# Liquid

## R&D on 2β

**ββ meeting France @ APC (Paris)**

(Sept 2018)

**Anatael Cabrera**

CNRS / IN2P3 @ APC (Paris)

what's this?

# LiquidGov

(first ever presentation)

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# LiquidO stands for both…

**LiquidO** = **new detection framework**
(liquid scintillator based)

**LiquidO** = **international proto-collaboration**
(**physics** ↔ **demonstration⊕R&D**)

**~40 scientists ⊕ 16 institutions ⊕ 9 countries**
**[Brasil, Canada, Chile, France, Germany, Italy, Japan, Spain, USA]**

# R&D

# a ββ appetiser ahead…

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# not a ββ expert…

(the real experts: 5 labs in 3 countries)

# our motivation & goals…

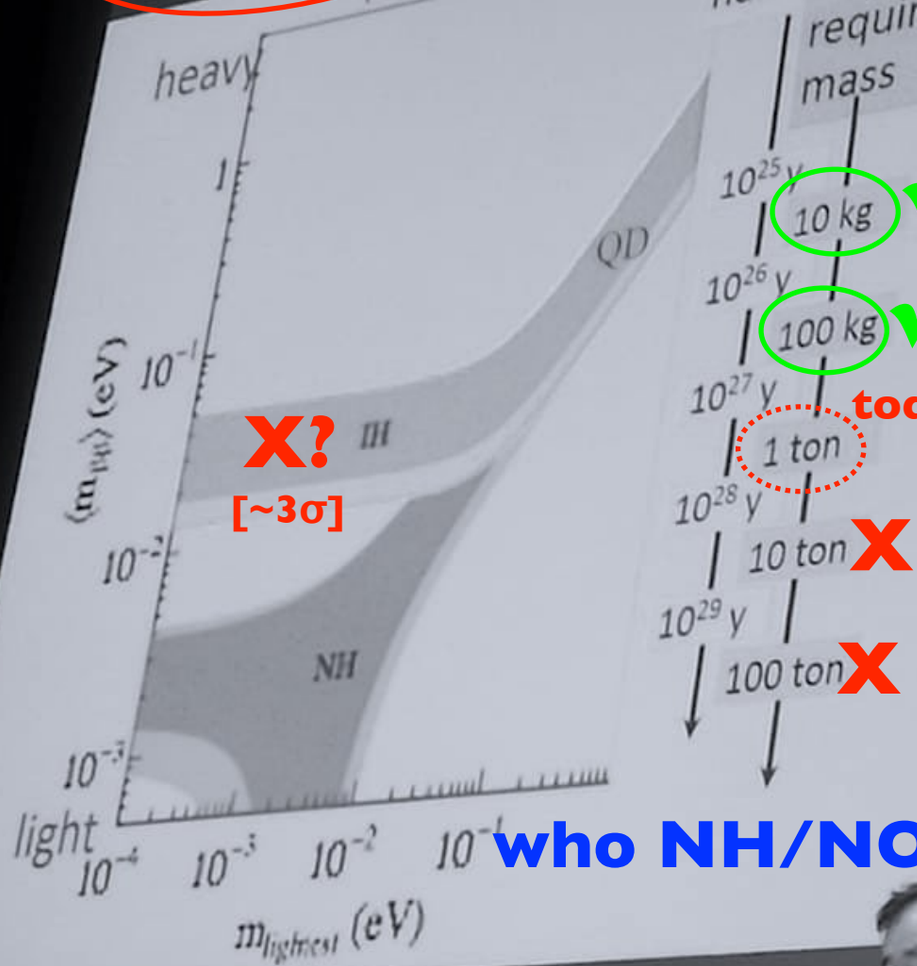
# LiquidO

# Kajita-san's (tough) view…

Liquid $0\nu\beta\beta$

## Toward NO

(K. Inoue, ICFA Seminar, 2017)




X? [~3σ]

approx. half lives




today's aim!

X

X

*If we want to cover most of NO, we need;*

- ✓ *~100 ton class detector,* ← ✓? **maybe?**
- ✓ *with reduced background* ← !!! **R&D**
  *(BG rate must be reduced by 1/mass·time or better),* ← ?
- ✓ ….

best results today!

*Because of the importance of 0νββ, I really think that the global neutrino community should work together, and find the best way to observe them.*

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**who NH/NO?**

can anybody reach ~100ton (isotopic)?


NEUTRINO 2018 Heidelberg 4–9 June

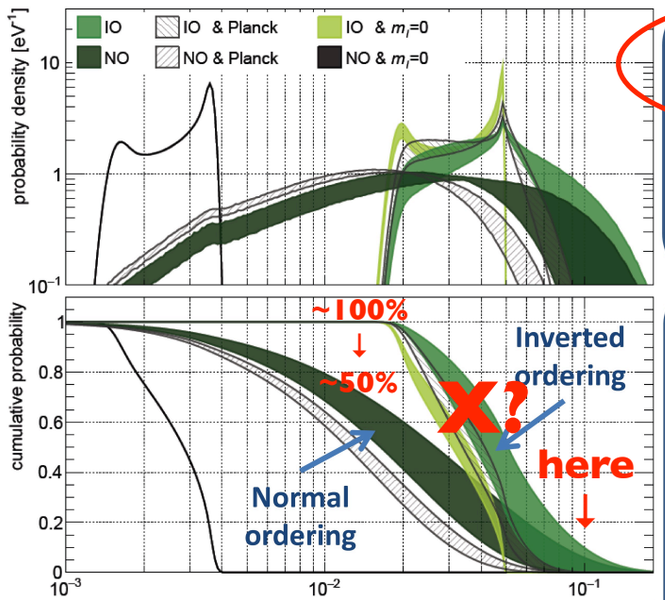
NEUTRINO 2018 Heidelberg 4–9 June

# Andrea's message @ Neutrino…

## $m_{\beta\beta}$ distribution in the parameter space

*Phys. Rev. D 96, 053001 (2017)*

**Probability densities and cumulative probabilities for $m_{\beta\beta}$**




Next-generation most promising experiments have a **high discovery potential**:
The **cumulative probability** for $m_{\beta\beta}$ to be higher than **20 meV** is
- **1** for Inverted Ordering
- **~0.5** for Normal Ordering

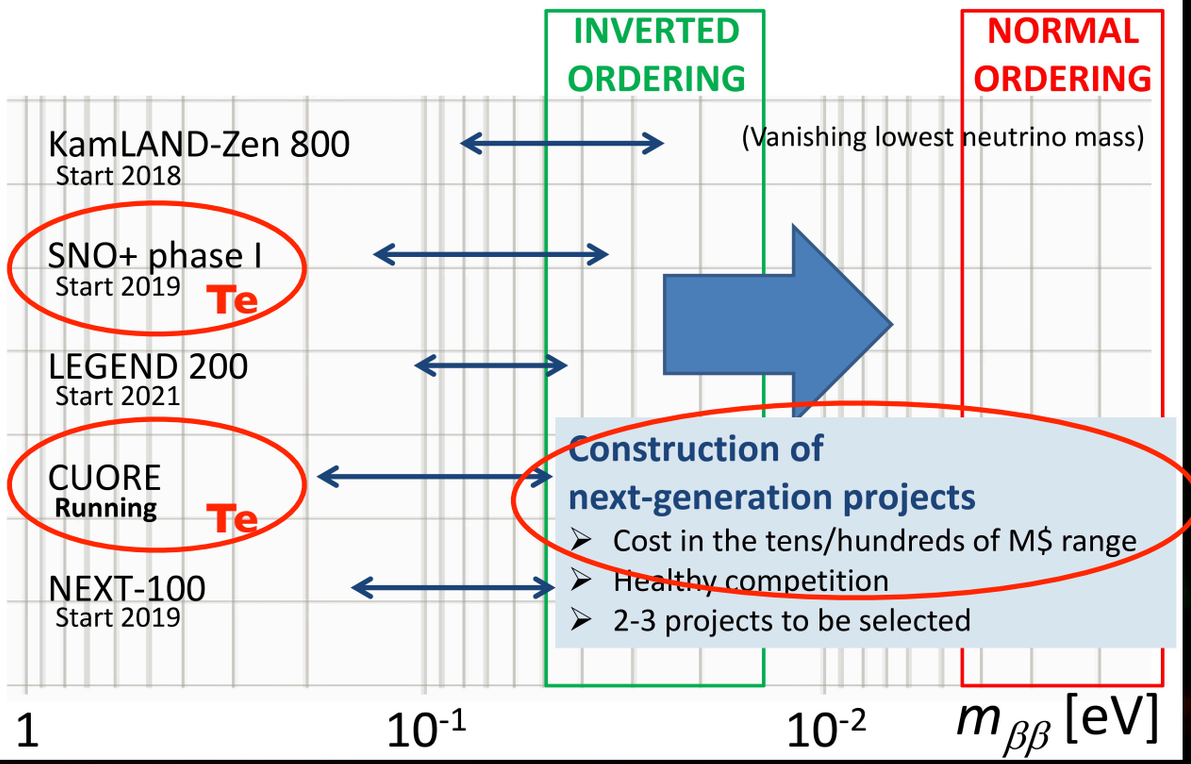
**Cosmology** has a relatively small impact on this scenario.

**$g_A$ quenching** has an important effect but not dramatic

**30% $g_A$ quenching** reduces the discover potential by
- **~15%** for Inverted Ordering
- **~25%** for Normal Ordering

## Possible scenario in 2024

Considering running or well advanced projects (for results, funding and infrastructures)




**1ton** **100ton**

**(if not IO/IH) at IO/IH lower bound ~50%**
[a non-existing ~10ton technology to be half-way?]

**(worse) 1ton costs ≥[10,70]M€**
[most based on enrichment >90%]

**(together)**

**a 10ton programme ~500M€**

[only "half way through"]

(problem) a single experiment cannot provide a "certain discovery" (need 2x)

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# a different way…?

- huge mass capability (no enrichment)
- powerful PID & exquisite radio-purity
- accurate BG model prediction (“BG redundancy”)
- excellent energy resolution (2$\beta$2$\nu$)
- “signal redundancy” → discovery vs new BG?

(only easy to say)

# take the challenge…

# Liquid $^{136}$Xe

(how far?)

