Forum on Tracking Detector Mechanics – Tübingen 2023

Mechanical structure of the CMS TEDD Detector

FEA dimensioning
Tests on prototype
& Comparison to simulation

E. Schibler, A. Bonnevaux, A. Eynard, M. Marchisone (IP2I Lyon / IN2P3 / CNRS), P. Chaudet (LAMCOS / INSA Lyon)
On behalf of the CMS-Tracker group

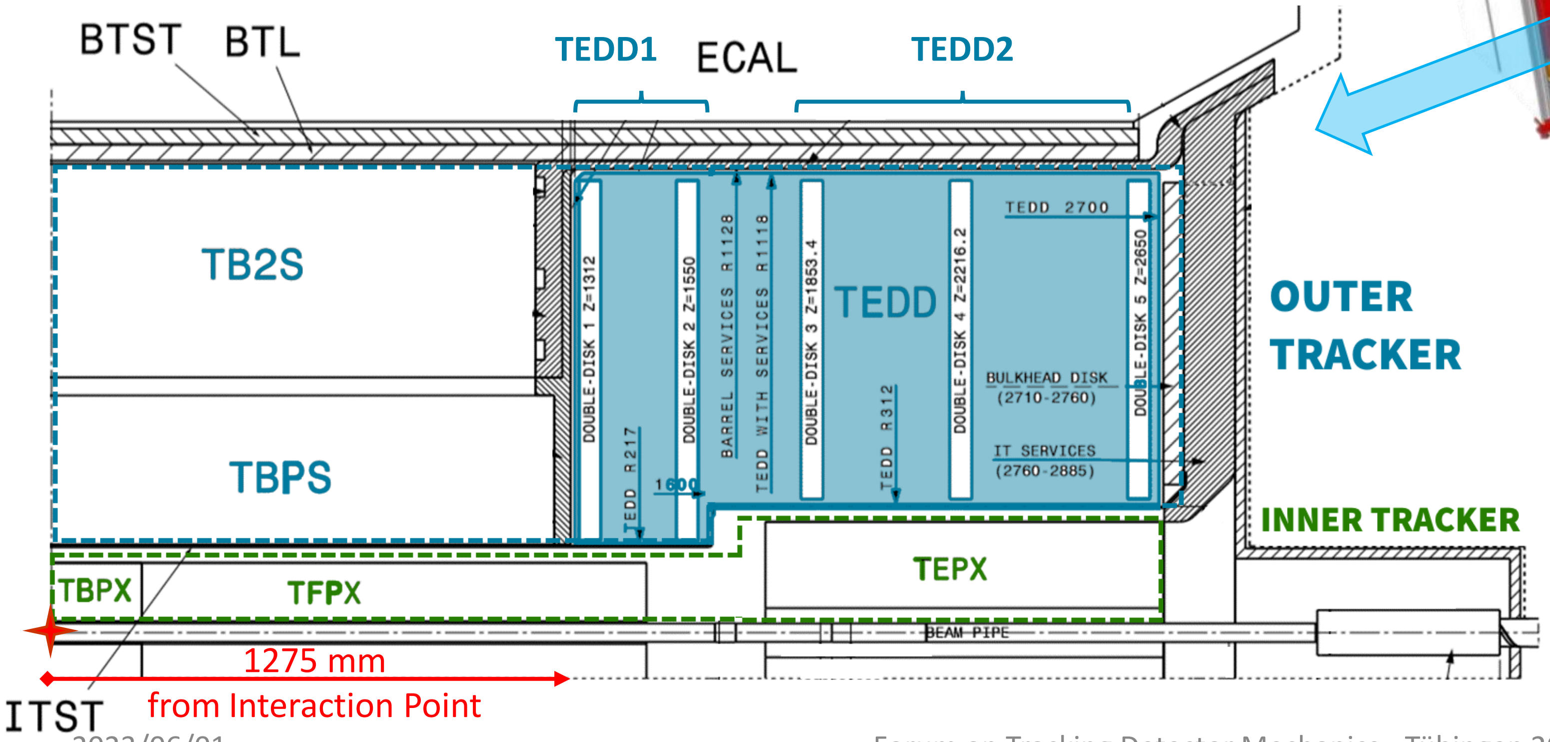
Outline

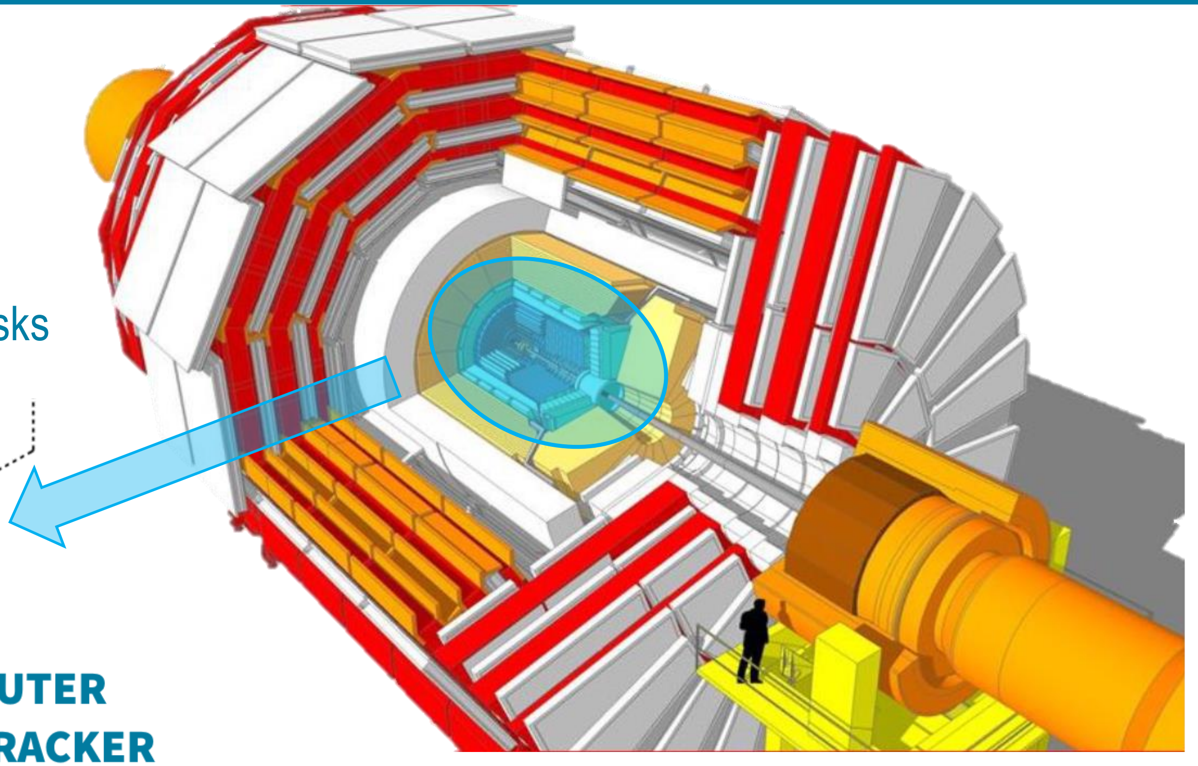
- TEDD mechanical structure: design & FEA dimensioning
- TEDD structure prototype: manufacturing & assembly testing
- Mechanical testing on parts: inserts strength, tensile tests, bending tests

- Comparison to FEA and conclusions

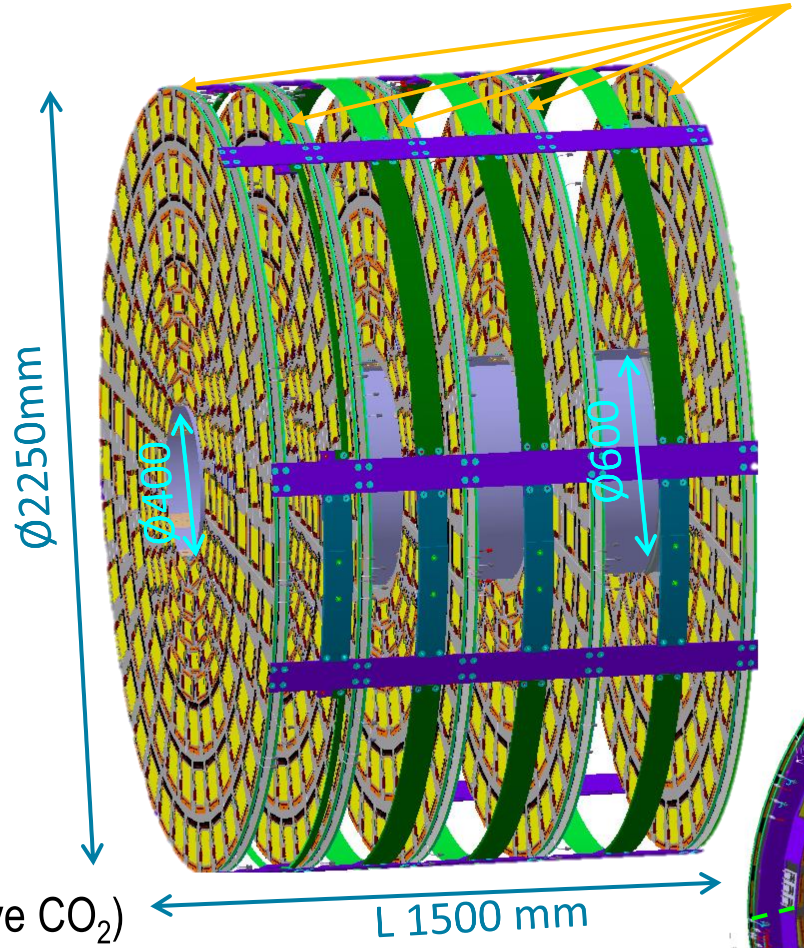
Overview
CMS & Outer Tracker

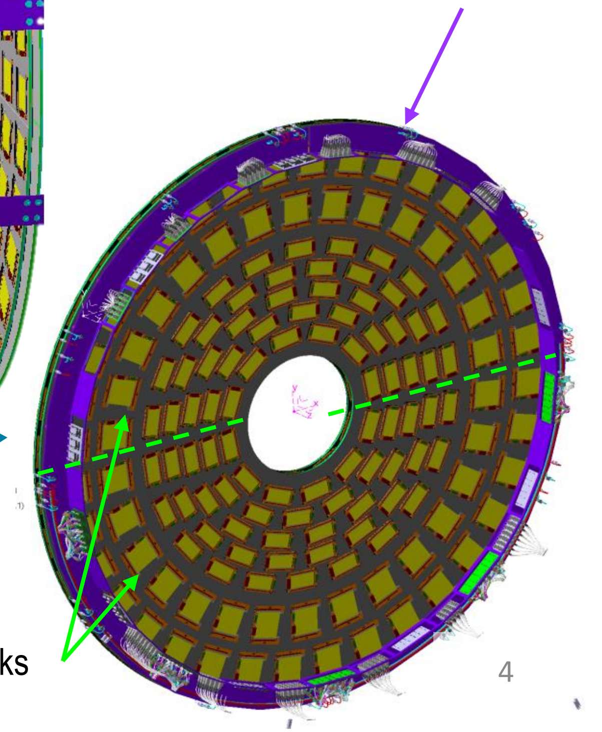
- CMS Experiment
  - ↳ Silicon detectors → Inner Tracker
    - ↘ Outer Tracker
      - ↳ 2 Endcaps (Z+ / Z-)
      - ↳ TEDD: Tracker Endcap Double-Disks





