

Liquid

... $\beta\beta$ detection potential



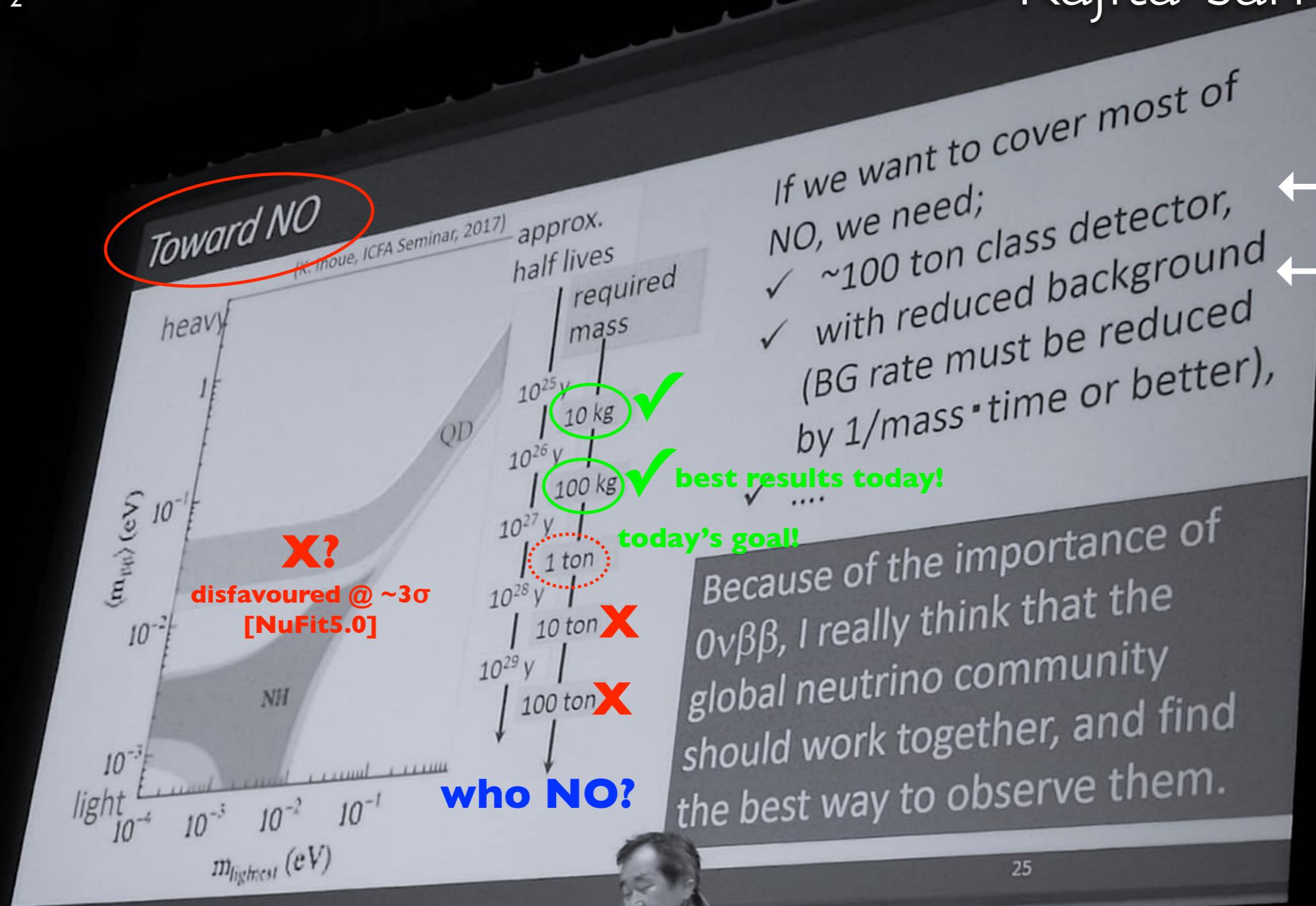
$\beta\beta$ -FR-II @ IJCLab (Orsay)

16th October 2020

Anatael Cabrera

CNRS/IN2P3
IJCLab (Orsay)
LNCA (Chooz)

Kajita-san's view...



reach ~100ton (isotopic)?

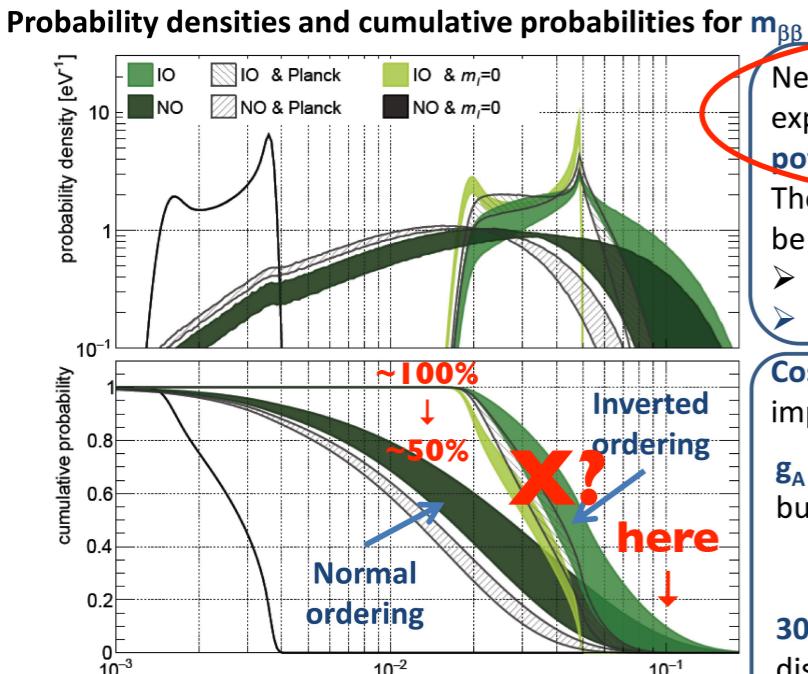
Because of the importance of $0\nu\beta\beta$, I really think that the global neutrino community should work together, and find the best way to observe them.

25



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

Phys. Rev. D 96, 053001 (2017)



Agostini et al

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

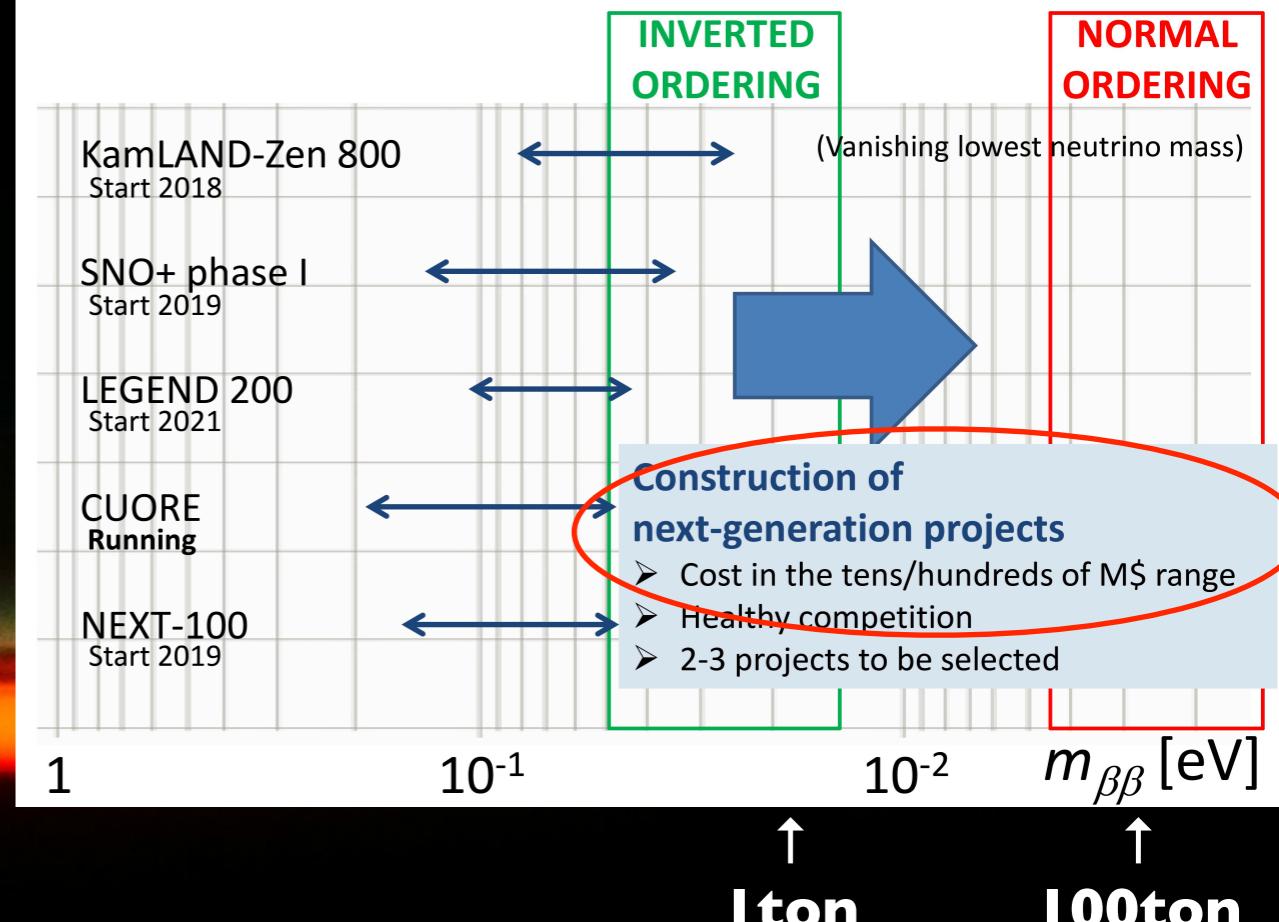
Cosmology has a relatively small impact on this scenario.

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)



(if not IMO) at NMO lower bound ~50%

[a “non-existing ~10ton technology” to be half-way?]

