Operational experience of the Upstream Tracker of LHCb

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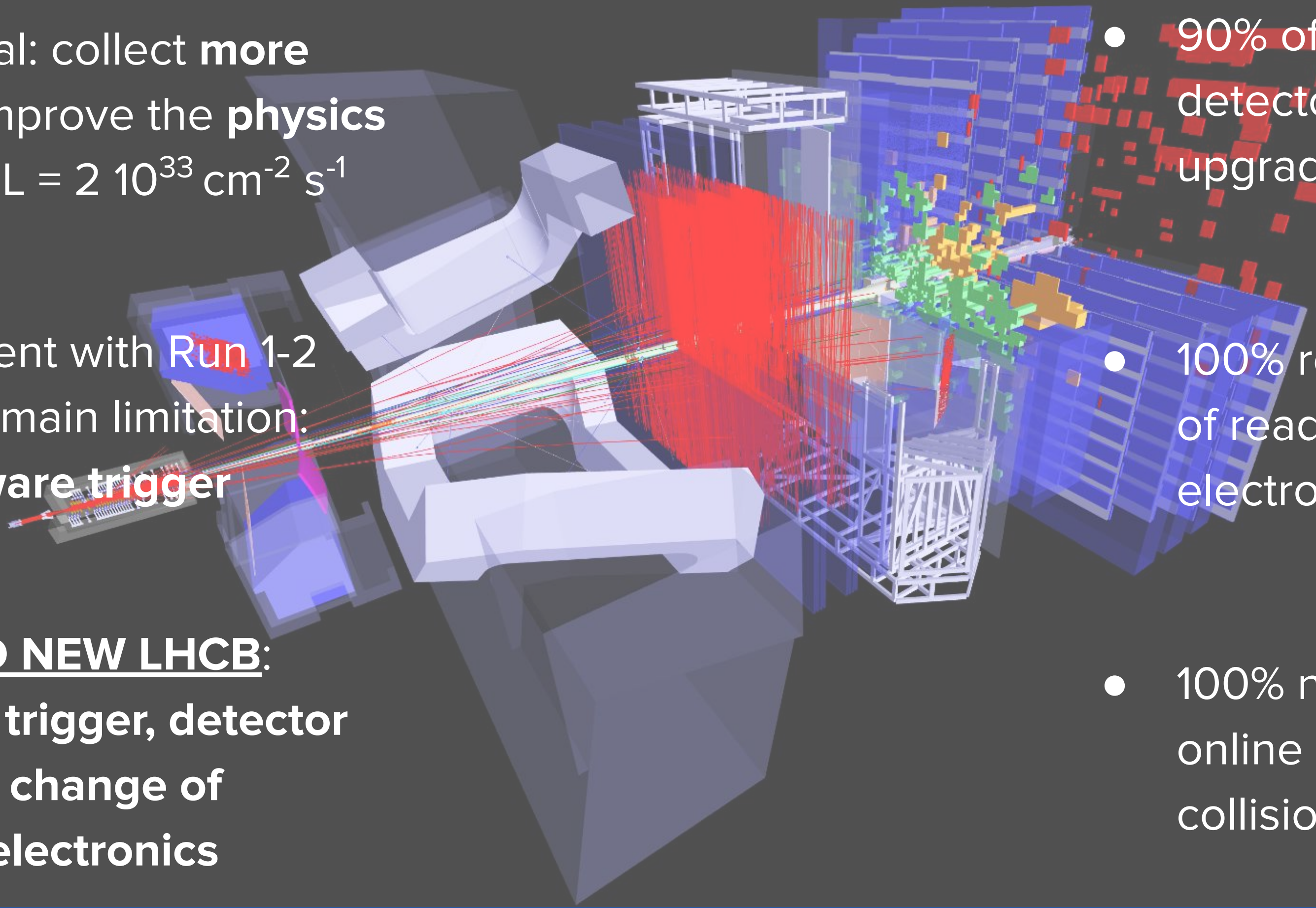
on behalf of the LHCb collaboration

VERTEX 2023 - 32nd International Workshop on Vertex Detectors

LHCb

UT Upstream Tracker

LHCb experiment



Run 3 goal: collect **more data** to improve the **physics results** → L = 2 10^{33} cm^{-2} s^{-1}

Not efficient with Run 1-2 detector, main limitation: **L0 hardware trigger**

→ **BRAND NEW LHCB**: **software trigger, detector upgrade, change of readout electronics**

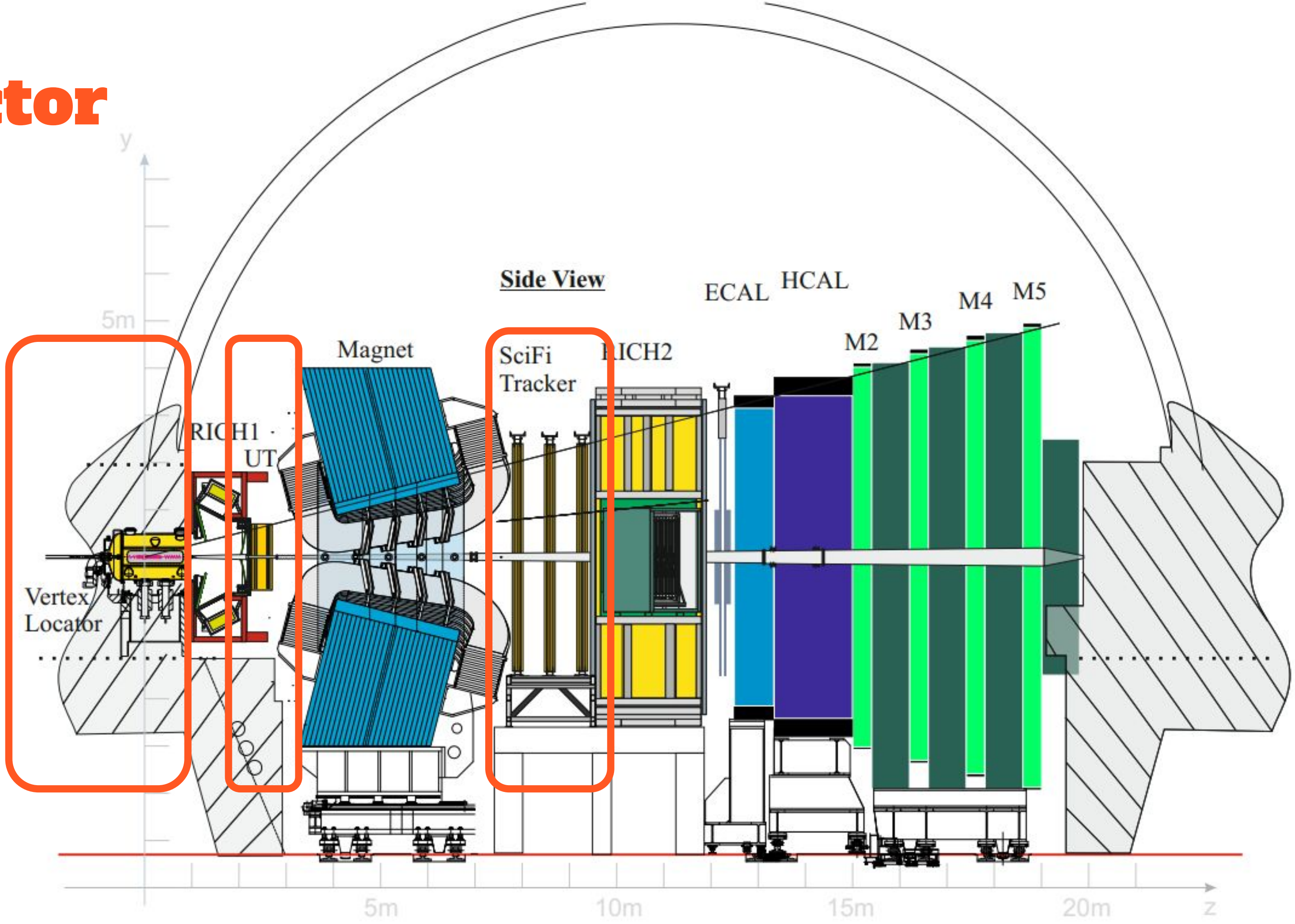
- 90% of the detector channels upgraded
- 100% replacement of readout electronics
- 100% new DAQ & online system @ collision rate

LHCb detector

Single-arm forward spectrometer

Pseudorapidity range: $2 < \eta < 5$

Tracking system



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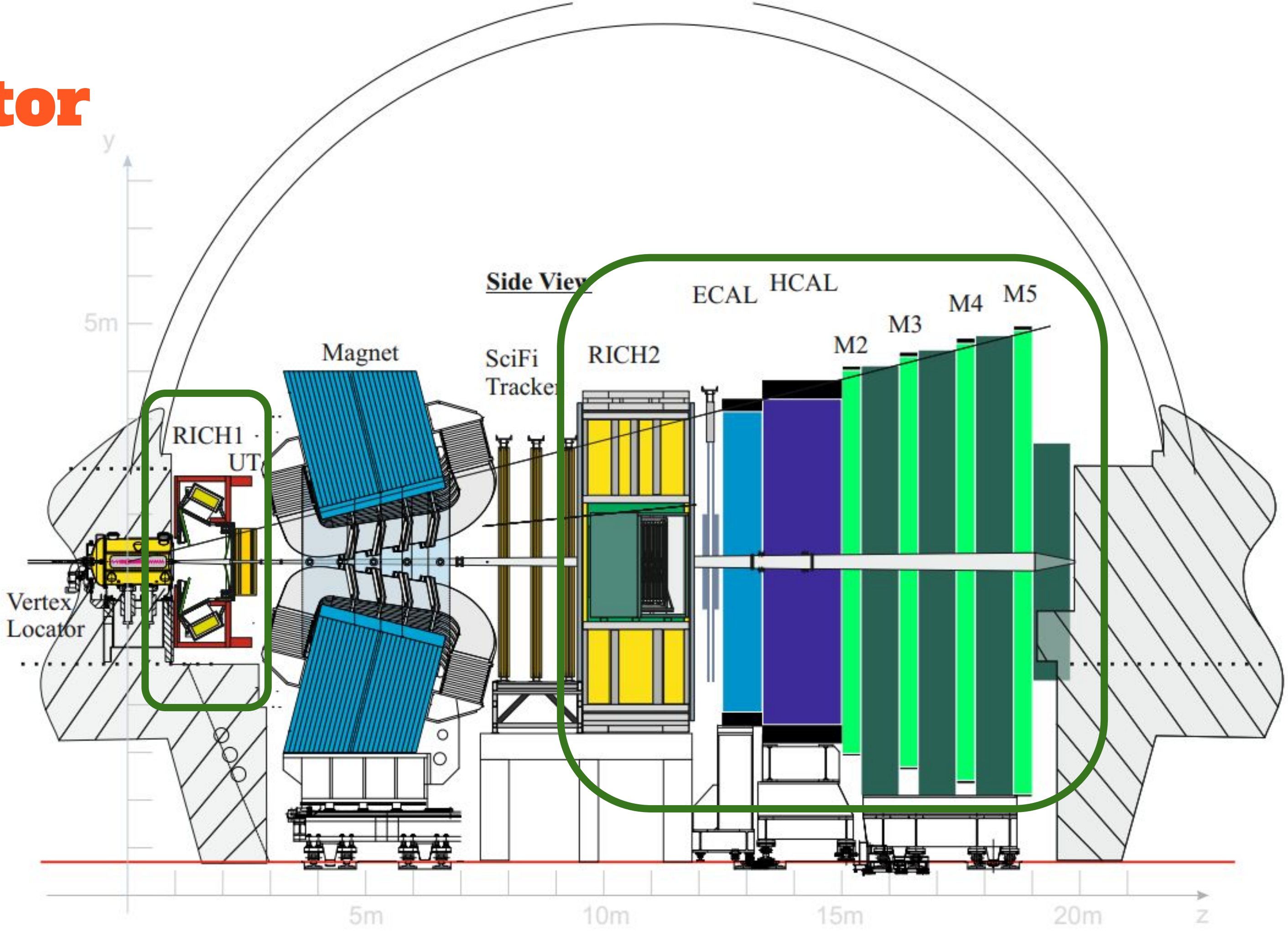
Particle identification system