- TEDD dimensions: cylinder
  - 1,5 m-long
  - $Ø_{ext}$ 2,25m $Ø_{int}$ 0,4/0,6m
- Detection for one TEDD
  - 5 Double-Disks (DD) i.e. 10 Disks
  - Each disk made of 2 Dees
  - 20 detection faces of sensors
  - Over 3000 silicon modules
  - Detection coverage without dead areas
- Services
  - Power (HV/LV) / Data (optical fibres) / Cooling (evaporative CO_2)
  - Grouped together by Double-Disk and connected on patchpanels (PP0)
  - 5 Supporting Ring for patch panels mounted on DD





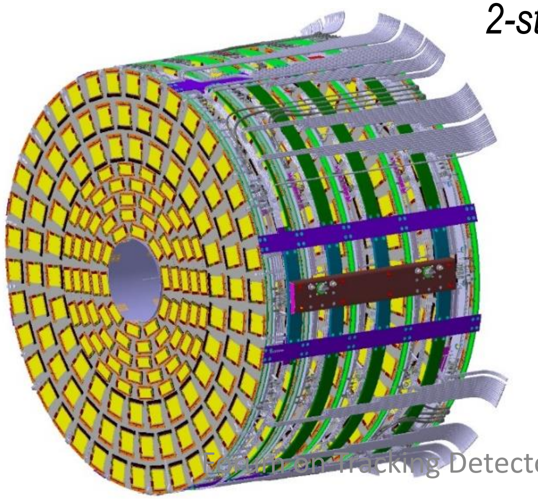
TEDD Mechanical Structure
General Design

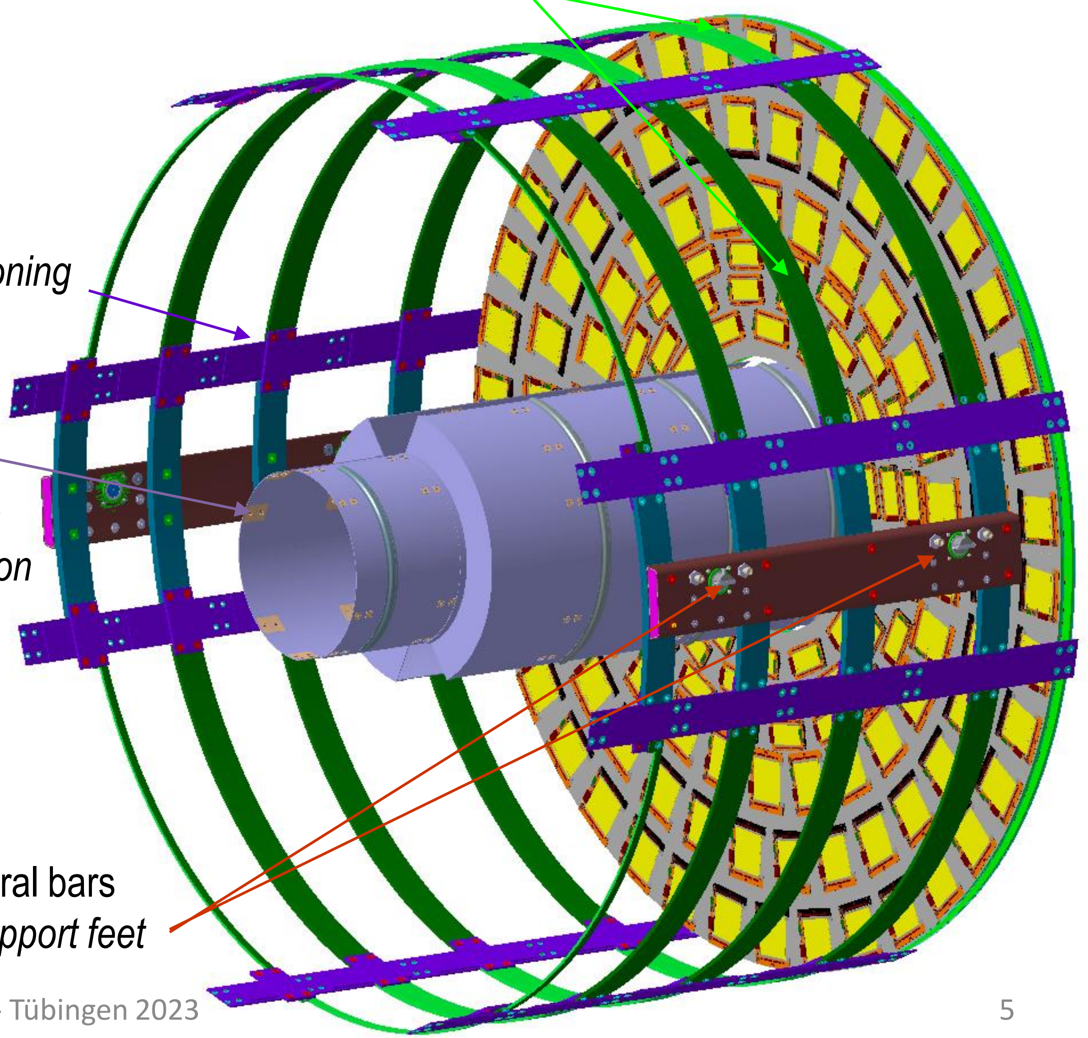
The TEDD Mechanical Structure joins and supports the Double-Disks, and the TEDD services

- Constraints
  - Lightness, particles transparency, outside detection area
  - Stiffness and low deformation

→ External CFRP framework
  - Massive or sandwich CFRP
  - External skeleton (1087<R<1103mm)
  - Assembled with screws on glued inserts

- Services
  - Grouped together by DD
  - Distributed on straps
    along TEDD until exit





TEDD Mechanical Structure
Optimization studies / Detailed design

Thinner strap ring between DD1&2

Strap 40°

Strap 55°

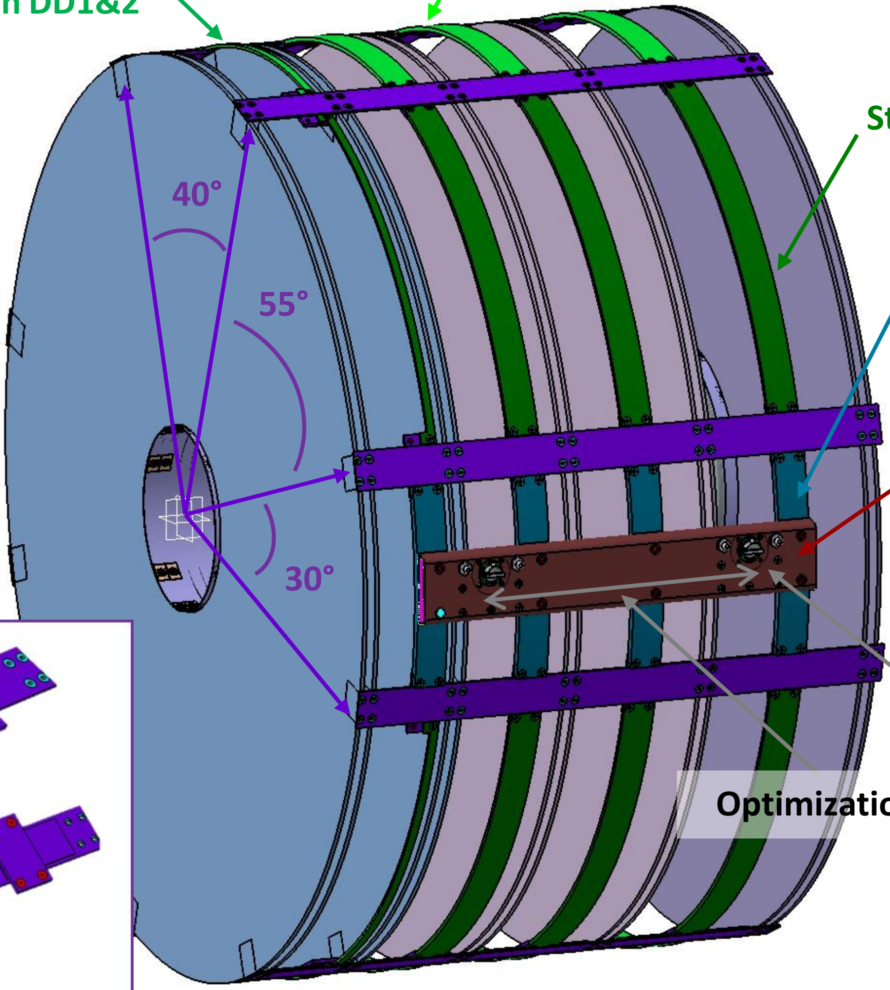
Beams
Optimization of angular repartition 40/55/30°

