CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Ai & Particle physics
IPHU Days

11/01/2021

AIDAQ Project Info

- **A**rtificial **I**ntelligence on FPGAs: a breakthrough for **D**ata **A**c**Q**uisition in high energy physics experiments and beyond (AIDAQ)

- AIDAQ Project already started at CPPM with an A*MIDEX funding
  - Part of an international project within the ATLAS collaboration
  - 2 Staff physicists (part time), 1 postdoc and 3 students started working on this project in 2020, PI is G. AAD.

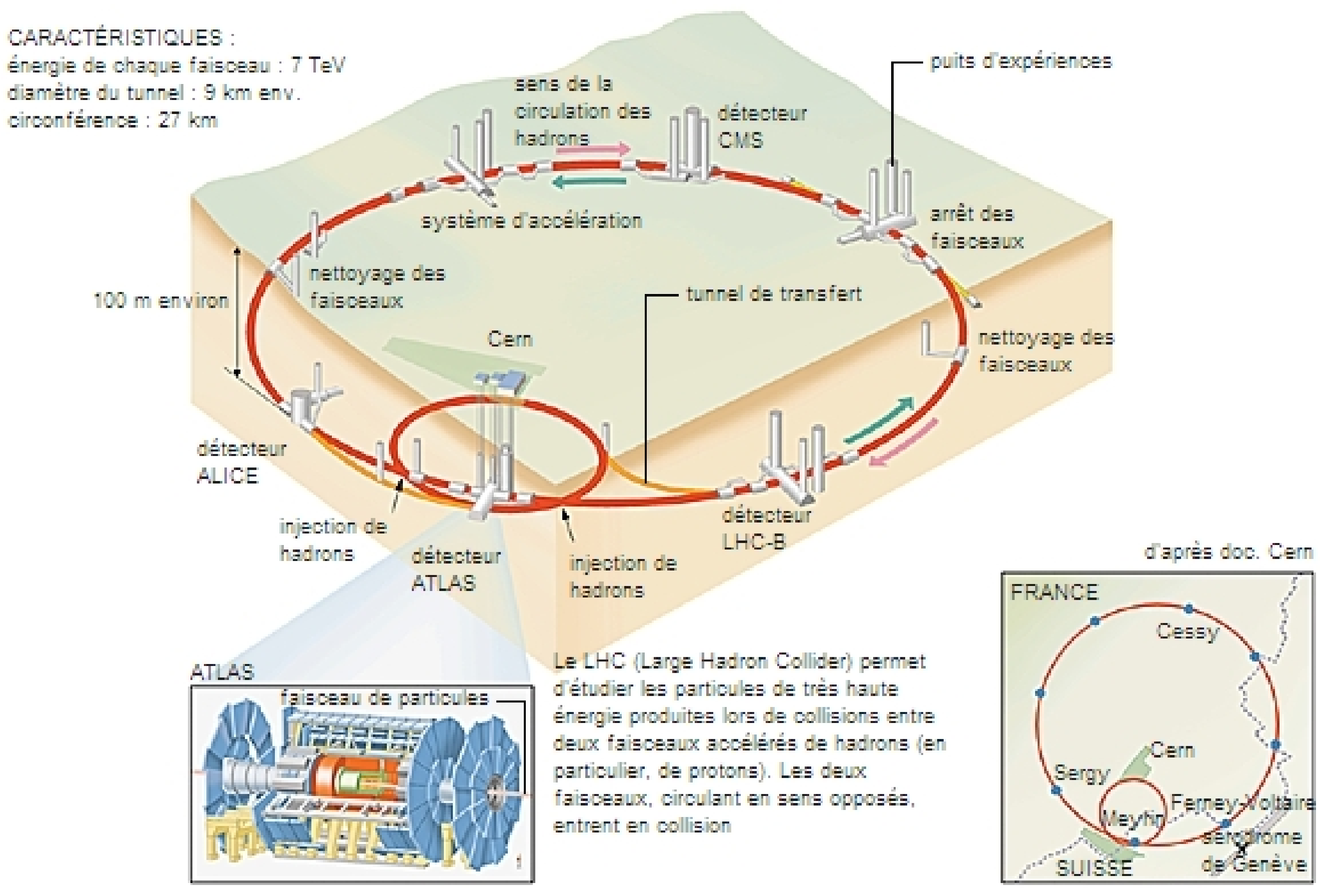
- One student funded by AMU-IPHU: Lauri Laatu

