Upstream Tracker (UT) for the LHCb Upgrade

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on behalf of the LHCb UT group

Meeting of the DPF of the APS
Northeastern University, Boston, 29 July - 2 August 2019
Role in LHCb upgrade

- A silicon strip tracker to replace TT
  - 1MHz -> 40MHz read-out electronics
  - Better geometrical acceptance (especially at high $\eta$ – closer to beam pipe)
  - Finer segmentation
  - Less material
  - Increased radiation hardness

- Benefits
  - Fast momentum measurement for the software trigger
  - Reducing “ghost” rate
  - Better $K_S$ and $\Lambda$ detection efficiency
  - Improving momentum resolution with higher efficiency

see talk by Manuel Franco Sevilla
UT core

- 4 planes (x-u-v-x)
- ~1k silicon sensors ~10cm wide

- Readout with custom 128-channel ASICs
- Staves (ATLAS-type integrated concept):
  - Sandwich structure of lightweight carbon foam/carbon face
  - Integrated C0₂ cooling via titanium tube under ASICs
  - Dataflex cable for read-out/power
- Modules
  - Sensor
  - Read-out hybrid with 4(8) ASICs
  - BN supporting stiffener
UT overview

Cooling plant side

Service bays (LV distribution)

Staves

Cable chains

UT box

PEPI electronics

Rails

Pigtails
Effort overview

**Components**
- BARE STAVE
- STAVE w FLEX
- FULLY-INSTRUMENTED STAVE
- MODULE
- HYBRID
- SENSOR
- STIFFENER
- SALT ASIC

**Software & Trigger**
- EOS SUB-ASSY
- TUBE SUB-ASSY

**Fabrication & QA**
- Test on almost all production steps

**CERN, Milano**
- Syracuse
- Milano
- CERN, Zurich
- Krakow
- INFRASTRUCTURE
- COOLING
- ELECTRONICS
- SOFTWARE & TRIGGER
- Maryland, IHEP
- CERN, Zurich
- MIT, Cincinnati, Krakow, Syracuse

**Stave installation into UT (CERN)**

**Syracuse, Milano, CERN, Zurich**

DPF meeting 2019, Boston
Bare stave production

- Gluing carbon/rohacell foam on carbon face + end-of-stave mount
  - holding carbon face with a vacuum
  - positioning with precision fixturing, pins, edges, ...
  - stencils for epoxy application

- Tube preparation: brazing, bending
- Tube insertion

- Side-B closure (second carbon face)

- Production finished: 86 bare staves made (68+18 spares)
DataFlex attachment

- Vacuum baseplate fixturing, positioning with pins
- Stencils for glue application
- More glue in regions of heat-transfer and wirebonds
- Control glue gap between stave and flex by shims

- First full stave done, both sides (i.e., 4 flexes), as well as several single faces
- Flex fabricated by CERN workshop (Rui De Oliveira et al.)
- Flexes in production now (June-October)
- First batch of cables received starting attachment process soon
SALT ASIC, development

- **Requirements**
  - 128 channels
  - Analog section with complex-pole shaper + preamplifier, \(~25\text{ns}\) pulse width
  - 6-bit SAR ADC
  - Advanced digital signal processing: common mode and pedestal subtraction, zero suppression
  - Power consumption \(\leq 0.6\text{W}\)

- Ambitious & time consuming project

- In late 2018 the design had been reworked, major changes in ADC part
SALT ASIC, beam test & production

- Beam test in March 2019
- Slice test in June 2019

- Have shown good performance, S/N~15

- Wafer production of SALT ASIC V3.5 ongoing
  ~80% chips passing QA tests
- SALT ASIC V3.8 design (for 8-ASIC hybrid) ready (minor modifications to V3.5)
Gluing ASICs to hybrid

- Use conductive epoxy (Loctite Ablestik 2902), dispense using robot
- Vacuum-based jigs for positioning and picking up the ASICs
  - 8 ASICs (2 hybrids) at a time
  - 3 panels (24 hybrids) a day
- Wirebond ASIC->hybrid with 25um Al wire
- Panel QA test
- Potting
- Shipment to Syracuse
- Prototypes being produced, waiting hybrid panels (early August)
Producing modules

- Cut out hybrid pairs from panels using ultrasonic cutter
- Glue: Hysol 9396 +30% diamond powder mix dispensing using robot
- Precision vacuum jigs to locate/pick-up/place (for pairs) several iterations of modifications & improvements
- Wirebonding:
  - >1100 wires per module
  - <0.1% failures (all out of 1600 tested are good)
  - double bonds in module->flex connection
- Electrical test
- Whole production: 2 days, 16 modules each day
- Stiffeners & A-type sensors are ready and passed QA
Waiting for hybrid panels from Milano (early August)
Mounting modules on staves

- Vacuum tools to locate/pick/place modules
- Glue with removable thermal interface material
  - TIM Thermflow T725
  - Heat to ~65°C
  - Successful module removal
- Support flipped stave using bars placed between modules for subsequent module attachment & wirebonding
- Two stave prototypes produced

![Image of mounting modules on staves with labels for bar to press-down, Place of support, Slice test stave prototype, Module removal (before cleaning with alcohol), and Stave fixture with alignment pins.](image-url)
Visual QA

- Sensor position on stave measurements
  - Input for alignment
  - A special rail-system of SmartScope + linear encoder was built
    -> precision ~50um

