Latest Results of the CRESST Dark Matter Search
-
a Short Overview

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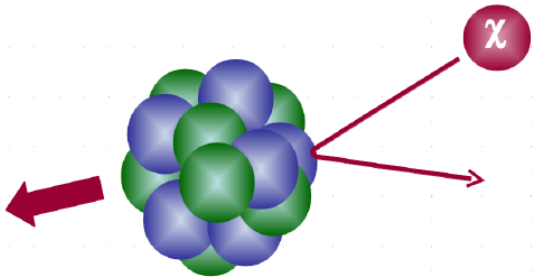
July 26th, 2012


Direct Dark Matter Search with the CRESST Experiment

- **C**ryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers
- **W**eakly **I**nteracting **M**assive **P**article

- CRESST aims for a WIMP detection via their elastic scattering off nuclei.



Challenges

- tiny recoil energies ($\mathcal{O}(10\,\mathrm{keV})$)
- featureless spectrum
- low event rates ($\mathcal{O}$ (10 per kg year))

→ passive background reduction: **shielding and use of radiopure materials**

→ active background reduction: **event-by-event discrimination**

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- feature
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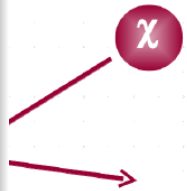
needle in haystack



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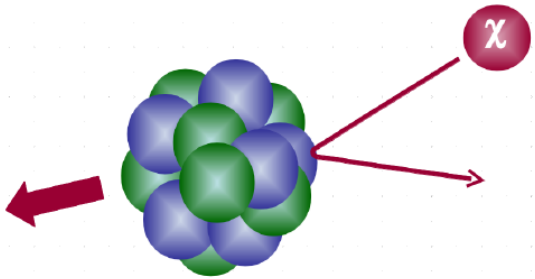

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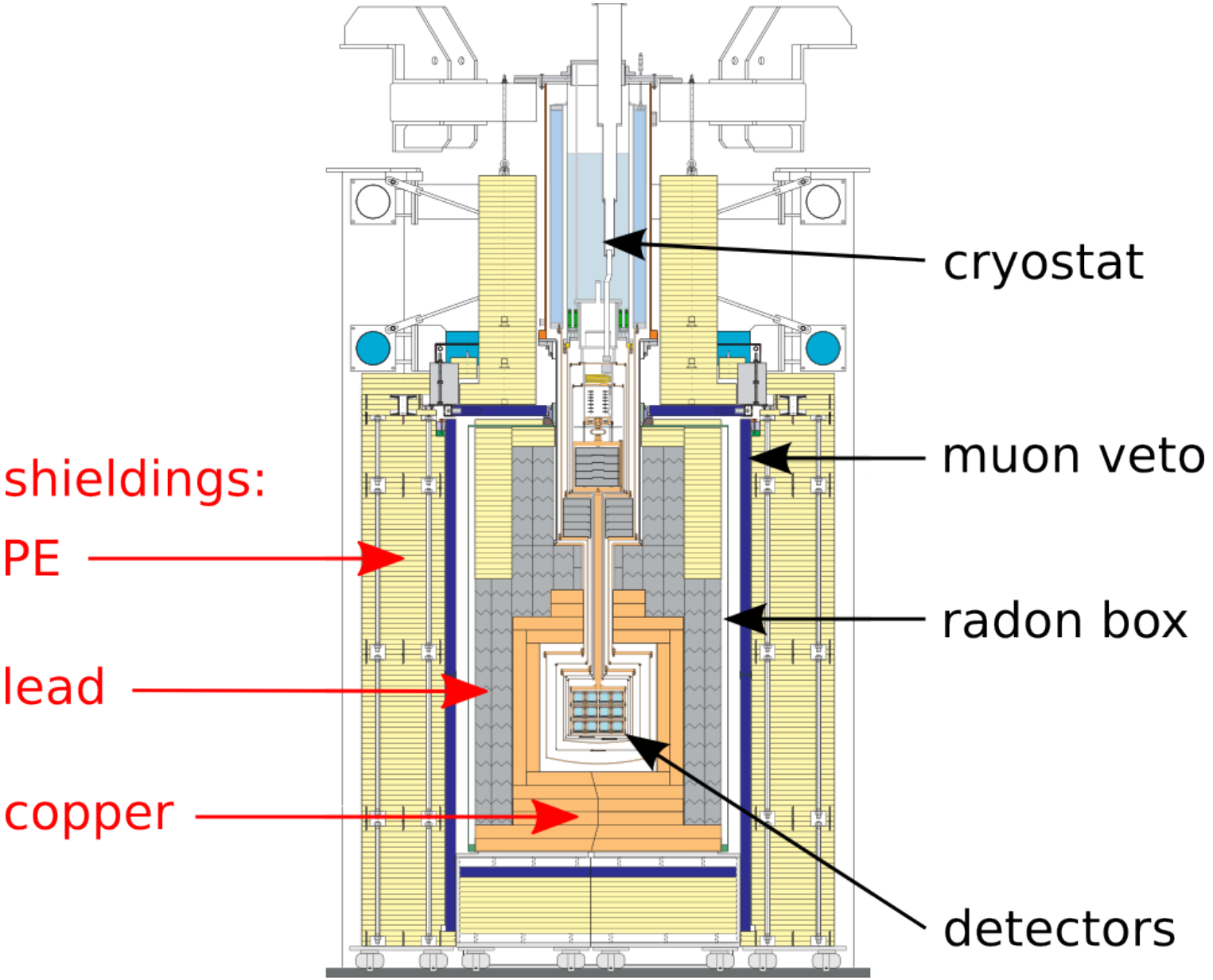
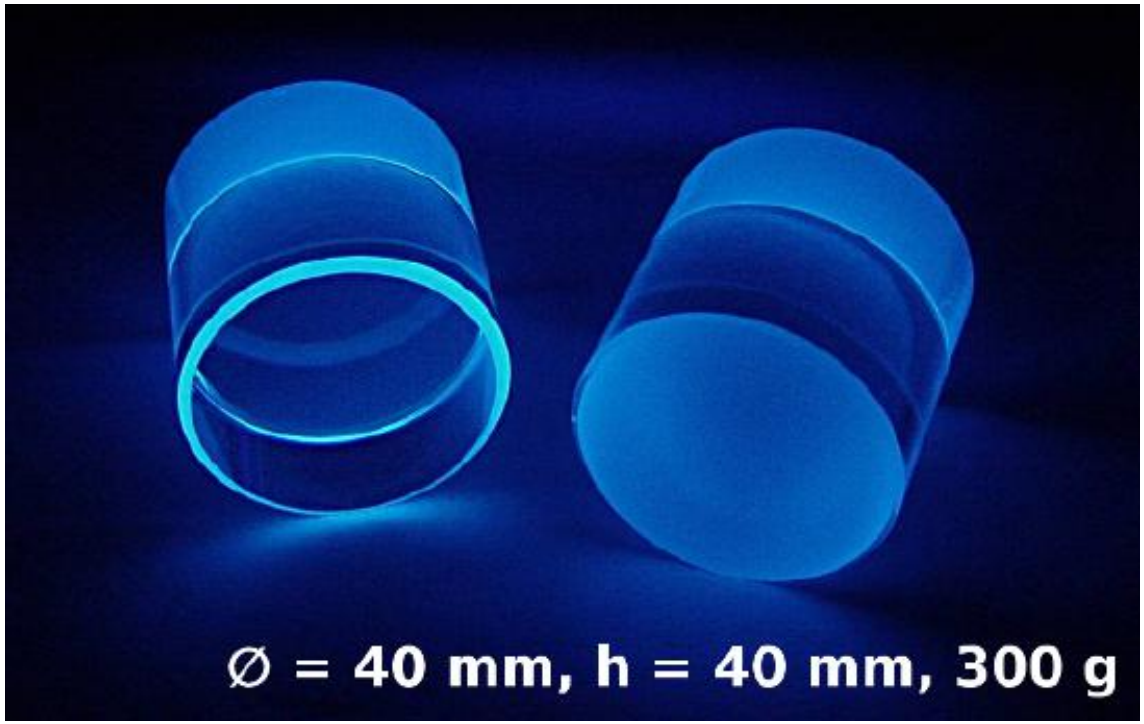
Experimental setup at Gran Sasso Underground Laboratory

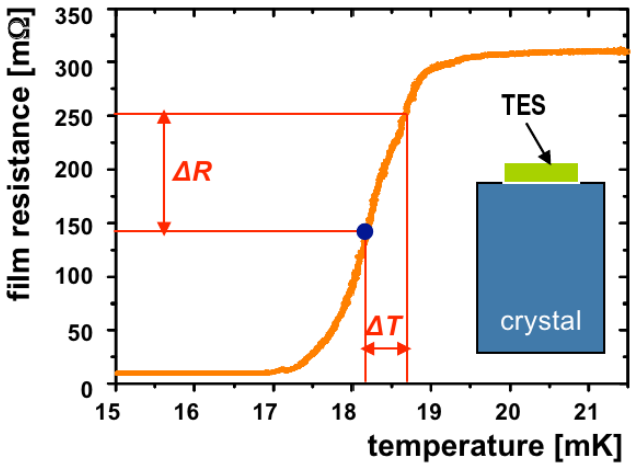


CRESST Detectors - Target Material

- scintillating $CaWO_4$ crystals
- coherent WIMP scattering off nuclei: $\sigma \sim A^2$

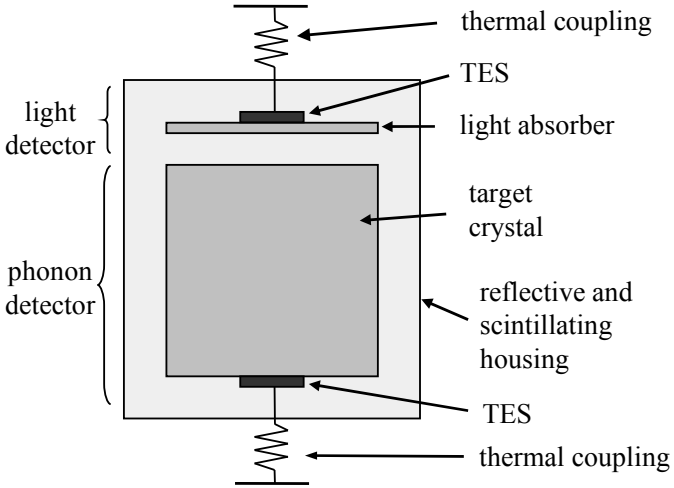


CRESST Detectors - Schematic



- particle interactions in the crystal excite phonons
- detectors are operated at mK temperatures
- temperature rise ($\mathcal{O}(\mu K)$) detected with Transition Edge Sensor (TES)

$\rightarrow$ measurement of deposited energy (few keV)

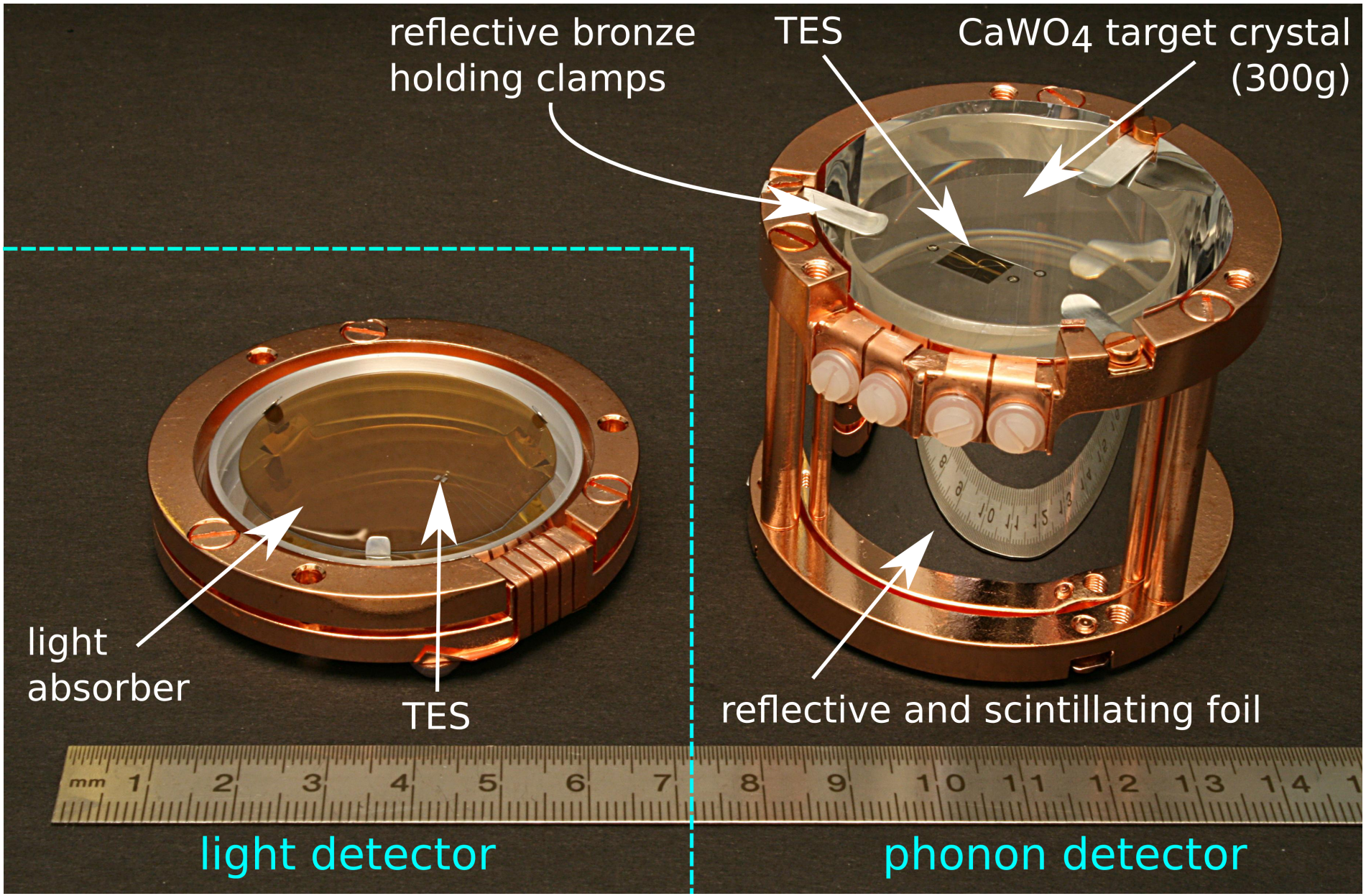


detector module:
simultaneous measurement of

- energy deposited in crystal E
- scintillation light L

$\rightarrow$ active background discrimination by light yield ($\frac{L}{E}$)

