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Experimental $k_{Q,Q0}$ Electron Beam Quality Correction Factors for the Types NACP02 and PTW34001 Plane-parallel Chambers

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Federal Office of Metrology

Experimental k_{Q,Q_0} Electron Beam Quality Correction Factors for the Types NACP02 and PTW34001 Plane-parallel Chambers

1) Irradiation facilities
2) Primary standard (electron beam)
3) Ionisation chamber calibration
4) Results for k_{Q,Q_0}
5) Comparison with TRS 398
6) Conclusions

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1) METAS Irradiation Facilities

- Electron accelerator (microtron) M22
- Electron energies 5.3 to 22.5 MeV
- Conventional treatment head
- 10 photon beams: $TPR_{20,10}$ = 0.639 to 0.802
- 10 electron beams: R_{50} = 1.75 to 8.54 $g{\cdot}cm^{-2}$
- ^{60}Co irradiation unit ALCYON II

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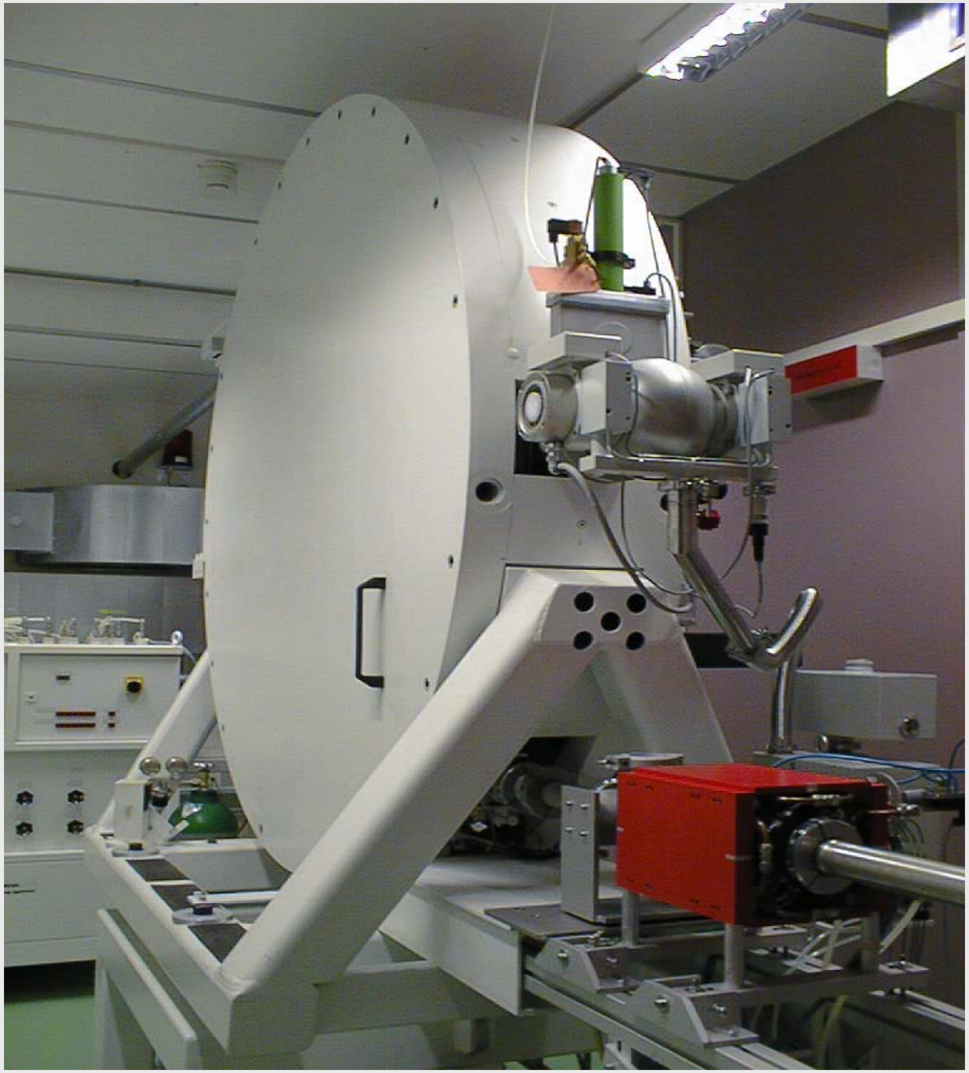
METAS microtron M22



METAS Standard Radiation Qualities for High - Energy Electron Beams

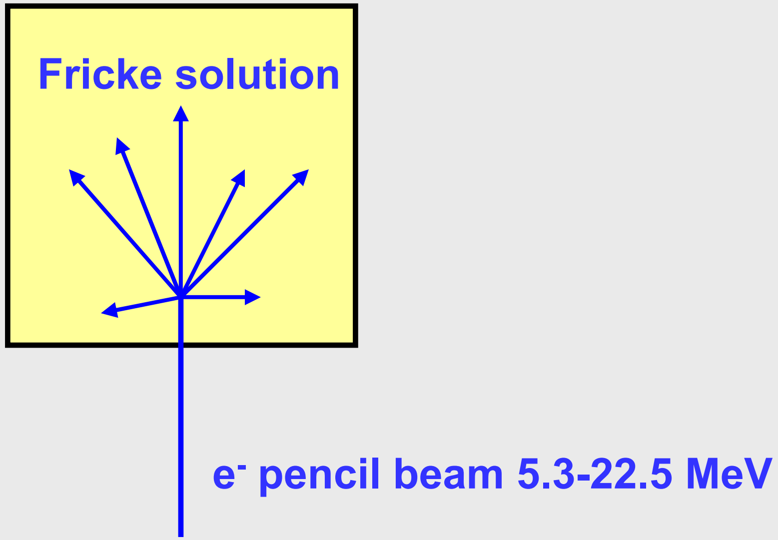
Nominal electron energy [MeV]	Radiation index Q (=R_{50}) [gcm^{-2}]	z_{ref} [gcm^{-2}]
5.5	1.75	0.95
6.0	1.95	1.07
7.5	2.62	1.47
9.0	3.31	1.89
10.0	3.70	2.12
12.0	4.35	2.51
15.0	5.67	3.30
18.0	6.90	4.04
20.5	7.52	4.41
22.5	8.54	5.02

2) Primary Standard : Chemical Dosimeter (Fricke)
Total Absorption Experiment

Irradiation experiment:

$$D_F = \frac{E_{abs}}{m} \qquad \textbf{(1)}$$

$$E_{abs} = E_e \cdot N$$



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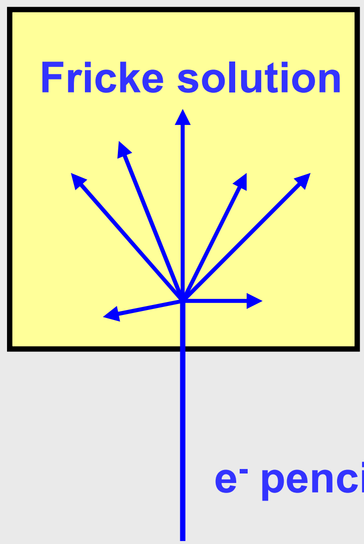
2) Primary Standard : Chemical Dosimeter (Fricke)

Total Absorption Experiment

UV- spectrometer read-out:



$$D_F = \frac{\Delta A_T}{\varepsilon \cdot G_E \cdot \rho \cdot l_T} \quad \textbf{(2)}$$

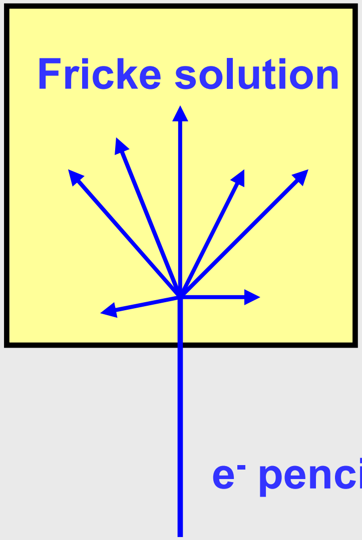
e^- pencil beam 5.3-22.5 MeV

2) Primary Standard : Chemical Dosimeter (Fricke)
Total Absorption Experiment

Irradiation experiment:

$$D_F = \frac{E_{abs}}{m} \qquad \textbf{(1)}$$

$$E_{abs} = E_e \cdot N$$



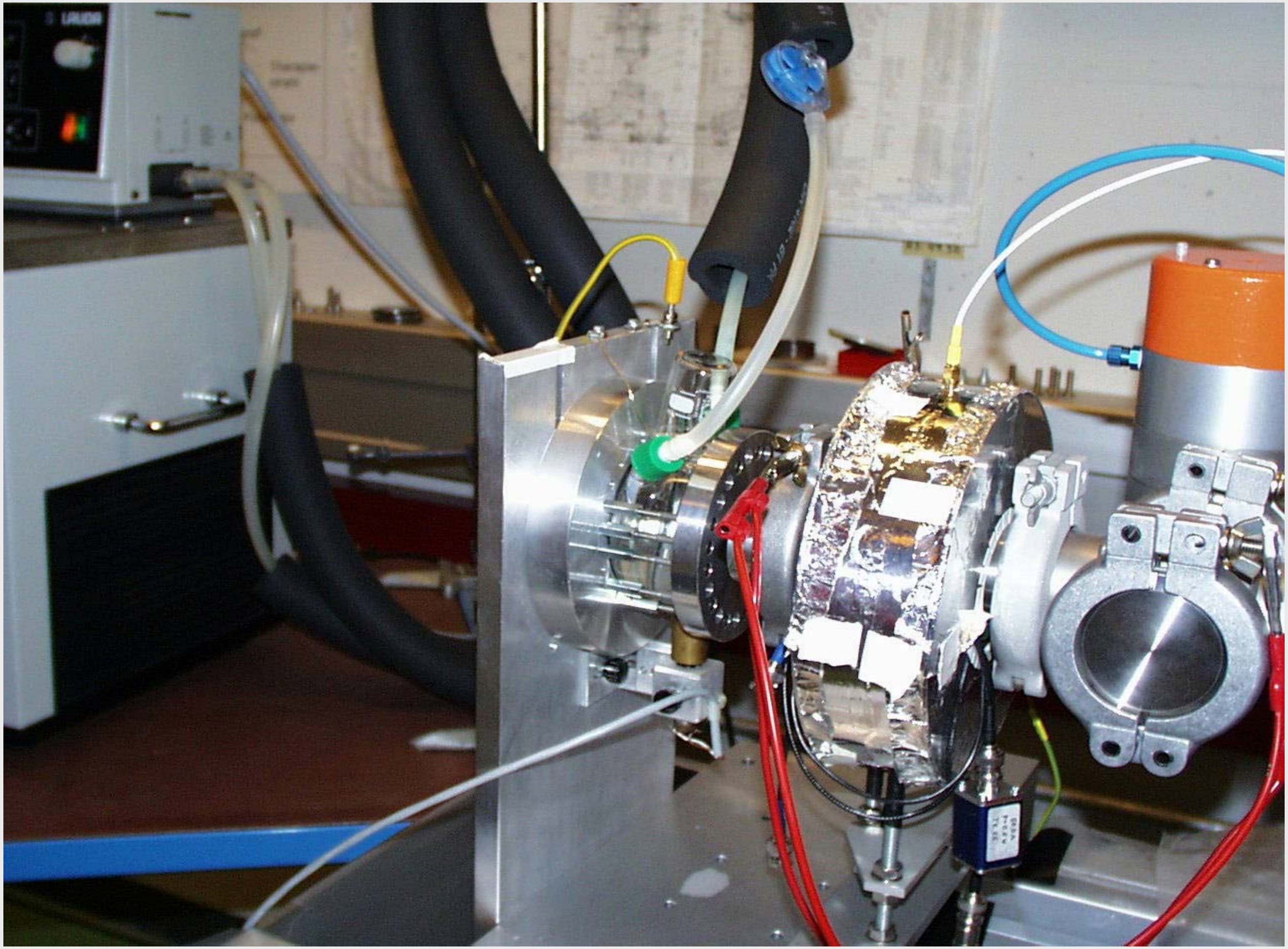
UV- spectrometer read-out:

$$D_F = \frac{\Delta A_T}{\varepsilon \cdot G_E \cdot \rho \cdot l_T} \qquad \textbf{(2)}$$

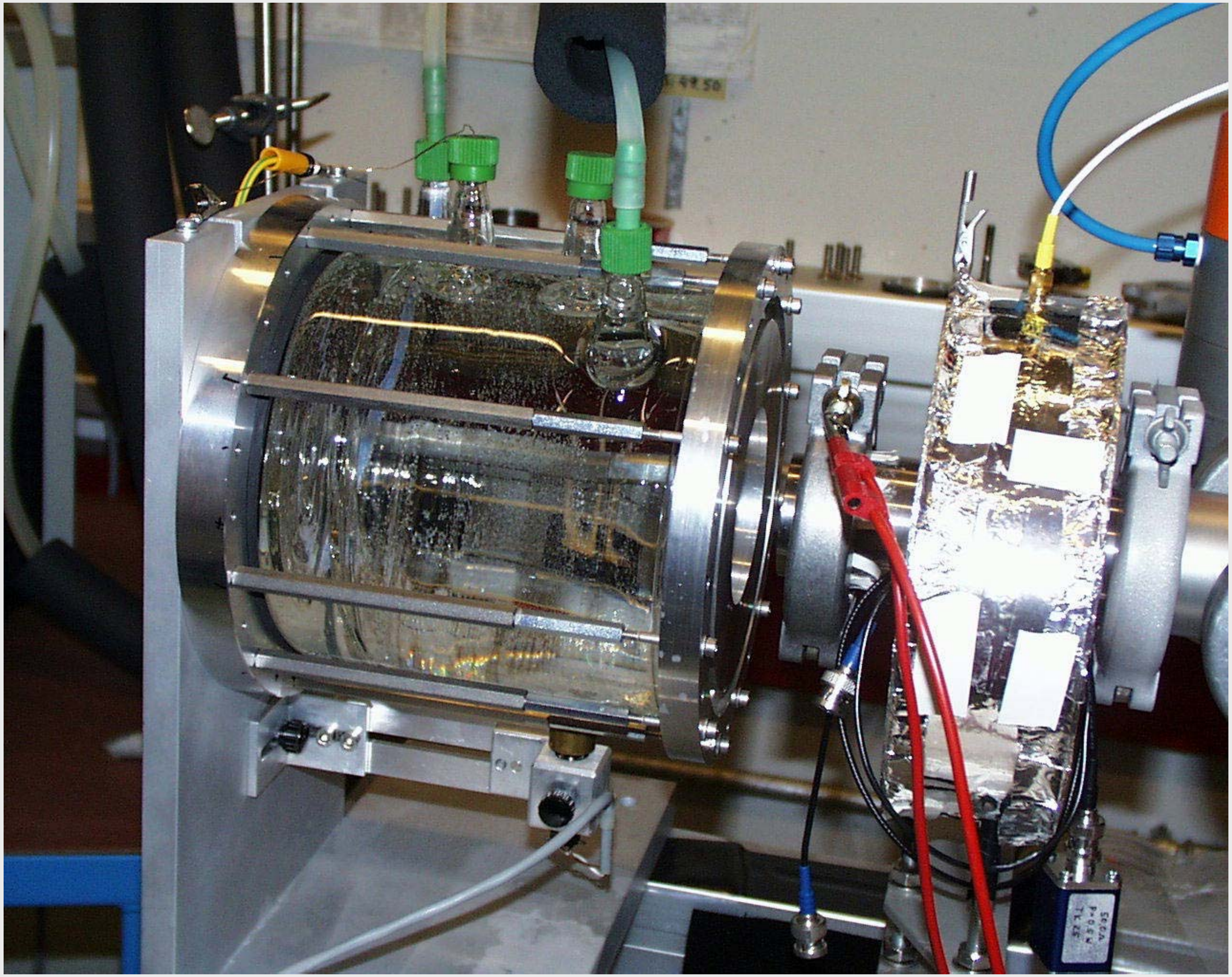
(1) + (2) →

$$G_E = \frac{\Delta A_T}{\varepsilon \cdot \rho \cdot l_T} \cdot \frac{m}{E_{abs}} \qquad \textbf{(3)}$$

Total absorption experiment, 6 MeV vessel



Total absorption experiment, 22 MeV vessel



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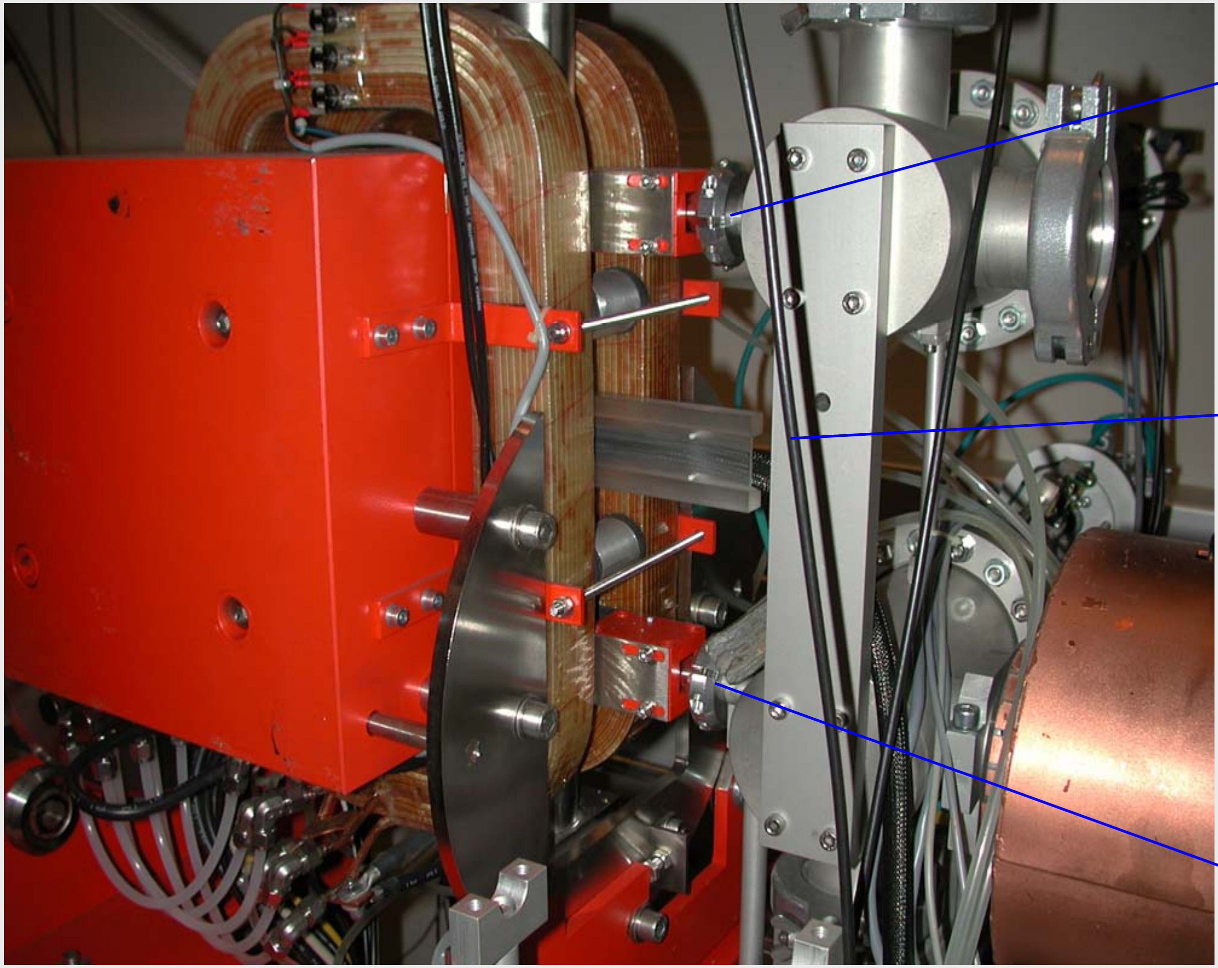
Magnetic spectrometer



