THE UNIVERSITY OF TENNESSEE KNOXVILLE

Data Quality Monitoring for the HL-LHC Upgrade to the CMS Outer Tracker

Brandi S. (University of Tennessee) on behalf of the CMS Collaboration

DPF-PHENO 2024

May 13, 3024

U.S. DEPARTMENT OF ENERGY

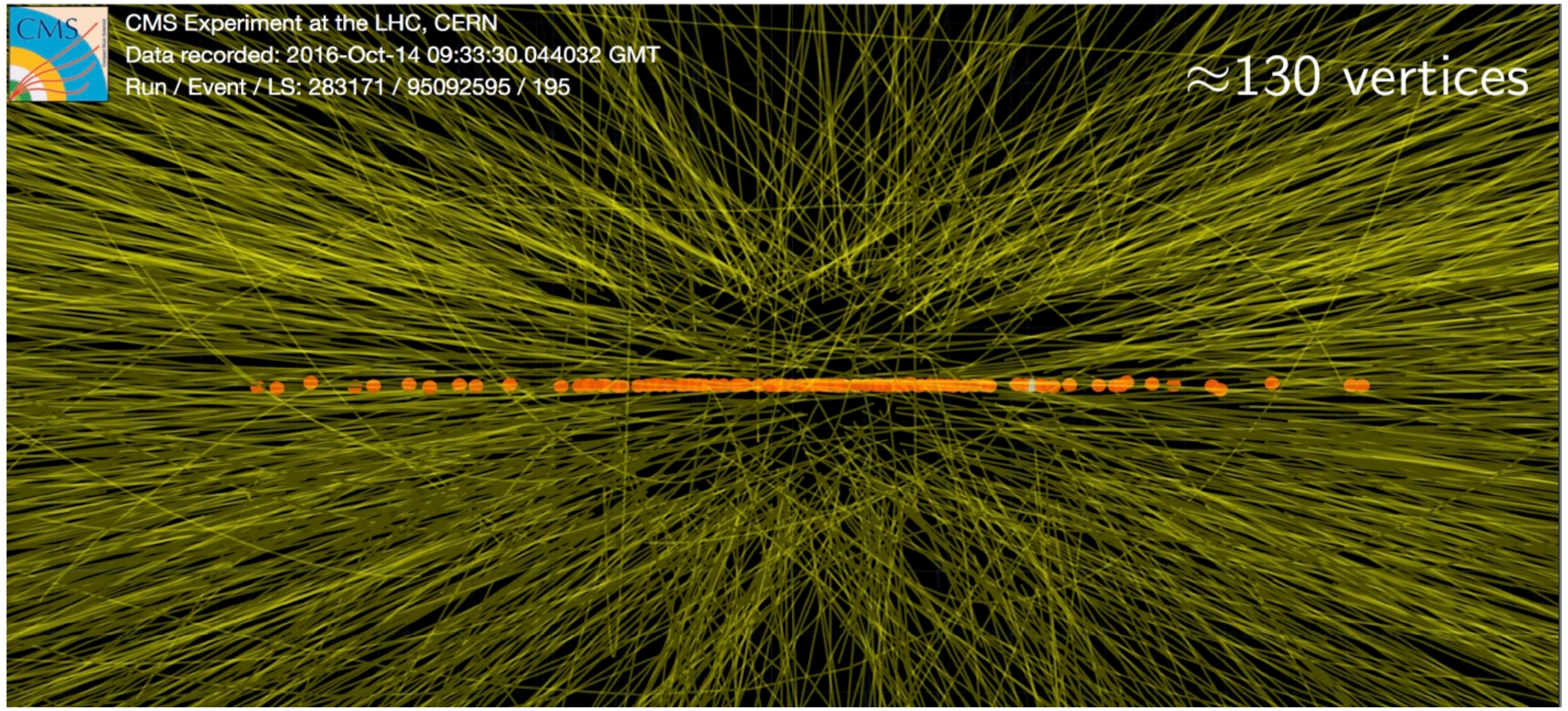
Outline

- Introduction to CMS Level 1 Trigger Upgrade
- Technical Enhancements
- Phase2 Tracker Upgrade
- Stubs: Role in Track Finding
- Data Quality Monitoring (DQM) Role and Implementation
- Results and Monitoring
- Summary

Phase II Upgrade for HL-LHC (2029)

For the first time at the LHC, hardware based tracking will be run for every bunch crossing.

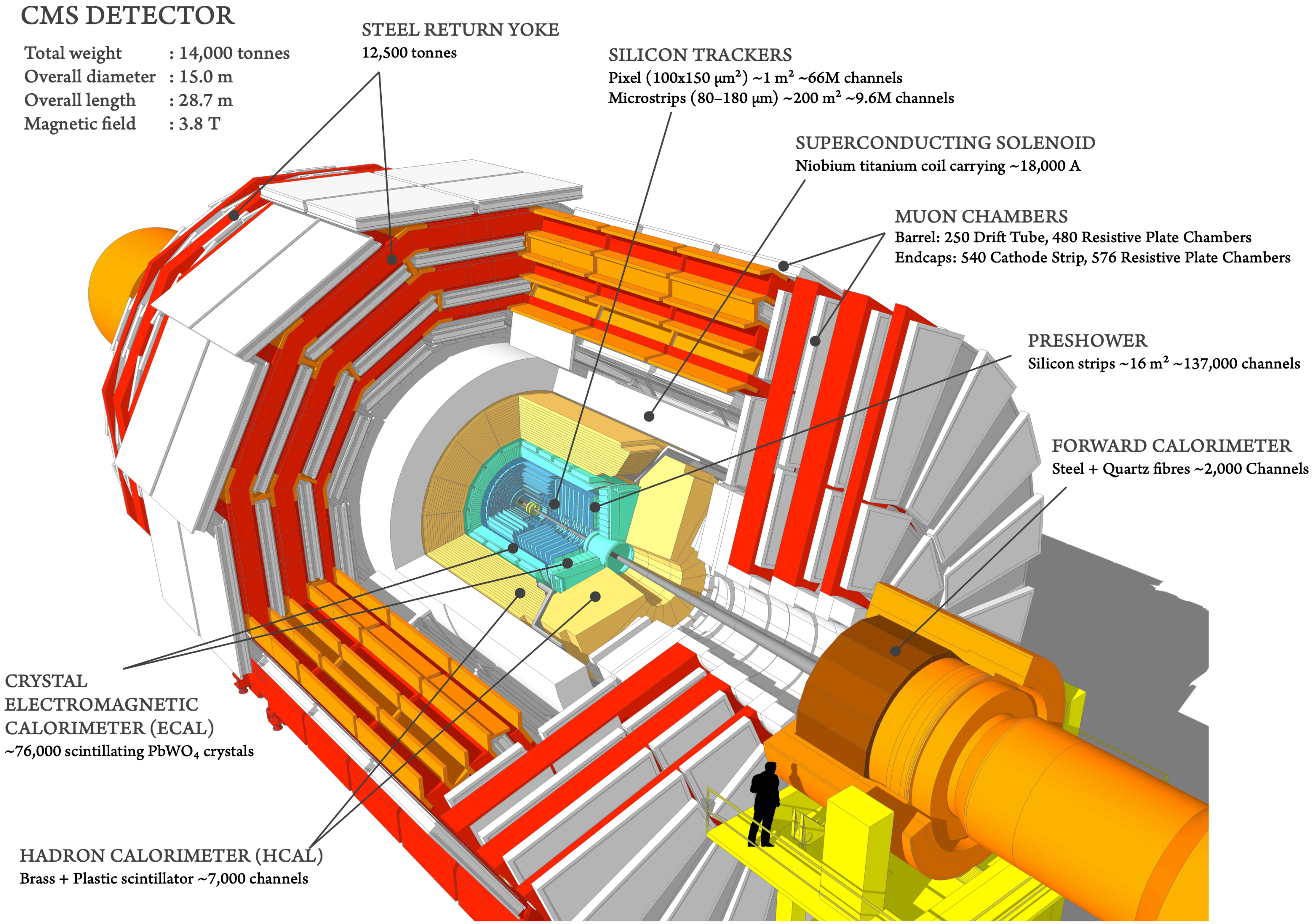
- For the HL-LHC upgrade:
  - Bunch crossings at 40 MHz
  - High pileup 140 - 200 for every bunch crossing
  - High irradiation
- CMS Phase II detector upgrade
  - On-detector filtering to reduce hit rate
  - Mitigating pileup effects
  - Radiation hardness



Real-life event with HL-LHC-like pileup from special run in 2016 with individual high intensity bunches.

https://cds.cern.ch/record/2231915

CMS (Compact Muon Solenoid) Detector



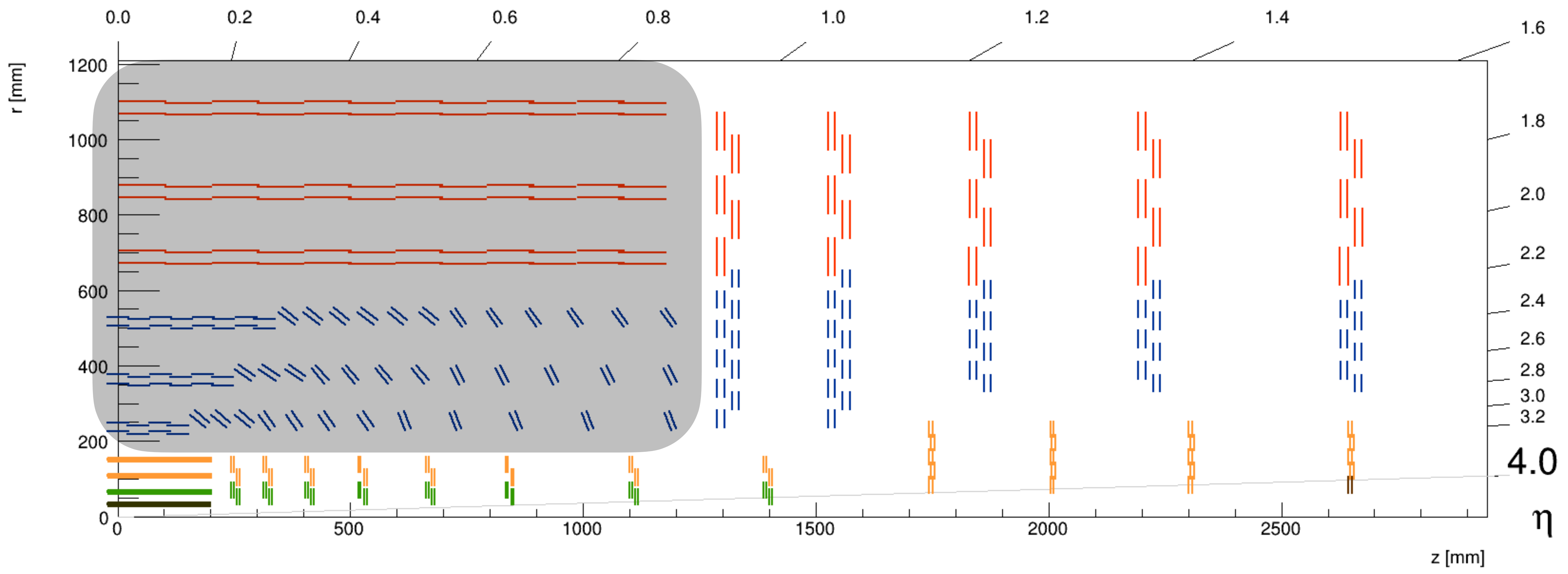
https://cds.cern.ch/record/2665537

B. Skipworth

Phase2 Outer Tracker

Tracker Barrel
with 2S modules

Tracker Barrel
with PS modules



Tracker Endcap
Double Discs

Tilted modules

- **Outer tracker region** has 6 layers in the barrel and 5 discs in the endcaps.
- **PS modules:** in the 1st 3 layers of the outer tracker, in the radial region 200-600 mm
- **2S modules:** in the outermost 3 layers, in the radial region above 600 mm

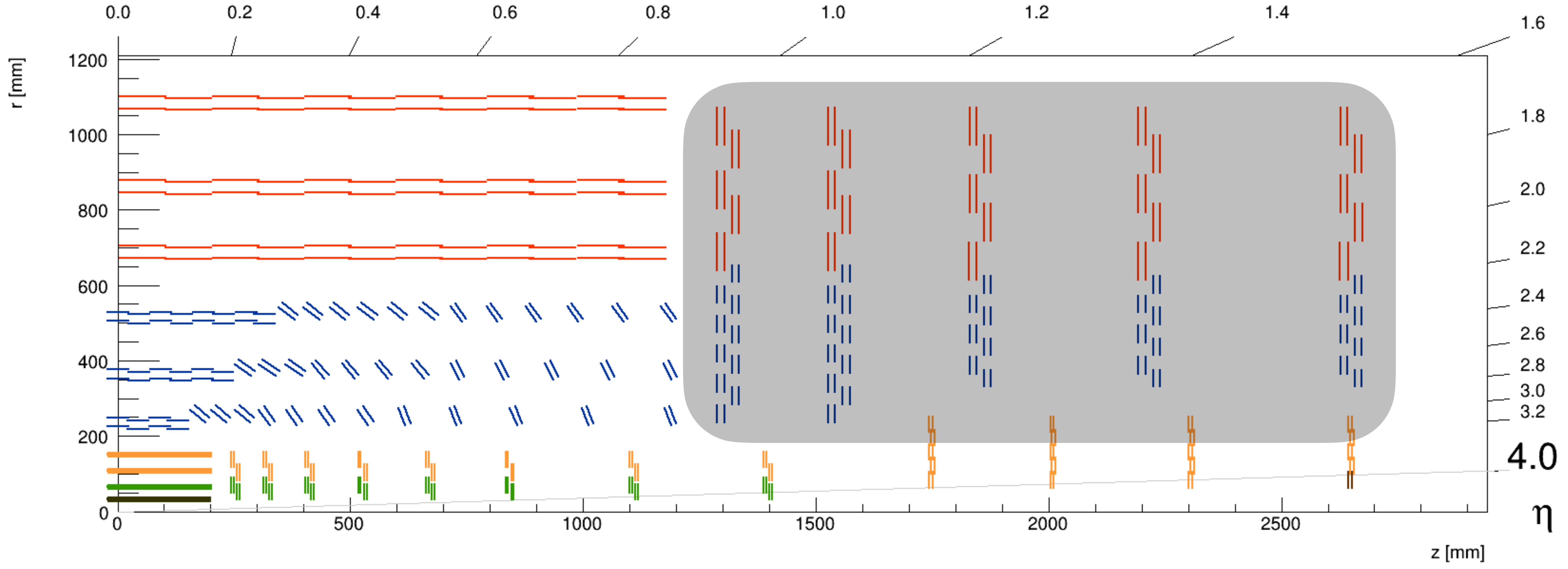
https://cms-tklayout.web.cern.ch/cms-tklayout/layouts-work/cmssw-models/ZG_OT800_IT711/index.html

