Results from HPK 35 & 50 µm UFSD

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- Comparison HPK 35 & 50 µm LGAD
- Doping Profile of 50 µm HPK LGAD
- Inter-pad gap

Comparison HPK 35 µm and 50 µm LGAD

50 µm thick LGAD (HPK 50D)
Single pad (1.3 mm^2 area)
capacitance 2.7 pF
For HGTD pad area= 1.7 mm^2 expect C(50 µm) =3.4 pF
Z. Gallowayet al.,arXiv: 1707.04961

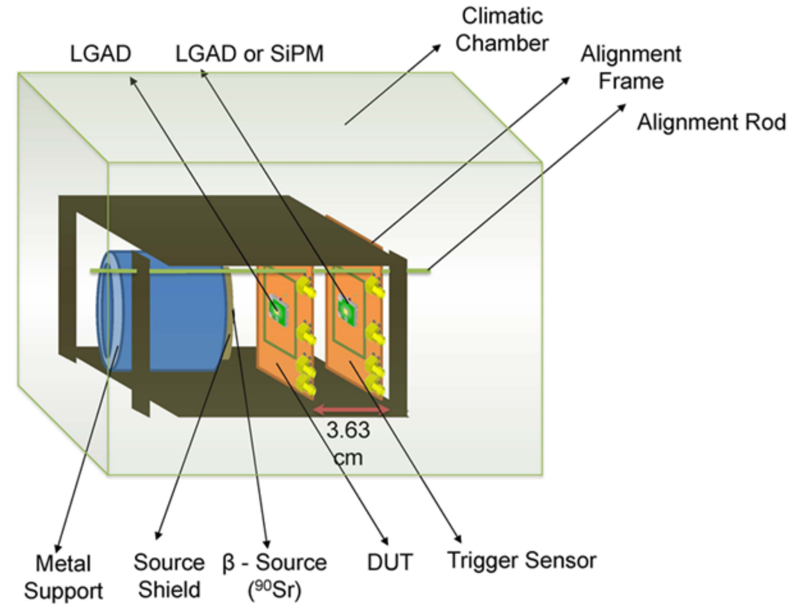
Comparing with

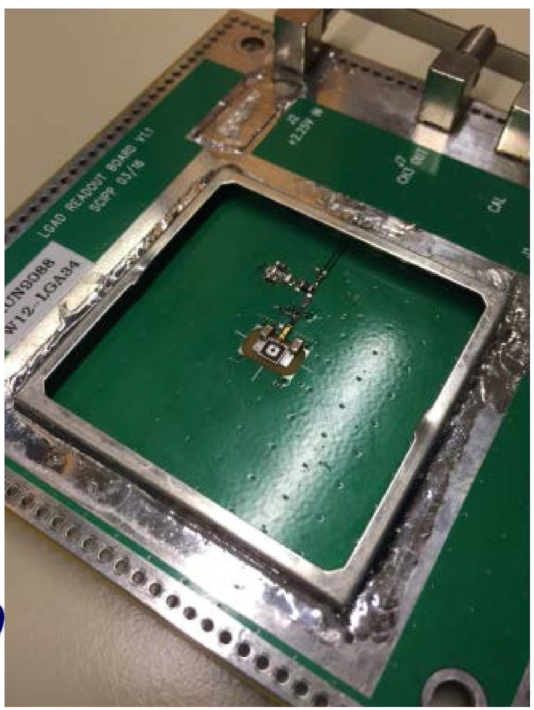
35 µm thick LGAD (HPK sample "B")
Single pad (1.3 mm^2 area)
capacitance 4.6 pF
For HGTD pad area= 1.7 mm^2 expect C(35 µm)= 4.8 pF

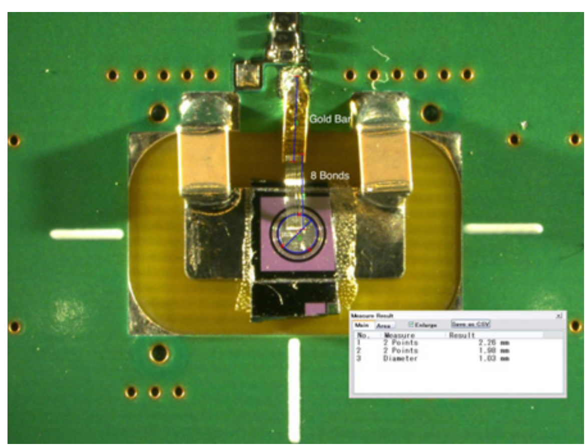
Measured in the β-telescope Pre-rad and post-rad 1e15 n/cm^2, -20° C

UCSC ^{90}Sr β-Source

^{90}Sr β-source Set-up:
DUT LGAD between source and trigger plane
Trigger: either known LGAD or quartz/SiPM
Climate chamber allows operation
between -30C and +20C

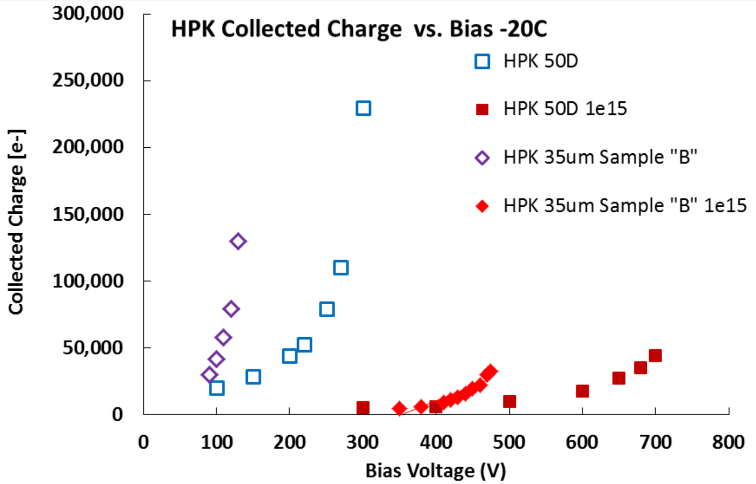






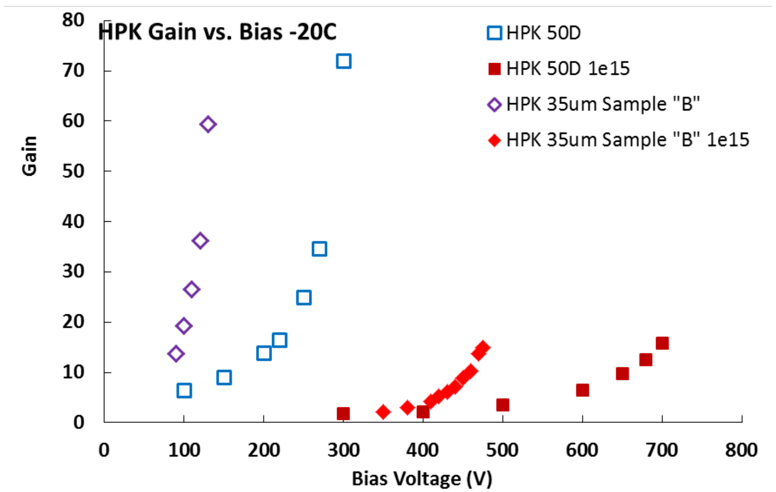
Measurement of pulse shapes with amplifier board
(Low-noise, fast ~3Ghz) developed at UCSC, now available from CERN

