Universität Zürich[UZH]
Physik-Institut
PAUL SCHERRER INSTITUT PSI

CMS Phase 2 upgrade: Extended Pixels (TEPX)

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PSI | UZH

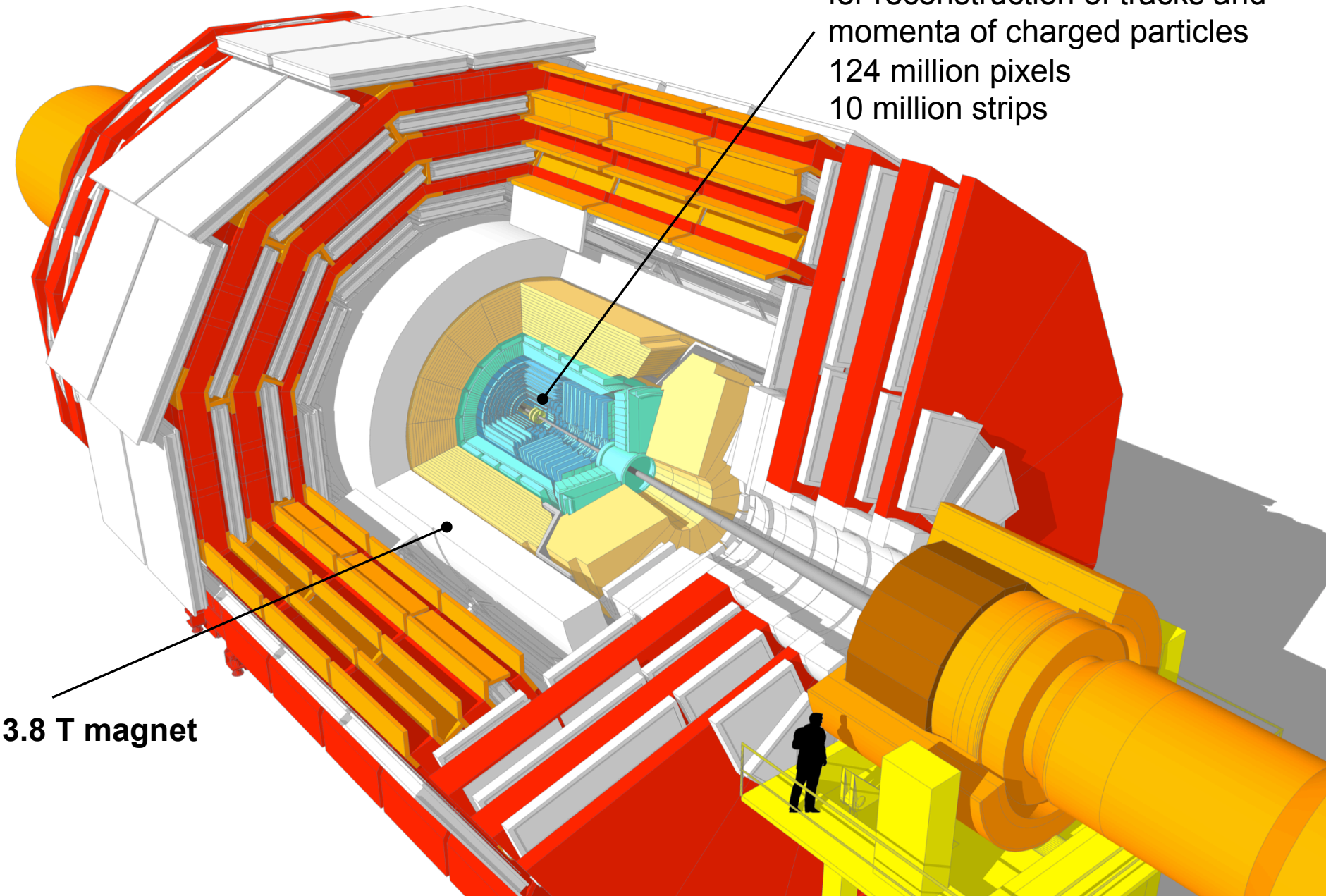
13 September 2018

Outline

- Tracking at CMS
- CMS Pixel Detector
- Phase 2 Upgrade – TEPX
  - Performance goals
  - Design
  - Contributors
  - Timeline
  - New involvement

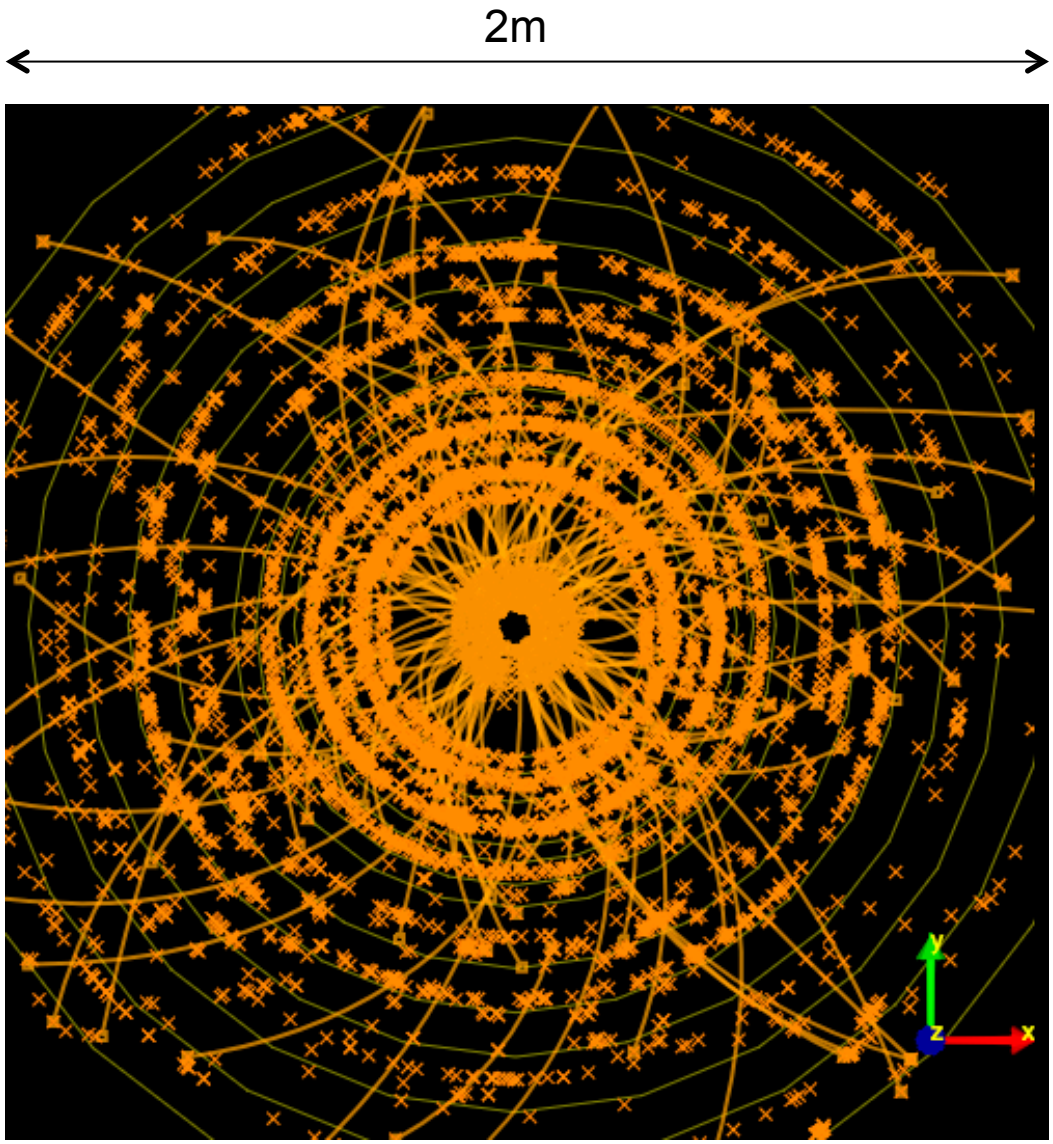
CMS Tracking System

Silicon pixel and strip detectors
for reconstruction of tracks and
momenta of charged particles
124 million pixels
10 million strips



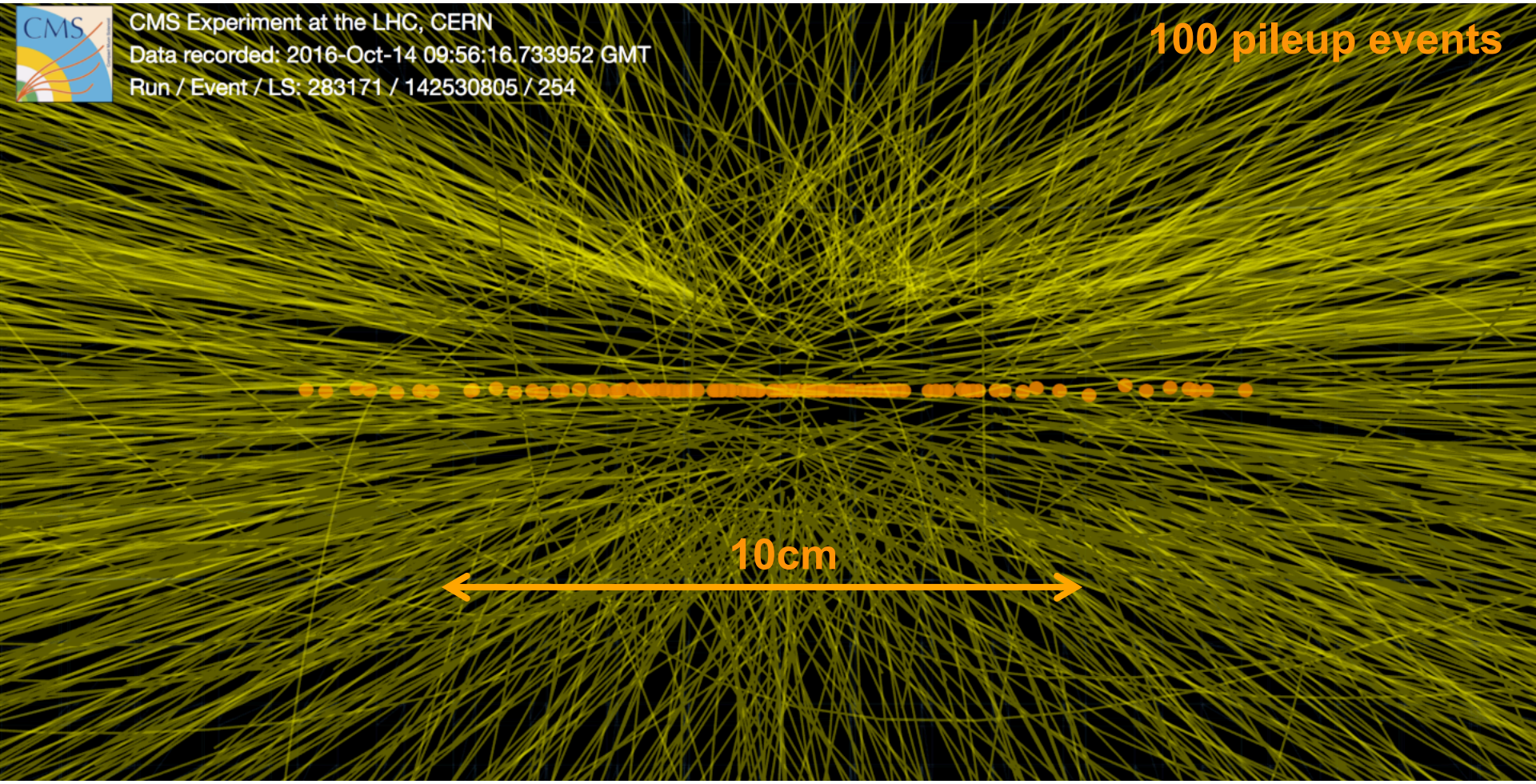
3.8 T magnet

Tracks



More than 1000 charged particles per event. All of these need to be reconstructed with high efficiency and low fake rate

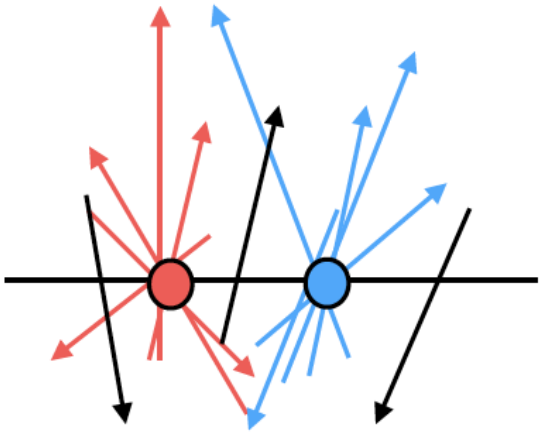
Vertices


CMS Experiment at the LHC, CERN
Data recorded: 2016-Oct-14 09:56:16.733952 GMT
Run / Event / LS: 283171 / 142530805 / 254
100 pileup events
10cm

