Further Comments of the HL-LHC Experiments concerning the LGAD Runs planned for 2018 at HPK.

Motivated by the highly successful meeting on Dec 19, 2018 in Hamamatsu, Japan, the representatives of ATLAS and CMS would like to continue the collaboration with HPK engineers on the new runs planned for 2018.

Important date for ATLAS-HGTD and CMS-ETL: Technical Design Report in late Summer 2018

The following fact needs to be emphasized again: for both experiments, the most important milestone is the submission of the Technical Design Report (TDR) in in the 3rd Quarter 2018, i.e. before the end of September 2018. For that date, we have to prove that LGADs can be produced reliably and with high yield in arrays of multiple pads, and the most important technical solutions need to be understood.

To achieve this goal, a production of large sensors has been planned at the Dec 19th meeting.

Spring 2018: production of full wafers containing large sensors for ATLAS and CMS (LargeSensor_HPK).

Both ATLAS and CMS need to prove the existence of large sensors (~ 100 pads), which can operate reliably when new and irradiated, with good gain uniformity.

For this reason, a production of large sensors (LargeSensor_HPK) is needed, where reliability and gain uniformity before and after irradiation are the two most essential parameters. We assume that many of the design details will be similar to those of the proven “Sample 50D” from the Nov 2016 delivery, with the exception of the pad size.

In Appendix A.1 and A.2 the top-level sensors layout for LargeSensor_HPK from ATLAS and CMS are presented.

We would like to receive soon feedback if there are any parts of our request which would prevent HPK from shipping the devices in or before June 2018 so that they can be irradiated and tested before the TDR. In that case we would like to propose a phone conference on this subject so that we can adjust the scope of our request.

Spring 2018: Sensor production for technology development of LGAD by HPK (TechSensor_HPK).

We are looking forward to further optimization of the LGAD technology by HPK in early 2018. For this reason, a production in early spring 2018 will be manufactured (TechSensor_HPK). Based on our measurements, we have recommended in this production studies with variations of important parameters so that they can be optimized in the final prototype next year: reduced inter-pad distance, reduced edge space, two thicknesses (50 & 35 μm), and the optimization of the doping concentration and depth of the p-type multiplication layer.

We expect that we will be doing most of the testing of the different variations including radiation testing, for which we believe we have developed a methodology tailored to the needs of the experiments. Testing includes I-V and C-V curves, charge collection, and timing studies.

The availability of 20-30 parts of each type made the previous studies of HPK a success, and therefore we recommend planning for this number of devices in each variation.

We would like to recommend that both the CMS basic cell with an external size ("pitch") of 1x3 mm^2 and the ATLAS basic cell with an external size ("pitch") of 1.3x1.3 mm^2 are proto-typed.

We are motivated to have a phone conference with HPK engineers to discuss and review proposed plans.

Path to the ATLAS and CMS TDR: LargeSensor_HPK + TechSensor_HPK

We understand that LargeSensor_HPK might not benefit from the technical developments studied in TechSensor_HPK, however this is not necessary for the ATLAS and CMS TDR. The combination of the technical development obtained in TechSensor_HPK with the uniformity studies of LargeSensor_HPK will provide a solid base for the TDR.

Schedule of future (2018-2022) ATLAS and CMS LGAD productions.

In the following, we would like to provide HPK the schedule for LGAD productions at ATLAS and CMS so that a long term R&D activity can be established.

ATLAS Schedule for HGTD sensor production:

Q2-3 2018: Production of TechSensor_HPK and LargeSensor_HPK

- ➔ Study of technical solutions (edge, fill factor, doping)
- ➔ Sensors with 225 pads, and many test structures

Q3 2018: TDR

2019 - 2020: Sensor2_HGTD production

- ➔ Large sensors, implementation of all the technical solutions

2021: Sensor3_HGTD production

- ➔ Pre-Production of sensors with full HGTD specifications

2022 - 2023: Sensor4_HGTD production

- ➔ Production of sensors for HGTD construction

CMS Schedule for ETL sensor production:

Q2-3 2018: Production of TechSensor_HPK and LargeSensor_HPK

Study of technical solutions (edge, fill factor, dopings)