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# our (new) detector first…

# LiquidGov

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# liquid scintillator state of the art…

**“perfection” since Reines&Cowan…**

- exquisite **radio-purity**
- **scintillation PSD** (“some” **PID**)

**at the expense…**

- **buffer volume** (PMT’s poor radio-purity)
- **PID loss? [this talk]**

**PMT**($\sim$ 1ns) $\Leftrightarrow$ **Transparency** $\Longrightarrow$ ~~**PID**~~**?**

**CTF @ Gran Sasso**
(Borexino R&D)

# an Opaque solution…?

# why "poor" PID?

**no PID** (beyond PSD) implies

**γ ≈ e⁻ ≈ e⁺ ≈ α ≈ p-recoil (fast-n)**

**PMT** ↔ medium **transparency** → **little PID**

↓

**σ(time)≳1ns ⇔ σ(space)≳20cm [unresolvable]**

↓

**σ(vertex)≈10cm [individual vertex]**

**liquid → (easy) loading BUT breaks transparency**

if **PID** implies

**γ ≠ e⁻ ≠ e⁺ & e⁺≠ (α & p-recoil)**

# Opaqueness corollary…

**PMT** (precious technology from 30's)…

but

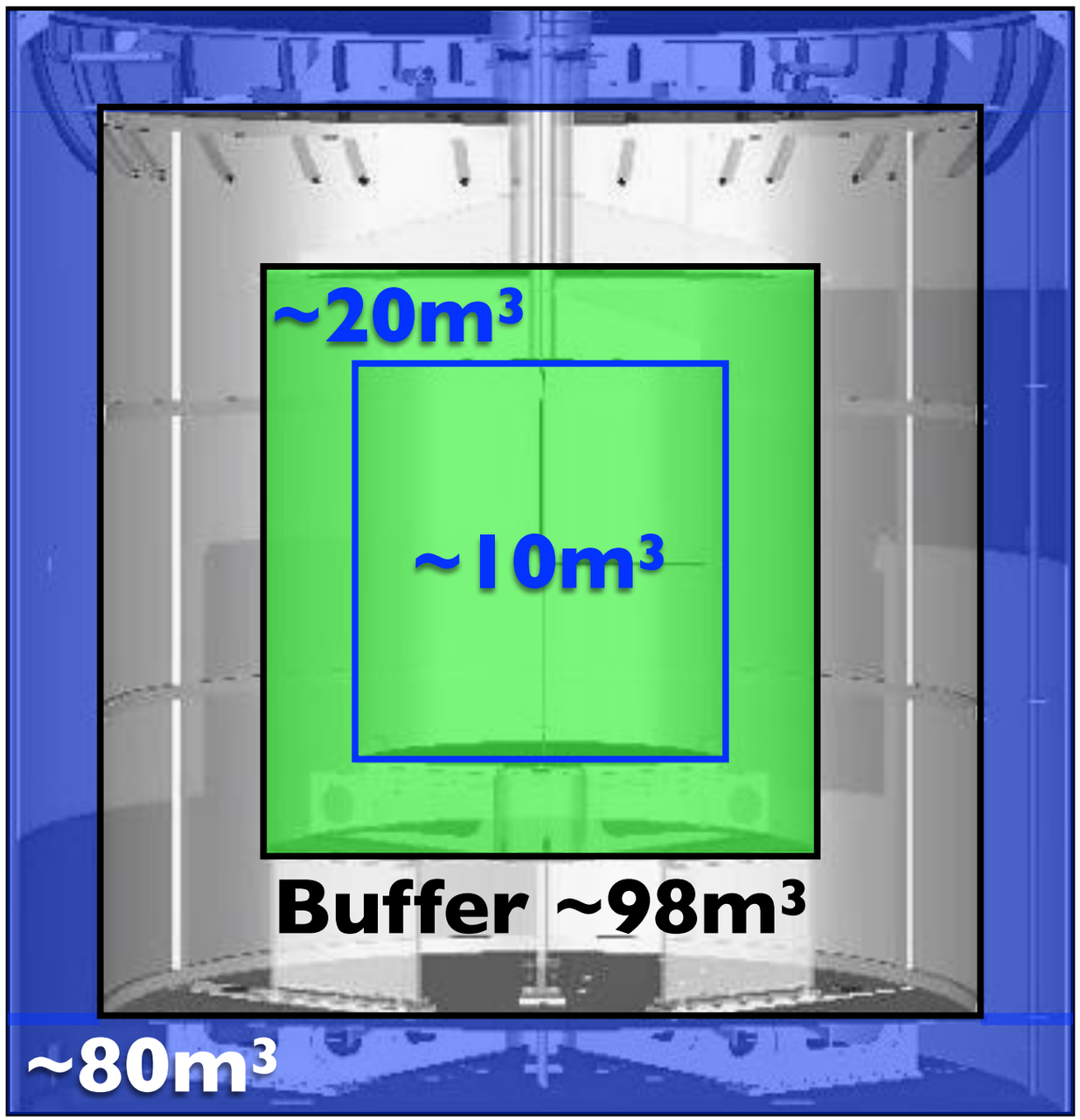
- **slow** (TTS ≥ 1 ns/PE)
[SiPM: 0.1 ns/PE]

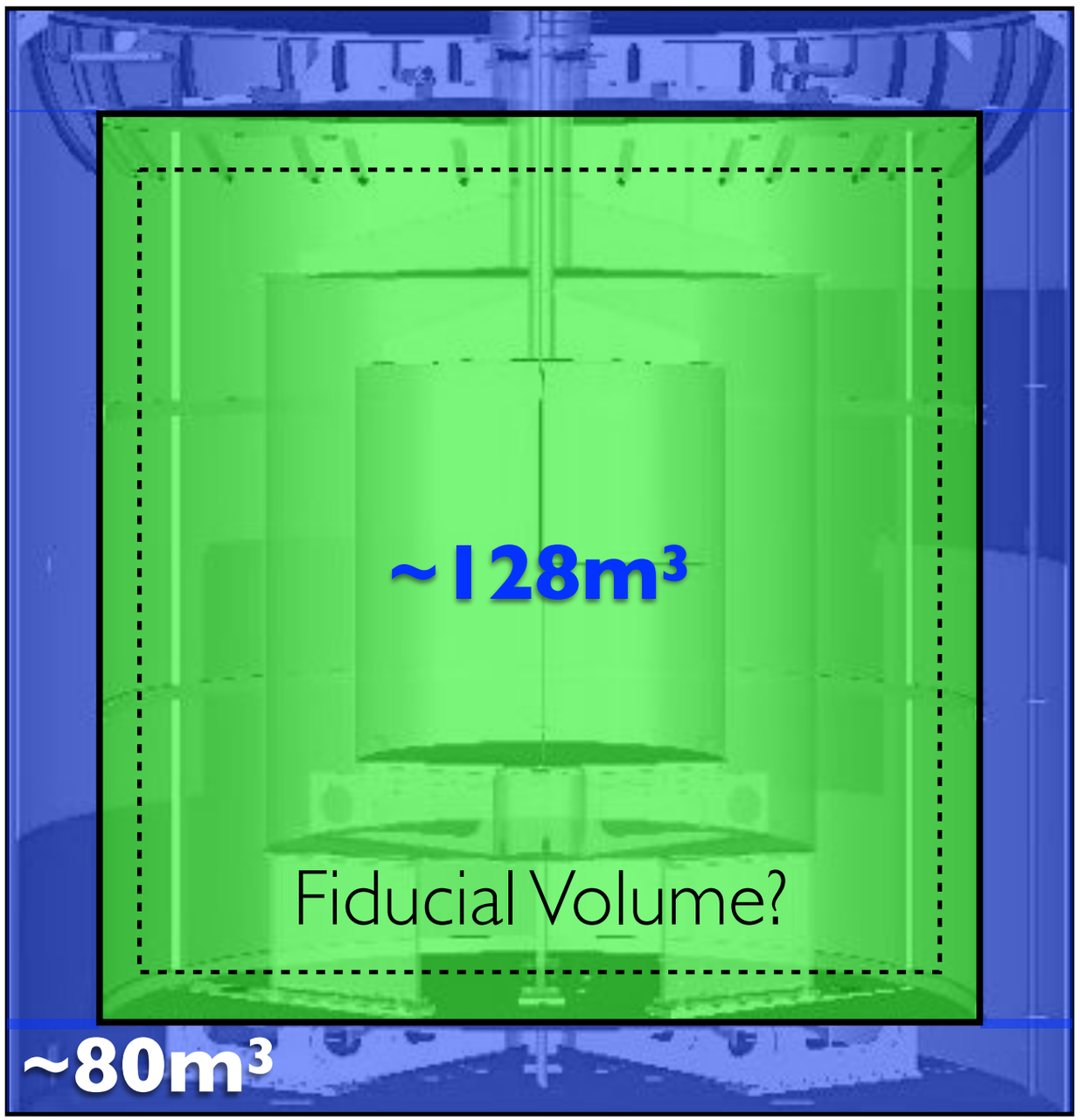
- **low-ish QE** (≤30%)
[SiPM: ≤60%]

- **radio-active**
[buffer → ≥50% volume]