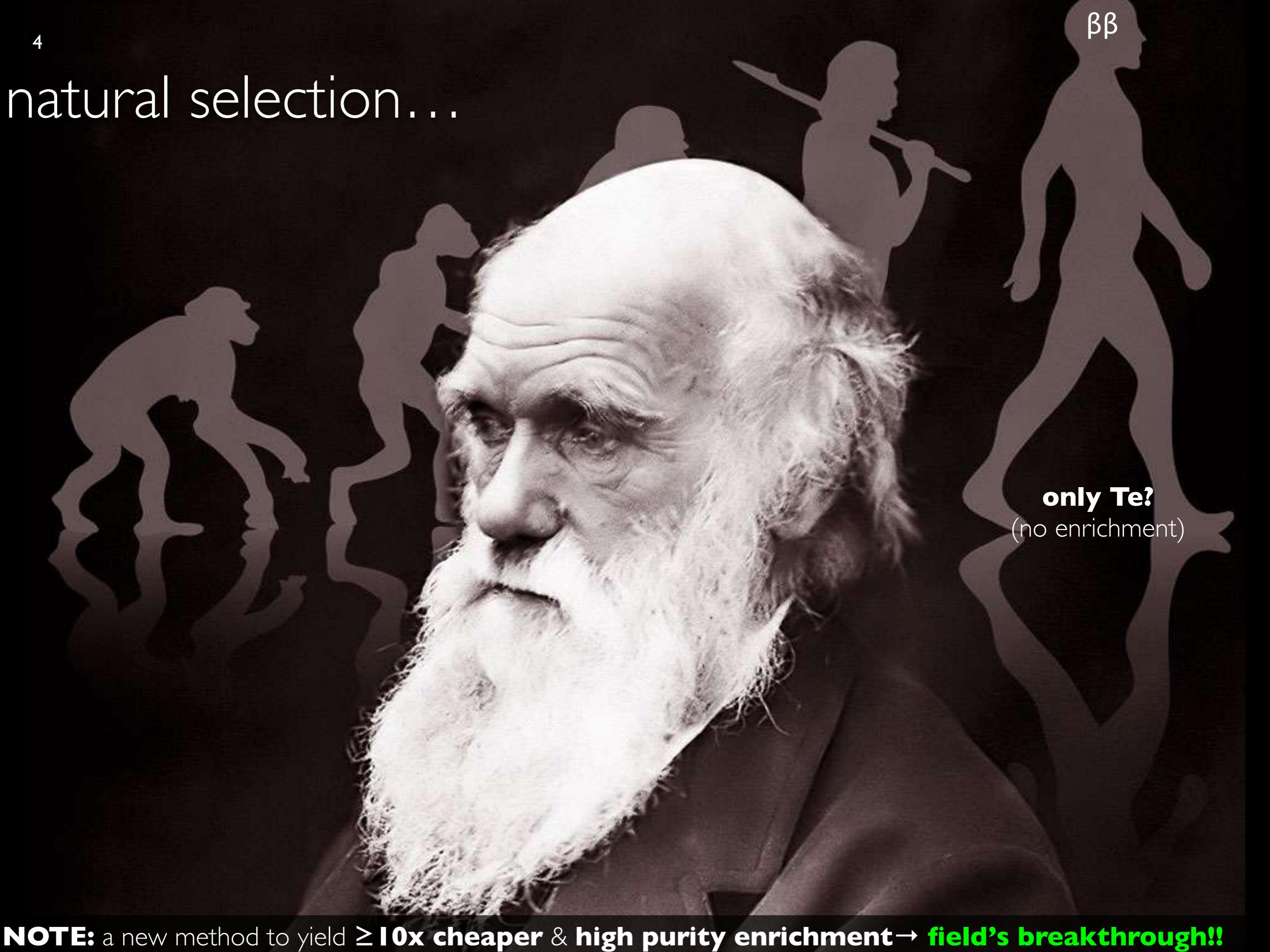
(worse) 1ton costs ≥[10,70]M€

[due to enrichment >90%]

(together)
a 10ton programme >100M€
[only “half way through”]

(worse²) one single experiment cannot provide a “certain discovery” (need 2x?)

natural selection...



only Te?
(no enrichment)

NOTE: a new method to yield $\geq 10x$ cheaper & high purity enrichment → field's breakthrough!!

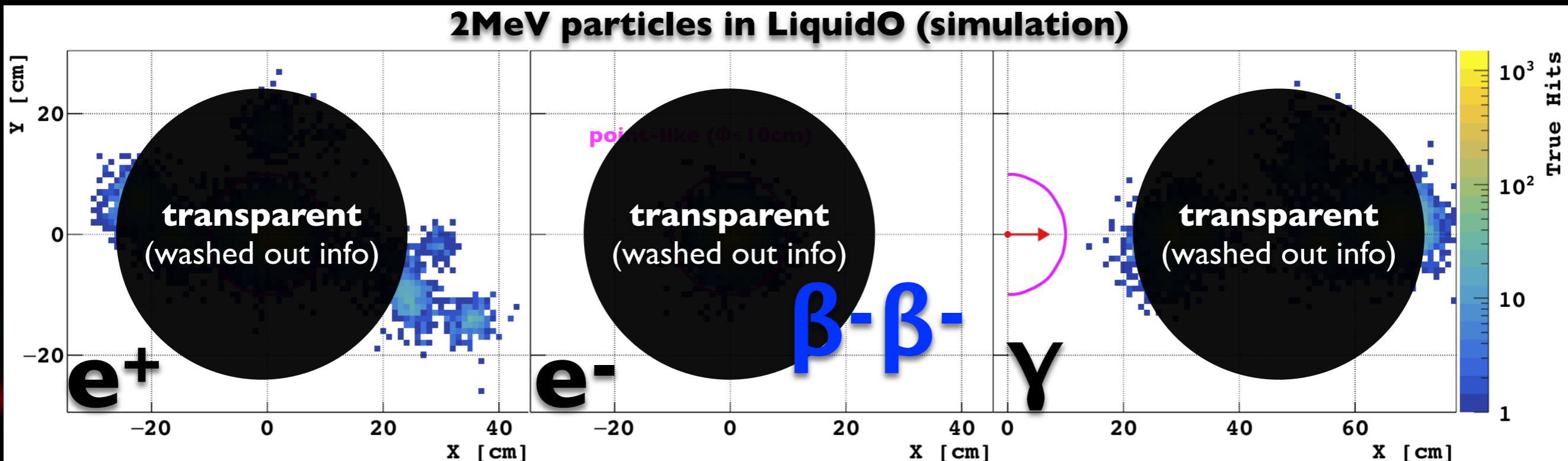
liquid scintillator technology: **transparency...**

huge isotopic mass potential

PMT[⊕]Transparency \Longrightarrow **no PID!**

LiquidO in a nut-shell...

powerful imaging → Particle-IDentification (PID)



LiquidO \approx PID \oplus (high) Doping!

physics beyond detector “native composition” (H,C)

diffusion \Rightarrow shap images!

an **Opaque** solution to $\beta\beta\dots?$

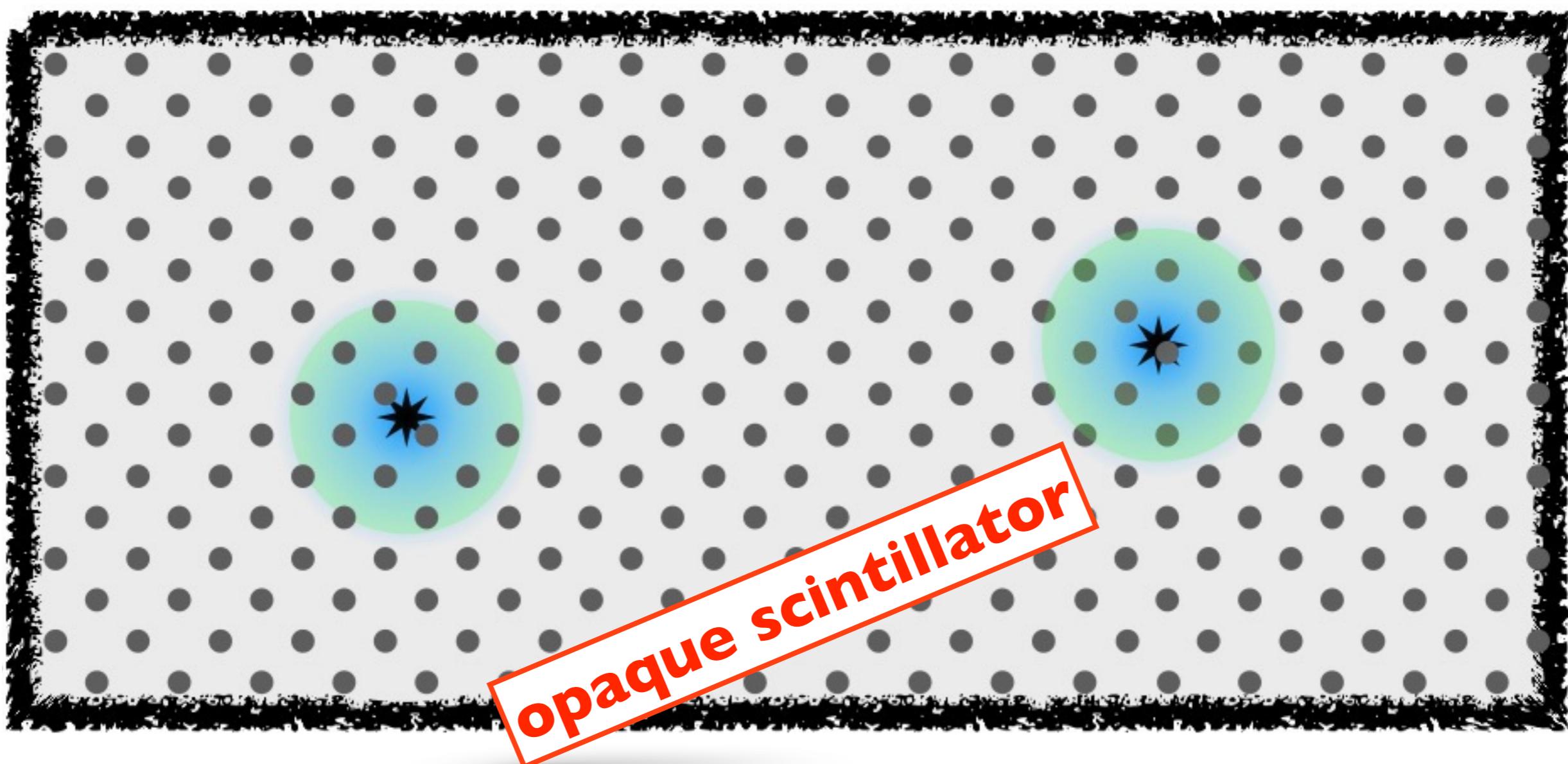
Liquid β ov

CNRS/IN2P3 team: CENBG, CPPM, IJCLab, LNCA, Subatech

[International Proto-Collaboration: ~20 institutions — **strong affinity to SNO+ R&D**]

LiquidO: the detection principle...

confine energy deposition locally → freeze information

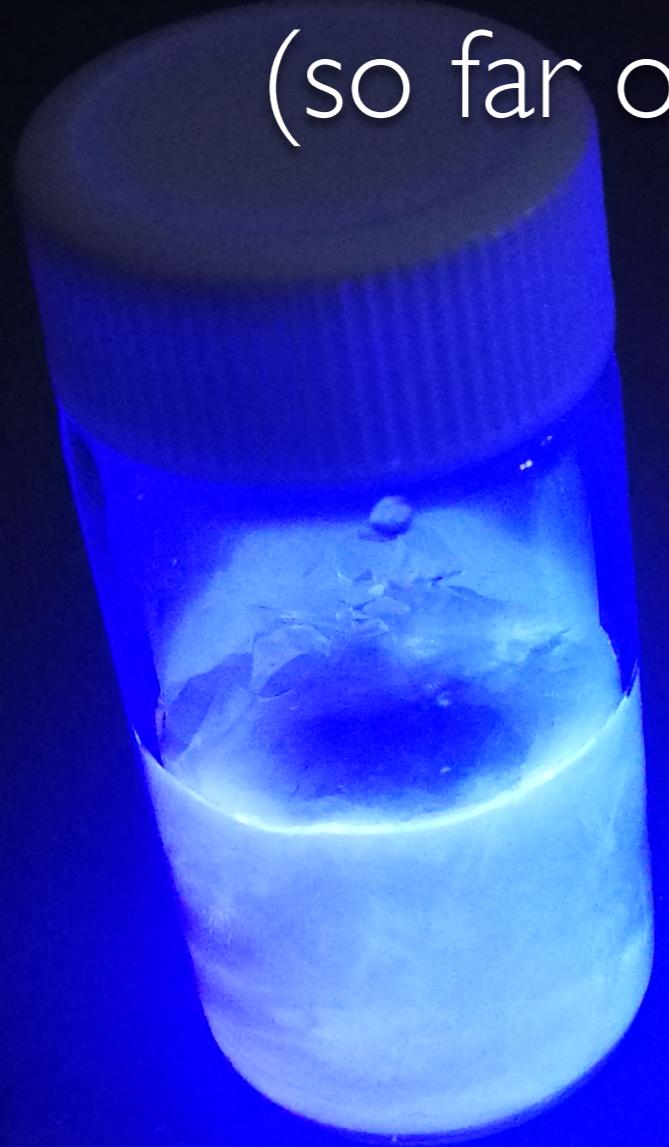


readout: wave-shifting-fibres \oplus SiPM's

PMTs → become useless (unreachable light)