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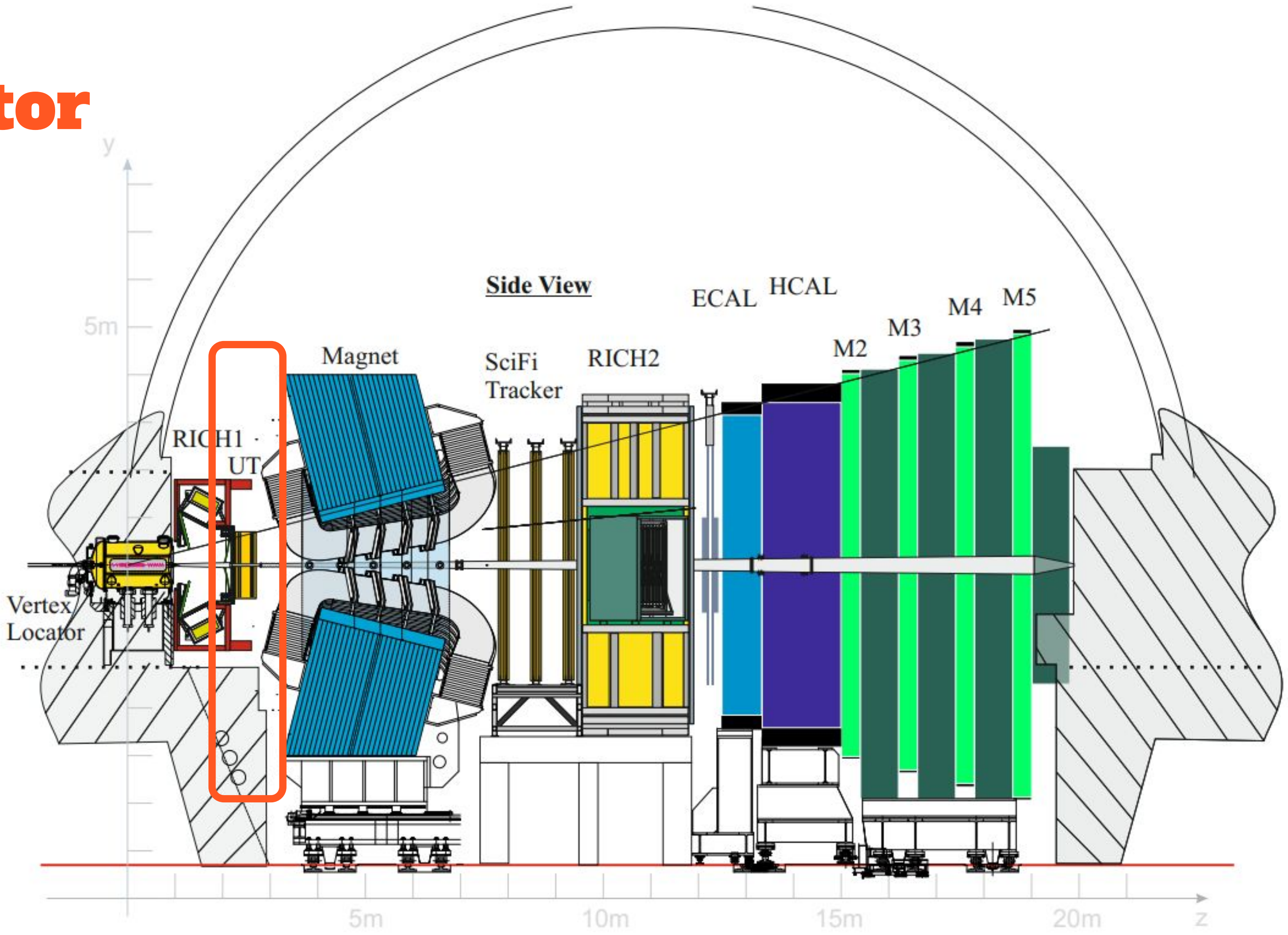


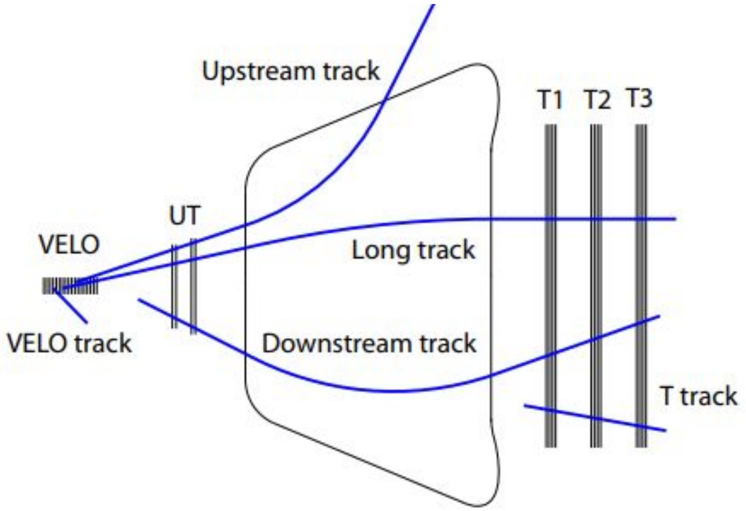
Upstream Tracker (UT): importance in LHCb

- Track reconstruction: UT fundamental to improve the **momentum resolution** of Long tracks

- **Ghost rate** reduction: factor 2 improvements,

  essential for the software trigger

- **Long lived particles reconstruction** decaying after the VELO (e.g. Λ, K^0_S)



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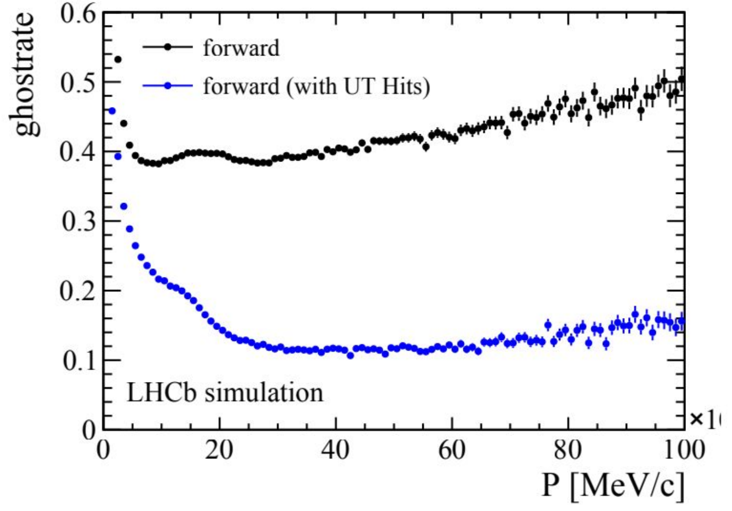

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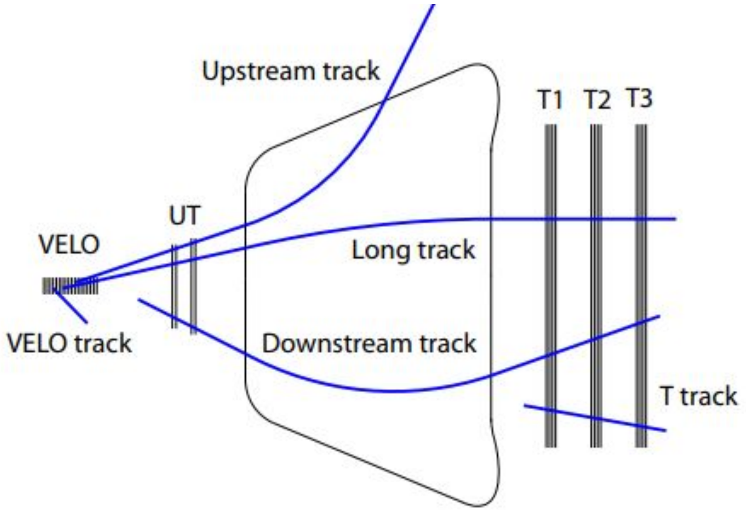
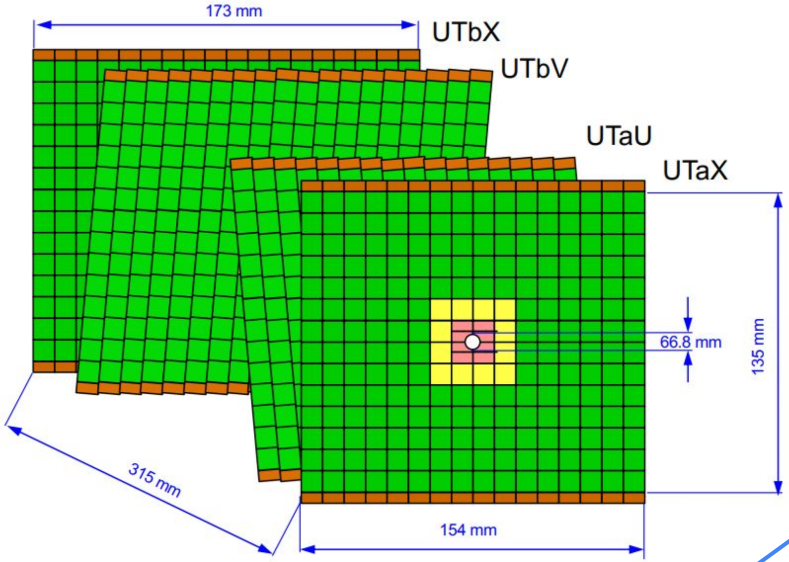
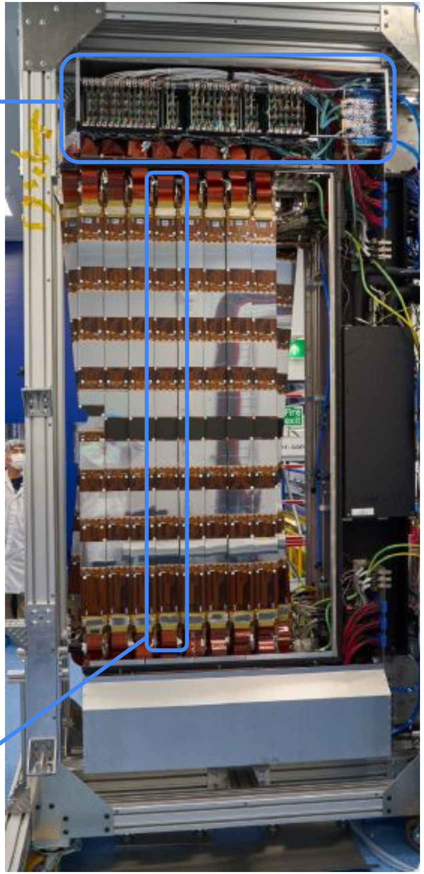


Upstream Tracker (UT)

- **Silicon strip** detector
- **4 layers** with vertical and stereo (+/- 5 deg) orientation
- divided in **2 sides**: A-side and C-side
- organized in 68 **staves**



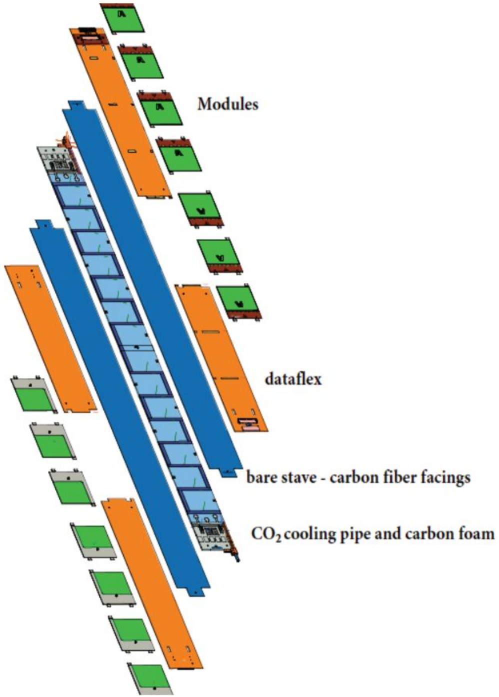


[The LHCb Upgrade (arxiv.org)](arxiv.org)

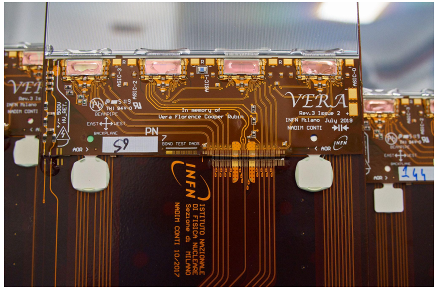
Upstream Tracker (UT)

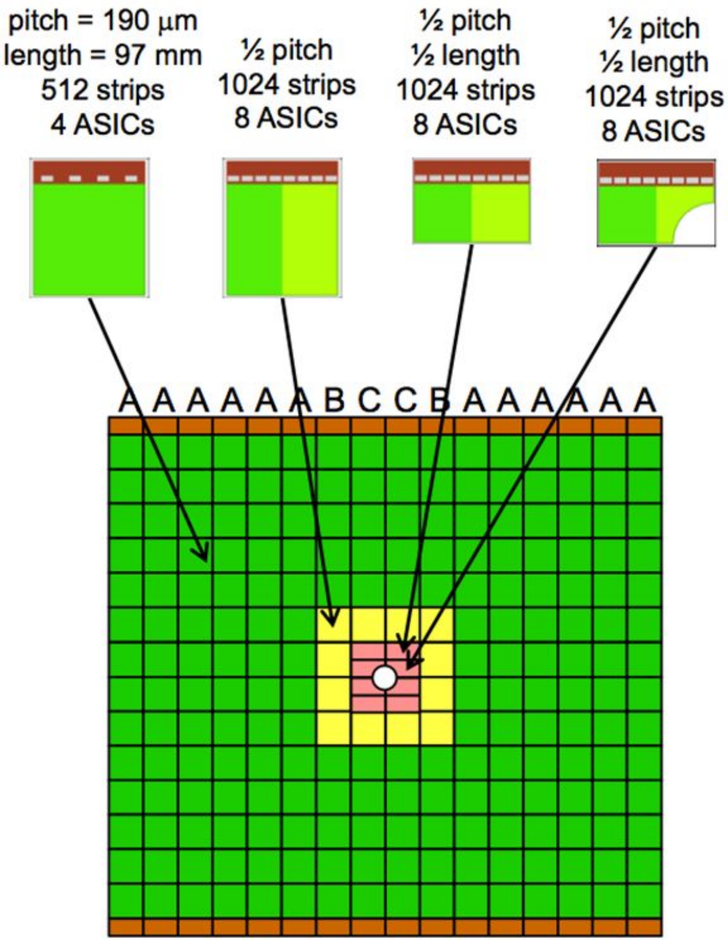
Stave:

- 99.5mm x 1640mm (width x length)
- **carbon fiber structure** with thermal and structural foam in between
- S-shaped titanium **cooling pipe**
- 4 Flex Cu- Kapton cables, power and data distribution
- Single stave can host 14 or 16 **modules**, on both sides



Upstream Tracker (UT)

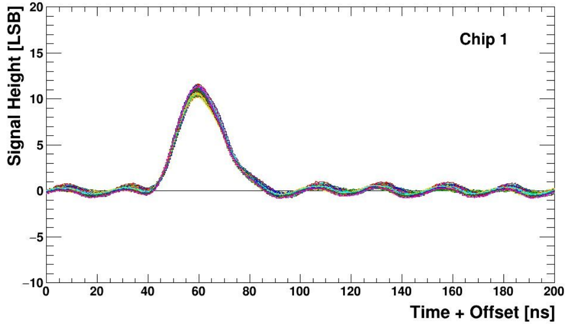




Modules

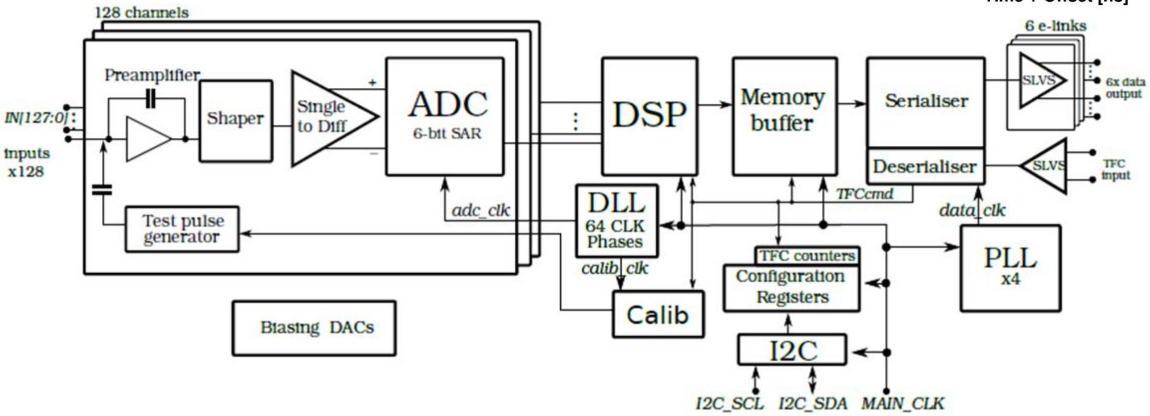
- **silicon** micro **strip** sensors (**A-Type**: p-in-n; **B-**, **C-**, **D-**type: n-in-p)
- Hybrids: VERA (4 ASICs), SUSI (8 ASICs)
- Front-end ASIC (**SALT**) glued and bonded to hybrid flex
- Ceramic stiffener (PBN): good thermal conductivity and electrical insulation

Upstream Tracker (UT)



Silicon ASIC for LHCb Tracking (SALT):

- **CMOS** 130 nm technology
- **128 channels** / ASIC
- **6 bit** ADC / channel

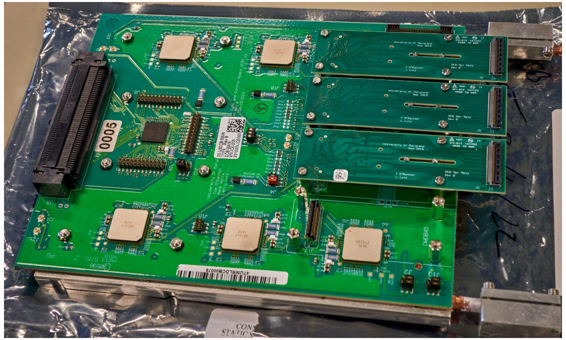


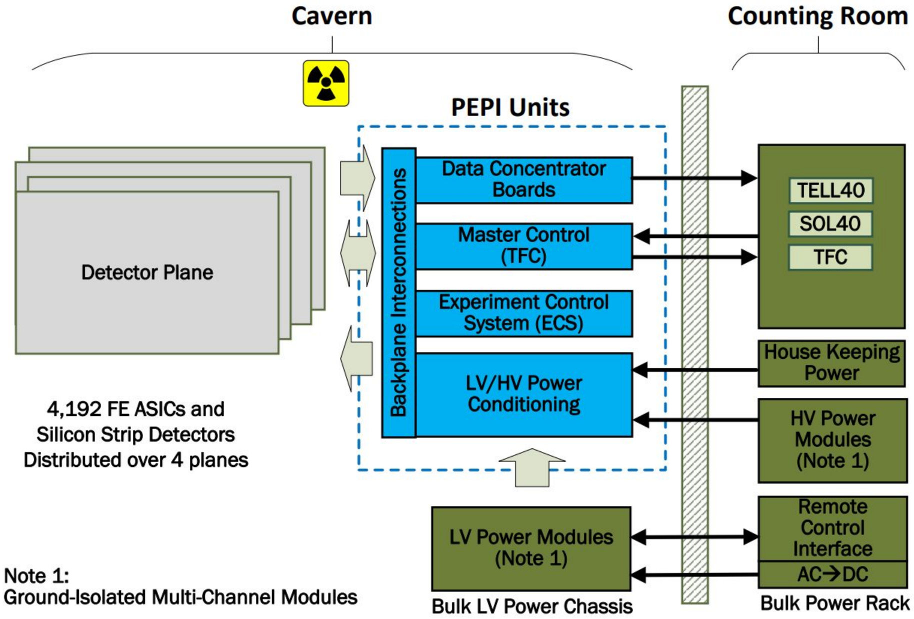
- Digital Signal Processing (DSP): pedestal and common mode noise subtraction, zero-suppression, data formatting, spillover correction
- peaking time~25 ns, S/N~20, input C=12 pF, power dissipation/channel < 6mW

Peripheral electronics

Periphery electronics processing interface (PEPI) to read out and control the detector:

- 24 **backplanes**
- 24 pigtail power breakout boards (**P2B2**s)
- 248 data and control boards (**DCB**s)





The **GBTx**, mounted on the DCBs, implements bidirectional **links** between the **detector** and the **counting room**

UT timeline

Installation

completed in March 2023

UT timeline

Installation

completed in
March 2023

Commissioning

NOW

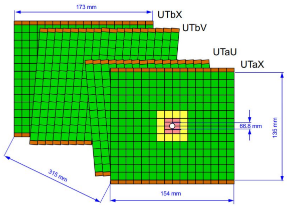
UT path to collect physics data...

to make UT work..

DETECTOR SAFETY

DETECTOR MONITORING

UT



to take data..

FIRMWARE

ECS

Software

to take good quality data for physics..

Time alignment

Space alignment

Calibration

Data quality monitoring

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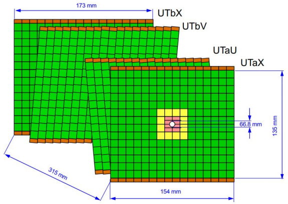

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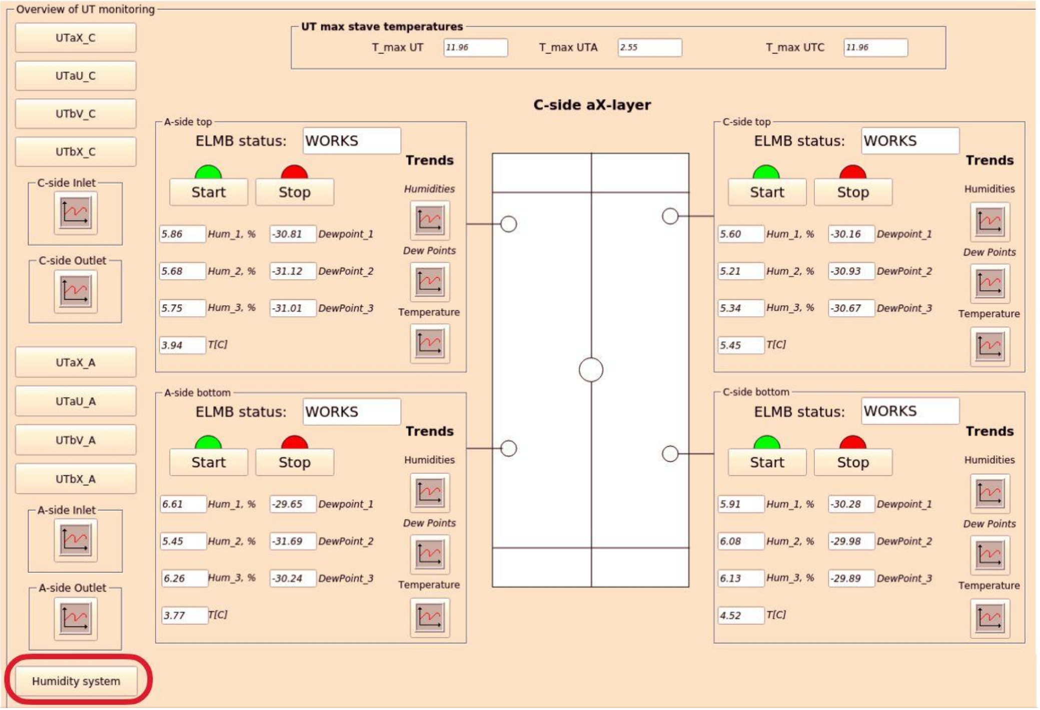
Detector safety:

- **Humidity** inside the box
- **Temperature** of the **electronics**
- **Stave temperature**
- **Current** and **Voltage**

  (high and low voltage)



Alarms

- exploiting sensors
- monitoring, warning the shifter
- action taken by expertes

DSS

All the switches and sensors installed and active, DSS panel working

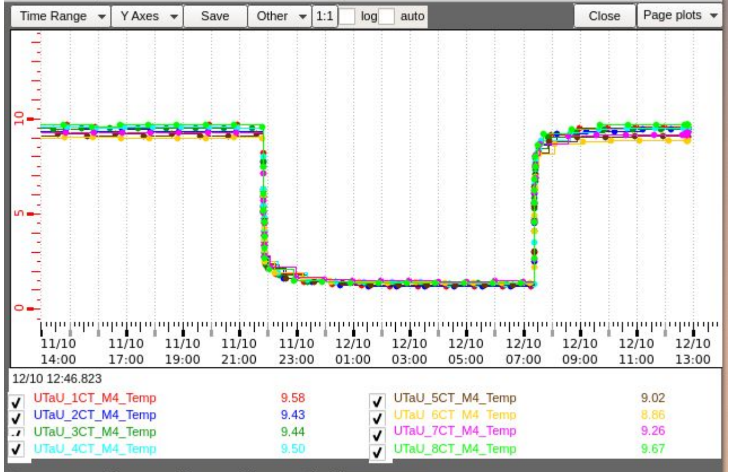
- thermal switches + sensors
- regulated to operate in a range
- action taken by DSS

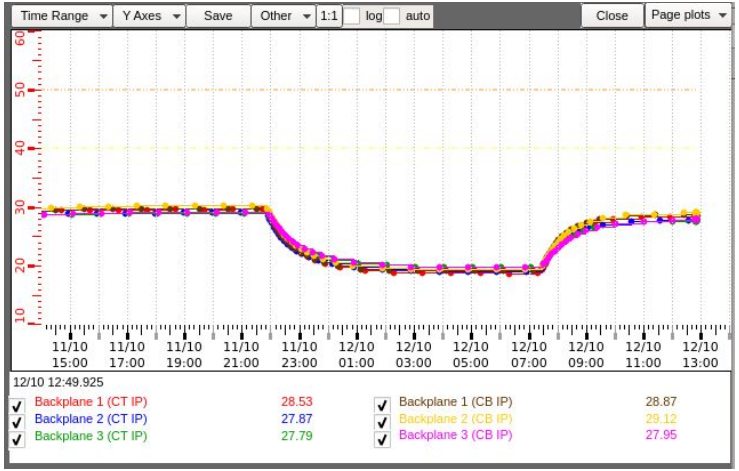
Cooling system

1. **module** cooling: bi-phase CO_2
   a. manifolds connect to the cooling tube of the stave
   b. single tube for each stave
   c. sensor design temperature: -5℃

   ➜ **current** setpoint **temperature 0℃** , need to optimized the box sealing to reach design temperature (during YETS)

