Realization of reference air-kerma rate for low-energy photon sources

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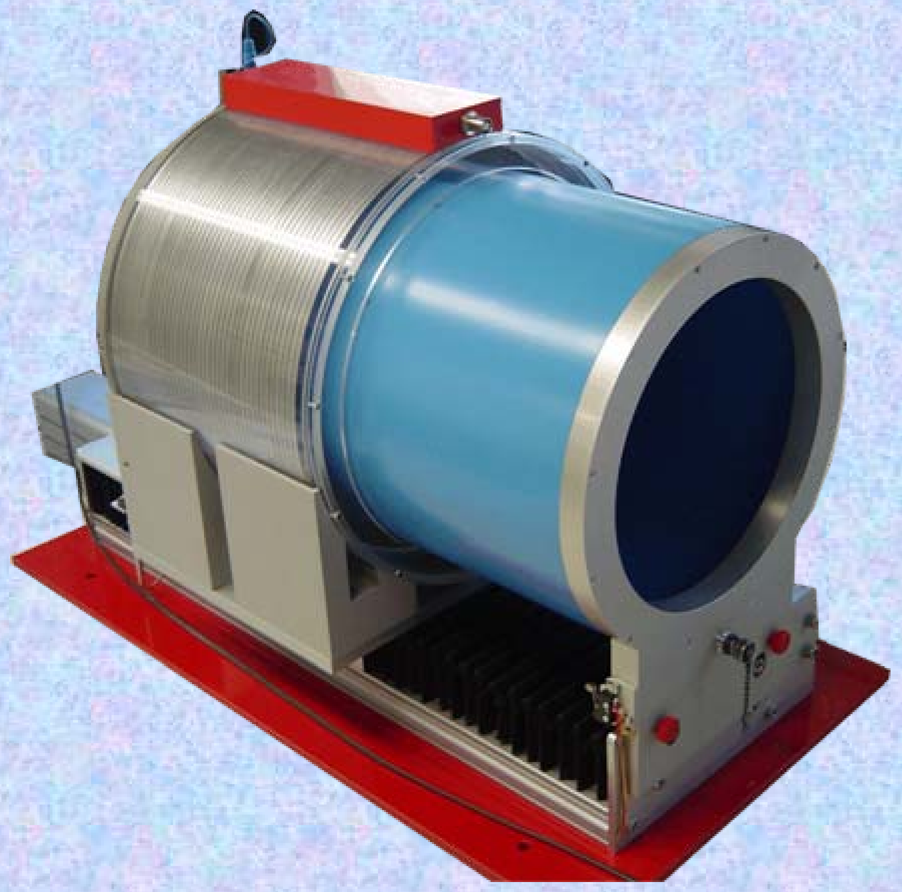
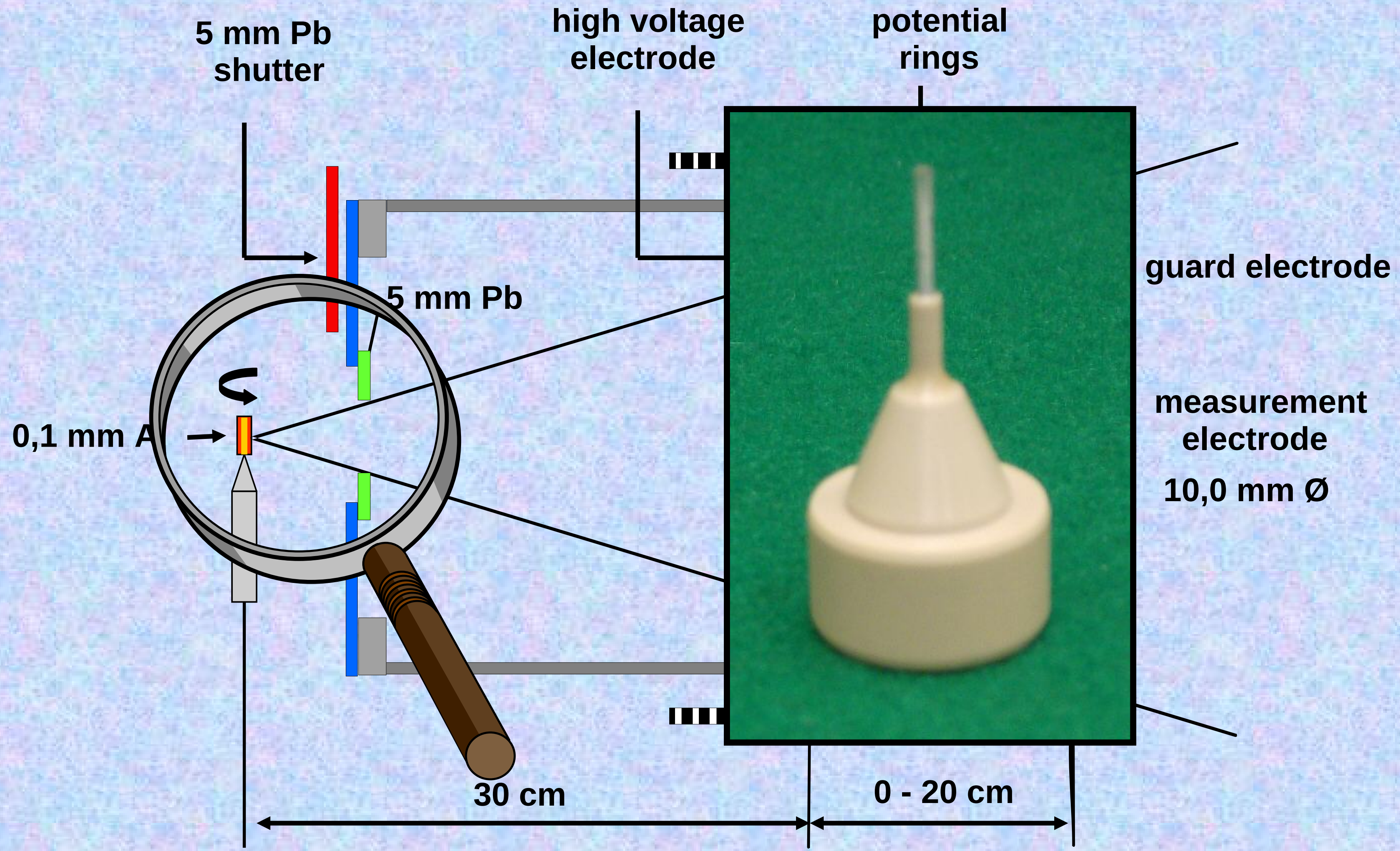


