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On the frequency dependence of the admittance of radiation damaged pad diodes

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35th RD50 Workshop
18.11.-20.11.2019

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INTRODUCTION

Questions:

- What is the cause of the frequency dependence of the capacitance of irradiated sensors?
- Is there a simple model for $Y(f; V, \Phi_{eq}, T)$ [admittance $Y = Z^{-1}$] ?

Common answer:

- $C(f)$ is the result of the response time of radiation-induced states

Our approach :

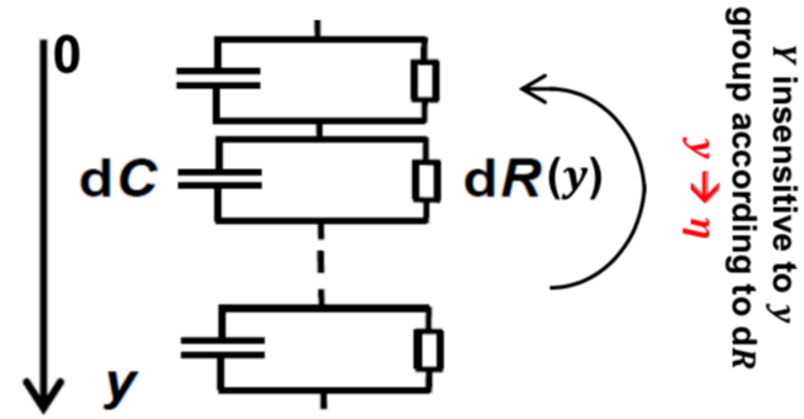
- Model fits to Y(f) data for irradiated pad diodes (Φ_{eq} = 3 to 13×10^{15} cm^{-2})

f-DEPENDENCE OF ADMITTANCE

Model:

- For interval dy: $dC = \epsilon \cdot A/dy$ and $dR(y) = \rho(y) \cdot dy/A$
  ➡ $dZ = (1/dR + i \cdot \omega \cdot dC)^{-1}$
- For entire sensor:

$$Z_{model} = \int_0^d dZ = \frac{1}{A}\int_0^d \frac{\rho(y)\,dy}{1 + i \cdot \omega \cdot \epsilon \cdot \rho(y)} = (Y_{model})^{-1}$$



Assumption for Y_{model}:

- Rad. damage affects only the resistivity $\rho(y)$ — no effects of response time to traps!

Expectation: for highly irradiated sensor

- In non-depleted (ohmic) region: $\rho = \rho_{intr}$ (generation = recombination)
- In depleted (high-field) region: $\rho \gg \rho_{intr}$ (free charge carrier density due to generation + current)

Analysis: For every voltage and Φ_{eq}: χ^2-fit of $C_p(f)$ = Im(Y/ω) and $\varphi(f)$ = atan(Im(Y/ω)/Re(Y/ω))

use a 3-parameter ad-hoc parametrisation: $\rho(\eta, V) = \rho_0(V) + \rho_1(V) \cdot e^{-\eta/\lambda(V)}$

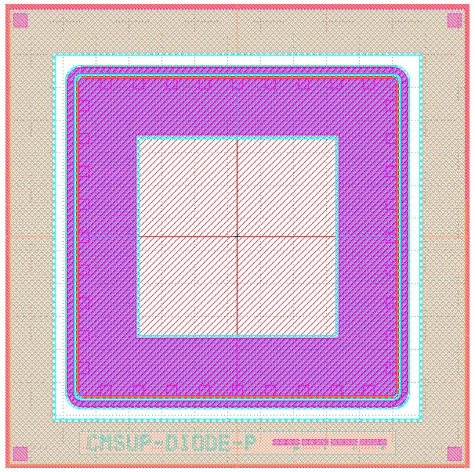
4 different ρ parametrisations used for fits → similar results for $\rho(\eta)$

SENSORS AND MEASUREMENTS

Large diodes from CMS HPK campaign:

1. Material
   - **p-type** (p-stop, p-spray)
     - Thinned **float zone FTH200** (200 µm thick)
2. Irradiations
   - **24 GeV/c**
     - Φ_{eq} = 3 , 6, 7.75, 13•10^{15} cm^{-2}
     - Annealing for **80min@60°C**
3. Measurements
   - Reverse voltage: 0 → 1000 V, **T= -20°C** and **-30°C** , 16 frequencies 100 Hz → 2 MHz (125 x 16 measurements per T and Φ_{eq})
   - Forward voltage: 0 → up to voltage for which current is 0.5 mA , **T= -20°C** and **-30°C** 16 frequencies 100 Hz → 2 MHz
   - n^+-contact and guard ring grounded
   - In addition I_{pad} and I_{guard} measured separately

