

Impurity profile from CV measurements

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AGATA week Legnaro
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Capacitance voltage analysis

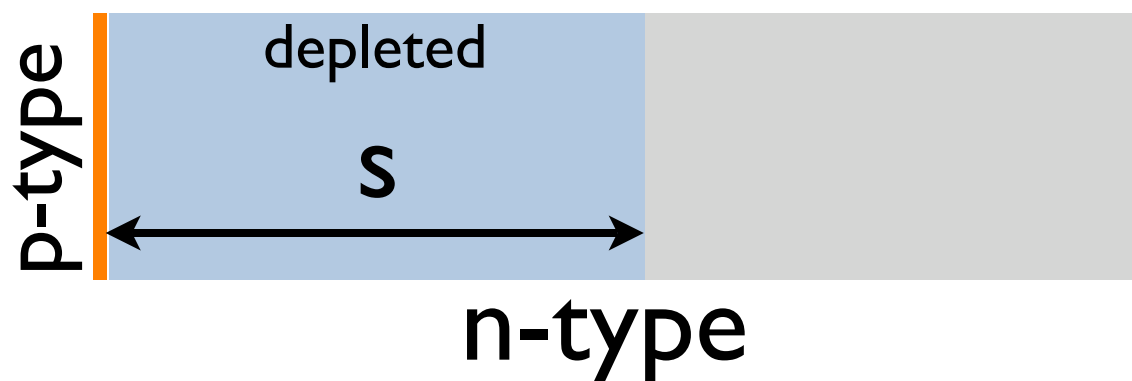
Poisson equation:

$$\nabla^2 \varphi = -\frac{\rho}{\epsilon}$$

planar diode:

$$C = \frac{\epsilon A}{s}$$

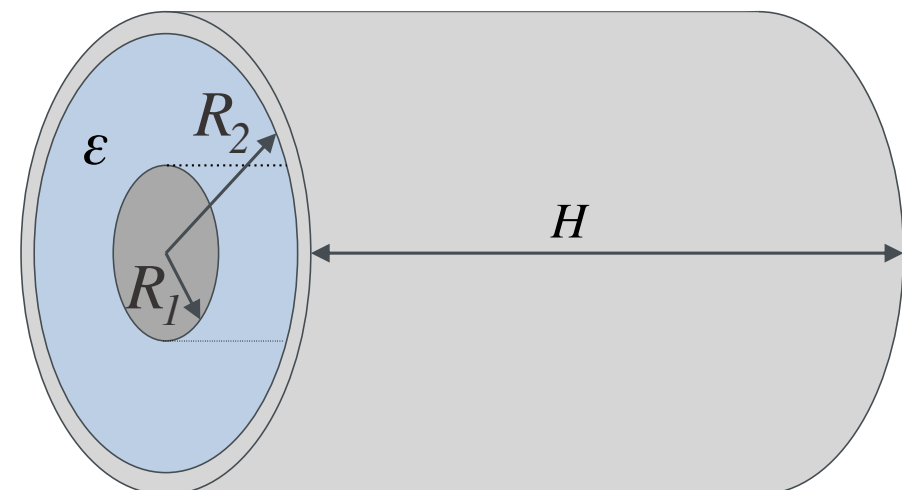
$$N_D = -\frac{C^3}{\epsilon e A^2} \left(\frac{dC}{dV} \right)^{-1}$$



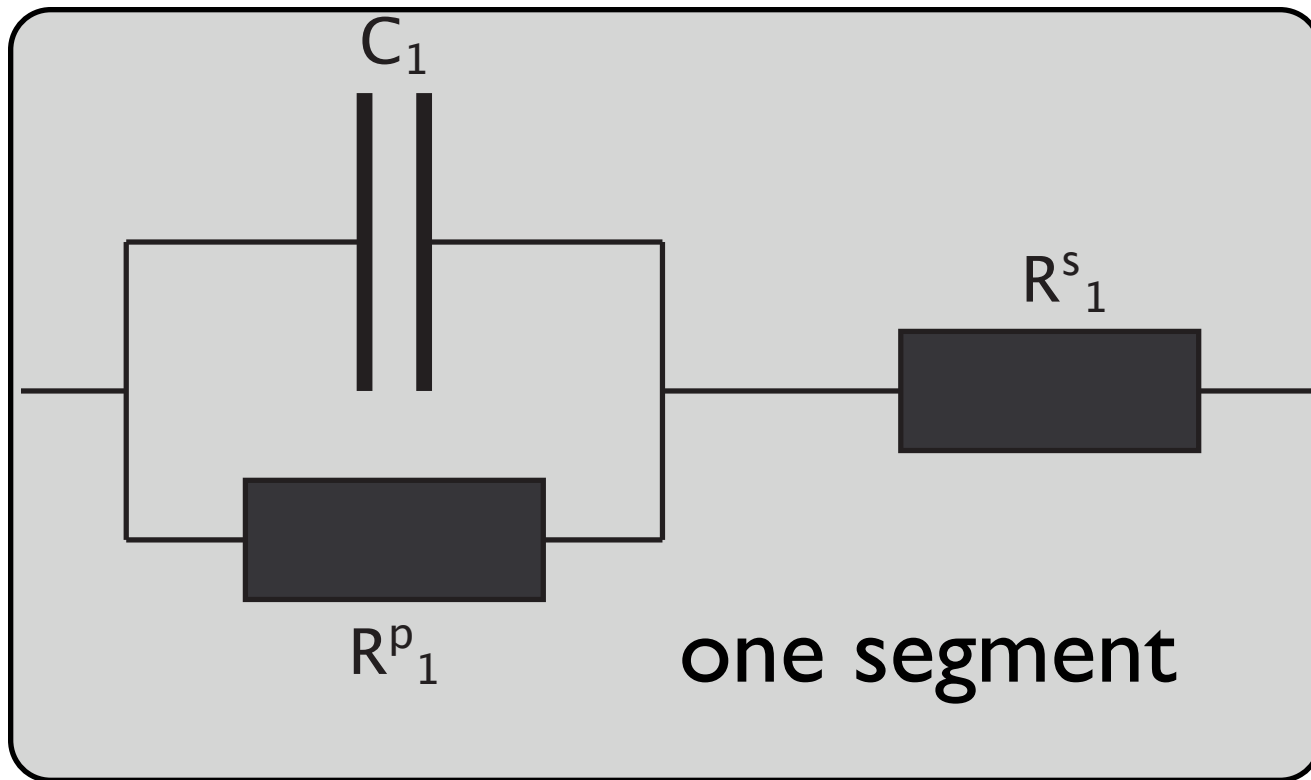
cylindric diode:

$$R_1^2 = R_2^2 e^{-\frac{4\pi\epsilon H}{C}}$$

$$N_D(R_1) = -\frac{C^3 e^{\frac{4\pi\epsilon H}{C}}}{4e\pi^2 H^2 \epsilon R_2^2 \frac{dC}{dV}}$$



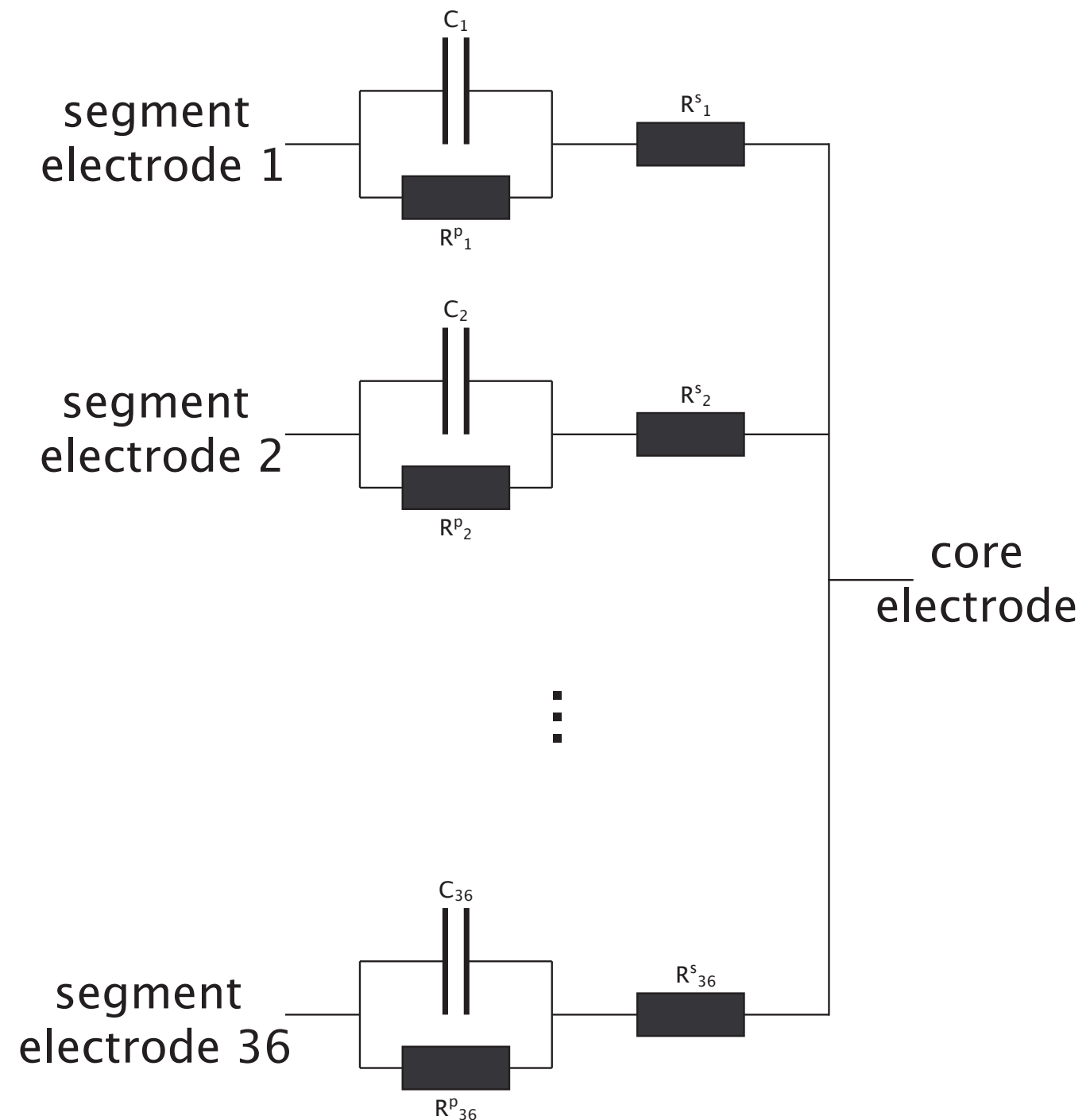
Model



$$36 \text{ pF} < C_{\text{total}} < 3,5 \text{ nF}$$

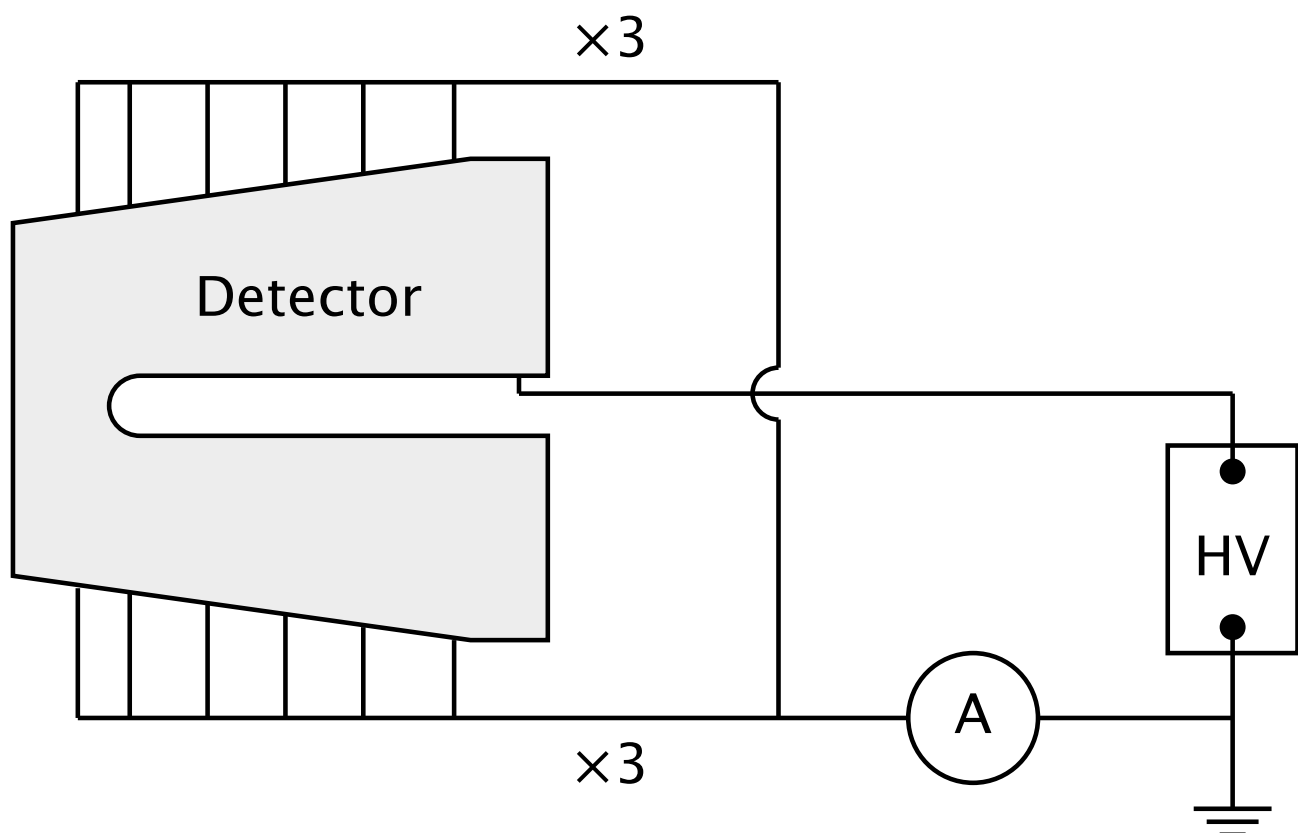
$$0 \leq R_{\text{total}}^s < 2 \text{ k}\Omega$$

