LHCb Upstream Tracker Upgrade

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For The LHCb UT Group

Vertex 2015
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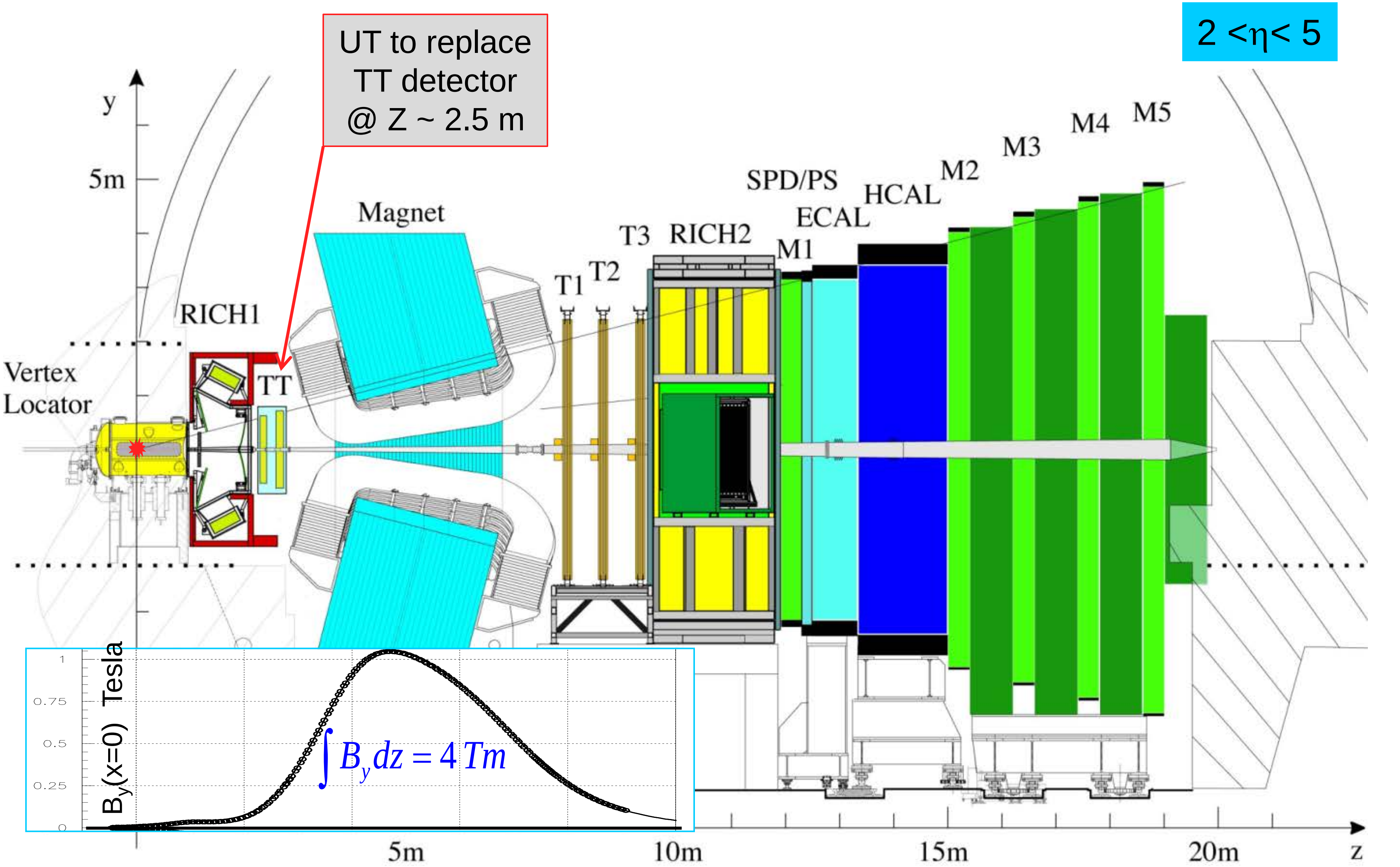
UT In The LHCb



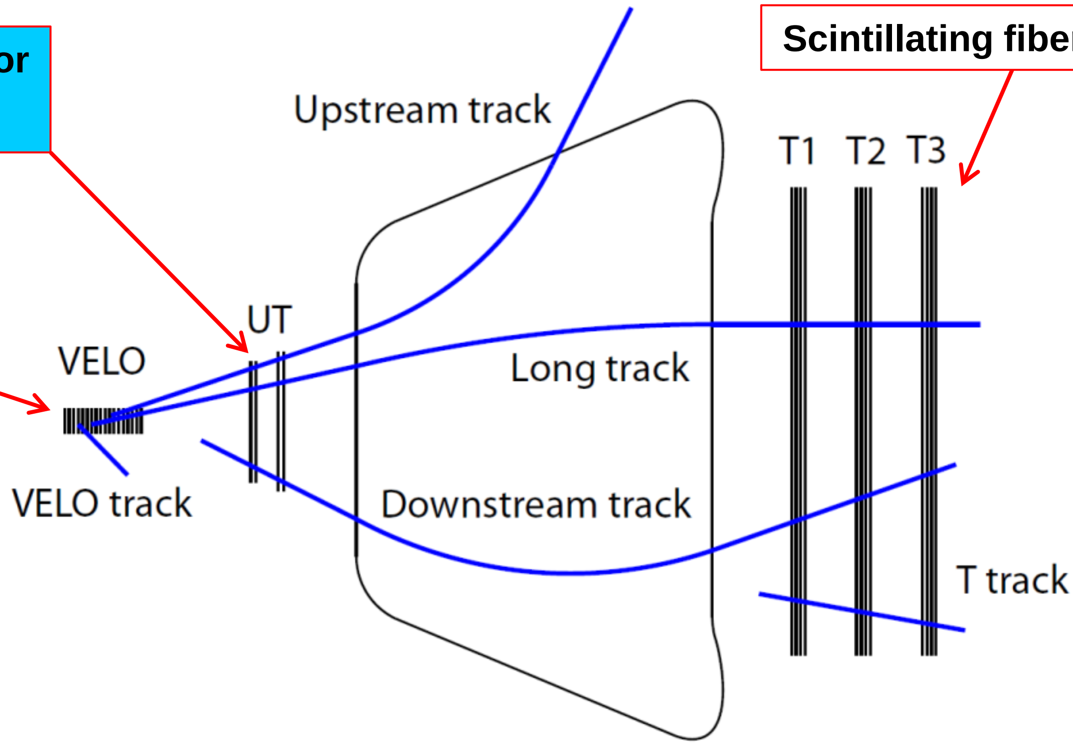
- The LHCb upgrade extend the physics reach by
  - Running at higher luminosity: L = 2x10^{33} cm^{-2} s^{-1}.
  - Reading out events at 40 MHz, & using full software trigger to increase trigger efficiency.
- All 3 tracking detectors are to be upgraded: Velo, UT, SciFi.

Silicon strip detector
This presentation

Silicon pixel detector
Sophie Richards

Overall tracking system
Stefano Gallorini

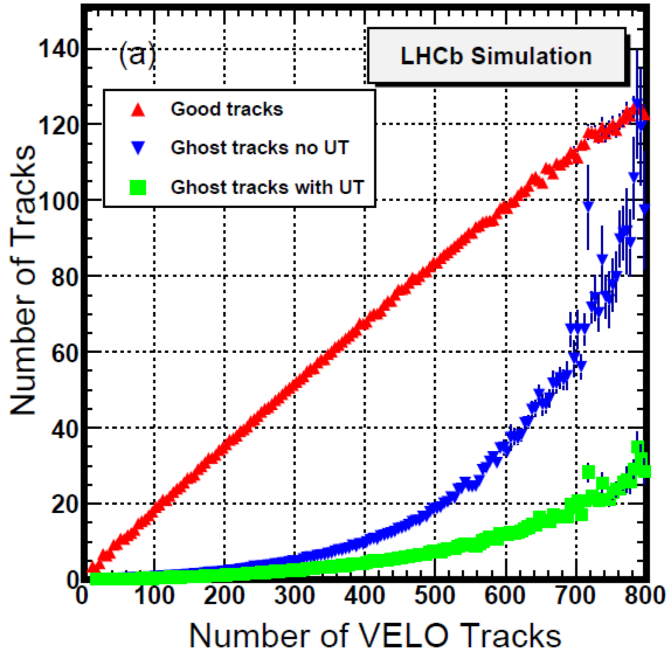
Scintillating fiber detector



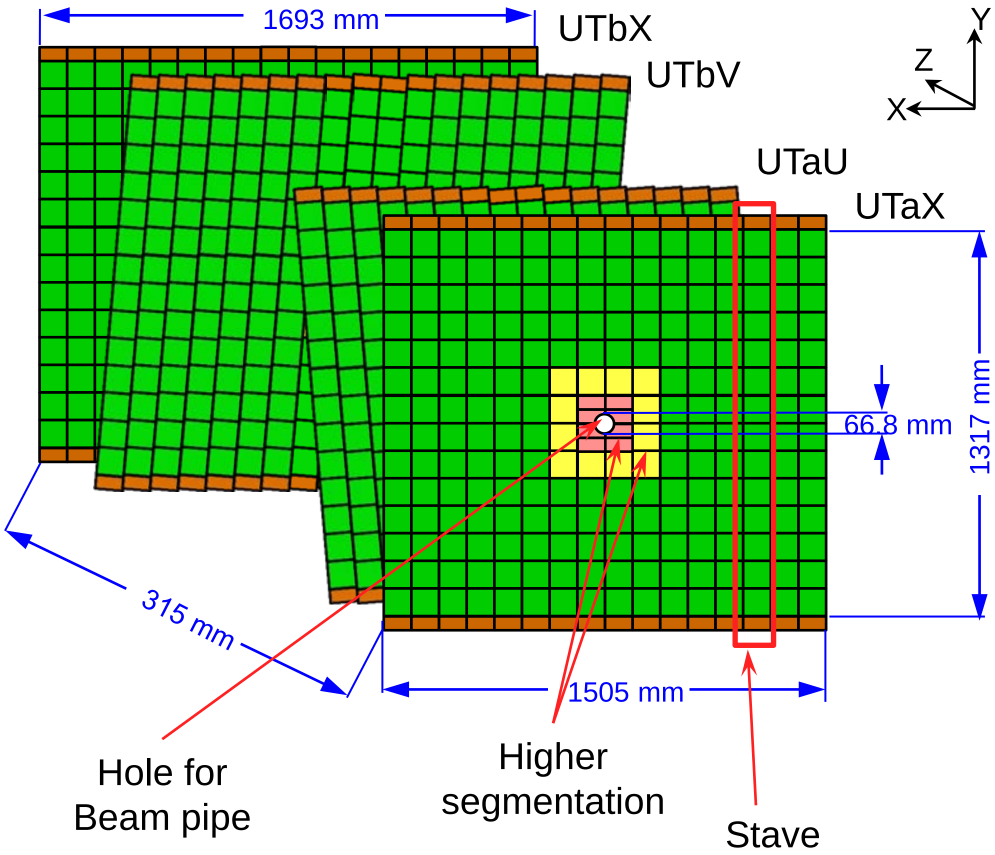
The UT Upgrade

- UT (Upstream Tracker) is to replace the TT detector:
  - Silicon strip sensors of finer granularity to cope with increased particle density.
  - Improved coverage at small polar angles.
  - Signal processing & digitization in sensor proximity at 40 MHz rate.
  - Improved radiation hardness for at least 50 fb^{-1} data collection.

