Challenges in ATLAS and CMS timing layers…

The timing layer battle…

How two reasonable groups of smart people end up taking absolutely opposite decisions….

UFSD R&D is performed within RD50, in ATLAS, CMS and other groups.
Their contribution is kindly acknowledged

Pileup and event density

Pile-up: number of concurrent scattering processes (140 – 200).

Density of events: number of events 1 mm (0.2 – 2 event/mm)

Why are they different?

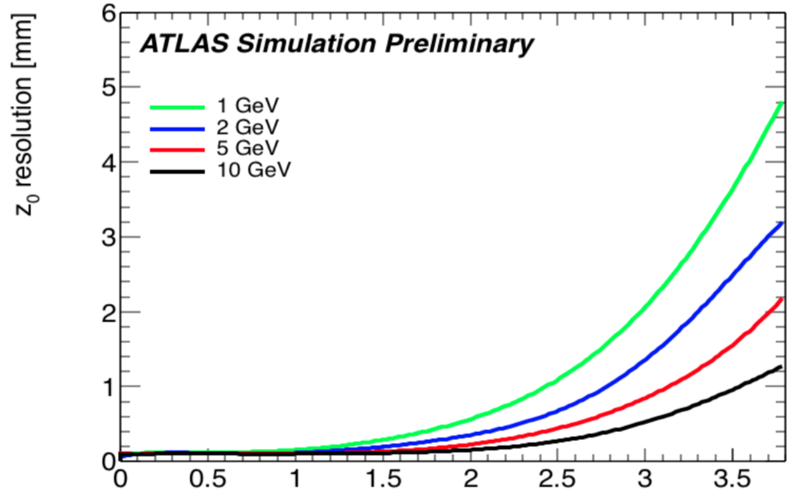
Pile-up is a global quantity, and it can be fought with very granularity.
It influences, for example, the total amount of tracks and neutral clusters

Density of events: it can be fought with longitudinal resolution and timing.

The metric of the problem

The problem arises when the tracking detector resolution along the z-axis is longer than the distance between vertices.

Track-to-vertex association is ambiguous when the tracking z-resolution is larger than the separation between vertices

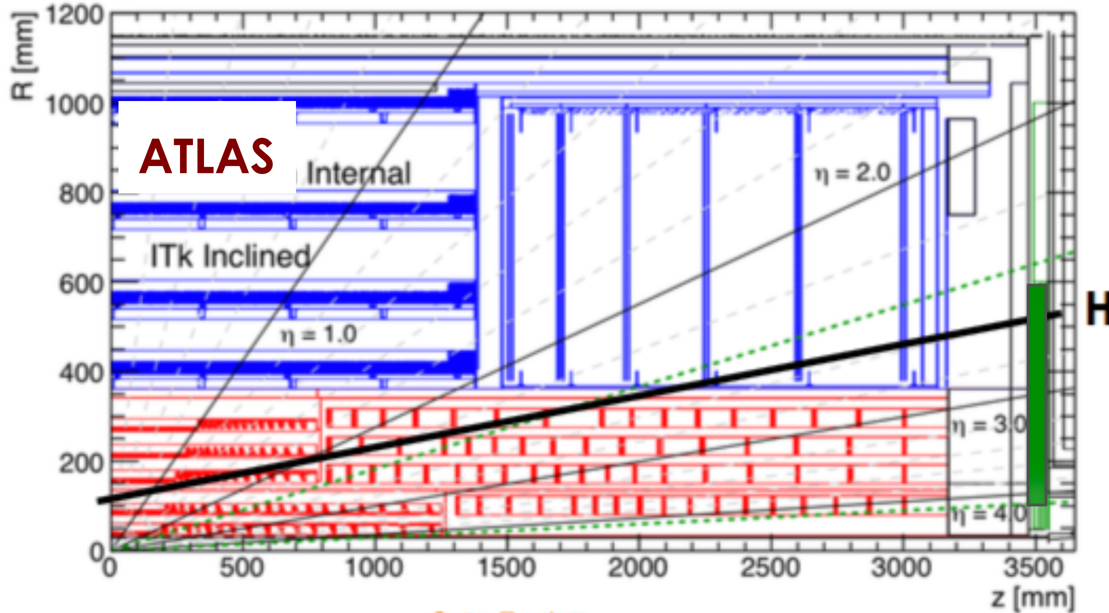


Z0 resolution of ITk as a function of η: for |η|>2.5 resolution increasing above the average vertex density (1.6vertex/mm).

The proposed solutions

ATLAS instruments the forward region,

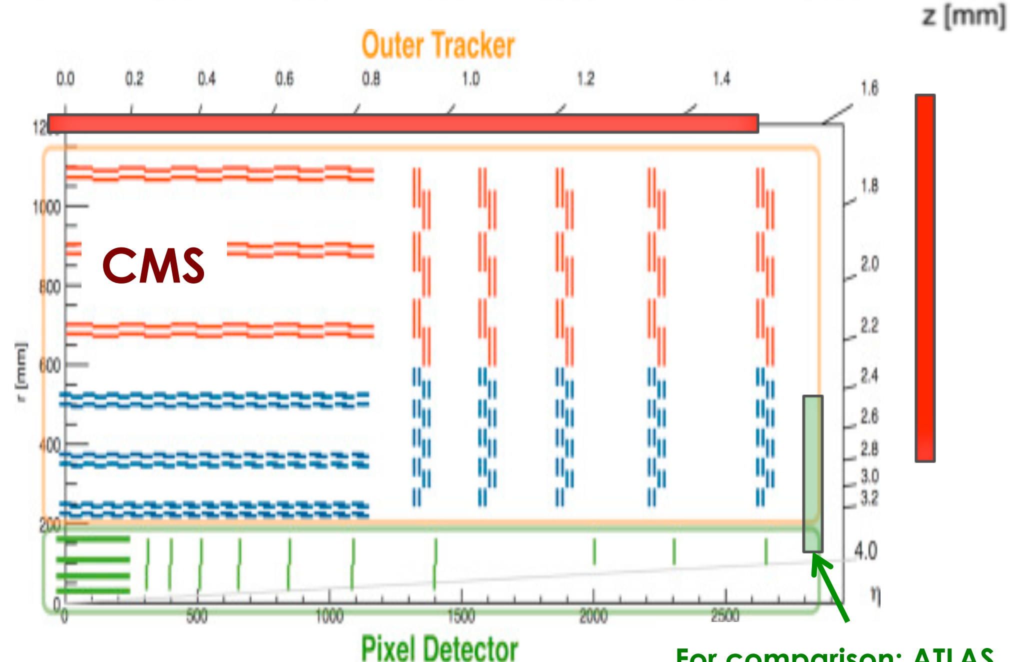
coverage: 2.4 < eta < 4



CMS instruments the central part:

coverage: 0 < eta < 3

(MTD: Mip Timing Detector)