- ANR AIDAQ JCJC project, funding for a postdoc for 3 years:
  - Starting 01/03/2021

- Main goal: Implement artificial intelligence algorithms on electronic boards to improve energy computation in particle physics detectors

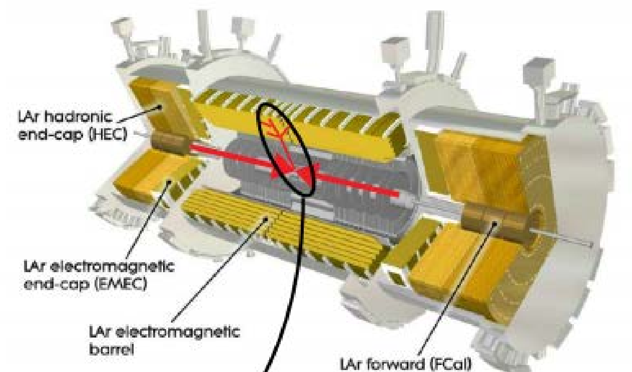
LHC and ATLAS

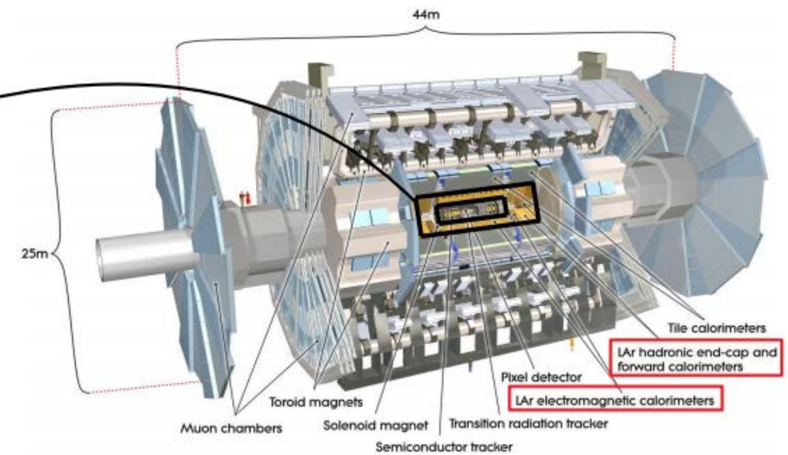
- LHC: proton-proton collider at high energy (14 Tera electron volts)
  - Allows to study the elementary structure of the universe
- ATLAS: One of the detectors studying the collisions at the LHC
  - Discovery of the Higgs boson in 2012 (Physics Nobel prize in 2013)



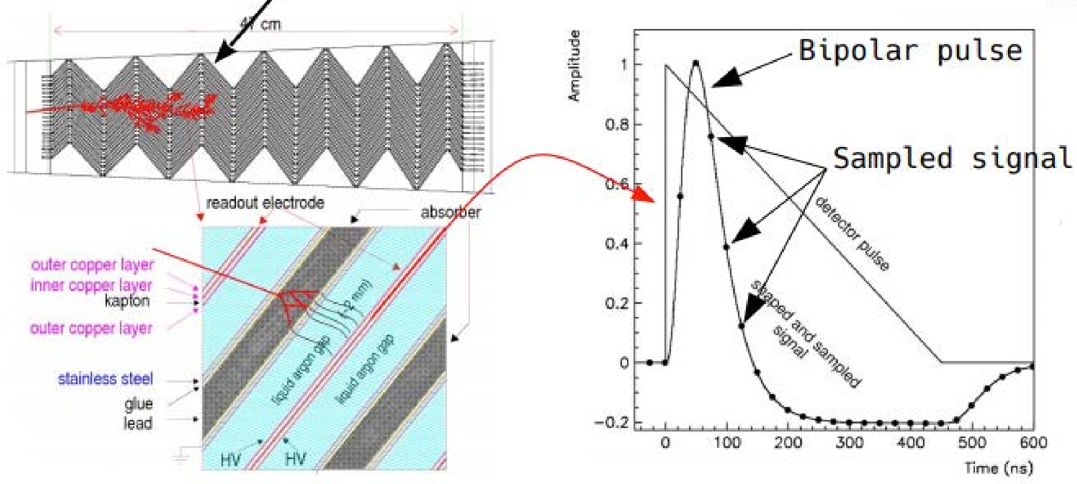
The Liquid Argon Calorimeter (LAr)