- UT in the LHCb tracking system
  - Provide fast estimates of momentum in the software trigger.
  - Increase reconstruction efficiency of long lived particles: e.g. $K_S^0 \to \pi^+\pi^-$, $\Lambda \to p\pi^-$.



The UT Detector System



- 4 planes constructed using "staves" with silicon on both sides, partially overlapping in X direction to ensure 100% coverage.
- Measuring XUVX coordinates.
- Higher segmentation in the region surrounding the beam pipe.
- Inner detectors with circular cuts to maximize acceptance.
- Basic mechanical unit "stave", total 68 UT staves.

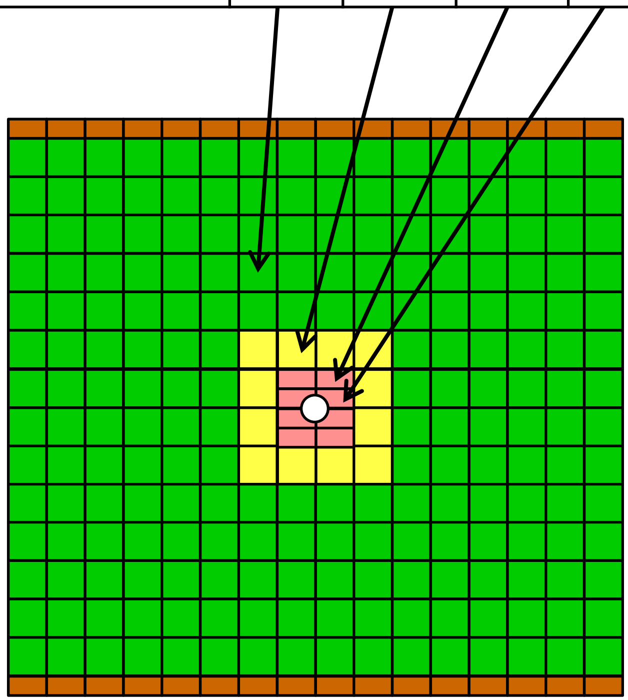
UT Constituents To Be Discussed

Main constituents of UT detector are introduced in the order that follows signal data flow:

1) Silicon sensor,
2) SALT ASIC,
3) Flex cable,
4) Readout electronics,
5) Mechanical & cooling.

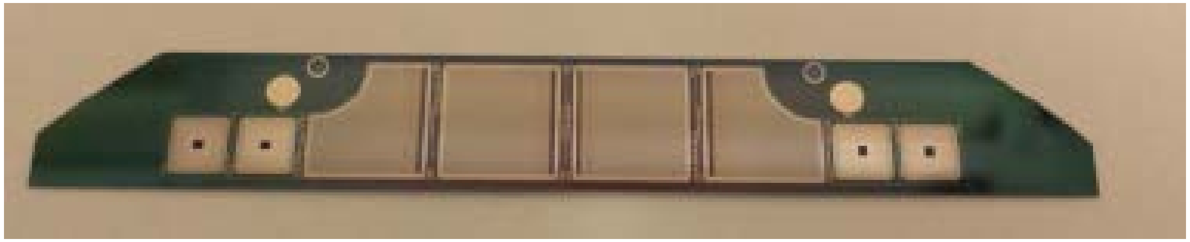
Silicon Sensors

Sensor	A	B	C	D
Pitch (μm)	~190	~95	~95	~95
Length (mm)	~100	~100	~50	~50
Strips/sensor	512	1024	1024	1024
Number	888	48	16	16



- Four different types of sensor.
- Sensor size: ~100×100 mm^2 (A & B), half length (C & D).
- Strip pitch: ~190 & 95 μm.
- Guard rings: 800 μm
- Thickness: 250 μm (maybe 320 μm for A)
- Wafer resistivity 3-5 KΩ•cm.
- n^+-in-p technology (maybe p^+-in-n for A).
- Sensor backside is passivated, & sensor is biased from front-side HV contact.
- Outer sensors (Type A) have much larger pitch than that of FE ASIC (~80 μm). Pitch adapters are needed, embedded or off sensor.

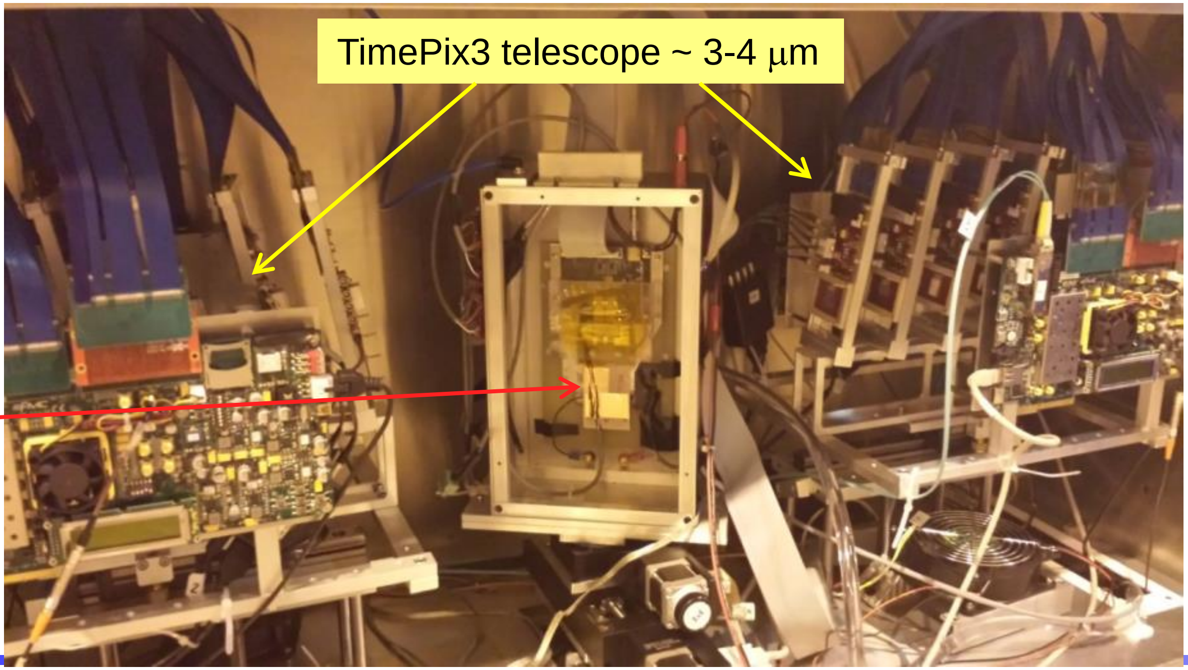
Sensor R&D - Phase I



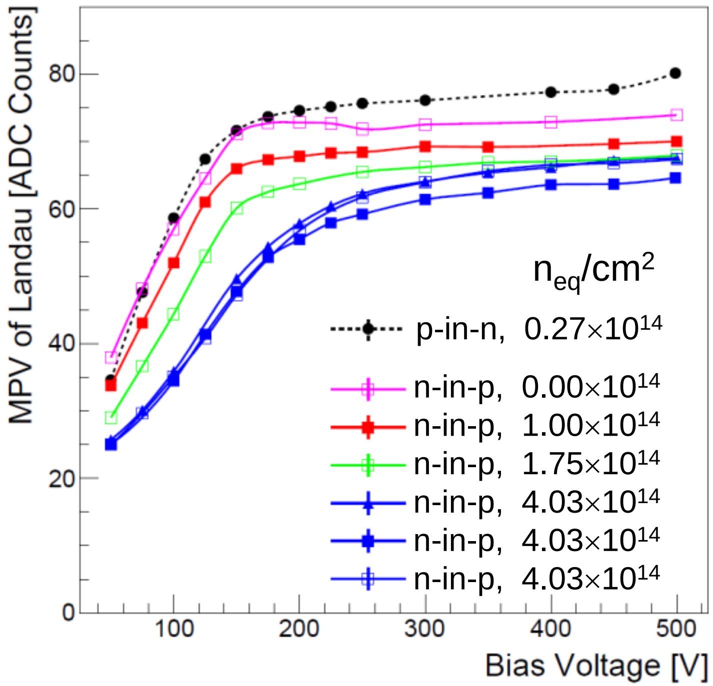
- Mini-sensors ~1.1×1.1 cm^2
- Both n^+-in-p & p^+-in-n types
- Strip pitch 80 μm.
- Different guard ring structure near circular cut.

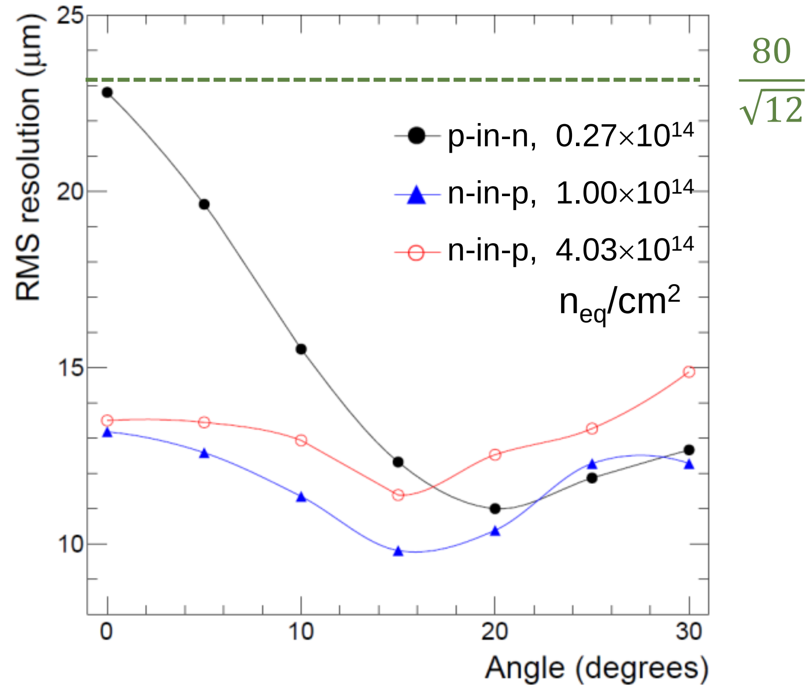
- Inner-most sensors need to sustain ~5×10^{14} 1-MeV n_{eq}/cm^2 fluence for 50 fb^{-1} running.
- Sensors were exposed to up to ~4×10^{14} n_{eq}/cm^2 at Mass. General Hospital in June 2014, and tested in a 180 GeV proton beam at CERN in Oct. 2014.