- ➔ Sensors with 96 pads (one CMS read-out chip), and many test structures

Q3 2018: TDR

2019 - 2020: Sensor2_CMS production

- ➔ Large sensors, implementation of all the technical solutions

2021: Sensor3_CMS production

- ➔ Pre-Production of sensors with full CMS specifications

2022 -2023: Sensor4_CMS production

- ➔ Production of sensors for CMS ETL construction

Appendix A

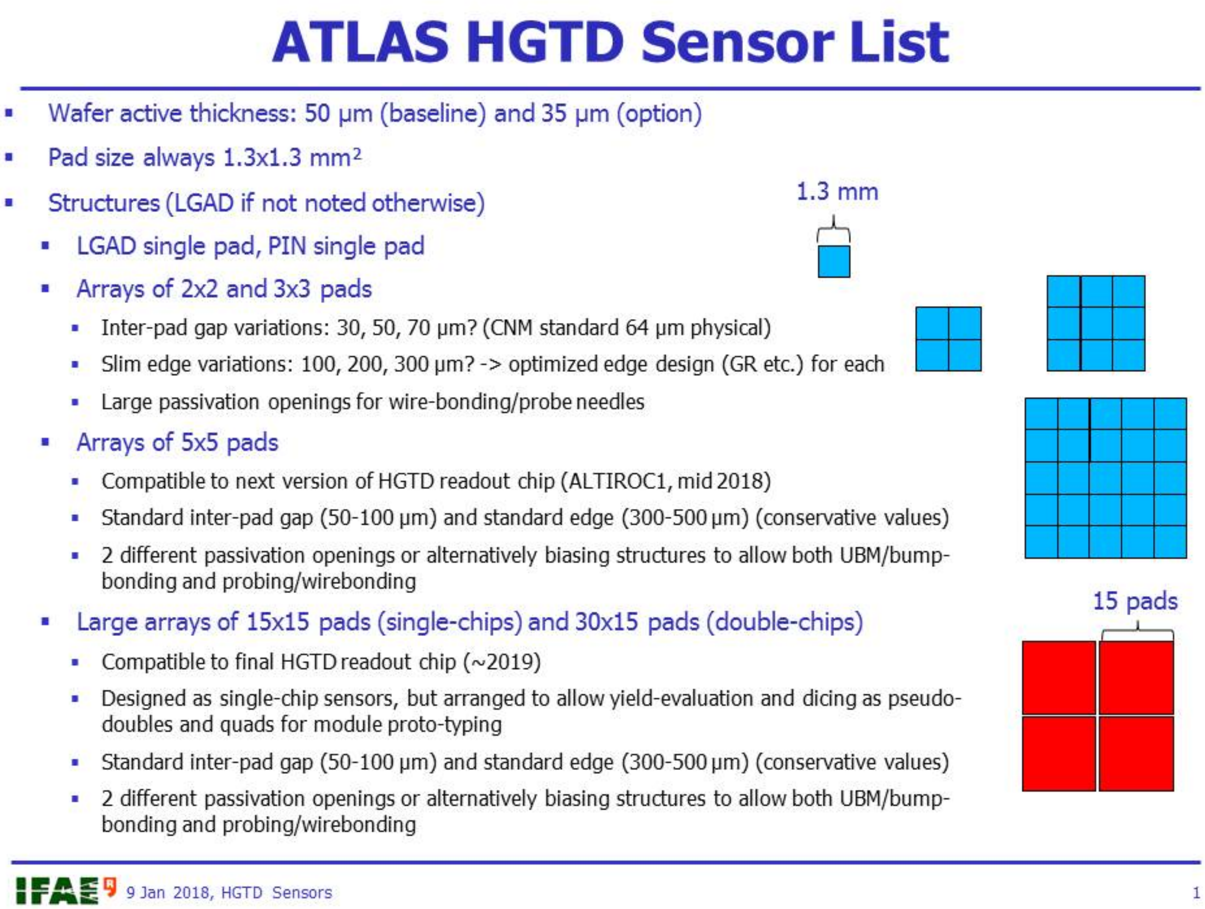
Top level wafer definition of CMS/ATLAS LGAD submission (approximate numbers)

- **Wafer active thickness: 50 µm (baseline) and 35 µm (option)**

A.1 ATLAS HGTD

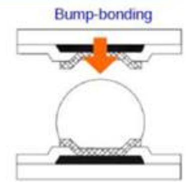
Basic cell (outside dimension) 1.3x1.3 mm^2

