CUPID

***C**uore **U**pgrade with **P**article **ID**entification*

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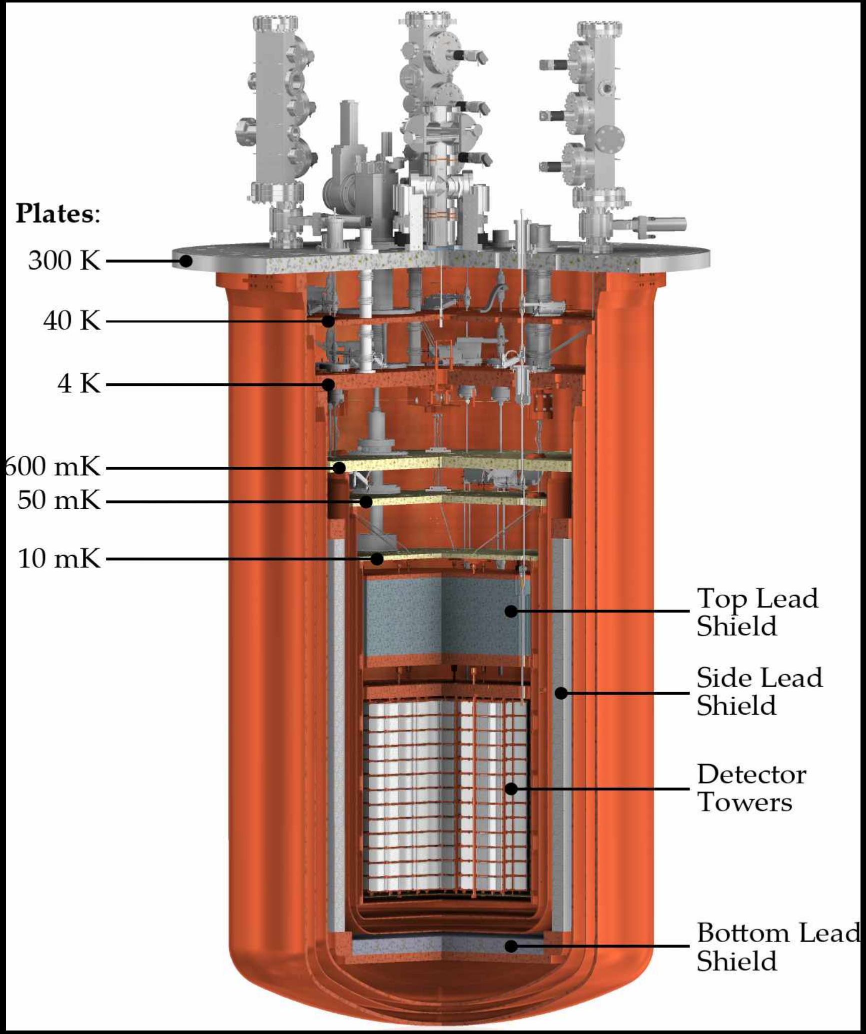
On behalf of the CUPID Collaboration

CUPID

Cuore Upgrade with Particle IDentification



CUORE infrastructure with a new detector

Discovery sensitivity:

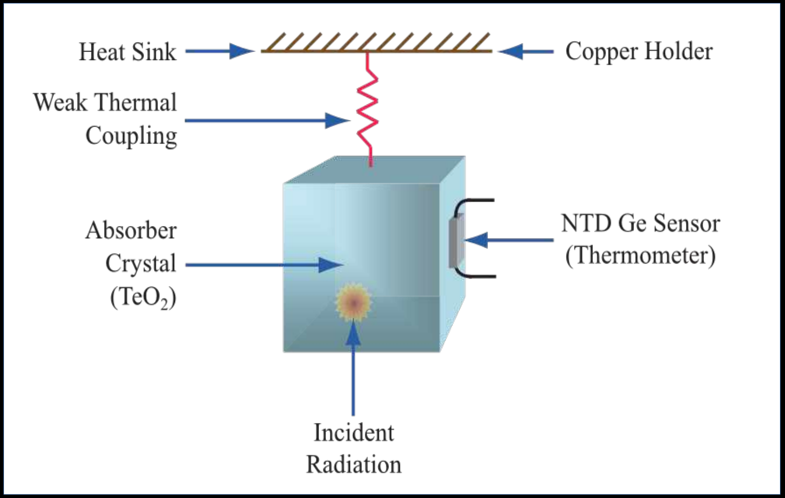
$\tau_{1/2}(^{100}\mathrm{Mo}) > 10^{27}$ y

$m_{\beta\beta} < 20$ meV

CUPID concept

CUORE ^{130}Te

pure thermal detector
(bolometer)

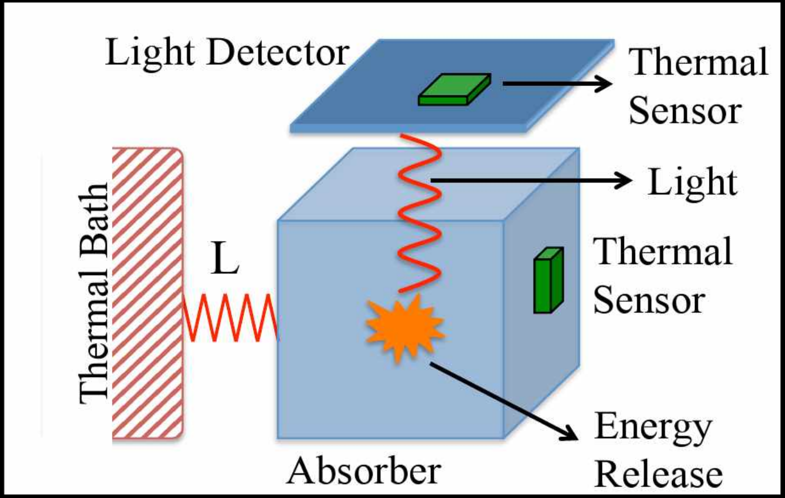


No PID

$Q_{\beta\beta} < 2615$ keV

CUPID ^{100}Mo

heat + light
(scintillating bolometer)

