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?***

R&T Workshop (IJCLab, Orsay)

October 2021

Anatael Cabrera

CNRS/IN2P3

IJCLab (Orsay)

LNCA (Chooz)

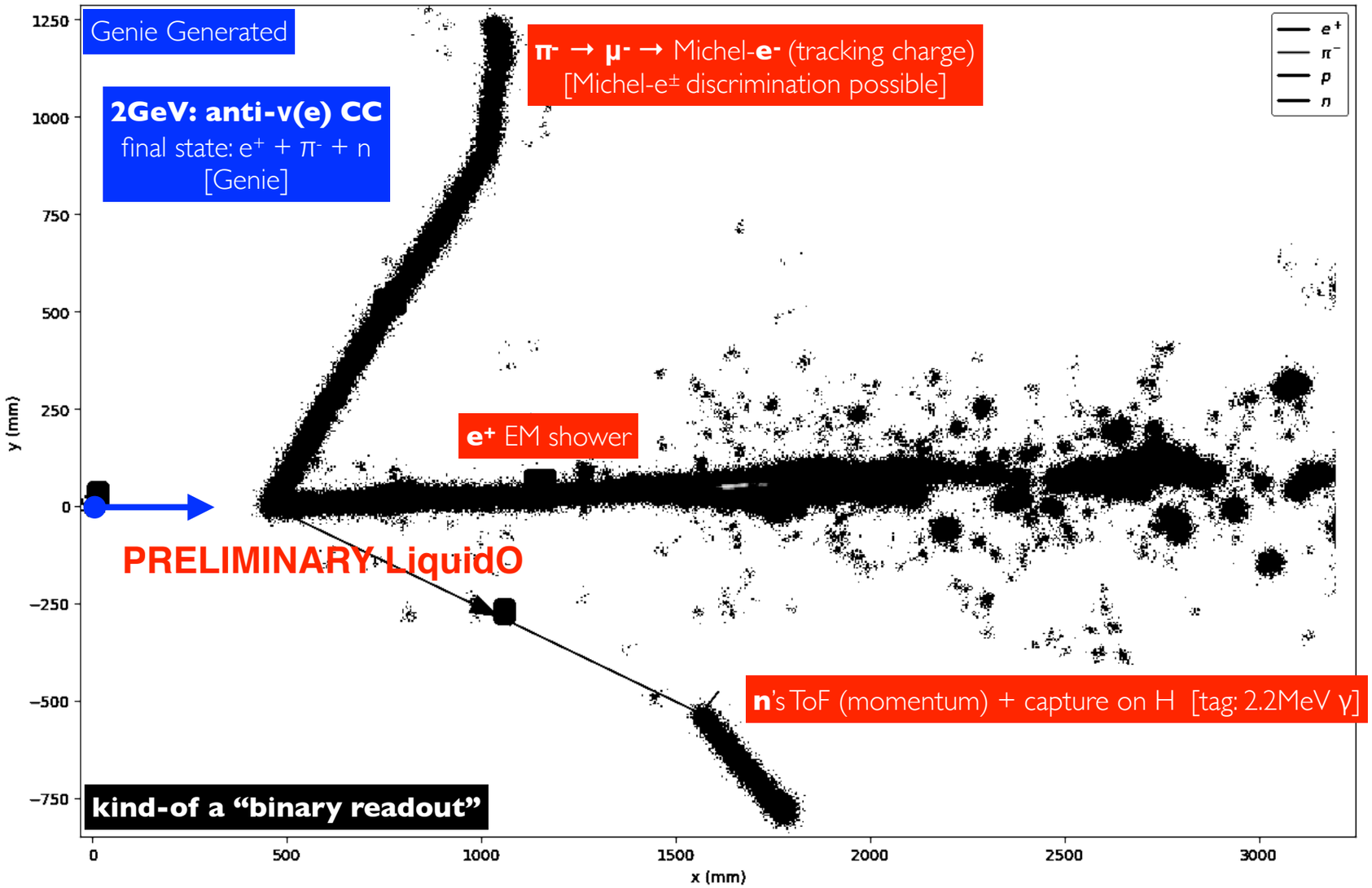
an **Opaque** solution…?

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

let’ see…

LiquidO potential @ GeV…

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



Large Events: low-z (H⊕C)
[H is ≤20%/volume]

Clean Nuclear Physics on H
(sub-sample ⇔ normalisation)

C (99%: 6n⊕6p) **+ any element** (doped)

Full Topology (track, showers, etc)
- tracking: ≤1mm precision
- shower: clean first radiation lengths

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

Neutral Charge Particle Detection too
(neutron, π^0, missing momenta, etc)

High Precision Calorimetry
(per mille precision)

GeV but sees MeV physics too
(more experimental handles)

Up to ~100ps resolution per channel
(enable **"energy-flow"**)

Highest Duty-Cycle⊕Stochastic Confinement
(close to surface)

Stochastic calorimetry term : ≈0.3% [~100 000 PE/GeV]
[10 000 γ's per MeV ⊕ **1%** detection ≈ 100 PE/MeV→ 10% calorimetry]

Cost:
- Liquid Scintillator (≤1.0k€/ton) / WbLS (≤??€/ton)
- Fibres (≤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 ν's...

EXPLORATION
HEP Calorimetry for Colliders@IJCLab
[PowderO]

EXPLORATION
[LiquidO]

vast physics range...

- **near-detector physics @ DUNE and/or @HyperK...**
  - **Native H (→*accurate neutrino energy reco*) and C (6n⊕6p)**
  - **@DUNE:** load with **Ar? (gas in liquid)**
  - **@HyperK:** load with **O? (gas in liquid) [→water based liquid scintillator?]**
  - **@NuStorm detector —** load with any strategical element **X (nuclear effects)**

- **far-detector physics: the 4th FD of DUNE? [order 10kton seems OK: NOvA]**

- **specialised atmospheric neutrino detector for CP-Violation?**

- **multi-channel proton-decay→ different models sensitivity**

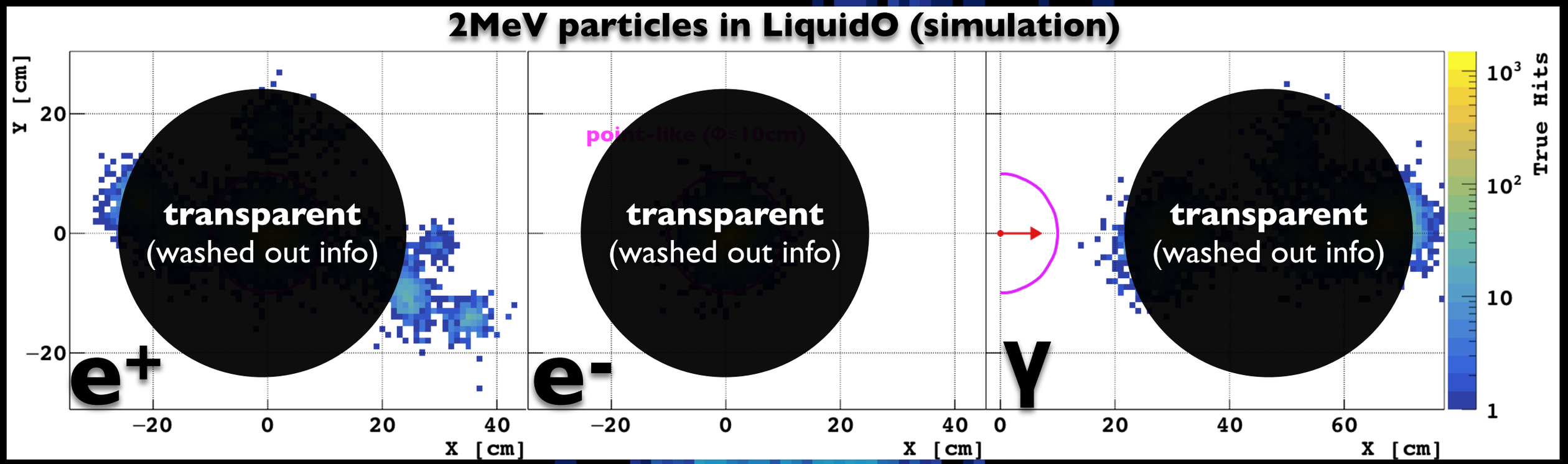
- **new ideas?**

GeV physics potential...