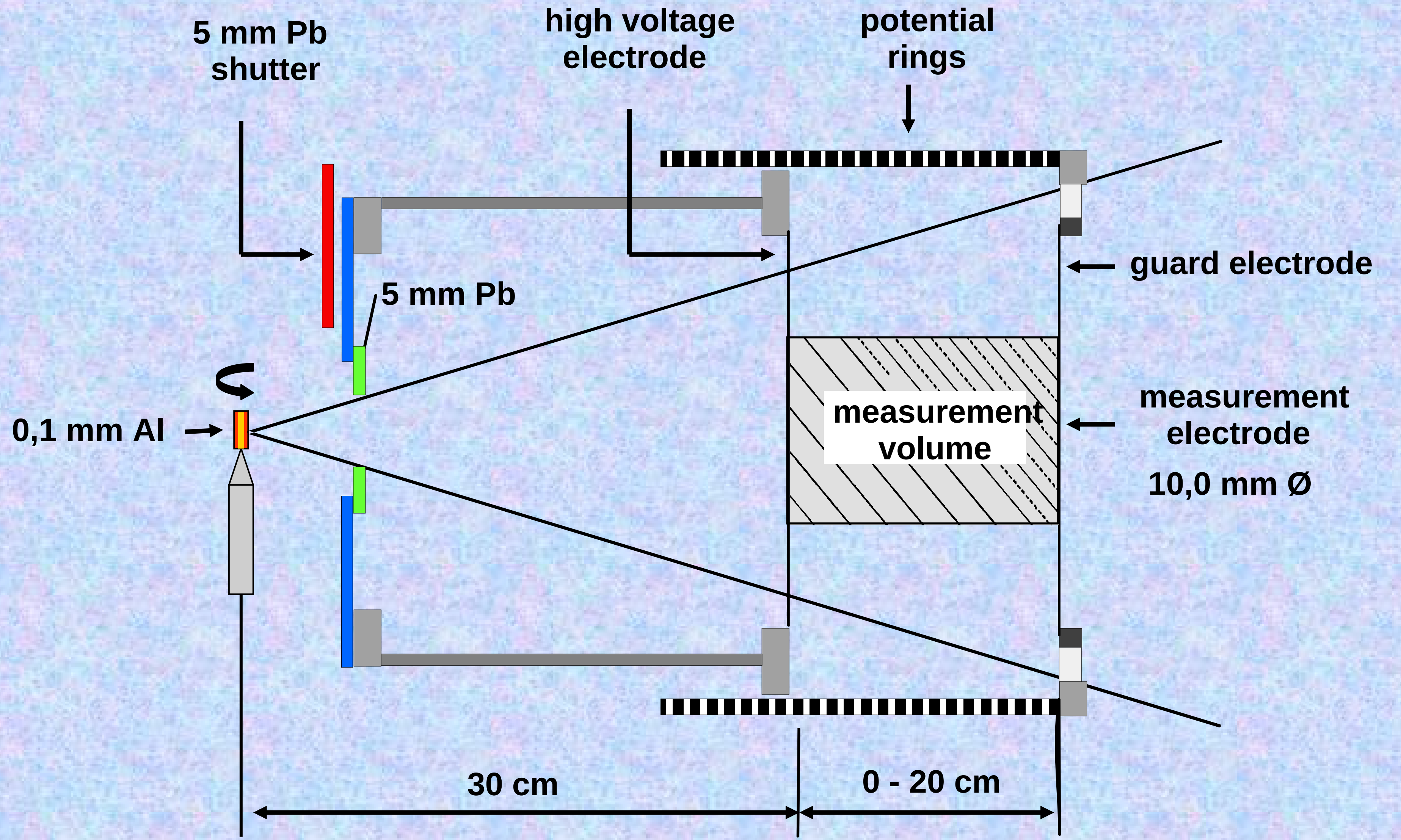
Introduction

- Radioactive ^{125}I and ^{103}Pd seed implantation is an increasingly popular treatment for localized prostate cancer
  - Since spring 2005 the treatment is accepted by the German health insurances
- Typical free-air chamber collecting volumes are too small
- The National Institute of Standards and Technology (NIST) uses a wide-angle free-air chamber (WAFAC) since 1993 (Loevinger)
  - Half-angle of 8°
  - Uses the difference between two collecting volumes
- New chamber was developed at the Physikalisch-Technische Bundesanstalt (PTB) in Germany in 2002
  - Large air-filled parallel-plate extrapolation chamber (GROVEX) with thin graphite coated polyethylene front and back electrodes
  - For low-energy photon emitting sources with energies up to 40 keV
  - Extrapolation chamber measurements and interface effect elimination

Schematic of the GROVEX measuring system



Schematic of the GROVEX measuring system



Realization of the reference air-kerma rate, $\dot{K}_\delta$, by means of the extrapolation chamber technique:

$$\dot{K}_\delta = \frac{\left(\frac{\overline{W}}{e}\right)_{air}}{\rho_{air} A_{eff} (1 - g_{air})} \left(\frac{d(kI)}{ds}\right) \prod_i k_i$$

$\left(\frac{\overline{W}}{e}\right)_{air}$ = 33,97 eV

ρ_{air} = 1,2046 kg/m³

A_{eff} = 7754±11 mm²

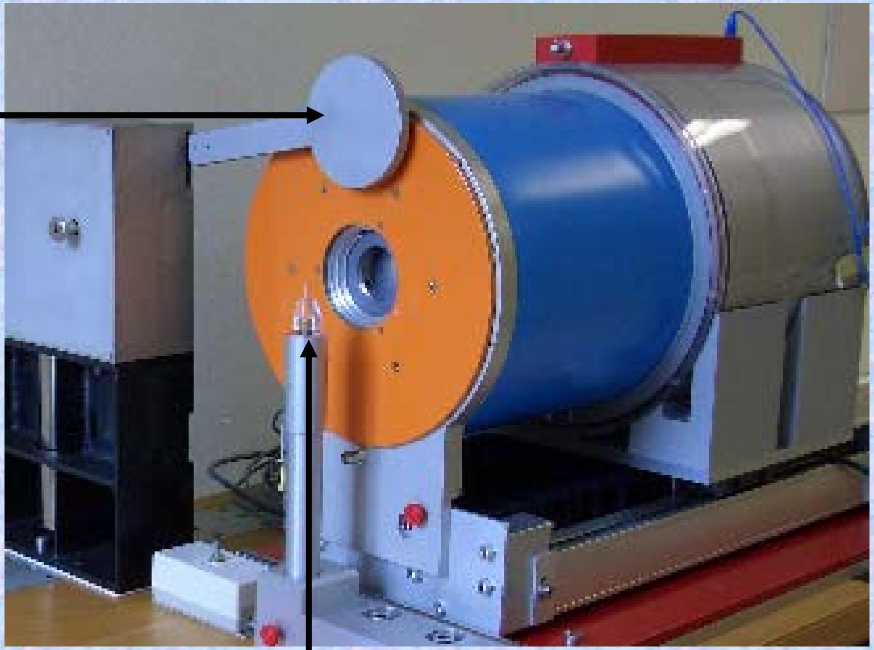
g_{air} = 0,0

$\left(\frac{d(kI)}{ds}\right)$ is the increment of corrected ionization current per increment of the chamber volume

