

on behalf of the LiquidO proto-collaboration...

# Liquid

novel liquid neutrino detection technology  
(a few examples of) **what to do with it?** & (a minimalistic) **how?**



**NeuTel XIX Workshop (virtual Venice, Italy)**

Feb 2021

**Anatael Cabrera**

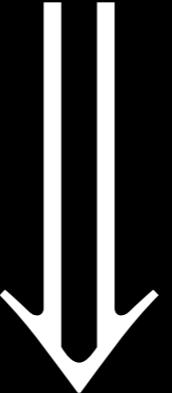
CNRS/IN2P3  
IJCLab (Orsay)  
LNCA (Chooz)



# LiquidO: light “opaque” medium

[*stochastic light confinement* → imaging ⊕ topology & **PID**]

**vocabulary:** “opacity” ≈ “brutal translucency”



# LiquidO ≈ “light TPC” ⊕ “4π ToF” (**4D info**)

[highest duty-cycle & high acceptance → minimal pile-up]

what's LiquidO?



# an **Opaque** solution...?

**assumption: traditional liquid scintillator (opacified)**  
[LiquidO works beyond scintillation]

let's see...

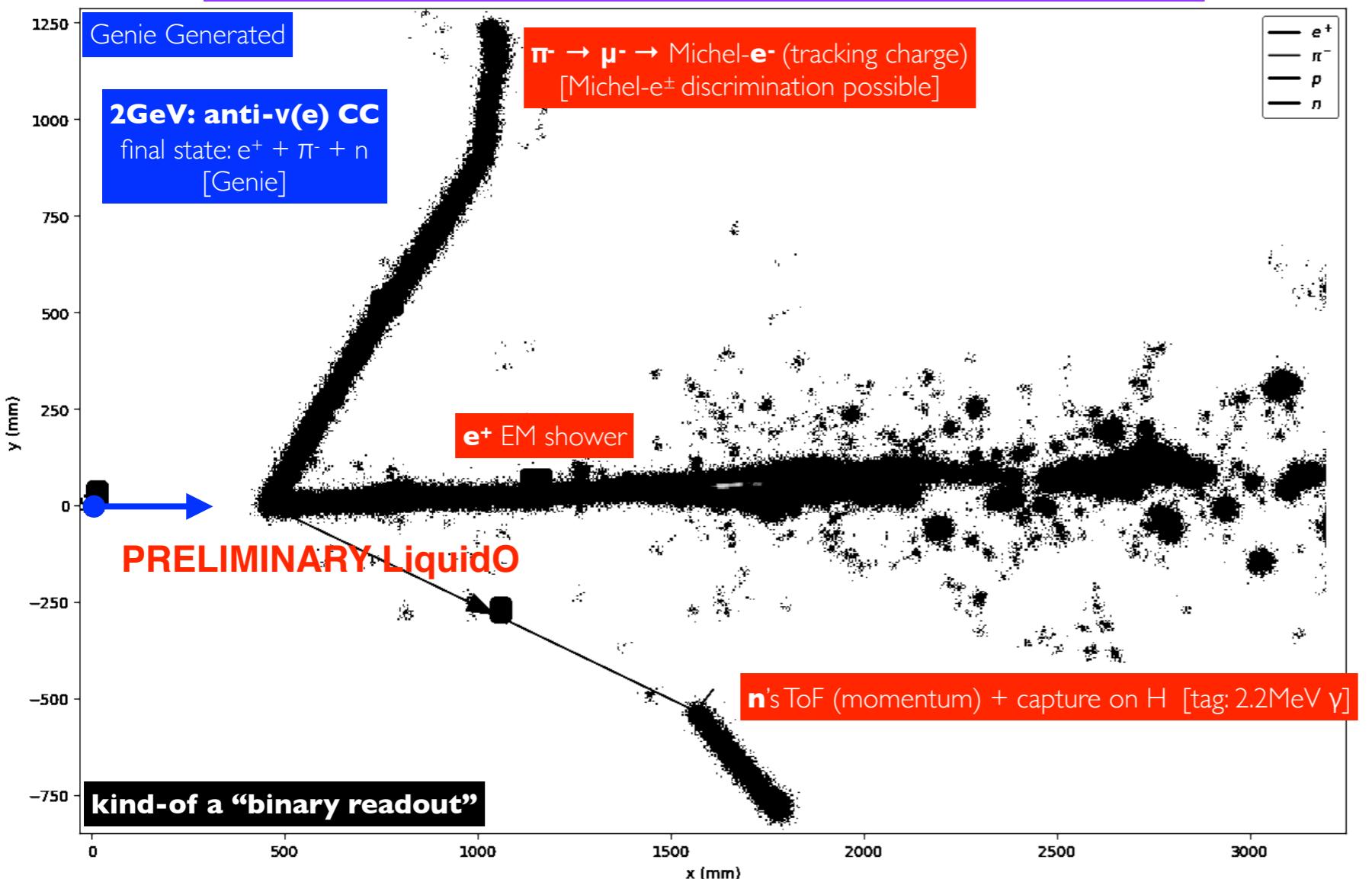


**disclaimer: I am not a GeV neutrino physics expert**  
[likely missing a few issues or a few inaccuracies]

# LiquidO potential @ GeV...

**Large Events: low-z (H $\oplus$ C)**  
[H is  $\leq 20\%$ /volume]

**LiquidO Configuration:** 4mm pitch (not impossible, but demanding for mechanics)



**PRELIMINARY LiquidO**

kind-of a “binary readout”

**Stochastic calorimetry term :  $\approx 0.3\%$  [ $\sim 100\,000$  PE/GeV]**

[10 000  $\gamma$ 's per MeV  $\oplus$  1% detection  $\approx 100$  PE/MeV  $\rightarrow$  10% calorimetry]

5

**Clean Nuclear Physics on H**  
(sub-sample  $\leftrightarrow$  normalisation)

**C** (99%: 6n $\oplus$ 6p) + any element (doped)

**Full Topology (track, showers, etc)**  
• tracking:  $\leq 1$  mm precision  
• shower: clean first radiation lengths

**Charge Particle Sign:** B-field or Final-State Tracking  
("event history tracking")

**Neutral Charge Particle Detection too**  
(neutron,  $\pi^0$ , missing momenta, etc)

**High Precision Calorimetry**  
(per mille precision)

**GeV but sees MeV physics too**  
(more experimental handles)

**Up to  $\sim 100$ ps resolution per channel**  
(enable “energy-flow”)

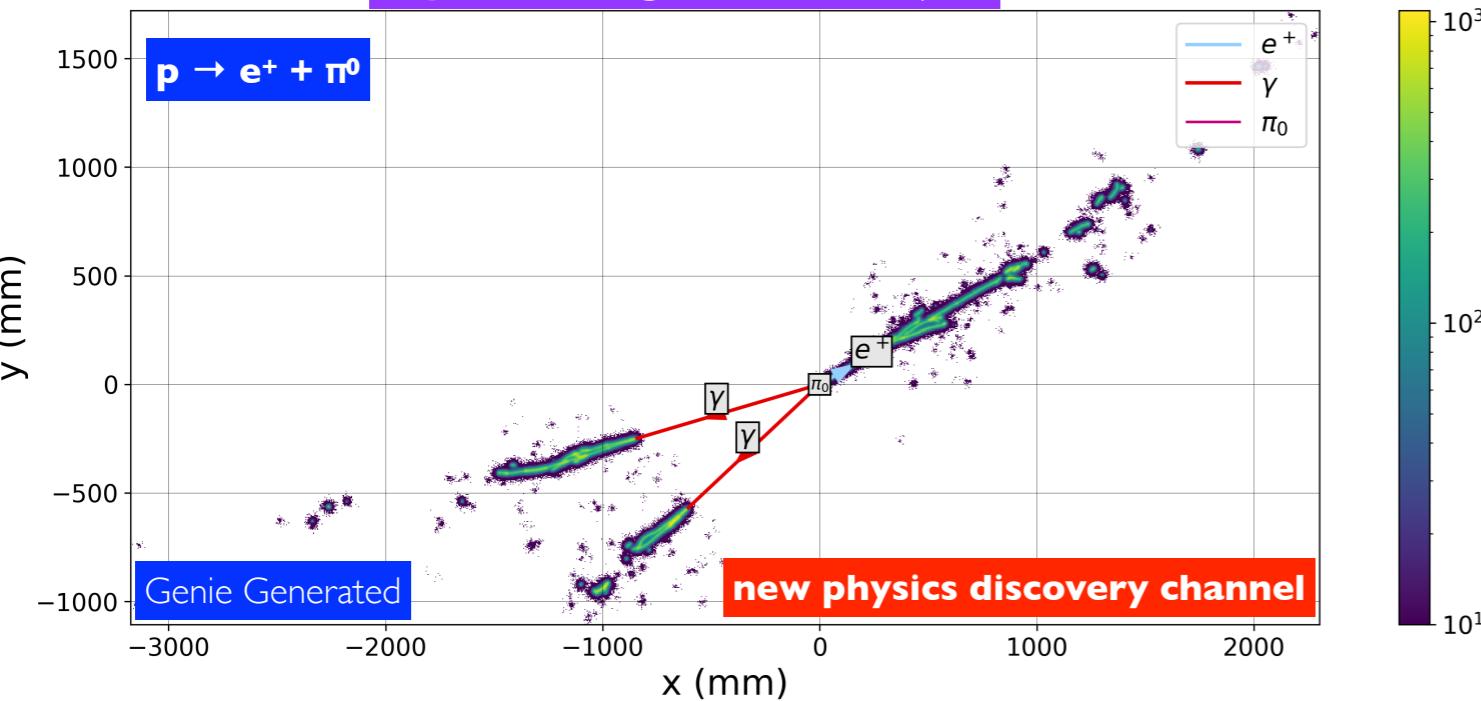
**Highest Duty-Cycle $\oplus$ Stochastic Confinement**  
(close to surface)

#### Cost:

- Liquid Scintillator ( $\lesssim 1.0$ k€/ton) / WbLS ( $\lesssim ??$ €/ton)
- Fibres ( $\lesssim 1.0$ €/m) [NOvA/MINOS/etc]
- Doping: depends on what(!) and how(!)
- overheads in mechanics & **readout**
- **optical multiplexing N(fibres):1(channel)**

a few GeV v's...

