European Innovation Council

UK Research and Innovation

C L O U D

deepening further into reactor neutrino physics

TWENTY-SECOND LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS
August, 21-27, 2025
MOSCOW STATE UNIVERSITY

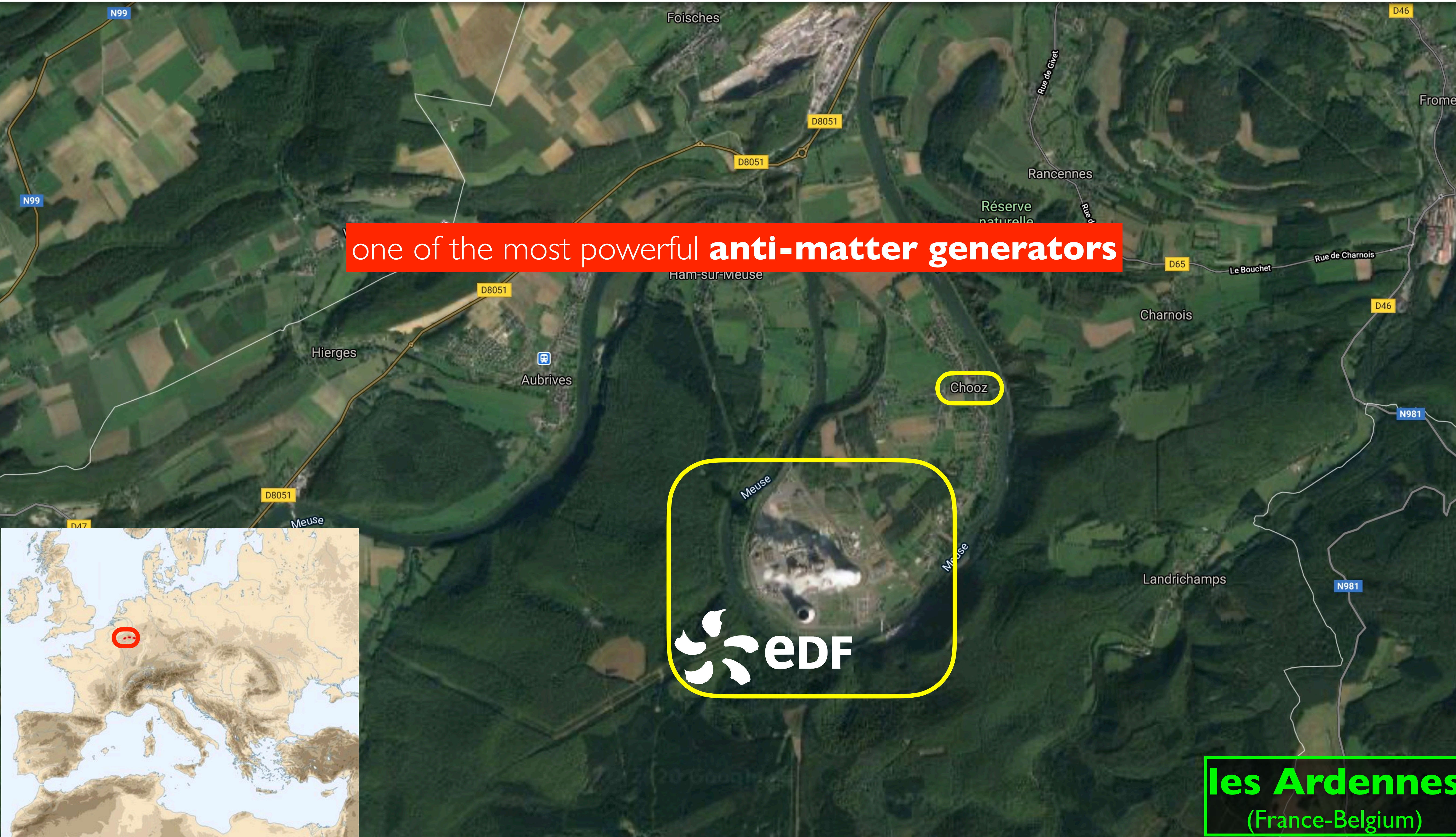
Lomonosov Conference
27 August 2025 — Moscow (Russia)

Anatael Cabrera
Université Paris-Saclay / CNRS — IJCLab / LNCA
Orsay/Chooz, France

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

IJCLab Irène Joliot-Curie
cnrs
université PARIS-SACLAY | FACULTÉ DES SCIENCES D'ORSAY
Université de Paris

in the **middle of central Europe** (between France-Belgium): **Chooz** [meeting point with Germany, Luxembourg, Netherlands]

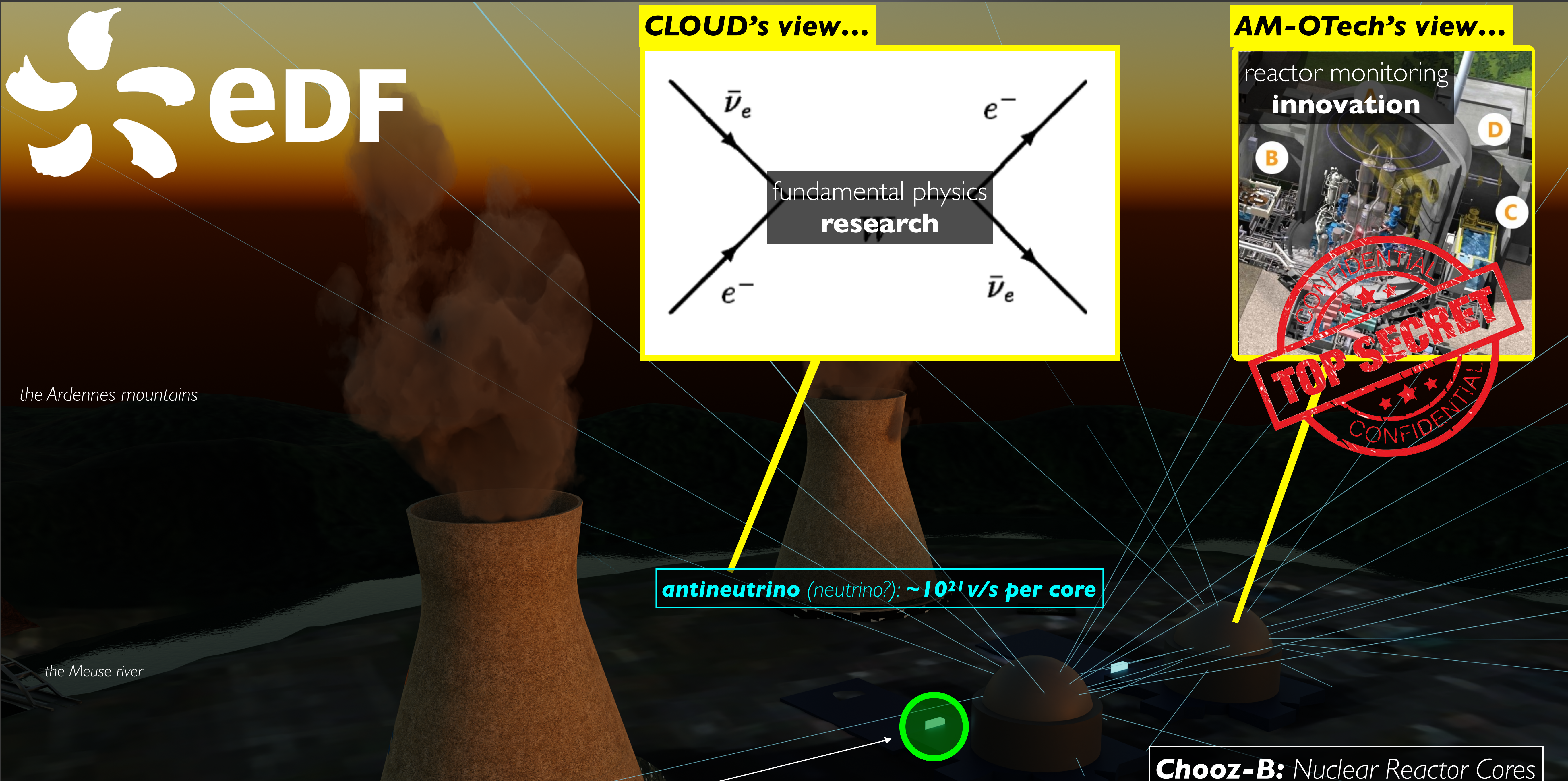


one of the most powerful **anti-matter generators**

les Ardennes
(France-Belgium)

Europe’s most powerful reactor site…

3rd generation of reactor neutrino experiments @ Chooz



experimental setup…

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

CLOUD vs AntiMatter-OTech…

CLOUD

reactor neutrinos **experimental methodology largely similar** for the last **~70 years** (Reines et al.)

powerful framework so far, but **good enough for discoveries ≥2025?**

on the shoulders of giants…

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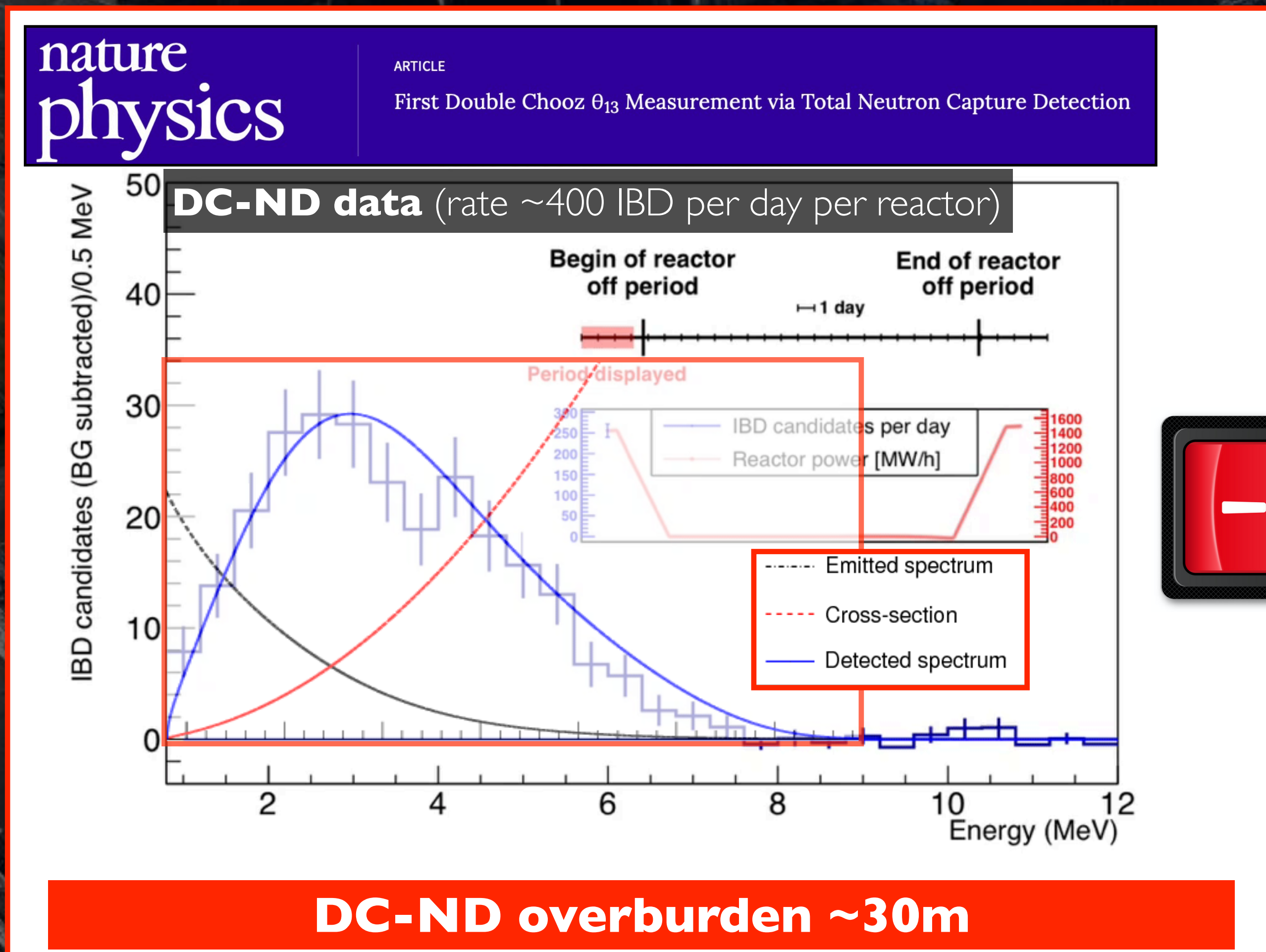
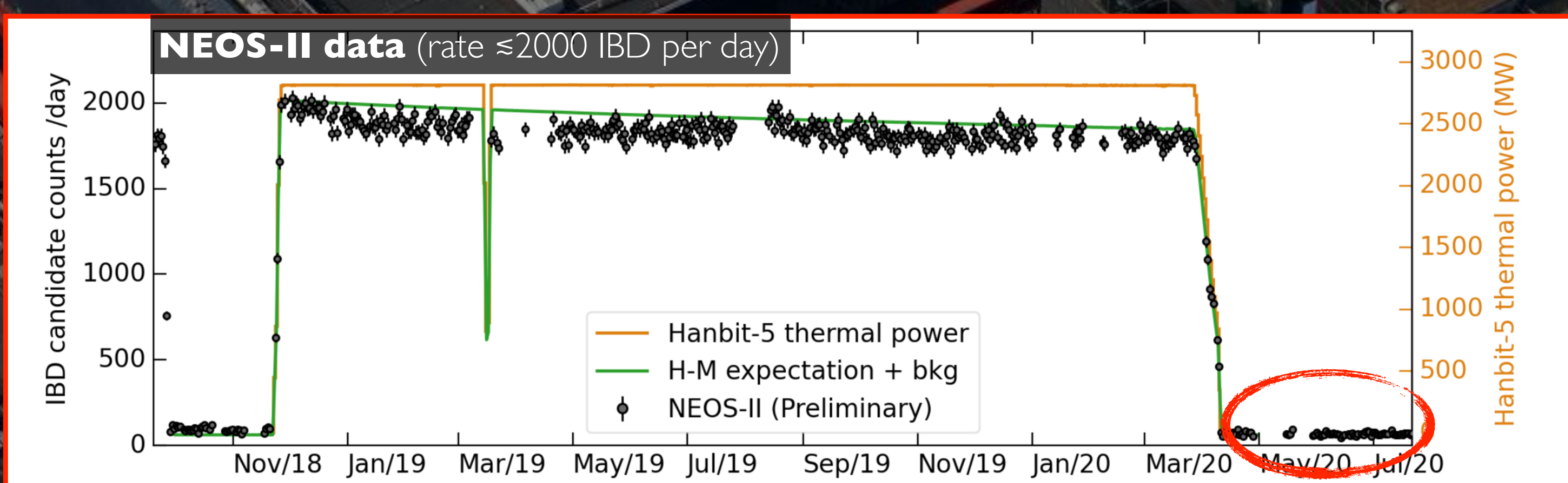
reactor neutrinos…

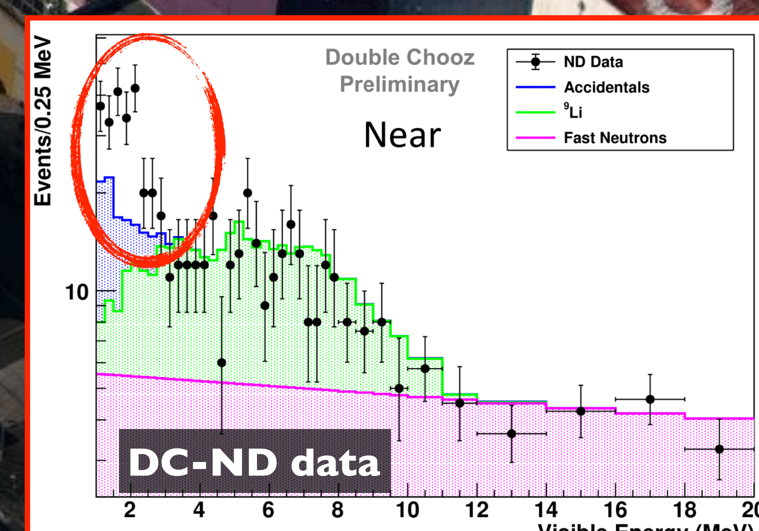


powerful experimental framework

- **IBD(p): one interaction (CC)**
  - →**NC** still very difficult
- **flux: several issues!**

status: issues vs physics?