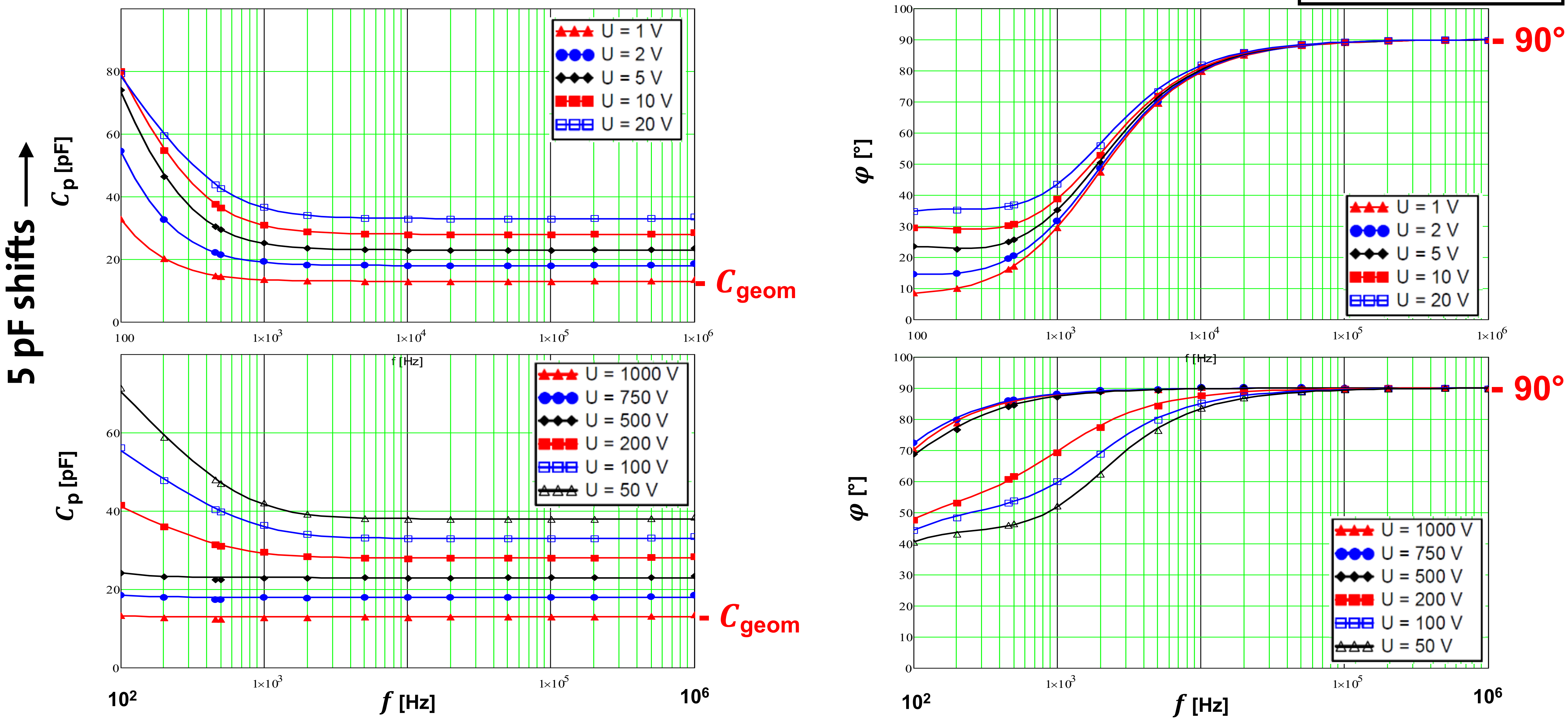
Diode 5mm x 5mm



QUALITY OF Y-F FITS

Fit of *Y(f)* for every V and Φ_{eq}: $\Phi_{eq} = 3\cdot10^{15}$ cm^{-2} and T = -30°C

