LHCb Upstream Tracker
Installation Overview for Upgrade I

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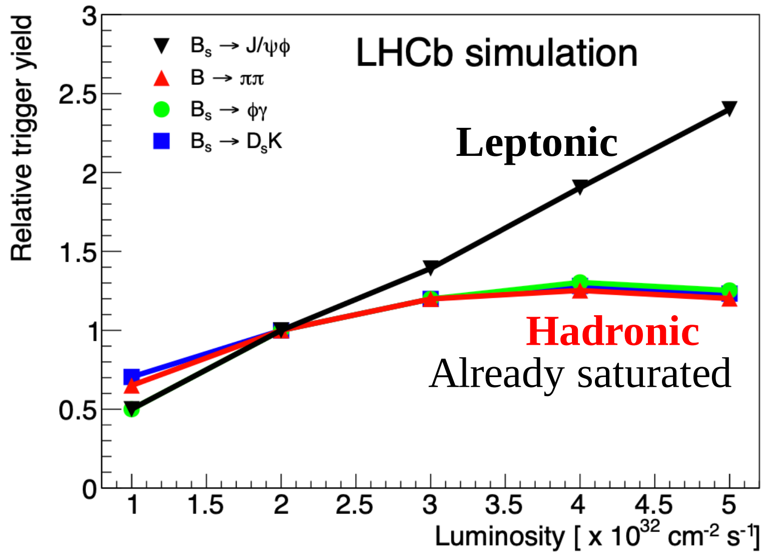
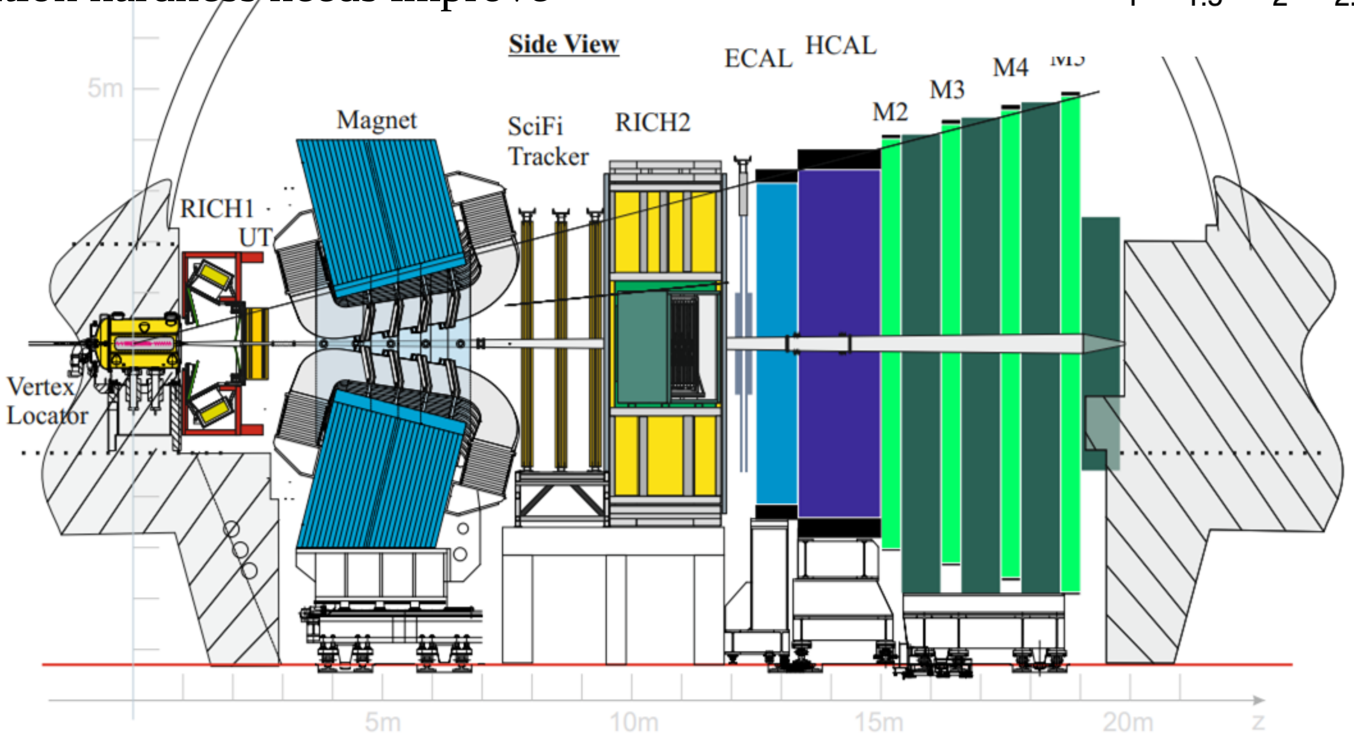
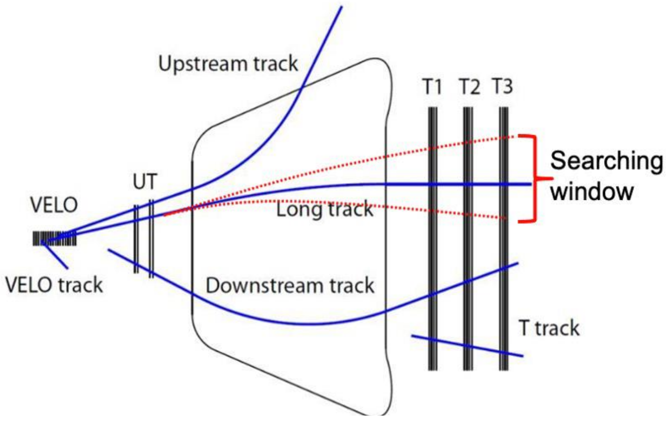
LHCb Detector

- General purpose single arm forward spectrometer
- Focus on **flavor physics**
  - Study *b* & *c* sectors on CP violation , rare decays, new physics
- Have been luminosity leveling at $\mathbf{4\times10^{32}cm^{-2}s^{-1}}$
  - **Low efficiency** on some channels for **hadronic decay** at high luminosity due to **hardware trigger**
  - Detector radiation hardness needs improve

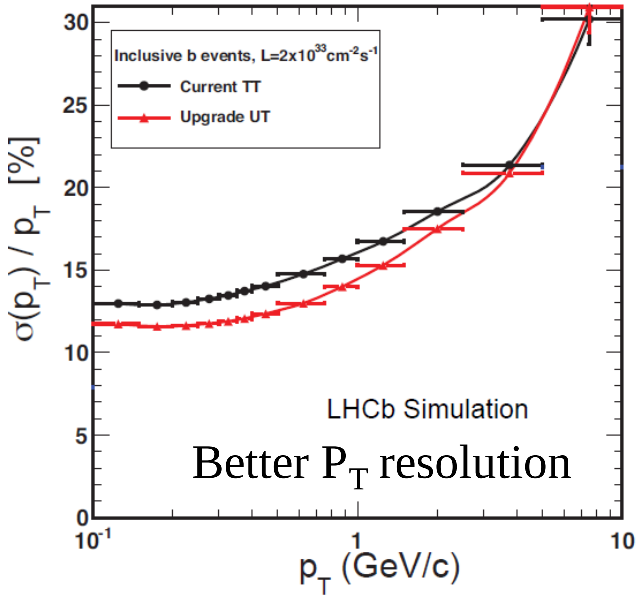




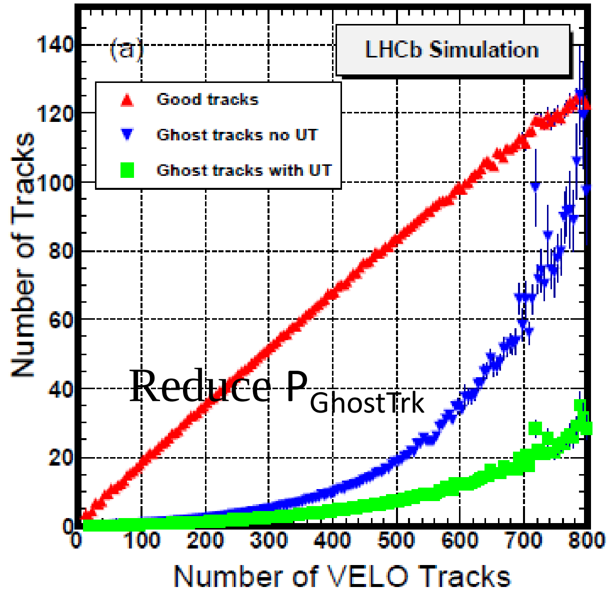
UT Role



LHCb tracking system



Better P_T resolution



Reduce $P_{GhostTrk}$

- UT detector improvement
  - **40 MHz readout**
  - High coverage, segmentation, resolution

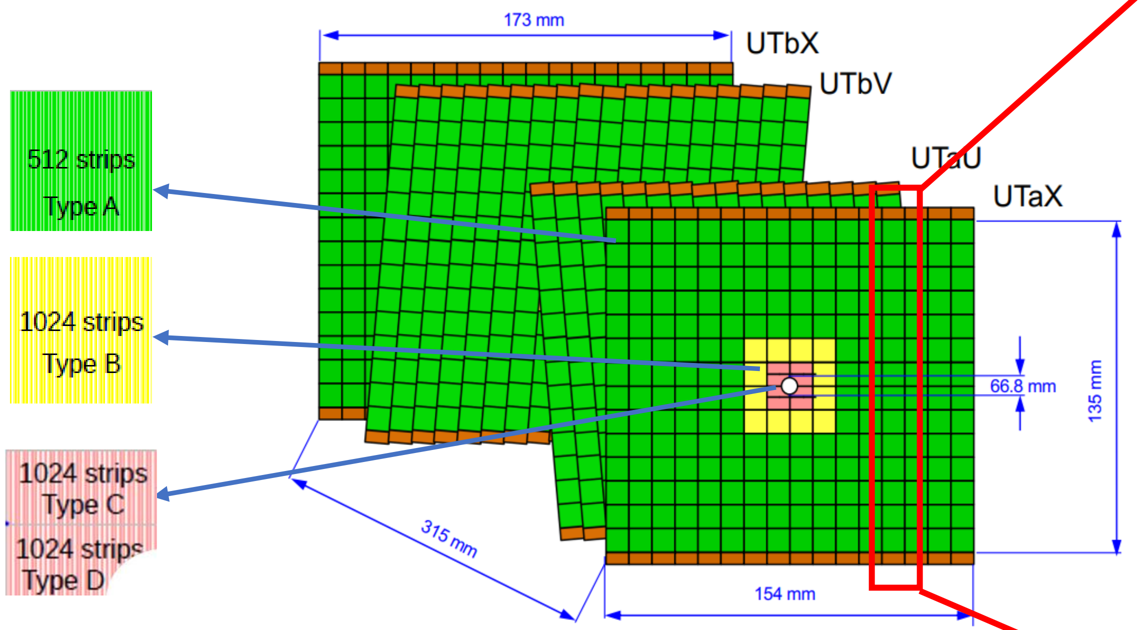
→ Physics impact
- → Increase **reconstruction efficiency**
- → Improve track reconstruction, **speed up reconstruction time**
- → **Reduce ghost tracks**

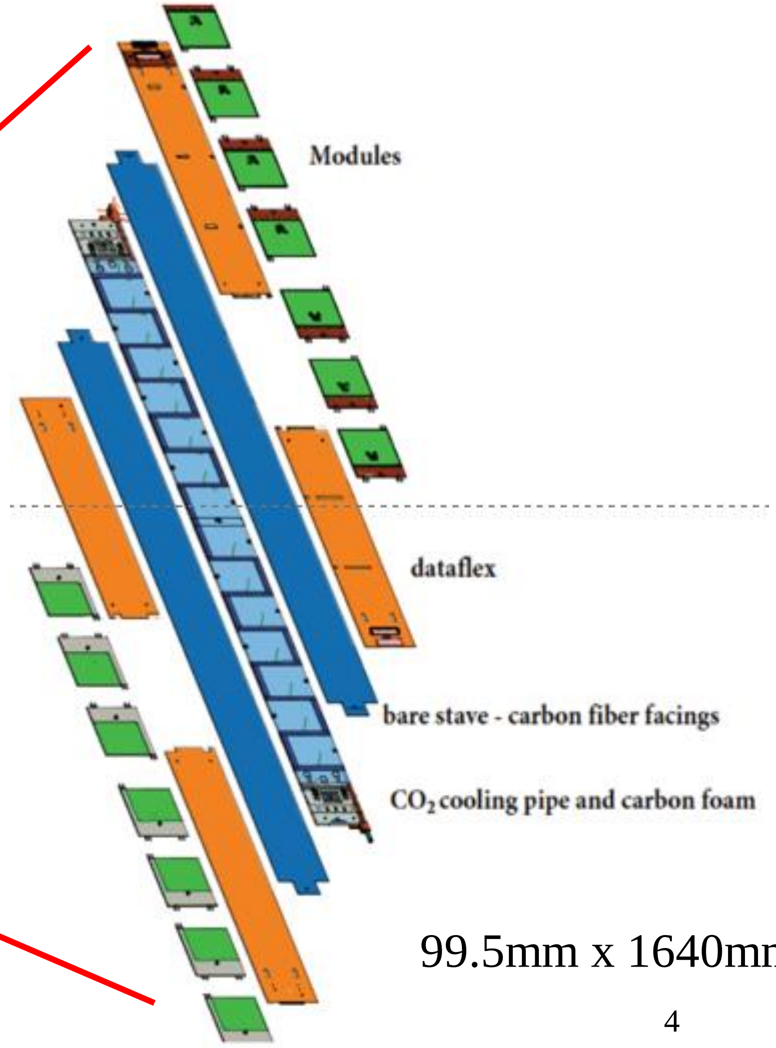
LHCb upgrade I
50 fb^{-1}
$2\times10^{33}cm^{-2}s^{-1}$
software-only trigger

