Working points of UFSD at HL-LHC

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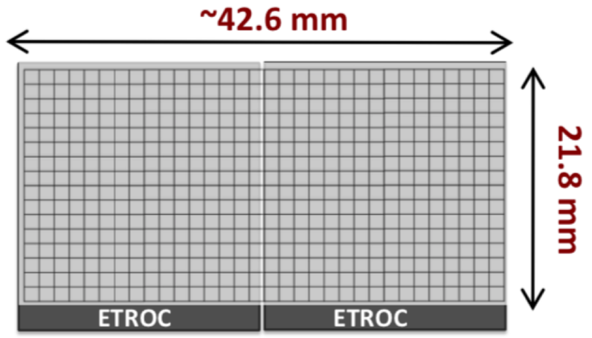
35rd RD50 Workshop, CERN, Geneva, 19th November 2019

Working points of UFSD at HL-LHC

(talk focused on CMS, easier than ATLAS)

CMS has approved the construction of 15 m² of LGAD

- Each sensor is made of 16x32 pads
- Each pad is 1.3 x 1.3 mm² (same as ATLAS)
- The CMS timing layer has two disks



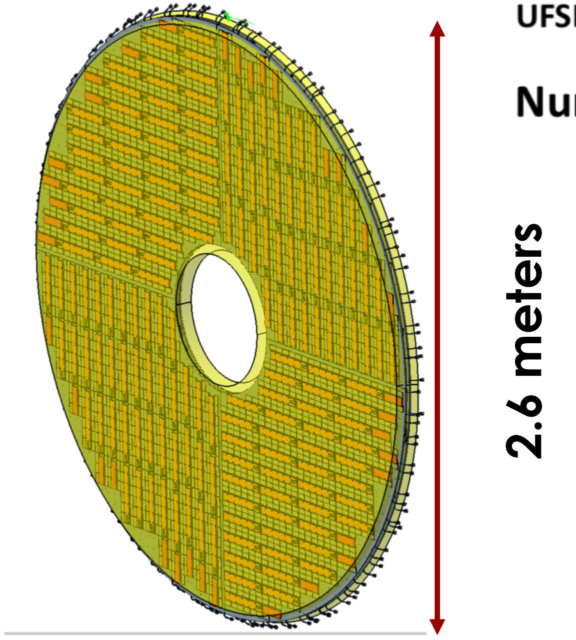
matrix of 32x16 pads

pad size: 1.3 x 1.3 mm² (C=3.4 pF)

UFSD 50 microns thick

Number of sensors: ~18500

X2 per side



The time resolution per hit is assumed to be 45 ps:

1. **30 ps due to the sensor intrinsic time resolution**
2. **30 ps due to the read-out,**

   ➔ Assuming minimum charge: 8 fC (gain ~ 15)

   ➔ Lower resolution at lower input charge

What are the working points for these two criteria to be met?

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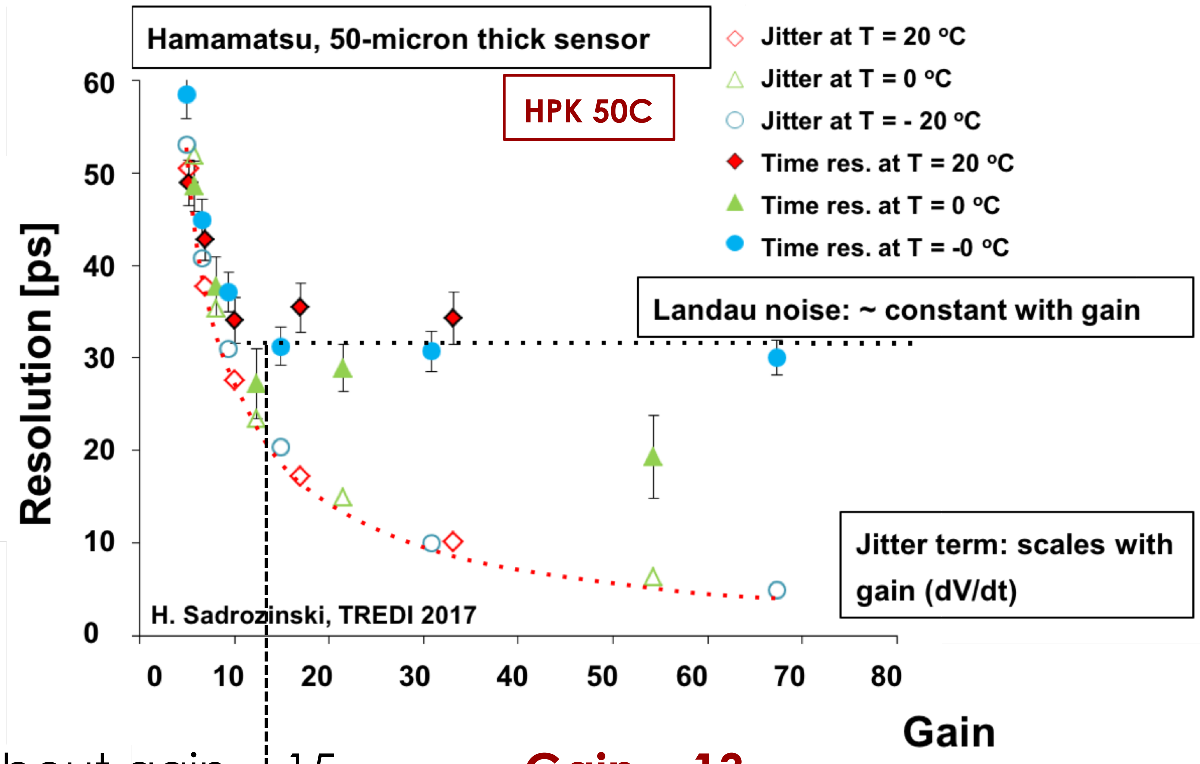
Jitter and intrinsic resolution

$$\sigma_{jitter}^2 = \left(\frac{Noise}{dV/dt}\right)^2$$

We often show this plot to explain the performance of UFSD.



