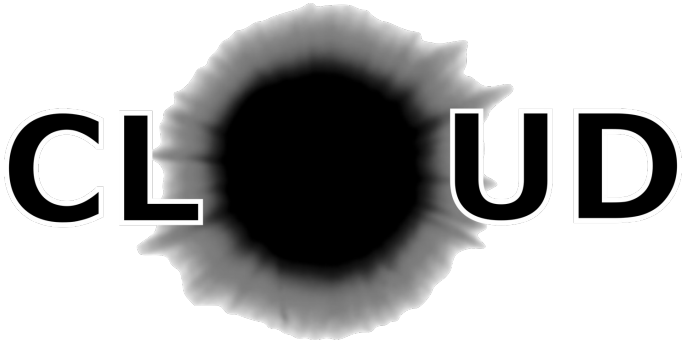
CLOUD: Opaque Scintillator for Reactor Neutrinos at Chooz



Chooz **L**iquid**O** **U**ltranear **D**etector

On behalf of the CLOUD Collaboration:

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University of Sussex

PASCOS

10th July 2024

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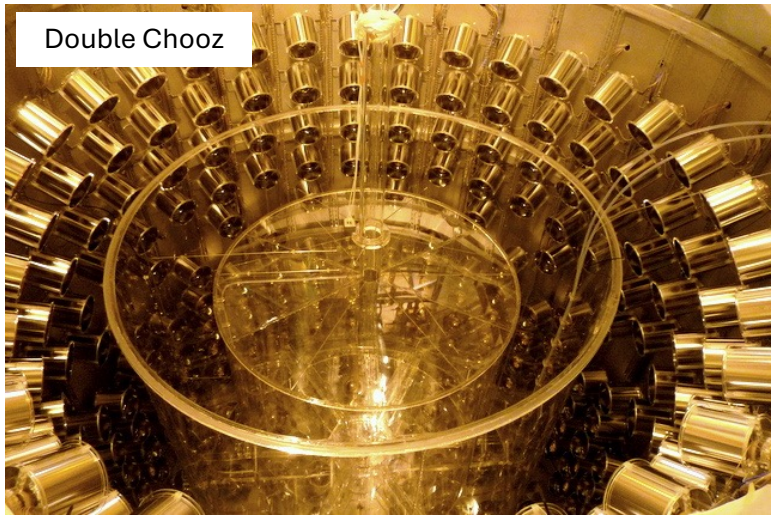
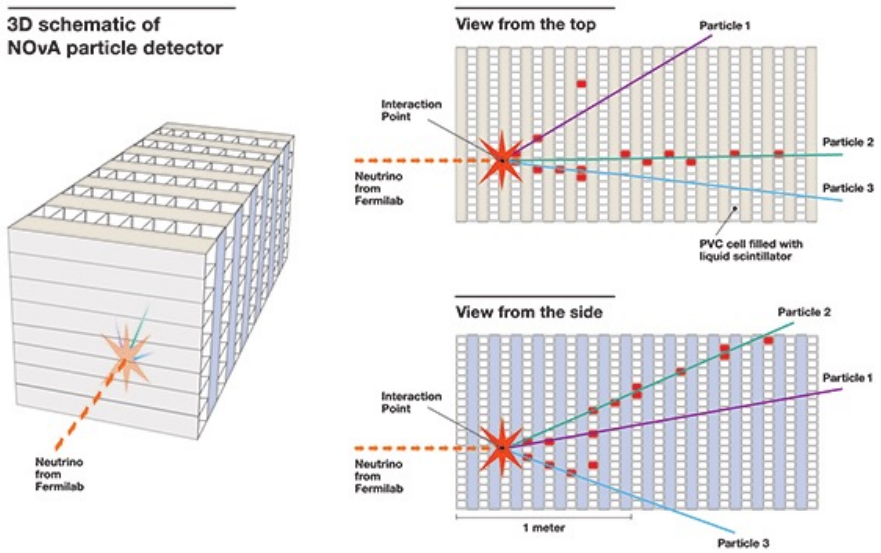
Scintillator Detectors

- Popular choice of detector for ~80 years
- Charged particles deposit energy that is converted to light
- Detecting location and magnitude of light gives trajectory, energy and PID info
- Transparency + physical segmentation



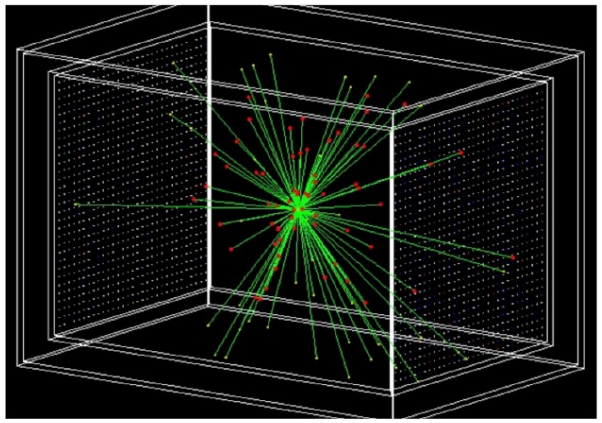


LiquidO – Opaque Scintillator

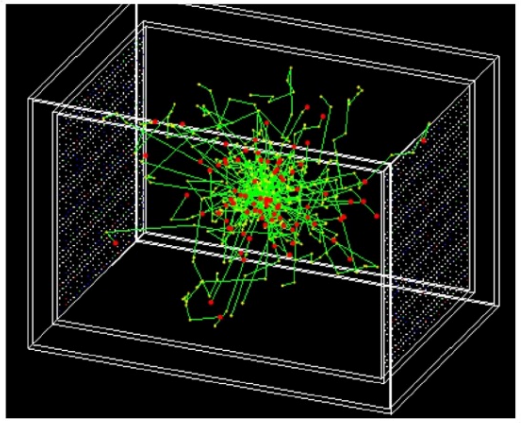
Short *absorption* length
Short scattering length