LiquidO potential @ MeV…

LiquidO in a nut-shell…

Imaging→powerful Particle-IDentification (PID)

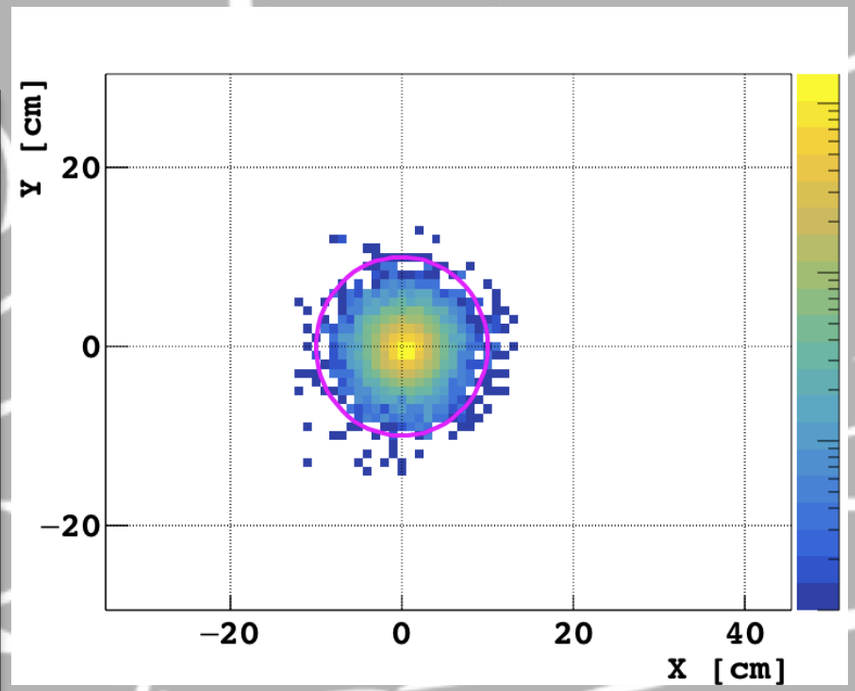


LiquidO ≈ PID ⊕ (high) Doping

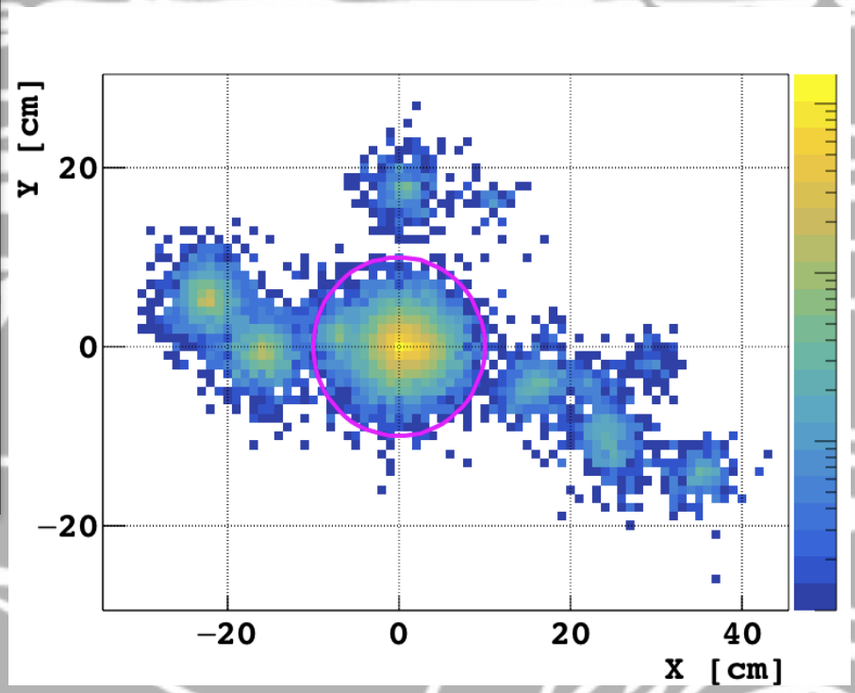
physics beyond detector "native composition" (H,C)

⟹ less shielding & no detector "buffer"

ν_e CC → e^-



$\bar{\nu}_e$ CC → e^+



a breakthrough capability up to ~1MeV

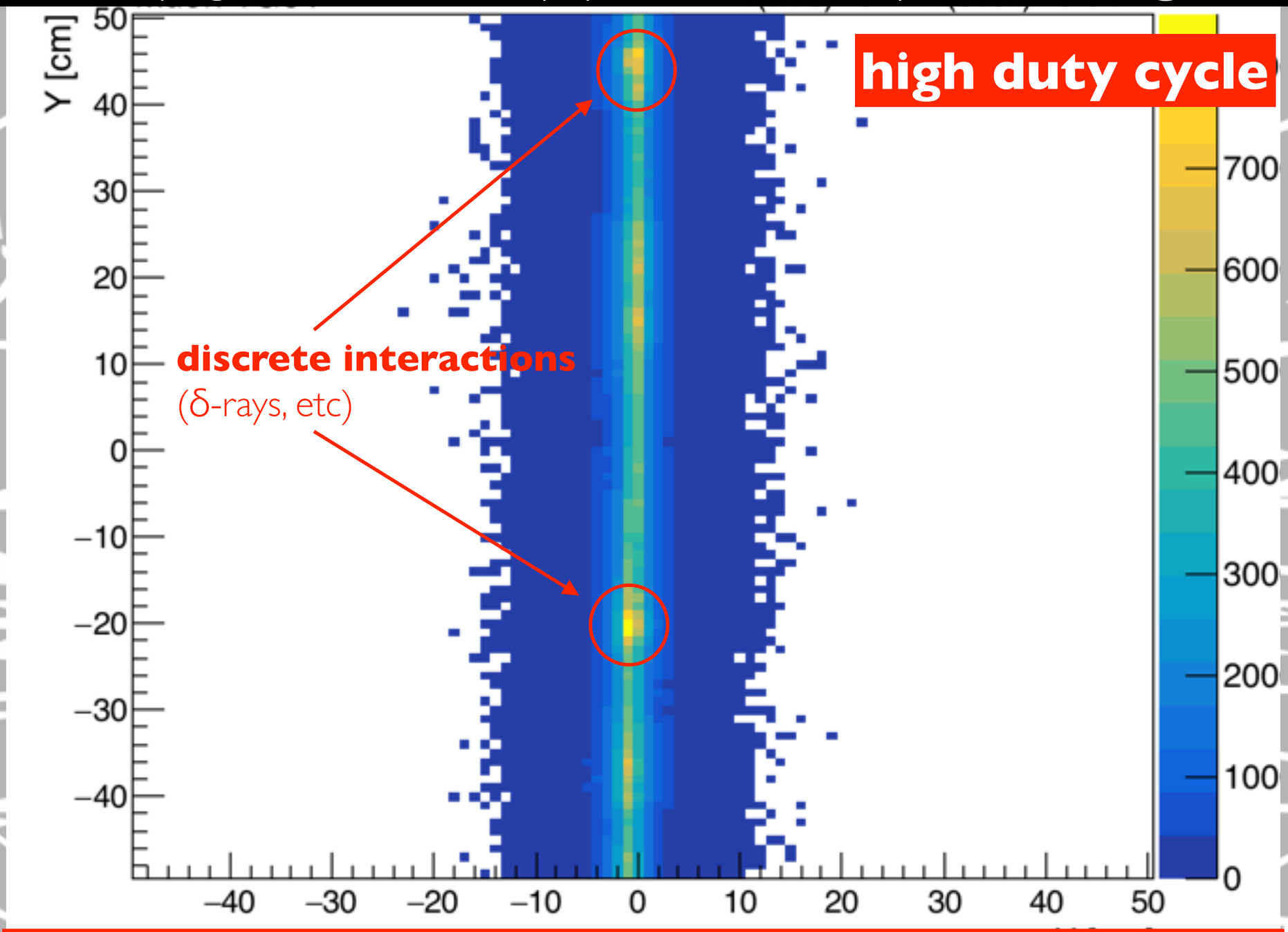
(CPV, supernovae, background rejection, etc)

alleviate an (expensive) issue…?

reduce (eliminate) overburden?

lesson: avoid (if possible) civil construction…

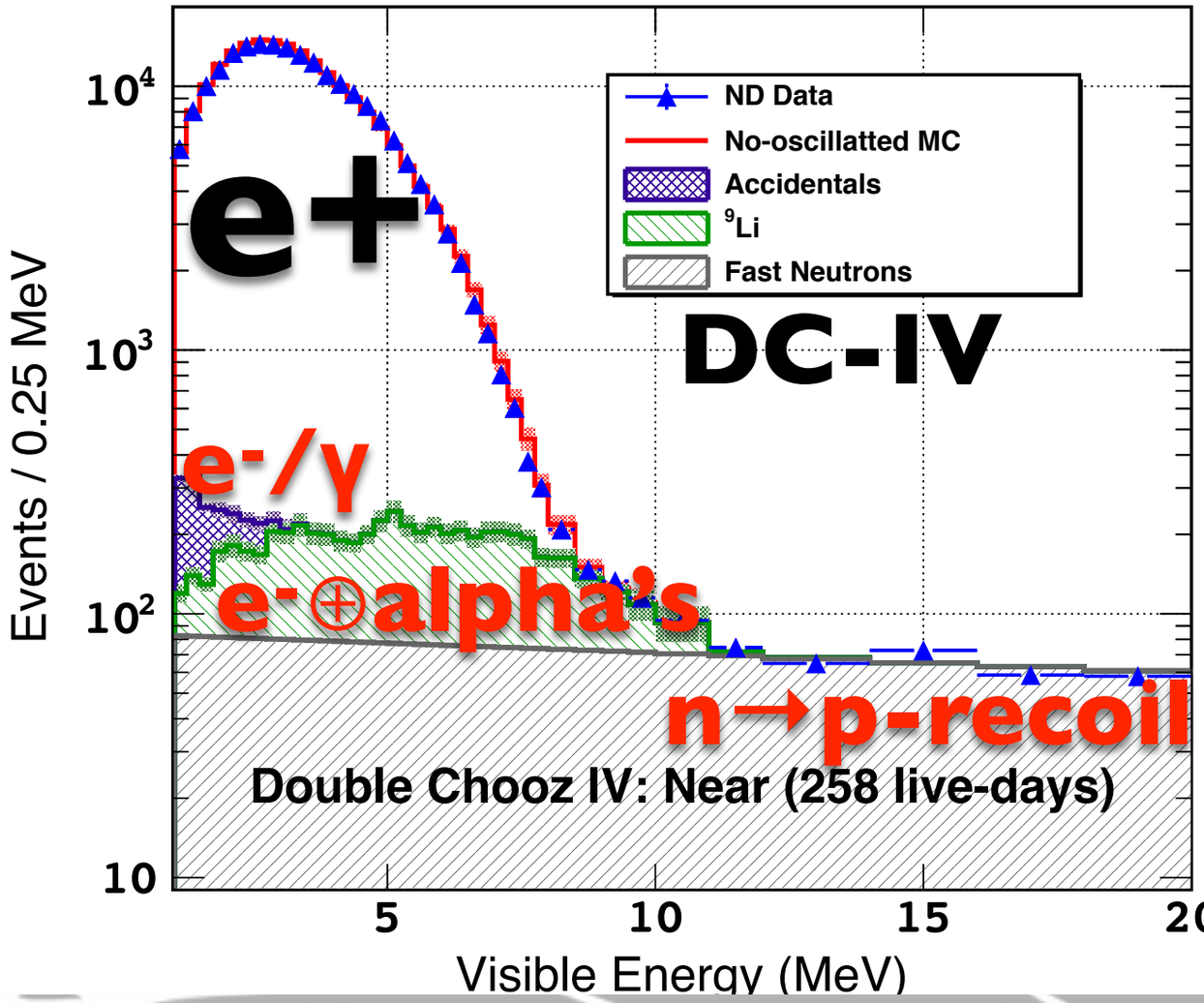
(**no μ saturation**) light confined locally (MIP≈2.2MeV/cm)→ **stunning mm-tracking**