Opaque scintillator → new technology! ⁹

(so far only transparent)



liquid~wax behaviour

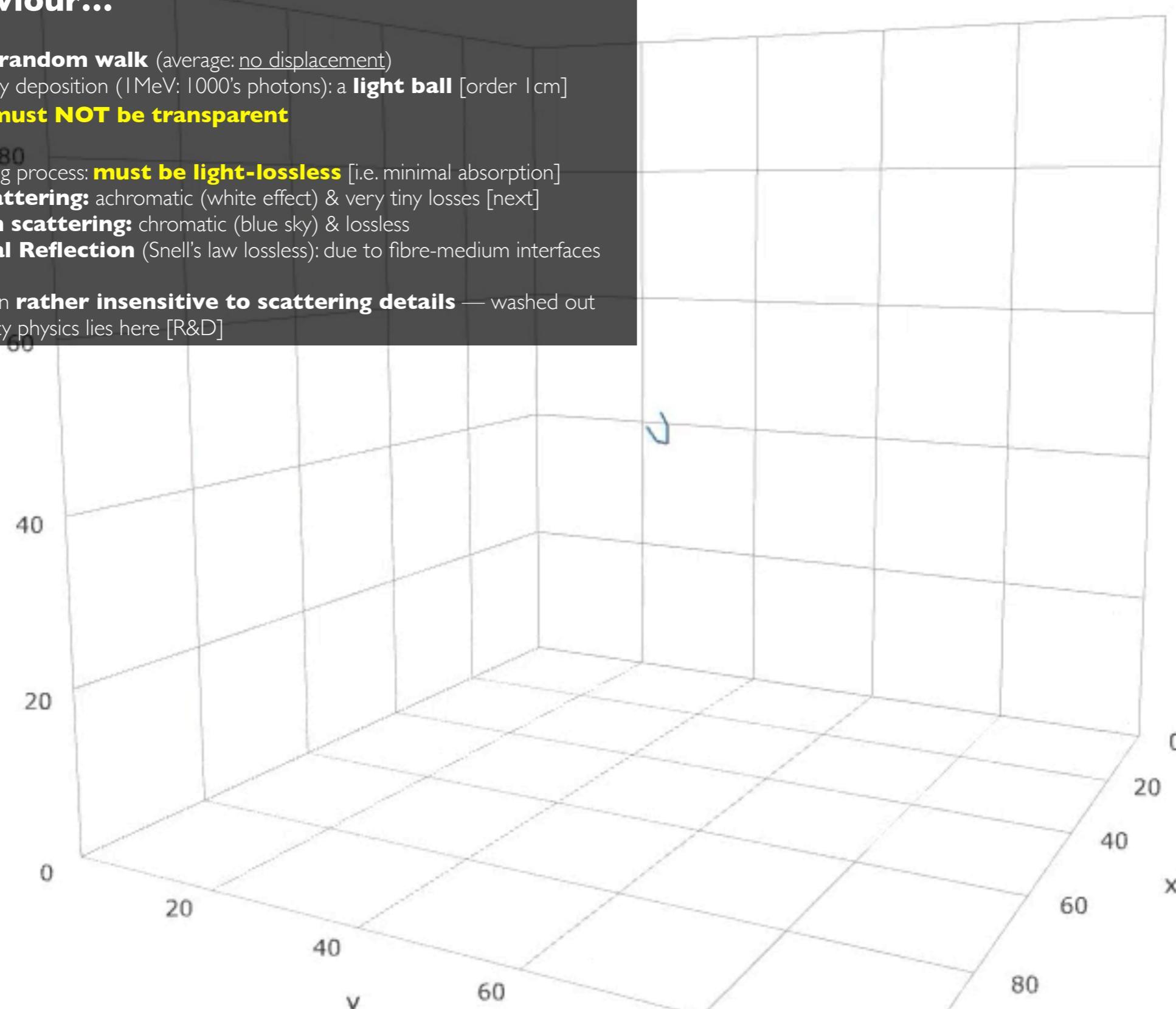
arXiv:1908.03334v2 [physics.ins-det] 5 Nov 2019

reality is more like this...

the life of LiquidO optical photon...

photon's behaviour...

- scattering → random walk (average: no displacement)
- collective energy deposition (1 MeV: 1000's photons): a **light ball** [order 1 cm]
- ⇒ **LiquidO must NOT be transparent**
- overall scattering process: **must be light-lossless** [i.e. minimal absorption]
 - **Mie scattering**: achromatic (white effect) & very tiny losses [next]
 - **Raleigh scattering**: chromatic (blue sky) & lossless
 - **Internal Reflection** (Snell's law lossless): due to fibre-medium interfaces
- overall detection **rather insensitive to scattering details** — washed out
 - BUT fancy physics lies here [R&D]



LiquidO ⇒ unique stochastic light confinement (mainly lossless)

scattering can be a “milky business”...

Computing the Scattering Properties of Participating Media Using Lorenz-Mie Theory

