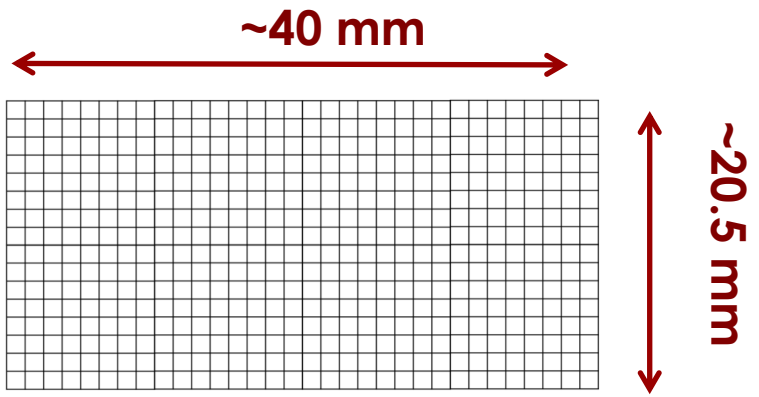
Operating conditions of LGAD at HL-LHC

ATLAS and CMS are considering very similar sensors for their timing layers

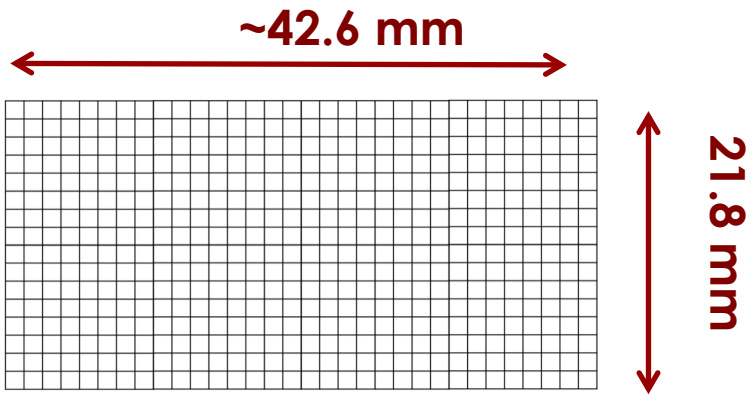
ATLAS



30 x15 pads

Each 1.3 x 1.3 mm^2

CMS



32 x16 pads

Each 1.3 x 1.3 mm^2

Too early to see if we can make them identical…

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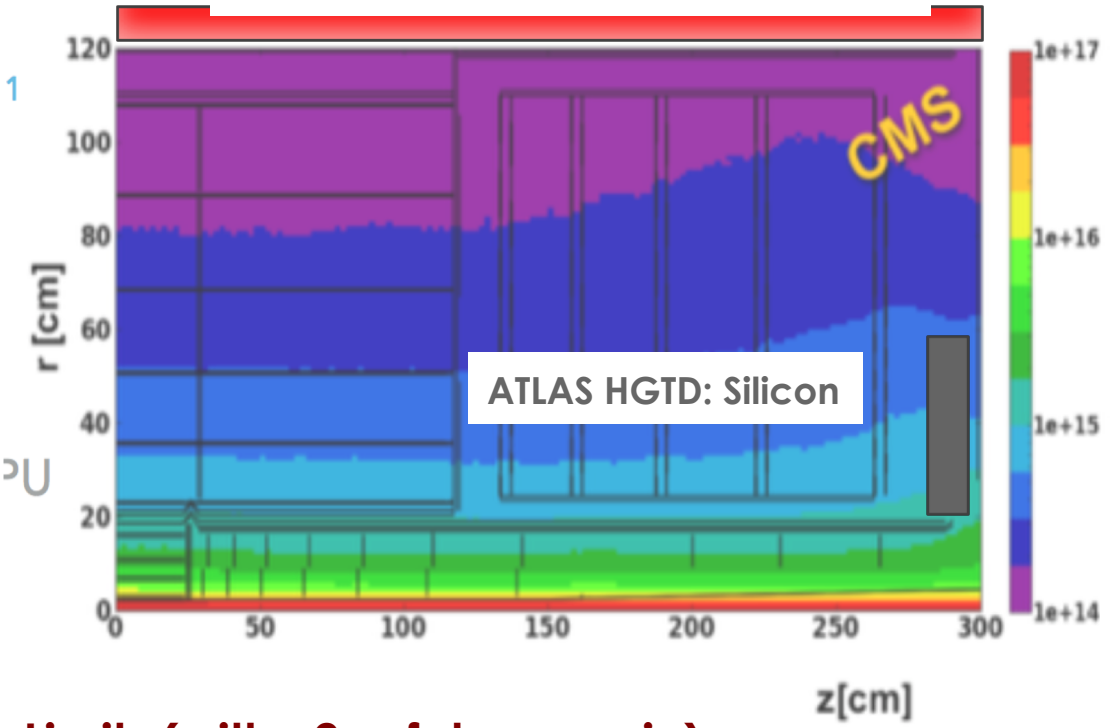
Technologies and Radiation levels

