NTG Beam Diagnostics

NTG-Beam Diagnostics and Special Topics

A. Bechtold and P. Strehl

- January 2011, NTG takes over PET (Peter Strehl & Hubert Kraus) after a long time business relationship.
- P. Strehl and H. Kraus are still NTGs consultants to enable NTG to provide the full scope of PET products.

Who We Are

Company Name:	NTG – Neue Technologien GmbH
Location:	Gelnhausen (60 km to NO from GSI)
Established:	1968
Staff members:	85
Fields of Activity:	UHV-resort
	- accelerators
	- **beam diagnostics**
	- nano-technology (IBF-plants)
Owner:	Fam. Gutmann

Outline

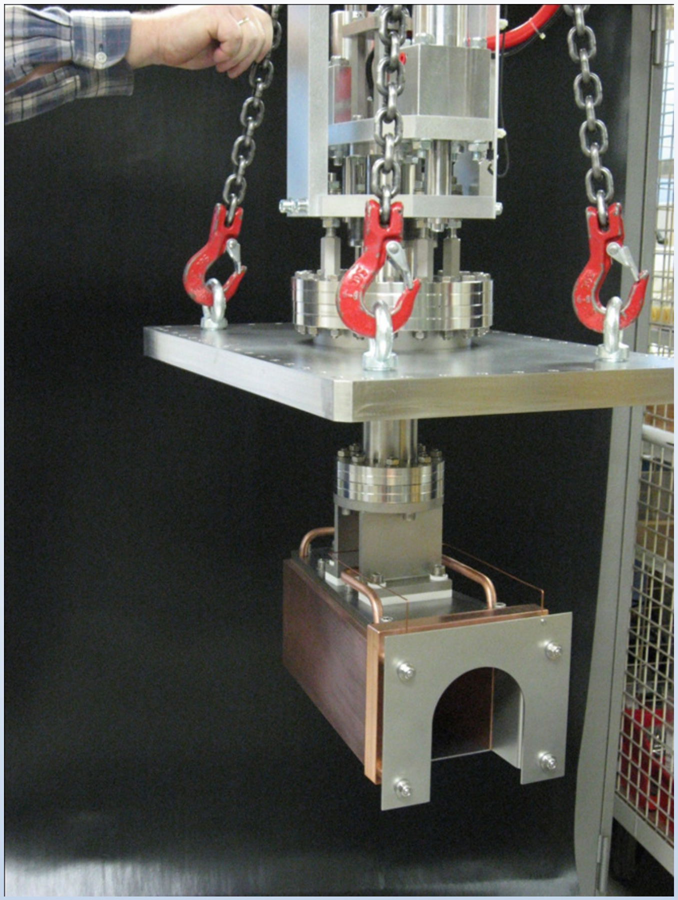
•Scope of NTG products and competencies (A. Bechtold)

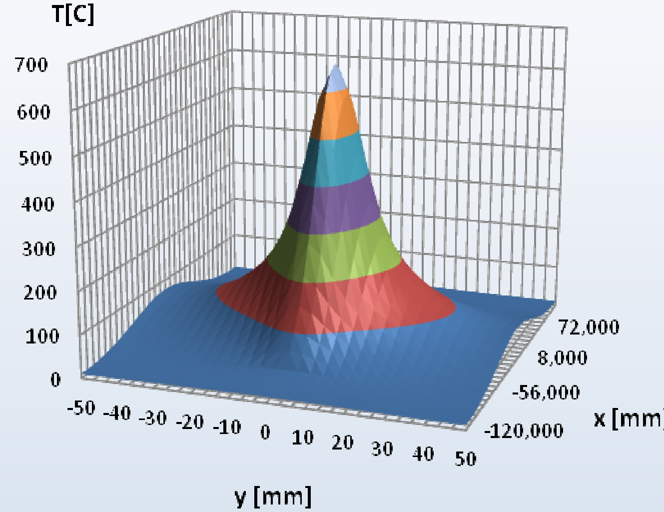
•Special Topics (P. Strehl)

Scope of NTG products and competencies

- Faraday Cups
- Profile Grids
- Capacitive BPMs and Phase Probes
- Slits
- Screens
- Feedthroughs of any kind
- Emittance Scanners
- Rotating Diagnostics Chamber
- etc.

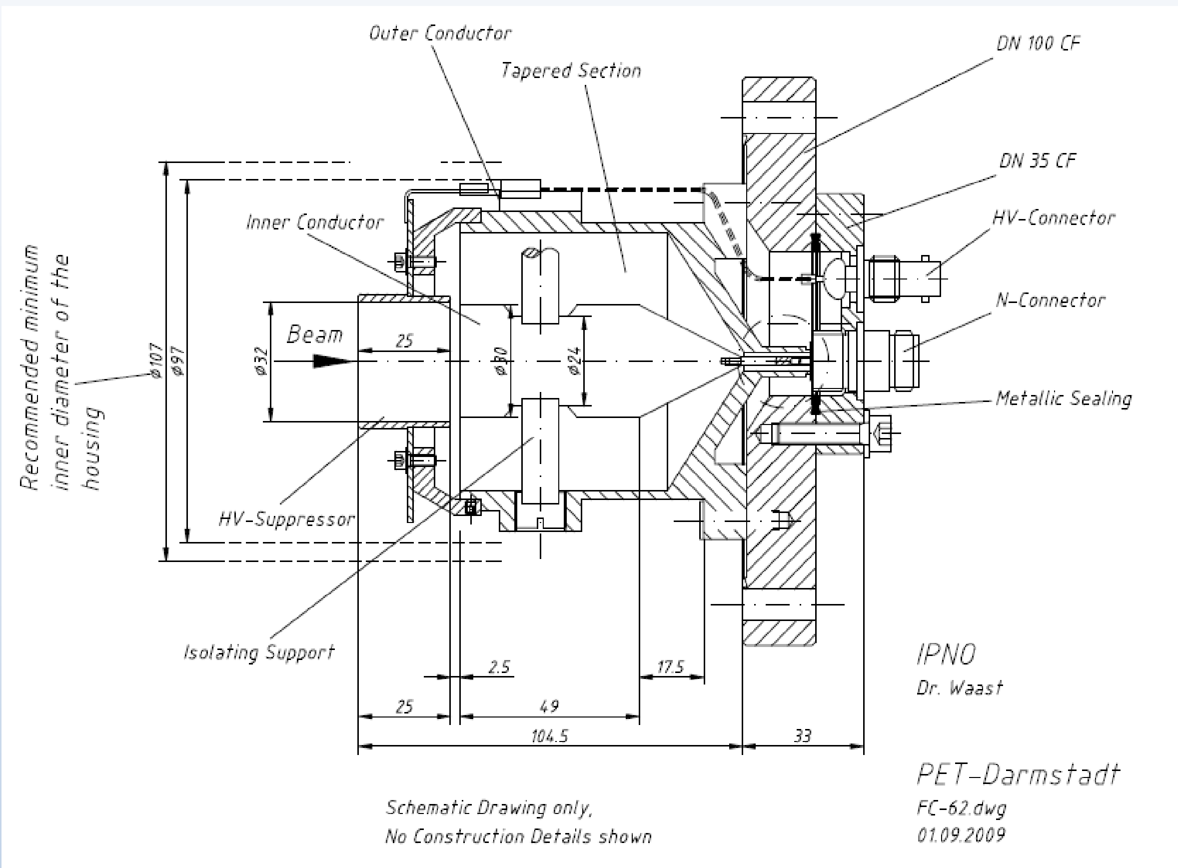
Slow Faraday Cups

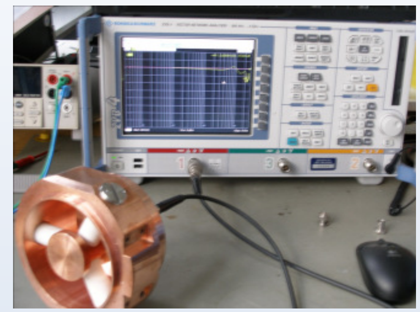




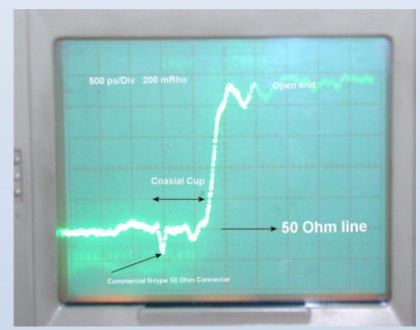
input parameters	
beam radius, [mm]	10
slope of the stopper plate Y : S	8
beam power, QG, [Watt]	24000
total width of the stopper plate, horizontal = Xmax, [mm]	100
total height of the stopper plate, vertical = Ymax, [mm]	240
total thickness of the stopper plate = Zmax, [mm]	35
penetration depth of the particles, Pd, [mm]	0,04

Coaxial Faraday Cups





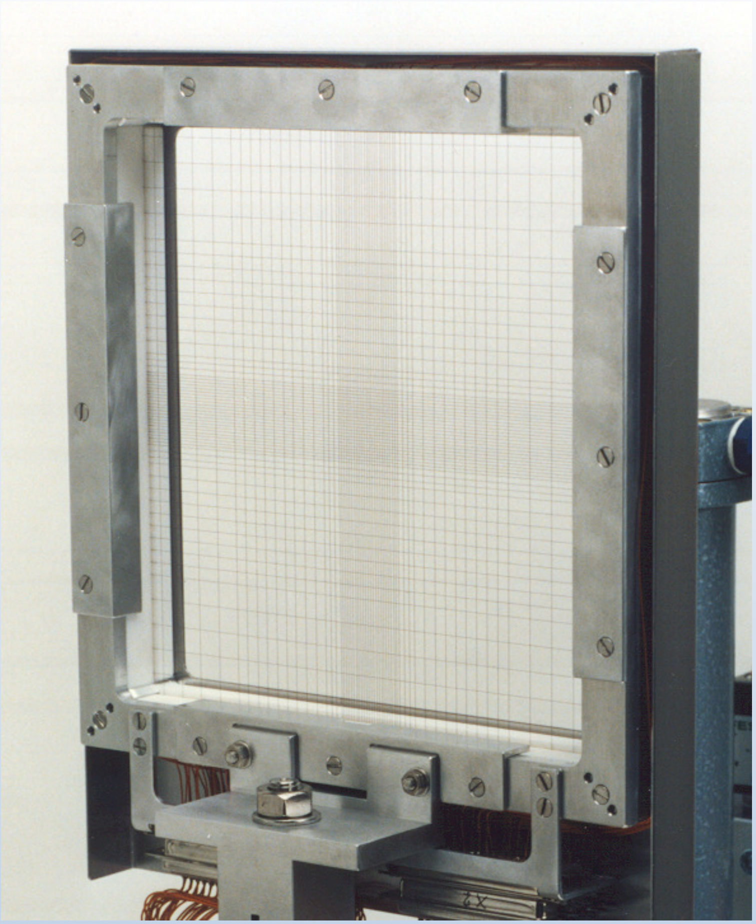
Testing a large coaxial Faraday cup with a spectrum analyzer

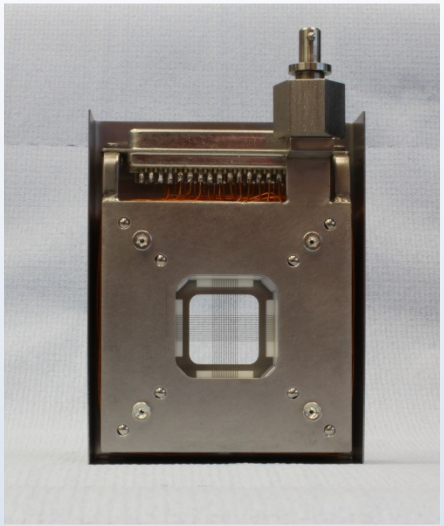


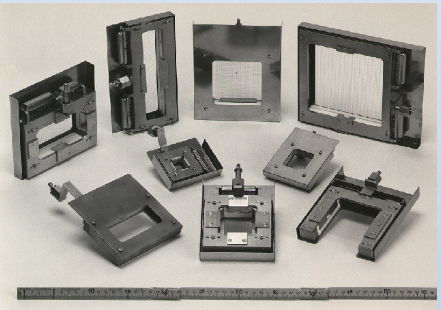
TDR – Impedance measurement on the coaxial Faraday cup

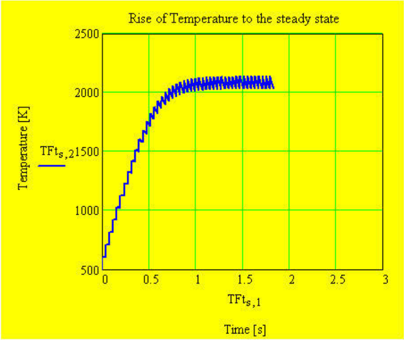
with 25 ps pulse rise time. Corresponds to a bandwidth of 14 GHz

