Readout Studies for the HIKE Main Electromagnetic Calorimeter

INFN

HIKE
High Intensity Kaon Experiments

Marco Francesconi on behalf of the **HIKE MEC Calorimeter group**

F.Ambrosino[1,2], A.Antonelli[3], G.De Nardo[1,2], C.Di Donato[2,4], E. Di Meco[3,5], E.Diociaiuti[3], R.Fiorenza[1,2,6], M.Francesconi[1], R.Giordano[1,2], P.Massarotti[1,2], M.Merola[1,2], M.Mirra[1], S.Martellotti[3], M.Moulson[3], M.Napolitano[1,2], D.Paesani[3,5], I.Rosa[1,2,6], G.Saracino[1,2], I.Sarra[3], M.Soldani[3], T.Spadaro[3], G.Tinti[3]

[1]INFN Sezione di Napoli, [2]Università di Napoli "Federico II", [4]Università Parthenope, [6]Scuola superiore Meridionale
[3]INFN Laboratori Nazionali di Frascati, [5]Università di Roma Tor Vergata

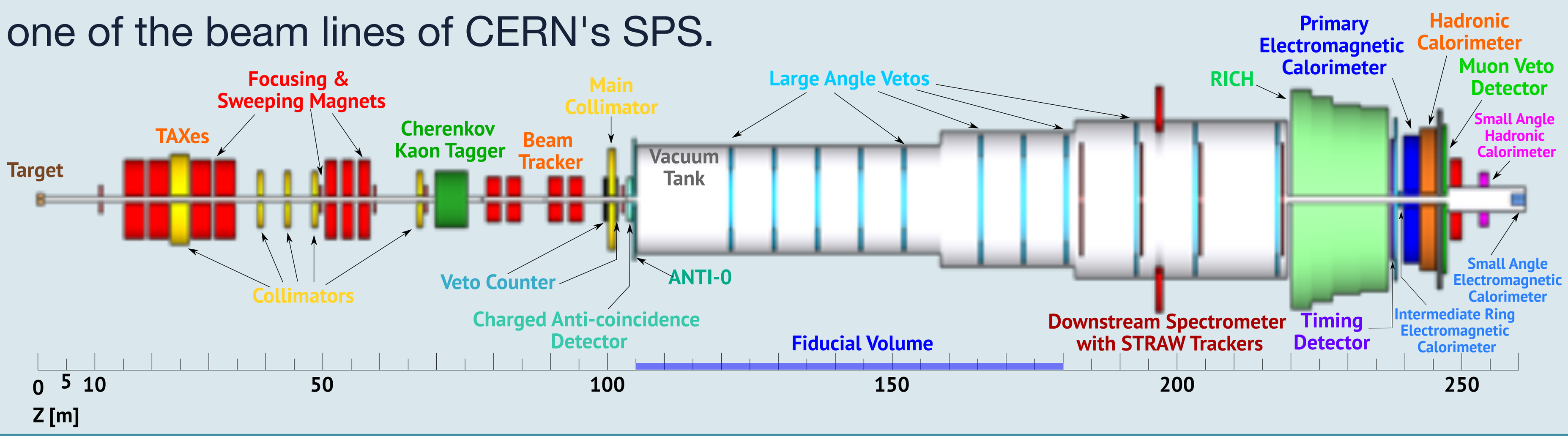
The High Intensity Kaon Experiment (HIKE)

The HIKE Experiment[1] is a proposed **future kaon experiment** ideated for one of the beam lines of CERN's SPS.