Mini sensors are read out by Beetle chips & Alibava DAQ system



Phase-I Sensor Test Beam Results

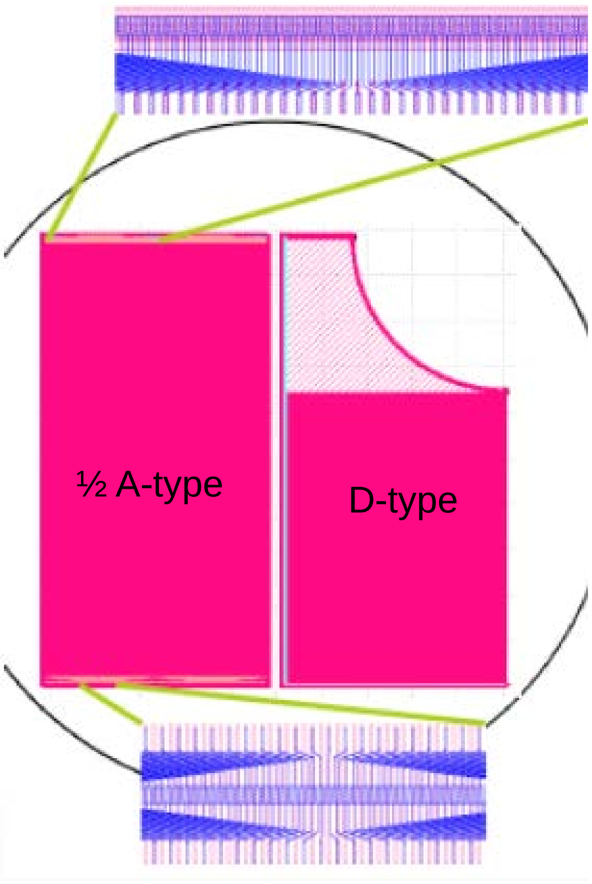




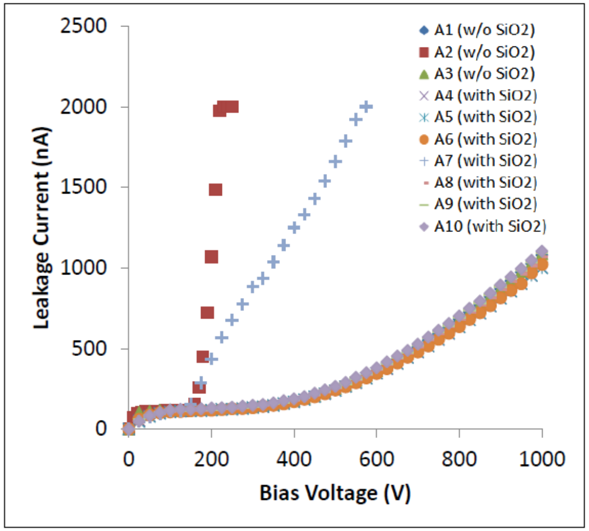
- For the n^+-in-p sensors, there is a gradual loss in total charge collected with increased radiation dose.
- All sensors reach plateaued @ 300-400V, S/N rate >~ 15. They should be efficient after 50 fb^{-1} running (5×10^{14} n_{eq}/cm^2).
- More charge sharing at normal incidence for irradiated n^+-in-p sensors.

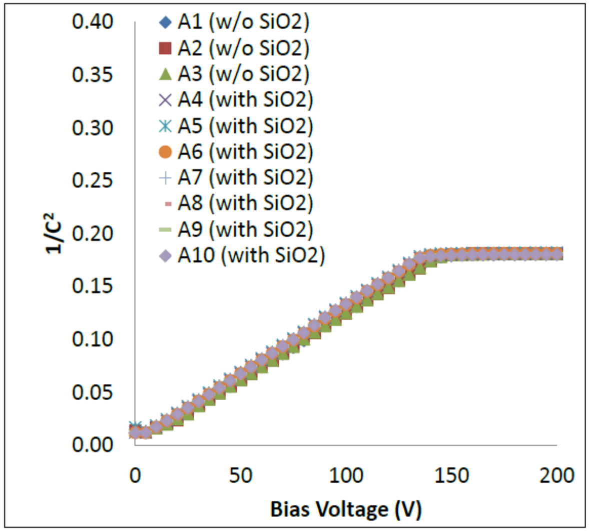
Sensor R&D Phase II

- What do we need to assess:
  - Functionalities of detectors (type D) with circular cut.
  - Performance of built-in pitch adapter for type A sensors.
  - In parallel glass pitch adapters to implement "external pitch adapter" solution in hand (produced by CNM)
- Evaluation of these devices will allow us to fix sensor sizes & constrain hybrid sizes.



IV, CV for ½ A sensors (D sensors are similar).

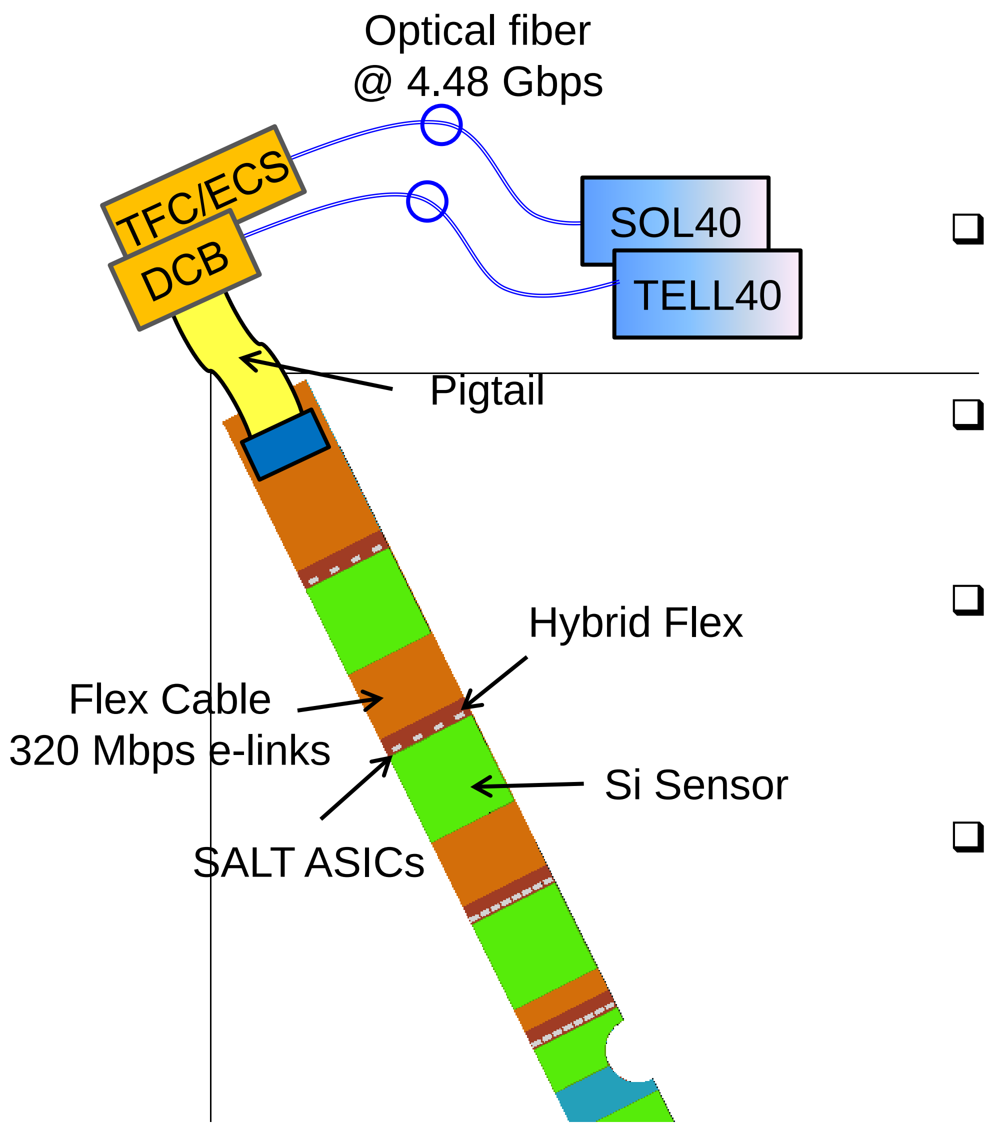




Test Beam In Summer 2015

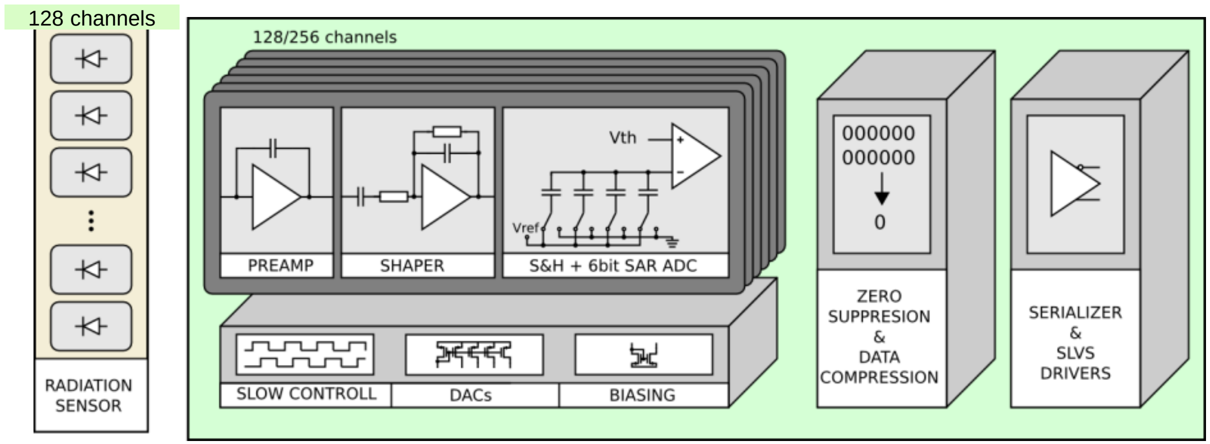
- Phase II prototype sensors were irradiated at CERN in May, and will be tested soon.
  - Type A sensors radiation dose ~1 MRad.
  - Type D sensors exposed to ~5×10^{14} n_{eq}/cm^2 (40 MRad).
- The irradiated sensors and un-irradiated reference sensors will be tested in proton beam at CERN this July.
- We want to learn:
  - Will the embedded pitch adapter work properly after 1 MRad irradiation?
  - Performance of type D sensor near the cutout.
  - Validate backside passivation and biasing scheme.
- As type A sensors ~92% of all sensors, we plan to submit RFQ of type A in August and start production if the performance is satisfactory.

UT Signal Readout Chain



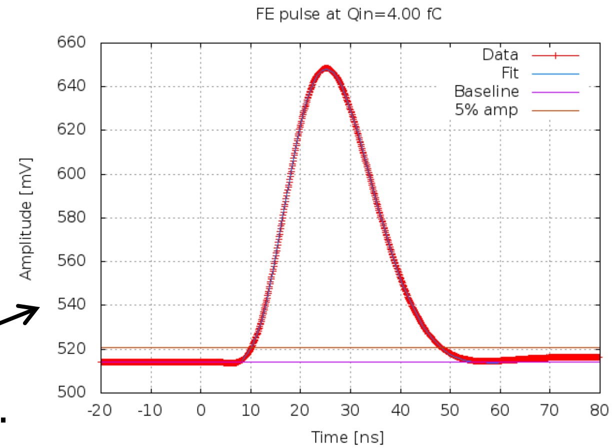
- UT signals from silicon strips are digitized and zero suppressed at ASICs (4 or 8 ASICs/sensor).
- ASIC sends out data as SLVS signals via 3-5 e-ports / e-links @320 Mbps in the flex cable.
- DCB (data concentrator board) receives data, packs passively into a GBT frame, converts into optical signal & sends to TELL40.
- TFC (timing & fast control) signals are sent similarly but in reverse direction and ECS (experiment control system) signal bi-directional.