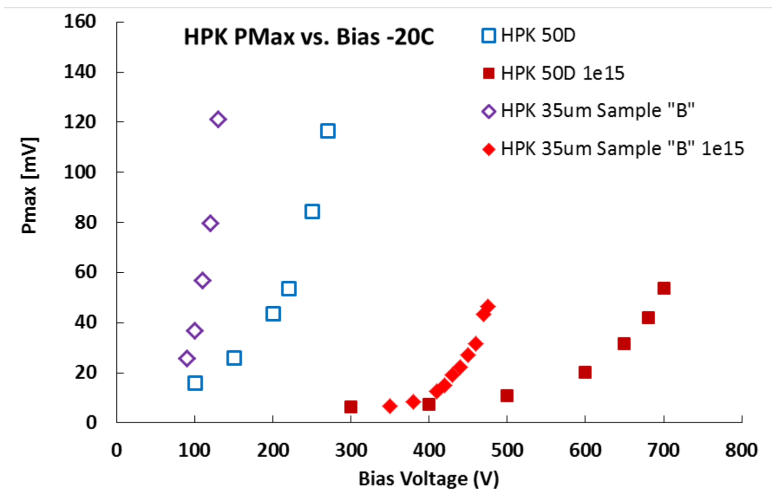
Bias Dependence of Coll. Charge, Gain & Pmax



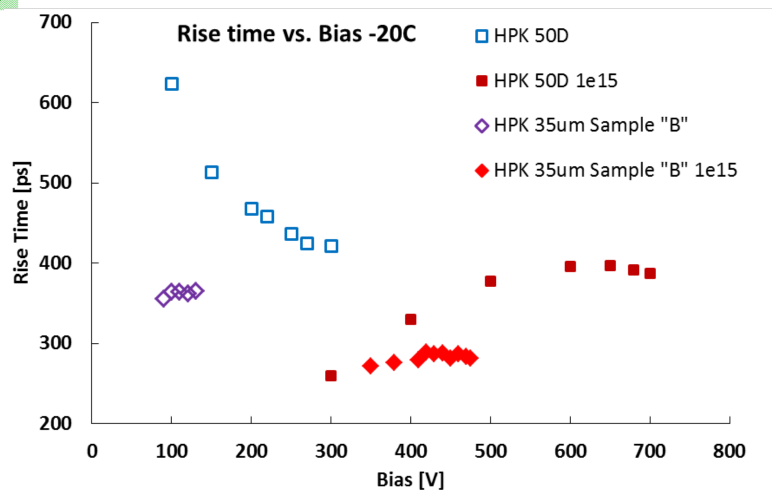
Post-rad performance similar
BUT
Lower bias voltage for 35 µm!

Bias voltage gap of ~ 200V is preserved through radiation.





Rise time (10% - 90%) and Noise



Rise Time

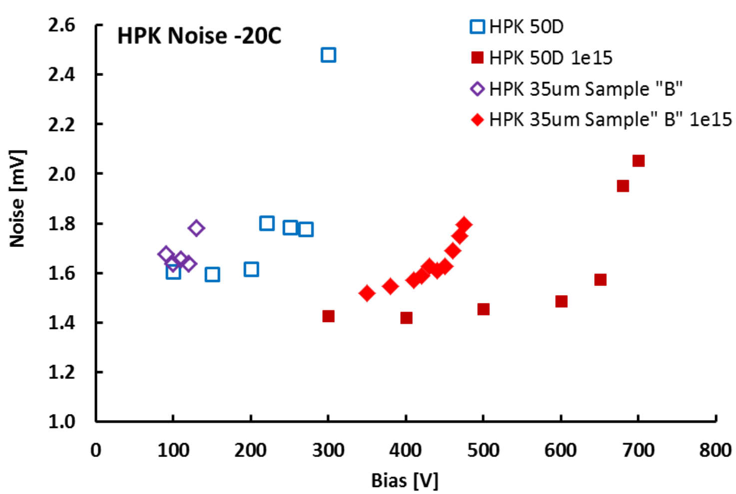
Before radiation:

- 363 ps (35 μm) vs. 422 ps (50 μm)

After 1e15 n/cm^2

- 281 ps (35 μm) vs. 387 ps (50 μm)

(Lower post-rad values explain the good post-rad performance)

