Beam Position Monitor:
Detector Principle, Hardware and Electronics

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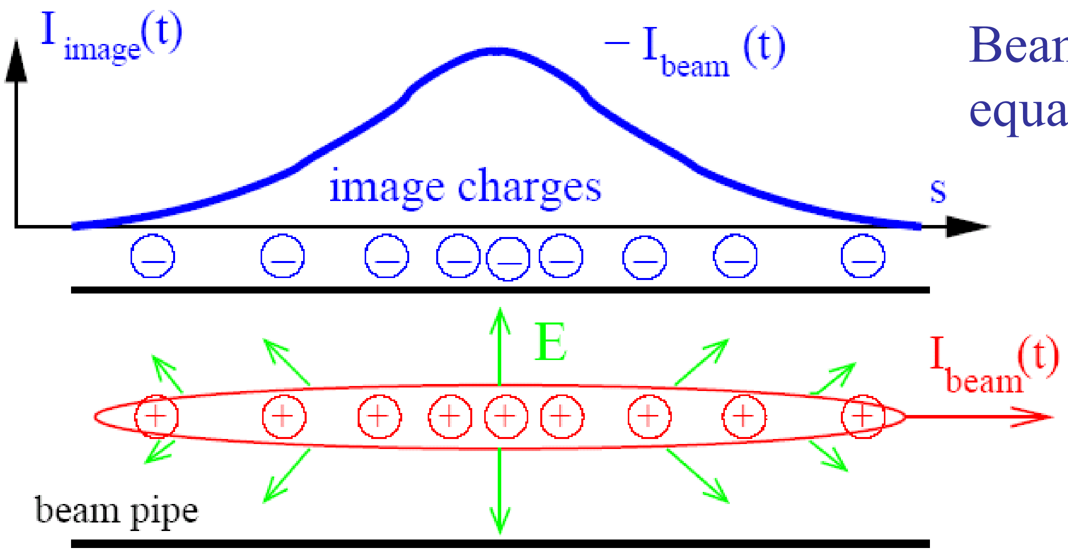
Outline:

- *Signal generation $\rightarrow$ transfer impedance*
- *Consideration for capacitive shoe box BPM*
- *Consideration for capacitive button BPM*
- *Other BPM principles: stripline $\rightarrow$ traveling wave, inductive $\rightarrow$ wall current, cavity $\rightarrow$ resonator for dipole mode*
- *Electronics for position evaluation*
- *Some examples for position evaluation and other applications*
- *Summary*

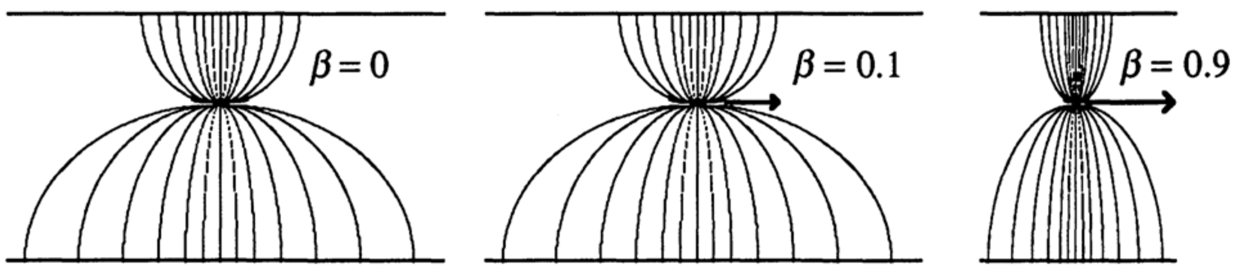
General Idea: Detection of Wall Charges

The image current at the vacuum wall is monitored on a high frequency basis i.e. the ac-part given by the bunched beam.



Beam Position Monitor BPM equals Pick-Up PU

For relativistic velocities, the electric field is mainly transversal: $E_{\perp,lab}(t) = \gamma \cdot E_{\perp,rest}(t)$



Usage of BPMs

A BPM is an non-destructive device

It has a low cut-off frequency i.e. dc-beam behavior can not be monitored
(exception: Schottky spectra, here the physics is due to finite number of particles)

⇒Usage with bunched beams!

It delivers information about:

1. The center of the beam

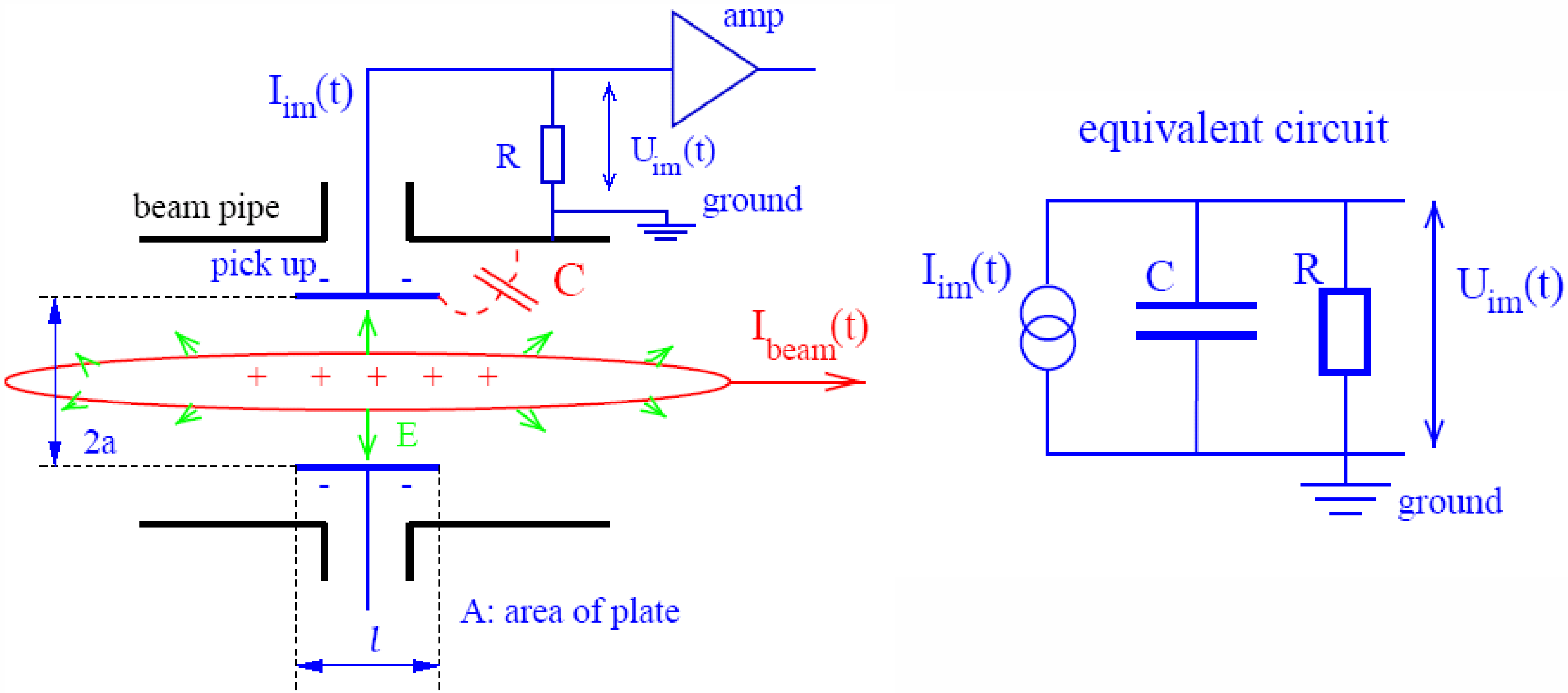
- Closed orbit
  i.e. central orbit averaged over a period much longer than a betatron oscillation
- Bunch position on a large time scale: bunch-by-bunch → turn-by-turn → averaged position
- Single bunch position → determination of parameters like tune, chromaticity, β-function
- Time evolution of a single bunch can be compared to 'macro-particle tracking' calculations
- Feedback: fast bunch-by-bunch damping → precise (and slow) closed orbit correction

2. Longitudinal bunch shapes

- Bunch behavior during storage and acceleration
- For proton LINACs: the beam velocity can be determined by two BPMs
- Low current ***relative*** measurement down to 10 nA.

Model for Signal Treatment of capacitive BPMs

The wall current is monitored by a plate or ring inserted in the beam pipe:



The image current I_{im} at the plate is given by the beam current and geometry:

$$I_{im}(t) \equiv dQ_{im}/dt = A/\pi al \cdot dQ_{beam}(t)/dt = A/\pi al \cdot l/\beta c \cdot dI_{beam}/dt = A/\pi a \cdot 1/\beta c \cdot i\omega I_{beam}(\omega)$$

Using a relation for Fourier transformation: $I_{beam} = I_0 e^{i\omega t} \Rightarrow dI_{beam}/dt = i\omega I_{beam}$.

Transfer Impedance for capacitive BPM

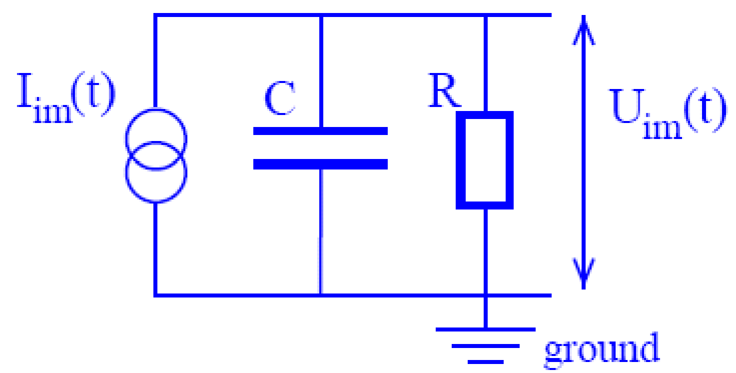
At a resistor R the voltage U_{im} from the image current is measured.
The transfer impedance Z_t is the ratio between voltage U_{im} and beam current I_{beam}
in ***frequency domain***: $\boldsymbol{U_{im}(\omega) = R \cdot I_{im}(\omega) = Z_t(\omega, \beta) \cdot I_{beam}(\omega)}$.

Capacitive BPM:

- The pick-up capacitance C:
  plate ↔ vacuum-pipe and cable.
- The amplifier with input resistor R.
- The beam is a high-impedance current source:

$$\begin{aligned} U_{im} &= \frac{R}{1+i\omega RC} \cdot I_{im} \\ &= \frac{A}{\pi a}\frac{1}{\beta c} \cdot \frac{1}{C} \cdot \frac{i\omega RC}{1+i\omega RC} \cdot I_{beam} \\ &\equiv Z_t(\omega,\beta) \cdot I_{beam} \end{aligned}$$

equivalent circuit



$$\frac{1}{Z} = \frac{1}{R} + i\omega C \Leftrightarrow Z = \frac{R}{1+i\omega RC}$$

This is a high-pass characteristic with $\boldsymbol{\omega_{cut} = 1/RC}$:

It is: $|Z_t(\omega)| = \frac{A}{\pi a}\frac{1}{\beta c C} \cdot \frac{\omega/\omega_{cut}}{\sqrt{1+\omega^2/\omega_{cut}^2}}$ and phase $\varphi(\omega) = \arctan(\omega_{cut}/\omega)$

Example of Transfer Impedance for Proton Synchrotron

The high-pass characteristic for typical synchrotron BPM.

$$U_{im}(\omega) = Z_t(\omega) \cdot I_{beam}(\omega)$$

$$|Z_t| = \frac{1}{C} \cdot \frac{1}{\beta c} \cdot \frac{A}{\pi a} \cdot \frac{\omega / \omega_{cut}}{\sqrt{1 + \omega^2 / \omega^2_{cut}}}$$

$$\varphi = \arctan(\omega_{cut} / \omega)$$

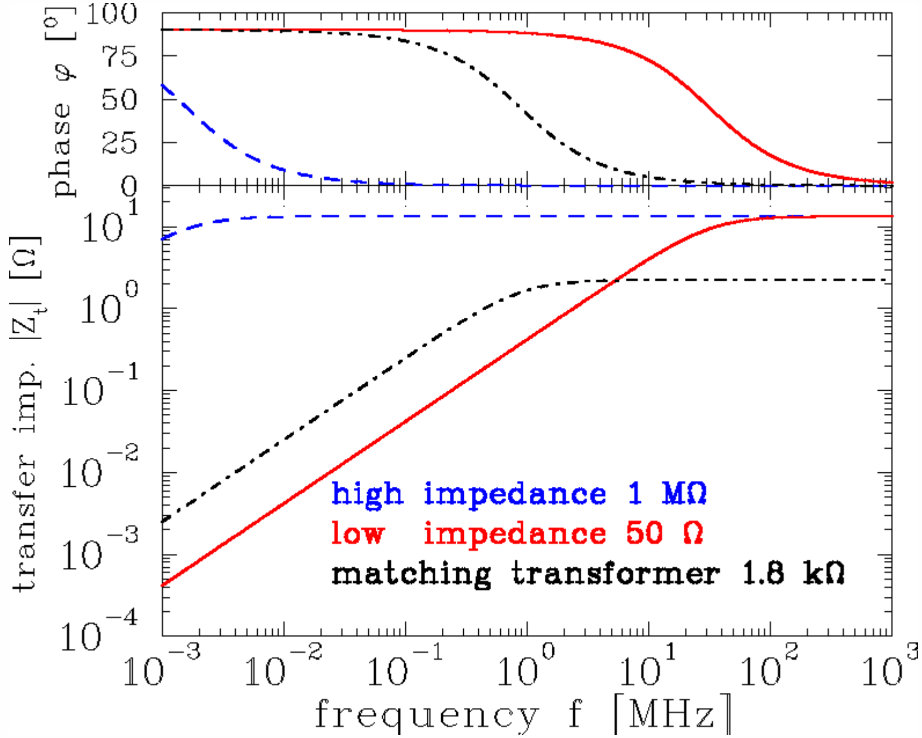
Parameter for shoe-box BPM:

C=100pF, l=10cm, β=50%

$f_{cut} = \omega/2\pi = (2\pi RC)^{-1}$

for R=50 Ω ⇒ f_{cut} = 32 MHz

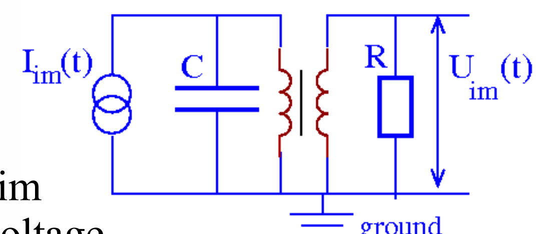
for R=1 MΩ ⇒ f_{cut} = 1.6 kHz



Large signal strength → **high impedance**

Smooth signal transmission → **50 Ω**

equivalent circuit



Compromise → ≈1.8 kΩ by transformer e.g. N_{prim}/N_{sec}=2:12

Impedance $Z_{prim} = (N_{prim}/N_{sec})^2 \cdot Z_{sec}$ voltage $U_{im} = N_{sec}/N_{prim} \cdot U_{prim}$

→ Smooth signal chain, medium cut-off frequency, but lower usable voltage

Depending on the frequency range ***and*** termination the signal looks different:

- ***High frequency range*** $\omega >> \omega_{cut}$:

$$Z_t \propto \frac{i\omega/\omega_{cut}}{1+i\omega/\omega_{cut}} \rightarrow 1 \Rightarrow U_{im}(t) = \frac{1}{C}\cdot\frac{1}{\beta c}\cdot\frac{A}{\pi a}\cdot I_{beam}(t)$$

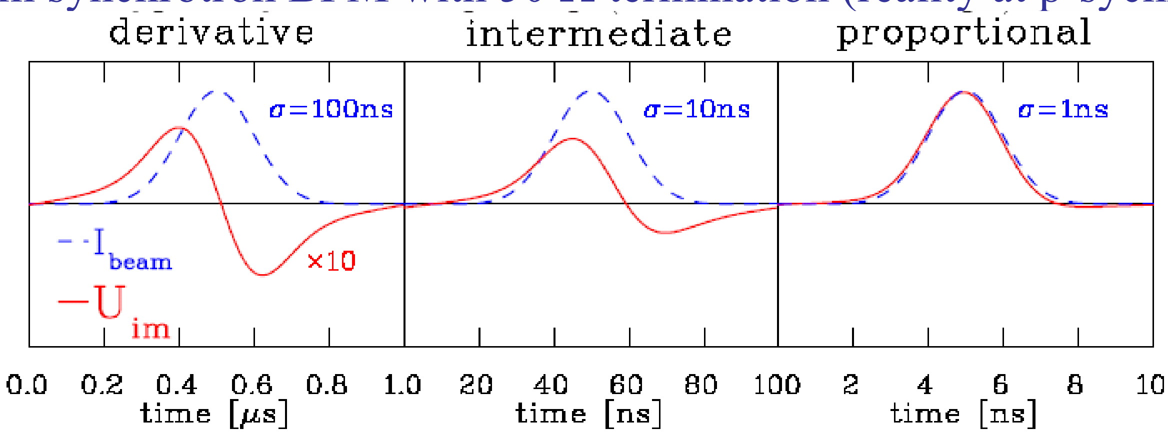
$\Rightarrow$ **direct image** of the bunch. Signal strength $Z_t \propto A/C$ i.e. nearly independent on length

- ***Low frequency range*** $\omega << \omega_{cut}$:

$$Z_t \propto \frac{i\omega/\omega_{cut}}{1+i\omega/\omega_{cut}} \rightarrow i\frac{\omega}{\omega_{cut}} \Rightarrow U_{im}(t) = R\cdot\frac{A}{\beta c\cdot\pi a}\cdot i\omega I_{beam}(t) = R\cdot\frac{A}{\beta c\cdot\pi a}\cdot\frac{dI_{beam}}{dt}$$