- Designed to compute the energy of particles interacting electromagnetically (photons, electrons)
- Provides trigger capabilities to reduce the data rate
  - 40 millions events per second (2 MB per event)
  - Impossible to write to disk (need to choose very fast interesting events)





180000 channels

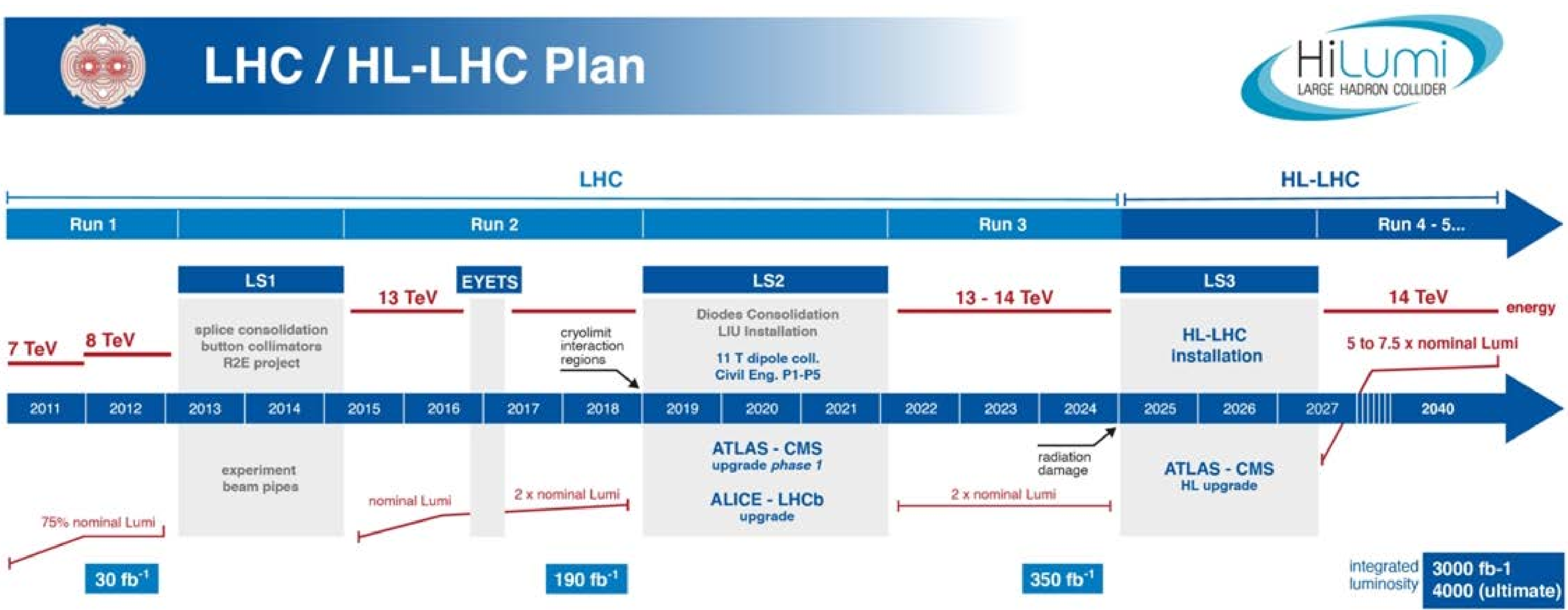


Sampled signal used to compute the deposited energy

⟶ Assume perfect pulse shape

Upgrade Plans of the LHC

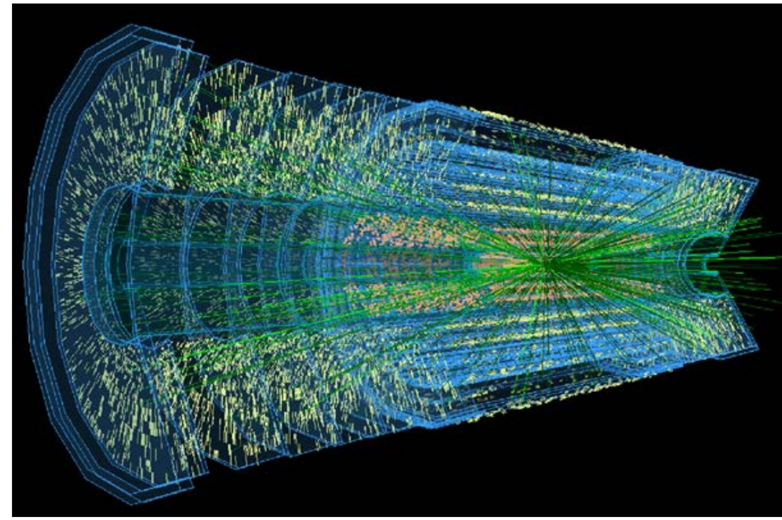
- Major upgrade of the LHC planned in 2025 (HL-LHC)
  - Multiply the rate of collisions by a factor 5
  - Major cornerstone of the European strategy for particle physics
  - Allows to discover new particles in rare events
  - Better study of the Higgs boson
- The ATLAS detector will be upgraded at the same time
  - Sustain higher radiation levels
  - Better electronics to handle the extremely high collision rate

