LUCIFER

M. Pavan on behalf of

the CUPID-0* Collaboration

LUCIFER

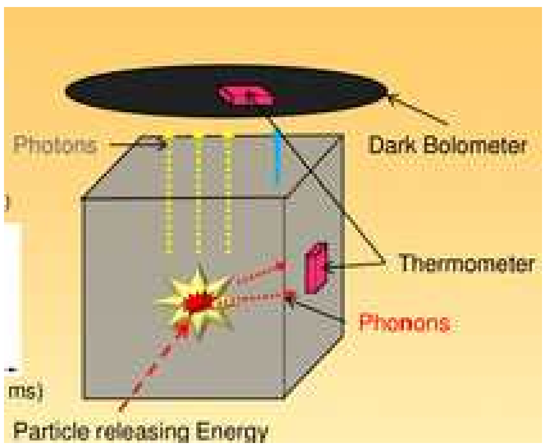
Outline

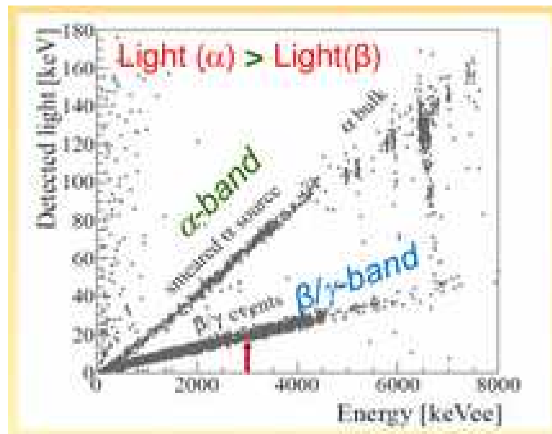
- transition from LUCIFER → CUPID-0
- status of the ZnSe LUCIFER tower
- CUPID-0 phase II ?

* *the name wants to echo the*
CUORE Upgrade with Particle Identification
https://arxiv.org/abs/1504.03612v1

LUCIFER

ZnSe scintillating bolometers





LUCIFER (ERC Adv. grant) is over

with 30 crystal ingots of $Zn^{82}Se$ ready to be operated as a scintillating bolometer array in Hall A refrigerator

→ CUPID-0

LUCIFER transition to a new Collaboration and new Funding Institutions

CUPID-0

Italy: Roma1+LNGS+Genova+Milano-Bicocca+LNL

France: Orsay+Saclay

- **increased number of participants**
- **main funding today from INFN and CALDER (ERC Starting grant) + LUCIFER heritage**
- **enlarged scientific program**

CUPID-0 Collaboration … today

CUPID-0

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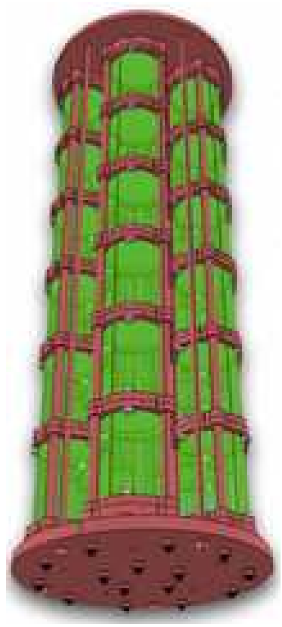
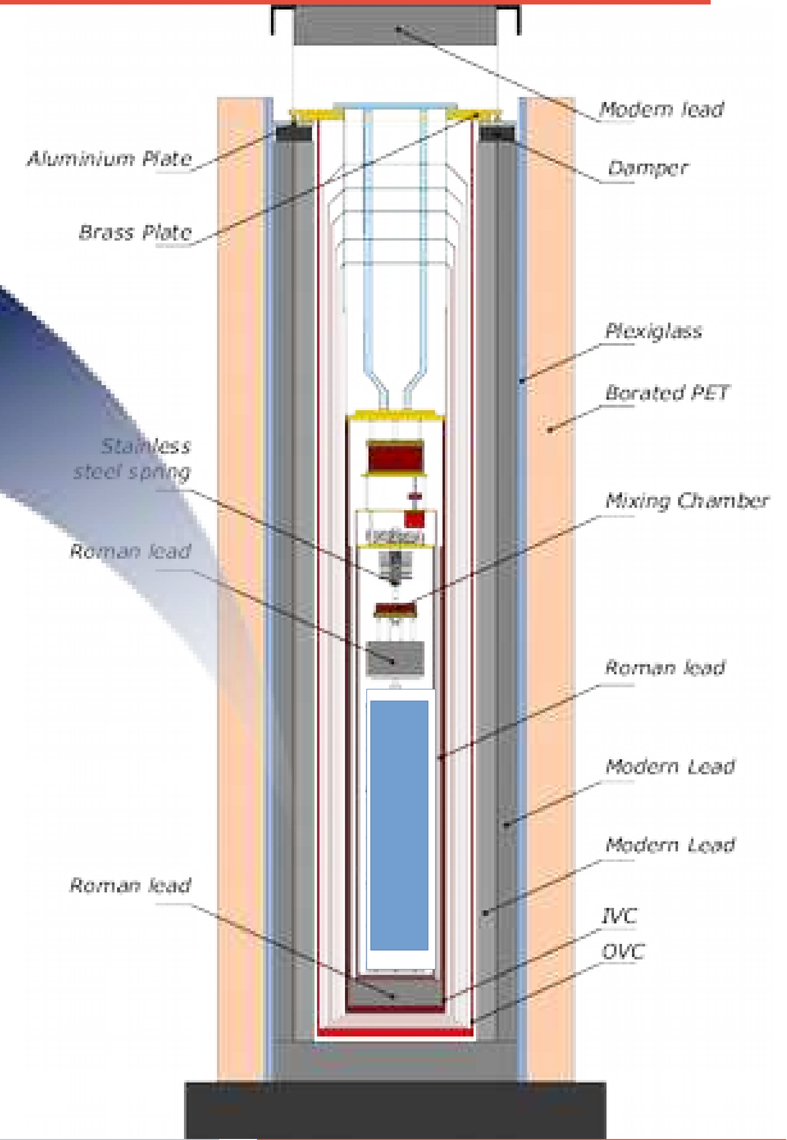
CUPID-0

