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AntiMatter Tech

project's first release



3rd IAEA Technical Workshop on Antineutrino
SNU, Seoul (South Korea) — April 2025

Anatael Cabrera

CNRS / Université Paris-Saclay — IJCLab (Orsay) / LNCA (Chooz)
France

Scientific collaboration @ Institute of Astrophysics of the Canaries.
Spain



(co)spokesperson:
• DoubleChooz
• LiquidO
• CLOUD — AntiMatter-OTech (EIC)
• SuperChooz Pathfinder

The origin of this idea: L.A. Mikaelyan – Neutrino '77 conference, Baksan

3. I want to talk about the development of the new technique of the remote reactor diagnostics by the neutrino radiation. Due to the novelty of the problem the consideration naturally will be incomplete and limited by two questions only:

- determination of the reactor power production and in prospect
- determination of the dynamics of the fissioning isotopes burning-out and accumulation (mainly ^{235}U and ^{239}Pu).

The principle promises of the proposed technique seem to be the remote analysis and fixing the plutonium accumulation immediately in the place of its production. This technique (if developed successfully) will be sufficiently important from the point of view of the control on the leakage of fissioning materials and on the non-proliferation of nuclear weapons, and also for the economics of nuclear fuel recycling. More detail consideration of these problems on this conference seems to be irrelevant.

all possible a priori — and more!

antineutrino in industry?

neutrino detection technological limitations...

(new methodology → **enough?**)

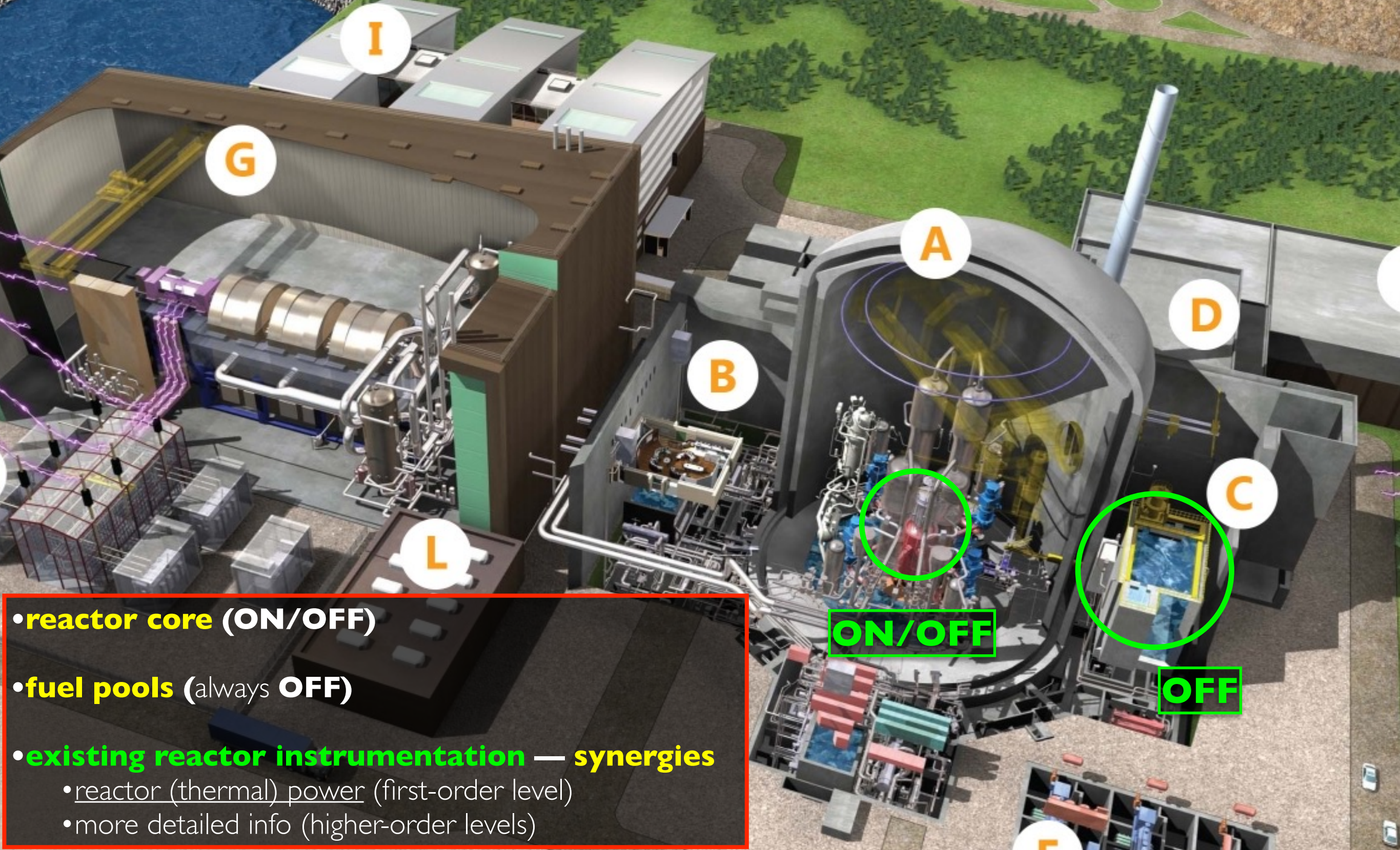
huge backgrounds (BG) → **overburden** (still needed)

(yield major rejection **> 10x better?**)

(if so) **antineutrino's full power may be further squeezed!**
(unique direct fission tracking)

all possible a priori — and more!

antineutrino in industry?



innermost elements of reactors...



handles for **non-proliferation** control?

an **extra layer of reactor** (regular or compromised) **info?**
(explore further safety? or running insight?, etc.)

a **uniform antineutrino reactor metric?**
(each antineutrino = ~ 6 per fissions)

practical reactor monitoring...?

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AntiMatter ● Tech

innovation demonstrator: neutrino-based reactor instrumentation

<https://antimatter-otech.ijclab.in2p3.fr/>

preliminary release — some information **still embargoed**

programme in a nutshell...

ICHEP 2024 PRAGUE



ichep2024.org

42nd International Conference on High Energy Physics

18-24 July · 2024 · Prague · Czech Republic

<https://ichep2024.org/#>

AntiMatterOTech Innovation Project
Europe-based institutions (6) with EDF in 5 countries

EIC(88%)+UKRI (12%): 6.5M€

Exploration of novel nuclear industry instrumentation using, for the first time, antineutrinos, as a direct probe and non-intrusive probe into the functioning of industrial nuclear reactors.

Novel Detector Design
novel LiquidO technology: e+ PID
⇒ Signal/Background ≥ 100 (low overburden)
• statistical sensitivity ($\geq 10,000$ IBD/day)
• $\leq 1.0\%$ per day
• $\leq 0.2\%$ per month

Innovation & Fundamental Physics
• reactor flux (rate@shape) complementary monitoring
• reactor-ON: industry & IAEA (Plutonium production)
• reactor-OFF: IAEA & accident scenario (e.g. Fukushima)

More Info: [https://antimatterotech.github.io/](#)

CLOUD @ICHEP2024: D. Nicolas
SuperChooz @ICHEP2024: A. Cabrera
LiquidO @ICHEP2024: S. Schoppmann

Chooz nuclear reactor (EDF)
Ultra Near Detector (UND) site

First LiquidO-based detector

e⁺ event

backgrounds

**ICHEP 2024
PRAGUE**

42nd International Conference on High Energy Physics
18-24 July · 2024 · Prague · Czech Republic

Technological Spin-offs and Industrial Applications

Maxim Titov (CEA Saclay, Irfu, France)

42nd INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS (ICHEP2024)
Prague, Czech Republic, July 18-24, 2024

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backgrounds

<https://indico.cern.ch/event/1291157/>

first mention @ ICHEP-2024

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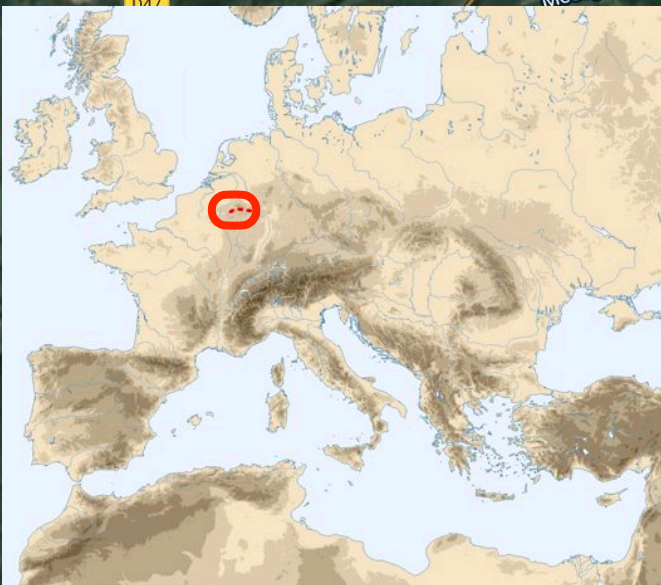
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- 1 • innovation project — funded **EU-EIC** ⊕ **UKRI** to **demonstrate industrial potential**
- 2 • neutrino experiment on fundamental science (called **CLOUD**) — **discoveries?**
- 3 • demonstrator of SuperChooz (exploration) — **fundamental physics flagship project Europe?**

programme's synergies...

in the **Western Europe** (between France-Belgium): **Chooz** [close to Germany, Luxembourg, Netherlands]

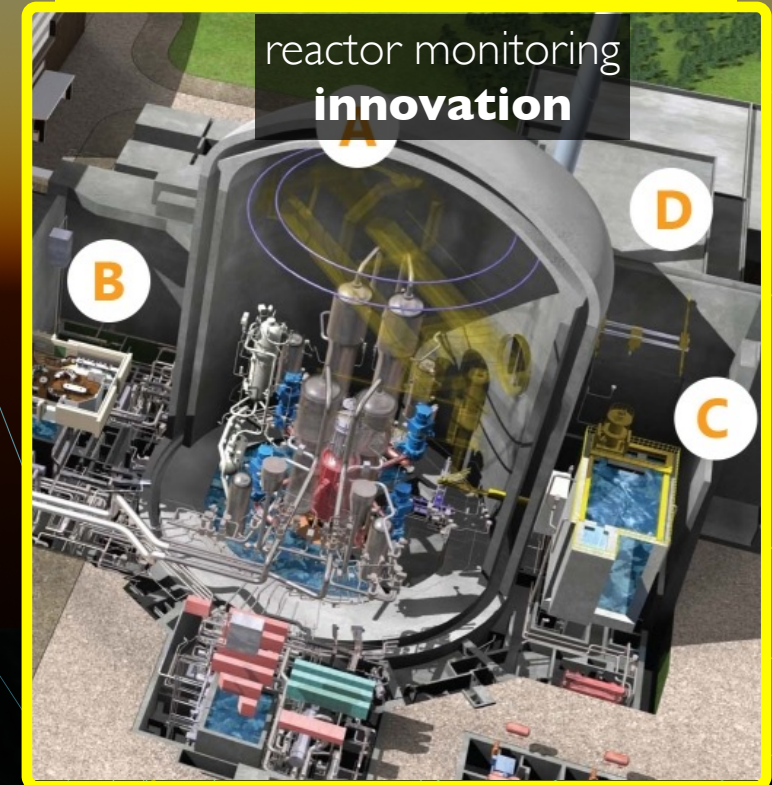
one of the most powerful **anti-matter generators**



les Ardennes
(France-Belgium)

Europe's powerful reactor site...

opens the 3rd generation of reactor neutrino experiments @ Chooz



reactor monitoring
innovation

antineutrino (neutrino?): $\sim 10^{21}$ v/s per core



experimental setup...

- Detector Mass: $\sim [5, 10]$ ton — **LiquidO** technology
- Overburden: ~ 3 mwe
- Baseline: ≥ 30 m (**Ultra Near Detector** site @ Chooz)
- Rate: $\sim 25,000$ anti- ν per day — $\sim 10M$ anti- ν per year

most projects (so far) focus on the neutrino
 $\Rightarrow$ the reactor may even be "nuisance"

Chooz-B: Nuclear Reactor Cores

goal: understanding reactors...

understanding **the reactor** $\approx$ understanding **its antineutrino absolute flux** (ON/OFF) — complex!

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confronting **absolute flux challenge**...

- **extreme signal** (and low BG) rates
- (must) the **best-known neutrino cross-section(s)** ($\leq 1\%$)
- **extreme energy control** ($\leq 1\%$) — avoid spectral distortions (**biases**)
- **redundancy** — *if lucky* (as much as Nature and technology allows)
 - **issue:** the unknown! $\Rightarrow$ **new neutrino physics?** (**biases**)

reactor's absolute flux knowledge...

absolute antineutrino flux challenge...

- **extreme control of everything** — no cancellations (multi-detector, etc.)
- **new physics** (if any) may manifest everywhere...

@production: β decay (weak-interaction) & nuclear physics, etc.

@propagation: standard neutrino oscillations ($\theta_{13} \oplus \Delta m_{ee}^2$), etc.

@detection: interactions on proton (i.e. **IBD**) — the lifetime of neutron (τ_n)

new physics impact: reactor bias

<2011: reactors were thought to be understood to $\leq 3\%$ [ILL $\oplus$ Bugey3 $\oplus$ Bugey4]

no conclusive sign of $\sim 1\text{eV}^2$ sterile neutrino $\Rightarrow$ only **reactor effects**

≥ 2012 : reactors **knowledge questioned** (now: $\leq 6\%?$) $\rightarrow$ **what's the uncertainty?**
 $\Rightarrow$ experiments ($\theta_{13} \oplus$ sterile) & better predictions (nuclear data, etc.)