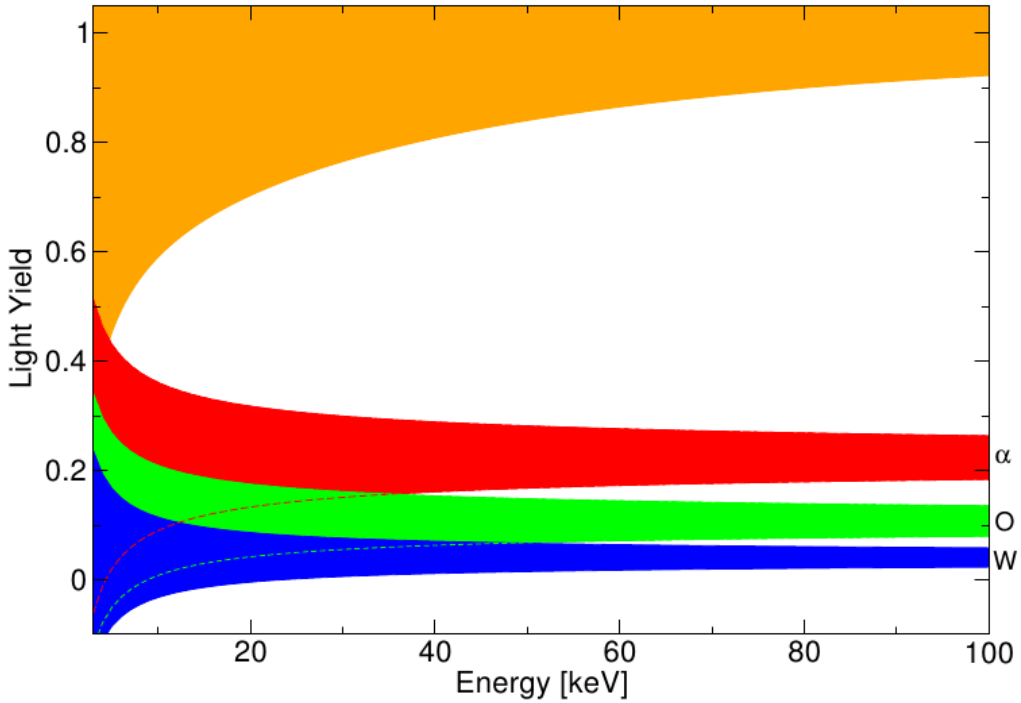
CRESST Detectors - Photograph of Opened Module



CRESST Detectors - Event-by-Event Discrimination

$$\text{light yield} = \frac{\text{light signal}}{\text{phonon signal}}$$

Different event types have a **characteristic** light yield.



CRESST detectors

- provide an excellent discrimination between:
  - e^--recoils: dominant radioactive background
  - nuclear recoils: potential signal events
- are to some extent able to identify the recoiling nucleus: probe WIMP interactions on multiple targets simultaneously (distinctive feature)

The Latest CRESST Run 32

- first extensive physics run between June 2009 and April 2011
- 8 $CaWO_4$ modules used for Dark Matter analysis
- total net exposure (after cuts): **730 kg days**
- additionally:
  - γ-calibrations: ^{57}Co and ^{232}Th
  - neutron calibrations (inside and outside shielding): AmBe

- **67 events observed in WIMP search region**
- data analyzed using maximum likelihood
- a detailed discussion can be found in:
  Results from 730 kg days of the CRESST-II Dark Matter Search
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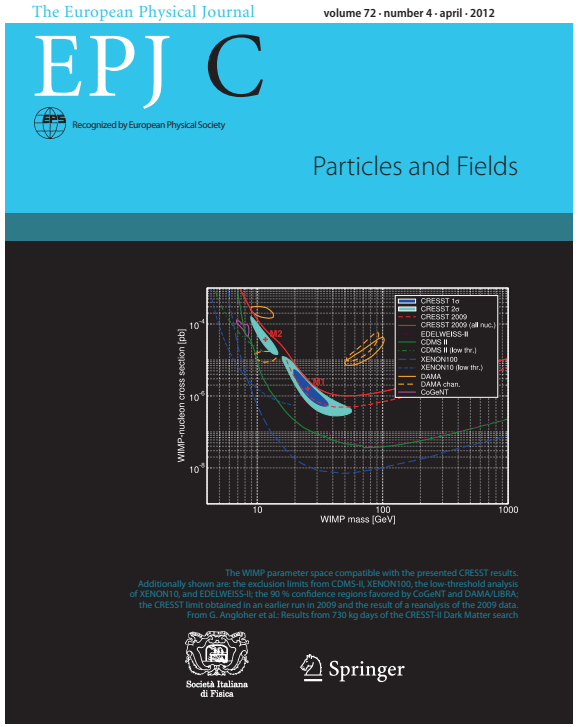


Maximum Likelihood Analysis

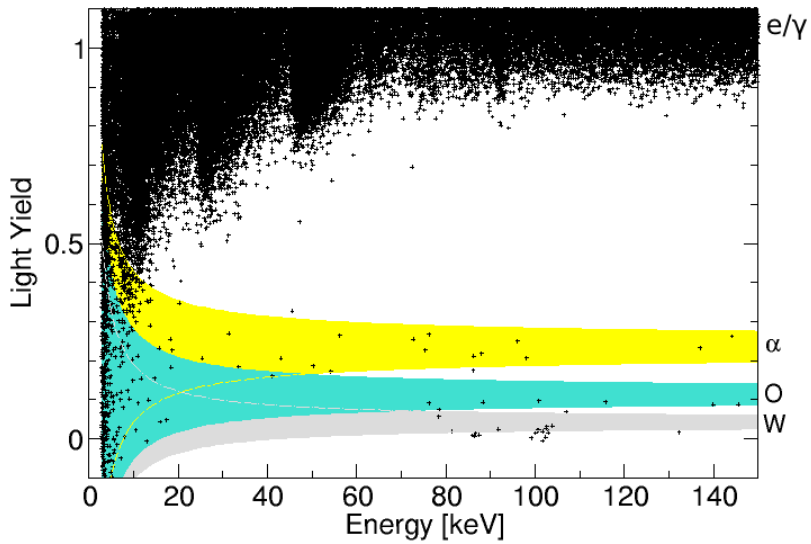
The likelihood analysis

- is based on a parametrized model of the backgrounds (discussed in the following) and a possible WIMP signal.
- uses full spectral information (light and light yield) of each event.
- is able to take differences between the detector modules into account (in particular: energy resolution).
- treats all parameters and their uncertainties simultaneously.

$\rightarrow$ in the following: discussion of relevant backgrounds

e^-/γ - Background

- dominant background source (mostly intrinsic radioactivity)
- excellent discrimination
- lower threshold of acceptance region defined by expected γ-leakage of one event per detector module



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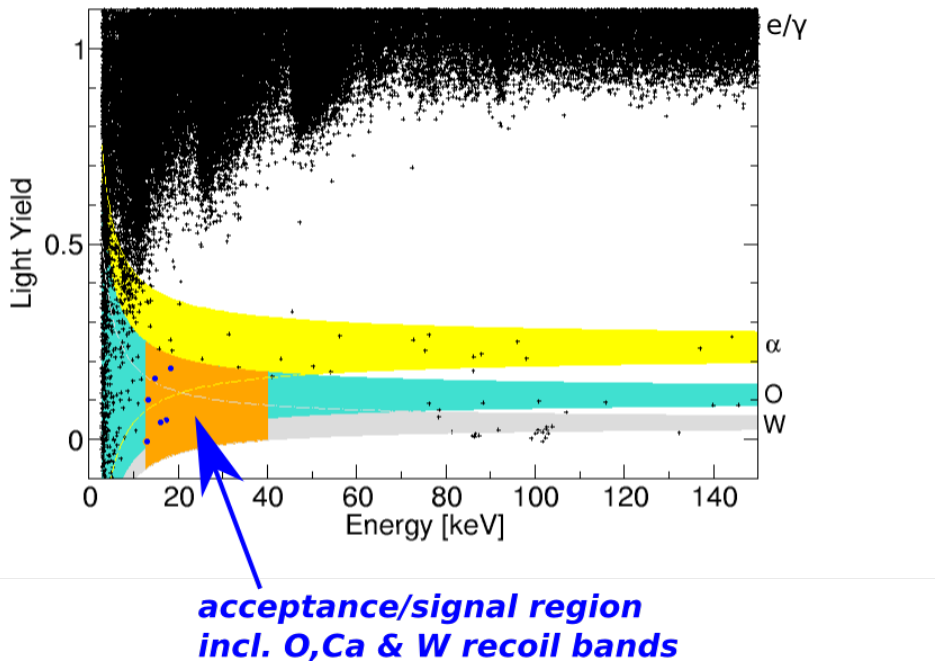
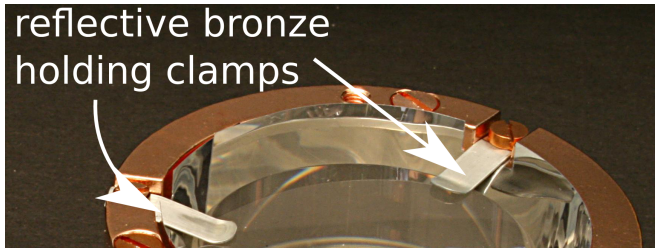
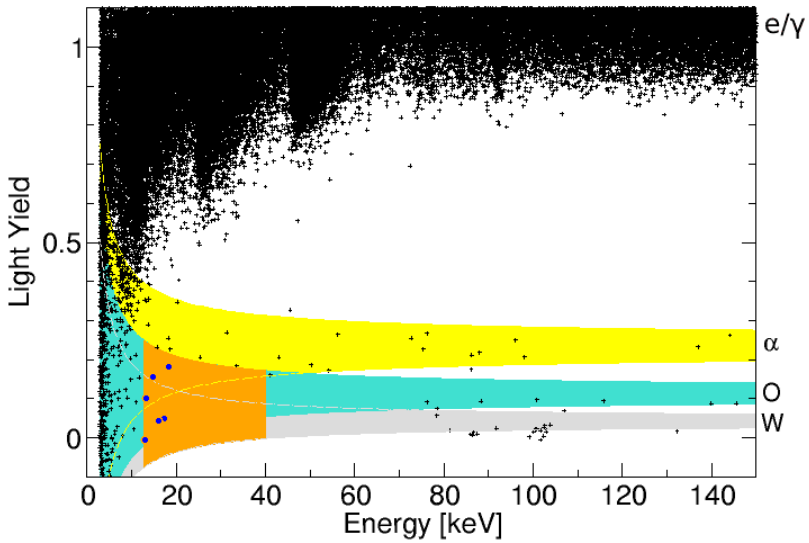


α - Background



- low-energy α's due to α-decays below non-scintillation surface ($\sim 10\,\mu m$) of holding clamps
- use reference region to estimate contribution in acc. region
- rate in reference region: ~ 1 event per module and month (of net measuring time)



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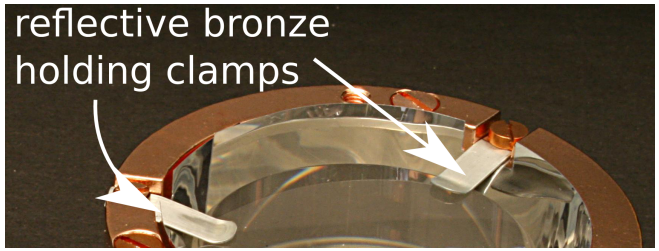

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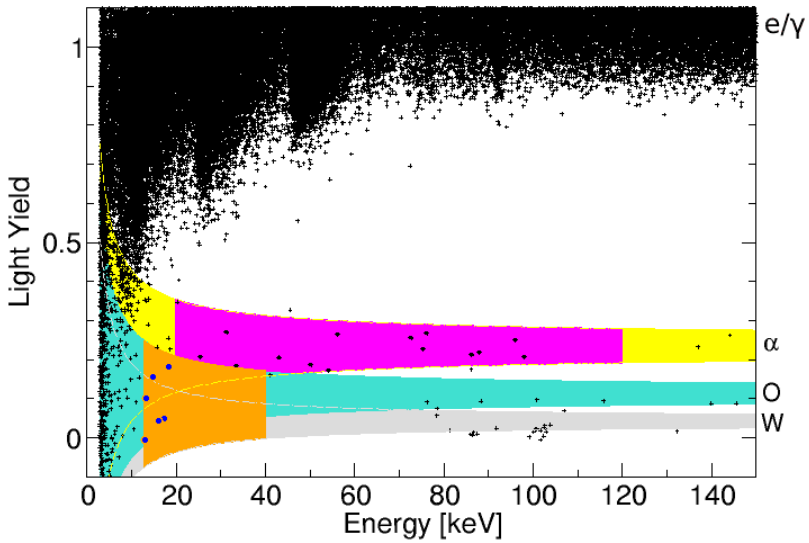
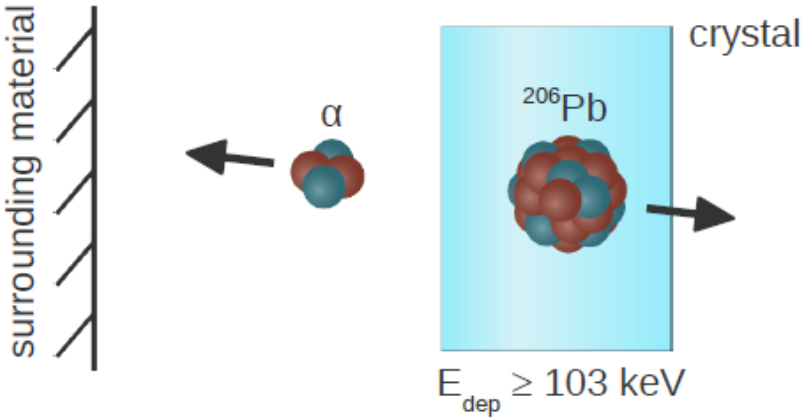
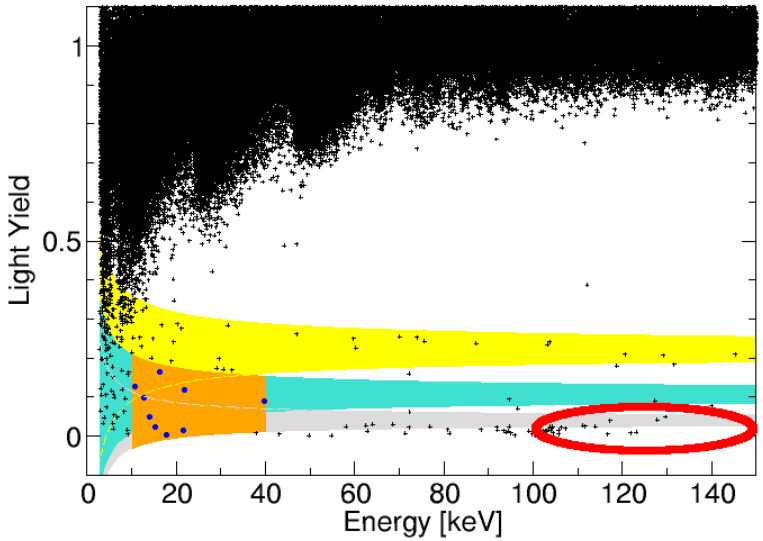