CMS barrel: SiPM+Scintillator tiles



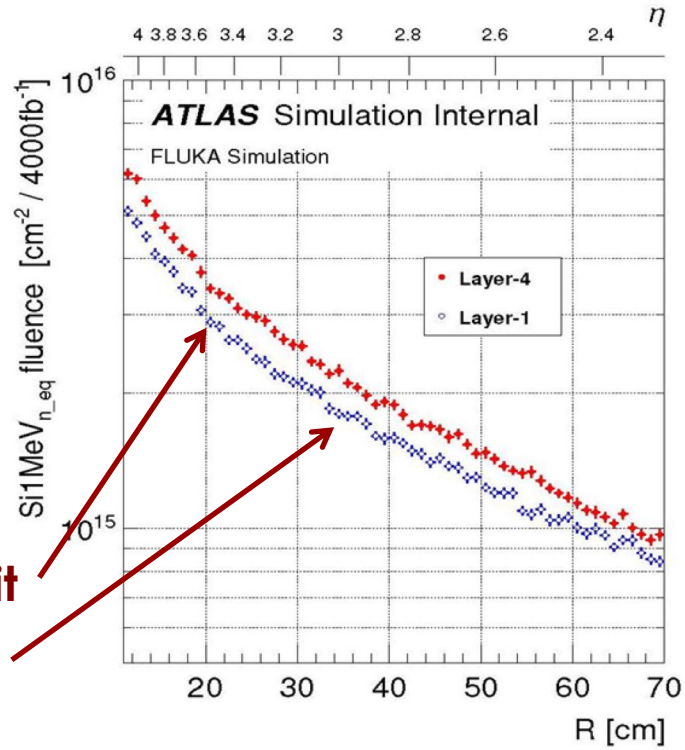
CMS ETL: Silicon

Limits (with x2 safety margin):

