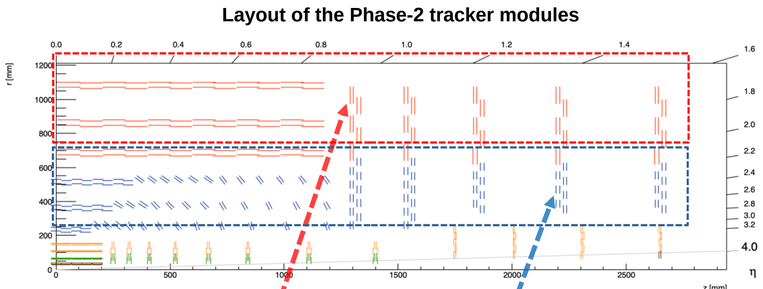
Qualification of macro-pixel sensor assemblies for the CMS Phase-2 tracker

Soham Bhattacharya* (DESY, Hamburg)
on behalf of the CMS Collaboration
[*] soham.bhattacharya@cern.ch

Scan for digital version

The Phase-2 upgrade of the CMS detector for the high luminosity era of the LHC (HL-LHC), will install a new tracking system to cope with the increased pileup and track multiplicity. The inner layers of the outer tracker will be equipped with pixel-strip (PS) modules that have a high segmentation to provide an accurate position measurement. A PS module contains two types of silicon sensors, namely, strip and macro-pixel (PS-p) sensors.
The PS-p sensor and its readout chip (the macro-pixel ASIC, or MPA) together form the macro-pixel sub-assembly (MaPSA).
A rigorous quality control (QC) procedure has been developed and validated using prototype MaPSAs. This poster describes the MaPSA QC setup and procedure, and the measurement results on the prototypes.

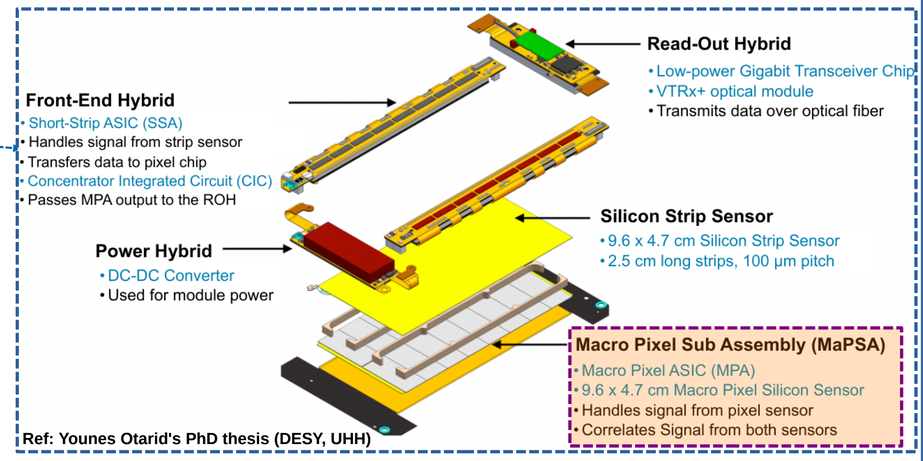
Layout of the Phase-2 tracker modules



- Lower granularity
- r>600 mm region

- Higher granularity
- 200<r<600 mm region

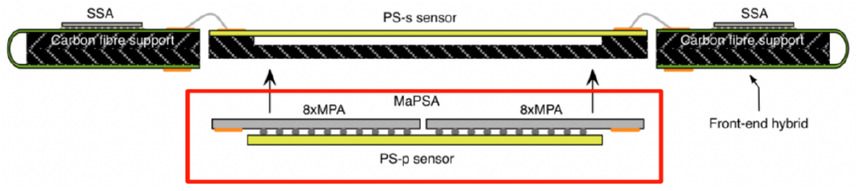
- **The HL-LHC era:**
  - Instantaneous luminosity of up to 7.5×10^{34} cm^{-2} s^{-1}
  - High pileup and track multiplicity.
  - Tracker needs to be upgraded
- **Phase-2 tracker requirements:**
  - Radiation hardness (up to 4000 fb^{-1} of integrated luminosity)
  - High granularity (low occupancy)
  - Low material in the tracking volume.
  - Extended tracking acceptance (up to $|\eta|=4$)



