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

Data Analysis in CRESST

IMPRS Young Scientists Workshop July 2019

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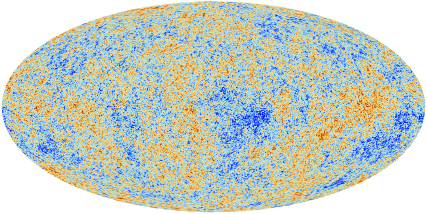
Technical University of Munich
Max Planck Institute for Physics

July 24, 2019

Outline

Evidence for Dark Matter



CMB Image:ESA

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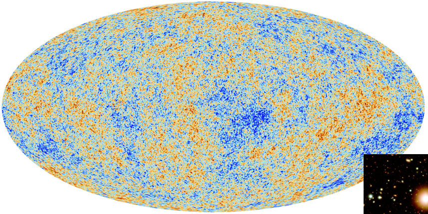

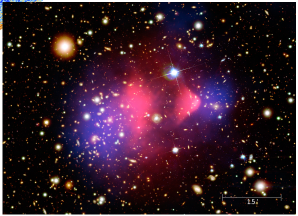

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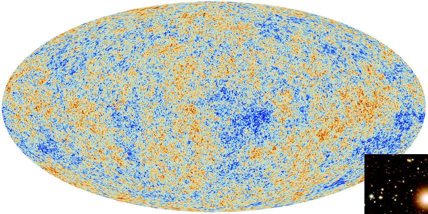

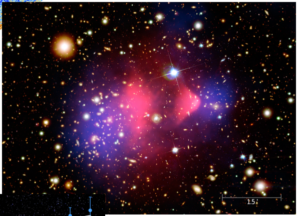

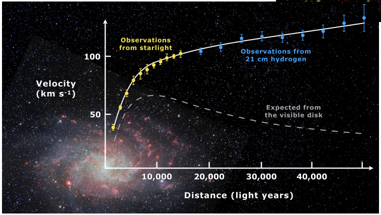

WIMPs

Weakly **I**nteracting **M**assive **P**articles

- Interactions with SM particles only on the weak scale or below
- Stable on cosmological time scale
- Lee-Weinberg-bound excludes WIMP masses below ~ 3 GeV/c^2
- Sub-GeV masses: light dark matter (asymmetric dark matter models)
- Asymmetric dark matter models are not bound to the Lee-Weinberg limit
- Predictions of masses in the range: [0.1-10] GeV/c^2

Dark Matter Halo Model

- Spherical halo of DM around center of Milky Way
- DM particles thermalized $\rightarrow$ Maxwellian velocity distribution
- Local DM density: $\rho_{\mathrm{DM}} = 0.3\,\mathrm{GeV}/\mathrm{cm}^3$
- Rotation of Milky Way $\rightarrow$ WIMP Wind

Outline

The CRESST Experiment

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

- $\sim$ 3600 m.w.e. deep
- μs: $\sim 3 \cdot 10^{-8}$ /(s cm^2)
- γs: ~ 0.73 /(s cm^2)
- neutrons: $4 \cdot 10^{-6}$ n/(s cm^2)

CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at $\sim$15 mK

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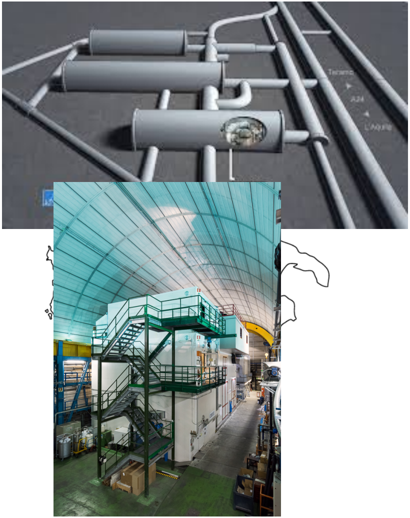

