Tapered Transitions Dominating the PETRA III Impedance Model.

ICFA Mini-Workshop:

Electromagnetic Wake Fields and Impedances

in Particle Accelerators

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DESY

April 26, 2014

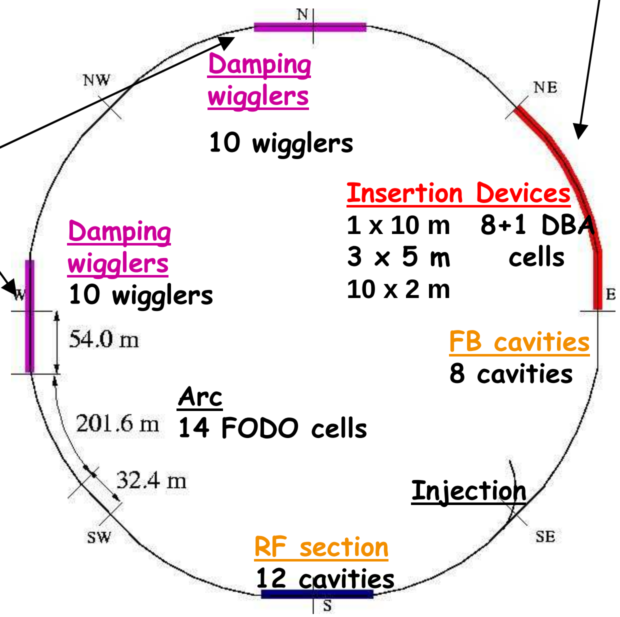
HELMHOLTZ ASSOCIATION

Outline

- PETRA III
- The Impedance Model
  - Kick and Lossparamerter
- Tapered Transitions
  - Modelling the tapered transitions
- Measurements
  - Intensity dependent tune shift
  - Intensity dependent betatron phase advance
- Conclusion

PETRA III - Overview

PETRA built in 1976
1978 to 1986, e- / e+ collider
PETRA II: 1988 to 2007
preaccelerator for the HERA
PETRA III
synchrotron light facility
2007 – 2008 (construction)
2009 – 2014 (operation)
2014 PETRA III extension



Circumference 2.3 km

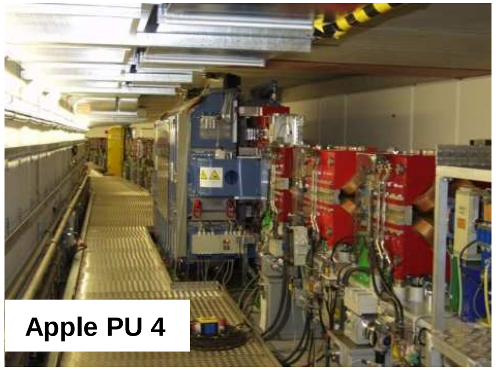
PETRA III Beamlines

Number	ID Type	Energy range (keV)
P01	10 m U32 (2 x 5 m)	5 – 40
P02	2 m U23	20 – 100
P03	2 m U29	8 – 25
P04	4 m UE65 (APPLE)	0.2 – 3.0
P05	2 m U29	8 – 50
P06	2 m U32	2.4 – 50
P07	4 m U19 (IV) (pres. 2m)	50 – 300
P08	2 m U29	5.4 – 30
P09	2 m U32	2.4 – 50
P10	5 m U29	4 – 25
P11	2 m U32	8 – 35
P12	2 m U29	4 - 20
P13	2 m U29	5 – 35
P14	2 m U29	5 - 35

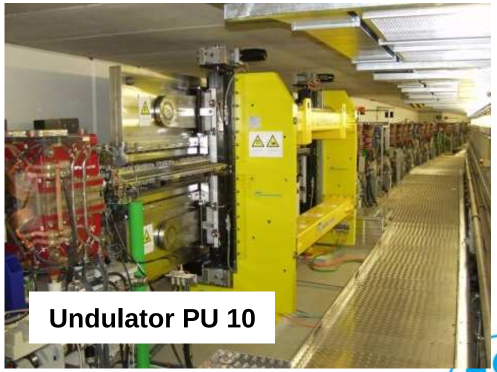
High β_x
Low β_x

Max von Laue Hall: 14 beam lines
8 DBA cells (length 23 m)

High beta: β_x = 20 m β_y = 4 m
Low beta : β_x = 1.4 m β_y = 4 m


Apple PU 4


Undulators PU 8 & PU 9


Undulator PU 10

DESY

PETRA III Extension (under construction)