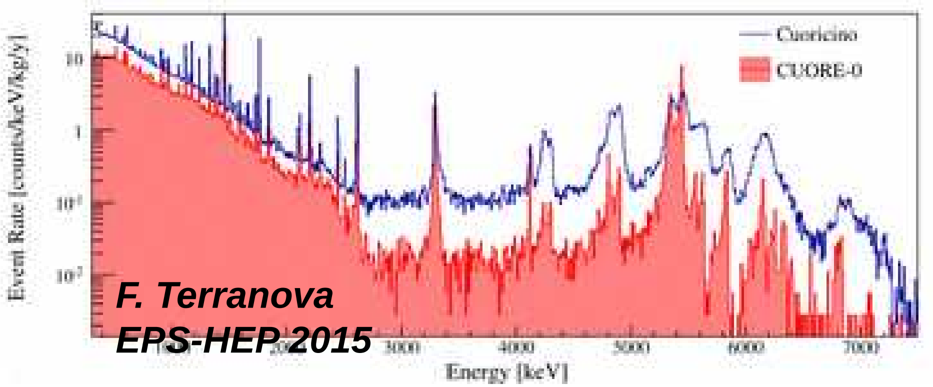




a tower of bolometers with double read-out LIGHT+HEAT
(→ w/ particle identification)
operated in CUORICINO/CUORE-0 cryostat

PURPOSE OF THE EXPERIMENT

- **prove the scalability to large arrays of the α rejection technique (based on the Heat+Light read-out)**



though impressively reduced in CUORE-0
α–induced background is still dominant for E>2.6 MeV

- **study 0νββ with LUCIFER**
  $Zn^{82}Se$ crystals

- **& (phase II) add other detectors ....**

ZnSe BOLOMETERS

^{82}Se isotopic enrichment ~ 95.4%
(enrichment @ URENCO Netherland)

Zn^{82}Se crystal mass ~ 0.4 kg
- mass defined by cut and polishing, still ongoing

(30 ingots grown in Ucraina ISMA)
- the detector holder allows the use of variable size crystals

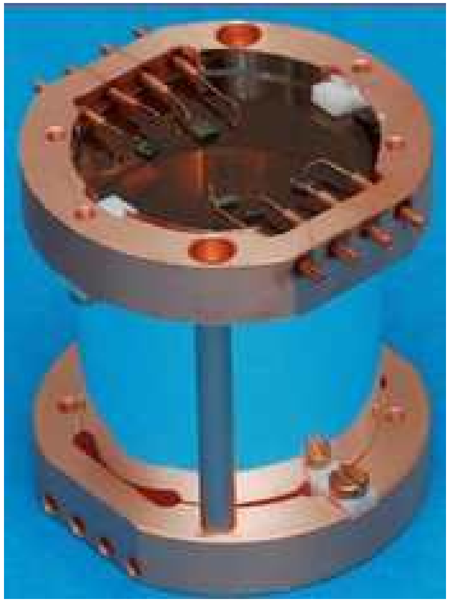
25 crystals of Zn^{82}Se
5.5 kg of ^{82}Se

