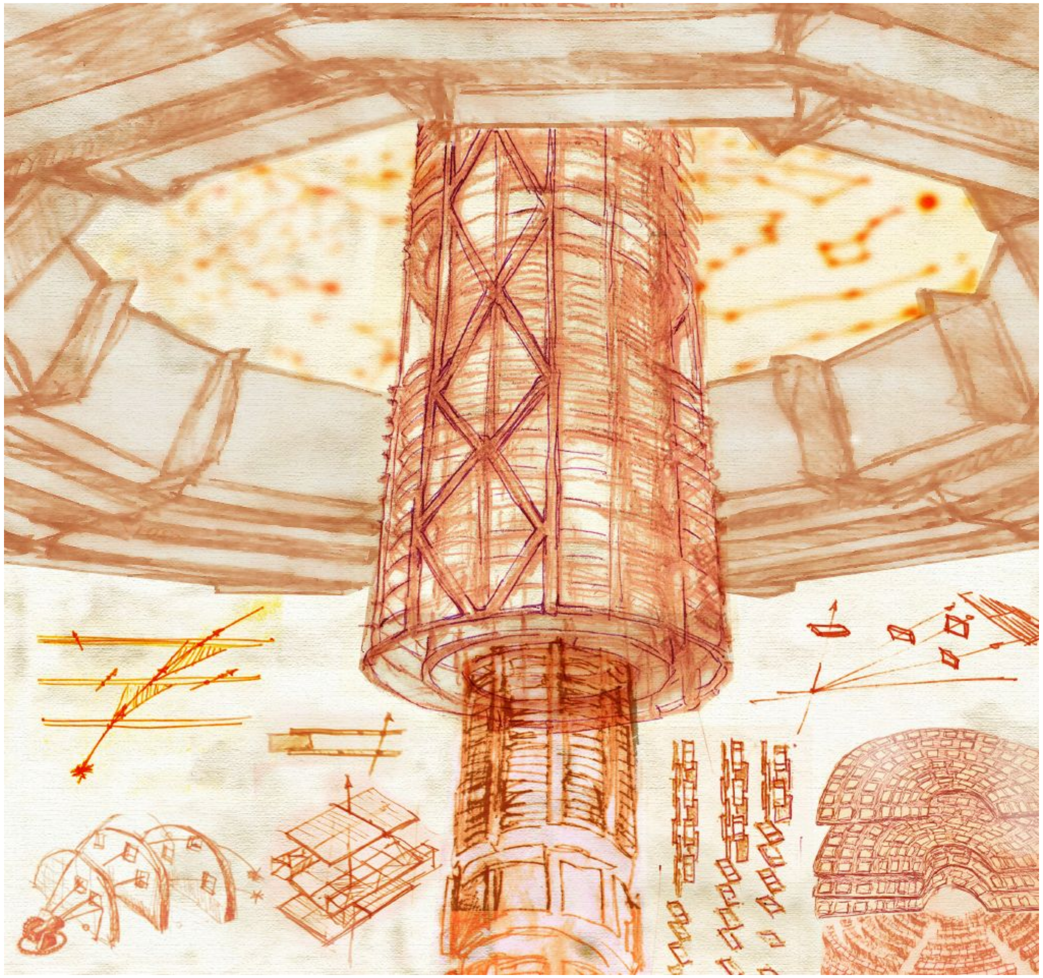
CMS Tracker Upgrade

"Phase 2"
for the High Luminositiy LHC



David Bertsche

July 2nd 2018

Namibia University of Science and Technology - NUST
Windhoek, Namibia

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

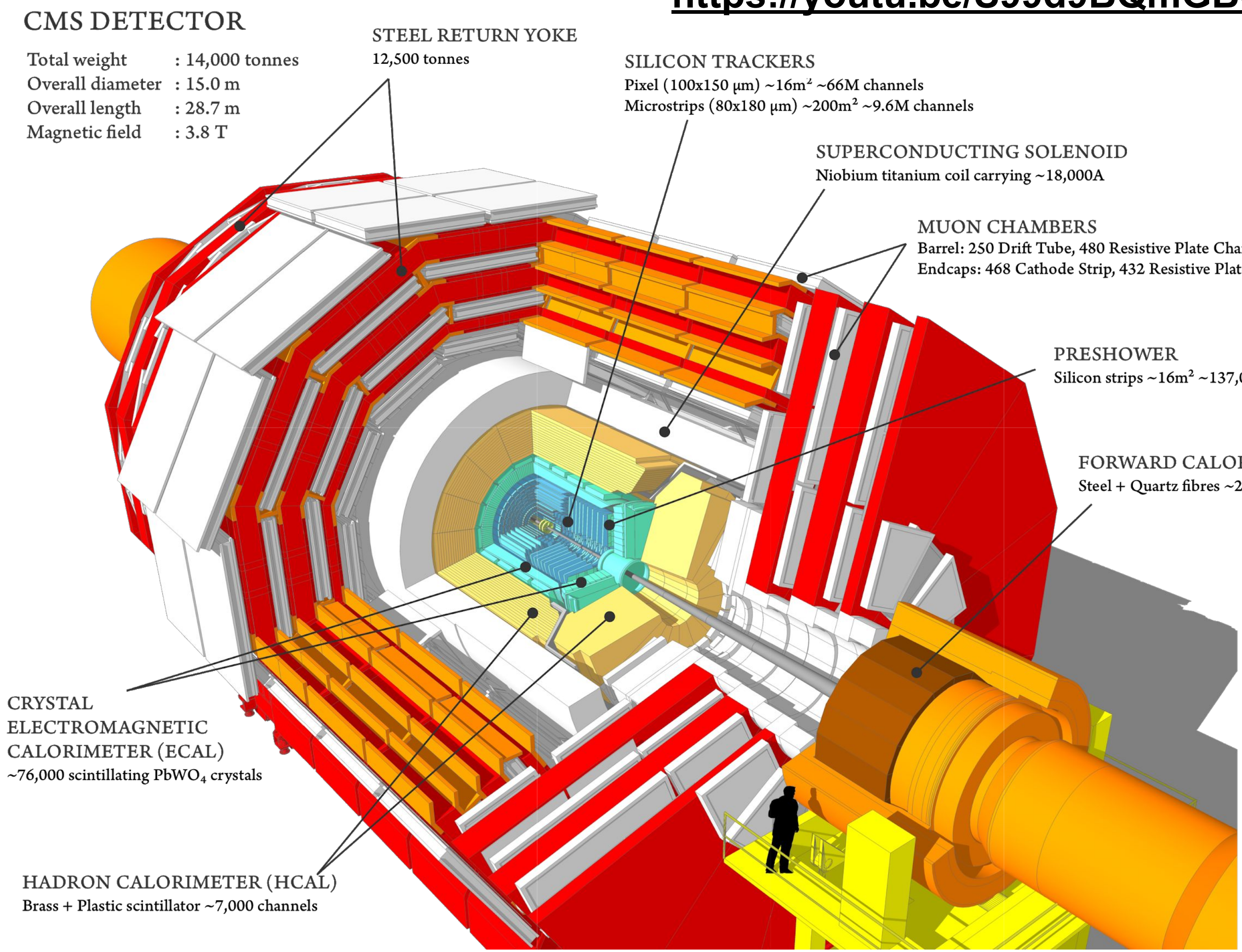
DESY.