The jitter term becomes sub-leading at about gain ~ 15, hence the paradigm often quoted:

Gain ~ 13

Voltage: 350V

Gain ~ 10-15, resolution 30 ps

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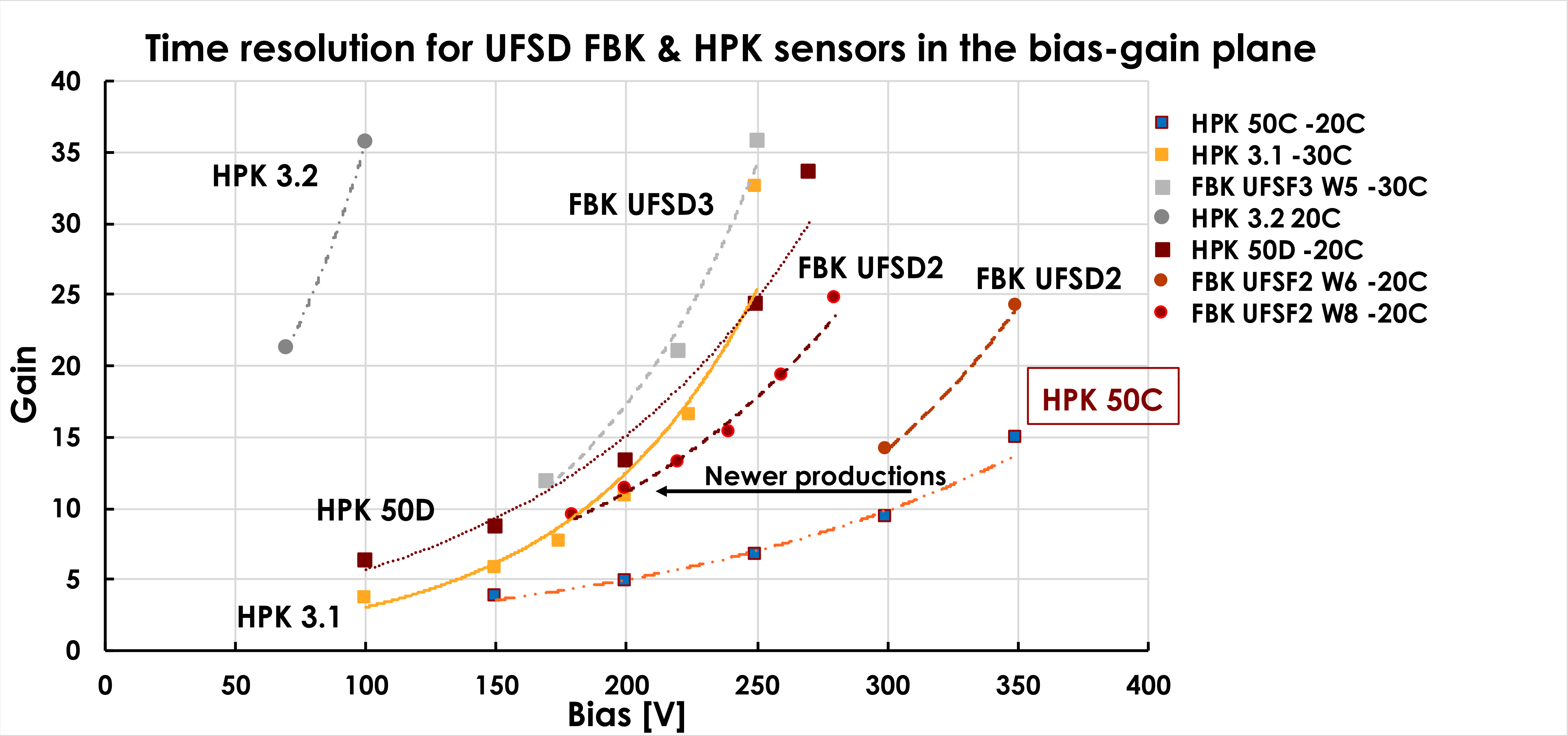
Gain vs bias for HPK and FBK productions



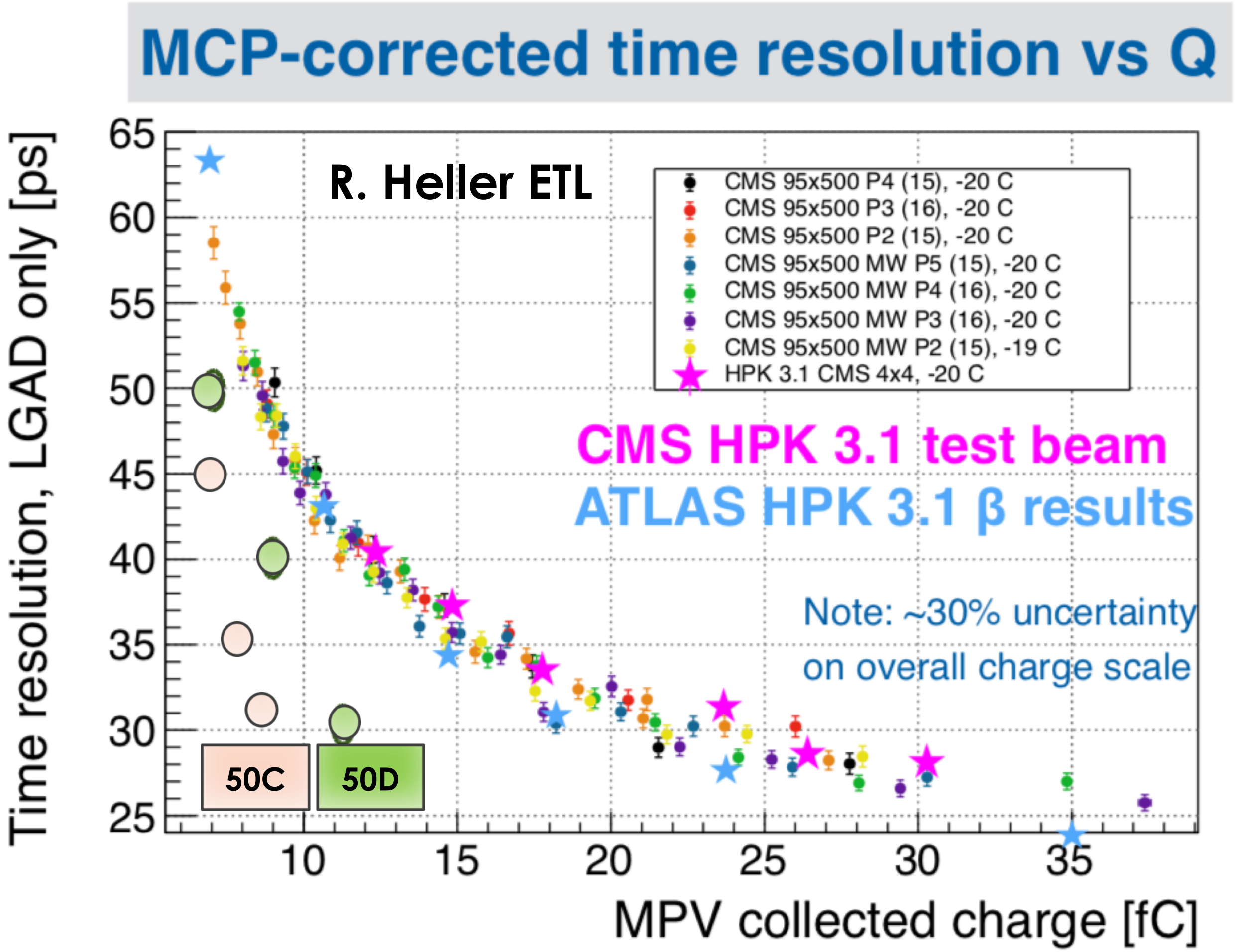
To enhance radiation hardness, the latest UFSD productions reach gain 10-15 at a much lower bias: ~ 200V instead of ~350V