Long *absorption* length
Short scattering length

Transparent vs high-scattering opaque

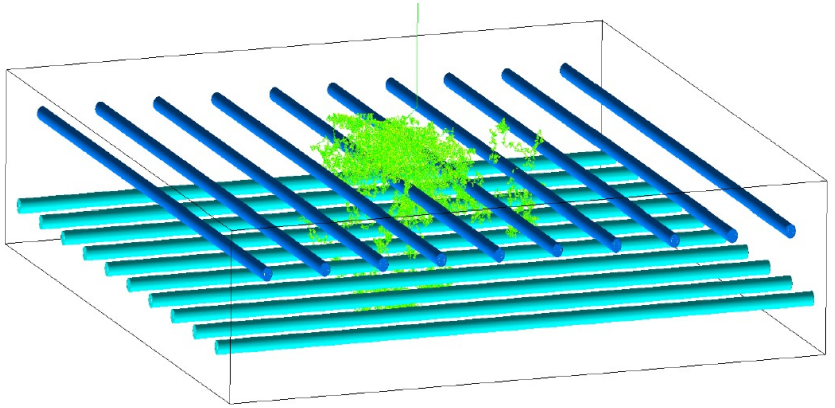


Transparent scintillator
Straight paths

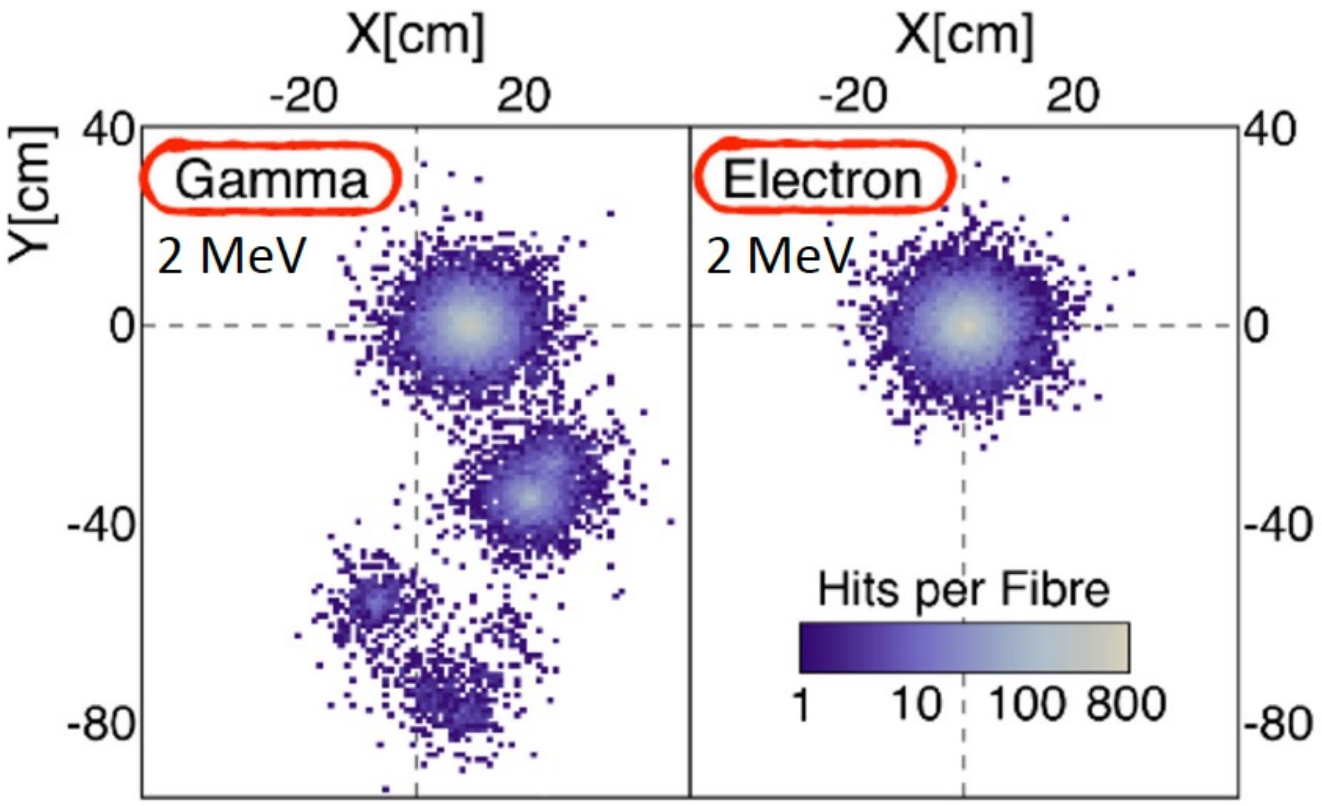


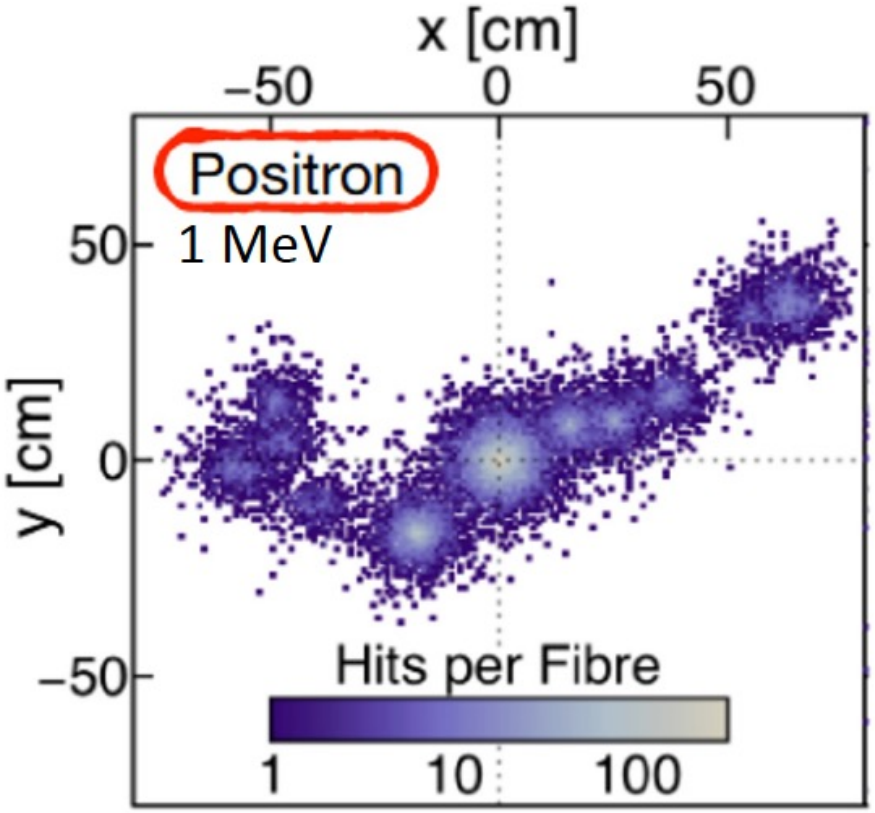
Opaque scintillator
Random walk

- Scattering keeps light local to point of production
- WLS fibres can collect the scintillation light