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Corrections 1)

$$E_{abs} = E_e \cdot N \cdot F_T$$

Bremsstrahlung (about 8 % @ 22 MeV)

Backscattering

Fringe field spectrometer

Energy losses (entrance- and exit windows, air gap, beam line)

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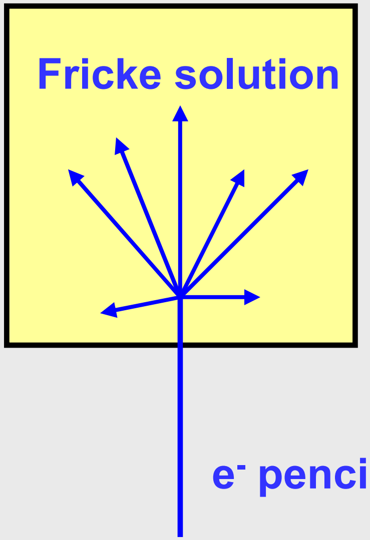
2)' Primary Standard : Chemical Dosimeter (Fricke)
Total Absorption Experiment

Irradiation experiment:

$$D_F = \frac{E_{abs}}{m} \qquad \textbf{(1)}$$

$$E_{abs} = E_e \cdot N \cdot F_T$$

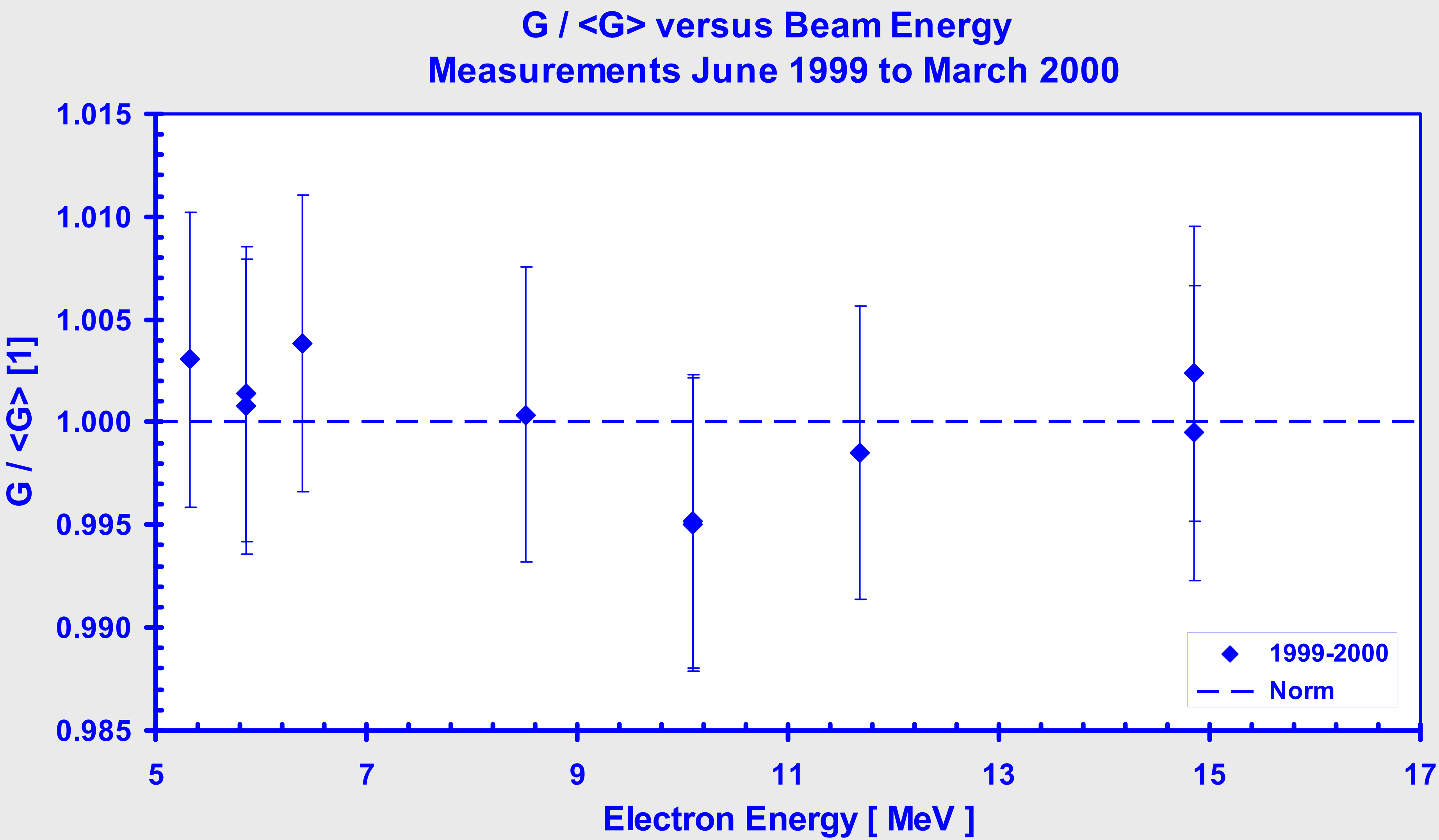


UV- spectrometer read-out:

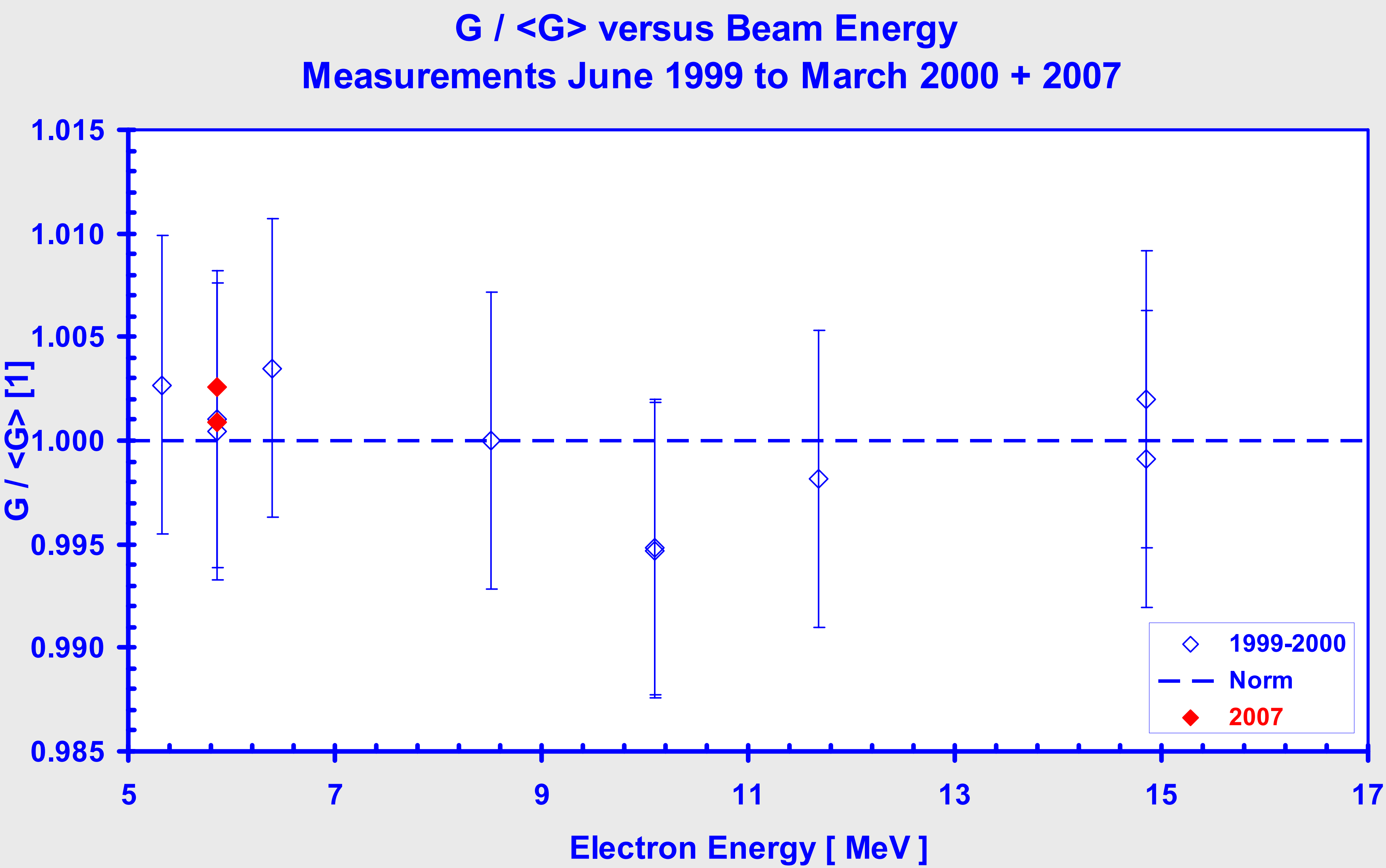
$$D_F = \frac{\Delta A_T}{\varepsilon \cdot G_E \cdot \rho \cdot l_T} \qquad \textbf{(2)}$$

(1) + (2) →

$$G_E = \frac{\Delta A_T}{\varepsilon \cdot \rho \cdot l_T} \cdot \frac{m}{E_{abs}} \qquad \textbf{(3)}$$



G ≠ f(E) within the given uncertainties


G / <G> versus Beam Energy
Measurements June 1999 to March 2000 + 2007
1.015
1.010
1.005
1.000
0.995
0.990
0.985
G / <G> [1]
5
7
9
11
13
15
17
Electron Energy [MeV]
1999-2000
Norm
2007