B. Skipworth

Phase2 Outer Tracker

Tracker Barrel
with 2S modules

Tracker Barrel
with PS modules



Tracker Endcap
Double Discs

Tilted modules

- **Outer tracker region** has 6 layers in the barrel and 5 discs in the endcaps.
- **PS modules:** in the 1st 3 layers of the outer tracker, in the radial region 200-600 mm
- **2S modules:** in the outermost 3 layers, in the radial region above 600 mm

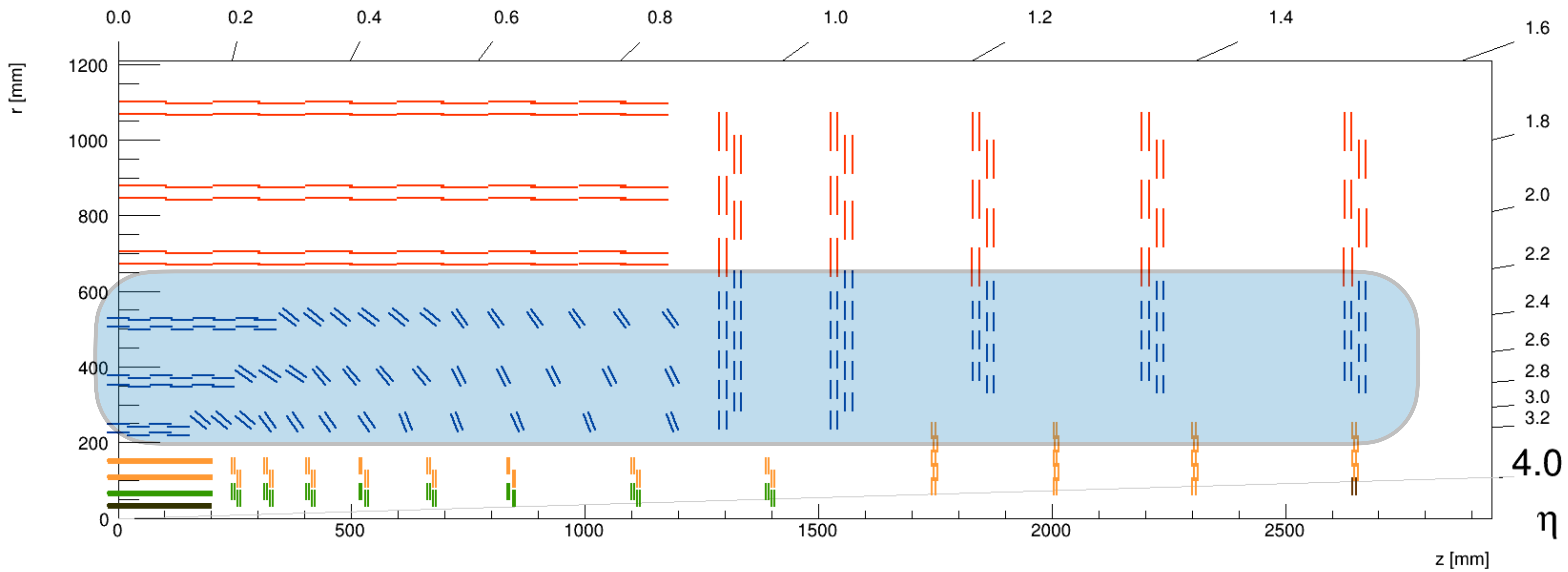
https://cms-tklayout.web.cern.ch/cms-tklayout/layouts-work/cmssw-models/ZG_OT800_IT711/index.html

B. Skipworth

Phase2 Outer Tracker

Tracker Barrel with 2S modules

Tracker Barrel with PS modules



Tracker Endcap Double Discs

Tilted modules

- **Outer tracker region** has 6 layers in the barrel and 5 discs in the endcaps.
- **PS modules:** in the 1st 3 layers of the outer tracker, in the radial region 200-600 mm
- **2S modules:** in the outermost 3 layers, in the radial region above 600 mm

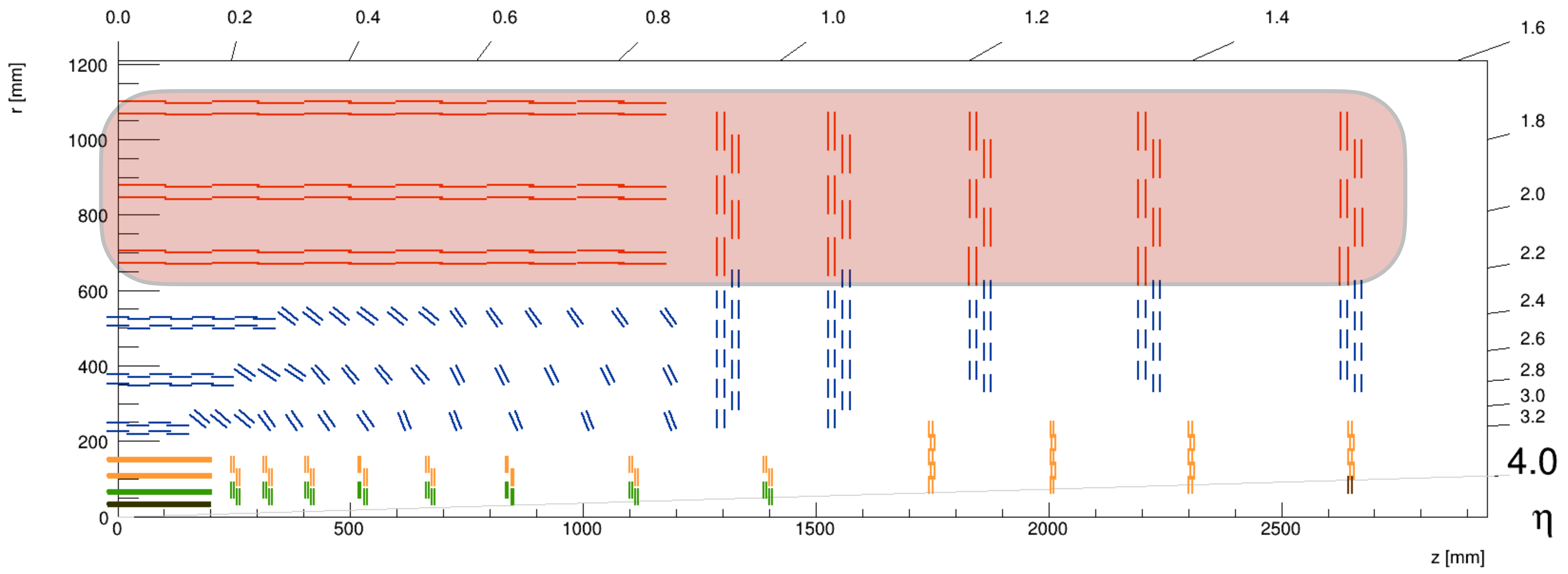
https://cms-tklayout.web.cern.ch/cms-tklayout/layouts-work/cmssw-models/ZG_OT800_IT711/index.html

B. Skipworth

Phase2 Outer Tracker

Tracker Barrel
with 2S modules

Tracker Barrel
with PS modules



Tracker Endcap
Double Discs

Tilted modules

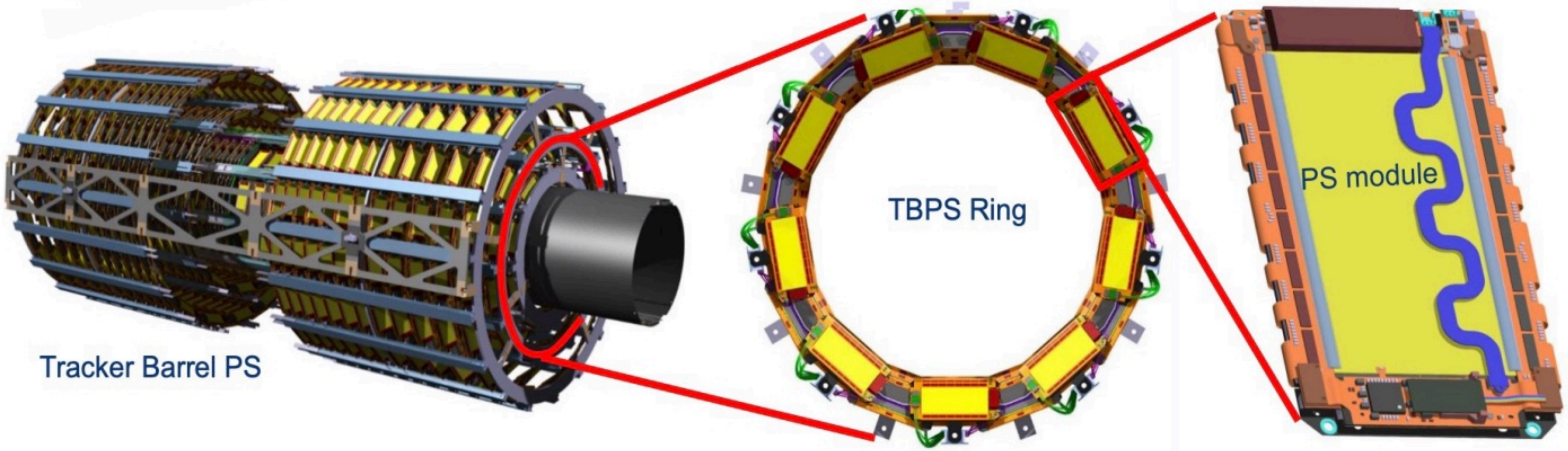
- **Outer tracker region** has 6 layers in the barrel and 5 discs in the endcaps.
- **PS modules:** in the 1st 3 layers of the outer tracker, in the radial region 200-600 mm
- **2S modules:** in the outermost 3 layers, in the radial region above 600 mm

https://cms-tklayout.web.cern.ch/cms-tklayout/layouts-work/cmssw-models/ZG_OT800_IT711/index.html