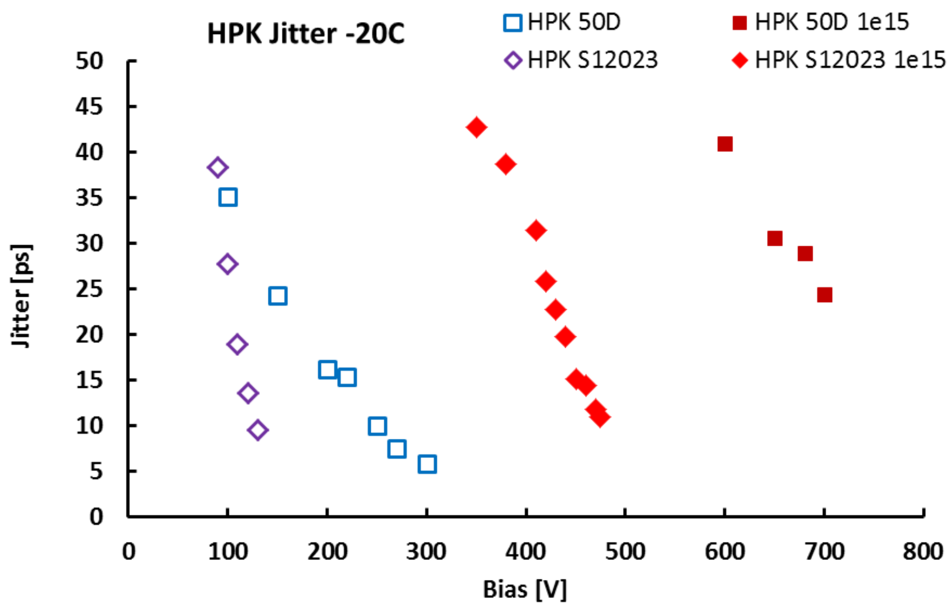


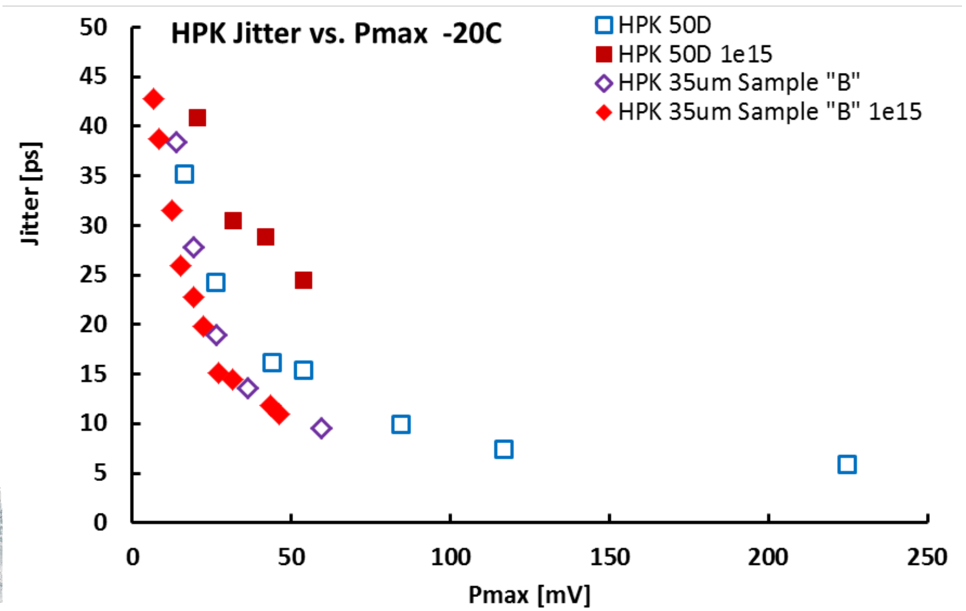
Noise

Increase of noise at large bias voltage (even before radiation for 50 μm) .

Large noise and increased rise time at large bias explain the relatively large jitter for 50 μm post-rad

Jitter vs. Bias and Pmax





$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

$$\sigma_{TimeWalk} = [\frac{V_{th}}{S/t_{rise}}]_{RMS} \propto \left[\frac{N}{\frac{dV}{dt}}\right]_{RMS},$$

$$\sigma_{Jitter} = \frac{N}{dV/dt} \approx \frac{t_{rise}}{S/N}$$

Jitter

Clear advantage of 35 µm wrt 50 µm

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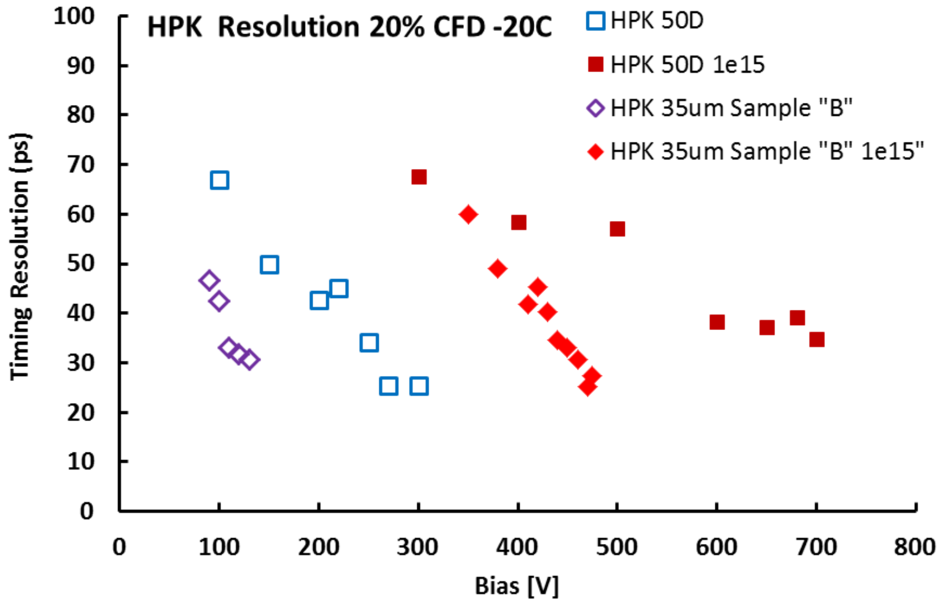
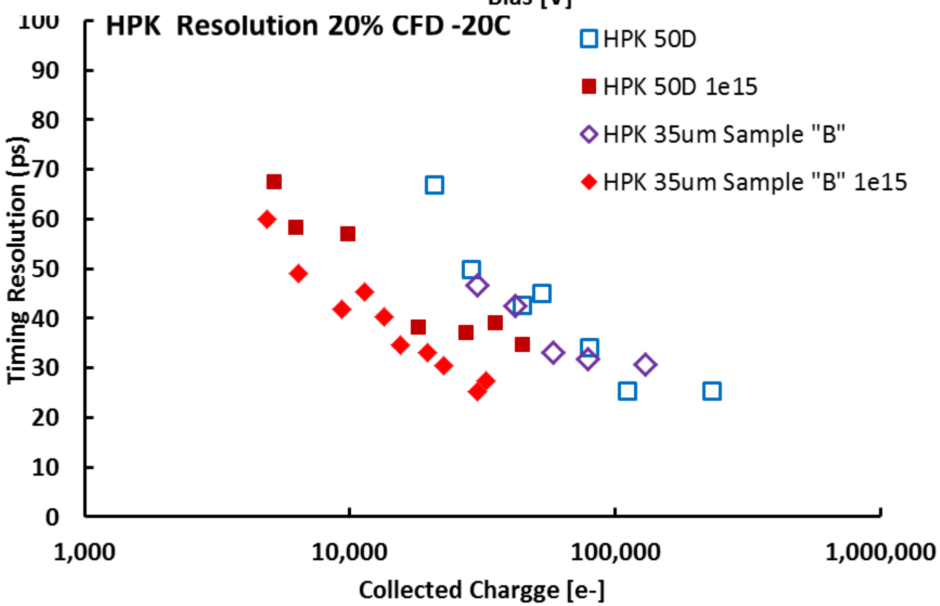
Timing resolution vs. Bias and Coll. Charge





Time Resolution (CFD 20%)

