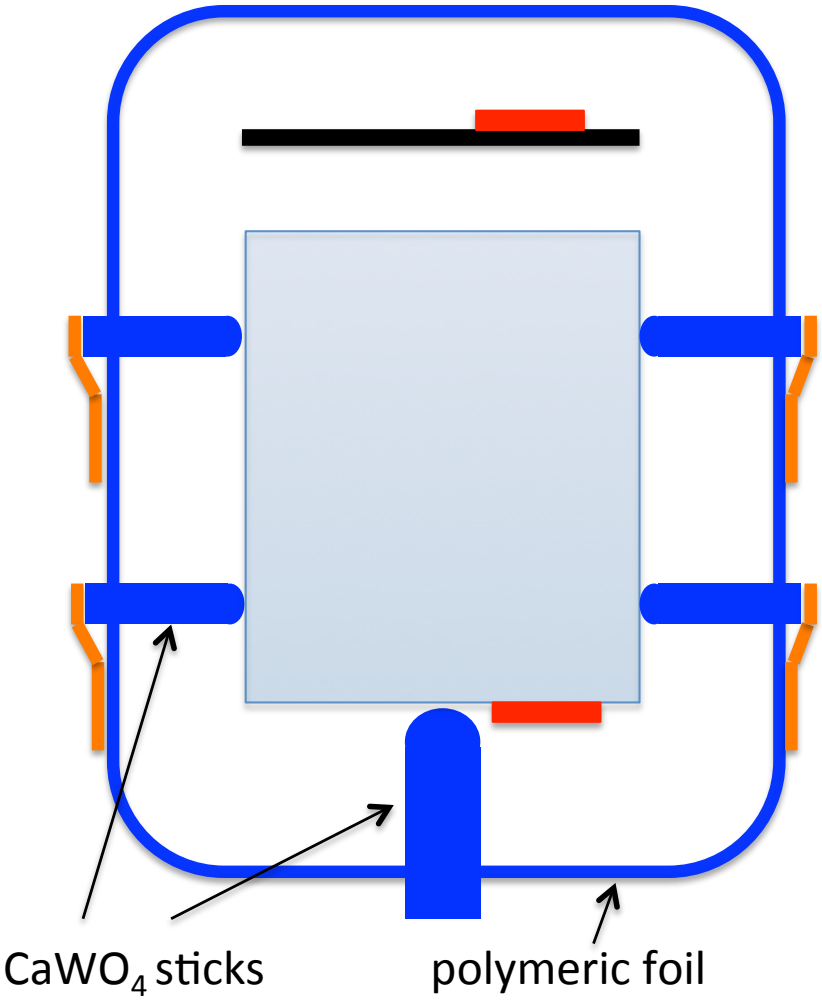
- Efficient surface-event rejection
- Best intrinsic background level
- Best *overall* performance



**2015 Results: "Lise"**

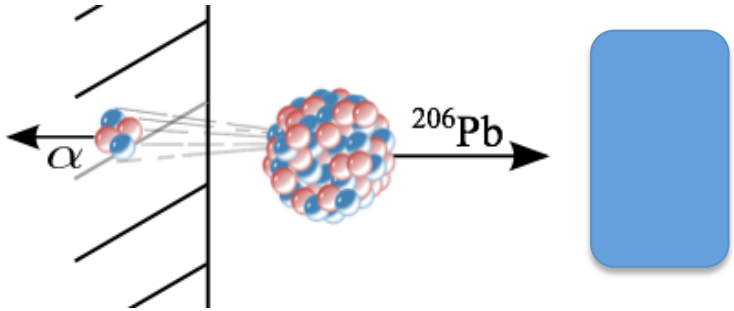
- Incomplete surface rejection
- Lowest threshold
- Factor ~2 higher background

# “TUM-40”: New Detector Design




Polymeric foil + $CaWO_4$ sticks

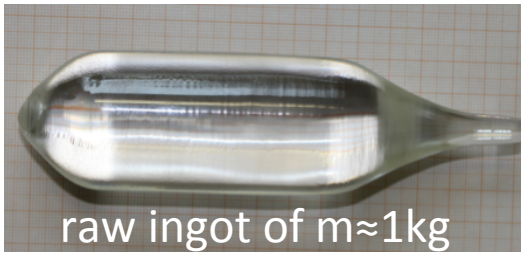
- Fully-scintillating detector housing
- Efficient rejection of surface backgrounds

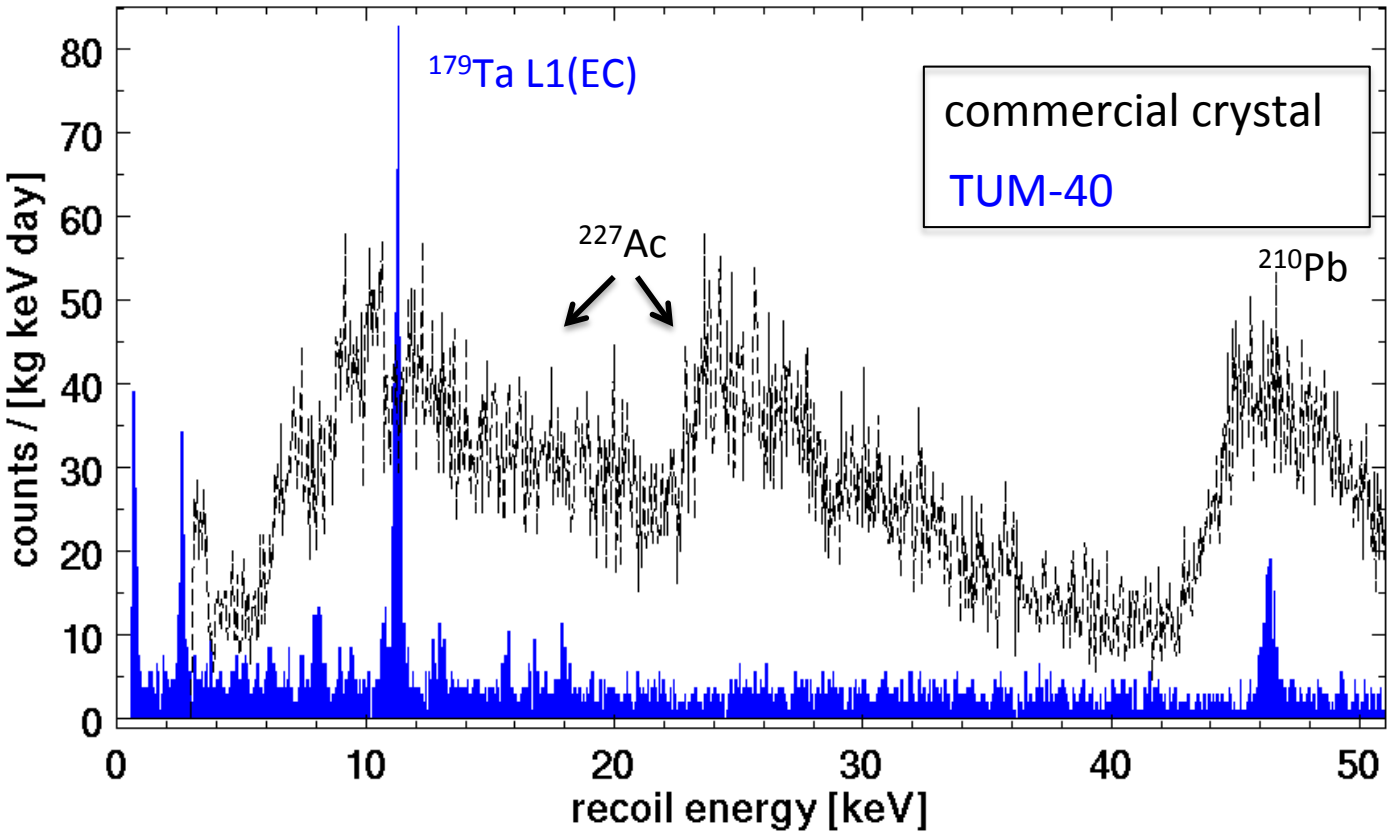



For details see recent publication:
*R. Strauss et al. arxiv:1410.1753 EPJ-C (2015)*

# “TUM-40”: Unprecedented Radiopurity

- $CaWO_4$-crystal **production at TU Munich**
- Unprecedented radiopurity (by factor 2-10)
- Room for further improvements




Average rate:
**~3.5 counts / [kg keV day]**

Gamma-lines from **cosmogenic activation**

Excellent resolution:
$\sigma \approx 90\text{eV}$

**See:** CRESST collab. G. Angloher et al. arXiv:1407.3146, EPJ-C (2014) 74
CRESST collab. *R. Strauss et al. arxiv:1410.4188, JCAP 06(2015)030*

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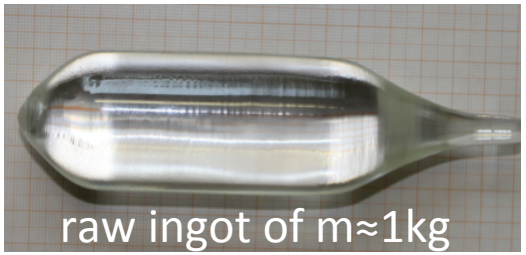