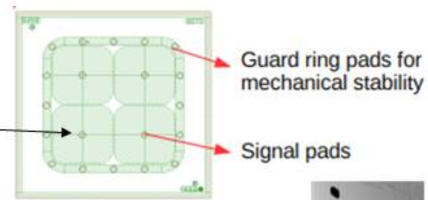
Single pad LGAD:		**~ 150**
Single pad PIN:		**~ 30**
Arrays	**2x2:**	**~ 25 per inter-pad distance (3 distances)**
	3x3:	**~ 7 per inter-pad distance (3 distances)**
	5x5:	**~ 30 devices, safe inter-pad distance, UBM**
	15x15	**~ 8 devices, safe inter-pad distance, UBM**



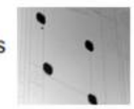
Bump-Bonding

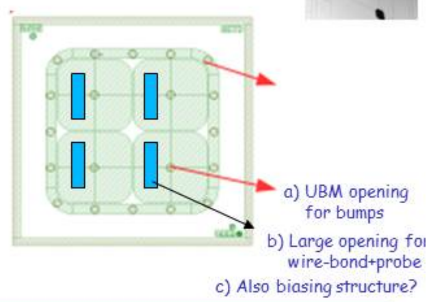
- Need to bump-bond sensor to readout chip
- Need Under-Bump-Metalization (UBM)
  - Provided by vendor?
  - Which process? Is a mask used to protect other metal not foreseen for UBM?
    - Do structures for UBM need to be on one part of the wafer?
- HGTD bump-bonding tests so far
  - On CNM HGTD run (2x2 arrays for first version of readout chip: ALTIROC0)
  - Passivation opening of 90 µm diameters
  - Electro-less UBM in house by CNM
  - Bump-deposition of 80 µm diameter bumps and flip-chipping
  - Good results: hybrid works and delivers signal; good mechanical stability
- How do we assure probing (IV) and sensor selection on wafer?
  - Several options possible
    1. Implement 2 passivation openings on same pad: both small opening for UBM and large opening for probing/wire-bonding -> allows to probe IV of large sensors with probe card
    2. Temporary metal to shorten all pads
    3. Biasing structures like for pixels (e.g. punch-through or poly-Si)