Particles in LiquidO



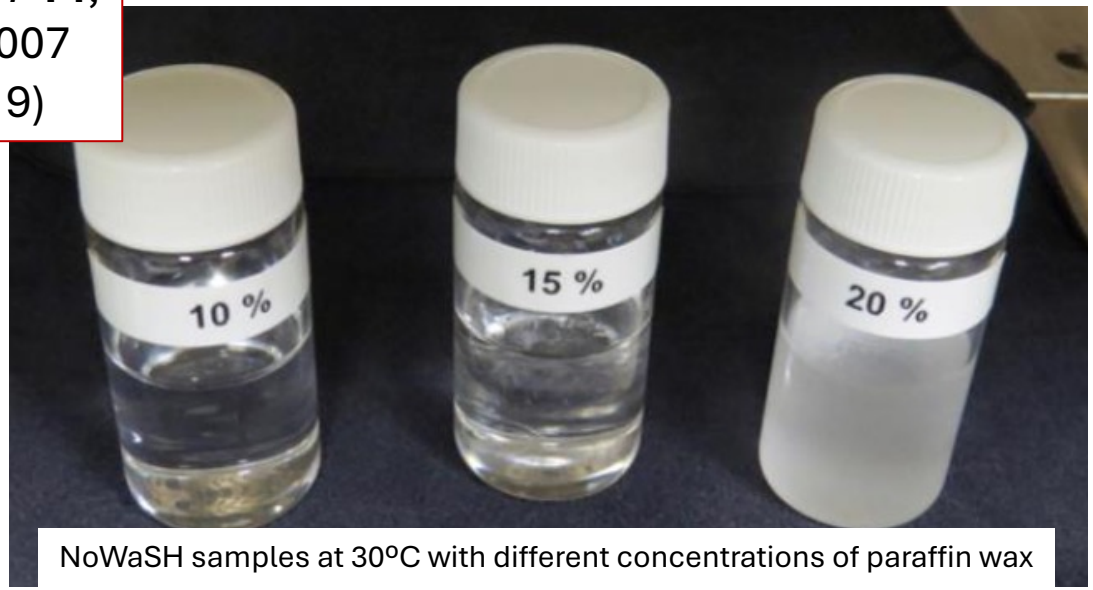


- Gammas, electrons and positrons have unique topologies
- Powerful PID capability
- Easily resolved with LiquidO's potential spatial and timing resolution

Opaque Scintillator Materials

Wax-based opacity

JINST **14**, P11007 (2019)



NoWaSH samples at 30ºC with different concentrations of paraffin wax

- **NoWaSH: No**vel **Wa**x **S**cintillator, **H**eidelberg
- Linear Alkyl Benzene (LAB) + PPO **+ Paraffin Wax**
- Viscosity and opacity depend on temperature

Emulsion-based opacity

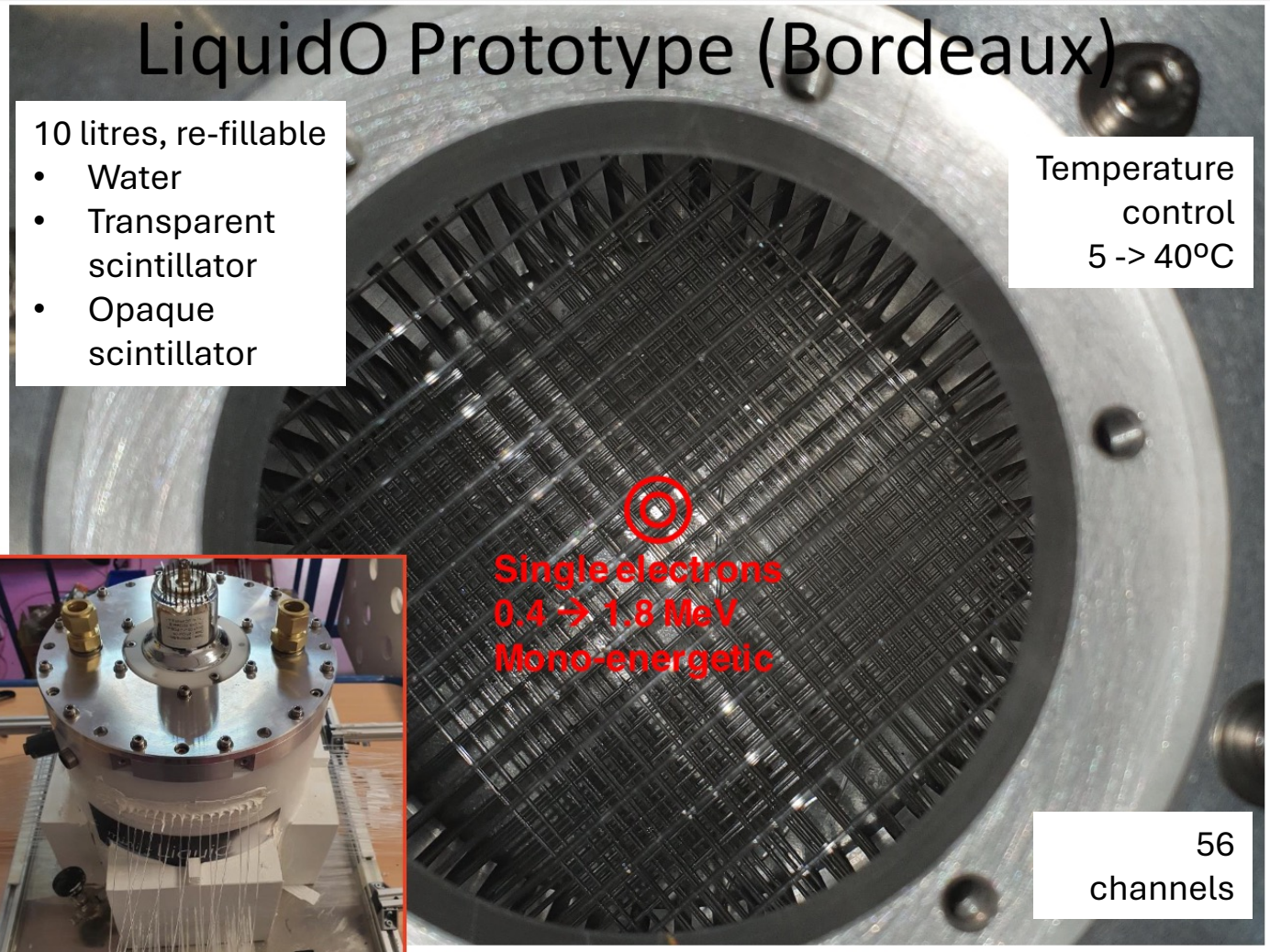
- Liquid scintillator + water + surfactant
- Use low-% water to preserve high light yield

