RESULTS OF THE FIRST NaI SCINTILLATING CALORIMETER PROTOTYPES BY COSINUS

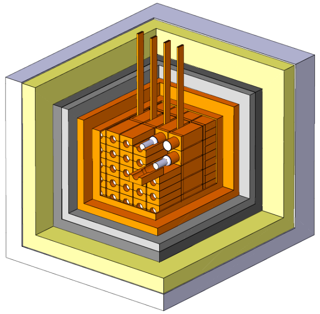
TAUP 2017

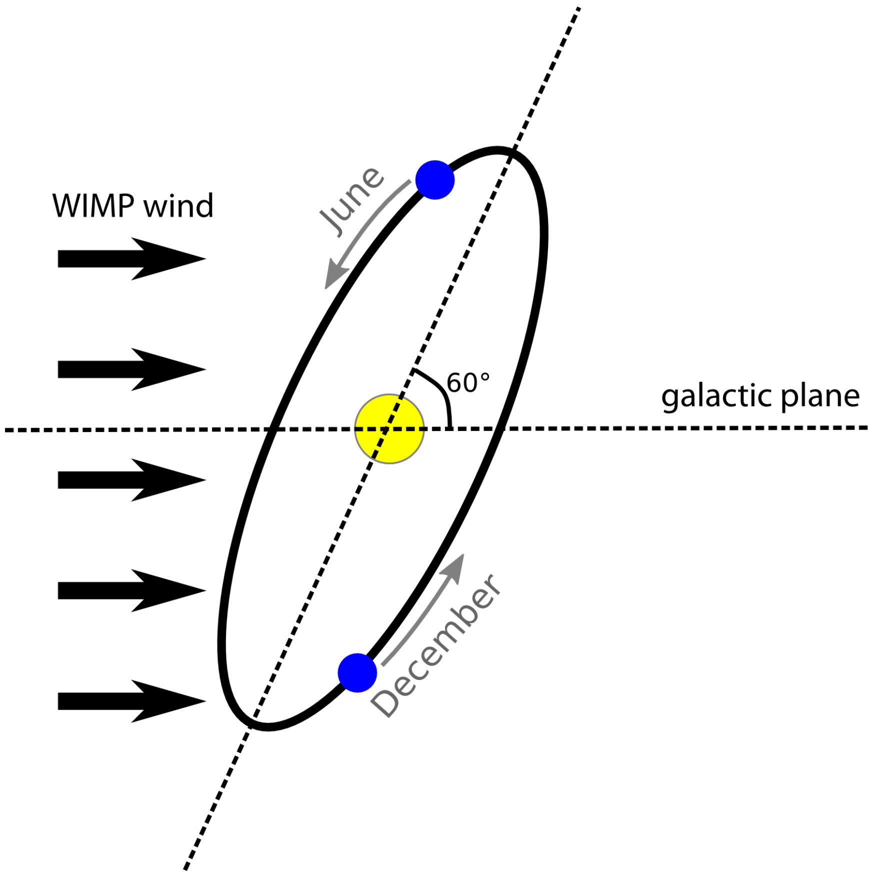
24 - 28 July 2017

Florian Reindl, INFN – Sezione di Roma 1

for the COSINUS collaboration

DARK MATTER – ANNUAL MODULATION

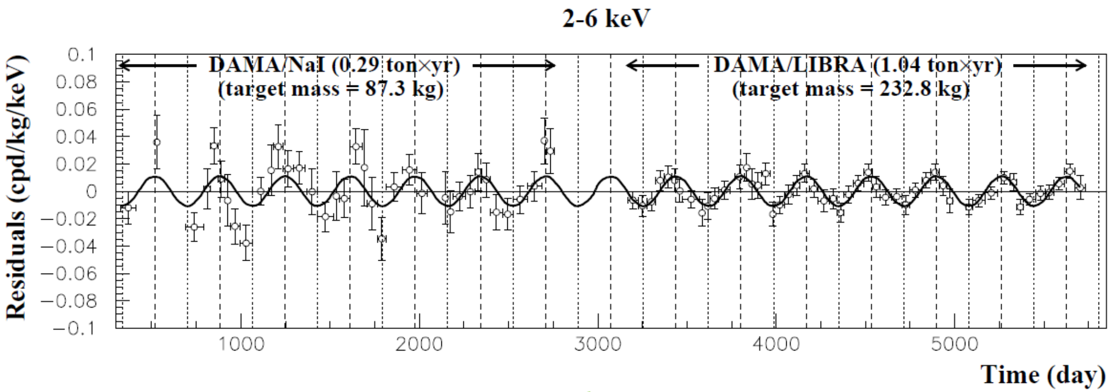




Period: 1 year
Phase: cosine peaking June 2nd

DAMA/LIBRA

Target: NaI (Tl)



EPJ C 56 333 (2008)

Statistics: >9σ ✓

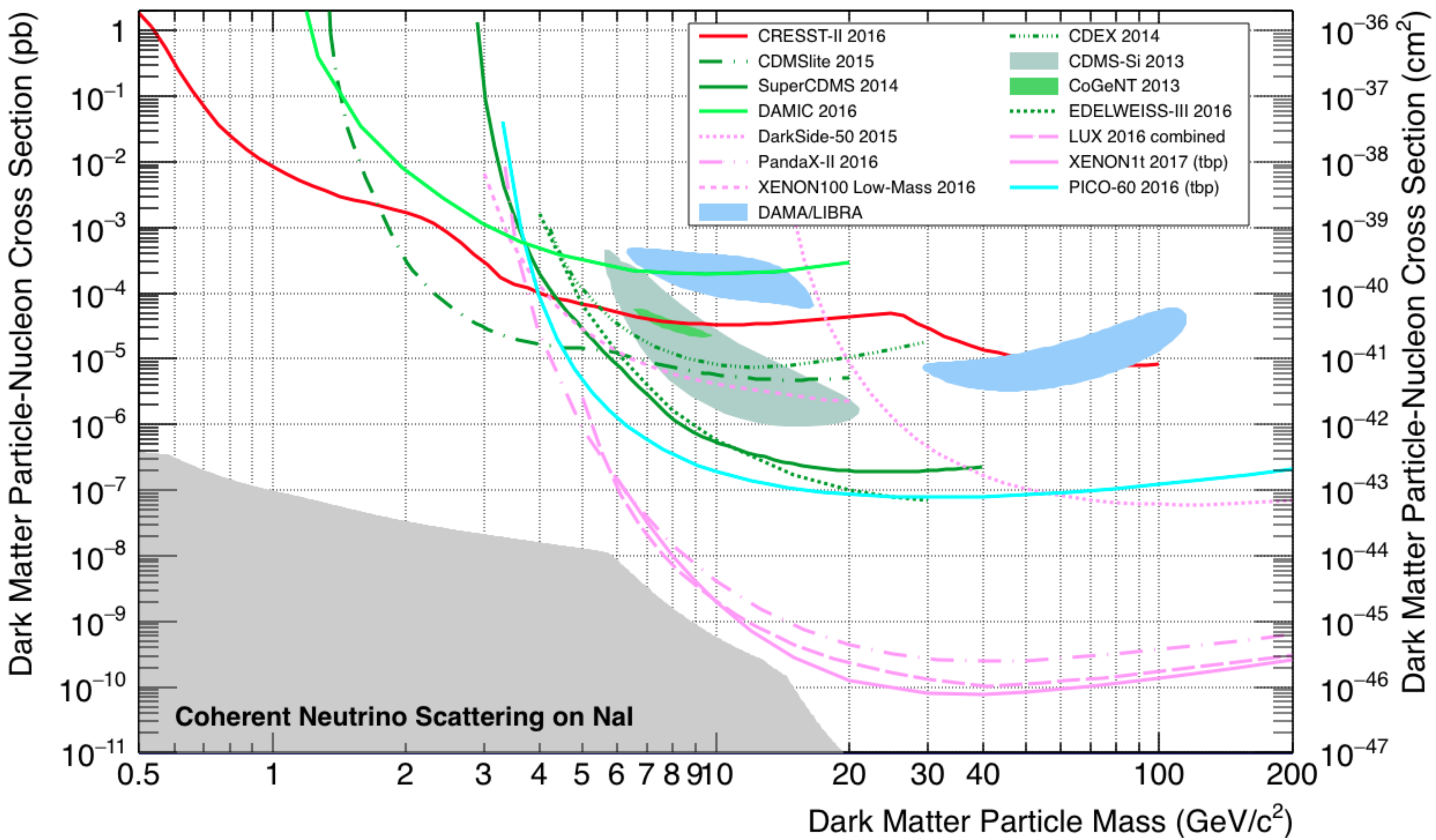
Period: 0.998 ± 0.002 years ✓

Phase: 24th May +/- 7 days ✓

Convincing non-DM explanation ✗

Contradiction

For standard assumptions



WHAT ARE THE UNKNOWNS?