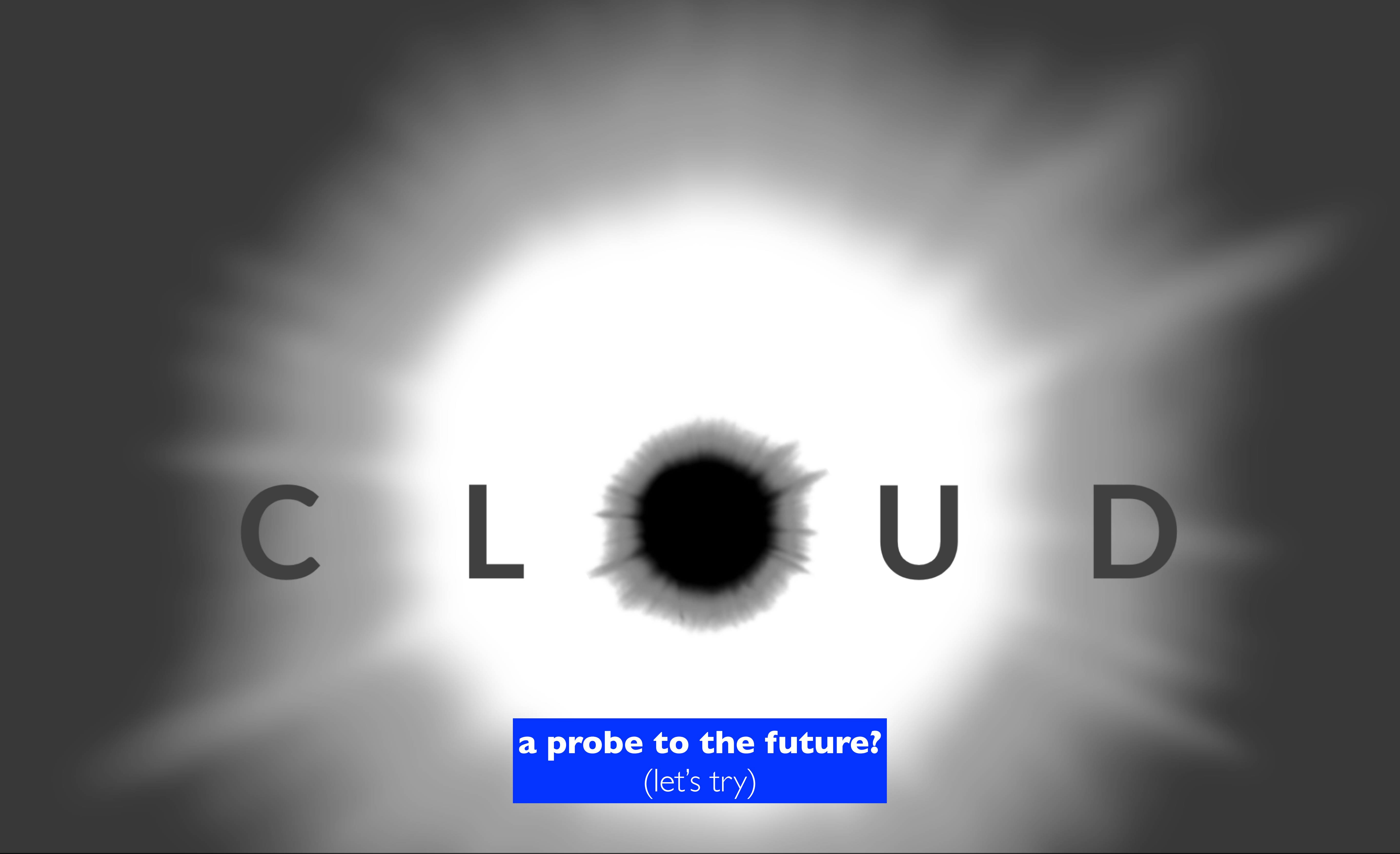
E(ν) controlled up to **≤0.5% accuracy/precision** via the **E(e+)** — demonstrated by **DC⊕DYB**

future: discoveries?

today's BG: *standard neutrino oscillation*

neutrino⊕weak-interaction remains **bizarre** (Majorana, etc)…

- new neutrino **phenomenology**? [ex. mixing and masses]
- new neutrino **interactions**?
- new neutrino **states**? [assume: "3+1 sterile" is largely ruled out]



a probe to the future?
(let's try)

the experiment…

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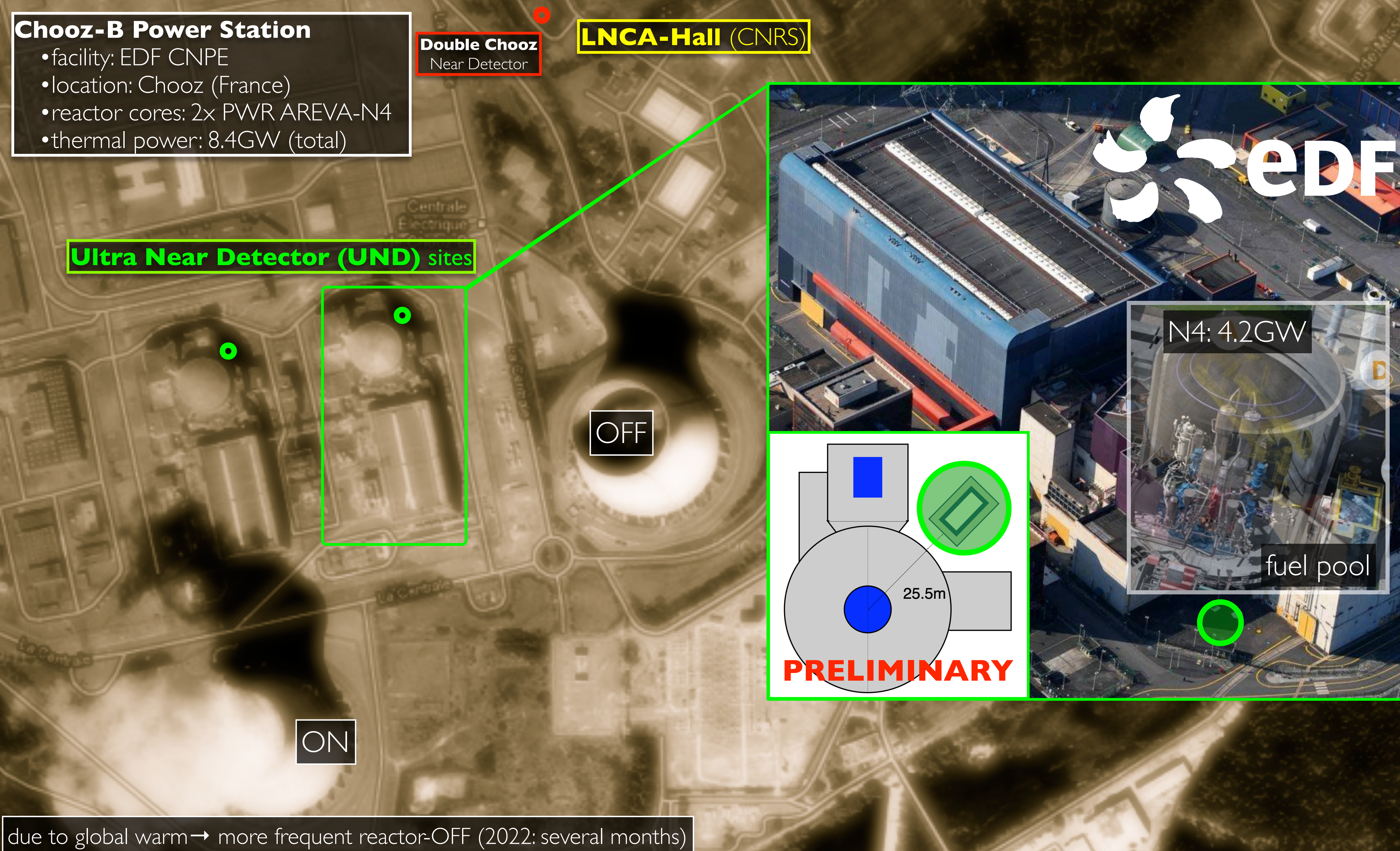
today, **most experiments** bypass (whenever possible) the **absolute flux knowledge** — complex!

relative knowledge (ex. multi-detector, etc.) well suited to **extract "known model" parameters**

CLOUD

confront ***absolute flux knowledge*** *for* ***new neutrino physics*** *via "flux bias explorations"*

- ***extreme signal*** *(to BG) rates — unprecedented*
- *must: the* ***best-known cross-section****(s) today (≤1%)*
- ***extreme energy control*** *(≤1%)— avoid spectral distortions (→flux biases)*
- ***much redundancy*** *— as much as Nature kindly allows…*



CLOUD = "**C**hooz **L**iquid**O** **U**ltranear **D**etector"

Europe's best reactor-ν site…

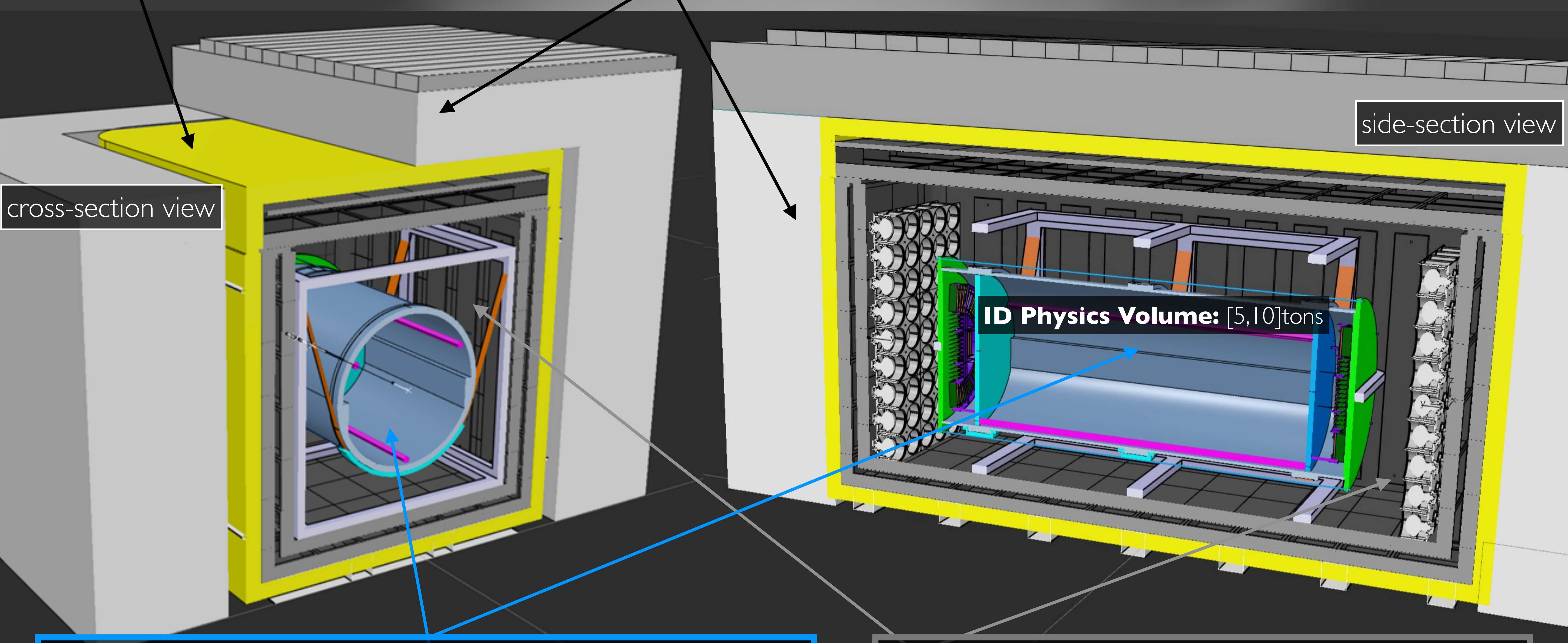
Double Chooz
Far Detector

Anatael Cabrera CNRS-IN2P3 / IJCLab (Orsay) - LNCA (Chooz) Laboratories

Water Pool [20,40]cm thick
- 4π shield & neutron moderator
- controllable thermal-bath

IGLOO [~3mwe]
- concrete **bunker** (with boron?)
- DC's iron steel shield (15cm thick)

Redundant "surface neutron" layers…
- **IGLOO** (absorption) — passive
- **Water** (moderator⊕absorption) — passive
- **Armour** (veto⊕moderator⊕absorption) — **OD**
- **Tracker** (PID⊕moderator) — **ID**



LiquidO-Tracker (or inner-detector) [**≤10tons fiducial**]
- opaque scintillator — new formulation(s) [more on this soon]
- **~10,000 fibres⊕SiPM** readout channels (GHz waveforms)
- designed light level: **≥200pe/MeV**

ARMOUR (or outer-detector) [**~0.5m thickness**]
- transparent scintillator (LAB⊕PPO⊕Bis-MSB)
- **≤180 DC-PMT**s & highly reflecting walls
- designed light yield **≥400pe/MeV**

CLOUD detector…

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

CLOUD is powered by…

L I Q U I D

First Release at CERN July 2019 (detector seminar)

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

Neutrino 2022
(June 2022)

https://zenodo.org/record/6697273

nature communications physics

Article | Open access | Published: 21 December 2021

Neutrino physics with an opaque detector

LiquidO Consortium

Communications Physics 4, Article number: 273 (2021) | Cite this article

Abstract

Publication "LiquidO-Zero"

In 1956 Reines & Cowan discovered the neutrino using a liquid scintillator detector. The neutrinos interacted with the scintillator, producing light that propagated across transparent volumes to surrounding photo-sensors. This approach has remained one of the most widespread and successful neutrino detection technologies used since. This article introduces a concept 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 optical fibres. This technique, called LiquidO, can provide high-resolution imaging to enable efficient identification of individual particles event-by-event. A natural affinity for adding dopants at high concentrations is provided by the use of an opaque medium. With these and other capabilities, the potential of our detector concept to unlock opportunities in neutrino physics is presented here, alongside the results of the first experimental validation.