Lead Recoil Background

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

1. Po on surface or implanted in crystal





- energy well above acc. region

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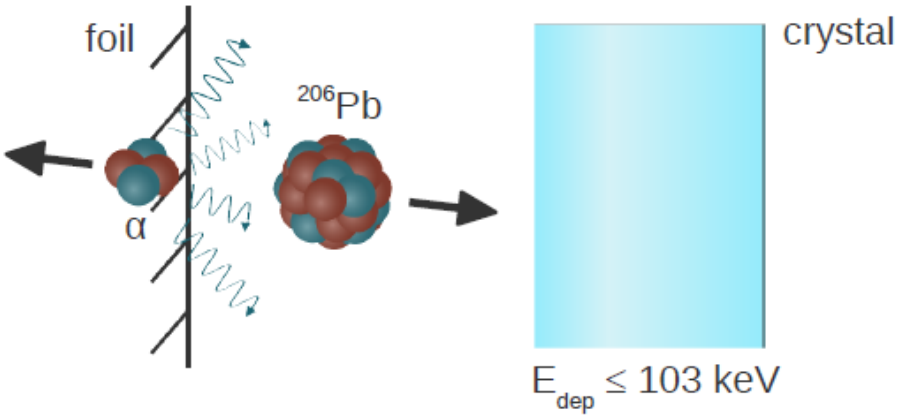

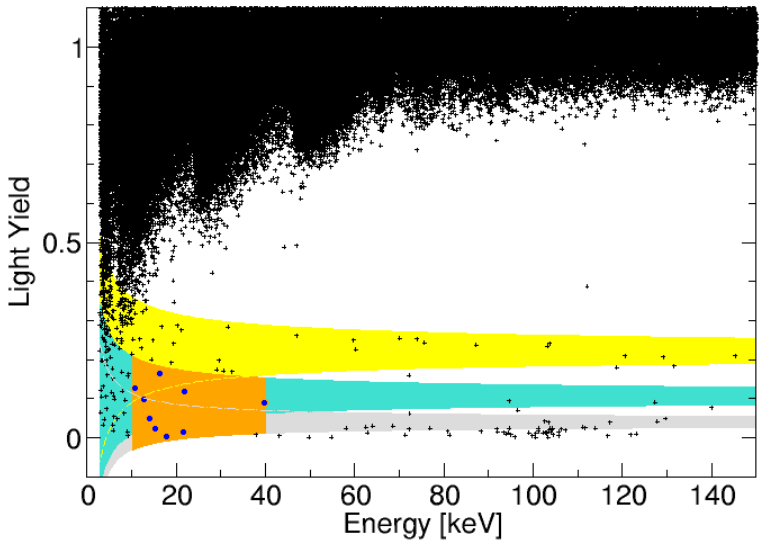

- if α hits scintillating surface: veto by additional light signal
- if α hits uncovered clamps: event with:
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  - in Pb recoil band (slightly below the W-band)

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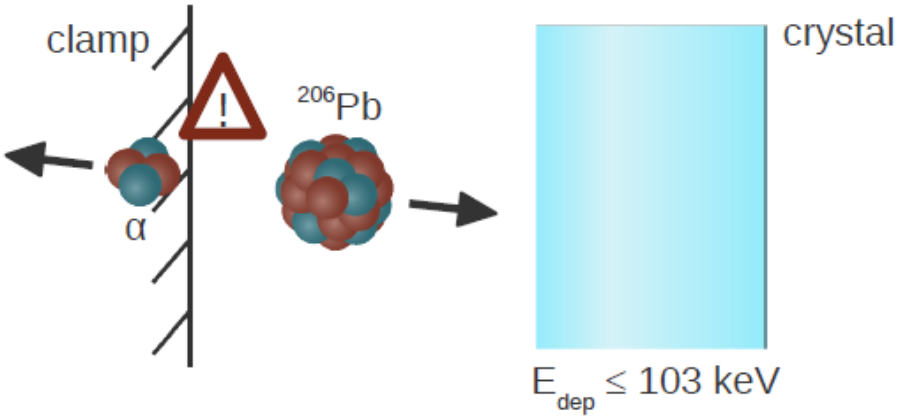

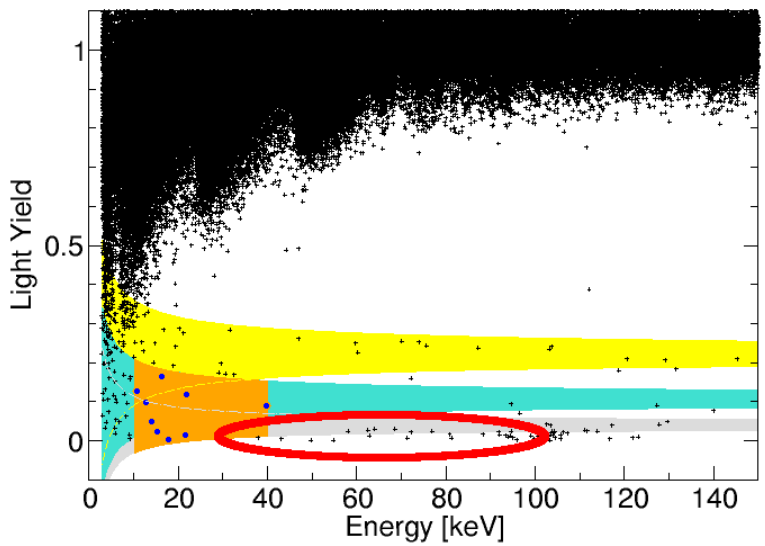

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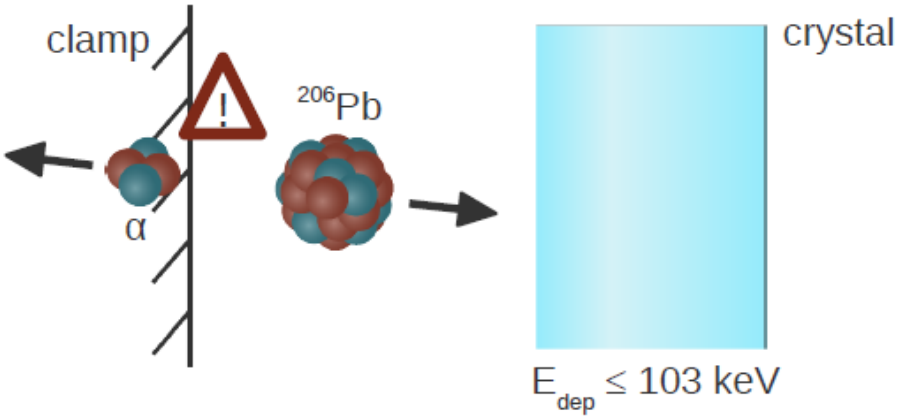

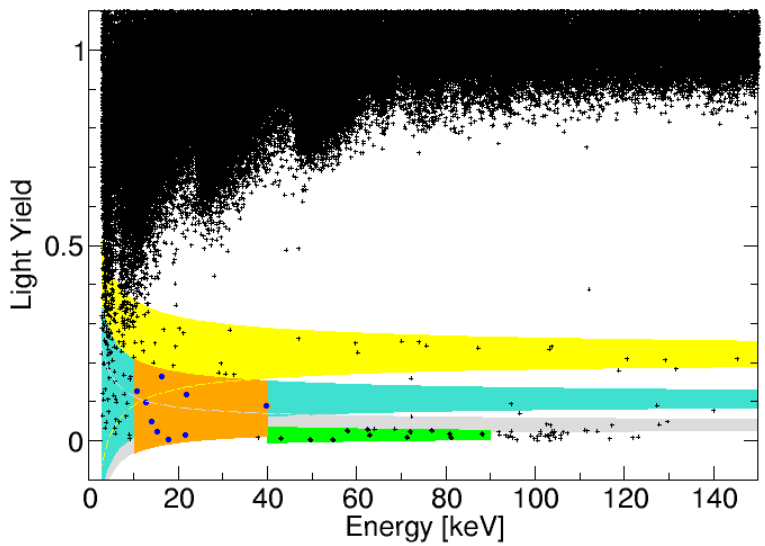

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Neutron Background

neutron sources

- source type: radioactive processes inside neutron shielding
- muon-induced type: muons interacting in Pb/Cu shield or in surrounding rock (and undetected by muon veto)

neutron signature

- neutrons can mimic (light) WIMP events
- unlike WIMPs, neutrons can scatter in multiple detectors

estimate of neutron background

1. in data: 3 multiple scatterings in acc. region
2. calibrate ratio of single to multiple scatterings (separately for both *types*)
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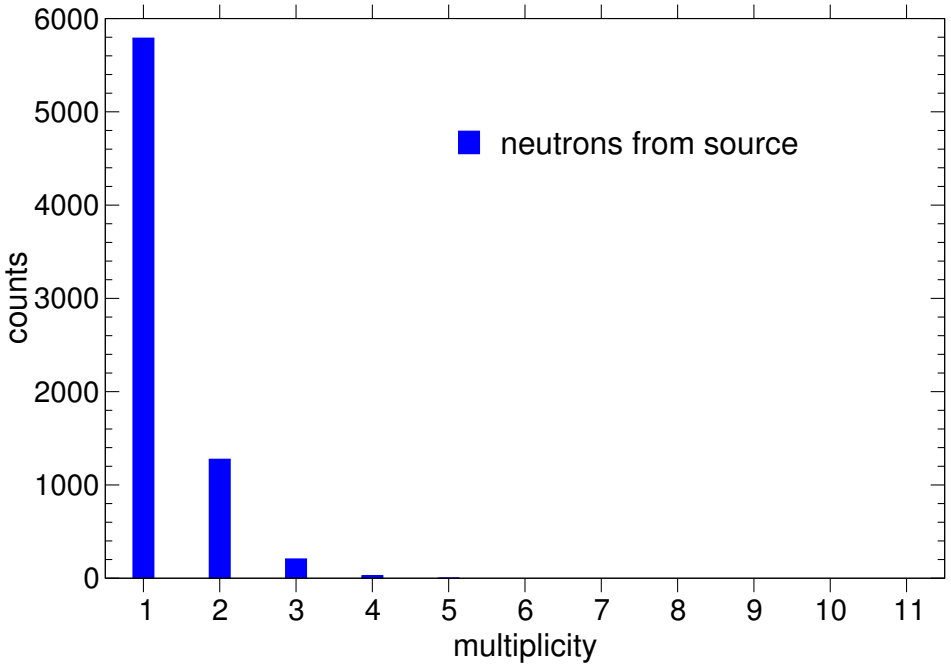

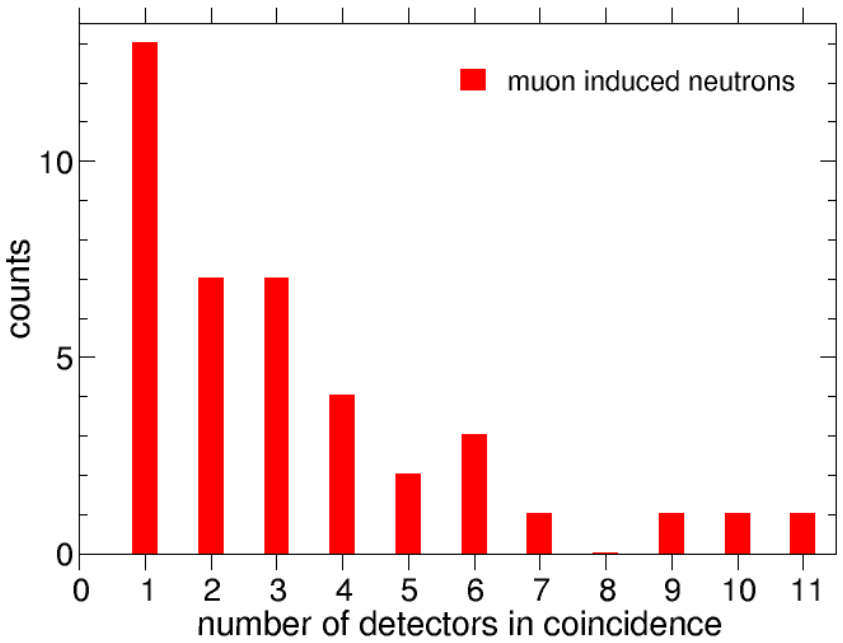

single/multiple: ~ 3.8 single/multiple: ~ 0.5

simple estimate of **limiting** cases[1]:

~ 11.4 single events expected ~ 1.5 single events expected

67 events in acc. region can not be explained by neutrons alone.

[1] result of full likelihood analysis between limiting cases

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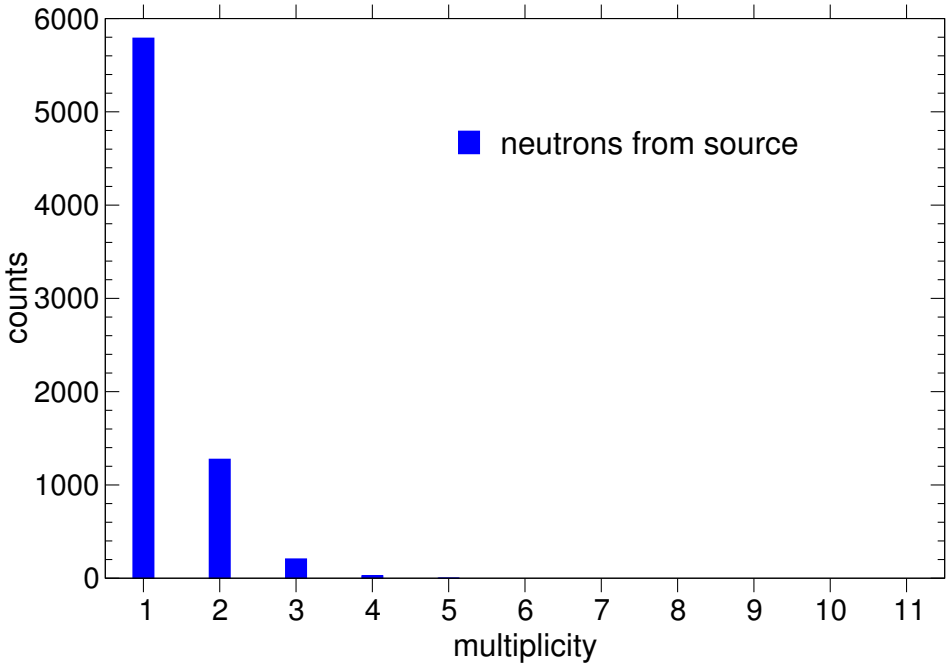

