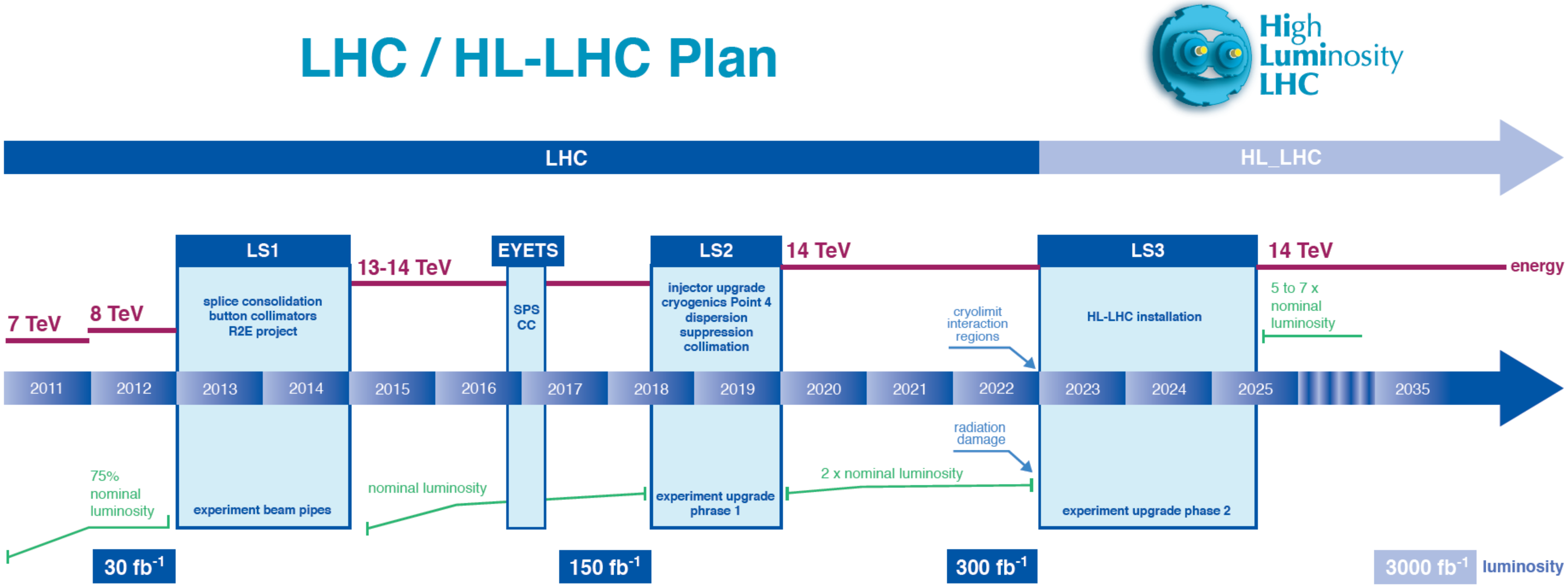
The CMS Phase 2 Tracker Upgrade

Andreas Mussgiller

LHC Physics Discussion

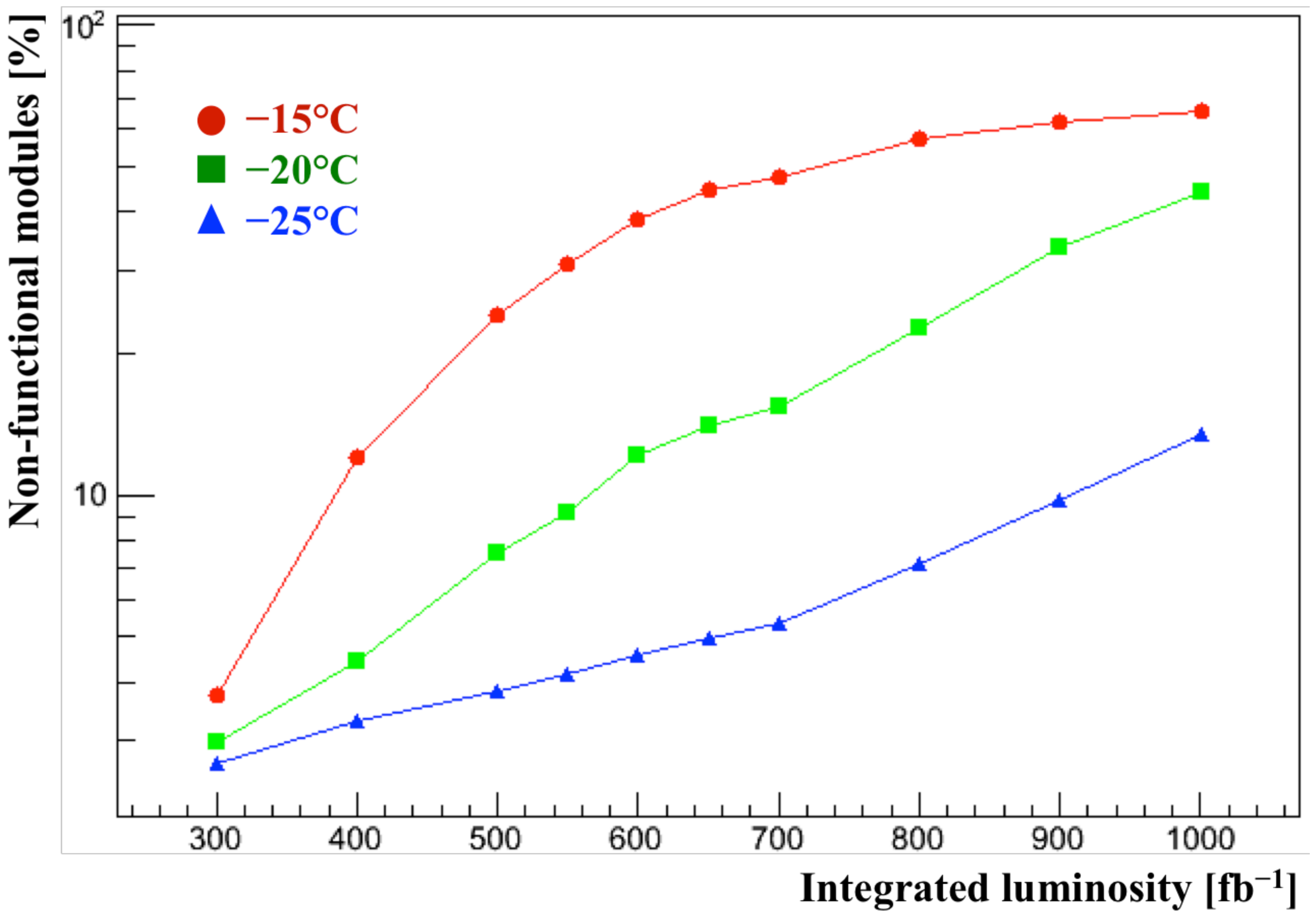
18/02/2019

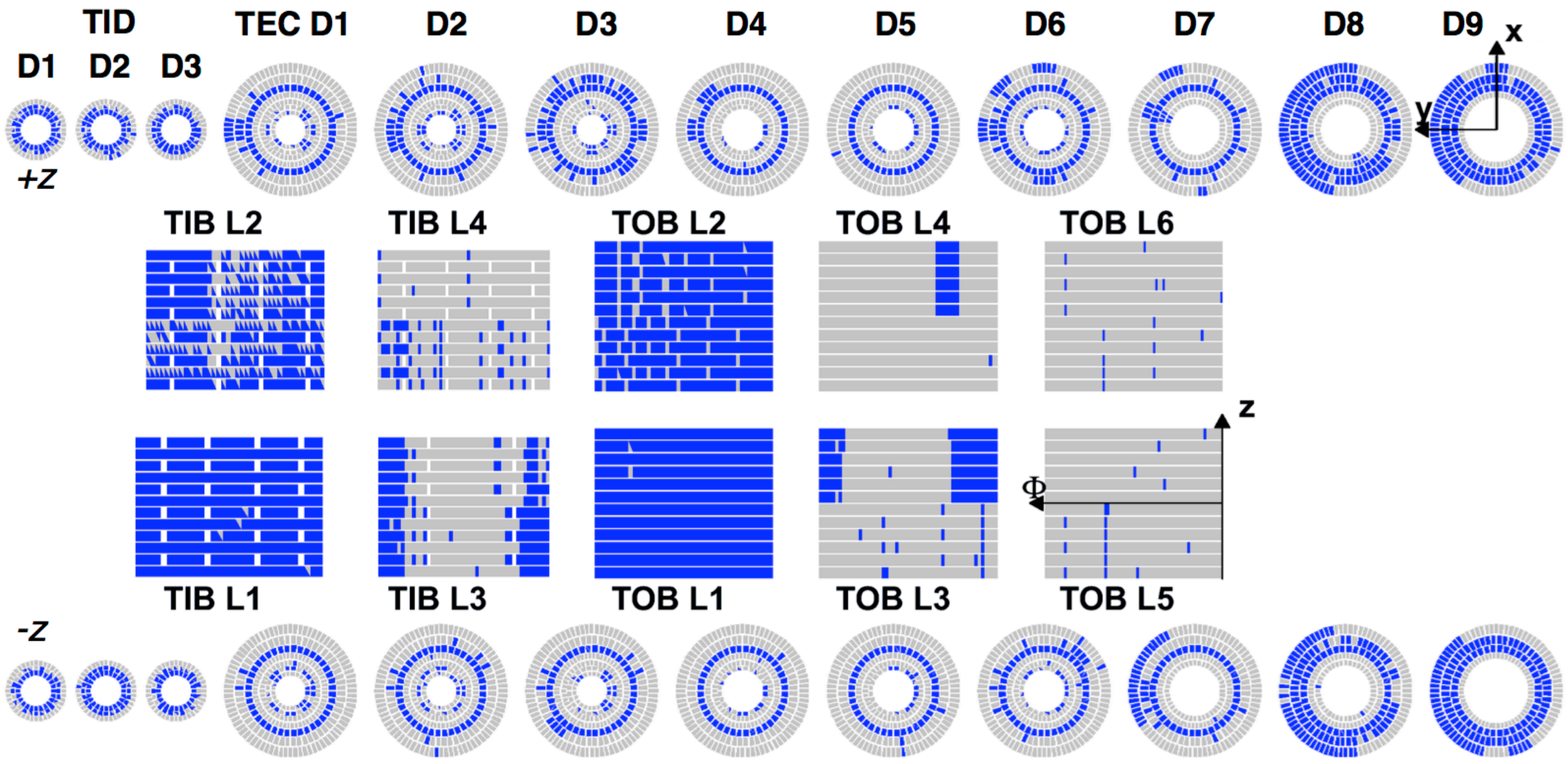
Introduction - LHC Schedule

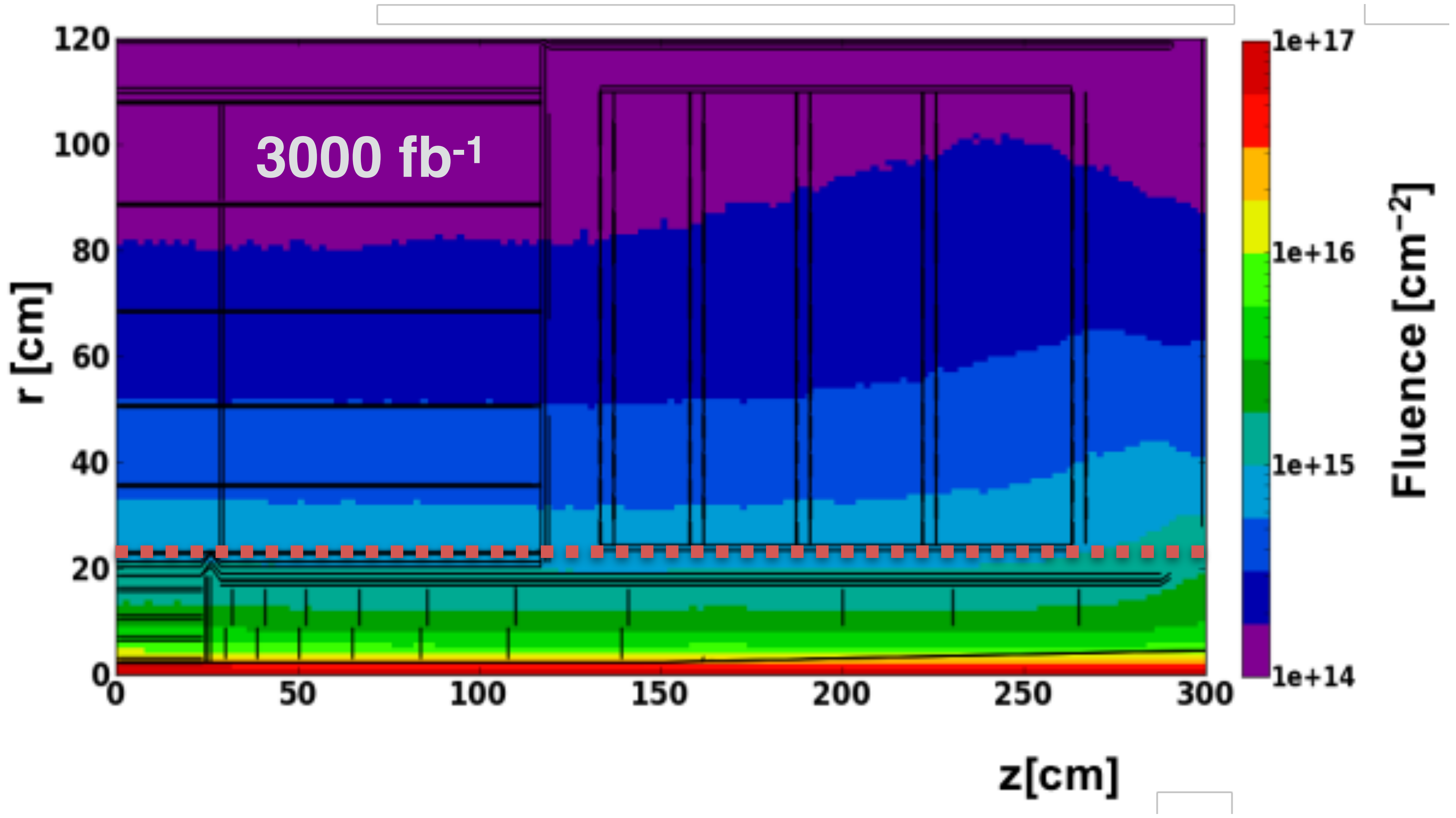


- During LS3 the accelerator will be upgraded to instantaneous peak luminosities of $5 \times 10^{34}\ cm^{-2}s^{-1}$
  - or even $7.5 \times 10^{34}\ cm^{-2}s^{-1}$ in the ultimate performance scenario
- This will allow CMS to collect 300 fb^{-1} per year and up to 3000 fb^{-1} during the accelerators projected lifetime of ten year
  - or 4500 fb^{-1} in case of the ultimate performance scenario
  - unprecedented radiation levels of up to 1.1×10^{15} neq x cm^{-2}