Astro physics

Dark matter halo ←→

Velocity distribution

Particle physics

Interaction mechanism

galactic escape velocity

velocity distribution

WIMP-nucleon cross section

$$\frac{dR}{dE_R} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{\text{min}}}^{v_{\text{esc}}} d^3\nu \, f(\vec{\nu}) \nu \, \frac{d\sigma(\vec{v}, E_R)}{dE_r}$$

minimal velocity to produce a recoil above threshold

~ A^2

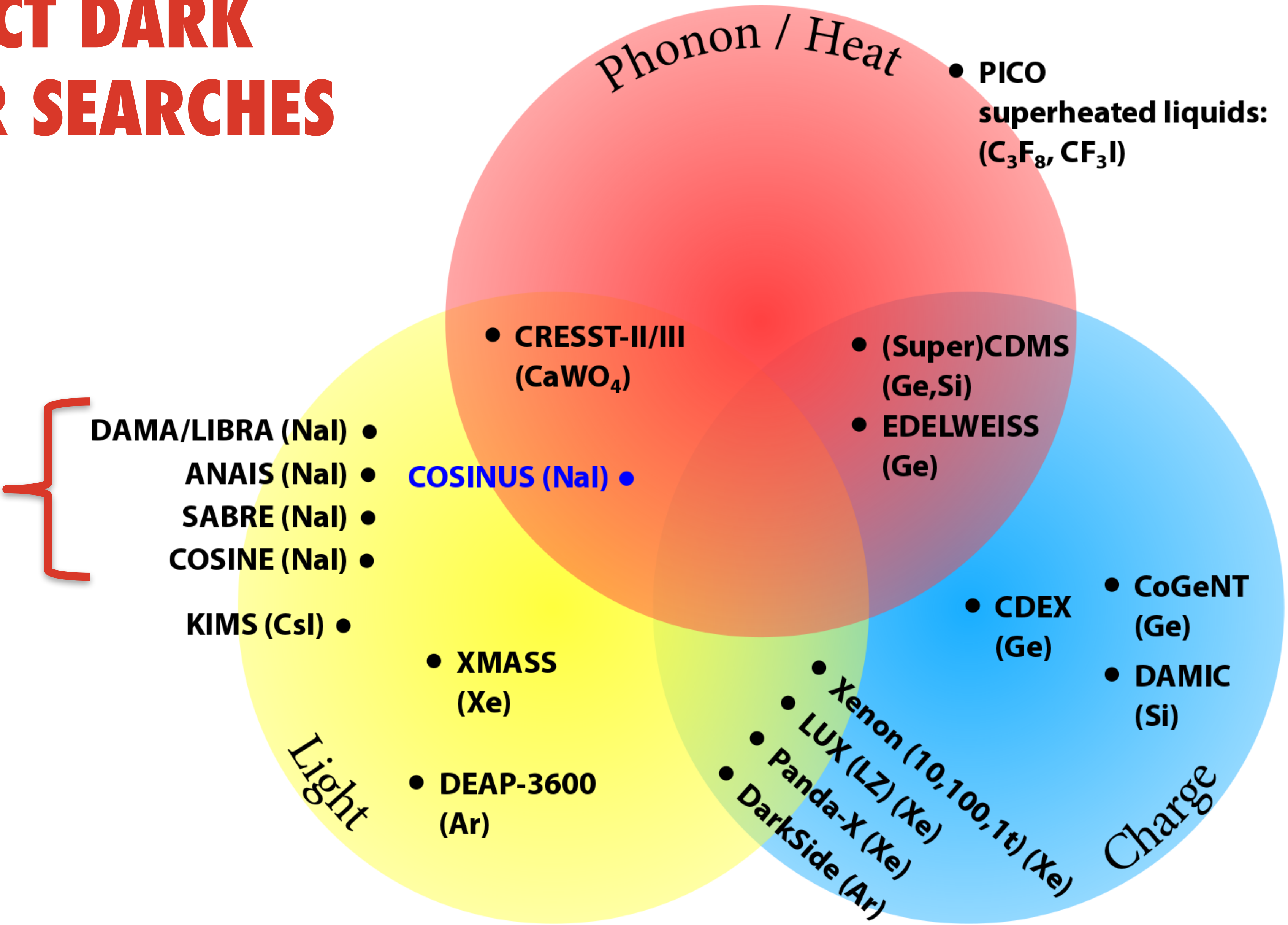
~ form factor

→ Target material dependence

→ → Test DAMA with NaI experiment(s)

DIRECT DARK MATTER SEARCHES

NaI experiments



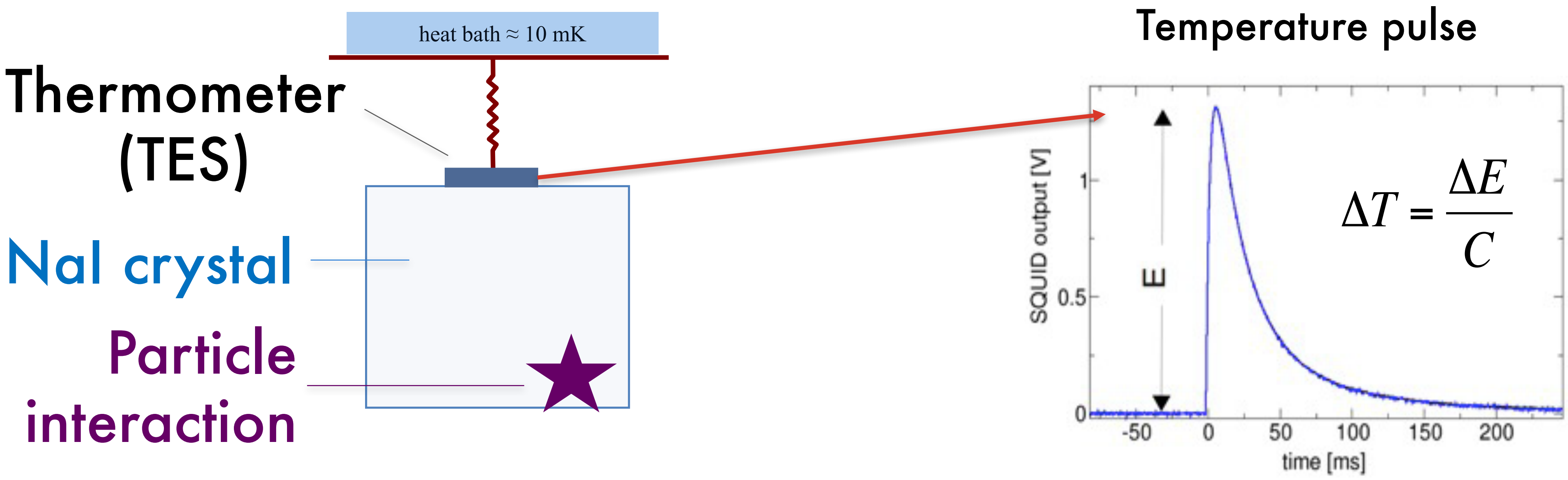
Incomplete compilation!

THE COSINUS R&D PROJECT

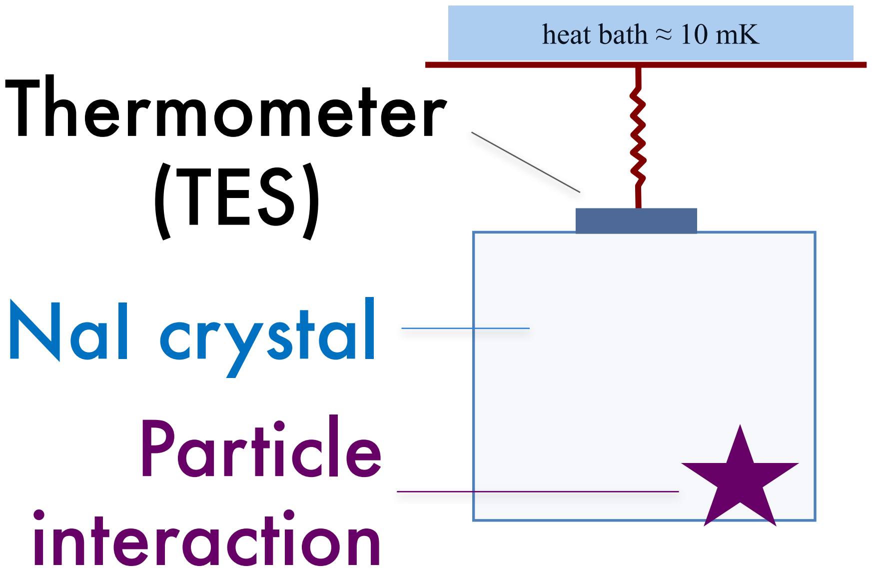
- R&D project, technological development
- Funded by the "CSN 5" of INFN
- Hosted at LNGS
- 3 years for prototype development [2016 – 2018]
- Eur. Phys. J. C (2016) 76:441

