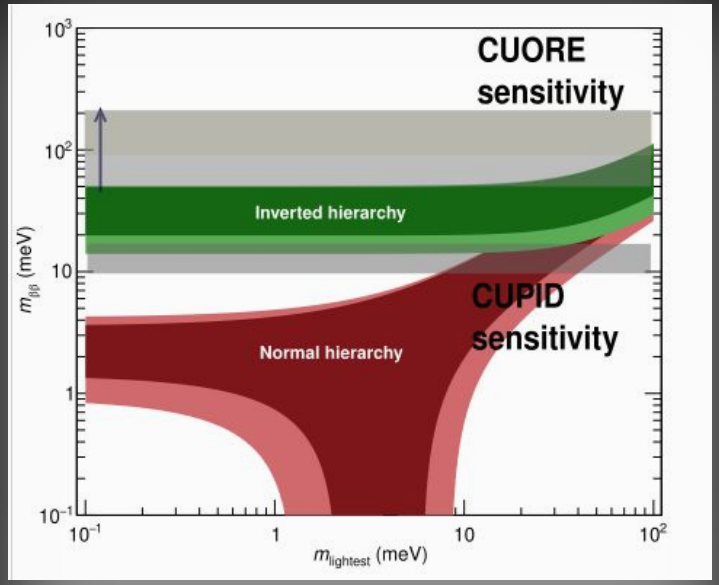
CUPID

1. pre-CDR (2019)
2. project progresses
3. timeline toward the TDR



Maura Pavan for the CUPID collaboration

APPEC Neutrinoless Double Beta Decay Meeting, 3 November 2020

Starting Point: 2019 pre-CDR

(base for the APPEC Report)

description of the experiment with a focus on the detector that will replace the CUORE 988-xtal-array:

- choice of ^{100}Mo and LMO crystals
- preliminary design of the array based on CUPID-0 & CUPID-Mo experience
- draft background budget

Starting Point: 2019 pre-CDR

(base for the APPEC Report)

overview of the organization/timeline/cost:

- three countries are identified as major contributors:
  Italy + US + France a 5 years construction plan
- a cost dominated by isotope ~ 20 MEuro

How we are moving from Conceptual DR to Technical DR

~2 years activity needed to finalize the Technical Design Report

activity short-list:

1. isotope & xtals
2. 2n-bb pile-up reduction
3. design of detector mechanical assembly
4. background budget

focused on the detector, indeed we foresee only minor interventions on the infrastructure

1- isotope & xtals

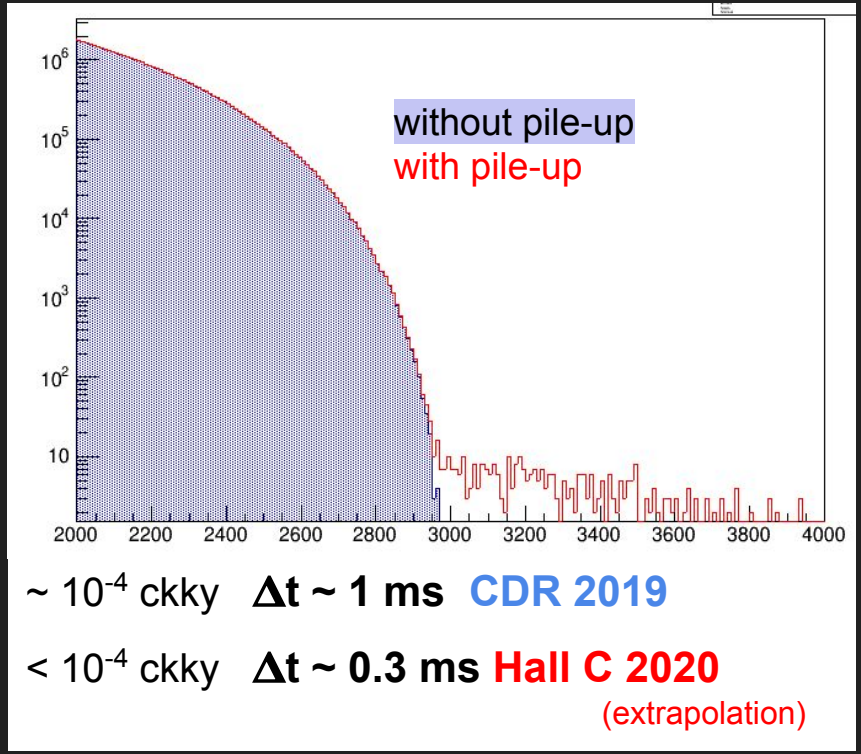
- production
  - critical points are material recovery and radio-purity
  - a small production batch will be measured at LNGS during 2021
  - xtal growers also in USA and China (risk mitigation strategy)

- shape and size: cube 4.5 cm on the side (~300 g)
  - improved occupancy in the cryostat
  - assembly is easier (similar to CUORE)
  - performances are OK (tested at LNGS & Canfranc - FWHM~6 keV)

2- 2vbb pile-up rejection

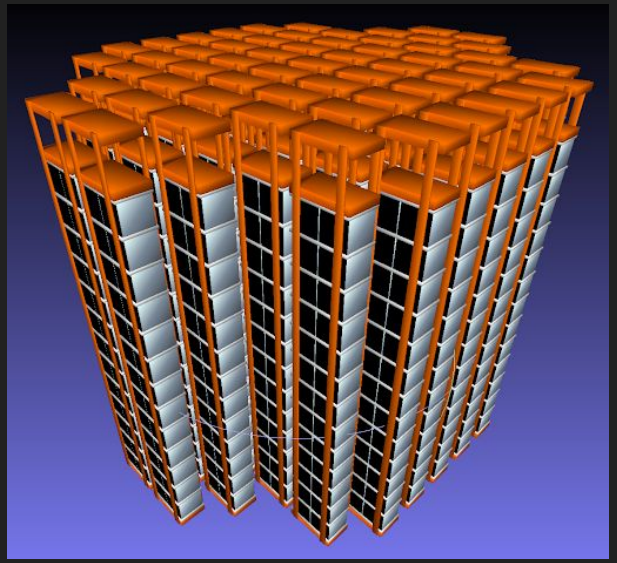
- **Present result - 1 ms**
  - Heat signal only (~15 ms rise-time)
  - test limited by bad-width

