Perugia involvement in MUonE experiment

Matteo Magherini (matteo.magherini@cern.ch)

on behalf of Perugia MUonE group

MUonE - Measuring a_μ^{HLO}

- MUonE: high precision measurement of a_μ^{HLO} via elastic muon-electron scattering
  - 160 GeV μ beam on atomic electrons in light target at CERN
- Hadronic contribution to the effective electromagnetic coupling, $\Delta\alpha_{had}(q^2)$ for space-like squared four-momentum transfers $q^2 = t < 0$, via scattering data

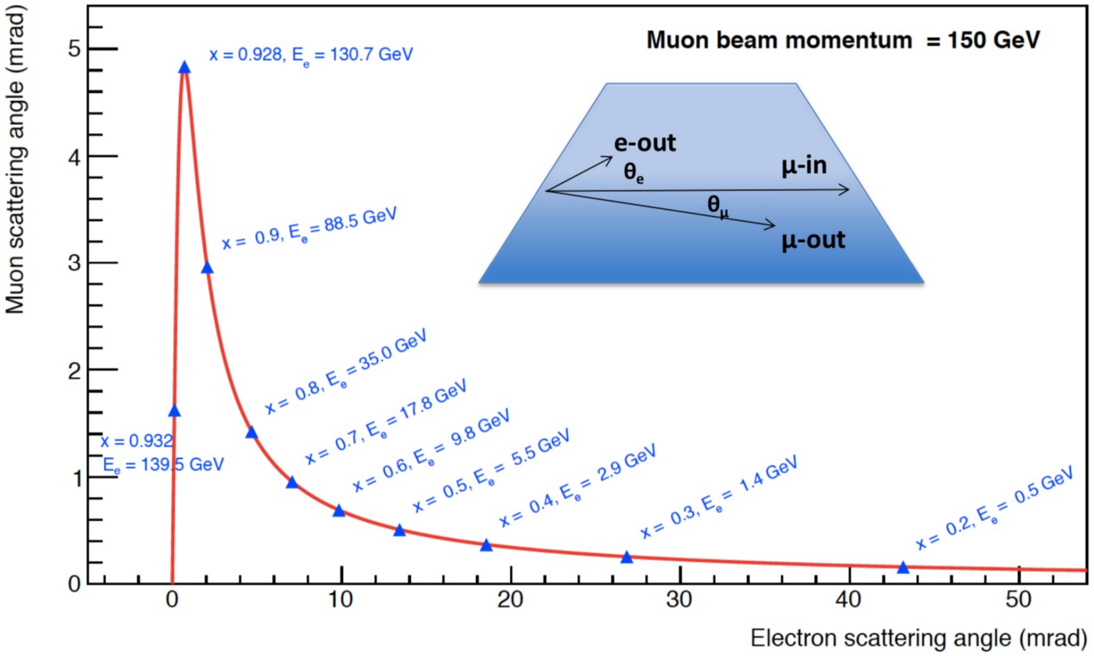
$$a_\mu^{HLO} = \frac{\alpha}{\pi} \int_0^1 (1-x)\Delta\alpha_{had}(t(x))dx$$

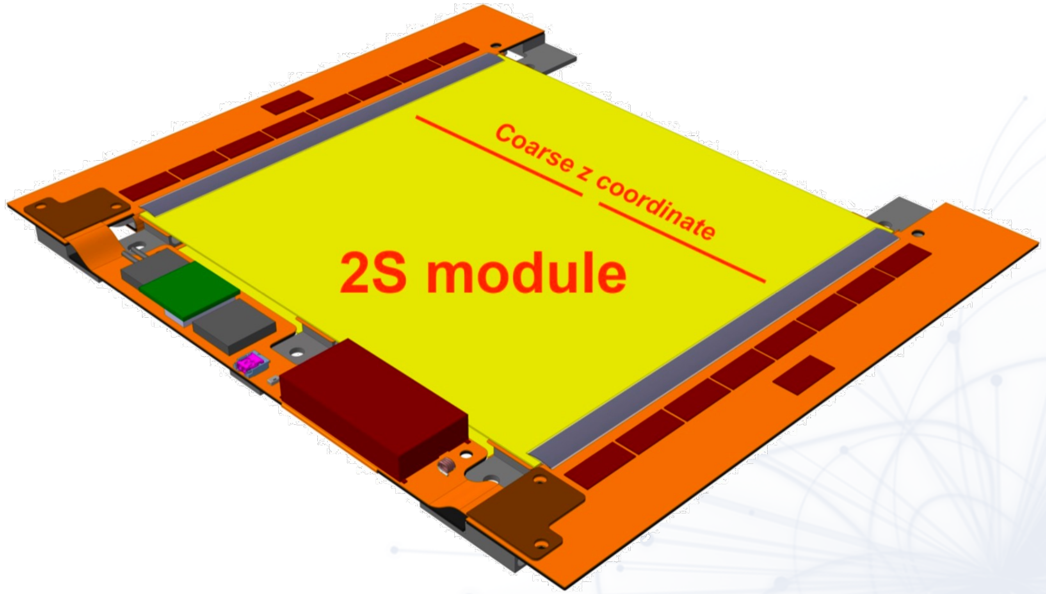
$$t(x) = \frac{x^2 m_\mu^2}{x-1} \quad (0 \leq -t \leq +\infty)$$

t : momentum trasfered in the reaction

MUonE - Measuring a_μ^{HLO}

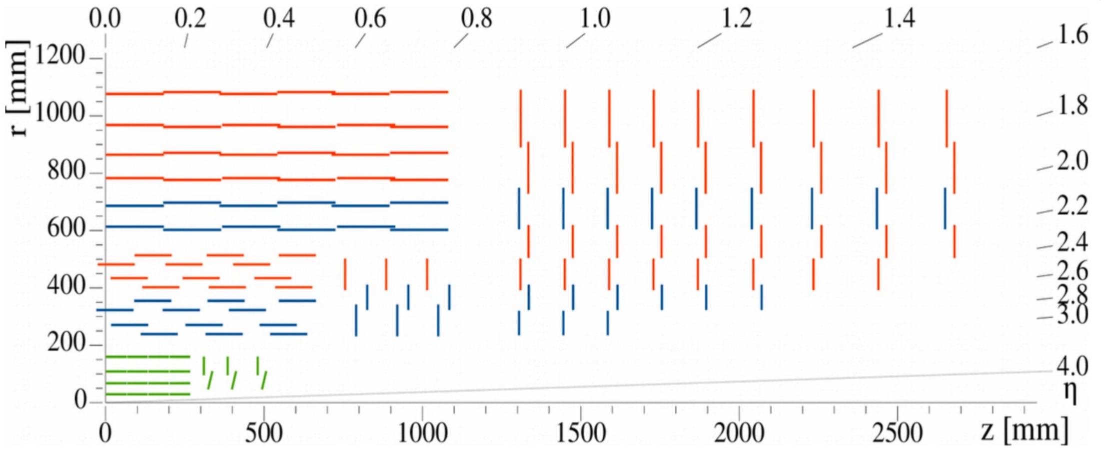
- Measure of the scattering angles → precise tracking + high rate acquisition
- Best solution: 2S modules from CMS phase2 upgrade



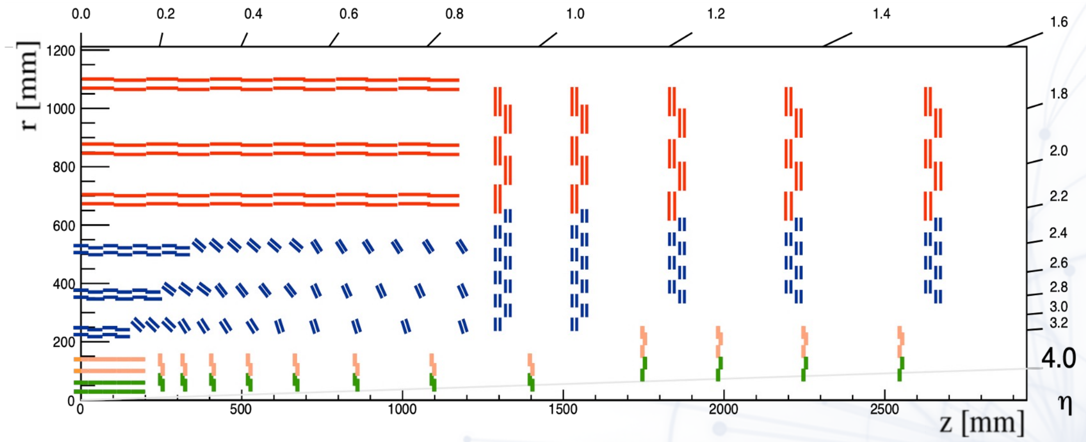


CMS outer tracker upgrade for High Luminosity

- Hi-Lumi upgrade of LHC after LS3 (~2026)
  - Peak Luminosity ~$7.5\times10^{34}cm^{-2}s^{-1}$
  - Expected Pile-up ~200
  - Higher rates and radiation doses wrt Run3
  - New Magnets (11T)
  - Etc..
- Necessary upgrade of current tracker:
  - leakage current or full depletion voltage limitations → big **part of current tracker will be inoperational**
  - Higher **radiation level** → upgraded tracker target: integrated luminosity of 3000 fb^{-1}
  - Efficient tracking + Higher pileup → **Increase of granularity needed**
  - Contribution to **level-1 trigger** → selection of interesting physics at the first trigger stage is extremely challenging at high luminosity



CMS Ph1 tracker



CMS Ph2 tracker

CMS outer tracker upgrade for High Luminosity

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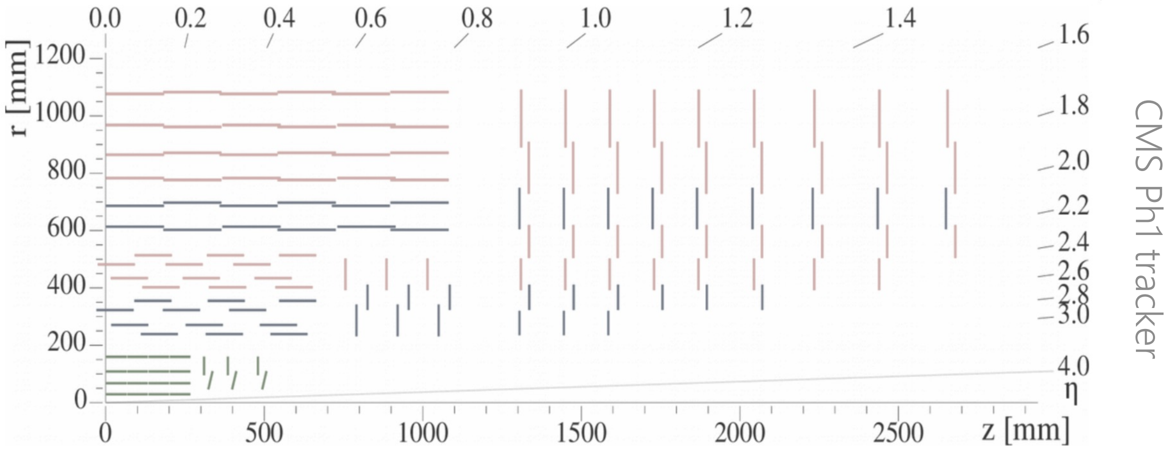
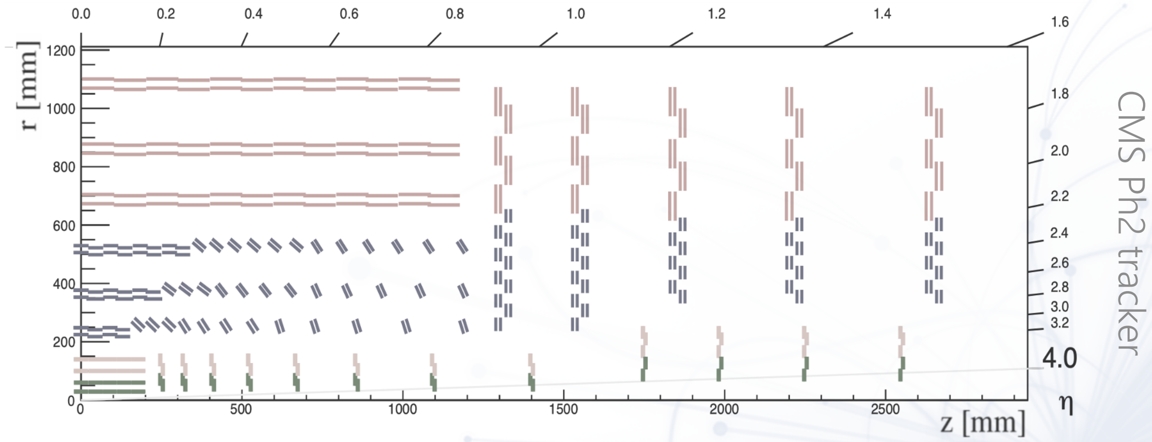
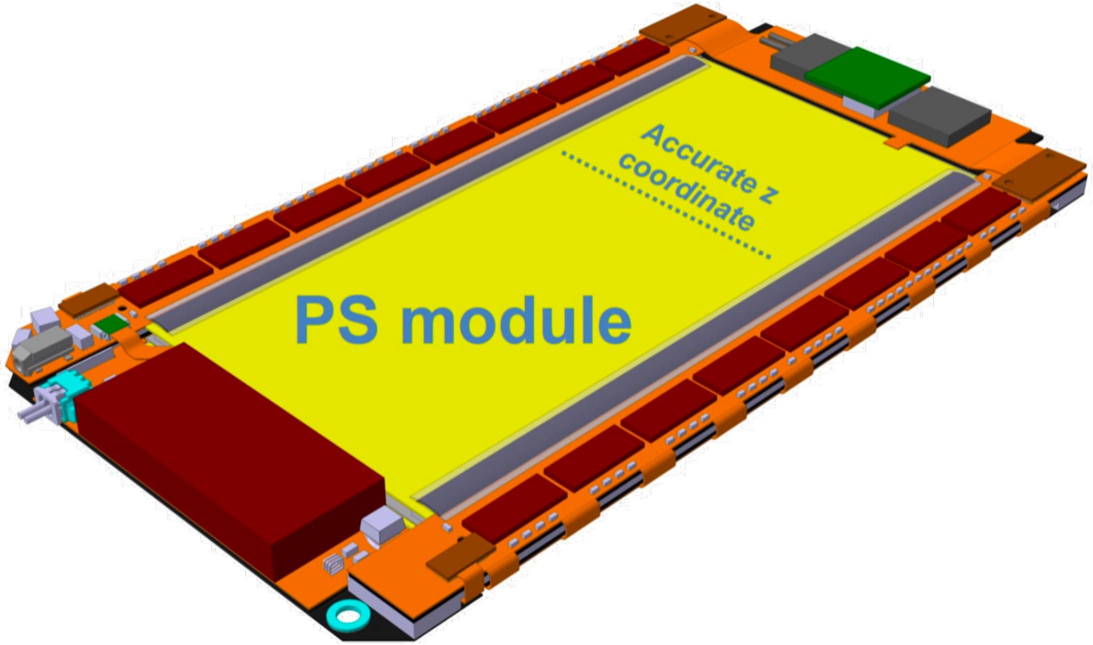
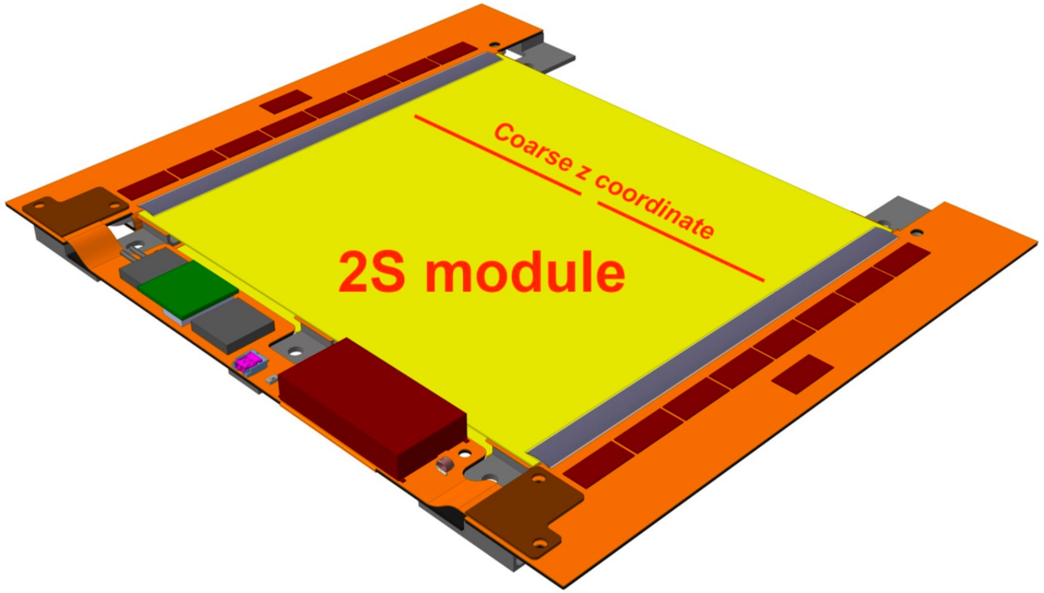