2. **peripheral electronics** cooling: demineralized/mixed water





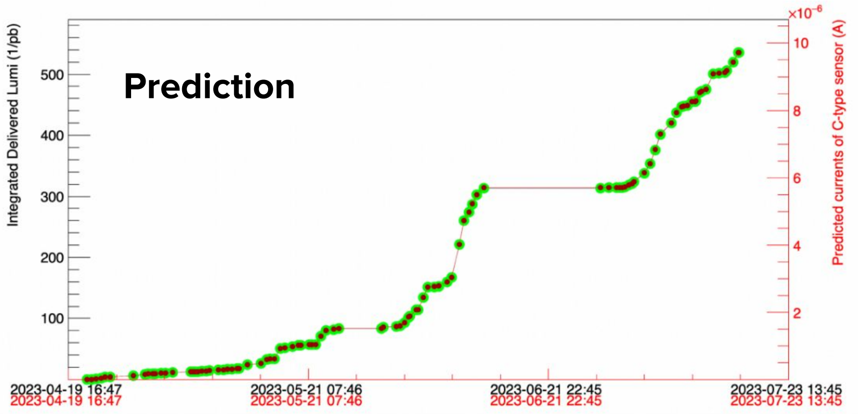
High voltage

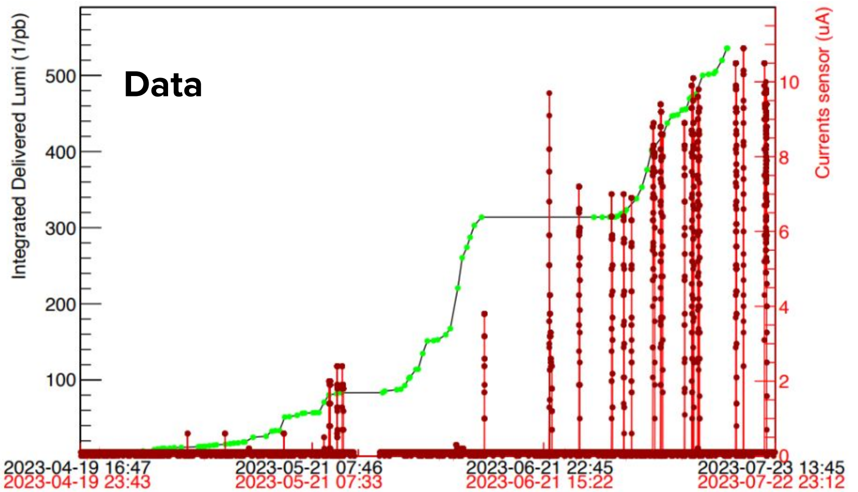
- High voltage for sensors depletion
- Monitoring panel in place: scan of the current over time

$$\Delta I = \alpha * \Phi * V$$

- Total Fluence Φ
- Damage rate α
- Sensor volume V

Only part of the detector considered





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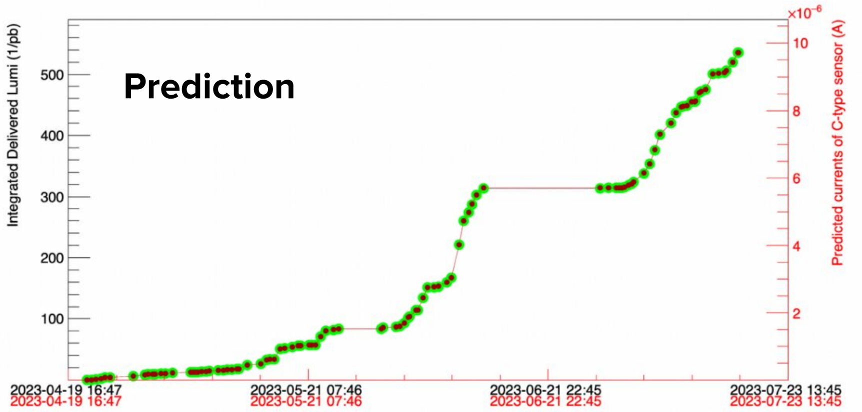
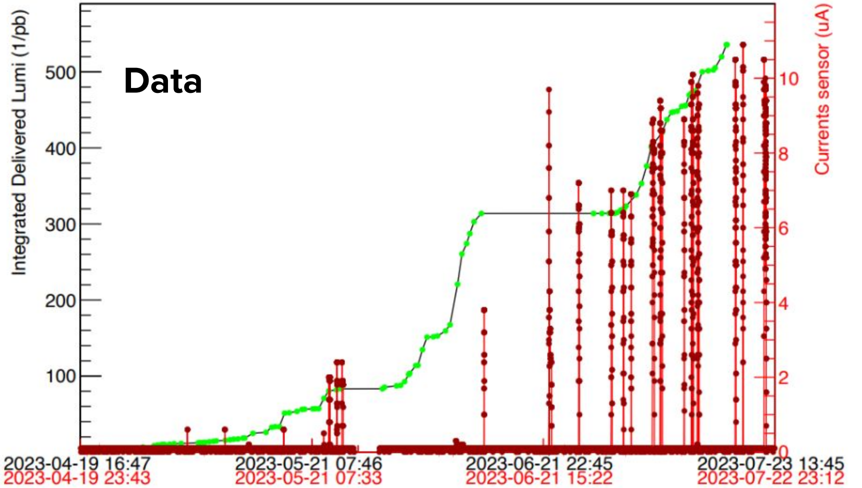


Good agreement between data and prediction:



- no **additional current** in the detector -> monitoring for the UT wellbeing
- extend to higher luminosity to predict **annealing**

UT path to collect physics data...

to make UT work..

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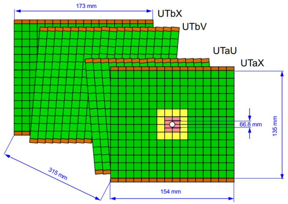

to take data..

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Space alignment

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Data quality monitoring

Firmware

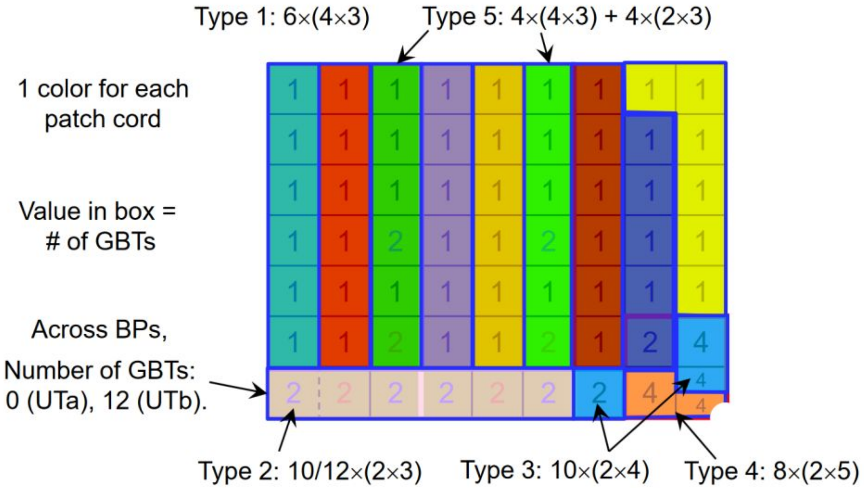
- **Readout of the detector** possible with PCIe40 cards hosting

  Intel Arria 10 **FPGA**: transforms the data from ASIC to PCIe format

- **5 flavours**, design to cope with different occupancies and to minimize the cost

flavour= (#ASICs x #e-links)

GBT frame byte	13	12	11	10	9	8	7	6	5	4	3	2	1	0
4 x 3-eports			24-bit			24-bit			24-bit			24-bit		
2 x 3-eports			24-bit					24-bit						
2 x 4-eports			32-bit					32-bit						
2 x 5-eports			40-bit					40-bit						



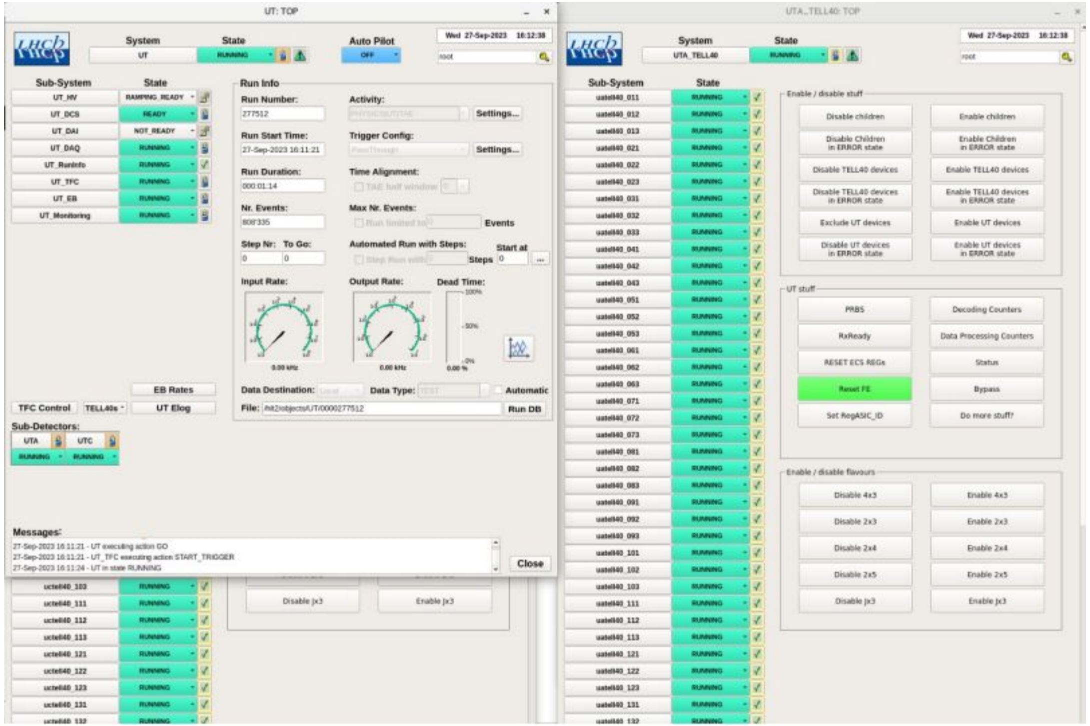
Implemented to work in Non-zero-suppressed (NZS) and in Zero-suppressed (ZS) mode

ECS

- Developed a complete Experiment Control System: **configure** and **control** the back-end and front-end electronics

- One panel for each part of the detector, organized in a **tree structure**

- Can be used as **debugging tool** for synchronization checks



Operating the detector with 92% of the ASICs enabled due to known power issues (to be recovered during YETS to run with 99% of the ASICs)

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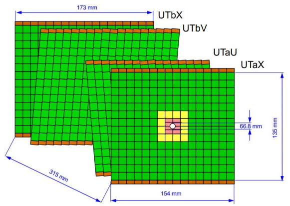

to take data..

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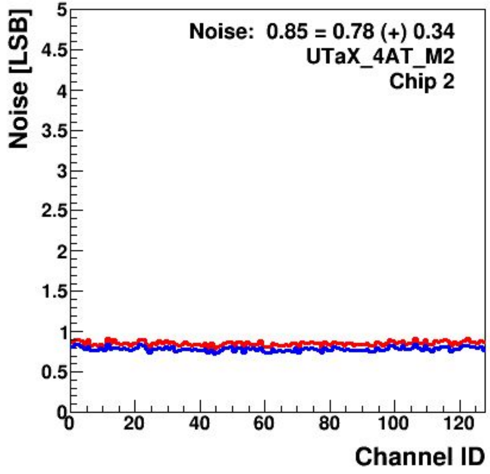
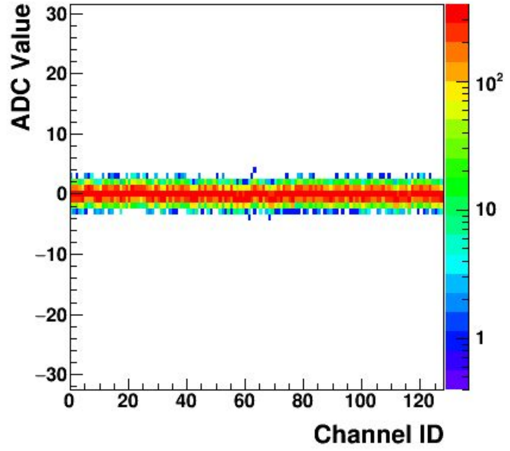
Performance studies