The LHC and CMS

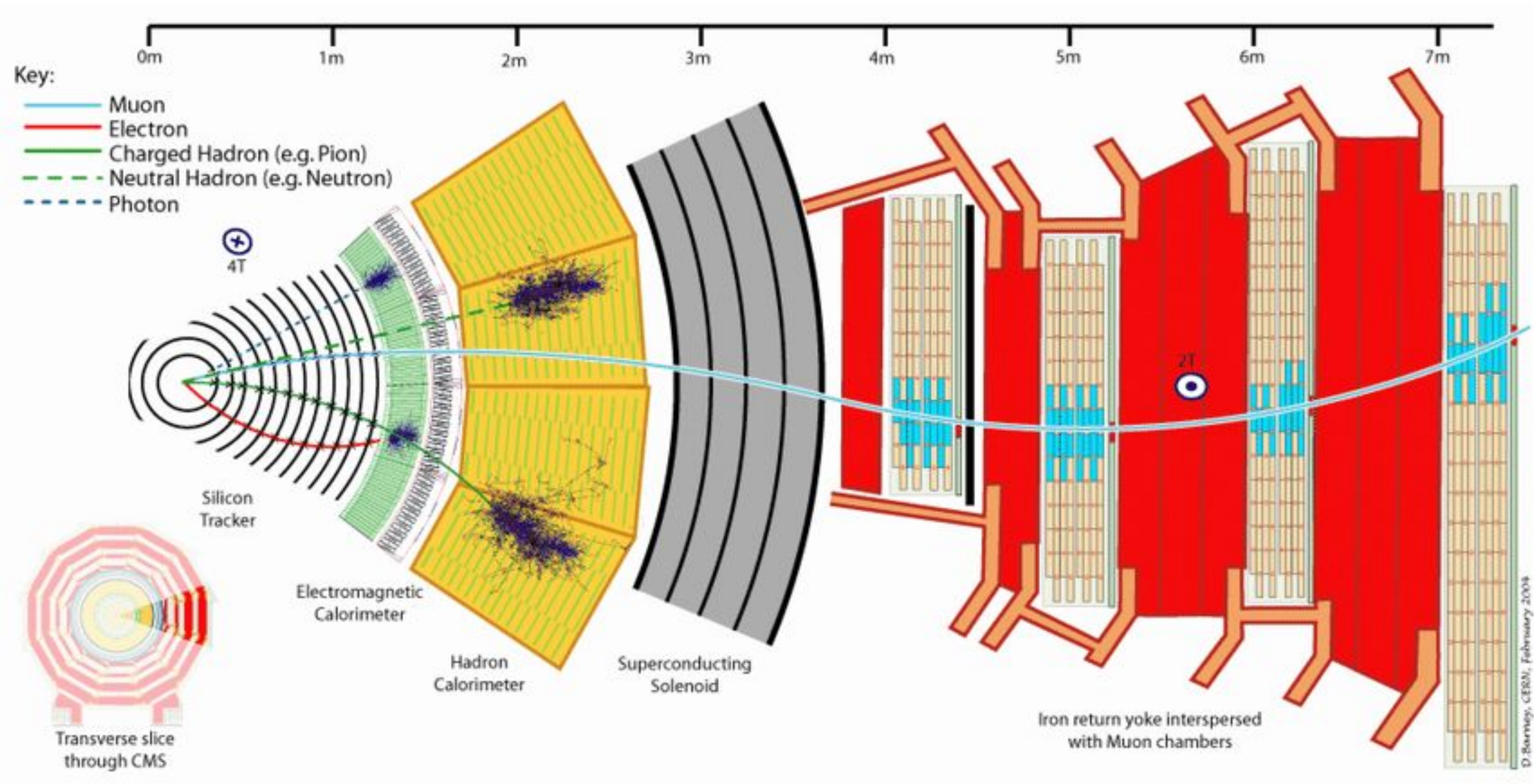
The LHC and CMS

https://cms.cern/

https://youtu.be/S99d9BQmGB0



Particle Tracking



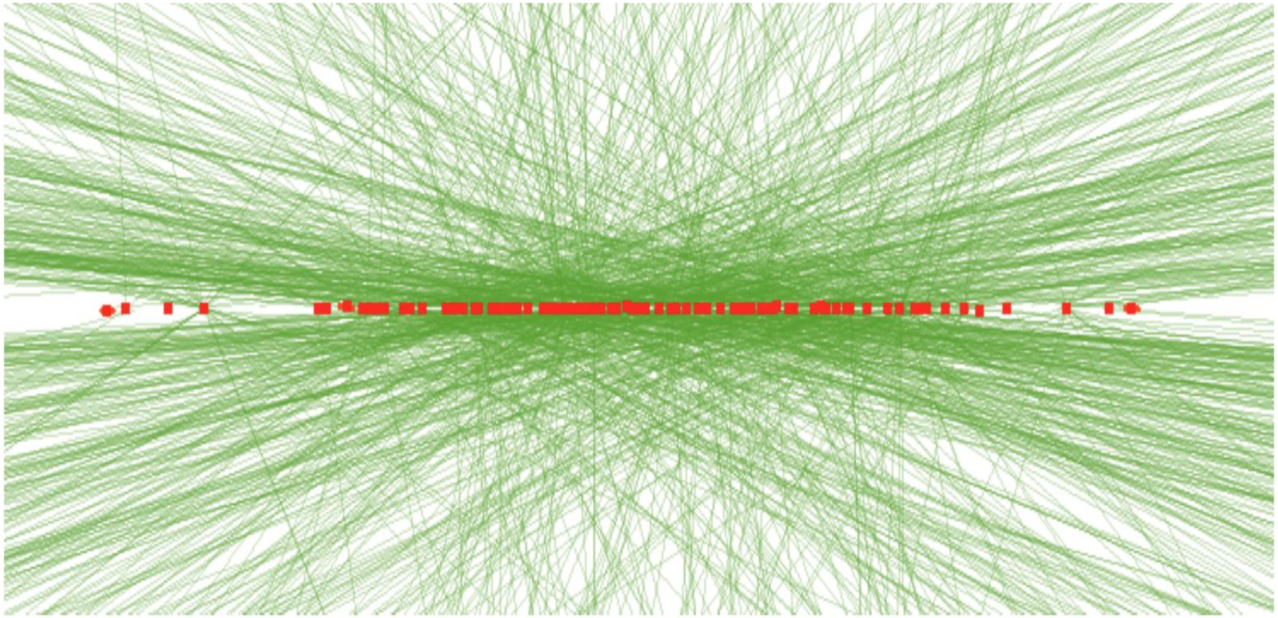
Timeline

http://hilumilhc.web.cern.ch/about/hl-lhc-project

Tacker upgrade is currently in development

Installation during Long Shut Down 3, 2024-2026

CMS Tracker for the HL-LHC



LHC to HL-LHC

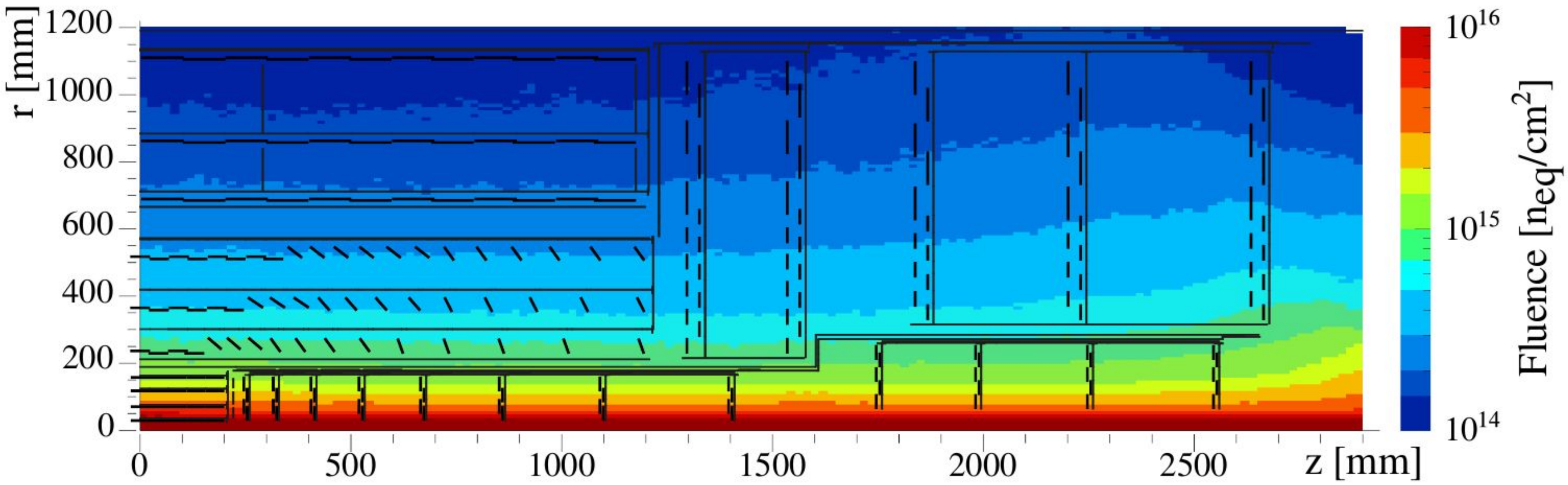
- Increase nominal instantaneous luminosity by 5-7 times
- 3000 fb^{-1} integrated luminosity over 12 years
- Radiation levels increase by ~6×

CMS Tracker Challenges

- Increased radiation and Increased pileup (PU)
- CMS already operating close to specifications (500/fb^{-1}, PU~20)
- The entire Tracker needs to be replaced -- radiation hard, fast electronics

HL-LHC radiation environment

Expected radiation levels increase by ~6×



Integrated particle fluence in 1 MeV neutron equivalent per cm^2 for the Phase-2 tracker. The estimates shown correspond to a total integrated luminosity of 3000 fb^{-1} of pp collisions at sqrt(s) = 14 TeV

Rates and Trigger Requirements

The Tracker must:

- provide high-pT tracks with high resolution to the L1 trigger system
- Operate up to 200 <PU> and keep occupancy a the ~1% level

But

- L1 trigger exclusively based on muons and calorimeters not sufficient

So

- A novel pT-module with on-board discrimination is being developed

Tilted Layout

New innovations:

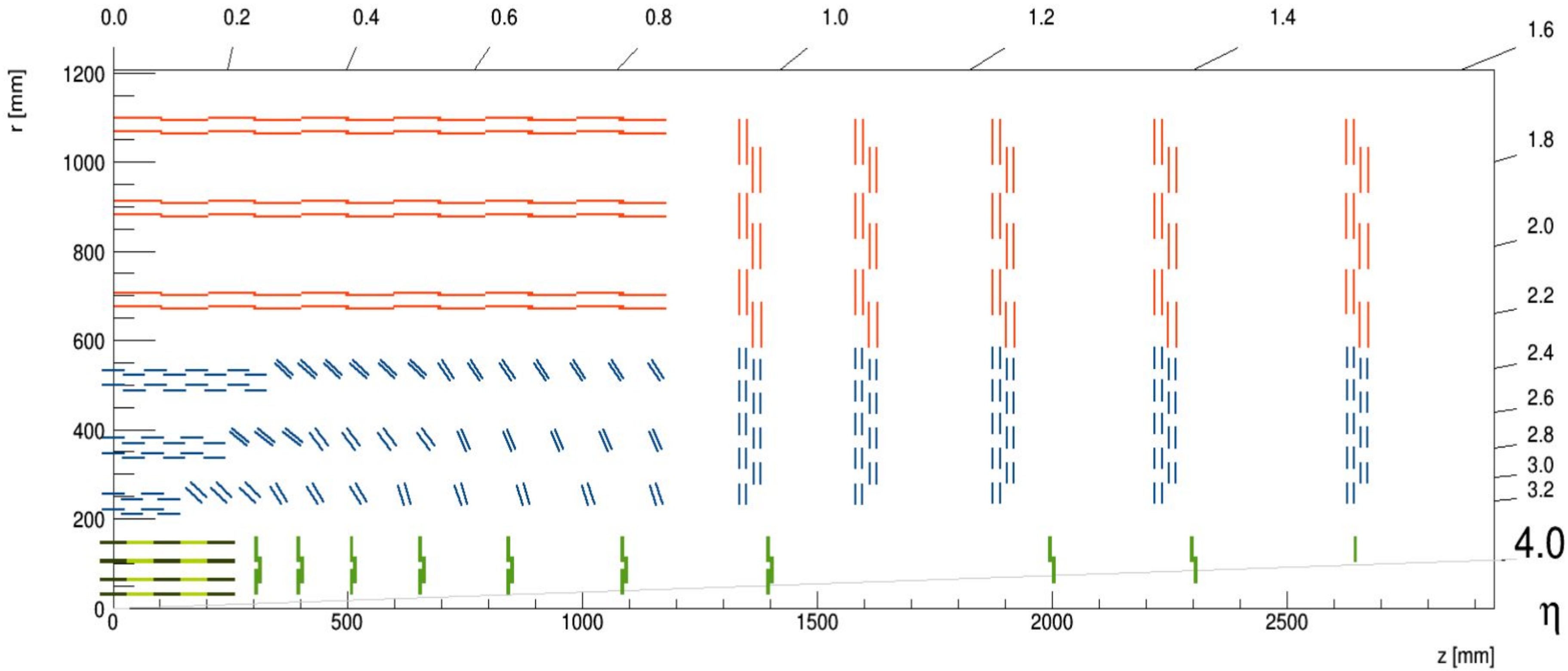
Some layers are tilted, which reduces the required number of modules