Profile Grids









$\rho = 19.3$ Tungsten/Re wires, [g/cm³]

$\mathrm{Ppmm2} \cdot 100 = 1.2 \times 10^{4}$ [W/cm²]

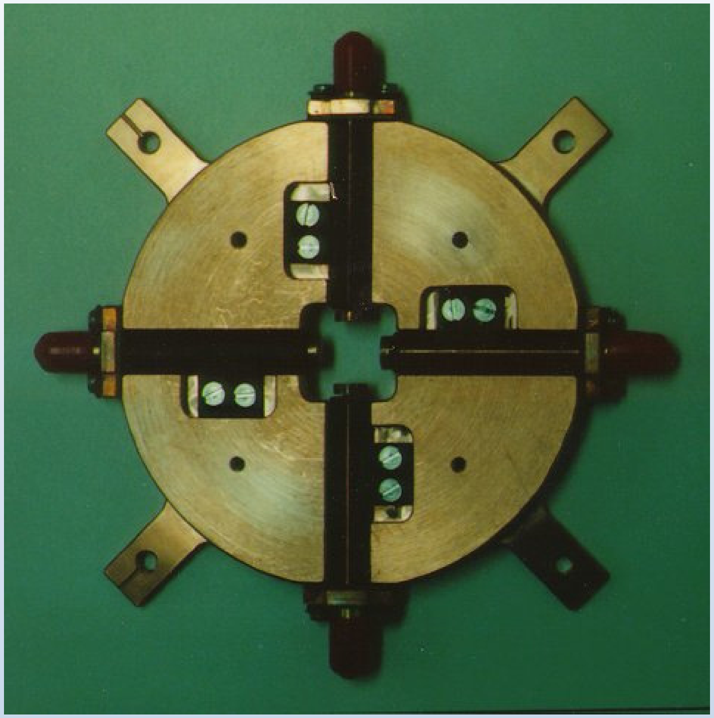
$\Delta t = 2 \times 10^{-4}$ pulse length, [s]

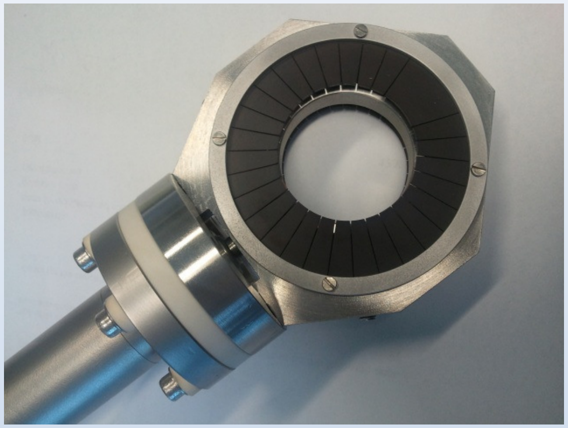
$f_r = 25$ repetition frequency, [Hz]

Calculation of the maximum thermal load on a profile grid for a pulsed beam.

The steady state is determined by radiation according to the Stefan-Boltzman law.

50 Ω Capacitive BPMs and Phase Probes





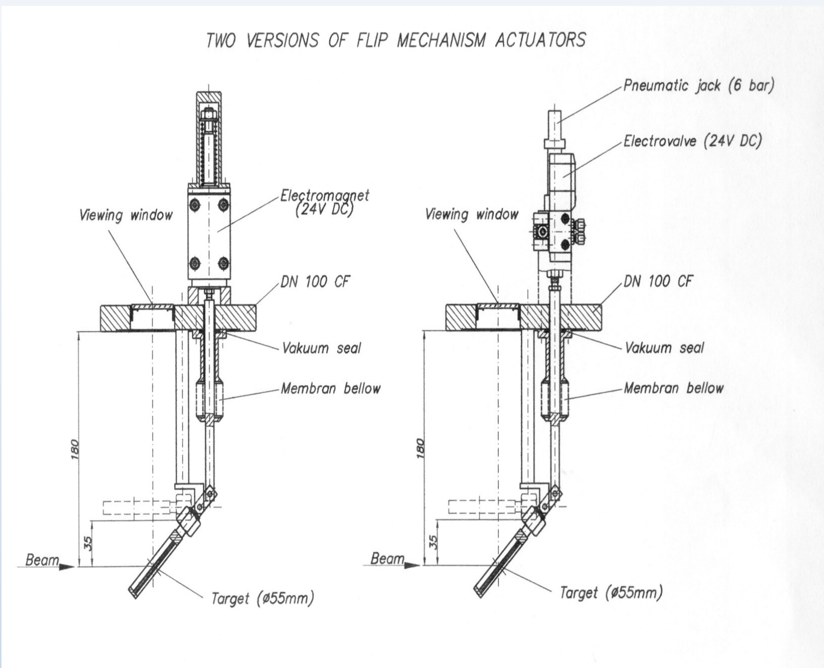
Bandwidth → 2 GHz

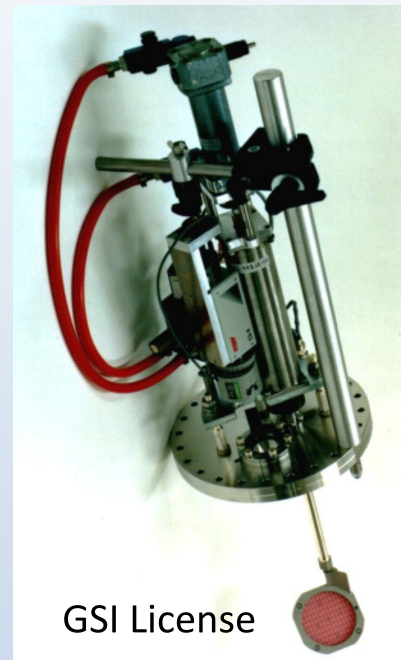
Sum signal: ca. 20-40 pA/e

Difference signal: ca. 3-5 pA/e

Screens

Viewing Screen,attached to a compressed Air Actuator





Screen material:

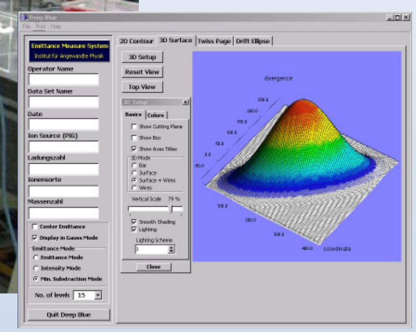
Chrolox 6,

Sensitivity:

10^6 Protons/mm²

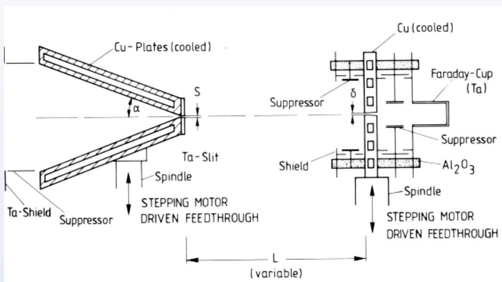
Decay time ~ 1 ms

λ = 700 nm



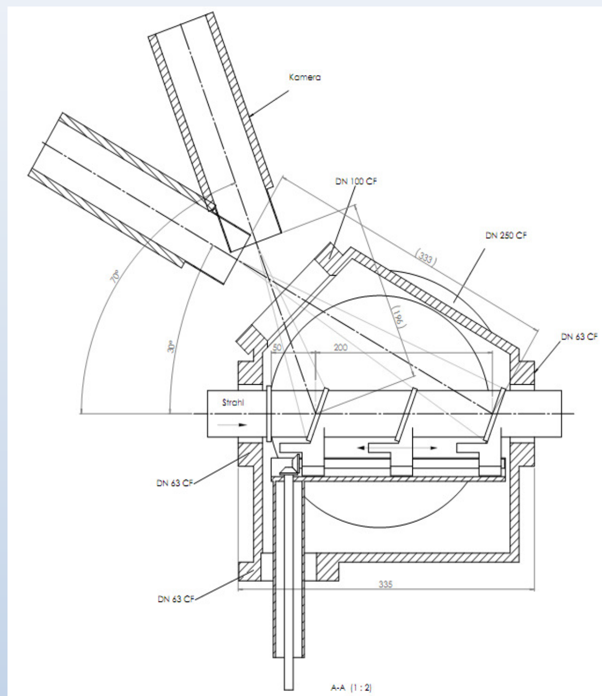
Emittance measuring system based on a stepping motor driven crossed slit and a profile grid (see next foil). Both units mounted onto a 45 degree Port.

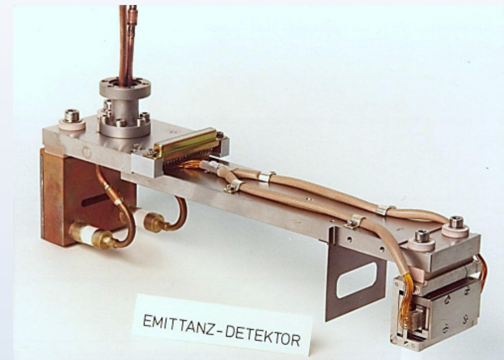
NTG Beam Diagnostics



High Power Scanner

Pepper Pot



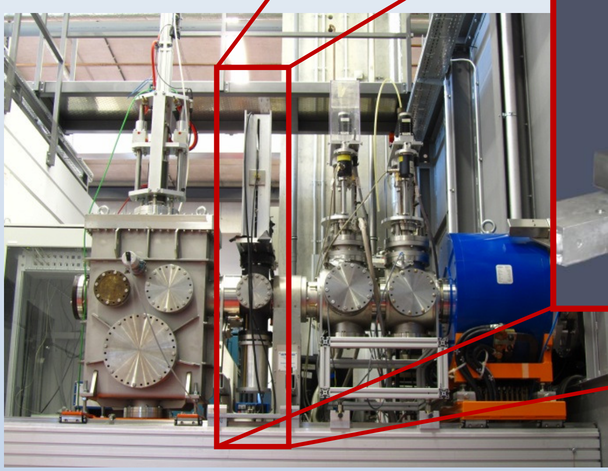


Slit-Sandwich Detector

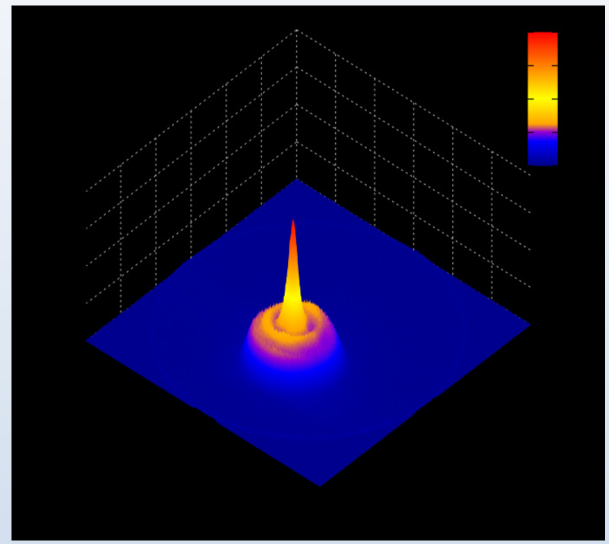
Rotating Diagnostics Chamber

(IAP – Uni Frankfurt)

FRANZ set up



Beam density distribution



$p_{work} = 5 \cdot 10^{-8}$ mbar

NTG Competence

Design of beam diagnostic systems:

- **System analysis**
- **Signal calculation for all kinds of monitors**
- **Thermal calculations**
- **High intensity beam diagnostics**
- **Emittance measuring systems**
- **Development of application software**
- **Particle dynamics**
- **Estimation of space charge effects**

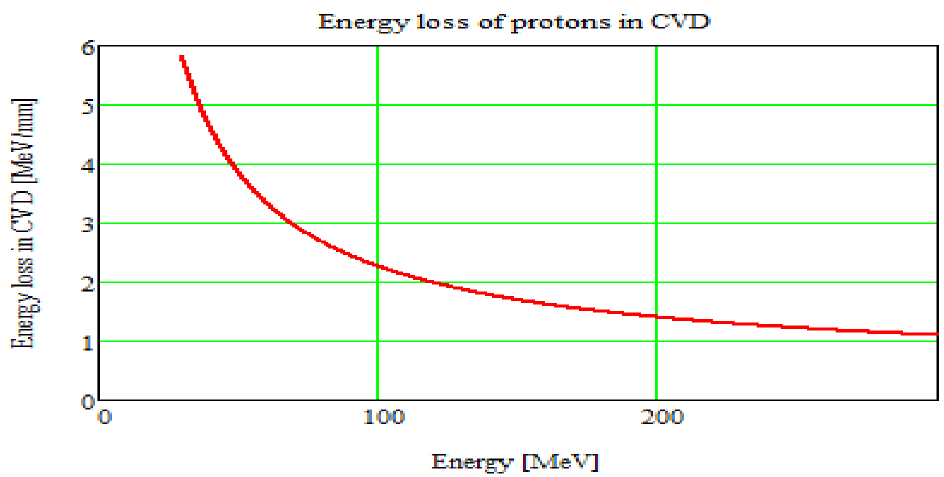
Consulting

Overview

- Counting and current measuring with CVD
- Remarks on signal calculation for capacitive pick ups
- Characteristics of a position pick up in button design
- Coaxial Faraday Cup and fast pulse transmission
- One example of signal degradation by cable dispersion
- Effect of Oscilloscope input impedance