k_i are corrections to the entire measurement

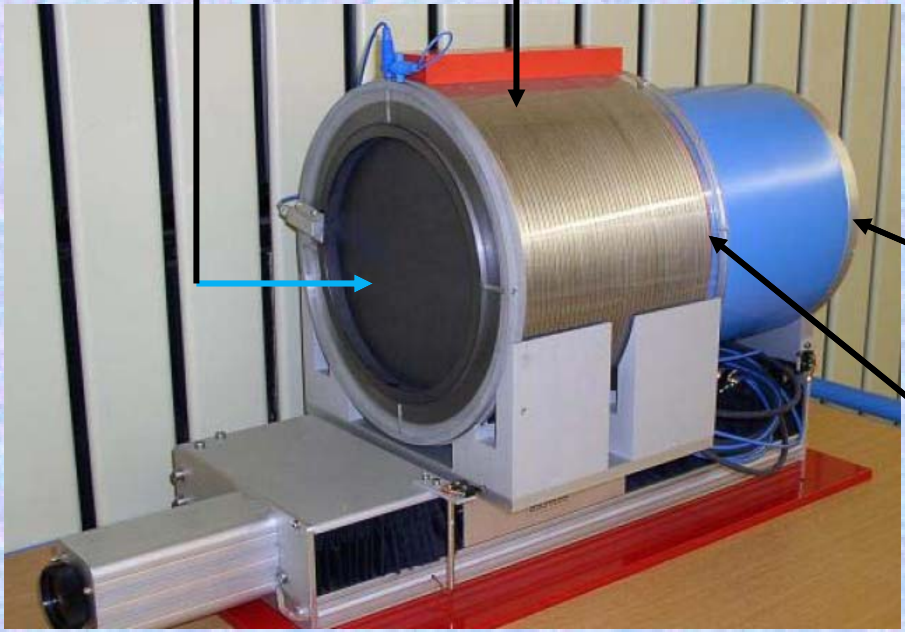
Front and back view of the GROVEX

shutter



collector electrode and guard ring

potential rings



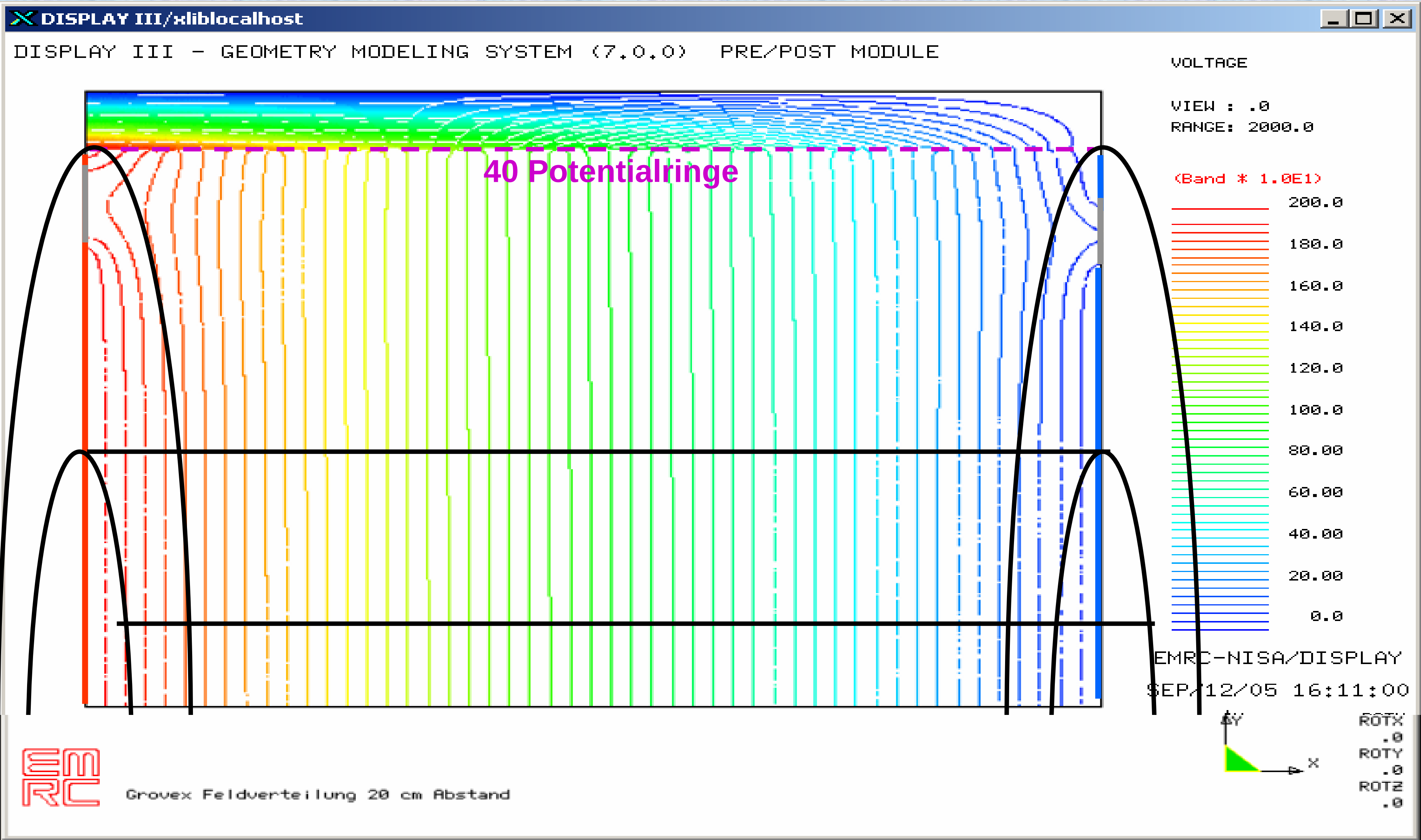
source position

high-voltage electrode
(hidden from view)

Determination of the measurement volume

- electrode separation
- electrical field homogeneity
- area of measurement electrode

Calculations of the electrical field distribution by means of finite element methods



Effective Electrode Area

- The area of the measurement electrode is difficult to measure by mechanical means due to the thin (12 µm) foil, which is graphitized from both sides