Time resolution of the HPK production

Unintended consequence:
in sensors with highly doped gain layers, the gain needed to reach a time resolution of 30 ps increases:

50C: gain ~ 15
50D: gain ~ 20
HPK 3.1: gain ~ 30

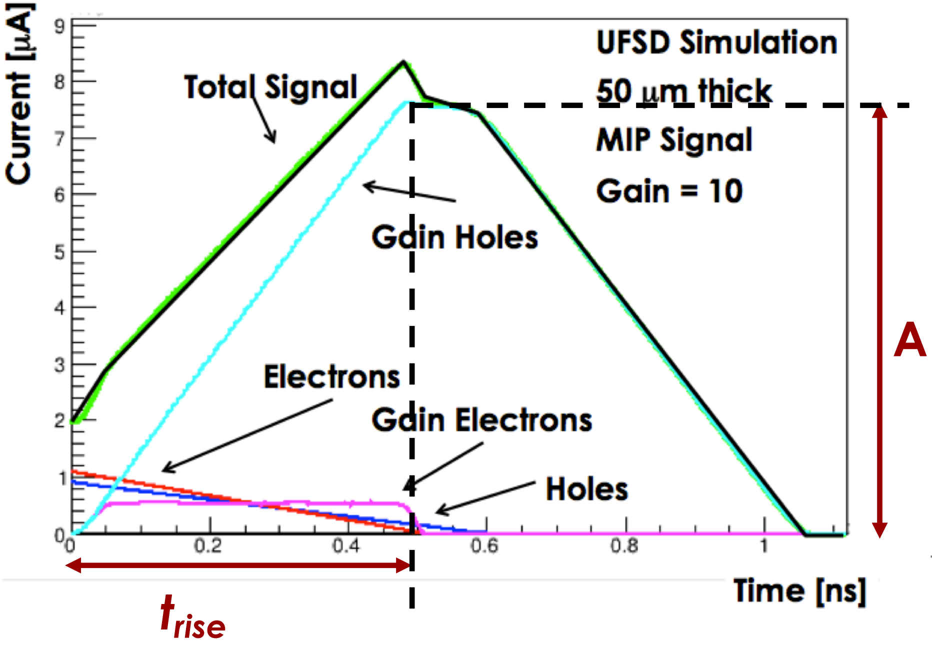
This fact depends on the hole drift velocity



The initial statement **"Gain ~ 10-15, resolution 30 ps"** is not applicable any longer

The shape of the signal is very important, a simple value of "gain = 15" is an incomplete request

Consider the holes' drift velocity



The amplitude depends on:

- Holes' drift velocity (Bias)
- Gain

The combination of gain and bias determines *dV*

$$\sigma^2_{jitter} = \left(\frac{Noise}{dV/dt}\right)^2 \sim \left(\frac{Noise}{A/t_{rise}}\right)^2$$

The rise time depends on the electrons' drift velocity

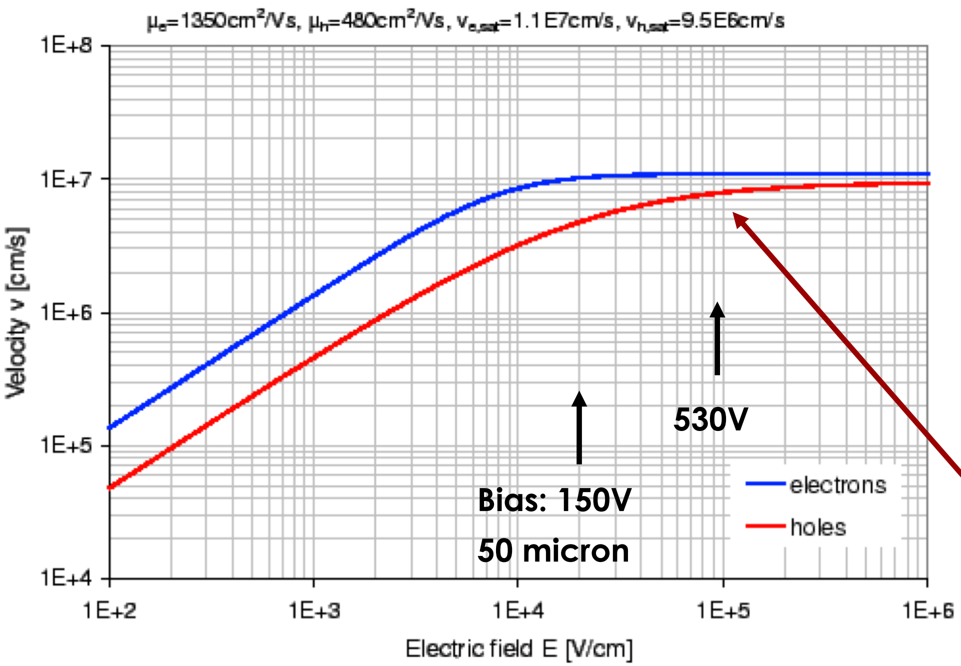


Figure: Electron and hole velocities vs. the electric field strength in silicon.