Thicker lateral straps

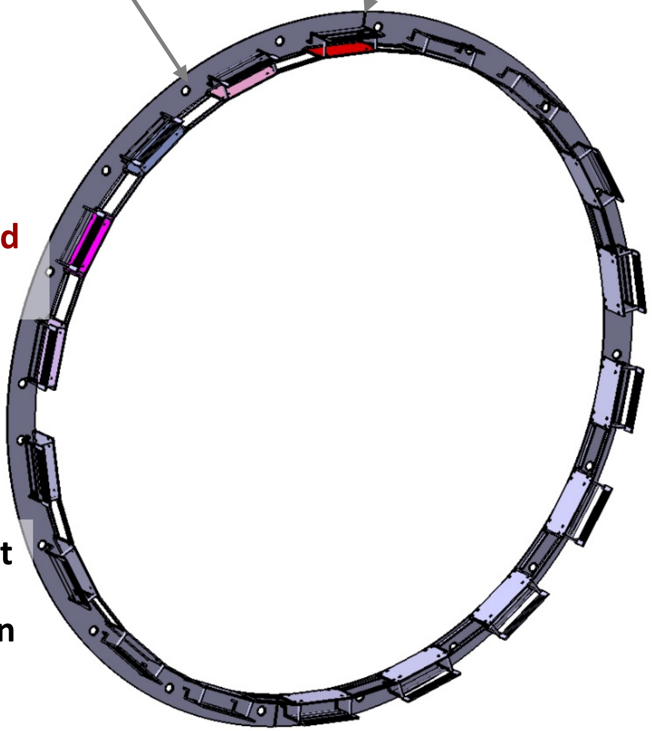
Lateral Bar adapted from TB2S design

TB2S support foot

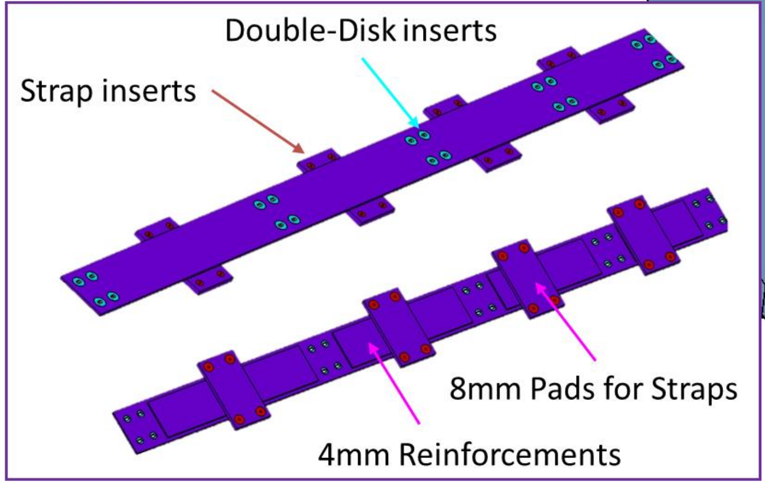
Optimization of longitudinal position



Patchpanel Support Ring
Thickness adapted to services weight (15kg)
Optimization of number/position of inserts
Left/Right division



Beam details

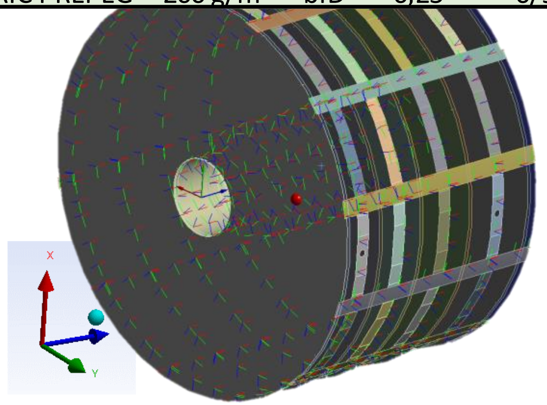


TEDD Mechanical Structure
Optimization studies / Material Definition

- Material optimization
  - Stacking
    - Beams: reduced available volume → massive CFRP
    - Straps: no volume restriction → foam sandwich
    - Lateral straps: improve stiffness → increase thickness
  - Fibre orientation
    - Beam: crucial longitudinal direction → preferably X/0° ply
    - Straps: crucial tangential direction → preferably Y/90° ply
    - For material cohesion → +/- 45° layers
  - Fibre choice
    - Lateral straps → short fibre: Carbon isotropic
    - Straps → Standard mechanical bi-directional fibre: T300 woven fabric
    - Beams → improved mechanical bi-directional fibre: M46J woven fabric
      → high mechanical uni-directional fibre: M55J

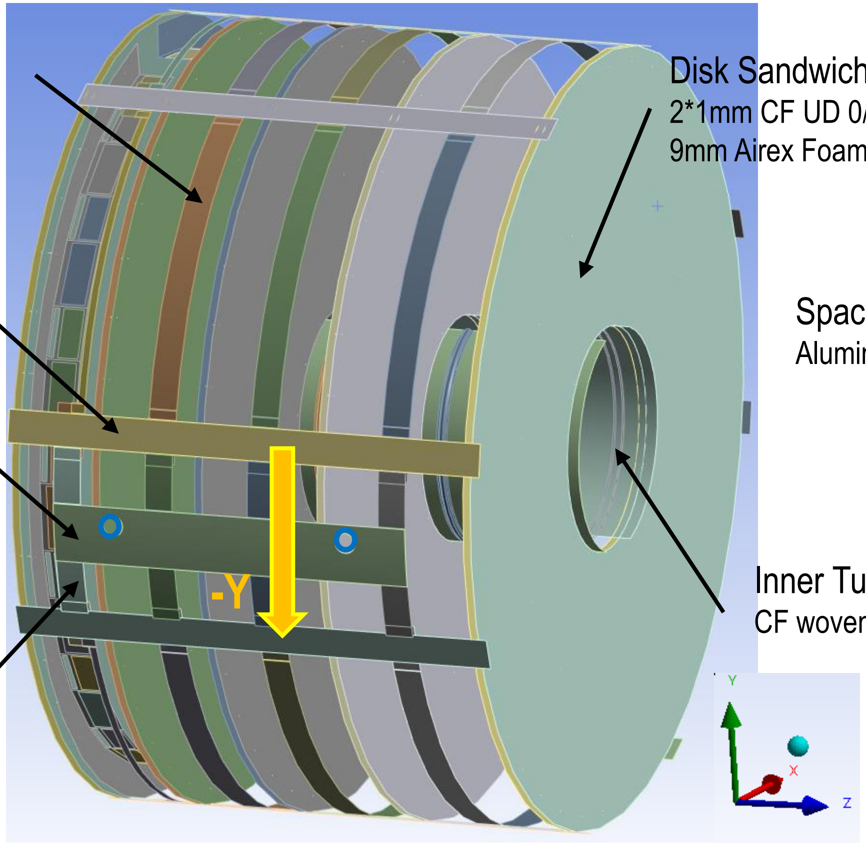
STRAP	1 mm	T300 FABRIC PREPEG	200 g/m²	biD	0,25	0/90	Upper skin	10 mm
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	45/-45		
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	45/-45		
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	0/90		
	8 mm	Filler Fibre biD eq. 4mm 0/90	Foam				Filler	
		Filler Fibre biD eq. 4mm 45/-45	Airex 82.80 80 kg/m3					
	1 mm	T300 FABRIC PREPEG	200 g/m²	biD	0,25	0/90	Lower skin	
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	45/-45		
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	45/-45		
		T300 FABRIC PREPEG	200 g/m²	biD	0,25	0/90		
		Fastening area	Central area				Fastening area	

BEAM	T300 1K PW FABRIC PREPEG	200 g/m²	biD	0,25	0/90	4mm
	M46J 6K PW FABRIC PREPEG	600 g/m²	biD	0,7	0/90	
	M46J 6K PW FABRIC PREPEG	600 g/m²	biD	0,7	45/-45	
	M55J 6K UD PREPREG	600 g/m²	**UD**	0,7	0	
	M46J 6K PW FABRIC PREPEG	600 g/m²	biD	0,7	45/-45	
	M46J 6K PW FABRIC PREPEG	600 g/m²	biD	0,7	0/90	
	T300 1K PW FABRIC PREPEG	200 g/m²	biD	0,25	0/90	

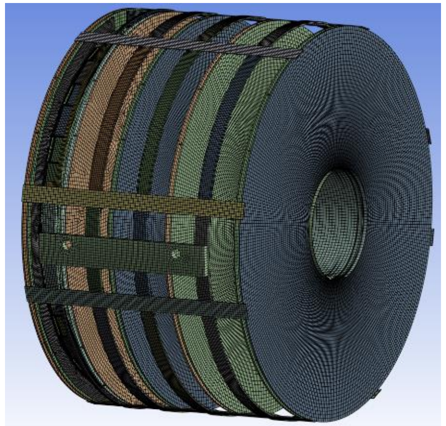


TEDD Mechanical Structure
FEA / Data input

- Ansys hypothesis & simplification
  - 3D face to 2D surface
  - Layered section for CFRP
  - Contacts totally bounded