NEW! www.cosinus.it

CRYOGENIC DETECTOR



CRYOGENIC DETECTOR

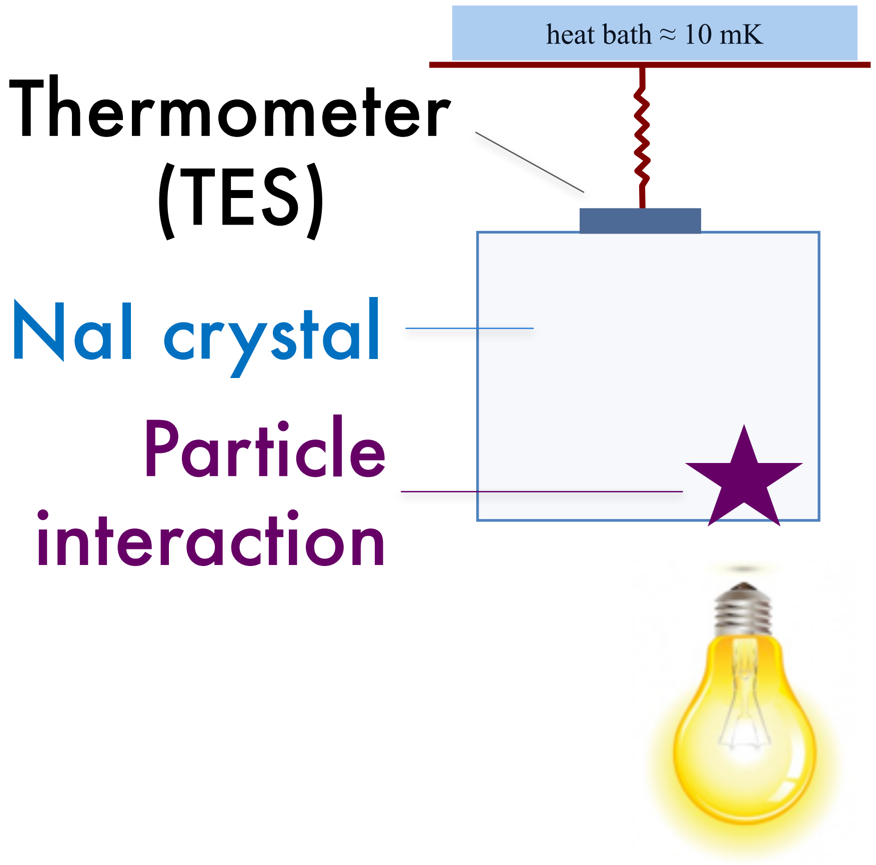


Phonon signal (~90 %)

(almost) independent of particle type

precise measurement of the deposited energy

SCINTILLATING CALORIMETER



Phonon signal (~90 %)

(almost) independent of particle type

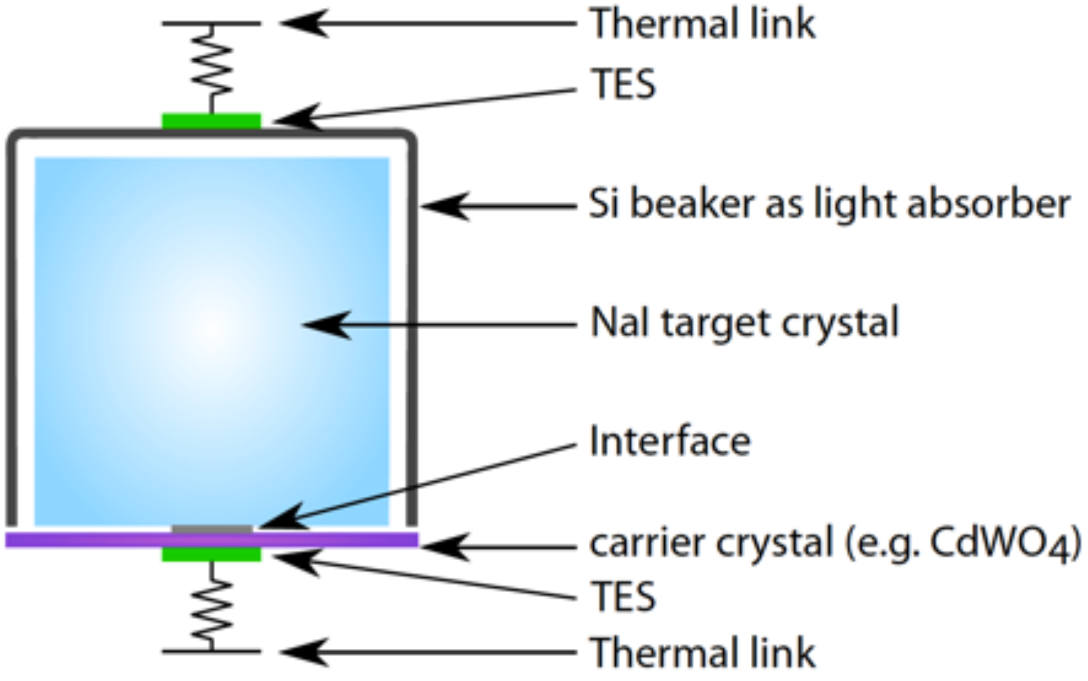
precise measurement of the deposited energy

Scintillation light (few %)

Particle-type dependent
→ LIGHT QUENCHING

COSINUS PERFORMANCE GOALS

Eur. Phys. J. C (2016) 76:441



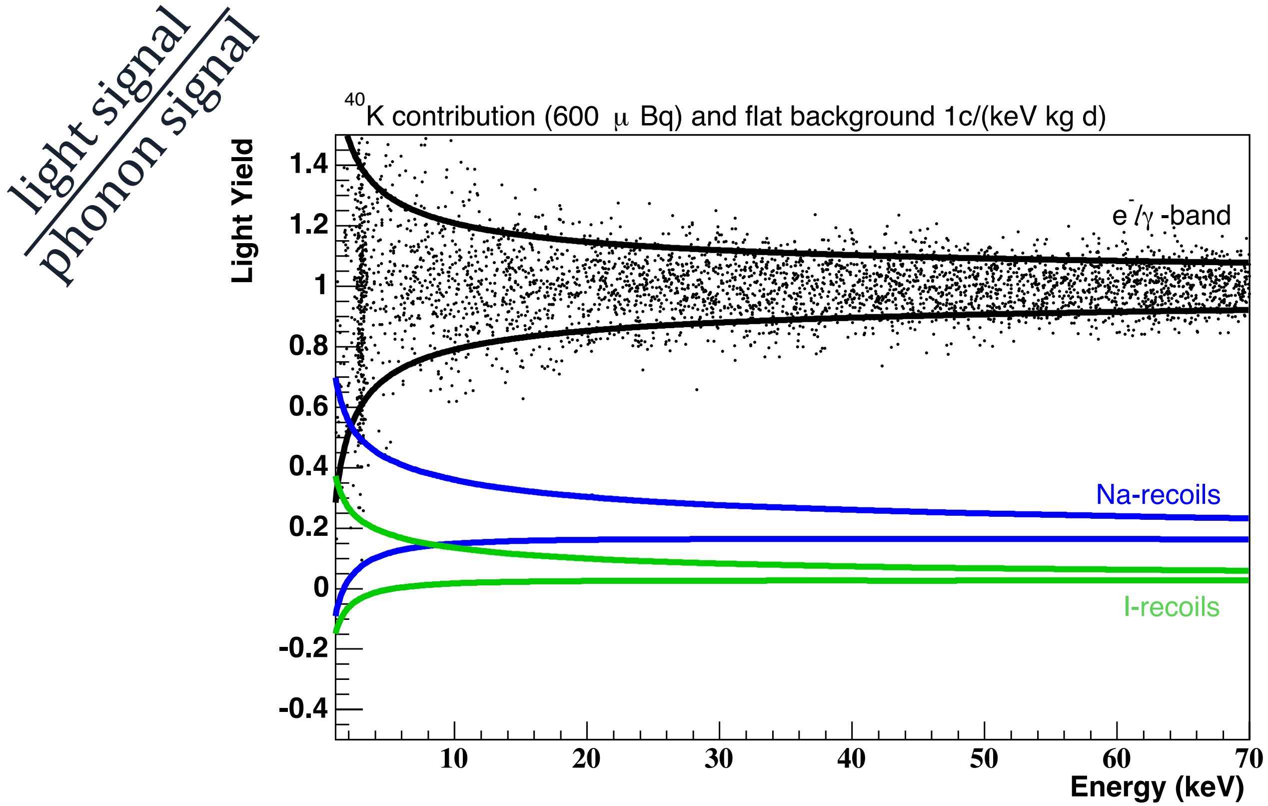
Bring NaI-based cryogenic detectors to level of existing ones (e.g. CRESST-II):