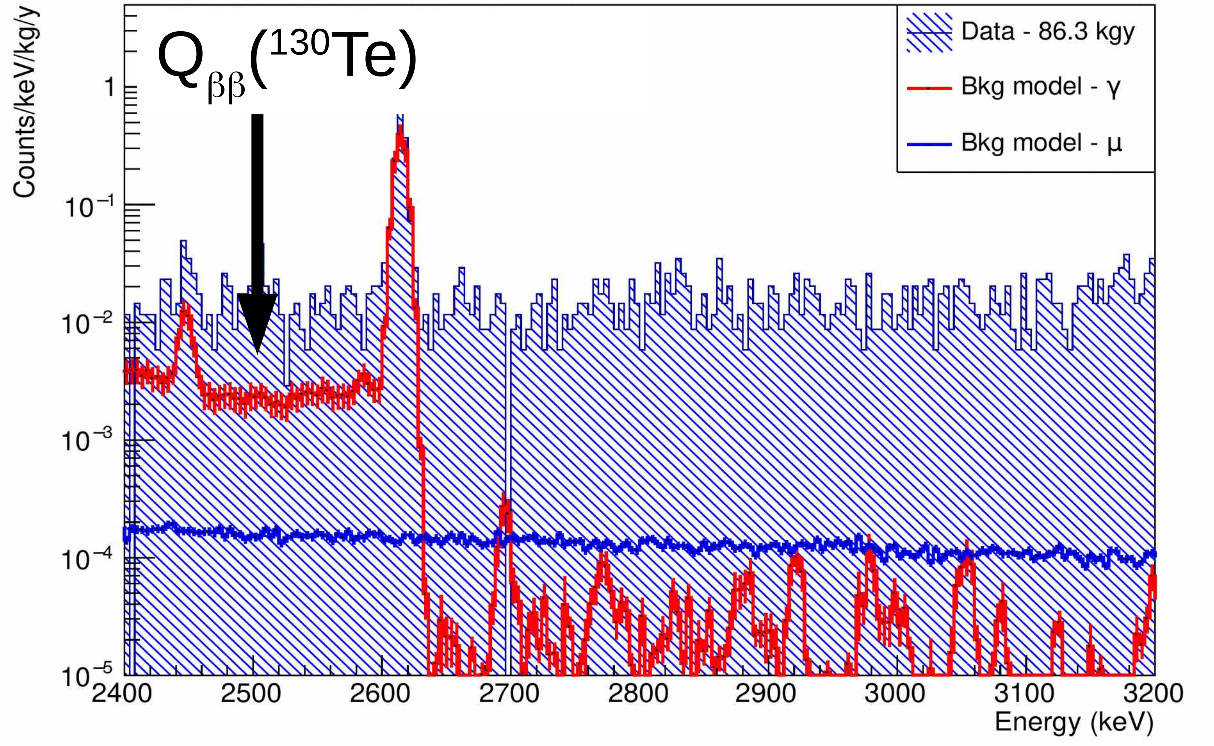


PID

$Q_{\beta\beta} > 2615$ keV

CUORE preliminary

CUORE bkg model

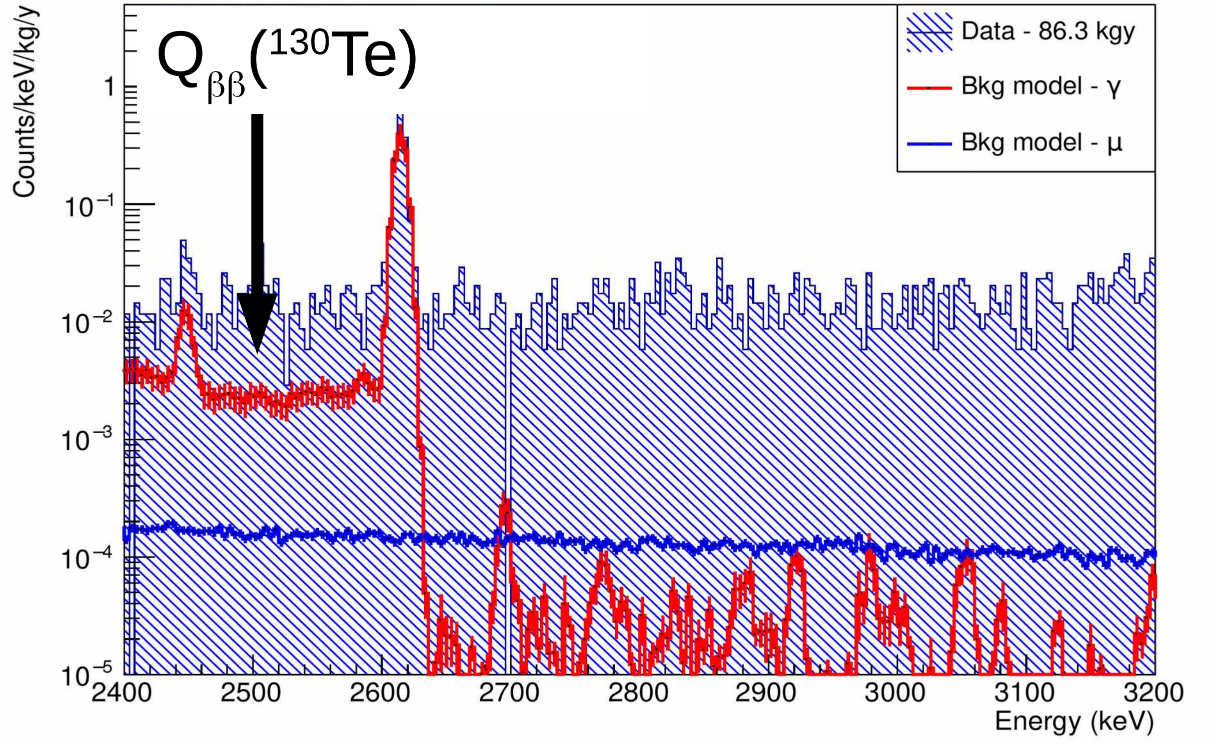


most measured background is due to α particles
(U/Th contaminations on surfaces close to the TeO_2 crystals)