$$R_{\text{total}}^p \sim \text{G}\Omega$$

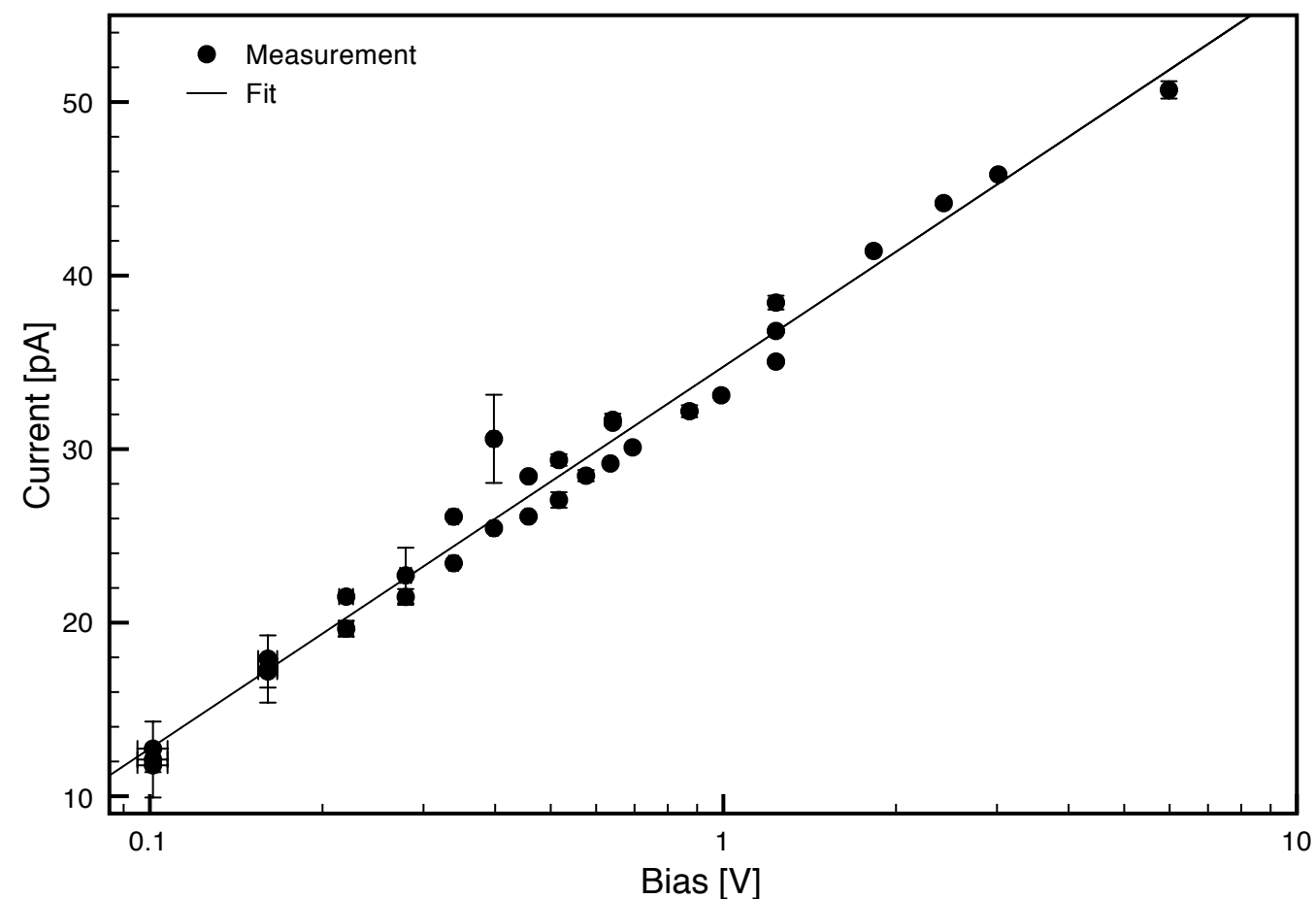
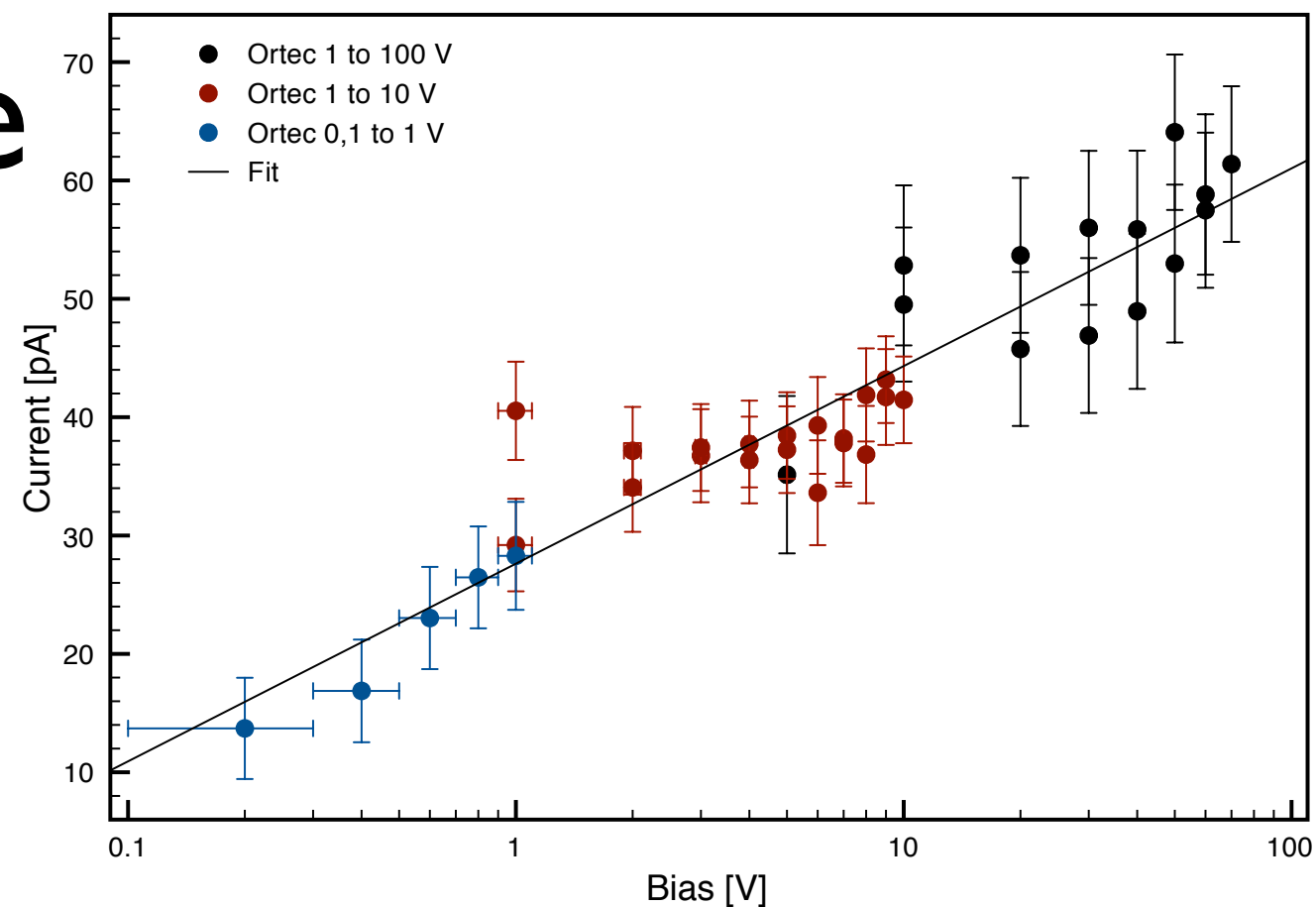


Characteristic curve

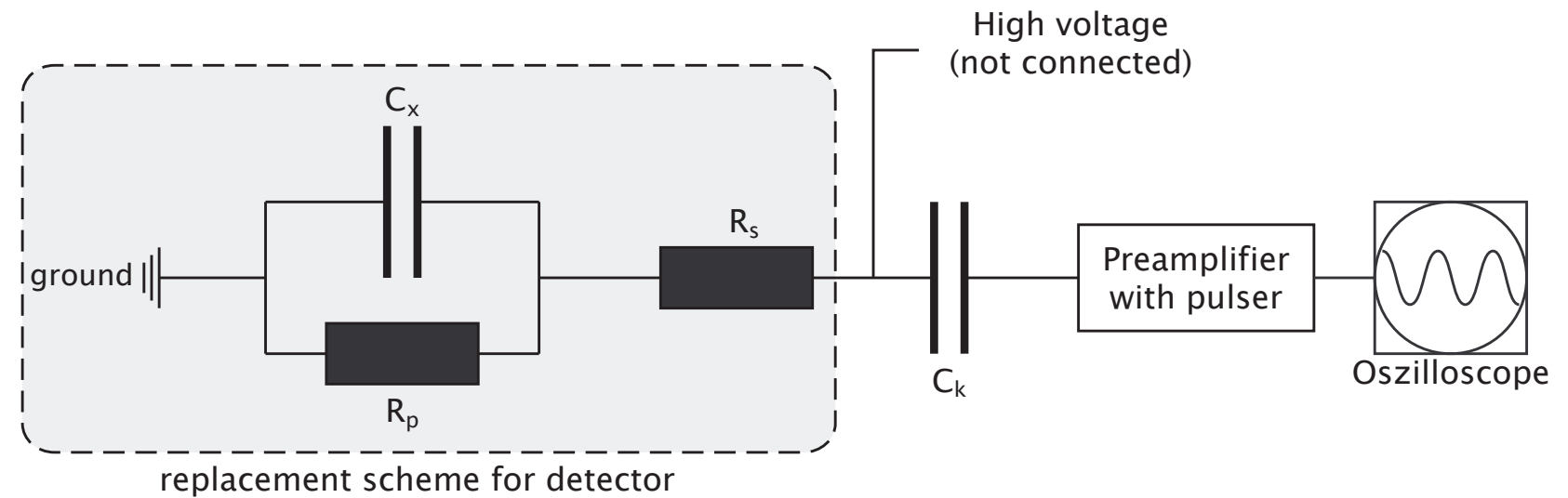
Detector S002
in the symmetric
triple cryostat



above 10 V: $R_{\text{total}}^{\text{P}} > 200 \text{ G}\Omega$



Capacity measurement with pulser

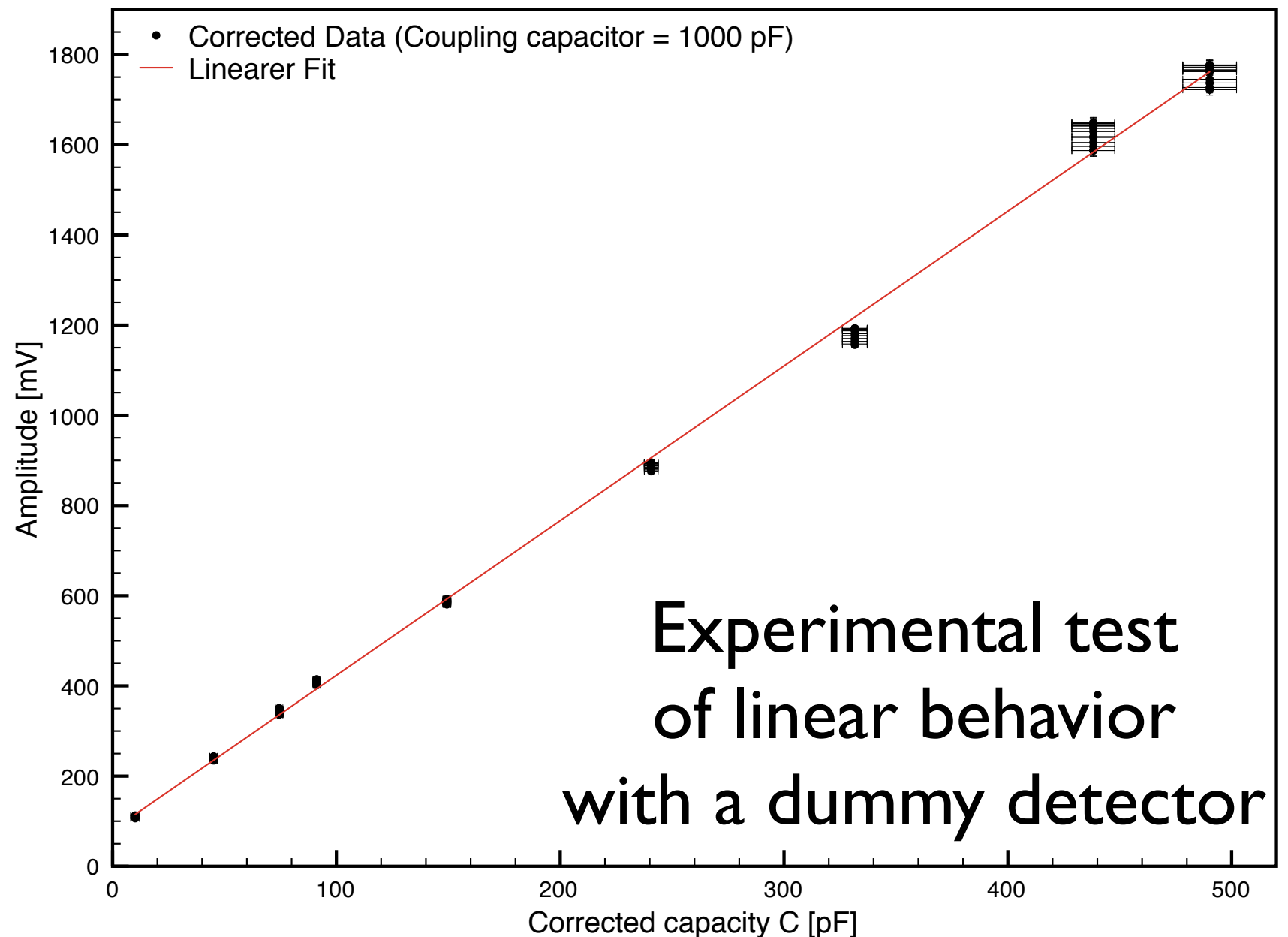


Pulser amplitude is a linear function of the detector capacitance

$$V_{\text{out}} = \left(\frac{C_{\text{FB}} + C_{\text{DET}}}{C_{\text{FB}}} \right) V_{\text{in}^*}$$