- **In progress**
  - Heat & Light Signal (20 times better rise-time, lower S/N)
  - increase the band-width
  - dedicated algorithms



3 - design of new mechanical assembly

new concept: xtals are stacked one over the other



- bounds from mechanical tolerances in this design are very weak
- parts production is easier and safer than in CUORE …
- assembly is faster and safer
- inert material can be reduced

alternative solution: a CUORE-like structure

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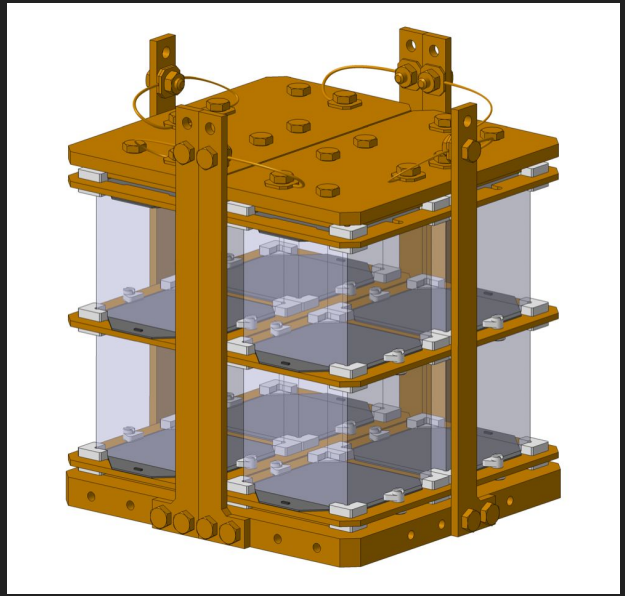
alternative solution: a CUORE-like structure

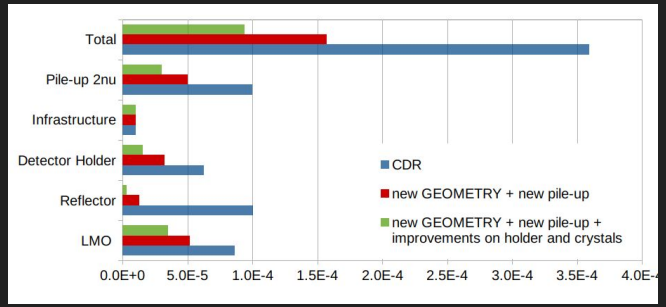
test in Hall C before the end of this year



4 - background model

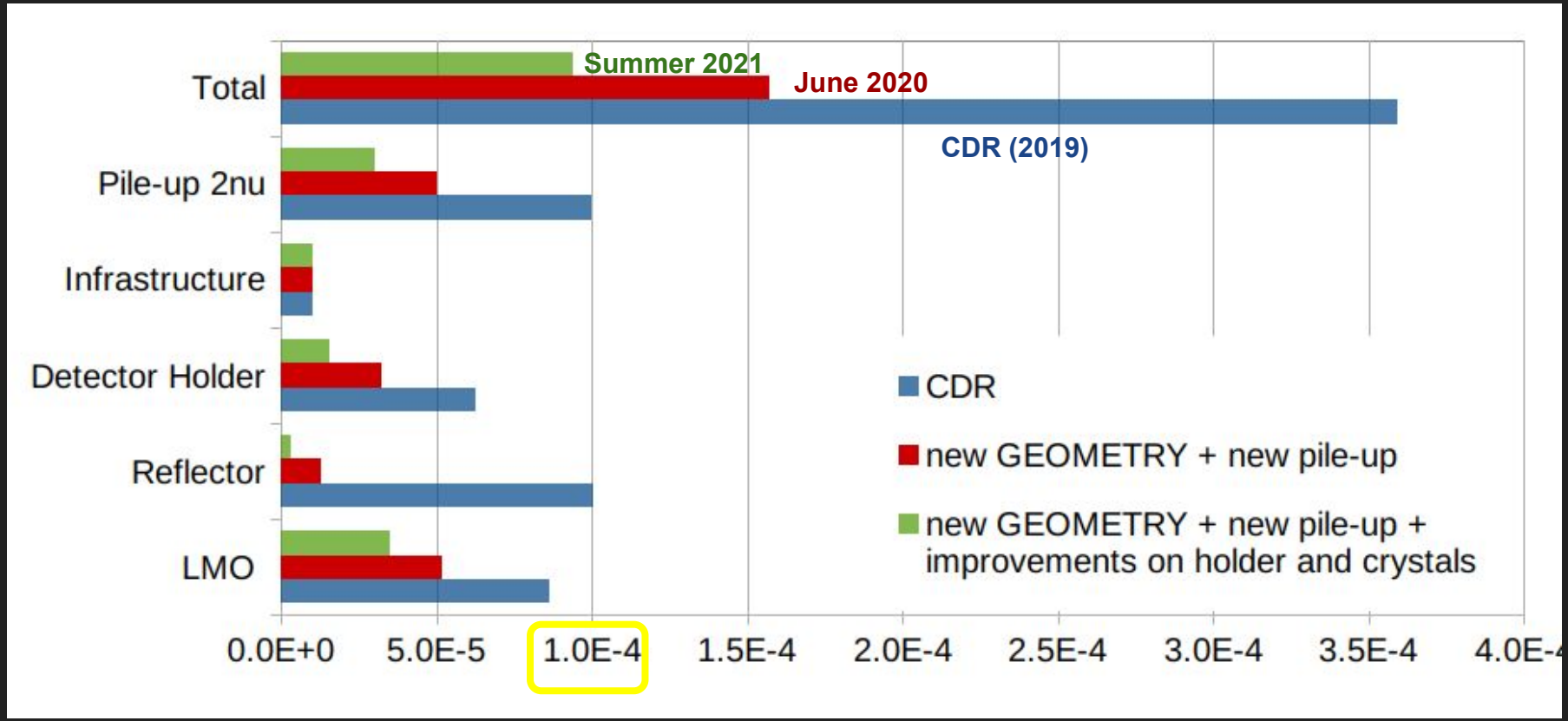
background model: cubic crystals & realistic assembly structure