Introduction - Limitations of the Current Tracker I

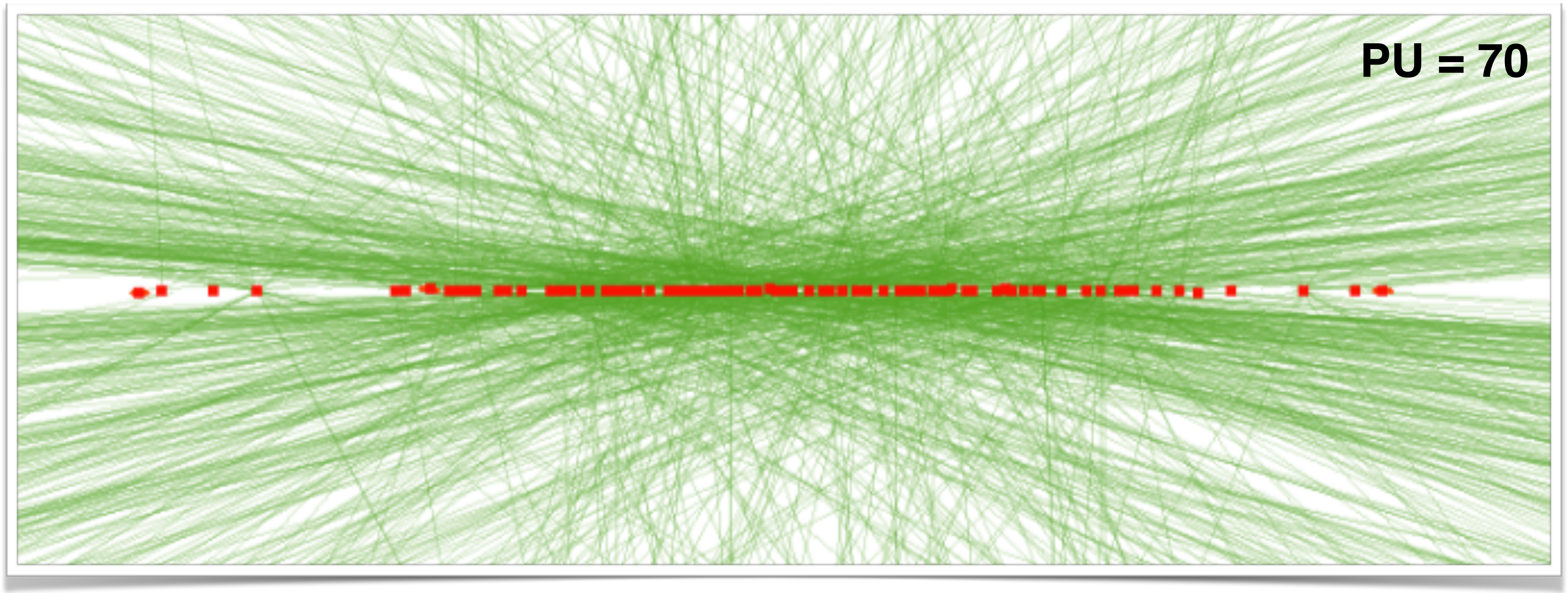




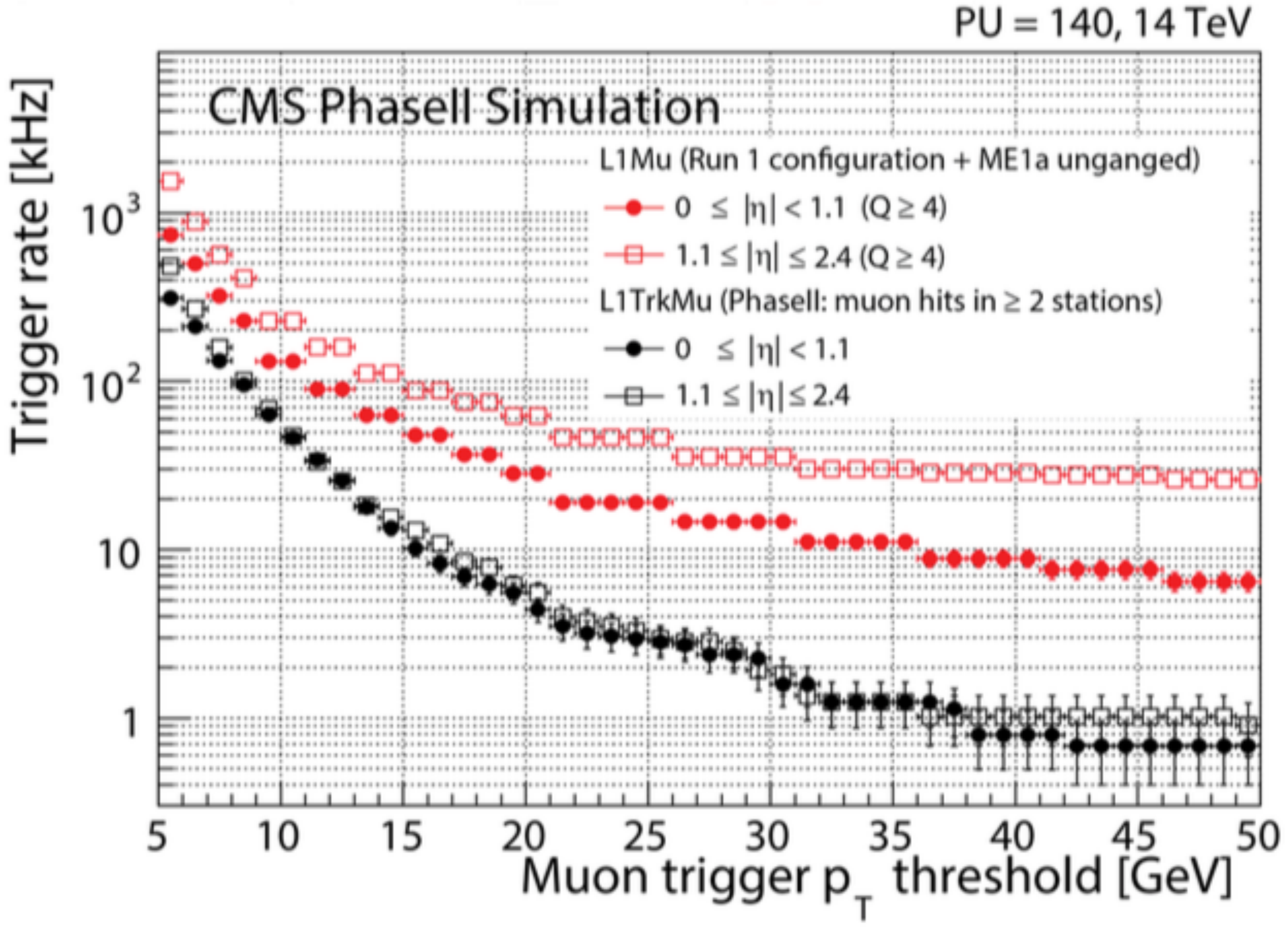


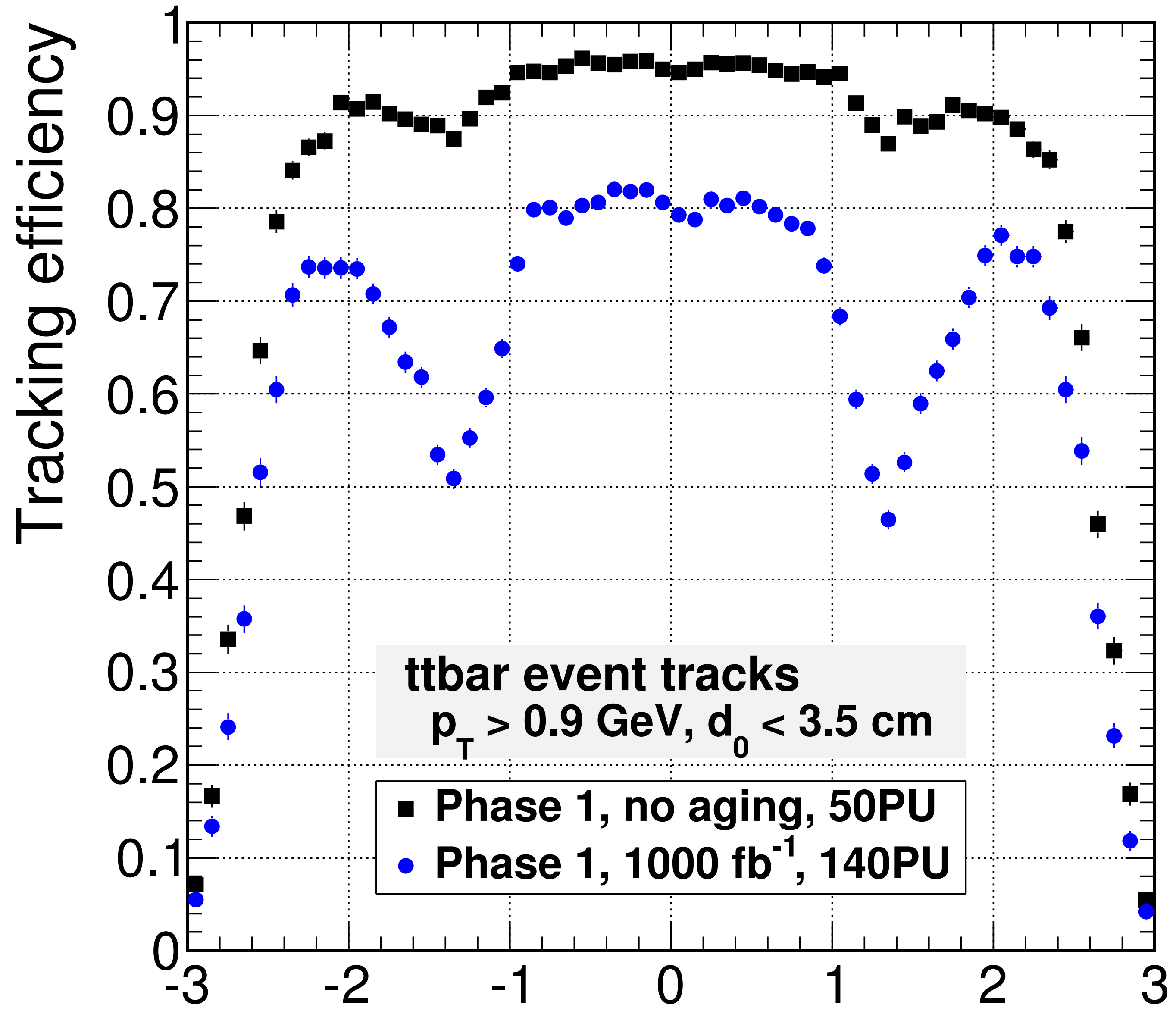
- Current tracker was designed for ~500 fb^{-1}
- Replacement of tracker every other year is not at all feasible
- A new more radiation tolerant tracker is needed

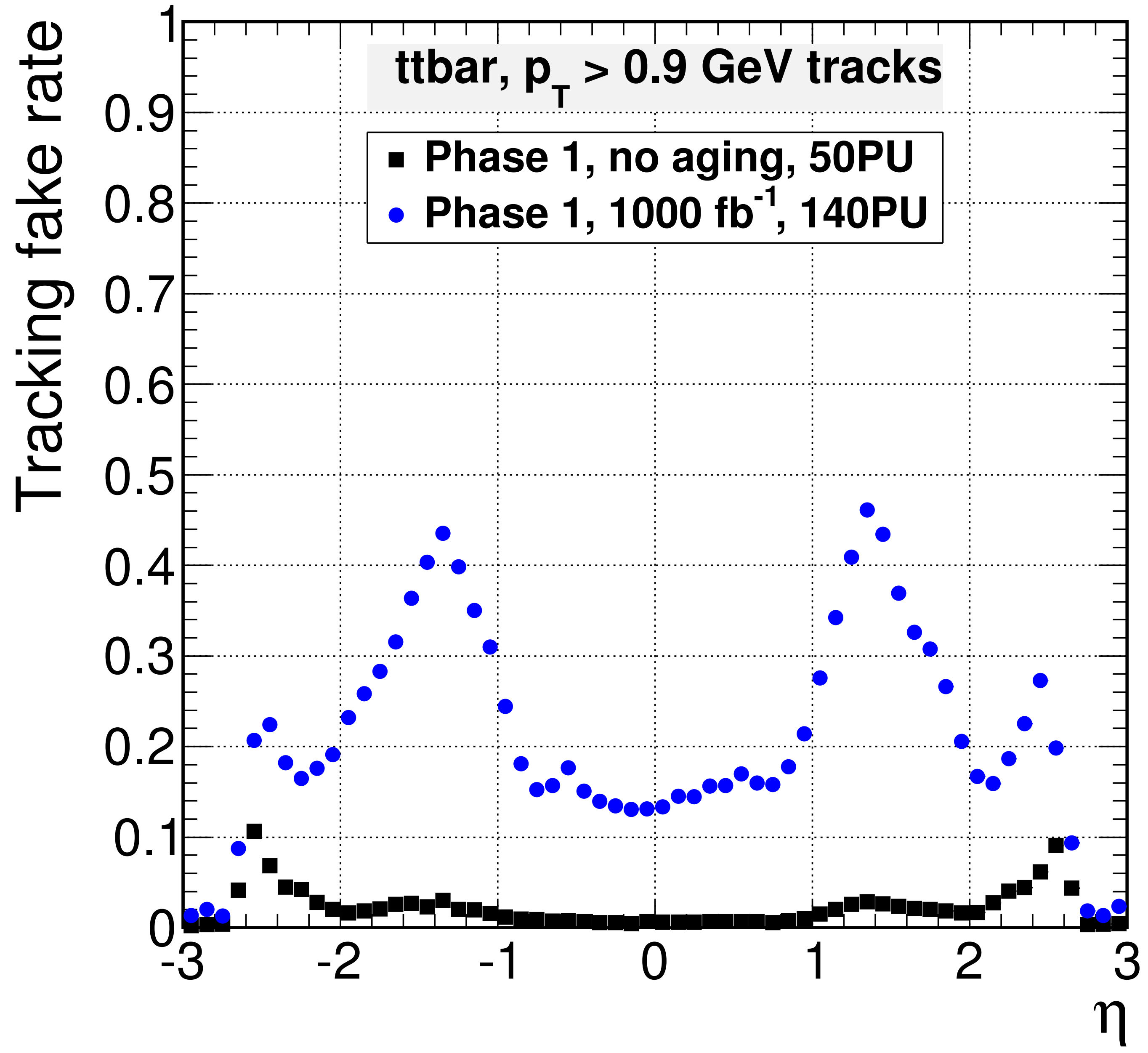
Introduction - Limitations of the Current Tracker II



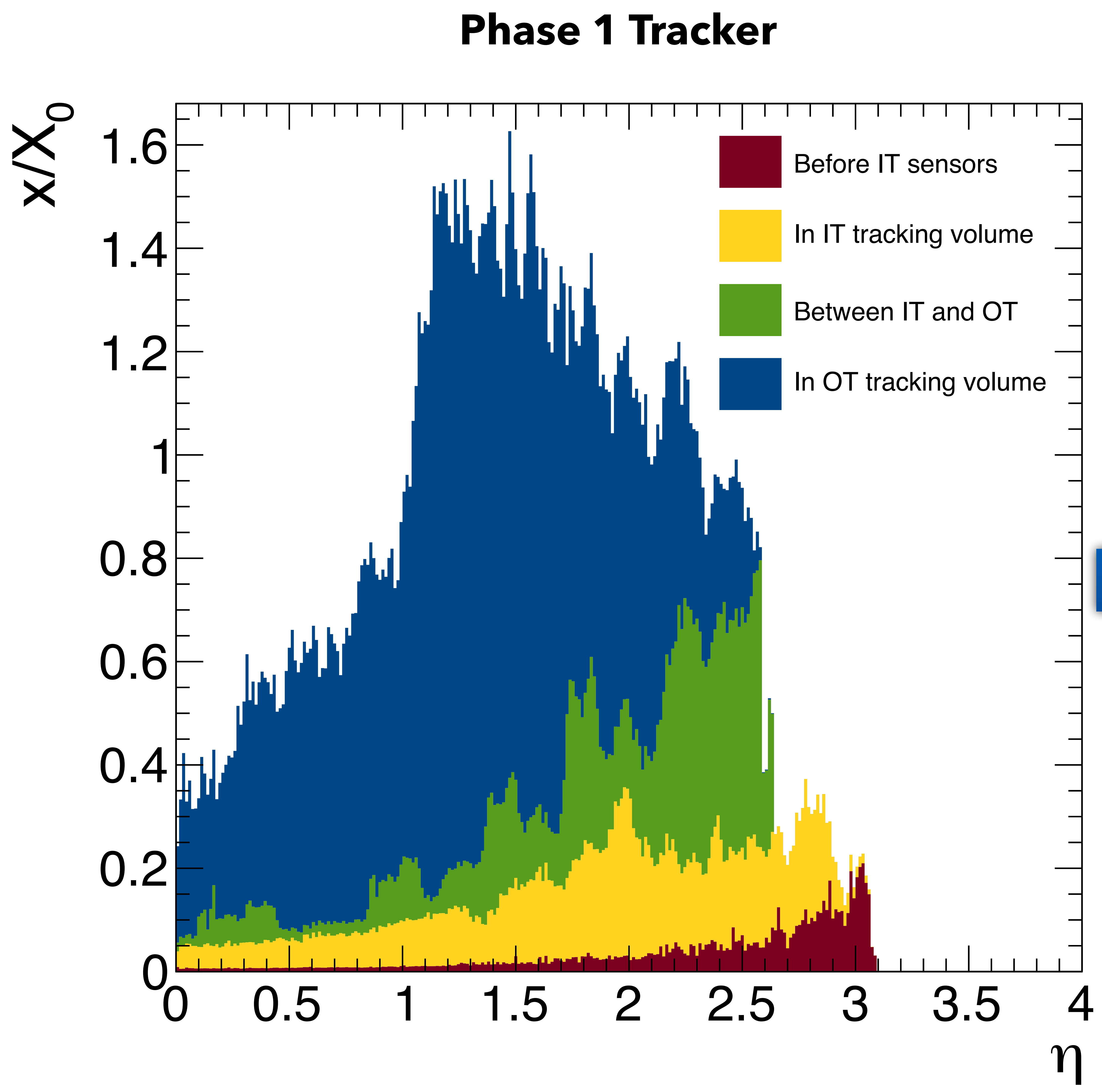
- New tracker must also provide high tracking efficiency under high pile-up conditions
- Information from tracker will be used in trigger system

