Verso soglie più basse: Materia Oscura con CRESST

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Laboratori Nazionali del Gran Sasso

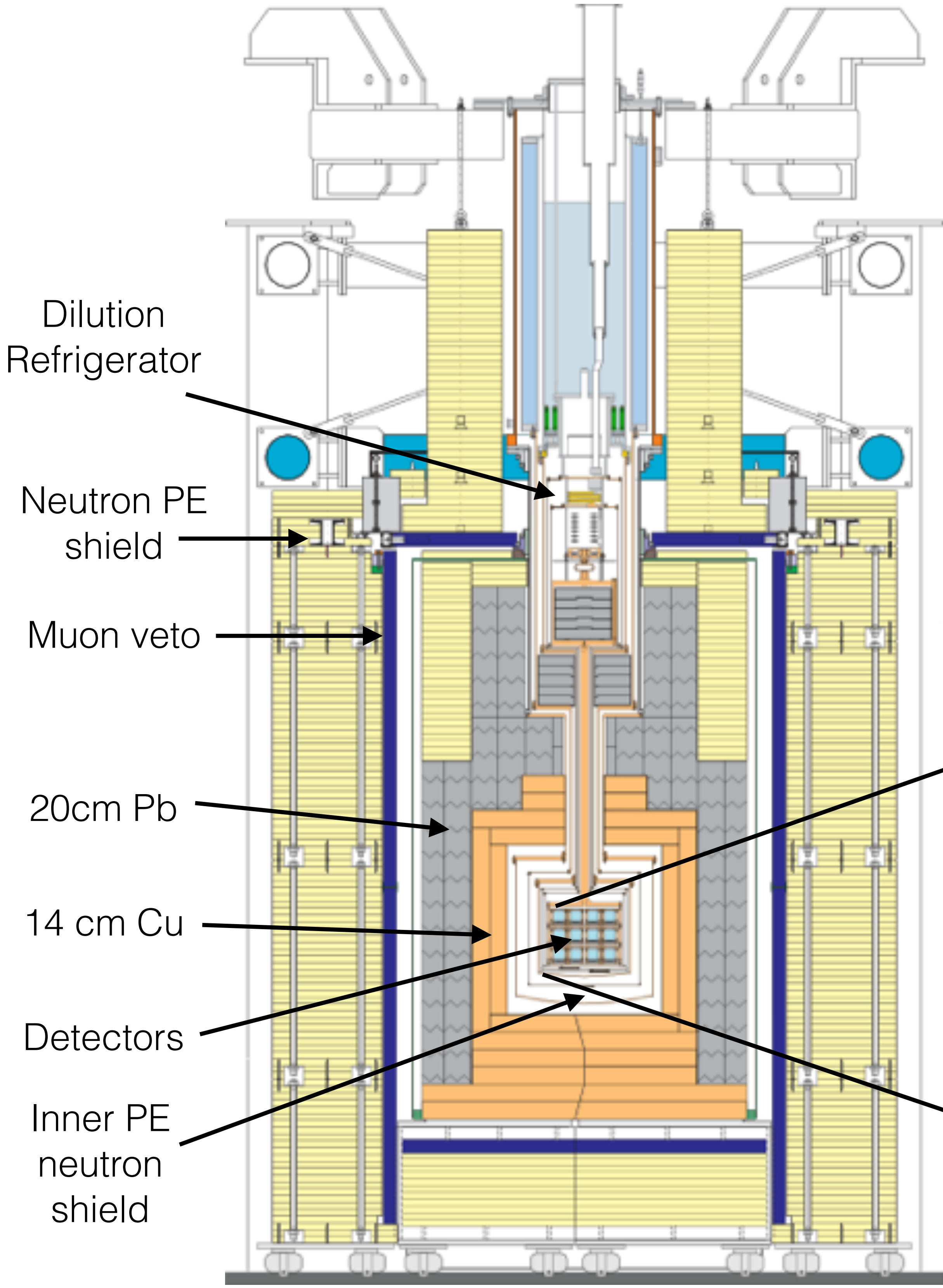
WhatNext-LNGS october 16, 2014

Outline

- L'esperimento CRESST: ricerca di DM con bolometri scintillanti
- Sensibilità a basse masse
- Nuove strategie per abbassare la soglia
- Prospettive

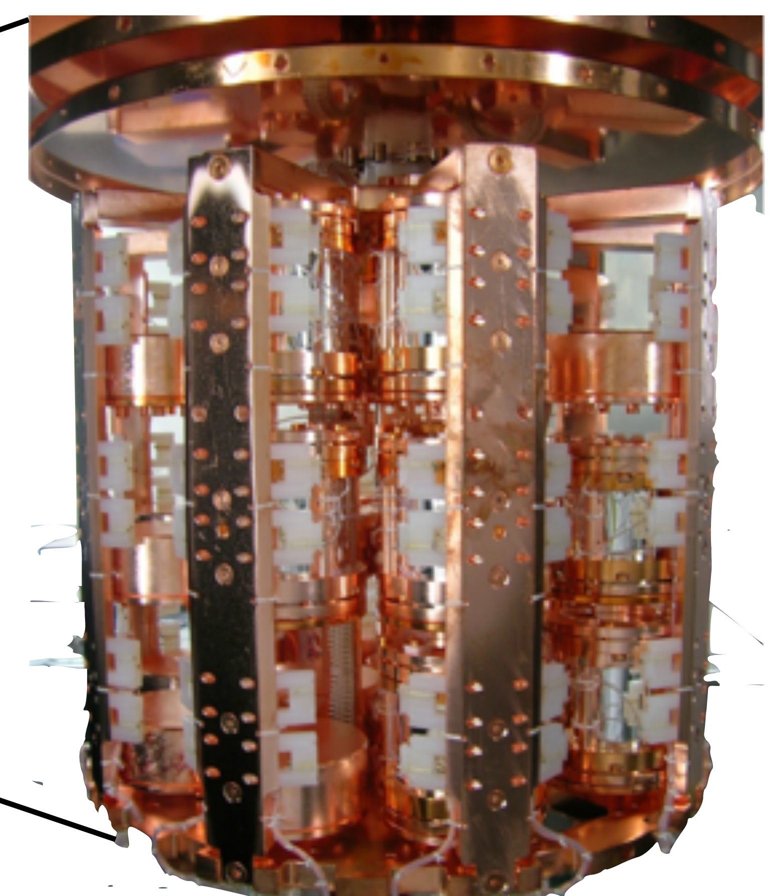
The CRESST Experiment

Cryogenic Rare Event Search with Superconducting Thermometers

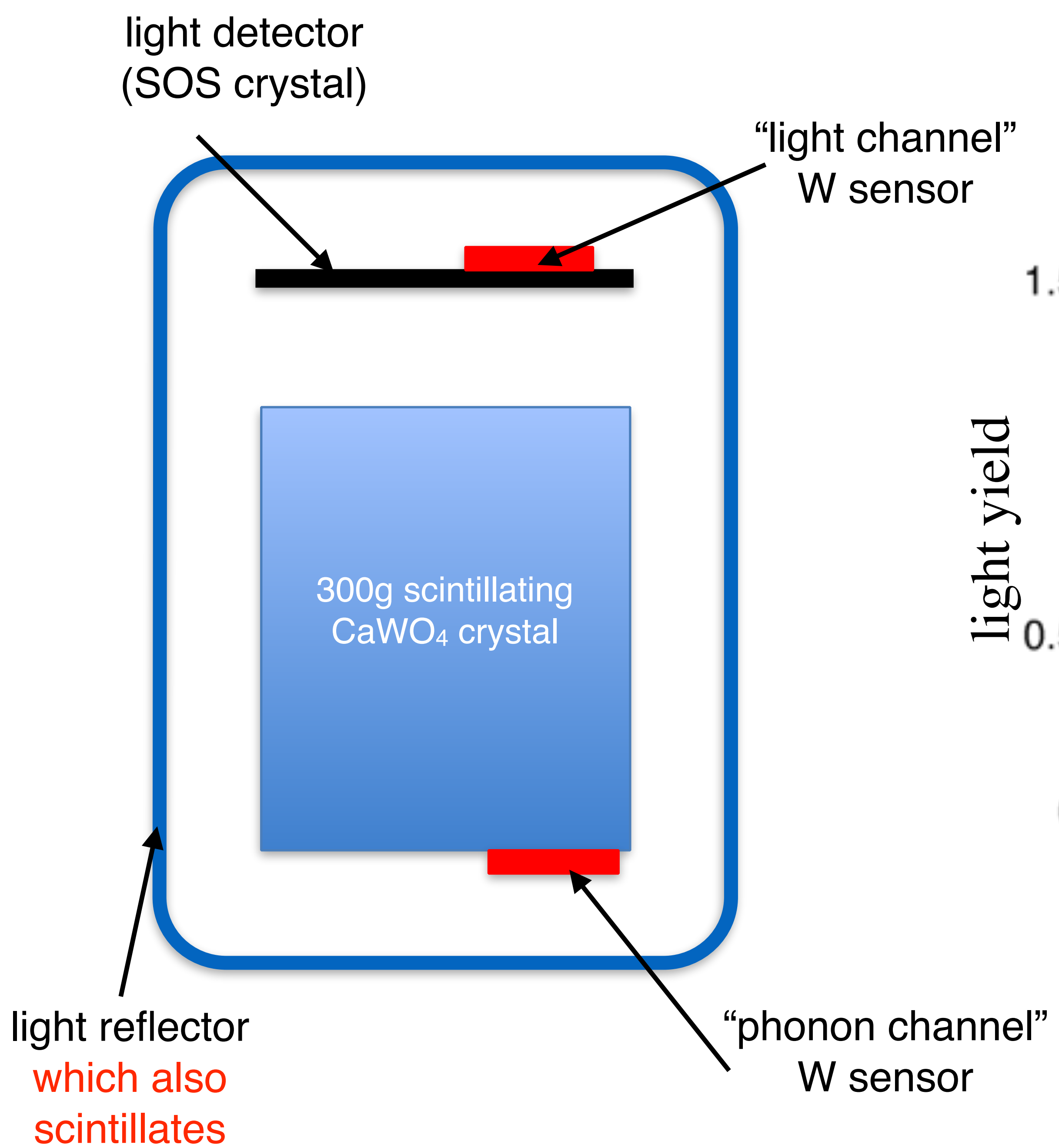


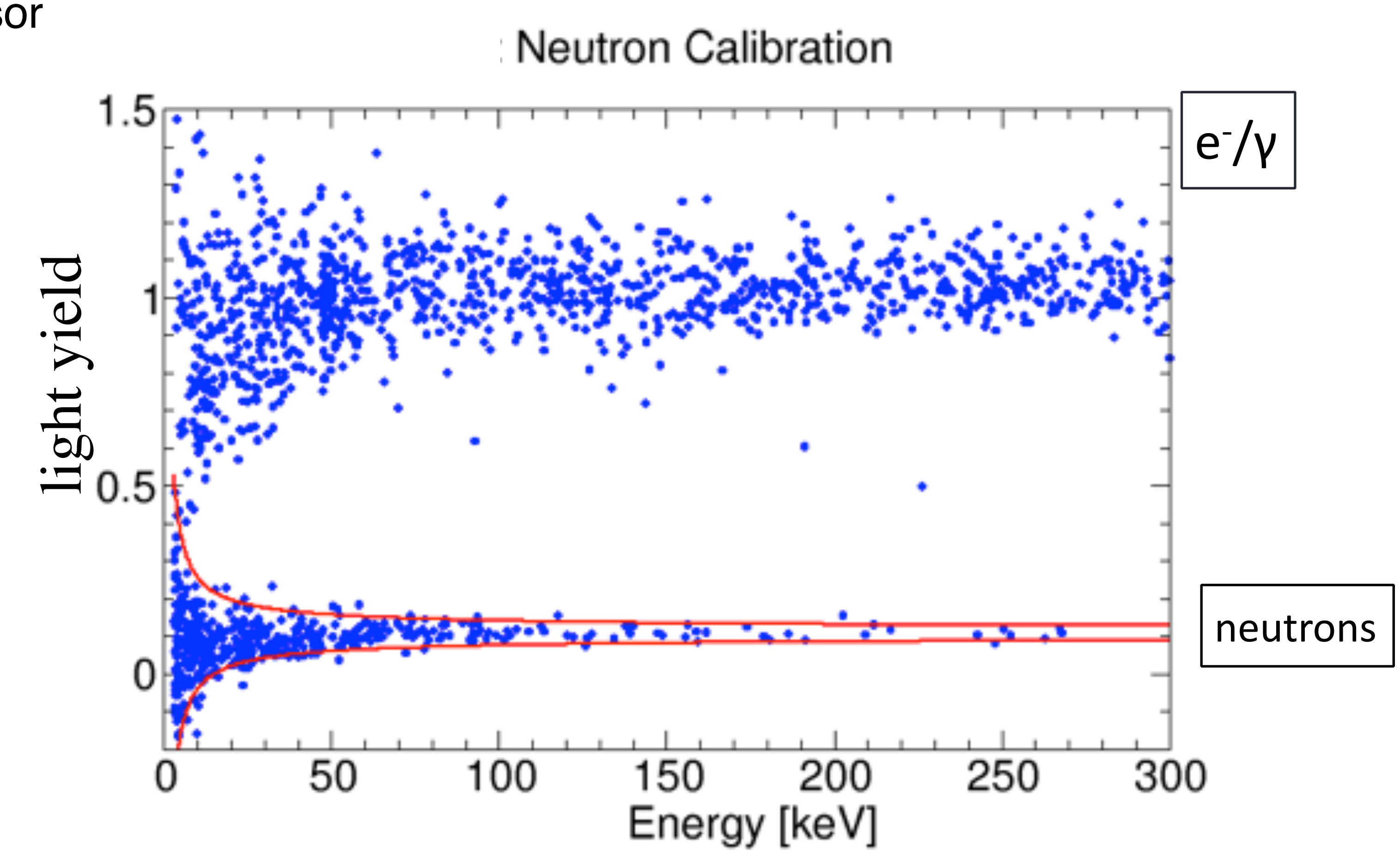
Detector “Carousel”

- Tightly packed array of bolometric detectors: up to 33 individual CRESST modules
- Up to 10 kg of CaWO4 to look for DM interactions.
- Excellent energy resolution near threshold (<500 eV)
- Extremely low threshold (<1 keV)
- Complex cryogenic set-up



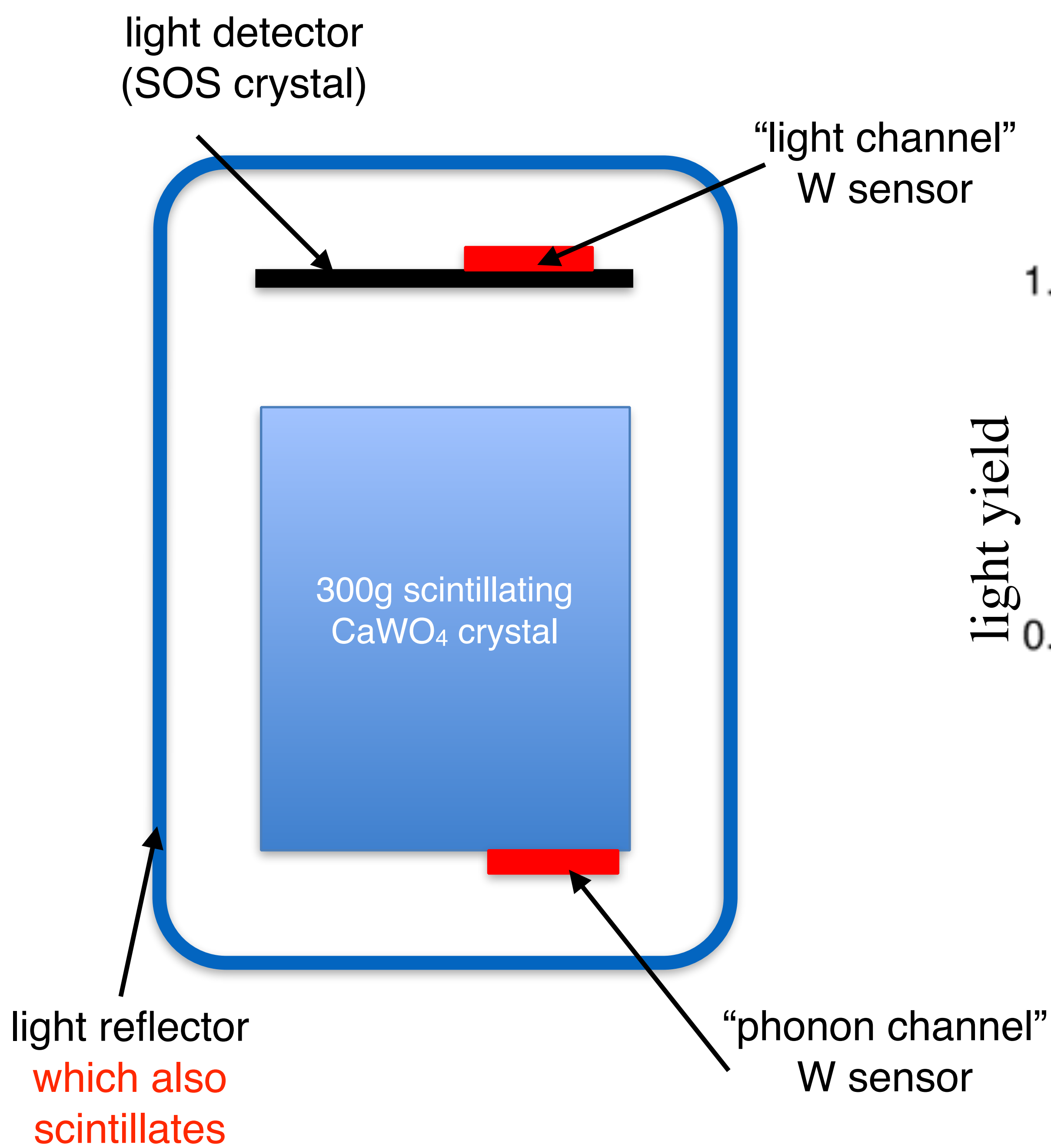
CRESST Detectors

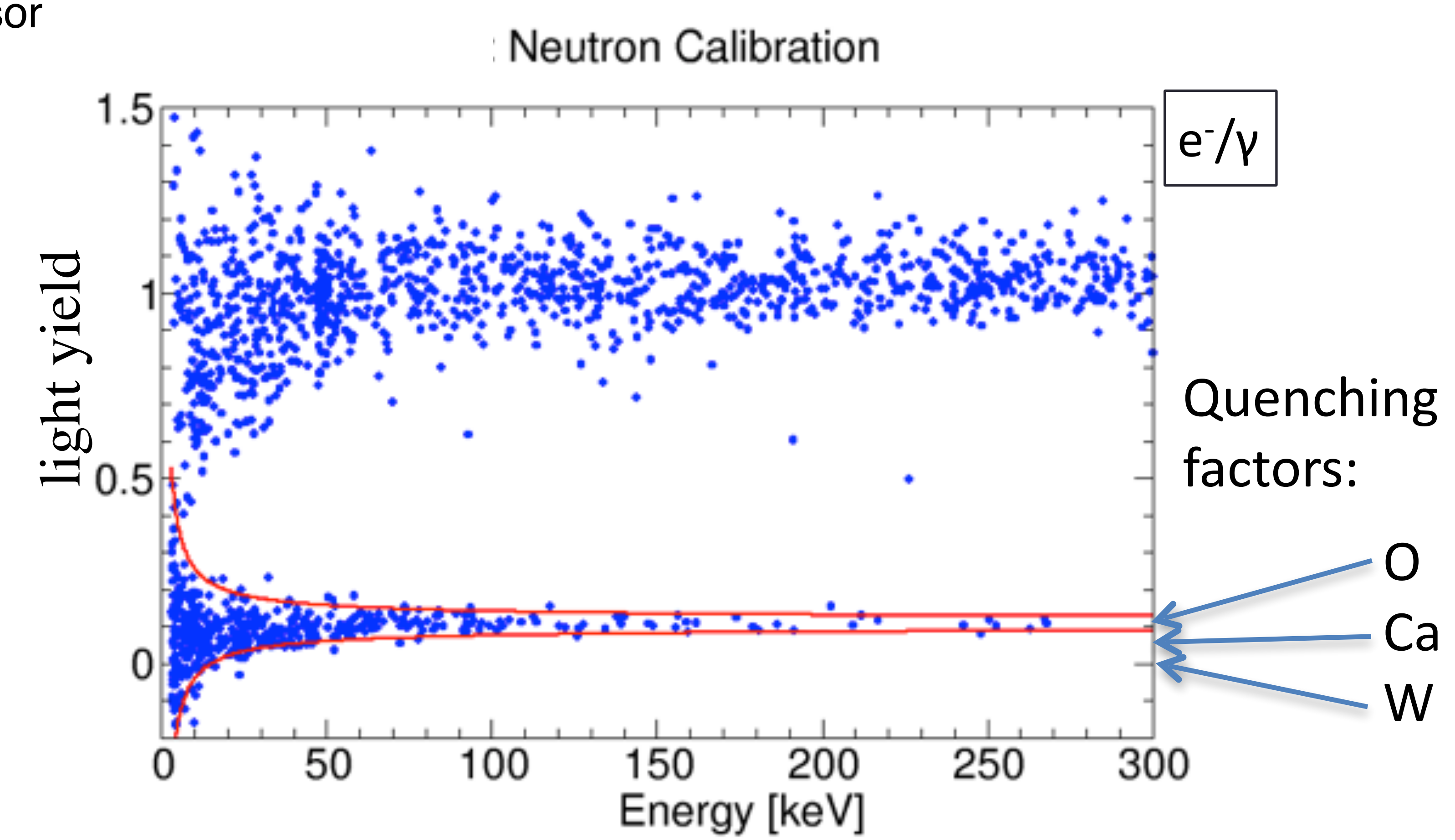




→ Phonon channel measures deposited energy with sub keV resolution and accuracy
→ Light channel serves to distinguish types of interaction
→ Types of recoiling nuclei distinguished by different slopes in energy-light plane