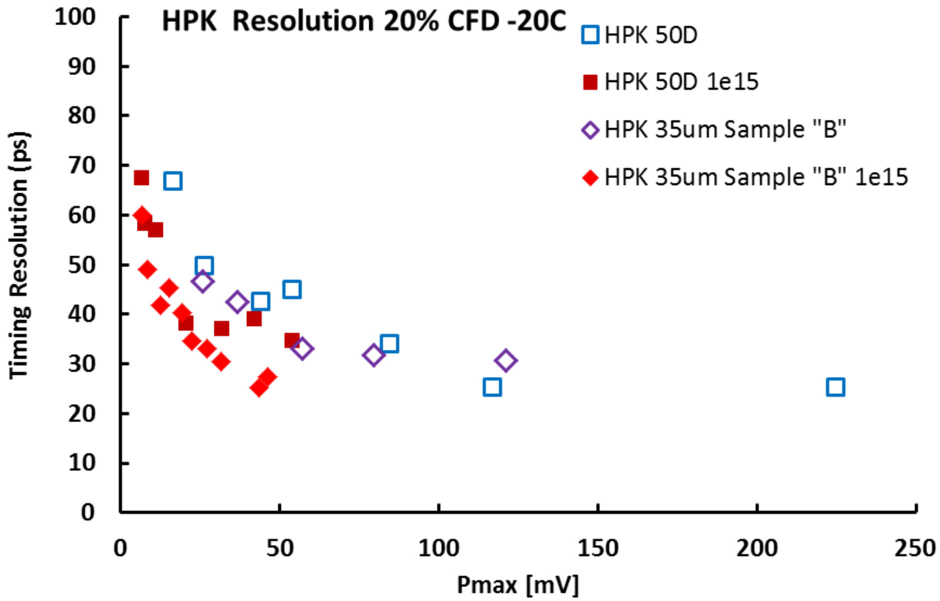
Before radiation:

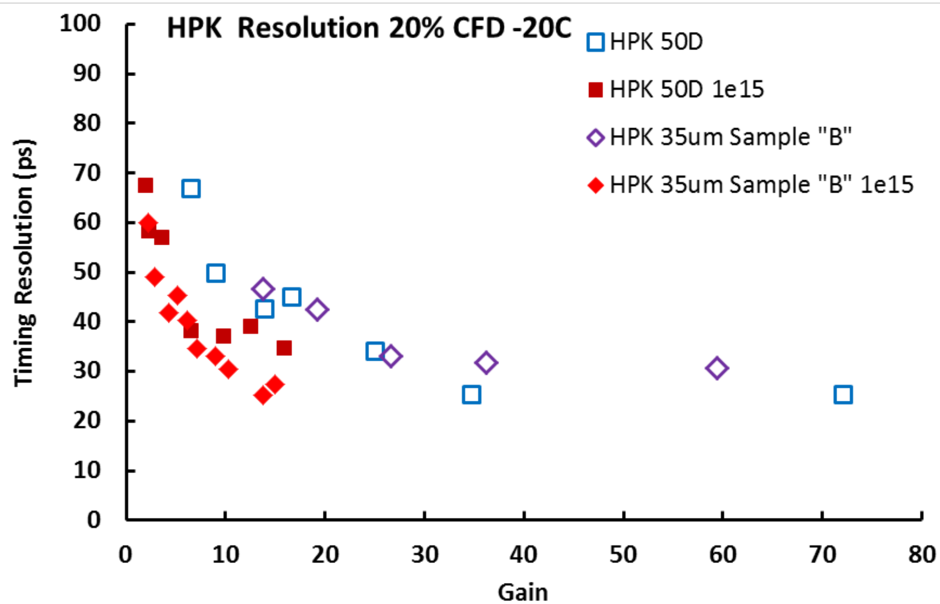
- 30 ps (35 µm) vs. 25 ps (50 µm)

After 1e15 n/cm^2

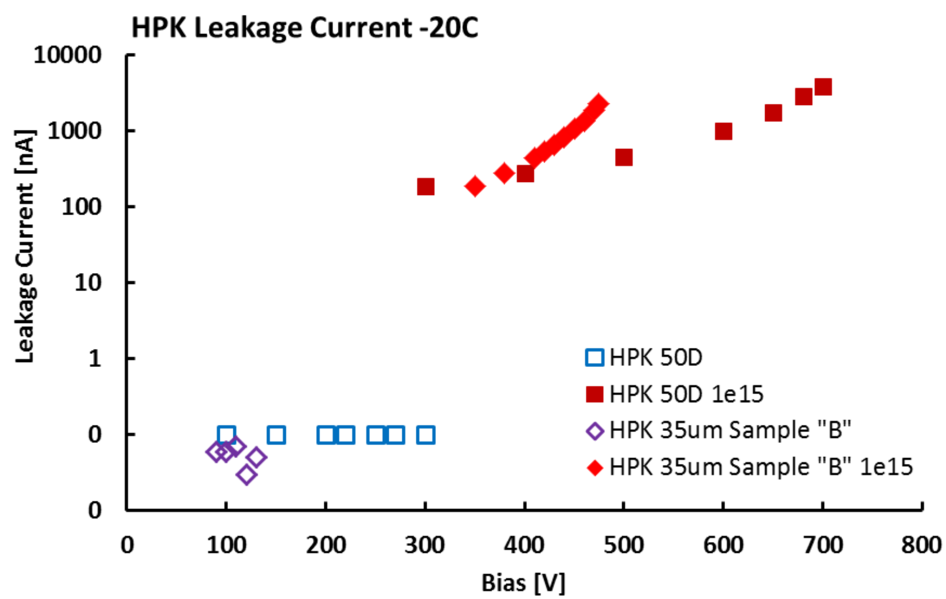
- 25 ps (35 µm) vs. 35 ps (50 µm)