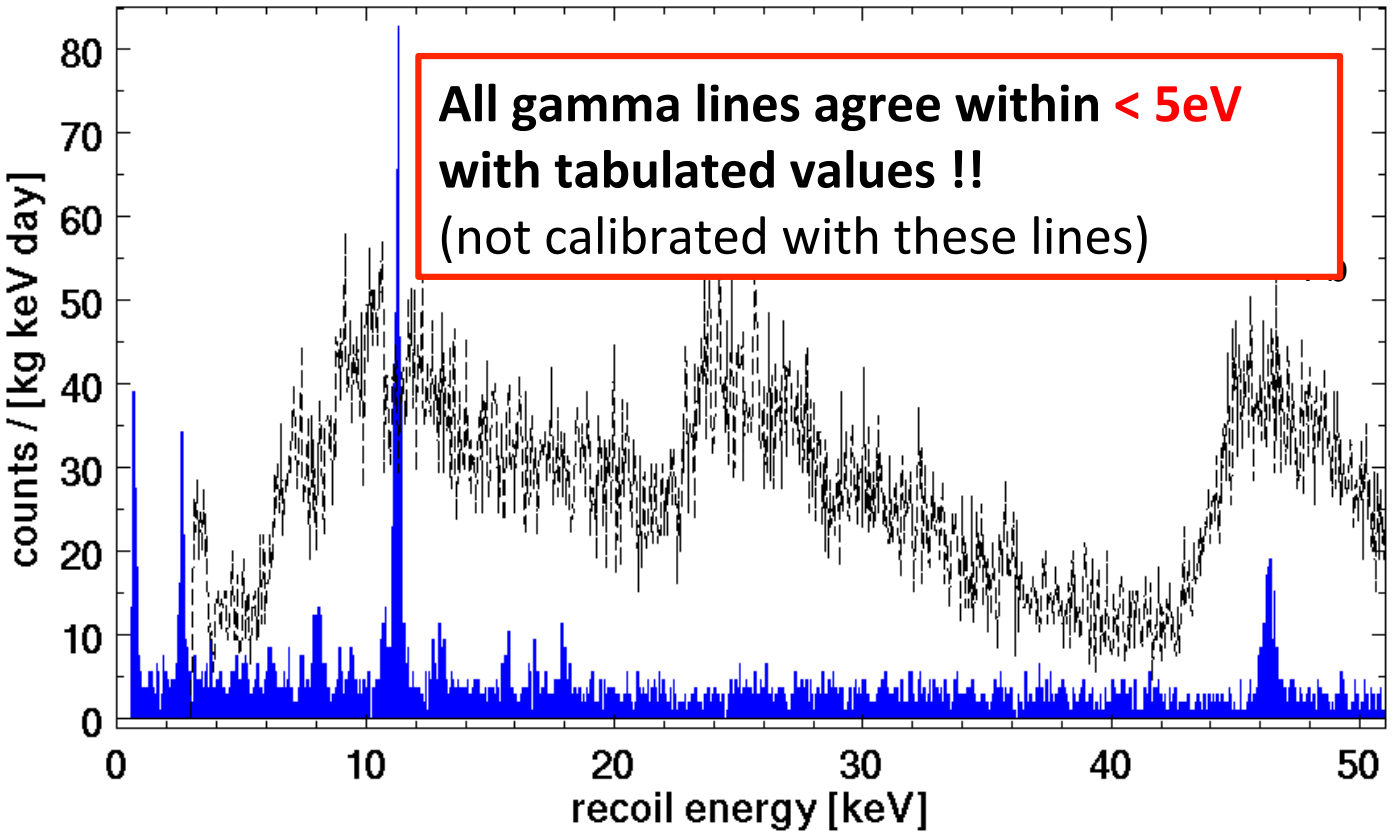


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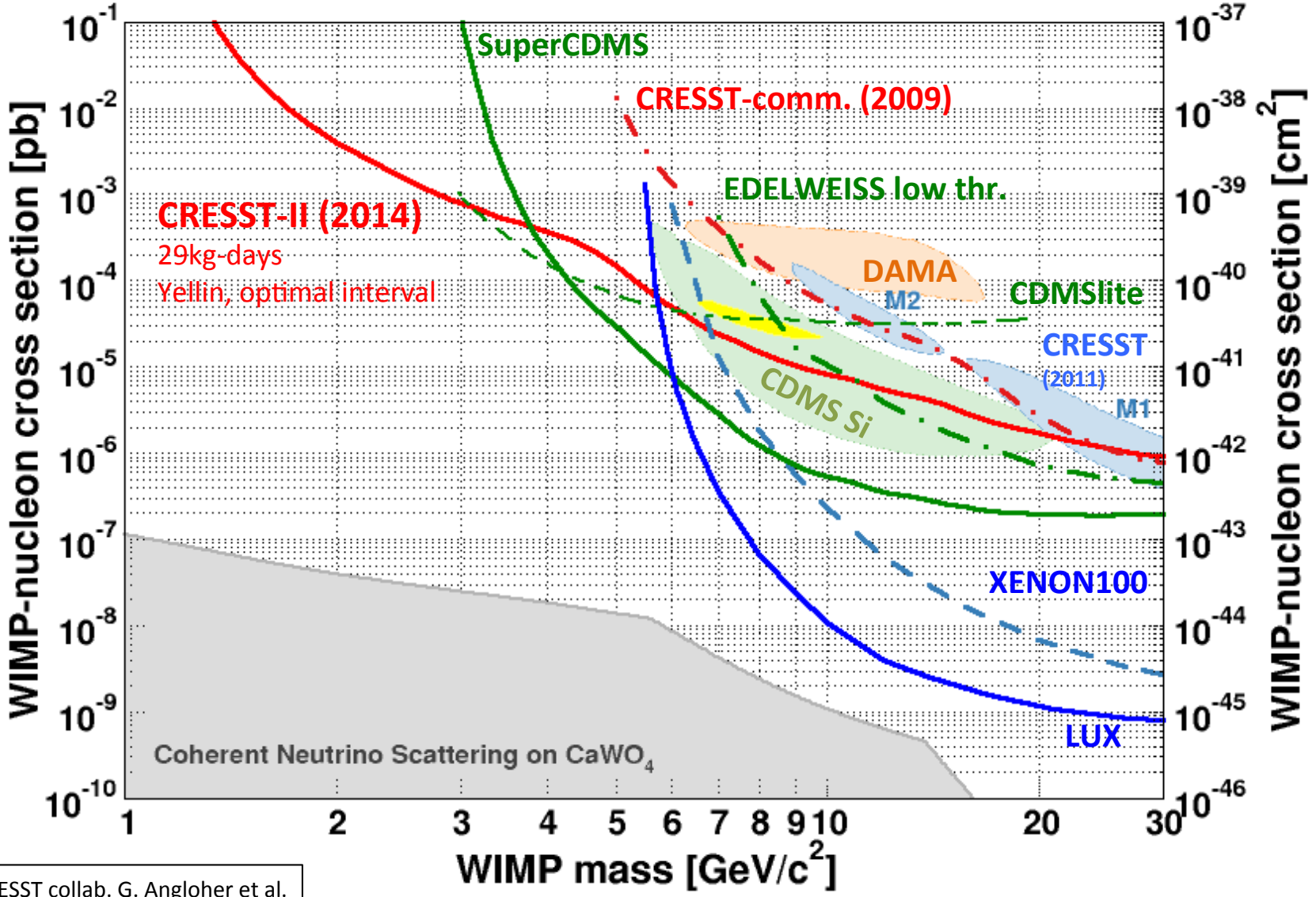
# Status 2014: “TUM-40” Results

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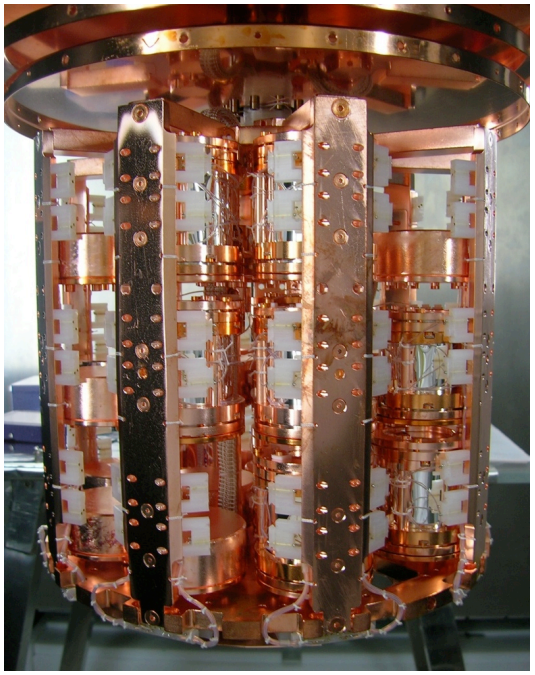

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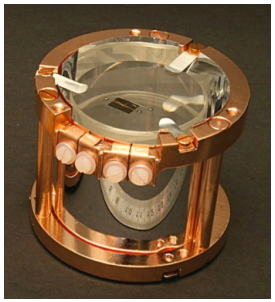

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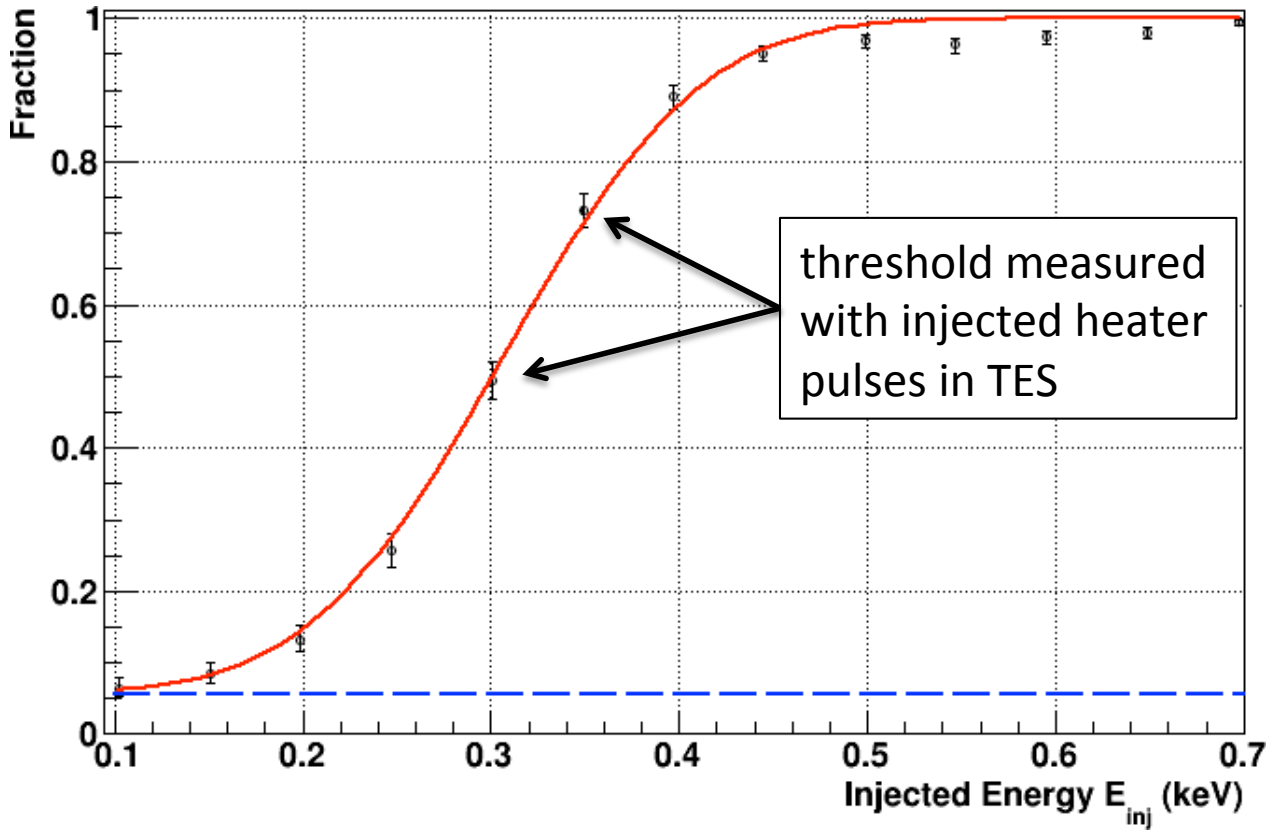
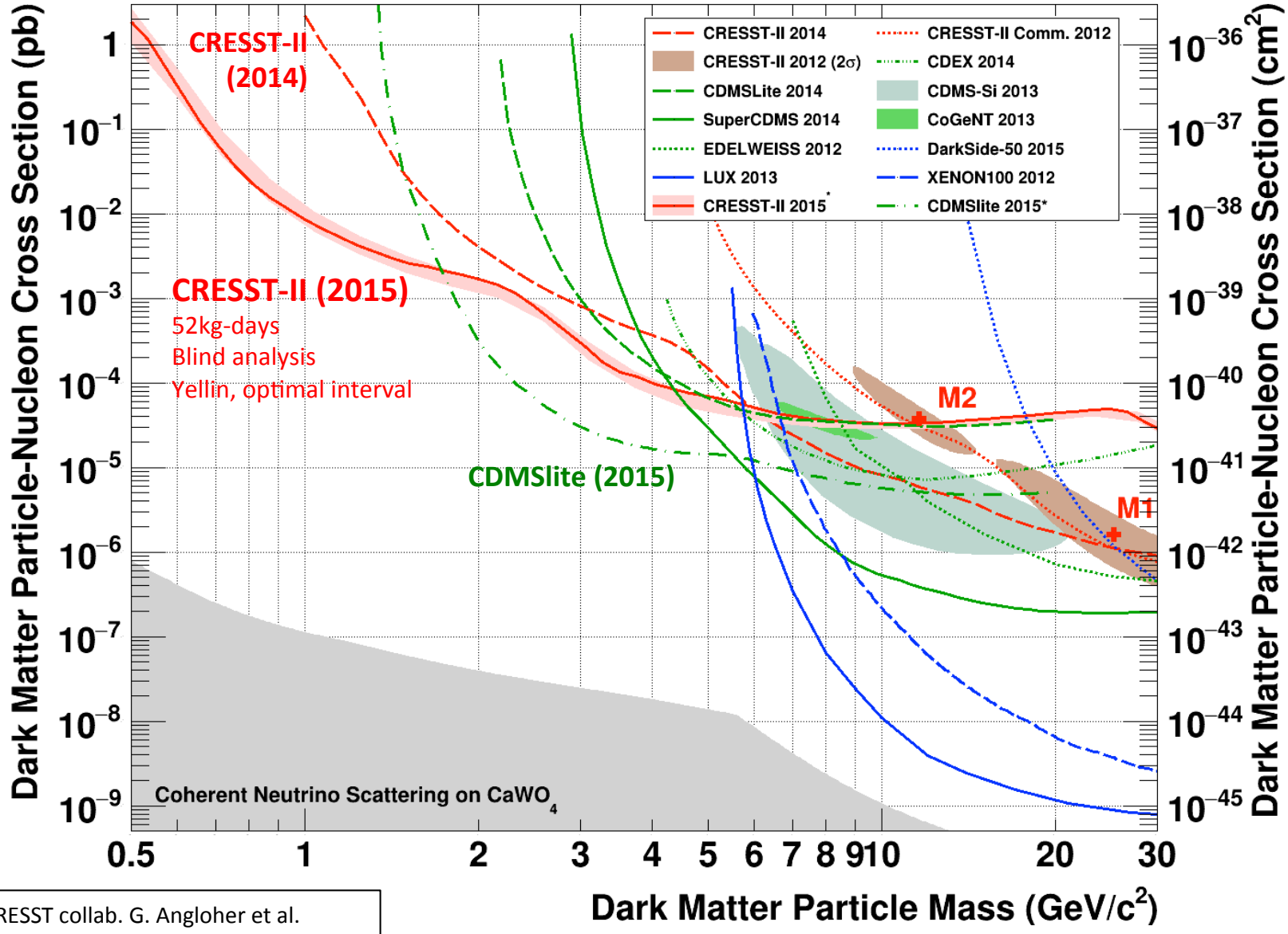
- Lowest threshold
- Factor ~2 higher background