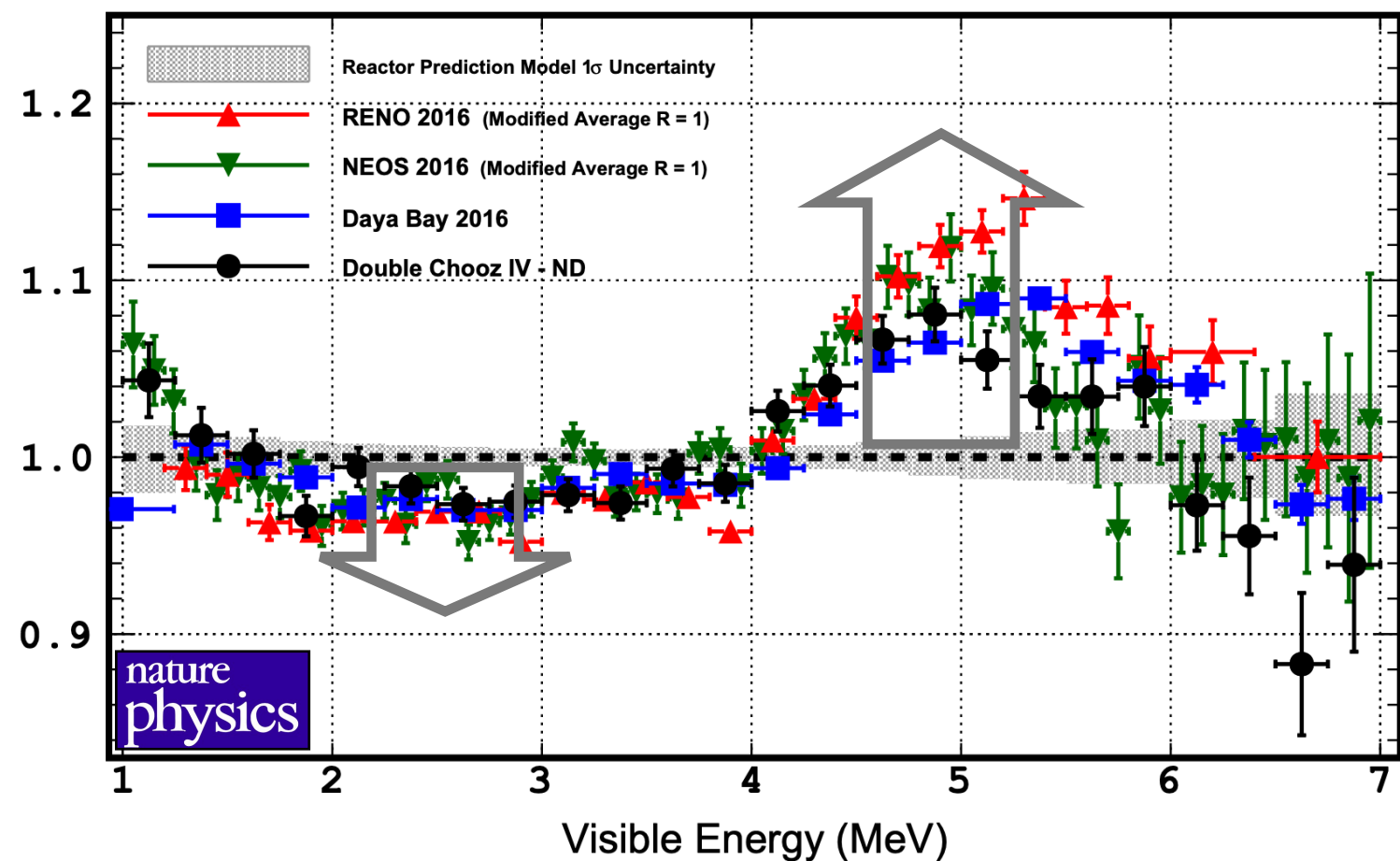
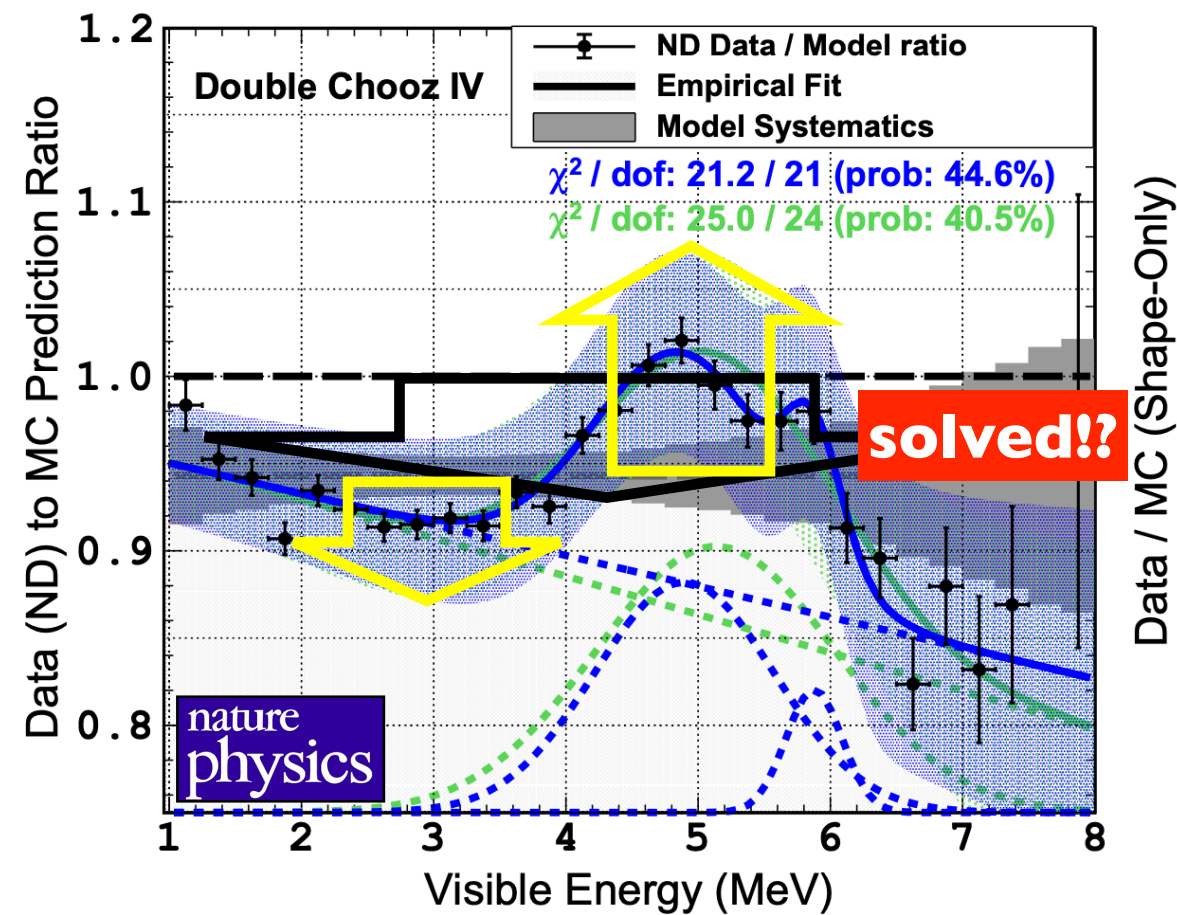
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warning! new physics (unknown) may change the **reactor's observables**
[must watch $\Rightarrow$ **unitarity violation** searches]

(example) sterile neutrino

most experiments are consistent(ish) — except **Bugey3?!**

ABSOLUTE FLUX: the future of reactor-antineutrino physics



solve these issues $\Rightarrow$ the reward the **a) better reactor** & **b) new physics** (if any)
(ideally, prediction should **not** use neutrino input)

understand absolute flux $\leq 1\%$?

much of **world's neutrino knowledge** is **reactor-driven** [including **JUNO**]
standard neutrino oscillations (θ_{12} , θ_{13} , θ_{23} , $+\delta m^2$, $\pm\Delta m^2$, δ_{CP}) — if **PMNS unitary**

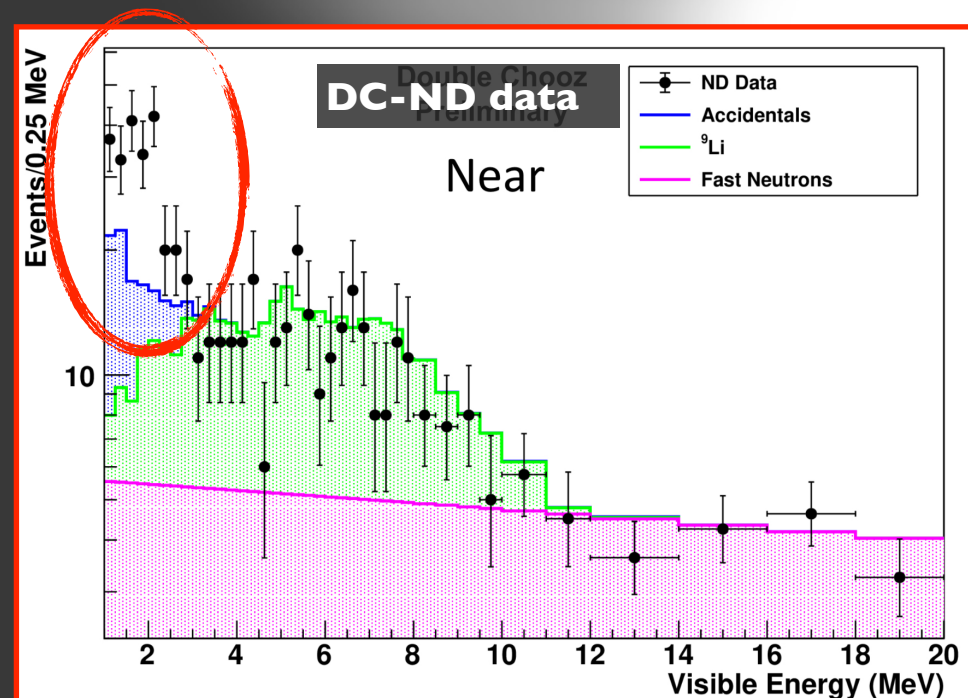
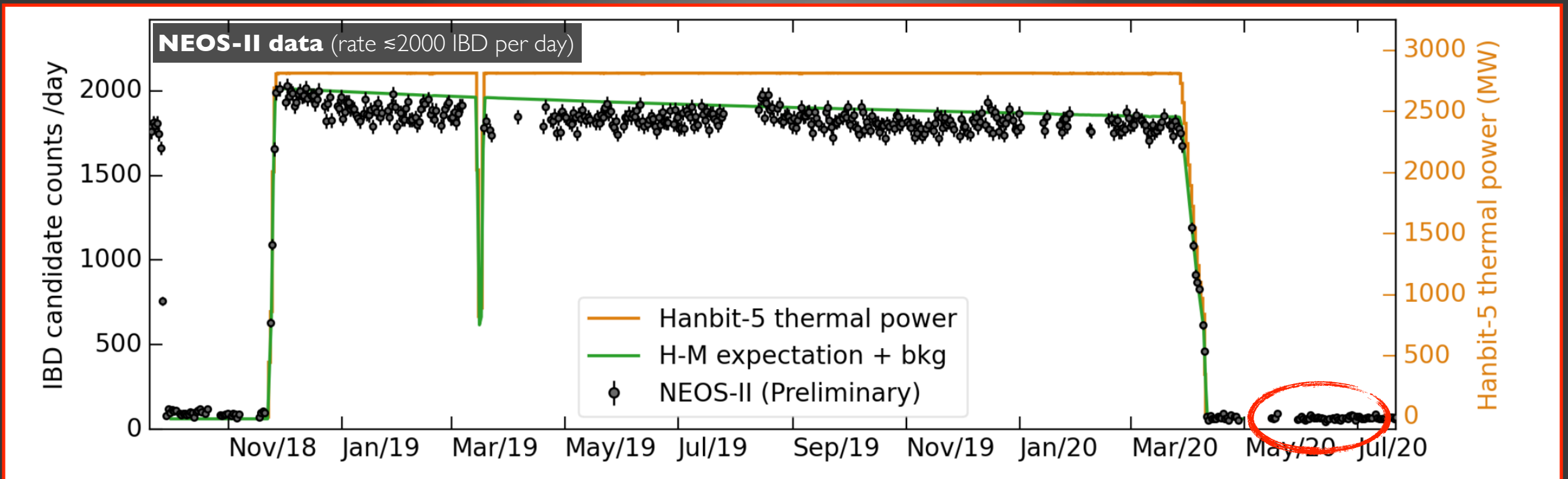
[**SuperChooz**: design to synergetically push θ_{23} -**octant** and δ_{CP} knowledge]

<https://zenodo.org/record/7504162>

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[e.g.] even **today's δ_{CP} info** arises the **combination** of **reactors $\oplus$ accelerators**

reactors: unique research tool...



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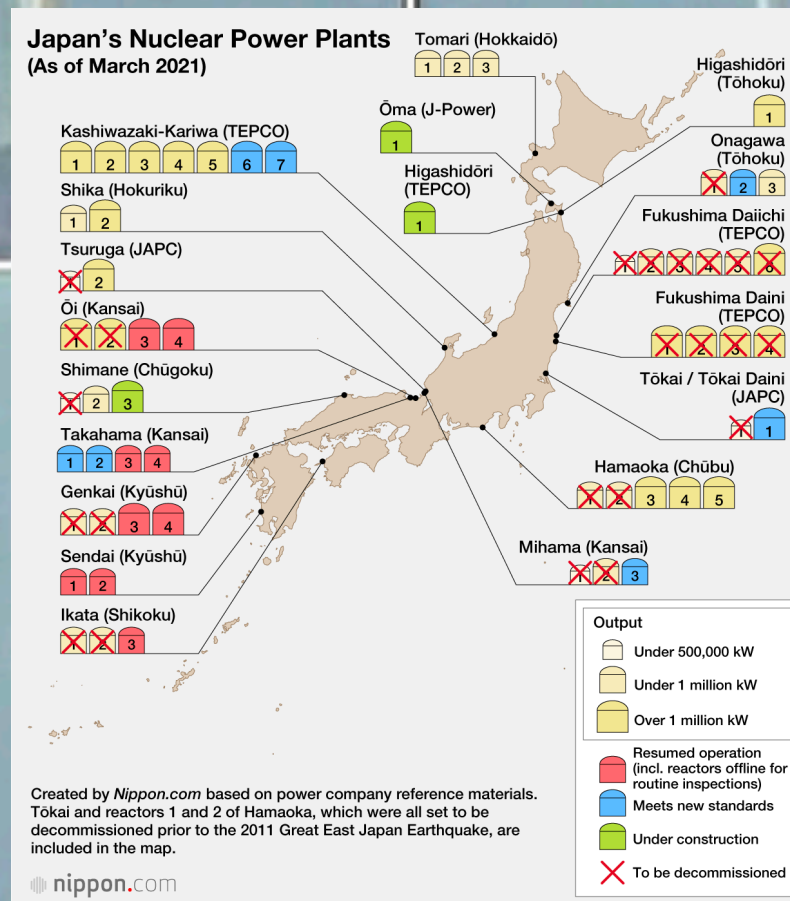
field's historical progress: 2010-2020

“brewed” the next generation!

AntiMatterOTech byproduct of **DoubleChooz** (byproduct of **CHOOZ**)

reactor information so far...

a marking moment in our lifetimes: the **Fukushima crisis**



could **OFF-anti-neutrino** data be helpful here?

Fukushima: do even more?

Imaging Fukushima Daiichi reactors with muons

Cite as: AIP Advances 3, 052133 (2013); <https://doi.org/10.1063/1.4808210>
Submitted: 11 February 2013 . Accepted: 17 May 2013 . Published Online: 24 May 2013

Haruo Miyadera, Konstantin N. Borozdin, Steve J. Greene, Zarija Lukić, Koji Masuda, Edward C. Milner, Christopher L. Morris, and John O. Perry