Front End ASIC - SALT



SALT – custom design for UT.

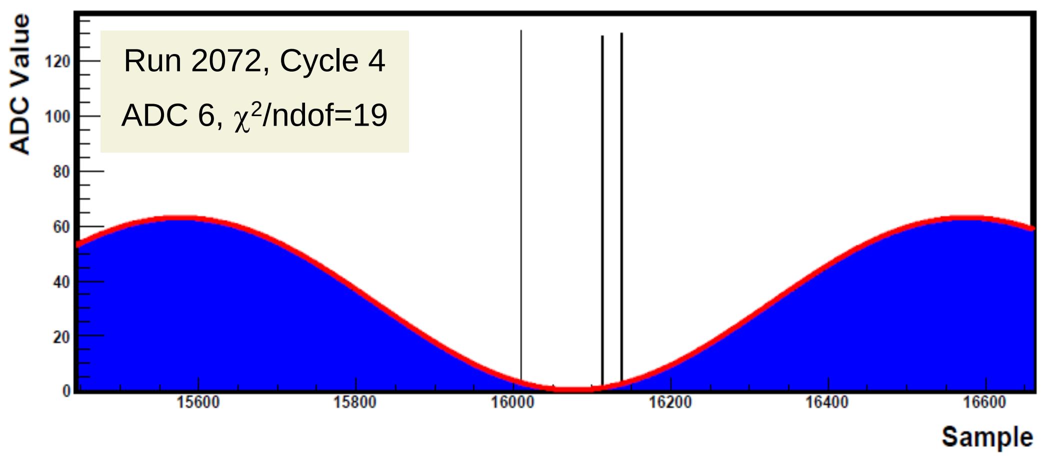
Preamp-shaper prototype



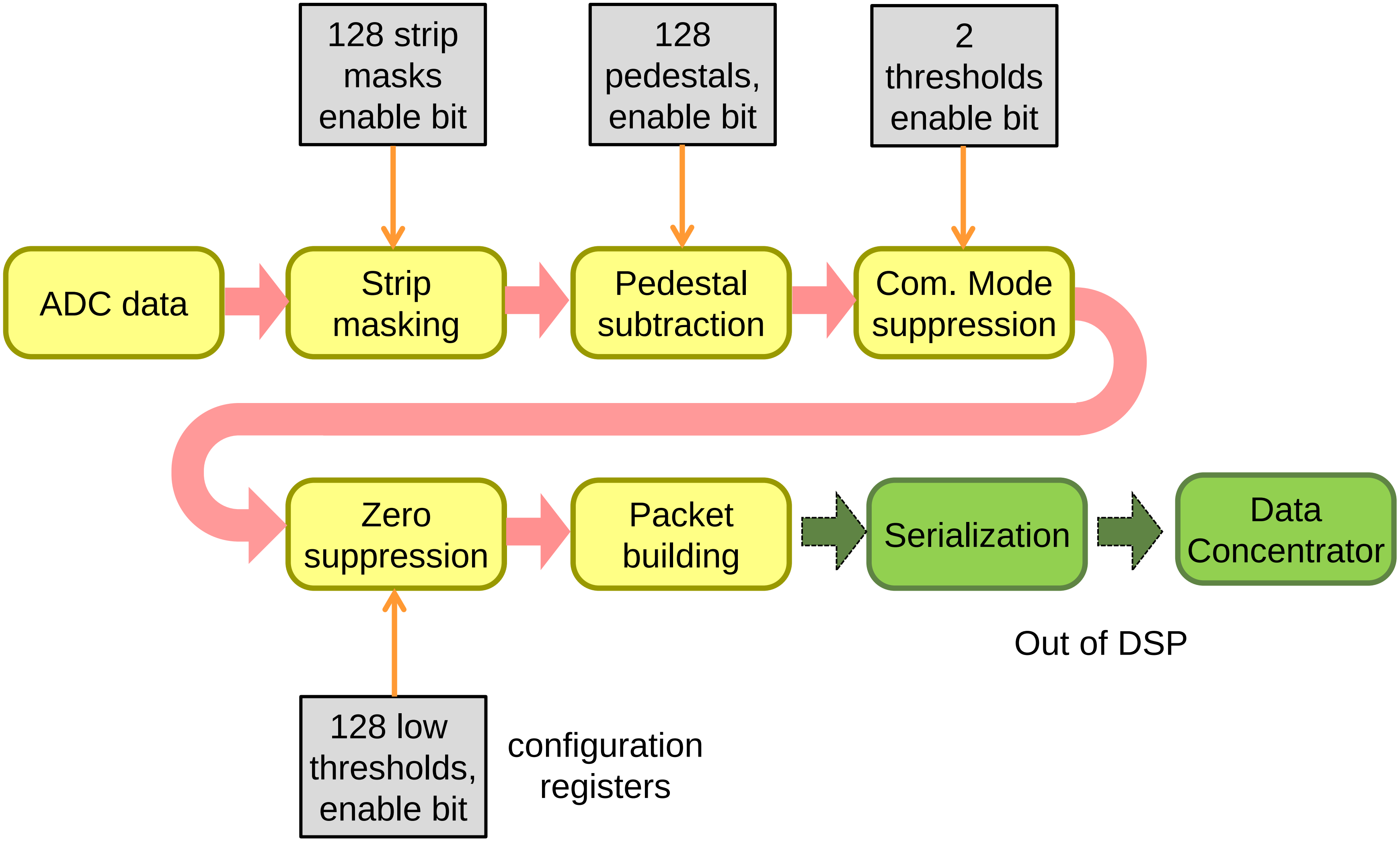
- CMOS 130 nm technology (IBM, TSMC).
- 128 channels, per channel preamplifier & 6-bit ADC.
- Sensor capacitance 5-20 pF, AC coupled.
- Dynamic range ~ 30 ke, both input signal polarities.
- Noise: ENC ~ 1000 e @ 10 pF + 50 e / pF.
- Pulse shape: T_{peak} < 25 ns, short tail ~5% @ 25ns+T_{peak}.
- DSP functions: pedestal, common mode subtraction, zero-suppression.
- Serialization & data transmission via 320 Mbps e-ports.
- Power consumption < 6 mW / channel.

Radiation Test Of SAR ADC

- SALT chip uses 6-bit SAR (*successive-approximation-register)* ADC, which is more susceptible to SEUs.
- A prototype 8-channel ADC (from IBM) was tested in 226 & 60 MeV proton beams at MGH in June 2014.
- Beam intensity: radiation level from ~ LHCb running to $\times$1000 to boost statistics.
- A 40 KHz sine wave signal was injected & digitized at 40 Msps. A SEU sample can be identified by comparing measurement against expectation from fit.
- A few SEU candidates were observed from 2×10^8 samples. $\Rightarrow$ Whole UT system has ~7×10^{-6} SEU channels per bunch crossing in LHCb nominal running.



SALT DSP Flow Chart

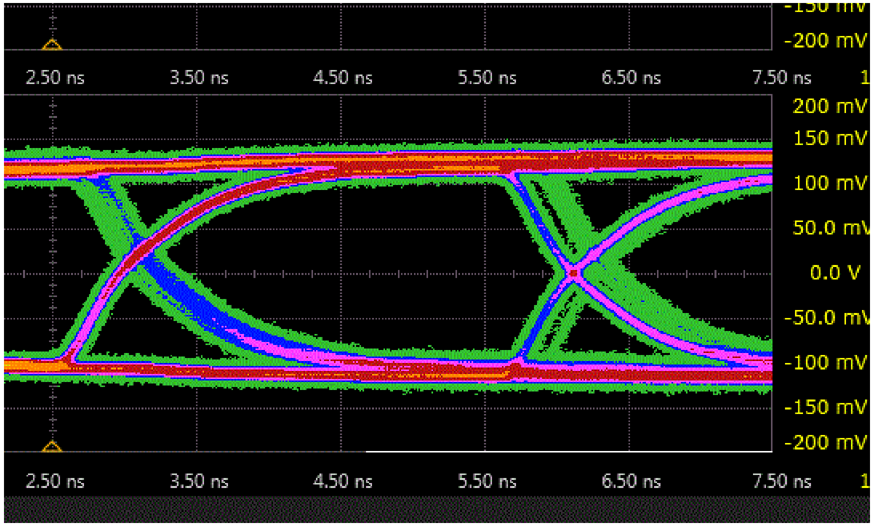


SALT ASIC Plan

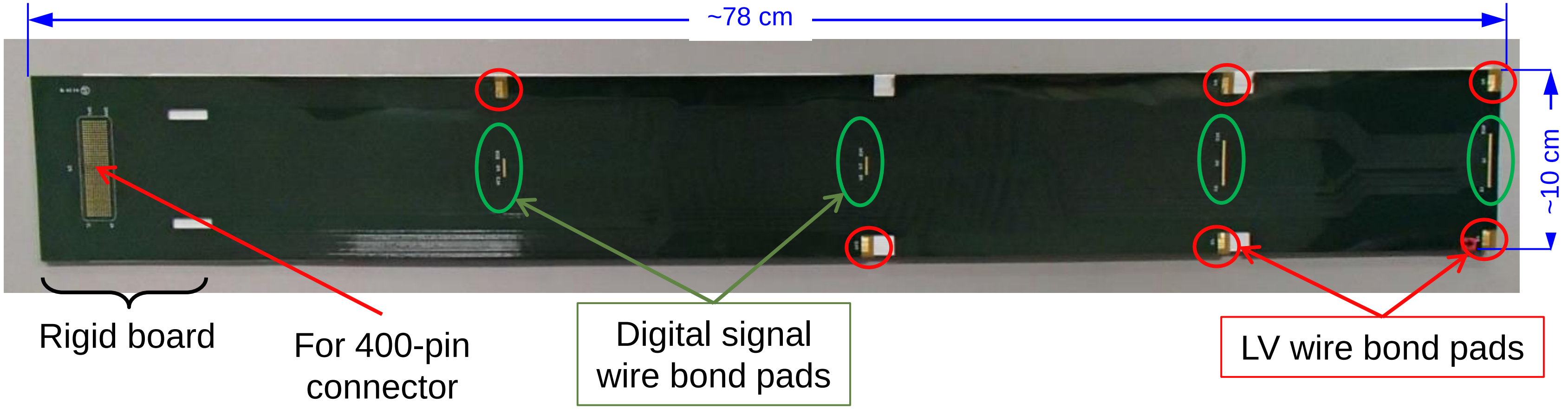
- Performance of SALT prototype functional blocks (by IBM) with separate analog and digital functions meet the specifications.
- SALT8 prototype ASICs from TSMC were delivered this April, which has 8 input channels and full digital functions.
- The ASICs are currently under test to verify functionalities & performance. Radiation tests for SEU rate & TID effect are in plan.
- The ASICs will also be used in UT electronics slice tests to validate the whole readout chain.
- The next submission will be 128-channel ASIC with full digital functions (Nov 2015).

