A Calorimeter for the LHCb upgrade II

Discussion – Tuesday 26th January 2021

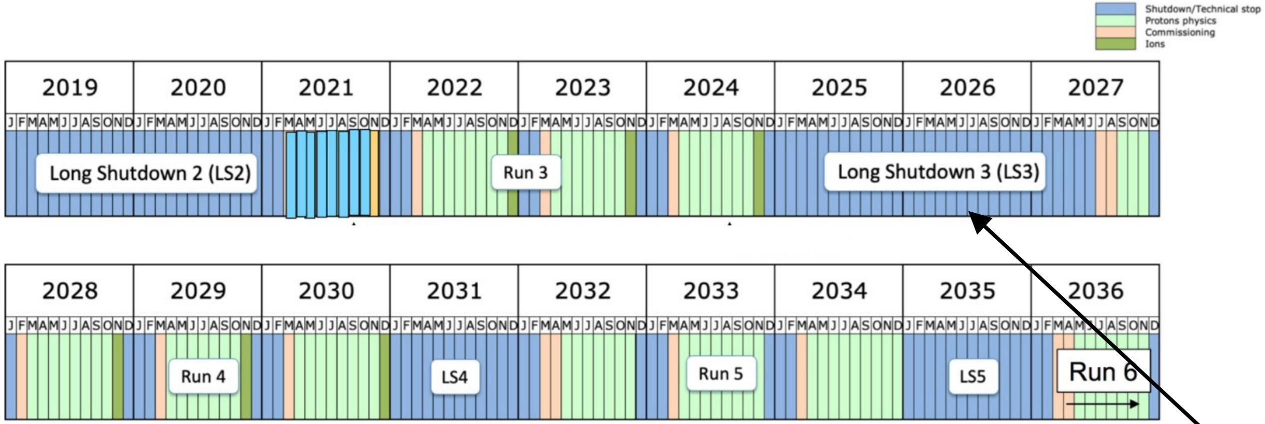
Frédéric Machefert (IJCLab, Orsay)

Presentation based on the talks of

Renaud Legac (Marseille), Andreas Schopper (CERN), Stéphane T'Jampens (LAPP), David Gascon (Barcelona), Christophe Beigbeder (IJCLab), Max Chefdeville (LAPP)

given during the calo upgrade workshop (IN2P3), Dec. 17th 2020 & the upgrade meeting, Jan 21th, 2021

Schedule : what are we talking about ?



Could imagine the installation of preliminary systems during the LS3(?)

	Date	Runs	Instantané $\mathcal{L}$ [cm^{-2} s^{-1}]	Intégré $\mathcal{L}$ [fb^{-1}]	Status
LHCb	2010 – 2018	Run 1 & 2	4×10^{32}	9	terminé
LHCb Upgrade 1	2022 – 2030	Run 3 & 4	2×10^{33}	50	approuvé
LHCb Upgrade 2	2032 –	Run 5 & au delà	1.5×10^{34}	300	

Situation

At present some documents have been published :

- Expression of Interest for the upgrade II [CERN-LHCC-2017-003]
- Physics case for an LHCb Upgrade II [CERN-LHCC-2018-027]
- LHCb upgrades and operation at 1034cm-2.s-1 Luminosity – a first study [CERN-ACC-NOTE-2018-0038]

In Sept 2019, the LHCC request a Framework TDR from the collaboration

- First technological choices, and gu-estimate of the performances reached
- Cost, Schedule and national contributions
- To be published in Sept 2021
  - Work has starting
  - The document has to be finalized during the summer

And what happened in France ?

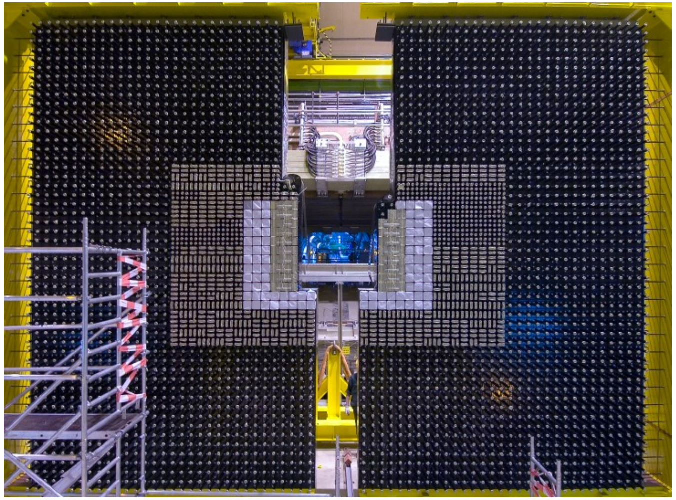
- A document was submitted to IN2P3 - Several projects : Tracking, Calo, Acquisition/Trigger
  - Calo concerns essentially IJCLab, LPC, LAPP… but other contributions would be welcome !

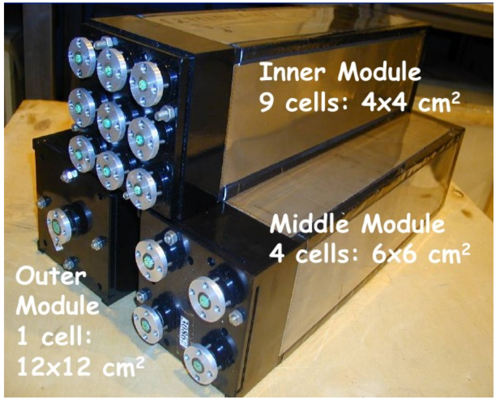
Present ECAL

The LHCb ECAL is made 3312 modules, or 6016 channels

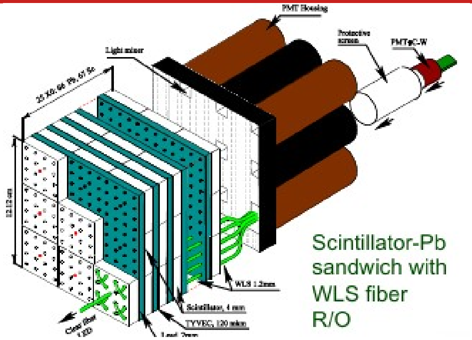
It is adapted to luminosities up to a couple of $10^{32}cm^{-2}.s^{-1}$ and to doses up to 40kGy