ARTICLES YOU MAY BE INTERESTED IN

Imaging a nuclear reactor using cosmic ray muons

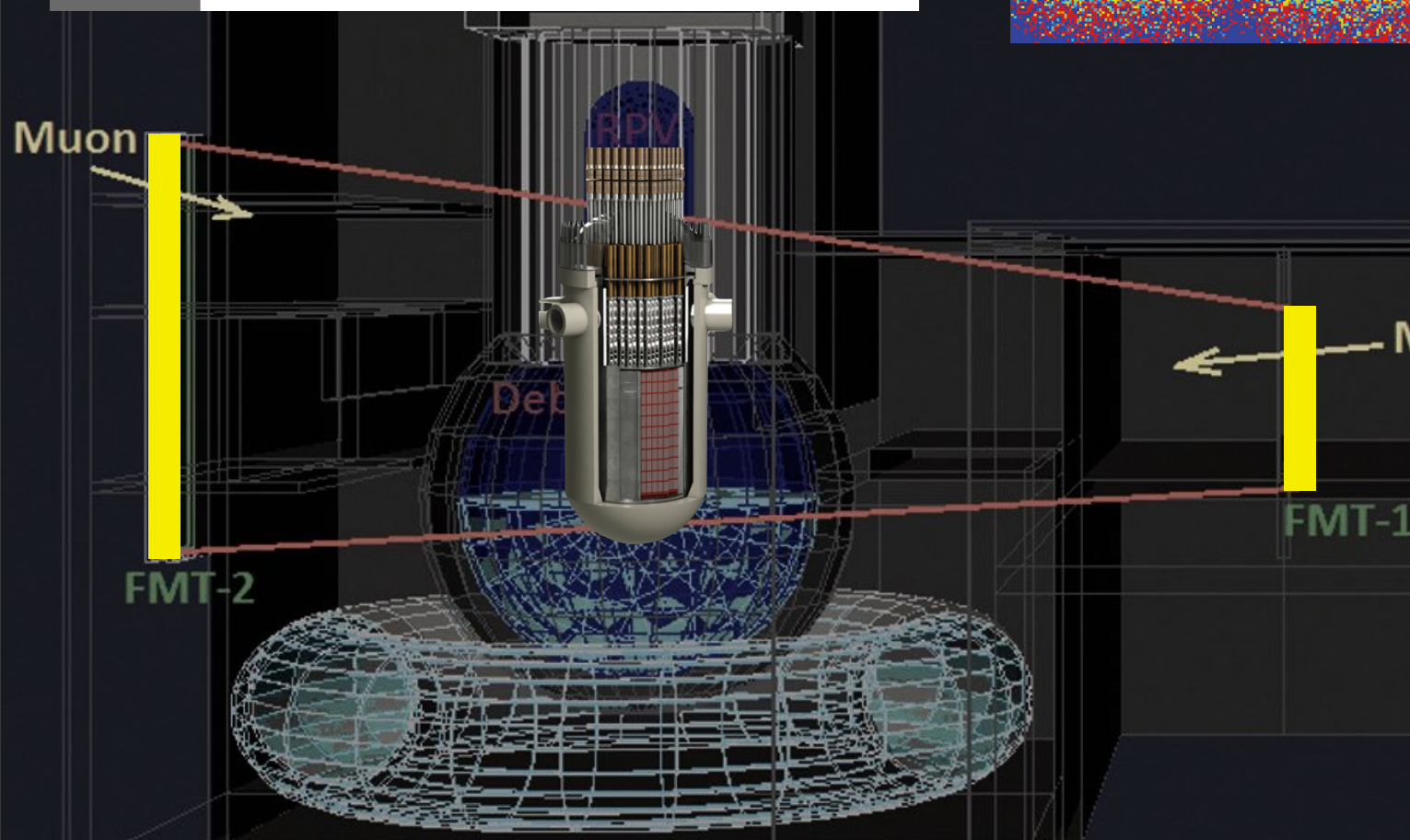
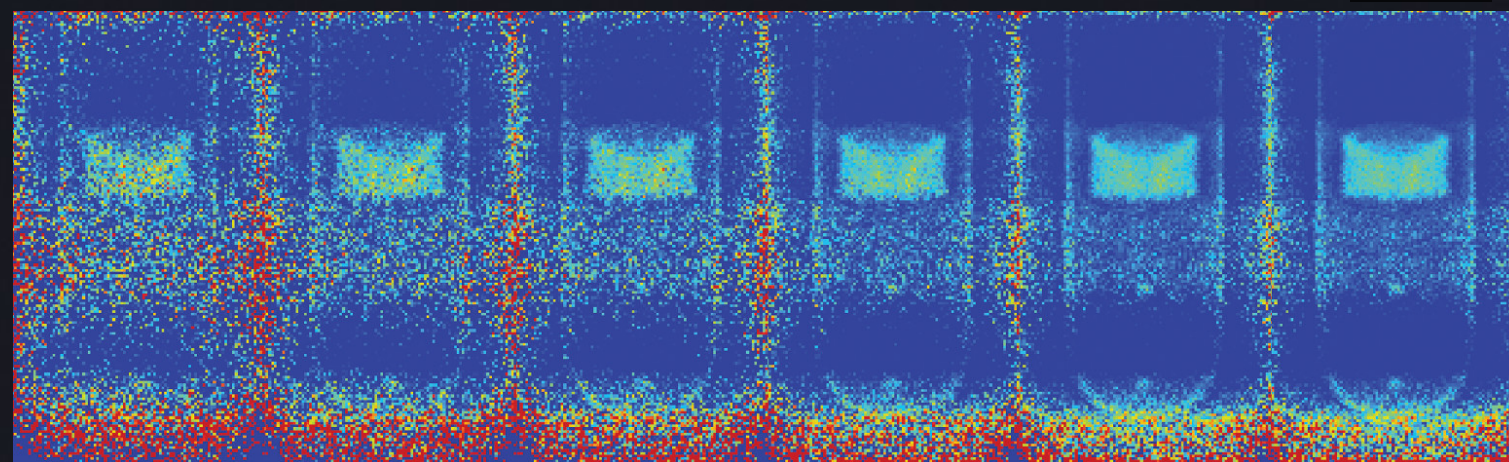
Journal of Applied Physics **113**, 184909 (2013); <https://doi.org/10.1063/1.4804660>

Analysis of muon radiography of the Toshiba nuclear critical assembly reactor

Applied Physics Letters **104**, 024110 (2014); <https://doi.org/10.1063/1.4862475>

Detection of high-Z objects using multiple scattering of cosmic ray muons

Review of Scientific Instruments **74**, 4294 (2003); <https://doi.org/10.1063/1.1606536>



μ tomography...

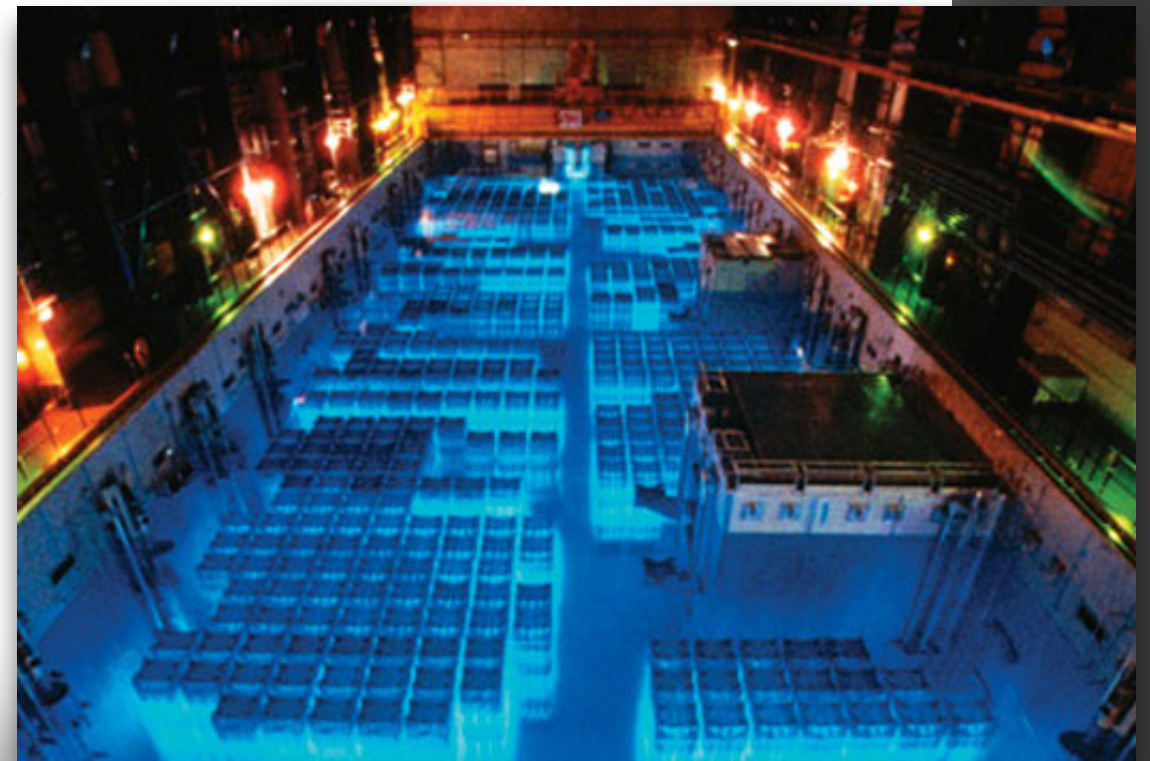
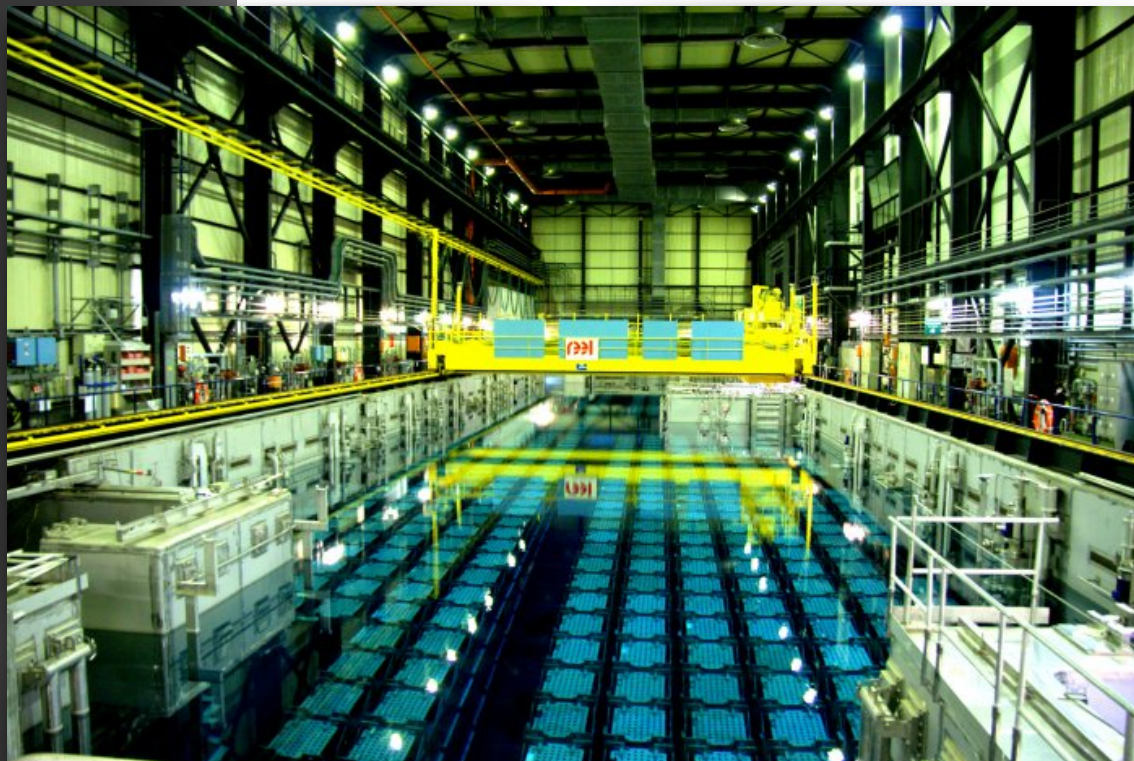
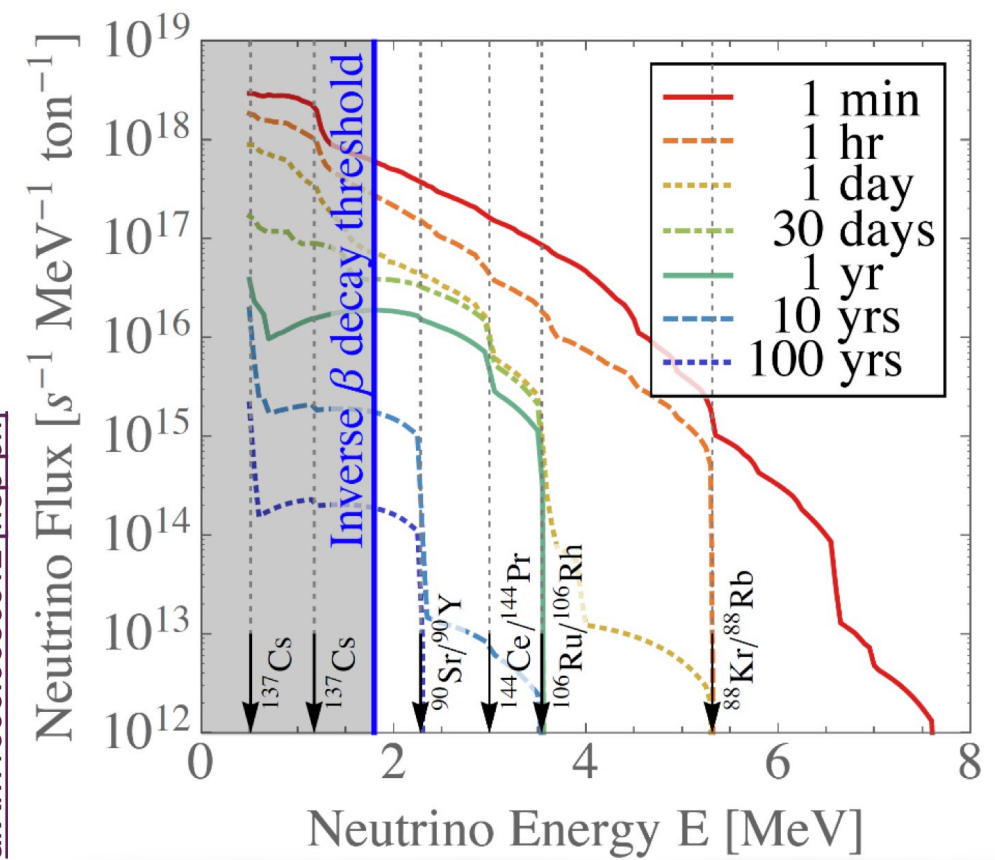
- **no fissile tracking** :- (
- **density map** [$\sim$ months]
- compromised geometry $\rightarrow$ **limitation** [i.e. after accident]

could **OFF-antineutrino detection** be helpful here?
(fission tracker $\oplus$ geometry independent)

open challenge: post-accident insight

^{91}Sr	9.63 h	2.699
^{93}Y	10.18 h	2.874
^{97}Zr	16.9 h	2.658
^{106}Ru	373.6 d	0.039
^{112}Pd	21.03 h	0.288
^{125}Sn	9.64 d	2.364
$^{131\text{m}}\text{Te}$	30 h	0.182
^{132}Te	3.204 d	0.493
^{159}Sm	9.4 h	0.722
^{140}Ba	12.75 d	1.047
^{144}Ce	284.9 d	0.319

arXiv:1606.06309v2 [hep-ph]



could **OFF-anti-neutrino** data be helpful here?

direct fuel monitoring?

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a **new way** into **reactor antineutrino detection**

the project & methodology...

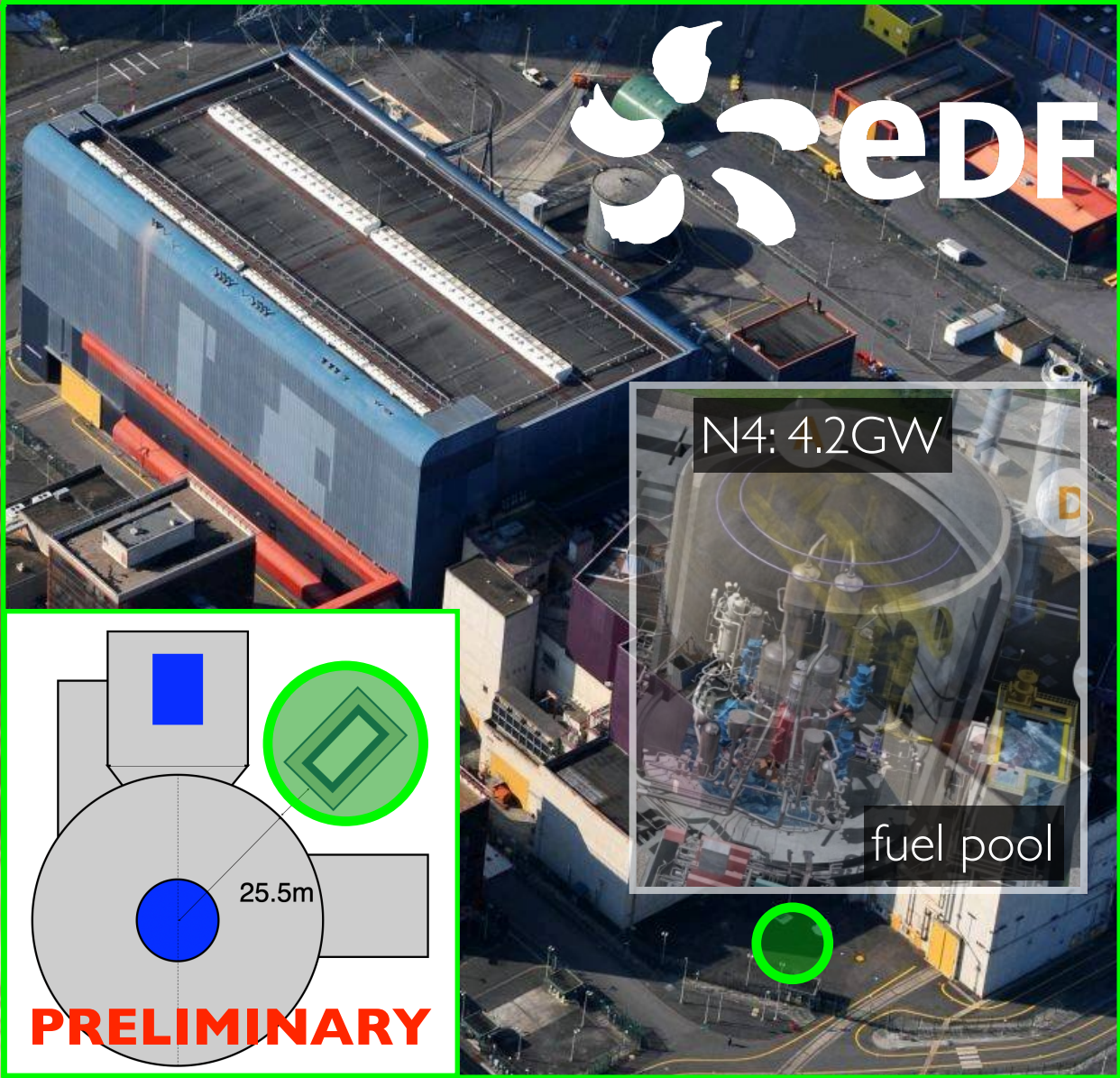
Chooz-B Power Station

- facility: EDF CNPE
- location: Chooz (France)
- reactor cores: 2x PWR AREVA-N4
- thermal power: 8.4GW (total)

Double Chooz
Near Detector

LNCA-Hall (CNRS)

Ultra Near Detector (UND) sites



due to global warm → more frequent reactor-OFF (2022: several months)

Europe's best reactor-V site...