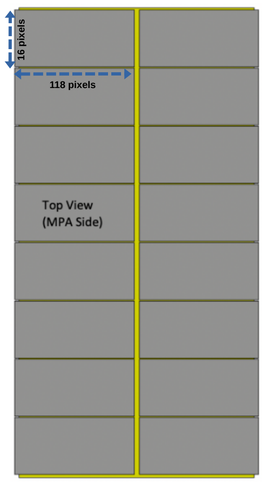
Ref: Younes Otarid's PhD thesis (DESY, UHH)

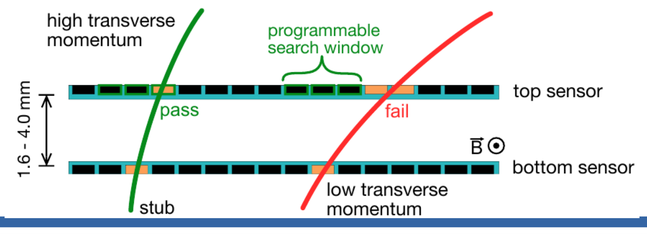
Ref: The Phase 2 Upgrade of the CMS Tracker, CERN-LHCC-2017-009 (2017) [https://cds.cern.ch/record/2272264]

The MaPSA

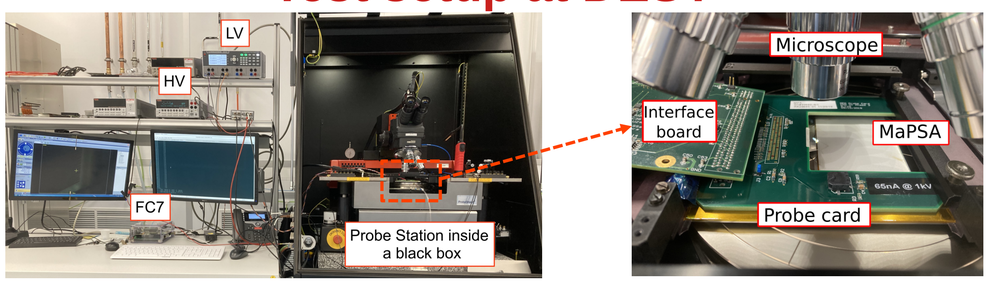


- The PS-p sensor is bump-bonded to 16 MPA chips
- **Each macro-pixel is 1467x100 µm**
  - Except wide-edge cells which are 1467x200 µm
- **Each MPA chip reads out 1888 pixels:**
  - 16 rows
  - 118 columns
- **The MPA:**
  - Correlates the signal from PS-p and PS-s sensors
  - **Implements the the p_T discrimination logic**
    - High p_T tracks curve less in the magnetic field (3.8T)
    - Look for 2 compatible hits in the 2 sensor layers (PS-p and PS-s)
    - 2 hits are compatible if within programmable search window (corresponds to p_T > 2 GeV)
    - **If compatible, produce a short track segment ("stub"), which is used in the Level-1 trigger**





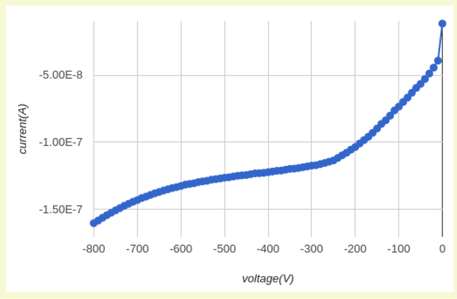
Test setup at DESY



- The probe card contains 119 needles
  - 118 for the MPA chips (via pads)
  - 1 for high voltage (HV)
- The interface board connects the probe card and the FC7 (µTCA card for DAQ)
- The user computer reads the data from the FC7