1keV nuclear recoil threshold

4% of deposited energy measured as scintillation light

SIMULATION

100 KG-DAYS BEFORE CUTS



Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3

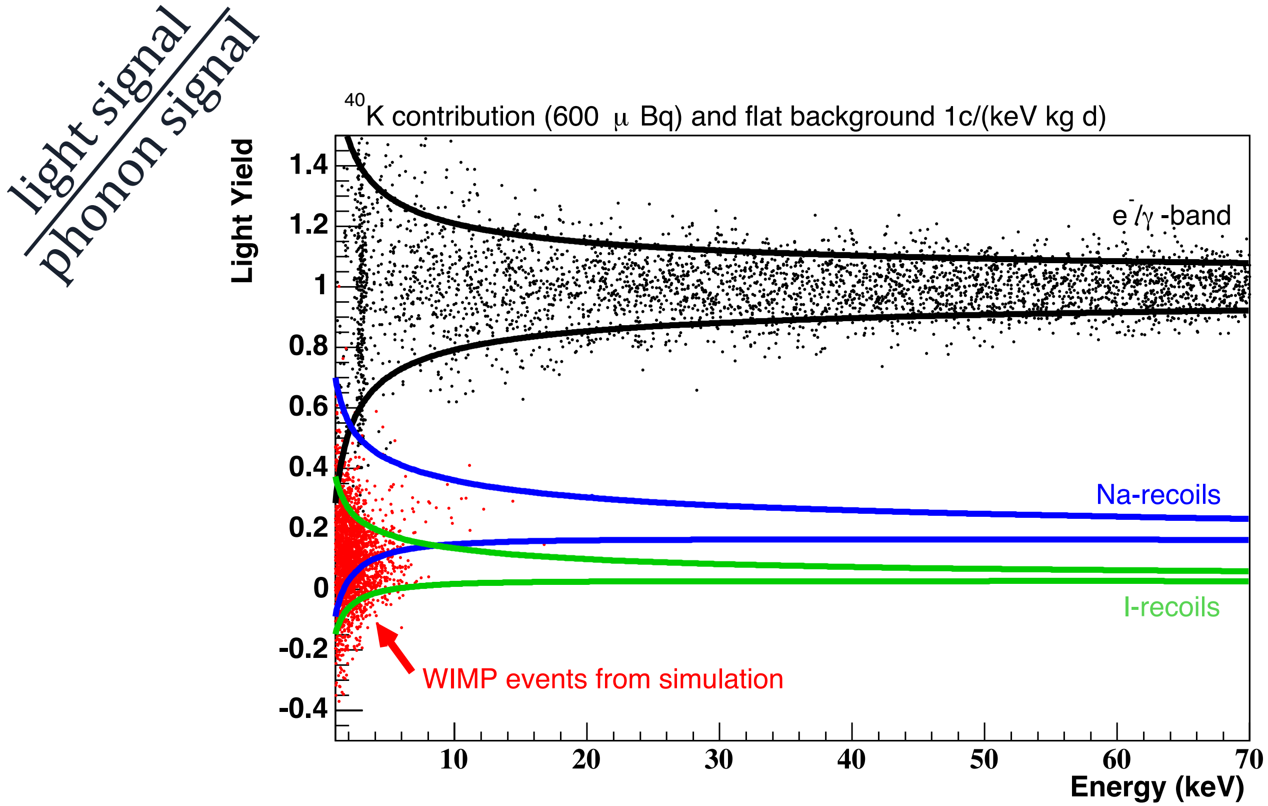
Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Recoils off Na
Recoils off I

Quenching factors by V. Tretyak, Astropart. Phys. 33, 40 (2010)

SIMULATION

100 KG-DAYS BEFORE CUTS



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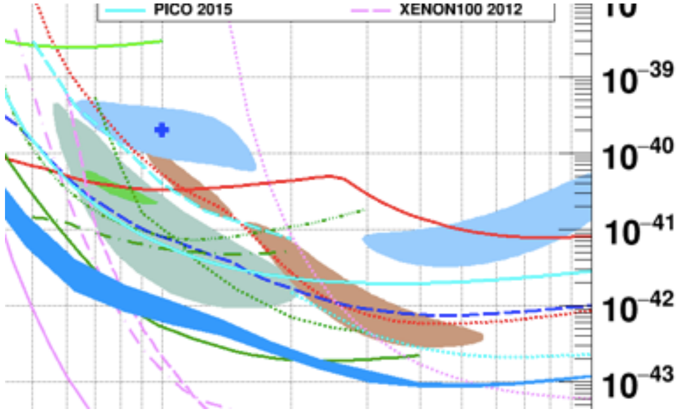
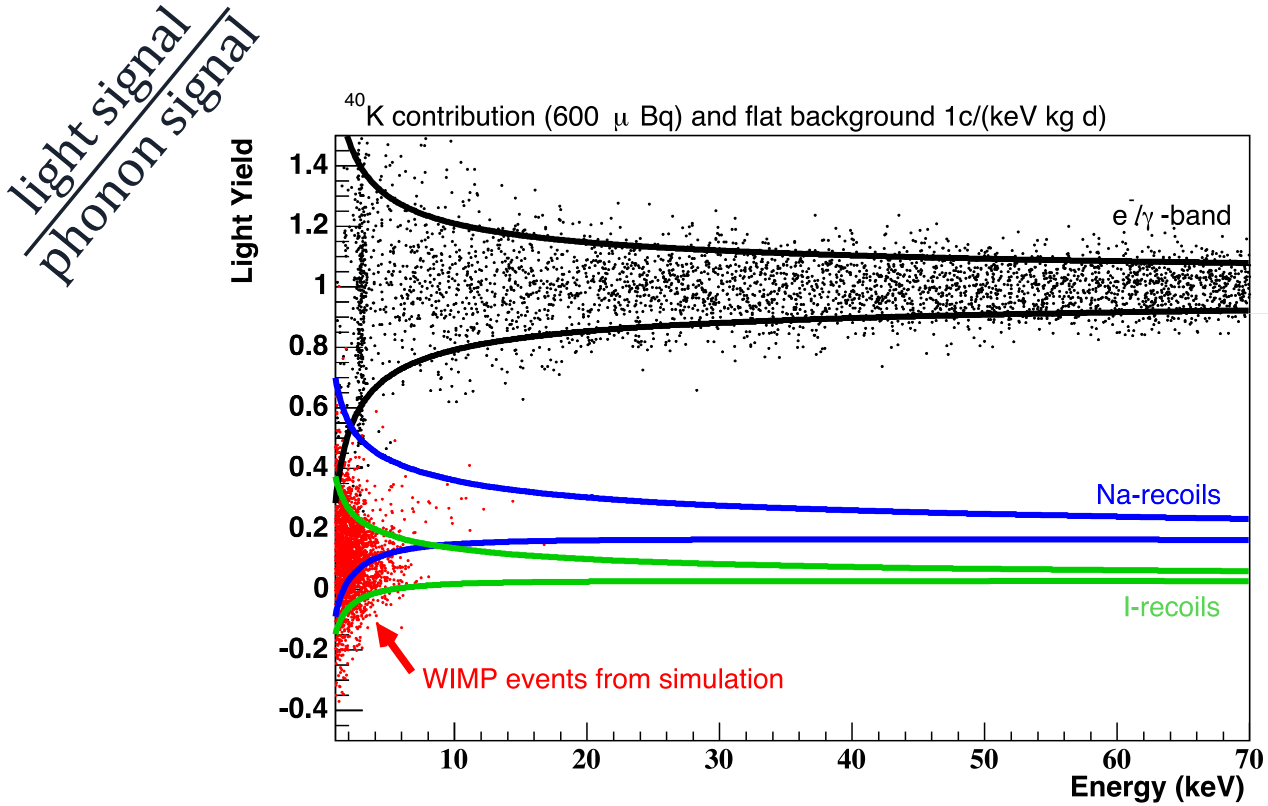
Black: β/γ-background
flat 1c /(keV kg day)
+ ^{40}K: 600μBq/kg

Red: 10 GeV/c^2 WIMP
with 2E-04 pb as from
Savage et al.



SIMULATION

100 KG-DAYS BEFORE CUTS



WIMP events

Energy	# Events	Fraction
1-2 keV	1078	45 %
2-6 keV	1262	53 %
> 6 keV	46	2 %
TOTAL	**2386**	**100 %**

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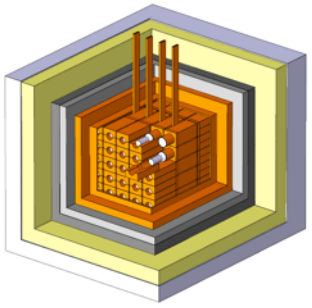
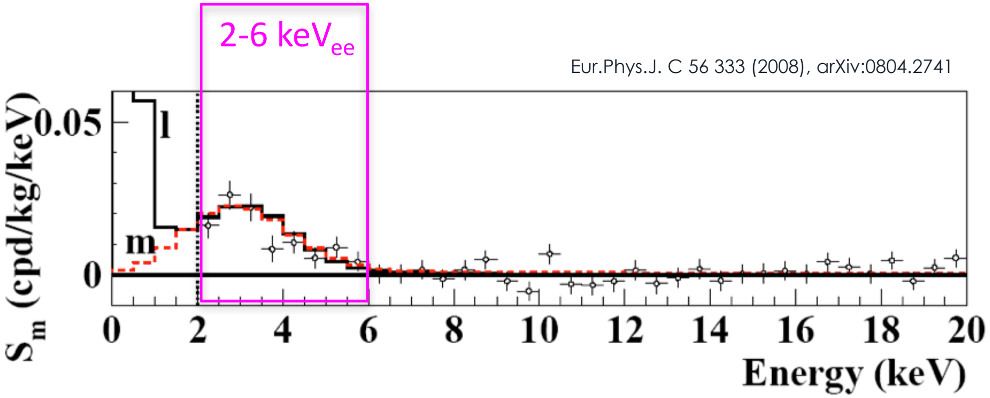
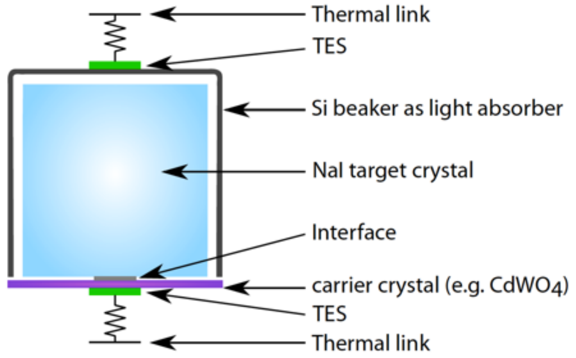
COMPARE DAMA TO COSINUS