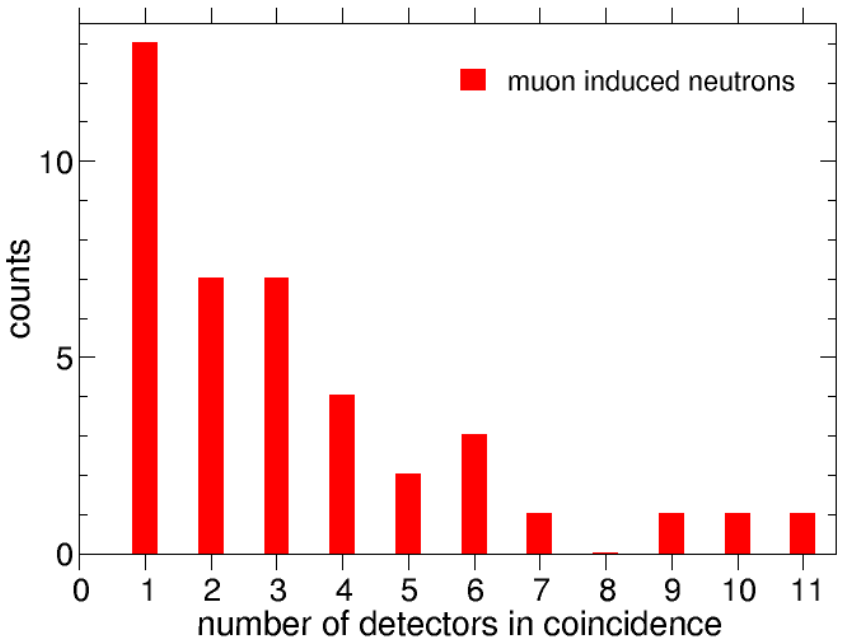

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Result of the likelihood analysis (paper)

Result (two maxima):

	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]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$
statistical significance	4.7 σ	4.2 σ

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→ additional source of events needed

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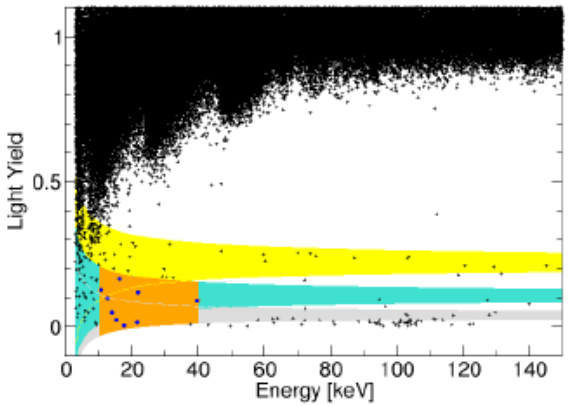

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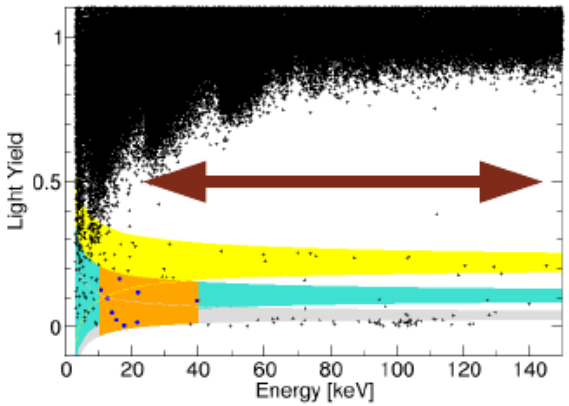
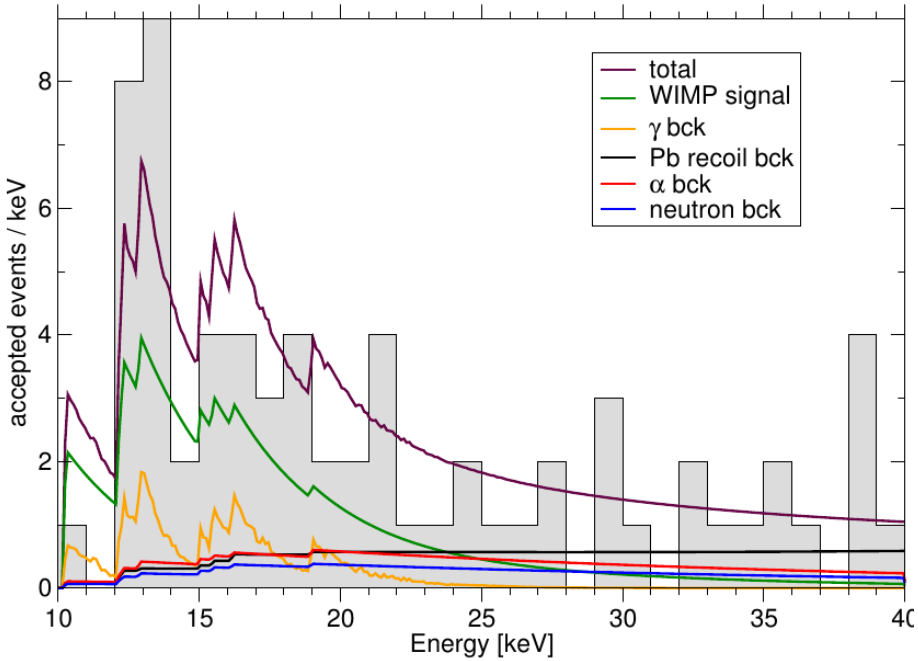


energy distribution (only M1)



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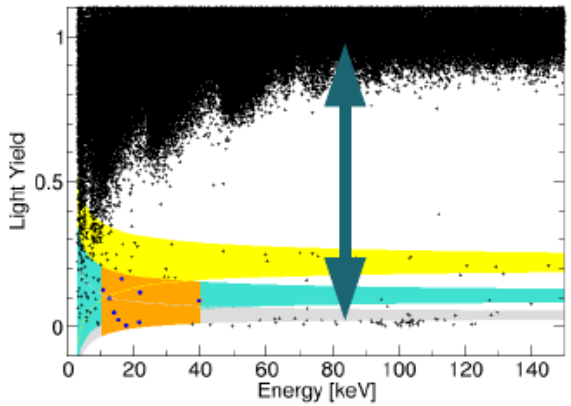

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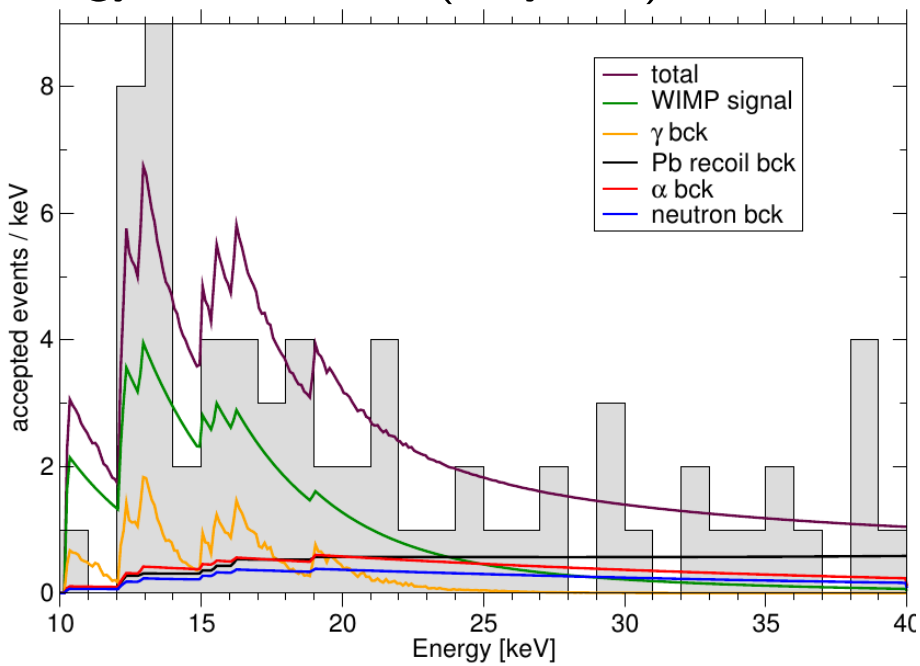
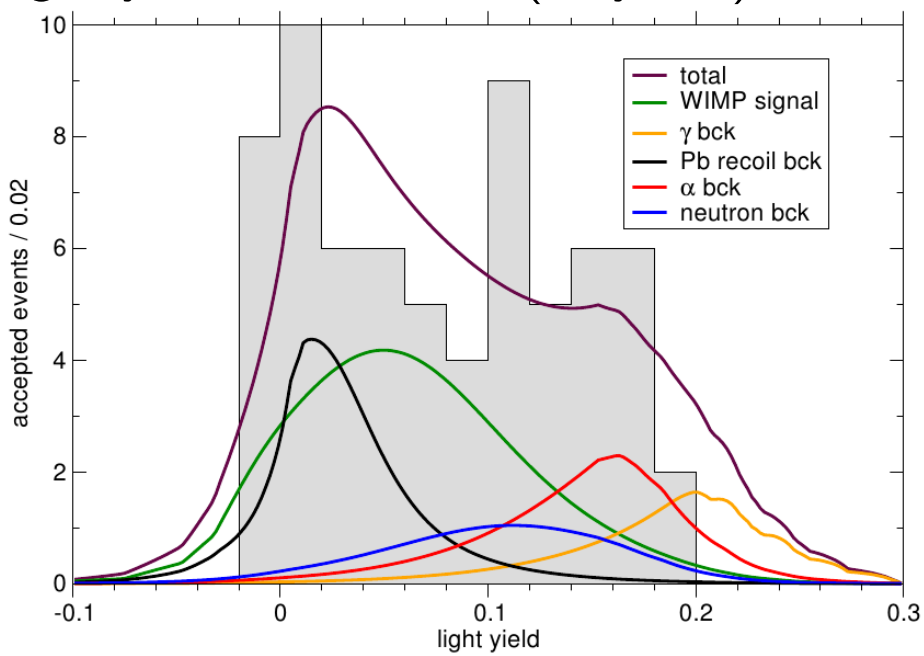


light yield distribution (only M1)



Spectral Distribution of Signal Events

- shape of energy spectra of γ-leakage and possible WIMP signal seem compatible

$\rightarrow$ underestimation of γ-leakage?

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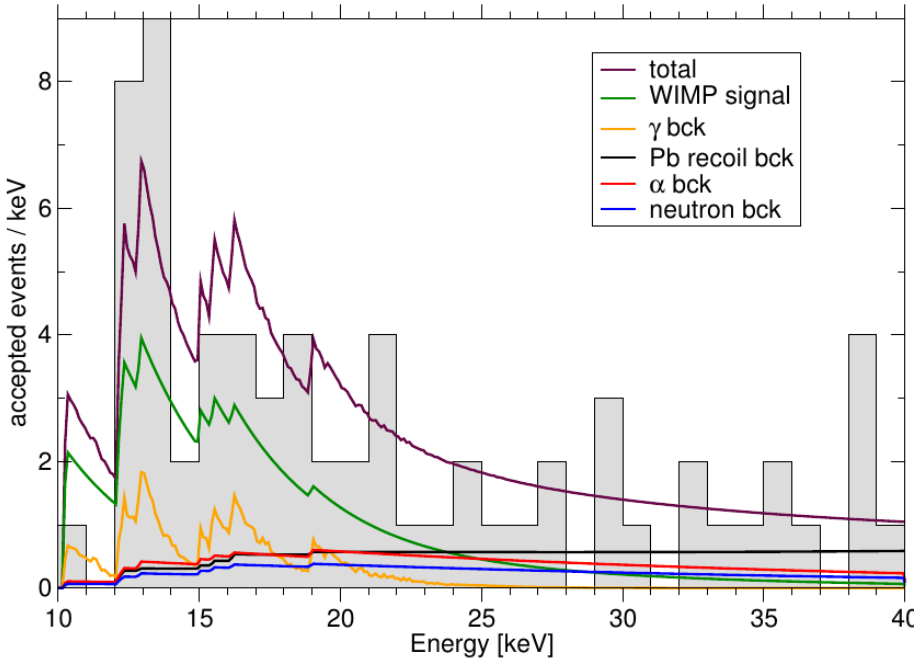

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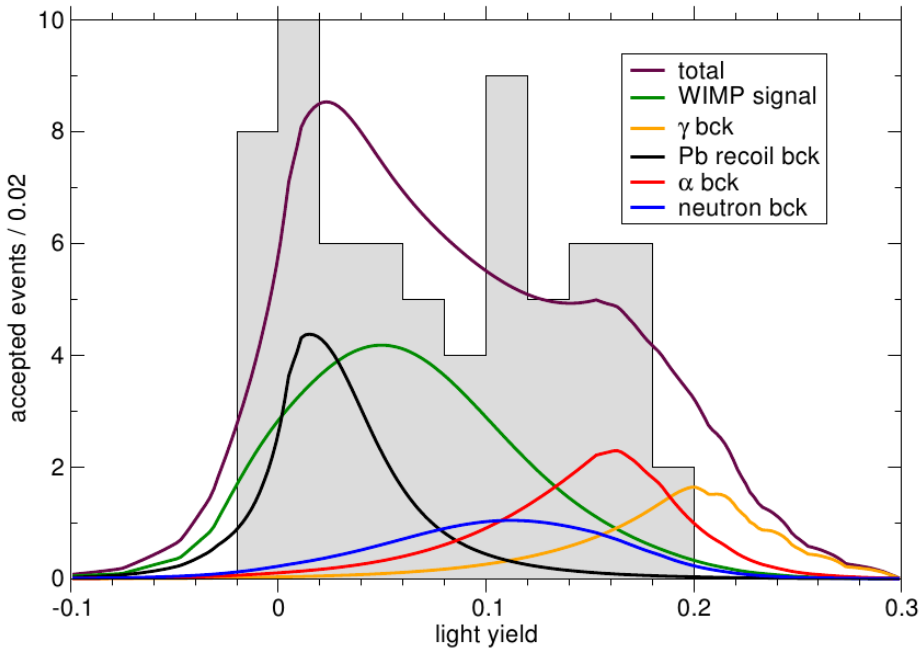