# “Lise”: Trigger Threshold



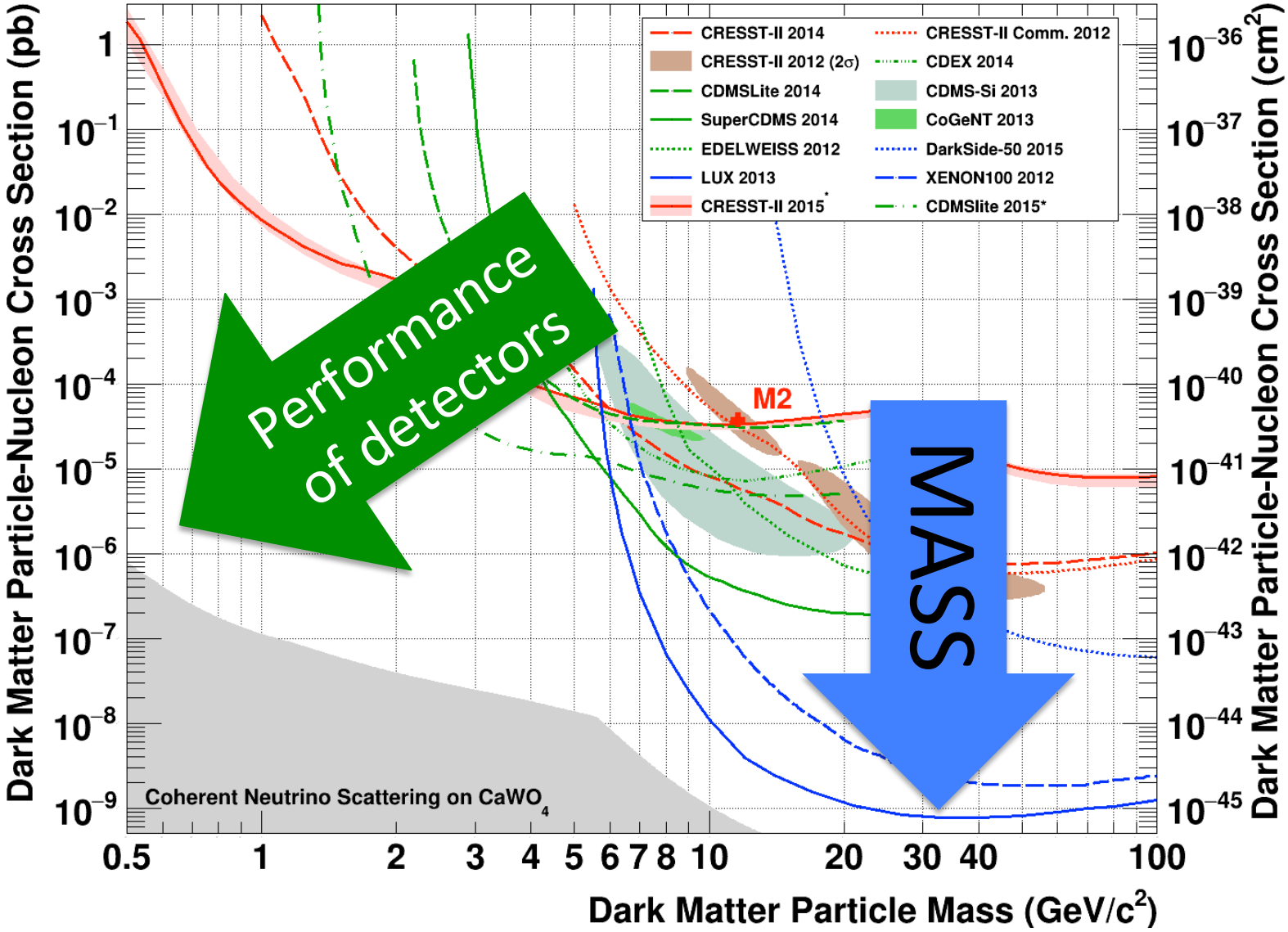

**Direct** measurement of nuclear-recoil energy with calorimetric detector!

# “Lise”: Results 2015




**See:** CRESST collab. G. Angloher et al. arXiv1509.01515

# Future of Dark Matter Searches



NEAR FUTURE

# CRESST III

# CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: **CRESST-III** Phase 1

Status quo

m = 250g
V = 32x32x40 $mm^3$

**Phonon threshold:** $E_{th} \lesssim 500eV$

**Light-detector res.:** $\sigma \approx 5$ eV

# CRESST-III: Low-Mass WIMP Search

Straight-forward approach for near future: **CRESST-III** Phase 1

Status quo

m = 250g
V = 32x32x40 $mm^3$

Scale down size by factor 10

m=24g

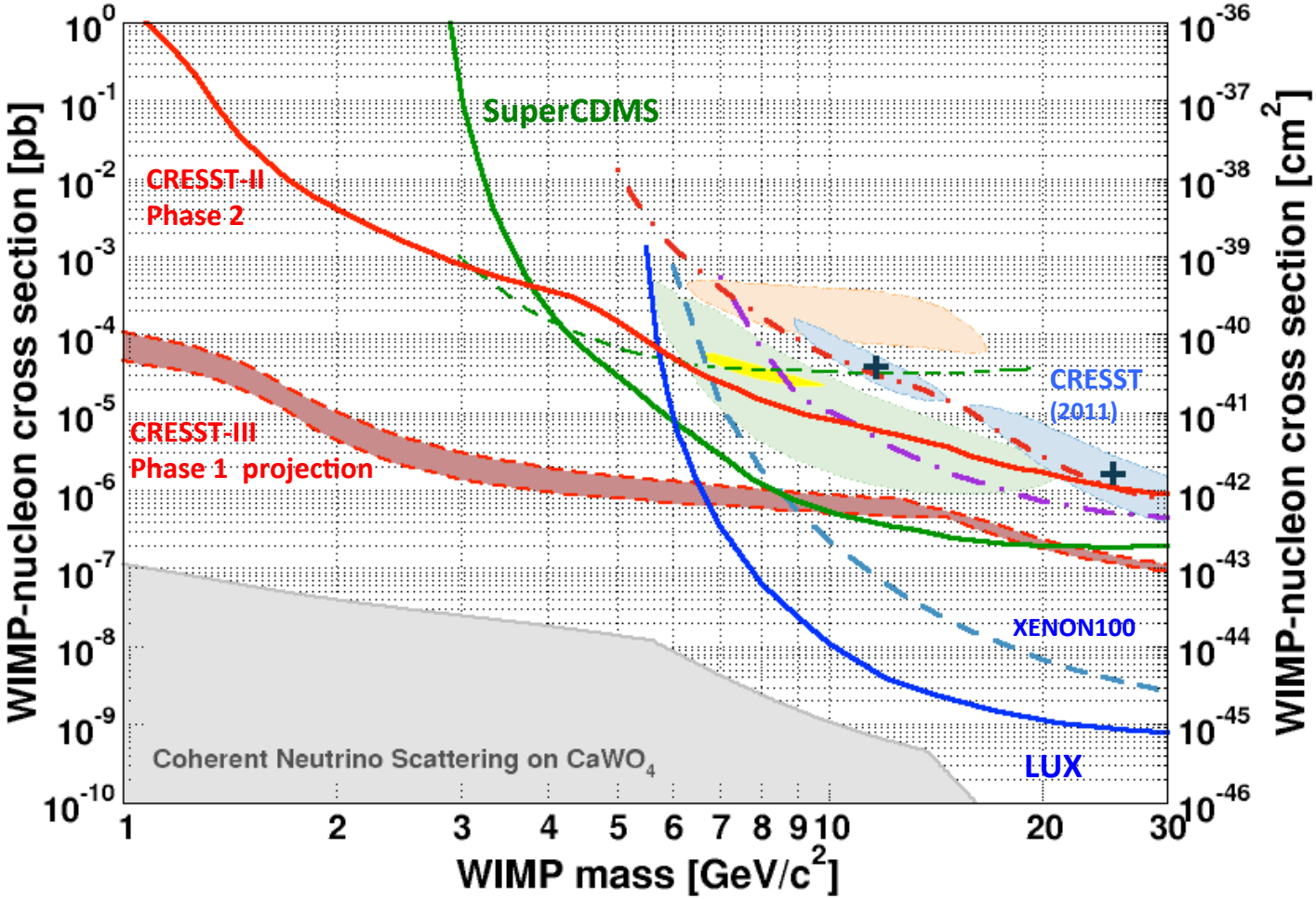
**Phonon threshold:** $E_{th} \lesssim 500eV$ **improvement by a factor of 5-10**

**Light-detector res.:** $\sigma \approx 5$ eV **improvement by a factor of 2**

# **CRESST-III** Phase 1

Assumptions:

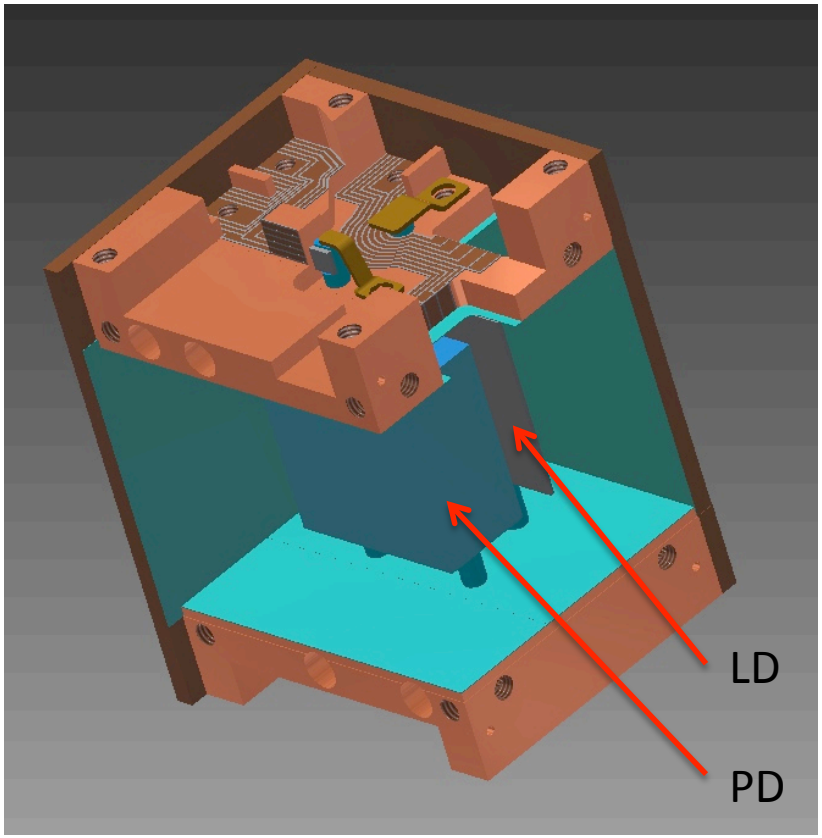
- 24g $CaWO_4$ crystal
- **$E_{th}$ = 100eV**
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- **CRESST-II radiopurity**

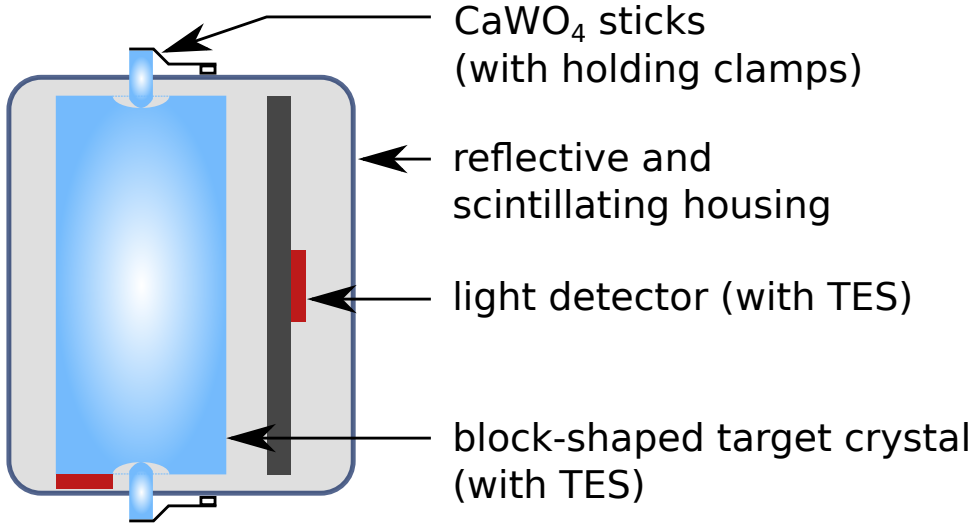



10 x 24g detectors operated for one year ≈ **50 kg-days** (net)