$\Rightarrow$ **derivative** of bunch, single strength $Z_t \propto A$, i.e. (nearly) independent on C

Example from synchrotron BPM with 50 Ω termination (reality at p-sychrotron : σ>>1 ns):



Examples for differentiated & proportional Shape

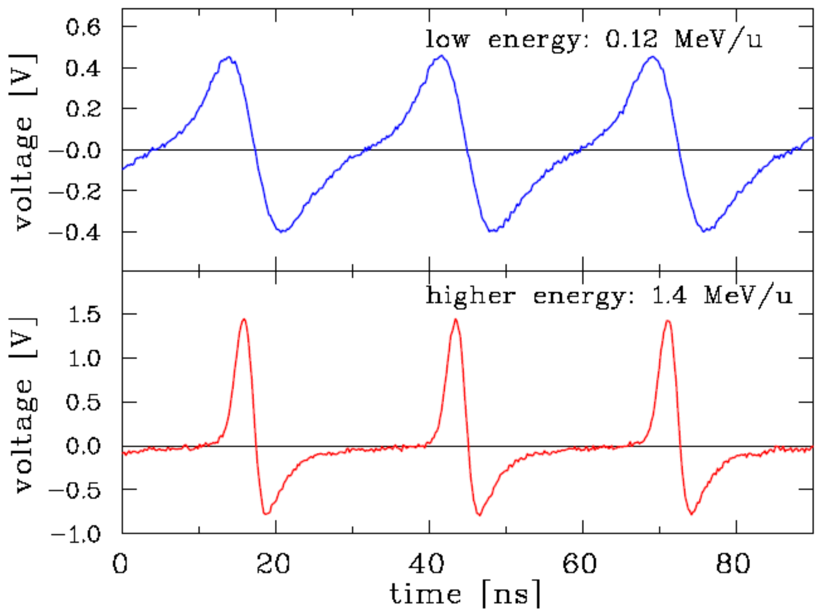
Proton LINAC, e⁻-LINAC&synchrotron:

100 MHz < f_{rf} < 1 GHz typically

R=50 Ω processing to reach bandwidth

C≈5 pF ⇒ $f_{cut} = 1/(2\pi RC) \approx$ 700 MHz

Example: 36 MHz GSI ion LINAC



Proton synchrotron:

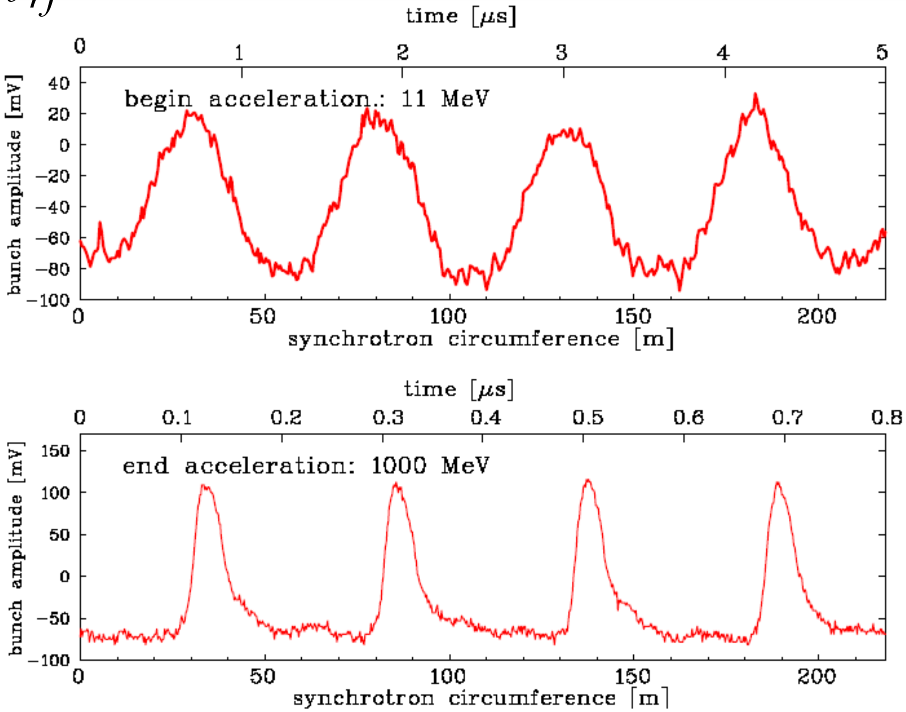
1 MHz < f_{rf} < 30 MHz typically

R=1 MΩ for large signal i.e. large Z_t

C≈100 pF ⇒ $f_{cut} = 1/(2\pi RC) \approx$10 kHz

Example: non-relativistic GSI synchrotron

f_{rf}: 0.8 MHz → 5 MHz

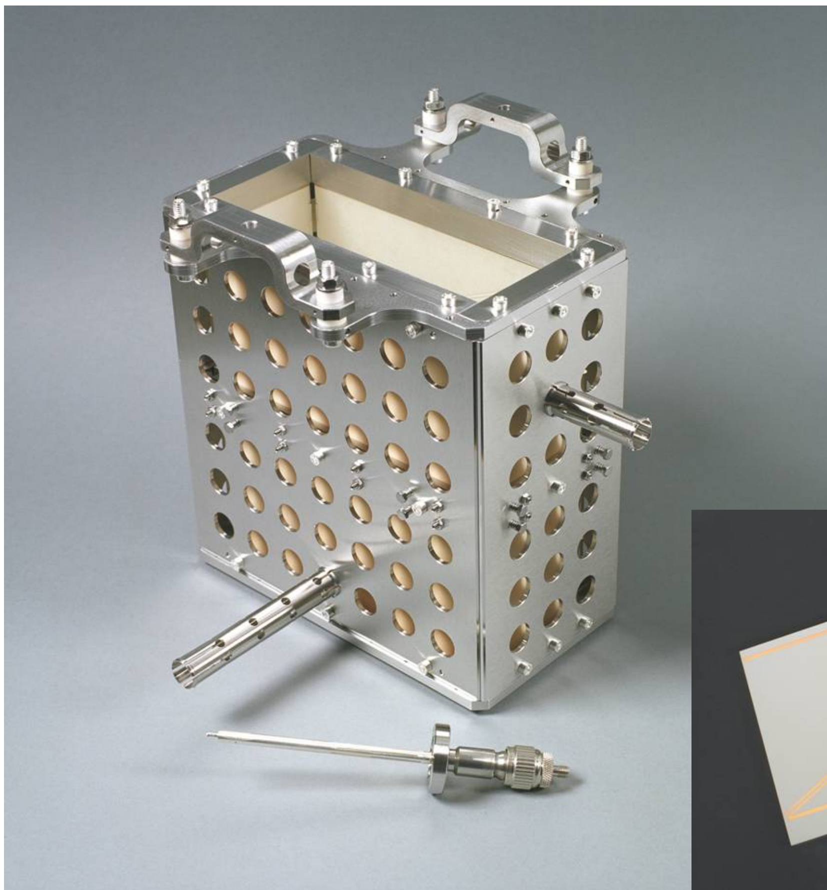


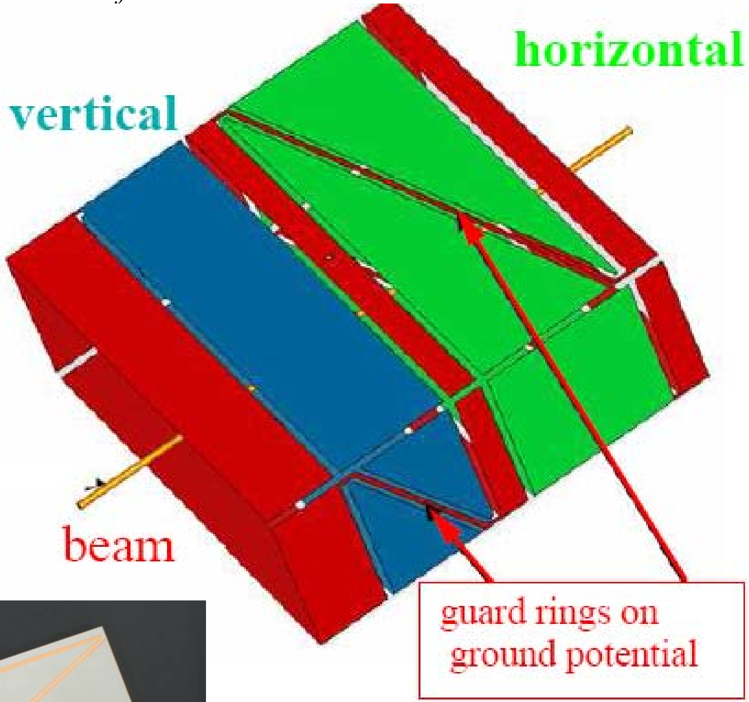
Remark: During acceleration the bunching-factor is increased: 'adiabatic damping'.

Shoe-box BPMs used at low β proton & ion synchrotron for 1MHz < f_{rf} < 10MHz.

Example: HIT cancer therapy synchrotron 0.8 MHz < f_{rf} < 5 MHz

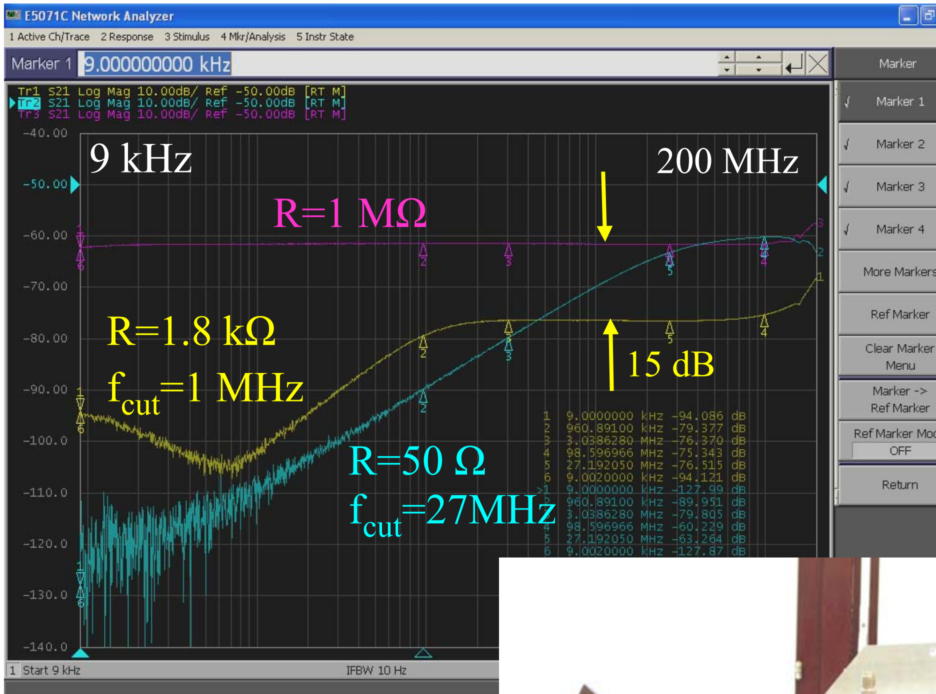
Aperture 180x70 mm^2

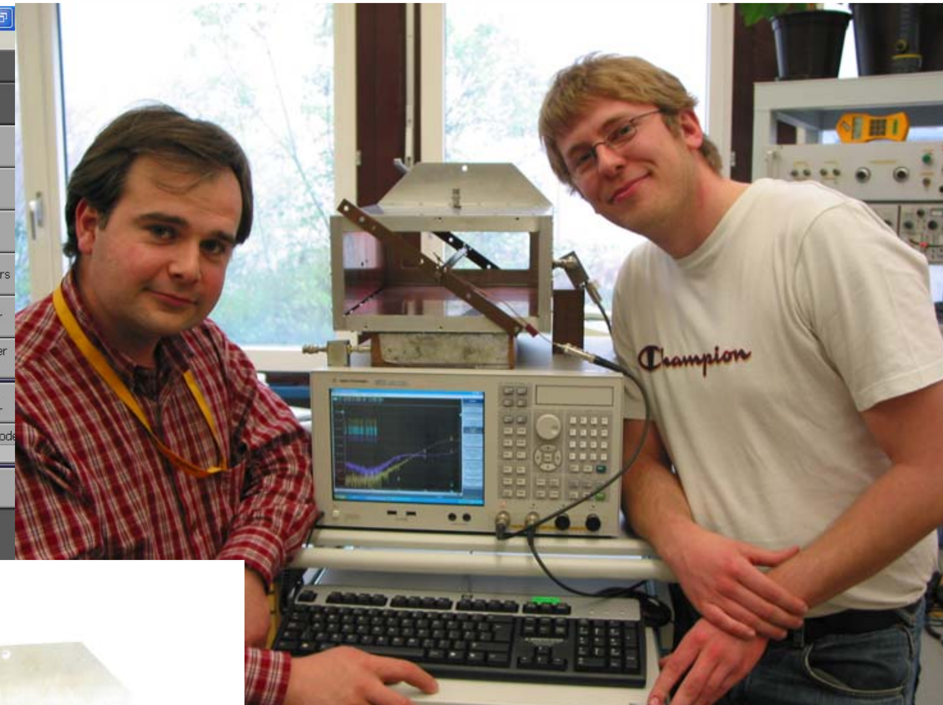




Transfer Impedance Measurement

With a network analyzer and an antenna the BPM properties can be determined.





Test BPM of 250x 80 mm^2

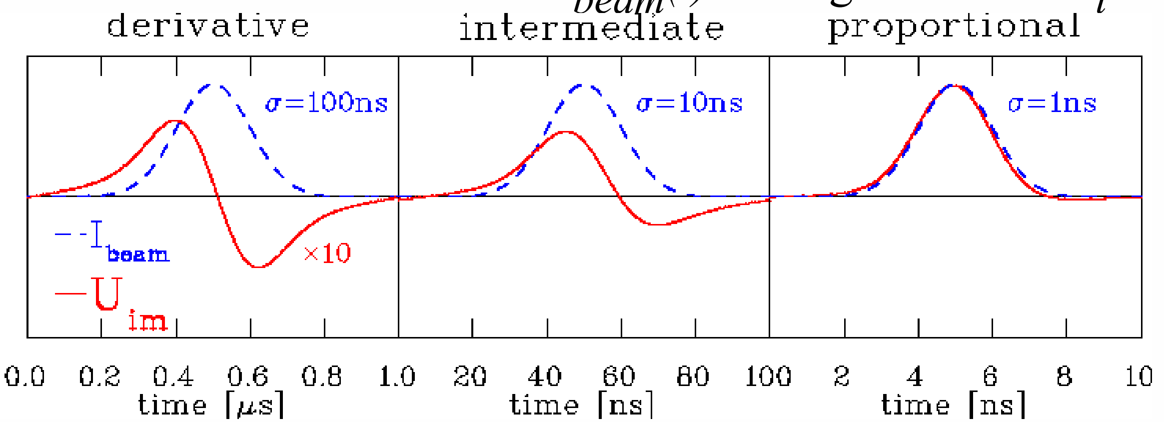
using a stripline antenna

of 300 MHz bandwidth

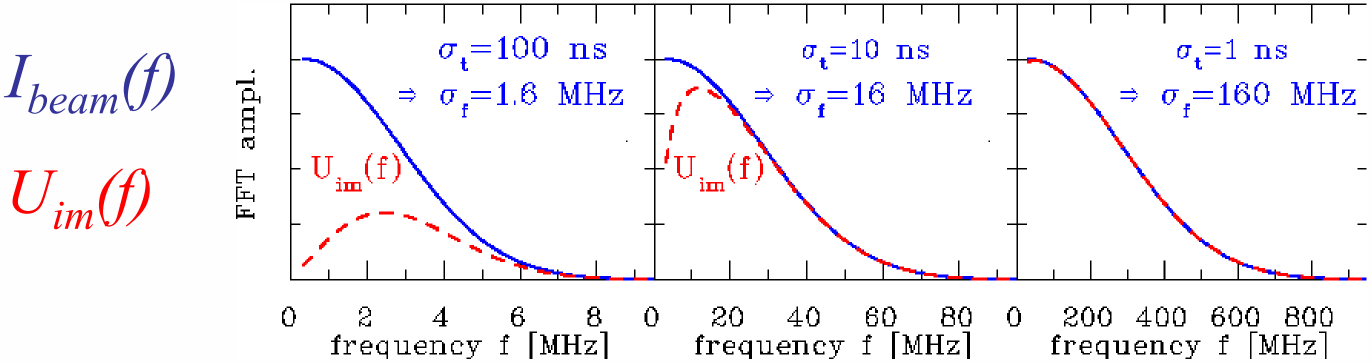
Calculation of Signal Shape: Single Bunch

The transfer impedance is used in frequency domain! The following is performed:

1. Start: Time domain Gaussian function $I_{beam}(t)$ having a width of σ_t



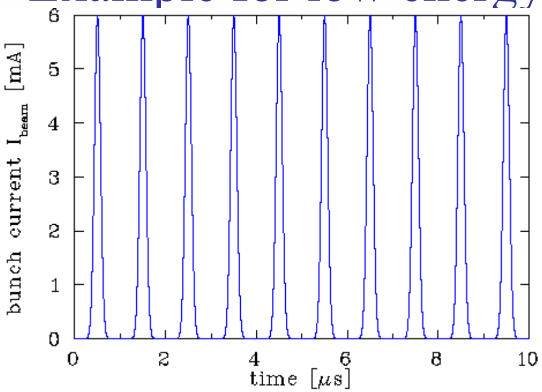
2. FFT of $I_{beam}(t)$ leads to the frequency domain Gaussian $I_{beam}(f)$ with $\sigma_f=(2\pi\sigma_t)^{-1}$