Extended tracking acceptance up to |η|~4

Reduce the amount of tracking material

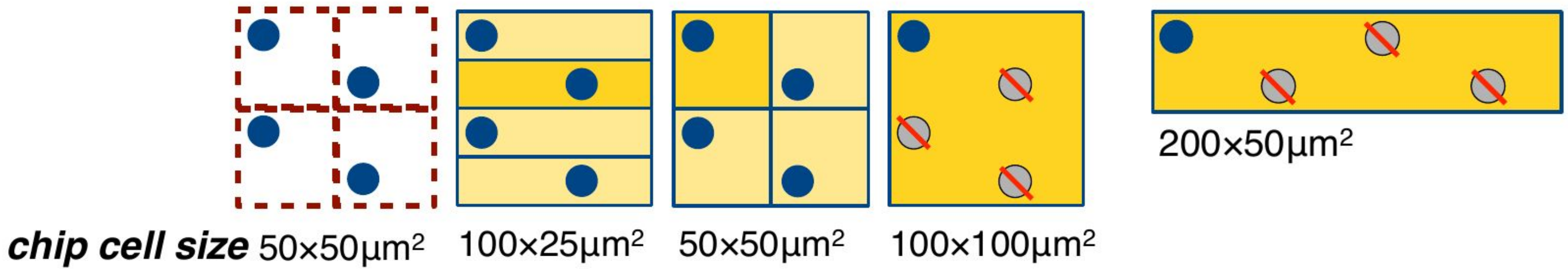
Red and Blue: Outer Tracker

Green: Inner or Pixel Tracker



Pixel Design Design Driving Concepts

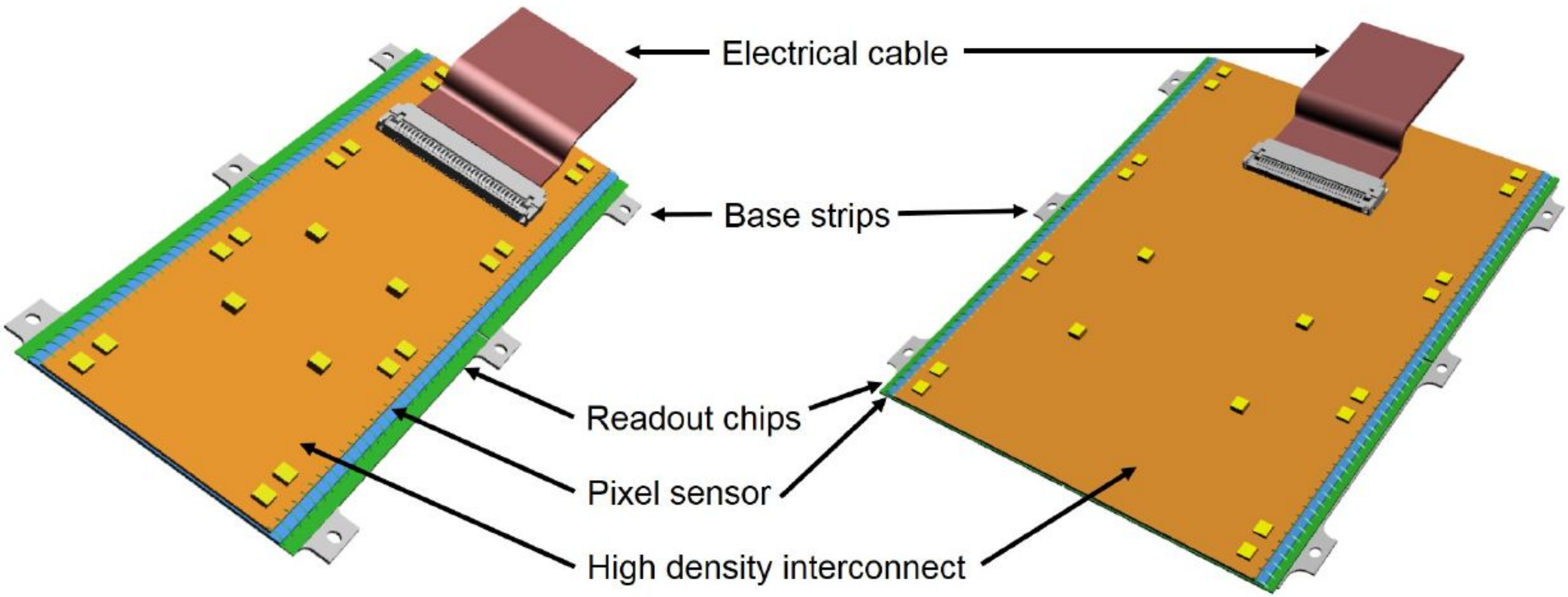
- Improved granularity: low occupancy, enhanced resolution and better track separation (especially in jets)
- a cell size of 2500μm^2 is the baseline (6x improvement wrt Pixel Phase 1)



- allows several aspect ratios (25x100μm^2, 50x50μm^2) with the same cell size or with larger cell size (50x200μm^2, 100x100μm^2)
- finer pitches in the innermost layers/rings; square pixels in the endcaps

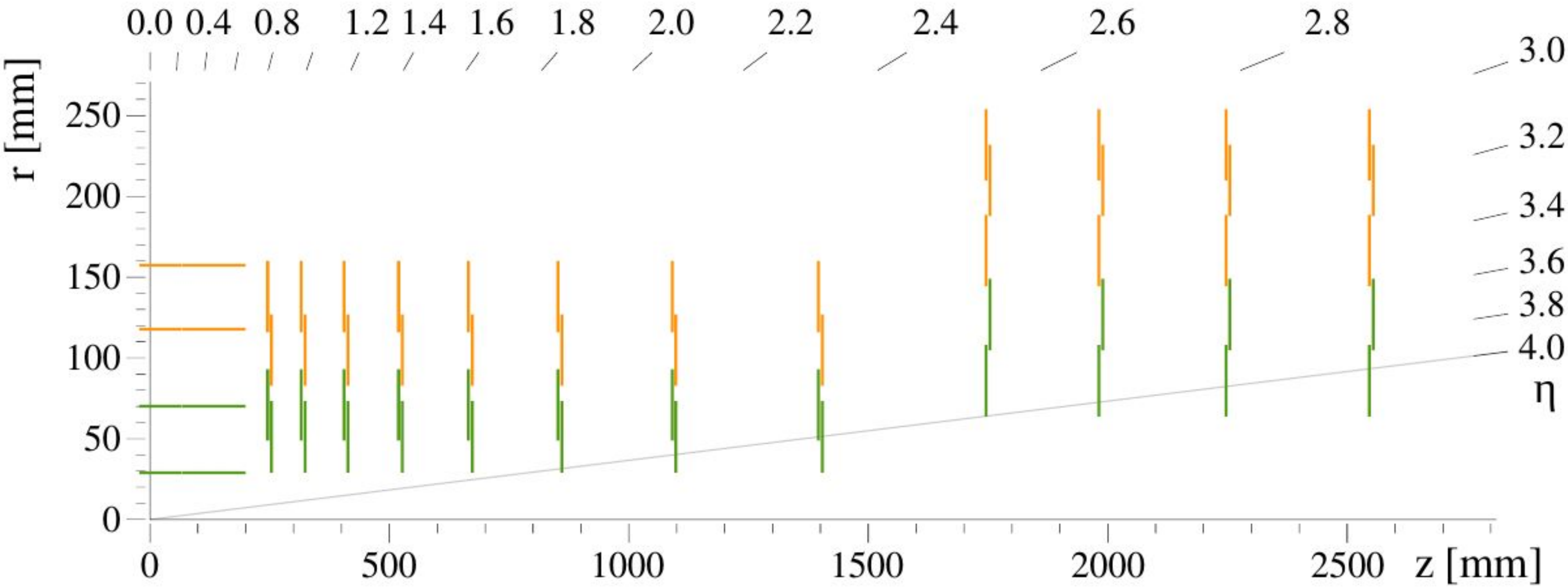
Pixel Design Design Driving Concepts

- Few module types, no wedge shaped modules
- simple and lightweight mechanics



1×2 (left) and 2×2 (right) pixel modules. The dimensions are roughly 1.8 × 4.4 cm^2 and 3.7 × 4.4 cm^2 for the 1×2 and 2×2 modules, respectively. The yellow elements symbolize passive electrical components.

Pixel Design Design Driving Concepts

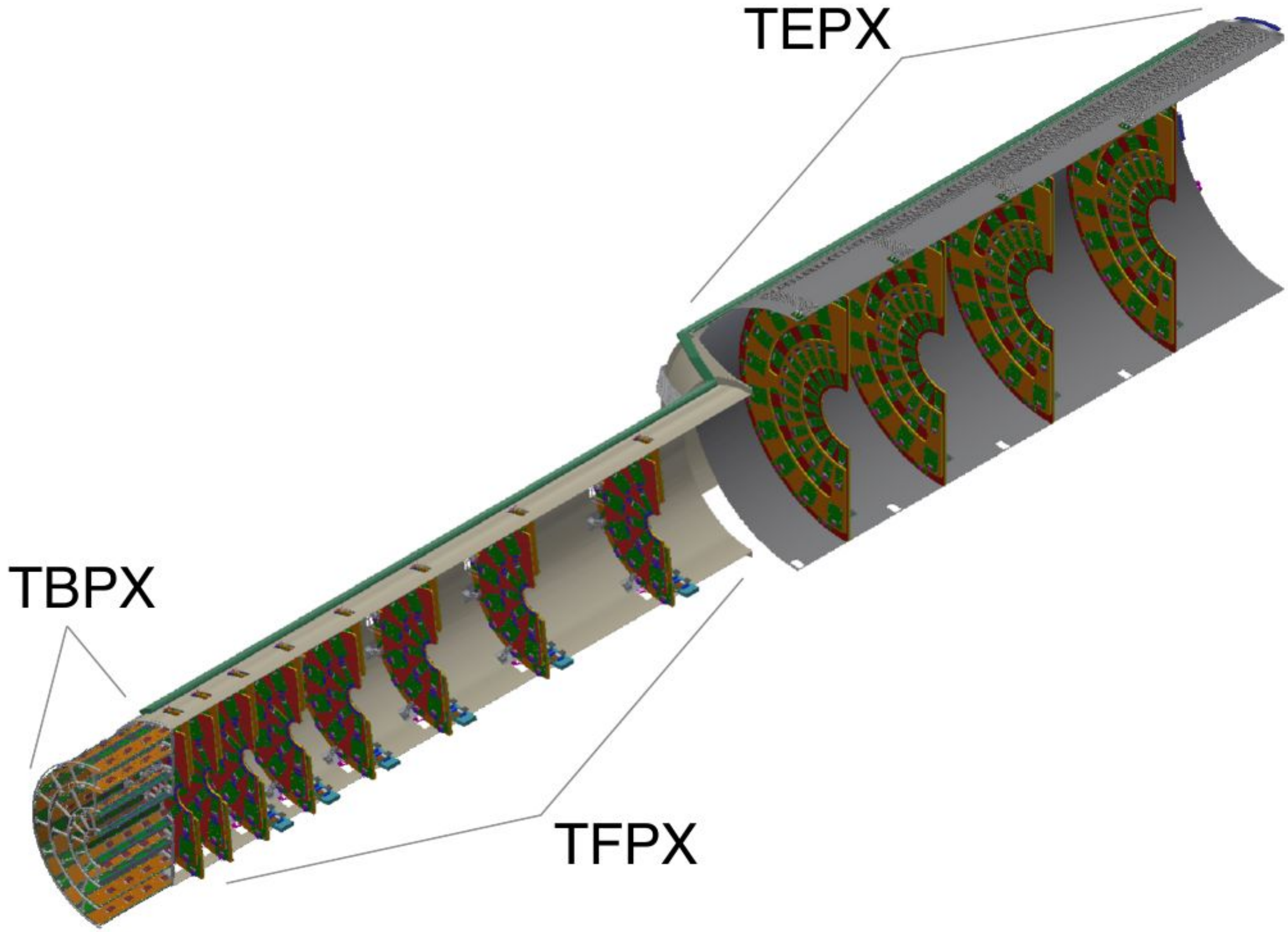


One quarter of the pixel detector layout in the r-z view.