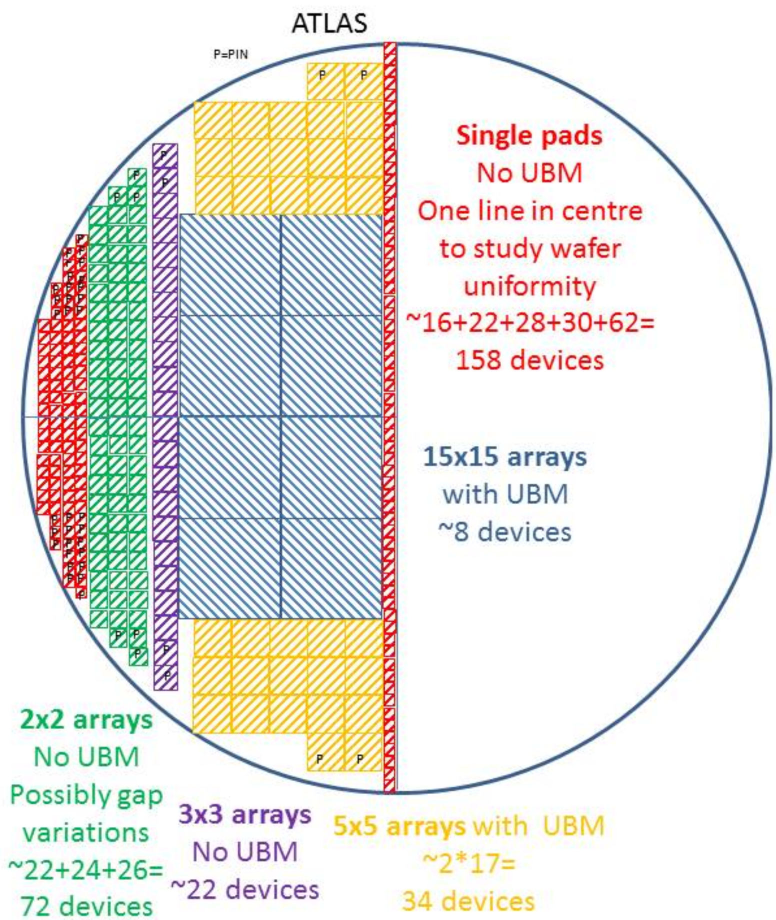




Matrix with 4 1x1 mm^2 channels







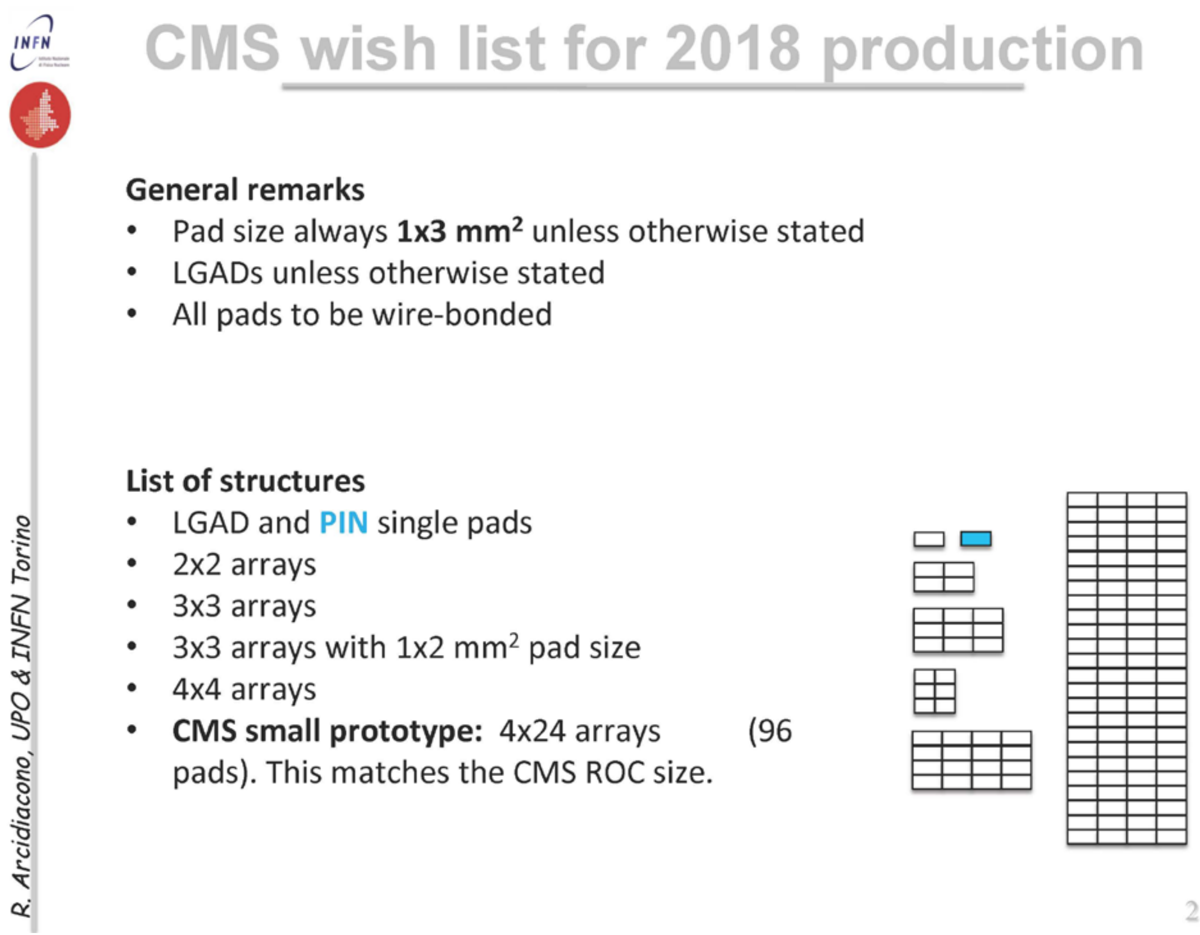
6“ LGAD wafer layout proposal (sketch)