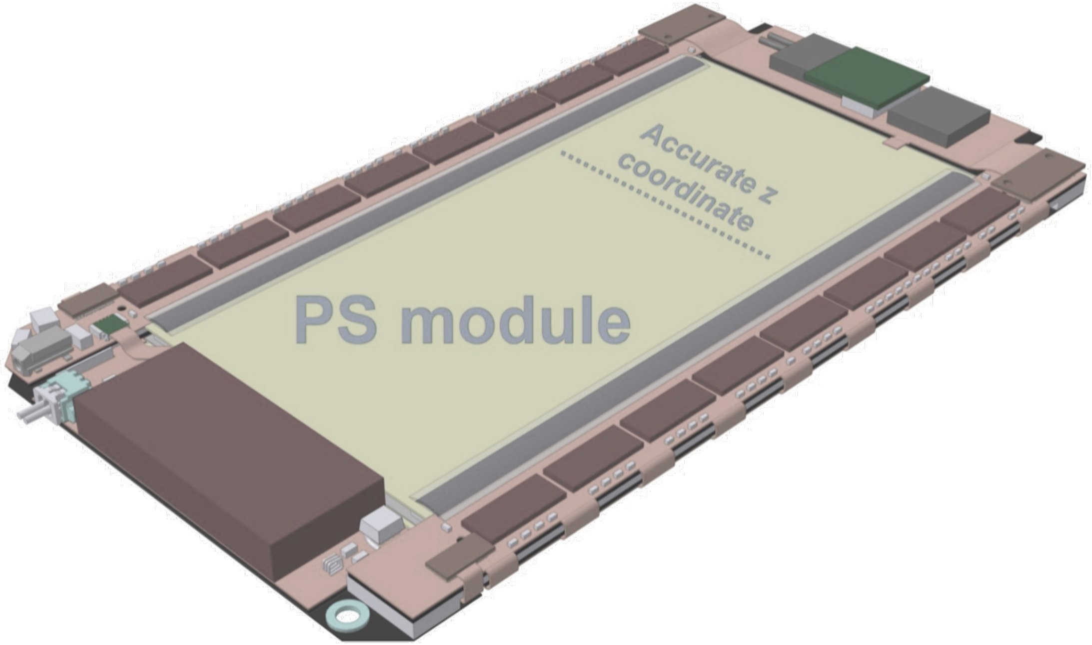
CMS outer tracker upgrade

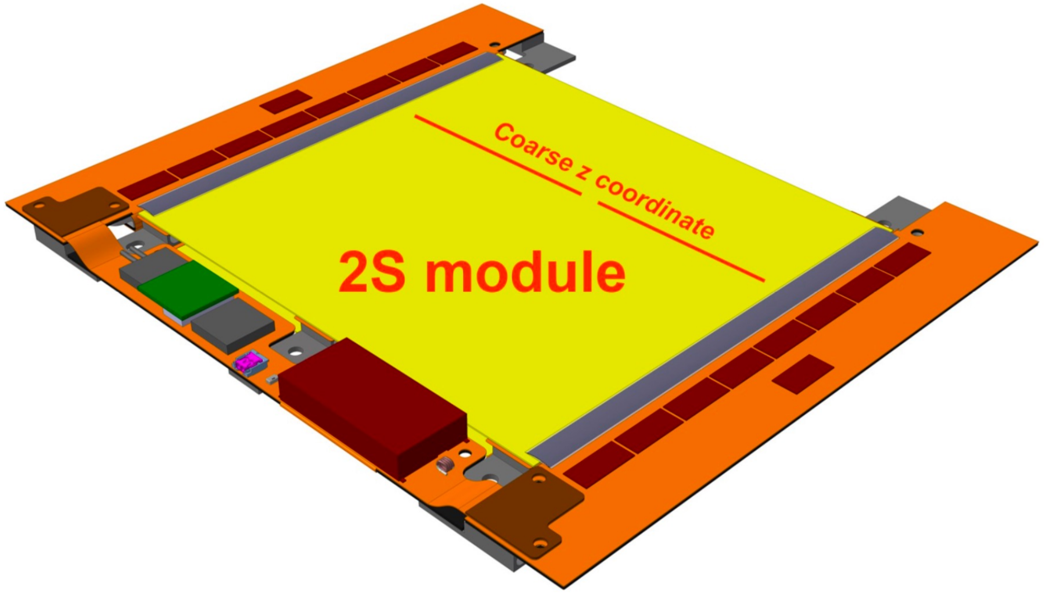




- PS Modules
  - 3 different spacings : 1.6mm & 2.6mm & 4mm
  - One strip sensor: 2.5cm x 100µm strips
  - One macro Pixel sensor : 1.5mm x 100µm pixels
  - Sensor dimensions 5cm x 10 cm
    - two column of 960 strips
    - 32x960 pixels
- 2S Modules
  - 2 different spacings: 1.8mm & 4mm
  - 2 micro strip sensors with 5cm x 90µm strips
  - Sensor dimensions are 10cm x 10cm
    - two column of 1016 strips

CMS outer tracker upgrade





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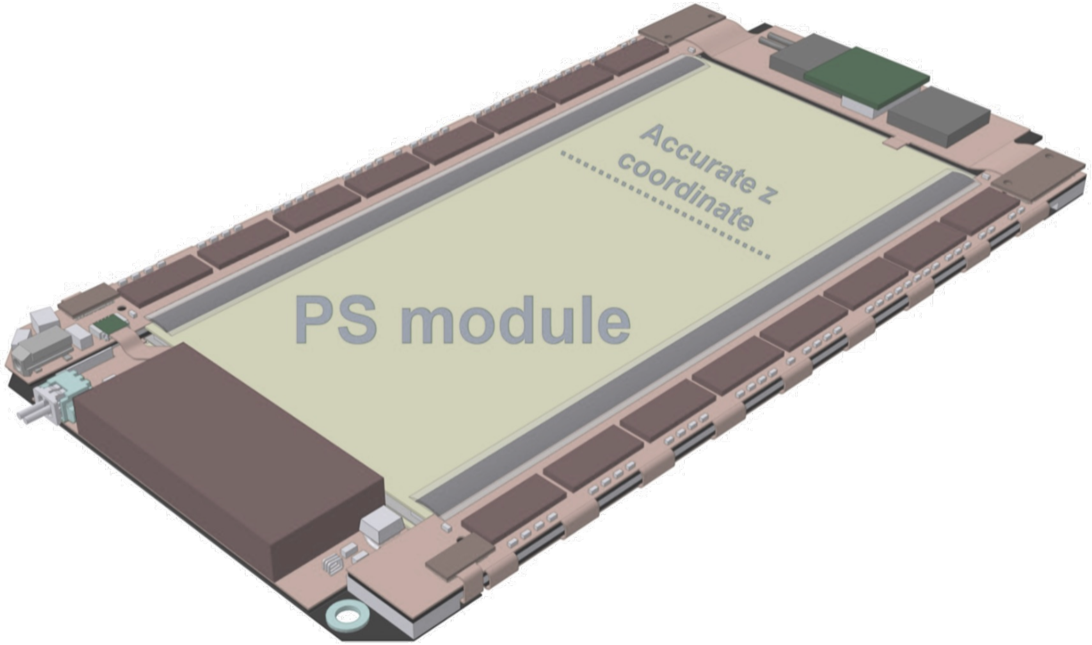
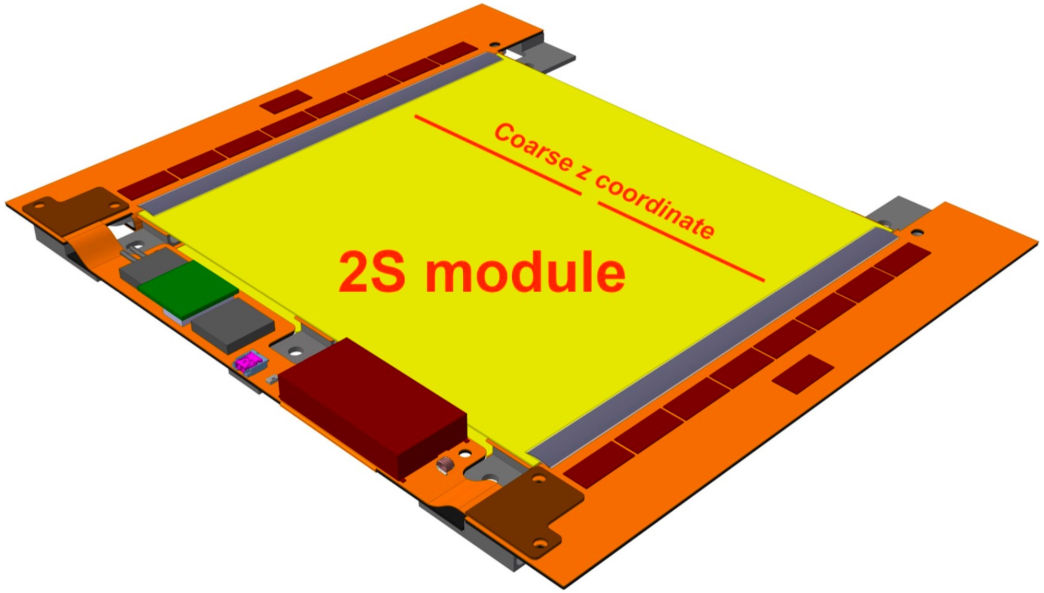
CMS outer tracker upgrade



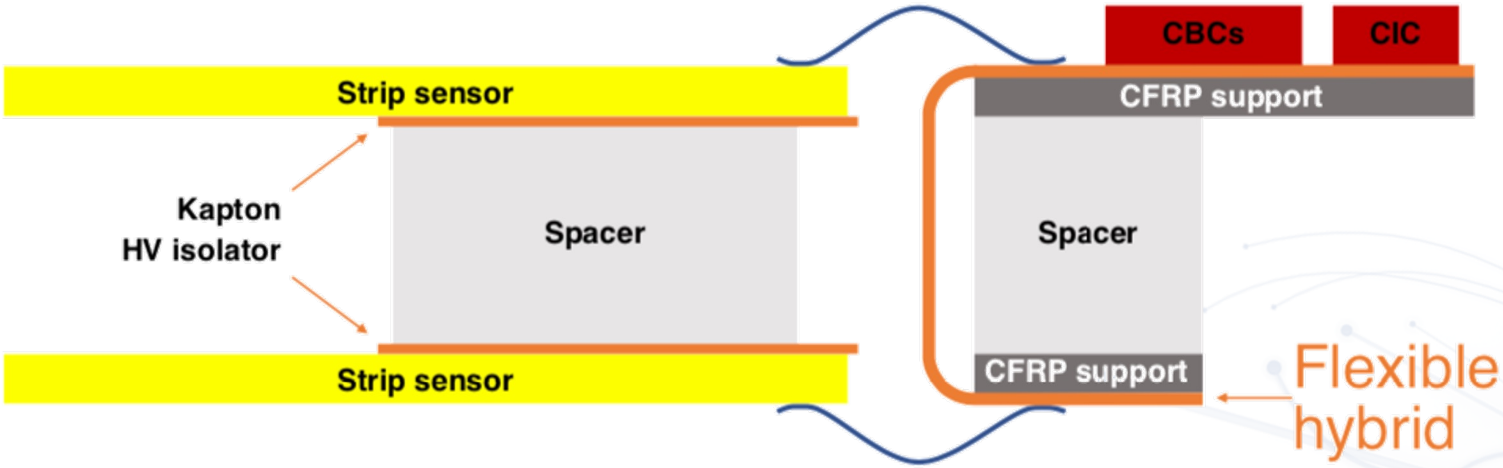


- PS Modules
- 2S Modules

Perugia is an an **official assembly center** for PS modules and a **backup assembly center for 2S**

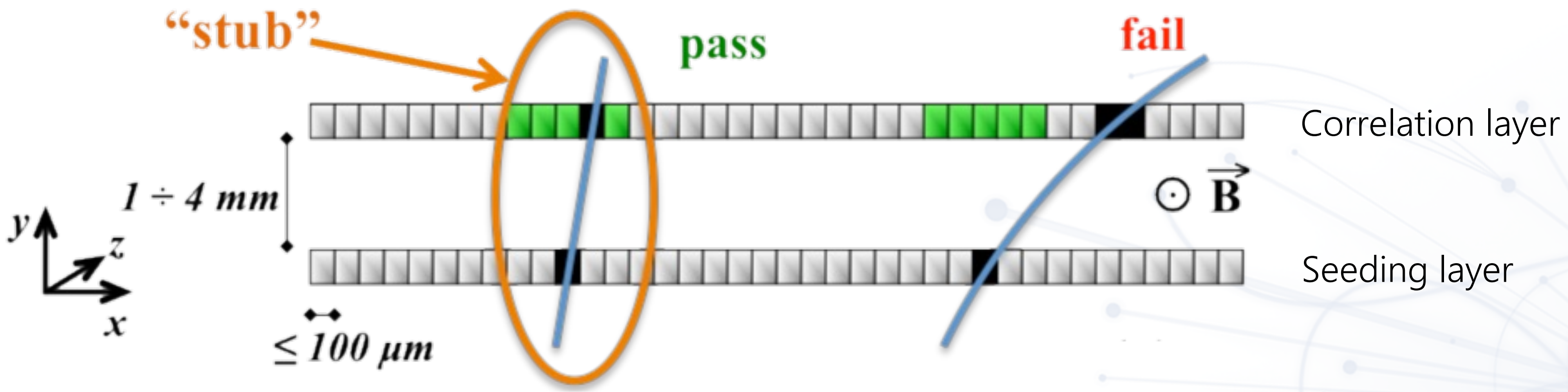
How does a 2S module work?

- Two silicon sensors with small spacing in a module
- Flex hybrid in order to get data from both sensors to one ASIC

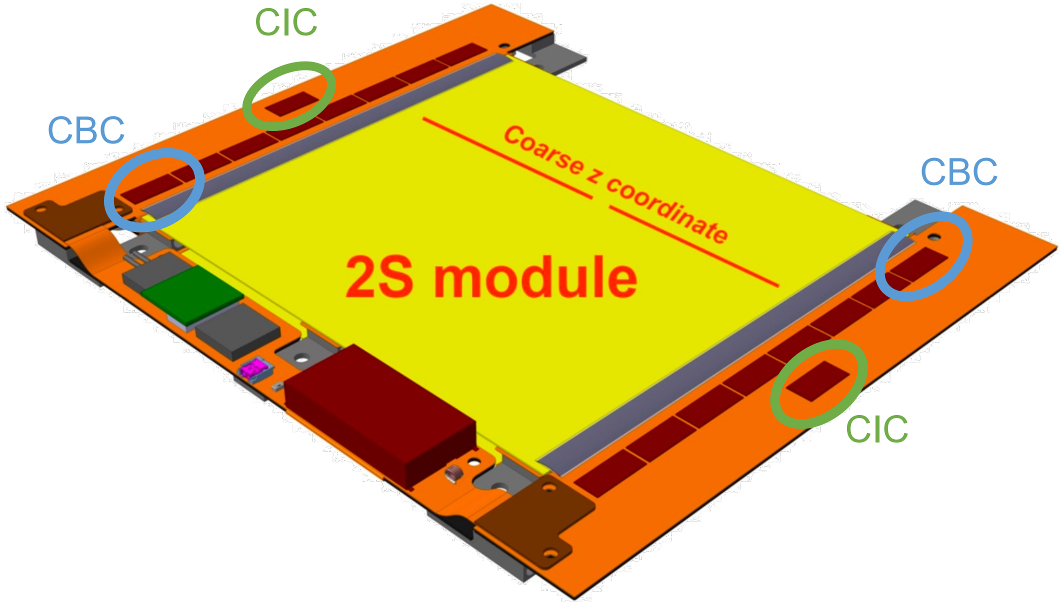


How does a 2S module work?