Green: modules made of two readout chips and

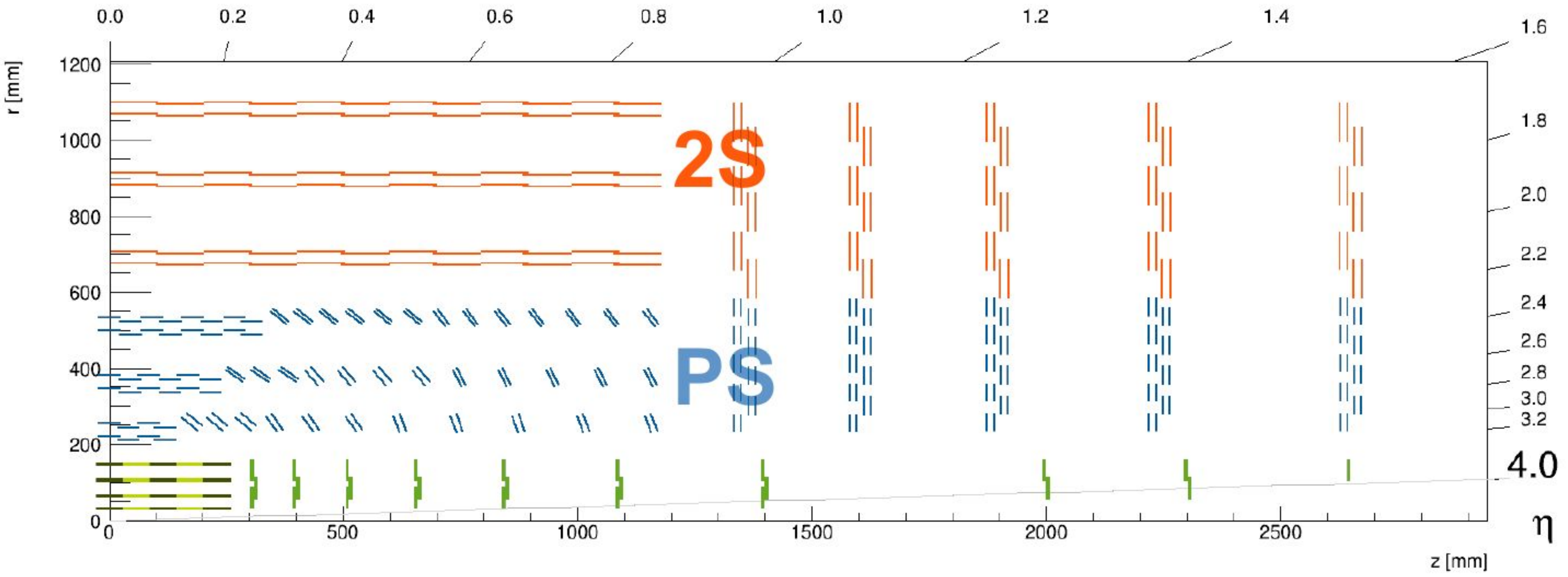
Orange: larger modules with four chips.

Pixel Design Design Driving Concepts



One quarter of the Pixel Detector

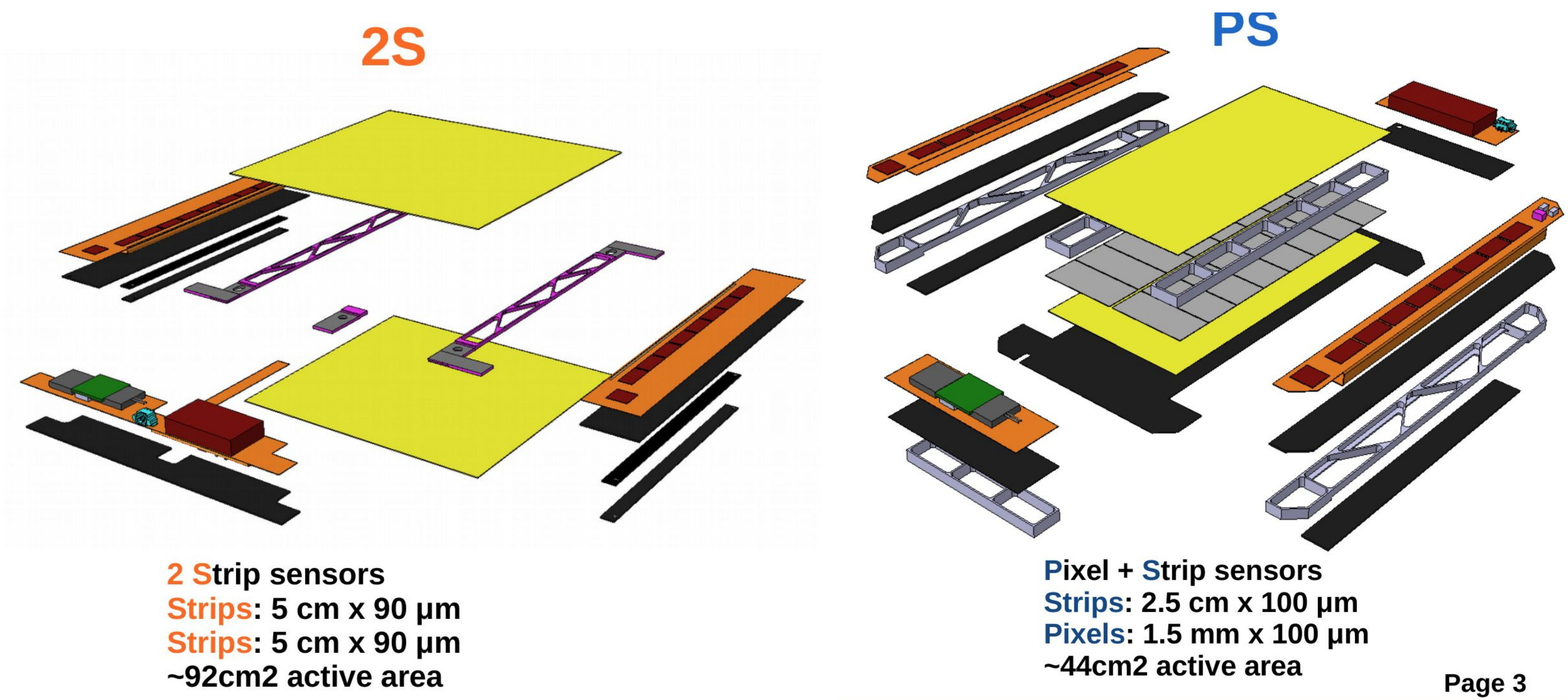
Outer Tracker Layout



Layout

- 6 barrel layers and 5 end-cap disks
- Extended coverage ~ |η| = 2.8
- Low material budget

Outer Tracker Modules

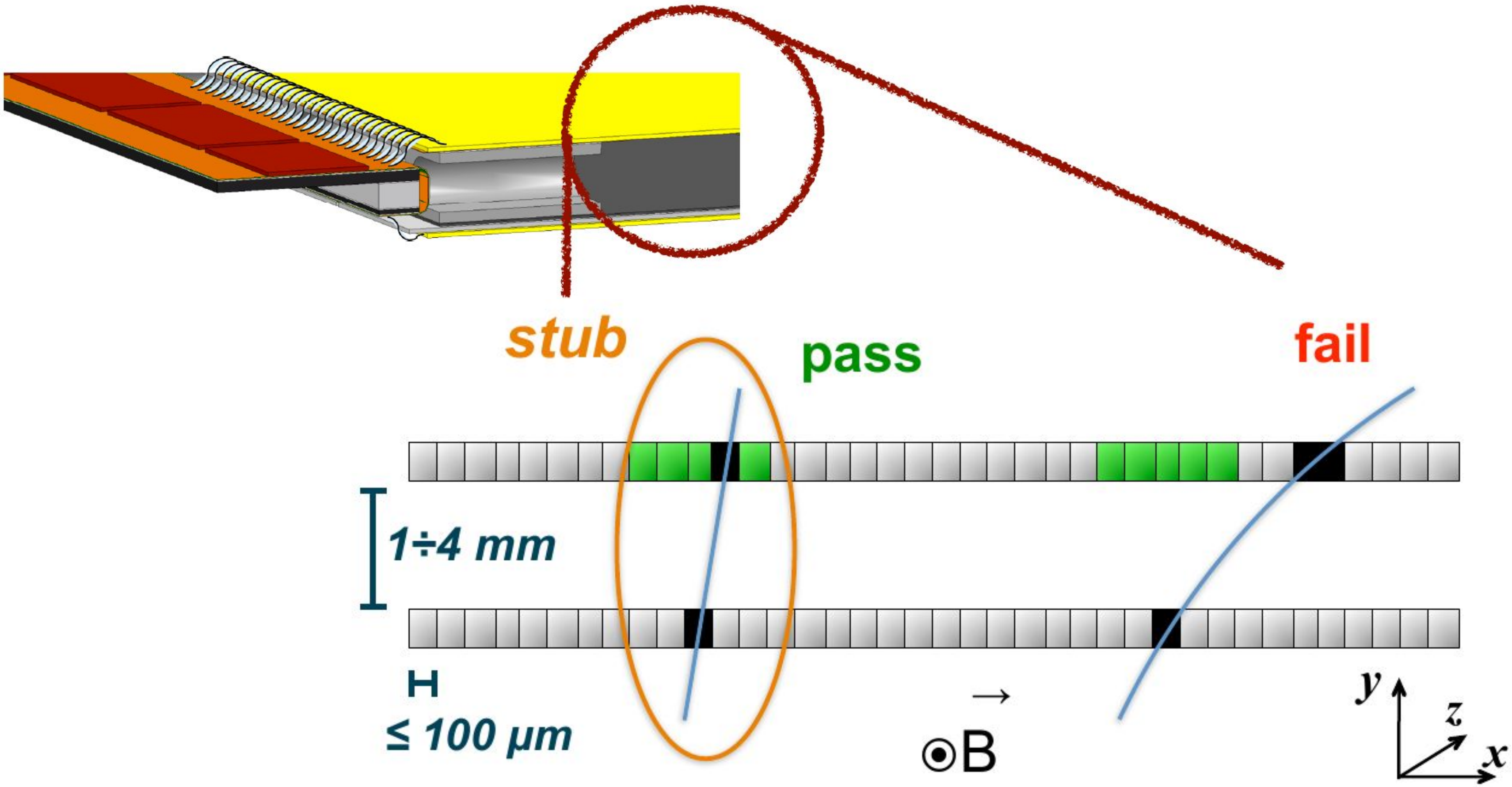


Modules

- Two types of modules
- Stacked silicon sensors with common read-out on-module trigger capabilities

