

# Direct dark matter search with the CRESST-III experiment

Michele Mancuso  
on behalf of the CRESST Collaboration

7 July 2018



Laboratori Nazionali del Gran Sasso



**TUM**  
TECHNISCHE  
UNIVERSITÄT  
MÜNCHEN



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



EBERHARD KARLS  
**UNIVERSITÄT**  
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- Overview
- Introduction
- CRESST-III detector
- CRESST-III first results
- Conclusions

# The CRESST collaboration

## Cryogenic Rare Event Search with Superconducting Thermometers



**6 institutions**

45 members: 16 senior scientists  
2 guest scientists  
11 Post Docs  
16 PhDs

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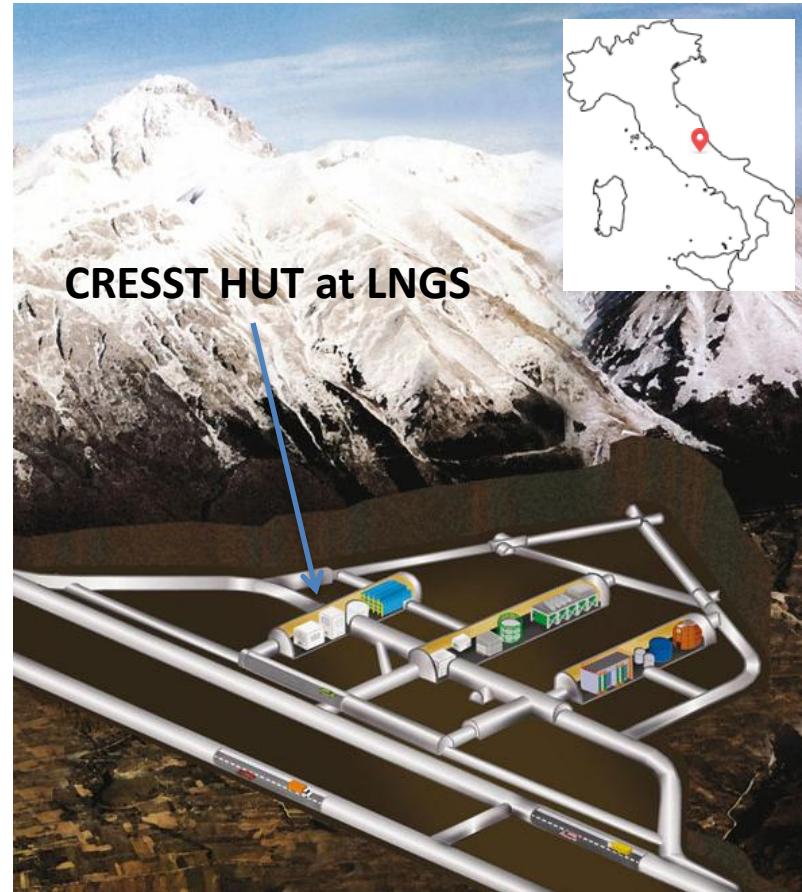
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## CRESST located at LNGS (Laboratori Nazionali del Gran Sasso) in Italy

- Cryogenic scintillating calorimeter
- Target material  $\text{CaWO}_4$
- Read out channels: phonon  
scintillation light

### CRESST-III Phase 1

- 10 detector modules



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The signature of dark matter in a direct detection experiment consists of a recoil spectrum of single scattering events.

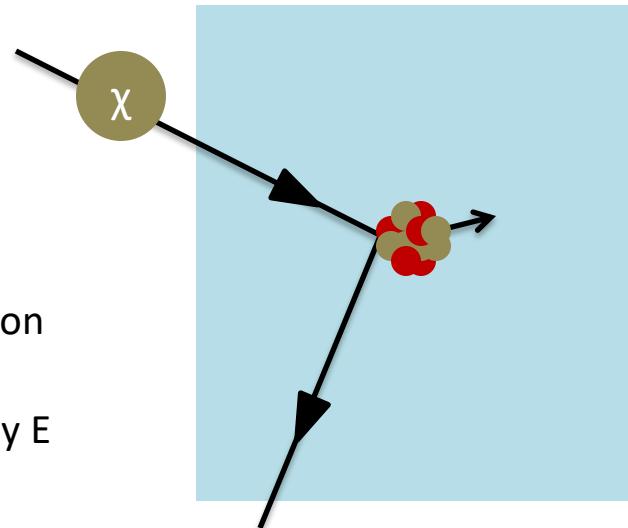
$$\frac{dR}{dE} (E, t) = \frac{\sigma_0}{m_\chi} \cdot F^2 \cdot \frac{\rho_0}{2\mu_A^2} \int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v}, t)}{v} d^3v$$

- $\rho_0$  : local DM density
- $\sigma_0$  : cross section at 0 momentum transfer
- $m_\chi$  : DM particle mass
- $\mu_A$  : reduced mass
- $F$  : nuclear form factor
- $\int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v}, t)}{v} d^3v$  Integral of the velocity distribution
- $v_{min}$  : minimal velocity to produce a recoil of energy E

Dark matter particles scatter

- off nuclei
- elastically
- coherently:  $\sim A^2$
- (spin-independent)

### Target material





## Towards low mass dark matter

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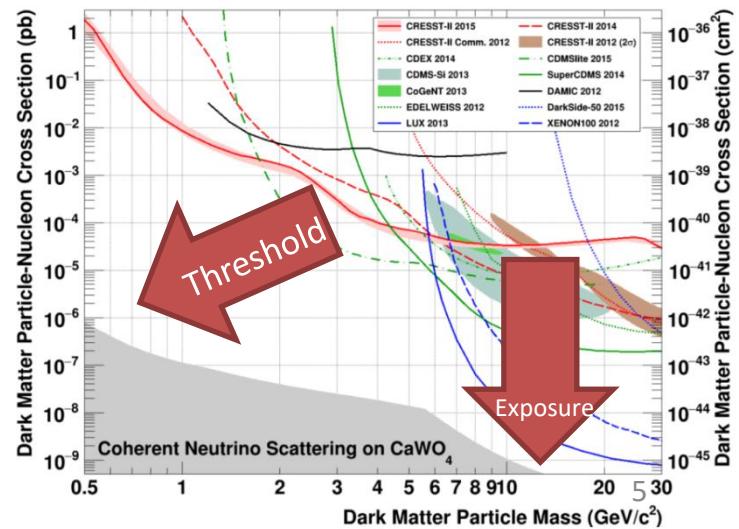
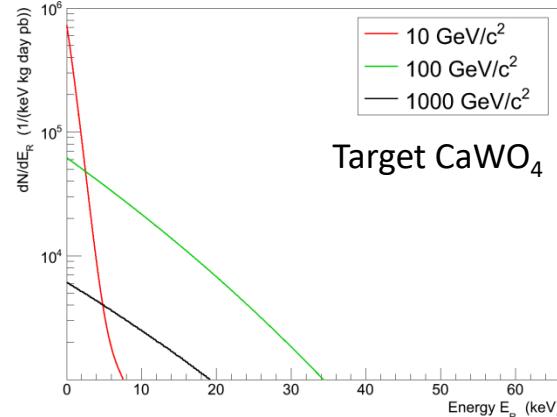
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For a given cross section:

- The rate increases exponentially towards lower energy
- End point of the spectrum decreases for lower DM particle mass

**CRESST has the best nuclear recoil threshold in the field**

Expected nuclear recoil spectra

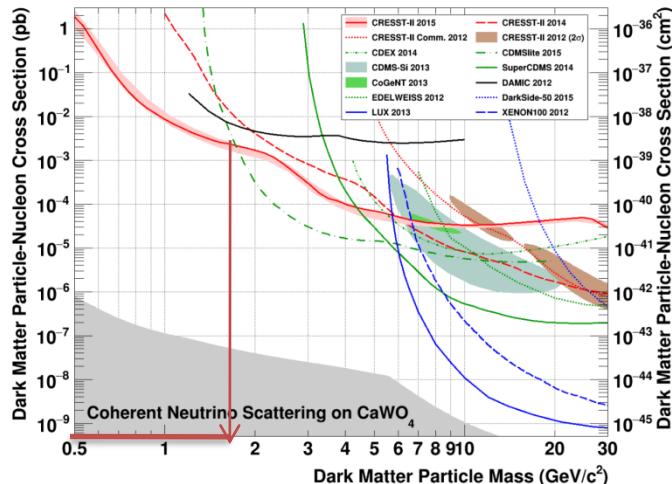




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## CRESST-II result

Angloher, G., Bento, A., Bucci, C. et al. Eur. Phys. J. C (2016) 76: 25.  
<https://doi.org/10.1140/epjc/s10052-016-3877-3>



Limit of the detector with the lowest threshold achieved in CRESST-II Phase2 (307 eV)



**Target mass:** 300g  
**Phonon threshold:**  $E_{th} \approx 307\text{eV}$   
**Light detector res.:**  $\sigma \approx 10\text{ eV}$   
**Crystals:** commercial  
**Background:**  $\approx 8.5\text{ cts}/(\text{keV kg d})$   
**Exposure:**  $\approx 52\text{ kg d}$

New region of the parameter space explored down to **500 MeV/c<sup>2</sup>** dark matter particle mass

## CRESST-III detector module

New improved detectors have been developed to enhance the desired characteristics.



**Target mass:**  $\sim 25\text{g}$

**Phonon threshold:**  $E_{th} \lesssim 100\text{ eV}$

***improvement by at least a factor of 3***

**Light detector res.:**  $\sigma \approx 5\text{ eV}$

***improvement by a factor of 2***

**Crystals:** only TUM

***improvement radio-purity***



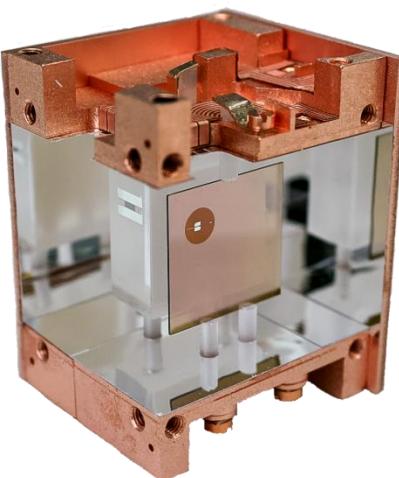
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## Energy resolution

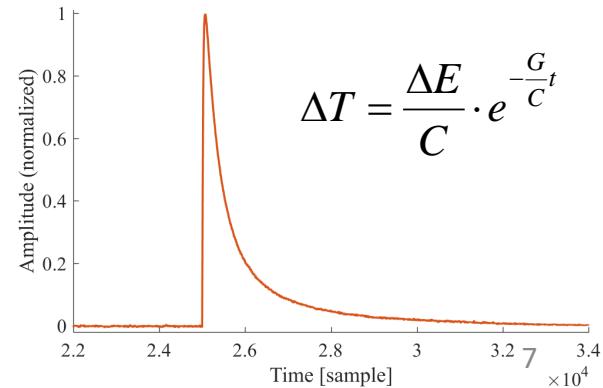
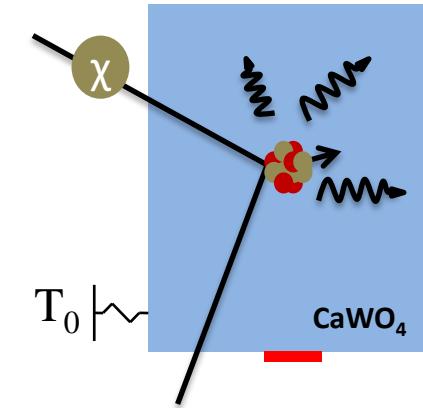
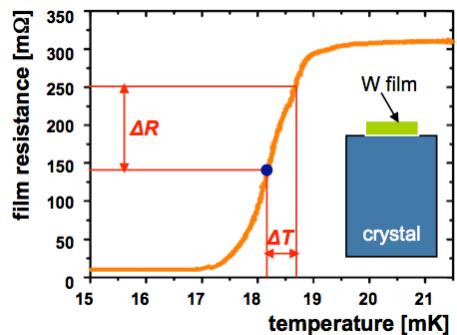
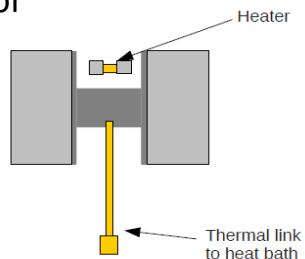
Scintillating 24 g CaWO<sub>4</sub> crystals as target

