ULB UNIVERSITÉ LIBRE DE BRUXELLES

CMS Compact Muon Solenoid

The upgrade of the CMS Outer Tracker detector

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Université libre de Bruxelles

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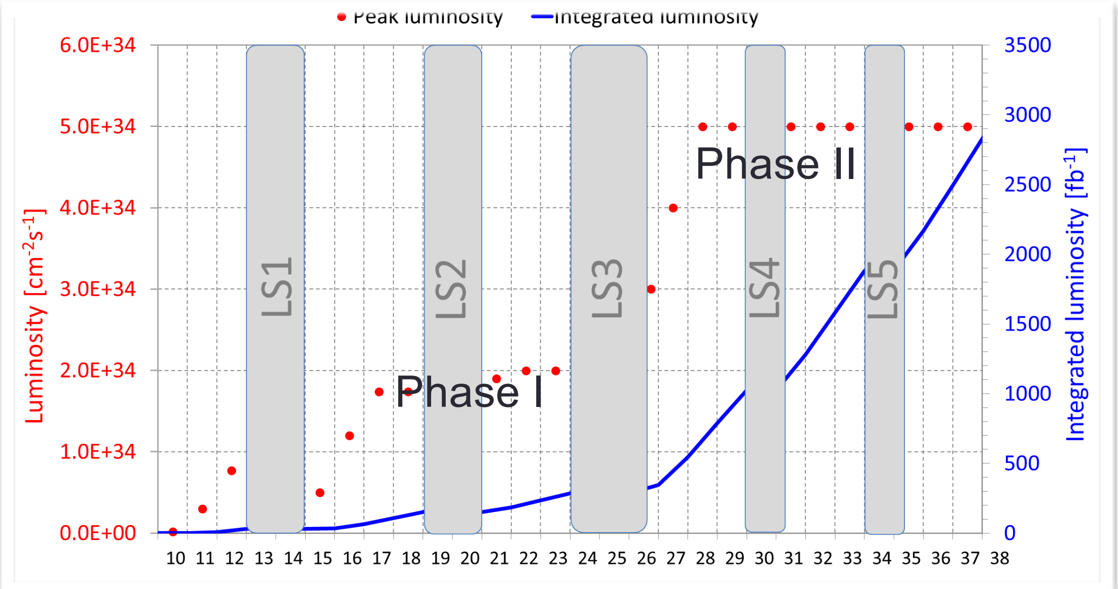
VERTEX/2017

Outline

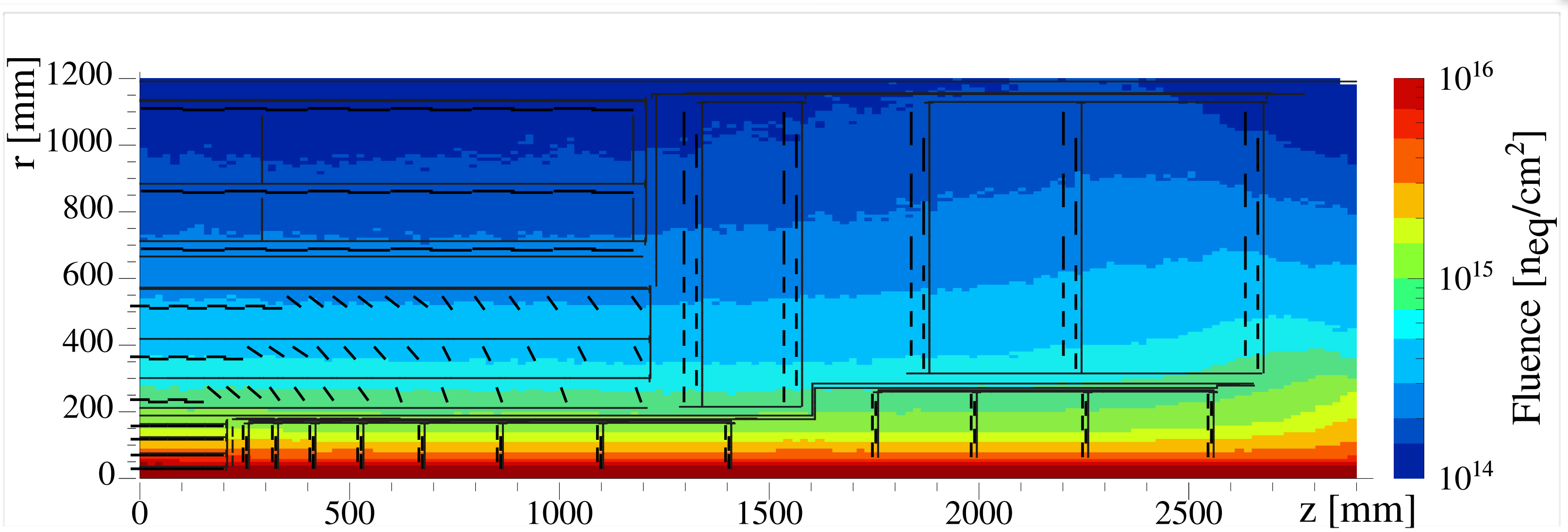
- HL-LHC upgrade aimed at expanding physics potential for rare and statistically limited processes, significant upgrades to the detectors needed
- Focusing mostly on technical aspects of the CMS Tracker upgrade for the HL-LHC:
    1. HL-LHC & CMS
    2. CMS Tracker present and future:
        1. p_T module concept
        2. Front-end electronics
        3. Prototyping and testing
    3. Expected performance improvements
    4. Summary

The HL-LHC upgrade

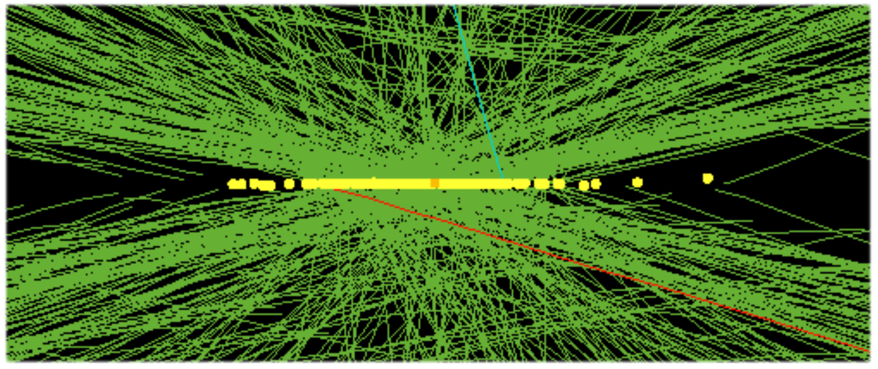
- **LHC upgrade**
  - Large increase in **instantaneous luminosity**
  - Increase in number of **pile-up** events
  - **Integrated luminosity** 3000-4000 fb^{-1}
  - Unprecedented **radiation** levels



Instantaneous luminosity up to 7.5×10^{34} $cm^{-2}s^{-1}$



Radiation levels up to 2×10^{16} n_{eq}/cm^2



Pile-up up to 200

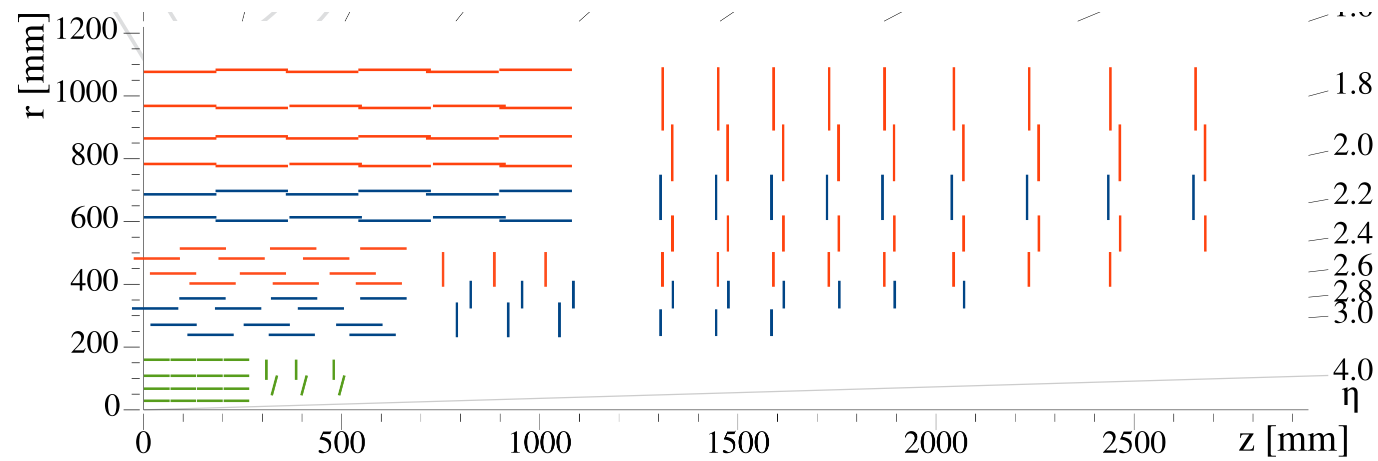
CMS Tracker upgrade

Tracker baseline geometry

CMS upgrade includes complete replacement of the Tracker detector

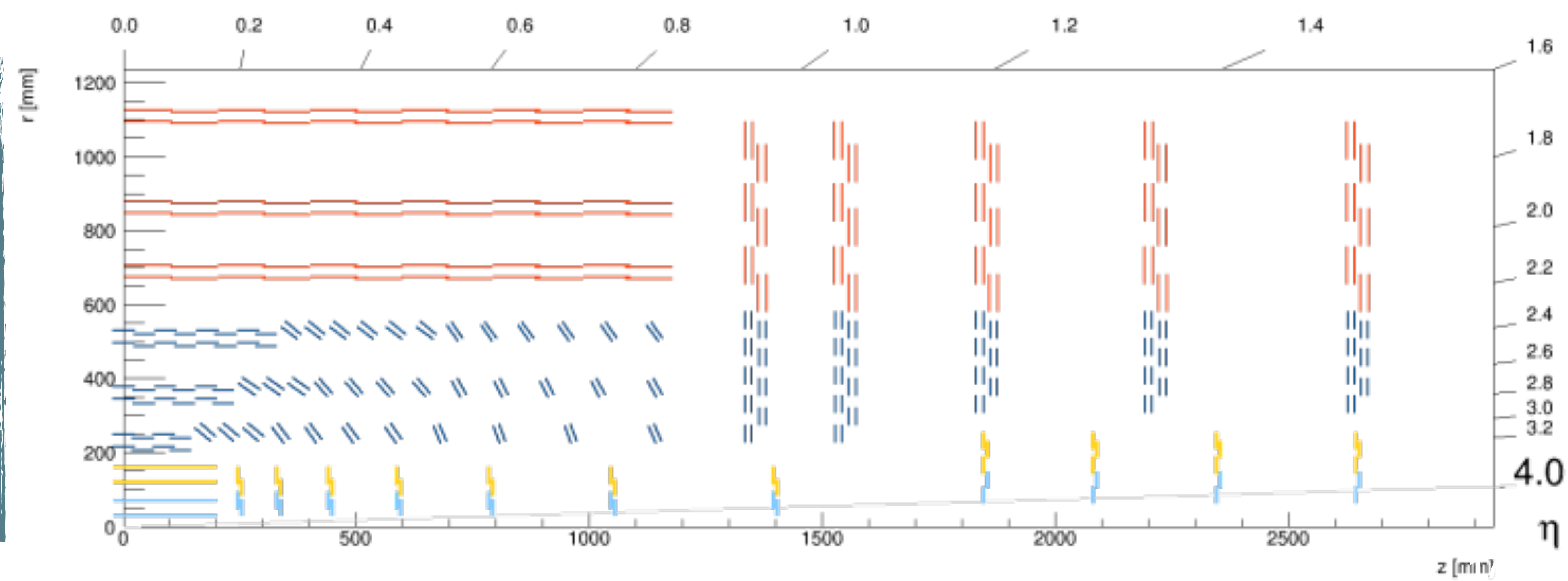
Current outer tracker:

- **~200 m²** silicon sensors
- **9.5 M** strips
- **100 kHz** L1 trigger rate



Upgraded outer tracker:

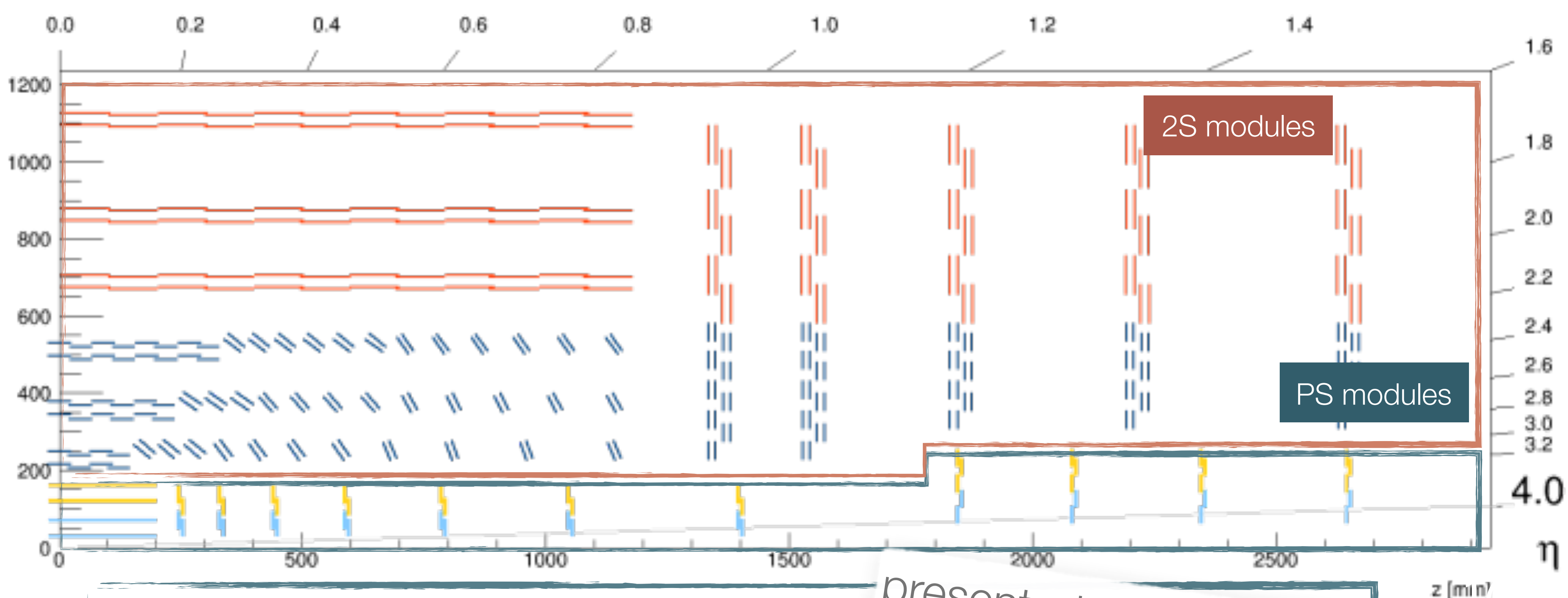
- **~200 m²** silicon sensors
- **44 M** strips
- **174 M** macro-pixels
- **40 MHz** stub rate
- **750 kHz** L1 trigger rate



Tracker baseline geometry

Outer tracker:

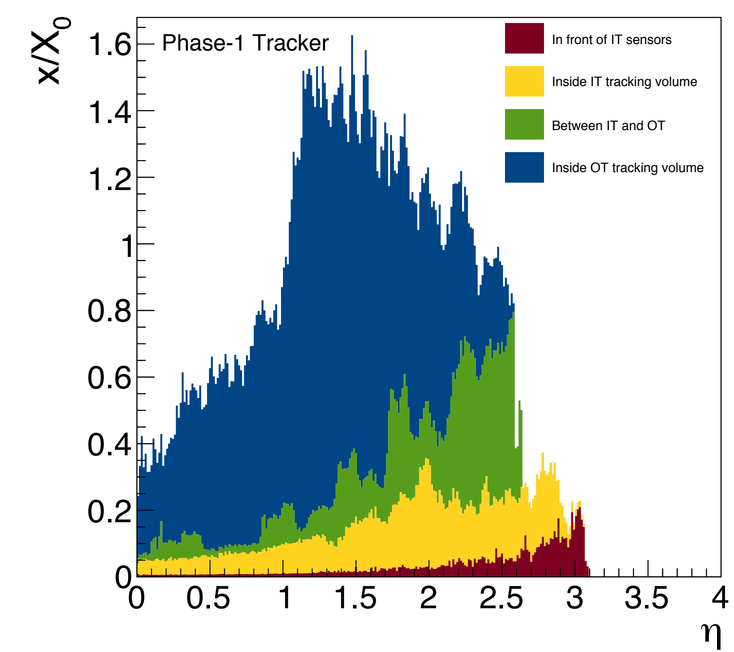
- **6 layers, 5 disks**
- 2 layer modules providing input (stubs) to the L1 trigger
- **high granularity and efficient track reconstruction**

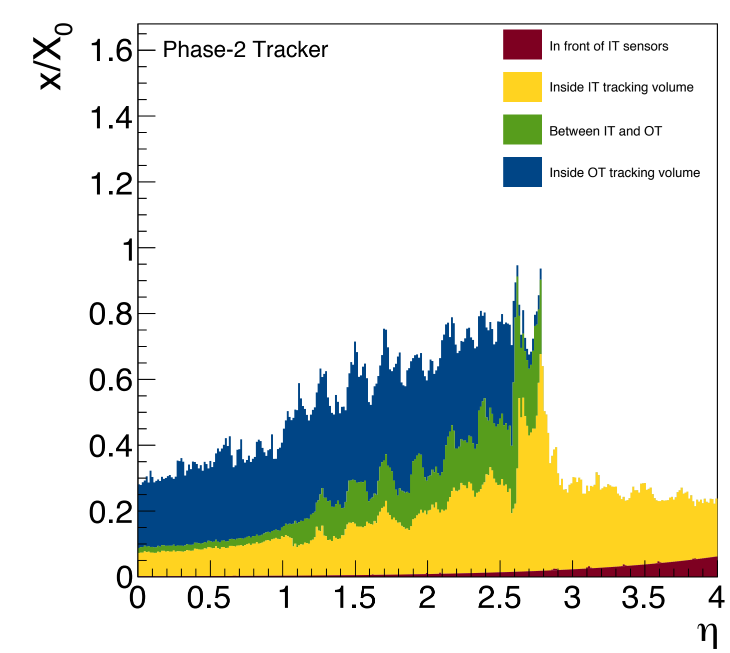


presented on Monday by L.Viliani

Inner tracker:

- **4 layers, 11 disks**, increased coverage |η|<4
- sensors still under development - thin planar 100um or 3D sensors
- **small pixels** (50x50 um^2 or 25x100 um^2)

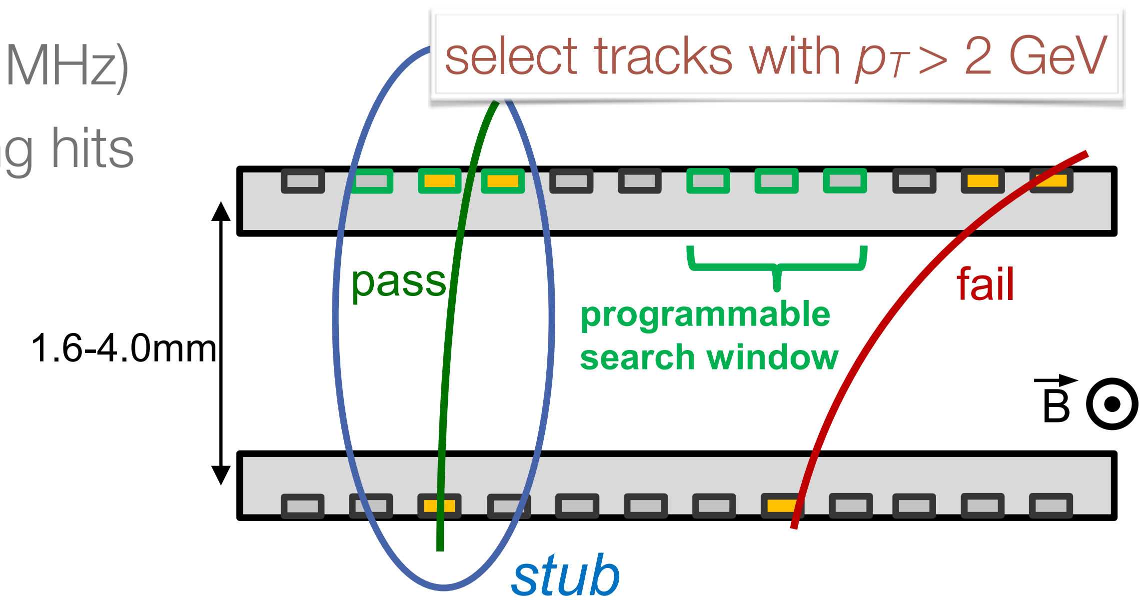


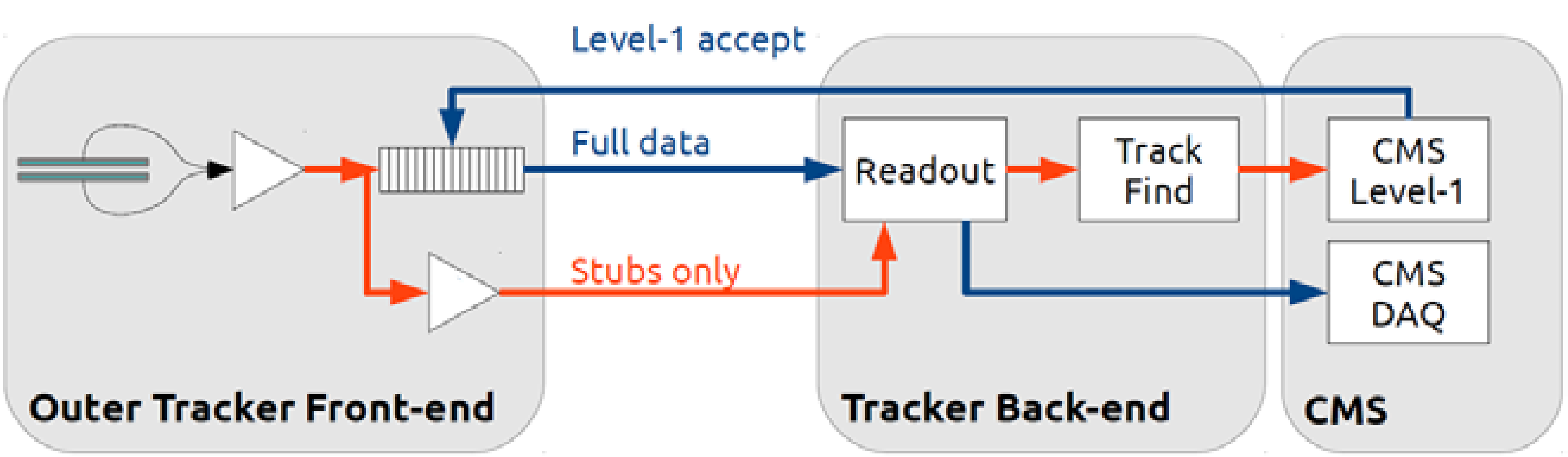


p_T module concept

Outer tracker p_T modules:

- sends information to the L1 trigger at BX frequency (40 MHz)
- detects high momentum tracks on module by correlating hits on two parallel sensors - **stubs**
- tuneable **offset** and **window size**
- **two data lines -** trigger information and hit data



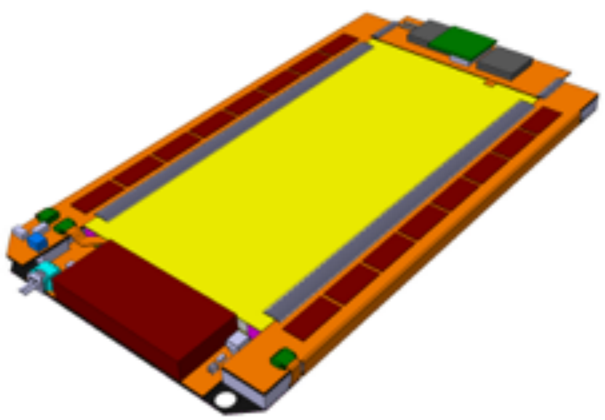


@ 40 MHz – Bunch crossing →Trigger Data
@ <750 kHz – CMS Level-1 trigger →L1 Readout Data

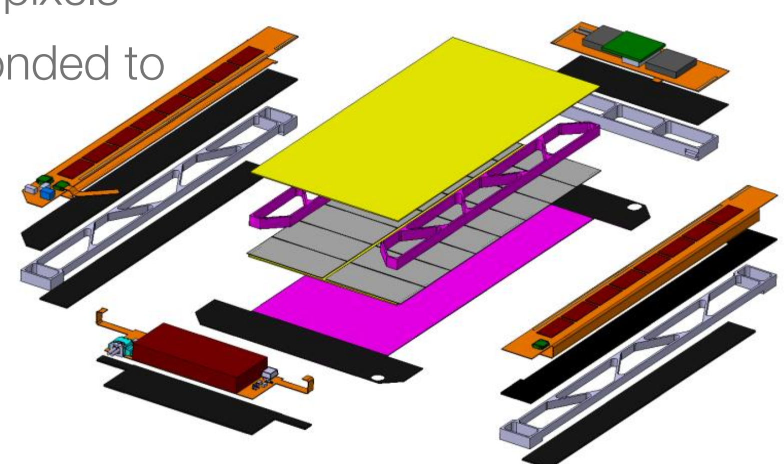
fast track reconstruction in the back-end

p_T modules

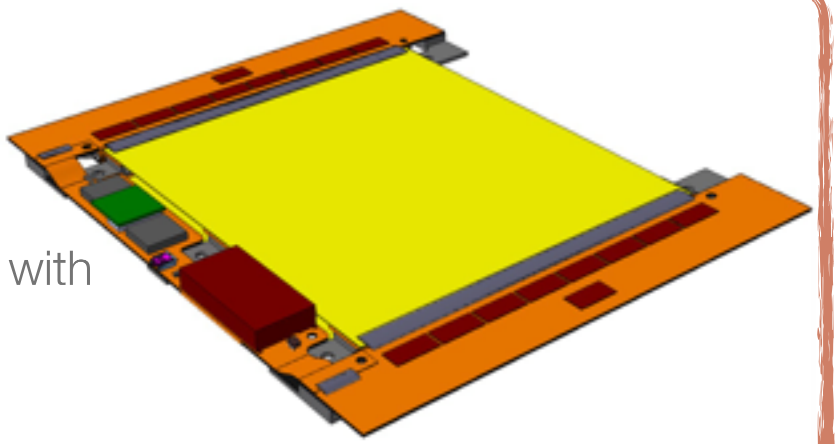
PS Modules



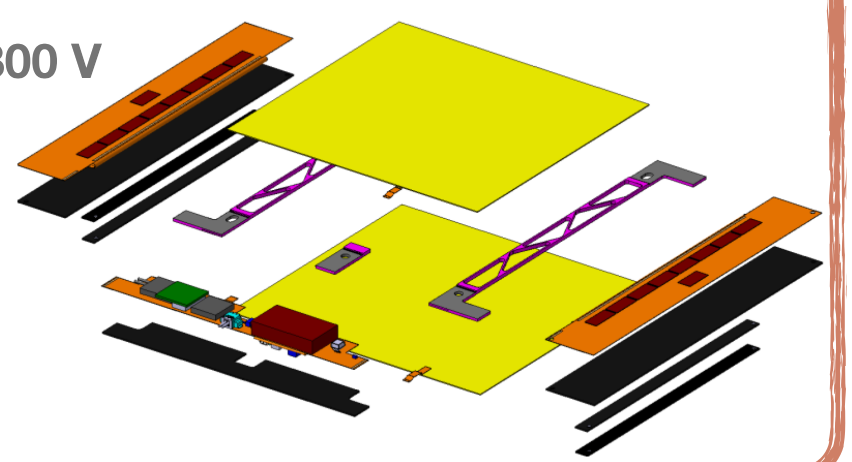
- one **strip** sensor
  - **10x5 cm^2** sensor
  - **2.35 cm** long strips
  - **960** strips @ **100 um** pitch
- one **macro-pixel** sensor
  - 1467x100 um^2 pixels
  - pixels bump-bonded to readout chips
- sensor spacing **1,6 mm, 2.6 mm** and **4 mm**



2S Modules



- 2 **strip** sensors
- **10x10 cm^2** sensors with **5 cm** long strips
- **90 um** pitch
- Total **2032 channels**
- **sensor spacing** 1.8 mm and 4 mm
- HV stability up to **-800 V**



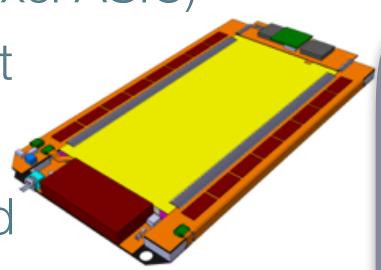
Sensors

- **n-in-p** planar technology
- **200-240 um** active thickness
- full depletion voltage below 300 V

Front-end electronics

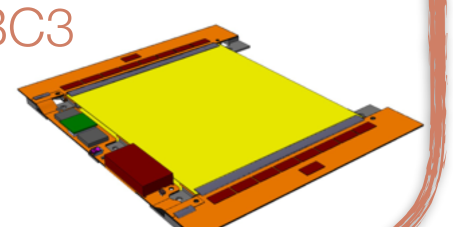
PS Front-end

- **SSA chip** (Short strip ASIC)
  - strip data readout and sends it to MPA
- **MPA chip** (Macro Pixel ASIC)
  - pixel data readout
  - stub data logic
- both chips submitted



2S Front-end

- **CBC chip** (CMS Binary Chip)
  - strip data readout from both sensors and stub data creation
  - inter-chip communication
  - current version CBC3



clock, I²C, HV

L1 and channel data

CIC chip

- common Concentrator IC
- buffers, aggregates and sparsifies data from each chip

data

L1 and channel data

clock, I²C, HV

Service hybrid

- **DC-DC converter**
  - provides necessary voltages for front-end chips and optoelectronics
- **LpGBT**
  - clock and trigger distribution
  - data serialisation/ deserialisation
  - slow control and monitoring
- **VTRx+**
  - converts data to optical/ electrical
  - radiation hard
- **HV** connectors

connection to the BE

Track trigger

- Filter tracks with $p_T > 2$ **GeV**
- data **reduction** 10 to 100 times
- **tuneable** stub finding logic
- different sensor **spacings**
- **Three approaches:**

- **Triggering @ 40 MHz:**
  - **10k stubs** at each bunch crossing
  - reconstruction in 5 μs

Associative memory	specially designed ASICs perform fast pattern recognition, full selection done by the FPGA
Hough transform	FPGA based, two stage track finding (Hough transform for coarse stub grouping+ Kalman filter for precision fitting)
Tracklet	FPGA based, road search algorithm, stubs in neighbouring layers form seed, linearised χ^2 fit for final parameters

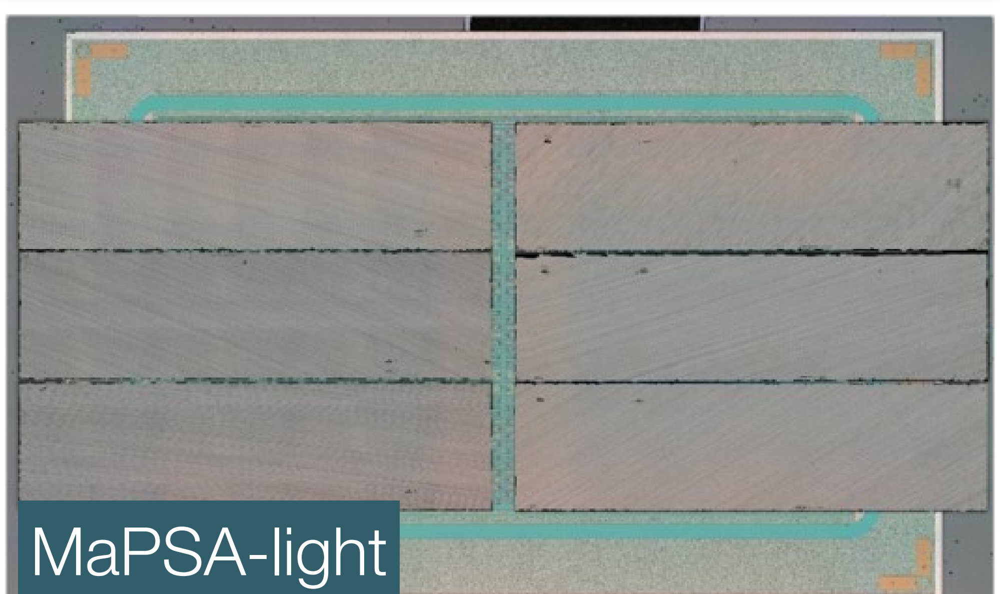
- hardware demonstrators built for each approach
- further studies ongoing