- Two silicon sensors with small spacing in a module
- Flex hybrid in order to get data from both sensors to one ASIC → Select track «stubs»
- Tunable correlation windows
- In CMS → direct selection of particles p_T
- In MUonE → use of the bend information to **improve resolution**

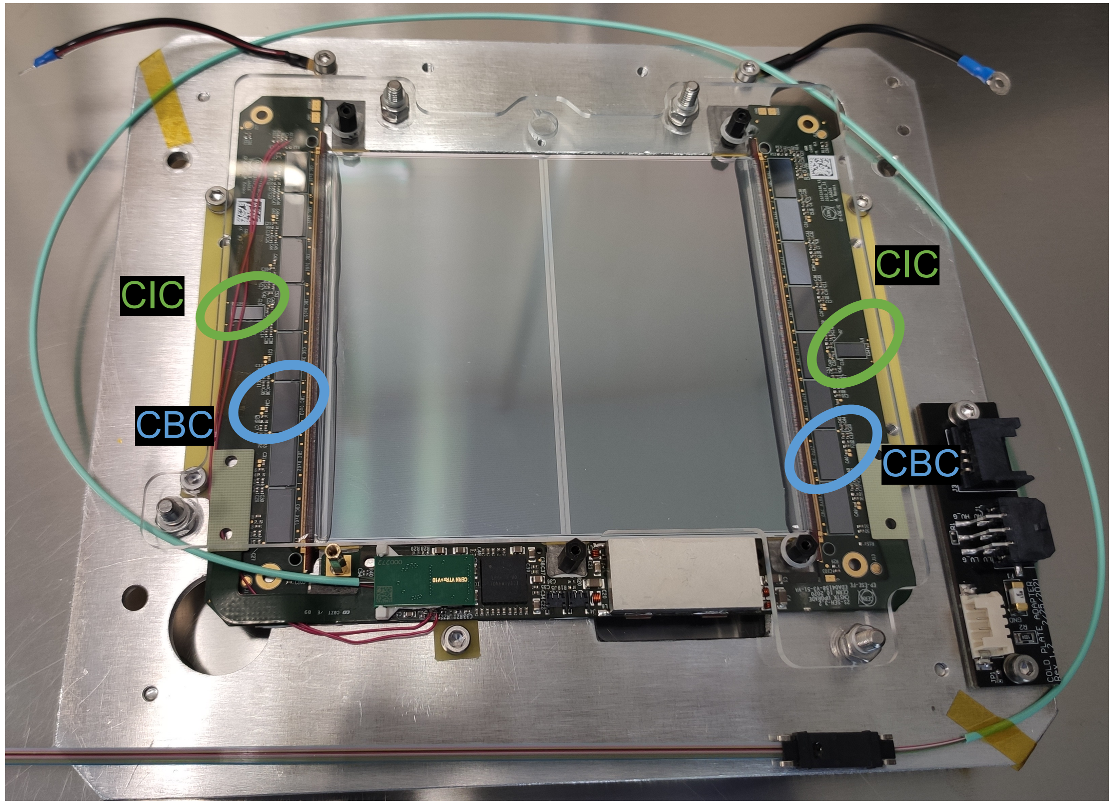


2S modules anatomy



- 2 silicon sensors "sandwiched" together at fixed distance read out by the same electronics
- Module split in two halves → each half is read out by a CIC (*Concentrator Integrated Circuit*)
- Each half is split in 8 parts, read out by CBCs (*Cms Binary Chip*)

2S modules anatomy



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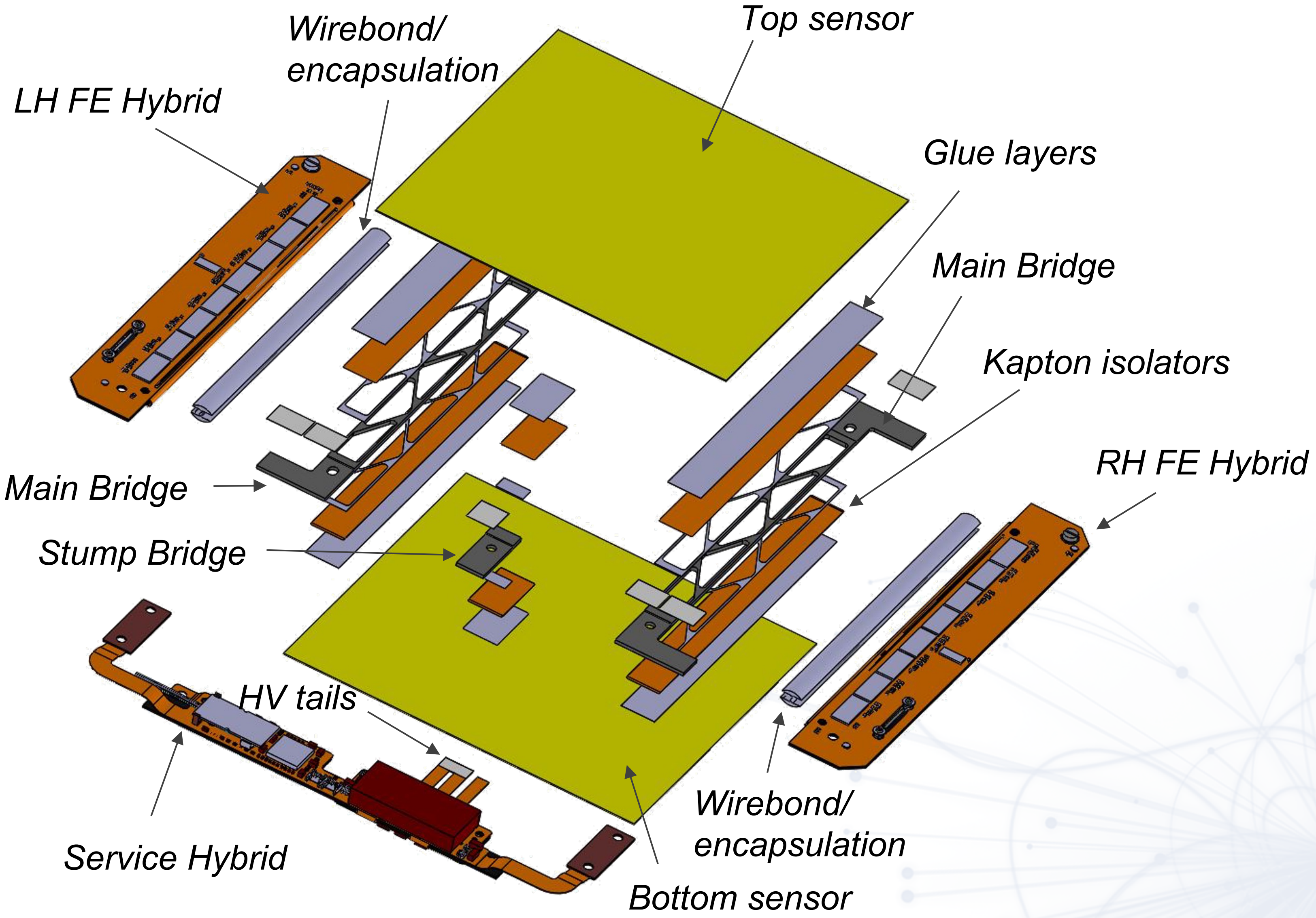
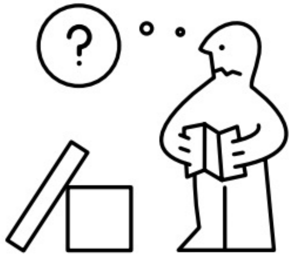
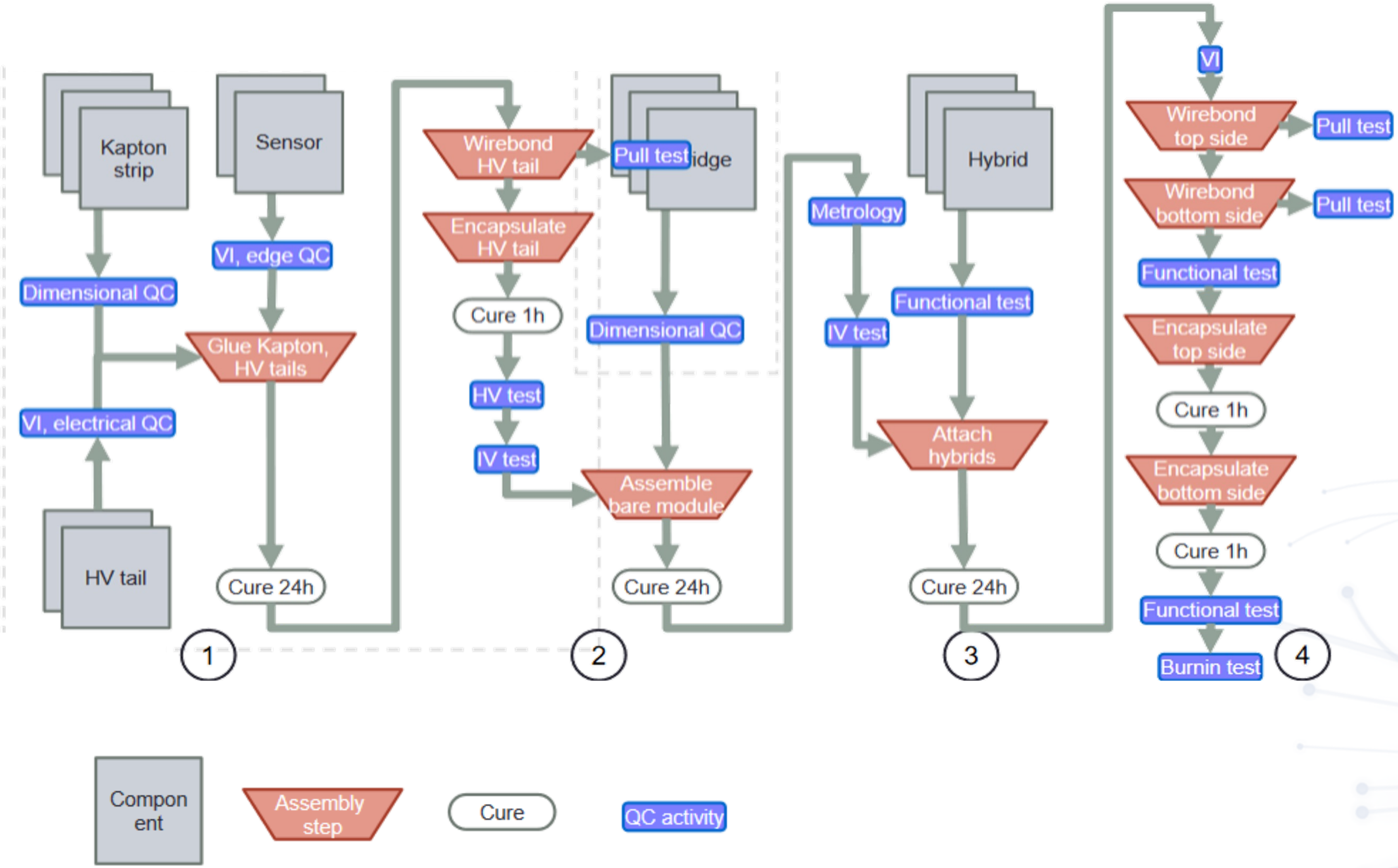
What's inside a module

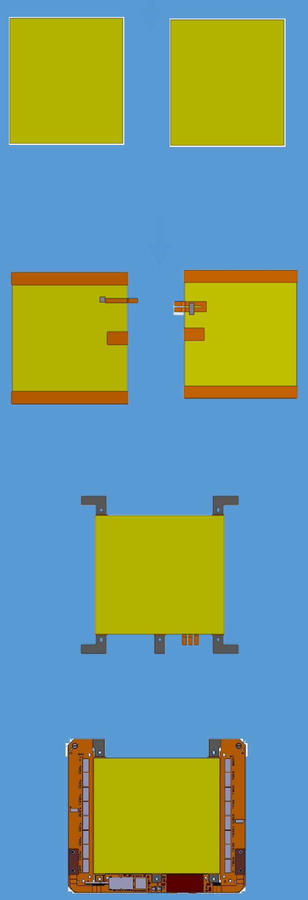


Assembly

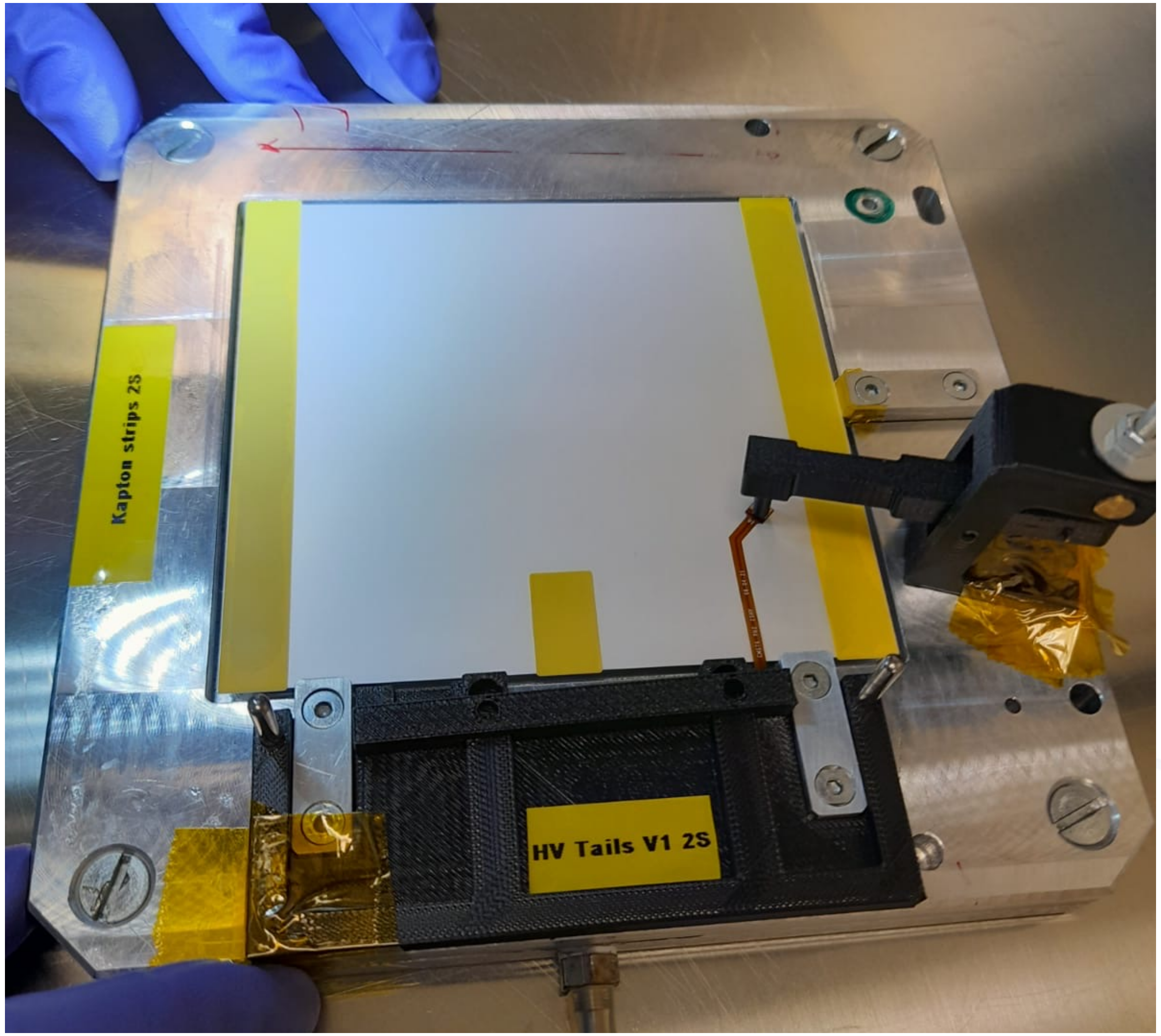


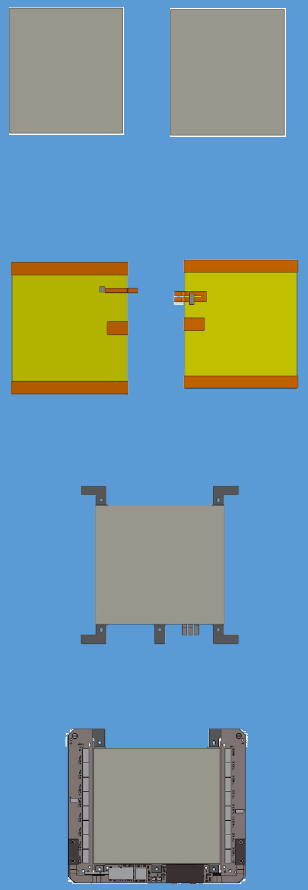


Kapton strip
Sensor
Wirebond HV tail
Pull test
Bridge
Hybrid
VI
Wirebond top side
Pull test
Dimensional QC
VI, edge QC
Encapsulate HV tail
Metrology
Wirebond bottom side
Pull test
Functional test
Glue Kapton, HV tails
Cure 1h
Dimensional QC
IV test
Functional test
Encapsulate top side
VI, electrical QC
HV test
Cure 1h
IV test
Attach hybrids
Encapsulate bottom side
Assemble bare module
HV tail
Cure 24h
Cure 24h
Cure 24h
Cure 1h
Functional test
1
2
3
Burnin test
4
Component
Assembly step
Cure
QC activity

