Contribution aux exercices de prospective nationale 2020-2030

Détecteurs et instrumentation associée

LiquidO: New Opaque Scintillation Fundamental Particle Detection Framework

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1. Informations générales

Titre : LiquidO: New Opaque Scintillation Fundamental Particle Detection Framework

Acronyme : ***LiquidO***

Résumé *(max. 600 caractères espaces compris)*

The LiquidO novel approach for neutrino detection has been recently developed. The concept is highly innovative and offers groundbreaking capabilities for fundamental neutrino research. Liquid scintillator detectors have traditionally required a transparent detection medium. Turning this notion on its head, our technique uniquely exploits the properties of a highly dispersive opaque scintillating medium. By reading out scintillation light from the inside using fibres, as opposed to requiring light to propagate out, LiquidO pioneers a new type of detector with remarkable features. The light for each particle interaction is stochastically confined thus resolving, for the first time, distinct space-time event images. The different manifestations of MeV-energy gamma rays, electrons and positrons can be readily identified, event-by-event, enabling powerful, active background rejection and unprecedented neutrino/anti-neutrino interaction separation. Powerful imaging of GeV neutrino interactions and proton-decay is also possible. Moreover, LiquidO's design simplicity allows for high radiopurity while its opaque medium welcomes high element doping by, at least, one order of magnitude. This combination, far from a mere technological spin-off, makes LiquidO a game-changing solution widening the physics programme beyond native detector composition. It will push neutrino physics beyond today's paradigm while opening the door to multi-ton double beta decay potential. Practical applications in medical physics, nuclear reactor monitoring and radio-protection technology are immediate by-products of our strategy.

Préciser le domaine technologique *(plusieurs choix possibles)*

- Scintillateurs
- Photo-détecteurs (SiPM, PMT…)

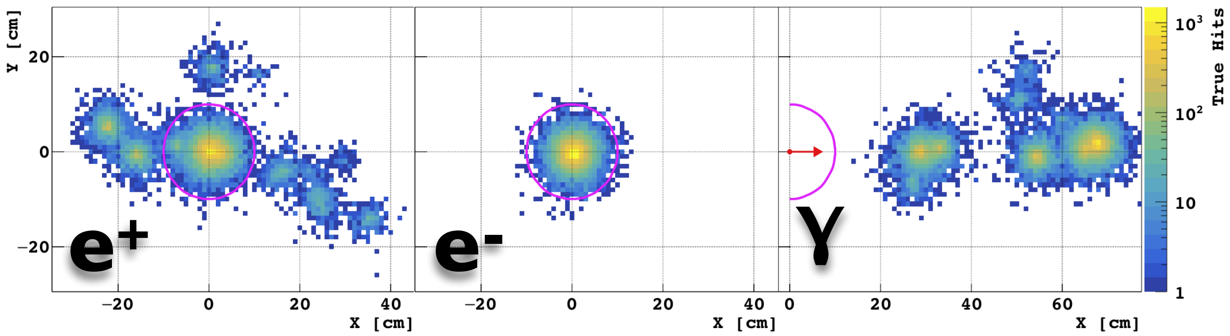
Préciser la motivation principale de recherche visée par la contribution :

- R&D Calorimétrie [✓]
- R&D Trajectographe [✓]
- R&D Identification de particules [✓]
- R&D Détection de neutrons [✓]
- R&D Détecteurs de neutrinos [✓]
- R&D Détection de gammas [✓]
- R&D Détecteurs imagerie médicale [✓]
- *Autre R&D spécifique :* LiquidO is a framework of detection — not just a specific detector — capable of accommodating many physics cases. Its birth took place within the neutrino detection, but exploration in other application in HEP is envisaged and ongoing. LiquidO is cable to provide simultaneously: calorimetry, tracking, PID, neutron and γ detection and its possible impact to medical physics is under active exploration.

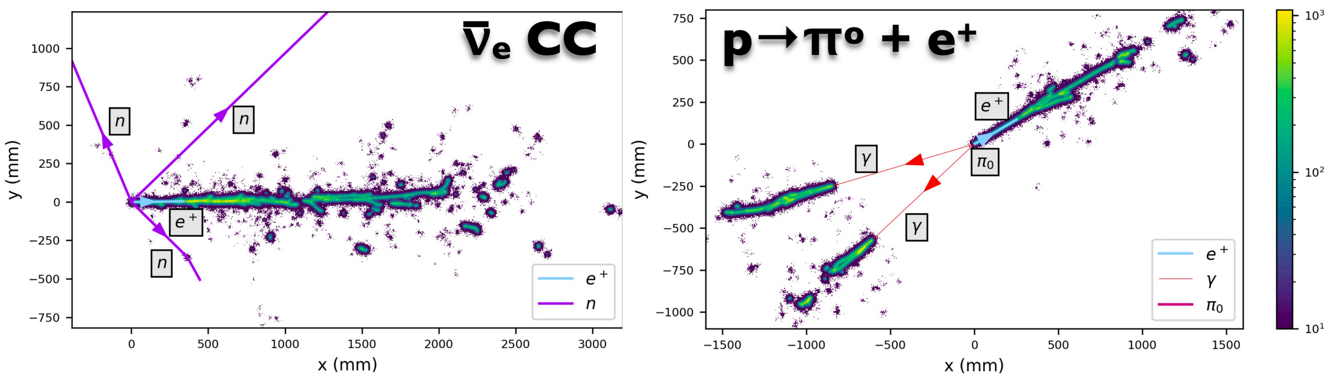
2. Description des objectifs scientifiques et techniques

(1 page max incl. figures)