You are allowed to be confused

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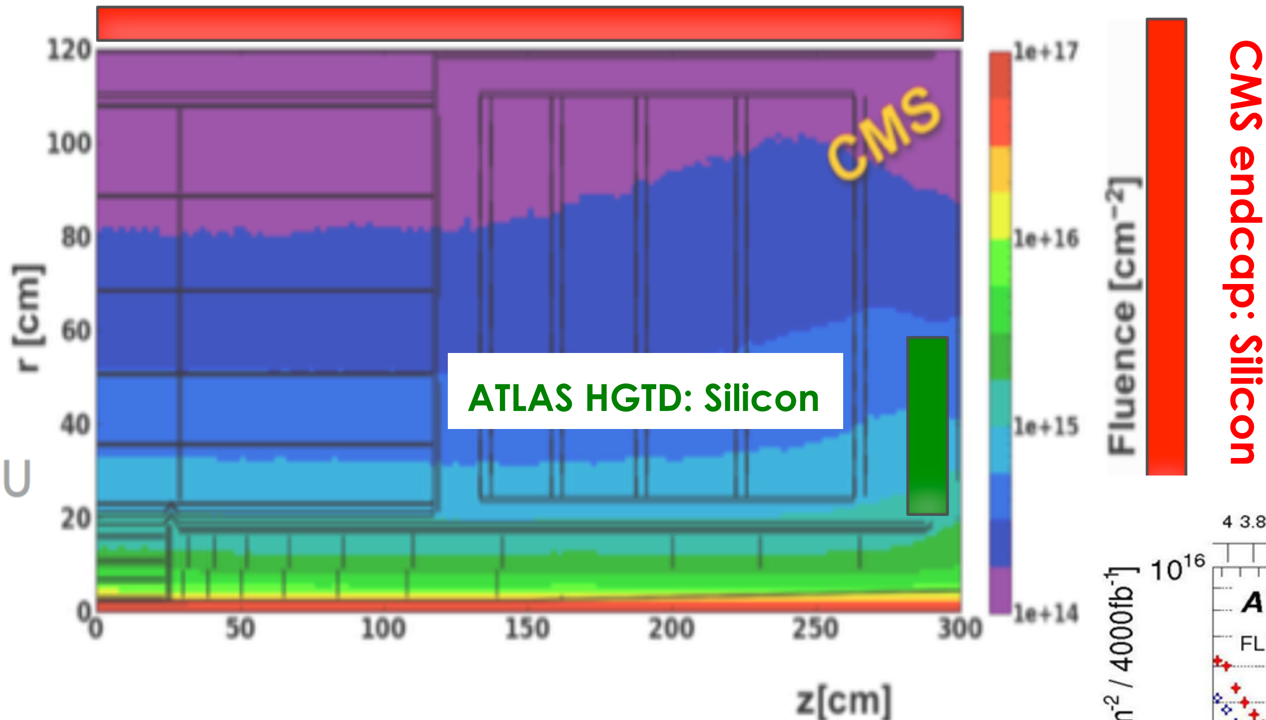
Technologies and Radiation levels

CMS barrel: SiPM+Scintillator tiles

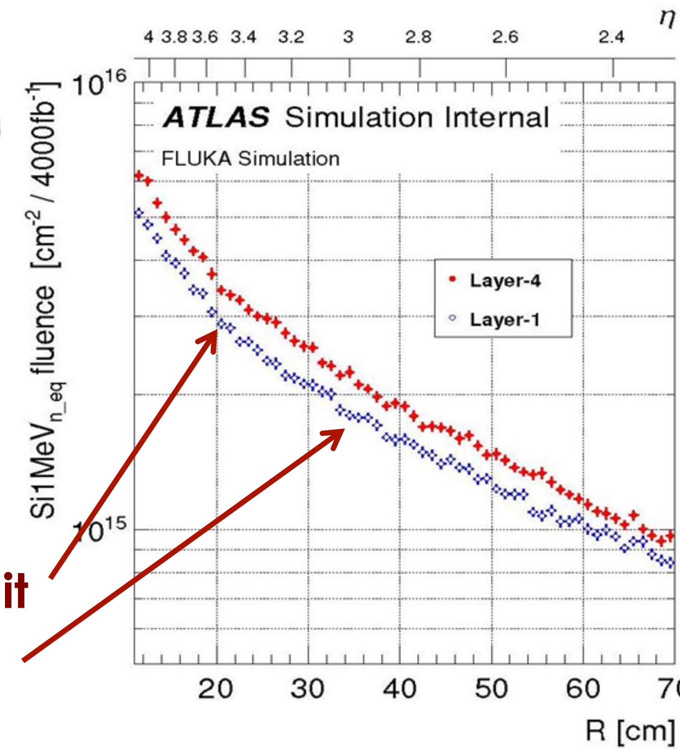


Limits (with x2 safety margin):

ATLAS: ~ 4.5e15 n/cm2

CMS~ 3e15 n/cm2

➔ Almost the same number…



ATLAS limit

CMS limit

The referee: LHCC

LHCC is asking "why are you guys doing things differently?"

The answer is remarkably difficult, we don't quite know it yet, however it will bring benefits to both collaborations..

Why is it difficult? Requires a full simulation of the detectors and of the physics processes, then you need to re-optimize the analysis.

Obviously the dynamic of the physics process under study determines if the endcap or the barrel provides the most useful coverage.

Grand summary of present status

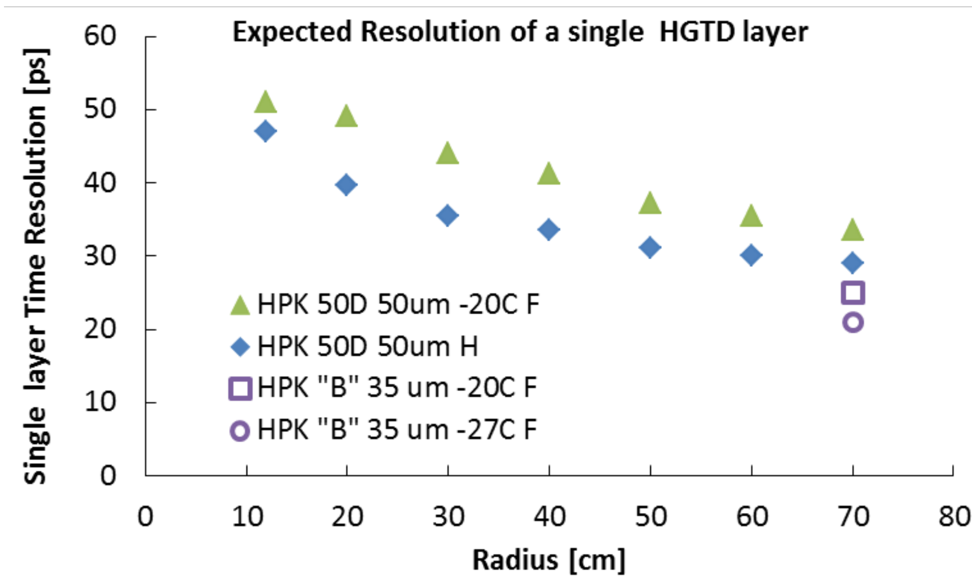
We have 3 foundries (CNM, FBK, HPK) able to deliver single pad UFSD , with good performances.