B. Skipworth

Phase2 Outer Tracker

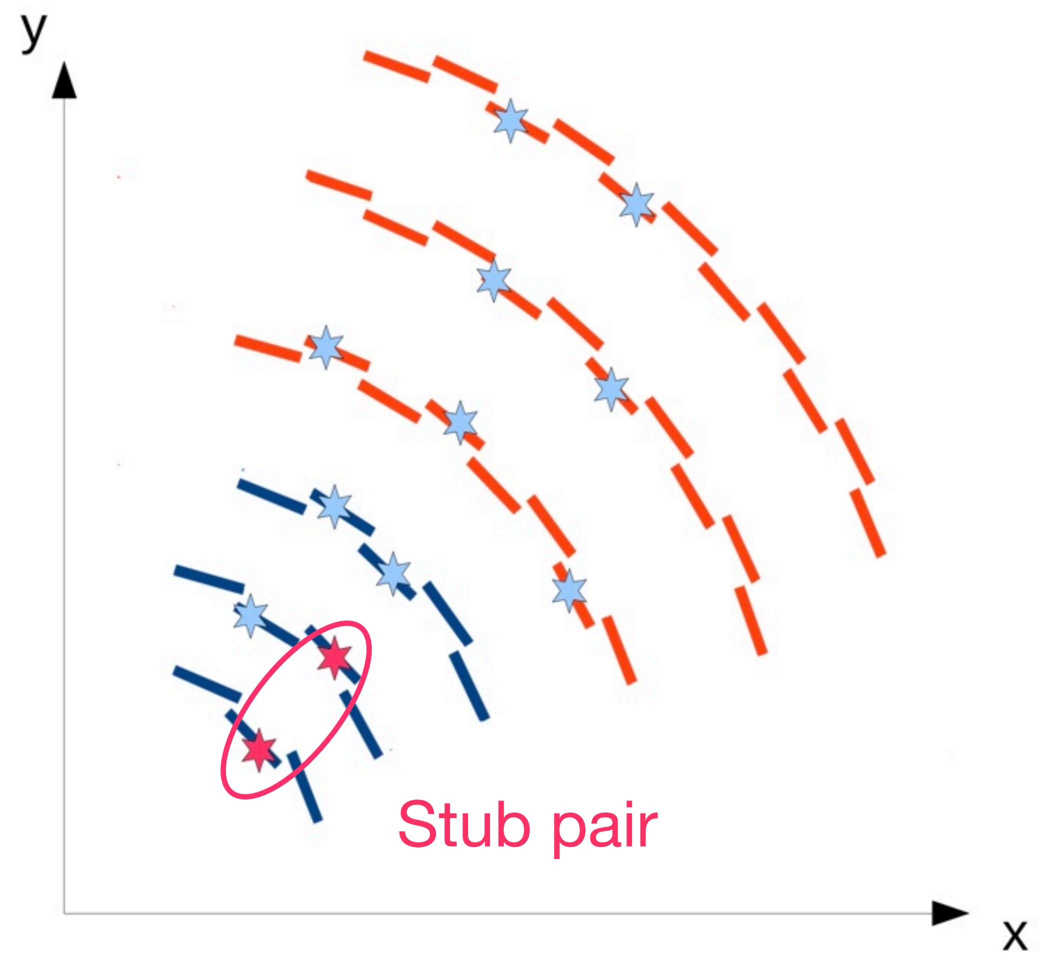
2S: two strip sensors

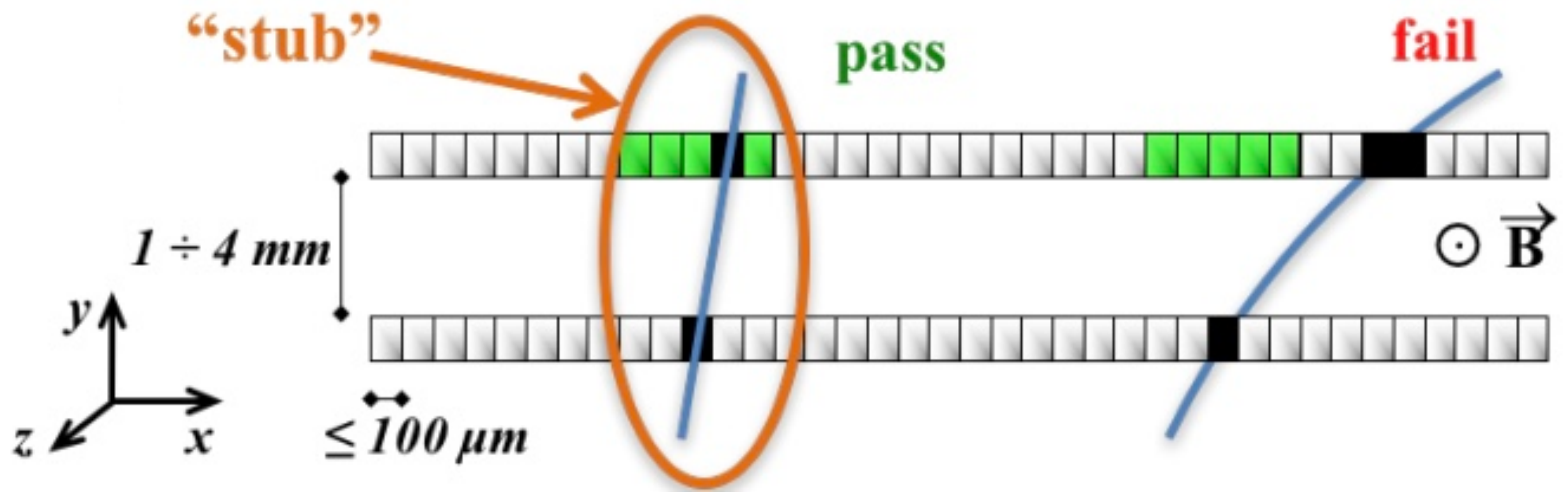


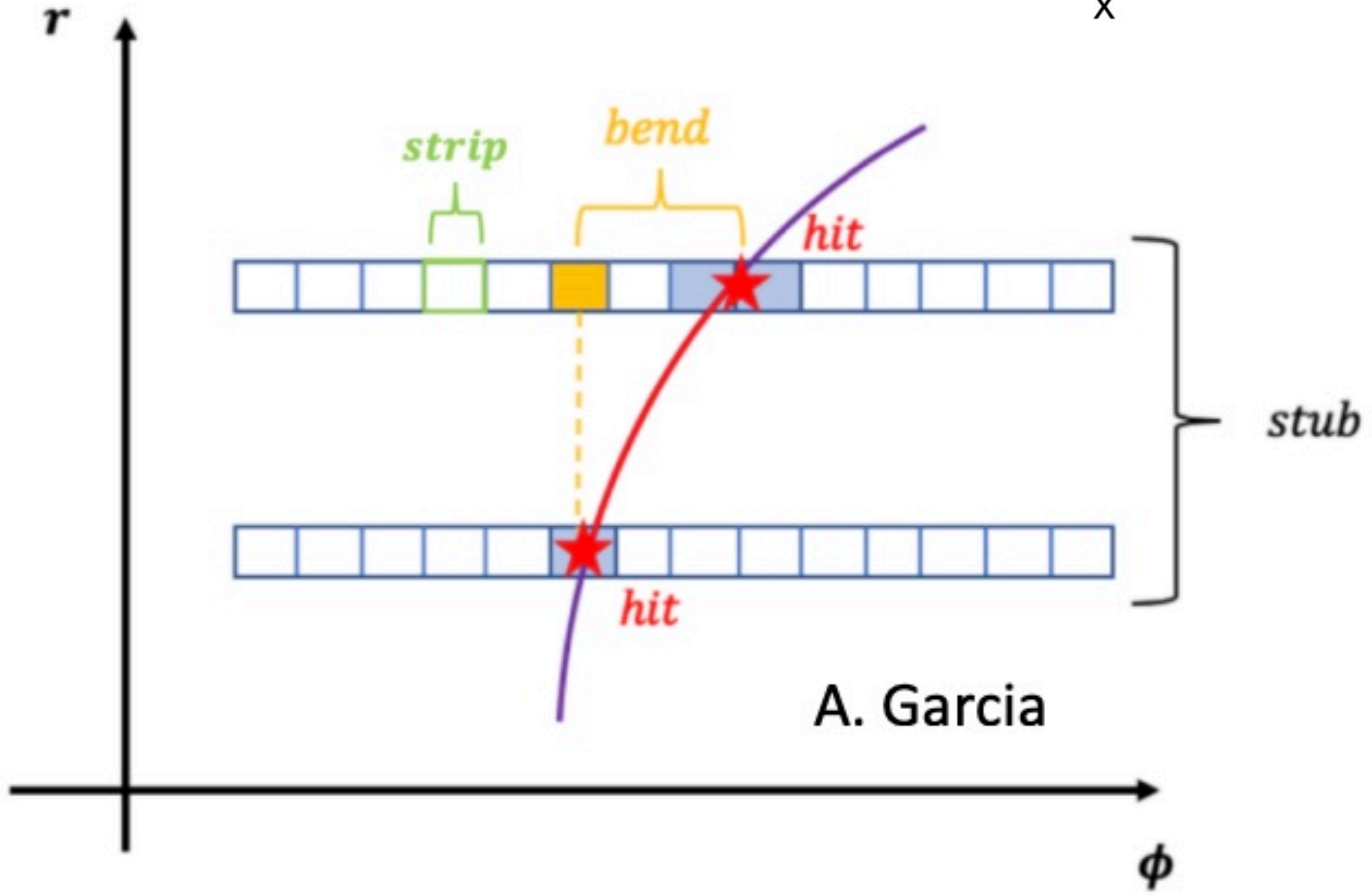
PS: one strip sensor
and one macro-pixel sensor

Stubs

- Stub
  - Correlated pair of clusters
  - Form input to track finding
- Bend
  - Difference between the centroids of two clusters that comprise a stub
  - Threshold of 2 GeV



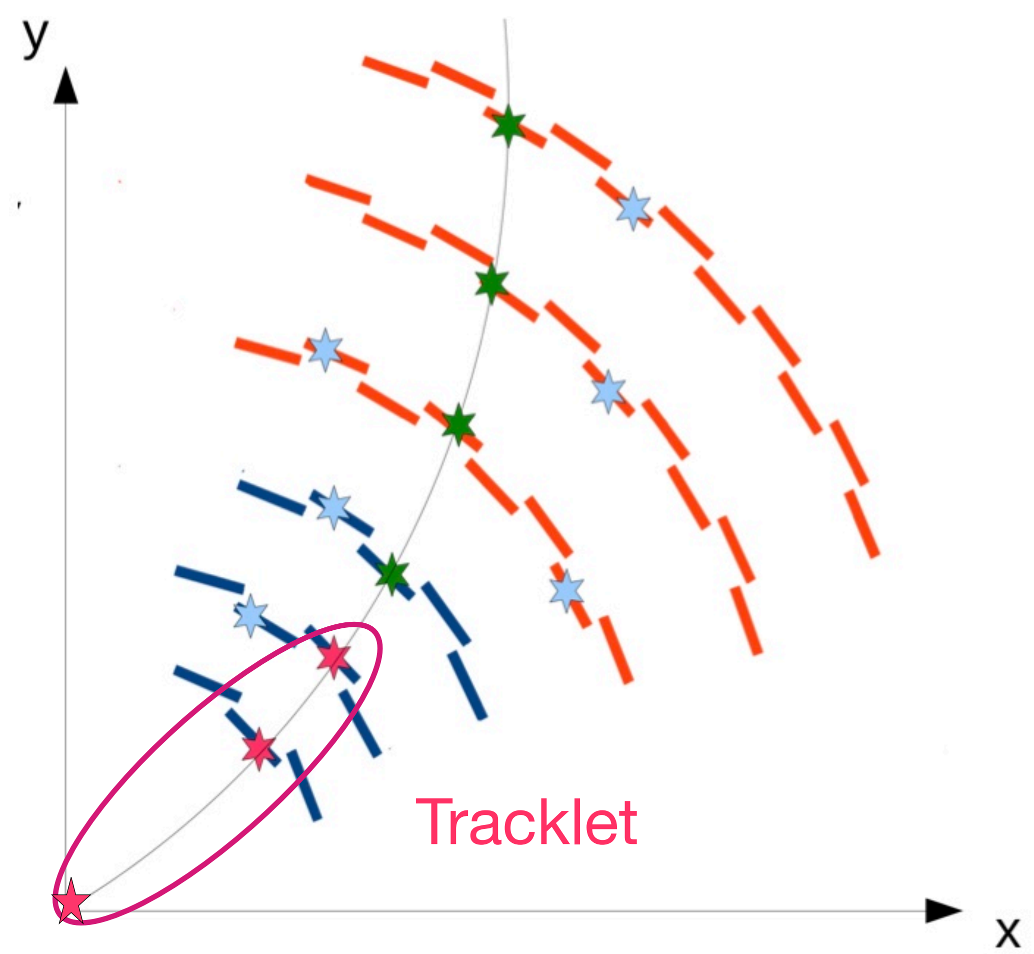


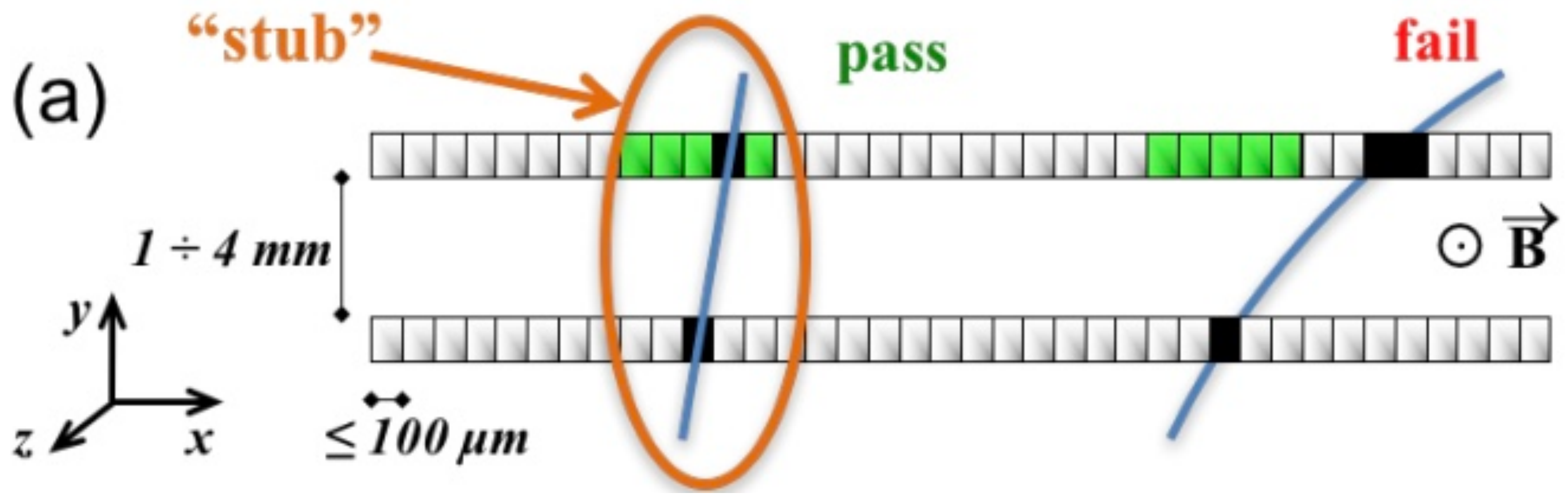


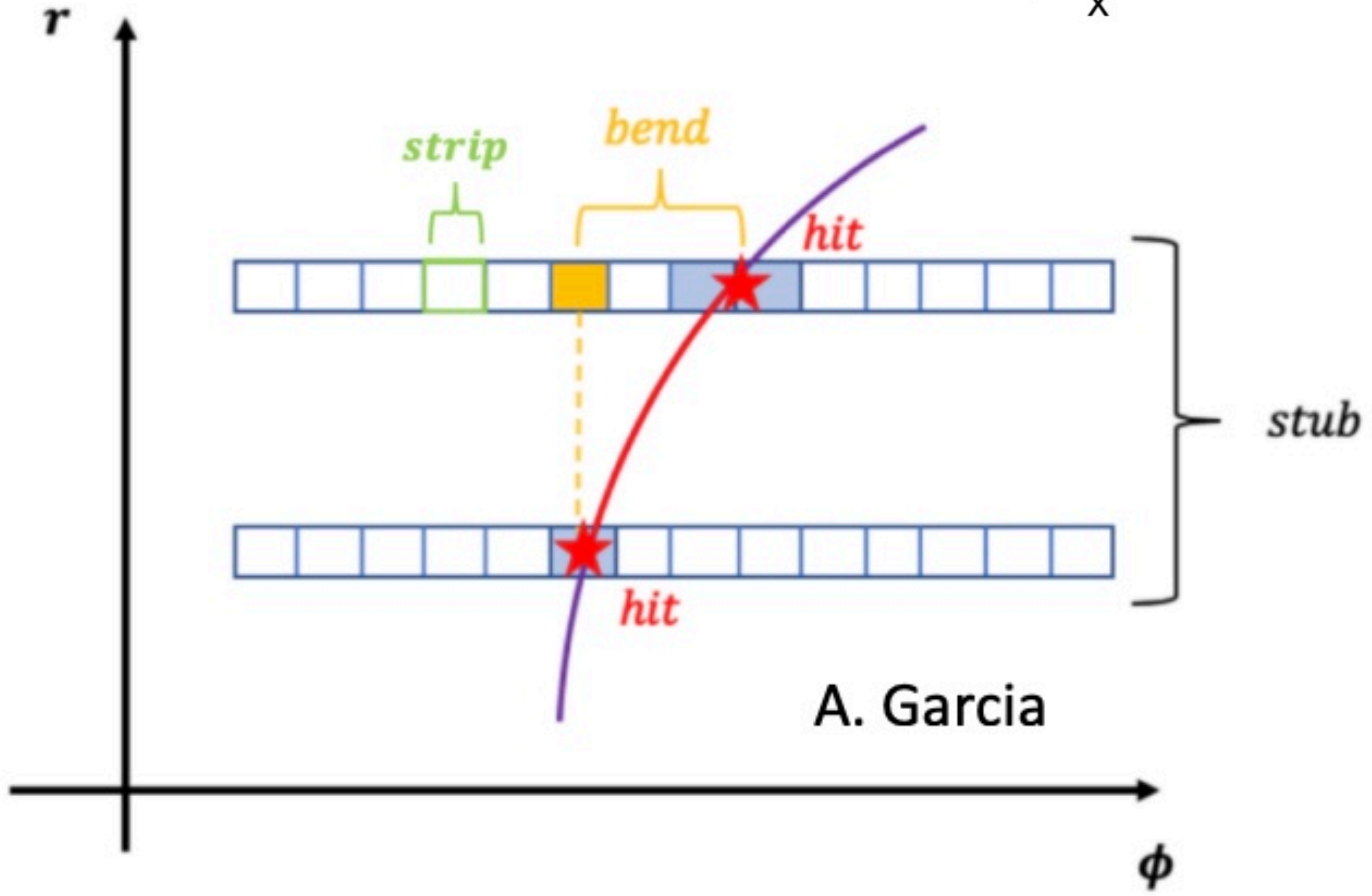
https://cds.cern.ch/record/2272264/files/CMS-TDR-014.pdf

