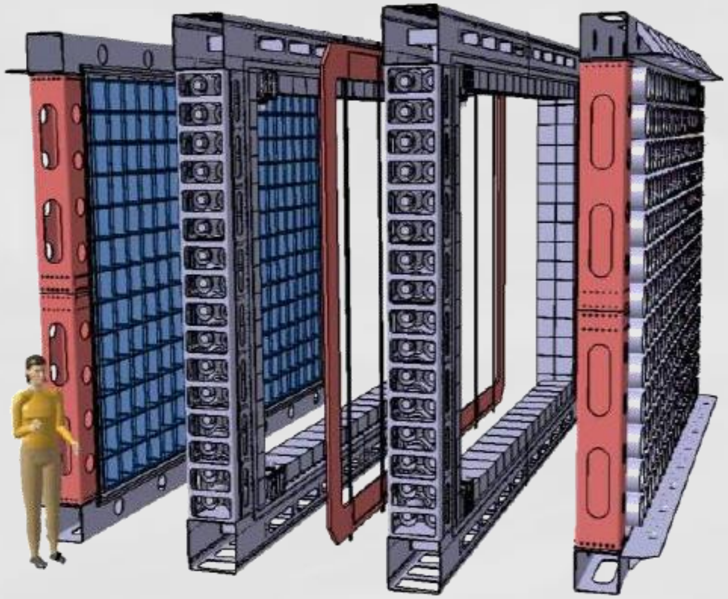
Trigger Architecture of the SuperNemo Experiment

Jihane Maalmi,

CNRS/IN2P3/LAL Orsay,

on behalf of SuperNemo Collaboration

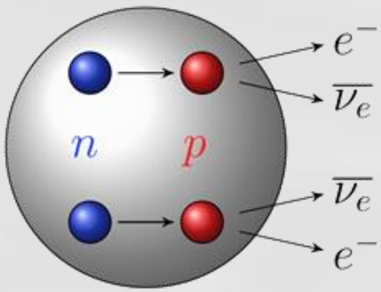


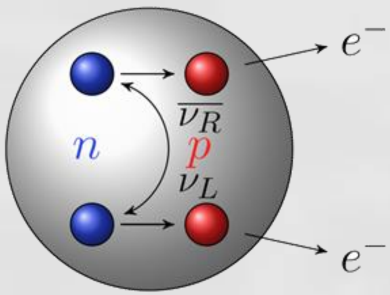
SuperNemo Physics Goal

Goal : Search for neutrinoless double β decay (2β0ν) which will prove that the neutrino is its own anti-particle (Majorana Particle)

2β2ν processus

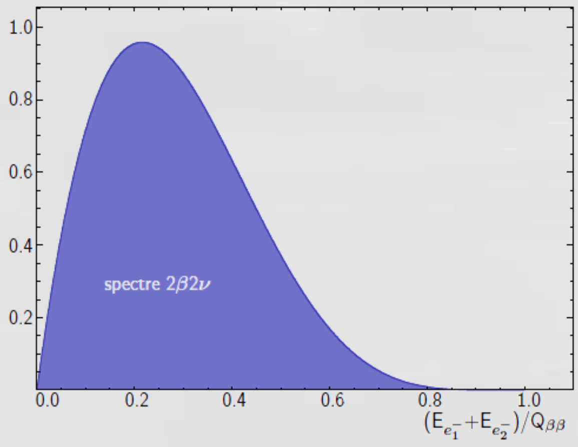
2β0ν processus

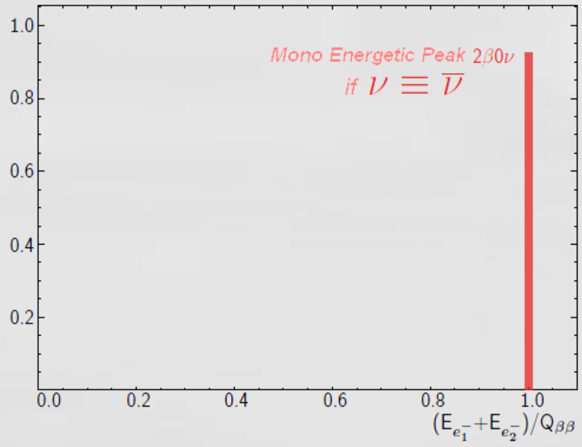


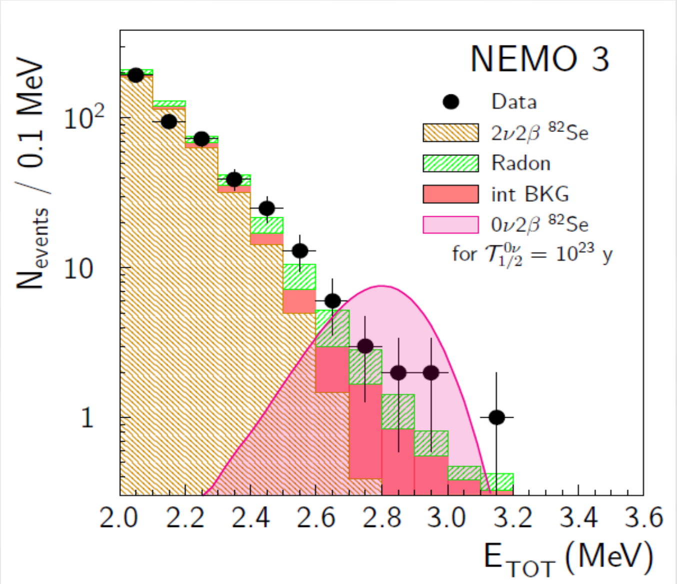


An ideal "*2β0ν experiment*" should:

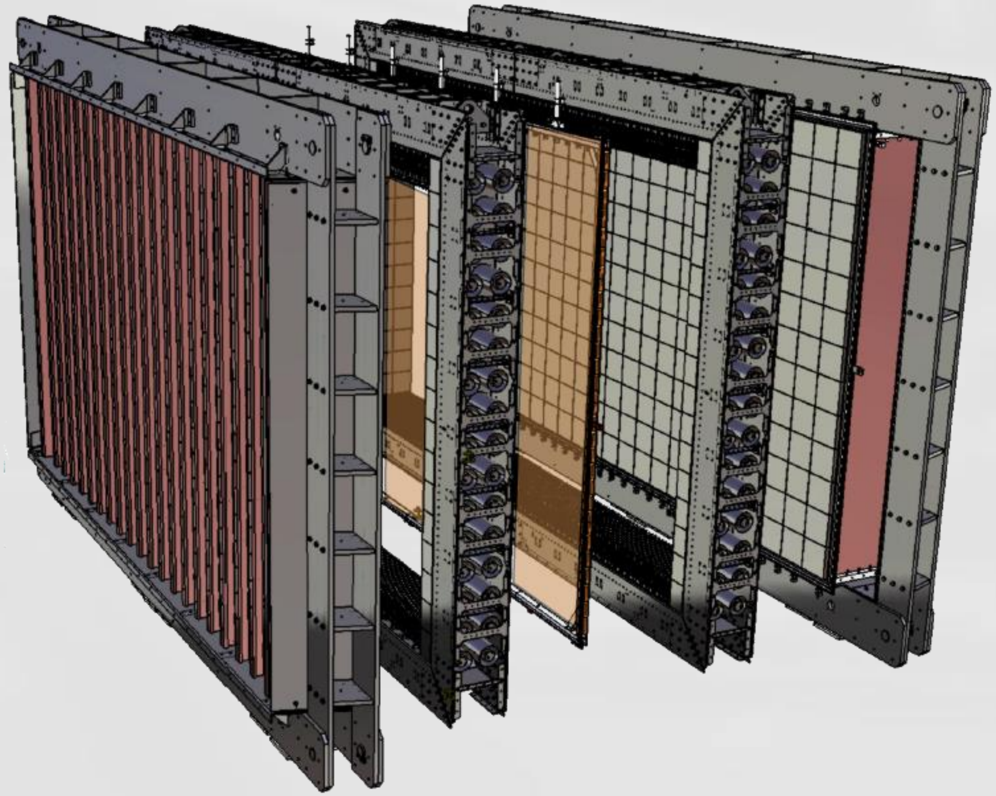
- Measure precisely the energy of the emitted electrons
- Identify individually all emitted particles





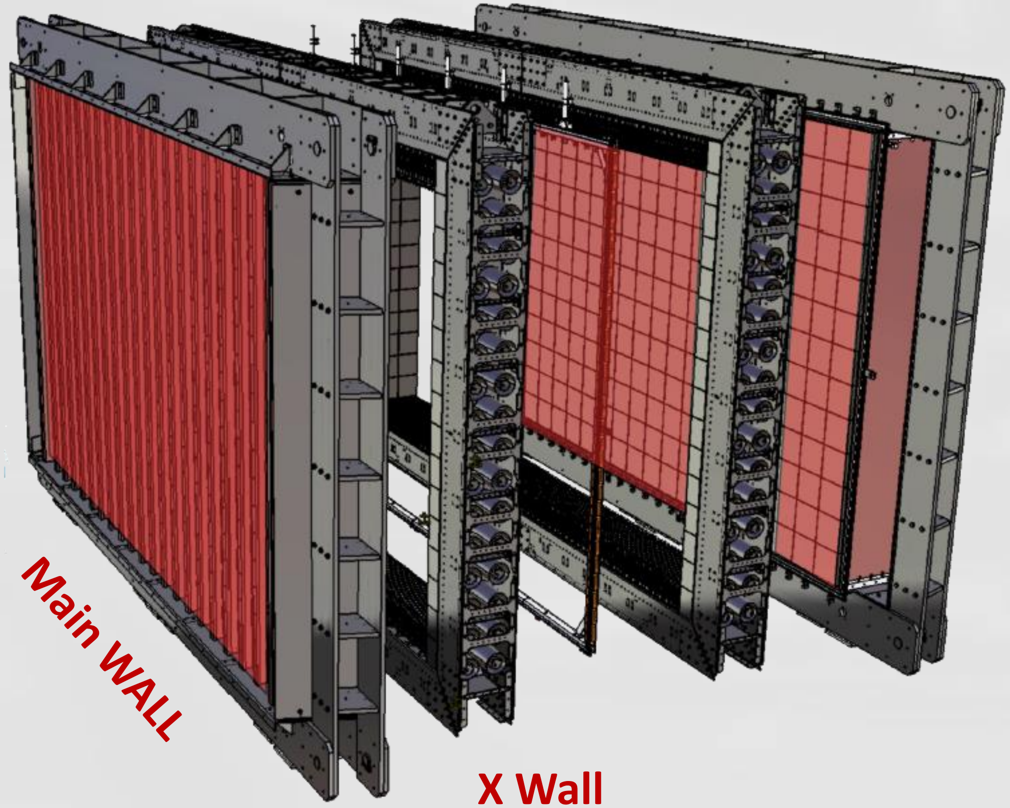


SuperNemo Detector Module



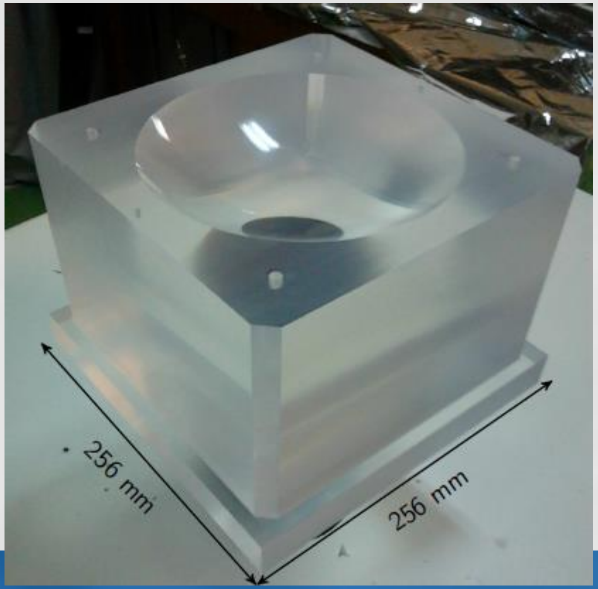
Source Foil of a ββ emitter: 7 kg of ^{82}Se (d= 53mg/cm^2)

