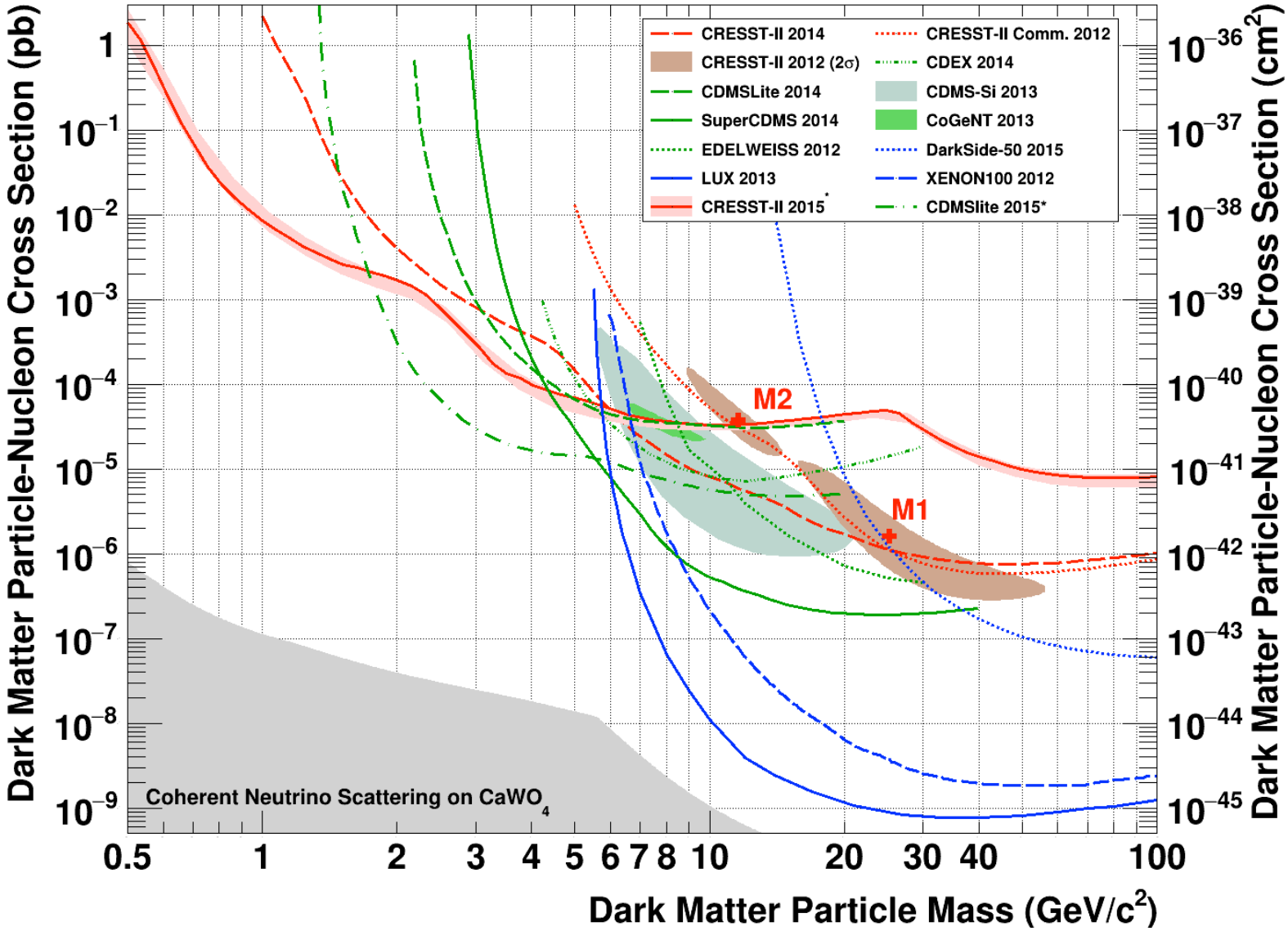
The CRESST Experiment

Search for Low-Mass Dark Matter

Raimund Strauss
Max-Planck-Institut für Physik
München,

Prospects in Low Mass Dark Matter
30.11.2015

Current Status of Direct Dark Matter Searches



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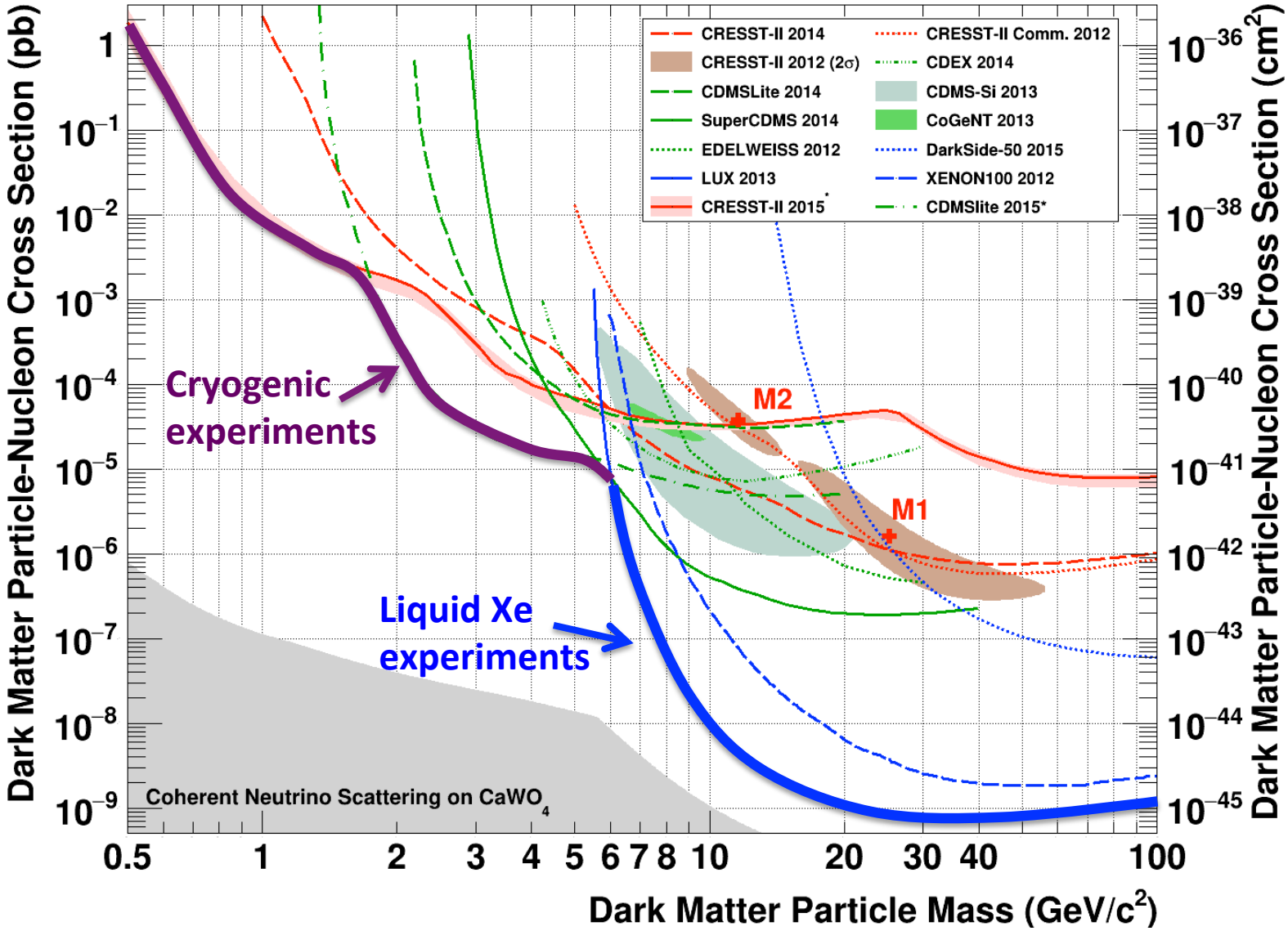
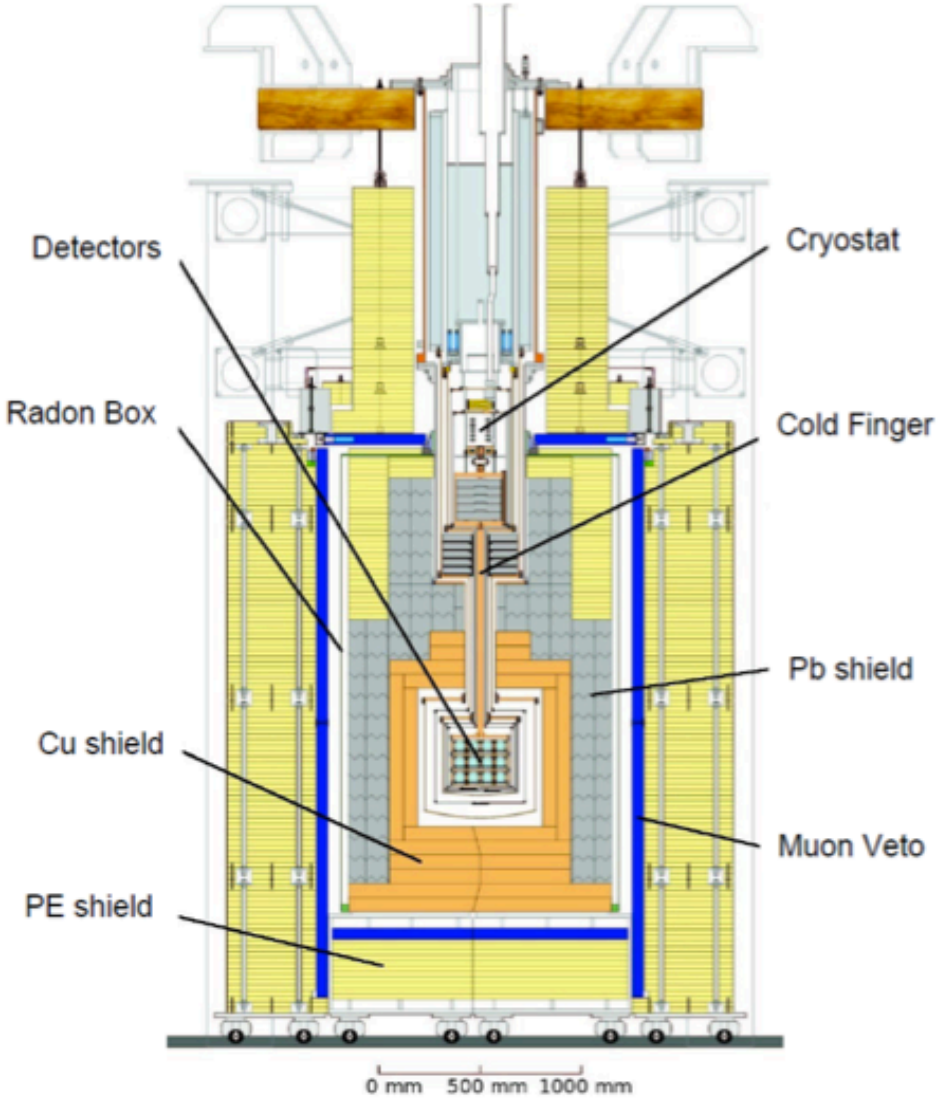
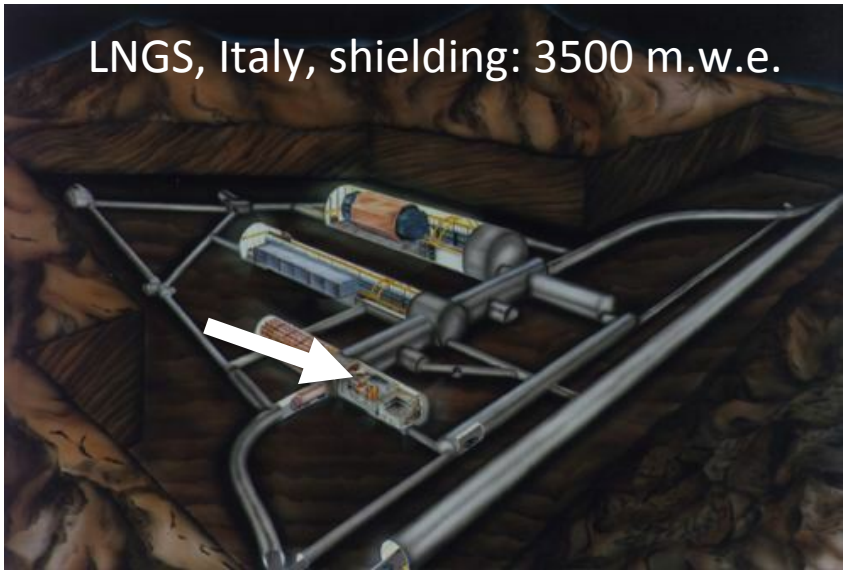


The CRESST Experiment

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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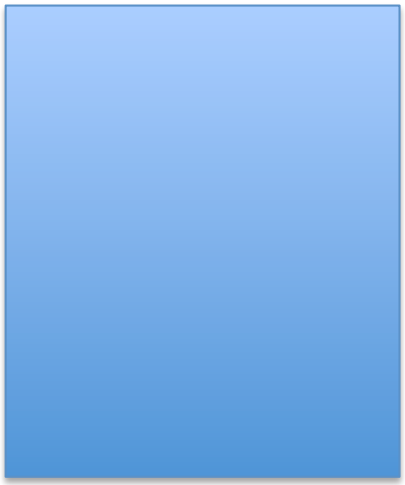
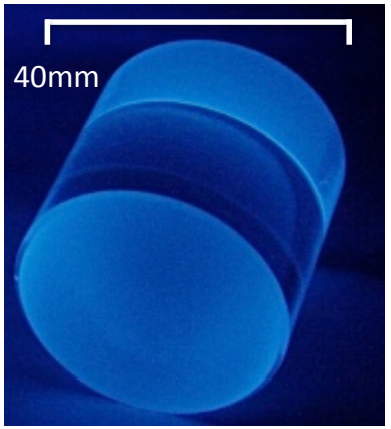


$CaWO_4$ Target Crystal

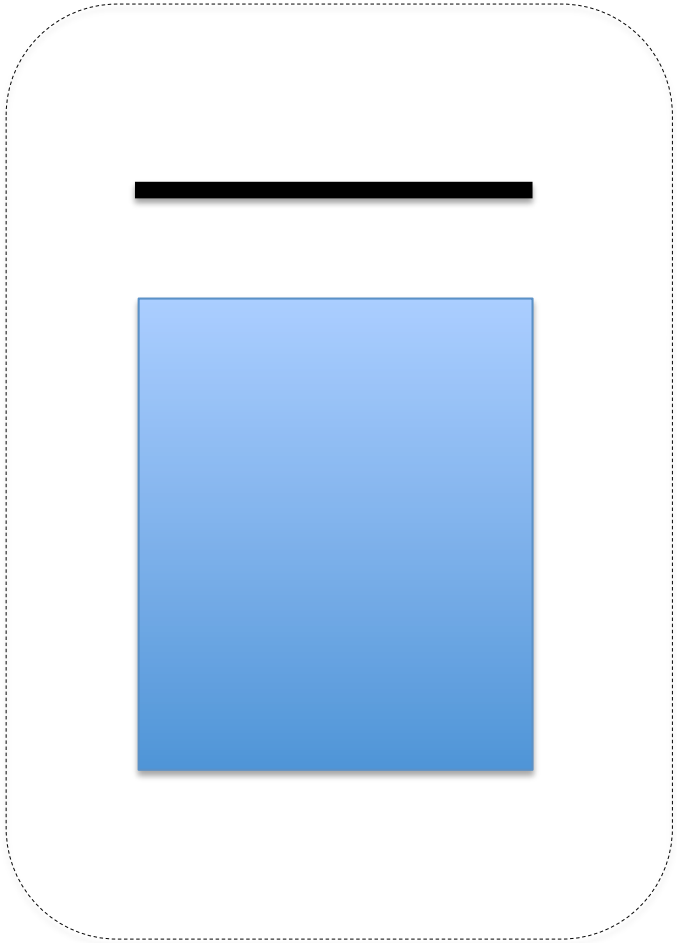


- scintillating
- multi-element target
- mass: 200 – 300 g

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

In-house production and processing at our institutes

The CRESST Detector Module

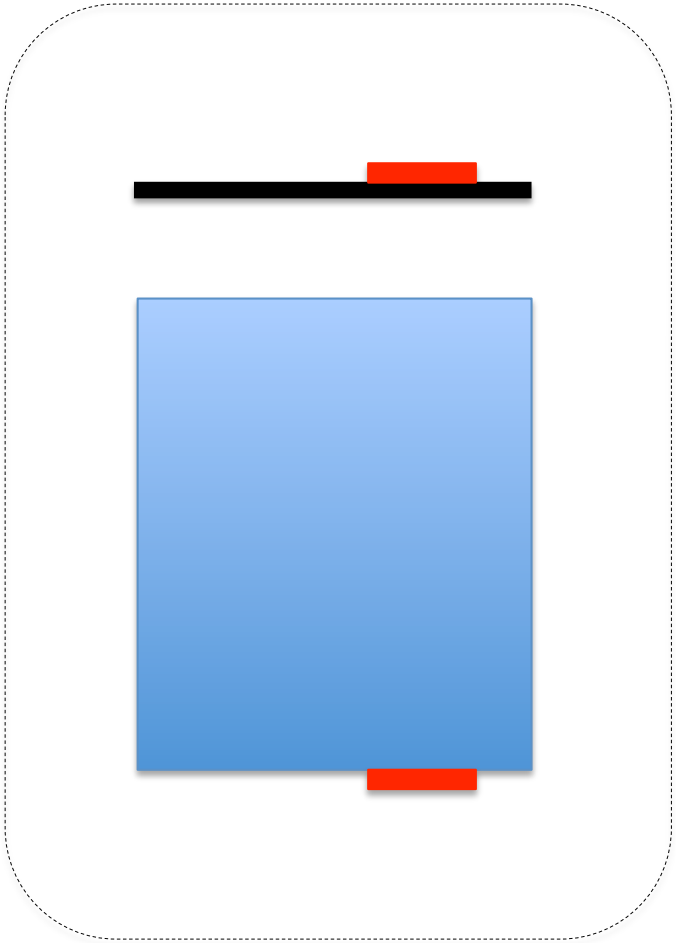


Light Absorber

for scintillation-light detection

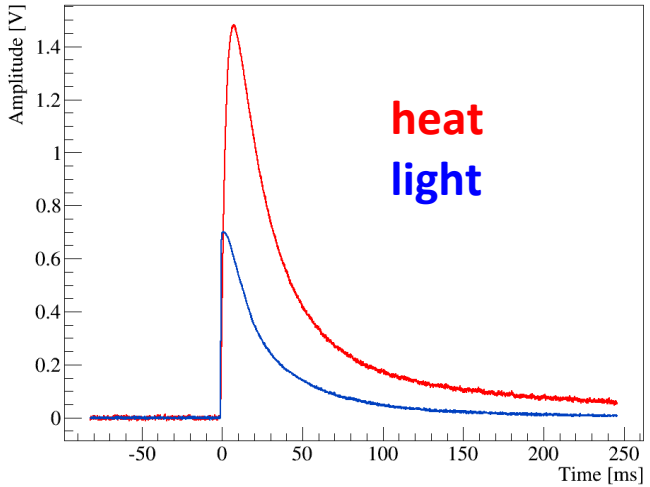
- silicon-on-sapphire disc
- diameter: 40mm
- thickness: 500µm