More LHCb upgrade details in Zhenwei Yang's presentation

UT Detector

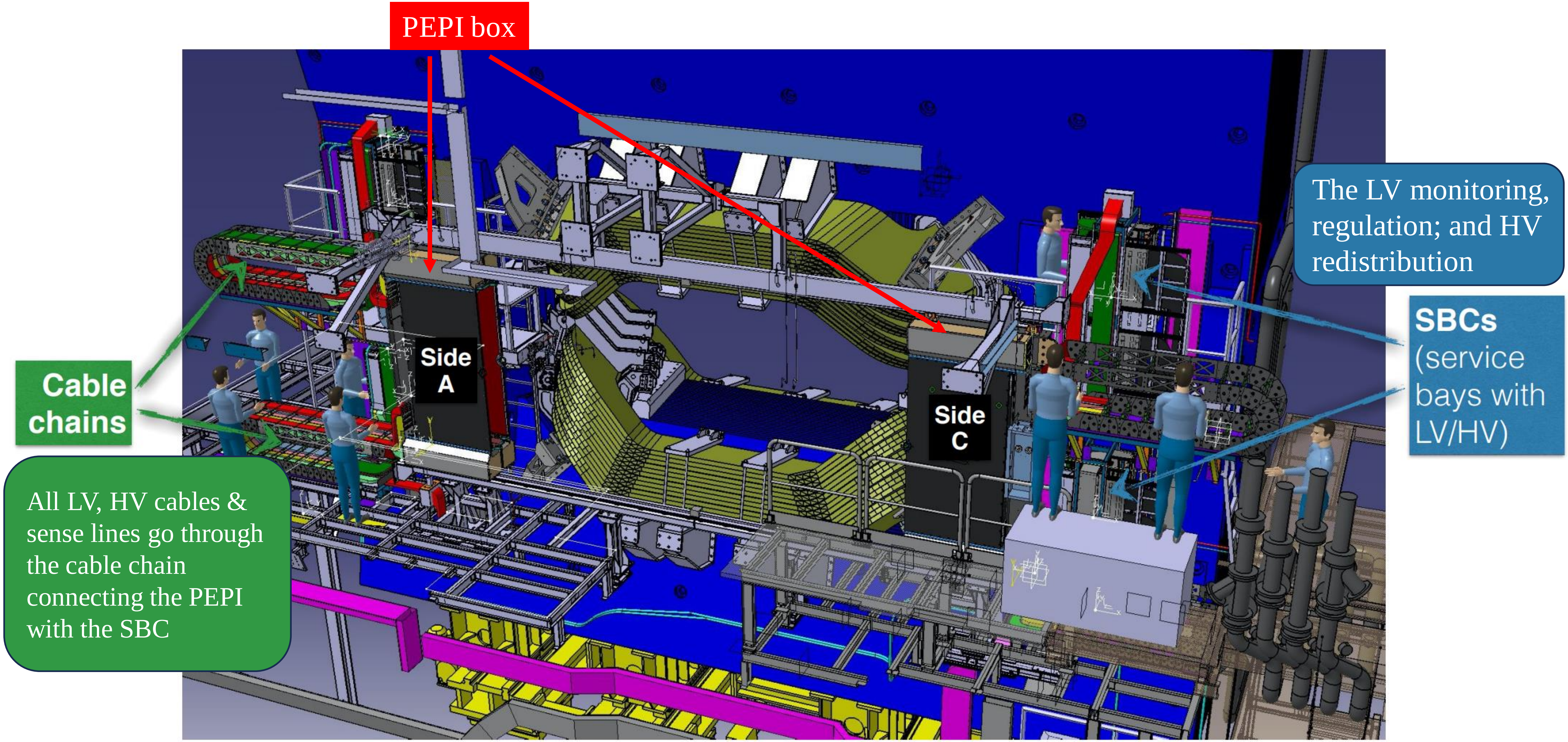
- Divided into A-side & C-side
- Consist of 4 layers of silicon strip detectors
  - organize in **68 staves**
  - **S-shaped** titanium cooling pipe
  - **Dower and data distribute in** Flex cables
- 4 types of modules with different silicon strip densities
- SALT (Silicon ASIC for LHCb Tracker) chip for front-end readout





99.5mm x 1640mm

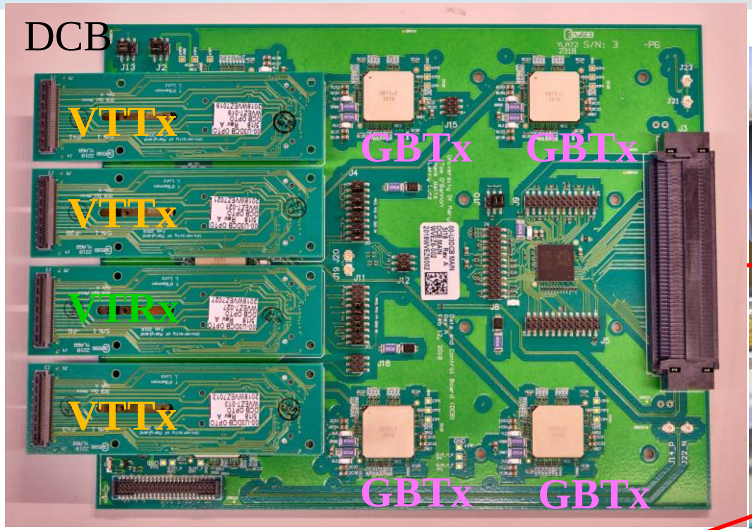
Underground Diagram



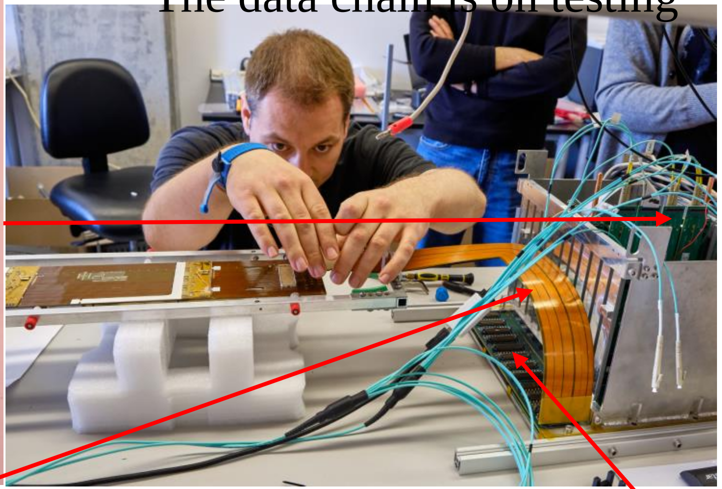
Peripheral Electronics Processing Interface (PEPI)

- To read out and control the detector
  - 136 **flexible pigtail cable** connects the stave to PEPI
  - 24 **backplane boards**
    - Various interfaces are integrated
  - 248 **Data Control Boards (DCBs)**
    - provide the communication with DAQ
    - monitoring and control of the front end devices

DCB

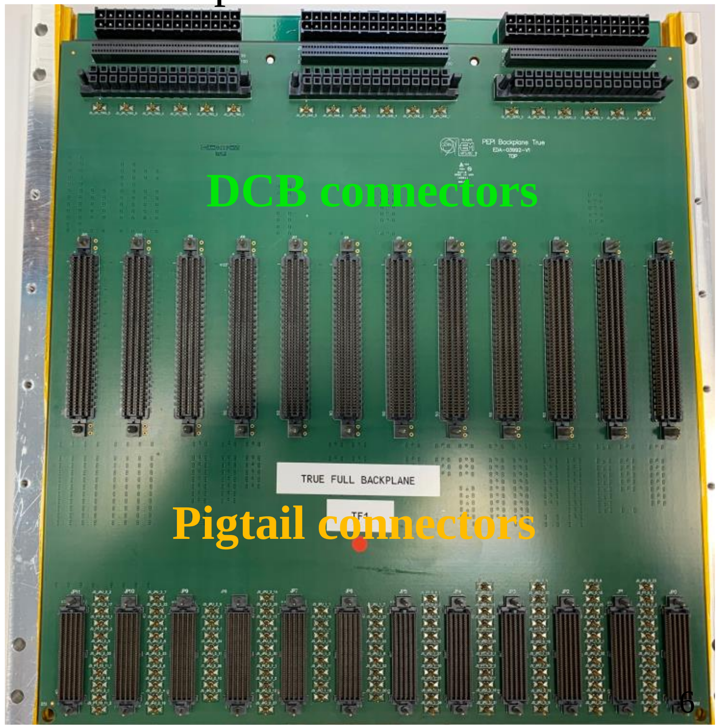


The data chain is on testing

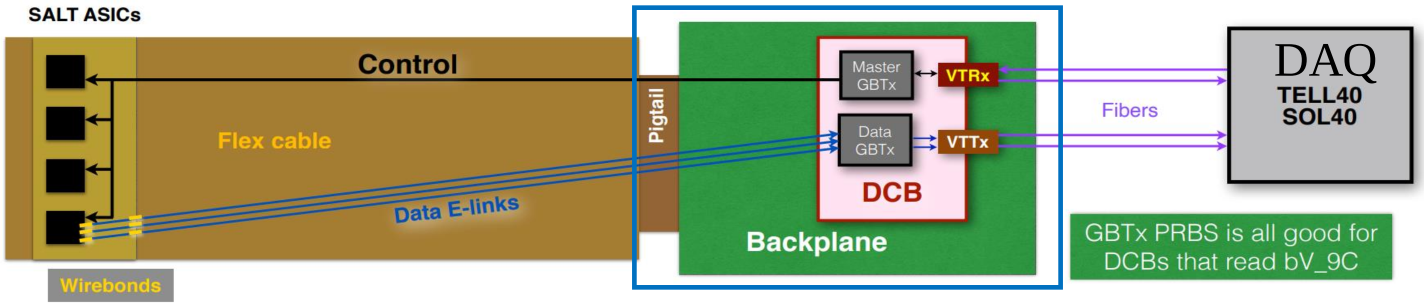


Pigtails picture

Backpalne board



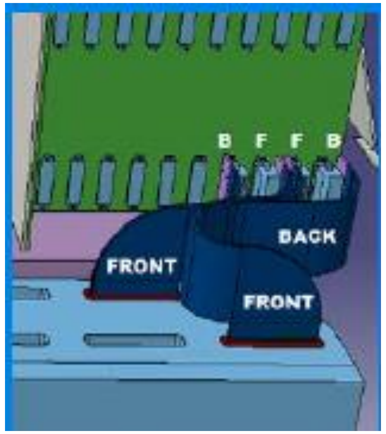
Data chain diagram (PEPI in blue)



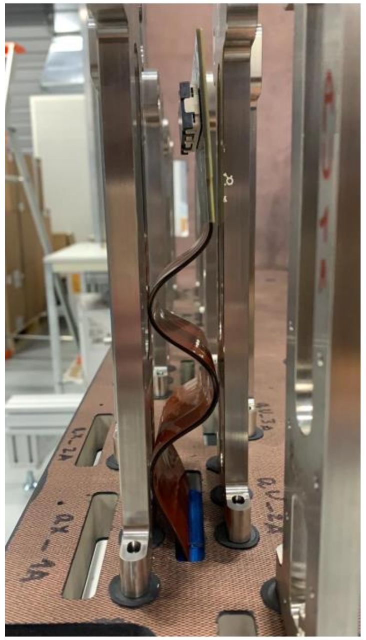
PEPI Installation

1. Install pigtails, backplanes, LV cables & service cables inside box
   - ☐ Length of pigtails are too long
2. Pigtail and Backplane connectivity validation

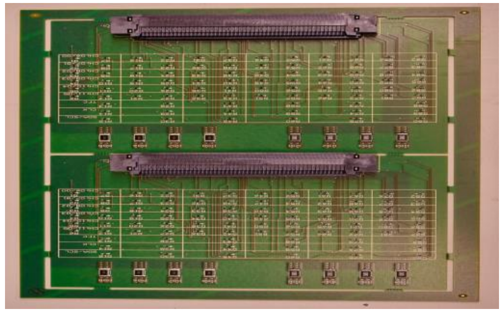
Flex Emulator



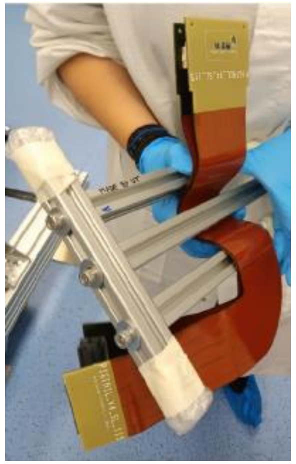
Design
Vs.
Reality

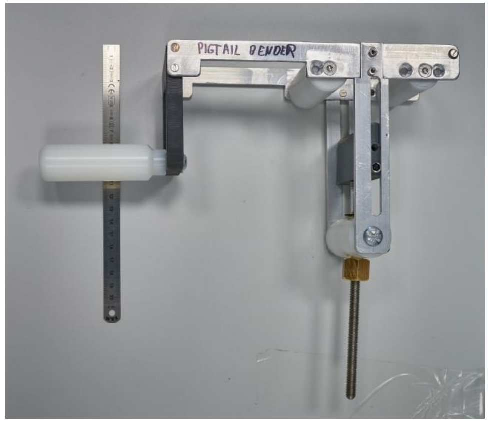


DCB simulator



The solution



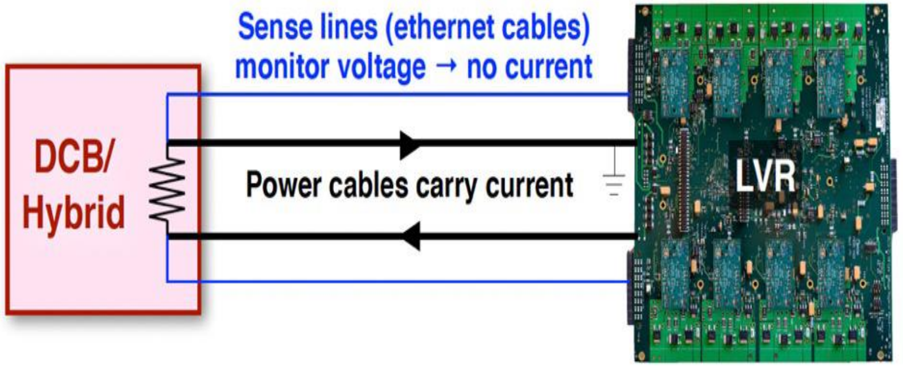


Develop new tools to bend pigtails

3.Pigtail/DCB LV-data validation

- Make sure the sense lines & power cables connect correctly by checking voltages and currents
- Kinds of problems, need a lot of time to train & debug
- Hard to debug because of the narrow space

The connections between DCBs & Low Voltage Regulators (LVRr)



All good	Isense	Vrs (master)	Vreg
Flex emul.	1.7	1.26	1.8
DCBsim 1.5V	2.3×2	1.5	1.9
DCBsim 2.5V	1.1	2.5	2.8

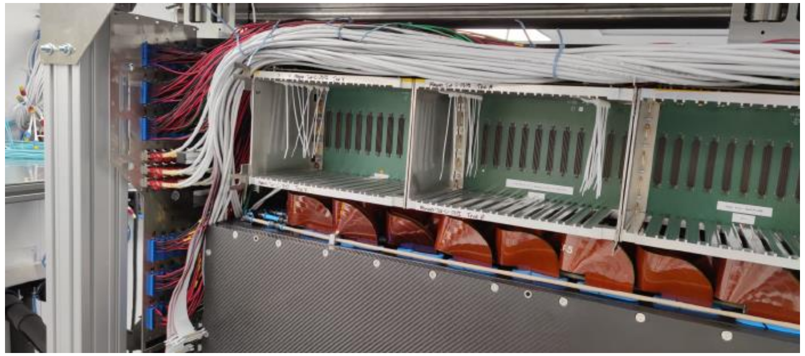
Sense connected to different place than power cable	Isense	Vrs (master)	Vreg
Flex emul.	Large	0	3.5
DCBsim 1.5V	Large	0	3.5
DCBsim 2.5V	Large	0	3.5