Estimation of maximum count rate with CVD

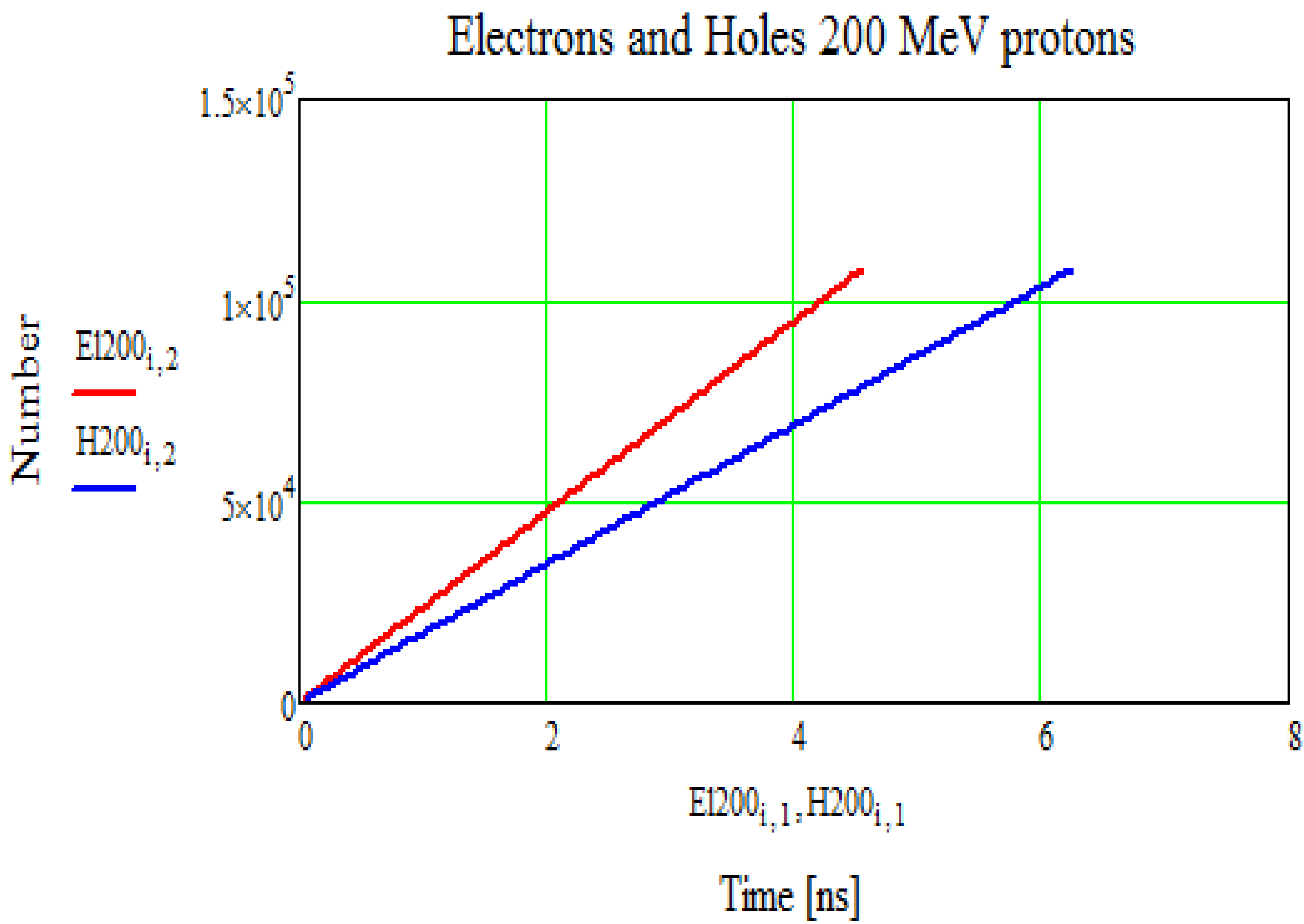
$\rho := 3.515$	g/cm³, specific weight
$\lambda := 1.9$	W/(mm C), heat conductivity
$\delta E := 13$	eV, required energy to create an electron hole pair
$b_e := 2200$	cm²/Vs, mobilty of electrons
$b_h := 1600$	cm²/Vs, mobility of holes

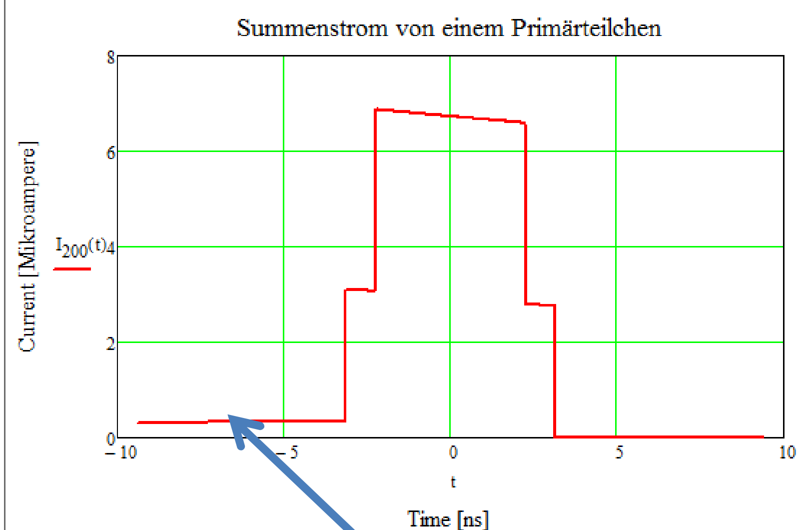


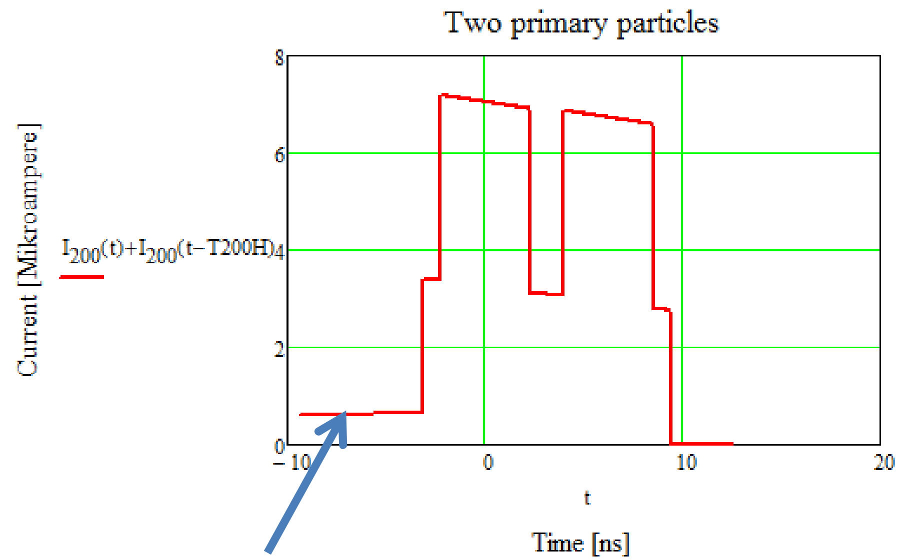
Loss in MeV/mm

Example: 200 MeV protons, 1 mm thickness of CVD, U = 1000 V

$b_e := 2200$	cm²/Vs, mobilty of electrons
$b_h := 1600$	cm²/Vs, mobility of holes
$v_e := .22$	mm/ns, velocity of electrons
$v_h := .16$	mm/ns, velocity holes
$\beta_p := .568$	v/c of 200 MeV protons
$T_p := 0.011$	ns, flight time of protons
$T_e := 4.545$	ns, flight of electrons
$T_h := 6.25$	ns, flight of holes


Electrons and Holes 200 MeV protons
1.5×10^5
1×10^5
5×10^4
0
0
2
4
6
8
Number
E1200i,2
H200i,2
E1200i,1, H200i,1
Time [ns]





Influenced field of electrons and holes

Conclusion: The maximum count rate is given if two primary particles arrive within
The flight time of the holes, which gives

$$\mathbf{MaxCount} := \frac{1}{T_h \cdot 10^{-9}} \qquad \mathbf{MaxCount} = 1.6 \times 10^{8}$$

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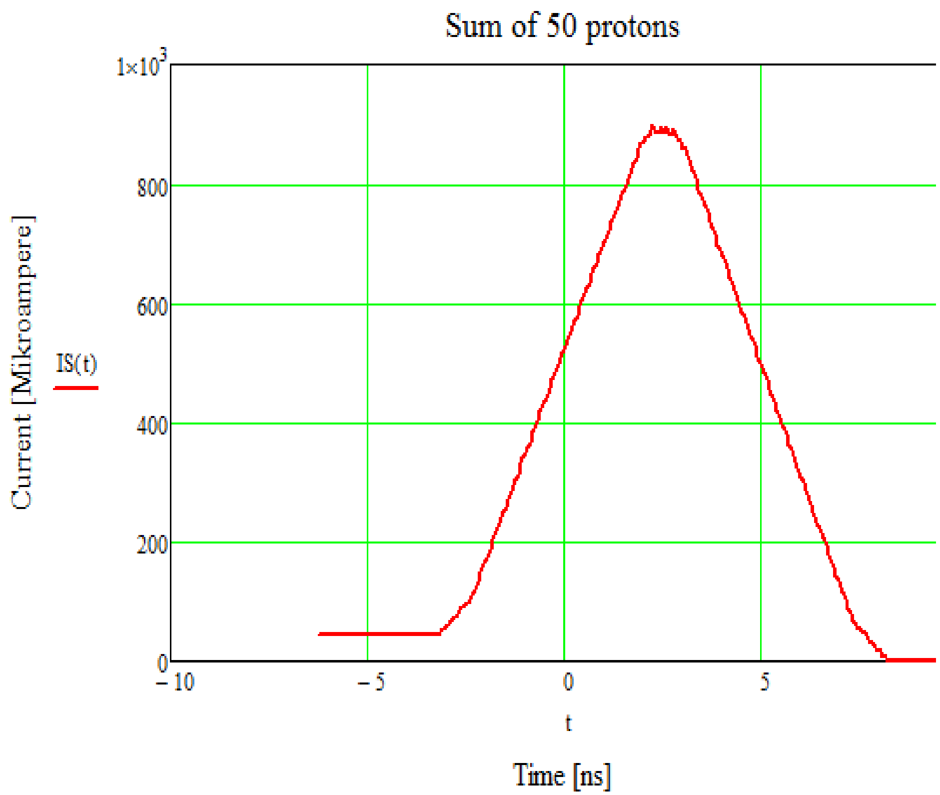
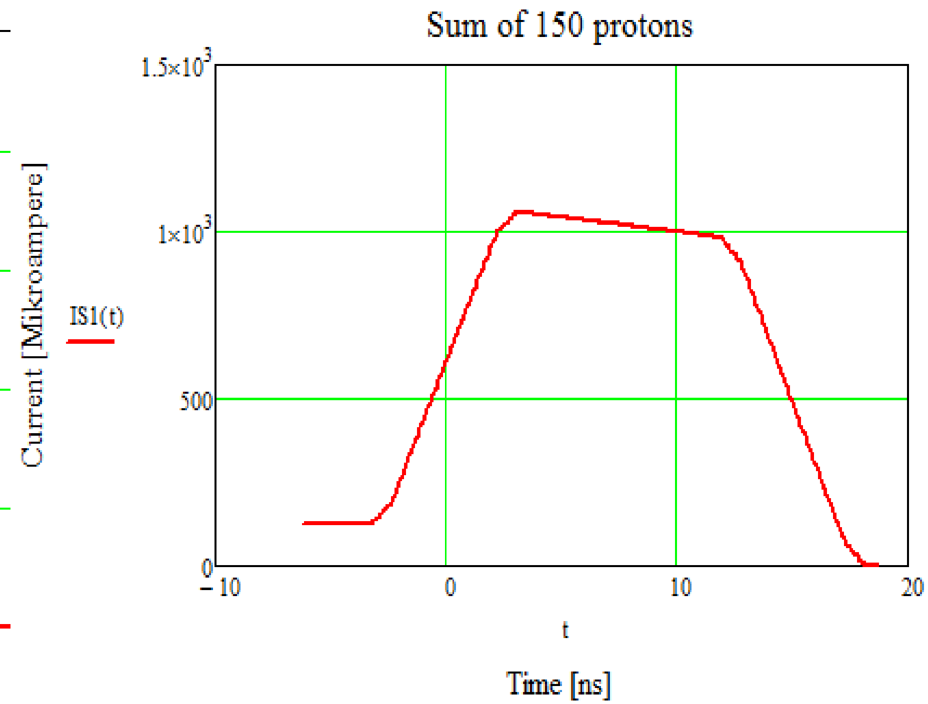
Estimation of current measurement:

We assume 10^{10} protons/s, corresponds to Δt=100ps

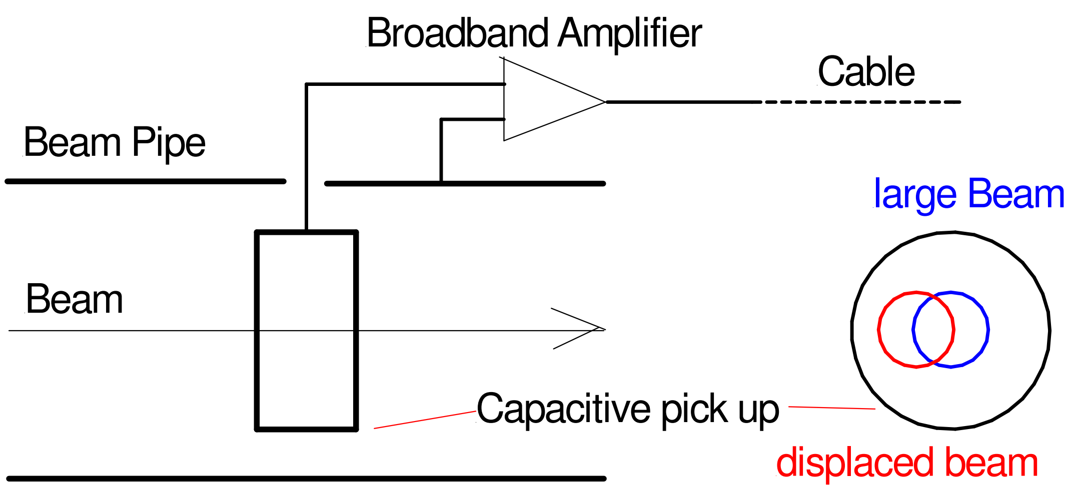




Some remarks on signal calculation for capacitive pick up's

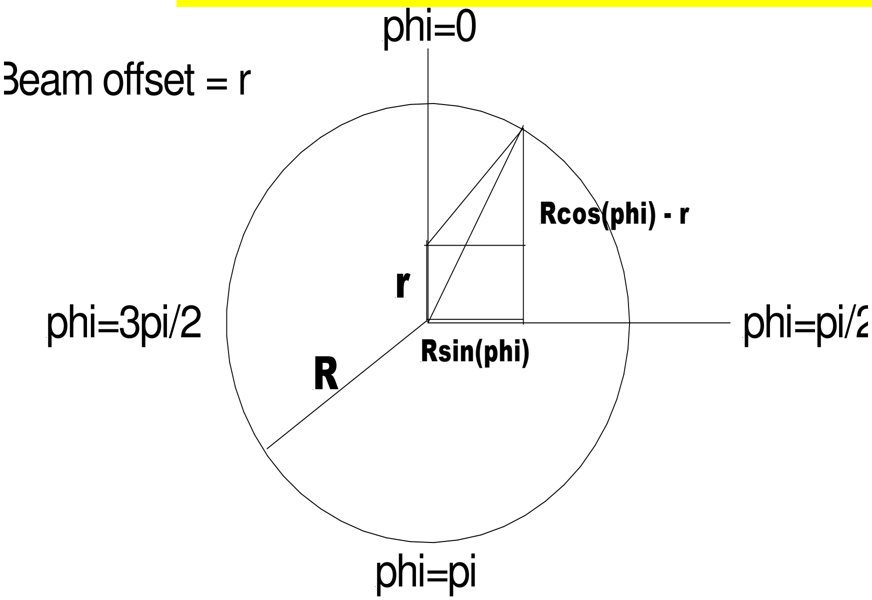
- Effect of displaced beam
- Effect of large beam
- Effect of beam pipe
- Effect of cable dispersion

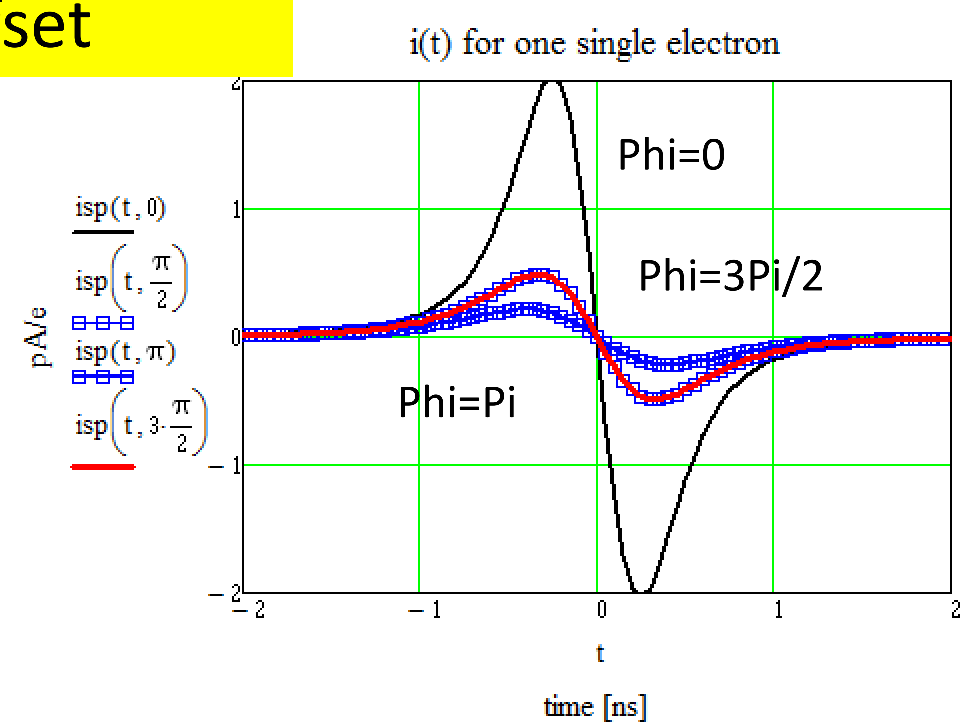
In comparison to the common method: Assuming a relativistic single electron with charge 1e, beam pipe radius infinitive



NTG Beam Diagnostics

Single Electron with offset



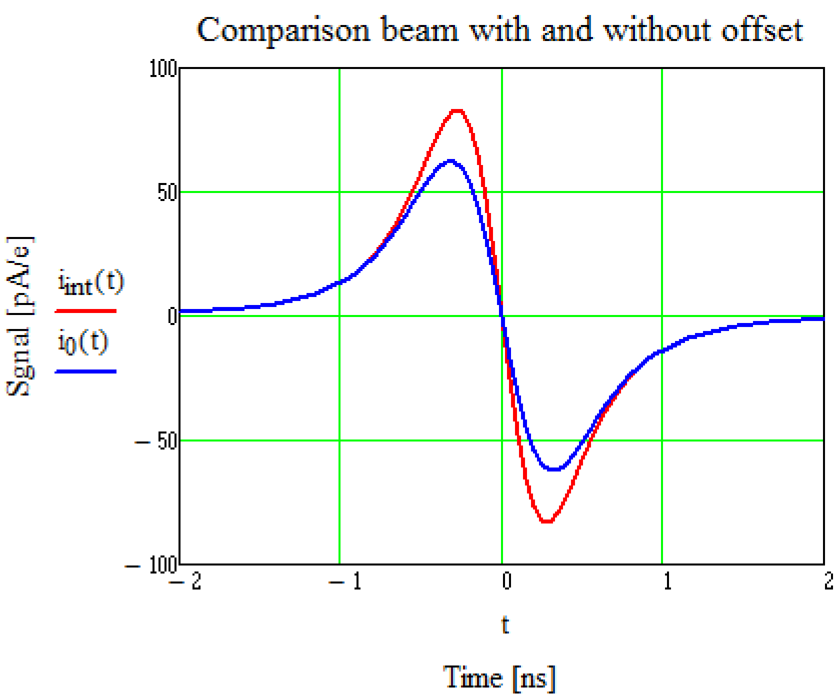


$$R_1(\phi) := \sqrt{R^2 - 2 \cdot R \cdot r_{off} \cdot \cos(\phi) + r_{off}^2}$$

$z = f(L, ßct)$

$R = 17.5$	$r_{off} = 5$	$L = 10$	mm
$\beta = 0.1$	$TOF = 0.334$		ns

Integration over Phi gives the sum signal compared with the signal of a centred beam



With the formulas derived for a beam offset it is straightforward to calculate for:

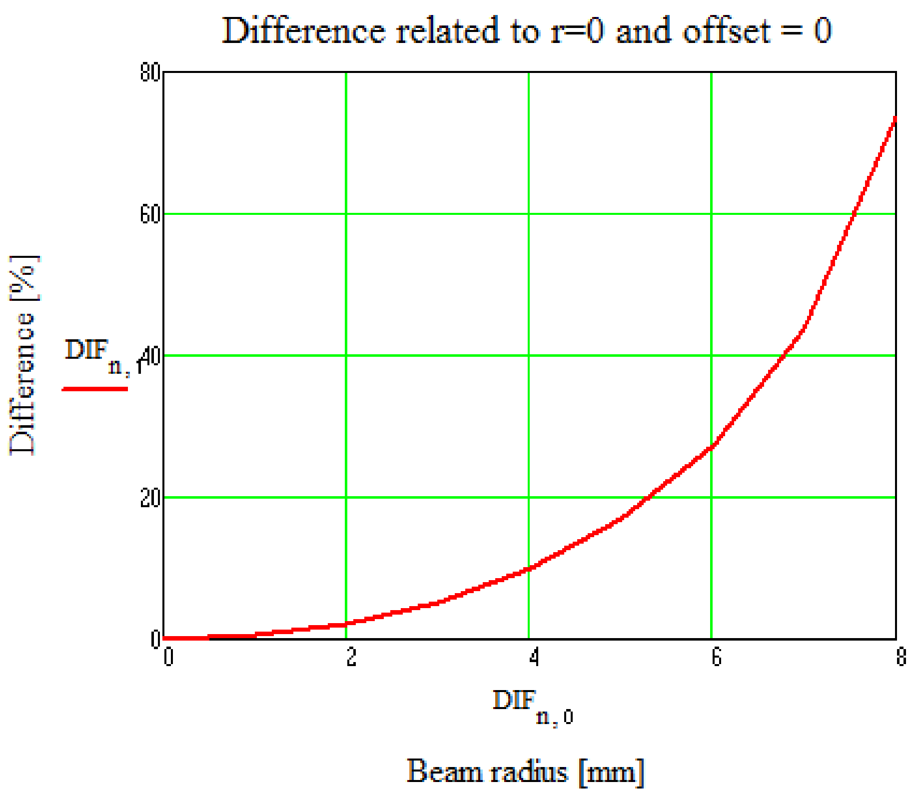
- Extended beam
- Extended beam with offset
- Is a very good approximation for a bunch with finite length in time

$R = 17.5$ $r_{off} = 5$ $L = 10$ mm

$\beta = 0.1$ $TOF = 0.334$ ns

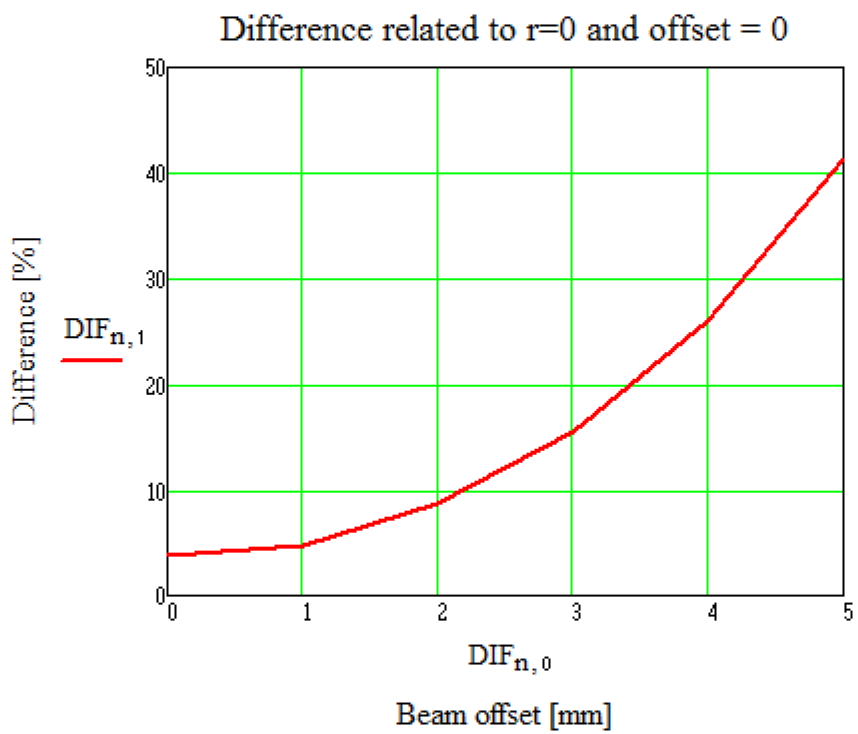
NTG Beam Diagnostics

Difference of signals between radial extended beam and beam with r = 0. Related to beam with r = 0