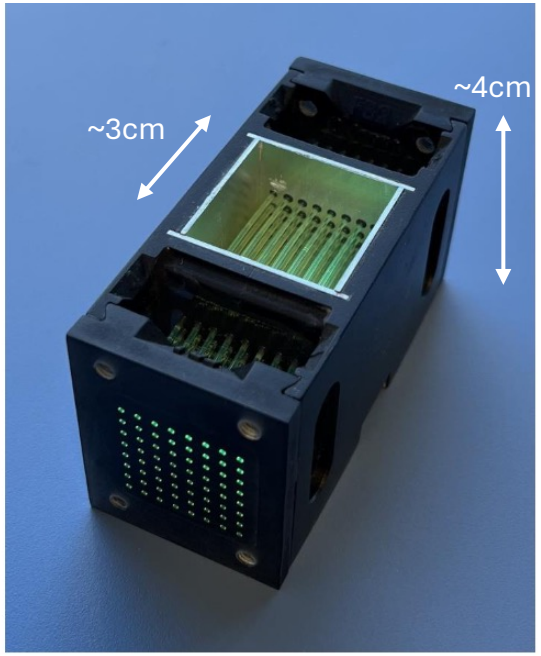
arXiv:2406.13054

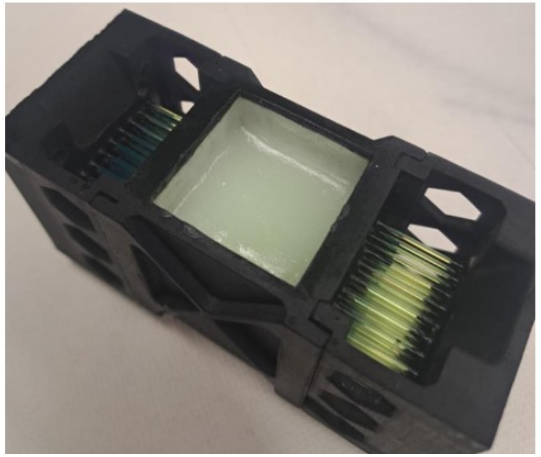
Three samples of opaque water-based liquid scintillator (oWbLS) with different scattering lengths

Prototypes

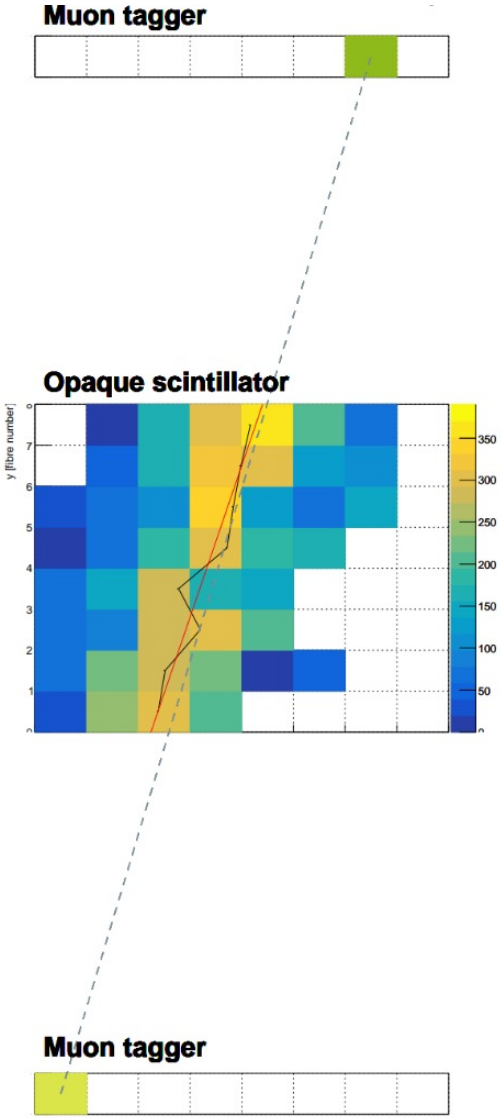
https://zenodo.org/record/6697273#.Y4DDdezMLfv