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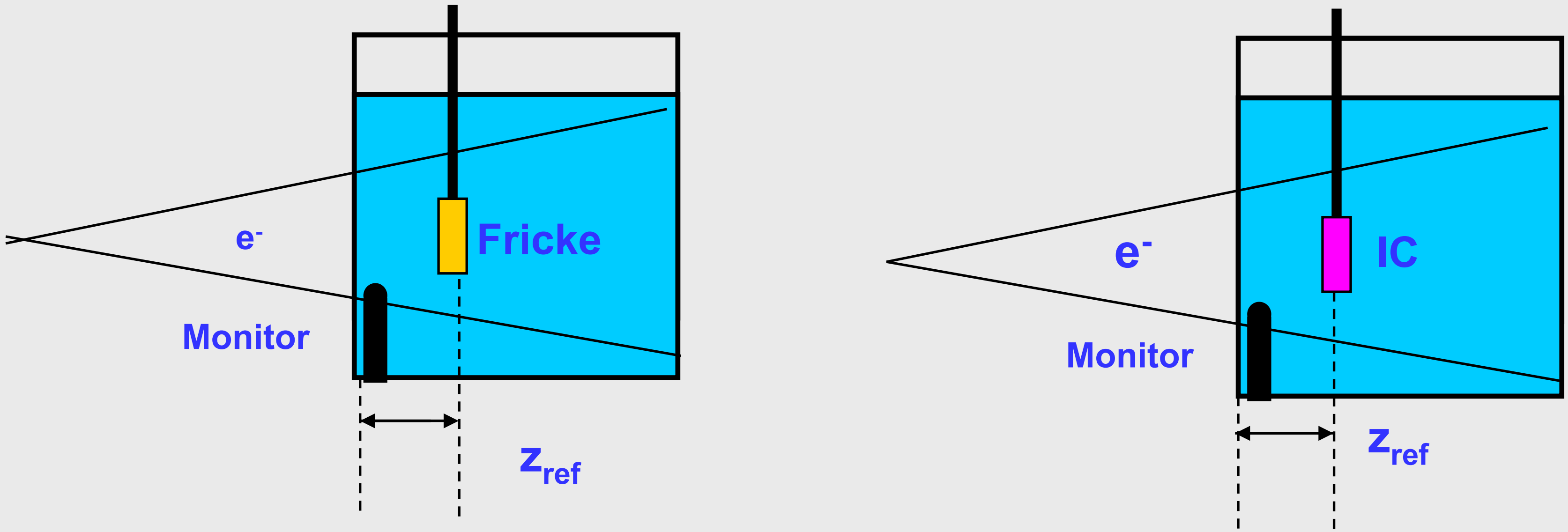
3) Ionisation Chamber Calibration Against Fricke Solution

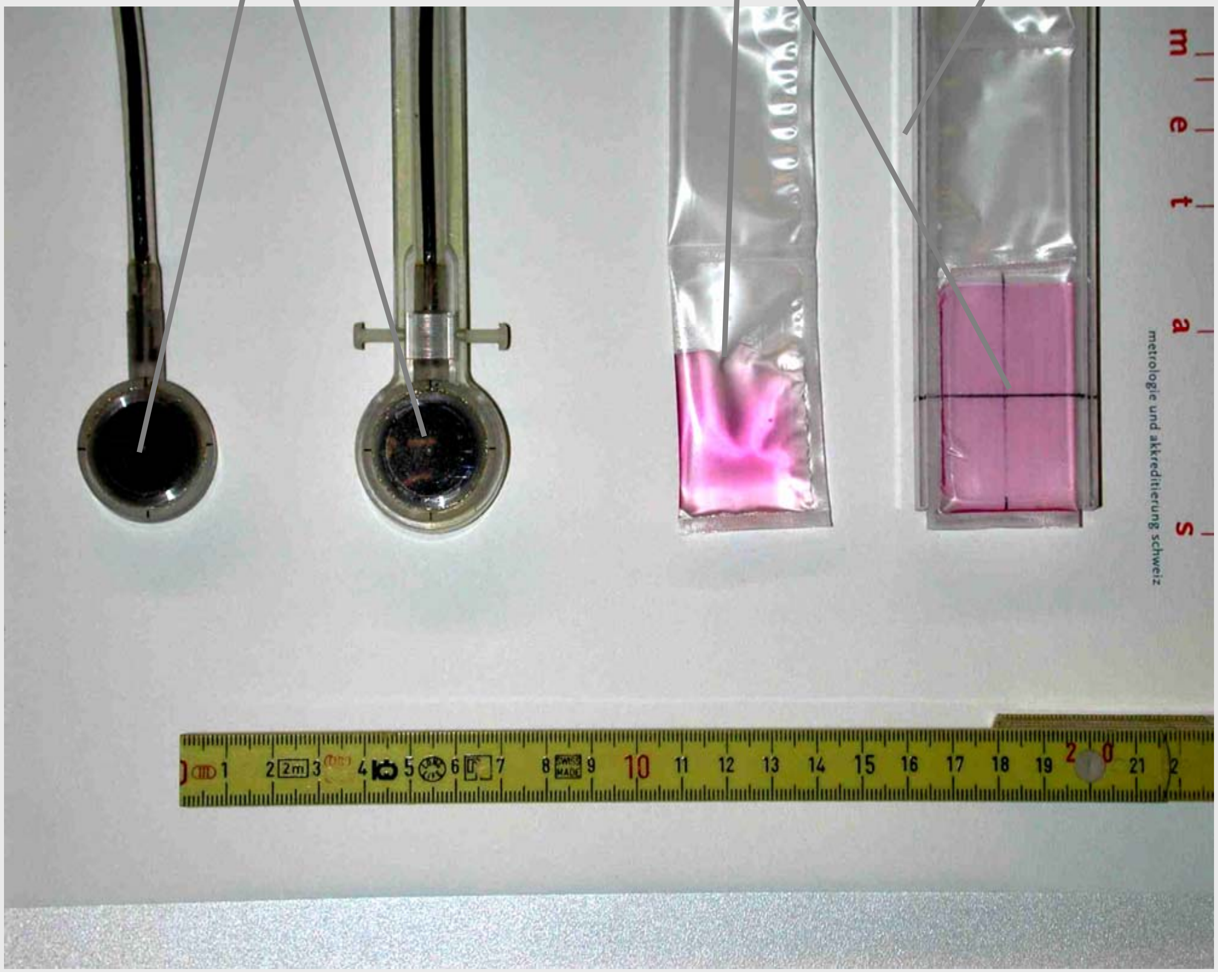


z_{ref} = 0.6 R_{50} - 0.1 gcm^{-2}

$$D_F = \frac{\Delta A}{\varepsilon \cdot G \cdot \rho \cdot l} \quad (3)$$

$$D_W = N_{D,W,Q} \cdot M_Q \quad (4)$$

NACP02 chamber PE bag PMMA holder



Corrections 2)

Fricke solution -> water -> f_e

Perturbations / wall effect due to PE foil, PMMA holder etc -> f_e

Temperatue, air pressure, humidity etc. -> Πf_i

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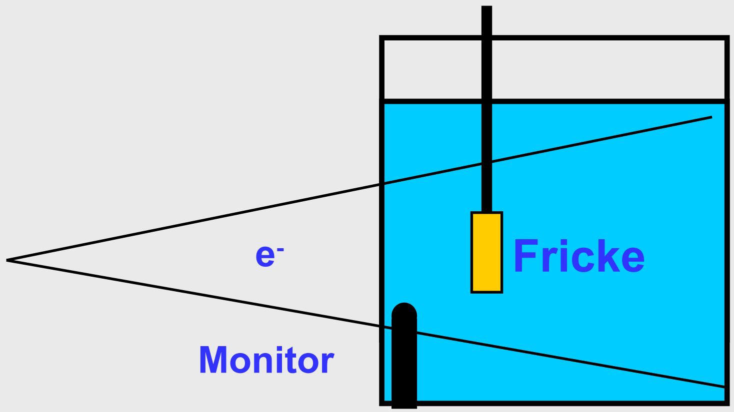
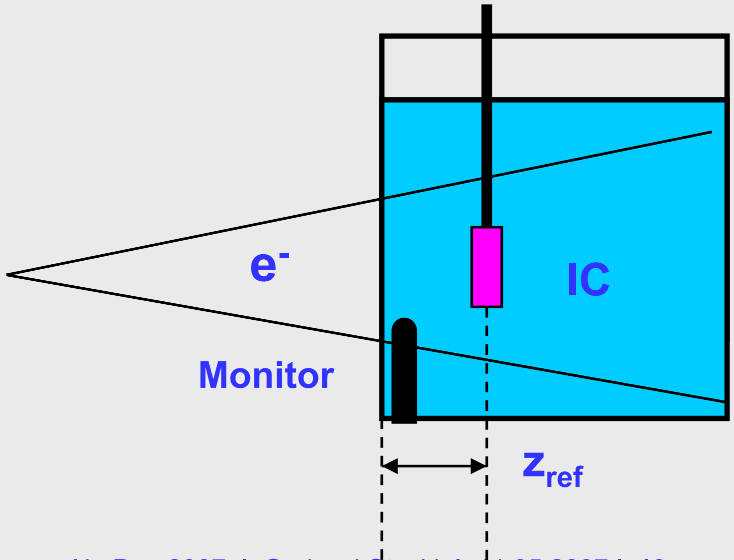
3)‘ Ionisation Chamber Calibration Against Fricke Solution



z_{ref} = 0.6 R_{50} - 0.1 gcm^{-2}



$$D_W = \frac{\Delta A_S}{\varepsilon \cdot G \cdot \rho \cdot l_S} \cdot f_e \quad (5)$$

$$= \frac{\Delta A_S}{\Delta A_T} \cdot \frac{I_T}{I_S} \cdot \frac{E_e \cdot N}{m} \cdot f_T \cdot f_e \quad (6)$$