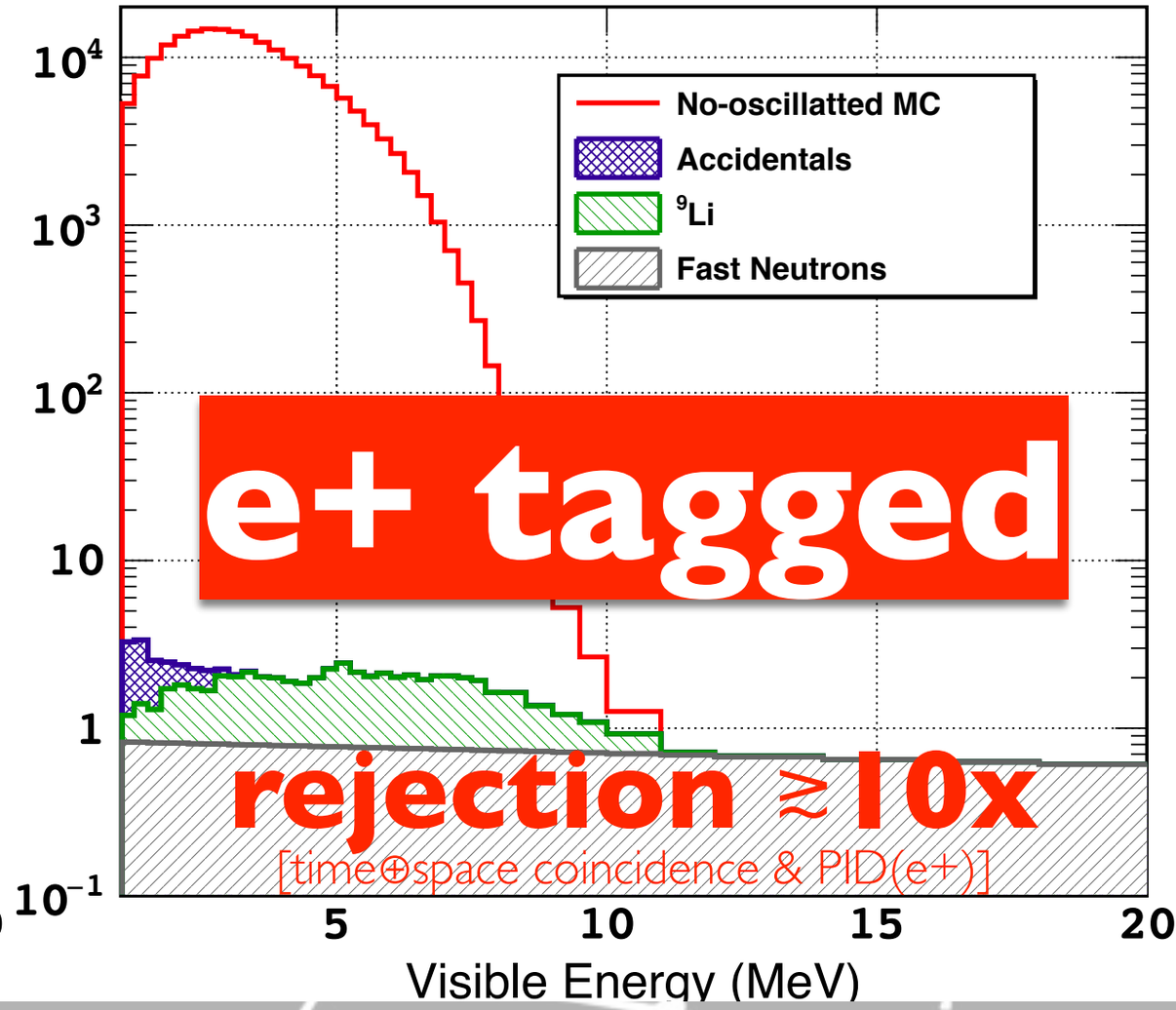


cosmogenic accurate tagging?

high precision (≤mm) μ-tracking…

(30m overburden)





state of the art

Signal:Background ~30:1 (30m overburden)

Background: few/day

LiquidO

Signal:Background ≳10×30:1

Background: few/year

towards background-less…

huge physics range...

EXPLORATION
[LiquidO]

- **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**?
- **ββ** → **multi-ton multi-isotope** (Te & Ne): active γ rejection & final-state analysis
- **supernovae** → simultaneous CC ν(e) and anti-ν(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!

LiquidO seems very versatile!

how does LiquidO work?

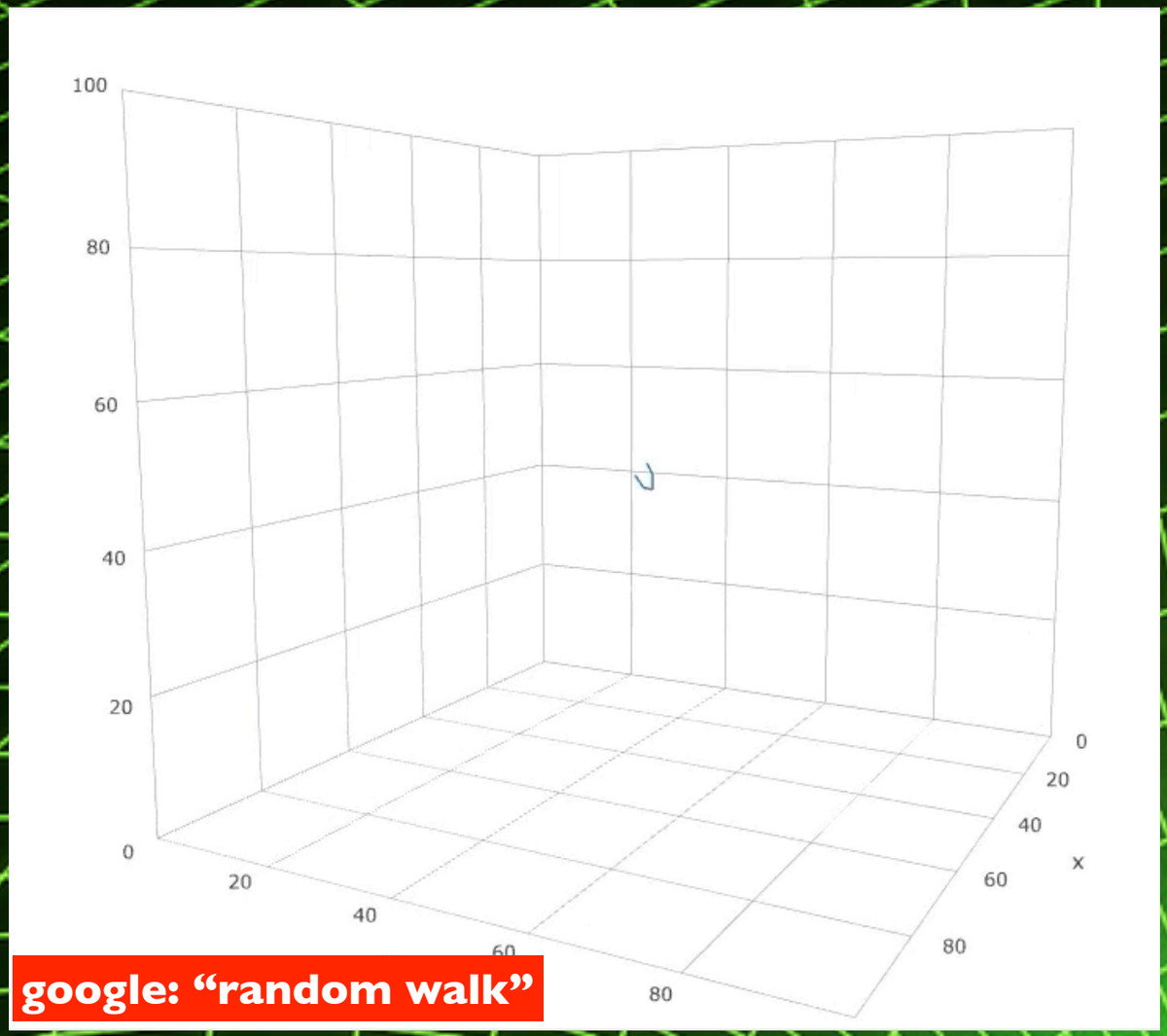
LiquidO: opacity-based light collection system

any source (Cherenkov / scintillation / others?)