Sense disconnected but power cable connected	Isense	Vrs (master)	Vreg
Flex emul.	1.4	1.26	1.4
DCBsim 1.5V	1.9×2	1.5	1.6
DCBsim 2.5V	0.9	2.5	2.65

Sense connected but power cable disconnected	Isense	Vrs (master)	Vreg
Flex emul.	0.2	0.3	3.5
DCBsim 1.5V	0.2	0.3	3.5
DCBsim 2.5V	0.2	0.3	3.5

Sense and power cables disconnected	Isense	Vrs (master)	Vreg
Flex emul.	0	1.26	1.4
DCBsim 1.5V	0	1.5	1.6
DCBsim 2.5V	0	2.5	2.65

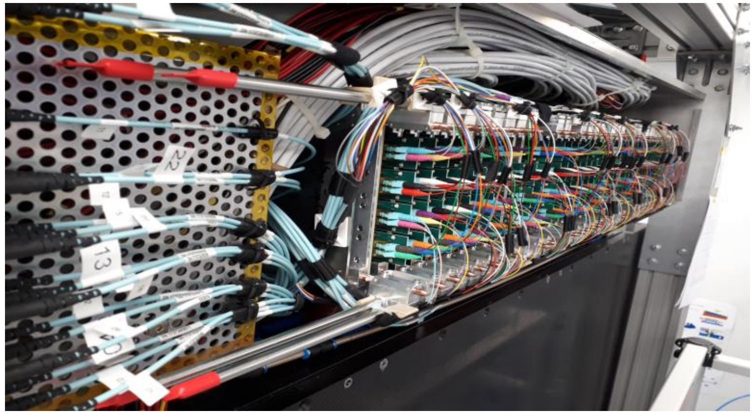
The narrow space between UT box & PEPI cage



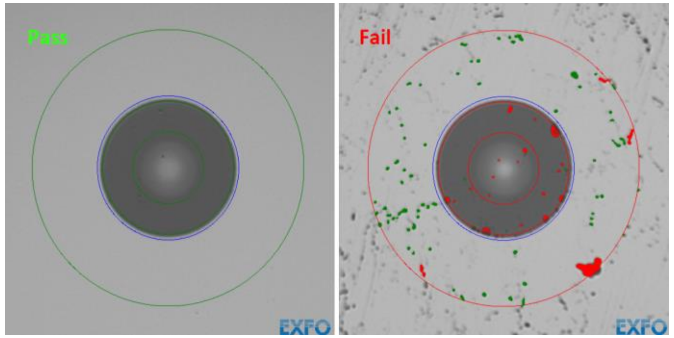
PEPI Installation

4. Install DCBs
   - Very careful when powered up, turn the power off if any higher voltages appeared
5. Connect optical fibers
   - Thousands fibers with complicated map
   - Mapping validation
   - Surface check
   - Re-routing the fibers

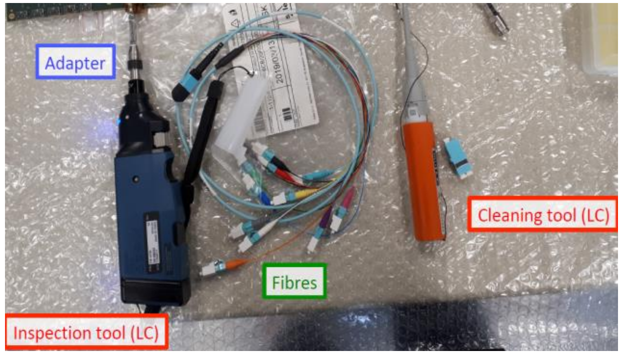
DCBs with optical fibers



Example: PASS/FAIL



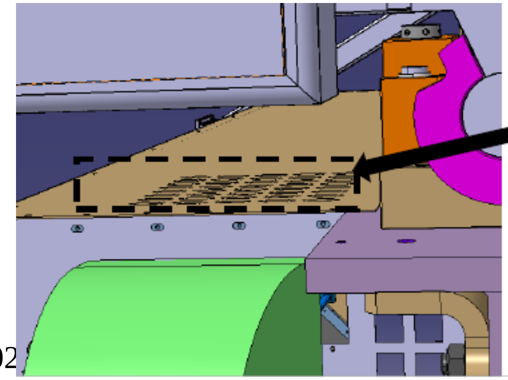
Required tools



The map

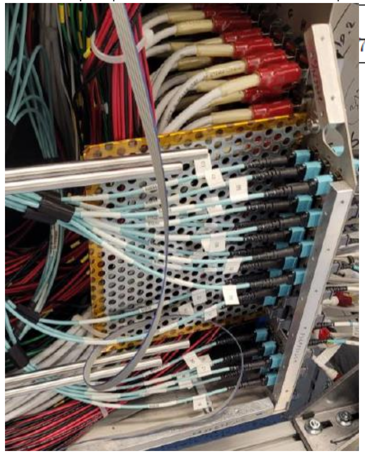
MAG CB3 (γ)												
GBTx	11	10	9	8	7	6	5	4	3	2	1	0
3	22.3	22.1	21.3	21.1	20.11	20.9	19.3	19.1	NC	NC	18.11	18.9
2	22.4	22.2	21.4	21.2	20.12	20.10	19.4	19.2	NC	NC	18.12	18.10
Tx	6.11	6.9	6.7	6.5	6.3	6.1	5.11	5.9	NC	NC	5.3	5.1
Rx	6.12	6.10	6.8	6.6	6.4	6.2	5.12	5.10	NC	NC	5.4	5.2
1	22.7	22.5	21.7	21.5	20.7	20.5	19.7	19.5	NC	NC	18.7	18.5
6	22.8	22.6	21.8	21.6	20.8	20.6	19.8	19.6	NC	NC	18.8	18.6
4	22.11	22.9	21.11	NC	20.3	NC	NC	19.9	NC	NC	NC	18.1
5	22.12	22.10	21.12	NC	20.4	NC	NC	19.11*	NC	NC	NC	18.2

PPP	CB3						CB2						CB1						Backplane
	10	8	6	4	2	0	10	8	6	4	2	0	10	8	6	4	2	0	DCB
								4	15		3	13		2	10		1	7	Top
								16		14			12	11		9	8		Bottom



Optical fibre and DSS plugs

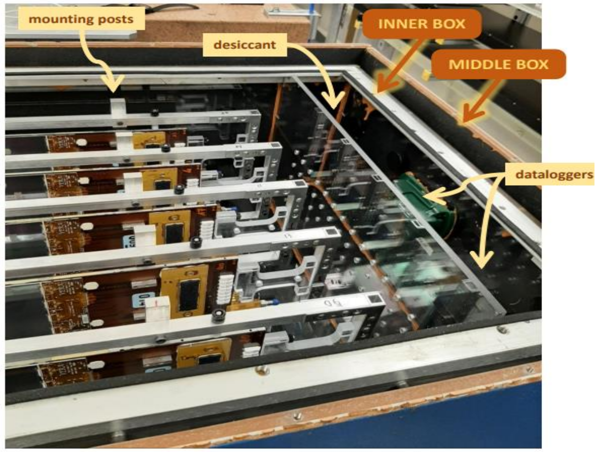
Too little space to bend & connect fibers →



Redesigned PEPI patch panel, much easier to connect fibers!

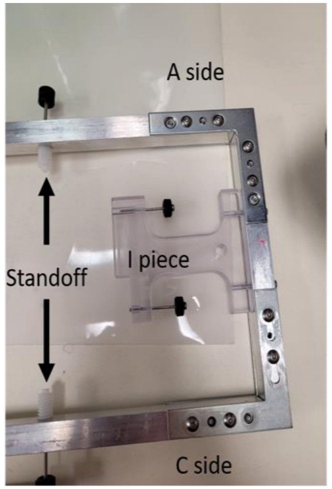
Stave Installation - Preparation

- Transport staves to CERN by shipment box, fixed on the strongback
- 2 cabinets are used to store staves (15 staves/cabinet) with dry air



The transport box
- ☐ 3 layers to give a better protect;
- ☐ Use dataloggers to record the temperature, humility and position information

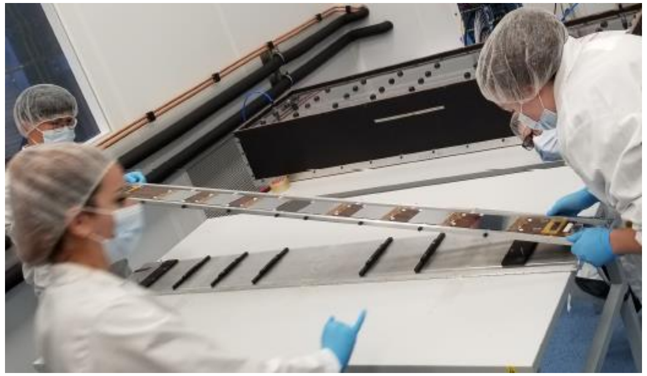
The strongback



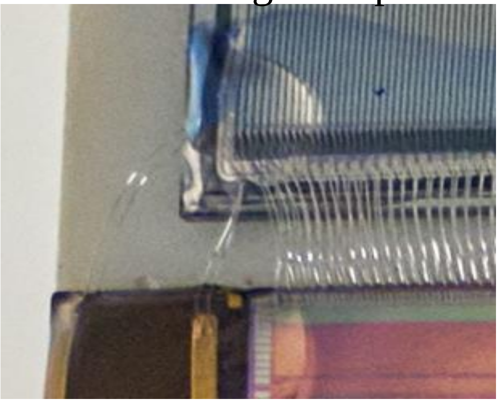
The cabinet

1. Move to the stave plate, and remove the strongback
2. Check the bonding wire by magnifying glass (don’t look directly above the stave)
3. Removal of protective caps (for cooling pipes & connectors)

Place carefully

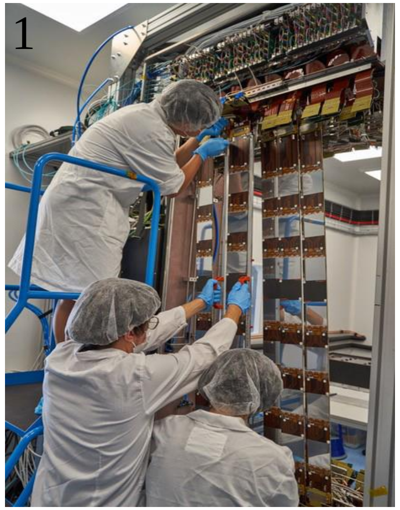


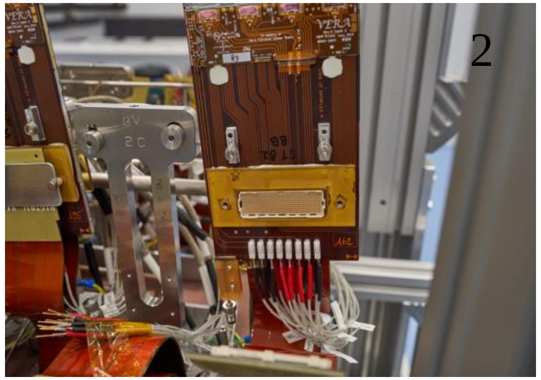
A bad bonding example

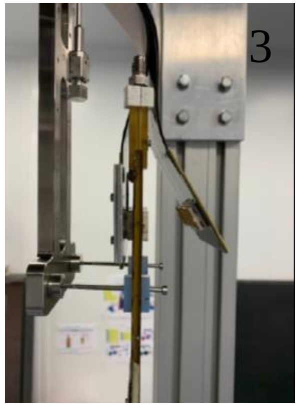


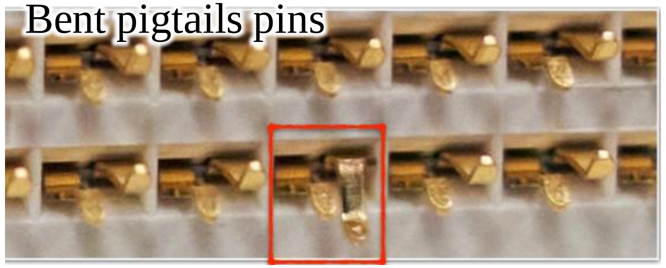
Stave Installation

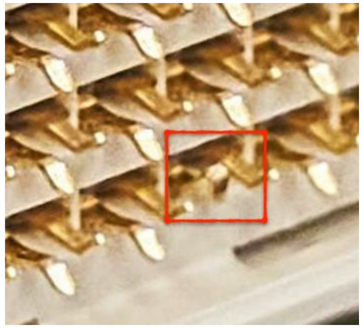
1. Stave installation on the stave supports (moved by handled strongback)
   - Always need one person to see if anything touch sensors
2. Connect the HV pins to the stave and test connectivity
3. Connection of back side pigtails

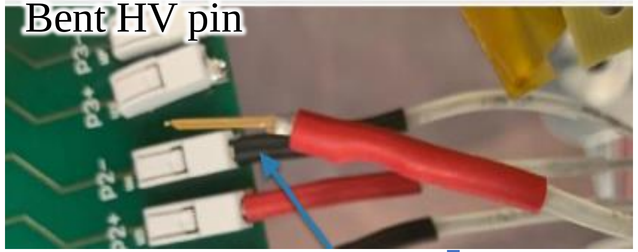




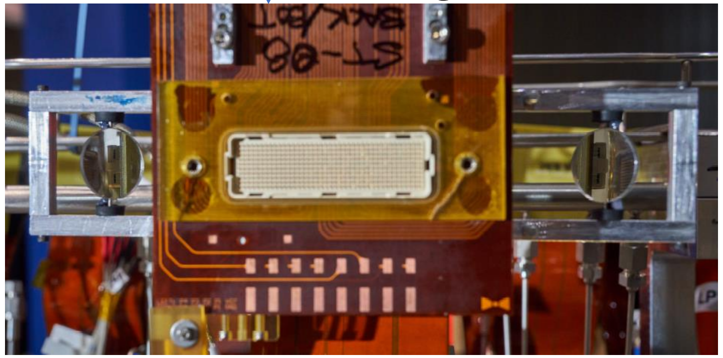








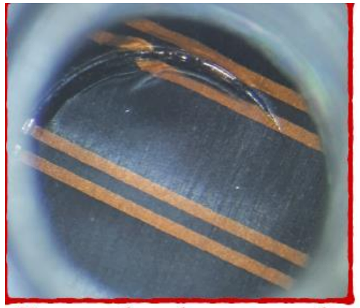
Pins are very delicate and fragile



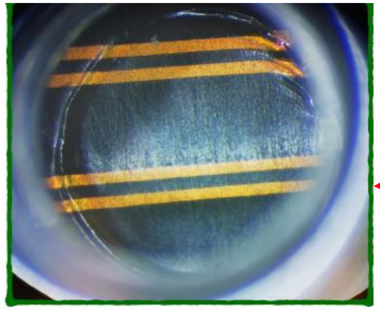
Use of mirrors that enables the view in the back side of the stave