data: symbols
fits: lines

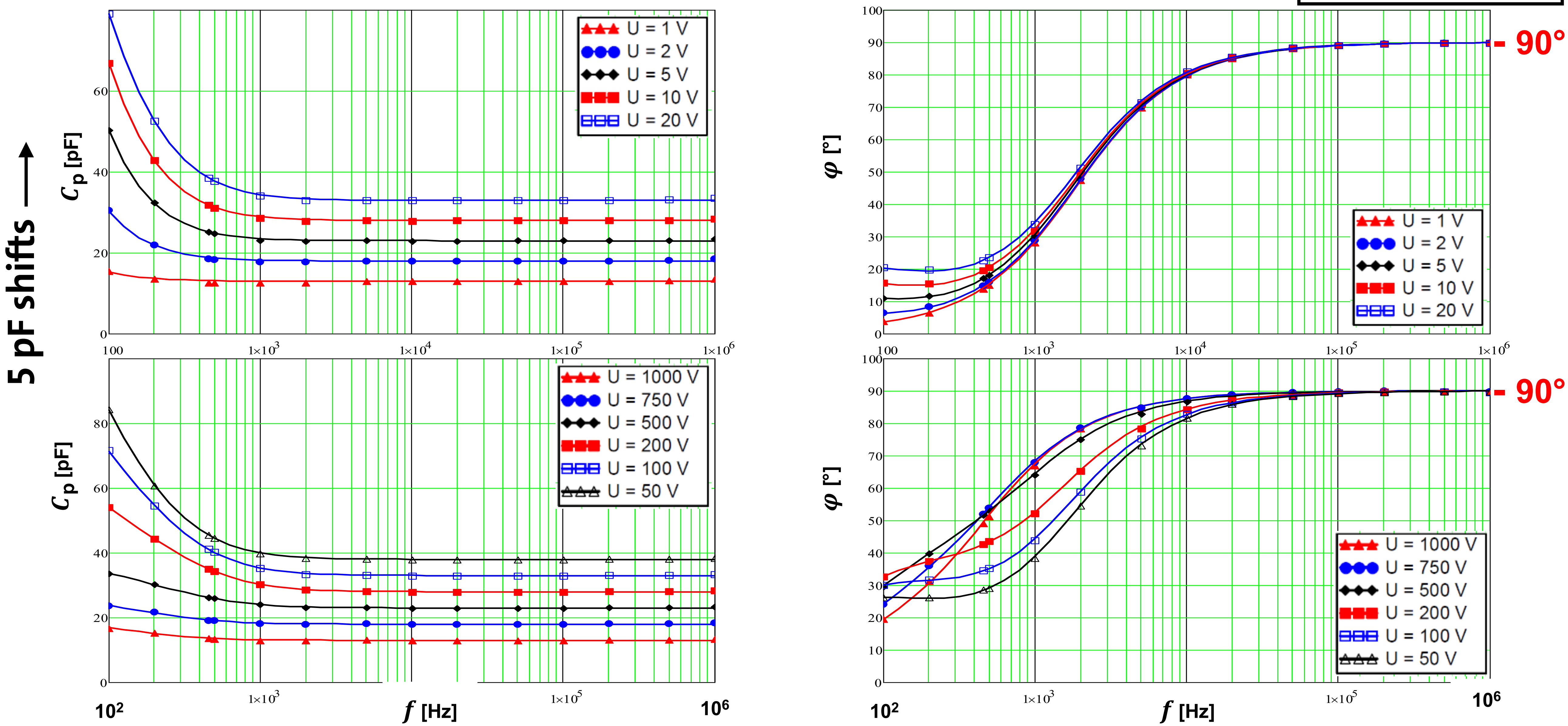


Data described by model: δC ~ 0.5 % , δφ ~ 0.5°

QUALITY OF Y-F FITS

data: symbols