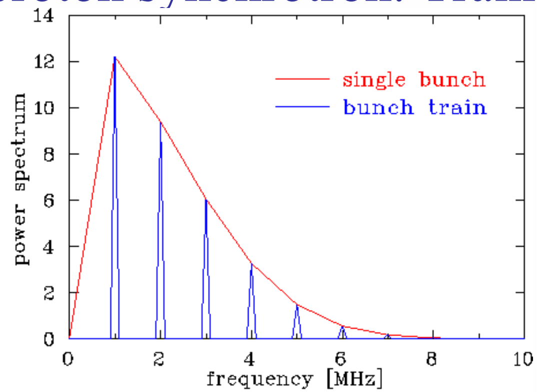


3. Multiplication with $Z_t(f)$ with f_{cut}=32 MHz leads to $U_{im}(f)=Z_t(f)\cdot I_{beam}(f)$

4. Inverse FFT leads to $U_{im}(t)$

Example for low energy proton synchrotron: Train of bunches with R=1 MΩ





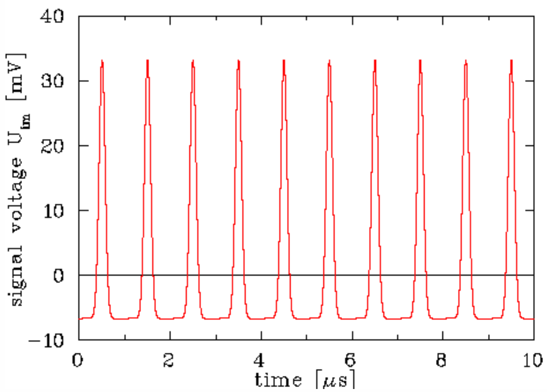
Calucalation of signal shape:

→ Bunch train $I_{beam}(t)$

→ FFT delivers $I_{beam}(\omega)$

→ $U_{im}(\omega)=Z_t \cdot I_{beam}(\omega)$

→ IFFT delivers $U_{im}(t)$



R=1 MΩ ⇒ f_{cut}=2kHz, Z_t=5Ω

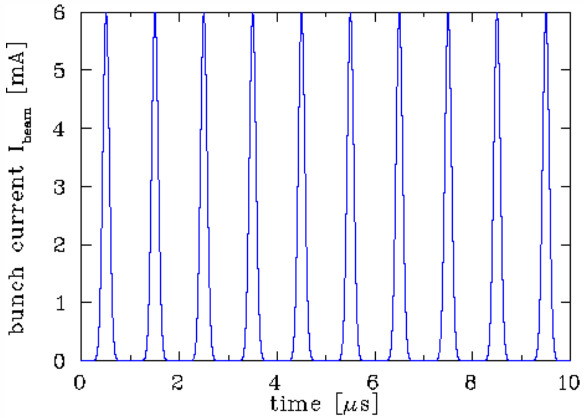
all buckets filled, no amp

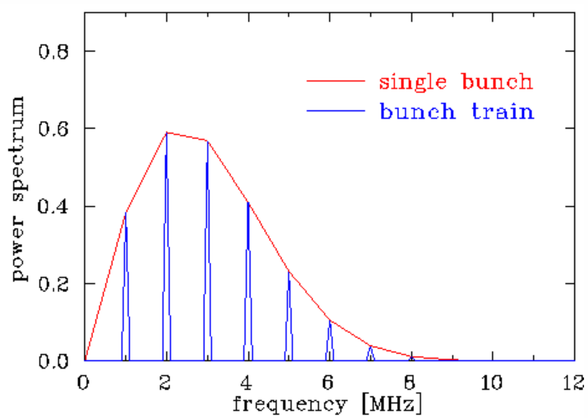
C=100pF, l=10cm, β=50%, σ_t=100 ns ⇒ σ_l=15m

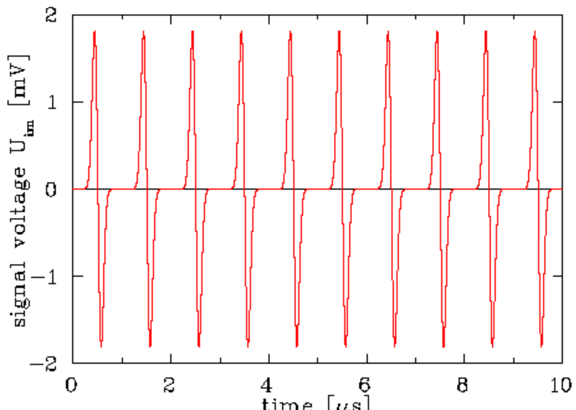
- Fourier spectrum is composed of lines separated by acceleration rf
- Envelope given by single bunch Fourier transformation
- Baseline shift due to ac-coupling

Remark: 1 MHz< f_{rf} <10MHz ⇒ Bandwidth ≈100MHz=10·f_{rf} for broadband observation

Train of bunches with R=50 Ω termination:







Parameter:

***R*=50 Ω ⇒ f_{cut}=32 MHz**

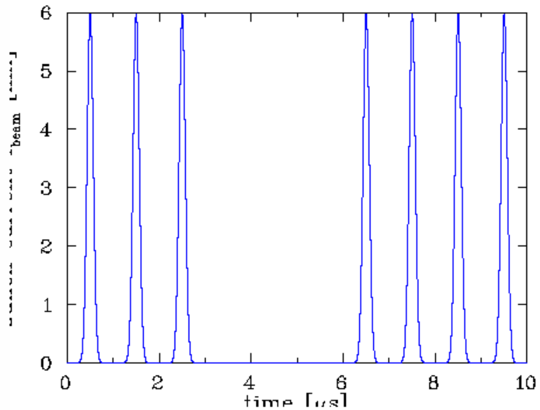
all buckets filled, no amp

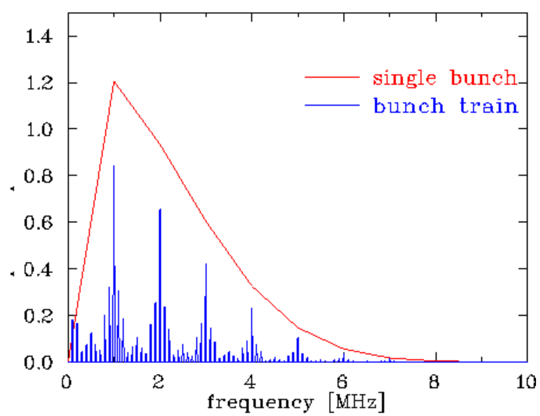
C=100pF, l=10cm, β=50%, σ_t=100 ns

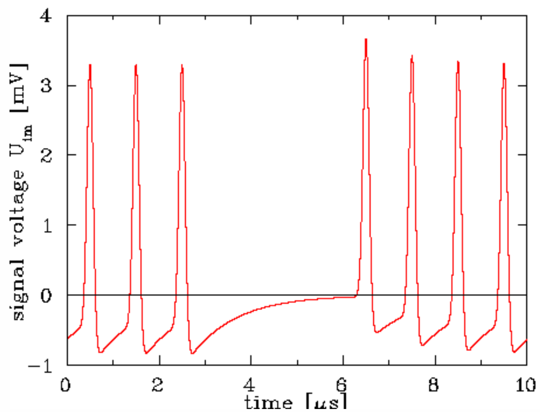
- Low frequency cut-off due to f_{cut}=32 MHz
- Differentiated bunches, 15 fold lower amplitude
- Modified Fourier spectrum with low amplitude value, maximum shift to higher frequencies

Calculation of Signal Shape: Bunch Train with empty Buckets

Synchrotron during filling: Empty buckets, R=10 kΩ termination:







Parameter:

***R*=10 kΩ ⇒ f_{cut}=160 kHz**

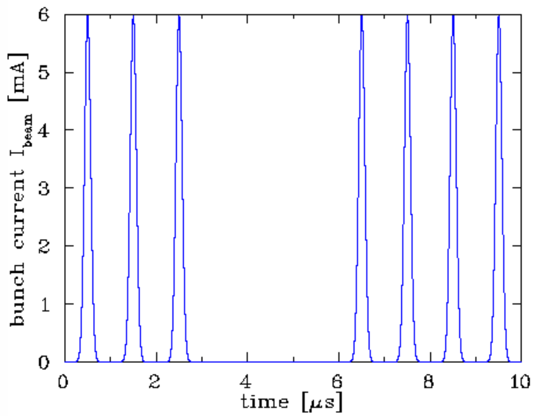
4 empty buckets

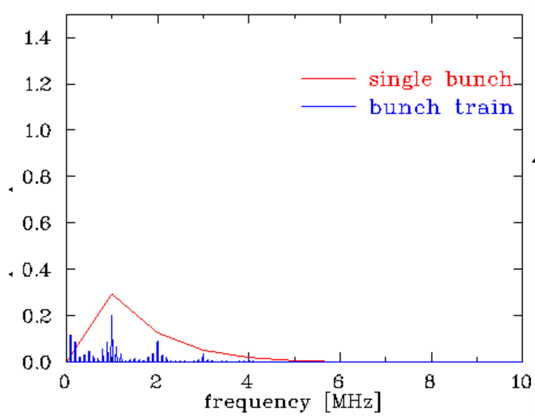
C=100pF, *l*=10cm, *β*=50%, σ=100 ns

- Fourier spectrum is more complex, harmonics are broader
- Varying baseline with $\tau = 1/3f_{cut} = 3$ μs
- Baseline shift calls for dedicated restoring algorithm for time domain processing.

Calculation of Signal Shape: Bunch Train with Cable Damping

Effect of cable or other electronics:



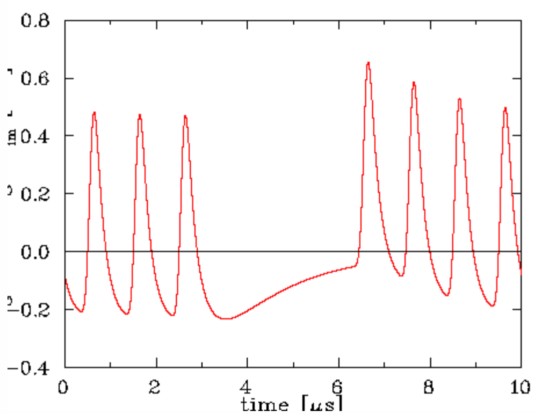


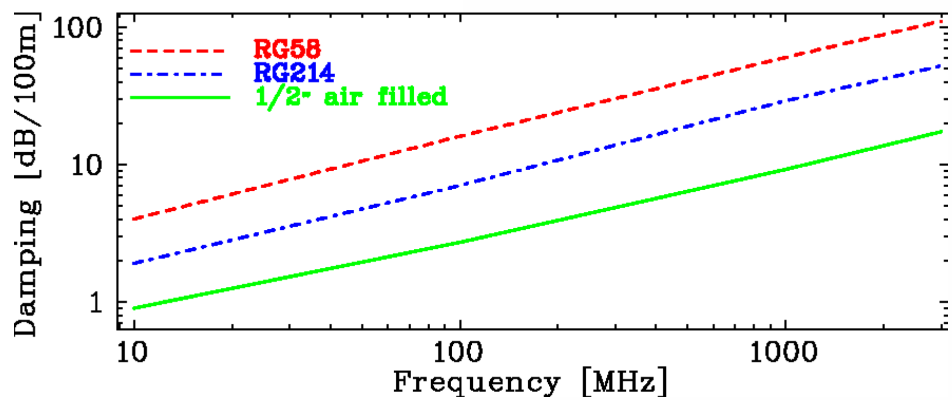
Cable damping given by:

$$Z_{cable}(\omega) = e^{-\sqrt{f/f_e}} \cdot e^{-i\sqrt{f/f_e}}$$

f_e: amplitude damping by ≈10 dB

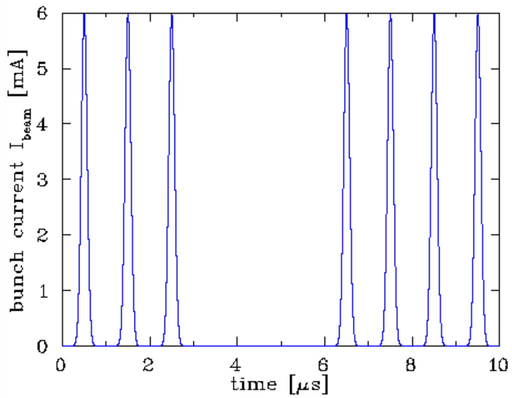
Here: f_e=0.5 MHz

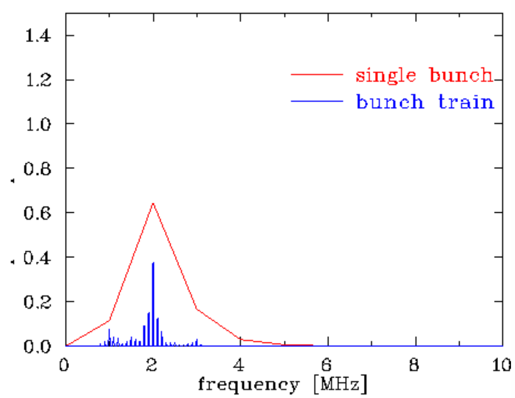


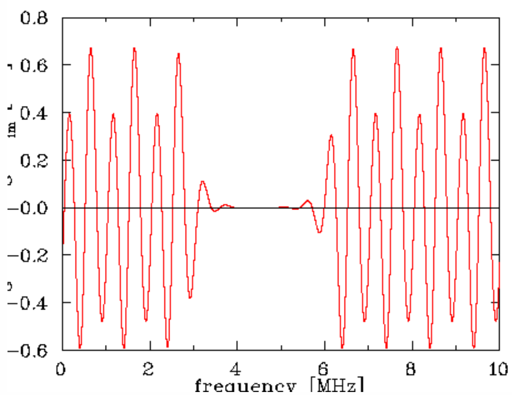


- Bunch signal is damped; 8 fold lower amplitude, higher frequencies are damped stronger
- Bunch signal gets asymmetric, baseline did not reach zero
- ⇒ 'Good cables' are a precaution for broadband signal transmission

Effect of filters, here bandpass:







n^{th} order Butterworth Filter:

(Math. simple, but **not** well suited)

$$|Z_{low}| = \frac{1}{\sqrt{1+(\omega/\omega_{cut})^{2n}}}$$

$$|Z_{high}| = \frac{(\omega/\omega_{cut})^{n}}{\sqrt{1+(\omega/\omega_{cut})^{2n}}}$$

$$Z_{filter} = Z_{high} \cdot Z_{low}$$

Parameter:

***R*=10 kΩ, 4^{th} order**

Butterworth filter at f_{cut}=2 MHz

C=100pF, *l*=10cm, *β*=50%, σ=100 ns

- Ringing due to sharp cutoff
- Other filter types more appropriate

Generally: $Z_{tot}(\omega) = Z_{cable}(\omega) \cdot Z_{filter}(\omega) \cdot Z_{amp}(\omega) \cdot \ldots \cdot Z_t(\omega)$

Calculation via FFT: $I_{beam}(t) \xrightarrow{FFT} I_{beam}(\omega) \rightarrow U_{im}(\omega) = Z_{tot}(\omega) \cdot I_{beam}(\omega) \xrightarrow{invFFT} U_{im}(t)$

Remark: For electronics calculation, time domain filters (FIR and IIR) are more appropriated

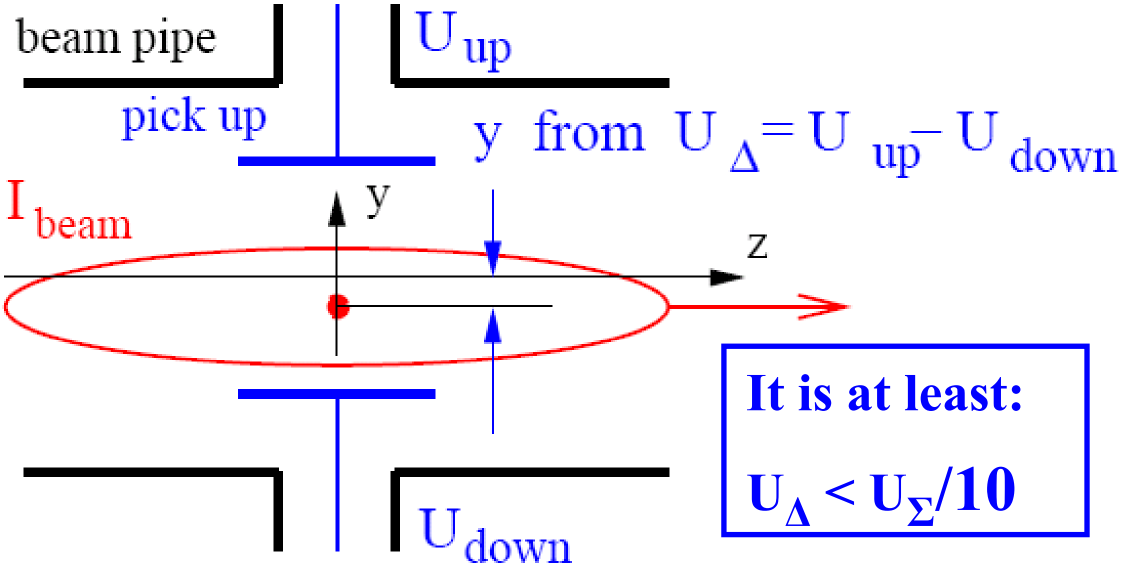
The difference between plates gives the beam's center-of-mass
→most frequent application

'Proximity' effect leads to different voltages at the plates:

$$y = k_y(\omega) \cdot \frac{U_{up} - U_{down}}{U_{up} + U_{down}} + \delta_y(\omega)$$

$$\equiv k_y \cdot \frac{U_\Delta}{U_\Sigma} + \delta_y \equiv k_y \cdot \frac{\Delta}{\Sigma} + \delta_y$$

$$x = k_x(\omega) \cdot \frac{U_{right} - U_{left}}{U_{right} + U_{left}} + \delta_x(\omega)$$



It is at least:
$$U_\Delta < U_\Sigma/10$$

Sometimes the transverse transfer impedance is defined via $U_\Delta = Z_\perp(\omega) \cdot x I_{beam}$

It can be assumed: $Z_\perp(\omega,x) = k(\omega,x) \cdot Z_t(\omega)$

with $k(\omega,x)$ or $S(\omega,x) = 1/k(\omega,x)$ called **displacement sensitivity**

They are geometry dependent, non-linear function, which have to be optimized.