# no PMTs→ more volume…

## Double Chooz: **buffer:detector 3:1**




## (1kton case) KamLAND: buffer:detector 2:1

# Liquid

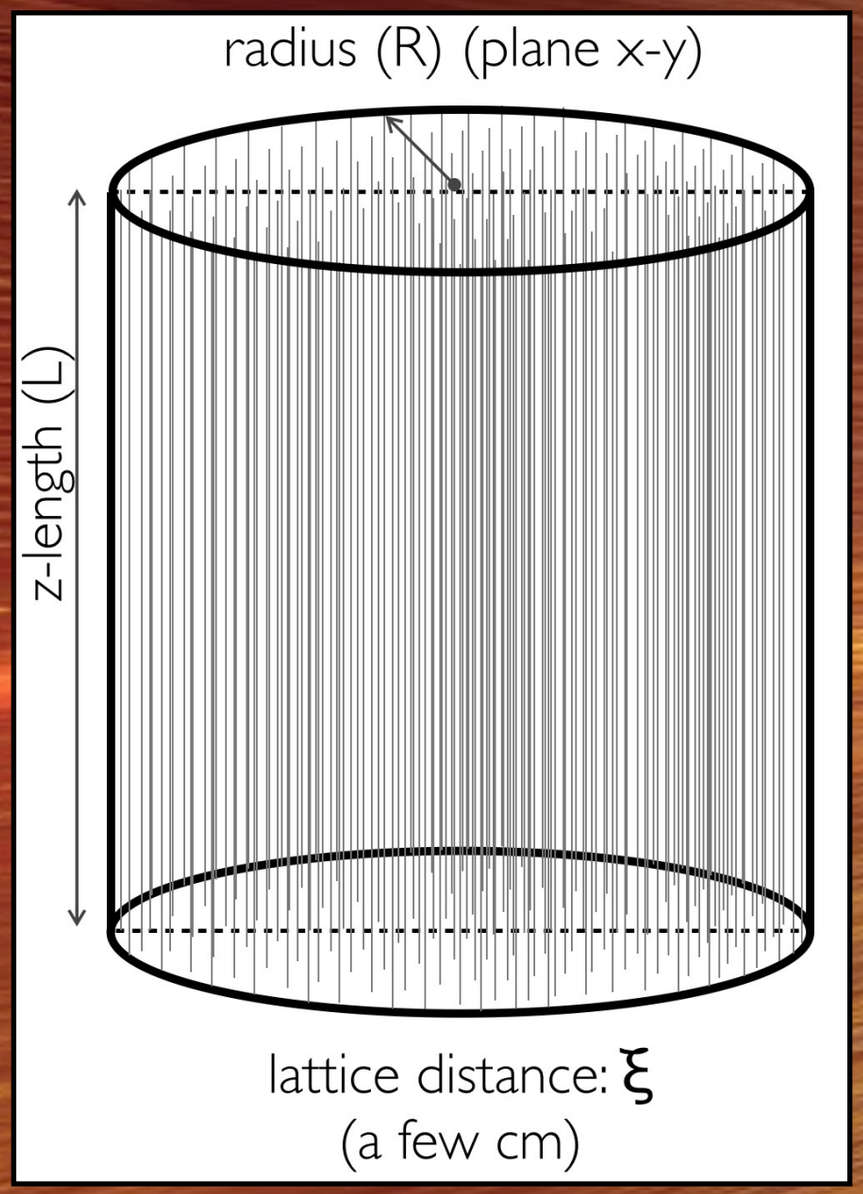
(first) **ν** opaque detector?

**liquid~wax behaviour**

# in reality, more like this…

# designing *LiquidO*: 3D info…

very simple: **fibres** (a lot) + **LS**



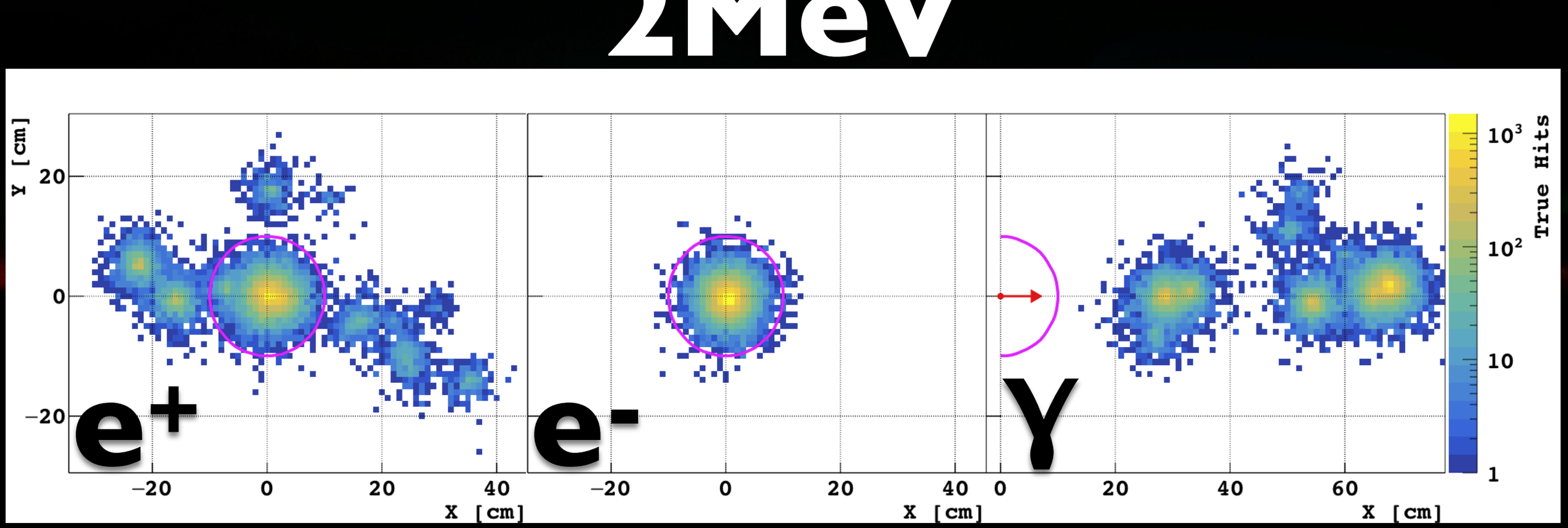

**(x,y) info** [lattice ξ]→ **image pixelation** (up to ~1 cm)
**(z) info** [along fibre]→ **time difference** (up to cm's)
(also z-pixelation possible→ envisaged for R&D)

**image: multi-wire chambe**
(by G. Charpak @ CERN)

# stunning event-pattern...

# powerful PID expected…

**2MeV**




(rather evident)

# powerful PID expected…

(evident)

# **doping:** beyond native-ness…

# isotope loading: w/wo enrichment…

**isotopic loading (% or kg/kg$^{LS}$)**

**isotopic fraction (abundance)**

| $m^{iso}$(kg) [V=128m$^3$] | **0.1** 1g/l | **0.5** 5g/l | **1.0** 10g/l | **5.0** 50g/l | **10.0** 100g/l | **50.0** 250g/l | **100.0** 1000g/l | |
|---|---|---|---|---|---|---|---|---|
| **1.0** **Cd** | 1.0 | 5.1 | 10.2 | 51.2 | 102.4 | 512 | 1024 | → 2β(+) |
| **5.0** **Nd** | 5.1 | 25.6 | 51.2 | 256.0 | 512.0 | 2560 | 5120 | → 2β(-) |
| **10.0** **Se, Xe, Cd** | 10.2 | 51.2 | 102.4 | 512.0 | 1024 | 5120 | 10240 | → 2β(-) |
| **34.0** **Te only** | 34.8 | 174.1 | 348.2 | 1741 | 3482 | 17408 | 34816 | → 2β(-) |
| **50.0** | 51.2 | 256.0 | 512.0 | 2560 | 5120 | 25600 | 51200 | |
| **90.0** **enriched** | 92.2 | 460.8 | **921.6** | 4608 | **9216** | 46080 | 92160 | |
| | ↓ Double Chooz | ↓ SNO+ | | | ↓ LENS & SNO+ R&D (done) | | ↓ **new R&D** | |

massive loading capability (**R&D**)⇒ **no enrichment!**

[natural abundance **≤100€/kg** vs **enriched ≥10k€/kg** or **≥10M€/ton**]

# back to the challenge…

# LiquidGov

# let's consider each…

- huge mass capability (no enrichment)
- powerful PID & exquisite radio-purity
- accurate BG model prediction ("BG redundancy")
- excellent energy resolution ($2\beta2\nu$)
- "signal redundancy" → discovery vs new BG?

# large isotopic mass…

# LiquidO's multi-tone ββ loading strategy…

| detector size | | 100m³ | | | | 3000m³ | |
|---|---|---|---|---|---|---|---|
| isotopic ton | | 0.1 | 1.0 | 10.0 | 100.0 | 100.0 | 1000.0 |
| enriched | mass | 0.1ton | ~1ton | 10ton | 100ton | 100ton | |
| | loading | **0.1%** | **1.0%** | **10.0%** | **100.0%?** | **3.3%** | |
| | cost | [1,5]M€ | **[10,50]M€** | **[100,500]M€** | **[1,5]G€** | **[1,5]G€** | |
| $^{nat}$Te | mass | 0.3ton | 2.9ton | 29ton | 290ton | 290ton | 2900ton |
| NA($^{130}$Te):33.8% | loading | **0.3%** | **2.9%** | **29.0%** | **290%** | **10%** | **100%?** |
| | cost | [2.9,29]k€ | [29,290]k€ | [0.3,2.9]M€ | [2.9,29]M€ | [2.9,29]M€ | [29,290]M€ |
| $^{nat}$Nd | mass | 1.8ton | 17.9ton | 179ton | | 1790ton | |
| NA($^{150}$Nd):5.6% | loading | **1.8%** | **17.9%** | **179%** | | **60%** | |
| | cost | [20,200]k€ | [0.2,2.0]M€ | [2,20]M€ | | [20,200]M€ | |
| $^{nat}$Cd | mass | 8.3ton | 83.3ton | | | | |
| NA($^{106}$Cd):1.2% | loading | **8.3%** | **83.3%?** | | | | |
| | cost | [83,833]k€ | [0.8,8.3]M€ | | | | |
| sensitivity | | ruled out | ~10 bound | Normal Ordering exploration | | | |