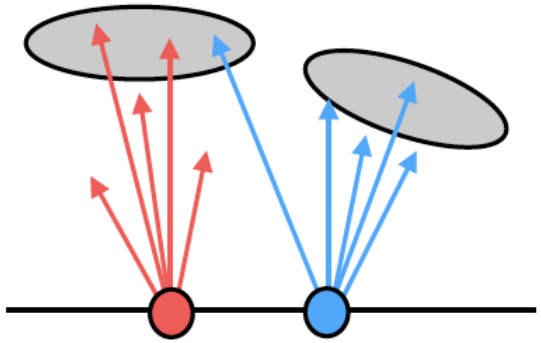
Tracking at CMS

- Track reconstruction is not just about the reconstruction of charged particles
- Tracks are used in almost every element of the event reconstruction
  - Leptons
  - Particle-flow jets
  - Primary vertices
  - Pileup removal for jets and missing energy
  - Jet flavor tagging

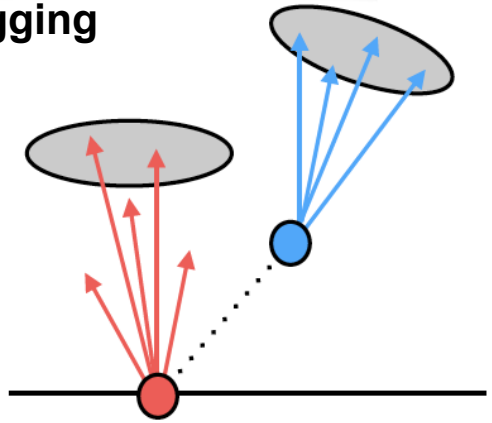
Primary vertex reconstruction



Pileup removal

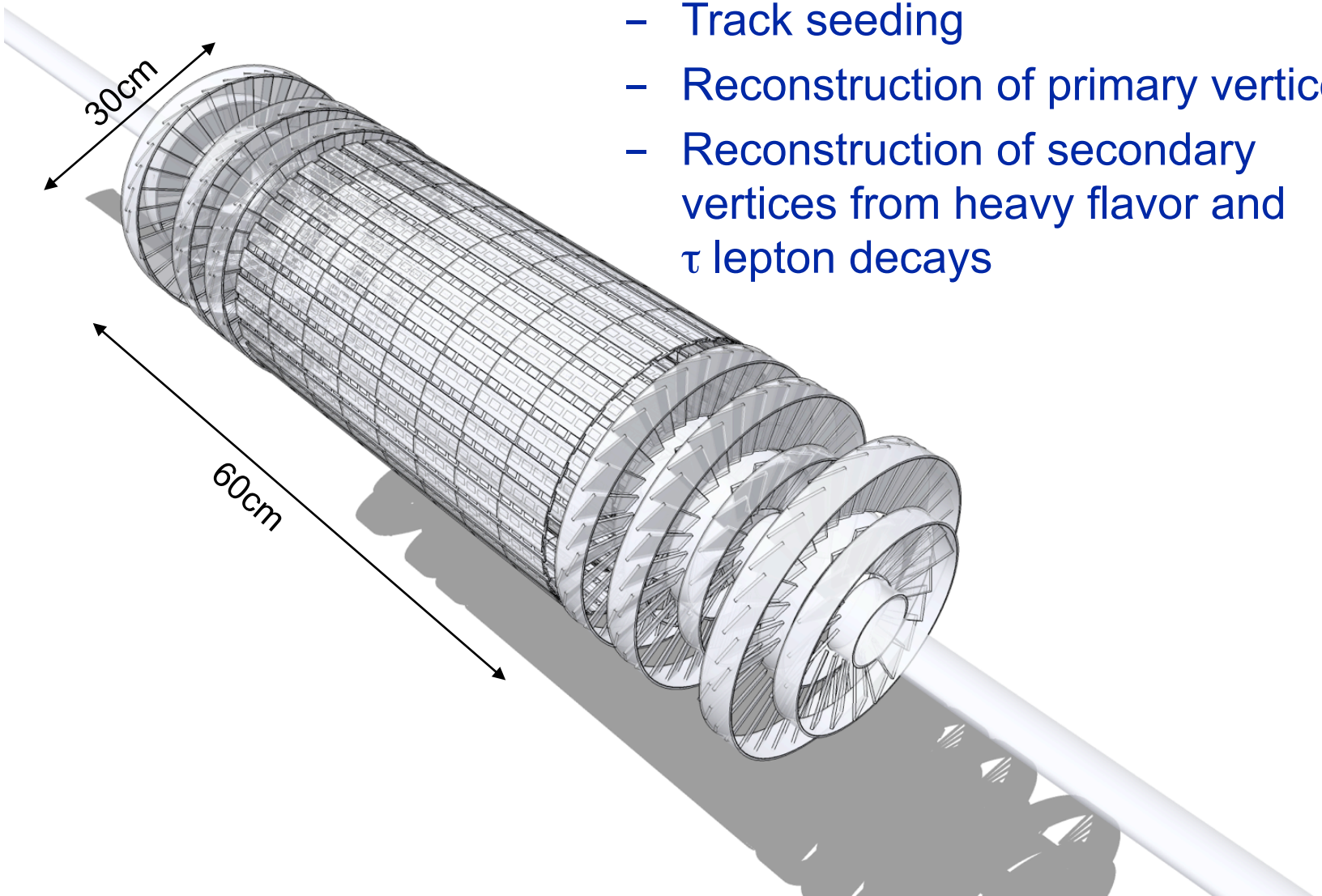


Jet flavor tagging



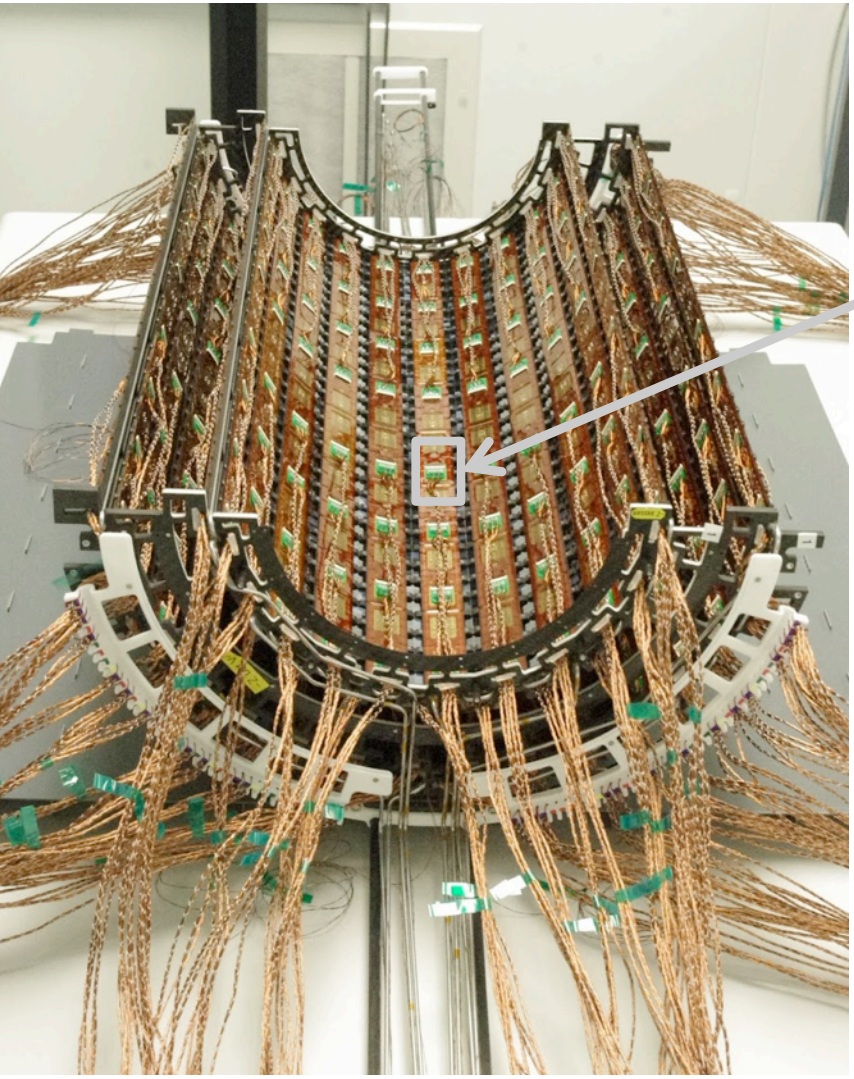
Pixel Detectors

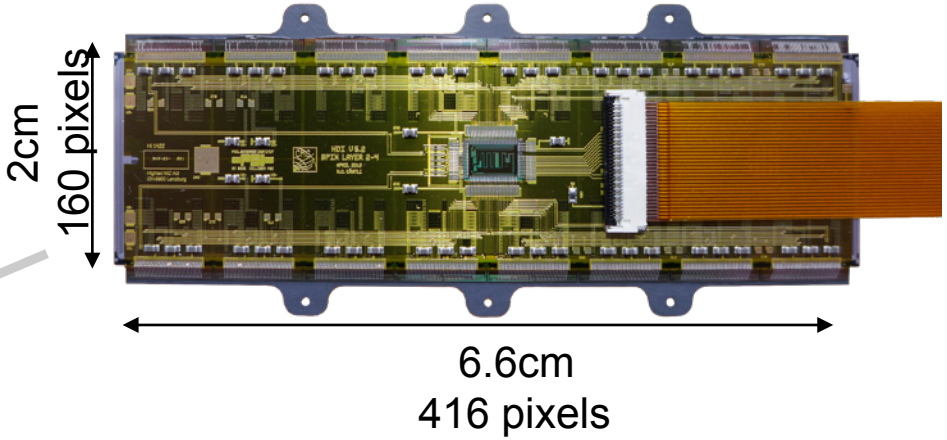
- High precision tracking closest to the proton-proton interaction point allows for:
  - Track seeding
  - Reconstruction of primary vertices
  - Reconstruction of secondary vertices from heavy flavor and τ lepton decays