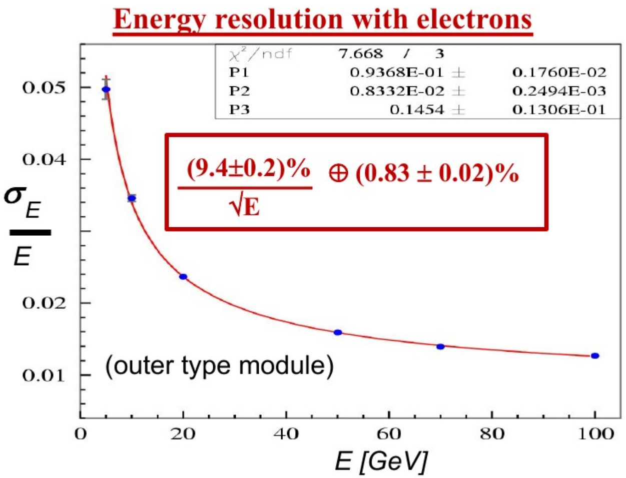
It contains 3 regions : $4x4cm^2$, $6x6cm^2$ and 12x12 cm^2





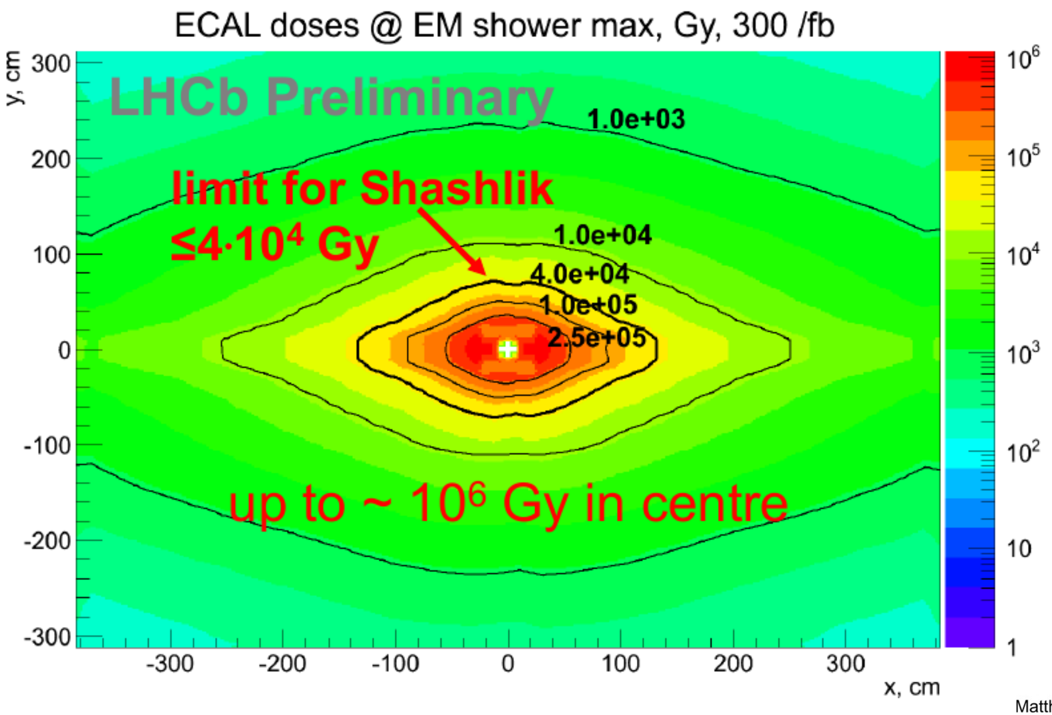
What is the aim ?