**R&D Te & Nd by SNO+**

**Te & Se?/Mo?→ 10ton** (DC-like detector)

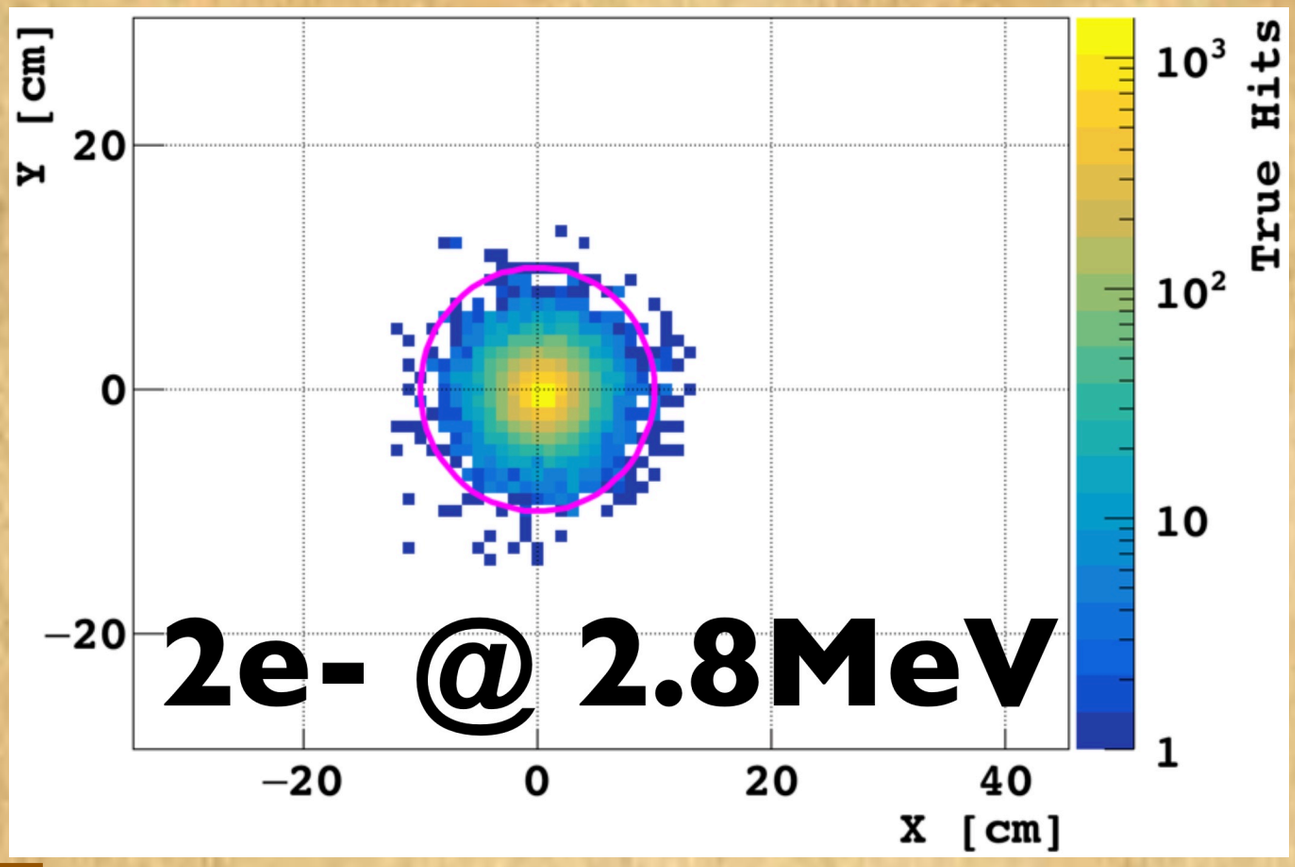
**Te & Nd→ several 100ton** (KLZ/SNO-like detector)

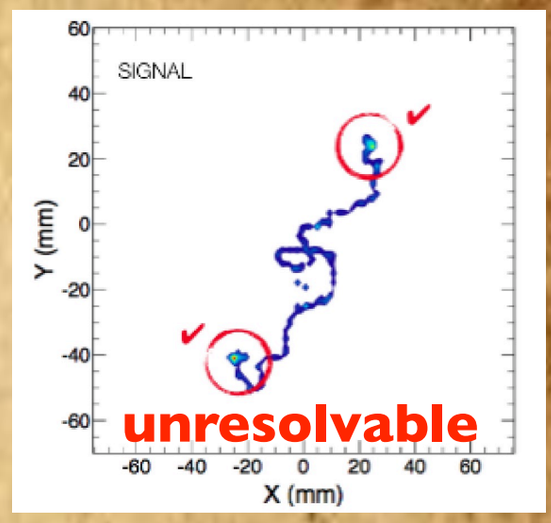
preliminary costing is promising thanks to the **large enriched costing**