**See:** CRESST collab. G. Angloher et al. arXiv:1503.08065

# CRESST-III Detector Prototype



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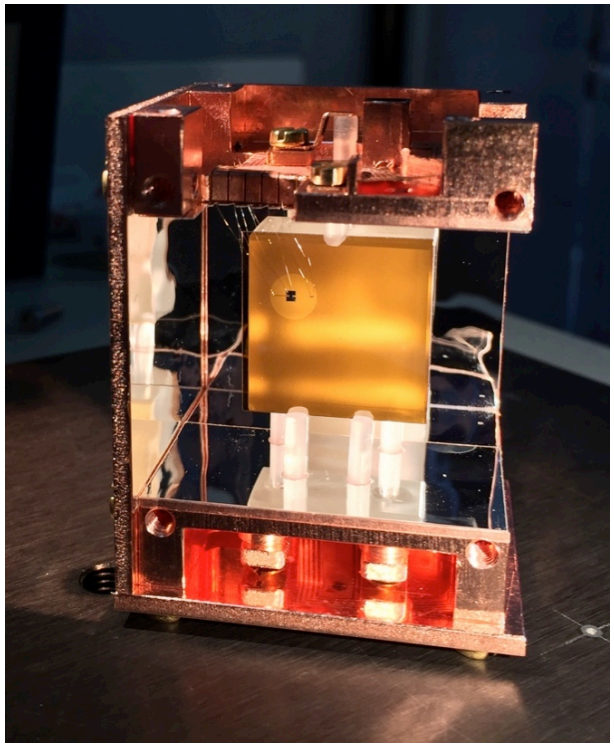
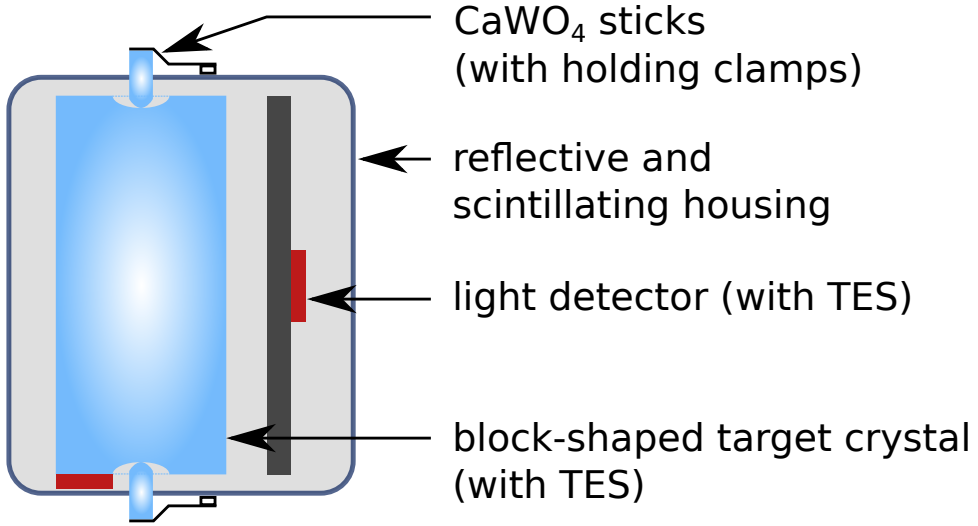
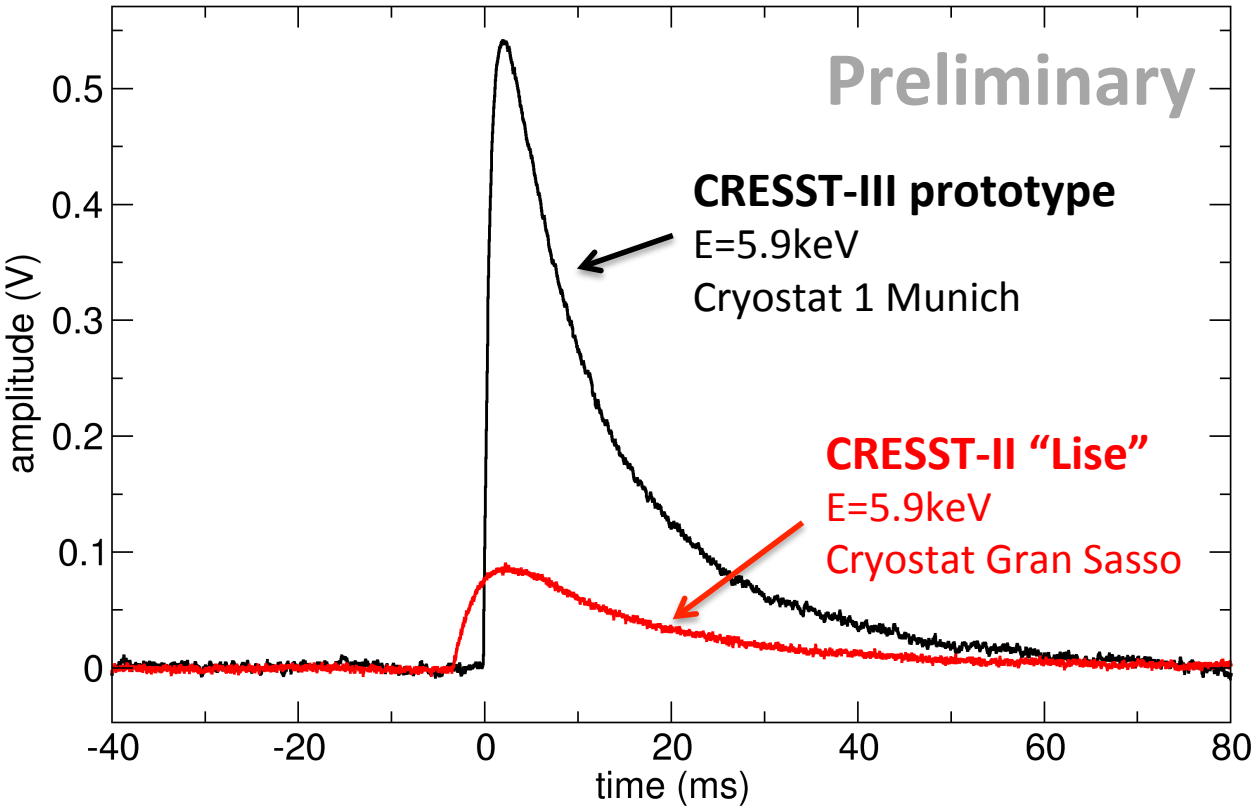


First modules ready



# First Results of CRESST-III Detector




Promising results:

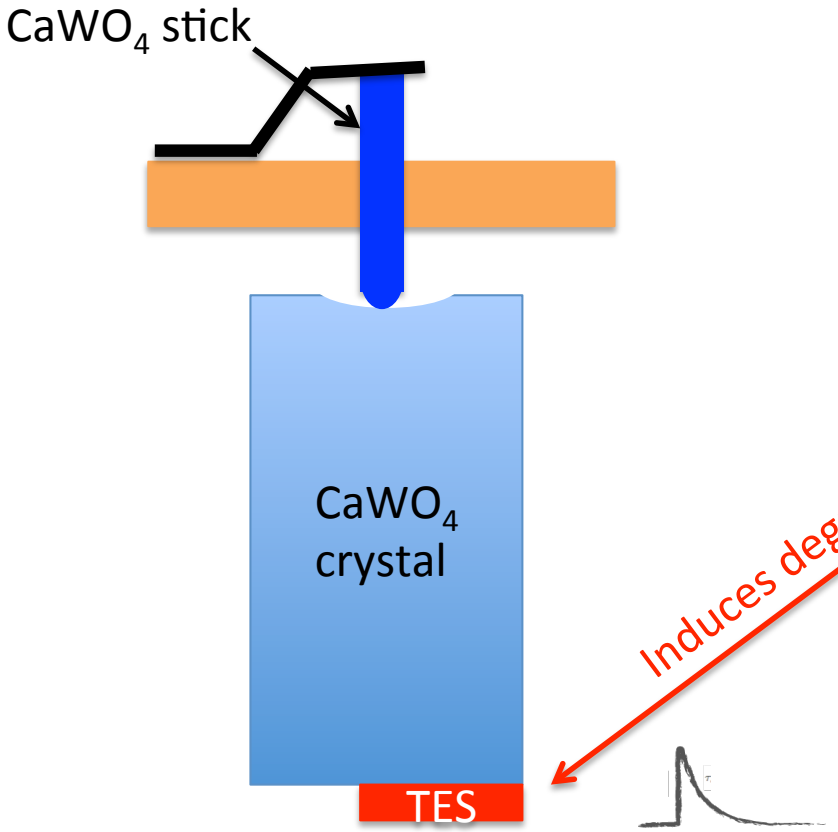
Improvement by **factor 6.2** compared to best CRESST-II detector ($E_{th}$ = 298eV)

→ Baseline noise @GS 1.8-3.0mV RMS

→ **Threshold: $E_{th}$= 45-60eV**

Design goal ($E_{th}$=100eV) for **CRESST-III** Phase 1 exceeded!

# Instrumented Holder - iSticks




- Particle events in sticks
- Surface backgrounds
- Stress relaxations
- …

Induces degraded signal

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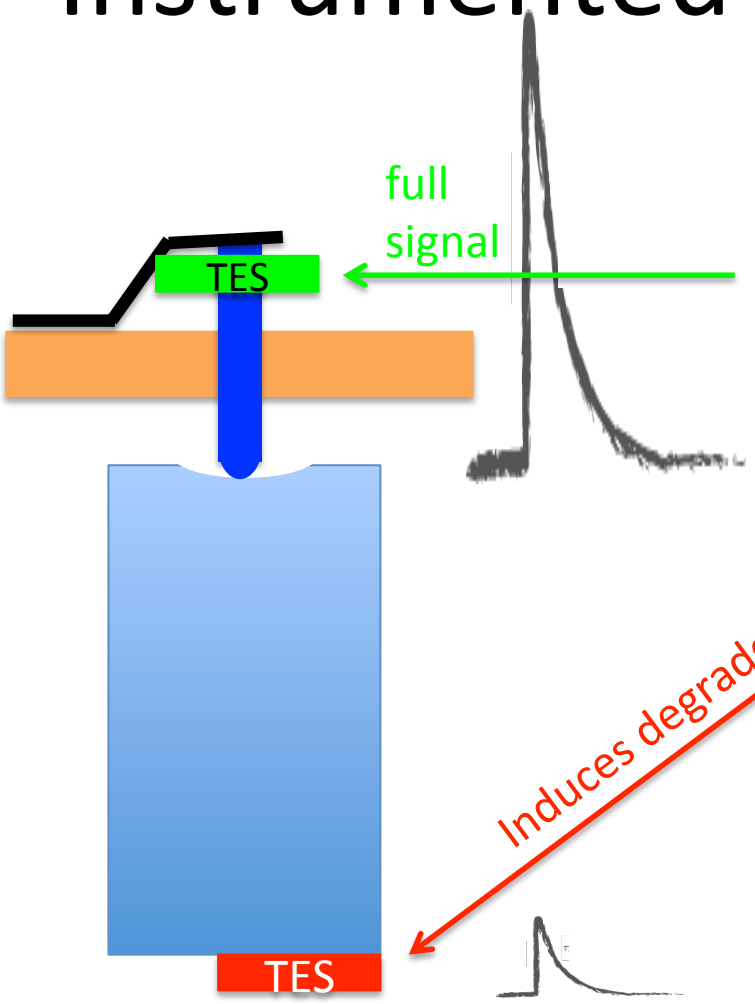


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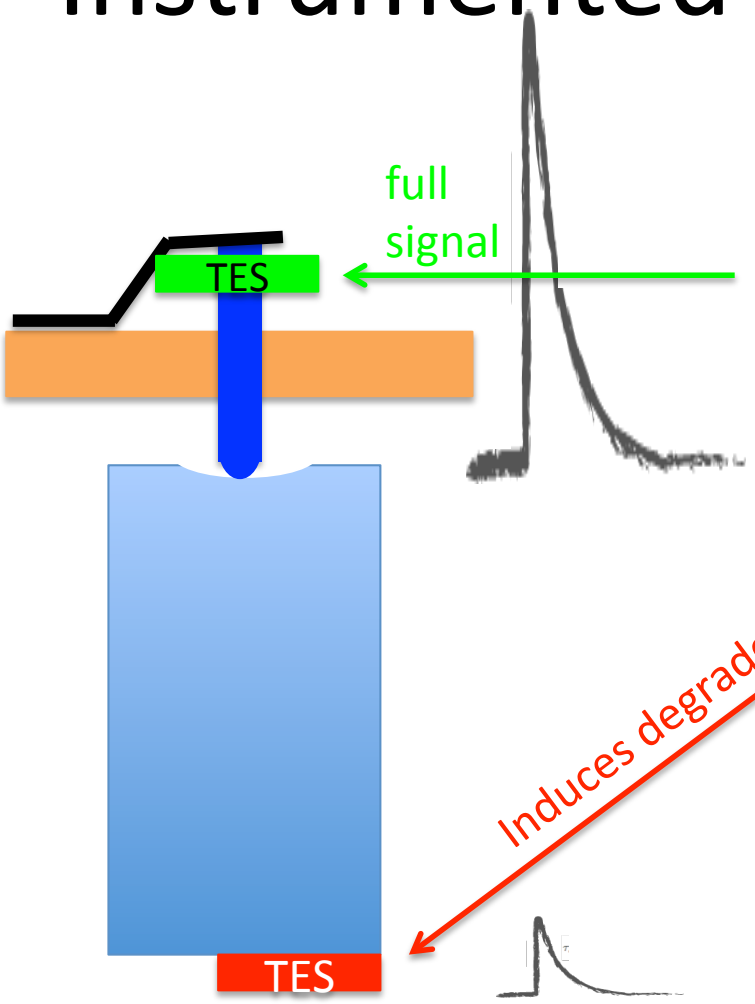


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Induces degraded signal

ratio $\frac{\text{stick}}{\text{absorber}}$

powerful tool to reject all kind of backgrounds related to holder!