SuperNemo Detector Module



Source Foil of a ββ emitter: 7 kg of ^{82}Se (d= 53mg/cm^2)

Calorimeter : 520 x 8'' PMTs + 192 x 5'' PMTs coupled with cubic Polystyrene Scintillators



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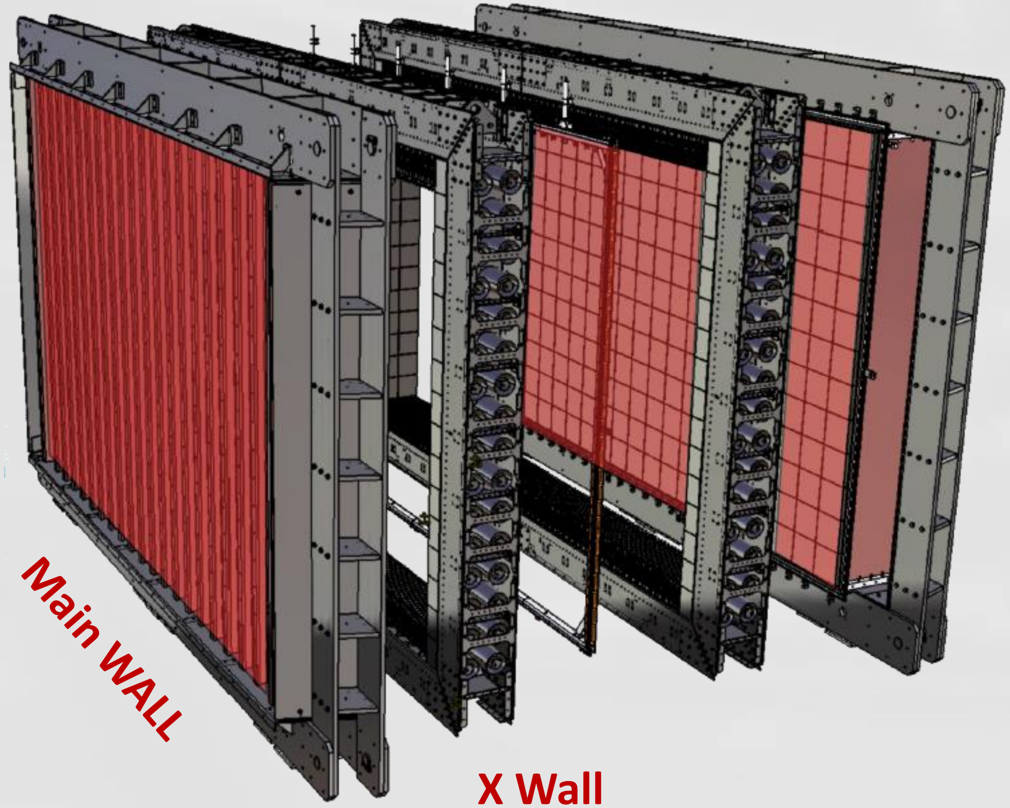

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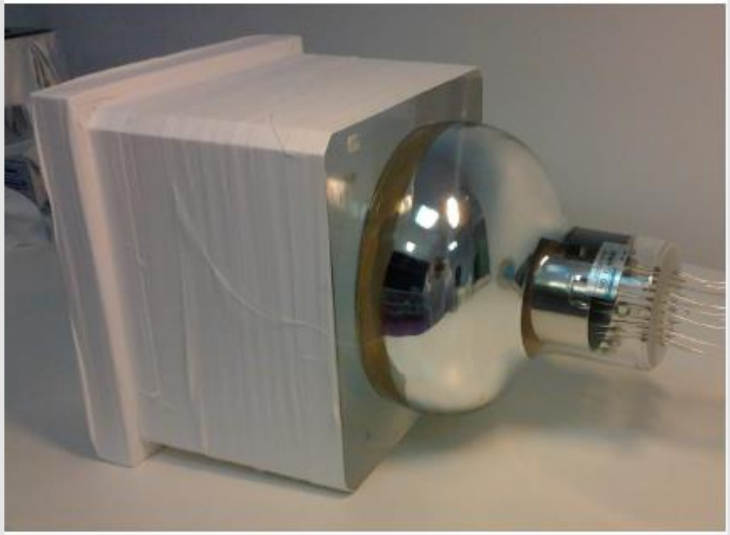

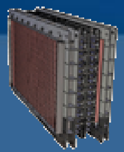

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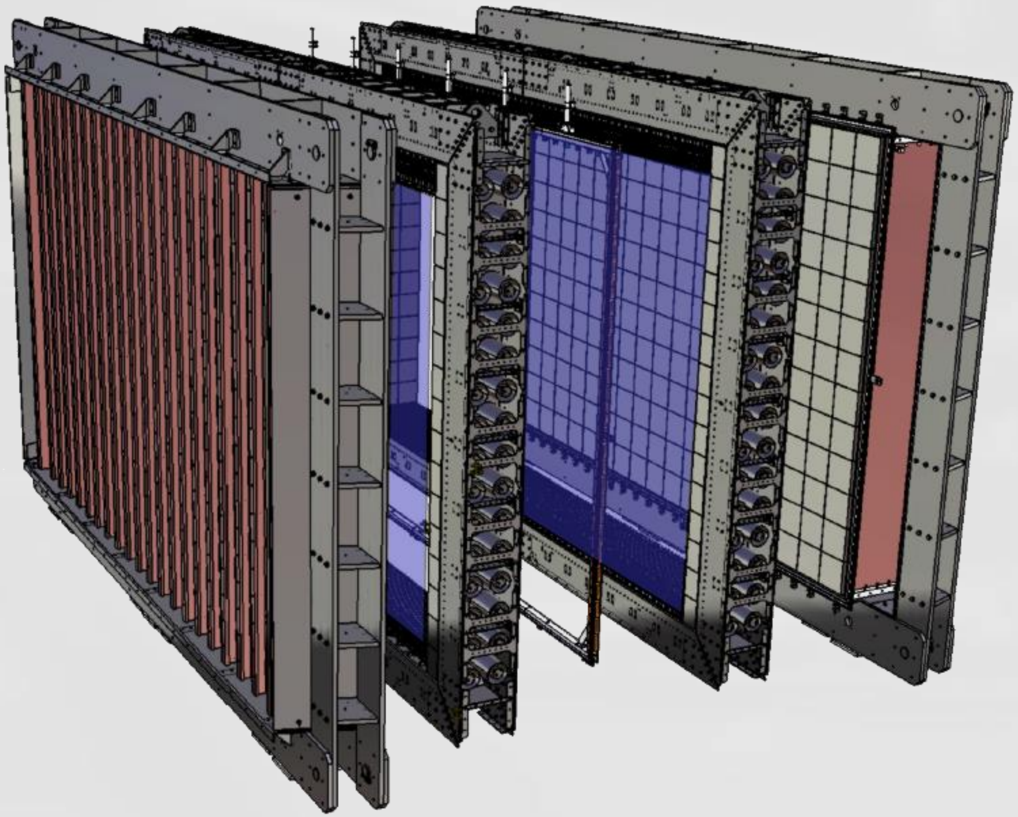
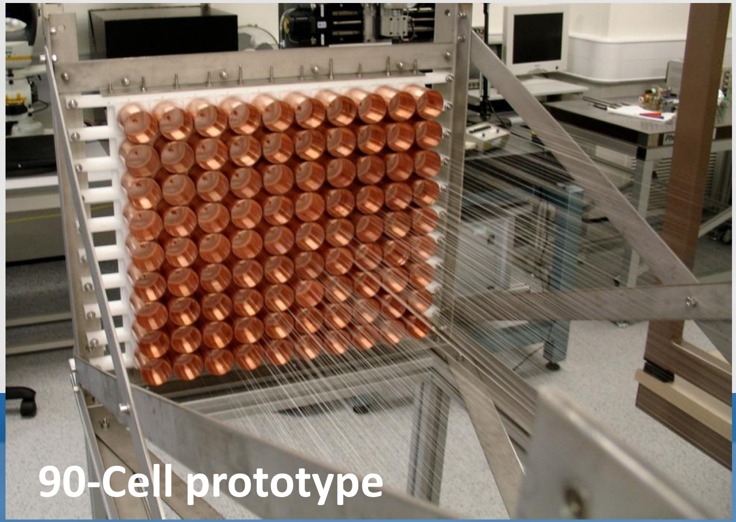


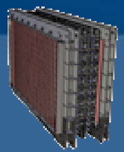
Source Foil of a ββ emitter: 7 kg of ^{82}Se (d= 53mg/cm^2)

Calorimeter : 520 x 8'' PMTs + 192 x 5'' PMTs coupled with cubic Polystyrene Scintillators

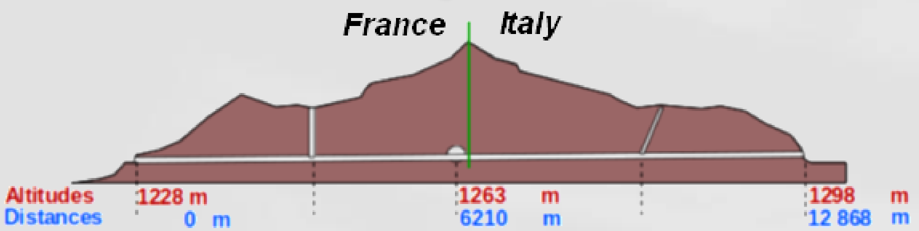
Tracker : array of 2034 vertical Geiger Cells