CMS Pixel Detector

- Layers built from ladders with sensor modules



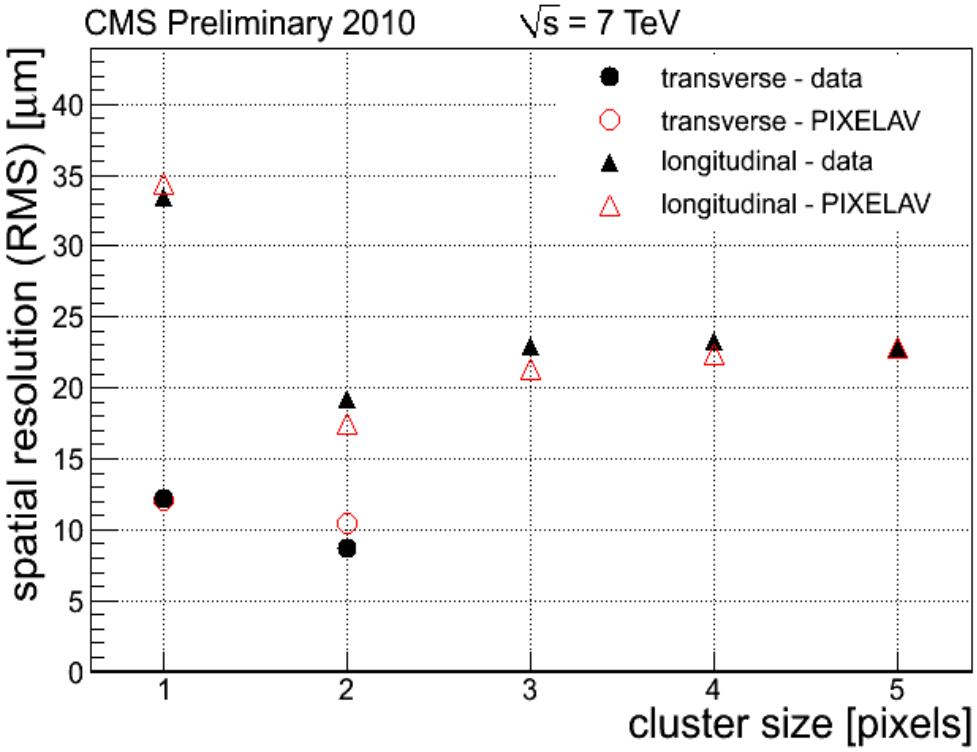


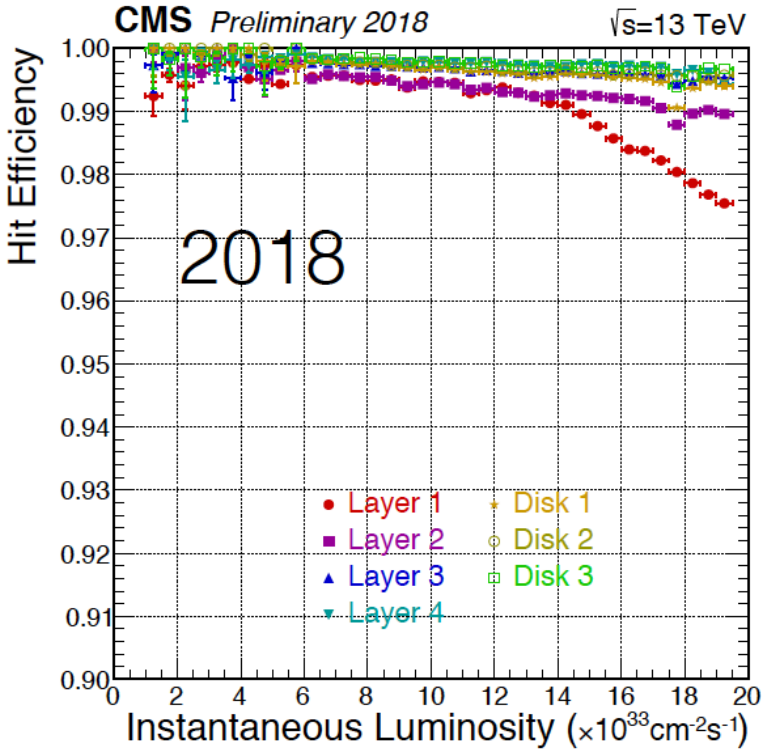
Sensor made from silicon segmented in 66’560 active pixels

Pixel size is 100x150 μm

CMS Pixel Detector Performance

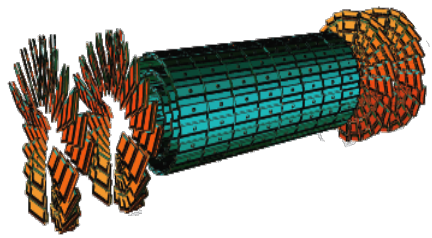
- Excellent performance during data-taking in Run 1+2
- Resolution <10μm in the transverse plane and <25μm in the longitudinal direction
- Hit efficiency >99% for outer barrel layers and forward disks
- Hit efficiency decreases at highest instantaneous luminosity due to dynamic inefficiencies



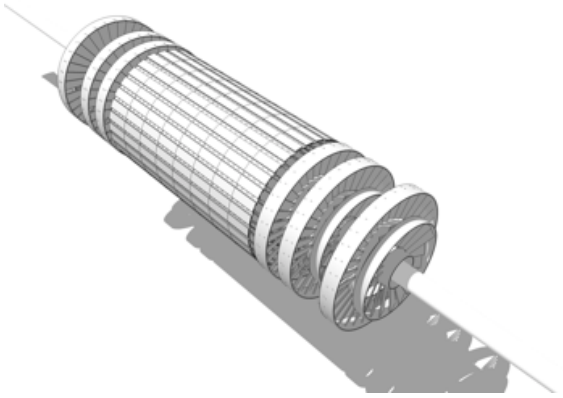


LHC/HL-LHC Plan

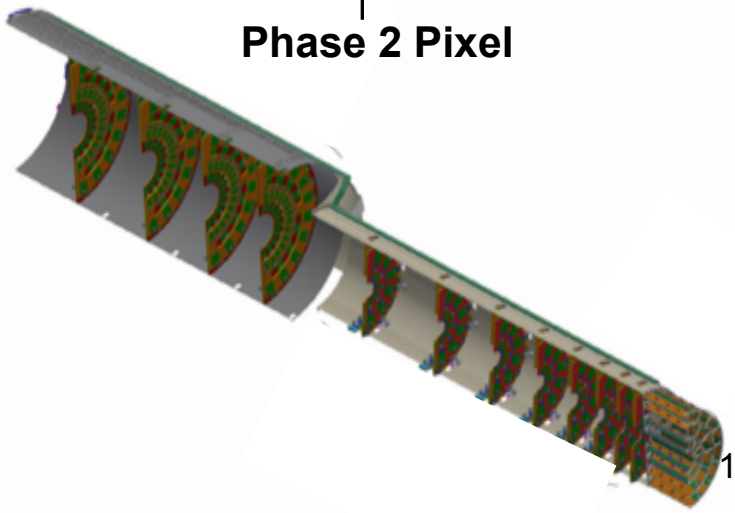
Phase 0 Pixel



Phase 1 Pixel



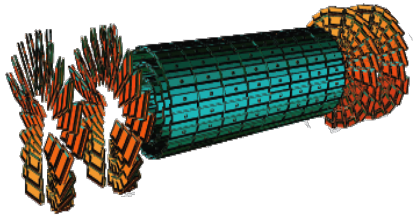
Phase 2 Pixel



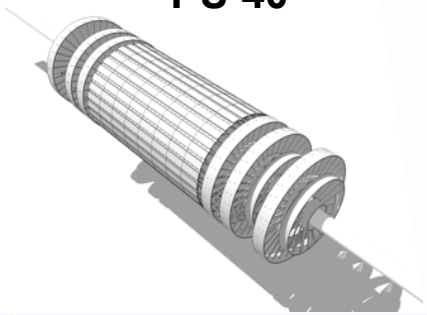
CMS Pixel Detector Upgrades

- Upgrades needed to cope with increasing LHC luminosity

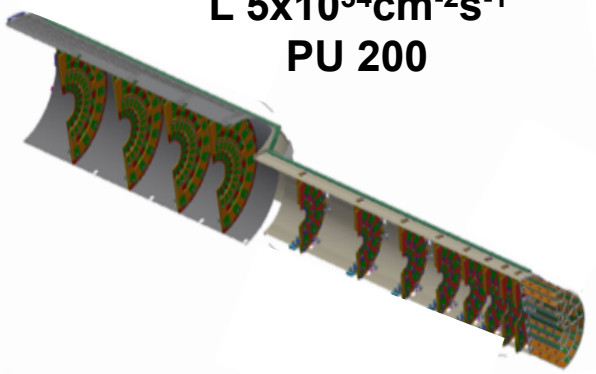
L $1x10^{34}cm^{-2}s^{-1}$
PU 20



L $2x10^{34}cm^{-2}s^{-1}$
PU 40



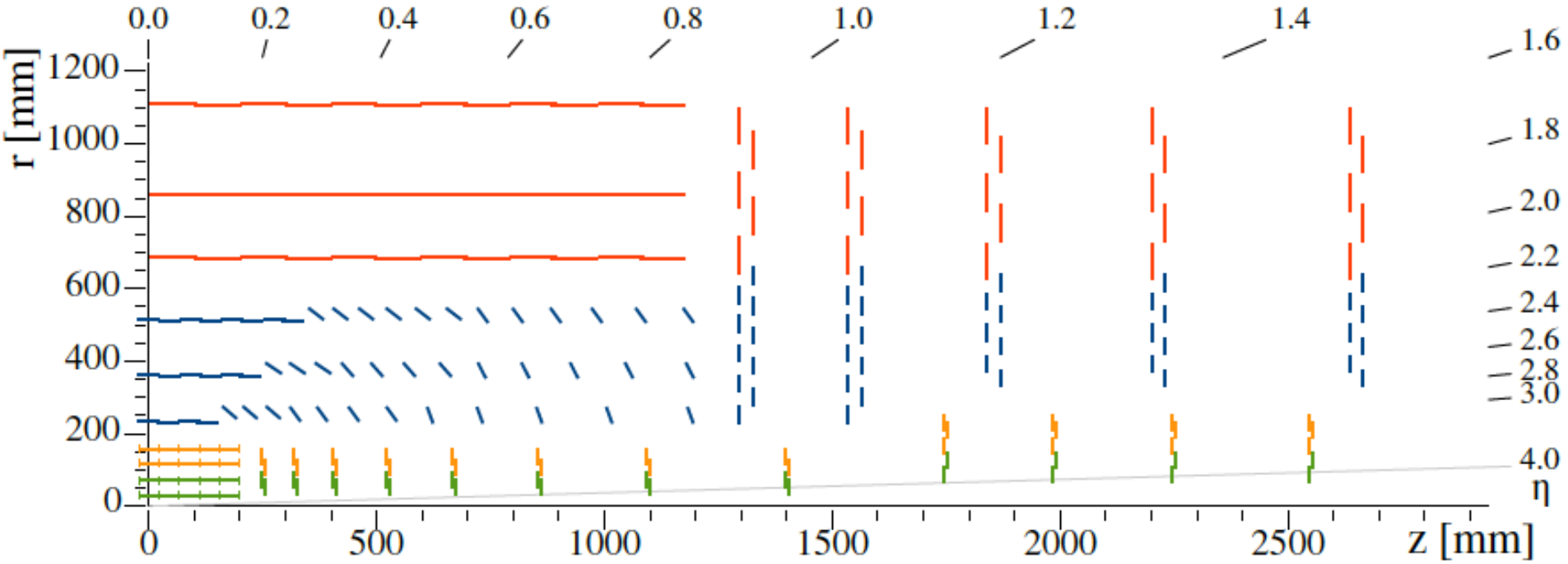
L $5x10^{34}cm^{-2}s^{-1}$
PU 200



	Phase 0	Phase 1	Phase 2
Mechanics	3 layers+ 4 disks	4 layers + 6 disks	4 layers + 24 disks
Inner radius	4 cm	3 cm	3 cm
Active Si area	1 m^2	1 m^2	5m^2
Channels	66M	124M	2000M
Pixel size	100x150 μm^2	100x150 μm^2	25x100/50x50 μm^2
Radiation tolerance	100 Mrad	300 Mrad	1000 Mrad

Phase 2 Tracker Upgrade

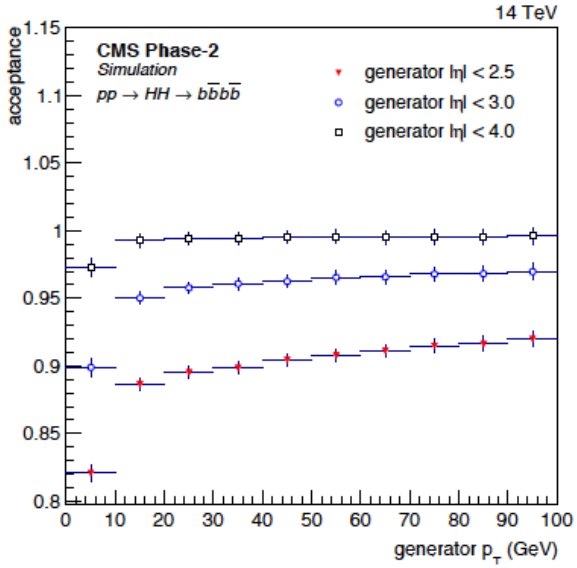
- Whole CMS tracker will be replaced with new system during LS3
- New tracker divided into: IT (pixels) + OT (strips)
- Extension of |η| coverage from 2.5 to 4



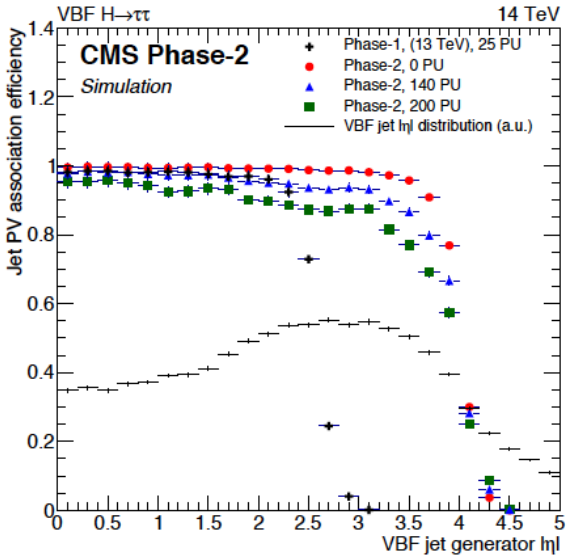
Tracker Phase 2 Performance Goals

- Maintain excellent tracking capability of CMS at HL-LHC:
  - Increase granularity to cope with dense tracking environment
  - Smaller pixels to improve impact parameter resolution
  - Increase rate and radiation tolerance
  - Increase coverage to extend forward acceptance and mitigate pileup effects