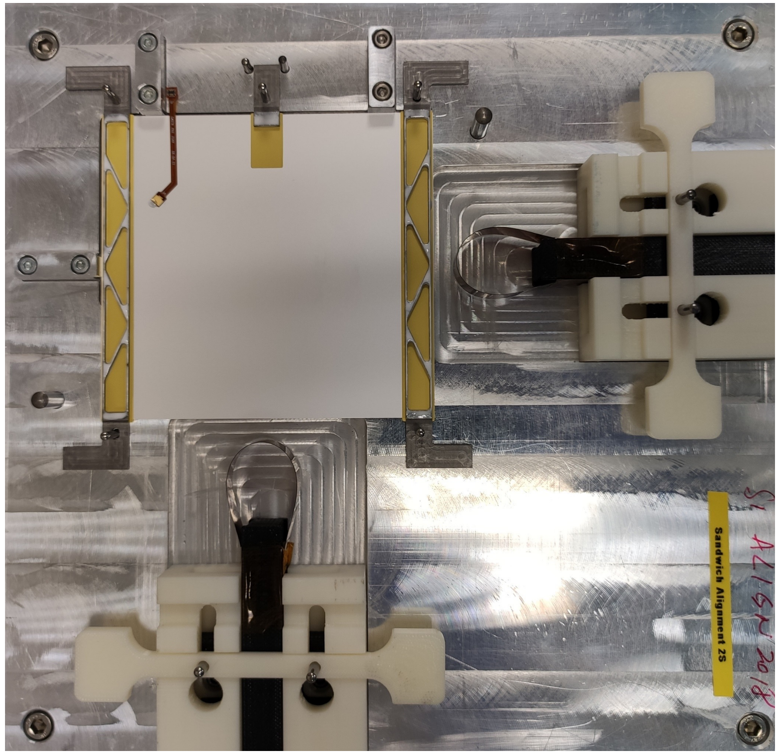


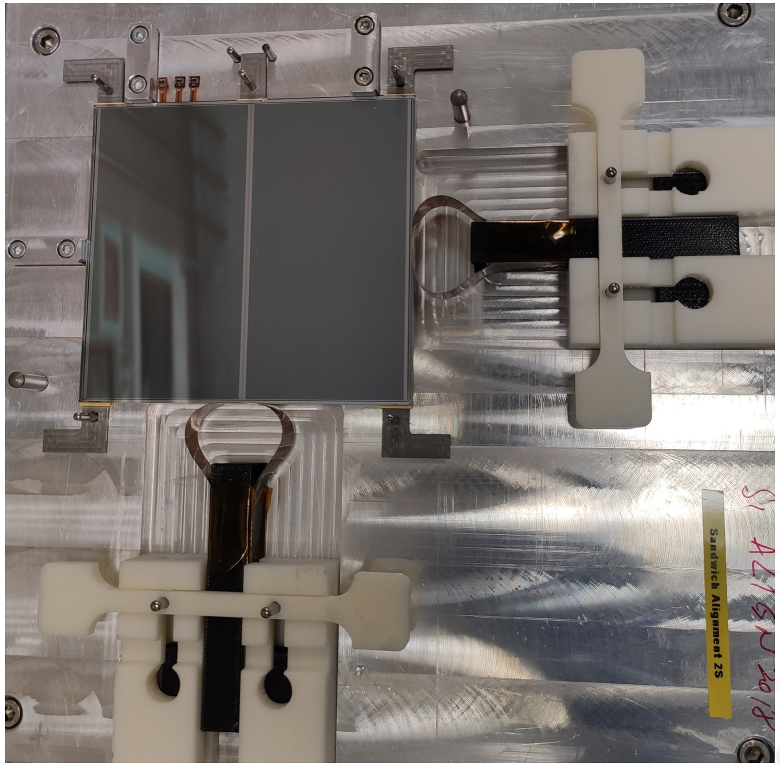
Assembly – sensor's isolator & HV tail gluing

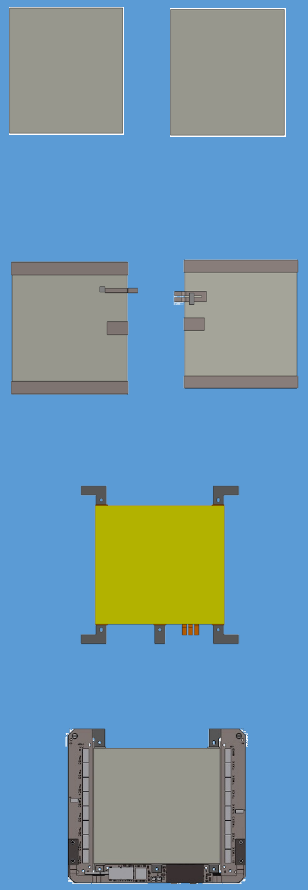




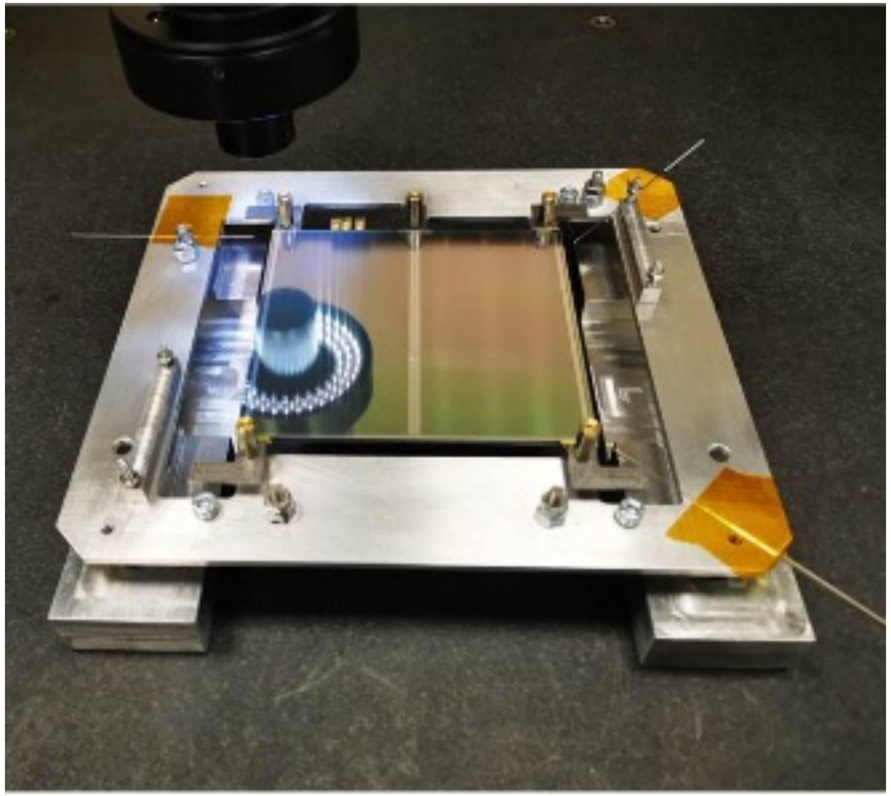
Assembly – sensors sandwich gluing

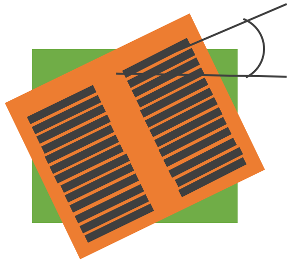




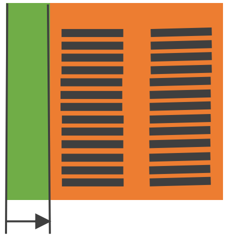


Assembly – mechanical metrology



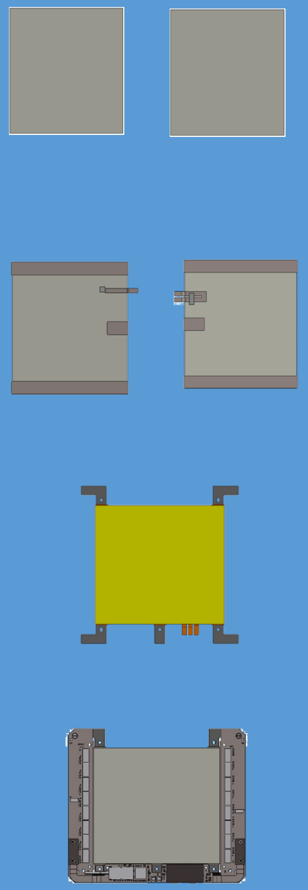


Θ < 400 µrad

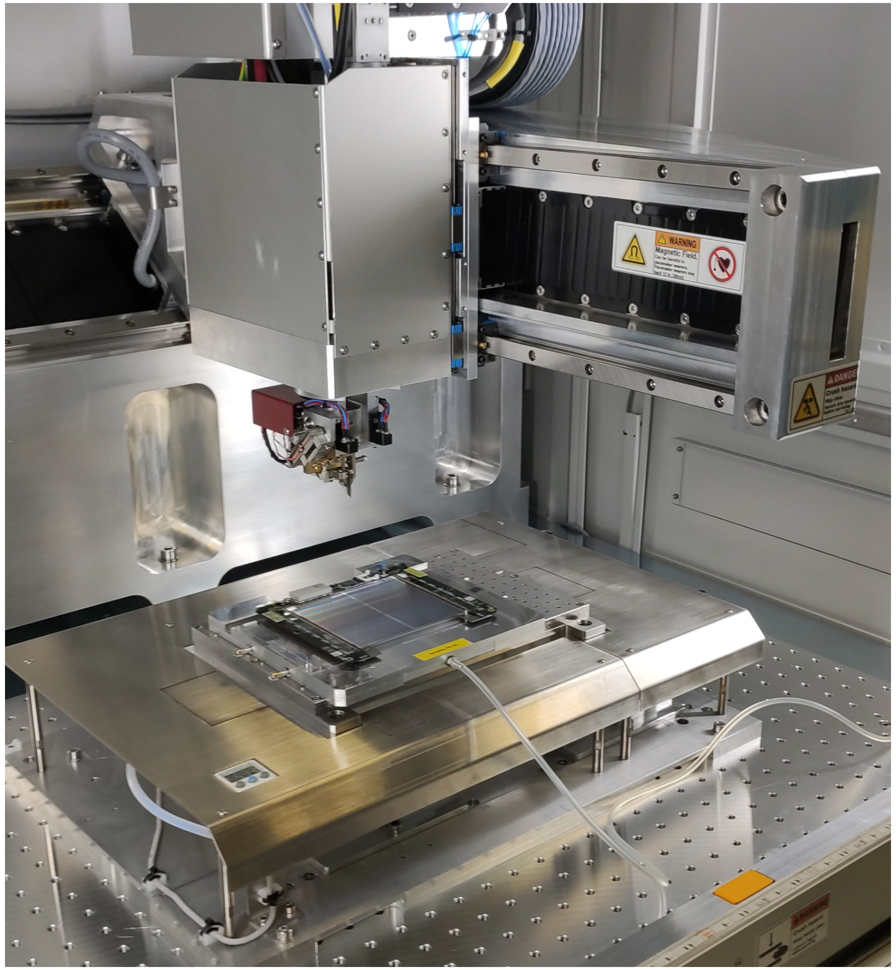


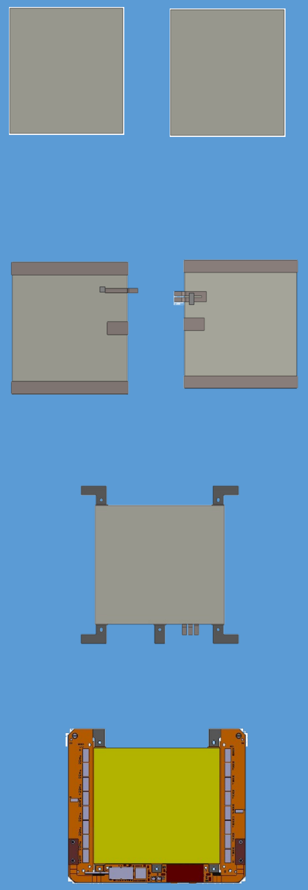
dY < 100 µm (//)

dX < 50 µm (⊥)