As distribution over the radial coordinate a cos²-shape has been assumed. The diagram holds for offset=0

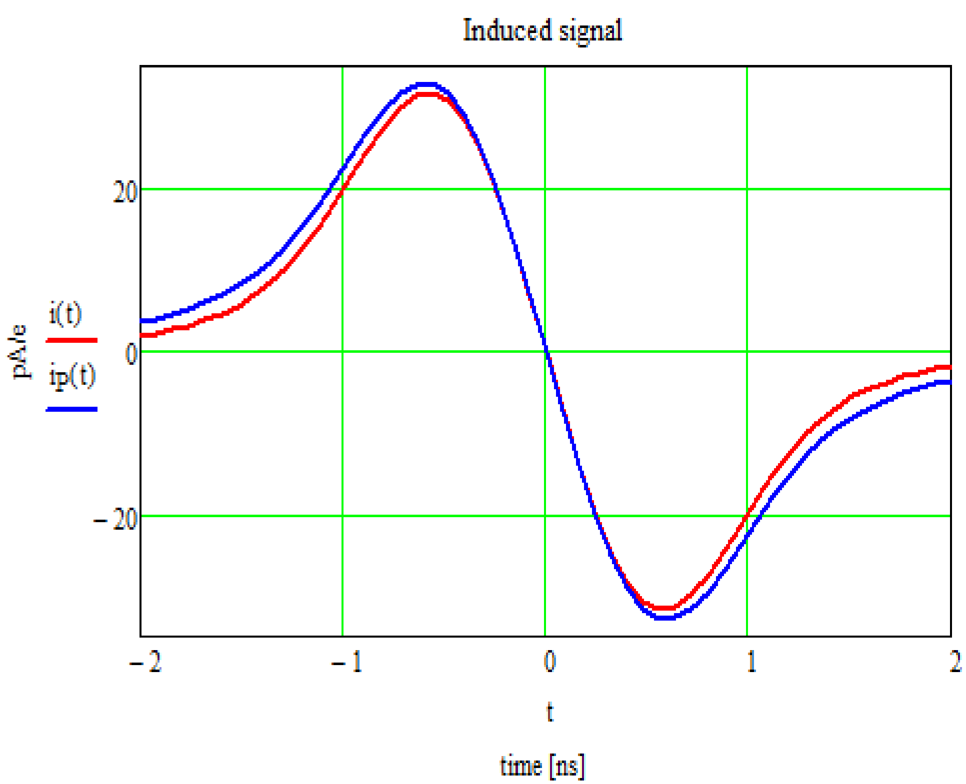
Difference in signal for beam with r = 5 mm in dependence of the beam offset.



Considering the effect of beam pipe

Probe length (mm) : $L = 10$ Probe radius (mm) : $R0 = 17.5$ pipe radius: $R_p = 50$

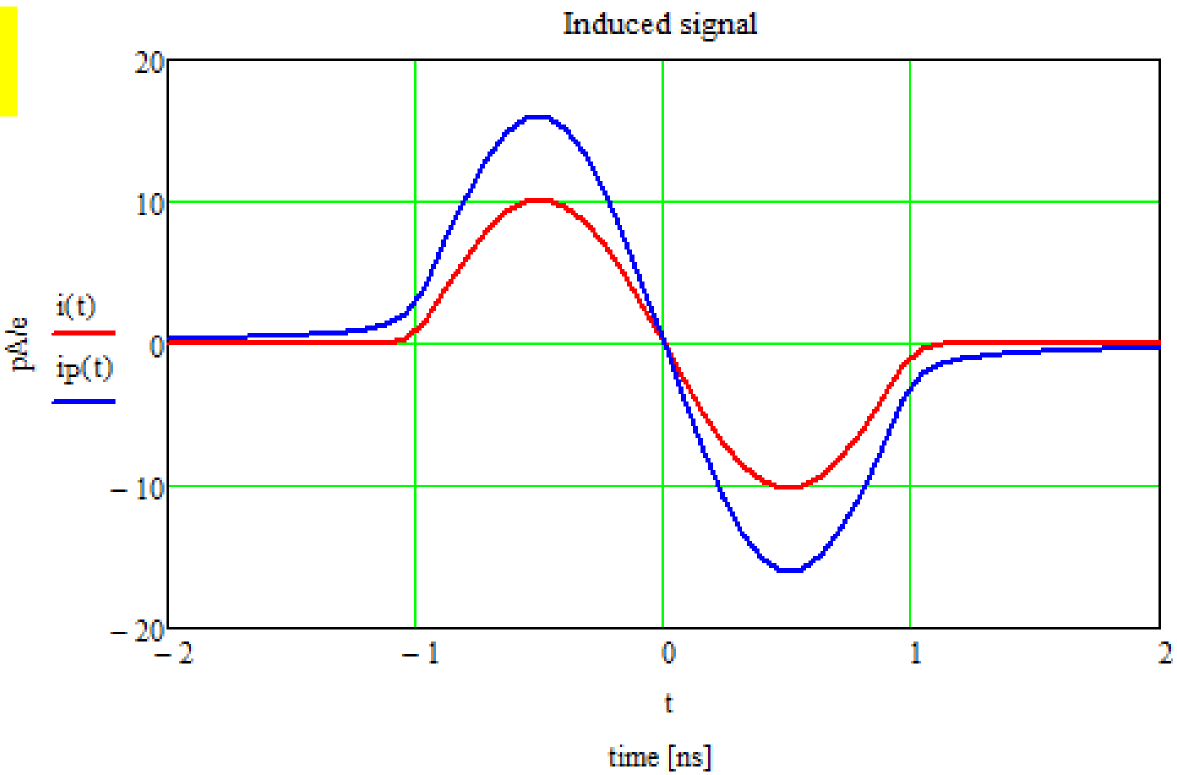
v/c $\beta = 0.1$ Bunch length FWHM (ns) : $\Delta t = 1$



NTG Beam Diagnostics

Probe length (mm) :	L = 10	Probe radius (mm) :	R0 = 17.5	pipe radius:	$R_p = 50$
v/c	$\beta = 0.8$	Bunch length FWHM (ns) :	$\Delta t = 1$		

Higher ß



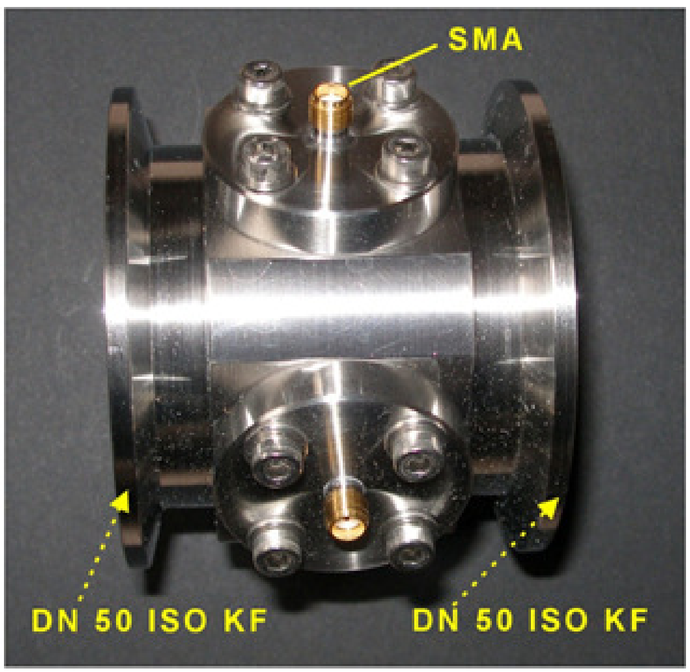
NTG Beam Diagnostics

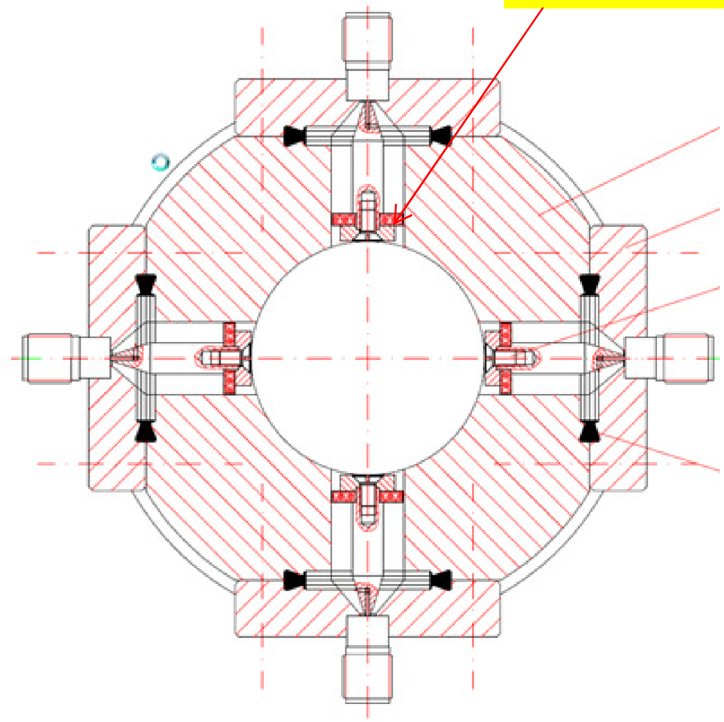
Beam Position Monitor for S-Band Accelerator

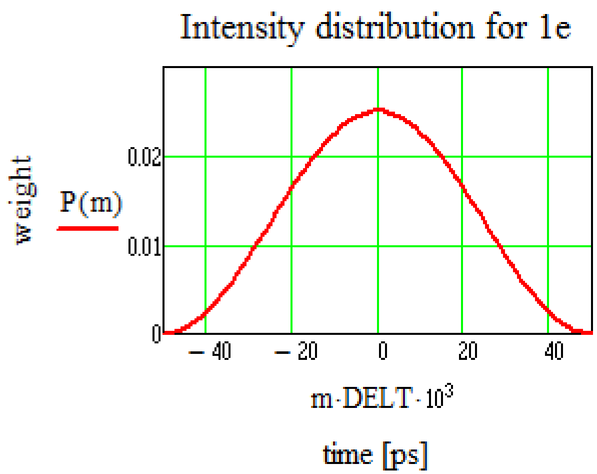
Particles:

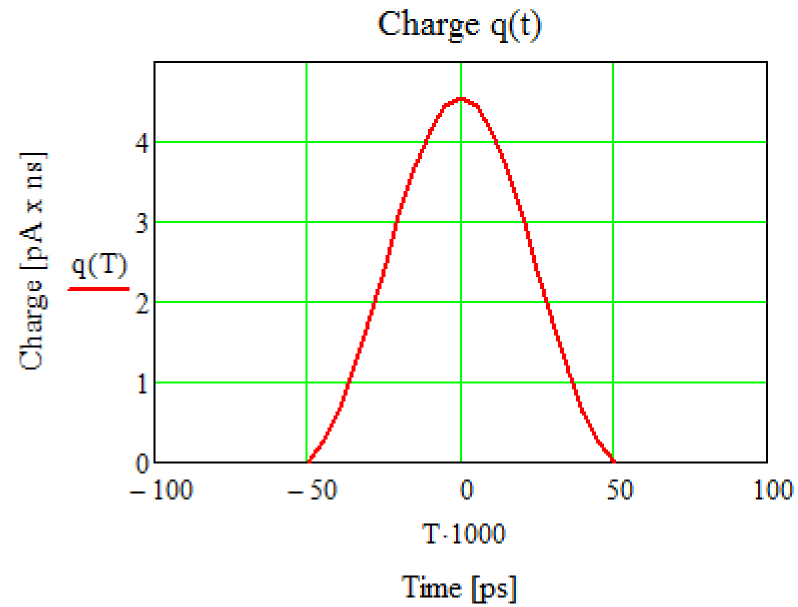
Type:	electrons
Energy:	3 MeV to 22.5 MeV
Beta (=v/c):	0.9854 to 0.9997