The CRESST Detector Module



Transition-**E**dge-**S**ensors

→ 2 independent calorimeters



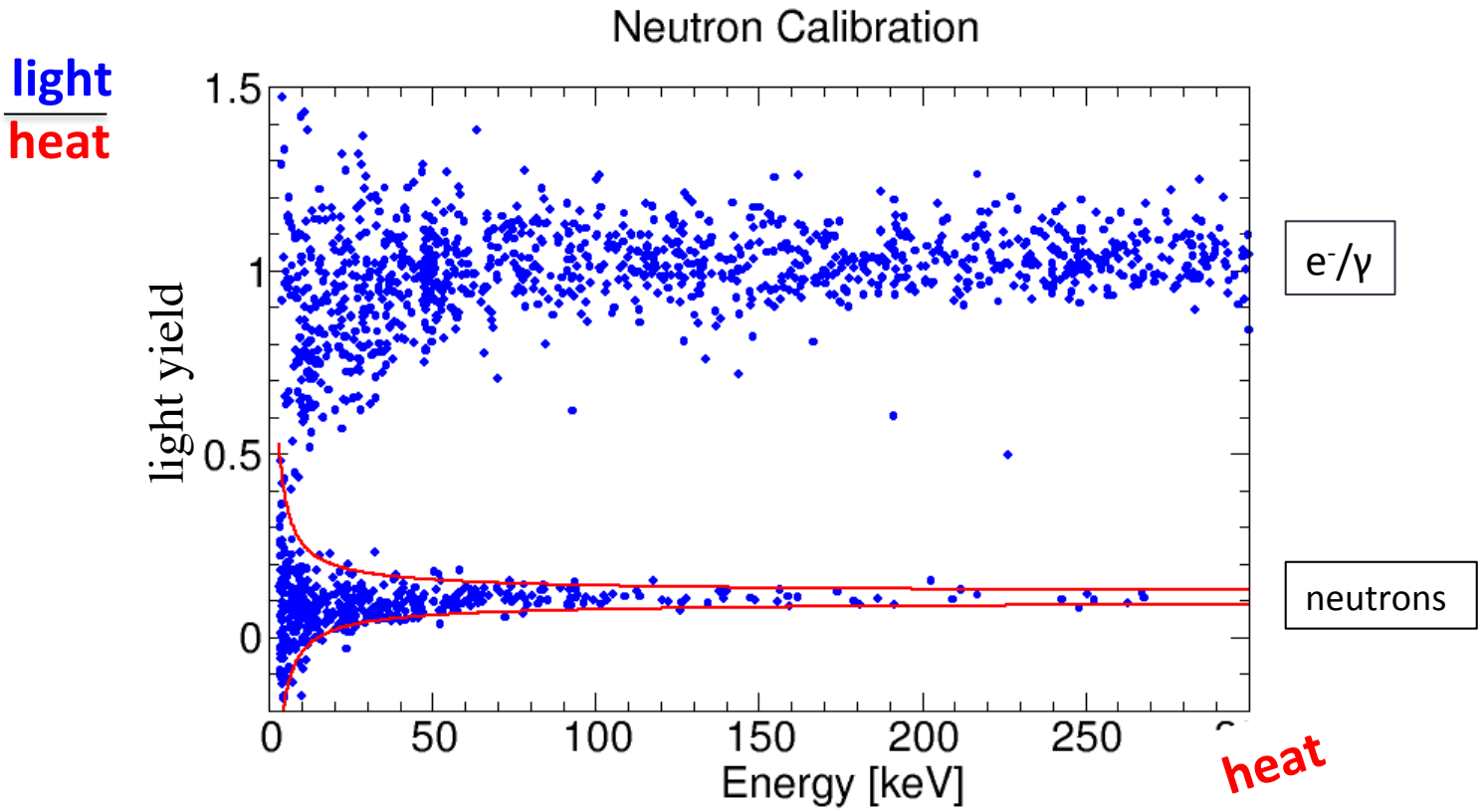
Phonon detector ($CaWO_4$)

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

Light detector (SOS)

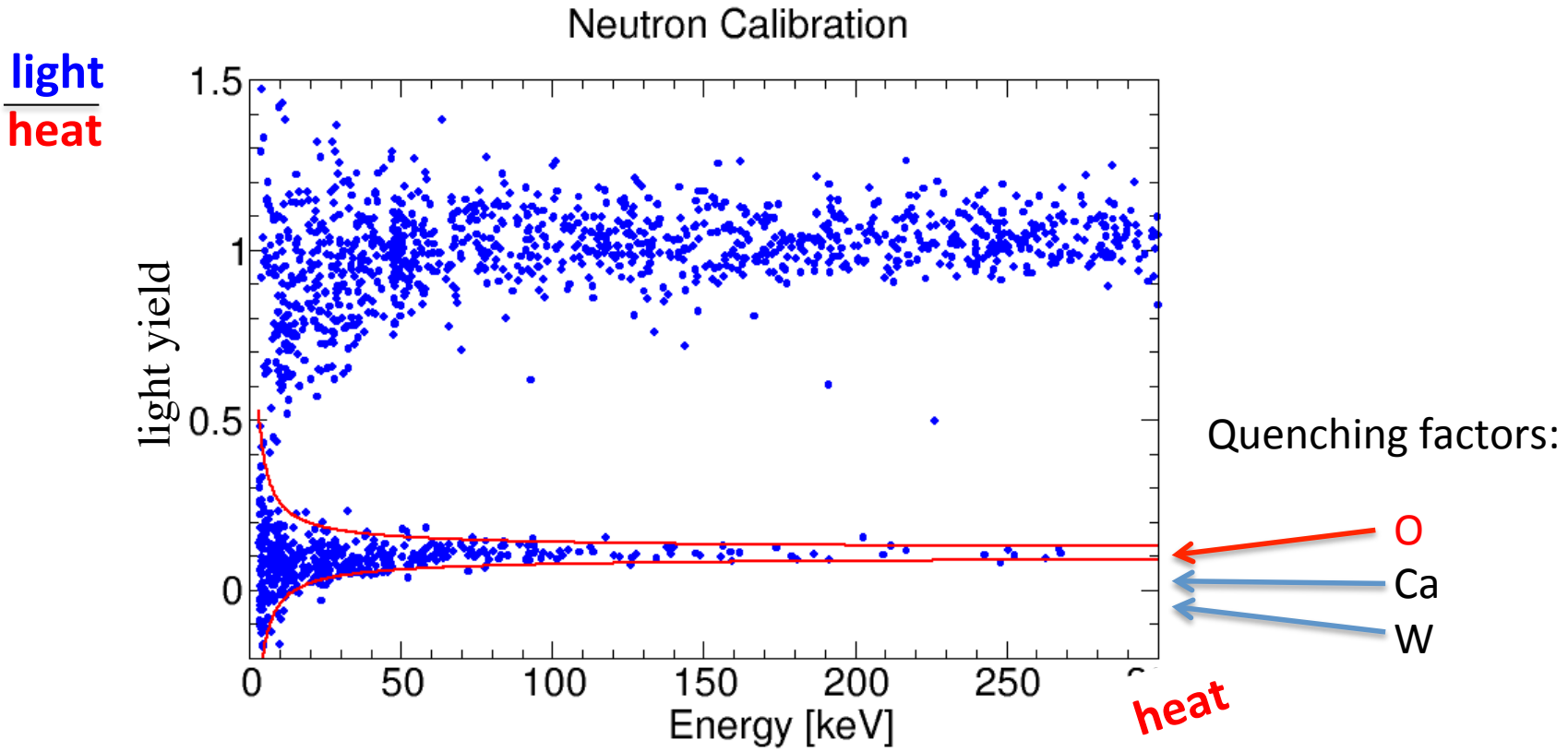
- Threshold $E_{th} \approx 5$eV

Phonon-Light Technique



Reduced light output for highly-ionizing particles ⟹ Quenching

Phonon-Light Technique



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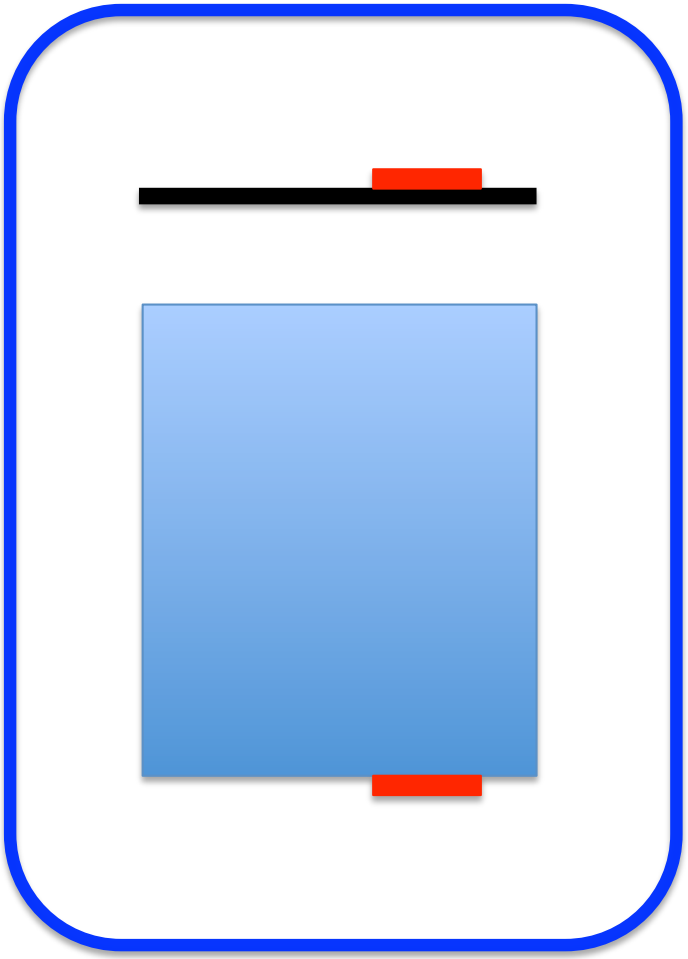


Polymeric Foil

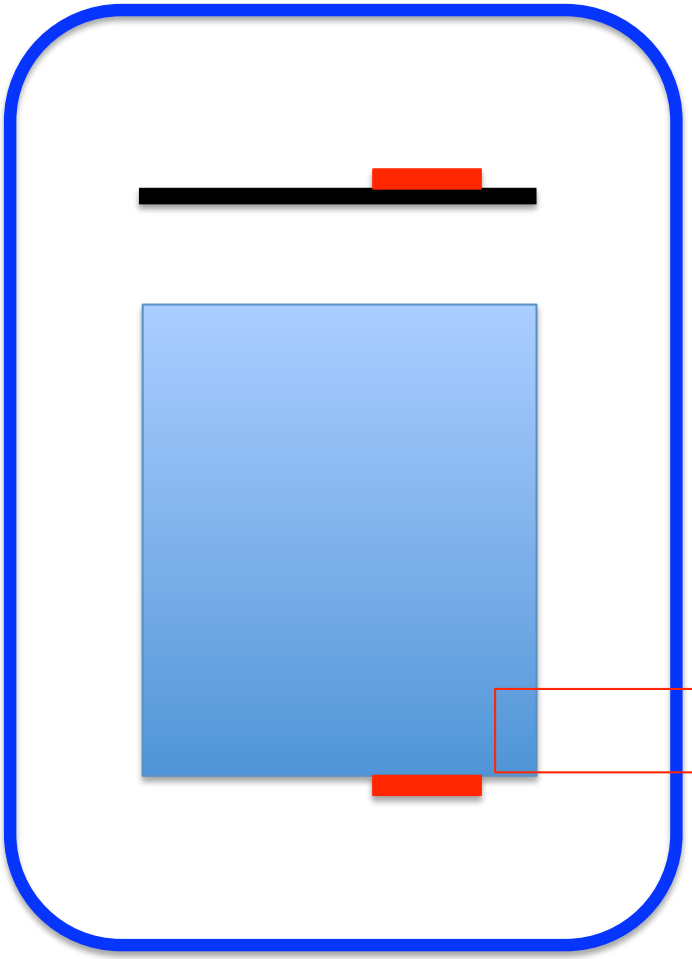
① Highly reflective

- ➢ light collection

② Scintillating

- ➢ rejection of surface events

The CRESST Detector Module



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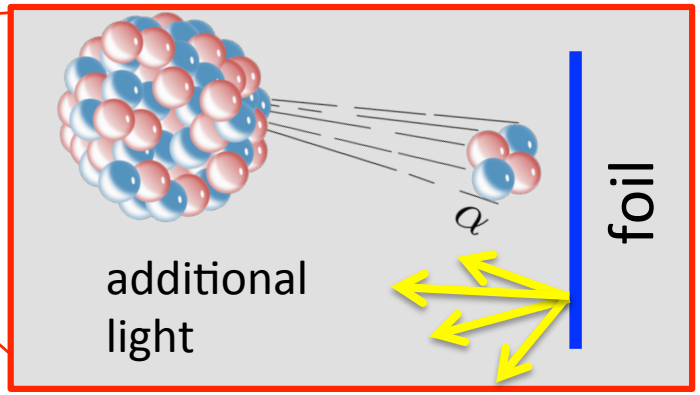

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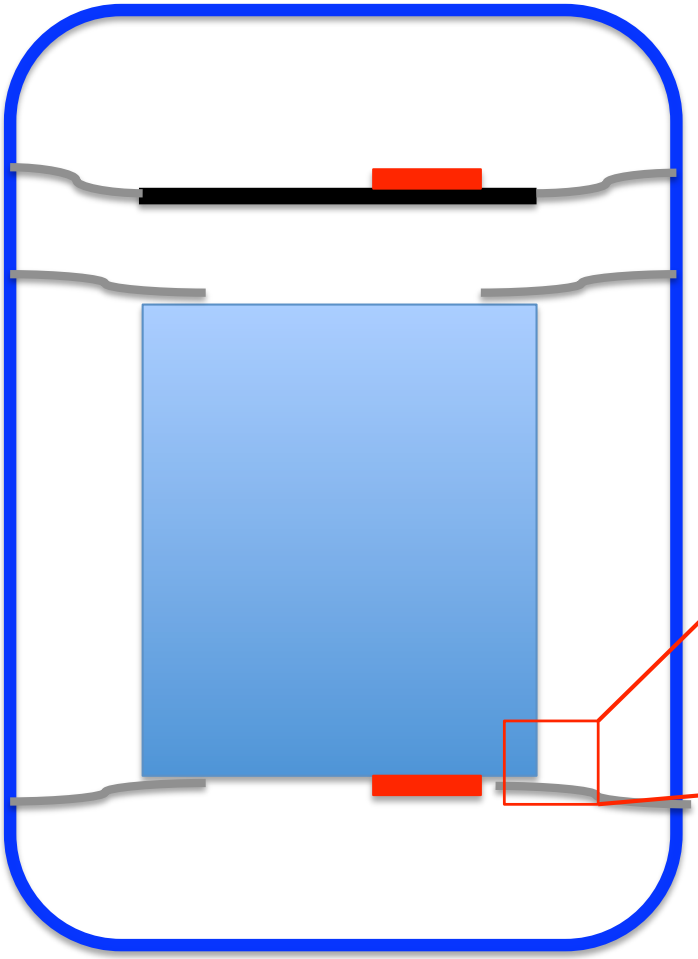
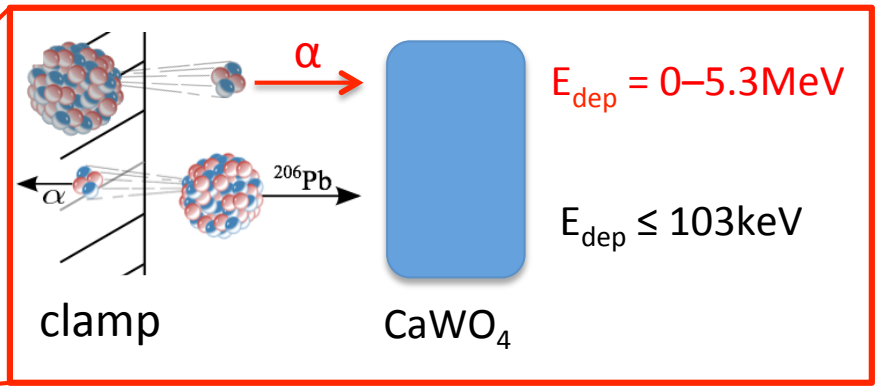


Dangerous Surface Backgrounds

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



→ Lead/alpha recoils can mimic WIMPs

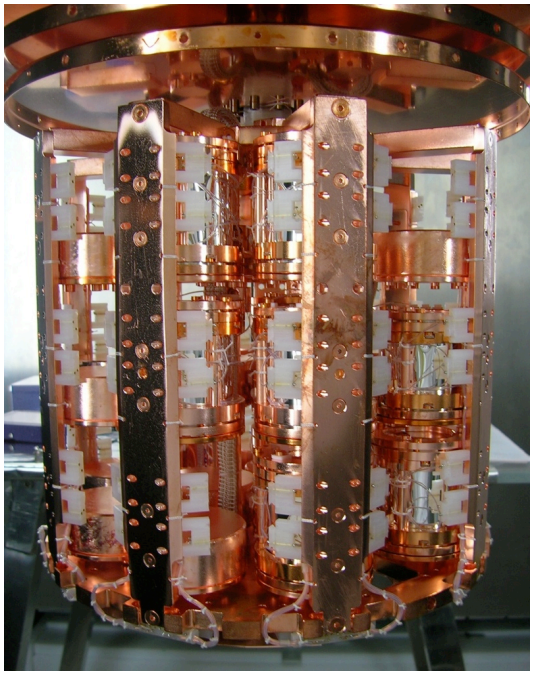
→ Avoid non-scintillating materials!