DAMA/LIBRA





COSINUS



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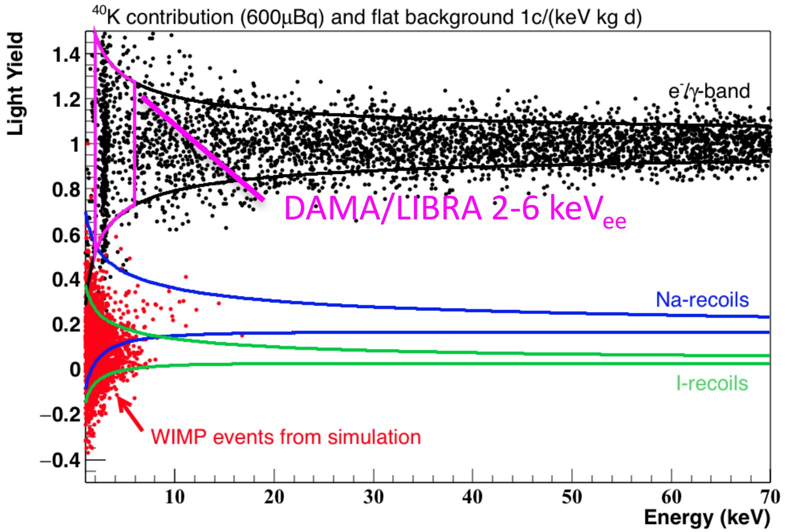

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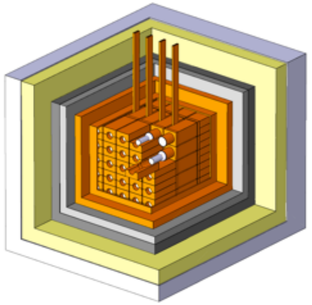

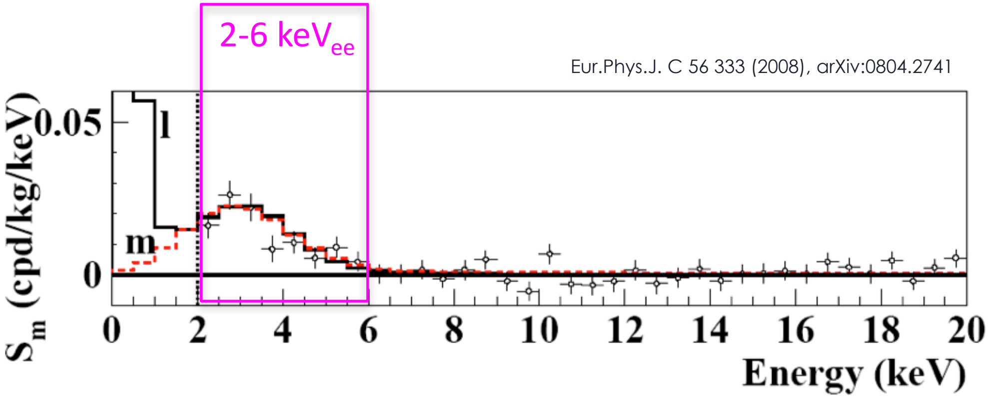

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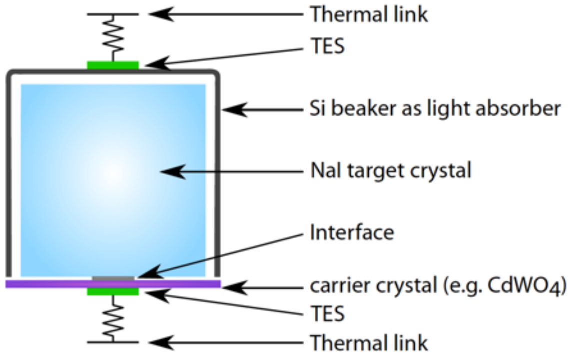

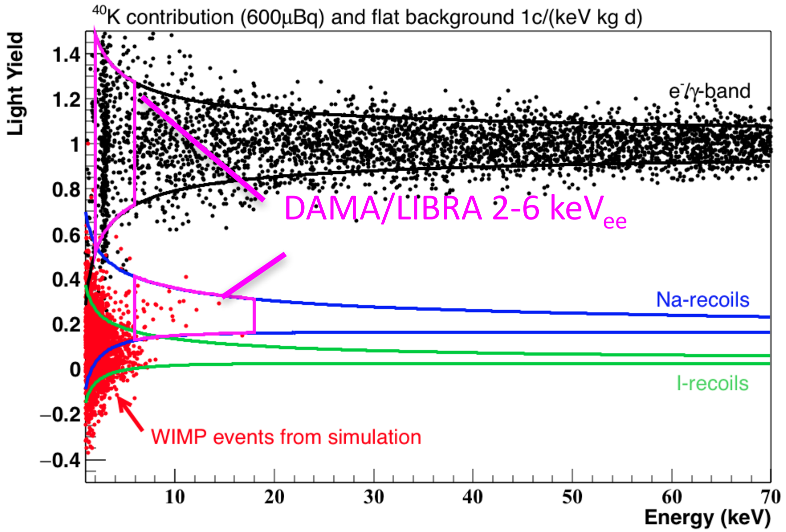

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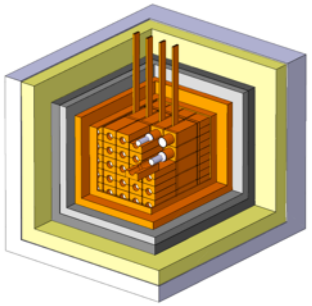

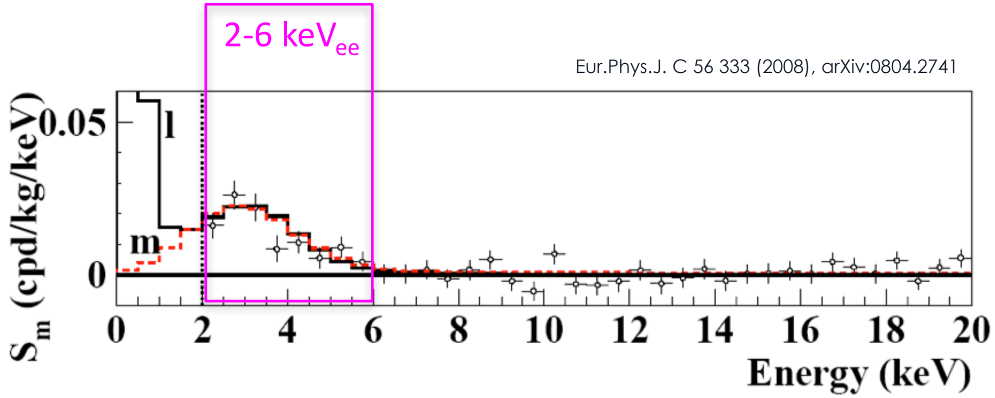

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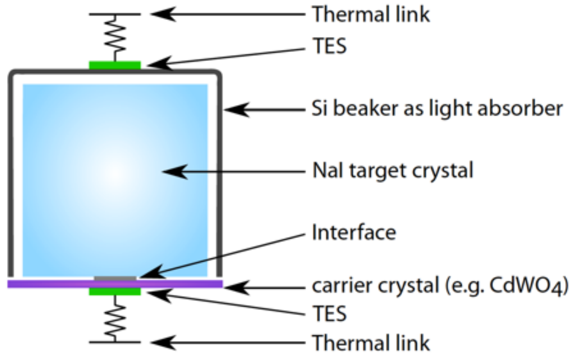