Double Chooz
Far Detector

Water Pool [20,40]cm thick

- 4π shield & neutron moderator
- controllable thermal-bath

IGLOO [~ 3 mwe]

- concrete **bunker** (with boron?)
- DC's iron steel shield (15cm thick)

Redundant “surface neutron” layers...

- **IGLOO** (absorption) — passive
- **Water** (moderator $\oplus$ absorption) — passive
- **Armour** (veto $\oplus$ moderator $\oplus$ absorption) — **OD**
- **Tracker** (PID $\oplus$ moderator) — **ID**

cross-section view

side-section view

LiquidO-Tracker (or **inner-detector**) [≤ 10 tons fiducial]

- opaque scintillator — new formulation(s)
- $\sim 10,000$ **fibres** $\oplus$ **SiPM** readout channels
- designed light level: ≥ 200 pe/MeV

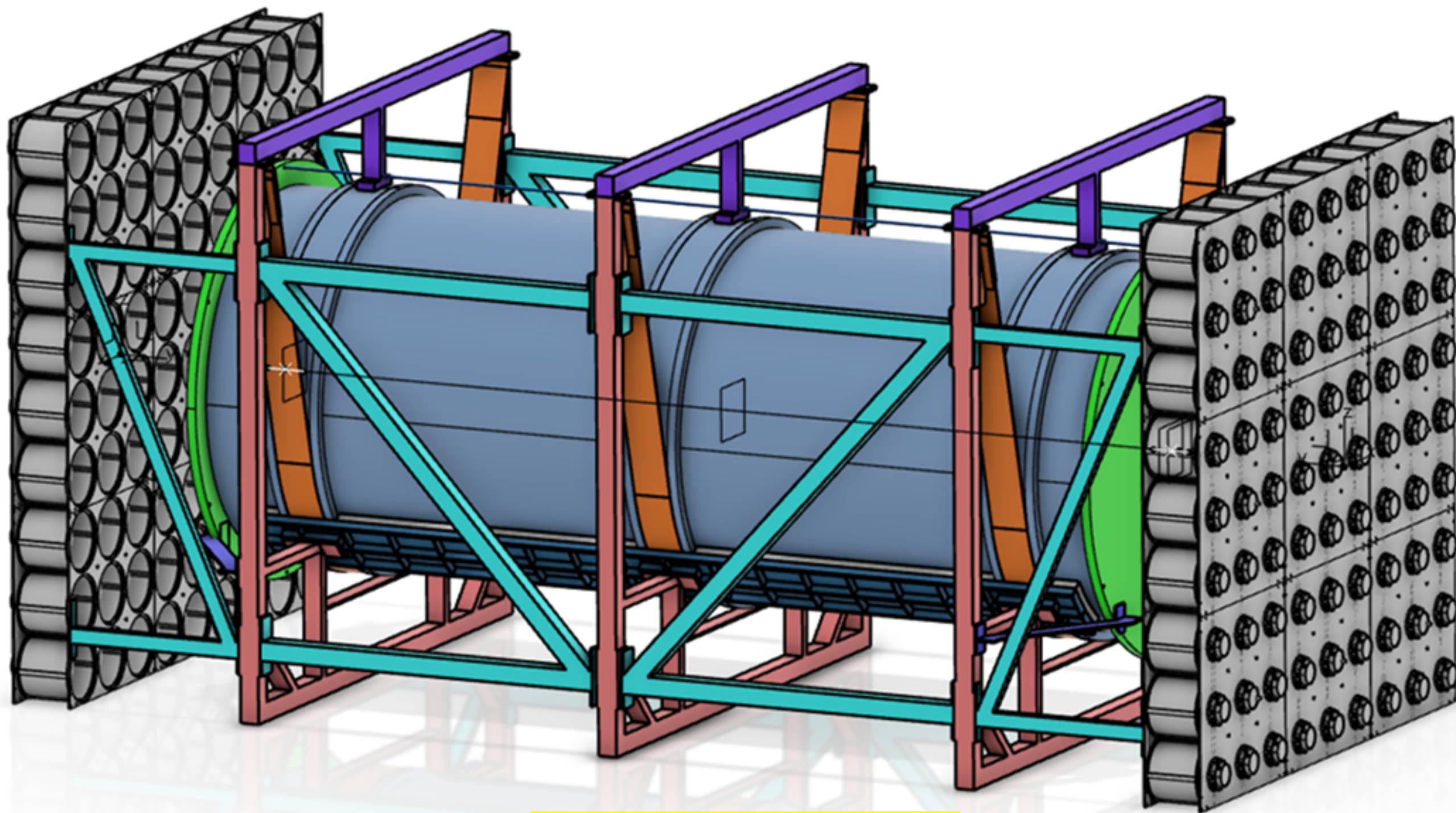
ARMOUR (or **outer-detector**) [~ 0.5 m thickness]

- transparent scintillator (LAB $\oplus$ PPO $\oplus$ Bis-MSB)
- ≤ 180 **DC-PMTs** & highly reflecting walls
- designed light yield ≥ 400 pe/MeV

experimental setup...

- Detector Mass: $\sim [5, 10]$ ton — **LiquidO** technology
- Overburden: ~ 3 mwe
- Baseline: ≥ 30 m (**Ultra Near Detector** site @ Chooz)
- Rate: $\sim 25,000$ anti- ν per day — ~ 10 M anti- ν per year

the detector...



design under review

the inner detector (the core)

DRD2@CERN WORKSHOP

OPAQUE SCINTILLATION

Anatael Cabrera (CNRS / Université Paris-Saclay - IJCLab@Orsay / LNCA@Chooz)

<https://doi.org/10.5281/zenodo.10629927>

pioneering opaque scintillation...



France, Germany, Portugal, Spain, UK with tight links to Canada



EIC approved **extra ~1M€** – LiquidO specialised technology

- new (opaque) scintillator formulation(s) [→photo-chemistry]

A n t i M a t t e r ● T e c h

- new (transparent) wave-shifting/scintillating fibres [→industry]

- outcome: technology beyond LiquidO only scope



more light? novel opaque scintillations

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AntiMatterOTech International consortium

- **EDF** (France) — **first time in neutrino science**
- **CIEMAT** (Spain)
- **IJCLab / Université Paris-Saclay** (France)
- **Johannes Gutenberg Universität Mainz** (Germany)
- **Subatech / Nantes Université** (France)
- **University of Sussex** (UK)

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Joining...

- **Imperial College London** (UK)
- **Instituto Superior Técnico** (Portugal)
- **LIP*** (Portugal)
- **Queen's University** (Canada)
- **Rutherford Appleton Laboratory** (UK)

*Laboratory of Instrumentation and Experimental Particle Physics

Scientific Coordination EU-EIC:

- A. Cabrera — IJCLab / Université Paris-Saclay (France)
- F. Yermia — Subatech / Nantes Université (France)

Scientific Coordination UKRI:

- J. Hartnell — Sussex University (UK)

Webs:

<https://antimatter-otech.ijclab.in2p3.fr/>

the consortium...

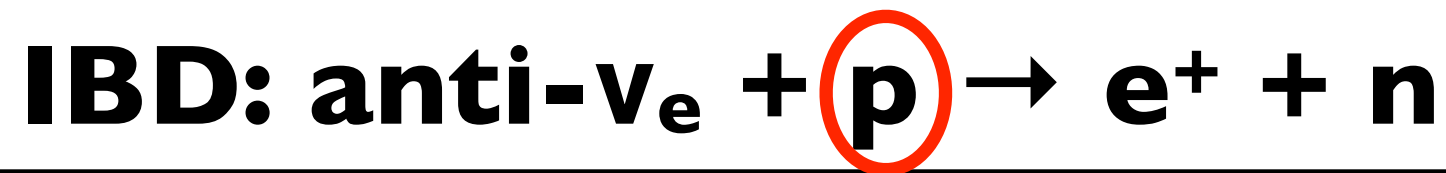
AntiMatterOTech is powered by...

L I Q U I D

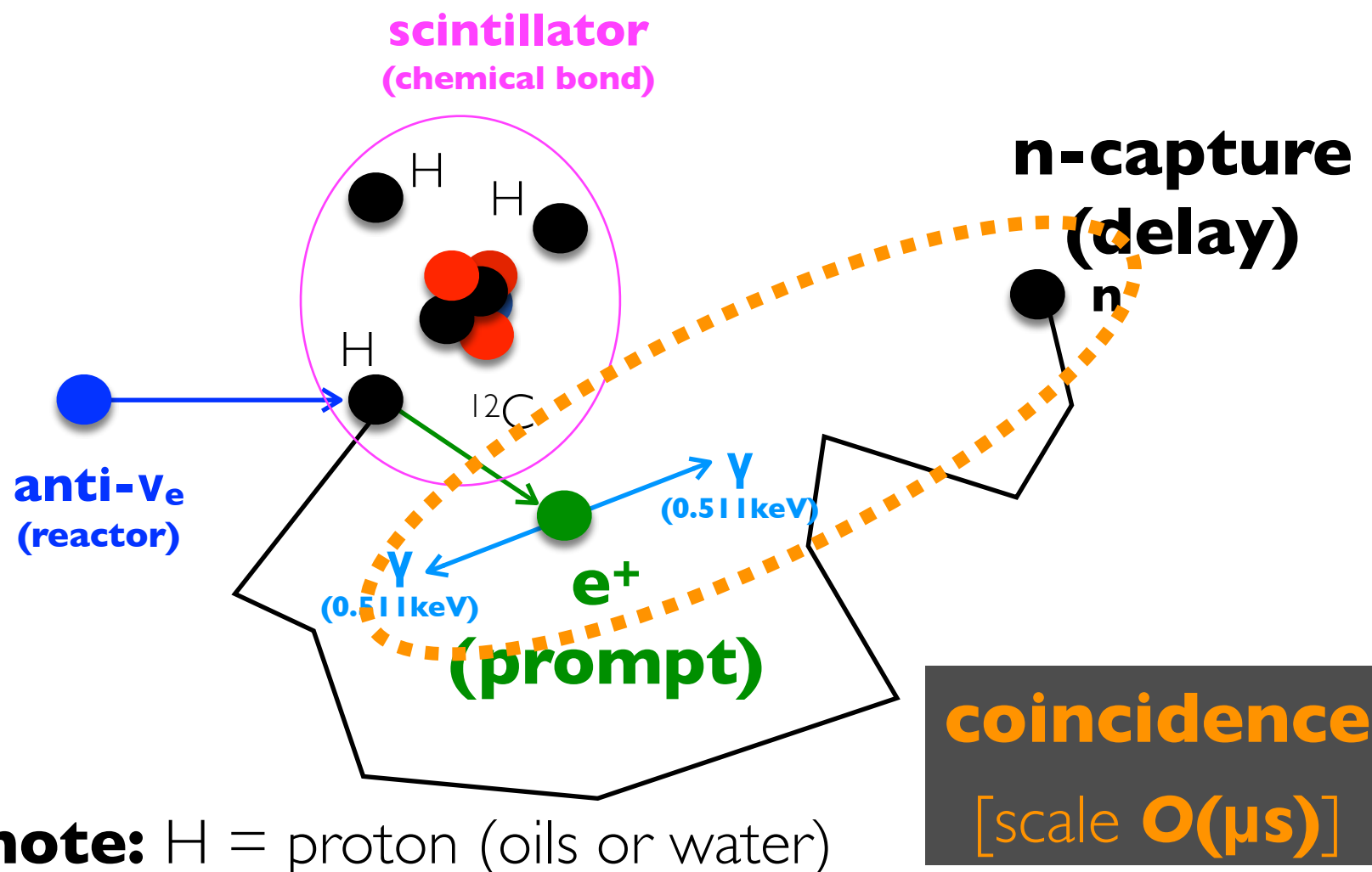


(secretly) also a byproduct of **Double Chooz**

inverse- β decay (IBD) interaction...



IBD detection art...



- n-H (**native**)
- n-C (**native oil**)
- n-O? (**native water**)
- n-Cd (non-native)
- n-Li (non-native)
- n-Gd (non-native)
- ^3He (non-native)

how to catch the n?

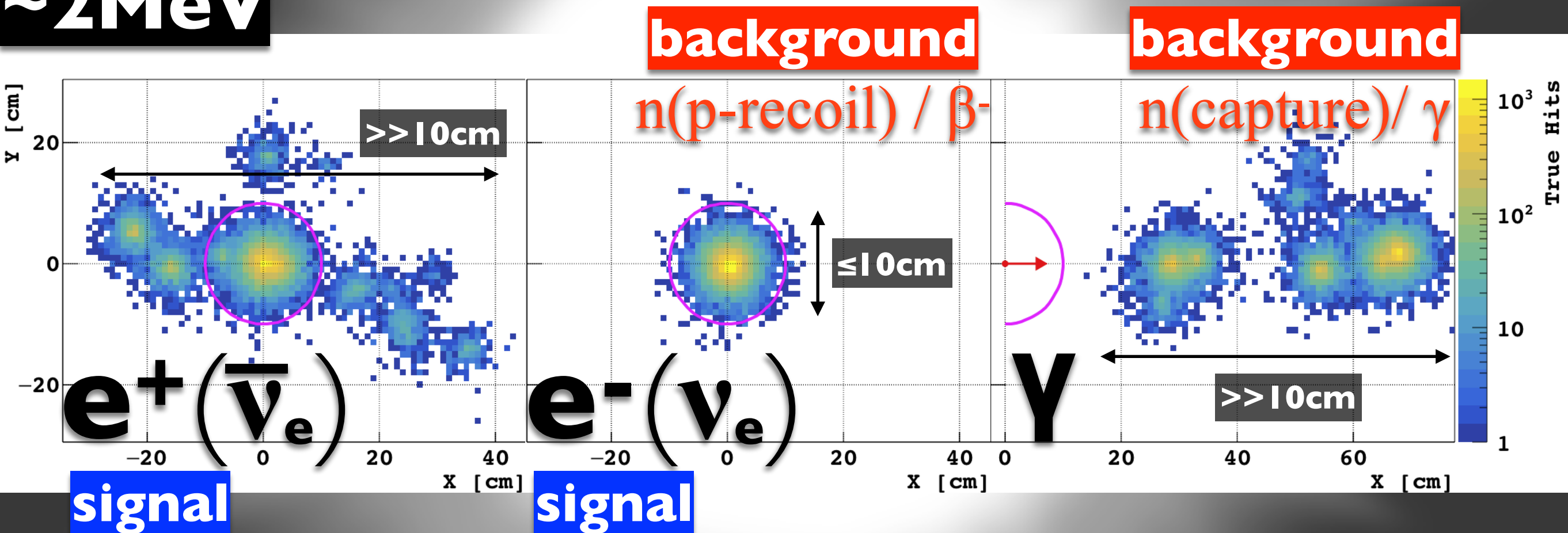
no e^+ PID implies

$$\gamma \approx e^- \approx e^+ \approx \alpha \approx \text{p-recoil (fast-n)}$$

unprecedented MeV imaging (ID)...