- cryostat and shields (infrastructure γ contribution) input from CUORE
- contaminants in Cu and PTFE (detector holder) input from CUORE
- contaminants in LMO input from CUPID-Mo



in the plot we compare

- **pre-CDR (cylindrical crystals)**
- **new design and new pile-up estimate (+ reflector discovered clean)**
- **expected improvement**


Summer 2021
June 2020
CDR (2019)
Total
Pile-up 2nu
Infrastructure
Detector Holder
Reflector
LMO
CDR
new GEOMETRY + new pile-up
new GEOMETRY + new pile-up + improvements on holder and crystals
0.0E+0
5.0E-5
1.0E-4
1.5E-4
2.0E-4
2.5E-4
3.0E-4
3.5E-4
4.0E-4

Conclusion (I): CUPID milestones

September 2019 - the CDR was presented to the INFN Astroparticle Committee that funded a 2 year program toward the TDR

September 2020 - the CDR and the new results presented to the LNGS Scientific Committee that gave green light to TDR preparation

> The LNSG Scientific Committee (SC) has carefully examined the Conceptual Design Report (CDR) submitted by the CUPID collaboration. The SC was very impressed by the high quality of the CDR in terms of physics justification as well as the technical description and concluded that the collaboration should be invited to proceed toward submitting the Technical Design Report.

by the end of 2020 - CDR updated with new results and presented to DOE

Conclusion (II): Activities Timeline

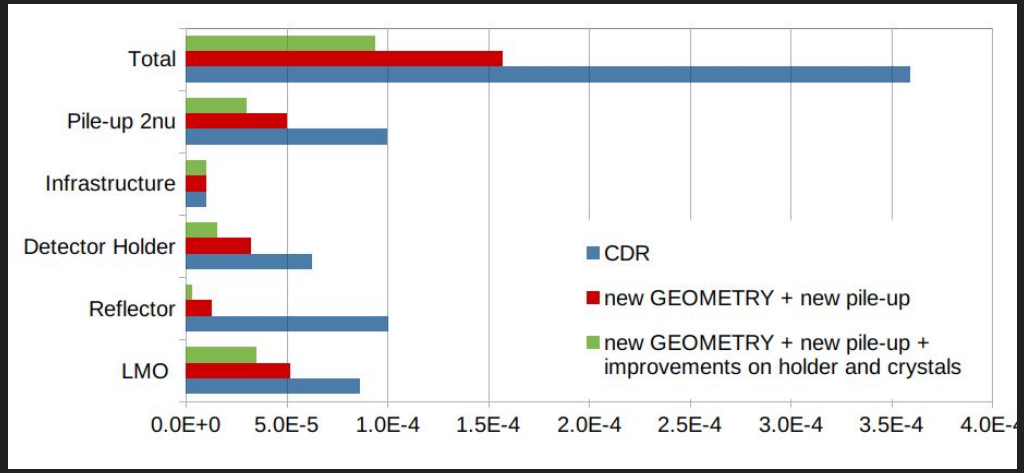
- December 2020 first test of the new assembly concept
- June 2021 test of new isotopically enriched xtals and selection of isotope purification
- June-September 2021 definition of the final detector design
- September 2021 test of a tower with the final detector design
- Fall 2021 TDR

(COVID free
ctions !)

BACKUP SLIDES

from CDR to new geometry

- pile-up
  -
- **detector holder**
  - the gain is due to the new design of the mechanical assembly structure with respect to the CDR one
- **reflector**
  - here is nearly removed, in any case in the CDR we overestimated its contamination
- **LMO**
  - dominant contribution comes from surfaces (extrapolated from CUORE xtals, LMO will be polished with same materials) the improvement is due to a reduction of the surface covered by the reflector



First test of cubic LMO xtals - @ LNGS

- xtals grown by NIIC - Russia (Cross production based on NEMO ^{100}Mo)
- slightly smaller than CUPID standard

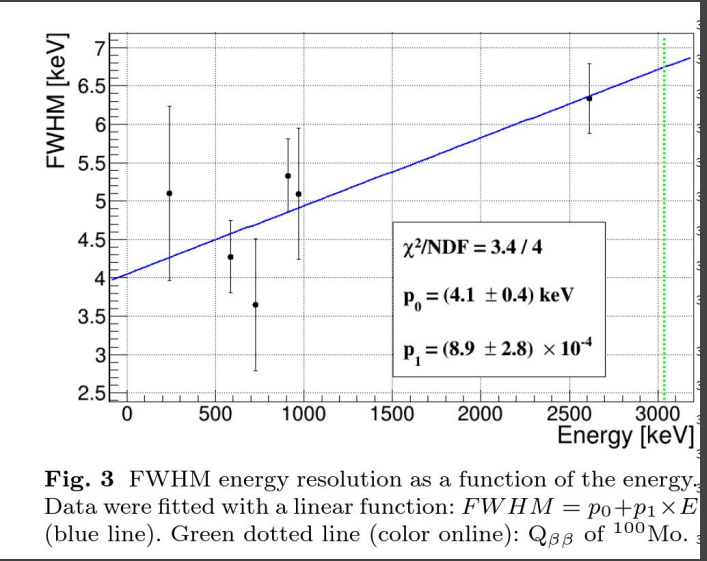


Fig. 3 FWHM energy resolution as a function of the energy. Data were fitted with a linear function: $FWHM = p_0 + p_1 \times E$ (blue line). Green dotted line (color online): $Q_{\beta\beta}$ of ^{100}Mo.