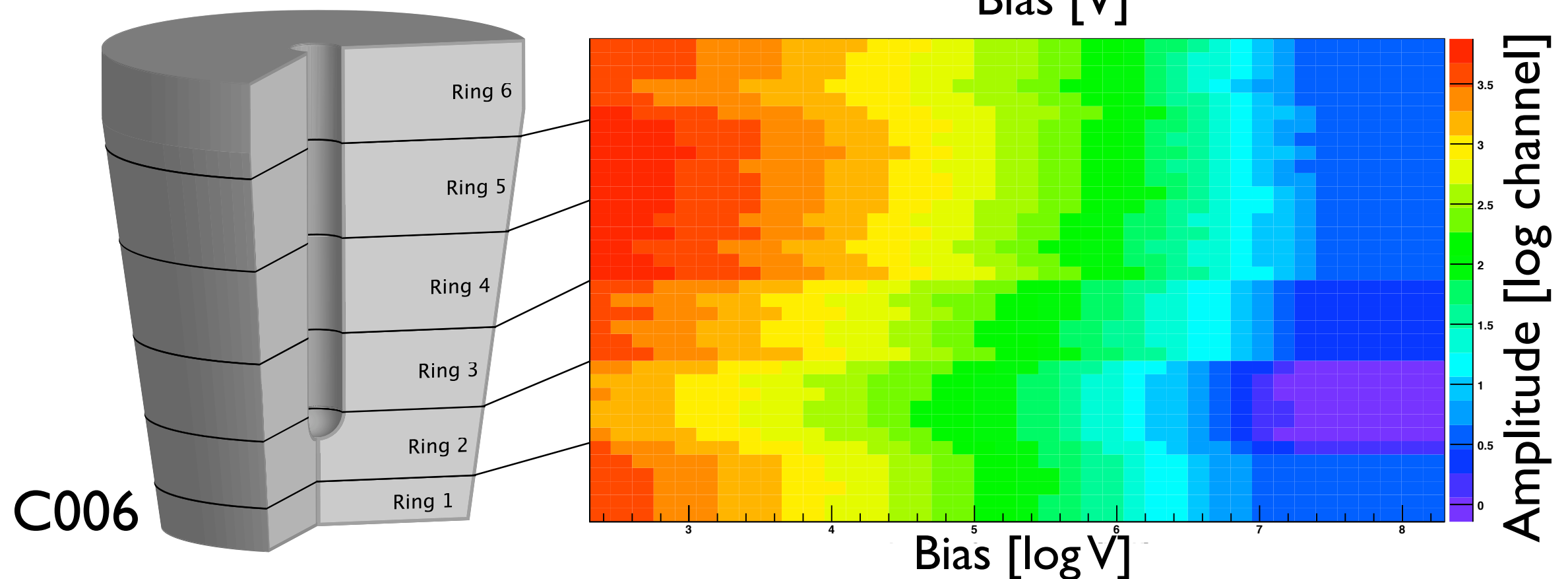
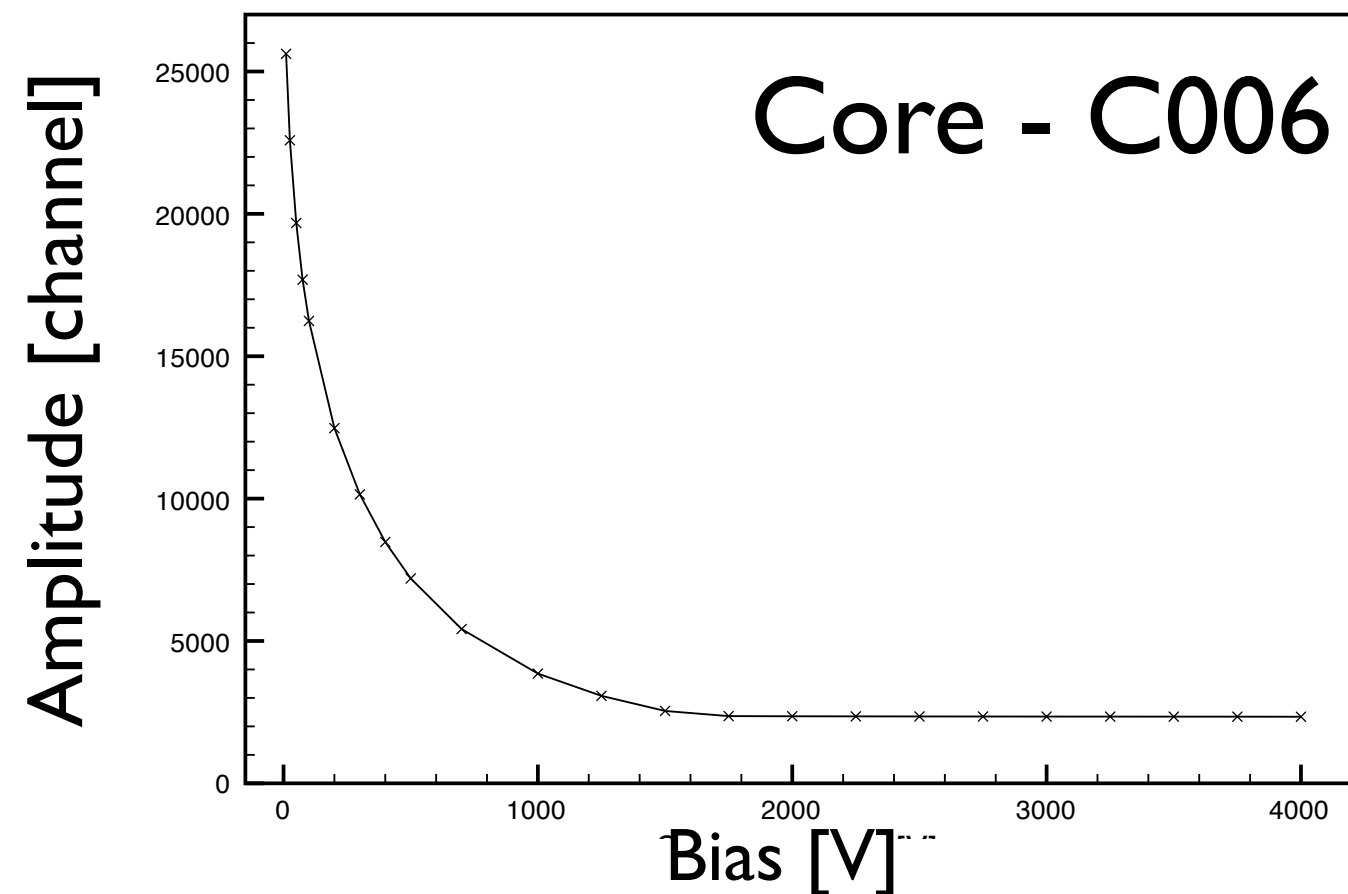
Segment signals

$$I_j = \frac{C_j}{\sum_{i=1}^{36} C_i} I_C$$



Pulsar measurements

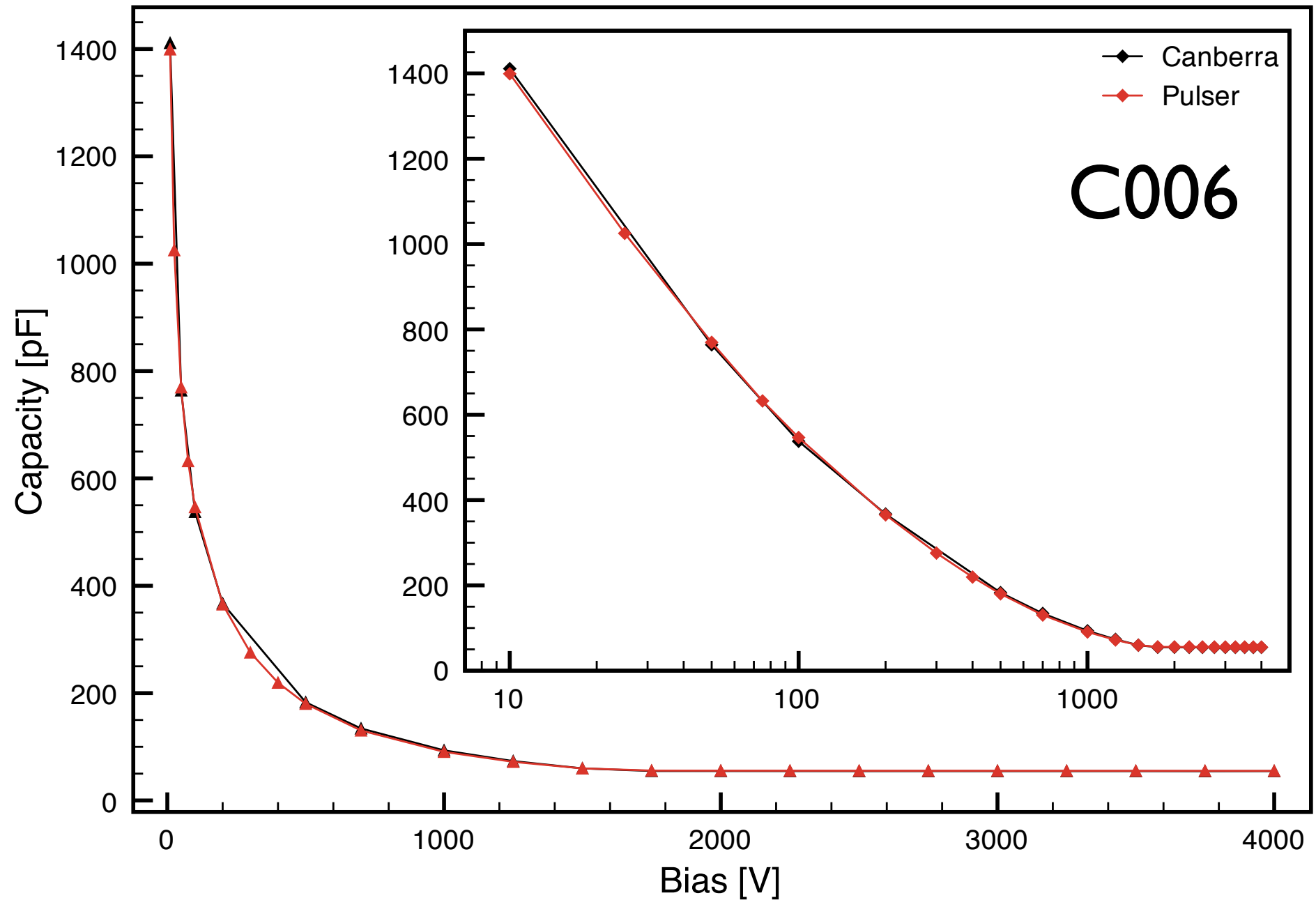
Detector	Segments
A003	no
B003	no
B005	yes
C005	yes
C006	yes
S002	yes