reduce overburden/shielding

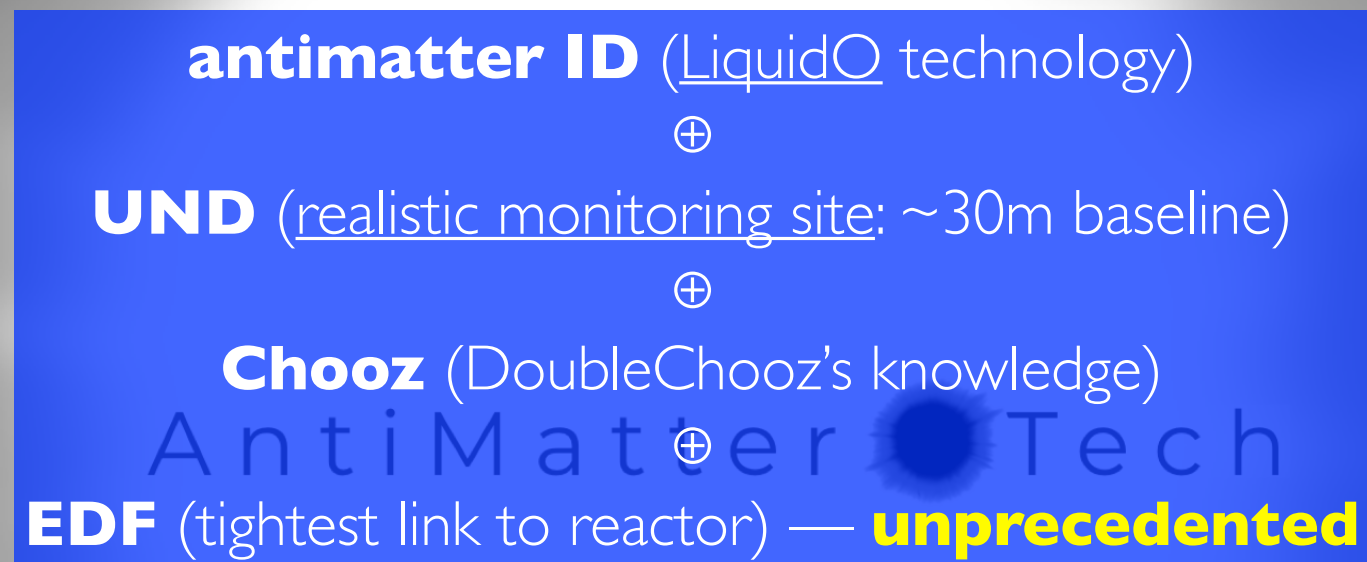
~2MeV



LiquidO: stochastic confinement → NO segmentation

The image shows two bright, circular spots of light against a dark blue background. Each spot has a bright yellow-green center that fades into a lighter blue and then into the dark blue background. The spots are positioned horizontally, one on the left and one on the right, with a significant gap between them. This visual representation likely corresponds to the 'annihilation pattern' mentioned in the text, where two particles meet and annihilate, producing two gamma rays that are detected as these spots.

e^+ PID: mainly an annihilation pattern (i.e. negligible kinetic energy)



antimatter's ID is not exploited since **Reines et al.** (neutrino discovery)

the (new) methodology...

BG rejection >3x better than DC-ND — LiquidO

(~10x less overburden and less shielding)

high efficiency signal (UND: $\geq 10,000$ IBDs per day)

non-intrusive reactor antineutrino detection on surface

(almost no overburden)

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goal: address **Industrial's & IAEA's agenda — in full?**

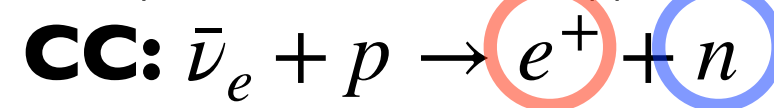
(also **reactor instrumentation synergies & correlations**)

ID strategy is the first step...

the main goals...

Reines et al '50s

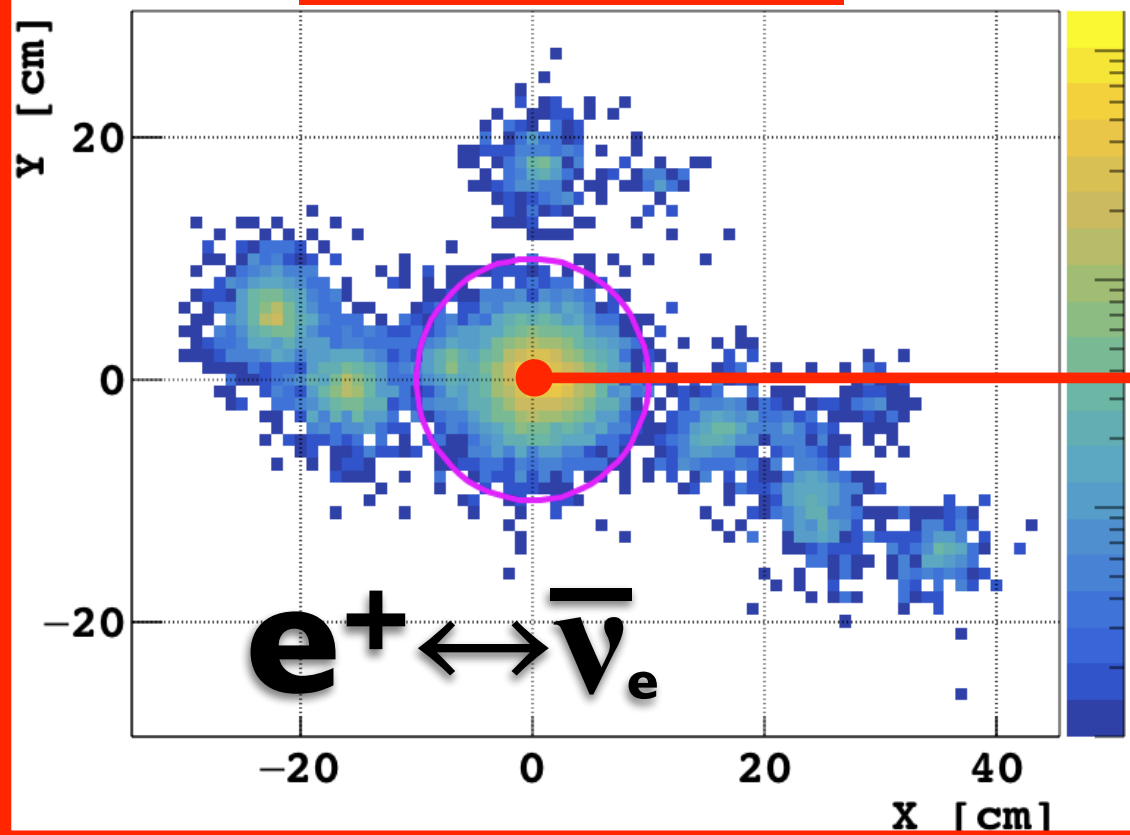
(neutrino discovery)



($\tau \approx 220\mu s$ for only $H\oplus C$)

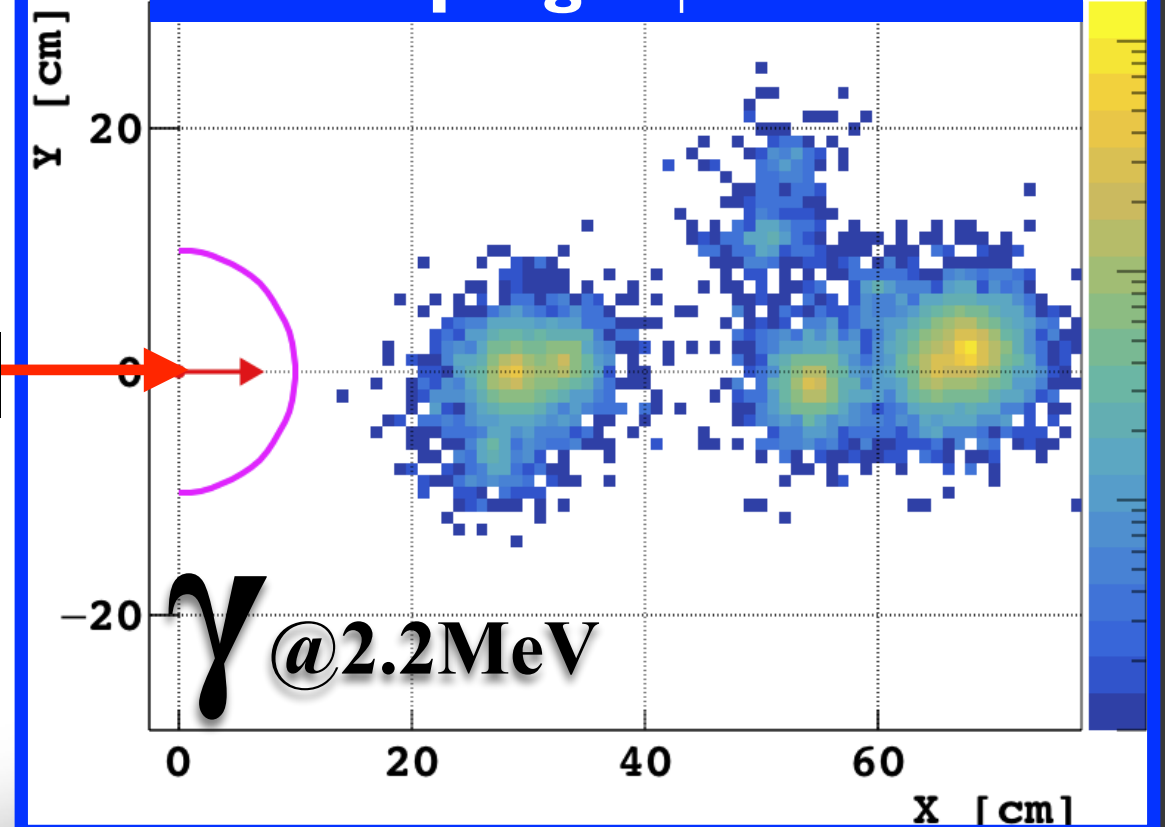
(anti)neutrino **discovery** [τ_n & $\Delta m_{p \sim n}$]

anti-matter



matter
 $\tau \approx 200\mu s$

NO doping → possible later

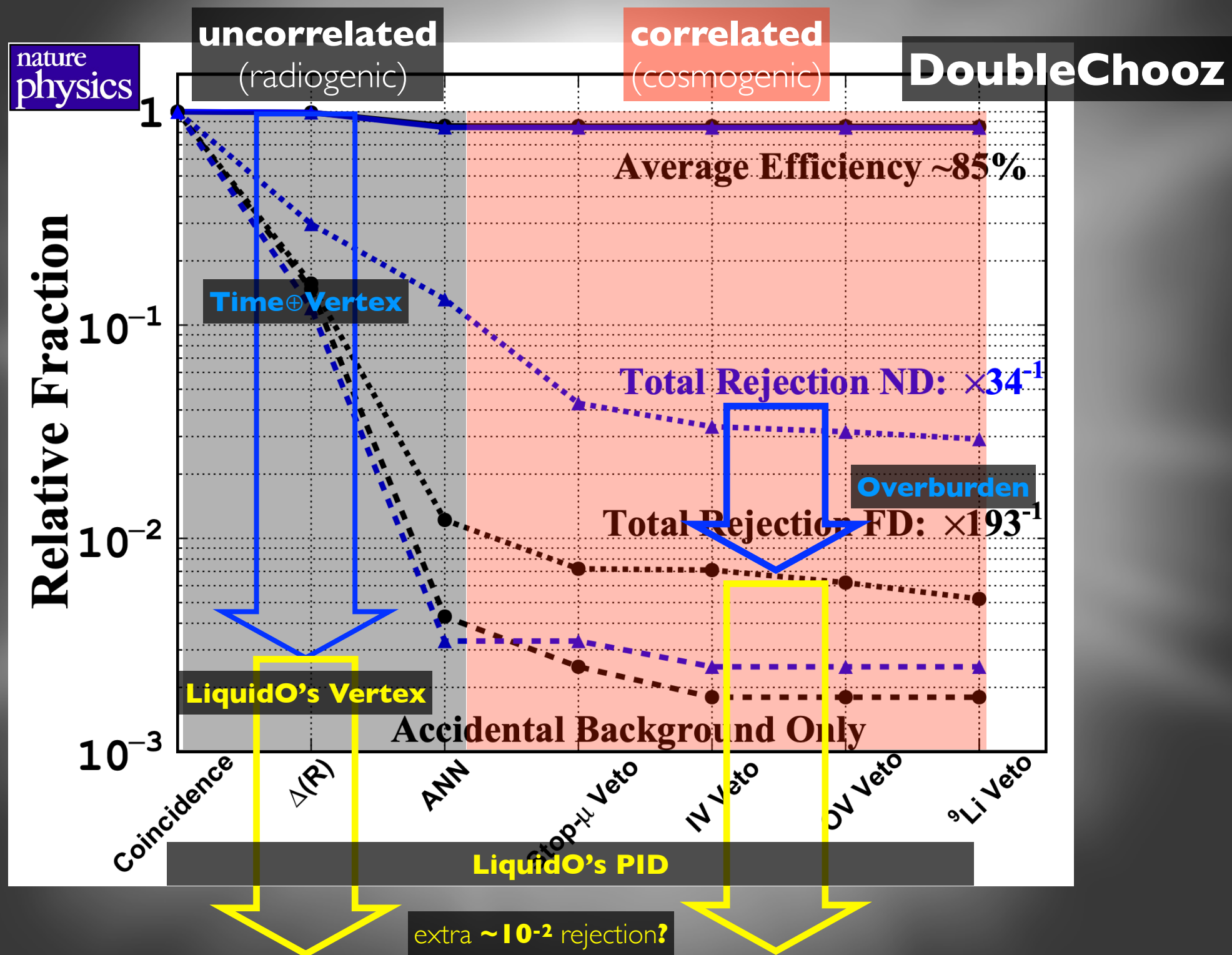


signal: IBD coincidence...



active BG rejection and control...