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

doping: a powerful (optional) "byproduct"

the quintessence of LiquidO…



google: “random walk”

- **scattering → random walk → light ball** [order 1 cm]
  - scattering mean-free-path order 1 mm: x10^{-4} smaller than usual

- **lossless scattering:**
  - **Mie scattering:** achromatic & tiny losses [“cloudy” touch]
  - **Raleigh scattering:** chromatic & lossless
  - **Internal Reflection** (Snell’s law lossless)

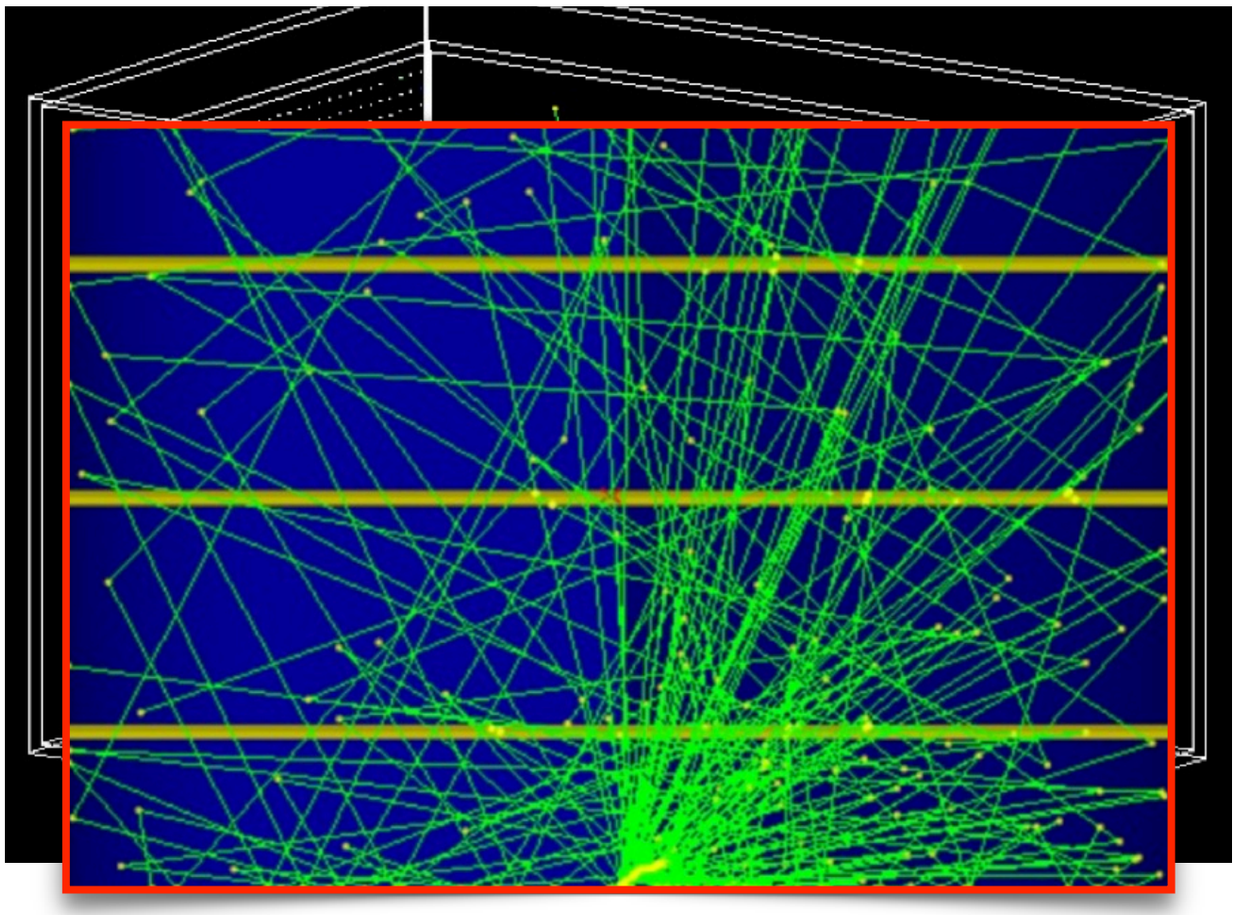
  warning: avoid reflection (losses @ order ~1%/reflection)

LiquidO ⇔ unique stochastic light confinement

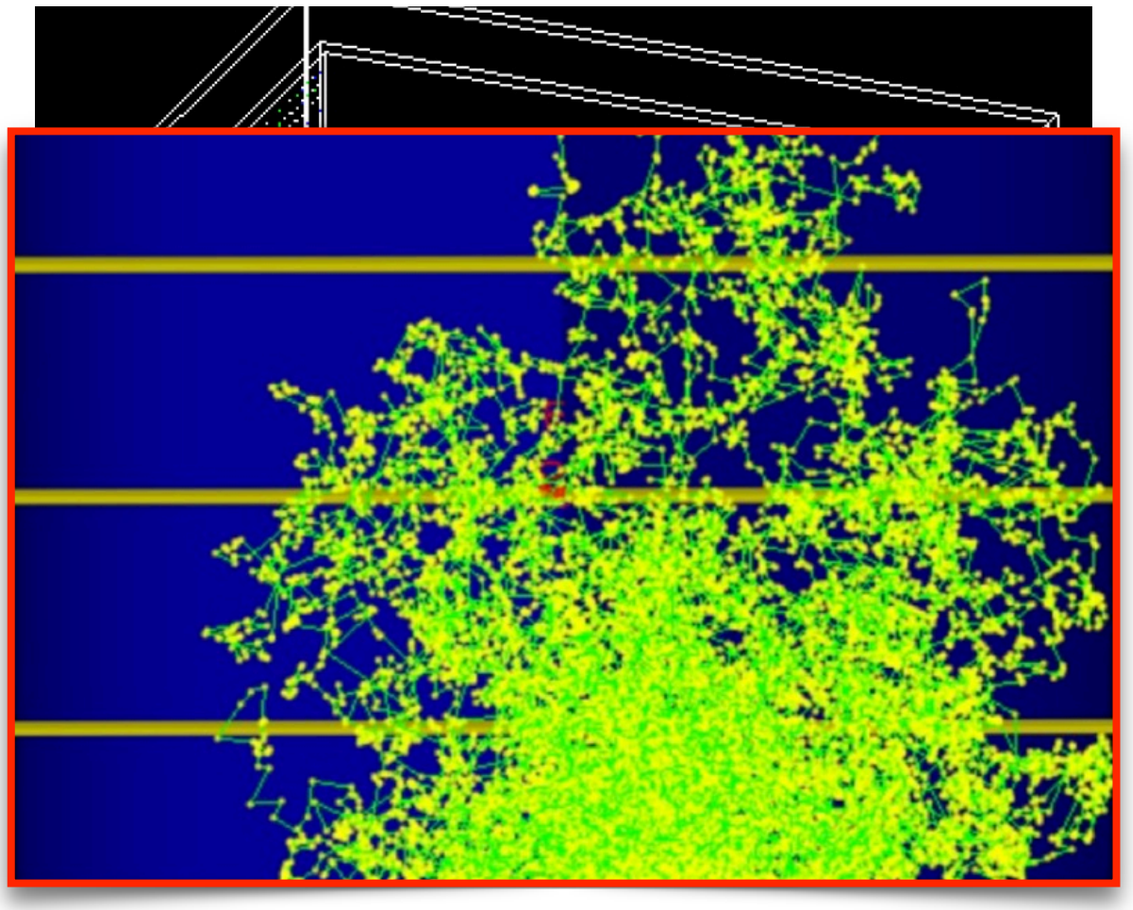
⟹ must NOT be transparent!!

stochastic light confinement…

LiquidO's new paradigm for light detection…



today's technology



LiquidO technology

light ball size: scattering⊕fibres

(sampling optimisation)

“waxy” behaviour
(solidifies @ room temperature)