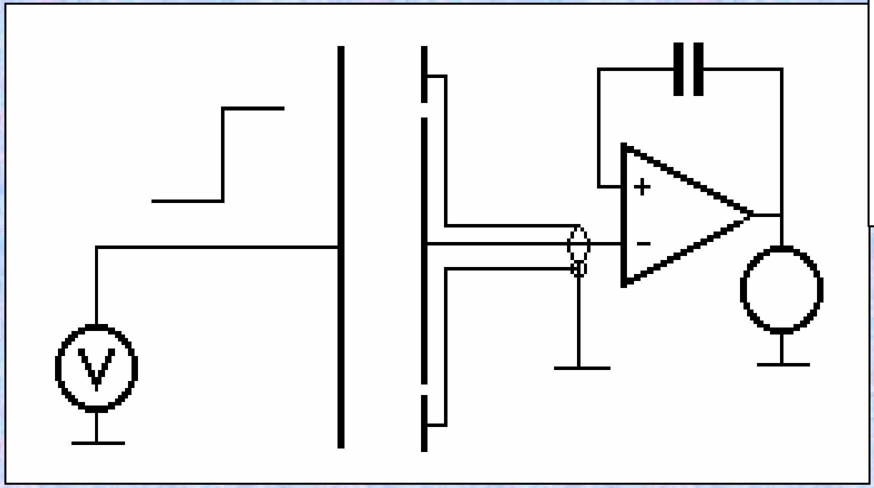
- As an alternative, the capacitance of the extrapolation chamber as a function of electrode separation *s* is measured, and from these measurements the area of the electrode is determined

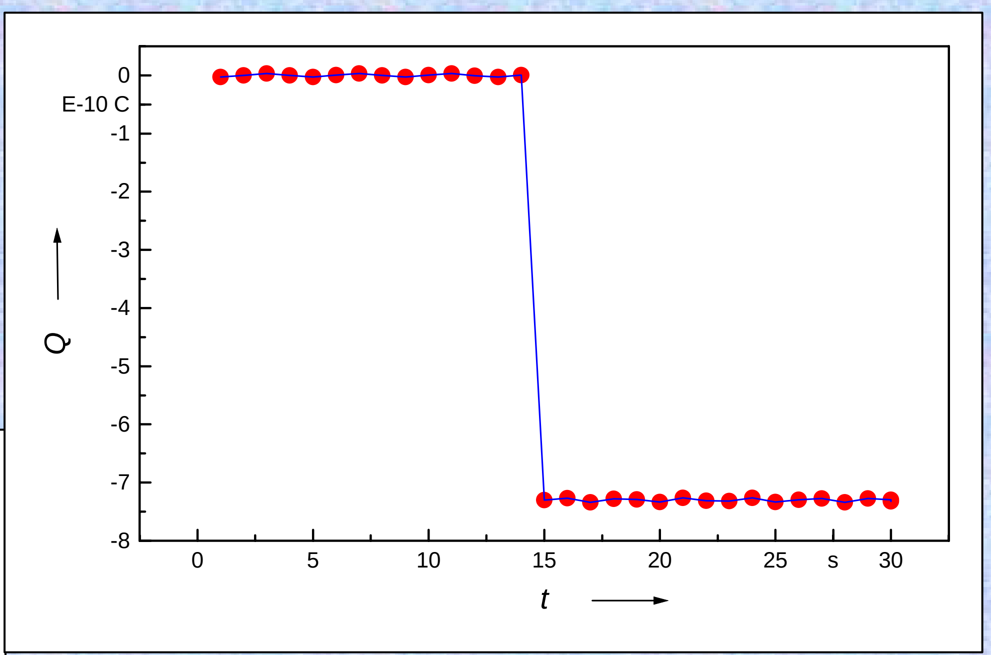
- The voltage-step method is used to measure the capacitance

Determination of the effective electrode area

$$C_0 = \Delta Q / \Delta U$$

$$C_0 = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot A_{eff}}{s}$$

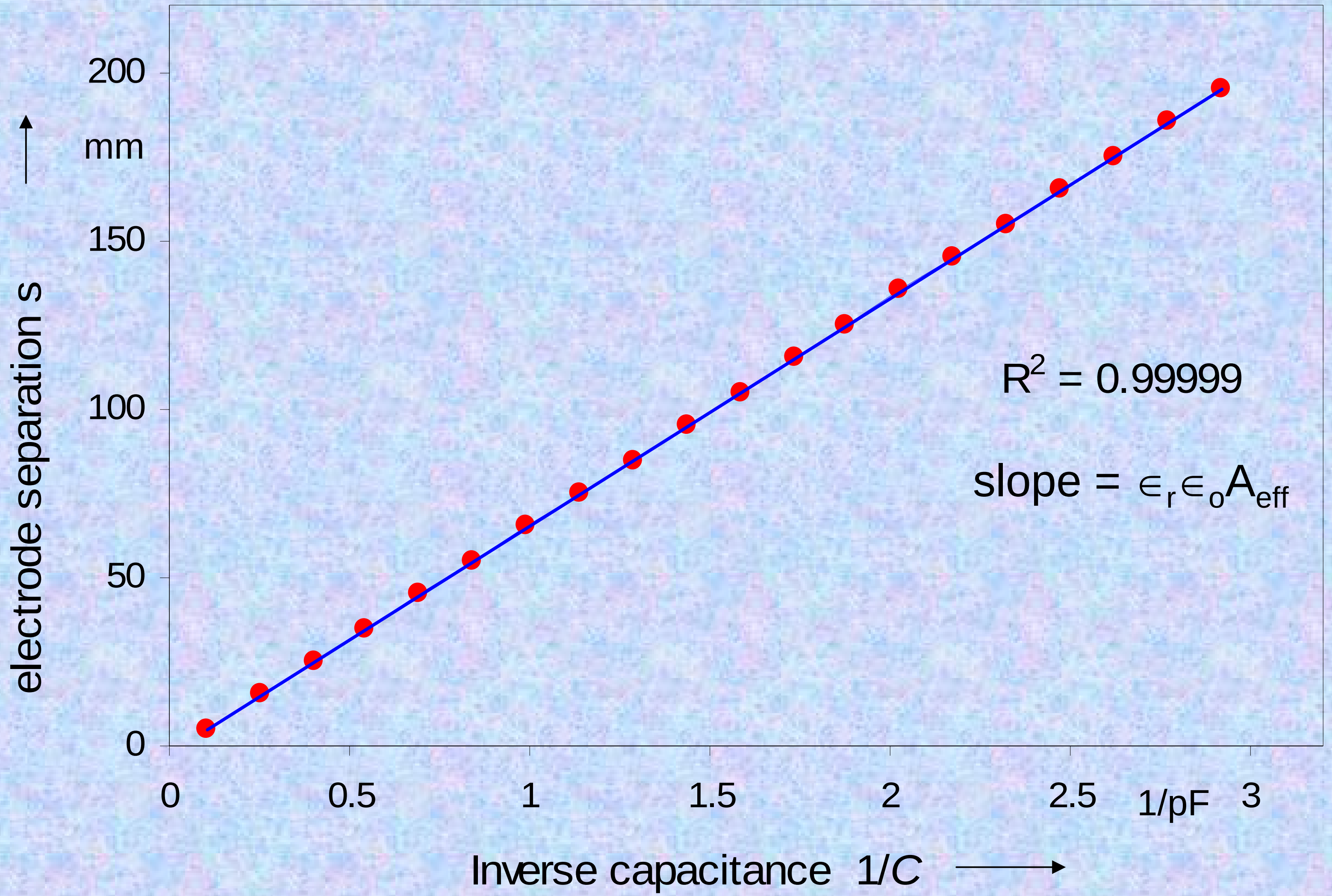




$$s = \frac{1}{C_0}\left(\varepsilon_0 \cdot \varepsilon_r \cdot A_{eff}\right)$$