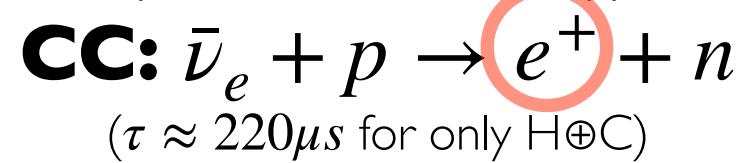
at right **place $\oplus$ time $\oplus$ energy $\oplus$ PID** — several orders of magnitude



combinatory-BG (knocked by ~ 3 orders of magnitude) but **cosmogenic-BG** are **rather immune**

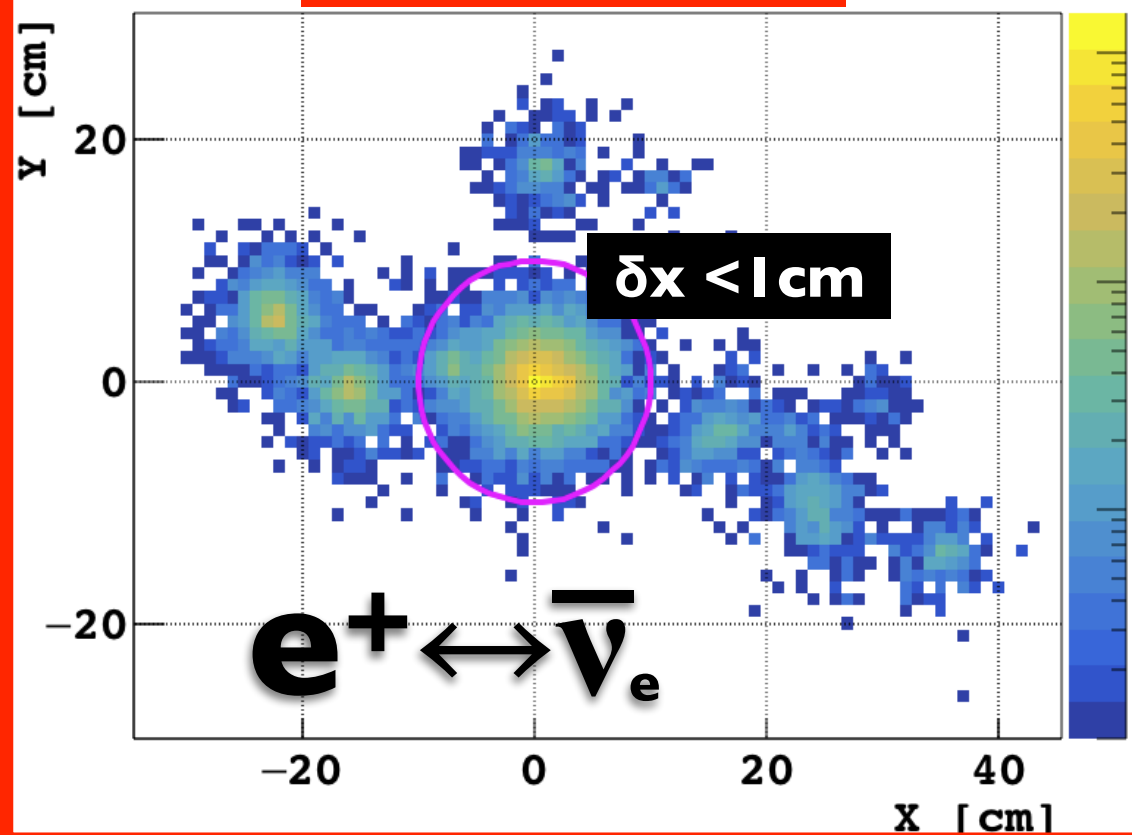
Reines et al '50s

(neutrino discovery)

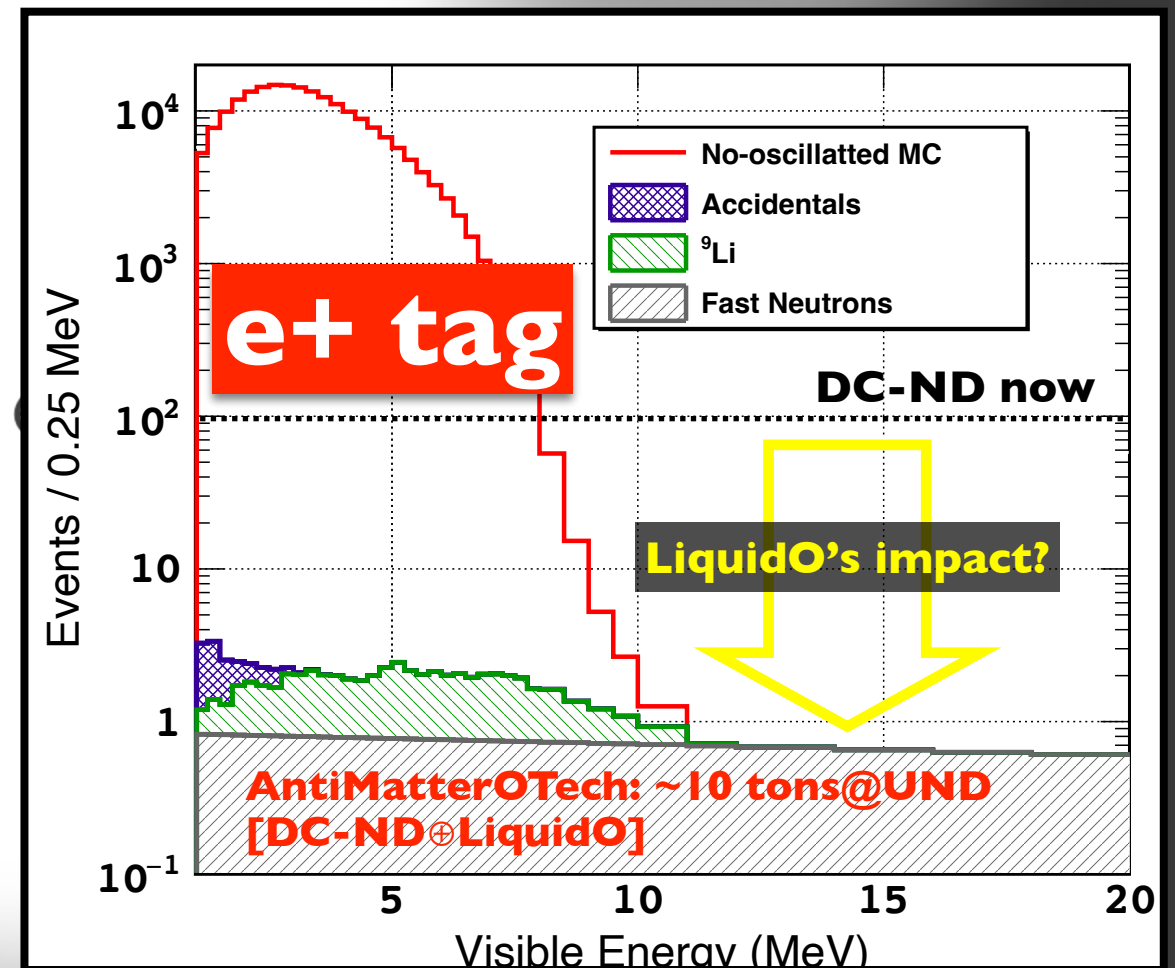


(anti)neutrino **discovery** [τ_n & $\Delta m_{p\sim n}$]

anti-matter



better e^+ position (few mm)

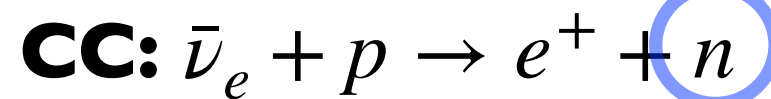


excellent e^+ calorimetry ($\leq 1\%$)

prompt: e^+ ID & calorimetry...

Reines et al '50s

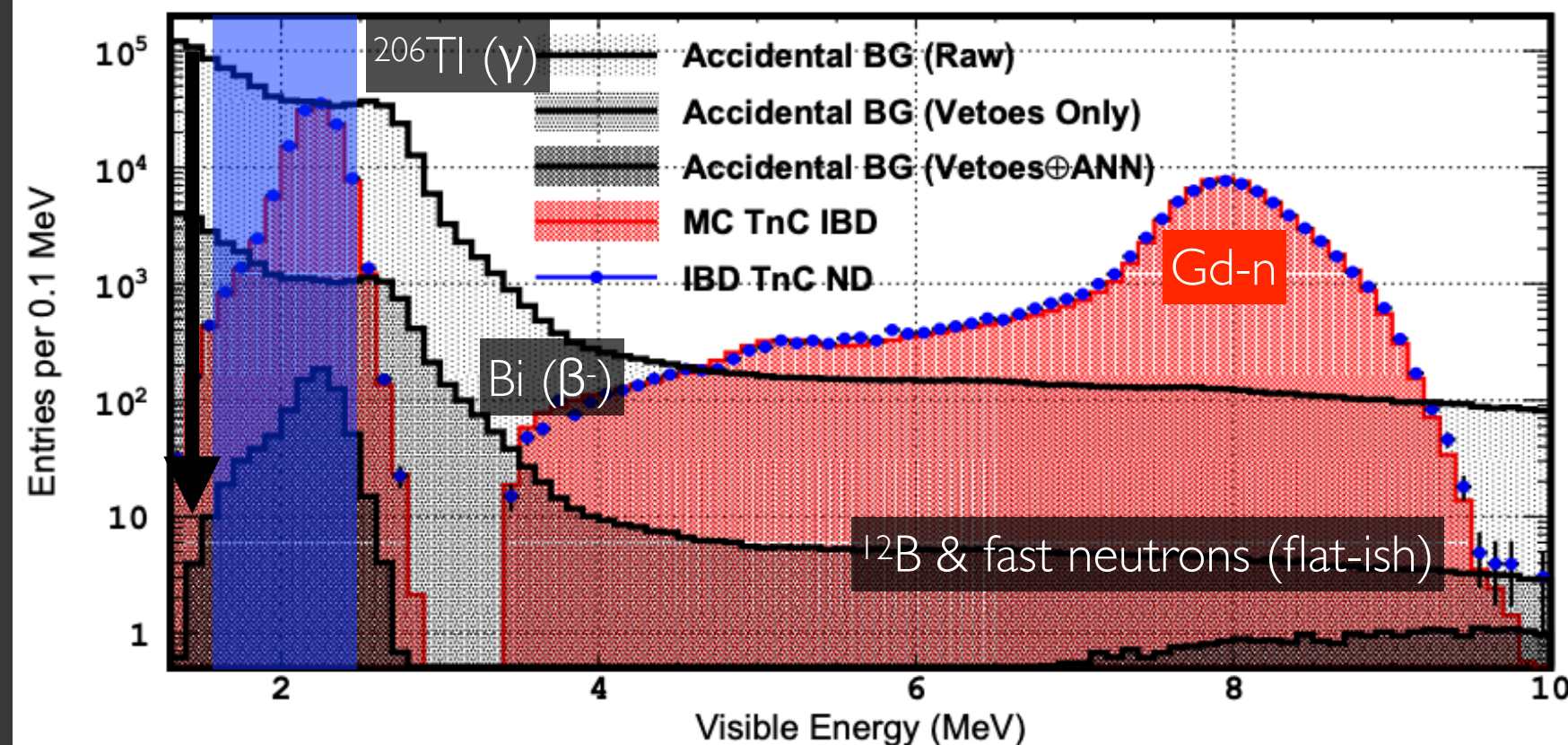
(neutrino discovery)



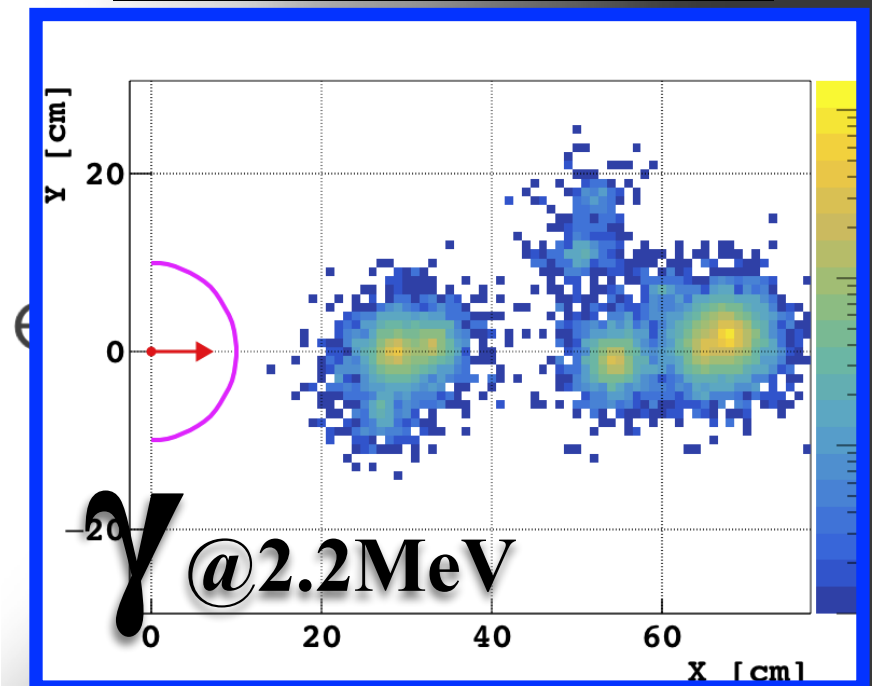
($\tau \approx 220\mu\text{s}$ for only H $\oplus$ C)

(anti)neutrino **discovery** [τ_n & $\Delta m_{p \sim n}$]

H-n — mono-energetic



$\delta x \sim 10\text{cm}$ (Compton)



excellent γ calorimetry (width: $\sim 5\%$ $\rightarrow$ light response)

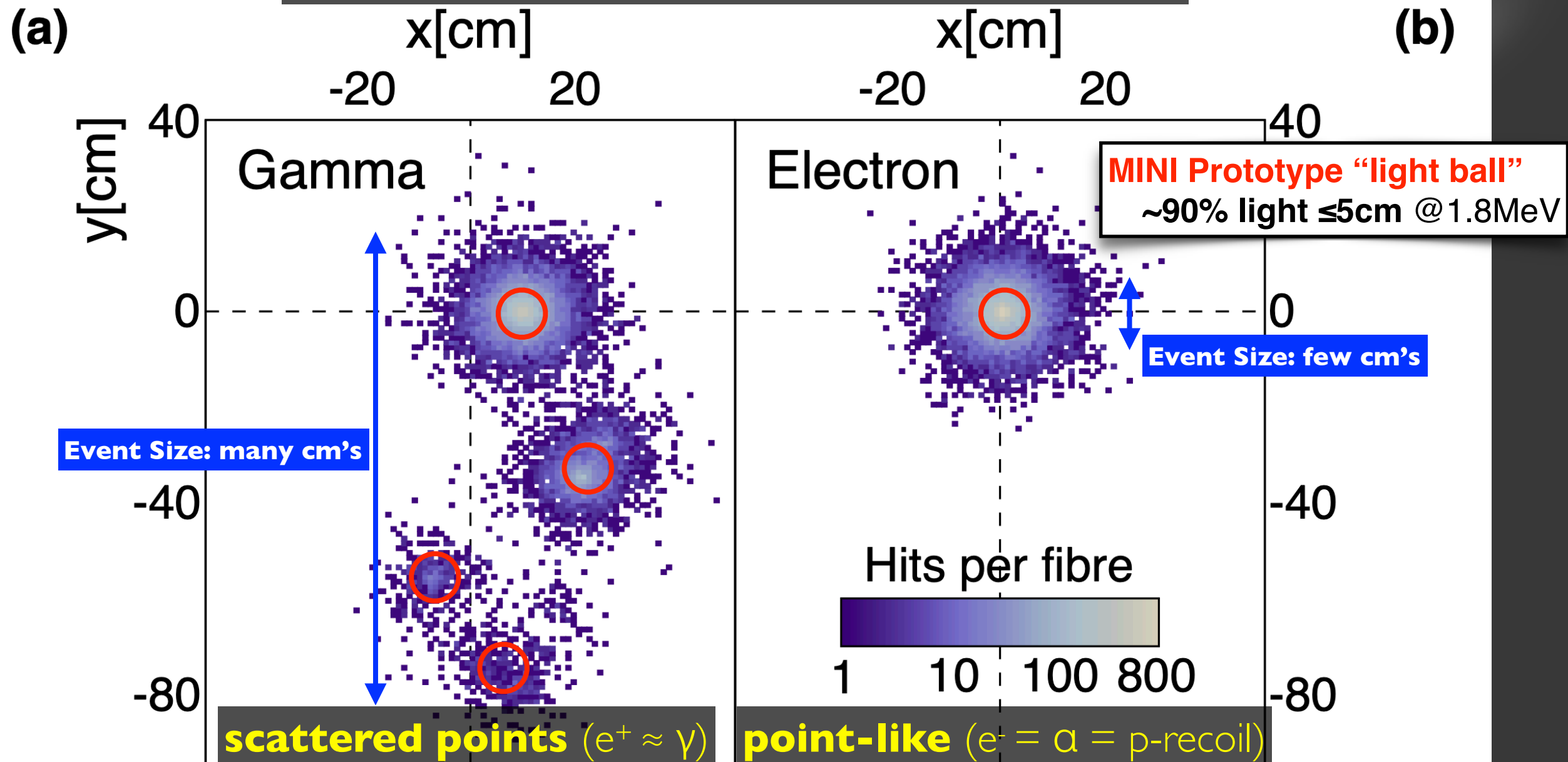
Gd not ideal for surface or small detectors — large energy window [4,10]MeV

delayed: ID and calorimetry...

topology's PID (no timing)...