# radio-purity ⊕ PID ⊕ BG...

# WANTED

## DEAD OR ALIVE

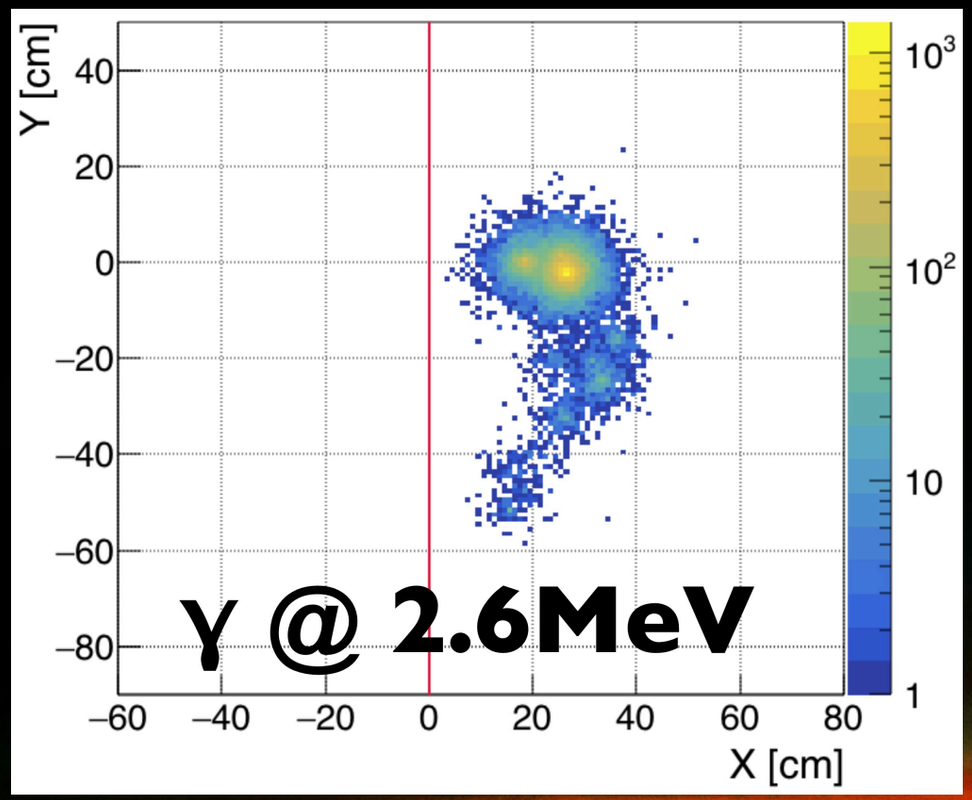


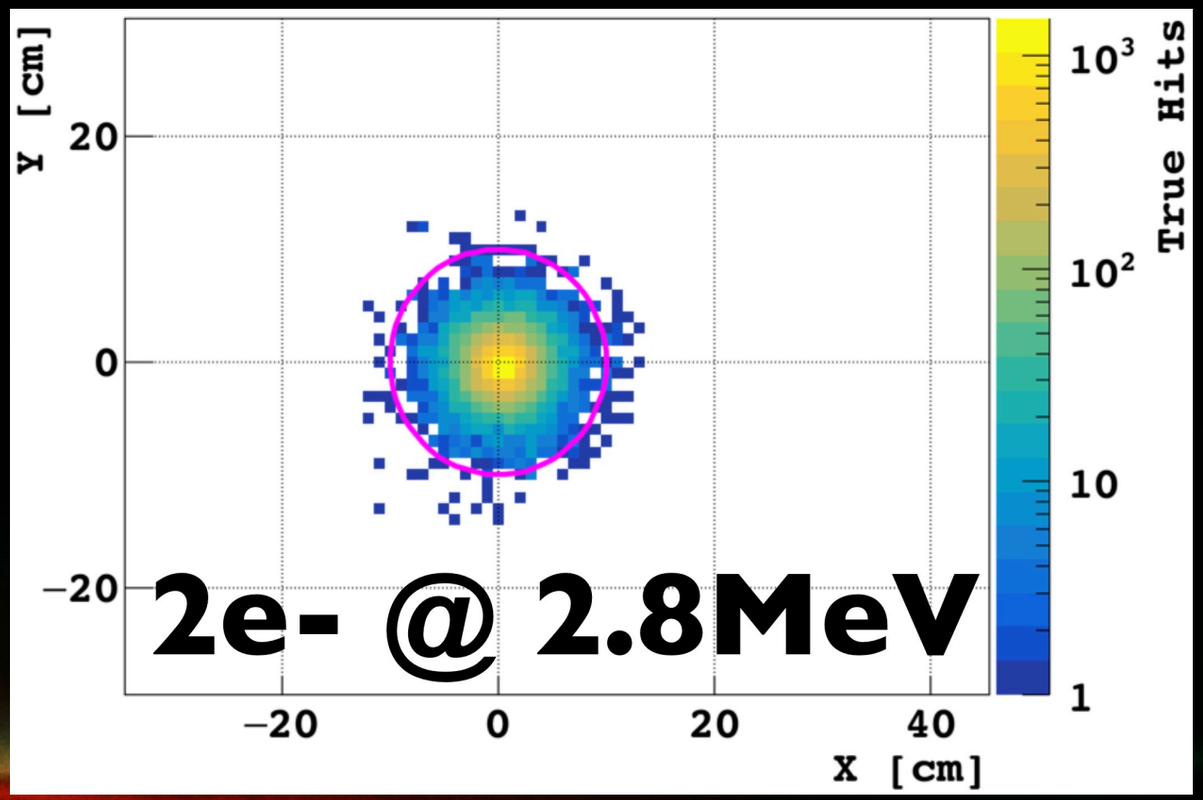




**REWARD** unprecedented neutrino physics!!

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# the main enemies…




## non point-like

**natural radio-activity (γ)**
- internal & external $^{208}$Tl and $^{214}$Bi

**→PID reduced & acceptance [next]**

**•no(?) exotic γ decays (no enrichment)**

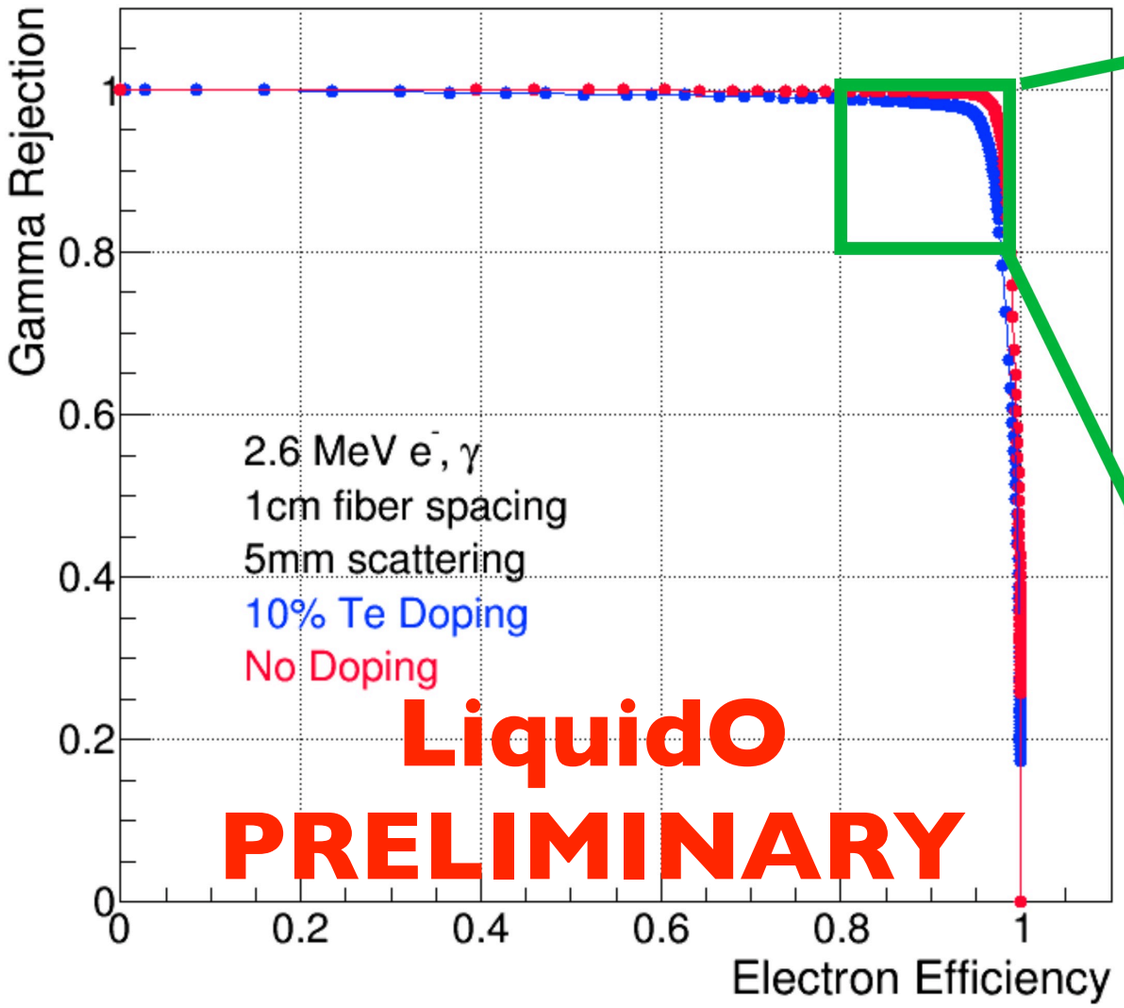
## point-like

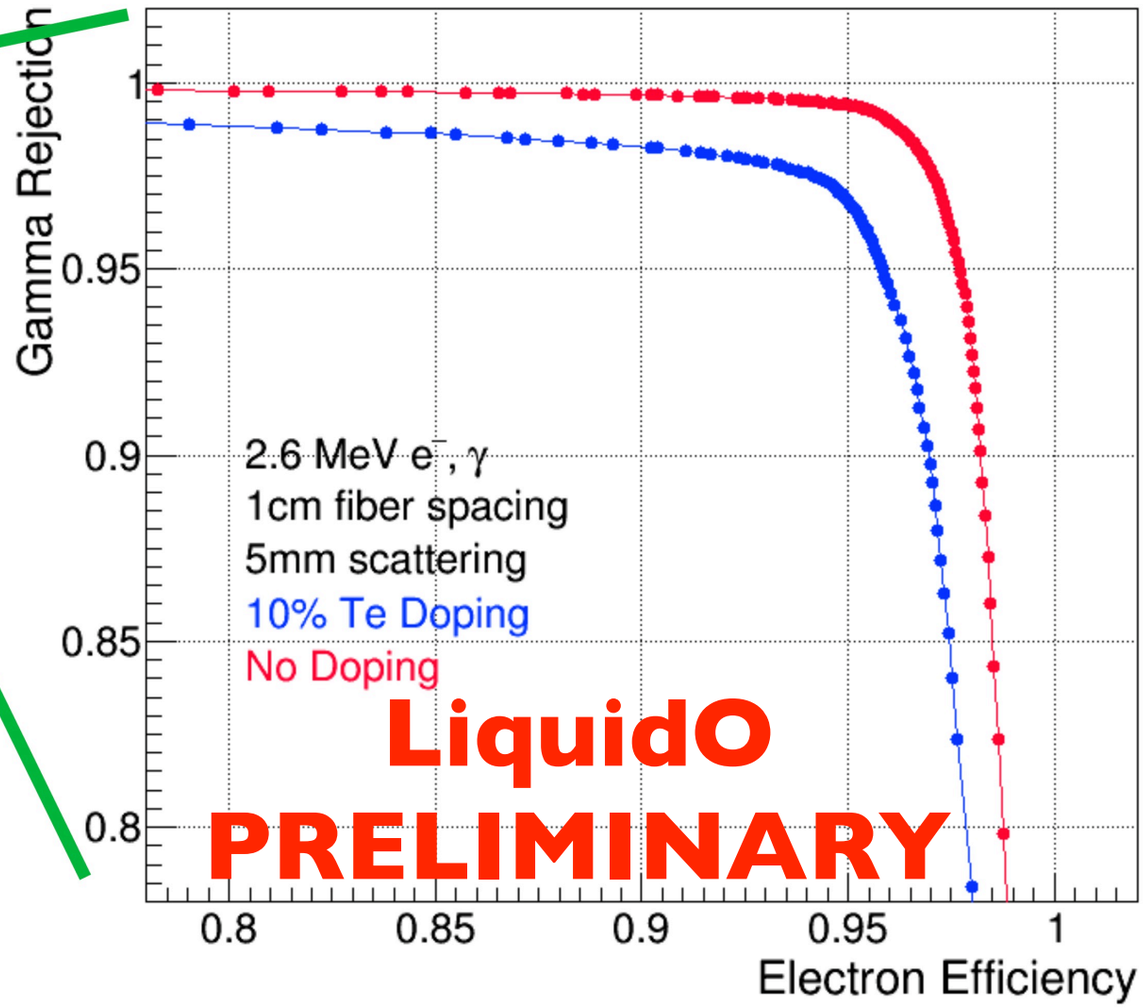
**natural radio-activity (e-) or 2β2ν**
internal & irreducible