12 New Beamlines

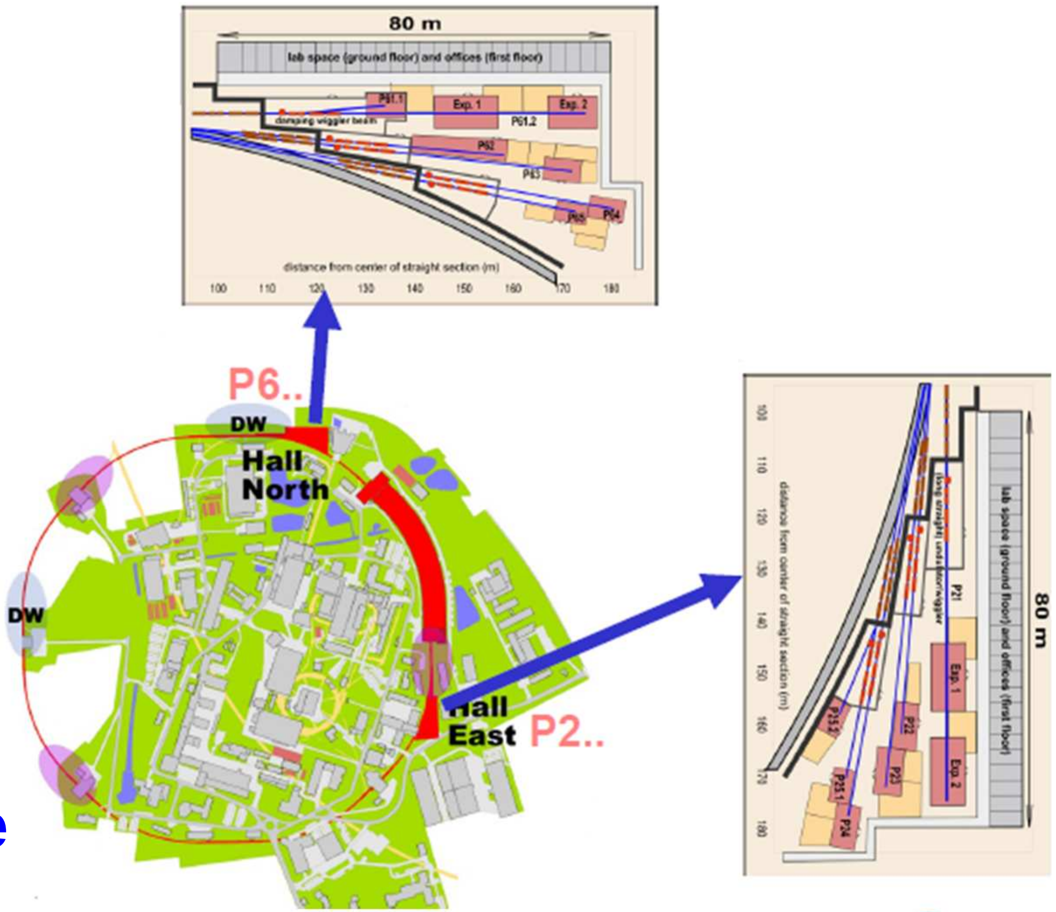
PETRA III: 14 + 12 = 26 Beamlines

North:
Damping Wiggler straigth
4 x new straight sections (2 m)
(2 DBA cells in the arc)
N - NE:
Dipole Radiation
East:
Long straigth section
room 2+1 Insertion devices
4 x new straight sections (2 m)
(2 DBA cells in the arc)

Web page:

petra3-extension.desy.de

with webcam of the construction sides



Impedance Model - Collaboration

Collaboration:

Contributions to the **ICFA Beam Dynamics Newsletter 45, April 2008**

E. Gjonaj, T. Lau, T. Weiland (**TEMF, Technische Universität Darmstadt**),
Computation of short range wake fields with PBCI,

M. Ivanyan, E. Laziev, V. Tsakanov, A. Vardanyan, (**CANDLE, Yerevan, Armenia**),
A. Tsakanian, (**Universität Hamburg**),
PETRA III storage ring resistive wall impedance,

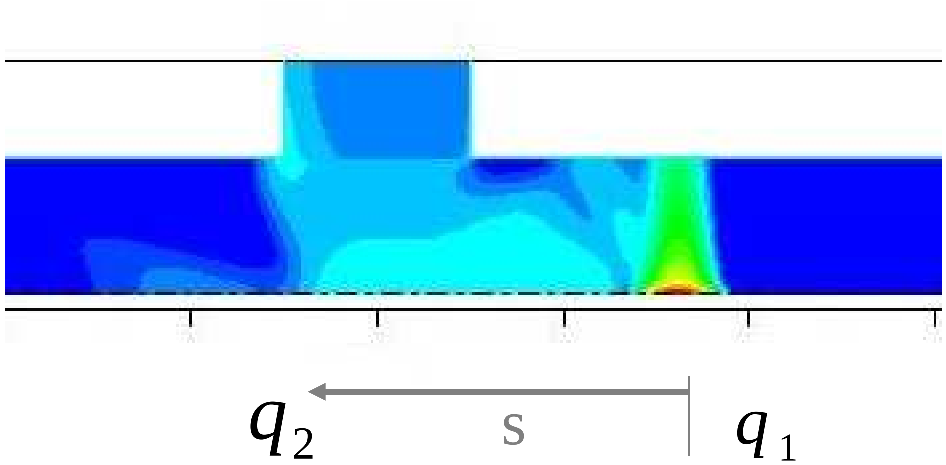
V. Smaluk (**Novosibirks, BINP**)
Geometrical impedance of the PETRA III damping wiggler section,

A.K. Bandyopadhyay, A. Jöstingmeier, A.S. Omar (**Otto-Von-Guericke University, Magdeburg**),
Wake computations for selected components of PETRA III

K. Balewski, R. Wanzenberg, O. Zagorodnova (**DESY**)
The Impedance Model of PETRA III

Wake Potential and Loss Parameter

$$W_z(s) = \frac{1}{q_1}\int dz \;\; E_z(r, z, t = (s+z)/c)$$



Equation of motion:

Bunch q_1 $z = c\,t$

Witness charge q_2 $z = c\,t - s$

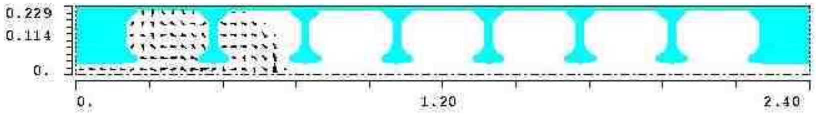
Lossparameter:

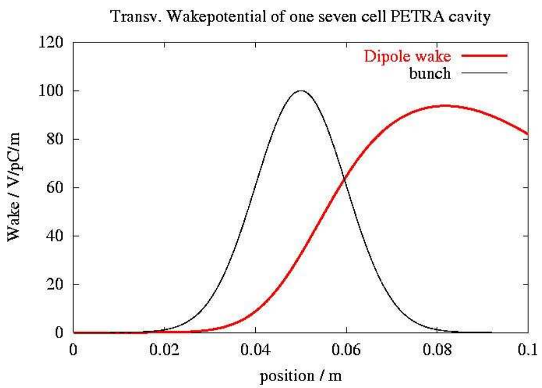
$$k_{loss} = \int_{-\infty}^{+\infty} ds \;\; \lambda(s) \;\; W(s)$$

$$\lambda(s) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{s}{\sigma}\right)^2\right)$$

Transverse Wake and Kick Parameter

Transverse Wake Potential:





k_{loss} (V/pC)	$k_{\perp}$ (V/ pC m)
-3.8	35.8

The kick parameter is related to the tune shift:

Kick Parameter:

$$k_{\perp} = \int ds \;\; W_{\perp}(s)\, \lambda(s)$$

$$\Delta Q_{\beta} = \frac{I_B \langle \beta \rangle T_0}{4\pi E / e} k_{\perp}$$

Impedance – Model and Budget

Impedance Model,
ICFA Beam Dynamics Newsletter 45, April 2008

Kick parameter:

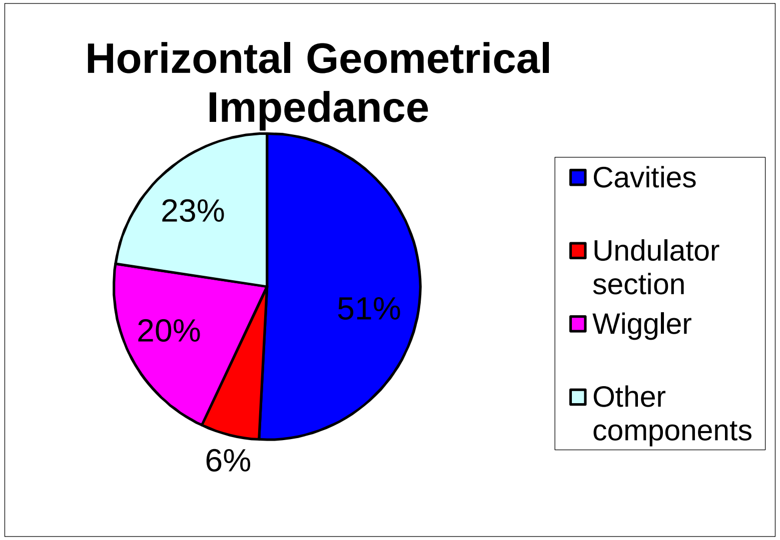
$$k_\perp = \int ds \; W_\perp(s)\, \lambda(s)$$

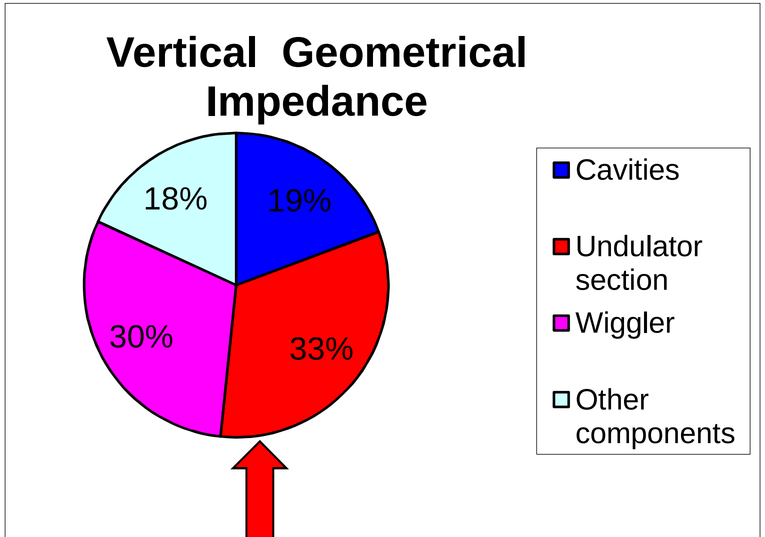
$$k_\perp = \frac{1}{2\pi}\,\frac{\sqrt{\pi}}{\sigma_z/c}\,Z_\perp^{\rm eff} = 7.05\,\frac{\rm V}{\rm pC\,m}\,\frac{Z_\perp^{\rm eff}}{{\rm k\Omega/m}}$$

PETRA III (reference beta 20 m)	$k_\perp$ (V/ pC/ m) Horz.	$k_\perp$ (V/ pC/ m) Vert.
Budget (2.5mA)	4800	4800
Impedance model	**750**	**2610**

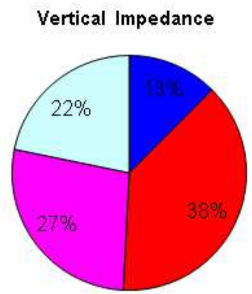
Effective Impedance:

Horz. 106 kΩ/m Vert. 370 kΩ/m





With resistive Wall wakes:



Large Contribution from tapered transitions

Predicted tune shifts

$$Q_s = 0.049$$

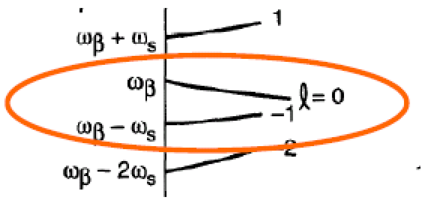
$$Q_s \; f_0 = 6.4 \;\text{kHz}$$

PETRA III	$k_\perp$ (V/ pC/ m) Horz.	$k_\perp$ (V/ pC/ m) Vert.
Budget (2.5mA)	4800	4800
Impedance model	**750**	**2610**

$$\Delta f_\beta = \frac{I_B}{4\pi E/e} \langle\beta\rangle \, k_\perp$$

weighted sum
ref. beta: 20 m

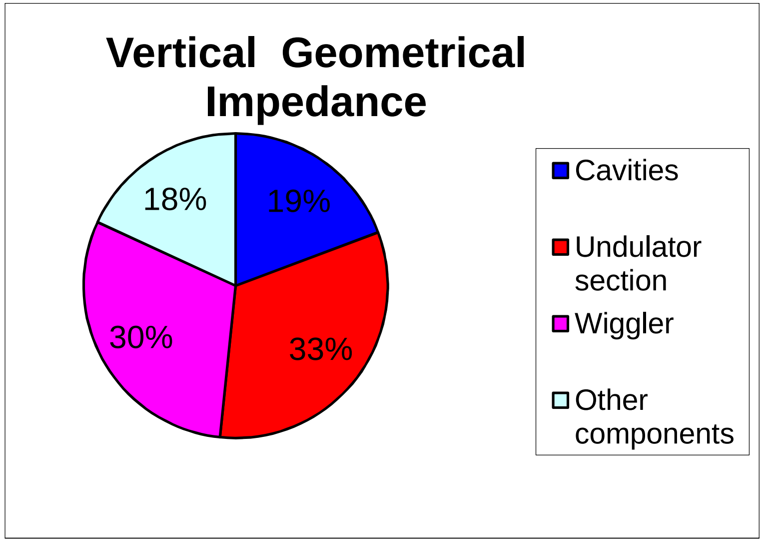
PETRA III	**Δf/ΔI (kHz / mA) Horz.**	**Δf/ΔI (kHz/mA) Vert.**
Budget (2.5mA)	1.28	1.28
Impedance model	**0.2**	**0.7**