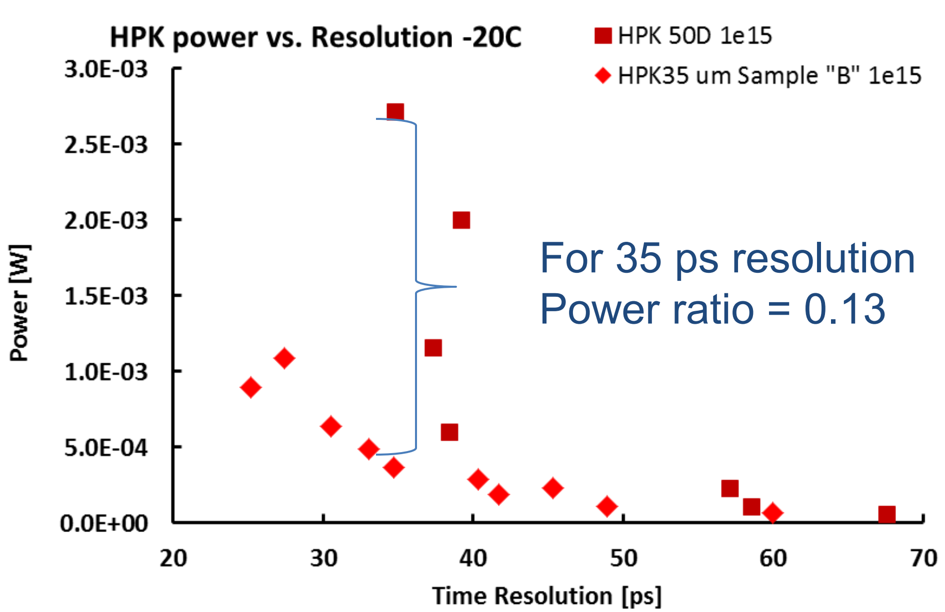
Timing resolution vs. Pmax and Gain





Leakage Current & Power vs. Timing resolution





Power Consumption:

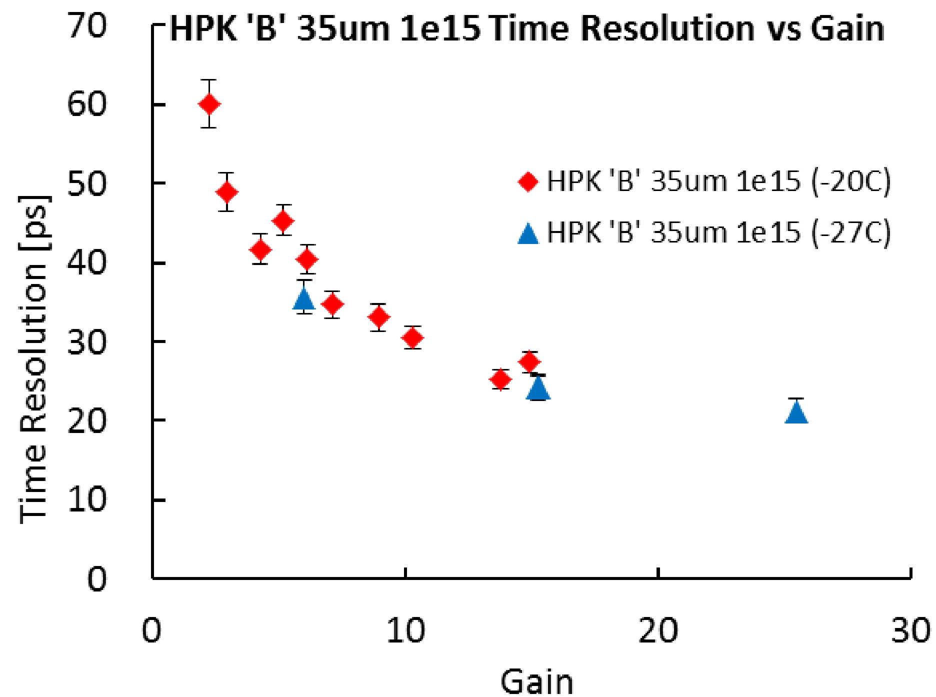
Lower current, lower bias
-> lower power

Comparison of power
for same time resolution

Effect of Temperature: Time Resolution

Hartmut F.-W. Sadrozinski, "HPK 35 um & 50 um UFSD"

New data with HPK “B” 35µm
Compare operation at -20C and -27C



Overall Improvement with 50 µm → 35 µm LGAD thickness:
(Fluence 1e15 n/cm^2)

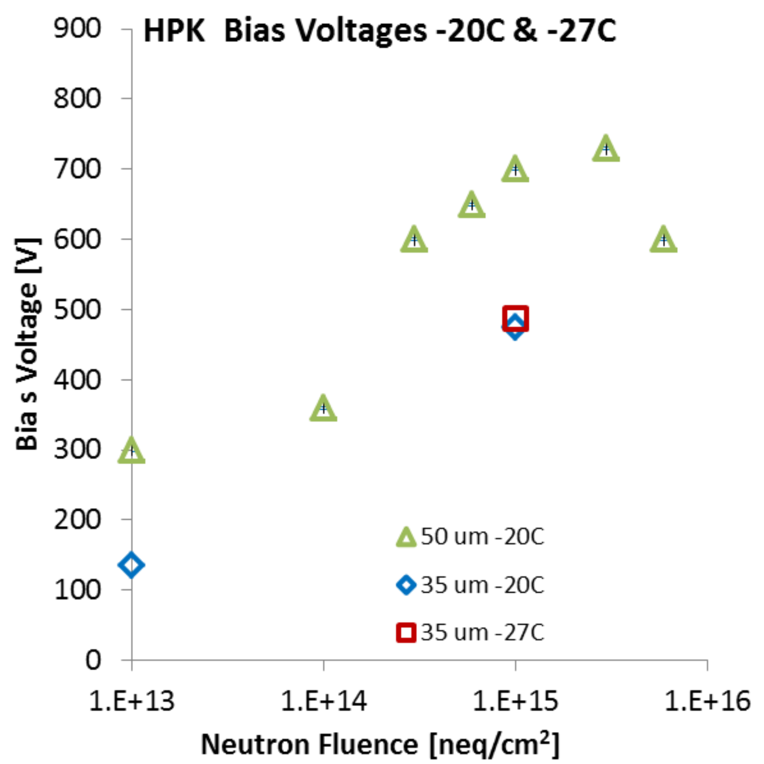
HPK 50D σ_t= 35 ps (-20C)
HPK “B” σ_t= 25 ps (-20C)
HPK “B” σ_t= 21 ps (-27C) (40% improvement)