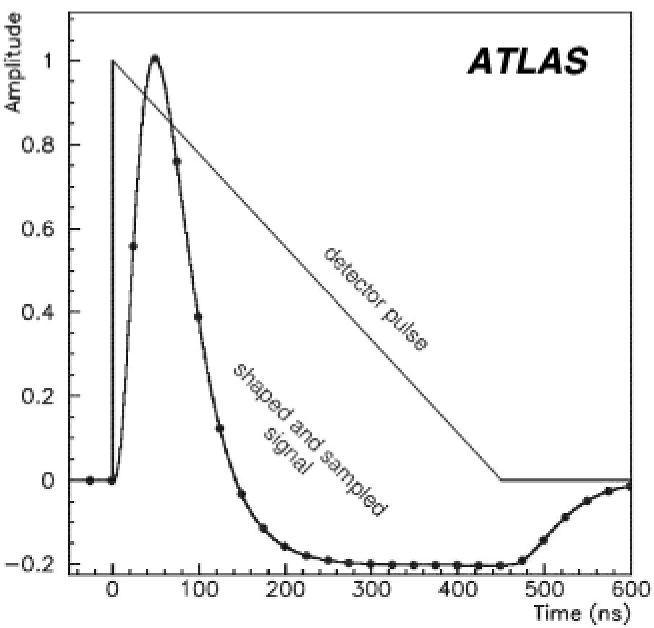


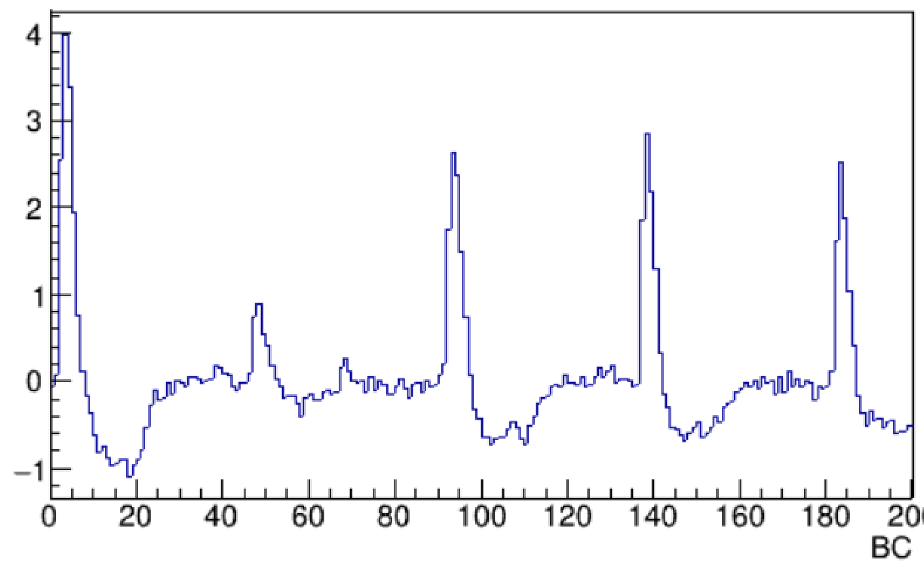
Upgrade of the LAr Electronics

- Upgraded electronics with state-of-the-art technologies
- High rate → overlapping events → distortion of the pulse shape
  - Need new algorithms to improve energy computation in these conditions

Event display of a collision at the HL-LHC



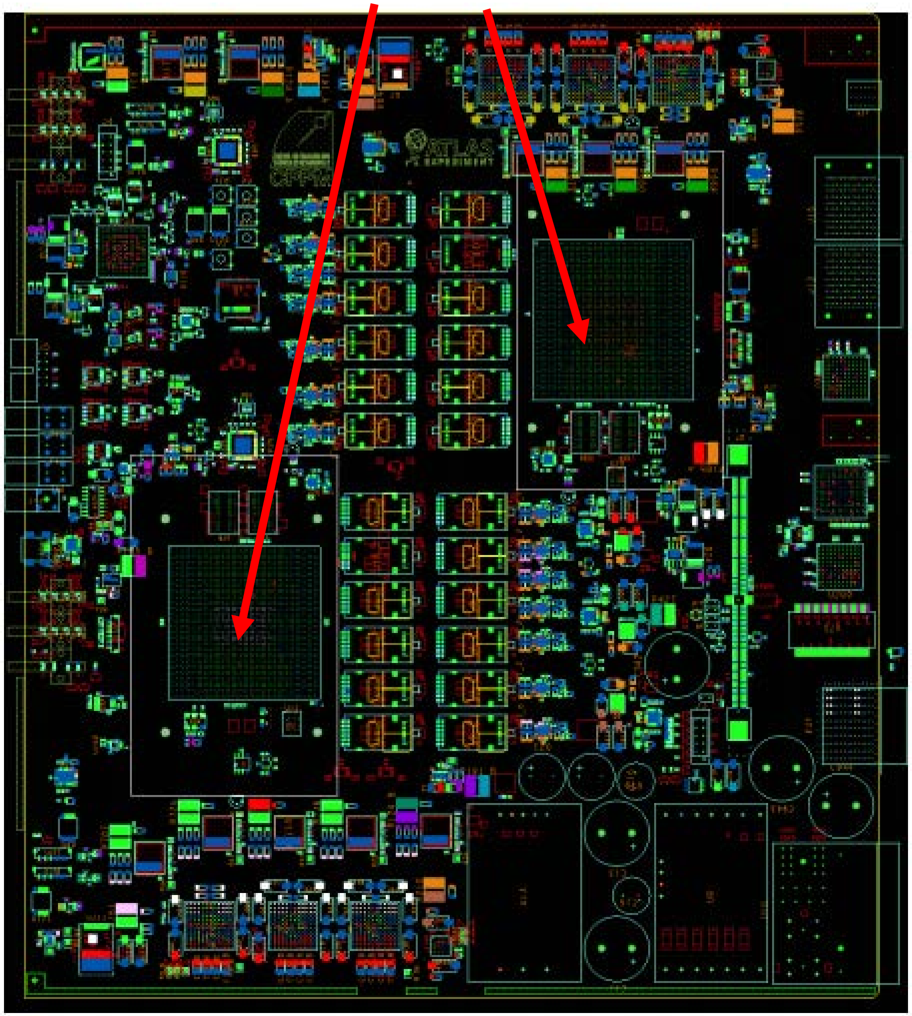




The LASP Electronic boards

- Electronic boards designed to compute the energies deposited in the LAr calorimeter
- Boards designed at CPPM
  - 200 boards to be produced
  - Already funded
- 90 input optical fibers at 10 Gb/s per FPGA
  - Process up to 2Tb/s per board
- Very fast processing
  - ~ 200 ns to compute energy
- This high rate can be only processed using FPGAs
  - Not possible with computers
- Latest generation FPGAs used
  - High computational power
  - Neural networks possible

