Integration and System Qualification of the ALICE Silicon Pixel Detector

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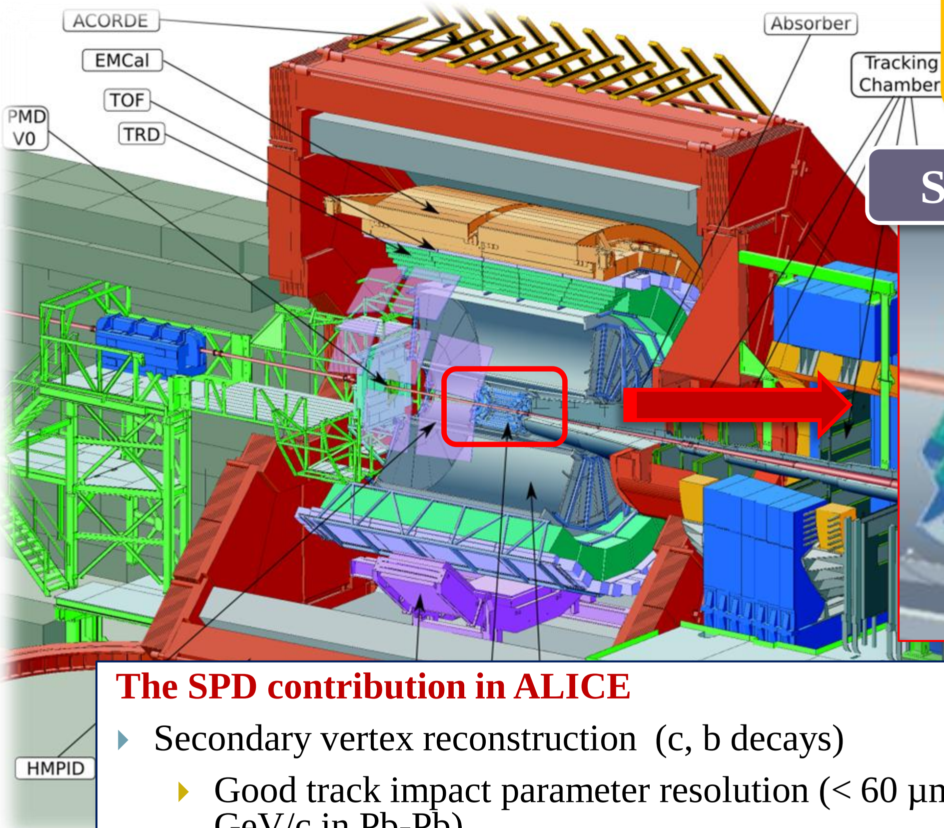
On behalf of the SPD collaboration in the ALICE experiment at LHC

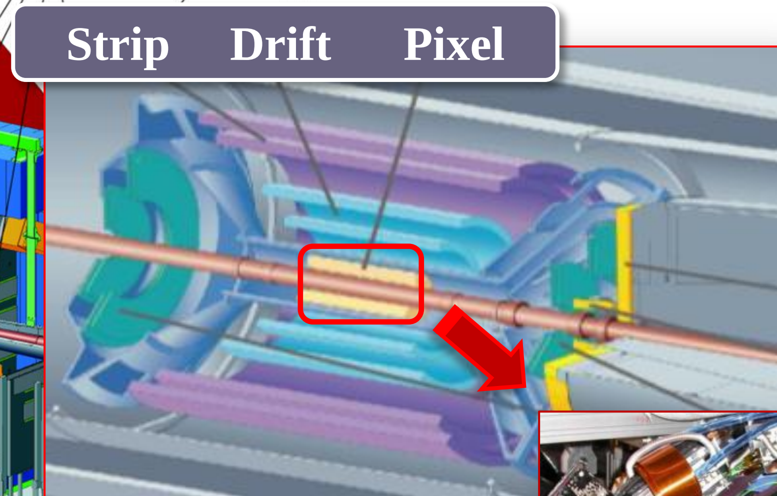
Outlook

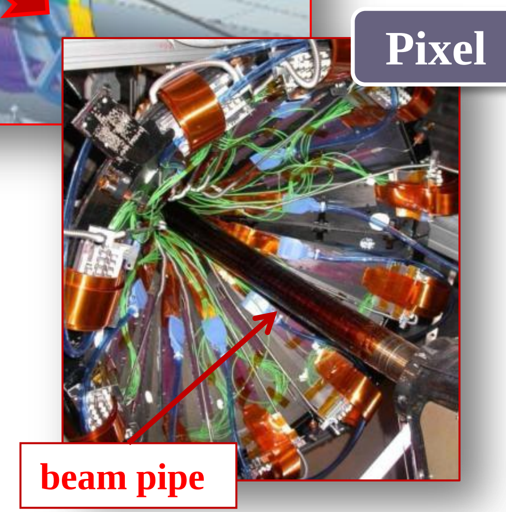
- Silicon Pixel Detector in the ALICE experiment
- Mechanical accuracy
- Pre-commissioning
- Installation
- Optical link synchronization
- Monitor and debug tools

SPD in the ALICE experiment



ITS: 3 different silicon detector technologies





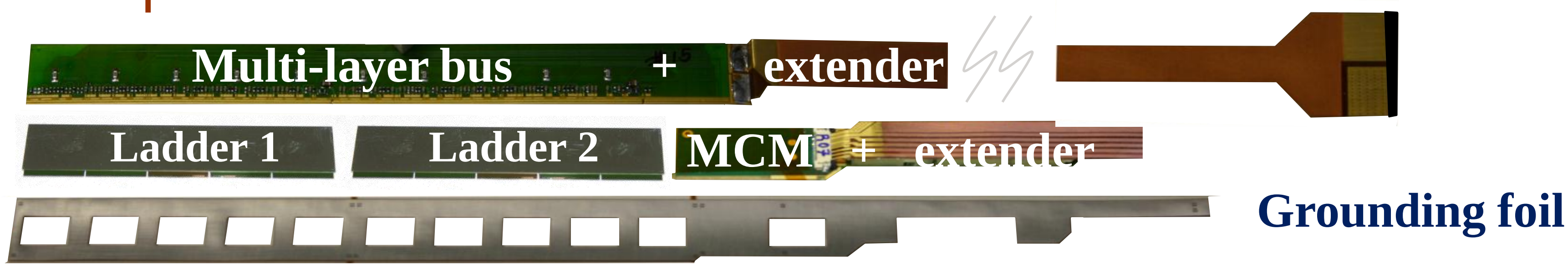
The SPD contribution in ALICE

- Secondary vertex reconstruction (c, b decays)
  - Good track impact parameter resolution (< 60 μm (rφ) for $p_t > 1$ GeV/c in Pb-Pb)
- Improve primary vertex reconstruction and momentum resolution
- Prompt L0 trigger capability (<800 ns)
- Measurements of charged particle pseudorapidity distribution
  - First Physics measurement both in p-p and Pb-Pb