$$i \propto q v E_w$$

V_{holes} never saturates, so higher the voltage, better dV/dt is

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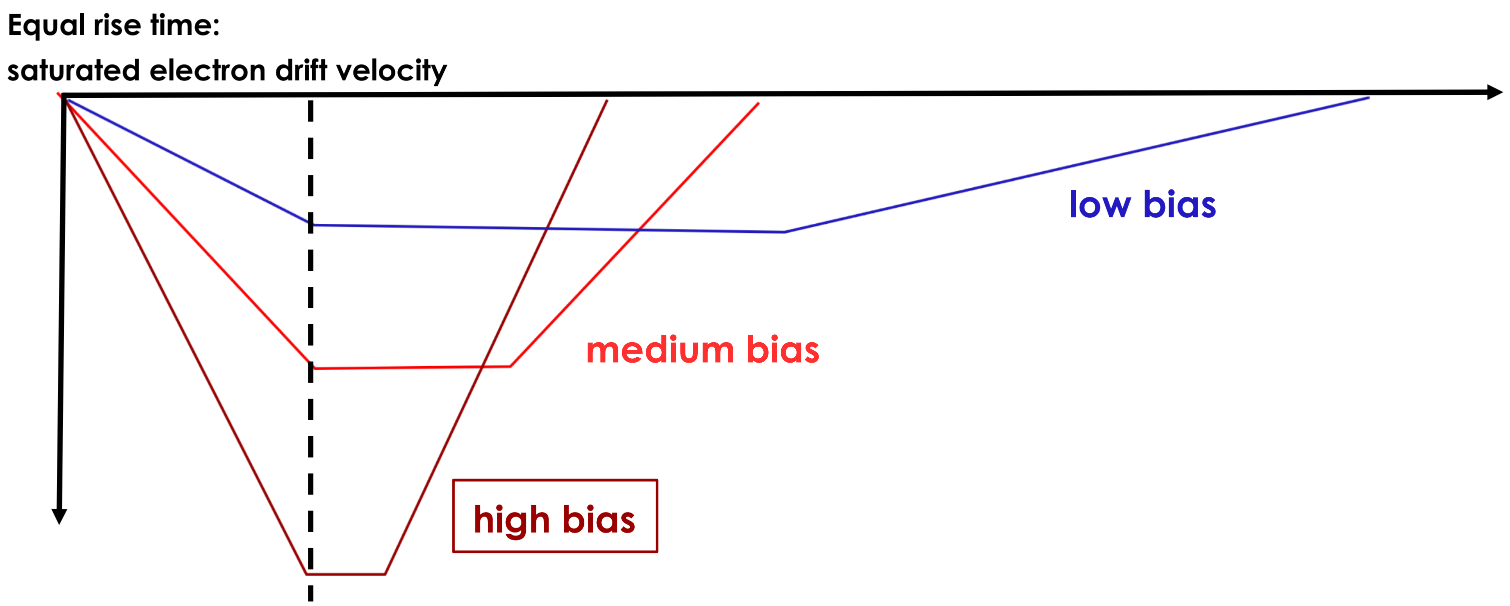
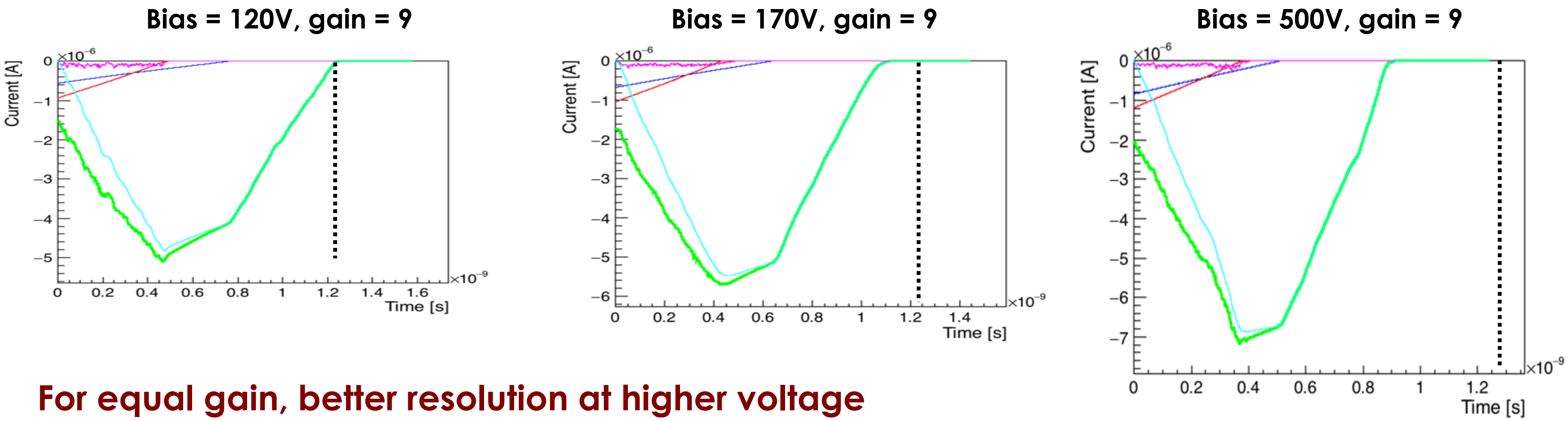
Signal shape for equal gain at different biases



The electrons' drift velocity saturates at about ~ 150V.
The holes' drift velocity never saturates. For equal gain:
Higher bias ➔ higher dV/dt