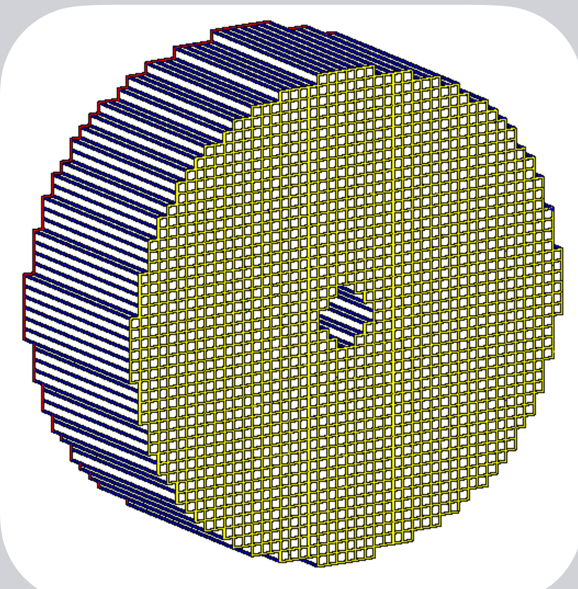
Its main goal is to improve $K^+ \to \pi^+ \nu \bar{\nu}$ Branching Ratio precision to 5%, complemented by a wide array of additional K^+ and dump physics.

The detector is based on the proven **NA62 layout** using the same $75\ \mathrm{GeV}/c$ hadron beam but at a **x4 higher beam intensity**.

A second running phase with a K_L beam is designed for complementary measurements in the neutral sector.



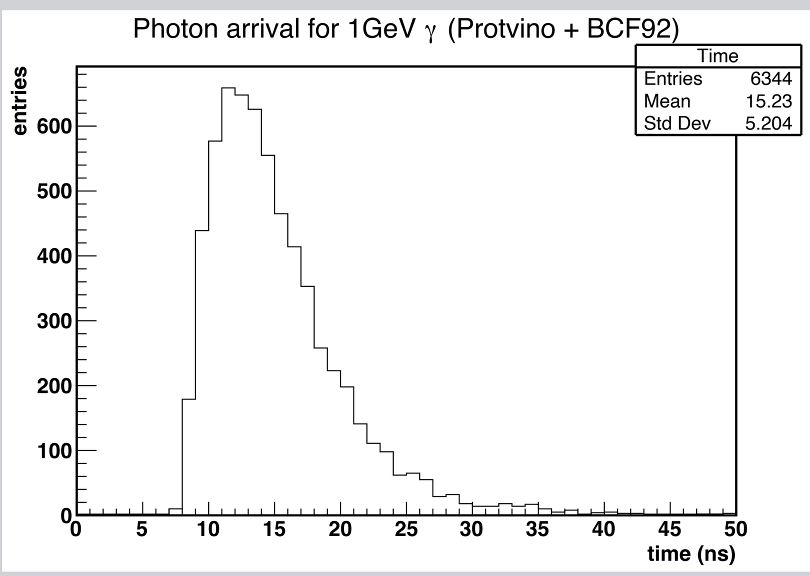
HIKE Main Electromagnetic Calorimeter (MEC)



The performances of the new detector must outclass the existing one of NA62 Liquid-Krypton calorimeter:

$$\begin{cases} \frac{\sigma E}{E} = 0.42\% \oplus \frac{3.2\%}{\sqrt{E(GeV)}} \oplus \frac{9\%}{E(GeV)} \\ \sigma_{x,y} = 0.6mm \oplus \frac{4.2mm}{\sqrt{E(GeV)}} \\ \sigma_t = \frac{2.5\ \mathrm{ns}}{\sqrt{E(GeV)}} \end{cases} \Rightarrow \sigma_t \approx 100\ \mathrm{ps} @ 40GeV$$

The major MEC requirement is **4x better time resolution** to maintain the same level of random veto.