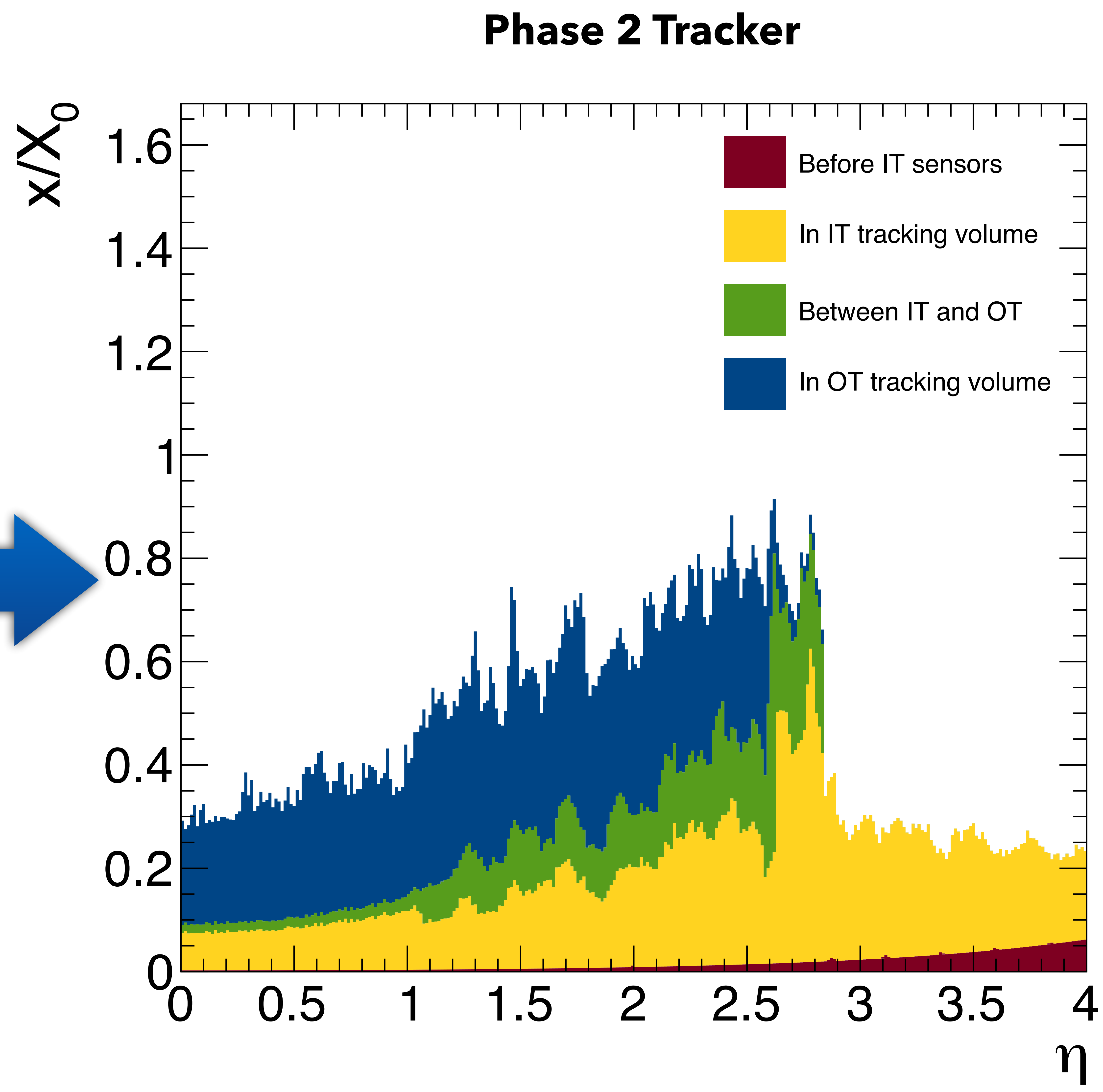






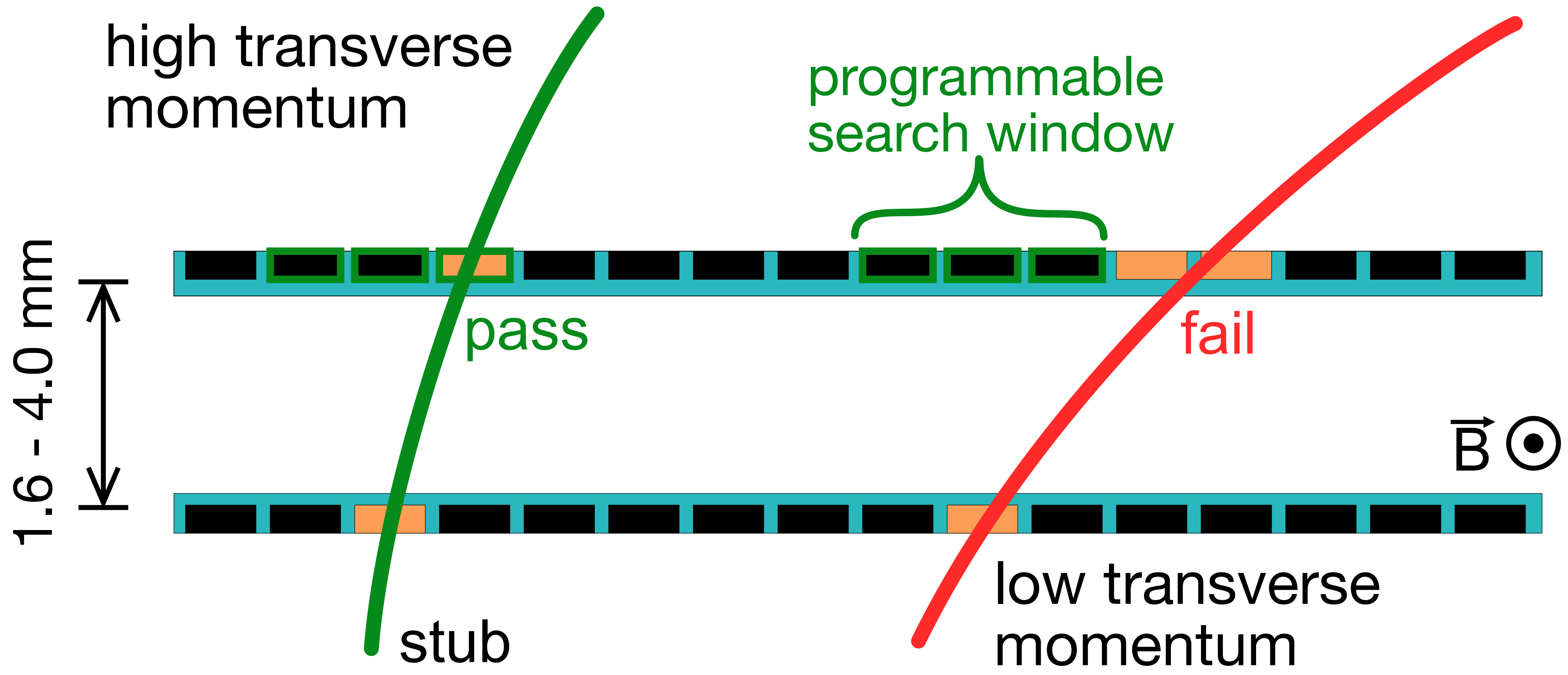
Introduction - Limitations of the Current Tracker III

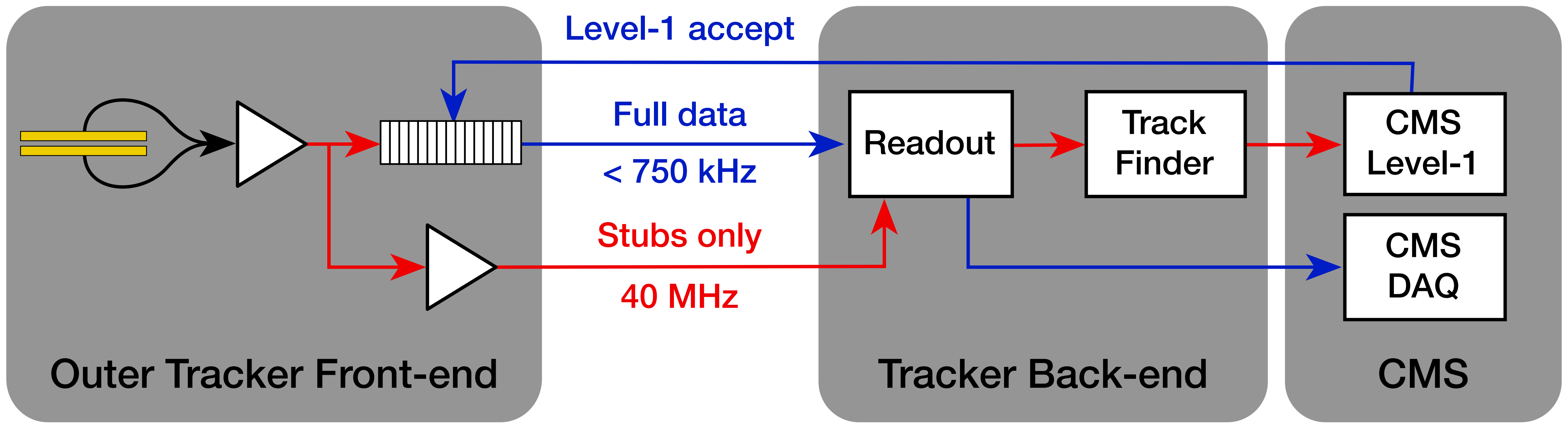




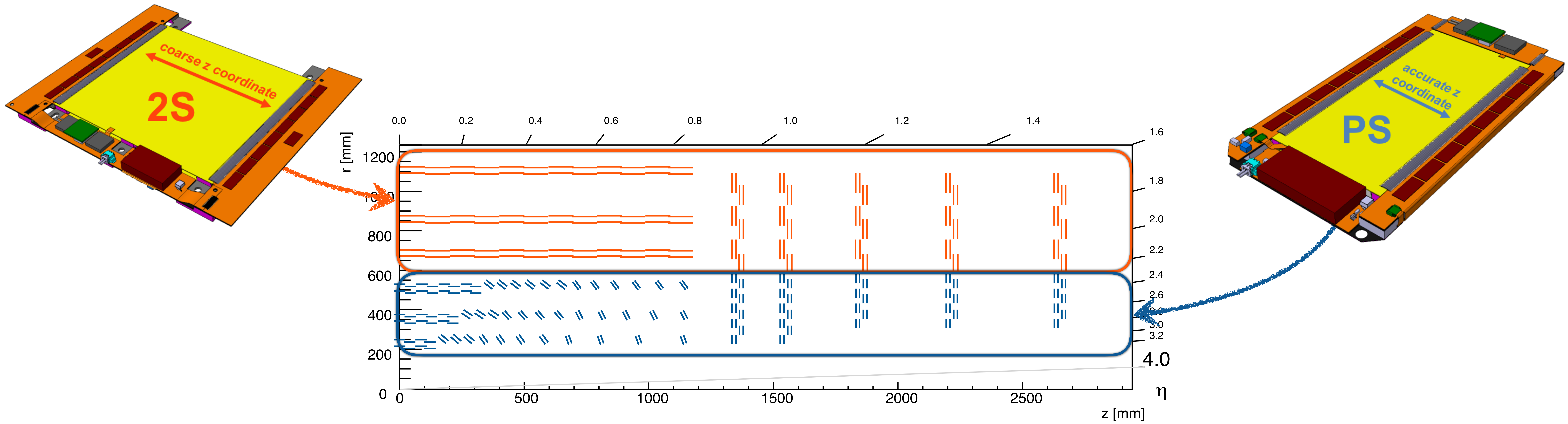
Module Concept of the new Tracker

- modules will have on-board pT discrimination
  - signals from two closely spaced sensors are correlated
  - exploit strong magnetic field for local pT measurement
  - local rejection of low-pT tracks to minimise data volume
- detector modules provide Level-1 and readout data at the same time
  - the whole tracker sends trigger data („stubs“) at each bunch crossing (40 MHz)
  - readout data up to 750 kHz
- „stubs“ are used to form Level-1 tracks
- cooling via evaporative CO_2
  - sensors at T ≤ -20 °C
- integrated at module level:
  - low power giga-bit transceiver (LP-GBT) as data link
  - powering via DC-DC conversion
- two different module types
  - different sensor spacings are treated as ‚variants'
  - requires optimisation of only two designs

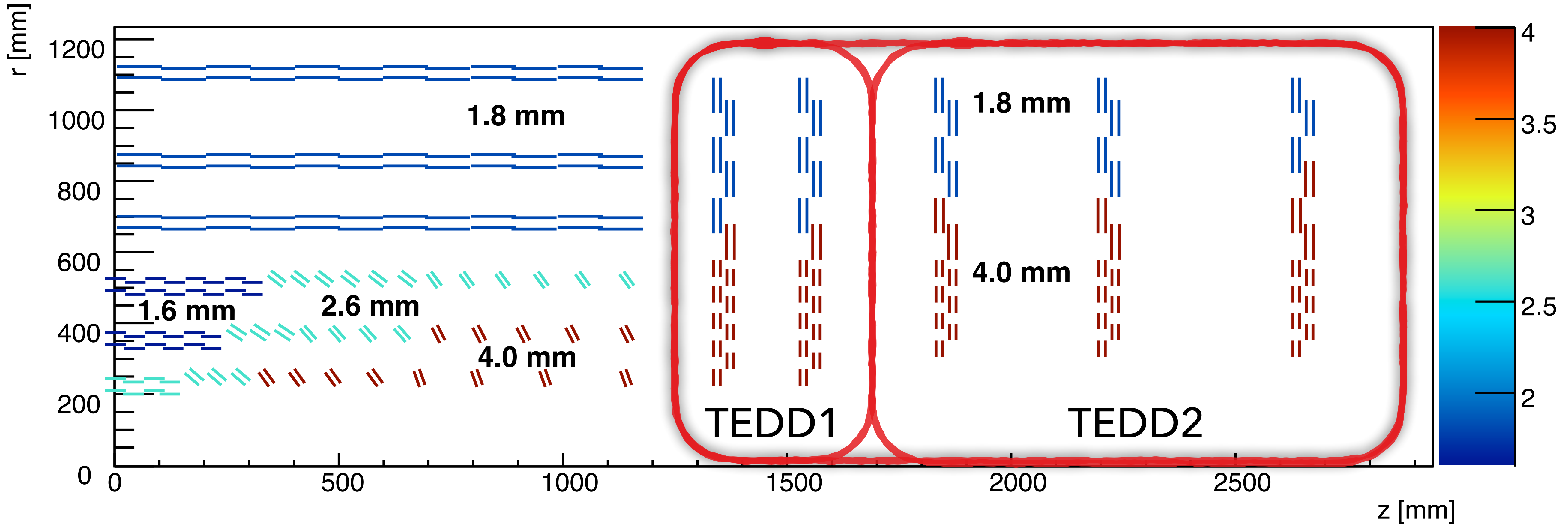




Tracker Layout



- layout with 6 barrel layers and 5 end cap double-disks
  - pixelated modules at r < 60 cm - stack of pixel and strip sensor (PS)
  - stack of two strip sensors at r > 60 cm (2S)
- PS modules
  - sensor spacings: 1.6 mm, 2.6 mm and 4 mm
- 2S modules
  - sensor spacings: 1.8 mm and 4 mm

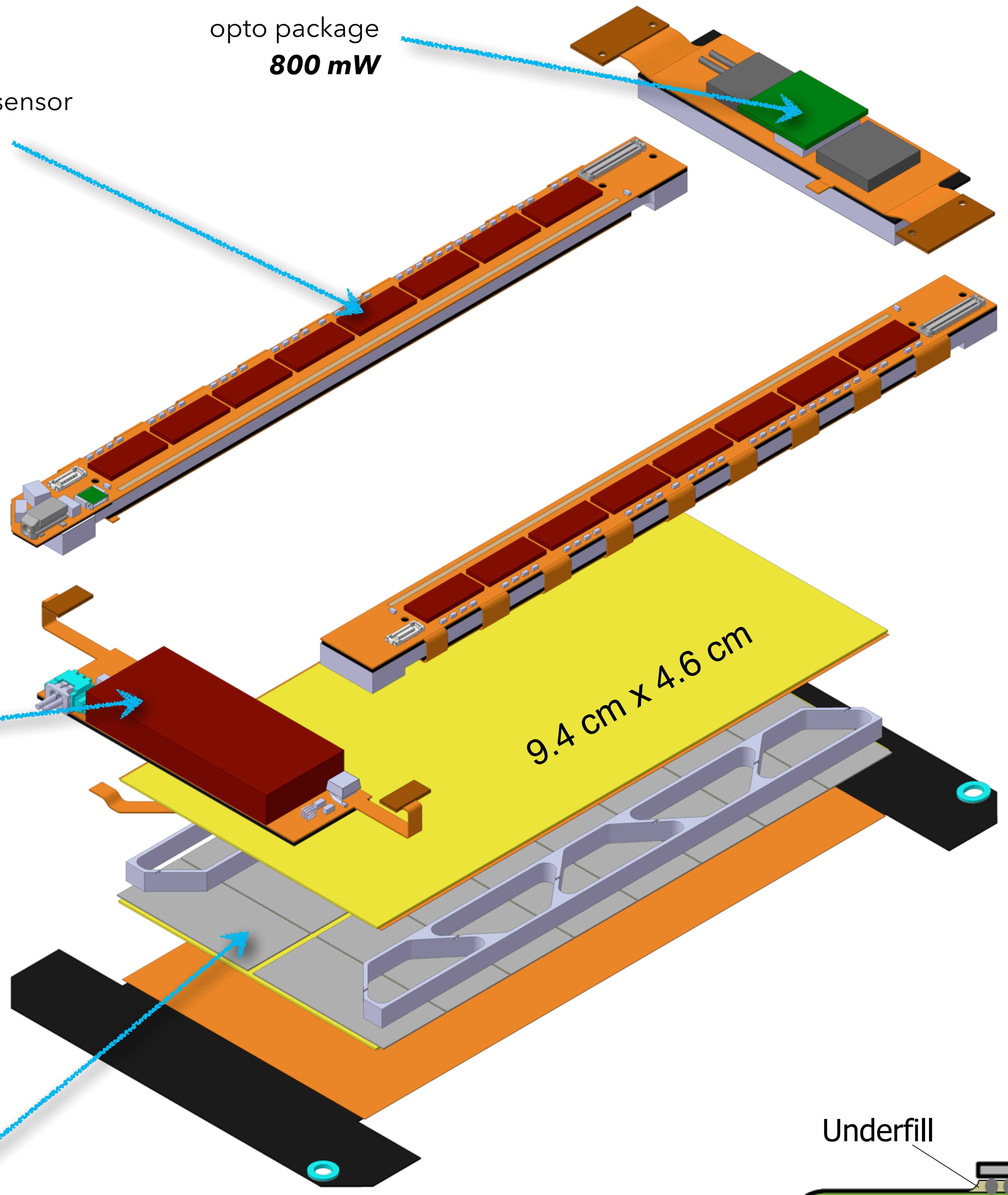


PS Module Assembly

SSA
- **Single Strip Asic**
- handles signals from strip sensor
- transfers data to pixel chip