CRESST Detectors





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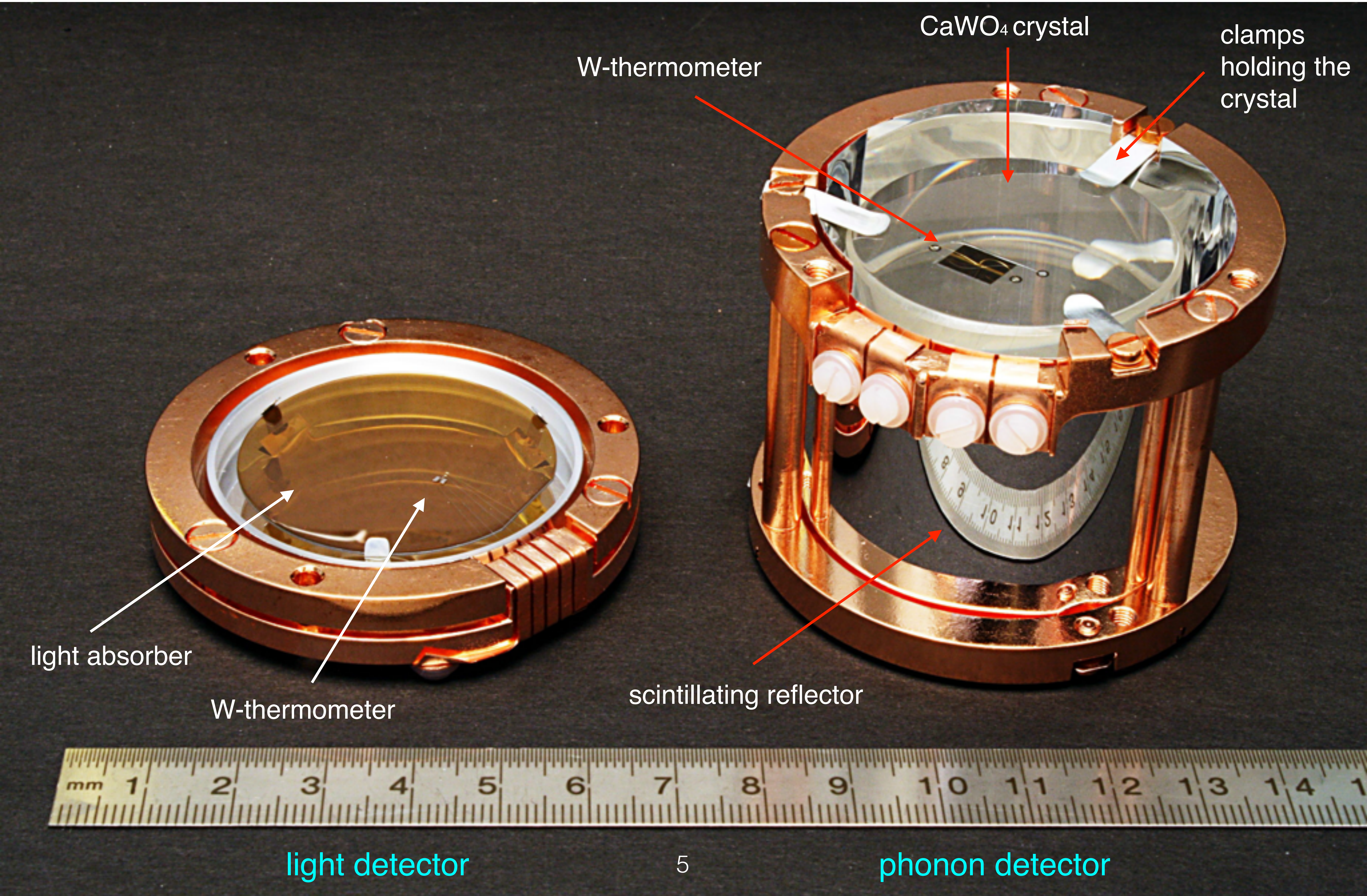
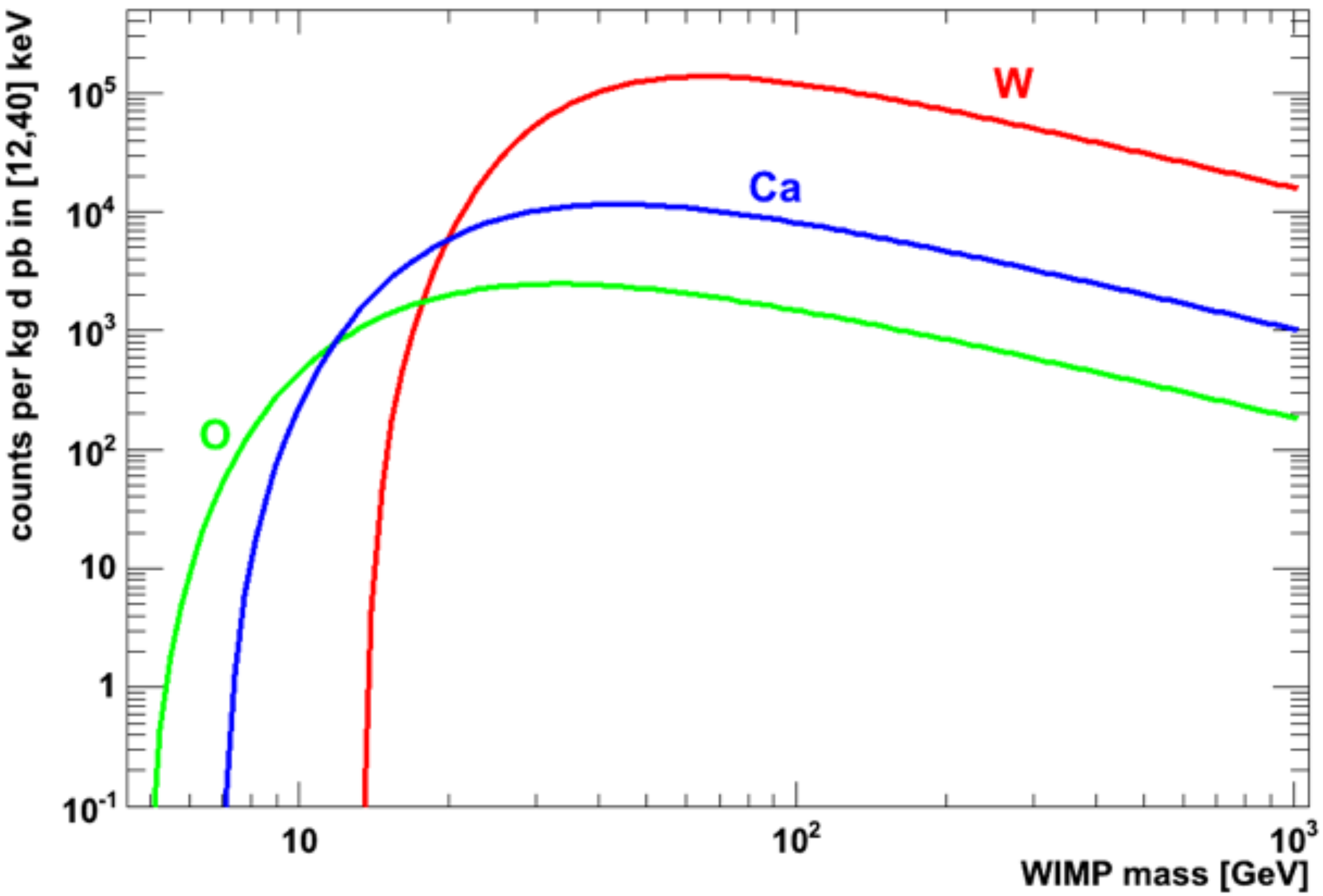
300 g Detector Module



Multielement recoils



Assuming:
- $\sigma \propto A^2$
- detection in 12 to 40 keV range

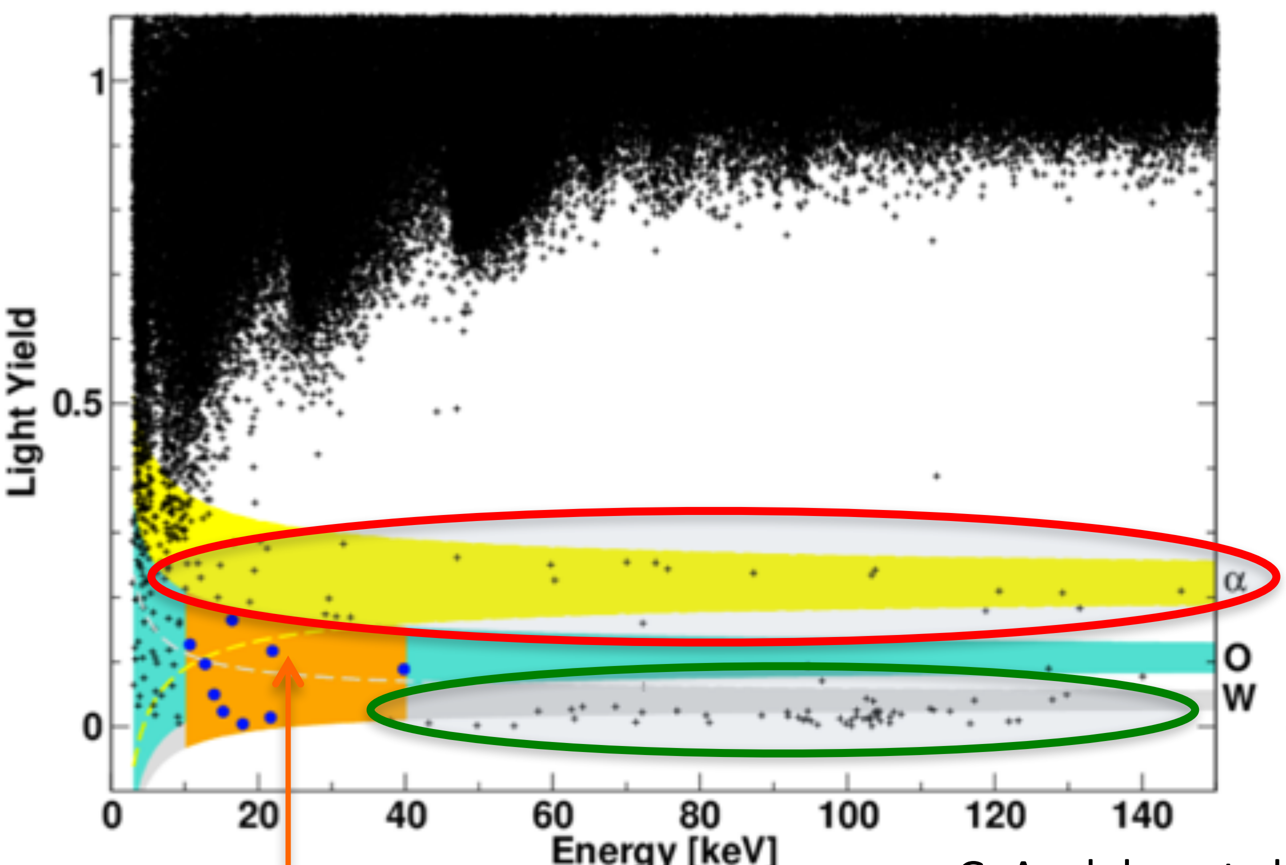
- Tungsten dominates at larger WIMP masses due to $\sigma \propto A^2$
- Calcium important around 10 GeV
- For M<10 GeV only oxygen above threshold

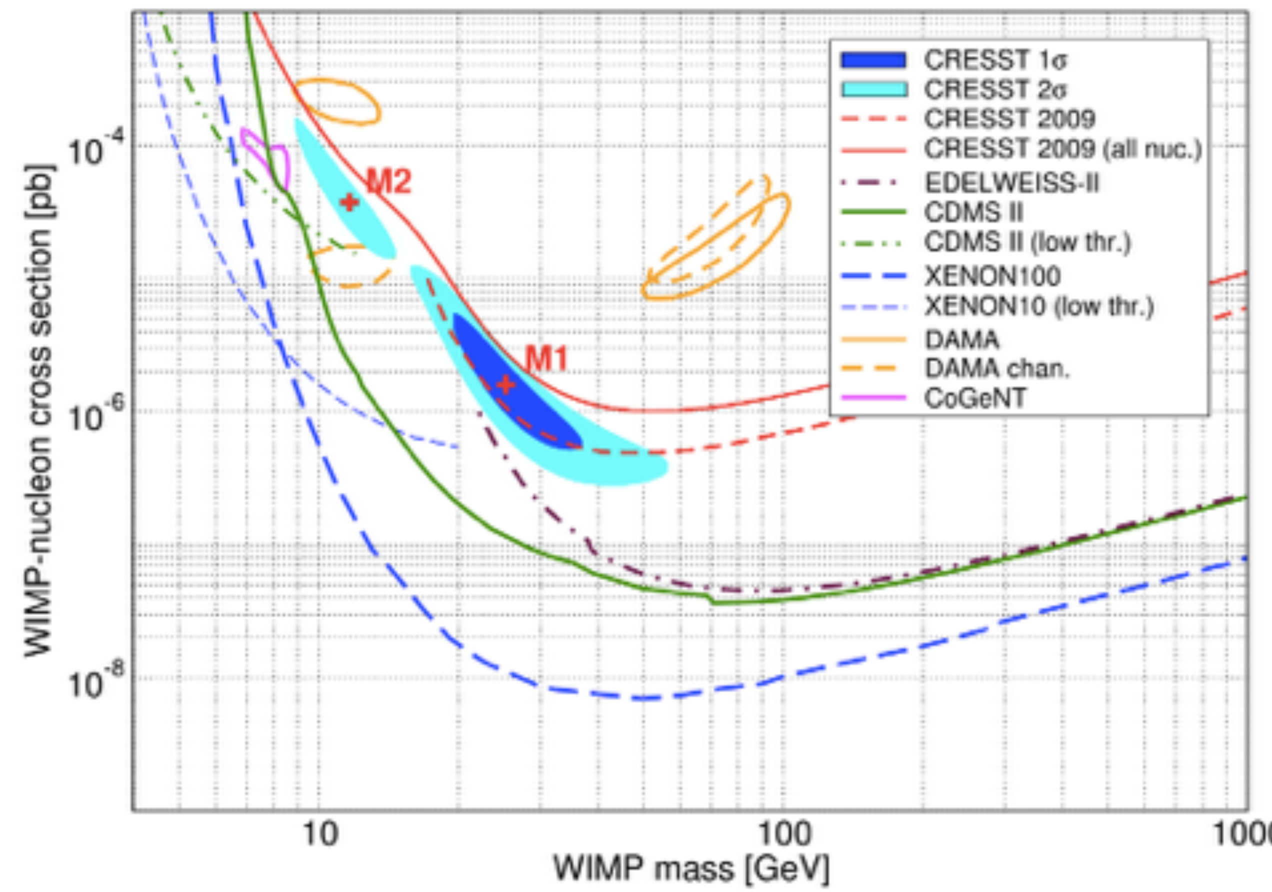
→ type of recoils, together with the recoil energy spectrum, offers very detailed information on mass of possible WIMP

Results from run 32

Extended physics run from June 2009 to April 2011:

- 8 $CaWO_4$ modules used for Dark Matter analysis
- Net exposure after cuts: 730 kg days
- 67 events observed in WIMP search region





degraded alphas

Pb recoils

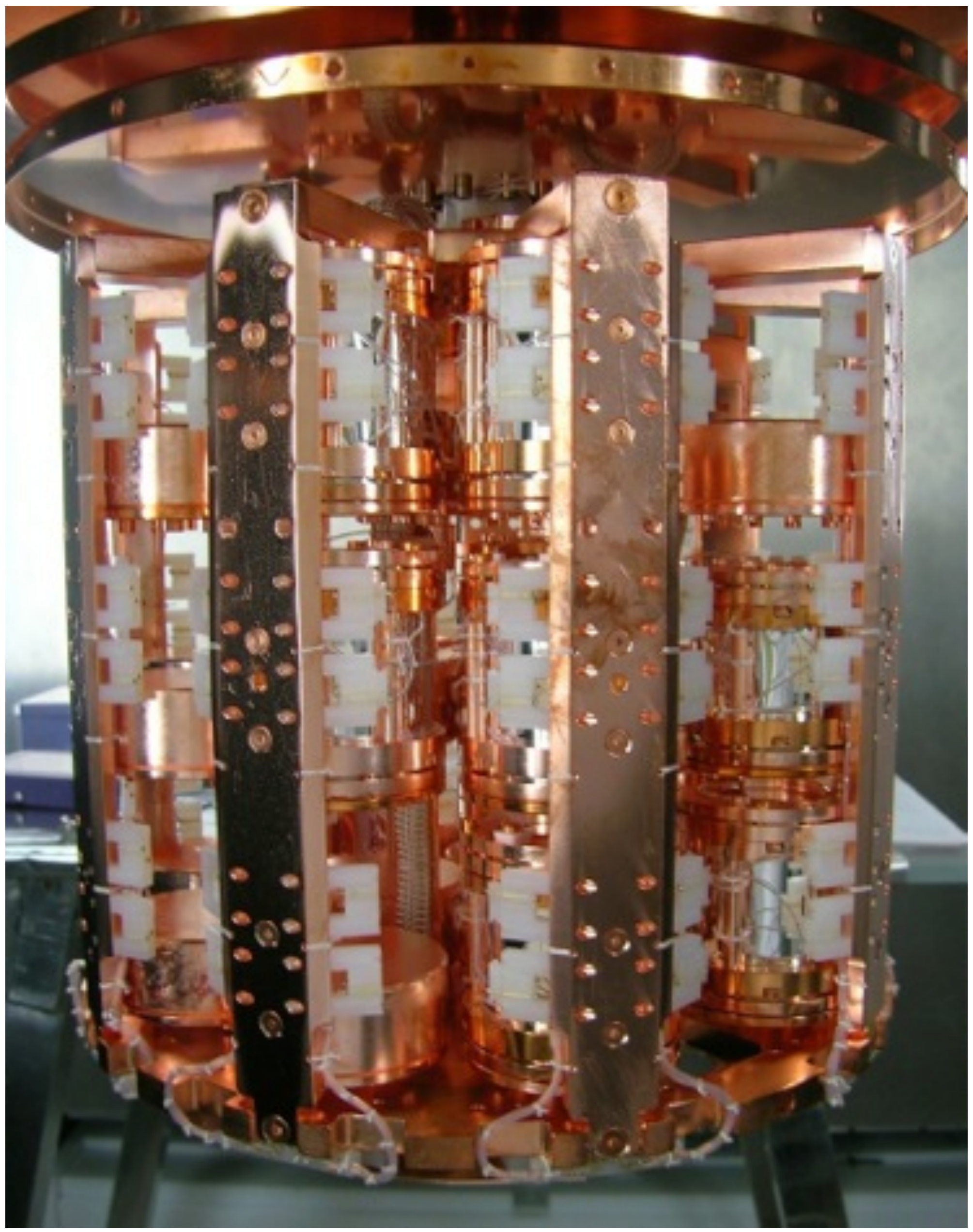
ROI 15-40keV

G. Angloher et al., Eur. Phys. J. C, 72, 4 (2012)

- Background only hypothesis rejected with rather high statistical significance (>4σ)
- Background contributions still relatively large
- Reduction is necessary for ultimate clarification

Run 33

CRESST-II Upgrade: Run 33

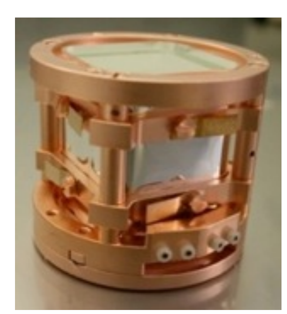


- Data-taking since July 2013
- 18 modules mounted (~ 5kg)

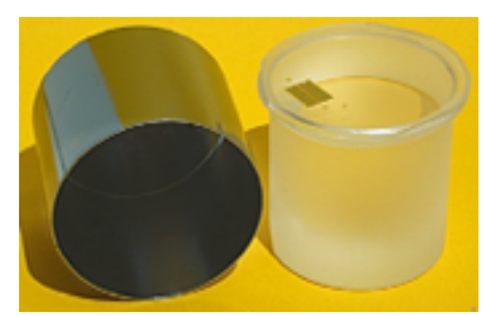
  → 17 of 18 are fully operational

✓ 11 x conventional design (improved)
- Use of radiopure clamps
- Radon prevention