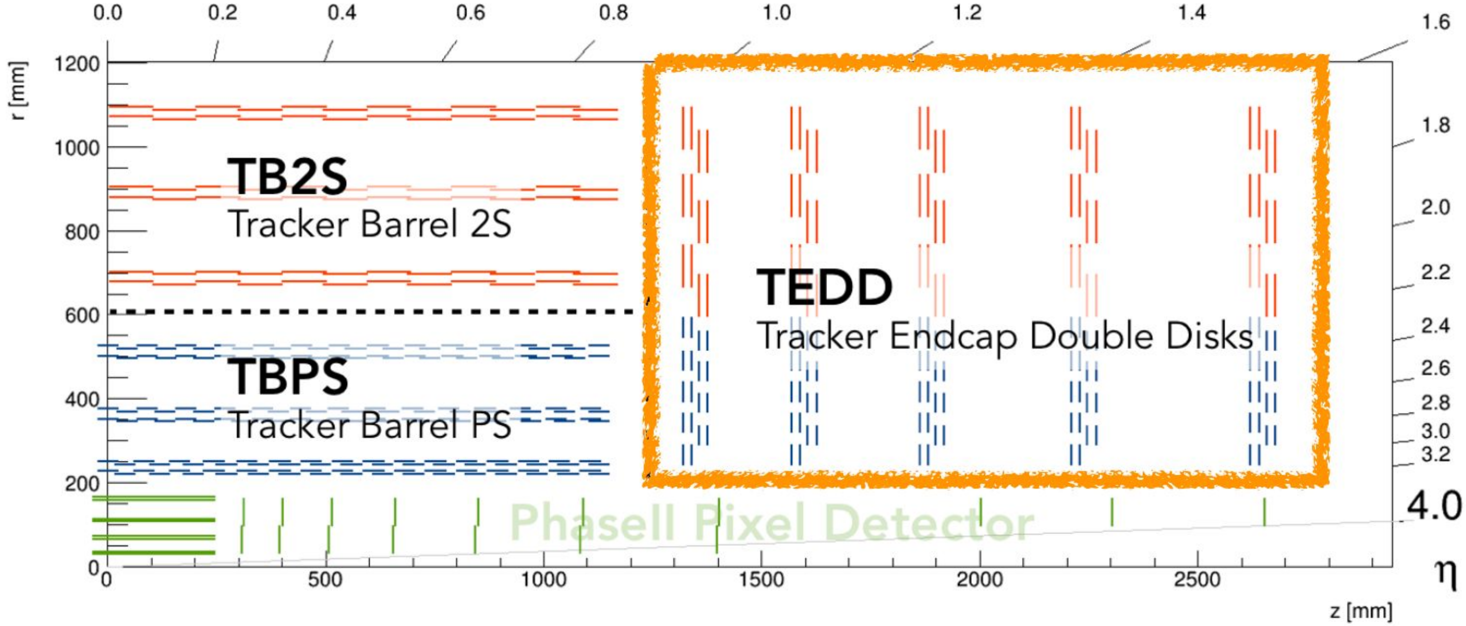
L1 trigger: pT-module Concept

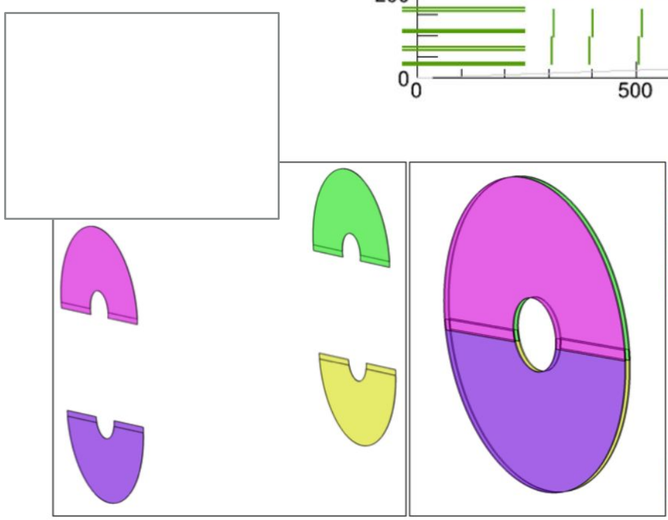
- Only high-pT tracks data are sent out @40MHz
- pT discrimination based on-board the module
- Uses momentum discrimination logic implemented on the common readout chip
- Passes only high-pT tracks, called “stubs”
- Benefiting from the CMS magnetic field

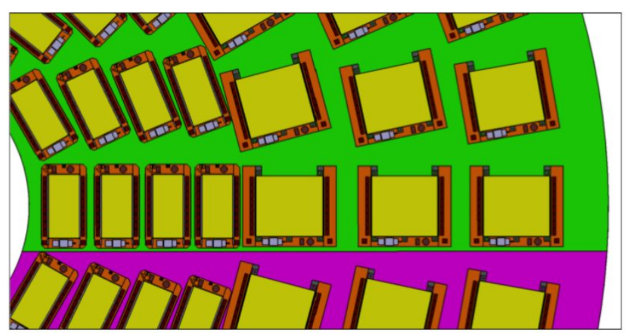


TEDD mechanics concept

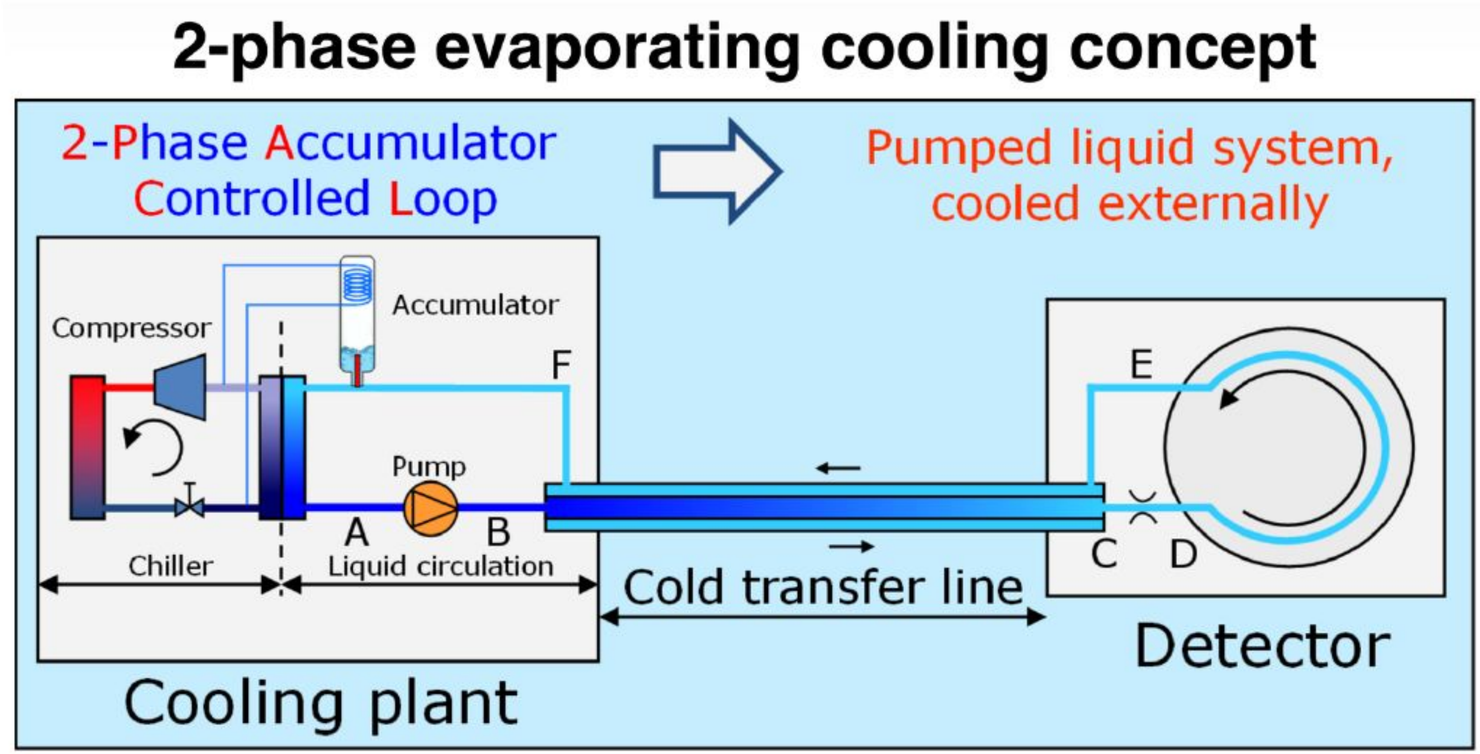
- Sandwich of D-shaped substructures with embedded cooling pipes
- No special modules (e.g. no wedge shaped modules as in current strip tracker)





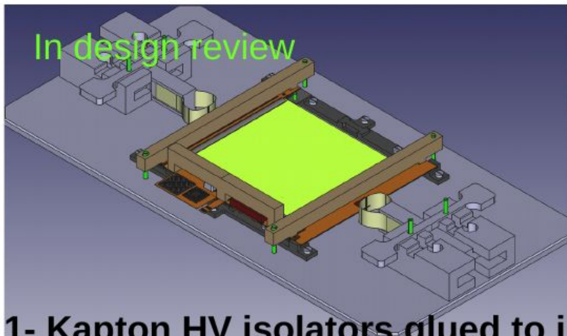


CO_2 Cooling

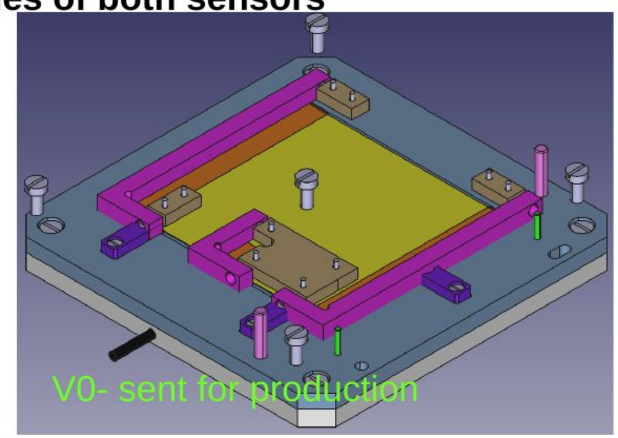


- Total required cooling power ~100kW subdivided in several redundant cooling plants
- Common to OT and Pixel
- Advantages of CO_2: large latent heat, low viscosity, low mass, cheap, environmental friendly
- Copper-nickel, stainless steel (easy to manufacture) or titanium
- Two-phase cooling concept, evaporation <50% to avoid dry-out risks
- Mature technology already used in many experiments