G cancels out, since G does not depend on beam energy

$$N_{D,W,Q} = \frac{\Delta A_S}{\Delta A_T} \cdot \frac{I_T}{I_S} \cdot \frac{1}{M_Q \cdot \Pi f_i} \cdot \frac{E_e \cdot N}{m} \cdot f_T \cdot f_e \quad (7)$$

4) Results k_{Q,Q_0} Electron Beam Quality Correction Factors

Definition of k_{Q,Q_0} (experimental):

$$k_{Q,Q_0} = \frac{N_{D,w,Q}}{N_{D,w,Q_0}}$$

Definition of k_{Q,Q_0} (theoretical):

$$k_{Q,Q_0} = \frac{(s_{w,air})_Q}{(s_{w,air})_{Q_0}} \cdot \frac{(W_{air})_Q}{(W_{air})_{Q_0}} \cdot \frac{p_Q}{p_{Q_0}}$$

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Measurements in ^{60}Co beam:
Primary standard: water calorimeter

Measurements in electron beams:
Primary standard: chemical dosimeter (total absorption in Fricke solution)

➡ **No correlations between primary standards**

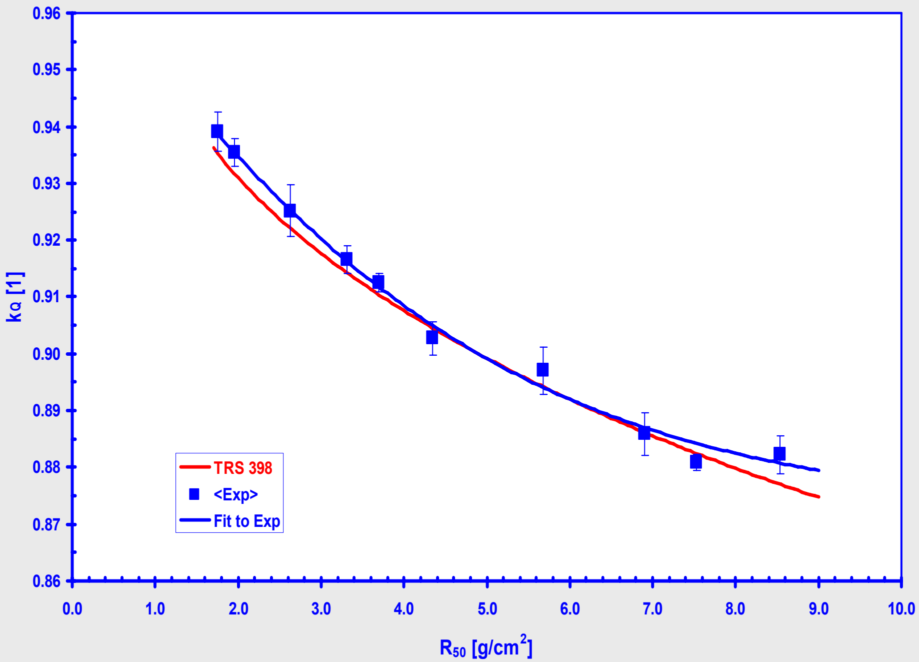
u_{k_Q} = 1 %, (k = 1)

$u_{k_{Q,Q_0}}$ = 0.5 %, (k = 1)

$$u_{k_Q} > u_{k_{Q,Q_0}}$$

Experimental k_{Q,Q_0} Factors NACP02 (13 chambers)

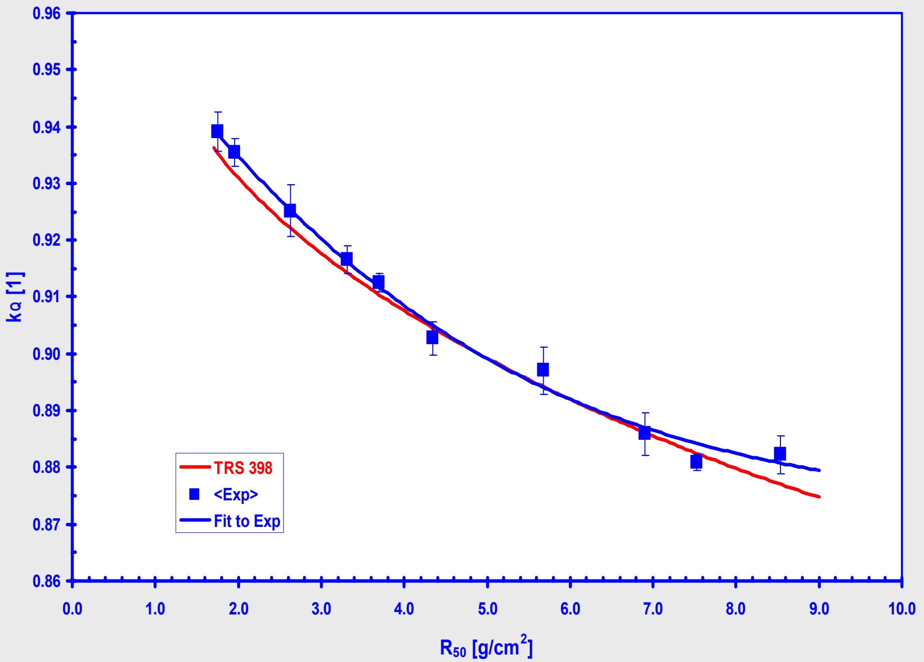
$Q_0 = {}^{60}Co$



$u_{k_Q} = 1\ \%, (k = 1)$

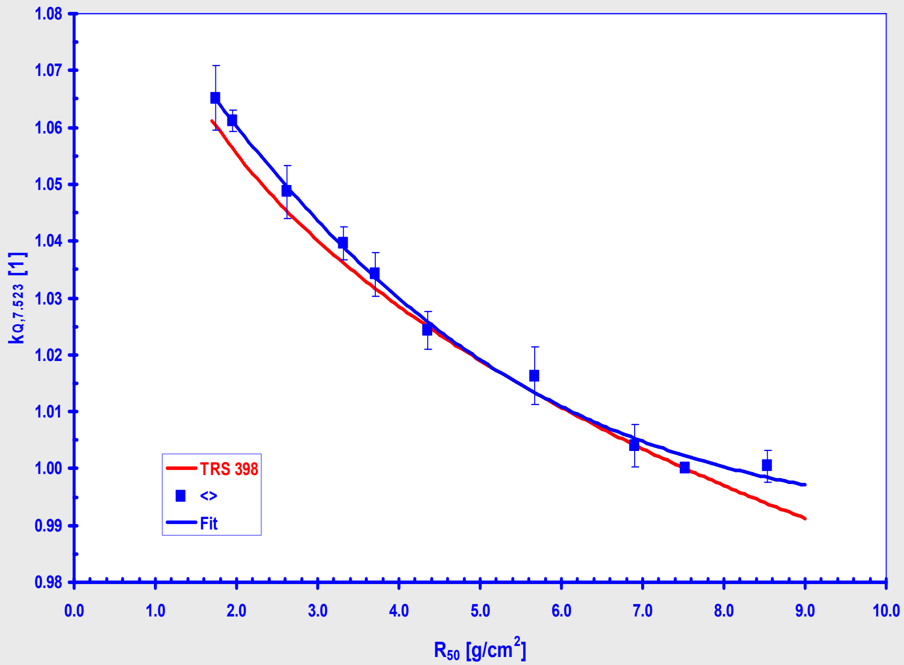
Experimental k_{Q,Q_0} Factors NACP02 (13 chambers)

$Q_0 = {}^{60}Co$



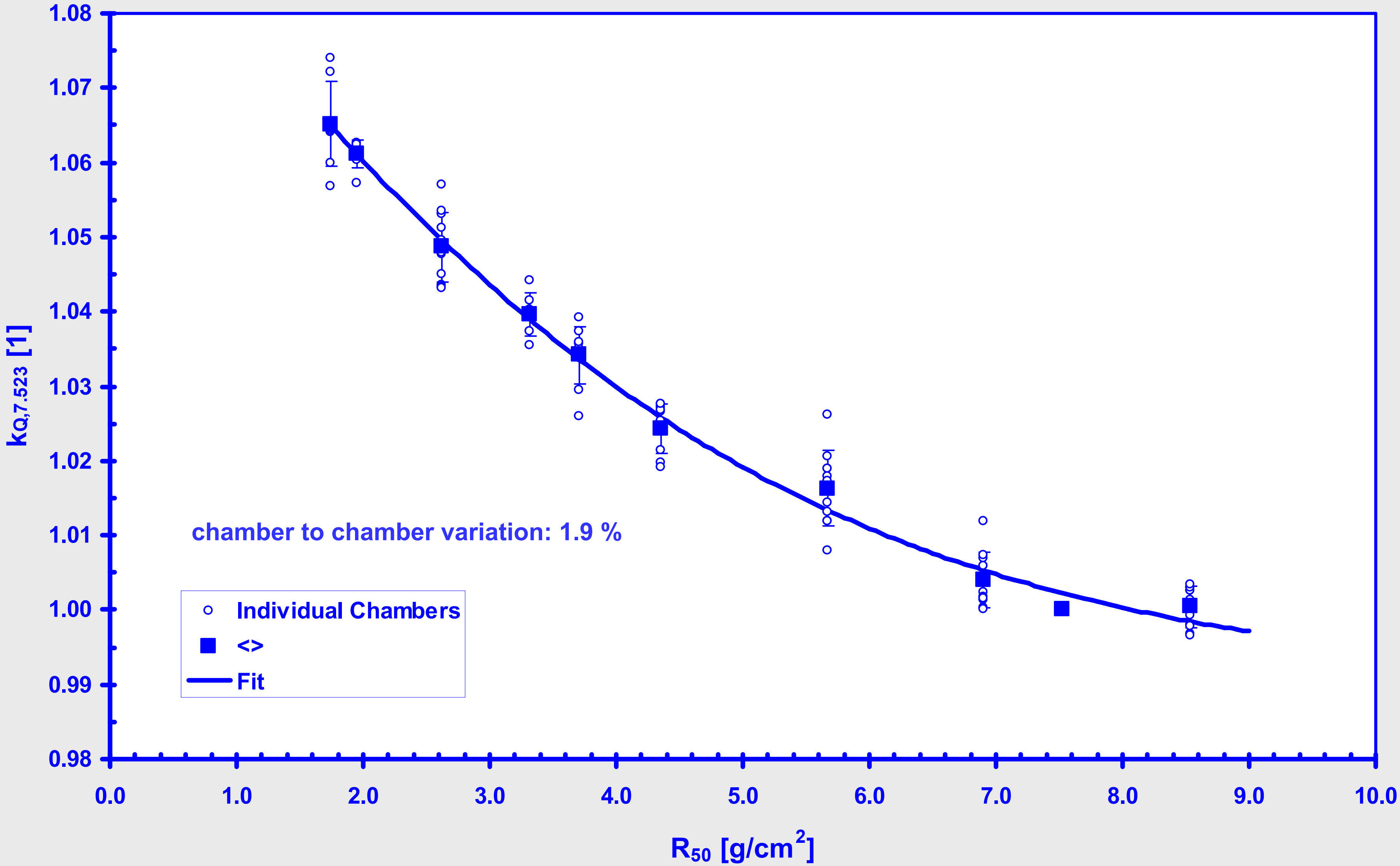
$u_{kQ} = 1$ %, (k = 1)