Units: k=[mm] and S=[%/mm] or S=[dB/mm]

Beam Position Monitor:
Detector Principle, Hardware and Electronics

Outline:

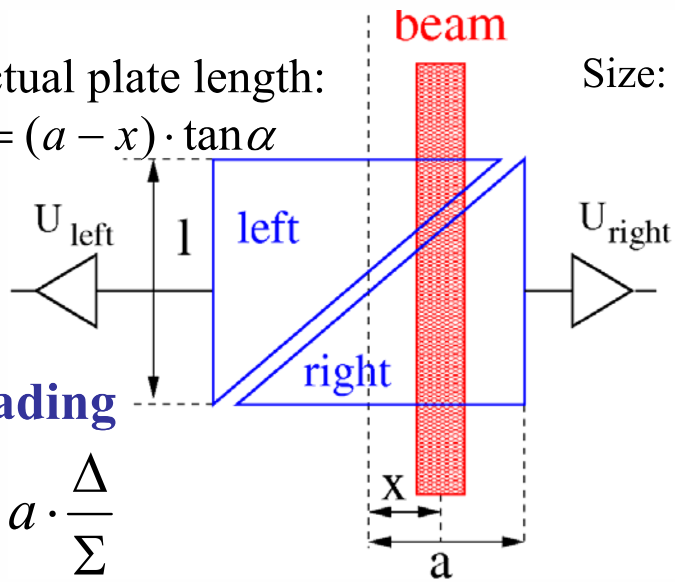
- *Signal generation → transfer impedance*
- ***Consideration for capacitive 'shoe box' = 'linear cut' BPM***
  position sensitivity calculation, crosstalk, realization
- ***Consideration for capacitive button BPM***
- ***Other BPM principles: stripline → traveling wave,***
  inductive → wall current, cavity → resonator for dipole mode
- ***Electronics for position evaluation***
- ***Some examples for position evaluation and other applications***
- ***Summary***

Frequency range: 1 MHz$<f_{rf}<$10 MHz $\Rightarrow$ bunch-length >> BPM length.

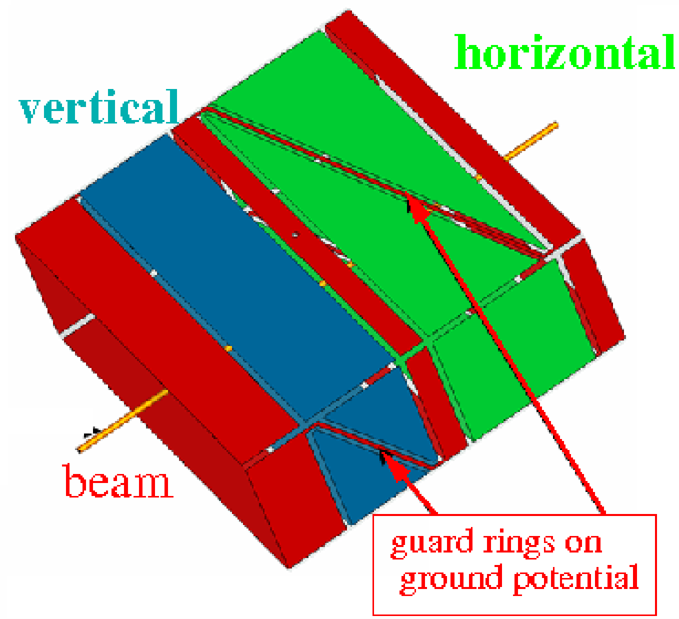
Signal is proportional to actual plate length:

$$l_{right} = (a+x)\cdot\tan\alpha,\; l_{left} = (a-x)\cdot\tan\alpha$$

$$\Rightarrow \frac{l_{right} - l_{left}}{l_{right} + l_{left}} = \frac{x}{a}$$

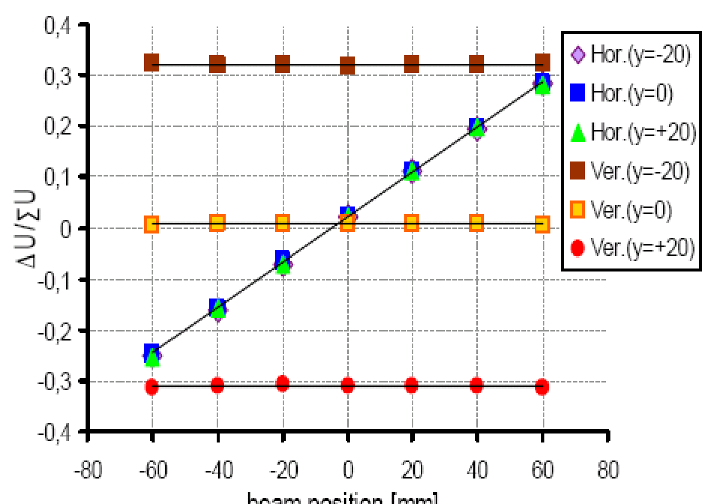


Size: 200x70 mm^2



In ideal case: linear reading

$$x = a\cdot\frac{U_{right} - U_{left}}{U_{right} + U_{left}} \equiv a\cdot\frac{\Delta}{\Sigma}$$



Shoe-box BPM:

Advantage: Very linear, low frequency dependence

Disadvantage: Large size, complex mechanics
high capacitance

Boundary Contribution $\Rightarrow$ FEM Calculation required

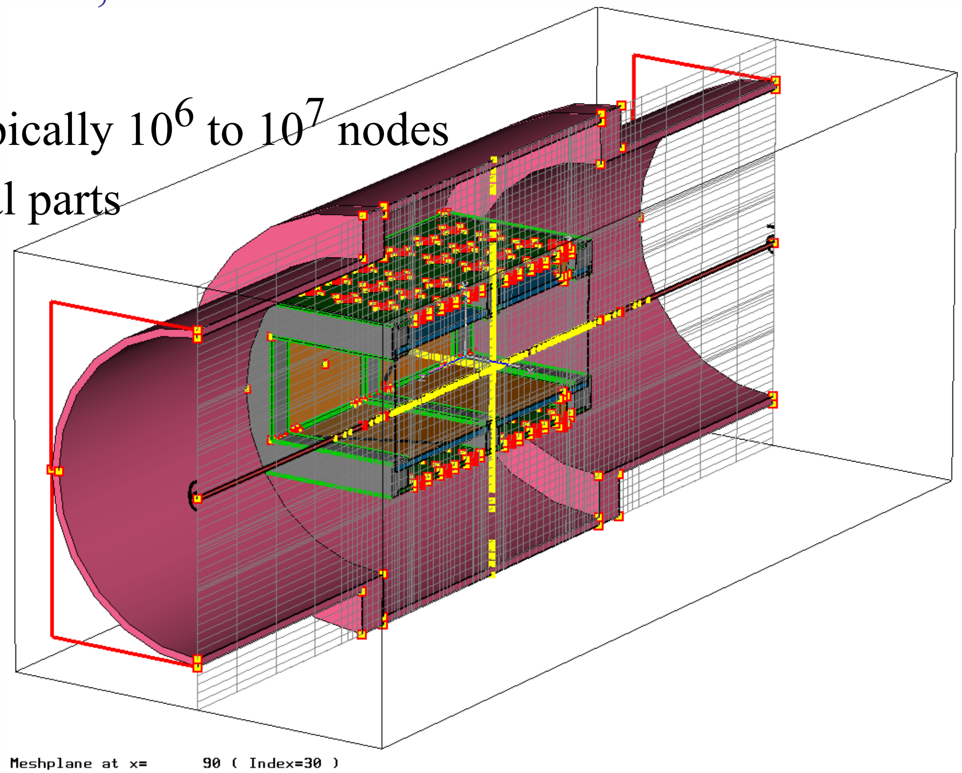
Boundary condition by the environment can significantly influence BPM properties

$\Rightarrow$ real properties have to be calculated numerically by **F**inite **E**lement **M**ethod:

Examples are: CST-Studio (MAFIA), Comsol, HFFS

General idea of FEM calculations:

- Volume is divided in 3-dim meshes with typically 10^6 to 10^7 nodes
- Fixed boundary conditions at the mechanical parts and eventually source terms
- Goal: Field distribution within the meshes
- The Maxwell equations are solved by iterative matrix inversion
- Time domain: Propagation of source terms (here: Gaussian shaped pulse corresponding to 200 MHz bandwidth)
- Frequency domain: e.g. eigenmodes



- Output: time dependent signal, frequency dependences, S-parameters, field distribution etc.

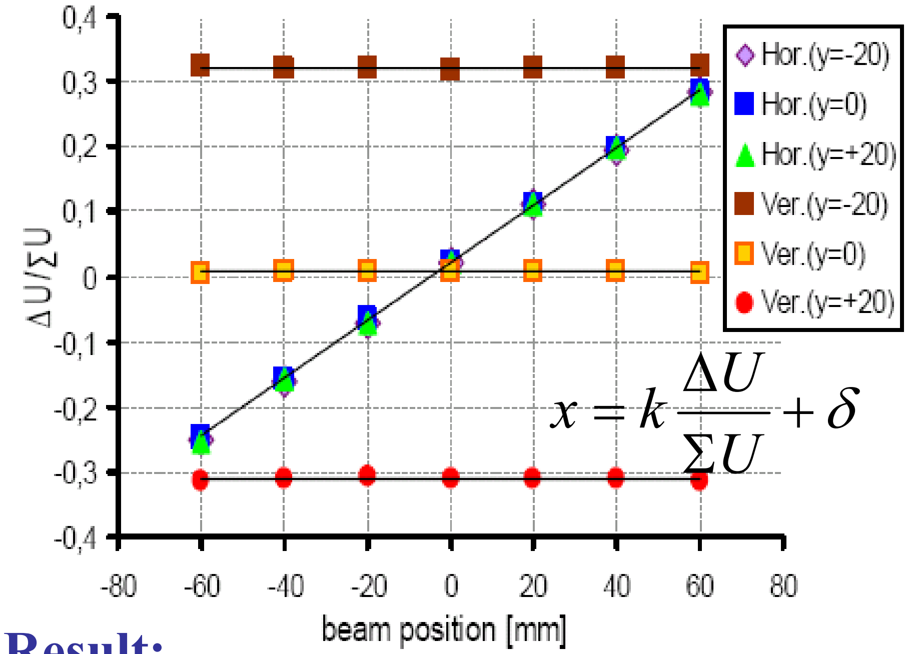
Optimization of Position Sensitivity

Simulation: Gaussian pulse travels on wire on different positions

→ induced voltage calculated on matched output ports

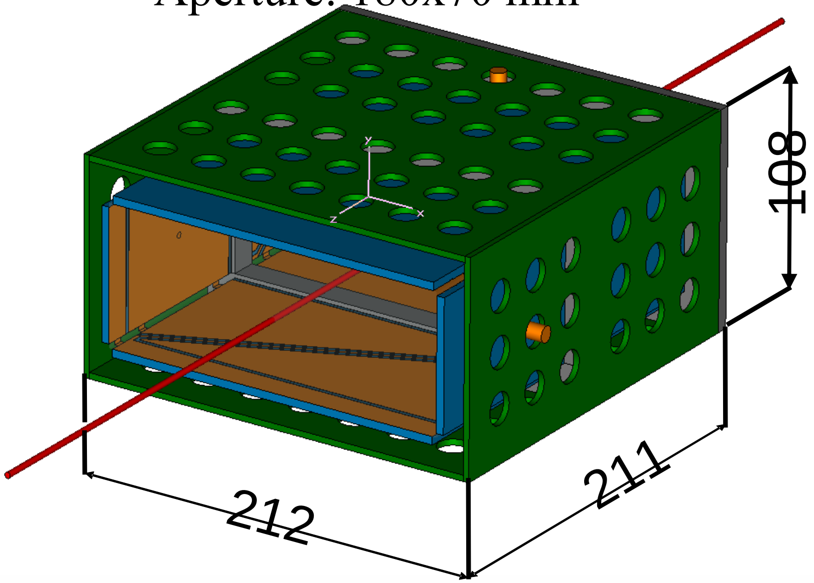
→ calculation of $\Delta U/\Sigma U$

Criteria of optimization: linearity, sensitivity, offset reduction, x-y plane independence



$$x = k\frac{\Delta U}{\Sigma U} + \delta$$

Aperture: 180x70 mm^2



Result:

Nearly perfect behavior: k_x=104mm, δ_x=-0.4mm (ideal value k_x=90mm, δ=0)

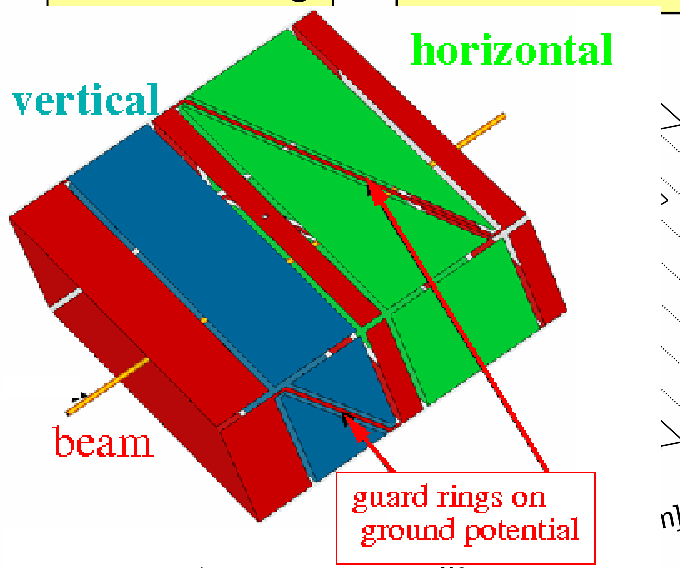
k_y=38mm, δ_y=-0.04mm (ideal value k_y=35mm, δ=0) **at 1 MHz**

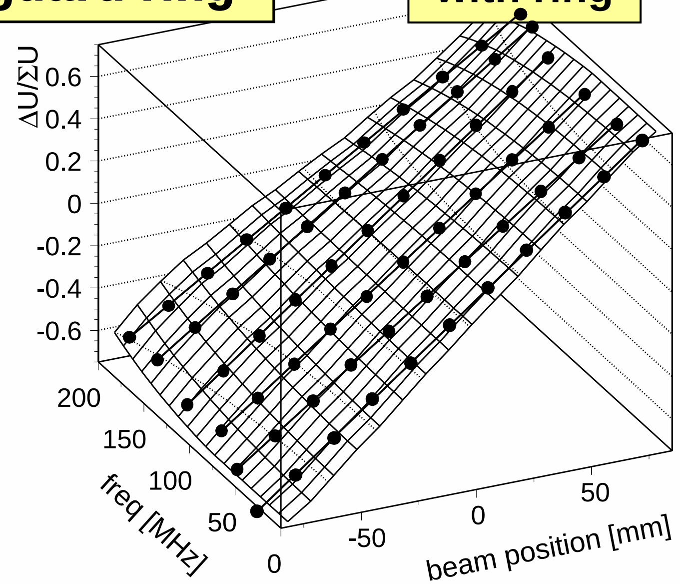
Frequency Dependence of Position Sensitivity

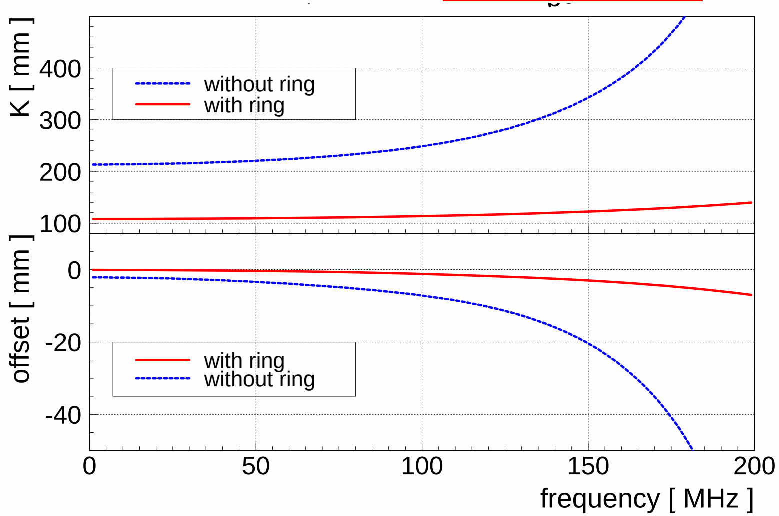
without ring

With/without guard ring

with ring







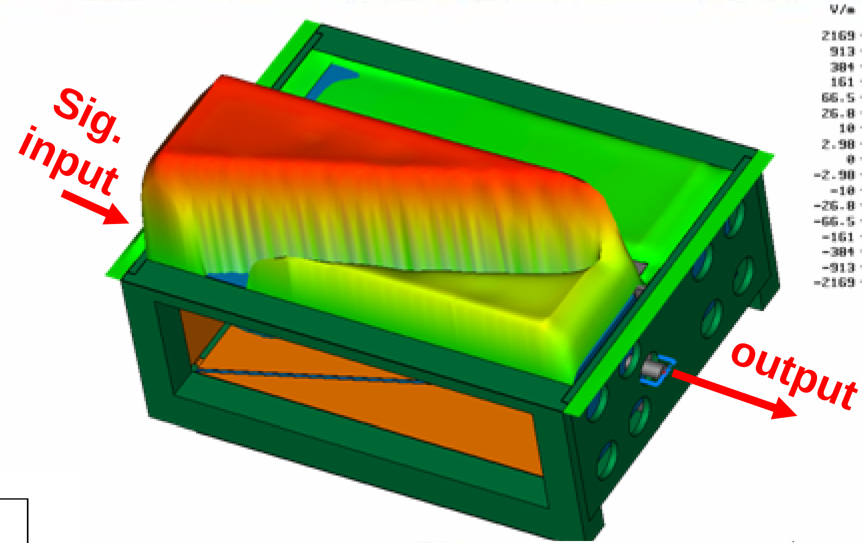
$$x = k(\omega)\frac{\Delta U}{\Sigma U} + \delta(\omega)$$