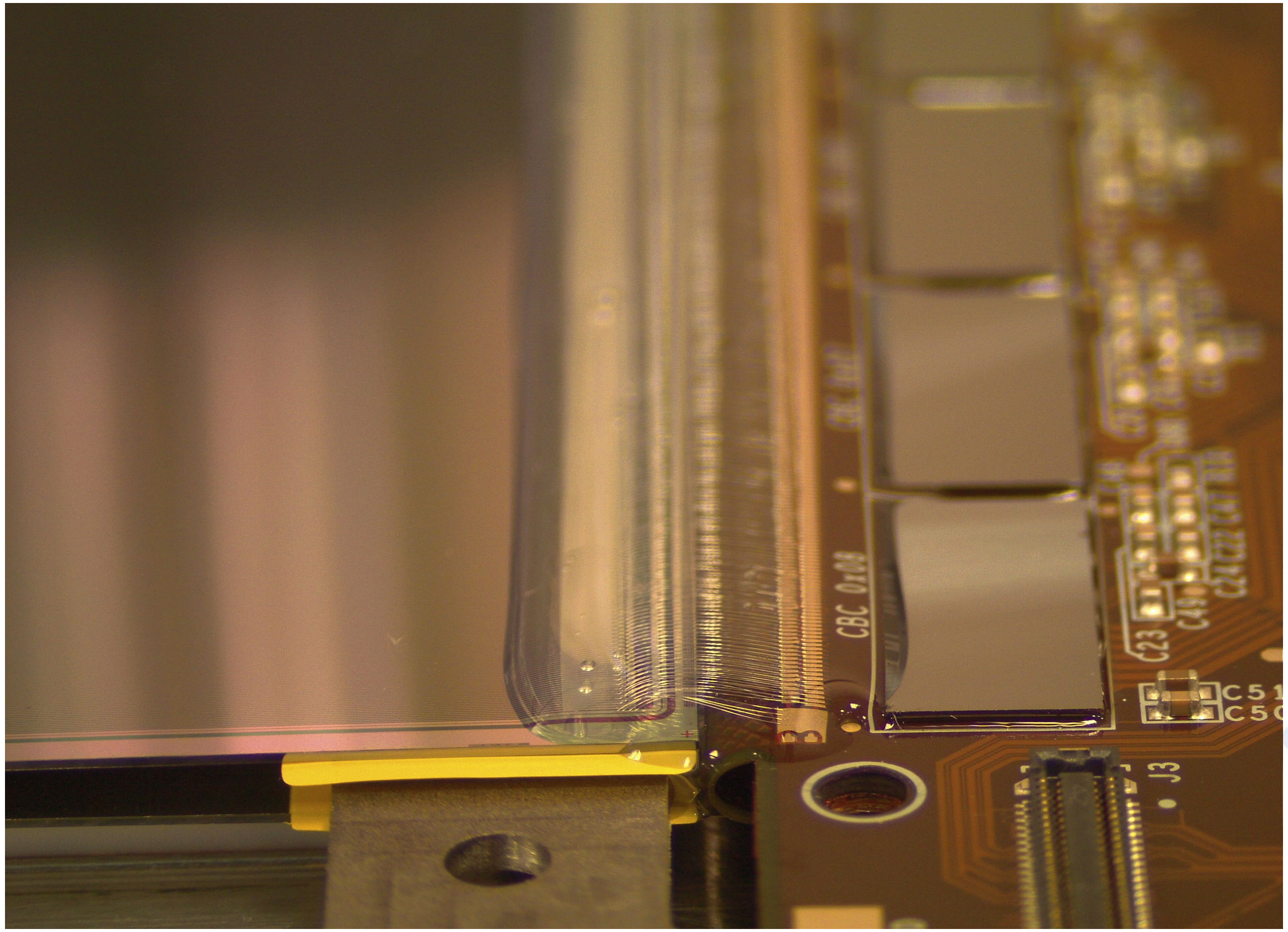


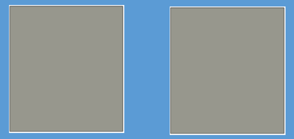
Assembly – Wirebonding

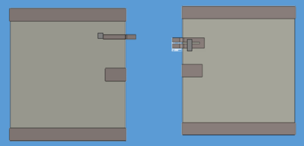


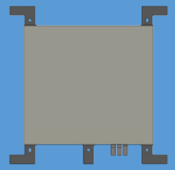


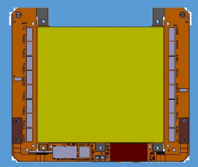
Assembly – Encapsulation



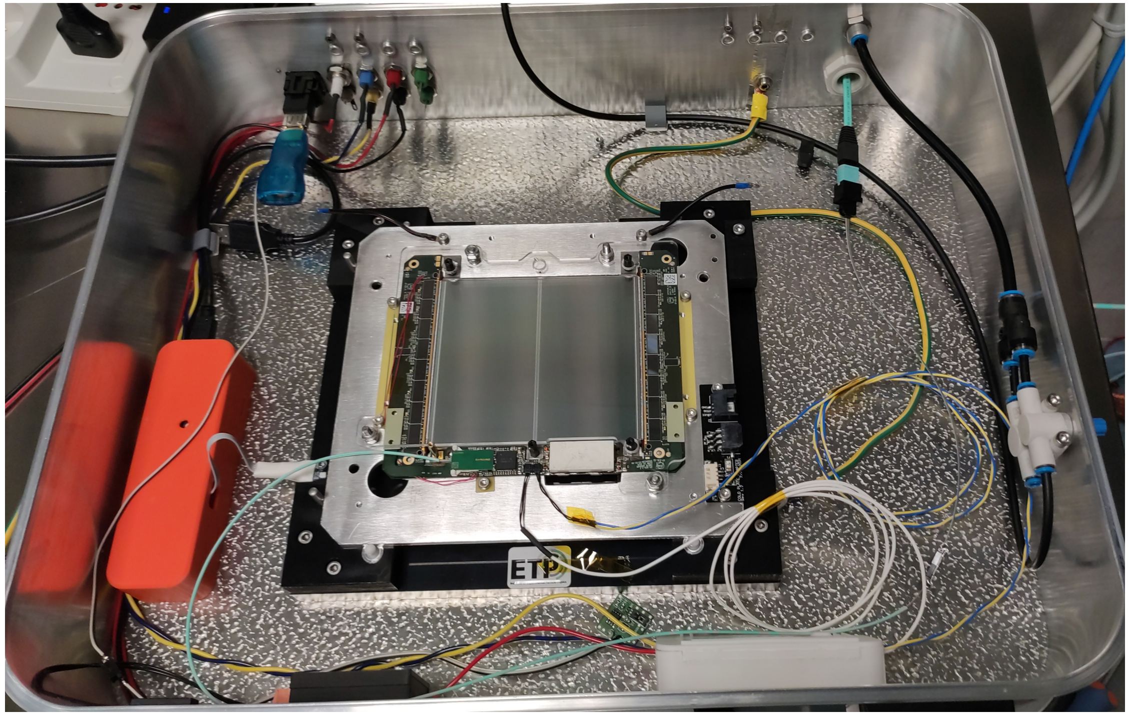


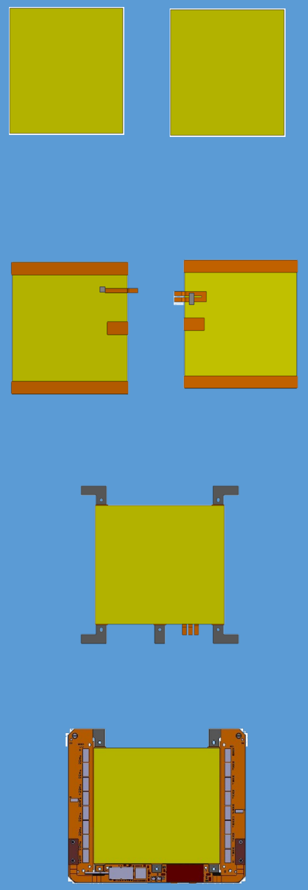






Assembly – electrical tests





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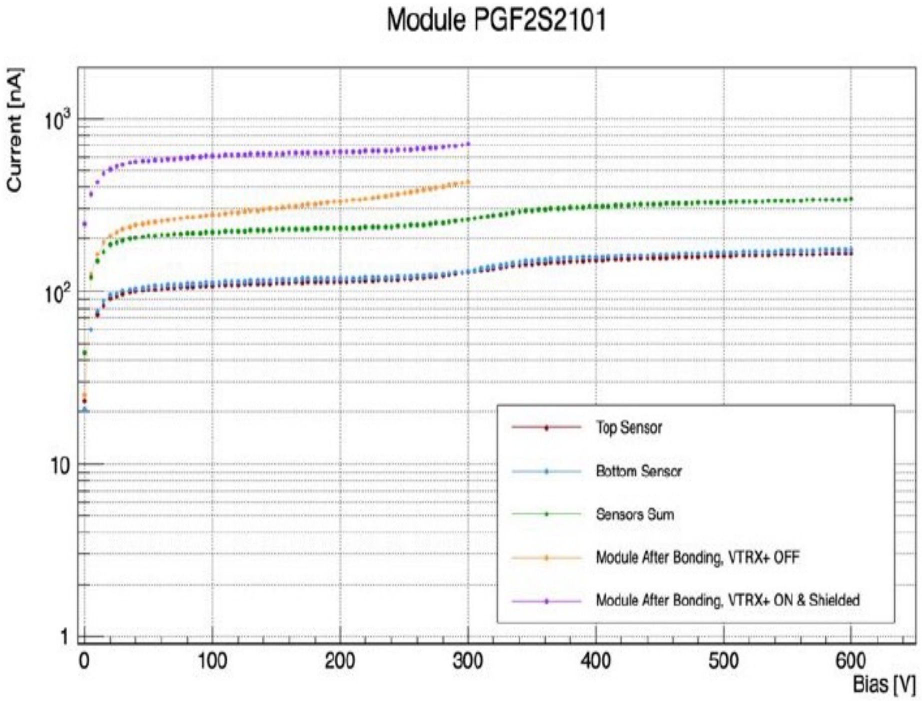
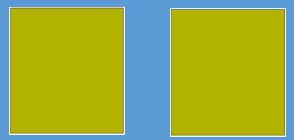
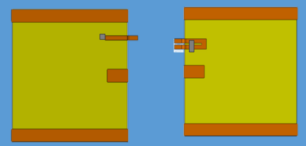
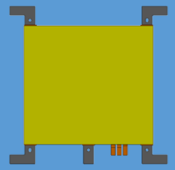
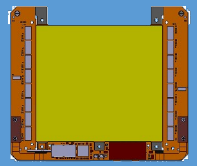


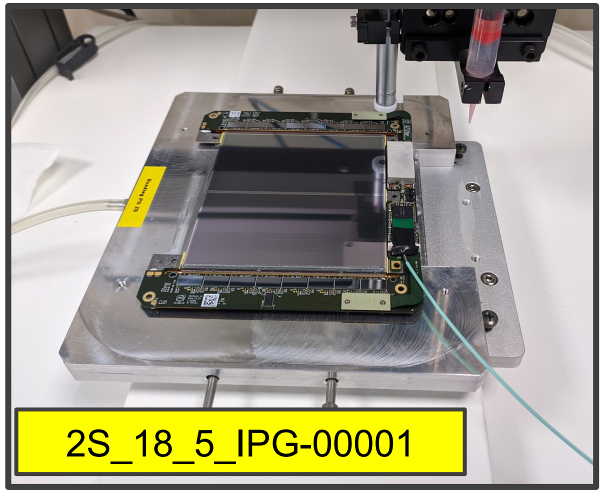




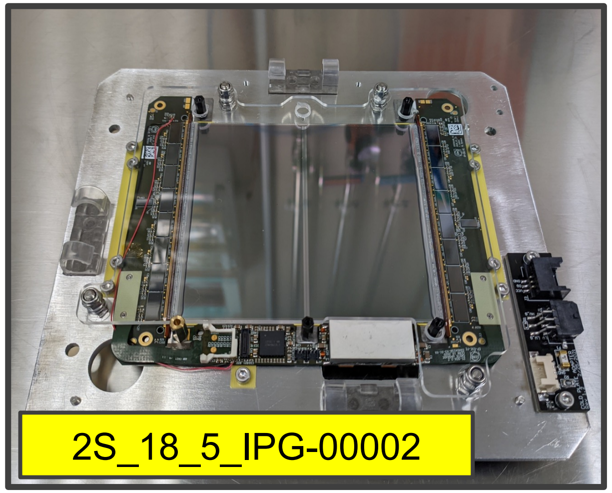




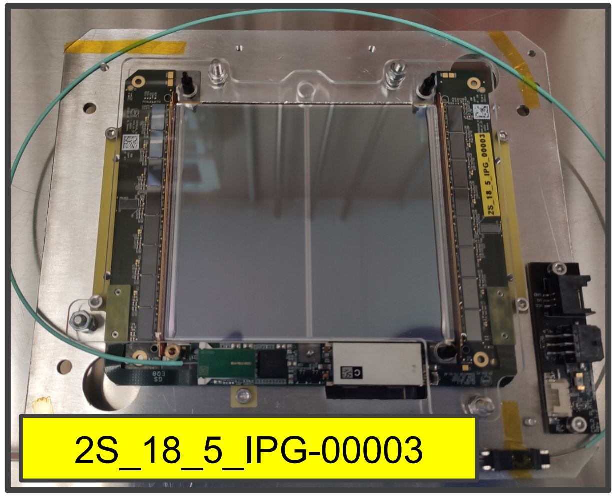
Assembled modules



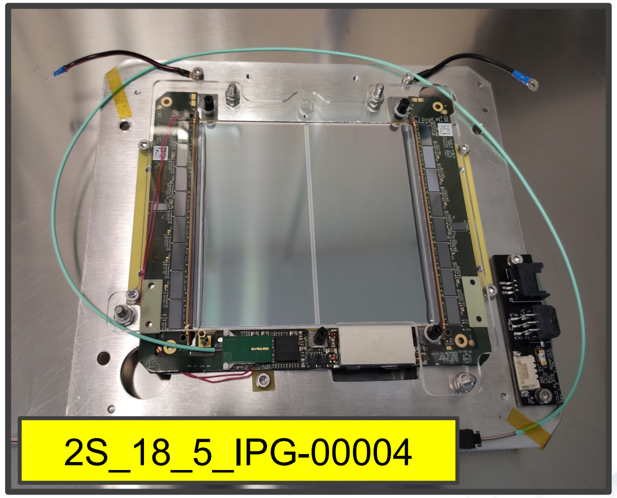
Top sensor	36241_030_2
Bottom sensor	36241_006_2
SEH	2SSEH-201000028
FEH-L	2SFEH18L-201000241
FEH-R	2SFEH18R-201000343
Rotation	135 [μrad]
Shift ⊥	13 [μm]
Shift //	-4 [μm]



Top sensor	36240_009_2
Bottom sensor	36241_042_2
SEH	2SSEH-201000024
FEH-L	2SFEH18L-201000243
FEH-R	2SFEH18R-201000342
Rotation	120 [μrad]
Shift ⊥	22 [μm]
Shift //	-10 [μm]

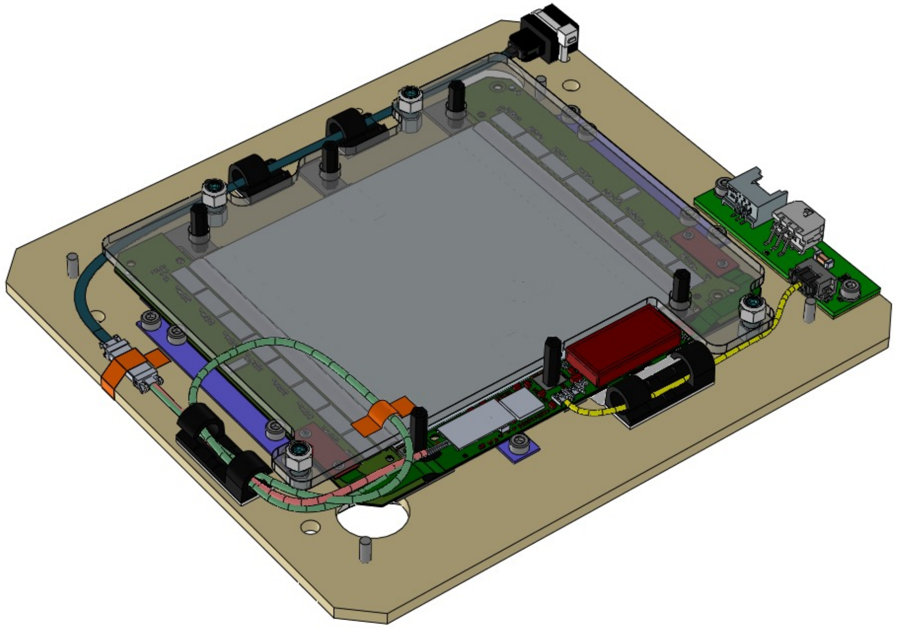


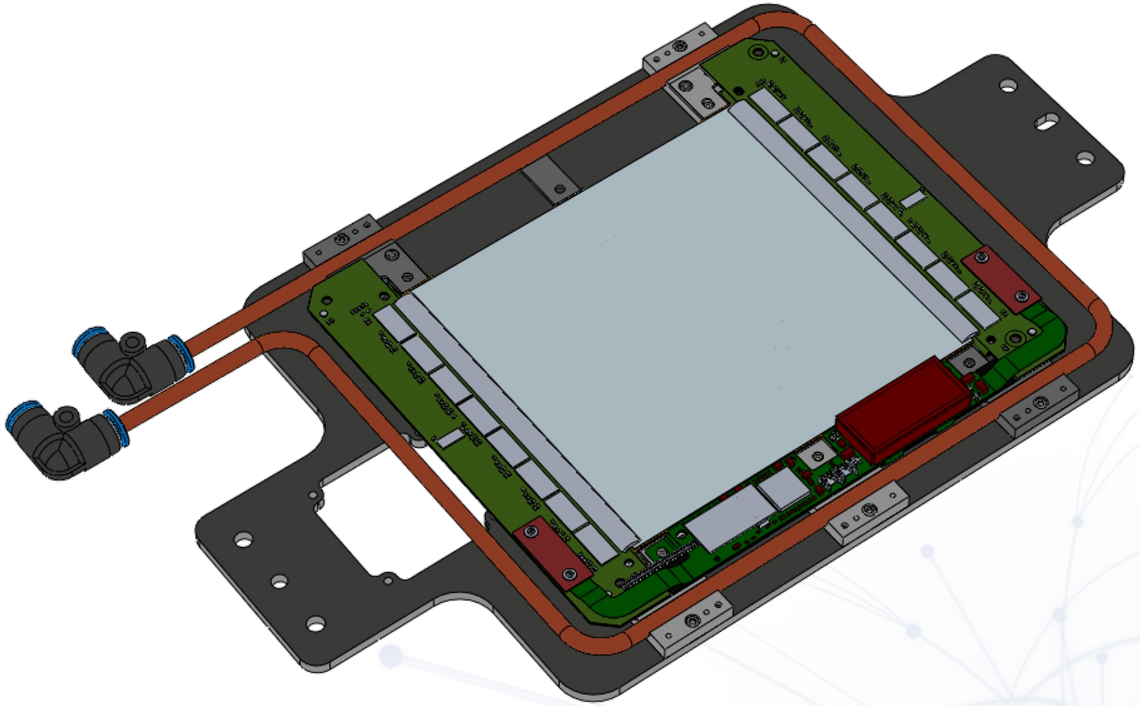
Top sensor	36240_031_2
Bottom sensor	36240_049_2
SEH	2SSEH-201000023
FEH-L	2SFEH18L-201000274
FEH-R	2SFEH18R-201000337
Rotation	170 [μrad]
Shift ⊥	39 [μm]
Shift //	4 [μm]



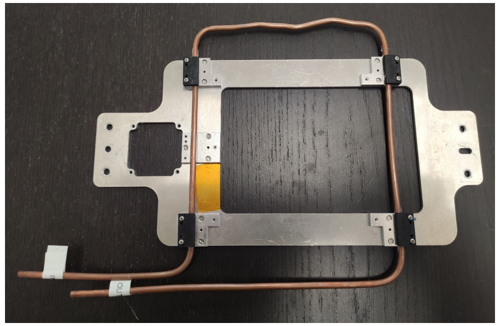
Top sensor	34332_005_2
Bottom sensor	34332_005_2
SEH	2SSEH-201000021
FEH-L	2SFEH18L-201000234
FEH-R	2SFEH18R-201000212
Rotation	45 [μrad]
Shift ⊥	6 [μm]
Shift //	-15 [μm]

MUonE logistics plans

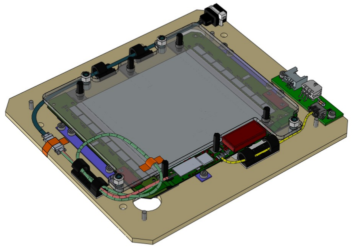


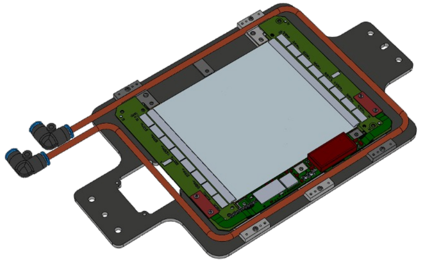


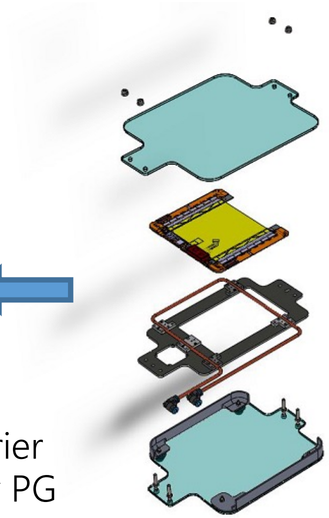
MUonE logistics plans



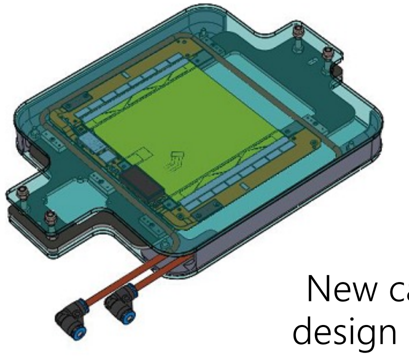
Shipping to
Perugia







New carrier
design by PG



Shipping to
integration center

Data streams for 2S in CMS

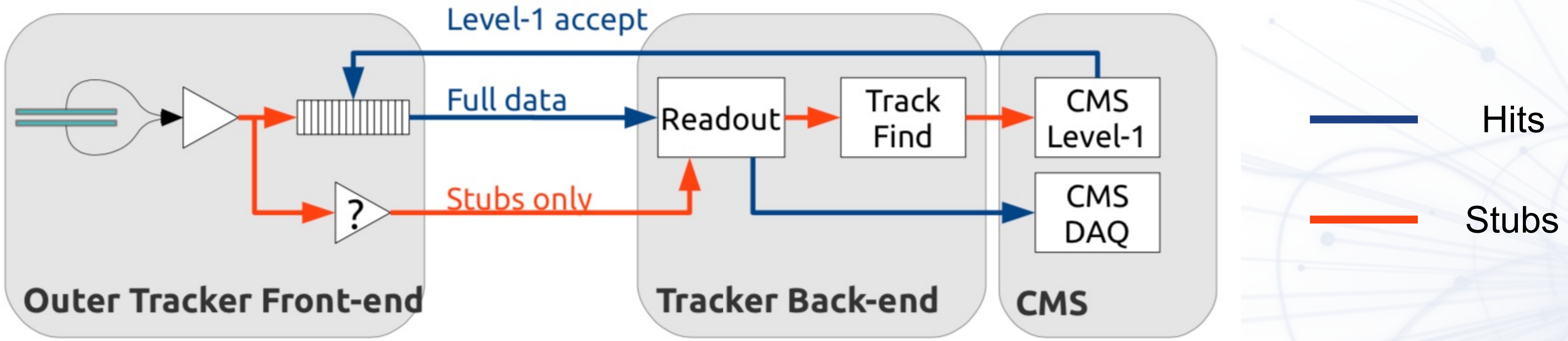
- Two different streams from 2S modules:

Stubs:

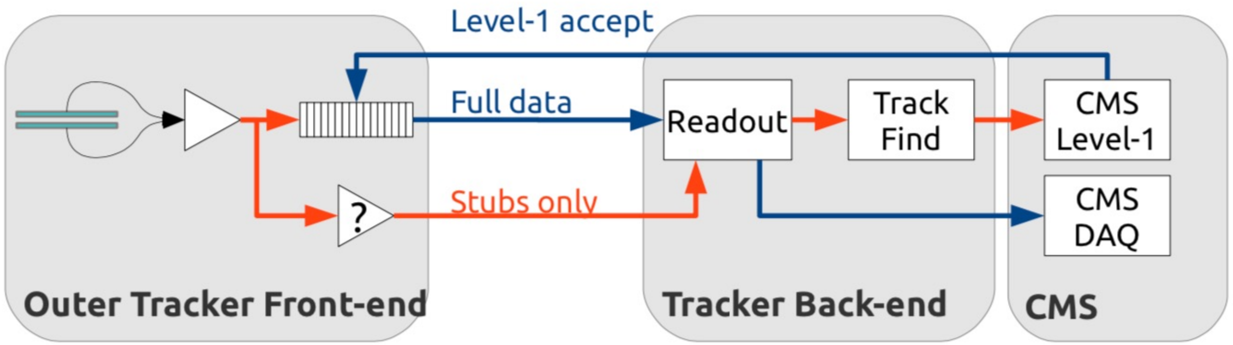
- And between seed strip of a cluster in one sensor and a tunable window in the second one
- Just two values:
  - Mean position of the cluster in the seed layer in half strips
  - Bend: distance between cluster in the first sensor and in the second sensor
- 40 MHz rate
- Untriggered

Hits:

- Full informations about the event: 1 bit per EACH strip (2032 bits)
- 750 kHz sampling rate → triggered acquisition

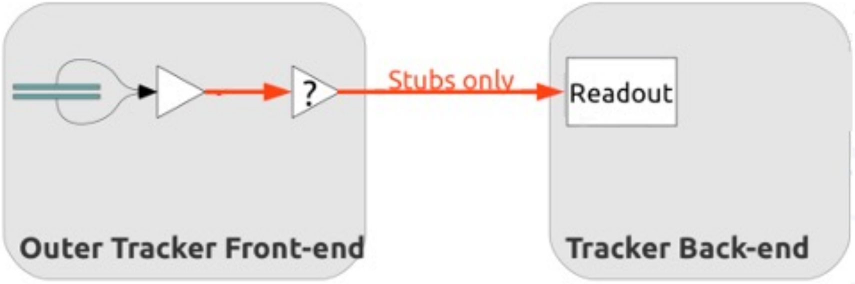


Data readout in CMS vs MUonE

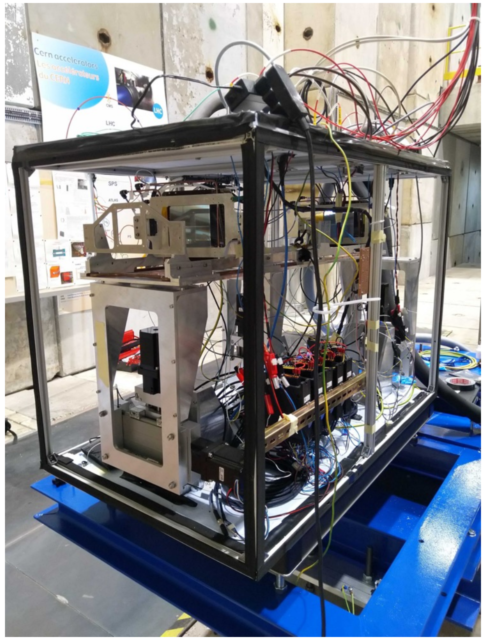


Hits

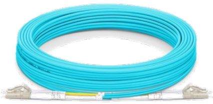
Stubs

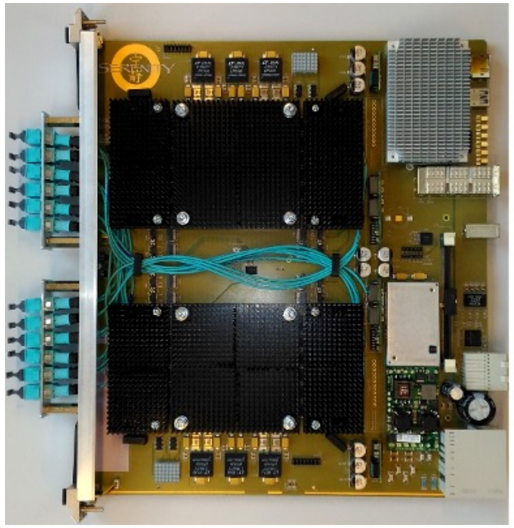


DAQ chain

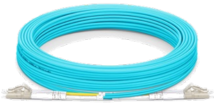


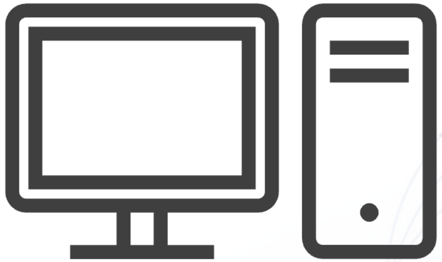
MUonE station





DTC readout board

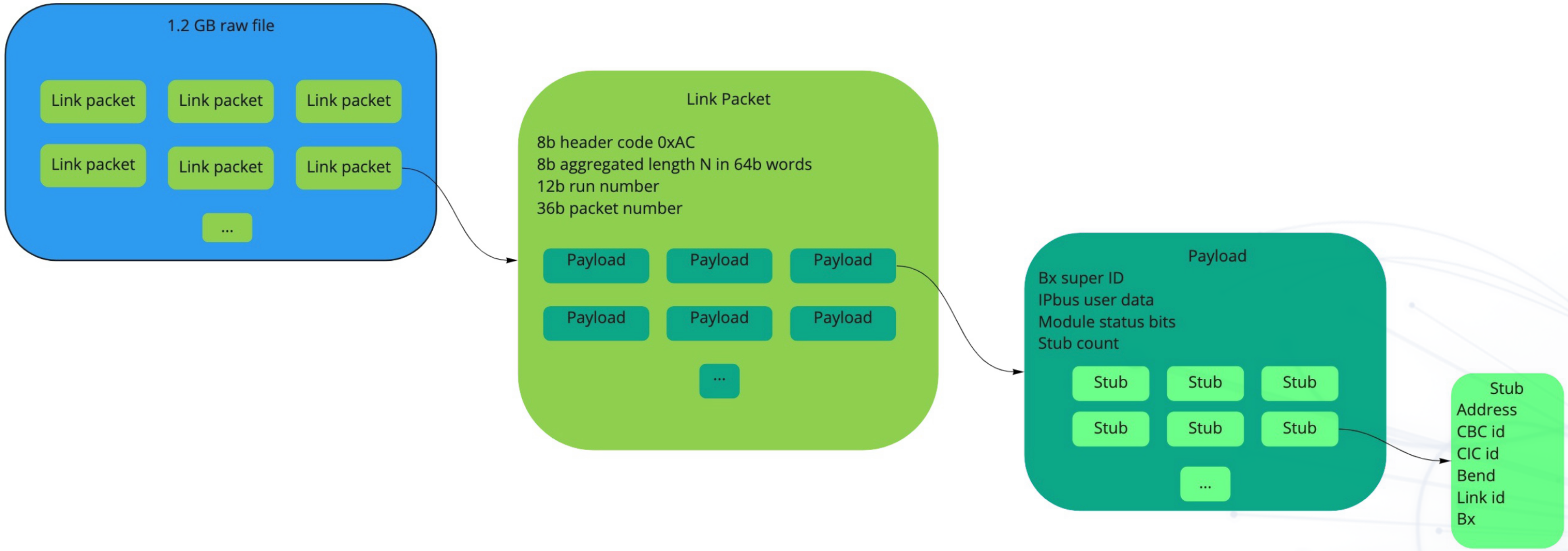




Data storage

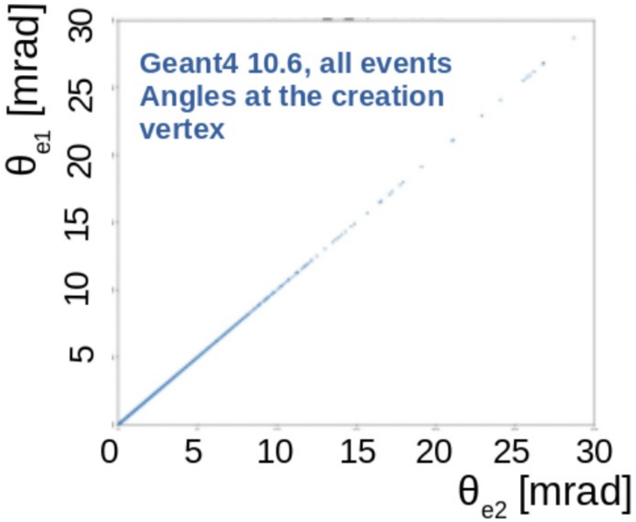
Data structure

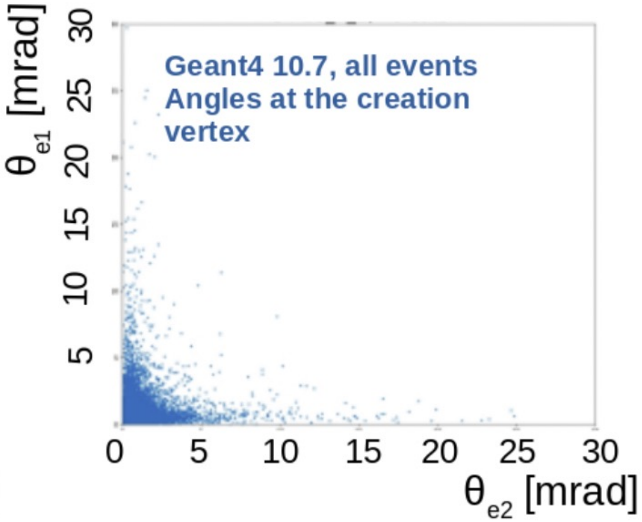
- Output from the modules as “raw” files → need to decode them to have physical quantities
- Involvement in: **decoding of raw data + definition of data format** for track reconstruction and other analysis

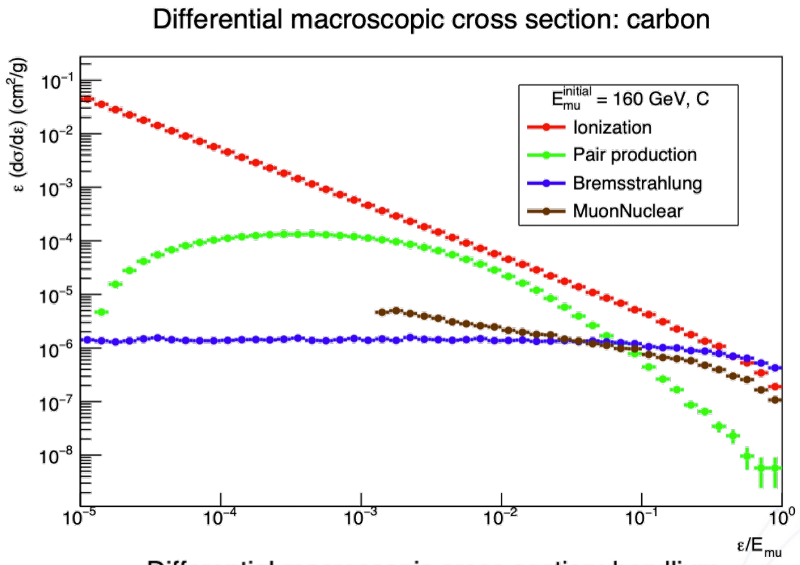


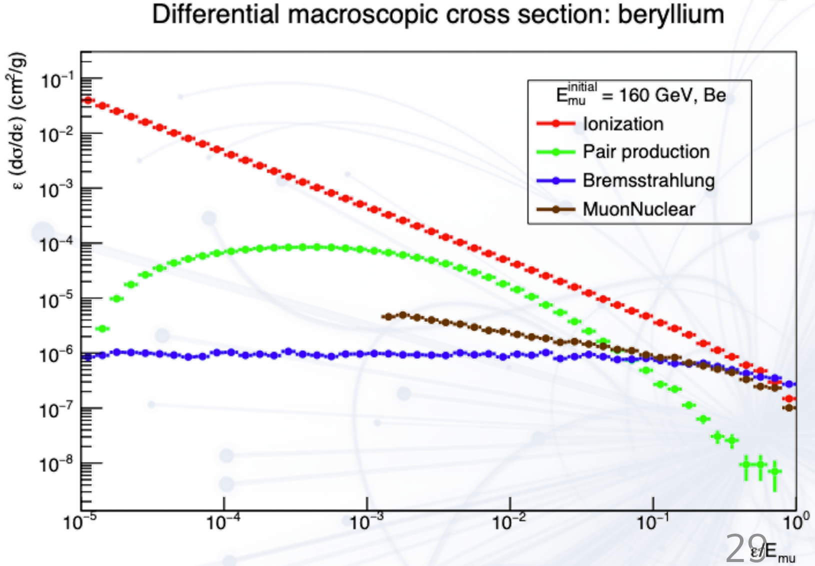
Other involvements from Perugia - simluations

- Estimate for the components of the MUonE preliminary setup:
  - angular correlation plots
  - contribution of interaction processes to the total energy loss
- Geant4 versions comparison from pre 10.7 vs 10.7 onward
  → improved simulations of the angular distribution of e^+e^- pairs