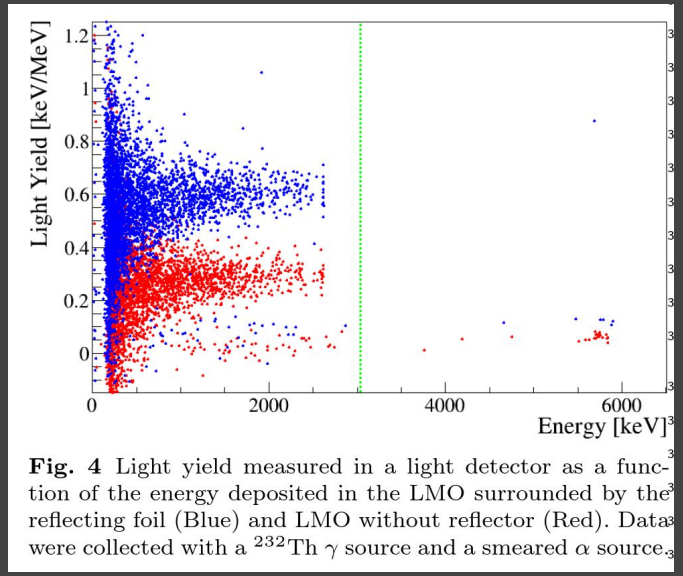


Fig. 4 Light yield measured in a light detector as a function of the energy deposited in the LMO surrounded by the reflecting foil (Blue) and LMO without reflector (Red). Data were collected with a ^{232}Th γ source and a smeared α source.

energy resolution

alpha discrimination with & without reflector

Second test of cubic LMO xtals - @ Canfranc

- xtals grown by NIIC - Russia (Cross production based on NEMO ^{100}Mo)
- slightly smaller than CUPID standard

run just started

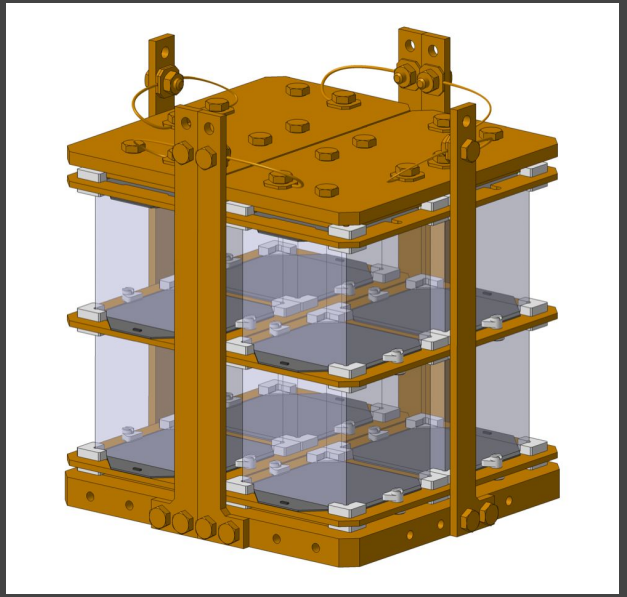
- light collection (Al coating (different thickness) on the lateral surface vs reflecting foil vs no reflection cavity
- light detectors different Ge producers, different wafer shapes
- NTD sensors shape and volume

Test of new assembly - @ LNGS

natural LMO xtals exactly with CUPID size

- new mechanical structure
- light detectors: different couplings

- pile-up study



Infrastructure

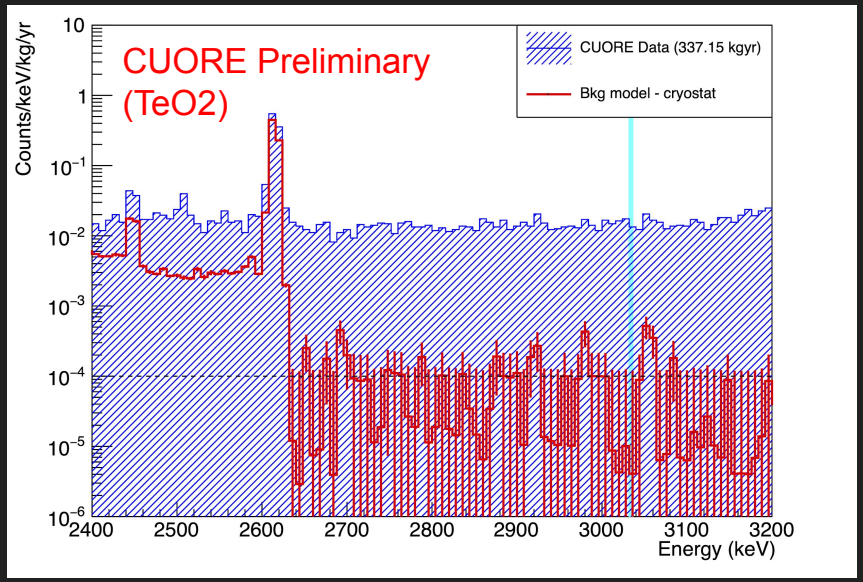
γ background induced by the infrastructure (cryostat+shields)

measured in CUORE $\ll 10^{-4}$ ckky

extrapolated in CUPID ~ 10^{-5} ckky

gain from:

- lower efficiency LMO vs. TeO (efficiency scales by a factor 2 - 3 see back-up slide)

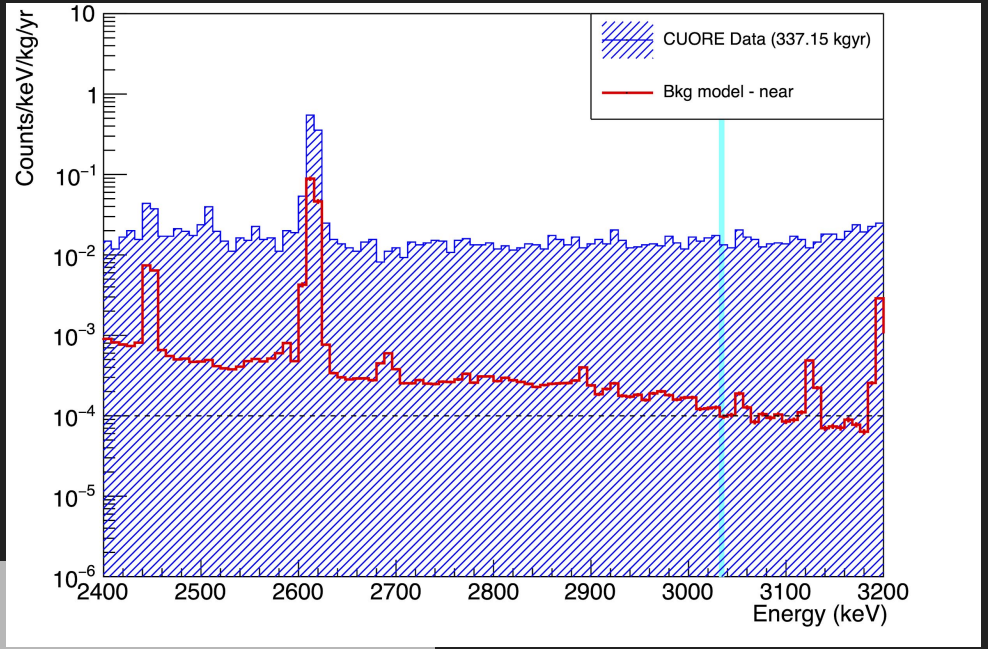


Detector Holder

γ & β background induced by passive components in the holder (copper, PTFE, PEN cables)

measured in CUORE ~ 10^{-4} ckky

extrapolated in CUPID 3 10^{-5} ckky



gain from:

- lower efficiency LMO vs. TeO
- lighter holder structure
- we add a reflecting foil now measured with high radiopurity

Activities

isotope (JSC - Russia) selection of the purification level that meets CUPID requirements

crystals (NIIC - Russia) optimization of crystal grow protocol and material recovery

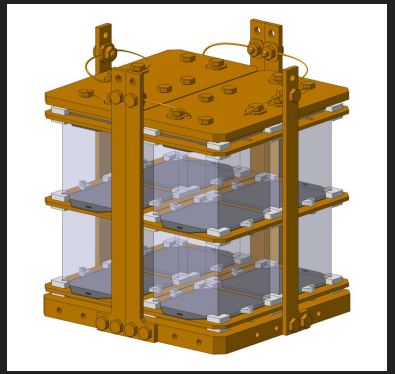
crystals produced with the 2 different isotopes are being purchased and will be tested at LNGS to compare their purity

optimization of light collection various options under study: reflecting foil / coating / bare crystals

run ongoing in Canfranc, several labs supporting the technological efforts, including other above ground cryogenic facilities in US, IT FR

Hall A & Hall C activities

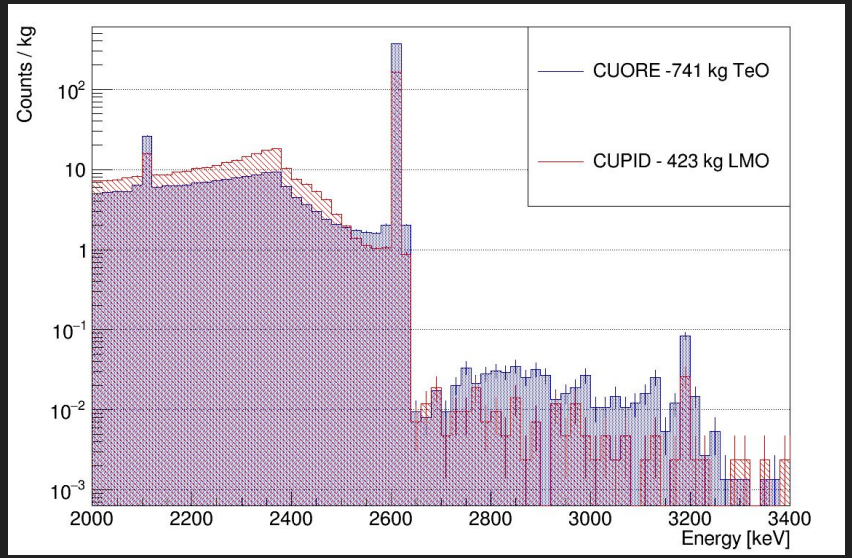
- Hall C
  - 2020-October first test of new detector assembly
    - pile-up rejection
    - light yield in an optimized configuration
  - 2021 test of crystal coating & enriched crystals