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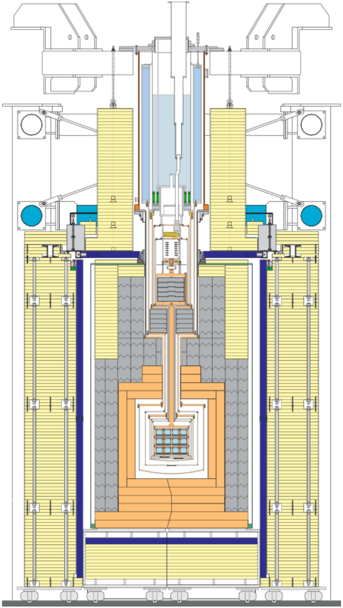
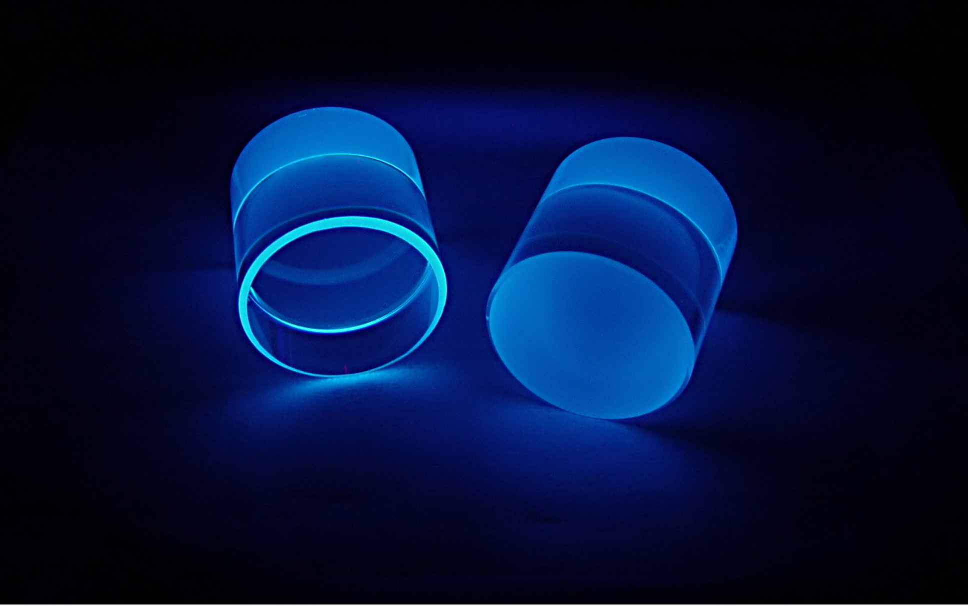
CRESST Setup

Shielding:

- polyethylene
- muon veto system
- lead
- copper
- polyethylene



Detector Modules



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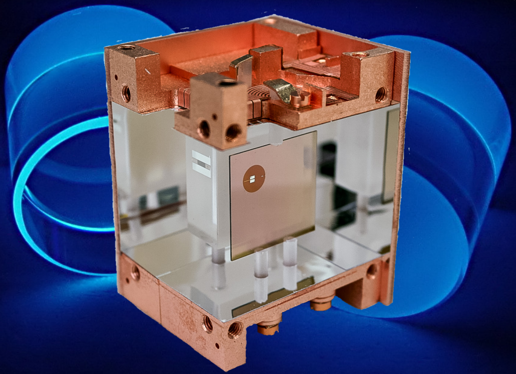
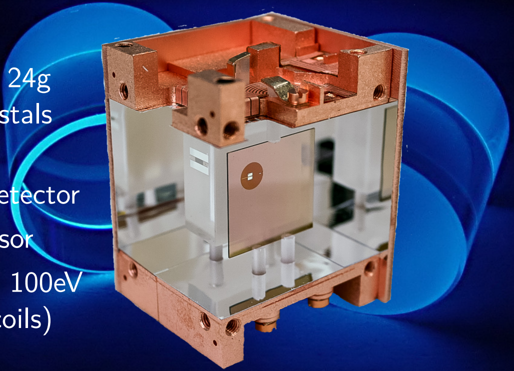


Detector Modules

Crystals:

- scintillating 24g $CaWO_4$ crystals as target
- cryogenic detector
- W-TES sensor
- $E_{threshold} \leq 100$eV (nuclear recoils)



