Contribution aux exercices de prospective nationale 2020-2030

Détecteurs et instrumentation associée

High granularity liquid argon calorimetry for a detector at a future circular electron-positron collider

Auteur principal

Nom : Guillemin Thibault

Affiliation : LAPP

Email et coordonnées : thibault.guillemin@cern.ch

Co-auteurs (inclure aussi les collaborateurs internationaux si existants)

- LAL : Nicolas Morange, Laurent Serin

- LAPP : Marco Delmastro

- OMEGA : Christophe de la Taille

1. Informations générales

Titre : High granularity liquid argon calorimetry for a detector at a future circular electron-positron collider

Acronyme : GRANULAR

Résumé

A future circular electron-positron collider will bring novel challenging experimental conditions at the intensity frontier, and an active R&D is required to create the best detectors possible to exploit these future data. The presented project focuses on the development of a very high granularity Liquid Argon (LAr) electromagnetic calorimeter, possible only thanks to a novel concept of readout electrode based on a multilayer PCB. The ambitious goal of the project is three-fold : to optimize the design of a LAr calorimeter with an unprecedented granularity for a detector at such a collider, to establish the technical feasability going up to a small-scale prototype and to measure the performance in view of the physics goals. A cold electronics approach, with front-end boards located inside the crysotat, will be explored to reduce as much as possible the electronics noise : operating a huge number of channels with this technique would constitute a breakthrough for a collider experiment.

Préciser le domaine technologique *(plusieurs choix possibles)*

- o Détecteurs semi-conducteurs (Si, Ge, HgCdTe, Diamant…)
- o X Détecteurs gazeux (Micromegas, GEM, TPC…)
- o Scintillateurs
- o Photo-détecteurs (SiPM, PMT…)
- o Détecteurs cryogéniques (KIDS, bolomètres…)
- o X Micro-électronique, Electronique Front End
- o Acquisition de données, Temps réel
- o X Mécanique, integration

Préciser la motivation principale de recherche visée par la contribution :

- o X R&D Calorimétrie
- o R&D Trajectographe
- o R&D Identification de particules
- o R&D Détection de neutrons
- o R&D Détection d'ondes gravitationnelles
- o R&D Détecteurs de neutrinos
- o R&D Détection de gammas
- o R&D Détecteurs imagerie médicale
- o *Autre R&D spécifique : (préciser)*

2. Description des objectifs scientifiques et techniques

While the update of the European Strategy for Particle Physics (ESPP) is currently ongoing to decide the path towards the next major collider project following the High-Luminosity LHC, there is an emerging consensus that the first priority is the precise study of the scalar sector, calling for an e^+e^- collider running at an energy above the *ZH* production threshold. This is the baseline strategy of the European Future Circular Collider (FCC) program [1], which is based on a 100-km tunnel at CERN, designed to host first a Z, *W*, Higgs and top-quark factory (FCC-ee phase) and subsequently host a hadron collider with a centre-of-mass energy of 100 TeV (FCC-hh phase). The FCC-ee collider will bring novel challenging experimental conditions at the intensity frontier, and an active R&D is required to create the best detectors possible to exploit these future data.

A high granularity Liquid Argon (LAr) calorimeter is a natural and compelling option for a detector at a future high energy hadron collider, because in particular of its intrinsic excellent radiation hardness, better than all other currently known technologies. This was studied in the FCC-hh Conceptual Design Report [2], where the fine longitudinal segmentation allows to reduce the impact of the many pileup events. But the idea of a highly granular LAr calorimeter is also very appealing for a detector at FCC-ee, as it could be optimized for the use of particle flow techniques to improve the energy resolutions. The foreseen technical solution to reach a fine segmentation, that is using large multilayer PCBs as readout electrodes, induces many challenges which need to be solved to establish the feasibility of the design. The ambitious goal of the presented project is three-fold : to optimize the design of a LAr calorimeter with an unprecedented granularity for a detector at FCC-ee, to establish the technical feasibility going up to a prototype and to measure the performance in view of the physics goals.