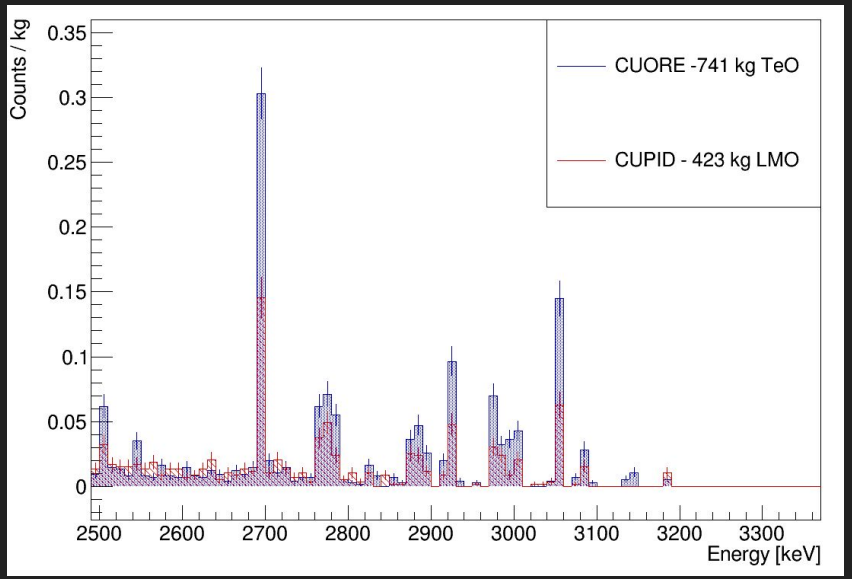


- Hall A
  - end 2020 de-commissioning of CUPID-0
  - 2021 organization of a new run using IT+FR crystals (from new production) and the final detector structure
    - radio-clean assembly
    - test of bulk and surface radiopurity
    - test of the new detector structure
    - expected background level is ~10^{-3} c/keV/kg/y dominated by muons

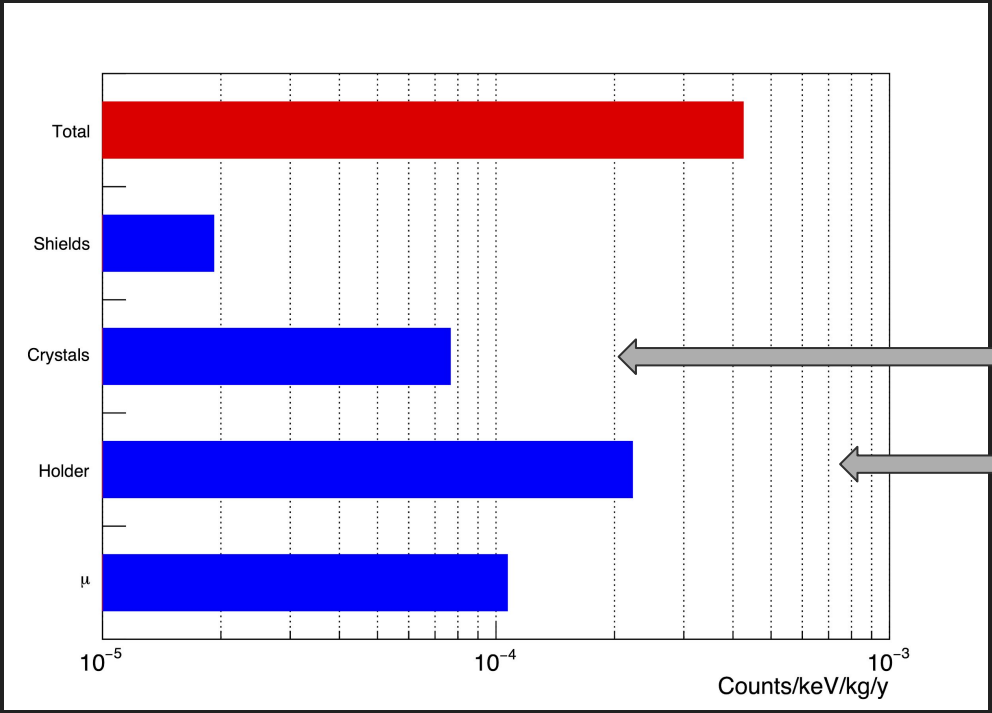
from TeO_2 to Li_2MoO_4

We need to have plots with higher statistics for the 13 July meeting





CUORE bkg composition



alpha particles !!!

Pile-up resolution: below 0.3 ms

Neganov-Luke Detectors

- fast rise-time
- high S/N
- only additional need = a bias line for the electrodes

successfully tested
need reproducibility study

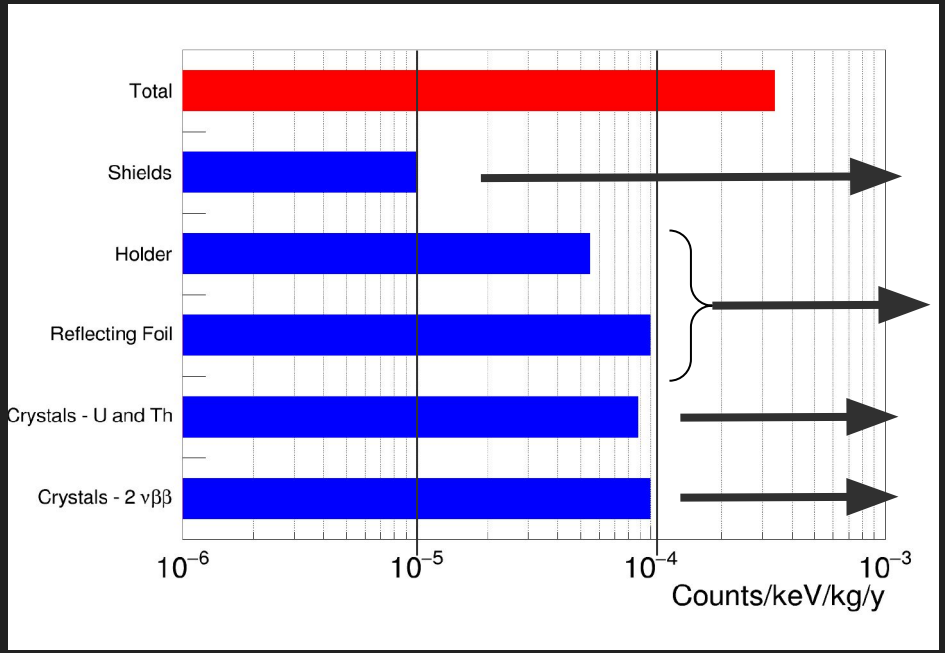
TES Detectors

- very fast signals
- very high S/N
- new read-out system

under development
used by other experiments
e.g. CRESST

Background: 4 major components

pre-CDR cylindrical crystals



U and Th in contaminations in **CUORE infrastructure**

U and Th in **detector holder (**passive components as copper, PTFE, reflecting foil ...)