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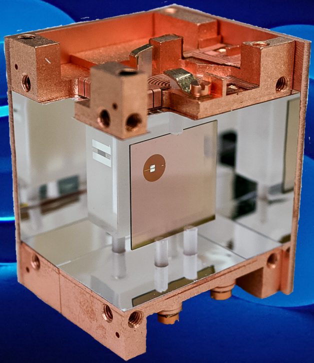

Particle discrimination:

- Light detector
- Light Yield characteristic of type of particle

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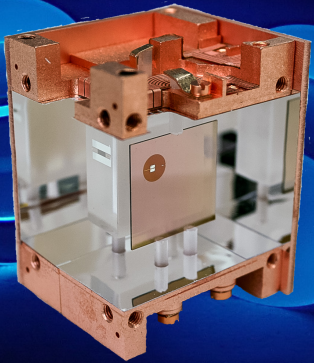

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- Light detector
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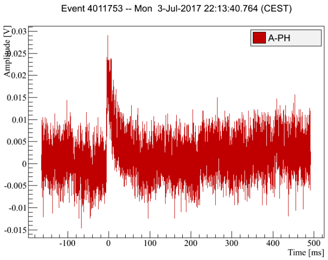
Background rejection:

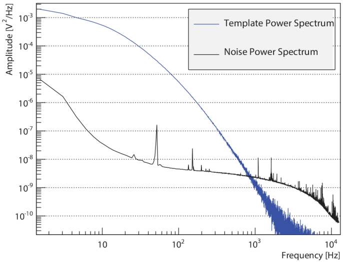
- Housing: reflecting and scintillating foil
- Instrumented holding system $\rightarrow$ Veto surface related Background

Outline

Continuous DAQ + Optimum Filter

- Dead-time free DAQ: detector output is continuously recorded with a sampling rate of 25 kHz
- Create Template Power Spectrum and Noise Power Spectrum

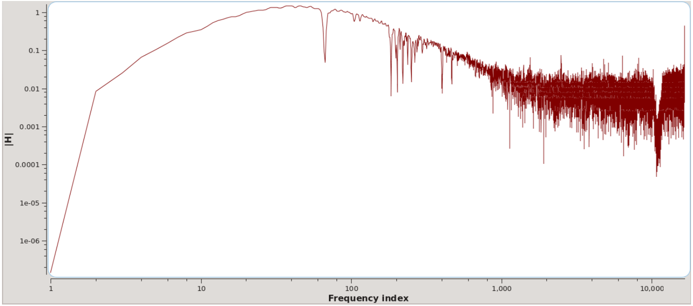




$$y_F(t) = \frac{A}{\sqrt{2\pi}} \int_{-\infty}^{\infty} H(\omega)\widehat{s}(\omega)e^{i\omega t}\,\mathrm{d}\omega$$

Optimum Filter

- Maximize Signal-to-Noise ratio in frequency space
- Transfer function: $H(\omega) = K \frac{\widehat{s^*}(\omega)}{N(\omega)} e^{-i\omega\tau_M}$



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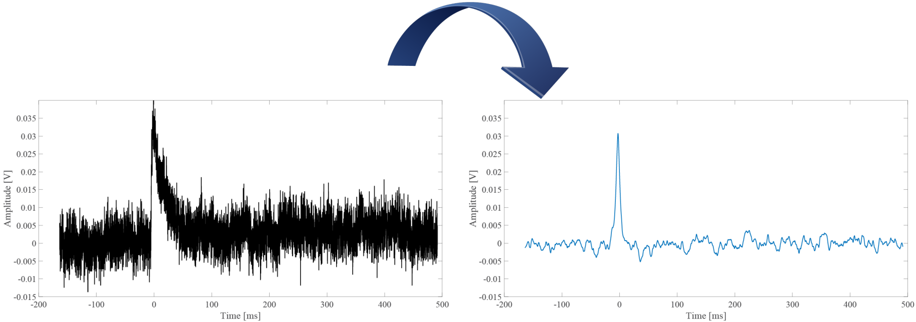