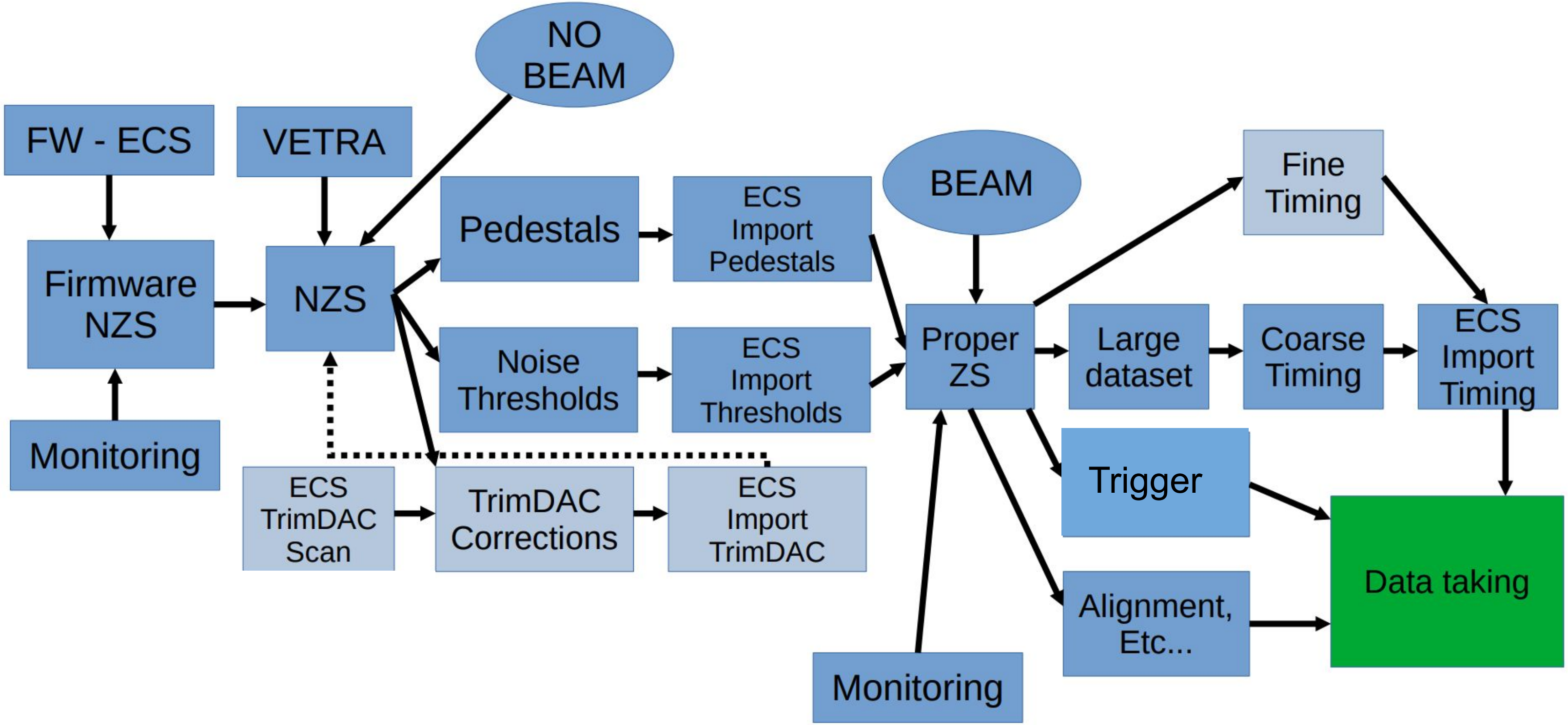
Characterization of the **hybrids** in the early stage of the commissioning to illustrate the **behaviour** of the **detector**

- Data collected in **bypass mode** (data not serialized by TELL40)
- Tests performed **before and after the installation**: good agreement of noise and bad channels
- Constant values of noise and pedestals during the installation time
- 0.16% of all the channels analysed are tagged as **bad channels** (0.07% pedestal shift, 0.09% high noise)



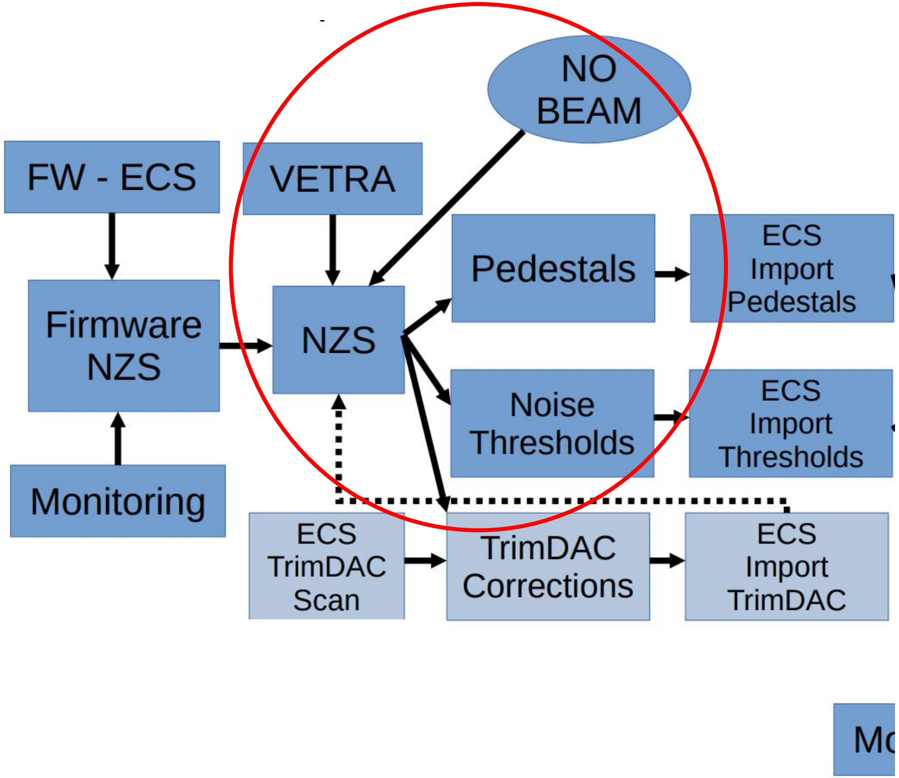


Path to the data taking



Path to the data taking

Calibration

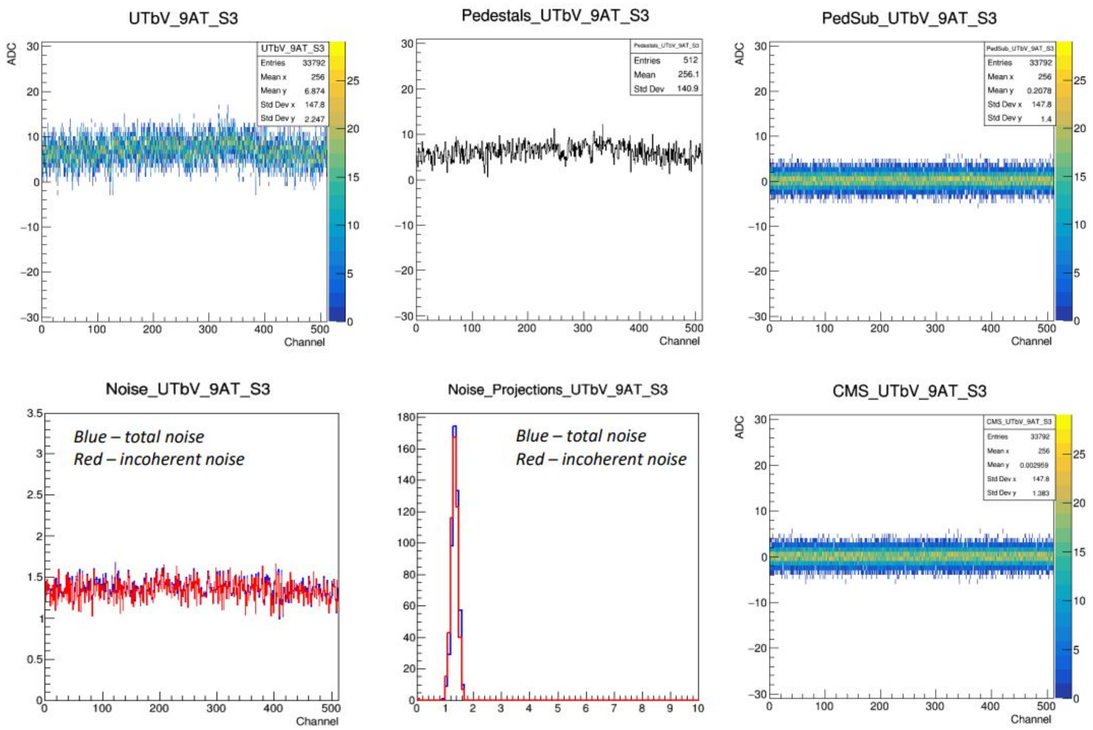


- Development of software to run **automated** detector **calibrations**
- **Pedestals** and **thresholds** computed exploiting End of Fill calibration runs (no LHC beam, only NZS data)
- Detector **parameters updated** automatically (ECS)
- **Precise knowledge** of the **noise** needed to run in **ZS** mode

Offline calibration

- Dedicated software package (VETRA), part of the LHCb software project

- Analysis of the decoded readout and compute sensors parameters:
  - Pedestal
  - Total noise
  - Coherent noise
  - Incoherent noise
  - CMS data monitoring

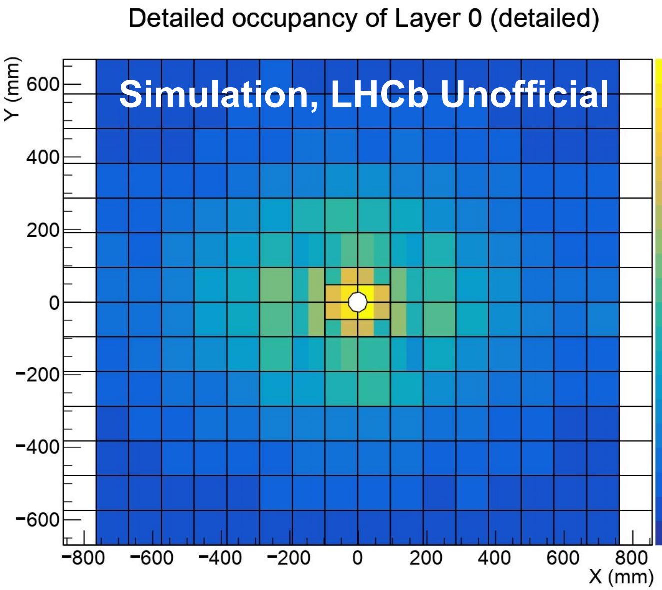


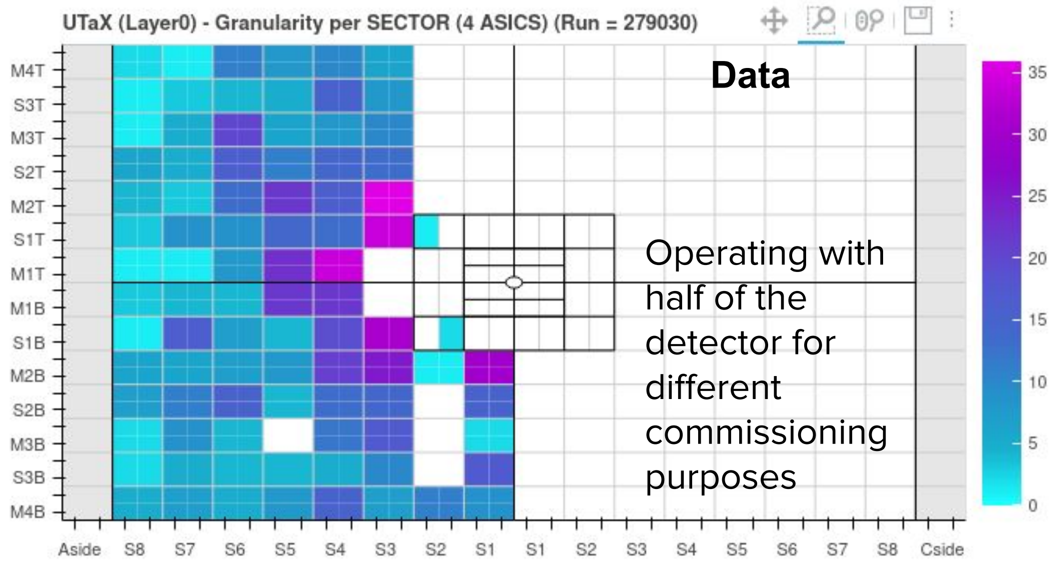
Preliminary results:

- observed the variation of pedestals across the layer
- uniform incoherent noise in the detector
- noise check after pedestal subtraction
- agreement with the early performance studies

Online monitoring

- Monitoring in place: small sample of the captured data sent to computer farm to monitor in real time
- Crucial for the commissioning phase: basic information e.g. hits per sensor, errors information, analogue response. More plots to be added at the need



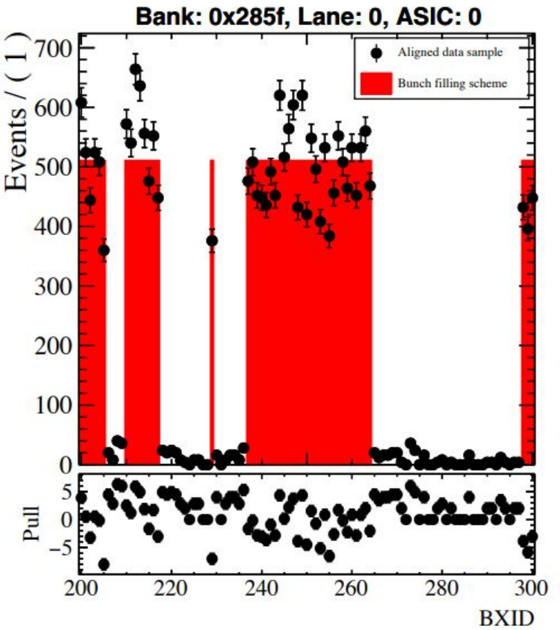


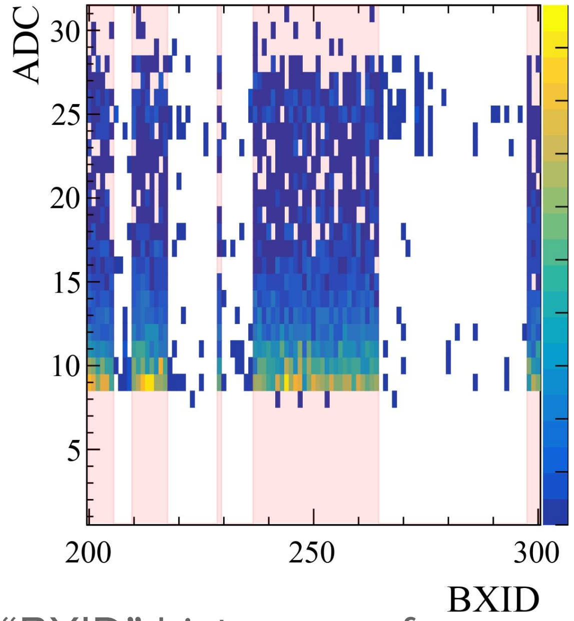
Operating with half of the detector for different commissioning purposes