Mechanical accuracy

Basic module assembly: Half-stave

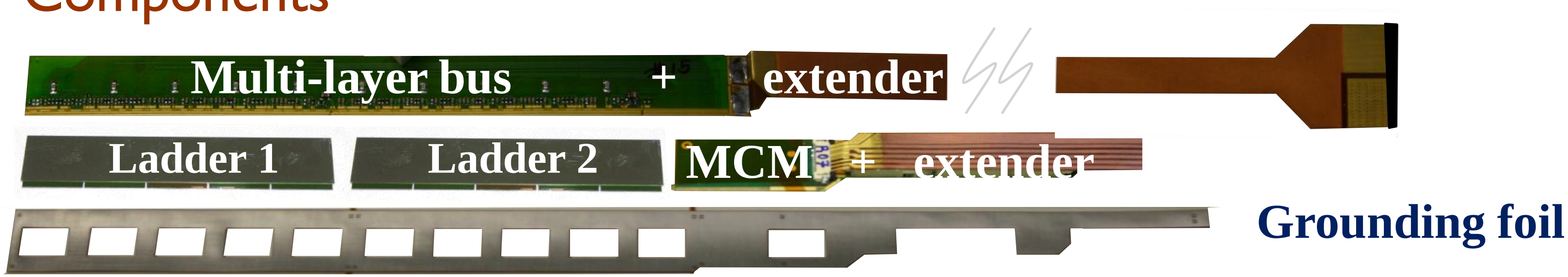
Components



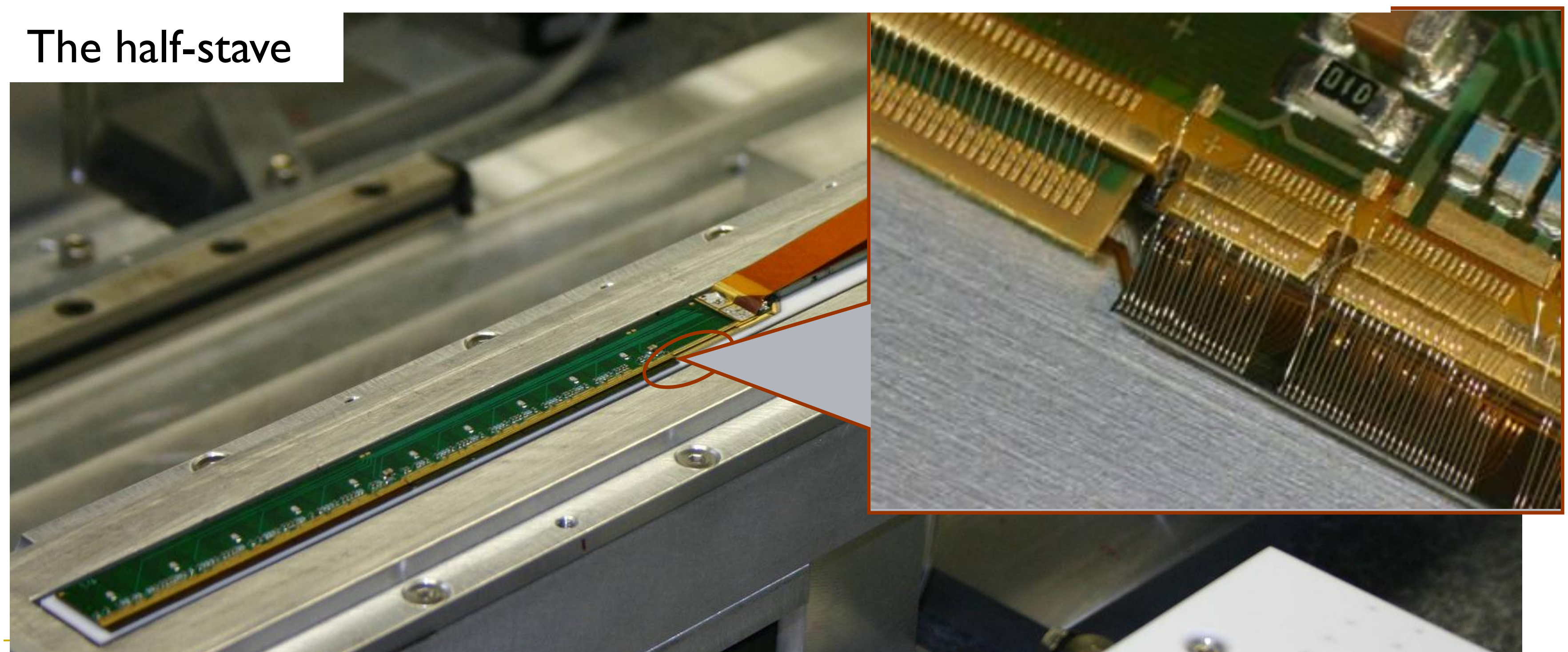
- Grounding foil: aluminum-polyimide foil (25 + 50 μm thick) with 11 windows to improve the thermal coupling between the backside of the FE chips and the cooling tube
- 2 hybrid pixel modules: ladders
  - A p+n silicon sensor matrix 200 μm thick with 40960 pixels arranged in 256 rows and 160 columns
  - 5 FE chips Flip-chip bonded to the sensor through Sn-Pb bumps
  - The pixel cell has the dimensions of 50 μm (rφ) x 425 μm (z)
- MCM: Multi Chip Module to configure and read-out the half-stave
- Pixel Bus: aluminum-polyimide multi-layer bus to connect the MCM and FE chip
  - More than 1,000 wire bonding for each half-stave

Basic module assembly: Half-stave

Components

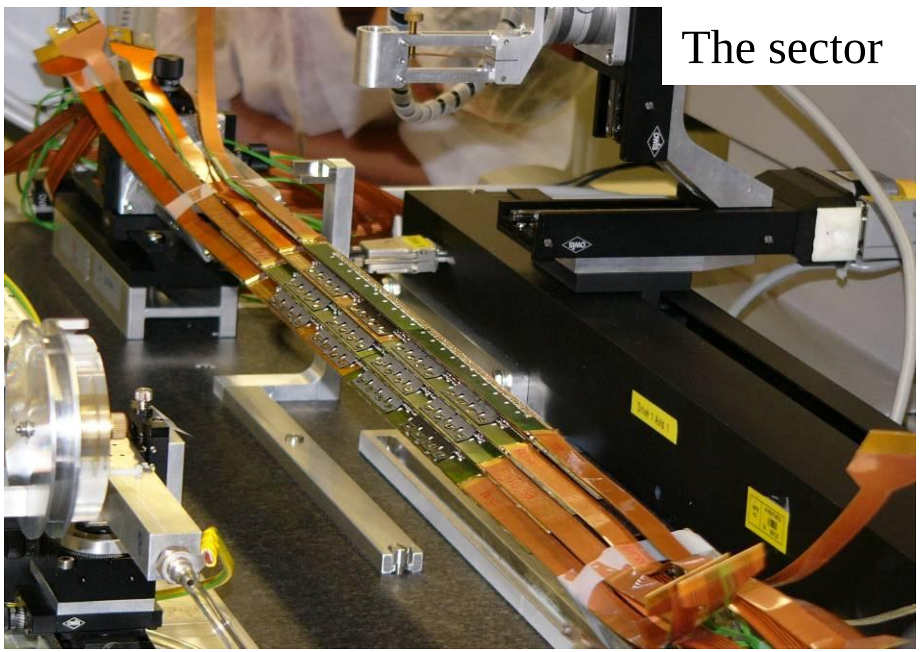


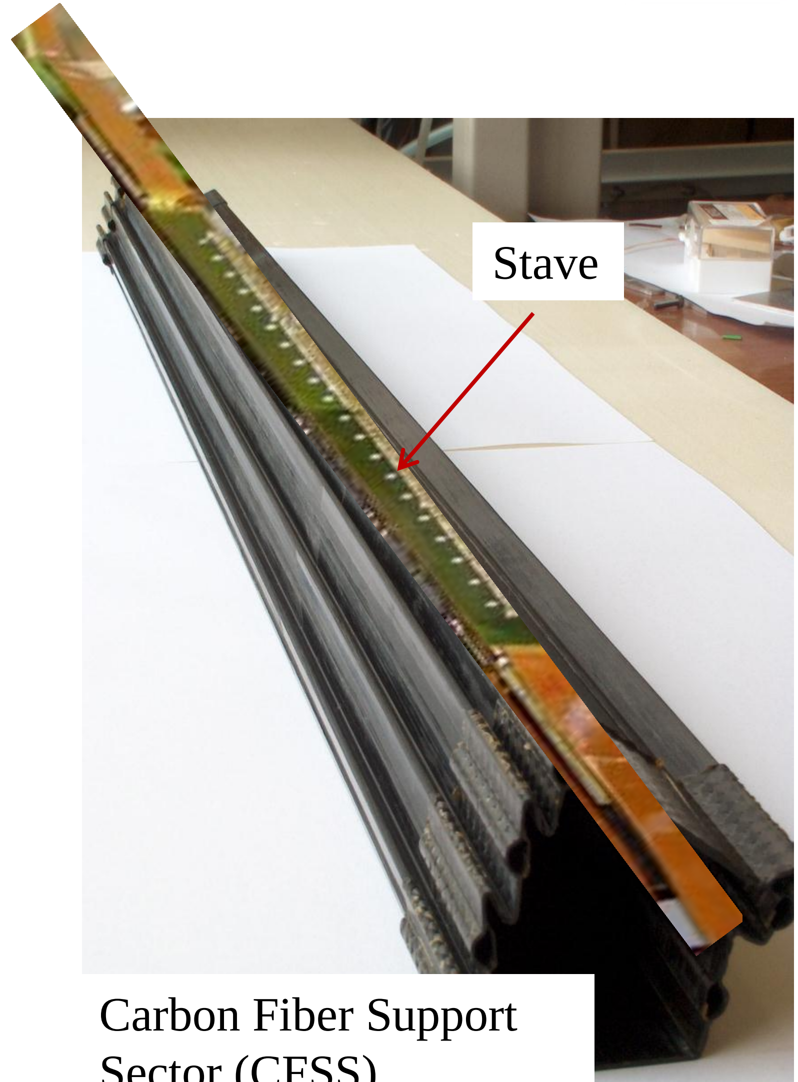
The half-stave



Sector

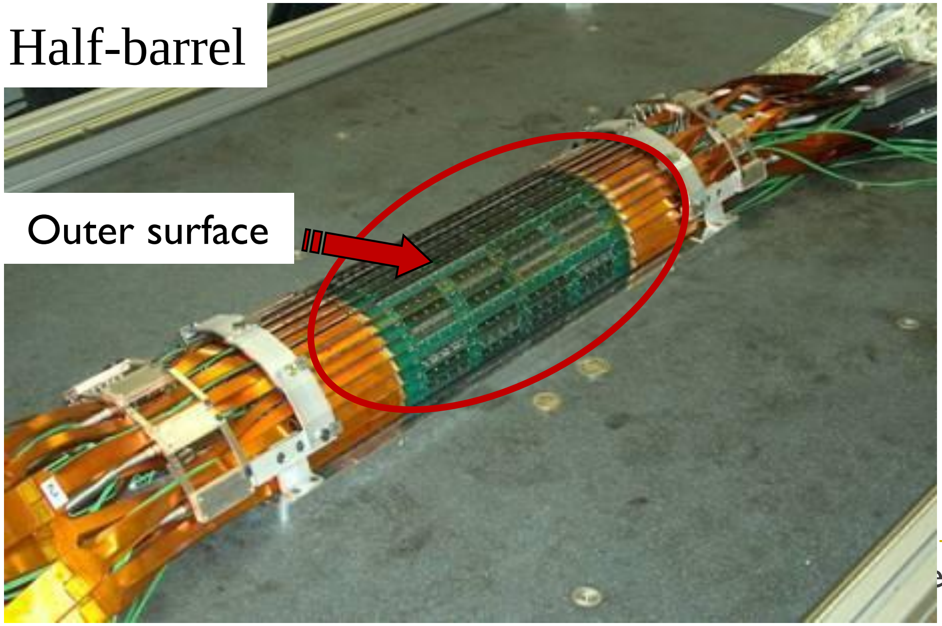
- 2 half-staves are coupled to form a stave
  - The sensitive area is in the center, while the services at the 2 edges
- The staves are mounted onto the low-mass carbon fiber support (sector) in the upper and bottom part to form the 2 layer-structure