- 2D Mesh
  - ~200000 nodes

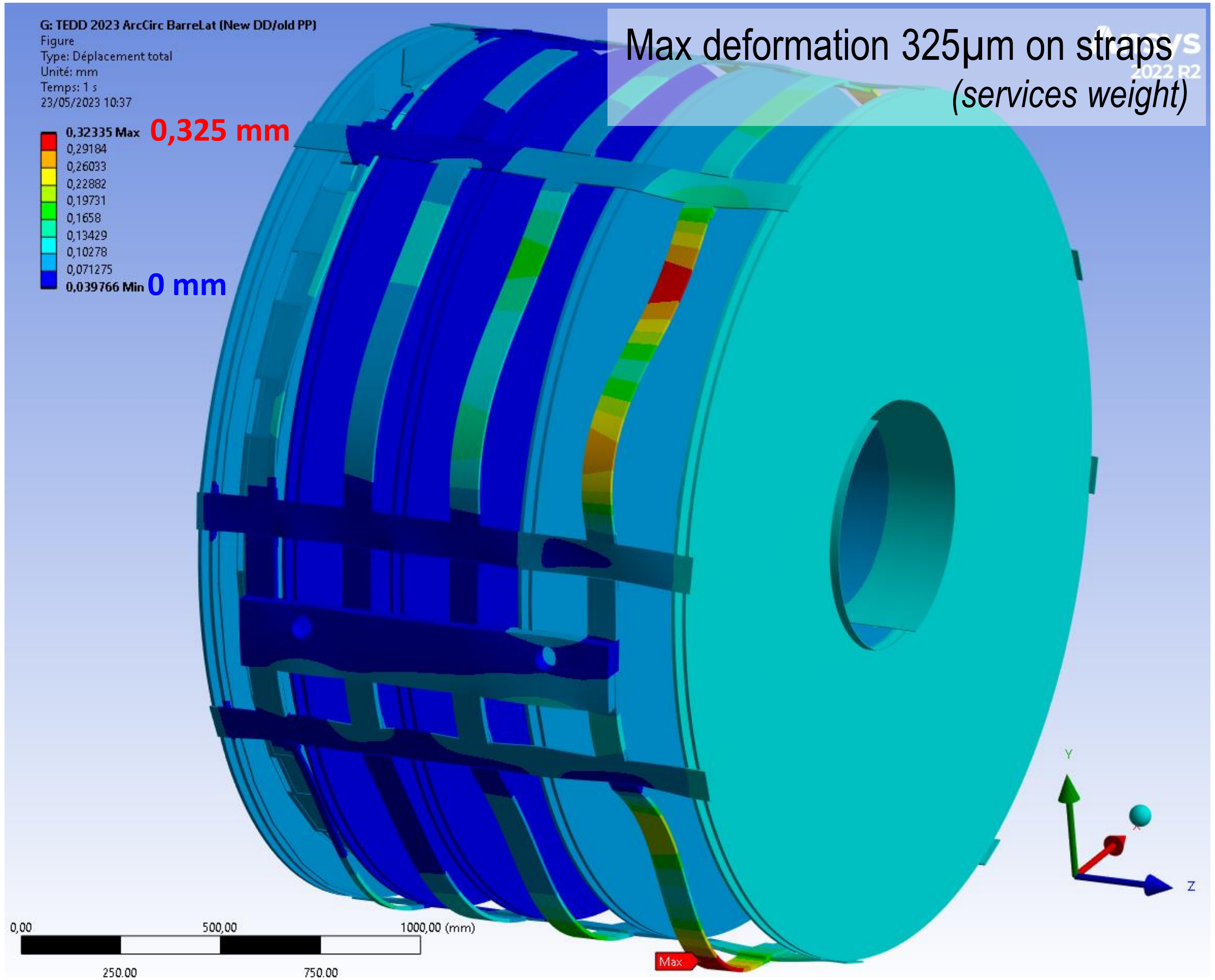


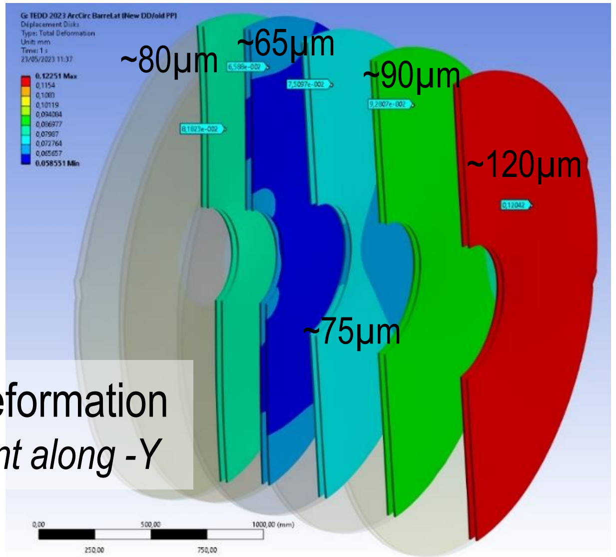
- Boundary conditions

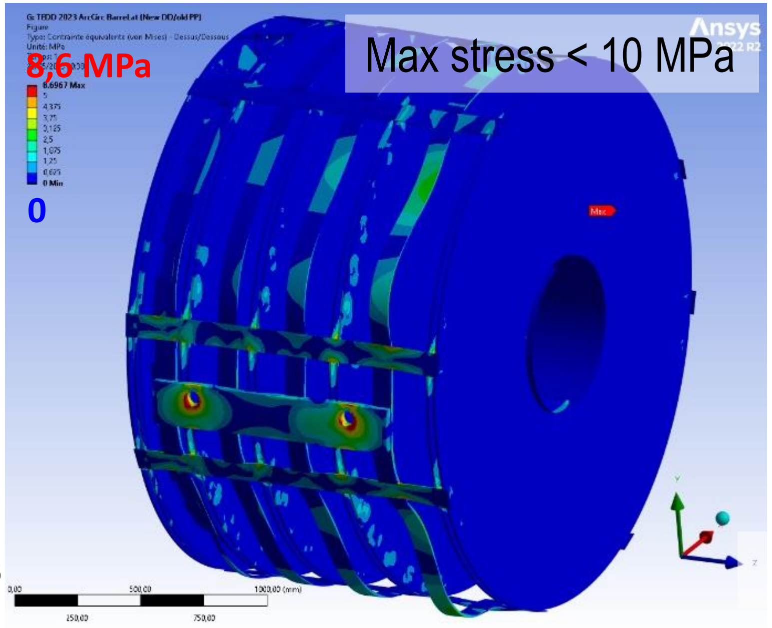
Distributed mass on disks	32 to 39 kg/disk	modules & cooling equipment	(350kg)
Peripheral services	150 kg cables	non uniform repartition along Z	(150kg)
PatchPanel Support Ring	#1 modelled	#2 to 5 distributed mass	(95 kg)
Remote support	4 lateral feet	remote displacement (DoF D_x in X^-, R_x, R_z)	
Gravity	-Y	Total 750kg	

TEDD Mechanical Structure

FEA / Results



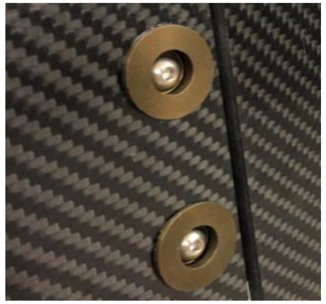


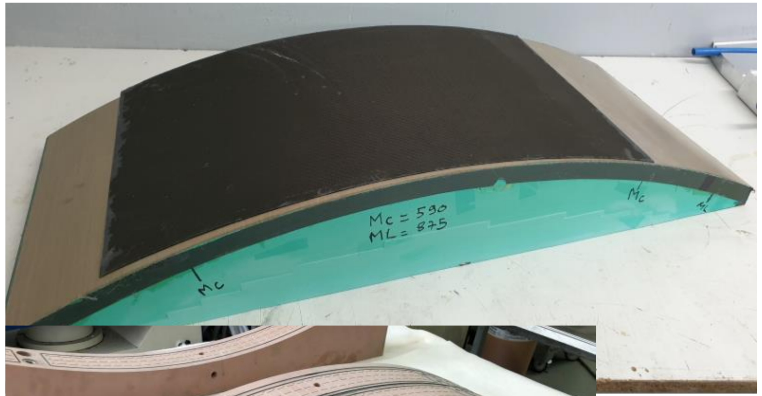


Prototype
Manufacturing

- Partial mock up
  - 4 beams / 4 straps 55° / 4 straps 40° (Less than ½ framework)
  - Not final fibres (less efficient/expensive) but same stacking
  - → Validation of process, tools & accuracy
  - → Understanding of mechanical behaviour under loads, estimation of deformation

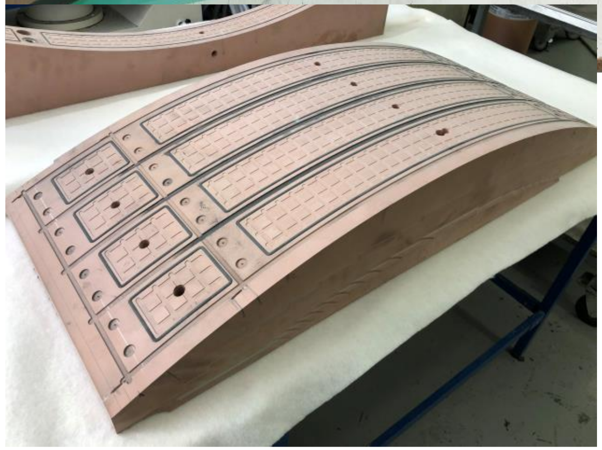
Pins for inserts positioning





Caul plate (curing)

Gluing & Control Jigs



Vacuum mould (machining)

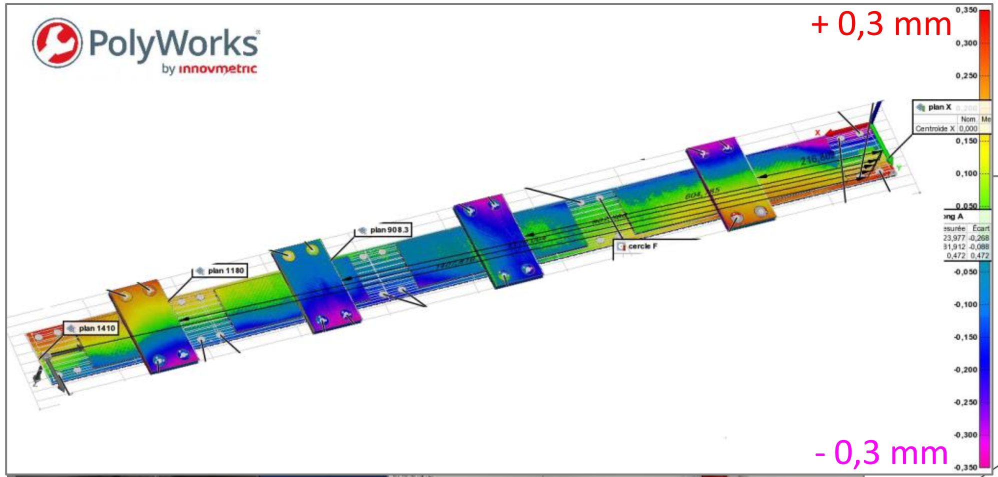
Foam core on strap

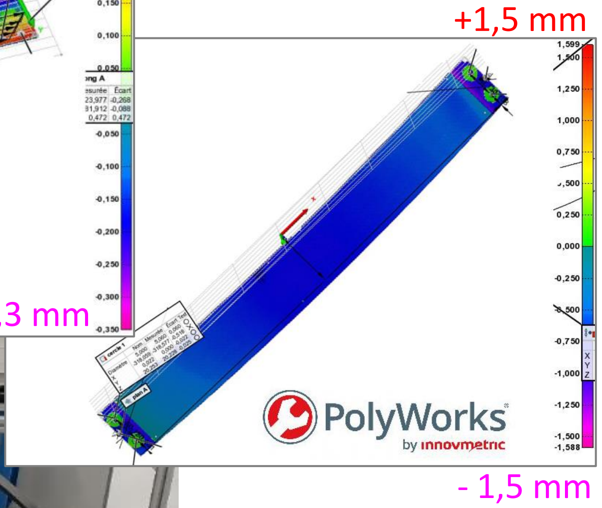
Prototype
Metrology & Assembly

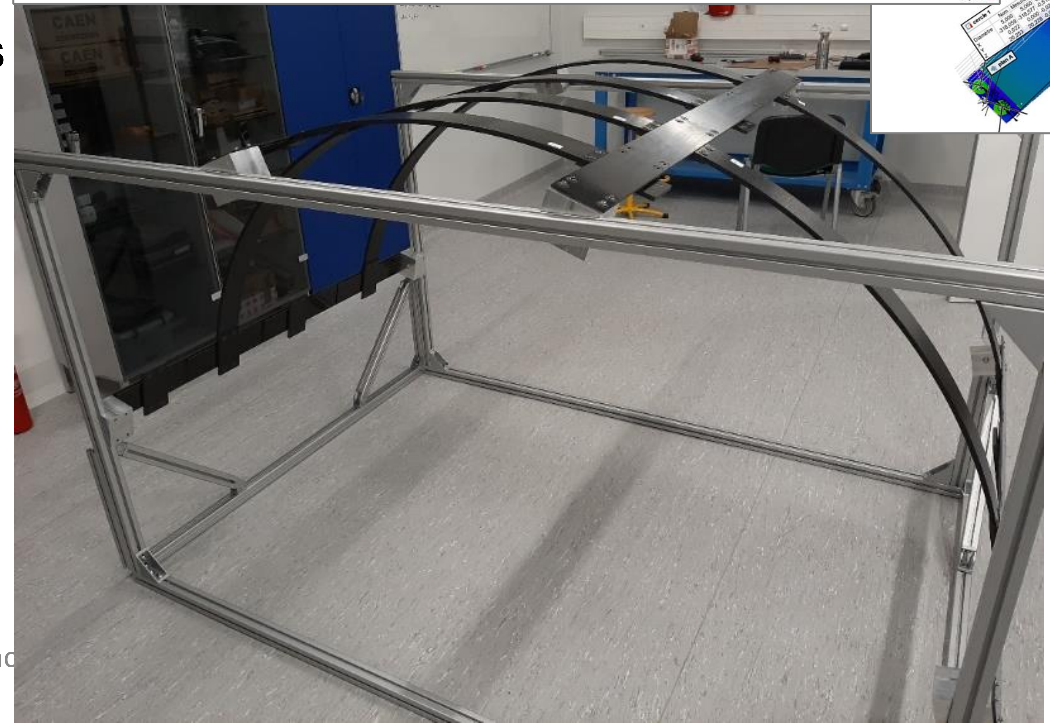
- Dimensional checking
  - Good accuracy for beams
  - Geometry of straps near tolerance limits
  - Good positioning of inserts