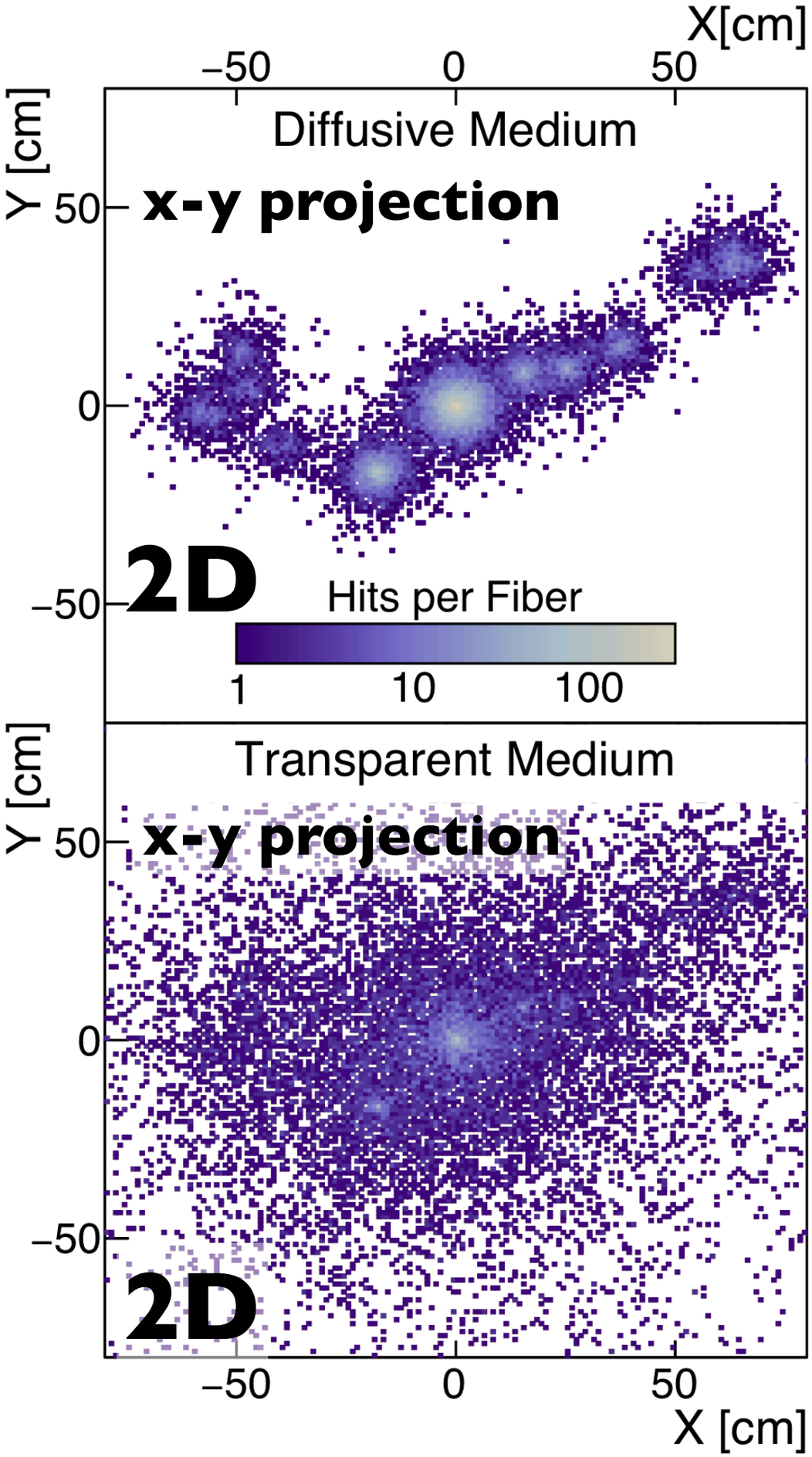
first Opaque (liquid) scintillators — new technology started here

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

our first opaque scintillator…

along with WF-fibres…

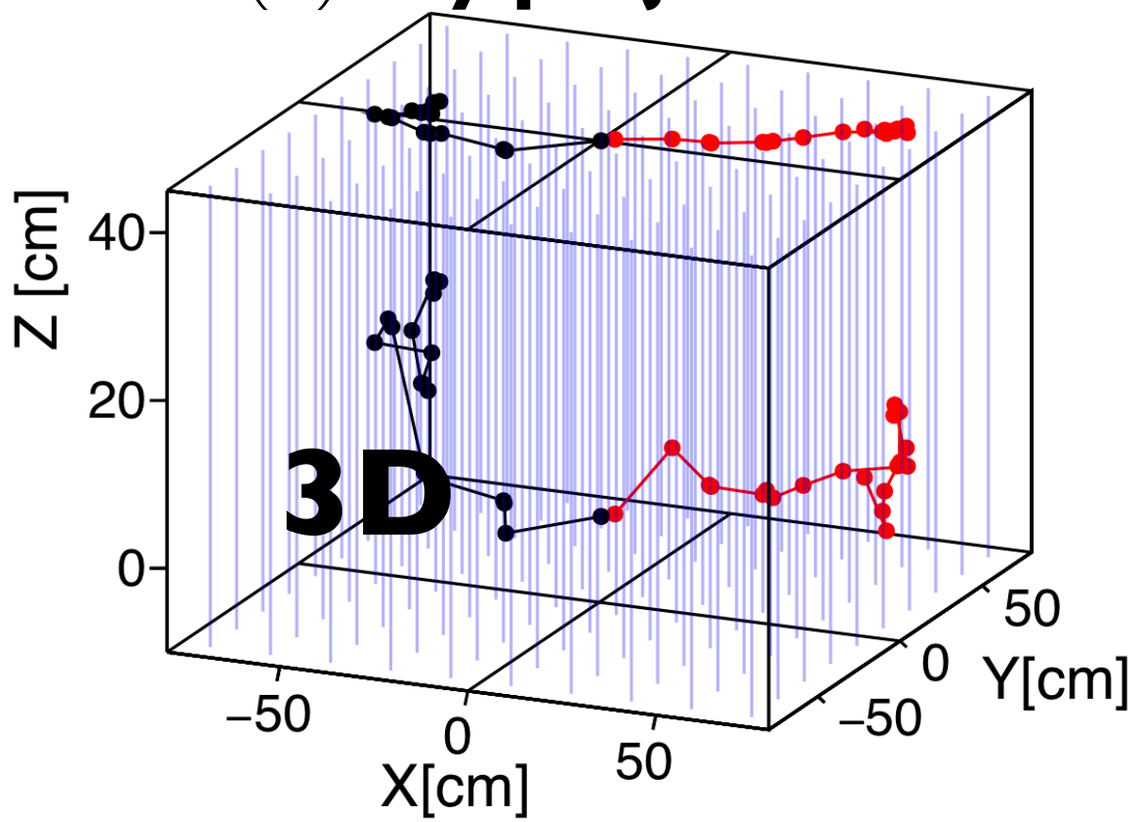
LiquidO's multi-axes…



LiquidO

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

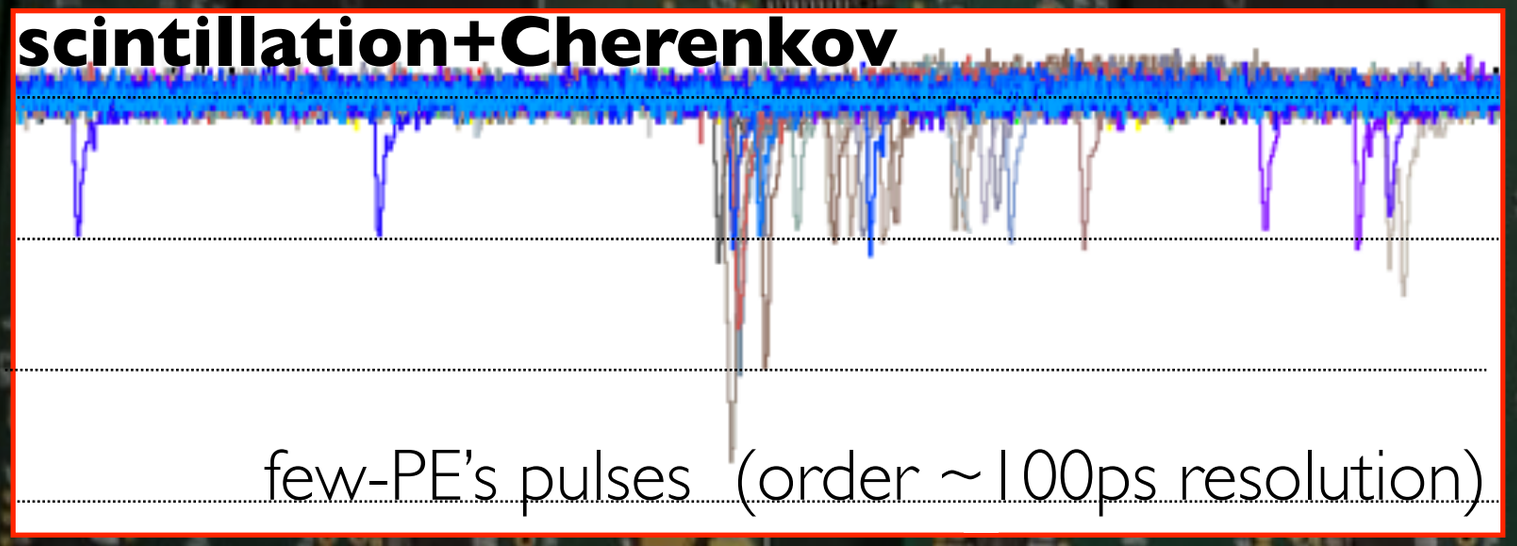
(↑) **x-y projection**

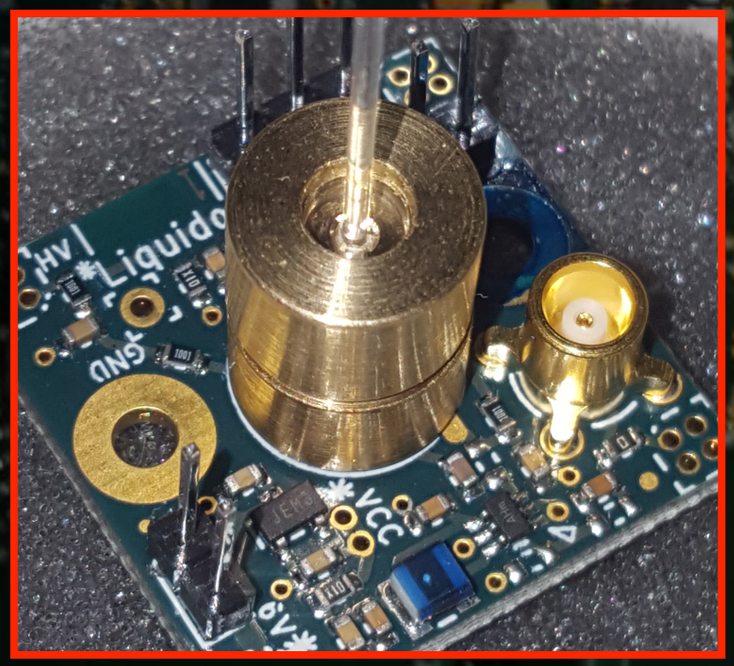


z projection (not yet fully exploited)

Transparent Scintillator⊕Fibres

powerful & fast readout...