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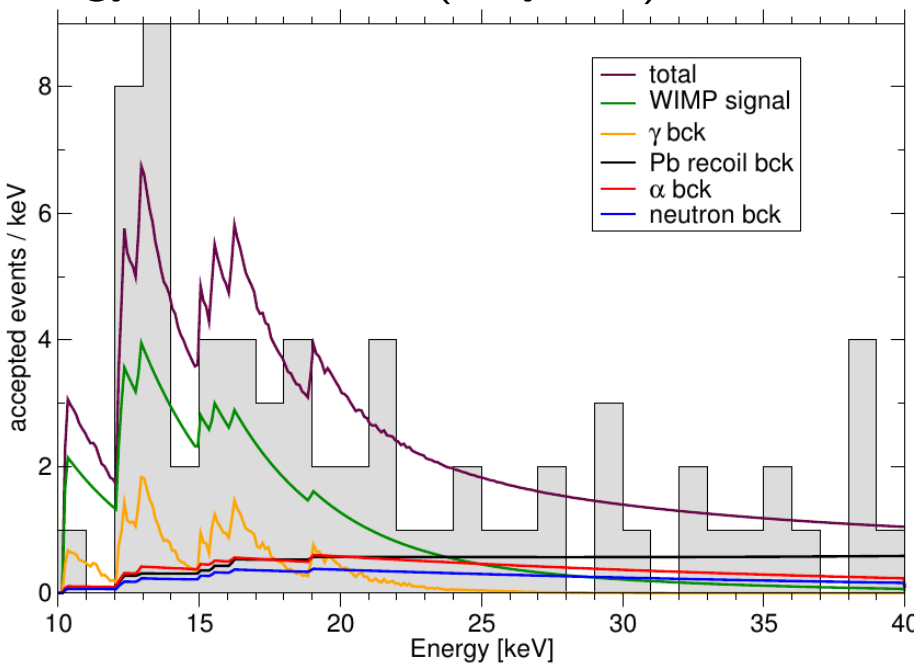
→ underestimation of γ-leakage?

but

- γ-leakage appears at high light yields
- possible WIMP signal at low light yields

→ γ-leakage ruled out as explanation for the excess

energy distribution (only M1)



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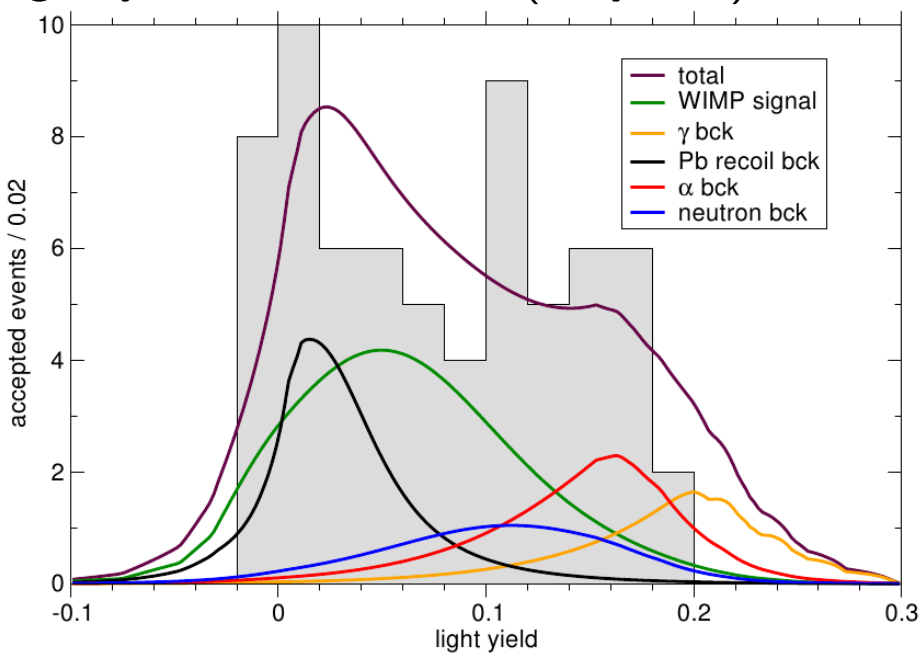
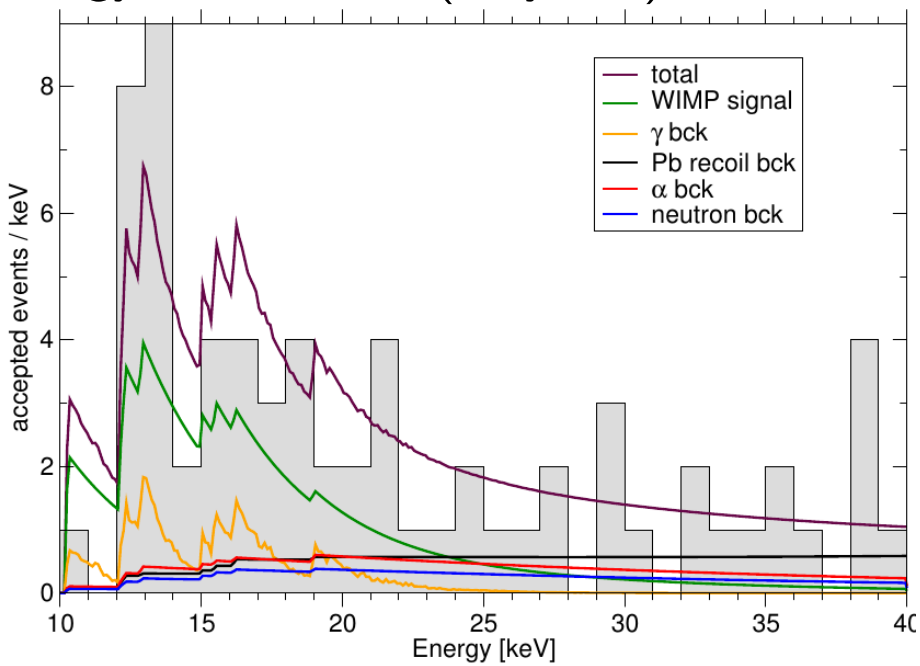


Spectral Distribution of Signal Events

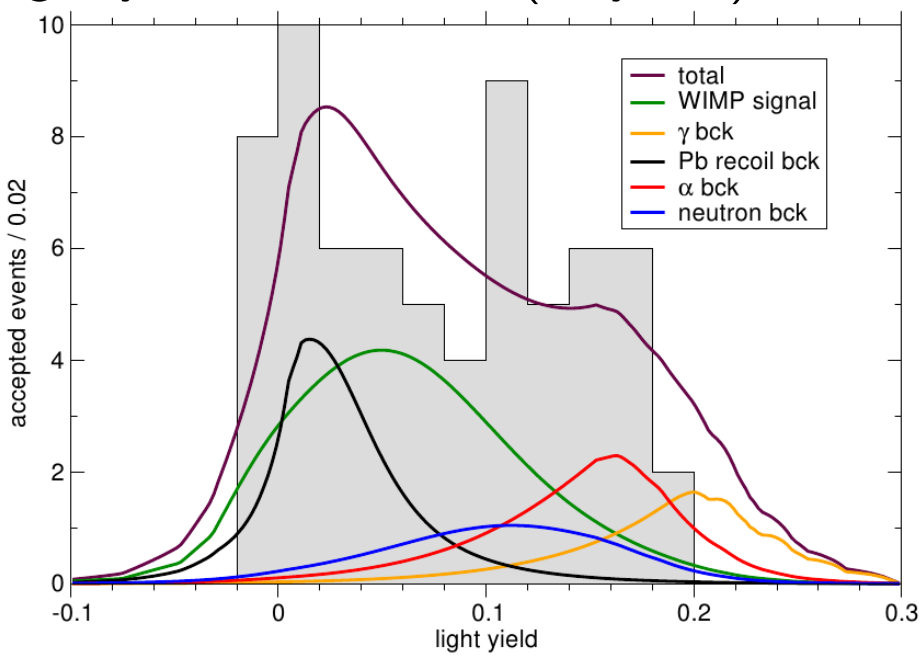
The other way round:

- Only the Pb recoil background has similar light yield as the possible WIMP signal

energy distribution (only M1)



light yield distribution (only M1)



Spectral Distribution of Signal Events

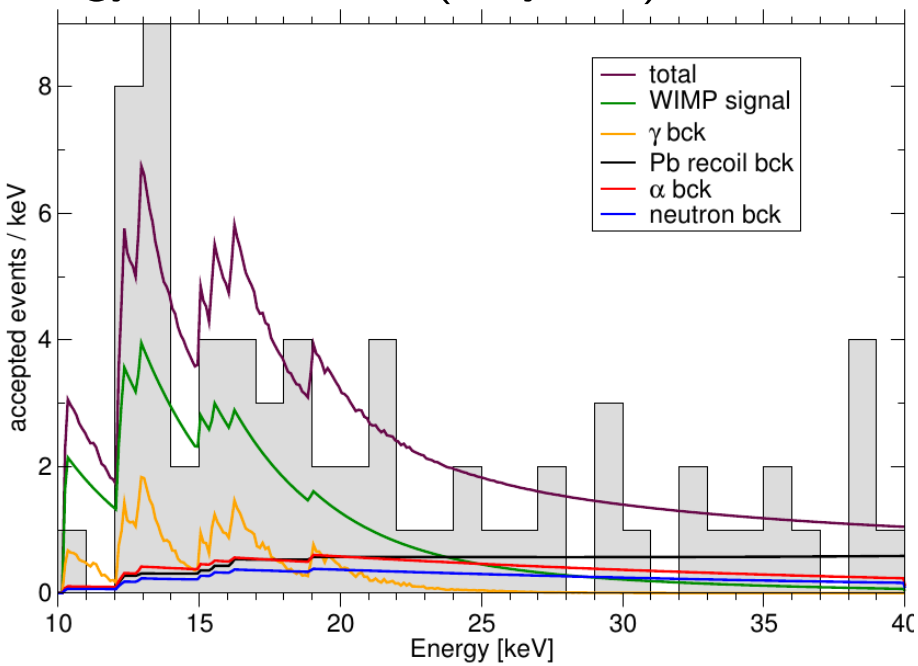
- energy spectrum of Pb recoils incompatible with possible WIMP signal

but

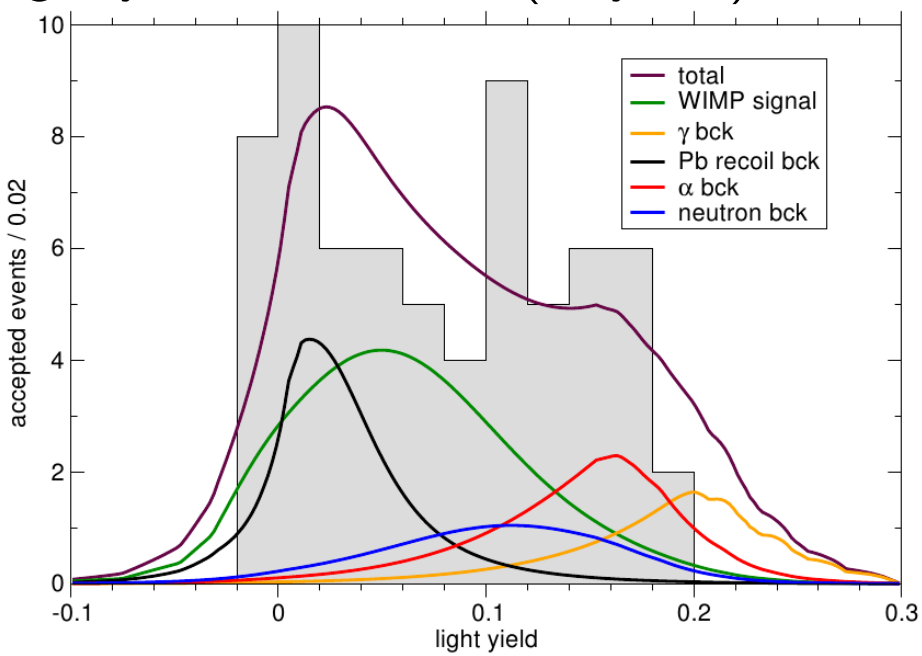
The other way round:

- Only the Pb recoil background has similar light yield as the possible WIMP signal

energy distribution (only M1)



light yield distribution (only M1)

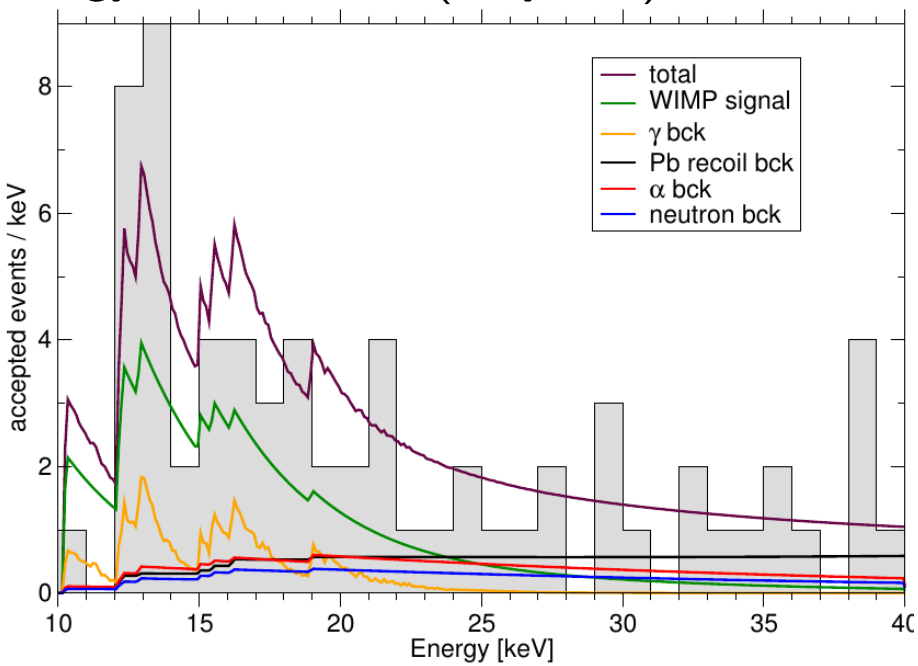


Spectral Distribution of Signal Events

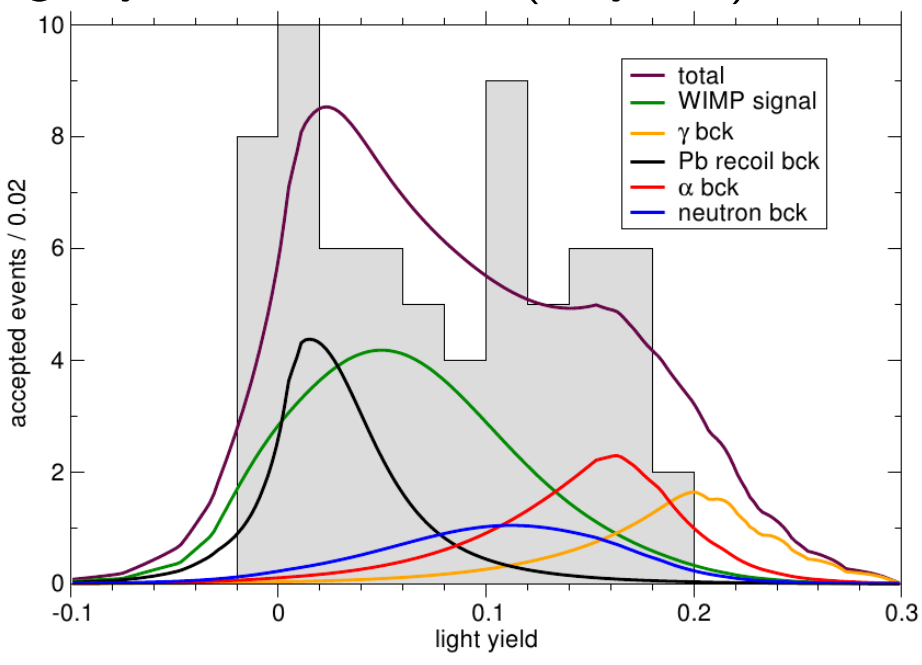
Conclusion:

- Simultaneous measurement of phonon and light is crucial to discriminate a possible WIMP signal from background.
- The excess can not be explained with the known backgrounds alone.