Effective Electrode Area

measure the capacitance of the extrapolation chamber as a function of electrode separation s



Correction factors

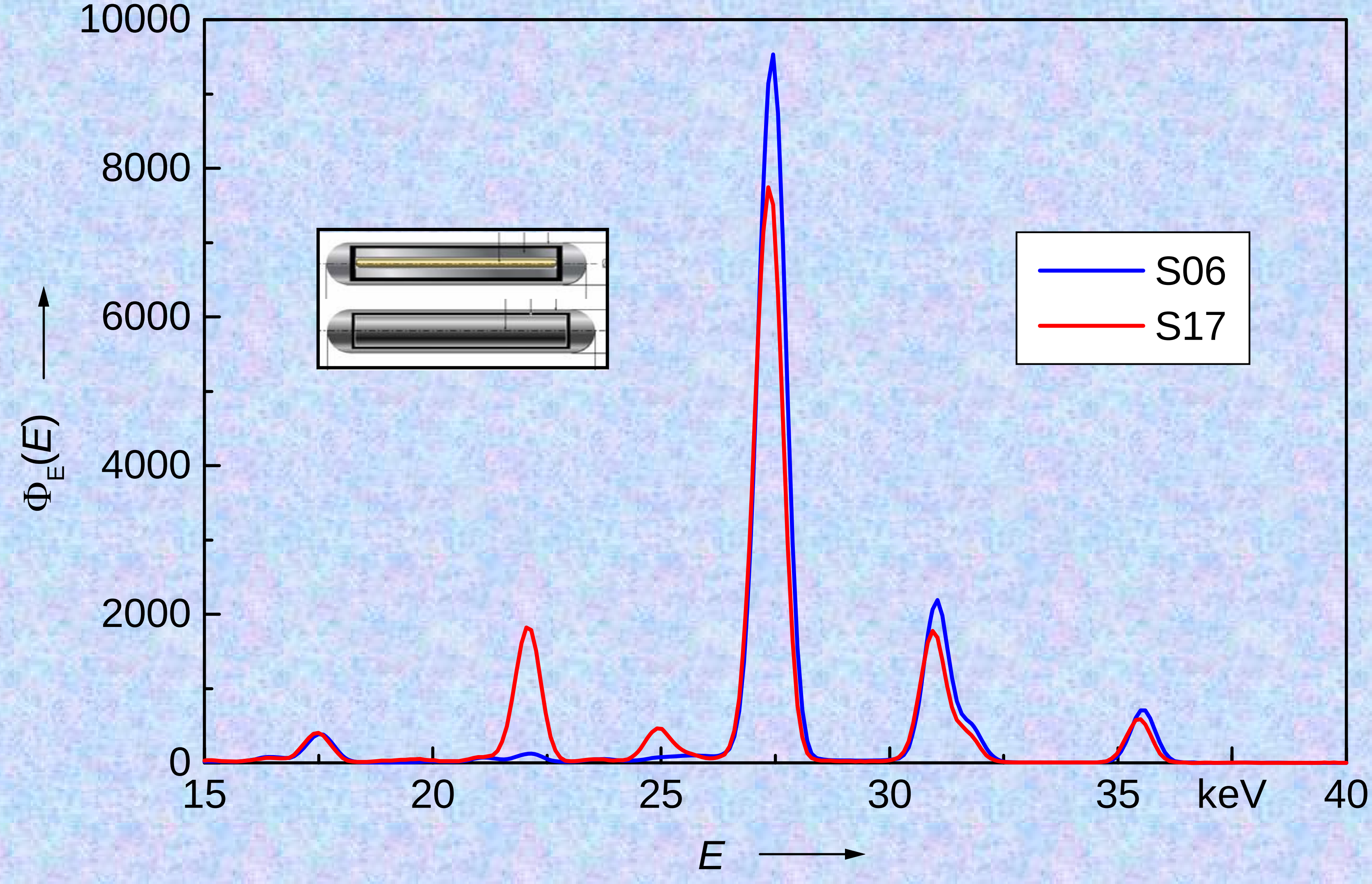
- Correction factors outside the chamber volume were determined by experiments and Monte Carlo Calculations

- Correction factors for attenuation, scattering in the air and in the walls, secondary electron equilibrium, etc inside the chamber volume were determined in total as the product of all single corrections by Monte Carlo Calculations (MCNPx)

- Nearly all correction factors are energy dependent

- Therefore, for each type of source the spectral distribution has to be measured

Spectral photon distribution of two different types of Iodine-seeds



Variation of some correction factors with the content of silver

Content of silver	0%	5%	10%	20%
Attenuation in the AL-filter	1,0384	1,0409	1,0428	1,0472
Attenuation in the entrance foil	1,0012	1,0012	1,0012	1,0013
Attenuation in the air from source to measurement point	1,0144	1,0150	1,0154	1,0164
	1,0546	1,0578	1,0601	1,0658