www.nature.com/articles/s42005-021-00763-5

D

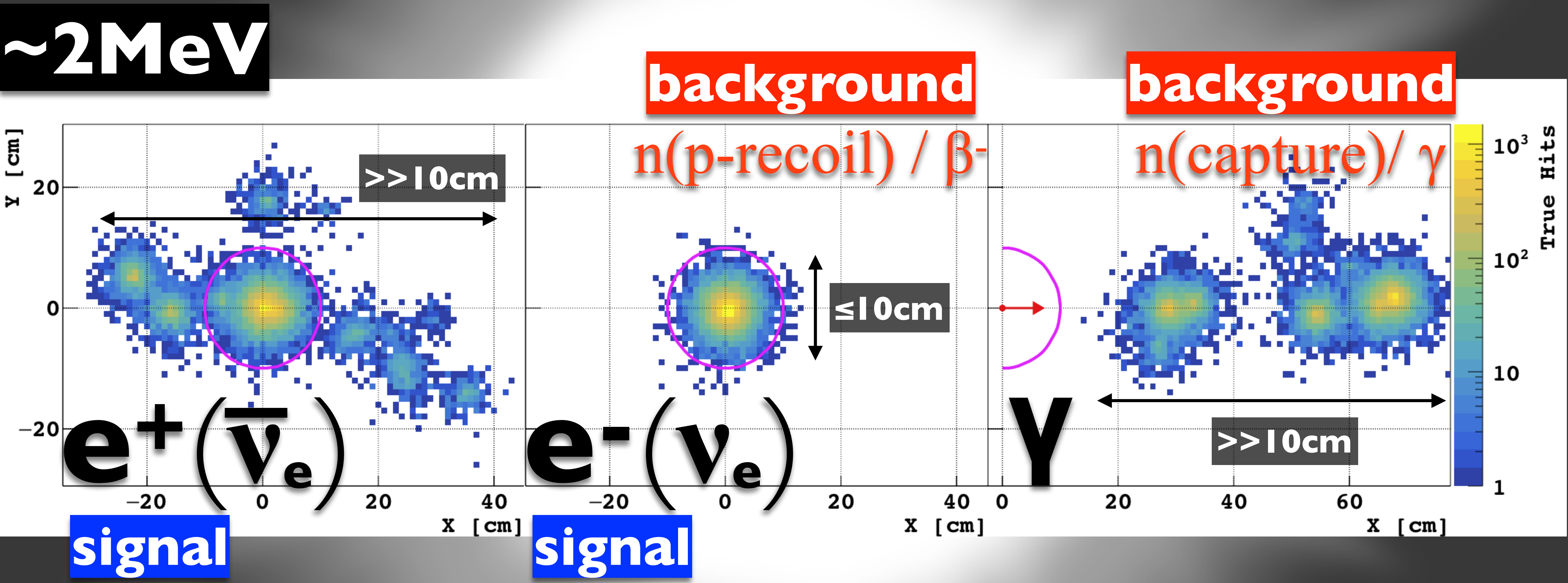
FNAL Seminar 2023
(May 2023)

https://zenodo.org/records/7922021

LiquidO Official WEB: https://liquido.ijclab.in2p3.fr/

unprecedented MeV imaging…

reduce overburden/shielding



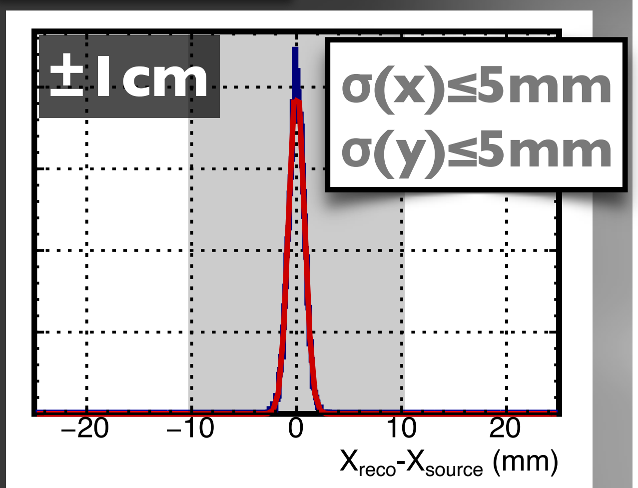
LiquidO: stochastic confinement (NO segmentation)

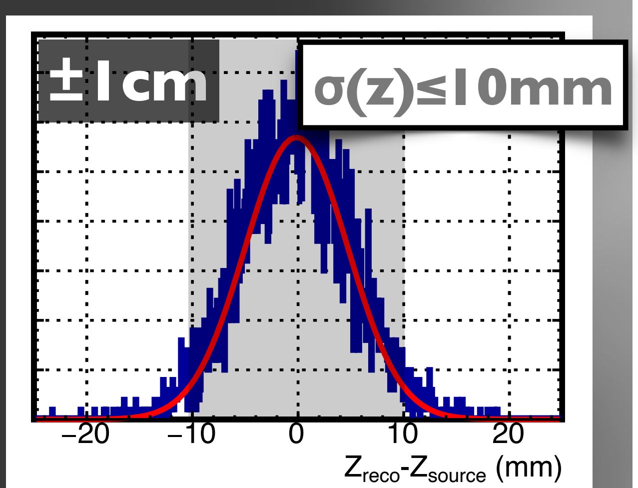
~1MeV: reactor, geoneutrino, solar, ββ-decay, etc

LiquidO ↔ stochastic light confinement

Topology (X,Y) direct & native (PID)→ possible sub-mm vertex precision

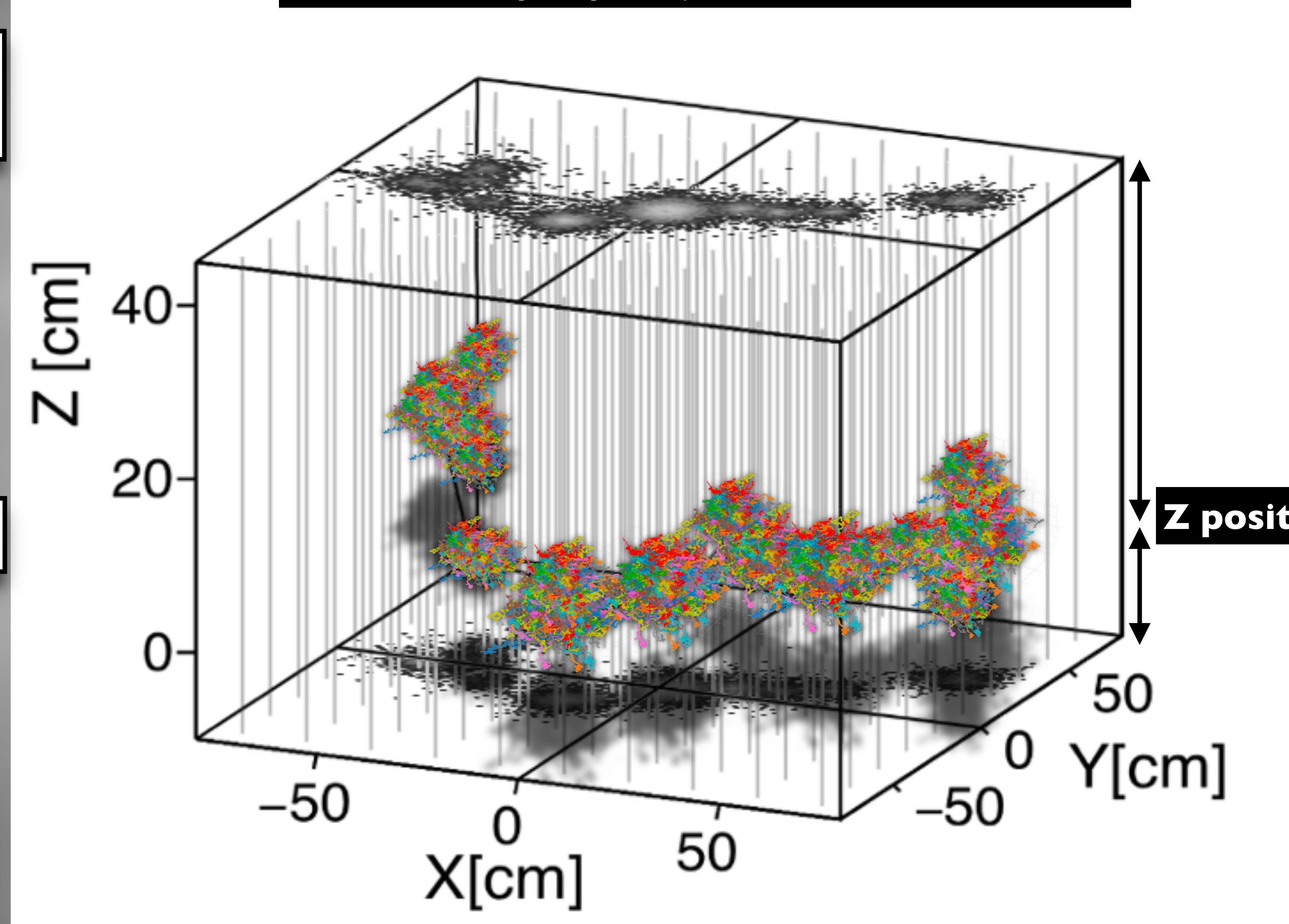
~1.0MeV





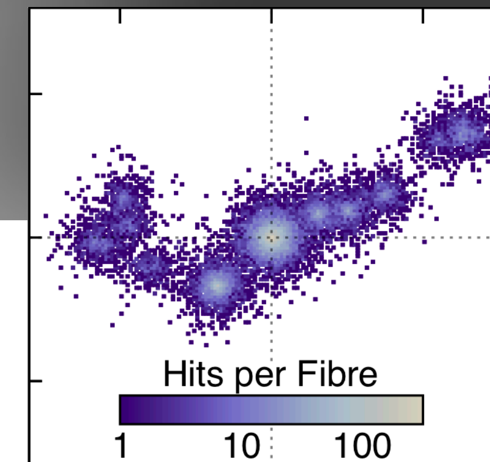
Vanilla LiquidO: 1D lattice (fibres along Z-axis only)

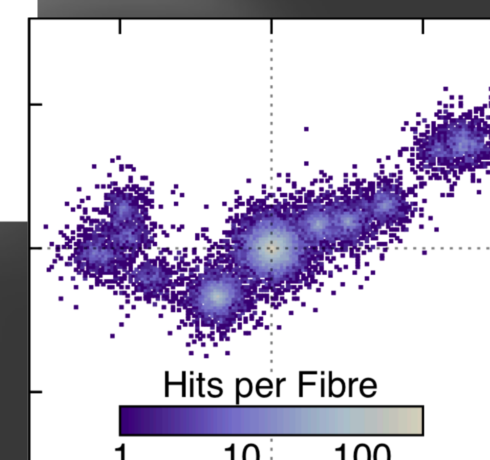
TOP VIEW: (X,Y) Projection→ direct readout



Z position: Δt (time difference)

BOTTOM VIEW: (X,Y) Projection→ direct readout





LiquidO can have up 3 orthogonal fibre lattice orientations (3D)

latest results — March 2025

The Stochastic Light Confinement of LiquidO

Publication "LiquidO-I"

LiquidO Collaboration[(a−z)*]

J. Apilluelo[l,z], L. Asquith[b], E. F. Bannister[b], N. P. Barradas[kα], J. L. Beney[p], M. Berberan e Santos[kβ], X. de la Bernardie[p], T. J. C. Bezerra[b], M. Bongrand[p], C. Bourgeois[q], D. Breton[q], C. Buck[1], J. Busto[n], K. Burns[q], A. Cabrera[q,c,2], A. Cadiou[p], E. Calvo[l], E. Chauveau[f], B. J. Cattermole[b], M. Chen[h], P. Chimenti[i], D. F. Cowen[xα,xβ], S. Dusini[rα], A. Earle[b], M. Felizardo[kα], C. Frigerio Martins[i], J. Galán[z], J. A. García[z], R. Gazzini[q], A. Gibson-Foster[b], C. Girard-Carillo[mα], B. Gramlich[1], M. Grassi[2,rβ], W. C. Griffith[b], J. J. Gómez-Cadenas[u], M. Guitière[p], F. Haddad[p], J. Hartnell[b], A. Holin[d], I. G. Irastorza[z], I. Jovanovic[a], A. Kling[kα], L. Koch[mα], P. Lasorak[b], J. F. Le Du[q,c], C. Lefebvre[h], F. Lefevre[p], P. Loaiza[q], J. A. Lock[b], G. Luzón[z], J. Maalmi[q], J. P. Malhado[j], F. Mantovani[eα,eβ], J. G. Marques[kα], C. Marquet[f], M. Martínez[z], D. Navas-Nicolás[q,1], H. Nunokawa[t], M. Obolensky[2], J. P. Ochoa-Ricoux[g], T. Palmeira[kβ], C. Palomares[l], B. Pedras[kβ], D. Petyt[d], P. Pillot[p], A. Pin[f], J. C. C. Porter[b], M. S. Pravikoff[f], N. Rodrigues[kβ], M. Roche[f], R. Rosero[y], B. Roskovec[s], N. Roy[q], M. L. Sarsa[z], S. Schoppmann[mβ,1], A. Serafini[rα,rβ], C. Shepherd-Themistocleous[d], W. Shorrock[b], M. Silva[kγ], L. Simard[q], S. R. Soleti[u], H. Th. J. Steiger[mα,mβ], D. Stocco[p], V. Strati[eα,eβ], J. S. Stutzmann[p], F. Suekane[v], A. Tunc[mα], N. Tuccori[b], A. Verdugo[l], B. Viaud[p], S. M. Wakely[mα], A. Weber[mα], G. Wendel[xβ], A. S. Wilhelm[a], M. Yeh[y], and F. Yermia[p]

arXiv:2503.02541 — under publication

latest results — July 2025

Muon tracking in a LiquidO opaque scintillator detector

Publication "LiquidO-II"

LiquidO Collaboration

J. Apilluelo,[z] L. Asquith,[b] E. F. Bannister,[b] N. P. Barradas,[kα] C. L. Baylis,[b] J. L. Beney,[p] M. Berberan e Santos,[kβ] X. de la Bernardie,[p] T. J. C. Bezerra,[b] M. Bongrand,[p] C. Bourgeois,[q] D. Breton,[q] J. Busto,[n] A. Cabrera,[q,c] A. Cadiou,[p] E. Calvo,[l] M. de Carlos Generowicz,[b] E. Chauveau,[f] B. J. Cattermole,[b] M. Chen,[h] P. Chimenti,[i] D. F. Cowen,[xα,xβ] S. Kr. Das,[b] S. Dusini,[rα] A. Earle,[b] M. Felizardo,[kα] C. Frigerio Martins,[i] J. Galán,[z] J. A. García,[z] A. Gibson-Foster,[b] C. Girard-Carillo,[mα] W. C. Griffith,[b] J. J. Gómez-Cadenas,[u] M. Guitière,[p] F. Haddad,[p] J. Hartnell,[b] A. Holin,[d] I. G. Irastorza,[z] I. Jovanovic,[a] A. Kling,[kα] L. Koch,[mα] P. Lasorak,[b] J. F. Le Du,[q,c] F. Lefevre,[p] P. Loaiza,[q] J. A. Lock,[b] G. Luzón,[z] J. Maalmi,[q] J. P. Malhado,[j] F. Mantovani,[eα,eβ] J. G. Marques,[kα] C. Marquet,[f] M. Martínez,[z] J. T. Moffat,[xβ] D. Navas-Nicolás,[l] H. Nunokawa,[t] J. P. Ochoa-Ricoux,[g] T. Palmeira,[kβ] C. Palomares,[l] D. Petyt,[d] P. Pillot,[p] A. Pin,[f] J. C. C. Porter,[b] M. S. Pravikoff,[f] S. Richards,[d] N. Rodrigues,[kβ] M. Roche,[f] R. Rosero,[y] B. Roskovec,[s] M. L. Sarsa,[z] S. Schoppmann,[mβ] A. Serafini,[rα,rβ] C. Shepherd-Themistocleous,[d] W. Shorrock,[b] M. Silva,[kγ] L. Simard,[q] S. R. Soleti,[u] D. Stocco,[p] V. Strati,[eα,eβ] J. S. Stutzmann,[p] F. Suekane,[v] N. Tuccori,[b] A. Verdugo,[l] B. Viaud,[p] S. M. Wakely,[mα] A. Weber,[mα] G. Wendel,[xβ] A. S. Wilhelm,[a] A. W. R. Wong,[b,d] M. Yeh,[y] F. Yermia[p]

arXiv:2507.13864 — under publication

IFAE just joined...