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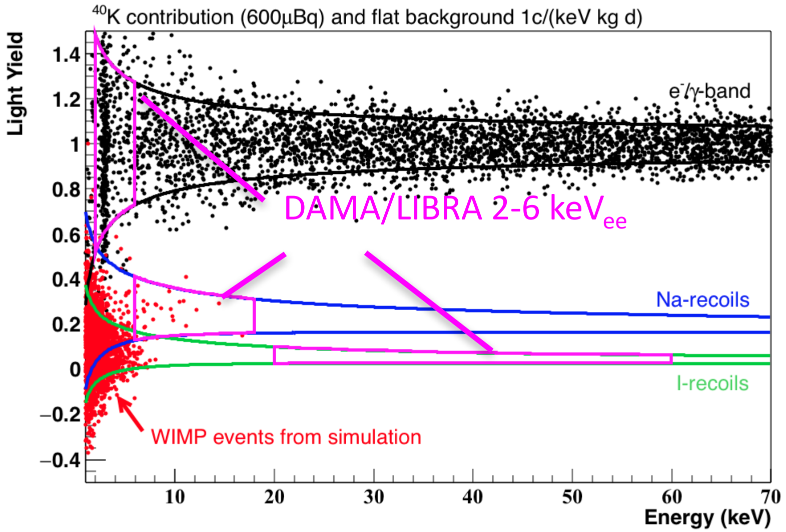
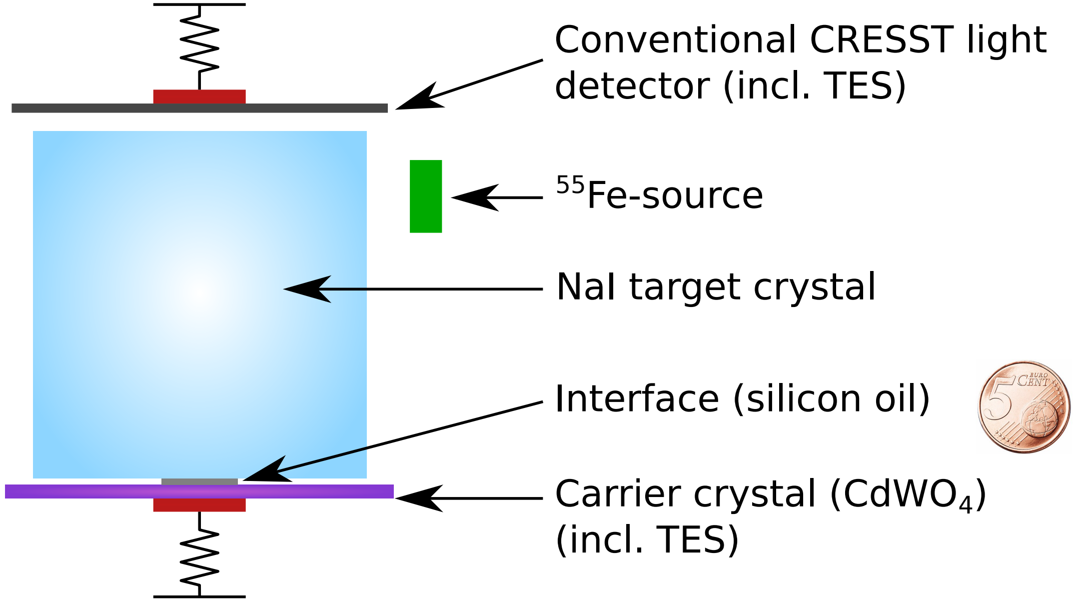
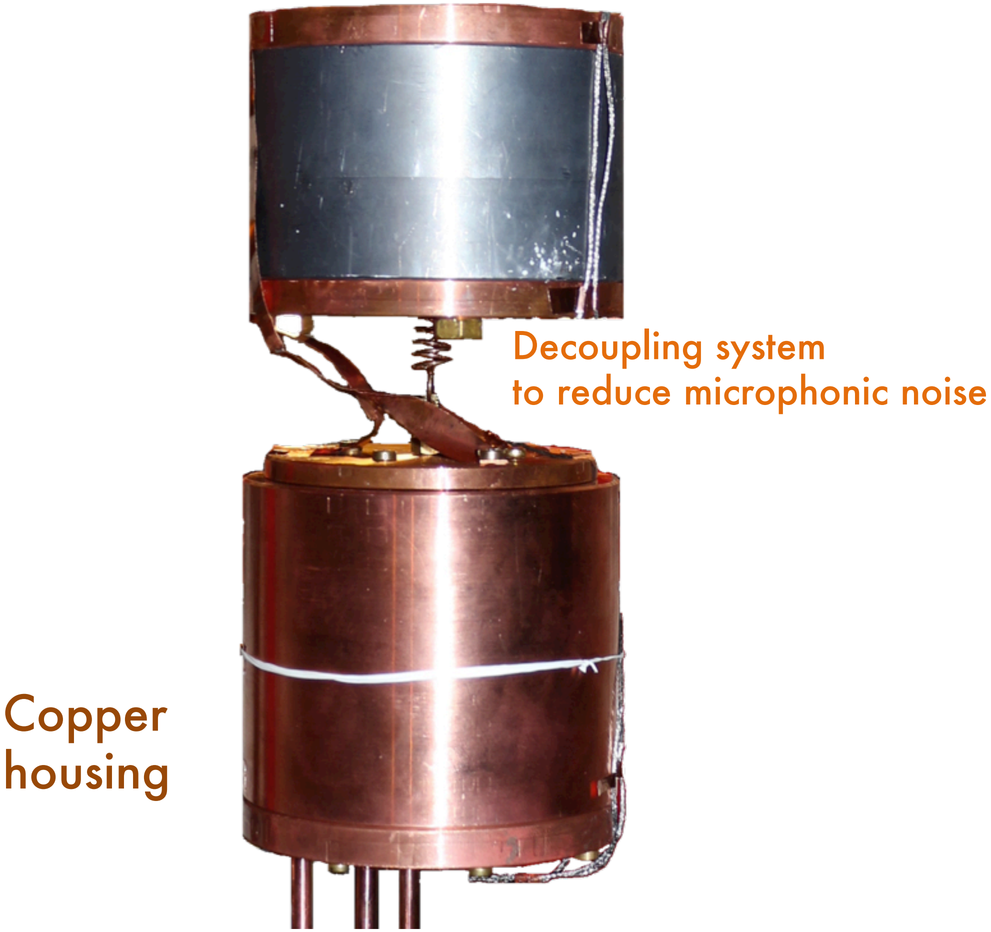
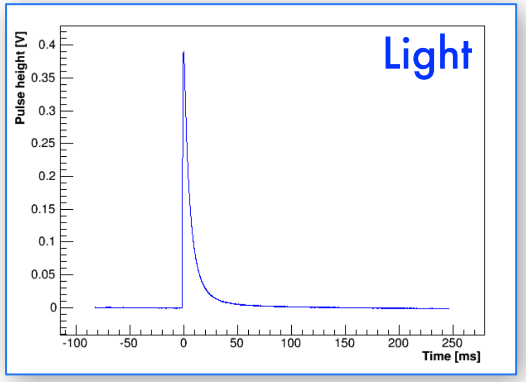