- Cryogenic detector  $T_0 \approx 10\text{ mK}$
- W-TES sensor for T read-out
- 100 eV threshold

➤ To an energy deposit in the target corresponds a proportional temperature rise



➤ The temperature readout is made with a tungsten transition edge sensor





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## Energy resolution

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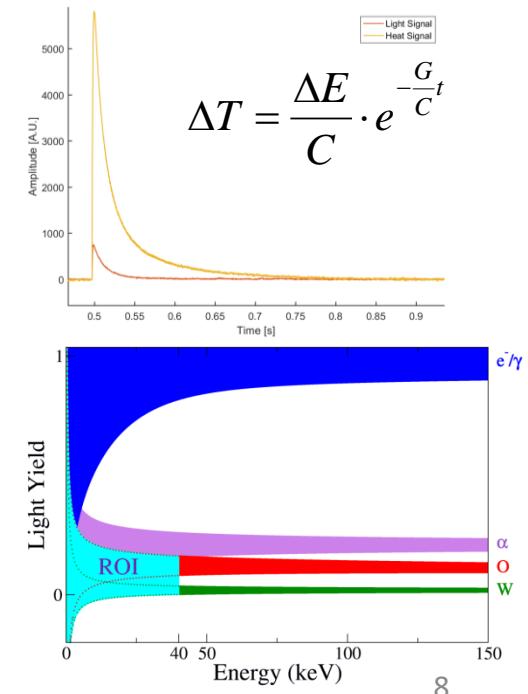


## Particle discrimination

Light detector SOS

- Cryogenic detector  $T_0 \approx 10\text{mK}$
- W-TES sensor for T read-out

Light yield characteristic of the type of particle → Particle discrimination





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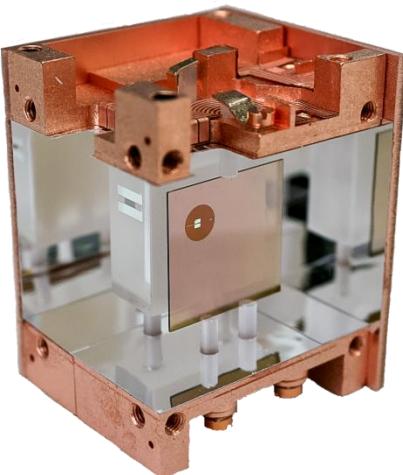
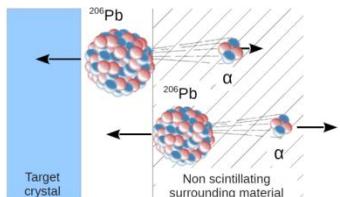
Light yield characteristic of the type of particle → Particle discrimination

## Background rejection

Veto surface  
related background

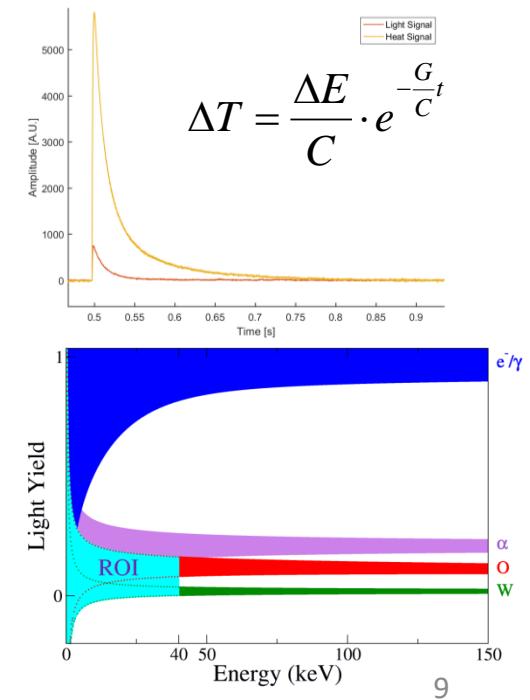
### Housing

- Reflecting & scintillating foil
- Fully scintillating



## Instrumented holding system

- CaWO<sub>4</sub> stick instrumented with W-TES

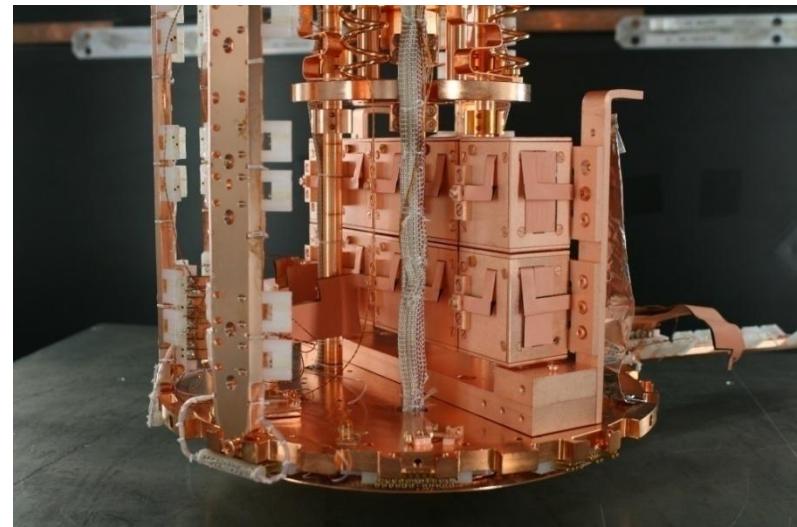


## CRESST-III Phase one Run commissioning

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- May 2016 ➤ 10 detector modules mounted
- June 2016 ➤ Cool down to mK temperature
- Sept 2016 ➤ Start physics run
- Oct 2016 ➤ Energy calibration
- April 2017 ➤ Neutron calibration
- Feb 2018 ➤ End of run
- Today ➤ Total raw exposure collected as of 02.2018 :  $\sim 30 \text{ kg} \cdot \text{day}$   
➤ **Unblinded 1 detector module above 100eV:  $2.39 \text{ kg} \cdot \text{day}$**