Flex Cables

- 4 flex cables per stave for digital signals (up to ~240/cable), LV & HV powers.
- Requirements:
  - Signal integrity.
  - Low material budget.
  - LV round trip drop < 0.5 V (for ~2.5A).
- 1st iteration cables made, single pair signal quality OK, low yield in production.
- 2nd generation design is submitted and will be produced at CERN.

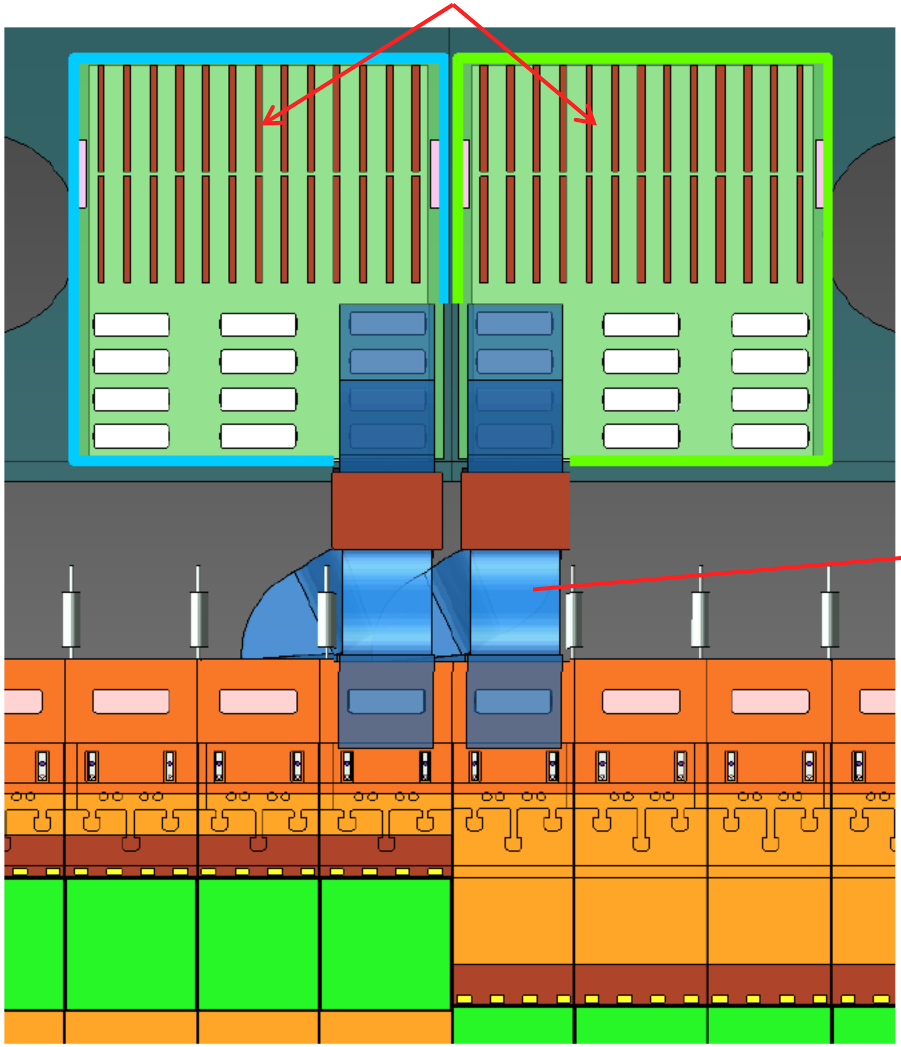


1st iteration cable

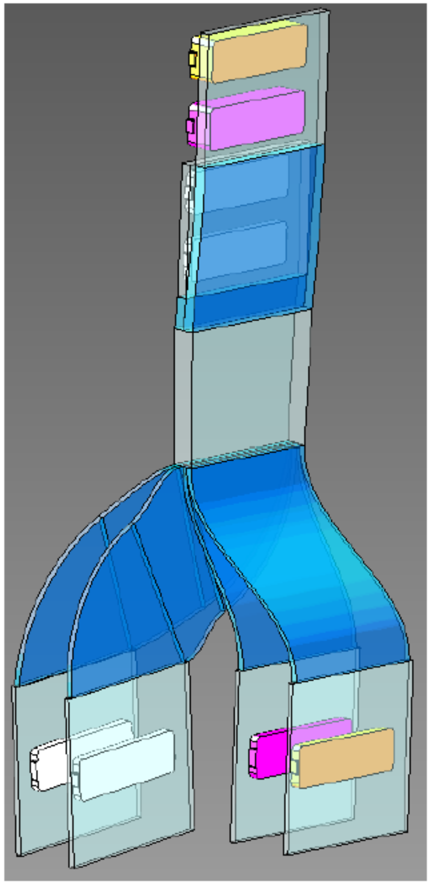


End of Stave Volume

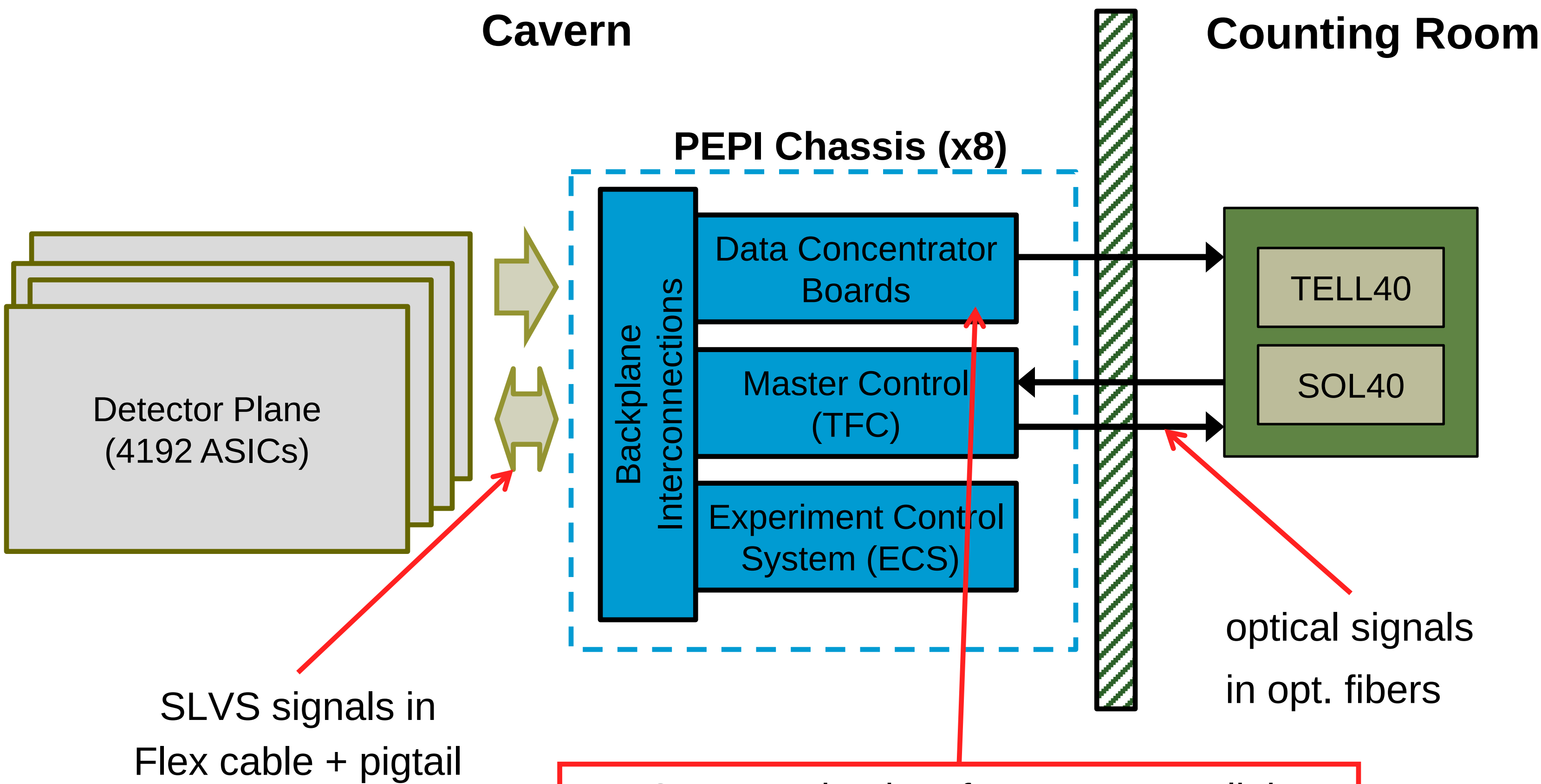
Back planes for DCB & TFC/ECS boards



Pigtails to connect back plane and flex cables on staves

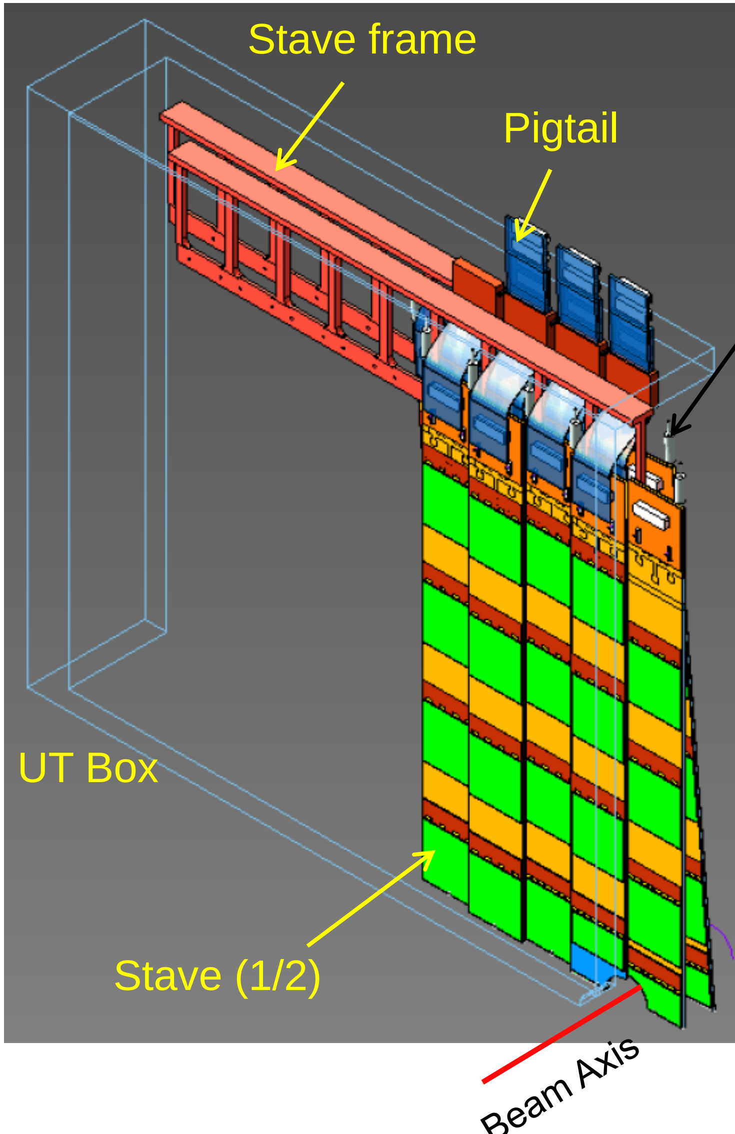


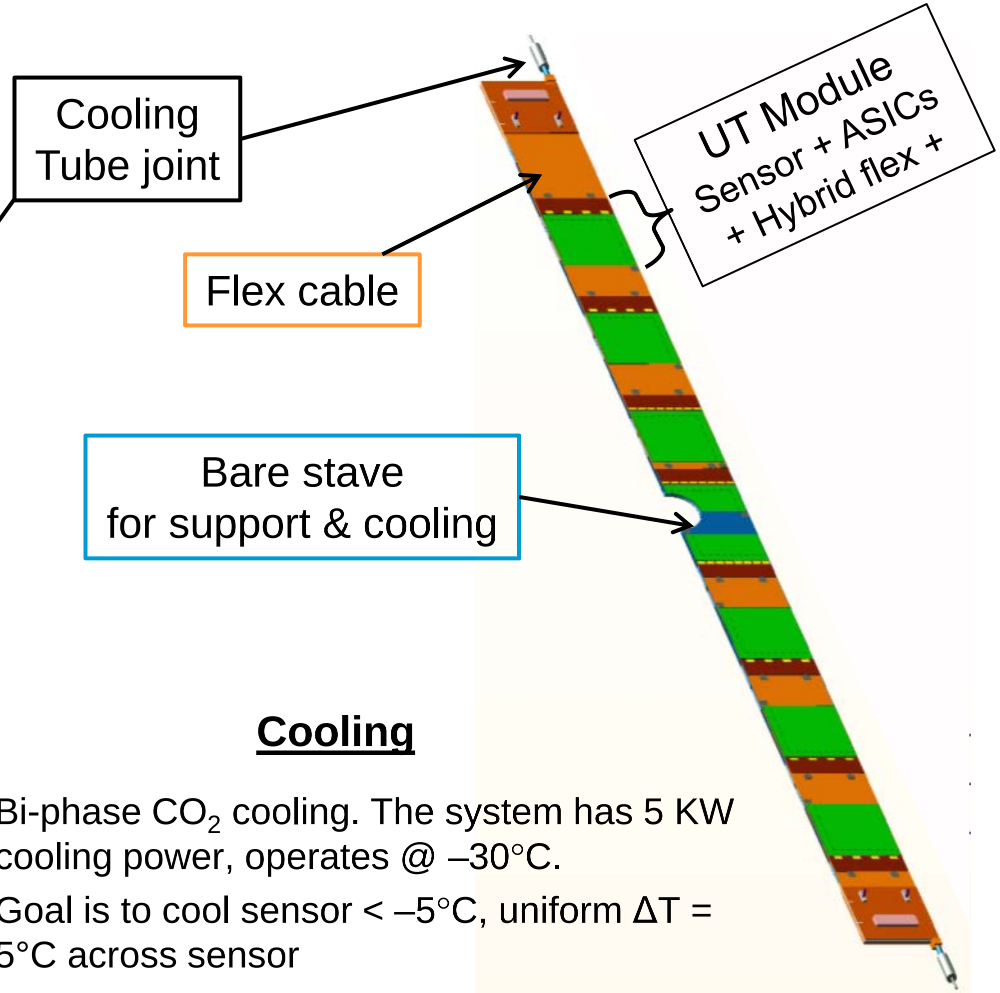
Readout Electronics



- GBTx packs data from max 14 e-links to 112 bits wide GBT frame data.
- Versatile link (VTTX) converts data to optical signals.

UT Mechanics And Cooling

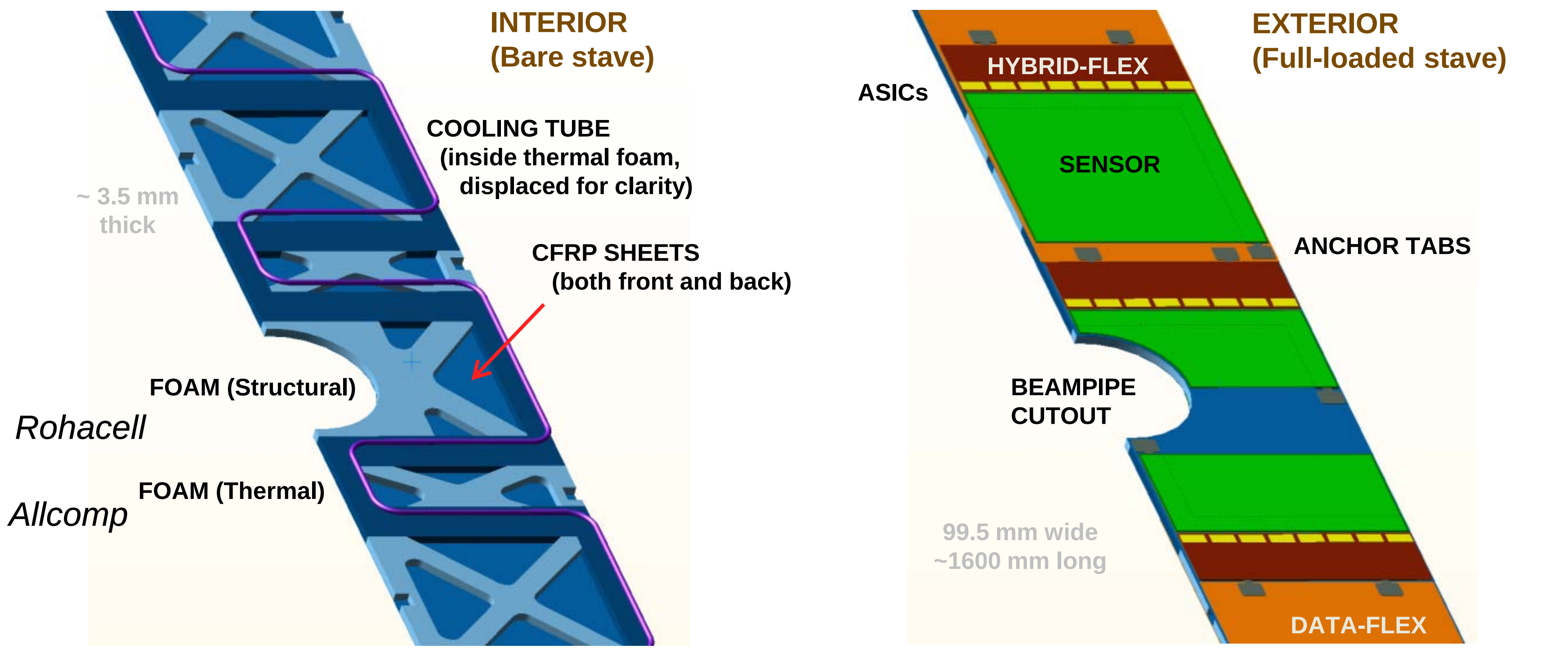




Cooling

- Bi-phase CO_2 cooling. The system has 5 KW cooling power, operates @ –30°C.
- Goal is to cool sensor < –5°C, uniform ΔT = 5°C across sensor