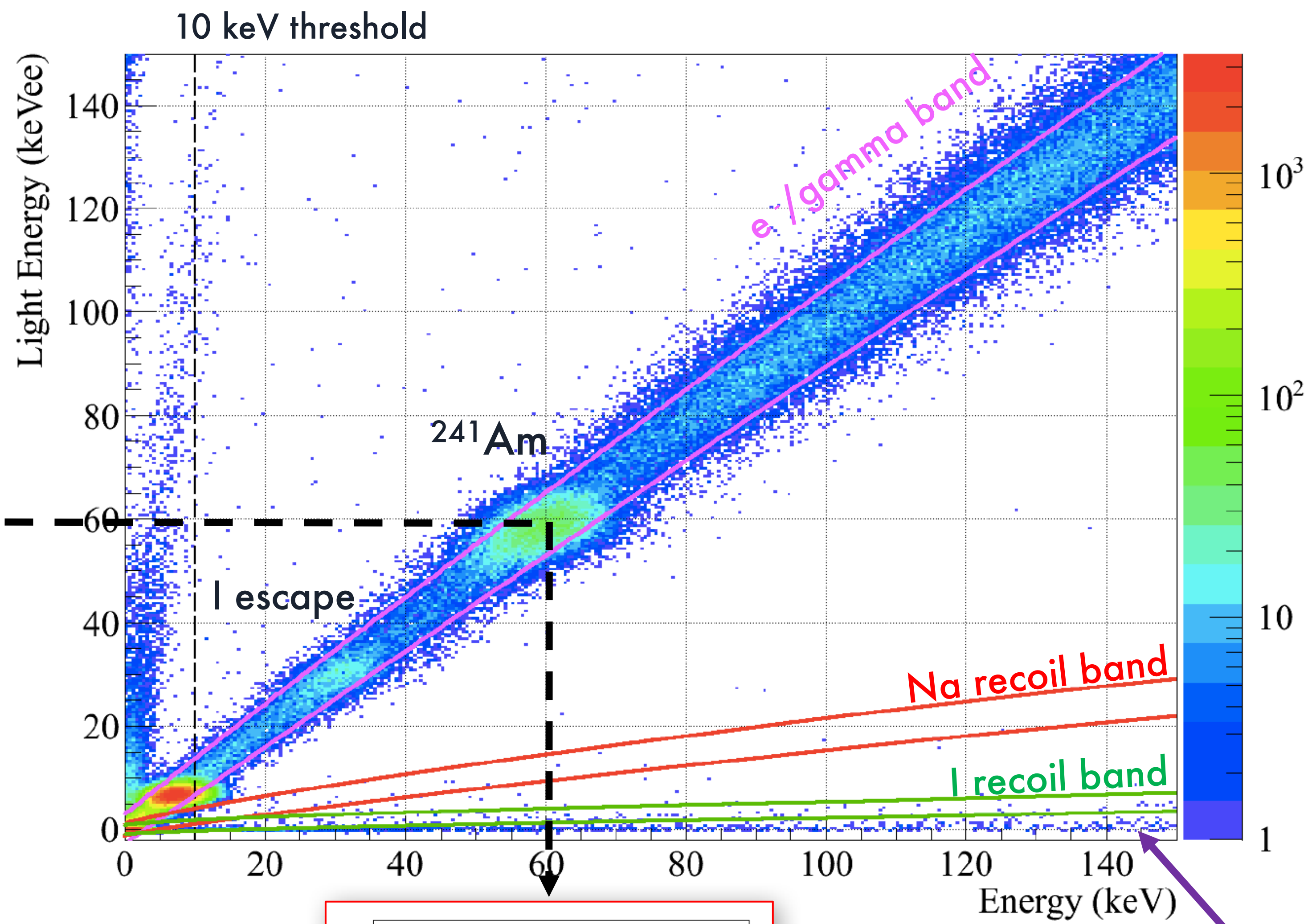
FIRST NAI PROTOTYPE

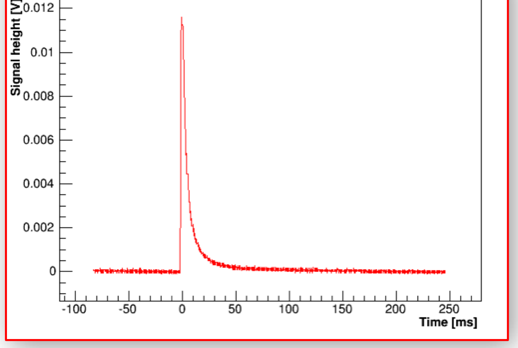


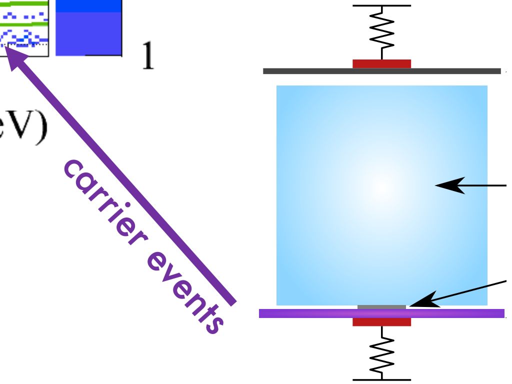


DATA FROM 1ST PROTOTYPE









plot: arXiv: 1705.11028
QF from Tretyak, Astropart. Phys. 33, 40 (2010)

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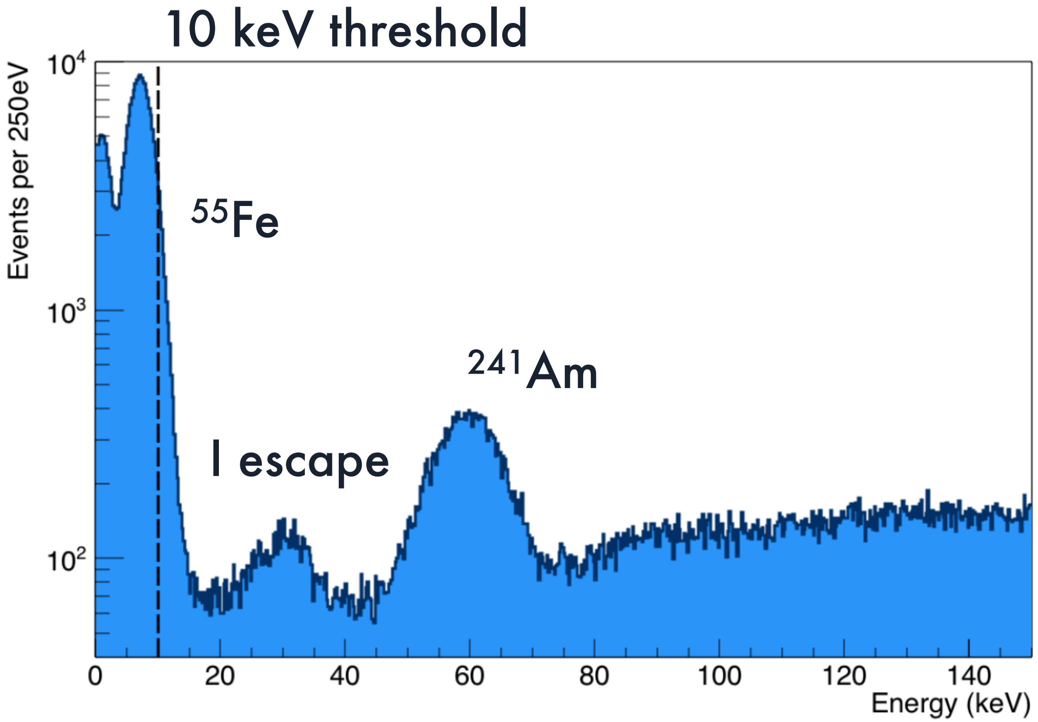


plot: arXiv: 1705.11028

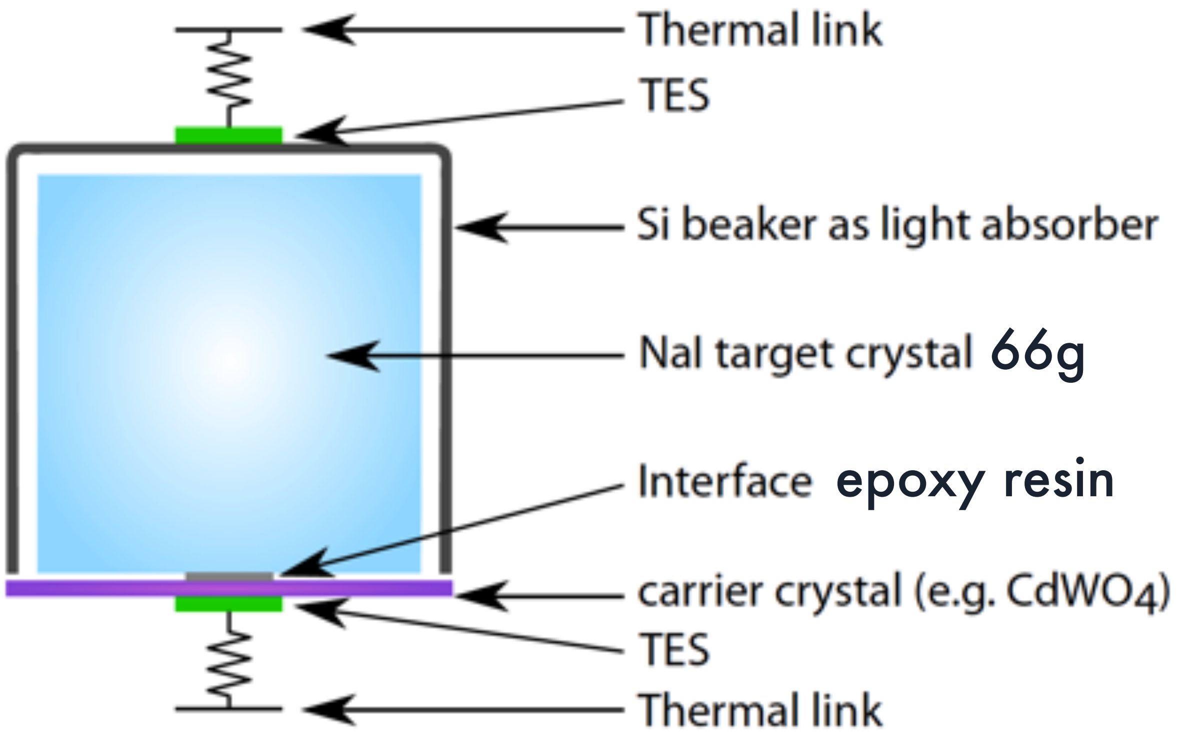
- Energy threshold: 10 keV
- For β/γ-events:
  3.7% of the energy deposited in the NaI crystal is measured by the light detector (design goal 4%)
  =
  11.2 detected photons per keV of energy deposition