## LiquidO Configuration: <1cm pitch



## staggering $\pi^0$ vs $e^\pm$ separation

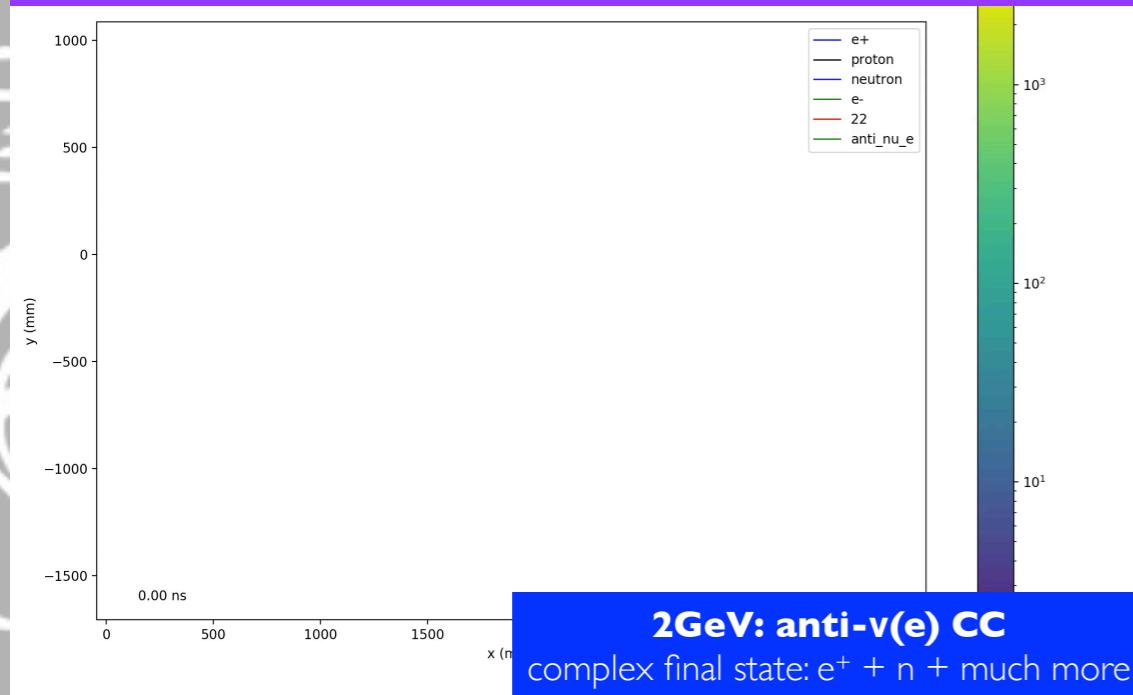
- proton-decay signature → BG-less?
- critical for **NC( $\pi^0$ )** vs  **$\nu(e)$  CC PID**

## free-H per unit of mass:

**water:** ~10%

**scintillator:** up to 20%

## LiquidO Configuration: 1cm pitch (mechanics design under validation)



**coarser system: sampling & less “opacity”**

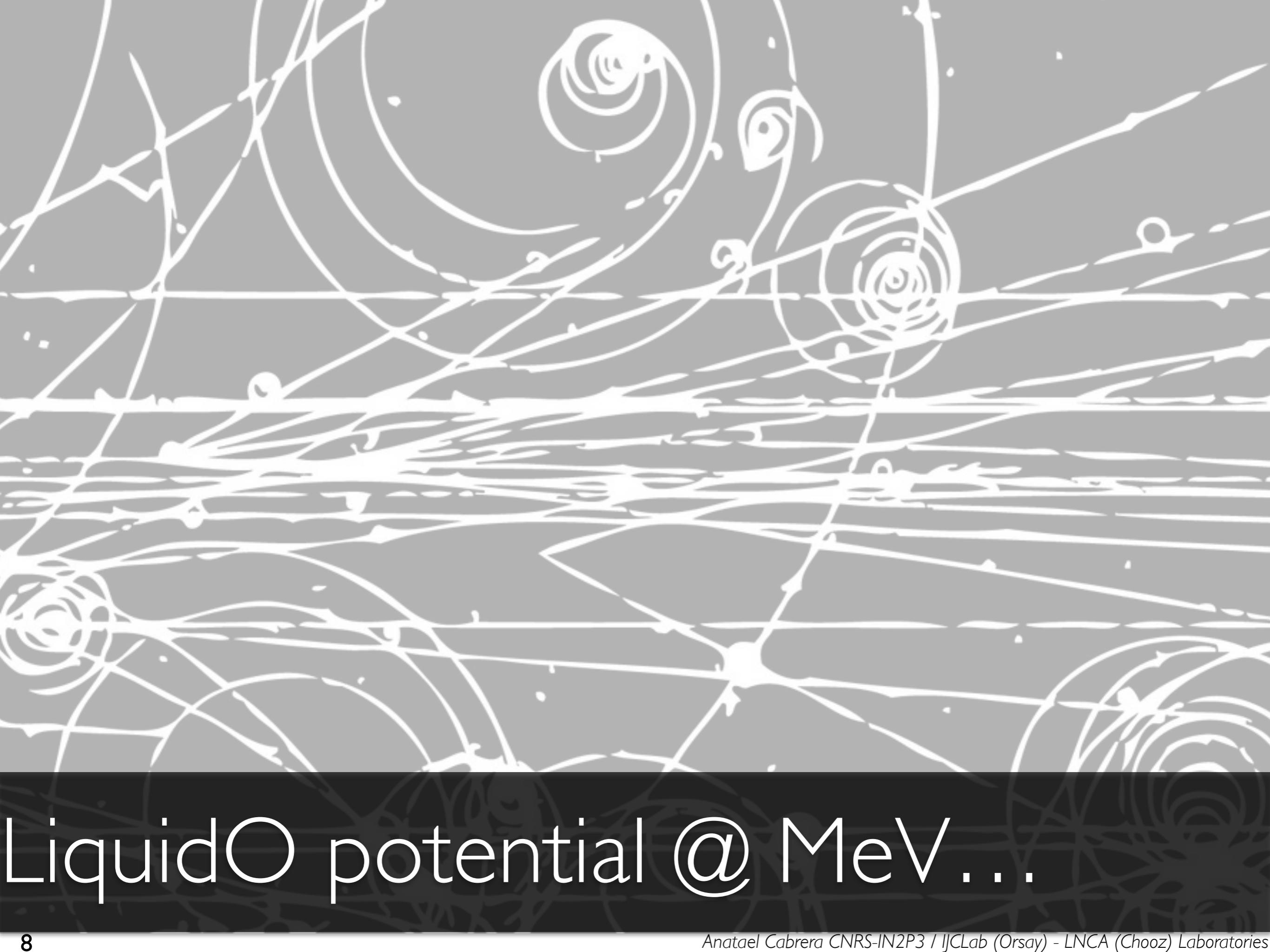
**energy-flow (dynamic images)**

time holds much information...

# vast physics range...

- near-detector physics @ DUNE and/or @HyperK...
  - Native H ( $\rightarrow$  accurate neutrino energy reco) and C (6n $\oplus$ 6p)
  - @DUNE: load with Ar? (gas in liquid)
  - @HyperK: load with O? (gas in liquid) [ $\rightarrow$  water based liquid scintillator?]
  - @NuStorm detector — load with any strategical element X (nuclear effects)
- far-detector physics: the 4<sup>th</sup> FD of DUNE? [order 10kton seems OK: NOvA]
- multi-channel proton-decay  $\rightarrow$  different models sensitivity
- new ideas?

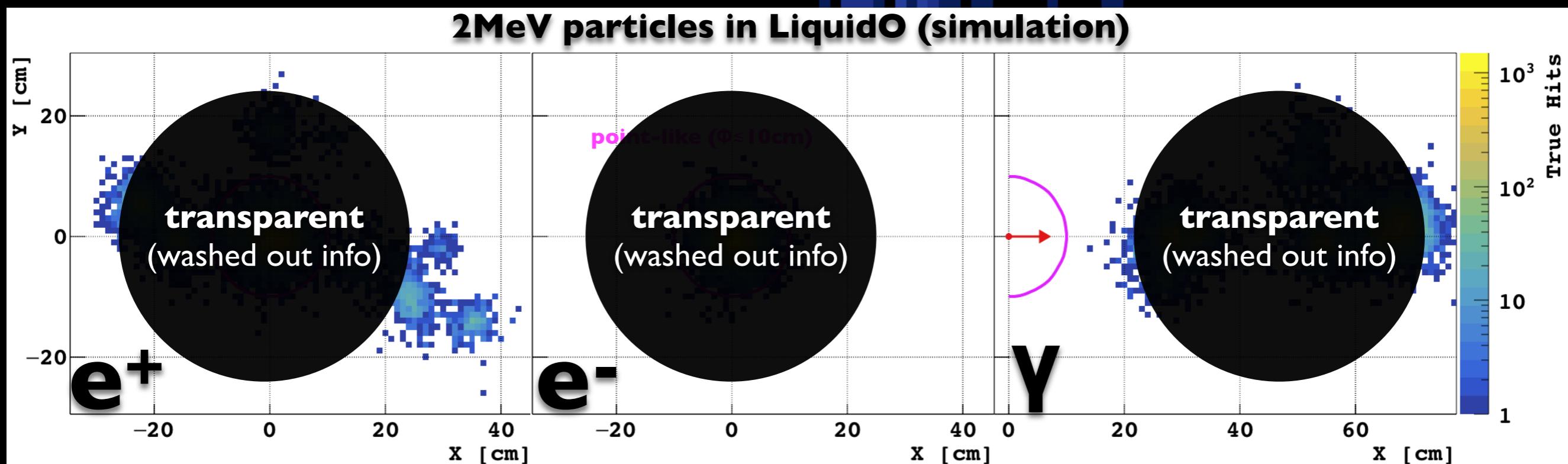
GeV physics potential...