Stubs

- Stub
  - Correlated pair of clusters
  - Form input to track finding
- Bend
  - Difference between the centroids of two clusters that comprise a stub
  - Threshold of 2 GeV





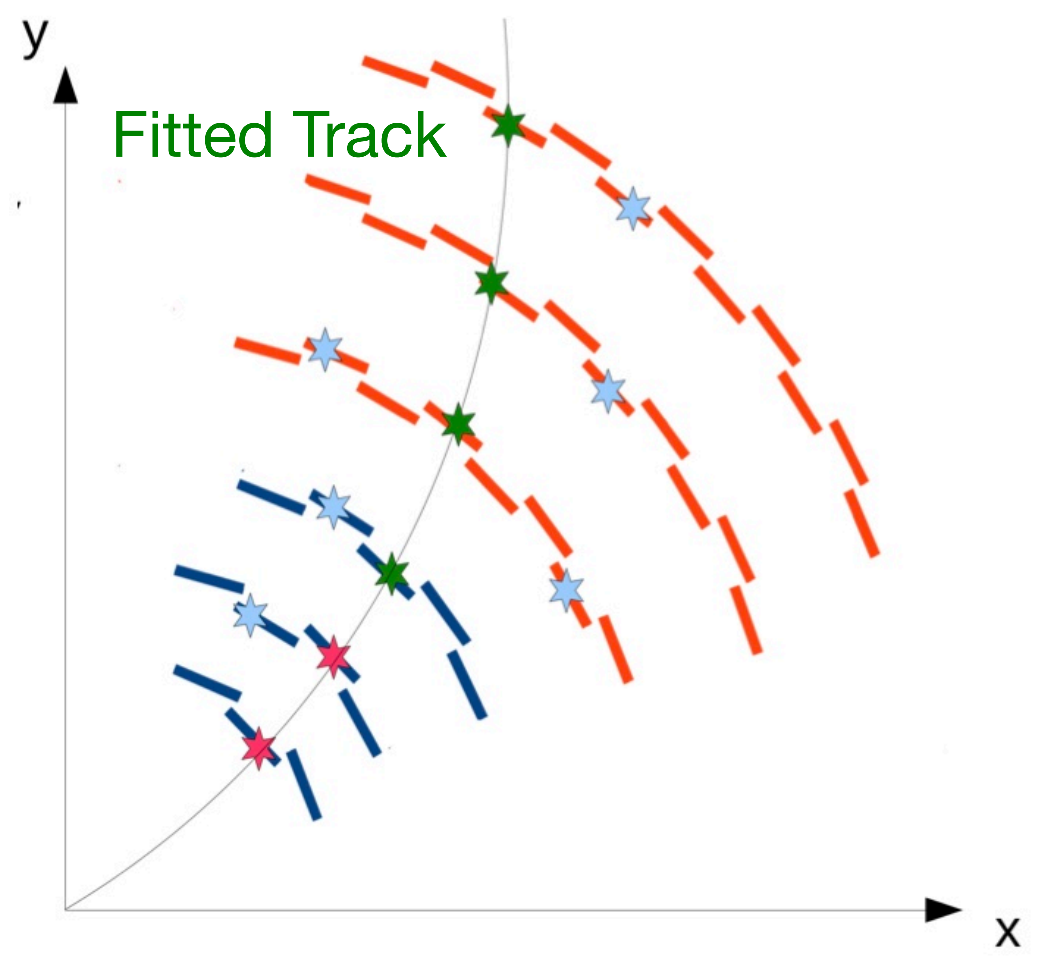


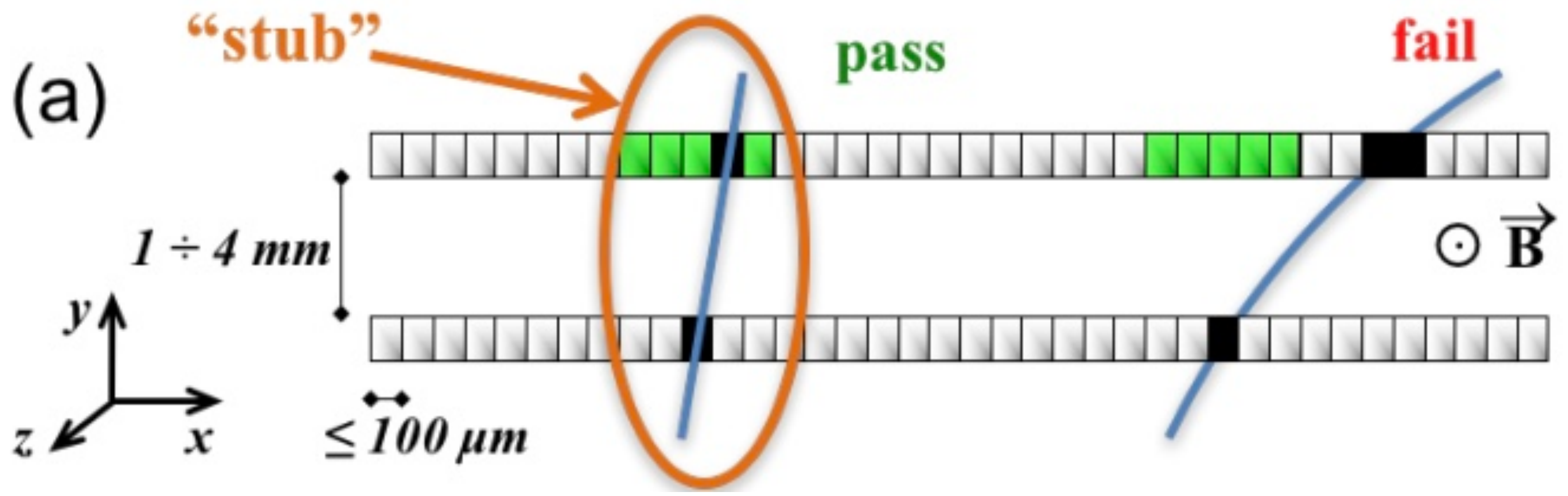
https://cds.cern.ch/record/2272264/files/CMS-TDR-014.pdf

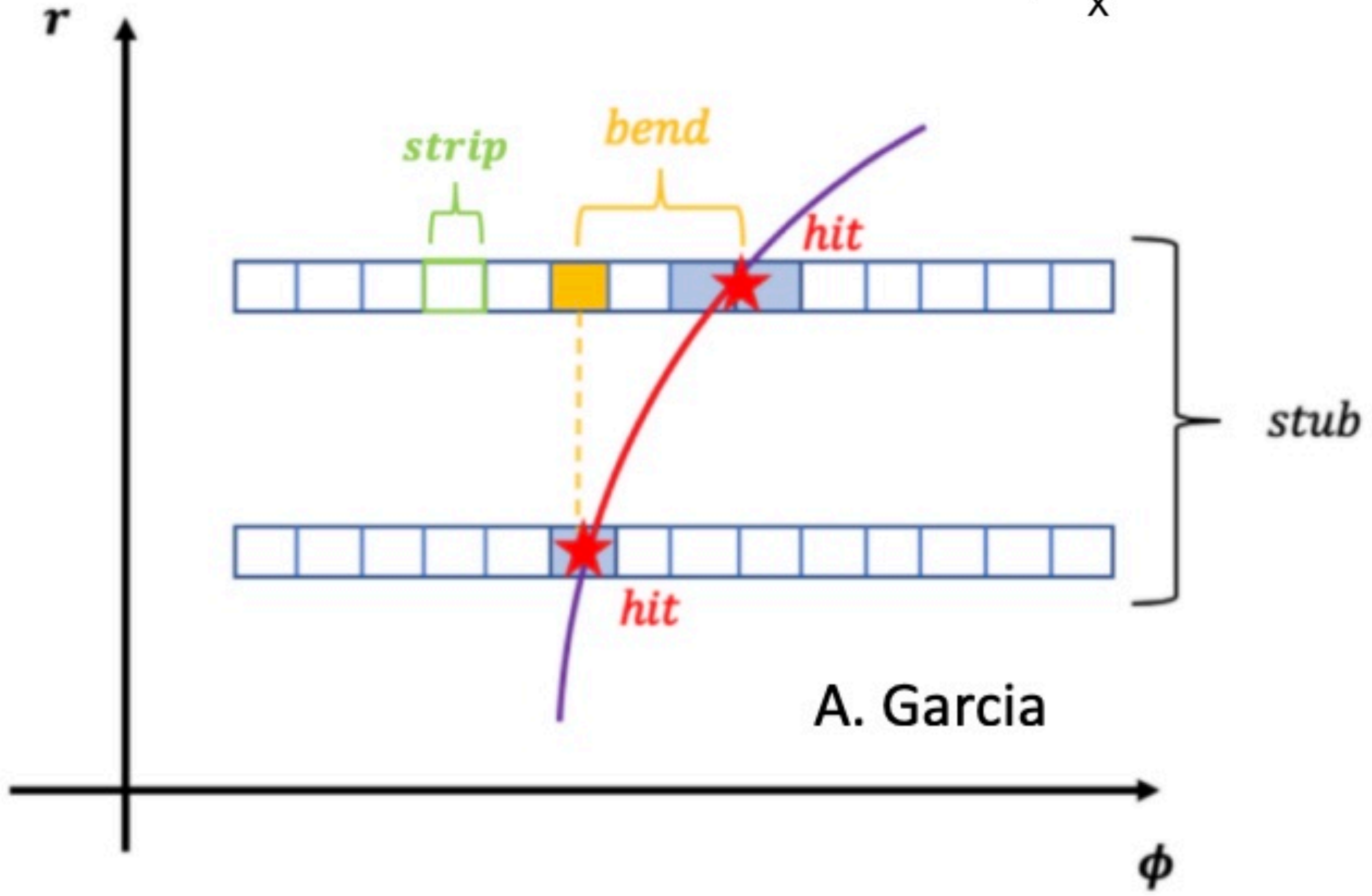
B. Skipworth

Stubs

- Stub
  - Correlated pair of clusters
  - Form input to track finding
- Bend
  - Difference between the centroids of two clusters that comprise a stub
  - Threshold of 2 GeV







https://cds.cern.ch/record/2272264/files/CMS-TDR-014.pdf

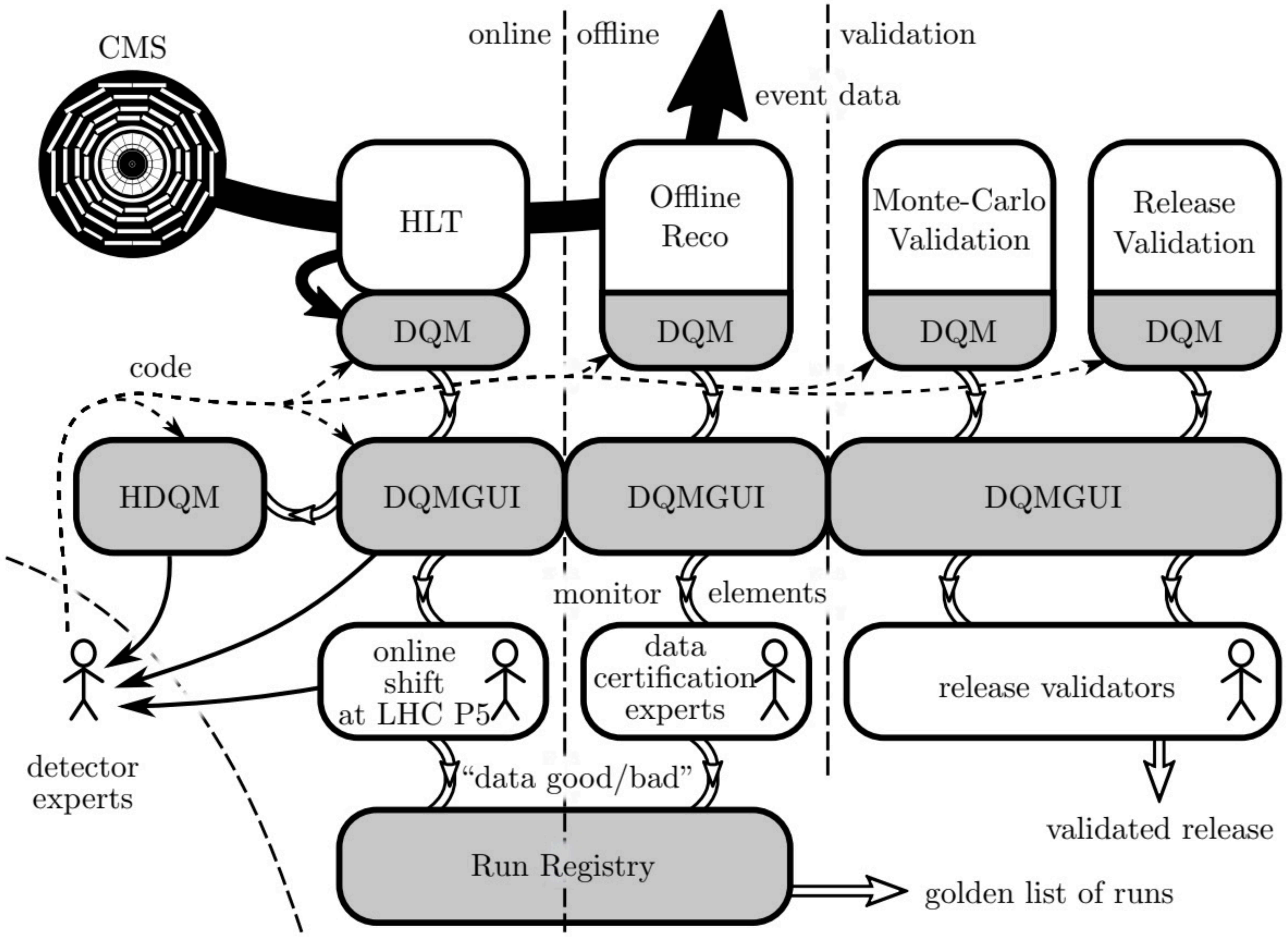
B. Skipworth

DQM (Data Quality Monitoring) Software

DQM is essential for keeping an eye on data quality at all stages, from when we first gather data to the final analysis.