ATLAS: 2.4 < eta < 4, Max ~ 4.5e15 n/cm2

CMS: 1.6 < eta < 2.9, Max ~ 3e15 n/cm2

➔ Almost the same number…



ATLAS limit

CMS limit

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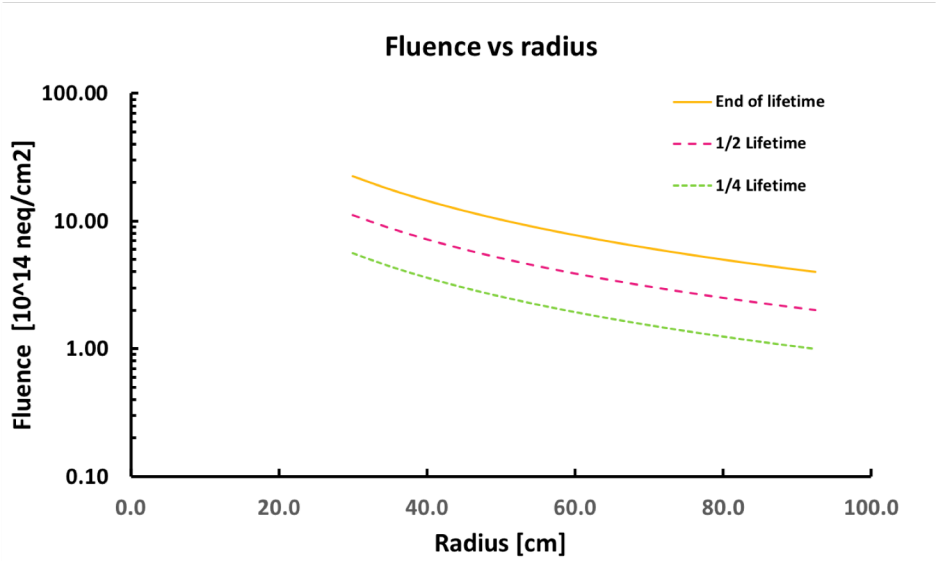
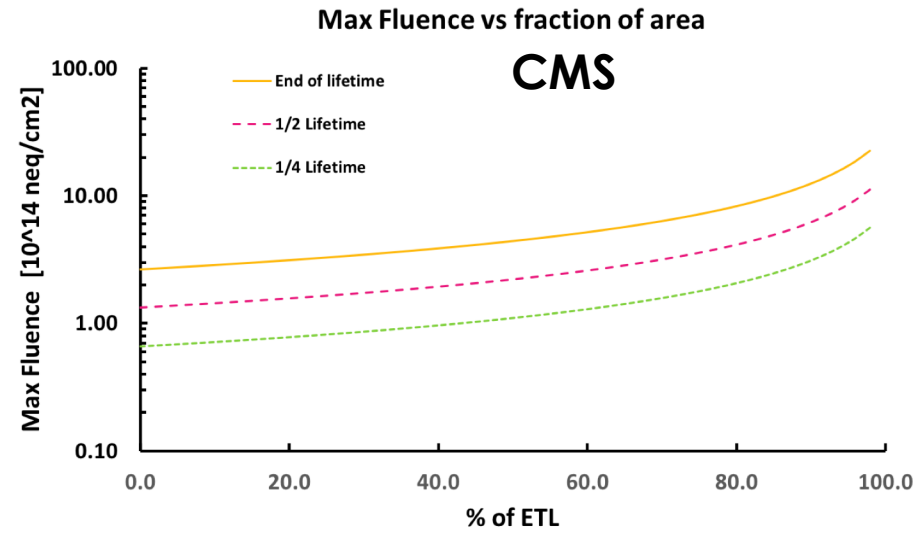
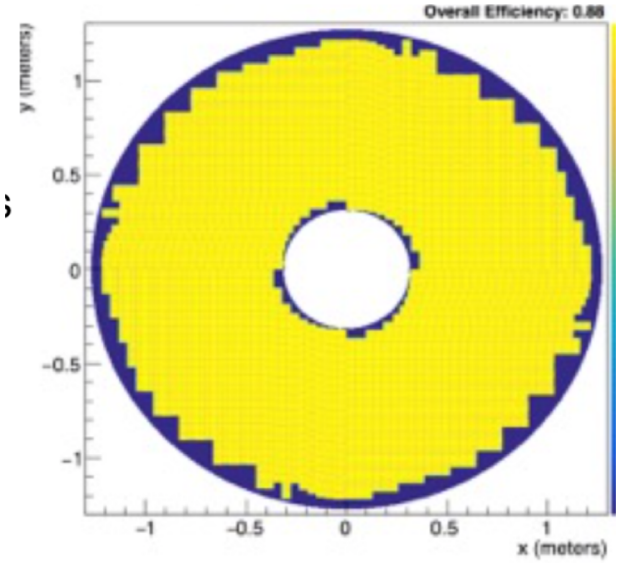
CMS good life, ATLAS







End of lifetime (4000 fb^{-1})

CMS

42% < 4E14 n/cm^2

80% < 8E14 n/cm^2

14%> 1E15 n/cm^2

ATLAS:

100%> 1E15 n/cm^2

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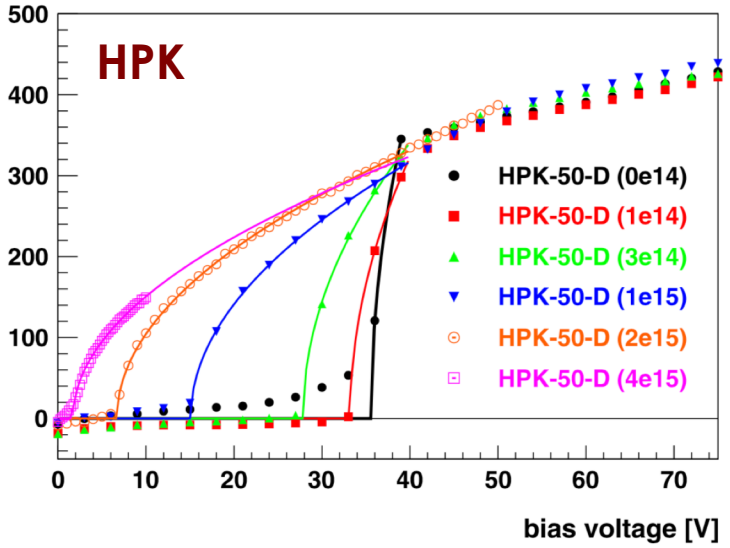
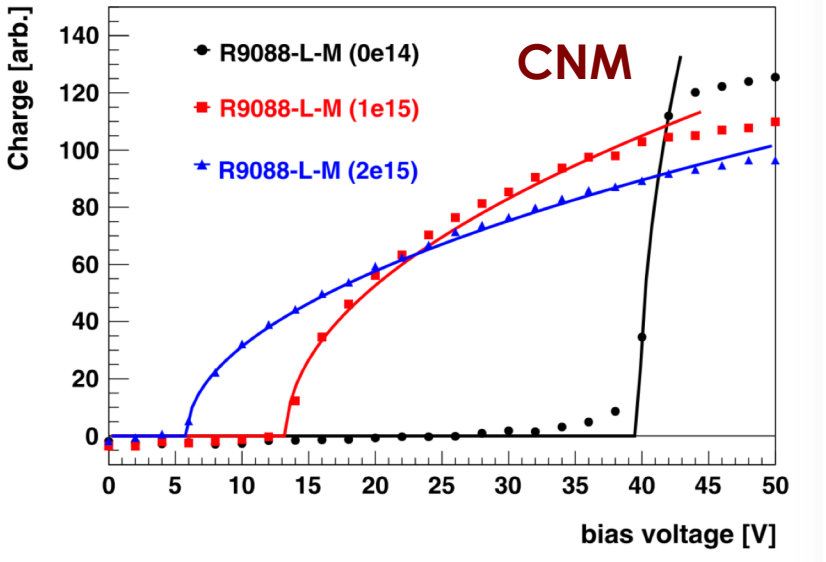
Gain layer de-activation due to irradiation