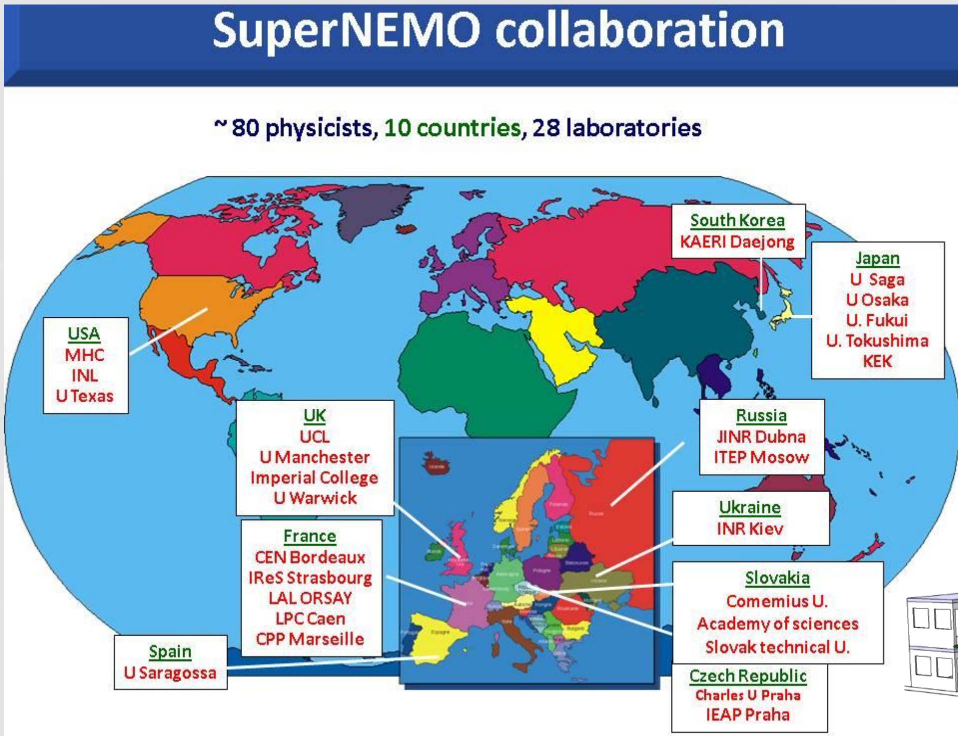
90-Cell prototype



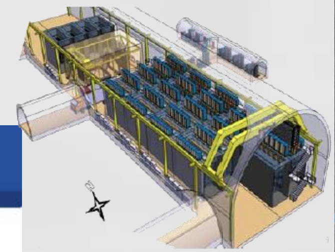
SuperNemo Collaboration

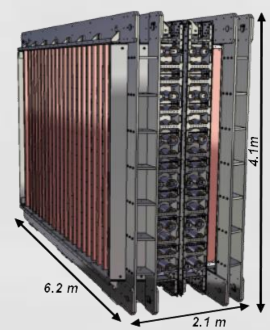


under 4800 m of water equivalent!