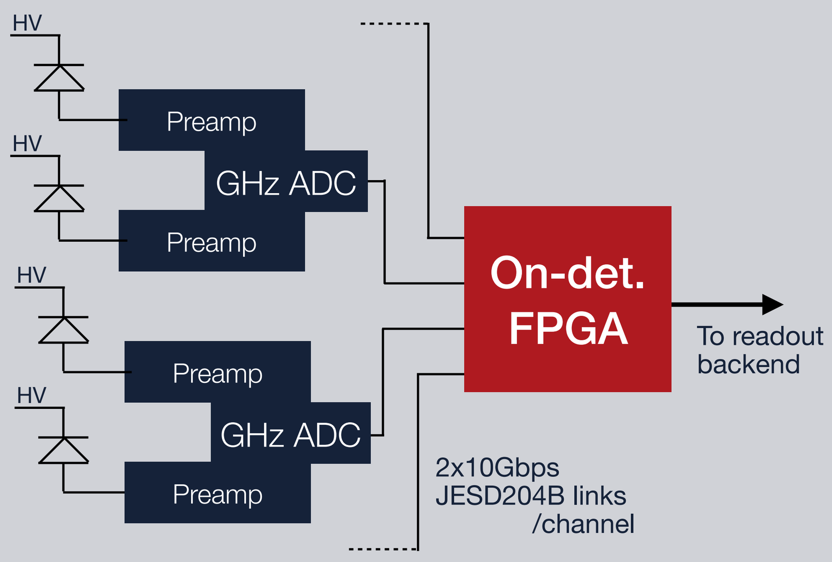


The HIKE baseline for the MEC is a **new fine-sampling shashlik calorimeter** and it will cover the radial region from 12 to 125 cm with $55 \times 55 \times 935\ \mathrm{mm}^3$ modules.

The stack is $275\ \mu$m lead - 1.5 mm plastic scintillator with fast WLS fibre (BCF-92 or YS1/YS2) for light collection, and either SiPM or PMT readout.

Preliminary Geant4 simulation of the detector shows photon arrival time with $\tau \sim 5$ ns, which requires **GHz sampling** of analog signals.

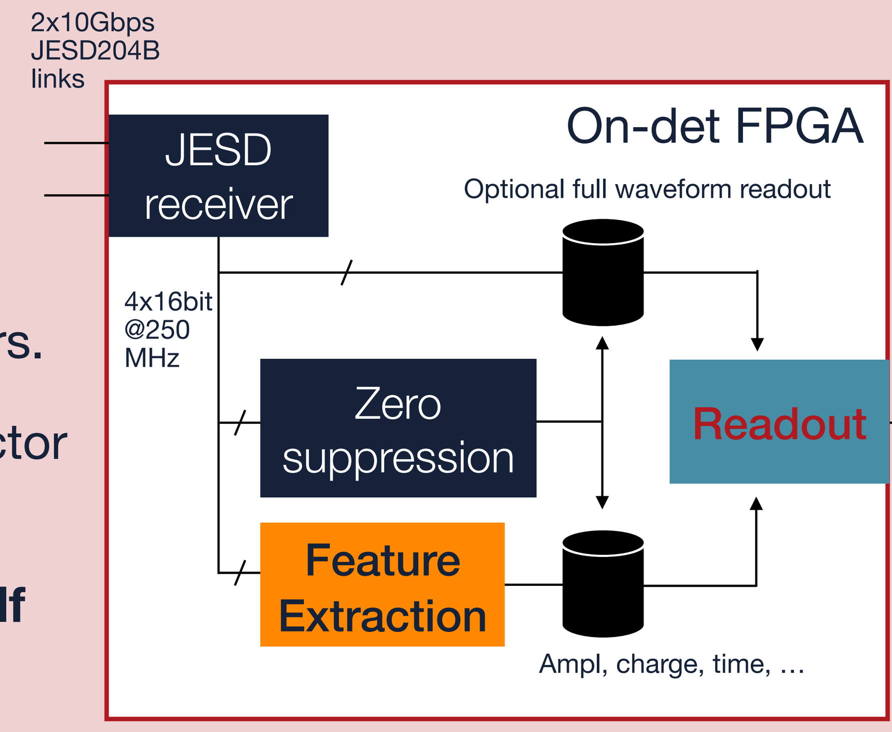
A full 3×3 cell **prototype** was funded[4] and is currently being assembled to be tested at CERN PS in October.



Benchtop Readout Prototype

The HIKE proposal included 1608 modules all equipped with 1 GSPS 14 bit ADCs, so **feature extraction** and **data reduction** is key.

For this reason **on-detector FPGAs** are expected to provide the required computing resources and aggregate data from multiple sensors.