First successful measurement of a NaI crystal as cryogenic detector

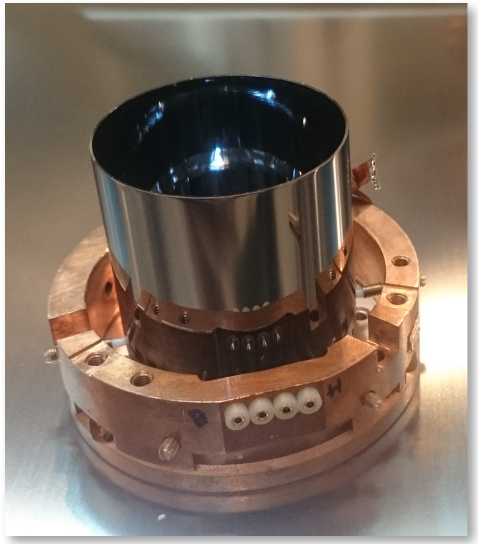
Improve detector performance

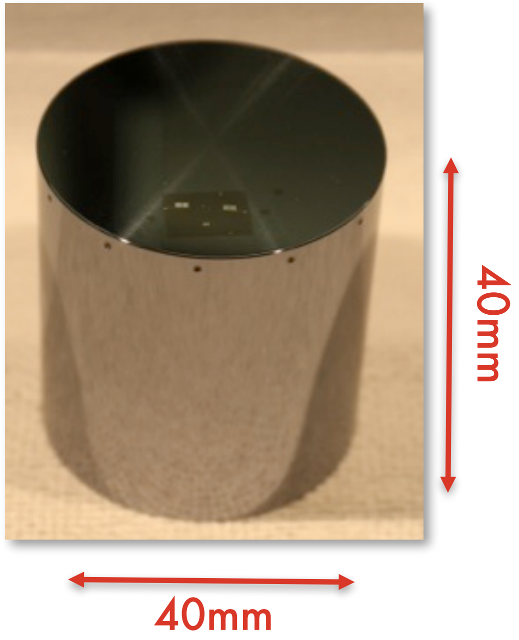
2ND PROTOTYPE

PROOF-OF-PRINCIPLE OF FINAL DETECTOR DESIGN

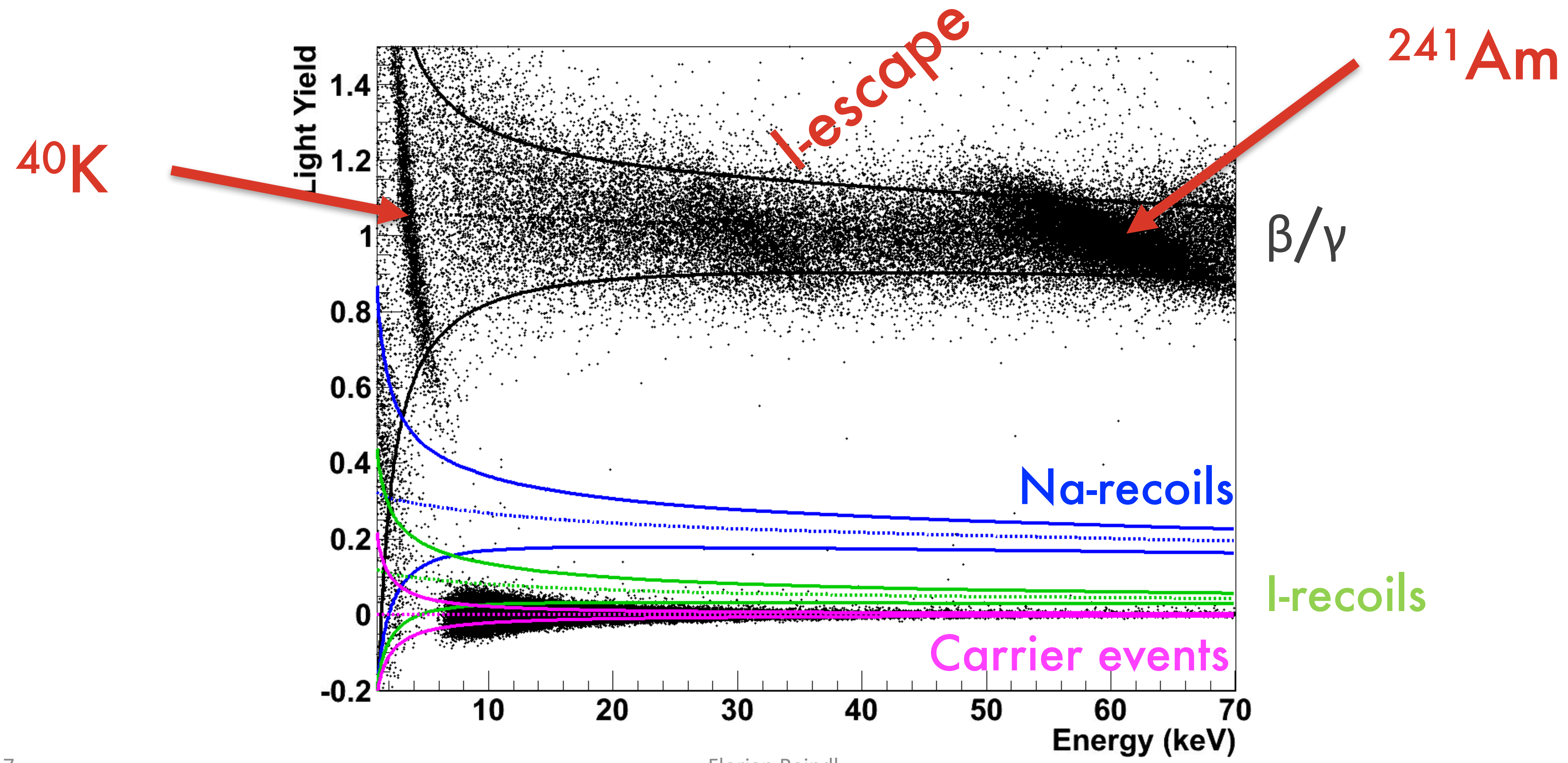


Final design with beaker-shaped light absorber





^{241}Am GAMMA CALIBRATION DATA FROM THE 2ND PROTOTYPE



PERFORMANCE OF THE 2ND PROTOTYPE

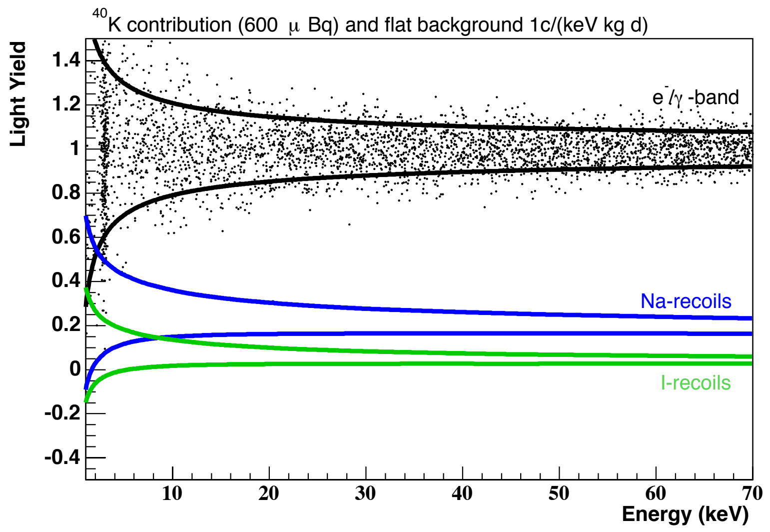
- Phonon detector resolution (at zero energy): 1.0keV
- Absolute light yield for a β/γ-event: **13 %** (~39 photons/keV)

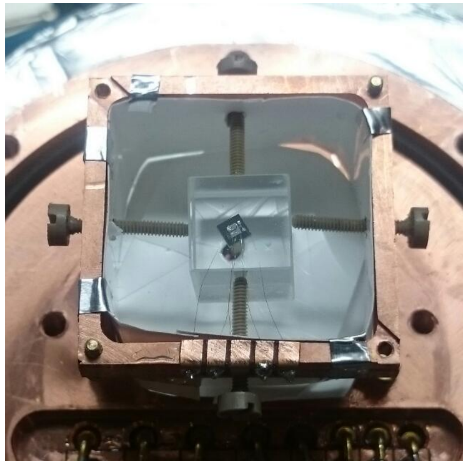
Successful test of detector concept

Undoped NaI is an excellent scintillator at low temperatures

Further improvement of phonon detector performance required

QUENCHING FACTOR MEASUREMENT





MLL - Tandem accelerator at TUM/LMU in Munich

11 MeV neutrons

Dilution cryostat available and ready to be used

Smaller version of the COSINUS detector module

GOAL:

Precise determination of light quenching factor for Na and I at mK-temperatures

beam-time approved for September

SUMMARY COSINUS

- ☑ 1st successful measurement of a NaI-based cryogenic calorimeter → publication submitted to journal
- ☑ 2nd measurement: proof-of-principle of final detector design (incl. beaker-shaped light absorber)
- ☑ 3rd measurement in lower background cryostat finished → analysis ongoing
- ☐ Precise measurement of QFs @MLL accelerator planned for 09/2017

OUTLOOK COSINUS

COSINUS is on a good way to achieve CRESST-II like performance. If we succeed:

- **COSINUS-1π** Comparatively little exposure $\mathcal{O}$(100kg day) needed to answer whether DAMA sees a nuclear recoil signal, or not
- **COSINUS-2π** With a significantly increased target mass → sensitivity for modulation signal