PID e/ γ should be $\geq 100:1$ rejection @ $\geq 90\%$

(γ resembles more $e^+ = e^- + 2\gamma$)



Neutrino physics with an opaque detector

[LiquidO Consortium](#)

[arXiv:2503.02541](#)

[Communications Physics](#) **4**, Article number: 273 (2021) | [Cite this article](#)

PID is **critical**

- **prompt (e^+)**

- **delayed (γ)**

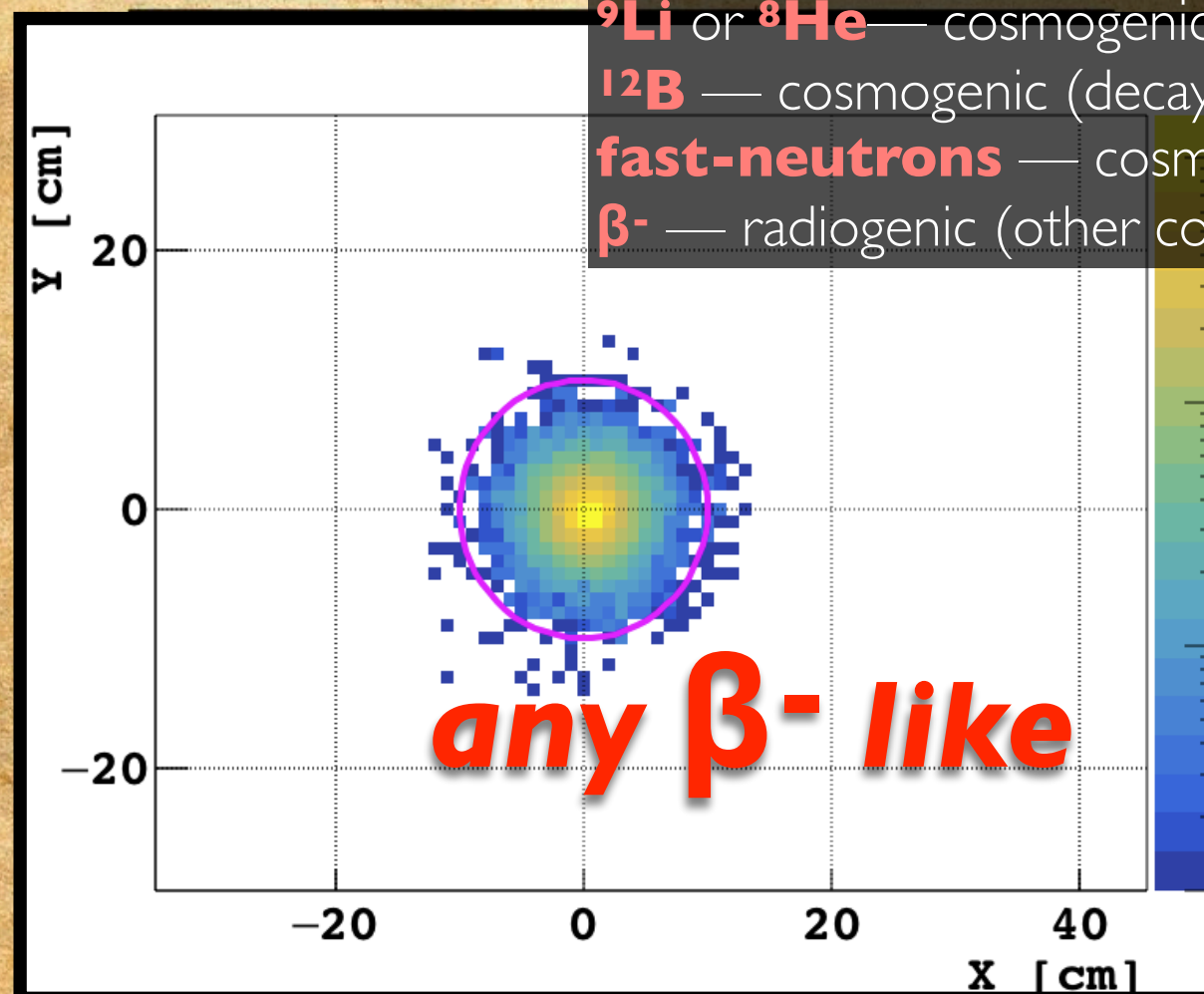
kill cosmogenics!
("correlated" immunity)

				10	11	12	13	14
				N	N	N	N	N
	8	9	10	11	12	13		
	C	C	C	C	C	C		
	7	8	9	10	11	12		
	B	B	B	B	B	B		
5	6	7	8	9	10	11		
Be	Be	Be	Be	Be	Be	Be		
4	5	6	7	8	9	10		
Li	Li	Li	Li	Li	Li	Li		
3	4	5	6	7	8	9		
He	He	He	He	He	He	He		
1	2	3	4	5	6			
H	H	H	H	H	H			

the vast family
of cosmogenics

WANTED

★ DEAD OR ALIVE ★



^9Li or ^8He — cosmogenic (decay β^-) [prompt]
 ^{12}B — cosmogenic (decay β^-) [prompt & delayed]
fast-neutrons — cosmogenic [prompt & delayed]
 β^- — radiogenic (other cosmogenics) [prompt & delayed]

any β^- like

also handles for...

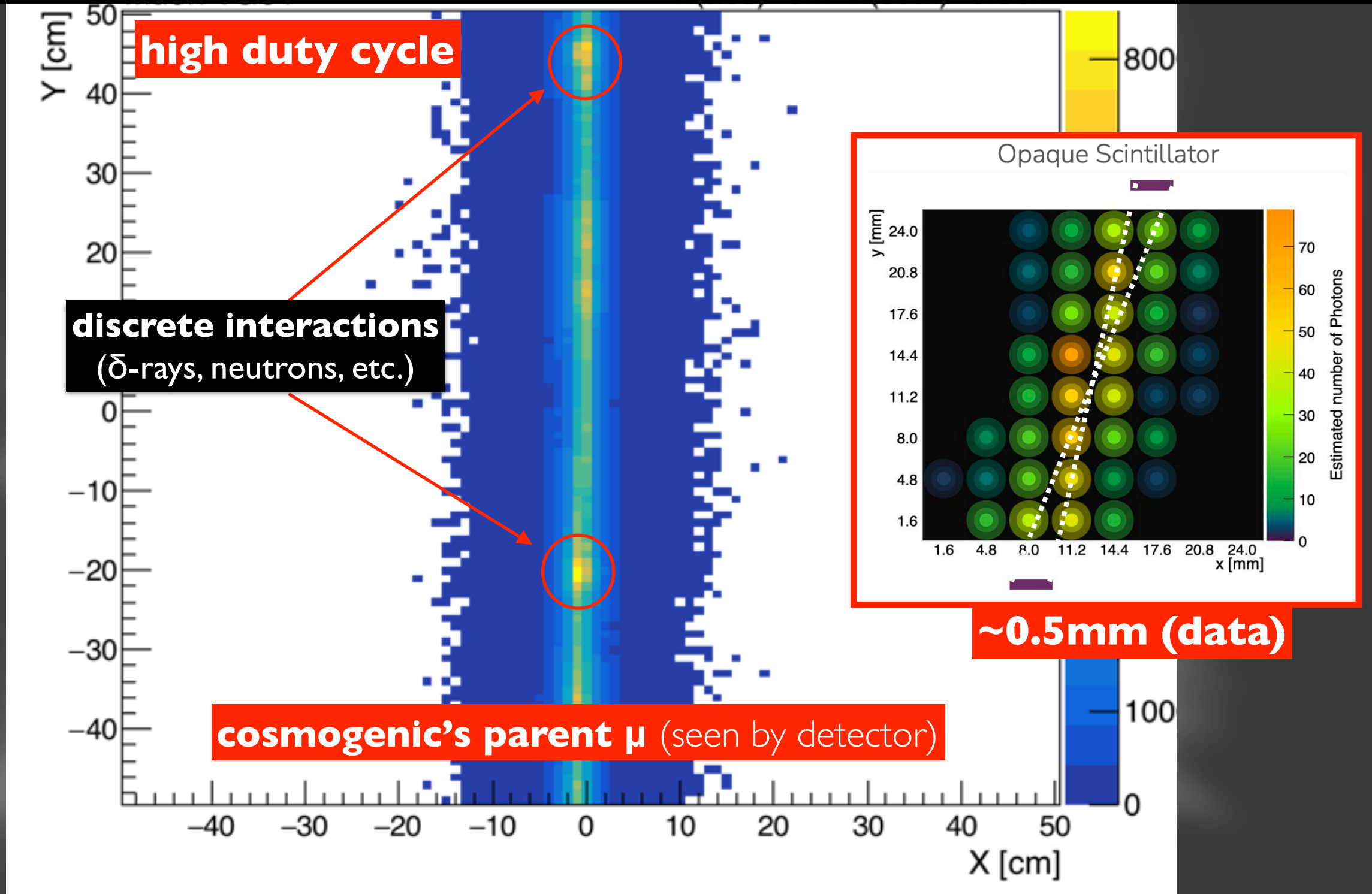
γ — radiogenic rejected by coincidence

^{12}Ni — cosmogenic (decay β^+)

^{11}C — cosmogenic (decay β^+)

worst BGs: one topology...

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



high precision muon-tracking (≤ 1 mm) is critical: **correlation to the previous muons!**

high-precision μ -tracking...



LiquidO enables **cosmogenics** to be **heavily rejected!**
(immune to the IBD's correlation)

potential reduction of overburden (→surface?)



^{12}B (cosmogenic)

^9Li (cosmogenic)

fast-neutrons (cosmogenic)

β^- (radiogenic)

^8He (cosmogenic)

(design) a cosmogenics' hoover...

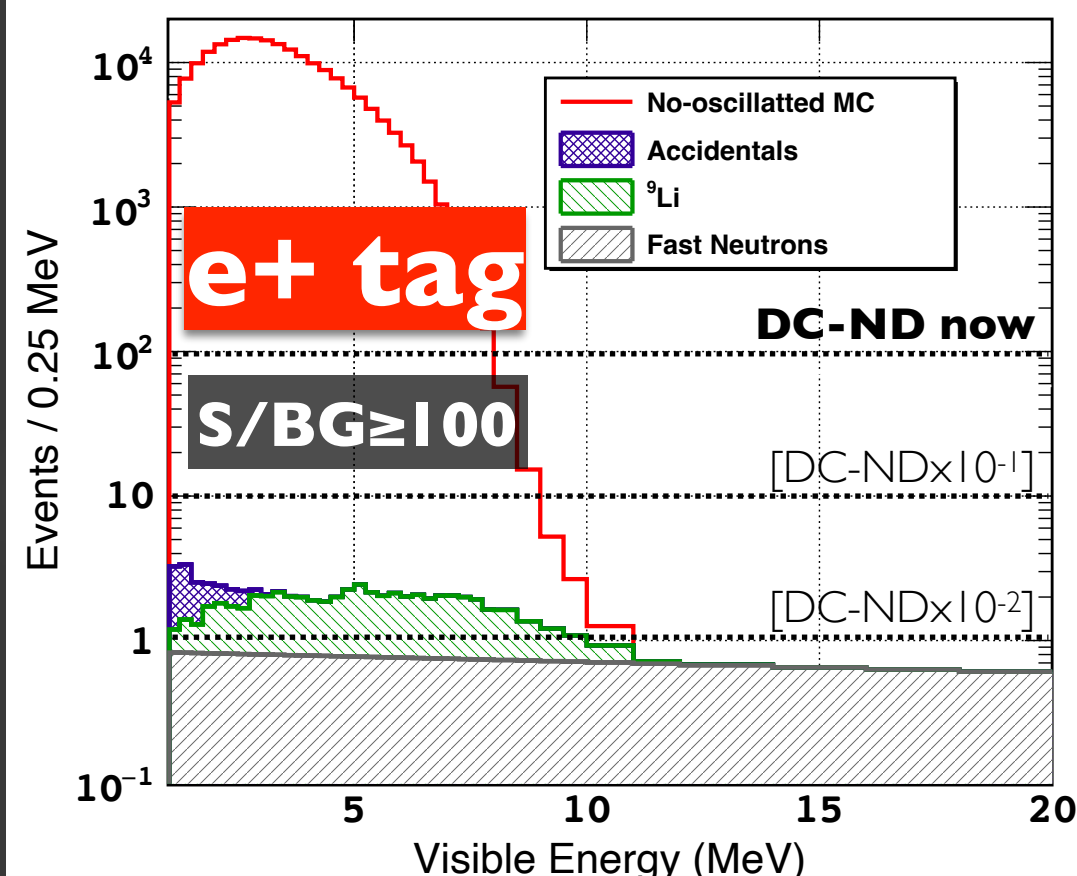
AntiMatter ● Tech

SuperChooz's antineutrino golden channel **demonstration** — byproduct

antineutrino CC (redundancy?)...

physics programme: **IBD@p**...

- **IBD@p** (anti- ν CC): $\geq 10,000$ interaction per day for **10tons ID** [$\geq 3M$ interactions per year]
- **LiquidO** reach a **background-less** regime — improve $\geq 3x$ today's BG control (ex. DC-ND)
- **Signal(ON)-to-BG ≥ 100** — unprecedented high precision reactor characterisation
 - dominant **$\sim 0.5(\text{thermal power})$ uncertainty** & accurate **U/Pu composition**
- **Signal(OFF)-to-BG ≥ 1** — unprecedented **reactor-fuel monitoring**
 - accurate monitoring of **transitions OFF-ON-OFF** — some interesting physics
- **unique test-bench data for accurate prediction** — validate uncertainties, too?



a t t

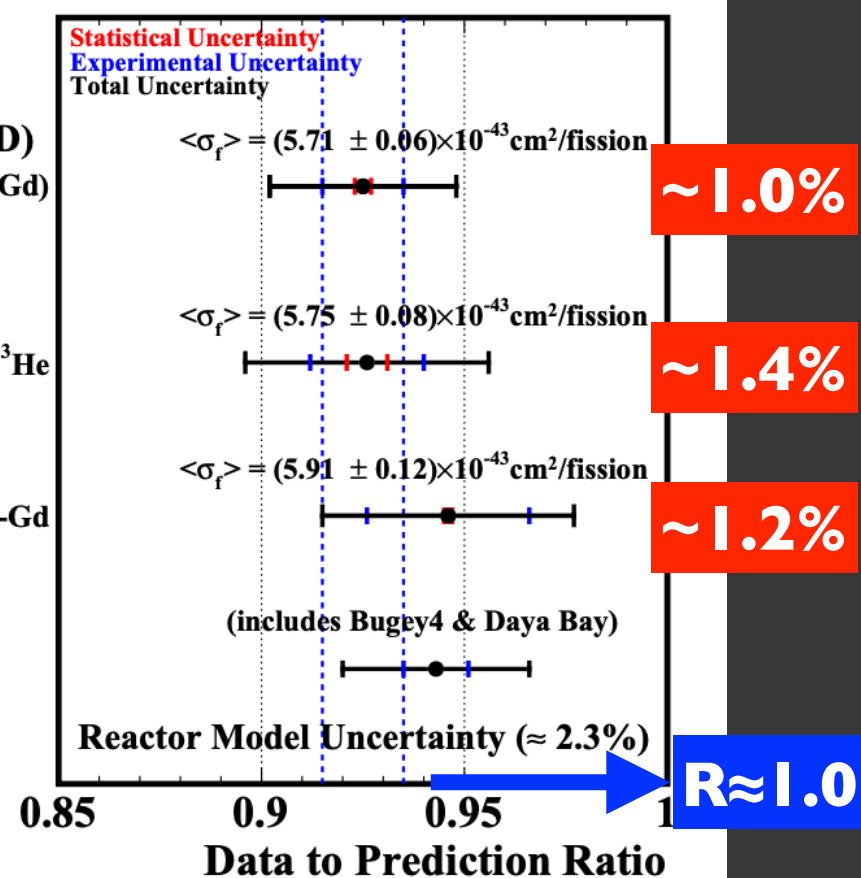
nature
physics

Double Chooz IV (ND)
TnC ($n\text{-H} \oplus n\text{-C} \oplus n\text{-Gd}$)