Used in the following key environments:

- **Online**: for real-time detector monitoring
- **Offline**: for prompt-offline-feedback and final fine grained data quality analysis and certification
- **Validation:** software and simulation



B. Skipworth

Improving Data Validation

Histograms for Comparison: Added histograms to compare measured quantities (stubs) with generated values to analyze resolutions.

Stub Residual Analysis: Developed capabilities to examine stub residuals, enhancing the understanding of measurement precision.

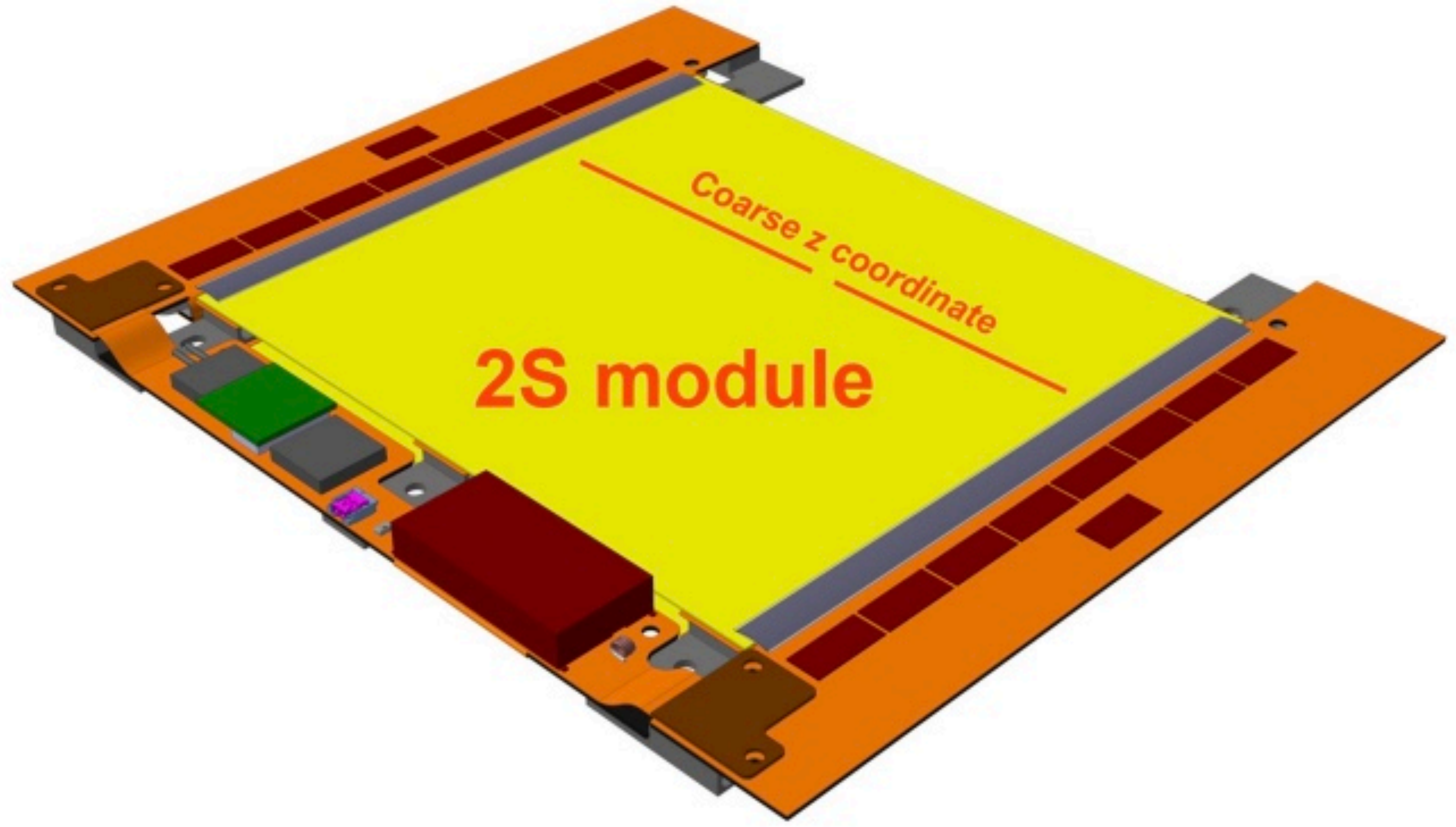
Generated Values: In this case, we focus on generator-level tracks, named Tracking Particles (TP). They are used as reference points for validation.

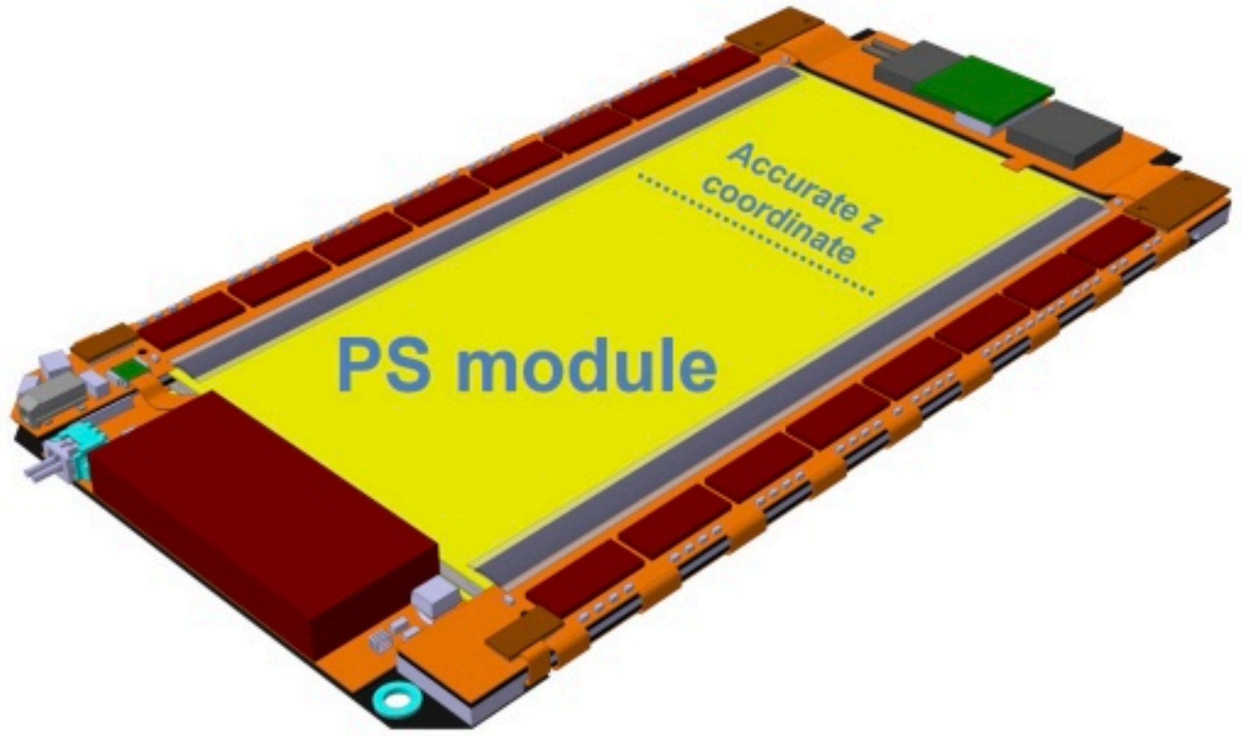
Measured Values ("stubs"): Simulated detector data, used to validate and compare against generated values.

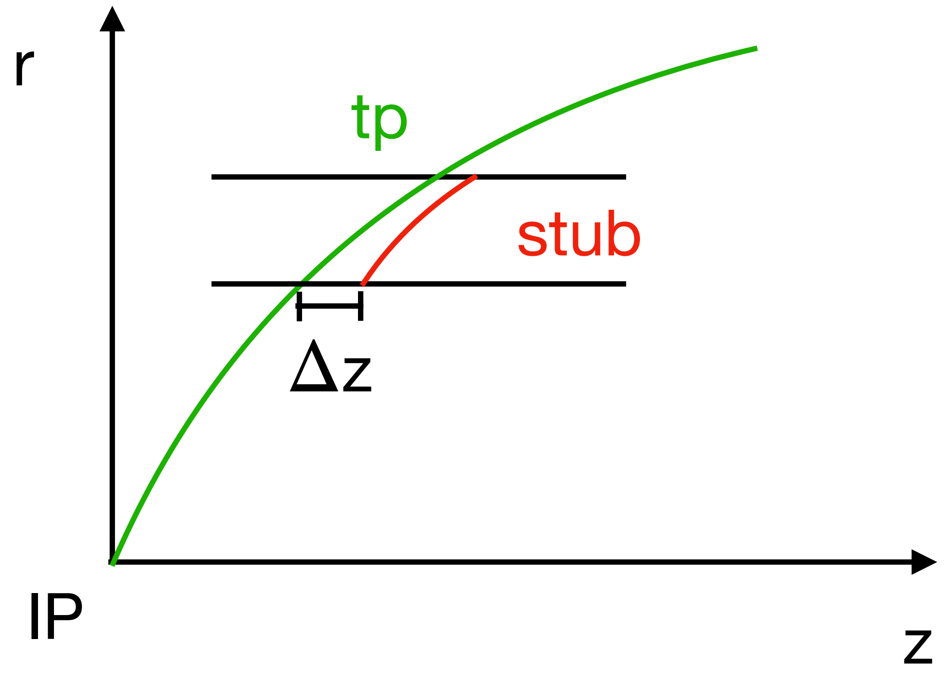
Δz

https://cds.cern.ch/record/2272264/files/CMS-TDR-014.pdf

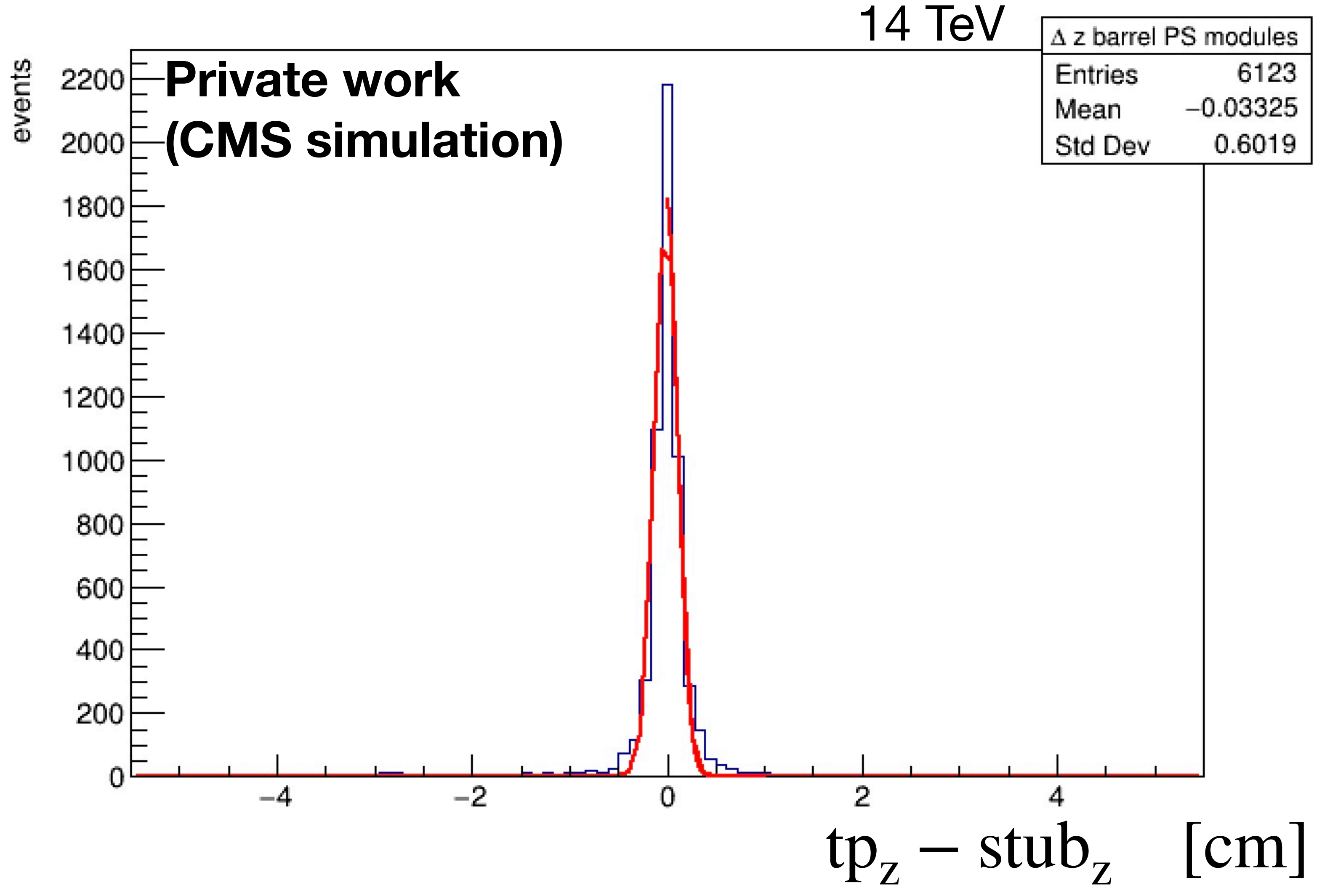
2S module		PS module	
$\sim 2 \times 90$ cm^2 active area		$\sim 2 \times 45$ cm^2 active area	
2×1016 strips:	~ 5 cm $\times$ 90 μm	2×960 strips:	~ 2.4 cm $\times$ 100 μm
2×1016 strips:	~ 5 cm $\times$ 90 μm	32×960 macro-pixels:	~ 1.5 mm $\times$ 100 μm