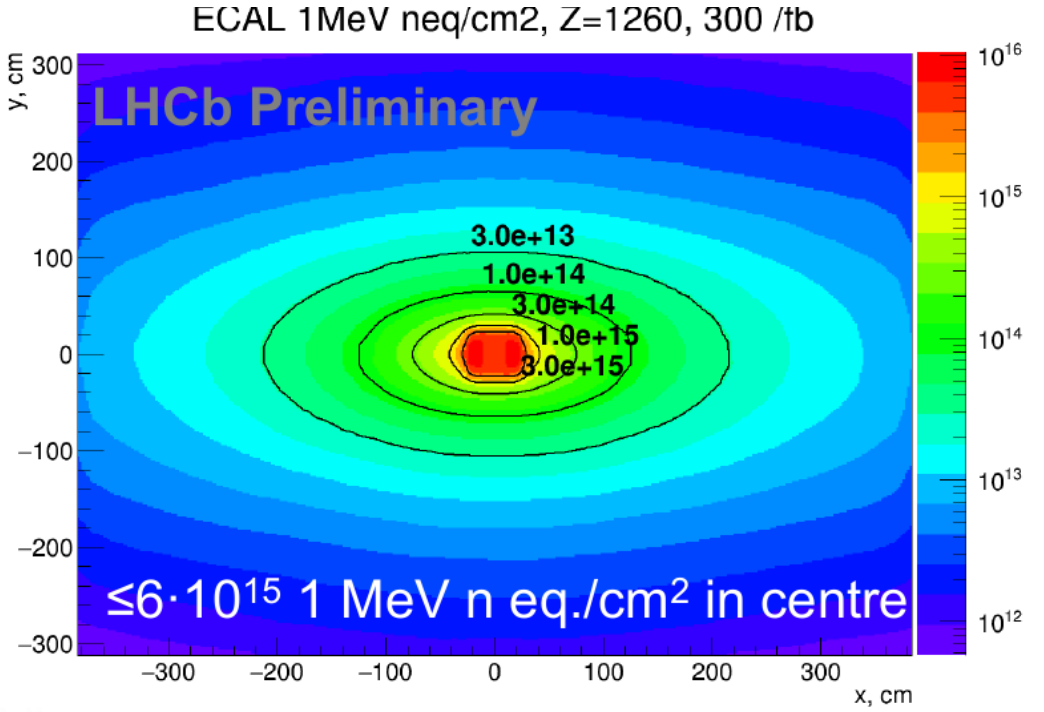




- Sustain a dose of up to 1MGy and 6.10^{15} 1MeV neq/cm², $300fb^{-1}$
- Concerning the occupancies
  - Increase the granularity, especially close to the beam pipe where the occupancy is the largest
    - We have in parallel to reduce the Moliere radius (density of the absorber)
  - Get a time measurement O(10ps) to reduce the combinatorics
  - Potentially include a longitudinal segmentation
    - Shower separation, improve timing capabilities
- The performances should not be (too much) affected
  - Keep a good energy resolution (10%/√E)
  - Keep the modularity of the present detector ($12x12cm^2$ modules)

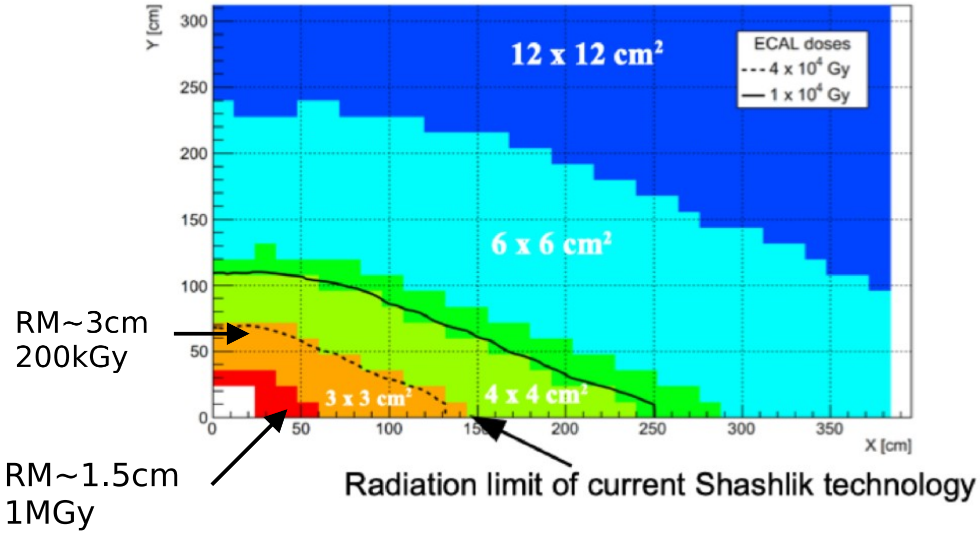
Radiation problem





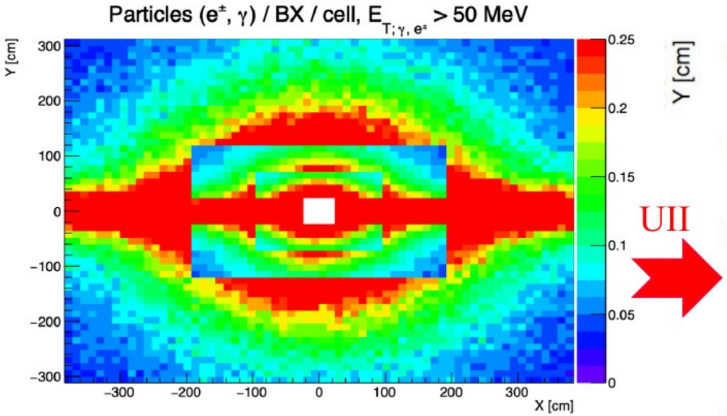
Matthias Karacson
& Yuri Guz

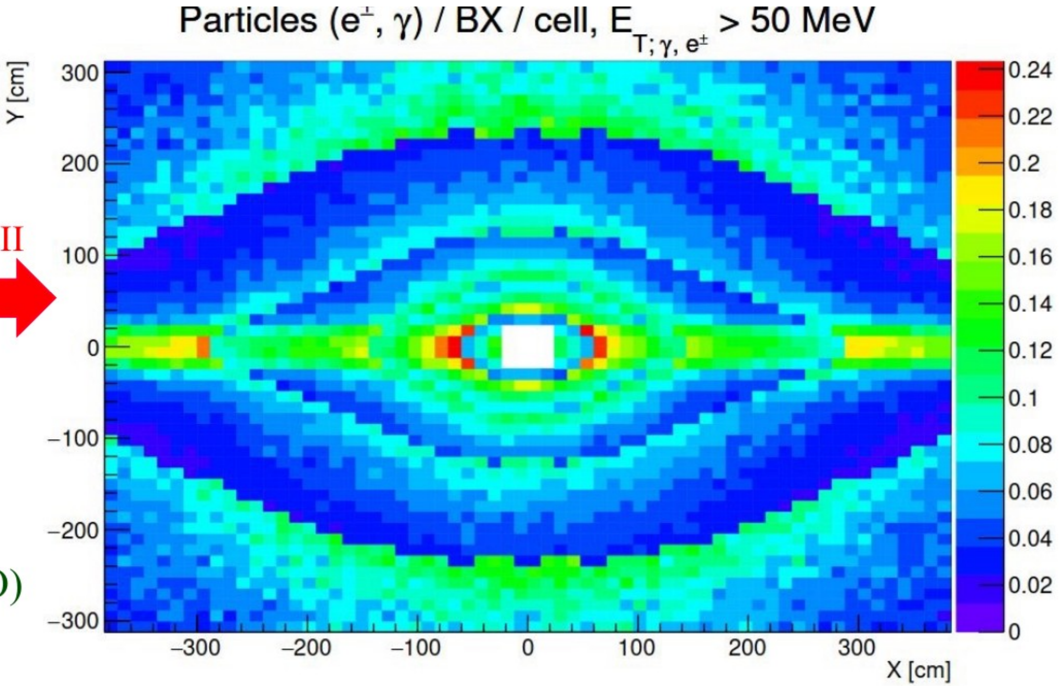
Proposal for a new Calorimeter – Upgrade II