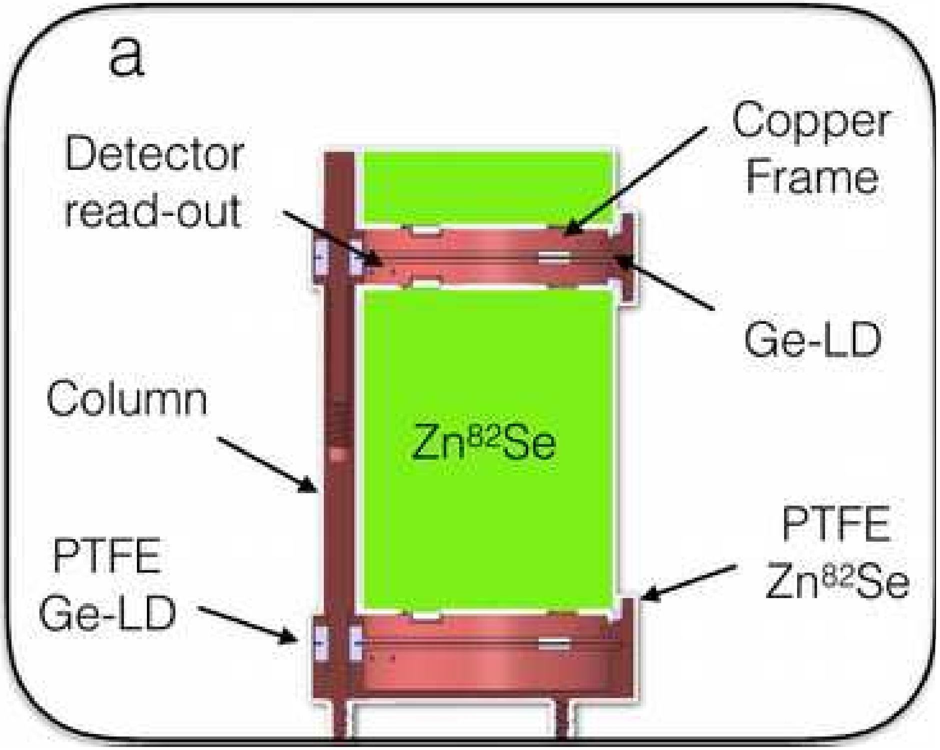
Ge LIGHT DETECTORs

2 Ge light detectors

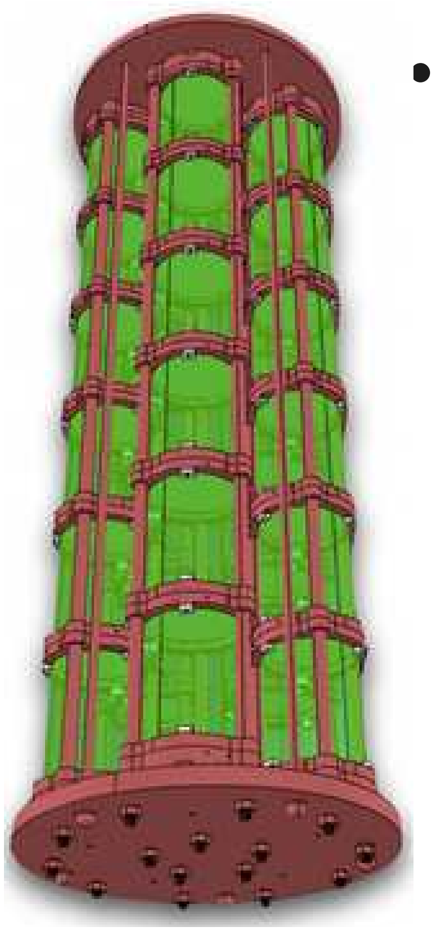
∅ 44.5 mm h=0.15 mm
coating with 60 nm SiO_2

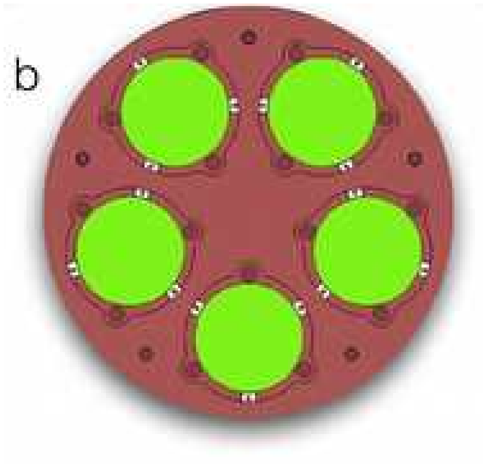
3M VM 2002
reflecting foil





ZnSe ARRAY





high purity Cu Holder

$2 < \mu Bq/kg\ ^{232}Th$

$0.6 < \mu Bq/kg\ ^{238}U$

Roman Lead shield

$0.3 < \mu Bq/kg\ ^{232}Th$

$0.4 < \mu Bq/kg\ ^{238}U$

CUPID-0 WORK IN PROGRESS

- **Hall A refurbishing**
  - **+ cabling**
  - **+ improvement of the anti-Rn system**
  - **+ installation of LHe refill**