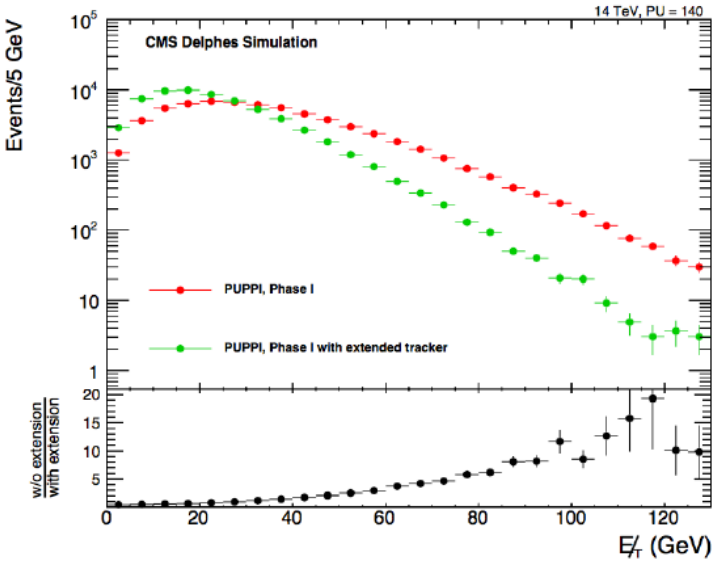
acceptance



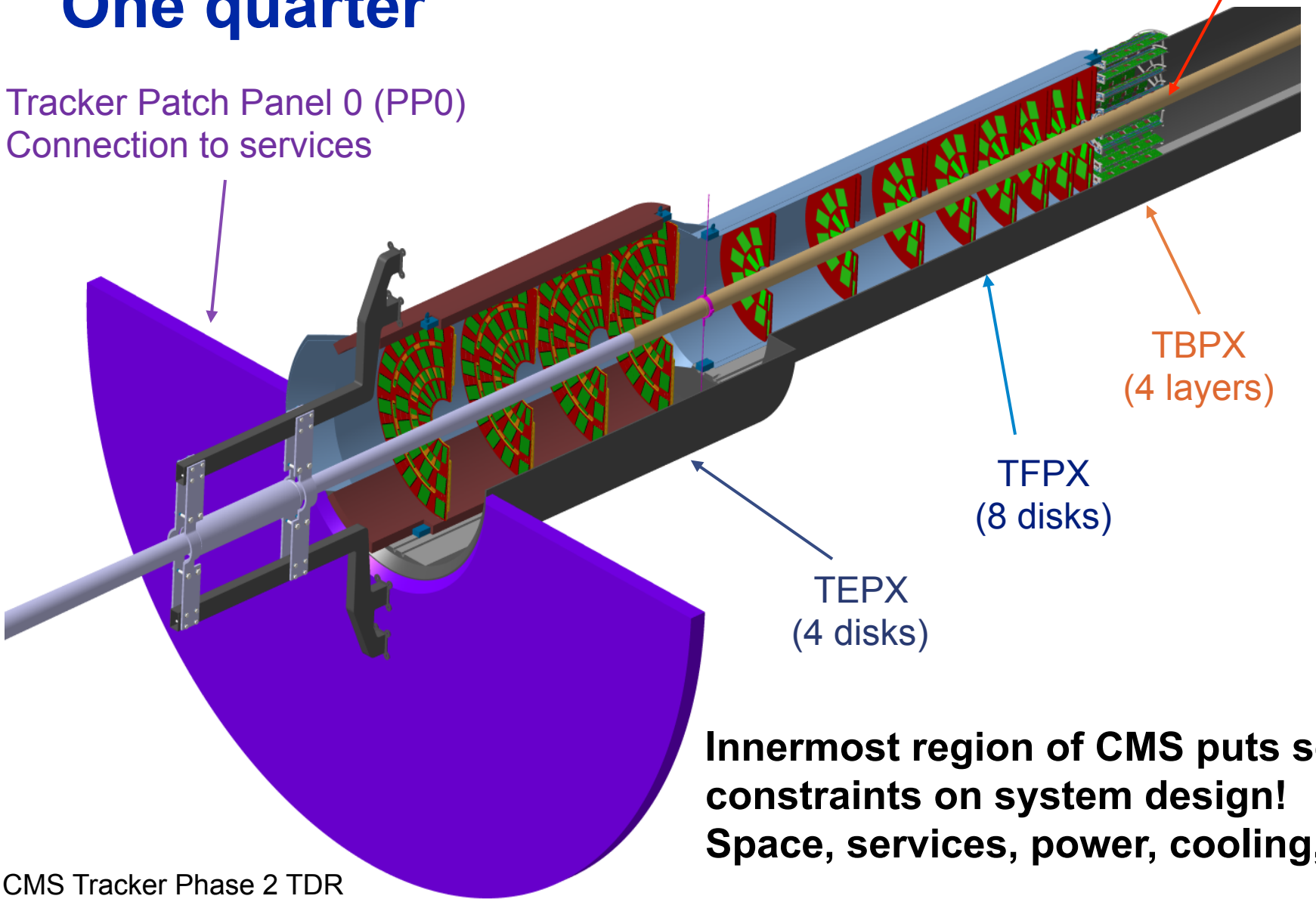
jet-vertex association efficiency



MET resolution



CMS Phase 2 Inner Tracker
One quarter

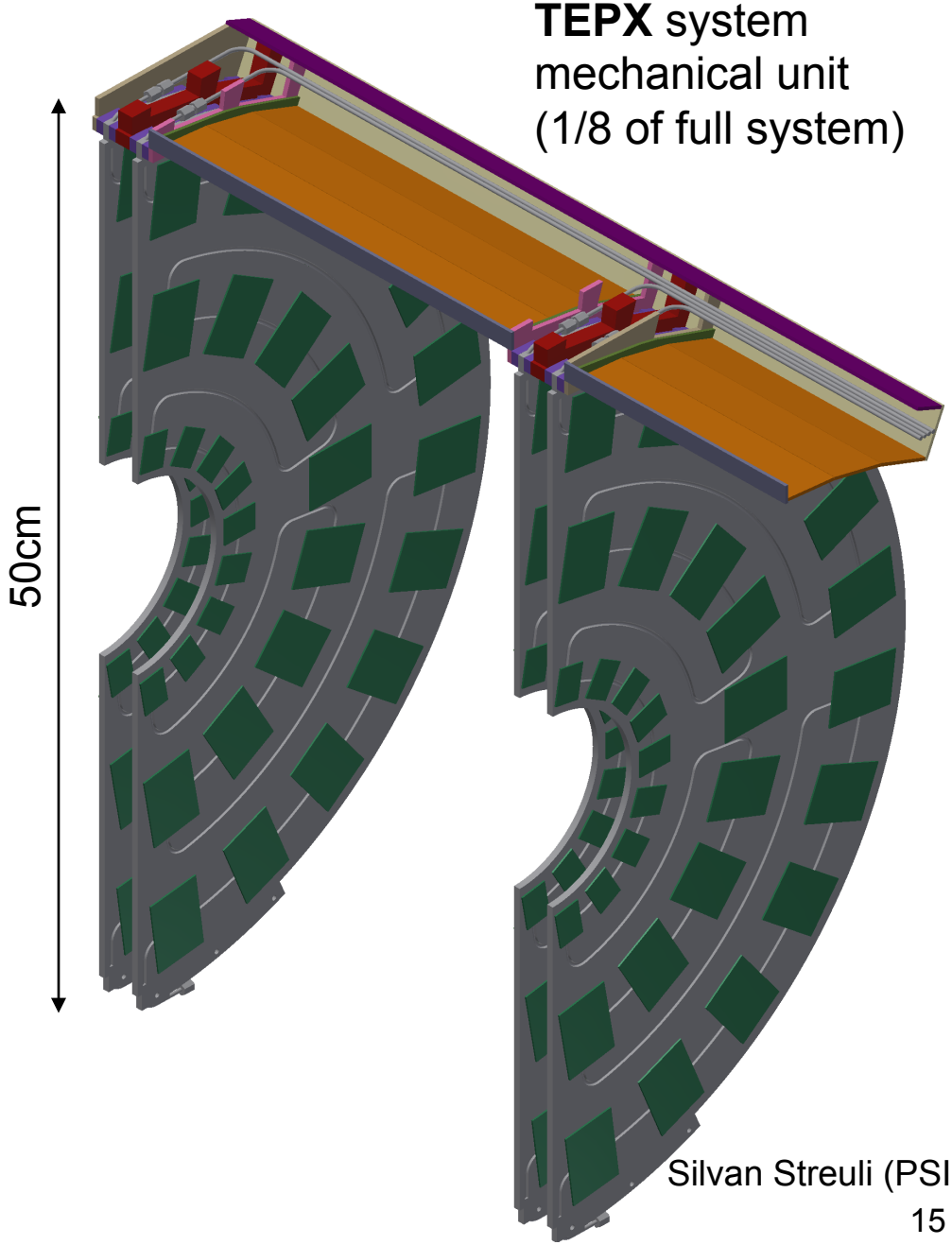


Innermost region of CMS puts severe constraints on system design!
Space, services, power, cooling, ...

CMS Tracker Phase 2 TDR
https://cds.cern.ch/record/2272264

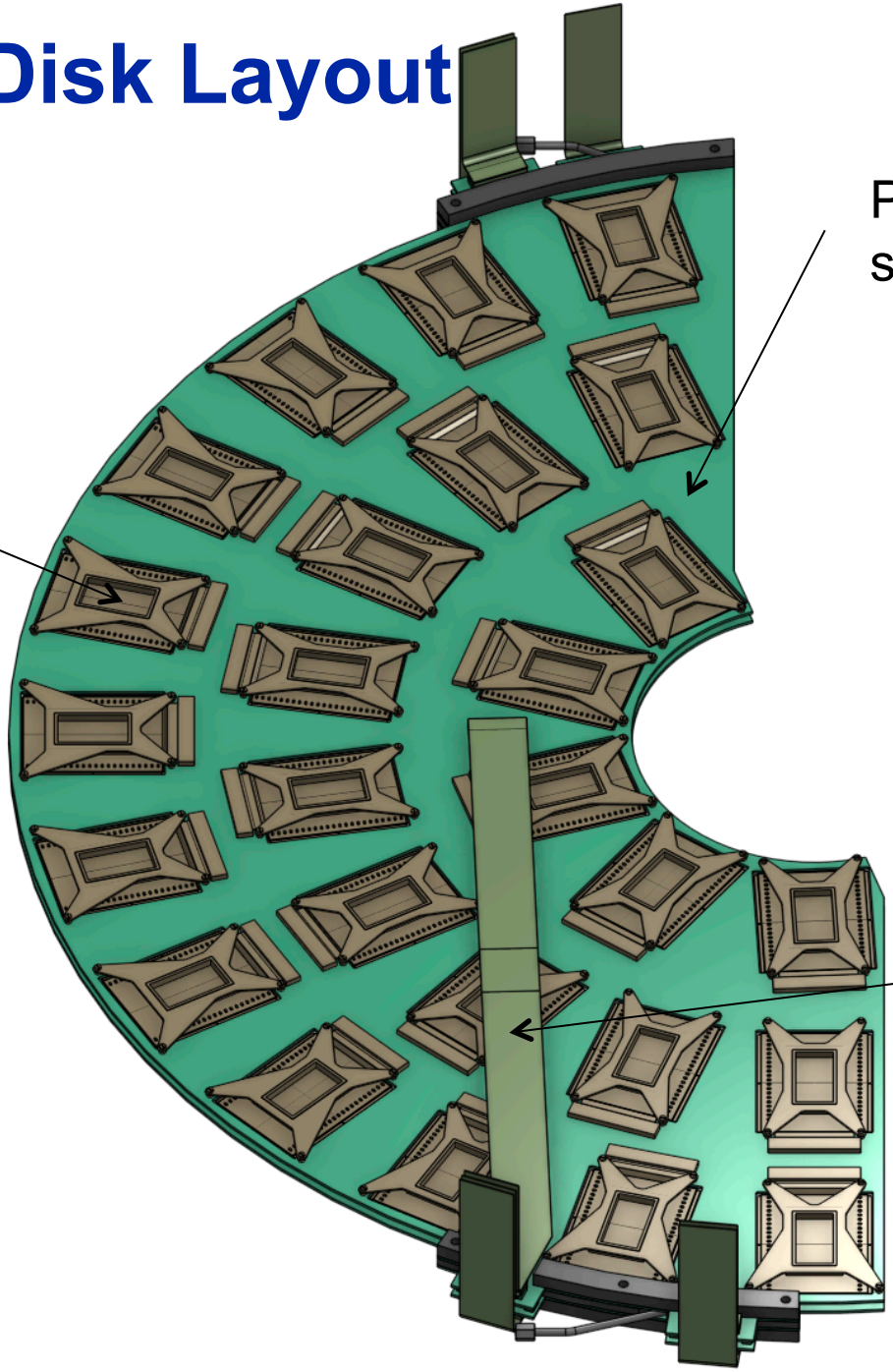
TEPX System

- 2 disks (double Dee) with modules on front and back side form one "z position"
- Modules arranged in 5 rings on double Dee
- Services, power and cooling lines carried within slots from/to modules