✓ 6 x fully-active new designs



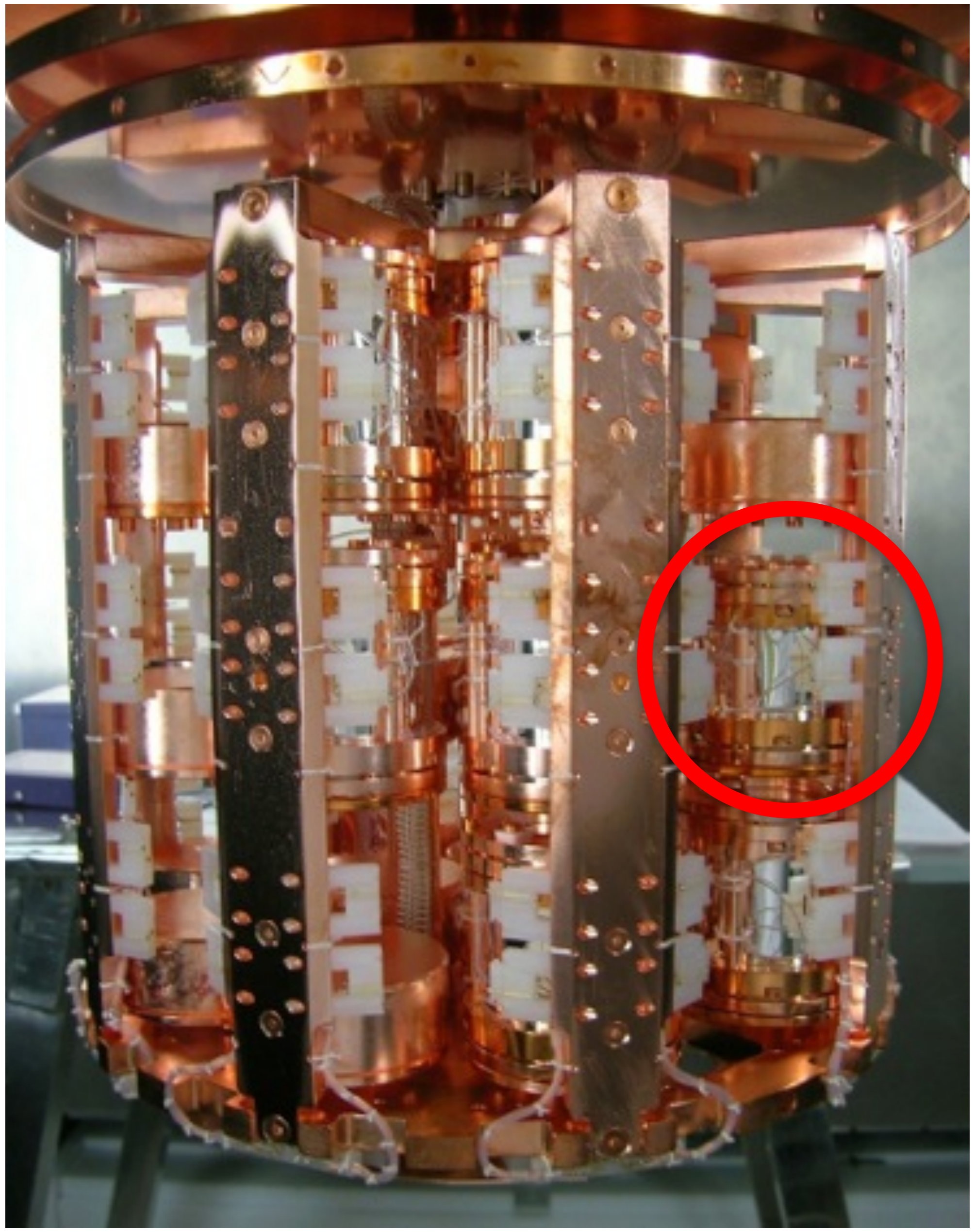
$CaWO_4$ sticks



beaker

K-14

CRESST-II Upgrade: Run 33



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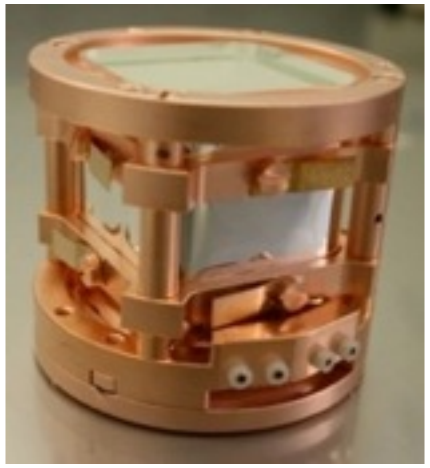
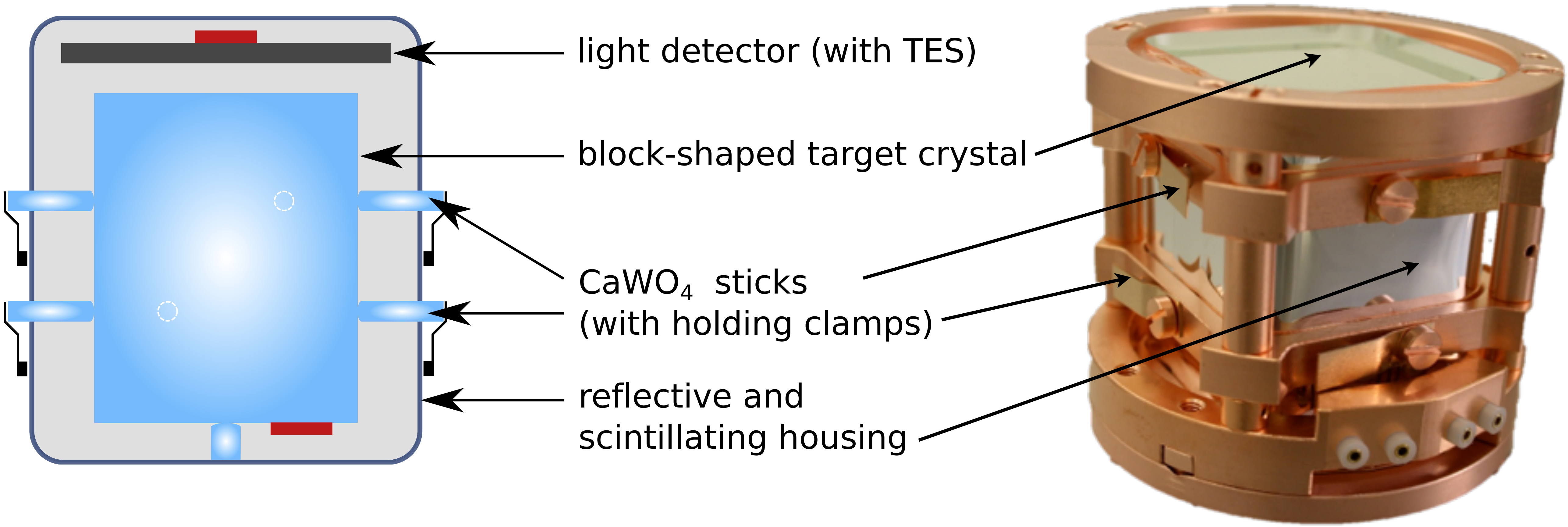


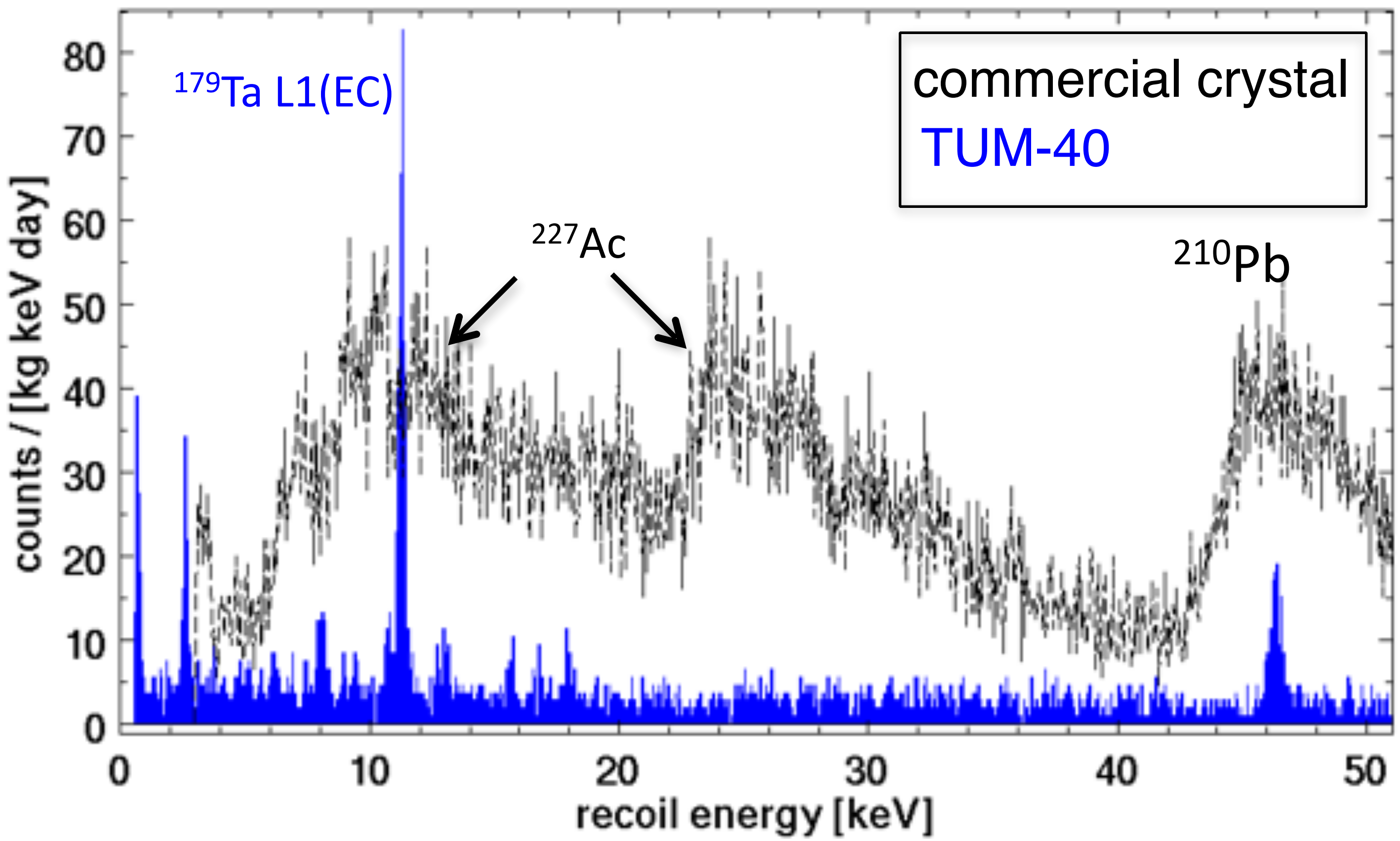
these results:
analysis of one detector module (TUM-40)
mass: 250g
exposure: 29 kg-days

Stick-Based Detector Holder



TUM 40

TUM-40: Radiopurity & Performance



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

Gamma-lines from **cosmogenic activation**

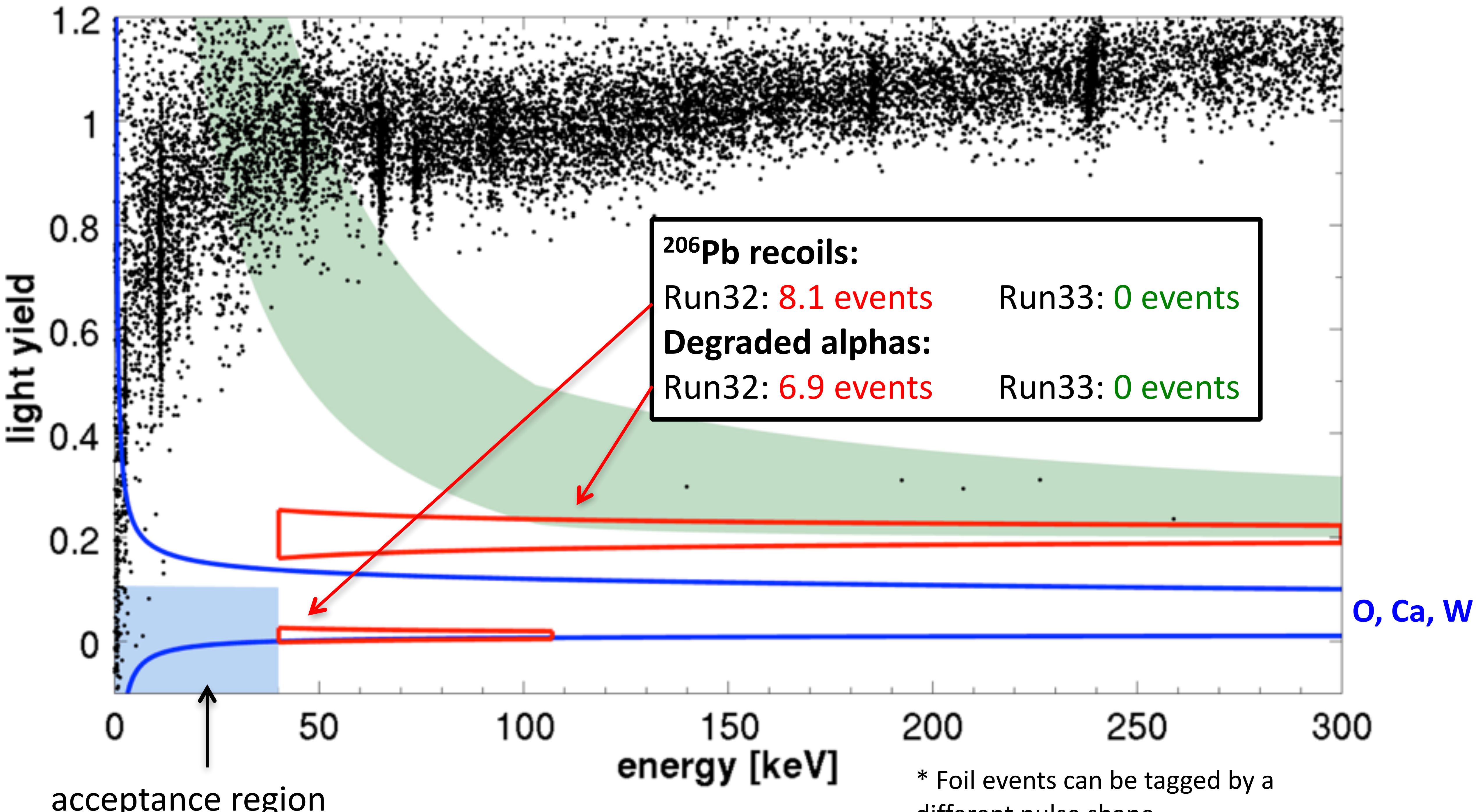
Excellent resolution:
$\sigma \approx$ 100eV

- No surface backgrounds
- Best radiopurity ($\approx$ 3.5 / [kg keV day])
- Low trigger threshold ($\approx$ 600 eV)
- High resolution ($\sigma \approx$ 100 eV)

→ **Low-threshold** Dark Matter analysis possible
→ Use non-blinded dataset of 29kg*days