$Q_0 = 7.523$ gcm^{-2}



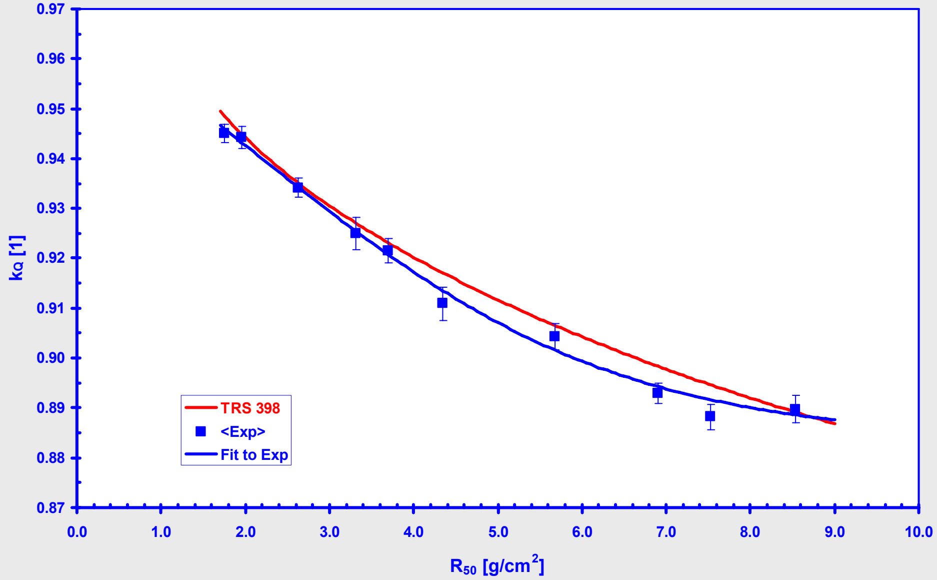
$u_{kQ,Q_0} = 0.5$ %, (k = 1)

Experimental k_{Q,Q_0} Factors
NACP02 Chambers, Q_0=7.523 gcm^{-2}



Experimental k_{Q,Q_0} Factors PTW 34001 (18 Chambers)

$Q_0 = {}^{60}Co$



$u_{k_Q} = 1$ %, ($k = 1$)

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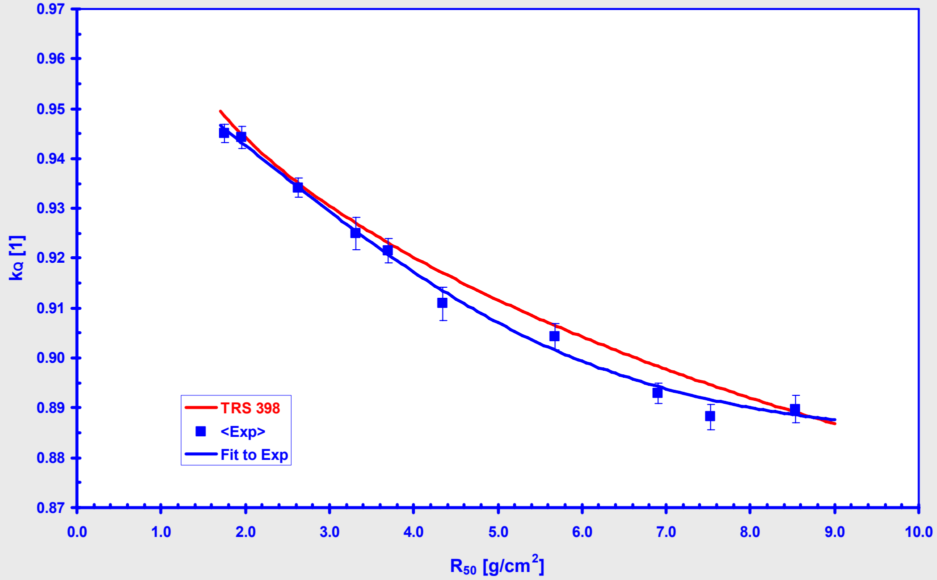
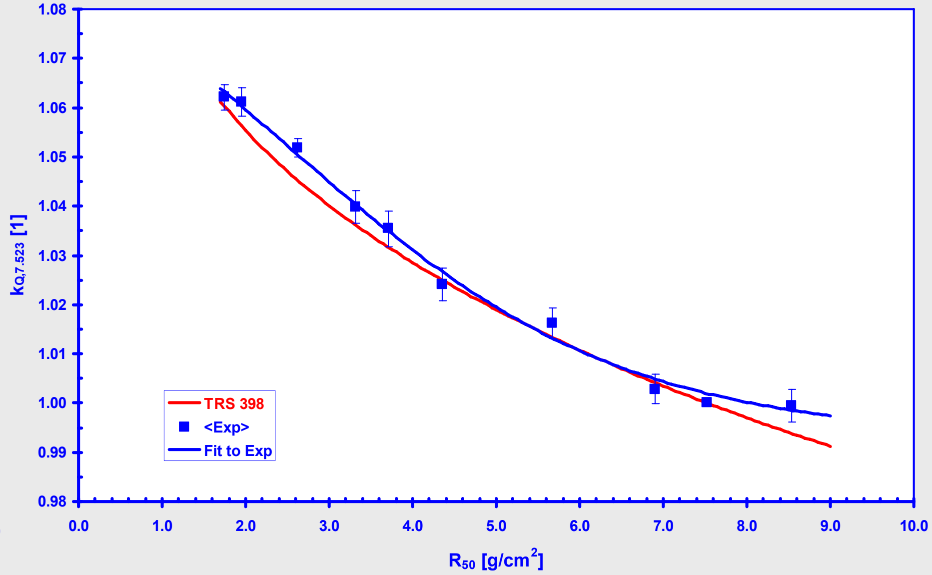
Experimental k_{Q,Q_0} Factors PTW 34001 (18 Chambers)

$Q_0 = {}^{60}Co$



u_{kQ} = 1 %, (k = 1)

Q_0=7.523 gcm^{-2}



u_{kQ,Q_0} = 0.5 %, (k = 1)

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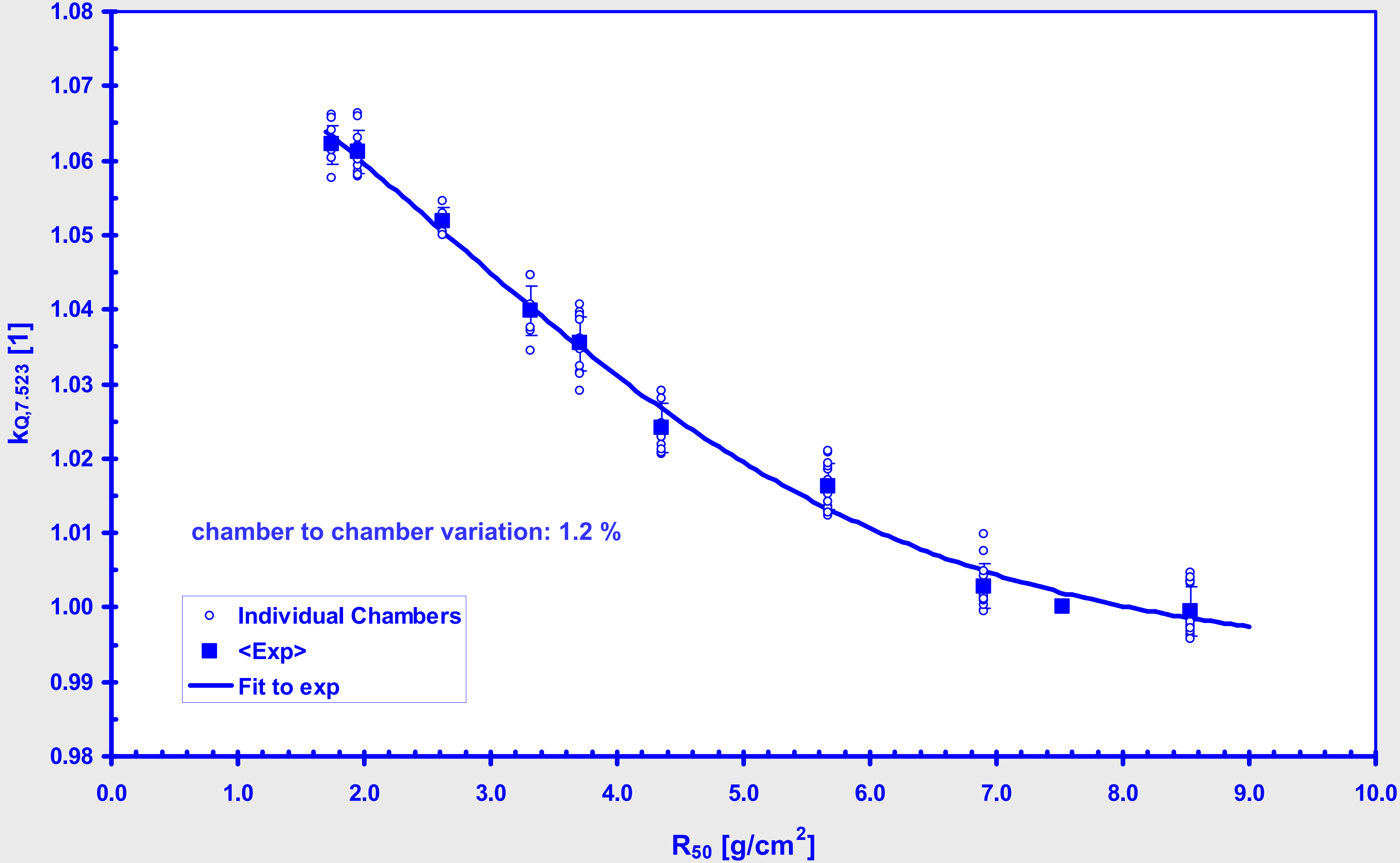
Experimental k_{Q,Q_0} Factors as a Function of R_{50}
Individual PTW34001 Chambers, Q_0=7.523 gcm^{-2}