4. Connect front side pigtails and fixed by clamps

- Some screws are too long to damage wiring channels

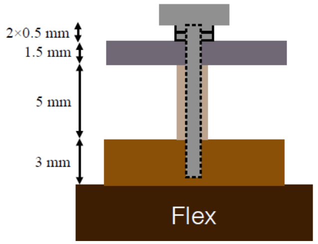


Trace clearly severed



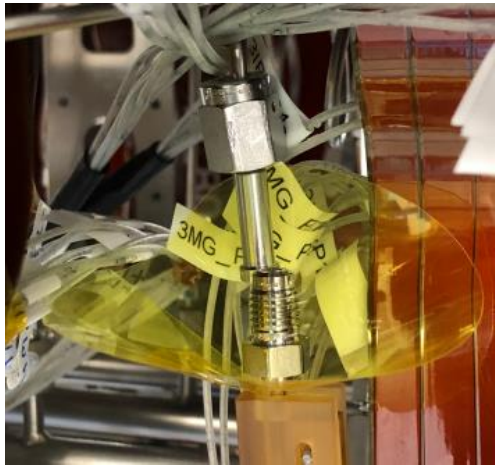
Damage even on working traces

Thinner clamps & shorter screws



5. CO2 interconnection

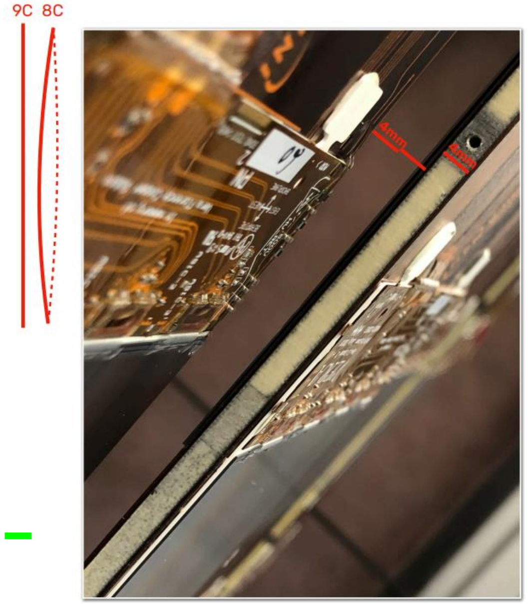
- The falling gaskets



Gasket falling protector made by plastic paper

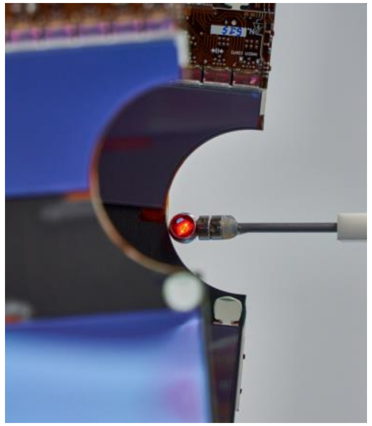
Stave Installation

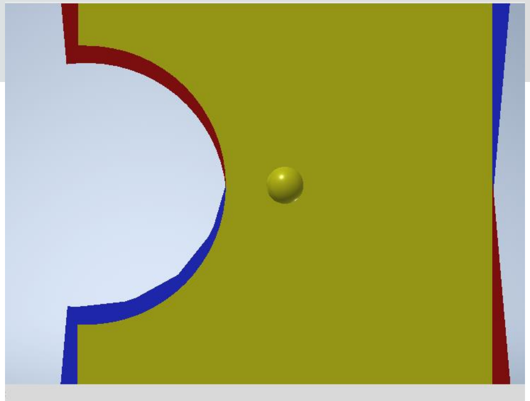
6. Global checking
- Bent staves (caused by long pigtails or stave support)
- The circle-cut staves are not easy to alignment
- Photogrammetry & laser survey (to evaluate the position of the stave)



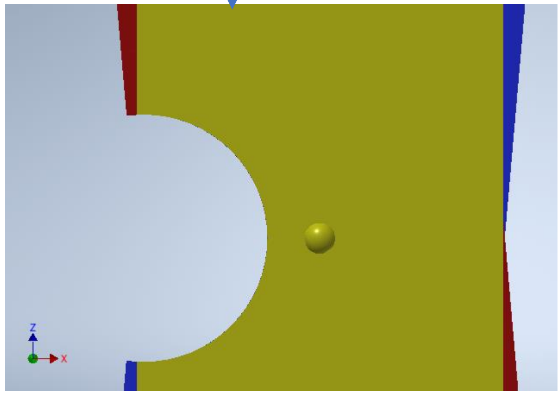
Bent stave with a dangerous distance

The laser survey

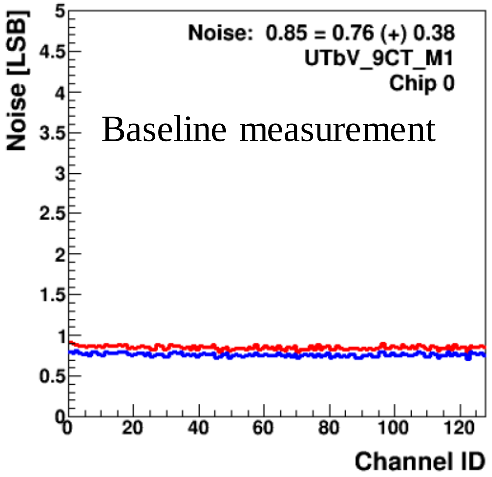


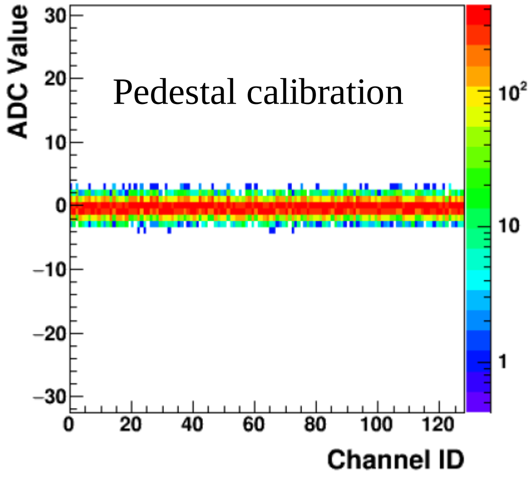


After alignment

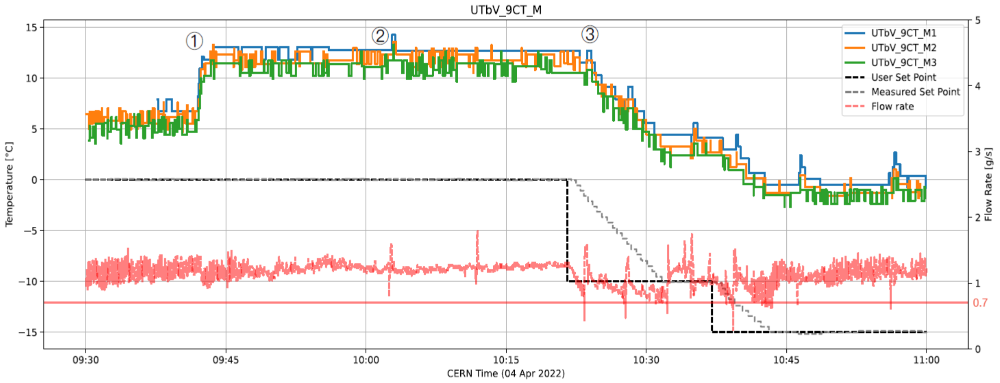


7. Performance studies, pedestal, noise measurements …

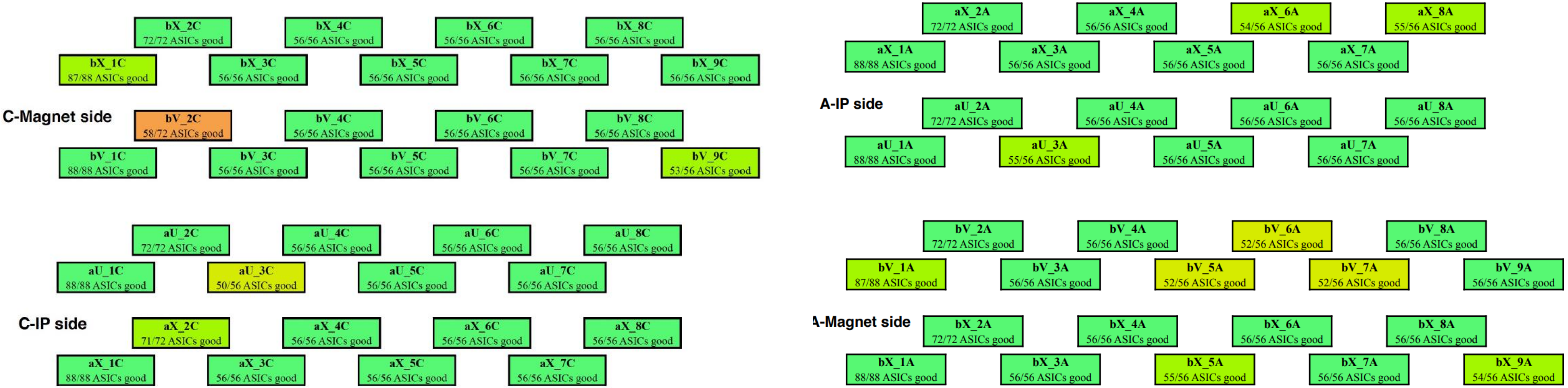




8. Pressure test & commissioning for CO2 system



- Move gasbomb carefully
- Pay attention to the CO2 concentrations indoor



0.16% of all the channels analysed are tagged as **bad channels**
(0.07% pedestal shift, 0.09% high noise)

Underground Service

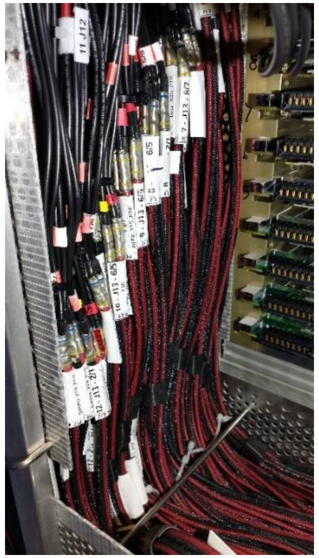
- Cable chain
  - Connect the PEPI patch panels with SBCs
  - 1668 LV power cables
  - 424 LV power RJ45 sense lines
  - 60 HV cables & other services

Bottom side cables are installing

The top side cables are Installing

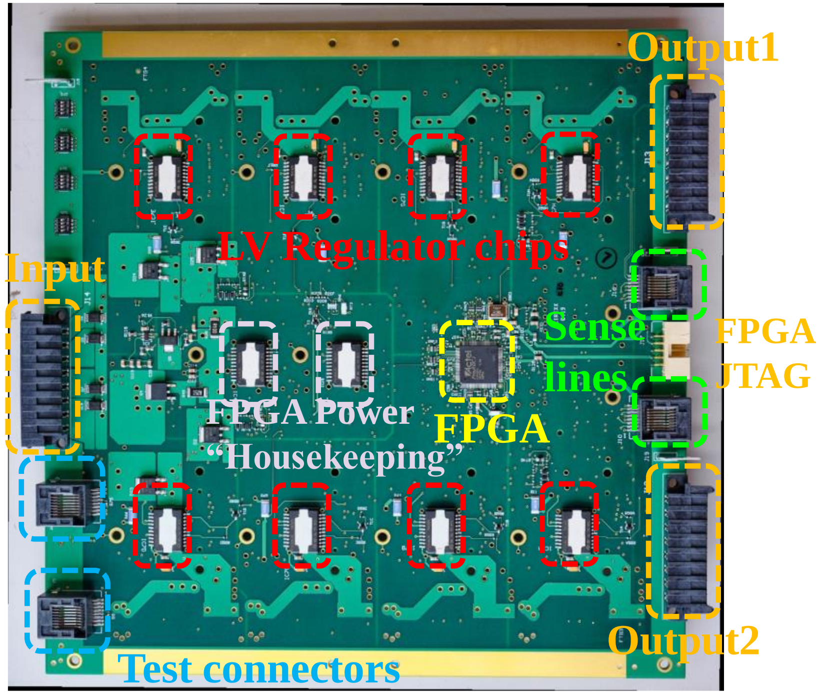
A finished cable chain

A finished SBC



Arranged cables on SBC side

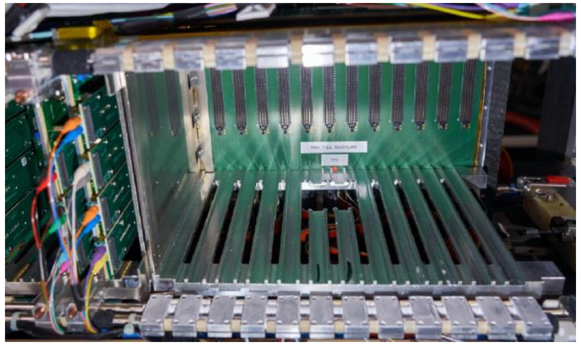
- **Service Bay Crates (SBCs)**
  - 8 Telemetry Control Boards
  - 268 LV Regulators boards
    - Service SALT ASICS
    - Voltage maintained by RJ45 sense lines
  - 524 “samtec”cables (to connect LVR and LV cables)
  - 248 sense line spliters
  - 1668 LV cable pairs



Underground Challenges

- UT transport to underground
  - Need very very gently
  - One pigtail fell off

To access the position by cutting cage

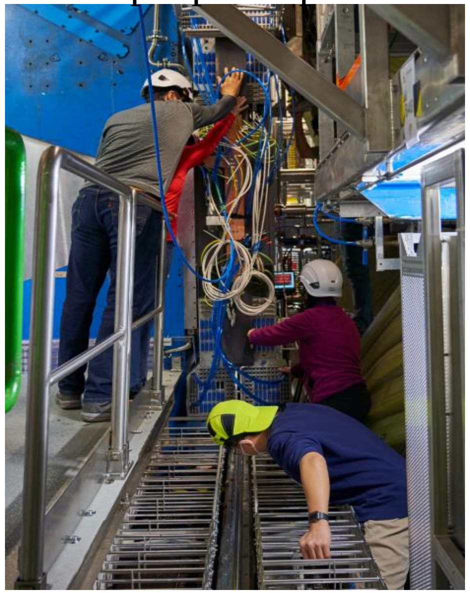


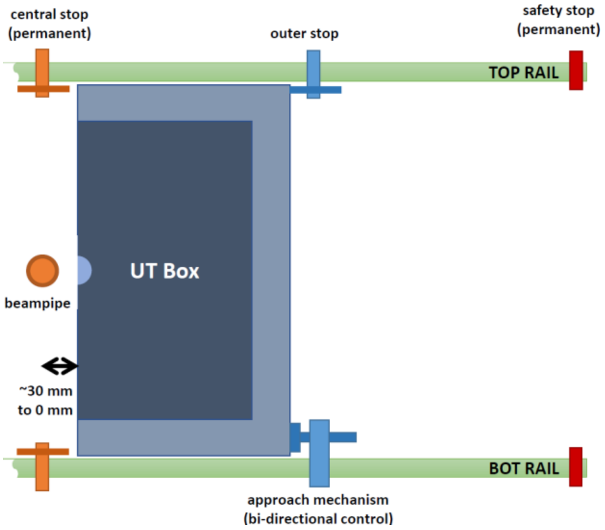
Tight the pigtail

- UT closure
  - Close to the beampipe
  - Heavy cable chains

Very close to beampipe

Need 4 people to push





Place stops to prevent a crash

- Thousands of cables need to be prepared
  - The sequence is very important because of the limited space
  - Manpower is tight