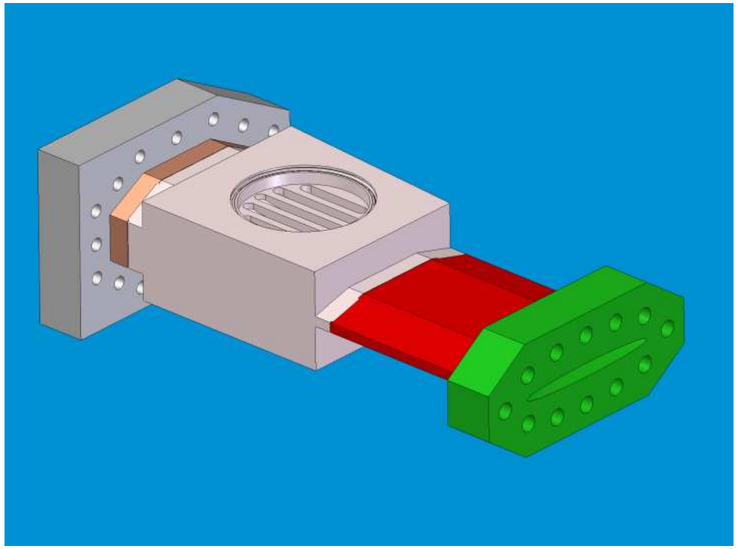


$$\frac{Q_s \; f_0}{2} \frac{1}{2.5 \;\text{mA}} = 1.28 \;\frac{\text{kHz}}{\text{mA}} \qquad \frac{Q_s}{2} \frac{1}{2.5 \;\text{mA}} = 0.01 \;\frac{1}{\text{mA}}$$

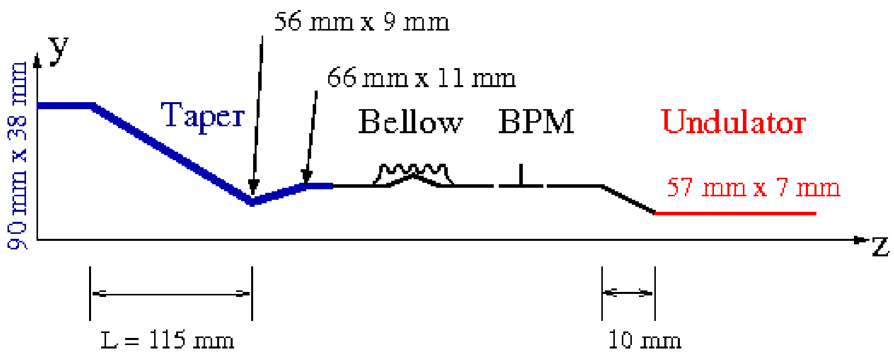
mode coupling: **m=1, l=0, l=-1**
longit. / traansverse mode number l, m
(radial modes are ignored)

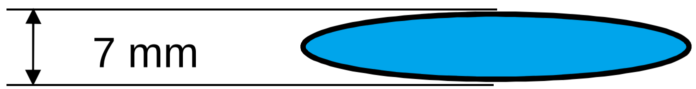
Tapered Transition



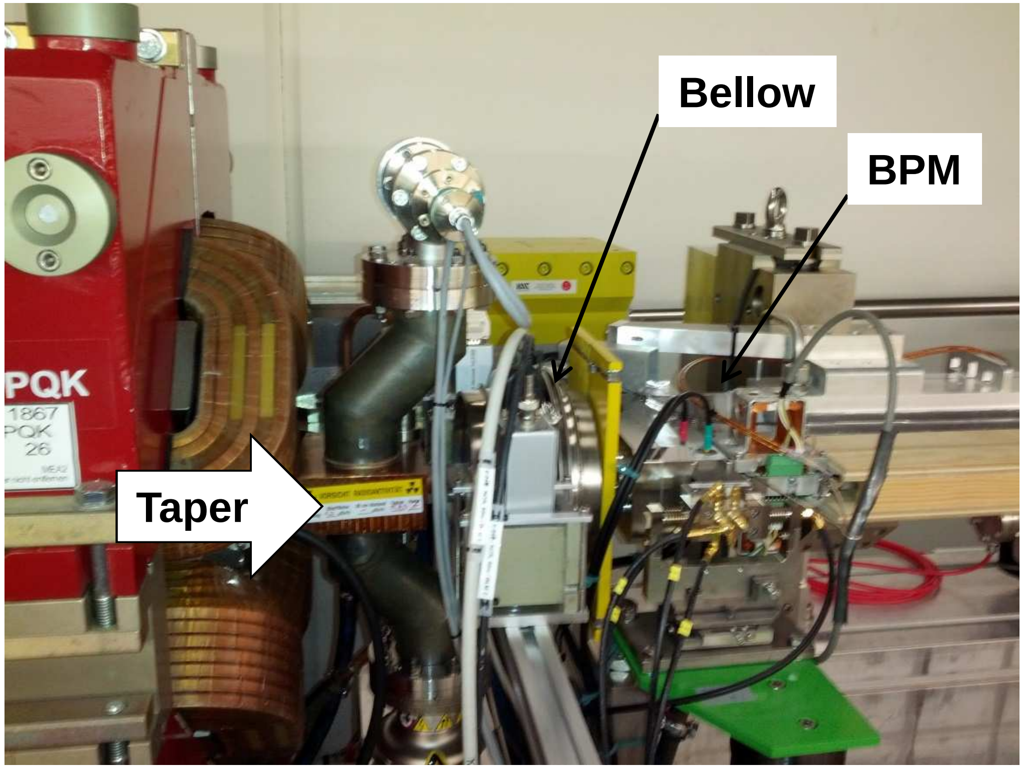


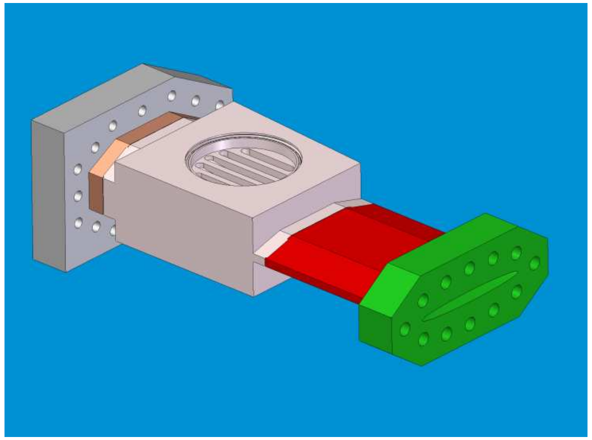
Transition from a 90 mm x 38 mm chamber to a small gap chamber 57 mm x 7 mm



