BASKET+

Project responsibles :

Maarten BOONEKAMP, Irakli MANDJAVIDZE, Maxence VANDENBROUCKE (CEA/IRFU)

1- Research objectives

The MESA accelerator and its associated experiments constitute a major research infrastructure dedicated to the study of electron-proton scattering at low energies, including tests of the Standard Model, direct and indirect searches for dark matter, and the determination of the proton form factors. The P2 experiment [1] in particular ambitions a world-leading determination of the electroweak mixing angle, $\sin^2\theta_W$, through the measurement of the scattering cross section asymmetry at forward angles ($25<\theta<45$ deg.). The smallness of the asymmetry and the target precision ($\sim 5\times10^{-8}$, to be measured with a relative precision of 1%) imposes high beam current and a long target, for a scattering rate of about 100 GHz. At these rates event-by-event reconstruction is impossible, and the scattered signal is integrated over time intervals matching the beam helicity-flip periods.

A prominent systematic uncertainty in this measurement stems from the proton form factors, which can be accurately measured in the backward direction, where the asymmetry is large ($\sim 6\times10^{-6}$), and mostly induced by these form factors. A dedicated detector system, BASKET, is being constructed for this purpose. A part of P2, it will measure the scattering asymmetry in the region $130^\circ<\theta<150^\circ$. The expected scattering rate, ~80 MHz, allows for event-by event reconstruction in a setup based on a highly segmented, three-layer tracking detector, high-frequency front-end electronics (VMM [2]), and an intelligent back-end system (ALINX [3]) performing hit pattern recognition and electron track reconstruction online. Event-by-event reconstruction allows measuring the asymmetry as a function of the scattering angle, vertex position, beam energy loss fluctuations in the target, etc; resulting in a scientifically rich measurement with many lever-arms to control systematic uncertainties.

The performance of BASKET is at present limited by the capacity of the ALINX back-ends to treat the volume of data sent by the front-ends. Its on-board FPGA only allows the analysis of hit “triplets” from projective detector modules, based on simple timing and position cuts, with limited acceptance and efficiency, and non-negligible backgrounds.

The present proposal aims at upgrading the BASKET back-end system using a high-performance back-end board, the AMD VCK190 [4]. The interest of this board are

- data flow increased by a factor of 5-10, which allows matching hits also from non-projective detector modules, significantly increasing the measurement acceptance;
- programmable logic resources (FPGA) increased by a factor of 100, which allows the evaluation of highly complex functions. Training and using artificial neural networks online will allow BASKET to go beyond simple cuts to reconstruct tracks, with improved efficiency and reduced backgrounds.

Preliminary studies indicate a measurement acceptance increased from 130°<θ<150° to about 120°<θ<160°, improved signal counting rates and a reduction of backgrounds by about a factor of two compared to the present solution.

This project will result in an improved determination of the proton form factors, covering enhanced angular and momentum transfer domains. It will also allow better exploitation of the first data from MESA, which will be recorded at the reduced energy of 55 MeV, with a higher scattering cross section and correspondingly increased detection rates.

While BASKET+ lives in the upcoming P2 experiment, the proposed methods are of general relevance and have many applications in the mid term. Planned experiments always aim for rarer processes and/or higher precision, and DAQ systems allowing enhanced algorithmic sophistication and higher event rates will benefit a wide class of experiments and our community at large.

2- Connection to Transnational Access infrastructures

The BASKET project is a collaboration between CEA/IRFU in France and KPH at JGU in Mainz, Germany. It contributes to promoting the access to MESA and P2 by external, non-German institutes, enhancing the visibility of these infrastructures. The DAQ system envisioned here will benefit from tests with beam at MAMI, SPS at CERN, and BNL.

3- Estimated budget request

A Postdoctoral researcher or senior computing engineer, three years (DAQ/FPGA expertise)
A PhD program for the scientific exploitation of BASKET+
20 kE for travel
45 kE for three AMD boards, including one spare

4- Participating and partner institutions

Primary confirmed participants, in the context of P2@MESA:

- France : CEA/IRFU
- Germany: JGU Mainz

Interest, in the context of future experiments

- France : IJCLab (for physics experiments at PERLE), IN2P3 (general R&D on high-rate fixed-target experiments)
- Germany : DESY
- International collaborations : EPIC at eIC (BNL)

References

[1] The P2 experiment, Eur.Phys.J.A 54 (2018) 11, 208
[2] G. De Geronimo, et al, “The vmm3a asic,” IEEE Transactions on Nuclear Science, 2022.
[3] AXKU040 development board from ALINX with Kintex UltraScale FPGA
[4] AMD Versal AI Core Series VCK190 Evaluation Kit