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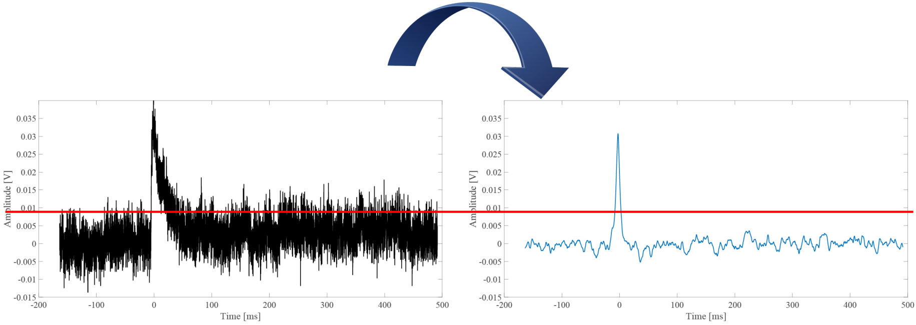
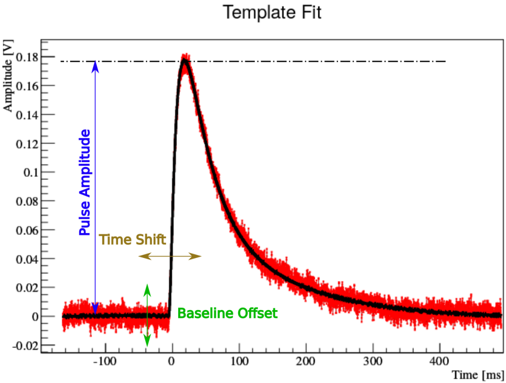
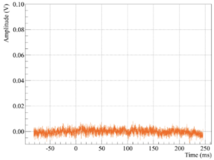


Template Fits

- Extract selection of 'good' pulses
- Average selection to create template pulse
- Fit template pulse to full list of pulses
- Fit results $\rightarrow$ further quality cuts on pulse shape
- Repeat with higher quality template