UFSD age gracefully with irradiation, however their time resolution decreases, and the bias need to be increased:

➔ **30 - 40 ps @ Vbias ~ 700** after **Φ = 1*10^{15} n/cm^2**

➔ **40 - 50 ps @ Vbias ~ 750** after **Φ = 3*10^{15} n/cm^2**

New results on irradiation might change the situation, in the following I will assume they won't.



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State of the art of UFSD capabilities

Laboratory measurements and beam test

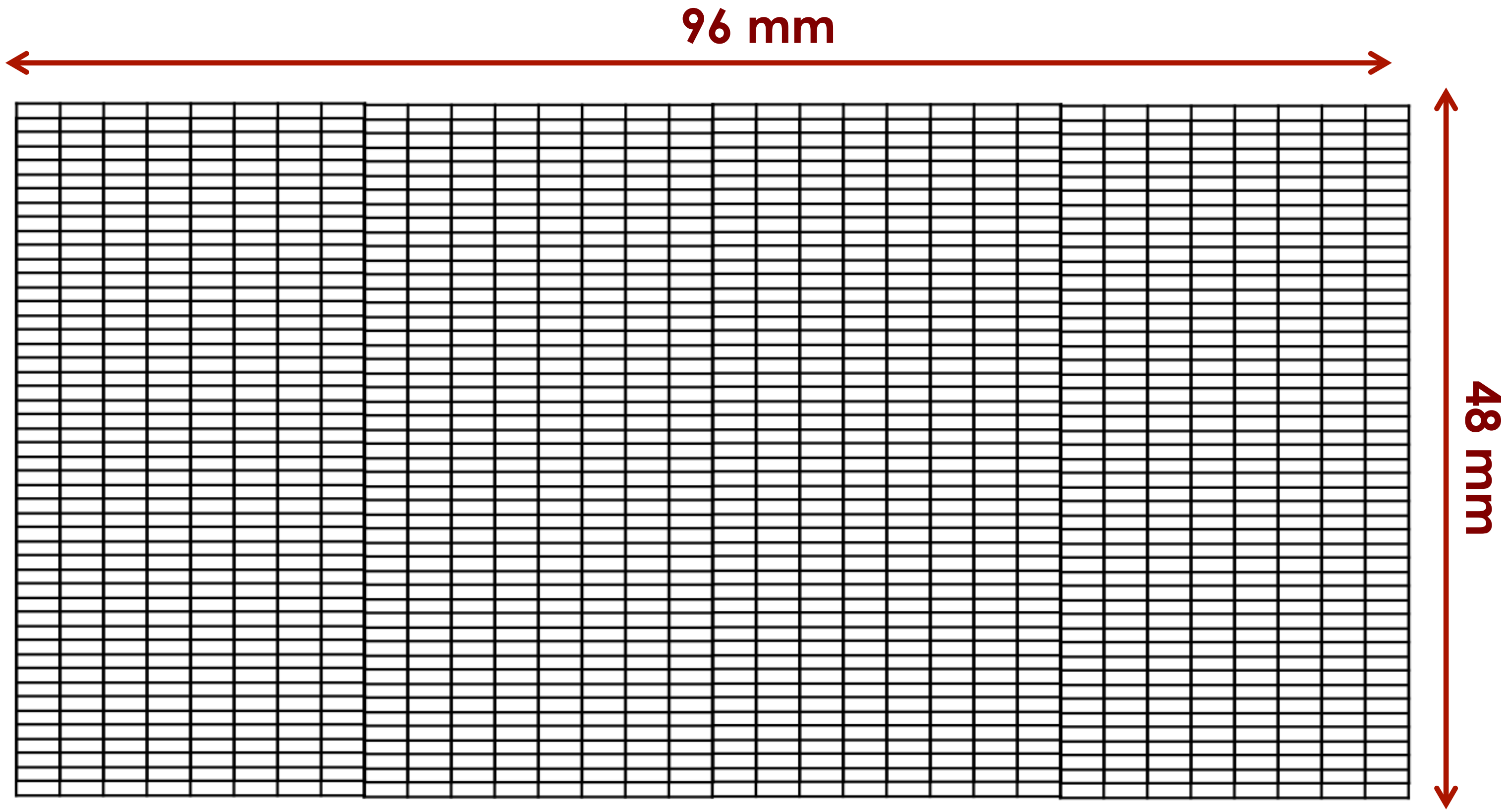
- **Uniformity of the signal amplitude, efficiency, time resolution, rise time, time offset** as a function of position on sensor
- **Inter-pixel gap** characterization
- **Multi-pixel**, **large area** sensors
- Compare various **doping profiles and processes** (CNM, HPK)
- Optimization of the **sensor thickness** and impact on time resolution and fill factor.
- Dependence of time resolution on **temperature**
- Time resolution of **irradiated sensors**

CMS Sensors

Final Goal:

- CMS needs to produce 2624 sensors; each sensor is 48 x 96 mm^2, it has 1536 pads,
- Each pad is 1x3 mm^2