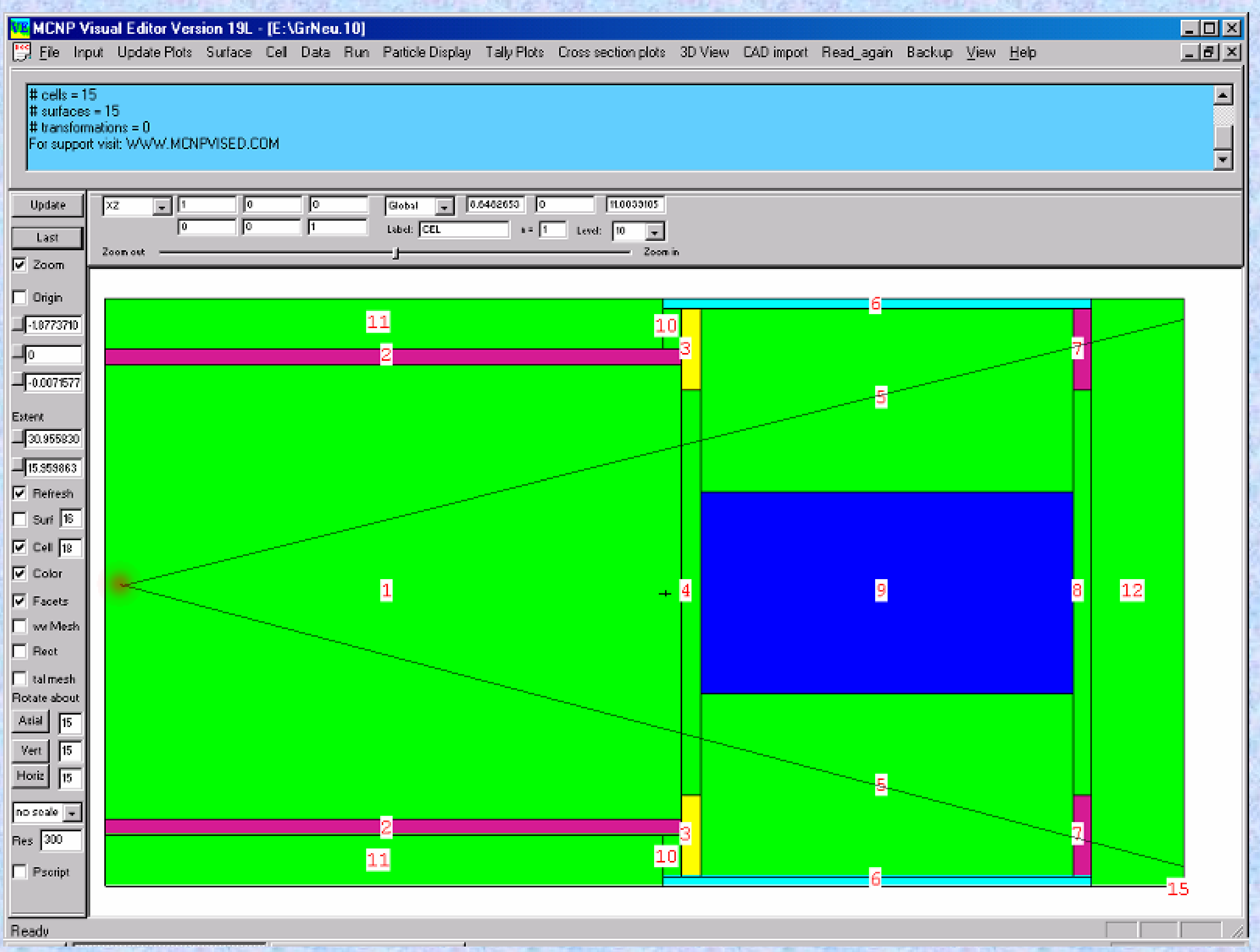
Correction factors for effects inside the chamber volume are determined by MCC

$$k_{inside}(s) = \prod_i k_i(s)$$

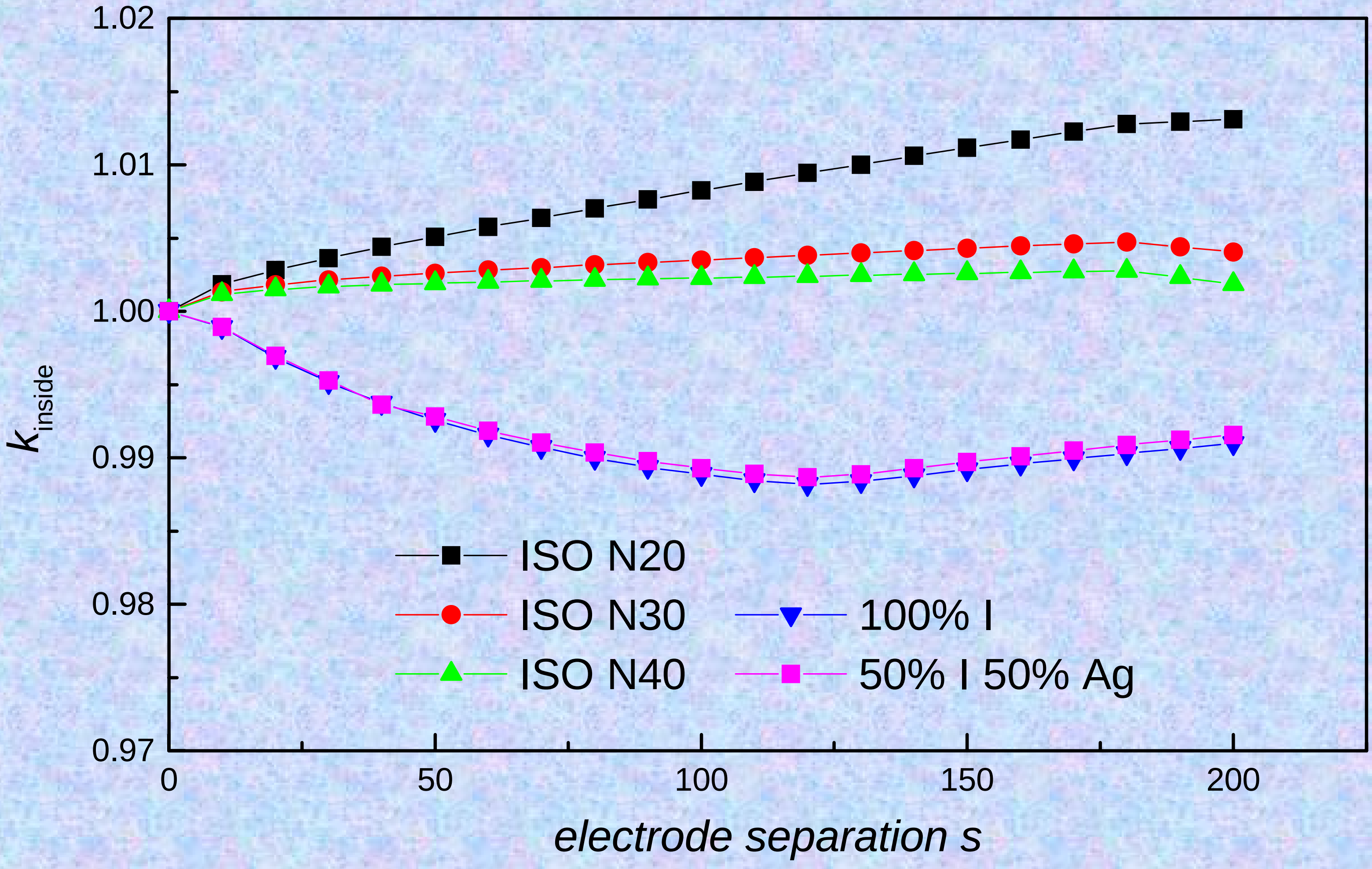
$$k_{inside}(s) = \frac{\lim\limits_{s'\to 0}\left(E_{dep}(s')/M(s')\right)}{E_{dep}(s)/M(s)} \cdot \frac{d+s}{s}$$