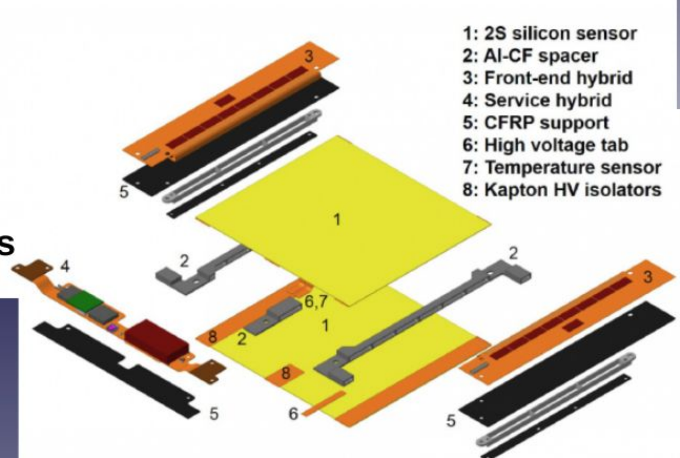
2S Module Assembly

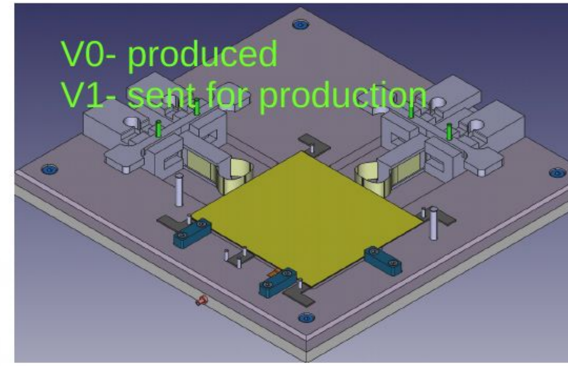


1- Kapton HV isolators glued to inners sides of both sensors



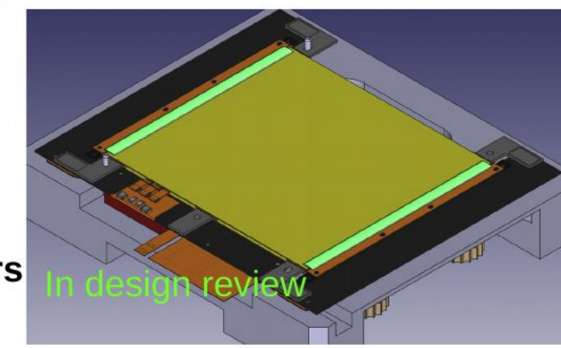
3-read-out and service hybrids are glued to the module





2- Bottom sensor/bridges/top sensor are glued together (sandwiched)

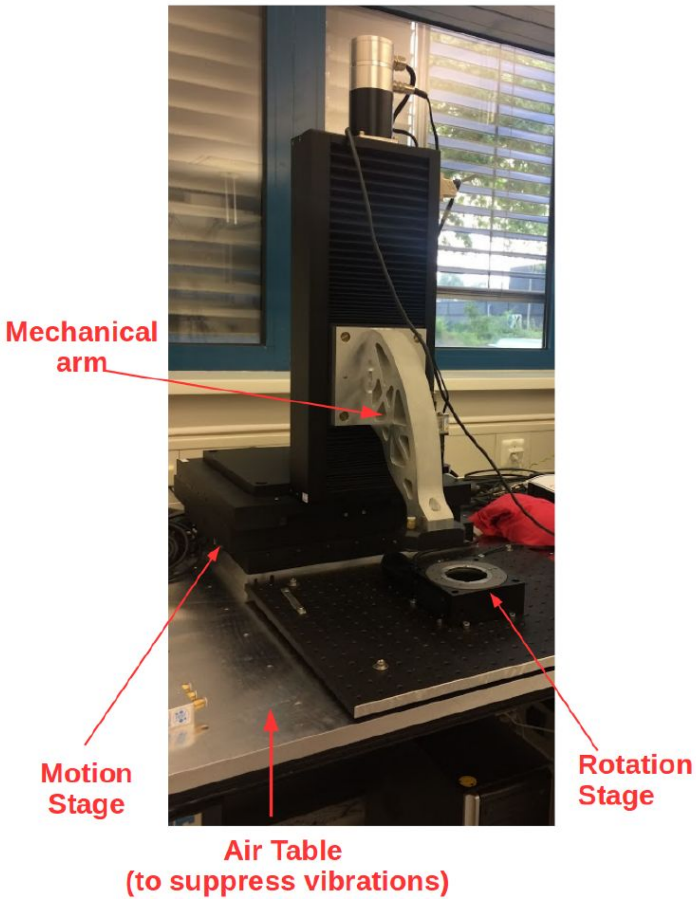
4- hybrids and sensors are wire bonded

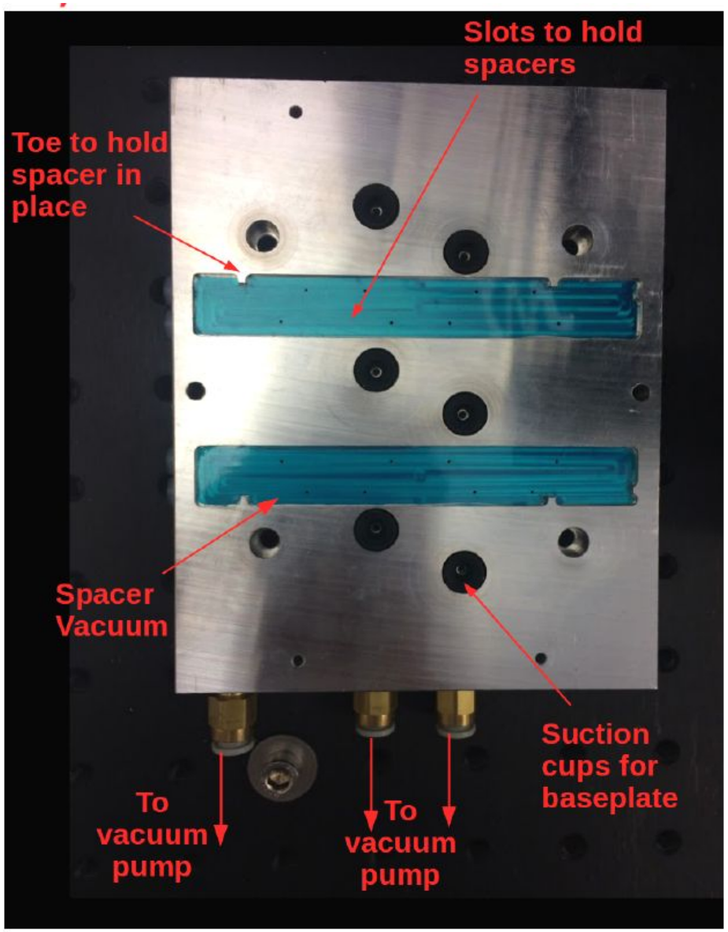


PS Module Automated Assembly Concept

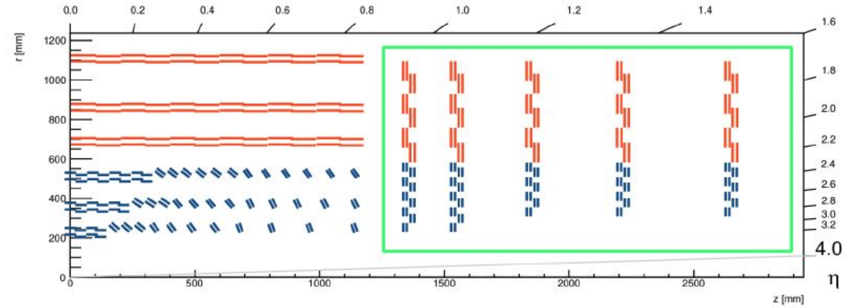
Automated assembly process is developed at DESY. to provide:

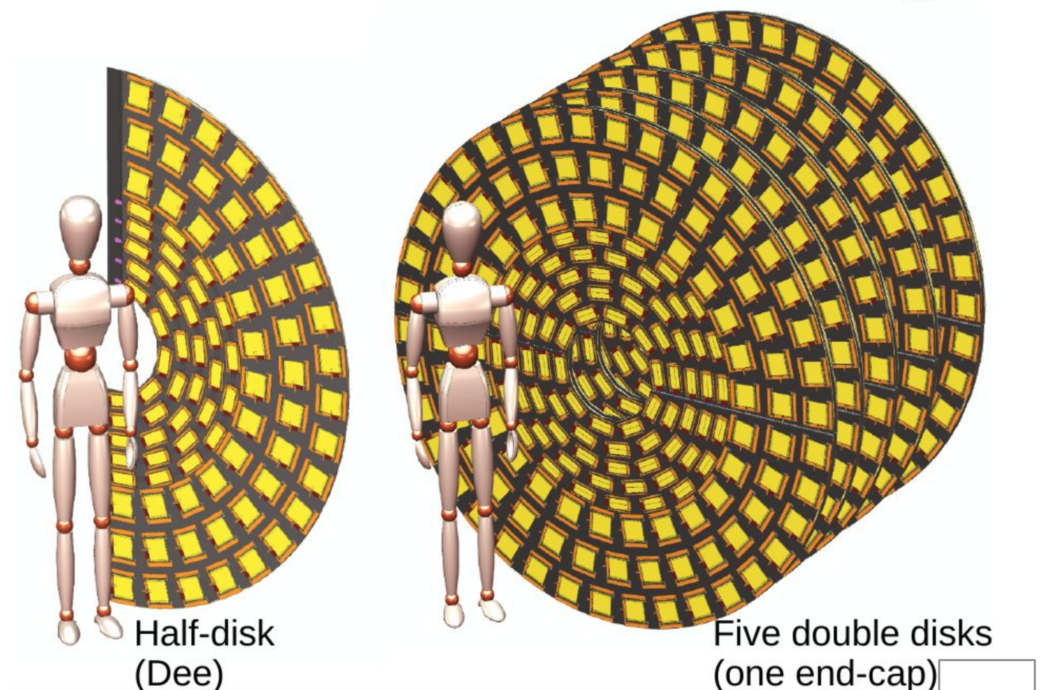
- Necessary precision alignment
- Repeatable results
- Automatic metrology





End-cap Integration





- One of the two tracker end-caps will be integrated at DESY.
- End-cap is built of 5 double disks
- Each double disk is made of two disks
- Each disk is formed from two half-disks (Dee)