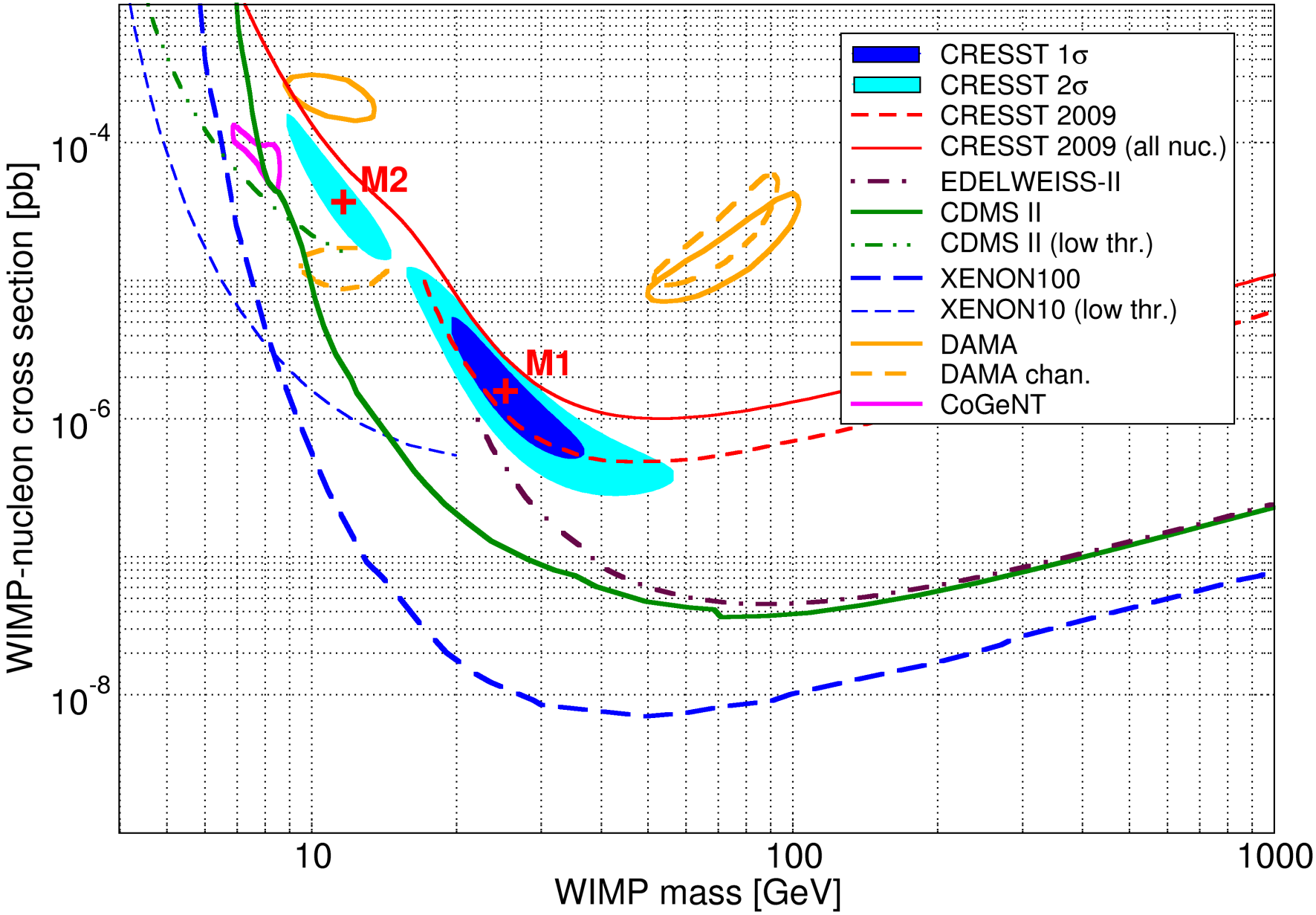
energy distribution (only M1)



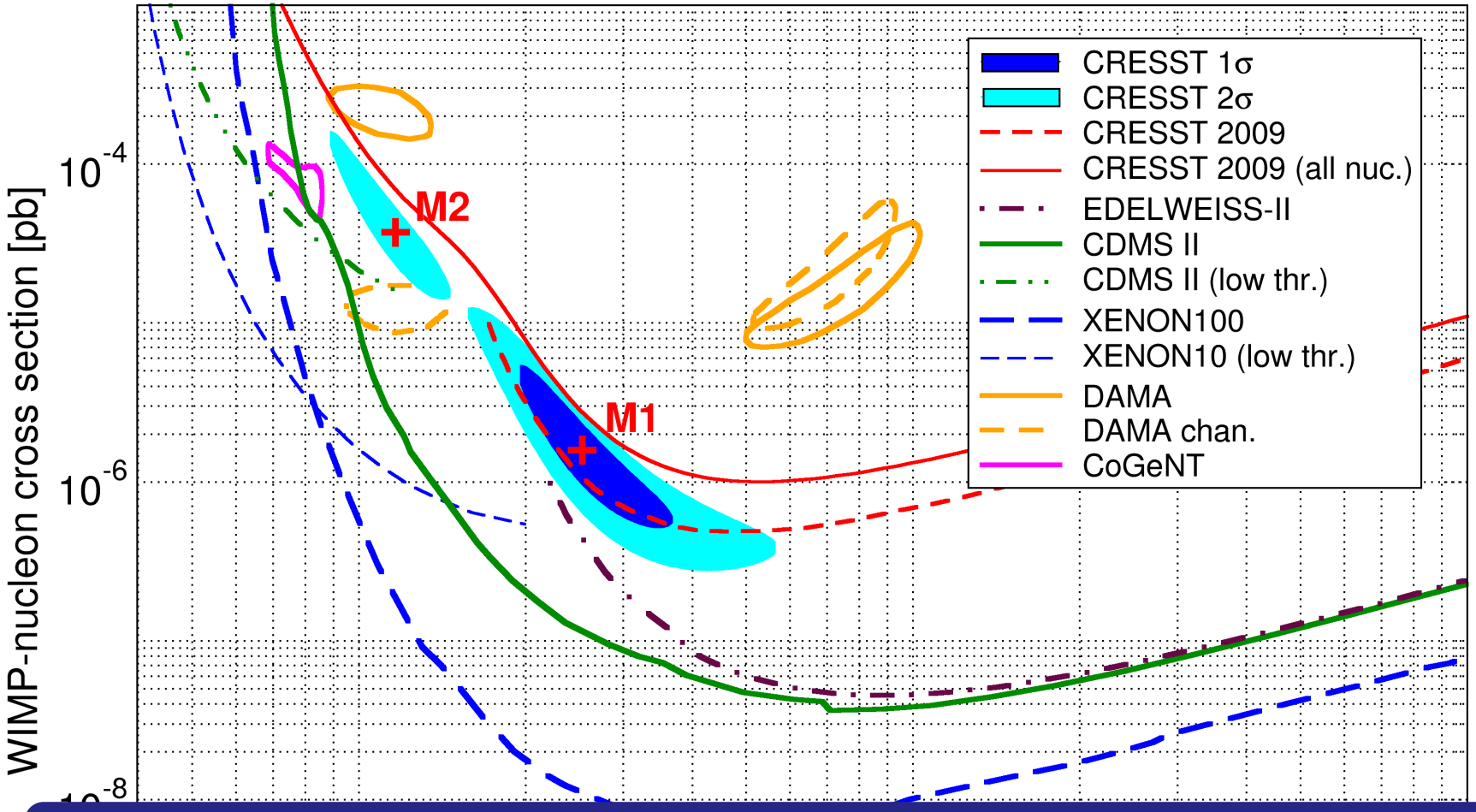
light yield distribution (only M1)



WIMP Parameter Space



WIMP Parameter Space



conclusion

- strong tension between direct Dark Matter search experiments
- stay tuned: the upcoming years will be interesting

WIMP Parameter Space

Current situation

WIMP Parameter Space

Future?

WIMP Parameter Space

Future?

Summary and Outlook

summary:

- extensive and successful physics run with 730 kg days of data
- 67 candidate events - not explainable with known backgrounds alone
- a light WIMP would fit as an explanation for this excess
- background level needs to be further reduced for clarification

outlook for the next run

- further background reduction:
  - new clamps (from ultra-radiopure material)
  - radon prevention during mounting
  - test of new and fully-scintillating module design(s)
  - additional neutron shielding (inside the lead/copper shielding)
- increase of target mass

Thank you.

Backup

Signal Composition

- coherent WIMP scattering of nuclei

$\rightarrow$ W recoils dominate

Signal Composition

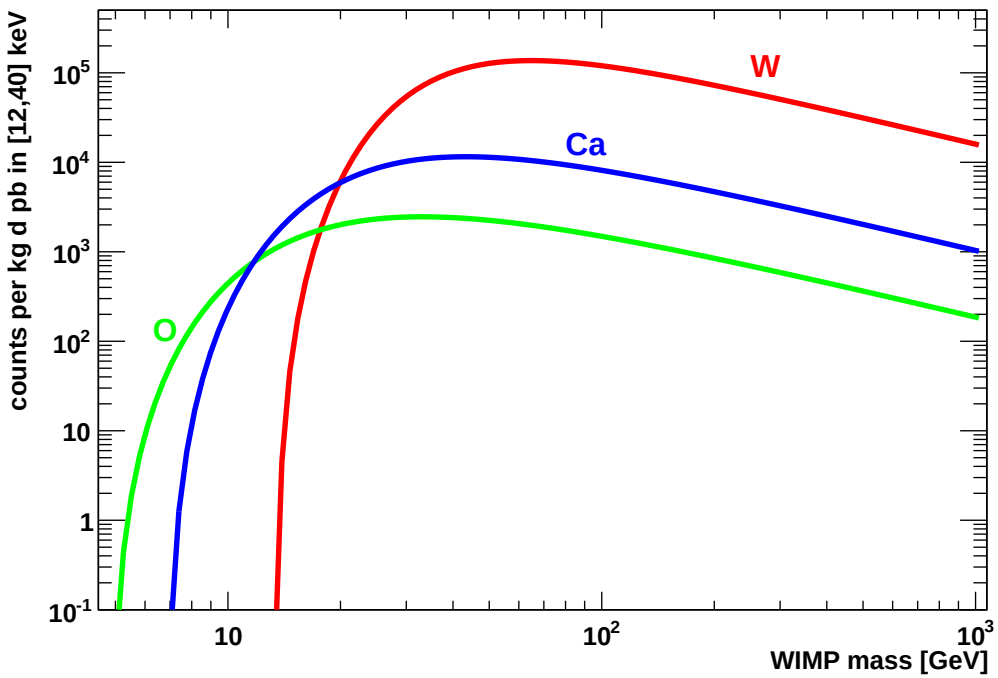
- coherent WIMP scattering of nuclei

→ W recoils dominate

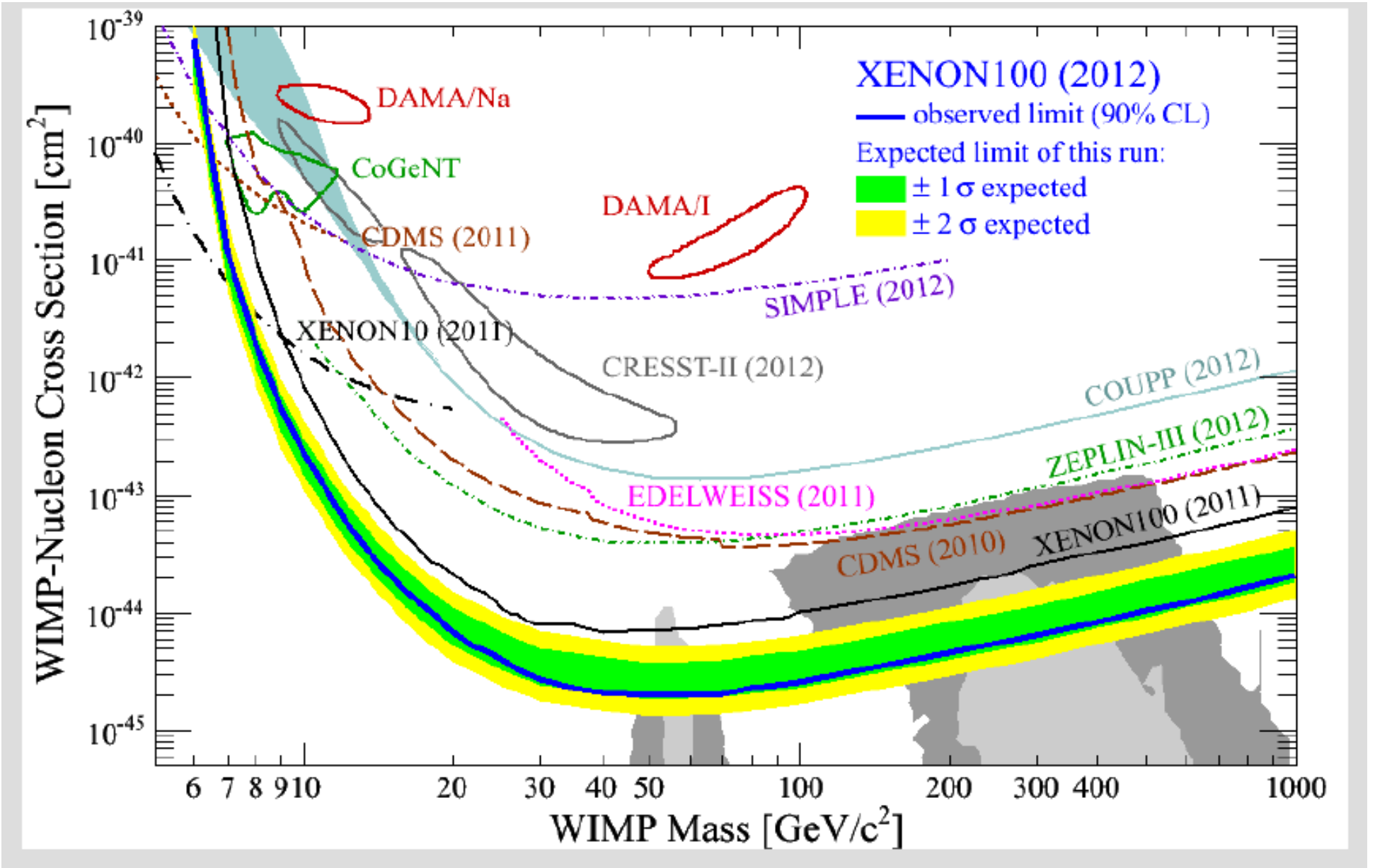
- but: finite low-energy threshold of detectors