- **crystal cut and polishing**

- **holder Cu parts production and cleaning**

  (CUORE-0-like surface treatment)

- **time-schedule**

  detector commissioning before end of June

  operation from 1th July

$Zn^{82}Se$ CRYSTALS : HALL C TEST

3 enriched crystals

crystals masses [g]	440.2 + 442.1 + 439.3
crystals average dimensions	h = 55 mm, Ø = 43.7 mm
total detector mass [g]	1321.6
isotopic abundance	96.3%
total ^{82}Se emitters	5.11×10^{24}

tested in Hall C @ T~ 20 mK

cryogenic problem prevented the cryostat from reaching the usual base T of ~ 5 mK

too high temperature spoiled performances

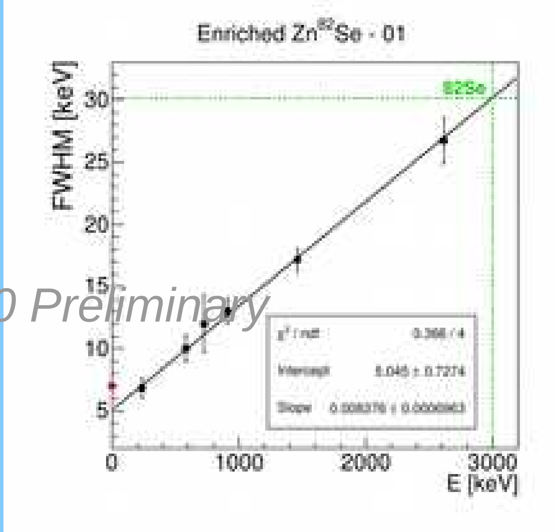
$Zn^{82}Se$ CRYSTALS : HALL C TEST

HEAT

$\sigma_{baseline}$ **3 – 6 - 7.9 keV**

dominated by electronic noise (low thermistor impedance due to high T)