The use of the noble liquid sampling calorimetry has not yet been thoroughly studied for a detector at FCC-ee. The existing designs considered so far are respectively a Si-W sampling calorimeter (CLD) and a fibre-sampling dual-readout calorimeter (IDEA). A sampling LAr calorimeter design outperforms these designs on the electromagnetic energy resolution. Considering electrons from Z decays, the expected resolution is typically 4% for CLD [3], while in ATLAS the observed resolution is better than 2% [4]. However, the hadronic resolution remains a major driver for the physics program at FCC-ee and has to be considered in the optimization. A key aspect is the ability to separate hadronic *W* and *Z* decays, resulting in a resolution goal of 4-5% on the energy of jets from *W*/*Z*. The current performance of the ATLAS detector (which uses steel as the absorber and scintillator as the active medium for the hadronic part) is typically 10% [5], ignoring the pileup contribution. Such a performance can be largely improved using a much higher granularity and particle flow techniques, in order to combine a good separation of showers from individual particles with the excellent energy measurement in LAr calorimeter cells. Given the limited energy range of jets produced in FCC-ee collisions (up to 200 GeV), an interesting path to explore is the use of the LAr technology for both the electromagnetic and the hadronic parts, using an adequate combination of absorbers.

The physics opportunities opened by the 'Tera-*Z*' factory phase, which is unique at FCC-ee, strengthens further the requirements on the electromagnetic calorimeter performance, since pushing the LEP precision by several orders of magnitude on key electroweak observables will require an unprecedented control of the systematic uncertainties. The number of readout channels about two orders of magnitude smaller for a LAr-based design with the respect to the alternative designs considered (typically 10^6 versus 10^8 readout channels) is a clear advantage to keep calibration systematic uncertainties under control. The excellent electromagnetic energy resolution and the ability of extremely precise calibration are compelling arguments in favor of the LAr technology. In addition, the cost of this technology is expected to be significantly lower (the CLD calorimeter is estimated to cost 480 M CHF [6]).

With the output of the ESPP update in 2020, the timeframe 2021-2024 is perfectly adequate to perform a R&D program on a highly granular LAr calorimeter for a FCC-ee detector, comprising the optimization of a design to reach the required excellent performance, and the establishment of the feasibility of this calorimeter by studying the most challenging technical points. The scientific program is structured around three complementary work packages (WP):
- WP1 : Development of the calorimeter geometry
- WP2 : Electrode and electronics readout prototypes
- WP3 : Test beam measurements of a small-scale calorimeter module

The obtained results will bring a definite answer for the possible use of the noble liquid calorimetry concept at FCC-ee.

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

Le projet présenté vient d'être soumis à l'appel à projet ANR générique 2020. Ce projet est inclus dans un consortium européen plus large, créé autour d'une *Expression of Interest* en vue de l'appel à projet H2020 (via AIDA++). Les autres instituts participant sont le CERN, l'Université de Prague et le CPPM.

Les points spécifiques de travail de la collaboration française sont :
- l'optimisation du design et de la granularité de l'électrode en PCB spécifiquement pour un collisionneur circulaire e^+e^- ;
- le développement d'un ASIC intégré, amplifiant et numérisant les signaux, opérant à froid à l'intérieur du cryostat ;
- l'intégration mécanique d'un module calorimétrique complet de petite taille, et la mesure de ses performances dans des tests en faisceau.

Pour la période 2020-2025, les besoins estimés en ressources humaines sont environ (en FTE par an):
- 1 FTE physicien (en additionnant les contributions des physiciens permanents engagés)

- 1 FTE postdoctorant
- 1 FTE ITA (principalement électronique mais aussi mécanique).

Pour le côté hardware, une première estimation est de 200 k€ :

- 100 k€ pour les ASICs
- 50 k€ pour les PCBs
- 50 k€ pour le prototype complet.

4. Références

[1] Future Circular Collider Study. Volume 1: Physics Opportunities. Conceptual Design Report, preprint edited by M. Mangano et al. CERN accelerator reports, CERN-ACC-2018-0056, Geneva, December 2018. Published in Eur. Phys. J. C
[2] Future Circular Collider Study. Volume 3: The Hadron Collider (FCC-hh) Conceptual Design Report, preprint edited by M. Benedikt et al. CERN accelerator reports, CERN-ACC-2018-0058, Geneva, December 2018. Published in Eur. Phys. J. ST.
[3] Future Circular Collider Study. Volume 2: The Lepton Collider (FCC-ee) Conceptual Design Report, preprint edited by M. Benedikt et al. CERN accelerator reports, CERN-ACC-2018-0057, Geneva, December 2018. Published in Eur. Phys. J. ST.
[4] Electron and photon energy calibration with the ATLAS detector using 2015−2016 LHC proton−proton collision data
ATLAS Collaboration, JINST 14 (2019) no.03, P03017, https://arxiv.org/abs/1812.03848
[5] Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at s √ =13 TeV with the ATLAS detector
ATLAS collaboration, Phys.Rev. D96 (2017) no.7, 072002, https://arxiv.org/abs/1703.09665
[6] Cost Estimate for the CLD detector at FCC-ee
https://edms.cern.ch/document/2041750/1