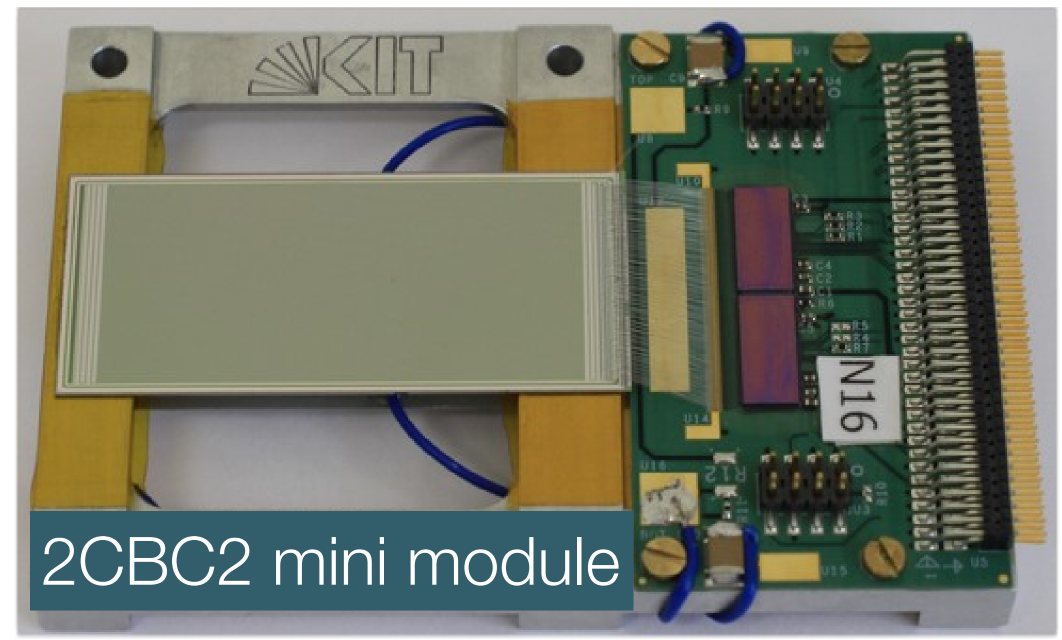
see talk from K. Hahn on Friday

Prototyping and testing

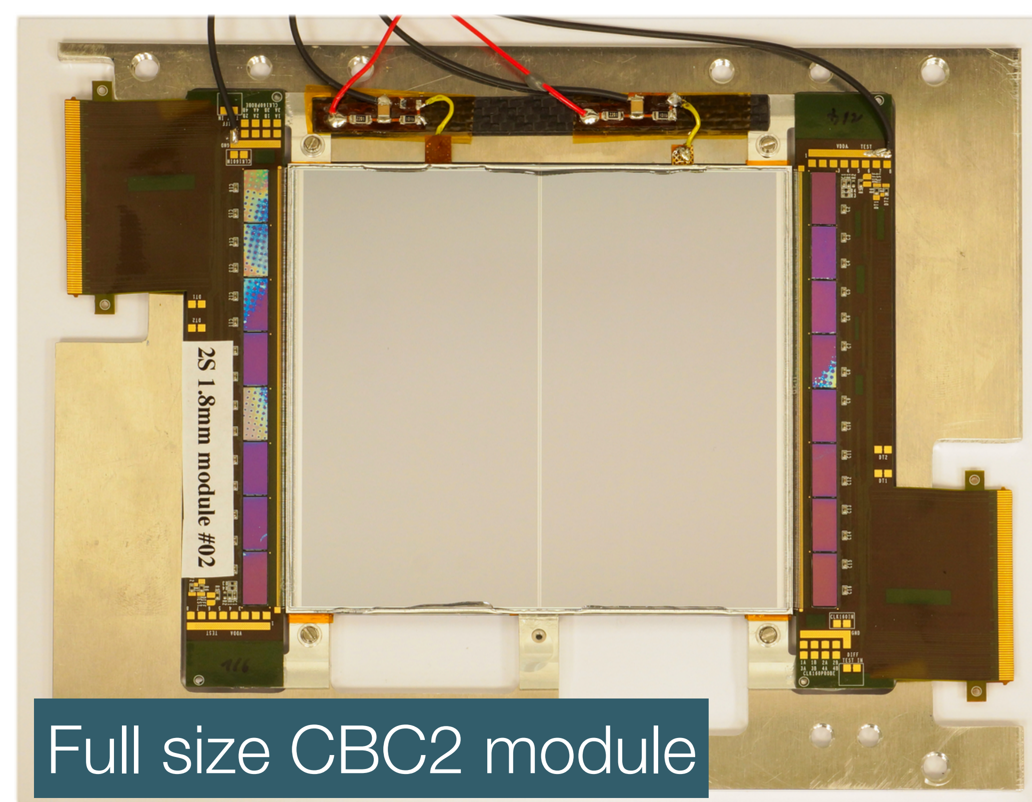
First prototypes

- first **prototypes** built
- **performance** and **robustness** evaluated
- operational **conditions** as close as possible to expected **running conditions**


MaPSA-light



2CBC2 mini module

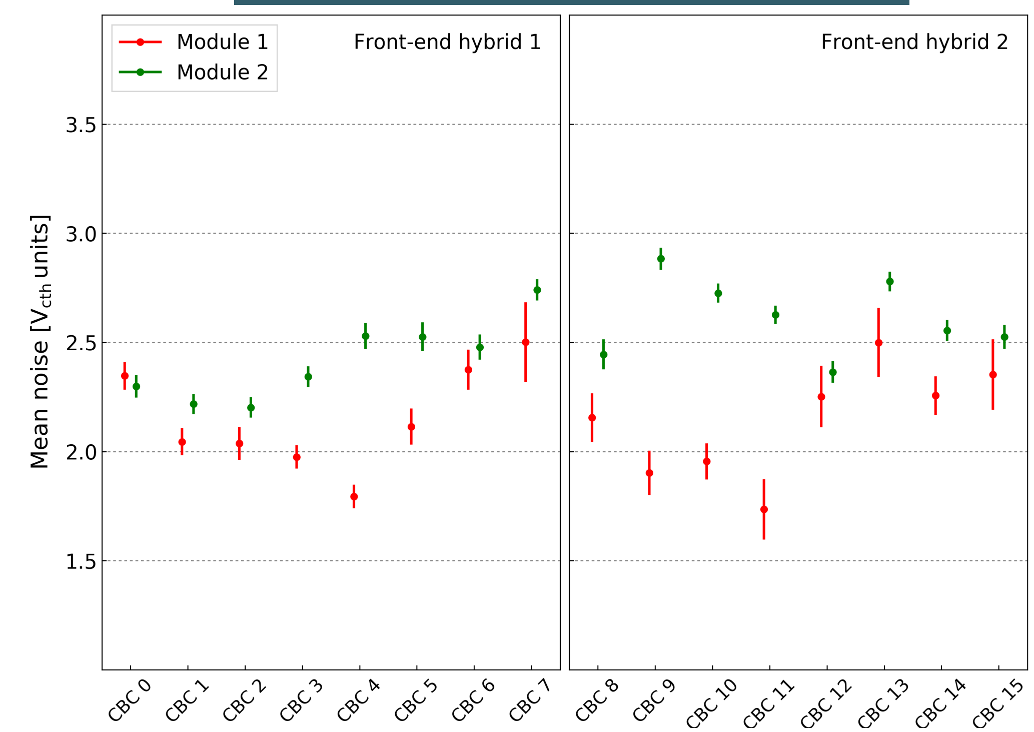


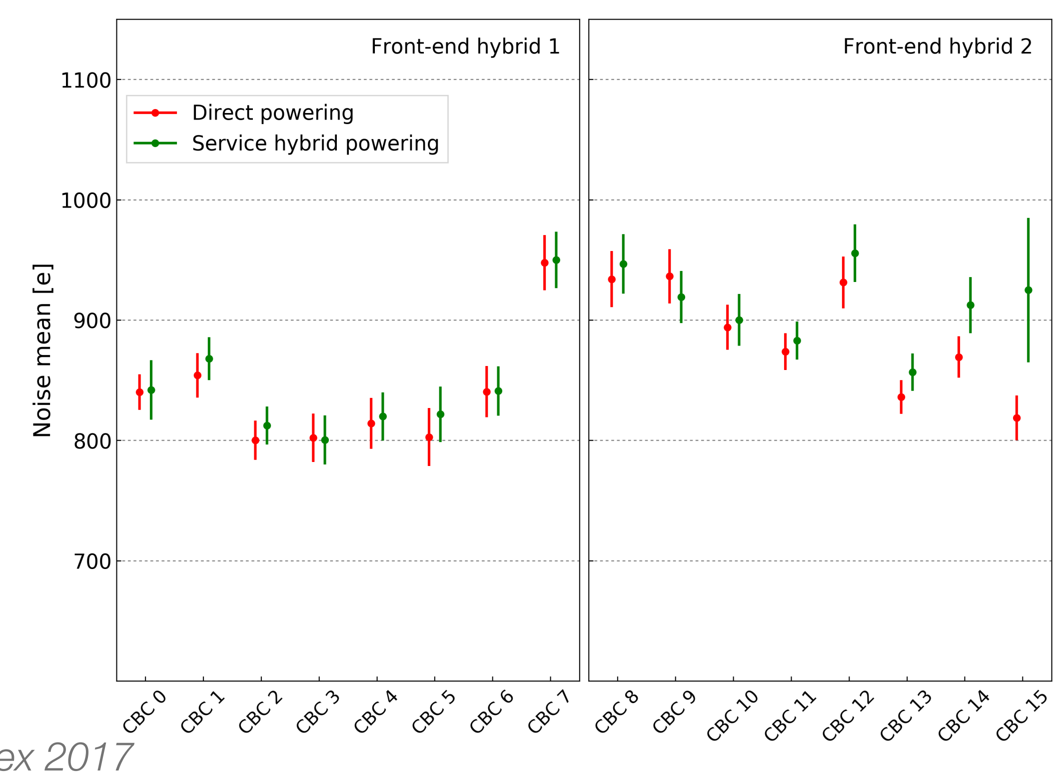
Full size CBC2 module

System tests

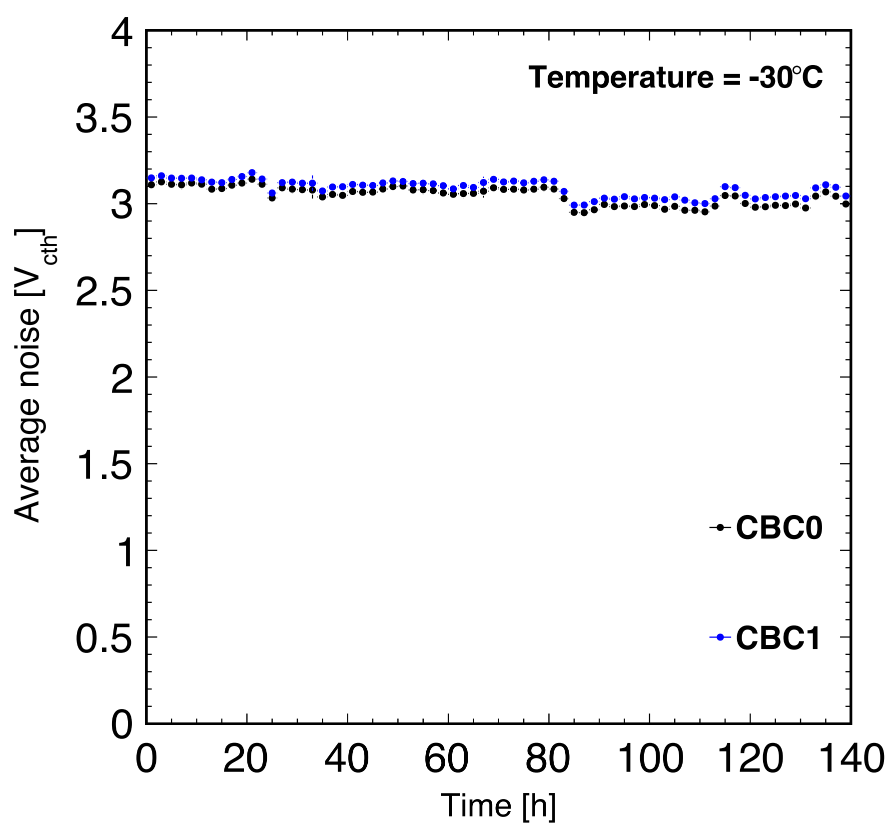
- determine negative effects of the **environmental conditions**
- stable operation over **time**
- interference between module **components**