	Cell size:	Modules:
SPACAL: GAGG & W	1.5 x 1.5 cm²	32 *new* modules for extreme conditions of up to 1 MGy
SPACAL: Polystyrene & Pb	3 x 3 cm²	144 *new* modules with “moderate” radiation requirements of up to ≈ 200 kGy
SPACAL + Shashlik	4 x 4 cm²	272 *new* modules + 176 refurbished existing modules (add long. segmentation?)
Shashlik	6 x 6 cm²	896 rebuilt + 448 refurbished existing modules (add long. segmentation?)
Shashlik	12 x 12 cm²	1344 refurbished existing modules (add long. segmentation?)

What would we obtain in term of occupancy ?





<u>Mitigate high occupancies</u> by:

- ✓ small cell size
- ✓ longitudinal segmentation (dual R/O)
- ✓ order 25-50 ps timing resolution
- ✓ optimized reconstruction algorithm

$L = 1.5 \times 10^{34} cm^{-2}.s^{-1}$

Foreseen technologies

Ongoing technological investigation

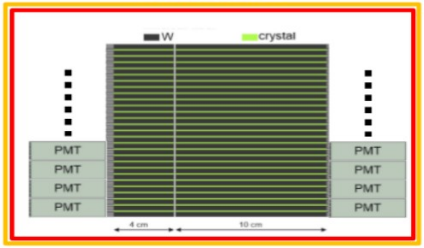
1.5 x 1.5 cm² cell size region (32 modules):
- **SPACAL W** with tungsten absorber (small Molière radius) and inorganic scintillator (radiation hard GAGG)
  Goal ≈ 20 - 50 ps -> *tested!*

3x3 cm² cell size region (144 modules):
- **SPACAL Pb** with lead absorber / polystyrene scintillating fibers (currently most promising option, preparing absorber)
  Goal ≈ 20 - 50 ps -> *tested with W absorber!*
- **Shashlik** (depending on radiation-hard wavelength shifting fibers) Goal ≈ 20 - 50 ps and reduced spill over-> *tested!*

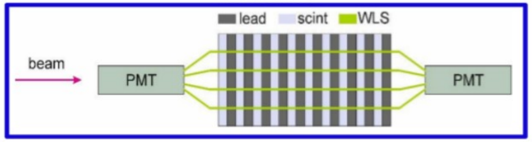
Timing layer:
- **MCP-PMT** (LAPPD) in the shower max, for improved Timing.
  Goal ≈ 15 - 20 ps precision -> *tested!*

- Alternative approach: Multi-layer Si-W ECAL
  → investigated in simulation

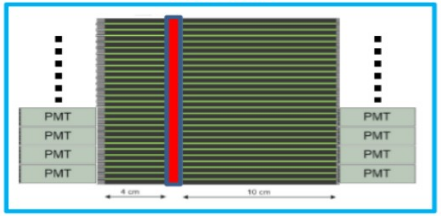
SPACAL W/Pb



Shashlik



MCP-PMT



« Spaghetti » calo and Shashlik have an already good intrinsic time resolution
Addition of an extra timing layer to reach ~ 20ps

Possible developments

The French groups are mostly interested by

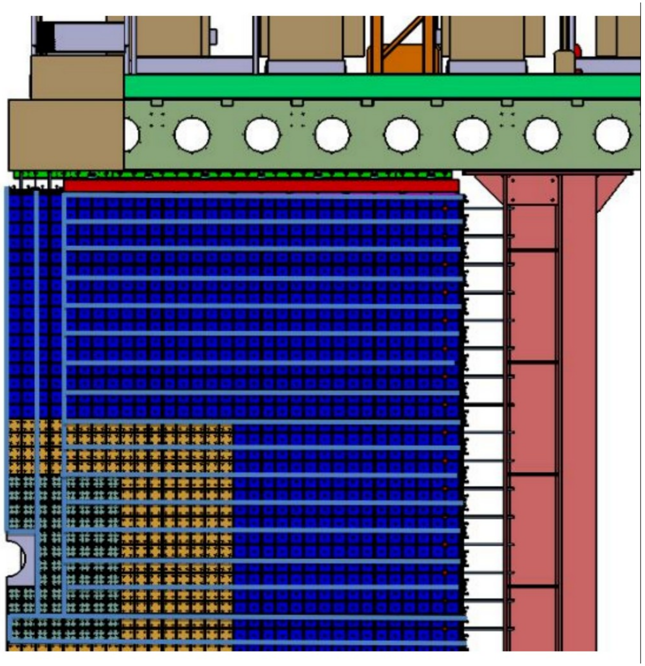
- Mechanics developments
- Detector design (sensitive and active medium)
- Electronics developments

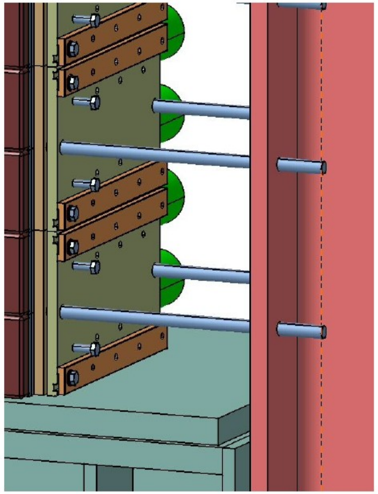
In the past we have been mostly involved in Mechanics and Electronics