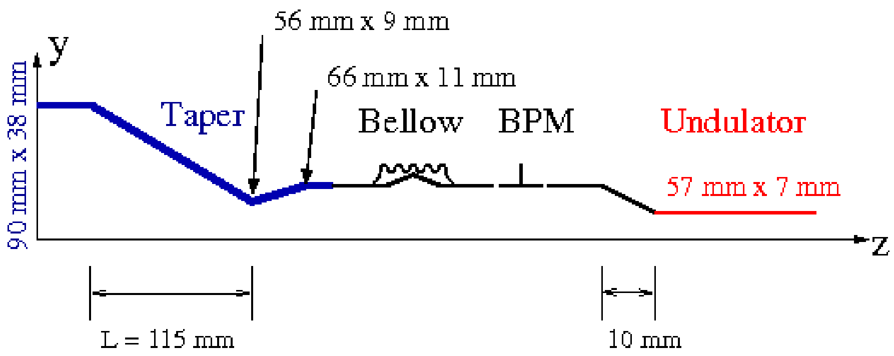


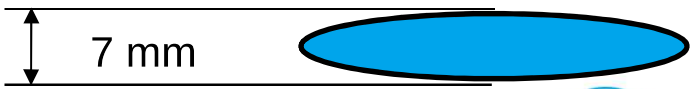
Tapered Transition (cont.)



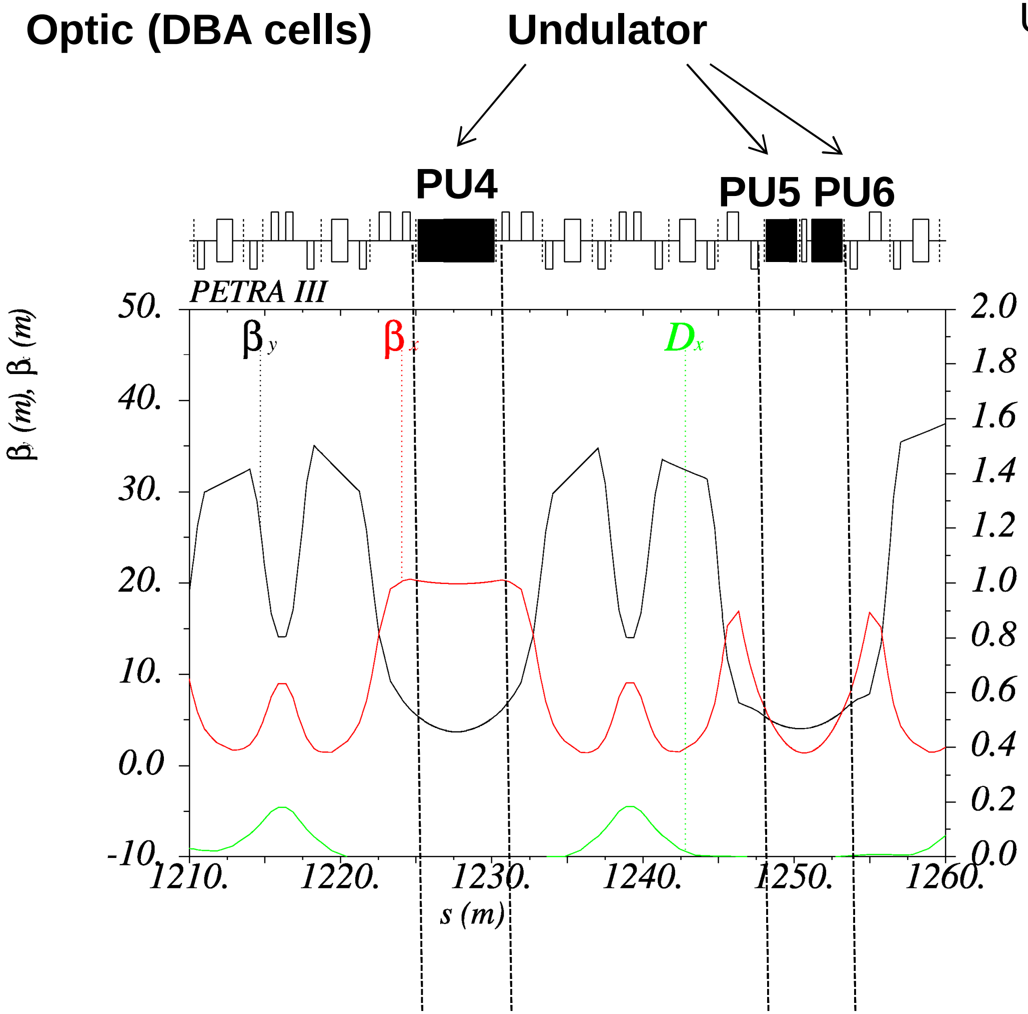


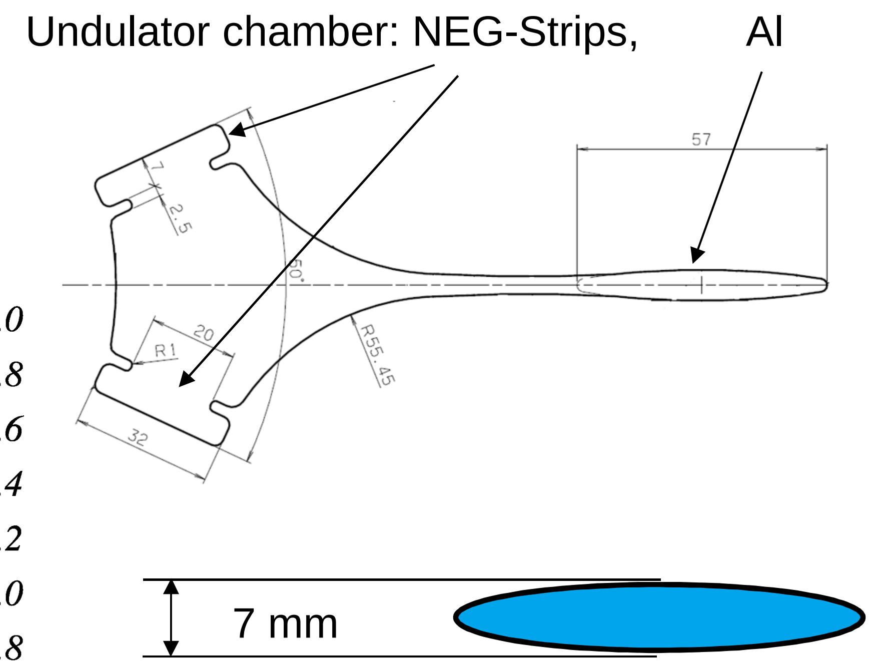
Transition from a 90 mm x 38 mm chamber to a small gap chamber 57 mm x 7 mm