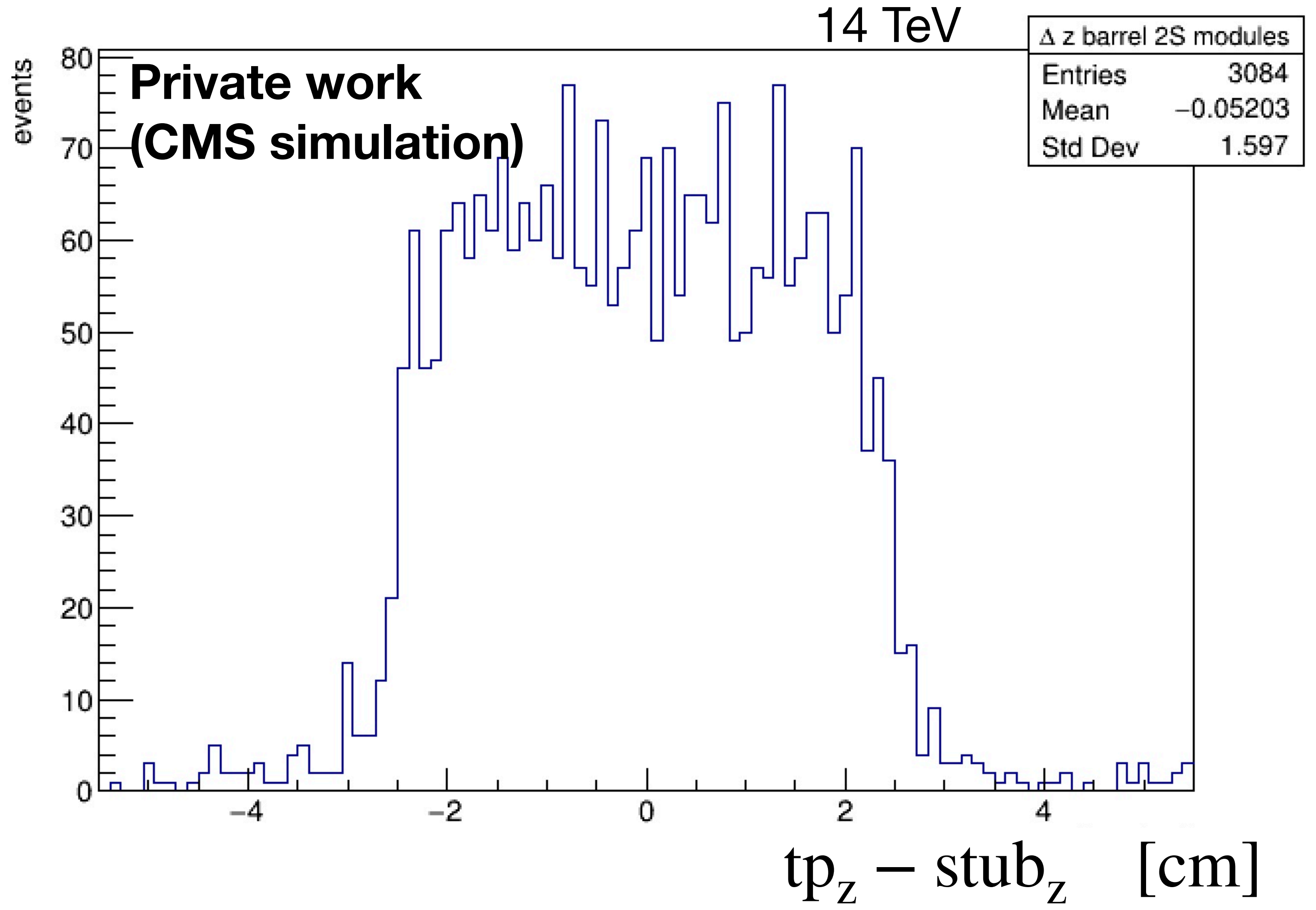




Δz barrel PS modules

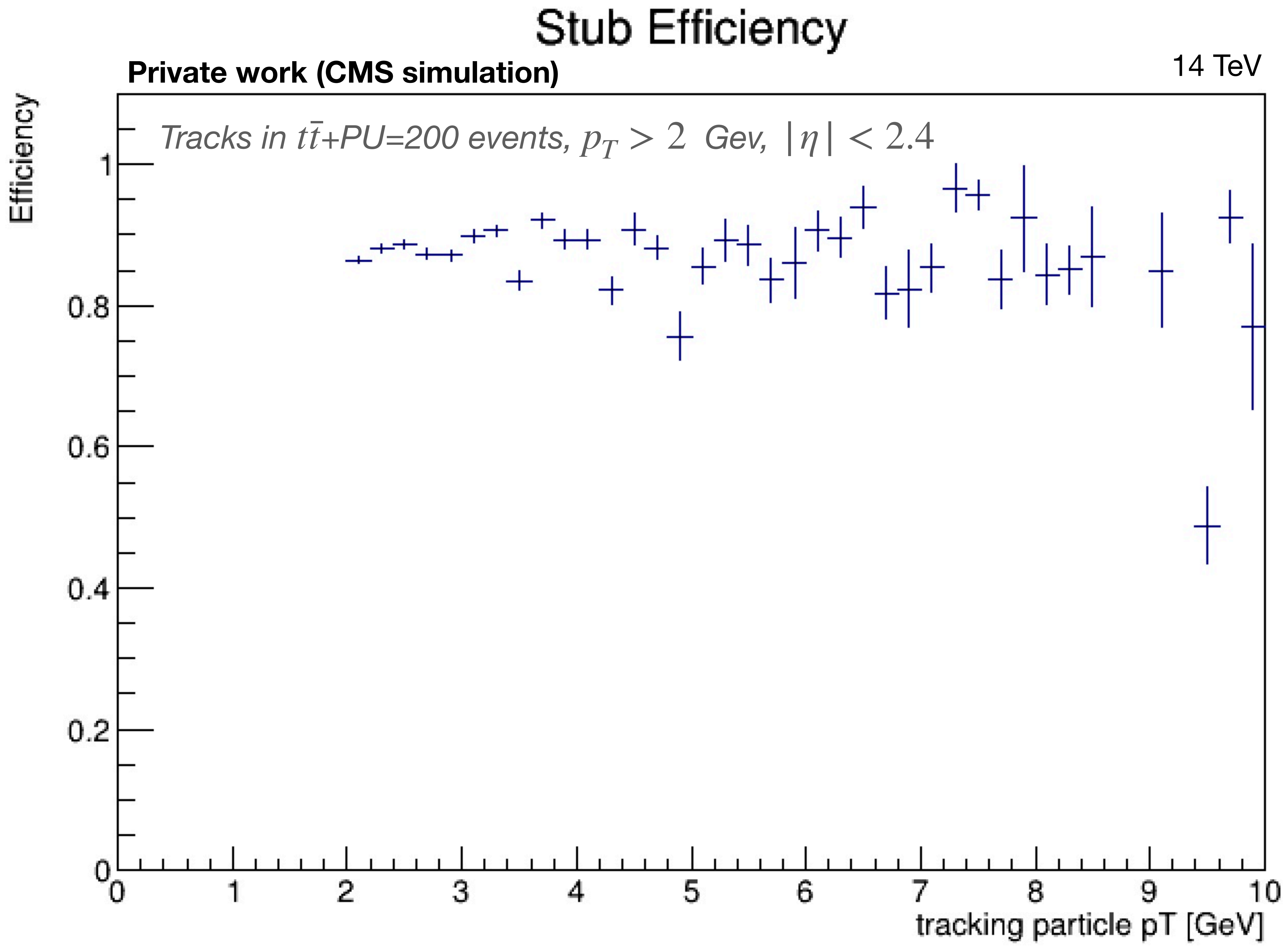


Δz barrel 2S modules



B. Skipworth

Stub Efficiency



$$\frac{\text{Number of genuine clusters if a genuine stub is found in a layer/disk}}{\text{Number of genuine clusters}}$$

B. Skipworth

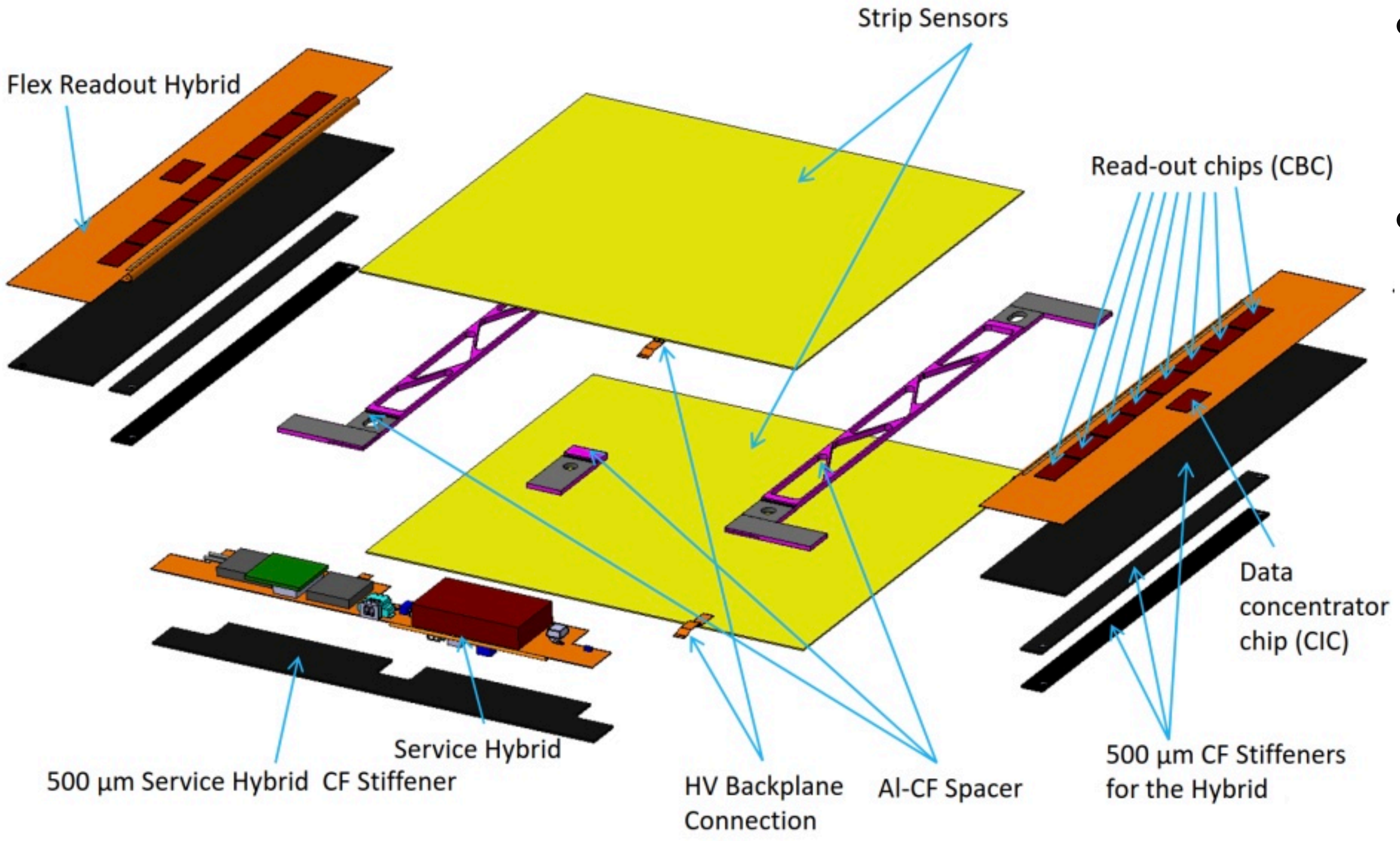
Summary

- For the **FIRST TIME** at the LHC,
  tracking information will be used at the Level 1 trigger
- The CMS outer tracker is being upgraded to manage the harsh radiation environment and complex events, ensuring efficient data reconstruction and processing.
- DQM is essential for continuously monitoring data quality, promptly identifying and alerting us to any detrimental changes caused by variations in detector conditions and operational scenarios.
- DQM acts at every data handling stage, from collection to analysis, with advanced checks integrated to swiftly address emerging issues.