10 CRESST-III detector module

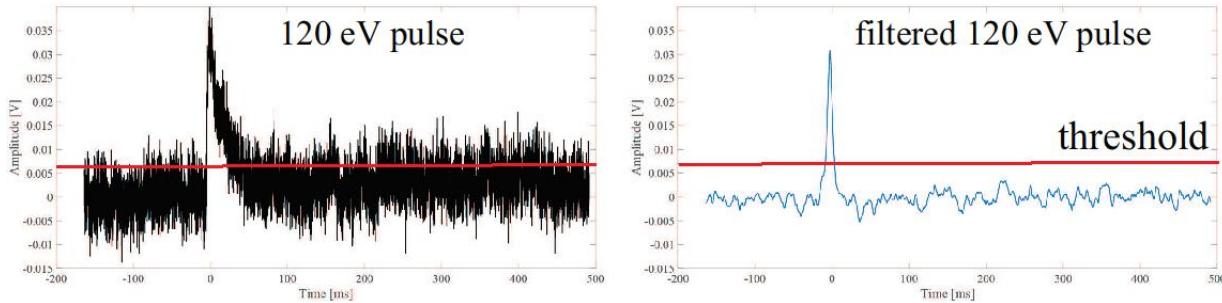


New data release and results will come soon

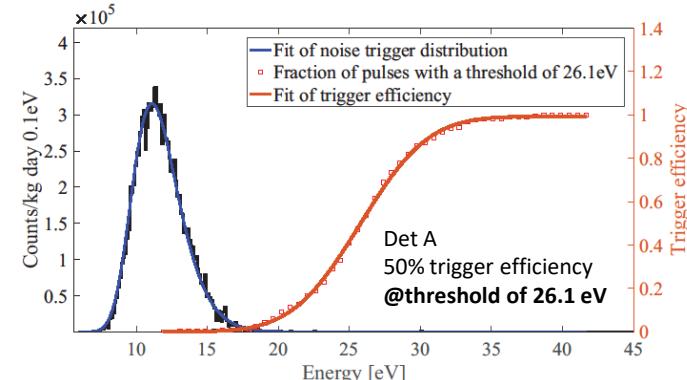
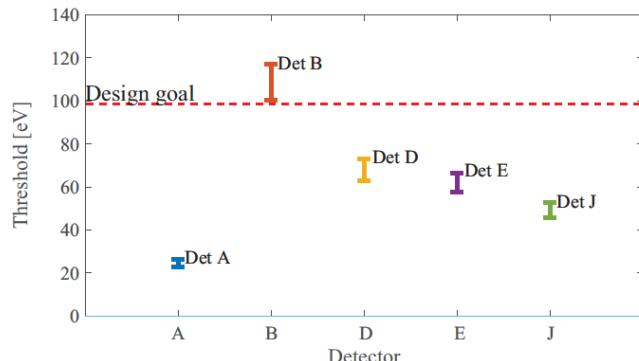
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## Threshold optimization

- In-depth study of energy calibration at low energy.
- Optimum Filter: Maximization of the signal-to-noise ratio



- Rigorous threshold analysis:  
threshold determined by accepted noise trigger rate

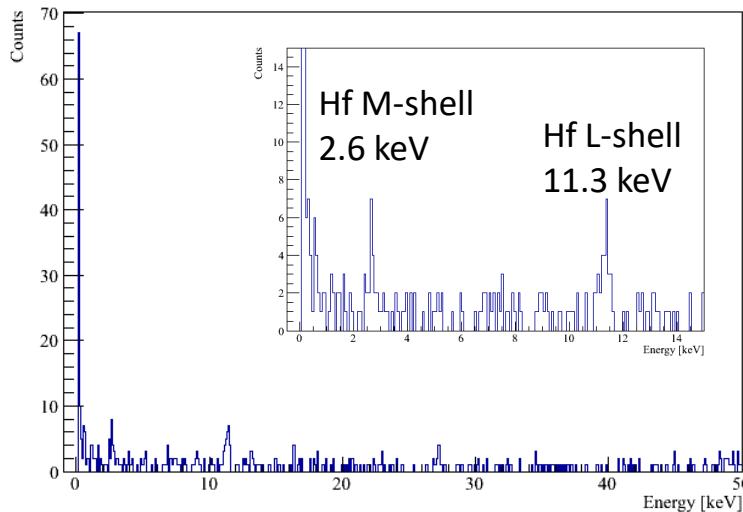


Noise-trigger rate	Det A	Det B	Det D	Det E	Det J
1 cts/(kg day)	6.69 mV	9.82 mV	6.65 mV	11.89 mV	5.57 mV
10 cts/(kg day)	6.26 mV	9.17 mV	6.21 mV	11.12 mV	5.21 mV
100 cts/(kg day)	5.80 mV	8.46 mV	5.73 mV	10.30 mV	4.82 mV
Energy range	22.6-26.1 eV	100.5-116.9 eV	63.0-73.2 eV	57.5-66.5 eV	45.5-52.6 eV

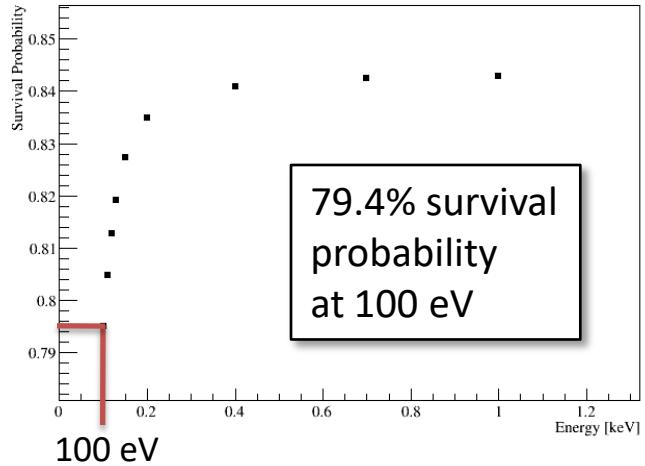
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## Physics data Detector A

- Data taking period: 31/10/16 to 05/07/17
- Detector mass: 24 g
- Total exposure: 2.39 kg days
- Net exposure (after cuts): 2.21 kg days
- Analysis Threshold: 100 eV