For equal gain, better resolution at higher voltage

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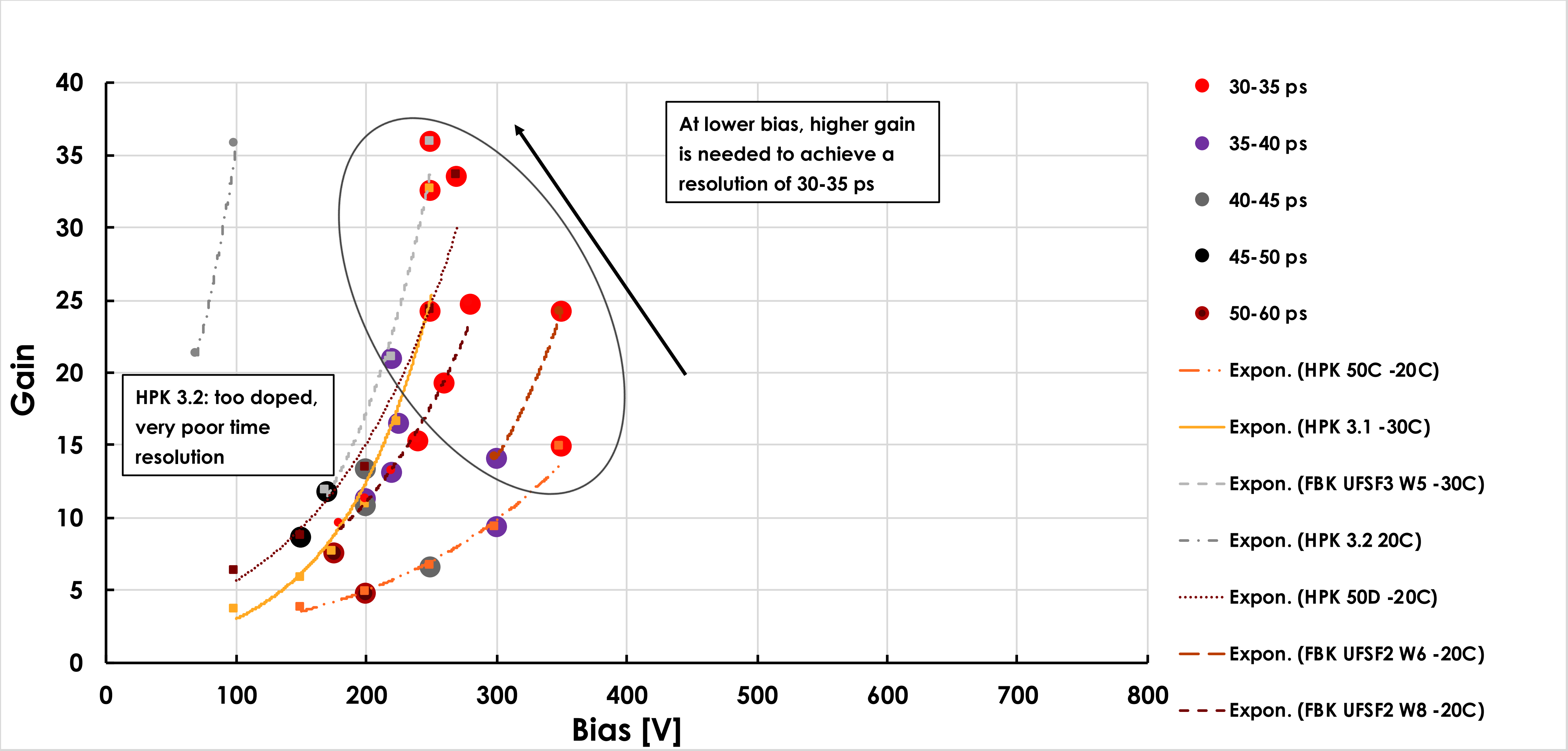
Time resolution for new UFSD FBK & HPK sensors in the bias-gain plane



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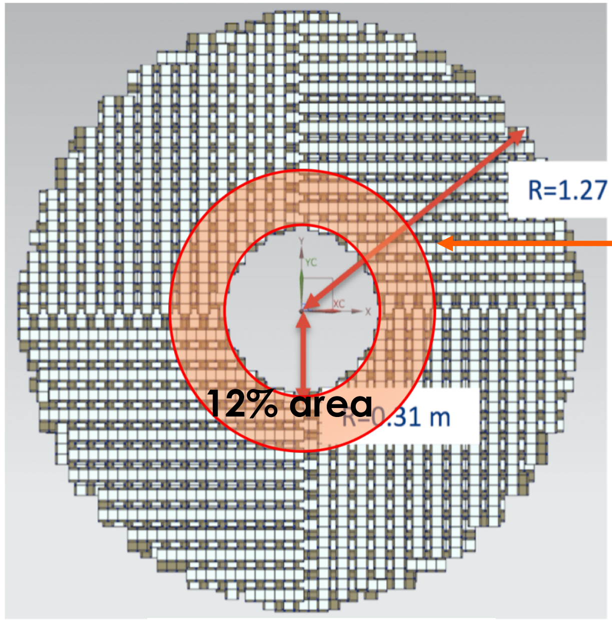
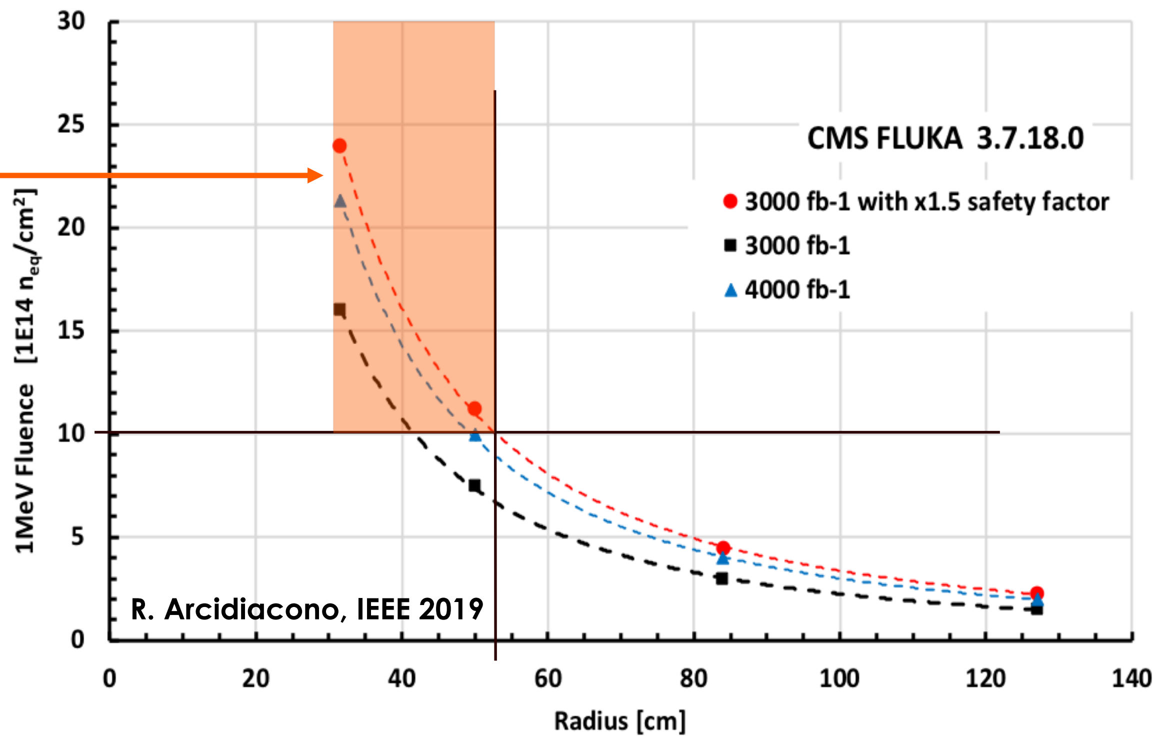
Irradiation levels of CMS-ETL @ HL-LHC