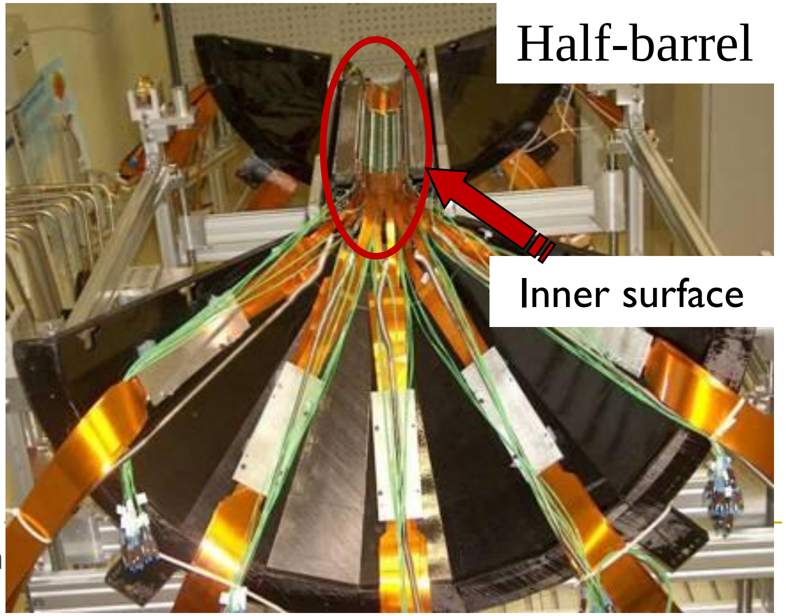




Half - barrels

- 5 sectors are joint one close to the other to form the half-barrel
- The 2 half-barrels are mounted face-to-face around the beam-pipe





Mechanical accuracy

- The ladders positioning in the half-stave has the accuracy of the order of few microns
- The stave positioning onto the sector has the accuracy of the order of tenths of microns
- The sectors were joint one close to the other in the half-barrel with the accuracy of the order of hundred microns
- The SPD positioning around the beam – pipe is of the order of few hundred of microns
- No survey was done at the end

Is this enough for the physics?

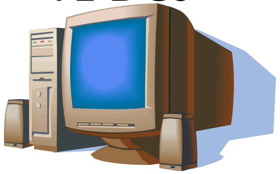
- Alignment:
  - The survey measurement is an important input for the alignment algorithm
  - Although, using the estimated mechanical accuracy as input, we aligned the detector within the expectation
- Simulation:
  - The description and the alignment of the passive components has to be very accurate. The transport code is unpredictable if you superimpose two materials in the same region
  - We experienced this problem which still has to be solved
    - Temporary solution adopted in ALICE: simulate collision with a perfectly aligned geometry and reconstruct the events with the residual misalignment geometry

System pre-commissioning

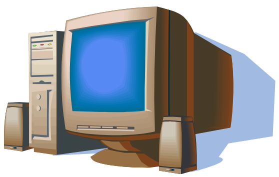
Pre-commissioning (I)

Test performed using the final readout chain, power supplies, DCS system, cooling system, cables, interlock …

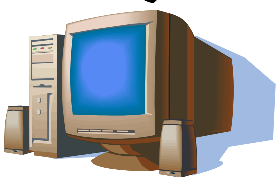
FE-DCS



On-line/Off-line

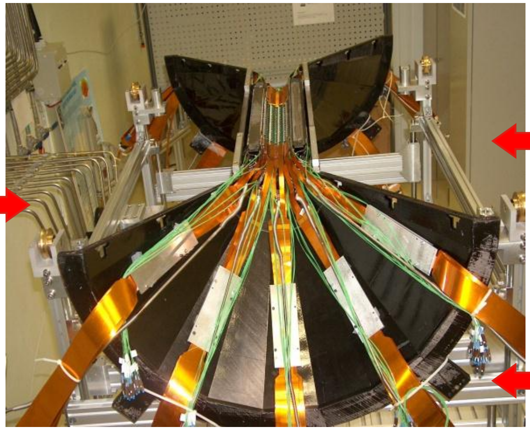


DAQ



Off-detector electronic and trigger

Half Barrel



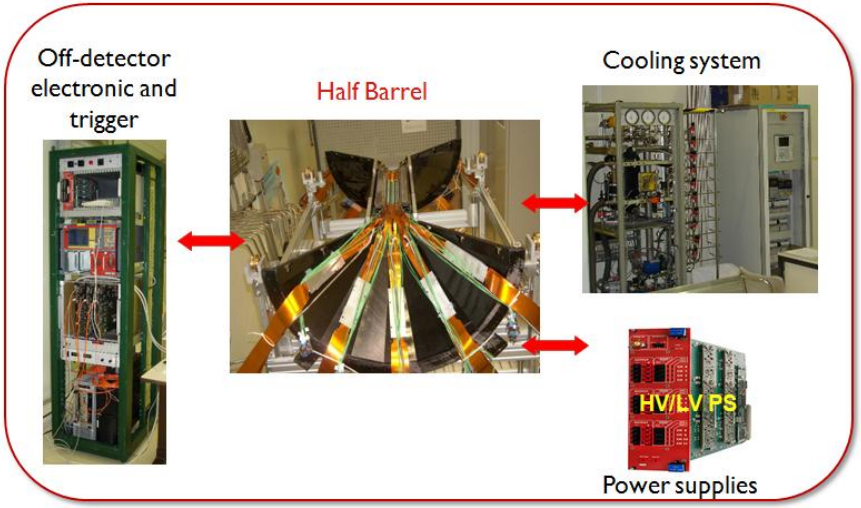
Cooling system

Power supplies

Pre-commissioning (II)

This is the first opportunity to commissioning the full system

- It is a crucial task:
  - You have to run the system by remote as in the experiment
  - You have to be sure that all the safety procedures (i.e. interlock) behave properly
  - The system has to be characterized and the informations stored in the construction DB
  - Everybody in the collaboration wants prompt feedback!!!

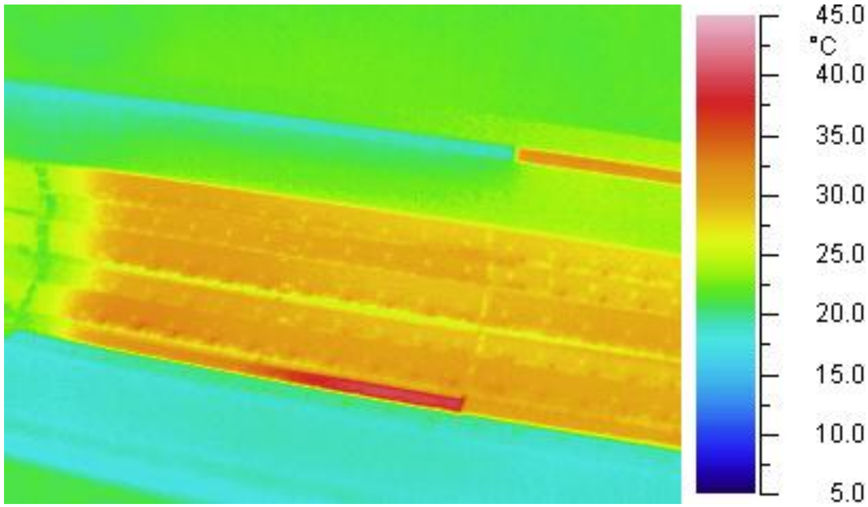


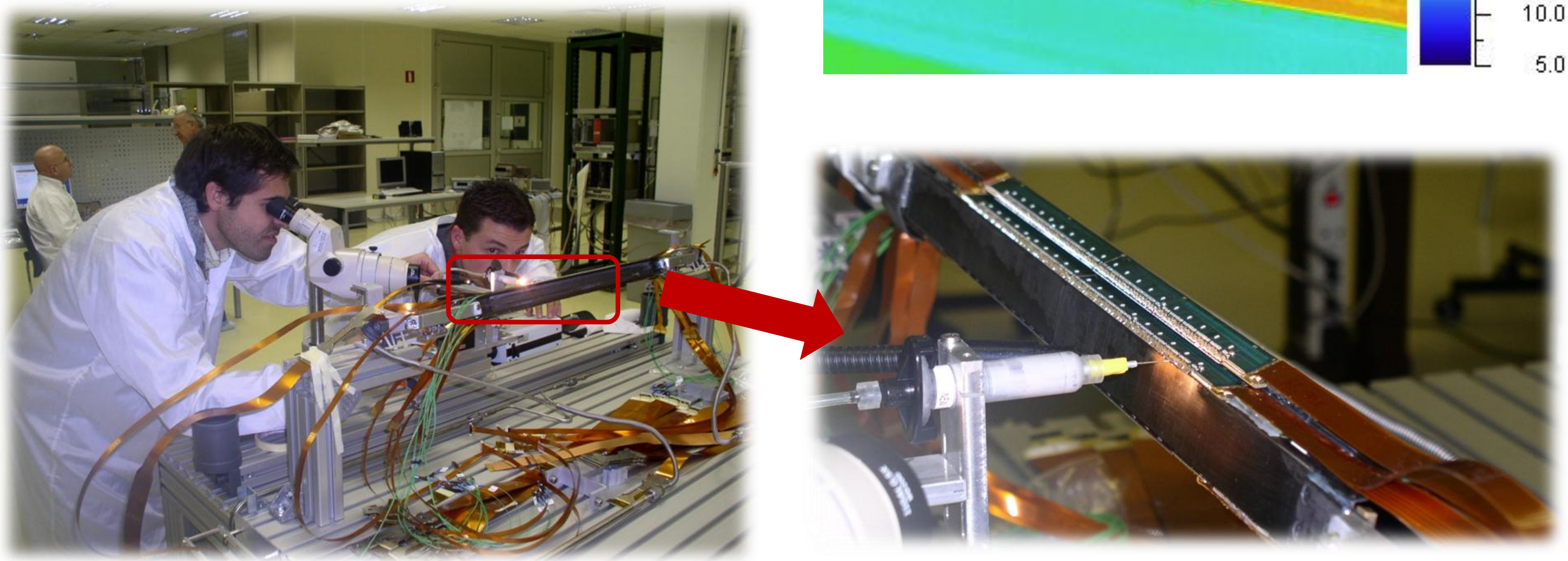
… but it is still better than the experiment because you have access to the hardware

- … and this is extremely useful to:
  - Debug the software and the integration
  - Tune the monitoring and archival tools (voltages, current and temperature measurements)
  - Fix the number convention (i.e. software-hardware module correspondence)
  - … and in case of small accident … there is still something that can be done!!!