(expected) **time resolution: ≤100ps/PE**

(i.e. ≤3cm/PE @ speed of light)

IEEE NSS (2014): The SAMPIC Waveform and Time to Digital Converter
NIM paper (2016): Measurements of timing resolution of ultra-fast silicon detectors with the SAMPIC Waveform Digitizer

LiquidO: light "opaque" medium

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

vocabulary: "opacity" ≈ "brutal translucency"

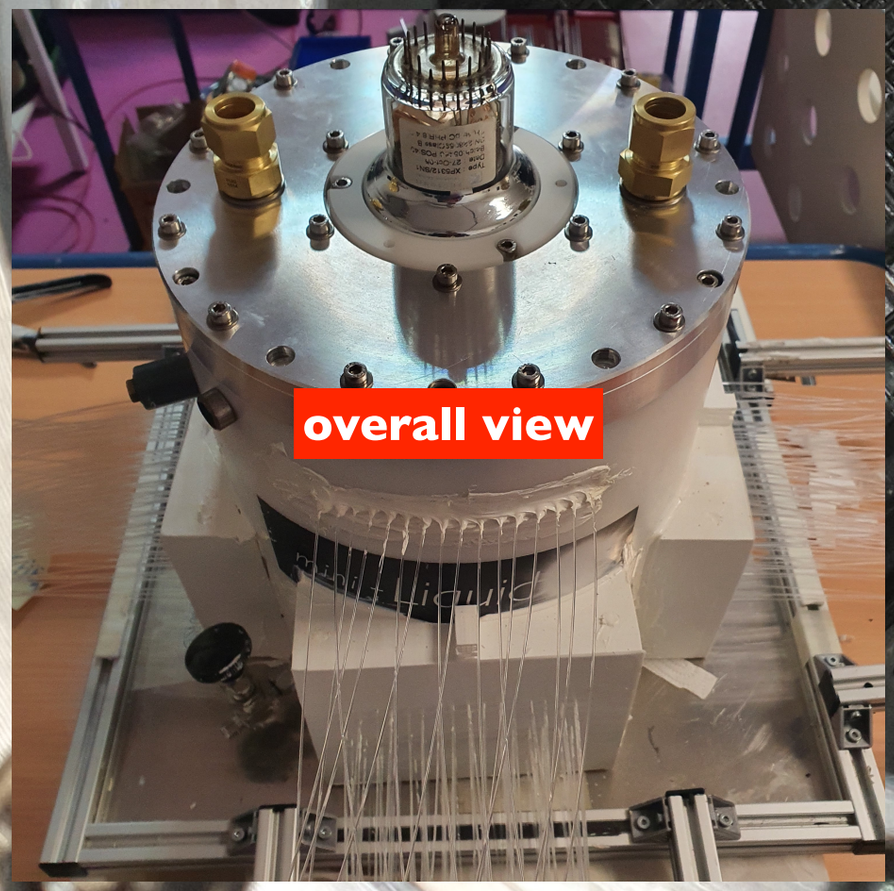
LiquidO ≈ "light TPC" ⊕ "4π ToF" (4D info)

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

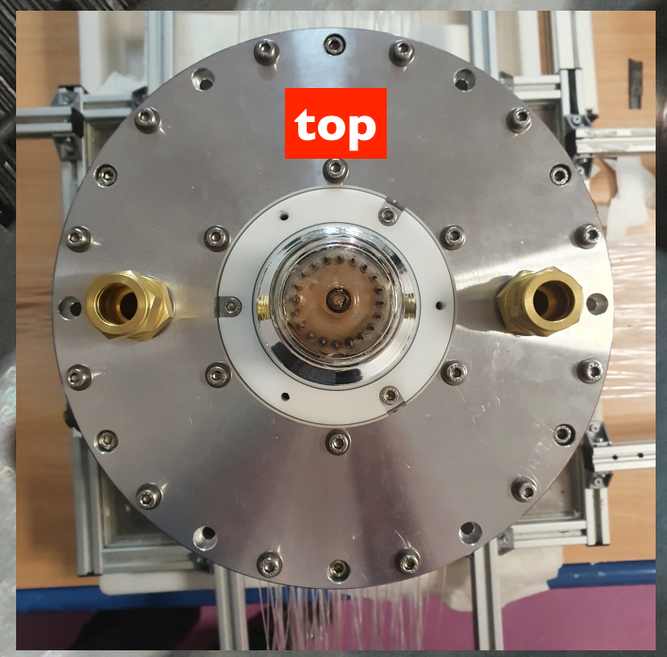
what's LiquidO?

LiquidO's prototype MINI-II (upgrade) located @ CENBG (e- 1MeV beam)
commissioning **data ≥MAY 2021**

IN2P3 (CENBG+CPPM+IJCLab+Subatech)



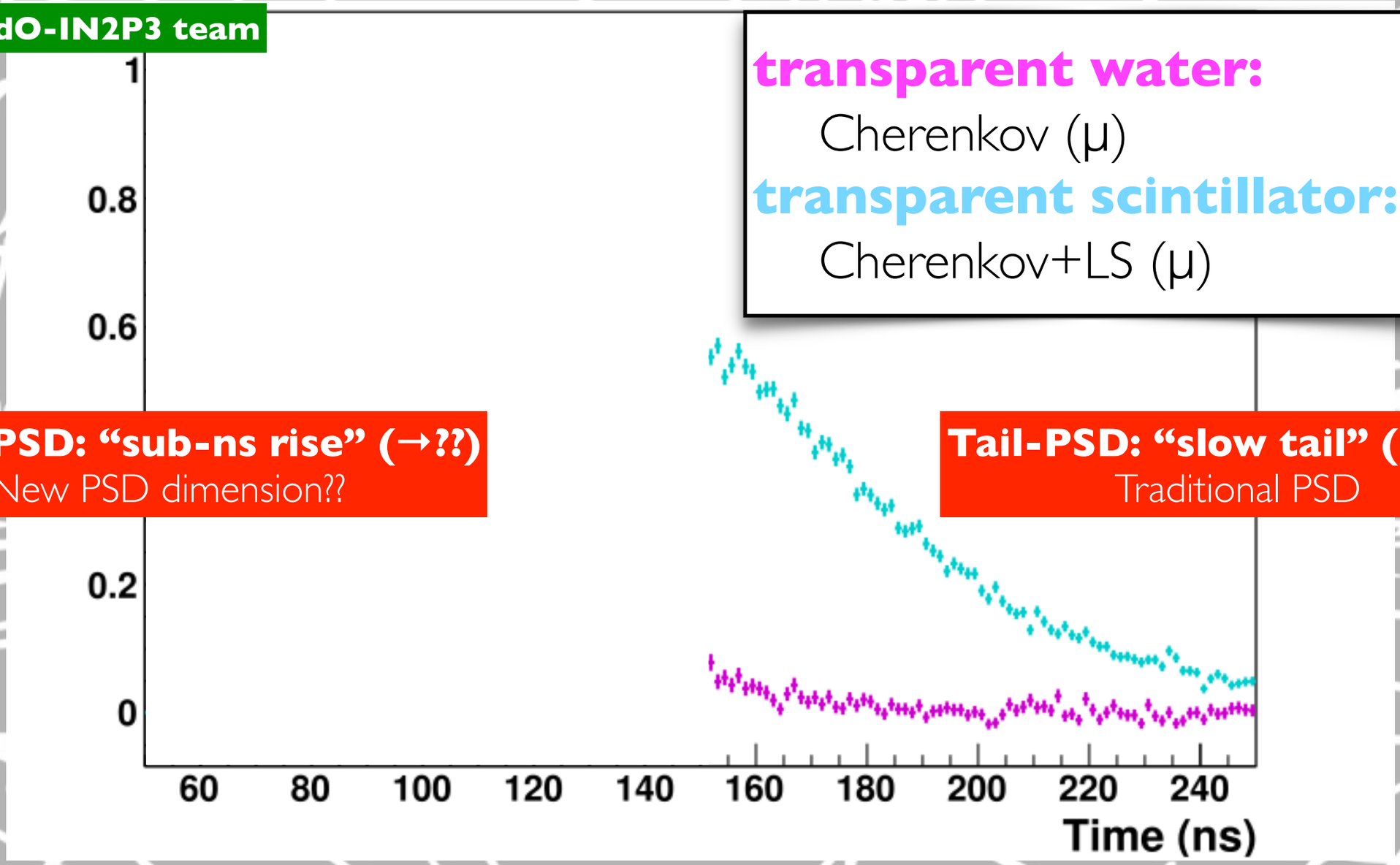
≲10 litres inside
(no scintillator yet)



Cherenkov vs scintillation light?

led by LiquidO-IN2P3 team

transparent water:
Cherenkov (μ)
transparent scintillator:
Cherenkov+LS (μ)



Front-PSD: "sub-ns rise" (→??)
New PSD dimension??