2624 X

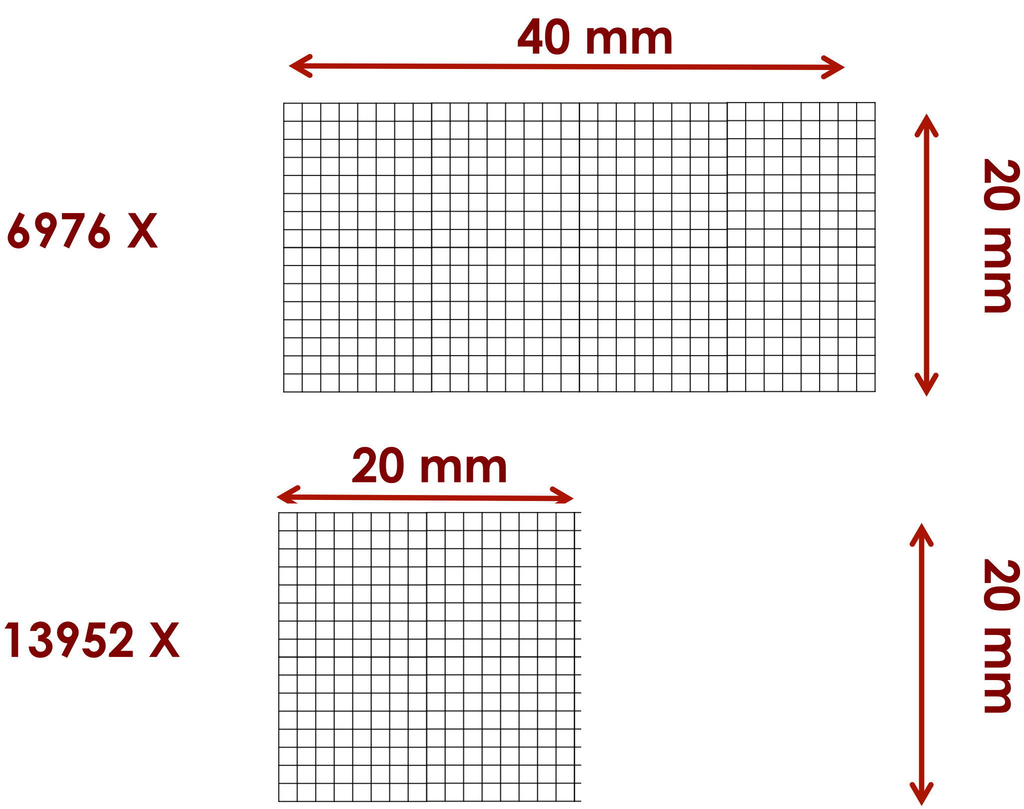


plus spares..

ATLAS Sensors

Final Goal:

- ATLAS needs to produce, assuming 2 layers, 13952 sensors 2x2 cm^2 (240 pads) or 6.976 sensors 2x4 cm^2 (480 pads)
- each pad is 1.3 x1. 3 mm^2



plus spares..

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Path to construction

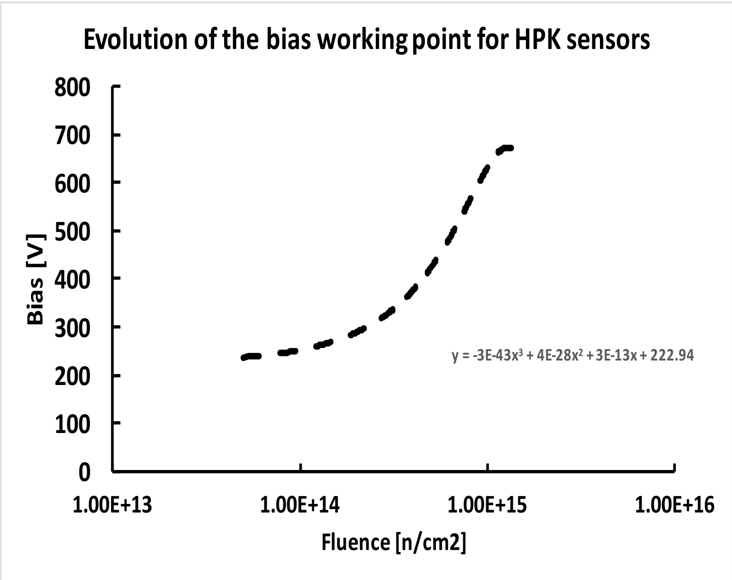
Key topics to be addressed:

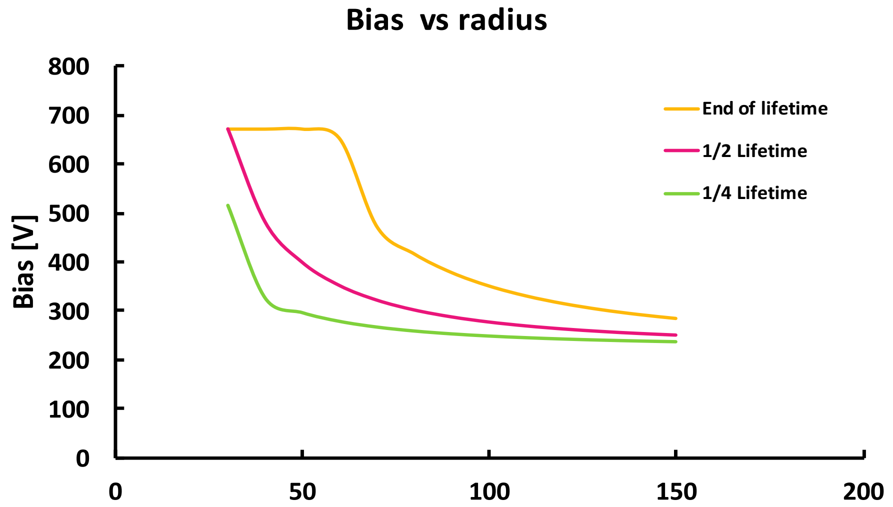
1. **Radiation hardness**: time resolution and operating conditions
2. **Highest possible fill factor:** dead area between pads and sensor dimensions
3. **Multi pad sensors:** pad isolation, breakdown voltage
4. **~ 30 ps time resolution at the end of lifetime**

Radiation hardness: operating conditions

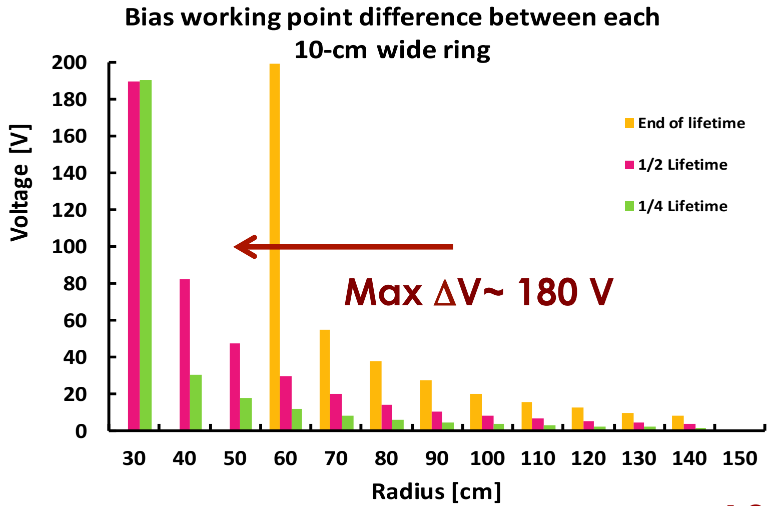
To keep the gain ~ constant (to keep the time resolution high) ⟶ increase Vbias

Operating conditions need to be adjusted as a function of fluence





➔ the ideal biasing point differs by ~ 180V at the two side of a 10-cm long detector.