1.6 < |η| < 3.0



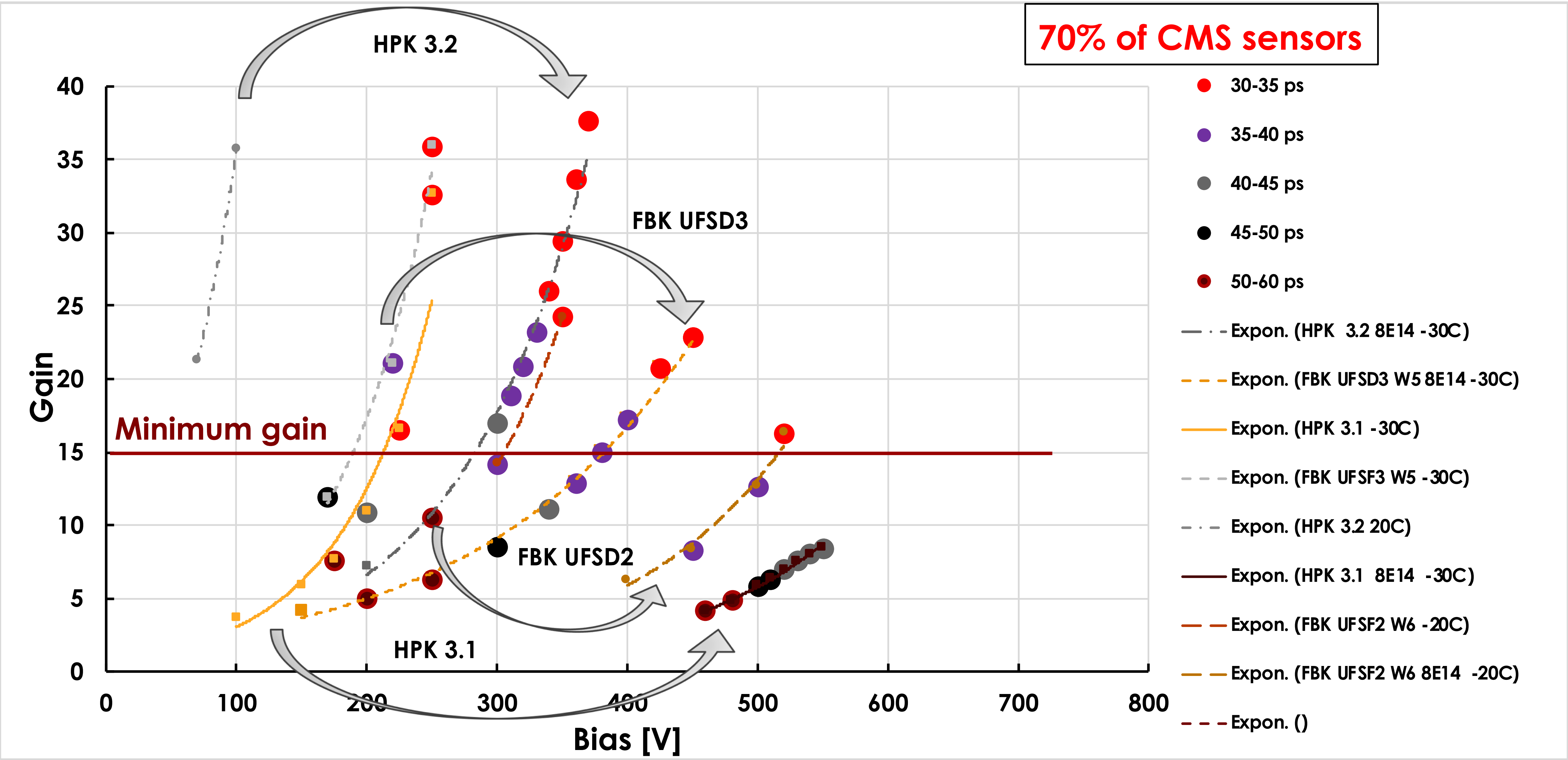
End of lifetime irradiation level (for $\mathcal{L}$ = 3000 fb^{-1} x1.5 SF):

70% of ETL < 8E14 n/cm^2

88% of ETL < 1E15 n/cm^2

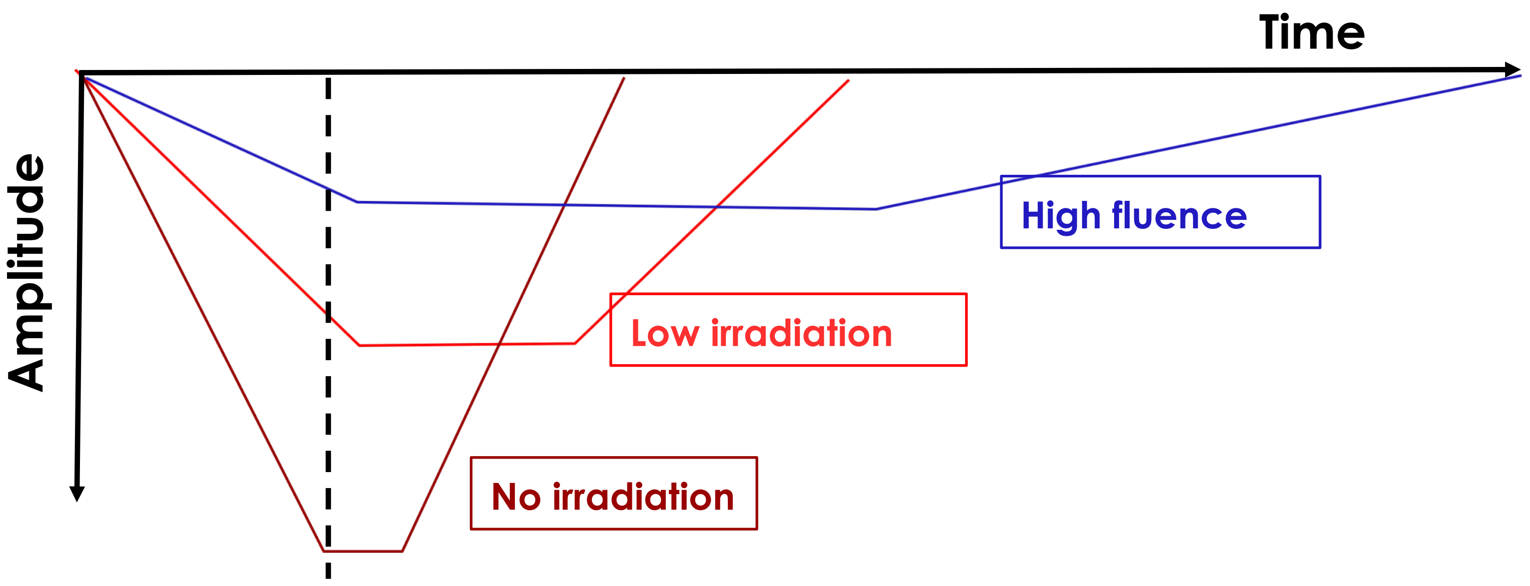
CMS radiation problem: not dramatic, only ~ 12% of sensors will receive fluences above 1E15 n/cm2. To increase the radiation hardness of the sensor, the density of the gain layer implant needs to be as high as possible.