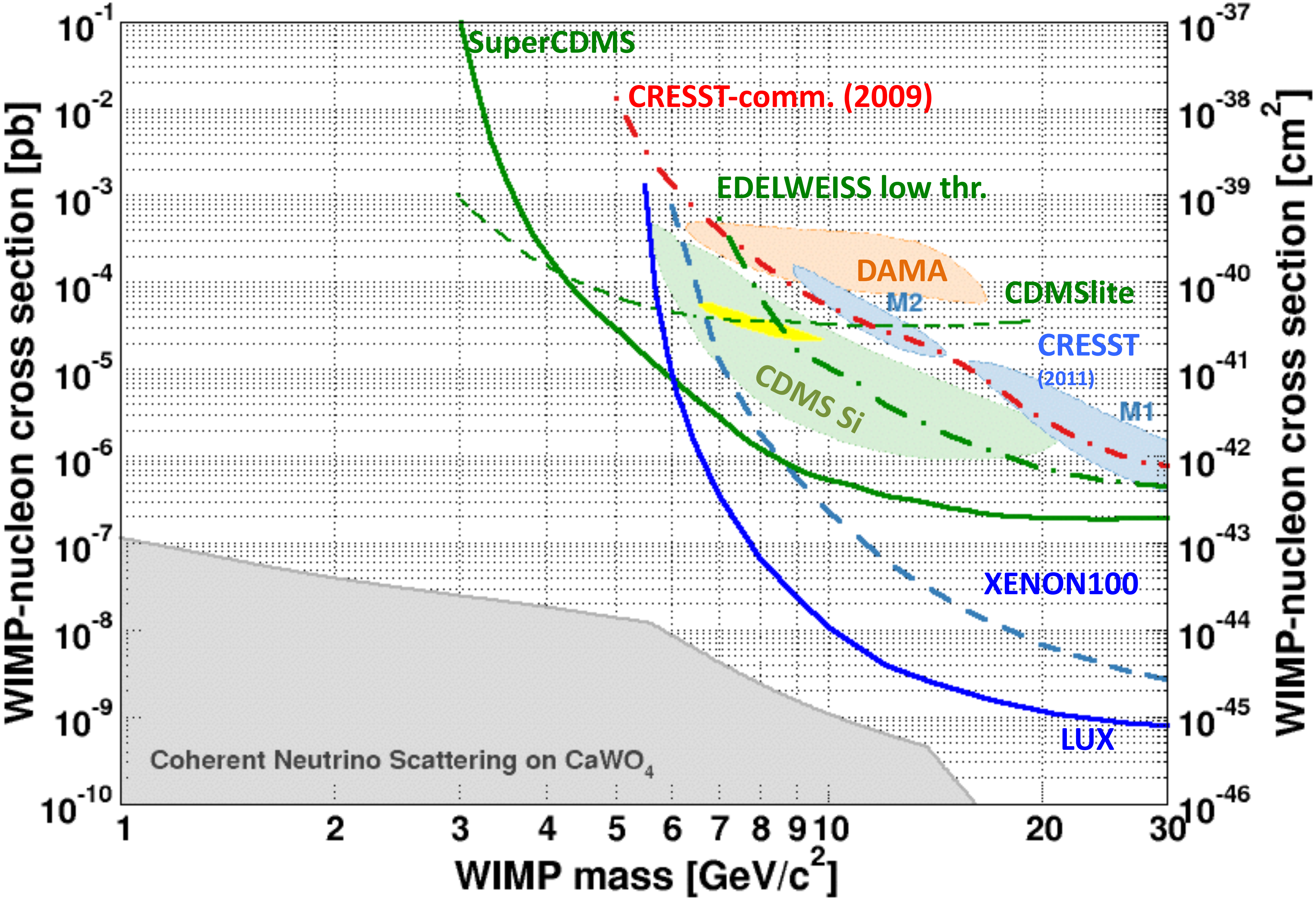
TUM-40: Surface Backgrounds

exposure: 29 kg-days

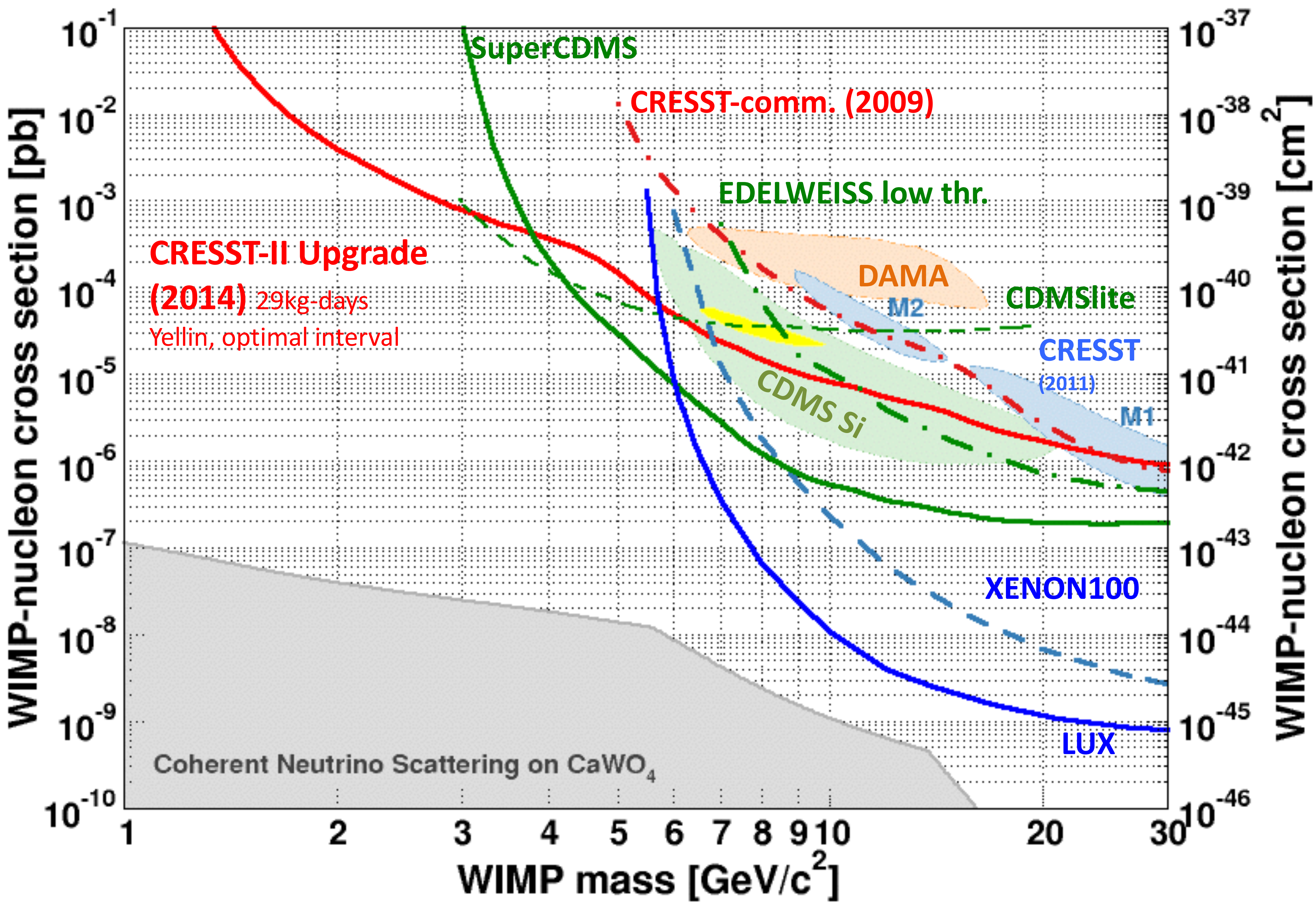


* Foil events can be tagged by a different pulse shape

Present WIMP Landscape

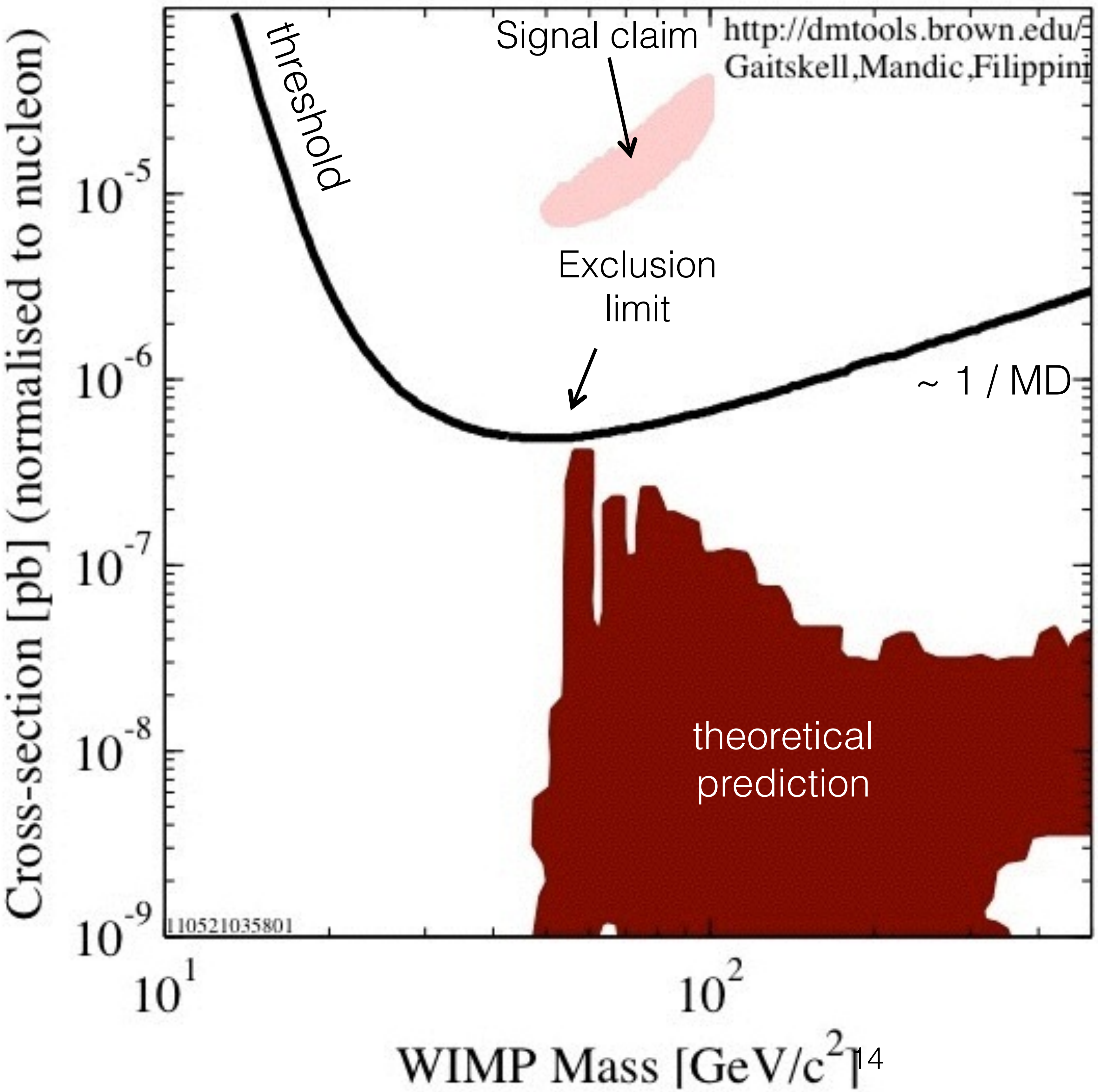


Results from 29kg-days of TUM-40



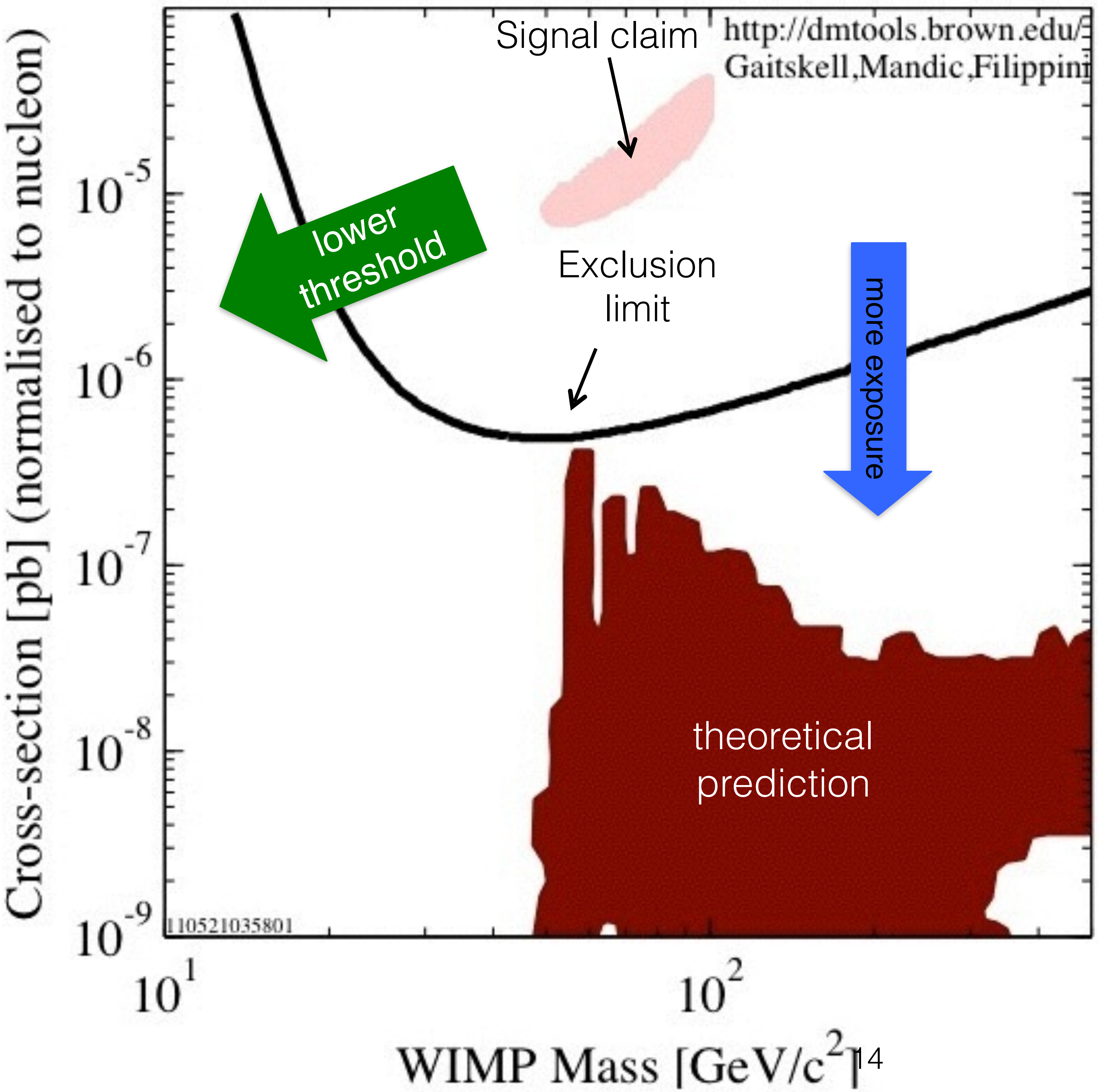
arXiv:1407.3146

Strategie future



Le caratteristiche dei rivelatori di CRESST lo rendono particolarmente adatto a esplorare la zona di WIMP a bassa massa (mentre ad alte masse [M_D> 1 ton], data la complessità della tecnica, è difficile essere competitivi con esperimenti come liquidi criogenici e NaI).

Strategie future



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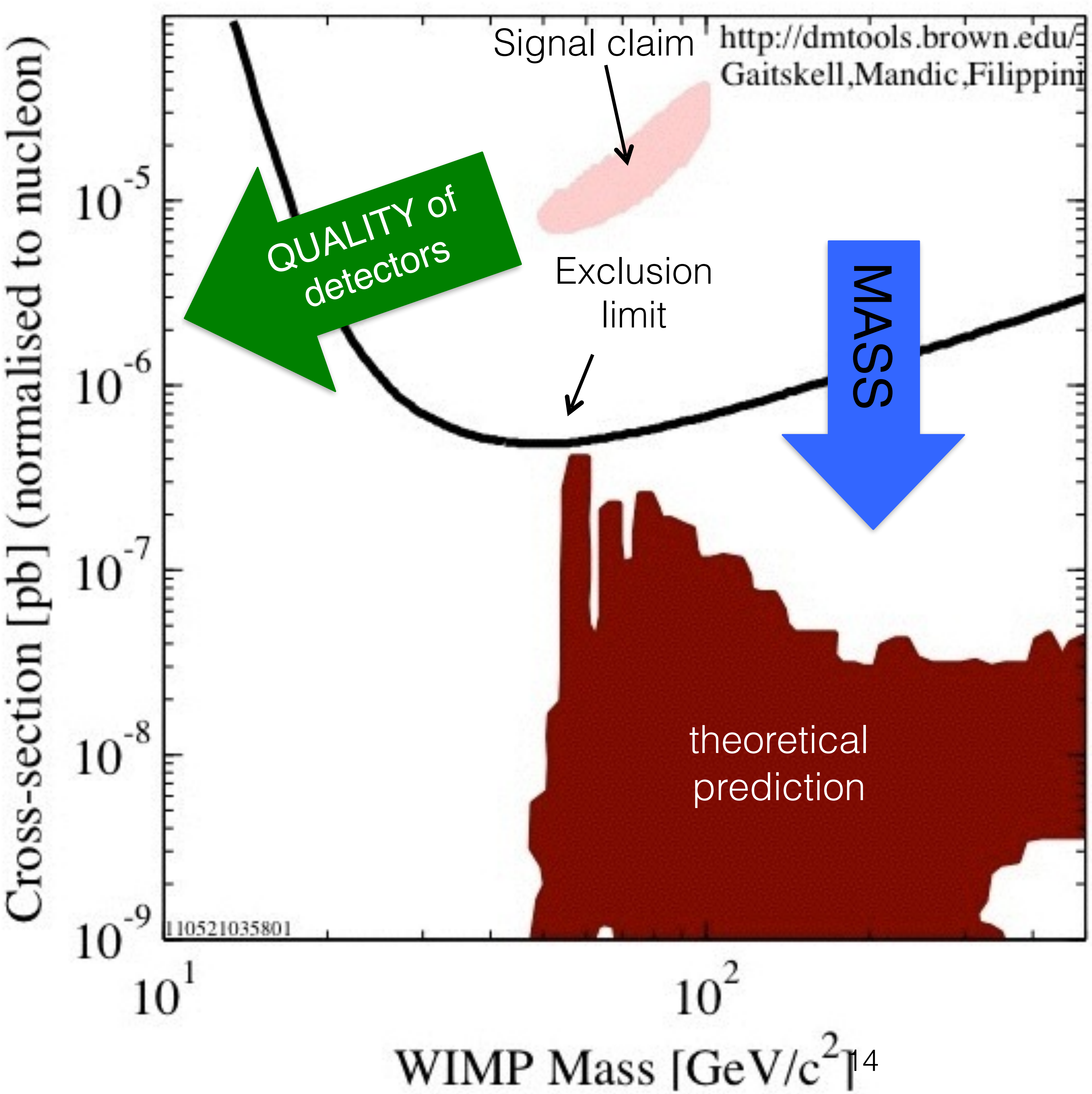

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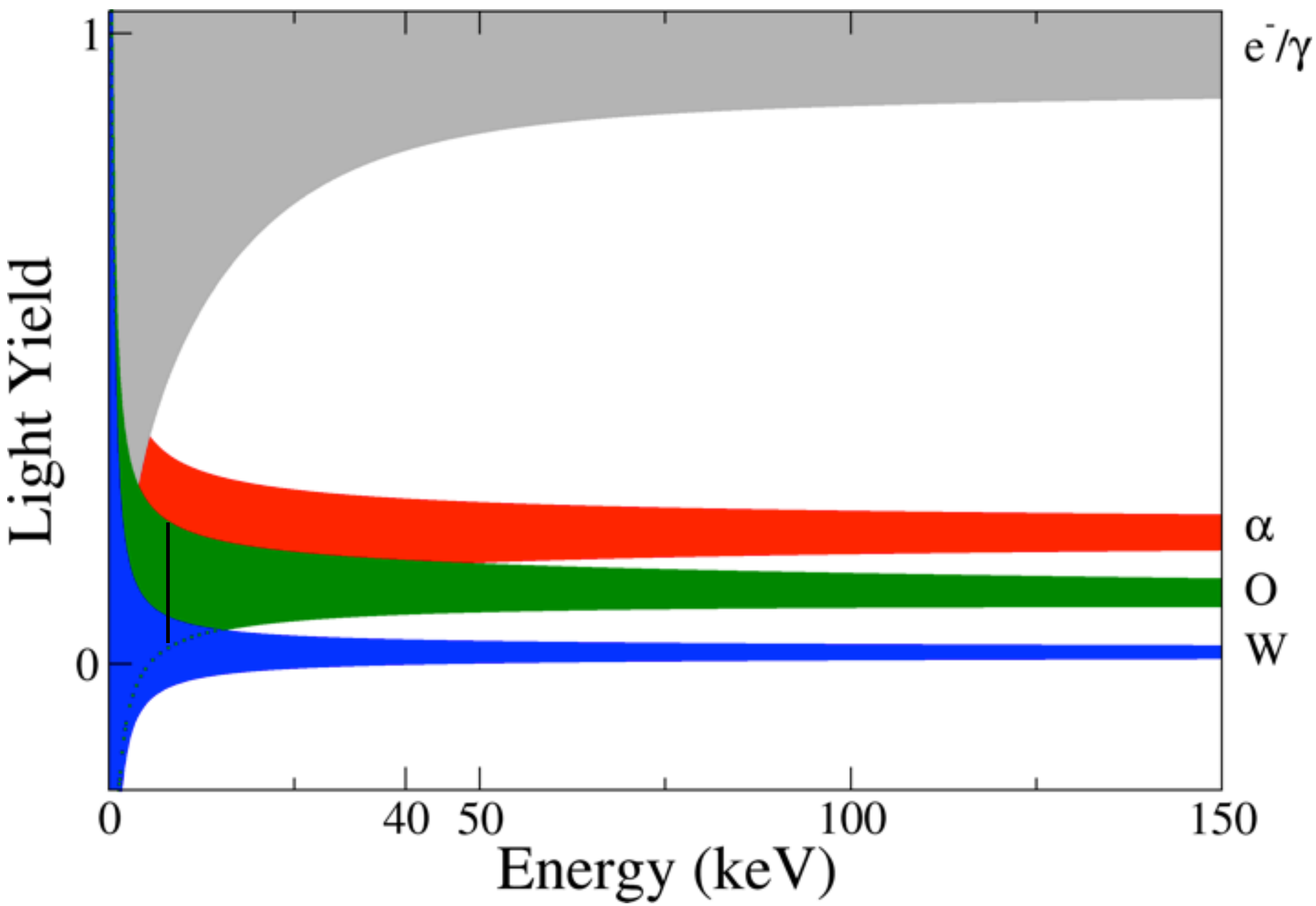
Migliorare la sensibilità a basse masse

Tre strategie fondamentali:



Migliorare la sensibilità a basse masse

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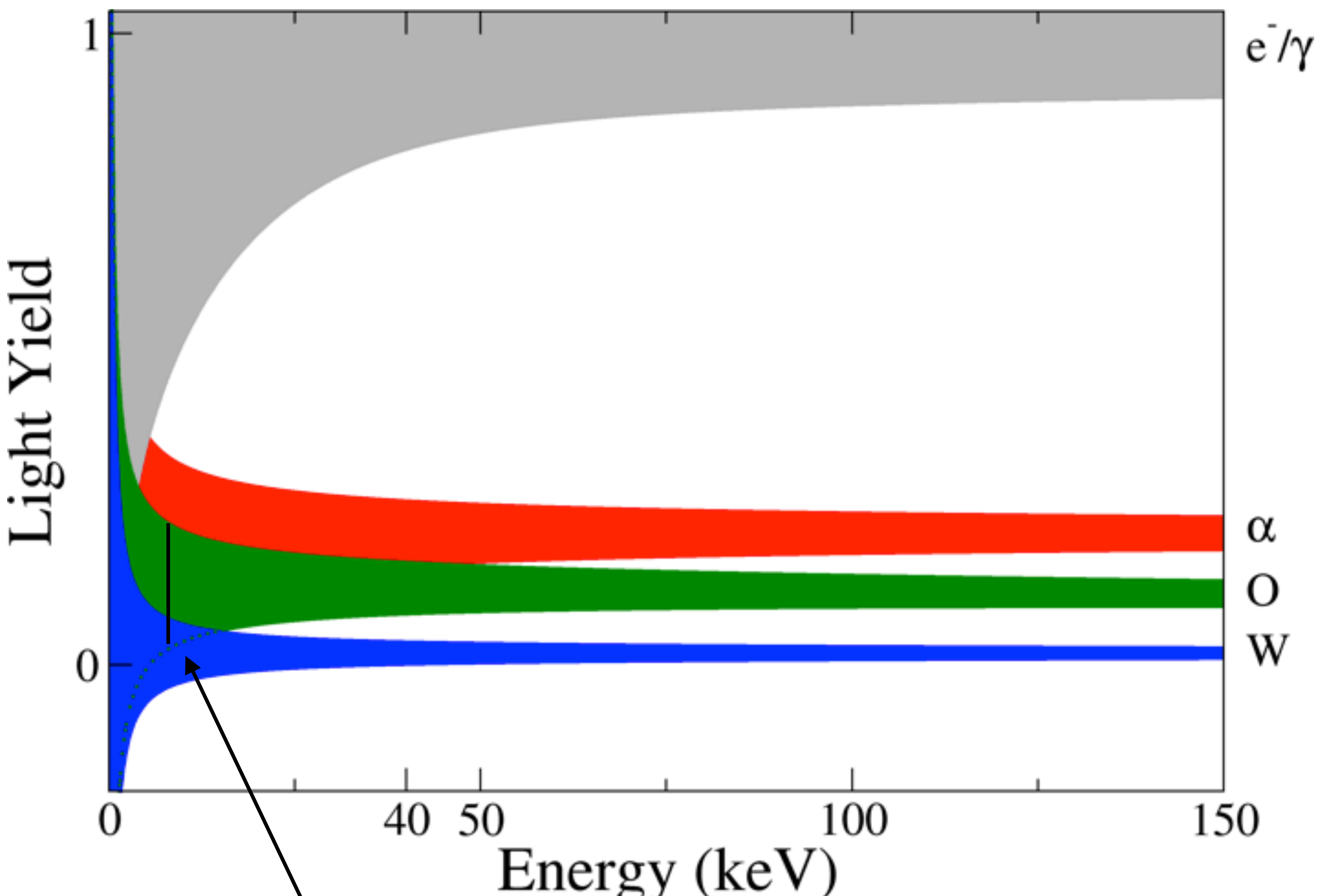
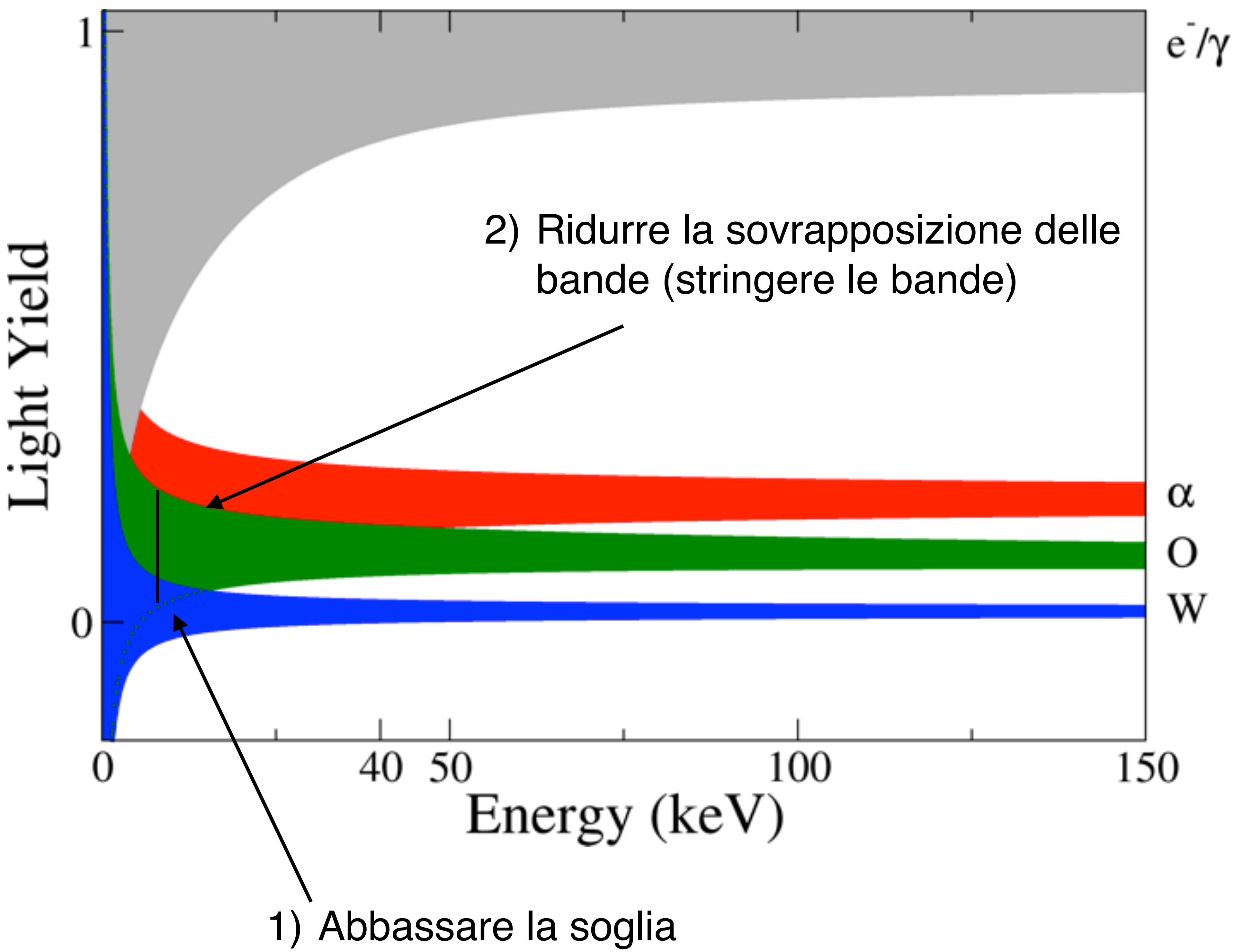


1) Abbassare la soglia

Migliorare la sensibilità a basse masse

Tre strategie fondamentali:

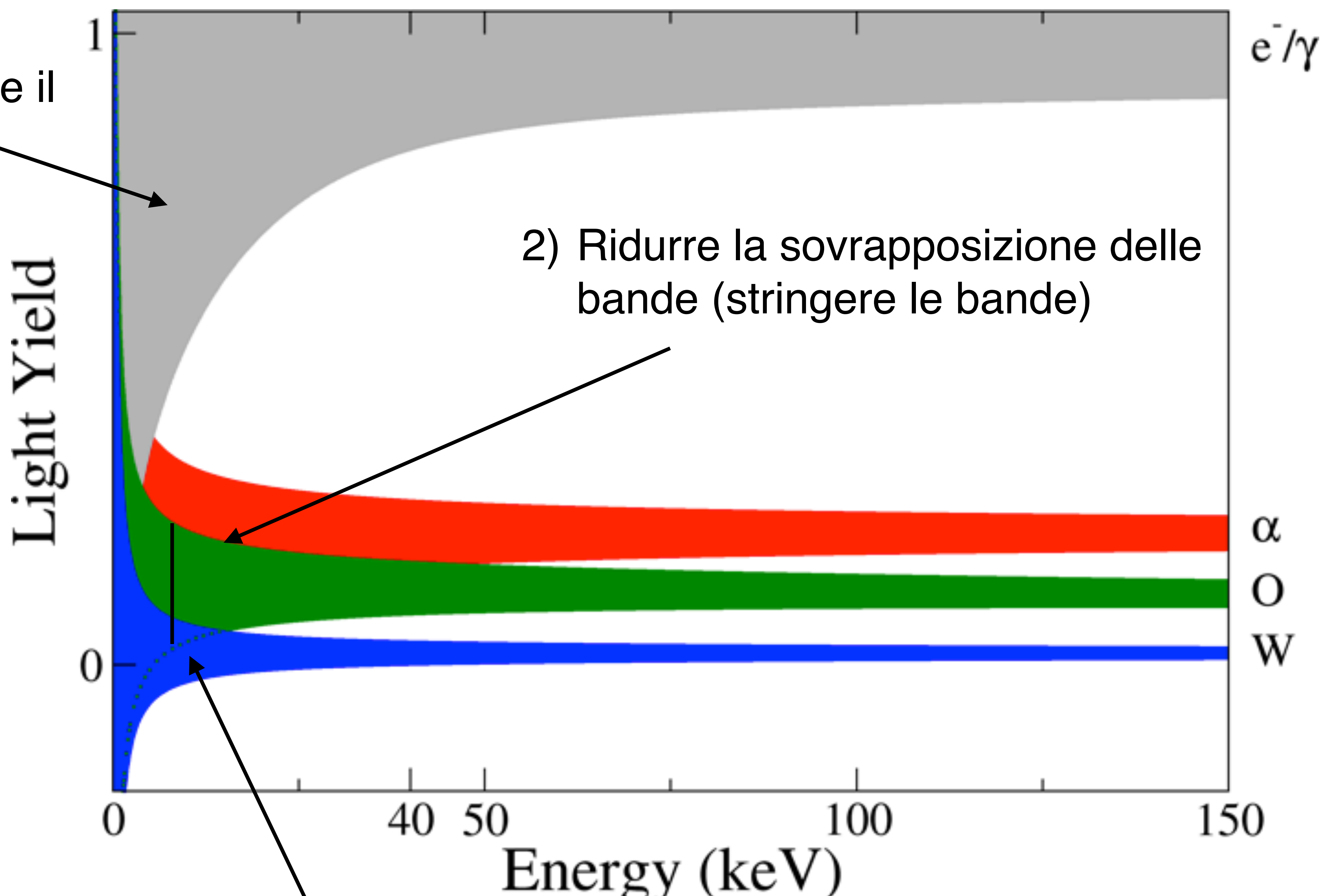


Migliorare la sensibilità a basse masse

Tre strategie fondamentali:

3) Migliorare il fondo

2) Ridurre la sovrapposizione delle bande (stringere le bande)



1) Abbassare la soglia

Abbassare la soglia

Soglia energetica per i rivelatori di CRESST-II con masse ~ 300 g: 300-800 eV.