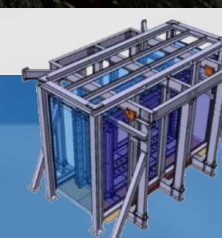


LSM extension:
Location for SuperNemo
20 Modules

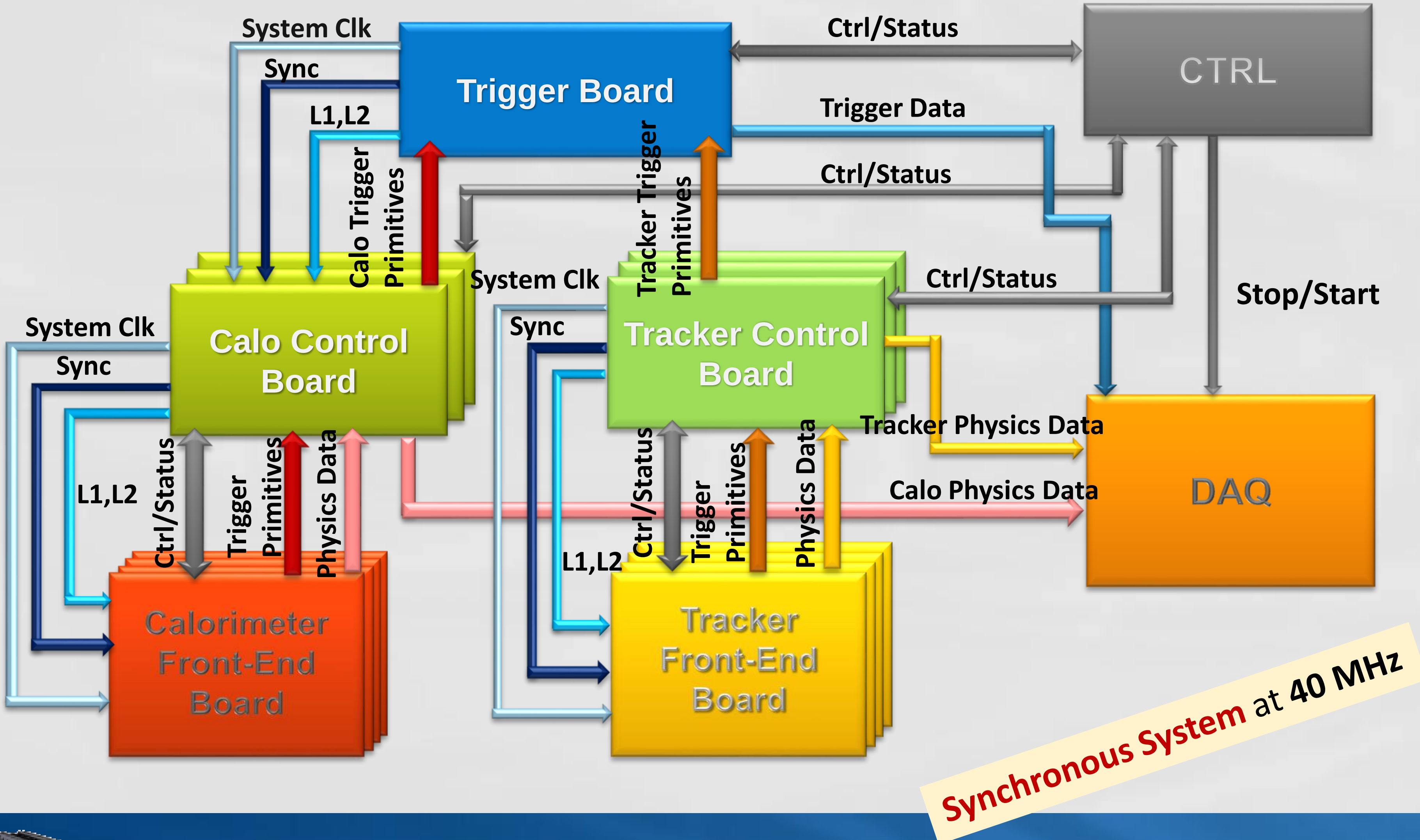




Actual LSM Lab :
Location for the
Demonstrator
Module



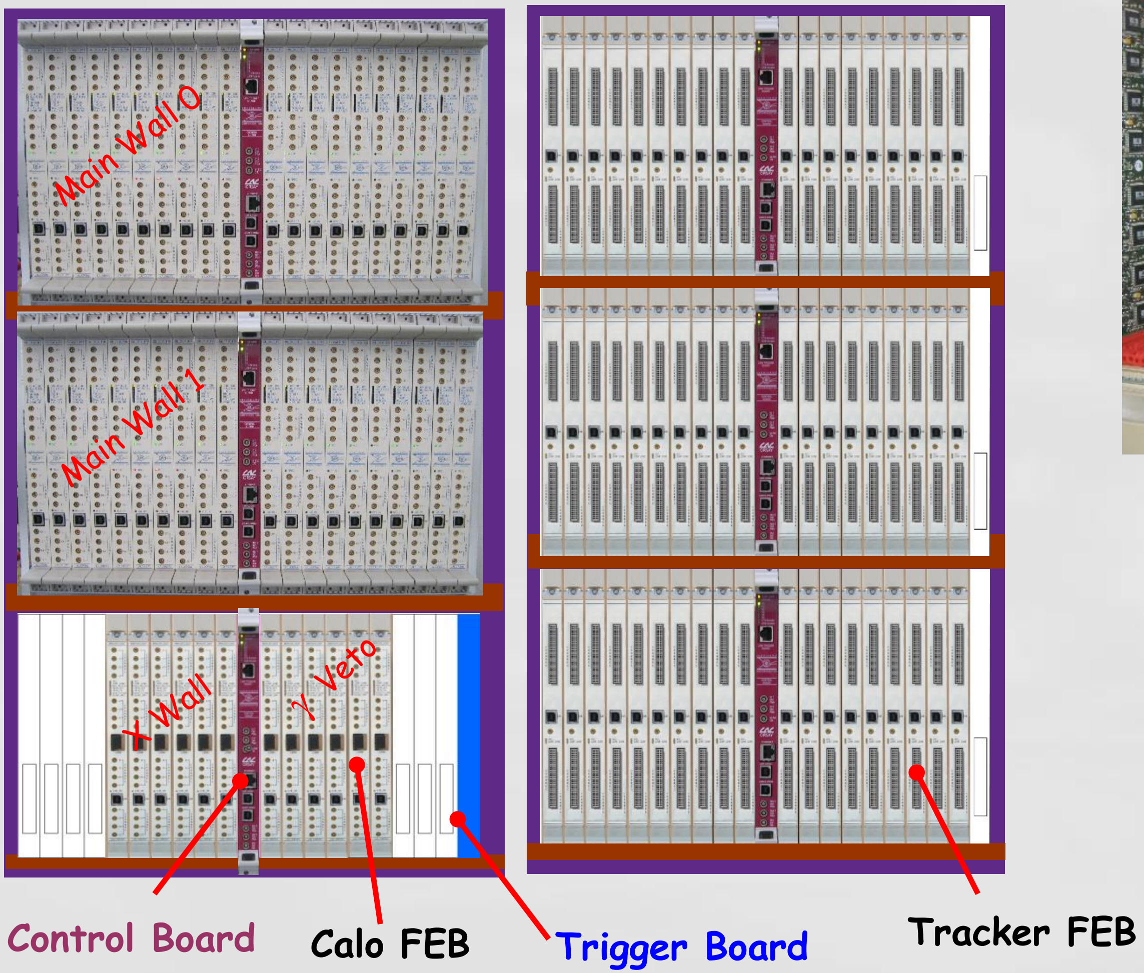
Electronics General Architecture

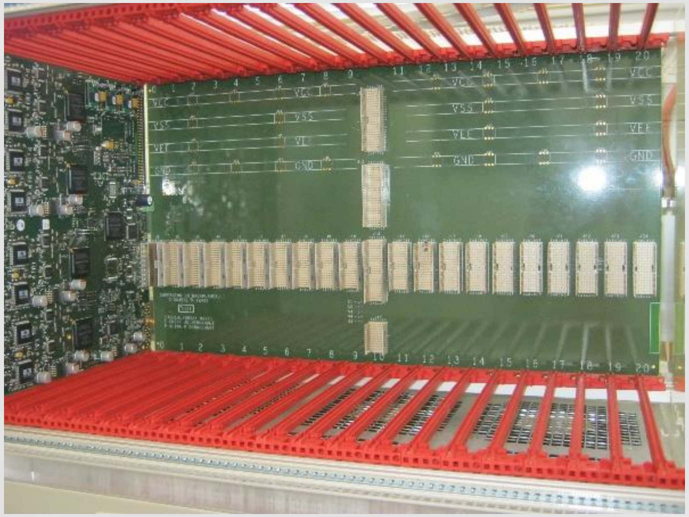


Physical Implementation

Calorimeter rack (3 crates)
712 Channels

Tracker rack (3 crates)
6102 Channels

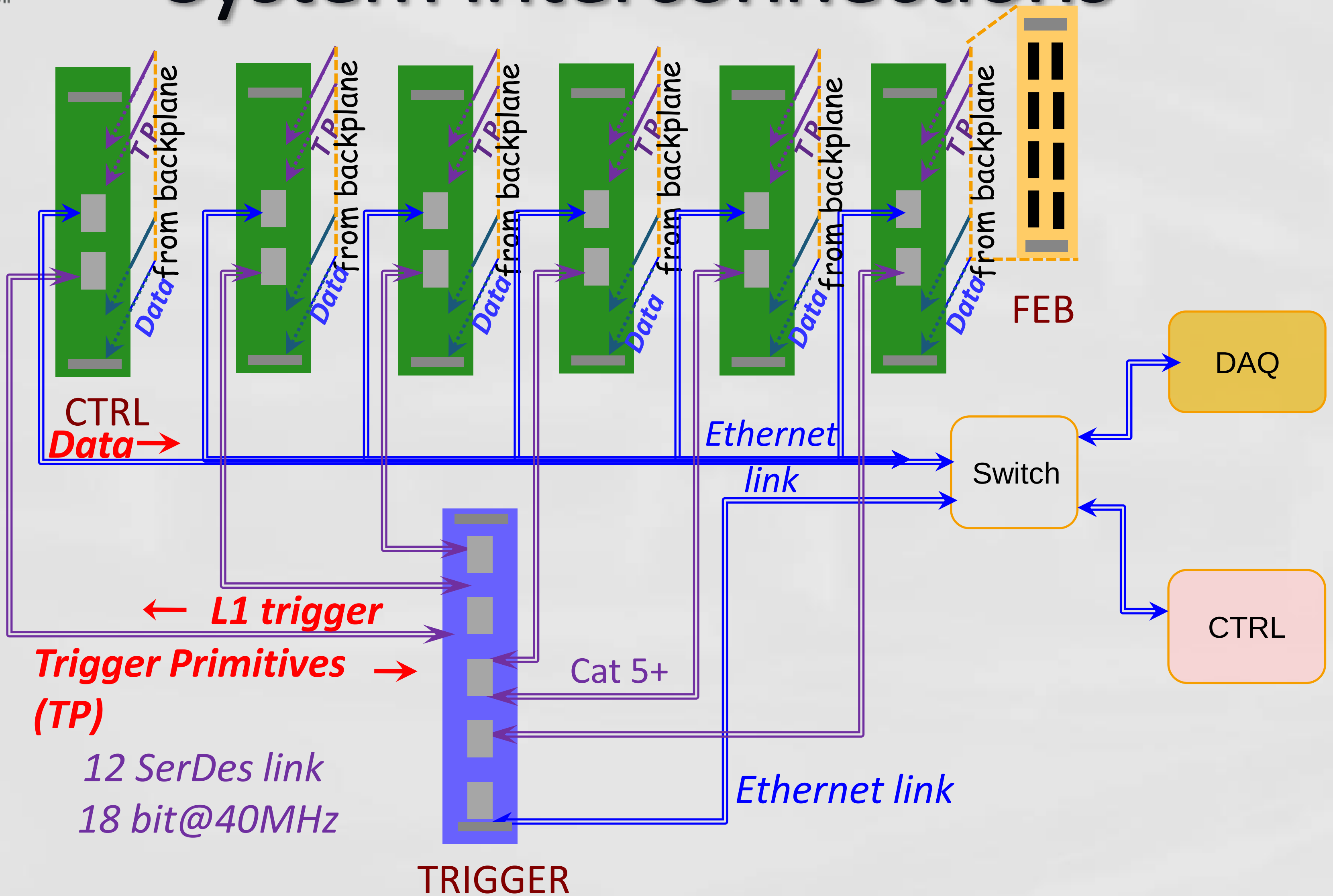




Custom Backplane for:

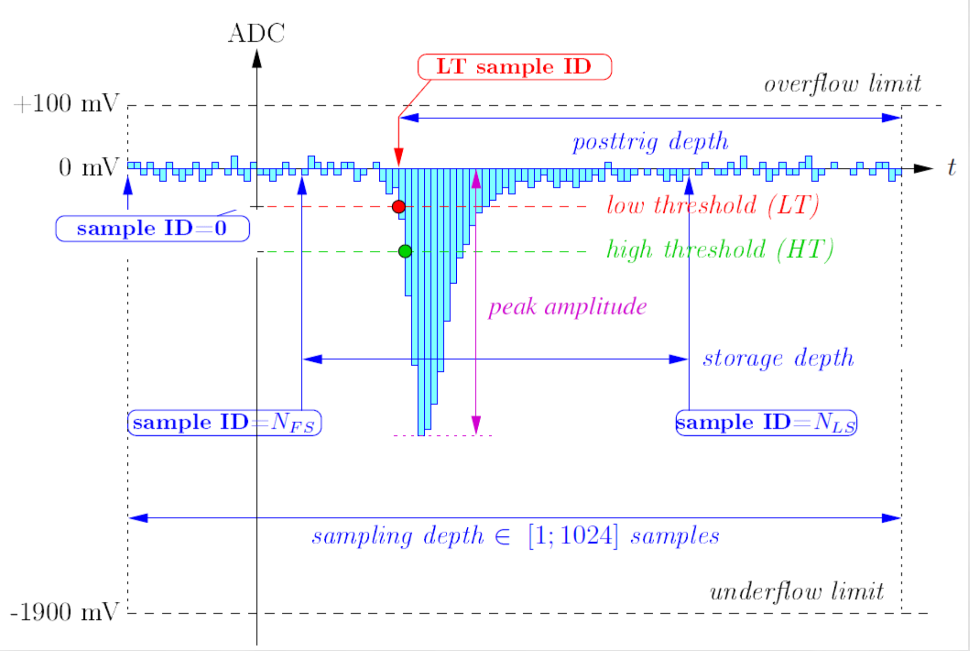
- **Clock distribution** (point to point)
- **Sync signal** (point to point)
- Rx/Tx **serialized links** (18 bits x 40 MHz)
- **Firmware Configuration**

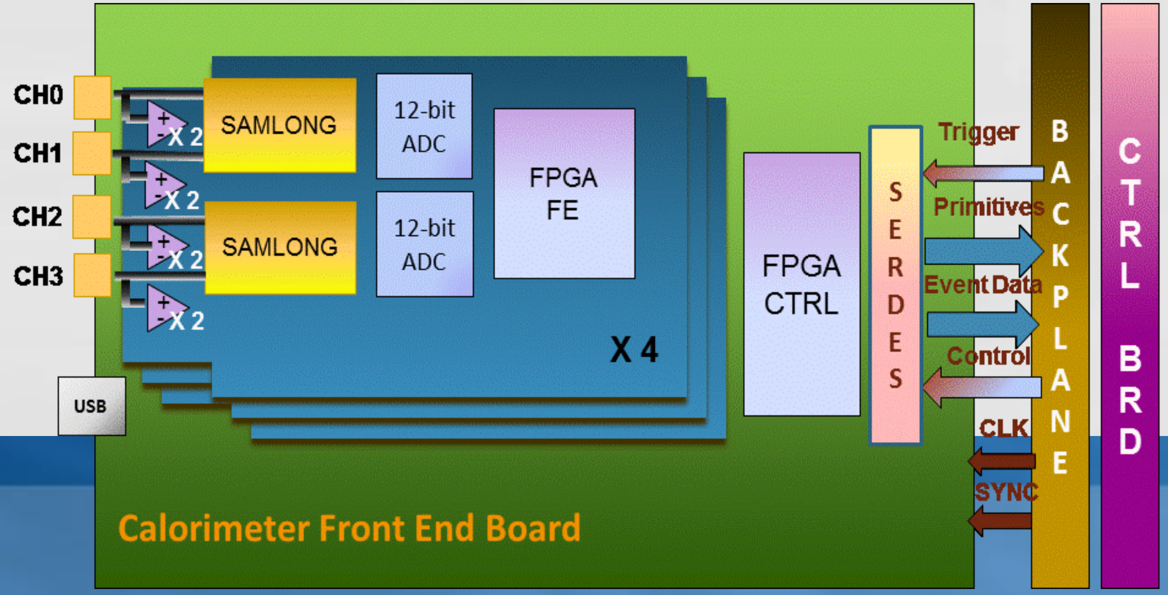
System Interconnections

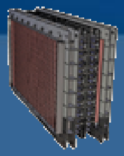


Calorimeter Front End Board

- The board is a **16-channel waveform digitizer** based on the **SAMLONG** ASIC running at **2.56 GS/s**. It permits recording a signal depth of 1024 samples and converting data over 12 bits.
- Data is time tagged at a **few ps rms**.
- There are **two different thresholds** on signal, which will be used to open gates for the calorimeter **trigger primitives**.
- Each channel includes a firmware block in charge of performing an **exhaustive signal feature extraction.**
- Selected segments of waveforms can also be sent to DAQ.