- Prototype test on a fully powered central stave shows that the goal is easily achievable with current stave cooling design.

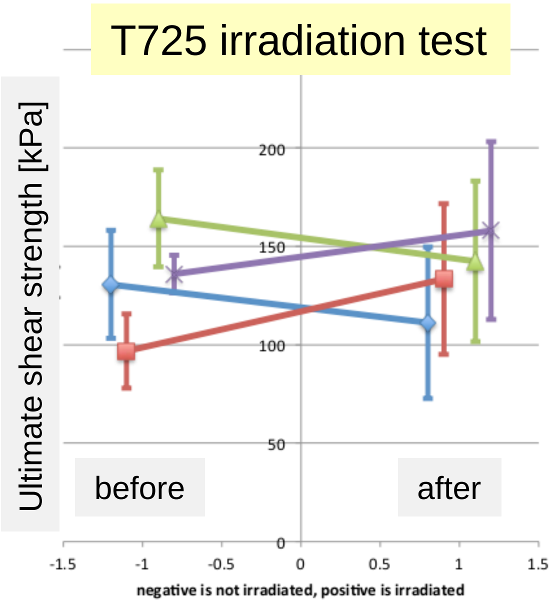
UT Stave



- 2 CFRP (Carbon fiber reinforce polymer) face sheets attached to foam core, forming a sandwich structure, all epoxy construction.
- Ti cooling tube is embedded in the thermal foam: 2.275 mm OD, 135 um wall.
- Cooling tube in "snake" shape to make run under all ASICs.

Recent Tests of Stave Components

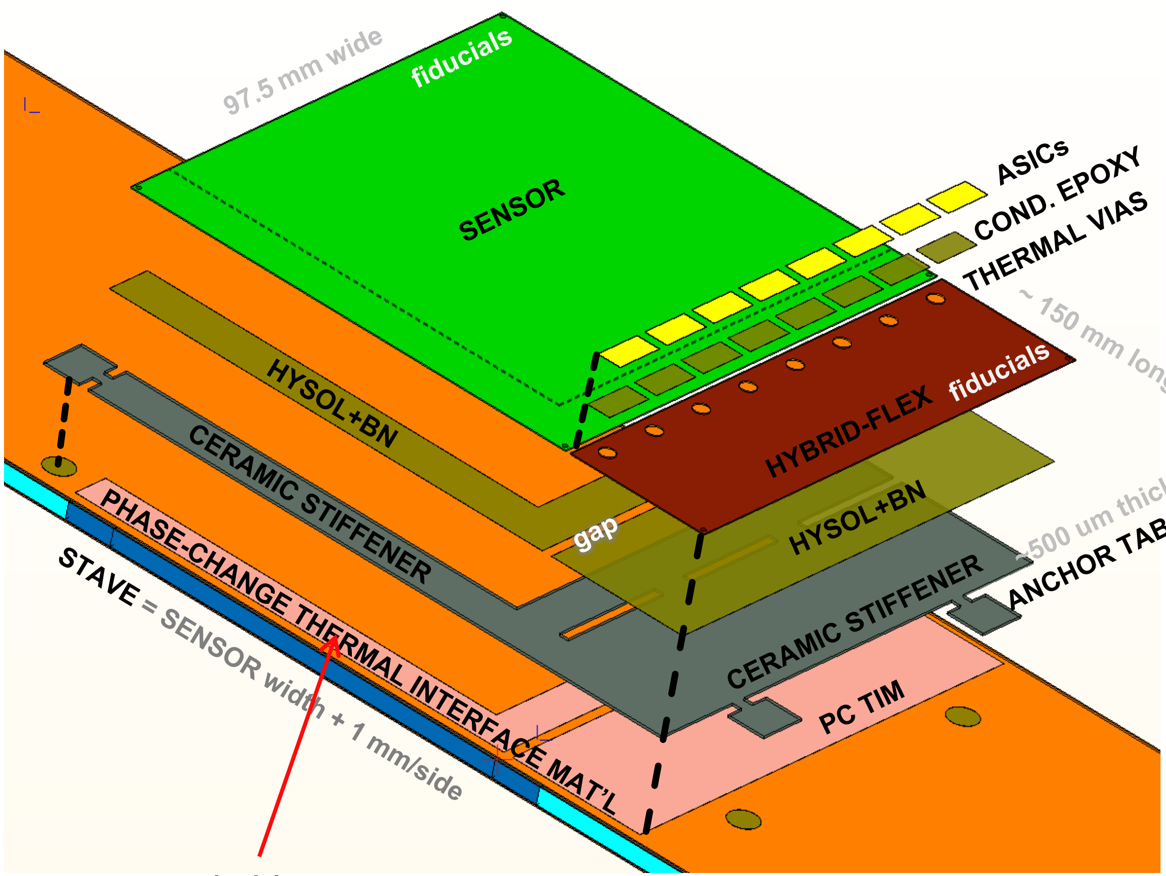
- Thermflow T725 epoxy
  - Reworkable epoxy (phase changing thermal interface material) for module to stave.
  - Measured ultimate shear strength, before & after irradiation (40 MRad) – OK.
  - Tested in low-temp – no change.
- Ti tube fittings
  - Braze (AgCu) vs epoxy (Araldit 2011 / Armstrong A12).
  - Pressure-tested samples before & after irradiation (100 kRad) – OK to 150 bar
  - Low-temp tests – in progress
- Rohacell structural foam
  - Measured ultimate tensile strength & ultimate shear strength.
  - Irradiated to 40 MRad, to be tested
  - Low-temp tests – in progress