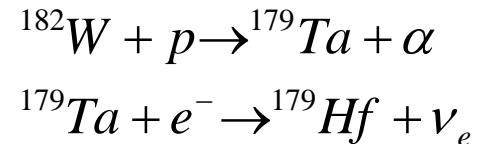


Survival Probability of Nuclear Recoil Events After Cuts



**Tot background level:**  
 3.5 counts / (keV kg day)

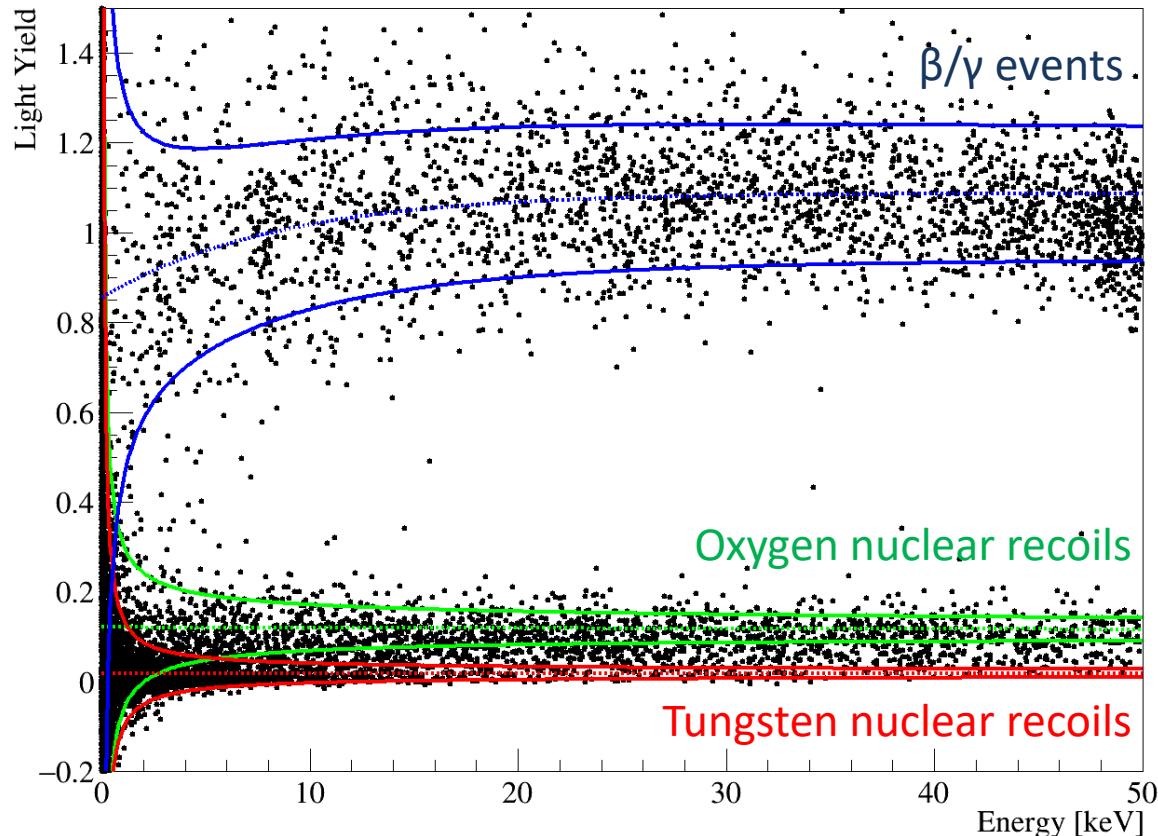
Background events from cosmogenic activation of tungsten





## Neutron Calibration Det A

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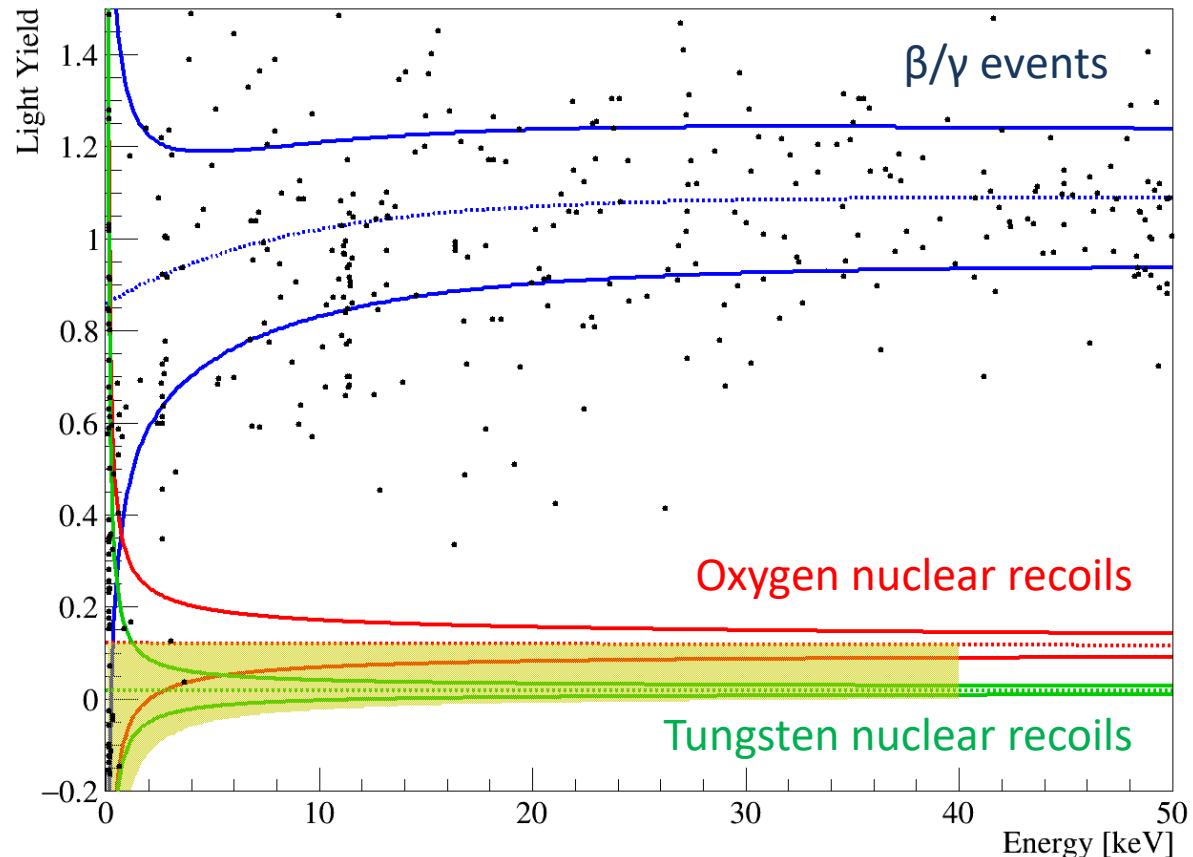