CUPID-0 and CUPID-Mo observe a similar flat continuum

CUORE preliminary

CUORE bkg model



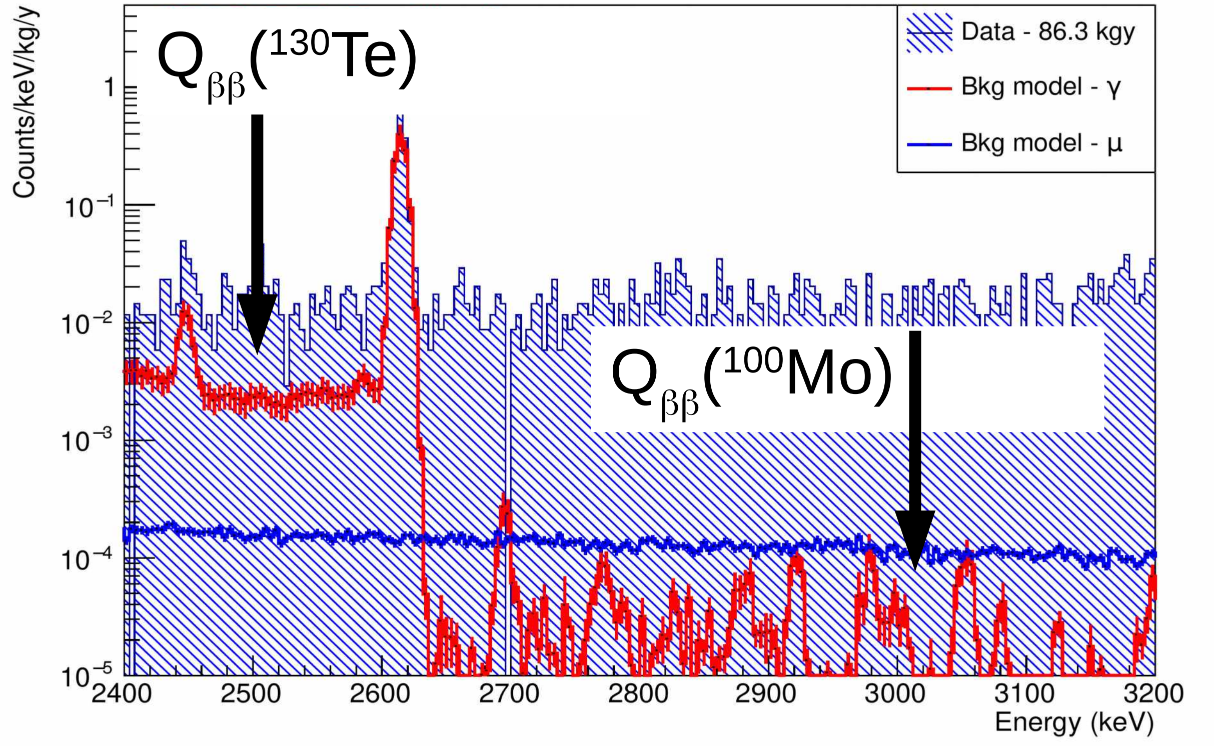
subdominant contributions are

- cosmogenic muons
- γ's from contaminations in cryostat & shields

intrinsic contribution of CUORE infrastrucure

CUORE preliminary

from CUORE to CUPID



CUPID new detector

→ PID allows to reject α's

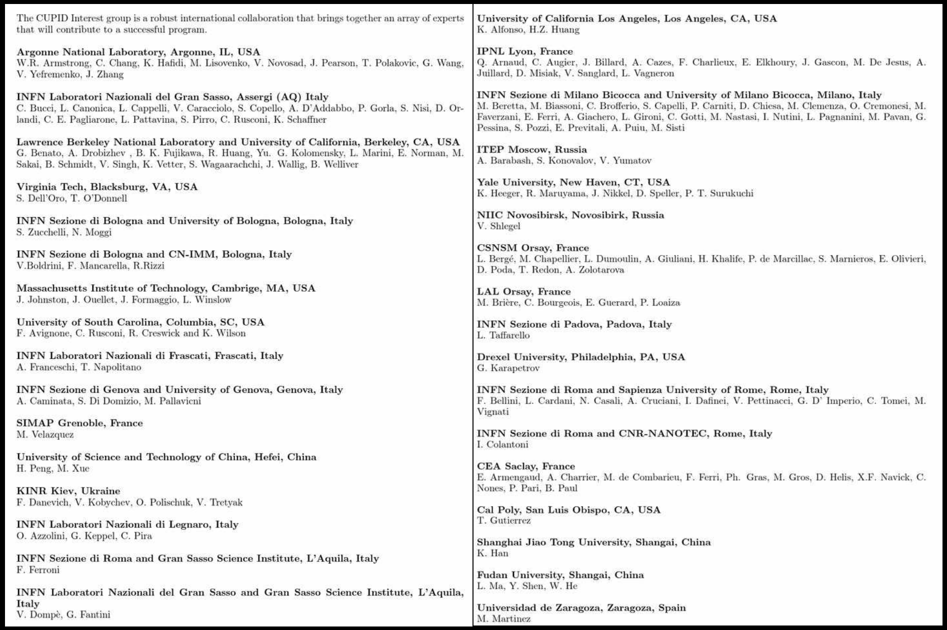
→ ^{100}Mo implies the $0\nu\beta\beta$ signal is at 3 MeV

Conceptual Design Report
(pre-CDR)

CUPID pre-CDR arXiv:1907.09376

~ 170 authors
7 countries

new contributions are welcome



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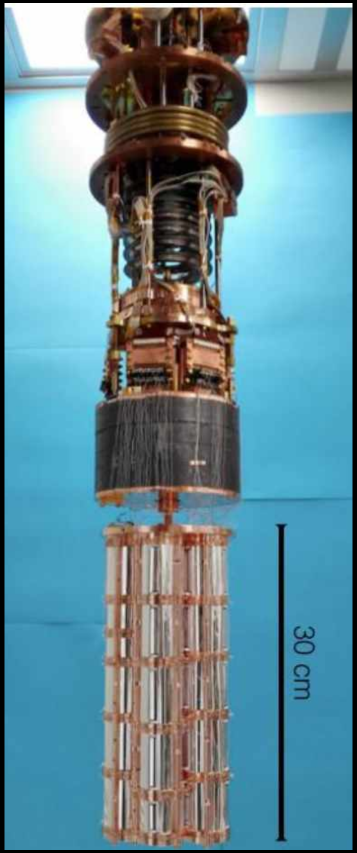
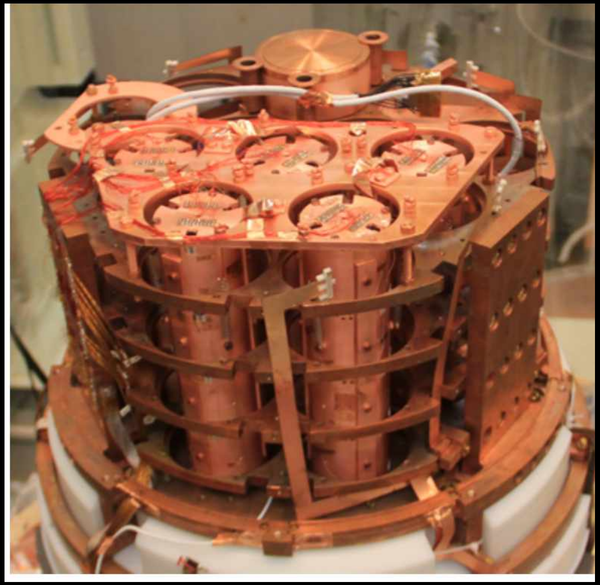
CUPID CDR

conservative & mature & data driven baseline design

CUORE



CUPID-0



CUPID-Mo

CUORE

Feasibility of a tonne scale experiment
with 1000 indipendent detectors

- Cryogenics
- Shield System
- Assembly
- Electronics + DAQ + DA

- Background Model

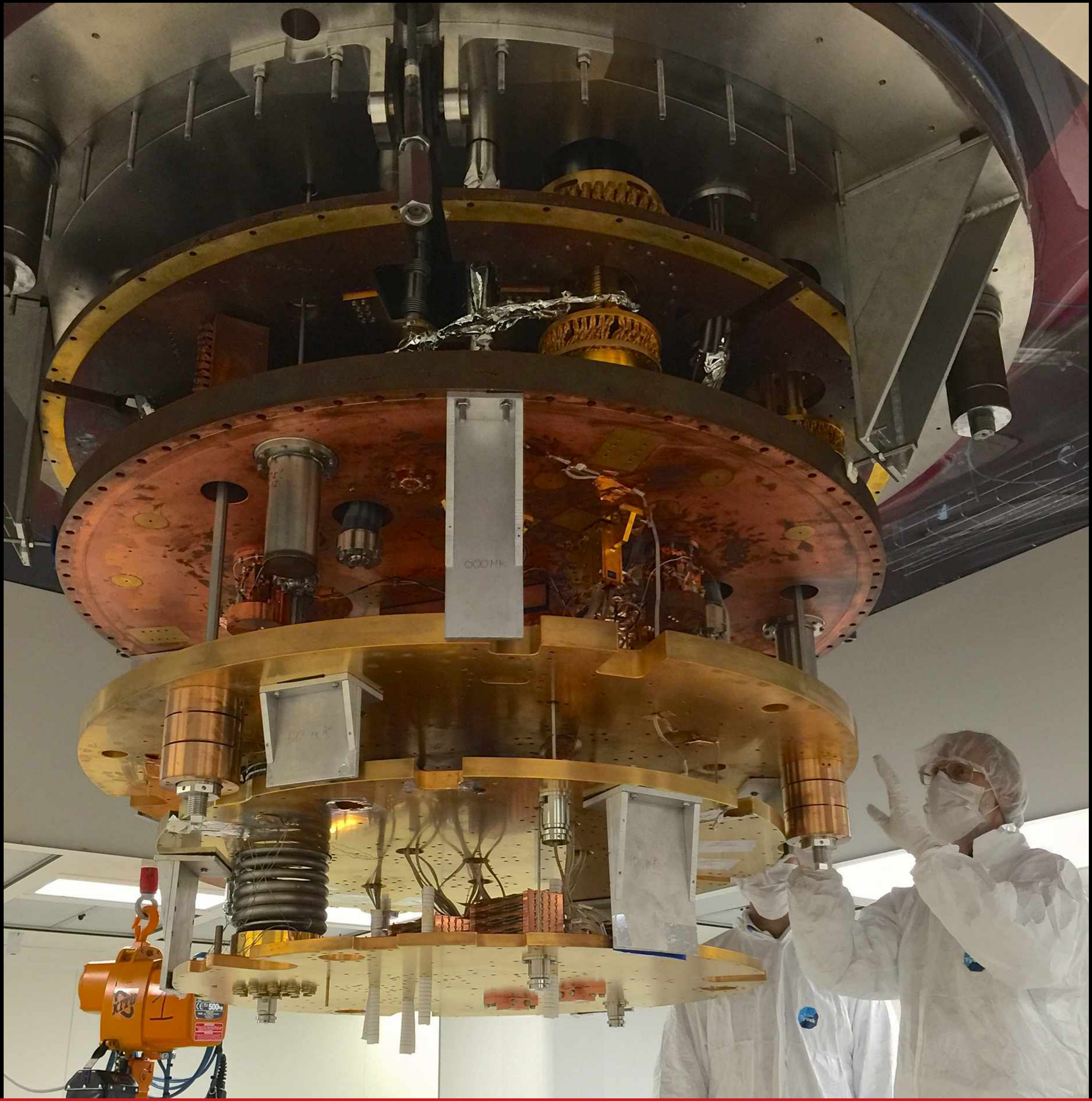
CUORE

Feasibility of a tonne scale experiment with 1000 indipendent detectors

- **Cryogenics**
- Shield System
- Assembly
- Electronics + DAQ + DA

- Background Model


600mK
10mK
500kg



- THE LARGEST 10 mK REFRIGERATOR EVER BUILT
- COOLING POWER EVEN BEYOND EXPECTATIONS
- NOW DUTY CYCLE (Physics Data) ~ 60%
- LARGE VOLUME AVAILABE FOR DETECTOR