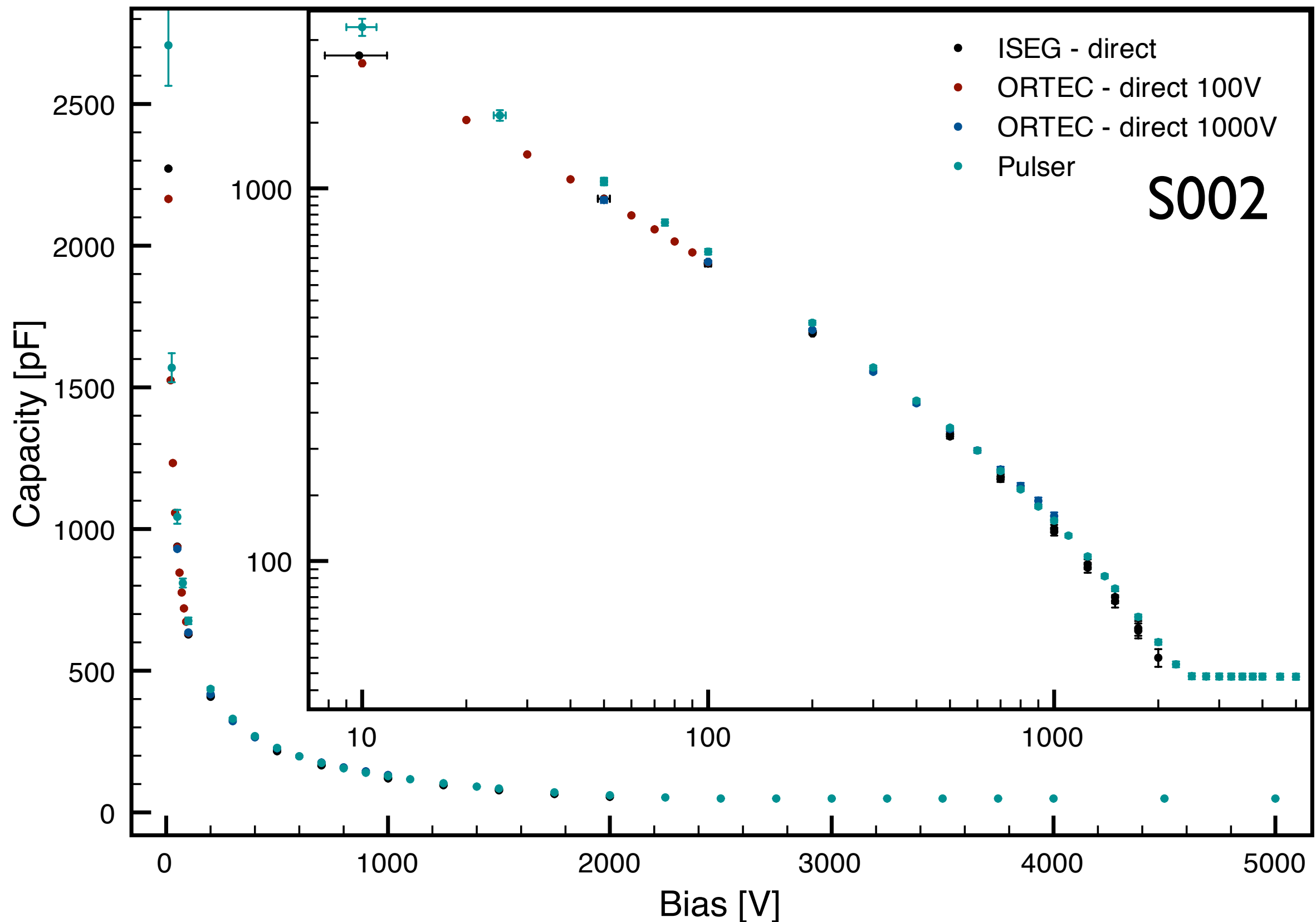
Normalisation

Relative pulser amplitudes are normalised to absolute values in Farad

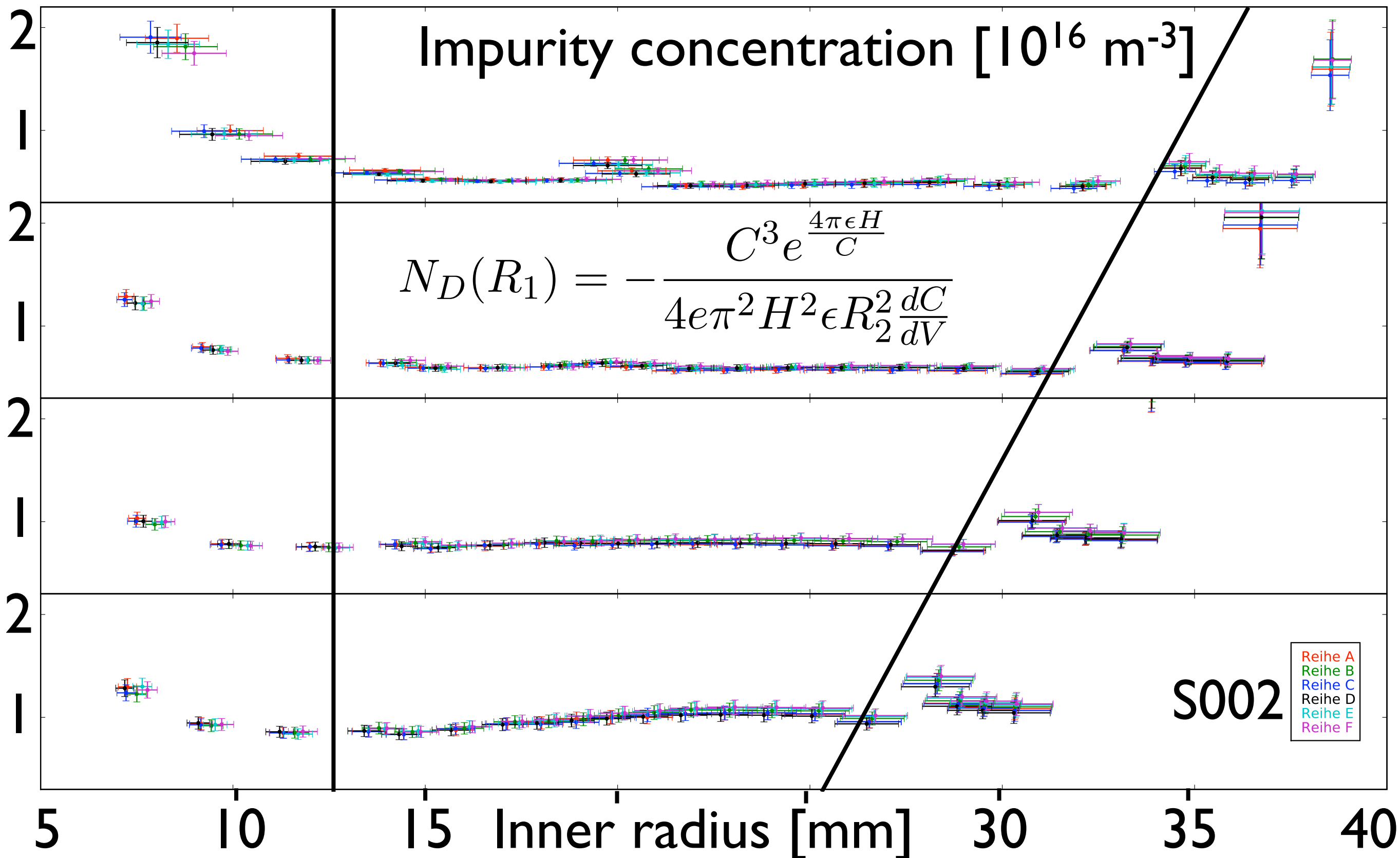
Corrections for coupling capacitors are applied



Comparison between pulser and direct measurement



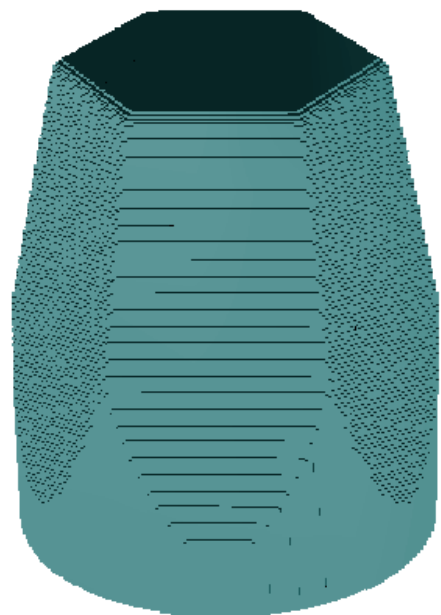
Analysis cylinder symmetry



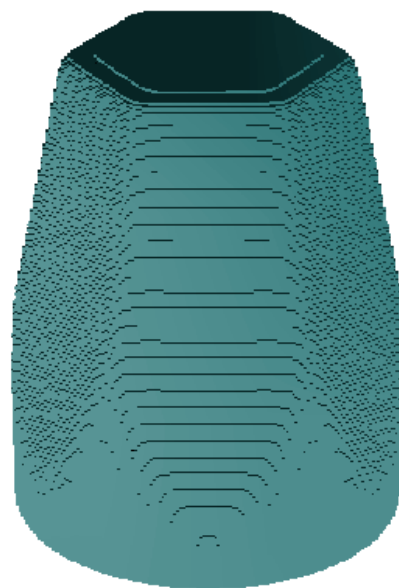
Computer simulations

Iterative solution of Poisson's equation

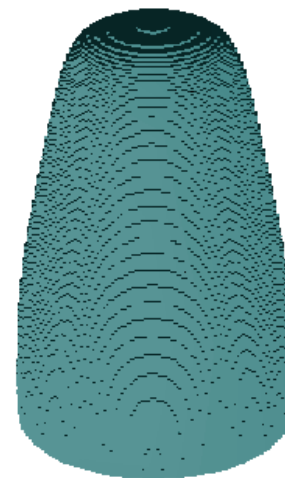
$$\nabla^2 \varphi = -\frac{eN(x)}{\epsilon}$$



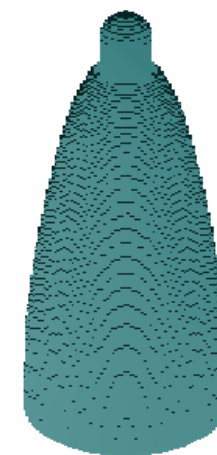
10 V



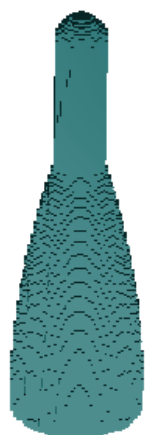
100 V



1000 V



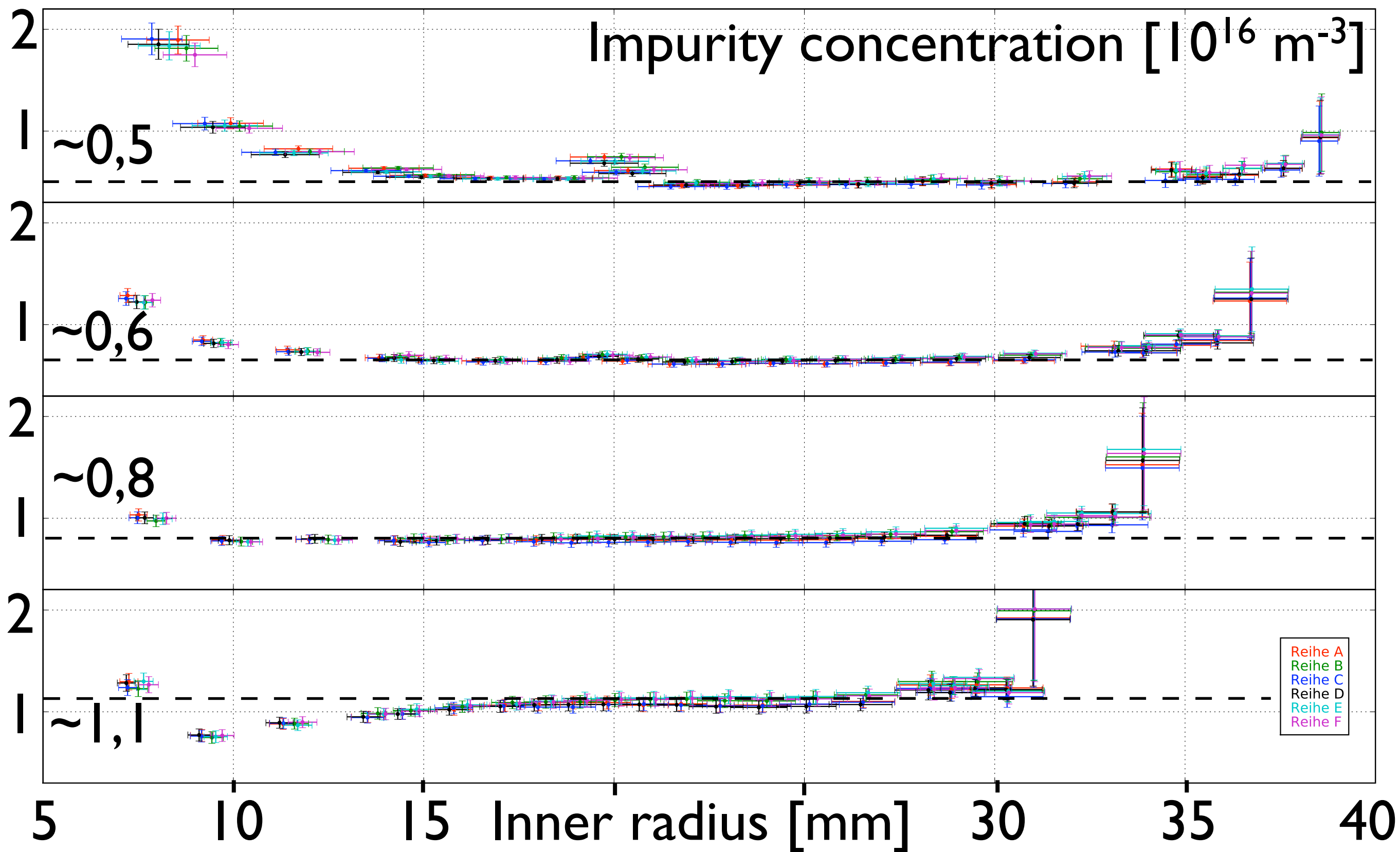
2000 V



3000 V

Border between depleted and non depleted area

Corrected Impurity Distribution

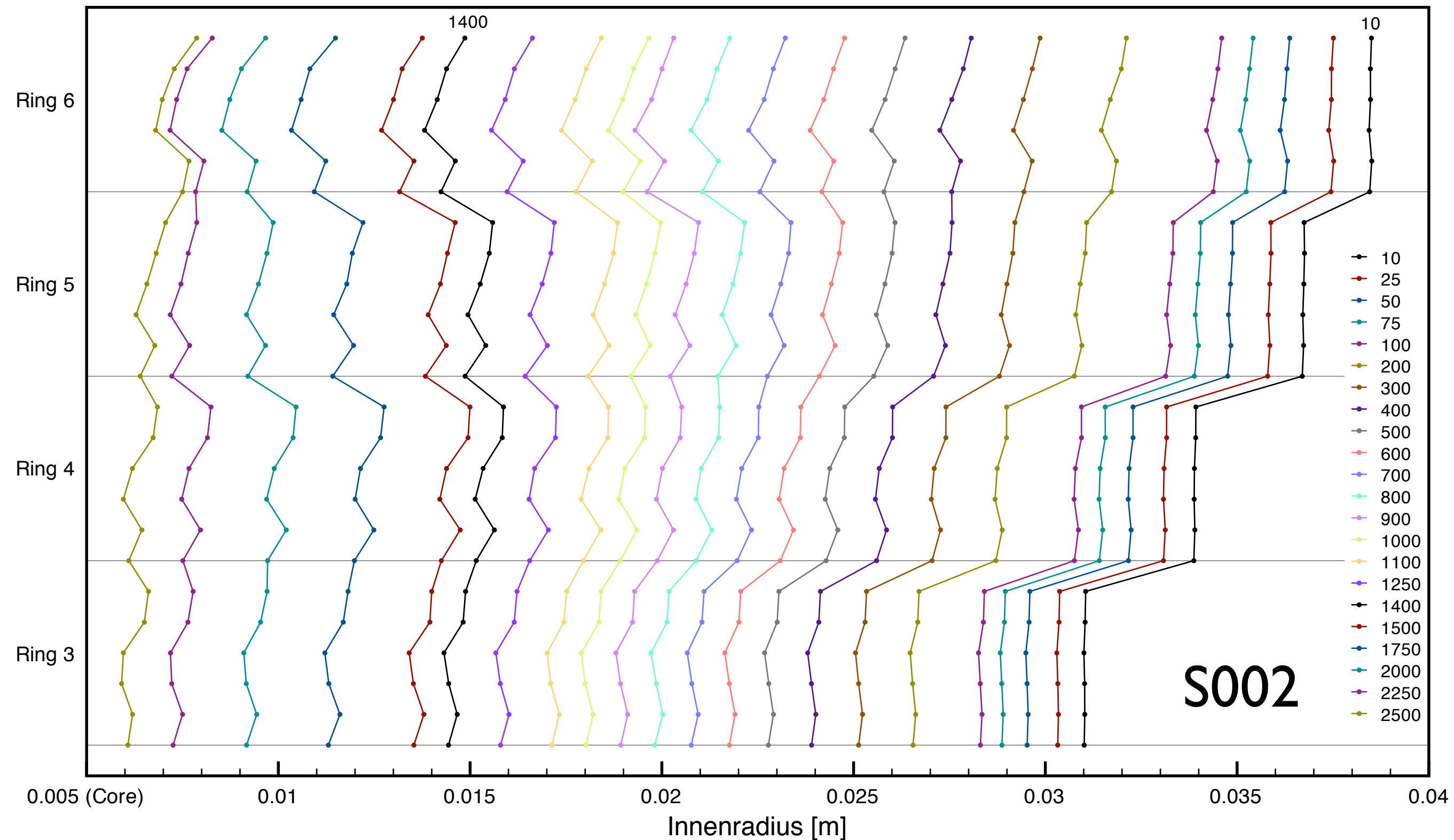


Summary

- Characteristic curve measured first time for an AGATA detector
- New capacity measurement with pulser
 - fast method with good resolution
 - no extra equipment needed
 - many crystals could be measured at the same time
- Impurity concentration measured for the last four rings of S002
 - gradient as expected from back to front
 - no radial dependency, at least for S002
 - a hint for some distortion in the last ring at 20 mm radius
- Computer simulations are used for precise reconstruction