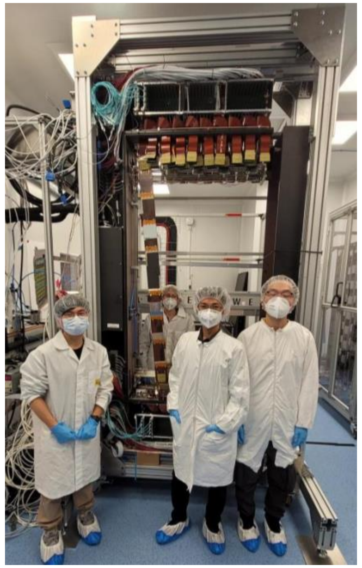
……

TimeLine

Empty Box

Full of PEPI

First stave



Last stave

Closed box

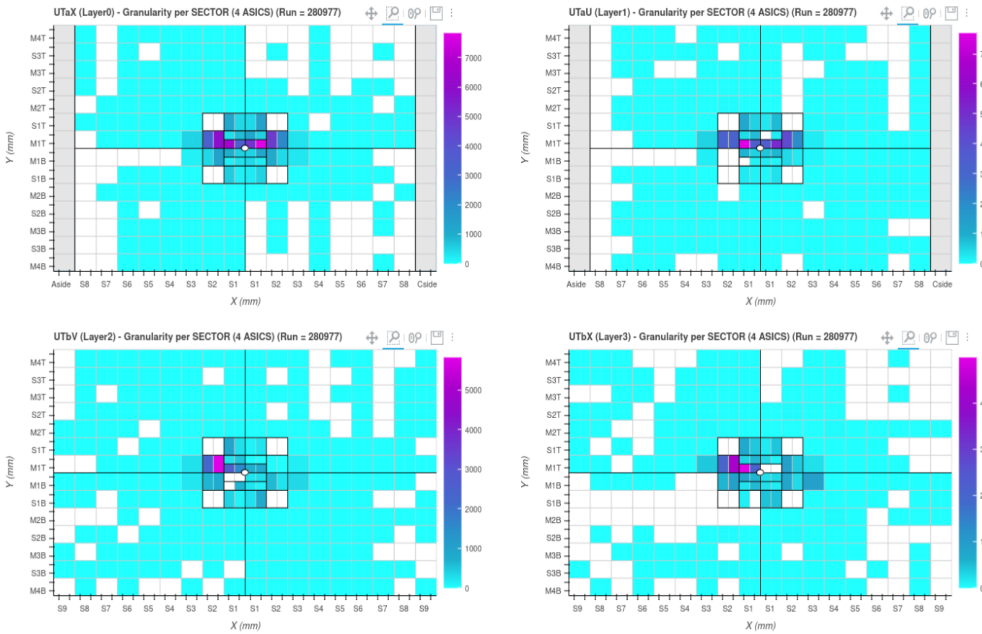
- 21/7/13 — Received First stave Box at CERN
- 21/9 — Finished staves production
- 22/2 — First stave installed
- 22/5 — Turn to A-side PEPI
- 22/6 — Second stave installed
- 22/10 — First stave for A-side
- 22/12/12 — Turn to underground
- 22/12/24 — First sense line pulled
- 23/3/15 — UT closed

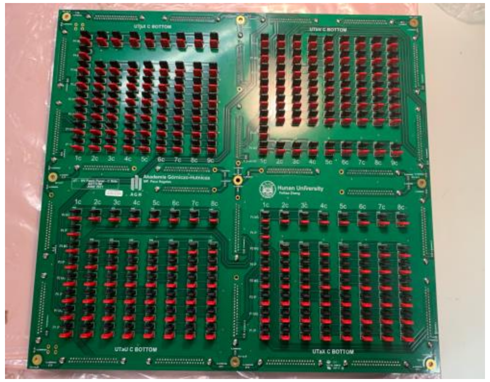
Amazing 20 months thanks to great team, an exciting project

Summary

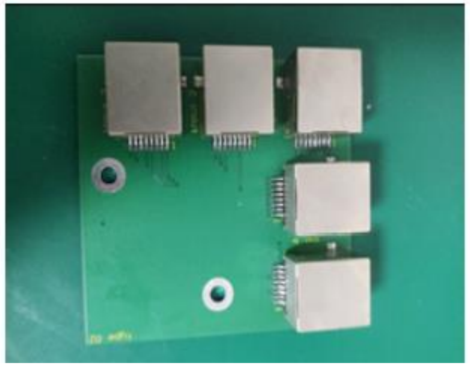
- A significant updating for LHCb
- Upstream Tracker is a key component of the upgrade
  - Chinese members have significant contributions
    - HV patch panel, LV spilter, PEPI patch panel, HV cable **designed and produced by HNU & IHEP**
    - IHEP/HNU/CCNU/UCAS/THU/SCNU all participated in installation
- **UT installation finished this March**
  - Commissioning is ongoing, run in global successfully on 28, Oct, 2023

Obtained entire Run 280977 (200+ GB)!

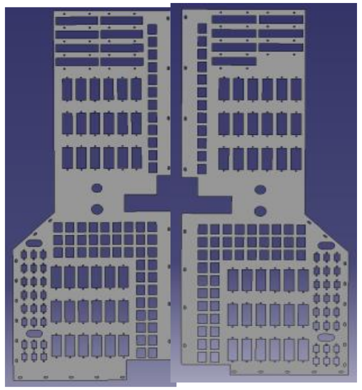




HV board



LV spilter

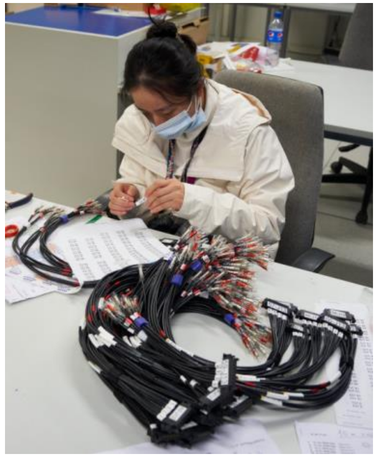


PEPI patch panel

HV cable

Thank You

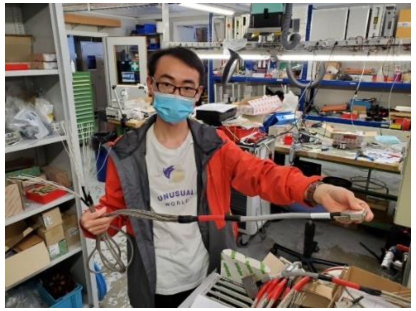













UT installation successfully completed, with a lot of memorable moments.
Best luck to our commissioning and operation team!

BackUp

LHCb Upgrade

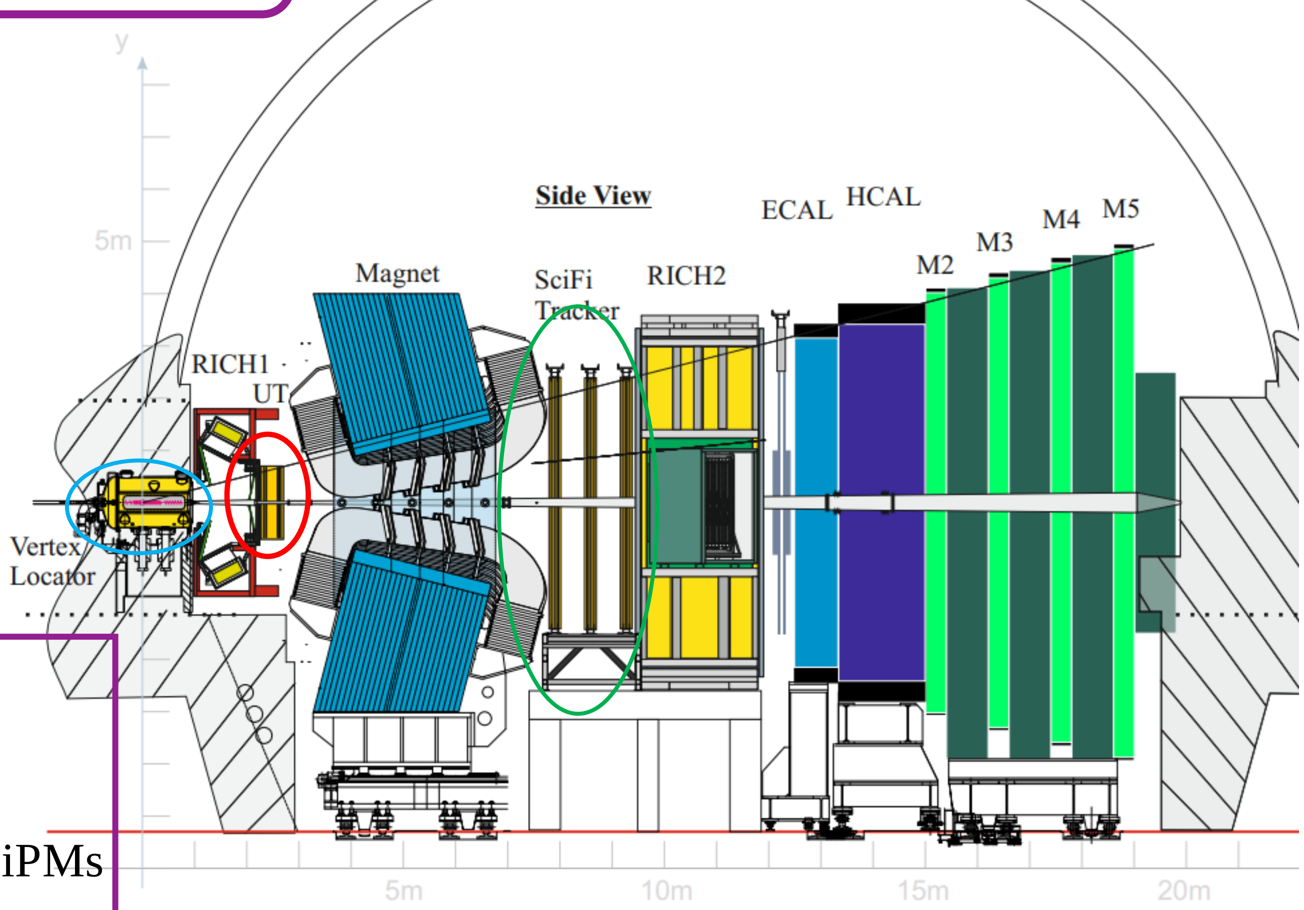
9 fb^{-1} | Upgrade I | Goal: 50 fb^{-1}

Run 1			LS 1		Run 2				LS 2				Run 3			LS 3			Run 4			
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032

Run 1 & 2

Upgrade 1

- No hardware trigger, **software-only trigger** to **40 MHz readout**
- Higher luminosity (5 x $L_{Run1\&2}$) to $\mathbf{2\times10^{33}cm^{-2}s^{-1}}$



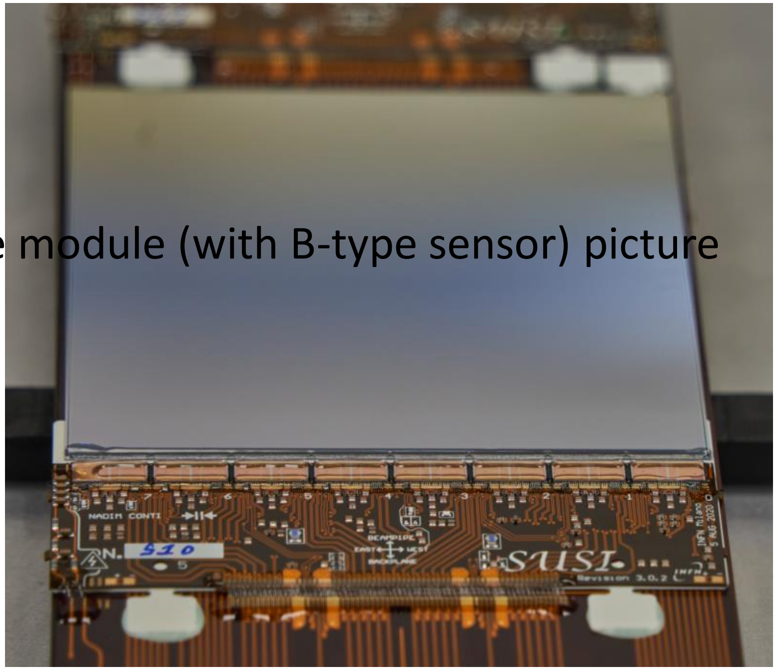
New tracking system

- VErtexLOcator (VELO): Si pixels
- Upstream Tracker (UT) : Si strips
- Scintillating Fiber Tracker (SciFi): Scintillating fibers, SiPMs
- Particle ID: New optics + photon detectors & Calos: Reduce PMT gain + new electronics

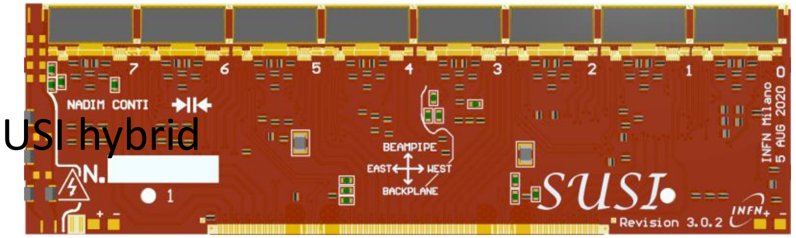
UT Detector - Module

- ➢ Divided into A-side & C-side
- ➢ Consist of 4 layers of silicon strip detectors
  - ❑ organize in 68 staves
- ➢ Single stave can host up to **16 modules** in both sides
  - ❑ 4 types of sensors A (p-in-n), B, C, D (n-in-p)
  - ❑ Hybrid flex: VERA (4 ASICs, A-Type sensor), SUSI (8 ASICs, B-, C-, D-type sensors)
  - ❑ Ceramic stiffener and thermal interface