fits: lines

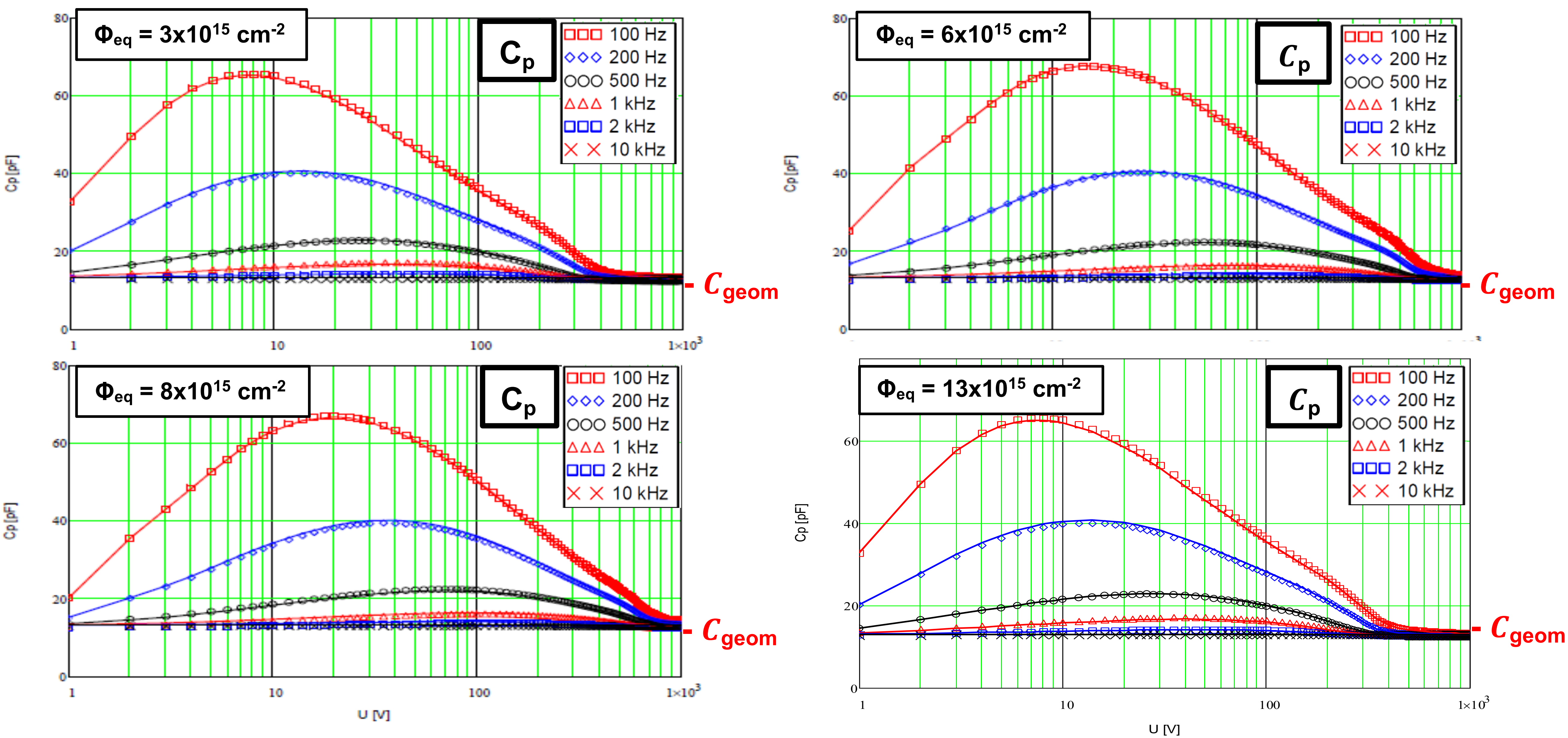
Fit of *Y(f)* for every V and Φ_{eq}: $\Phi_{eq} = 13 \cdot 10^{15}$ cm^{-2} and T = -30°C