- Assembly on Aluminium cradle
  - Easy mounting
  - sufficient inserts clearance / no over-constraints
  - Controlled with metrology arm

- Mechanical tests & measures
  - Load mass applied on single points
  - Deflection measured by indicator



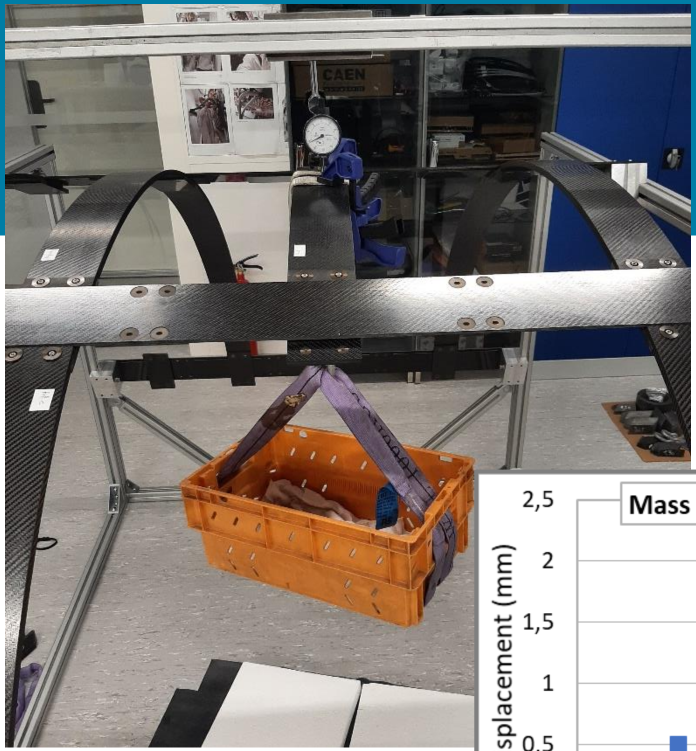




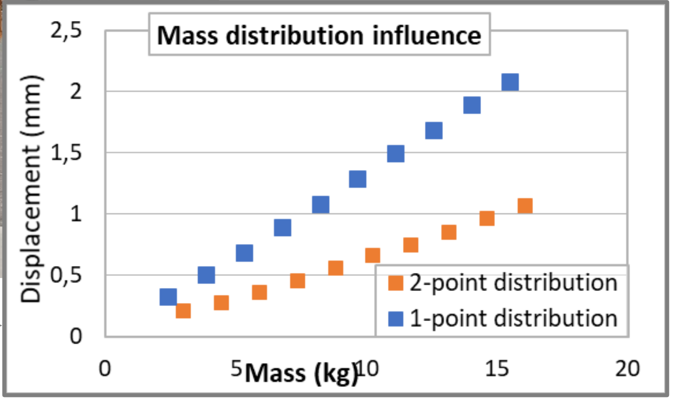
Prototype
Tests & results

Uncomplete half-structure → global behaviour & deformation estimation

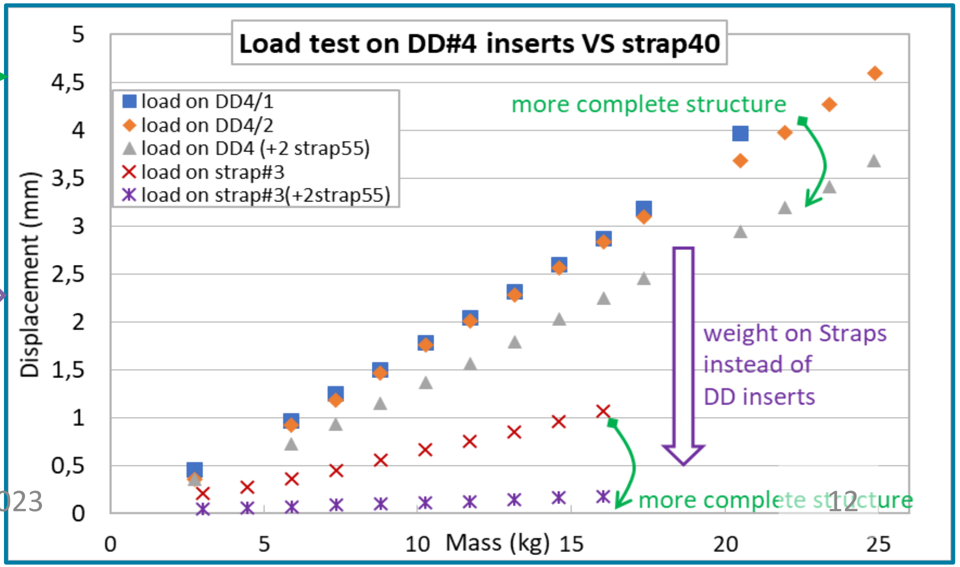
- Linearity, repeatability, symmetry
  - Elastic domain, no damage
  - No geometry distortion induced by insert clearance or mounting



- Mass distribution
  - Deformation divided by 2 from a single-point to a 2-point load distribution
  - → on TEDD: uniform mass repartition → lower deformation



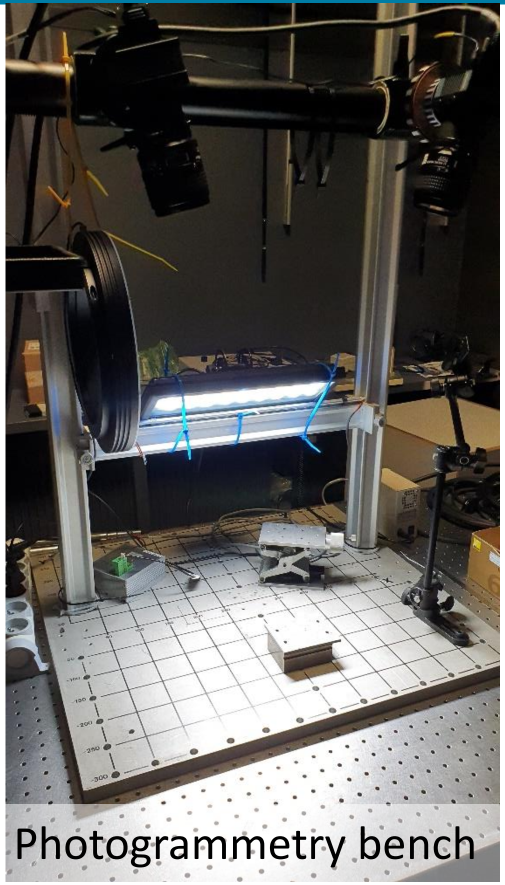
- Structure influence
  - Deformation decreases by adding 2 adjacent straps on structure
  - → on TEDD: complete structure → improved stiffness
- Mass localization
  - Less deformation with load on straps inserts VS DD inserts
  - → on TEDD: services weight applied on straps → lower deformation



Mechanical tests @ INSA Lyon
Set-up

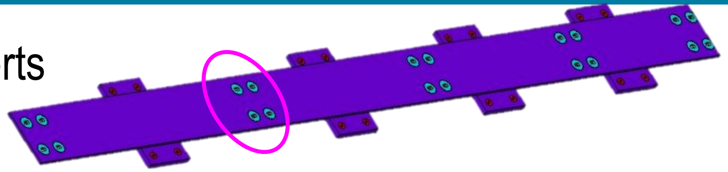
- Tensile machine
  - Zwick 100 kN
  - Test on beam sample
    - → characterization of beam CFRP
  - Test on beam inserts
    - → strength of glued inserts
- Photogrammetry
  - Determination of residual deformation
- Bending machine
  - Schenck 250 kN (hydraulic press)
  - 3-point bending test
  - Beam sample → characterization of beam CFRP
  - Free & clamped strap → characterization of strap sandwich