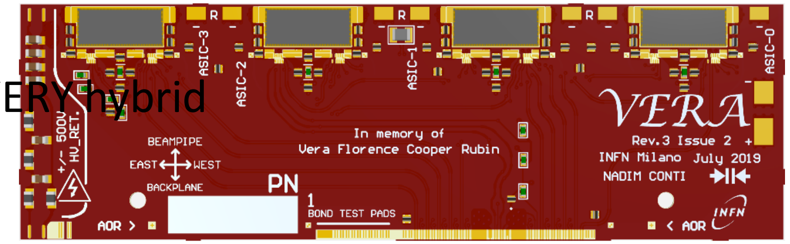
Sensor	Type	Pitch	Length	Strips	# sensors
A	p-in-n	187.5 μm	99.5 mm	512	888
B	n-in-p	93.5 μm	99.5 mm	1024	48
C	n-in-p	93.5 μm	50 mm	1024	16
D	n-in-p	93.5 μm	50 mm	1024	16



The module (with B-type sensor) picture



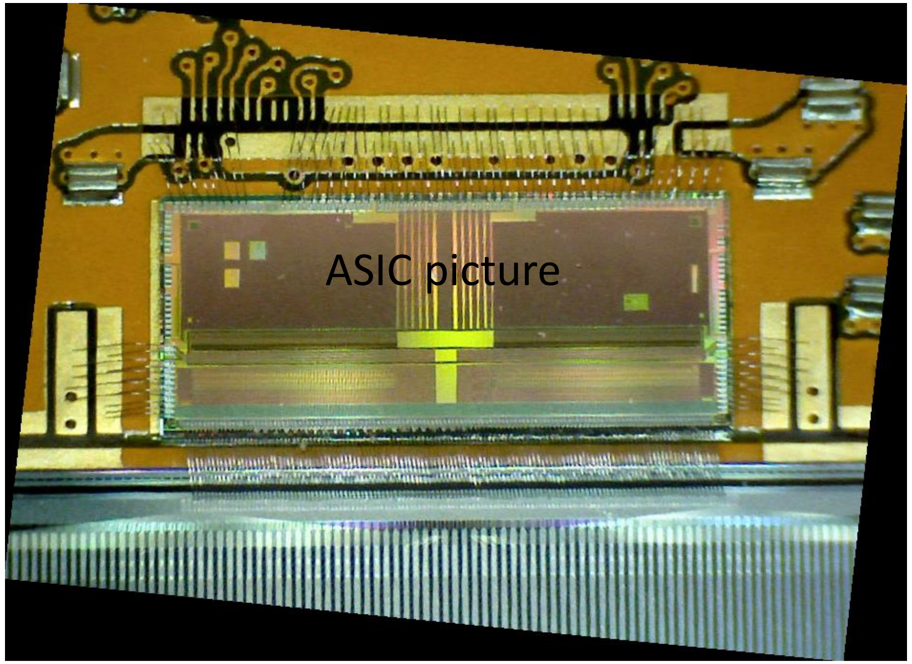
SUSI hybrid

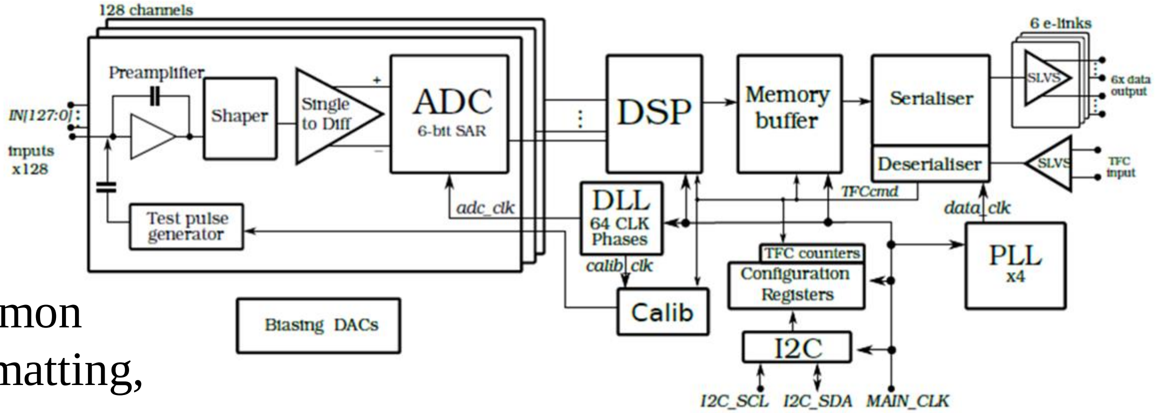


VERY hybrid

UT Detector – ASIC chip

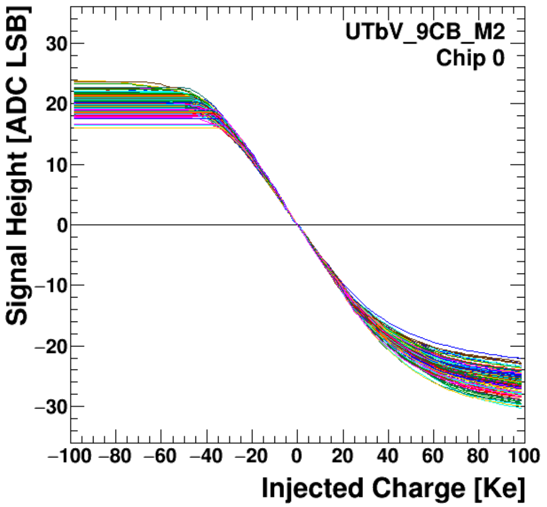
- Divided into A-side & C-side
- Consist of 4 layers of silicon strip detectors
  - organize in 68 staves
- Single stave can host up to 16 modules in both sides
- Front-end ASIC (SALT) glued and bonded to hybrid flex
  - **S**ilicon **A**SIC for **L**HCb **T**racking **(SALT)**
  - **4192 ASICs** with **128 channels** each
    - 130 nm-CMOS technology
    - 6-bit ADC/channel
  - peaking time ≤ 25 ns, Signal to Noise ratio > 10



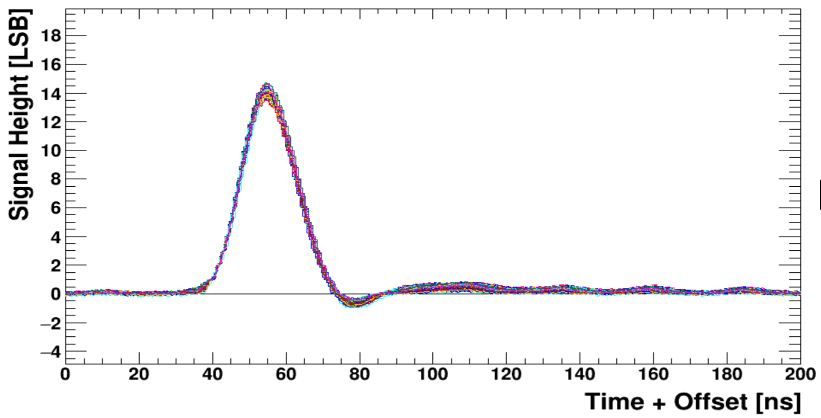


- Digital Signal Processing (DSP): pedestal and common mode noise subtraction, zero-suppression, data formatting, spillover correction