# LiquidO potential @ MeV...

# LiquidO in a nut-shell...

## Imaging → powerful Particle-IDentification (PID)



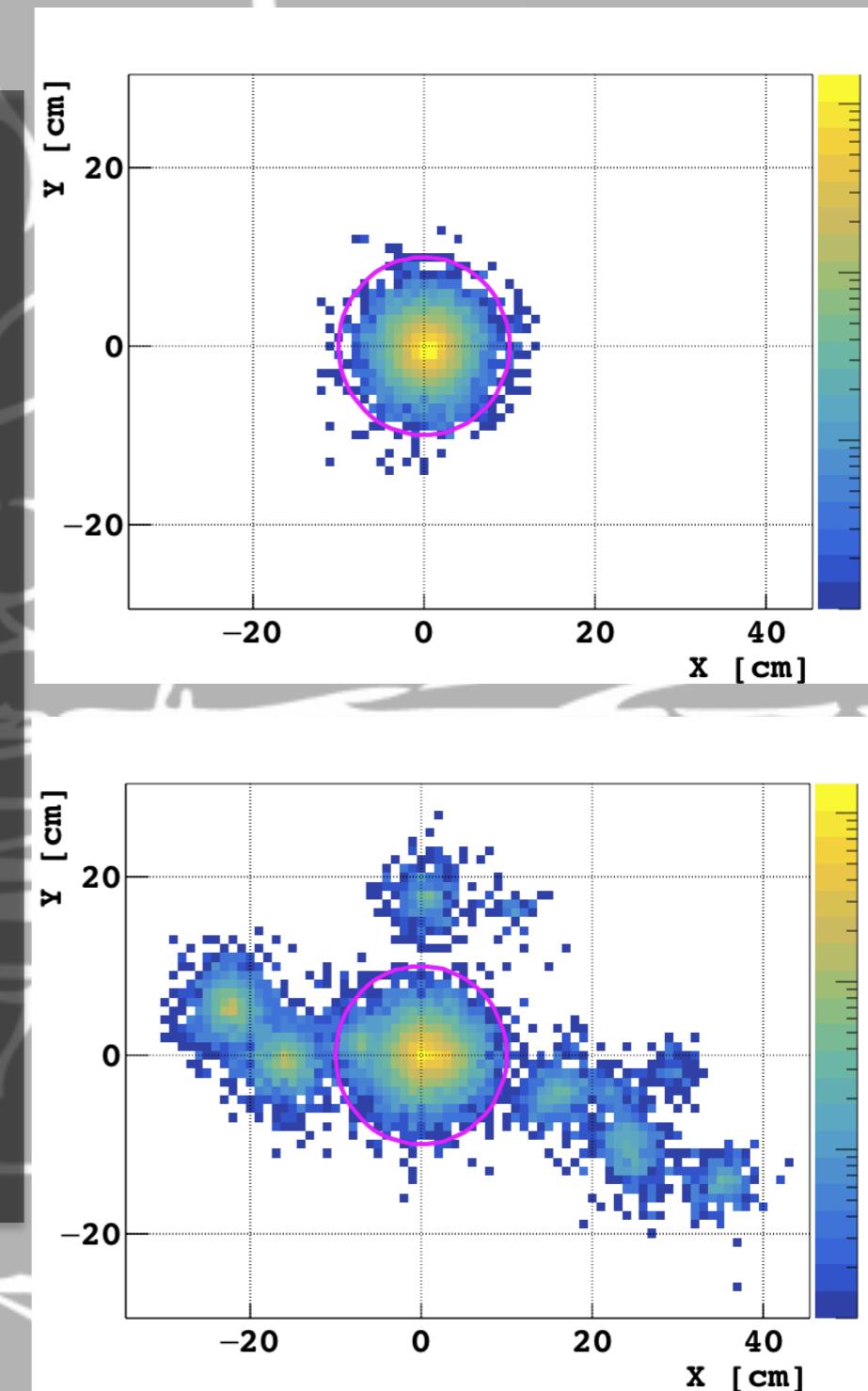
**LiquidO ≈ PID ⊕ (high) Doping**

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

⇒ less shielding & no detector “buffer”

$\nu_e CC \rightarrow e^-$

$\bar{\nu}_e CC \rightarrow e^+$



**a breakthrough capability up to  $\sim 1$  MeV**  
(CPV, supernovae, background rejection, etc)

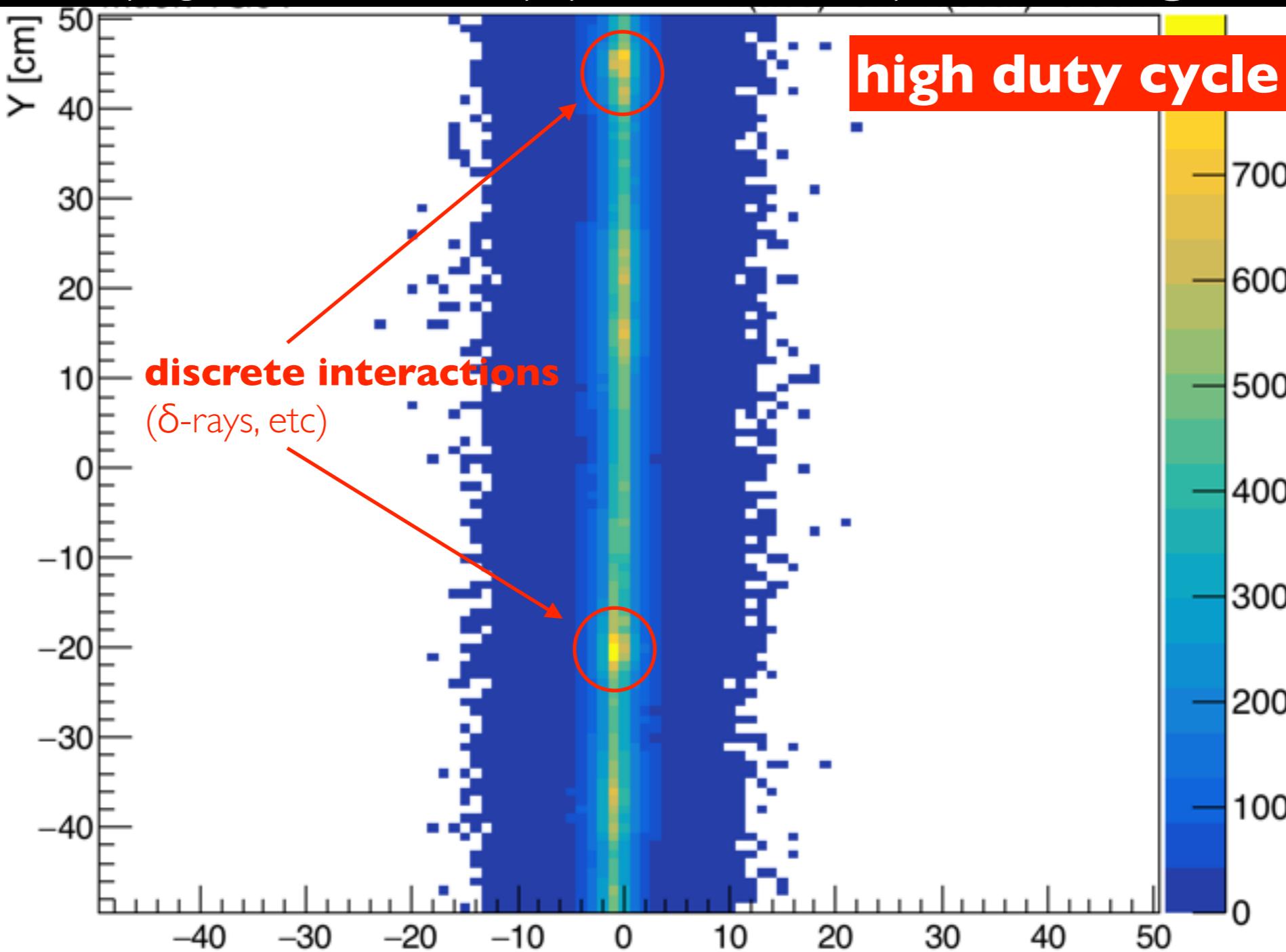
alleviate an (expensive) issue...?

# reduce (eliminate) overburden?



**lesson:** avoid (if possible) civil construction...

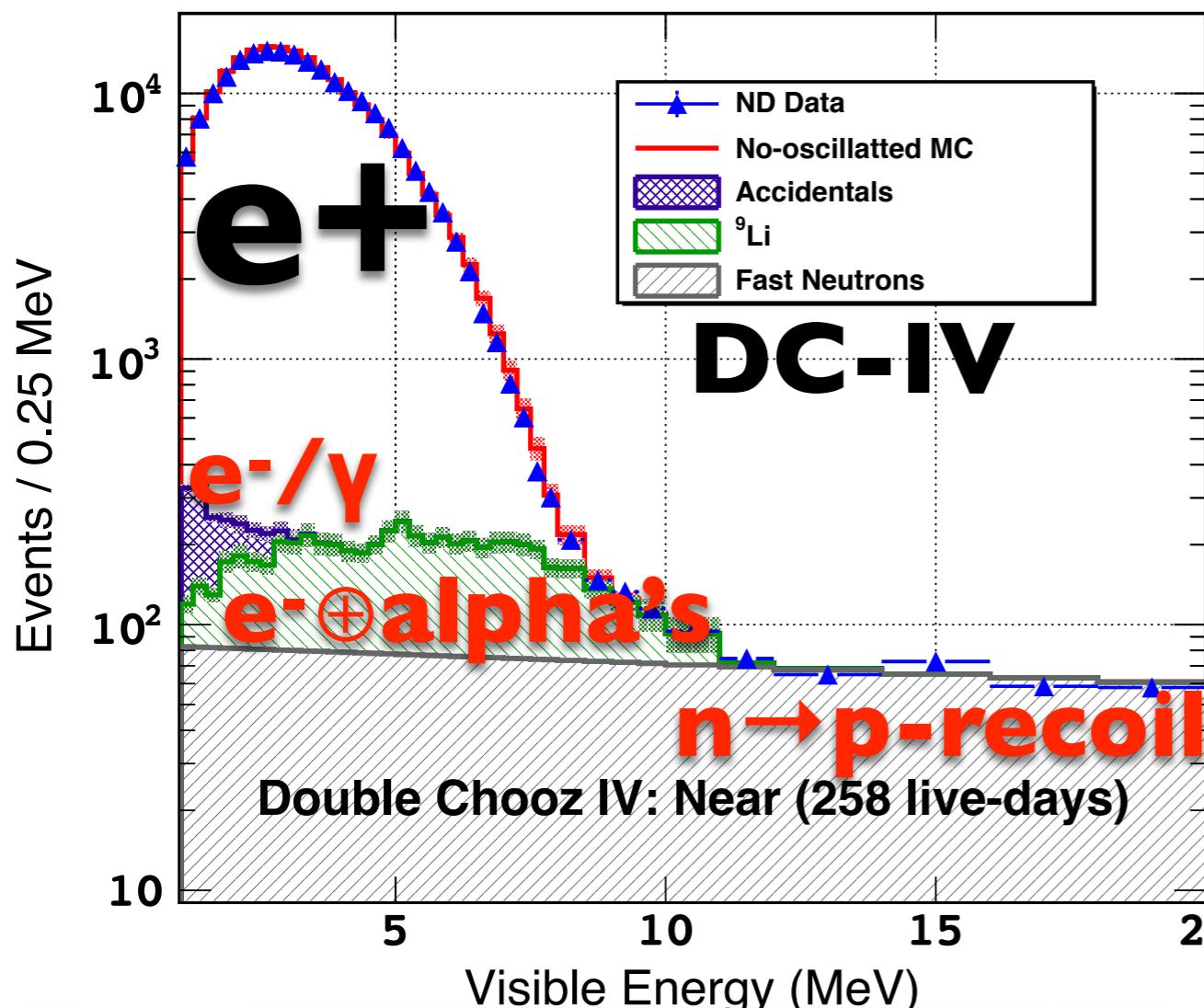
**(no  $\mu$  saturation)** light confined locally ( $MIP \approx 2.2\text{MeV}/\text{cm}$ )  $\rightarrow$  **stunning mm-tracking**