Jeppe Revall Frisvad¹

Niels Jørgen Christensen¹

Henrik Wann Jensen²

¹Informatics and Mathematical Modelling, Technical University of Denmark

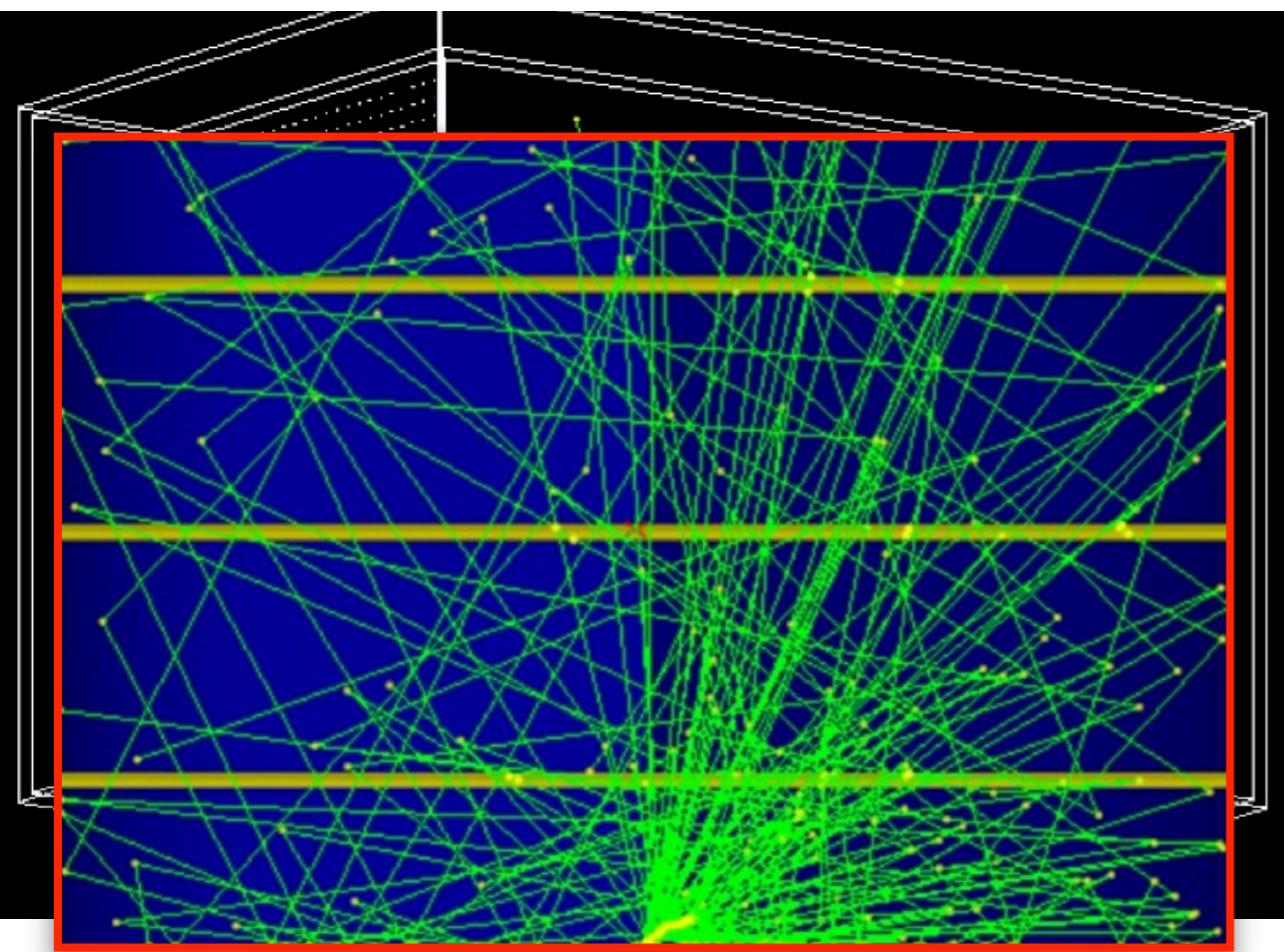
²University of California, San Diego



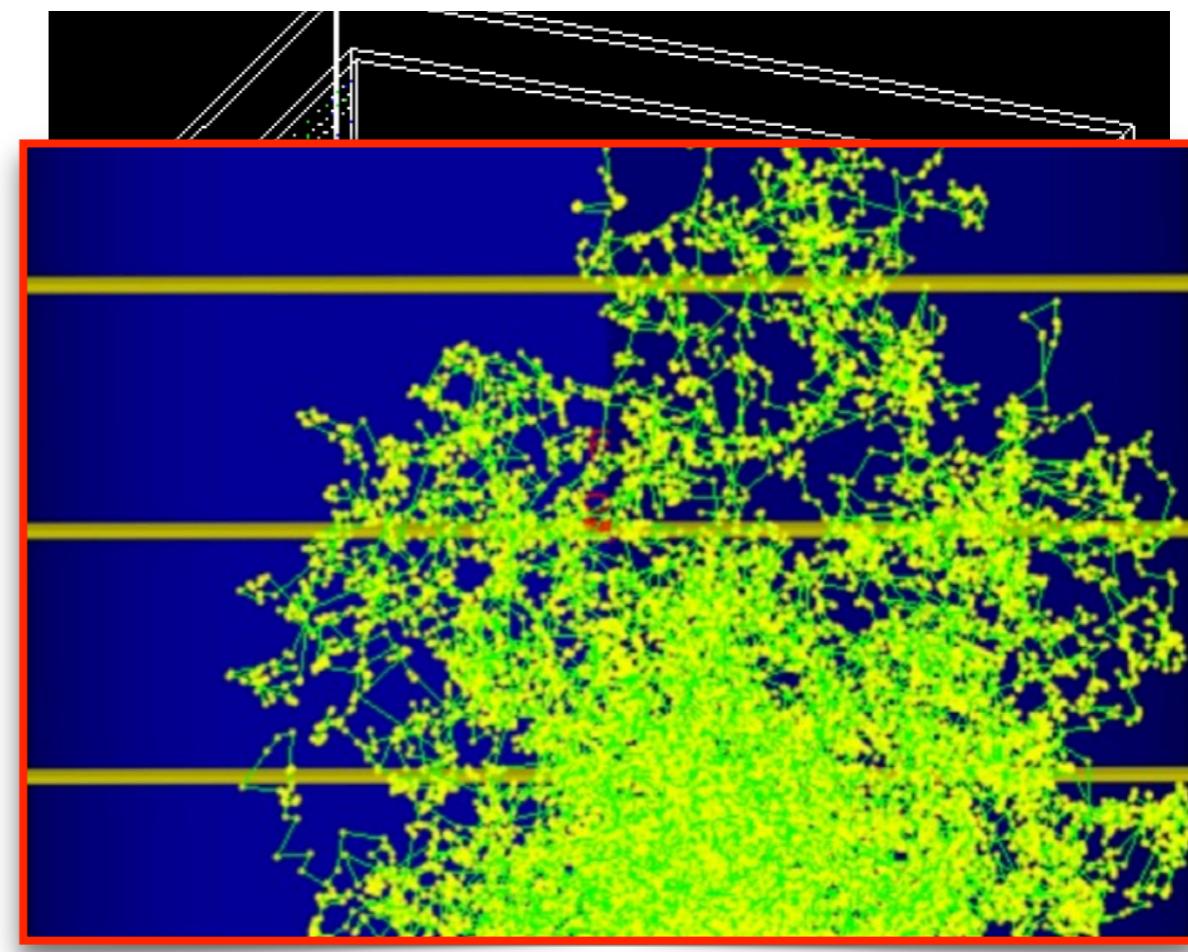
Figure 1: Rendered images of the components in milk as well as mixed concentrations. The optical properties of the components and the milk have been computed using the generalization of the Lorenz-Mie theory presented in this paper. From left to right the glasses contain: Water, water and vitamin B2, water and protein, water and fat, skimmed milk, regular milk, and whole milk.

Mie scattering (well known) used to study samples

LiquidO recipe: just “bread & butter” physics...



today's technology



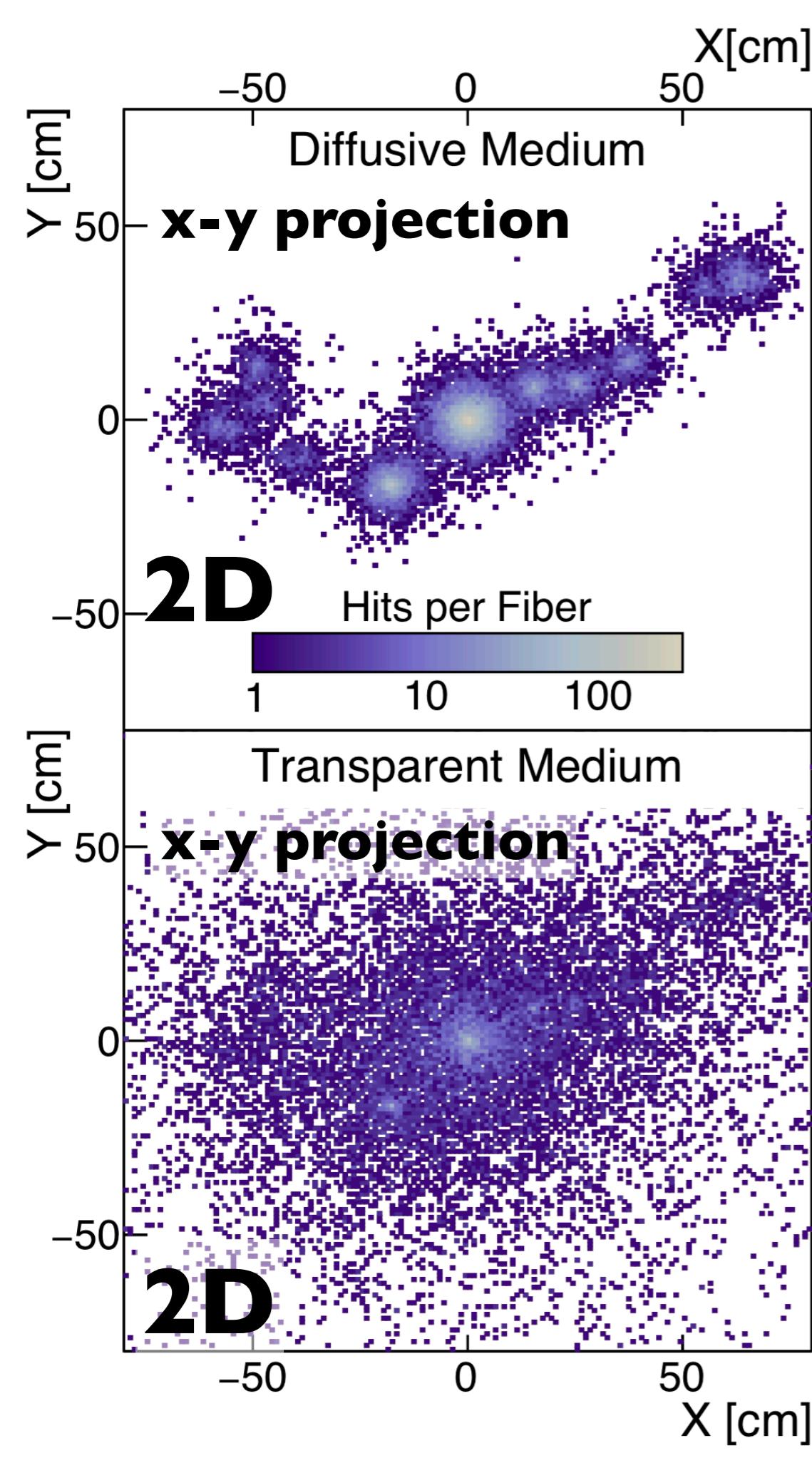
LiquidO technology

light ball size: scattering \oplus fibres
(sampling optimisation)



a LiquidO detector...

LiquidO's multi-axes...

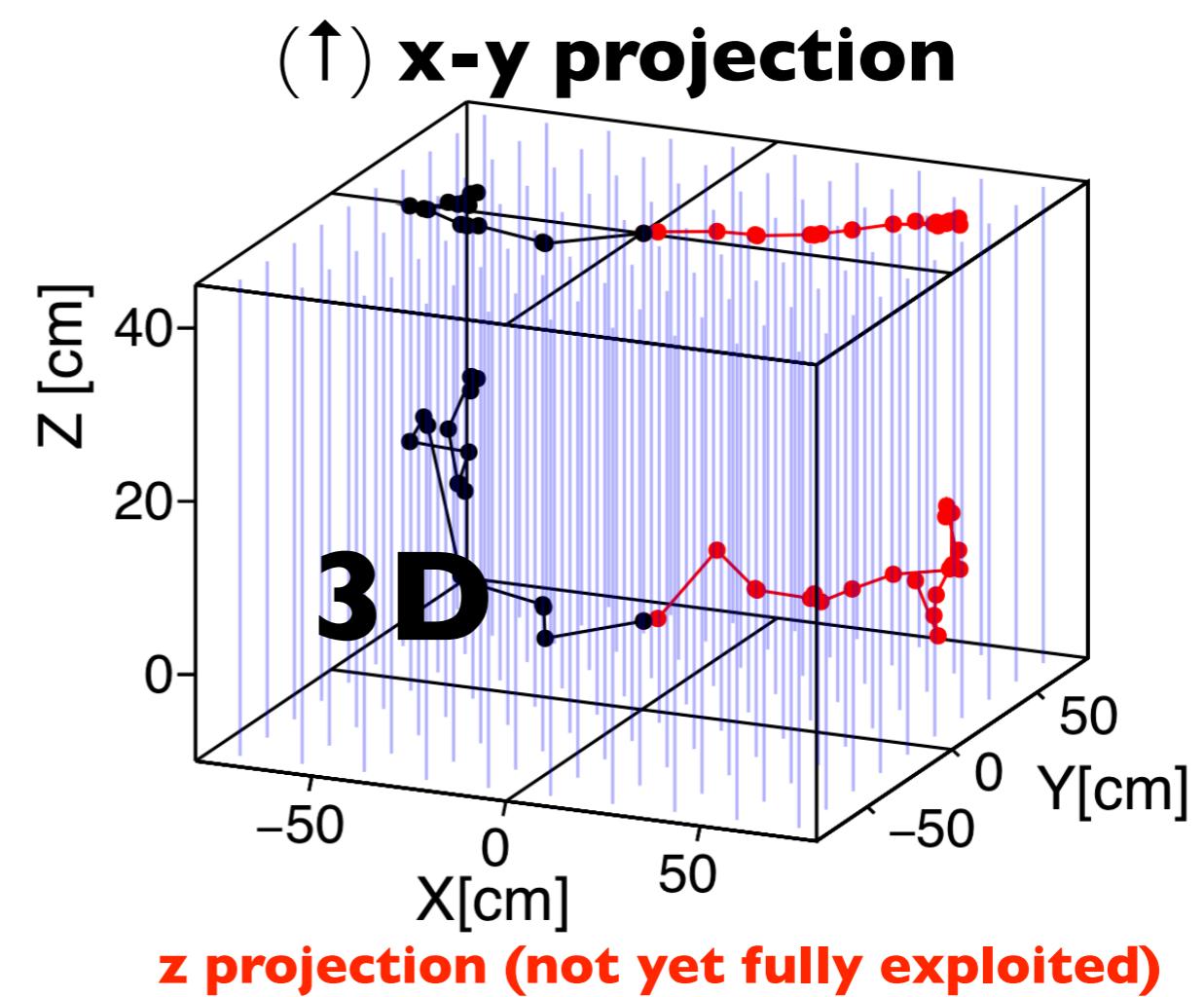


LiquidO

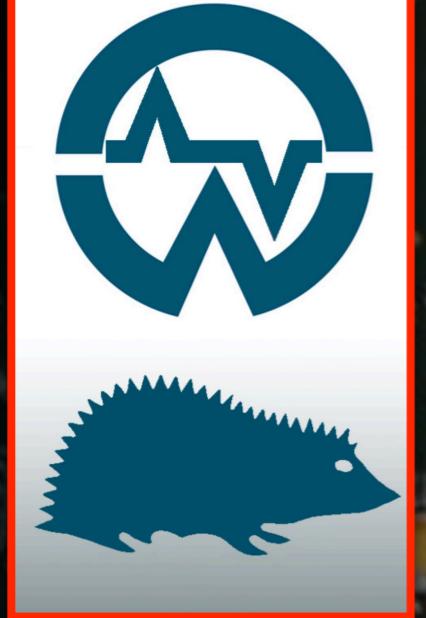
up to 3 axes (unlike drift-TPC) → **needed?**