Full size CBC2 module





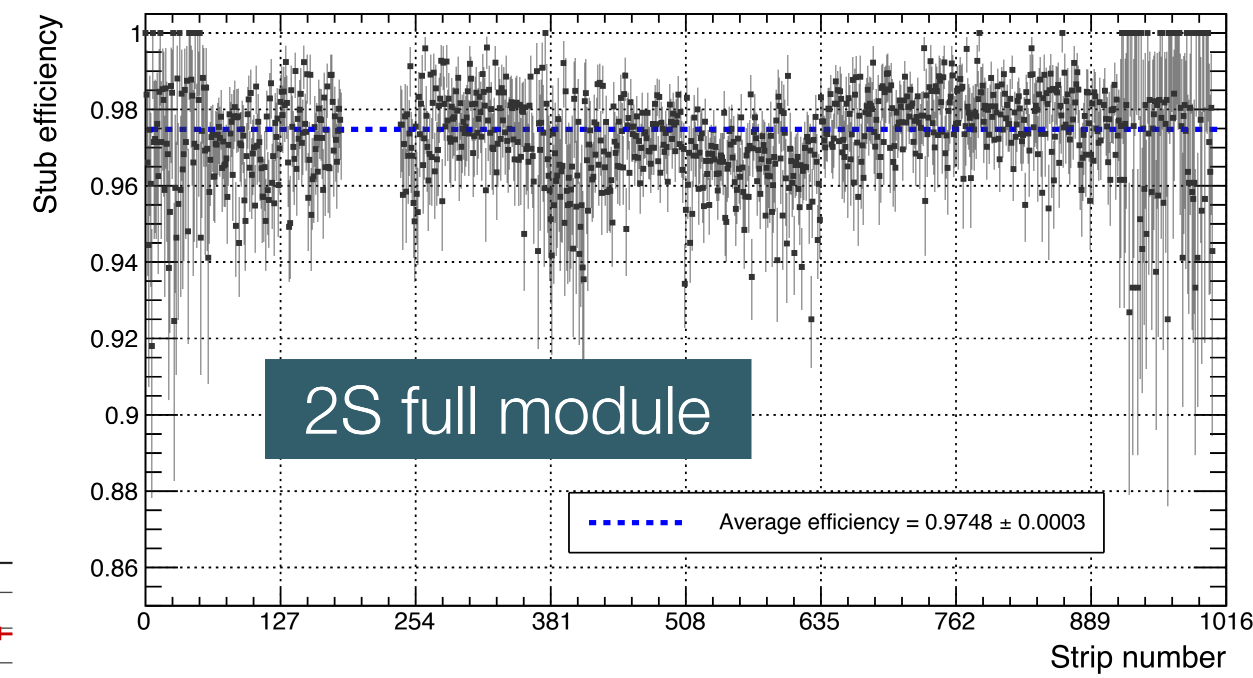
2S mini module @ -30°C

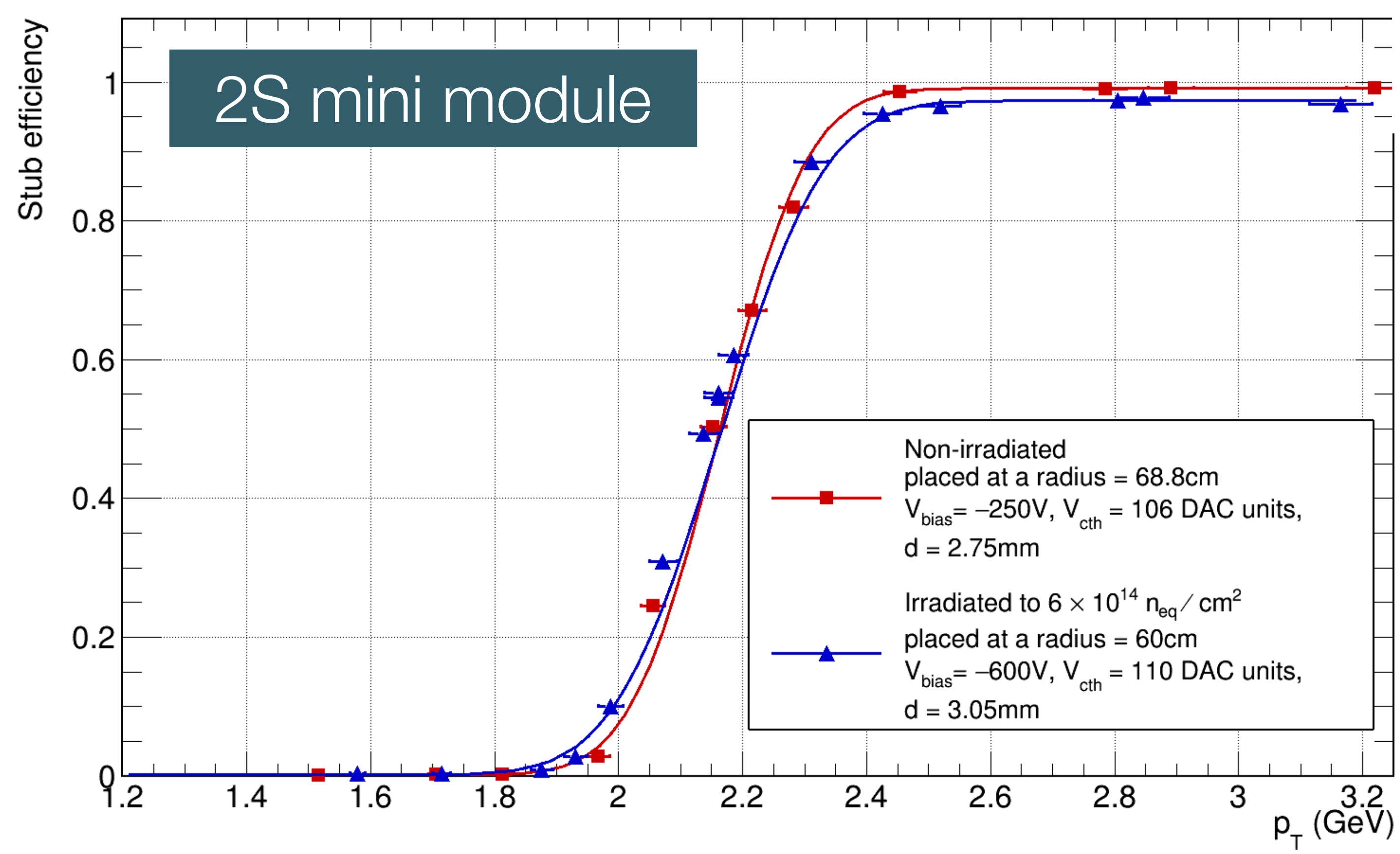


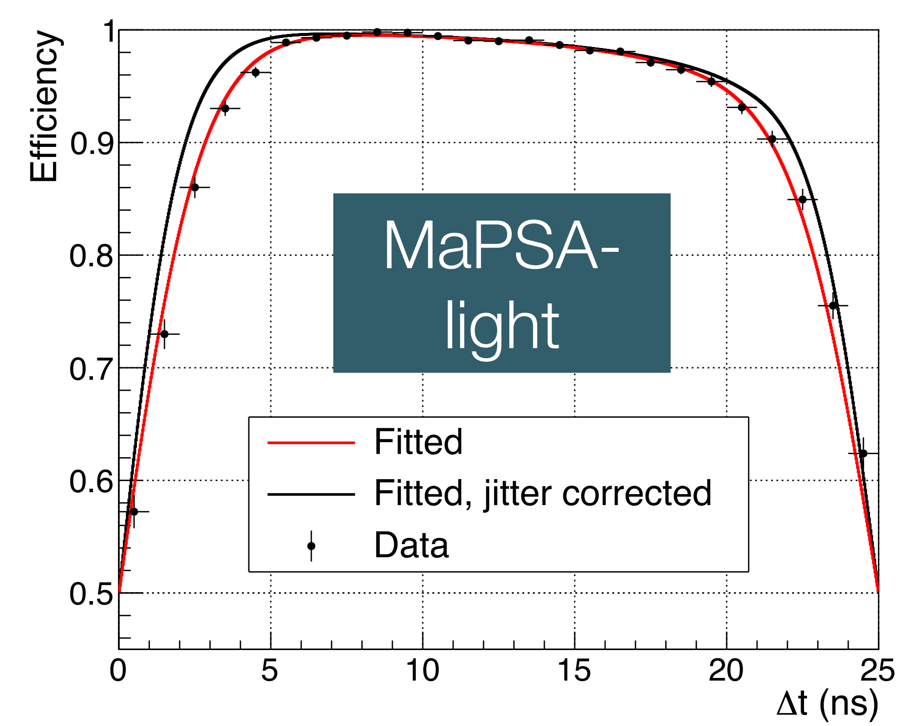
Noise ~1000 electrons

Beam tests

- evaluating effects of **irradiation** on module performance in beam tests
- verify the **stub finding mechanism** and hit reconstruction **efficiency**