500 mW (total)

opto package
800 mW

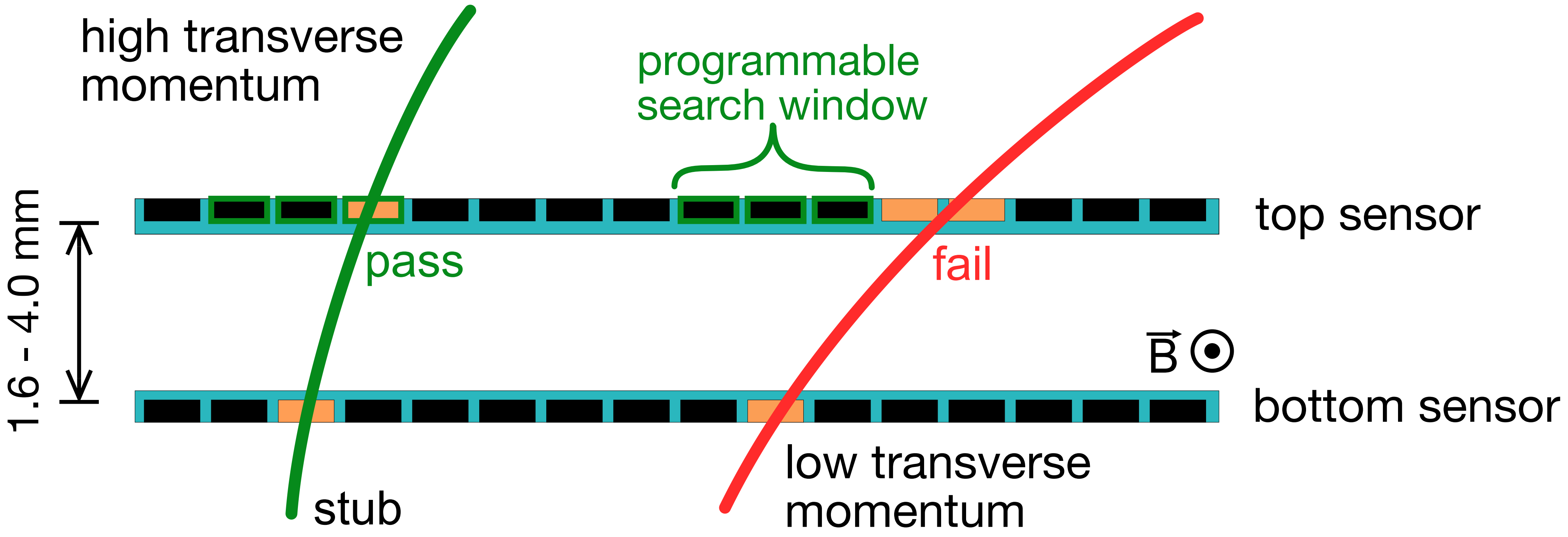


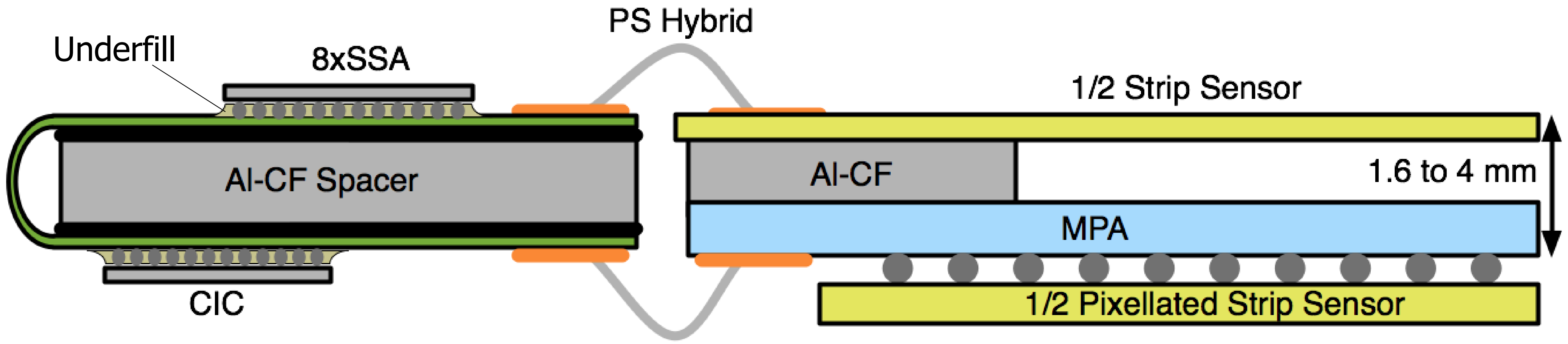
power converter
~2000 mW

MPA
- **Macro Pixel Asic**
- pixel size: 1400 x 100 µm
- correlates signals from both sensors

3000 mW (total)

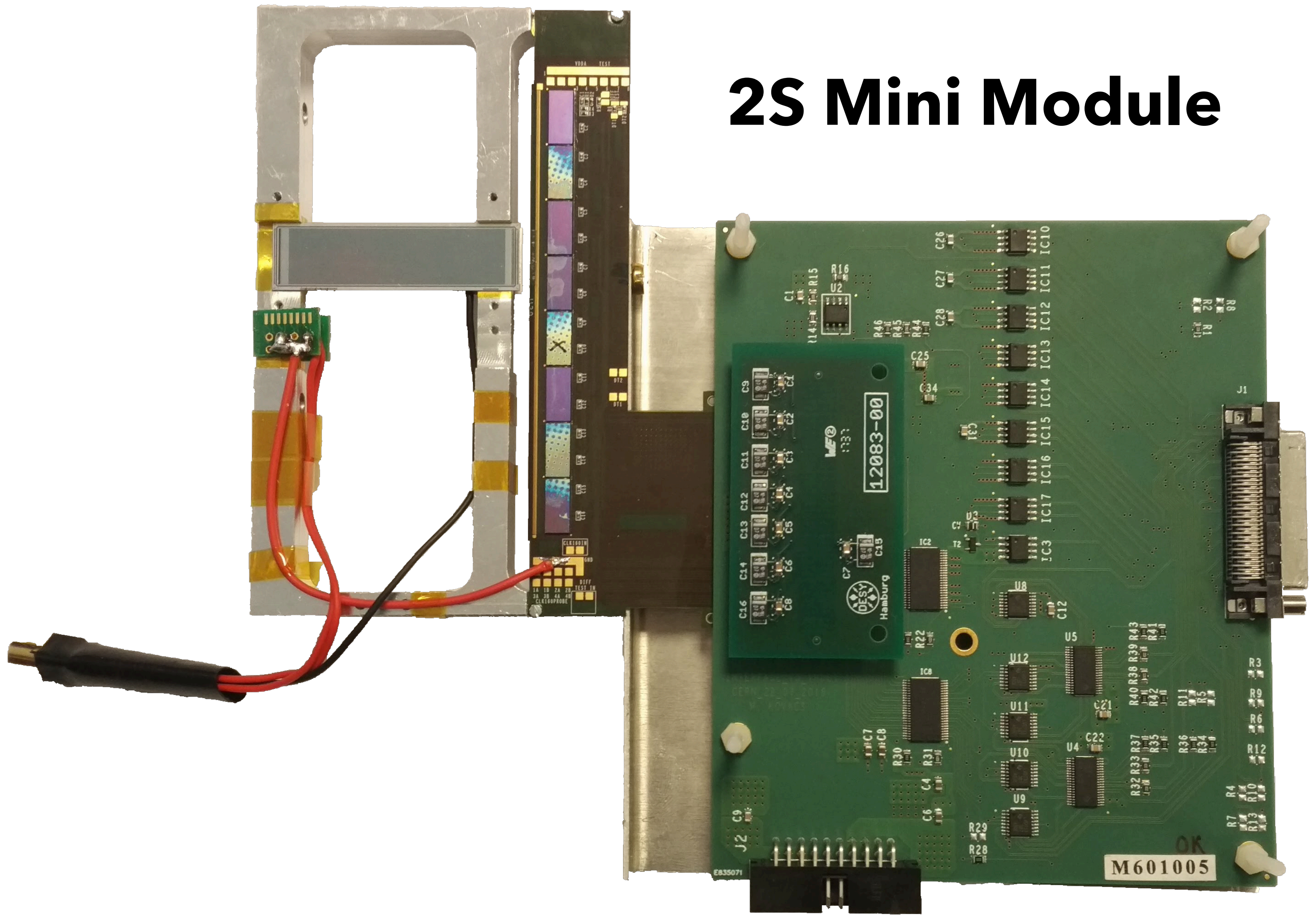
- MPAs and sensors are cooled through base plate
  - requires a large-area glue joint between pixel sensor and base plate
- sensors are supported by spacer elements
  - either Al-CF or AlN
  - coefficient of thermal expansion match to Silicon
- no or minimal thermal stress when module is operated at low temperature