G. Kramberger et al, NIMA 891 (2018) 68–77

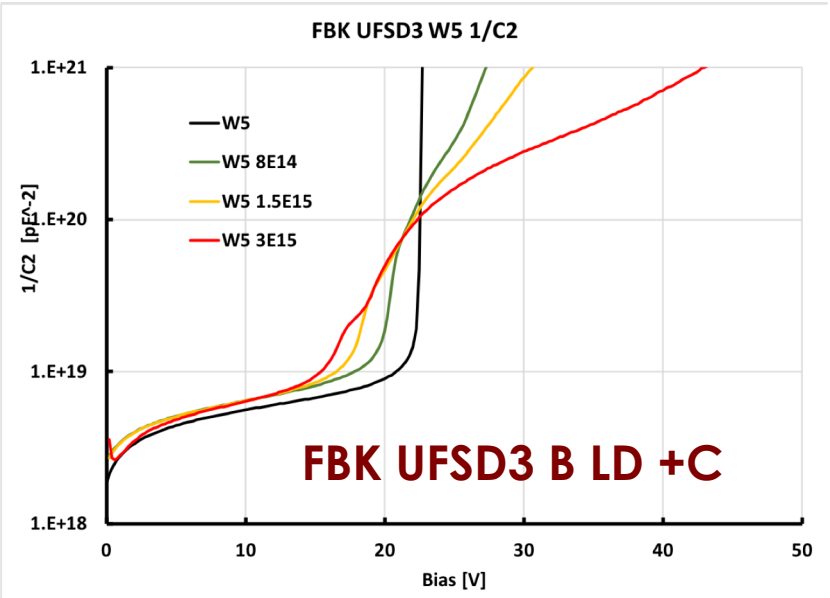




The rate of inactivation of the gain layer with irradiation varies among the producers.

FBK Carbon addition has beneficial effects.

See M. Ferrero, this workshop



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ASIC Designers: gain 10 minimum

Both ATLAS and CMS ASIC teams are requesting a minimum gain (G ~ 10) to assure good time resolution and good efficiency.

Sensors need to guarantee enough charge, without increasing the noise contributions.

Request from ASIC designers:

please provide at least 5 fC during the HL-LHC lifetime

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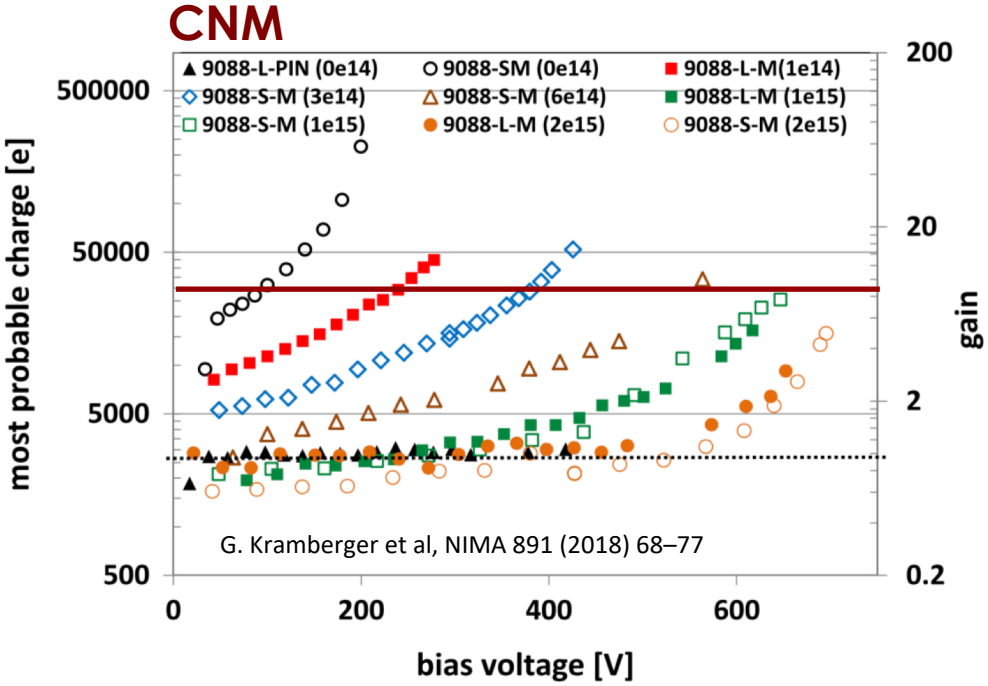
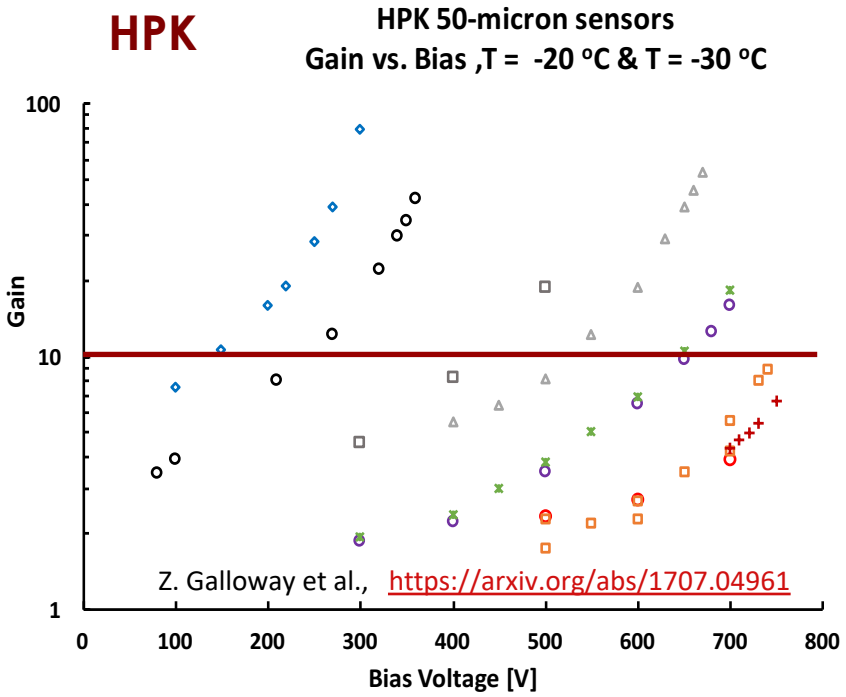
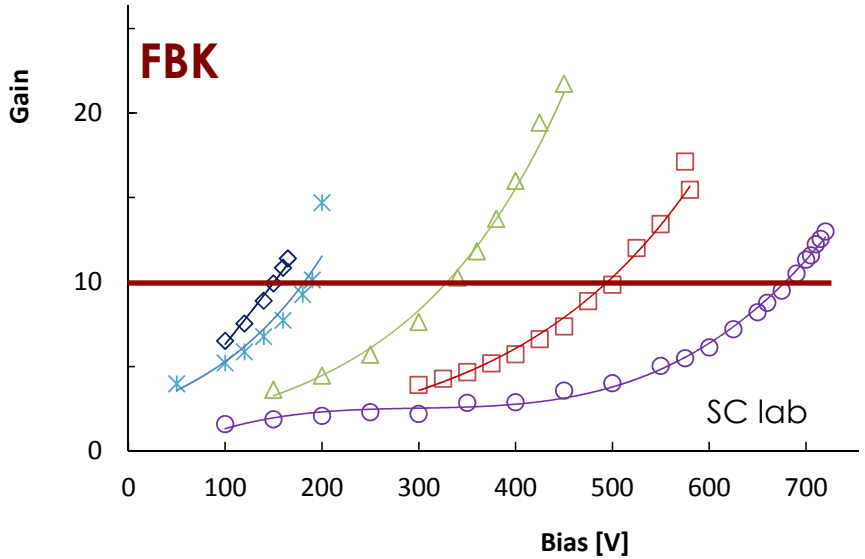
Gain (charge) vs voltage for 50um LGAD







FBK UFSD3 W5 2x2 Array PreRad -30C (Single Channel)
FBK UFSD3 W5 2x2 Array NEU 1E14 -30C (Single Channel)
FBK UFSD3 W5 2x2 Array NEU 8E14 -30C (Single Channel)
FBK UFSD3 W5 2x2 Array NEU 1.5E15 -30C (Single Channel)
FBK UFSD3 W5 2x2 Array NEU 3E15 -30C (Single Channel)