IV characteristics

- During operation:
  - Radiation damage shrinks sensor depletion region
  - Increase reverse bias voltage to compensate
- Test IV characteristics down to a bias voltage of -800 V
- **No breakdown**
- **Leakage current does not exceed 1 µA at -800 V**



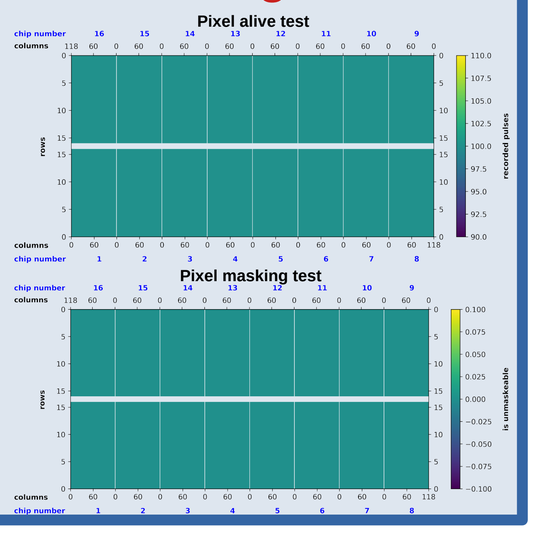
MaPSA qualification tests

- **Global test:**
  - **Sensor IV characteristics**
- **Tests for each chip:**
  - **Pixel alive test**
  - **Pixel masking test**
  - **Trimming test**
  - **Bump bonding test**
  - **Register test** (not in the poster)**:**
    - **Write values to all configurable registers**
    - **Read back and check if the values match**

Task:
- **Develop test setup and procedure**
- **Optimize and validate on prototype MaPSAs**

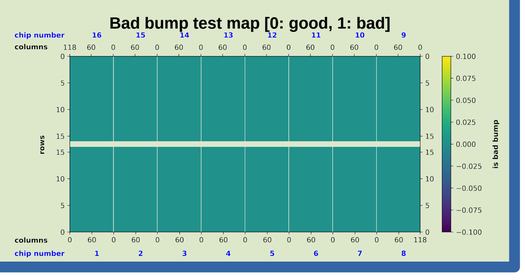
Pixel alive and masking test

- Inject 100 pulses
- Pixel alive:
  - Check if 100 pulses are read out
  - **All values at 100 – no dead pixels found**
- During operation, pixel may have to be masked if noise is too high. **Otherwise may blow up trigger rate**
- **All values at 0 – all pixels can be masked**