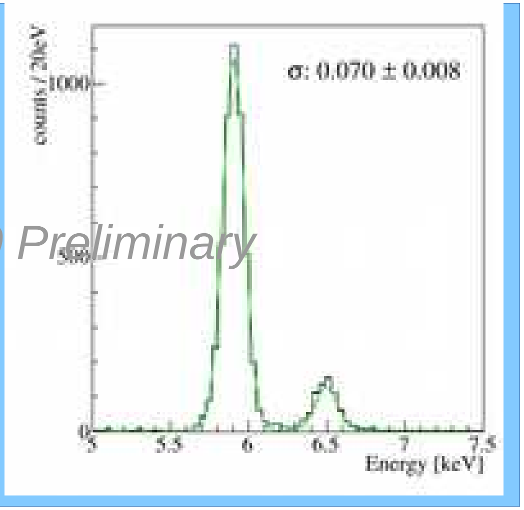
FWHM @ Se 0νββ ~ 30 keV



LIGHT

$\sigma_{baseline}$ **~ 40 eV**

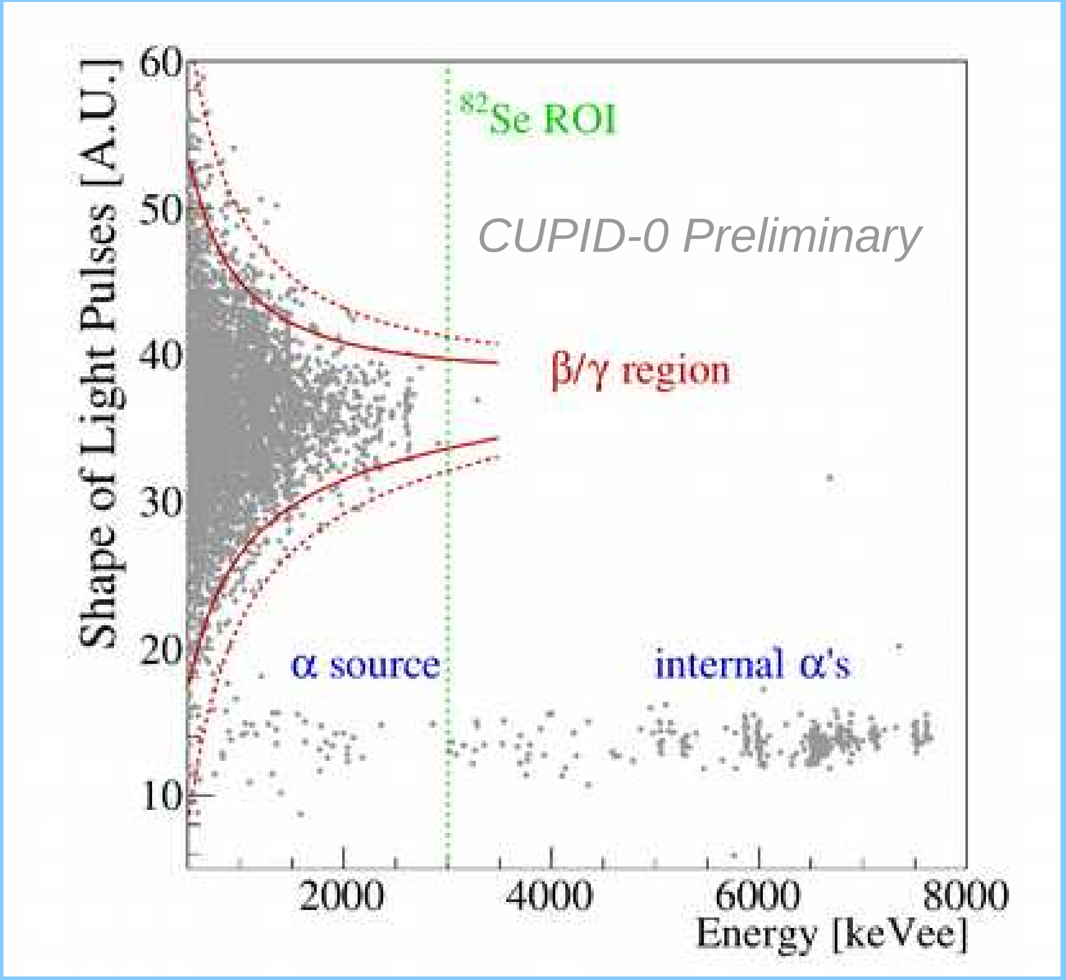
σ @ 5.5 keV ~ 70 eV



$Zn^{82}Se$ CRYSTALS – HALL C TEST

CUPID-0 Preliminary

	CG-1 [μBq/kg]	CG-2 [μBq/kg]	CG-3 [μBq/kg]
^{238}U	17 ± 4	20 ± 5	<10
^{234}U	23 ± 5	18 ± 5	<10
^{230}Th	18 ± 5	19 ± 5	17 ± 4
^{226}Ra	20 ± 5	25 ± 5	21 ± 5
^{210}Po	100 ± 11	250 ± 17	100 ± 12
^{232}Th	13 ± 4	13 ± 4	<5
^{228}Th	36 ± 7	30 ± 6	26 ± 6



CUPID-0 GOALS

BACKGROUND

(CUORE-0 E>2.6 MeV = 2 10-^{2} c/keV/kg/y)

- **from detector** (Cu+ZnSe+small parts) after rejection of α-background

  < 10^{-3} c/keV/kg/y

- **from cryostat/environment**

  ~ 10^{-3} c/keV/kg/y

  depending on the ^{214}Bi content of cryostat and Pb shields

CUPID-0 GOALS

$0\nu\beta\beta$ ^{82}Se

NEMO3 $\tau_{1/2}^{0\nu} > 0.3\ 10^{24}$ y

~ 25 crystals = 11 kg ZnSe → 5.5 kg ^{82}Se
FWHM ~ 30 keV
background ~ 10^{-3} c/keV/kg/y

0.3 counts in 1 y in 30 keV
nearly zero bkg approximation
$S^{0\nu\beta\beta}_{1y}$ ~ 0.9 10^{25} y   90% C.L.

$2\nu\beta\beta$ ^{82}Se

NEMO3 $\tau_{1/2}=(9.2 \pm 0.24_{-0.59}^{+0.67})\ 10^{19}$ y

use two natural crystal for bkg subtraction

CUPID-0 not only ZnSe ....

a phase II of Cupid-0 is possible

option (1)

add a Molibdate array (scintillating bolometers)

option (2)

add a TeO_2 array (Cerenkov light read-out)

^{100}Mo option

- ✔ $Q_{\beta\beta}$ = 3034 keV (above 2.6 MeV ^{208}Tl line)
- ✔ $LiMoO_4$/$ZnMoO_4$ are good scintillators w/ better resolution than ZnSe
- ? large scale scalability (purity, reproducibility and cost) still to be assessed

$LiMoO_4$ selected for a **~7 kg technology demonstrator** (**LUCINEU**) **because of:**

Excellent energy resolution (4 – 7 keV FWHM at 2615 keV)