TEPX system mechanical unit (1/8 of full system)

TEPX Disk Layout

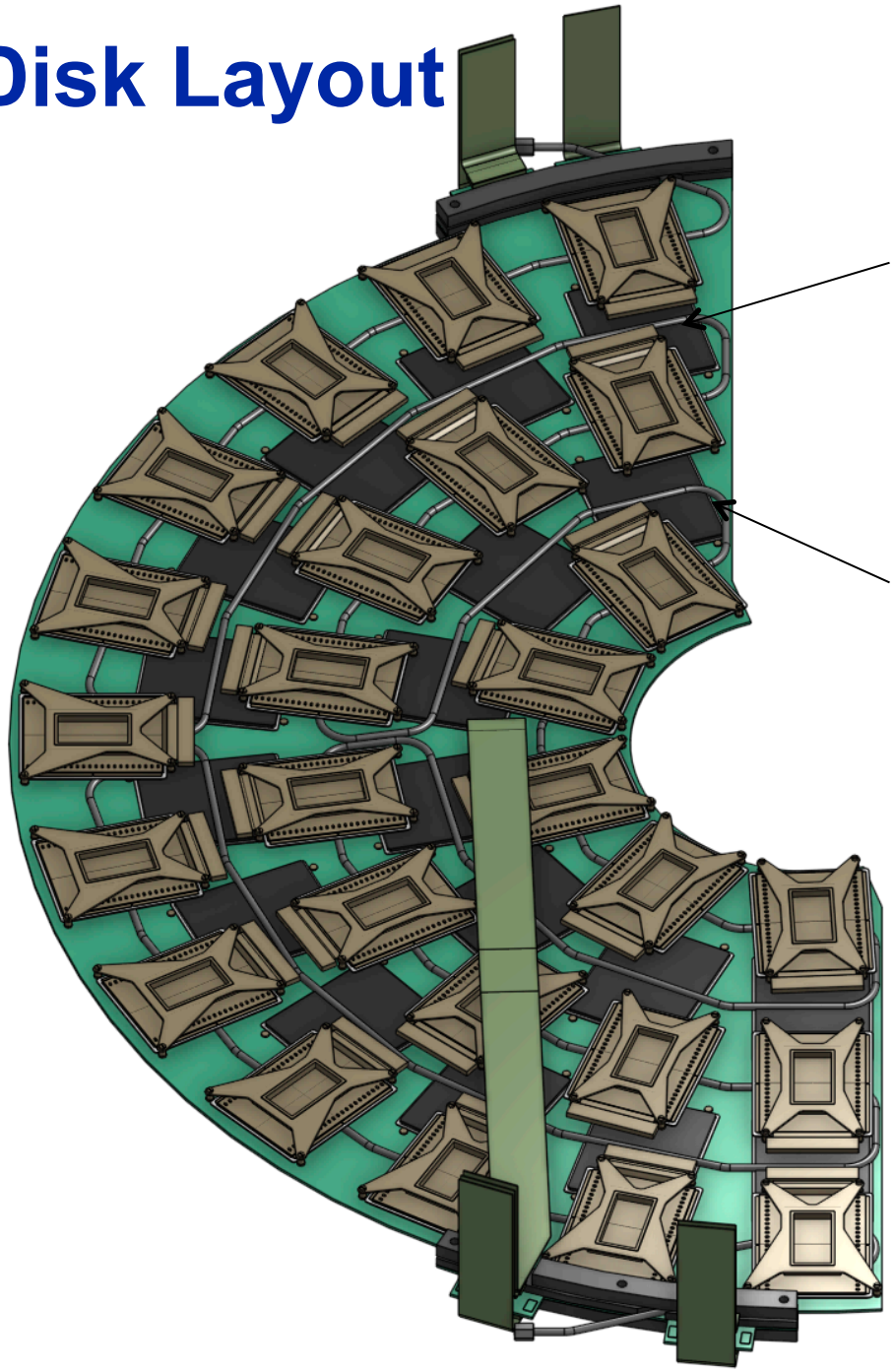


PCB which carries signal and power lines

Modules

Signal cables to supply tube

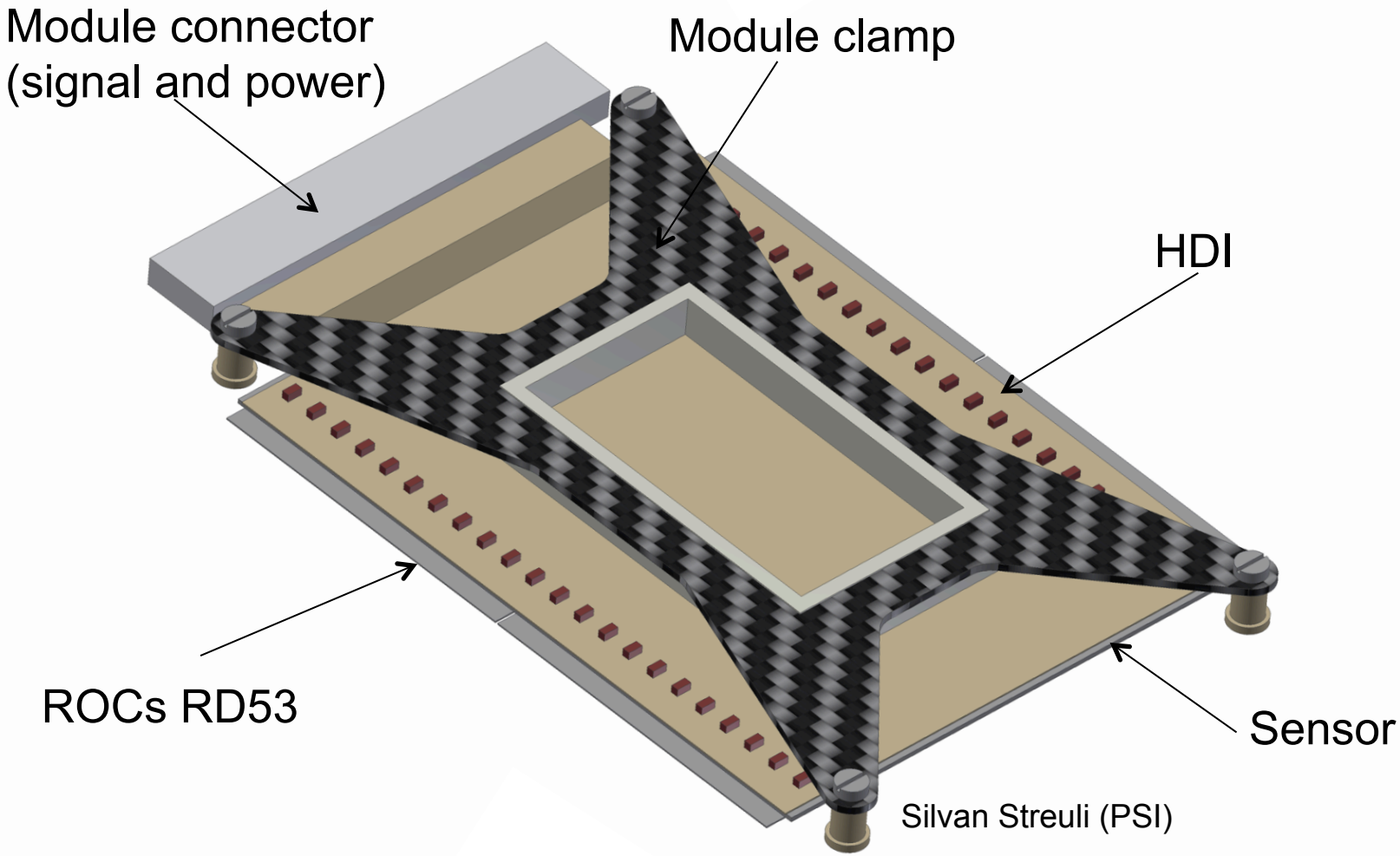
TEPX Disk Layout



Module base plates for thermal contact (ceramic + TPG)

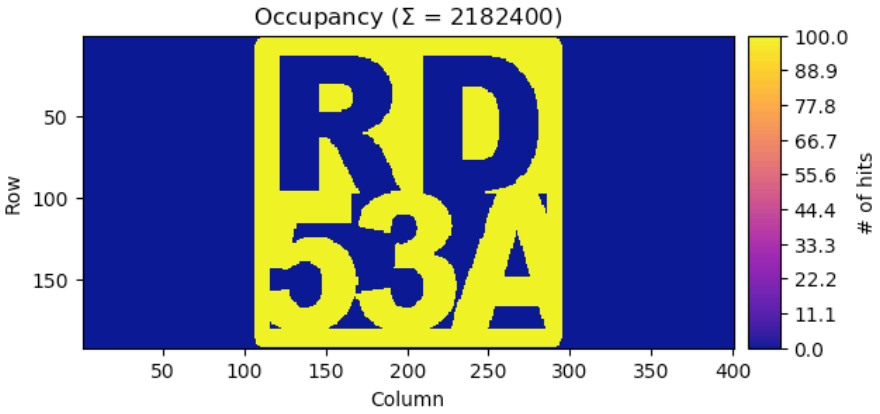
Cooling loops

TEPX Module (2x2, i.e. 4 ROCs per sensor)

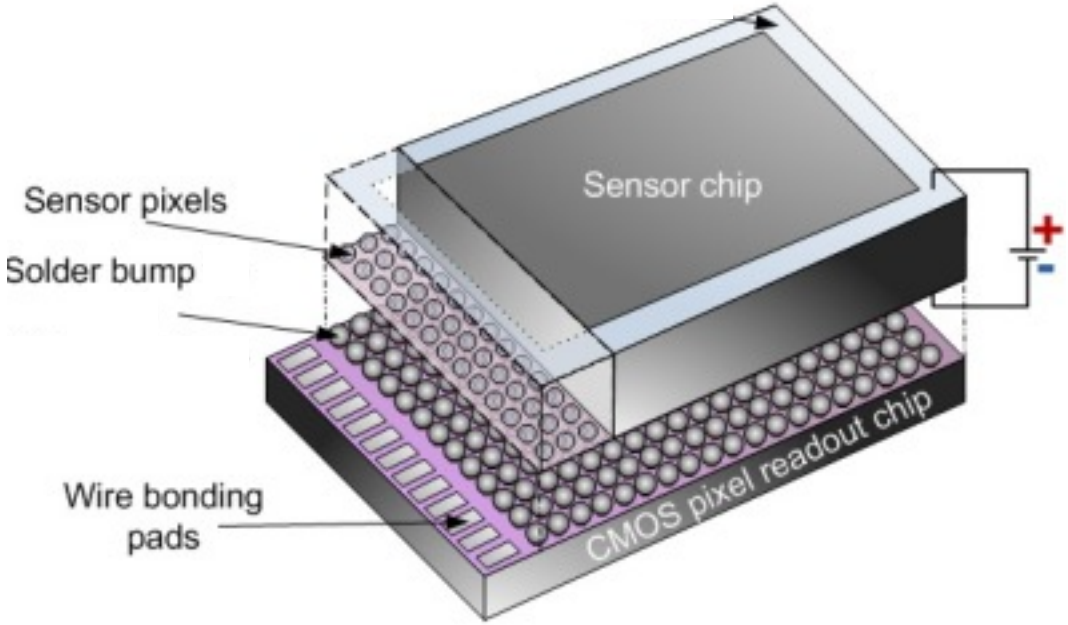


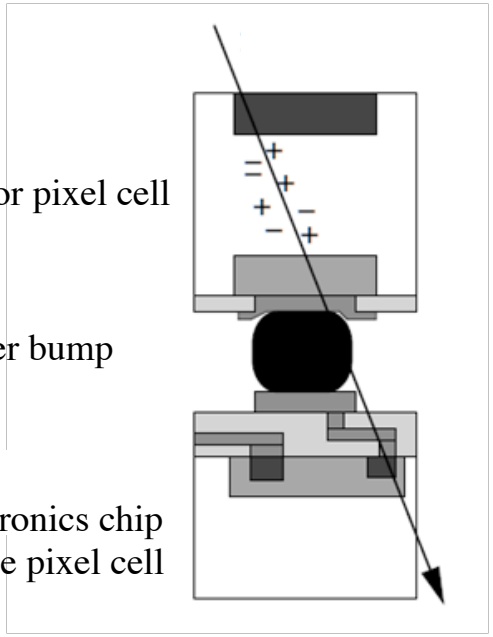
Sensor and Readout Chip

- Sensor and readout chip as common development of TBPX, TFPX and TEPX
  - RD53 collaboration (ATLAS+CMS) for chip development
  - Different options for sensor choice (planar, 3D) being studied