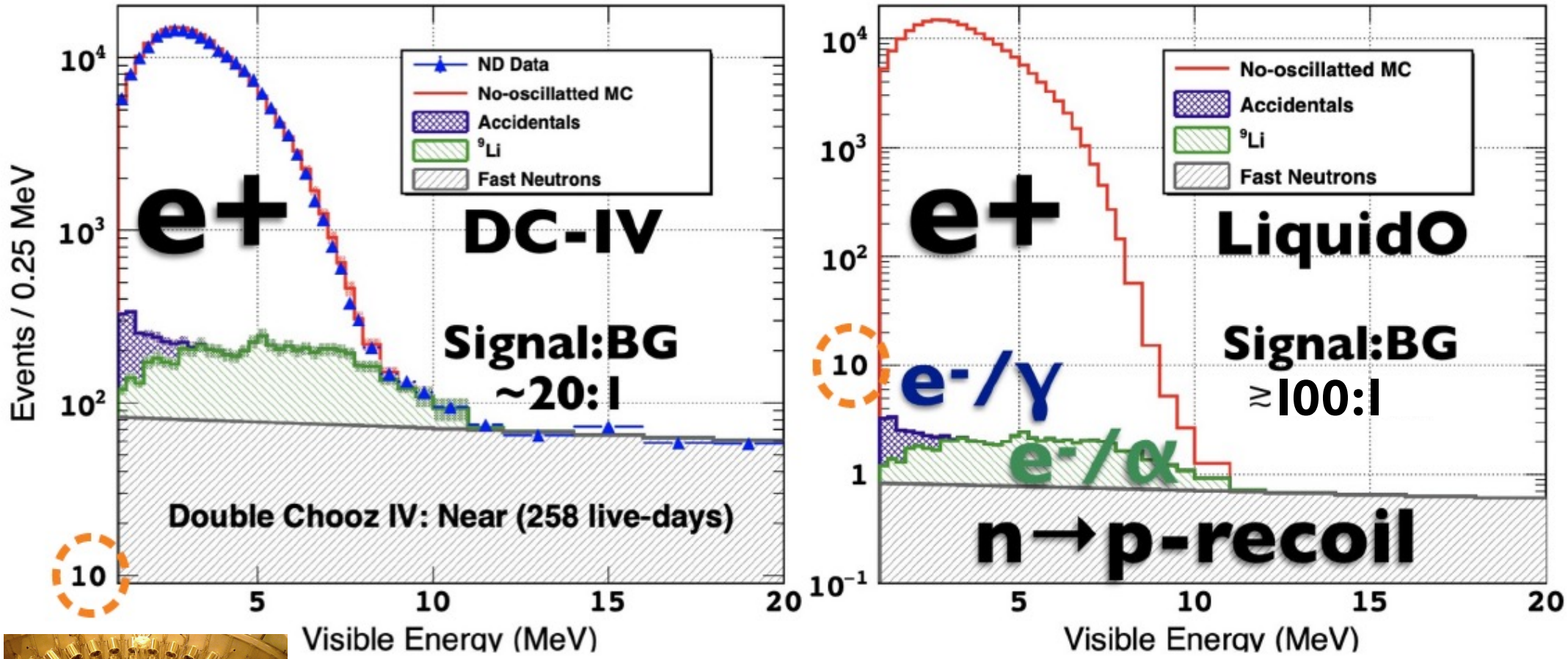


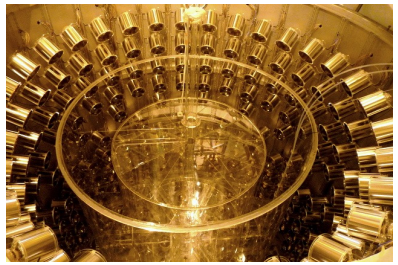


Sussex Prototypes



Why is this useful?





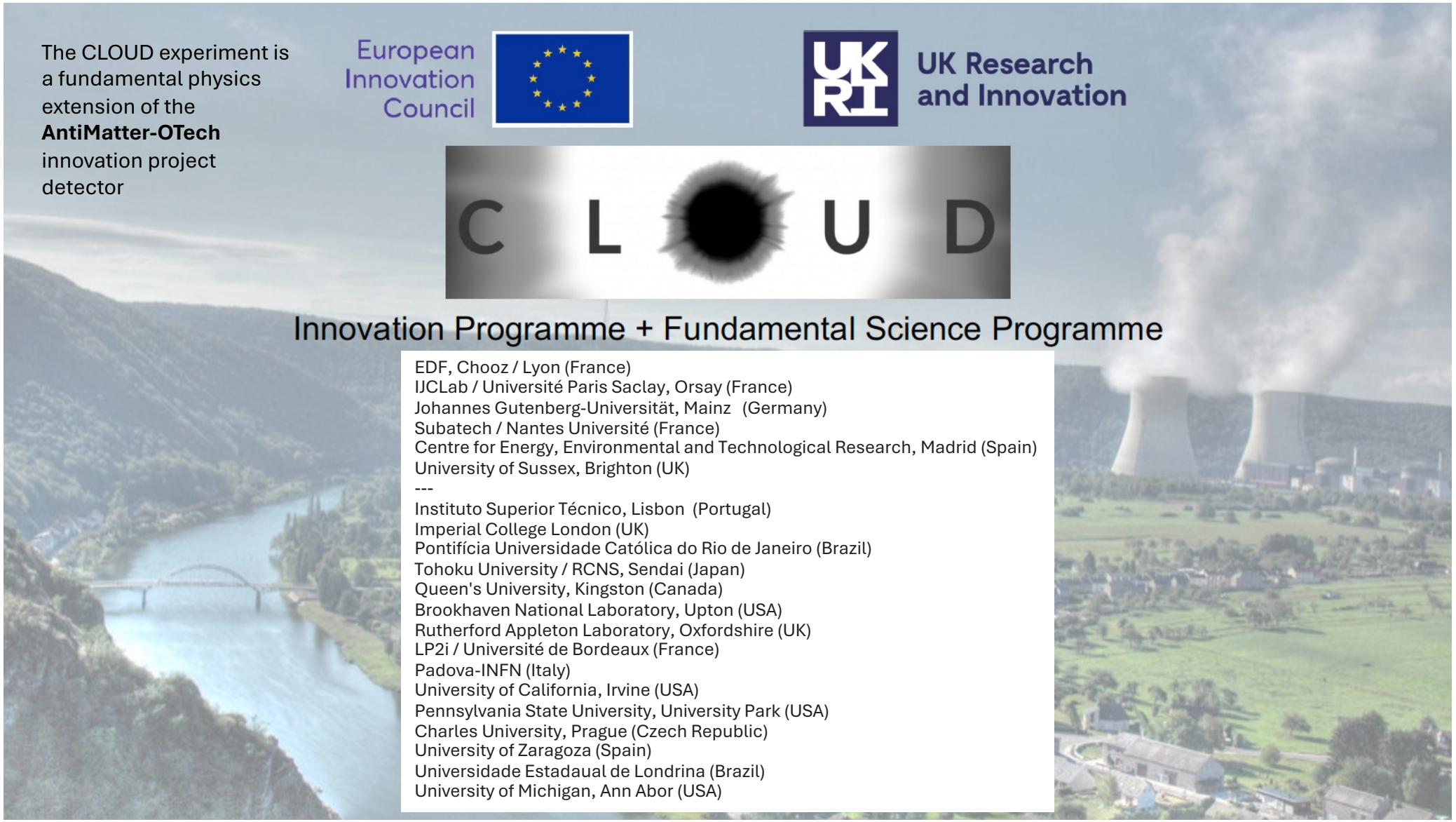
Applying expected PID for BG rejection (100:1)