## Physics data Detector A - $2.39 \text{ kg} \cdot \text{day}$

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(Werner-Heisenberg-Institut)

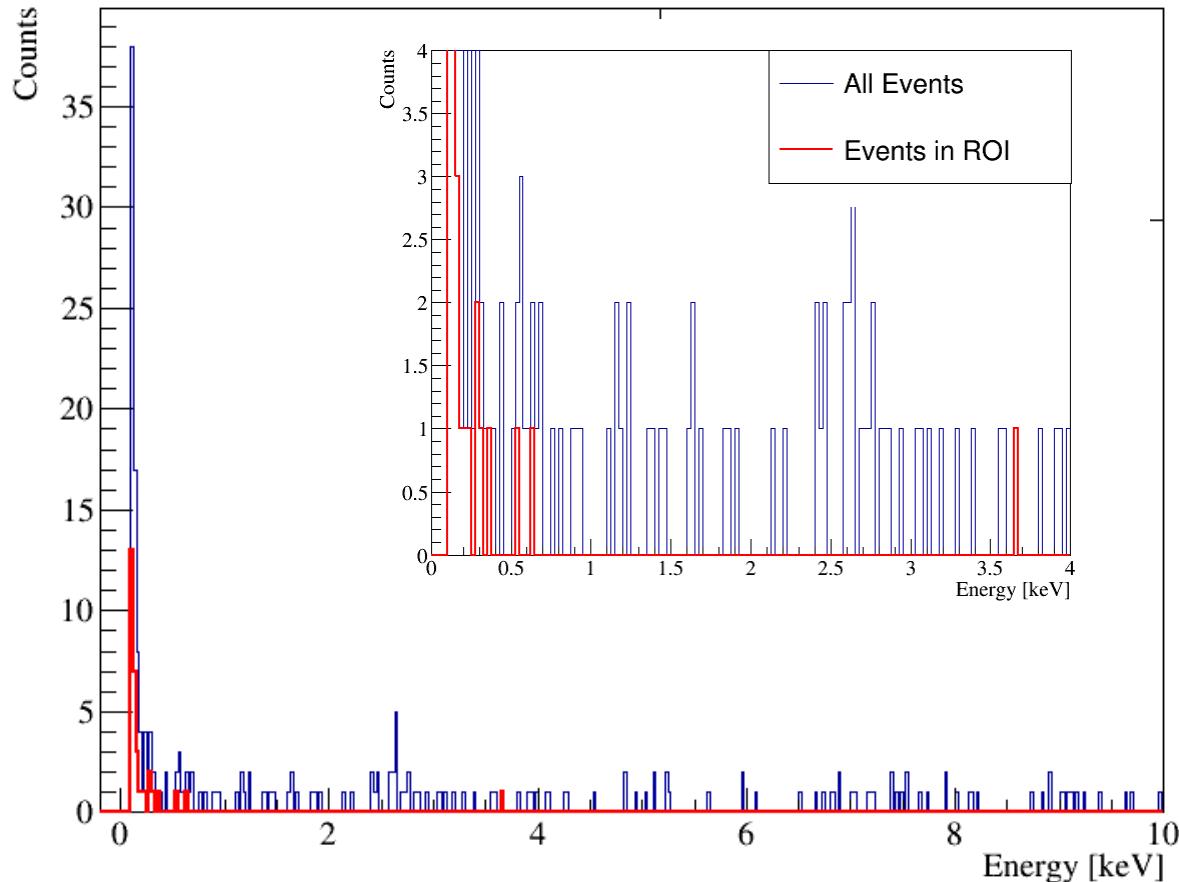