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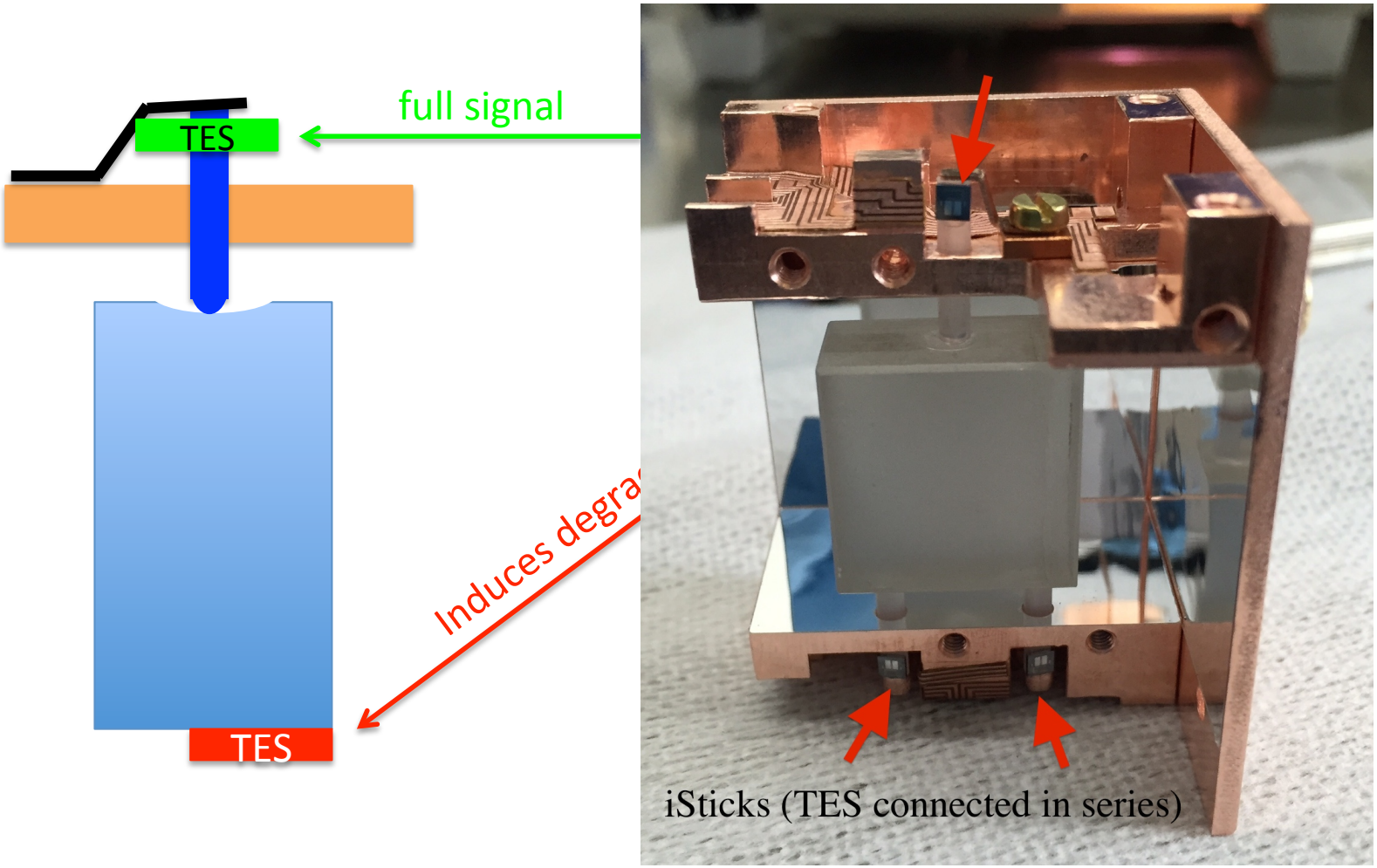

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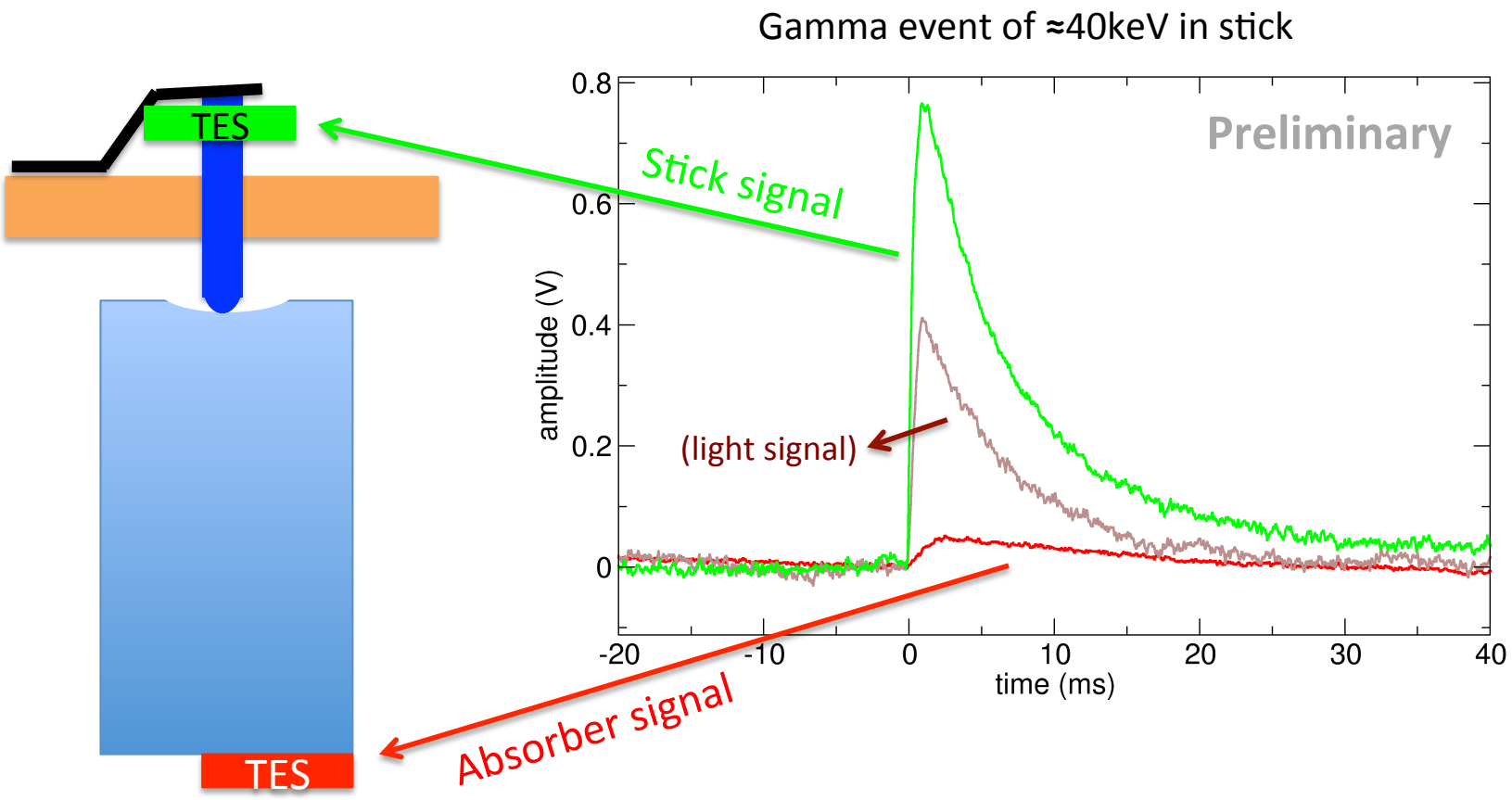
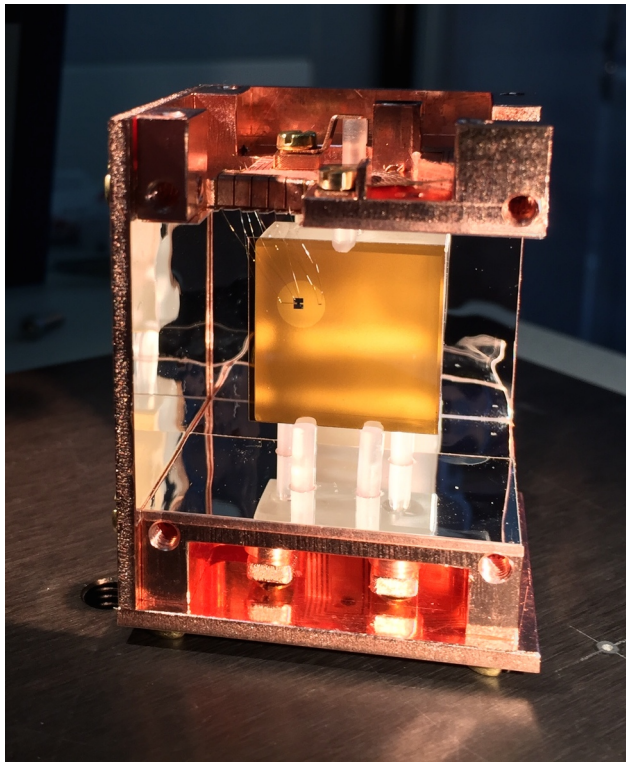