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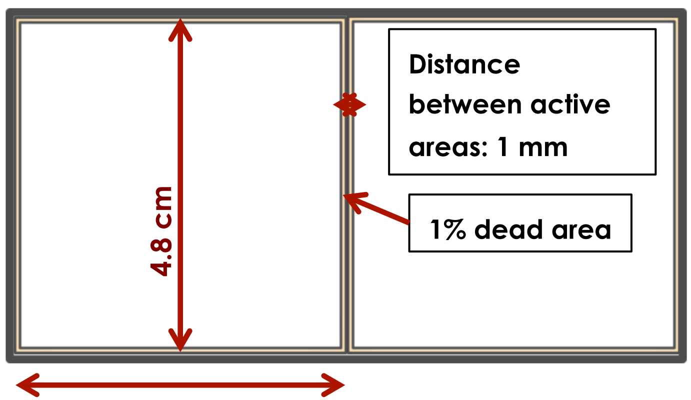
Sensor dimension and operating conditions

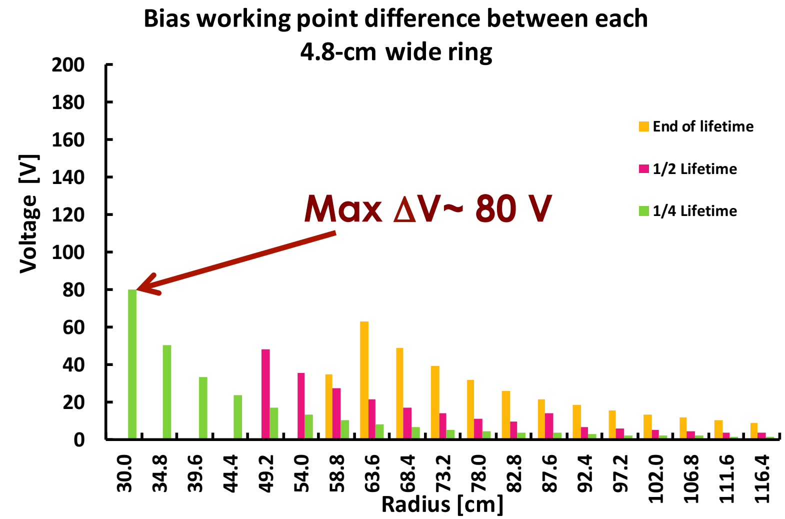
If mitigation of radiation damage not successful:

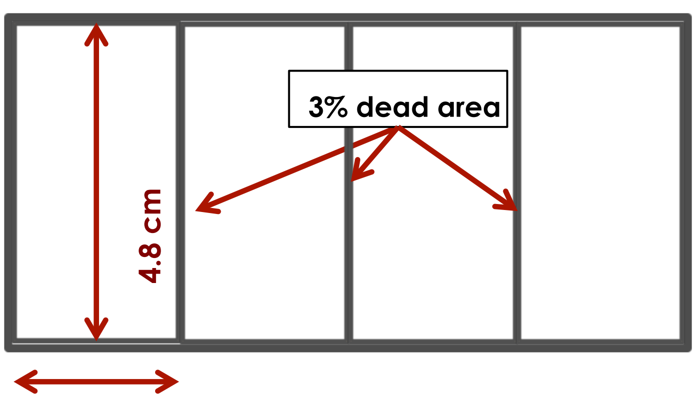
1)turn the sensor by 90 degrees or 2)split it into 2 parts or 4 parts.

Price: more complex installation, smaller fill factor (each separation is ~ 1%)

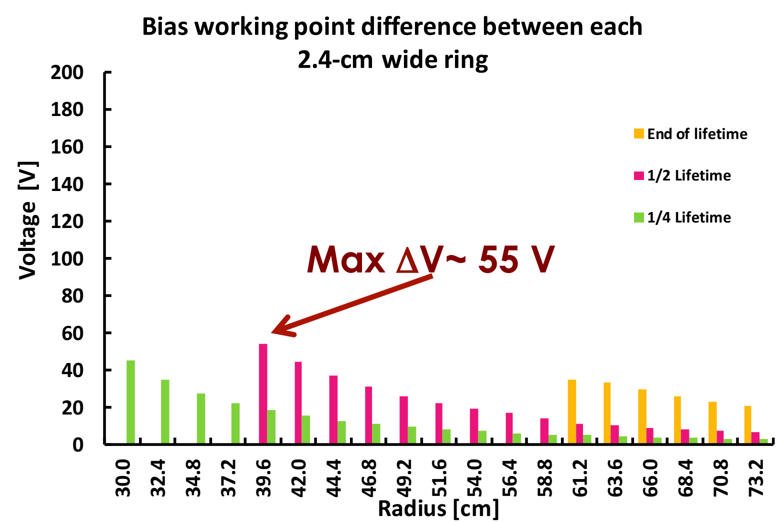


4.8 cm, difference in operating point: ΔV = 80V





2.4 cm, difference in operating point: ΔV = 55 V



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Highest possible fill factor

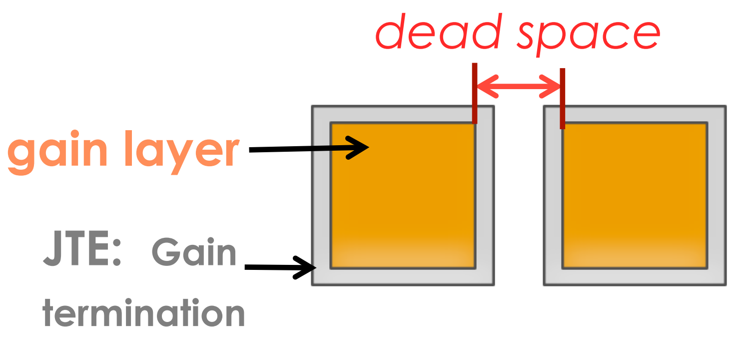
The fill factor is mainly determined by the inactive gap between sensors.