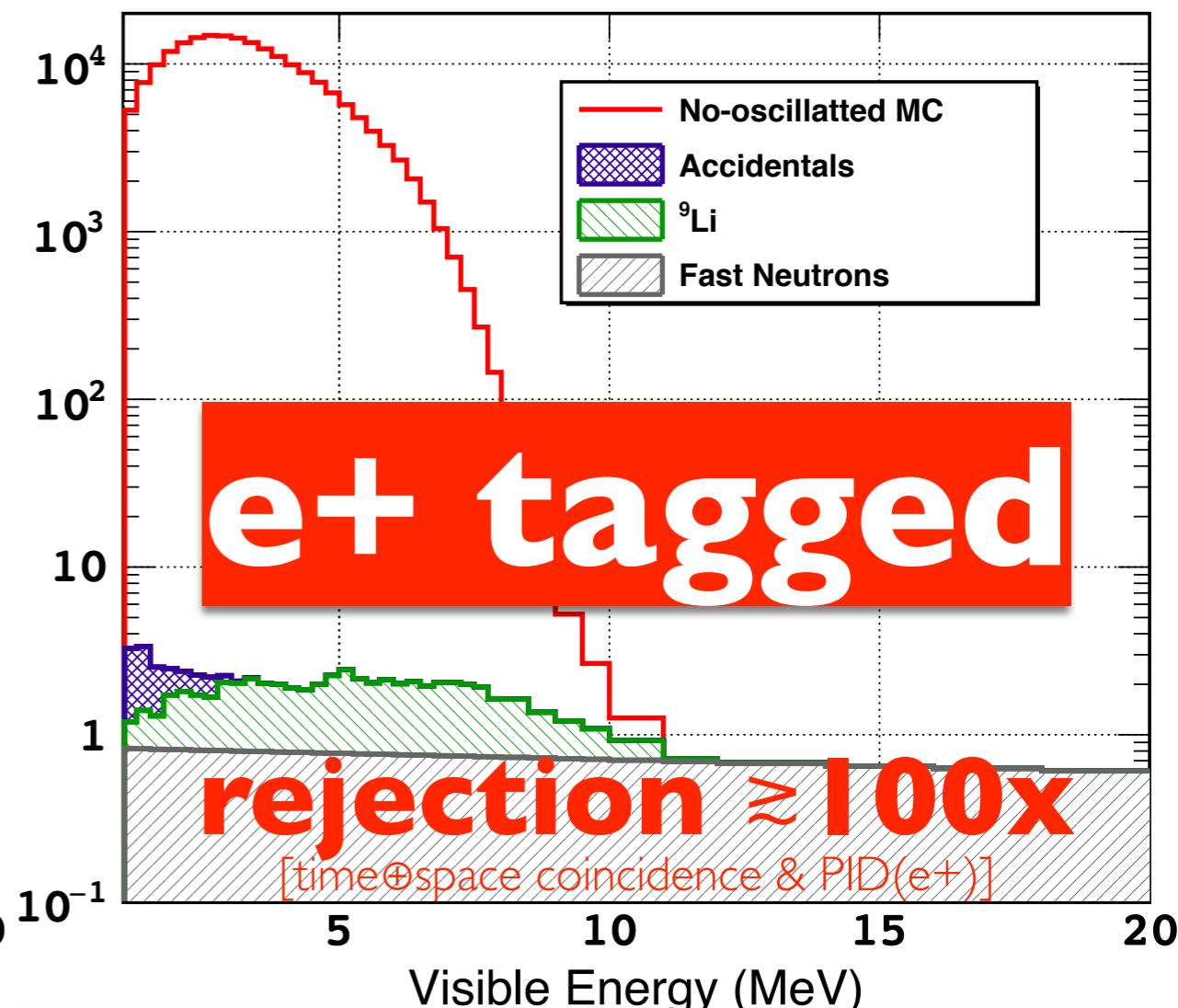
**cosmogenic accurate tagging?**

high precision ( $\leq \text{mm}$ )  $\mu$ -tracking...

(30m overburden)



Double Chooz IV: Near (258 live-days)



state of the art

Signal:Background ~30:I (30m overburden)

Background: few/day

LiquidO

Signal:Background ≥ 100×30:I

Background: few/year

towards background-less...

# huge physics range...

- reduce overburden / passive shield dependences? [very expensive]
- reactor neutrino → BG-less? / on surface? [fundamental & innovation]
- geo-neutrino → high precision U/Th & the unobserved K component?
- solar neutrino → revival indium (i.e. coincidence): “high precision pp”?
- $\beta\beta$  → multi-ton Te (only solution?): active  $\gamma$  rejection & final-state analysis
- supernovae → simultaneous CC  $\nu(e)$  and anti- $\nu(e)$  and NC?
- discoveries beyond neutrino oscillation: CPT and/or Unitarity violation?
- new ideas?

MeV physics potential...



my bias (I could be wrong): **not easy for LiquidO** (with liquid scintillation)

→ **too little light & little (or no) topology info (density)**

# LiquidO potential @ keV...?

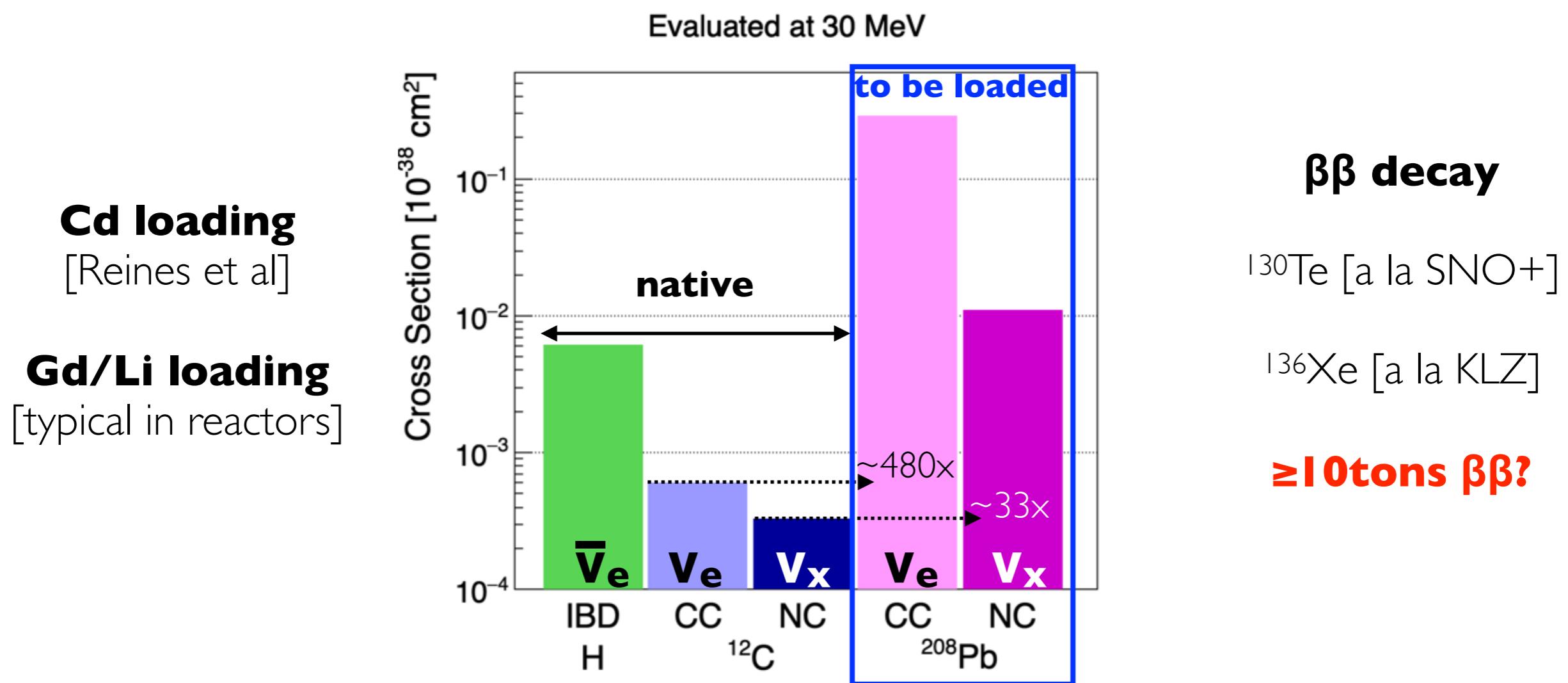
indeed, **Opaque** seems **a solution...**!  
(the solution?)