LiquidO Collaboration$^{(a-z)*}$

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Spokespersons:
- A. Cabrera — IJCLab / Université Paris-Saclay (France)
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Web: https://liquido.ijclab.in2p3.fr/

Contact: LiquidO-Contact-L@in2p3.fr

Chooz (most powerful reactor) ⊕ **UND** (≥25m baseline) ⊕ **LiquidO** (BG rejection)
[**EDF** within the team — unprecedented]

C L O U D

I - II - III

CLOUD's sequence…

the power of coincidences

being at **the right "place & time & energy & PID" — huge rejection(s)**

Reines et al '50s

(neutrino discovery)

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

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

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

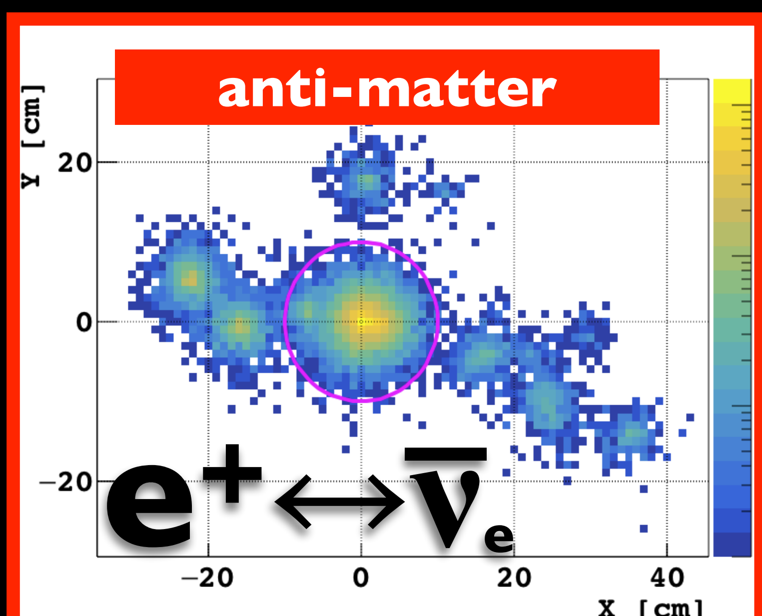
Raghavan et al '70s

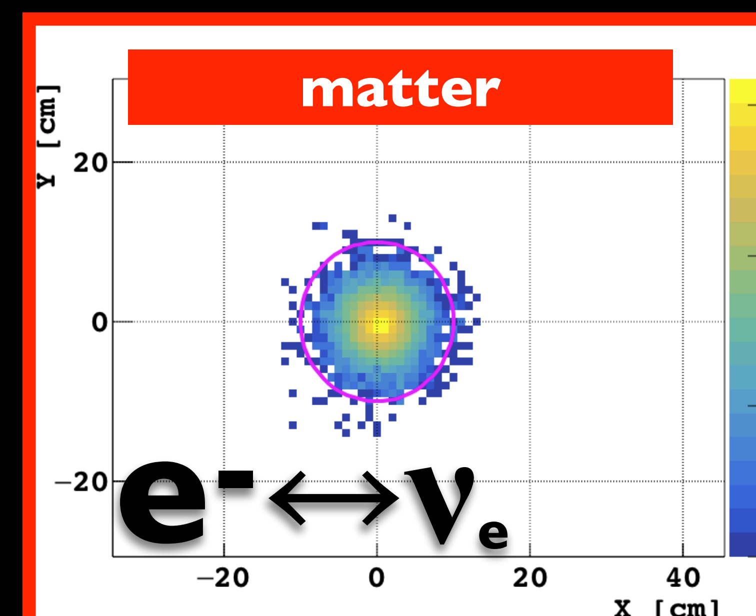
(pp solar neutrino — unobserved)

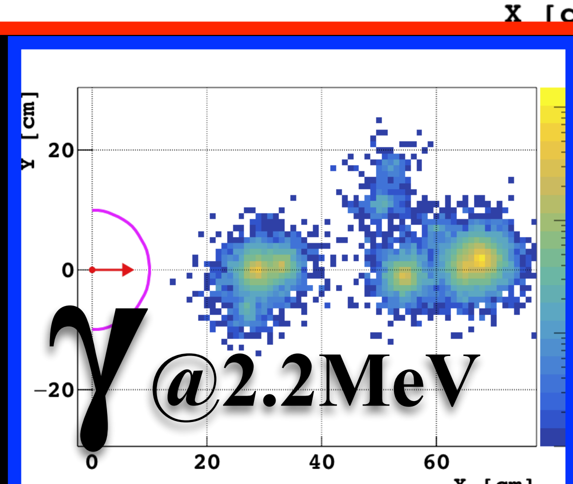
CC: $\nu_e + {}^{115}In \rightarrow e^- + \gamma + \gamma/e^-$

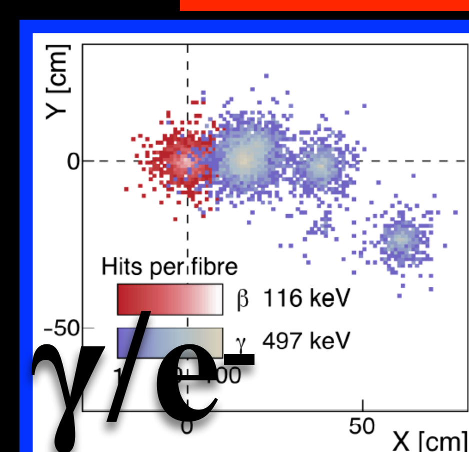
($\tau \approx 4.7\mu s$ decay of **Sn***)

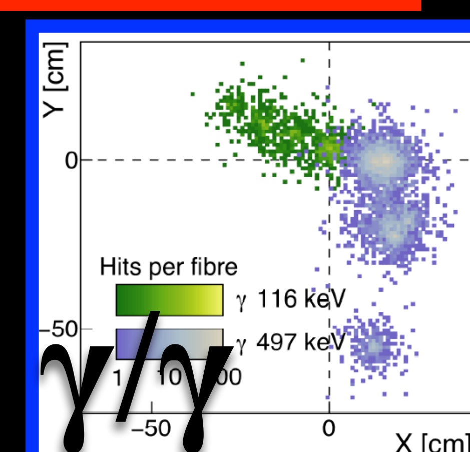
major **R&D** [~2 decades] by **LENS** *et al.*











Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

C L I U D

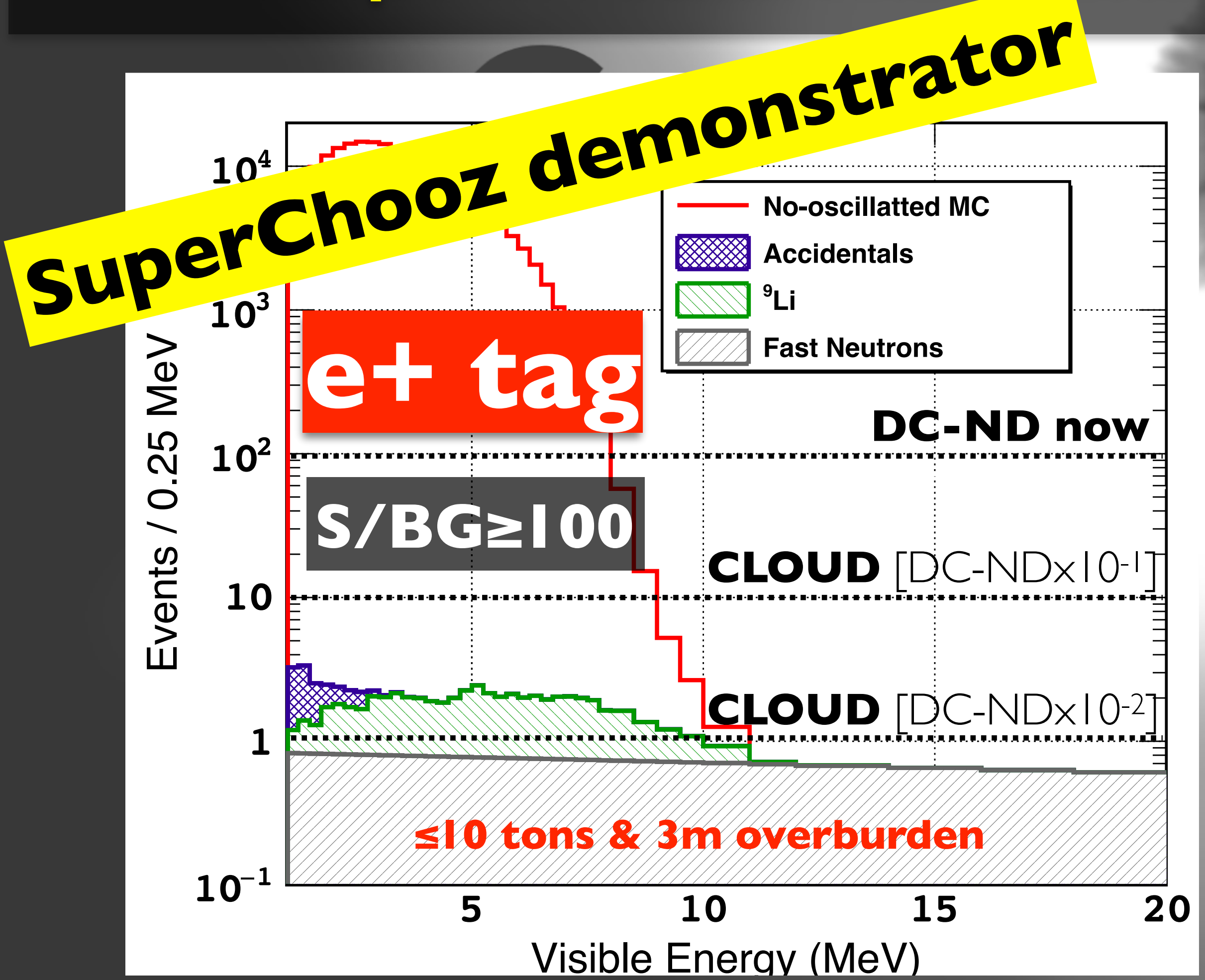
AntiMatter-OTech — synergy
SuperChooz's antineutrino golden channel **demonstration** — byproduct

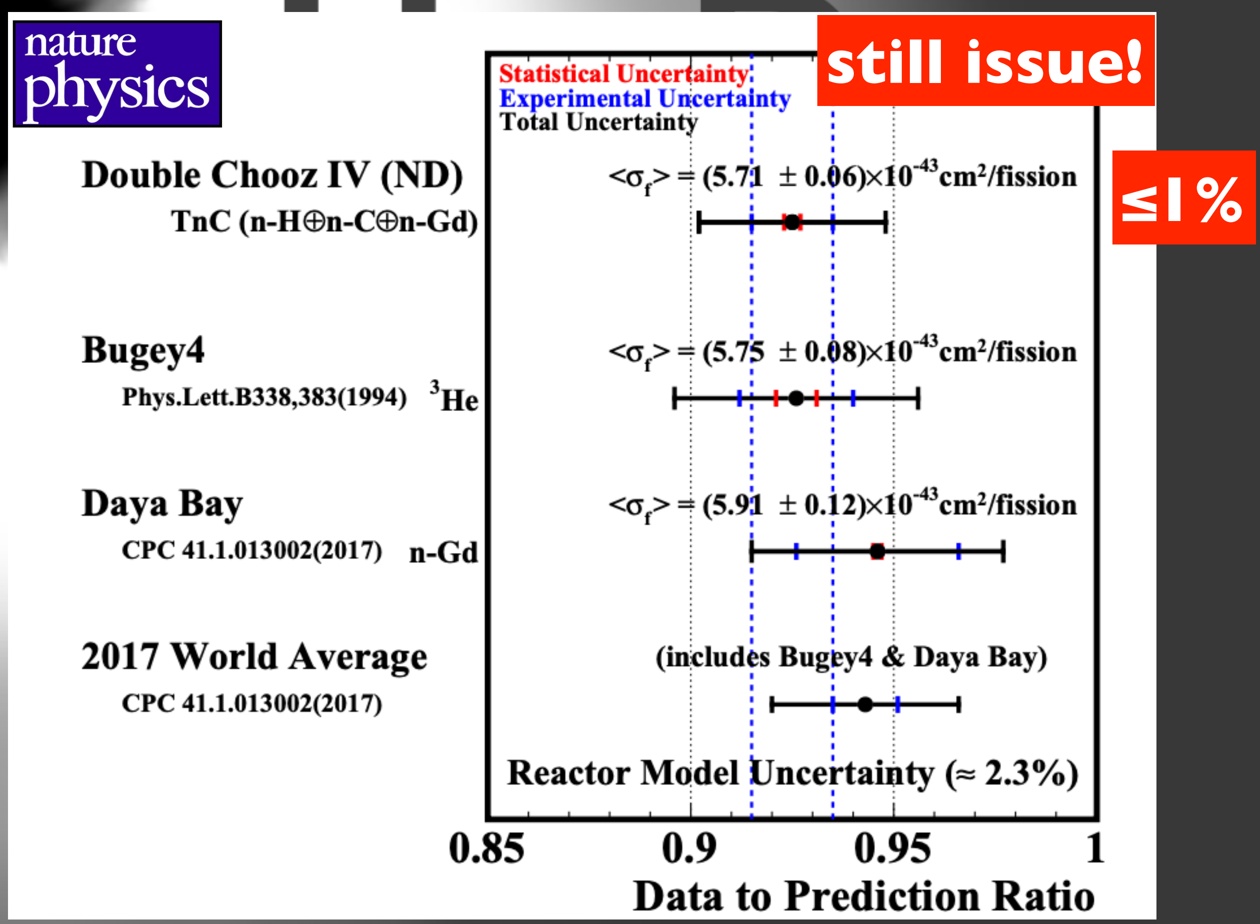
antineutrino CC & NC? (~~doping~~)...

Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

CLOUD-I physics programme: **IBD@p**…

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



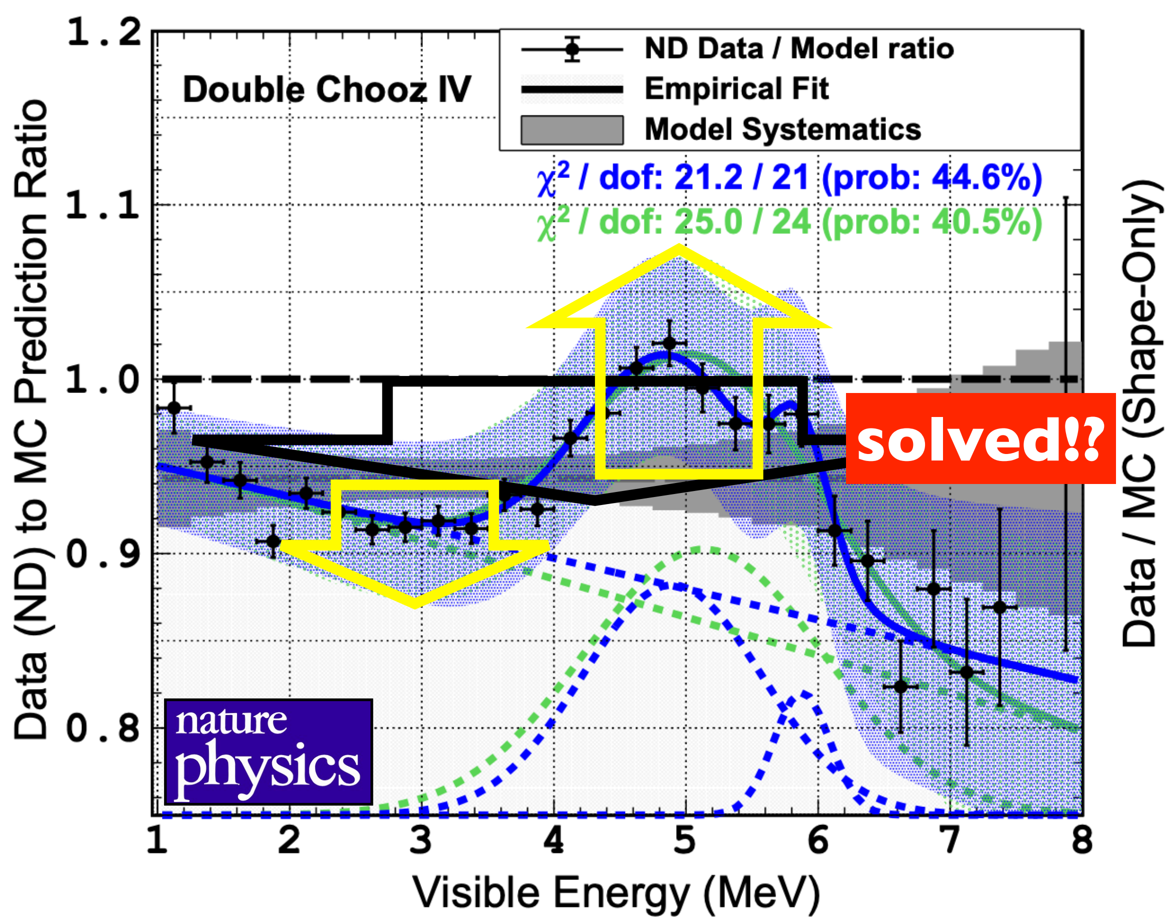


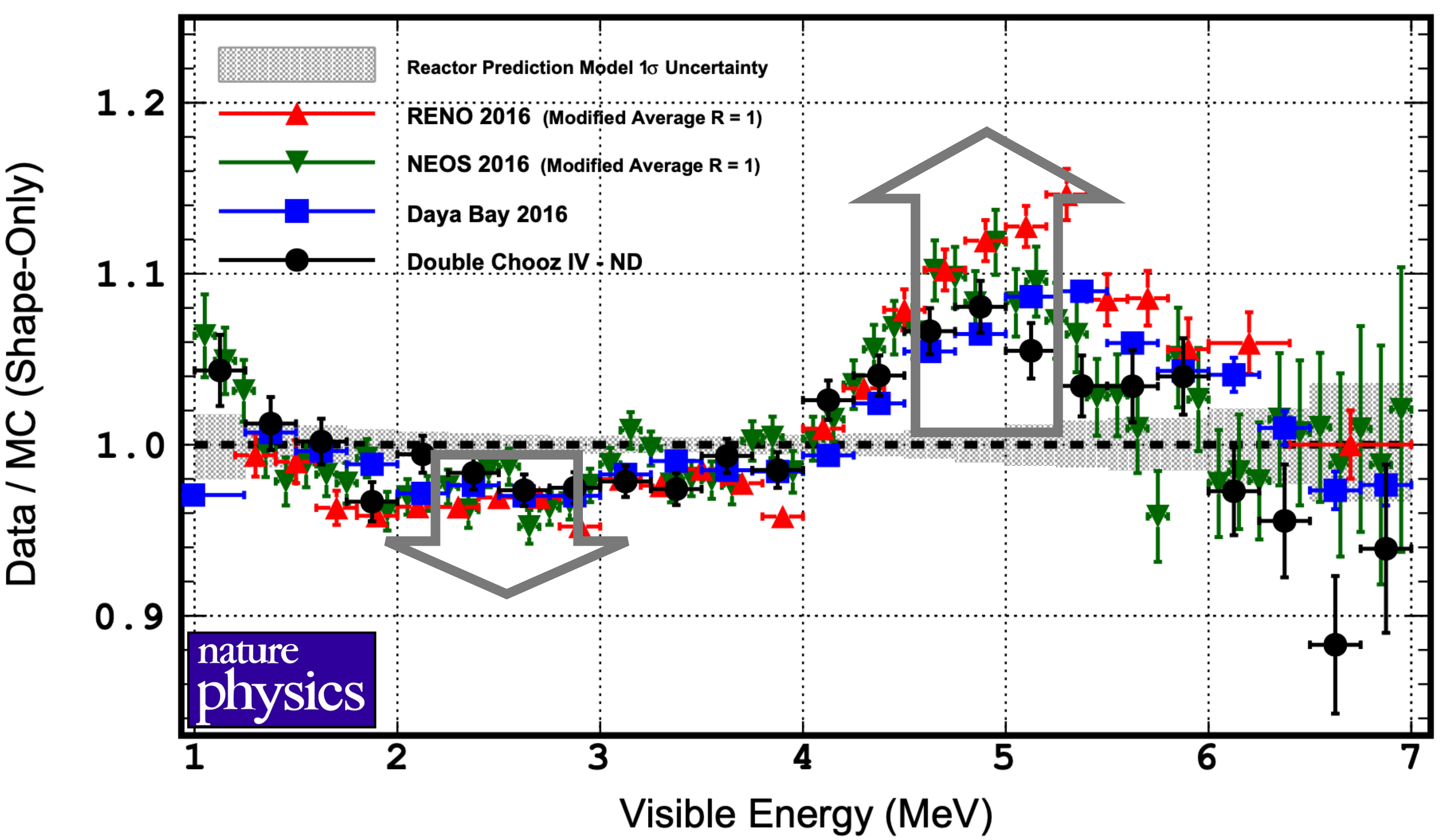
CLOUD precision ≥0.6%⟹ Unitarity Violation? (if predictions are improved)!

Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

still issues to be resolved — beyond the sterile neutrino hypothesis (disfavoured)

all experiments consistent — except **Bugey3?!**





ABSOLUTE FLUX: the future of reactor-antineutrino physics

we must solve this "mess" ⟹ the reward **possible new physics!**

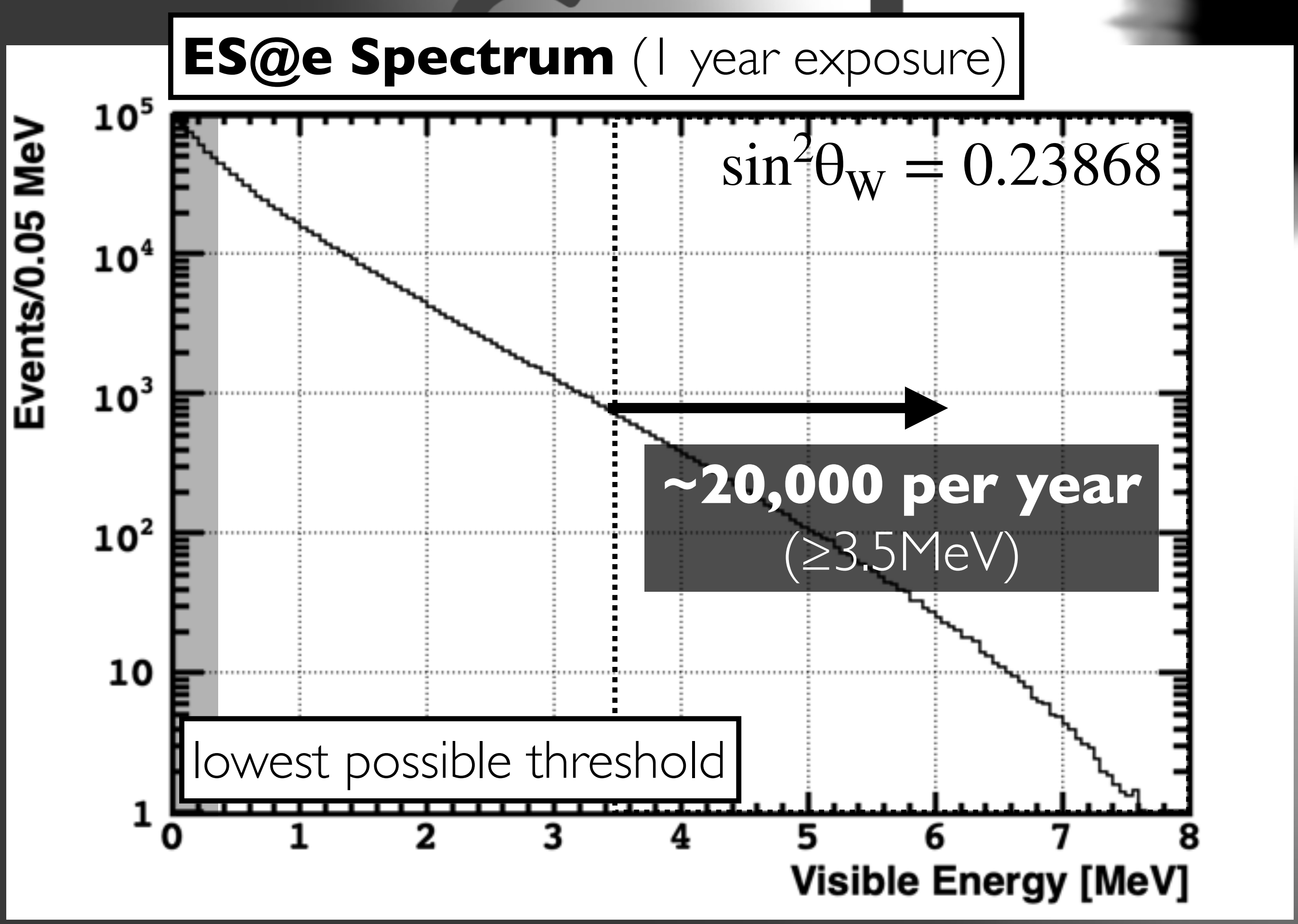
(if so, prediction should not use neutrino input⟹**no** new physics)

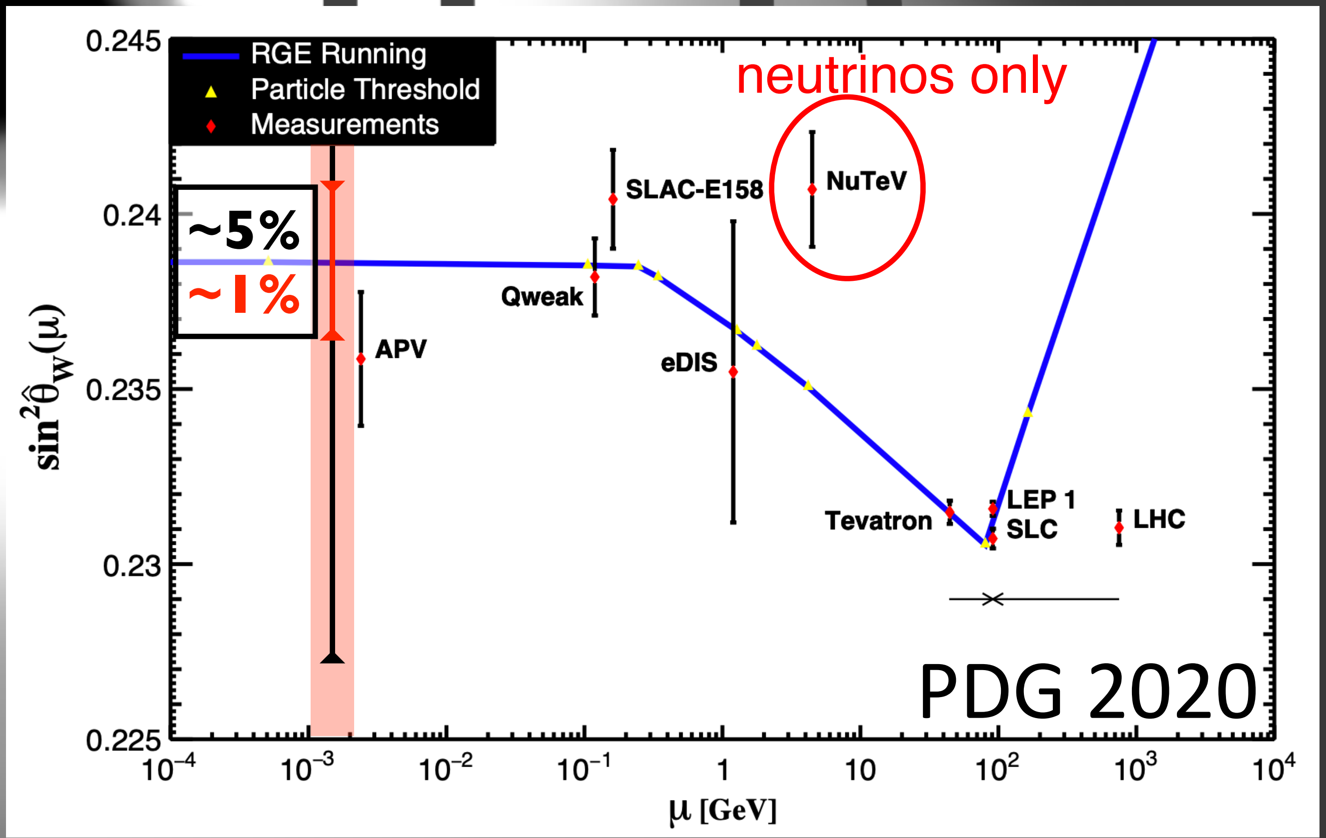
must understand flux ≤1%...

Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

CLOUD-I physics programme: **ES@e**…

- **eES** (anti-ν CC⊕NC): **≲5,000** interactions per day for **10tons ID** [≲**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
  - **≲10% precision** (≥5σ observation) tolerates much BG but **≲1%⟹ S/BG≥2(!!) impossible?**