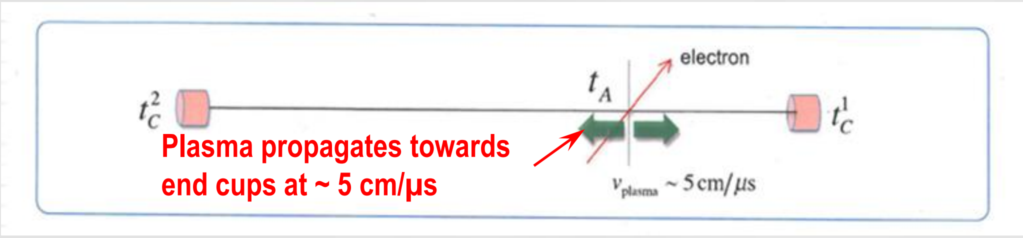


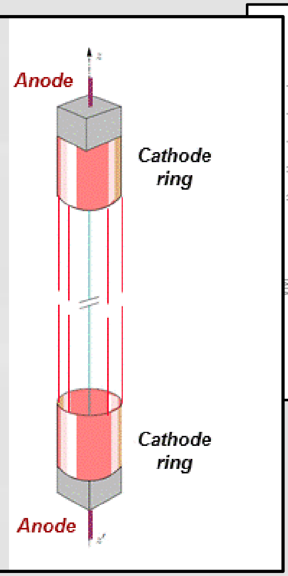


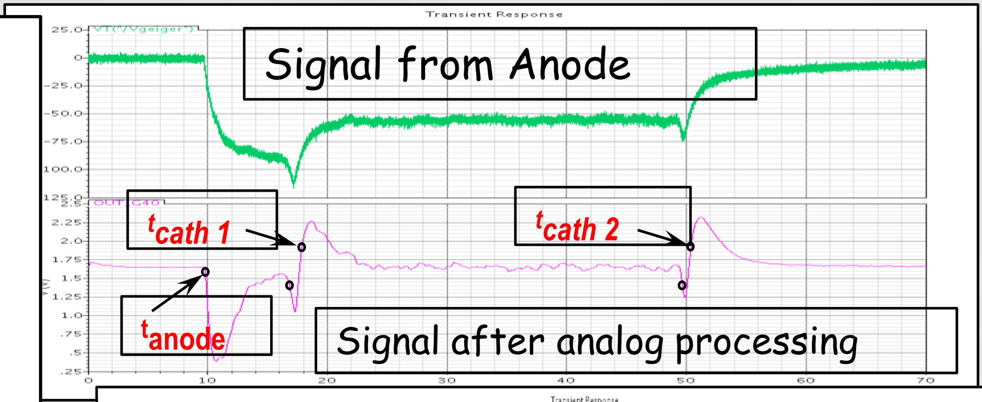


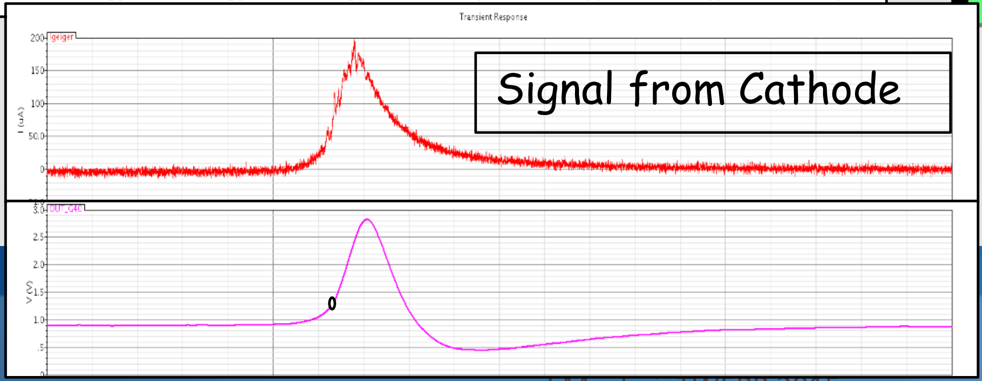
Tracker Front End Board

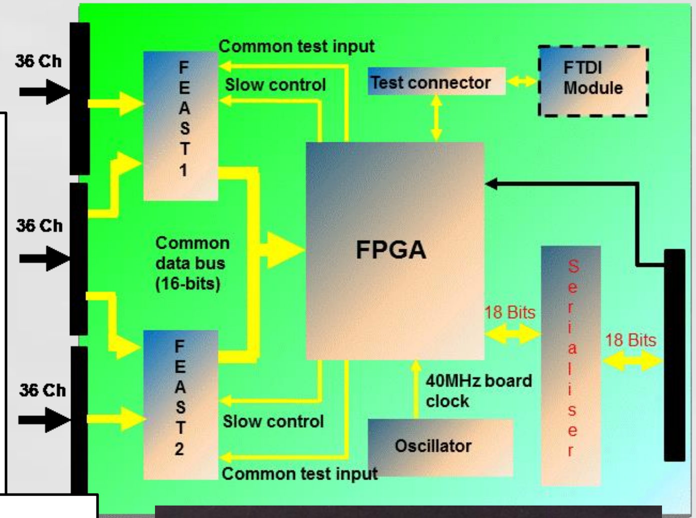
- The board houses **108 channels** which can be shared in groups of 2 (Anode + 1 Cathode) or 3 (Anode + 2 Cathodes).
- It is based on a pair of **custom ASICs** called **FEAST** which extract all the **timing information** from the anode and cathode signals (**analog treatment** + **80-MHz TDC**). They also prepare the seeds for the tracker trigger primitives.

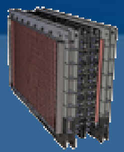






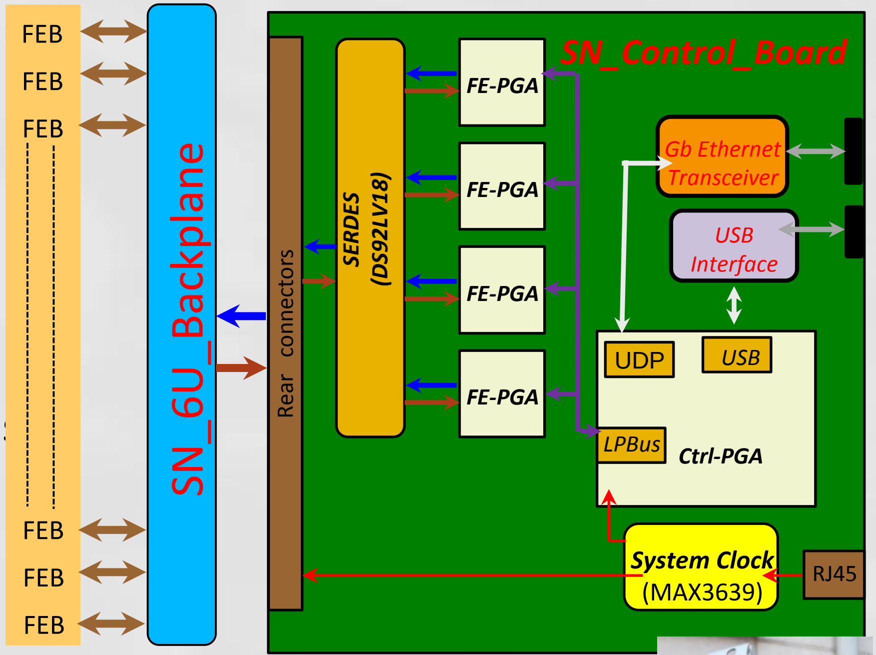


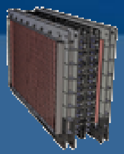




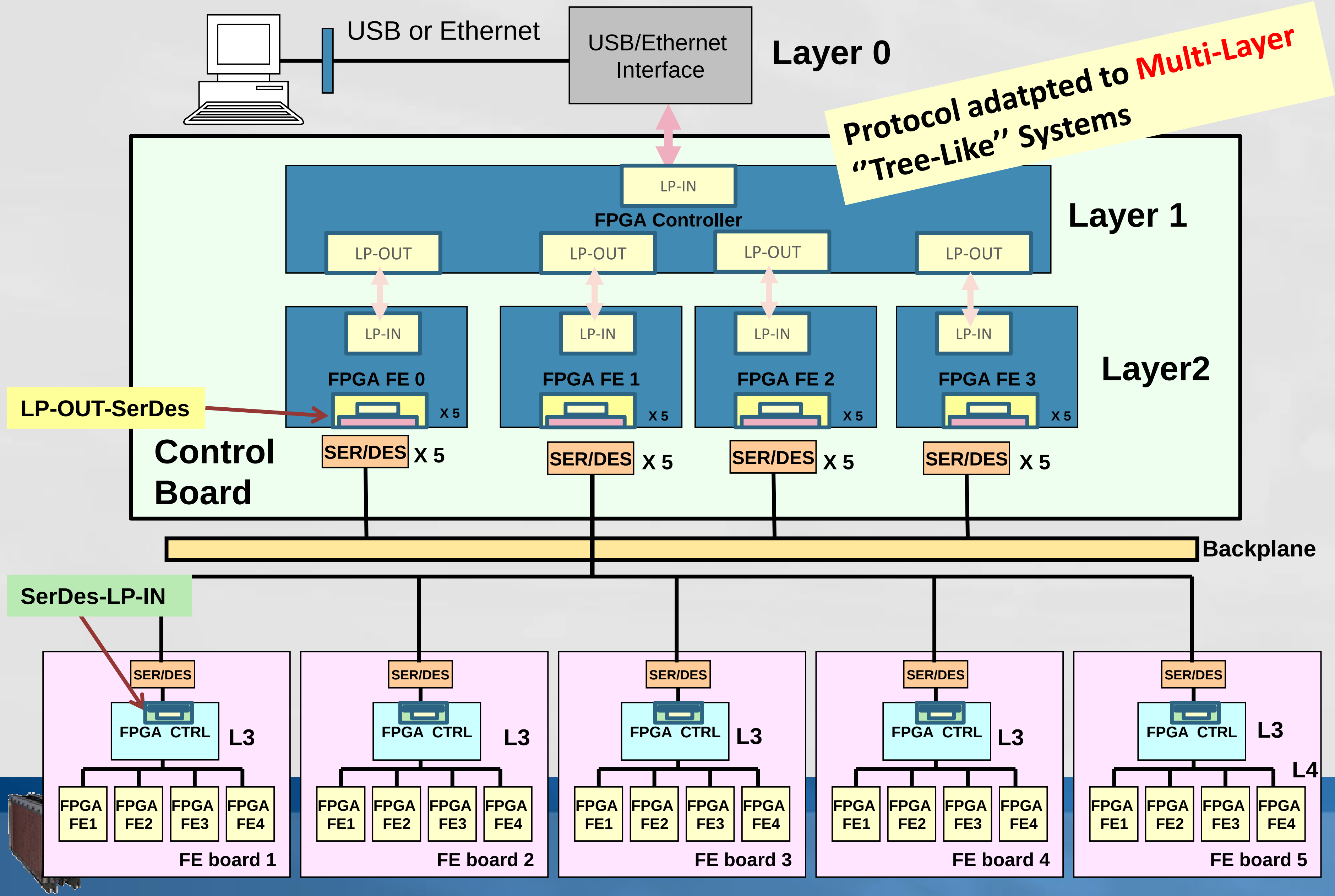
Control Board

- The Ctrl Board is in charge of **controling** and **reading** out the crates.
- It distributes:
  - The **40-MHz clock** to the FEBs
  - The **Sync signals**
  - The calorimeter and tracker **trigger decisions** (L1,L2)
  - The **serial control links towards** the FEB
  - The signals for FEBs' **FPGA re-configuration** (via its dedicated USB interface)
- It gathers the **serial data links from** the FEBs.
- It builds the **crate Trigger Primitives.**
- Via its single **Gbit-UDP interface**, physics data is sent to **DAQ** whereas control data is sent to **Control System**.