**LiquidO is still more!**

beyond the native composition...

**organic scintillator = H +  $^{12}\text{C}$  +  $^{12}\text{C}$ (~1%)** [+ impurities]

**detection efficiency enhancement**    **neutrino interaction(s) enhancement**    **rare decay source enhancement**



# LiquidO seems very versatile!

how does LiquidO work?



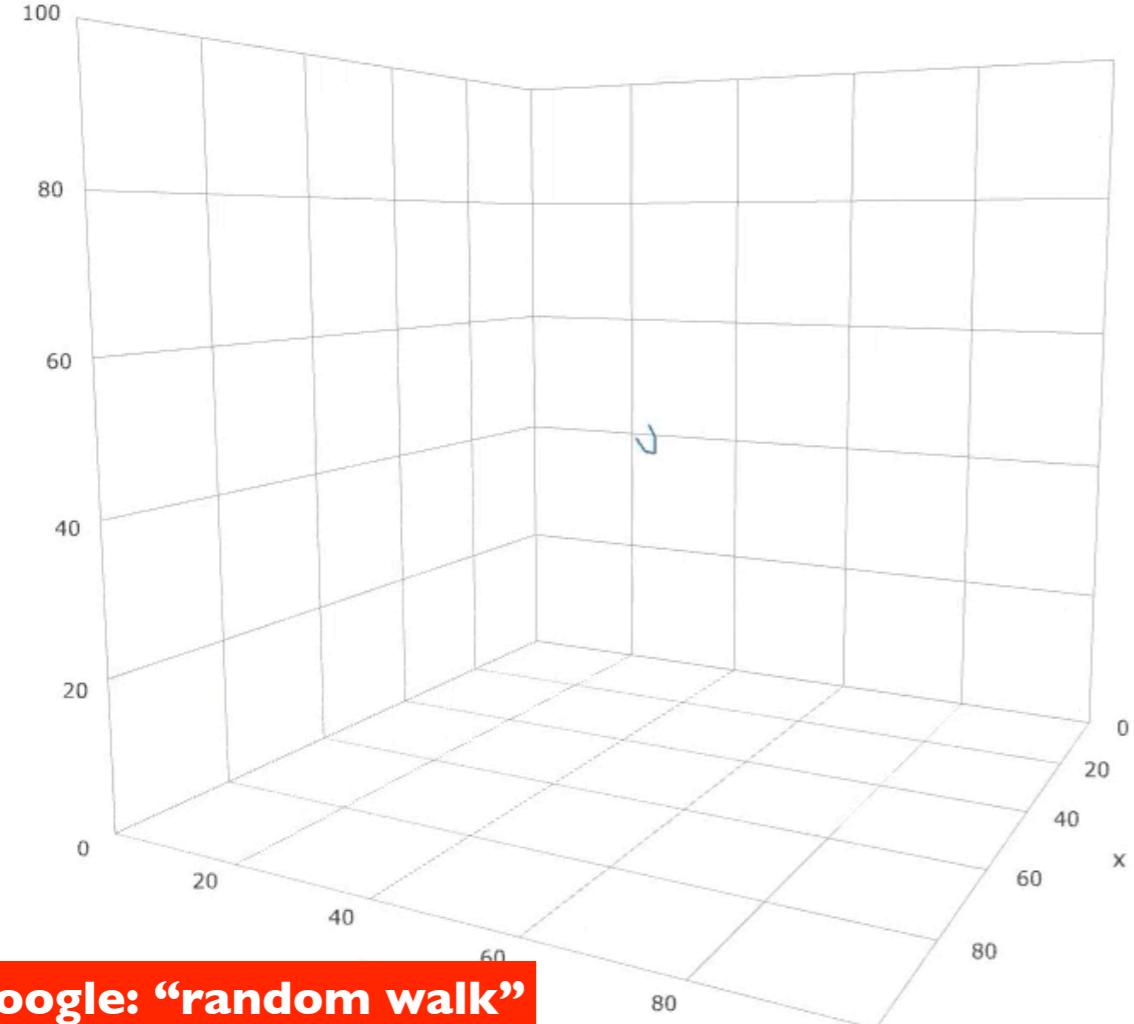
## LiquidO: opacity-based light collection system

**any source** (Cherenkov / scintillation / others?)

**any media** (liquid / solid / (impractical?) gas)

**doping:** a powerful (optional) “byproduct”

the quintessence of LiquidO...



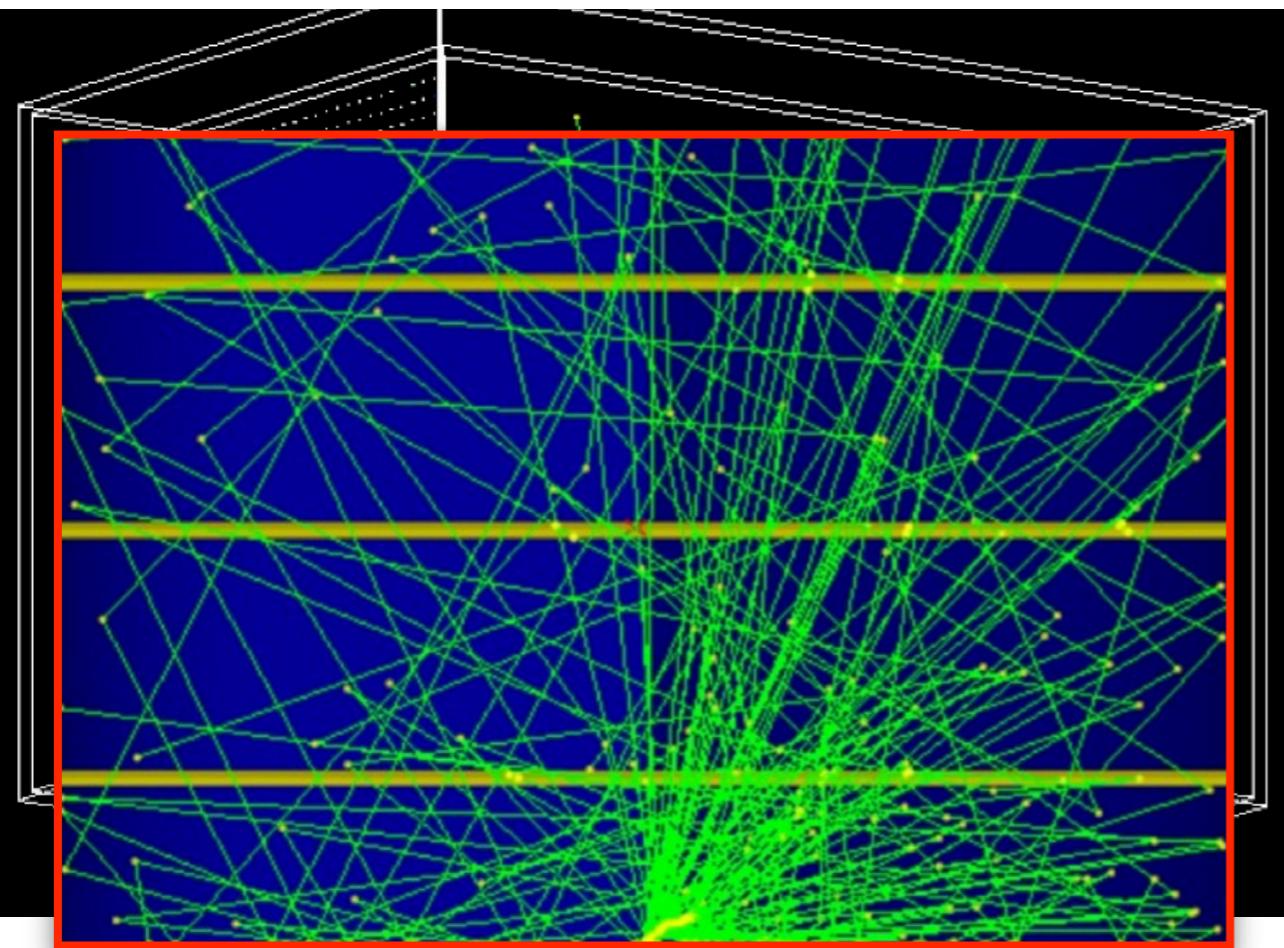
- **scattering → random walk → light ball** [order 1 cm]
    - scattering mean-free-path order 1 mm:  $\times 10^{-4}$  smaller than usual
  - **lossless scattering:**
    - **Mie scattering:** achromatic & tiny losses (“cloudy” touch)
    - **Raleigh scattering:** chromatic & lossless
    - **Internal Reflection** (Snell’s law lossless)
- warning:** avoid reflection (losses @ order  $\sim 1\%/\text{reflection}$ )