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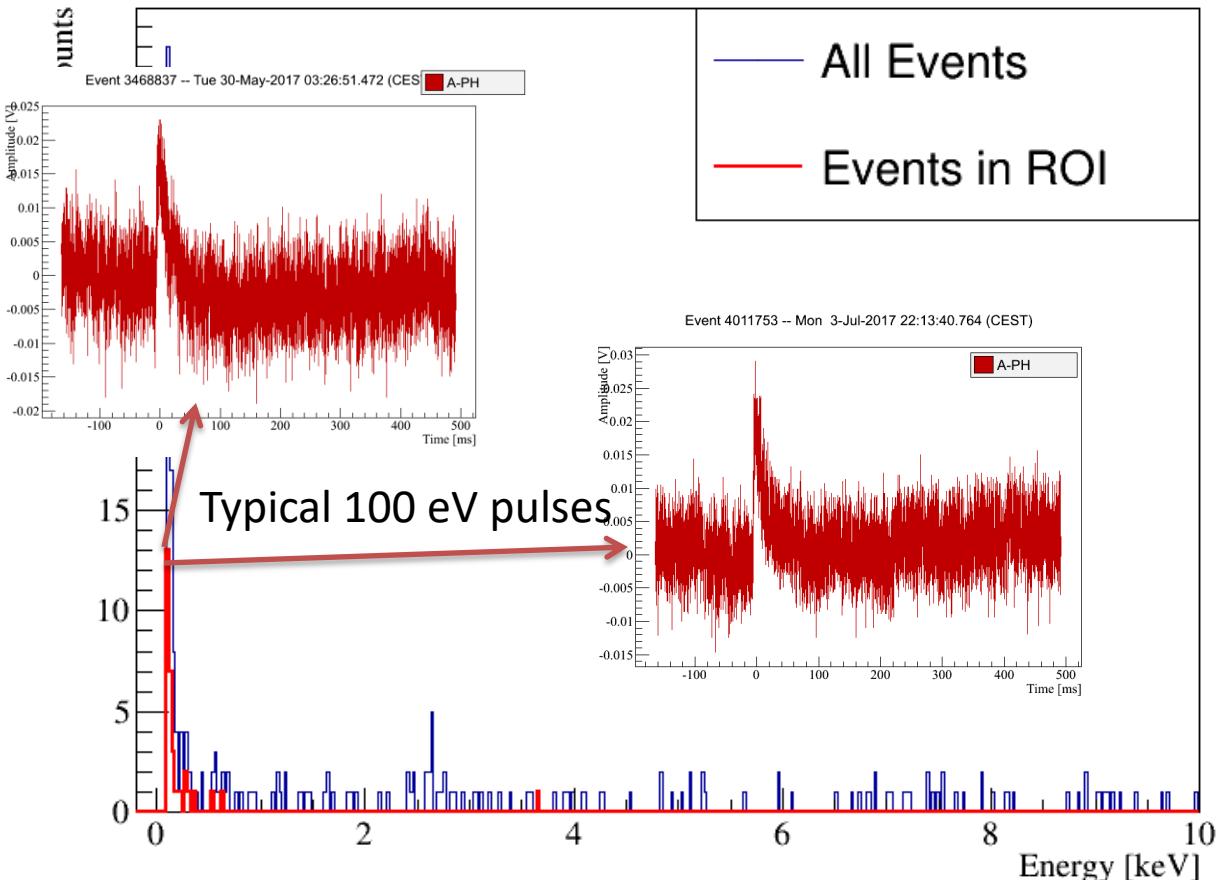
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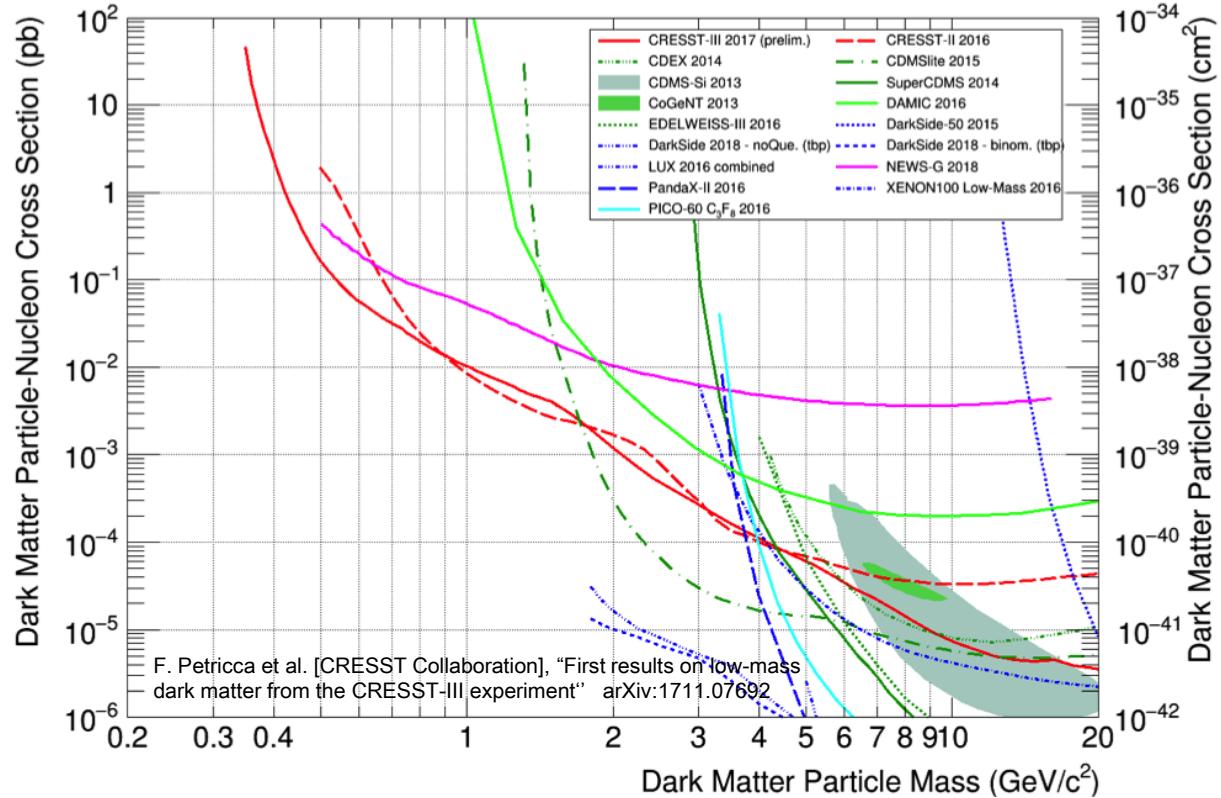