SALT tests



Preliminary Gain Scan

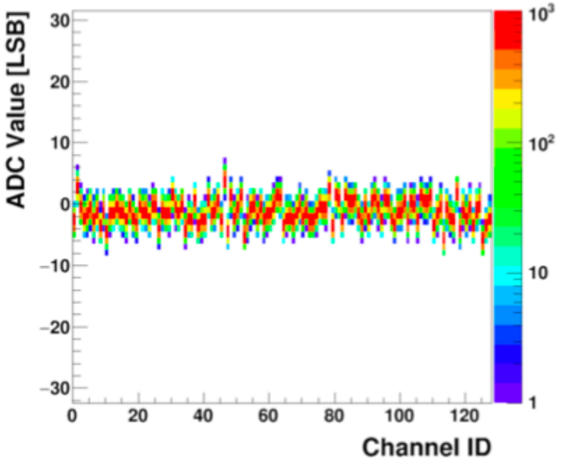


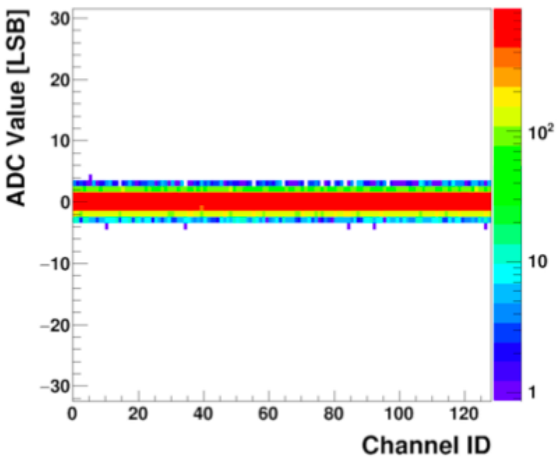
Pulse shape scan

With AQ, PRBS tests
to verify the data flow

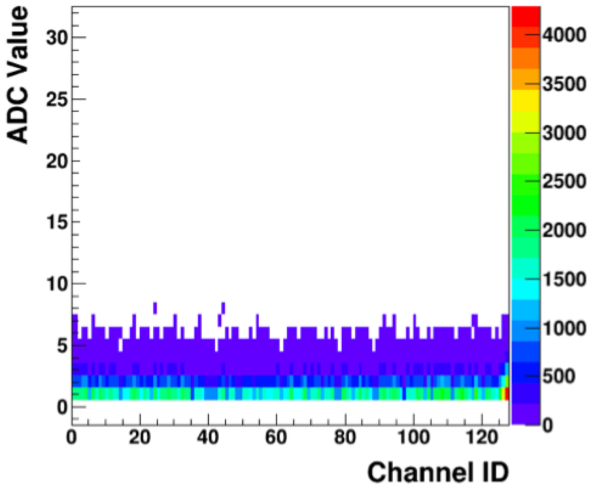
The calibration

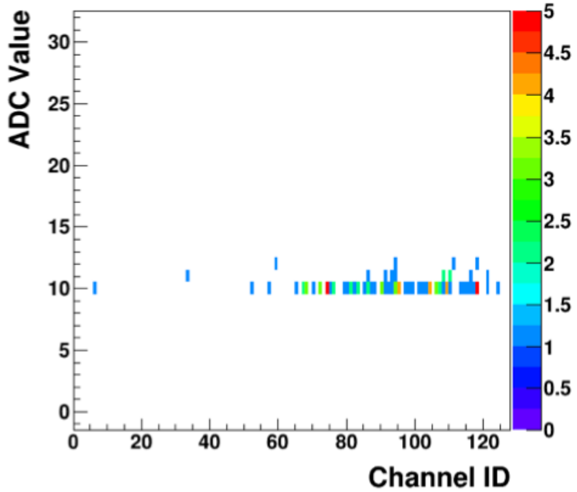
pedestal subtraction





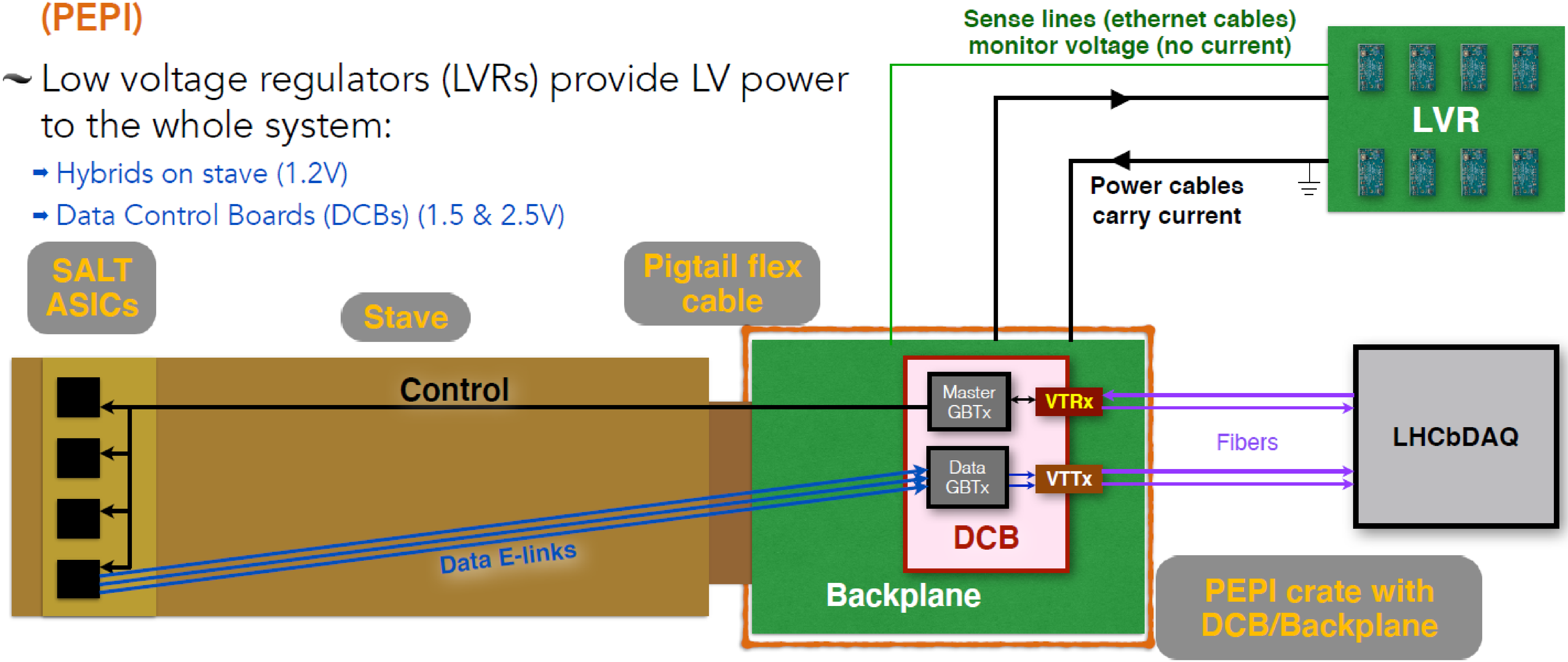
Zero suppression



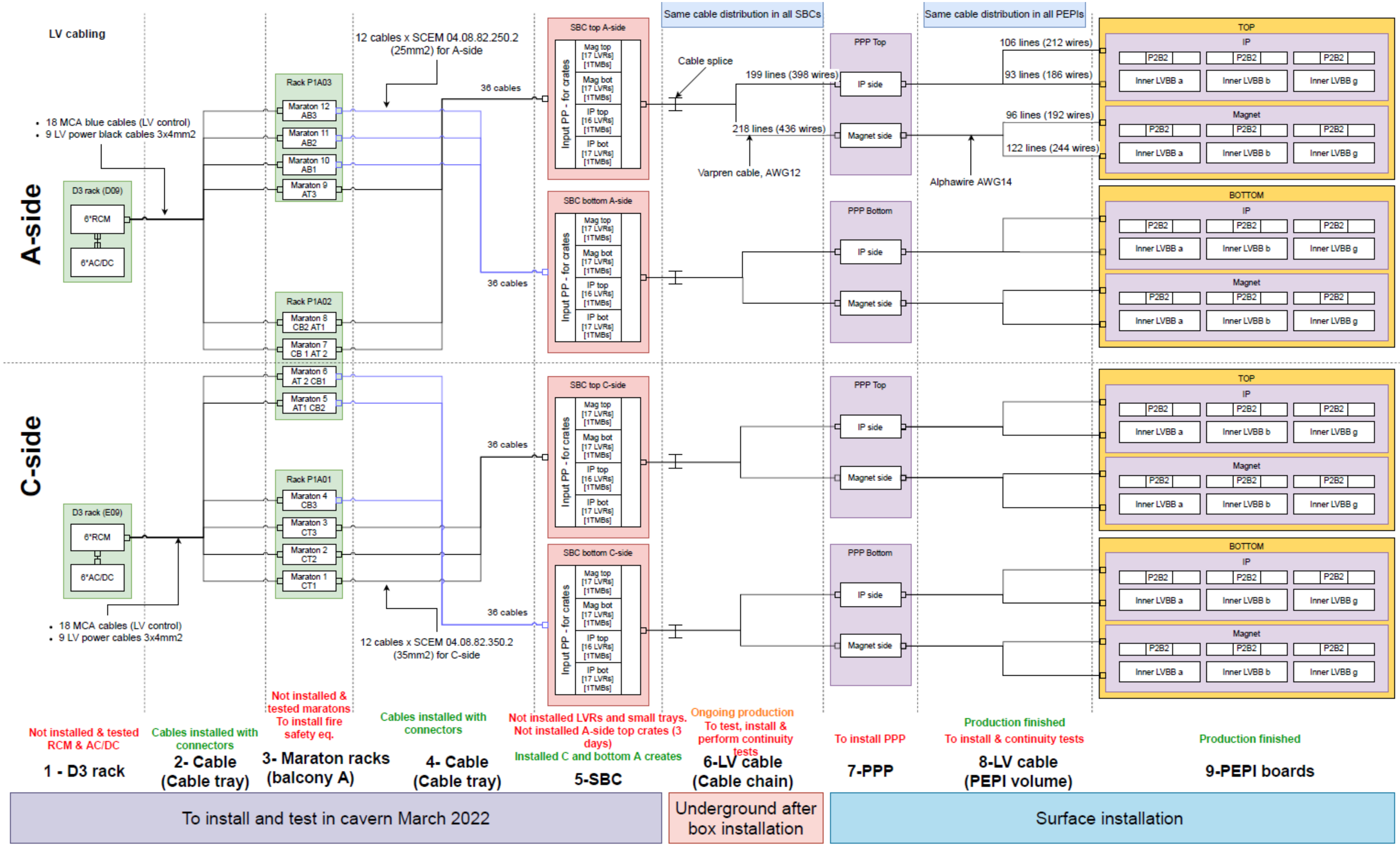


Readout and Power Electronics

- Stave is readout by **Peripheral Electronics (PEPI)**
- Low voltage regulators (LVRs) provide LV power to the whole system:
  - ➡ Hybrids on stave (1.2V)
  - ➡ Data Control Boards (DCBs) (1.5 & 2.5V)

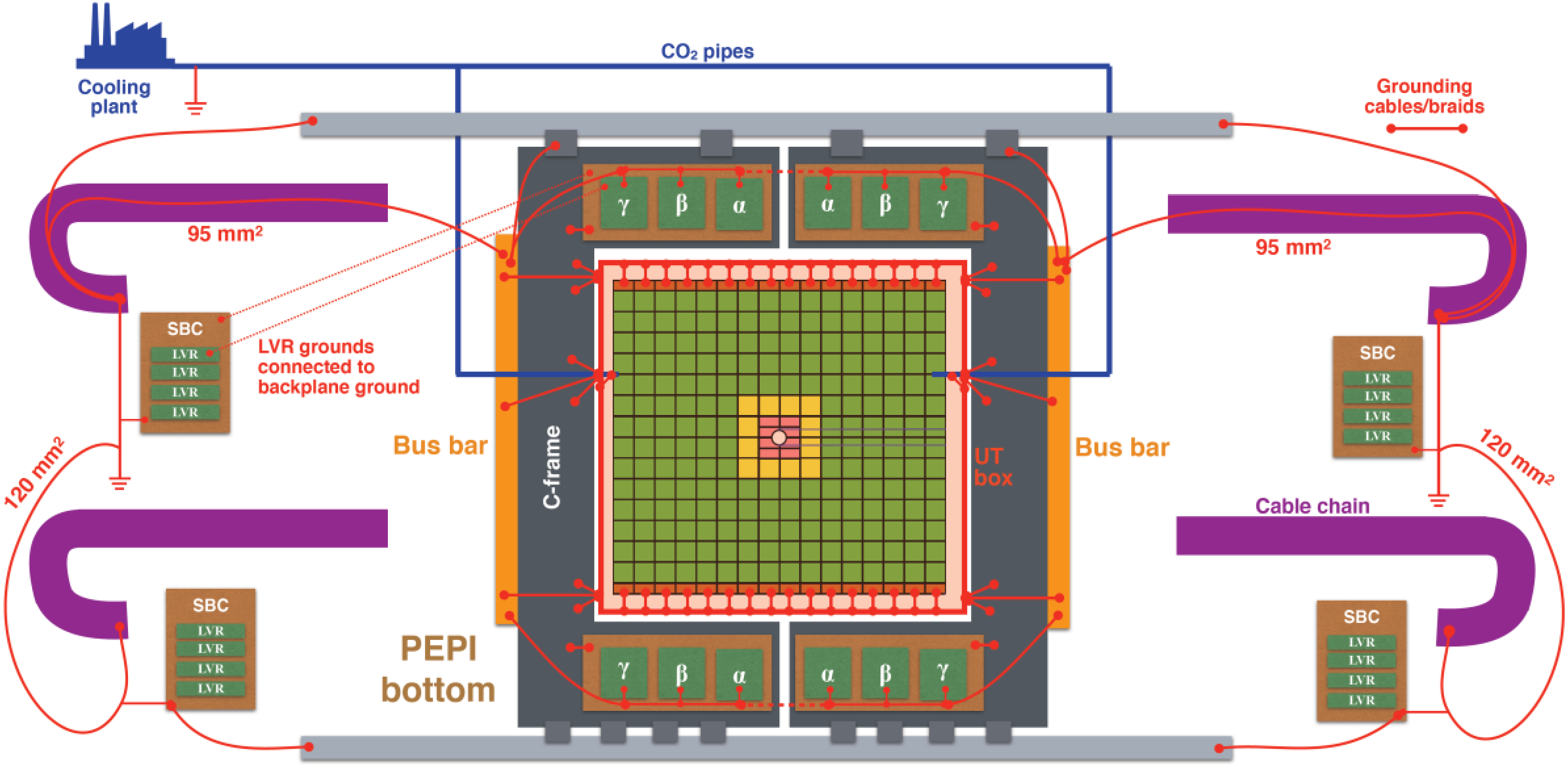


LV diagram

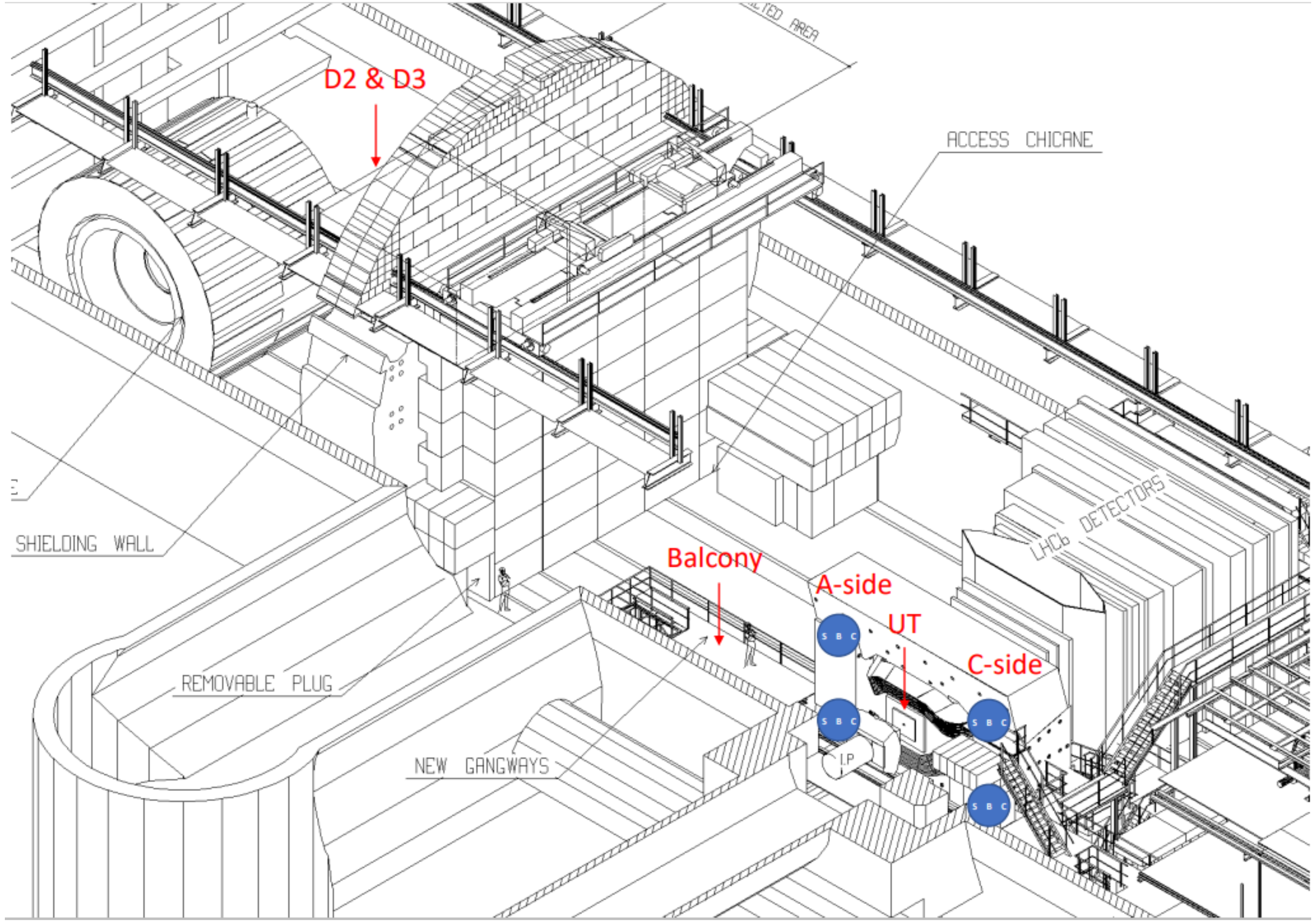


LV cabling
A-side
C-side
D3 rack (D09)
6*RCM
6*AC/DC
D3 rack (E09)
• 18 MCA blue cables (LV control)
• 9 LV power black cables 3x4mm2
• 18 MCA cables (LV control)
• 9 LV power cables 3x4mm2
Rack P1A03
Maraton 12 AB3
Maraton 11 AB2
Maraton 10 AB1
Maraton 9 AT3
Rack P1A02
Maraton 8 CB2 AT1
Maraton 7 CB 1 AT 2
Maraton 6 AT 2 CB1
Maraton 5 AT1 CB2
Rack P1A01
Maraton 4 CB3
Maraton 3 CT3
Maraton 2 CT2
Maraton 1 CT1
12 cables x SCEM 04.08.82.250.2 (25mm2) for A-side
12 cables x SCEM 04.08.82.350.2 (35mm2) for C-side
36 cables
SBC top A-side
SBC bottom A-side
SBC top C-side
SBC bottom C-side
Input PP - for crates
Mag top [17 LVRs] [1TMBs]
Mag bot [17 LVRs] [1TMBs]
IP top [16 LVRs] [1TMBs]
IP bot [17 LVRs] [1TMBs]
Same cable distribution in all SBCs
Cable splice
199 lines (398 wires)
218 lines (436 wires)
Varpren cable, AWG12
PPP Top
PPP Bottom
IP side
Magnet side
Same cable distribution in all PEPIs
106 lines (212 wires)
93 lines (186 wires)
96 lines (192 wires)
122 lines (244 wires)
Alphawire AWG14
TOP
BOTTOM
IP
Magnet
P2B2
Inner LVBB a
Inner LVBB b
Inner LVBB g
Not installed & tested RCM & AC/DC
1 - D3 rack
Cables installed with connectors
2- Cable (Cable tray)
Not installed & tested maratons
To install fire safety eq.
3- Maraton racks (balcony A)
Cables installed with connectors
4- Cable (Cable tray)
Not installed LVRs and small trays.
Not installed A-side top crates (3 days)
Installed C and bottom A creates
5-SBC
Ongoing production
To test, install & perform continuity tests
6-LV cable (Cable chain)
To install PPP
7-PPP
Production finished
To install & continuity tests
8-LV cable (PEPI volume)
Production finished
9-PEPI boards
To install and test in cavern March 2022
Underground after box installation
Surface installation