Data described by model: δC ~ 0.5 % , δφ ~ 0.5°

QUALITY OF Y-F FITS

$C_p(V,\Phi_{eq})$ for selected f

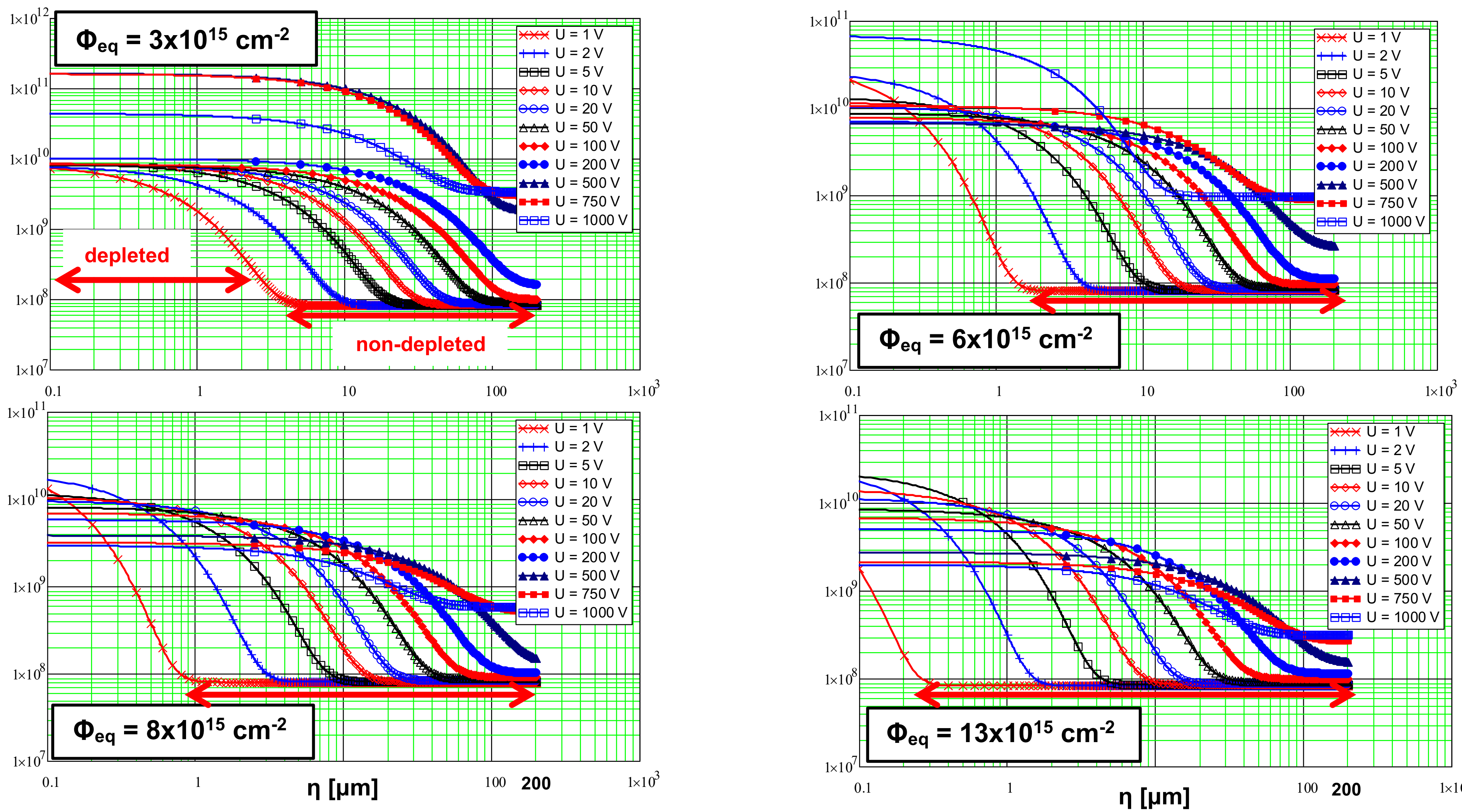


Data described by model: No need for response time of rad.-induced traps

RESISTIVITY

Resistivity $\rho(\eta)$ vs. Φ_{eq}

T = -30°C:
ρ_{intr} = 70 MΩ·cm (calc.)
ρ_{min} = 81 MΩ·cm (fit)
T = -20°C:
ρ_{intr} = 23 MΩ·cm (calc.)
ρ_{min} = 27 MΩ·cm (fit)
Approx. agreement



Non-depleted region:
➡ $\rho \sim \rho_{intr}$ = constant (generation-recombination equilibrium) width decreases with V and increases with Φ_{eq}

Width depleted region:
➡ increases with V and decreases with Φ_{eq} for V > 500 V → fully depleted
➡ For high ρ, ρ is only poorly determined

η-region with $\rho \gg \rho_{intr}$ → "effective" depletion depth

SUMMARY

Frequency dependence of Y

- Simple model with a position-dependent resistivity $\rho(\eta)$ describes the $Y(f;V,\Phi_{eq})$ data of highly-irradiated sensors
- Low field region with $\rho \sim \rho_{intr}$, which decreases with V and increases with Φ_{eq}
- High $\rho \rightarrow$ depleted region, high field region increases with V until the entire sensor is depleted
- No need to include the response-time of radiation-induced traps in the model!!!

Progress towards understanding of the f-dependence of *C* but the understanding of the results is not so clear

Thank you for your attention!