UT Module (Exploded View)

Sensor: –5°C, ΔT=5°C

Bias: up to 500 V



Reworkable epoxy

- **Requirement:**
  - Provide connection between ASICs & flex cable.
  - Protect wire bonds during testing and handling.
  - Maximize heat transfer from ASICs to stave, minimize heat transfer to sensor.
  - Isolate sensor bias from stave facings (ground).
  - Stiffener CTE match to Si. Not to over-constrain sensor, allows for bow.
- **Design options:**
  - Hybrid flex + Pyrolytic BN ceramic stiffener (500 μm).
  - AlN ceramics (250 μm) + multilayer printed traces.

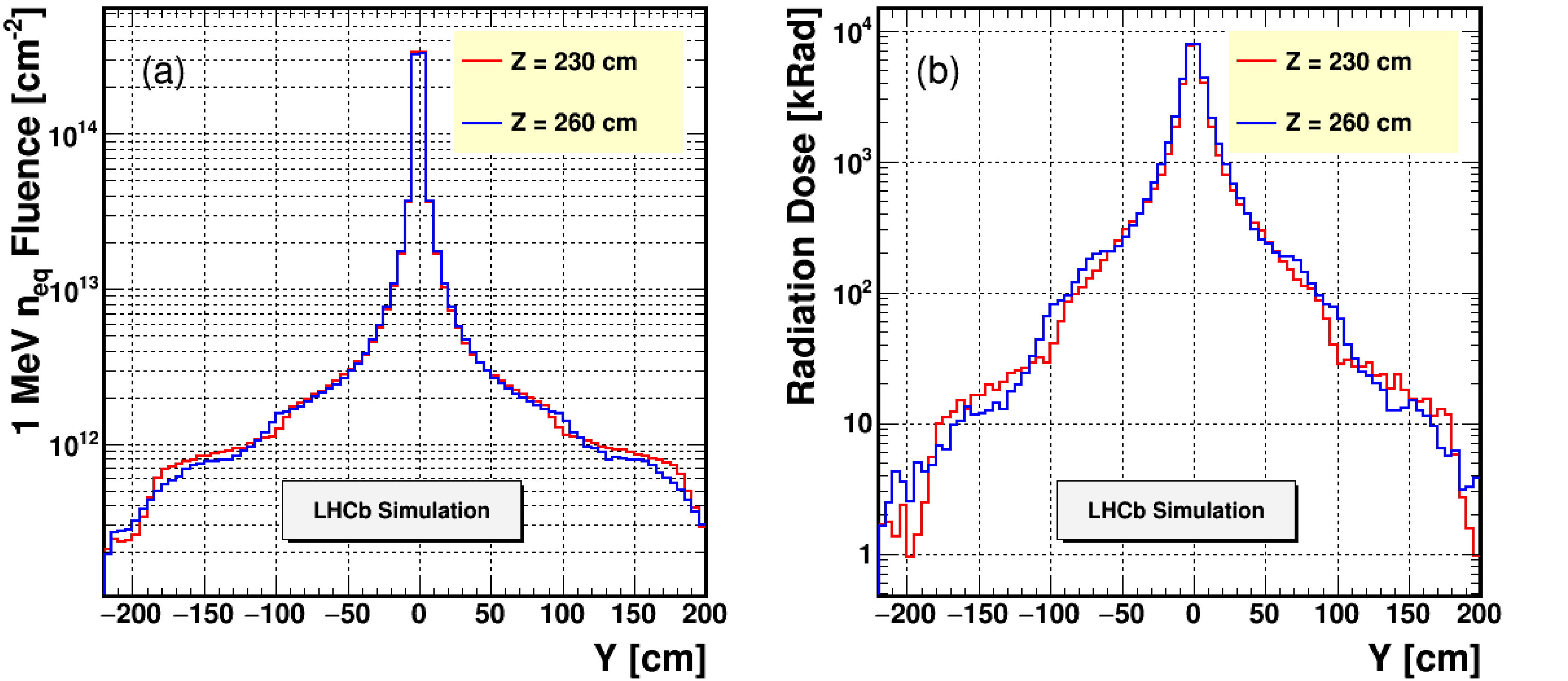
Summary

- UT is silicon strip tracker to replace the TT detector in the LHCb upgrade. It has better granularity, front end electronics in sensor proximity, & taking data at 40 MHz rate.
- R&D work is in advanced stage and will transit to construction in a staged manner starting with "bare stave" assembly.
- Preproduction of Si sensor will start soon, first the type A sensor (majority of detector coverage).
- An active program of test beam studies of subsystems with increasing complexity will validate all the aspects of the design. Focus in year 2015 is on irradiated detectors.
- UT installation will start in Jan 2019.

Backup Slides

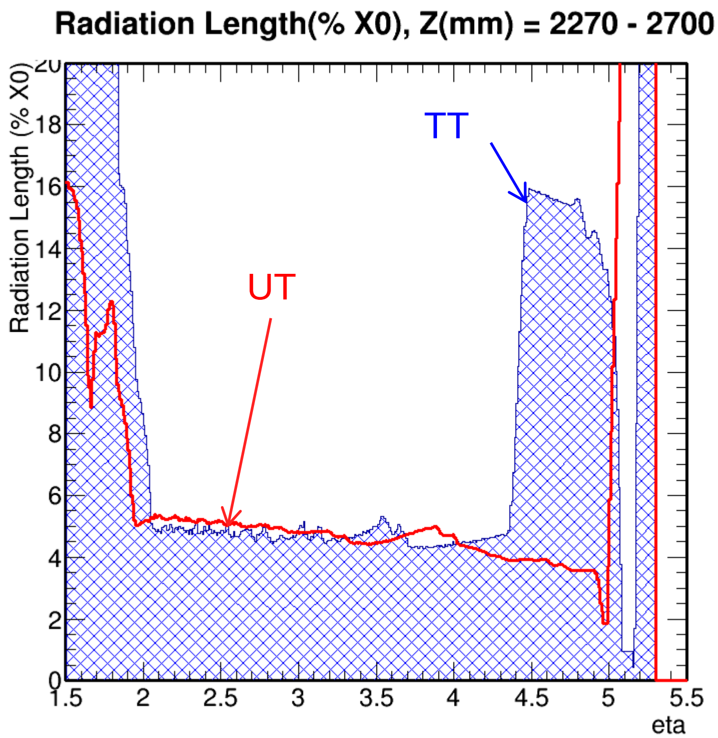
Radiation Constraint

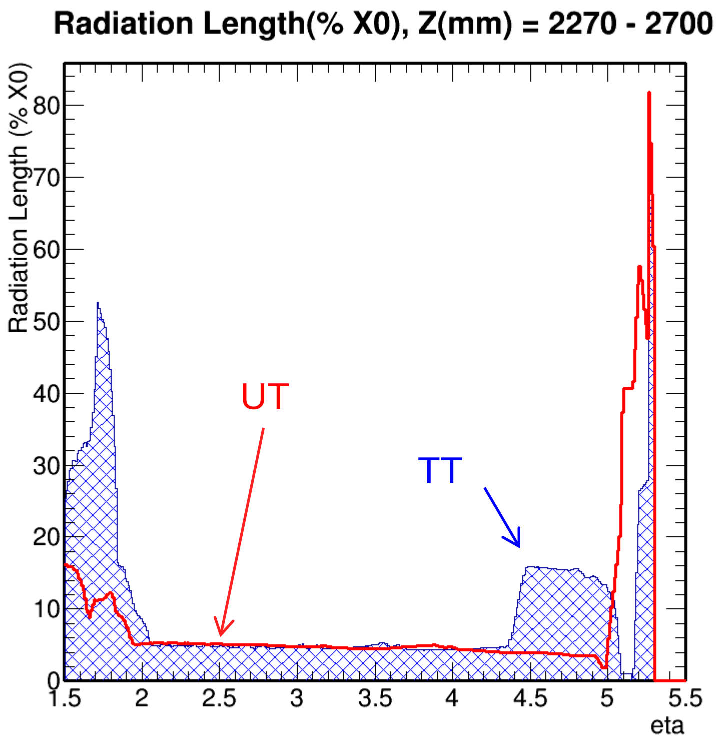
Integral over 50 fb^{-1}



- Sensor closest to beam: ~ 40 MRad, or ~ 5×10^{14} n_{eq}/cm^2 fluence.
- Sensor cooled to –5°C, bias voltage up to 500 V.
- Closest readout ASIC: ~ 20 MRad.

Radiation Length Plots

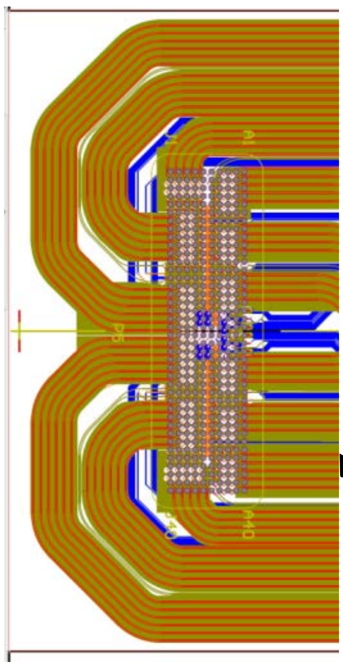




- Radiation length between Z=2270-2700 mm, including 0.14% X_0 of air, 0.34% of UT box.
- The total radiation length between 2<η<4.9 in the new UT release (2) is 4.6% X_0. RL per UT plane is 1.02% X_0.
- Beam jacket is from the current best design. The overall $\int RL \cdot d\eta = 7.02\% X_0$ in this design, slightly smaller than 7.49% X_0 in the TT design. More importantly, it occupies much smaller angle (η>5), instead of (4.4 < η < 5) where tracks are used in physics study.