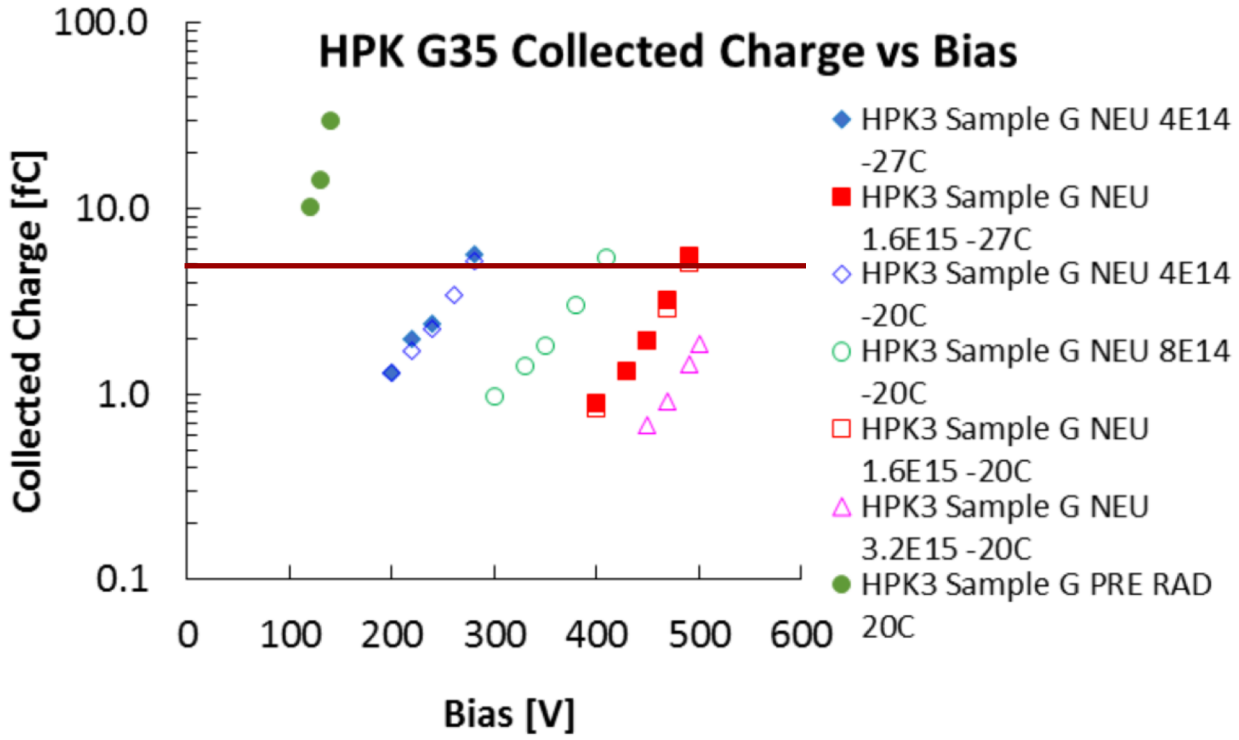
HPK 50D pre-rad T = -20C
HPK 50D 1e14 T = -20C
HPK 50D 3e14 T = -20C
HPK 50D 6e14 T = -20C
HPK 50D 1e15 T = -20C
HPK 50D 3e15 T = -20C
HPK 50D 6e15 T = -20C
HPK 50D 1e15 T = -30C
HPK 50D 6e15 T = -30C