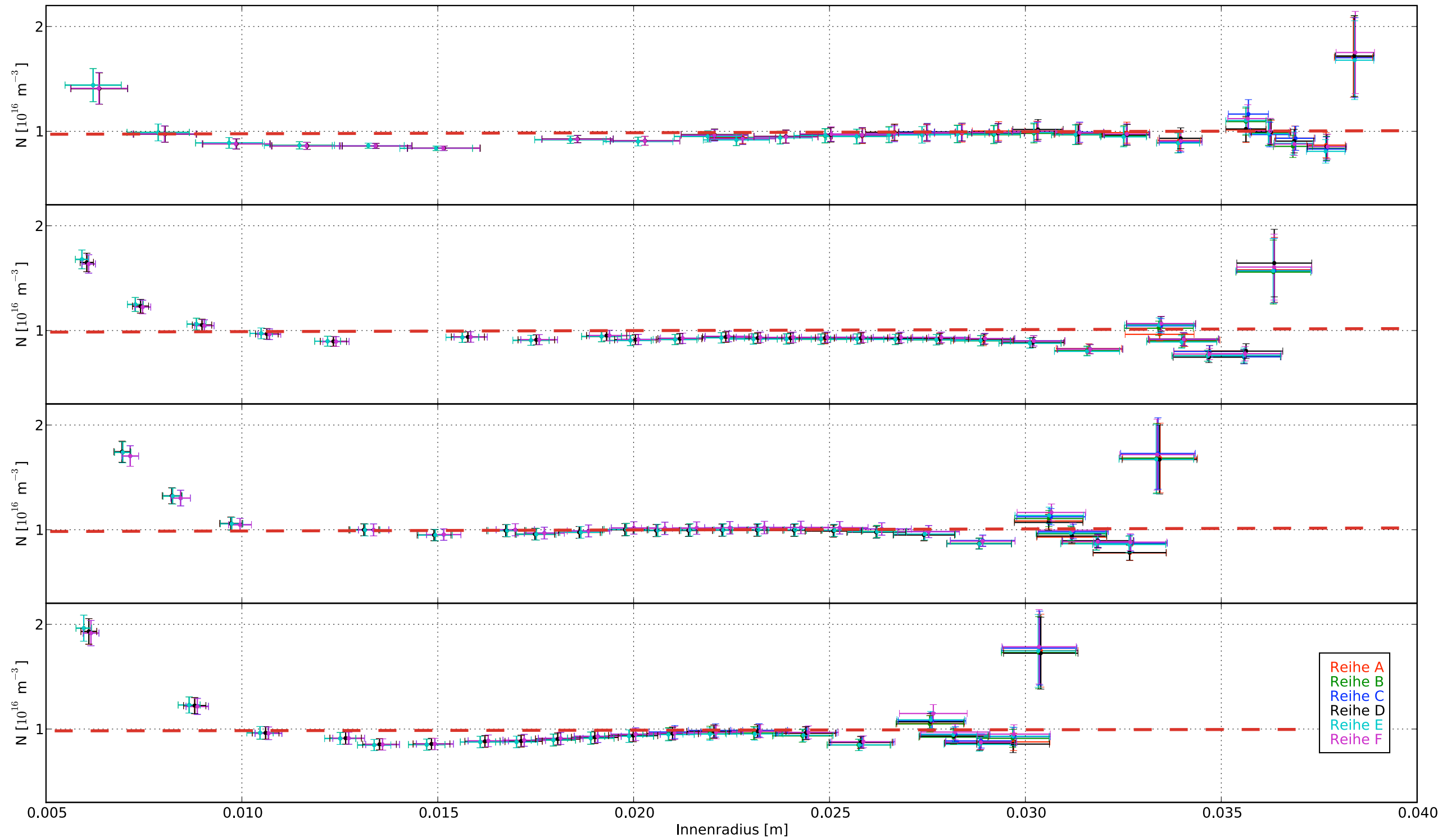
Thanks for your attention!

Ausdehnung der Verarmungszone

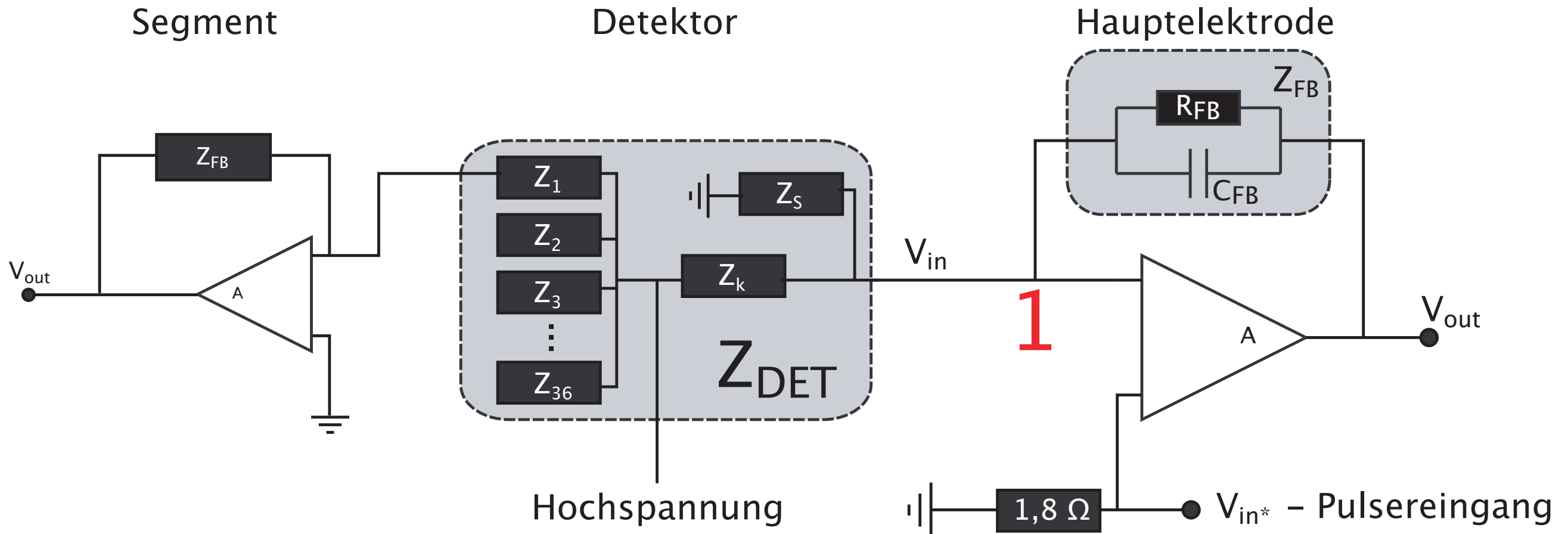


Korrektur

Computersimulation mit homogener Verunreinigung



Kapazitätsmessung mit Hilfe des Pulsers



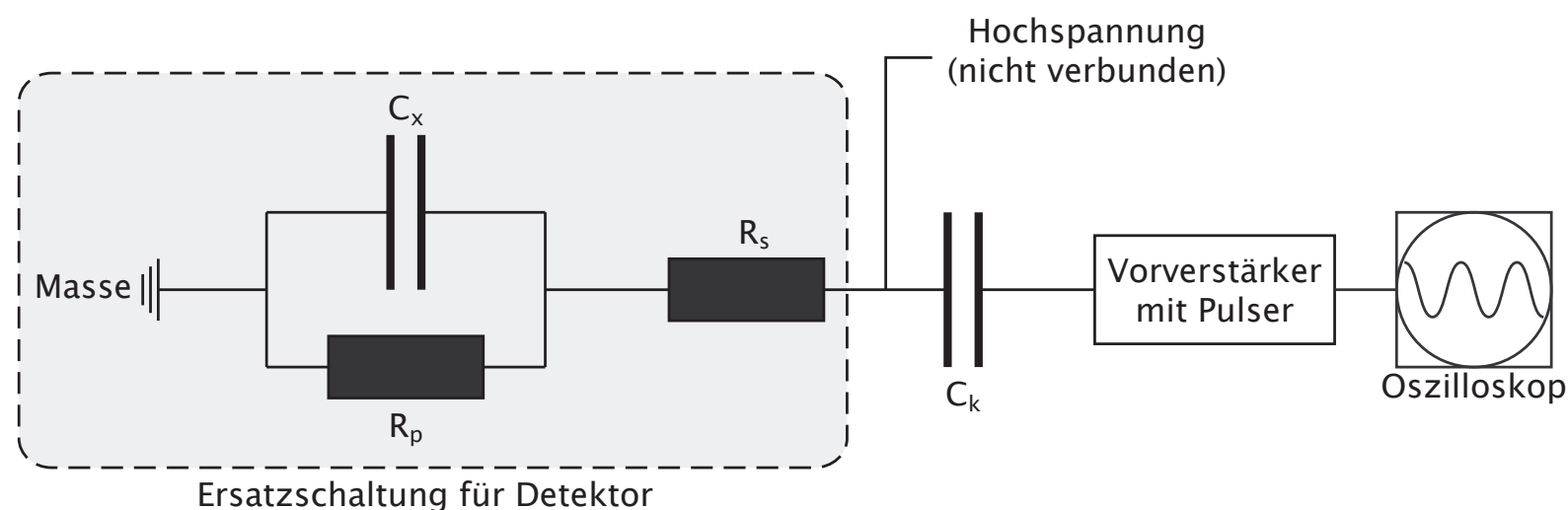
Core - Vorverstärker

$$V_{out} = \left(\frac{C_{FB} + C_{DET}}{C_{FB}} \right) V_{in}^*$$

Segment - Signale

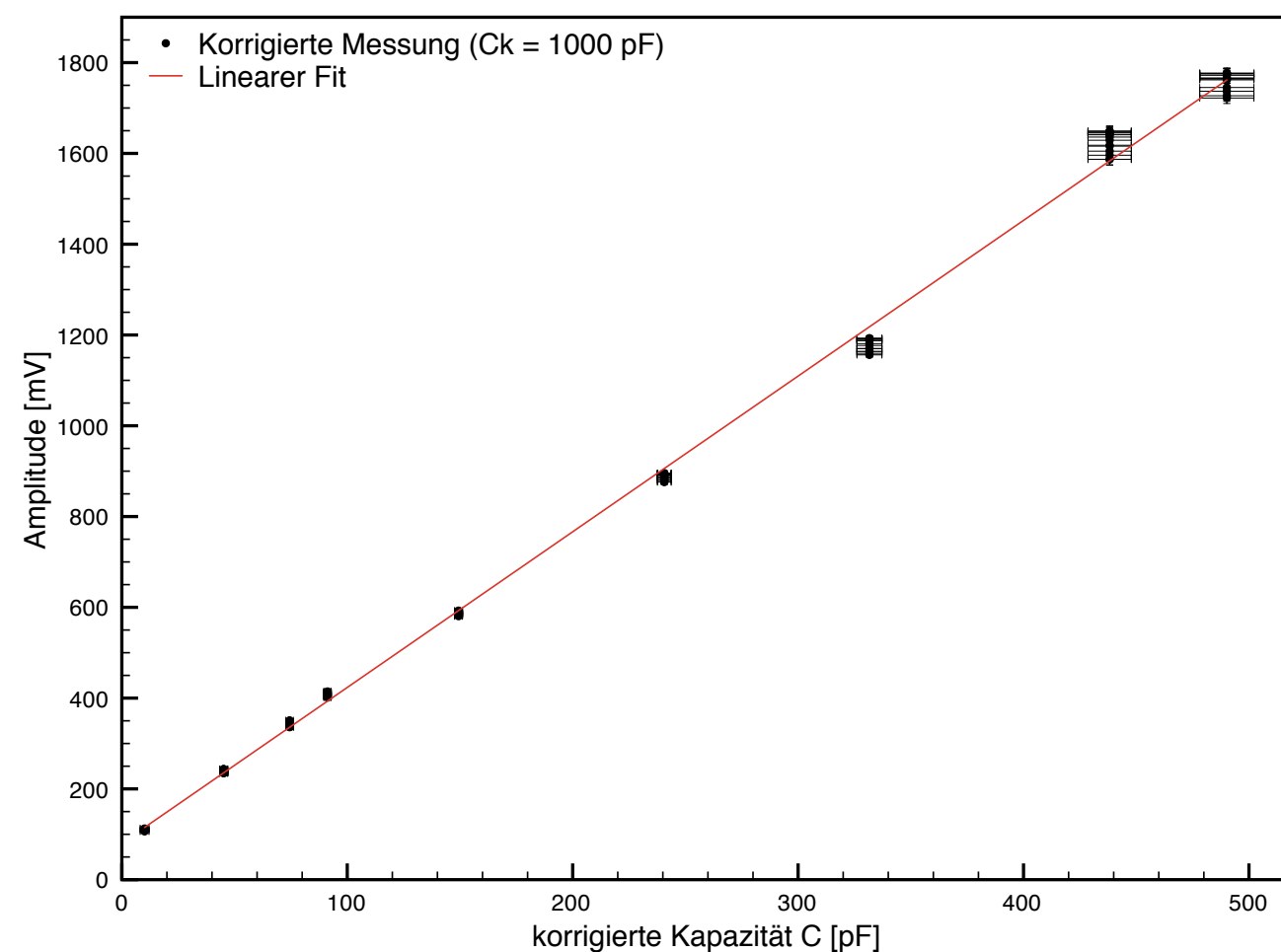
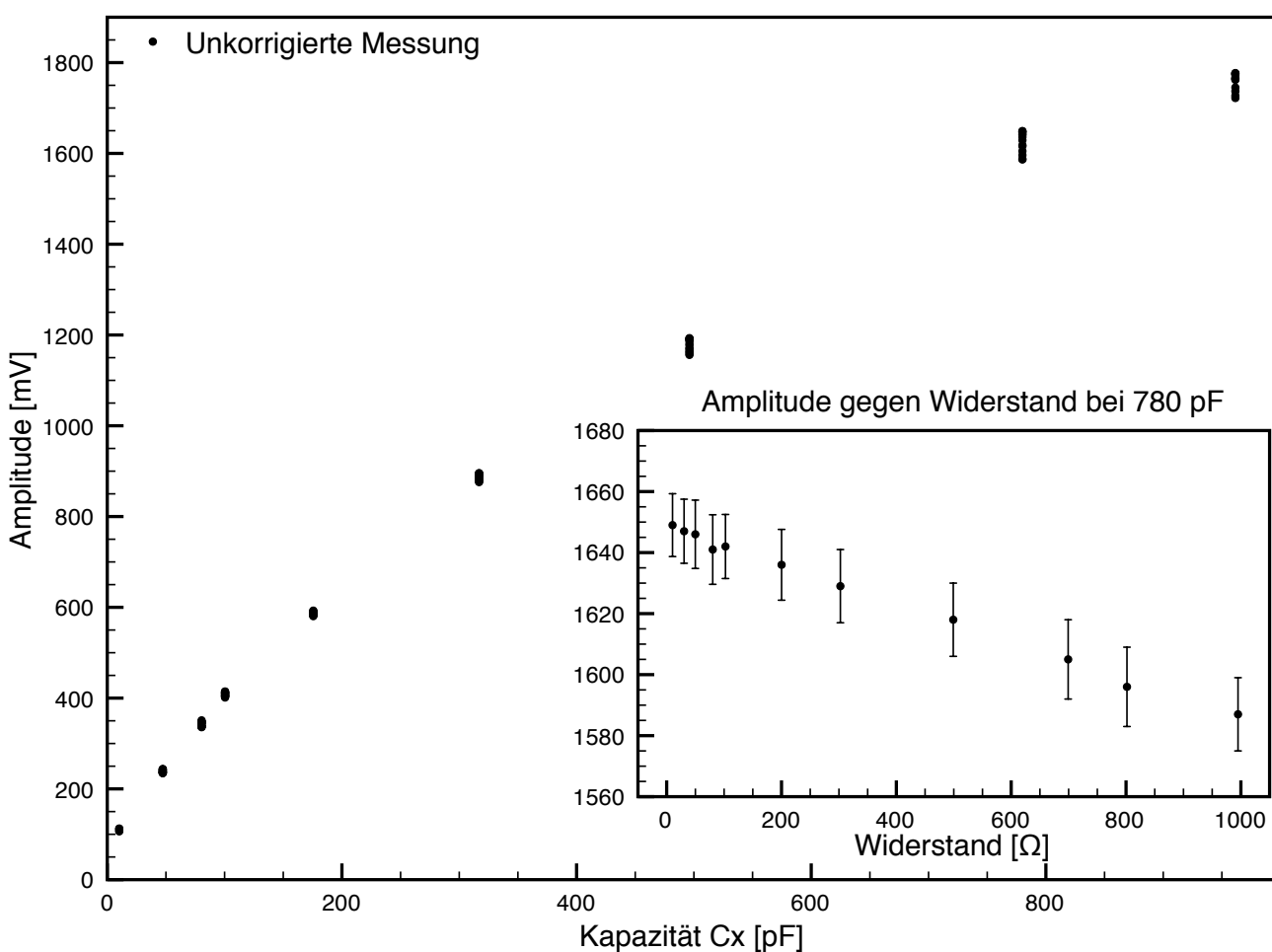
$$I_j = \frac{C_j}{\sum_{i=1}^{36} C_i} I_C$$