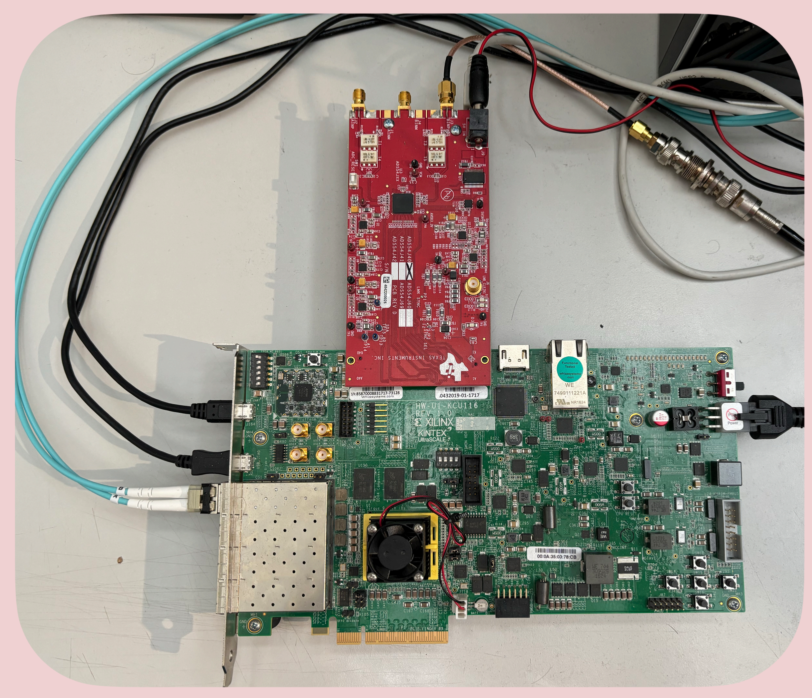
Waiting for the final detector design we focused on a readout prototype using **commercial off-the-shelf boards**.

Limited choice for ADCs:

- 2-channel Texas Instrument ADS54J40
- 2-channelAnalog Devices AD9680-1000

All using a "compatible" JESD204B interface, also future ADCs will likely have a similar output logic.

We designed a single-channel prototype, described in the following sections.