**LiquidO  $\Leftrightarrow$  unique stochastic light confinement**  
 $\Rightarrow$  must NOT be transparent!!

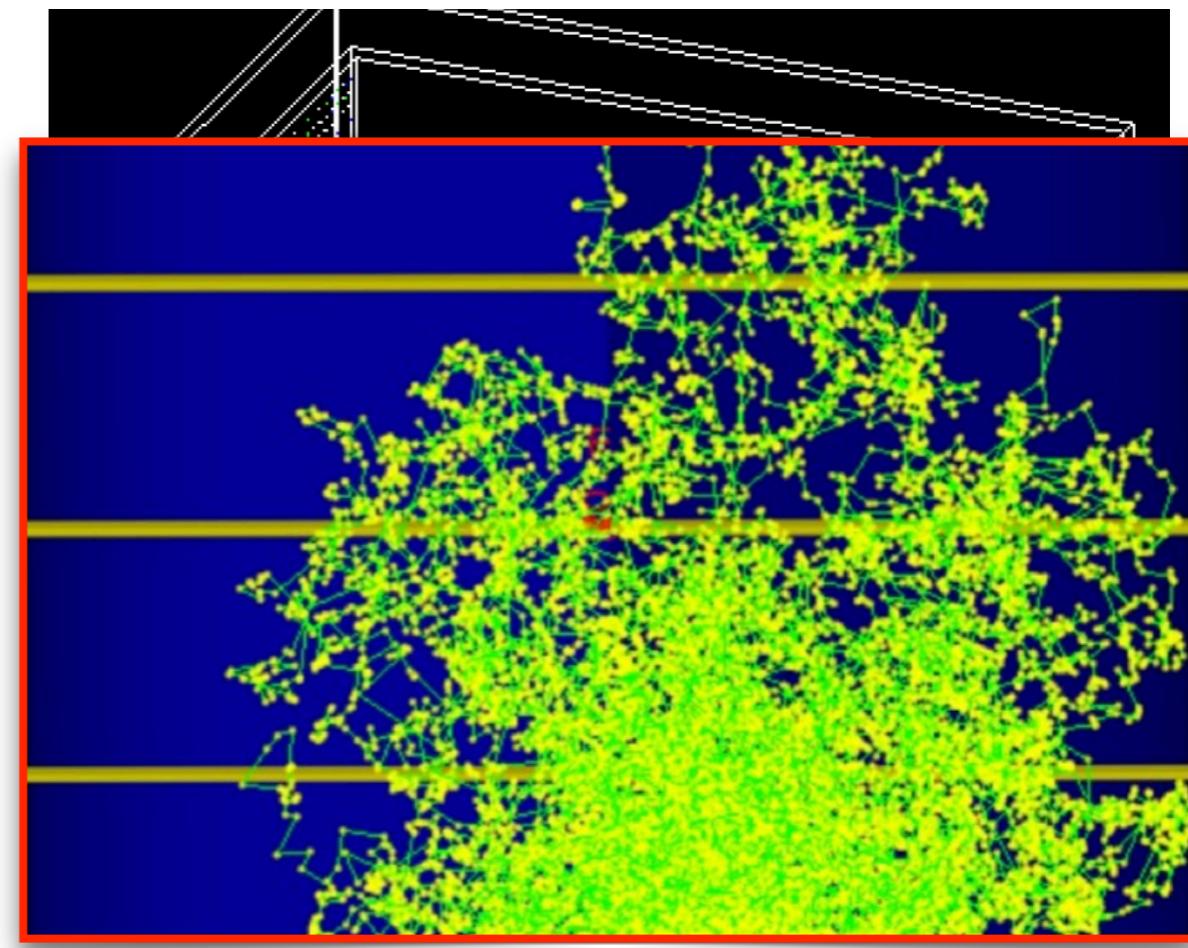


confine light locally...

# LiquidO's new paradigm for light detection...

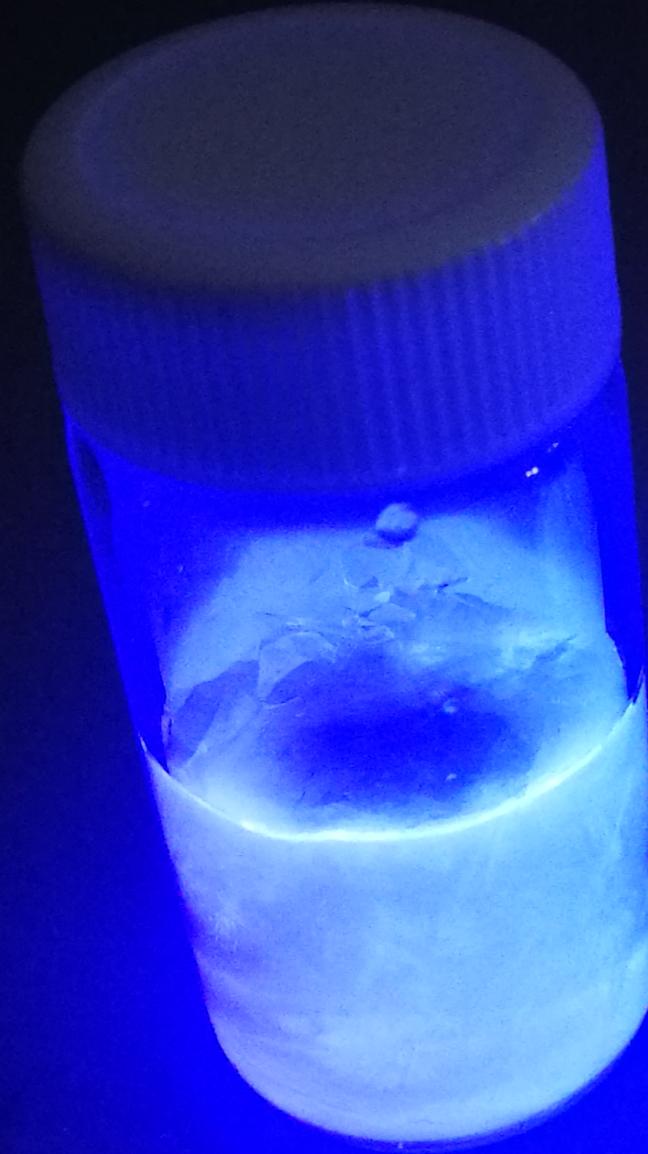


**today's technology**



**LiquidO technology**

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



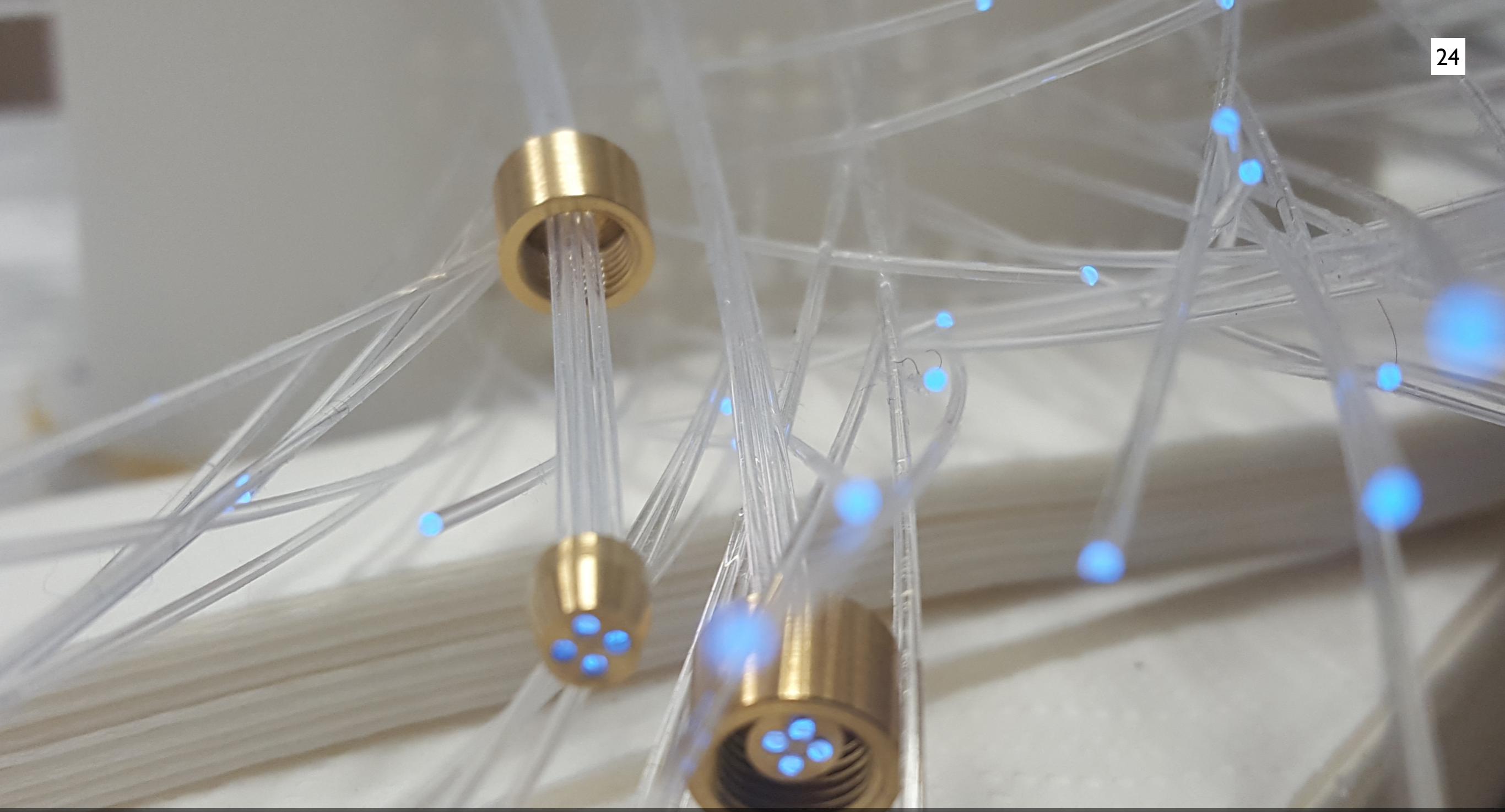
**“waxy” behaviour**  
**(solidifies @ room temperature)**