with $$\frac{d+s}{s} = \frac{1}{k_{div}}$$

MCNPX - Model of the GROVEX



Product of the correction factors inside the chamber volume, $k_{inside}(s)$



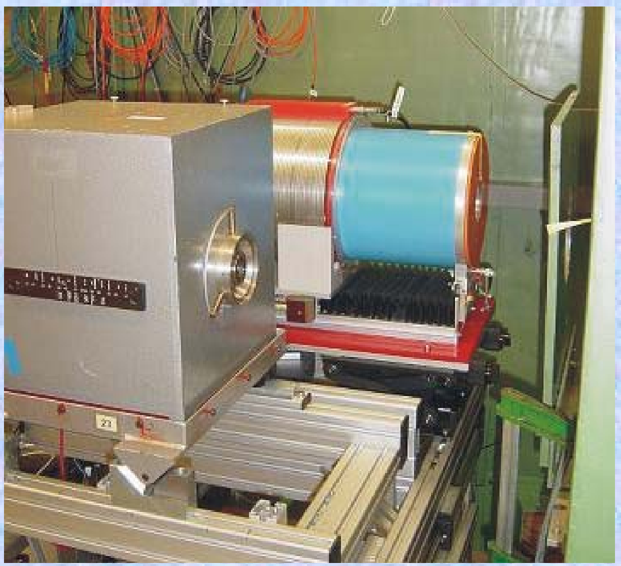
Uncertainty budget of the GROVEX according to the GUM

Reason of the uncertainty	u [%]	index
Ionization current measurement (reproducibility)	0,5	32,6%
Electrode separation	0,06	0,4%
Air density and humidity	0,05	0,3%
Electrode area	0,5	33,0%
Source-to-measurement point distance	0,035	0,2%
Incomplete ion collection	0,03	0,1%
Attenuation in the Al-filter	0,5	27,8%
Attenuation in the entrance window	0,12	1,7%
Attenuation and scatter between source and entrance window	0,12	1,7%
Attenuation and scatter in the chamber volume	0,12	1,7%
Source holder	0,06	0,4%
combined uncertainty (k=1)	0,9	
Uncertainty U(k=2)	**1,8**	

Intercomparisons (2005)

GROVEX / PTB-primary standard for air-kerma PK100

PTB Beam Code	Measured air kerma rate per monitor chamber current reading ($\times 10^5$ Gy/C) GROVEX	PK100	GROVEX / PK100
A20	1.735	1.751	0.991
A25	1.738	1.747	0.995
A30	1.685	1.692	0.996
A40	1.658	1.659	0.999



GROVEX (PTB) / VAFAC (UW) / WAFAC (NIST)

Seed	PTB GROVEX S_K ($cGy\,cm^2\,h^{-1}$)	UW VAFAC S_K ($cGy\,cm^2\,h^{-1}$)	NIST WAFAC S_K ($cGy\,cm^2\,h^{-1}$)	$\frac{GROVEX}{VAFAC}$	$\frac{GROVEX}{WAFAC}$
^{103}Pd (model 200) No.1	26.307	26.389	26.40	0.997	0.997
^{103}Pd (model 200) No.3	26.327	26.380	26.44	0.998	0.996
^{103}Pd (model 200) No.10	27.973	26.951	26.90	1.001	1.003
^{125}I (model 6711) No.1	17.288	17.138	17.16	1.009	1.007
^{125}I (model 6711) No.2	12.191	12.226	12.25	0.997	0.995
^{125}I (model 6711) No.3	17.093	17.053	17.18	1.002	0.995

Reference: Wes Culberson, Dissertation, University of Wisconsin (2006)

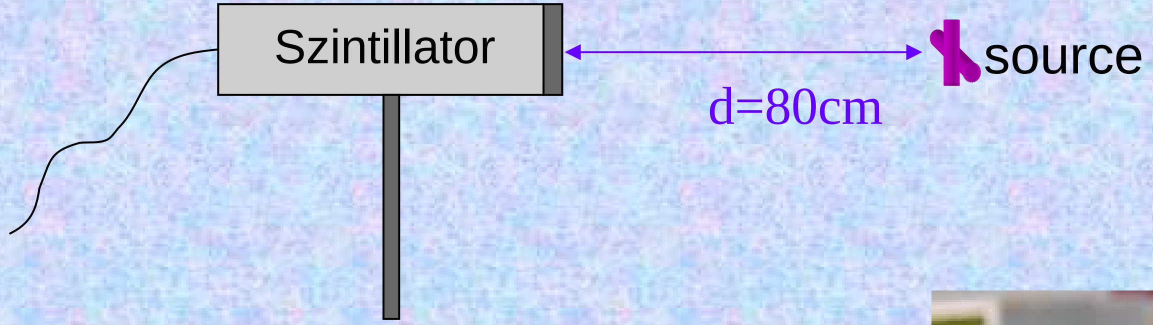
Calibration results (regardless of anisotropy effects)

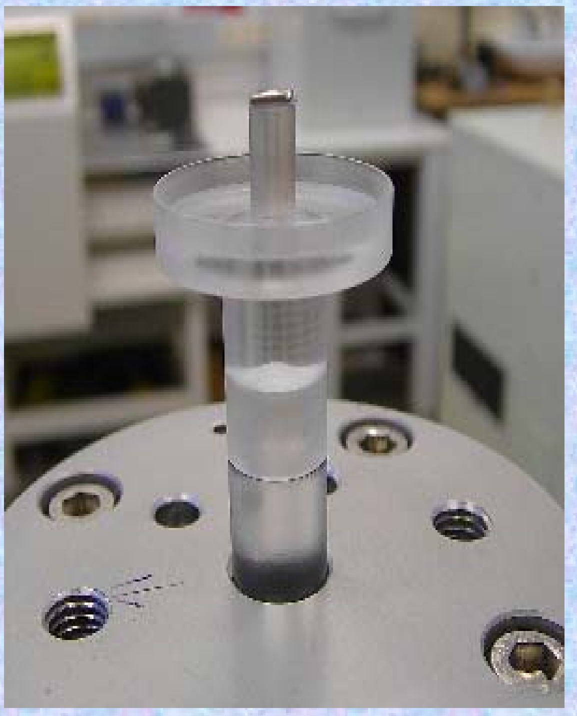
IsoSeed I-125 S06 E07/0008		
Messung		
Oben1	5.595E+00	
Oben2	5.535E+00	
Unten1	5.545E+00	
Unten2	5.564E+00	
Mittelwert	5.560E+00	µGy/h
StdAbw	0.48	%
BEBIG	5.5260	µGy/h
PTB/BEBIG	1.0061	