→ for light WIMPs scatterings off W are below detection threshold

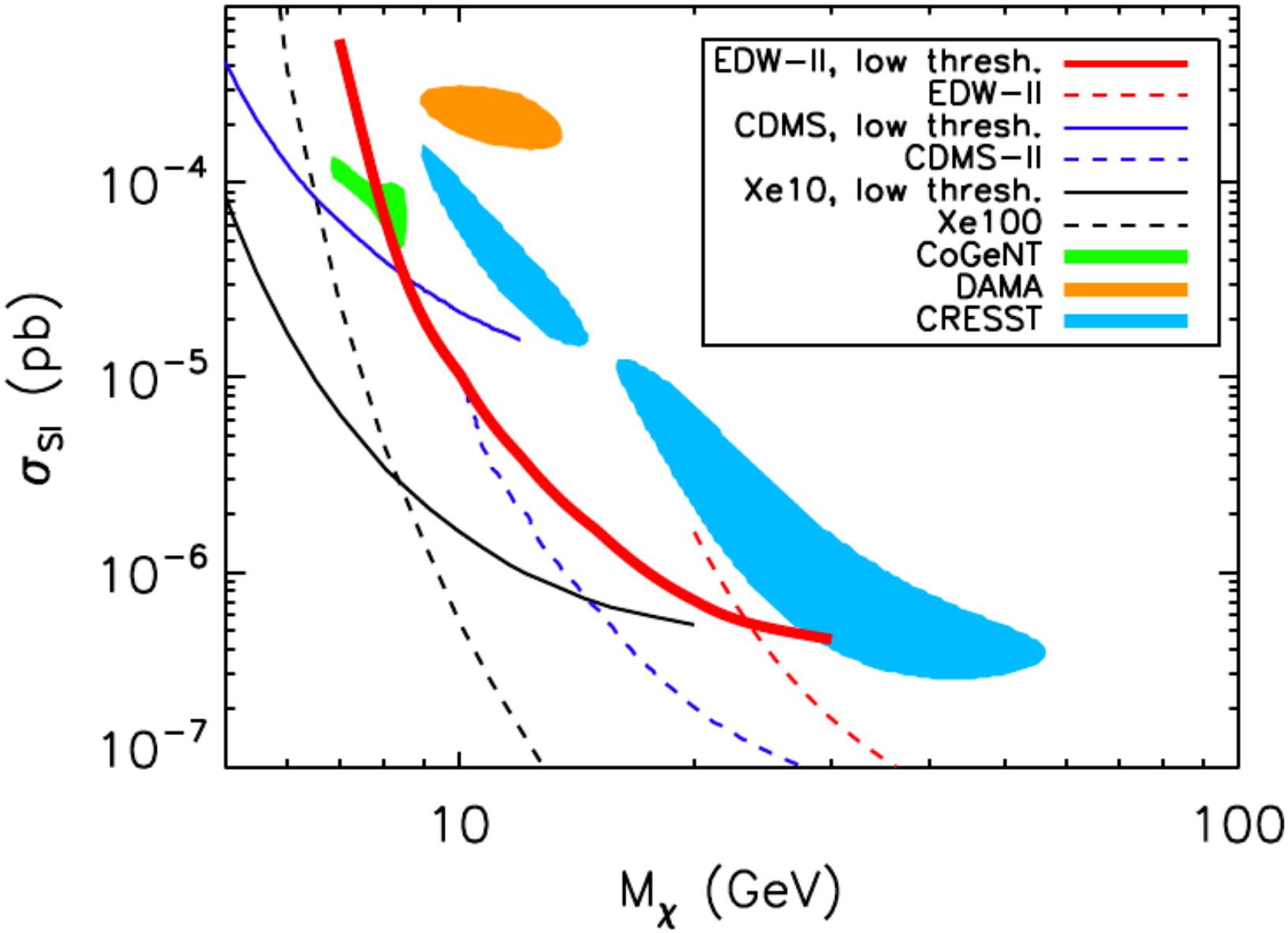
→ signal: O and Ca recoils



Xenon100 - 2012 Result



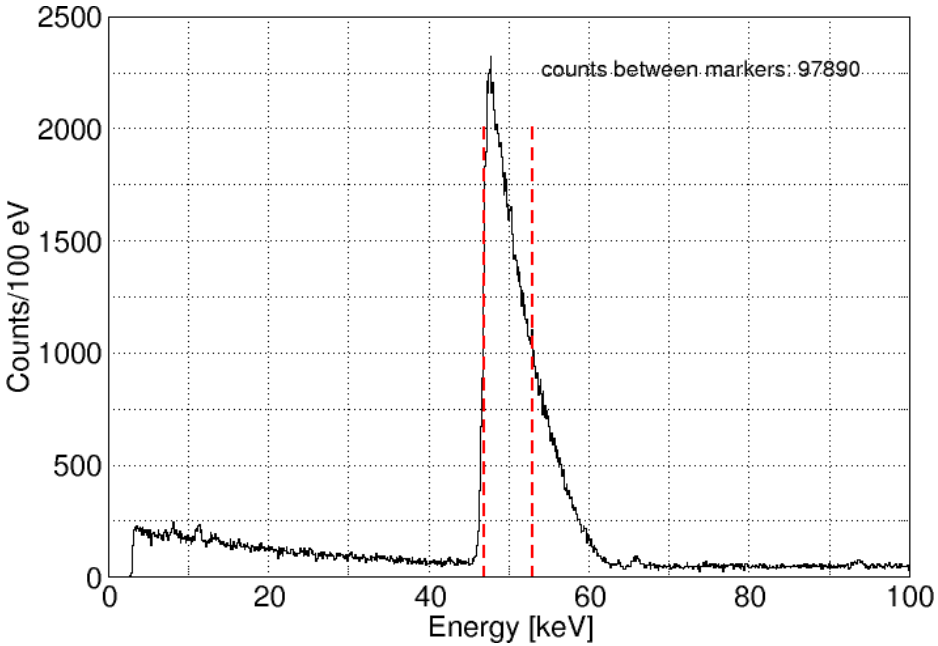
Edelweiss - low Threshold Analysis 2012

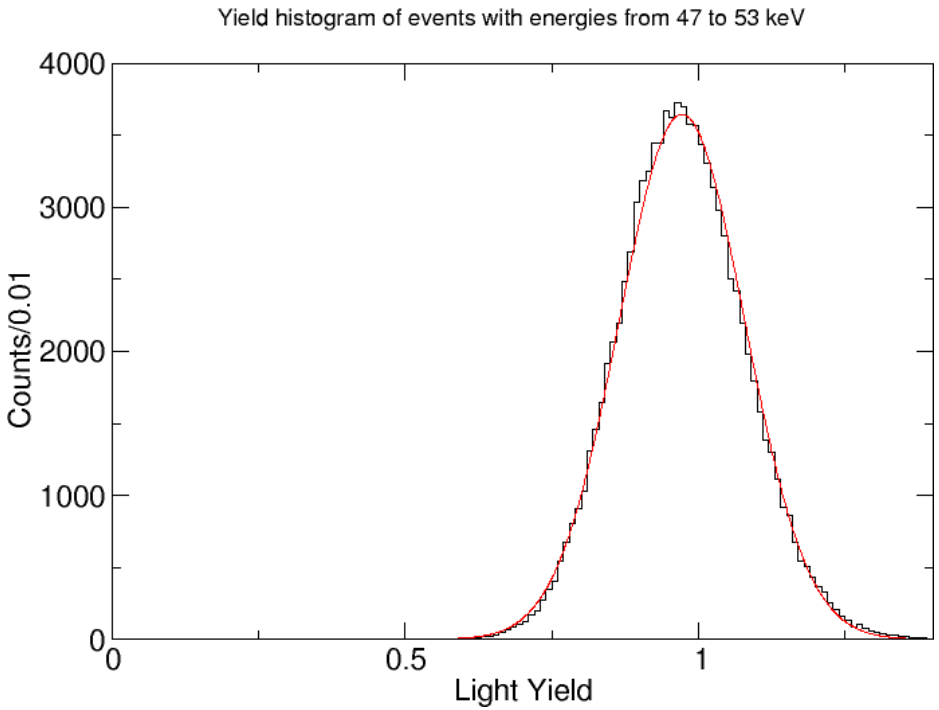


Overview Detector Modules

module	exposure [kg d]	$E_{\mathrm{acc}}^{\mathrm{min}}$ [keV]	acc. events
Ch05	91.1	12.3	11
Ch20	83.0	12.9	6
Ch29	81.1	12.1	17
Ch33	97.0	15.0	6
Ch43	98.1	15.5	9
Ch45	93.1	16.2	4
Ch47	99.0	19.0	5
Ch51	88.5	10.2	9
total	730.9	-	**67**

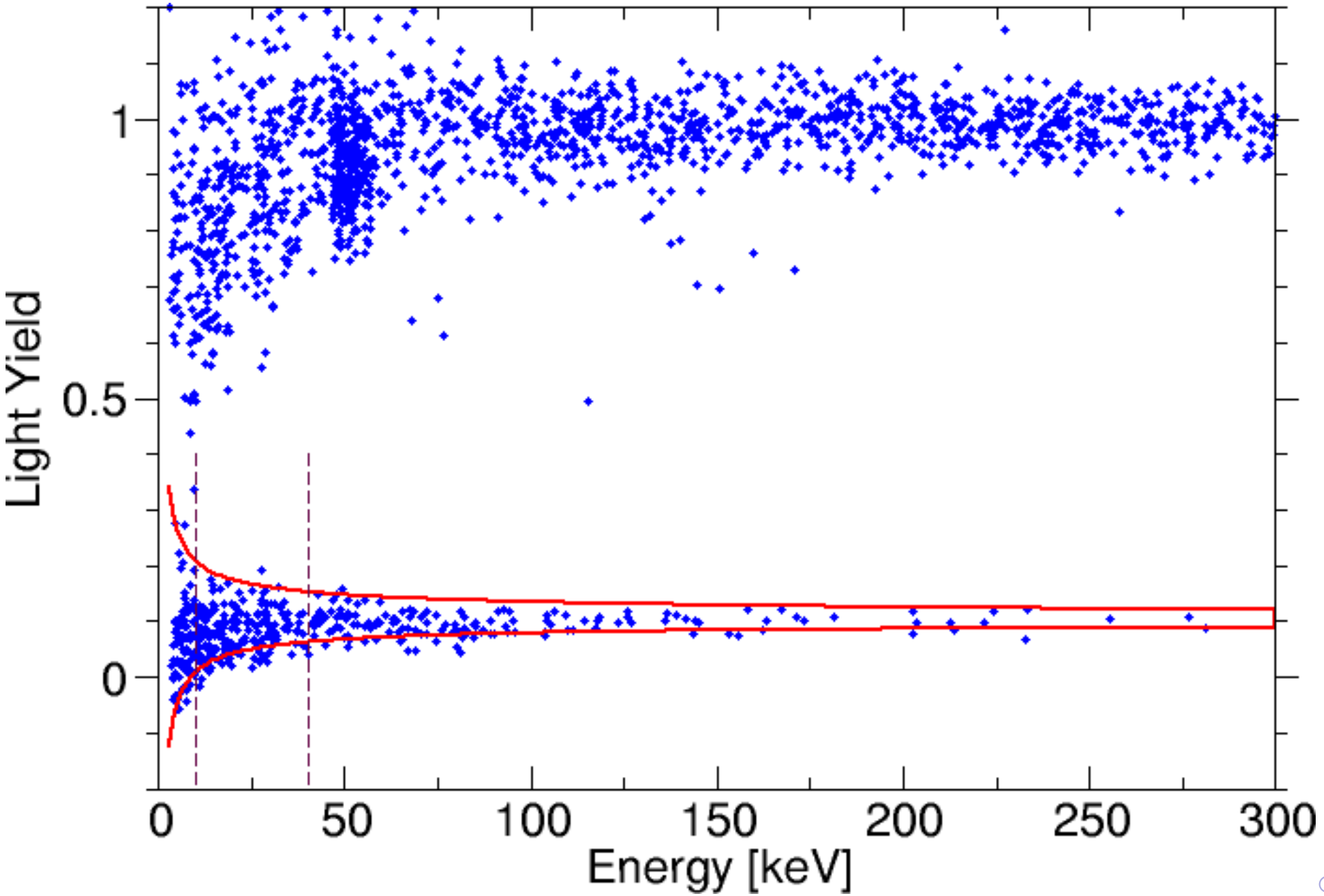
Gaussianity



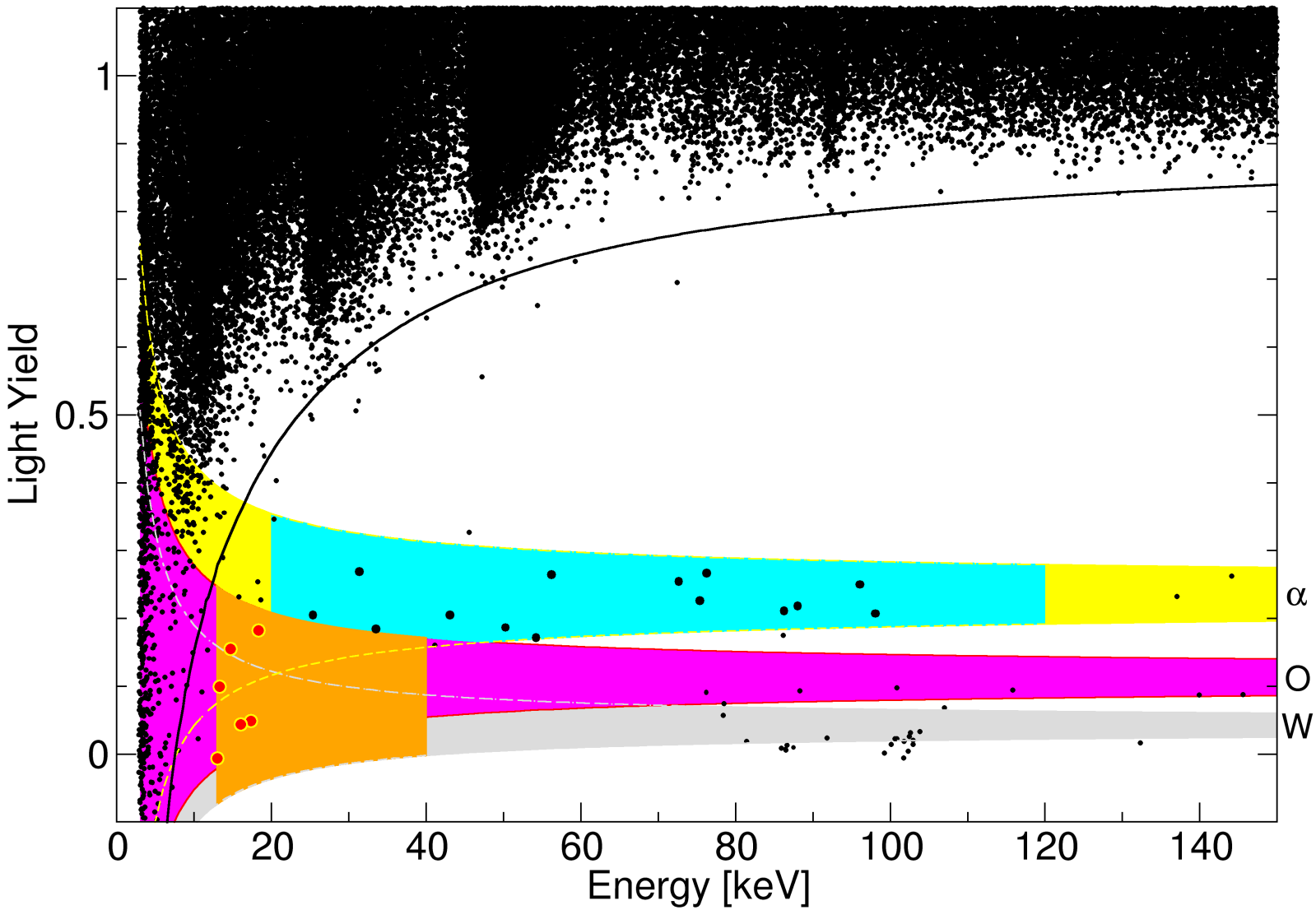


- only one event outside distriubtion (probably an α-event)
- 10^5 events inside peak