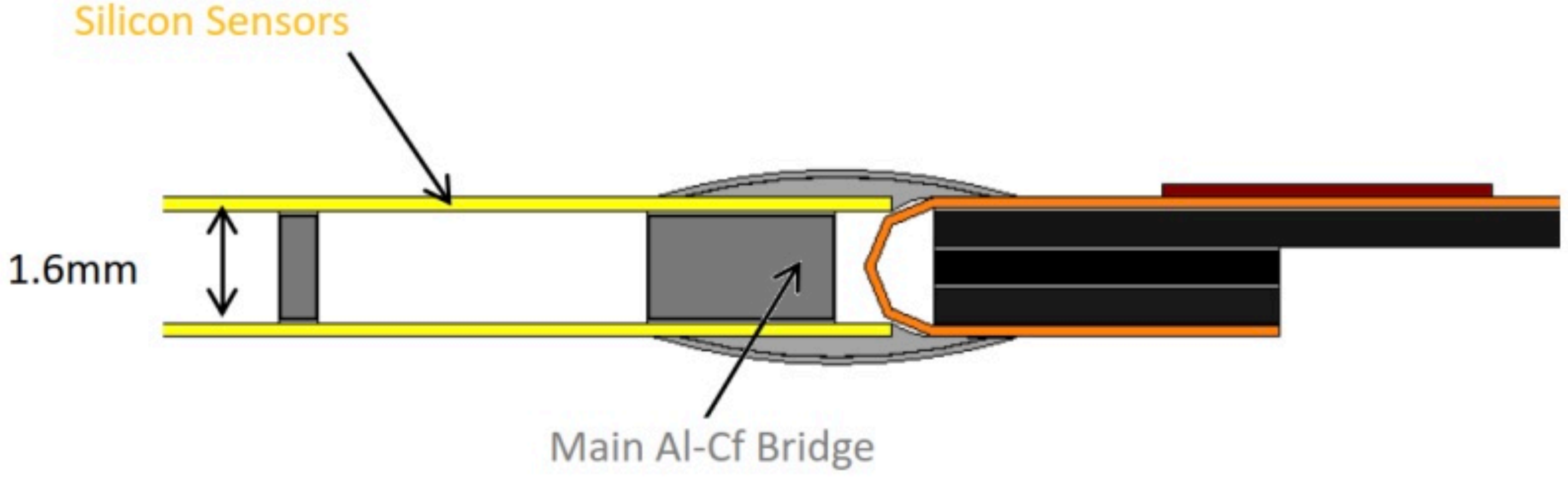
Backup

Outer Tracker 2S Modules

2S (two strip sensors)



- **Structure**: Each 2S module consists of two parallel sensors, each with 2032 strip lines.
- **Front-End Hybrids**: Each module has two front-end read-out hybrids.
- **Service Hybrid**: Provides optical data connectivity, power to the front-end hybrids, and biasing for the sensors.



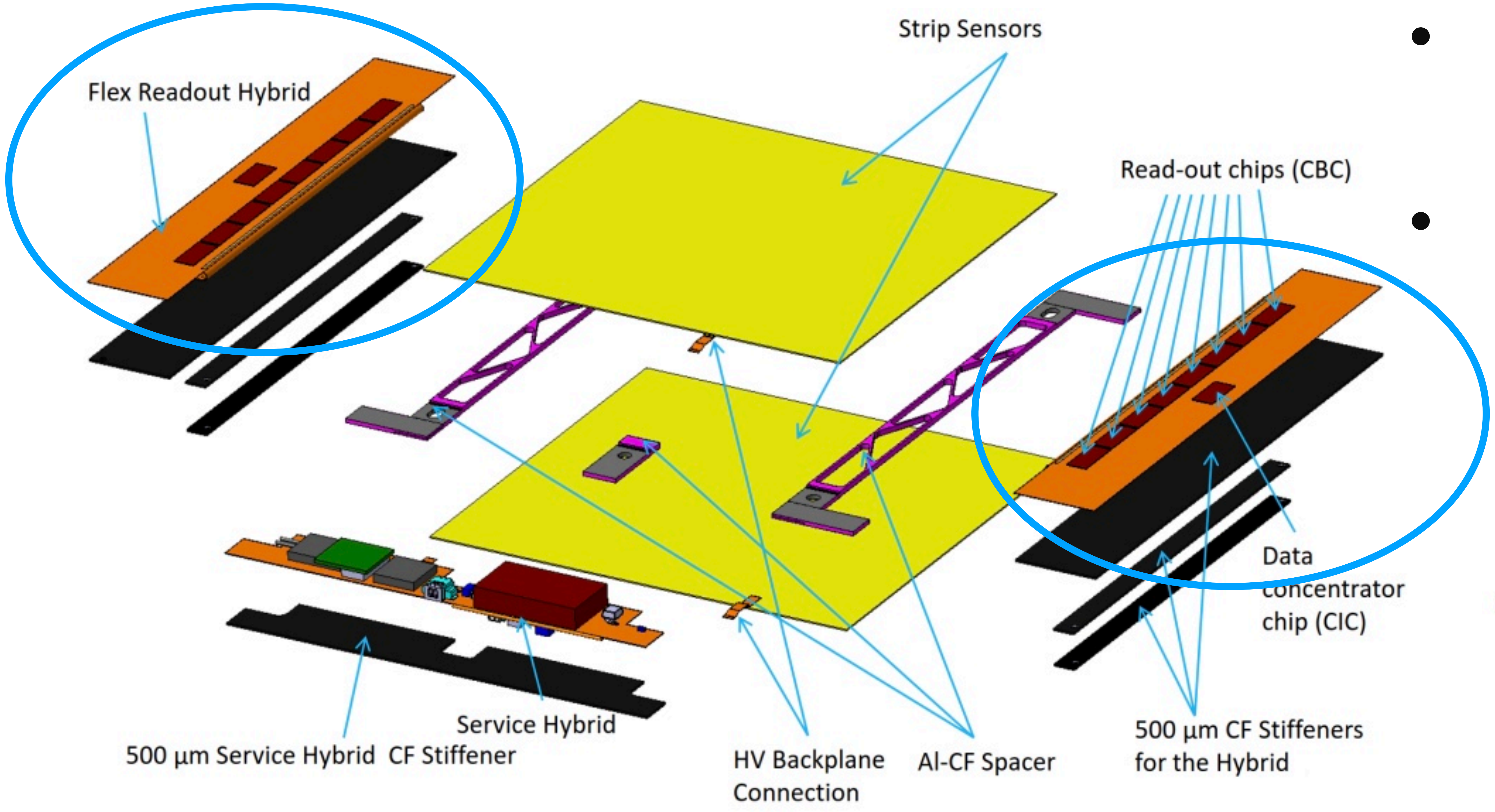
A cross section view showing wire bond interconnections of both sensors to a folded front-end hybrid

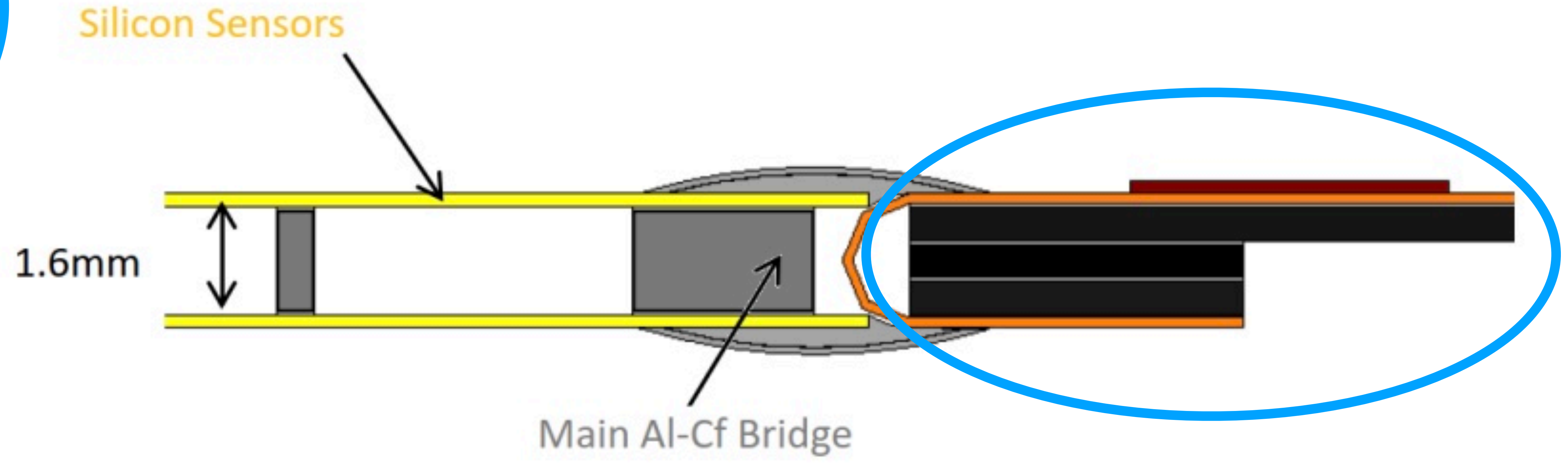
https://indico.cern.ch/event/697988/contributions/3056091/attachments/1718845/2773934/TWEPP-18_Tomasz_Gadek_Poster_2S_FEH.pdf

Outer Tracker 2S Modules

2S (two strip sensors)

- **Structure**: Each 2S module consists of two parallel sensors, each with 2032 strip lines.
- **Front-End Hybrids**: Each module has two front-end read-out hybrids.
- **Service Hybrid**: Provides optical data connectivity, power to the front-end hybrids, and biasing for the sensors.



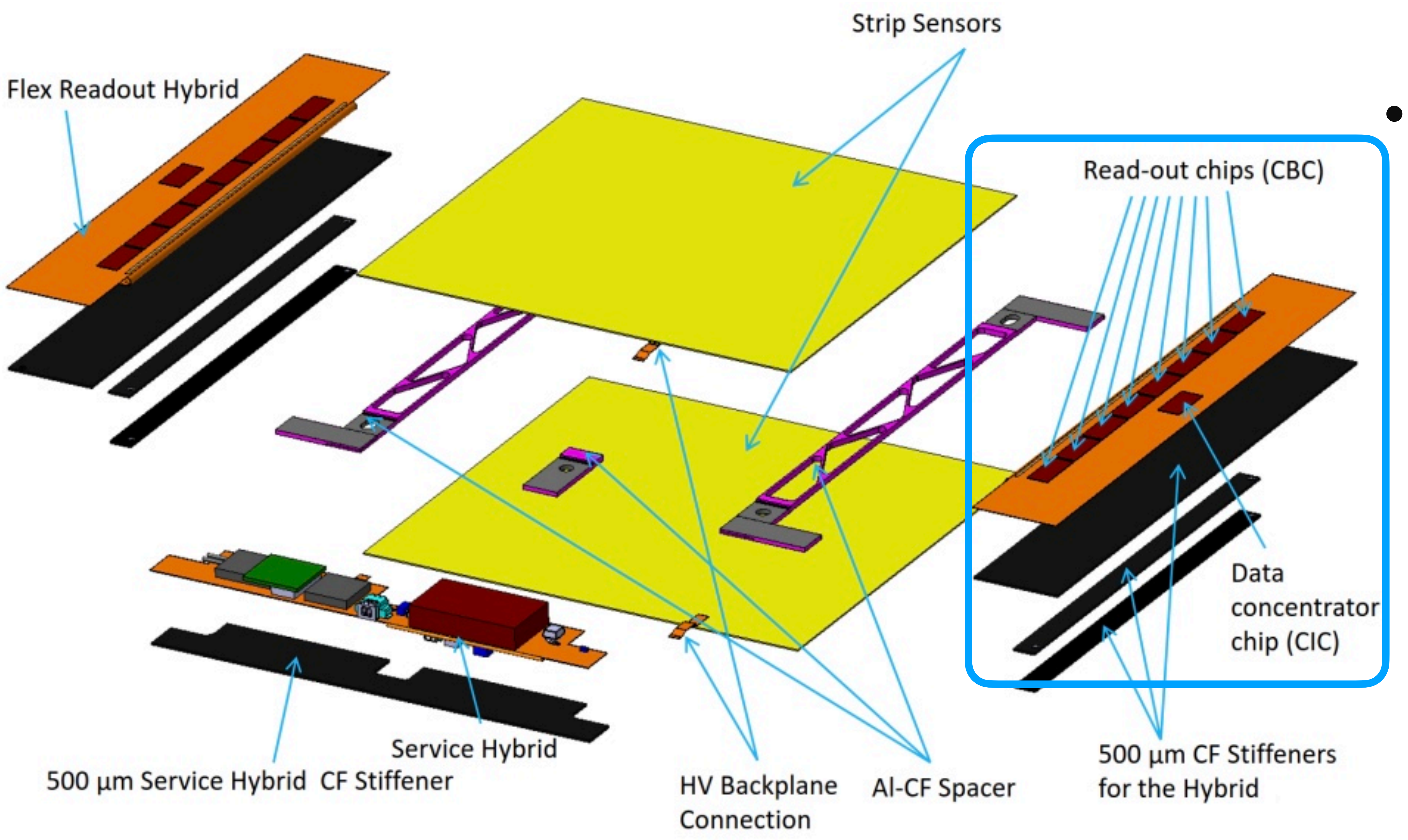


A cross section view showing wire bond interconnections of both sensors to a folded front-end hybrid

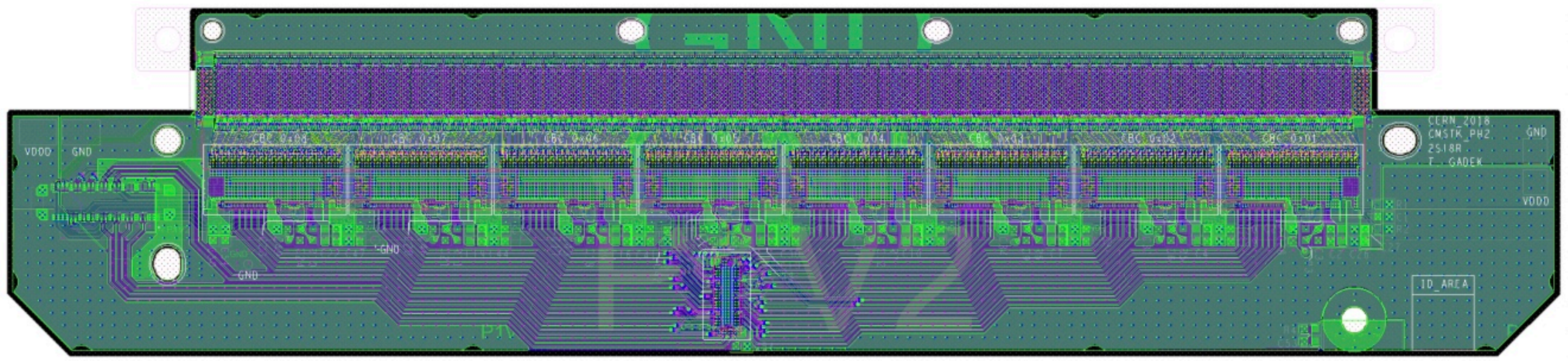
https://indico.cern.ch/event/697988/contributions/3056091/attachments/1718845/2773934/TWEPP-18_Tomasz_Gadek_Poster_2S_FEH.pdf

Outer Tracker 2S Modules

2S (two strip sensors)



- **CBC (CMS Binary Chip)**: **Front-End Hybrids**: Each CBC reads signals from 254 silicon strip sensors, performing critical hit correlation tasks that help identify potential particle tracks by forming stubs.
- **CIC (Concentrator Integrated Circuit)**: The CIC aggregates and processes data from multiple CBCs, performing data sparsification and formatting the data for efficient transmission to the main CMS data acquisition system.