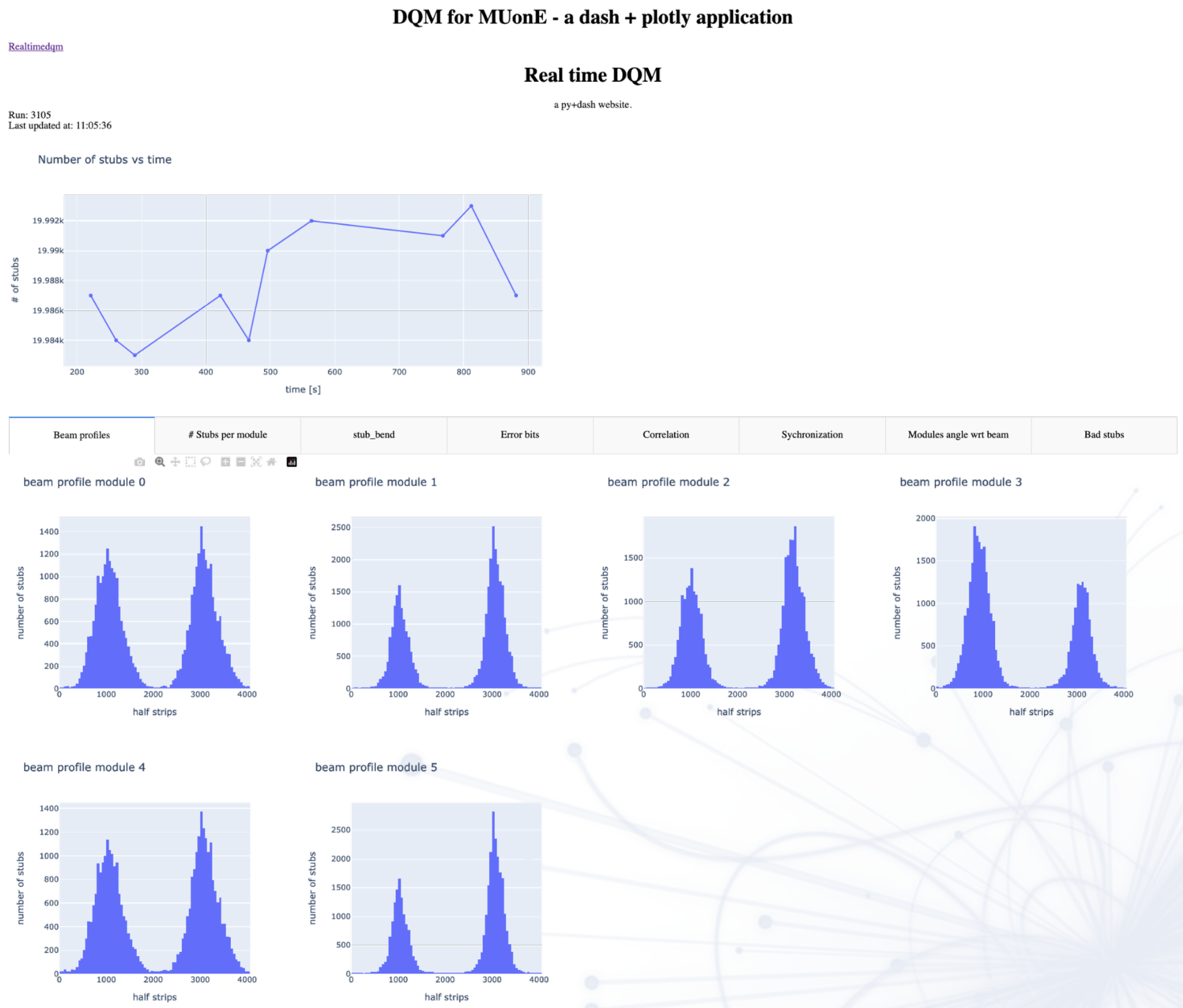






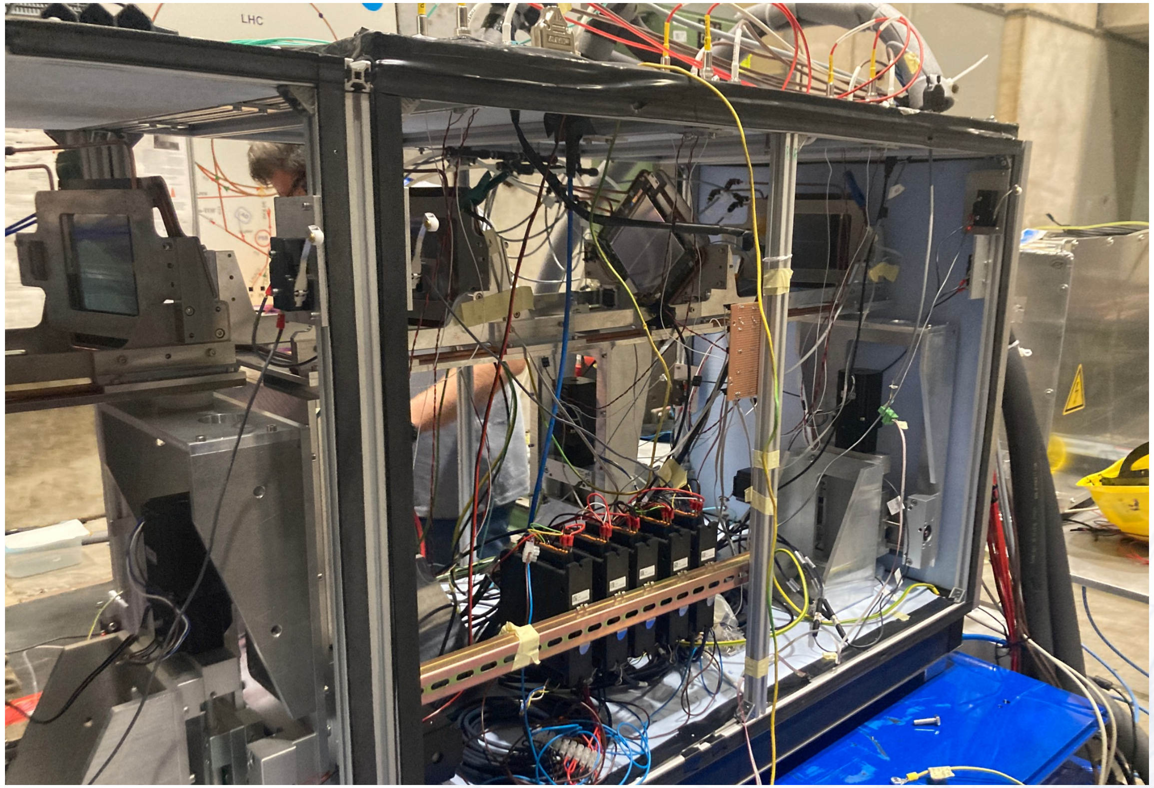
Other involvements from Perugia – data quality monitoring and offline analysis

- Deployment of DQM tools:
  - Fast
  - Interactive
  - Keeping track of both firmware errors and hardware conditions
  - With an eye on scalability for the future
  - In progress: adding fast reconstruction of tracks
- Offline analysis: search for firmware **bugs**, estimate modules **performances**, track reconstruction



MUonE – 2022 test beam setup

- **First time:** 6 modules readout at high intensity
- **2 of them built in Perugia**
  - Originally 6 → parts shortage + newly found issues in already present part brought them down to 2
- One completely equipped station + target → first possibility to reconstruct tracks and study MUonE capabilities and resolution
- Stress test for DAQ final system (~ 20 MHz)
- More info in Mark Pesaresi's talk!

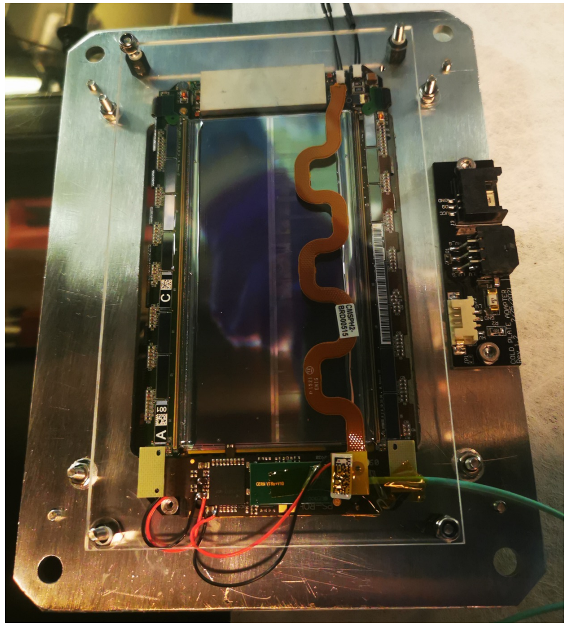


Conclusions

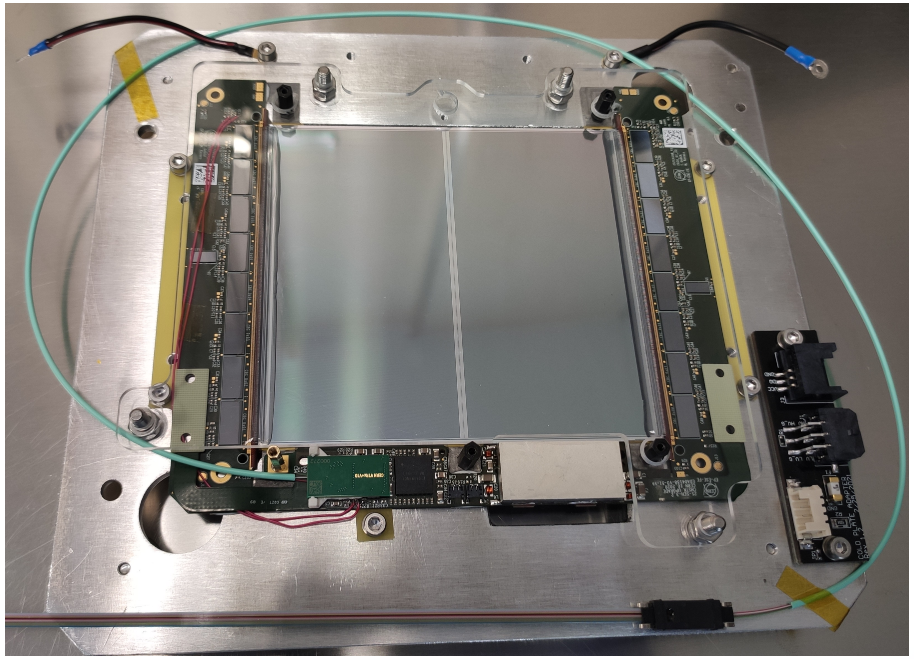
- Main involvement from Perugia: 2S modules construction and test
- Overview of why 2S modules have been chosen
- Overview of the production processes
- Other involvements:
  - Simulations
  - Shift from CMS daq test sytem to final system
  - DQM
  - Offline analysis
  - Data format definition

Backup

CMS outer tracker

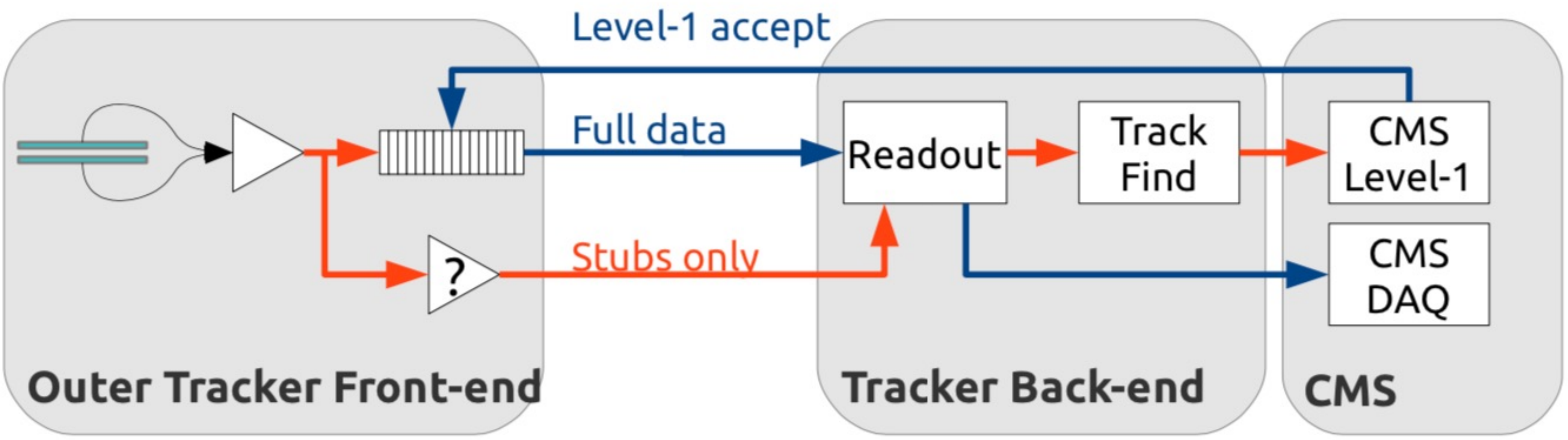


- PS Modules
  - 3 different spacing : 1.6mm & 2.6mm & 4mm
  - One strip sensor: 2.5cm x 100µm strips
  - One macro Pixel sensor : 1.5mm x 100µm pixels
  - Sensor dimension 5cm x 10 cm
    - two column of 960 strips
    - 32x960 pixels



- 2S Modules
  - 2 different spacing : 1.8mm & 4mm
  - 2 micro strip sensors with 5cm x 90µm strips
  - Sensor dimension are 10cm x 10cm
    - two column of 1016 strips

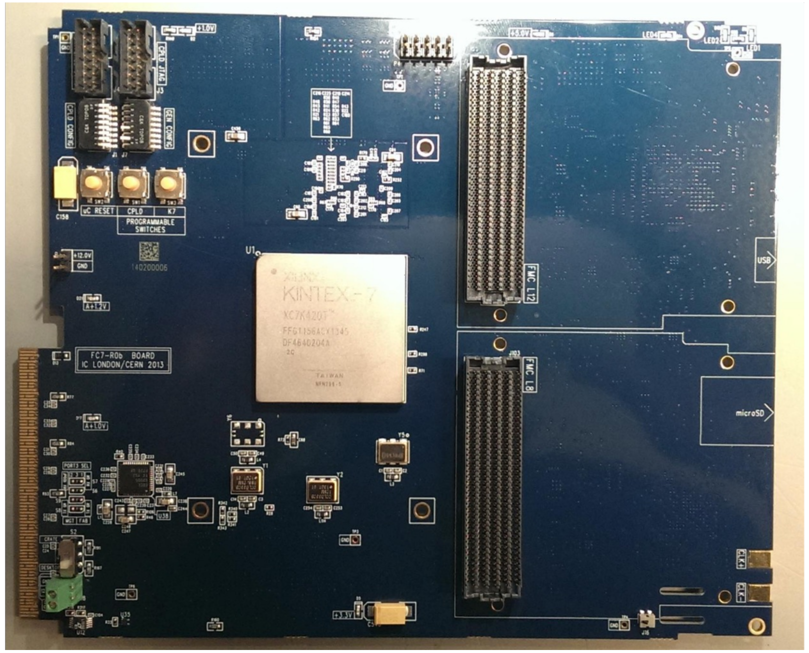
DAQ for CMS modules

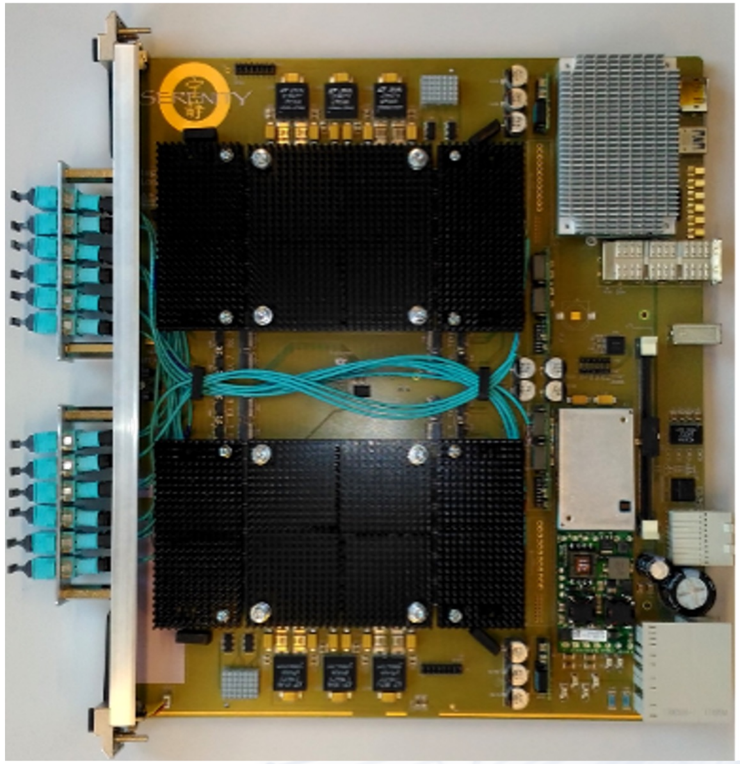


- Stubs: average position of the seed cluster + average position of the correlation cluster
  - L1 trigger
  - 40 MHz readout
- Hits: information on ALL the strips/pixel in a module (one bit per strip/pixel)
  - Final DAQ
  - 750 kHz readout

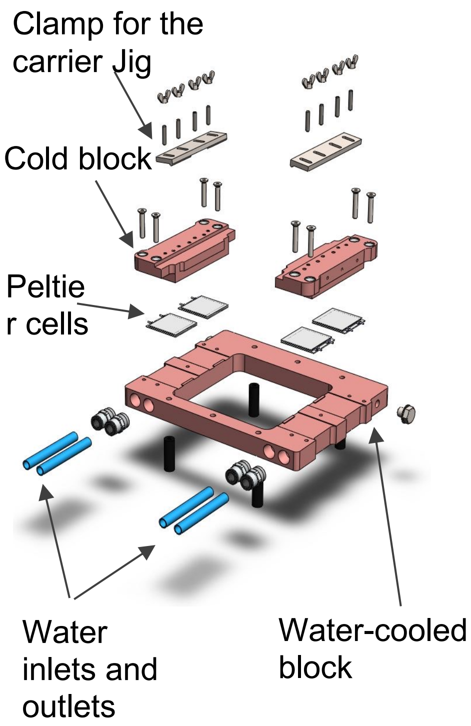
Involvement for DAQ chain

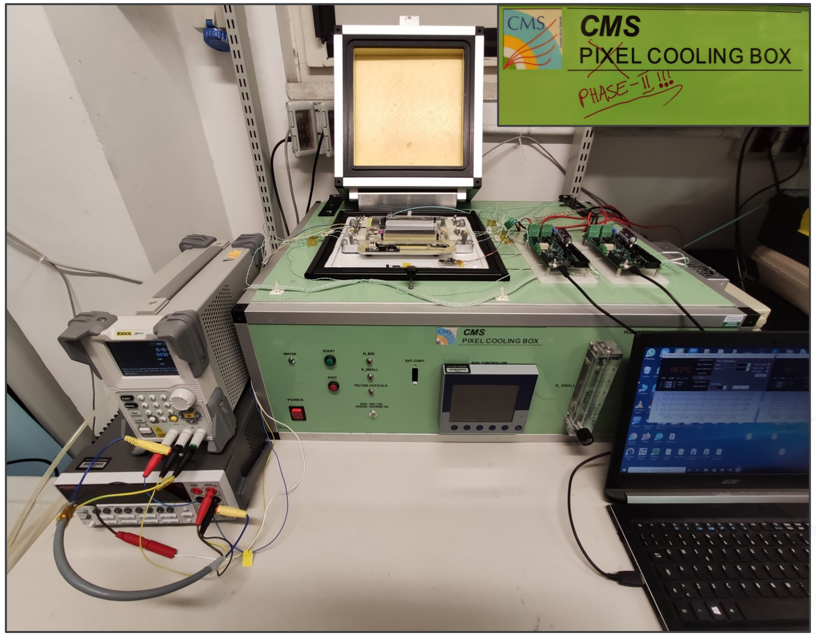
- Passage from test system (uDTC) to final readout system (DTC)
  - Transition of the calibration software for 2S modules → calibration SW for PS has just been deployed on the test system, time to transition also that!