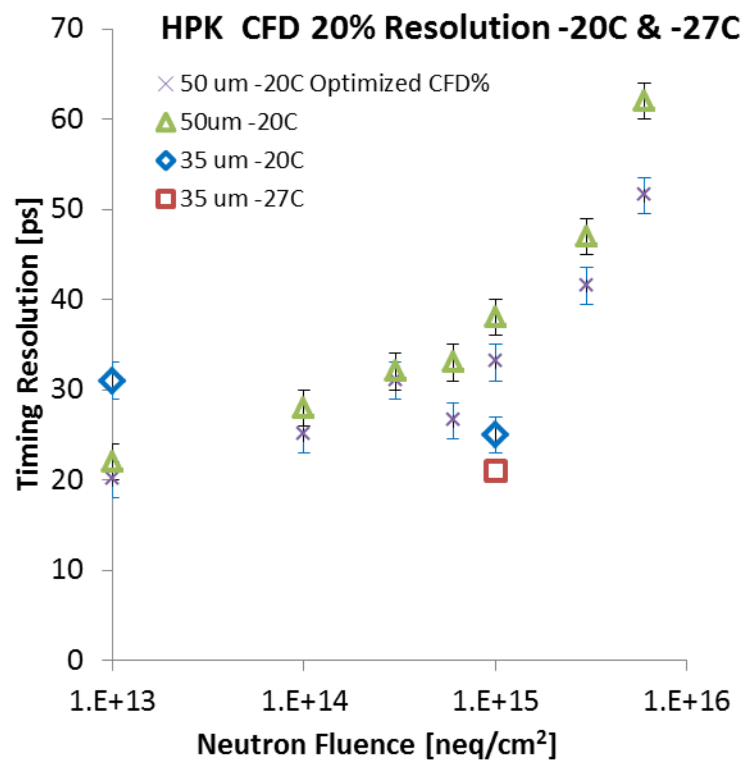
N.B. Advantage of lower temperature in reaching high gain -> better resolution

Score card 50 μm vs. 35 μm

HPK "B" 35μm:

Lower bias voltage, better resolution





N.B. use CFD 20% resolution, which for 50 μm is worse than the one with optimized CFD fraction.

Summary on LGAD Thickness

Measure in β-telescope two LGAD from HPK with thickness 35 µm and 50 µm.

Pre-rad both sensors have similar performance

30 ps (35 µm) vs. 25 ps (50 µm) @ -20C

(35 µm has low bias voltage)

After 1e15 n/cm^2 :

35 µm sensor superior to 50 µm sensor due to lower rise time and lower bias:

Superior time resolution:

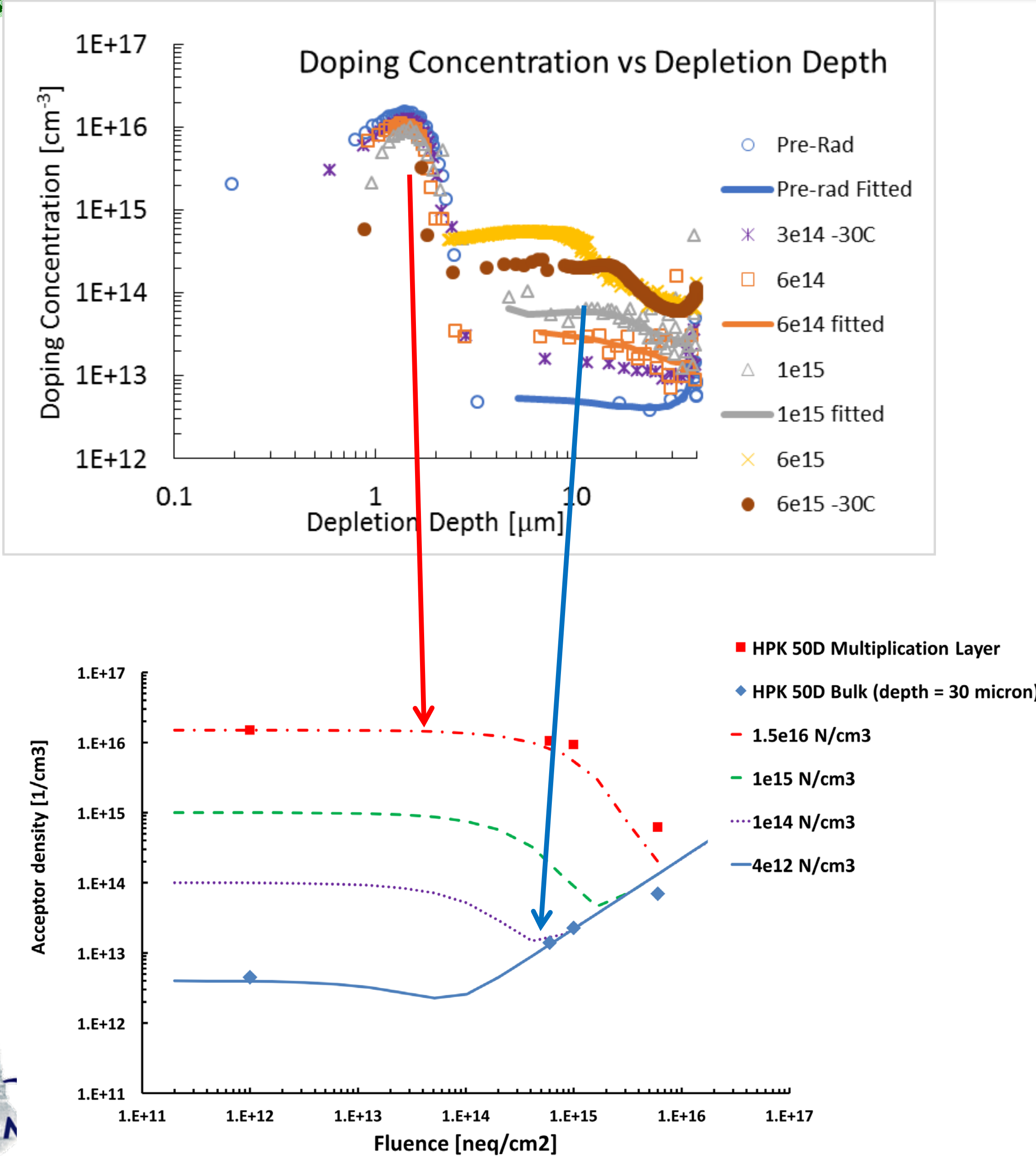
25 ps (35 µm) vs. 35 ps (50 µm) @ -20C

21 ps (35 µm) @ -27C

Reduced bias voltage : 500 V (35 µm) vs. 700 V (50 µm)

Reduced power

Acceptor Dynamics: neutrons



For HPK 50μm 50D LGAD
Neutron fluence: 0-6e15 n/cm^2

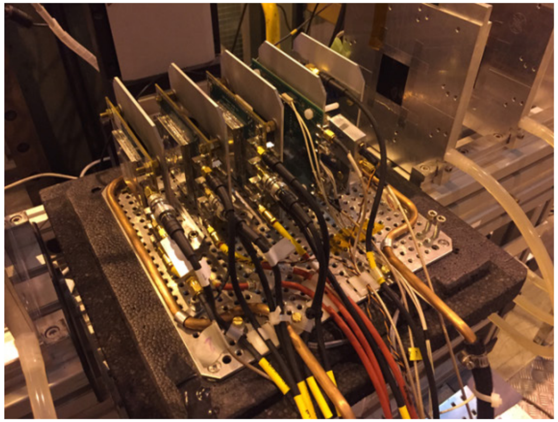
C-V at -20C (200Hz)
Measure simultaneously acceptor removal and creation.
Annealed for ~ 2hrs at +60C,