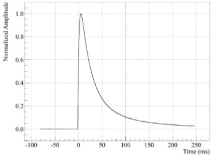


Efficiency



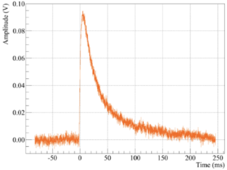
Empty baseline

+

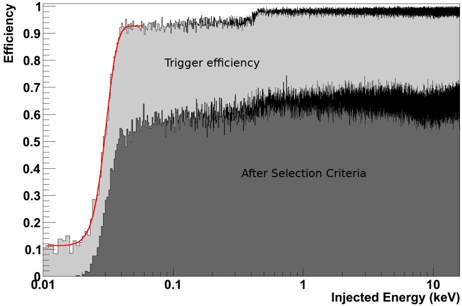


Averaged pulse

=



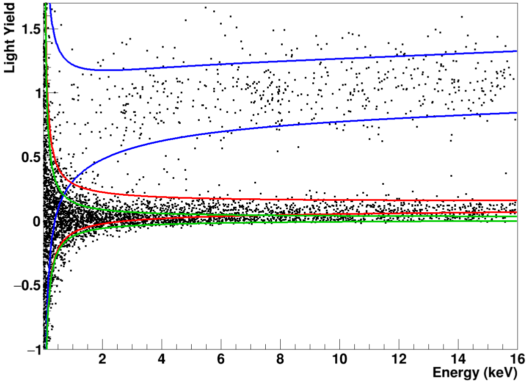
Simulated pulse



Calibration

Light Yield: $\mathrm{LY} = \mathrm{E_L}/\mathrm{E_{Ph}}$

Band Fits QF



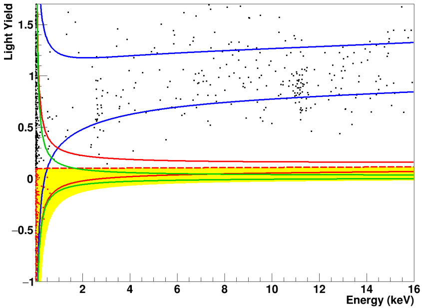
e/γ events

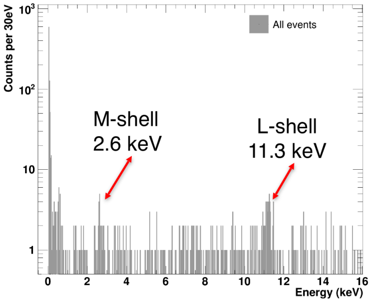
oxygen nuclear recoils

Tunsten nuclear recoils

Light Yield Plot + ROI

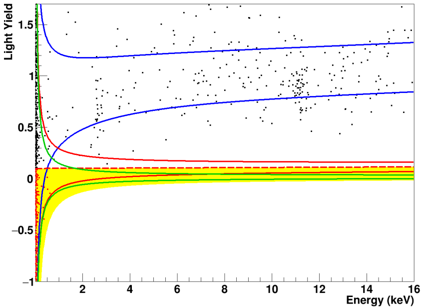
Cosmogenic activation lines: $^{179}\text{Ta} + e^- \rightarrow \; ^{179}\text{Hf} + \nu_e$

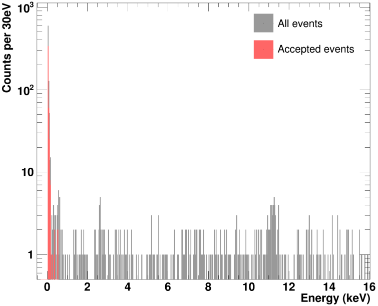




Light Yield Plot + ROI

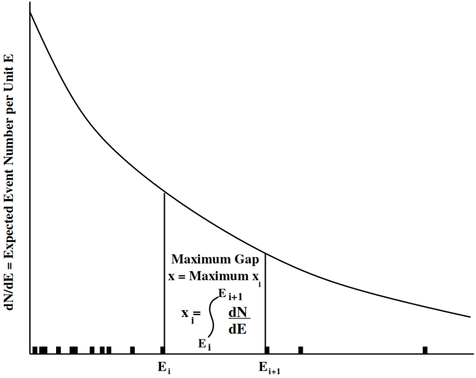
Region of Interest: From mean of oxygen band down to 99.5% lower boundary of Tungsten band





Yellin maximum gap method

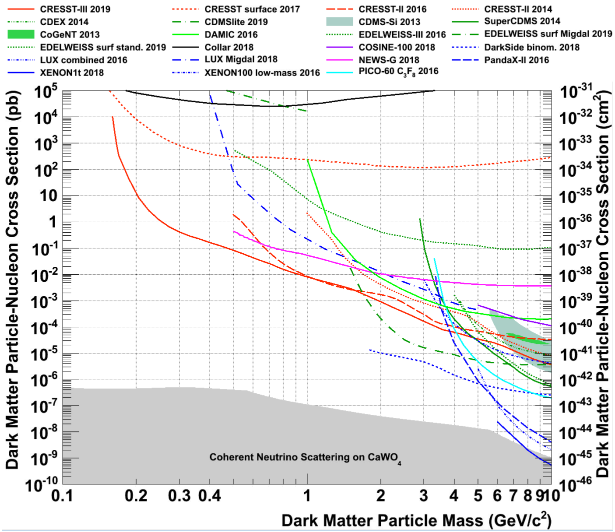
$$x_i(\sigma, m_\chi) \equiv \int_{E_i}^{E_{i+1}} \frac{d\Gamma(\sigma, m_\chi)}{dE} dE$$



S. Yellin, "Finding an upper limit in the presence of an unknown background"

- Simulate spectra for different masses
- Use maximum gap between two events to determine limits on cross-section
- For each mass calculate cross-section which excludes observed data with certain confidence level
- Extend to Yellin optimum interval method

Dark Matter Limits



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- Build and run Optimum Filter on raw data stream
- Trigger filtered stream
- Perform cuts and build template
- Fit pulses
- Perform further cuts (and fit again)
- Produce Light Yield plot
- Perform calibration and band fits
- Select data in ROI and create spectrum
- Compare data spectrum to simulated spectrum
  $\Rightarrow$ Calculate Limits on Dark Matter

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