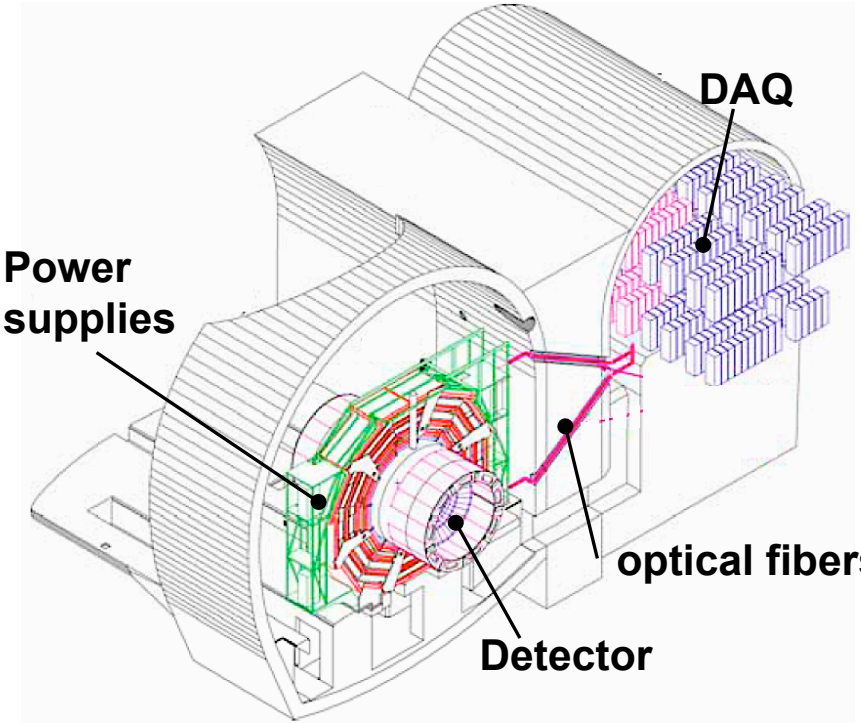
http://rd53.web.cern.ch/rd53/

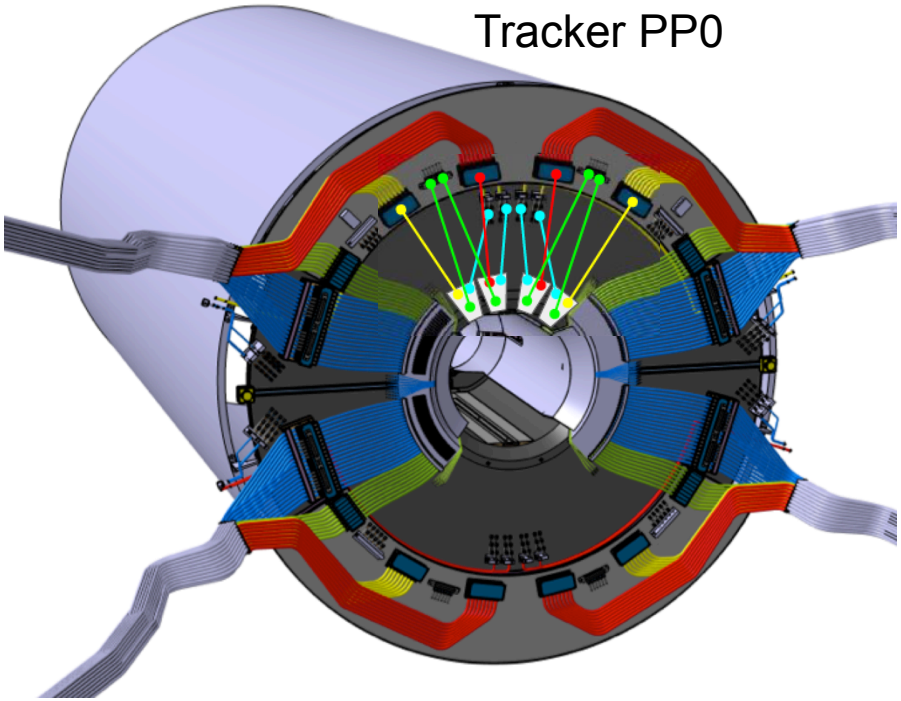




Readout Electronics, Power and Cooling

- High hit rates → large bandwidth for optical links
  - CERN development: lpGBT/VL+ @10Gbs
- More pixels, larger area → significant increase in power consumption
  - adoption of serial powering scheme
- Low mass 2-phase CO_2 cooling system to operate silicon sensors below -20°C





TEPX Contributors

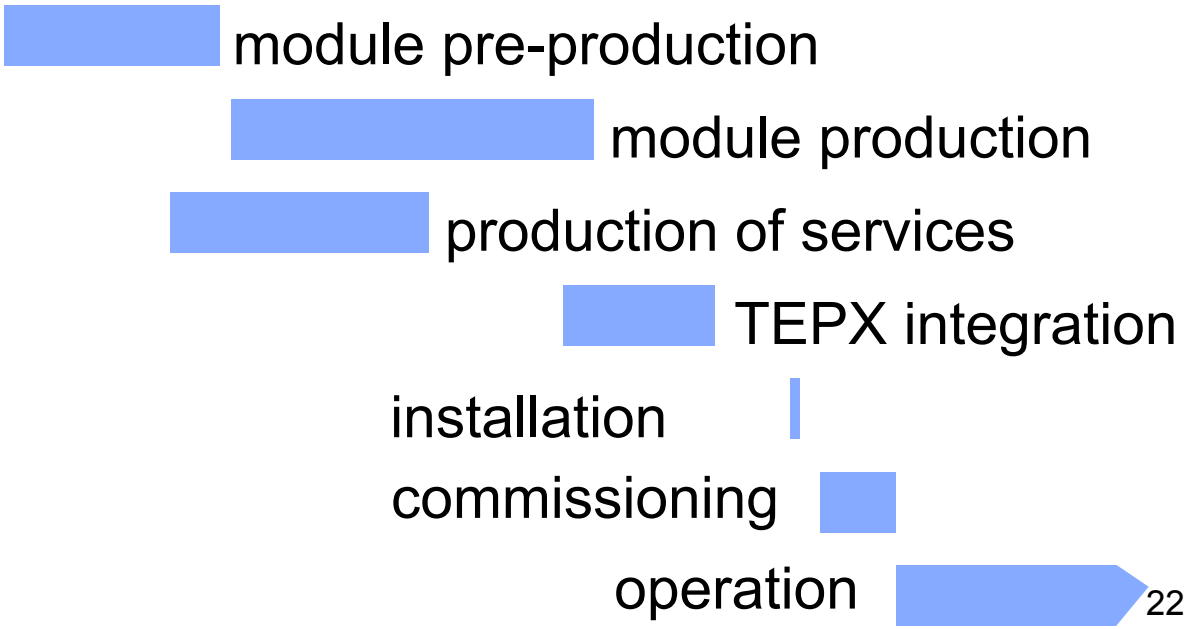
- Efforts in Switzerland for Phase 2 starting up (PSI, UZH, ETH)
  - Leading institutes in design&construction of current and upgrade CMS pixel detectors (Phase 0 BPIX, Phase 1 BPIX, Phase 2 TEPX)
  - Key competences in readout chip and sensor design, module design and construction, readout and services, cooling, mechanical design and installation
- Interest from RBI Zagreb to contribute to TEPX module construction and testing
  - Established collaboration
  - Knowledge transfer through participation in construction and commissioning of replacement L1 of Phase 1 BPIX (installation in 2020)
- Common developments of components within CMS Phase 2 Tracker
  - Readout chip (RD53) and sensors, optical links (lbGBT+)

Timeline

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Run 2	LS 2		Run 3			LS 3		HL-LHC	

R&D → **Production** → **Installation, commissioning & operation**

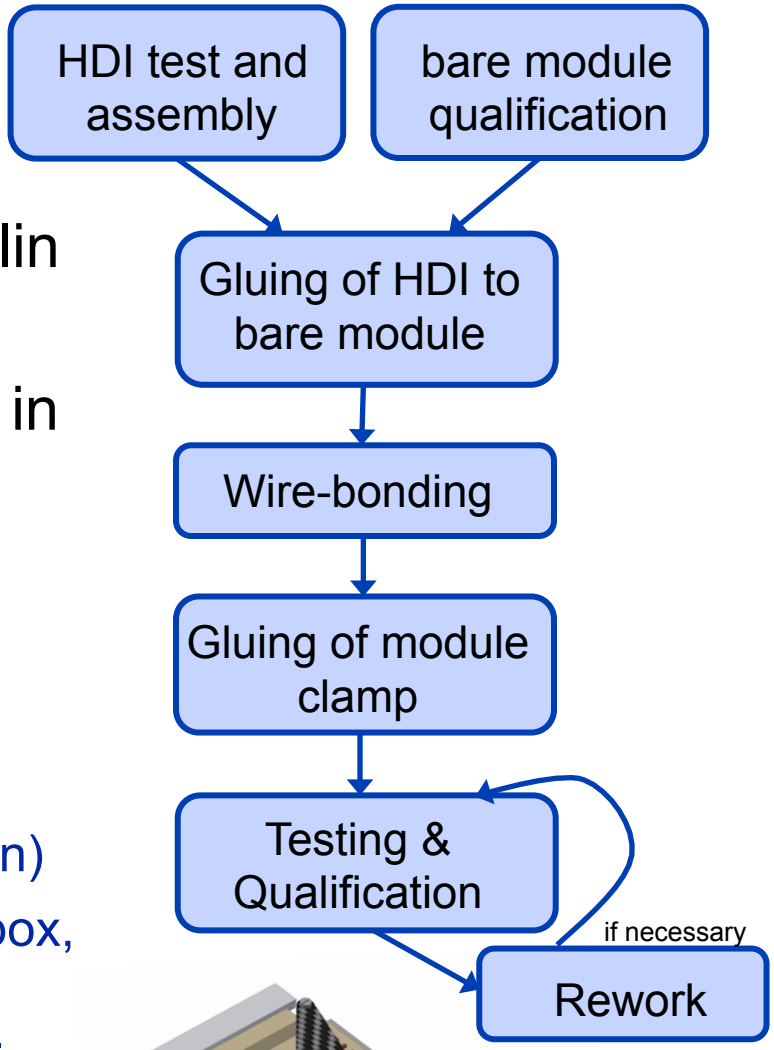
R&D of
- readout chip
- sensor
- module concept
- optical links
- serial powering
- mechanical design

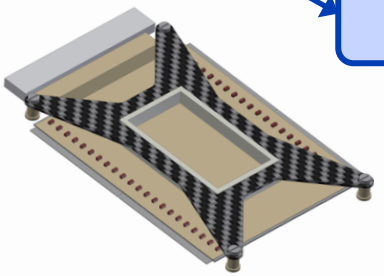


Module Production

- Need to produce O(2000) modules for TEPX
- Bare modules (sensors bump bonded to readout chips) produced @ IZM Berlin
- Manual and semi-automated (gantry) procedures used for module assembly in the past
- Needed infrastructure and skills:
  - production line for module & clamp gluing (tools, jigs, alignment)
  - Wire-bonding machine with operator
  - Setup for bare module testing (probe station)
  - Setup for module testing (test board, cold box, x-ray box)
  - Person power manual procedures and testing
- Option of having distributed system with competence centers