PETRA III – Insertion devices





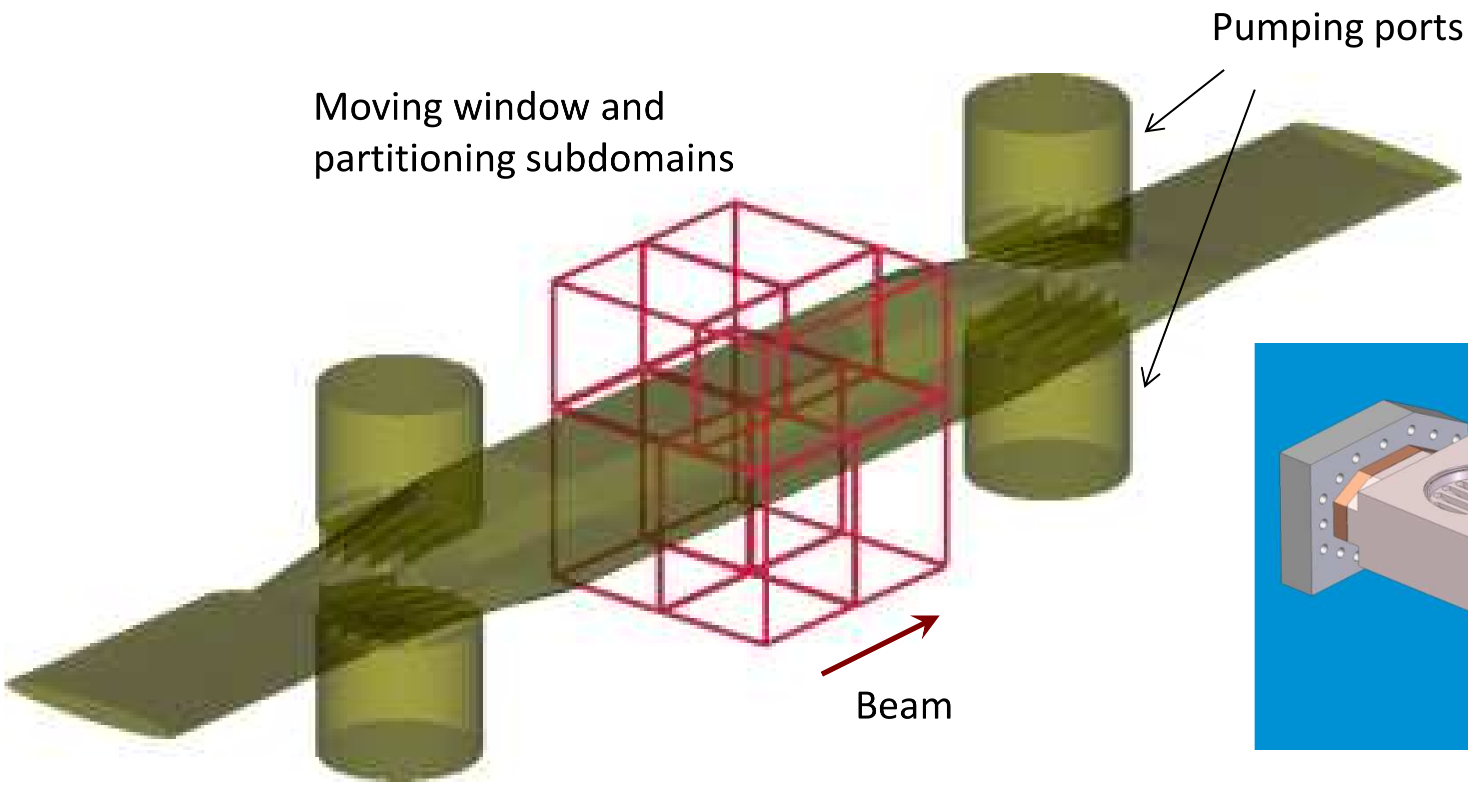
Rms beam size:
Horz. 40 … 140 μm
Vert. 6 μm (0.1 % coupling)

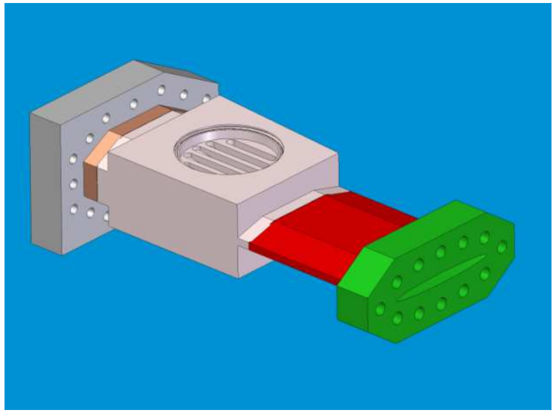
Tapered Transitions before and after each 5 m long straigth section !