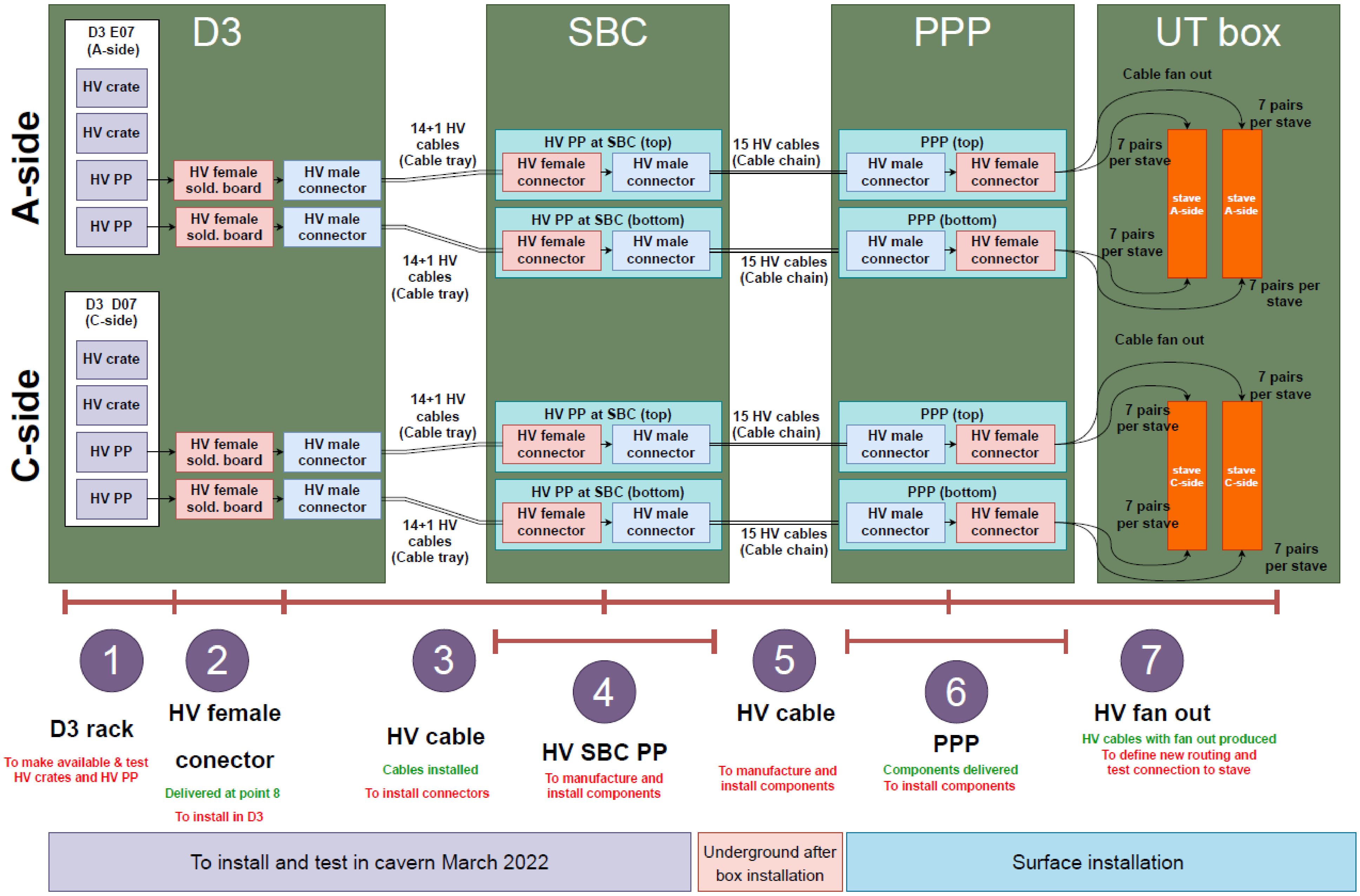
Grounding


Cooling plant
CO₂ pipes
Grounding cables/braids
95 mm²
95 mm²
SBC
LVR
LVR
LVR
LVR
LVR grounds connected to backplane ground
Bus bar
C-frame
UT box
Bus bar
120 mm²
120 mm²
Cable chain
PEPI bottom
γ β α α β γ
γ β α α β γ

Underground Layout



HV diagram

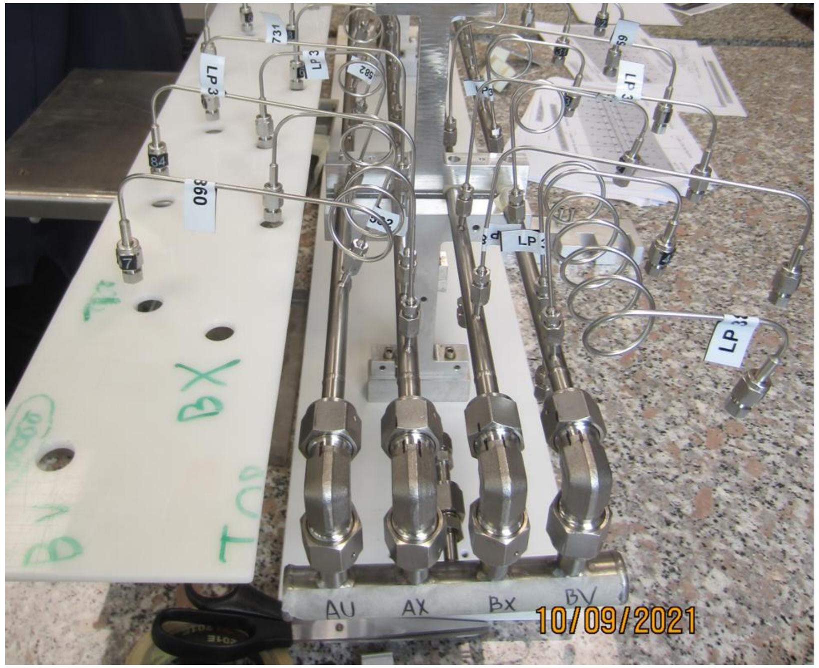


A-side
C-side
D3
D3 E07 (A-side)
HV crate
HV crate
HV PP
HV PP
HV female sold. board
HV male connector
HV female sold. board
HV male connector
D3 D07 (C-side)
HV crate
HV crate
HV PP
HV PP
HV female sold. board
HV male connector
HV female sold. board
HV male connector
14+1 HV cables (Cable tray)
14+1 HV cables (Cable tray)
14+1 HV cables (Cable tray)
14+1 HV cables (Cable tray)
SBC
HV PP at SBC (top)
HV female connector
HV male connector
HV PP at SBC (bottom)
HV female connector
HV male connector
HV PP at SBC (top)
HV female connector
HV male connector
HV PP at SBC (bottom)
HV female connector
HV male connector
15 HV cables (Cable chain)
15 HV cables (Cable chain)
15 HV cables (Cable chain)
15 HV cables (Cable chain)
PPP
PPP (top)
HV male connector
HV female connector
PPP (bottom)
HV male connector
HV female connector
PPP (top)
HV male connector
HV female connector
PPP (bottom)
HV male connector
HV female connector
UT box
Cable fan out
7 pairs per stave
7 pairs per stave
stave A-side
stave A-side
7 pairs per stave
7 pairs per stave
Cable fan out
7 pairs per stave
7 pairs per stave
stave C-side
stave C-side
7 pairs per stave
7 pairs per stave
1
D3 rack
To make available & test HV crates and HV PP
2
HV female conector
Delivered at point 8
To install in D3
3
HV cable
Cables installed
To install connectors
4
HV SBC PP
To manufacture and install components
5
HV cable
To manufacture and install components
6
PPP
Components delivered
To install components
7
HV fan out
HV cables with fan out produced
To define new routing and test connection to stave
To install and test in cavern March 2022
Underground after box installation
Surface installation

Cooling System

- **CO2 for staves**
  - Bi-phase CO2
  - Manifolds connect to the cooling tube of the stave
  - Stave temperature during operation: 0-100C

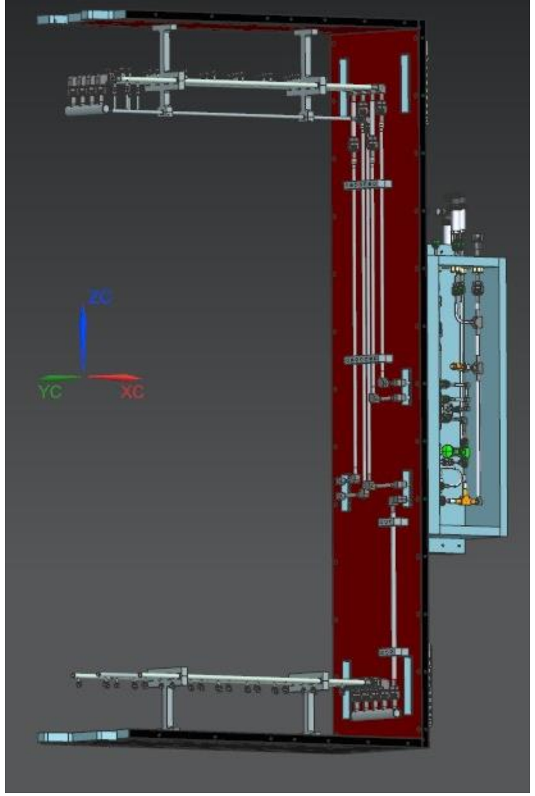
The CO2 cooling pipes are preparing & labeling



Picture of connectors

The CO2 cooling pipes are installing

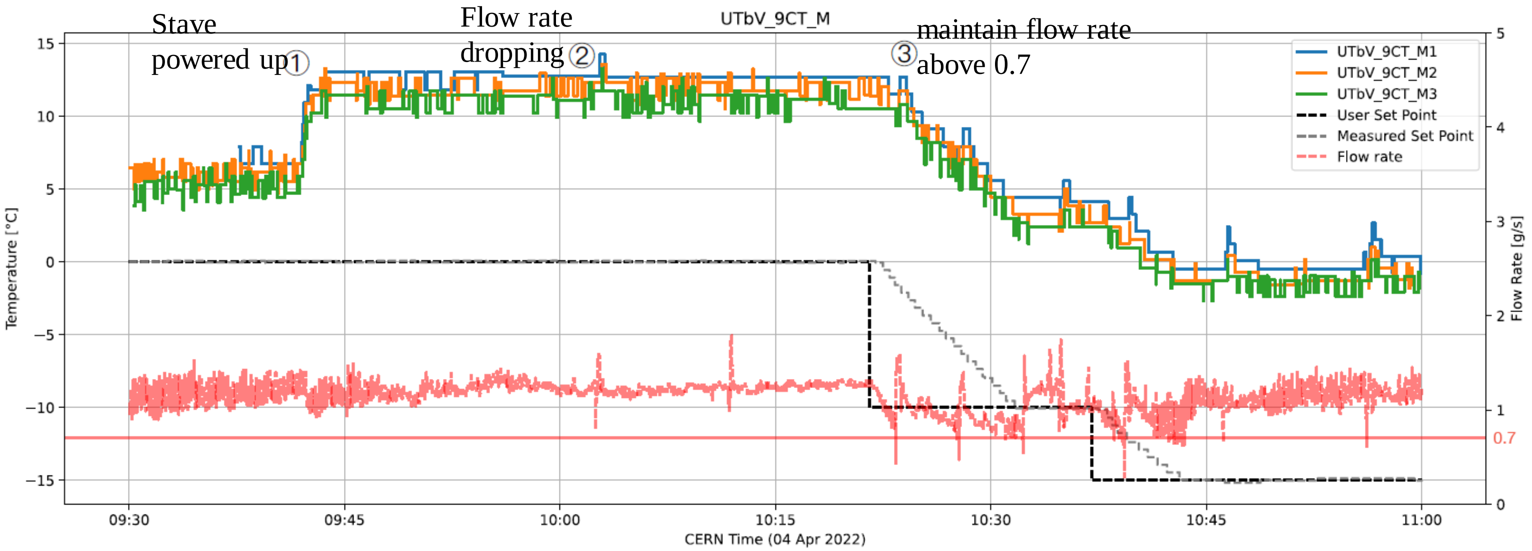
Completed overview



- **CO2 for staves**
  - Bi-phase CO2
  - Manifolds connect to the cooling tube of the stave
  - Stave temperature during operation: 0-100C
- Tests
  - Up pressure from 10 to 50bar, leave at overnight, See if pressure holds
  - commissioning

Pressure monitor

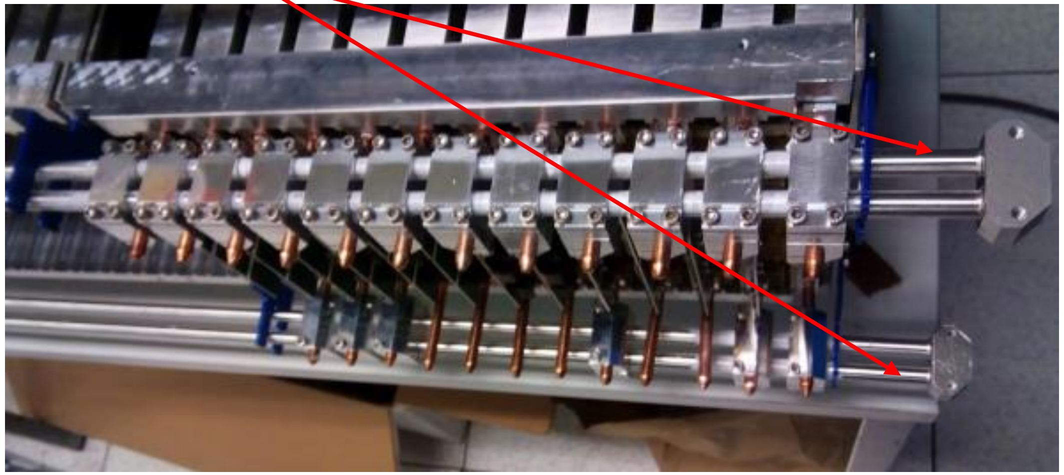
Commissioning example



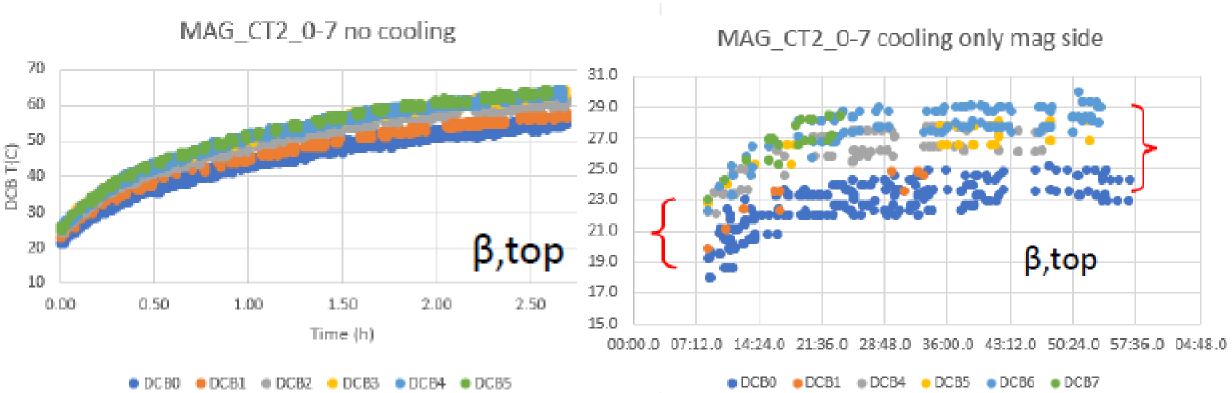
Cooling System

- **CO2 for staves**
  - Bi-phase CO2
  - Manifolds connect to the cooling tube of the stave
  - Stave temperature during operation: 0-10°C
- Tests
  - Up pressure from 10 to 50bar, leave at overnight, See if pressure holds
  - Commissioning

DCB cooling pipes with couplers



- **Water for PEPI**
  - Demineralised water
  - Water pipes: 2 sets of two pipes on the top and bottom part of each PEPI
  - DCB temperature 30°C
- Tests
  - Leak test
  - Hydraulic test



Useful in controlling DCB temperature