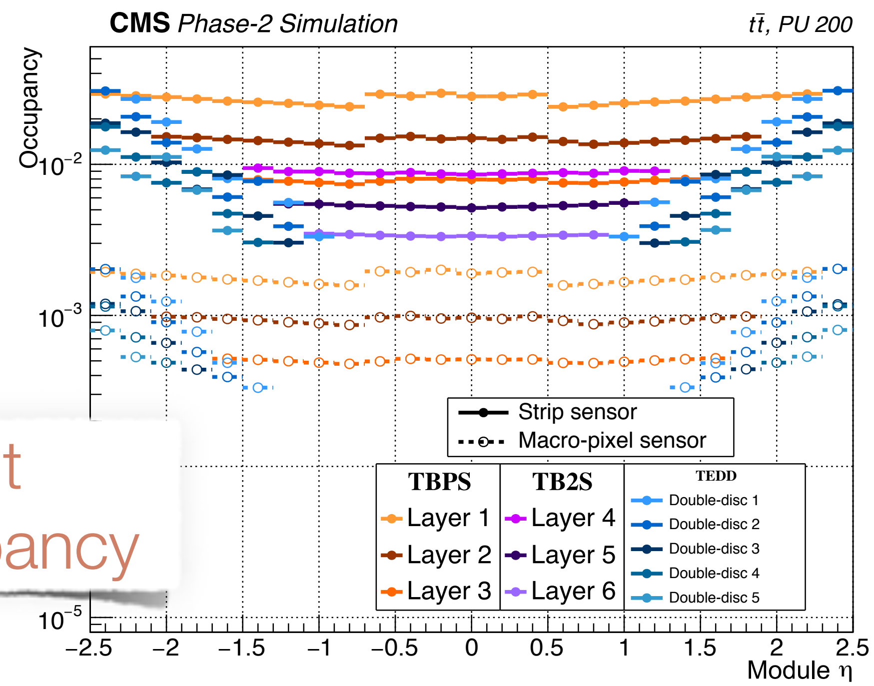




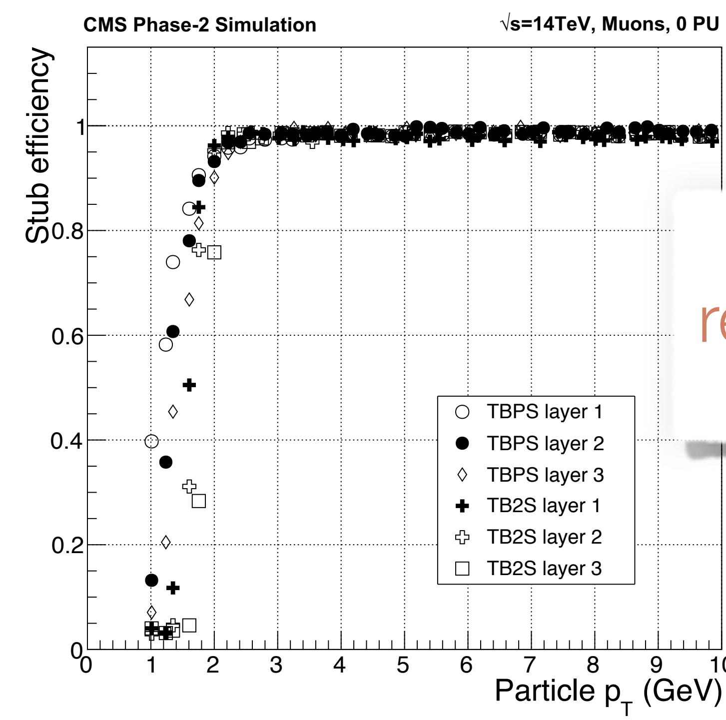
Performance

Performance

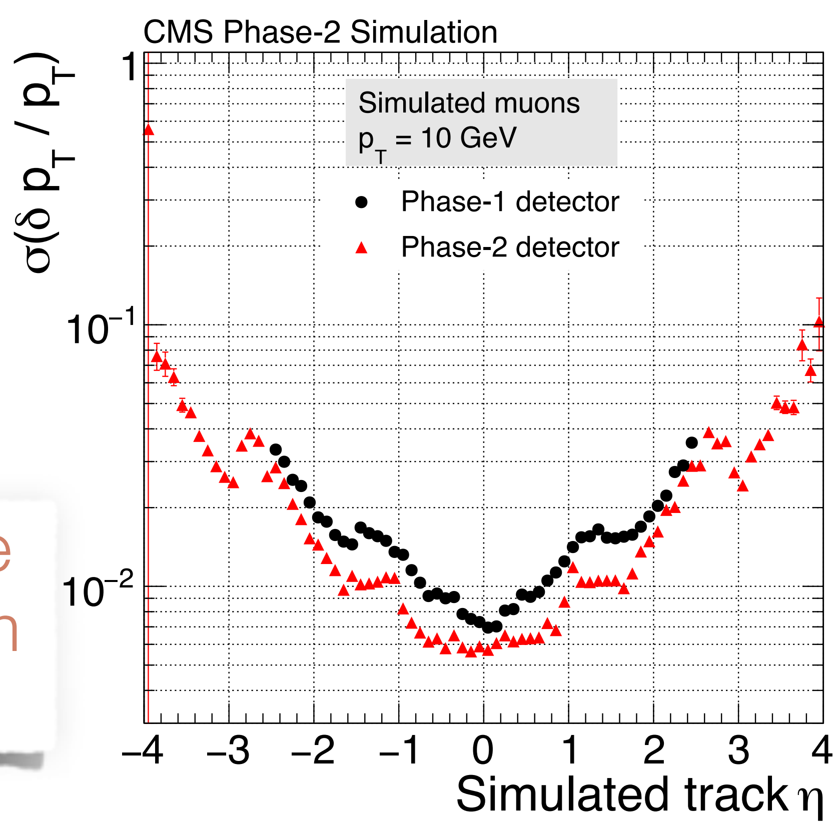
- All performance results obtained in the simulation