Mechanics

Modules are groupes in double rows with are maintained by stainless-steel tape and tightened to the side structure of the ECAL

This permits a precise positioning of the row and a dense structure

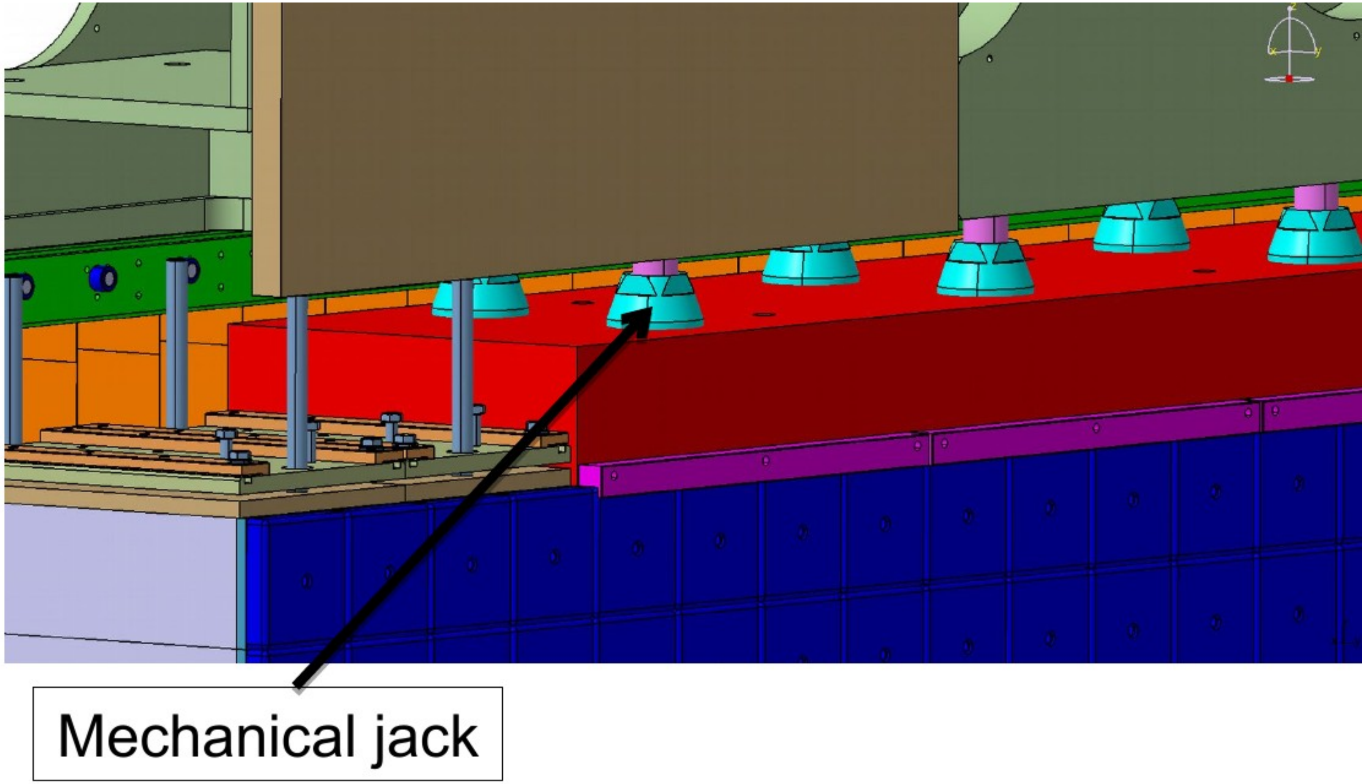




Mechanics

Uniform load

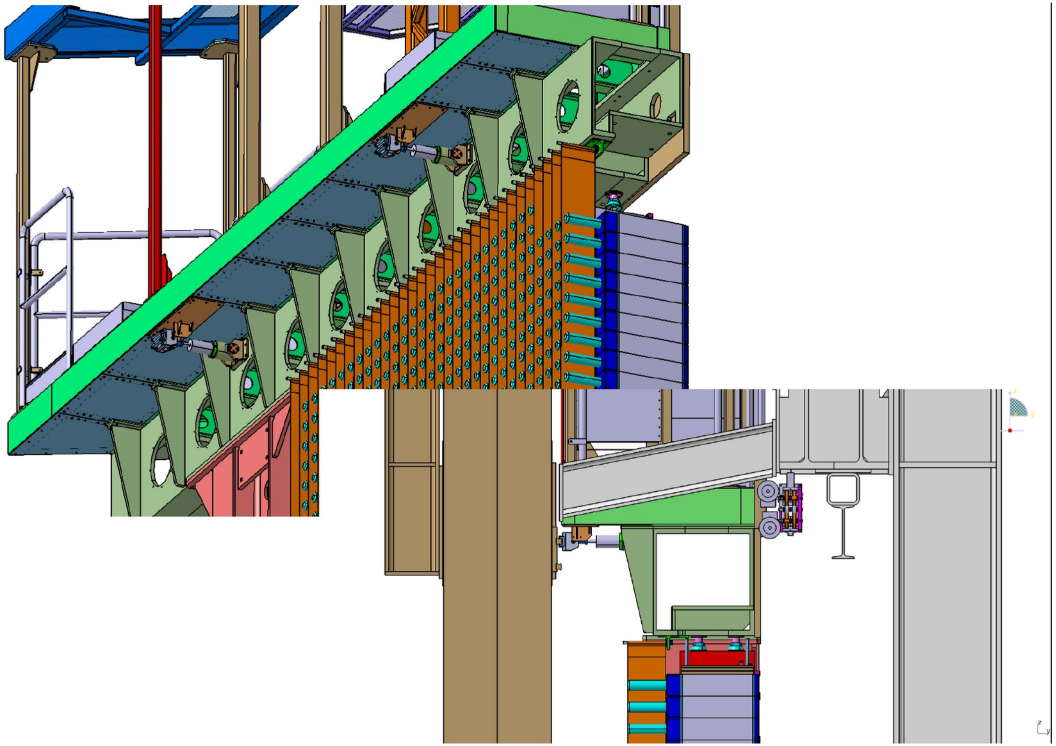
applied at the top of the ECAL and maintained with mechanical jacks