Time resolution for new and 8E14 n/cm2 UFSD FBK & HPK sensors

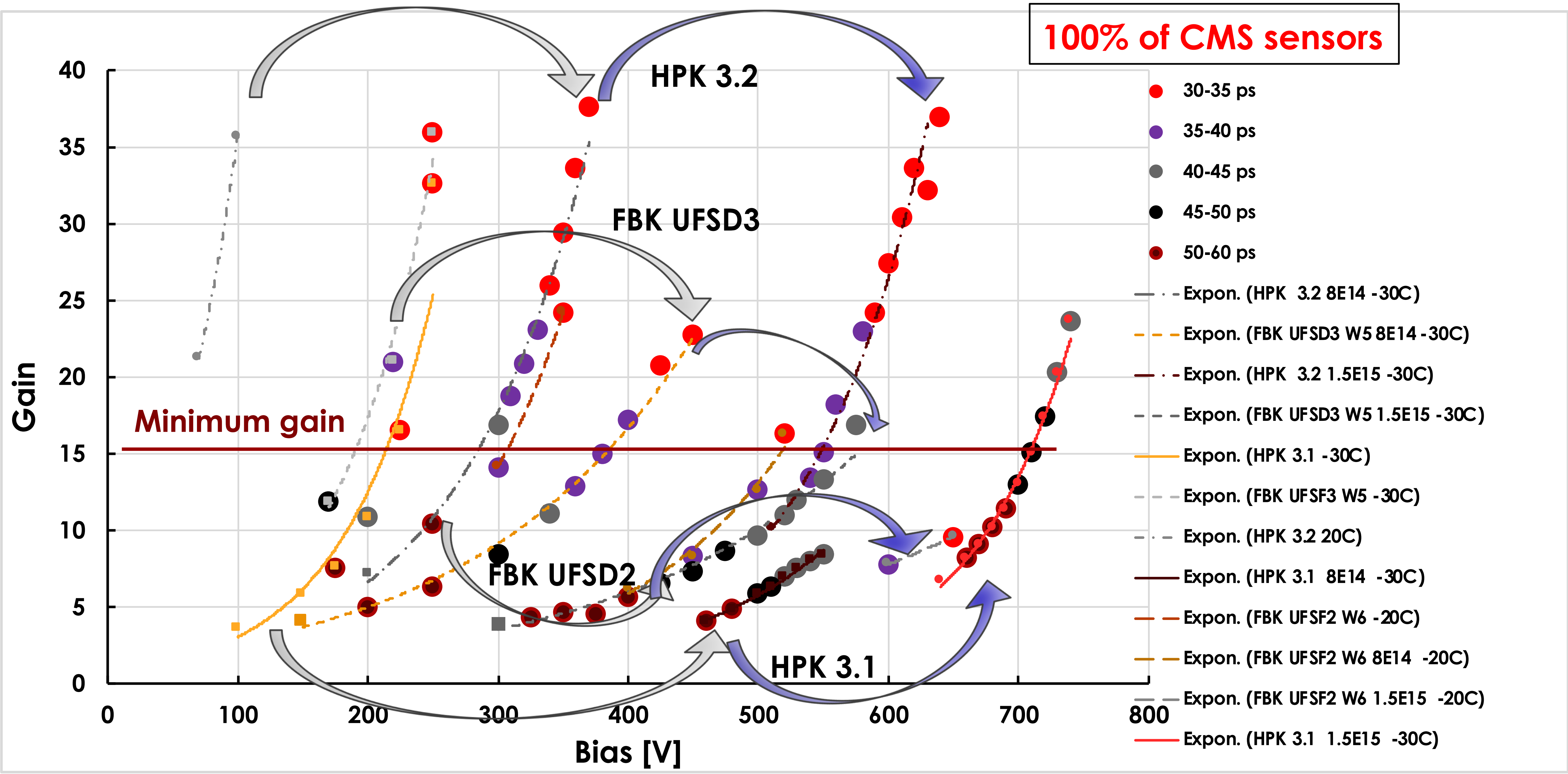


High fluence regime (> 8E14 n/cm2)

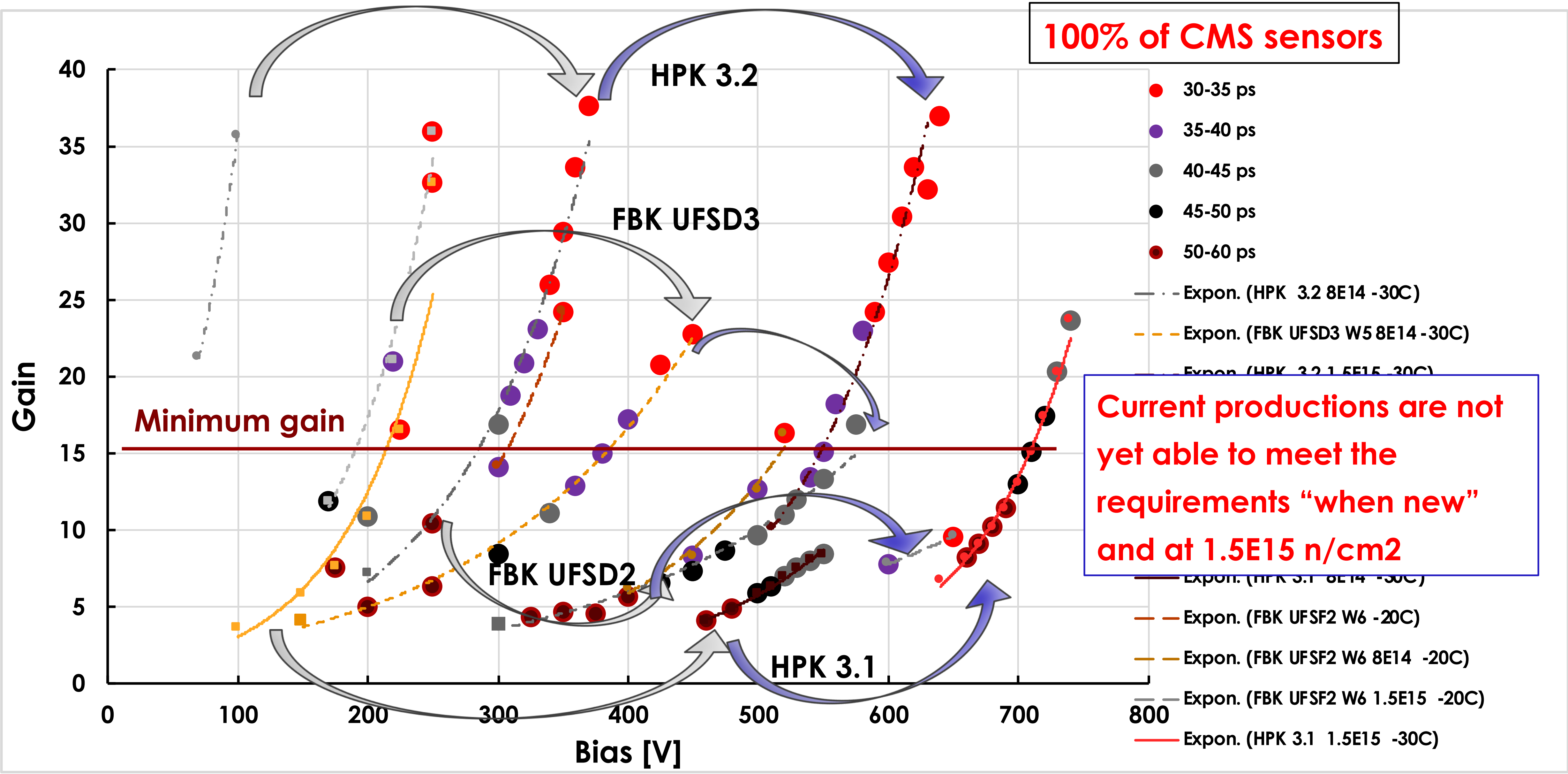
Irradiation not only decreases the gain layer doping, but decreases the drift velocity, yielding to a poorer time resolution