Tensile machine

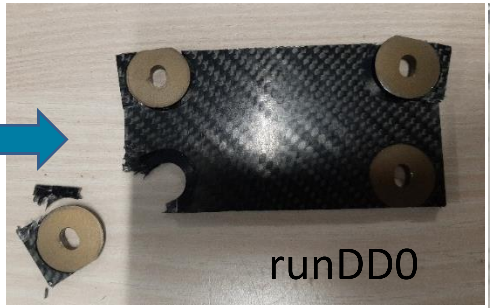

Photogrammetry bench

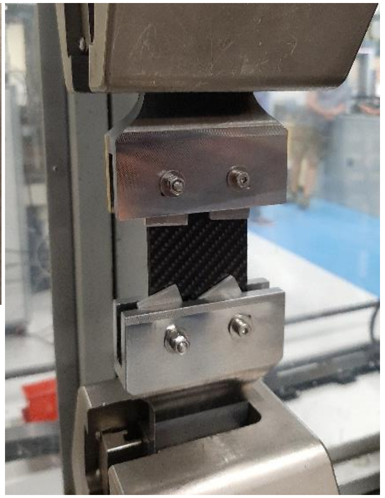

Bending machine

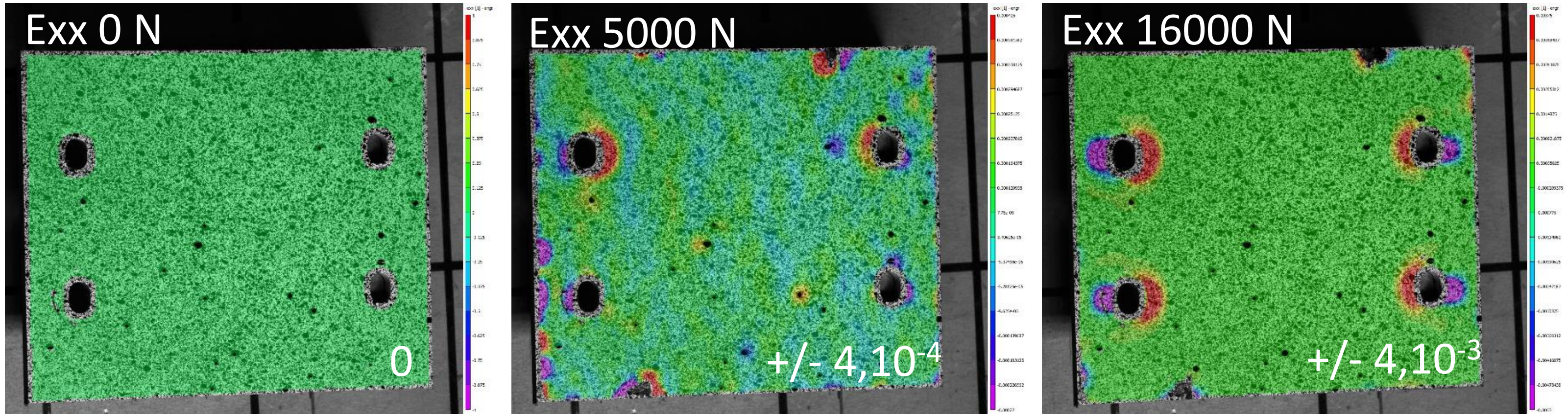
- Double-Disks inserts



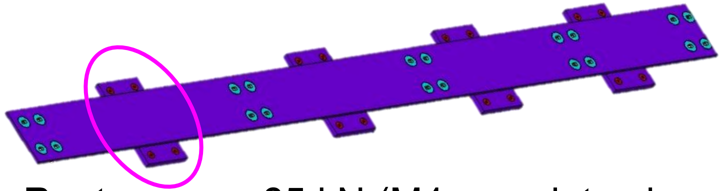
  - runDD0: Rupture around 10kN (insert pull-out, cut too close to edge)
  - runDD1: Linear up to 1 kN
  - runDD2: Rupture over 16 kN (16850 N: complete M4 screw shearing)



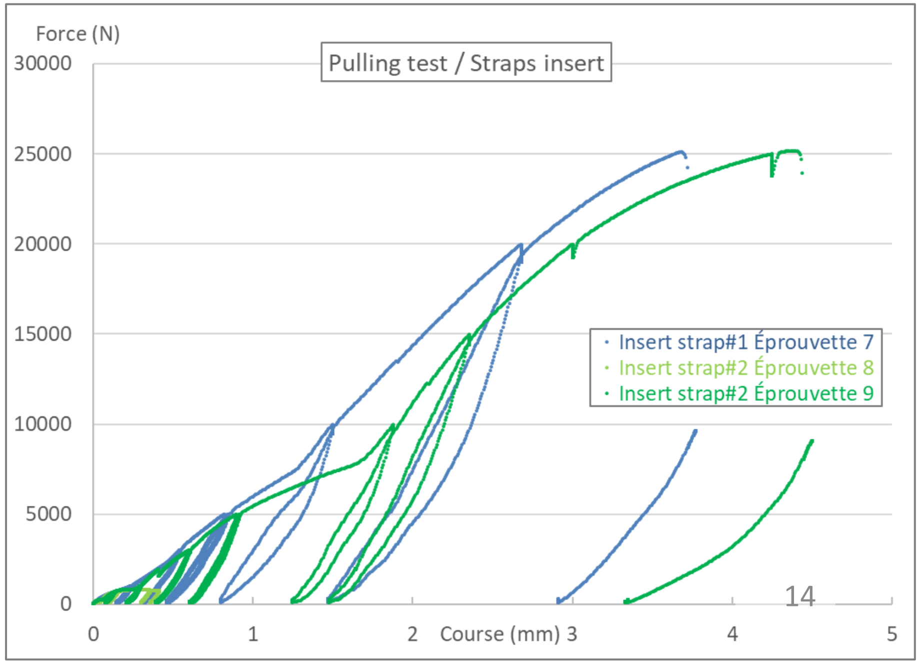




Strain on runDD2

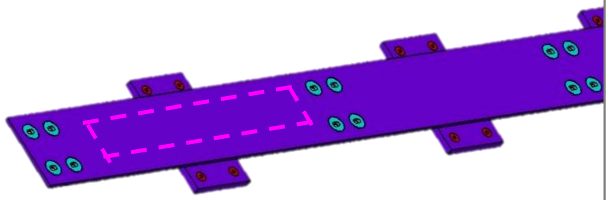


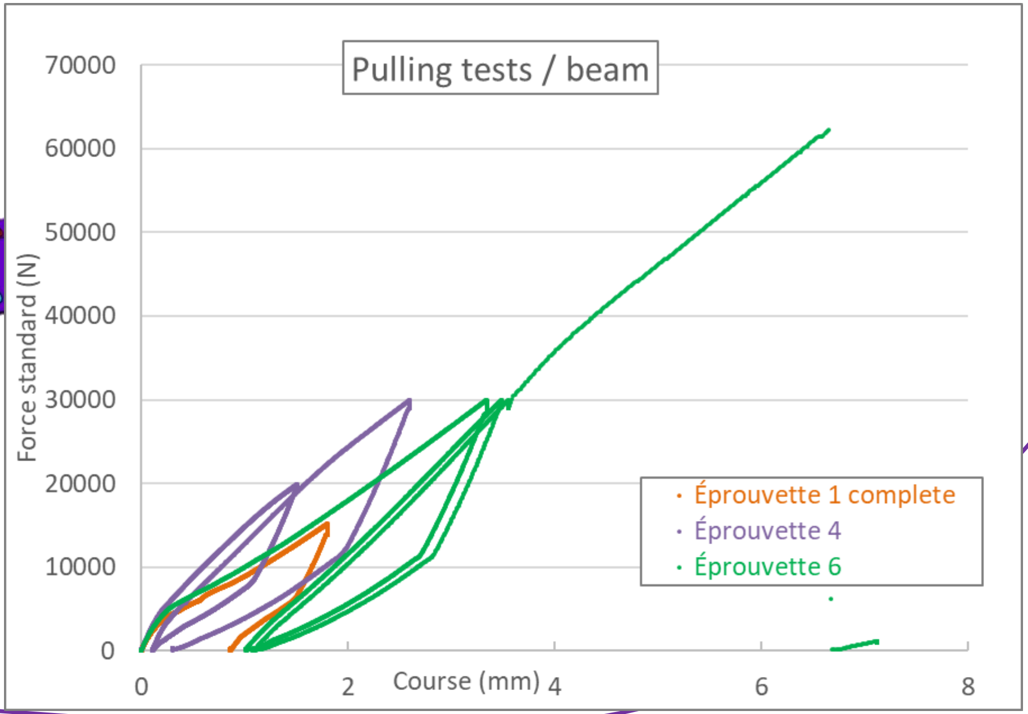
- Strap inserts
  - run1 & 3: Rupture over 25 kN (M4 complete shearing)



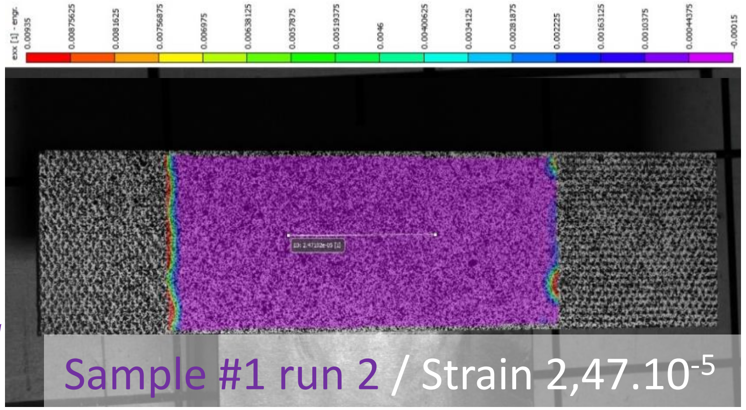
Mechanical tests / Tensile
Beam sample characterization

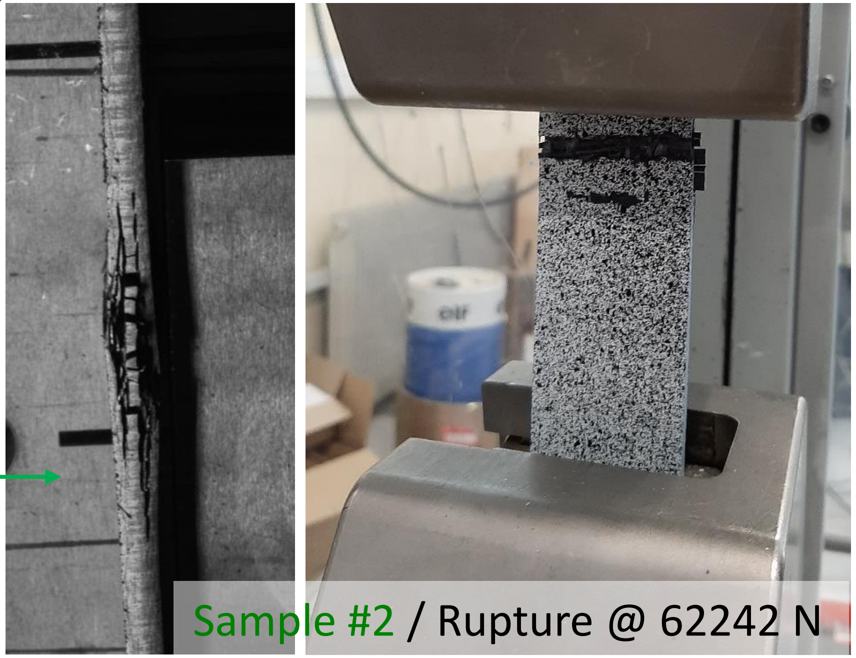
- 2 longitudinal samples
- No inserts
- 3 runs until failure