… one example

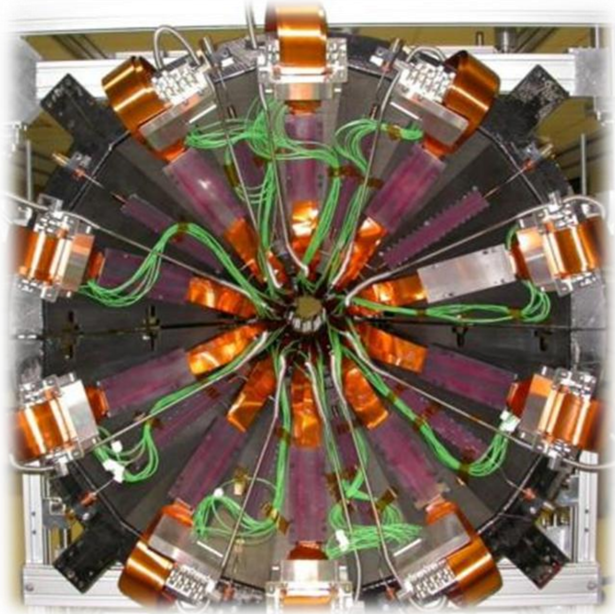
- We measured a poor thermal contact which caused higher temperature in one half-stave …
- We decided to operate surgically the stave instead of rework the full sector





Mechanical integration

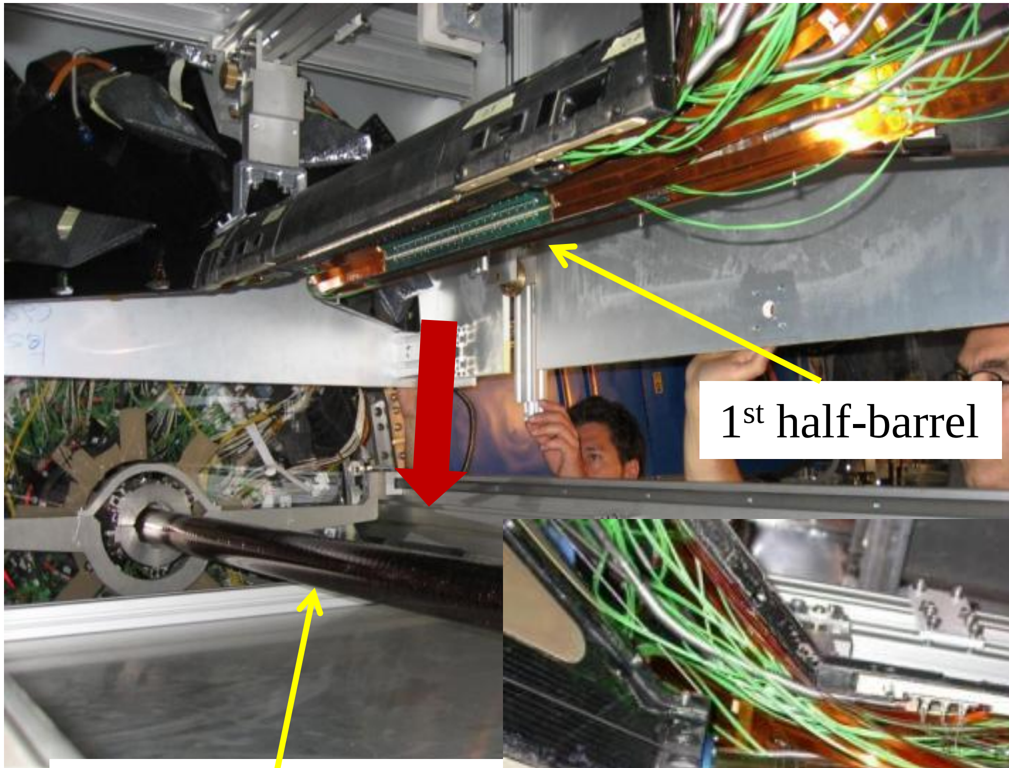
Integration in the Department Silicon Facility



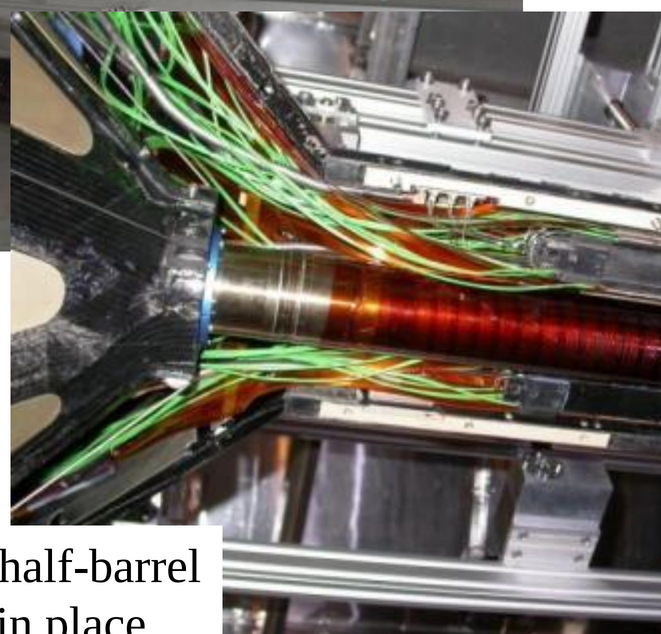
The travel inside the heart of ALICE

Installation: …for the press (I)

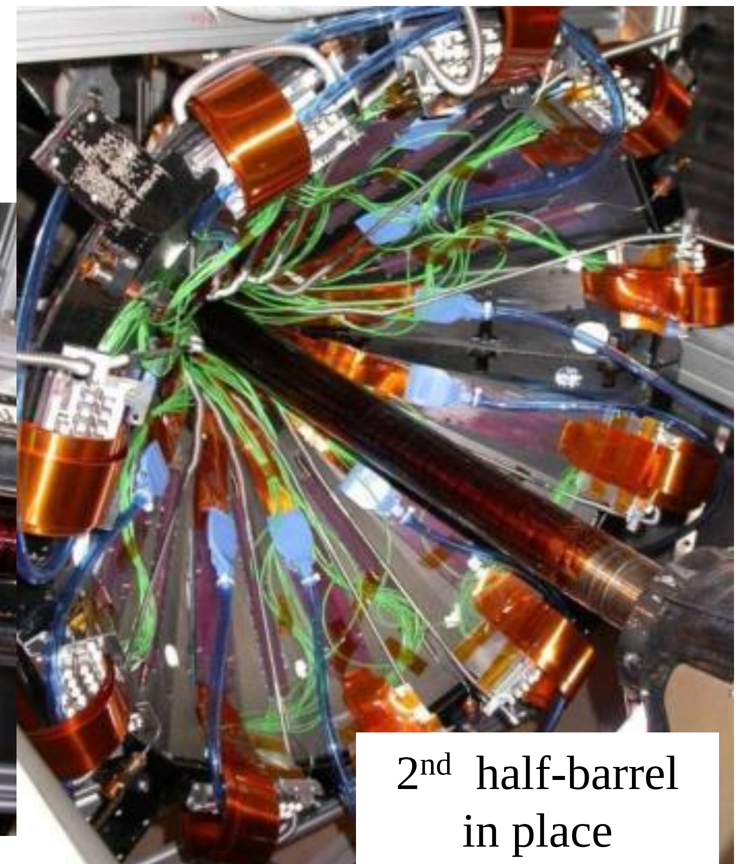
SPD Internal mean radius ≈ 3.9 cm
Beam pipe radius ≈ 3 cm