Assembly Steps

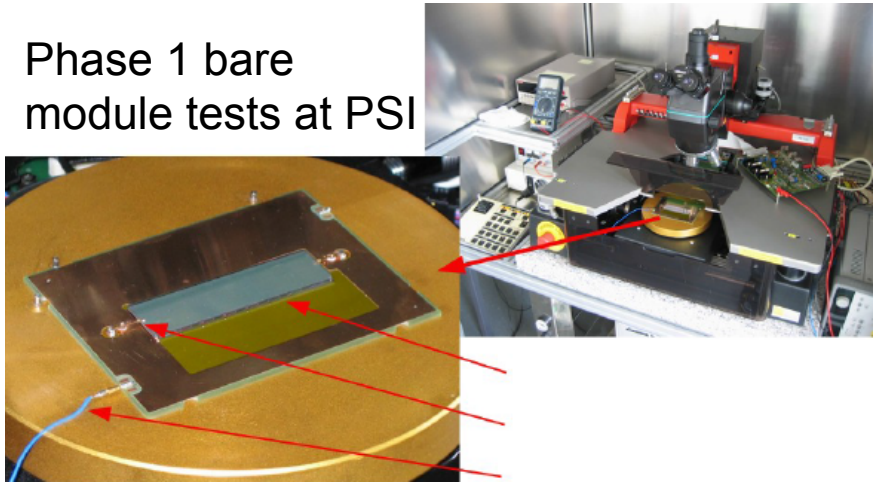


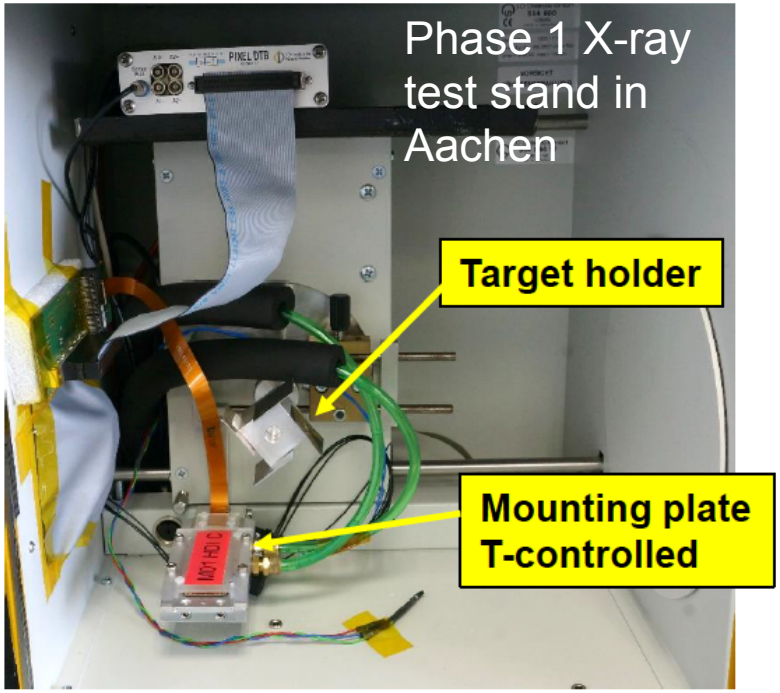


Module Testing

- Bare-module tests to test sensors and ROCs right after bump-bonding
  - IV curves, ID/IA, basic functionality, bump-bonds
- Full module tests and qualification according to well-defined procedure
  - IV curves
  - ROC and pixel functionality
  - Thermal cycling (±30°C)
  - High-rate x-ray tests
  - x-ray calibration
- Module grading, maintenance of data base, module storage, logistics,...

Phase 1 bare module tests at PSI





Involvement of Baltic groups

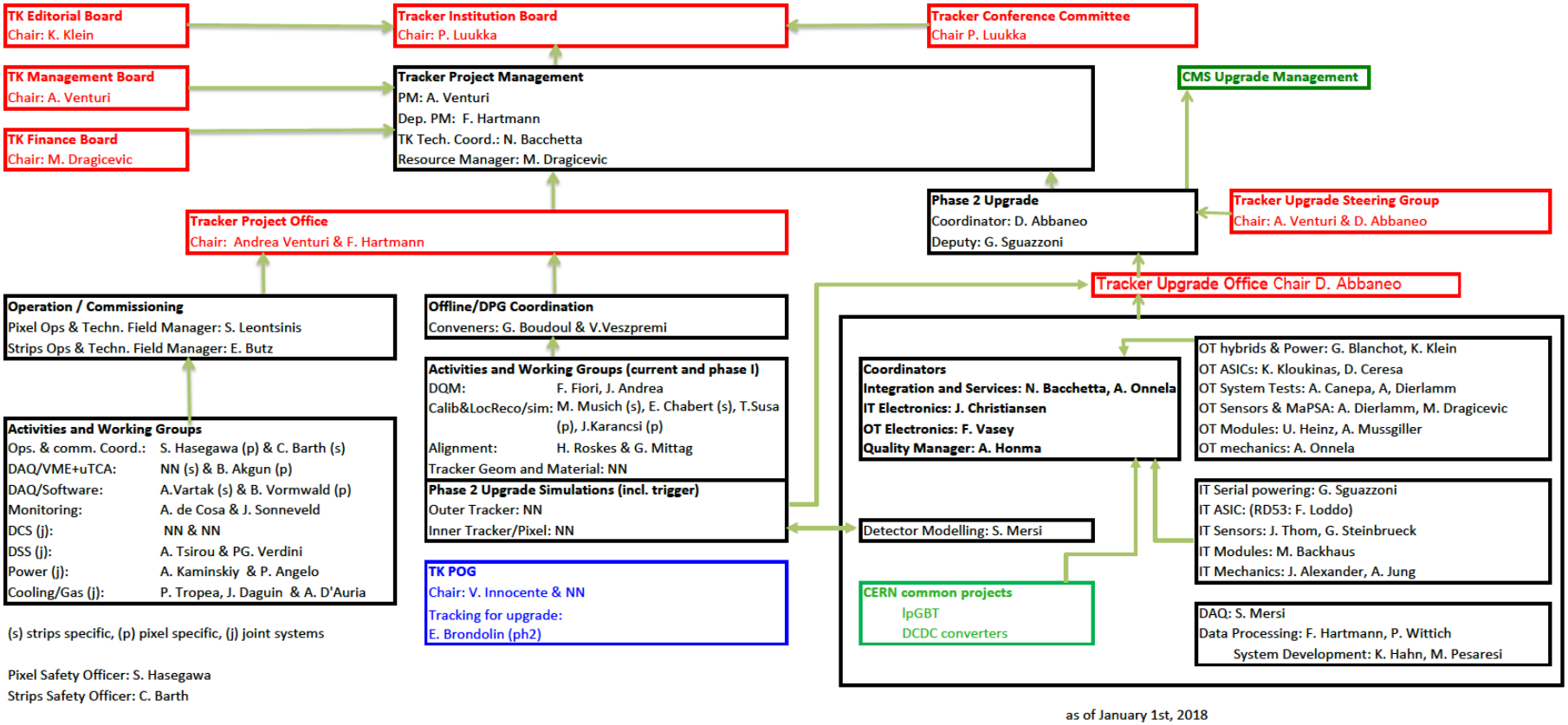
- Room for contributions in module production & qualification
- Establish production center that delivers key parts for TEPX
- Knowledge transfer from Swiss groups together with existing experience in tracking detectors of members of Baltic groups allow to grow expertise in detector design and construction
- Building detector hardware and auxiliary tools (mechanical parts, electronics, software) initiates links with industry
- Involvement of students to obtain crucial skills: experience in hardware and software works, key knowledge useful for physics data analyses, organization, data base, soft skills
- Application of silicon detectors in other fields of research (space, imaging, light sources) as well as medical applications

→ In summary: Contribution that is well visible within CMS collaboration and allows to strengthen research in Baltics

Thank you!

Backup

Tracker Organization in 2018



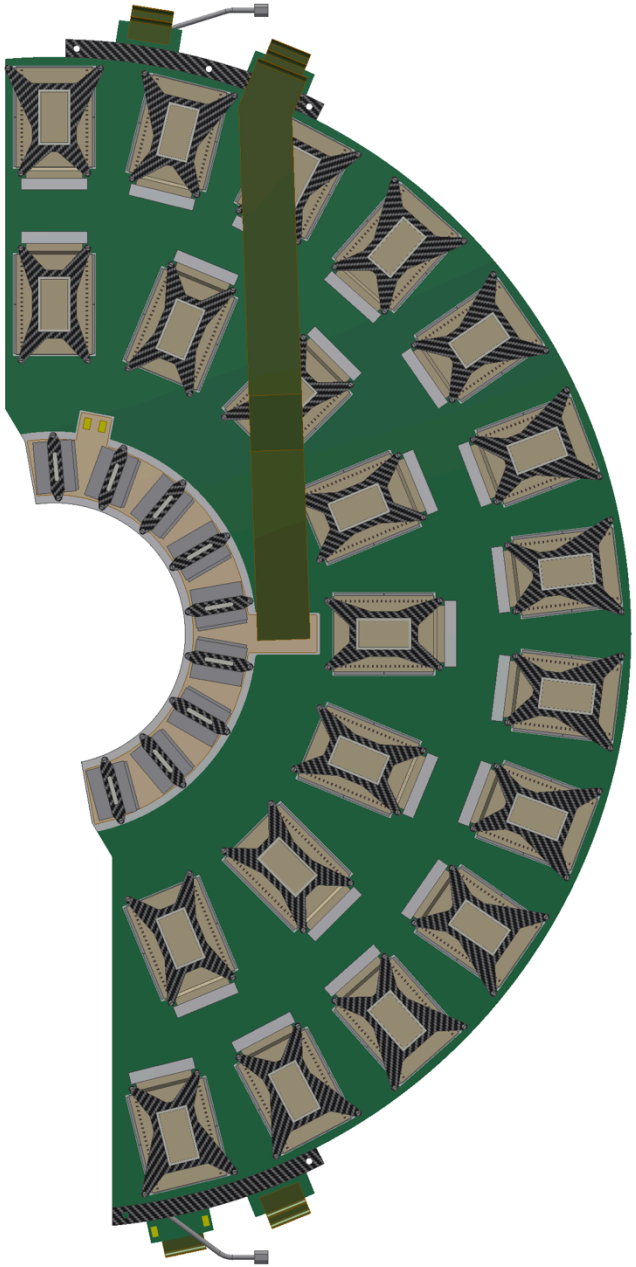
(s) strips specific, (p) pixel specific, (j) joint systems

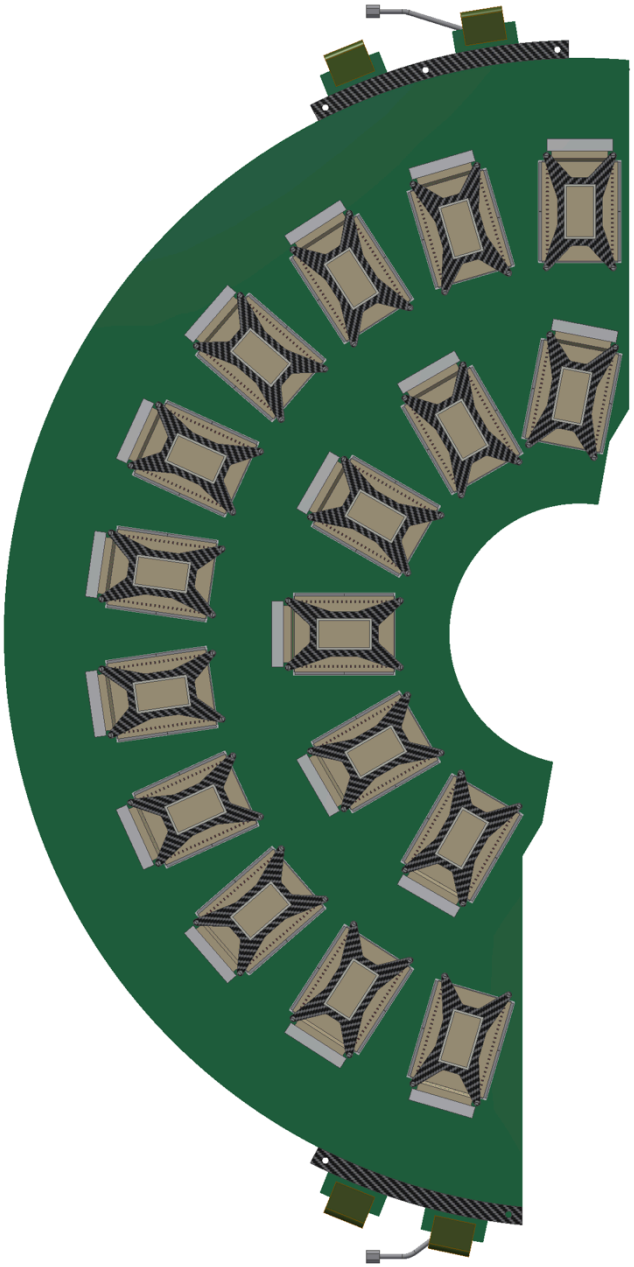
Pixel Safety Officer: S. Hasegawa
Strips Safety Officer: C. Barth