LiquidO

up to 3 axes (unlike drift-TPC) → **needed?**



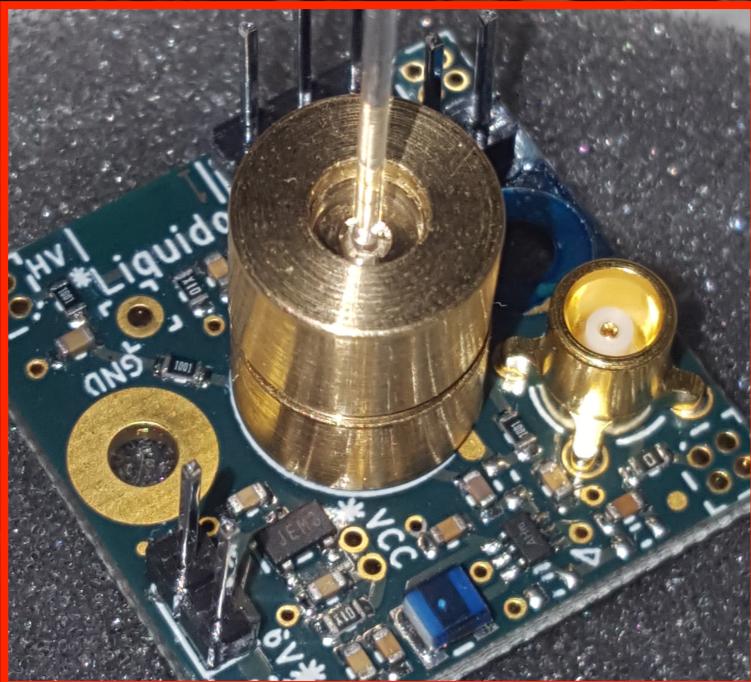
Transparent Scintillator[⊕] Fibres



our digitisation electronics...

scintillation+Cherenkov

few-PE's pulses (100's of ns sampling)

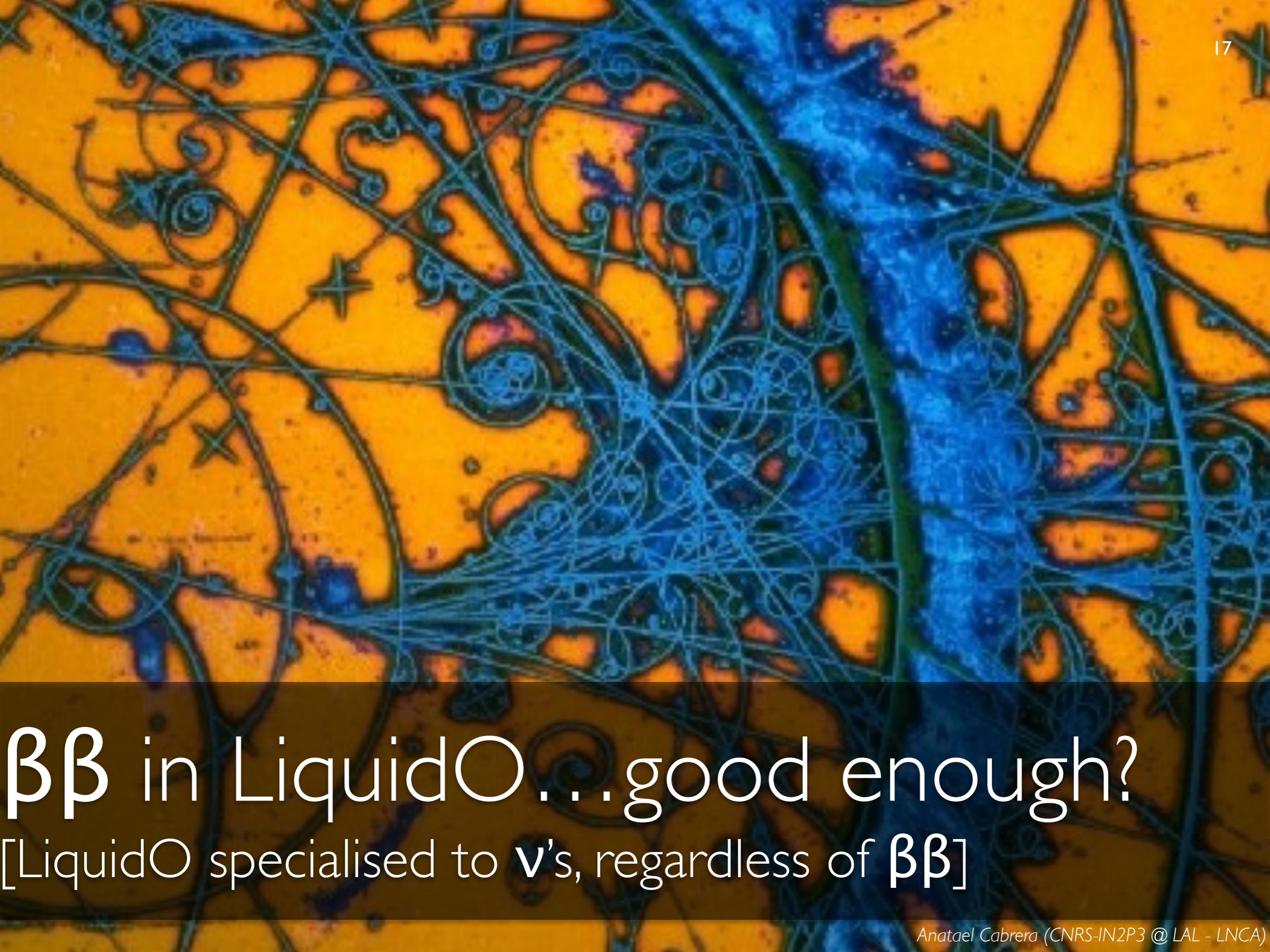


~150ps per sample

(expected) **time resolution: $\leq 100\text{ps/PE}$**
(i.e. $\leq 3\text{cm/PE}$ @ speed of light)

(instrumentation-wise)

LiquidO \approx “light TPC” \oplus 4 π -ToF



$\beta\beta$ in LiquidO...good enough?
[LiquidO specialised to ν 's, regardless of $\beta\beta$]

Detection-wise...

• passive BG handles [unique features]

- high loading capability
- hermitical volume & dead materials
- radio-purity
- deep underground
- α -quenching

active BG rejection [unique features]

- Pulse Shape Discrimination [e^-/γ vs p (neutron) vs α]
- PID: topology

toughest BG [unique features]

- cosmogenic **BG: how to be sure?**
- the ultimate BG: **solar (8B)**

Signal-wise...

- isotopic mass **NO NEED for enrichment** (Te mainly)
 - multi-isotope capability
 - isotope purity
- energy resolution [**KLZ-like?**]
- β vs $\beta\beta$ discrimination?
- signal redundancy

Sensitivity appetiser...

$\beta\beta$ necessary conditions...

scintillator → R&D ✓ (Borexino)

⊕

fibres → R&D ✓?

[0.1% of mass]

(under study)

⊕

photo-detector → **(outside!)** ✓

⊕

Te- $\beta\beta$ @10% doping → R&D ✓ (à la SNO+)

or

Nd- $\beta\beta$ @10% doping → R&D ✓ (à la SNO+)

only natural radio-activity

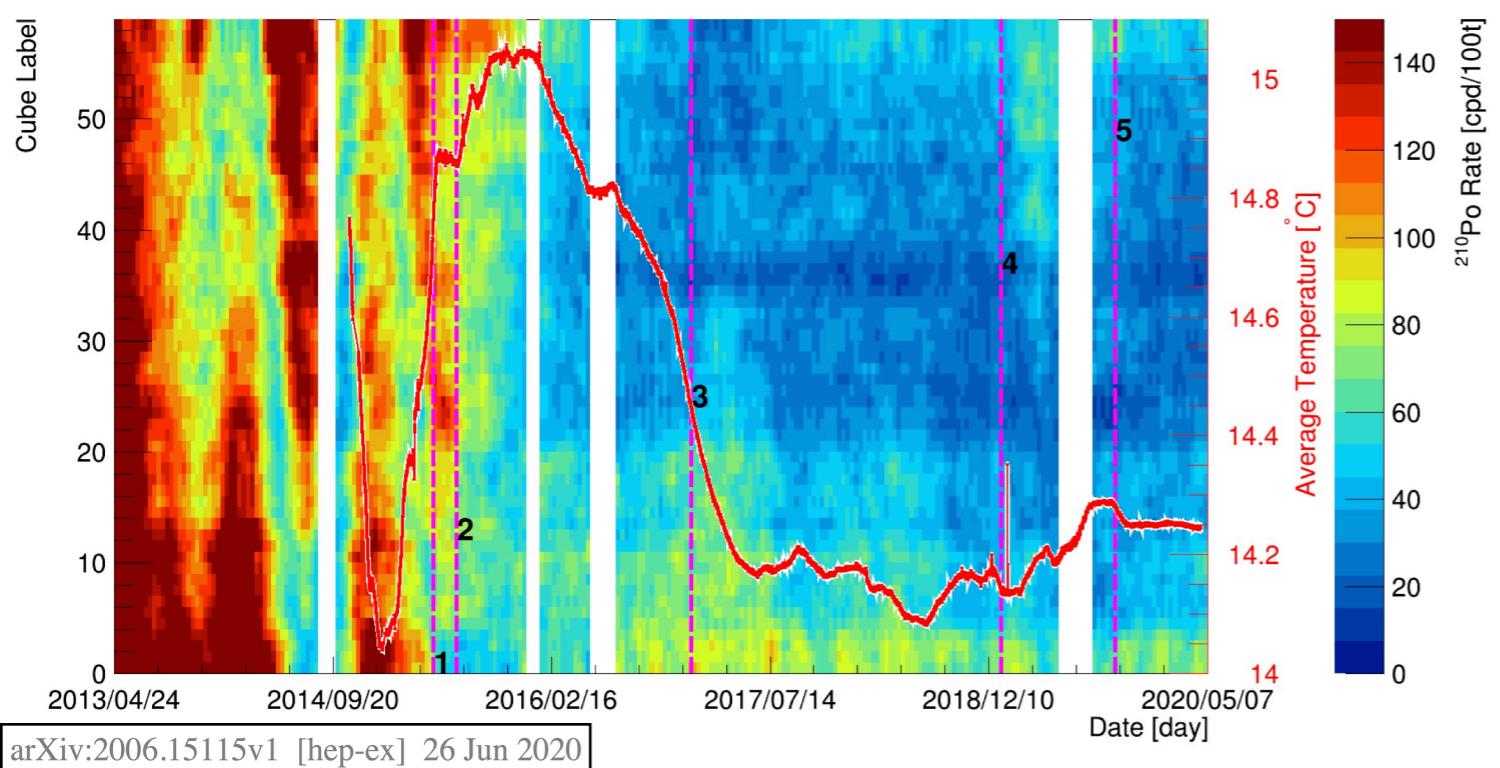
[no enrichment → much **lower cost** & avoid **contamination risk**]

GERDA's fibre curtain...



fibres are rather ok!! **good enough?**
(under estimation)

- **liquid/gas:** convention → higher diffusion contamination (Ra)
- **Borexino:** ^{210}Po diffusion 20cm a priori (negligible)
⇒ large distance (main limitation on CNO observation)
- **solidification** (or high viscosity): **hermitic detector!!**



solidification: no BG wandering...
(also higher loading stability)

Detection-wise...