Project management

Currently 14 participating Countries:
Austria, Belgium, CERN, Finland, France, Germany, Greece, India, Italy, Pakistan, Spain, Switzerland, UK, US

- The Tracker Upgrade project is embedded in the Tracker Organization

Complete Design Report on the Tracker Upgrade:
https://cds.cern.ch/record/2272264?ln=en

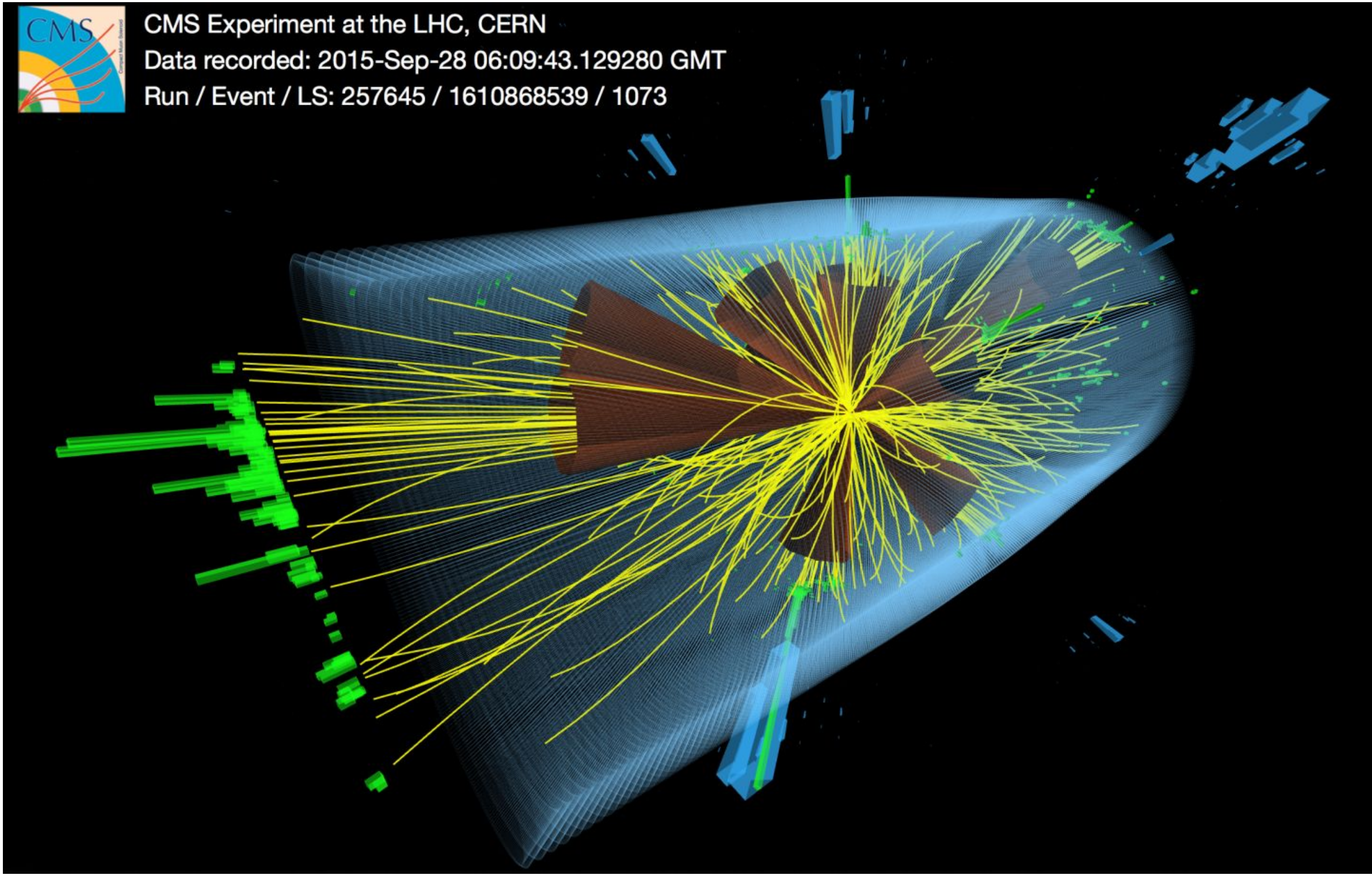
Thank you!

Contact

David Bertsche
Particle Physics - FH
david.bertsche@desy.de

www.desy.de

Backup


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2015-Sep-28 06:09:43.129280 GMT
Run / Event / LS: 257645 / 1610868539 / 1073

CMS Tracker for the HL-LHC

LHC to HL-LHC

- Increase nominal instantaneous luminosity by 5-7 times
- 3000 fb^{-1} integrated luminosity over 12 years

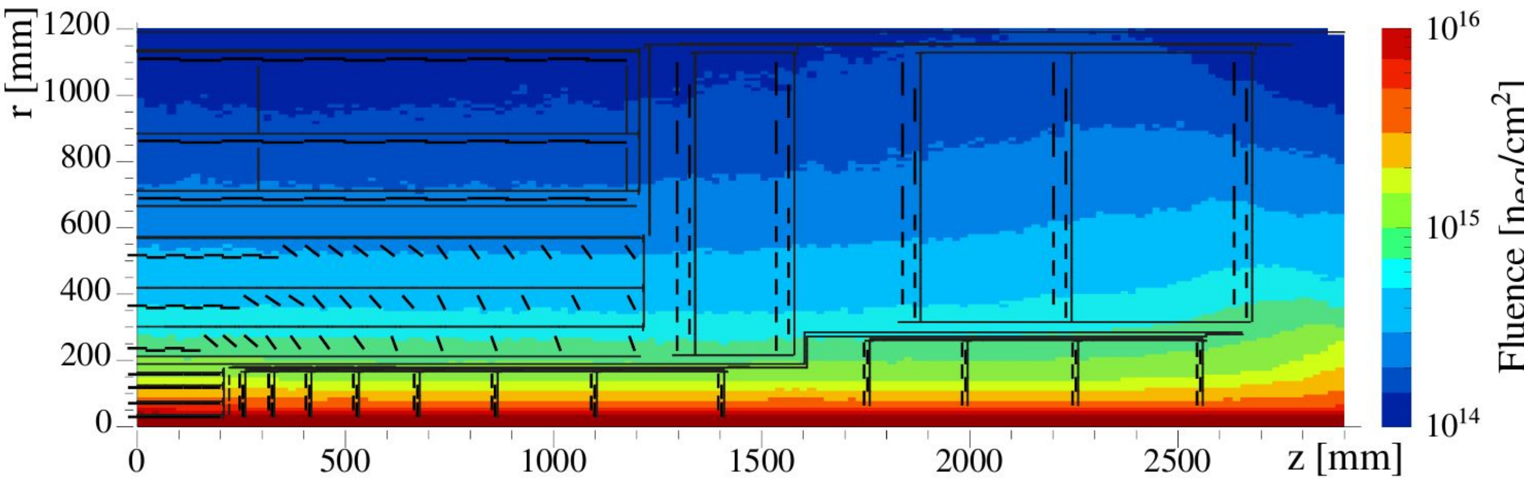
CMS Tracker Challenges

- Increased radiation and Increased pileup (PU)

Requirements

- A new tracking detector is needed to keep up a good performance, Radiation hard sensors, Increased sensor granularity
- Contribution to the first level trigger → reduce data rates
- CMS already operating close to specifications (500/fb^{-1}, PU~20)
- Radiation levels ~6× the design ones
- The entire Tracker (OT and Pixels) needs to be replaced

HL-LHC radiation environment



Requirements

- Operate up to 200 <PU> and keep occupancy athe ~1% level
- higher granularity in the strip detectors
- Radiation tolerance up to 3000 fb^{-1}
- HL-LHC requirements are ~10× than present tracker ones
- Challenging for silicon sensors and electronics (notably in the pixel region), but the inner parts of the pixel detector could be replaced if needed

Figure shows integrated particle fluence in 1 MeV neutron equivalent per cm2 for the Phase-2 tracker. The estimates shown correspond to a total integrated luminosity of 3000 fb− 1 of pp collisions at s = 14 TeV

Rates, Trigger and Other Improvements

Despite the foreseen improvements (among other also an higher rate, from 100kHz to 750kHz), at HL- LHC a L1 trigger exclusively based on muons and calorimeters will not be able to stand spurious rates due to the higher PU and the limited resolution: e.g., in the muon case, no transverse momentum (pT) threshold is effective in reducing the rate. L1 latency is increased from ~3μs to 12.8μs to allow for more time to digest the tracker information

Additional Improvements

Extended tracking acceptance up to |η|~4

- physics goal is Vector Boson Fusion and Vector Boson Scattering
- being able to do Particle Flow up to |η|~4 (PU mitigation, track/jet to vertex assignment, track-to-muon and track-to-calorimetric deposit association)

• Reduce the amount of tracking material

- tracker material is a limiting factor for ECAL performance (energy corrections)
- tracker material is the main source of track reconstruction inefficiency (nuclear interactions)
- tracker material is a difficulty in the track candidate propagation for pattern recognition and fitting of track reconstruction

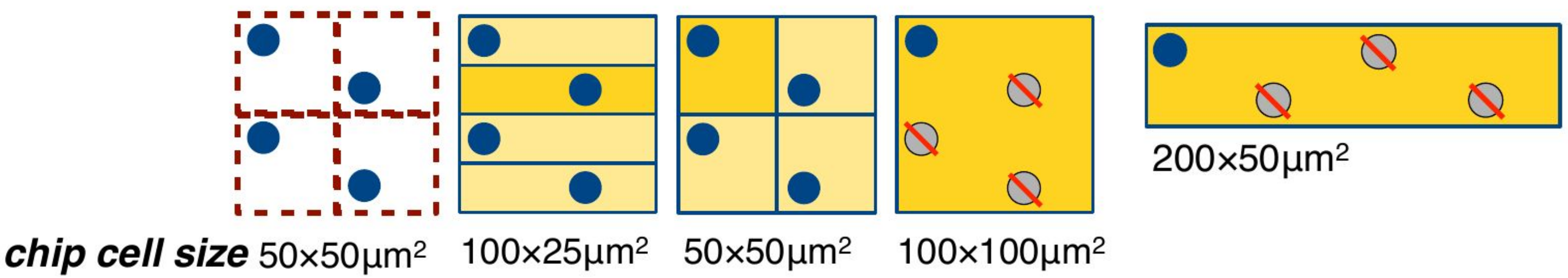
Pixel Design Design Driving Concepts

• Improved granularity: low occupancy, enhanced resolution and better track separation (especially in jets)

‣ a cell size of 2500μm^2 is the baseline (6x improvement wrt Pixel Phase1)