35 um thick sensors

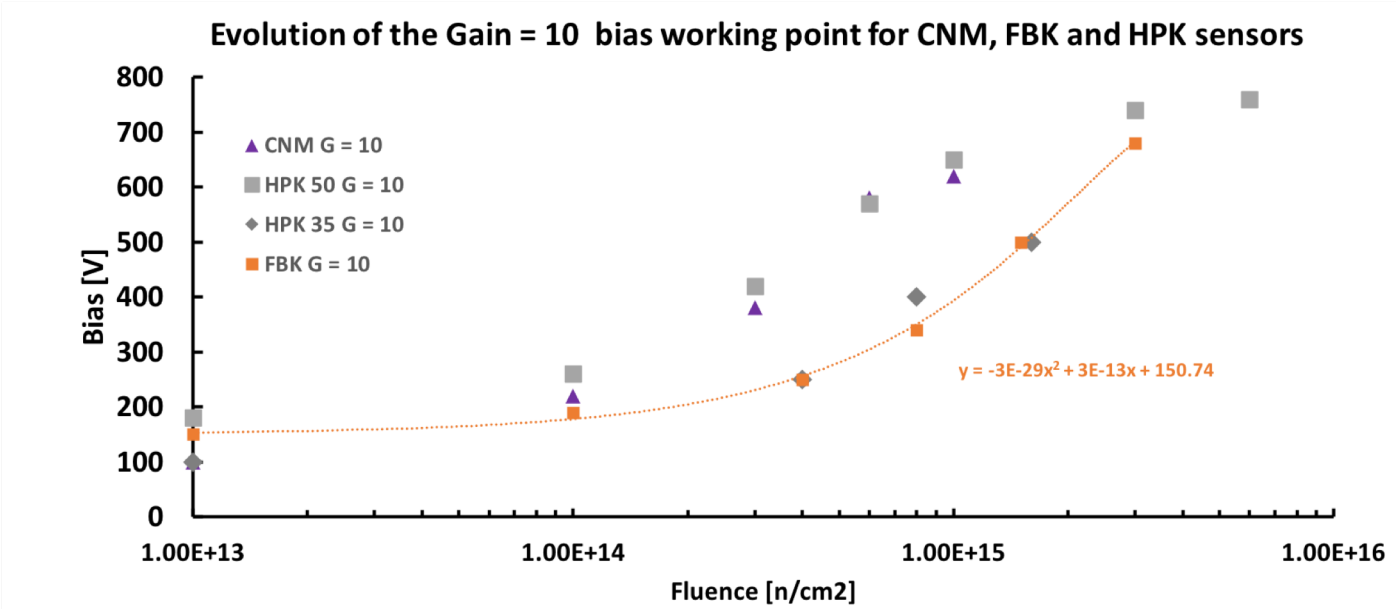
Thinner sensors have **higher capacitance** and deliver **lower charge**

However, they need less voltage to reach higher gain…

For CMS: not an option so far



Bias for Gain = 10 vs fluence



Important aspects:

- Carbon reduces the need for higher bias for equal fluence
- The **"voltage reach"** of the detectors: sensors should hold high bias since it **extends the possibility to go to higher fluences.**
- Two families: HPK 50 and CNM, HPK 35 and FBK

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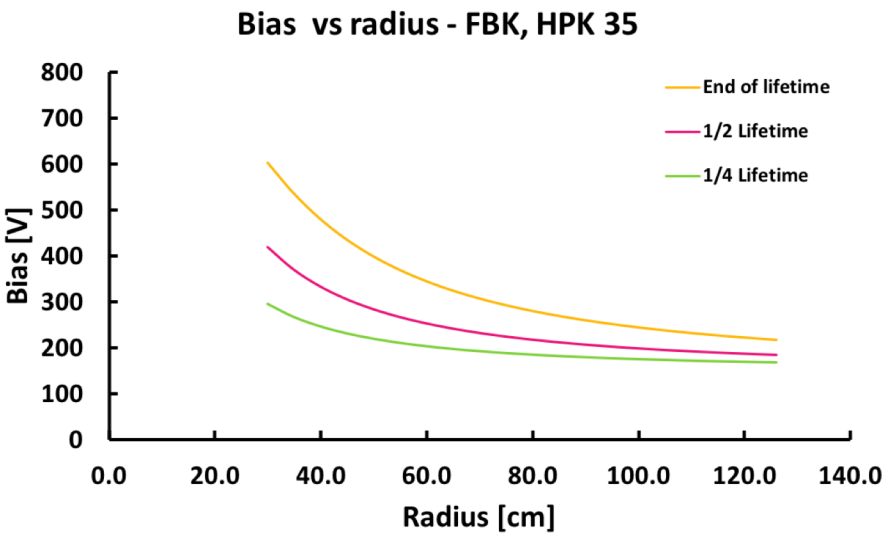
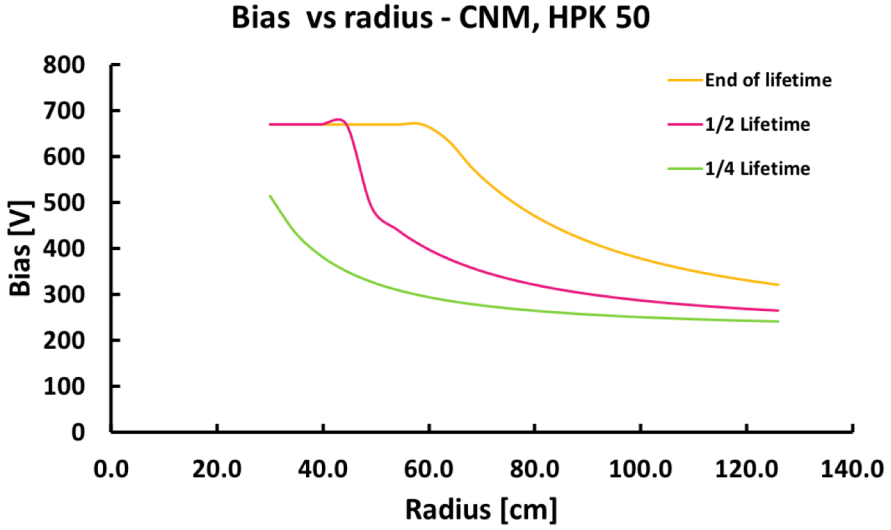
Voltage vs Radius