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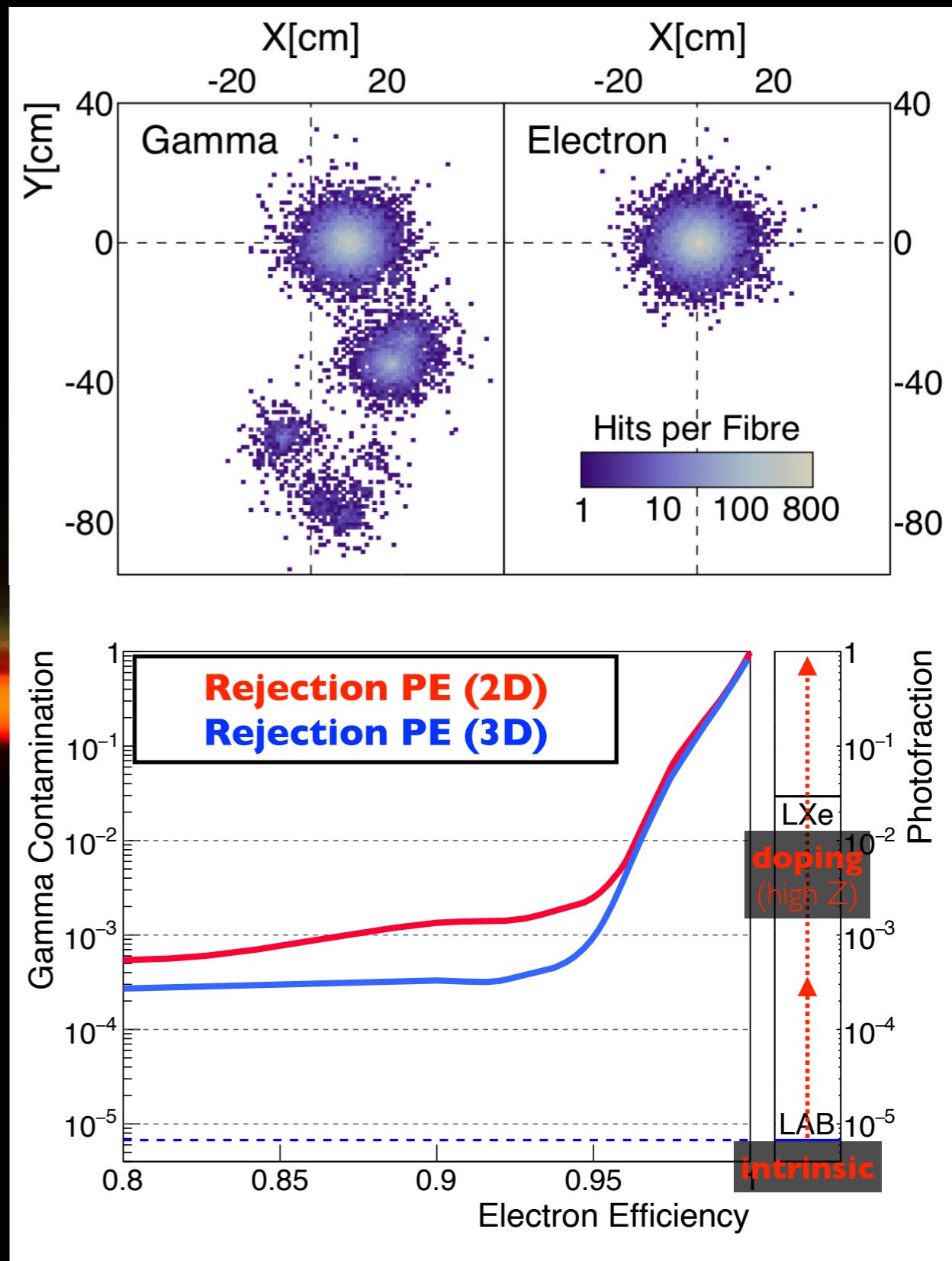
Sensitivity appetiser...

$\beta\beta$ necessary conditions...

Powerful PID:

- $\geq 10^3$ rejection
[2D only: no timing]

- $\geq 85\%$ efficiency

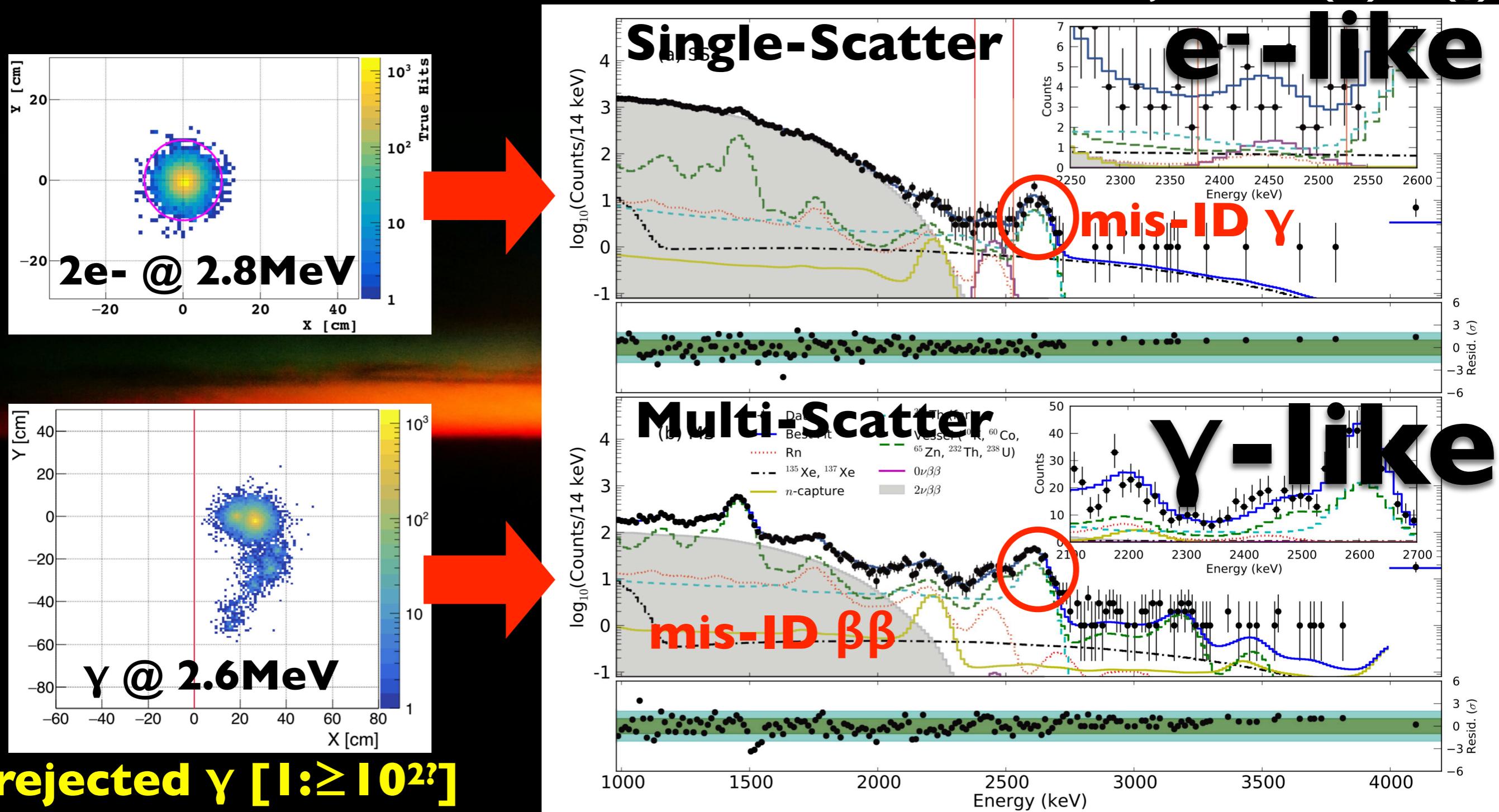


PID power is variable doping

data-driven BG model prediction (à la EXO)...

predict e⁻-like BG-model & efficiency ($\beta\beta 2\nu$)

EXO's rejection I(e⁻):I0(γ)



no PID → only one spectra with ALL BG in [KLZ → SNO+/JUNO]

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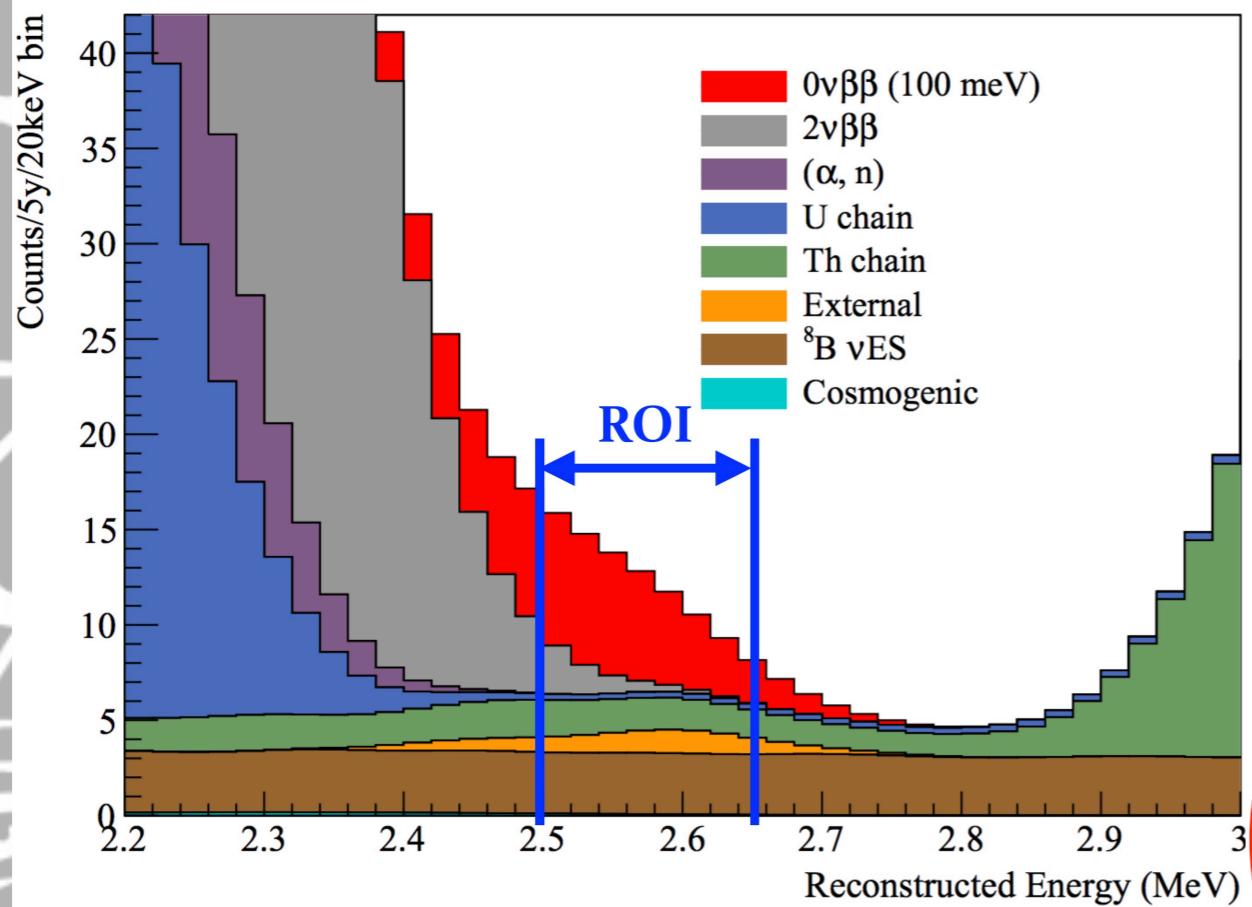
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Sensitivity appetiser...