5) Comparison with TRS 398

$$k_{Q,Q_0} = \frac{(s_{w,air})_Q}{(s_{w,air})_{Q_0}} \cdot \frac{(W_{air})_Q}{(W_{air})_{Q_0}} \cdot \frac{p_Q}{p_{Q_0}}$$

Assumptions IAEA TRS 398, Appendix II:

$$(W_{air})_Q := (W_{air})_{Q_0}$$

$p_Q := p_{cav} \cdot p_{dis} \cdot p_{wall} \cdot p_{cel}$ and $p_{cav} = p_{dis} = p_{cel} := 1$

➡ $p_Q = p_{wall}$

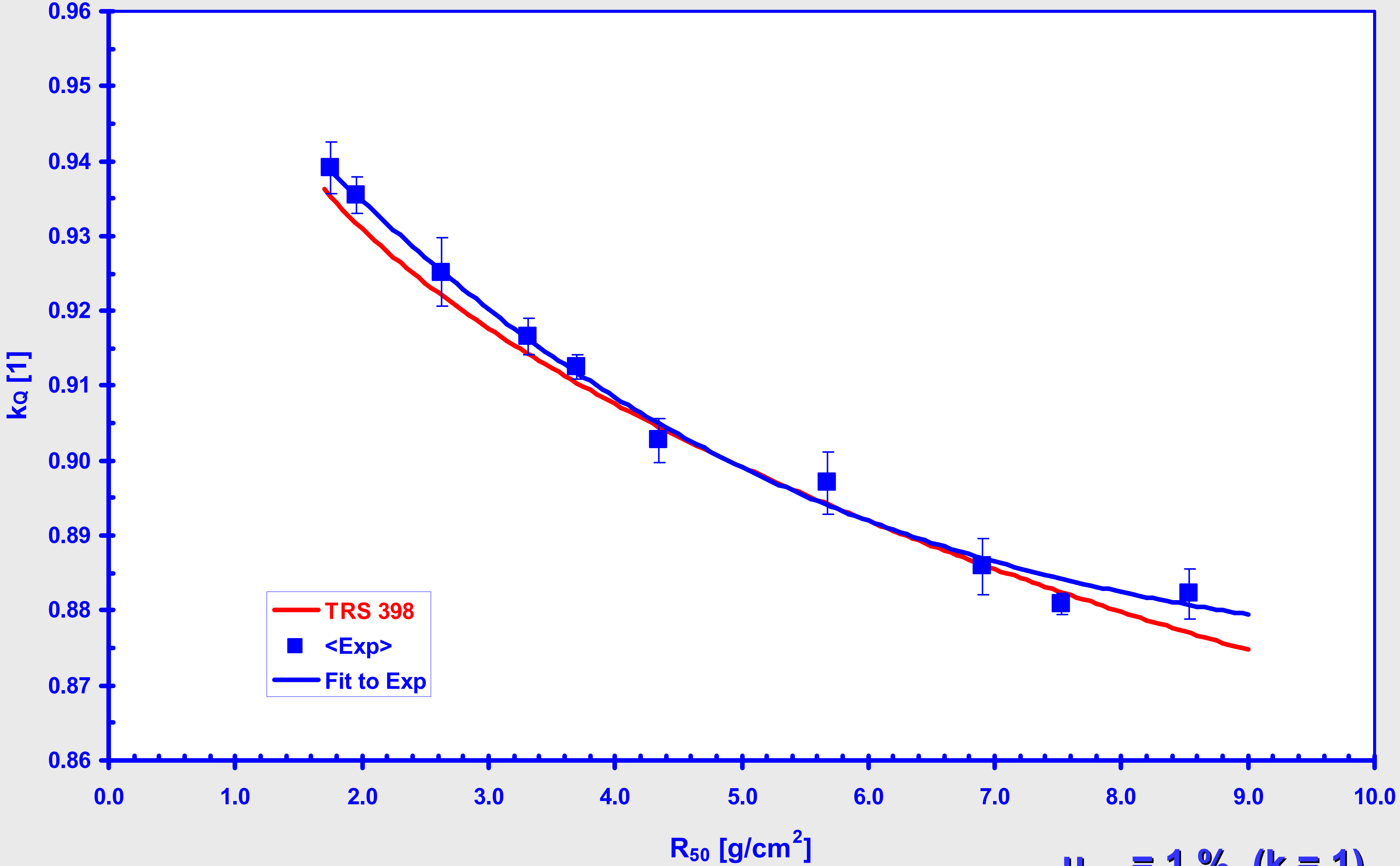
$p_{wall} := 1$, in electron beams

$p_{wall} \neq 1$, if $Q = {}^{60}Co$

➡ $$k_{Q,Q_0} = \frac{(s_{w,air})_Q}{(s_{w,air})_{Q_0}}$$

➡ $$k_Q = \frac{(s_{w,air})_Q}{(s_{w,air})_{60_{Co}}} \cdot \frac{1}{p_{wall}}$$

NACP02: k_Q Factors, Experiment <> TRS 398

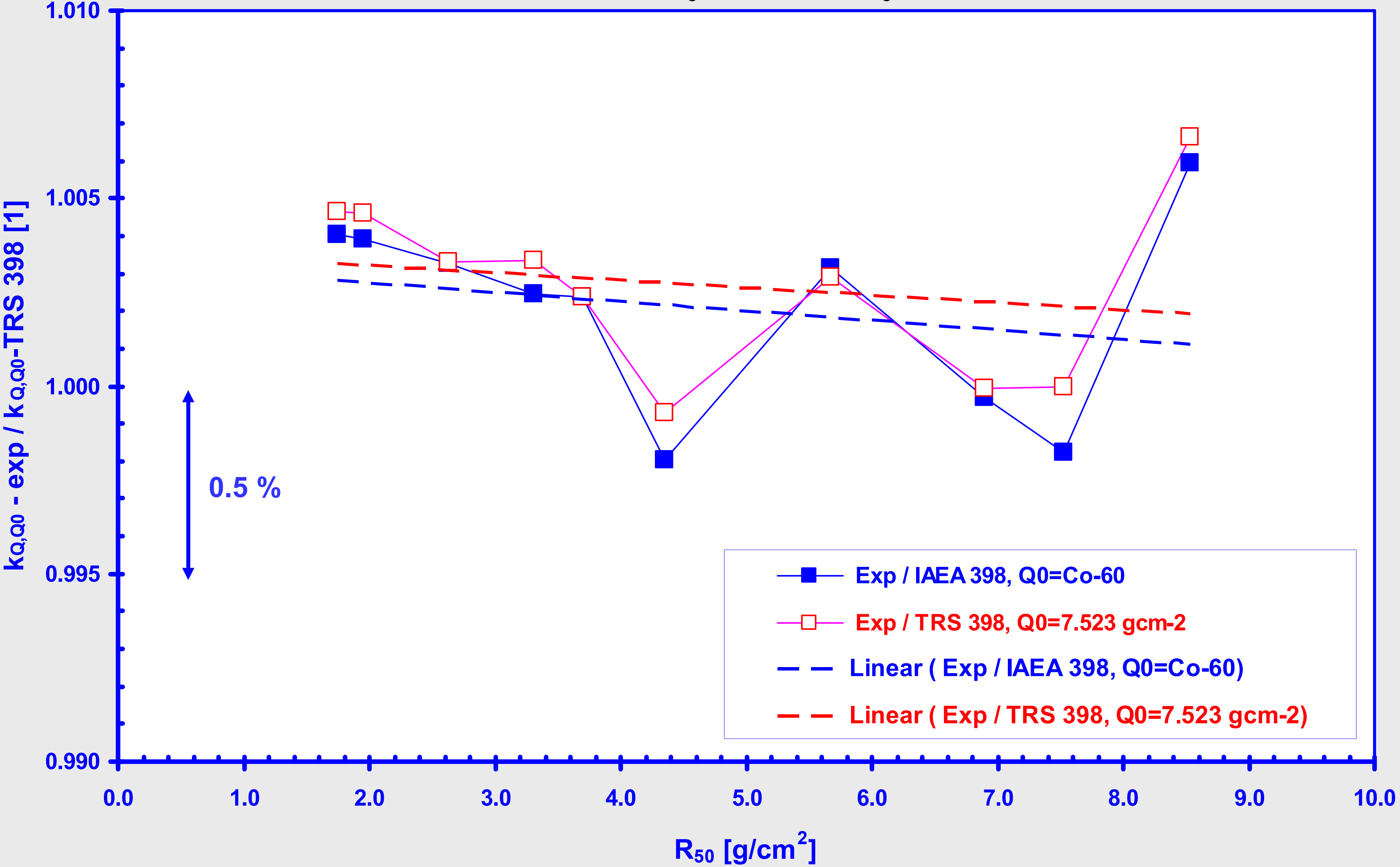


u_{k_Q} = 1 %, (k = 1)