**no(?) α-BG**
α-response quenched ≤1MeV
[cross-check Ge or Bolometers]

**no(?) Rn**
hermetic solidified scintillator
(no liquid convection)

# PID(e⁻:γ) ⟹ γ rejection…



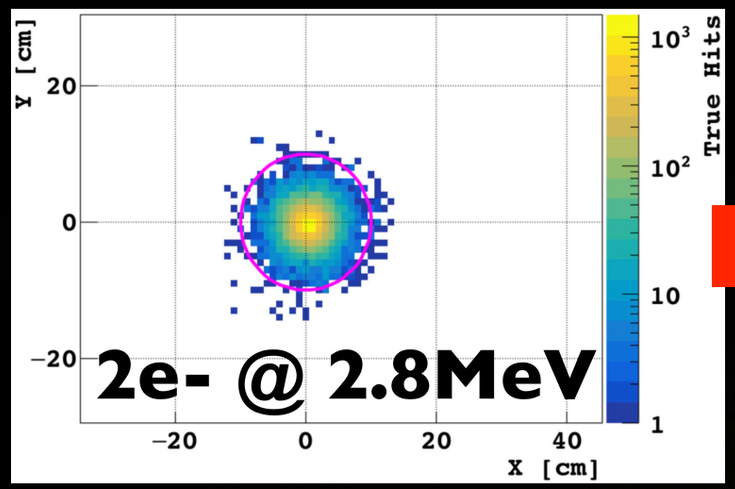

**PID γ:e⁻ separation**

- **1:≳10³ (native)**
- **1:≳10² (10% heavy loading)**

**[@ 80% detection efficiency]**

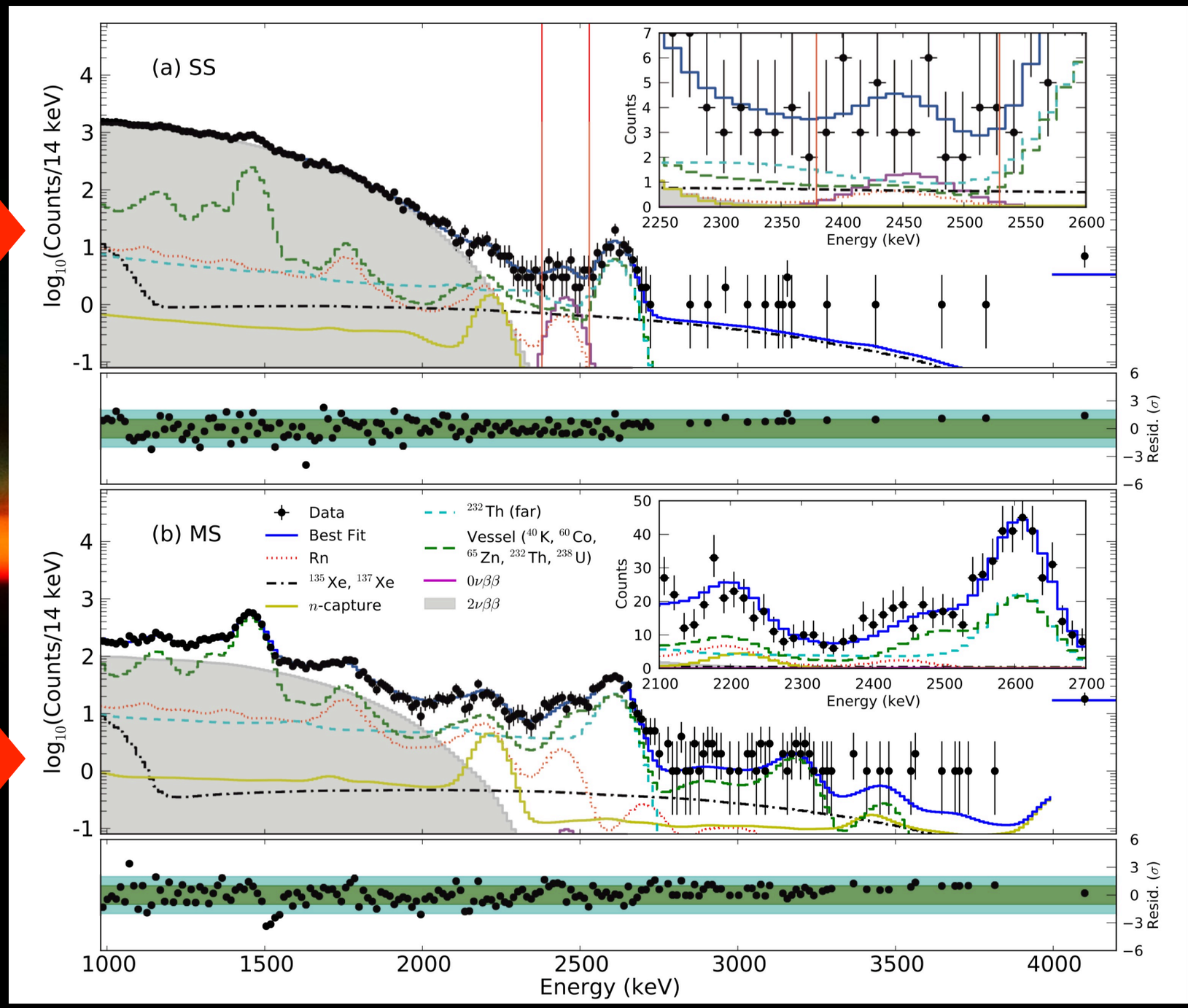
**unprecedented (major) γ-rejection! (≳100)**

# data-driven BG model prediction (like EXO)…










**rejected γ's: predict BG-model(e-) & efficiency (ββ2ν)**

**scintillator** → R&D Borexino ✓

⊕

**fibres** → R&D GERDA ✓**?**

**(under study)**

⊕

~~**photo-detector**~~ (**outside!**) ✓

⊕

**Te** → R&D SNO+/CUORE ✓**?**

or

**Nd** → R&D SNO+ ✓**?**

# only natural radioactivity

[no enrichment → less contamination risk?]

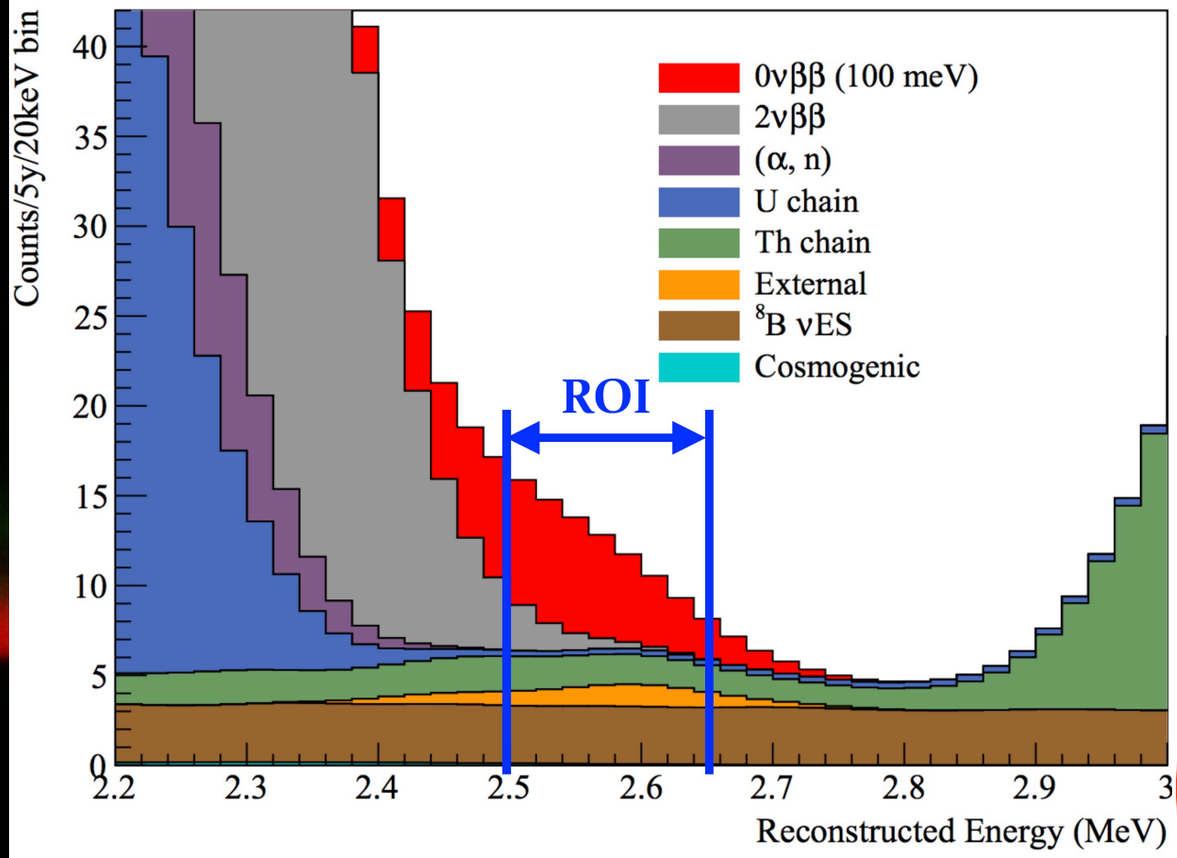
# GERDA's fibre curtain…

fibres are rather ok!! **good enough?**

**(under estimation)**

# LiquidO-ββ(Te) = SNO+ ⊕ fibres ⊕ PID…

## SNO+ Spectrum

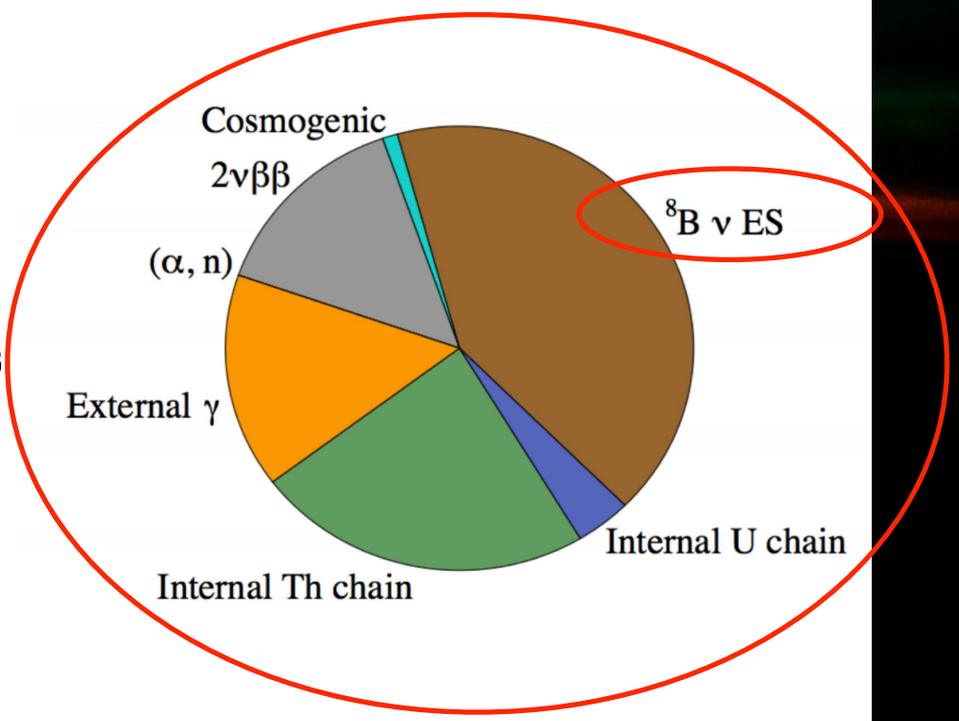



**Detector configuration:**

0.5% natural Te

5 years live time

3.3m fiducial volume (17%)