Time resolution for new, 8E14, and 1.5E15 n/cm2 UFSD FBK & HPK sensors



Time resolution for new, 8E14, and 1.5E15 n/cm2 UFSD FBK & HPK sensors



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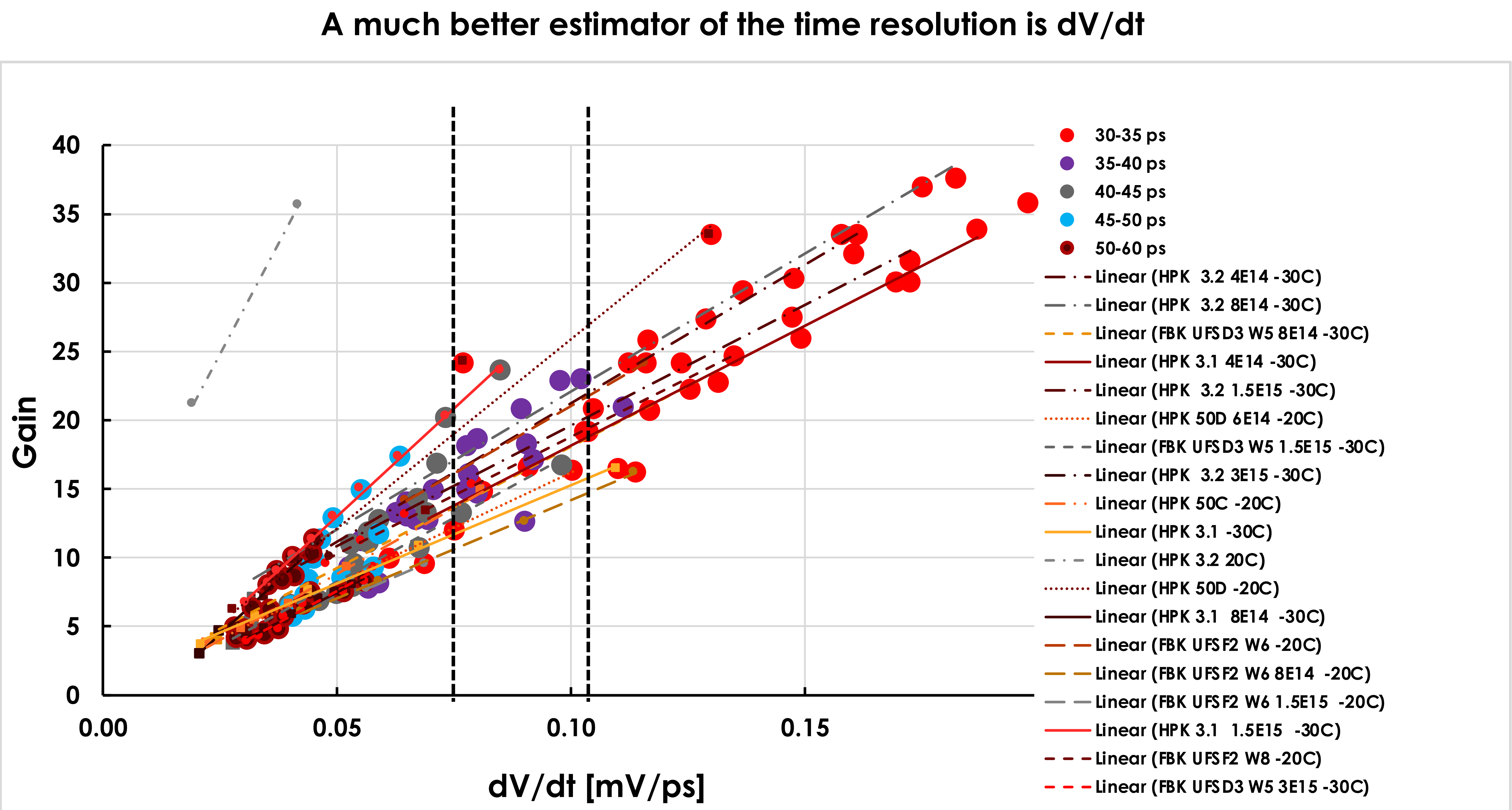
Time resolution for UFSD FBK & HPK sensors in the dV/dt - gain plane



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Conclusions

CMS is aiming at a single hit time resolution of 45 ps with an input charge of 8 fC (G =15).

New sensors should achieve G ~ 15 at a bias ~ 200-250V at T = -30C

Sensors irradiated at 8E14 n/cm2 achieve G = 15 at about 400V-450V with good time resolution.

Sensors irradiated at 1.5E15 n/cm2 need higher gain to obtain 30 ps time resolution since the drift velocity is lower