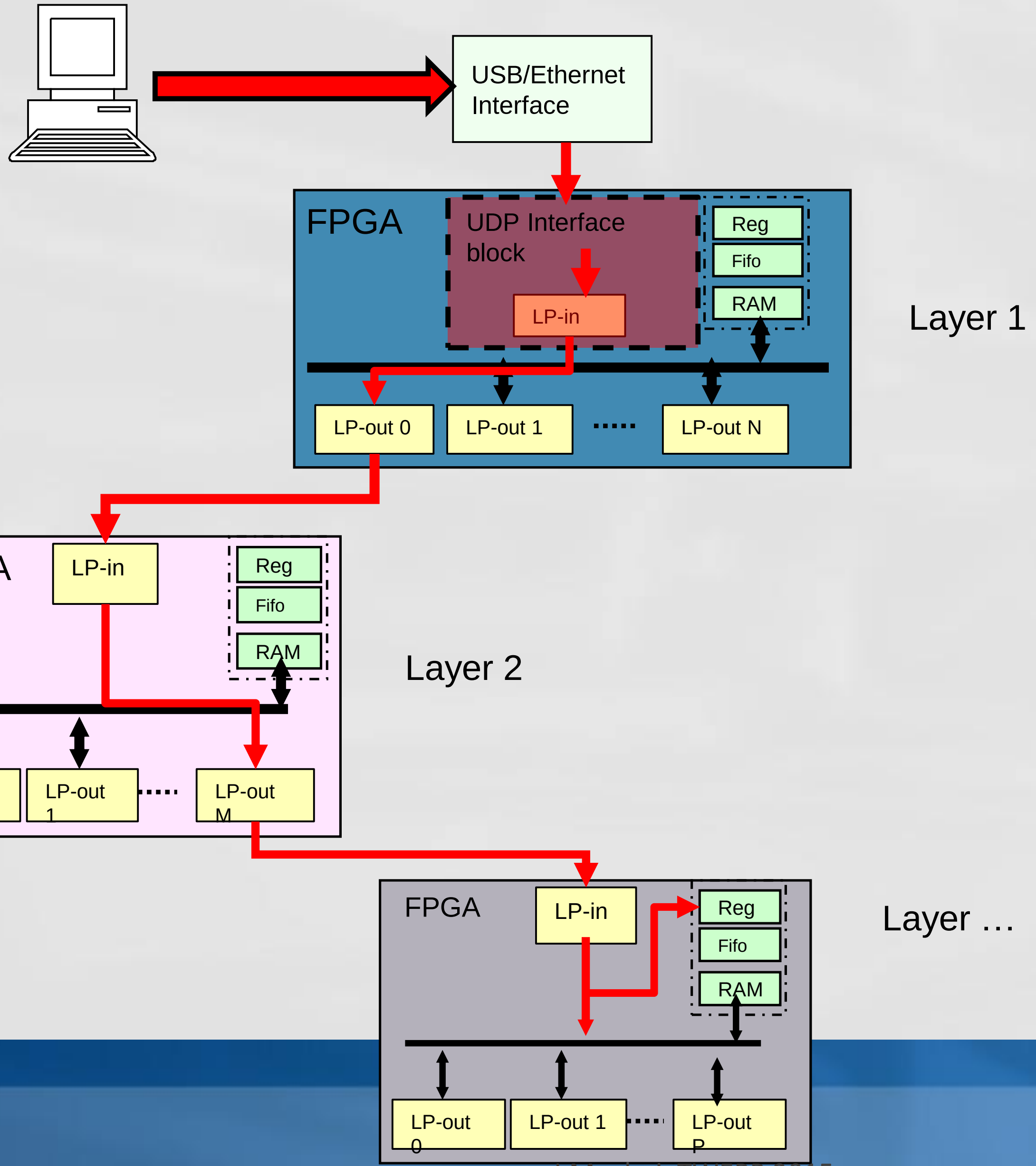




CTRL and Readout Architecture



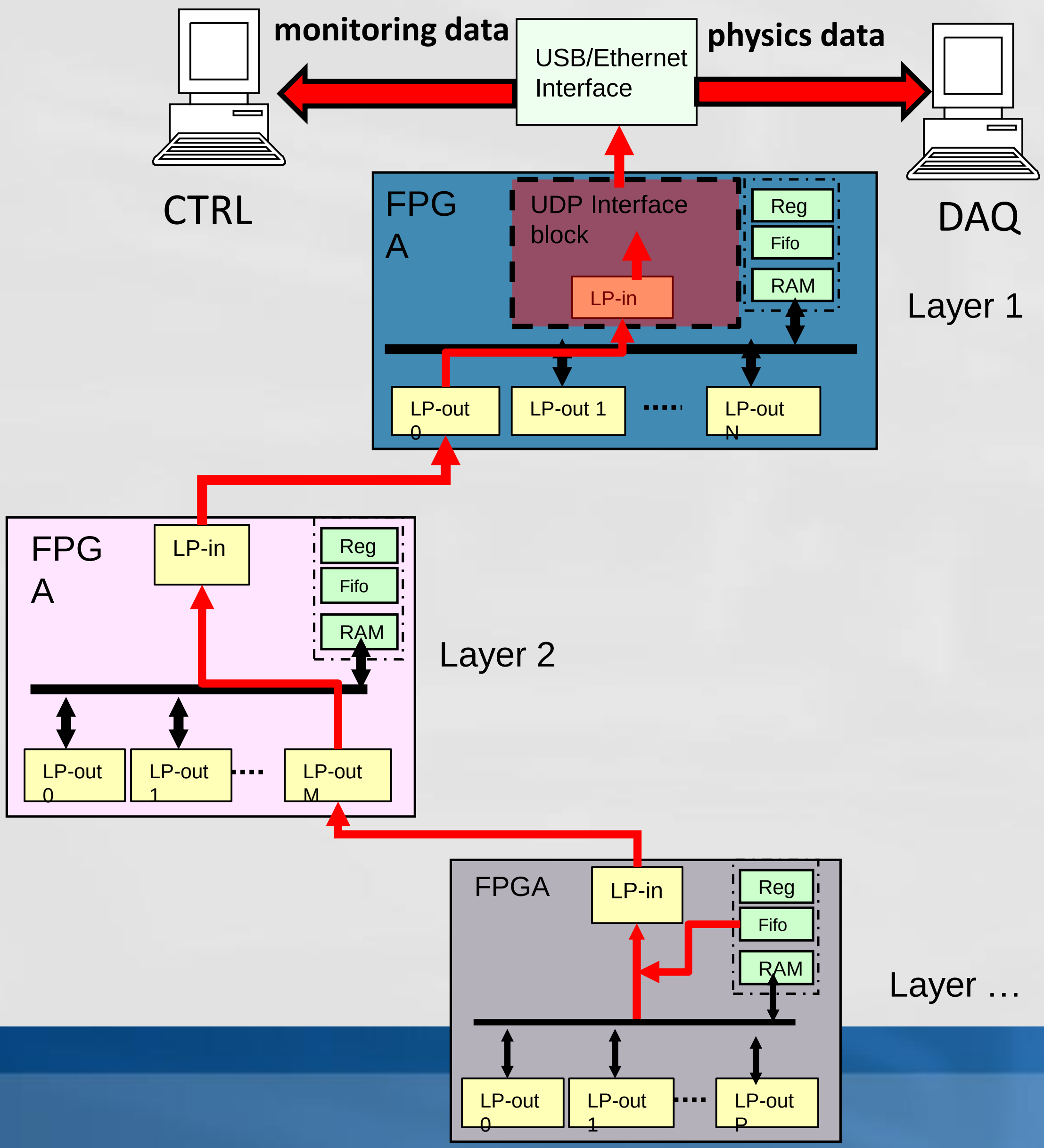
CONTROL



"**Russian Dolls**" home made protocol:

- Here the frames are decapsulated at each layer
- The frame crosses each layer **transparently** towards its final target.

DATA READOUT



"**Russian Dolls**" home made protocol:

- Here the frames are encapsulated at each layer
- Data frame goes through each layer **transparently** and is switched between DAQ or CTRL depending on its nature.(detected in the header frame)

Trigger Architecture

- **Trigger path**
  - FEBs send Trigger Primitive (TP) via the backplane to the Control Board (CB)
  - CB pre-processes TP and sends via serial links to Trigger Board.
  - Trigger Board (TB)
    - receives the primitives (TP)
    - builds calorimeter (L1, ~1 µs latency) and tracker (L2, <10µs) triggers
    - sends trigger decisions back to CBs via serial links
  - CBs forwards them to FEBs
  - FEBs transmit data to DAQ or reject the event if no trigger received