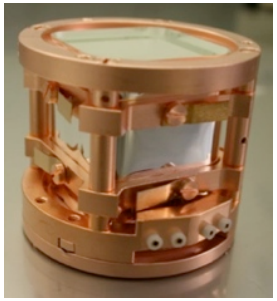
STATE-OF-THE-ART

CRESST II

Recently Finished – CRESST-II Phase 2

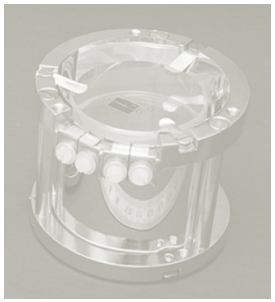
Data-taking from July 2013 to August 2015





2014 Results: "TUM-40"

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



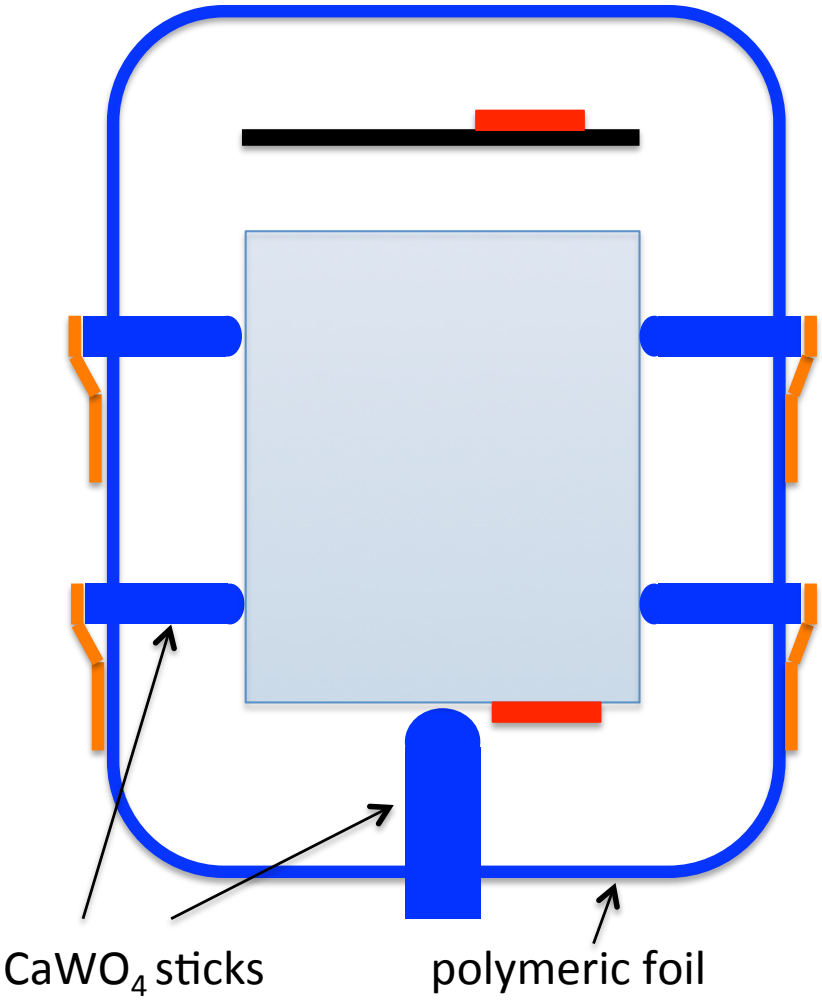
2015 Results: "Lise"

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

Final Data: Total exposure

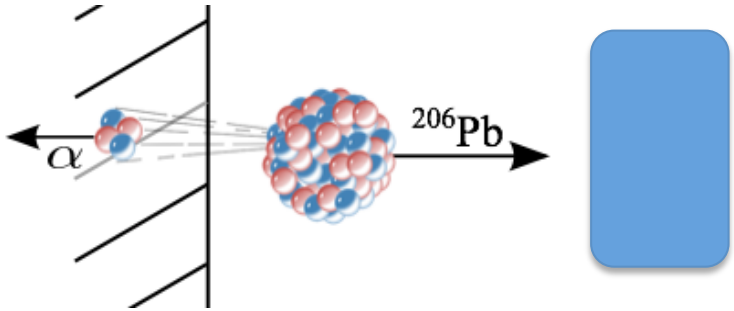
- About 500 kg-days acquired
- Data release end of 2015

“TUM-40”: New Detector Design



Polymeric foil + $CaWO_4$ sticks

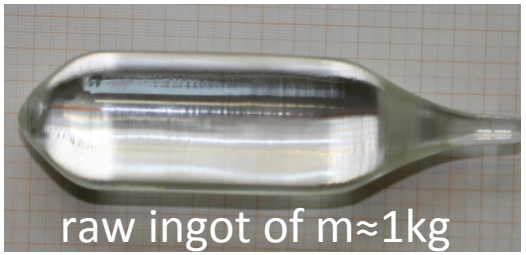
- Fully-scintillating detector housing
- Efficient rejection of surface backgrounds

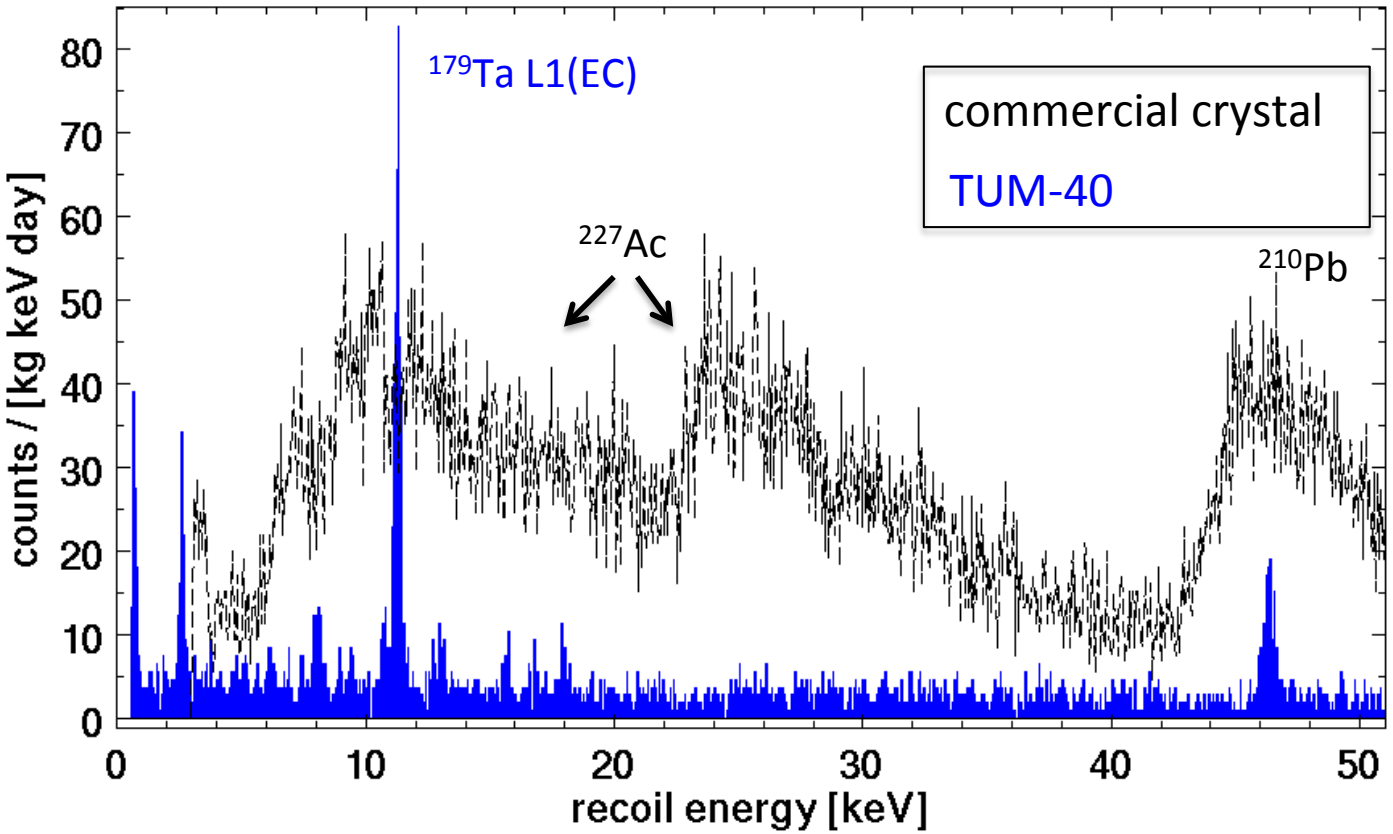


For details see recent publication:
R. Strauss et al. arxiv:1410.1753 EPJ-C (2015)

“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:
$\sigma \approx 90$eV
$\rightarrow E_{th} \approx 600$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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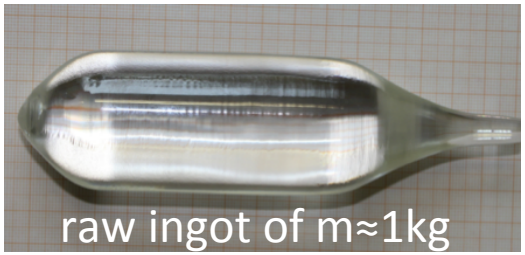

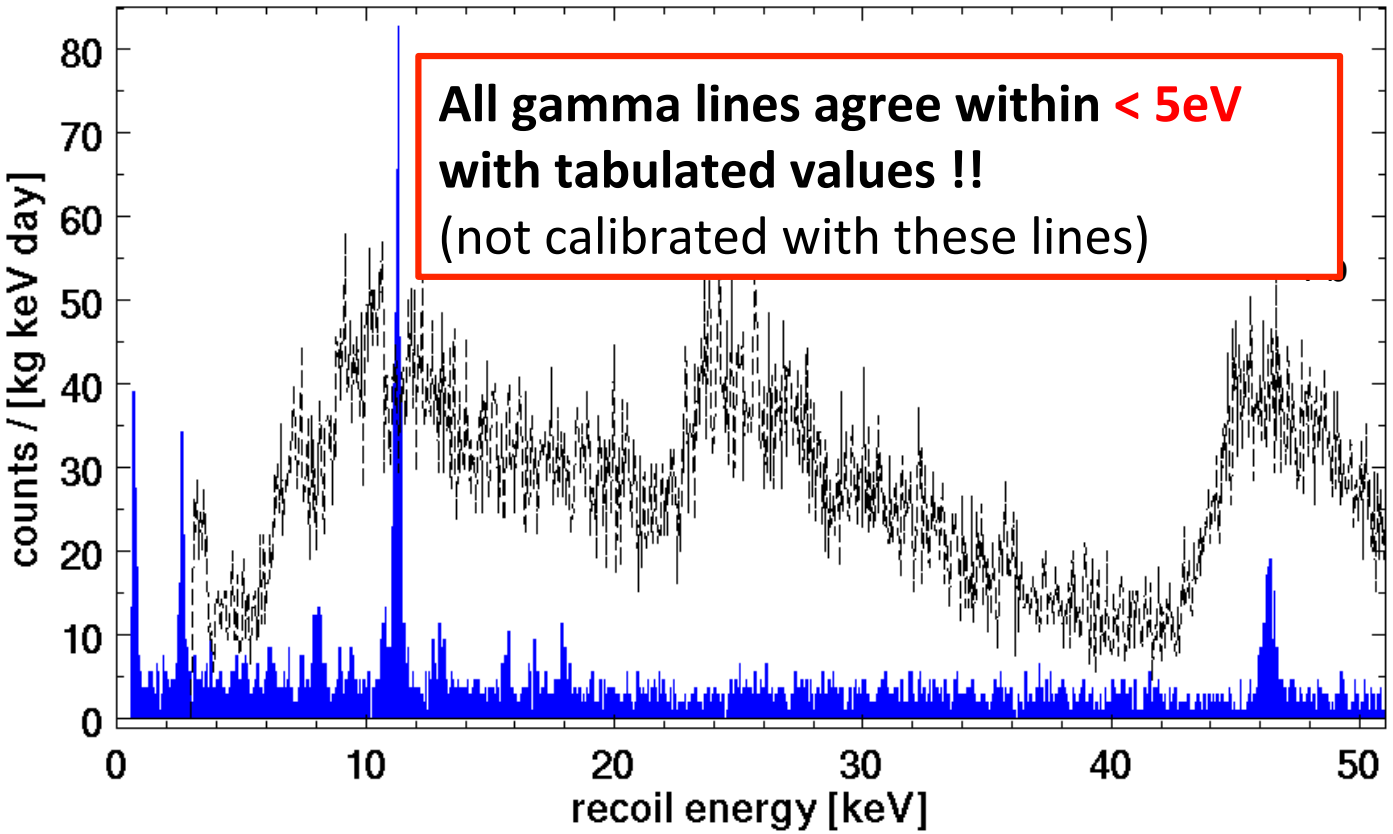

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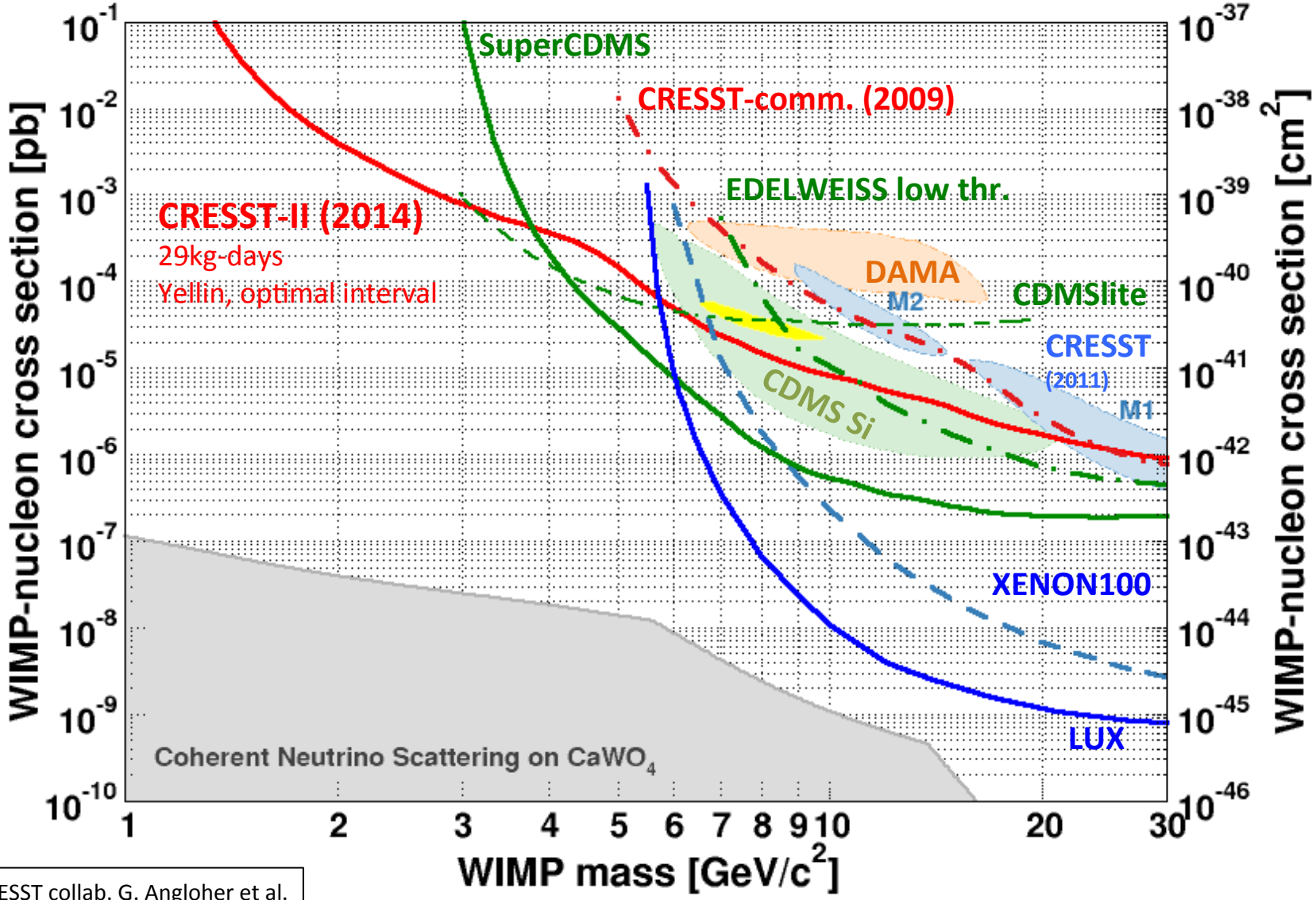
Status 2014: “TUM-40” Results



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Recently Finished – CRESST-II Phase 2

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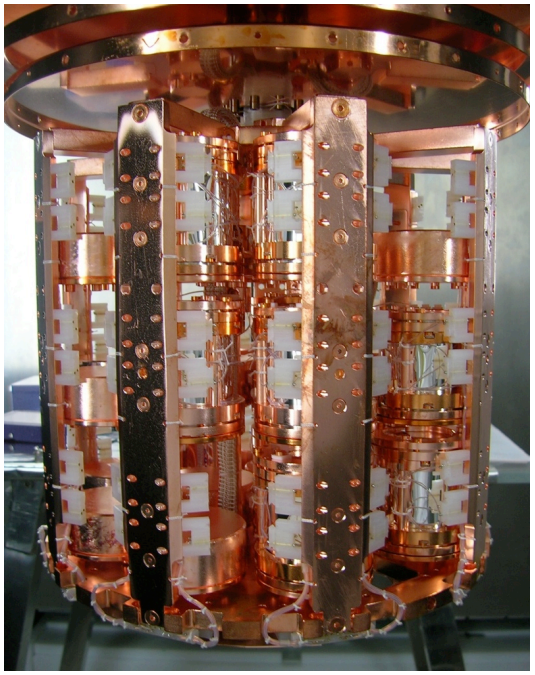

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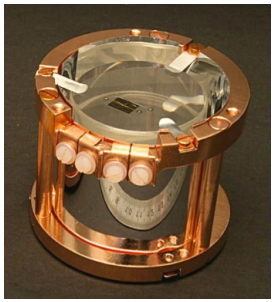