IsoSeed I-125 S06 E07/0007		
Messung		
Oben1	5.294E+00	
Oben2	5.386E+00	
Unten1	5.350E+00	
Unten2	5.339E+00	
Mittelwert	5.342E+00	µGy/h
StdAbw	0.71	%
BEBIG	5.2590	µGy/h
PTB/BEBIG	1.0158	

Quelle 8 / Quelle 7	
BEBIG	1.051
HDR1000	1.050
Grovex	1.041

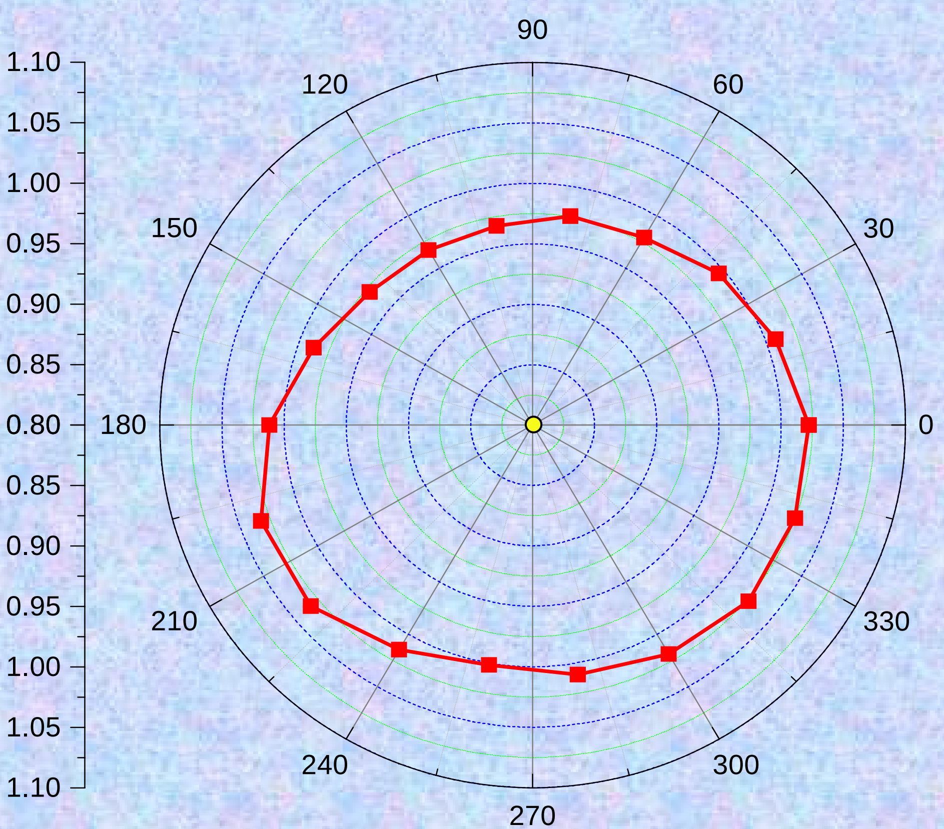
Determination of the azimuthal and polar anisotropy





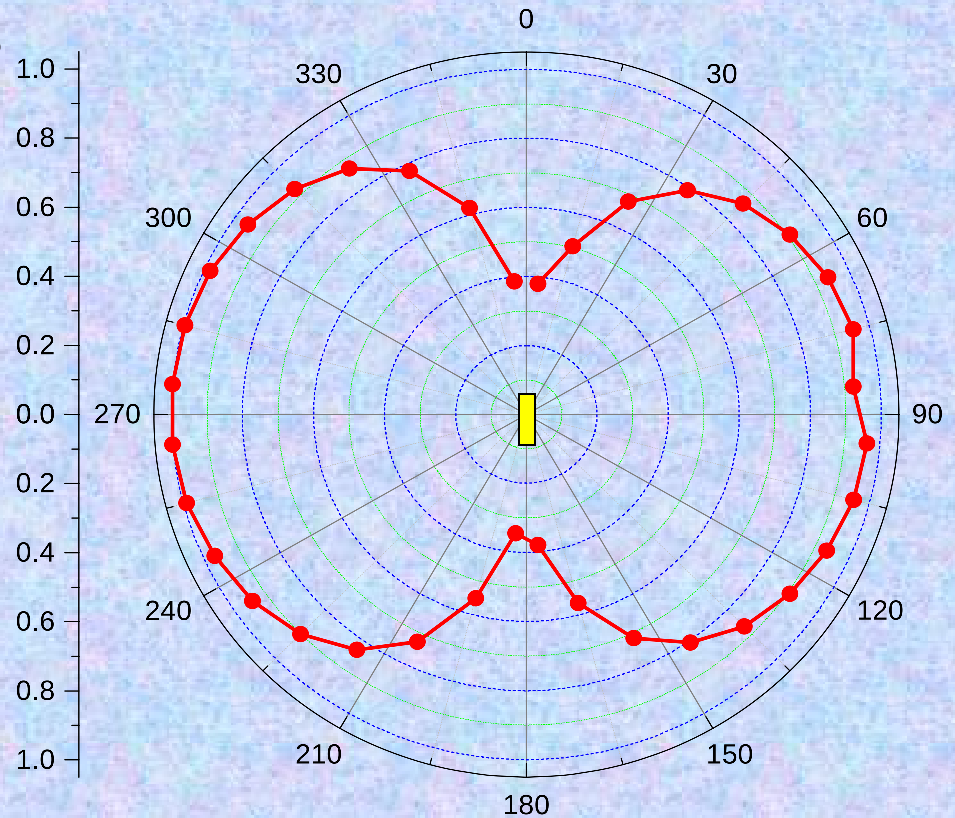
Athimuthal and polar anisotropy

source E 07-0007



azimuthal

polar



Conclusions and outlook

- PTB has developed a primary standard for low energy photon sources
  - GROVEX measurement geometry is different than NIST WAFAC
  - Extrapolation measurements instead of two-volume technique
  - Uncertainty for the mesurement of reference air-kerma rate is 1,8 %
- intercomparison with PTB air kerma standards agree within ca. 1%
- Intercomparison with ^{125}I and ^{103}Pd brachytherapy seeds calibrated at NIST, PTB and Univ. Wisconsin show agreement better than 1%
- The overall uncertainty of a calibration of a specific source is about 3 % due to anisotropy effects
- Future activities
  - A key comparison under the leadership of BIPM is desirable
  - An European calibration network should be installed in the near future
  - An European protocol (on the basis of TG43) should be developed (DIN 6808-2 is just under review)
  - Performance standard on dosemeters for low energy photon sources should be developed (IEC work for well-type chambers is already in progress)

Thank you for your attention