CUORE

Feasibility of a tonne scale experiment
with 1000 indipendent detectors

- Cryogenics
- **Shield System**
- Assembly
- Electronics + DAQ + DA
- Background Model

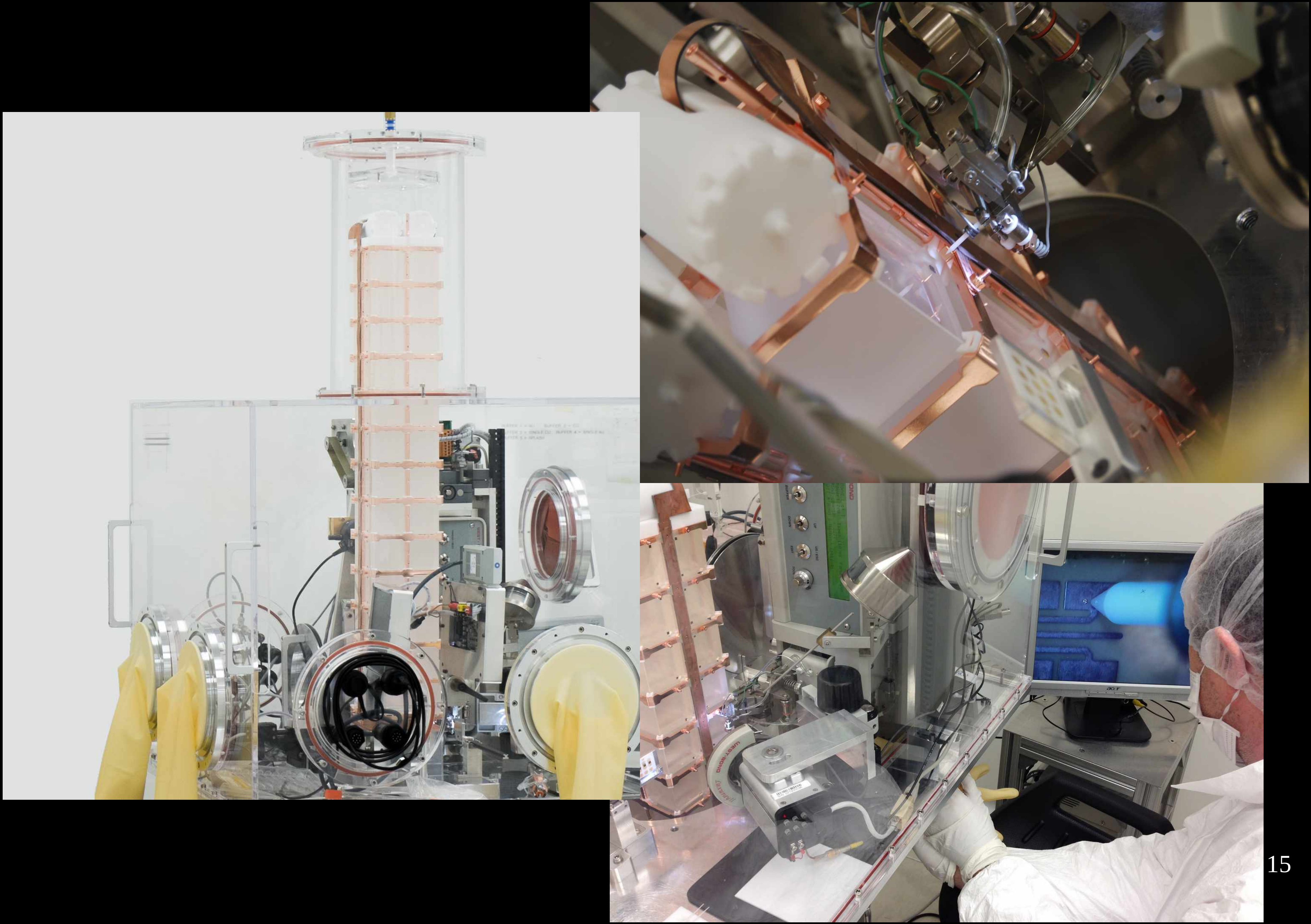
- **ROMAN Pb SURROUNDING THE DETECTOR (6 cm @ 4K)**
- **COMMERCIAL Pb (25 cm @ 300K)**
- **NEUTRON SHIELD**
- **NO MUON VETO**

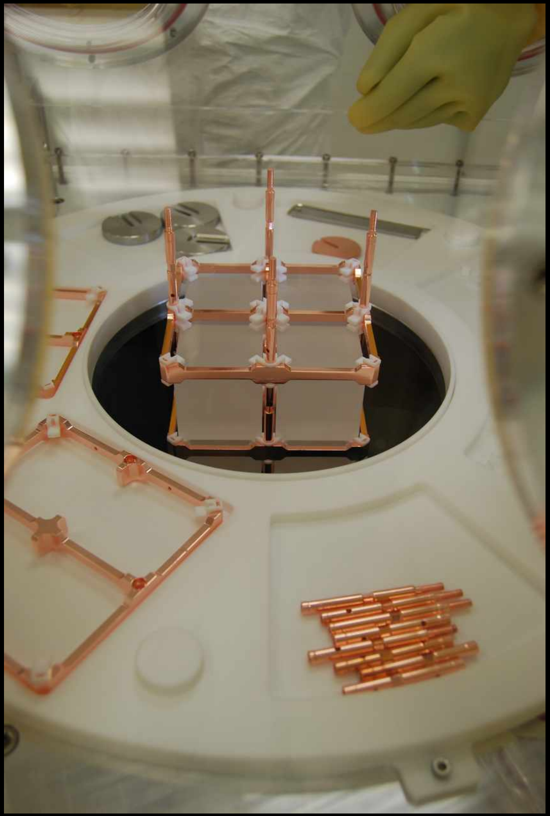
CUORE

Feasibility of a tonne scale experiment with 1000 indipendent detectors

- Cryogenics
- Shield System
- **Assembly**
- Electronics + DAQ + DA
- Background Model

- **1000 DETECTORS ASSEMBLED IN CLEAN ROOM**
- **DEDICATED TOOLS FOR GLUING & BONDING**
- **HIGH REPRODUCIBILITY**






TOWER 11
TOWER 06

CUORE

Feasibility of a tonne scale experiment
with 1000 indipendent detectors

- Cryogenics
- Shield System
- Assembly
- **Electronics + DAQ + DA**

- **ELECTRONICS FULLY OPTIMIZED**
- **COMMERCIAL DAQ → CUSTOM DAQ**
- **DA FOR 1000 DETECTORS**

- Background Model

CUORE

Feasibility of a tonne scale experiment
with 1000 indipendent detectors

- Cryogenics
- Shield System
- Assembly
- Electronics + DAQ + DA
- **Background Model**