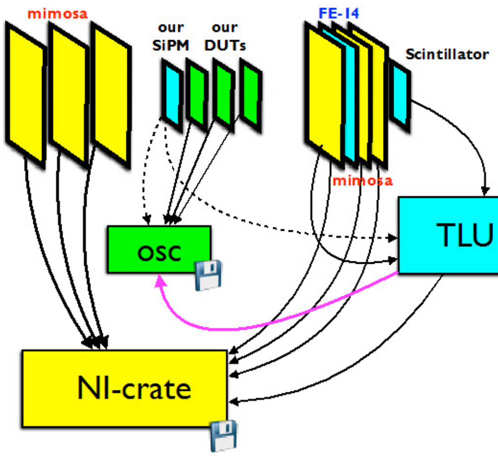
Thin sensor minimizes interference from "double-junction".

Clear agreement with the acceptor removal/creation picture.

Looking forward for surprises with proton data

Fill-Factor in the HGTD beam tests at CERN

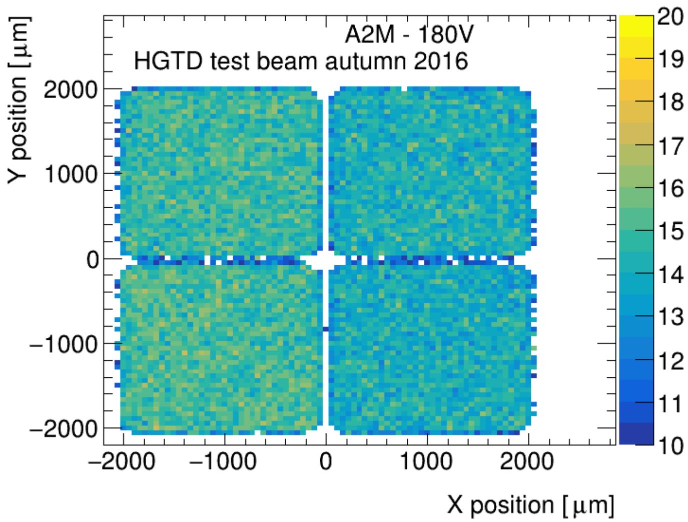




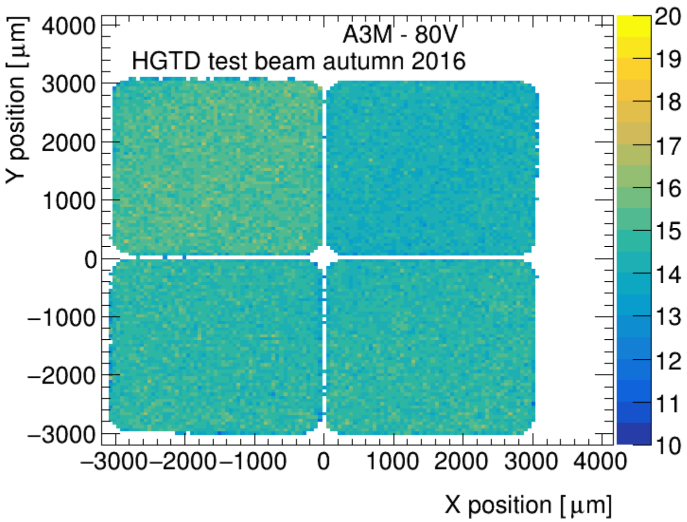
Fill-factor =
Active area / geometrical area
depends on inter-pad gap

Gain and occupancy maps show inter-pad gap

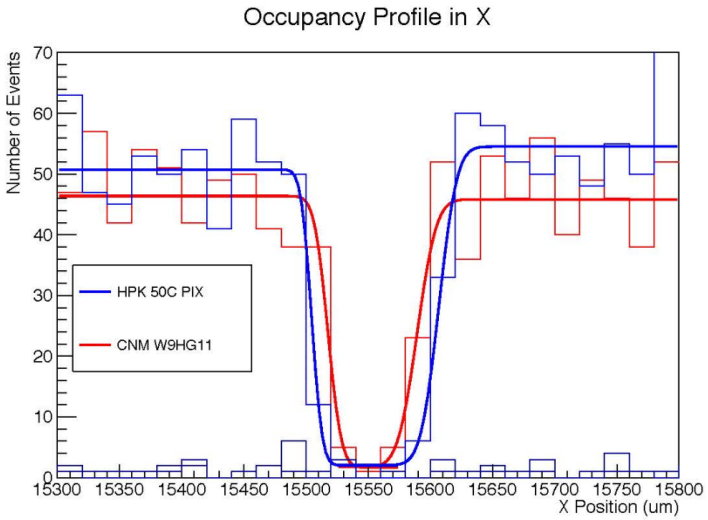
W7 HG22



W8 HG11

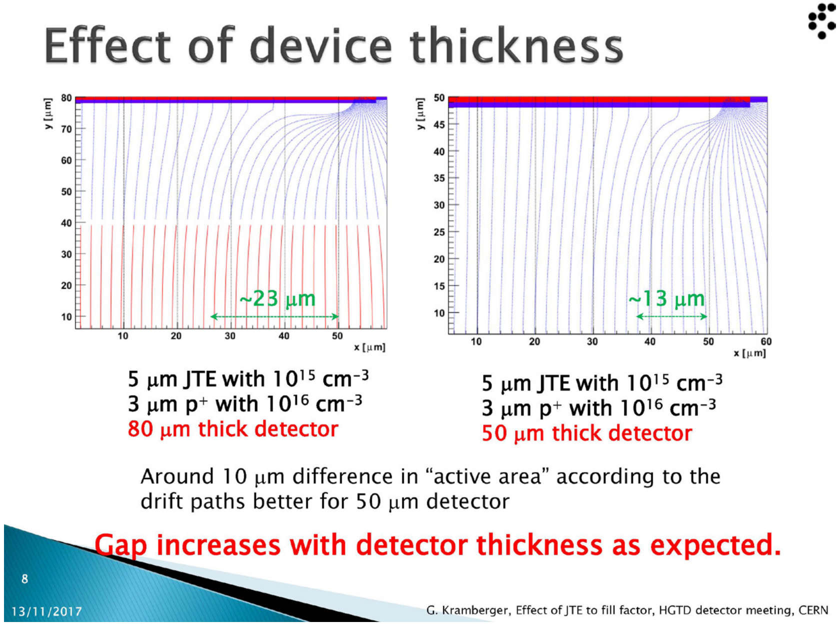


Fill-Factor: Inter-pad gap



Fill-factor depends on manufacturer:
Occupancy scan of two 2x2 array of 3x3 mm^2 pads showing different width of the inter-pad gap:
CNM (red) : 70 µm
HPK (blue) : 100 µm

Patrick Freeman, UCSC MS Thesis



Fill-factor depends on LGAD thickness:
TCAD simulations of field lines show the inter-pad gap depending on the LGAD thickness

G. Kramberger
https://indico.cern.ch/event/672871/contributions/2752995/attachments/1557256/2449555/EdgeSimulation-HGTD-Nov2017.pdf

What about thinner sensors (35 µm)?