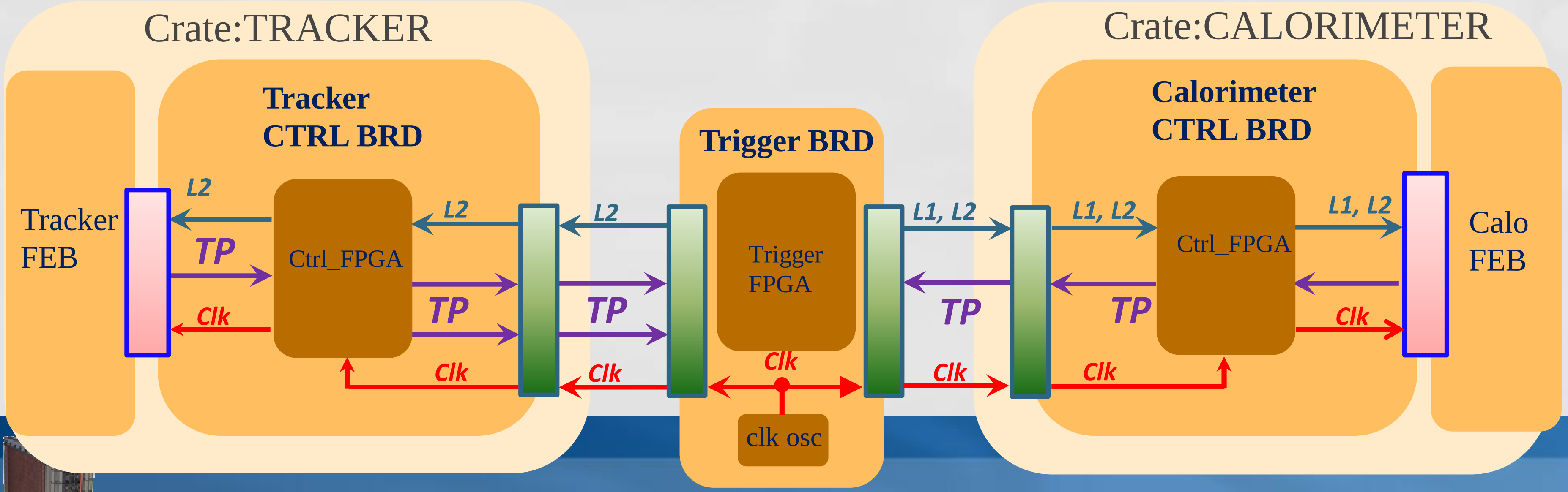
TP : Trigger Primitives

RJ45

Backplane

L1 : Level 1 Trigger

L2 : Level 2 Trigger

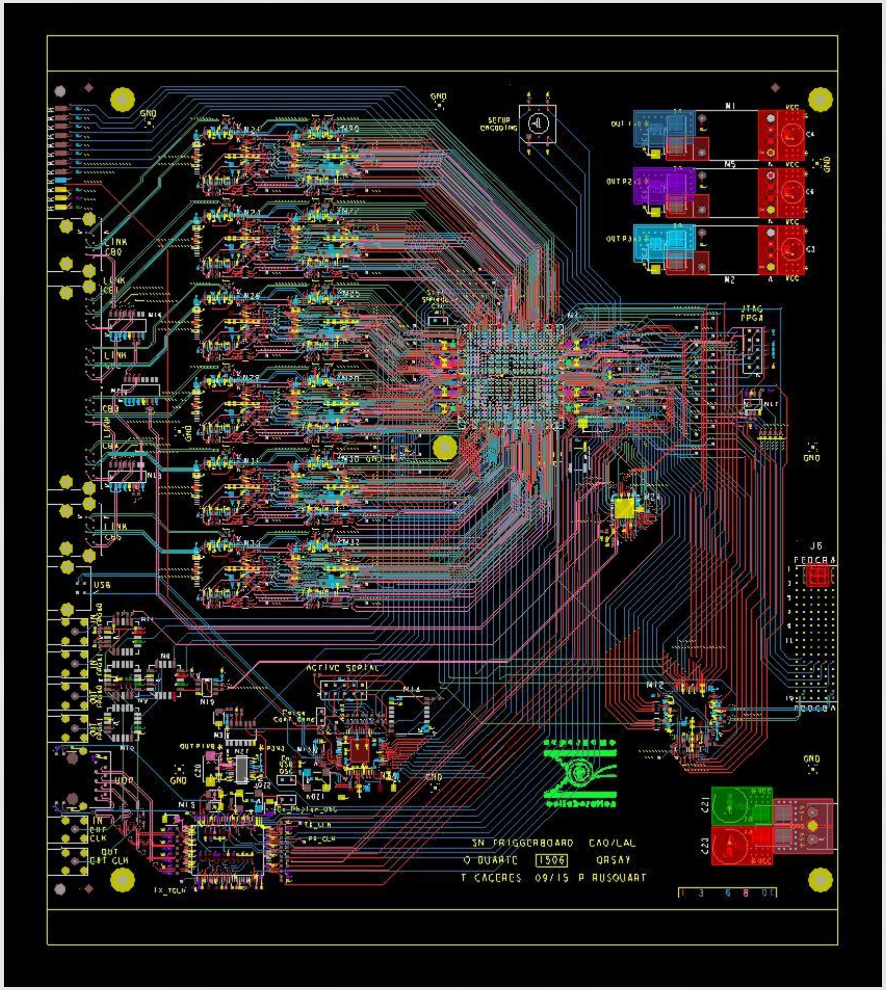


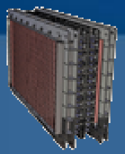
supernemo collaboration

Trigger Board

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

- The board is the **heart** of the **trigger** and **timing System**.
- It is built around a **Cyclone IV** FPGA.
- It is in charge of building the **trigger decisions** and of **distributing** via CAT5+ cables to the **Control** boards:
    - The **40-MHz clock**
    - The **Sync signals**
    - Serial links with Calorimeter and Tracker **triggers decisions (L1, L2)**
- It gathers from the control boards the serial links carrying the **Trigger Primitives**
- It is located in a Calorimeter Crate but it is connected to **Control System** and **DAQ** via its own **Gbit-UDP interface.**
- It has been sent for PCB production last week.

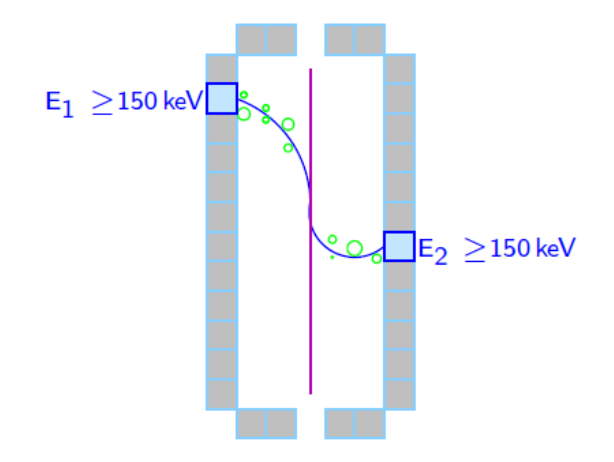




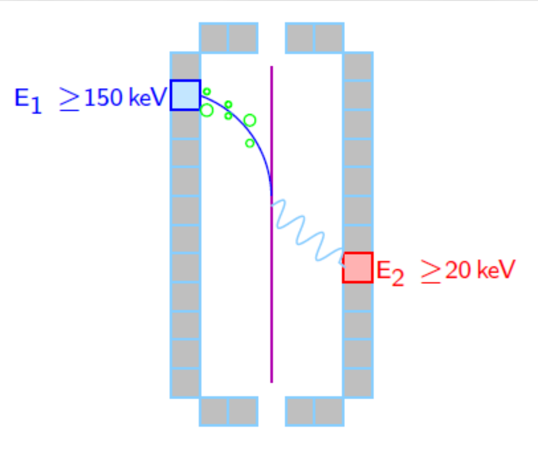
Trigger Strategy

Global Trigger **Strategy** :

- Noise rejection by a factor ~ 100 :
  estimated event rate ~ **5 to 10 Hz**
- Keep all **Physics events** : **2 e⁻, e⁻ n γ, n e⁻ + delayed α**
  - Association of a **energy** deposit in the Calorimeter and a **track** in the Tracker.
  - Detection of **delayed alpha** particles. (cf.BiPo Cascade)



a 2 e^- Event
Scintillator Hits associated with tracks in the Geiger Chamber

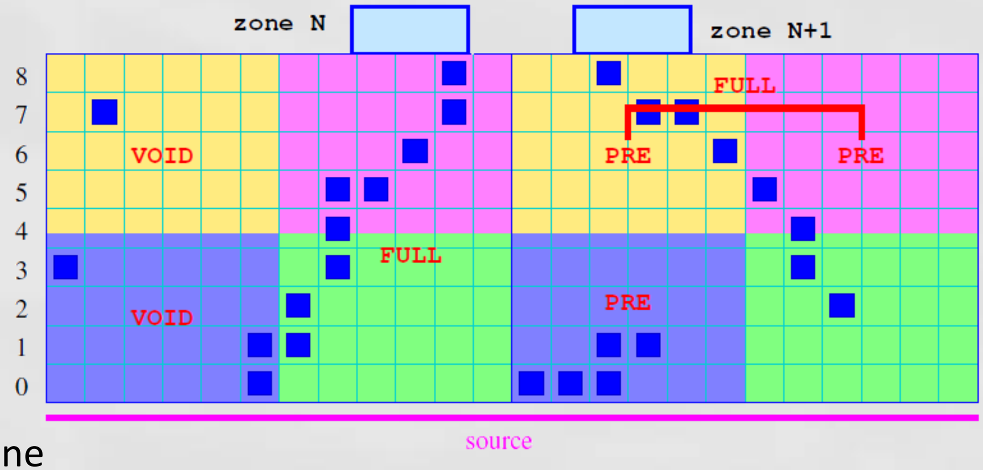


e- γ Event :
γ crossing the Low energy threshold in association with a High Energy deposit due to the e-

Trigger Strategy (2)

Calorimeter : decision made from a simple criteria based on multiplicity threshold crossing.

- 1st Level decision (L1 or L_{calo}):
  N_{tot} PMTs Hit >= 1, 2, 3…
- preserve zoning triggers for further coincidence search

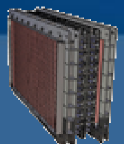


Tracker : search for very basic track patterns

- Zone Classication :
  10 zones per sub-module, 4 subzones per zone
- step by step reduction of the combinatories
- only 3 patterns **VOID, FULL_TRACK, PRE_TRACK**

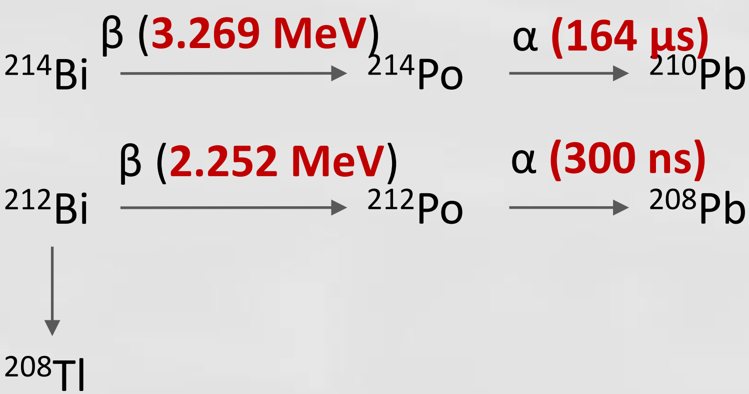
Full detector:

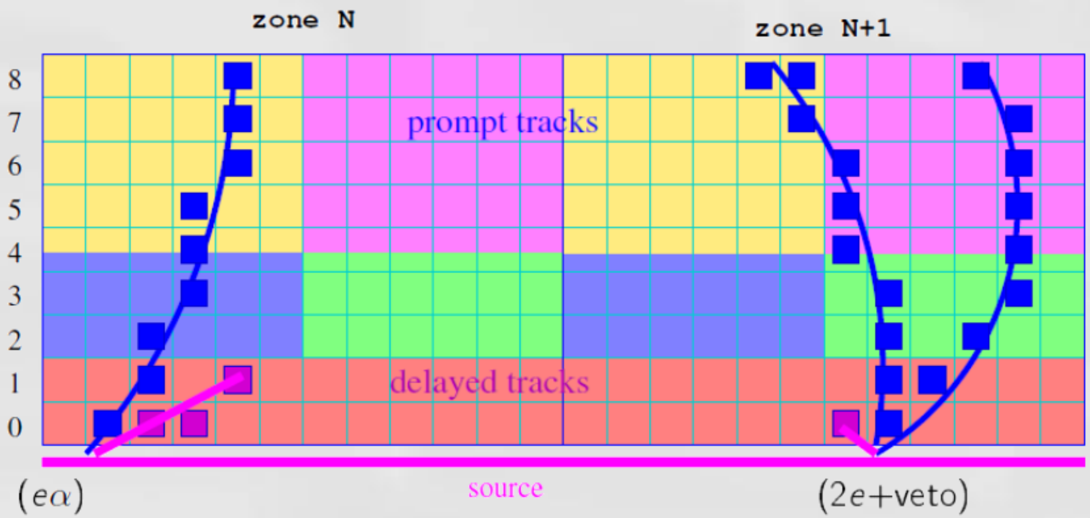
- synchronization of both Calorimeter and Tracker decisions
- search for some calorimeter/tracker, **space/time coincidences**
- Reject lonely self trigger/single rate triggering cells
- search for **special patterns** (delayed alpha) :
  between events coincidences (ex : **Bi-Po cascades**)



BiPo cascade special case

Goal : **M**easure **^{208}Tl** and **^{214}Bi** contaminations (due to **Radon**) through the detection of the so-called BiPo process, which corresponds to the detection of an electron followed by a delayed alpha particle.