LiquidO detection is based on using opaque scintillator using opacity via light scattering. Thus, photons from the scintillator undergo a random walk about their origin, giving rise to stochastic light confinement. This enables the accurate imaging of sub-atomic particules to an unprecedented so far in liquid scintillators with no segmentation whatsoever. This imaging translates into powerful particle ID, tracking while retaining calorimetry capability with <10% precision at 1MeV. A e+ (including annihilation), e- and γ a 2MeV are illustrated below. Since the discovery of the neutrino (led by Reines&Cowan in1956) most scintillator neutrino detectors relies at heart in transparency. LiquidO inherits all such technology and expertise, while additional revolutionise its event-wise imaging capability. To extract the light a lattice of wavelength-shifting fibres runs through the scintillator readout by SiPMs. Many configurations are possible but fibres running in only one direction might suffice for most purposes. This configuration, referred as 2D, is simpler than two orthogonal lattices (3D). LiquidO's unique ability to yield self-segmentation enhances the radiopurity potential. The opaque articulation opens for new capabilities: a) high detector doping with elements (new physics beyond native composition — many examples) and b) explore new higher light yield scintillators. Doping is today, typically, limited to ≤1% levels, whether LiquidO aims for levels ≥10% — a breakthrough, if possible. The conception as well as the first simulation and the first experimental proof-of-principles have been successfully achieved by the IN2P3 teams in collaboration with the LiquidO proto-collaboration (18 institutions in 10 countries) led by F. Suekane (RCNS, Tohoku, Japan) and A. Cabrera (FLUO/LAL-LNCA, CNRS/IN2P3, France).



LiquidO is currently explored as detection technique for several physics cases. First technique capable to prove feasible detection of ^{40}K geo-neutrino, supernova neutrino physics, background-less reactor neutrino detection for high precision neutrino oscillation, multi-ton ββ decay searches as well as neutrino physics in GeV neutrino beams and proton decay — events below. More physics is expected.



3. Livrables associés, calendrier et budget indicatifs (1 page max. incl. figures)

Goals & deliverables:

Detector R&D:

- Full e- confinement prototype (Mini-LiquidO): first data & publication [ongoing]
- Full γ confinement prototype (Macro-LiquidO) [waiting resources]
- Full-scale detector mechanics, readout and electronics prototyping [ongoing]
- Radiopurity control development (active & passive) of fibres (liaison with industry) [ongoing]

Resources: ~40k€ + 1 postdoc

Fundamental Research Physics:

- Physics studies: geo-neutrinos [ongoing]
- Physics studies: supernova neutrinos [ongoing]
- Physics studies: CP-Violation with μ/π beam at rest [ongoing]
- Physics studies: most precise θ13 and Δm^2(ee) [ongoing]
- Physics studies: leptonic Unitarity violation physics [ongoing]
- Physics studies: multi-ton ββ decay potential [ongoing]
- Physics / Feasibility studies: Super Chooz project [ongoing]

Resources: 1 postdoc

Technological Application:

- Physics studies: inexpensive full-body PET system [ongoing]

Resources: 1 postdoc (+ Macro-LiquidO prototype — see above)

Funding/Support:

- ERC-Synergy-2020: waiting for outcome [ERC-Synergy-2019: classed-A+reserved list]

Resources: culminate above preparation within 2020.

4. Impact *(1/2 page max.) (optionnel)*

LiquidO has the potential for high impact to fundamental research as well as both industrial and societal applications via new technology. The main 3 applications, so far, are nuclear reactor monitoring (non-proliferation), medical imaging (novel inexpensive full body PET technology) and radioprotection (radioactive gases, such as Rn). As spin-off of our detection technology for industry, we expected also developments on novel scintillation materials, better fibres (radiopurity and transparency) and robust SiPM-based readout systems. Finally, the main goal of LiquidO effort now is to be able to design and demonstrate the feasibility of new breakthrough experiments in fundamental research of neutrino and rare-decay experiments.

5. Références

[first publication]
LiquidO Proto-Collab. (A. Cabrera et al) Pre-print: arXiv:1908.02859 (2019)

[first official release of LiquidO technology]
LiquidO Proto-Collab. (A. Cabrera) Seminar at CERN (June 2019)
Web: https://indico.cern.ch/event/823865/

[first opaque liquid scintillator formulation]
C.~Buck et al. Submitted to JINST. Pre-Print arXiv:1908.03334 (2019)

[first release of GeV neutrino physics and proton-decay potential]
LiquidO Proto-Collab. (Pedro Ochoa-Ricoux). Workshop "DUNE 4th Module Opportunity".
Brookhaven, New York (2019)
Web (workshop): https://www.bnl.gov/dmo2019/index.php
Web (agenda): https://indico.fnal.gov/event/21535/other-view?view=standard

[first proposal for first observation of the ^{40}K geo-neutrino with LiquidO]
LiquidO Proto-Collab. (A.Serafini et al.) Talk at Neutrino Geoscience Conference (2019)
Web: https://indico.cern.ch/event/825708/contributions/3550280/

[first proposal for possible exploration of leptonic Unitarity at Super Chooz]
LiquidO Proto-Collab. (A. Cabrera et al.) Talk at EPS-HEP Conference (2019)
Web: https://indico.cern.ch/event/577856/contributions/3421609/

[first proposal for μ/π beam for CP-Violation with LiquidO]
LiquidO Proto-Collab. (M. Grassi et al.) NIM A 61209 (2018)

[first proposal for multi-ton ββ framework R&D with LiquidO]
LiquidO Proto-Collab. (A. Cabrera et al.) Talk at Neutrino Oscillation Workshop Conference (2018)
Web: http://www.ba.infn.it/$\sim$now/now2018/assets/2018sept_firstliquido\%40now2018_anatael.pdf