Strategia:

- Ridurre la massa dei rivelatori.
    - Dal modello termico (confermato sperimentalmente) dei rivelatori la risposta è dominata dalla capacita termica del TES a parità di raccolta di fononi

$$\Delta T \sim \Delta E / C$$

Essendo il rumore dominato da contributi non termici (i.e. non fononi sul main bolometer), S/N migliora.
Riducendo la massa dei rivelatori da ~ 250 g a 24 g (2x2x1 cm^2) ci aspettiamo di raggiungere una soglia (conservativa) dell’ordine di 50 - 100 eV.

Migliorare la raccolta di luce

L'allargamento delle singole bande si riduce all'aumentare della luce raccolta.

Strategia:

- Ridurre la massa dei rivelatori.
    - Diminuzione dell'auto-assorbimento
- Aumentare la superficie di raccolta della luce (doppi rivelatori o rivelatori a backer)

Raccolta di luce aumentata di un fattore 3 (atteso)

Ridurre il fondo

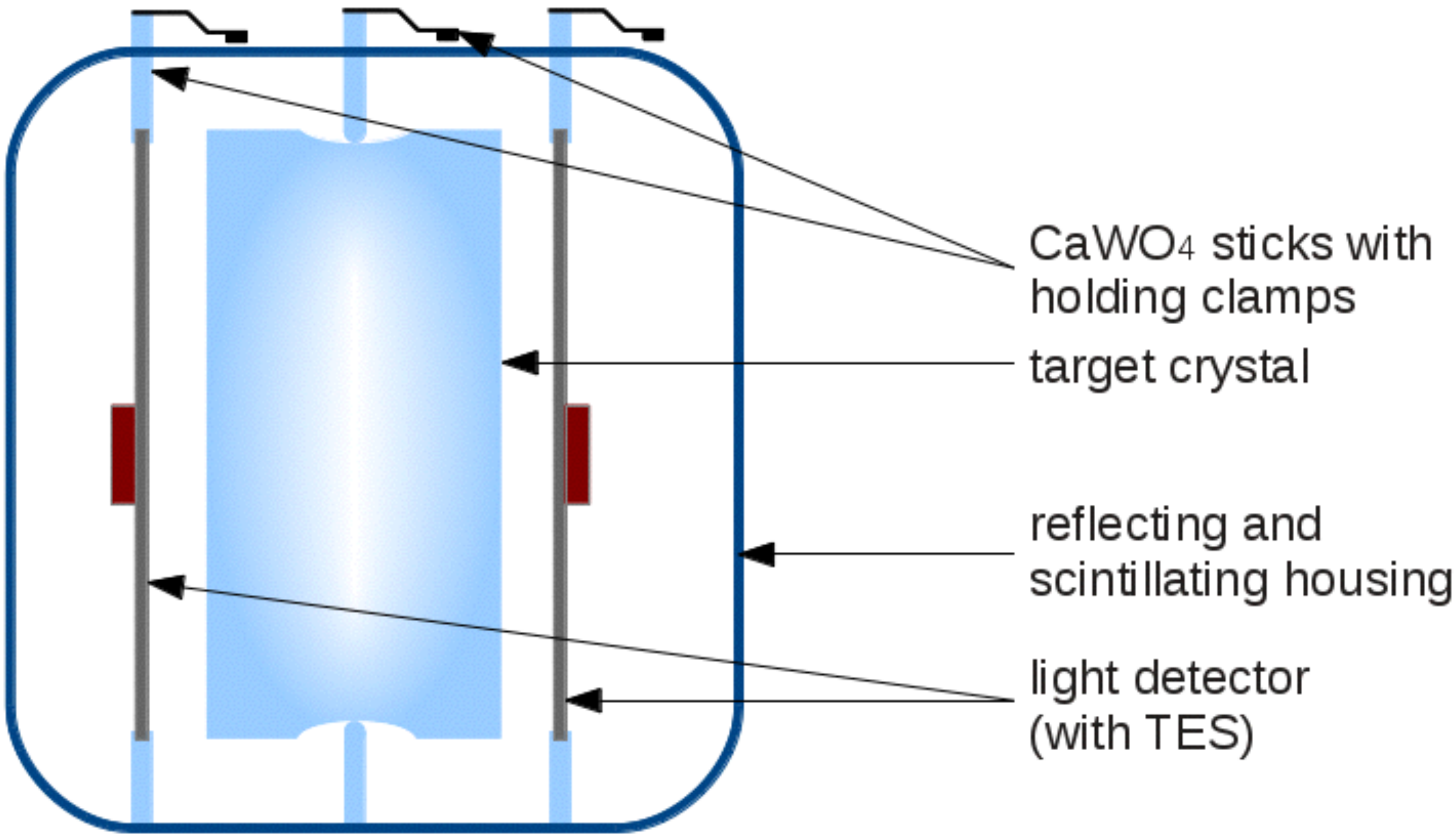
Il fondo e-/γ originato principalmente nei cristalli e nelle strutture attorno.

Strategia:

- Selezione delle polveri ha già provato un fattore 10.
- Ri-cristallizzazione migliora il fondo ad ogni passaggio (dimostrato). Grazie alla facilty di crescita alle TUM è possibile tenere sotto controllo questi processi.
- Selezione dei materiali, Rn suppression.

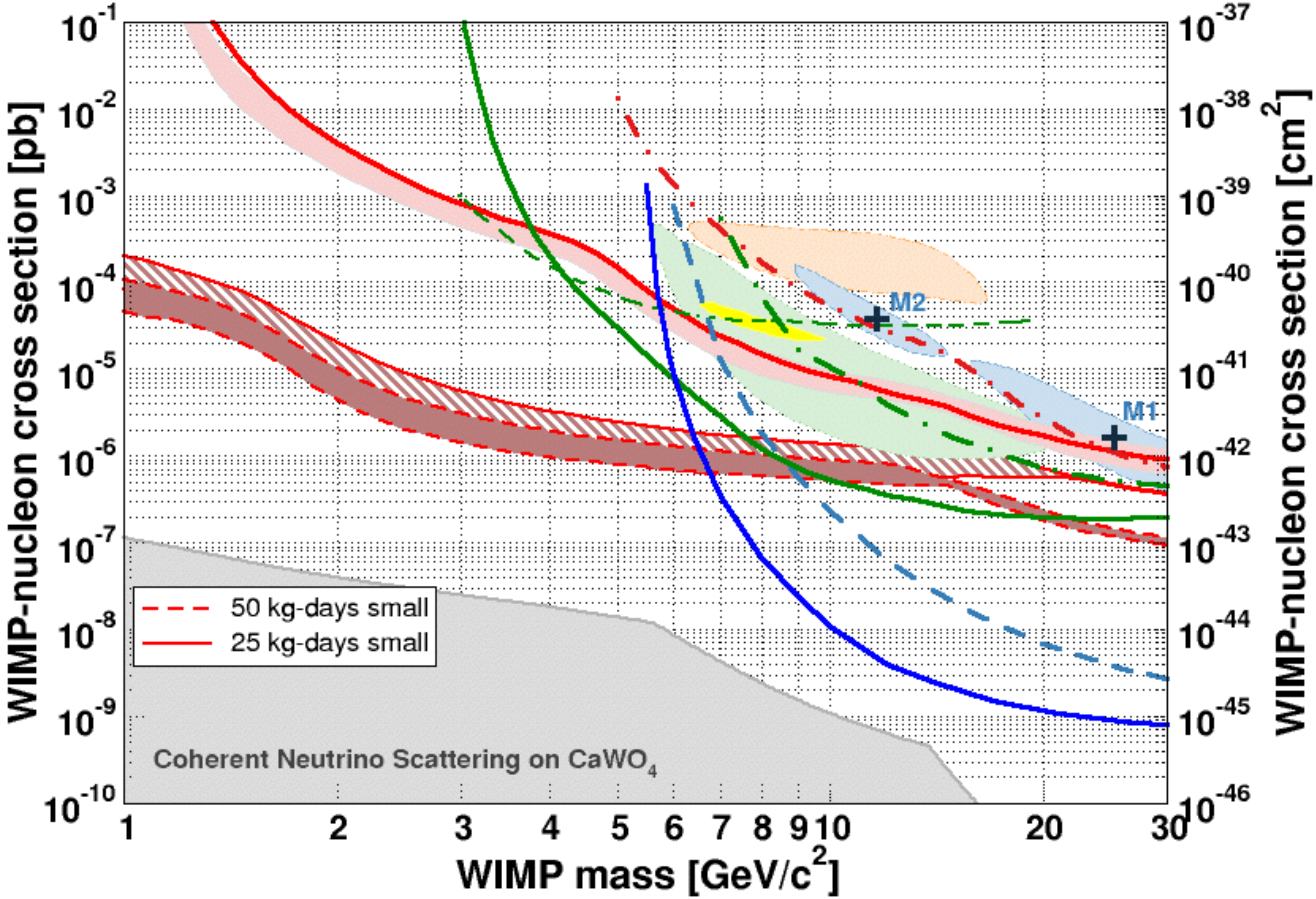
Goal: fattore ~50 (ottimistico 100)

Nuovo rivelatore



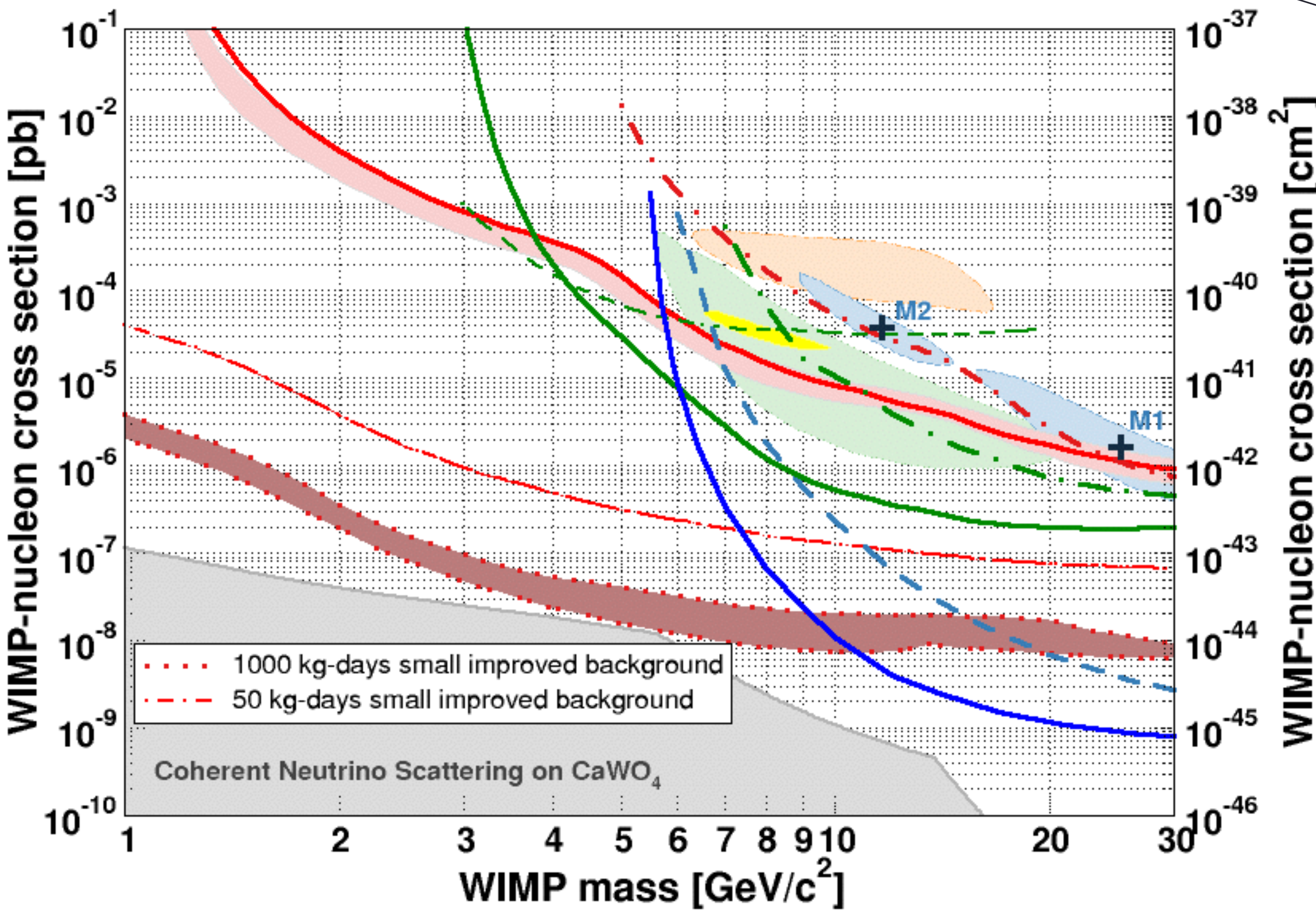
Sensibilità (I)

Preliminary



Sensibilità (I)

Preliminary



Conclusioni

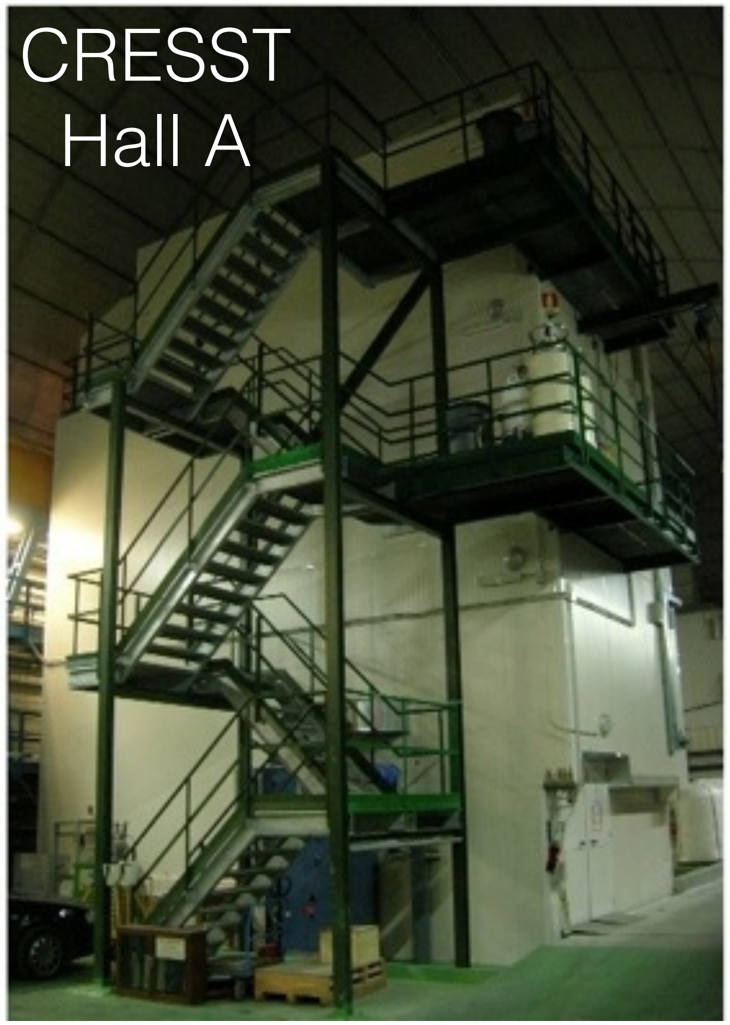
- Con rivelatori a bassissima soglia e alta radio-purezza si apre una nuova era per la rivelazione di WIMP leggere

- Un radicale cambiamento nello sviluppo dei rivelatori (micro-macrobolometri) ci può portare a sensibilità leading a livello mondiale

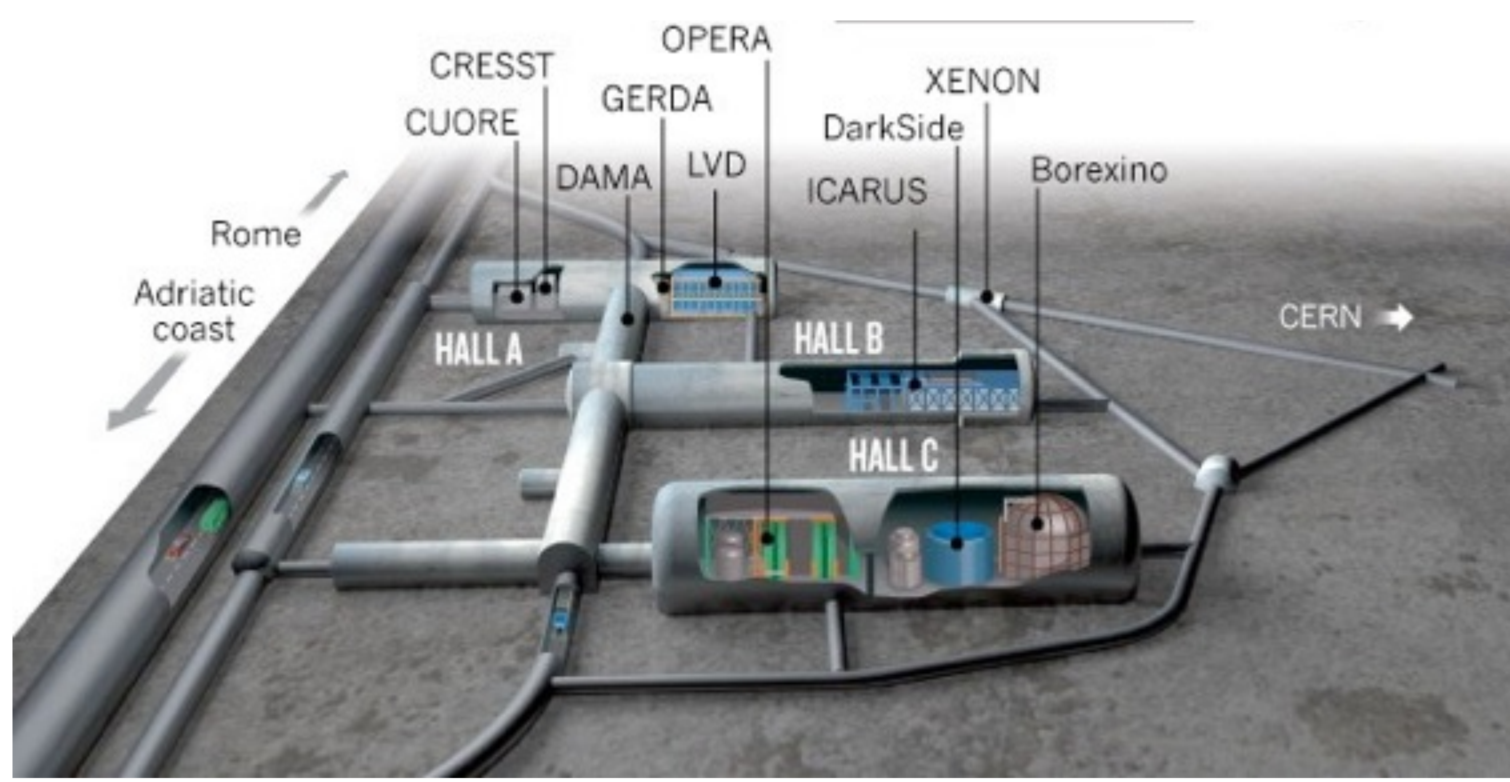
- Un programma di ricerca aggressivo è accessibile senza modifiche maggiori del setup sperimentale nei prossimi 5 anni

Backup slides

CRESST @ Gran Sasso



- ~3600 m.w.e. deep
- μs: ~3x10^{-8}/(s cm^2)
- γs: ~0.73/(s cm^2)
- neutrons: 4x10^{-6} n/(s cm^2)



Collaboration

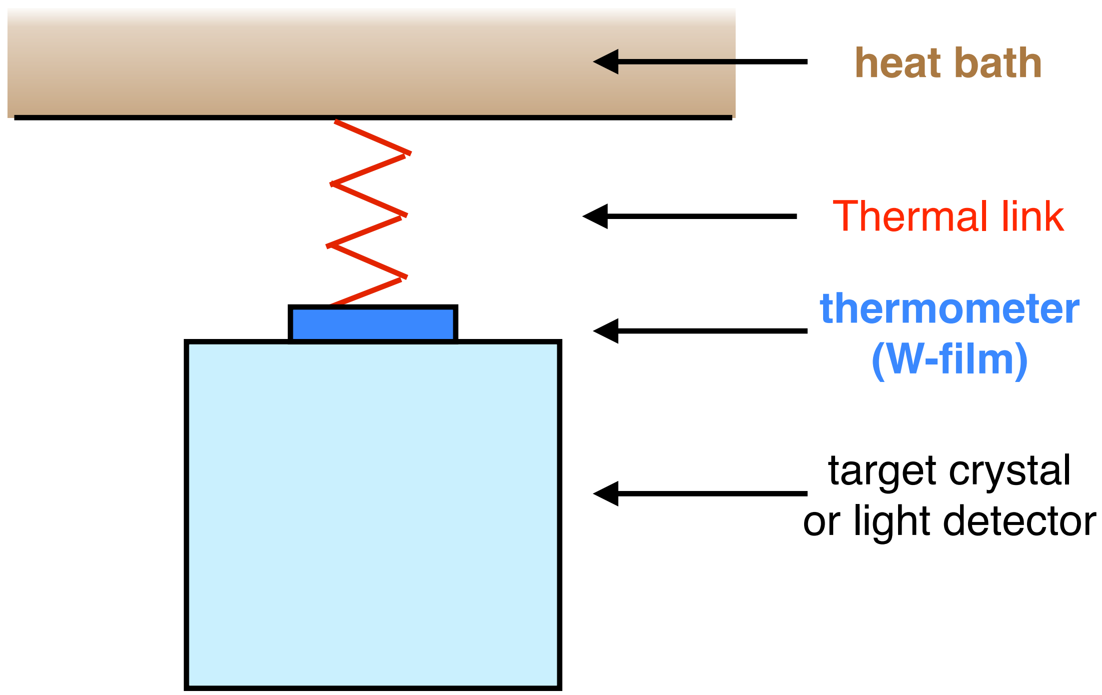
CRESST collaboration: ~40 scientist from 7 institution (mainly Germany + Italy, UK, Austria, Spain)