- **LOCALIZATION OF BACKGROUND SOURCES IN THE CUORE INFRASTRUCTURE WITH A SENSITIVITY HIGHER THAN THAT ACHIEVABLE BY MATERIAL SCREENING**

CUPID-0

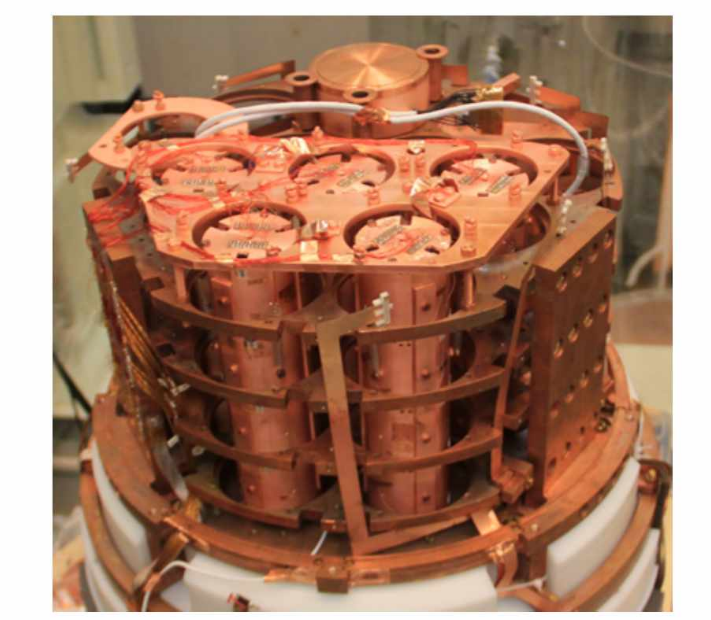
25 crystals of Zn^{82}Se
(5.5 kg of ^{82}Se LNGS Hall A)

First $0\nu\beta\beta$ experiment with scint. bolometers

- first direct evidence that “flat bkg” is α
- demonstrator of dual read-out technique

Background Model

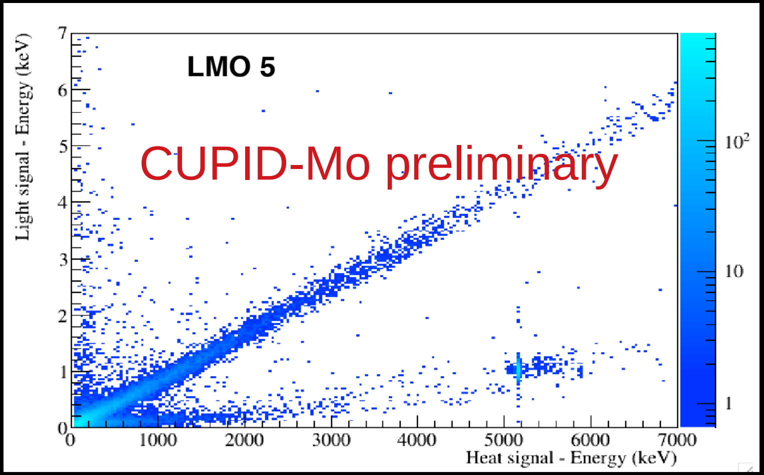
CUPID-Mo



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

(2.264 kg of ^{100}Mo @ Modane)

- first experiment 0νββ with $Li_2{}^{100}MoO_4$ scintillating bolometers
- demonstrator of performances and crystal internal contaminations



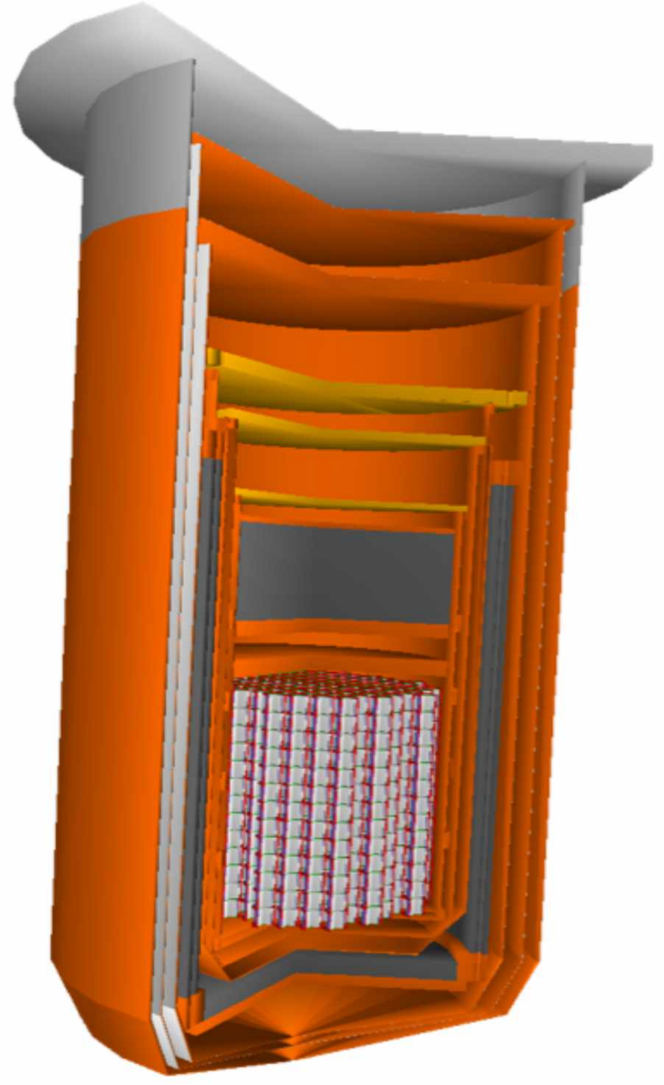
CUPID conceptual design

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

- enrichment > 95%
- $\varnothing$=50mm, h=50mm → 308 g
- ~1534 crystals ~250 kg of ^{100}Mo
- ΔE FWHM ~ 5 keV at $Q_{\beta\beta}$ ~3034 keV
- α rejection using light signal