Mechanics

Seismic shock absorbers

- located at the top of the ECAL structure, under the electronics platform

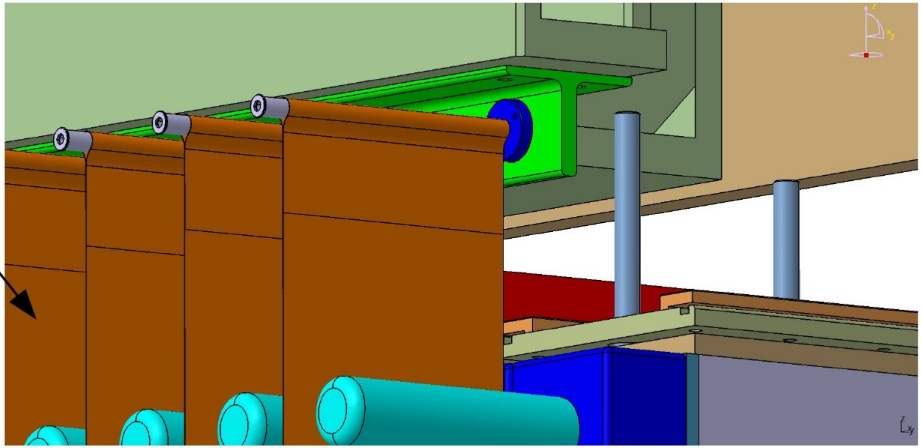


Mechanics

Cables, pipes, etc...

- Signal cables
- Power supplies (PMT, HV)
- Calibration systems
  - LEDs
- Cooling ?

steel cabling tapes



Mechanics

Dismantling : tools and procedures

Addressing the problem of modules with different depth

- Non uniform load
- Can it be solved by adding some mechanical structure at the back of the shorter modules ? What is the impact of such an addition ?
- Effect on the seismic constraints ?
- Can we still pack the modules in groups of rows ?

Cables and electronic platform

- We may have to go from ~6000 channels to more than 32000… applying this factor on the electronics we go from 14 to 59 crates… can probably be handled by increasing the number of channels/FEB. However, the electronics location and space is an issue.

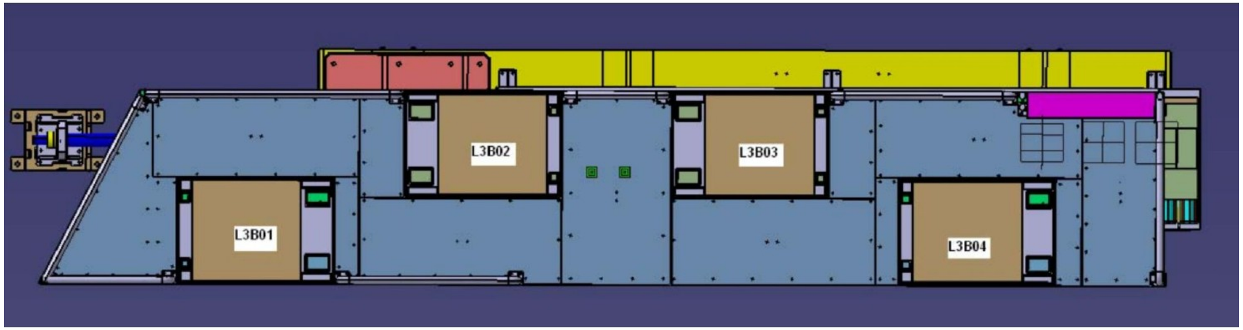
Assembly

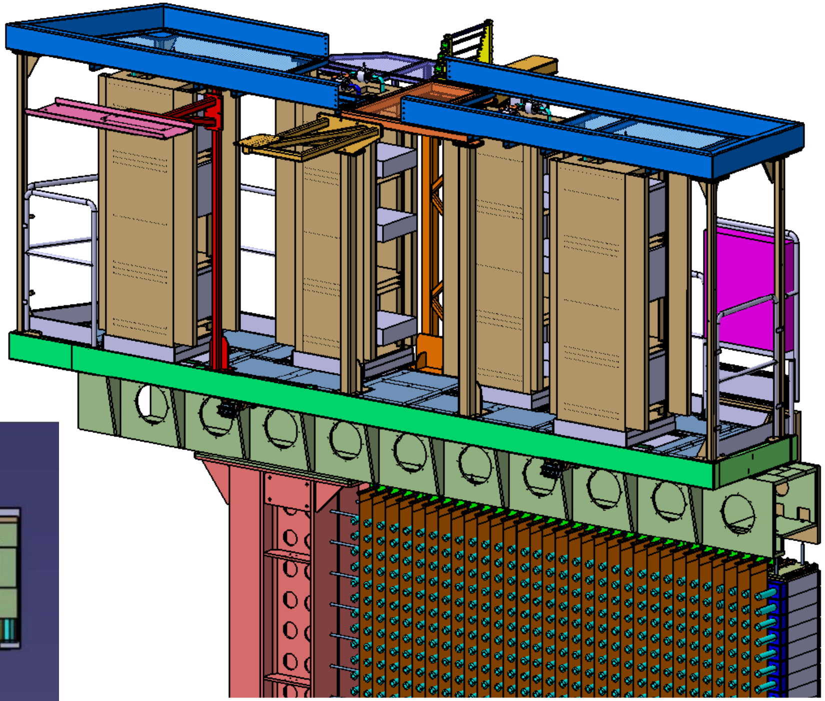
- Tools have to be designed to assemble the detector (alignment, tools to carry the modules, etc…)