Testmessungen mit Ersatzschaltung

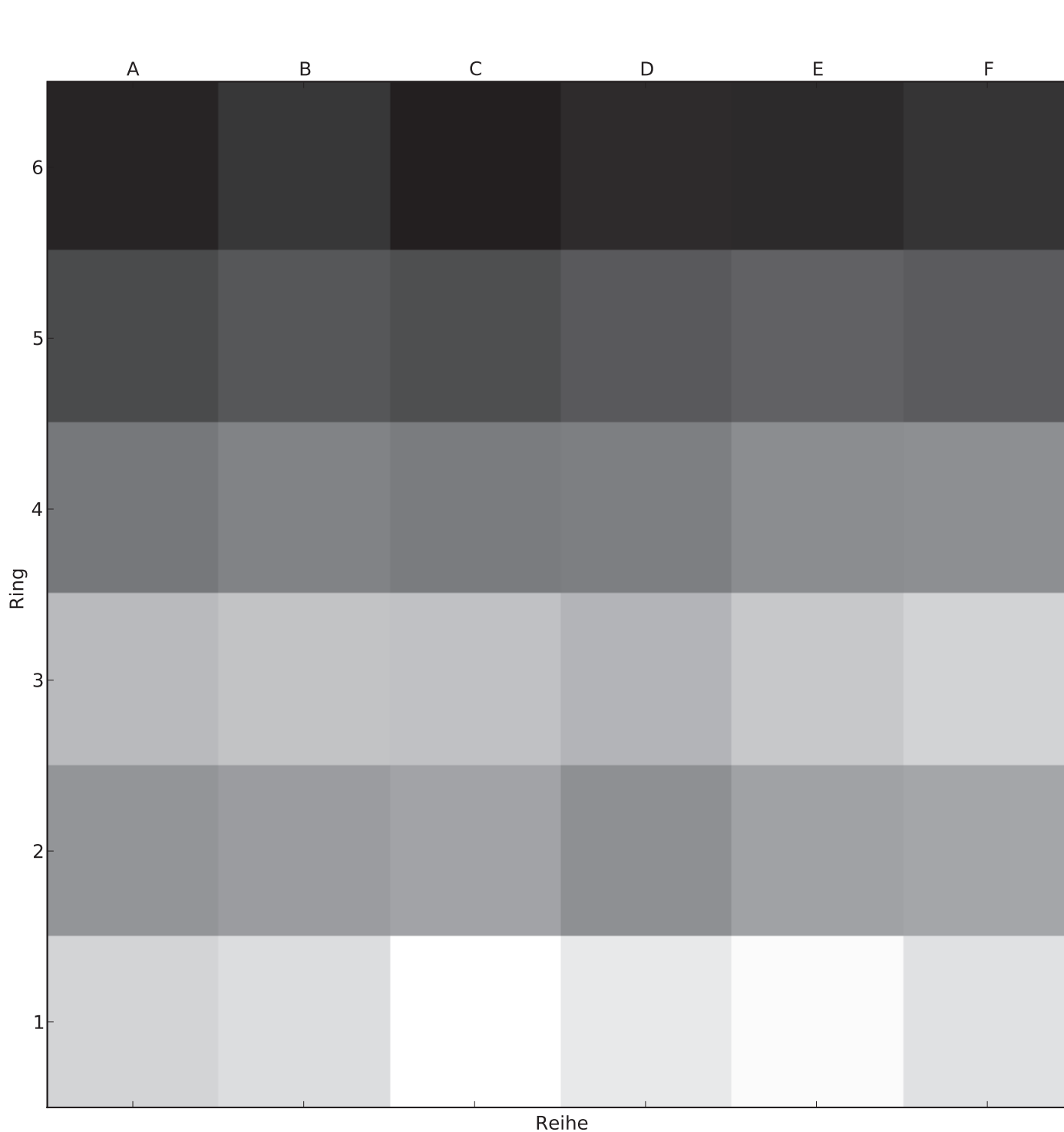


Korrektur des Koppelkondensators nötig

$$C = \frac{C_x \cdot C_k}{C_x + C_k}$$

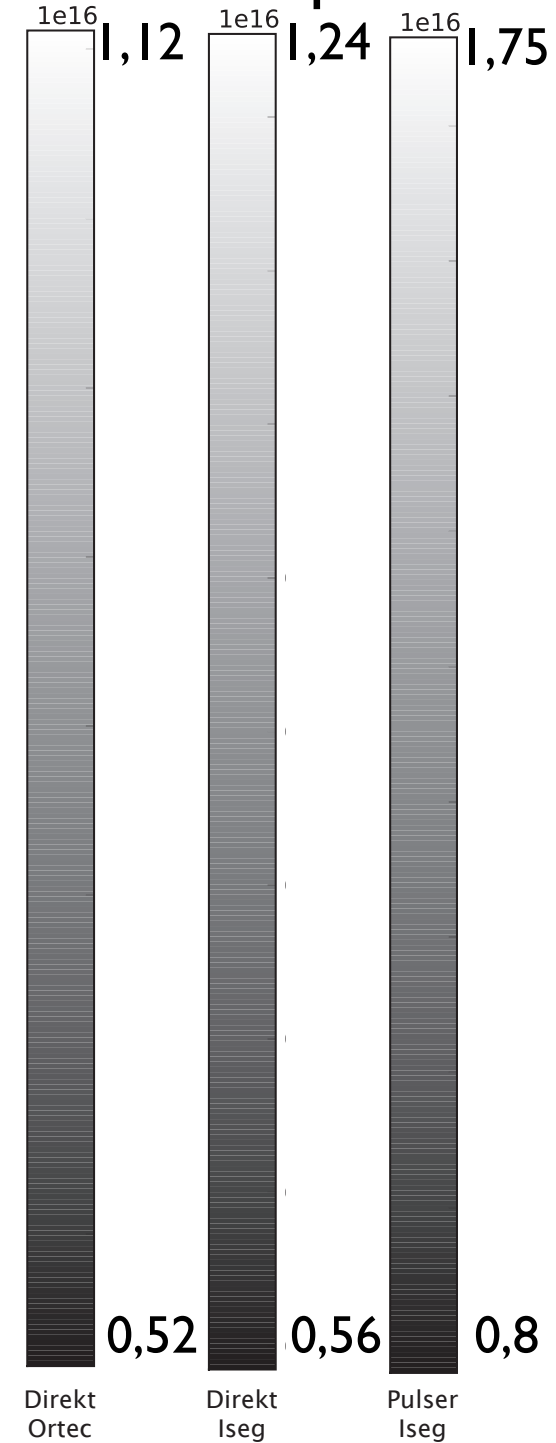


Surface analysis



S002

10^{16} Atoms per m^3



At 10 V:

$$C = \frac{\epsilon}{s} \simeq \sqrt{\frac{e\epsilon N_D}{2V}}$$



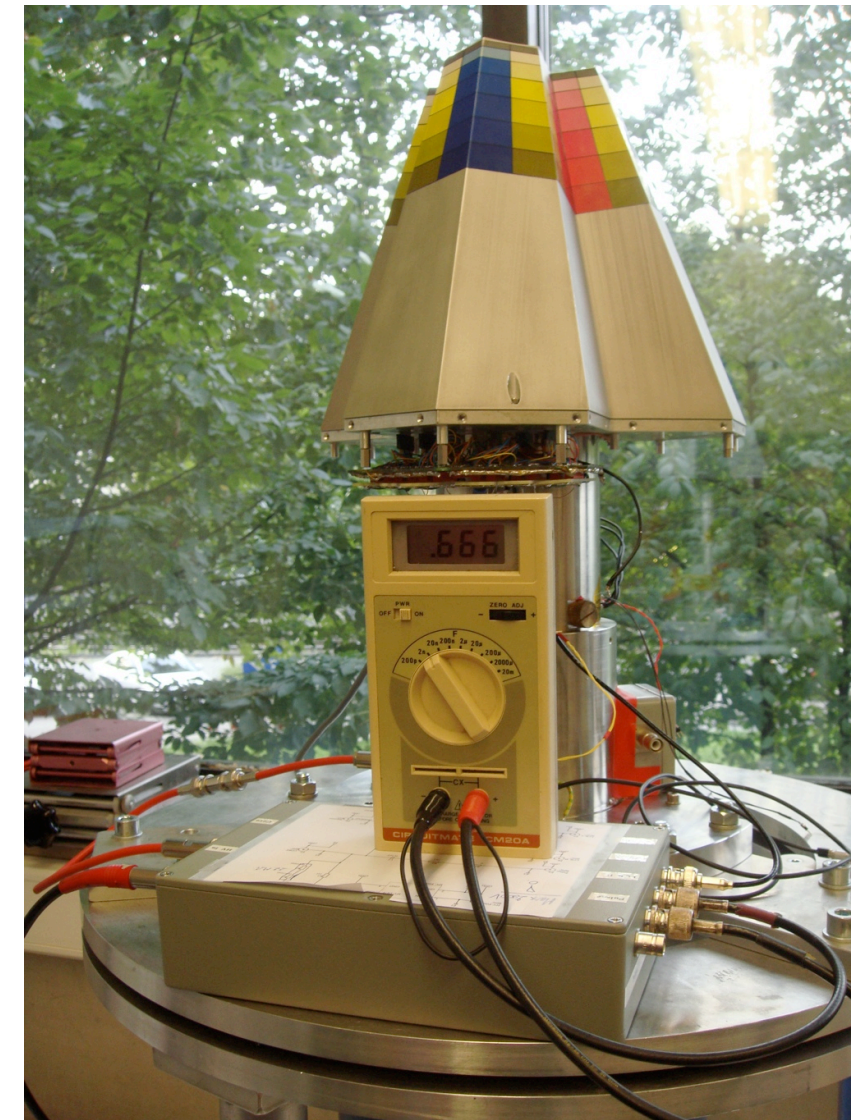
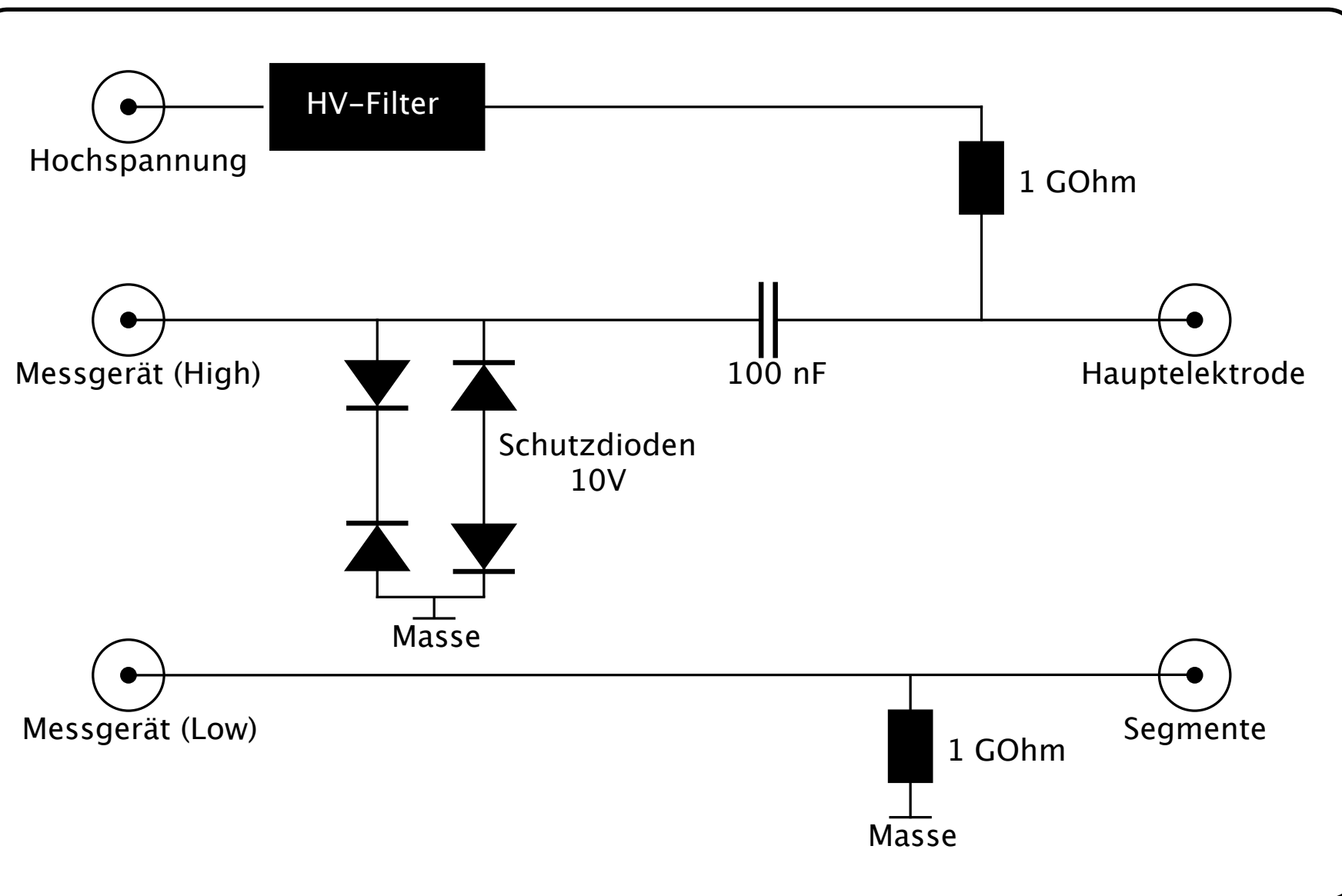
$$N_D \simeq \frac{2VC^2}{e\epsilon A^2}$$

producer info:

0.51 (Ring 6)