@MPIK

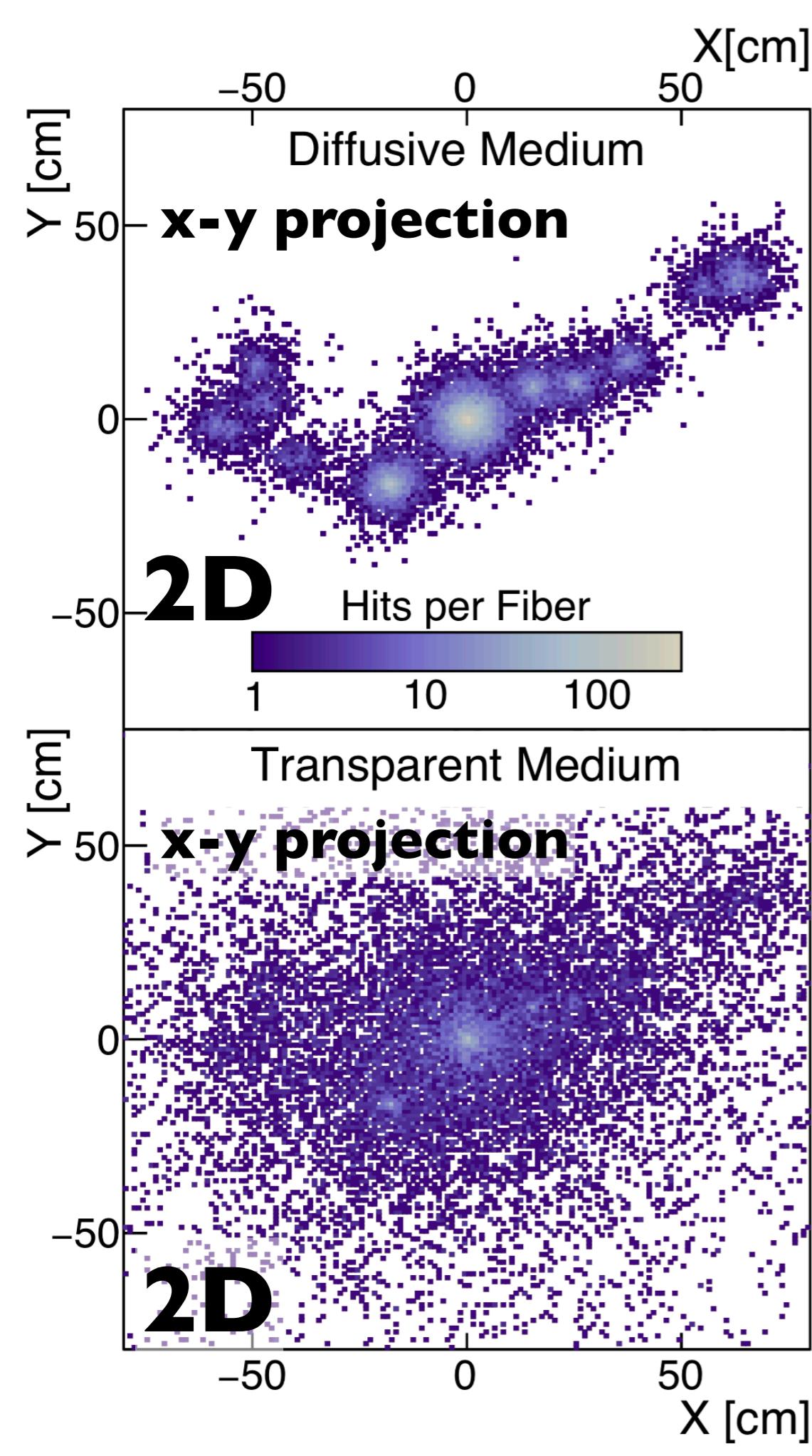
arXiv:1908.03334v2 [physics.ins-det] 5 Nov 2019

our first opaque scintillator...



along with WF-fibres...

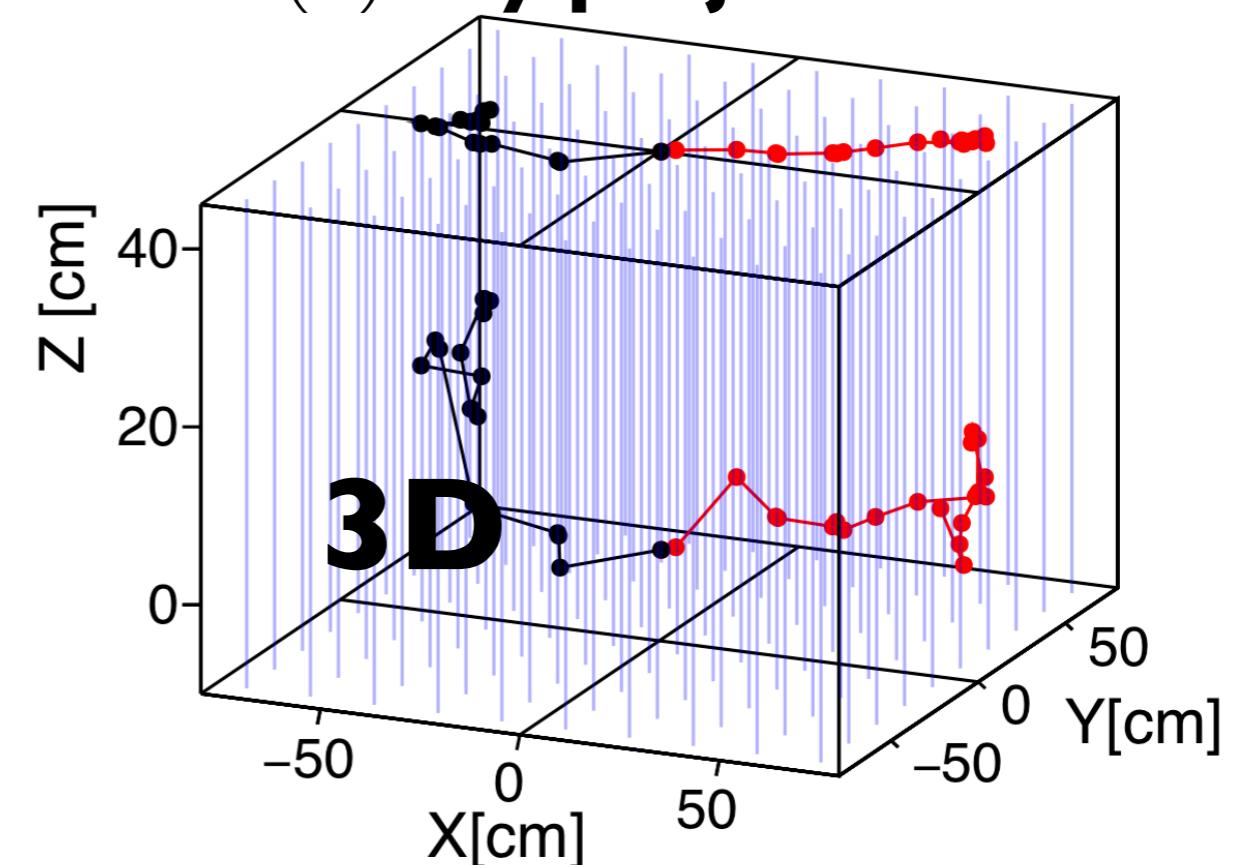
LiquidO's multi-axes...



# LiquidO

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

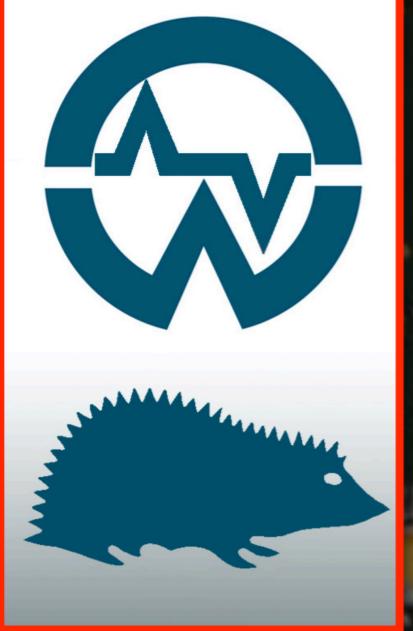
(↑) **x-y projection**



**z projection (not yet fully exploited)**

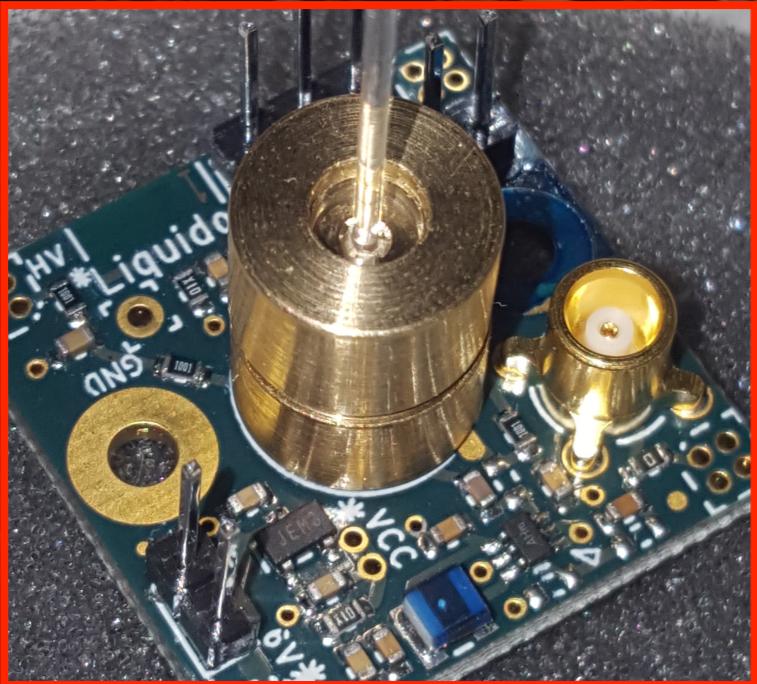
**Transparent Scintillator<sup>⊕</sup> Fibres**

# powerful & fast readout...



scintillation+Cherenkov

few-PE's pulses (order  $\sim 100\text{ps}$  resolution)

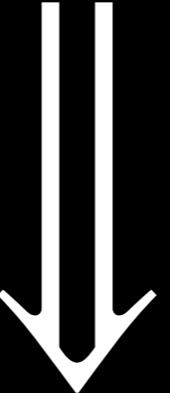


(expected) **time resolution:  $\leq 100\text{ps/PE}$**   
(i.e.  $\leq 3\text{cm/PE}$  @ speed of light)

# LiquidO: light “opaque” medium

[*stochastic light confinement* → imaging ⊕ topology & **PID**]

**vocabulary:** “opacity” ≈ “brutal translucency”



# LiquidO ≈ “light TPC” ⊕ “4π ToF” (**4D info**)

[highest duty-cycle & high acceptance → minimal pile-up]

what's LiquidO?



# LiquidO [scintillation based for now, but also beyond]

art of **clustering light (transparency)** with **excellent imaging/PID** & lots of **doping** (purity)  
 [light clustering for direct imaging]

## main features...

- **static images [photo-like]**
- **dynamic images expected [film-like]**
  
- **low Z** ( $\leq 20\%$  of H &  $^{12}\text{C}$  + **doping**)
  - excellent **native radiopurity** and **isotopic-purity**
  
- **fast duty cycle** (detection at speed of light)
  
- a priori **scaling to large size** (MeV in a NOvA size detector?)
  