Two High-end INTEL FPGAs per board



Goals of the AIDAQ Project

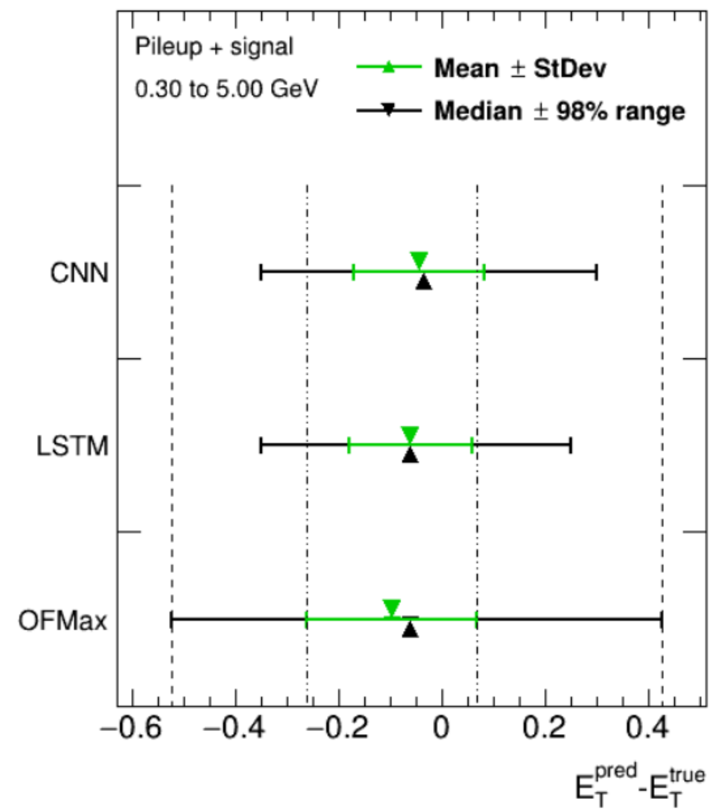
- Profit from a unique opportunity to combine the high processing rate of FPGAs with the high performance of artificial intelligence
  - Possible only recently with the increase of the computing power of High-end FPGAs such as the ones used on the LASP boards
- Main challenge: capability to fit performant and very fast neural networks into FPGAs
- Several goals
  - Improve the energy reconstructed in the LAr calorimeter
    - Develop the Neural Network architectures which is adapted to process the data from the LAr calorimeter
    - Adapt these algorithms for FPGA processing and implement them on LASP boards
  - Assess the impact of this improvement on physics analysis
  - Develop general tools allowing to automatically convert Neural Networks to firmware code that is used to program FPGAs
    - In collaboration with the HLS4ML project (CERN and other labs) and with INTEL

Project Advancement

- Working in parallel on several fronts:
  - Preparing simulation data
  - Neural Network (NN) development
  - Implementation on FPGAs

- Developing and studying the performance of NNs (Lauri Laatu IPHU PhD) (5 Talks in LAr meetings)
  - Two architecture studied: LSTM and CNN
  - Clear improvement with simulated data compared to the current algorithm (OFMax)
- First implementation with FPGA code (HLS and VHDL)
  - Quantifying the occupancy and the speed of the code

Effect on energy resolution
(L. Laatu, T. Calvet work)



Expected Results

- Implementing advanced algorithms (NNs) on the LASP boards to improve the energy reconstruction within ATLAS
    - First usage of NNs in particle physics to process raw detector data at high speed
- Development of a general tool to automatically convert neural networks to firmware code implementable on FPGAs
    - Several network architectures for INTEL FPGAs
- Prospects for implementing NNs in future particle experiments with high speed processing at trigger level
    - Improve drastically trigger capacity that rely currently on very simple algorithms
- Prospects for industrial applications outside the particle physics field
    - Partenariat with INTEL and NexVision (Marseille company specialized in electronic reference design)
    - Civil security applications, autonomous driving, ...