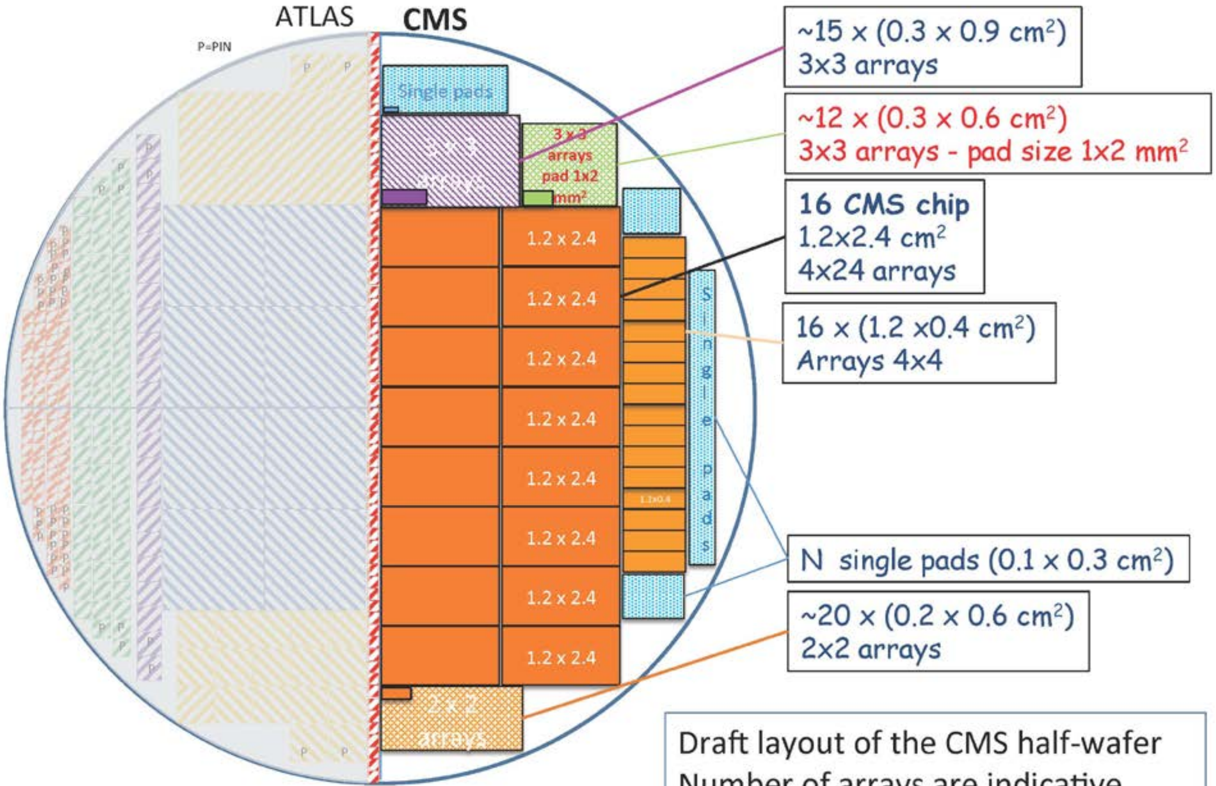
- Shared between ATLAS/CMS (half-half)
- **ATLAS pad: 1.3x1.3 mm² active area**
- Some PINs for each structure
- Here not completely closely packed/well aligned (just a sketch) and each sensor has conservative 500 µm inactive width at each edge (incl. GR, margin, cut line) -> slightly higher density possible
- Typically arrays have safe standard inter-pad gap like 50D
- 2x2 arrays can have variations
  - Gap of e.g. 30, 50, 70 µm to optimise fill factor
  - Slim edge (100, 200, 300 µm)
- Large sensors (5x5, 15x15)
  - UBM (90 µm passivation hole in centre)
  - Additional structures for probing (larger openings for needles/wire bonds, maybe biasing structure)
  - 8 15x15 single-chip sensors
    - Designed as single-chip sensors, but arranged to allow yield-evaluation and dicing as pseudo-doubles and quads for module proto-typing

A.2 CMS ETL

Basic cell (outside dimension) 1.0 x 3.0 mm^2

Single pad LGAD:		**~ 100**
Single pad PIN:		**~ 20**
Arrays	**2x2:**	**~ 20**
	2x2 PIN:	**~ 2**
	3x3:	**~ 15 per inter-pad distance**
	4x4:	**~ 16 devices,**
	4x24	**~ 16 devices,**
	3x3 (1x2 mm^2):	**~ 12**





Draft layout of the CMS half-wafer
Number of arrays are indicative
PIN: 20% of single pads
10% of 2x2 arrays