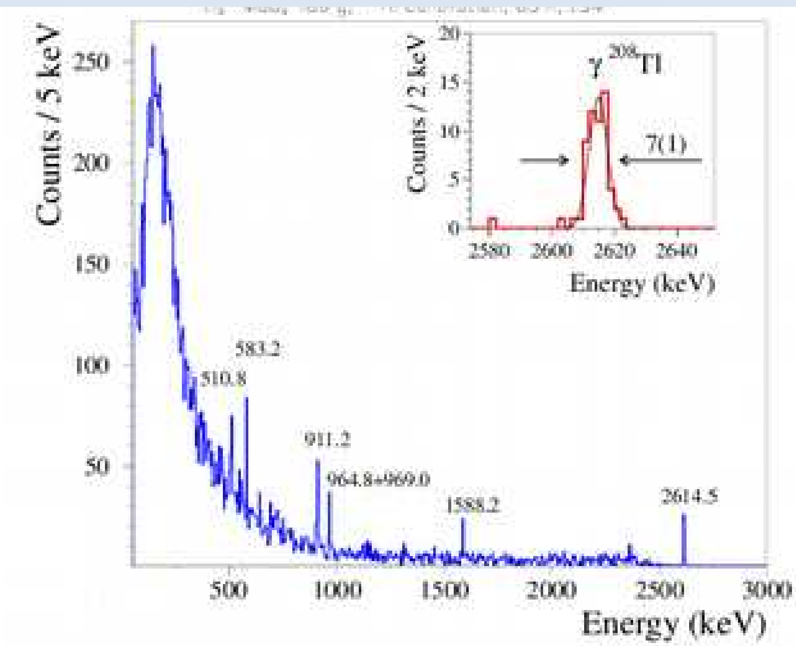
Easier crystallization procedure

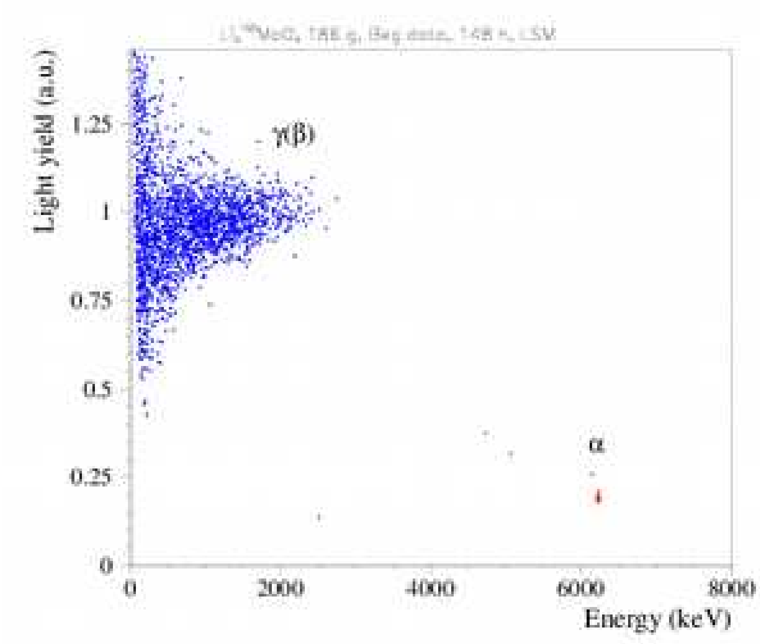
Systematic production of **40 enriched crystals will start in May 2016** (**MoU INFN/IN2P3/ITEP**) → **20 to be installed in LSM and 20 in LNGS**

^{100}Mo option

- $Q_{\beta\beta}$ = 3034 keV (above 2.6 MeV ^{208}Tl line)
- $LiMoO_4$/$ZnMoO_4$ are good scintillators w/ better resolution than ZnSe
- ? large scale scalability (purity, reproducibility and cost) still to be assessed

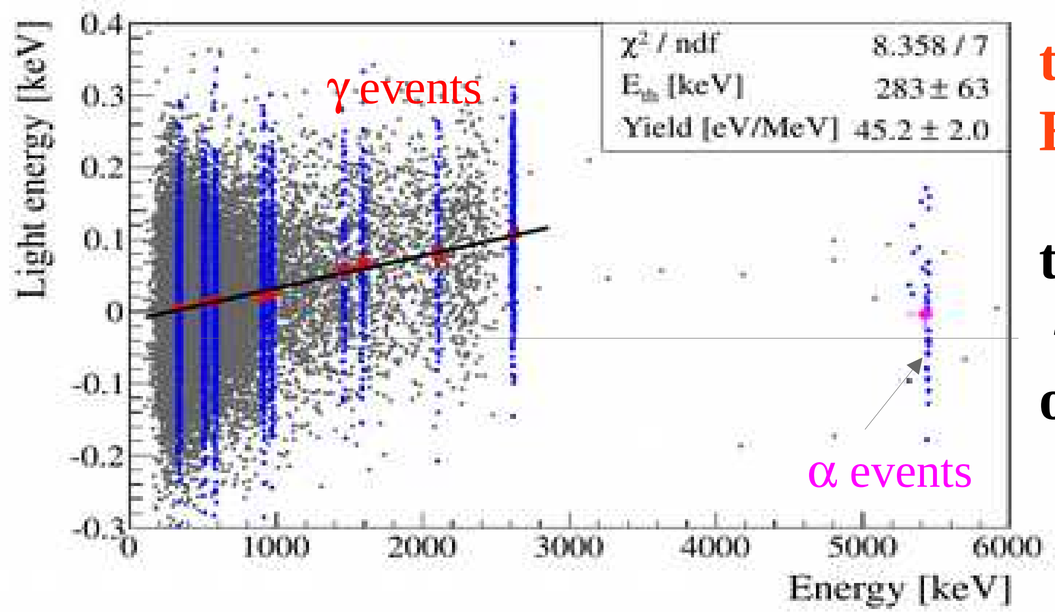
Test is ongoing on a 186 g enriched LMO crystal in LSM (EDELWEISS cryostat) at 20 mK