Electronics

The electronics is located on the calo platform, above the detector

- Cables length from PMT to FEB ~ 15m
- 14 crates for the ECAL for ~250 FEB (32 channels/board)
- 6016 channels in the readout





Electronics

The FEB perform at 40MHz

- Shaping and integration of the analog signal after 15m long cables
- 12 ADC conversion of the integrated signal
- Signal treatment in MICROCHIP (ACTEL flash-based) FPGA
  - Pedestal substraction and low noise fluctuation removal
  - Numerical corrections and event formatting
  - Some trigger calculations which are sent to the PC farm (Upgrade I)
- The trigger calculations are sums over 2x2 clusters (E_T, E_T^{Max}, occupancy)
  - Exchange of information at the borders of the regions treated by the FEBs
- The data stream (Data+Trig) is sent on 4 optical links / FEB

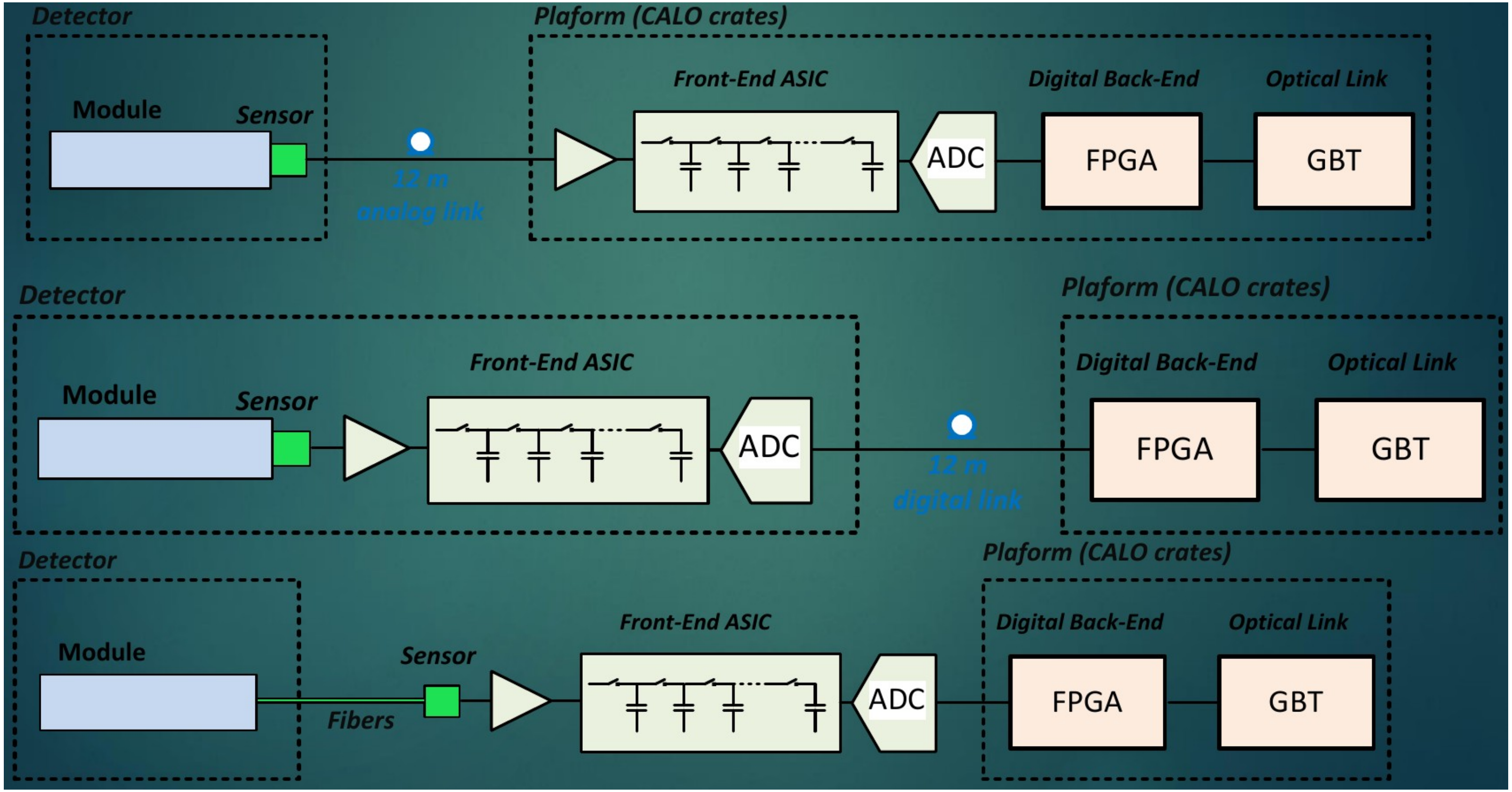
Electronics

The plan is to

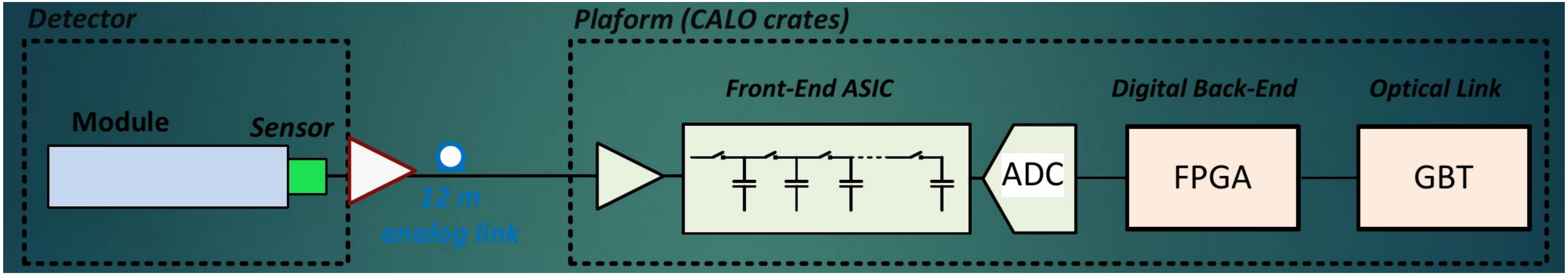
- Introduce a time measurement with a precision in the range of 25-50ps
- Increase the number of channels from 6k to >30k channels
- The dynamic range should be at least 12 bits
- Include a double side readout