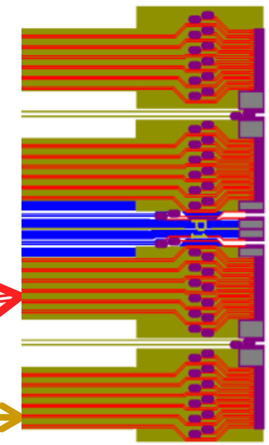
Flex Cables – 2nd Iteration

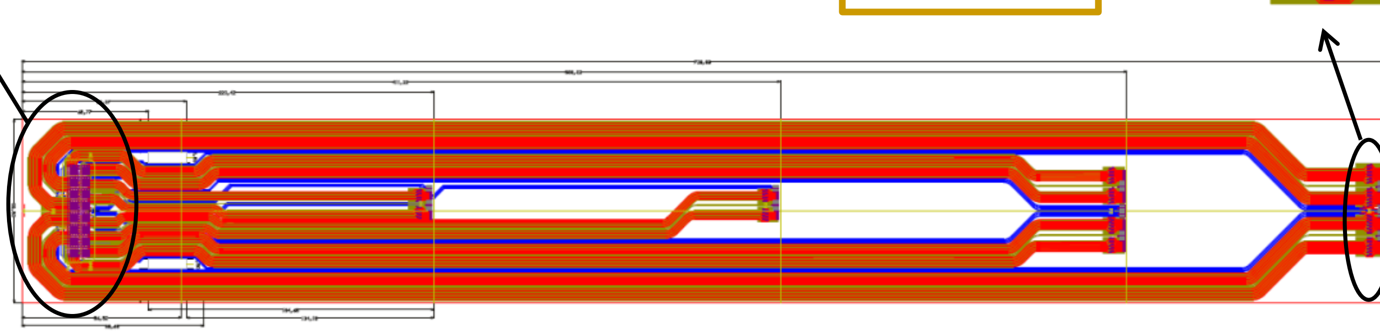
- The 2nd generation design is submitted and will be produced at CERN.
- 4 conductive layers: 2 for signals, 1 for LV power, 1 for test purpose.
- Signal traces run on top of power traces all the way for better impedance uniformity.



Board Stack Report

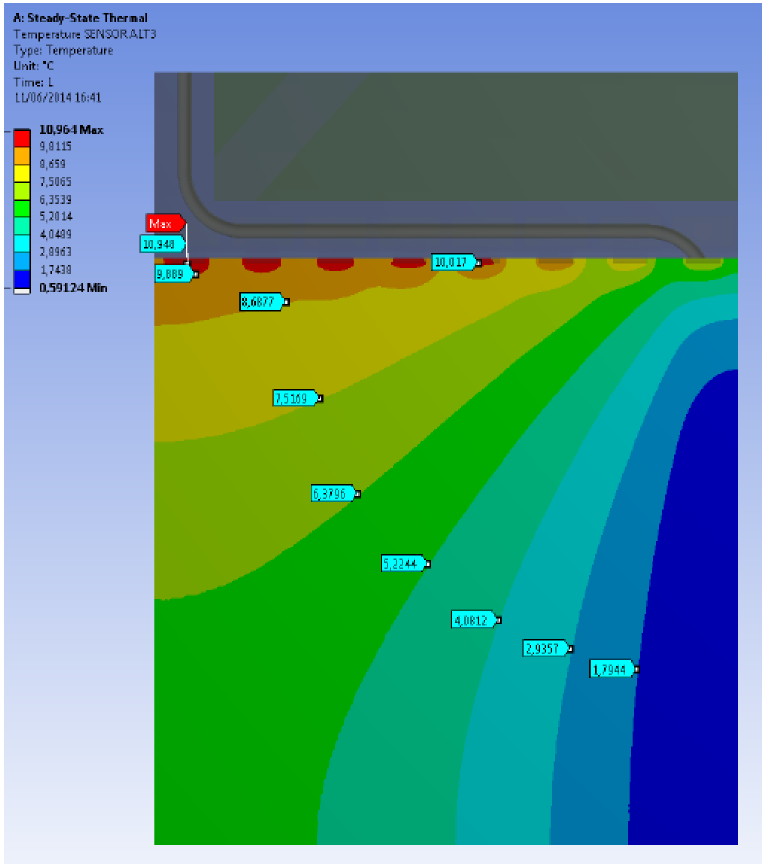
Stack Up			Layer Stack			
Layer	RIGID STACK	FLEX STACKUP	Name	Material	Thickness	Constant
1			Top Paste			
2			Top Overlay			
3			Top Solder	Solder Resist	0,010mm	4,8
4			Top Layer	Copper	0,017mm	
5			Dielectric1	Poliammide	0,100mm	3,4
6			Inner-1	Copper	0,017mm	
7			Dielectric2	Poliammide	0,100mm	3,4
8			Inner-2	Copper	0,017mm	
9			Dielectric3	Poliammide	0,100mm	3,4
10			Bottom Layer	Copper	0,017mm	
11			Bottom Solder	Solder Resist	0,010mm	4,8
12			Bottom Paste			
	Height : 1.6mm	Height : 0,388mm				



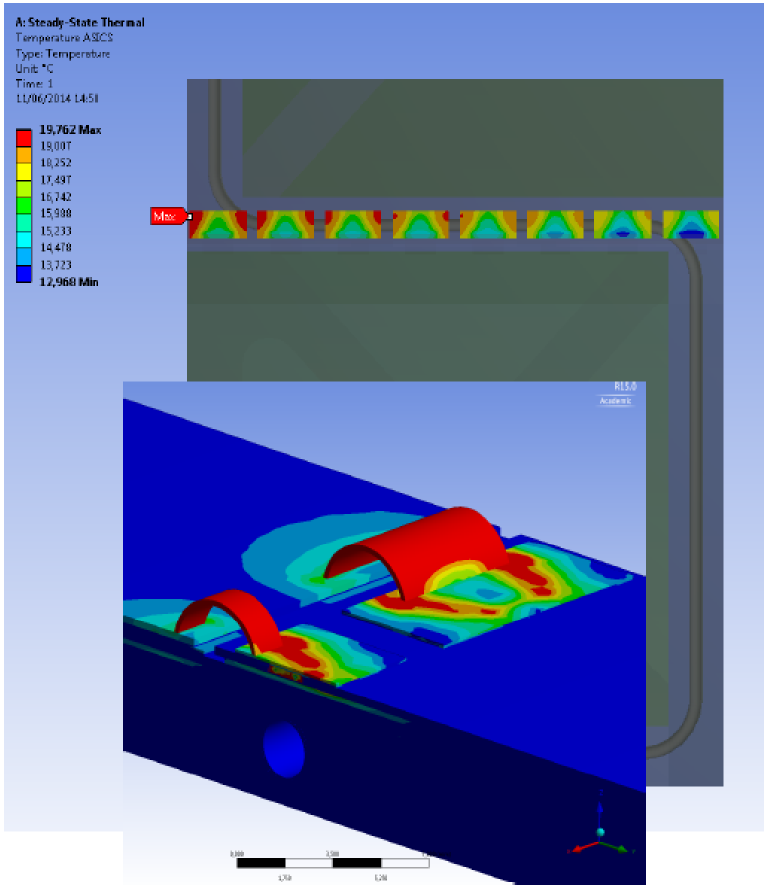


Thermal Simulation

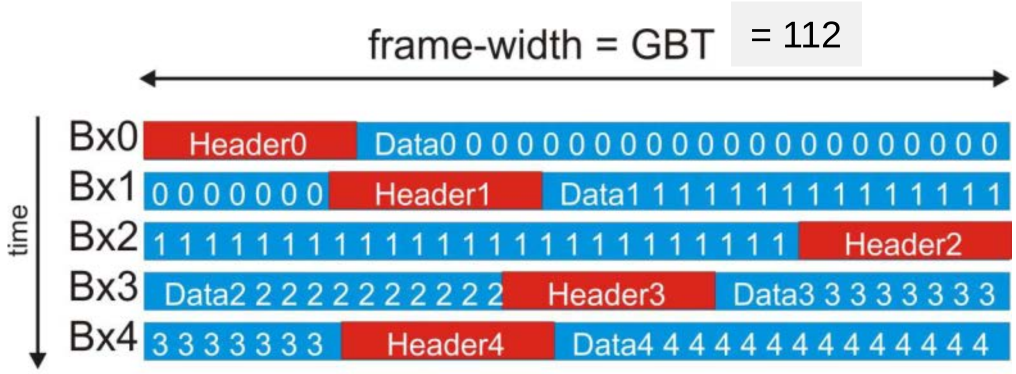
sensor temperature



ASICs temperature

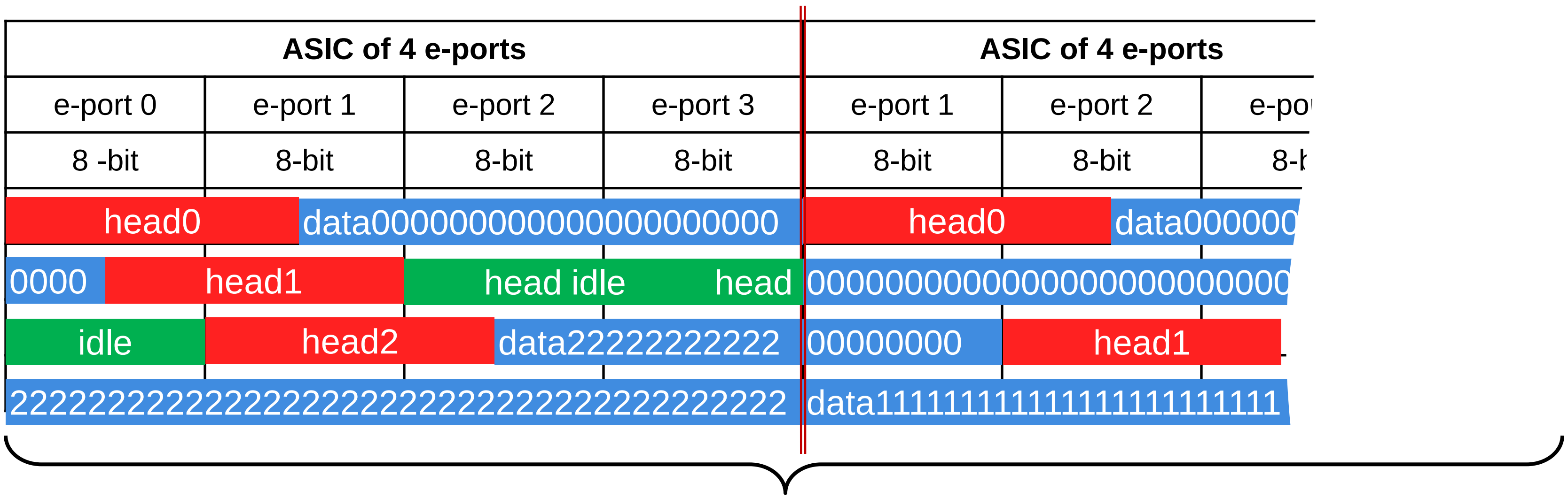


UT GBT Sub-Frame Format



From “Electronics Architecture of the LHCb Upgrade”
http://cds.cern.ch/record/1340939

UT ASICs are independent. E-ports within an ASIC send data coherently. Each ASIC data form its own GBT sub-frame.



Up to 14 e-ports per GBTx