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Final Data: Total exposure

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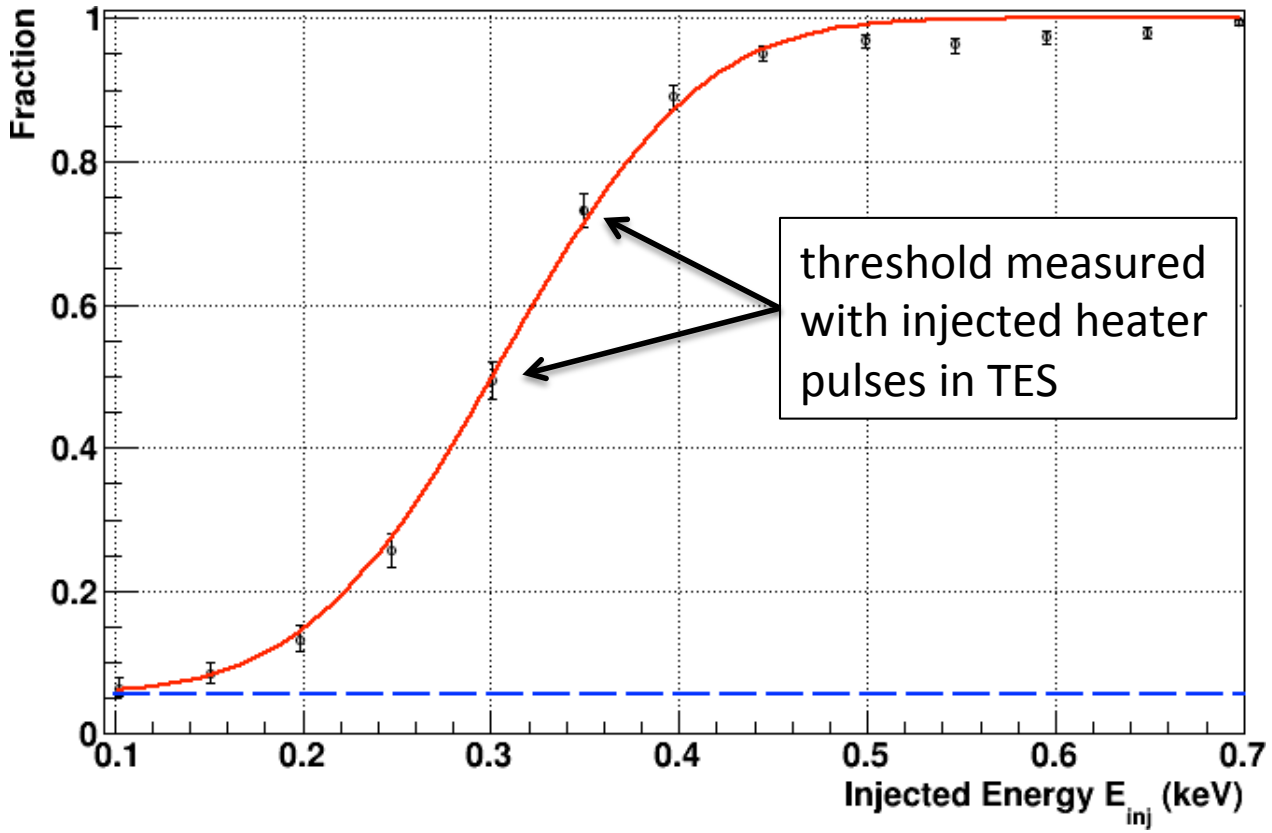
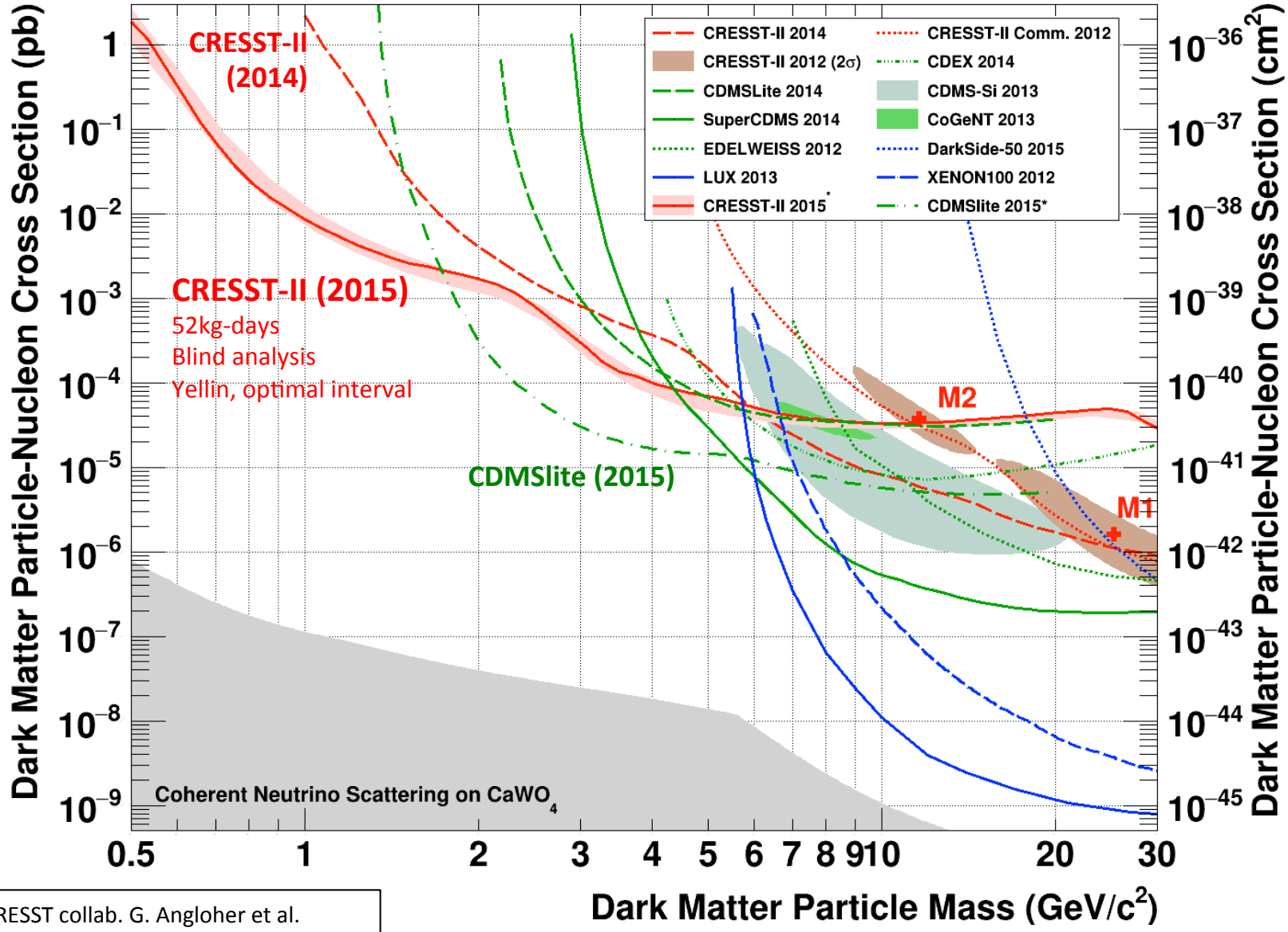
- Data release end of 2015

“Lise”: Trigger Threshold



Direct measurement of nuclear-recoil energy with calorimetric detector!

“Lise”: Results 2015



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

Recently Finished – CRESST-II Phase 2

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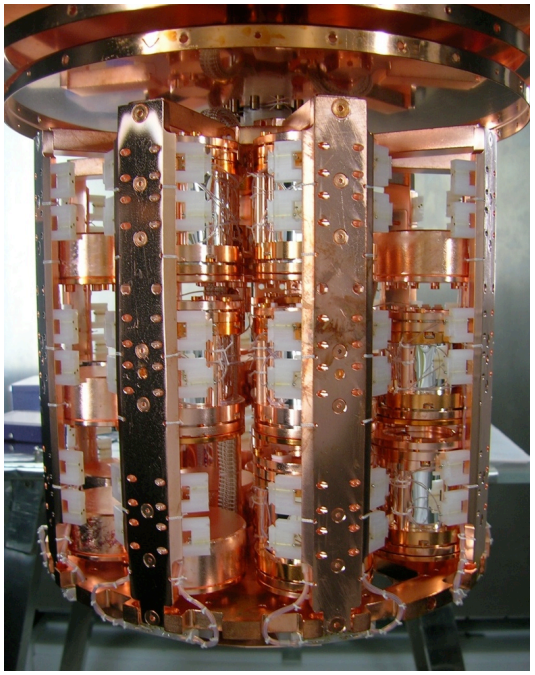

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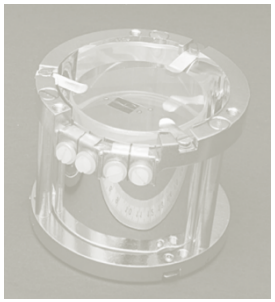


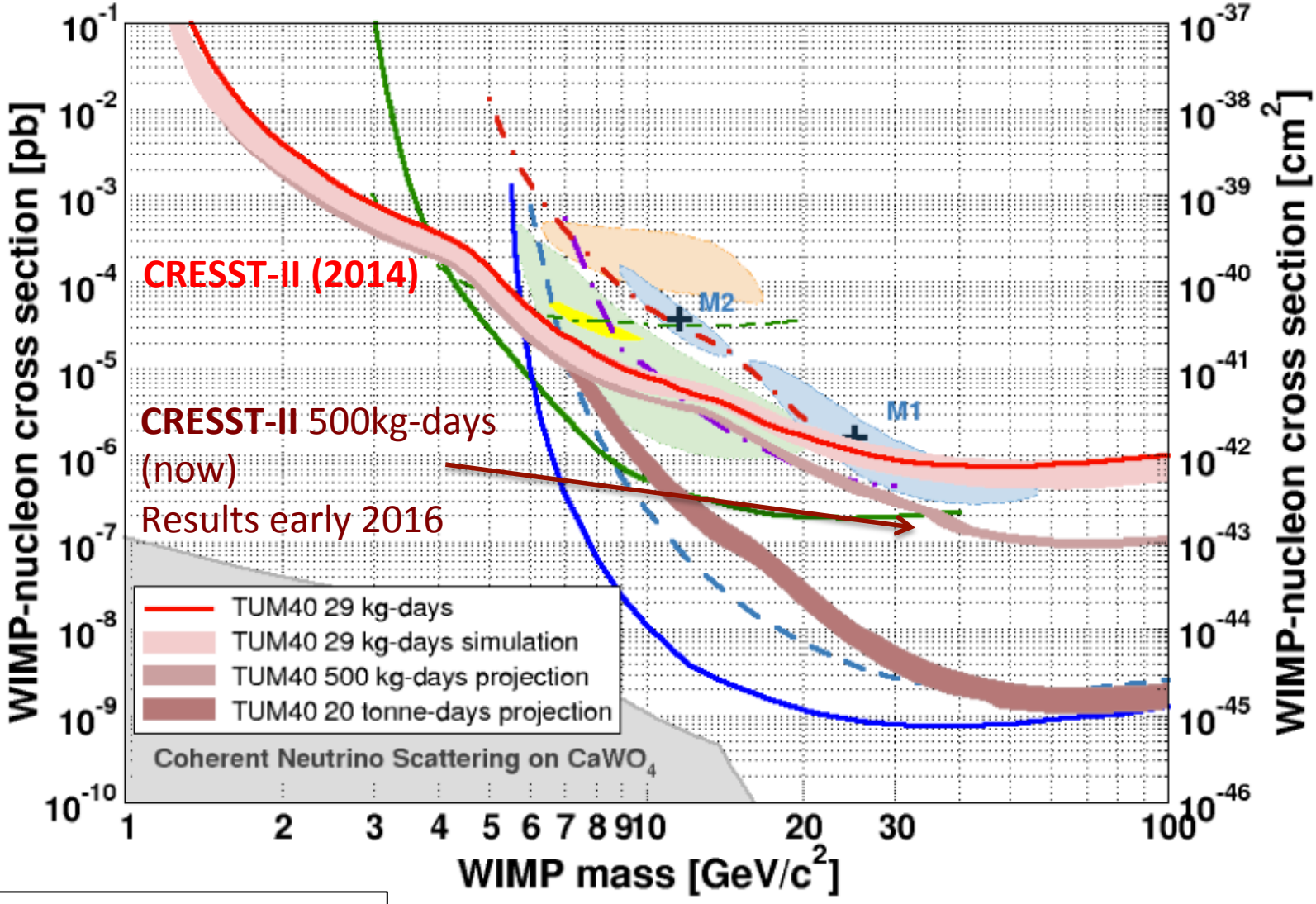
2015 Results: "Lise"

- No surface rejection
- Lowest threshold
- Factor ~2 more higher background

Final Data: Total exposure

- About 500 kg-days acquired
- Data release early 2016

Final Data Release: Projections

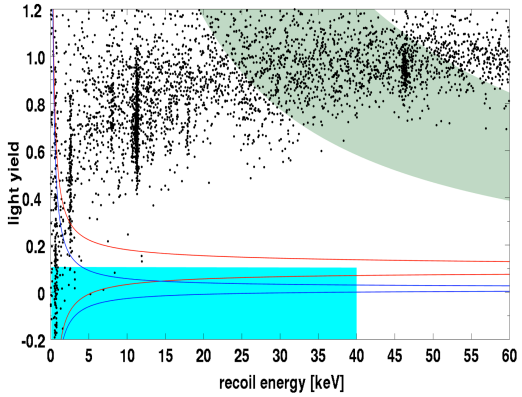


G. Angloher et al. arXiv:1503.08065

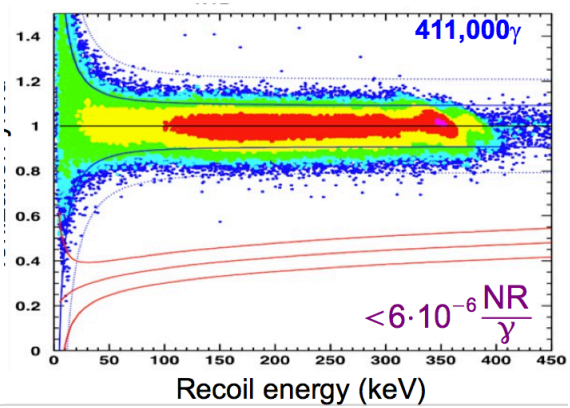
A Remark...

Search for standard (high-mass) WIMPs:

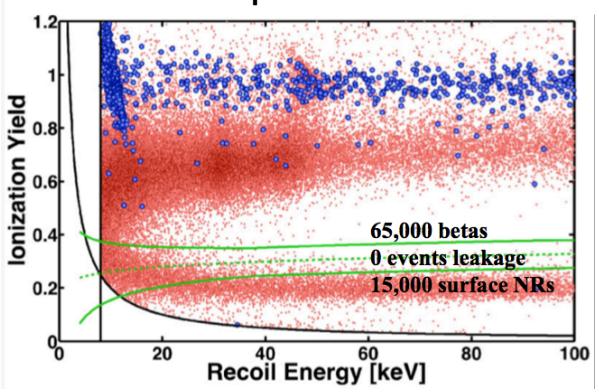
CRESST-II



EDELWEISS-III

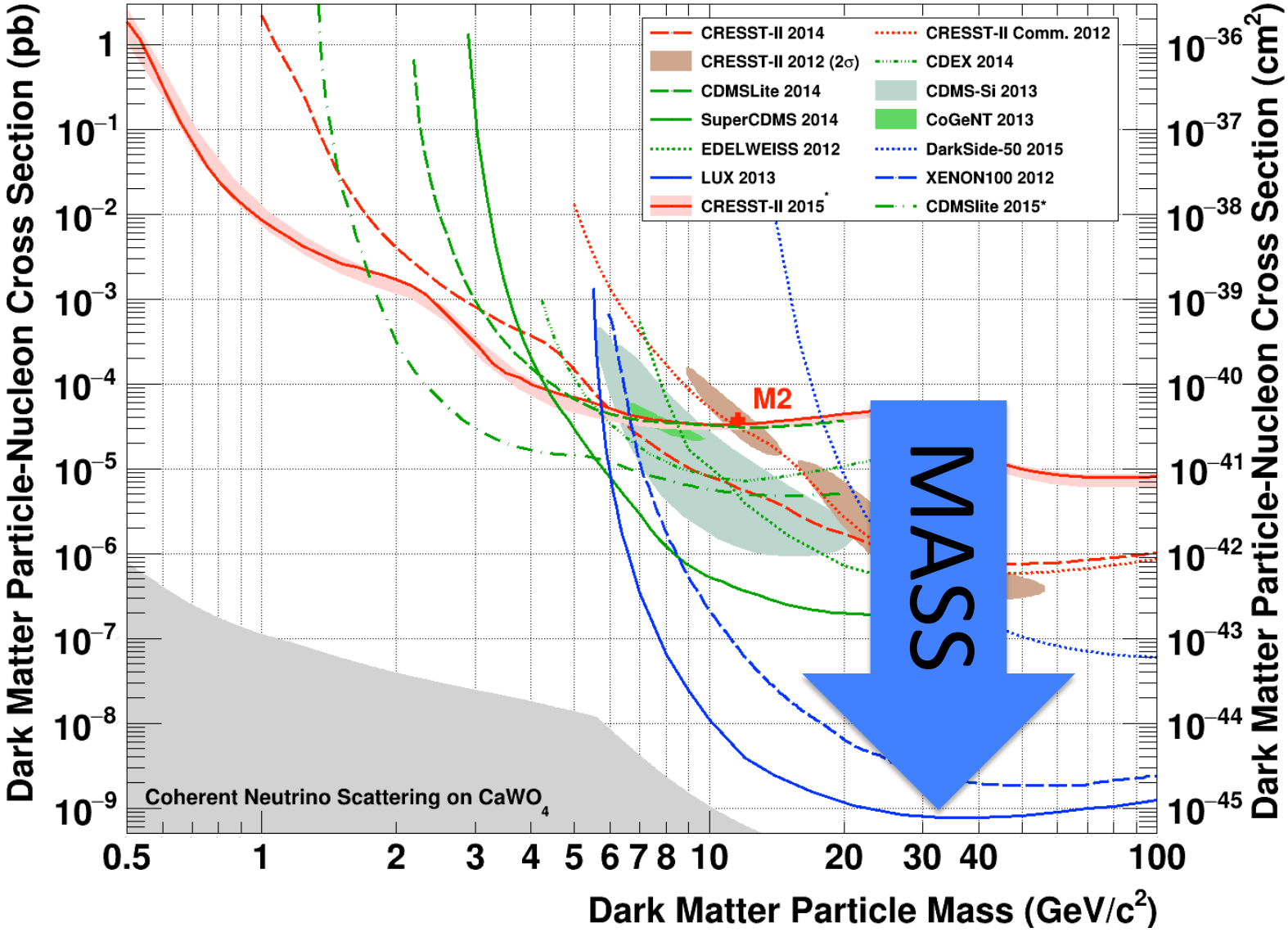


SuperCDMS



- background-free technology (above ~15keV)
- Ton scale feasible

Future of Dark Matter Searches



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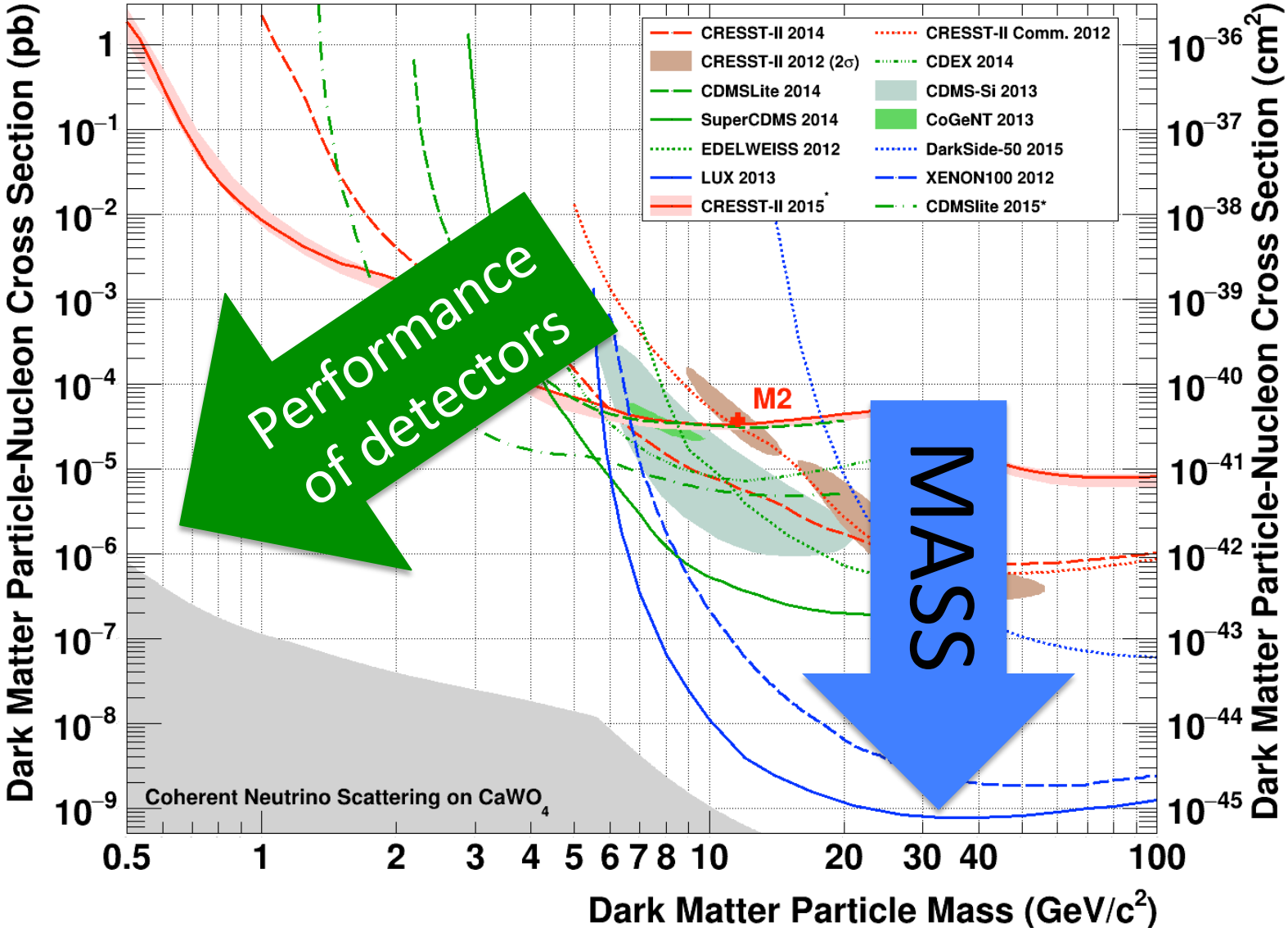