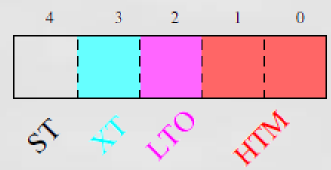




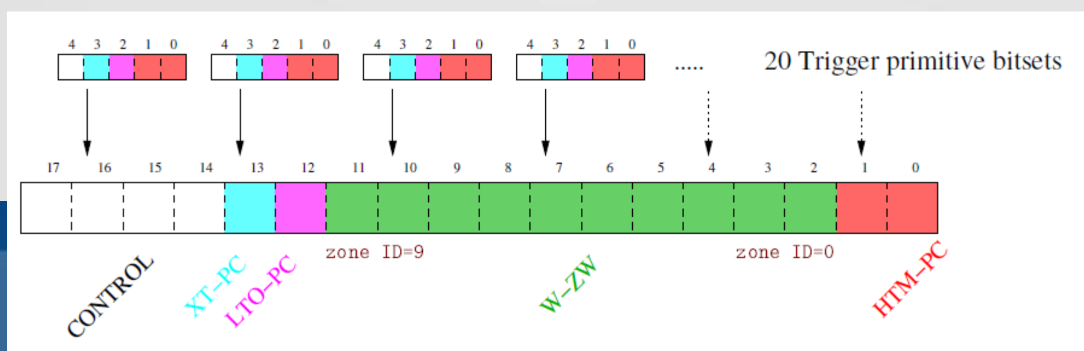
- α particle must probably will leave no energy in the Calorimeter (**no Calo Trigger**)
- Need to make coincidence between tracks in the same zone over a long time window
- **Tracker patterns** must be 'kept' in the Trigger Board for ~ 300 us. In the case of coincidence, a **Tracker Trigger Only** will be generated

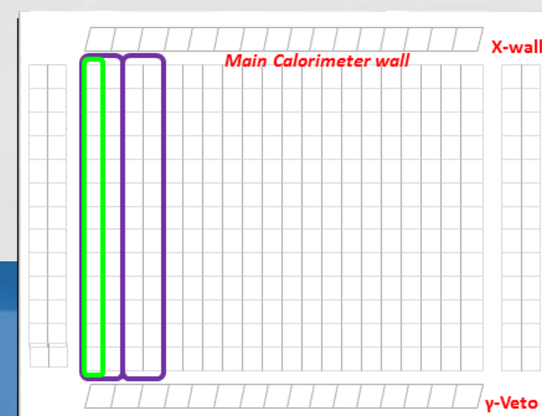
Calorimeter Trigger Primitives

- Each column of **optical module** (OM) is connected to a **FEB**.
- Each FEB builds a **Trigger Primitive** Bitset [**5 bits**] which will be sent to the control board at 40 MHz (**each 25 ns**):
  - **HTM**: High Threshold Multiplicity [2 bits]: Number of channels above high threshold (~ 150 keV) in the column (up to 16 OMs)
  - LTO: Low Threshold Only [1 bit]: at least 1 channel above low threshold only (~ 20 keV) => not above high threshold
  - XT and ST [2 bits]: currently => spare bits



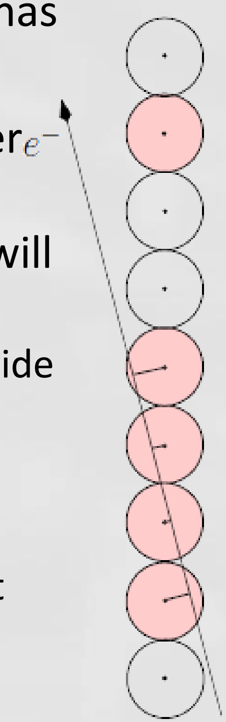
- The **Control Board merges** the TPBs coming from the FEBs (up to [100 bits]) and computes the 18-bits **Calorimeter Crate Trigger Word** (C-CTW):
  - **HTM-PC:** High Threshold Multiplicity Per Crate [2 bits]
  - **Zoning Word** [10 bits] depends on the type of the crate: Wall or Gamma veto and X-wall Zoning Word. Each bit can be activated in case of hit in the corresponding zone (zone ID=0-9).
  - LTO-PC: Low Trigger Only Per Crate [1 bit]: this is defined by the 'OR' of all LTOs from FEBs.
  - CONTROL: control bits [4 bits]



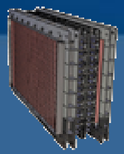


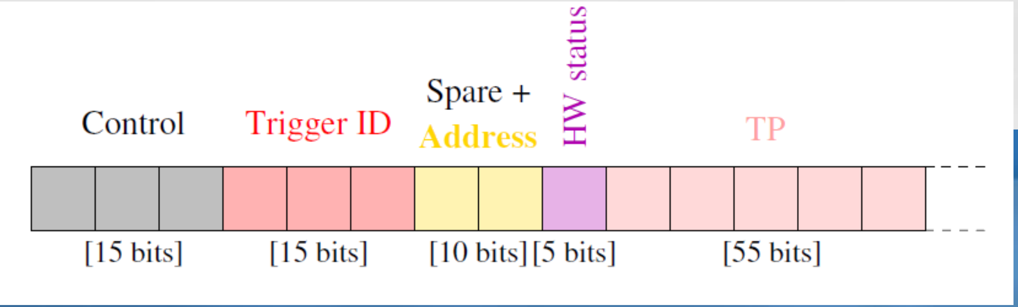
Tracker Trigger Primitives

- The principle is to build for each cell, a **trigger primitive** that indicates if the **cell** has been **recently hit** by a track.
- Therefore, a specific time period of **1600ns** (64 x 25 ns) is dedicated to the tracker trigger.



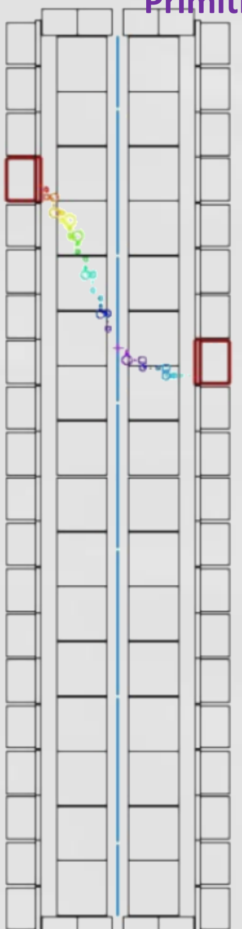
- When a cell is hit, a **gate** (5-bit) is opened and decreased each 1600 ns. The cell will participate in the trigger decision as long as the gated signal is present.
  - **This permits covering the longest possible drift time** of ~ **8µs** towards the anode inside the chamber
- **Every 1600 ns**, each FEB provides a 100-bit word made of:
  - Control : [15 bits]
  - TTID : Tracker Trigger ID [15 bits]: used to check T-TPB synchronization from different FEBs.
  - **THWS** : Tracker HardWare Status [5 bits]
  - TP : **Trigger primitive Word** [**55 bits**]
- The Control Board **merges** the T-TPBs coming from the FEBs to build the Tracker Crate Trigger Word (T-CTW), and **transmits it directly** to the Trigger board.

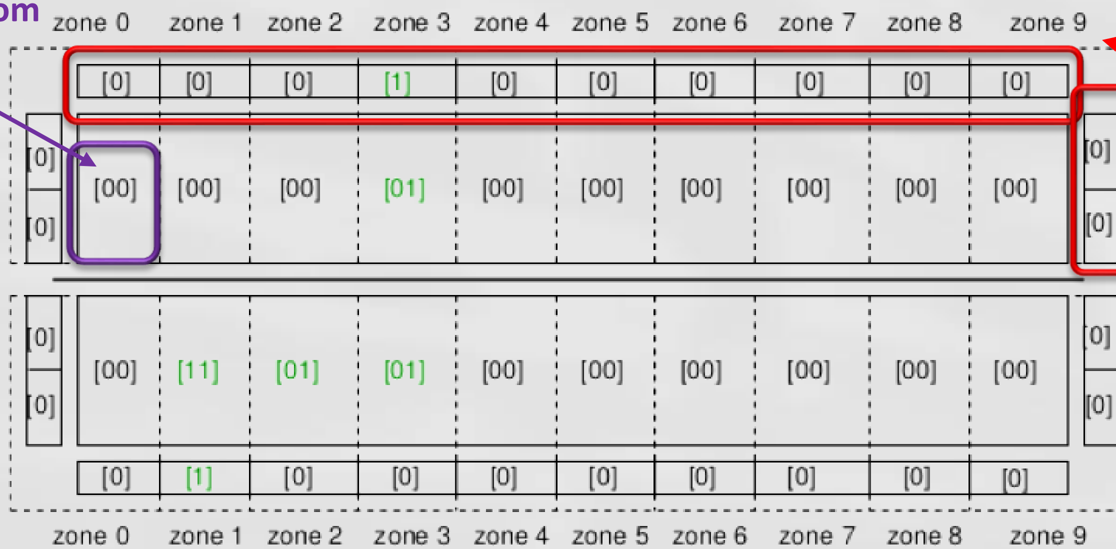




Trigger Processing

Tracker Zoning Word Constructed from Primitives





Calorimeter Sided Zoning Words constructed from primitives

Trigger View

Simulated Event : True Hits View

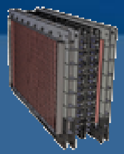
Intermediate Trigger View

Post-Trigger Data Readout

- **For the calorimeter FEB:**
  - Once the **Low Threshold** has been crossed, **recording** in the SAMLONG **analog memories** is **stopped**, waiting for the return of the trigger signals to perform the **Analog to Digital Conversion** and **send data** to DAQ.
  - If the latency of any of L1 or L2 is trespassed, recording is resumed.

- **For the tracker FEB:**
  - The FPGA waits for the **return** of the **Tracker Trigger decision(L2)** to select the channels whose data will be sent to DAQ once the Cathodic signals will have arrived

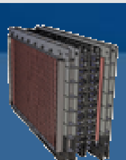
=> needs to wait for **~70 µs.**



Estimation of Trigger Efficiency

- Preliminary estimations with track recognition patterns similar to those used in NEMO3

Process	VOID (%)	FULL TRACK (%)	PRE TRACK (%)
^{82}Se$(0\nu\beta\beta)$	$0,5 \pm 1,0.10^{-2}_{\text{stat}}$	$97,9 \pm 1,4.10^{-1}_{\text{stat}}$	$1,6 \pm 1,8.10^{-2}_{\text{stat}}$
^{82}Se$(2\nu\beta\beta)$	$5,6 \pm 3,3.10^{-2}_{\text{stat}}$	$91,0 \pm 1,3.10^{-1}_{\text{stat}}$	$3,5 \pm 2,6.10^{-2}_{\text{stat}}$
^{214}Bi(foil)	$23,1 \pm 6,8.10^{-2}_{\text{stat}}$	$69,7 \pm 1,2.10^{-1}_{\text{stat}}$	$7,2 \pm 3,8.10^{-2}_{\text{stat}}$
^{208}Tl(foil)	$23,0 \pm 6,8.10^{-2}_{\text{stat}}$	$71,4 \pm 1,2.10^{-1}_{\text{stat}}$	$5,6 \pm 3,4.10^{-2}_{\text{stat}}$



Conclusion

- The **goal** of the **SuperNemo demonstrator** is to prove the functionality of the system and the feasibility of a **“zero-background”** detector
  - Then the experiment could be extended to 20 such modules.

- We have designed a system architecture tailored to the needs of physics:
  - Low cost, based on two **custom front-end ASICs** and Cyclone III & IV FPGAs.
  - Custom crate and backplane => **320 ch/Calorimeter** and **2160 ch/Tracker** Crate
  - **Gbit-UDP**-based crate readout
  - Total electronics cost per calorimeter channel: **~ 140 €** (712ch/module)
  - Total electronics cost per tracker channel: **~ 15 €** (6102 ch/module)

- The way the **trigger logics** is designed permits a **flexible parametrization** with:
  - Calorimeter only, Tracker only, Calorimeter&Tracker, Event to Event Coincidence (implies an Event Builder post-processing)
  - more if needed . . .