In a drastically more difficult environment (radiations, 100Mrad)

Several architectures could be envisaged



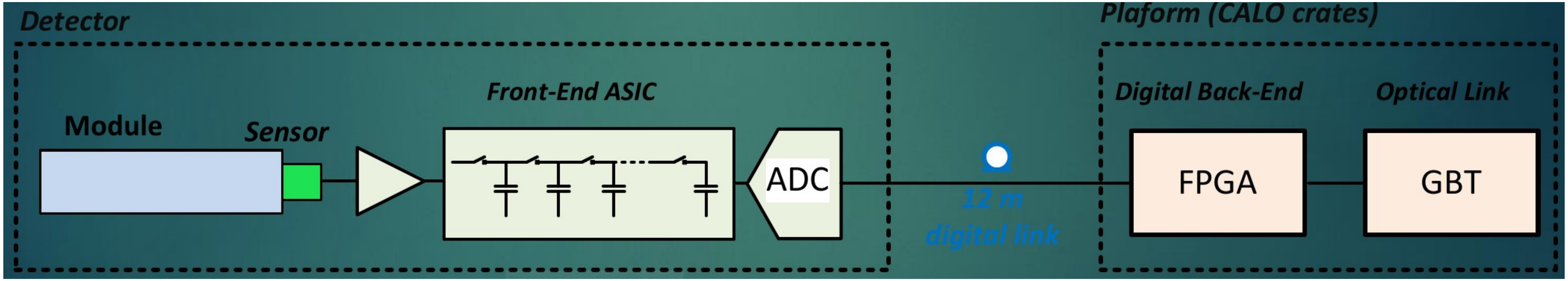
Electronics



One possibility may consist in

- Sending the analog signal, potentially after amplification, to the FE on the platform
- A degradation of the time resolution could be expected beyond 15m

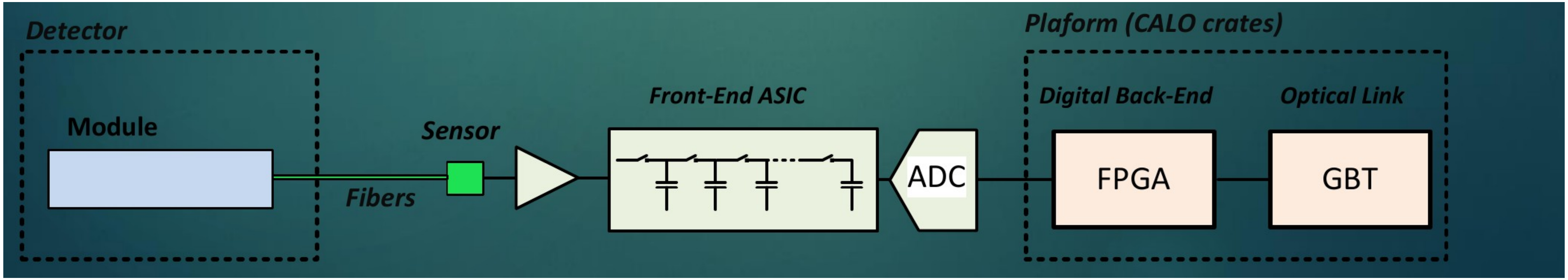
Electronics



But, a digital link could be used between a VFE and the platform

- Challenging development as the ASIC would be in the high radiation region
- The data bandwidth is also a challenging issue as each channel should be readout
- Some treatments needed on the platform
  - Zero suppression, derandomization, sparsification, clusterisation, etc…

Electronics



Or optical links could transmit the signal to the sensors

- Would remove the sensors from the hottest region
- Light losses in the couplings could affect the time resolution

Electronics

A sampling of 500Ms/s should be sufficient for the time precision needed

8 samples at 320MS/s would mean

- Energy → 12 bits, Time → 11 bits, Add → 5bits
- 32 channels x 40MHz x (Energy + Time) ~ 30Gbits/s

Zero suppression and compression of the data are probably mandatory

- Adding a 10% occupancy and a header (Bxid, Add) ~6Gbits/s

If we stick to 32 channels/FEB and use the SPD/PS crates which are available we may double the number of channels and reach 12000 channels

- But this is probably not good enough
- Difficulty to handle many more channels on a single board (connectors)

Electronics

These are just ideas of designs

Some working groups are being defined

https://indico.cern.ch/event/960837/contributions/4044878/

https://indico.cern.ch/event/982989/

https://indico.cern.ch/event/960837/contributions/4044878/

Conclusions

Converging towards an upgraded calorimeter for LHCb

A baseline proposal should be prepared soon (TDR)

- It is being defined now
- However, many options, detectors and design are still on the table
- This TDR is to give some ideas on the direction where would like to go to
  - New ideas and new contributions are welcome !
  - Spacal/Schashlik design, mechanics, light readout, time layer integration, long transmission line effect, analog signal processing, digital processing (FPGAs ? How to handle clusterisation, compression, zero suppression, etc... ?), board design, firmware development, crates, interconnections, power supplies, optical links, software and acquisition control, etc...