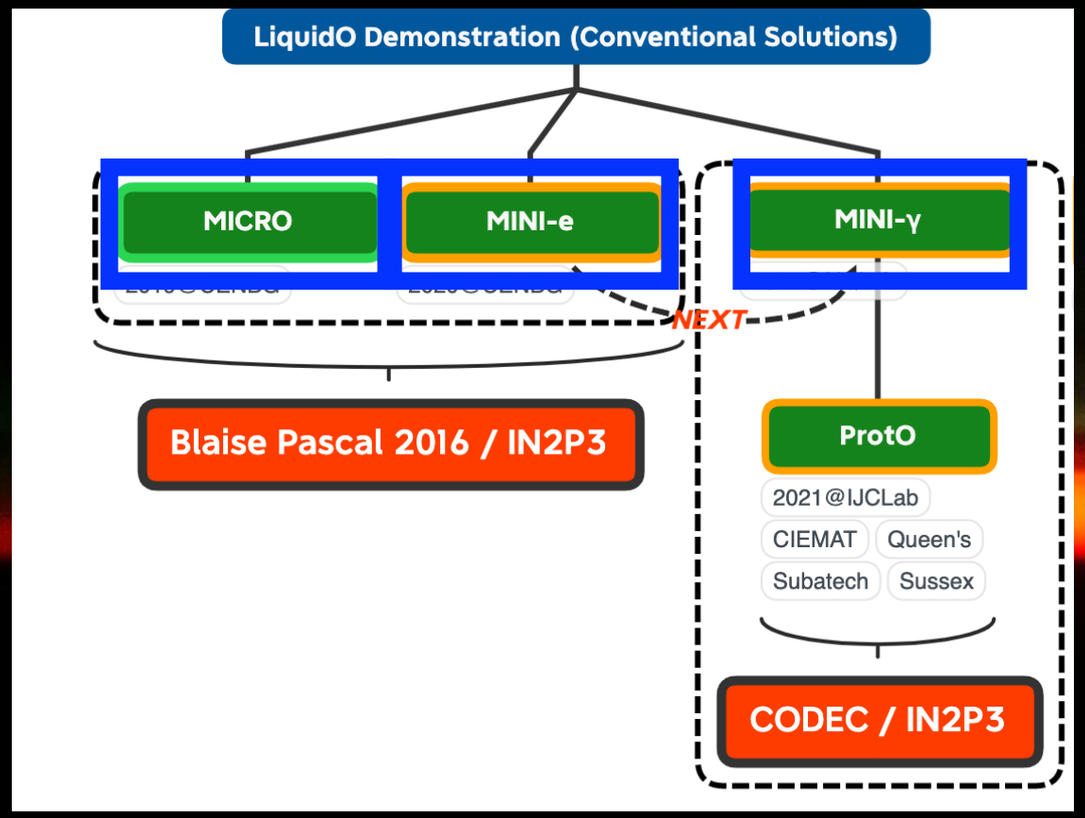
Tail-PSD: "slow tail" (→PID)
Traditional PSD

commissioning runs: transparent ("semi" LiquidO), no same μ acceptance, etc

a new dimension of PSD?

prototyping (R&D) projects…

Prototyping LiquidO Detector

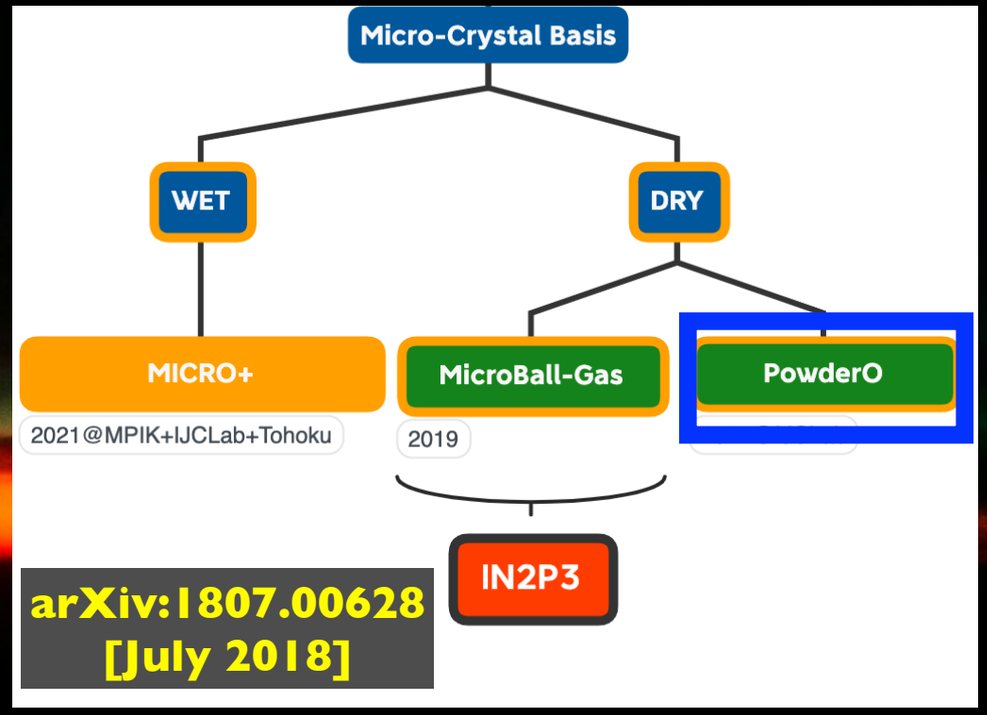


Status: success! (2018-2019) [TRL 3-4]
PUB: submitted Nature's Physics Communications

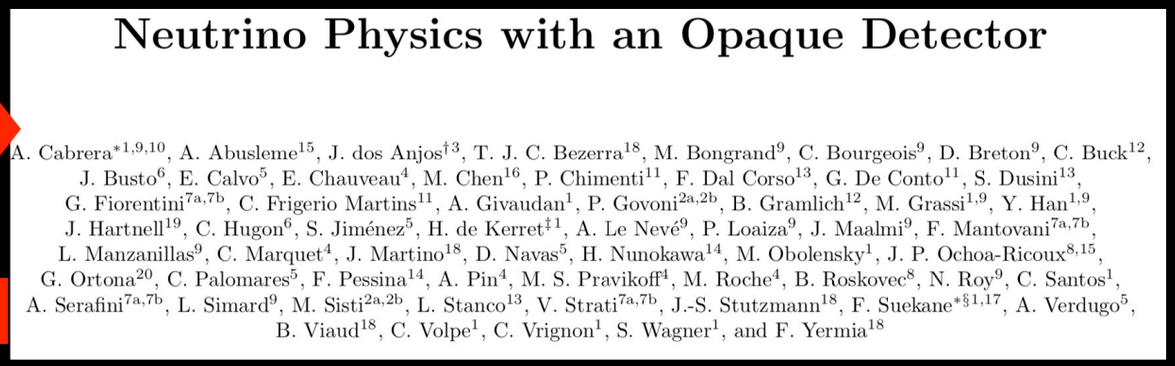
Status: ongoing! (data 2021- COVID)
PUB: expected by the end 2021? [JINST?]

Status: construction (→2022- COVID) [TRL→4-5]
PUB: ≥mid-2022 [JINST & **first physics explorations**]

Prototyping New Technology (R&D)



arXiv:1807.00628 [July 2018]



Neutrino Physics with an Opaque Detector

A. Cabrera*[1,9,10], A. Abusleme[15], J. dos Anjos†[3], T. J. C. Bezerra[18], M. Bongrand[9], C. Bourgeois[9], D. Breton[9], C. Buck[12], J. Busto[6], E. Calvo[5], E. Chauveau[4], M. Chen[16], P. Chimenti[11], F. Dal Corso[13], G. De Conto[11], S. Dusini[13], G. Fiorentini[7a,7b], C. Frigerio Martins[11], A. Givaudan[1], P. Govoni[2a,2b], B. Gramlich[12], M. Grassi[1,9], Y. Han[1,9], J. Hartnell[19], C. Hugon[6], S. Jiménez[5], H. de Kerret‡[1], A. Le Nevé[9], P. Loaiza[9], J. Maalmi[9], F. Mantovani[7a,7b], L. Manzanillas[9], C. Marquet[4], J. Martino[18], D. Navas[5], H. Nunokawa[14], M. Obolensky[1], J. P. Ochoa-Ricoux[8,15], G. Ortona[20], C. Palomares[5], F. Pessina[14], A. Pin[4], M. S. Pravikoff[4], M. Roche[4], B. Roskovec[8], N. Roy[9], C. Santos[1], A. Serafini[7a,7b], L. Simard[9], M. Sisti[2a,2b], L. Stanco[13], V. Strati[7a,7b], J.-S. Stutzmann[18], F. Suekane*§[1,17], A. Verdugo[5], B. Viaud[18], C. Volpe[1], C. Vrignon[1], S. Wagner[1], and F. Yermia[18]

arXiv:1908.02859 [Aug-Dec 2019]

next slide

last slide

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** (≤20% of H & ^{12}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?