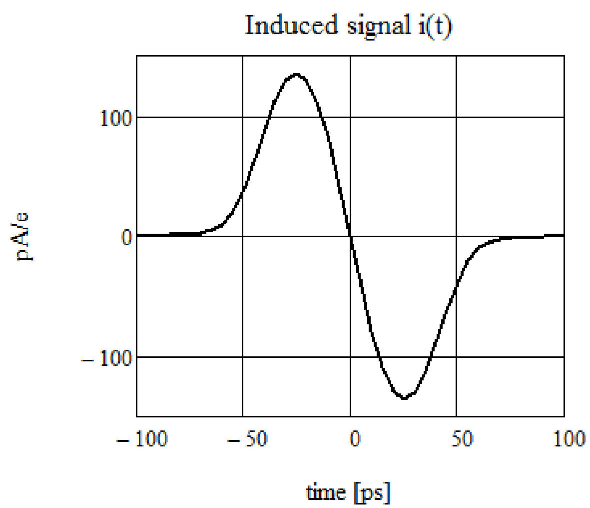
Area of the buttons about 49 mm²









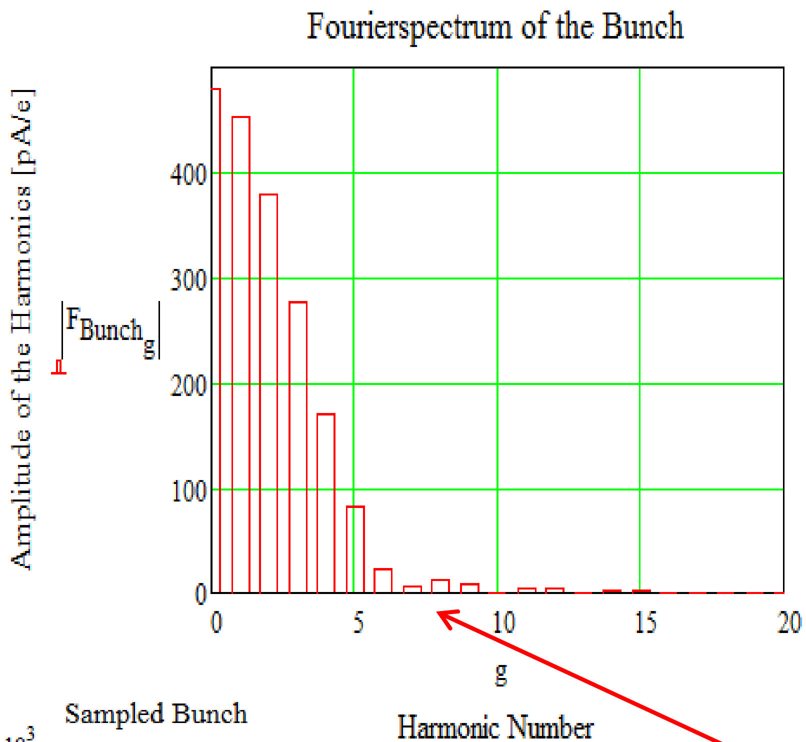


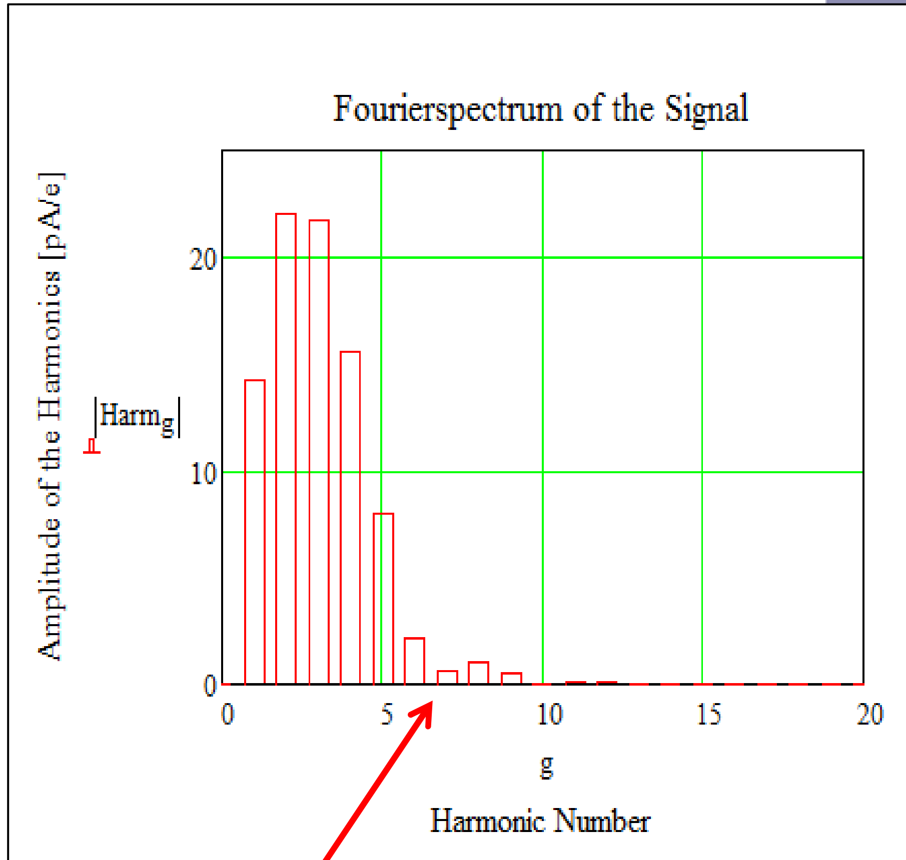
The coupling impedance figures out to:

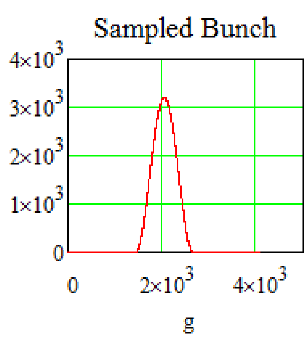
$C_{tot} := 3 \cdot 10^{-12}$ As/V $DT = 0.05$ ns $q_{max} = 4.558$ pA x ns

$$U_{max} := \frac{q_{max} \cdot 10^{-12} \cdot 10^{-9}}{C_{tot}} \qquad U_{max} = 1.519 \times 10^{-9} \text{ Volt/1e}$$

$$ele := 1.6 \cdot 10^{-19} \text{ As} \qquad Z_k := \frac{U_{max} \cdot 50 \cdot 10^{-12}}{ele} \qquad Z_k = 0.475 \text{ Ohm}$$