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

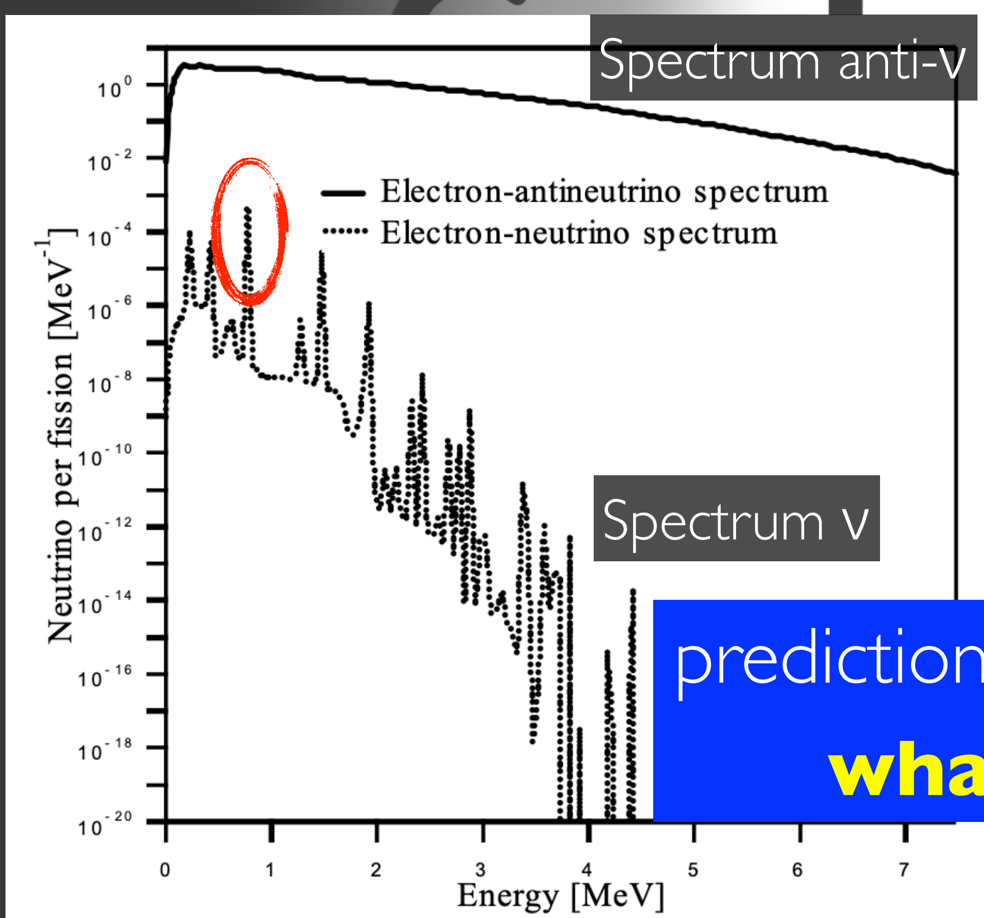
CLOUD

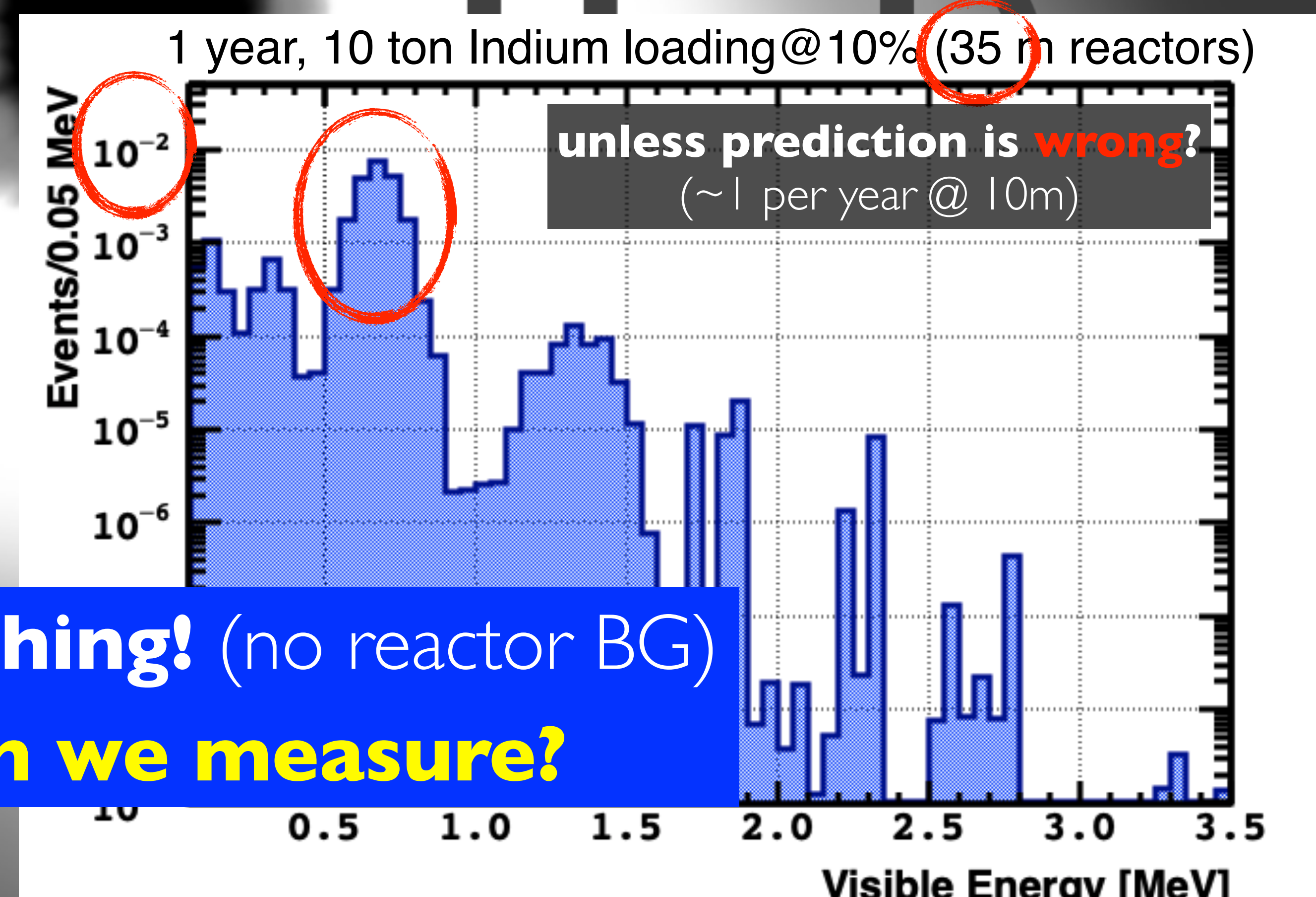
SuperChooz's <u>neutrino golden channel</u> **demonstration** — byproduct

neutrino CC (doping)...

CLOUD-II physics programme: **neutrino**…

- loading **indium** on the detector — **unique strong coincidence ≥114keV** ("solar-pp" in mind)
  - low threshold ⊕ high natural-abundance ⊕ high-ish cross-section ⊕ BG-killer (coincidence)
  - CC interaction: ν_e + ^{115}**In** → **e-** + ^{115}Sn* [τ:4.8μs decay: **γ/e**(116keV) + **γ**(496keV)]
  - reactor neutrino **modulate with the reactor power** — no ambiguity whatsoever
- why to detector neutrinos close to a reactor?
  - **reactor neutrinos** (from β+/EC): **rate(ν) ≈ 10^{-5} rate(anti-ν)** — prediction (both correlated)
  - could **reactors be the missing MeV neutrino source?** [otherwise impractical]





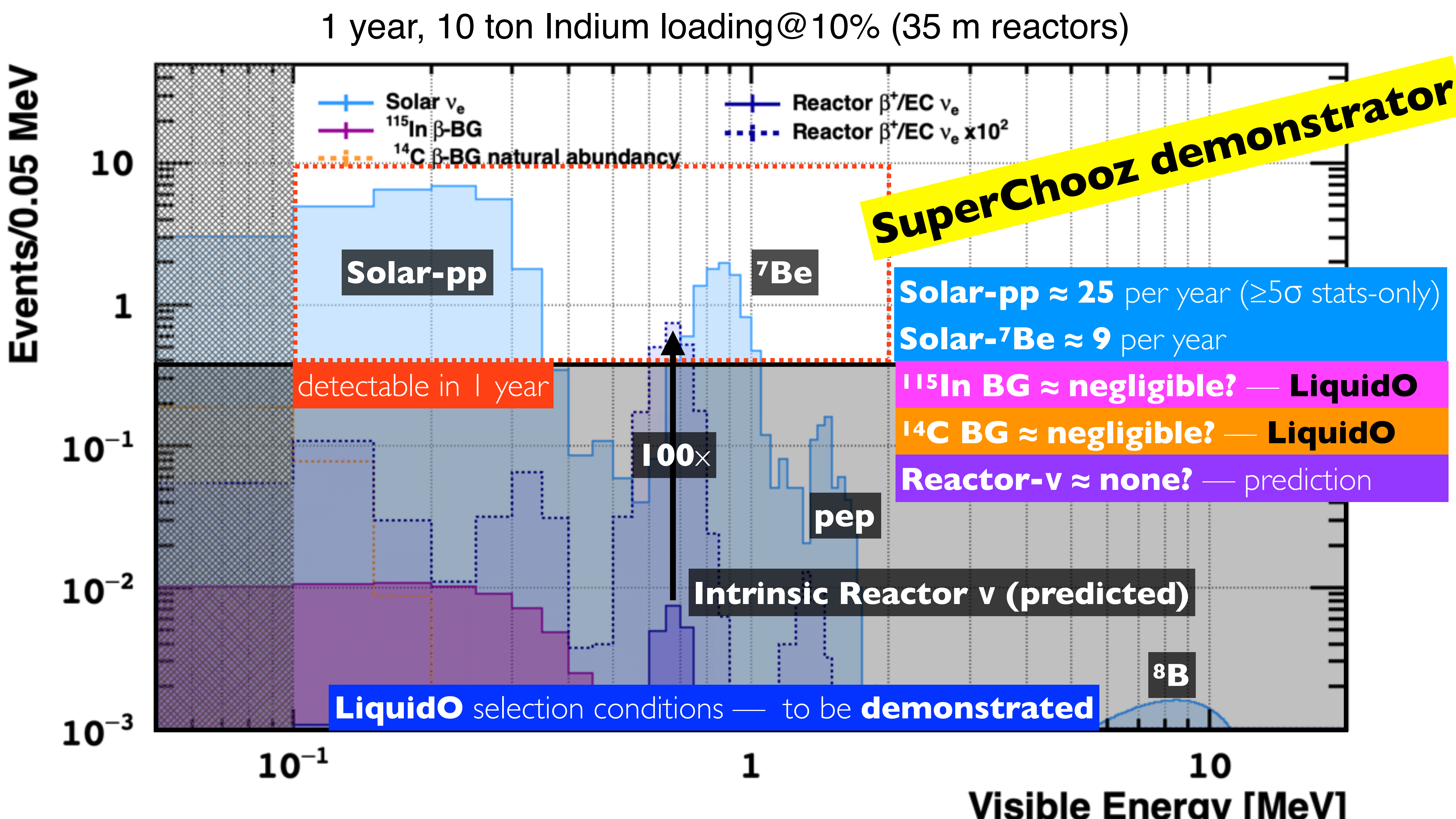
prediction: **nothing!** (no reactor BG)

what can we measure?

T. Nishimura et al., AIP Conference Proceedings **769**, 1702 (2005); https://doi.org/10.1063/1.1945337

the big picture of neutrinos @CLOUD…

assuming the **LENS "BG model"** — valid at **overburden ~3m?** (to be demonstrated)



detection **solar-pp neutrinos** on a **10ton** detector **almost on surface** right **next a nuclear reactor?**

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R&D for **low energy reactor-fuel monitoring** & **geoneutrino ^{40}K discovery** — demonstration

new antineutrino CC (doping)…

arXiv:2308.04154

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

A. Cabrera[*12α,2,a], M. Chen[†6], F. Mantovani[‡3α,3β], A. Serafini[§3α,3β,13α,13β], V. Strati[¶3α,3β], J. Apilluelo[18], L. Asquith[1], J.L. Beney[11], T.J.C. Bezerra[1], M. Bongrand[11], C. Bourgeois[12α], D. Breton[12α], M. Briere[12α], J. Busto[10], A. Cadiou[11], E. Calvo[8], V. Chaumat[12α], E. Chauveau[4], B.J. Cattermole[1], P. Chimenti[7], C. Delafosse[12α], H. de Kerret[‖a], S. Dusini[13α], A. Earle[1], C. Frigerio-Martins[7], J. Galán[18], J. A. García[18], R. Gazzini[12α], A. Gibson-Foster[1], A. Gallas[12α], C. Girard-Carillo[9α], W.C. Griffith[1], F. Haddad[11], J. Hartnell[1], A. Hourlier[17], G. Hull[12α], I. G. Irastorza[18], L. Koch[9α], P. Laniéce[12α,12β], J.F. Le Du[12α,2], C. Lefebvre[6], F. Lefevre[11], F. Legrand[12α], P. Loaiza[12α], J. A. Lock[1], G. Luzón[18], J. Maalmi[12α], C. Marquet[4], M. Martínez[18], B. Mathon[12α], L. Ménard[12α,12β], D. Navas-Nicolás[12α], H. Nunokawa[15], J.P. Ochoa-Ricoux[5], M. Obolensky[a], C. Palomares[8], P. Pillot[11], J.C.C. Porter[1], M.S. Pravikoff[4], H. Ramarijaona[12α], M. Roche[4], P. Rosier[12α], B. Roskovec[14], M.L. Sarsa[18], S. Schoppmann[9β], W. Shorrock[1], L. Simard[12α], H.Th.J. Steiger[9α,9β], D. Stocco[11], J.S. Stutzmann[11], F. Suekane[16,a], A. Tunc[9α], M.-A. Verdier[12α,12β], A. Verdugo[8], B. Viaud[11], S. M. Wakely[9α], A. Weber[9α], and F. Yermia[11]

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(LiquidO Consortium)

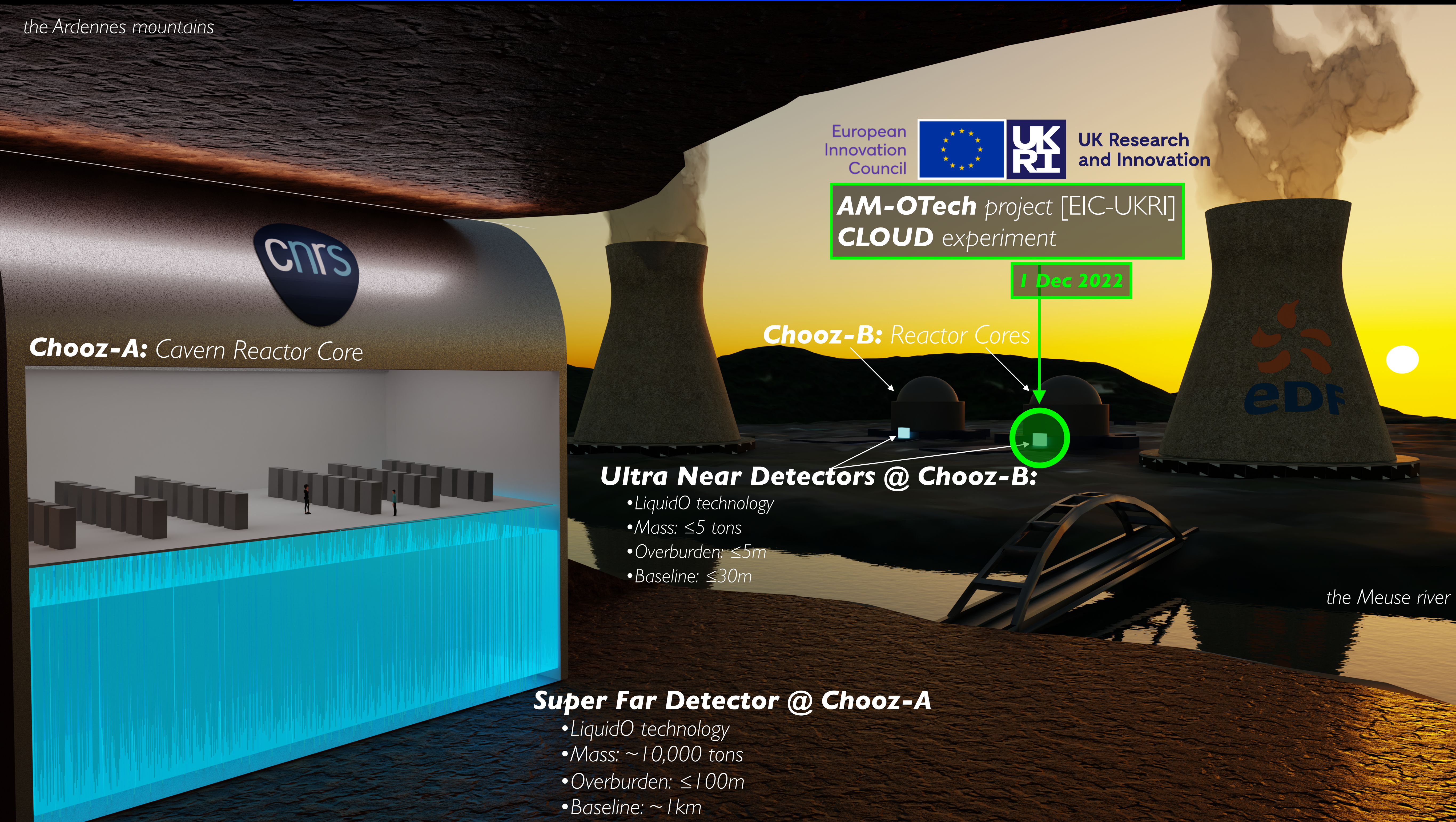
^{40}K geoneutrino new methodology → good enough for discovery?

CLOUD

a long story short…

SuperChooz exploration…

flagship neutrino oscillation experiment in Europe?