- **liquid** (fill & purify) → possible **solidification [new!]**
  - “cooled” **room temperature** — **NO cryogenics**
  
- possible **magnetisation**
  
- ⇒ **huge physics potential !!**

**our R&D still ongoing: several results in 2021 (COVID allowing)**

**questions, please?**

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merci...  
 спасиб...  
 ありがとう...  
 danke...  
 고맙습니다...  
 obrigado...  
 Спасибо...  
 grazie...  
 谢谢...  
 hvala...  
 gracias...  
 شکرا...  
 thanks...

## Neutrino Physics with an Opaque Detector

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August 9, 2019

The discovery of the neutrino by Reines & Cowan in 1956 revolutionised our understanding of the universe at its most fundamental level and provided a new probe with which to explore the cosmos. Furthermore, it laid the groundwork for one of the most successful and widely used neutrino detection technologies to date: the liquid scintillator detector. In these detectors, the light produced by particle interactions propagates across transparent scintillator volumes to surrounding photo-sensors. This article introduces a new approach, called LiquidO, that breaks

with the conventional paradigm of transparency by confining and collecting light near its creation point with an opaque scintillator and a dense array of fibres. The principles behind LiquidO's detection technique and the results of the first experimental validation are presented. The LiquidO technique provides high-resolution imaging that enables highly efficient identification of individual particles event-by-event. Additionally, the exploitation of an opaque medium gives LiquidO natural affinity for using dopants at unprecedented levels. With these and other capabilities, LiquidO has the potential to unlock new opportunities in neutrino physics, some of which are discussed here.

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<sup>†</sup>Also at Observatório Nacional, Rio de Janeiro, Brasil

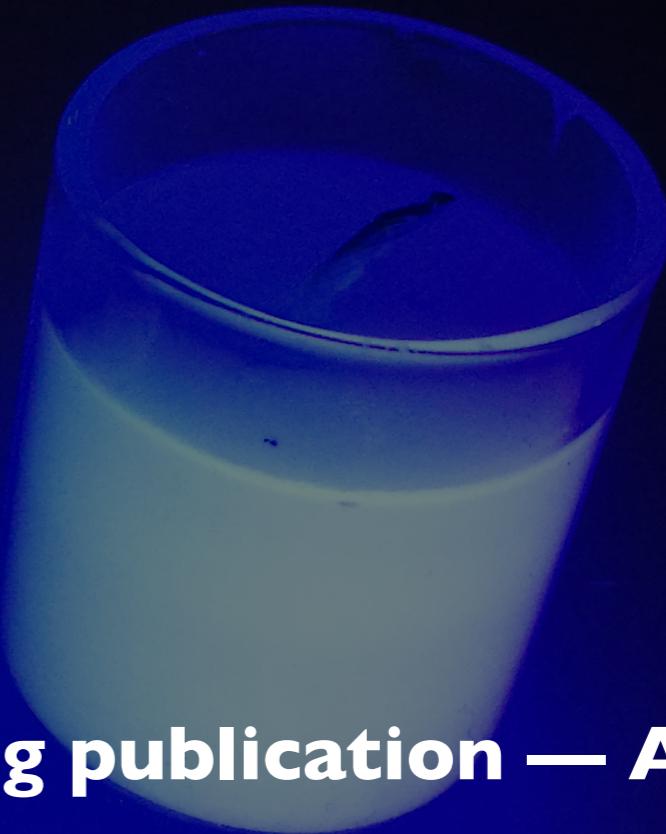
<sup>‡</sup>Deceased.

<sup>§</sup>Blaise Paschal Chaire Fellow.

# LiquidO full release 2019...

## Seminar@CERN — June 2019

Web: <https://indico.cern.ch/event/823865/>



## Igniting publication — Aug 2019

### LiquidO @ arXiv:1908.02859

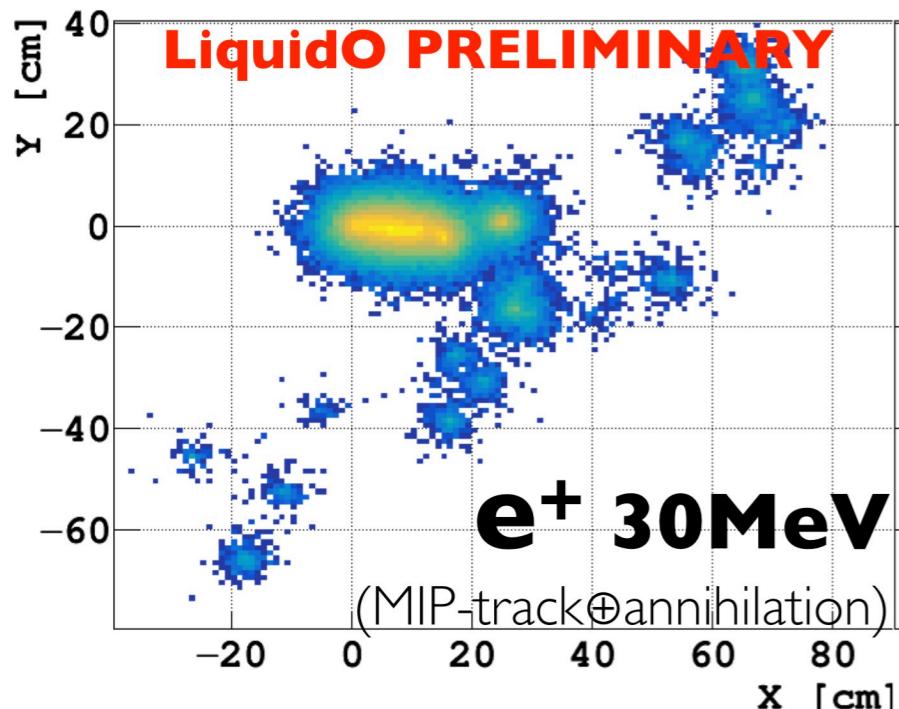
- new detection principle
- first experimental proof-of principle
- vast neutrino physics prospect

Submitted to Nature's “Physics Communication”

First Opaque Liquid Scintillator @ [arXiv:1908.03334](https://arxiv.org/abs/1908.03334)

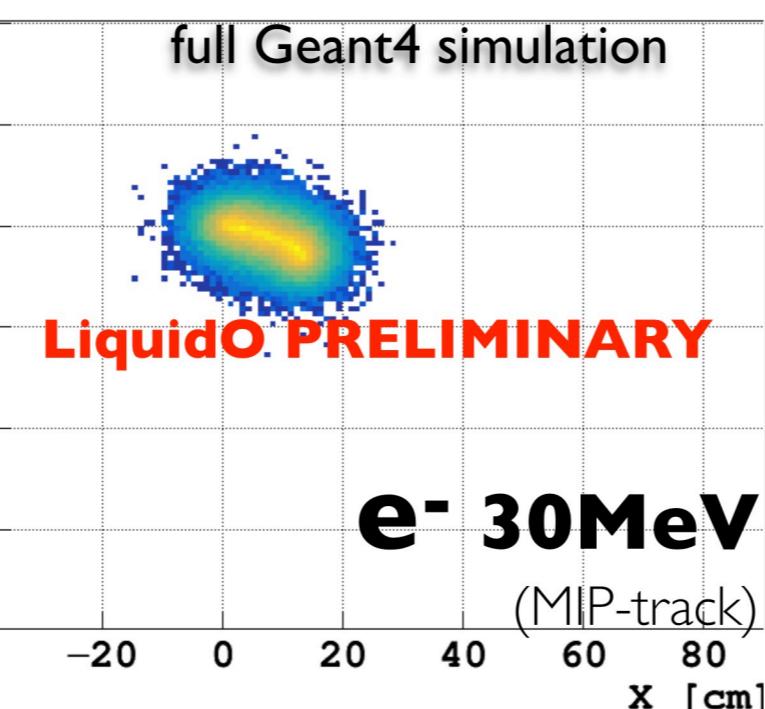
$e^+ \leftrightarrow \text{anti-}\nu(e)$

[IBD interaction]

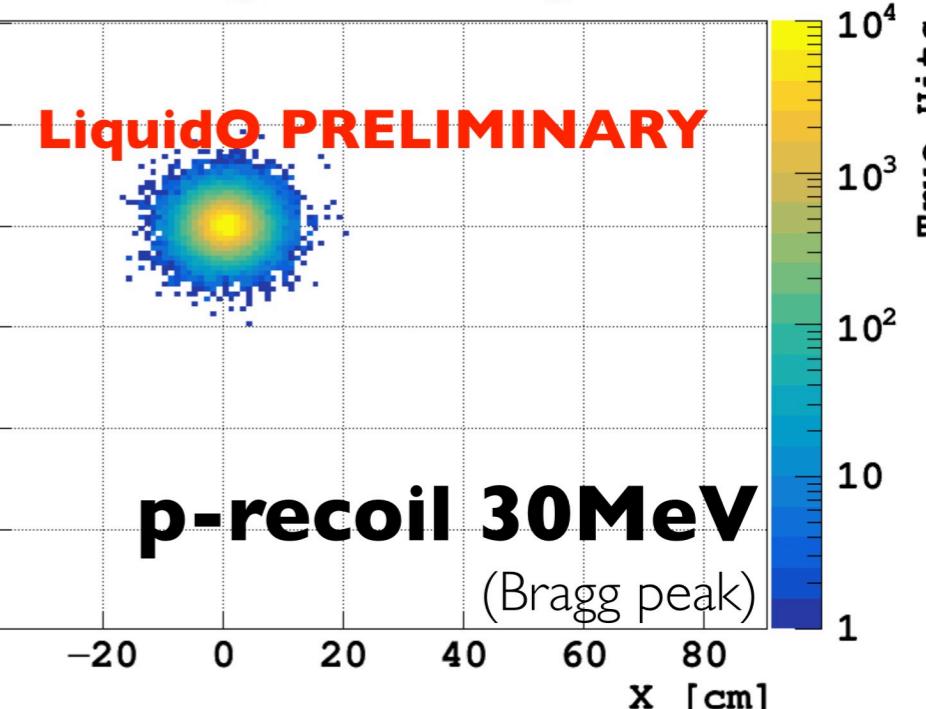


$e^- \leftrightarrow \nu(e)$

[ $^{12}\text{C}/\text{new interaction}$ ] [cosmogenic background]



p-recoil



PID  $\leq 100\text{MeV}$  (limited Bremsing)