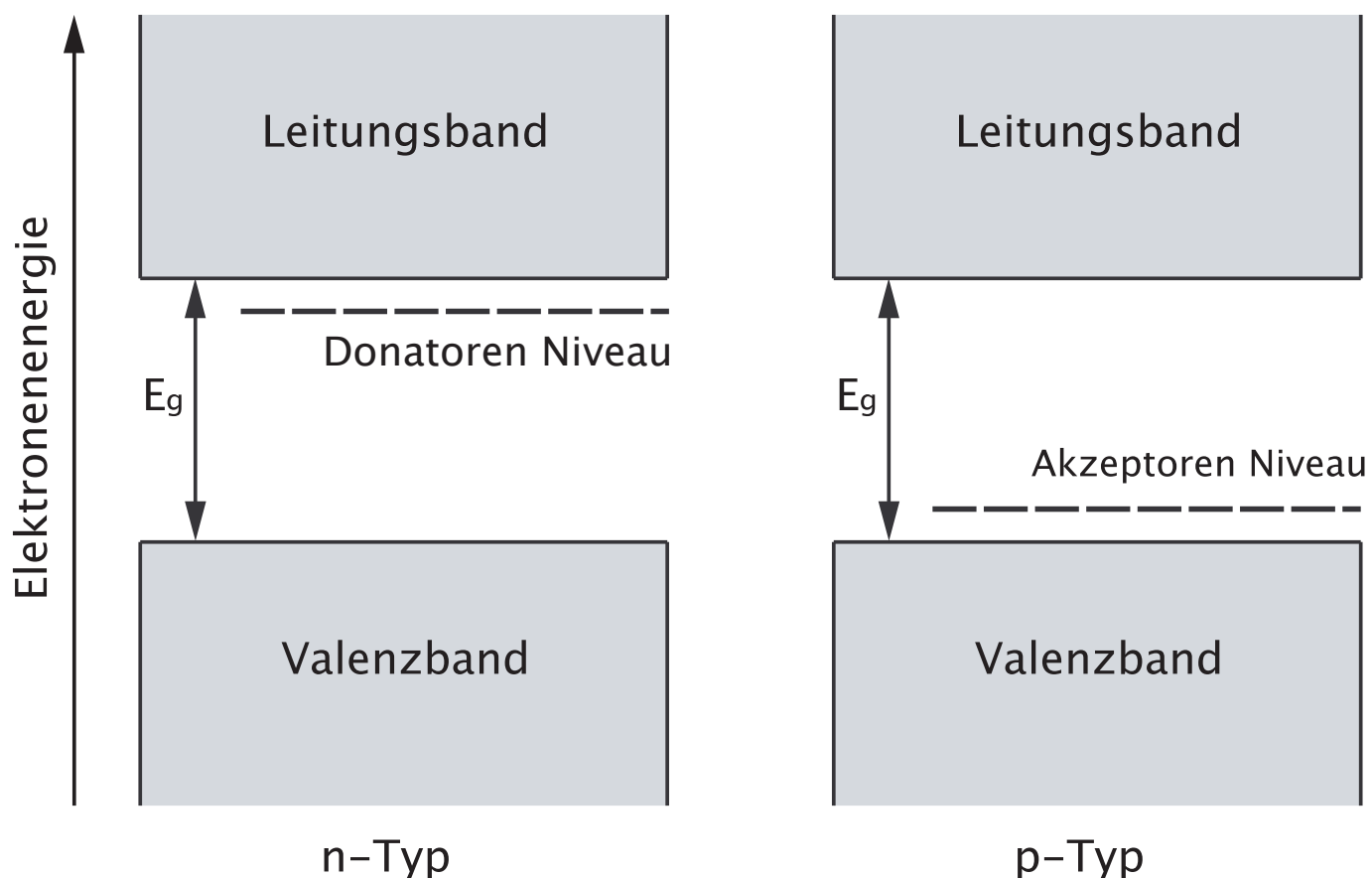
1.80 (Ring 1)

Direkte Messung



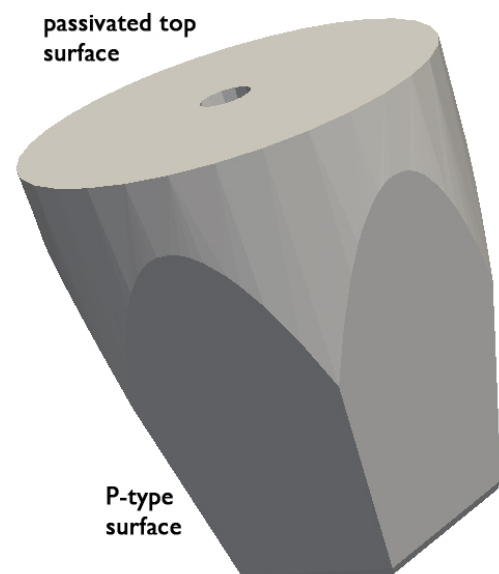
Kapazitätsmessgeräte müssen geschützt werden

Halbleiter und Verunreinigungen



	14 Si Silicium 28,086 2/8/4	32 Ge Germanium 72,59 2/8/18/4
Elektronen - Lochpaar [eV]	3,76	2,96
Energielücke [eV]	1,1	0,7
Dielektrische Konstante	12	16
Mobilität Elektron bei 300 / 90 K [cm^2 / Vs]	1350 / 20 000	3900 / 40 000
Mobilität Loch bei 300 / 90 K [cm^2 / Vs]	480 / 10 000	1900 / > 50 000

Ein AGATA-Detektor ist aus n-Typ Germanium mit einer Verunreinigungskonzentration von $0,4$ bis $1,8 \times 10^{16}$ Atomen pro Kubikmeter (99,99 %).



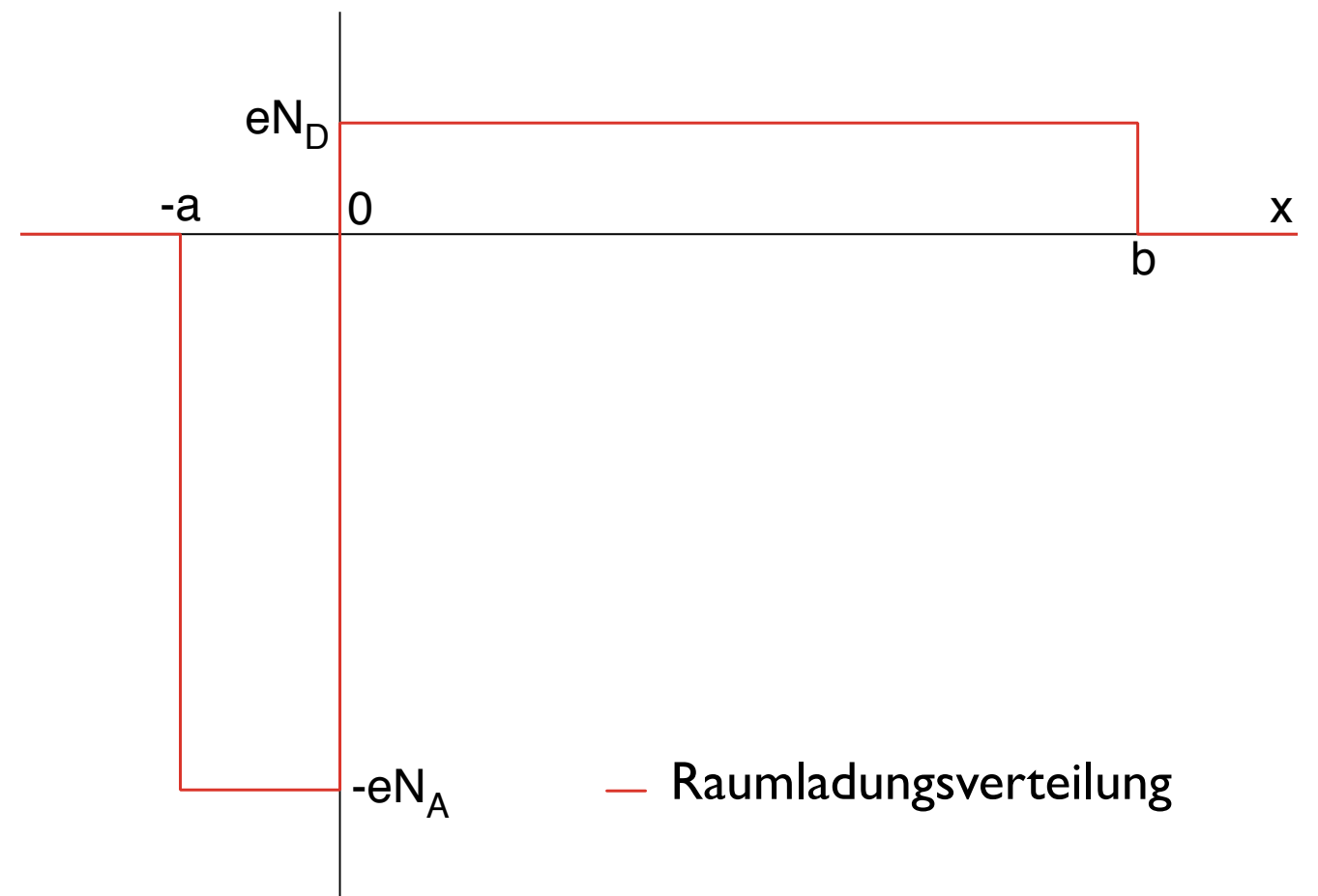
pn-Übergang

- Elektronen auf der n-Typ Seite wandern zur p-Typ Seite
- Löcher auf der p-Typ Seite entsprechend zur n-Typ Seite
- Spannung in Sperrrichtung

Poissongleichung

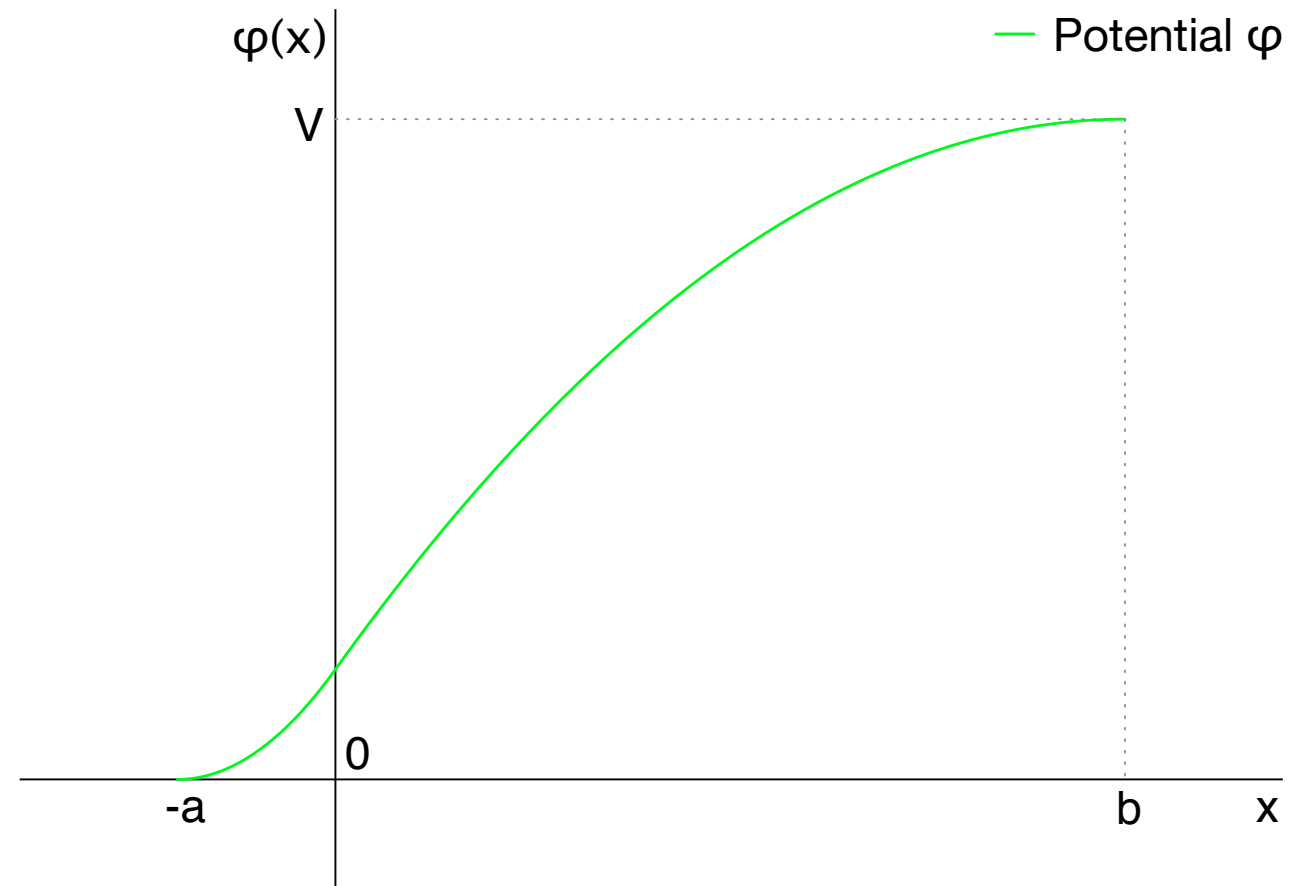
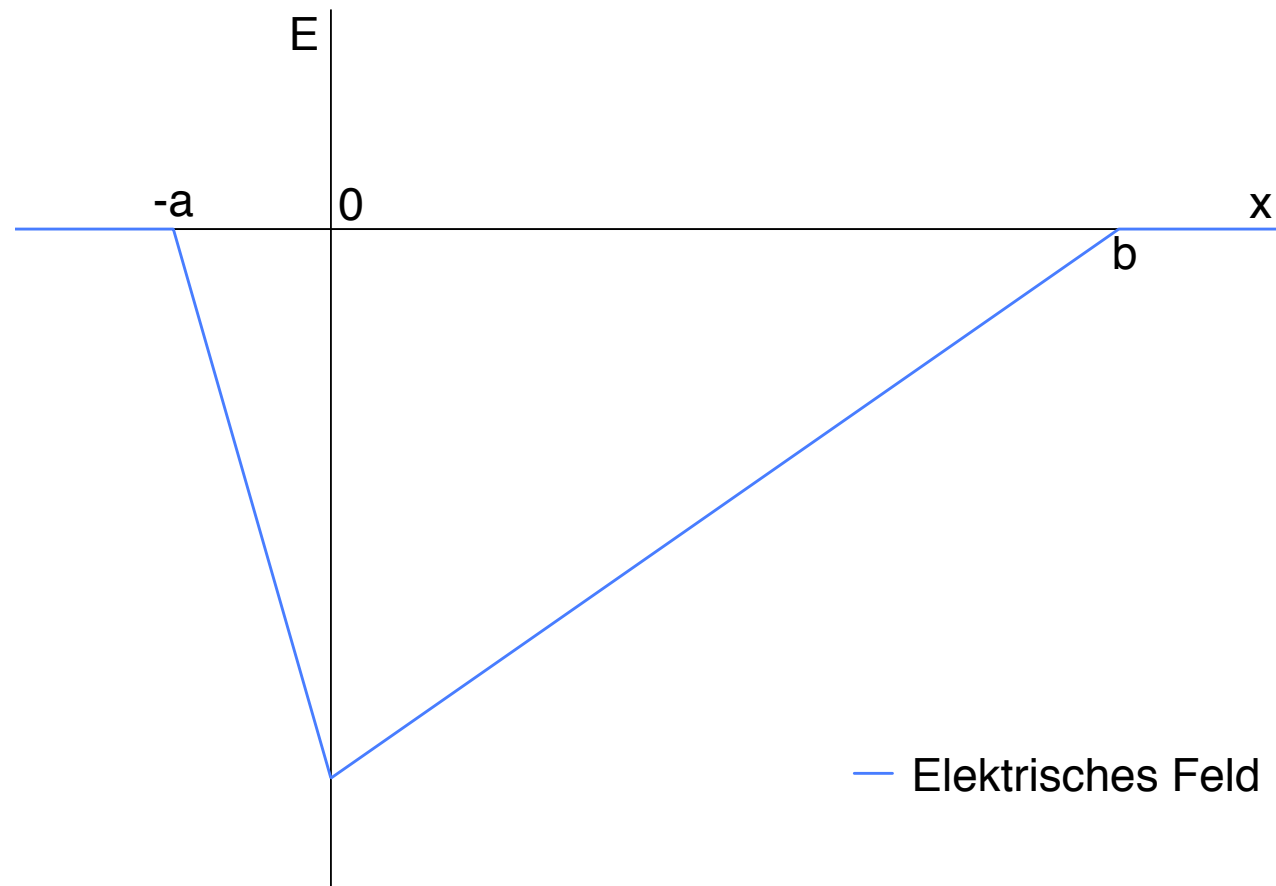
$$\nabla^2 \varphi = -\frac{\rho}{\epsilon}$$

$$\frac{d^2 \varphi}{dx^2} = \begin{cases} +\frac{eN_A}{\epsilon} & (-a < x \leq 0) \\ -\frac{eN_D}{\epsilon} & (0 \leq x < b) \end{cases}$$