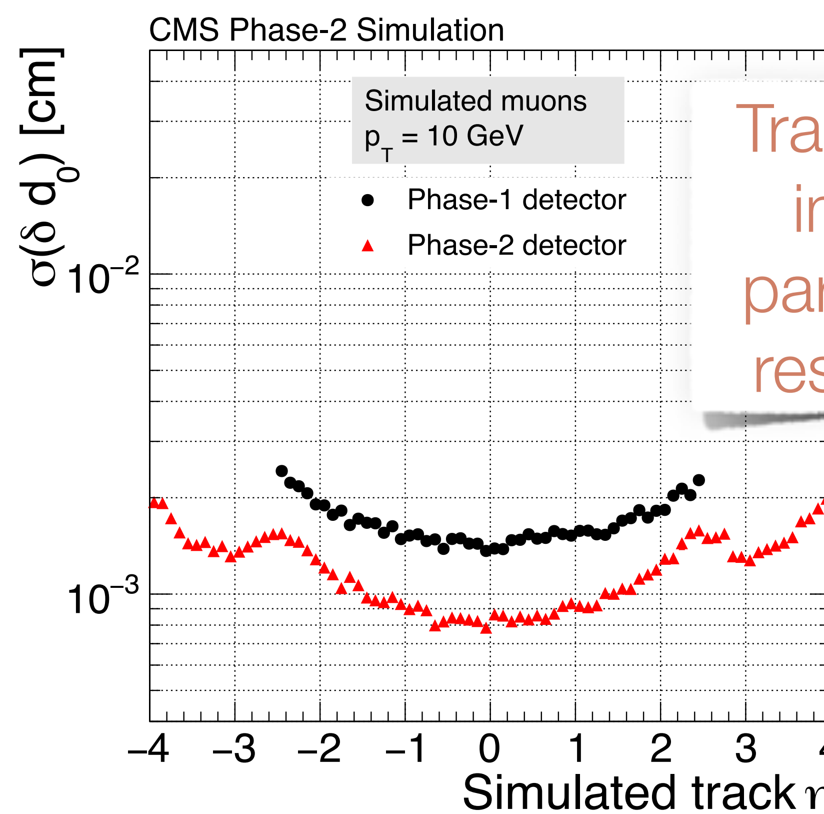
Hit occupancy



Stub reconstruction efficiency

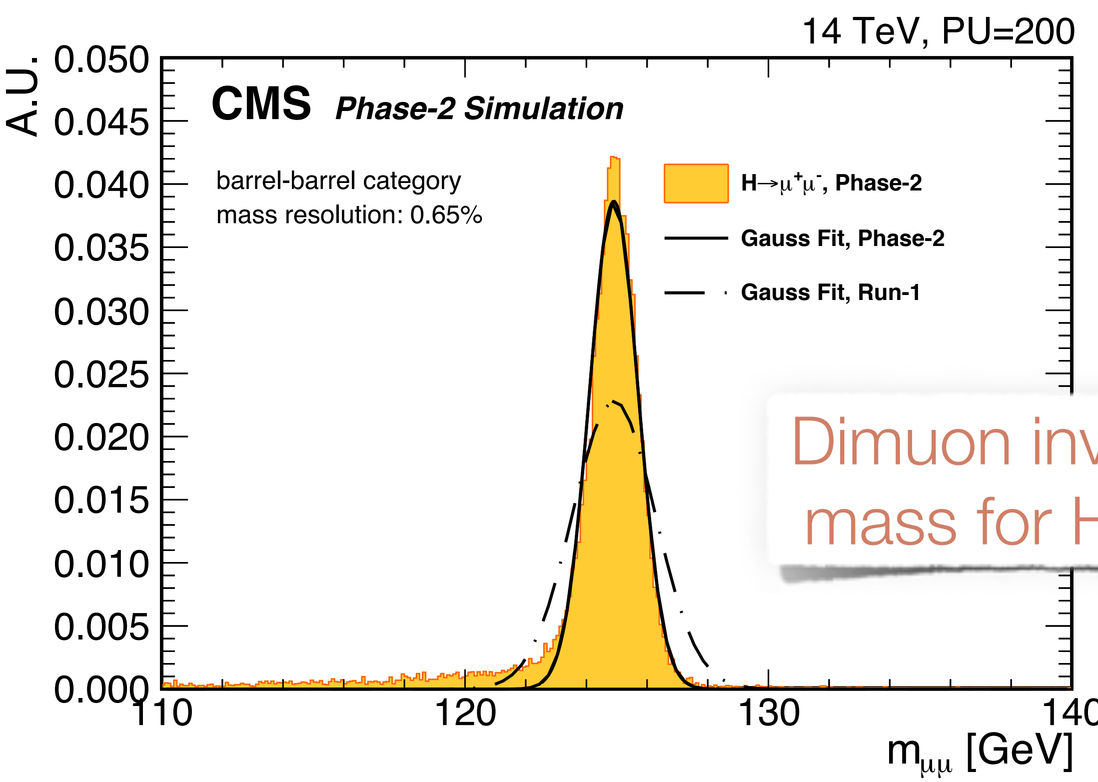


Transverse momentum resolution

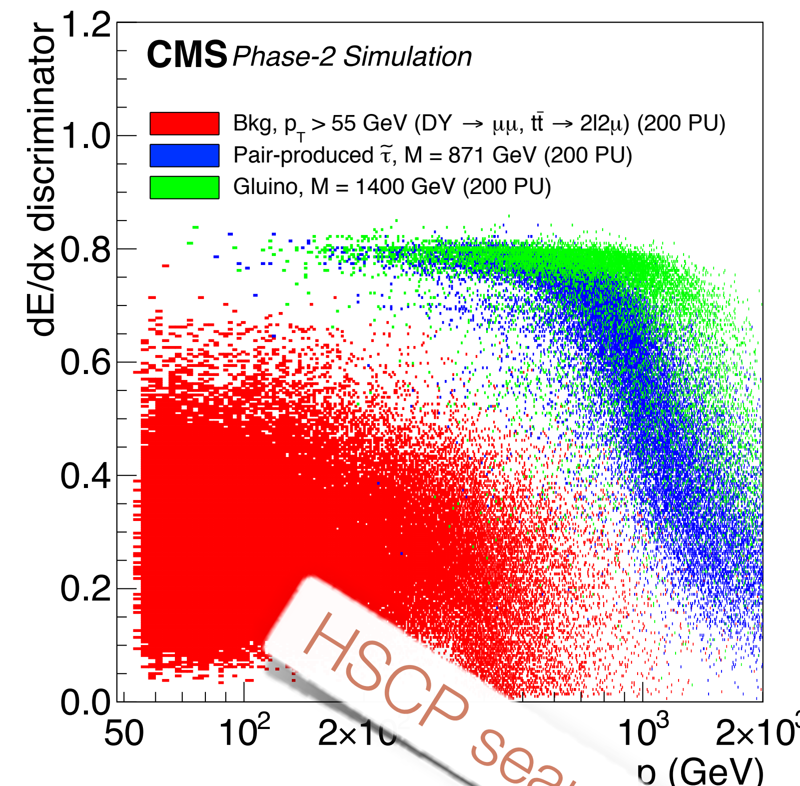


Transverse impact parameter resolution

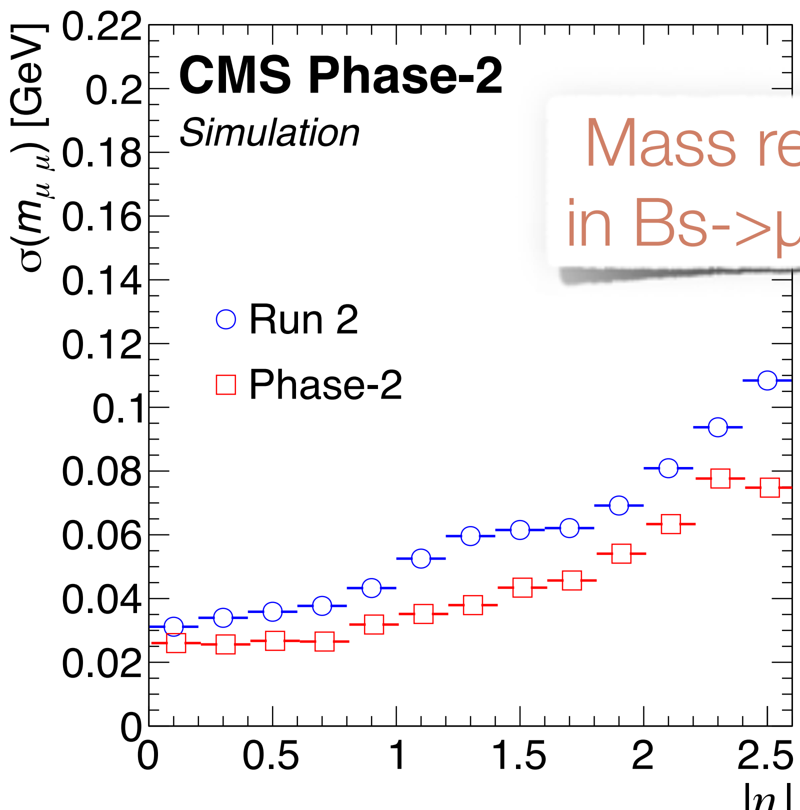
Performance - physics



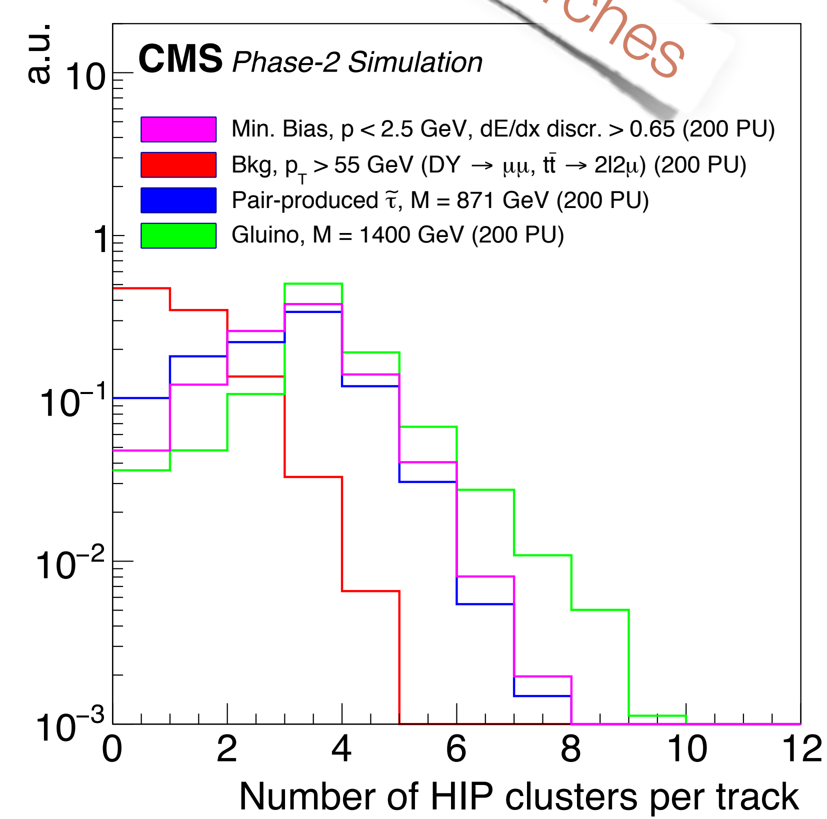
Dimuon invariant mass for H->μμ



HSCP searches



Mass resolution in Bs->μμ events



Summary and conclusions

- Full CMS Tracker replacement scheduled for HL-LHC:
  - radiation damage of the present detector, increased granularity, increased pseudorapidity coverage , L1 tracking
- R&D efforts ongoing
- Preparations for production starting

Reference: The Phase-2 Upgrade of the CMS Tracker, CERN-LHCC-2017-009

Backup

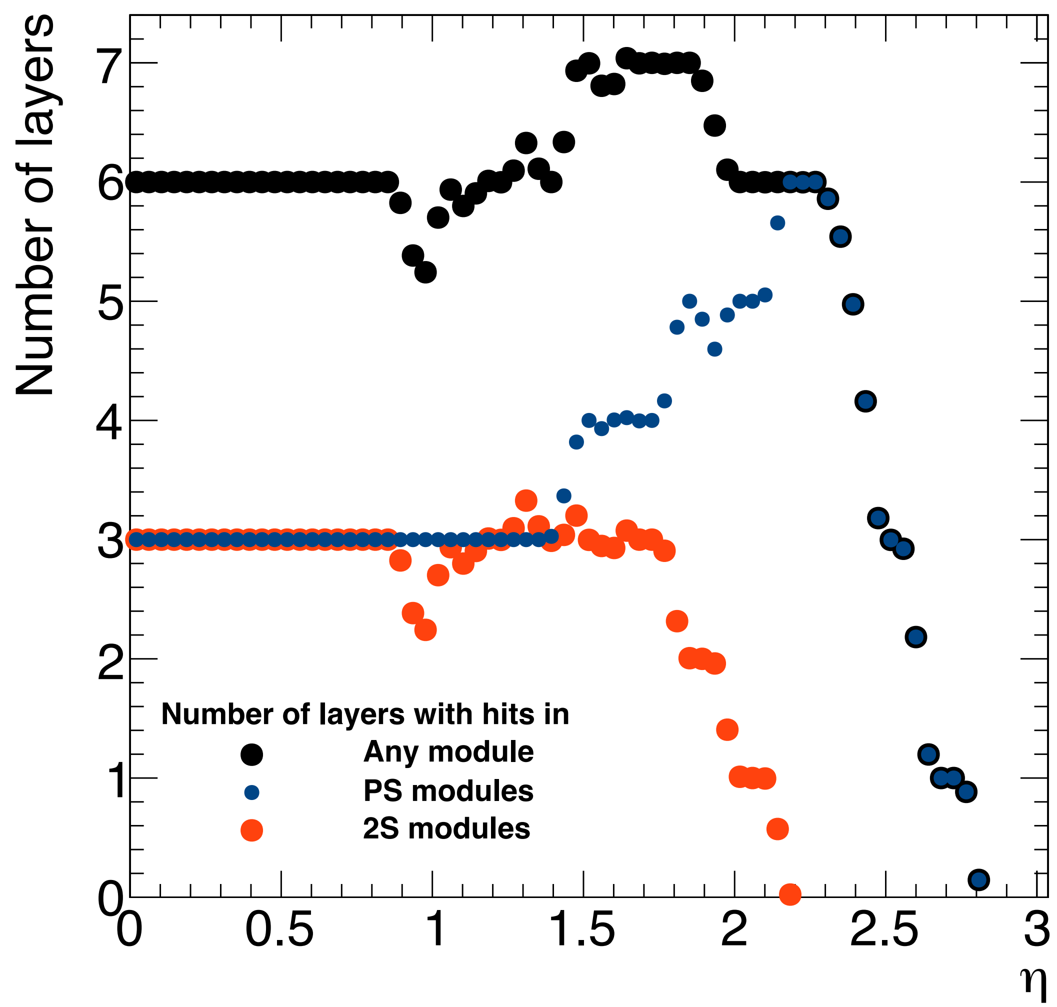
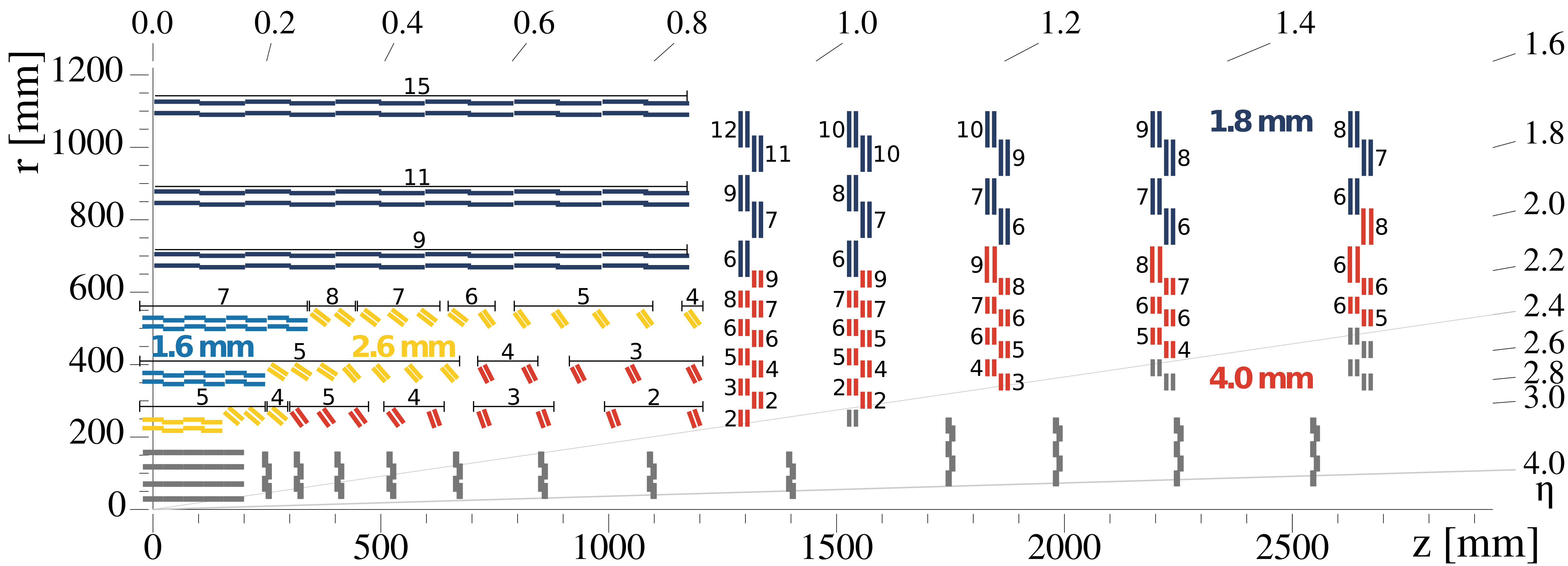


Figure 3.2: Number of module layers traversed by particles, including both PS (blue) and 2S (red) modules, as well as the total (black). Particle trajectories are approximated by straight lines, using a flat distribution of primary vertices within $|z_0| < 70\,\mathrm{mm}$, and multiple scattering is not included.