**ROI: -0.5 - 1.5 σ (2.49-2.65 MeV)**

**Predict 12.4 counts/yr in yr 1**

**~$10^{-6}$/keV.kg.yr**

LiquidO-ββ(Nd) = SNO+(R&D-Nd) ⊕ fibres ⊕ PID

**[potentially more BG robust via Q-value]**

# energy resolution?
(like KLZ or SNO+)

**7%@1MeV→4%@3MeV**
[LiquidO expected ≤400PE/MeV(max)]

# 2β2ν not a show-stopper
[sensitivity demonstrated]

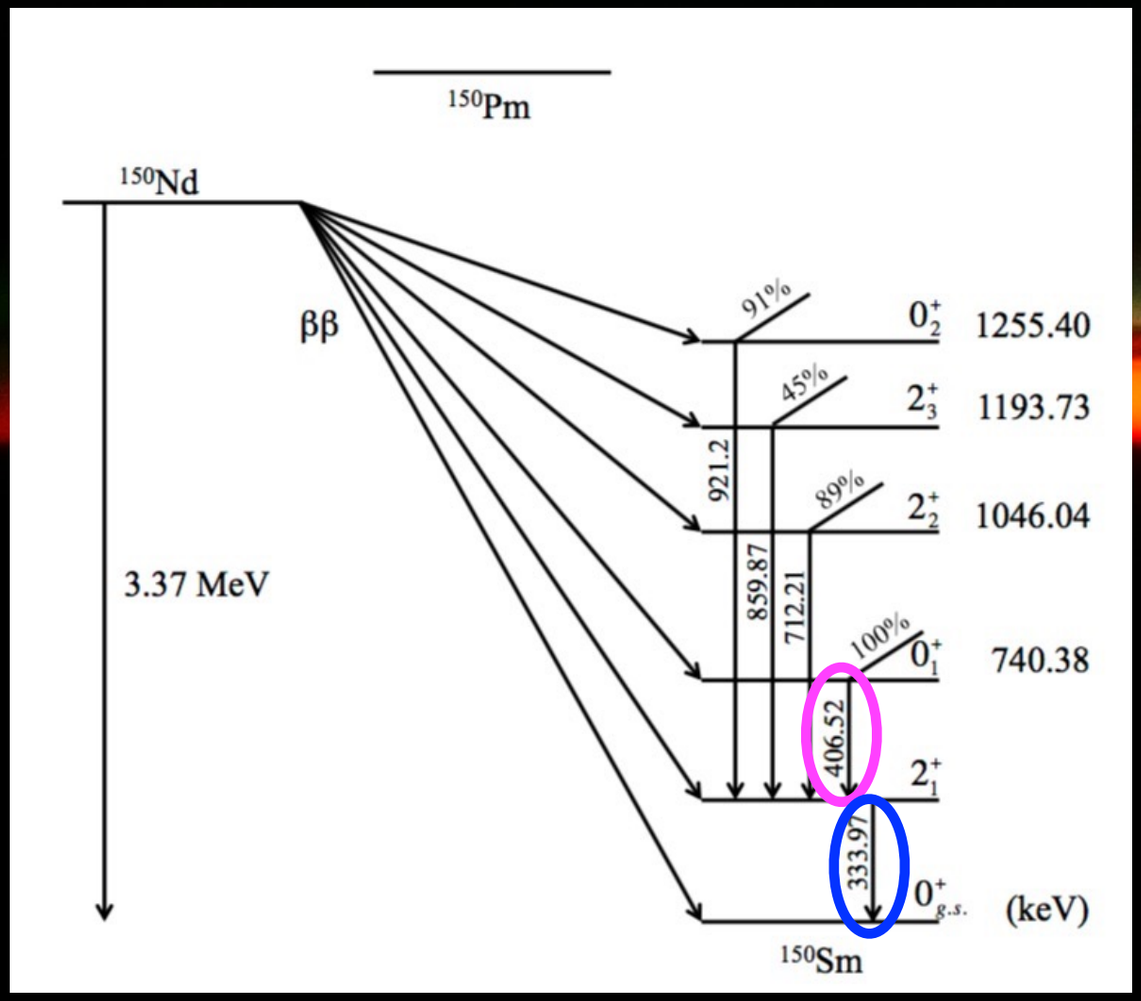
# signal redundancy…

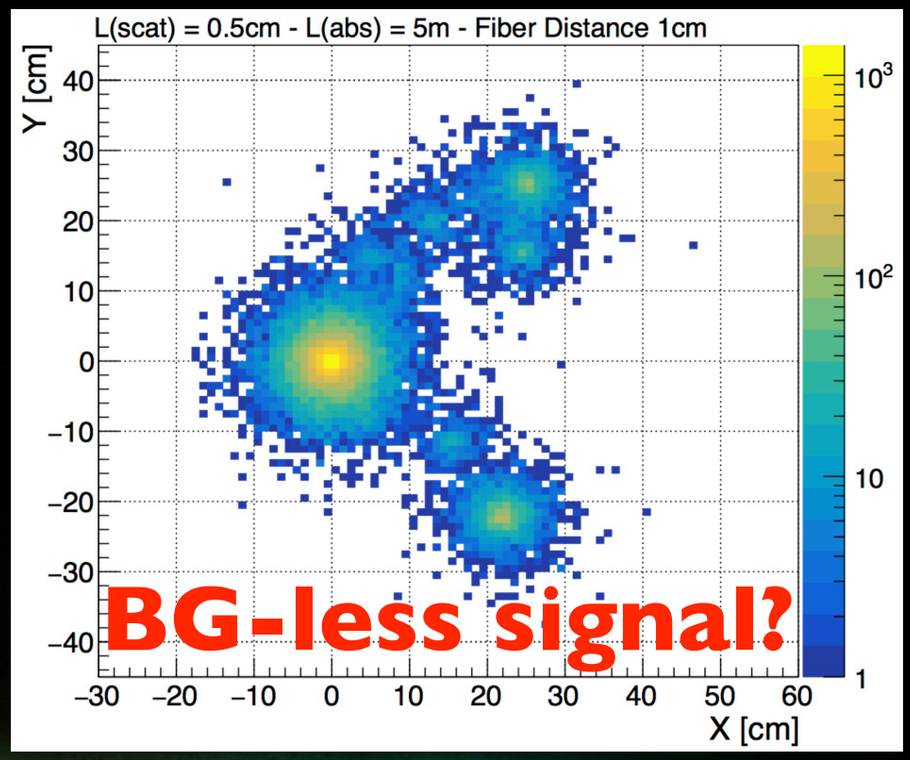
# both Te and Nd excited decay…

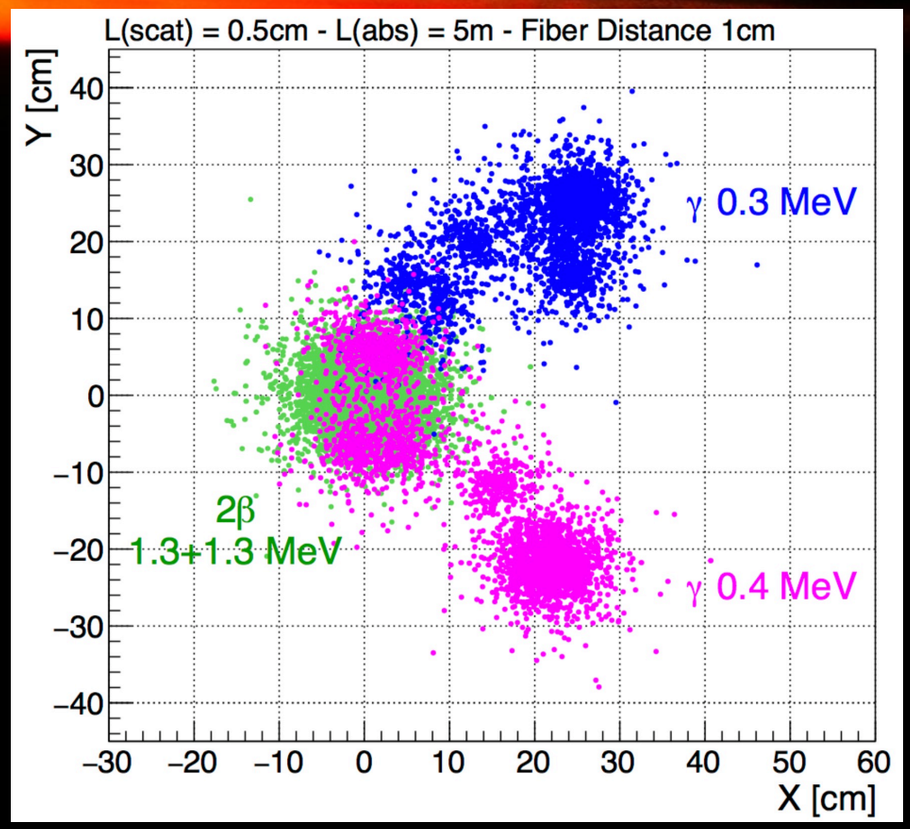
**ββ [E = Q(3370keV) - E(γ1) - E(γ2)]**

**γ1 (~406 / ~712 / ~859 / ~921)keV**

**γ2(~334keV)**



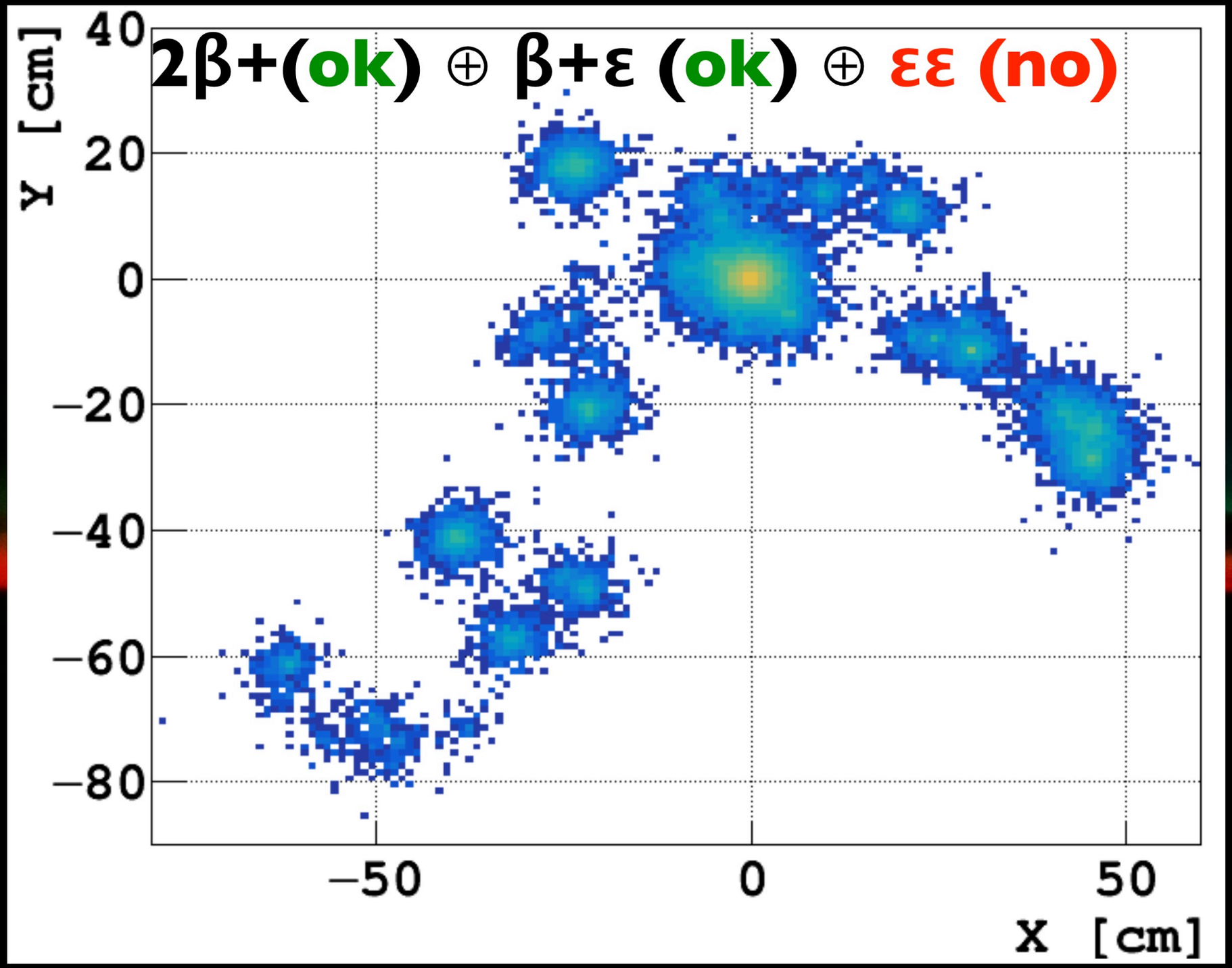




**if discovery→ internal validation!**

(same detector ⊕ same Q-value ⊕ **different BG**)