$\beta\beta$ necessary conditions...

SNO+ Spectrum

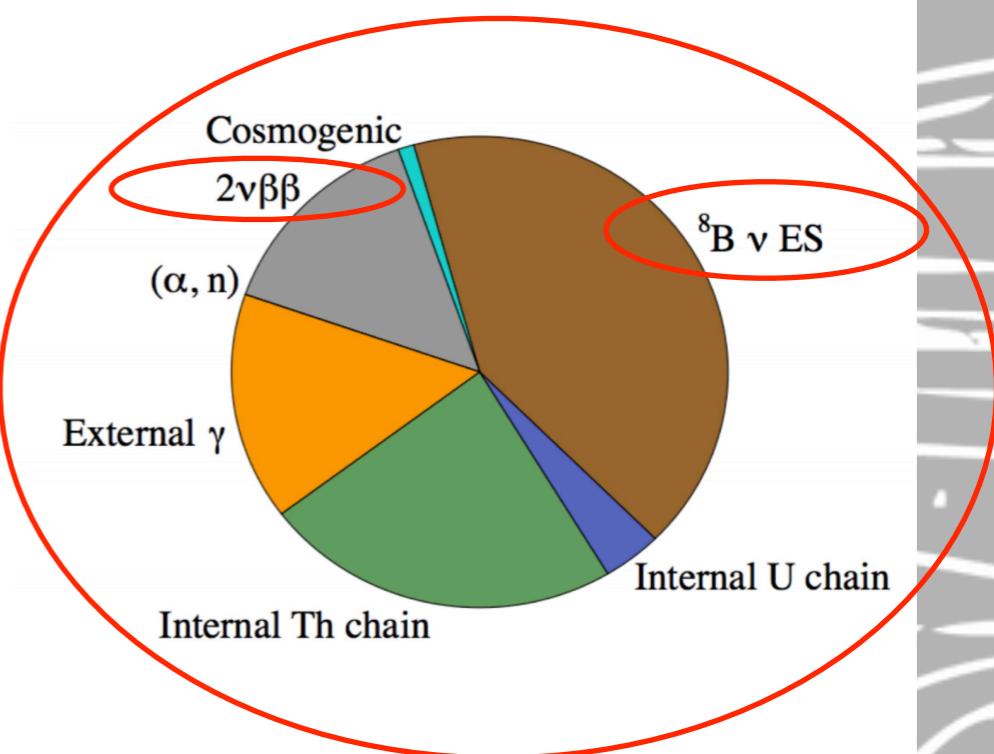


Detector configuration:

0.5% natural Te

5 years live time

3.3m fiducial volume (17%)



only possible mitigation $\rightarrow \geq 10x$ higher doping!

LiquidO- $\beta\beta$ solar BG: no issue?

Detection-wise...

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- multi-isotope capability
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• energy resolution [**KLZ-like?**]

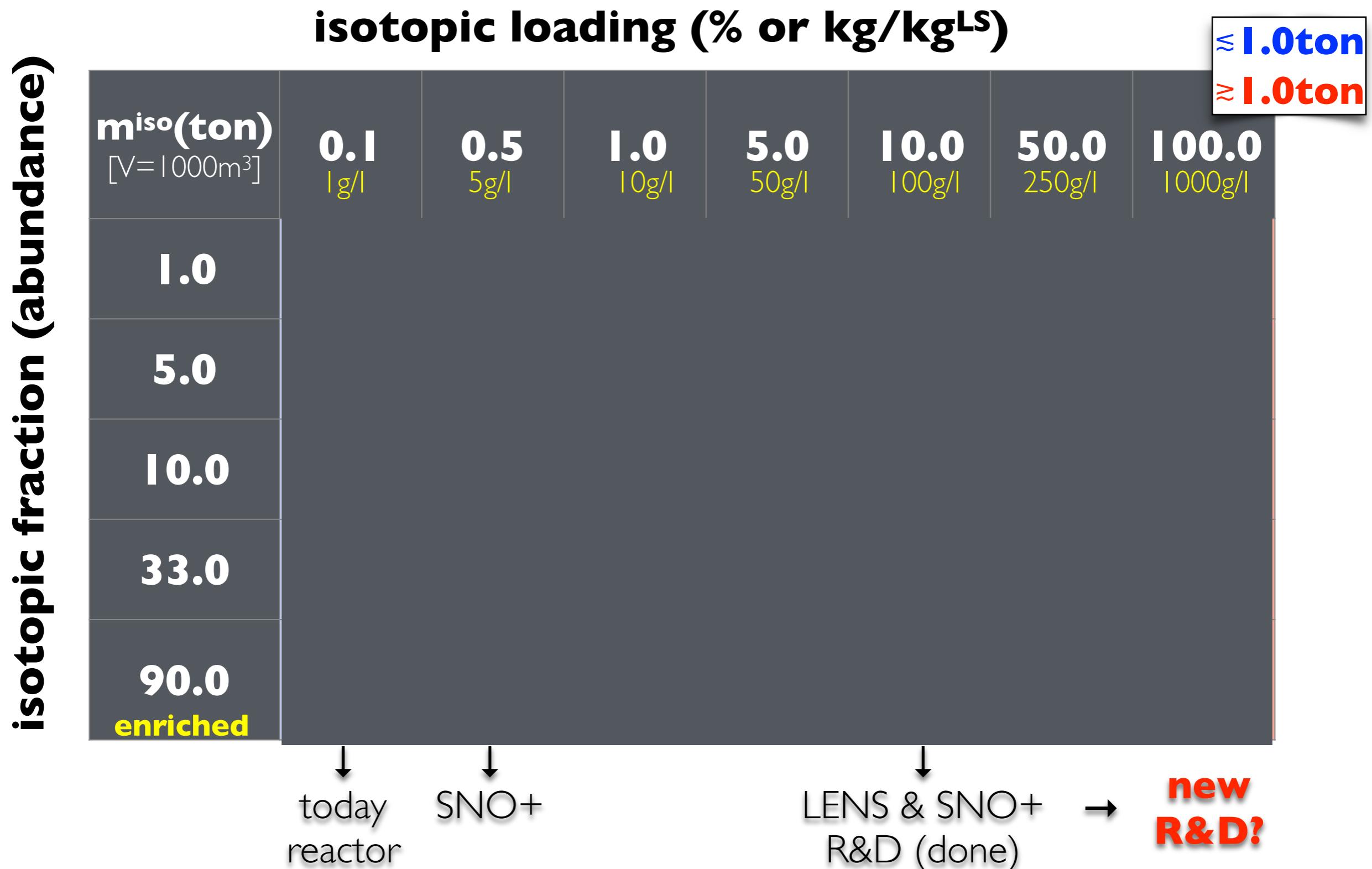
• β vs $\beta\beta$ discrimination?

• signal redundancy?

Sensitivity appetiser...

$\beta\beta$ necessary conditions...

isotopic mass: loading vs enrichment...



massive loading capability (**R&D**) \Rightarrow **no enrichment!**
enrichment costing: [10,100]M€/ton

energy resolution?
(like KLZ at best — SNO+ soon)

7%@1 MeV → 4%@3 MeV
[LiquidO expected $\leq 300 \text{PE/MeV(max)}$]

2β2ν dominant BG: show-stopper?
[sensitivity studies]

Detection-wise...

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- signal redundancy?

Sensitivity appetiser...