Signal to BG increased massively for IBD detection!

Nat. Phys. **16**, 558-564 (2020)

Commun Physics **4**, 273 (2021)

CLOUD – First LiquidO Experiment



The CLOUD experiment is a fundamental physics extension of the **AntiMatter-OTech** innovation project detector

European Innovation Council

UK Research and Innovation

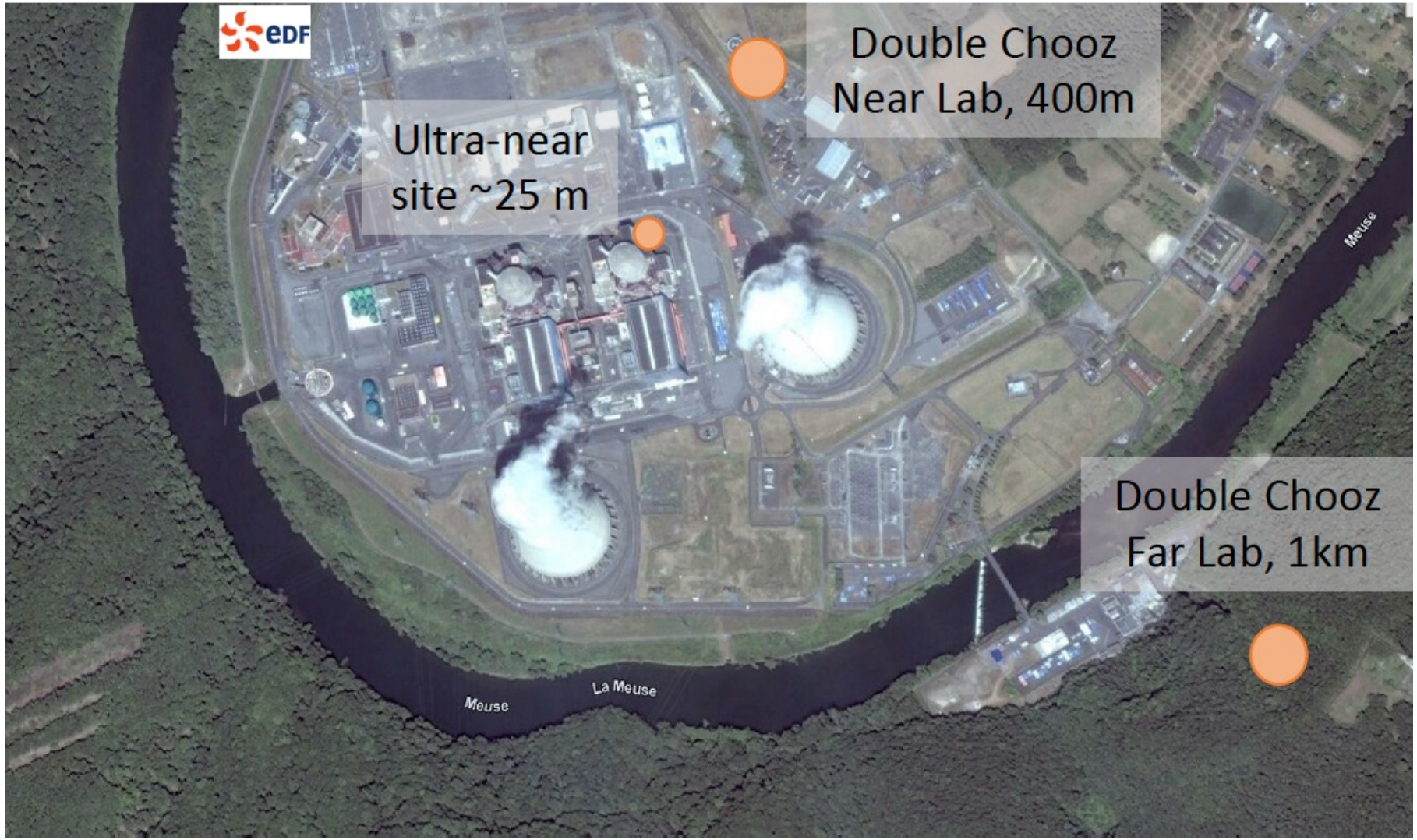
C L O U D

Innovation Programme + Fundamental Science Programme

EDF, Chooz / Lyon (France)
IJCLab / Université Paris Saclay, Orsay (France)
Johannes Gutenberg-Universität, Mainz (Germany)
Subatech / Nantes Université (France)
Centre for Energy, Environmental and Technological Research, Madrid (Spain)
University of Sussex, Brighton (UK)