Bias point as a function of radius: FBK, HPK 35 do not "saturate" the voltage

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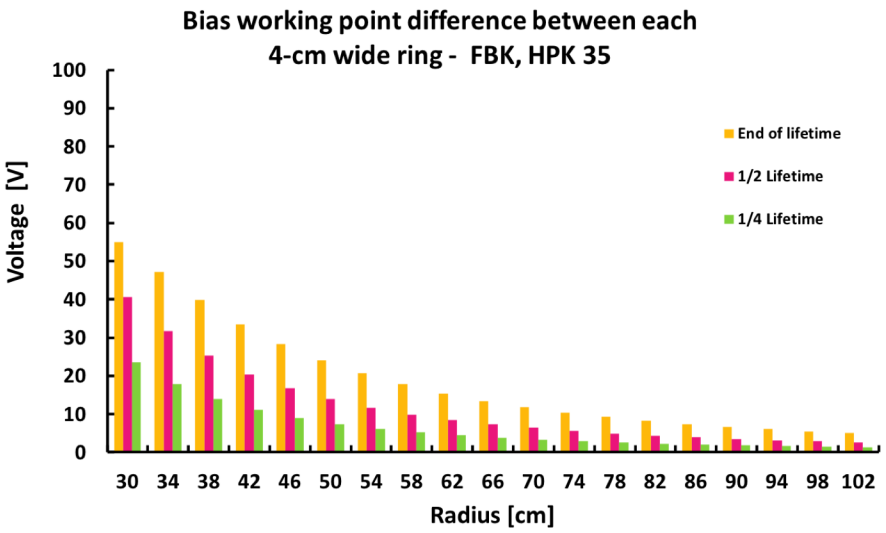
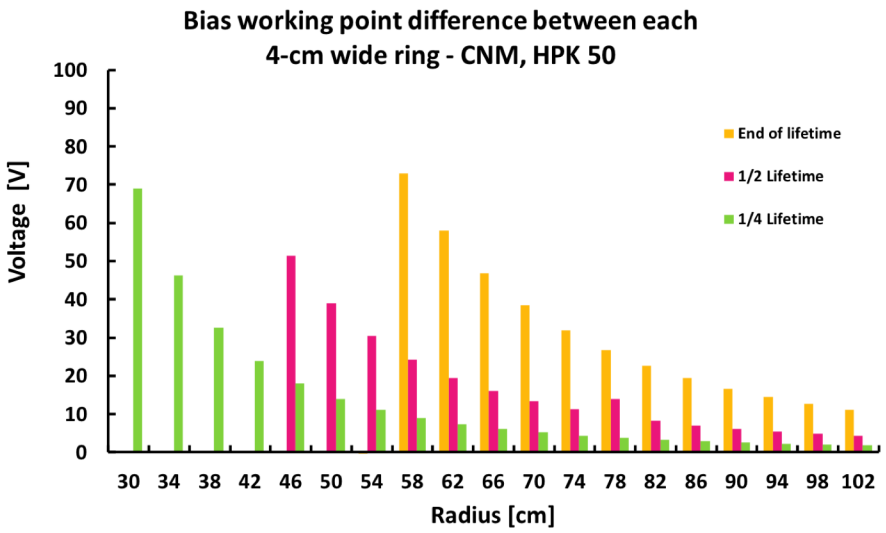
ΔV vs Radius in 4 cm steps





This is the difference in optimum voltage in 4 cm steps: the sensor edge at higher rapidity would require higher bias, so it will be under-biased to prevent breakdown at the sensor edge at lower rapidity.

Can we afford an "underbias" of 50-70 Volt?

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Outlook

- The ASIC designers of the timing layer front-end are requesting at least 5 fC at the end of the HL-LHC lifetime, corresponding to a gain > 10.
- This amount of charge should be enough to assure ~ 45 ps time resolution and a good hit efficiency (S/N>10).
- Very important for this goal in the sensor "voltage reach", the possibility to hold high bias without breakdown. HPK sensors have the highest reach so far, with S/N>10 after 3E15 n/cm2.
- To deliver gain = 10 , FBK UFSD3 and HPK 35 sensors require a lower bias than CNM and HPK 50 sensors
- Given the eta-dependent irradiation, part of each sensor positioned at high eta will be under-biased, decreasing the gain.
- Headroom: we want the run the sensors below their breakdown voltage. This is always possible but at the highest voltage