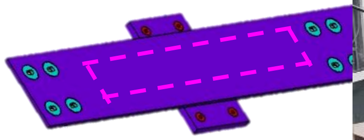


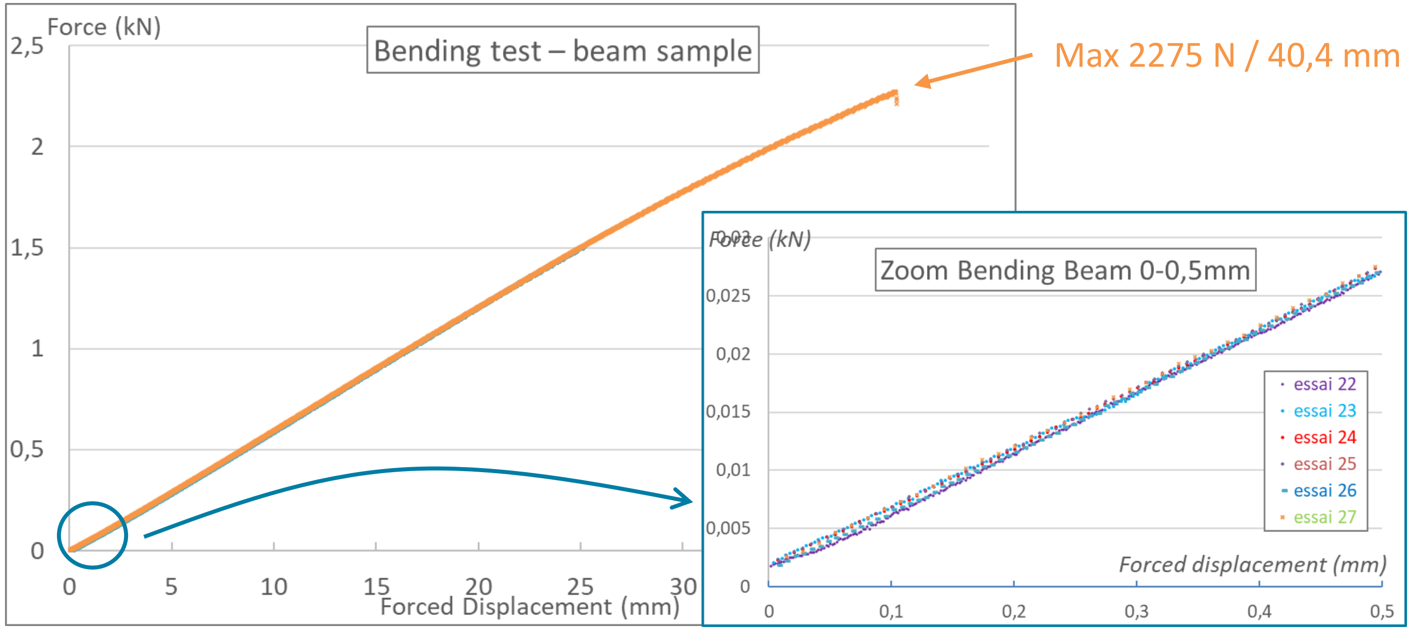
- Sample #1 run 1
  - Up to 15000 N
- Sample #1 run 2
  - Up to 30000 N
  - Residual deformation <<1
- Sample #2 run 3
  - Breaking at 62242 N / ΔL=6,65 mm (delamination)
  - $R_m = F_{max}/S$ = 350 MPa





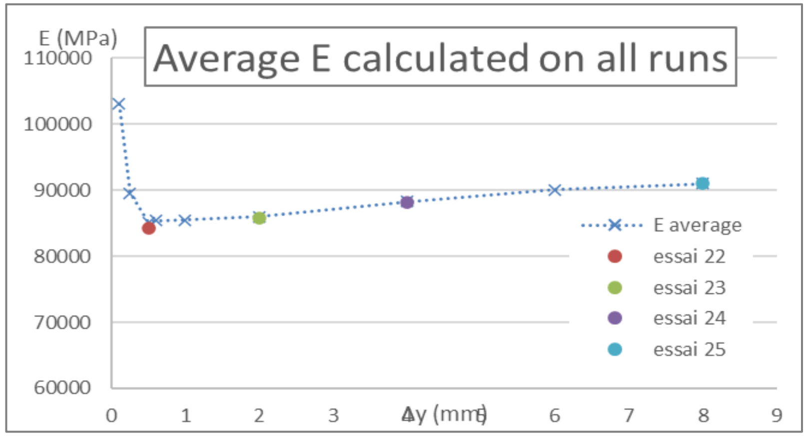
- 6 iterative runs with increased displacement
  - Linearity & very good reproducibility
  - Up to 2275 N / 40 mm





- Young modulus
  - E_{max} calculated at Δy_{max} on each run
  - $E_{average}$ calculated on all runs
    - → E_{test} ~ 85000 MPa
    - → $E_{test} > E_{Ansys}$ (68000 MPa)

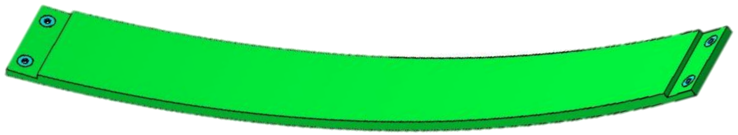
Emax calculated at Δymax of each run			
	max Δy	F kN	E=-PL^3/48ΔyIgz
essai 22	0,500	0,027	84252
essai 23	2,000	0,111	85818
essai 24	4,000	0,229	88223
essai 25	8,000	0,472	91134
essai 26	25,000	1,503	92808
essai 27	40,467	2,275	86802

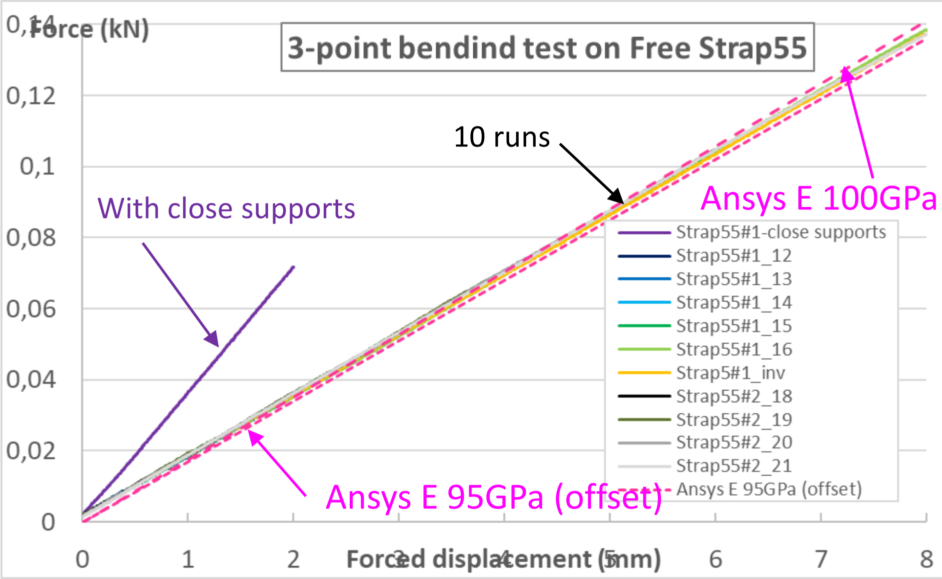


Mechanical tests / Bending
Free strap

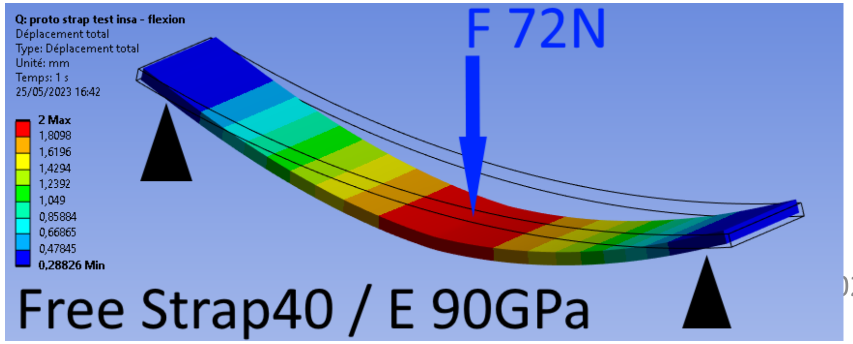
- Strap 55
  - 11 runs with 2 parts
  - Up to 8 mm (140 N)
- Strap 40
  - 9 runs (2 parts)
  - Up to 4 mm (140 N)

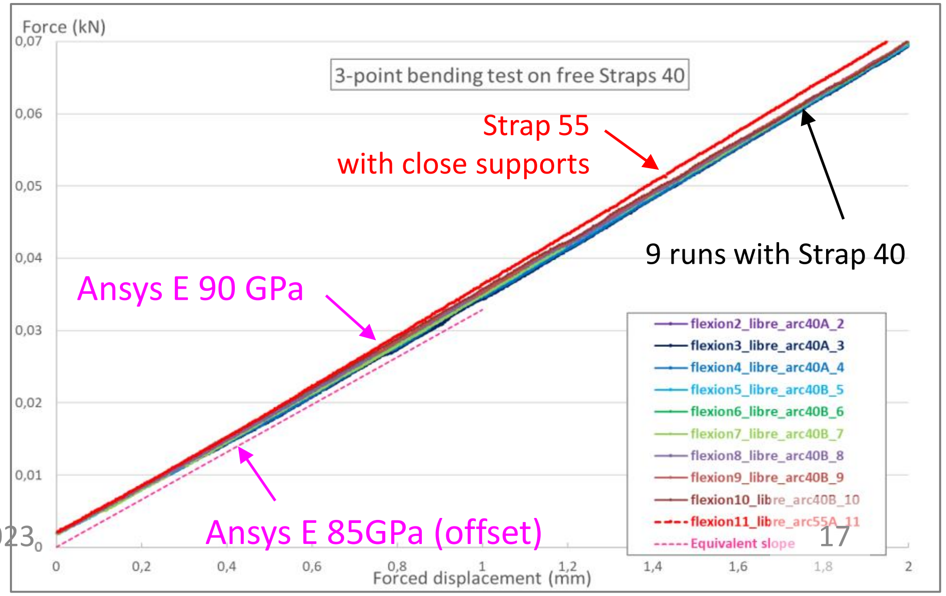
→ Linearity and repeatability





- Determination of E_{ply} to be used in Ansys for same results:
  - Strap 55
    - $E_{calculated}$ = 100 GPa
    - $E_{corrected\ offset}$= 95 GPa *(E_{Ansys} =68 GPa)*
  - Strap 40
    - $E_{calculated}$ = 90 GPa
    - $E_{corrected\ offset}$= 85 GPa