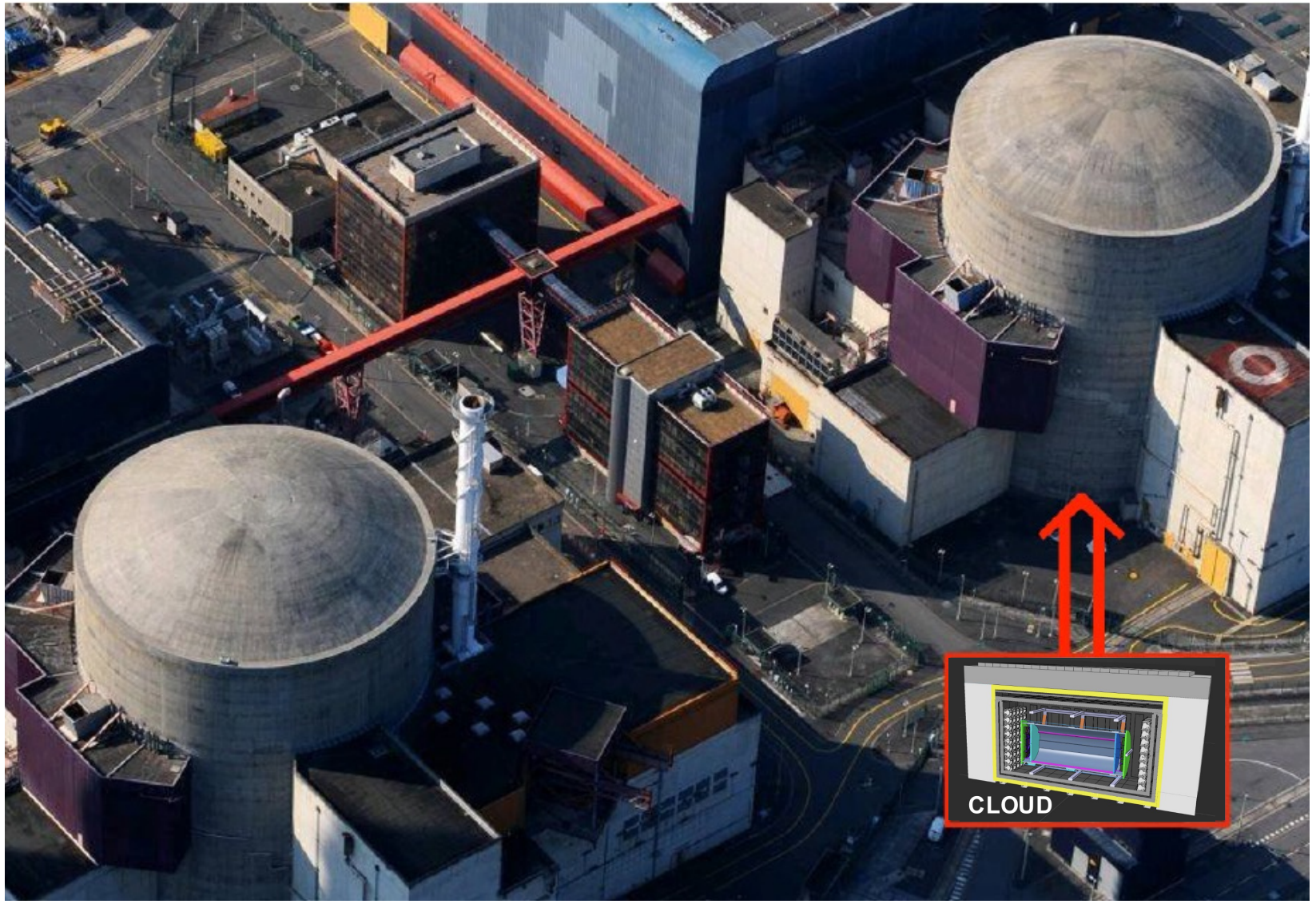
Instituto Superior Técnico, Lisbon (Portugal)
Imperial College London (UK)
Pontifícia Universidade Católica do Rio de Janeiro (Brazil)
Tohoku University / RCNS, Sendai (Japan)
Queen's University, Kingston (Canada)
Brookhaven National Laboratory, Upton (USA)
Rutherford Appleton Laboratory, Oxfordshire (UK)
LP2i / Université de Bordeaux (France)
Padova-INFN (Italy)
University of California, Irvine (USA)
Pennsylvania State University, University Park (USA)
Charles University, Prague (Czech Republic)
University of Zaragoza (Spain)
Universidade Estadaual de Londrina (Brazil)
University of Michigan, Ann Abor (USA)

CLOUD – Chooz LiquidO Ultranear Detector



- >5 ton LiquidO detector at Chooz
- Goals:
  - Reactor monitoring
  - Low-E ν physics
- **10,000 IBD events/day!**
- **Unprecedented >100 S/B**
- High-res imaging allows **detector at surface**
- Aiming to start data taking in two years