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## Limit with Det A 2.39 kg · day

Yellin 1D optimum interval method

Replicated and improved result from CRESST-II with only small fraction of the data set

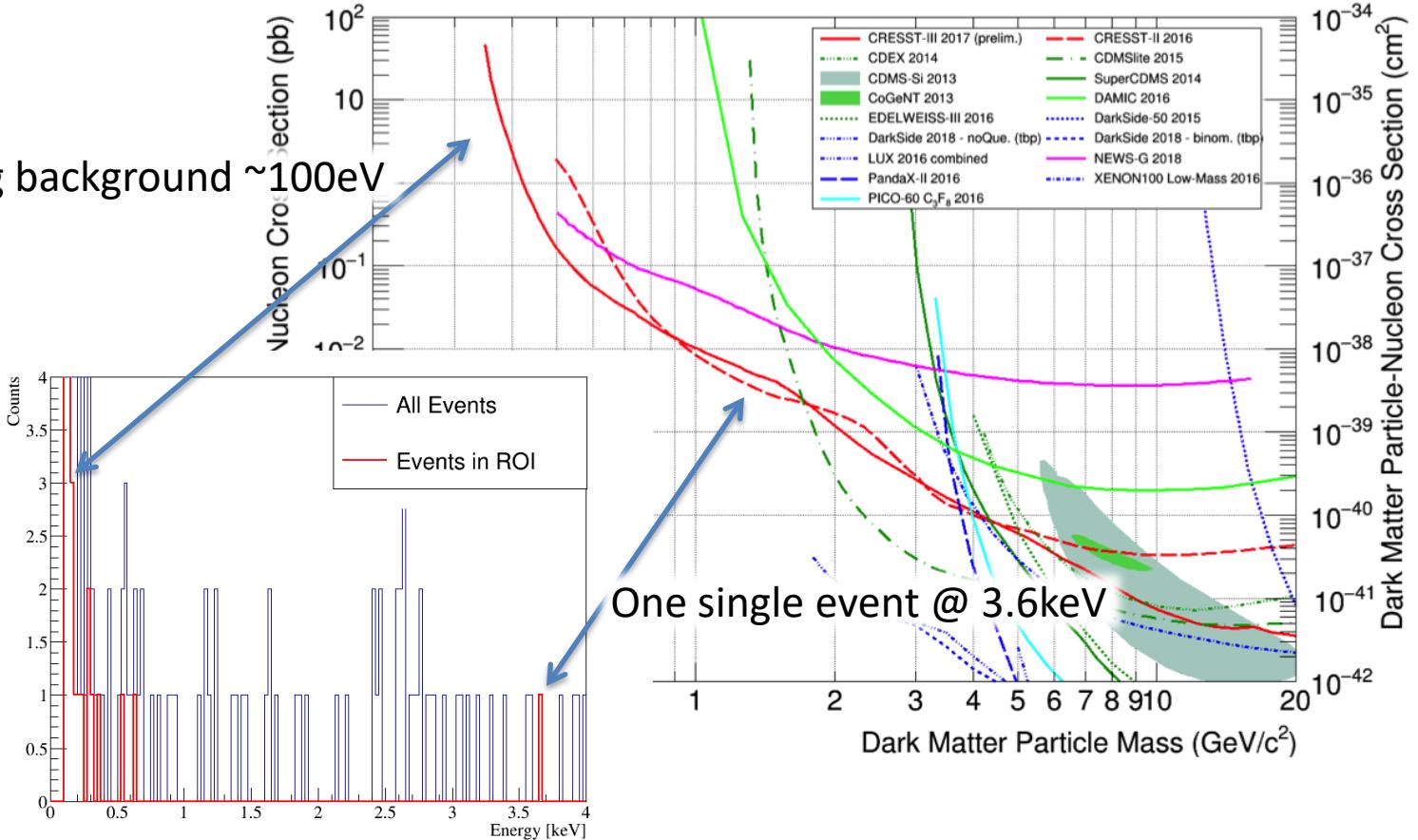


Exponential background rising towards low energies limits the sensitivity at low DM masses

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## Limit with Det A 2.39 kg · day

Rising background  $\sim 100\text{eV}$

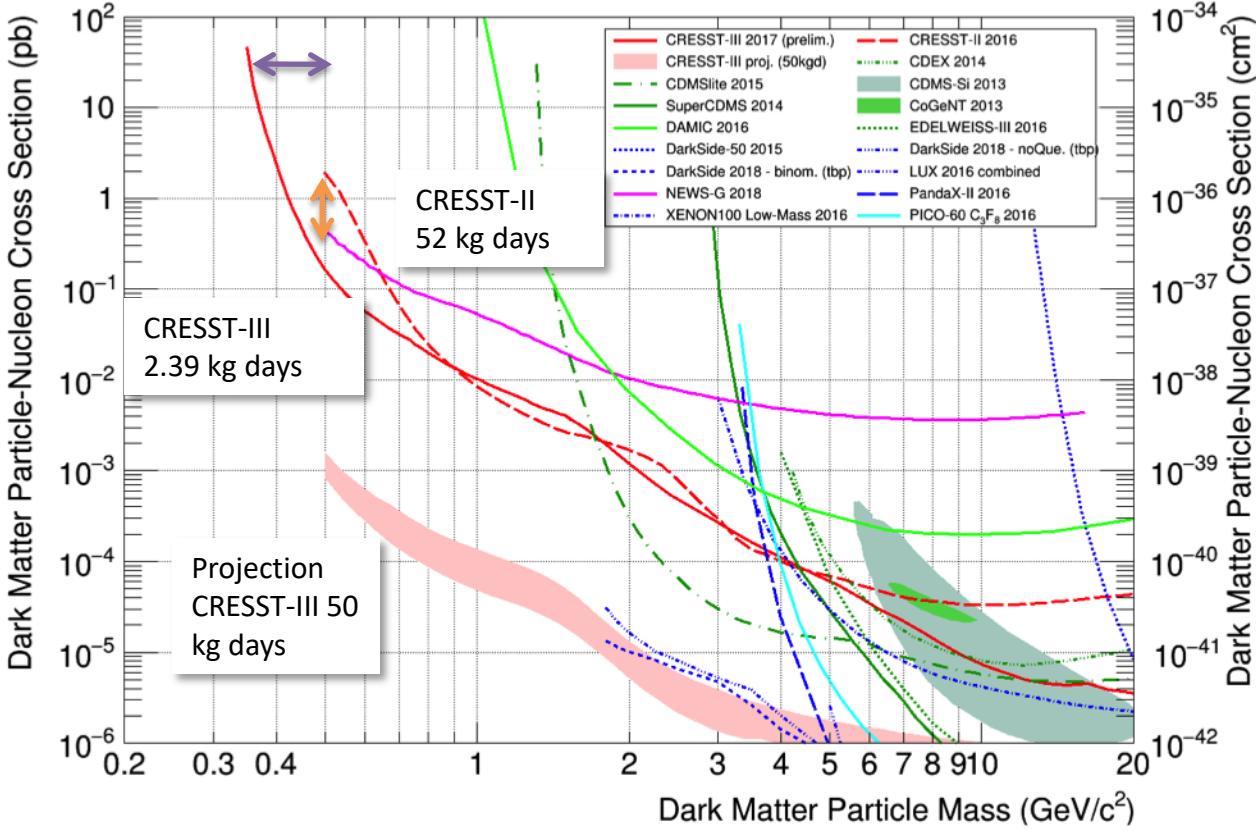


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## Limit with Det A 2.39 kg · day

Extend reach from 0.5GeV/c<sup>2</sup> to 0.35GeV/c<sup>2</sup>

One order of magnitude improvement at 0.5 GeV/c<sup>2</sup>



➤ Upgraded detector modules with dedicated hardware changes to understand low energy spectrum

## Outlook

**CRESST has an outstanding potential to explore the low mass region of the parameter space for DM nucleus scattering with unprecedented sensitivity**

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### **CRESST-III Phase 1 RUN1 07/2016 – 02/2018**

- Analysis ongoing:
  - 26.1eV optimum threshold for detector A
  - 3 other detector with sub-100eV thresholds
- Background investigation (in analysis) at low energies before the total unblinding

**Data with full exposure and threshold  
about to be published**

### **CRESST-III Phase 1 RUN2 07/2018**

- Upgraded detector modules with dedicated hardware changes to understand low energy spectrum