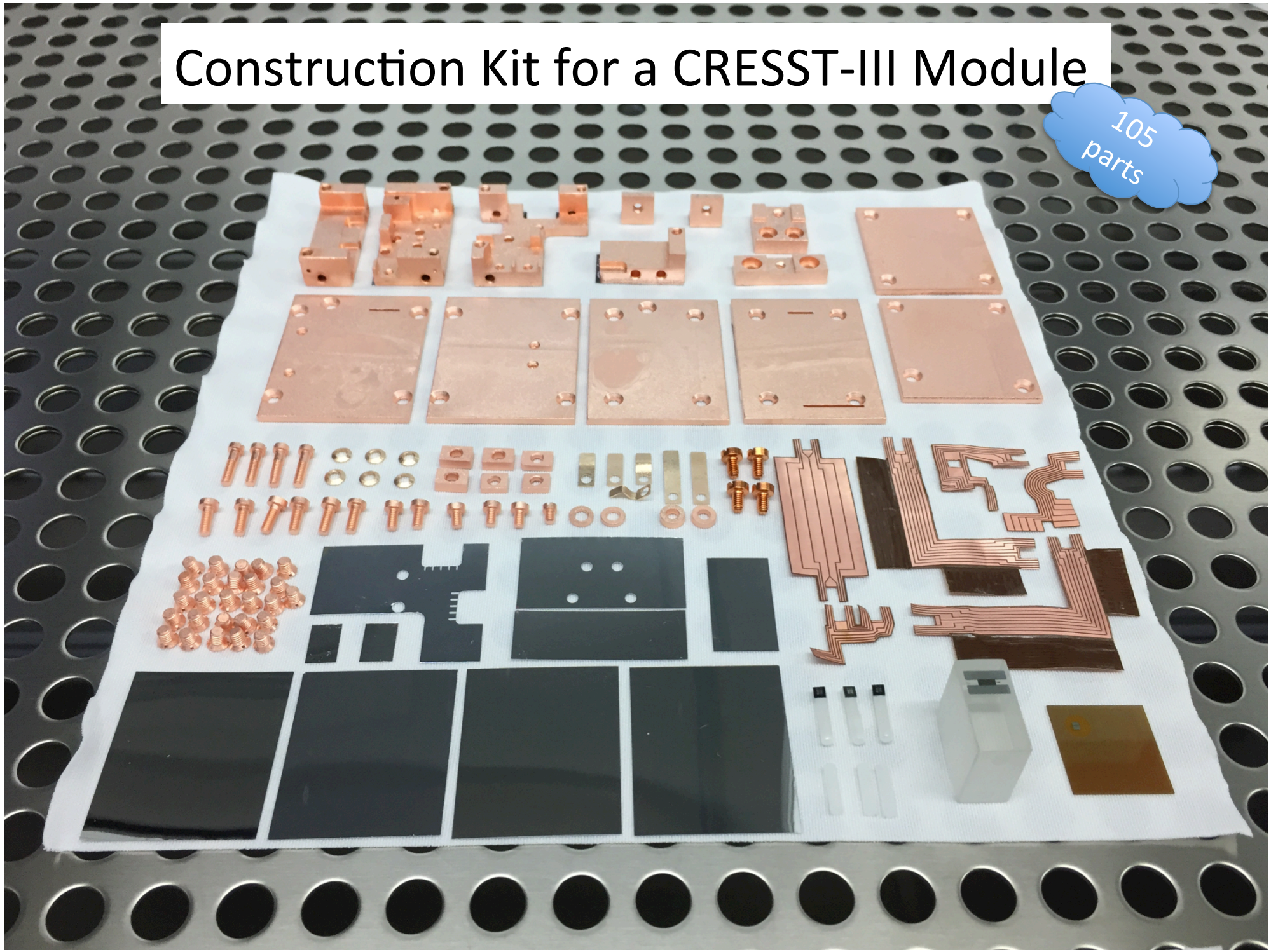
# Timeline for CRESST-III

**Phase 1:**

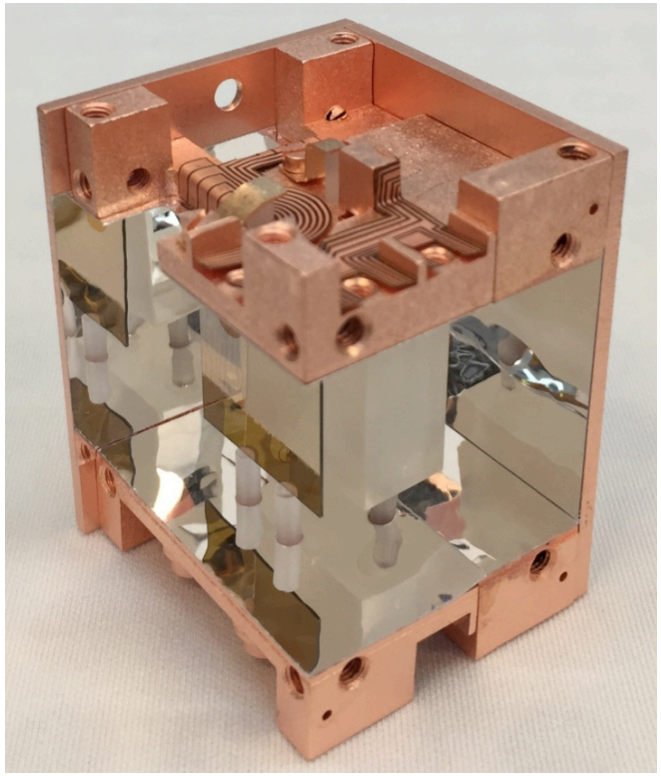
- Prototype detectors ready
- Production of ~ 15 modules ongoing
- All parts ready
- Assembly & mounting  Jan 2015
- **Start Feb 2016**

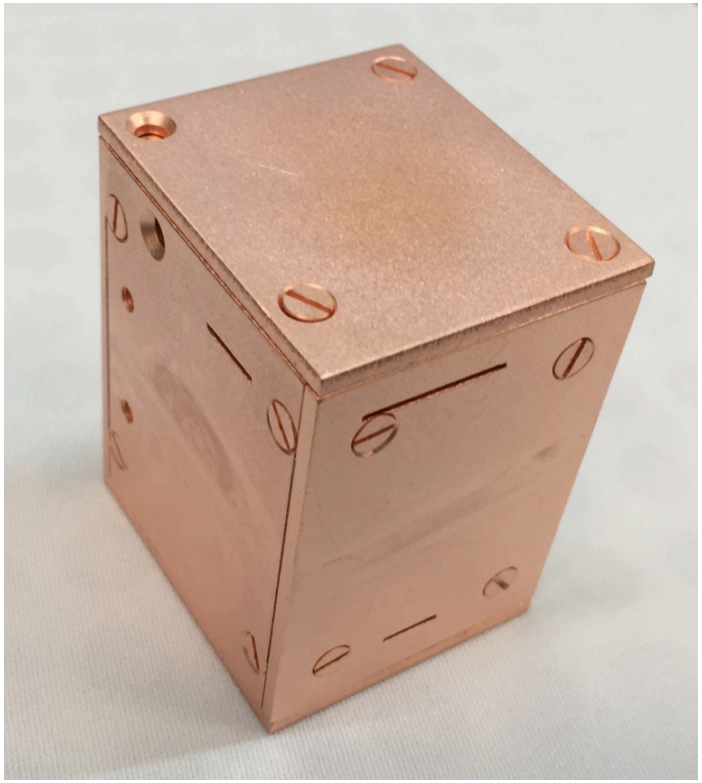


# Construction Kit for a CRESST-III Module



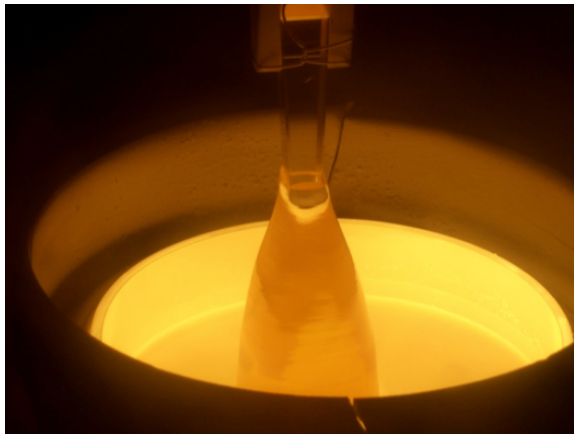
# Mounting in Progress…





First module for CRESST-III phase 1 assembled one week ago!
New dedicated cleanroom at MPI

# **CRESST-III** Phase 2



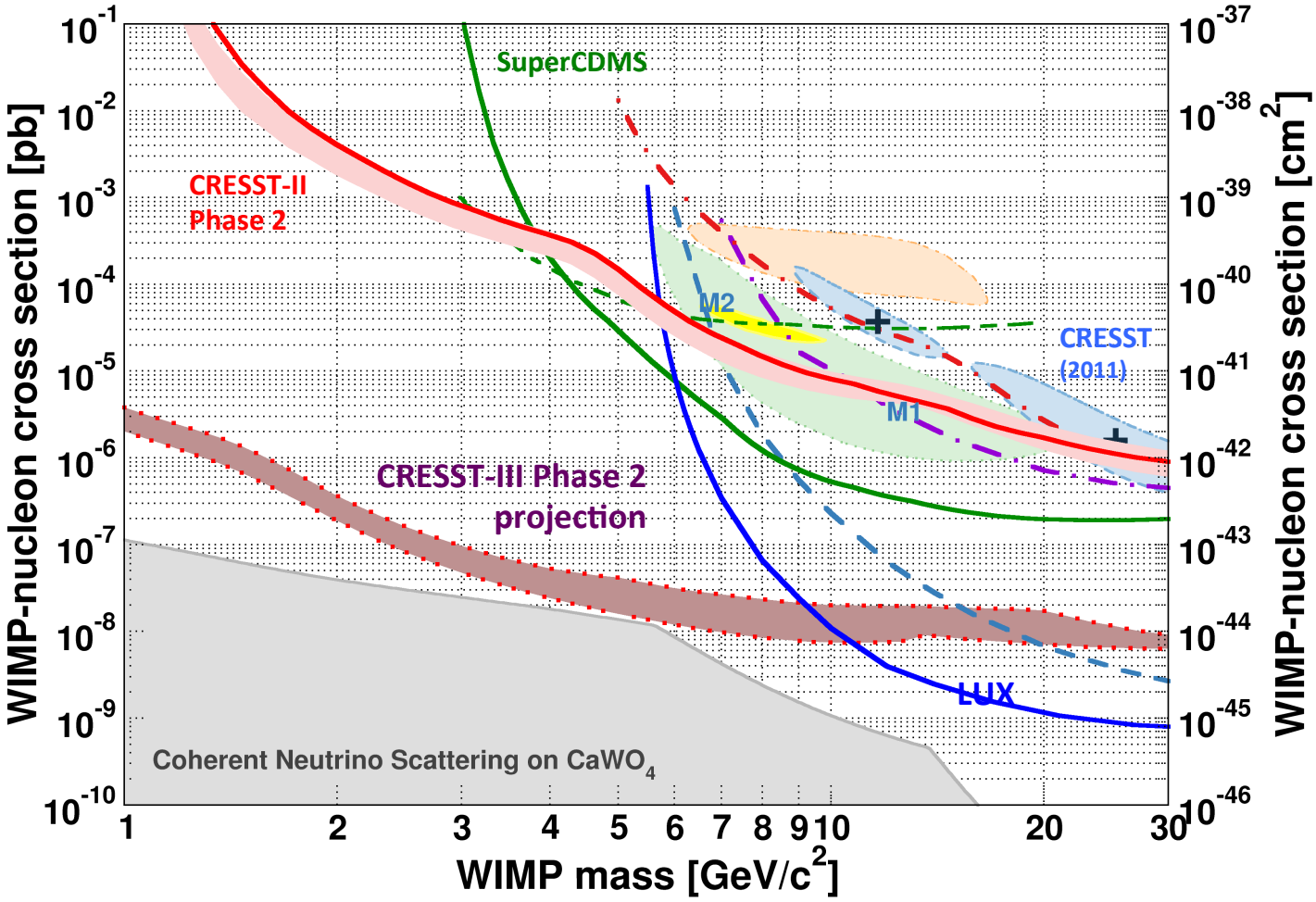
Reduce intrinsic background level of crystals!

- Growth of $CaWO_4$ crystals in-house (TUM)
- All production steps under control
- Improvement by factor 10 already achieved
- Cleaning procedure e.g. by re-crystallization, chemical purification of raw materials

**REALISTIC GOAL (in 2 years):**

Reduction of background level to $10^{-2}$ counts /[kg keV day]
(2 orders of magnitude compared to present $CaWO_4$ crystals)

# **CRESST-III** Phase 2




100 x 24g detectors of improved quality operated for 2 year ≈ 1000 kg-days (net)

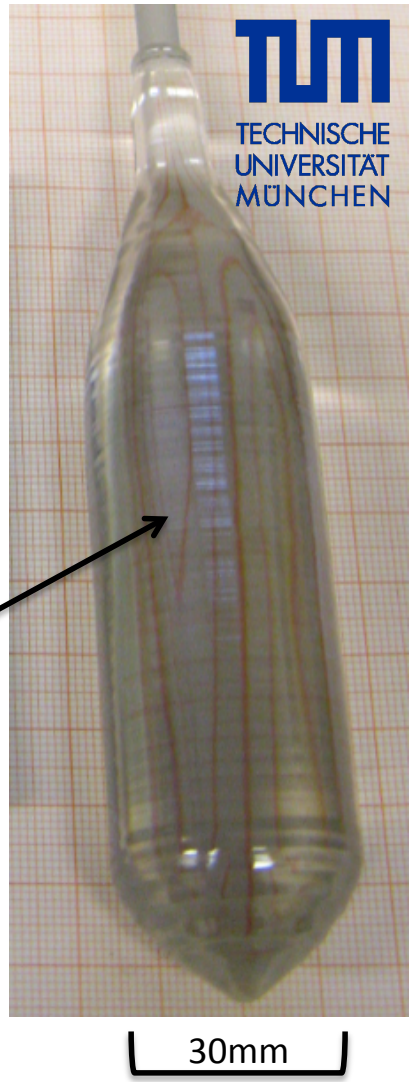
# Recent Exciting Progress at TUM

**First steps in 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 successful

Raw ingot enough for 3-4 CRESST-III detectors

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



# Summary

- CRESST technology proved high potential for **low-mass WIMP search**
  - ✓ Lowest thresholds in the field: 300eV
  - ✓ Nuclear-recoil energy scale precisely known
  - ✓ Background discrimination down to low energies
  - ✓ Efficient rejection of surface backgrounds
  - ✓ Multi-element target