anatael@in2p3.fr

merci…
спасибі…
ありがとう…
danke…
고맙습니다…
obrigado…
Спасибо…
grazie…
谢谢…
hvala…
gracias…
شكرا…
thanks…

LiquidO full release 2019…

Neutrino Physics with an Opaque Detector

A. Cabrera*[1,9,10], A. Abusleme[15], J. dos Anjos†[3], T. J. C. Bezerra[18], M. Bongrand[9], C. Bourgeois[9], D. Breton[9], C. Buck[12], J. Busto[6], E. Calvo[5], E. Chauveau[4], M. Chen[16], P. Chimenti[11], F. Dal Corso[13], G. De Conto[11], S. Dusini[13], G. Fiorentini[7a,7b], C. Frigerio Martins[11], A. Givaudan[1], P. Govoni[2a,2b], B. Gramlich[12], M. Grassi[1,9], Y. Han[1,9], J. Hartnell[19], C. Hugon[6], S. Jiménez[5], H. de Kerret‡[1], A. Le Nevé[9], P. Loaiza[9], J. Maalmi[9], F. Mantovani[7a,7b], L. Manzanillas[9], C. Marquet[4], J. Martino[18], D. Navas[5], H. Nunokawa[14], M. Obolensky[1], J. P. Ochoa-Ricoux[8,15], G. Ortona[20], C. Palomares[5], F. Pessina[14], A. Pin[4], M. S. Pravikoff[4], M. Roche[4], B. Roskovec[8], N. Roy[9], C. Santos[1], A. Serafini[7a,7b], L. Simard[9], M. Sisti[2a,2b], L. Stanco[13], V. Strati[7a,7b], J.-S. Stutzmann[18], F. Suekane*§[1,17], A. Verdugo[5], B. Viaud[18], C. Volpe[1], C. Vrignon[1], S. Wagner[1], and F. Yermia[18]

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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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†Also at Observatório Nacional. Rio de Janeiro, Brasil
‡Deceased.
§Blaise Paschal Chaire Fellow.

Seminar@CERN — June 2019

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

Igniting publication — Aug 2019

LiquidO @ arXiv:1908.02859

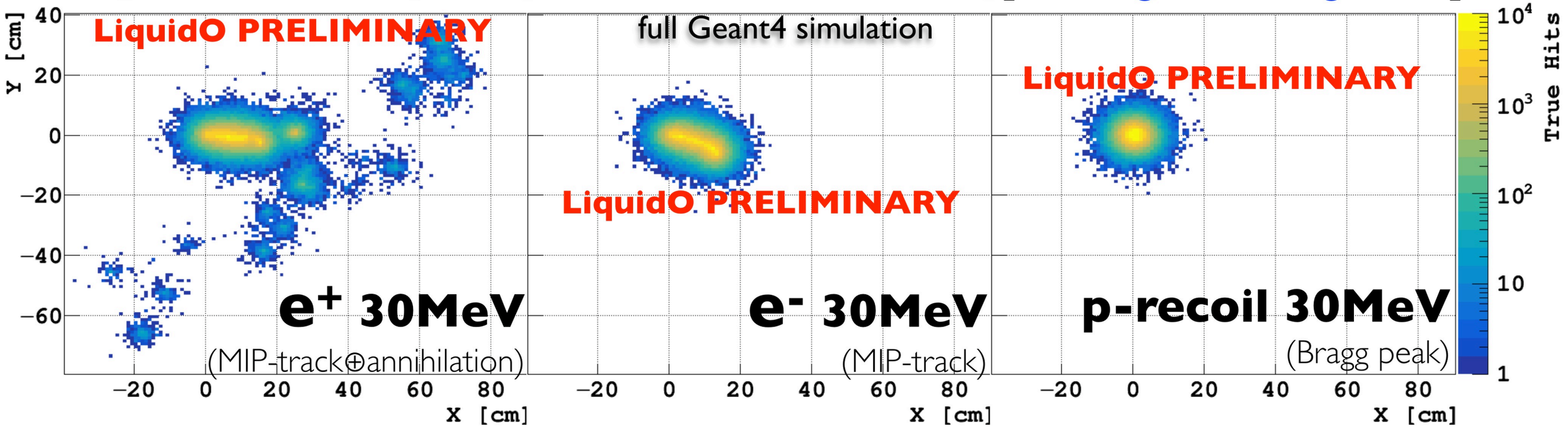
- new detection principle
- first experimental proof-of principle
- vast neutrino physics prospect

Submitted to Nature's "Physics Communication"

First Opaque Liquid Scintillator @ arXiv:1908.03334

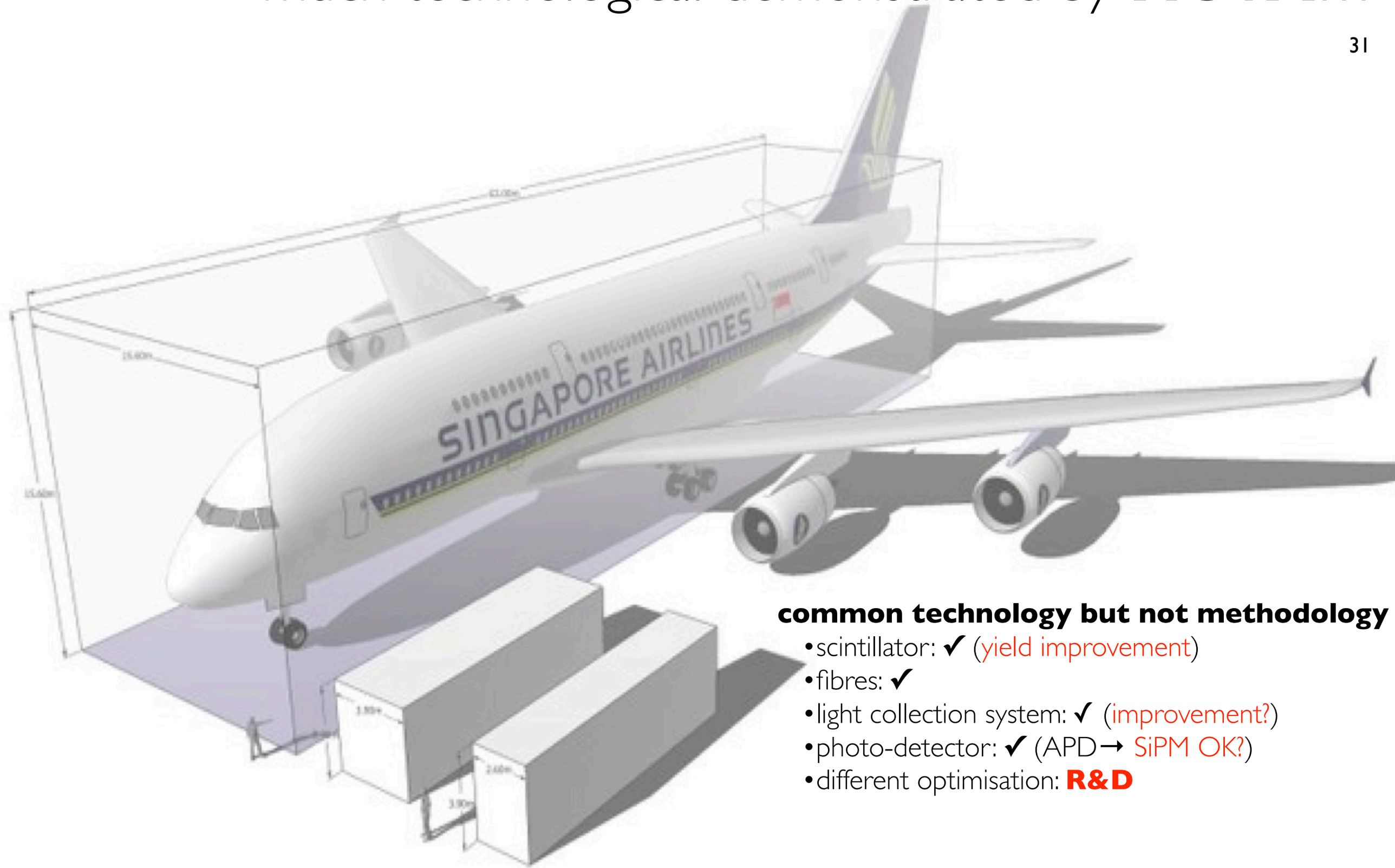
e+ ⇔ anti-ν(e) **e- ⇔ ν(e)** **p-recoil**

[IBD interaction] [**^{12}C/new interaction**] [cosmogenic background]



PID ≤100MeV (limited Breming)

much technological demonstrated by **NOvA**…



common technology but not methodology

- scintillator: ✓ (yield improvement)
- fibres: ✓
- light collection system: ✓ (improvement?)
- photo-detector: ✓ (APD→ SiPM OK?)
- different optimisation: **R&D**

GeV OK!! But **~1MeV physics @ 10kton?**

(**R&D**)