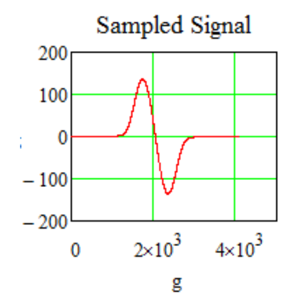


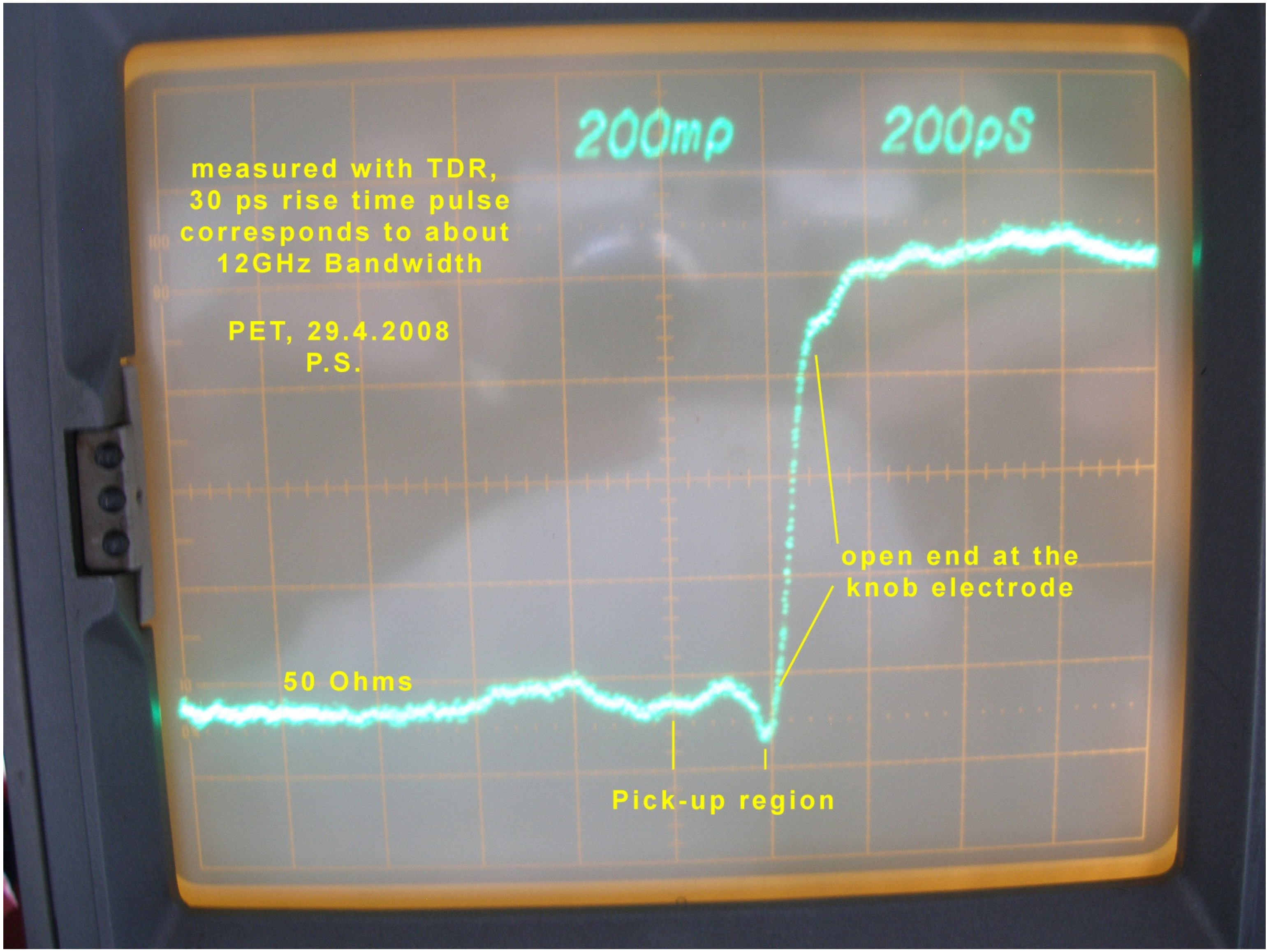
$T_{Rf} = 0.333$

$DT = 0.05$

$$\frac{T_{Rf}}{DT} = 6.667$$

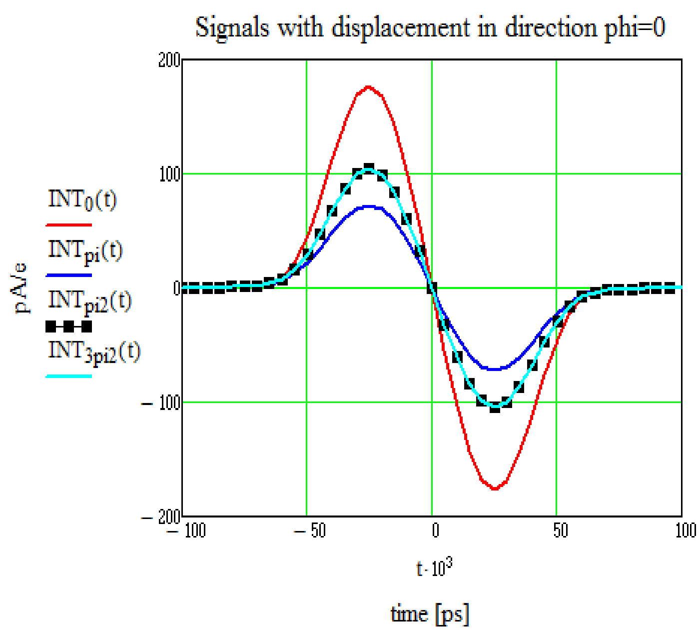
First minimum in
the frequency spectrum

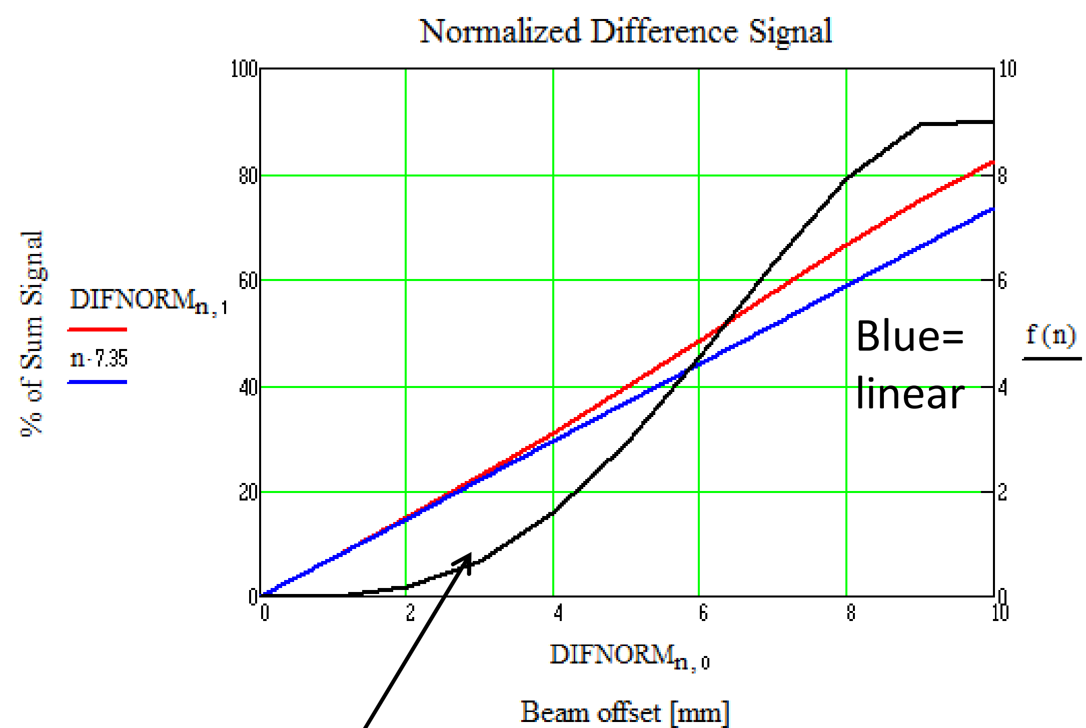



200mp
200pS
measured with TDR,
30 ps rise time pulse
corresponds to about
12GHz Bandwidth
PET, 29.4.2008
P.S.
open end at the
knob electrode
50 Ohms
Pick-up region

Linearity in dependence of beam displacement

Red line



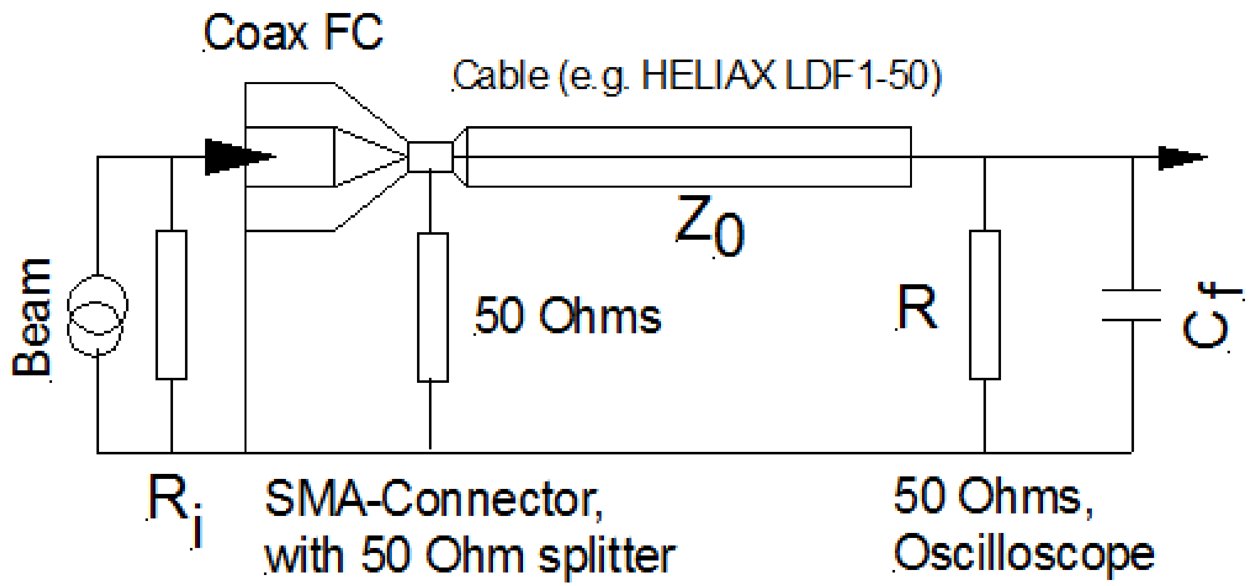


$$Norm := INT_0\left(\frac{-DT}{2}\right) + INT_{pi}\left(\frac{-DT}{2}\right) + INT_{pi2}\left(\frac{-DT}{2}\right) + INT_{3pi2}\left(\frac{-DT}{2}\right)$$

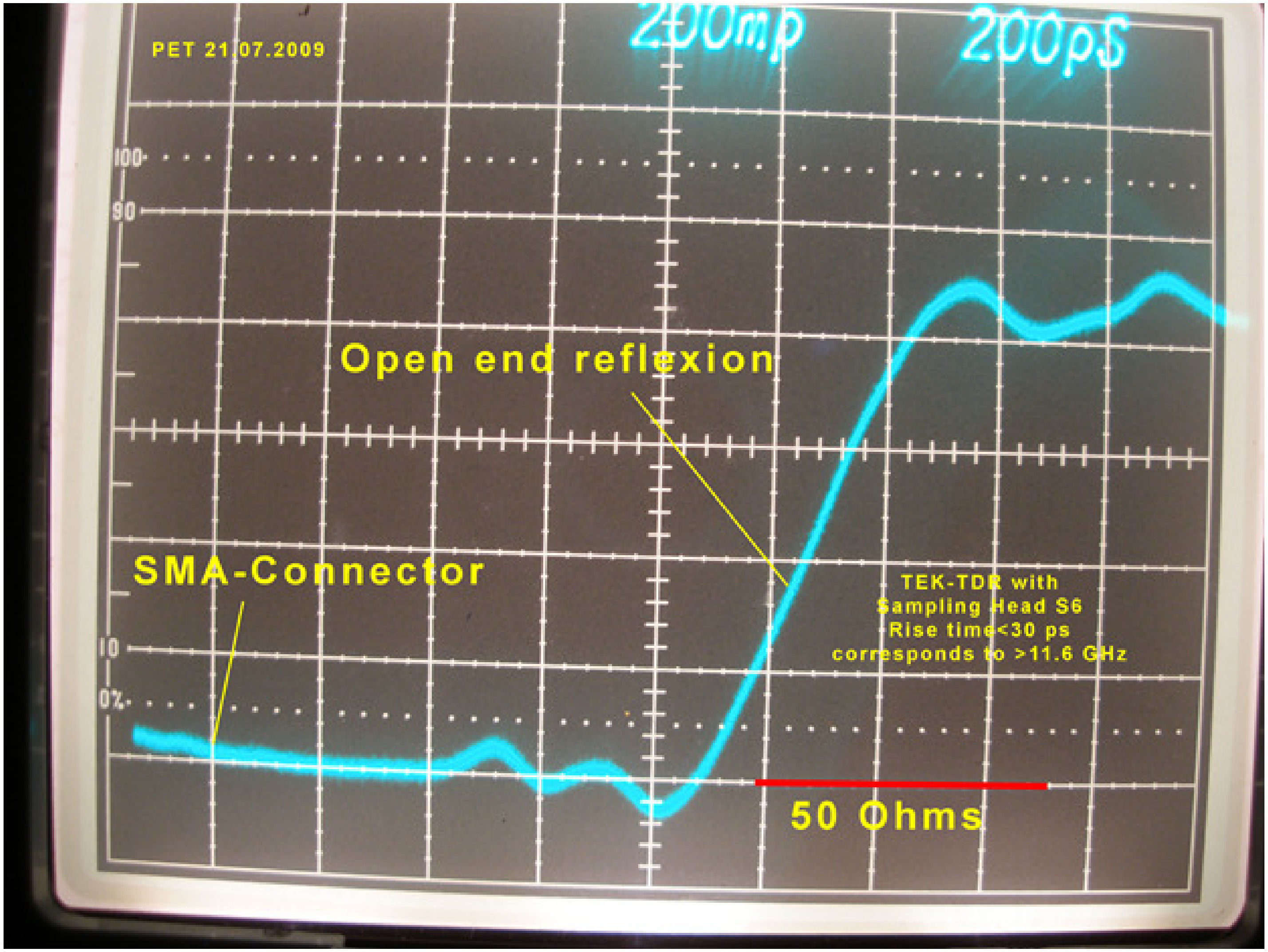
Black line = deviation from linearity
right scale, f(n)

Coaxial Faraday Cup and Fast Pulse Transmission

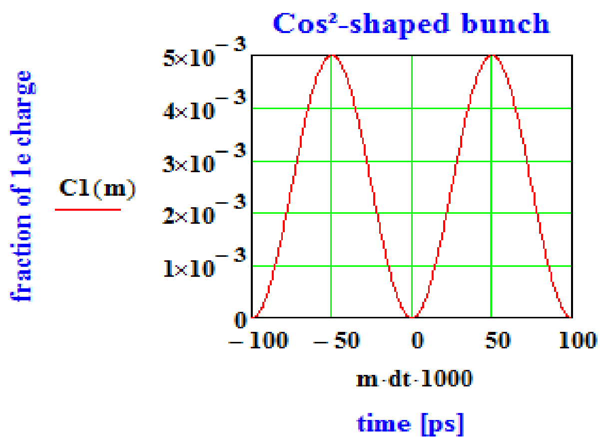
Problem:
Coaxial FC with 50 ps resolution required



Conclusion: The Coax FC will not be the problem


PET 21.07.2009
200mp
200pS
100
90
10
0%
Open end reflexion
SMA-Connector
TEK-TDR with
Sampling Head S6
Rise time<30 ps
corresponds to >11.6 GHz
50 Ohms

NTG Beam Diagnostics



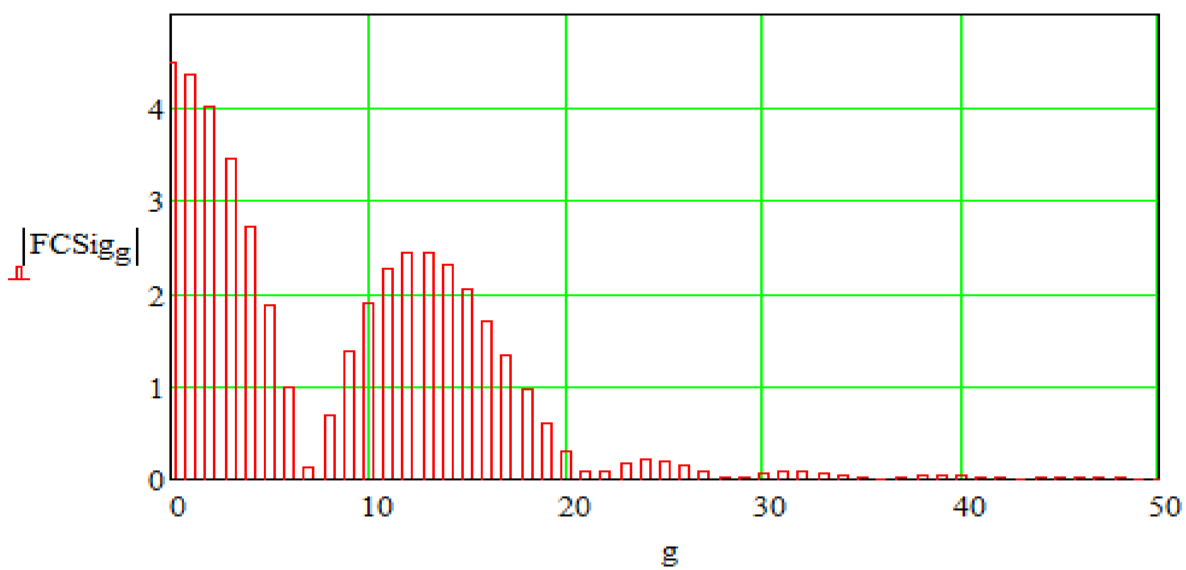
rameters related to the problem :

riod [ps] $T := 1428$

nch length [ps] $DT := 50$

ty DT/T=α $\alpha := \frac{DT}{T}$ $\alpha = 0.035$

. . equency [GHz] $FRQ := \frac{1000}{T}$ $FRQ = 0.7$ First harmonic, GHz



a is the radius of the inner conductor and b is the inner radius of the outer conductor of the cup

$a := 20$ $\quad b := 46$ First part, mm

$lae := 70$ Length of the first part:

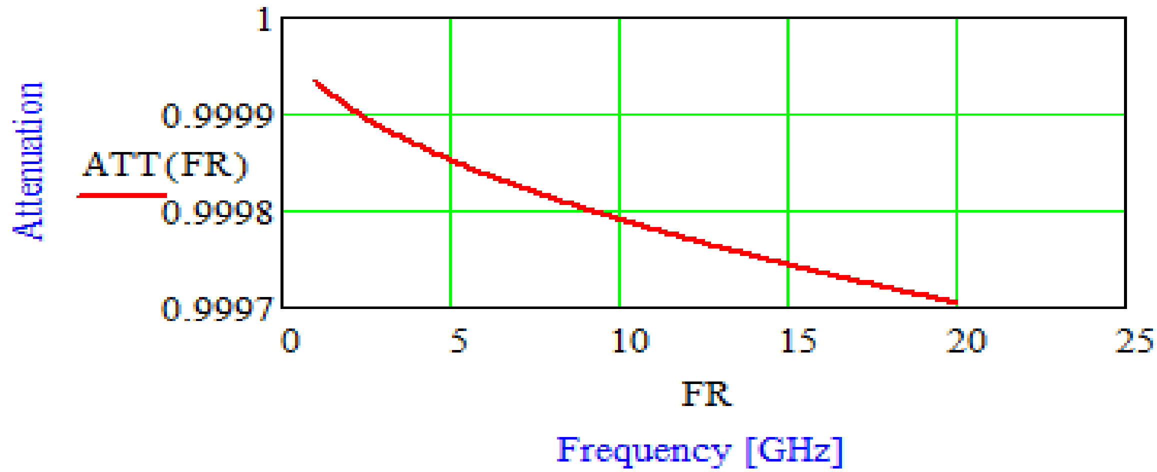
$$\gamma(f) := \frac{\rho_e \cdot 10^{-3}}{2 \cdot \delta(f)} \cdot \sqrt{\frac{\varepsilon 0}{\mu 0}} \cdot \frac{\frac{1}{a} + \frac{1}{b}}{\ln\left(\frac{b}{a}\right)}$$

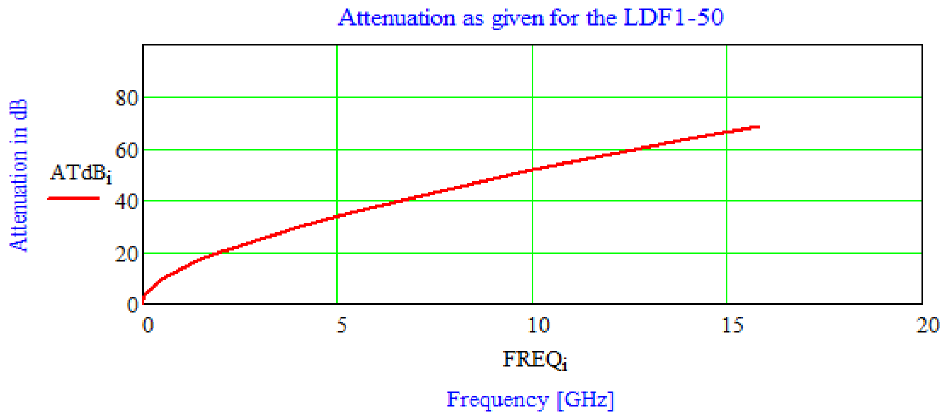
Jackson, p. 385

$$ATT(f) := e^{-\gamma(f) \cdot lae}$$

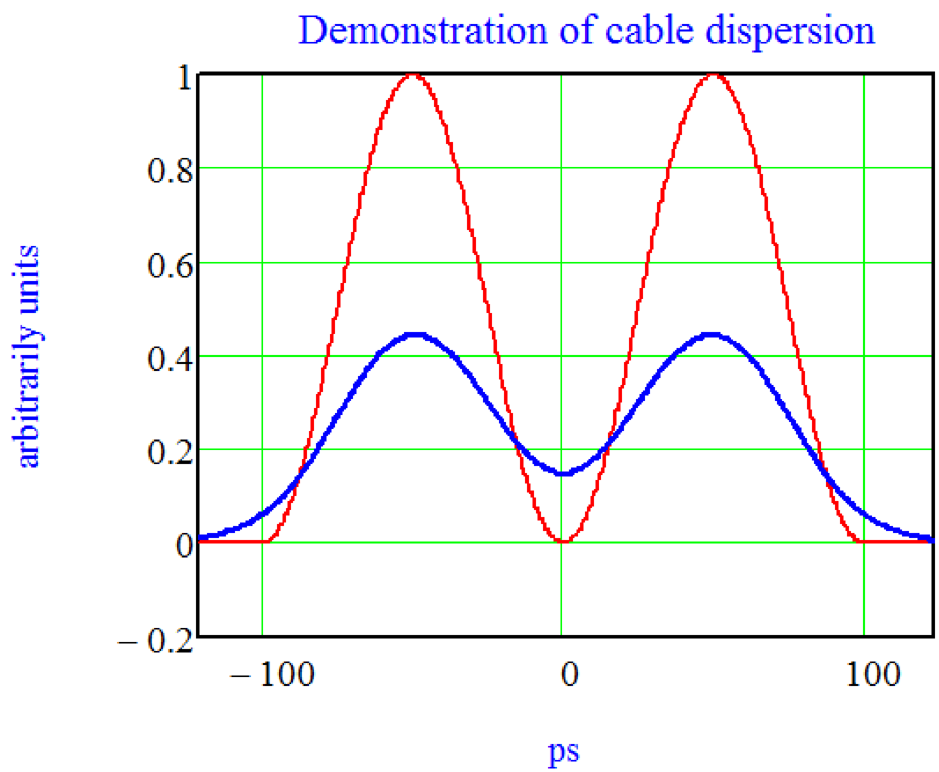
f, [GHz], ρ_ε [Ωmm/m], a [mm], b[mm], γ [1/mm]

Attenuation Factor for FC

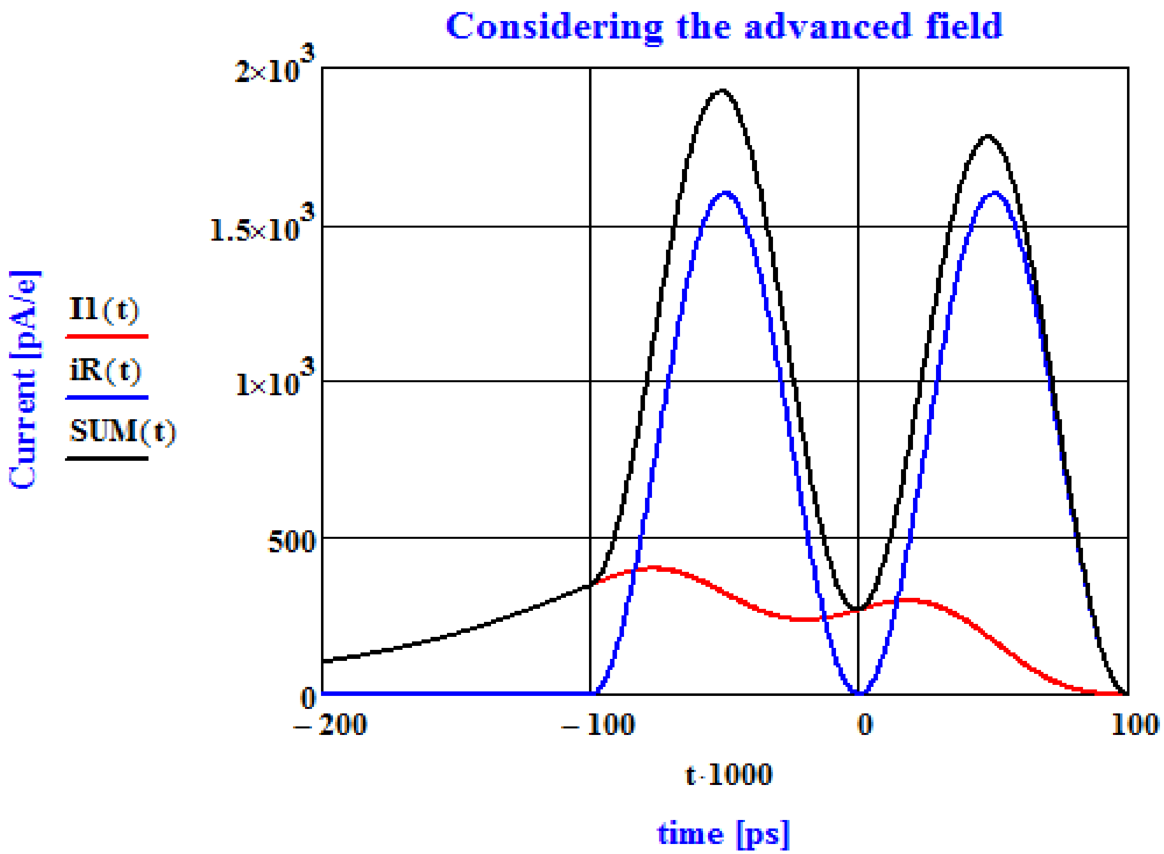




Attenuation for the cable LDF1-50, BW=15.8 GHz



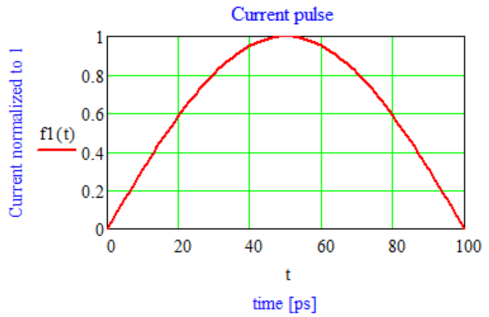
The diagram holds for the cable type given above and a length of 20 m



Red line: advanced electrical field. Blue line: pure current signal, black line: resulting sum signal

Effect of the oscilloscope input impedance

$$\pi \cdot DT_c \cdot \frac{1 + e^{-DT_c \cdot s}}{DT_c^{\,2} \cdot s^2 + \pi^2} \text{ invlaplace}, \rightarrow$$ which gives f1(t)



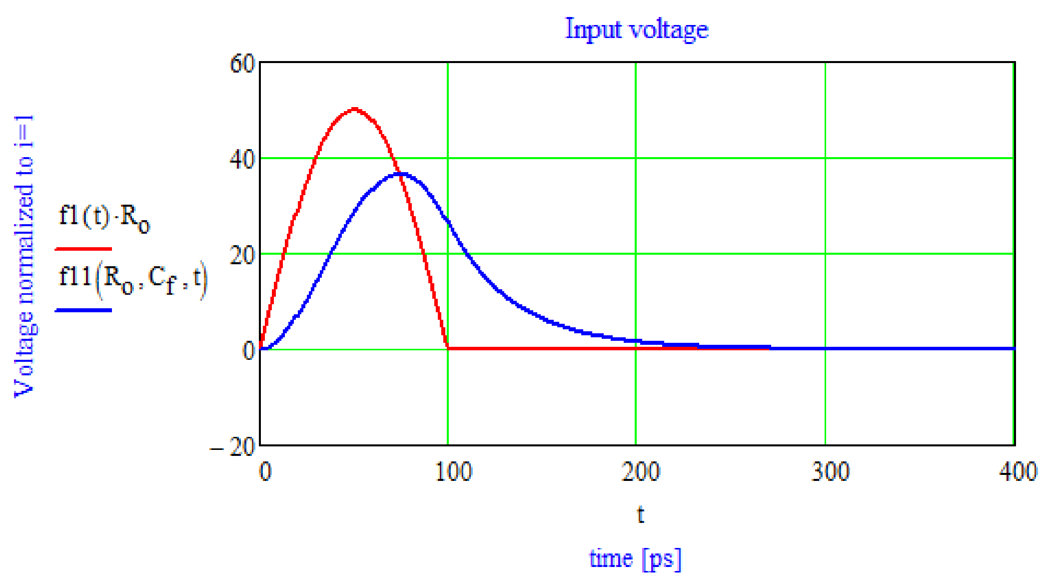
$t_{r4} := 35$ Specified rise time of a fast oscilloscope, 10-90%, ps

Therefore we calculate the fictitious capacity from:

$$C_f := \frac{t_{r4}}{R_o} \qquad C_f = 0.7$$

$$\pi \cdot DT_c \cdot \frac{1 + e^{-DT_c \cdot s}}{DT_c^{\,2} \cdot s^2 + \pi^2} \cdot \frac{R}{R \cdot C \cdot s + 1} \text{ invlaplace}, \rightarrow$$

50 Ohms parallel with the fictitious capacity at the input of the oscilloscope



Beam Diagnostics

Reflexion due to the input capacity and mismatched impedance

$$\frac{1-e^{-DT_c \cdot s}}{s} \cdot \left(\frac{\frac{R}{R \cdot C \cdot s + 1} - Z_0}{\frac{R}{R \cdot C \cdot s + 1} + Z_0} \right) \cdot \frac{R}{R \cdot C \cdot s + 1} \text{ invlaplace}, \rightarrow$$

$Z_0 = 50 \qquad R_o = 50 \qquad C_f = 0.7$