$0\nu\beta\beta$ sensitivity → $\tau_{1/2}$~ 10^{27} y

→ $m_{\beta\beta}$ 12-20 meV



CUPID

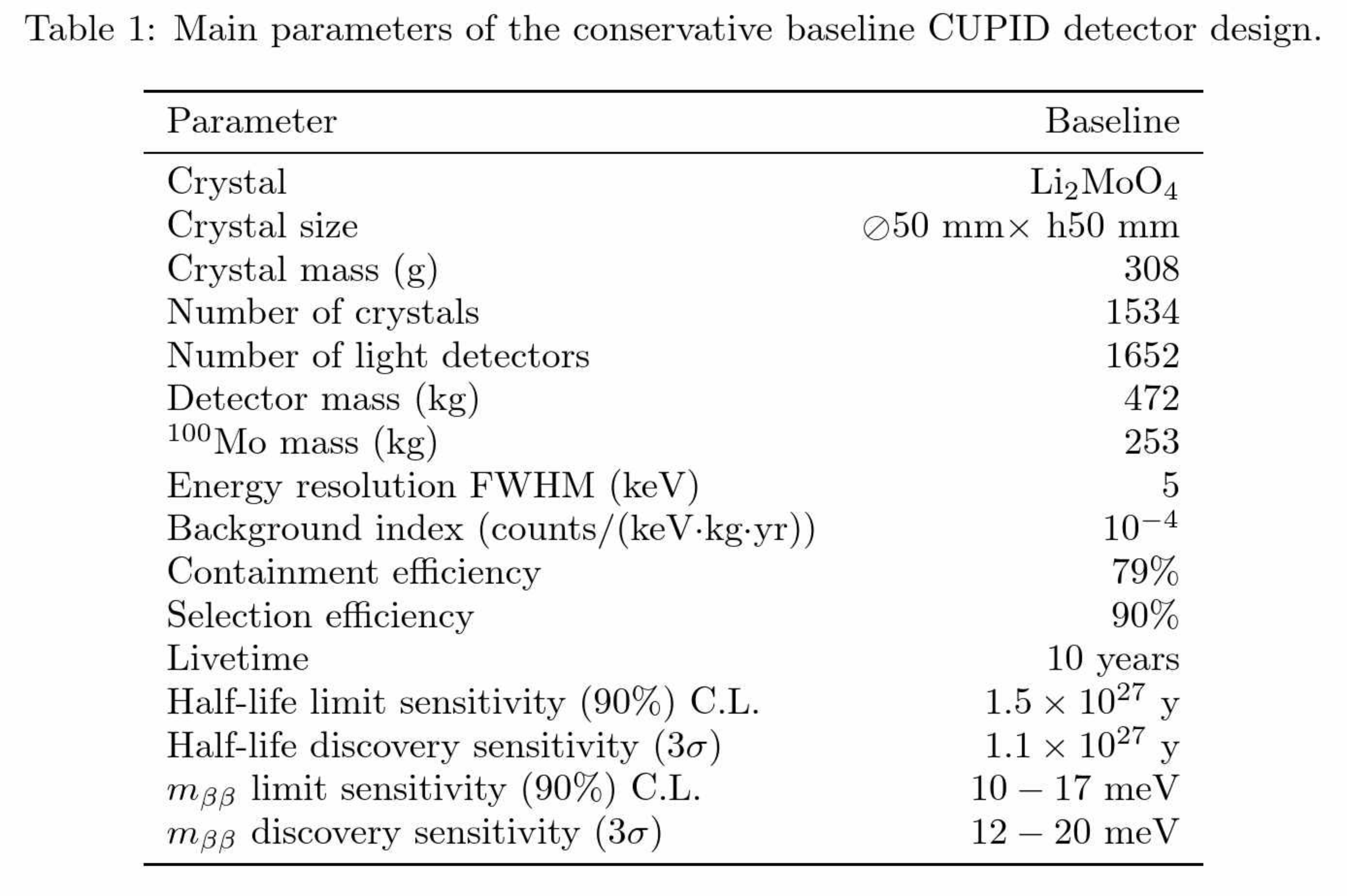


Table 1: Main parameters of the conservative baseline CUPID detector design.

Parameter	Baseline
Crystal	Li_2MoO_4
Crystal size	$\varnothing$50 mm× h50 mm
Crystal mass (g)	308
Number of crystals	1534
Number of light detectors	1652
Detector mass (kg)	472
^{100}Mo mass (kg)	253
Energy resolution FWHM (keV)	5
Background index (counts/(keV·kg·yr))	10^{-4}
Containment efficiency	79%
Selection efficiency	90%
Livetime	10 years
Half-life limit sensitivity (90%) C.L.	1.5×10^{27} y
Half-life discovery sensitivity (3σ)	1.1×10^{27} y
$m_{\beta\beta}$ limit sensitivity (90%) C.L.	$10 - 17$ meV
$m_{\beta\beta}$ discovery sensitivity (3σ)	$12 - 20$ meV

CUPID background projection

Crystals

→ U/Th bulk (from CUPID-Mo)

→ U/Th surface (CUORE bkg model)

→ $2\nu\beta\beta$ pile-up

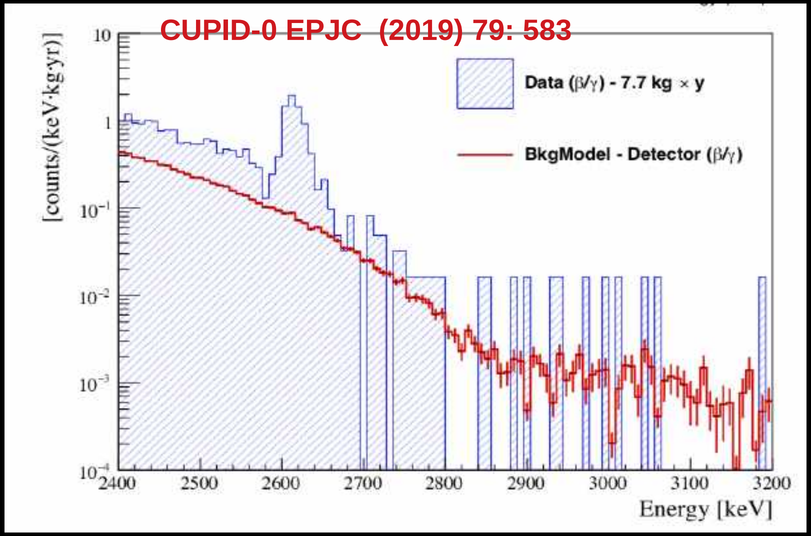
($\tau_{1/2}$= 7.1 10^{18} y → xtal mass is a compromise)

CUPID background projection

Holder

→ U/Th surfaces

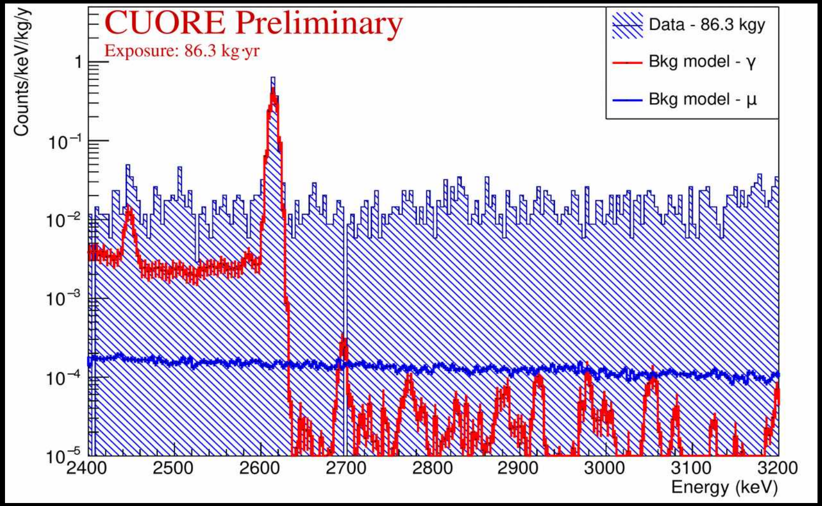
(CUPID-0 bkg model)


CUPID-0 EPJC (2019) 79: 583

Cryogenic & Shielding Infrastructure

→ U/Th bulk

(CUORE bkg model)