- **CLOUD** demonstrator for **LiquidO's (anti)neutrino detection capabilities** — **a revolution?**
  - byproduct to **new reactor monitoring capability**? [a dream since '70s]
- **CLOUD-I: approved** & **funded [AM-OTech]** **plan: data by 2025**
  - **goal:** possible **background-less regime?** [→LiquidO]
  - **most precise absolute CC-antineutrino flux** — **new physics?**
  - possible **first NC-(anti)neutrino flux** — **new physics?**
- **CLOUD-II: under feasibility study** (→new **indium**-loaded opaque scintillator)
  - (first) **absolute CC-neutrino flux reactor** — **new physics?**
  - **measure solar-pp (≥5σ)** in a "tiny detector" almost on the surface?⟹ **a breakthrough?**
- **CLOUD-III: under feasibility study** (→new **copper**-loaded opaque scintillator)
  - probe **reactor flux at low energies?** — **surprises?** [first time ever below 1.8MeV]
  - demonstration for **^{40}K detection methodology** — **a discovery one day?**

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

conclusions…

SuperChooz demonstrator

Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

our collaboration…

European Innovation Council

UK Research and Innovation

C L O U D

CLOUD International collaboration

- **EDF** (France) — **first time in neutrino science**
- **Brookhaven National Laboratory** (USA)
- **Charles University** (Czechia)
- **CIEMAT** (Spain)
- **IJCLab** / Université Paris-Saclay (France)
- **Imperial College London** (UK)
- **INFN-Padova** (Italy)
- **Instituto Superior Técnico** (Portugal)
- **Johannes Gutenberg Universität Mainz** (Germany)
- **Pennsylvania State University** (USA)
- **Pontifícia Universidade Católica do Rio de Janeiro** (Brazil)
- **Queen's University** (Canada)
- **Subatech** / **Nantes Université** (France)
- **Tohoku University** / **RCNS** (Japan)
- **Universidad de Zaragoza** (Spain)
- **Universidade Estadual de Londrina** (Brazil)
- **University of California Irvine** (USA)
- **University of Michigan** (USA)
- **University of Sussex** (UK)

$\Longrightarrow$ **19 institutions in 11 countries**

Spokespersons:
- A. Cabrera — IJCLab / Université Paris-Saclay (France)
- J. Hartnell — Sussex University (UK)

IB Chair:
- M. Chen — Queen's University (Canada)

Webs:

https://antimatter-otech.ijclab.in2p3.fr/ [AMOTech]
https://liquido.ijclab.in2p3.fr/nucloud [via LiquidO]

backup slides…

HEP-European Physical Society
(July 2019 @ Ghent Belgium)

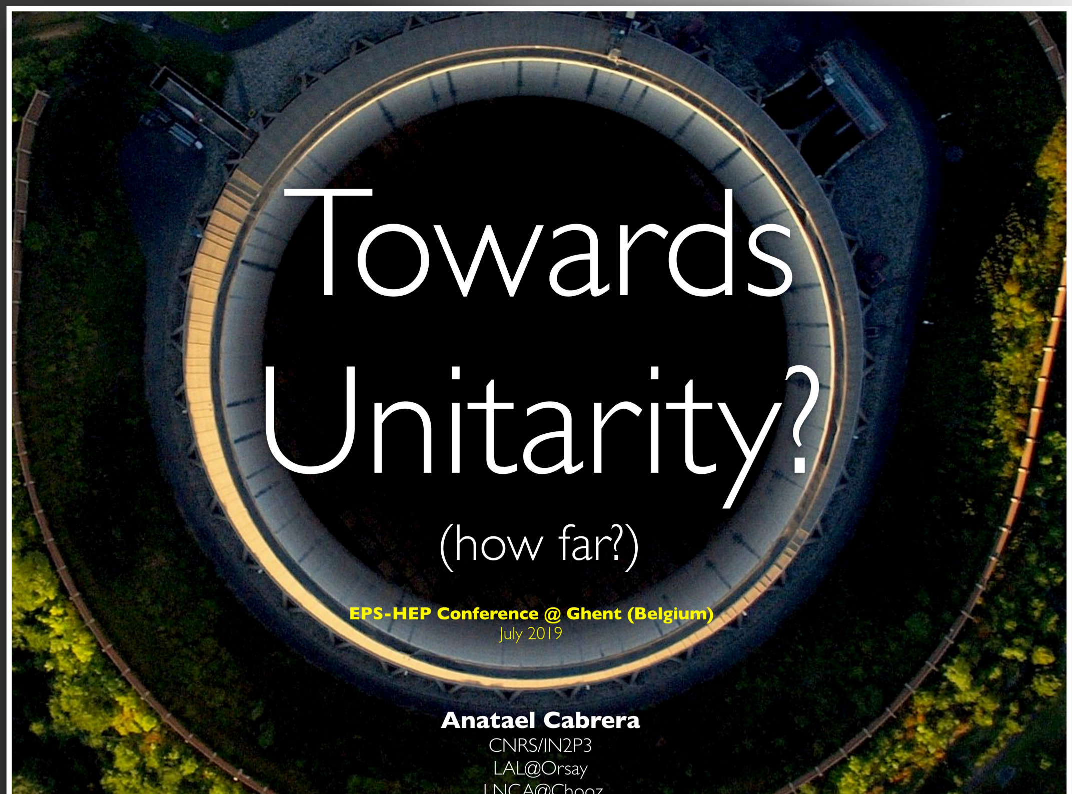
EP Seminar

The SuperChooz Experiment: Unveiling the Opportunity

by Dr Anatael CABRERA (IJCLab - IN2P3/CNRS)

Tuesday 29 Nov 2022, 11:00 → 12:00 Europe/Zurich

222/R-001 (CERN)



https://indico.cern.ch/event/577856/contributions/3421609/

https://indico.cern.ch/event/1215214/

https://zenodo.org/record/7504162

https://liquido.ijclab.in2p3.fr/

exploring since 2018...

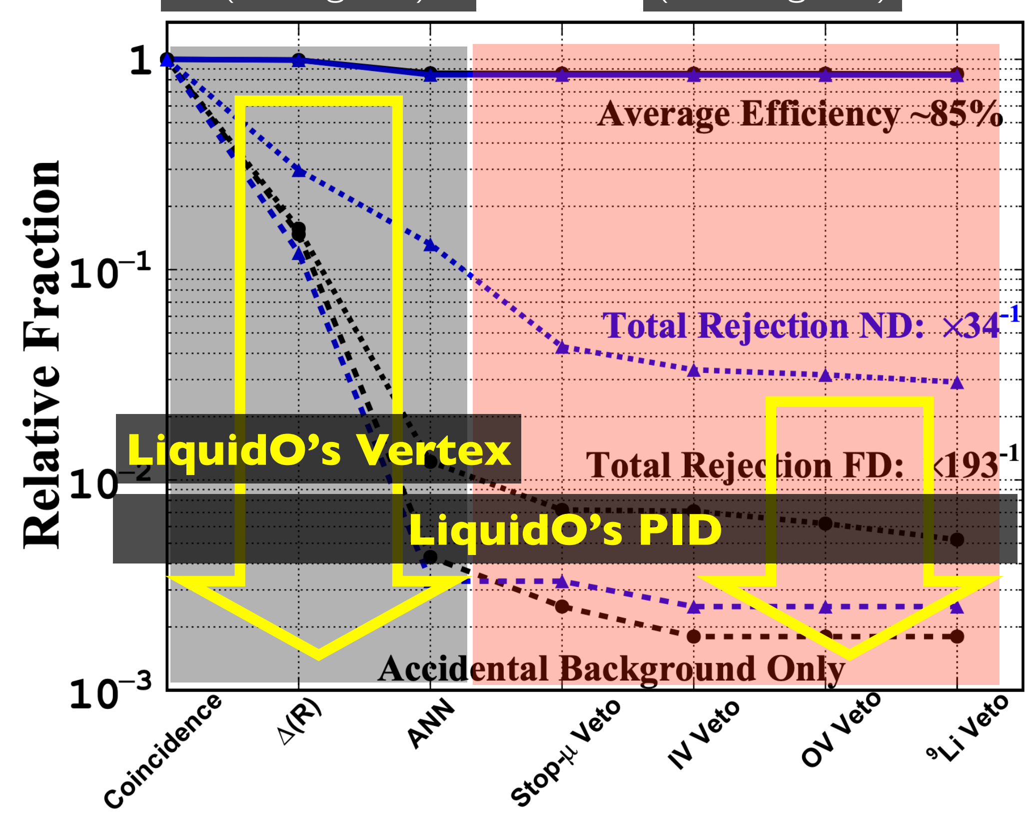
active BG rejection and control…

- detection using **coincidence-signal** (ex. **IBD@p**)⟹ prompt-delayed correlations
  - **combinatory (uncorrelated) BG(s): 5D-coincidence** (Δt⊕Δr⊕ΔE) — **LiquidO's** mm-vertex
  - **cosmogenic (correlated) BG(s): particle-ID** — **LiquidO's** imaging **[impossible so far]**
- **active rejection**→ rejected-BG as **data-driven BG input** (high accuracy physics extraction)
  - **radiogenic control:** in-situ radiogenic BG model tuning (radiopurity control order ≤10^{-14}g/g)

at right **place⊕time⊕energy⊕PID — many orders of magnitude**

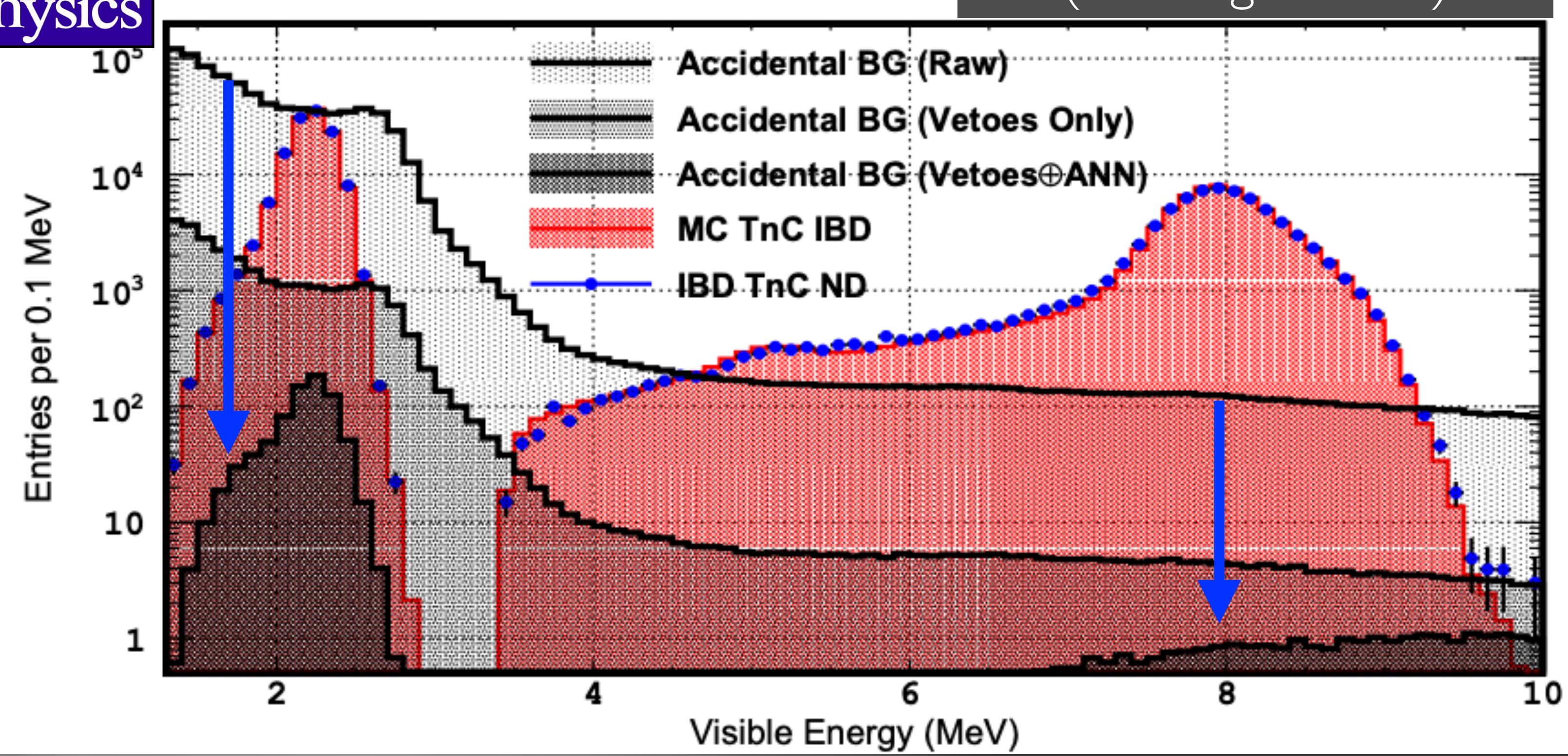
uncorrelated (radiogenic)

correlated (cosmogenic)



nature physics

DC: no need for Gd? (cosmogenic BG)

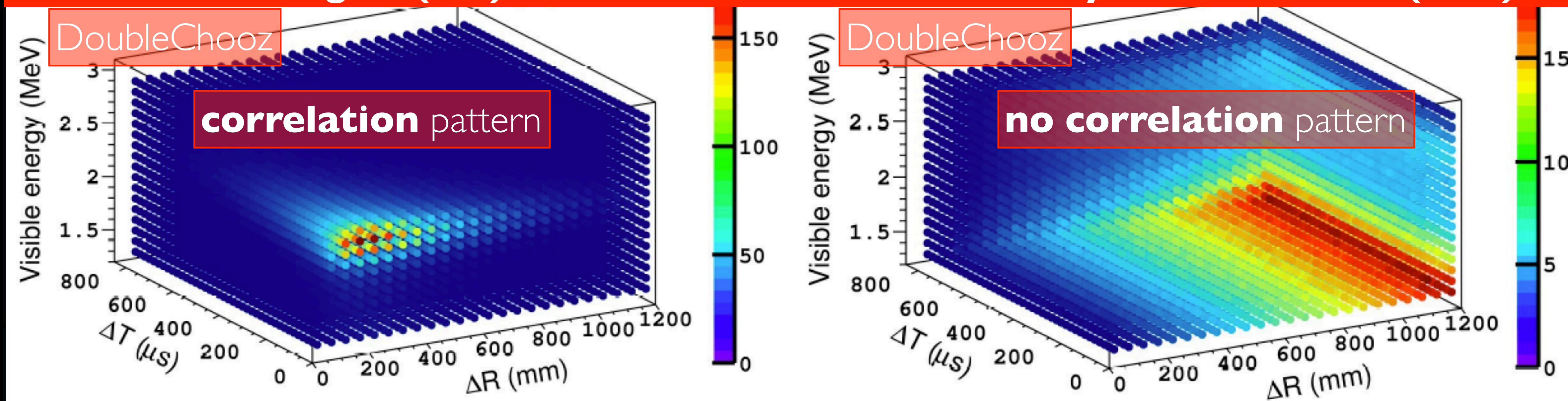


easier to lower **combinatory-BG** (~3 orders of magnitude) than **cosmogenic-BG** (~1 order of magnitude)

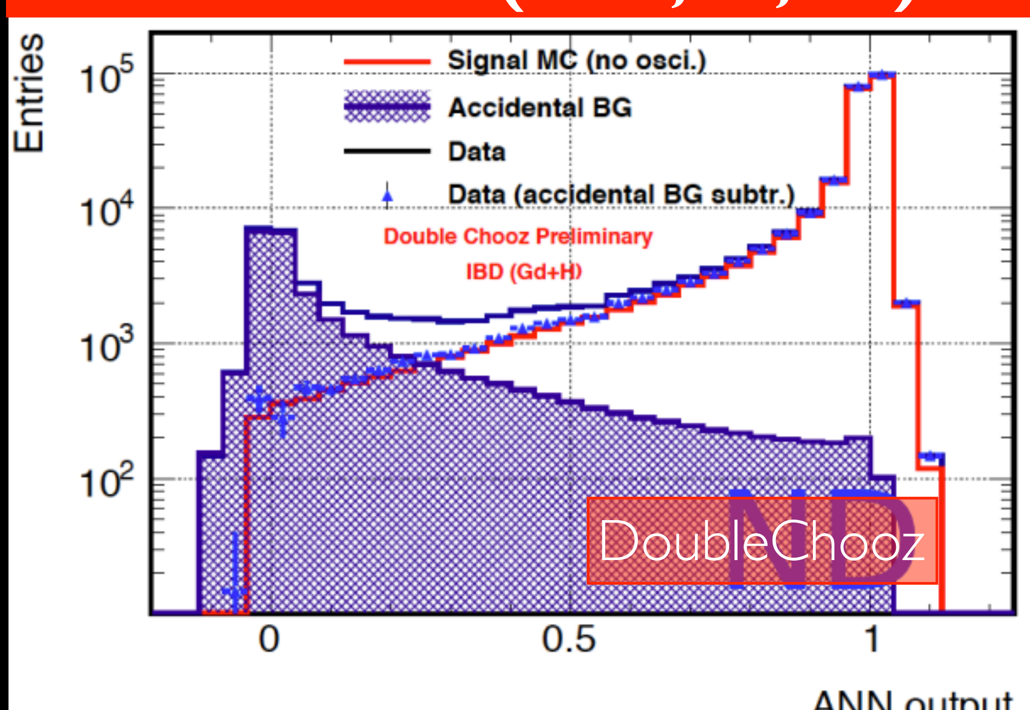
"combinatory" background…

at ~**1MeV** **backgrounds** due to **radiogenic** (radio-purity only **~10^{-15}g/g**) & **cosmogenic**