Time alignment

Goal: match the UT hits with the bunch filling scheme of the LHC

Fit a linear regression model: minimization of Residual Sum of Squares





- The ZS bank decoder has to provide“Number of hits” vs. “BXID” histograms for each ASIC using the
- First a global alignment, then performed for every ASIC
- No need for dedicated TAE runs
- Ongoing studies on data with ion run, waiting for calibration to perform coarse time alignment

Current status

Commissioning phase started in March 2023

- **Detector alignment** developed for one degree of freedom on MC
- **Decoder** ready to be used in the trigger
- Many **surveys** performed to check the status of the detector
- **Data taking** ongoing in local during the ions runs
- Faced **issues** in the **integration** of UT in the rest of the infrastructure: **desynchronization** with experiment clock ➔ commissioning slowed down➔ affected the data taking stability ➔ made significant progresses, learnt how to operate
- Working to guarantee **continuity** in the **data taking**

UT timeline

Installation

completed in March 2023

Commissioning

NOW

YETS

November 2023

- Repairs and adjustments of the electronics, fibers
- Mechanics: surveys, improved beam pipe seal, improved approach mechanism

Categories:

1. recover loss of efficiency in data taking
2. guarantee detector safety
3. operation

UT timeline

Installation

completed in March 2023

Commissioning

NOW

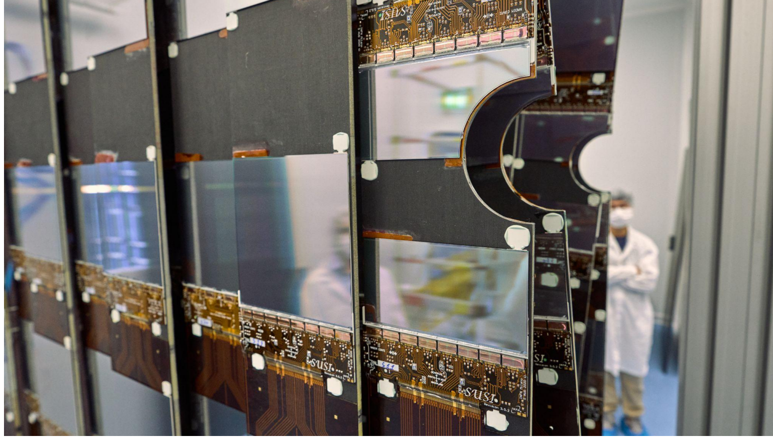
YETS

November 2023

Global commissioning + data taking

March 2024

Summary



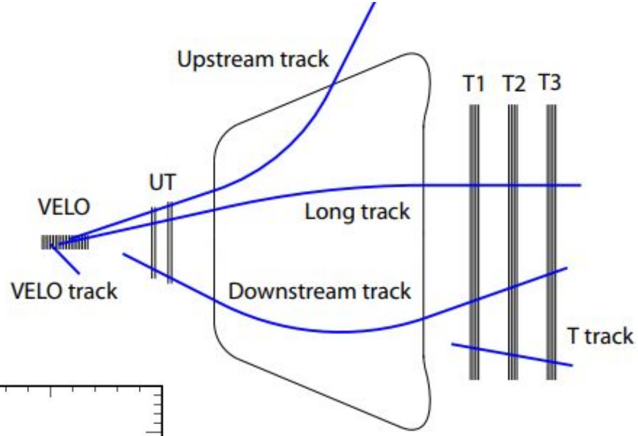
- **Installation completed** successfully in March
- **Detector performance** matches specifications
- Analysing the **first commissioning data**
- Working to ensure **stability** in the data taking (5 flavour firmware)
- **YETS** plan to recover 99% of the detector **efficiency**
- Work in progress to have UT in the **global LHCb data taking**

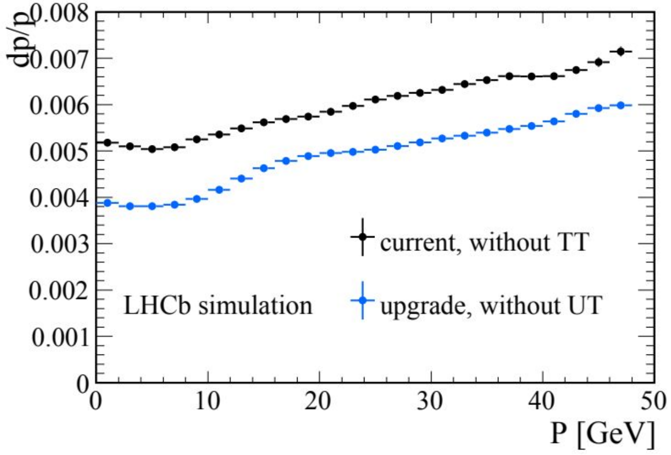
Thank you

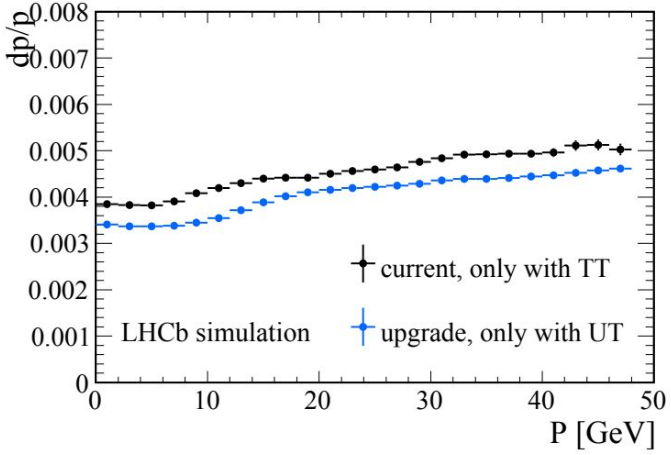
Backup

Upstream Tracker: importance in LHCb

- Track reconstruction: UT fundamental to improve the momentum resolution of long tracks

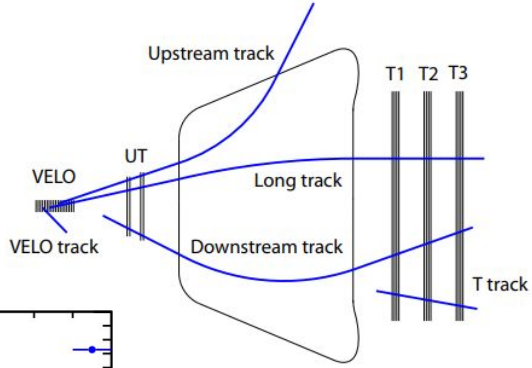


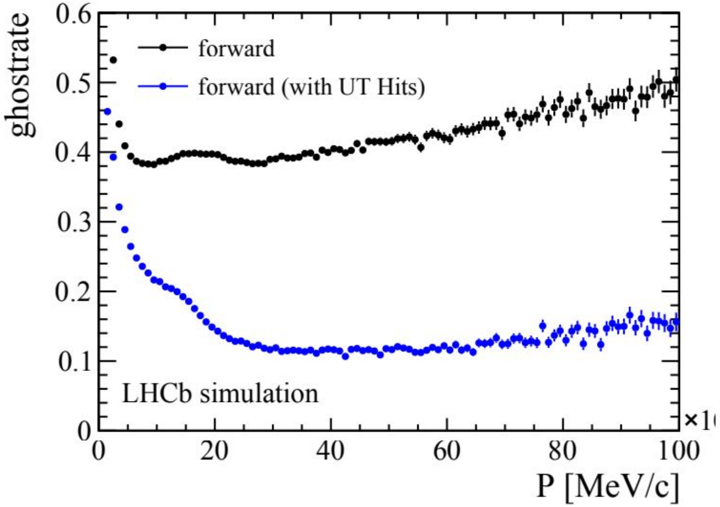


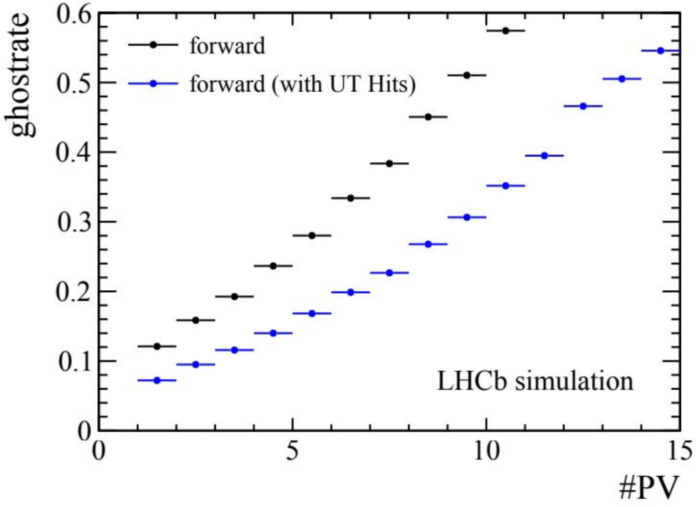


Upstream Tracker: importance in LHCb

- Track reconstruction
- Ghost rate reduction: factor 2 improvements with only less than 1% drop in efficiency

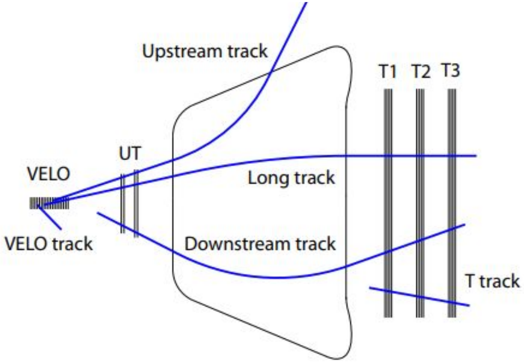






Upstream Tracker: importance in LHCb

- Track reconstruction
- Ghost rate reduction
- Long lived particle reconstruction decaying after the VELO



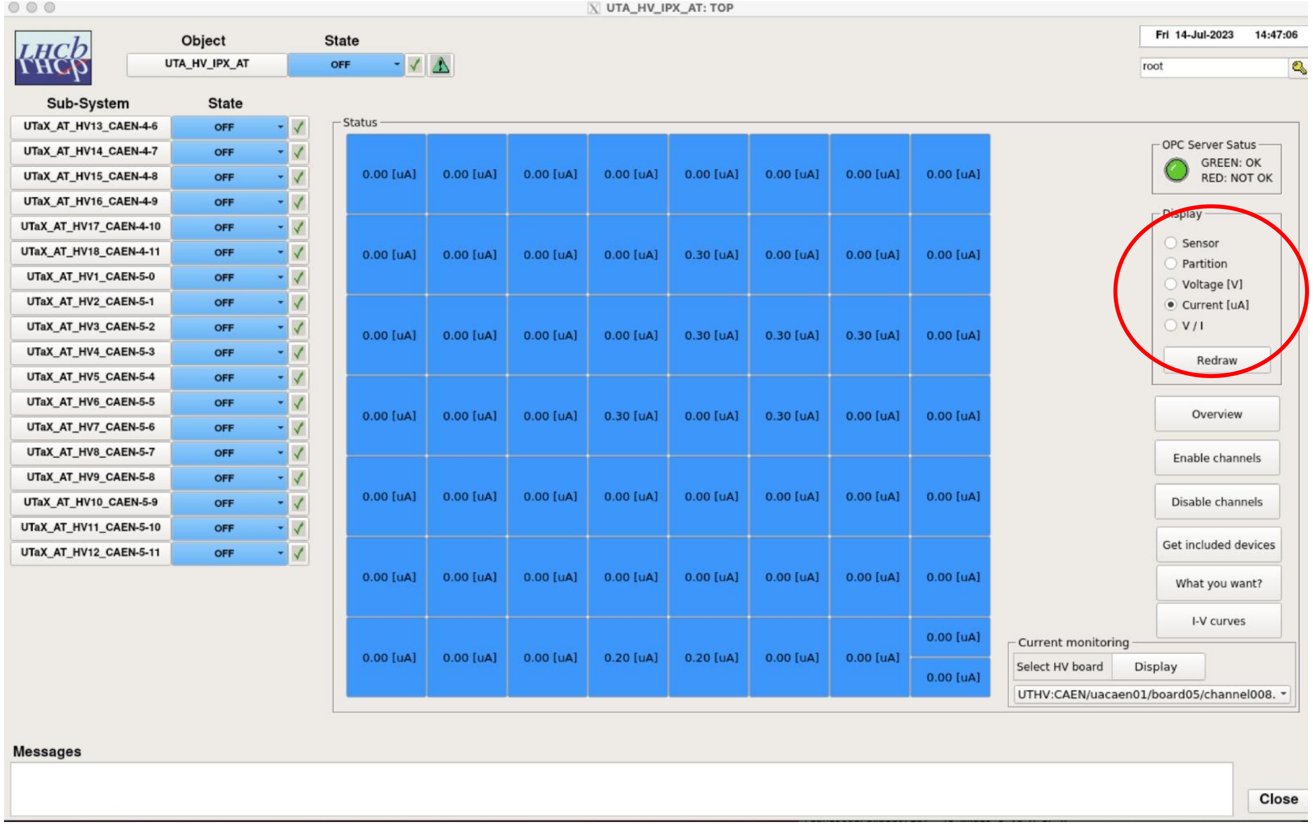
	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	19.5	15.3	20.3
Reconstruction efficiency			
VELO + UT(TT)	80.9	86.7	84.5
VELO + UT(TT) $p > 5$ GeV	90.7	96.2	94.4
VELO + UT(TT) + not Long	66.6	69.6	67.9
VELO + UT(TT) + not long $p > 5$ GeV	89.2	94.5	93.2