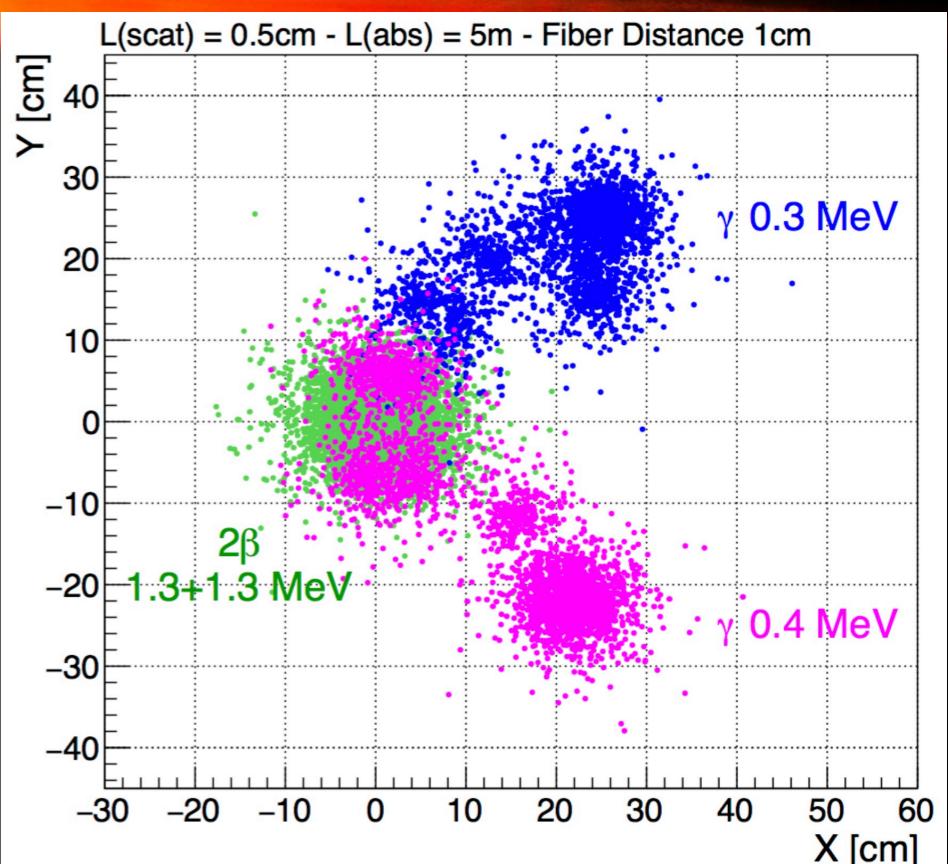
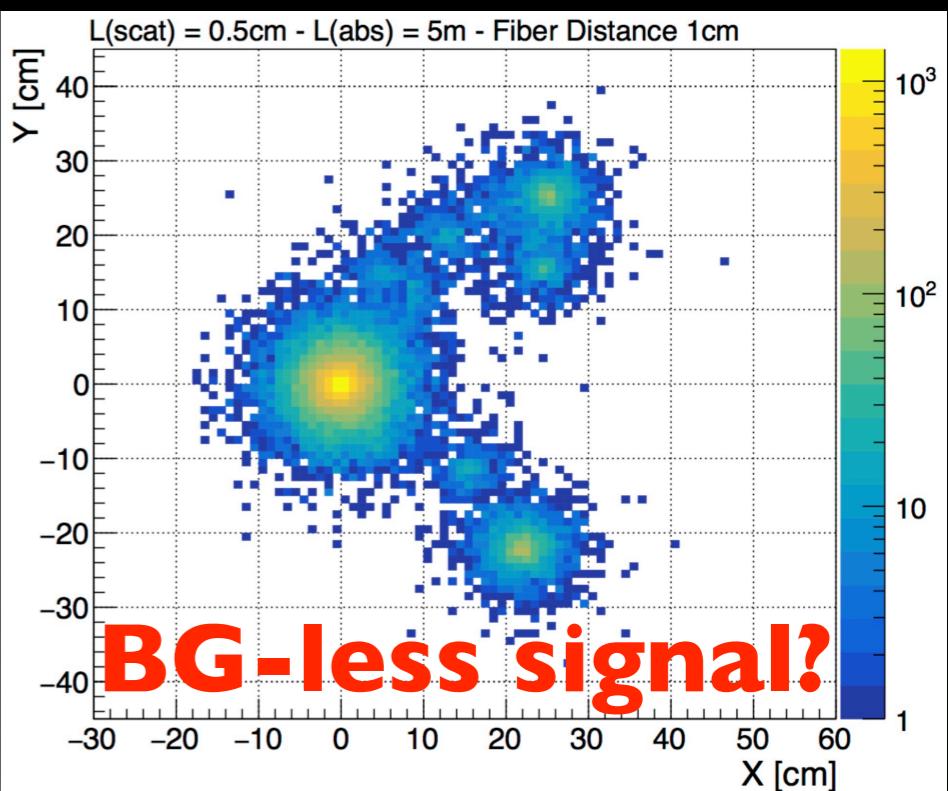
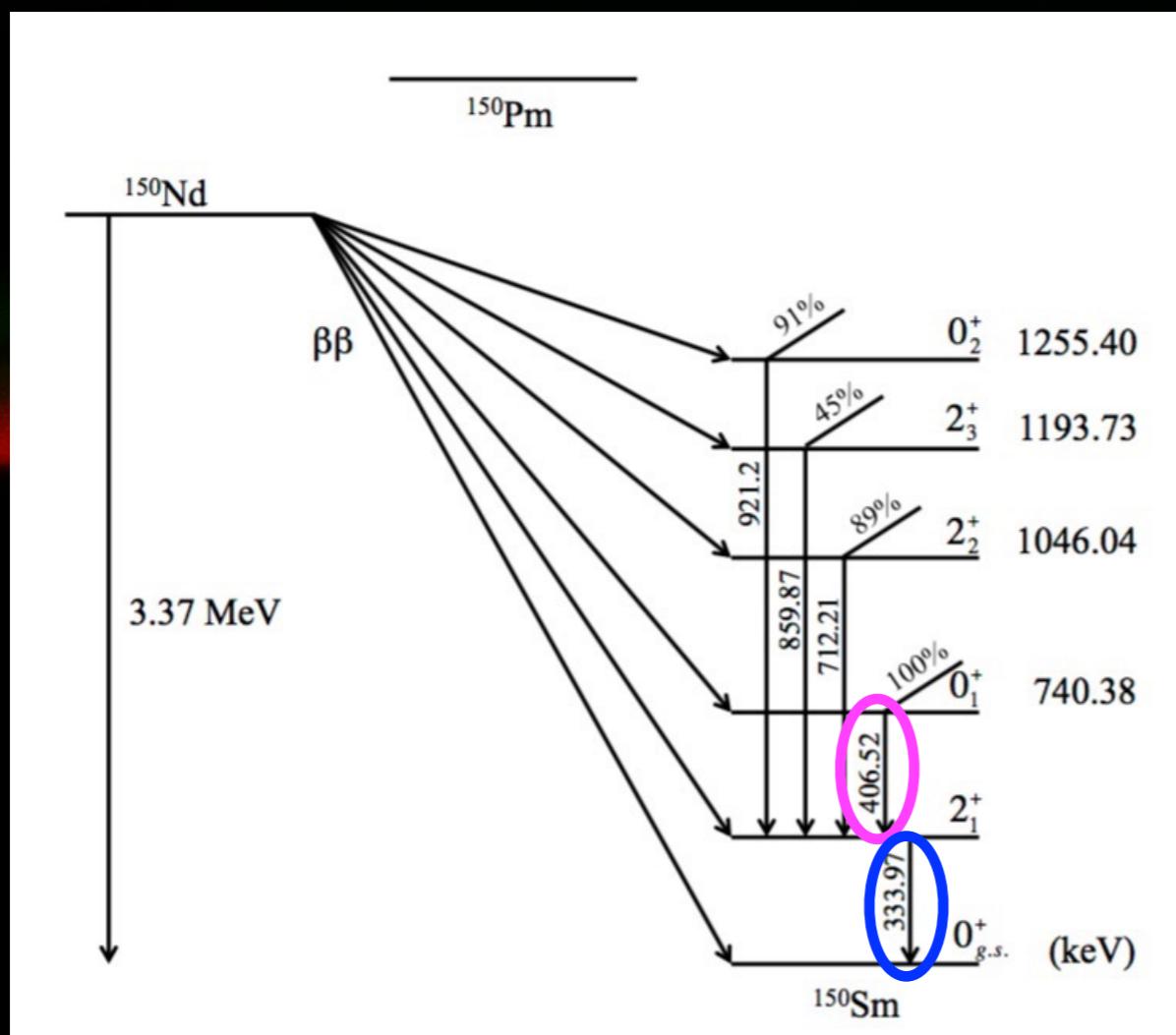
$\beta\beta$ necessary conditions...

exciting (Te and Nd) excited state decay...

$\beta\beta$ [$E = Q(3370\text{keV}) - E(\gamma 1) - E(\gamma 2)$]

$\gamma 1 (\sim 406 / \sim 712 / \sim 859 / \sim 921)\text{keV}$

$\gamma 2 (\sim 334\text{keV})$



if discovery \rightarrow internal validation!
 (same detector \oplus same Q-value \oplus **different BG**)

Detection-wise...

• passive BG handles [unique features]

- high loading capability [LiquidO]
- hermitical volume & dead materials [LiquidO]
- radio-purity [Bx/KLZ \oplus GERDA]
- deep underground [OK]
- α -quenching [OK — KLZ, etc]

active BG rejection [unique features]

- Pulse Shape Discrimination [e^-/γ vs p (neutron) vs $\alpha \rightarrow$ possible?]
- PID: topology [LiquidO]

toughest BG [unique features]

- cosmogenic **BG: how to be sure?**
- the ultimate BG: **solar (8B)**

Signal-wise...

- isotopic mass **NO NEED for enrichment** (Te mainly)
 - high loading capability [LiquidO]
 - multi-isotope capability [YES: SNO+ R&D]
 - isotope purity [SNO+ R&D]
- energy resolution [**KLZ-like?** further improve?]
- β vs $\beta\beta$ discrimination? [LiquidO]
- signal redundancy [LiquidO]

Sensitivity appetiser...

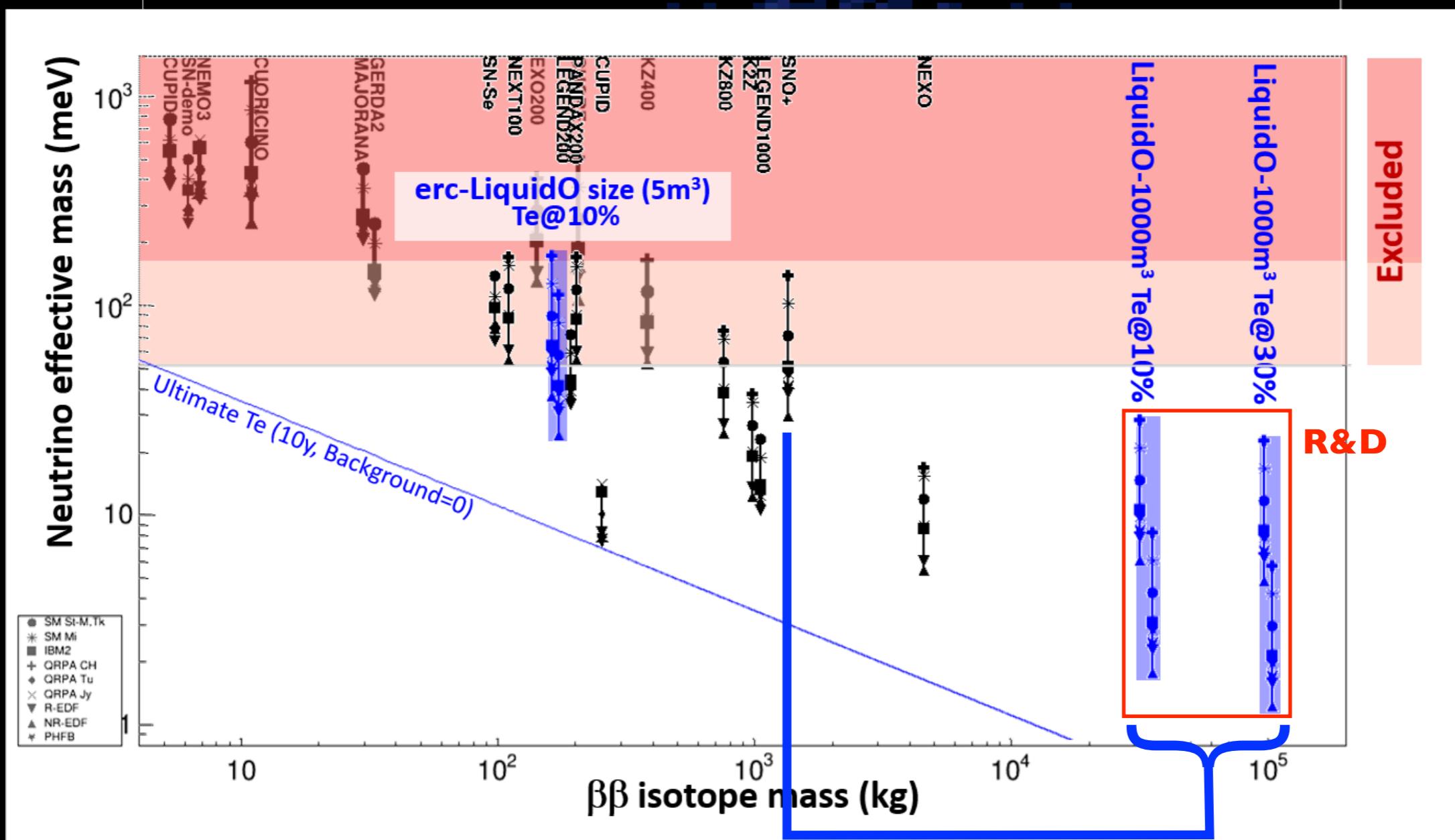
KLZ demonstration — world best limits!

$\beta\beta$ necessary conditions... **sufficient?**

high isotopic mass $\beta\beta$ -decay with LiquidO?

BG-Index ($1e-3$), loading (10% Te a la SNO+), conservative PID (not optimised)

$\beta\beta$ -decay sensitivity potential → 10meV sensitivity?



LiquidO

- **heavy loading** (no enrichment)
- **powerful PID**
- **radiopurity**
- **multi-isotope** (R&D SNO+)

LiquidO same detector size
⇒ **loading $\geq 10x$**

R&D

Potential BG Index (events in **R₀₁** per kg per keV per year)

- **LiquidO:** ~1e-3? (today's knowledge \oplus **PID**) [**passive fibre**]
- **LiquidO*:** ~1e-4? (active fibres & **R&D***) [$\beta\beta2\nu \Leftrightarrow$ resolution]
- **LiquidO**:** ~1e-5? (**R&D**** better resolution) [**solar 8B @ 10% loading**]

NOTE: none of the “fancy ideas” used for BGI estimation \rightarrow **room for improvements!**

under exploration... **maybe!**

a good framework for $\beta\beta$ research? (targeting ≥ 10 tons for NMO)

much R&D ahead to be able to answer
(toughest question so far for LiquidO)

questions, please?



merci...
ありがとう...

danke...
고맙습니다...

obrigado...

Спасибо...

grazie...
謝謝...

hvala...
gracias...
شكرا...
thanks...