Signal (MC) | **Combinatory/Accidental BG (data)**



PID Variable (ANN, LL, etc)



LiquidO's vertex precision sub-cm — major

CC antineutrino (reactor)

- **sub-dominant BG** — enough shielding (easy)
- **dominant: correlated cosmogenic**

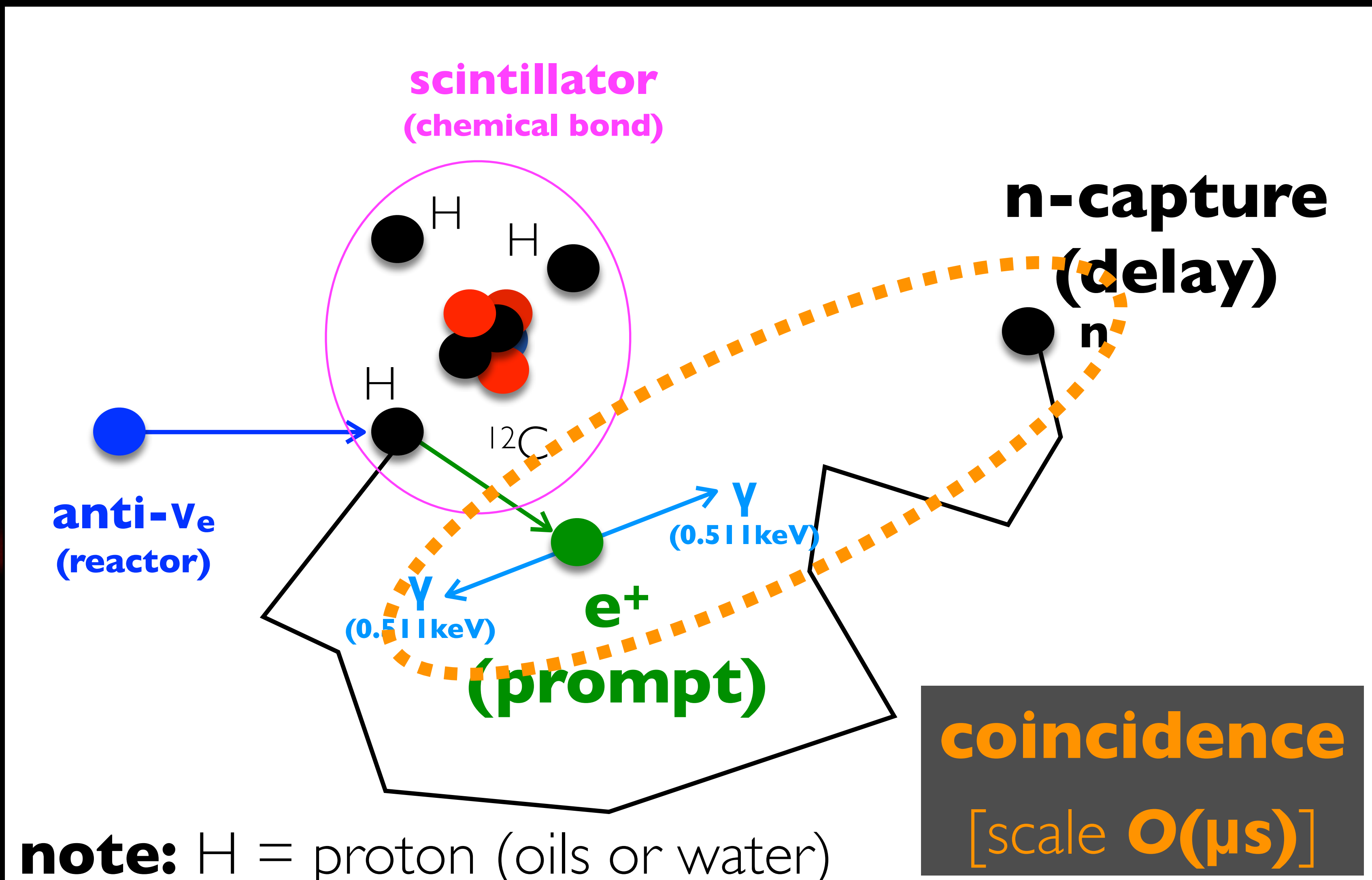
CC neutrino (solar)

- **dominant BG: β- decay of ^{115}In**

[^{14}C is lower: oil from underground petrol]

inverse-β decay (IBD) interaction…

IBD: anti-ν_e + p → e^+ + n



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)

^{3}He (non-native)

how to catch the n?

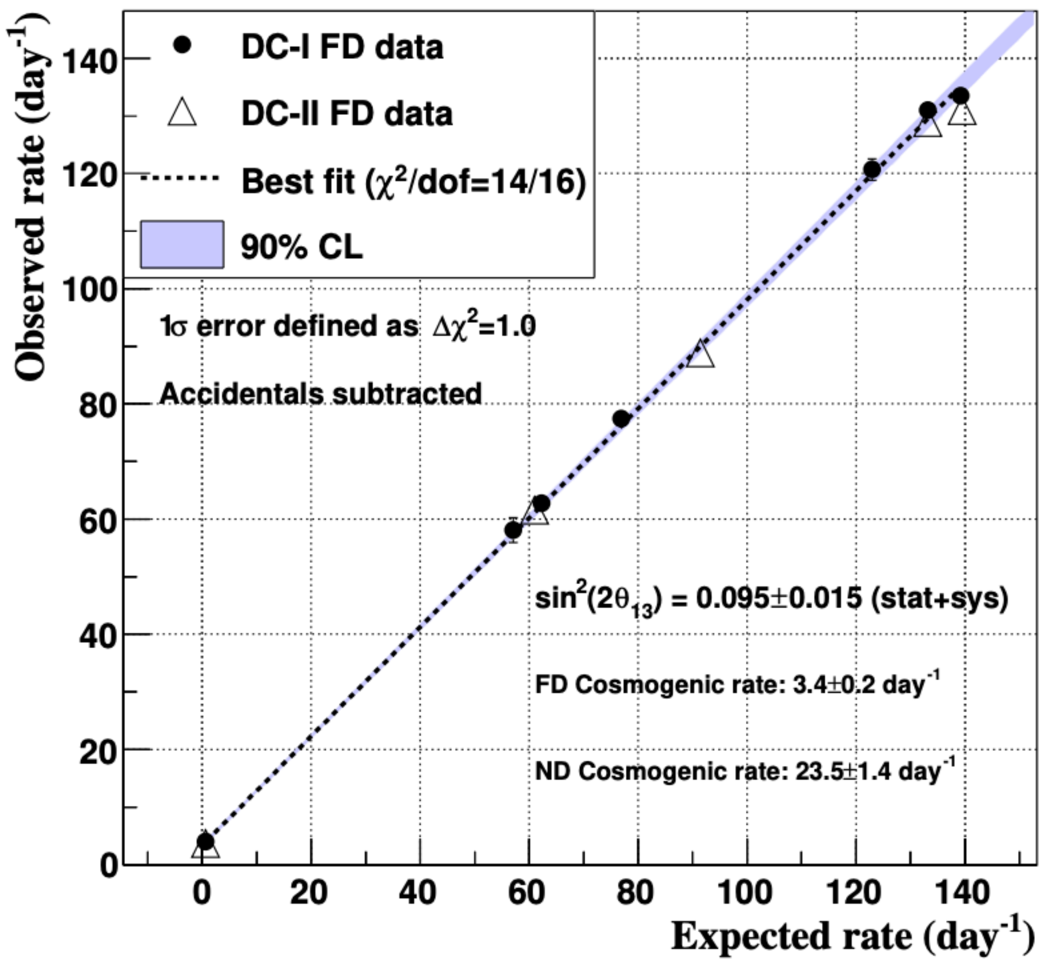
no e+ PID implies

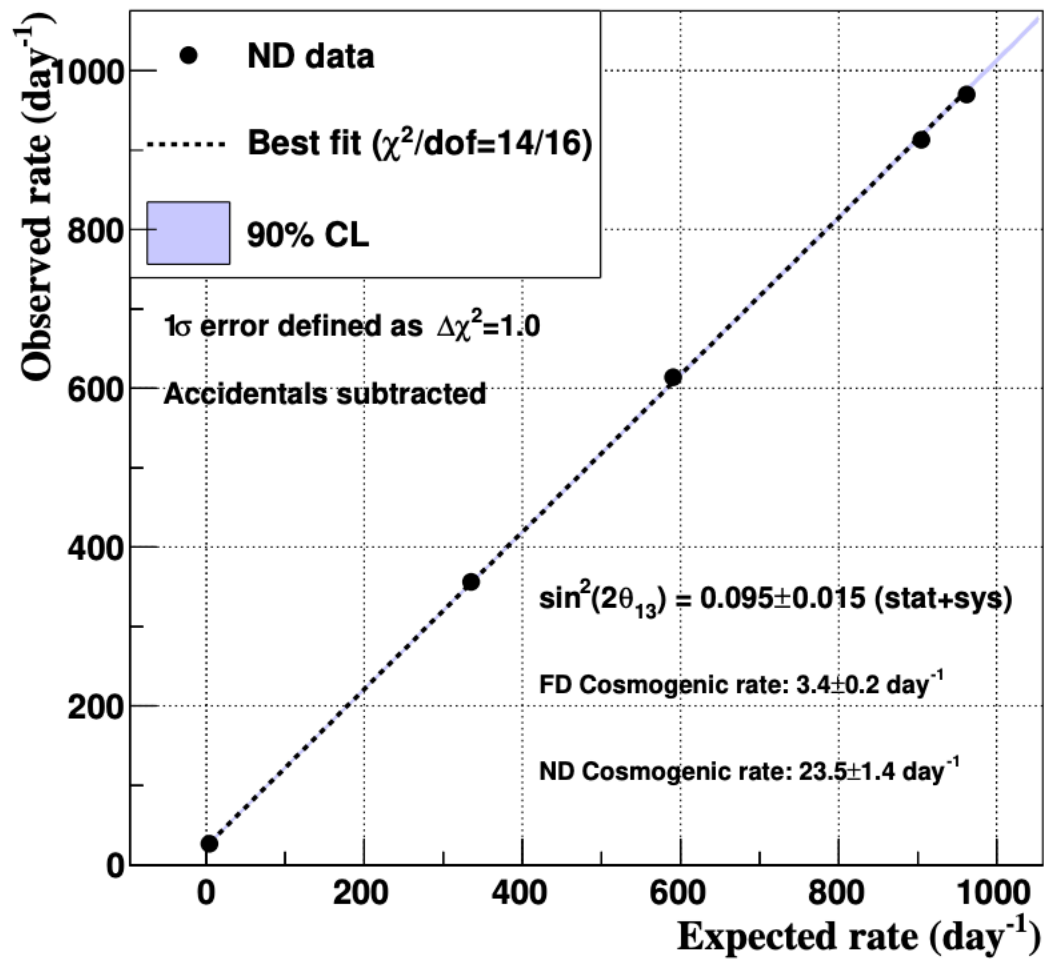
$\gamma \approx e^- \approx e^+ \approx \alpha \approx$ **p-recoil (fast-n)**

powerful analysis handles (II)…

Rate⊕Shape⊕Rate-Modulation Analysis: differentiates…

- something **scaling with reactor power: reactor-signal**
- something **not-scaling with reactor power: background or non-reactor-signal**





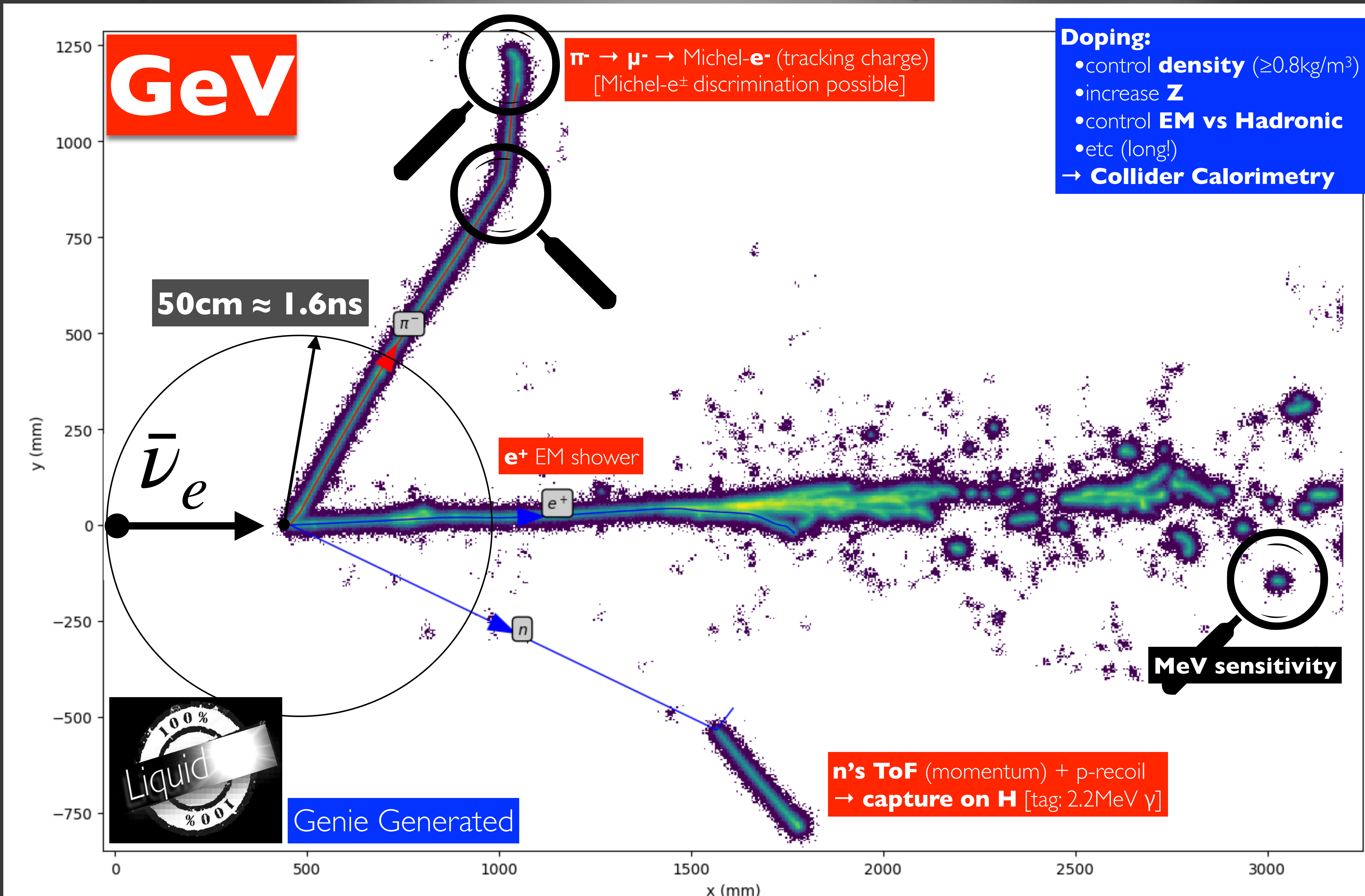
Rate⊕Shape⊕Rate-Modulation Analysis: works…

- **for any "something" (agnostic) — explorations beyond IBD?**
- **Signal & BG** estimates are **inclusive — i.e. Signal-model or BG-model indendent**
  - ⟹ **no need to understand your BG!!** (except one little caveat)

Powerful way to target unknown discovery channels?

Anatael Cabrera (CNRS-IN2P3) — IJCLab / Université Paris-Saclay (Orsay)

complex GeV with LiquidO…



Stochastic calorimetry order 0.1% [~10⁵ PE/GeV] — excellent control of non-stochastic

≥100MeV: accelerator, atmospheric, p-decay, etc

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