as of January 1st, 2018

TEPX mechanical disk

Front side

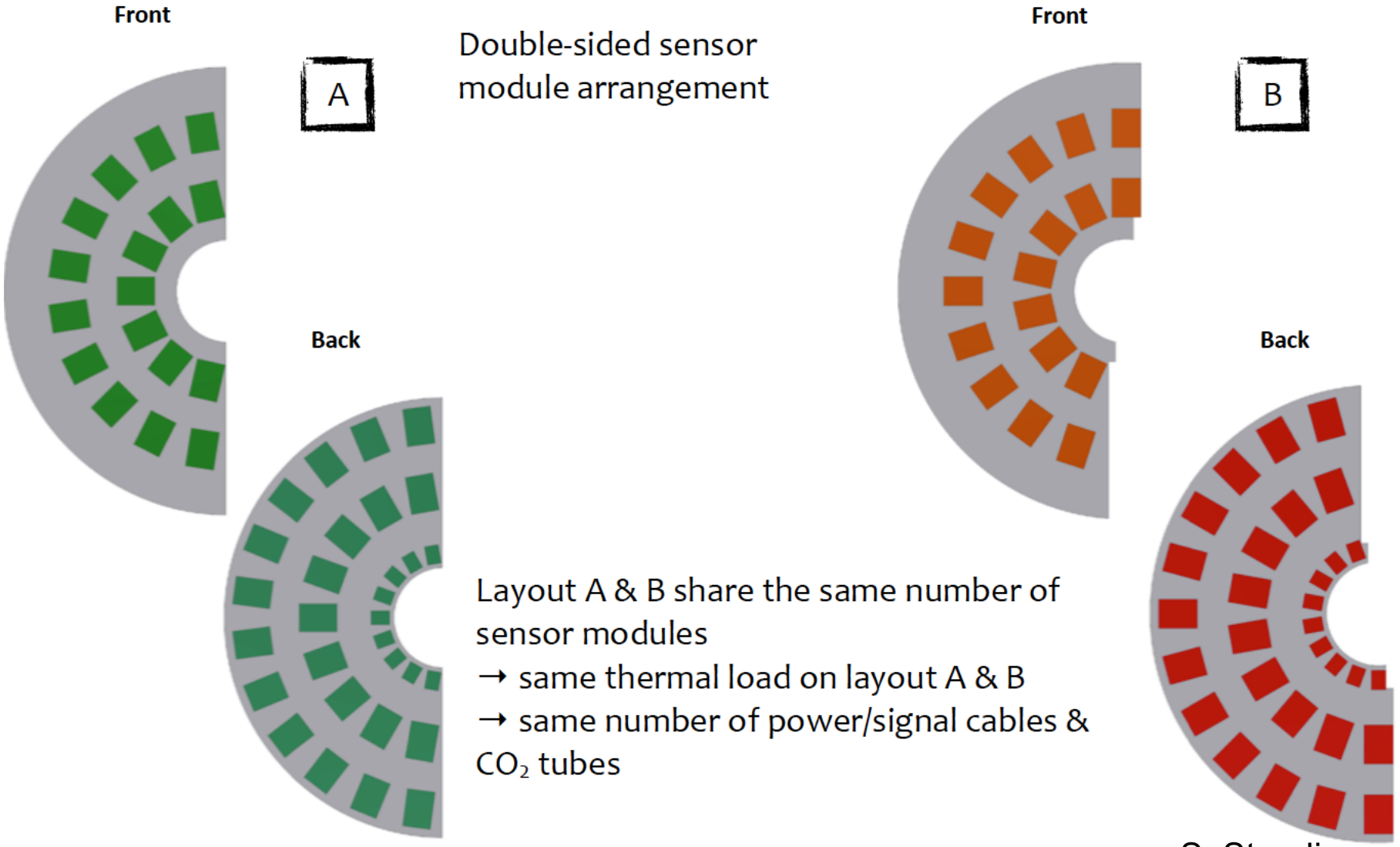




Back side

TEPX Disks

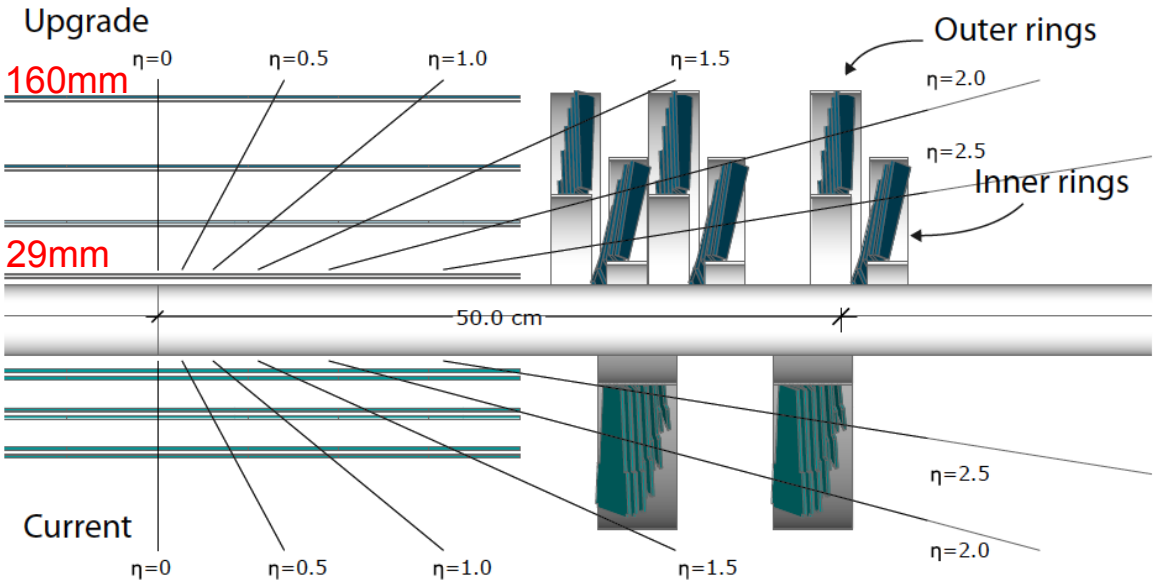
- Two disks with modules on front and back form one "z position"

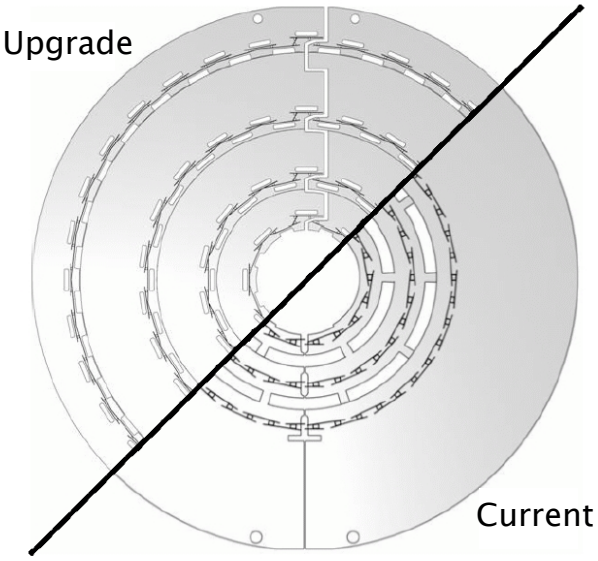


S. Streuli

Phase 1 Pixel Project

- 2012: Phase 1 Pixel TDR
- 2012 – 2015: R&D and prototyping
- 2015 – 2016: Production of all components, Supply Tube fabrication and assembly, detector assembly, commissioning
- YETS 2016/2017: Installation into CMS
- 2017-2023: Physics data-taking





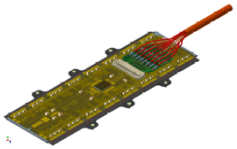
Building up the complete system

2015

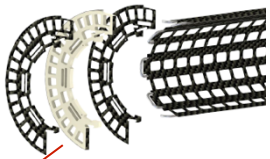
2016

2017

Module production and testing (PSI/ETH, I/FIN/D)

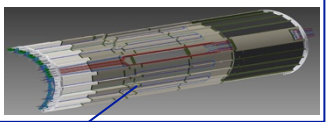


BPIX mechanics and cooling (PSI/UZH)



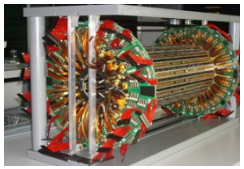
Readout and power board Production (UZH, RWTH, Wigner)

ST mechanics and cooling (UZH)

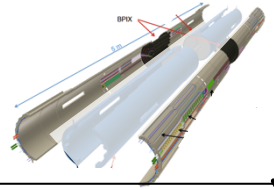


Supply tube assembly (UZH)

Module mounting (PSI)



BPIX and ST integration and testing (PSI)



Transport to CERN and checkout

Installation

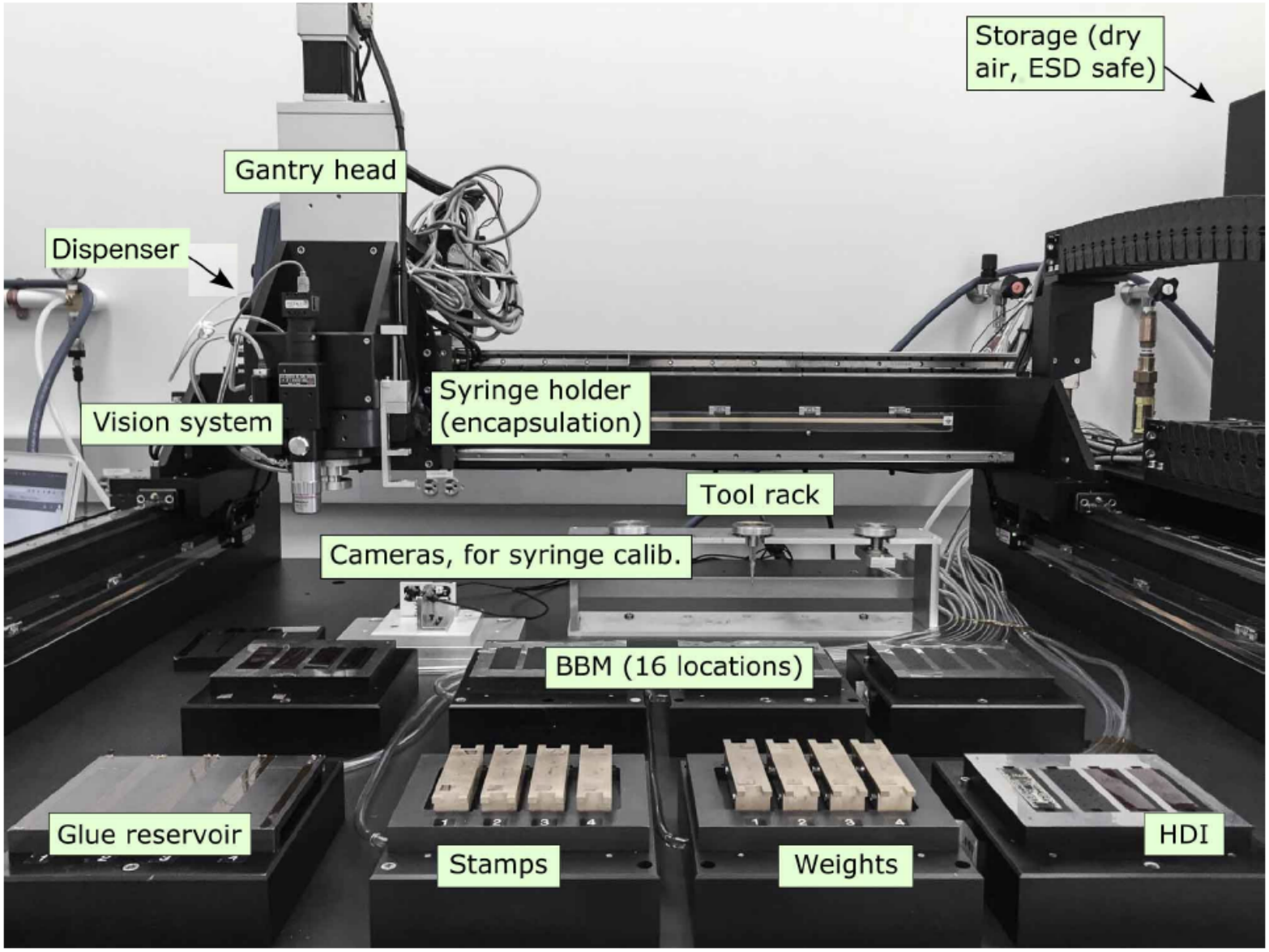
Commissioning at CERN

DAQ & Online Software

VME (testing)

mTCA (operation)

Phase 1 FPIX Gantry



Phase 1 BPIX

- Gluing jigs developed at PSI
- Alignment is key
  - 50 um precision required
  - Computer program developed o use measurements from CMM to set micrometric screws on jig for alignment