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Back-up

Acceptor Dynamics: neutrons

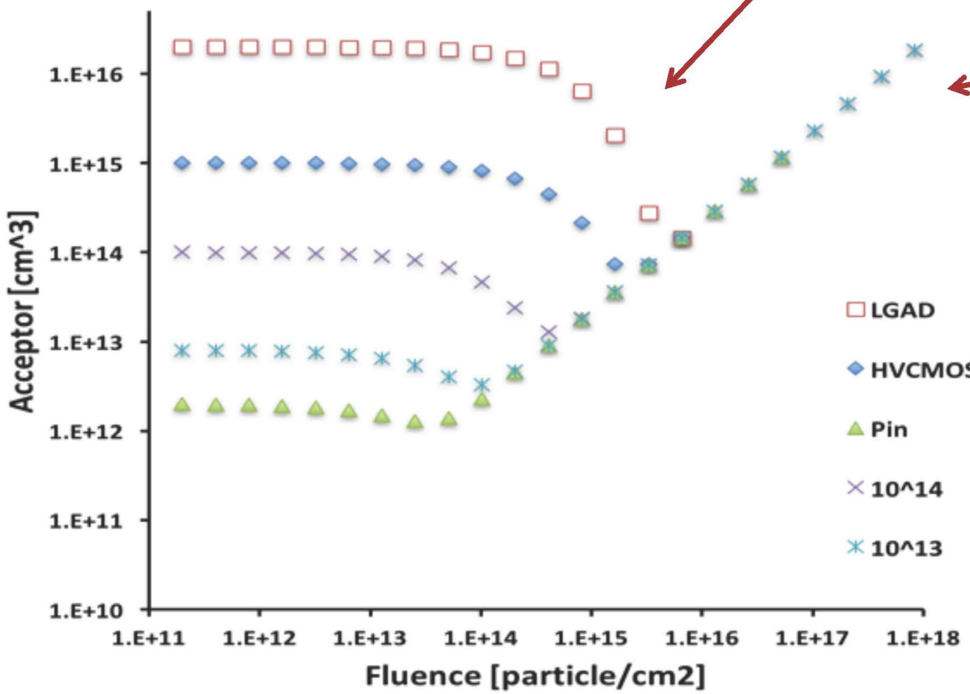
Initial acceptor (Boron) removal

Density of the boron doping vs irradiation:

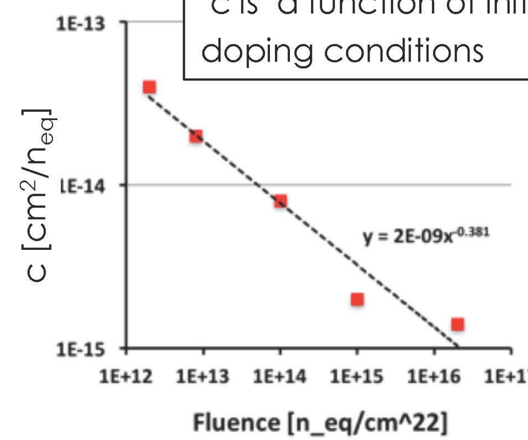
$$N_D = N_0 e^{-c\phi} + \beta\phi$$

Initial acceptor removal

Deep level creation
p-doping lookalike

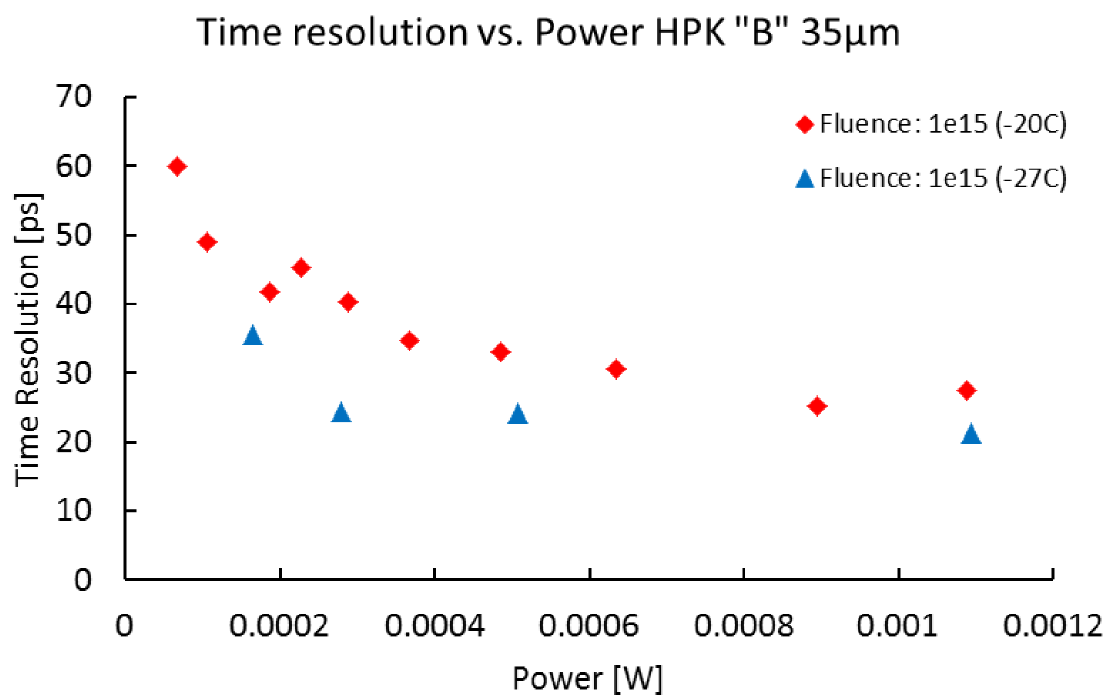


c is a function of initial doping conditions



Effect of Temperature: Power

New data with HPK "B" 35µm
Compare operation at -20C and -27C



N.B. Advantage of lower temperature in reaching high gain -> better resolution