# powerful searches for 2β+ too? ($^{106}$Cd)




impractical for 2β0ν searches (unless high mββ)

# LiquidO-ββ under-definition…

vintage⊕new ideas

past⊕new R&D

LiquidO

*Anatael Cabrera (CNRS-IN2P3 & APC)*

# exploring potential R&D…

- ✓ **huge mass capability** (→ enrichment cost impractical)
- ✓ **powerful PID** [full reconstruction → better?]
  - ?? exquisite radio-purity potential → **good enough?**
  - ✓ **BG redundancy** → accurate BG model prediction & control
- ✓ modest energy resolution (→ $2\beta2\nu$ seems acceptable)
- ✓ **unique signal redundancy** → discovery ambiguity

# full sensitivity (not yet)…

**≥100ton potential needed for NO**

(BG will tell if possible)

(BG evaluation)

# what to remember?

# LiquidGov

# R&D

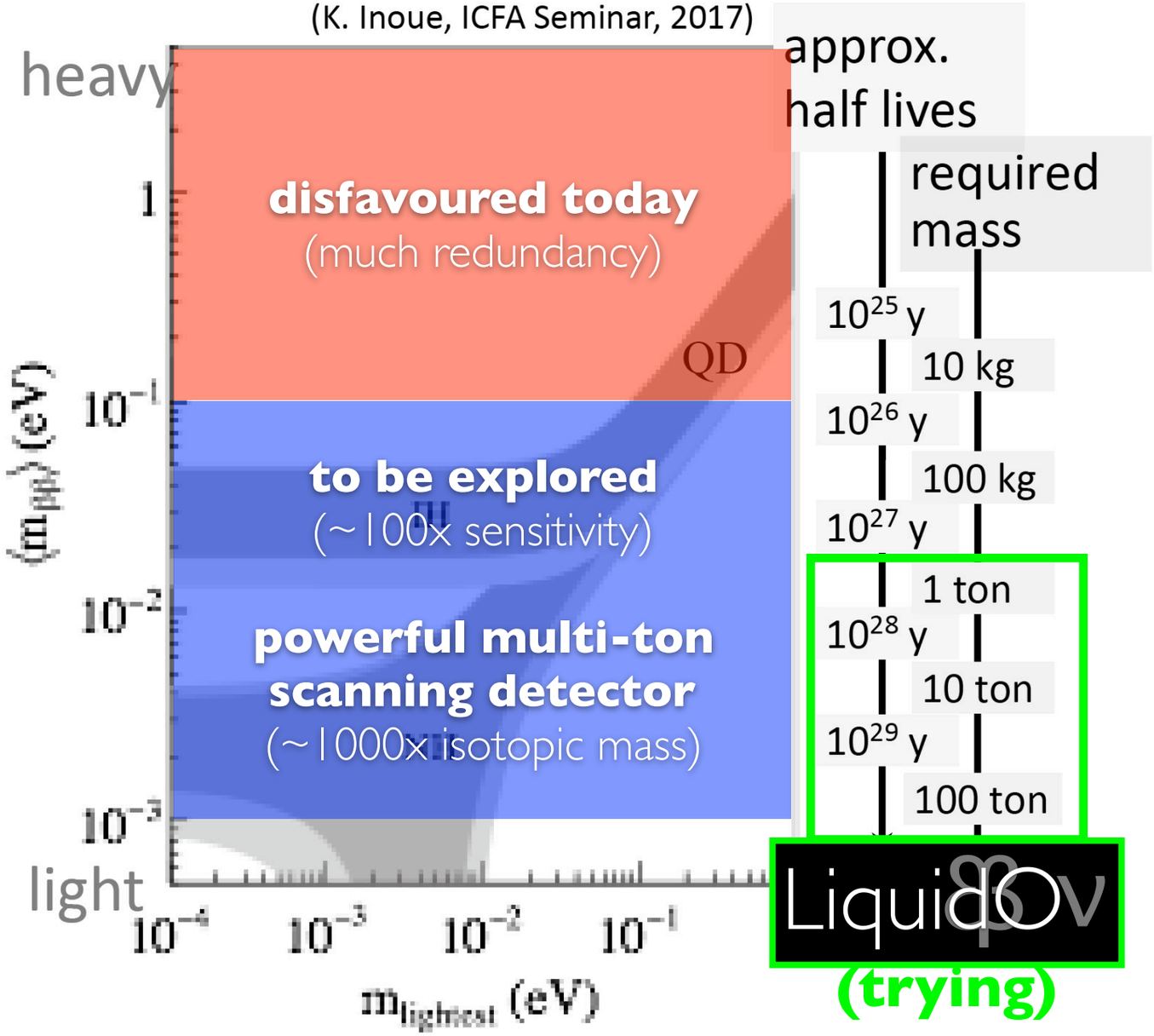
more soon…

# a vast scale in ββ phase-space…

## Toward NO

NEUTRINO 2018 Heidelberg 4–9 June

(K. Inoue, ICFA Seminar, 2017)




If we want to cover most of NO, we need;

- ✓ ~100 ton class detector,
- ✓ with reduced background (BG rate must be reduced by 1/mass·time or better),
- ✓ ….

Because of the importance of 0νββ, I really think that the global neutrino community should work together, and find the best way to observe them.



**phase-I: vast exploring machine** (LHC-like; i.e. not a "Ferrari") → **LiquidO pragmatic enough?**]

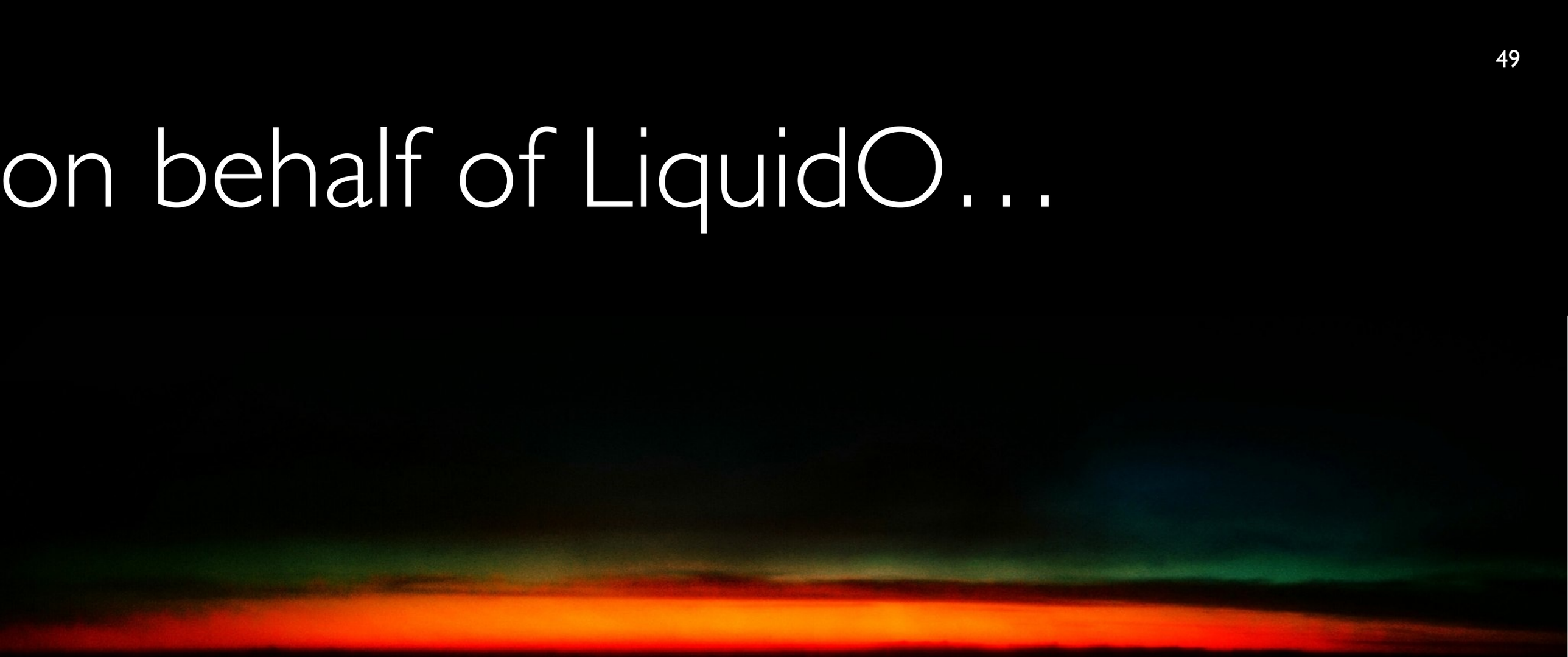
**phase-II: upon discovery** → high precision on signal (LEP-like) → **the ultimate "Ferrari"?**

# the first ≥ 10ton detector R&D…?

# LiquidO

(no competition → 1ton must happen)

# on behalf of LiquidO…



# thank you…