NEAR FUTURE

CRESST III

CRESST-III: Low-Mass Dark Matter 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 Dark Matter 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

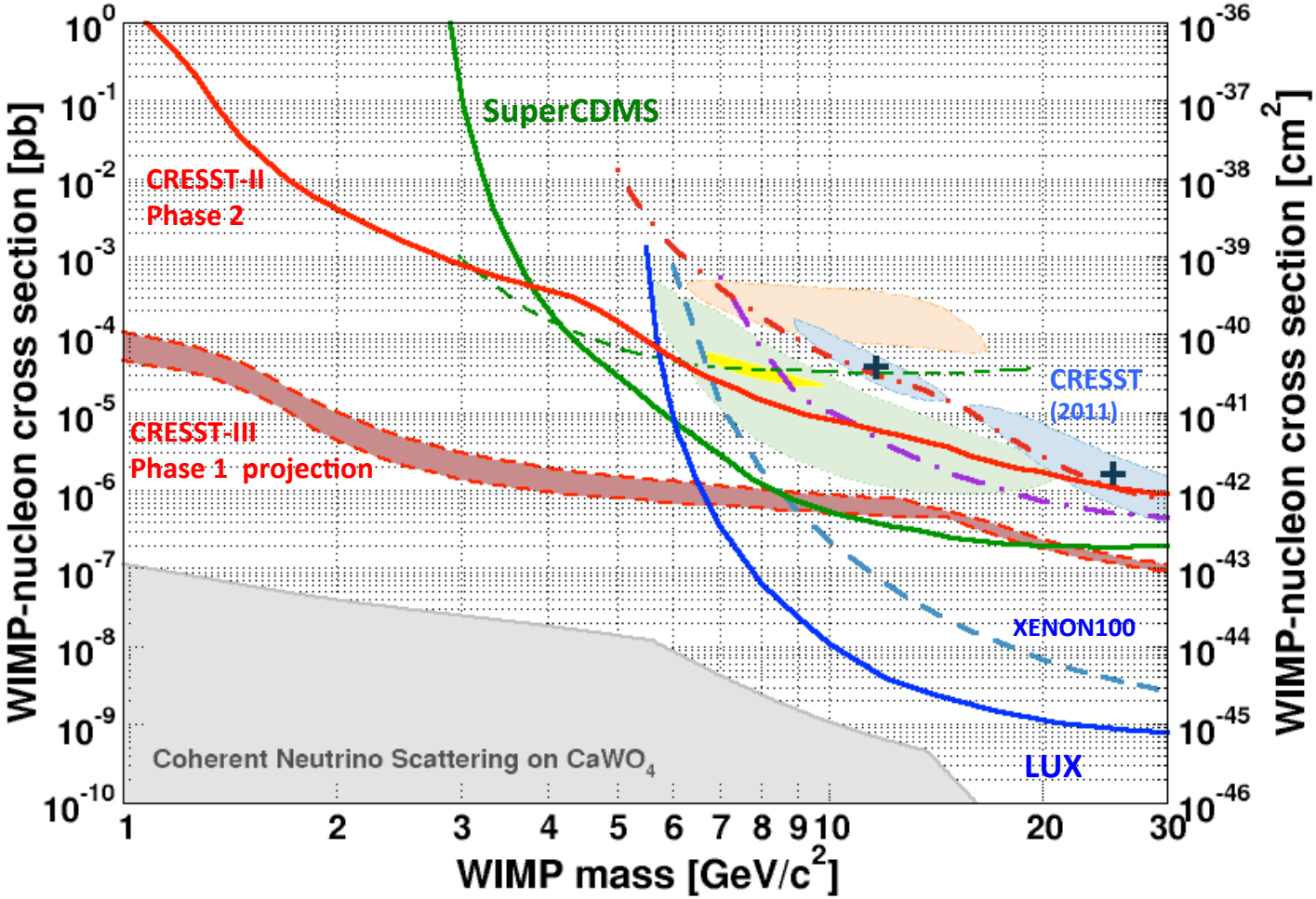
Phonon threshold: $E_{th} \lesssim 500$eV **improvement by a factor of 5-10**

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

CRESST-III Phase 1

Assumptions:

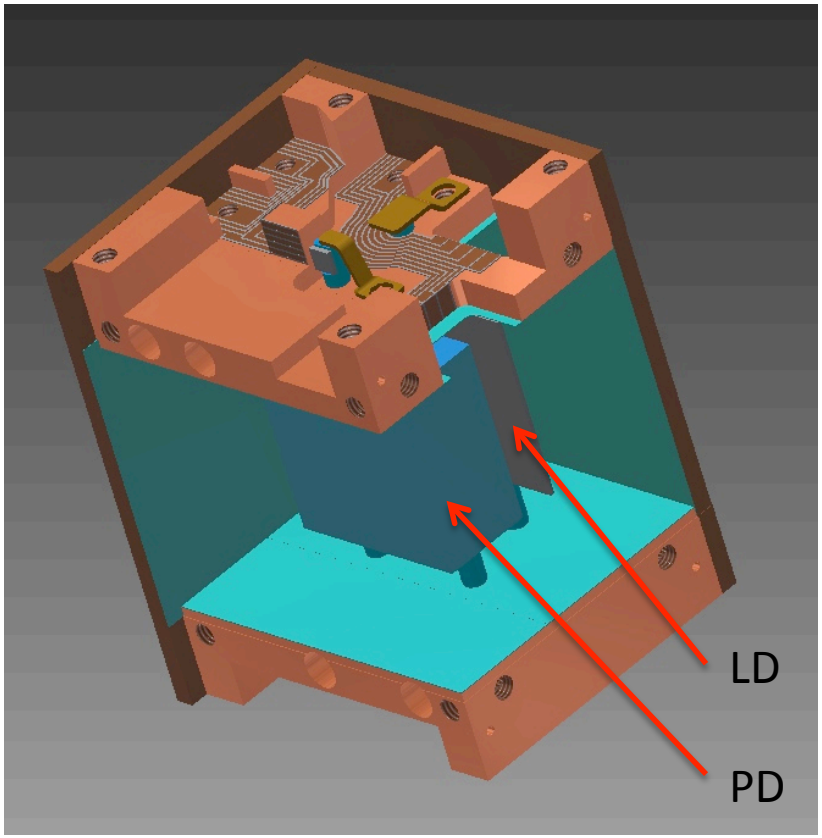
- 24g $CaWO_4$ crystal
- **E_{th} = 100eV**
- Light detector improved by factor 2 (due to smaller volume)
- 2x more detected light: due to thin crystal
- **CRESST-II radiopurity**

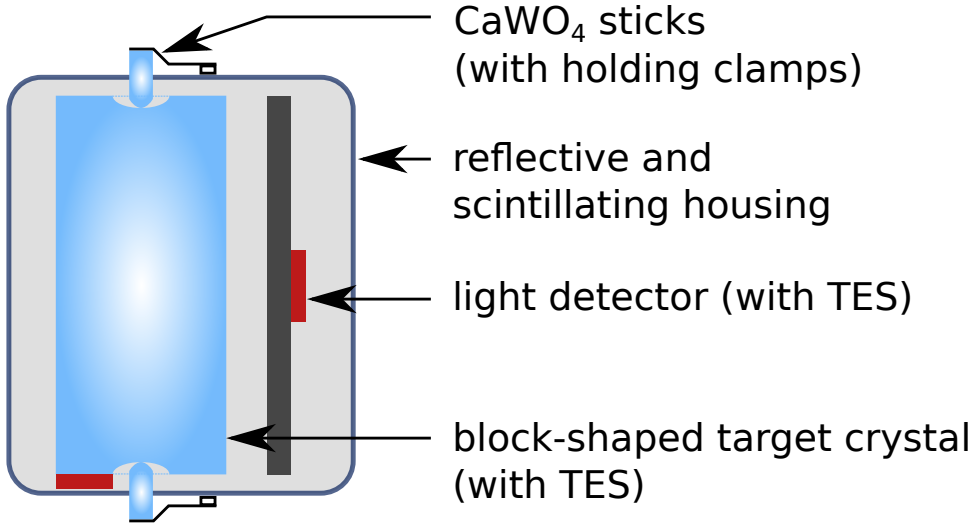


10 x 24g detectors operated for one year ≈ **50 kg-days** (net)

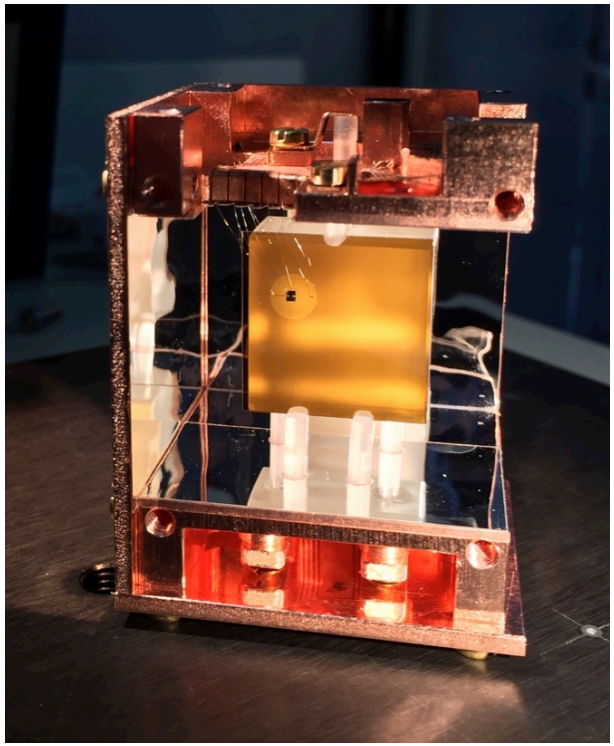
See: CRESST collab. G. Angloher et al. arXiv:1503.08065

CRESST-III Detector Prototype

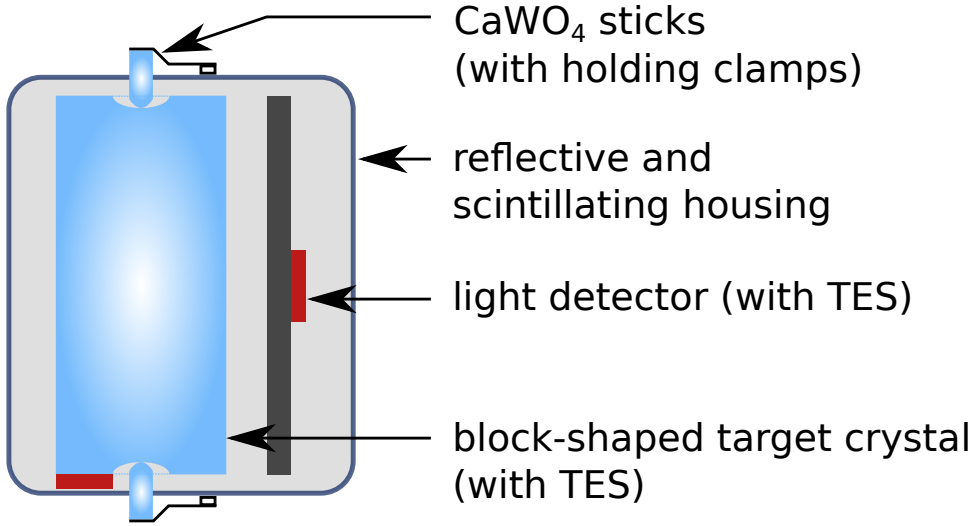




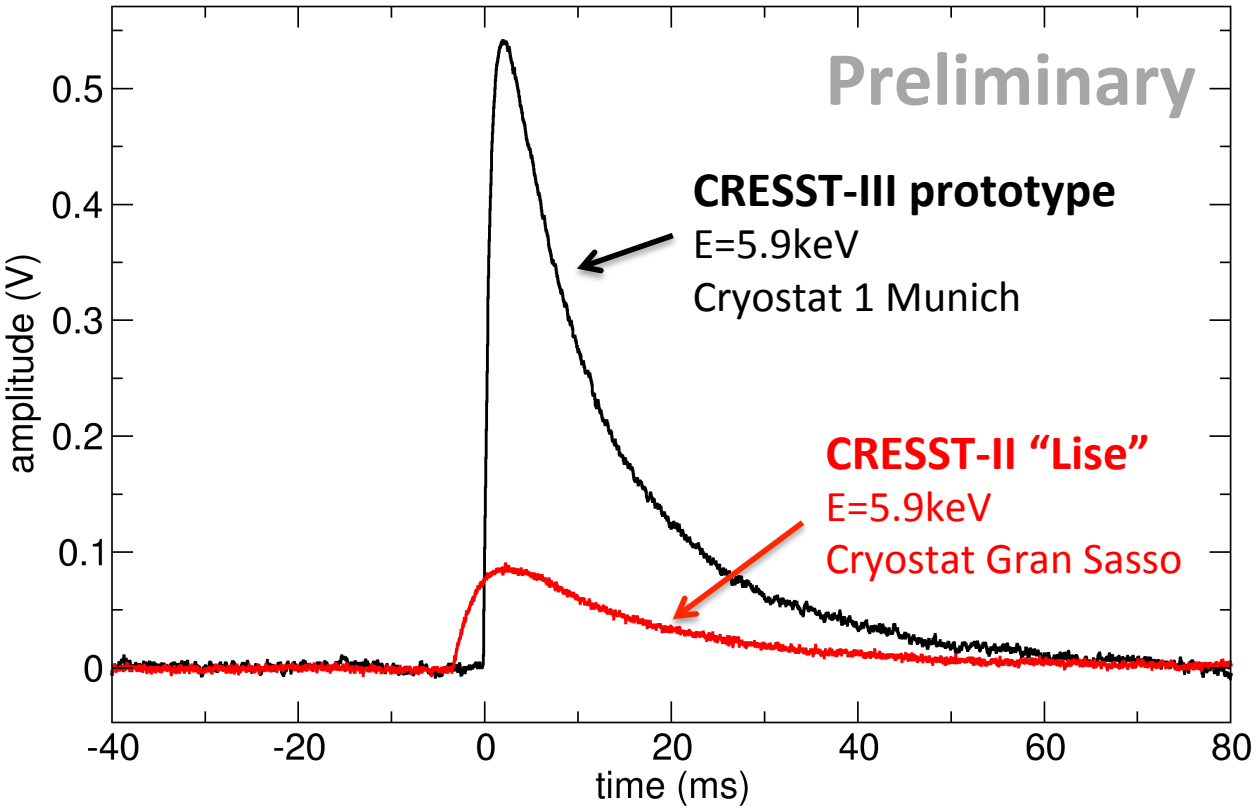
CRESST-III Detector Prototype



First modules ready



First Results of CRESST-III Detector



Promising results:

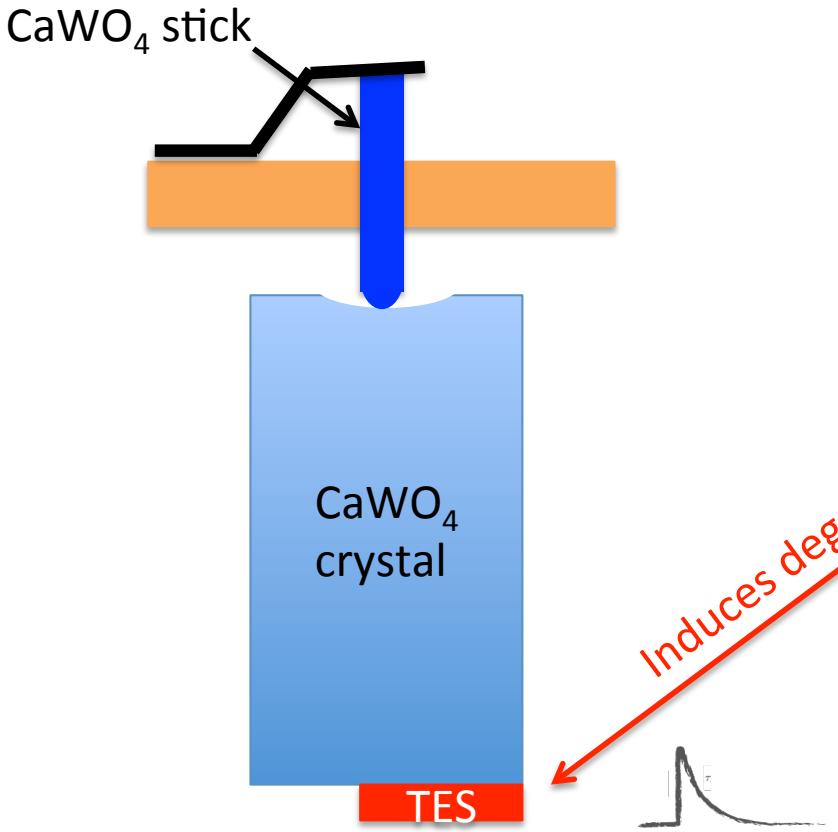
Improvement by **factor 6.2** compared to best CRESST-II detector (E_{th} = 298eV)