Neutron Calibration - Calculation of Nuclear Recoil Bands



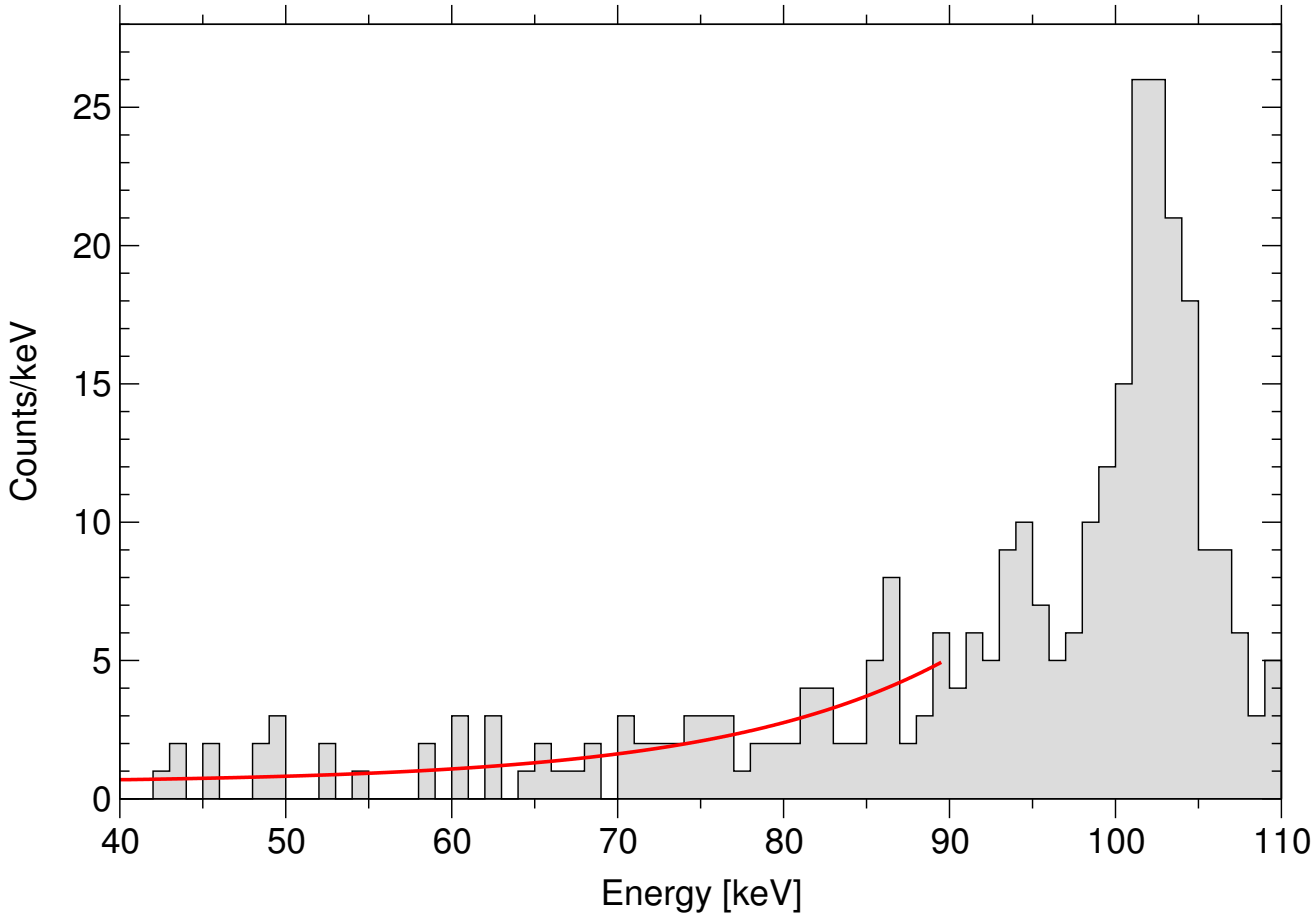
Gamma Leakage



99.9% of the e^-/γ-events expected above black line

Pb Recoil Background - Reference Region

module	$n_{\text{ref}}^{\text{Pb}}$
Ch05	17
Ch20	6
Ch29	14
Ch33	6
Ch43	12
Ch45	15
Ch47	7
Ch51	12
total	**89**

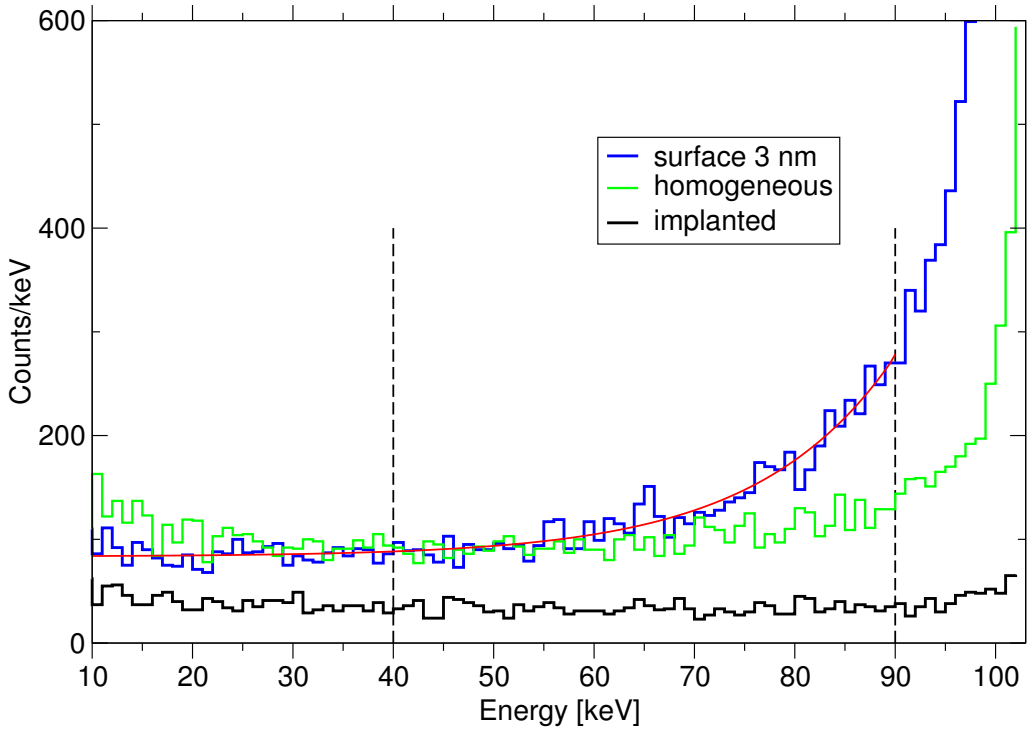


fit function: exponential + constant

Pb Recoil Background - SRIM simulation

To check the validity of Pb background estimate $\rightarrow$ SRIM simulation for three implantation profiles of ^{210}Po:

- exp. profile; 3 nm decay length; peaking at surface
- uniform distribution in volume
- ^{222}Rd at surface $\rightarrow$ 2 α-decays $\rightarrow$ ^{210}Po



No configuration produces rise towards lower energies $\rightarrow$ estimation valid.

Result of DM analysis - Diploma Thesis - I

input to the likelihood analysis EPJ C, 2012, Volume 72, Number 4, 1971

- processed raw data with a net exposure of 572kg days (compared to 730kg days for the run 32 paper)
- resolution fit $\Leftrightarrow$ definition of the recoil bands
- multiplicity spectra for muon-coincident events and coincident events in acc. region

Result of DM analysis - Diploma Thesis - II

Detector Module		Analysis of this Work		Analysis of Run32 Paper	
Name	Channel	E_{acc}^{min} [kev]	Acc. Events	E_{acc}^{min} [kev]	Acc. Events
VK33/F.	Ch05	15.2	3	12.3	11
Ver./B/Q	Ch20	15.5	5	12.9	6
Maja/H.	Ch29	13.2	12	12.1	17
Sabine/J	Ch33	15.3	5	15.0	6
Wibke/X	Ch43	16.2	9	15.5	9
K07/D.	Ch45	17.7	7	16.2	4
Daisy/S.	Ch47	16.5	5	19.0	5
Rita/S.	Ch51	11.5	6	10.2	9
Total			52		67
Rate			0.091/(kg day)		0.092/(kg day)

- The rates of signal events are in good agreement!
- The resolution fit of this analysis overestimates the γ−leakage.

→ A new version of the resolution fit is currently under investigation/development.

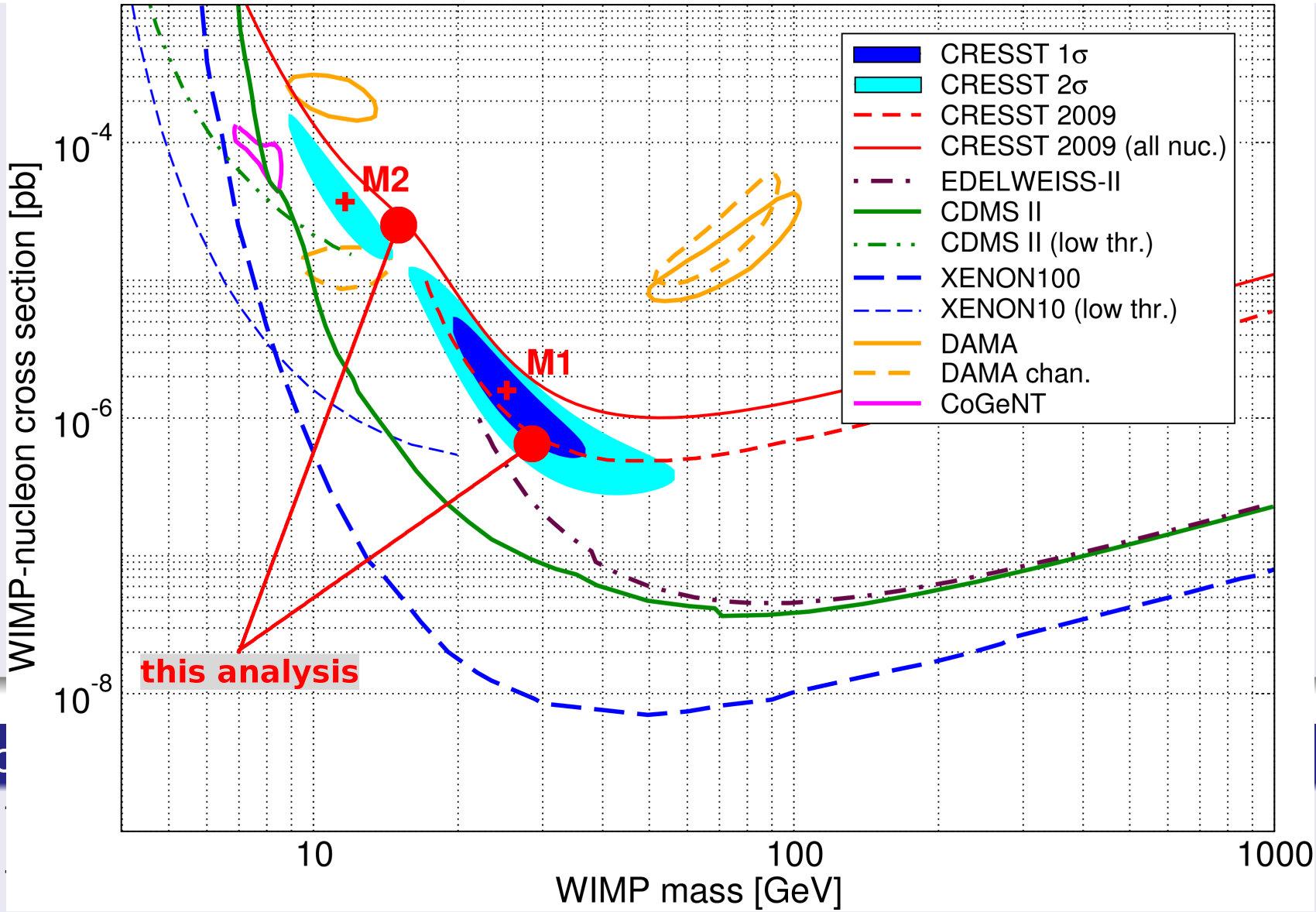
Result of DM analysis - Diploma Thesis - III

	Analysis of this Work		Analysis of run32 paper	
	M1	M2	M1	M2
e/γ-Events	8.0	8.0	8.0	8.0
α-Events	9.8	9.6	11.5	11.2
Neutron Events	7.7	9.1	7.5	9.7
Pb Recoils	11.1	12.5	15.0	18.7
Signal Events	13.0	10.2	29.4	24.2
m_χ [GeV]	28.9	13.0	25.3	11.6
σ_{WN} [pb]	$7.6 \cdot 10^{-7}$	$1.6 \cdot 10^{-5}$	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$
Significance	2.5σ	1.9σ	4.7σ	4.2σ

conclusion

- The WIMP parameters are compatible between both analyses.
- The significance for a WIMP signal is much lower in this analysis.

Result of DM analysis - Diploma Thesis - III



conc

Result of DM analysis - Diploma Thesis - IV - Conclusion

The analysis of this work and the CRESST analysis (run32 paper)

- are compatible concerning the rate of signal events.
- agree in mass and cross-section for a possible WIMP signal.
- disagree in the significance for a WIMP signal.

The resolution fit plays the major role in the explanation of the discrepancy between both analyses.