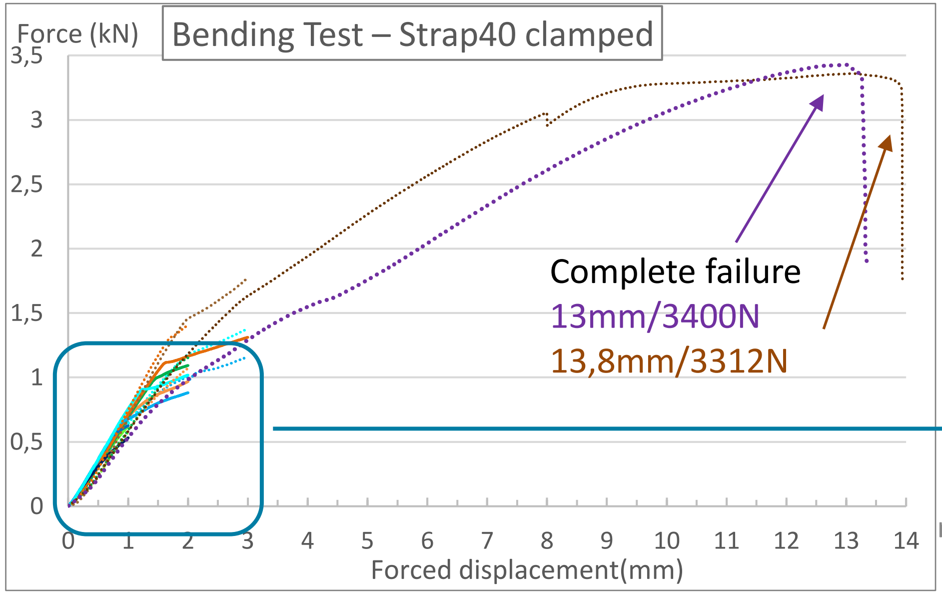


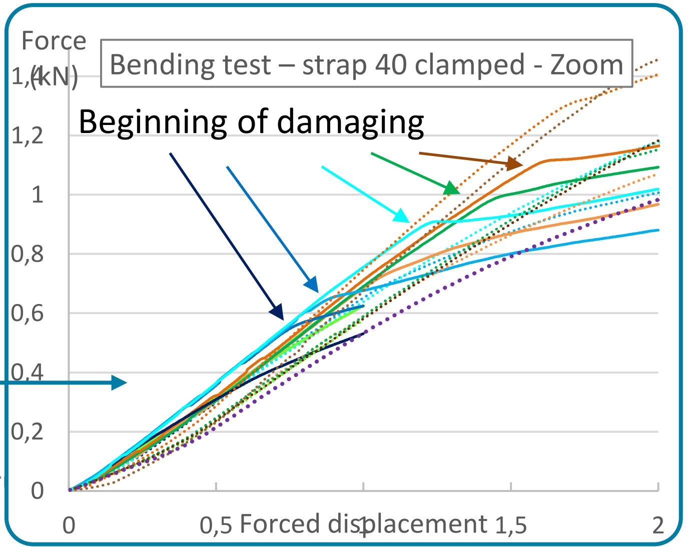


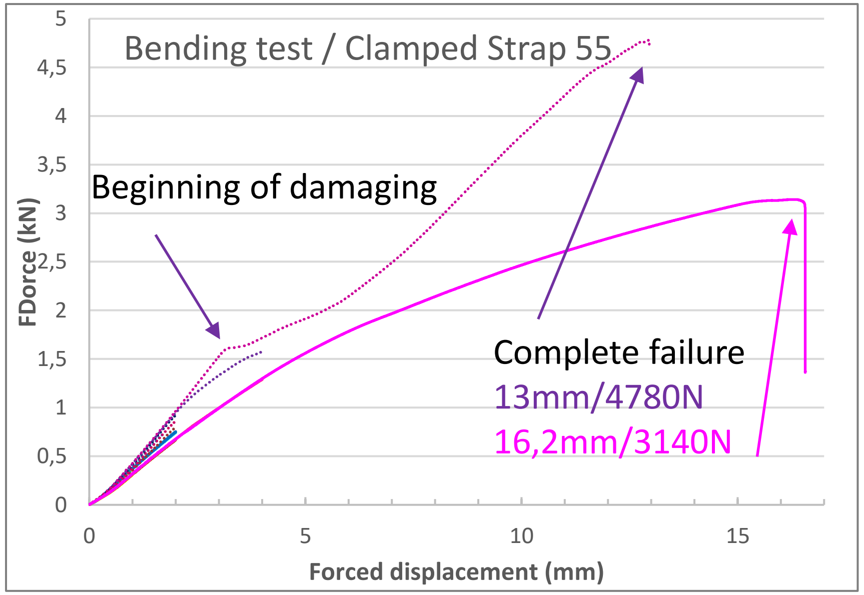
Mechanical tests / Bending
Clamped Strap

- Straps clamped on mounting flanges
- Iterative runs with increased forced displacement
- Upper or lower configurations / Strap 40&55

- Results
  - Non-linear and non-reproducible measurements → damage
  - Up to 5000 N and 14 mm for complete failure (other values > 3000 N / 10 mm)

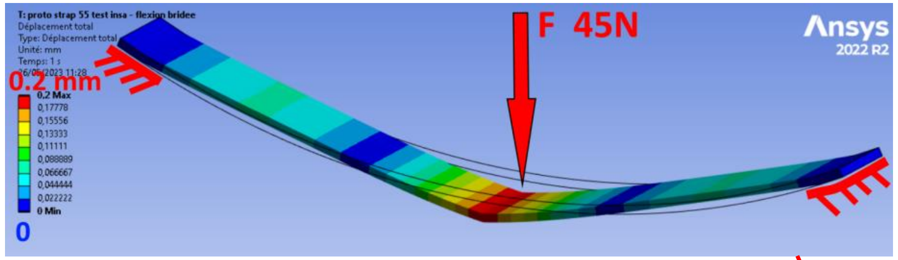


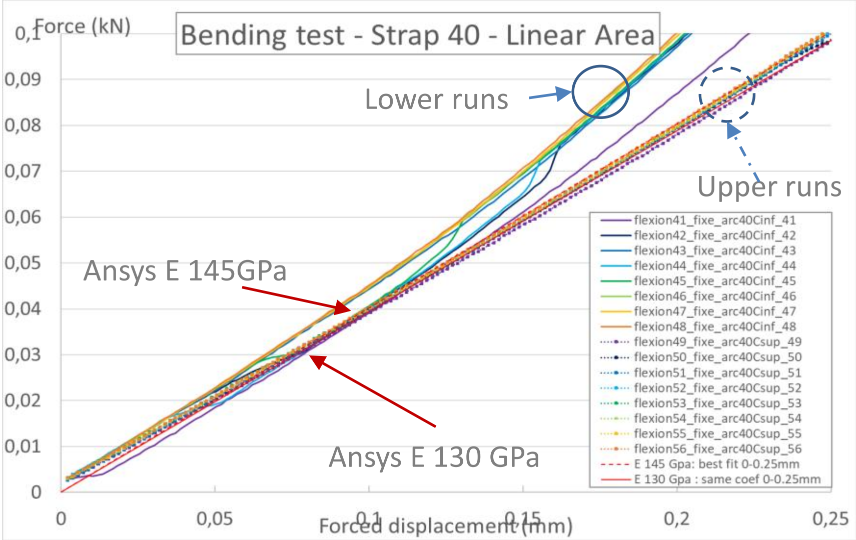


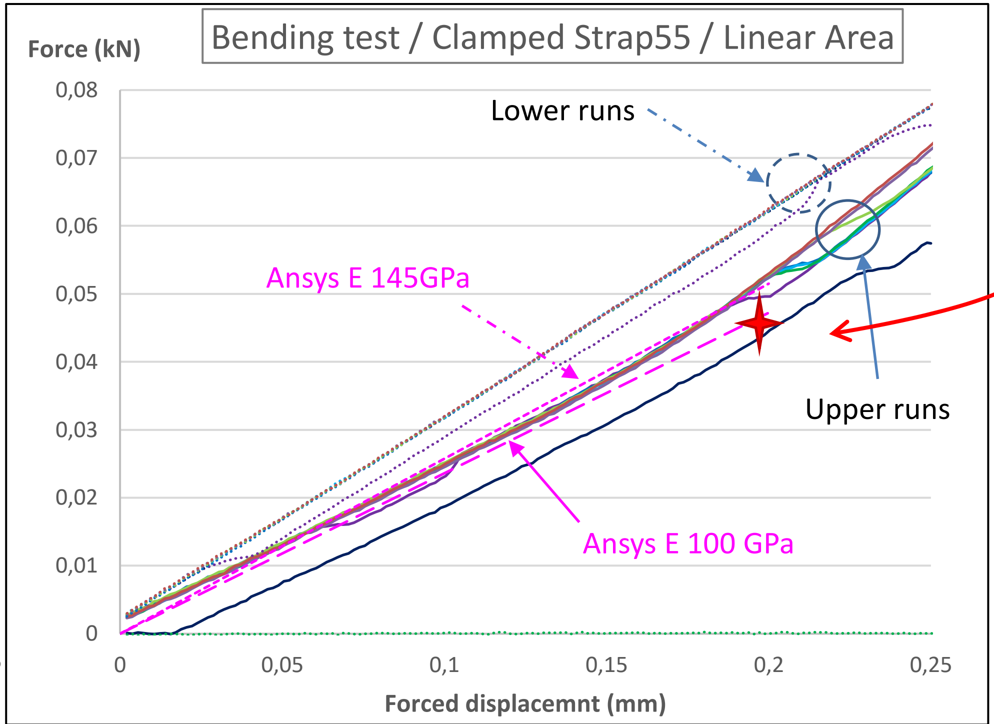


Mechanical tests / Bending
Clamped Strap /E

- Damaging and plasticity
  - → Use only the beginning of the first runs on each strap to determine E (Δy<0,5mm)
- Lower configuration & Strap40 stiffer (in theory no)
  - Influence of simplifications (inserts, massive fastening area, carbon lateral side)
  - → Use strap 55 upper configuration to determine E
- Determination of Equivalent modulus to be used in Ansys to obtain same values
  - E_{Ansys} = 145 GPa
  - With correction of initial offset: E_{Ansys} = 100 GPa







Manufacturing

- Good precision and mechanical behaviour

→ Validation of manufacturing process

Mechanical tests

- High strength of glued inserts
  - > 15 kN (screw shear strength)
- High strength level for beam sample and straps with punctual mass loading
  - On TEDD: uniform mass distribution for even better behaviour
- Characterization of beam material (equivalent Young modulus for ply)
  - $E_{test} > E_{used\ in\ Ansys}$ → keep using these underestimated values

→ Validation of TEDD design & FEA studies

- Design: Fastening type (glued inserts), carbon fibres choice, orientation and stacking
- Simulation: Data material used, deformation levels…

Thanks for your attention