Bugey4
Phys.Lett.B338,383(1994) ^3He

Daya Bay
CPC 41.1.013002(2017) $n\text{-Gd}$

2017 World Average
CPC 41.1.013002(2017)



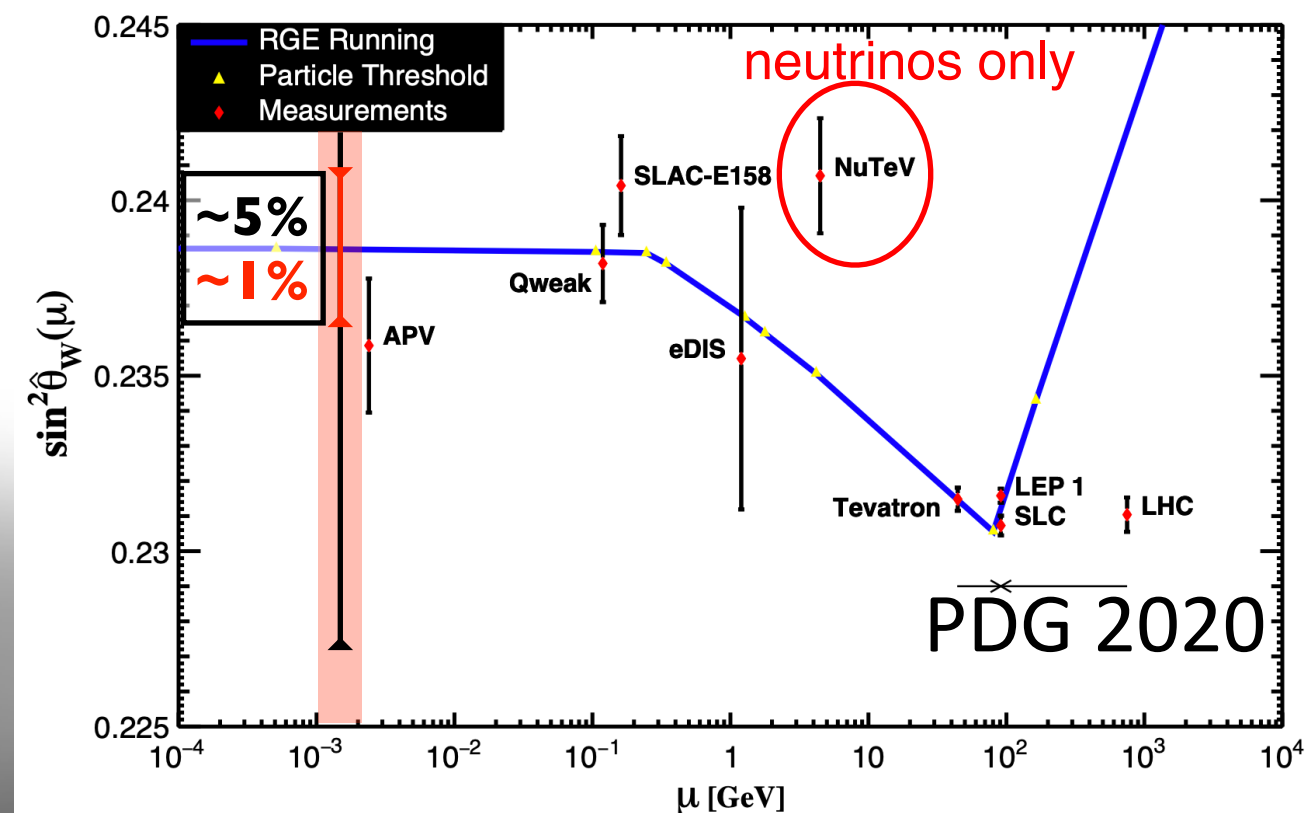
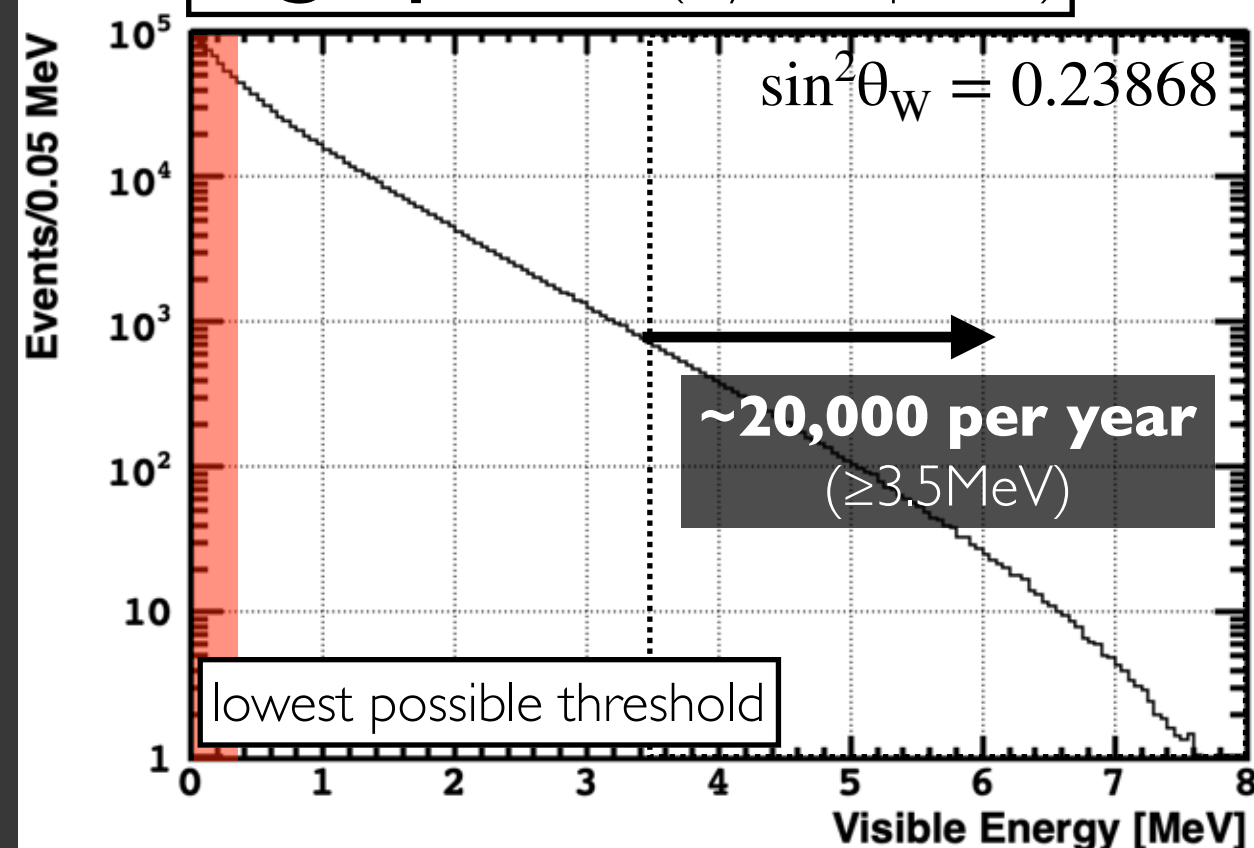
precision $\geq 0.6\%$ $\Rightarrow$ Unitarity Violation test (if predictions are improved)!

redundancy: Elastic Scattering...

- **eES** (anti- ν CC $\oplus$ NC): **$\leq 5,000$** interactions per day for **10tons ID** [$\approx 2M$ interactions per year]
 - interference CC & NC — different for neutrino (easier) and antineutrino (harder)
 - measure θ_w or use to **decompose the NC flux** component
 - PDG-2022's $\sin^2\theta_w \approx [0.231, 0.239]$ — running due to SM's renormalisation
- **major challenge: LiquidO** isolate “e-like” PID and exploit **high-rate reactor modulation**
 - likely strong **fiducial volume** & **higher energies** — reduce detected rate drastically
 - **$\leq 10\%$ precision** ($\geq 5\sigma$ observation) tolerates much BG but **$\leq 1\%$ precision** $\Rightarrow$ **higher S/BG?**

AntiMatter Tech

ES@e Spectrum (1 year exposure)



R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)



CLOUD's programme first released in Oct. 2023

<https://doi.org/10.5281/zenodo.10049845>

beyond AntiMatter-OTech...

- **reactor antineutrino via IBD (on proton) — threshold $\geq 1.8\text{MeV}$**
 - ON ✓ — since Reines *et al.*
 - OFF ✓
- **reactor antineutrino $\oplus$ neutrino via elastic scattering (on electrons) — ~thresholdless**
 - ON ✓ — poor precision $\Rightarrow$ **improve?** (tough BGs!!) probing the **NC component!**
- **reactor neutrino via Indium interactions — threshold $\geq 0.1\text{MeV}$**
 - **CLOUD-II**'s scientific programme (**under exploration**)
 - probe complementary **β^+/EC contribution** — **never seen** ($\sim 10^{-5}\times$ less than antineutrino)
 - **help predict antineutrino data?** [complementary data set]
- **reactor antineutrino via IBD (beyond proton): Cu — threshold $\geq 1.2\text{MeV}$**
 - **CLOUD-III**'s scientific programme (**under exploration**)
 - new methodology (proposed by us): [arXiv:2308.04154](https://arxiv.org/abs/2308.04154) — being published
 - **less smooth features $[1.0, 1.8]\text{MeV}$** by Kopeikin *et al.* — **never seen**
 - **help predict antineutrino data?** [complementary data set]

after AntiMatterOTech timeline...

arXiv:2308.04154

Probing Earth's Missing Potassium using the Unique Antimatter Signature of Geoneutrinos

A. Cabrera^{*12 α ,2,a}, M. Chen^{†6}, F. Mantovani^{‡3 α ,3 β} , A. Serafini^{§3 α ,3 β ,13 α ,13 β} , V. Strati^{*3 α ,3 β} , J. Apilluelo¹⁸, L. Asquith¹, J.L. Beney¹¹, T.J.C. Bezerra¹, M. Bongrand¹¹, C. Bourgeois^{12 α} , D. Breton^{12 α} , M. Briere^{12 α} , J. Busto¹⁰, A. Cadiou¹¹, E. Calvo⁸, V. Chaumat^{12 α} , E. Chauveau⁴, B.J. Cattermole¹, P. Chimenti⁷, C. Delafosse^{12 α} , H. de Kerret^{1a}, S. Dusini^{13 α} , A. Earle¹, C. Frigerio-Martins⁷, J. Galán¹⁸, J. A. García¹⁸, R. Gazzini^{12 α} , A. Gibson-Foster¹, A. Gallas^{12 α} , C. Girard-Carillo^{9 α} , W.C. Griffith¹, F. Haddad¹¹, J. Hartnell¹, A. Hourlier¹⁷, G. Hull^{12 α} , I. G. Irastorza¹⁸, L. Koch^{9 α} , P. Lanièce^{12 α ,12 β} , J.F. Le Du^{12 α ,2}, C. Lefebvre⁶, F. Lefevre¹¹, F. Legrand^{12 α} , P. Loaiza^{12 α} , J. A. Lock¹, G. Luzón¹⁸, J. Maalmi^{12 α} , C. Marquet⁴, M. Martínez¹⁸, B. Mathon^{12 α} , L. Ménard^{12 α ,12 β} , D. Navas-Nicolás^{12 α} , H. Nunokawa¹⁵, J.P. Ochoa-Ricoux⁵, M. Obolensky^a, C. Palomares⁸, P. Pillot¹¹, J.C.C. Porter¹, M.S. Pravikoff⁴, H. Ramarijaona^{12 α} , M. Roche⁴, P. Rosier^{12 α} , B. Roskovec¹⁴, M.L. Sarsa¹⁸, S. Schoppmann^{9 β} , W. Shorrocks¹, L. Simard^{12 α} , H.Th.J. Steiger^{9 α ,9 β} , D. Stocco¹¹, J.S. Stutzmann¹¹, F. Suekane^{16,a}, A. Tunc^{9 α} , M.-A. Verdier^{12 α ,12 β} , A. Verdugo⁸, B. Viaud¹¹, S. M. Wakely^{9 α} , A. Weber^{9 α} , and F. Yermia¹¹

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(LiquidO Consortium)

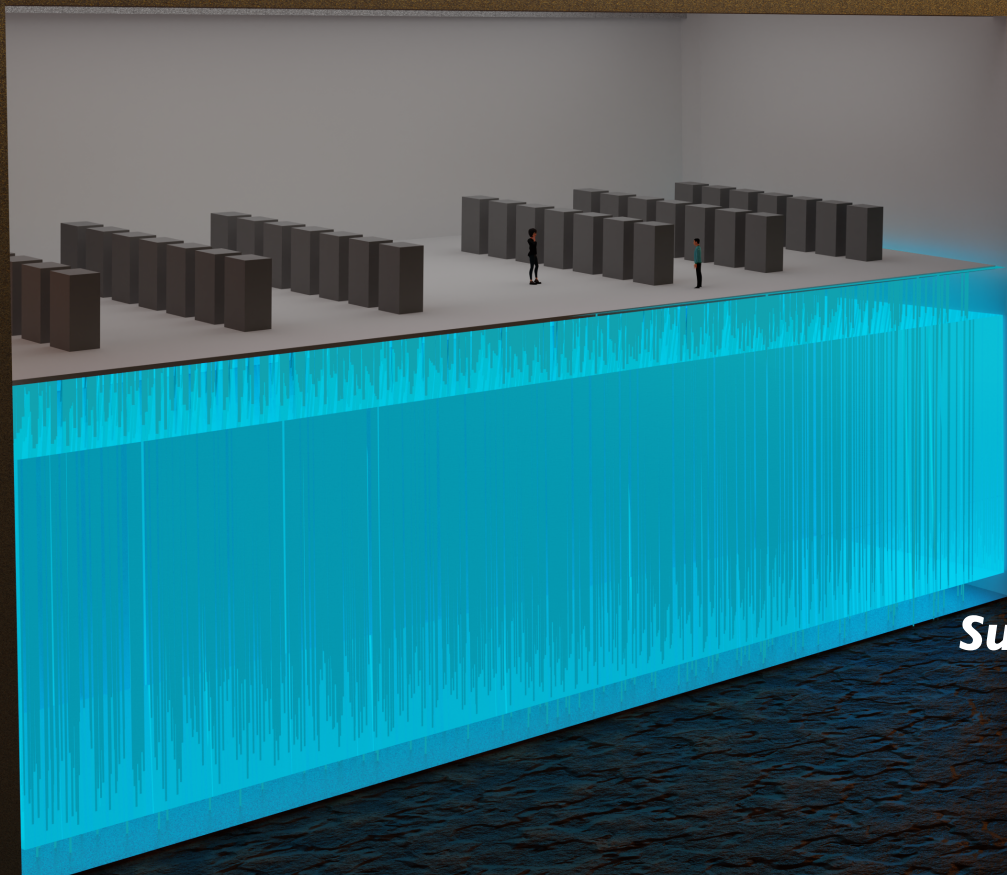
⁴⁰K geoneutrino new methodology — the missing component

SuperChooz exploration...

flagship neutrino oscillation experiment in Europe?

the Ardennes mountains

Chooz-A: Cavern Reactor Core



European
Innovation
Council



UK Research
and Innovation

AM-OTech project [EIC-UKRI]
CLOUD experiment

1 Dec 2022

Chooz-B: Reactor Cores

Ultra Near Detectors @ Chooz-B:

- LiquidO technology
- Mass: ≤ 5 tons
- Overburden: ≤ 5 m
- Baseline: ≤ 30 m

Super Far Detector @ Chooz-A

- LiquidO technology
- Mass: $\sim 10,000$ tons
- Overburden: ≤ 100 m
- Baseline: ~ 1 km

<https://zenodo.org/record/7504162>

the Meuse river

AntiMatter●Tech

a long story short...

an even **vaster future** of **reactor (anti)neutrinos** on **surface** ahead?

- **AntiMatterOTech** (likely) very **ambitious & fully funded** (Europe) for **reactor neutrinos**
 - (goal) **demonstrate industrial reactor antineutrino direct fissile monitoring**
 - **complementarity** to today's instrumentation — synergies & correlations
 - (byproduct) potential to address much of the **IAEA wishlist too** — all?
 - **robust design: reactor's ON / OFF** (over their entire **lifespan**) & **compromised** cases?
- **AntiMatterOTech** builds on decades of experience — thanks to **LiquidO** & **Double Chooz** (field)
 - **LiquidO's topological information** is at the core... (many years of **R&D** and experience now)
 - **step #1: e+'s antimatter ID** — [building block's demo @ [arXiv:2503.02541](https://arxiv.org/abs/2503.02541)]
 - **step #2: high-precision γ (2.2MeV) detection** (ID, calorimetry, etc.) [same as above]
 - **step #3: sub-mm μ -tracking** is critical [**publication very soon!**]
 - **improving (anti)neutrino detection** (less cosmogenics) **remains open** — **more ideas!!**

new schedule: data by 2028

the main points...

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Дякую...

thanks...

danke...

고맙습니다...

merci...

ありがとう...

obrigado...

спасибі...

grazie...

谢谢...

hvala...

gracias...

شكرا...

AntiMatter  Tech

questions?