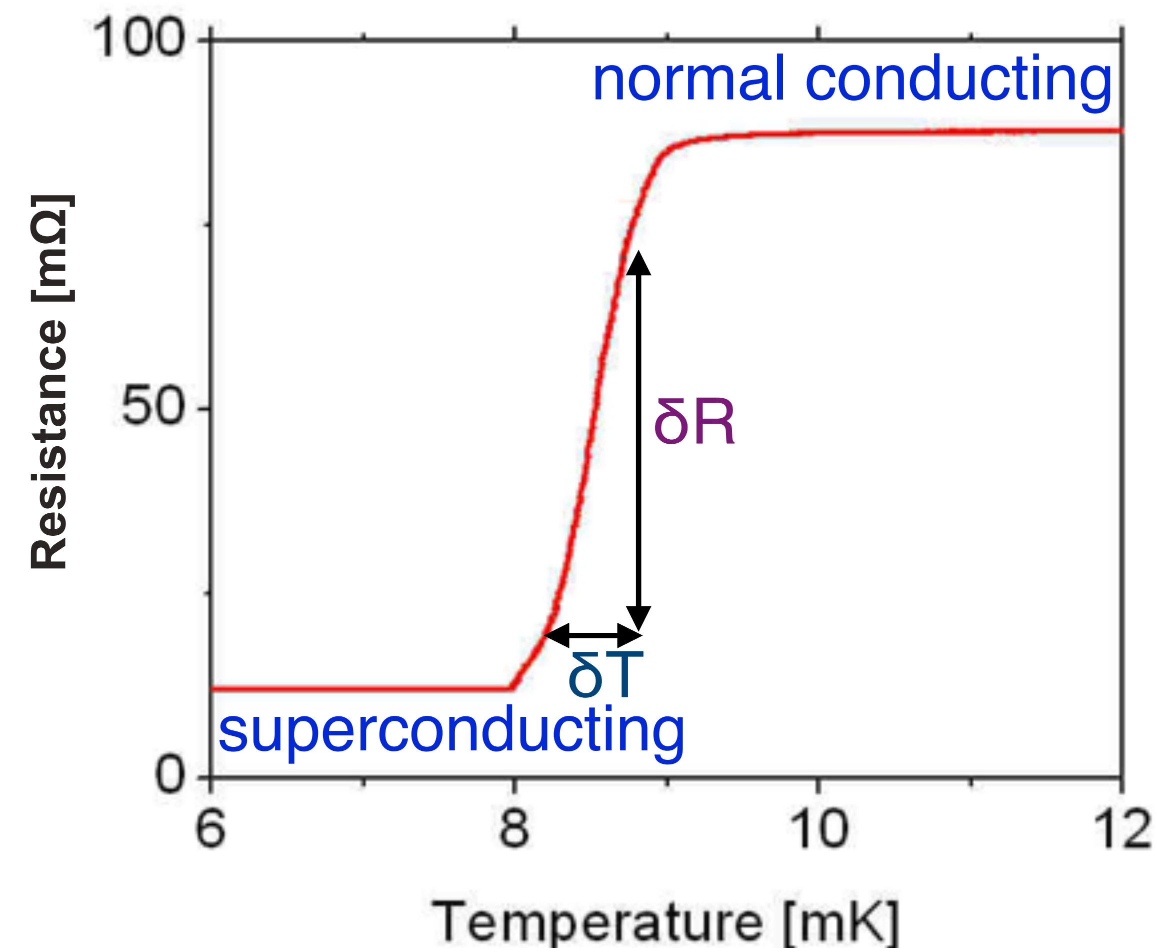
Max-Planck-Institut für Physik, München
Physik-Department E15, Technische Universität München
INFN Laboratori Nazionali del Gran Sasso
Eberhard-Karls-Univerität Tübingen
Department of Physics, University of Oxford
HEPHY, Österreichische Akademie der Wissenschaften and Technische Universität Wien
Grupo de Física Nuclear y Astropartículas,
Universidad de Zaragoza and Laboratorio Subterránea de Canfranc.

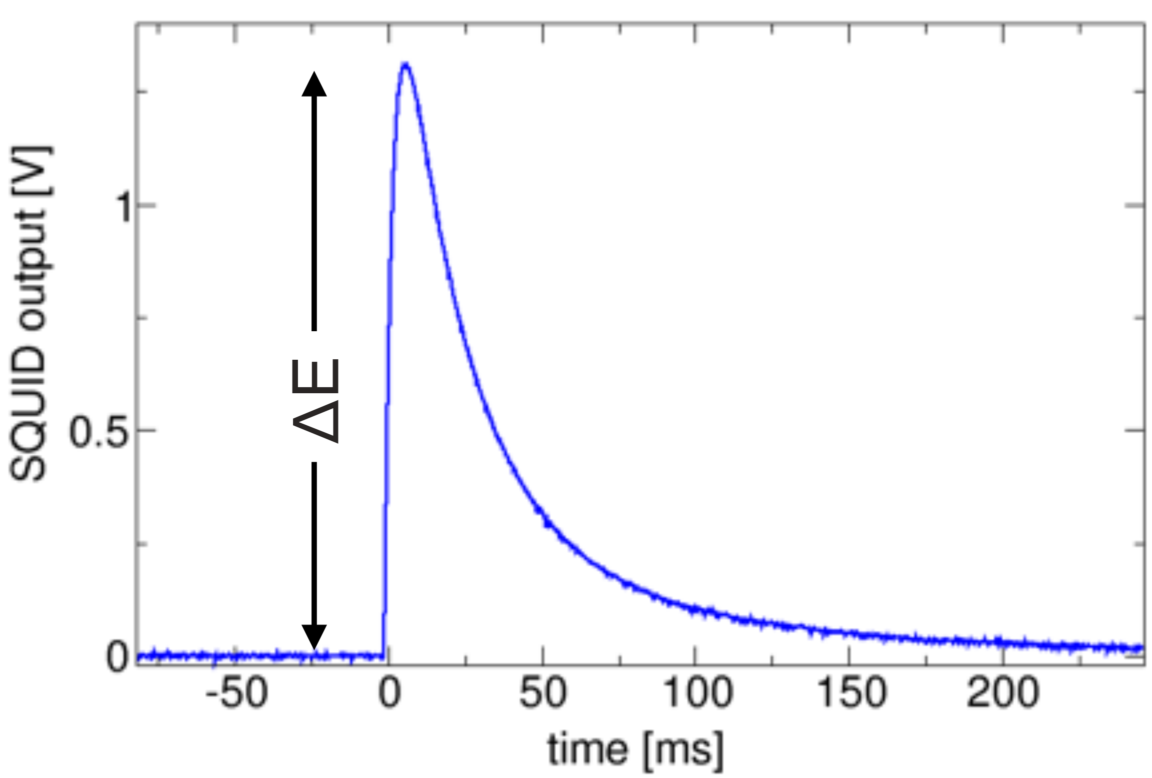
New spokesperson: **F. Petricca**, MPP München (replacing W. Seidel)

INFN participation:
historically: individual participation from C.Bucci (LNGS) since 1995.
Since 2013 P.Gorla and L.Canonica joined the project.

Operating principles





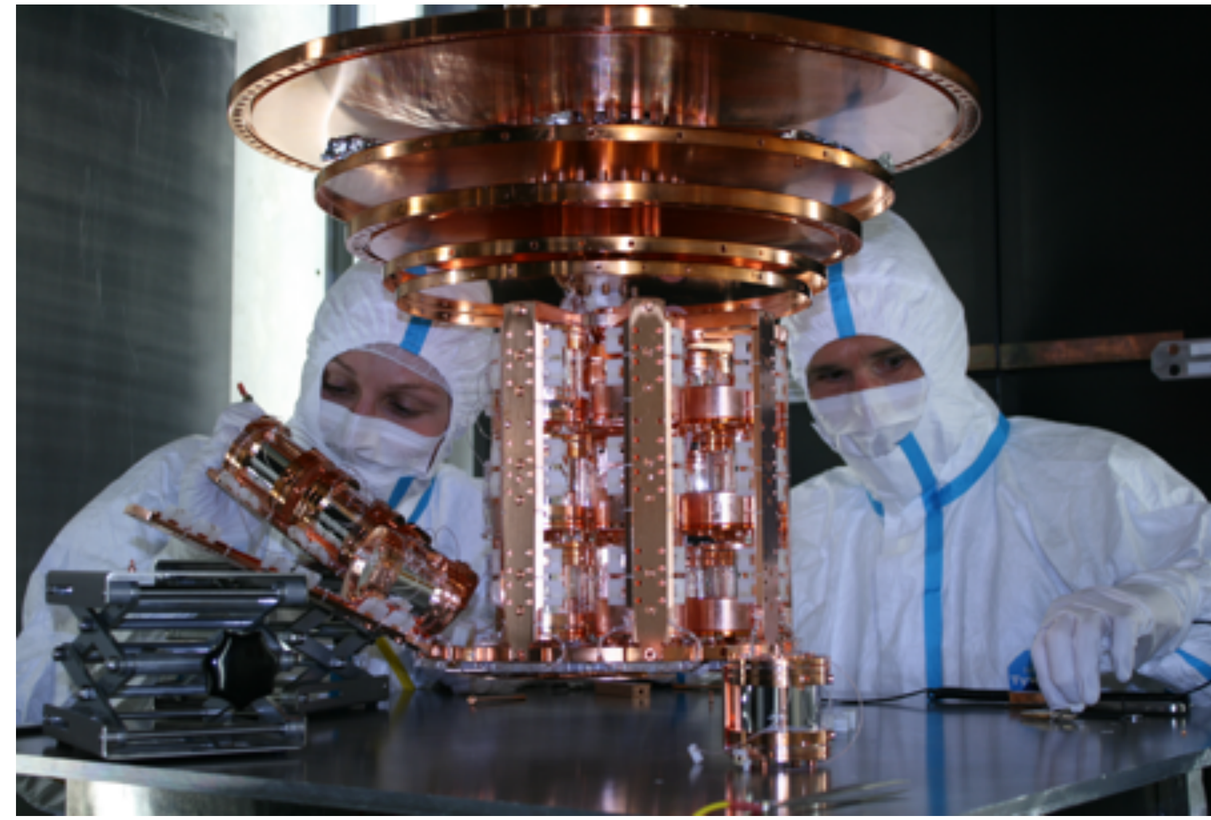


SQUID based read out
Operating temperature: 10 to 20 mK
Width of transition: ~1mK, keV signals: ~ μK
Longterm stability: ~ μK

Advantages of technique:
- Precise calorimetric measurement of deposited energy
- Low energy threshold and excellent energy resolution
- Different materials

CRESST-II: a phased program

The flexible carousel design and the accessibility of the setup were projected to make CRESST-II a phased program. New improvement are introduced preserving the quality of the experiment.

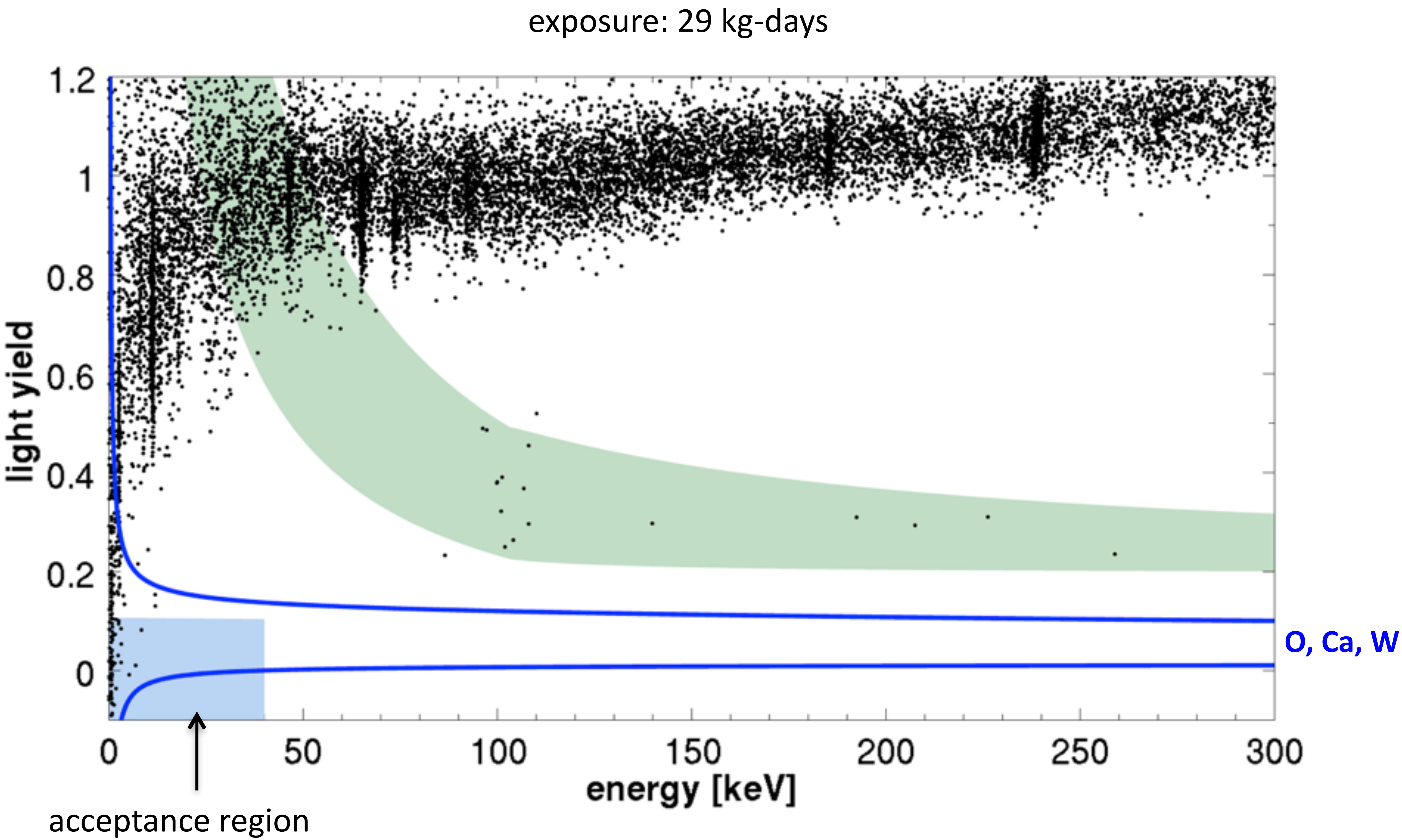


…

- Run 32 (2009-2011): 8 CaWO4 modules used for Dark Matter analysis. Net exposure after cuts: 730 kg days.
- Run 33 (2013-present): introduced 6 zero-bkg modules, low mass WIMP measurement
- Run 34 (2015-?): full zero-bkg setup

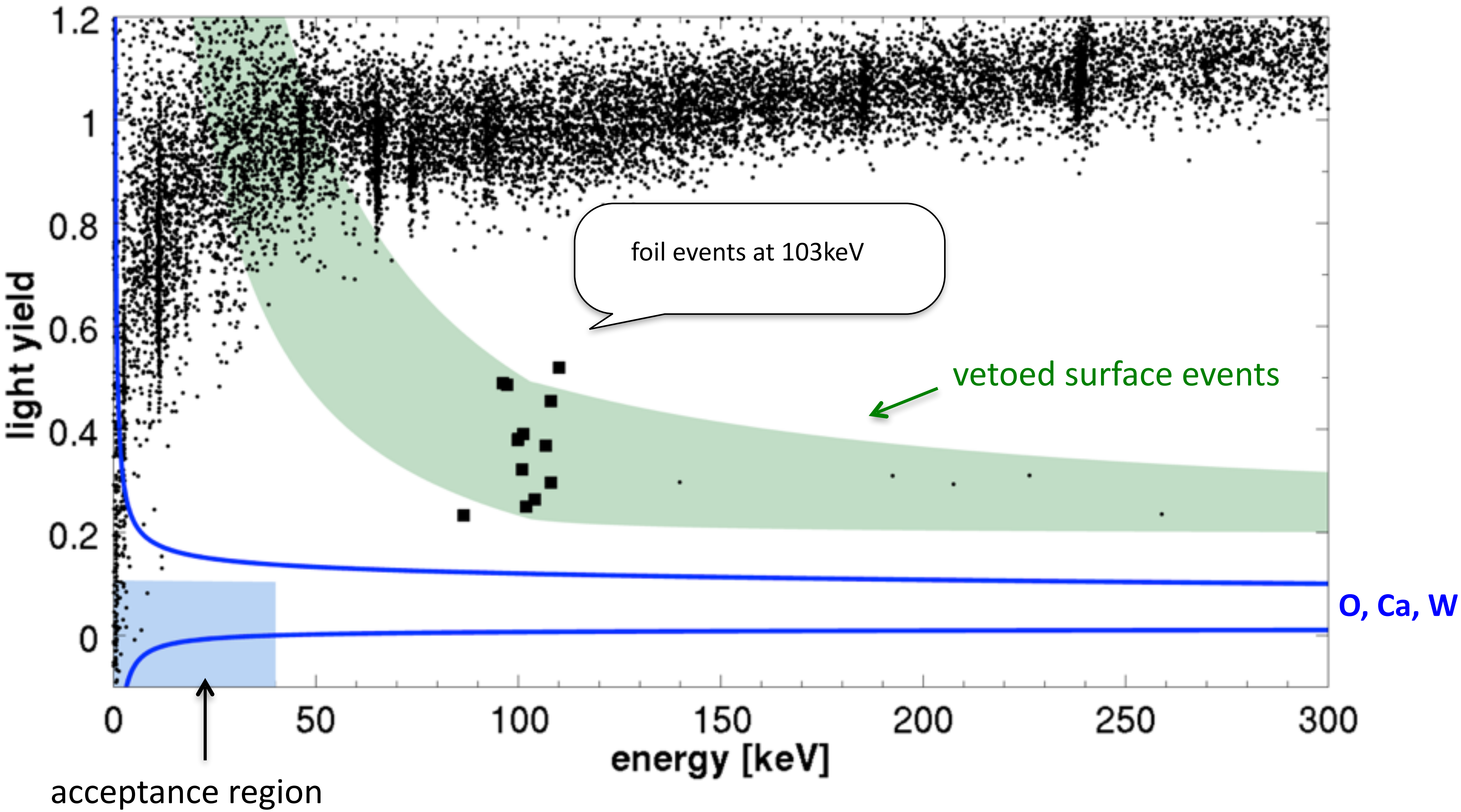
…

TUM-40: Surface Backgrounds



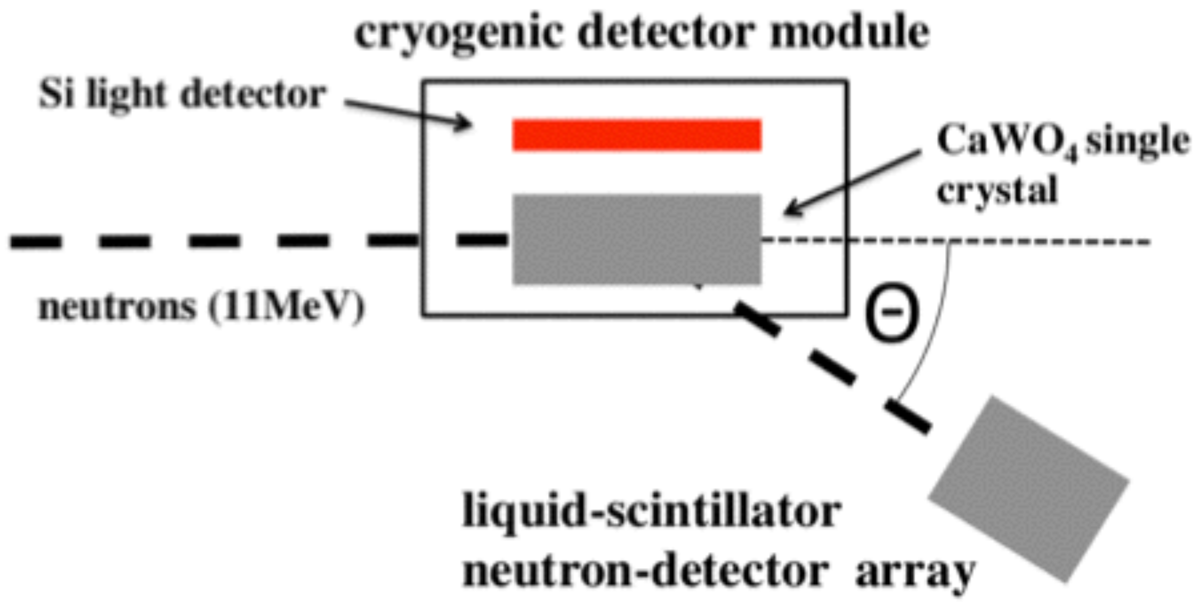
TUM-40: Surface Backgrounds

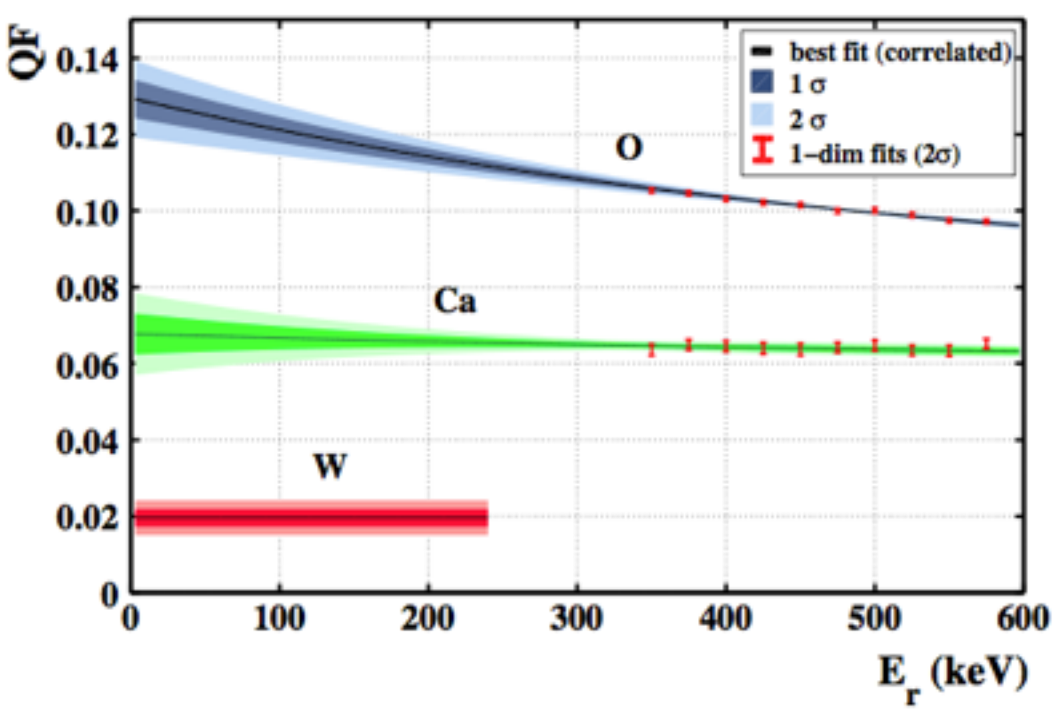
exposure: 29 kg-days



Quenching factor measurement

Neutron-Scattering Facility at MLL Accelerator





Precise measurement of QF of O, Ca and W at mK temperatures

For CRESST detectors in ROI:

QFO = (11.2 ± 0.5)%

QFCa = (5.94 ± 0.49)%

QFW = (1.72 ± 0.21)%

R.Strauss et al., accepted for EPJ-C, arXiv: 1401.3332

$CaWO_4$ Crystal Production at TU Munich

Furnace for **Czochralski process**

Dedicated machine for CRESST:

- All production steps under control
- Machining of crystals in-house

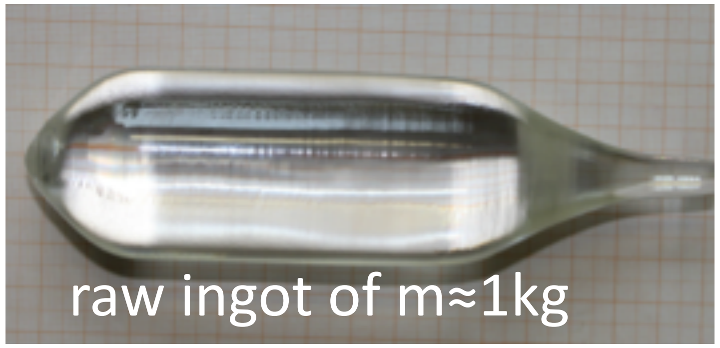
Goals :

- Increase **radiopurity**
- Increase **light output**
- Ensure supply

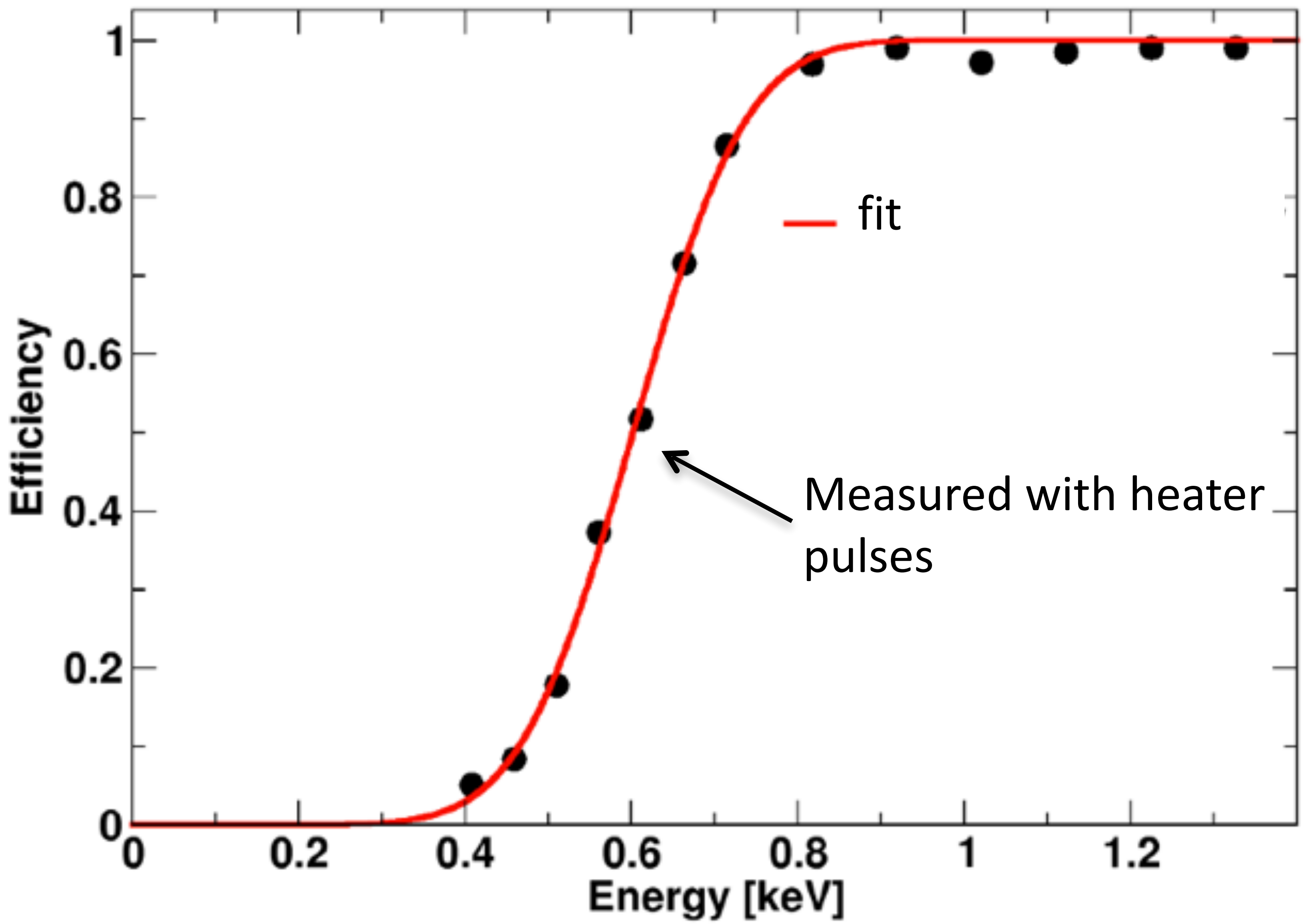
Major achievements:

- Reproducible growth process
- Crystals of CRESST size
- Unprecedented intrinsic radiopurity

A. Erb and J.-C. Lanfranchi, *CrystEngComm*, 2013,**15**, 2301-2304
M. von Sivers, Opt. Mat. 34, 11 (2012) 1843-1848, arXiv:1206.1588



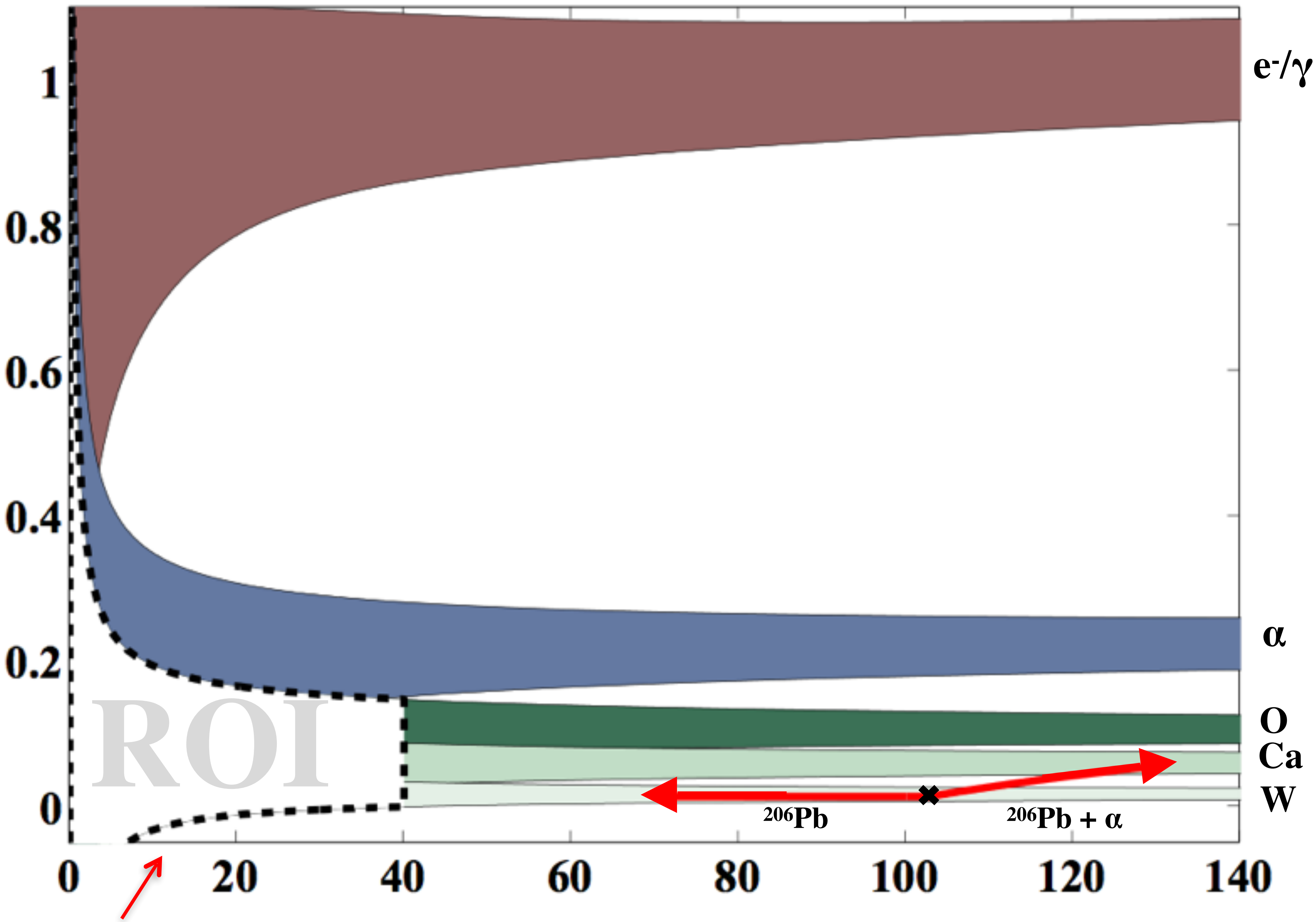
TUM-40: Trigger Threshold



- Extremely low trigger threshold of $\mathbf{E_{th} \approx 603eV}$
- Resolution of $\sigma \approx$ **107eV** in agreement with resolution of gamma lines

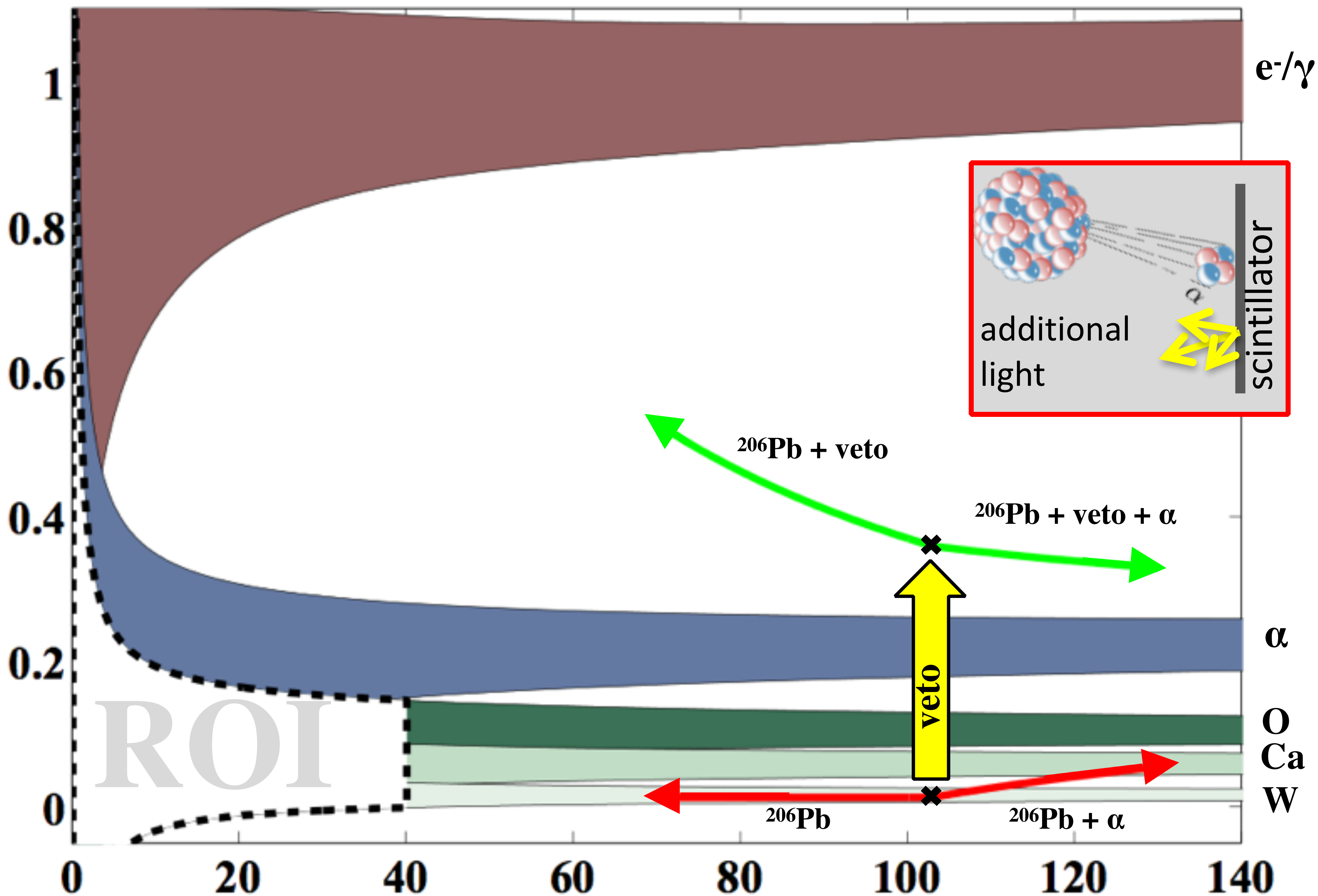
- Nuclear-recoil energy **precisely known**!

Signal and Backgrounds

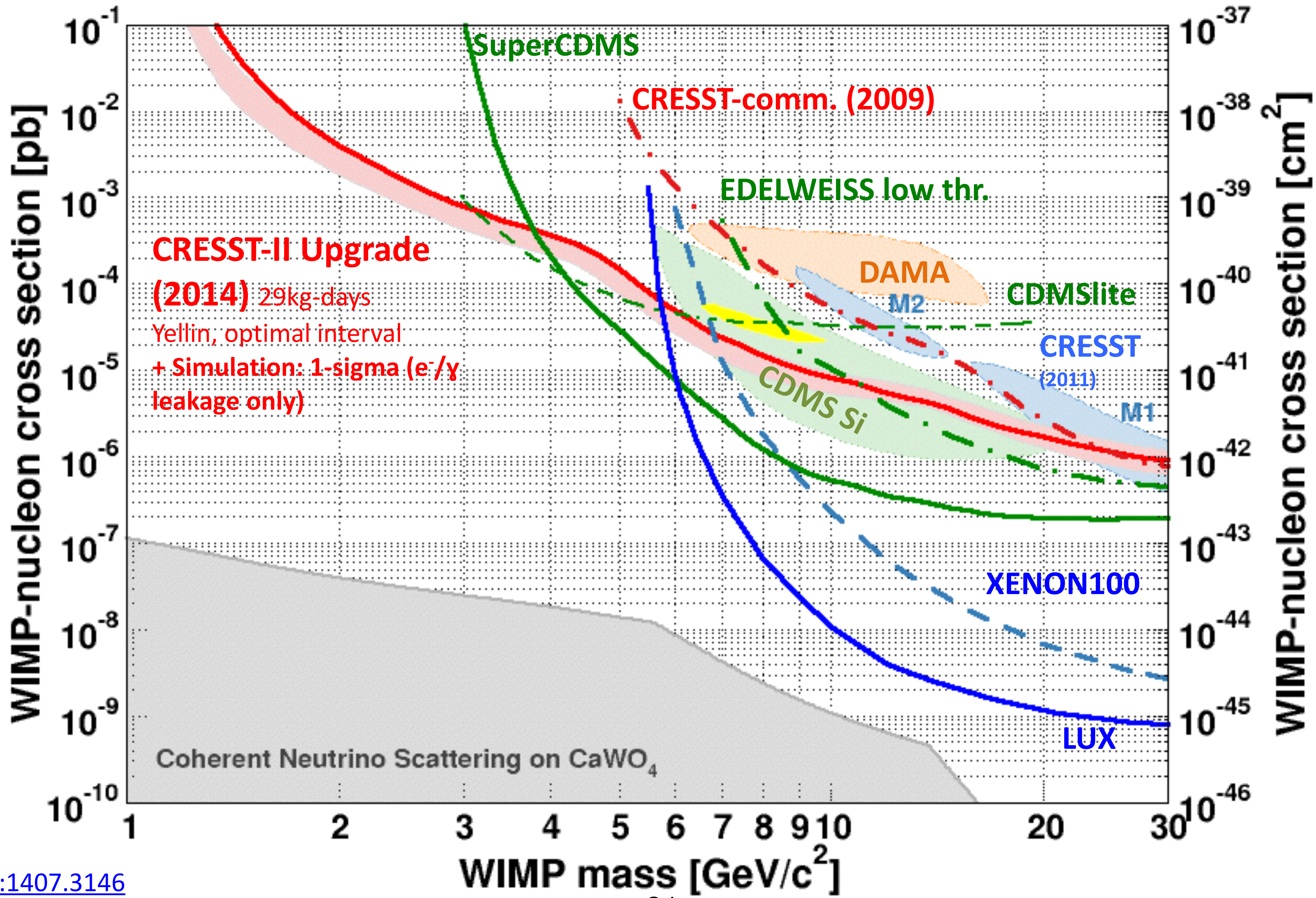


Region of interest for Dark Matter Search

Efficient Veto of Surface Backgrounds

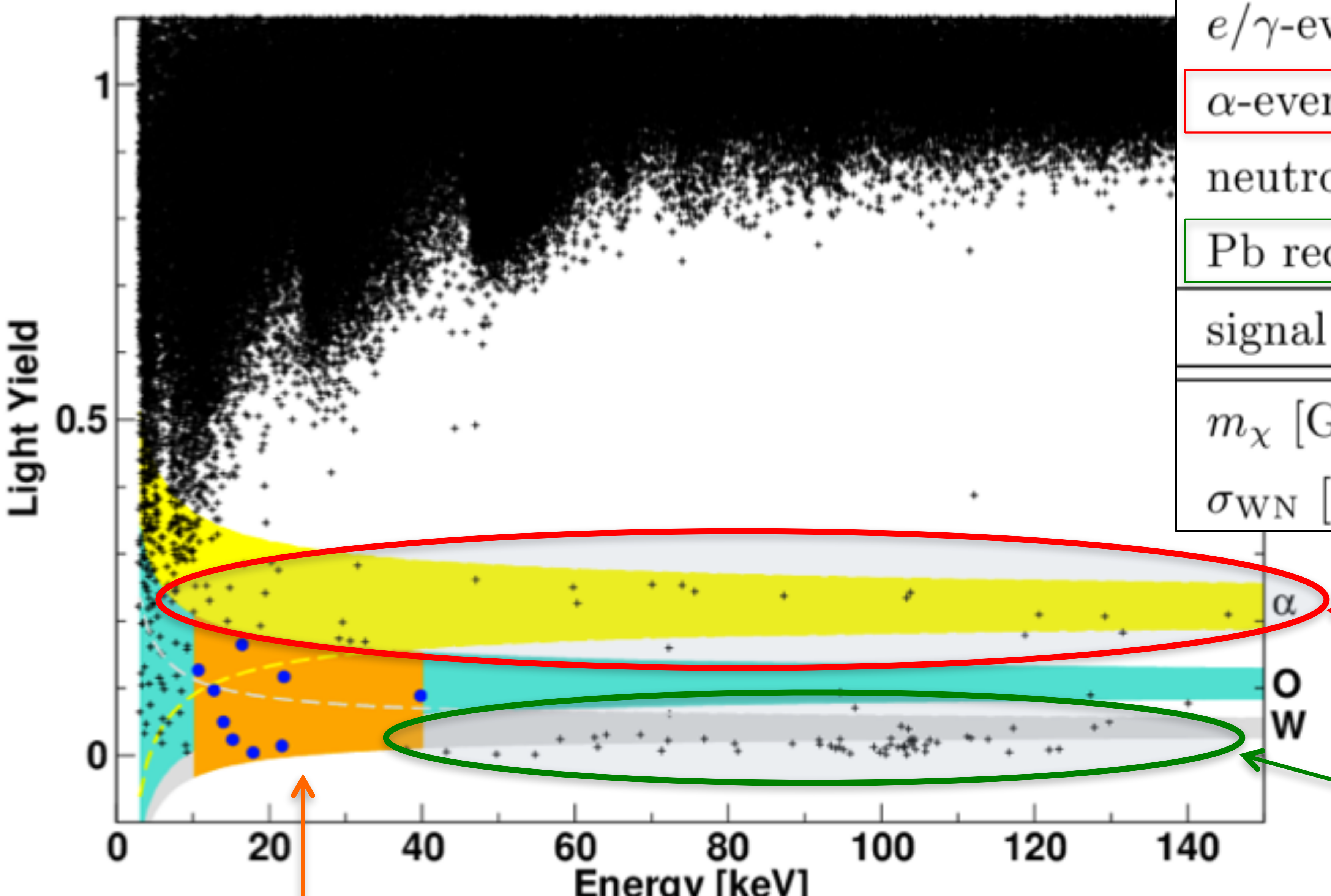


Data vs. Simulation



arXiv:1407.3146

Results from run 32



	M2
e/γ-events	8.00 ± 0.05
α-events	$11.2^{+2.5}_{-2.3}$
neutron events	$9.7^{+6.1}_{-5.1}$
Pb recoils	$18.7^{+4.9}_{-4.7}$
signal events	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	11.6
σ_{WN} [pb]	$3.7 \cdot 10^{-5}$