CUPID background projection

CUPID CDR: arXiv:1907.09376

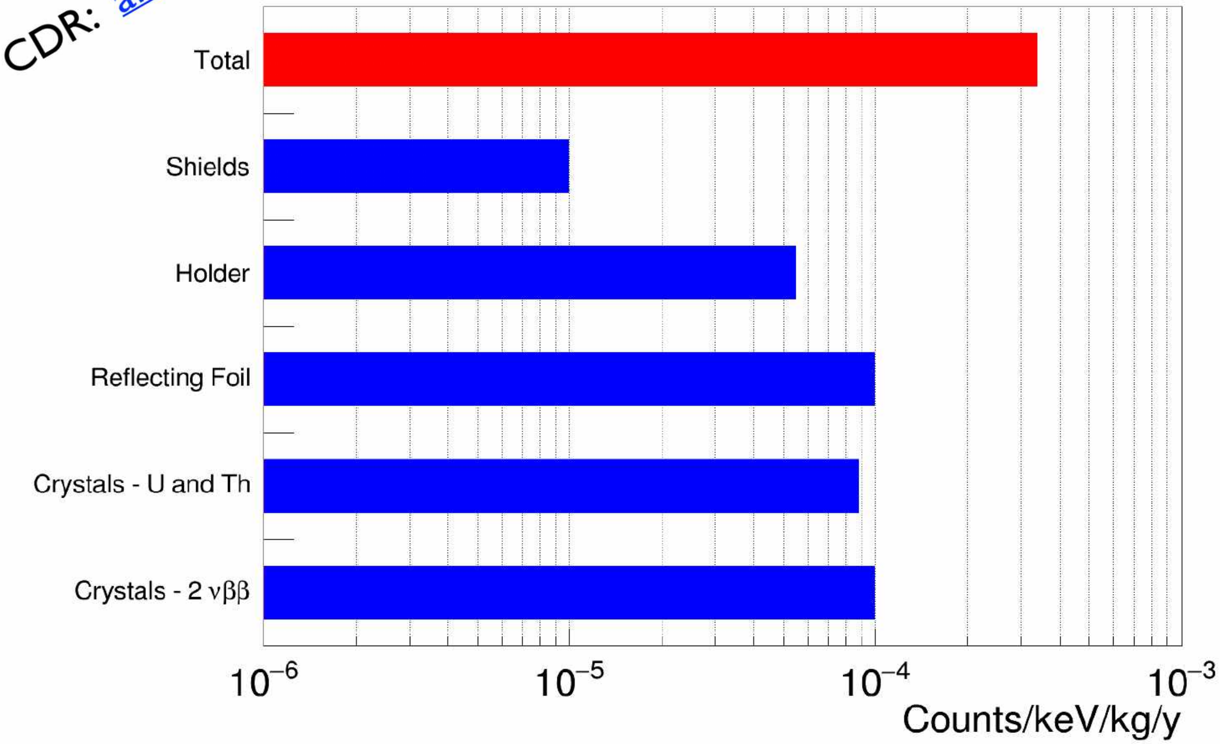


Figure 45: Breakdown of the CUPID β/γ counting rate predicted by the BM in the ^{100}Mo ROI. Here, the baseline configuration is considered. As discussed in the text, the substitution of the reflective foil with a reflective coating on Li_2MoO_4 crystals would dramatically reduce both the U and Th contributions of crystals (here dominated by surface contaminants) and that of the reflector itself.

Ultraconservative: no improvement in signal timing (2νββ pile-up)
no improvement in reflecting foil contribution (coating)

CUPID sensitivity

CUPID CDR = ultraconservative approach
→ exactly what we have today

CUPID reach = improvement at reach before construction
→ signal timing (from NTD performances to TES)
→ surface radiopurity & crystal coating

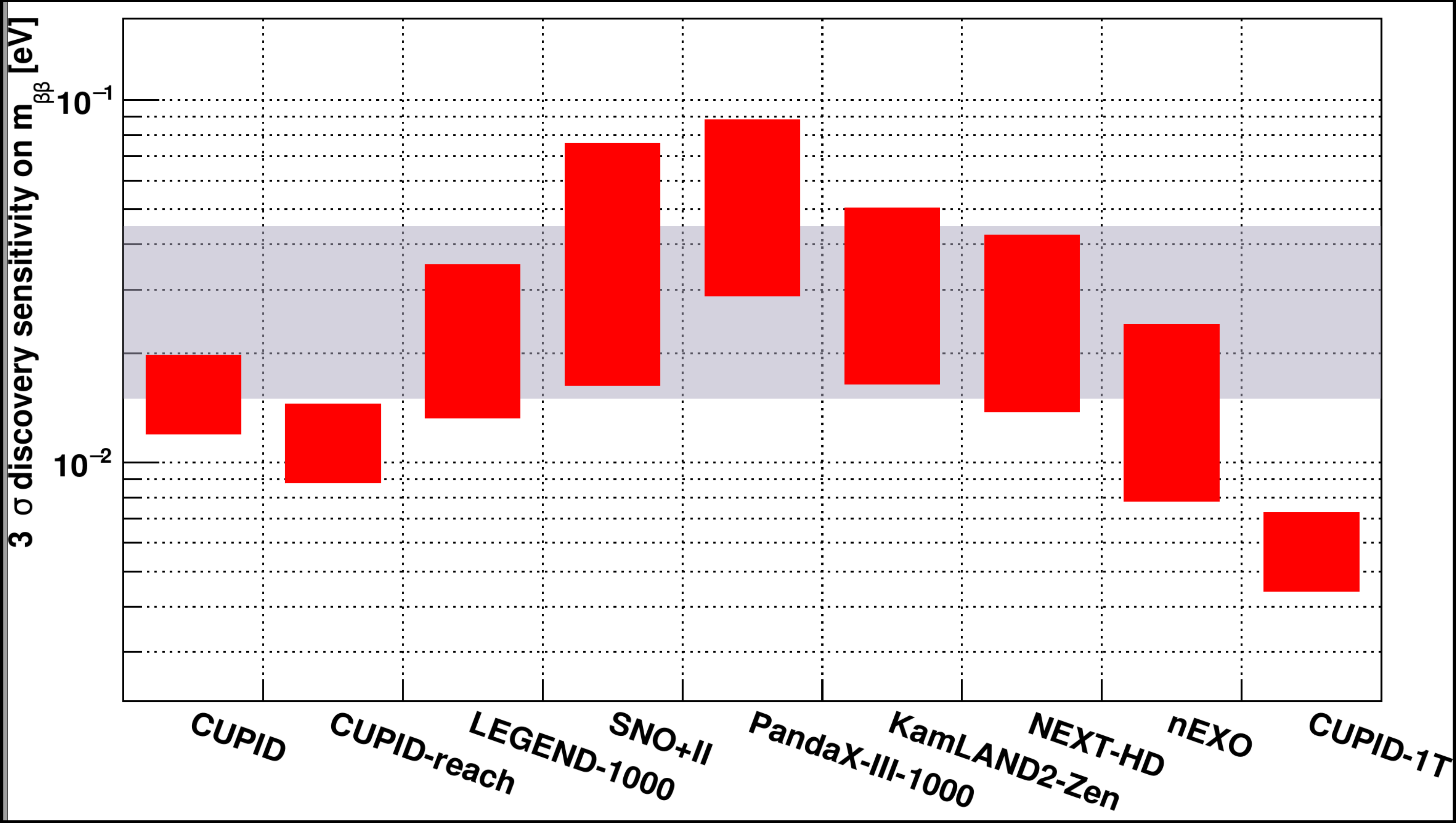
zero bkg condition ~ 2 10^{-5} c/keV/kg/y

CUPID1-ton = new 4 times larger cryostat

1 ton ^{100}Mo and (in case of discovery) other isotopes

bkg ~ 5 10^{-6} c/keV/kg/y

Sensitivity



Timeline, Cost & Future

TDR and construction readiness for end 2021

Schedule and budget will be driven by ^{100}Mo enrichment
~4 years

Modest cost, compared to the next-generation experiments with similar sensitivity.
enriched material < 20 Meuro

