Prototyping, Integration and Assembly of the CMS Phase-2 Outer Tracker Endcap

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on behalf of the CMS collaboration

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Overview

• Introduction to the CMS Phase-2 tracker endcap (TEDD = Tracker End Cap Double-Disks)
• Dee prototyping at DESY and IPNL
• Dee production quality control
• Integration and assembly
New CMS Tracking Detector

The HL-LHC will put challenging demands on the new tracker system

- High radiation ➞ Radiation hard sensors
- High pileup ➞ Increased sensors granularity
- Tracker input to CMS trigger system upgrade ➞ New modules with Pt sensitive trigger output

A new tracking detector is needed to meet the challenges

- 2 module types (2S & PS) with on-module trigger capability
- 6 Barrel layers (3 in TB2S & 3 in TBPS)
- 2 end-caps (TEDD) with 5 Double-Disks each
TEDD Elements

- The **Dee** is the main element of the TEDD mechanics
  - A half disk of highly integrated CFRP sandwich with embedded inserts, cooling elements and pipes
- Exploiting symmetries: Minimizing number of different types of parts.
- A step on the straight edges for Dee to Dee assembly.
- 6 cooling sectors per Dee (wedge shaped)

- Two Dees ➟ Disk
- Two Disks ➟ Double Disk
- Five Double-Disks ➟ TEDD

Edge steps to combine Dees (on opposite sides due to symmetry)
Dee prototyping
Taking place in two institutes: IPNL (Lyon) and DESY (Hamburg).
Both institutes are planning to build a full size prototype this year.
Currently assembly procedure developed in parallel, but will converge for final production.
Details of assembly sequence was shown in last years forum report: link

Cooling sector with 6.7 meter total length
OD: 2.5 mm ID: 2.2 mm
Approx. 80 bends

Carbon foam heat-spreader

PS module mounting point

Dee to Dee insert

2S mounting inserts

3 reference inserts
Production steps:

- Carbon fiber: NGF YS-95A (epoxy resin, UD prepreg)
- Layup: [60/-60/0]s
- Cured at 120°C, 4h, 3bar in vacuum bag
- Sandwiched between plastic plates for machining:
  - Holes milled by CNC machine
  - Edges cut by water jet
- Ears cut off by hand
CAD models for full Dee prototype finalized
- All parts are available or ordered
- Gluing will start as soon as we receive the jigs
- Production together with industry partners
- Aim to have prototype completed by ~September, tested by year end.
Dee production quality control
Thermal Testing at Lyon

Nick Lumb, IPNL

Fridge installation:
- Aluminium PS and 2S dummy modules
- Equipped with heating foils and pt100 sensors

Reliable measurement but time consuming in final production

![Graph showing DeltaT pipe > module @-30C on pipe]

PS modules  2S modules
Infrared Imaging at DESY

Setup and Test piece

• Camera: InfraTec VarioCAM HD research 900
  • Up to 2,048 x 1,536 IR pixels
  • Standard lense (30 mm focal distance).

• Black fabric cover to minimize reflections and external IR ray

• External cooling supply (coolant: Novec™ 7100, in final setup: CO₂)

• Measurement of temperature on surface while cooling.
  • Heating for thermal gradient by ambient air.
  • Warm spots indicate bad thermal contact.

• Test piece with defective gluing is used to study sensitivity with this method.
Infrared Imaging

Results

- Test piece with two PS module carbon foam cooling blocks.
- Grooves in carbon foam (100 µm & 200 µm)
- 200 µm step easily visible.
- Method not sensitive for 100 µm step.
Results

- Flat carbon foam piece, but areas without adhesive.
- 15 mm adhesive gap easily visible
- Method not sensitive enough for gaps smaller than 9 mm.
Metrology

Setup and Results

- All mechanical TEDD components should be checked with metrology.
- **Tactile probing**: e.g. Dee insert positions.
- **Laser scanner**: e.g. envelope of mechanical components

40 x 35 cm Prototype:
- Measurement of module mounting inserts
- Comparison with CAD model
- Deviations are within specifications

Dee holding tool:
- Flat on table, no clamping
- Laser scan of inner profile
- Data fitted to CAD
- +/- 1 mm deviation from radius
Cooling pipe
Pressure Test and Ovalisation

- Pipe raw material in rings
- Stainless steel 1.4301
- Bending done in industry

Pressure Test:
- 160 bar required
- Test up to 400 bar.
- Theoretical damage at approx: 700 bar

Ovalisation from bedding:
Area 93.5% of ideal shape measured at highest bending angle

Vacuum braising of end sleeve, to be done at CERN and DESY.
Module integration and TEDD assembly
TEDD Assembly Concept

• Challenge: Endcap reaches mechanical stability only when all parts are connected.
  • Individual Dees are fragile and need mechanical support.
  • Arc frame will be used to support Dee during all integration steps and transport between institutes.