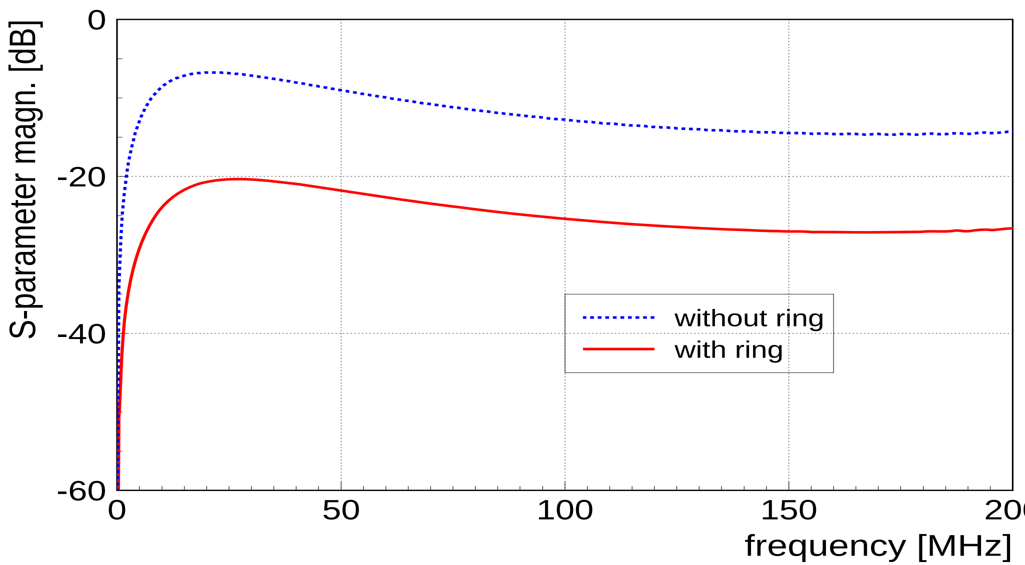
- Displacement sensitivity is nearly frequency independent only with separation ring
- Sensitivity with separating rings is a factor of two larger as without ring.
- Capacitive coupling spoils the sensitivity

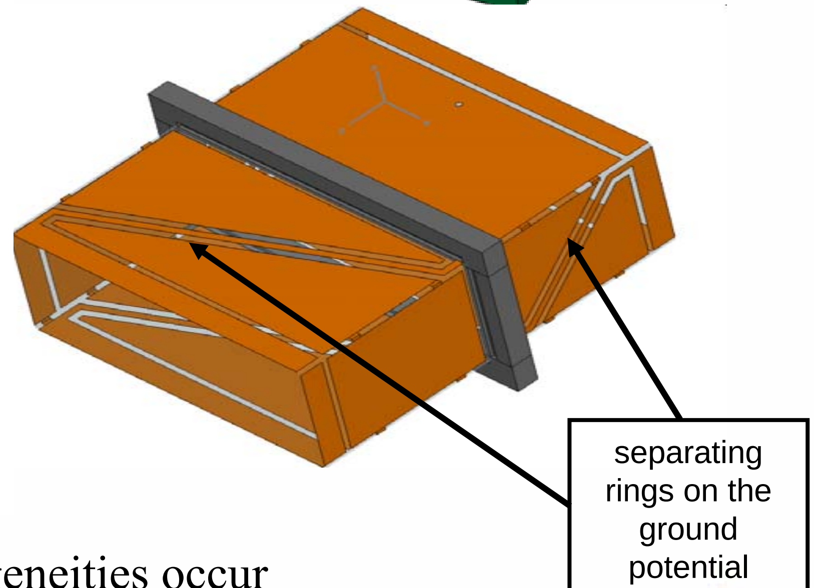
Plate—to-Plate Cross-Talk reduces Sensitivity

- Capacitive coubling determines position sensitivity
- Plate-to-plate cross talk caused by ceramic permittivity ε=9.6 resulting in high coupling capacitance between adjacent plates

⇒Insertion of the guard-ring between plates reduces cross talks by more than 10dB





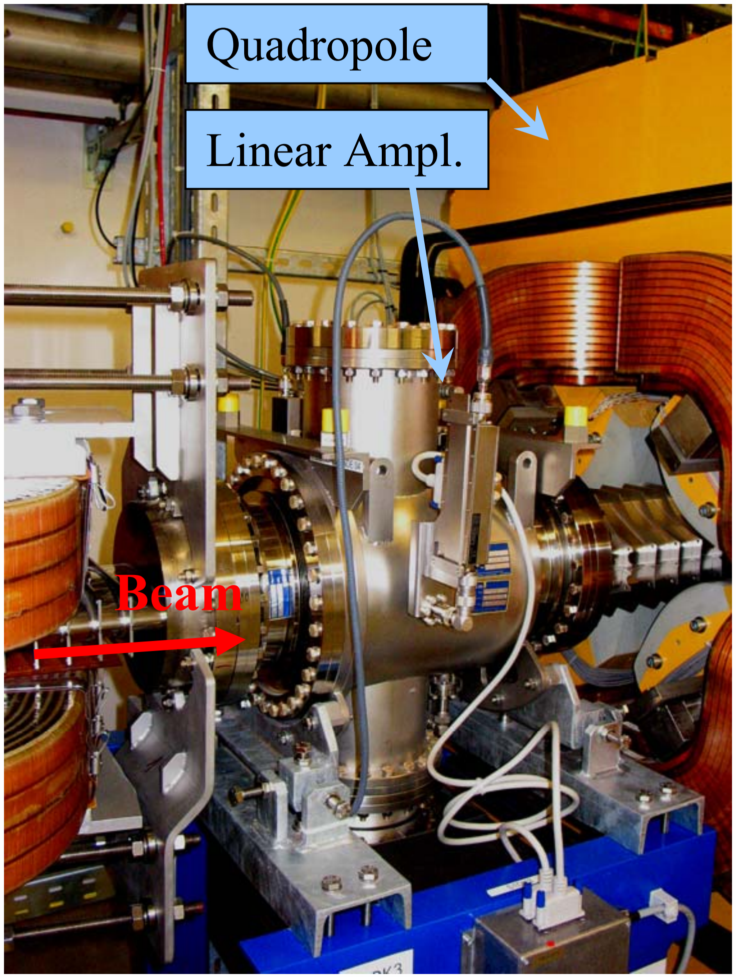


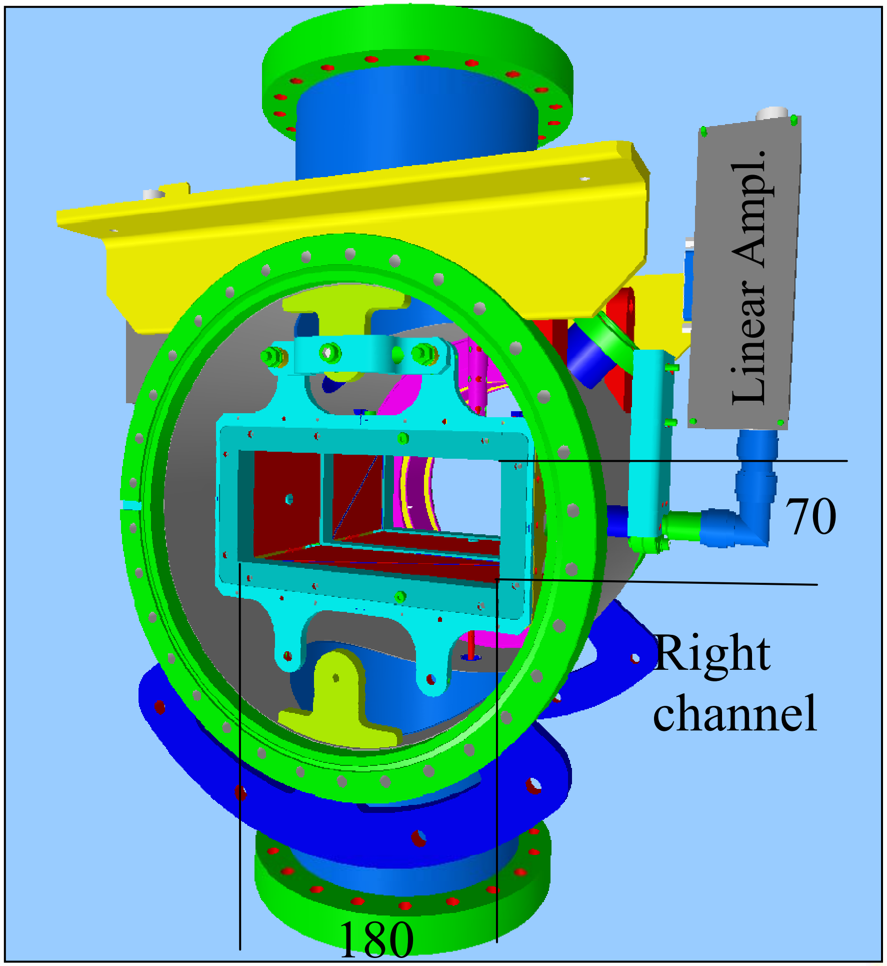
Remark: If guard rings are too large: E-field in-homogeneities occur

Technical Realization of Shoe-Box BPM

Technical realization at HIT synchrotron of 46 m length for 7 MeV/u→440 MeV/u

BPM clearance: 180x70 mm^2, standard beam pipe diameter: 200 mm.





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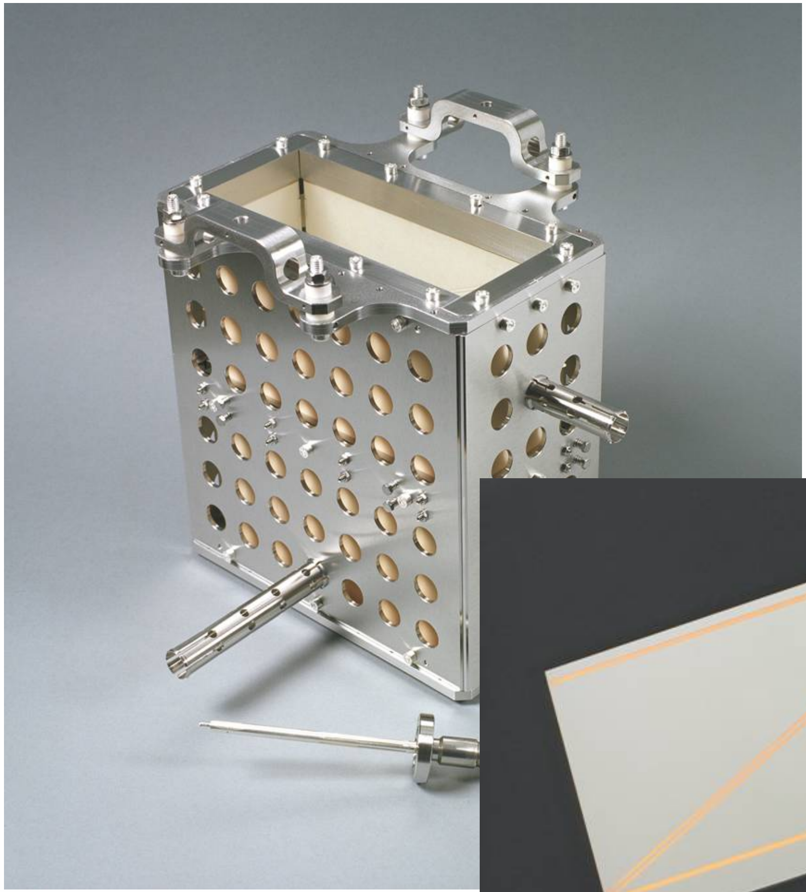
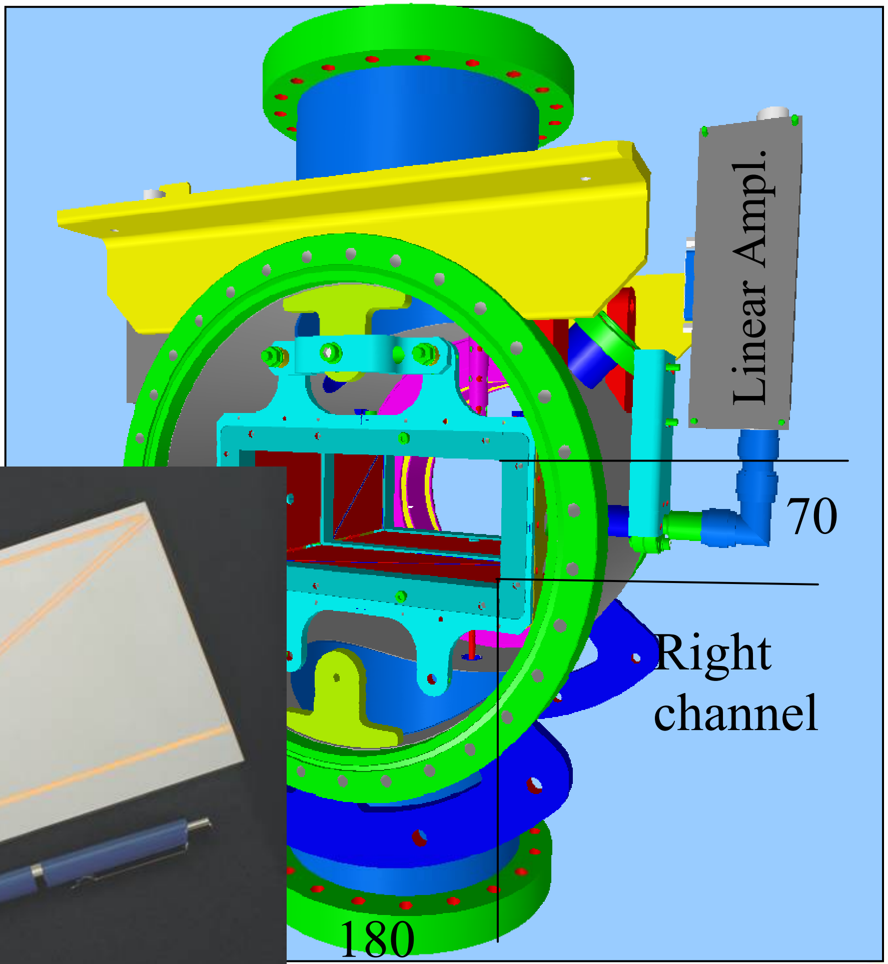
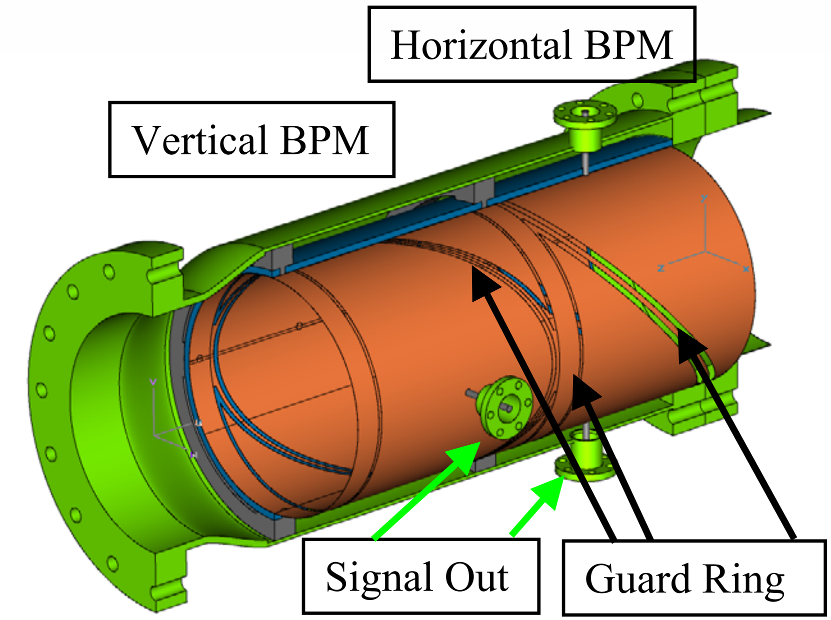




Other Types of diagonal cut BPM

Round type: cut cylinder

Same properties as shoe-box:



Other realization: Full metal plates

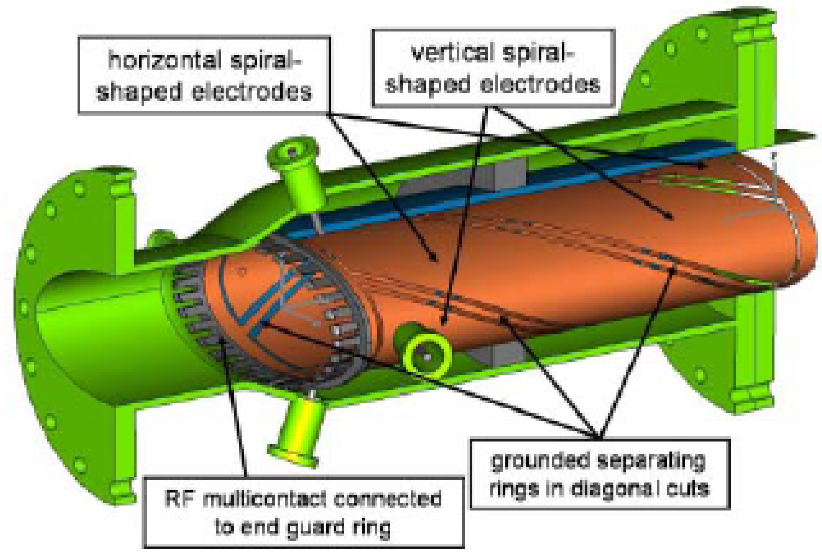
→ No guard rings required

→ but mechanical alignment more difficult

Wounded strips:

Same distance from beam and capacitance for all plates

But horizontal-vertical coupling.