CLOUD – Chooz Liquid**O U**ltranear **D**etector



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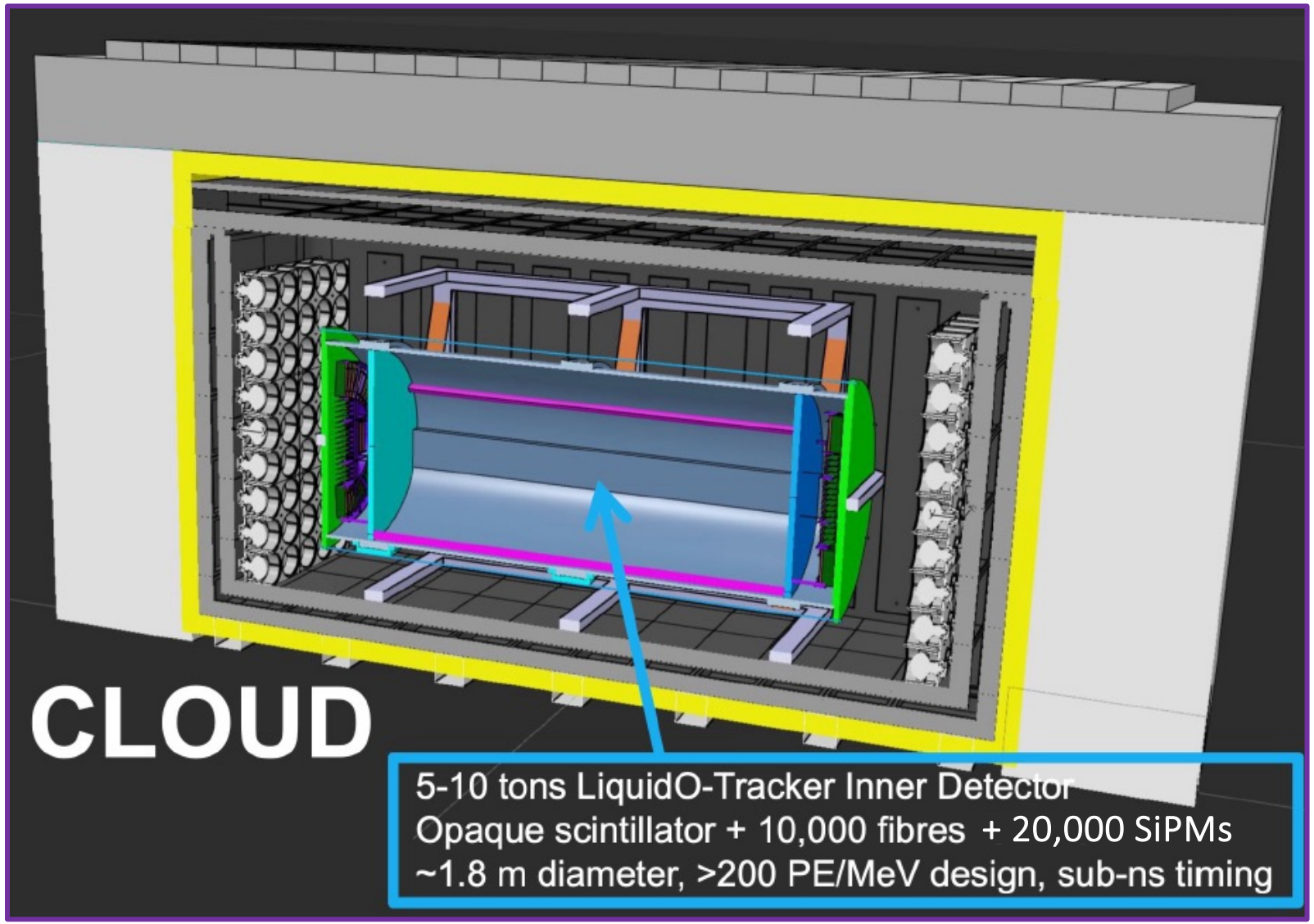
CLOUD Design



- Inverse Beta Decay (IBD)

$$\bar{\nu}_e + p^+ \rightarrow e^+ + n$$
$$\hookrightarrow \gamma + \gamma \quad \hookrightarrow \gamma$$

- 1.8 MeV threshold
- Signature:
  - e^+ annihilation
  - n-capture on p^+ gives 2.2 MeV γ (~200 μs delay)

CLOUD 3-Phase Run Plan

Phase 1: Pure Opaque Scintillator

- Precision reactor characterisation
- <1% flux measurement, U/Pu composition
- Reactor OFF measurements
  - Quantify backgrounds
  - Reactor fuel monitoring
  - ON-OFF-ON transitions

$$\bar{\nu}_e + p^+ \rightarrow e^+ + n$$
$$\hookrightarrow \gamma + \gamma \qquad \hookrightarrow \gamma$$

Phase 2: Indium Loading

- Sensitivity to electron neutrinos
- Low 114 keV threshold
- Solar neutrino observations

$$\nu_e + {}^{115}In \rightarrow e^- + {}^{115}Sn^*$$
$$\hookrightarrow \gamma/e^- \ (116\ keV) + \gamma\ (497\ keV)$$

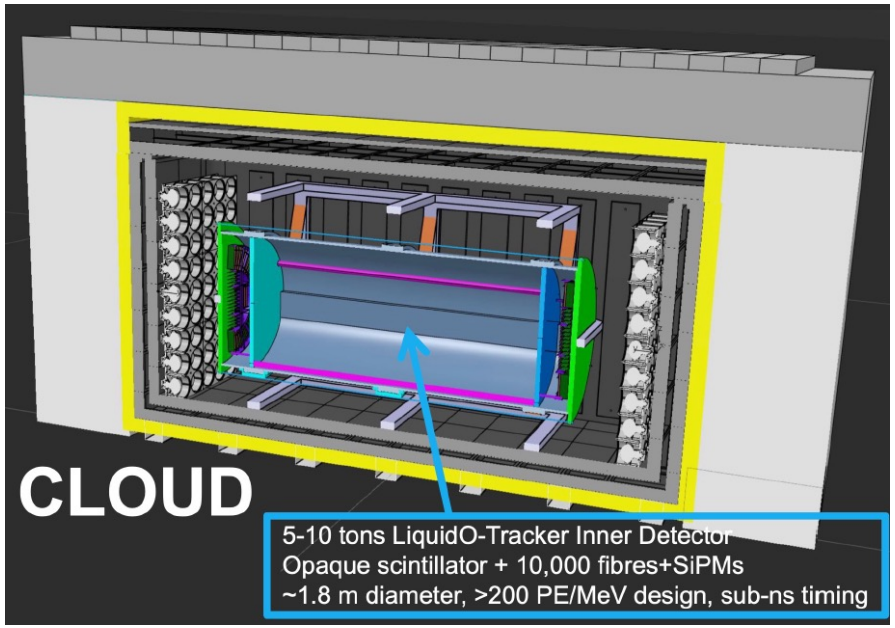
Phase 3: Copper Loading

- Lower energy threshold (1.2 MeV) for electron antineutrino detection
- First observation of IBD on copper
- Proof of principle for ^{40}K geo-neutrinos (arXiv:2308.04154)

$$\bar{\nu}_e + {}^{63}Cu \rightarrow e^+ + {}^{63}Ni^{(*)}$$
$$\hookrightarrow \gamma\ (87\ keV) \quad \text{[if Ni was excited]}$$

Summary

- LiquidO: new scintillator detector technology using opaque scintillator
- CLOUD: First-of-its-kind detector project
  - 5–10 tons LiquidO precision imaging calorimeter
  - Demonstrator for even larger projects
- Phase I, pure opaque scintillator
- Phase II, Indium loading
- Phase III, Copper loading
- This is a whole new way of thinking about scintillator detectors
  Many possibilities we haven't even thought of yet!



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

Proof of principle paper:
https://doi.org/10.1038/s42005-021-00763-5