Spacers and windows



2S modules

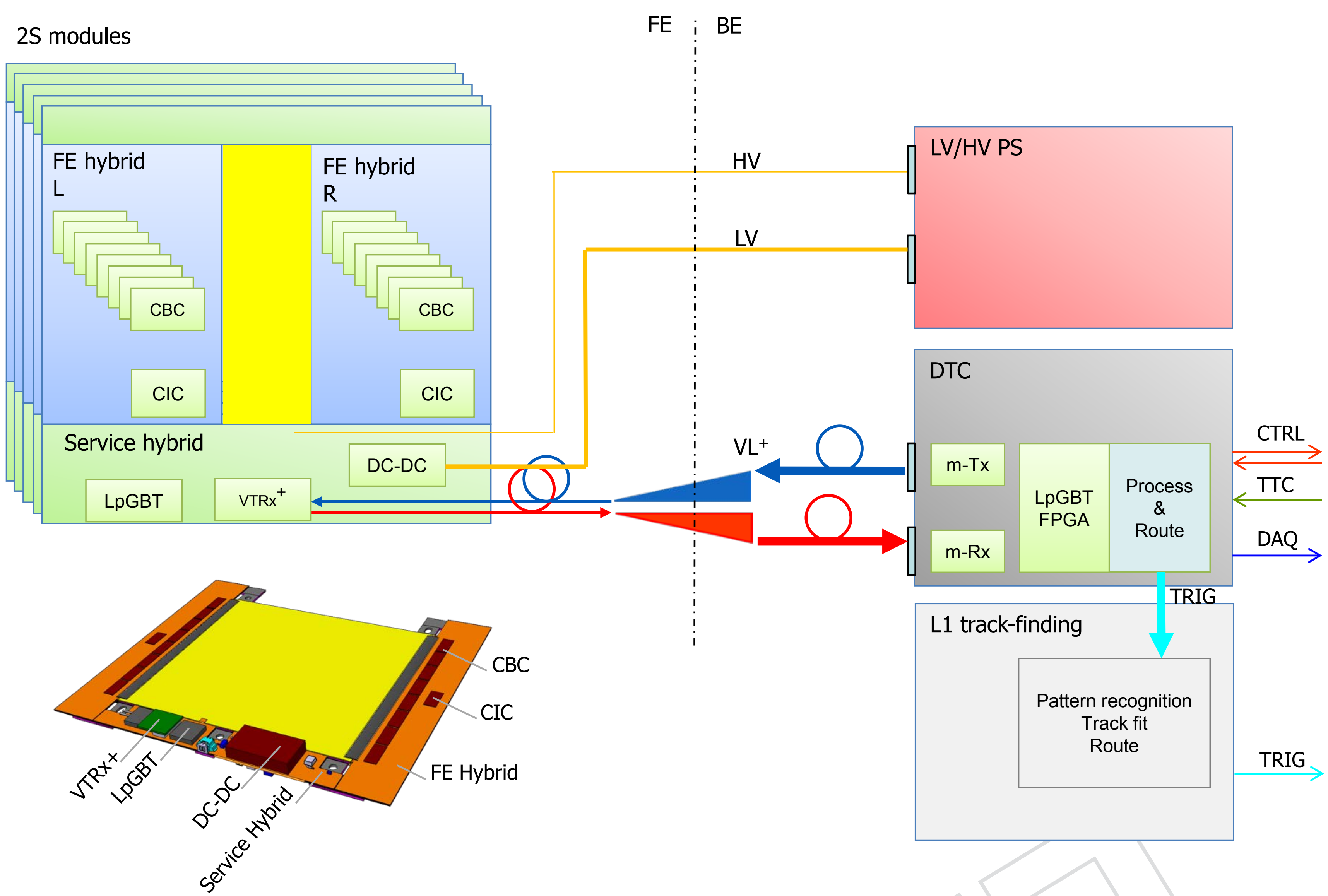
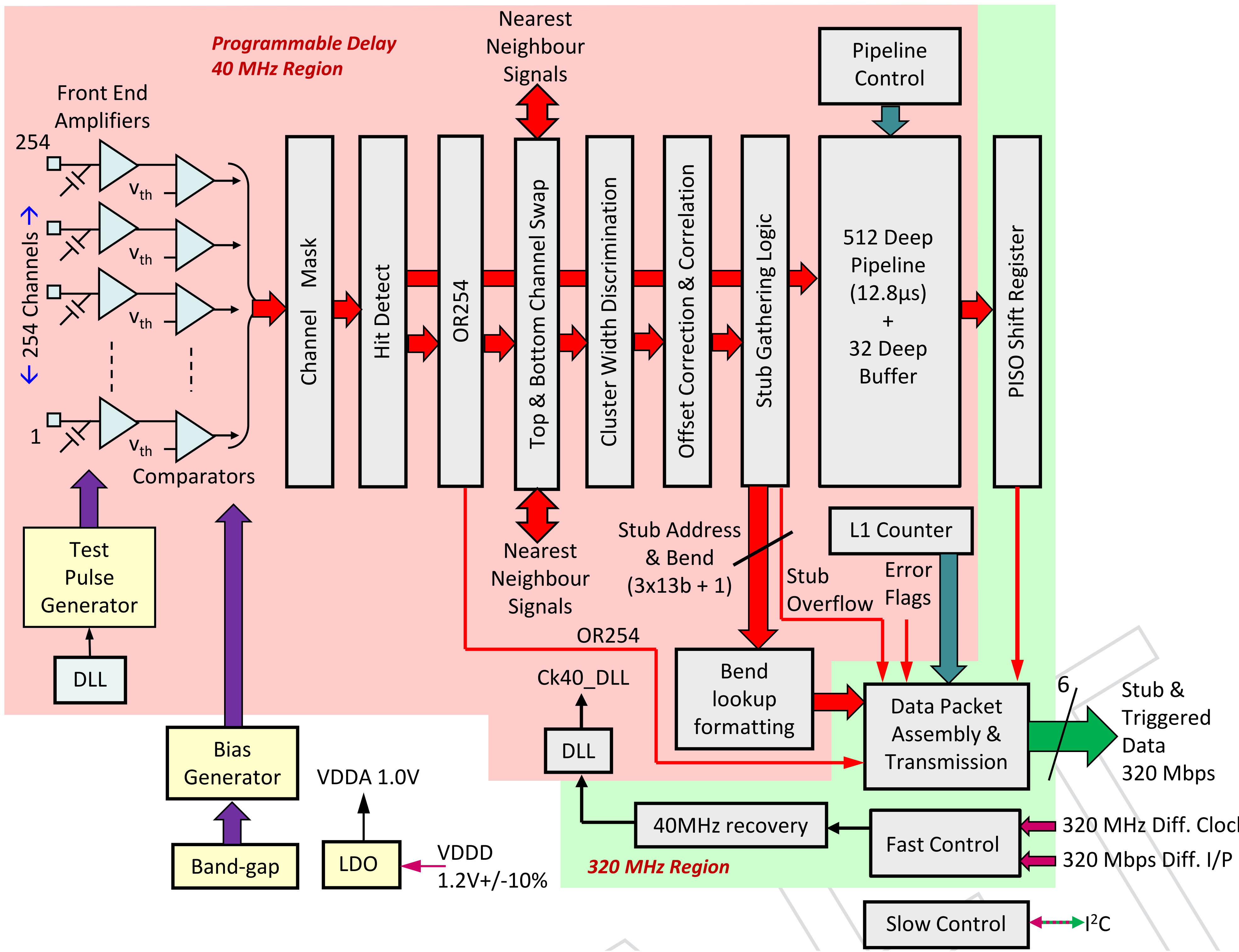
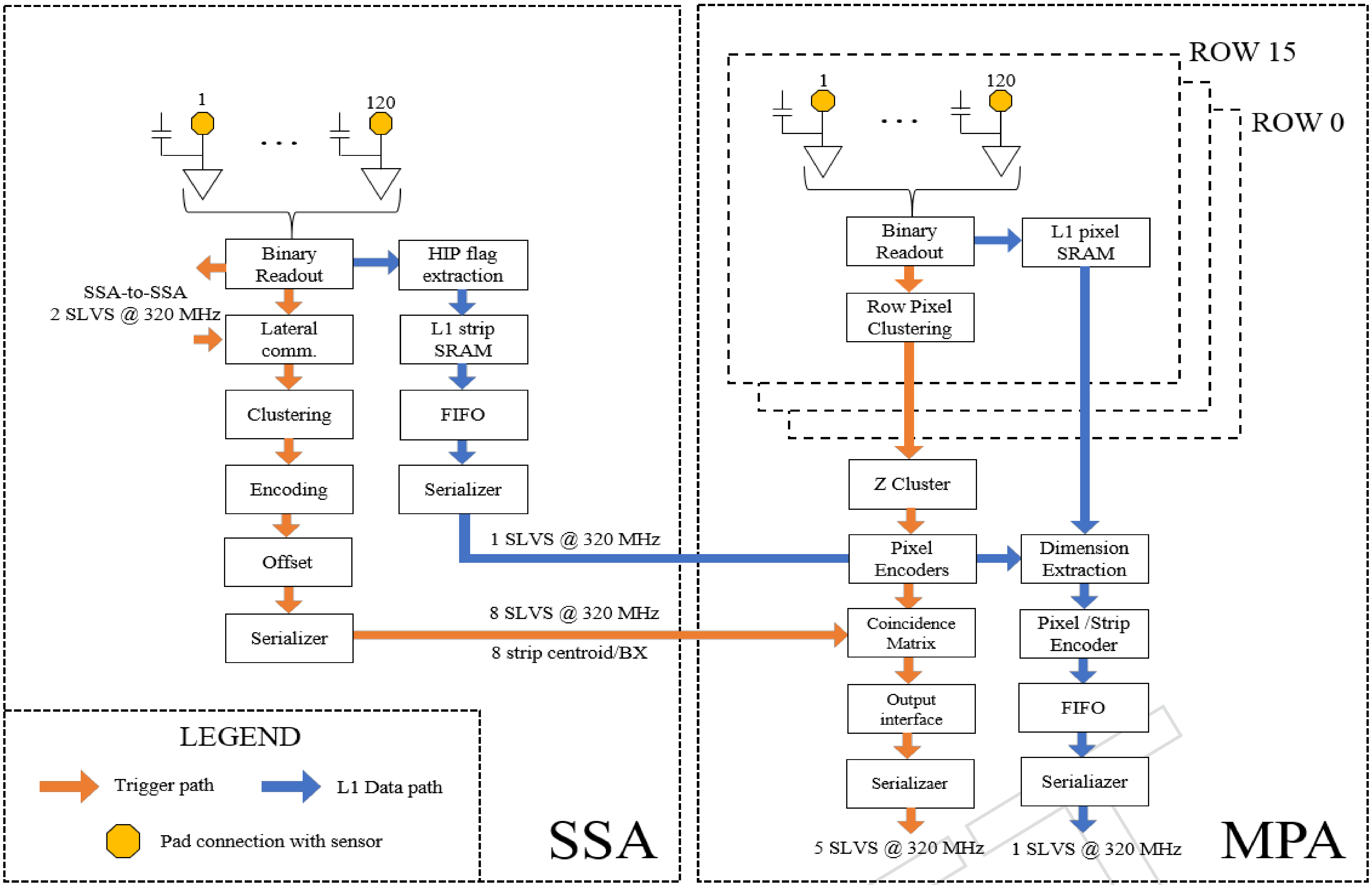


Figure 3.7: Electronic system block diagram, exemplified for the 2S module, together with a labelled sketch of the module. Details are provided in the text. On the DTC board, m-Tx and m-Rx are multi-channel transmit and receive optical modules. The L1 track-finding block is covered in Section 3.5.

CBC3


Programmable Delay
40 MHz Region
Nearest Neighbour Signals
Pipeline Control
Front End Amplifiers
254
254 Channels
1
V_{th}
Comparators
Channel Mask
Hit Detect
OR254
Top & Bottom Channel Swap
Cluster Width Discrimination
Offset Correction & Correlation
Stub Gathering Logic
512 Deep Pipeline (12.8μs) + 32 Deep Buffer
PISO Shift Register
Test Pulse Generator
DLL
Stub Address & Bend (3x13b + 1)
L1 Counter
Nearest Neighbour Signals
Stub Overflow
Error Flags
OR254
Ck40_DLL
Bend lookup formatting
Data Packet Assembly & Transmission
6
Stub & Triggered Data 320 Mbps
Bias Generator
VDDA 1.0V
DLL
40MHz recovery
Fast Control
320 MHz Diff. Clock
320 Mbps Diff. I/P
Band-gap
LDO
VDDD 1.2V+/-10%
320 MHz Region
Slow Control
I²C

PS modules



ROW 15
ROW 0
1
120
. . .
Binary Readout
HIP flag extraction
SSA-to-SSA
2 SLVS @ 320 MHz
Lateral comm.
L1 strip SRAM
Clustering
FIFO
Encoding
Serializer
Offset
Serializer
1 SLVS @ 320 MHz
8 SLVS @ 320 MHz
8 strip centroid/BX
Binary Readout
L1 pixel SRAM
Row Pixel Clustering
Z Cluster
Pixel Encoders
Dimension Extraction
Coincidence Matrix
Pixel /Strip Encoder
Output interface
FIFO
Serialzaer
Serialiazer
5 SLVS @ 320 MHz
1 SLVS @ 320 MHz
LEGEND
Trigger path
L1 Data path
Pad connection with sensor
SSA
MPA

Performance - b tagging