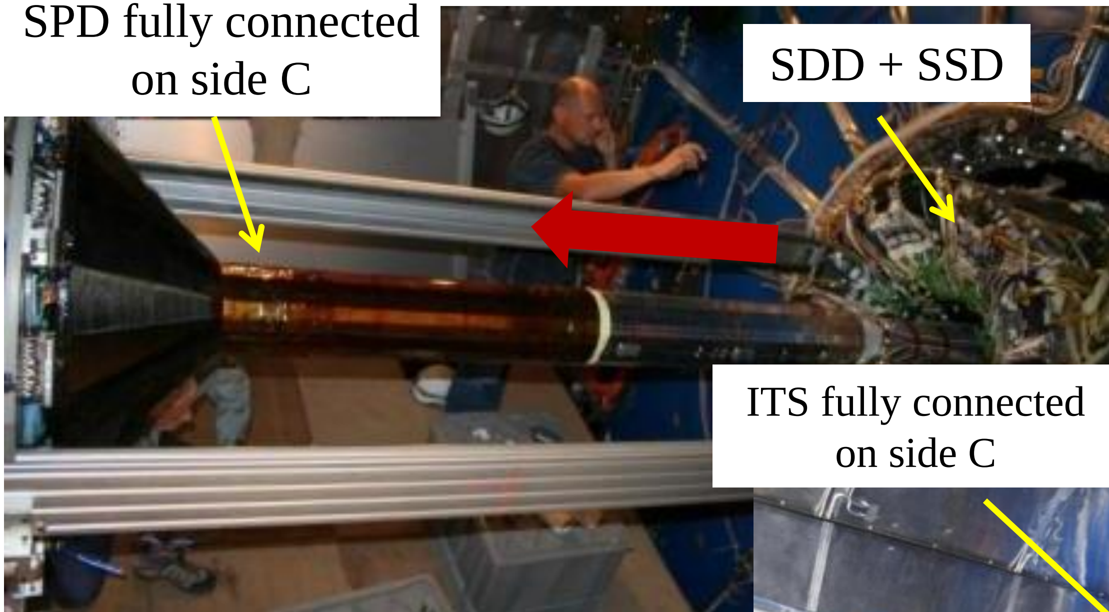
Beryllium Beam pipe



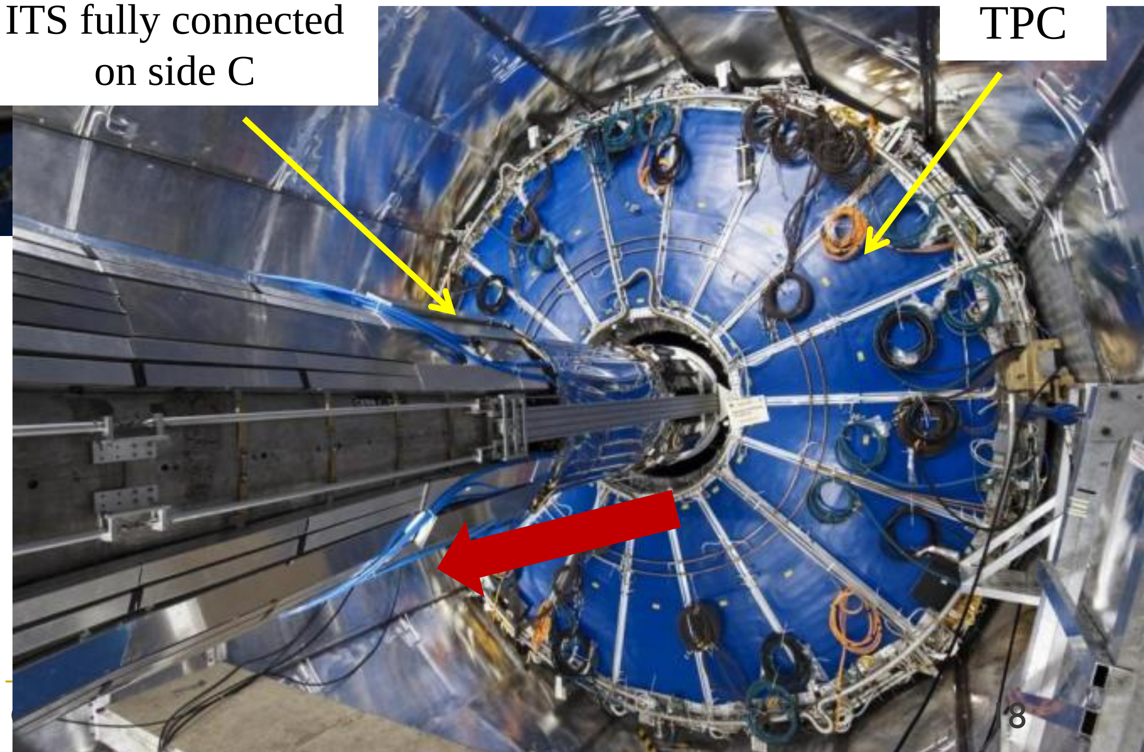
1^{st} half-barrel
in place



Installation: …for the press (II)