Current measured gap size:

~ 70 micron for CNM

~ 100 micron for HPK

~ 70 micron for FBK



This gap affects directly the detector acceptance as we have only one layer: a 70 micron gap corresponds to a 91% fill factor

Goal: 30 micron gap = 96% fill factor

Currently under study, looks possible…

Reduction of gap between pads

The gap is due to **two components**:

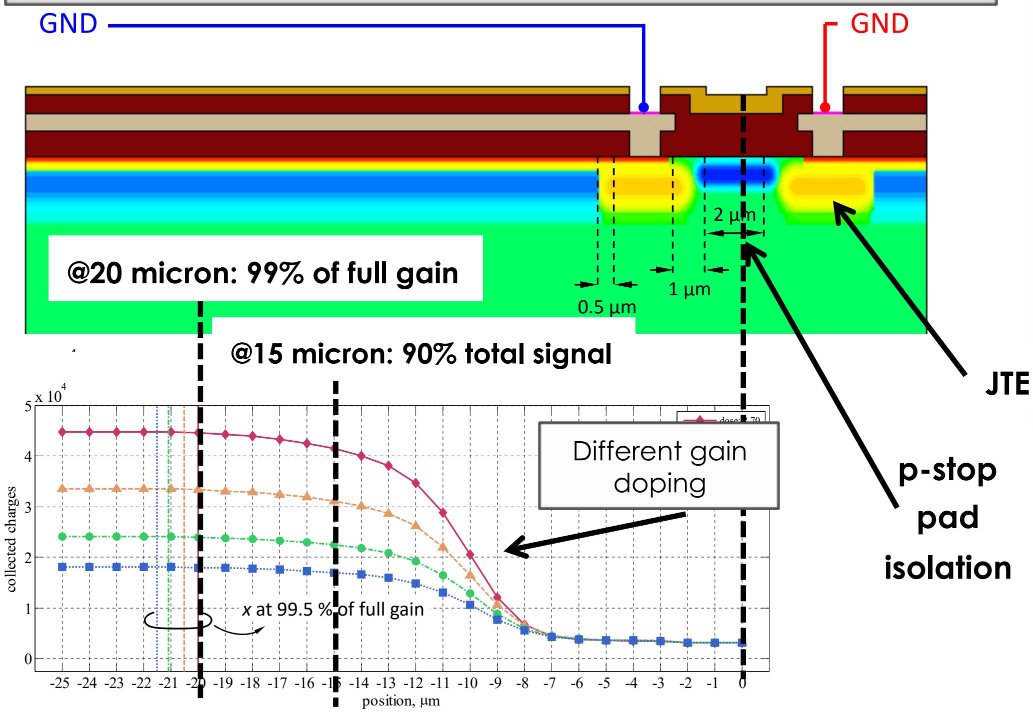
1) Adjacent gain layers need to be isolated (**JTE & p-stop**)

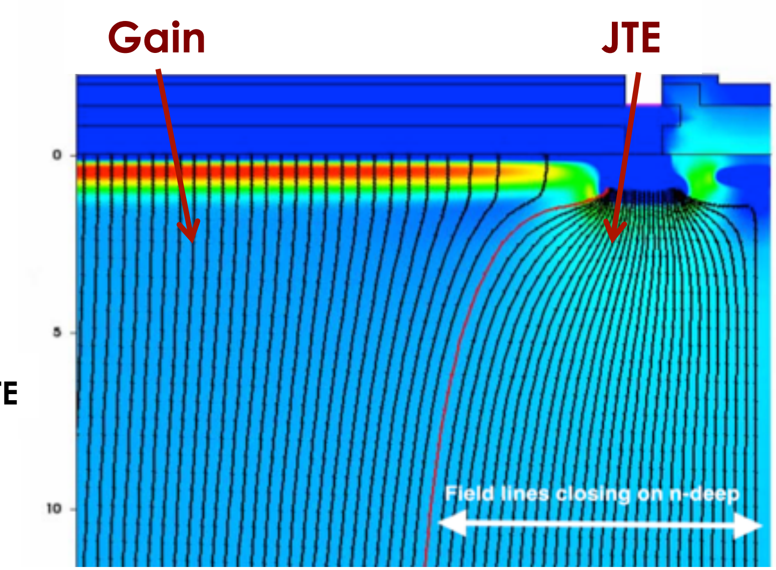
2) Bending of the E field lines in the region around the JTE area

Both under optimization   Different junction termination/p-stop design

➢ **Goal: 30 micron gap = 96% fill factor**

Current estimate: 15 – 20 micron per side





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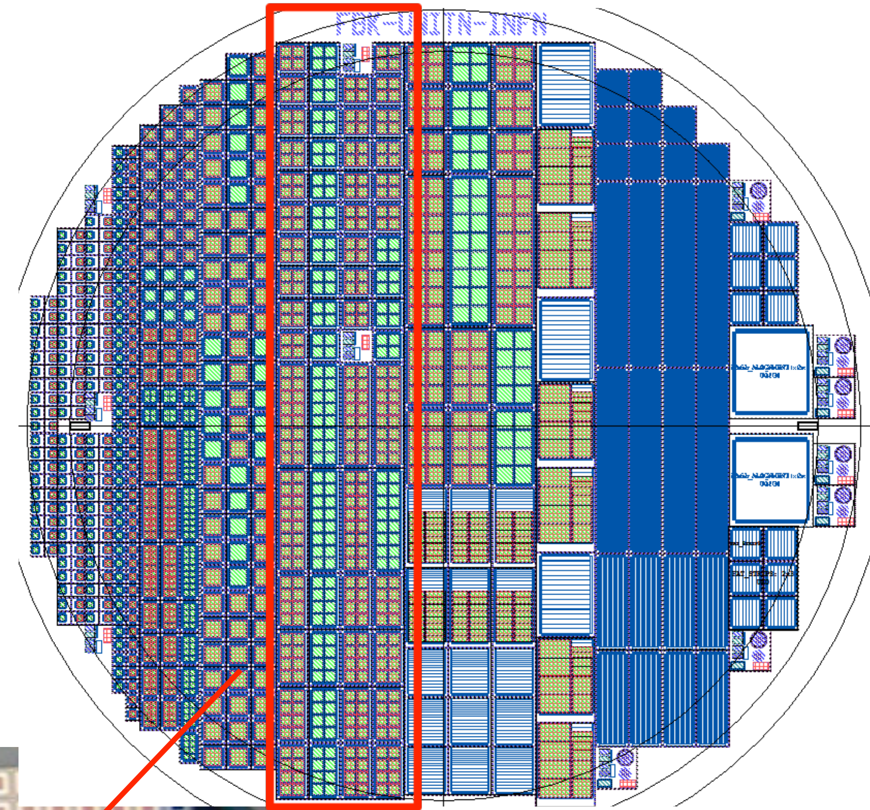
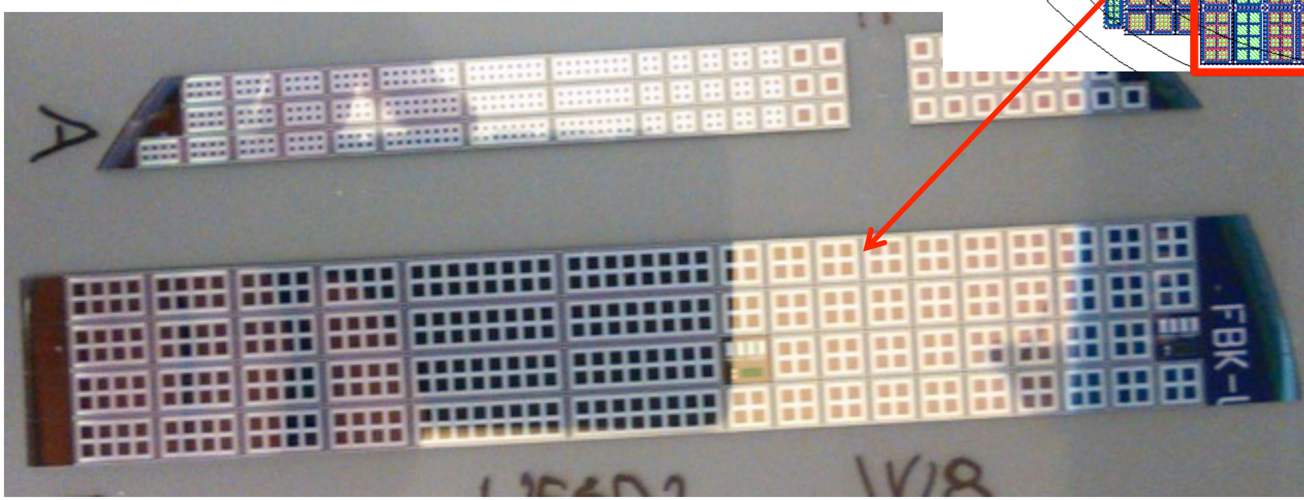
Multi-pad sensors