Outline:

- *Signal generation → transfer impedance*
- *Consideration for capacitive shoe box BPM*
- ***Consideration for capacitive button BPM***

  simple electro-static model, low β effect, modification for synch. light source

  Comparison shoe box button BPM
- ***Other BPM principles: stripline → traveling wave,***

  inductive → wall current, cavity → resonator for dipole mode
- ***Electronics for position evaluation***
- ***Some examples for position evaluation and other applications***
- ***Summary***

LINACs, e^--synchrotrons: 100 MHz < f_{rf} < 3 GHz → bunch length ≈ BPM length

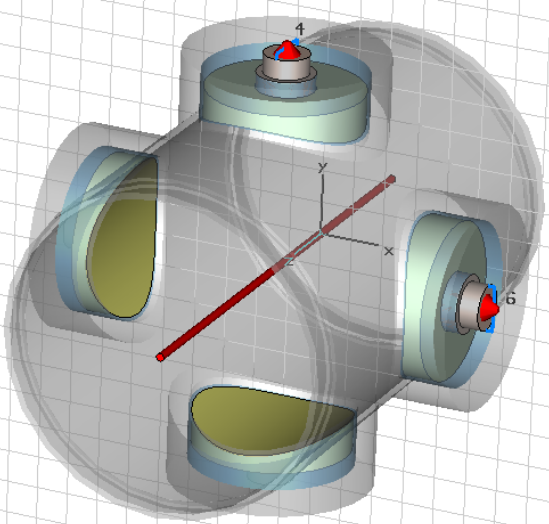
→ 50 Ω signal path to prevent reflections

Button BPM with 50 Ω ⇒ $U_{im}(t) = R \cdot \frac{A}{\beta c \cdot \pi a} \cdot \frac{dI_{beam}}{dt}$

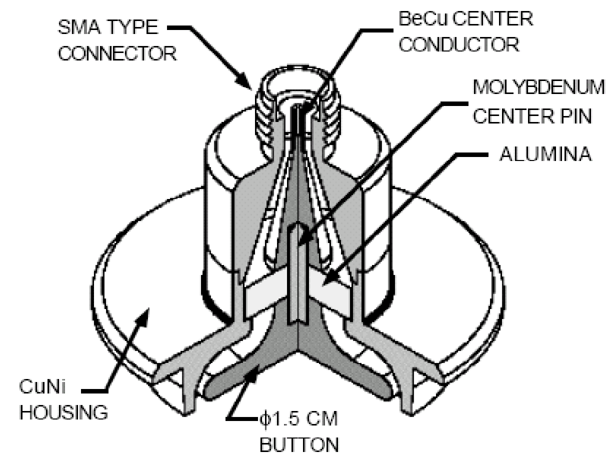
Example: LHC-type inside cryostat:

∅24 mm, half aperture a=25 mm, C=8 pF

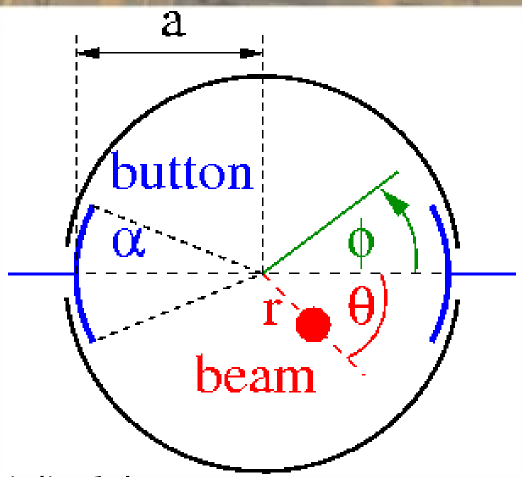
⇒ f_{cut}=400 MHz, Z_∞ = 1.3 Ω:



From C. Boccard (CERN)



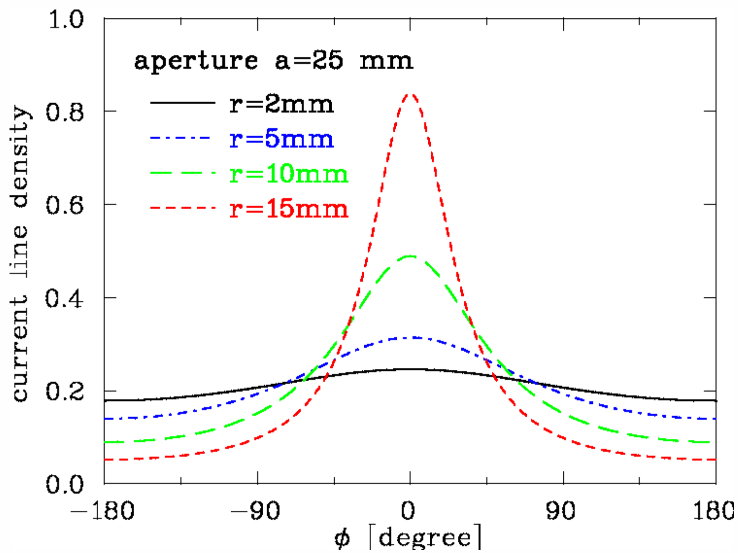
'Proximity effect': larger signal for closer plate

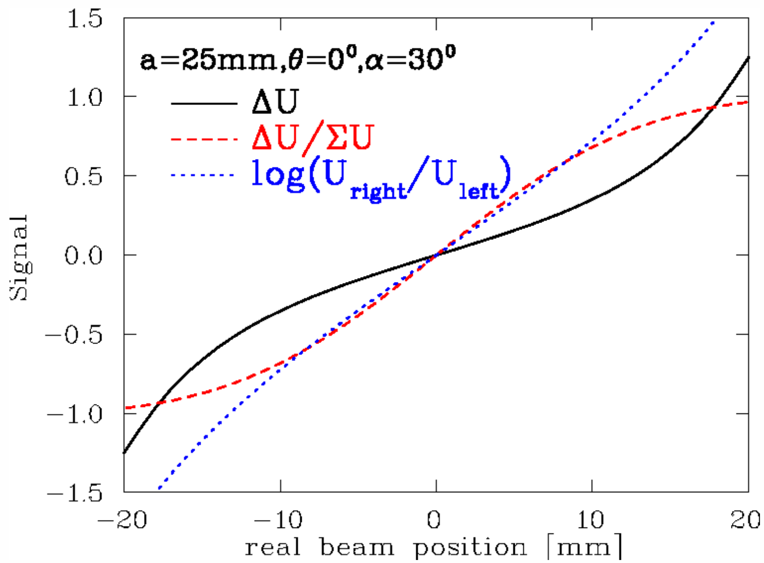


Ideal 2-dim case: Cylindrical pipe → image current density via 'image charge method' for 'pensile' beam:

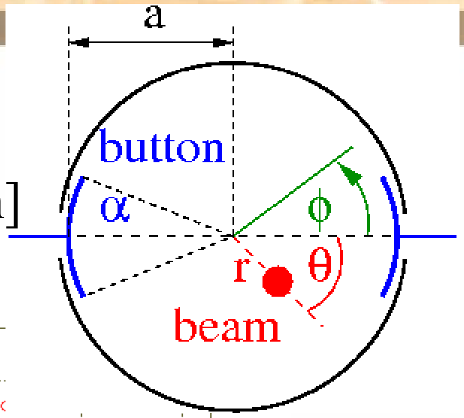
$$j_{im}(\phi) = \frac{I_{beam}}{2\pi a} \cdot \left(\frac{a^2 - r^2}{a^2 + r^2 - 2ar \cdot \cos(\phi - \theta)} \right)$$

Image current: Integration of finite BPM size: $I_{im} = \int_{-\alpha/2}^{\alpha/2} j_{im}(\phi) d\phi$





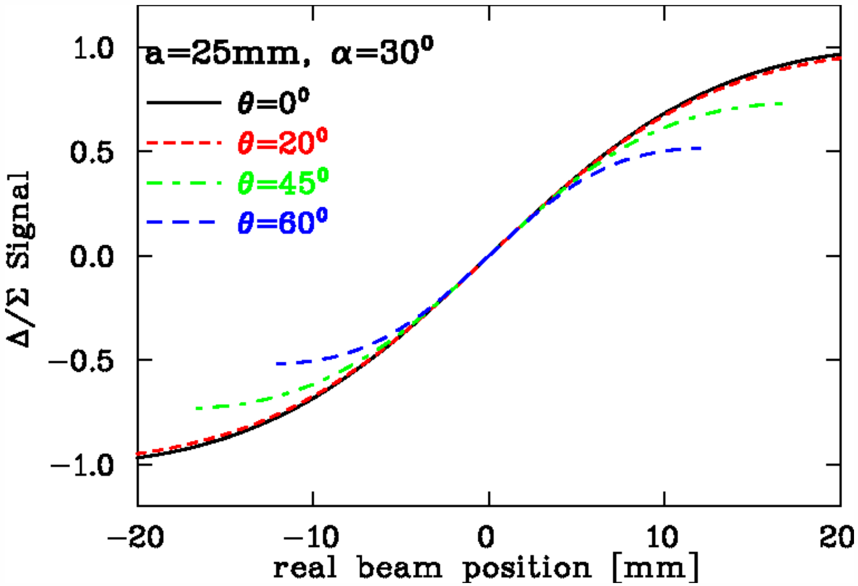
2-dim Model for Button BPM

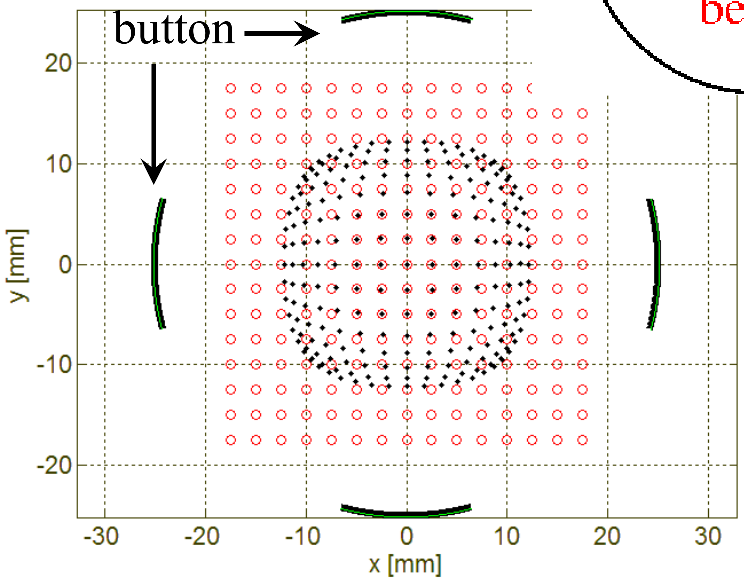


Ideal 2-dim model: Non-linear behavior and hor-vert coupling:

Sensitivity: $x=k\cdot\Delta/\Sigma = 1/S\cdot\Delta/\Sigma$ with k [mm], S [%/mm] or [dB/mm]

For this example: center part S=7.4%/mm ⇔ $k=1/S$=14mm





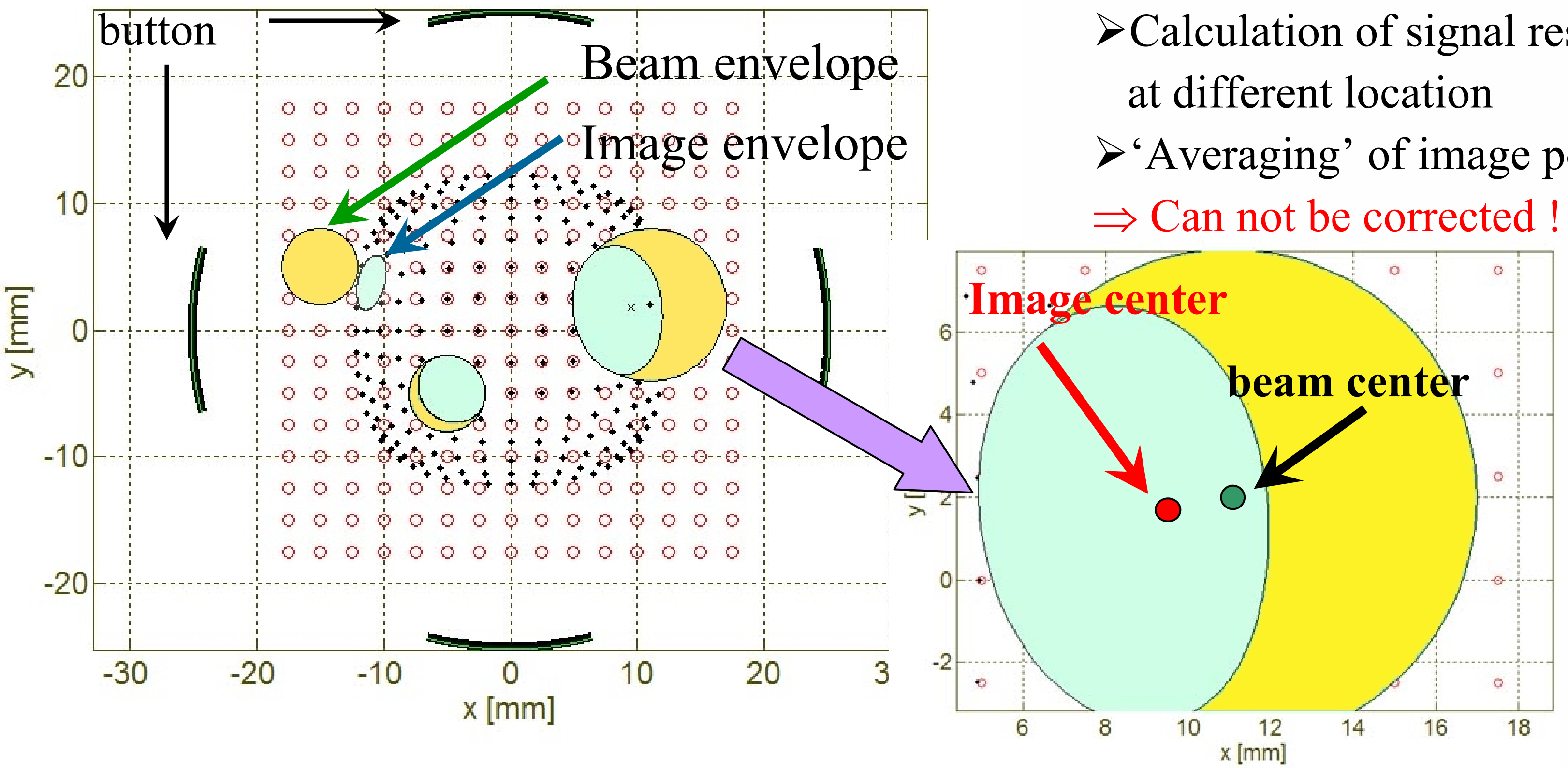
Current density can also be calculated by Laplace equation for Fourier components

$$I_{beam} = \langle I_{beam} \rangle + 2\langle I_{beam} \rangle \cdot \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t) \quad \text{for Gaussian bunches}: A_n = \exp(-n^2\omega^2\sigma_t^2/2)$$

In addition, frequency dependence can be calculated by this method.

Ideal 2-dim model:

Due to the non-linearity, the beam size enters in the position reading.