U and Th in **crystals & light detector**

^{100}Mo 2nbb decay induced background

From CUORE to CUPID: how we build the background budget

CUORE background

- Infrastructure (cryostat+shields) $\ll 1\times10^{-4}$ counts/(keV×kg×y)
- Detector Passive Components $\sim 2\times10^{-4}$ counts/(keV×kg×y)

CUPID-0 + CUPID-Mo + Hall C test

- α-rejection (>99.9%)
- LMO radiopurity (~μBq/kg)
- Reflectors radiopurity (NEW BiPo measurement!!)
- Light Detector contribution negligible
- 2νββ Pile-up rejection

Scaling from CUORE to CUPID:

- Lower detection eff. for γs (2.3 times at 2615 keV, 3.6 times at 2.8 - 3.1 keV)
- Muon tagging with external veto (>99%)

Isotope & crystal procurement

Isotope producer: JSC Isotope (Russia)

- provides ^{68}Ge to LEGEND and provided ^{100}Mo to AMORE ⇨ highly reliable
- high production capability (~300 kg of ^{100}Mo in 3 years)
- two levels of purification (different price same i.a.) ⇨ we have to choose which one to buy

Crystal producer: NIIC Nikolaev Institute of Inorganic Chemistry (Russia)

- Cupid-Mo/CROSS crystals used so far were produced by NIIC ⇨ crystal quality and radiopurity matches CUPID requirements (but raw materials come from an old production)
- need to asses crystal radiopurity with CUPID materials as project starts we will need a dedicated production line for CUPID
- risk mitigation ⇨ we have the possibility to purchase crystals from other vendors

… in progress

Requirements:

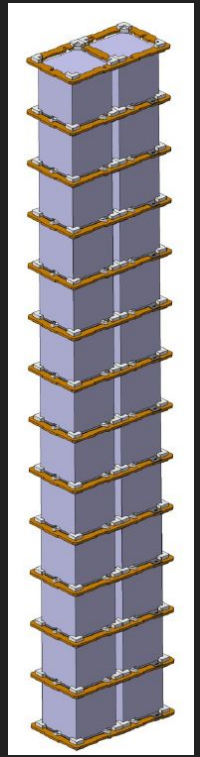
- low amount of inert material (radioactivity)
- ease and fast assembly

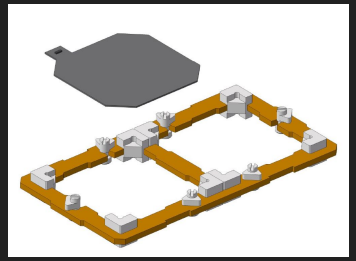
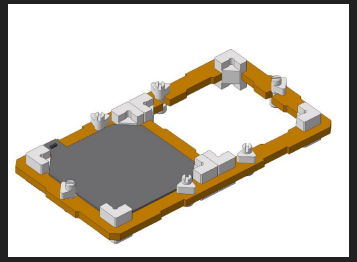
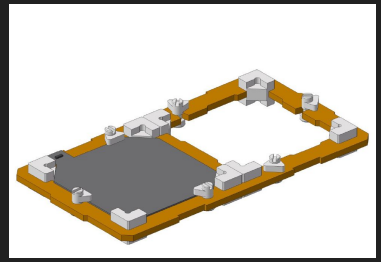
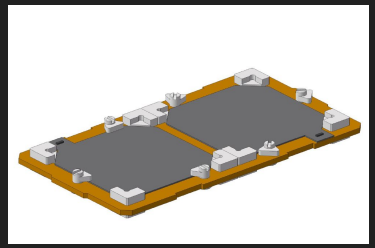
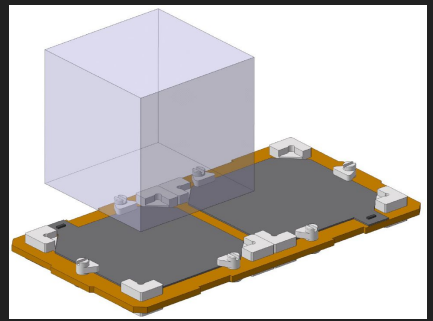
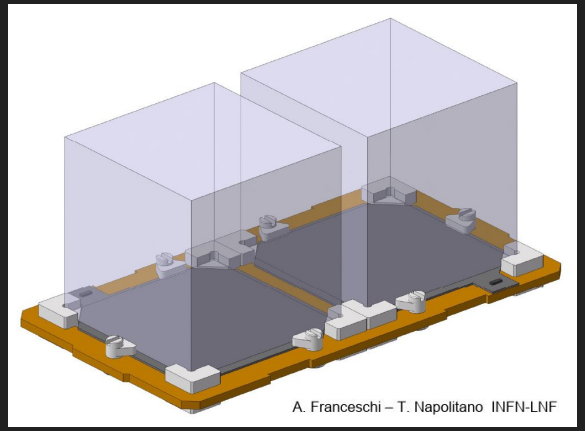
New System (better space occupancy + faster/easier assembly)