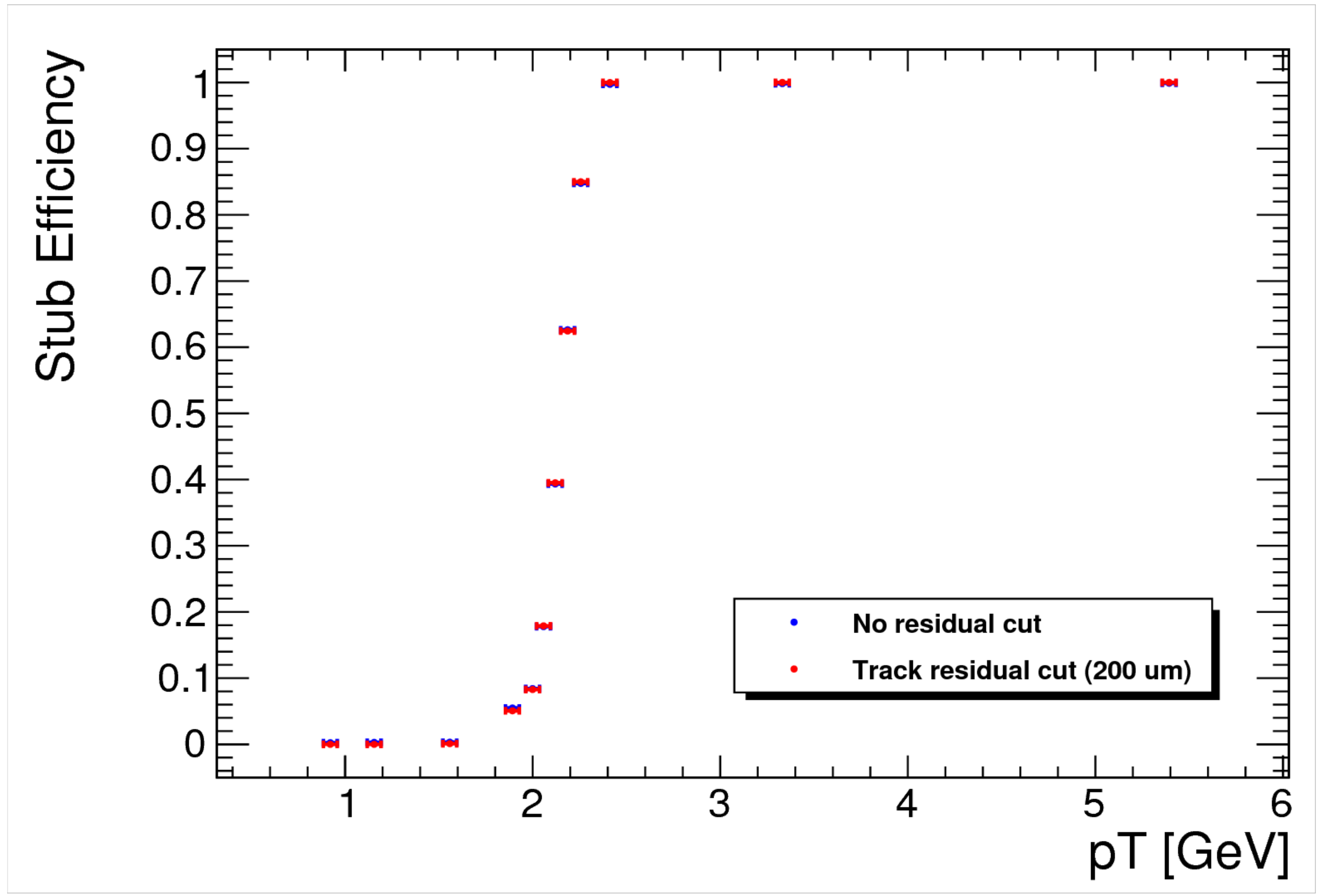




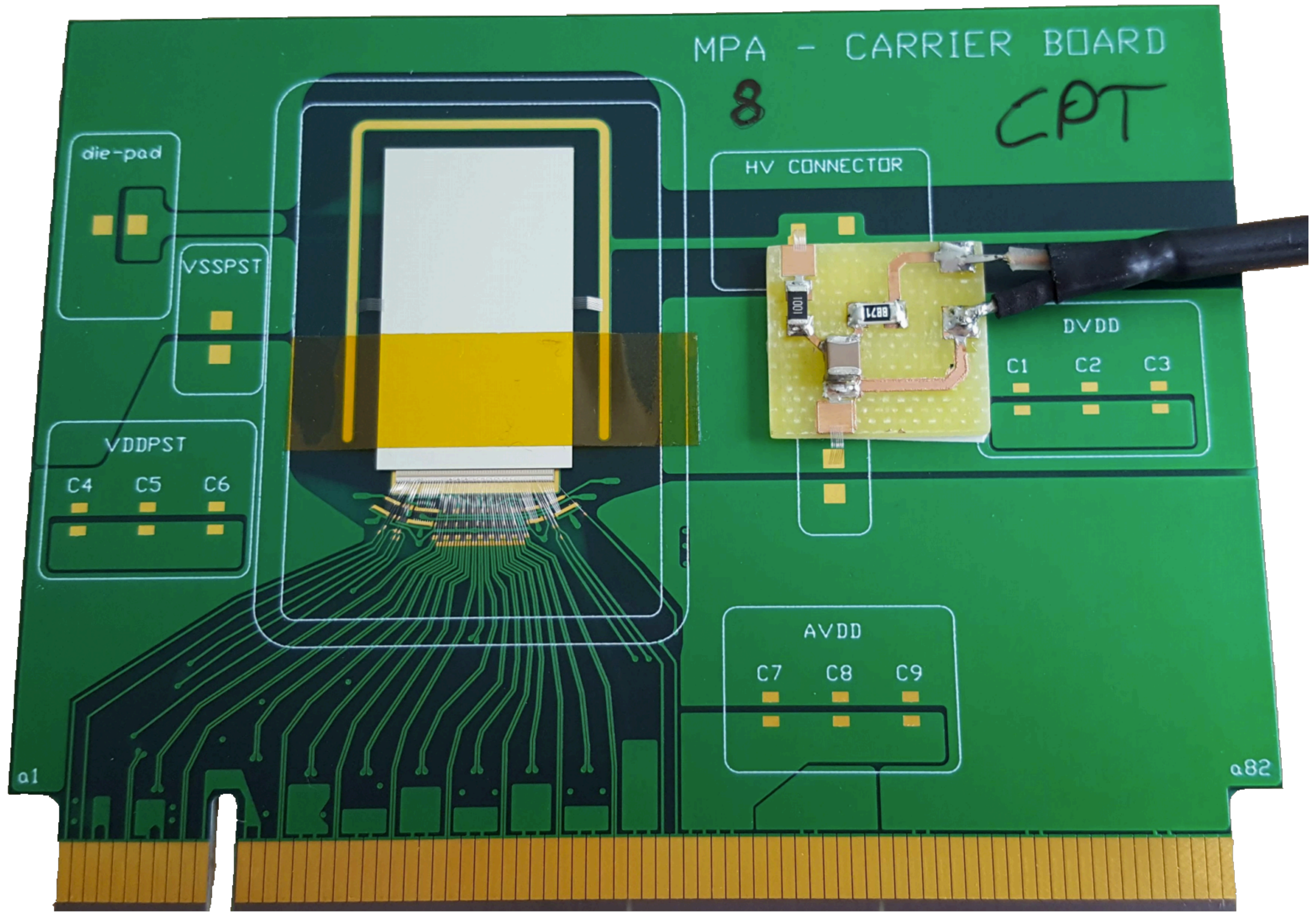
Test Beams

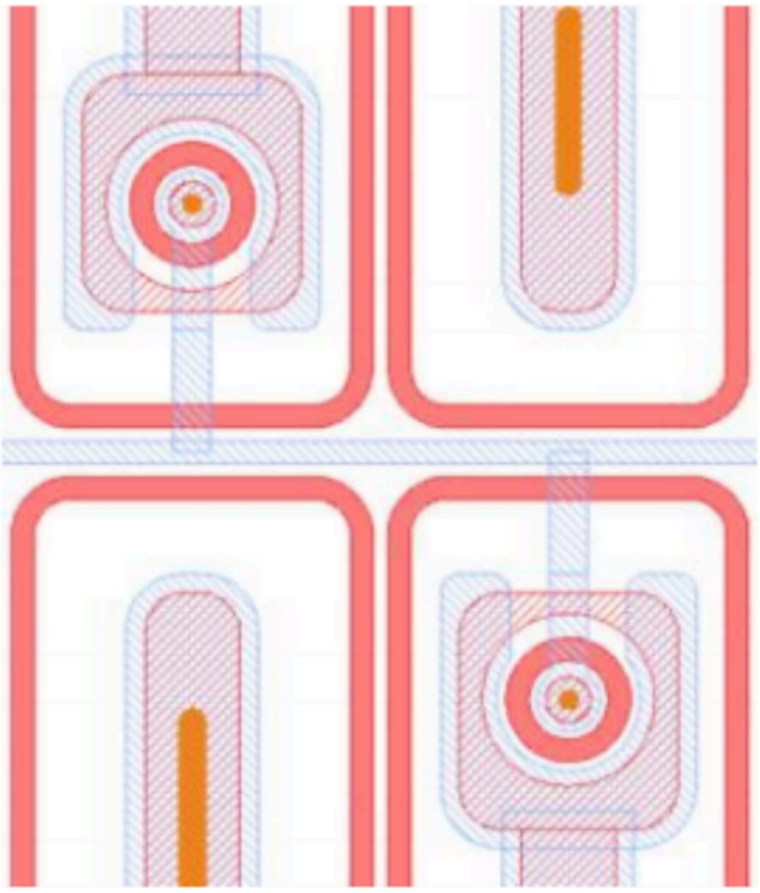
2S Mini Module

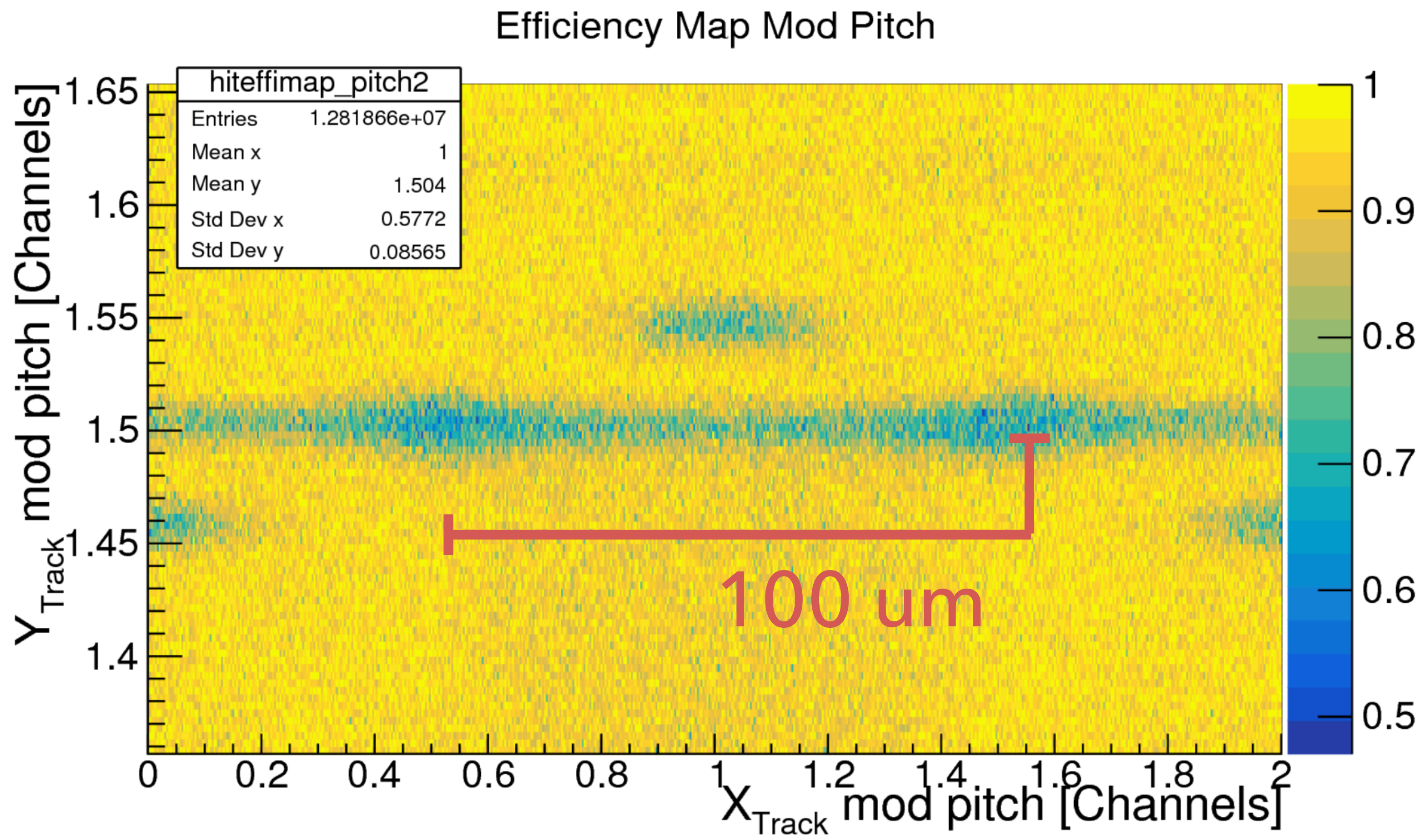




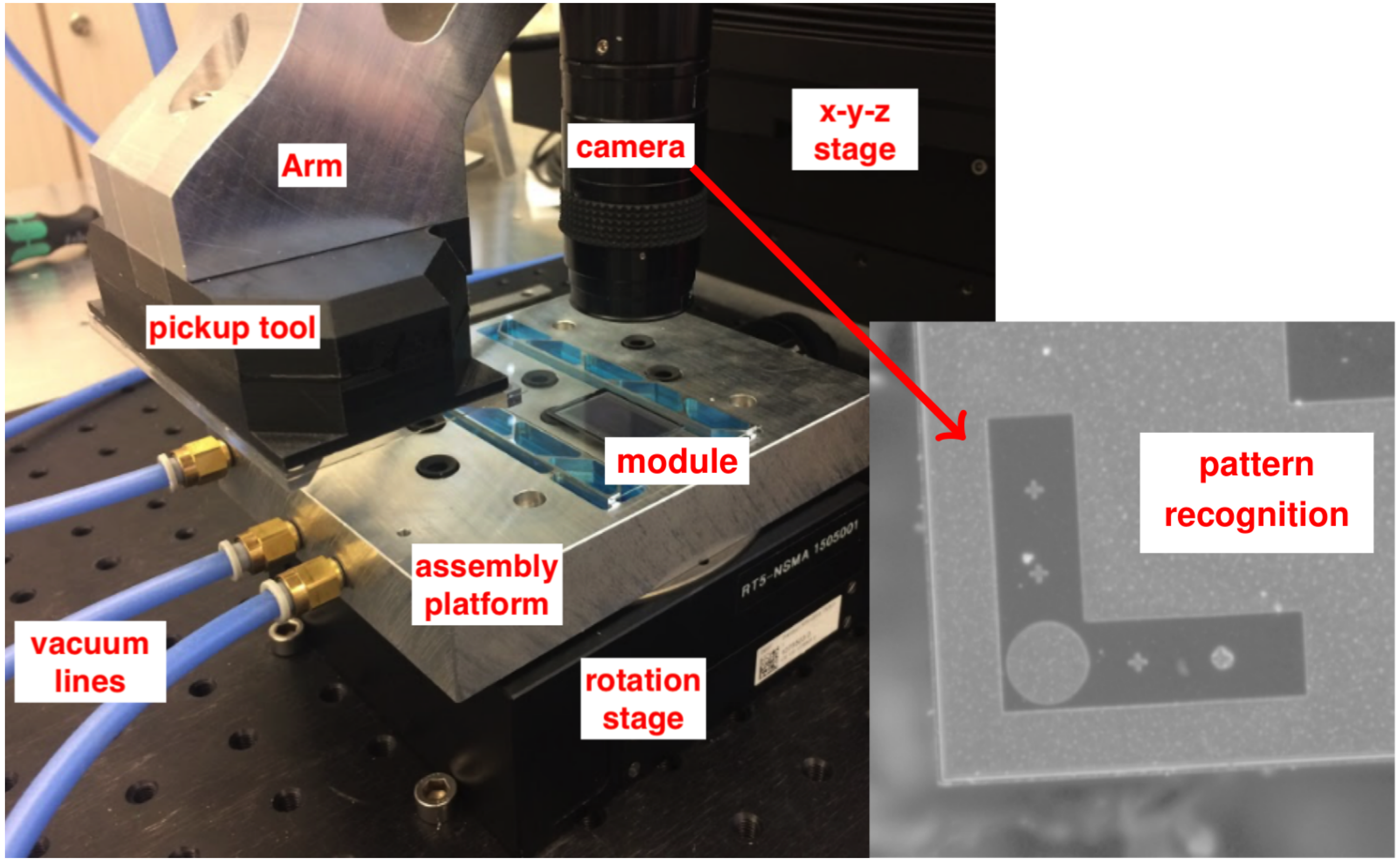
Single-Chip MaPSA





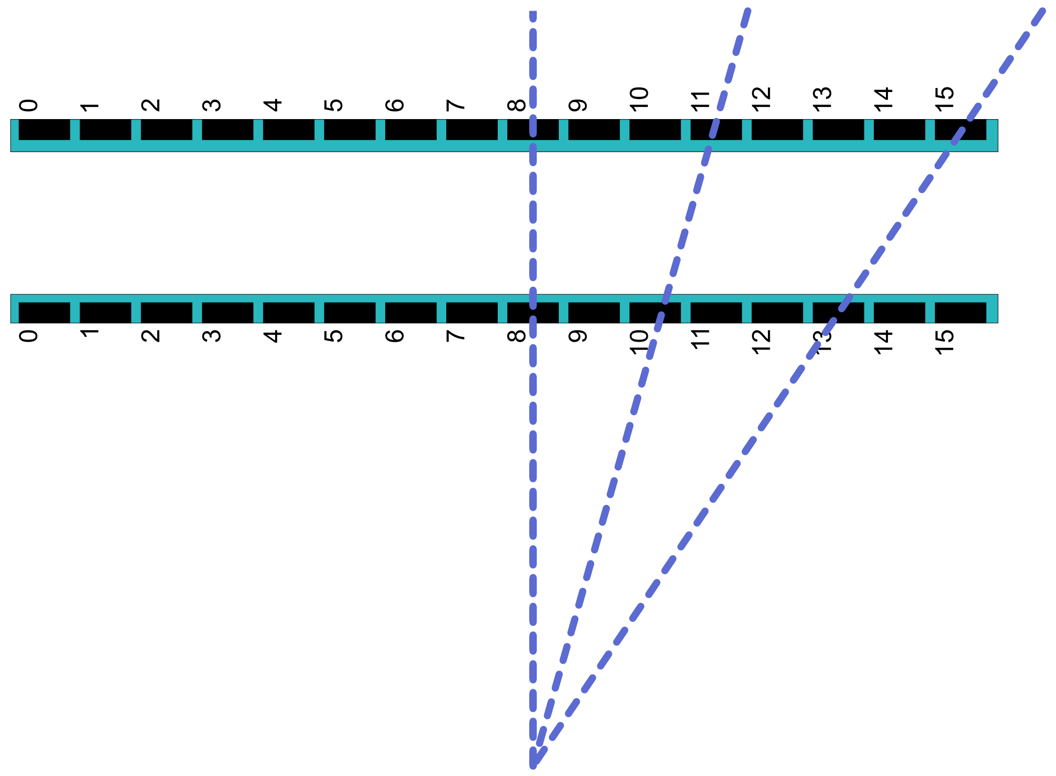


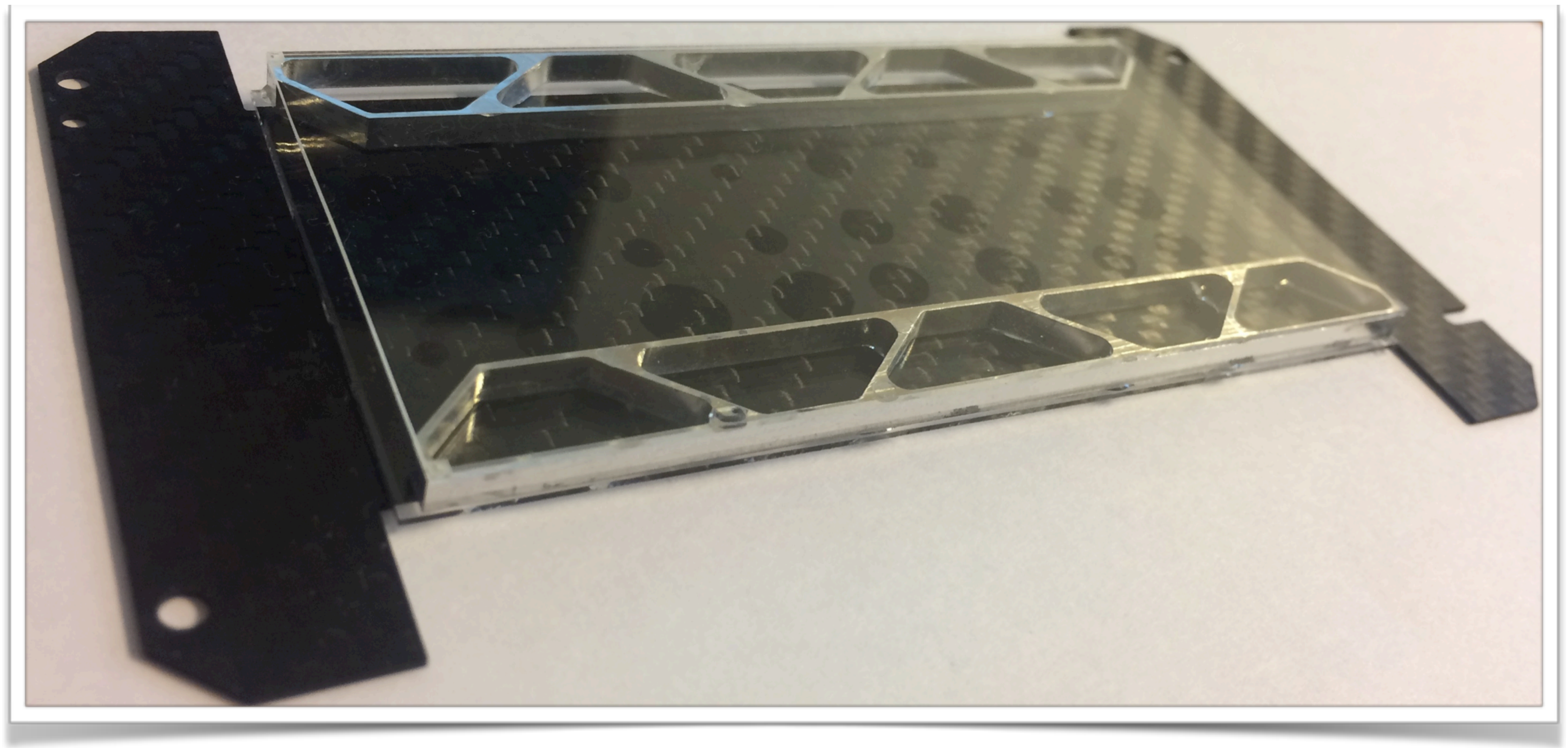
PS Module Assembly



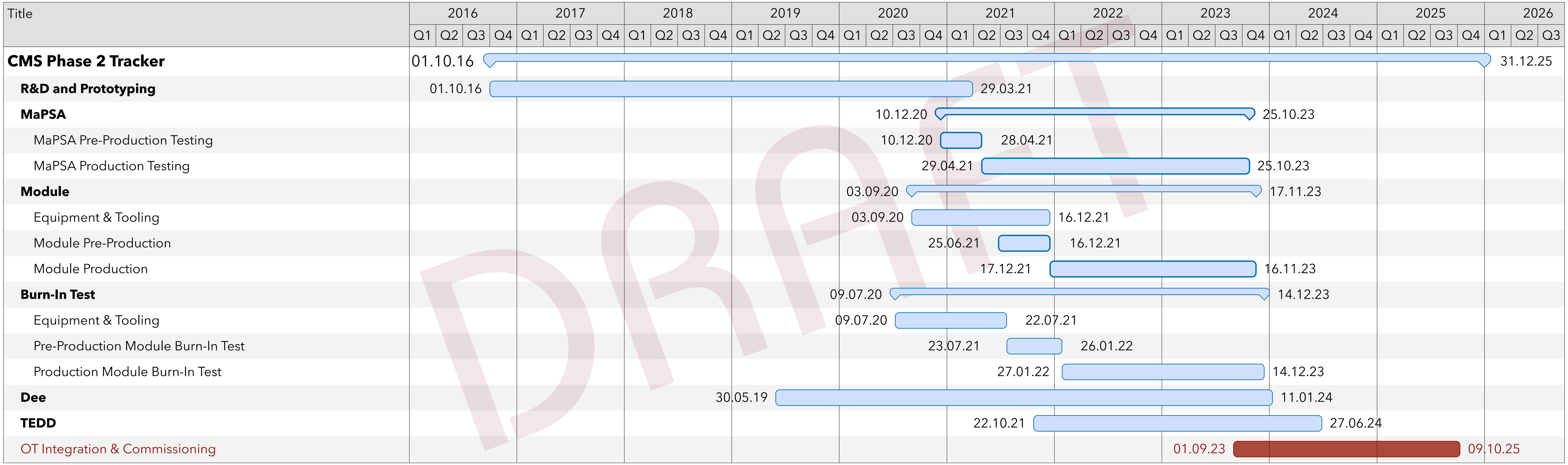
- Sensor sandwich is built on a robotic stage
  - relative alignment of object is measured with microscope camera and pattern recognition
  - assembly precision does not rely on cut edges of sensors
- Assembly of hybrids is done manually with jigs

- On-module pT discrimination requires precise sensor to sensor alignment
  - rotational misalignment < 20 µm
    - offline correction not possible ➟ already during module assembly
  - shift can be corrected for on the module