Finite beam size:

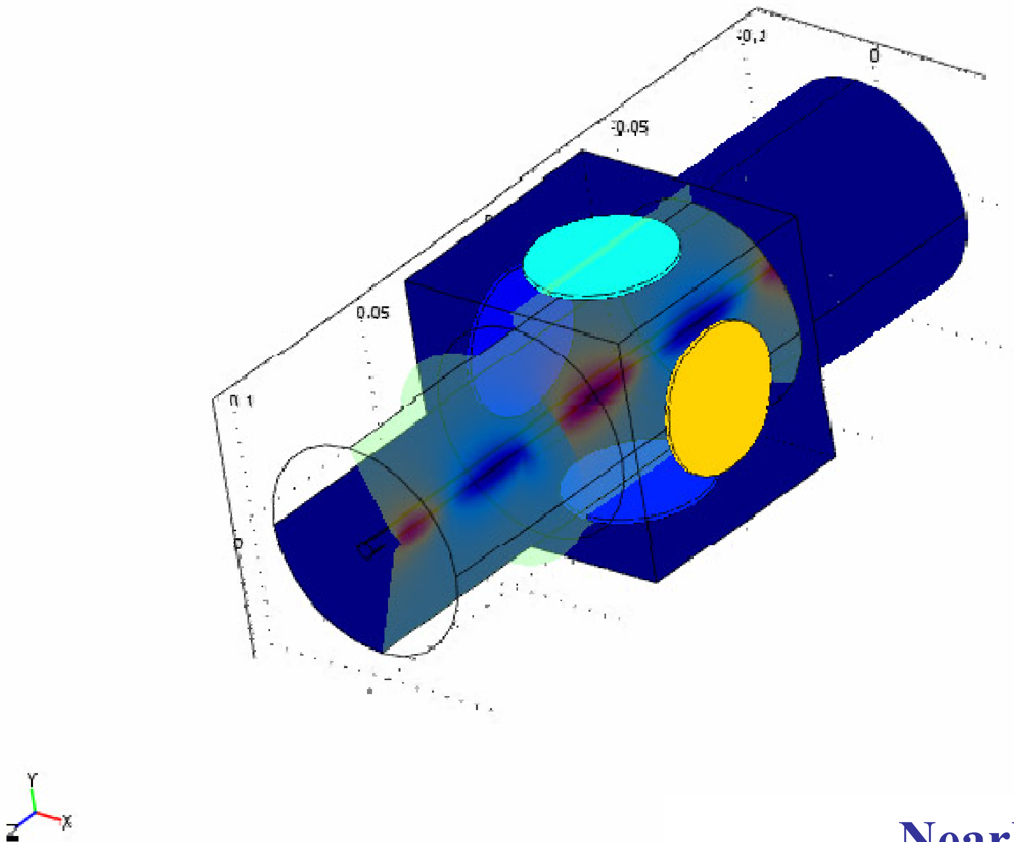
- Calculation of signal response at different location
- 'Averaging' of image position

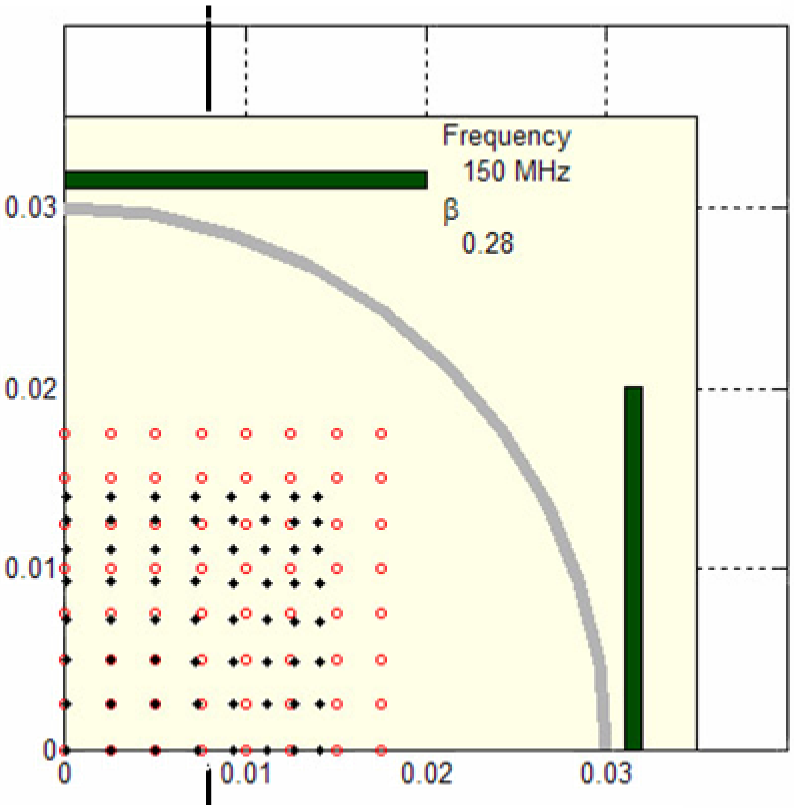
⇒ Can not be corrected !

Remark: For most LINACs: Linearity is less important, because beam has to be centered → correction as feed-forward for next macro-pulse.

For realistic beam, 3-dim FEM calculations are required.

Example: Button BPM at r=3 cm beam-pipe, flat, round ∅ 4cm frequency f_{rf}=150 MHz, effect for higher harmonics calculated





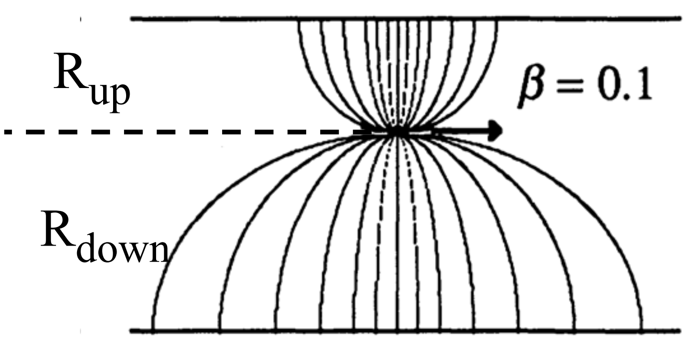
Nearly same result as ideal case!

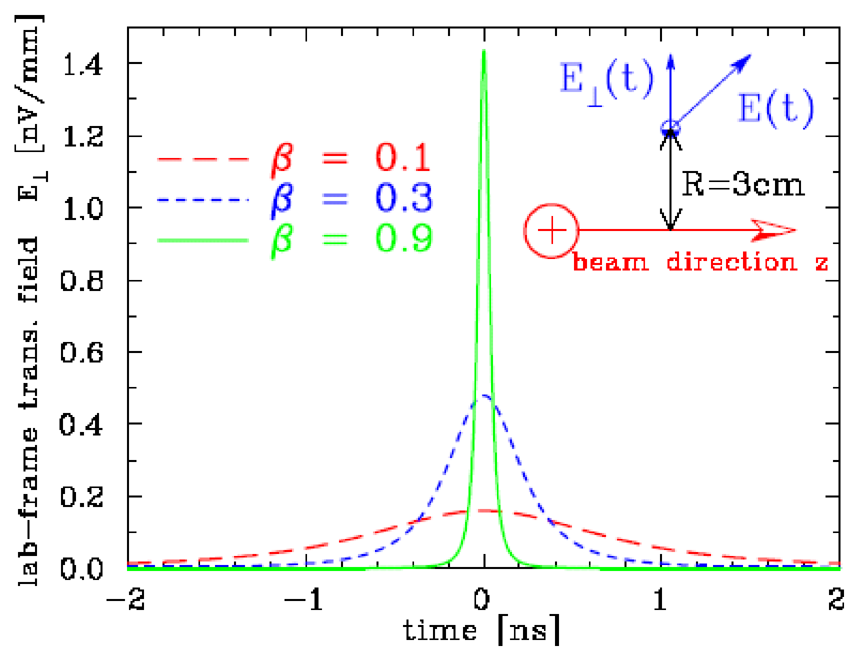
Low Velocity Effect: General Consideration

Simple Lorentz transformation of single point-like charge:

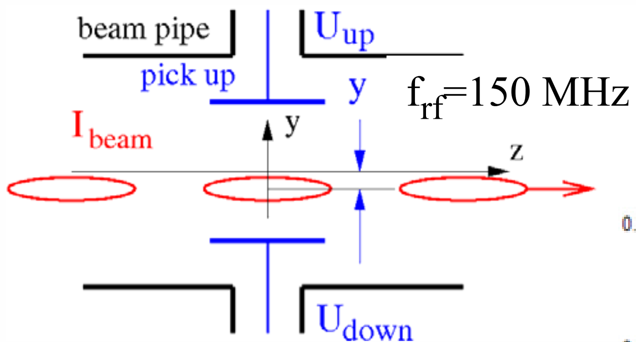
Lorentz boost and transformation of time: $E_\perp(t) = \gamma E'(t')$ and $t \to t'$

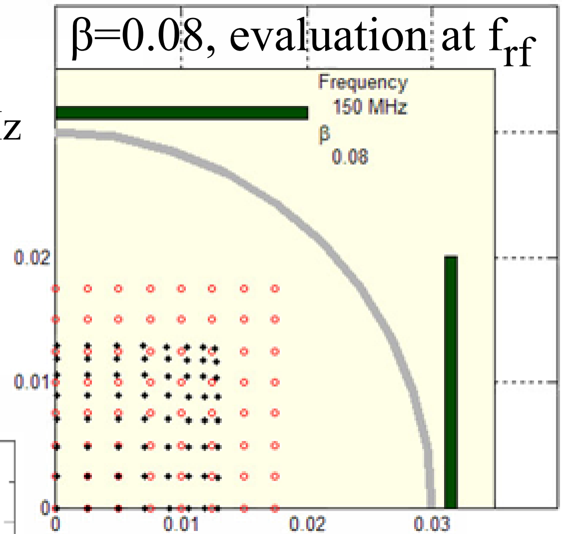
E-field of a point-like charge: $$E_\perp(t) = \frac{e}{4\pi\varepsilon_0} \cdot \frac{\gamma R}{\left[R^2 + (\gamma\beta c t)^2\right]^{3/2}}$$

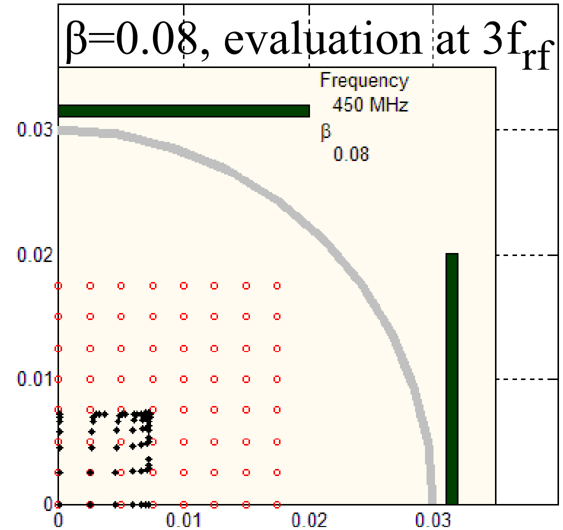


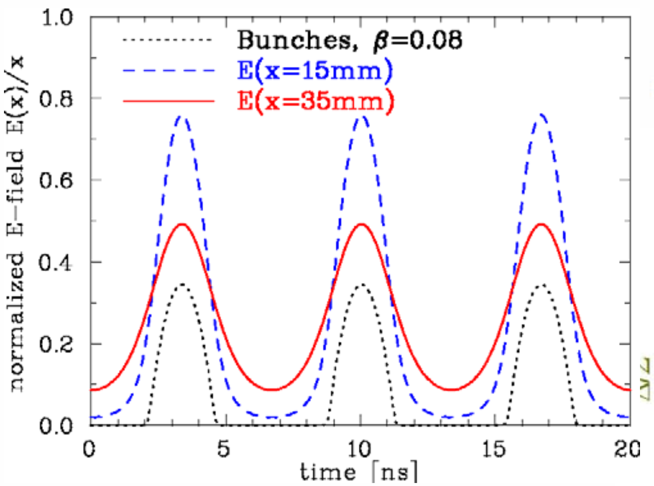


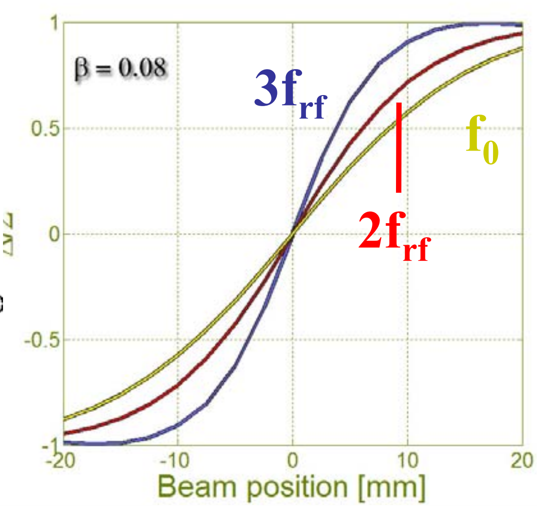
FEM Calculation of low β Effect for p-LINAC

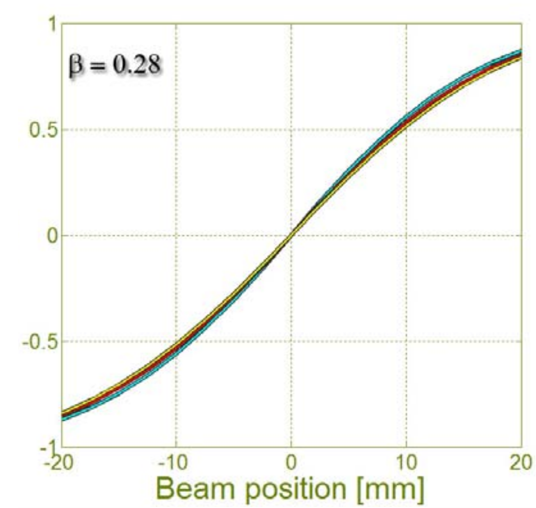








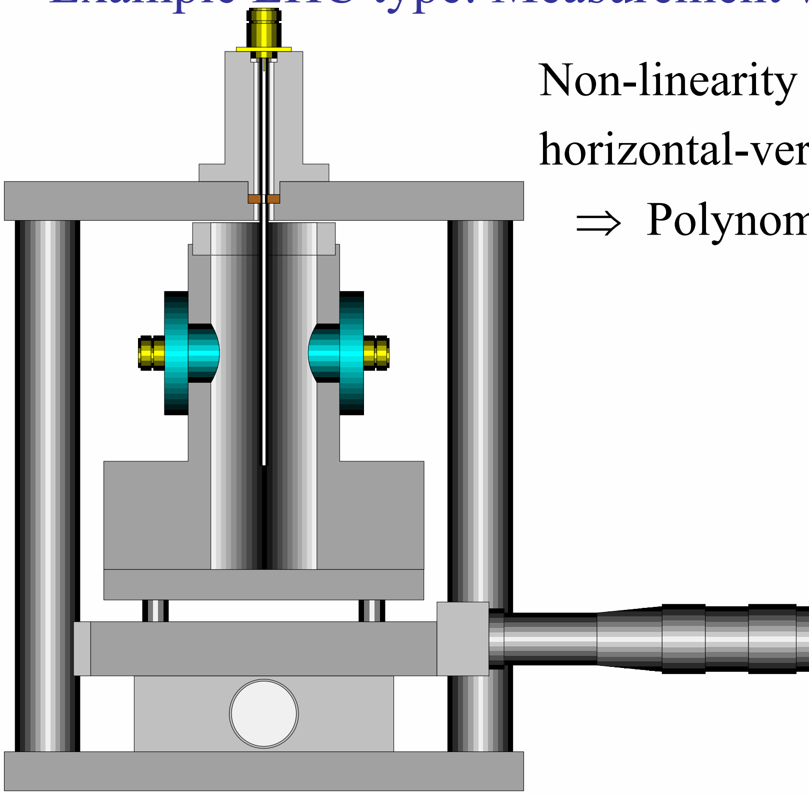


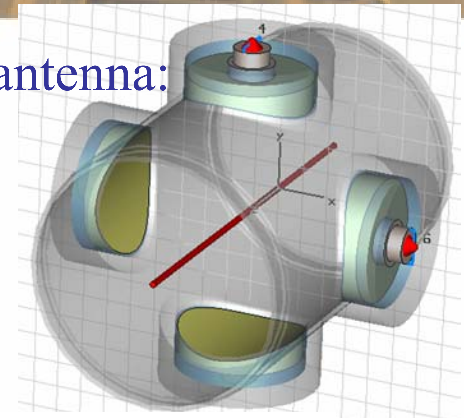


- Effect increases with f_{rf}
- Can also be calculated by Fourier-components.

Position Measurement for Button BPM

Example LHC type: Measurement with movable 50 Ω matched antenna:

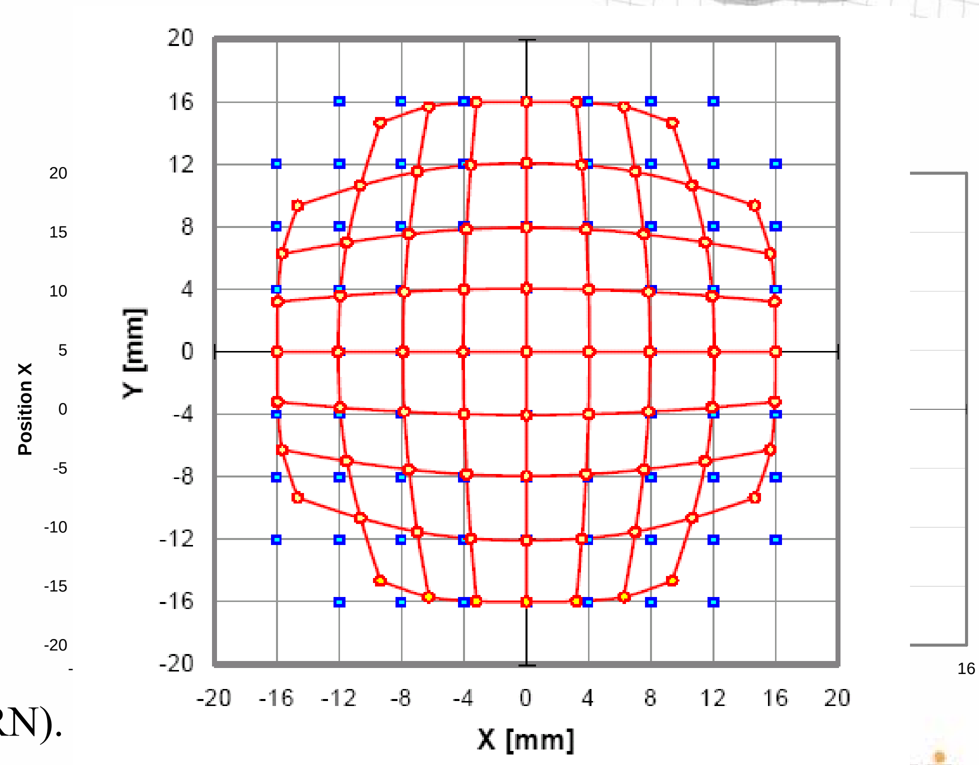




Non-linearity and

horizontal-vertical coupling

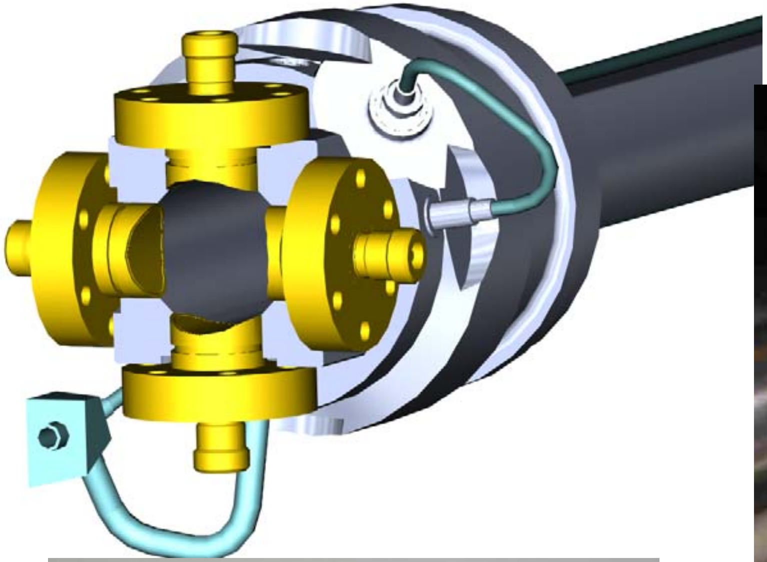
$\Rightarrow$ Polynomial fit with x and y dependence



From C. Boccard, C. Palau-Montava et al.(CERN).