^{130}Te option

- TeO$_2$ same crystal of CUORE !!
- easy and cheap – (already done for MiDBD and Cuoricino)
- ! low $Q_{\beta\beta}$ (2530 keV) environmental γ's are important (2615 keV)
- ! no scintillation observed – one possibility is **Cerenkov light**



test on a CUORE-like (790 g) crystal
Eur. Phys. J. C 75 (2015) 12

to improve discrimination
~ 20 eV resolution
on LD is needed

INFN-Cupid activities

LIGHT DETECTOR

requirements for the optimal LD

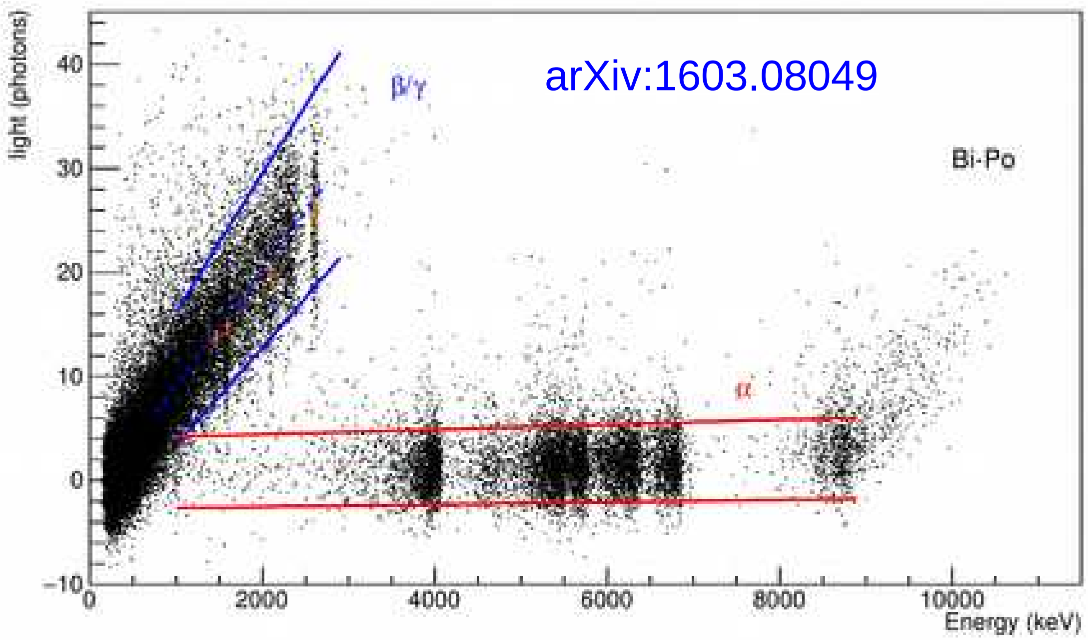
- reproducibility
- easy production and instrumentation as bolometers
- 20 eV energy threshold