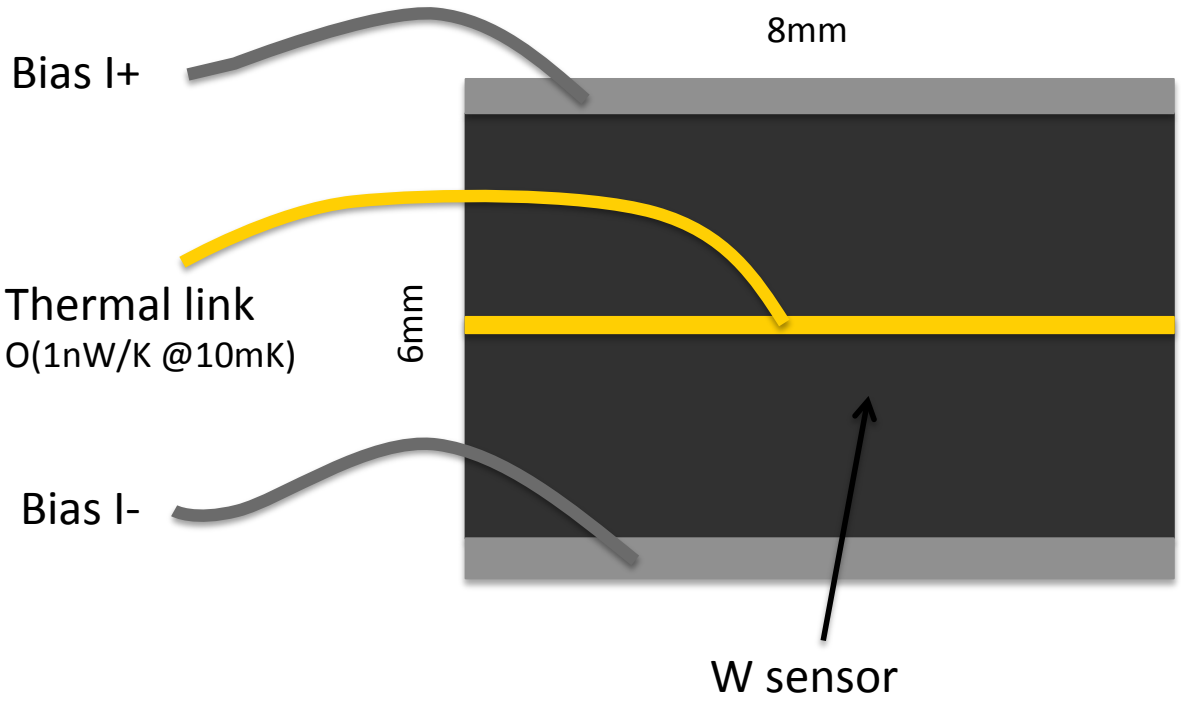
- **CRESST-II** probed new region of parameter space for WIMP masses below 3GeV/$c^2$

- **CRESST-III** has unique potential to explore low-mass WIMP region
  - ✓ Threshold of <=100eV reached with prototype detector
  - ✓ iStick technology to reject holder-related events
  - ✓ First crystals of improved quality already in phase 1

**Start: Jan 2016**

# BACKUP SLIDES

# Crucial: Energy Threshold

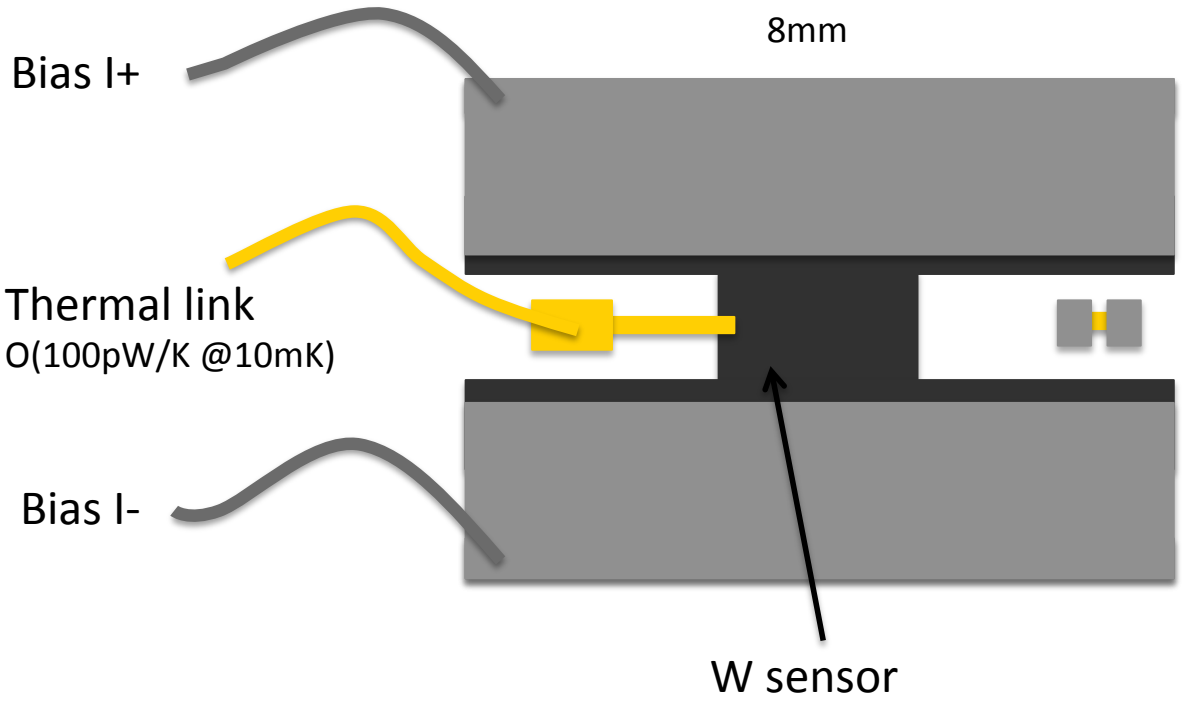



Old TES design for 300g crystals:

- **bolometric** operation
- large collection area
- strong thermal coupling to bath
- not optimized for low threshold !

Threshold $E_{th} \lesssim 500$eV reached!

# Crucial: Energy Threshold

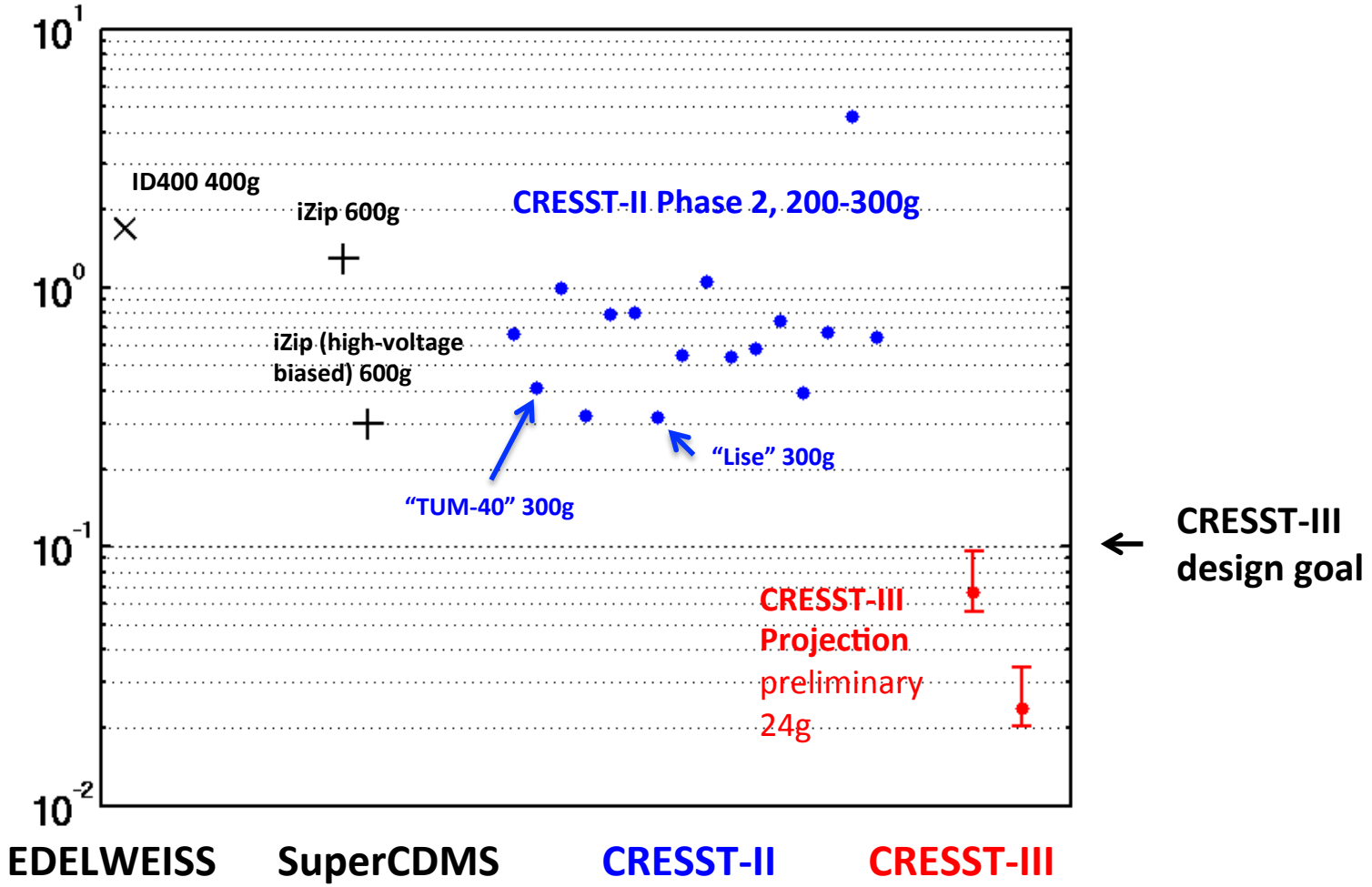



New TES design for 24g crystals:

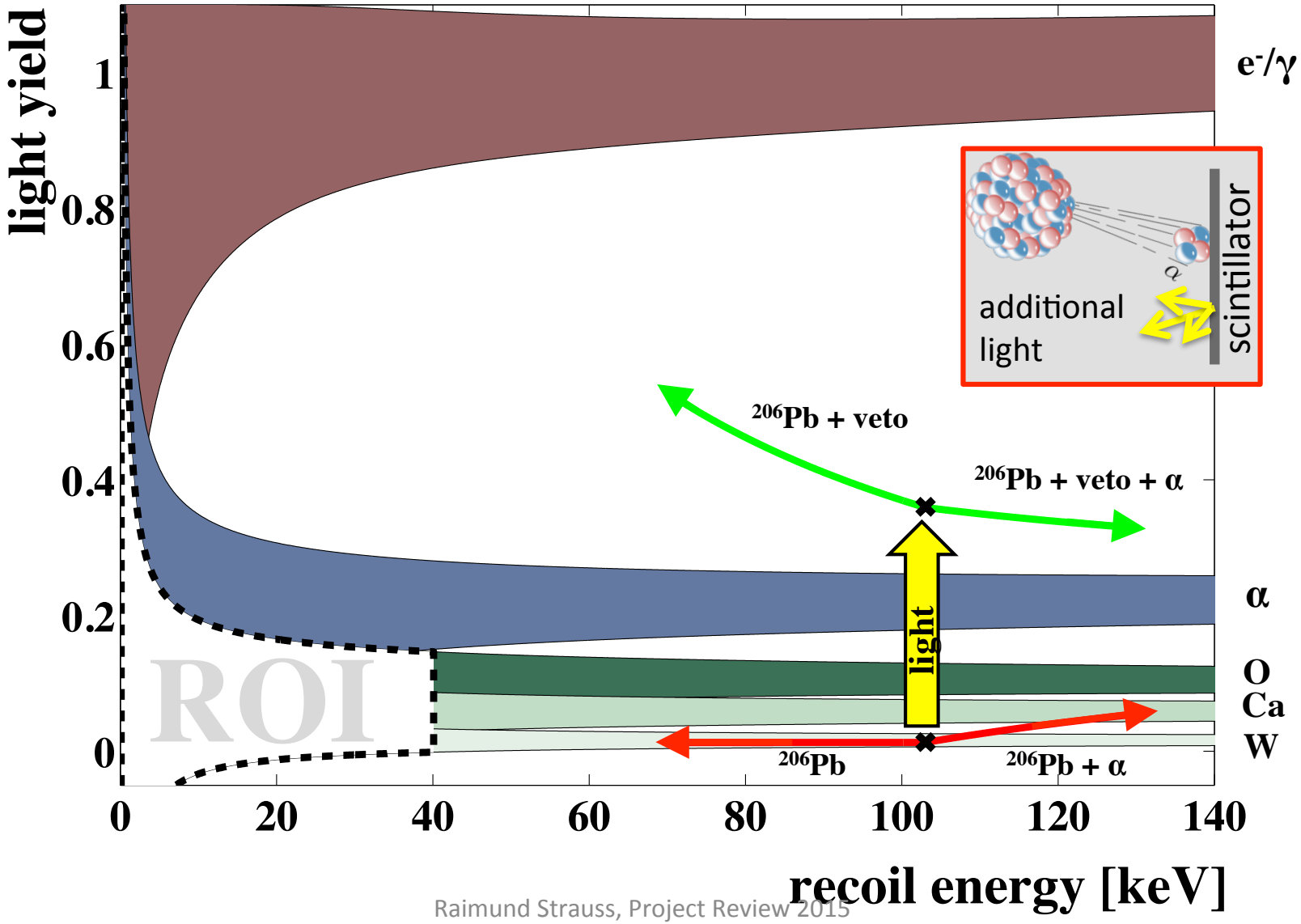
- **calorimetric** operation
- Similar to CRESST light detector
- W film: 8 times smaller
- weak thermal coupling to bath
- large-area Al phonon collectors