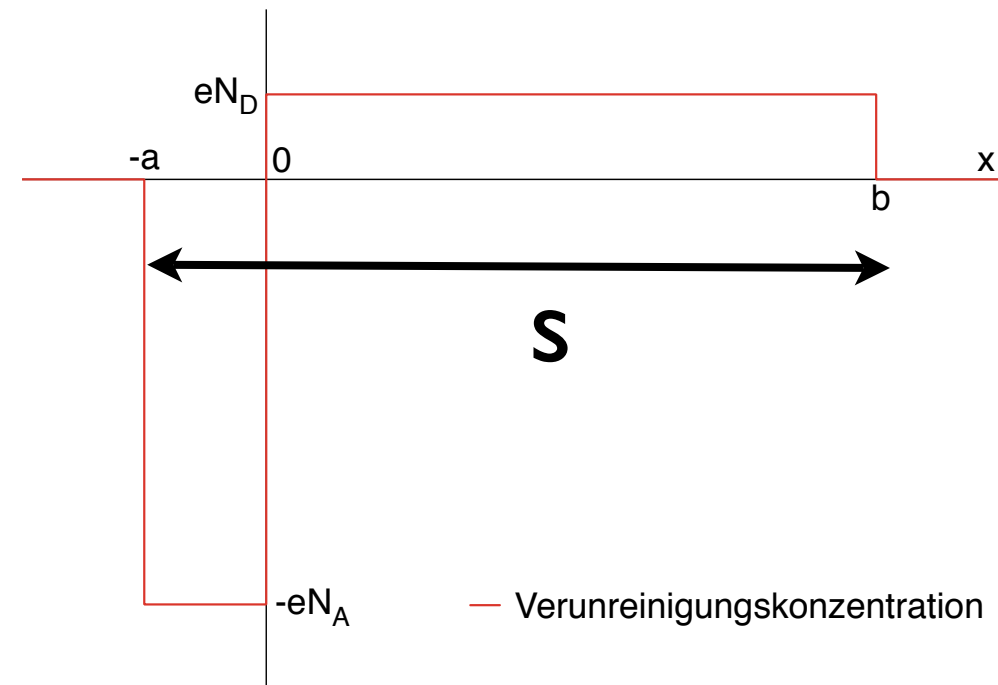
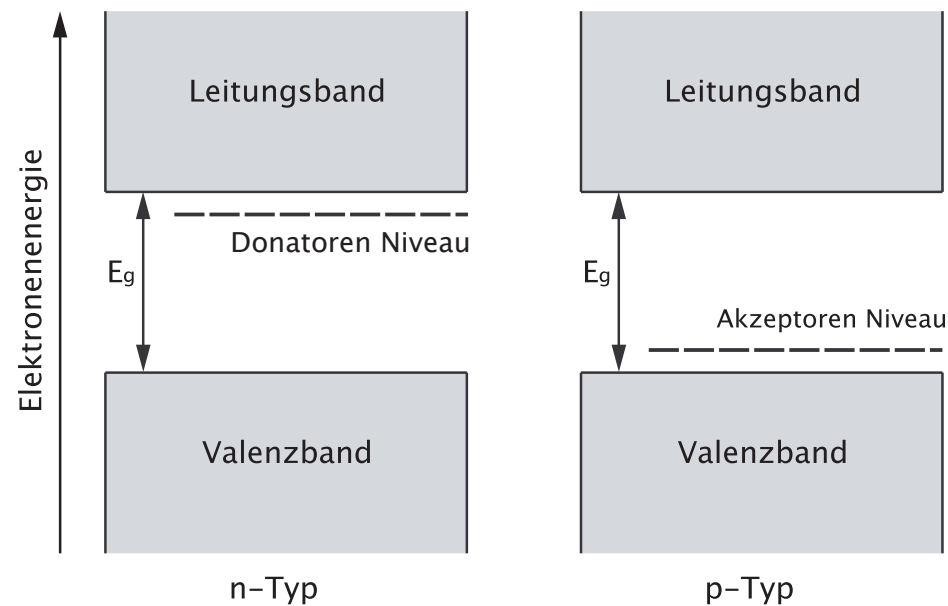
$$\rho(x) = \begin{cases} -eN_A & (-a < x \leq 0) \\ eN_D & (0 \leq x < b) \end{cases}$$

pn-Übergang



$$\frac{d\varphi}{dx} = \begin{cases} +\frac{eN_A}{\epsilon}(x+a) & (-a < x \leq 0) \\ -\frac{eN_D}{\epsilon}(x-b) & (0 \leq x < b) \end{cases} \quad \varphi(x) = \begin{cases} +\frac{eN_A}{2\epsilon}(x+a)^2 & (-a < x \leq 0) \\ -\frac{eN_D}{2\epsilon}(x-b)^2 + V & (0 \leq x < b) \end{cases}$$

pn-Übergang und Verarmungszone



- Poissongleichung

$$\nabla^2 \varphi = -\frac{\rho}{\epsilon}$$

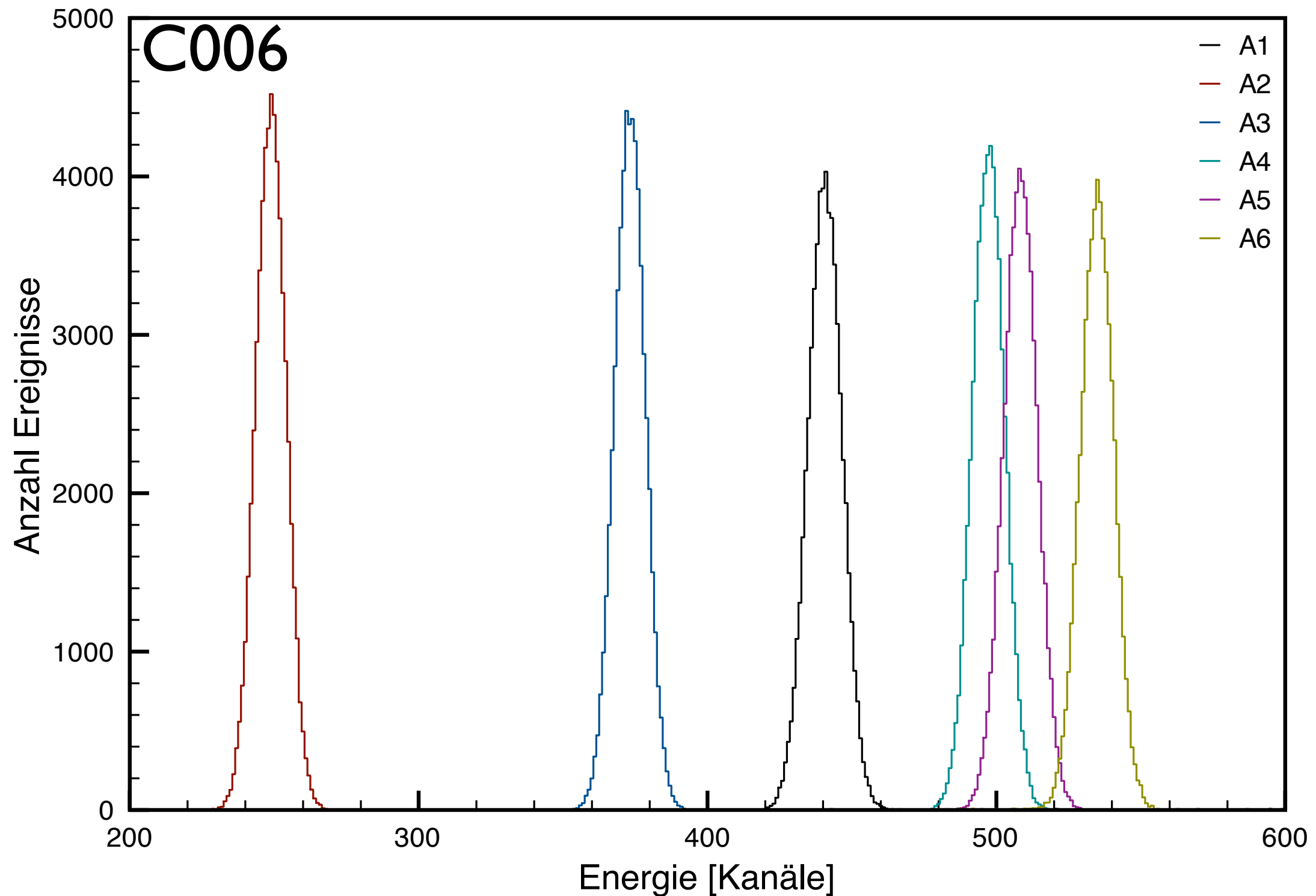
- Breite der Verarmungszone

$$s \approx \sqrt{\frac{2\epsilon V}{eN_D}}$$

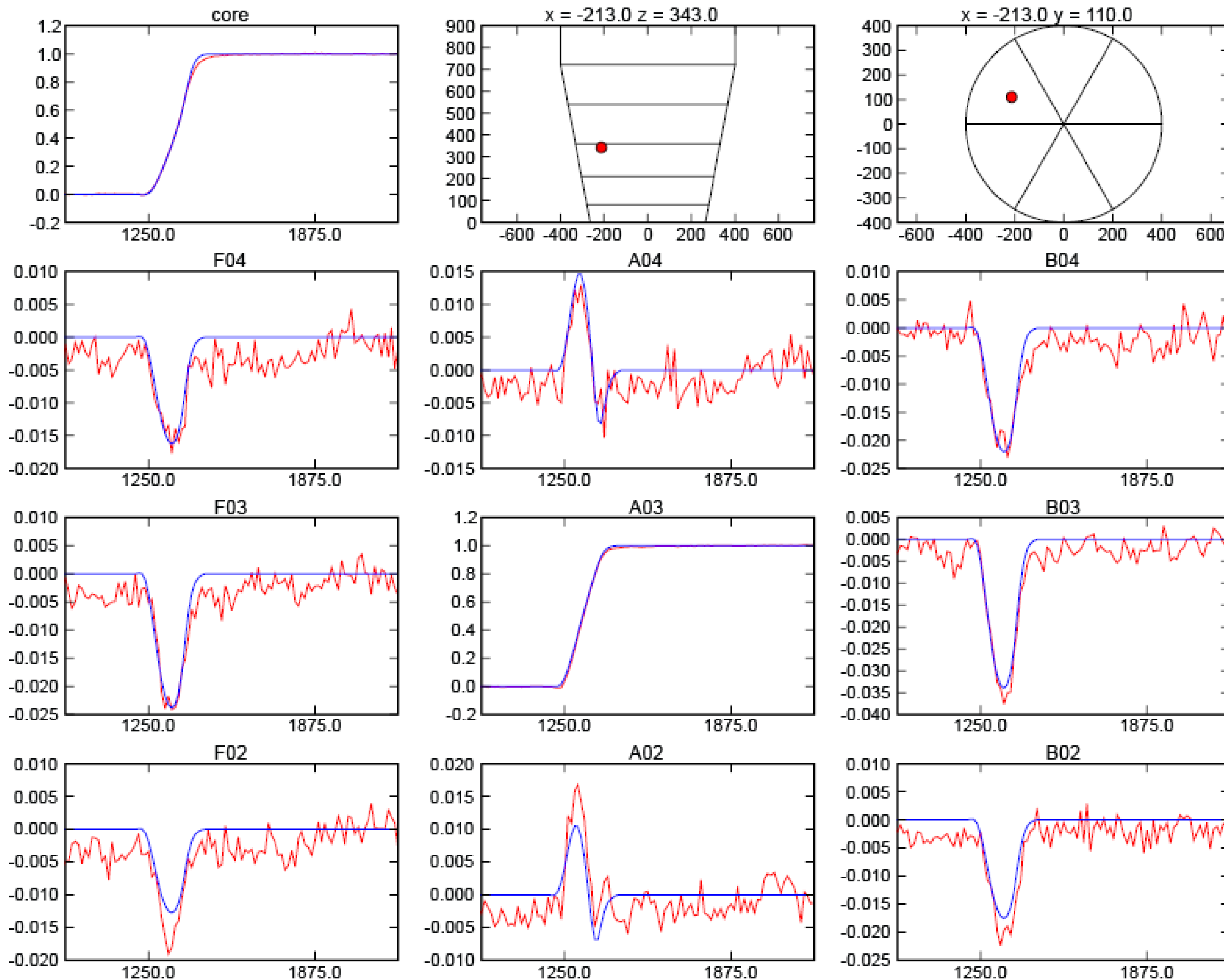
- Kapazität gegeben durch

$$C = \frac{\epsilon}{s} \approx \sqrt{\frac{e\epsilon N_D}{2V}}$$

Pulsermessung



Positionsbestimmung mit Hilfe der Impulsform-Analyse



Simulierte Impulsformen ADL Köln

Gemittelte Impulsformen des Liverpool Scannings