High voltage

High voltage cables for sensors depletion

Monitoring panel in place:

- access to each channel
- sensor name
- voltage per sensor
- current per sensor
- V/I per sensor

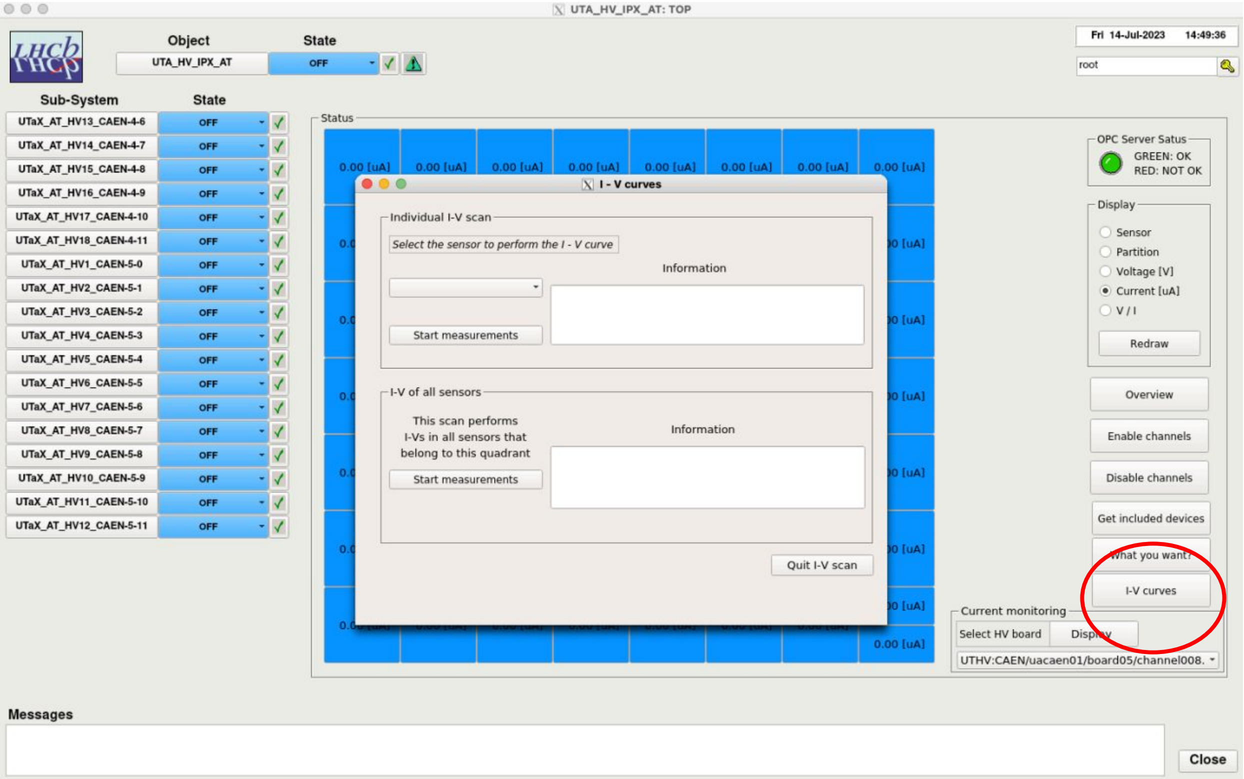


High voltage

I - V curves

- Single sensor scan
- List of sensors scan
- Scan all sensors that belong to a subsystem

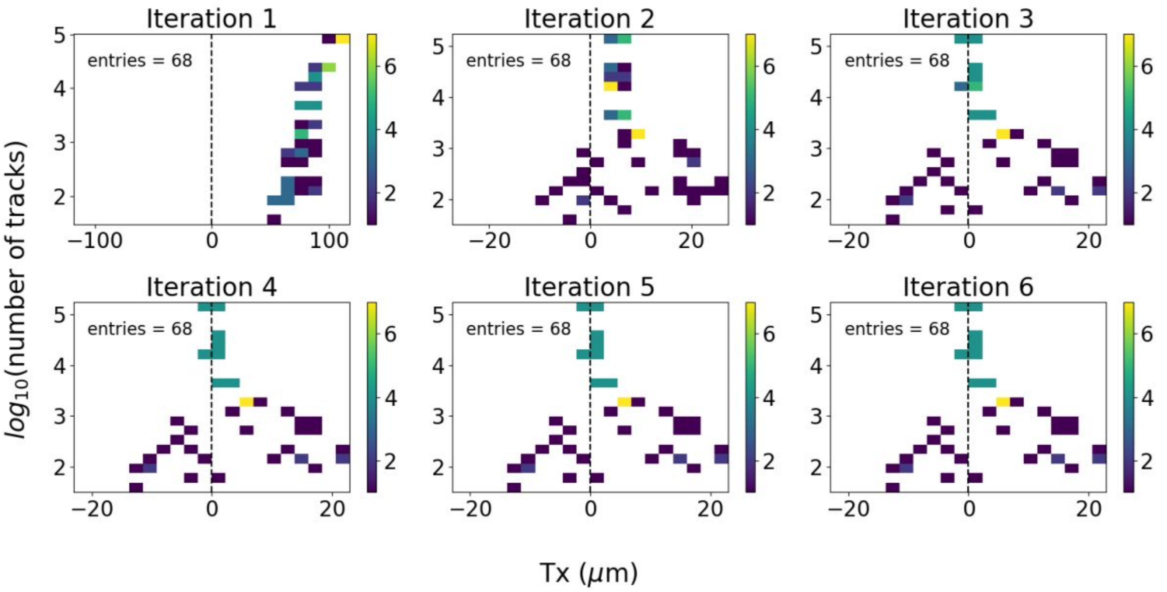
Scan of the current over time



Space alignment

Implementation in DD4hep:

- after simulation and digitisation, with sub-detectors at the **design position**: no misalignment

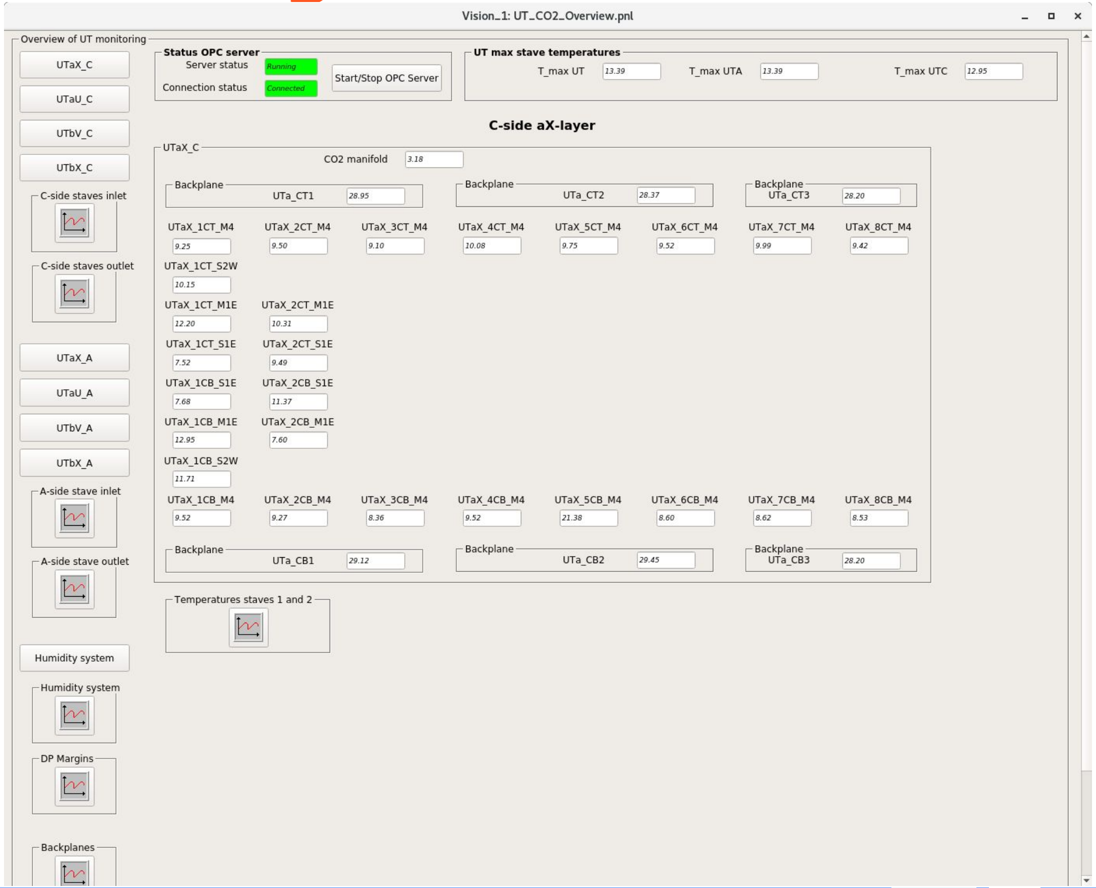


- Run Alignment software with some **initial misalignment** in UT
- Expect **Alignment** to correct the misalignment after a few iterations using pure tracking (no constraints applied) : obtained after 4 iterations
- 10^4 tracks needed to reach good results
- Single degree of freedom (DOF), multiple DOFs studies ongoing

Cooling system monitoring

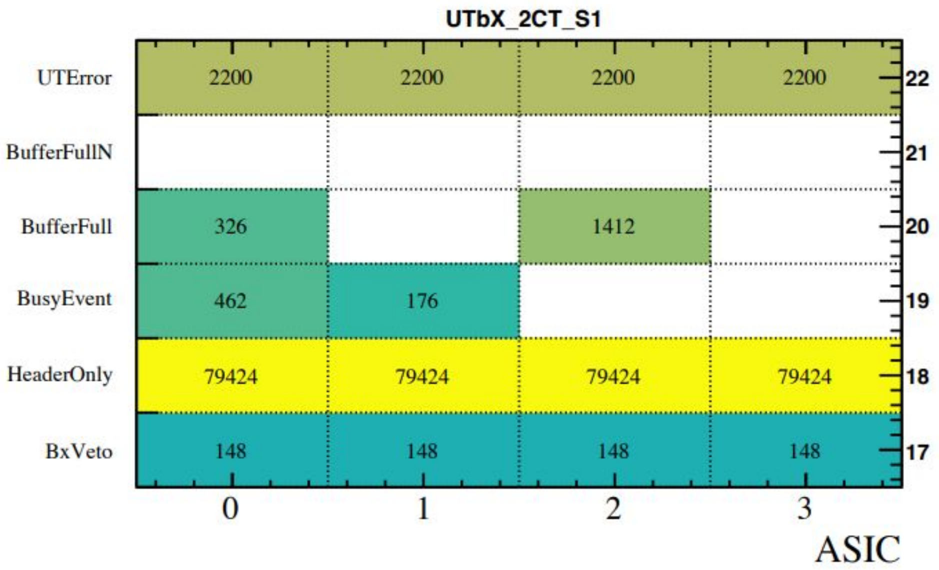
Online temperature monitoring of manifold, backplanes and modules

Monitoring of temperature and humidity **trend** in **time** (useful during commissioning)



Online monitoring

- Monitoring in place: small sample of the captured data sent to computer farm to monitor in real time
- Adding plots to help the commissioning phase: basic information i.g. errors information
  - UT errors
  - UT specials
  - work in progress to add more errors



Firmware data format

Input data:

Normal Data packet

<table>
<tr><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="12" rowspan="2">BXID [12b]</td><td rowspan="2">Parity</td><td rowspan="2">0</td><td colspan="6" rowspan="2"># Hits[6b]</td><td colspan="4">HIT XXX</td></tr>
<tr><td colspan="4">CH_XXX [6..3]</td></tr>
<tr><td colspan="8">HIT XXX (cont...)</td><td colspan="12">HIT YYY</td><td colspan="4">HIT ZZZ</td></tr>
<tr><td colspan="3">CH_XXX[2..0]</td><td colspan="5">VAL_XXX[5b]</td><td colspan="7">CH_YYY[7b]</td><td colspan="5">VAL_YYY[5b]</td><td colspan="4">CH_ZZZ [6..3]</td></tr>
</table>

Output data:

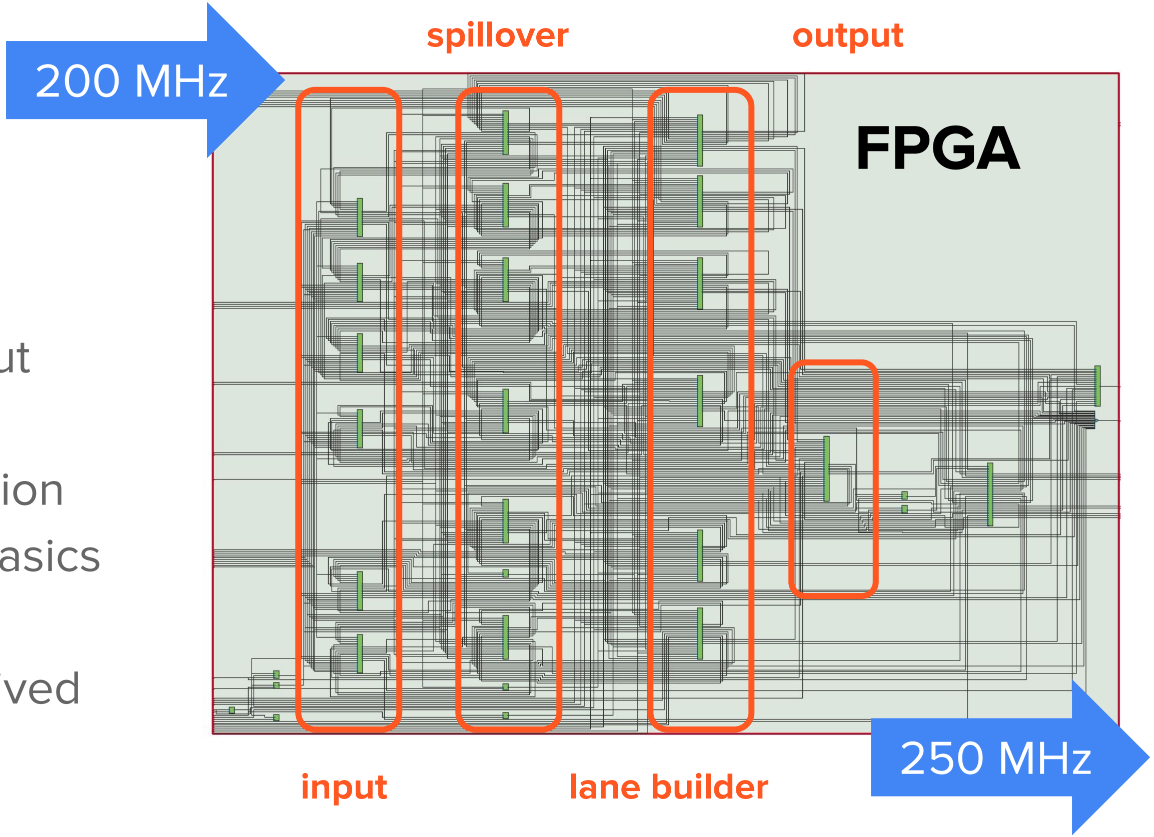
Example of a normal event

<table>
<tr><td colspan="8">Event Headers & Flags</td><td colspan="4">LANE 5</td><td colspan="4">LANE 4</td><td colspan="4">LANE 3</td><td colspan="4">LANE 2</td><td colspan="4">LANE 1</td><td colspan="4">LANE 0</td></tr>
<tr><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td><td colspan="2">16b</td></tr>
<tr><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td><td>8b</td></tr>
<tr><td colspan="8">Event 0 Header</td><td colspan="2">Hit1</td><td colspan="2">Hit0</td><td colspan="2"></td><td colspan="2">Hit0</td><td colspan="2">Hit1</td><td colspan="2">Hit0</td><td colspan="2">Hit1</td><td colspan="2">Hit0</td><td colspan="2">Hit1</td><td colspan="2">Hit0</td><td colspan="2">Hit1</td><td colspan="2">Hit0</td></tr>
<tr><td colspan="8"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">Hit2</td><td colspan="2">Hit3</td><td colspan="2">Hit2</td><td colspan="2"></td><td colspan="2">Hit2</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="8"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">Hit4</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

Firmware

Functionalities

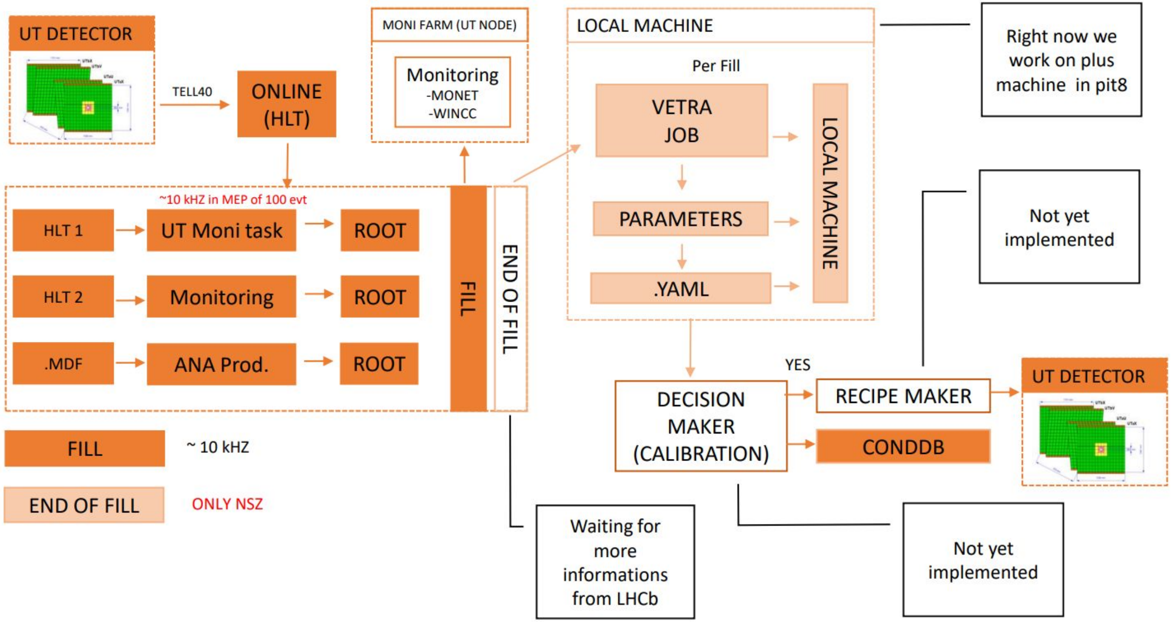
1. flavour independence output data format
2. spillover correction application
3. merging the information all asics in a flow (one output)
4. tag different data type received



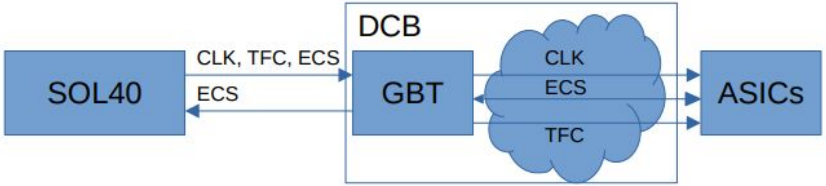
Status: implemented to work in Non-zero-suppressed (NZS) and in Zero-suppressed (ZS) mode

Calibration

- Development of software to run **automated** detector **calibrations**
- **Pedestals** and **thresholds** computed exploiting End of Fill calibration runs (no LHC beam, only NZS data)
- Detector **parameters updated** automatically (ECS)



Desynchronization issue



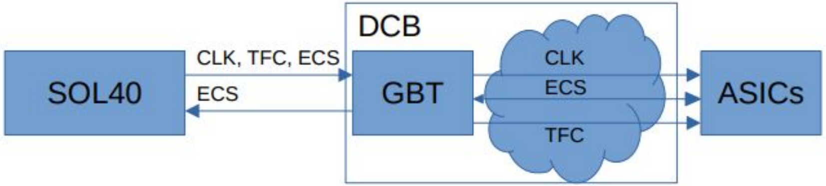
Biggest problem during commissioning: random **lost of ASICs configuration**

Unstable clock signal received from the ASICs, related to the TFC sequence:

TFC sequence quiet for a relatively long time + a single command bit activated ➔ GBT loses synchronization with the SOL40 board which sent the clock

GBT not able to send a valid signal back to the SOL40 card ➔ both the FEC in the GBT and in the SOL40 are activated ➔ clock signal GBTs deliver to the ASICs is disturbed ➔ confuse the ASICs and put them in a state of which they can not recover on their own

Desynchronization issue



UT not the only detector seeing this effect on the GBT chip, other detectors using it have reported similar problems.

Palliation strategy was found: if at least 1 of the 8 bits of the TFC command is asserted at all times, then the GBT suffers many less losses of synchronization

In the UT the SNAPSHOT bit has been sacrificed for this purpose: by activating it in every event, the command becomes useless, but the situation improves enough that it allows us to take some data for commissioning.

The reason why this works is theorized to be related to signal DC balance, but it is not fully understood or proven. It is not a complete cure either, as errors become much less frequent but still happen. Several improvements are currently being studied. We hope the situation will be enhanced in the future.

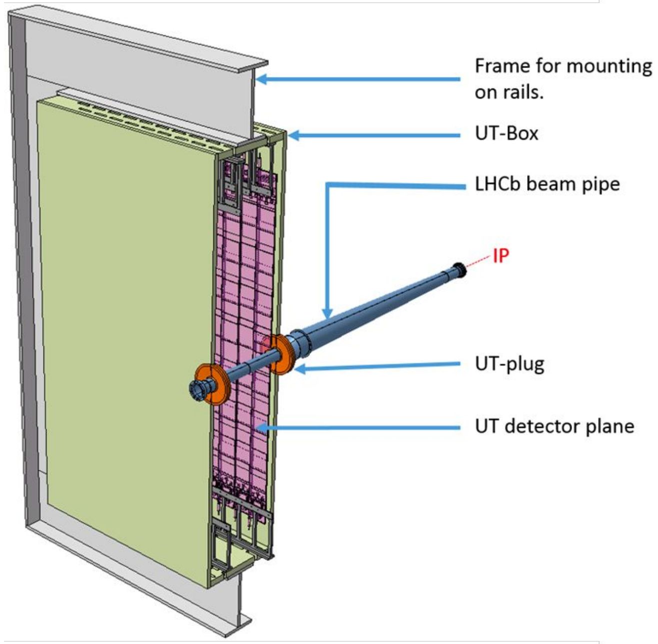
UT box deformation

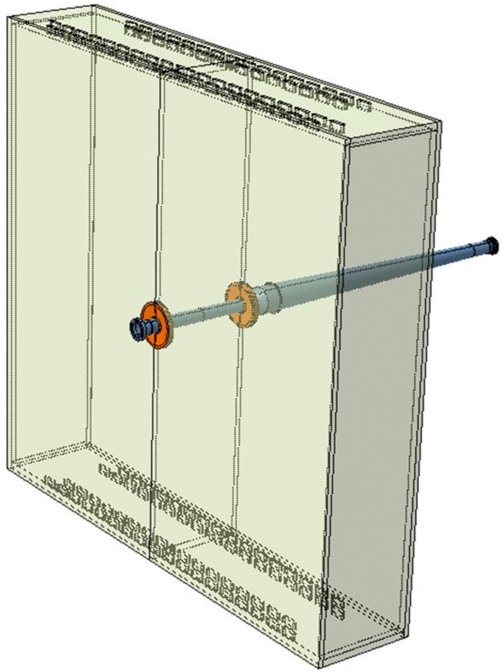
UT box deformation ➜ not properly closed ➜ higher temperature

➜ decreased humidity, nitrogen leakage

Surveys and monitoring of the sensors behaviour:

possible to run at 0°C ➜ YETS: stop the Nitrogen leakage with a beam pipe seal + surveys






Trending Page: UT CO2 Summary
Time Range
Y Axes
Save
Other
1:1
log
auto
Close
Page plots
12/10 12:47.481
Humidity Sensor 1 (AT) 6.56
Humidity Sensor 2 (AT) 6.32
Humidity Sensor 3 (AT) 6.46
Humidity Sensor 1 (AB) 7.61
Humidity Sensor 2 (AB) 6.36
Humidity Sensor 3 (AB) 7.24
12/10 12:47.695
Humidity Sensor 1 (CT) 7.16
Humidity Sensor 2 (CT) 7.05
Humidity Sensor 3 (CT) 6.69
Humidity Sensor 1 (CB) 6.79
Humidity Sensor 2 (CB) 6.94
Humidity Sensor 3 (CB) 7.04
12/10 12:47.802
Dew point 1 (AT) -28.55
Dew point 2 (AT) -28.94
Dew point 3 (AT) -28.71
Set Point Cooling Plant 0.00
Dew point 1 (AB) -26.55
Dew point 2 (AB) -28.50
Dew point 3 (AB) -27.10
Dew point Local Box A side -37.27
12/10 12:47.803
Dew point 1 (CT) -26.82
Dew point 2 (CT) -26.98
Dew point 3 (CT) -27.55
Set Point Cooling Plant 0.00
Dew point 1 (CB) -27.73
Dew point 2 (CB) -27.49
Dew point 3 (CB) -27.35
Dew point Local box C side -42.91
12/10 12:47.620
Temperature (AT) [C] 5.36
Set Point Cooling Plant [C] 0.00
Beam-pipe Temperature (IP) [C] 15.14
Beam-pipe Temperature (Magnet) [C] 16.90
Temperature (AB) [C] 5.86
12/10 12:47.620
Temperature (CT) [C] 6.41
Set Point Cooling Plant [C] 0.00
Beam-pipe Temperature (IP) [C] 15.14
Beam-pipe Temperature (Magnet) [C] 16.90
Temperature (CB) [C] 5.95