Example LHC: ∅ 24 mm, half aperture a=25 mm, installed inside cryostat

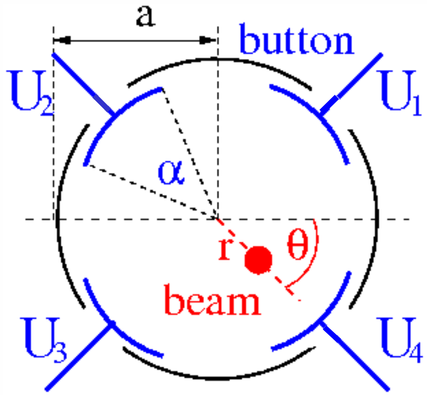
Critically: 50 Ω matching of button to standard feed-through.



From C. Boccard, C. Palau-Montava et al.(CERN).

The button BPM can be rotated by 45^0 to avoid exposure by synchrotron light:

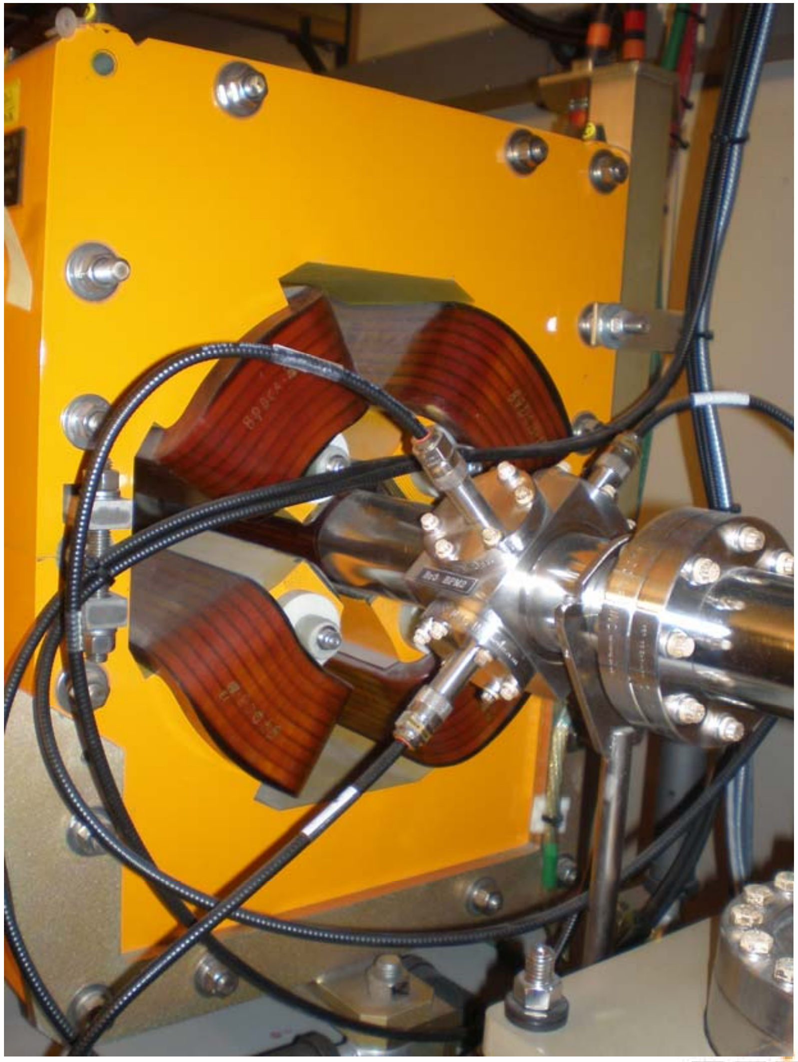
Frequently used at boosters for light sources



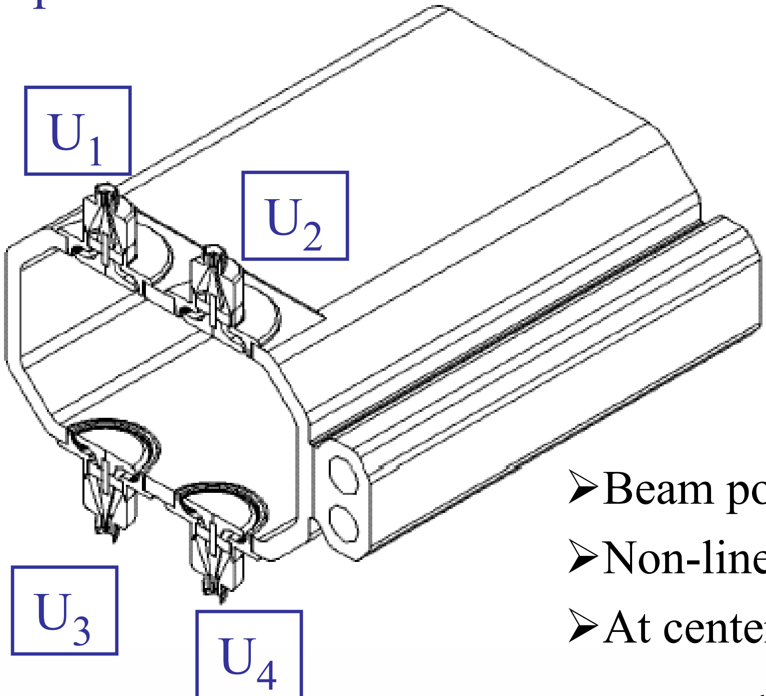
$$\text{horizontal}: x = \frac{1}{S} \cdot \frac{(U_1 + U_4) - (U_2 + U_3)}{U_1 + U_2 + U_3 + U_4}$$

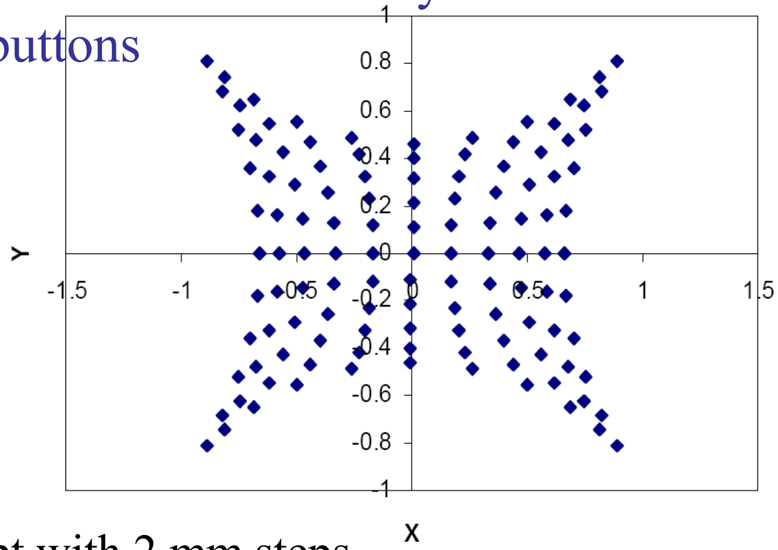
$$\text{vertical}: \quad y = \frac{1}{S} \cdot \frac{(U_1 + U_2) - (U_3 + U_4)}{U_1 + U_2 + U_3 + U_4}$$

Example: Booster of ALS, Berkeley



Due to synchrotron radiation, the button insulation might be destroyed
⇒buttons only in vertical plane possible ⇒ increased non-linearity
Optimization: horizontal distance and size of buttons





- Beam position swept with 2 mm steps
- Non-linear and inter-plane dependent sensitivity
- At center S_x=8.5%/mm in this case

$$\text{horizontal}: x = \frac{1}{S_x} \cdot \frac{(U_2+U_4)-(U_1+U_3)}{U_1+U_2+U_3+U_4}$$

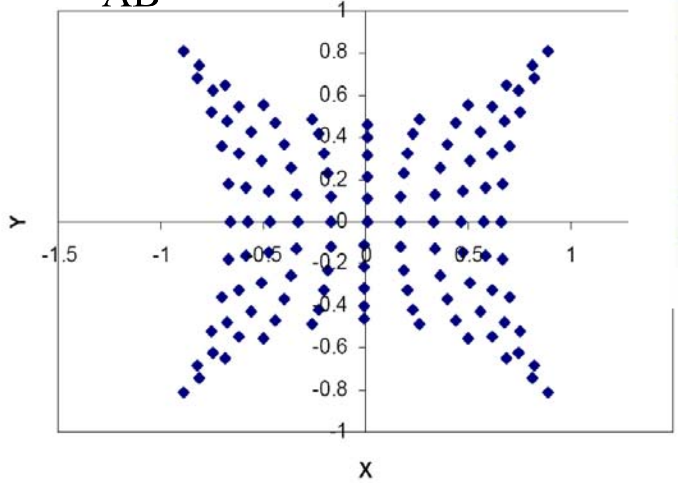
$$\text{vertical}: y = \frac{1}{S_y} \cdot \frac{(U_1+U_2)-(U_3+U_4)}{U_1+U_2+U_3+U_4}$$

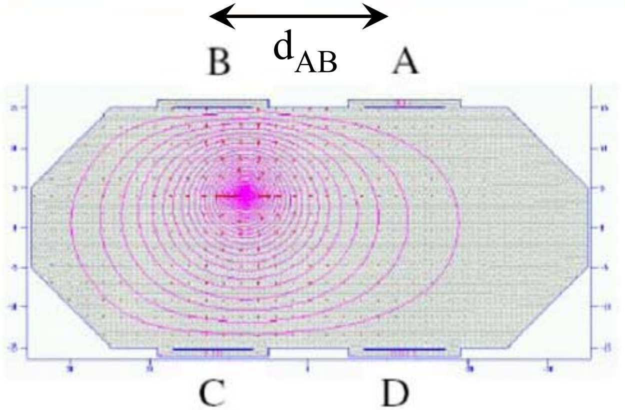
From S. Varnasseri, SESAME, DIPAC 2005

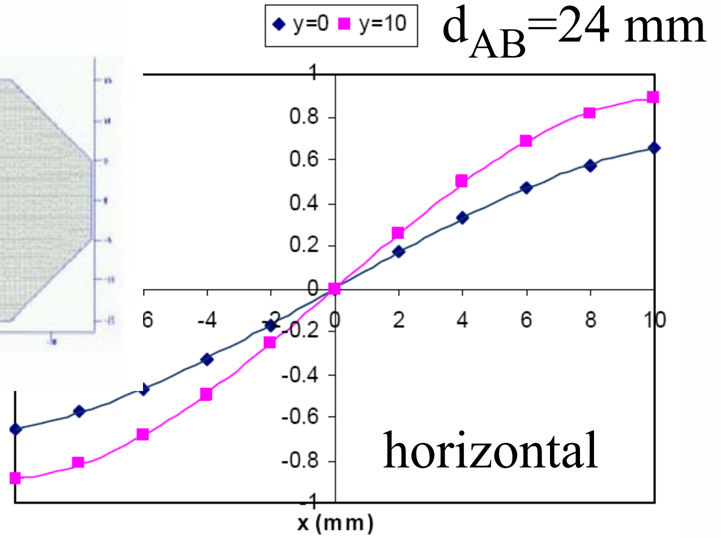
Button BPM at Synchrotron Light Sources

2-dim electro-static simulation:

d_{AB}=24 mm

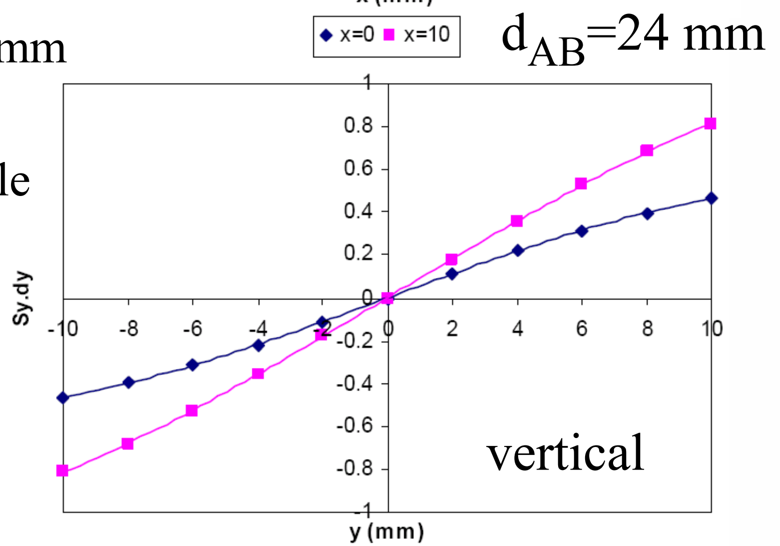






Result:

- Hori. S_x=8.5%/mm
- Vertical S_y=5.6%/mm
- x&y dependent polynomial fit possible



From S. Varnasseri, SESAME, DIPAC 2005

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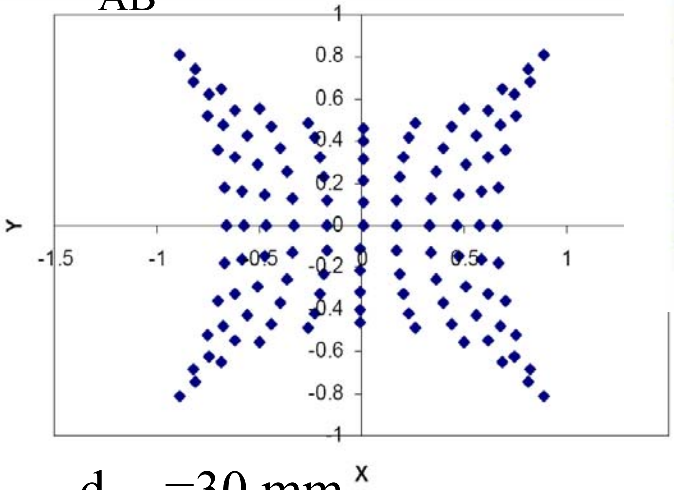
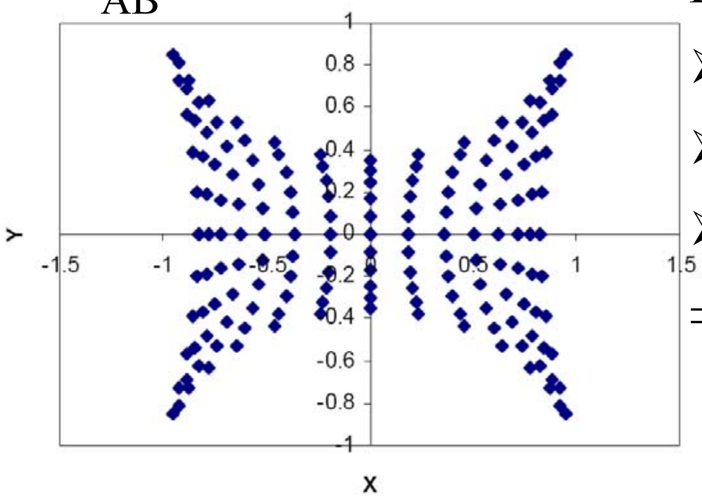
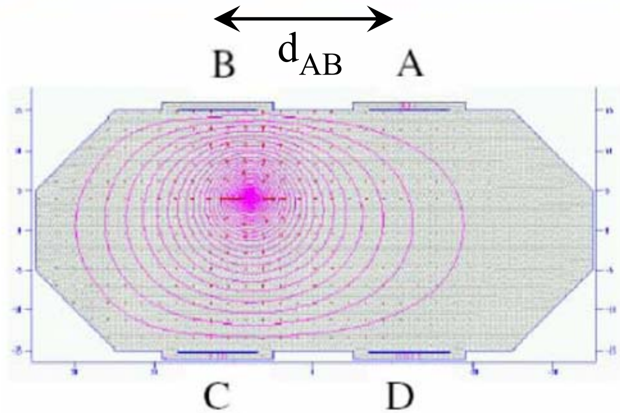
d_{AB}=24 mm



d_{AB}=30 mm



Beam position swept with 2 mm steps



Result:

Distance d_{AB} influences the sensitivity

Larger d_{AB} has the effect:

- higher sensitivity in x-direction
- lower sensitivity in y-direction
- linearity in influenced

⇒ Numerical optimization required

From S. Varnasseri, SESAME, DIPAC 2005

Comparison Shoe-Box and Button BPM

	Shoe-Box BPM	Button BPM
Precaution	Bunches longer than BPM	Bunch length comparable to BPM
Shape	Rectangular, cut cylinder	Orthogonal or in-plane orientation
BPM length (typical)	10 to 20 cm length per plane	∅1 to 3 cm per button
Bandwidth (typical)	0.1 to 100 MHz	100 MHz to 5 GHz
Coupling	1 MΩ or ≈1 kΩ (transformer)	50 Ω
Cutoff frequency (typical)	0.01… 10 MHz (C=30…100pF)	0.3… 1 GHz (C=2…10pF)
Linearity	Very good, no x-y coupling	Non-linear, x-y coupling
Sensitivity	Good, care: plate cross talk	Good, care signal matching
Usage	At (low energy) proton synchrotrons	All electron acc., proton Linacs, high energy synchrotrons