Si wafers w/ Luke-Neganov effect **&/or** MKIDs

phase II demonstrator scintillation/Cerenkov

INFN-Cupid activities

Si wafers w/ Luke-Neganov effect



caution: result obtained on 1 cm^3 crystal

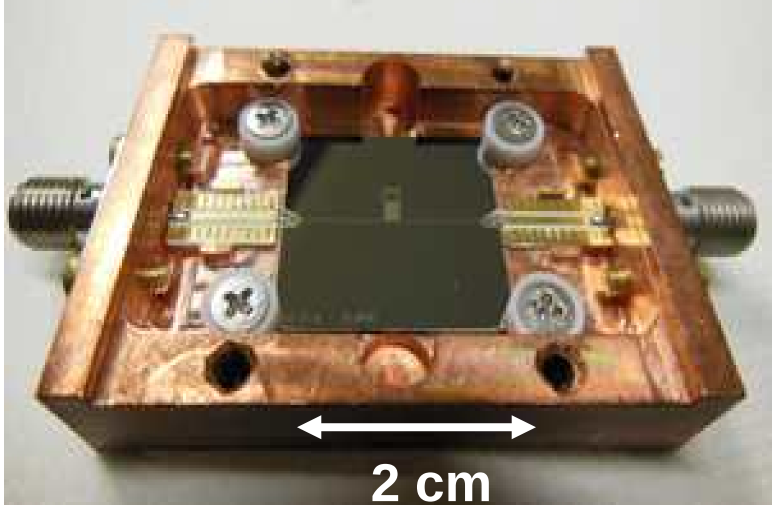
INFN-Cupid activities

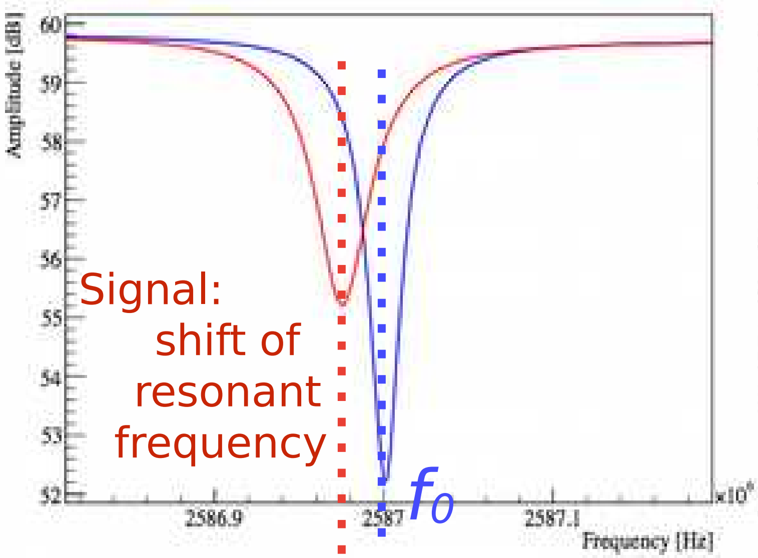
CALDER R&D (ERC StG 2014-2018) www.roma1.infn.it/exp/calder

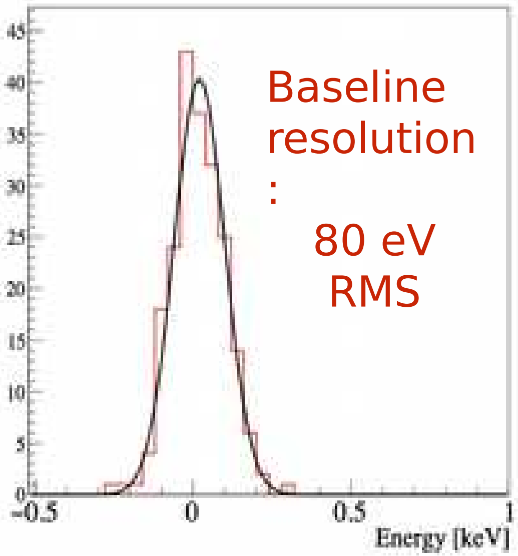
Alternate sensor to NTD and TES: Microwave Kinetic Inductance Detector (MKID).

Pros of MKIDs: high scalability and multiplexing, no microphonic noise.

- **Phase I** - completed: single pixel, high-Q (1.5×10^5) Aluminum resonator.







- **Phase II** - ongoing: test more sensitive superconductors (TiAl, TiN and Ti+TiN).
  - Goal: 20 eV RMS resolution. *TiAl preliminary: 55 eV RMS.*
- **Phase III** - 2017: test at LNGS with TeO_2 / ZnSe bolometers.

Conclusions: from CUPID-0 to CUPID

Cupid-0 aims at exploring the (at least some) possible options for the CUPID detector

a 1-ton 0-background experiment requires much more than this

- **improvement in purity control of materials**
- **enrichment and crystal production**
-
- **improvement in main detector performances**

new ideas & collaborators needed and WELCOME !

LUCIFER → CUPID0

$$F^{\mathrm{ZB}}_{0\nu} = \ln 2 N_{\beta\beta}\epsilon \frac{T}{n_L} = \ln 2 \times \frac{x\eta\epsilon N_A}{A}\frac{MT}{n_L}$$

$$= \ln 2 \times \frac{\epsilon N_A}{A_{\beta\beta}}\frac{M_{\beta\beta}T}{n_L}.$$

ε = detection efficiency ~ 0.8
A = 82
M_{bb} = 5.5 kg
T = 1 y
n_L = Poisson maximum number of counts compatible with 0 bkg
= 2.44 @ 90% C.L.

$S^{0\nu\beta\beta}_{1y} \sim 0.9\ 10^{25}$ y   90% C.L.