• Dedicated assembly stations for:
  • Double disk assembly
  • TEDD assembly

Final detector
  • Outer Skeleton installed
  • Only now mechanically stable

Dee inside Arc frame
  • Installation of modules
  • Thermal treatment
  • Cold test
  • Transport

Disk and double disk assembly
  • Relative alignment of Dees
  • Installation of patch panels and cooling manifold

TEDD assembly frame
  • Alignment of double disks
  • Installation of support skeleton and services
Arc frame (Dee support)

• Requirements:
  • Support of Dee, minimal deformation of Dee in all operations.
  • Combines to form a ring without stress on disk.
    • End pieces need to be aligned precisely wrt Dee.
  • Connects to all production stations like module mounting, disk assembly, storage etc.
  • Holds temporary patch panels.
• Prototype build from bent Aluminium profiles.
  • Two profiles linked with spacers for radial stiffness.
  • Current baseline design 40mm wide. (Initial 20mm prototype was too floppy.)
  • Connection piece between both ends with support of Arc in the center.
Arc frame stability

• Test of stiffness:
  • Lift Arc on one end (by 25mm) to simulate worst case scenario
  • Laser scan of Arc placed flat and lifted.
  • Difference shows deformation due to sagging.
• Arc suffers 7-8 mm deformation.
• Addition of bar connecting both ends -> Sagging reduces to about 3 mm.
• Further optimization of Arc frame geometry ongoing to optimize: Stiffness, precisions and weight.
Module integration, hot/cold oven, transport

Module installation station
• Facilitates comfortable access to all module locations.
• Rotation mechanism allows vertical, horizontal and tilted installation.

Mockup installation
• Test of installing dummy modules on wooden mockup.
• Plan to assemble one 30°-sector with modules, cables and patch panels.
• Particularly cabling of PS modules will be tricky due to uneven pattern.

Phase change and cold test box:
• Can take one Dee (incl. Arc)
• Heat up for phase change thermal interface material.
• Cooling, electrical and optical connections routed to outside.
• Cool down for test of thermal connection module to support structure.
Disk and double disk assembly

- Dee to Dee alignment
  - Upper Dee is fixed to frame
  - Lower Dee rests on linear X/Y/Z stages
  - Match 6 dimensional position based on metrology measurement

- Arc frames are combined to form support ring.

- Disk to disk alignment.
  - Assembled disk is picked up by service frame
  - Assembly of second disk, stays on stages
  - Installation of spacers
  - Relative alignment of both disks.

- Disks and Arc frames are combined
- Installation of patch panels, cooling manifold.
- Full checkout (verify connections)

With second disk on service frame.
Details on mechanical and service design

Service design ongoing at UCLouvain, pictures by Nicolas Szilasi

Patch panel support ring
• Carries patch panels and cooling manifold
• Important also for mechanical stability and Dee to Dee connection.

Optical patch panel

Electrical patch panel

Cooling manifold
TEDD assembly I

- Alignment of all double-disk s. (Each resting on linear stages)
- Installation of inner tube and longitudinal bars (no straps yet)
  - Must not introduce stress/movement

➢ TEDD has reached intrinsic stability
TEDD assembly II

- Install **rotation mechanism**: insert “plug” in inner tube.
  - Each disk is individually supported
- Load transfer to rotation mechanism
  - Remove upper Arcs (TEDD rests in lower Arcs)
  - Lift rotation mechanism until it carries weight.
  - Remove lower Arcs.
- Install services and straps.
  - Needs rotation of TEDD to reach all sides.
  - Order of installation to be studied based on services design.
- Assemble transport carriage around TEDD for shipment.
TEDD mechanical stability

• FEM simulation to predict deformation of TEDD from its weight.

• Studies to optimize skeleton geometry.
  • Original 12-bar proposal was reduced to 8 bars with optimized position (30°-55°-40°)
  • Deformation: max. 280 µm, module displacement: 140 µm.
  • Planned to study position of strap rings to optimize access to patch panels.
TEDD stability during service installation

- Simulation stability in the situation when lifting TEDD by the rotation mechanism.
  - Lifted by inner tube, no straps, no services
  - Check of different orientations to simulate rotation.
  - Maximum displacement < 20 um.
  - Lifting TEDD by inner tube creates little stress on disks.
    - Disk deformation when held by normal mounting points mostly due to stress from straps and bars.

- Lifting TEDD by rotation mechanism without straps is possible.
Summary

• Final TEDD design well on track, service design ongoing.
• Dee prototyping ongoing to finalize design and improve production process.
  • Full size prototypes available soon.
• Dee QA testing procedures are being established.
• Dee integration tooling design and integration procedure under development.
• Disk and TEDD assembly procedure defined and tooling prototypes under preparation.
• Mechanical stability of final TEDD and during assembly verified.
Thank you

Contact

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Cut of edges
Tools: scissors with mikro tooth, sand paper

After shooting threw the plates with hot water beam

Easter egg
Delamination
DESY TEDD Prototyping