→ 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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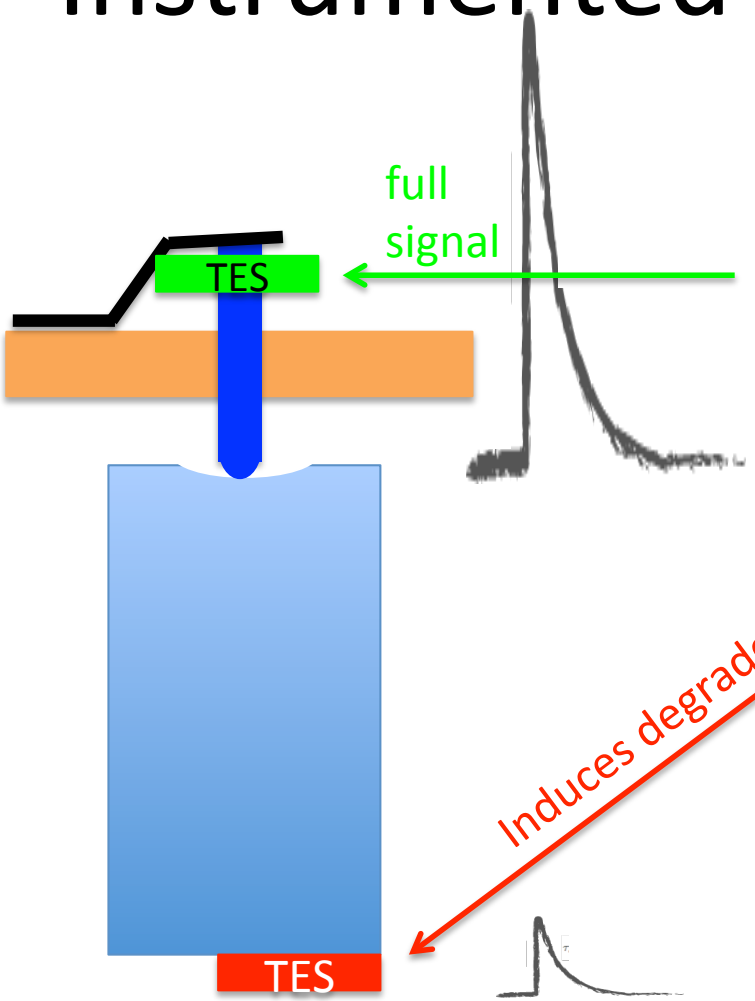

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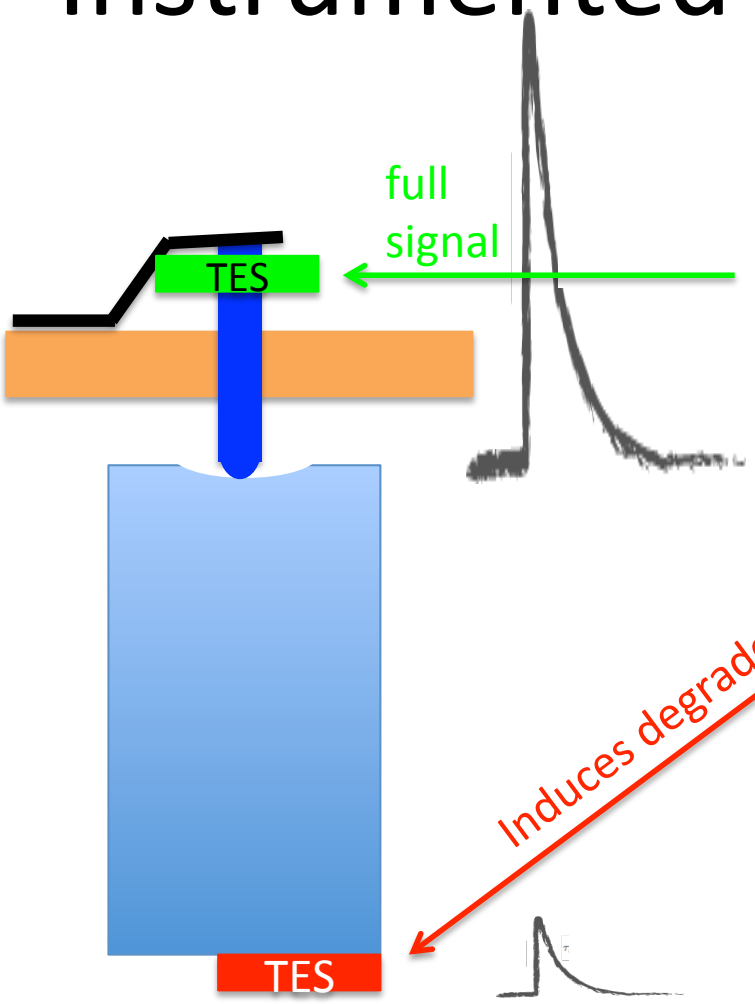

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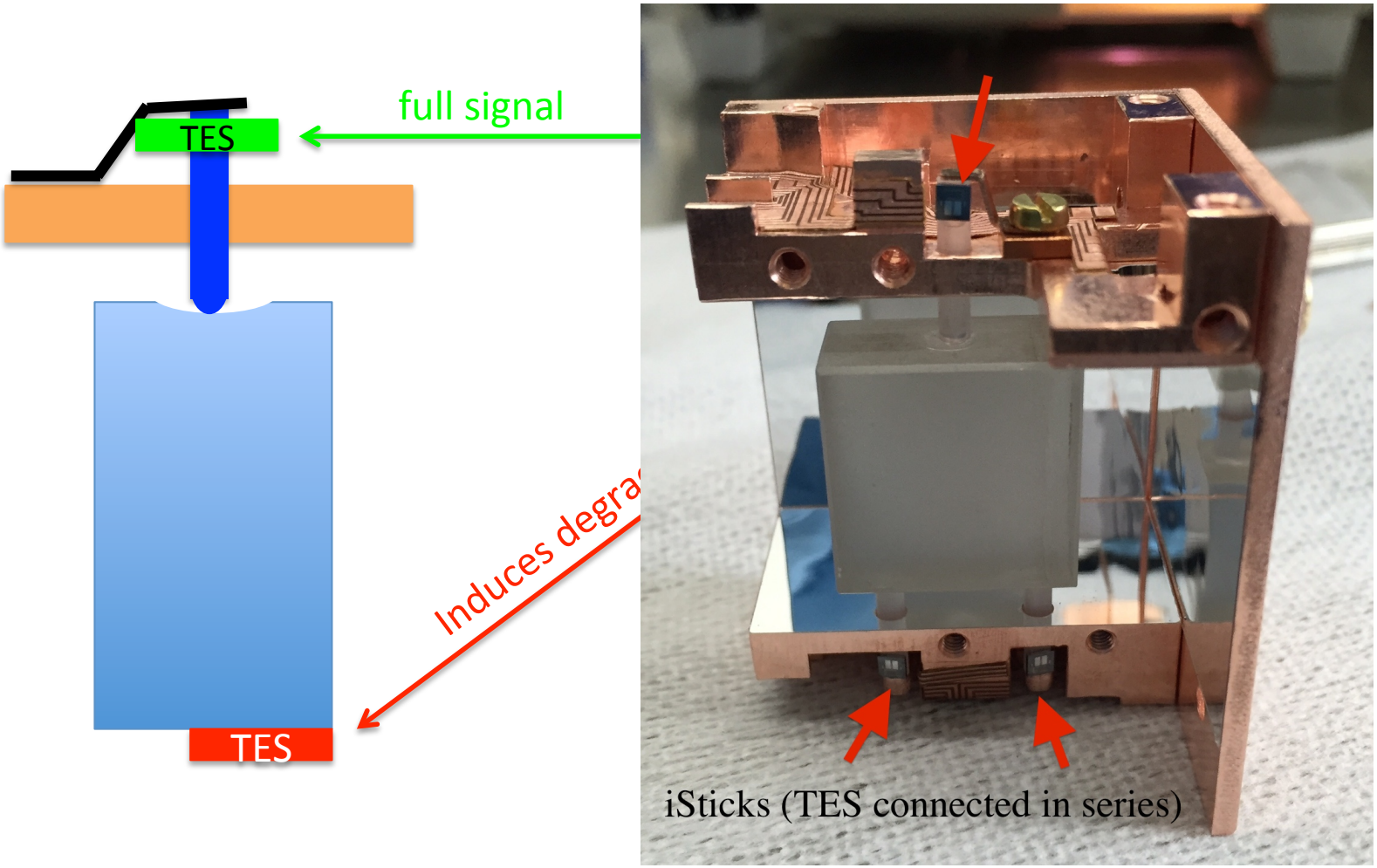
- Stress relaxations
- …

Induces degraded signal

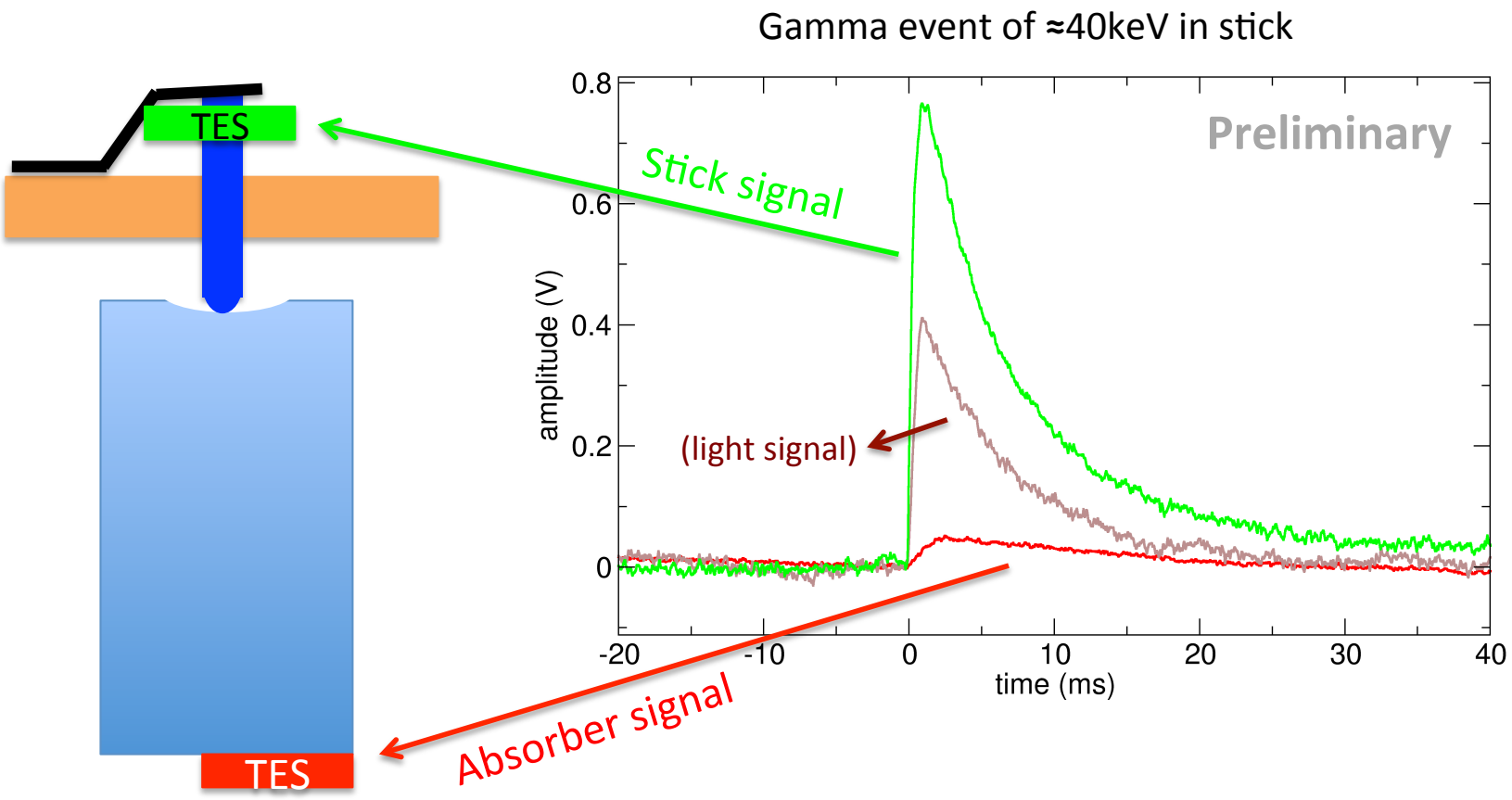
ratio $\frac{\text{stick}}{\text{absorber}}$

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

Instrumented Holder - iSticks



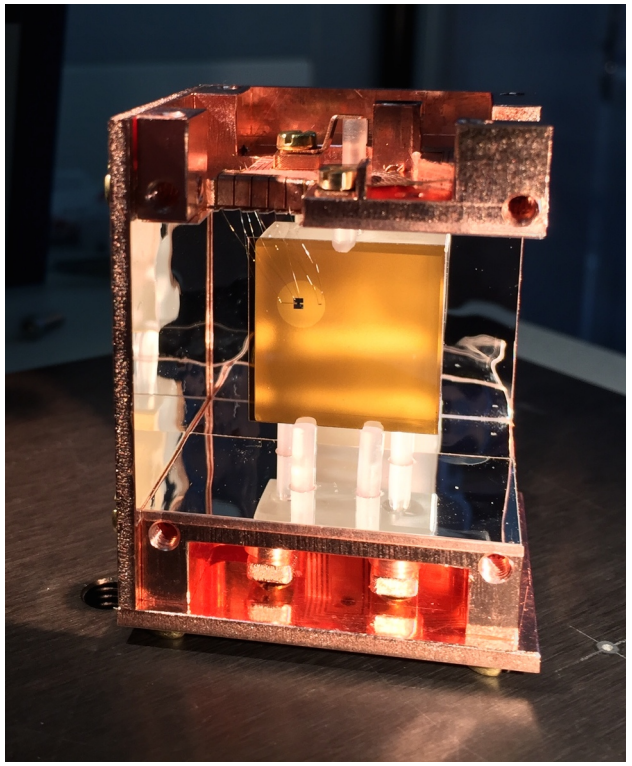
Instrumented Holder - iSticks



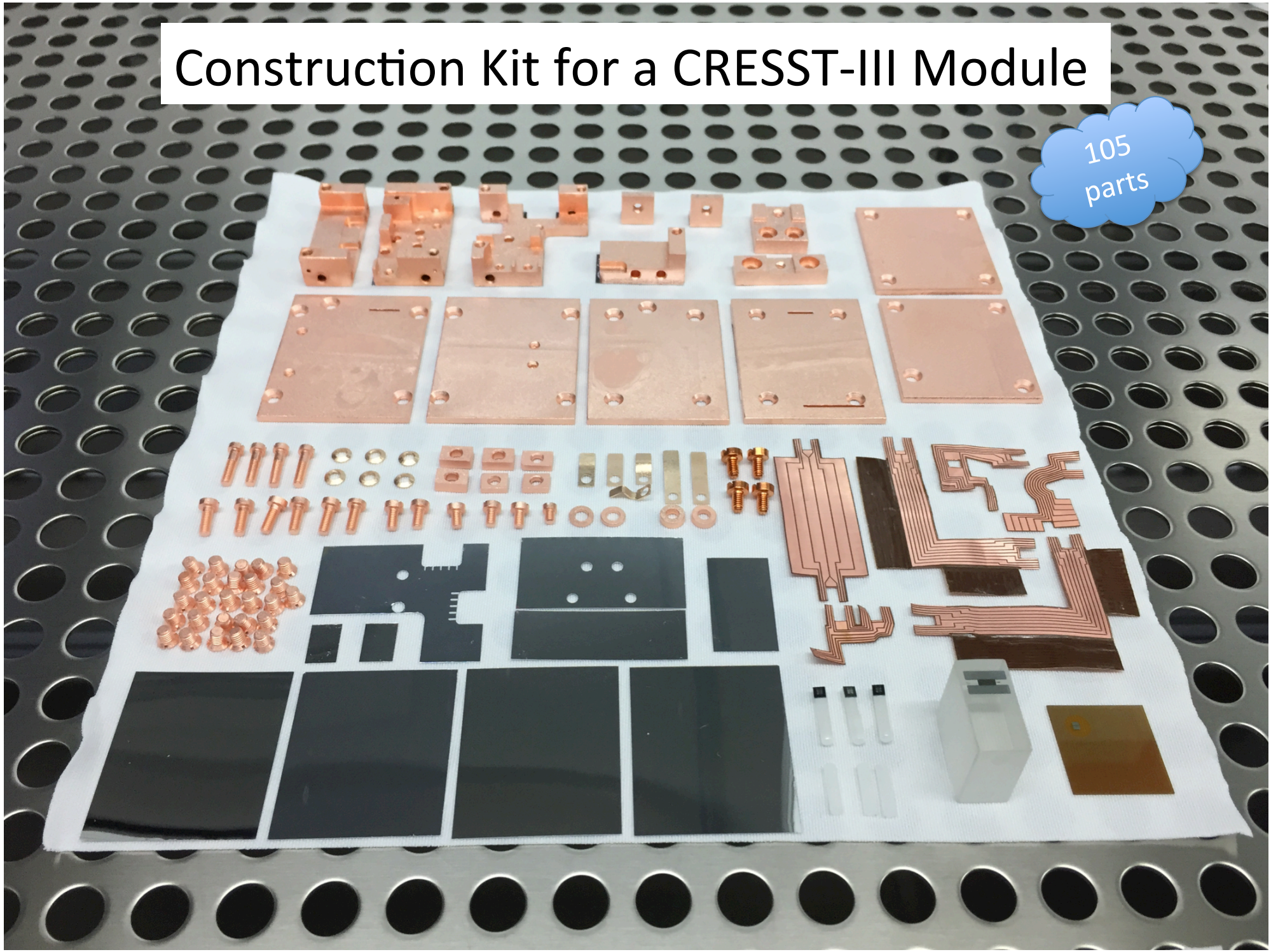
Timeline for CRESST-III

Phase 1:

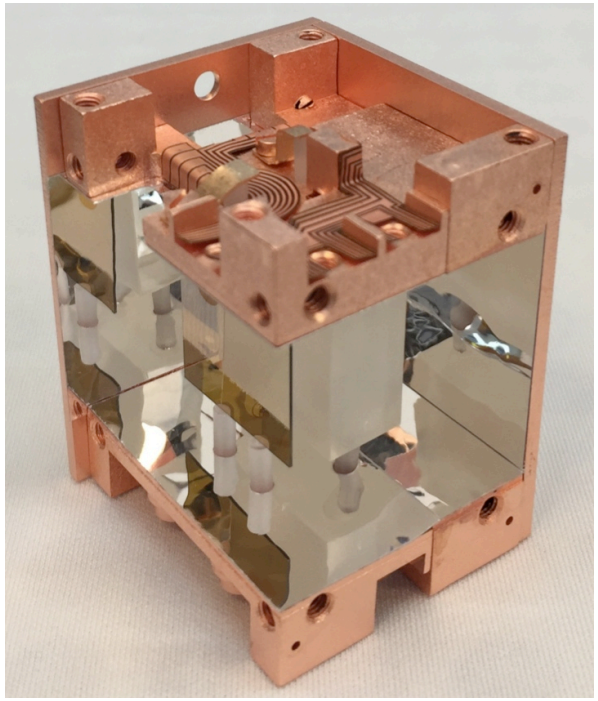
- Production of ~ 15 modules ongoing
- All parts ready by now
- Assembly ongoing
- Mounting Jan/Feb 2016
- **Start Feb 2016**

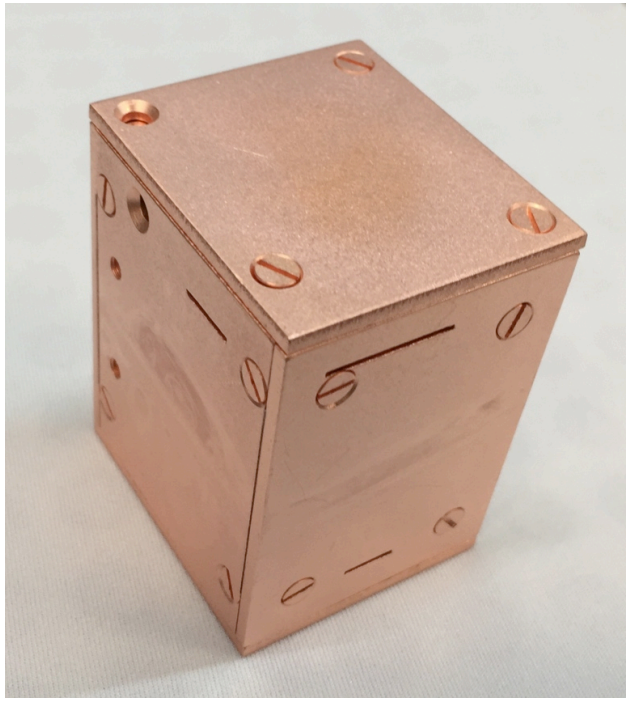


Construction Kit for a CRESST-III Module



Assembly in Progress…





New dedicated cleanroom for CRESST-III at MPI Munich

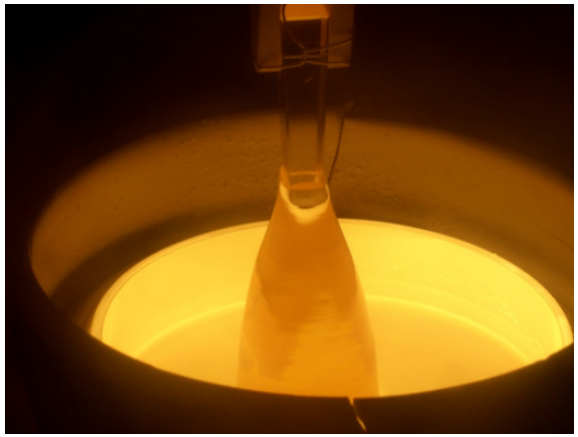
Very recently: first module for CRESST-III phase 1 ready

Special thanks to:
Dieter Hauff, Marc Wüstrich, Nahuel Ferreiro, Anja Tanzke, Johannes Rothe (MPI) + MPI workshop
Andrea Münster, Andreas Erb, Stephan Wawoczny, Michael Stanger (TUM)

Next Step

CRESST-III PHASE 2

CRESST-III Phase 2



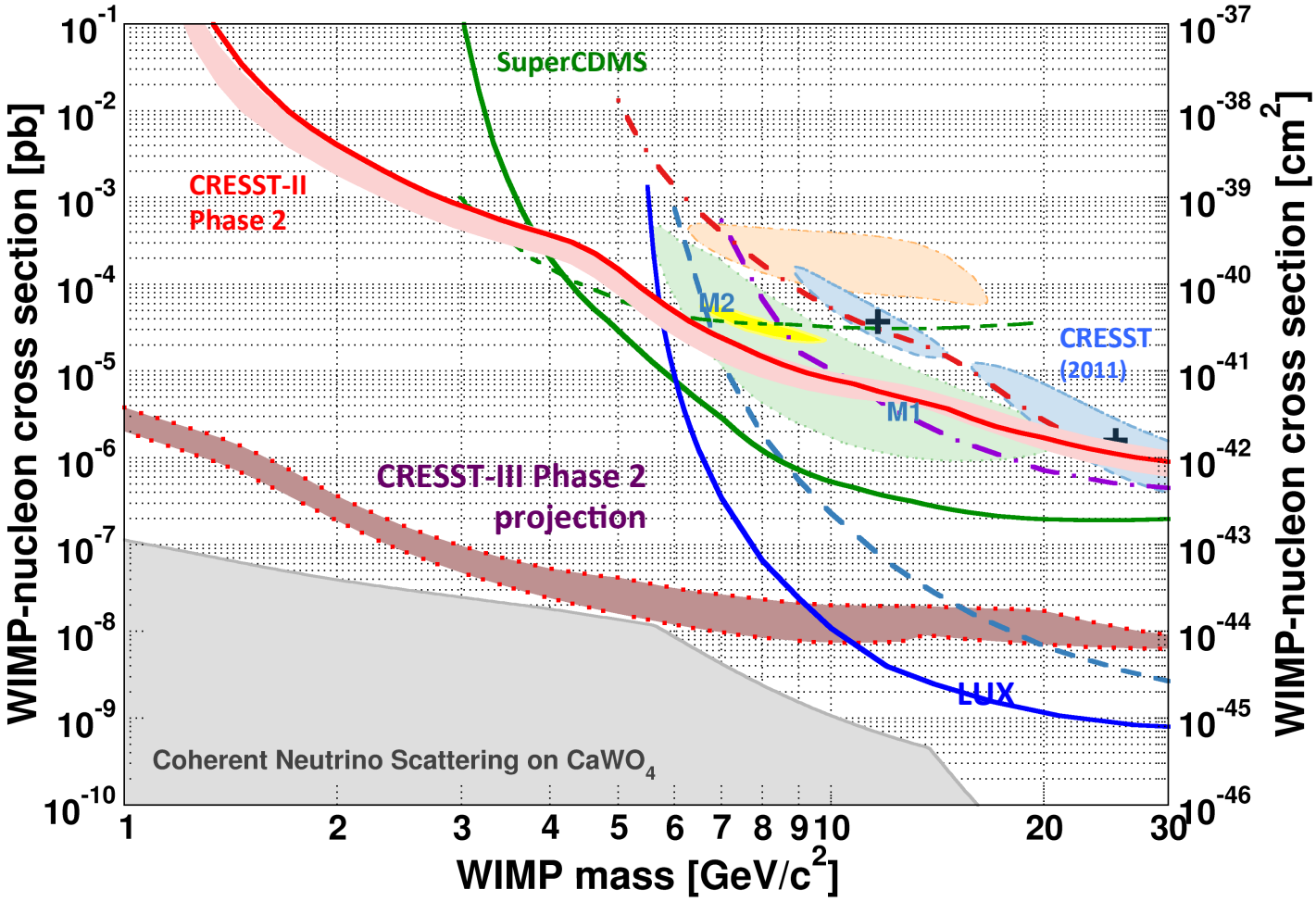
Reduce intrinsic background level of crystals!

- 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

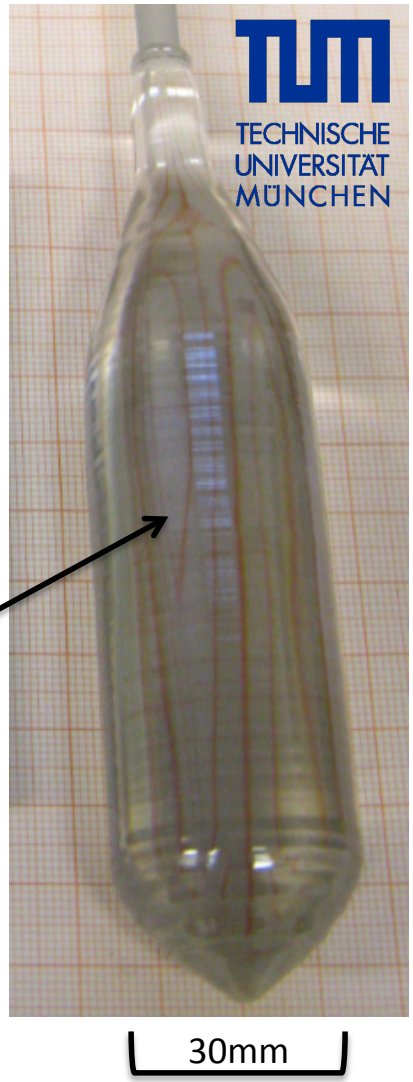
First steps in chemical purification of $CaCO_3$ powder:

- 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 !!

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



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

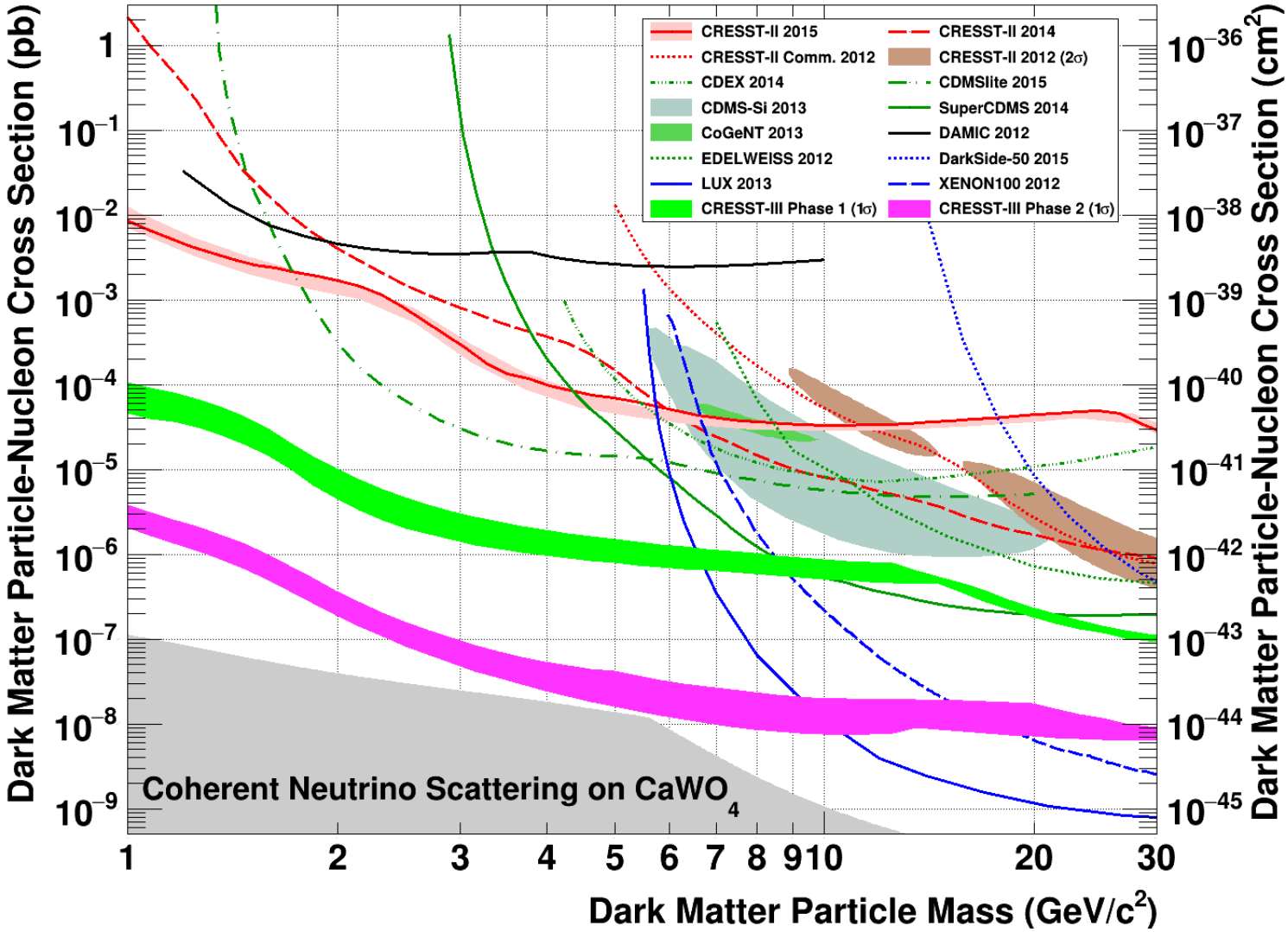
- **CRESST-II** probed new region of parameter space for WIMP masses below 3GeV/c^2

- **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

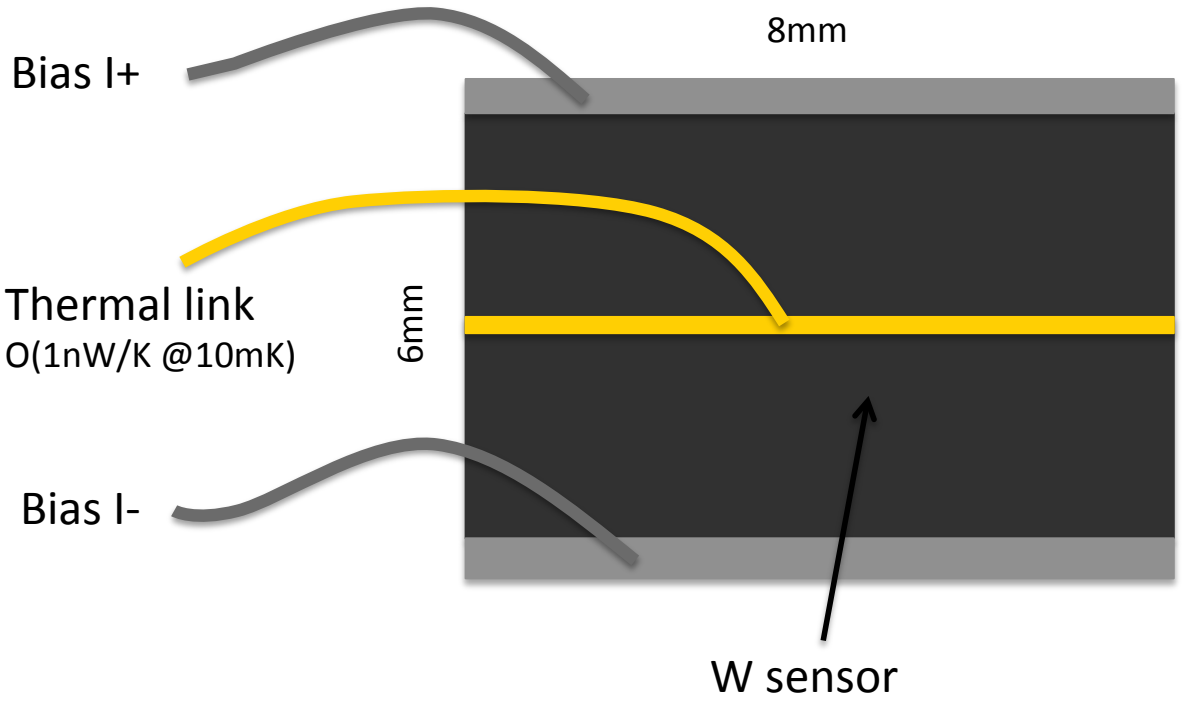
Start: Jan 2016

BACKUP SLIDES

Projections for CRESST-III



TES Design: Crucial for Energy Threshold

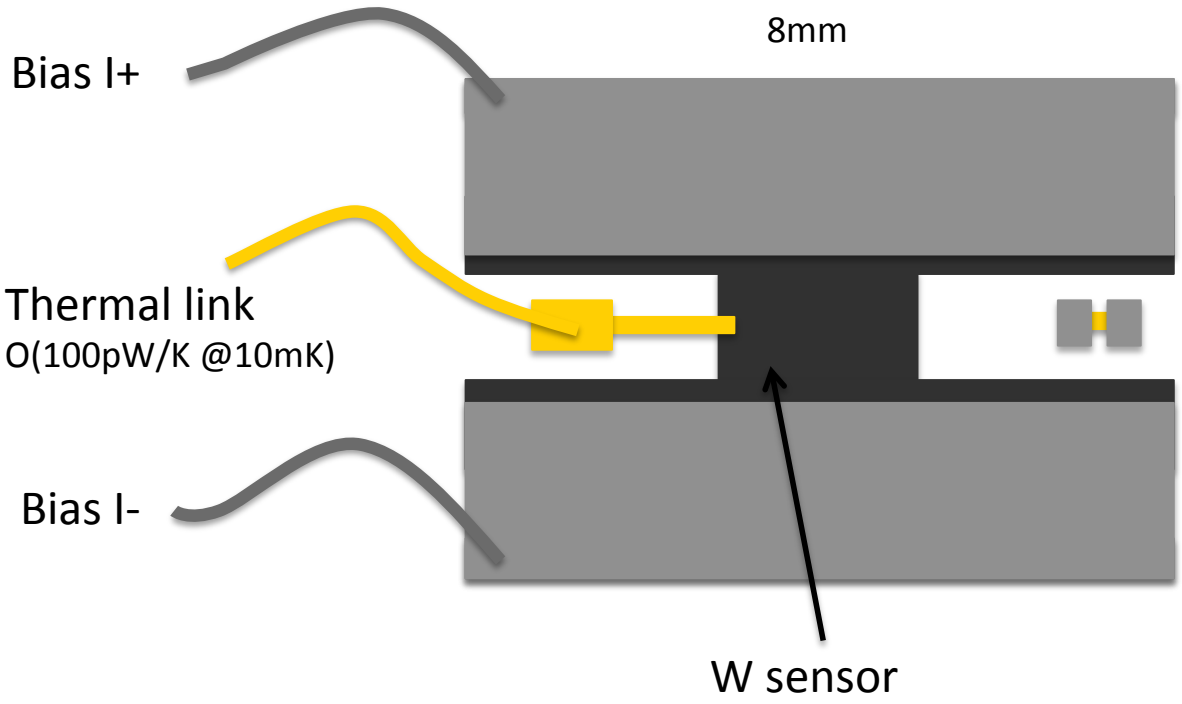


Old TES design for 300g crystals:

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

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

TES Design: Crucial for Energy Threshold

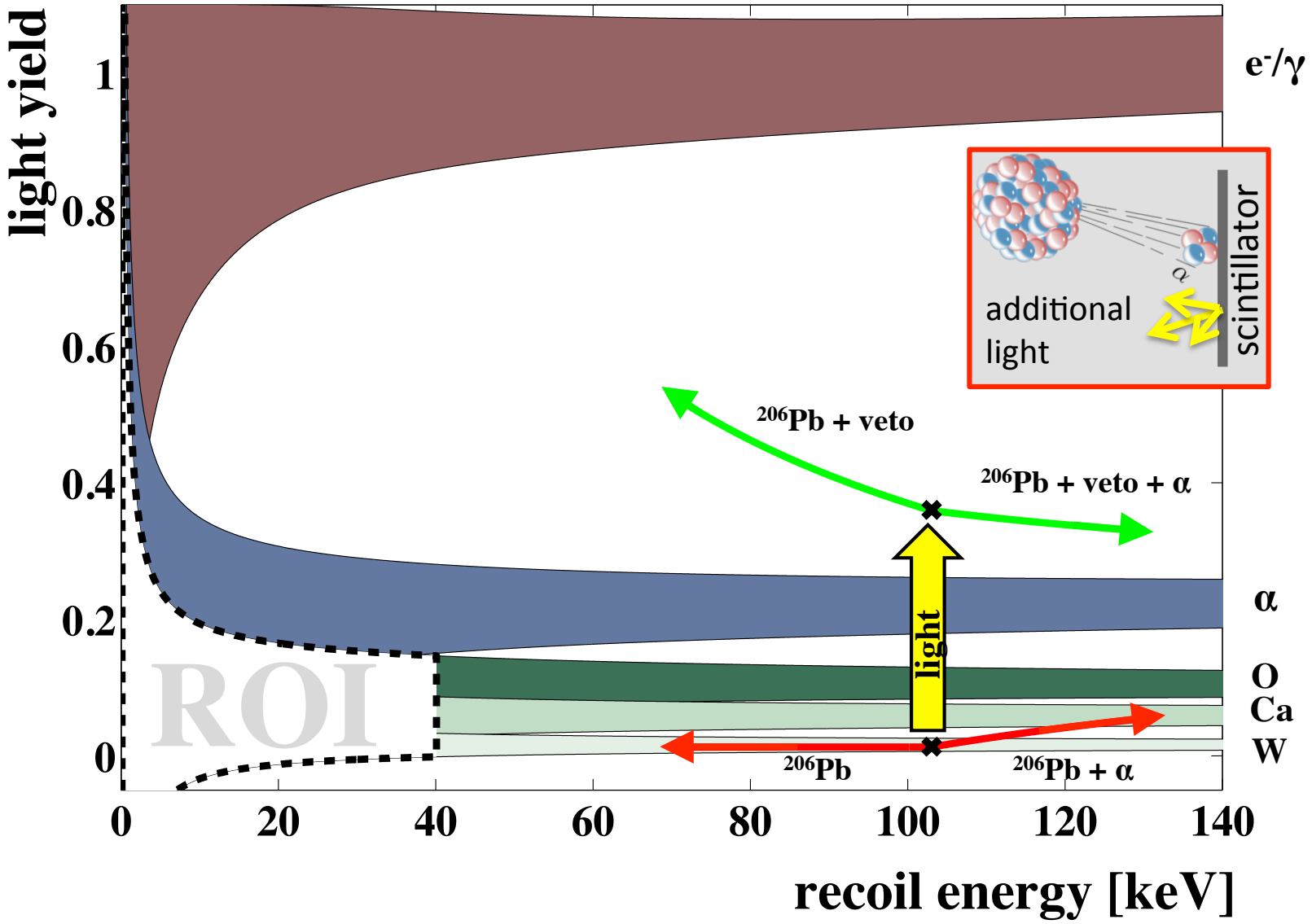


New TES design for 24g crystals:

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

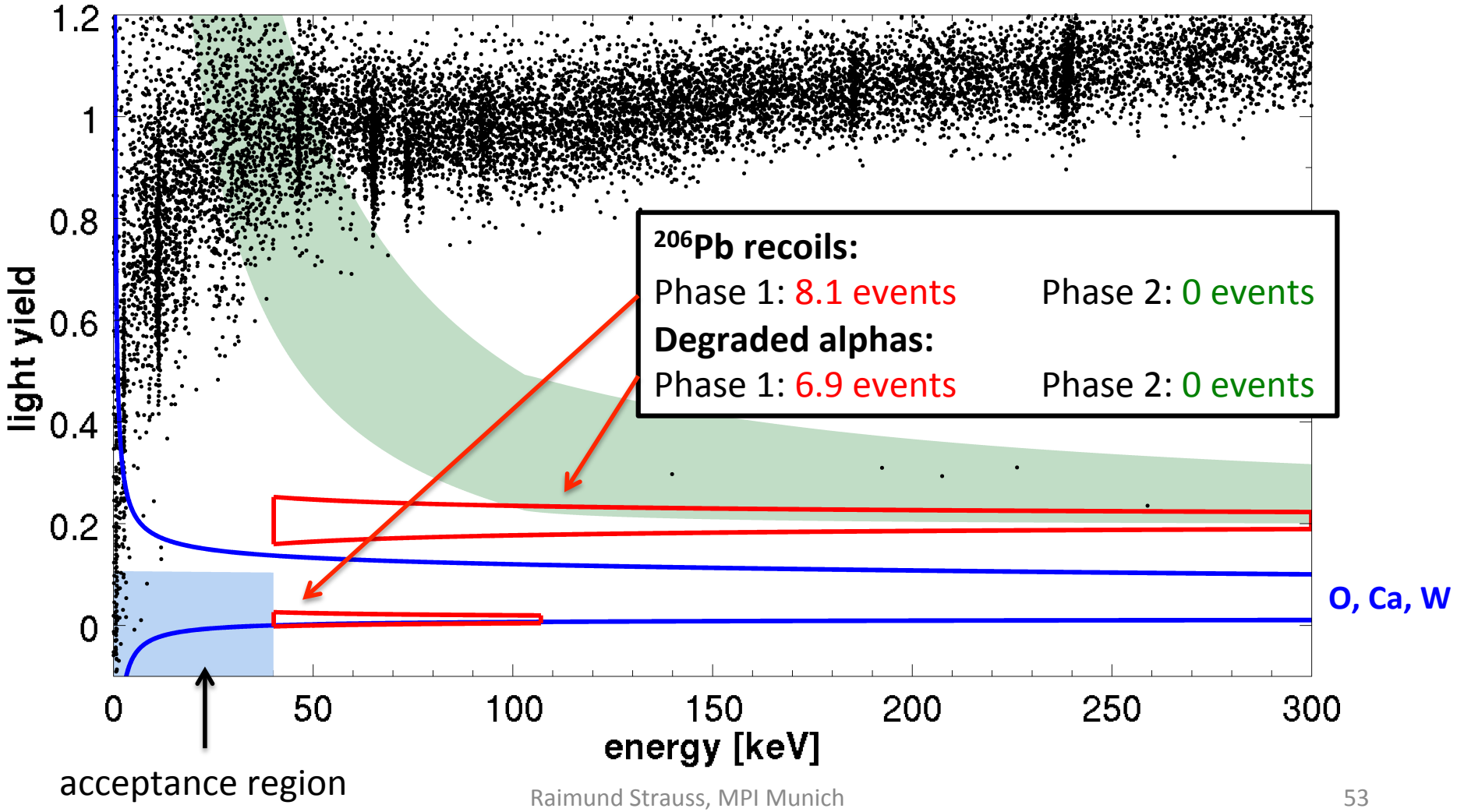
Theoretical improvement: factor **5-10** in signal/noise

Efficient Veto of Surface Backgrounds

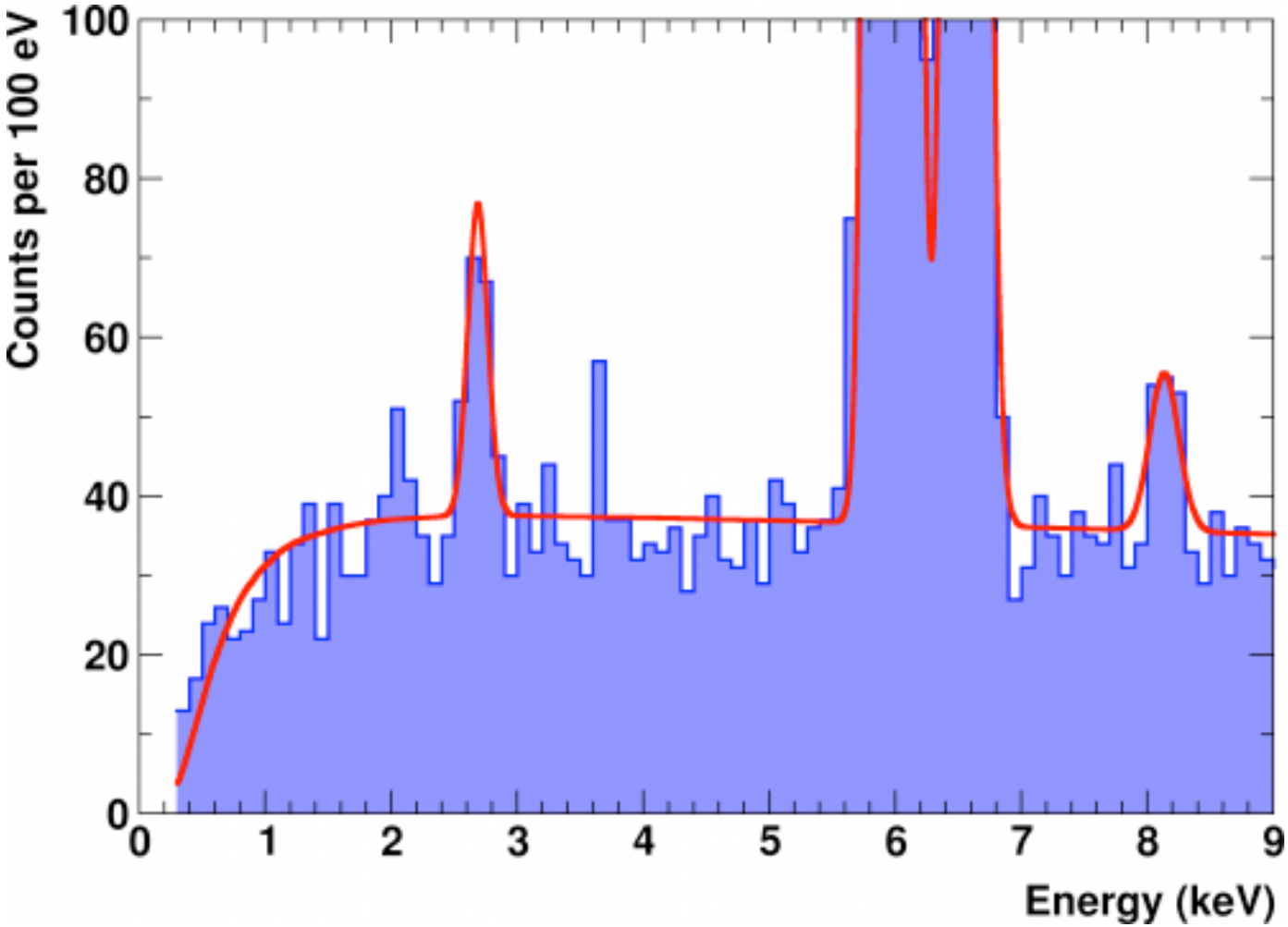


TUM-40: Surface Backgrounds

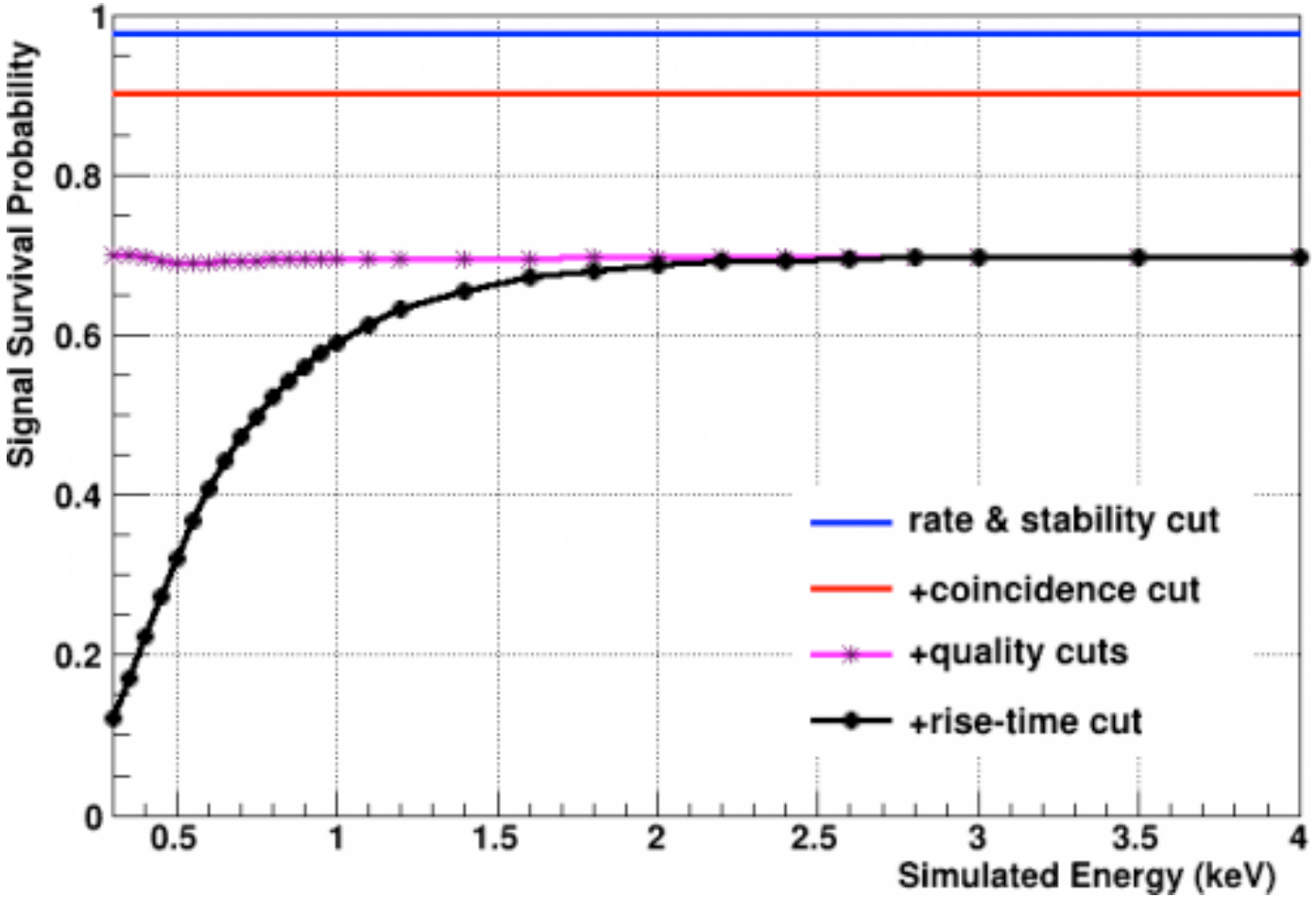
exposure: 29 kg-days



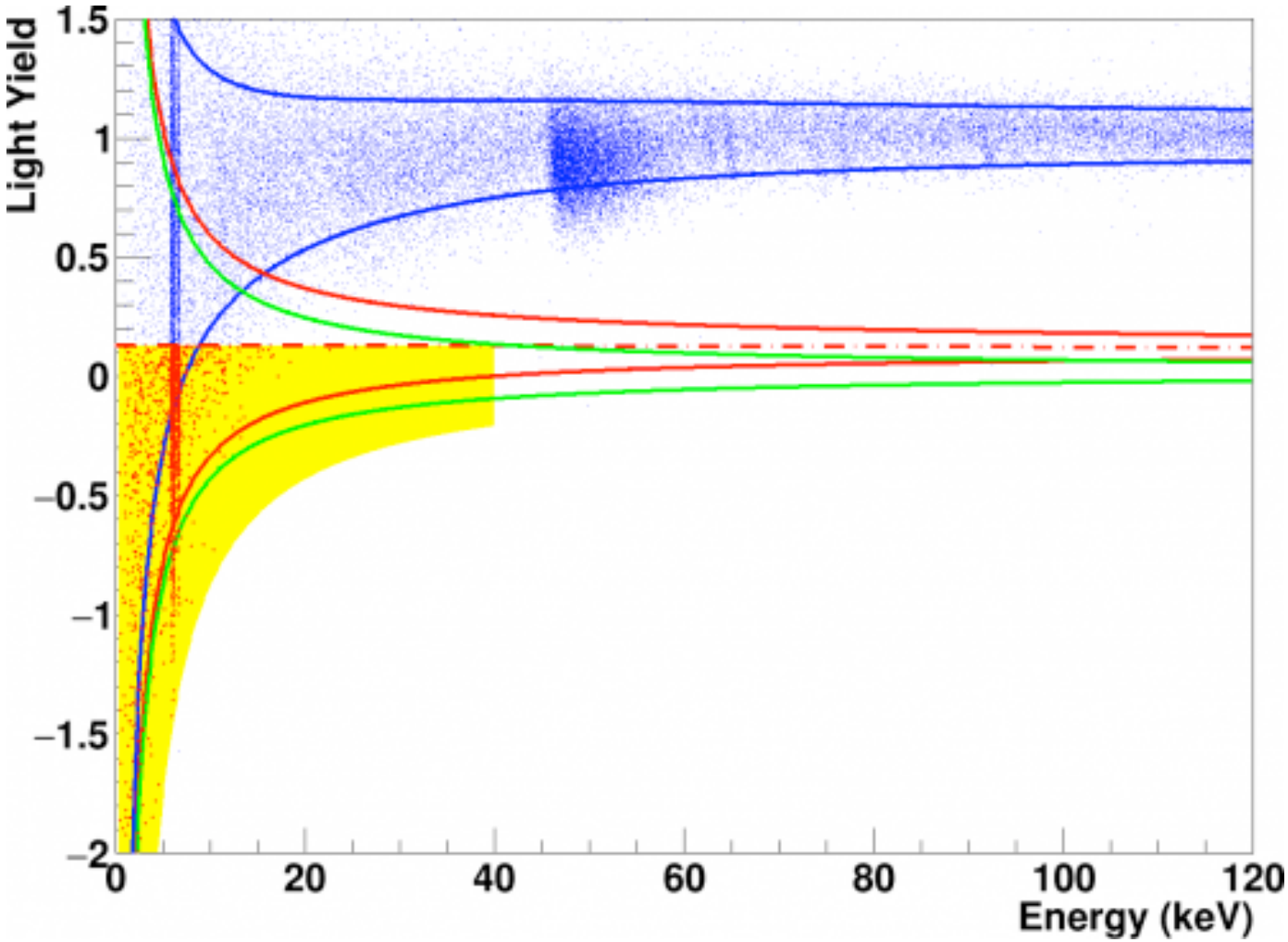
Lise: Low Energy Spectrum



Lise: Detector Efficiency



Lise: Observed Events



Thresholds of Cryogenic Experiments