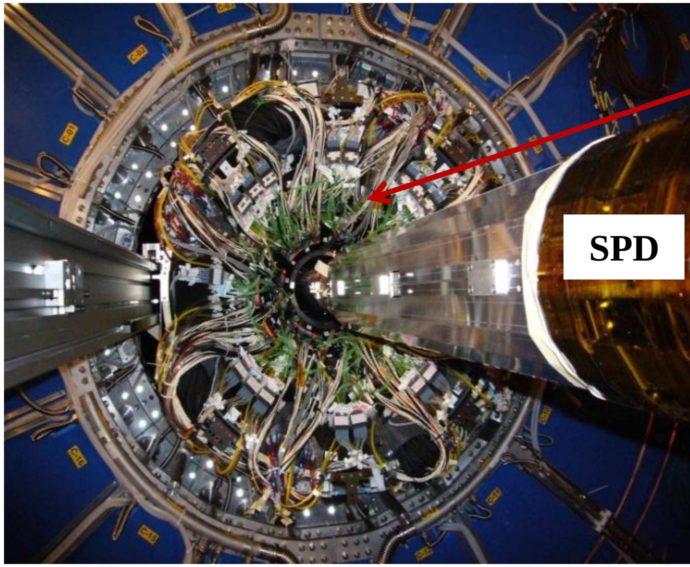


SDD+SSD moved over the SPD to form the ITS

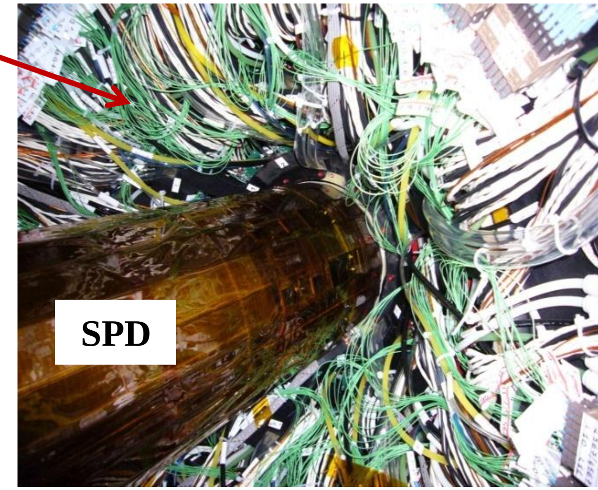


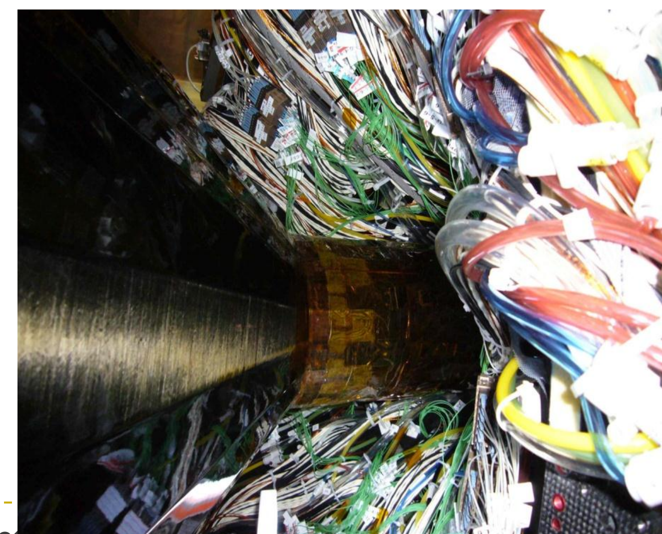
TPC moved over the ITS

Installation: ...what really happened

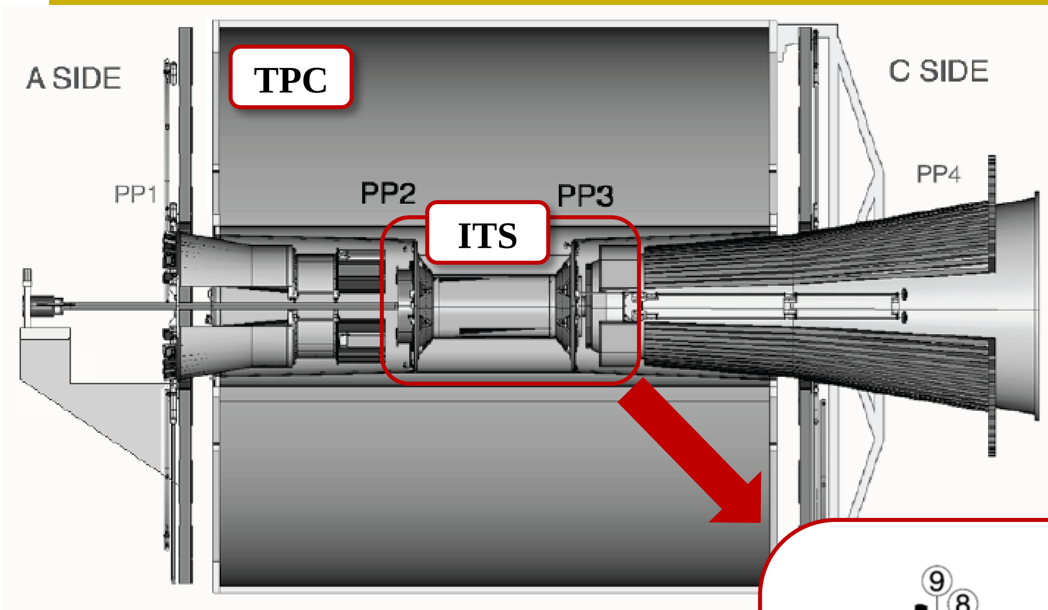


SDD + SSD services

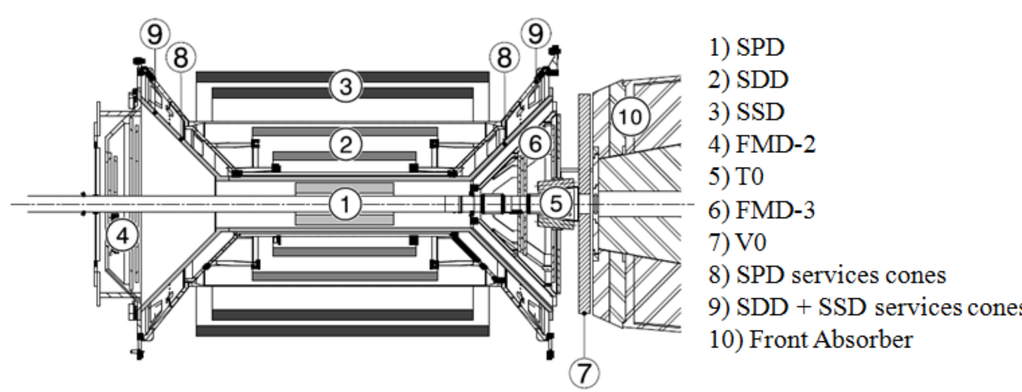




ITS + TPC: section view



Once the TPC is moved in the final position, there is no more access to the ITS and to the Forward detectors. In addition, two of the 4 patch panels (PP2 and PP3) used for services connections are not accessible anymore



Any access to the detectors or to the services needs a very long and risky procedure:

The time estimate to access the ITS has been recently estimated to be of the order of 7 months

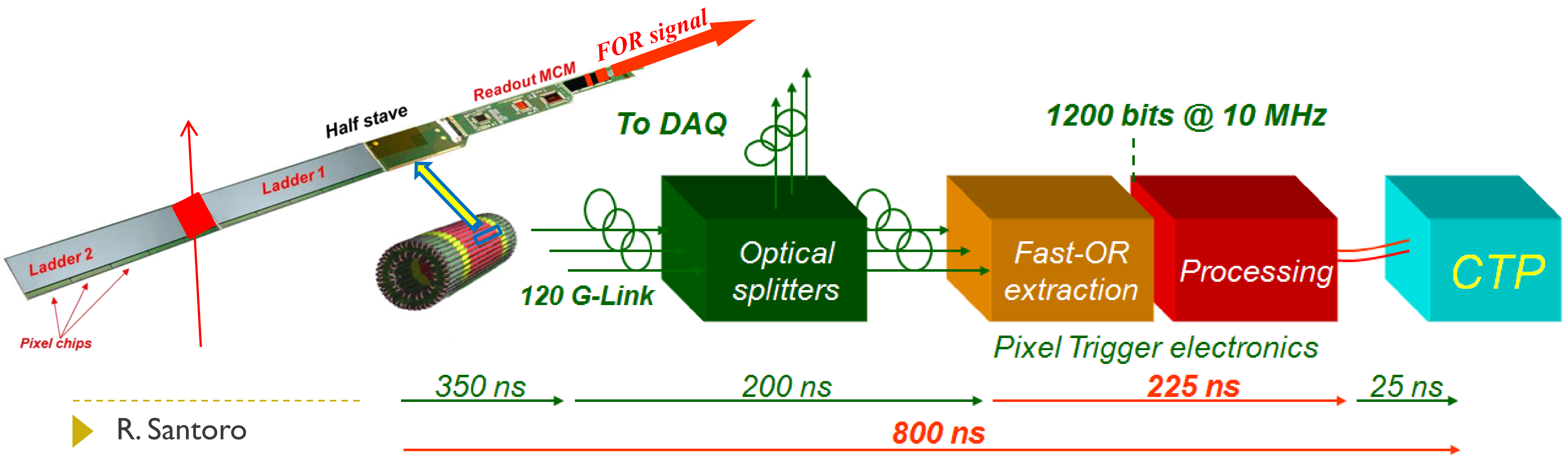
What we experienced?

- Mechanical integration
  - In such a complex and extremely packed detector the good communication between teams or, even better, to have a unique team for the integration could help during the installation
  - Integration tests are also preferable although are not always easy
- Services: better accessibility has to be a must
  - See SPD cooling experience (Rosario Turrisi)
  - Cabling failure (1/120 HS in the SPD)

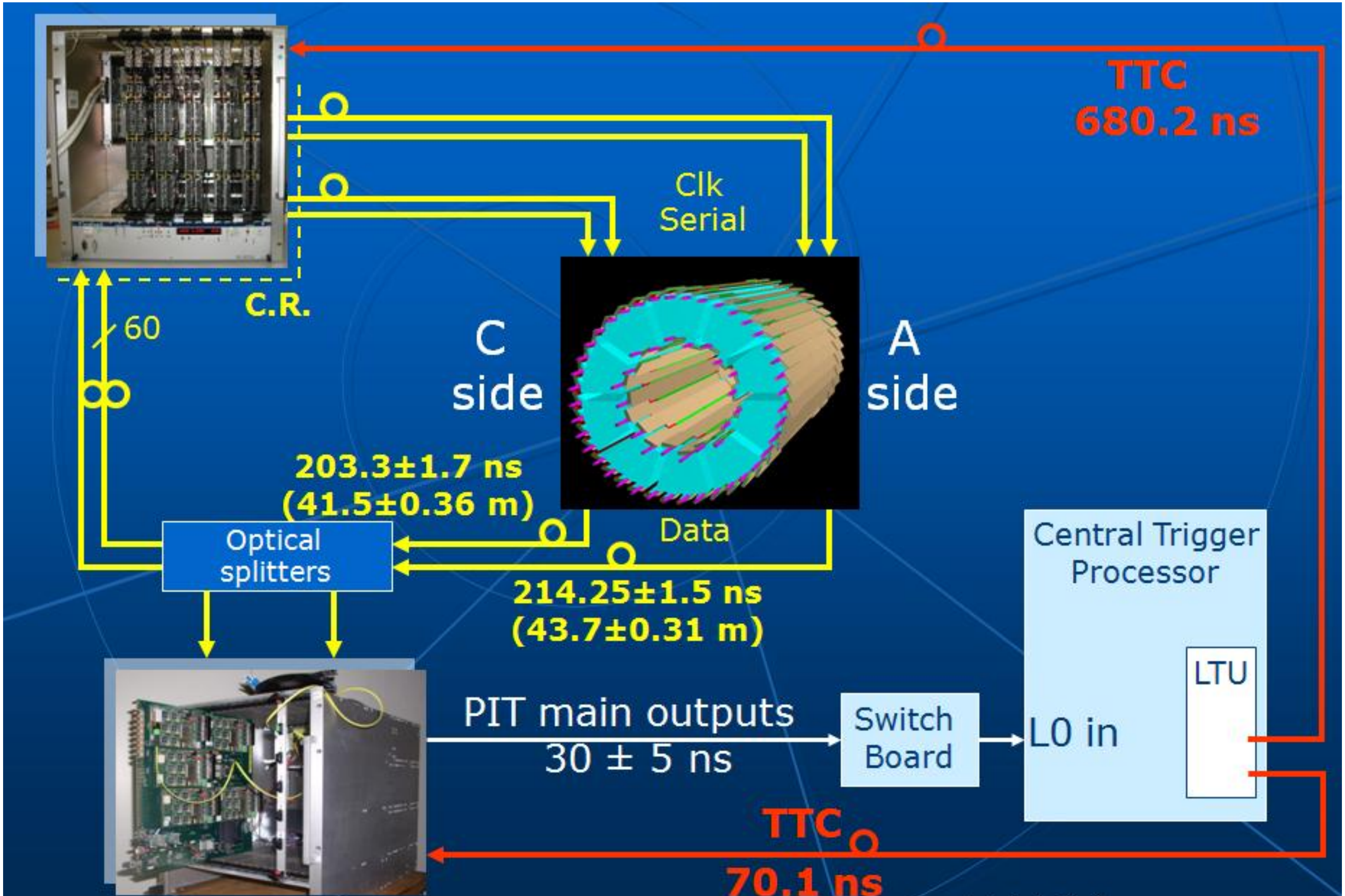
Optical link synchronization

L0 trigger capability

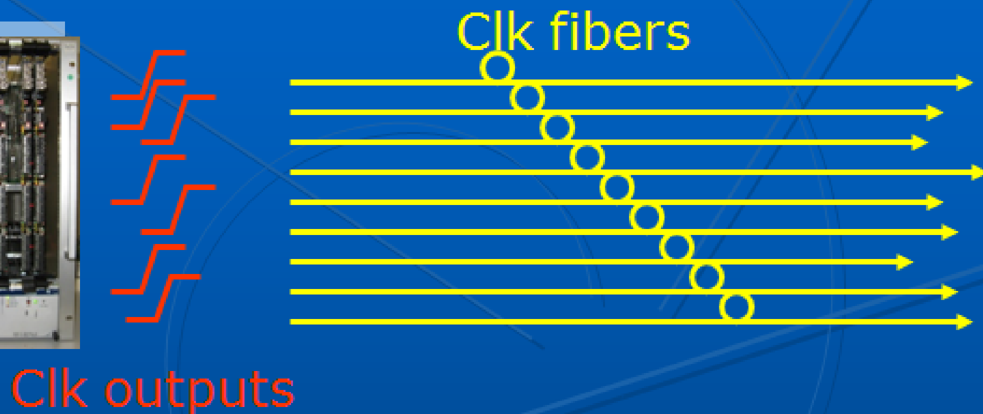
- Pixel chip prompt Fast-OR
  - Active if at least one pixel hit in the chip matrix
  - 10 signals in each half-stave (1200 signals in total)
  - Transmitted every 100 ns
- Overall latency constrain 800 ns (CTP)
- Key timing processes are data deserialization and Fast-OR extraction
  - Algorithm processing time < 25 ns
- 10 Algorithms provided in parallel: useful for detectors commissioning, p-p and Pb-Pb physic
  - Cosmic, minimum bias and multiplicity algorithms
- FPGA remote programmable to guarantee maximum flexibility