Theoretical improvement: factor **5-10** in signal/noise

# Thresholds of Cryogenic Experiments

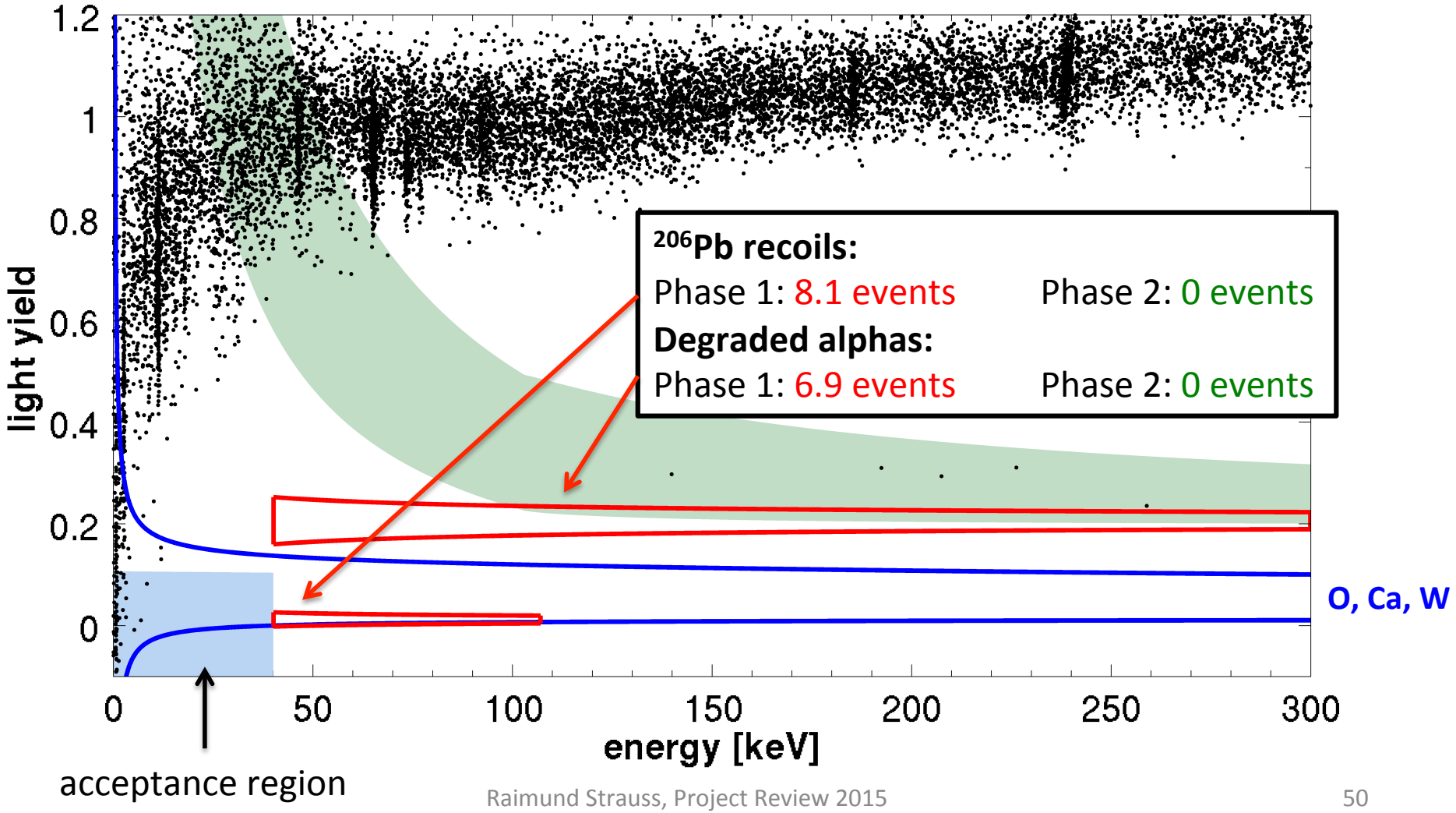


# Efficient Veto of Surface Backgrounds

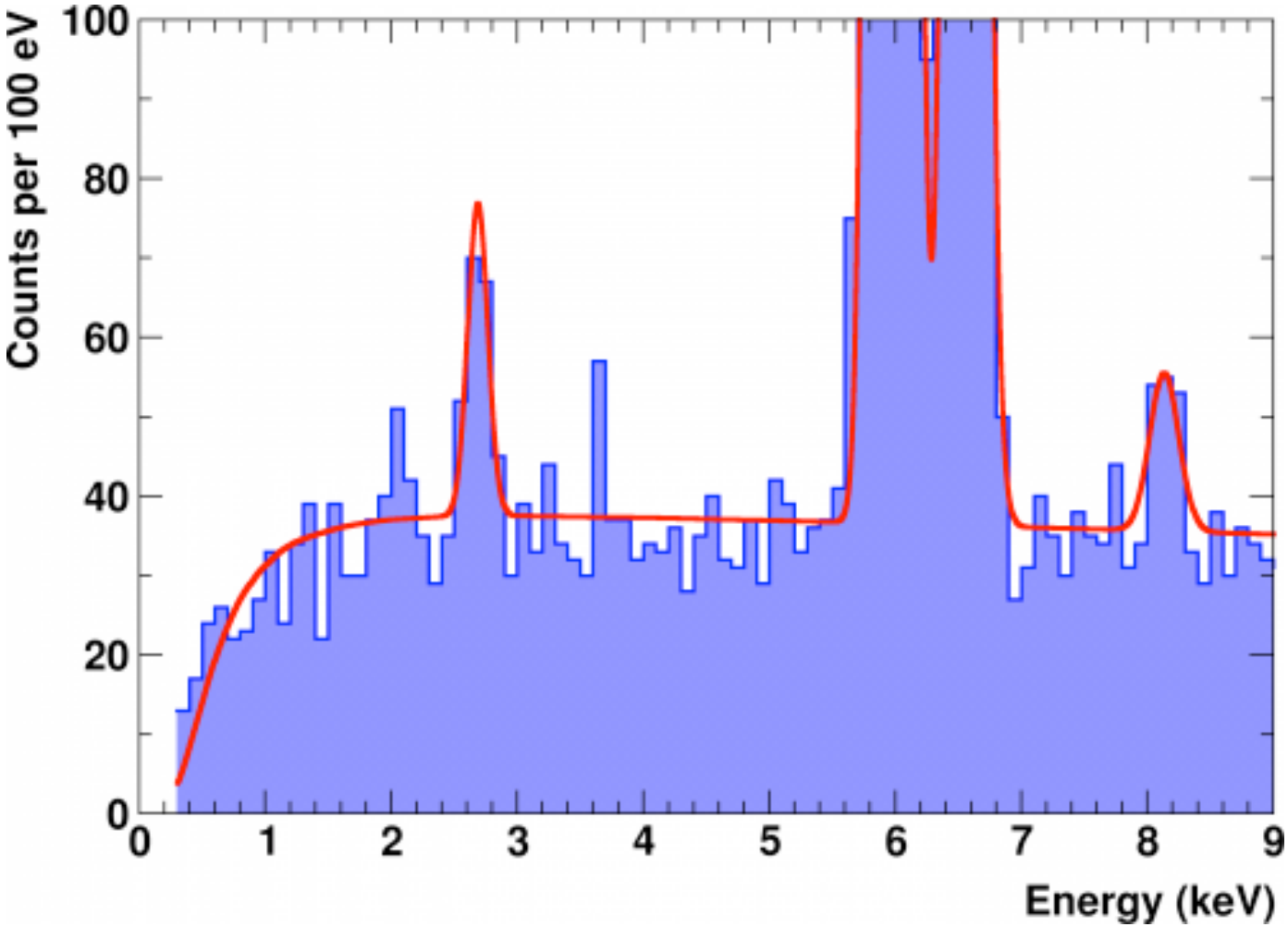


# TUM-40: Surface Backgrounds

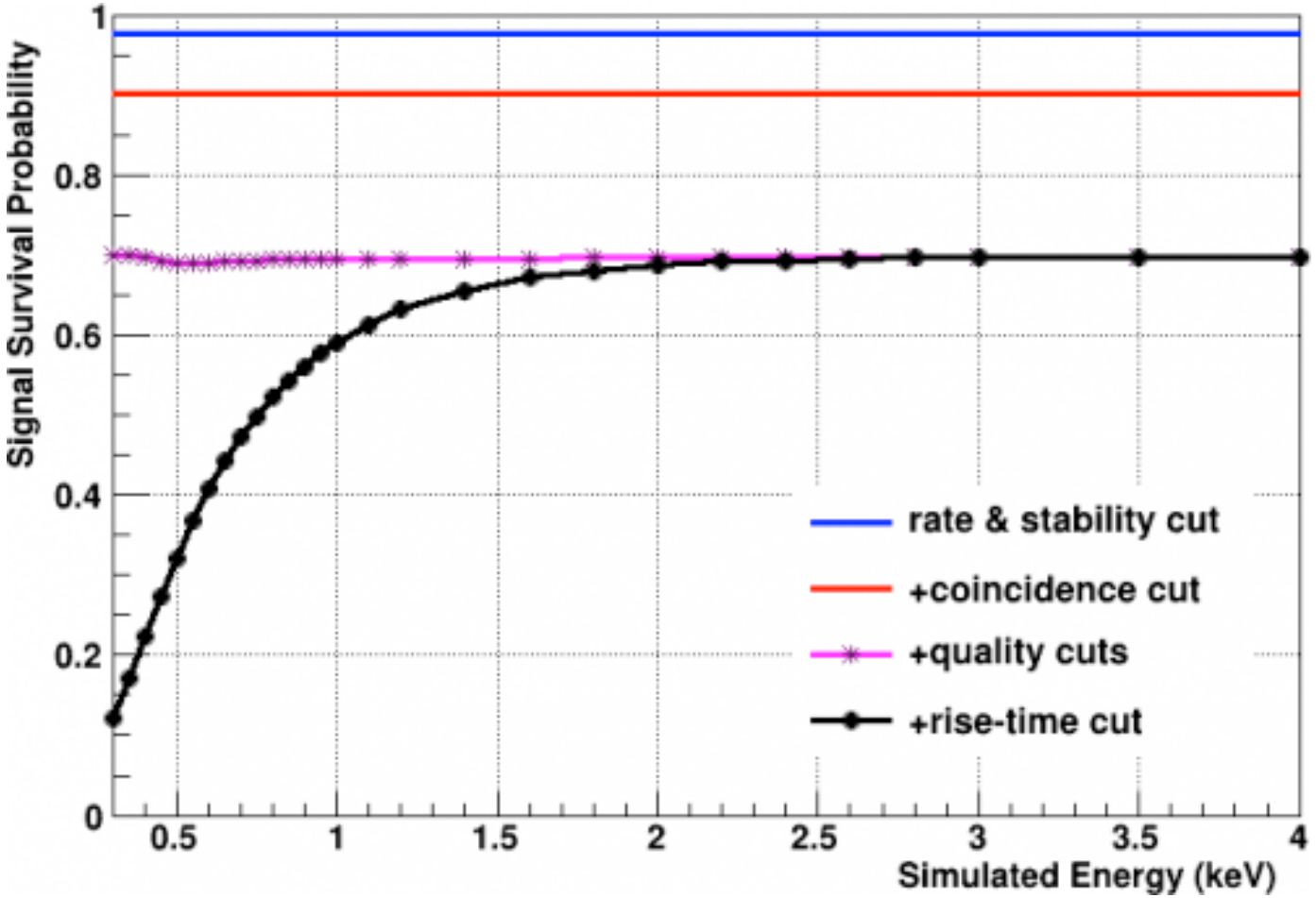
exposure: 29 kg-days



# Lise: Low Energy Spectrum



# Lise: Detector Efficiency



# Lise: Observed Events