degraded alphas

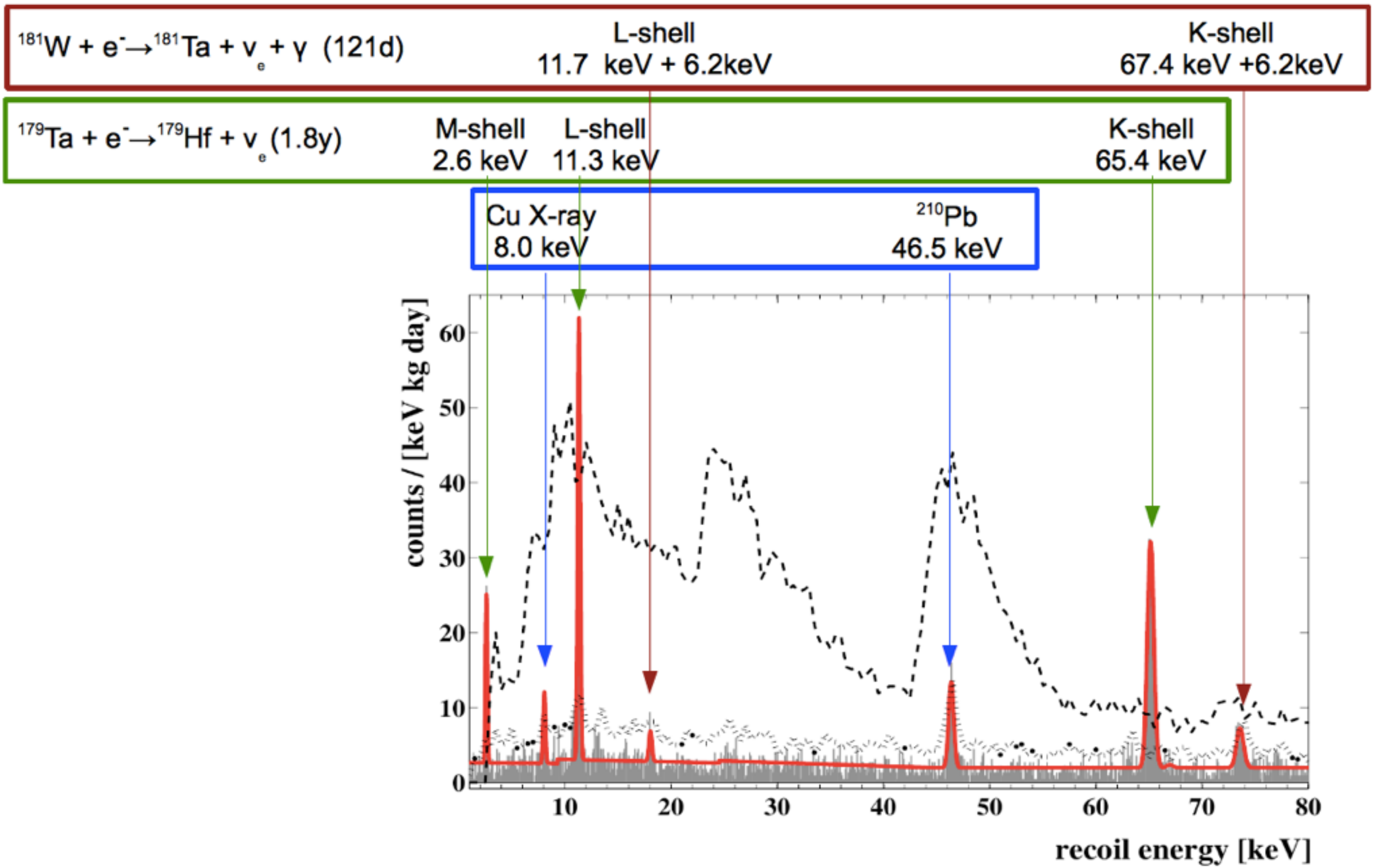
Pb recoils

ROI 15-40keV

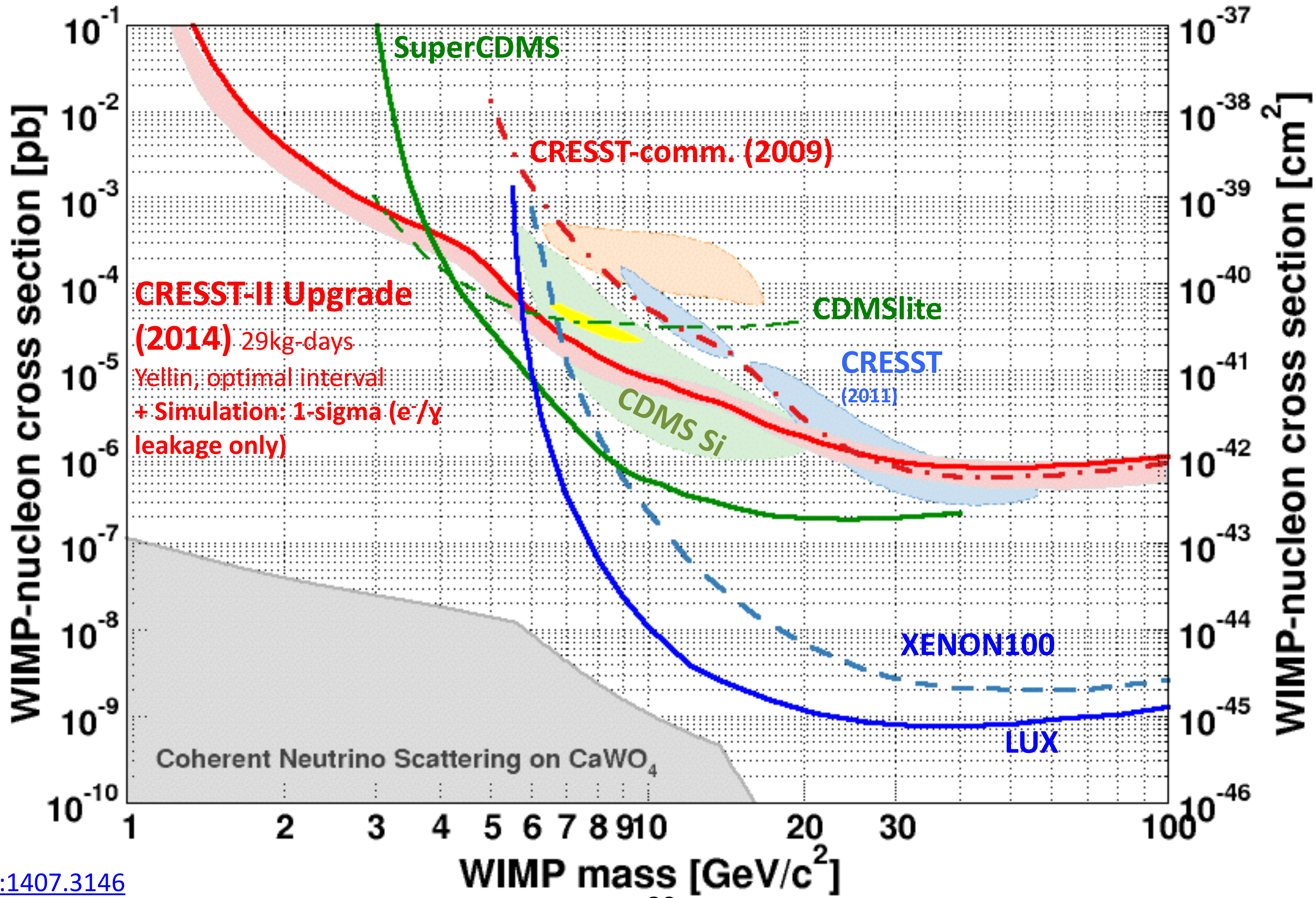
G. Angloher et al., Eur. Phys. J. C, 72, 4 (2012)

	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]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

TUM-40 contaminations



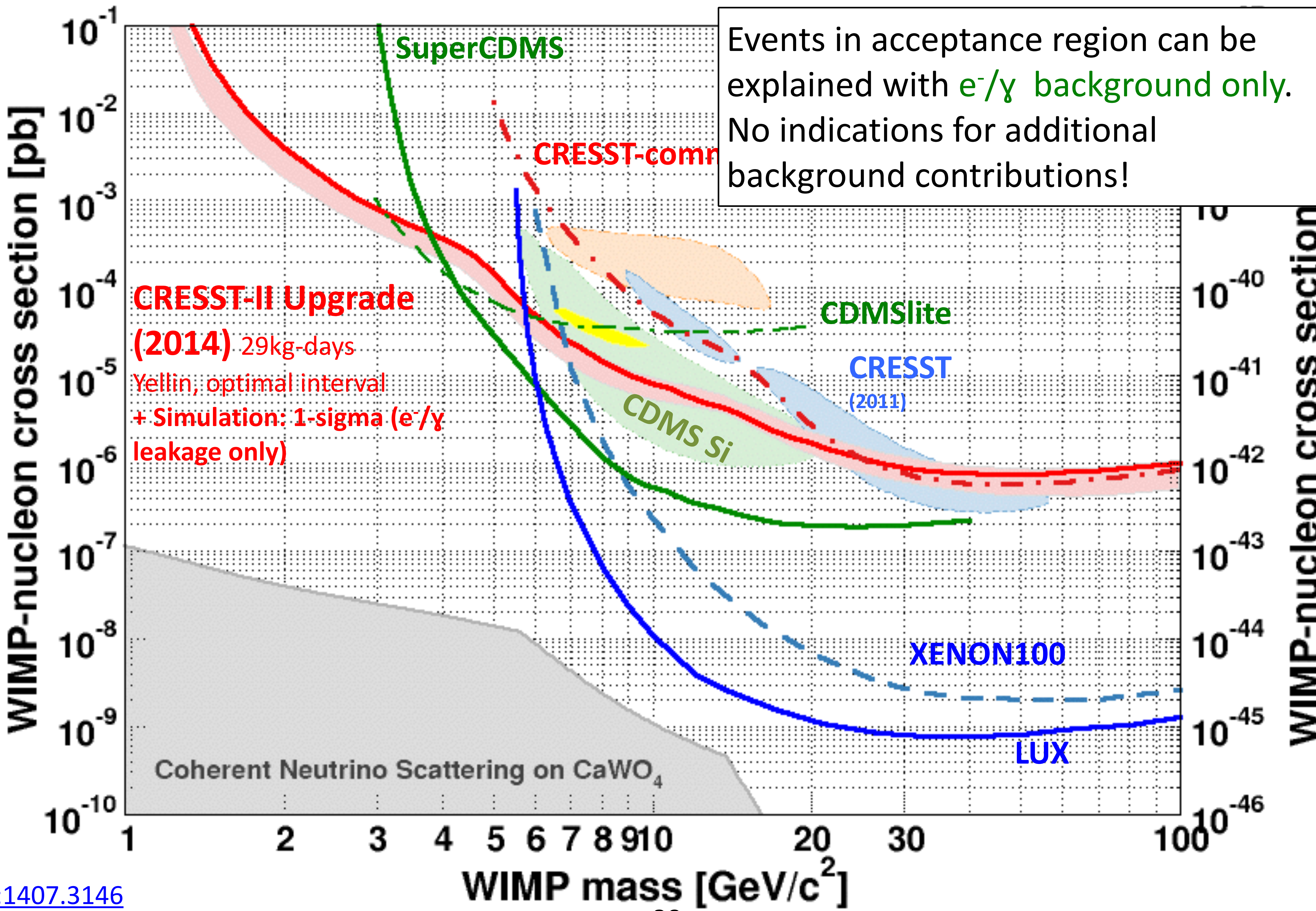
Data vs. Simulation



arXiv:1407.3146

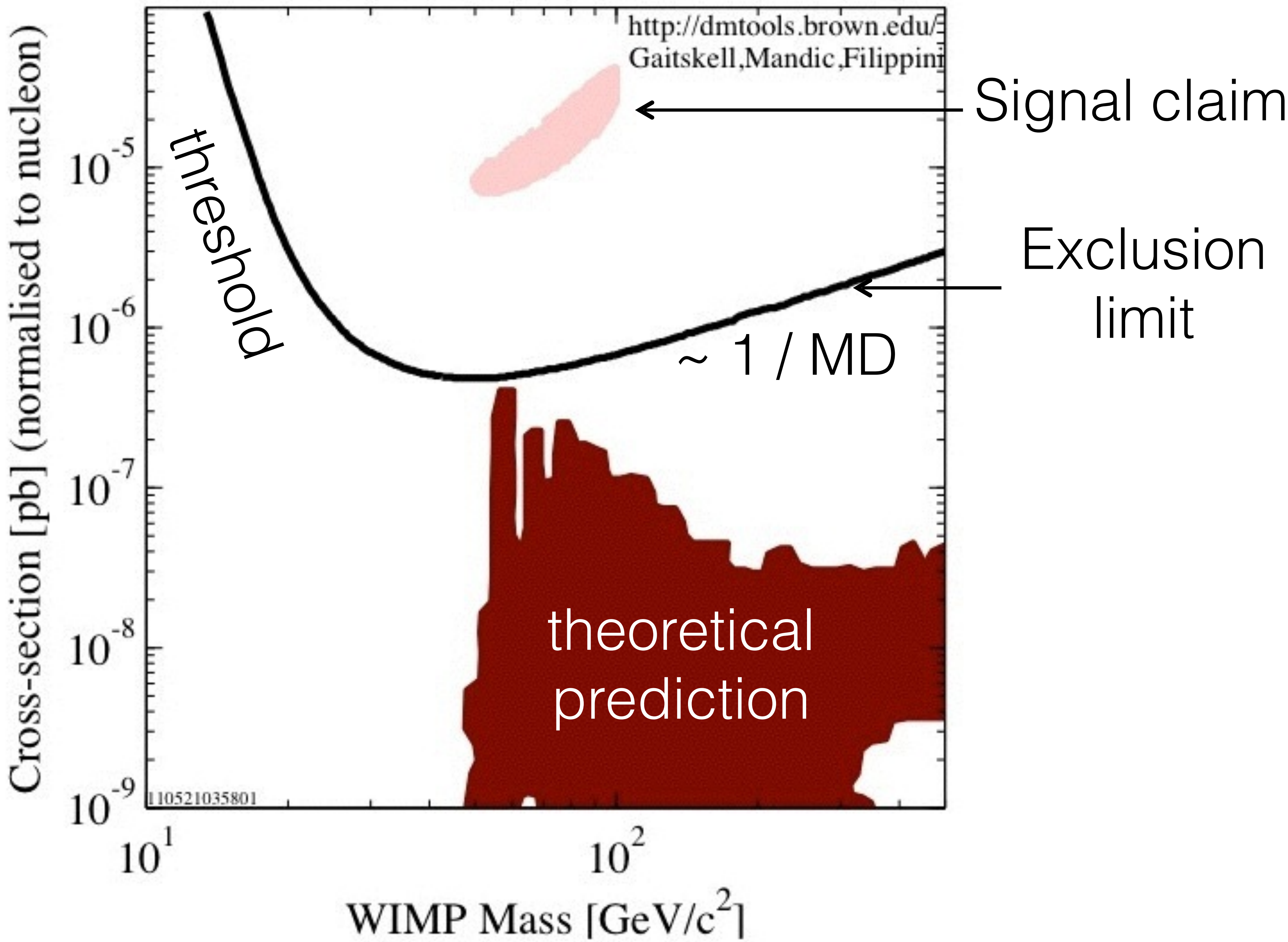
Data vs. Simulation

Events in acceptance region can be explained with e⁻/ɣ background only. No indications for additional background contributions!

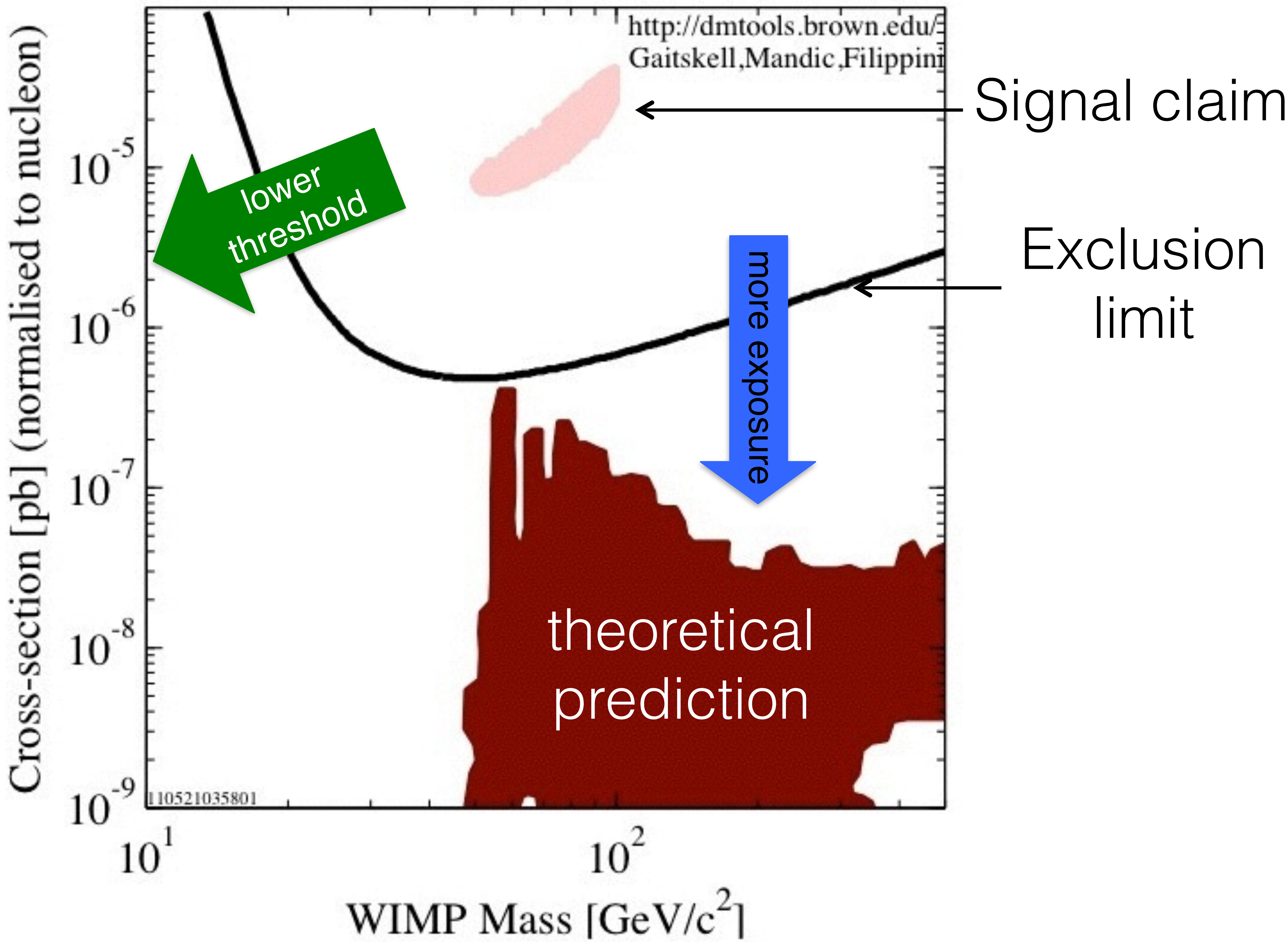


arXiv:1407.3146

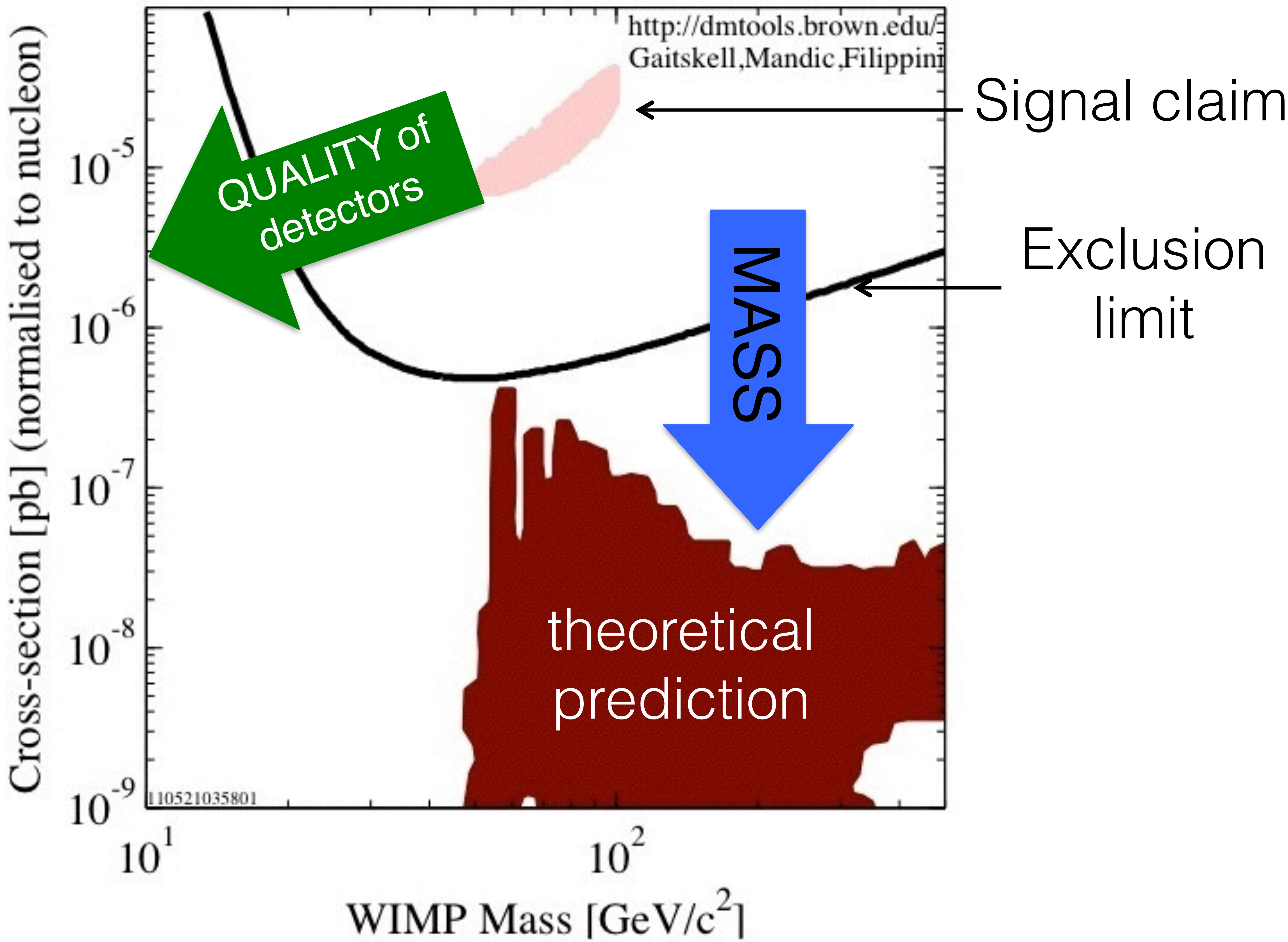
Exclusion Plot – Comparison of Results



Exclusion Plot – Comparison of Results



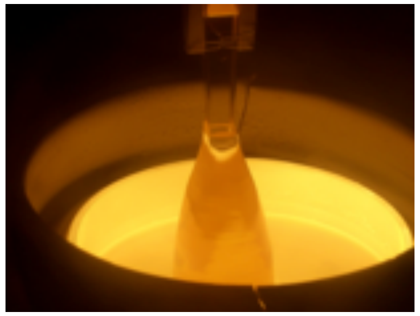
Exclusion Plot – Comparison of Results



Future plans

Goals:

- Background reduction by a factor of 50:
    - Bulk: re-crystallisation of $CaWO_4$ (proved)
    - External: material selection, new holder,better shielding.



- Increase of scintillation light output by a factor of 2
    - Slower growing speed (proved)
    - Smaller crystals (proved)

- Improvement of light detectors noise (factor 2):
    - Thinner detectors (?), new holder (?)