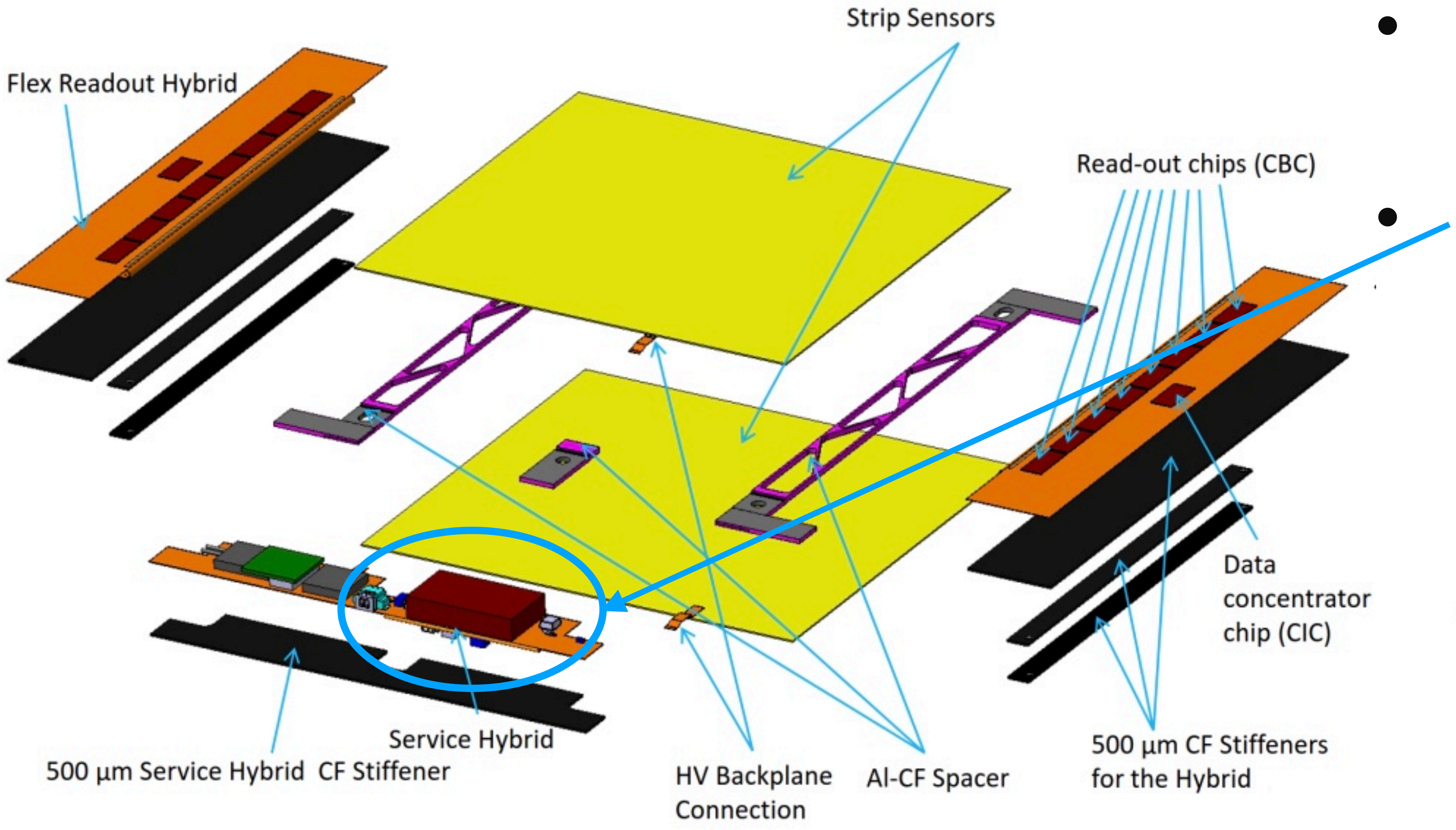


Detailed Layout of the 2S Module Front-End Flex: Showcasing the Bump-Bondable Footprint for the Concentrator ASIC.

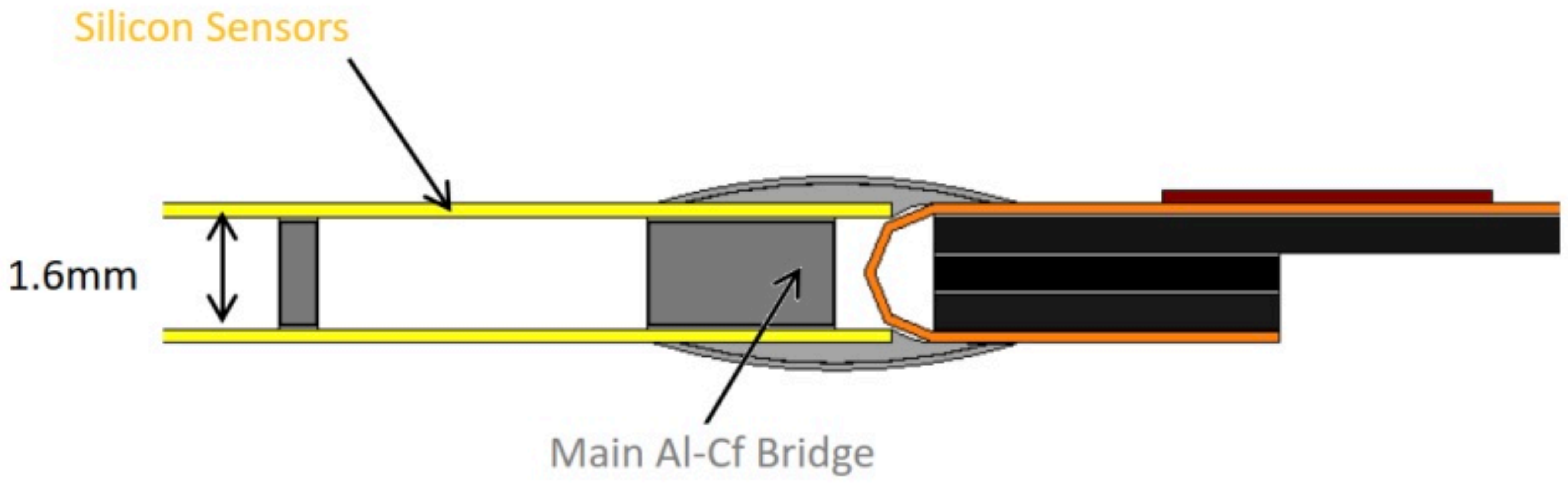
https://indico.cern.ch/event/697988/contributions/3056091/attachments/1718845/2773934/TWEPP-18_Tomasz_Gadek_Poster_2S_FEH.pdf

Outer Tracker 2S Modules

2S (two strip sensors)



- **Structure**: Each 2S module consists of two parallel sensors, each with 2032 strip lines.
- **Front-End Hybrids**: Each module has two front-end read-out hybrids.
- **Service Hybrid**: Provides optical data connectivity, power to the front-end hybrids, and biasing for the sensors.

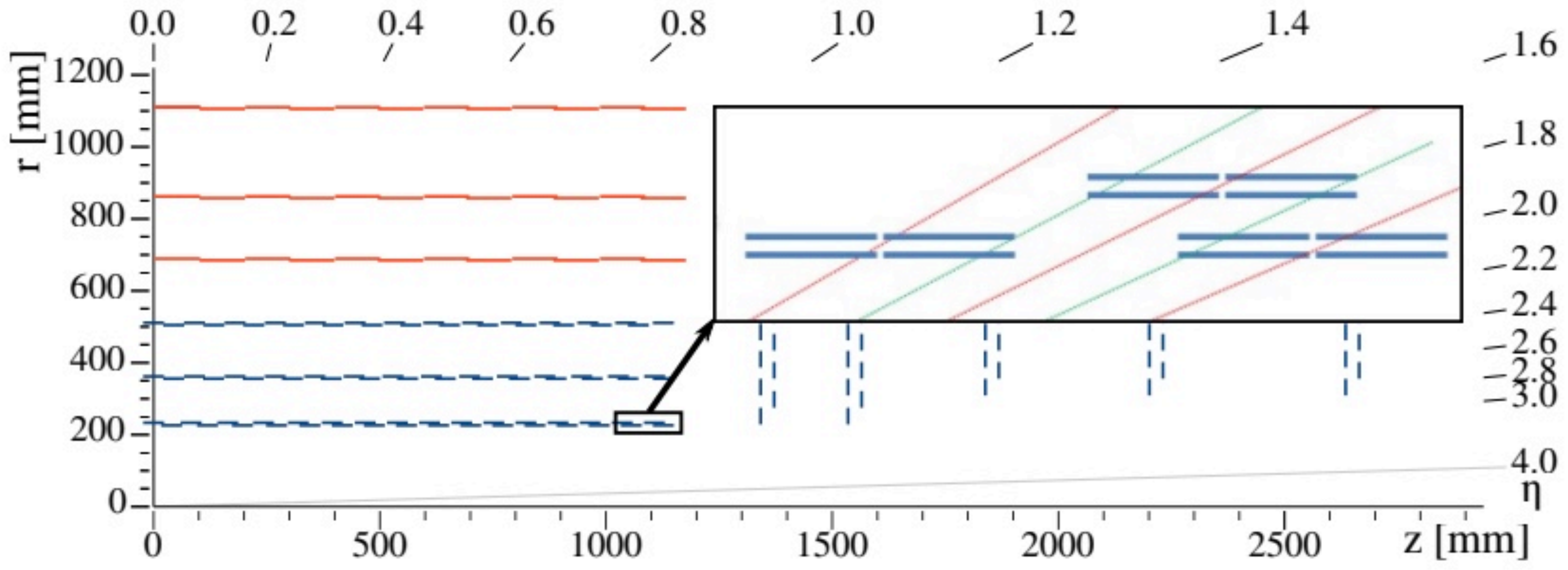


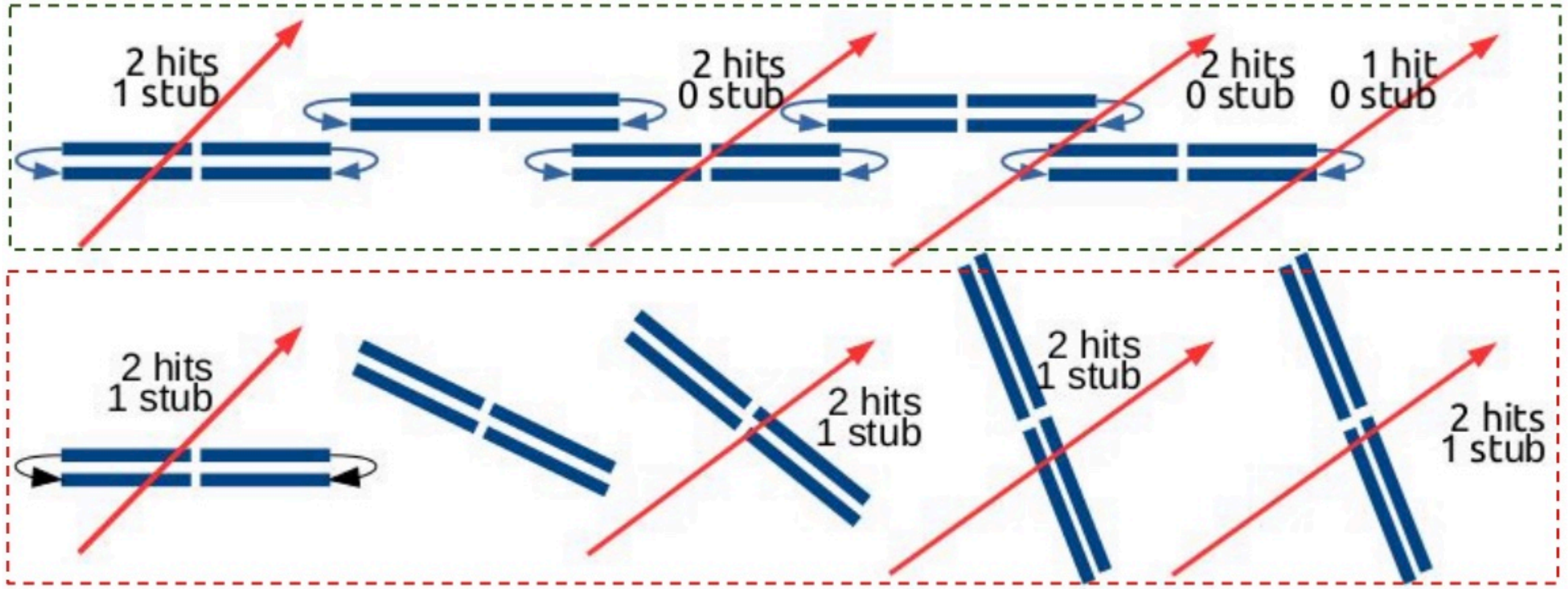
A cross section view showing wire bond interconnections of both sensors to a folded front-end hybrid

https://indico.cern.ch/event/697988/contributions/3056091/attachments/1718845/2773934/TWEPP-18_Tomasz_Gadek_Poster_2S_FEH.pdf

Flat Barrel Layout

- Both the top and bottom silicon sensors of a module must be connected to the readout electronic that performs stub finding
- The two halves of each module are read out independently
- Flat barrel layout would cause geometrical inefficiency of stub finding





B. Skipworth