FBK-UFSD2 production has many pad arrays.

Preliminary studies indicate very good isolation between pads.

Pads/arrays will be distributed shortly to CMS institutions for extensive testing





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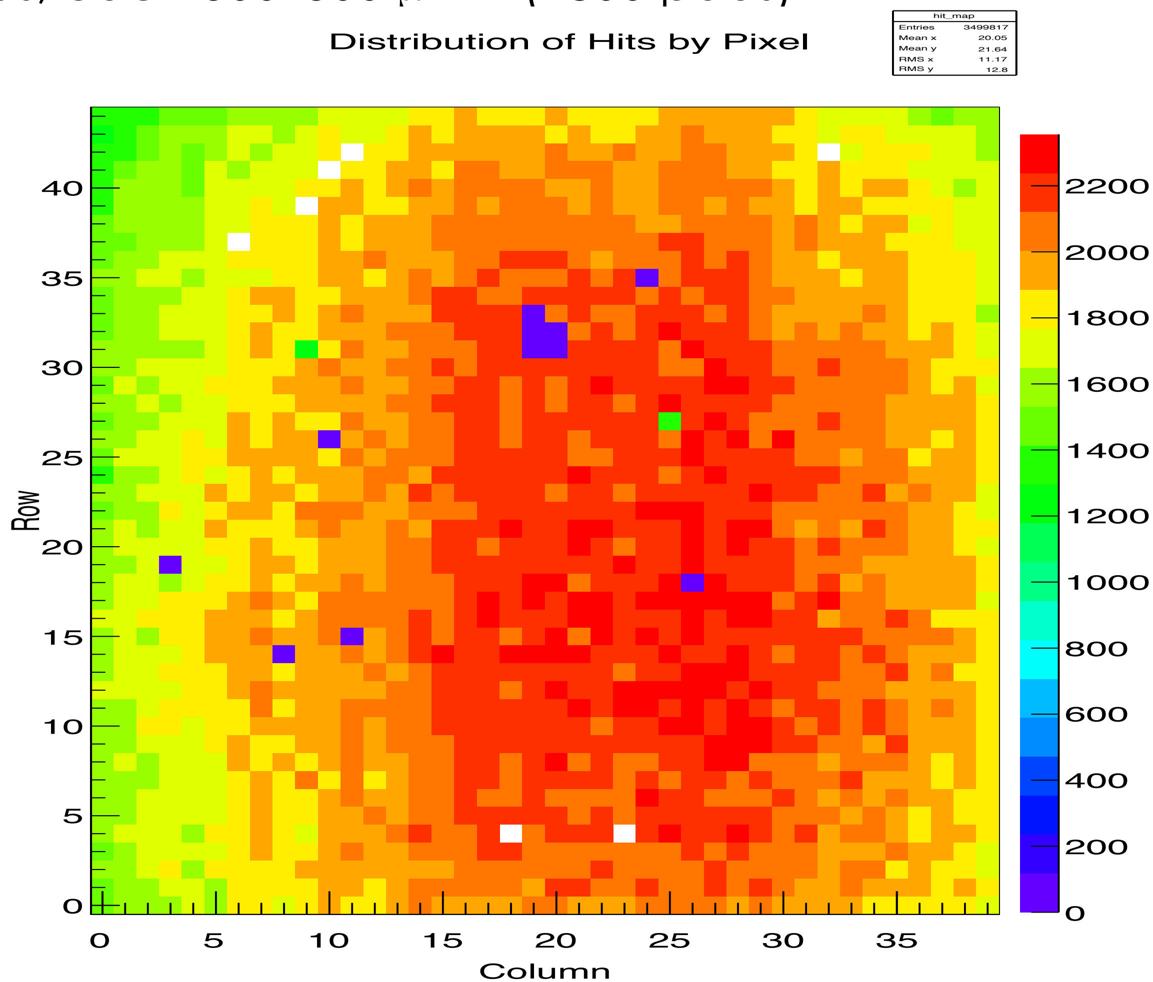
Multi-pad sensors: TDCpix & UFSD

Bump-bonded NA62 TDCpix ROC to UFSD sensor (6 assemblies)

NA62 geometry: 40x45 pads, each 300x300 μm^2 (1800 pads)

- Very recent beam test @ SPS-H8
- More than 99% of pads working
- Same voltage behavior as single pad: breakdown above 280 V
- More pads than in a full TE sensor