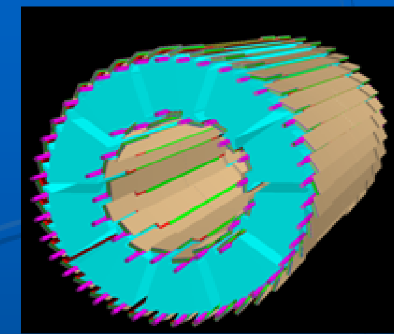


Electronic layout



Detector clock phases alignment





Relative phases of 120 clocks of CR electronics: $\sigma = 0.63$ ns
Propagation delays due to 120 fibers measured: $\sigma = 0.9$ ns

Clock phases at SPD inputs <u>without</u> correction: $\sigma = 1.1$ ns

Delays added to the clock transmitters to compensate for differences
Clock phases at SPD inputs <u>with</u> correction: $\sigma = 0.08$ ns

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What we learned?

- Use optical fibers with the same length is an important requirement but …
- A flexible system is also better
  - Settings to equalize the delays in each channel
  - Settings to adjust the overall time w.r.t. the LHC clock

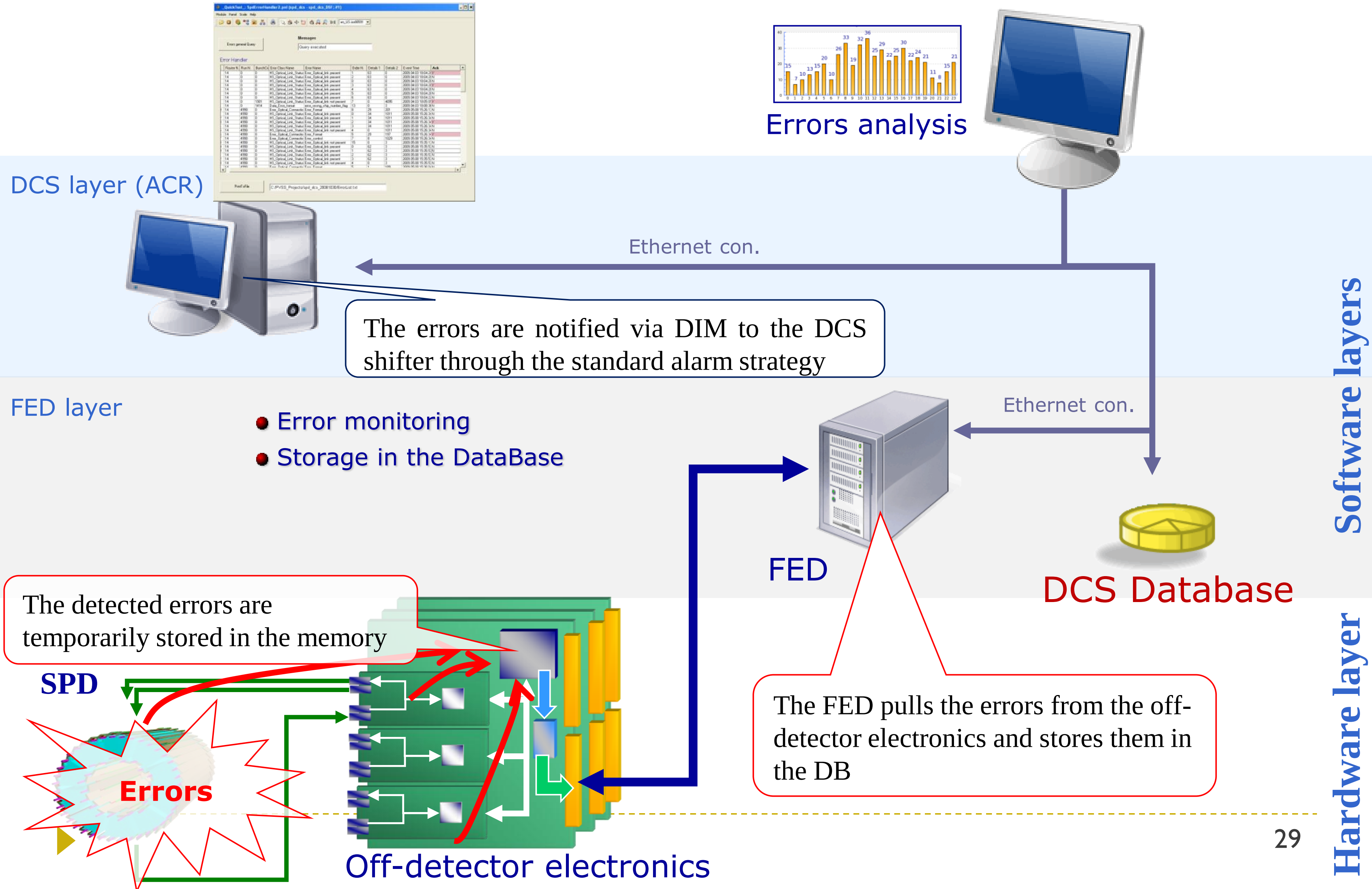
Tools to monitor the data output

Motivation

- Identify the source of problems and fix the failures in complex systems it is always a very hard tasks
  - FEE-electronics, Off-detector electronics, Link communication …
- It is often hard and extremely time consuming to reproduce the problem and to correlate it with external condition
  - Trigger schema, partition schema, beam dependence …

- This is the reason why a system capable to monitor the data output, to flag errors and to store the hardware conditions without disturbing the acquisition would help the expert… but, is that feasible?
- If the system would also be able to suggest the proper action and even to fix the problem by himself… it would be a dream!!!!
  - … but don't be so excited… we don't have it!!!
  - Although, the "Error handler" tool is extremely useful

"Error handler" strategy



What we learned?

- The tool is extremely powerful and makes track of the low level information when the errors occur
- It is important to group errors in categories which can be masked accordingly to the expert needs
  - Useful to avoid that warnings fulfill the DB
- Statistic studies could be useful to monitor the electronics stability or to identify frequent failures

Thanks for your attention

Spares

Fast-OR Algorithms

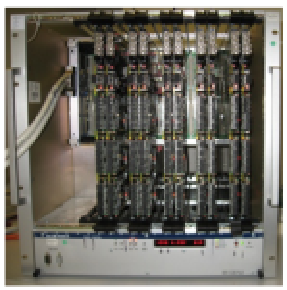
1	Minimum Bias	$(I+O)\geq th_{IO,mb}$ *and* $I\geq th_{I,mb}$ *and* $O\geq th_{O,mb}$
2	High Multiplicity 1	$I\geq th_{I,hm1}$ *and* $O\geq th_{O,hm1}$
3	High Multiplicity 2	$I\geq th_{I,hm2}$ *and* $O\geq th_{O,hm2}$
4	High Multiplicity 3	$I\geq th_{I,hm3}$ *and* $O\geq th_{O,hm3}$
5	High Multiplicity 4	$I\geq th_{I,hm4}$ *and* $O\geq th_{O,hm4}$
6	Past Future Prot	$(I+O)\geq th_{IO,pfp}$ *and* $I\geq th_{I,pfp}$ *and* $O\geq th_{O,pfp}$
7	Background(0)	$I \geq O+ offset_O$
8	Background(1)	$O \geq I+ offset_I$
9	Background(2)	$(I+O) \geq th_{(I+O),bnd}$
10	Cosmic	*Selectable coincidence, see following list*

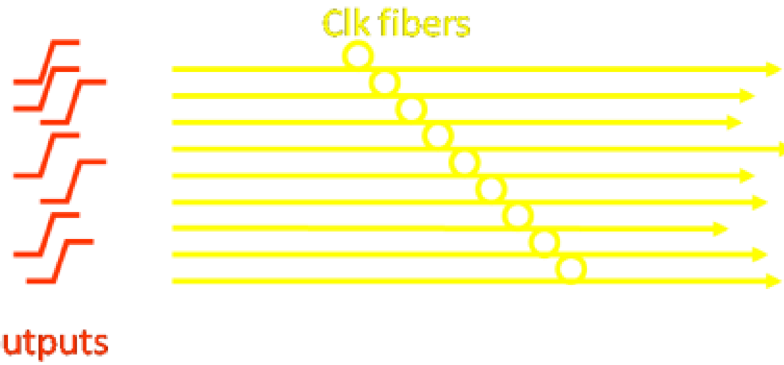
Cosmic algorithms:

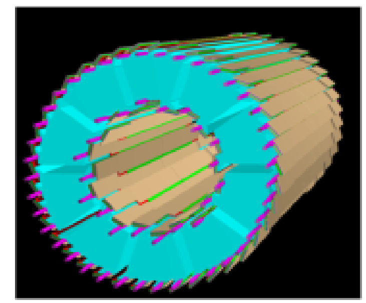
- TOP_outer and BOTTOM_outer
- OR_OUTER and OR_INNER
- DLAYER (≥ 2 FOs in the INNER and ≥ 2 FOs in the OUTER)
- TOP_outer and BOTTOM_outer and TOP_inner and BOTTOM_inner
- TOP_outer and BOTTOM_outer and OR_INNER
- GLOBAL_OR

Timing optimization

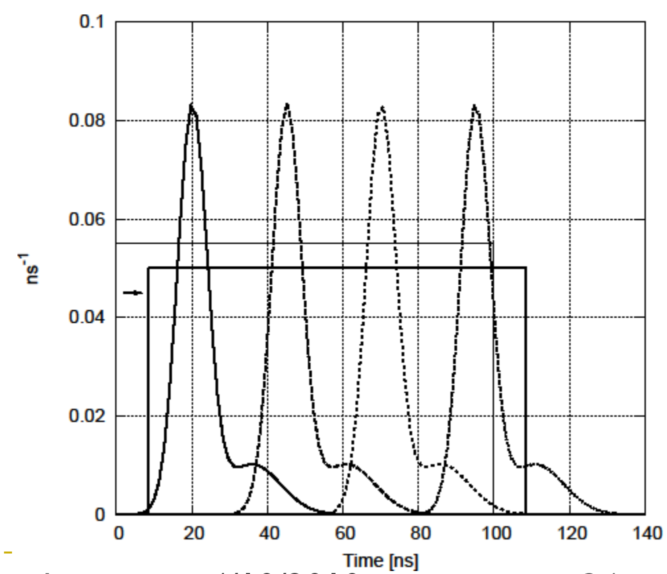
- Fine tuning of the timing for each individual Half-Stave
  - delay added to the clock transmitters to compensate for differences
  - Distribution of clock phases at SPD inputs after correction: $\sigma = 0.08$ ns



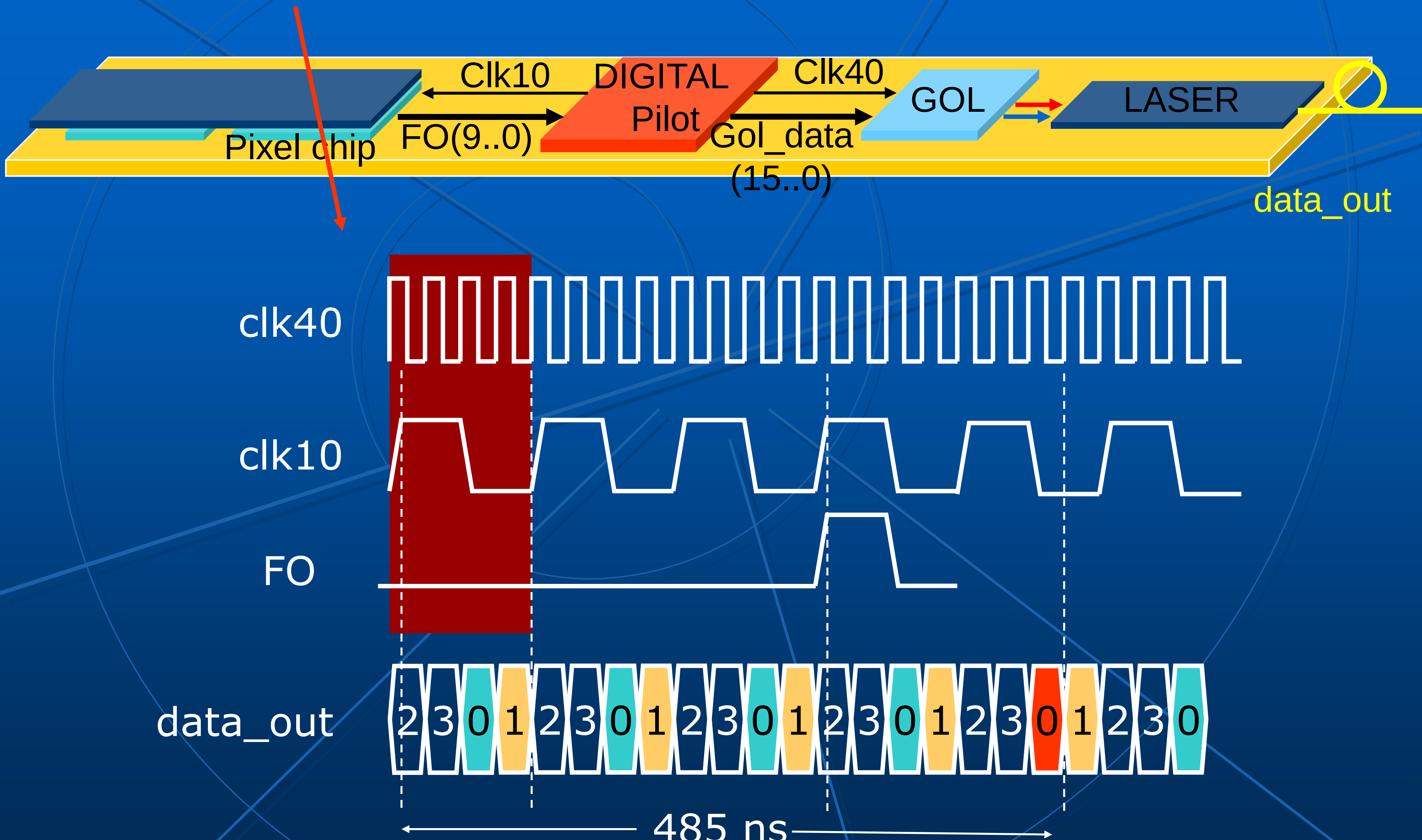




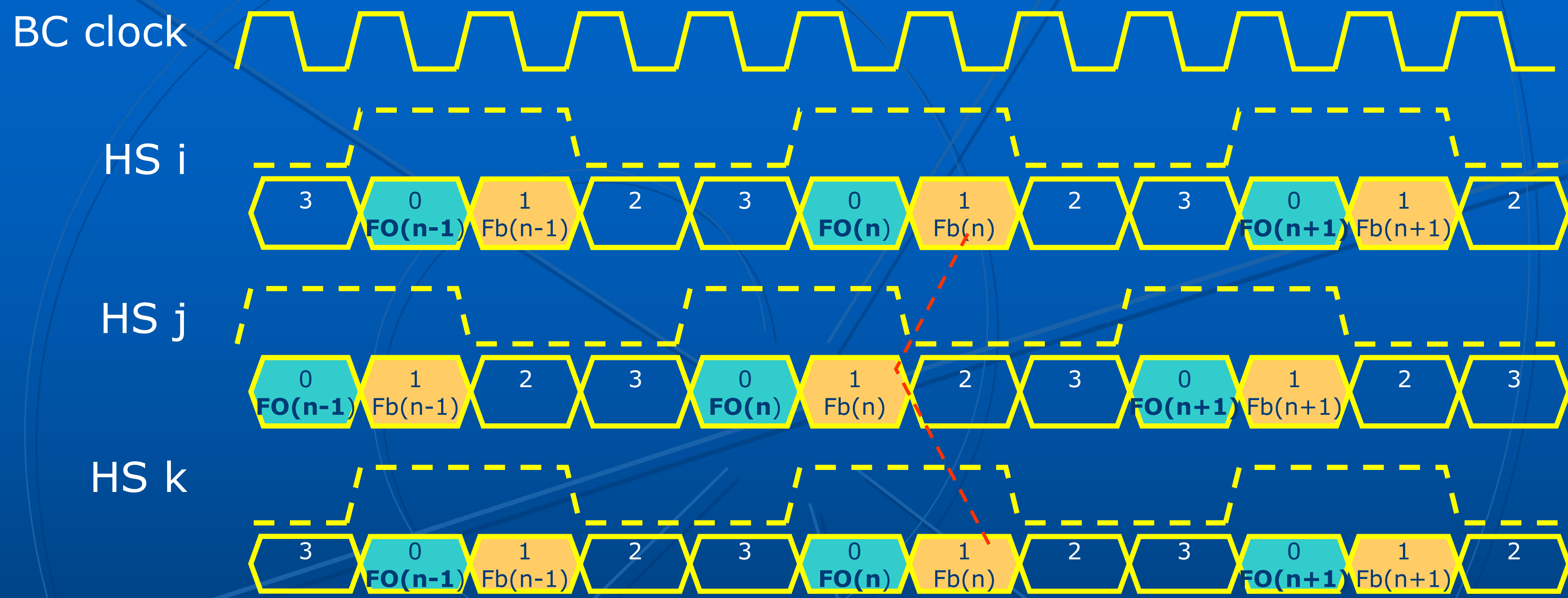
- Fine tuning of the SPD clock phase with respect to the LHC clock (SPD clock 10MHz)
  - Dedicated calibration during collisions has been performed
  - Measure pixel multiplicities versus clock phases
  - Set optimal phase in the clock domain



Fast OR timing



Synchronization



- 40 MHz clocks aligned by equalizing fibers length
- 10 MHz clock phases aligned by broadcast signal on TTC

- One clock period uncertainty left -> Measure relative phases
  - ***Measure arrival time of trigger feedback***

Frame alignment