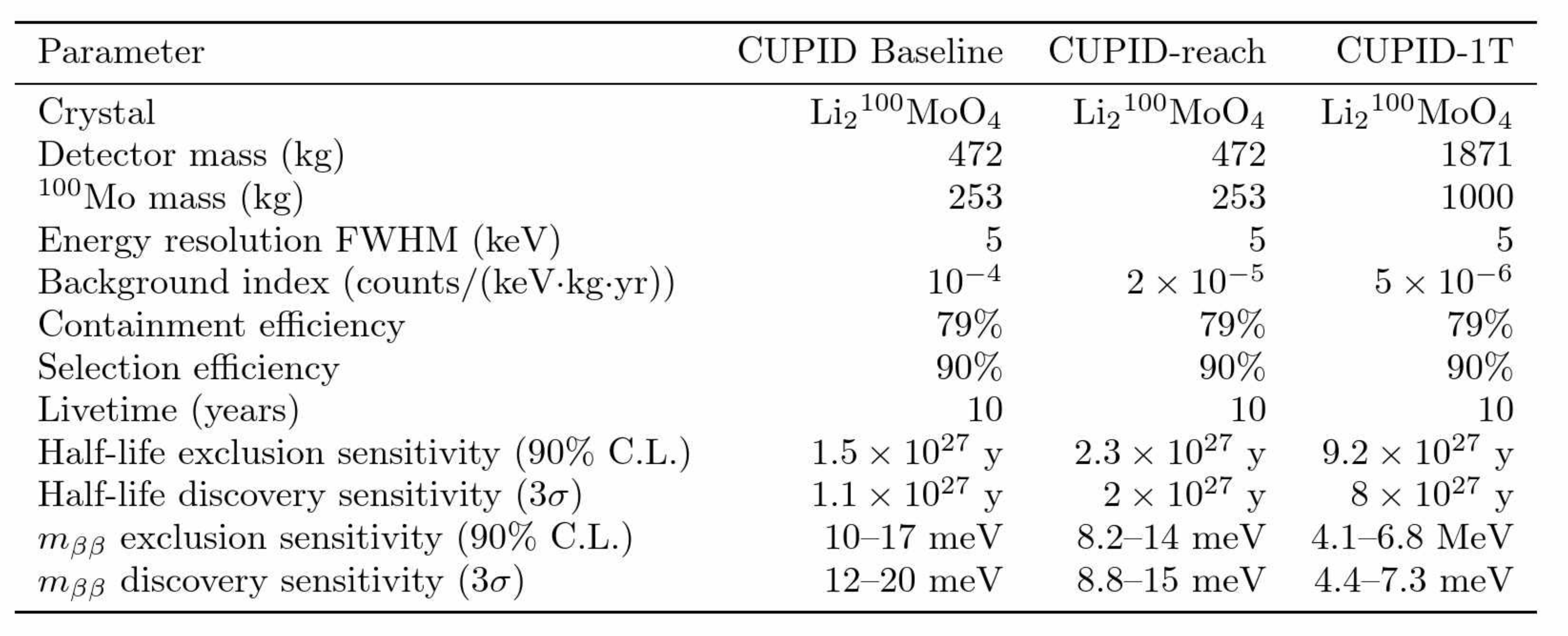
Future:

- Bkg reduction & mass increase is feasible
- real opportunity of exploring more isotopes with the same technique **Te**O_2 - Zn**Se** – Li_2**Mo**O_4 – **Cd**WO_4

Thanks

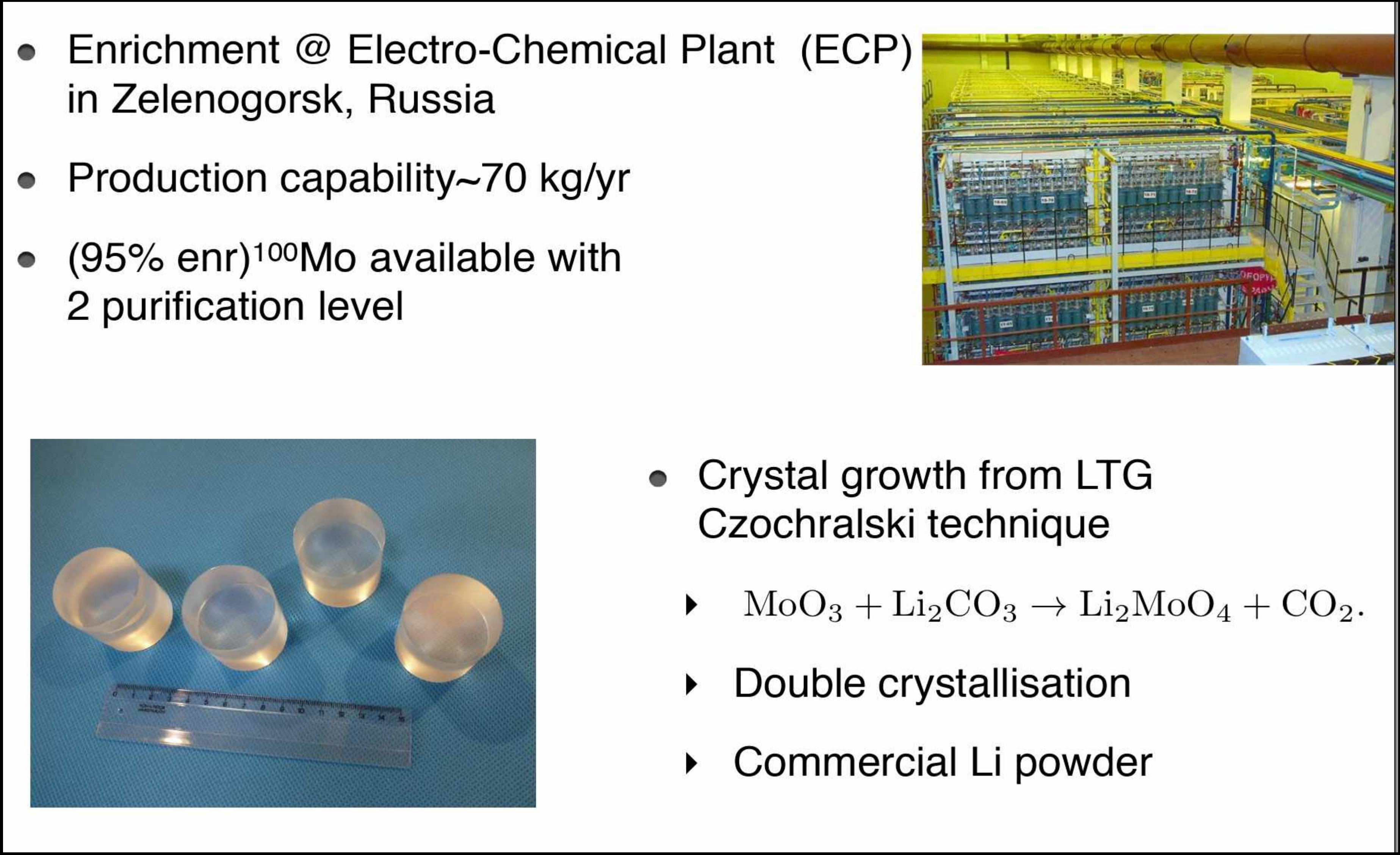
BACKUP SLIDES

CUPID sensitivity



Parameter	CUPID Baseline	CUPID-reach	CUPID-1T
Crystal	$Li_2{}^{100}MoO_4$	$Li_2{}^{100}MoO_4$	$Li_2{}^{100}MoO_4$
Detector mass (kg)	472	472	1871
^{100}Mo mass (kg)	253	253	1000
Energy resolution FWHM (keV)	5	5	5
Background index (counts/(keV·kg·yr))	10^{-4}	2×10^{-5}	5×10^{-6}
Containment efficiency	79%	79%	79%
Selection efficiency	90%	90%	90%
Livetime (years)	10	10	10
Half-life exclusion sensitivity (90% C.L.)	1.5×10^{27} y	2.3×10^{27} y	9.2×10^{27} y
Half-life discovery sensitivity (3σ)	1.1×10^{27} y	2×10^{27} y	8×10^{27} y
$m_{\beta\beta}$ exclusion sensitivity (90% C.L.)	10–17 meV	8.2–14 meV	4.1–6.8 MeV
$m_{\beta\beta}$ discovery sensitivity (3σ)	12–20 meV	8.8–15 meV	4.4–7.3 meV

Crystals & Enrichment



- Enrichment @ Electro-Chemical Plant (ECP) in Zelenogorsk, Russia
- Production capability~70 kg/yr
- (95% enr)^{100}Mo available with 2 purification level

- Crystal growth from LTG Czochralski technique
  - $MoO_3 + Li_2CO_3 \rightarrow Li_2MoO_4 + CO_2.$
  - Double crystallisation
  - Commercial Li powder