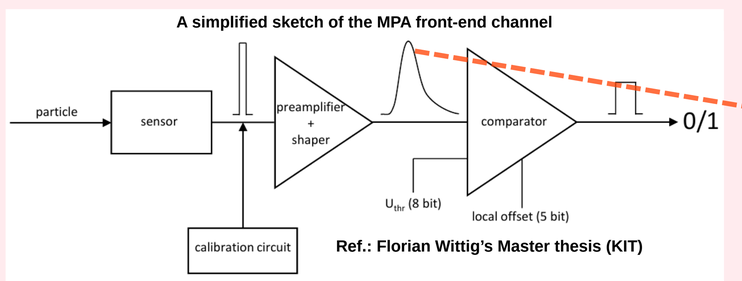


Bump bonding test

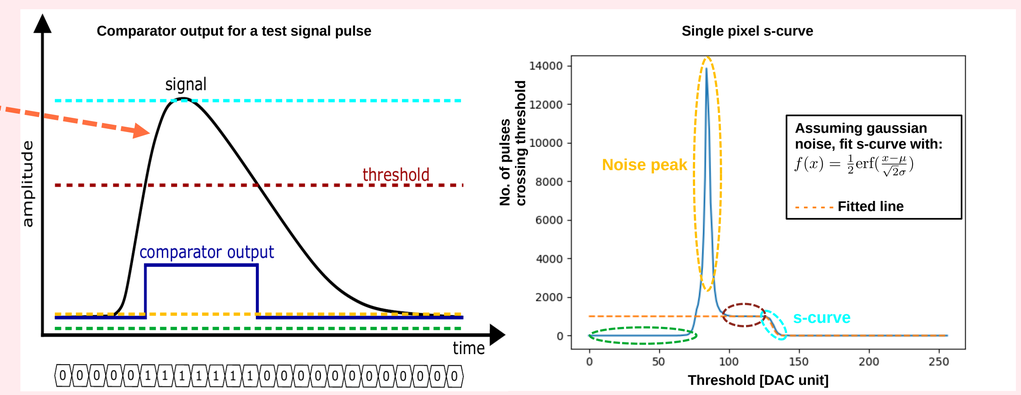
- Apply a small bias voltage of -2 V
- Measure noise by fitting the s-curve (see "Trimming test" section)
- Criteria for bad bump bonding
  - Pixel noise remains low, i.e. bad contact [low: <5σ w.r.t. the mean noise]
- **All values 0: no bad bump bonds**



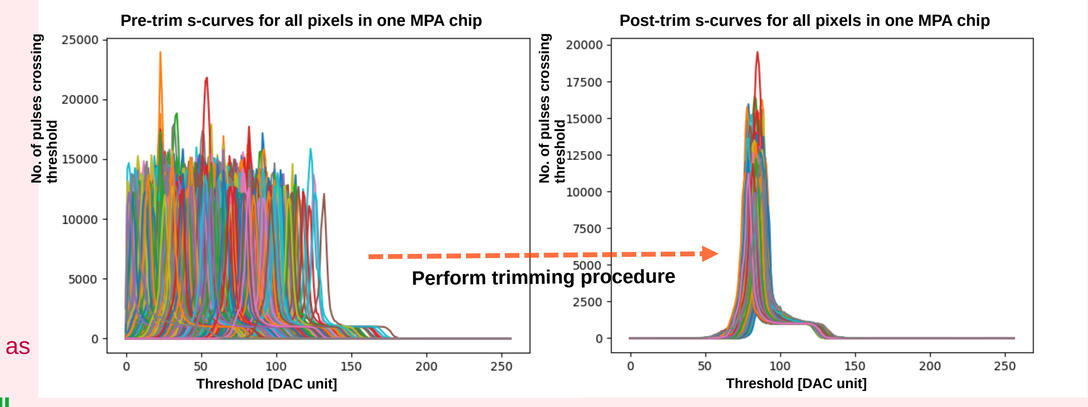
Trimming test



Ref.: Florian Wittig's Master thesis (KIT)



- **Amplifier baselines are different** even for identical charge injection (because of chip manufacturing variation)
- **Trimming**: equalizing the responses of the front-end readout channels
- **Procedure:**
  - **Obtain the "s-curve" for each pixel:**
    - Inject 1000 pulses (fixed amplitude)
    - Vary comparator threshold
    - For each threshold value, count the number of pulses crossing threshold (ripple counter)
  - **Fit the s-curve** with: $f(x) = \frac{1}{2}\mathrm{erf}(\frac{x-\mu}{\sqrt{2}\sigma})$
    - **µ = pedestal**
    - **σ = noise**
  - The µ will be different pixel to pixel – **choose a reference (target) value for µ**
  - **Apply offsets** such that, the new µ of each pixel is as close as possible to the target
- **Post-trim s-curves overlap – trimming procedure works well**



Summary

- A **rigorous procedure** has been developed for qualifying the MaPSA quality
- The QC procedure has been **thoroughly tested** on prototype MaPSAs
- **Test system fully functional at DESY**
- (Almost) same test system and procedure to be used across all MaPSA test sites
- Production at DESY:
  - Will assemble 1250 PS modules
  - Will receive 1250 MaPSAs (tested by US sites beforehand)
  - **Will retest 10% these MaPSAs before module assembly**

References

- The Phase 2 Upgrade of the CMS Tracker, CERN-LHCC-2017-009 (2017) [https://cds.cern.ch/record/2272264]
- Younes Otarid's PhD thesis (DESY, UHH)
- Florian Wittig's Master thesis (KIT)