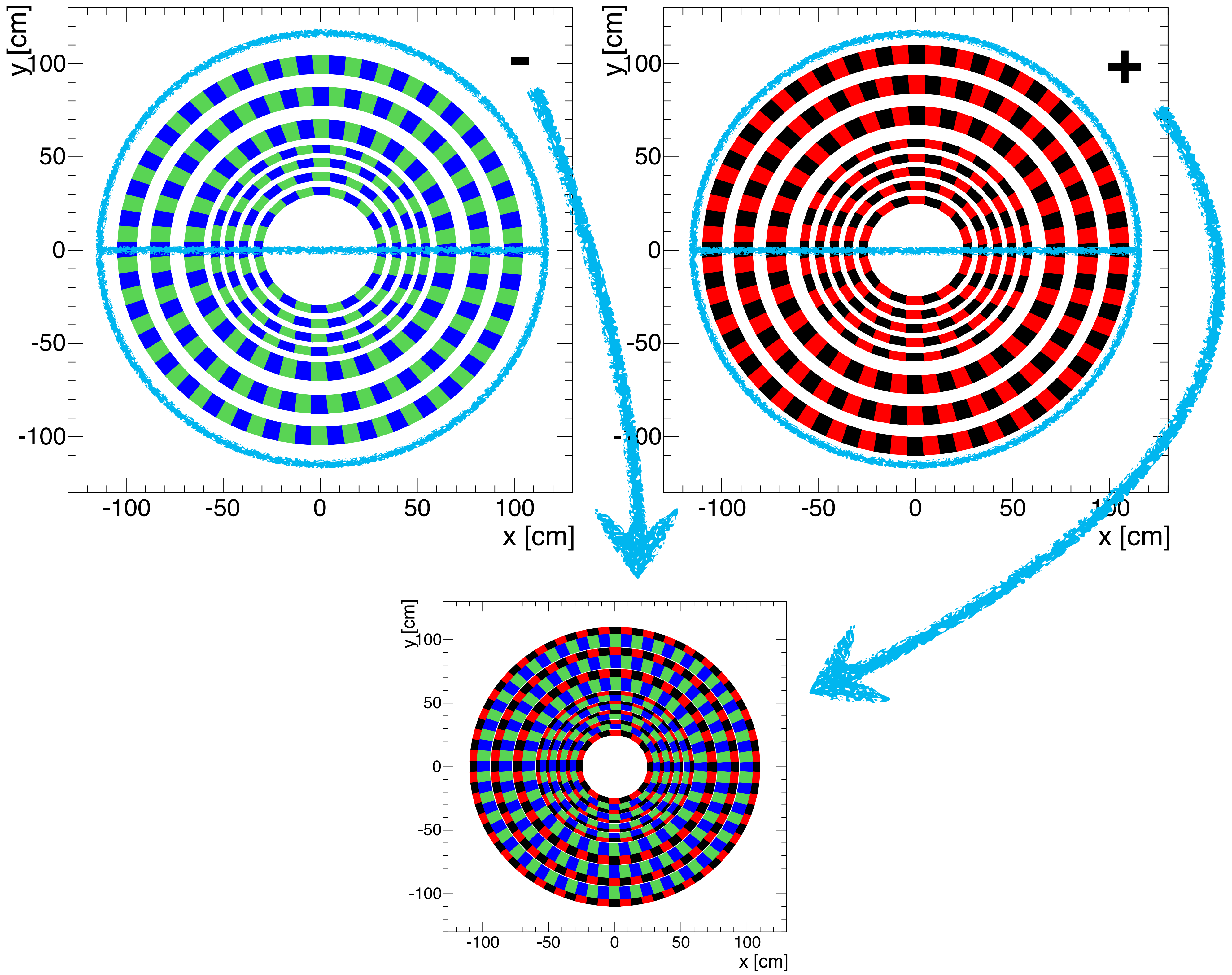
Project Schedule - Modules

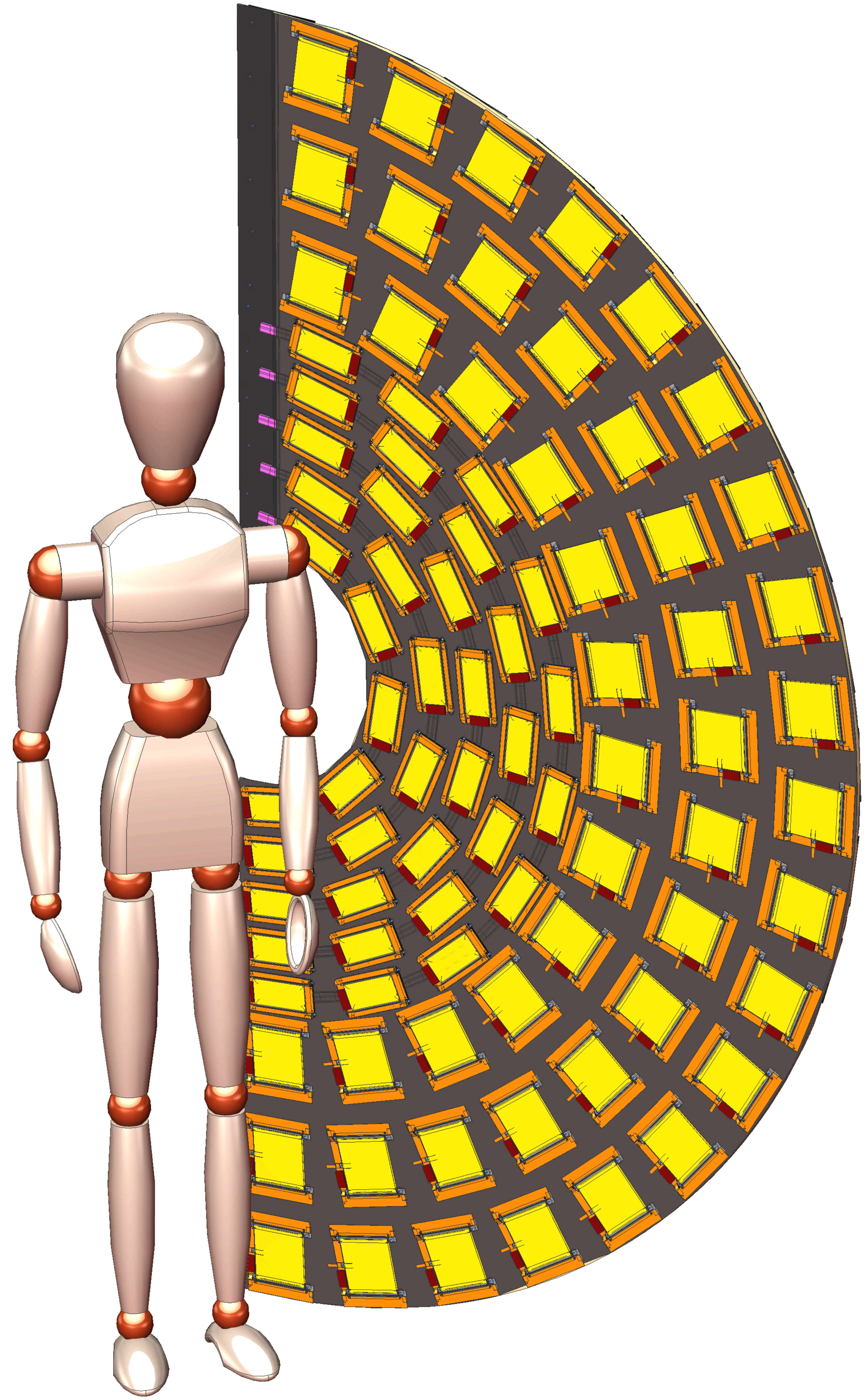


- DESY will produce O(1000) PS modules
  - schedule foresees almost two years
- MaPSAs (**Ma**cro-**P**ixel **S**ub-**A**ssemblies) will be fully tested in industry
  - reception tests at DESY prior to module assembly
- Still plenty of time for R&D and prototyping
  - start of pre-production mid 2021

- All modules will undergo burn-in tests prior to integration on sub-structures
  - extensive stress test at low temperatures
  - will be the only long-term test of modules at cold
    - modules passing burn-in test will end up in the detector
  - DESY will also perform burn-in test for modules produced at KIT and in Aachen
    - KIT: 2000 2S modules
    - Aachen: 1000 2S modules

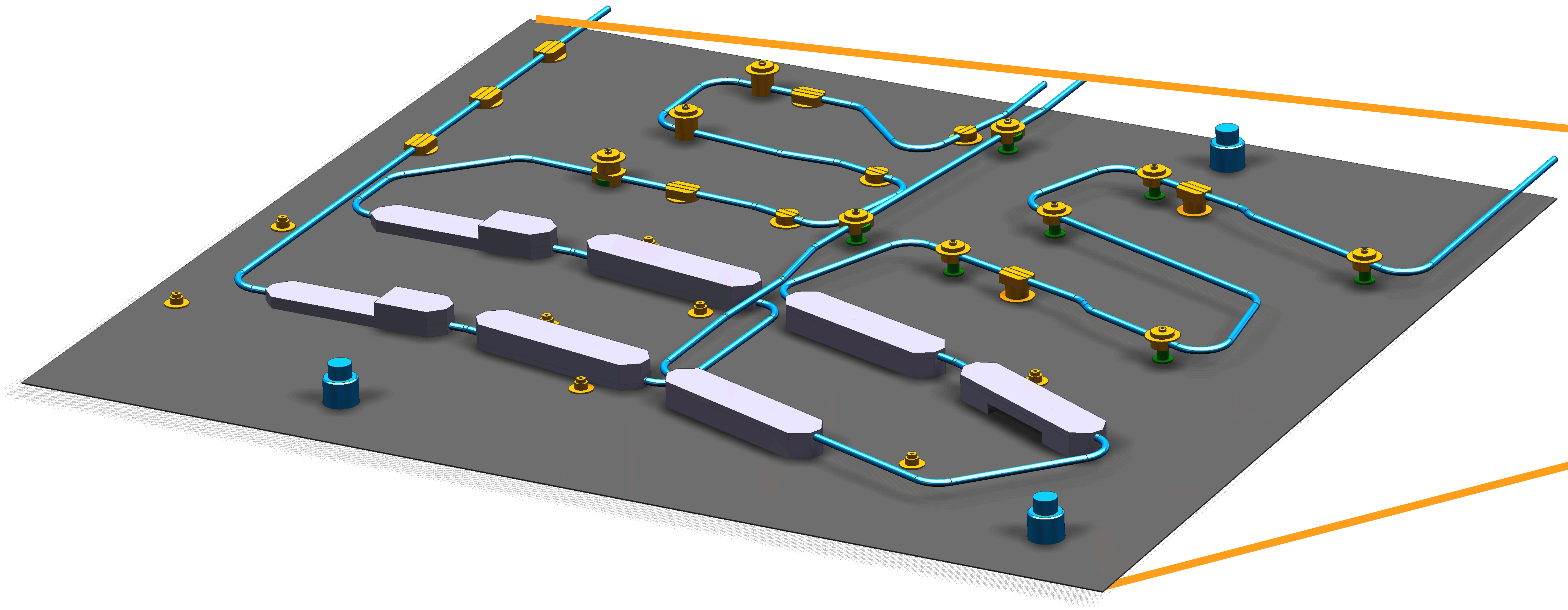
TEDD Support Structure - Dee

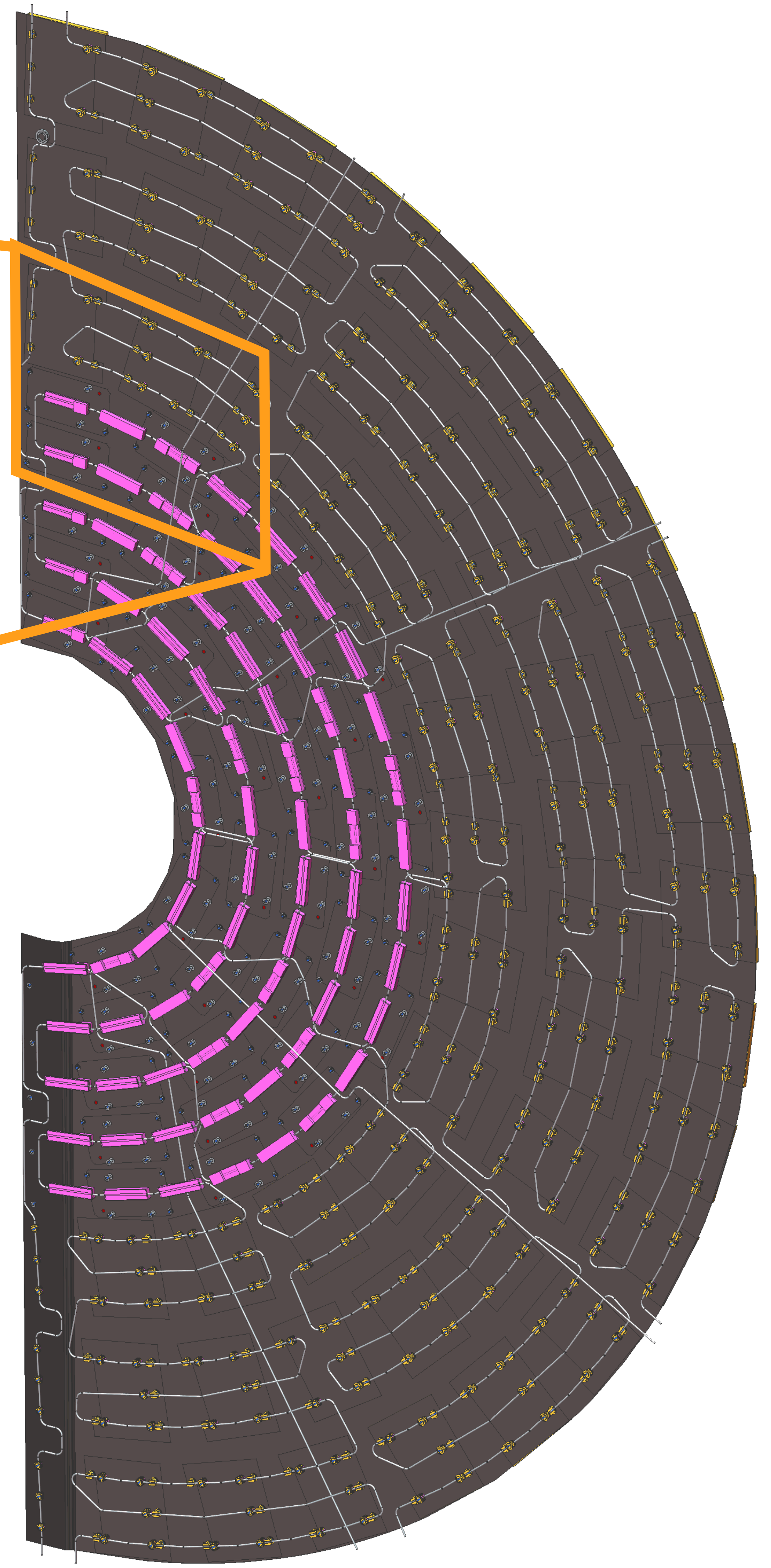




- Backbone is a carbon fibre sandwich half-disk structure (Dee)
  - ~225 cm in diameter
  - 10 mm thickness
- Modules are mounted from both sides onto structure
  - O(300 µm) positioning precision
- 20 Dees are combined to build one TEDD
  - 150 cm total length

Dee Design

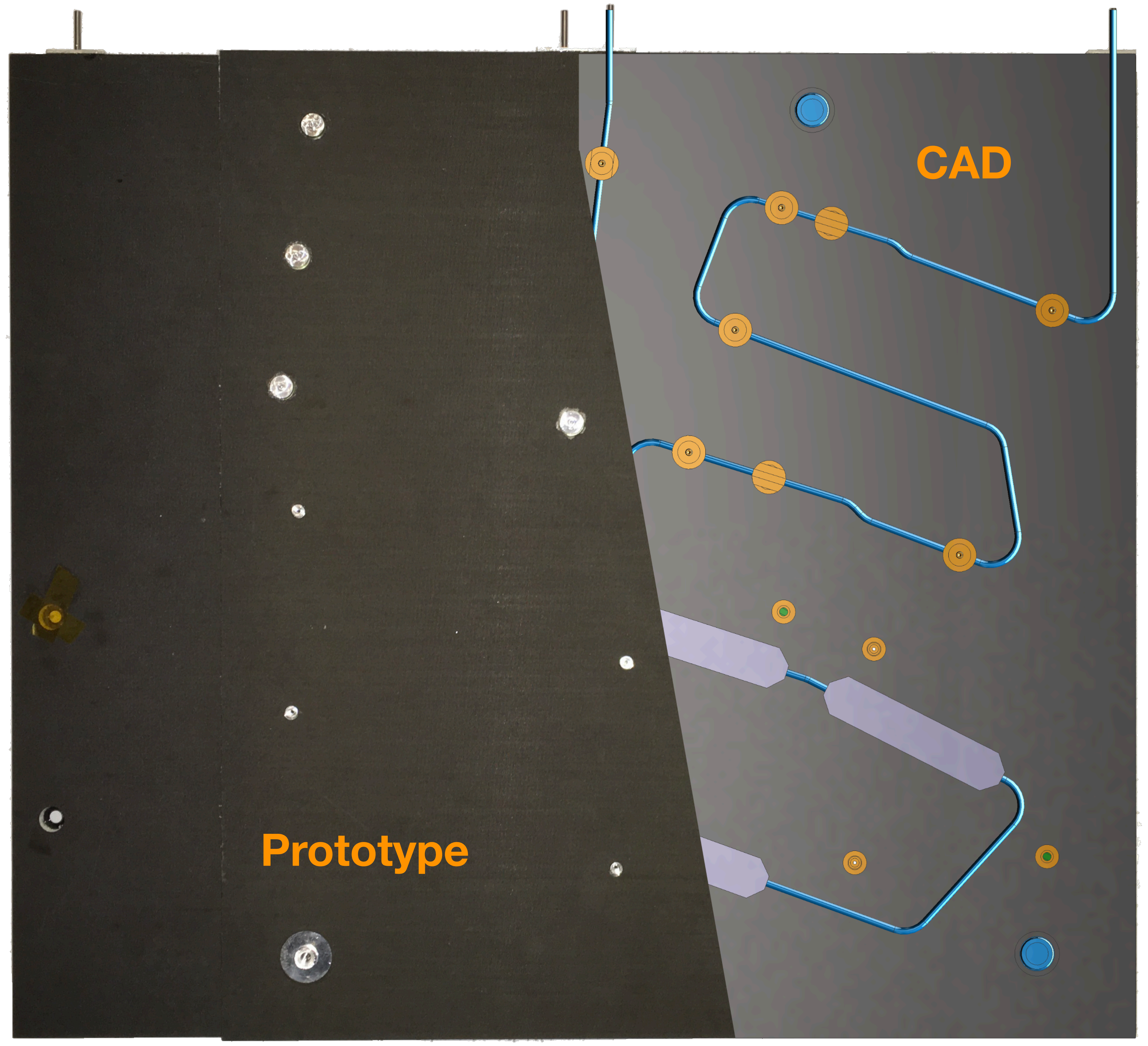


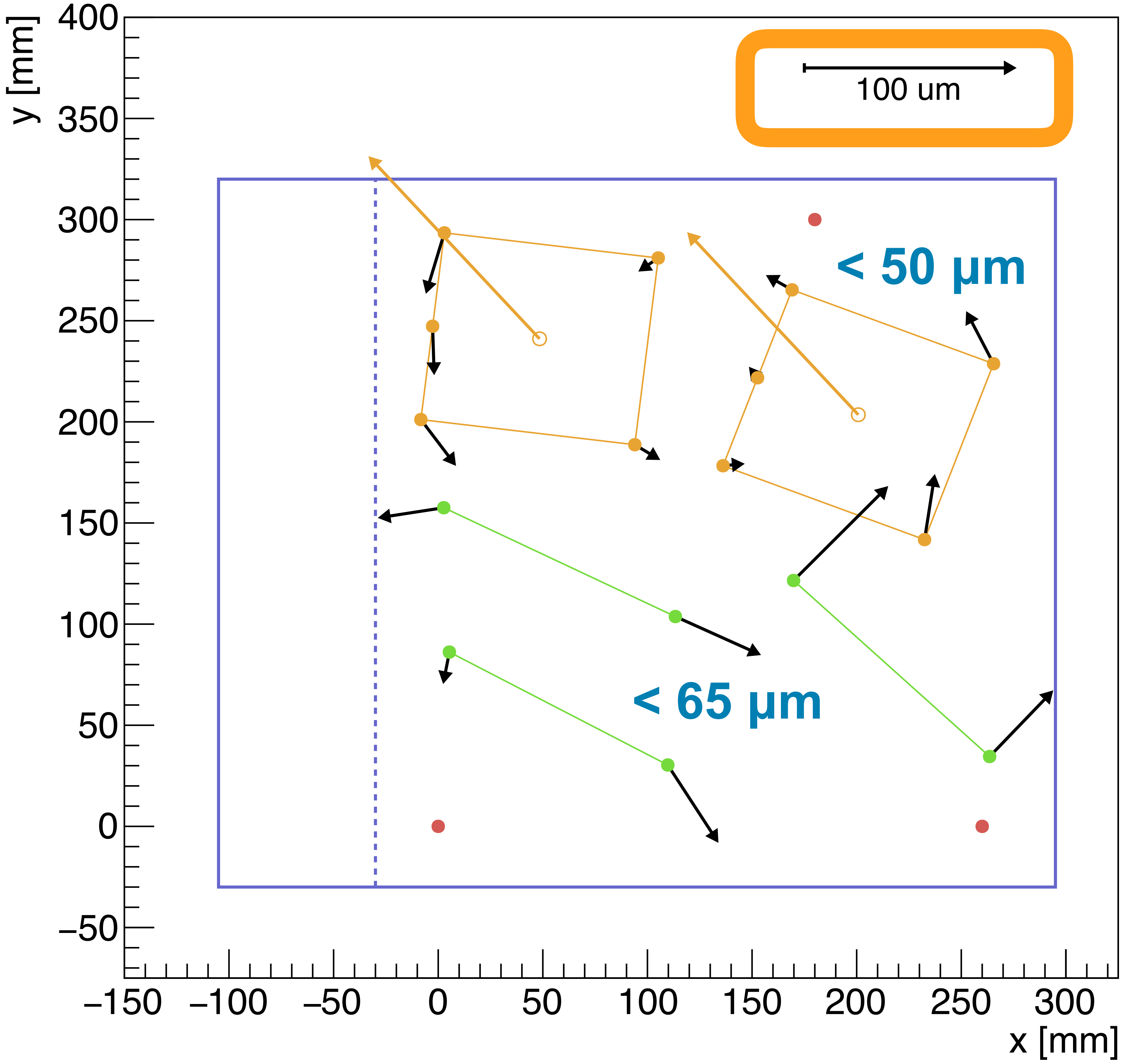


- Six cooling sectors each with ~6 m length
  - 2.2 (2.4) mm inner (outer) diameter
- Cooling pipes embedded in
  - 480 cooling and positioning inserts
  - 76 carbon foam heat spreaders spanning through the full thickness of the sandwich
- Sandwich core is a mixture of structural and Carbon foam
- 228 additional positioning inserts