➢ **Very good news!**



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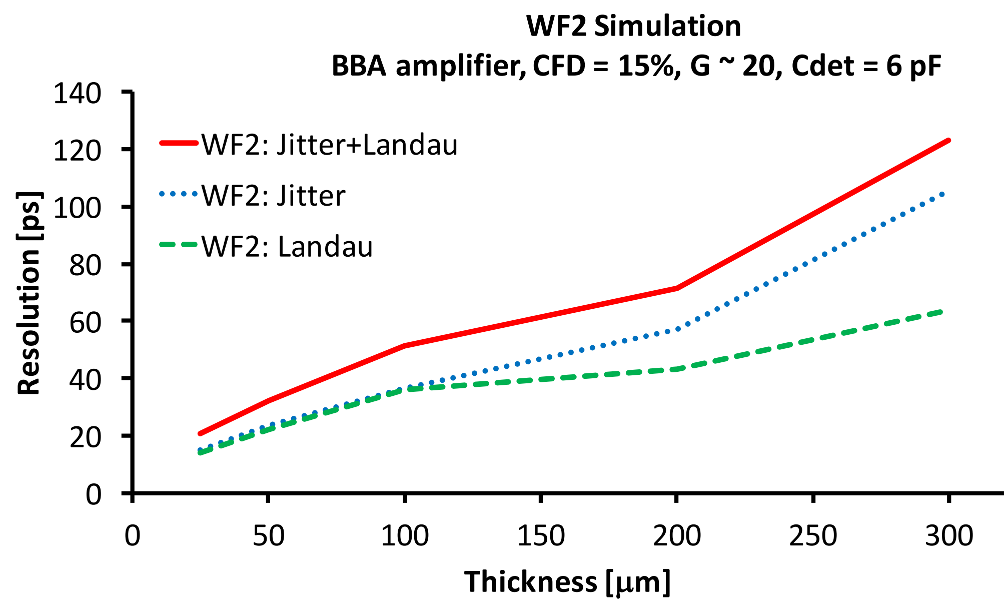
~ 30 ps time resolution at end of lifetime

In the present design we reach 40-50 ps at the end of lifetime.

According to simulation, time resolution improves in thinner sensors.



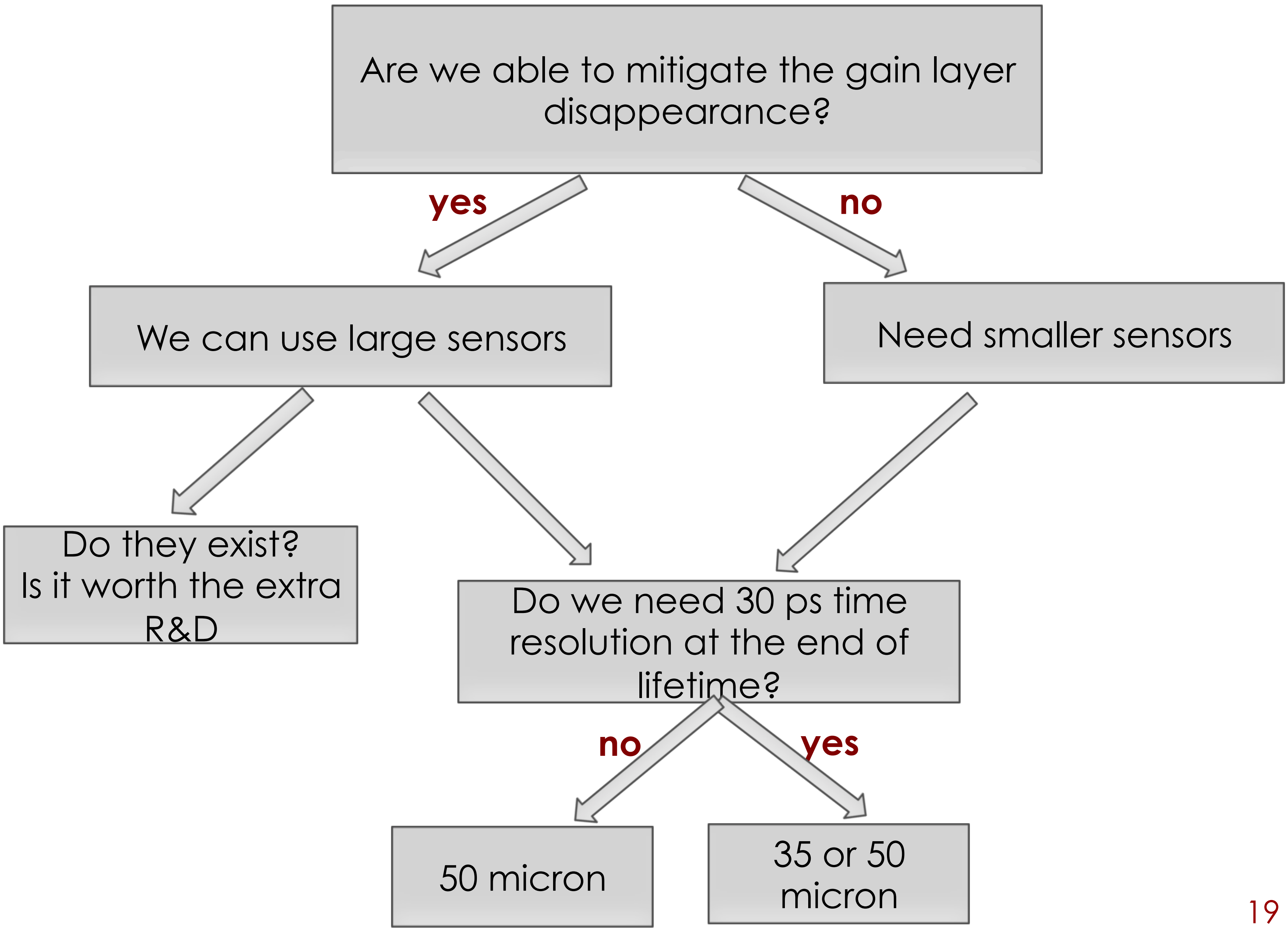
HPK manufactured 35-micron thick UFSD with excellent time resolution

- new, σ = 25 ps, bias = 120 V (50-micron: σ ~ 25 ps, bias ~ 280 V)
- after Φ = 10^{15} n/cm^2 , σ = 25 ps, bias = 450 V (50-micron: σ ~ 35 ps, bias ~ 700 V)

- ➢ **Shall we explore this option?**
- ➢ **Can we afford higher capacitance?**

  CMS: 6pF ➔ 8.6 pF, ATLAS: 3.5 ➔ 4.8 pF

Key steps



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Steps forward

Next production, 2018 (FBK, CNM, HPK):

- Smaller gap between pads:
  - ➔ several ideas to decrease it to ~ 30 micron
- Multi pad sensors with CMS - ATLAS geometry
  - ➔ Sensors with large number of pads already exist, good starting point
  - ➔ Make prototypes matching existing sensors
- Study of yield and uniformity on large areas.
- Assess the need for better time resolution ➔ thinner sensors

Next-to-next production, 2019 (FBK, CNM, HPK):

- ~ ½ dimension final sensor, with full design specifications