16 transitions (8 DBA cells) + 2 additional transitions

Modelling the tapered transitions with CST studio / PBCI

Wakefield Calculation with the
Parallel Beam Cavity Interaction (PBCI) code





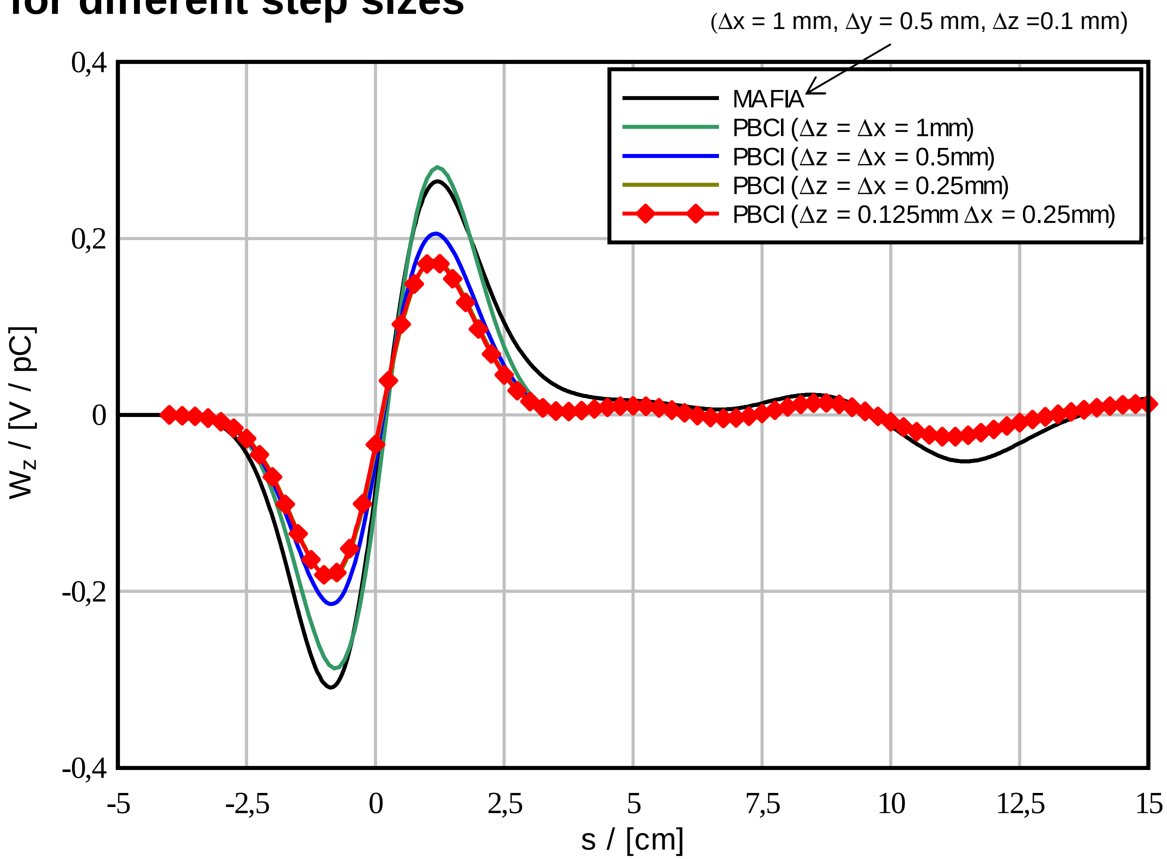
(total length of the modeled structure ~ 1 m, rms bunch length 1 cm)

Erion Gjonaj, Thomas Lau, Thomas Weiland,
Technical University of Darmstadt
Computation of Short Range Wake Fields with PBCI
ICFA Beam Dynamics Newsletter No. 45, 2008

Wakefield of the Tapered Transition

The wake potentials of the tapered transition have been calculated for different mesh resolutions. A convergent result was obtained in PBCI using a discretization with $\Delta x = \Delta y = \Delta z = 0.25\text{mm}$

Longitudinal Wakepotential (rms bunch length 1 cm) for different step sizes



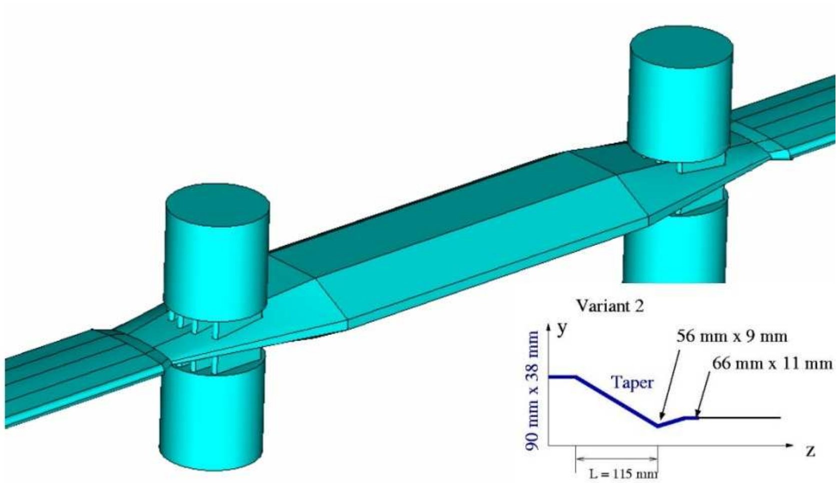
Structure length ~ 1 m

comparably long
Bunch (rms length) 1 cm

But a convergent result required a mesh step size of 0.25 mm

Therefore one needs a large computual mesh for this Complex 3D structure

Kick parameter of the tapered transition

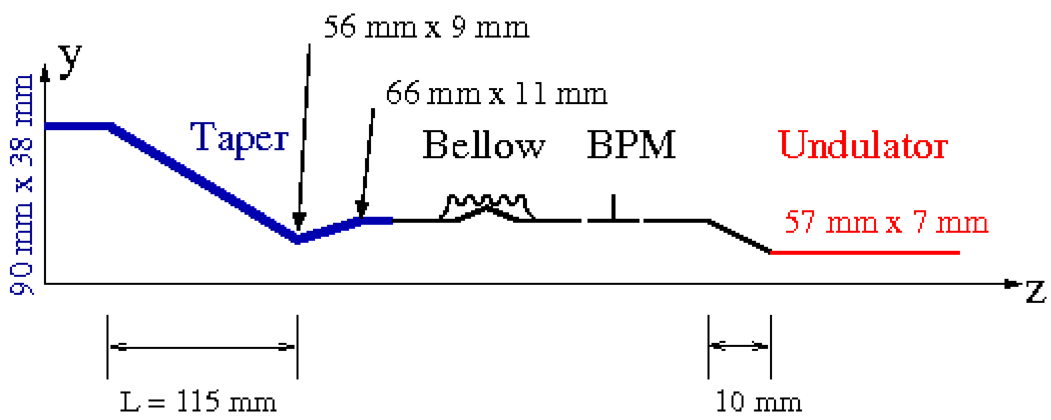


Loss and Kick Parameters of the Tapered Transition.