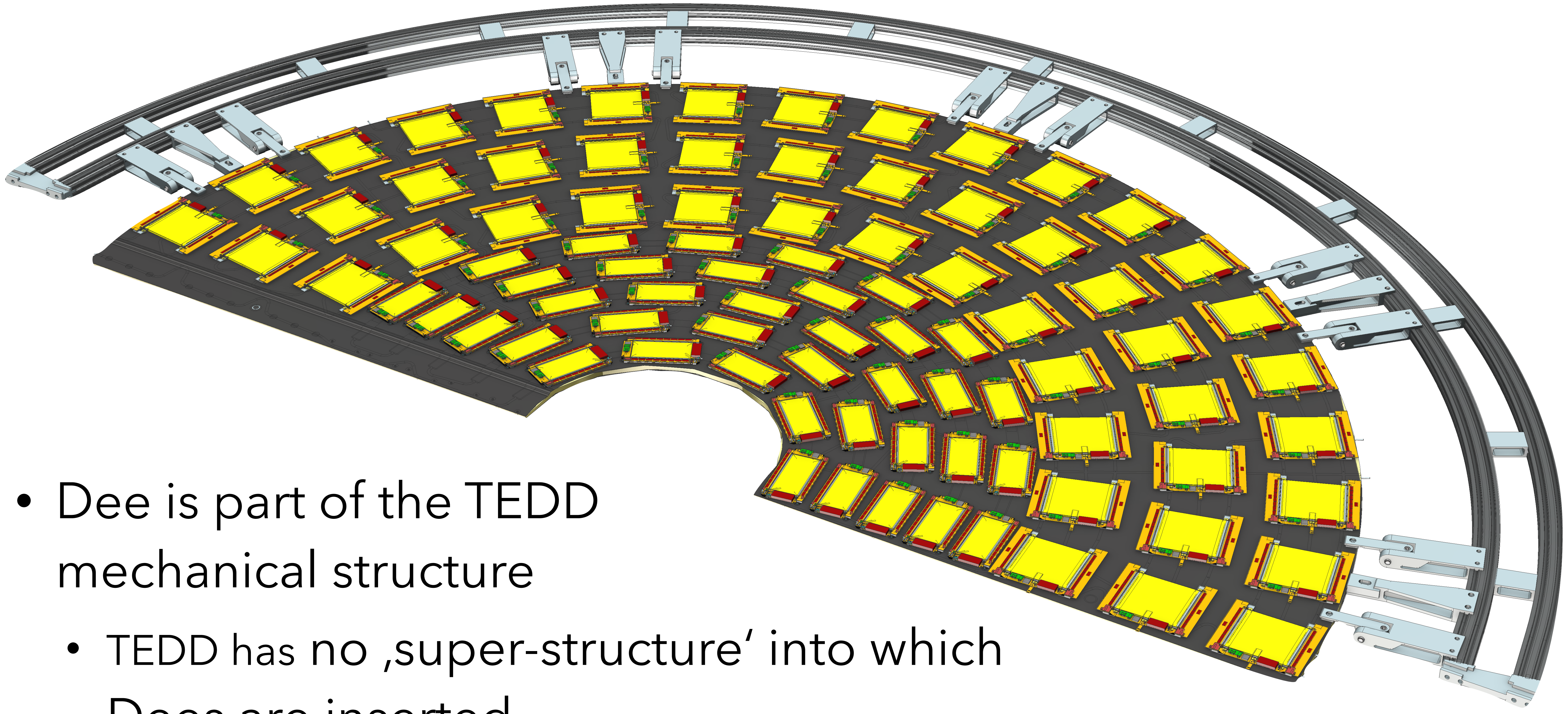
Dee Prototyping

- Small Scale Prototype of a Dee
  - 35 cm x 40 cm in size
  - Two cooling loops and corresponding inserts and cooling blocks
- Study assembly sequence and precision, and cooling performance
- Measured offset to nominal insert positions < 65 µm





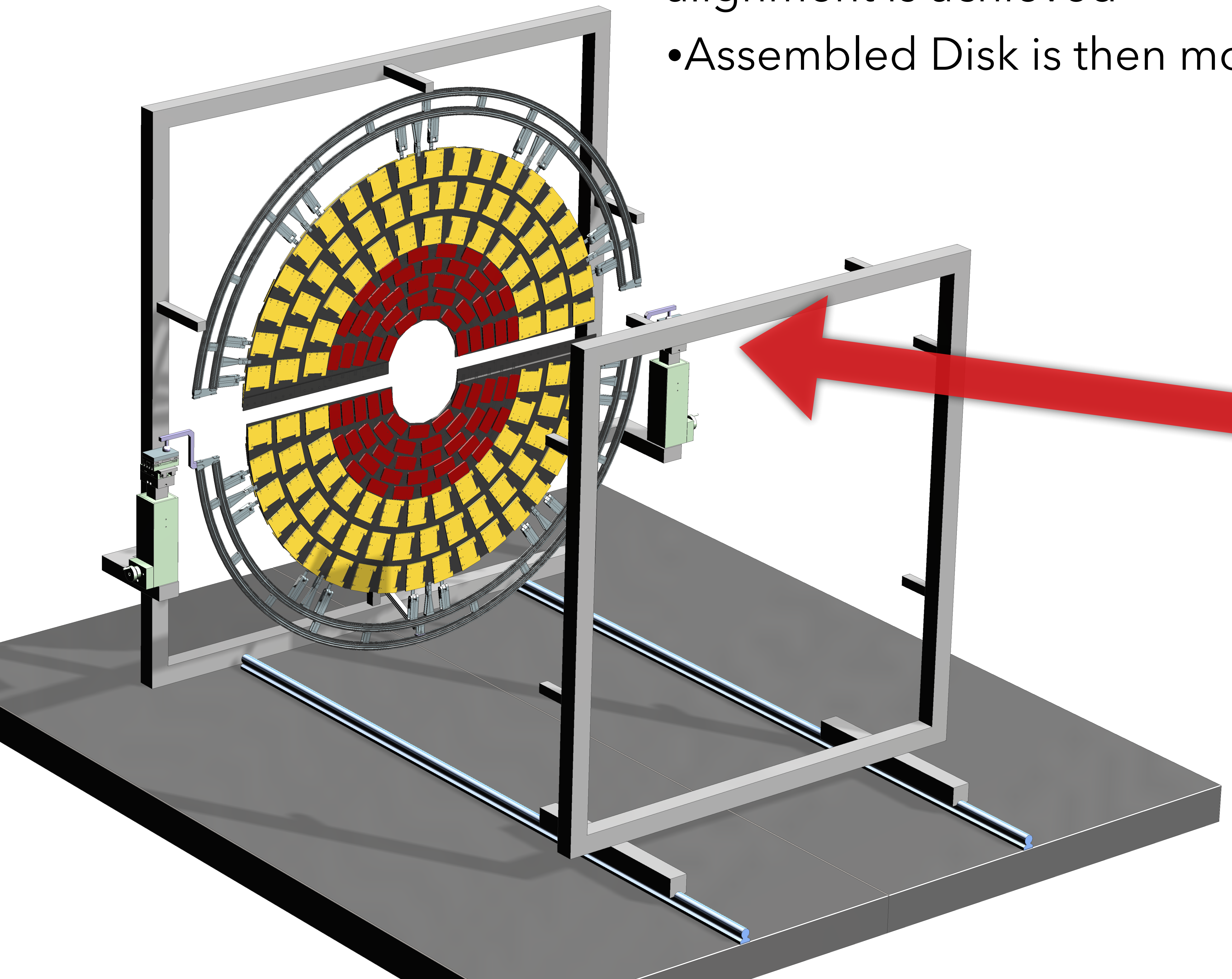
End Cap Integration - Arc-Frame

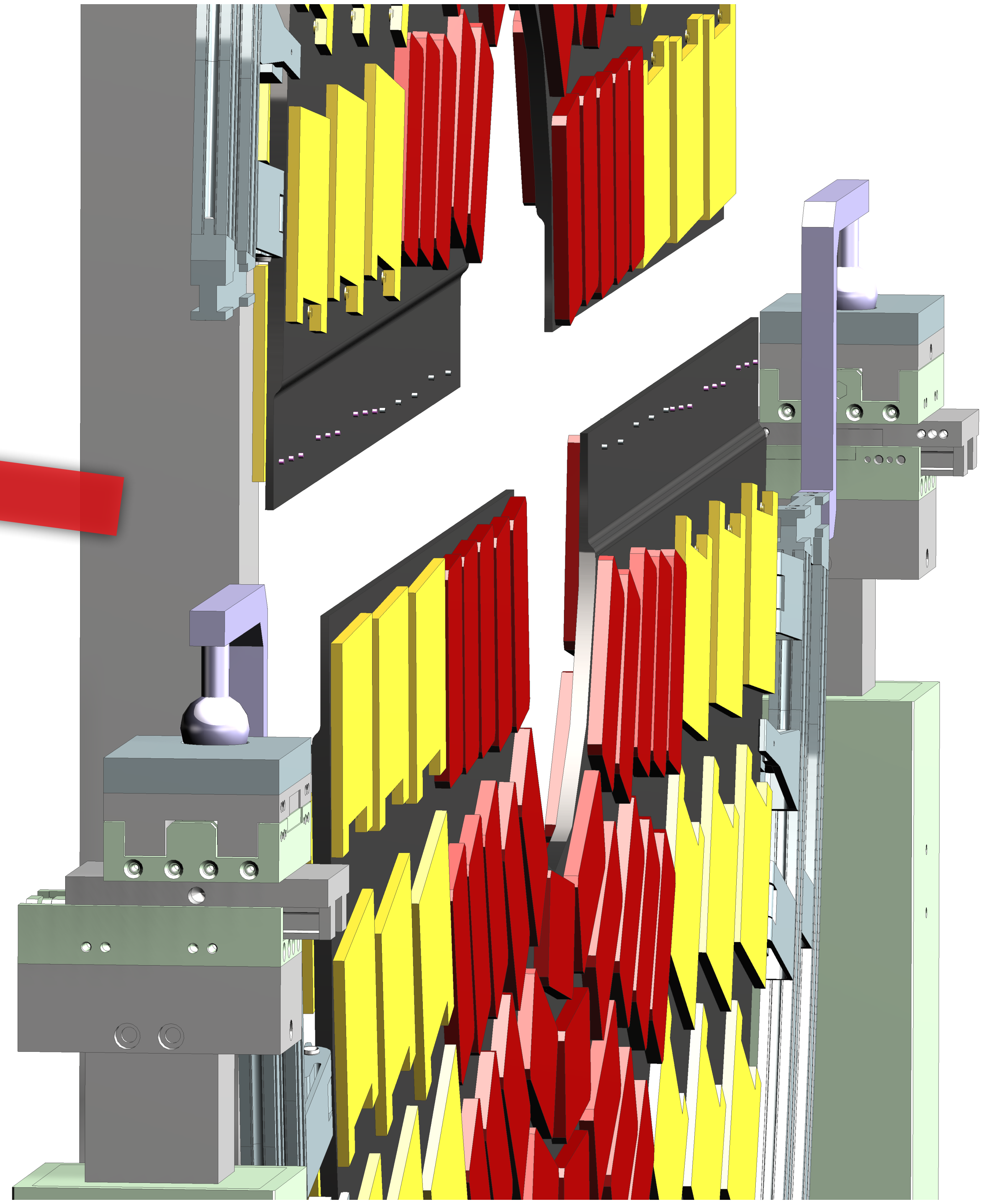


- Dee is part of the TEDD mechanical structure
  - TEDD has no ‚super-structure' into which Dees are inserted
- A single Dee is a rather floppy object
- Dees will stay in dedicated handling frame through-out integration process
  - reception tests ➟ module integration ➟ TEDD assembly
- Only when all 20 Dees are combined they become a stiff object
  - 4 Dees ➟ 2 Disks ➟ Double-Disk
  - 5 Double-Disks ➟ TEDD
- Arc-frame design has to be compatible with all integration steps

End Cap Integration - Disk & Double-Disk Assembly

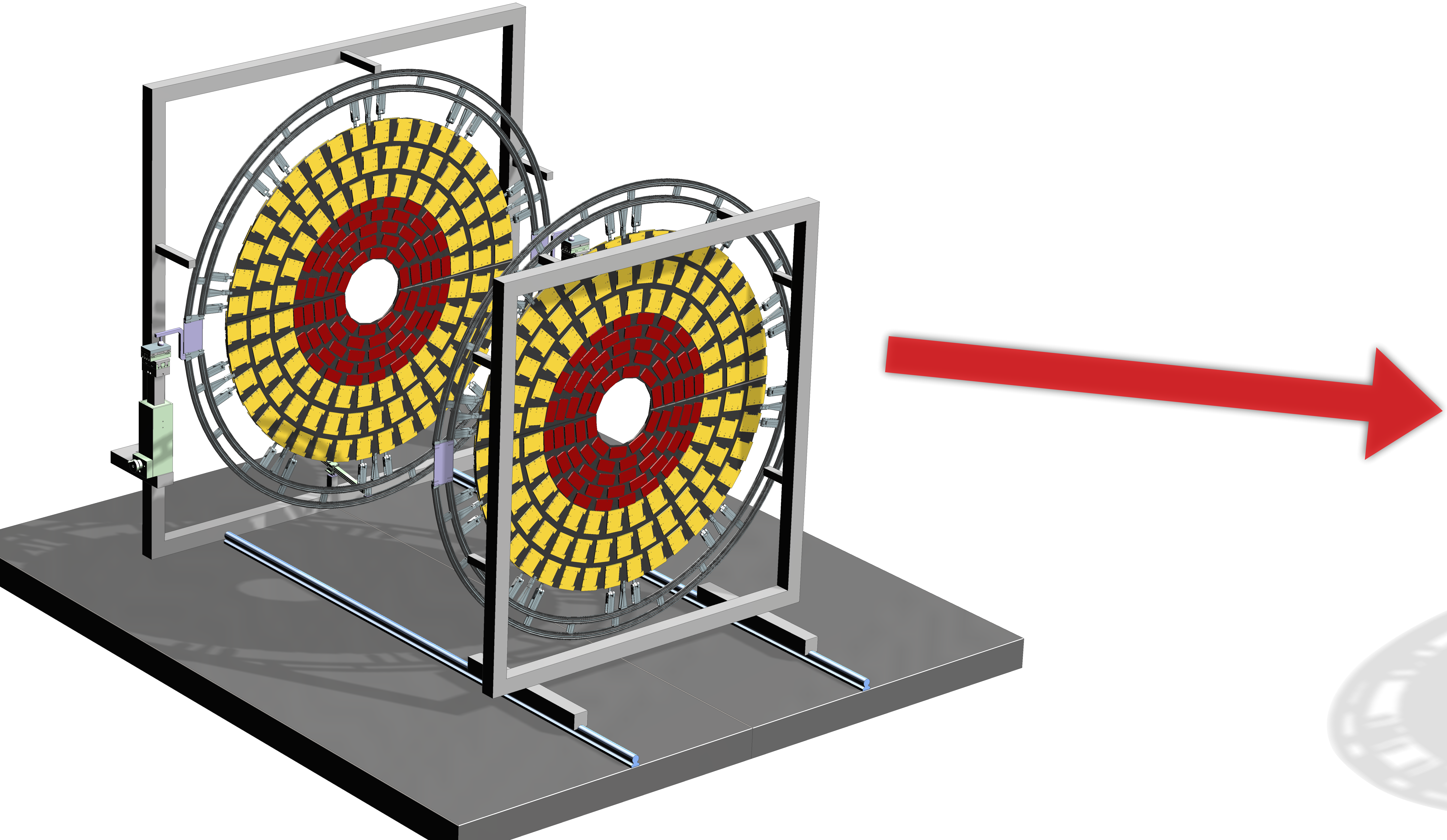
- Upper Dee is mounted in a static holding frame, lower Dee is supported by manual motion stages
- Relative alignment via metrology and motion stages
- Upper and lower Dees are pinned together and both Arc-Frames are mechanically connected when alignment is achieved
- Assembled Disk is then moved to ‚parking' position