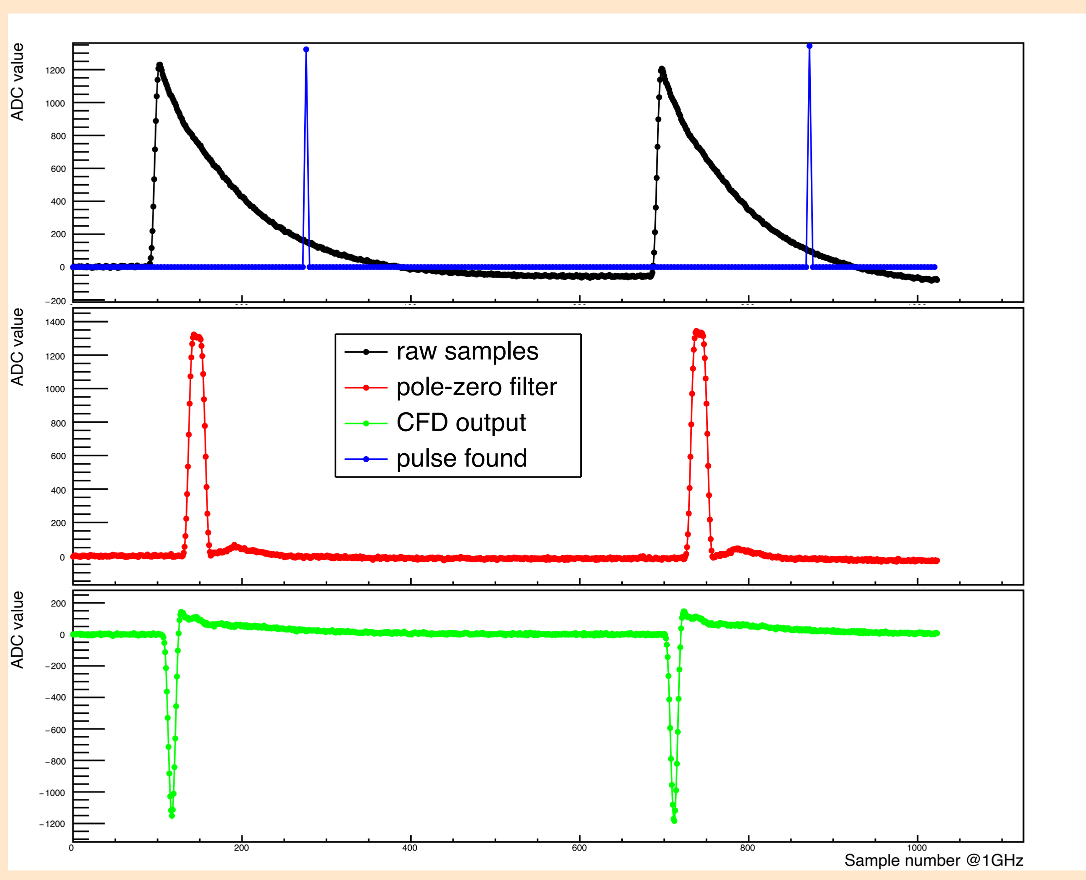
Feature extraction logic

We tested algorithms on a in **Xilinx Kintex Ultrascale+** using CAEN DT5810 and Agilent 33250A waveform generators.

With SiPM readout, falling time will be defined by detector capacitance: **pole-zero filter**[2] used to remove the tail and improve pileup identification.

The output of the shaper has, by construction, a fixed pulse length so can be used to identify event pileup.

Distribution of output has amplitude resolution below 0.5% with 1% shift due to input coupling in the evaluation board.



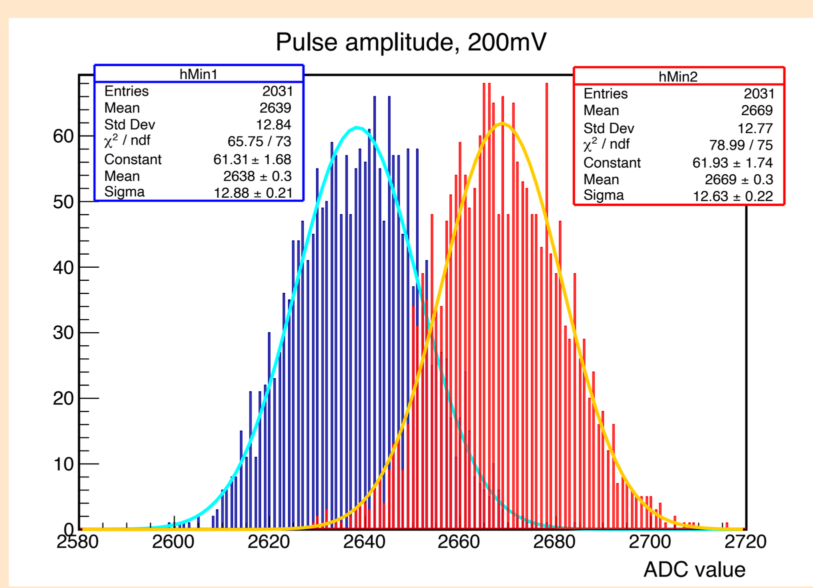
Pulse timing obtained using **Constant Fraction Discriminator** technique and Linear interpolation around zero.

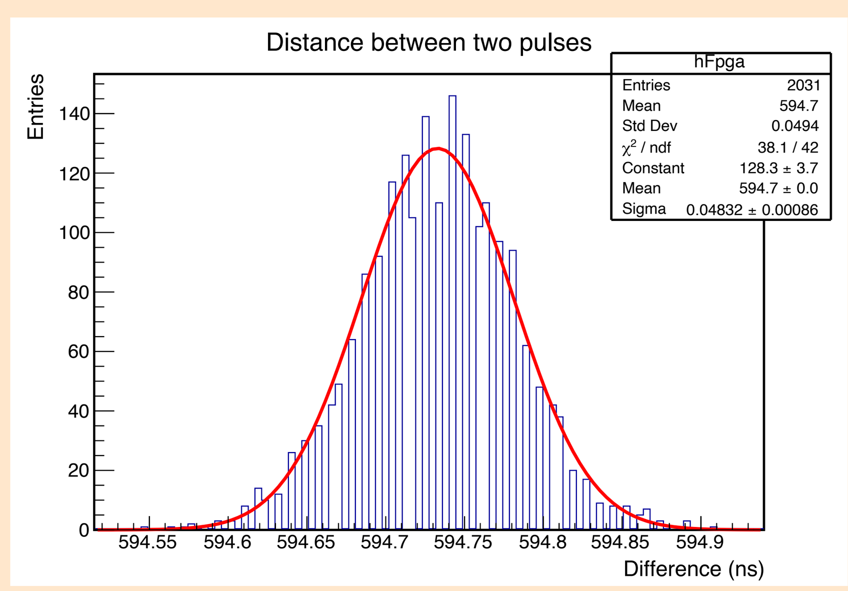
Tests with double pulse distribution from generator:

$\sigma_{t_1 - t_0} < 50$ ps

(CFD fraction 50%)

All the algorithms are fully pipelined with 4 ADC sample processed for each clock cycle.





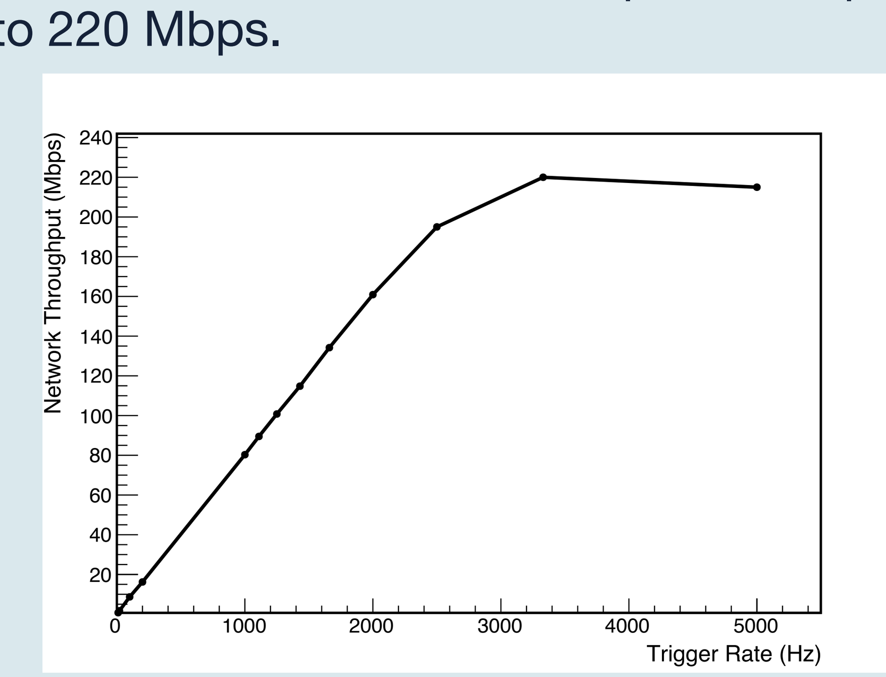
Readout

HIKE data acquisition is designed around **streaming readout** of all the detector.

However, for test beams with a limited amount of channels, an **ethernet-based readout** is preferred.

The current prototype runs on "FakerNet" [3], a TCP/IP open source interface fully embedded in FPGA paired with Xilinx 1G 1GBase-X PCS/PMA for fibre readout.

We confirmed a successful operation up to 220 Mbps.



[1] HIKE collaboration. (2023). High Intensity Kaon Experiments (HIKE) at the CERN SPS proposal for phases 1 and 2. arXiv preprint arXiv:2311.08231.
[2] Jordanov, V. T., Knoll, G. F., Huber, A. C., & Pantazis, J. A. (1994). Digital techniques for real-time pulse shaping in radiation measurements. Nuclear Instruments and Methods in Physics Research Section A, 353(1-3), 261-264.
[3] Johansson, H. T., Furufors, A., & Klenze, P. (2020). Fakernet--small and fast FPGA-based TCP and UDP communication. arXiv preprint arXiv:2003.12527.
[4] Italian PRIN prin_2022hny9jc (HetCal)