- Stave flatness
  - deviation from plane <100um

- Inspection of sensors
  - Automatic bow measurements
  - Semi-automatic inspection for surface defects
    >1000 sensors inspected (+ electrical test):
    3 discarded, 43 leaved for spares

![RLS® LM10 linear magnetic encoder Δy = 5 μm](image)
Stave shipment to CERN

- Transport options:
  - cart for 35 staves (half of UT)
  - box for 5 staves

- several layers of shock absorption
- pressure relief valves with air filtering & dessicant

construction close to finish

- First stave at CERN at slice test
CO₂ cooling

- CO₂ distribution inside UT
- Tested on prototype at -37 C (sensor at -5 C) during slice test
- Assembly ongoing
PEPI

- PEPI (Periphery Electronics Processing Interface)
  - Connected to stave at top&bottom via pigtail flex cables
  - Collects & transmits data from ASICs
  - Distribute clock and control signals
  - Powering via low-voltage regulators (LVR)

- Tested on a prototype stave at CERN
- Production till September, installation during autumn
Store information about all components: sensors, hybrids, modules, staves, flex cables, DCBs
- Log/guide for production/QA
- Track relationships
- Summary statistics
- Log of lab conditions
Conclusions

- Bare stave construction complete
- A-type sensor QA finished
  - B/C/D during autumn
- ASIC design validated with test beam
- Flex attachment & module construction starting now
- First production stave to be made in August
- First half of staves (35) to be delivered to CERN by end of 2019
  Second half early next 2020
- Assembly of staves in UT box to be done at CERN surface,
  aiming to install first half at LHCb by January 2020
Appendix
Wirebonding

- 3 wirebonding steps
  - ASICs -> hybrid (at Milano)
    - 135 bonds per ASIC, 540(1080) per module, pads 60-120um wide
  - Sensor -> ASICs (at Syracuse)
    - 512(1024) bonds, pads 60-65um wide
  - Hybrid -> Flex Cable (at Syracuse)
    - ~80 bonds per module, pads ~200um wide

  ~15k wirebonds per stave, >1M overall

- Quality requirements
  - Reliability: <<0.1% failures
  - Bond strength: >5g (with mean at 8-10g)
    (~5 test bonds per module)

- Equipment (aluminum wire, 25um=1mil)
  - Syracuse:
    - F&K Delvetek G4 6400 (+ F&K Delvetek G5 64000 DA)
    - Dage 4000 Pull Tester
  - Milano:
    - F&K Delvetek G4 6400, Dage 4000 Pull Tester
Bonding optimization

- Use old ASICs as test sample
- Dage 4000 pull tester for QA

- Probed many various configurations and parameters (various forces, deformation, ultrasonic power, … always same for 1st and 2nd bonds)

- The outcome is ~0.5-1% of “failed” bonds (<5g) independently on all probed configurations…

Raw break force geometry corrected

Many thanks to CERN Bondlab for many helpful advices
Improvements

Adjusted BondProcessControl (BPC)
- Feature of Delvotec wirebonders
- Adjust ultrasonic power / stop bonding based on wire deformation measured online (see Appendix for more info)

Loop shape process adjustments
- Most of the bonds broke in the same place: near the foot of the 1st bond
  suspect the heel cracks caused by extensive wire bending during loop formation
- Change from option set by FK Delvotec technician to other + change clamping sequence

Andreas Hanreich, FK Delvotec

"Wire Bonding", George Harman
All out of 1600 bonds are good!
Again, different settings were varied, the performance is very stable
For “optimal” bond force settings (20/18/18 grams) only 1/800 broke at less than 8g!

Typical break points:

Contaminations found to degrade performance (test with cleanroom tape)
Repairing a bond on a place of an old/broken one found to be hard due to small bond pad size: chance of full success is only ~25%
Corrosion protection

- Observed corrosion after several cooling cycles (to -25C for 15min and back to 15-20C), no humidity control and hence condensation formation.

- White residue appeared on the bonds, pull tests showed severe bond strength degradation.

- Consistent with issue reported for ATLAS IBL reported by Alan Honma (link), explain it as a Al reaction with water giving Al(OH)$_2$+H$_2$.

- Pot feet with Sylgard 186 for all the bonds (inspired by CMS experience: link 1, link 2), not mechanical protection, but only corrosion.

- Glue is very liquid -> spreads out with time (minimal line width ~1mm).
Electronics

Cavern

4,192 FE ASICs and Silicon Strip Detectors Distributed over 4 planes

Detector Plane

HV Passive Power Conditioning

Nominal ~17-34 meter Paths (W.C.)

Nominal ~9.6m Path (Nominal 150-meter Path)

PEPI Chassis (x8)

x6 Data GBTx
x1 Master Control GBTx (TFC)
Exp. Control System x1 GBT-SCA (ECS)
Data Control Boards (x12 Max/BP)

TELL40 (Data)
SOL40 (TPD+ECS)

Linear Regulator Banks (Located in Service Bays)

HV Power Modules (Note 1)
House Keeping Power

LV Power Modules (Note 1)
Remote Control Interface
AC→DC

Bulk LV Power Chassis (Located on Equip. Balcony)

Bulk Power Rack

Electronics Barrack

Counting Room

Tom O’Bannon – PEPI electronics review
https://indico.cern.ch/event/739379/

DAQ Workshop

DPF meeting 2019, Boston