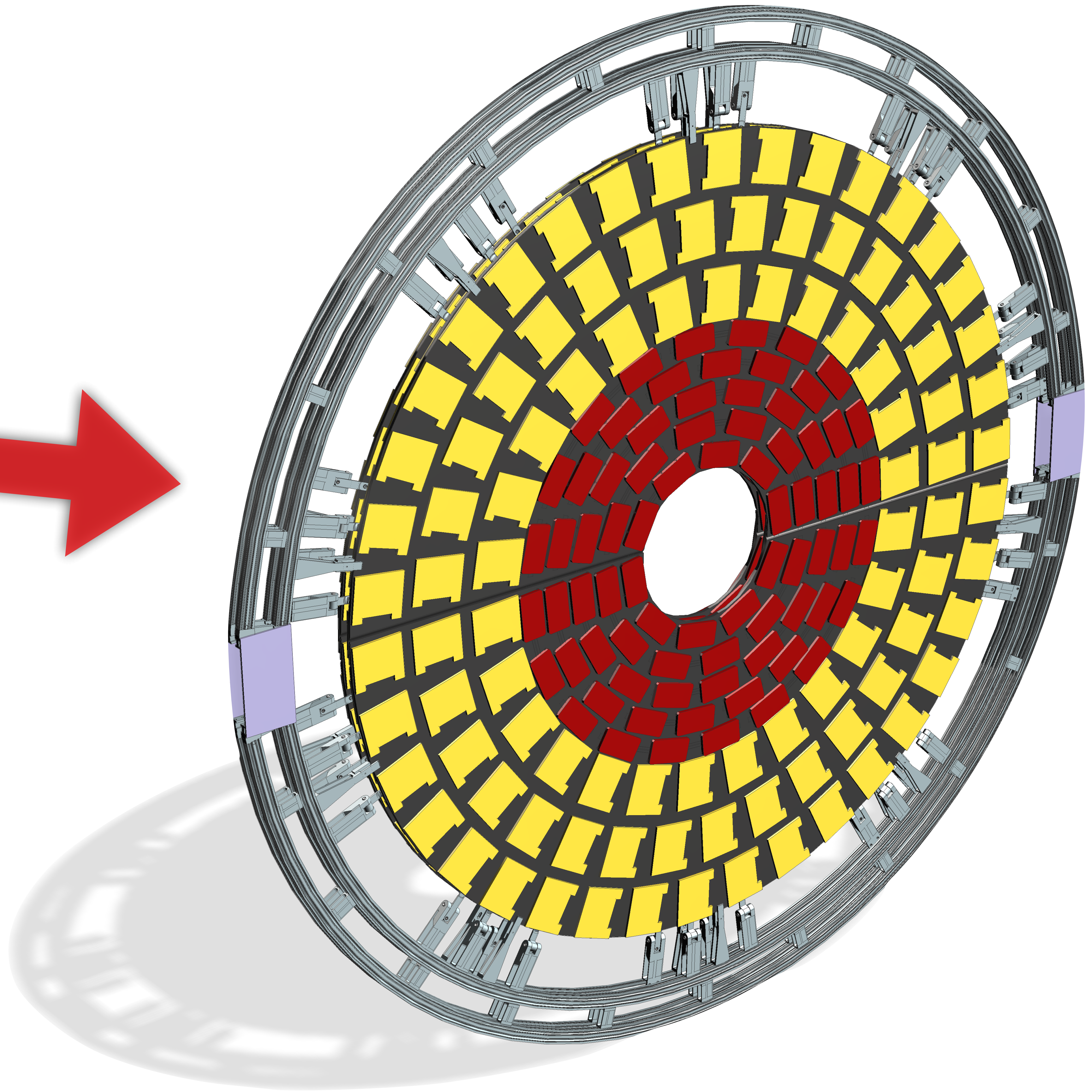




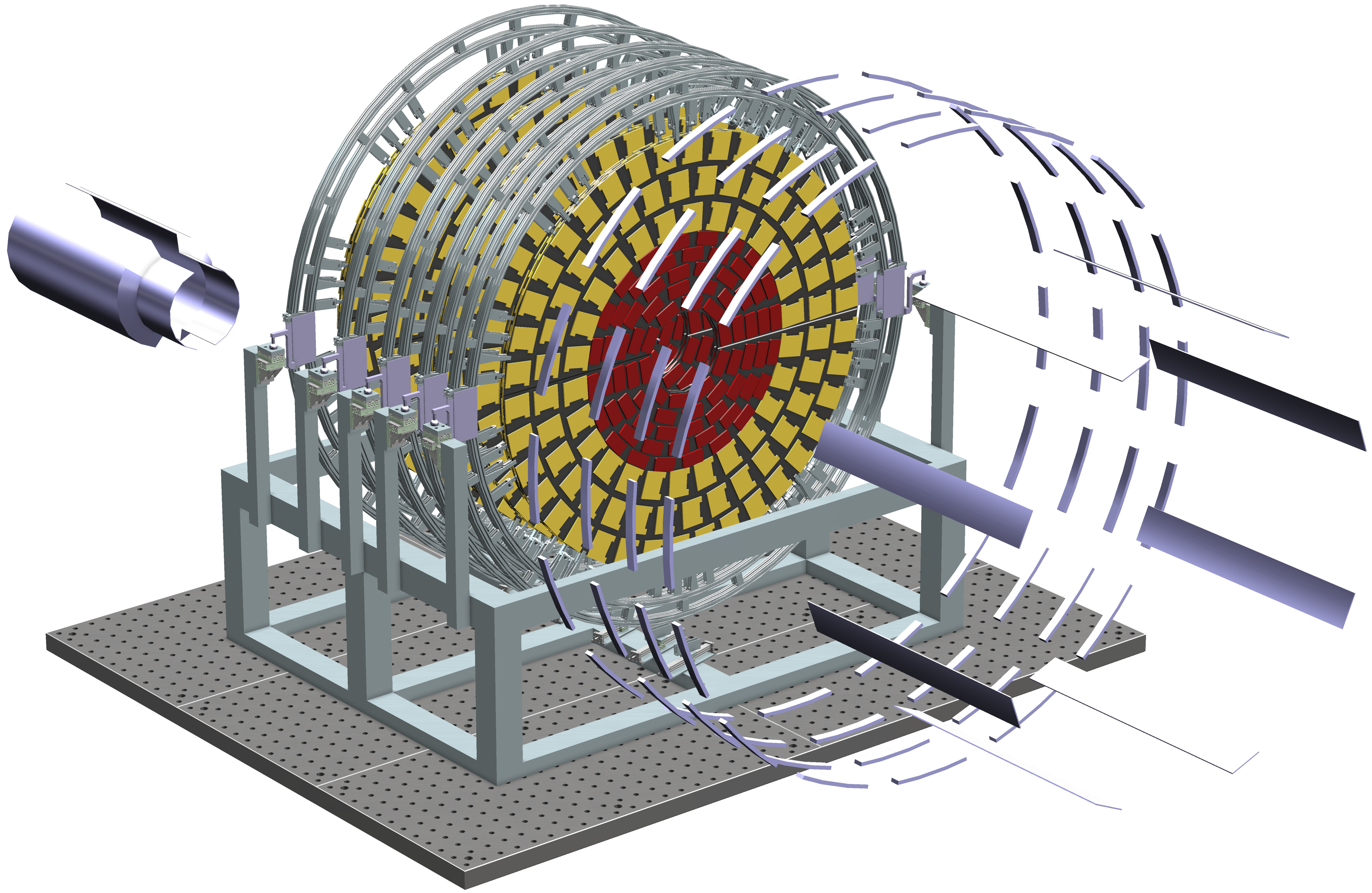
End Cap Integration - Disk & Double-Disk Assembly

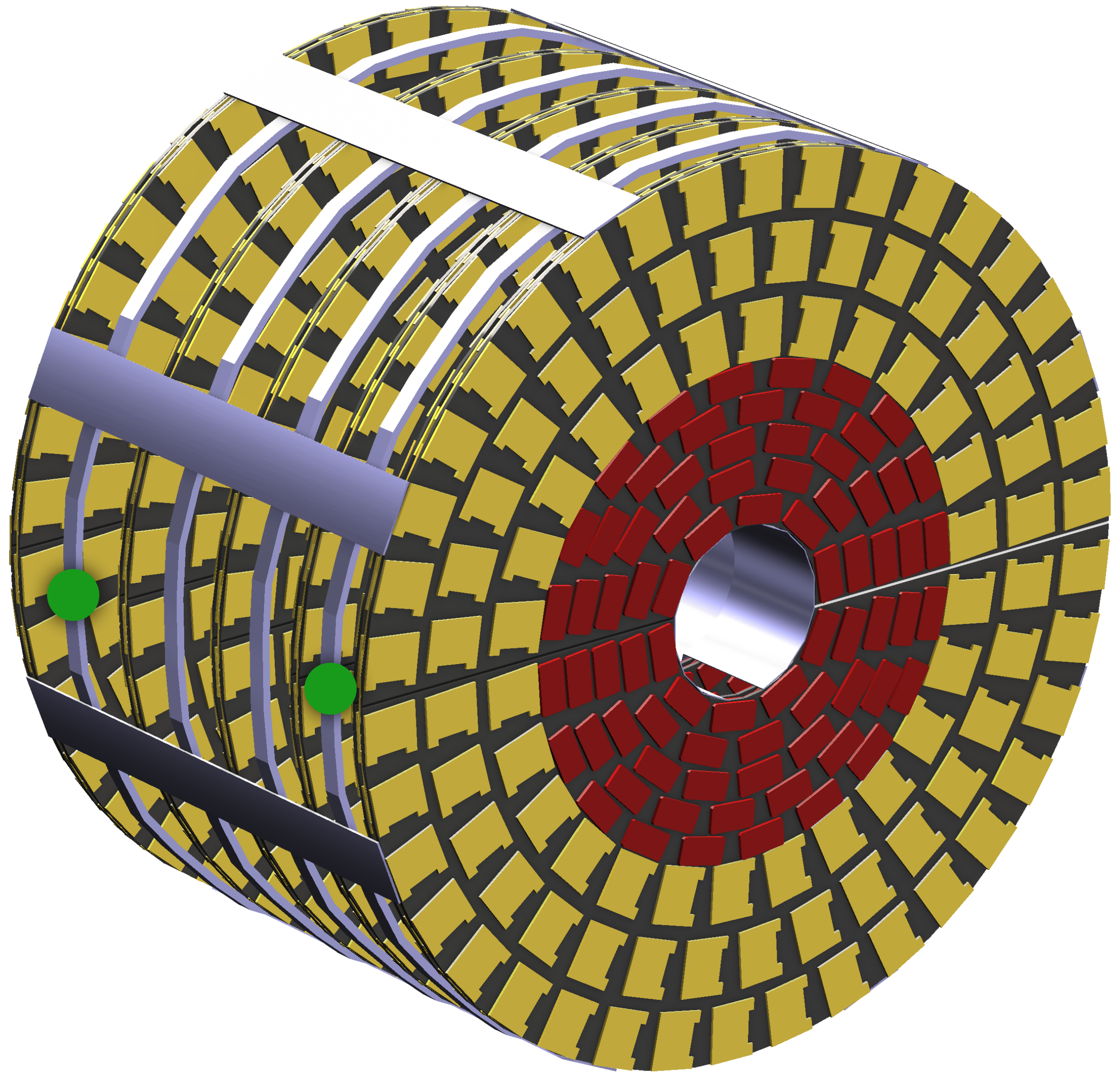
- Second Disk is assembled and remains in static holding frame
- First Disk is moved back from ‚parking' position and supported by manual motion stages
- Relative alignment via metrology and motion stages
- Both Disk are bolted together and Arc-Frames are mechanically connected when alignment is achieved

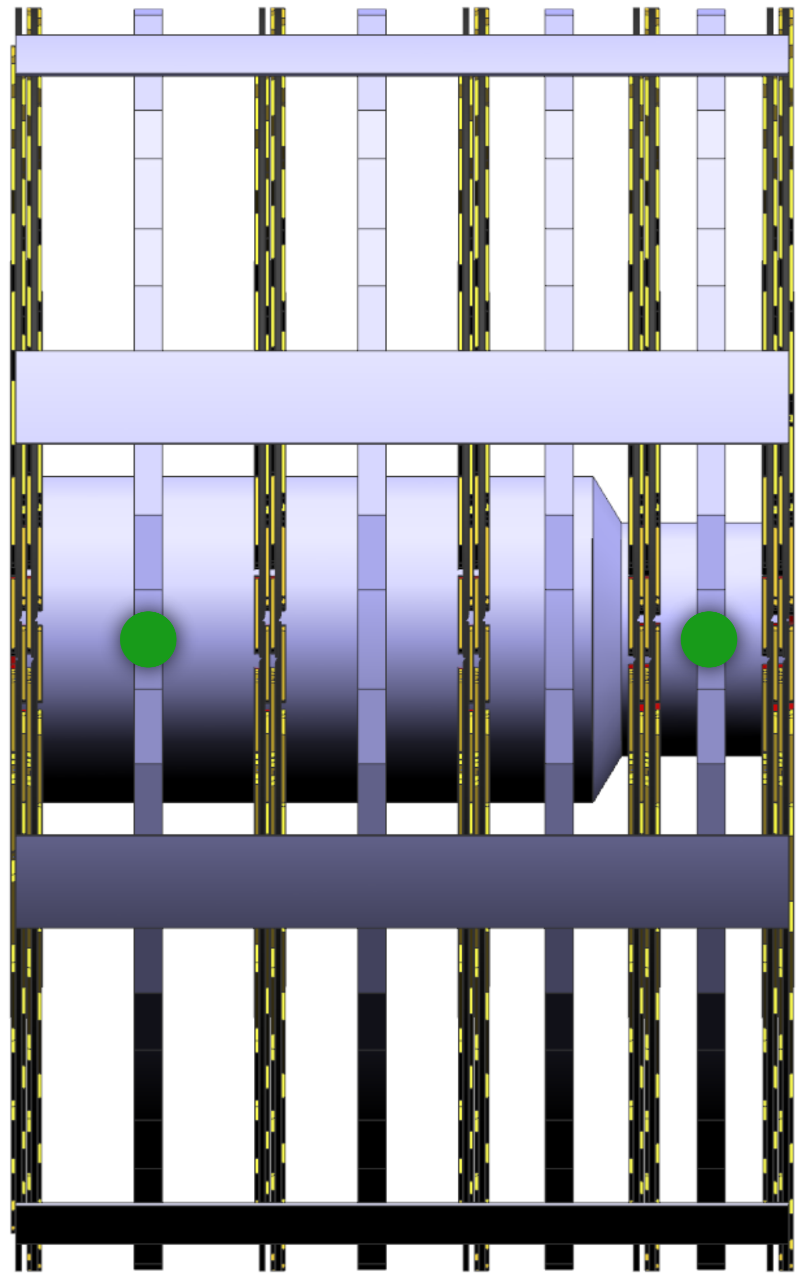




End Cap Integration

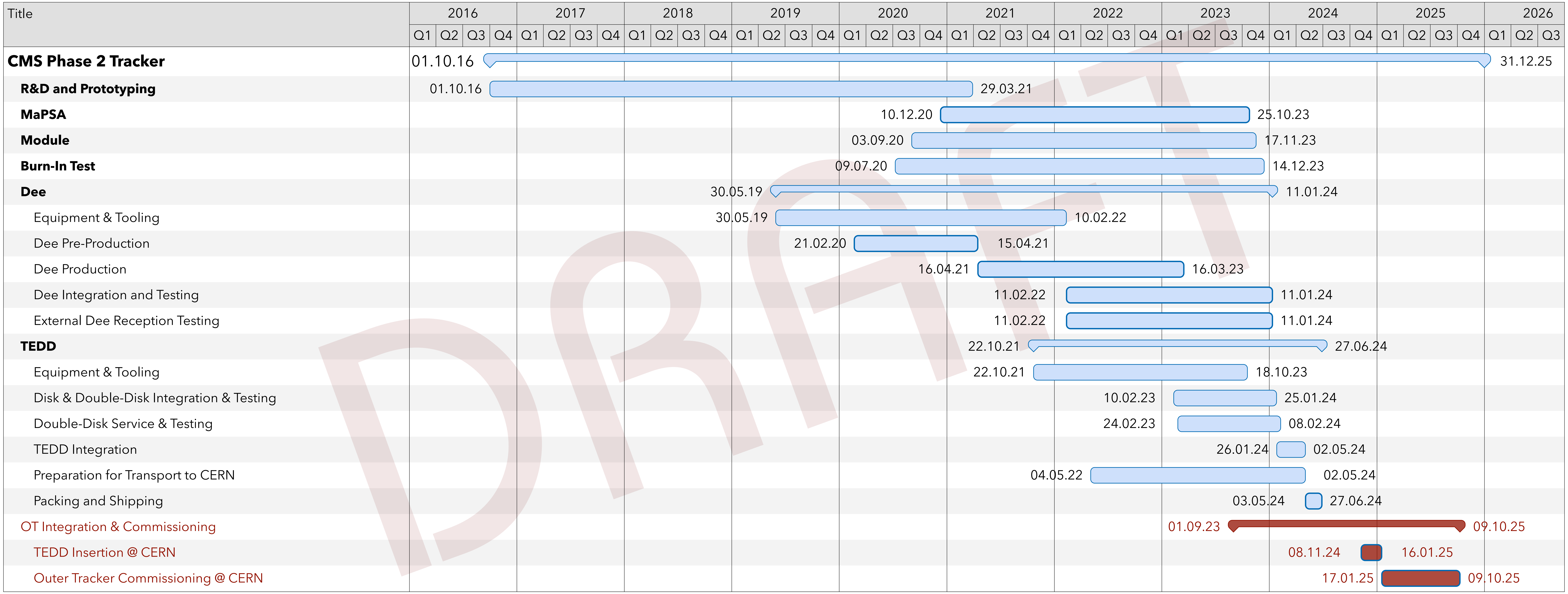






- Relative alignment of all five Double-Disks via metrology and manual motion stages
- Insertion of inner tube, longitudinal support bars and support rings when alignment is achieved

Project Schedule - End Cap Integration



- Responsibilities shared between DESY, Lyon & Louvain
  - Dee design & production: Lyon & DESY
  - Super-structure design: Lyon
  - Services: Louvain
  - Integration Tooling: DESY
  - Dee integration: Lyon, Louvain & DESY
  - Test equipment: Louvain
  - TEDD assembly: Louvain & DESY