- 2 crystals tower
- light detector pre-assembled in the copper frame
- simplified design of the frame

Plans:

- test program 2020-2021 in Hall C
- finalization and final test in Hall A with new crystals



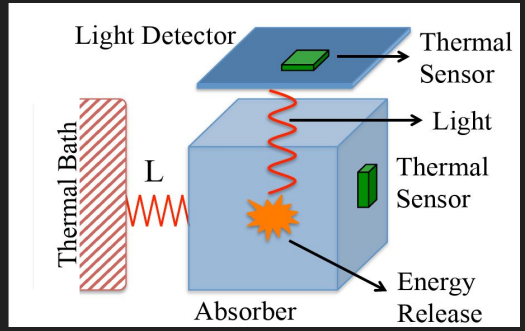






A. Franceschi – T. Napolitano INFN-LNF

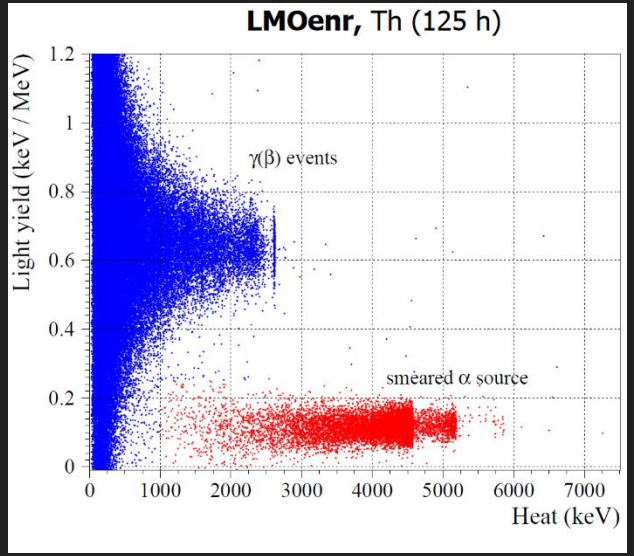
CUPID project

$Li_2{}^{100}MoO_4$ scintillating crystals

- enrichment > 95% ⇒ ~250 kg of ^{100}Mo
- ~ 1500 crystals, ~300 g each
- ΔE FWHM ~5 keV at $Q_{\beta\beta}$ ~3034 keV
- alpha-particle rejection using light signal

CUORE infrastructure

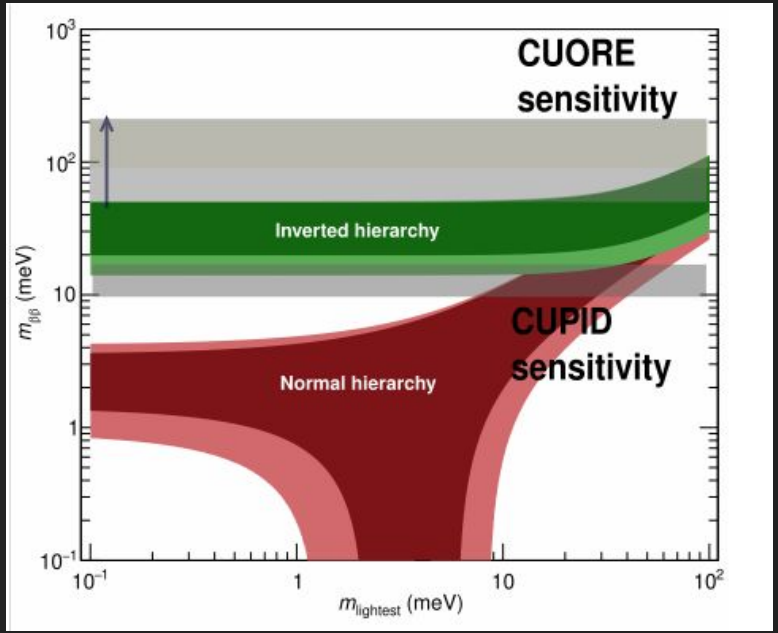




Project overview:

new detector in CUORE infrastructure

- **CUORE**
  - TeO_2 xtals ~ 300 kg ^{130}Te
  - background ~ 10^{-2} ckky
- **CUPID**
  - $Li^{100}Mo$ xtals ~250 kg ^{100}Mo
  - background < 10^{-4} ckky



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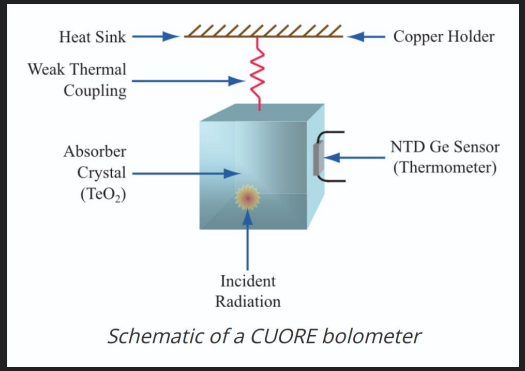
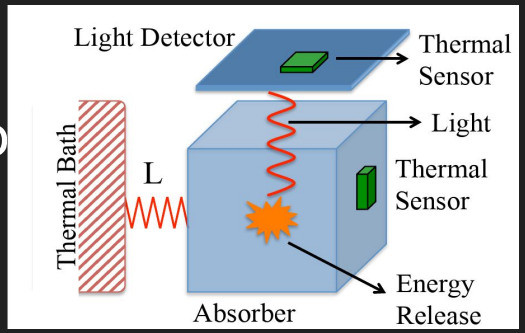


Schematic of a CUORE bolometer

HEAT

- **CUPID**
  - $Li^{100}Mo$ xtals ~250 kg ^{100}Mo
  - background < 10^{-4} ckky



HEAT + LIGHT