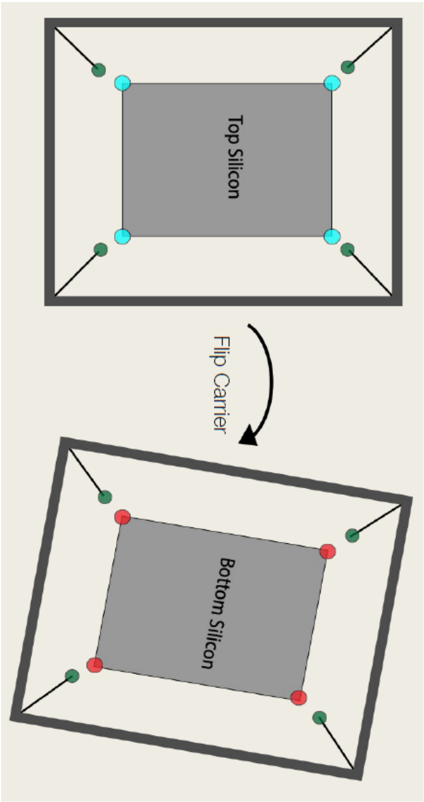


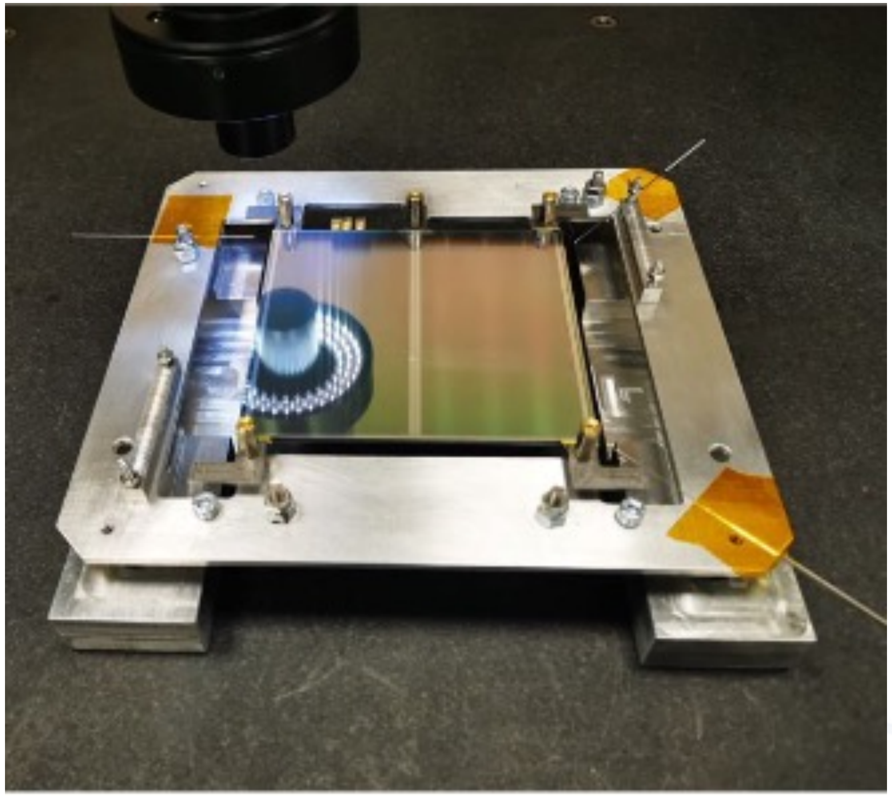
Cooling box

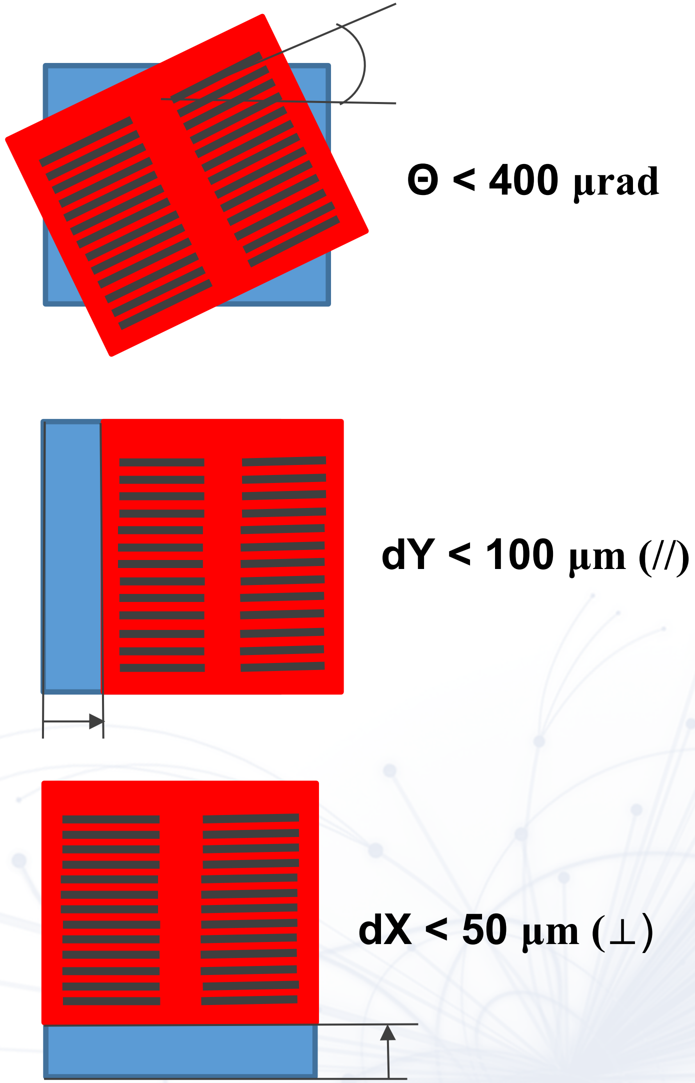

Clamp for the carrier Jig
Cold block
Peltie
r cells
Water inlets and outlets
Water-cooled block


CMS
CMS
PIXEL COOLING BOX
PHASE-II !!!

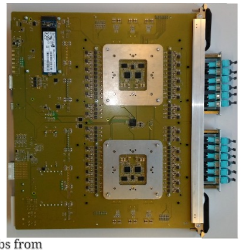
Assembly – mechanical metrology

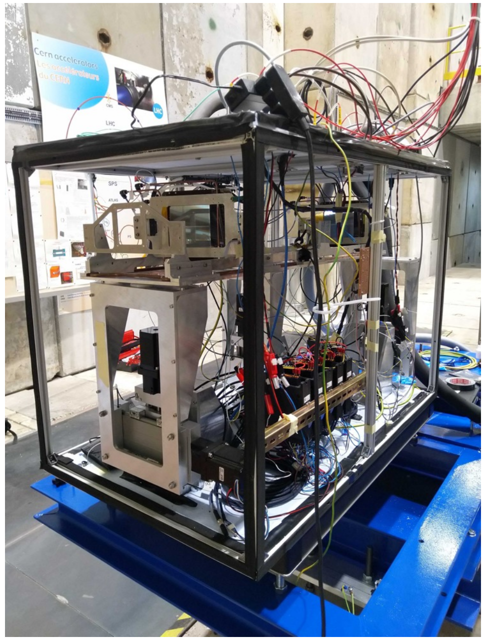


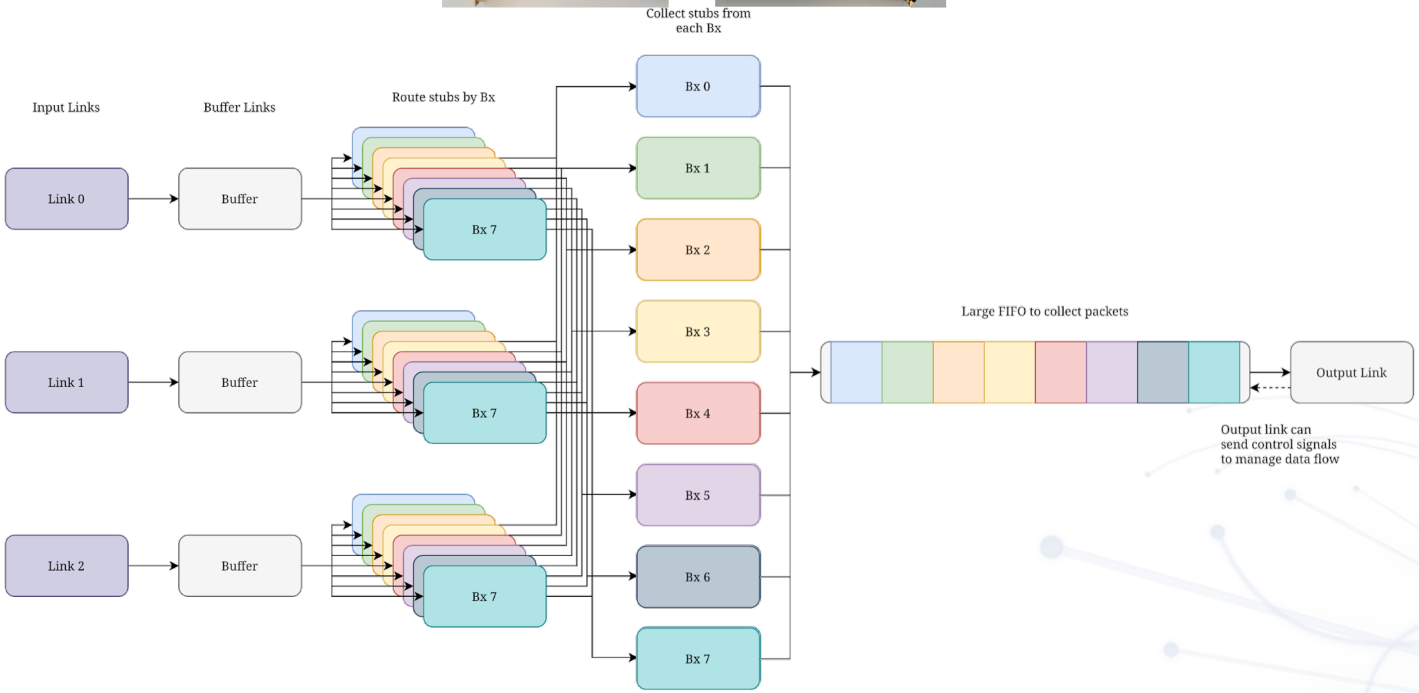




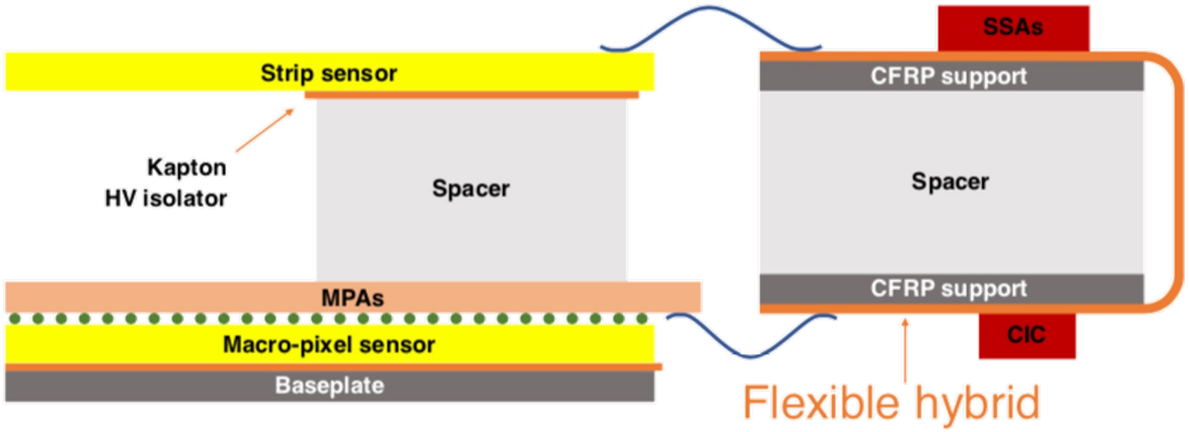
MUonE DAQ chain

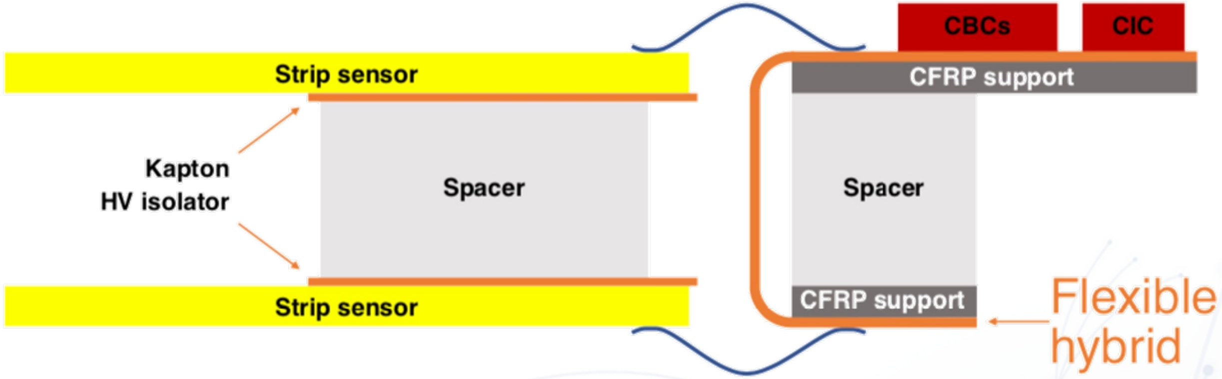




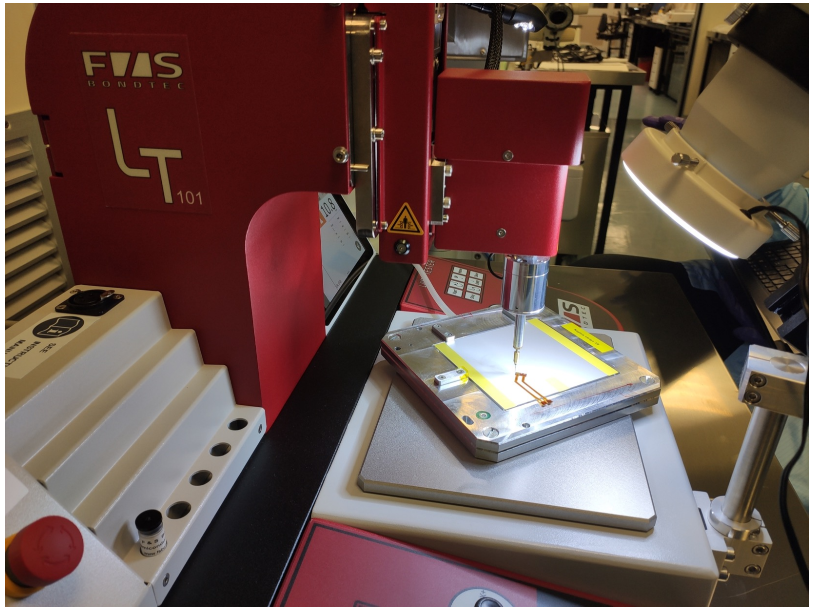


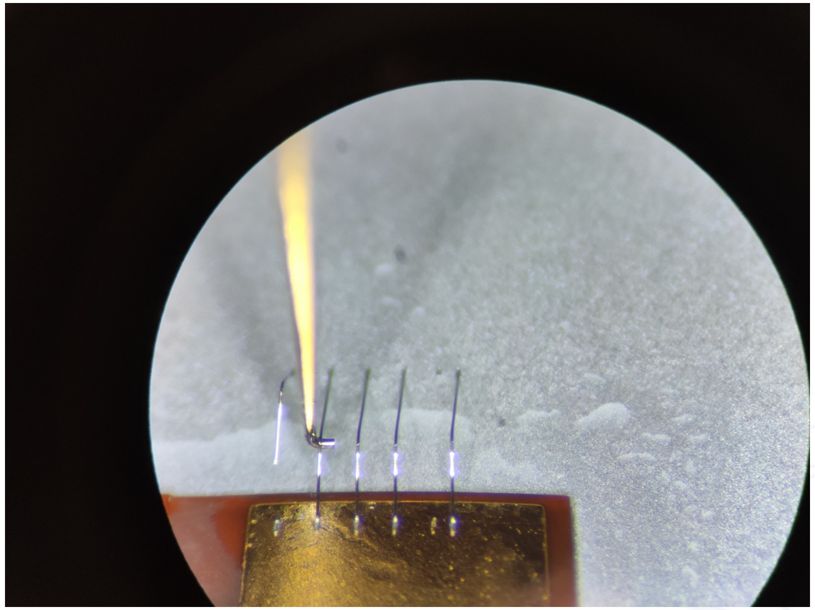
DAQ for CMS modules





Pull tests





Test bench