<p_{wall} (exp)> = 1.022, σ = 0.004

p_{wall} (TRS 398, V_12, 5 June 2006) = 1.024

NACP02: k_{Q,Q_0}- exp / k_{Q,Q_0}-TRS398



<>=1.0021, σ=0.0026

Q_0= ^{60}Co

<>=1.0028, σ=0.0024

Q_0= 7.523 gcm^{-2}

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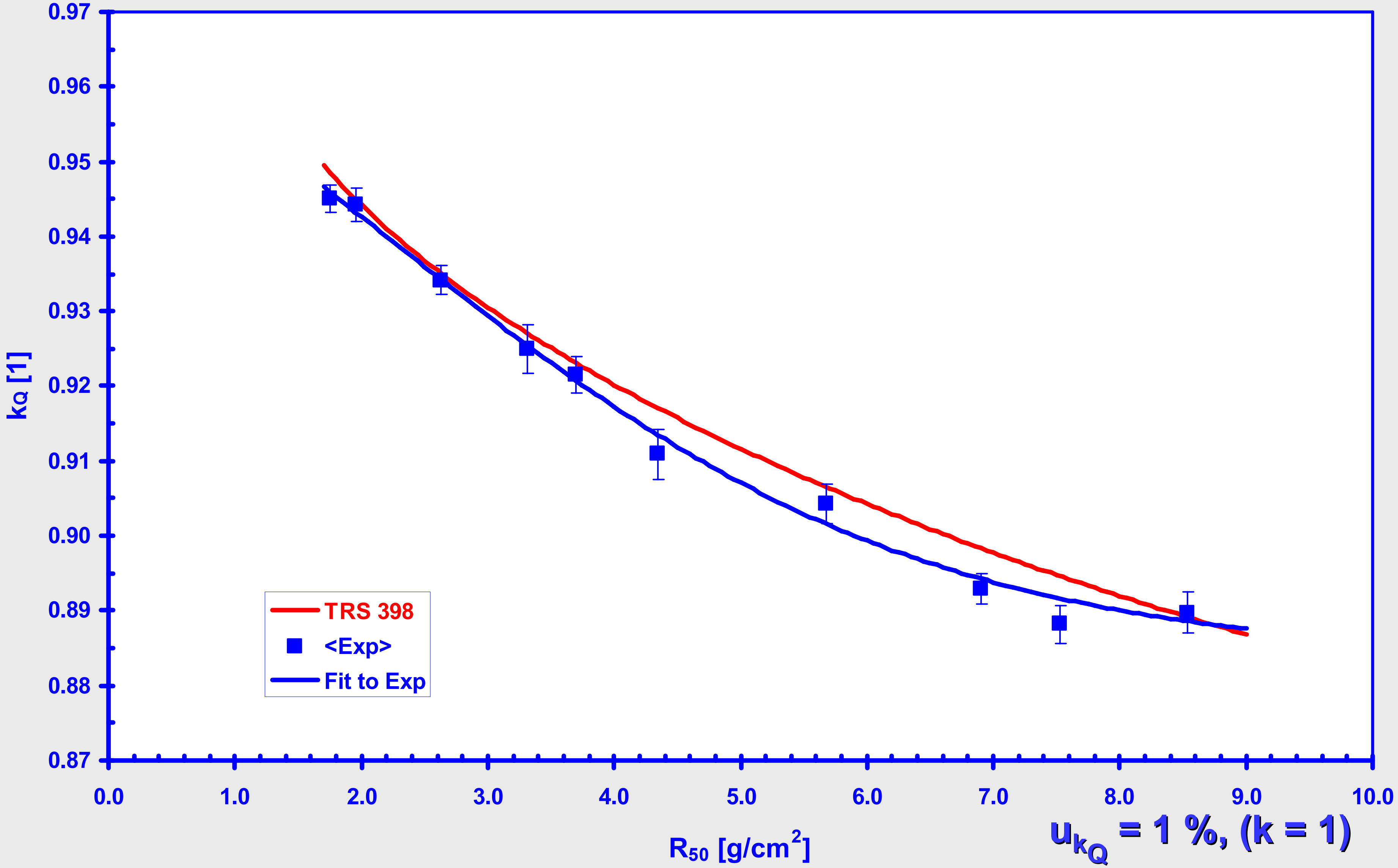
PTW 34001 : k_Q Factors, Experiment <> TRS 398



u_{k_Q} = 1 %, (k = 1)

<p_{wall} (exp)> = 1.013, σ = 0.004

p_{wall} (TRS 398, V_12, 5 June 2006) = 1.010

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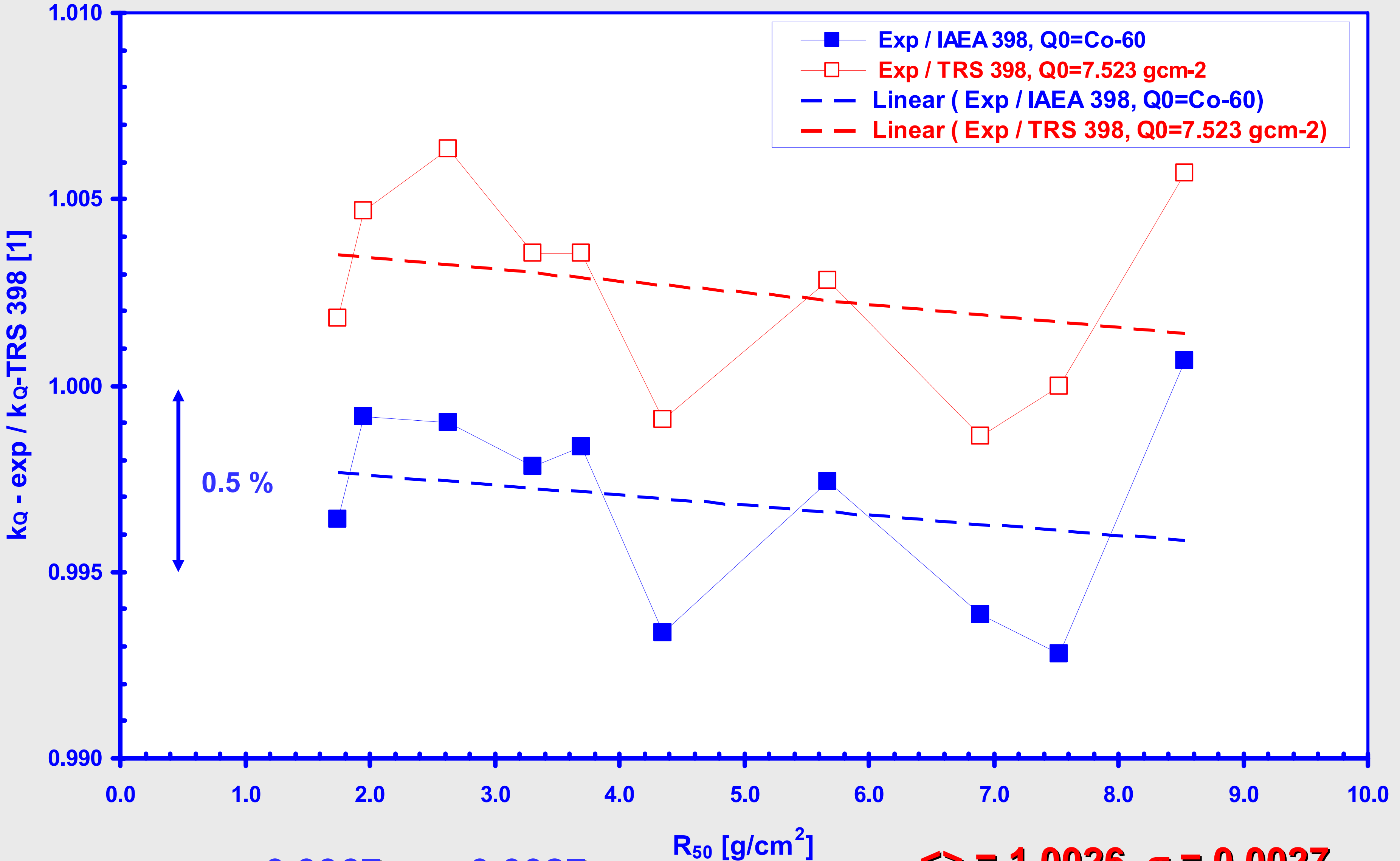
PTW 34001: k_{Q,Q_0}- exp / k_{Q,Q_0}-TRS398



<> = 0.9967, σ = 0.0027
Q_0= ^{60}Co

<> = 1.0026, σ = 0.0027
Q_0 = 7.523 gcm^{-2}

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Conclusions

- <P_Q> (electron beams) : constant (within uncertainty)
- <k_{Q,Q_0} (exp)> in agreement with k_{Q,Q_0} (TRS 398 (V_12))

NACP02 chamber:

- <P_{wall} (exp)> = 1.022 in agreement with p_{wall} (TRS 398 (V_12)) = 1.024
- mean ratio k_{Q,Q_0}(exp)/k_{Q,Q_0}(TRS), Q_0 = ^{60}Co: 1.0021 (σ: 0.26 %)
- mean ratio k_{Q,Q_0}(exp)/k_{Q,Q_0}(TRS), Q_0 = 7.523 gcm^{-2} : 1.0028 (σ: 0.24 %)
- chamber to chamber variation: 1.9 % !

PTW34001 chamber:

- <P_{wall} (exp)> = 1.013 in agreement with p_{wall} (TRS 398 (V_12)) = 1.010
- mean ratio k_{Q,Q_0}(exp)/k_{Q,Q_0}(TRS), Q_0 = ^{60}Co: 0.9967 (σ: 0.27 %)
- mean ratio k_{Q,Q_0} (exp)/k_{Q,Q_0}(TRS), Q_0 = 7.523 gcm^{-2} : 1.0026 (σ: 0.27 %)
- chamber to chamber variation: 1.2 % !

Thank you for your attention !