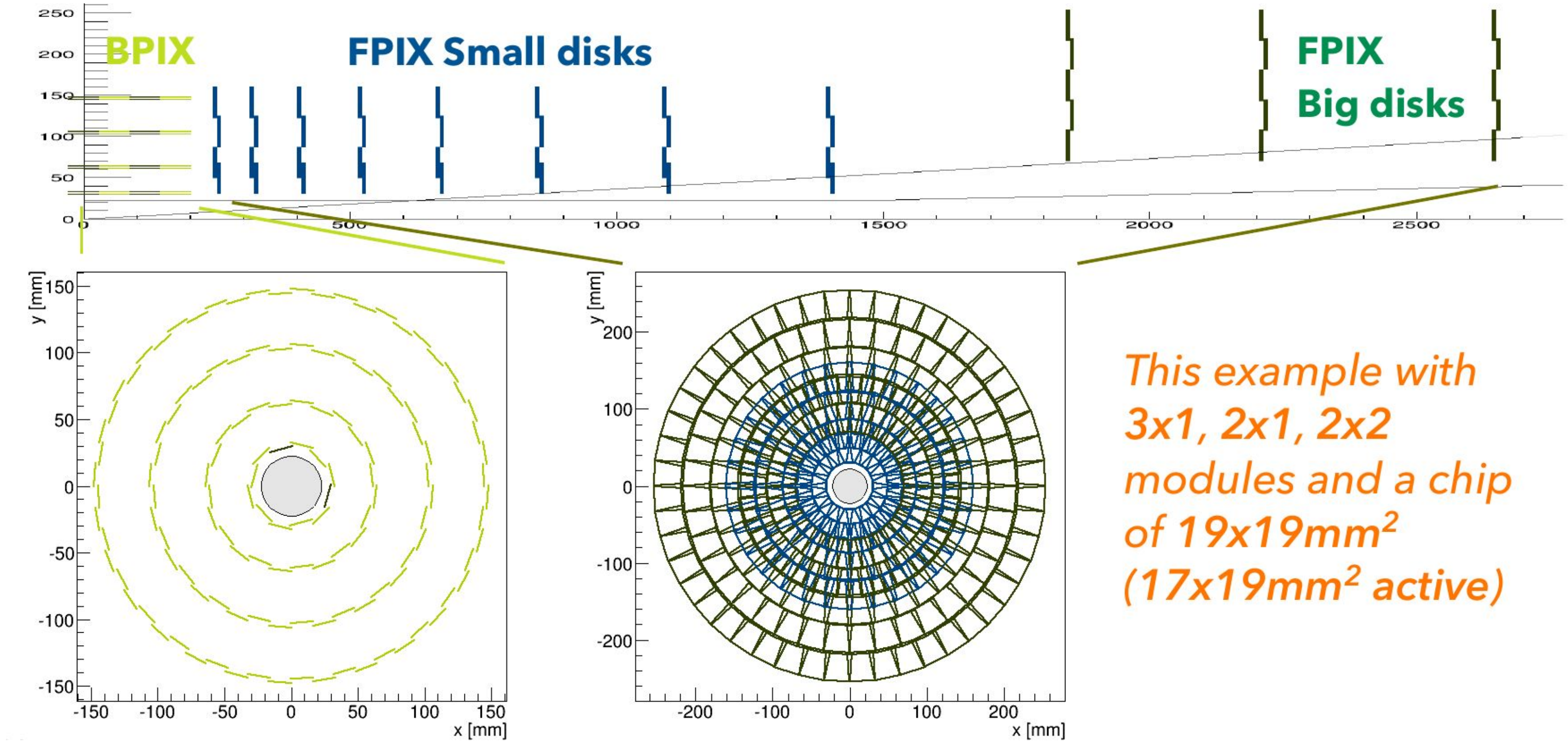
Technologically feasible: ROCs with similar cell size exist (MEDIPIX family); above currently affordable minimum distance between bumps in bump bonding technology limit (~25-30μm)

‣ allows several aspect ratios (25x100μm^2, 50x50μm^2) with the same cell size or with larger cell size (50x200μm^2, 100x100μm^2) if readout pattern can be appropriately configured to save power; finer pitches in the innermost layers/rings; square pixels in the endcaps



Pixel Design Design Driving Concepts

- Few module types, no wedge shaped modules, no turbines
- simple and lightweight mechanics chip size ~2x2cm^2
- sensors may differ in sensor pitch depending on radius

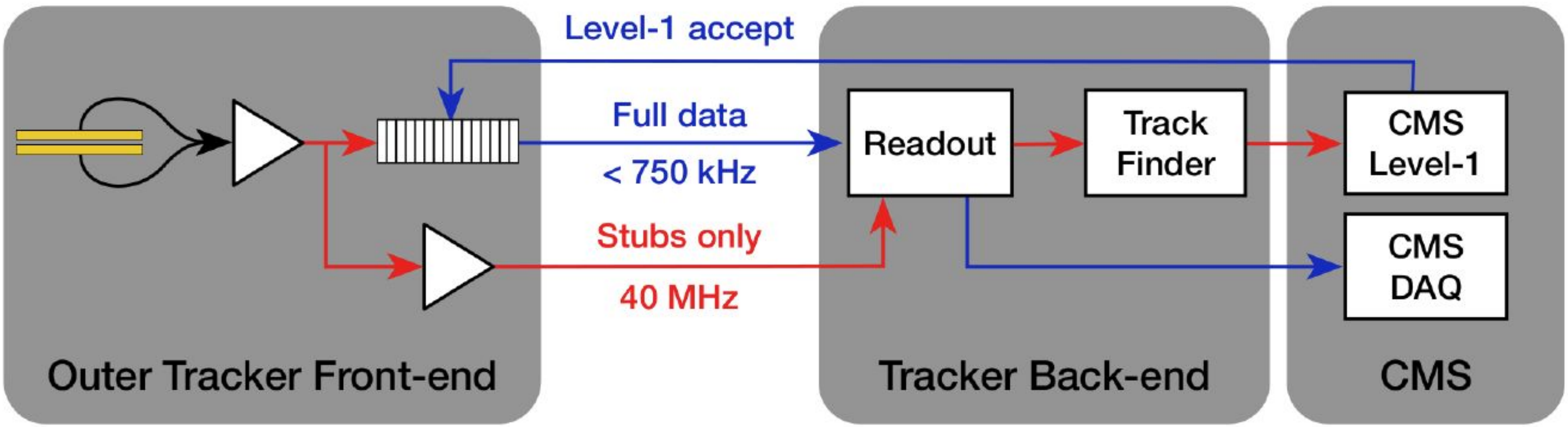


*This example with **3x1, 2x1, 2x2** modules and a chip of **19x19mm^2** (**17x19mm^2** active)*

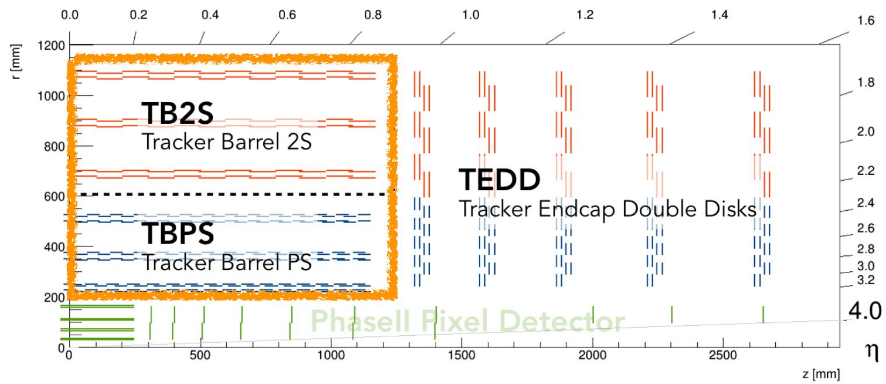
Tracker Trigger Concept Processing

Processing

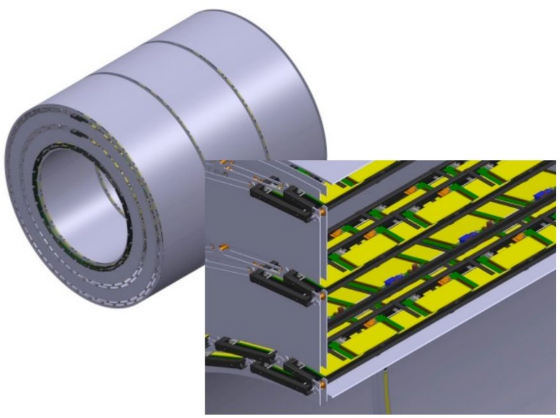
- Stub data are sent at 40 MHz to the track trigger in the back-end of the tracker for the track finding
- Event data buffered in front-ends awaiting for L1-accept signal

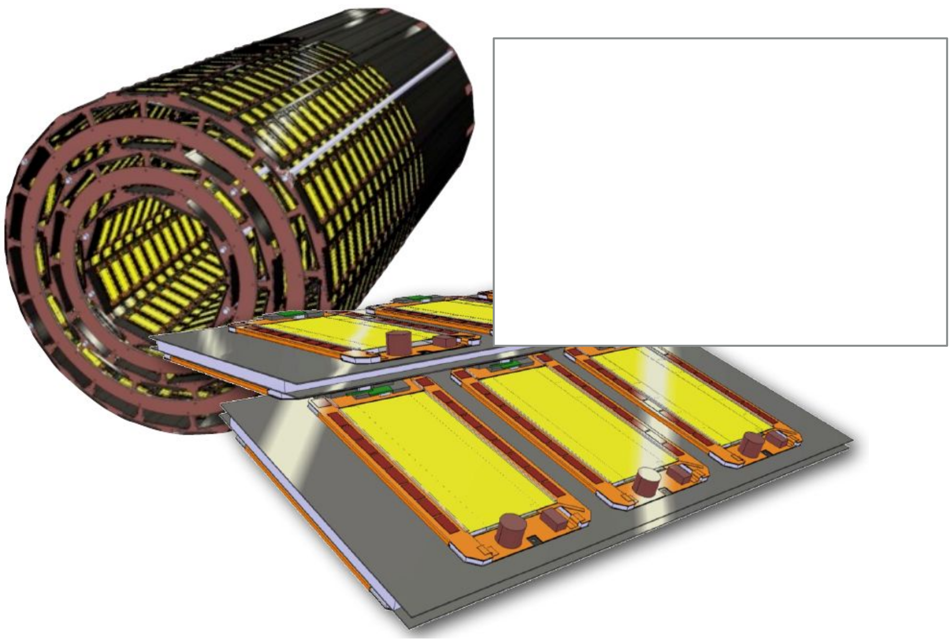


TB2S and TBPS mechanics concept



- TB2S, barrel part with 2S modules: ladders into wheel concept (similar to current TOB)
- TBPS, barrel part with PS modules glued on composite trays





2S Module Assembly Progress at DESY

First Tests

- Done using dummy components
- Measured Missalignment:
  ~5 microns in x and ~20 microns in y
- optimization and improvement of the jig is on going