Code	$k_{\|\|}$ / (V/nC)	$k_{\perp}$ ***/ (V/pC)***
Variant 1 / MAFIA	-7.4	138.6
Variant 1 / PBCI	-7.1	75.6
Variant 2 / PBCI	-5.2	**62.8**

Variant 2 was implemented

(Variant 1 differs from Variant 2 with respect of the second taper 9 mm → 11 mm)



(The bellow, the BPM and the second short taper are included in the impedance model, but not in the kick of 62.8 V/pC)

Measurements

- **Intensity dependent tune shift (global measurement)**
- **Intensity dependent betatron phase advance (local measurement)**

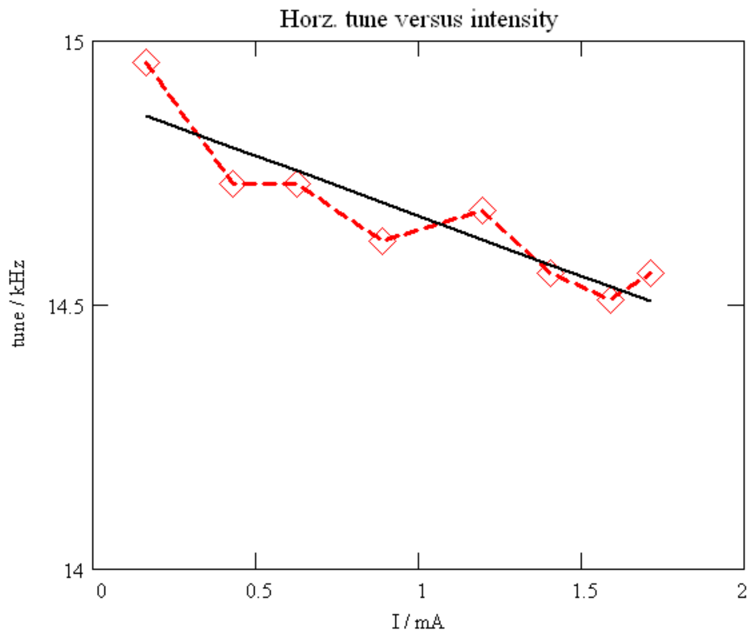
Remember the prediction from the impedance model:

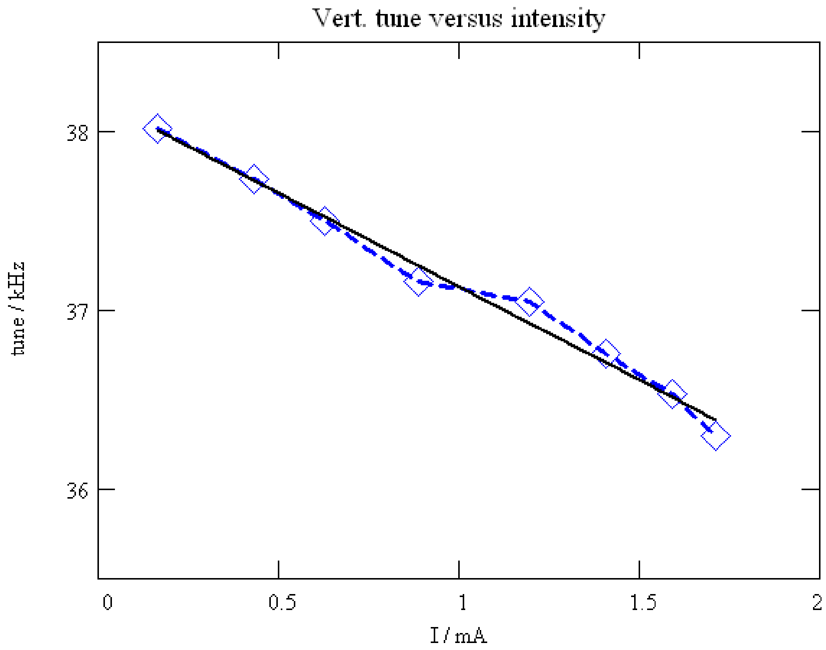
PETRA III	Δf/ΔI (kHz / mA) Horz.	Δf/ΔI (kHz/mA) Vert.
Budget (2.5mA)	1.28	1.28
Impedance model	**0.2**	**0.7**

$$\Delta f_{\beta} = \frac{I_{\mathrm{B}}}{4\pi E / e} \langle \beta \rangle \, k_{\perp}$$

Measurement, Aug 14, 2009

Horz. and Vert. tune versus single bunch current (positron beam)





$$\frac{\Delta f_x}{\Delta I} = -0.228 \frac{\text{kHz}}{\text{mA}}$$ **(0.2 kHz/mA)**

$$\frac{\Delta f_y}{\Delta I} = -1.046 \frac{\text{kHz}}{\text{mA}}$$ **(0.7 kHz/mA)**

(Revolution frequency 130 kHz, Δf = 1 kHz => Δq = 0.008)

⇒Kick parameter : horz. 860 V/pC/m vert. 3950 V/pC/m

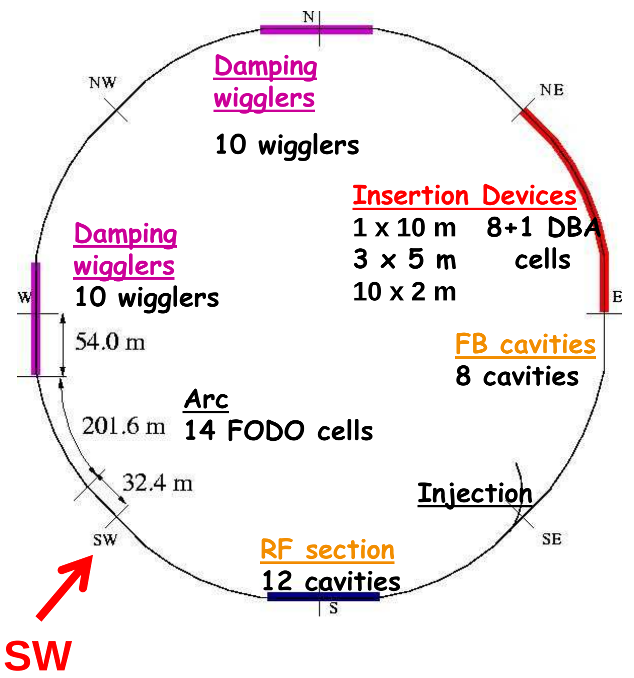
reference: 20 m beta function

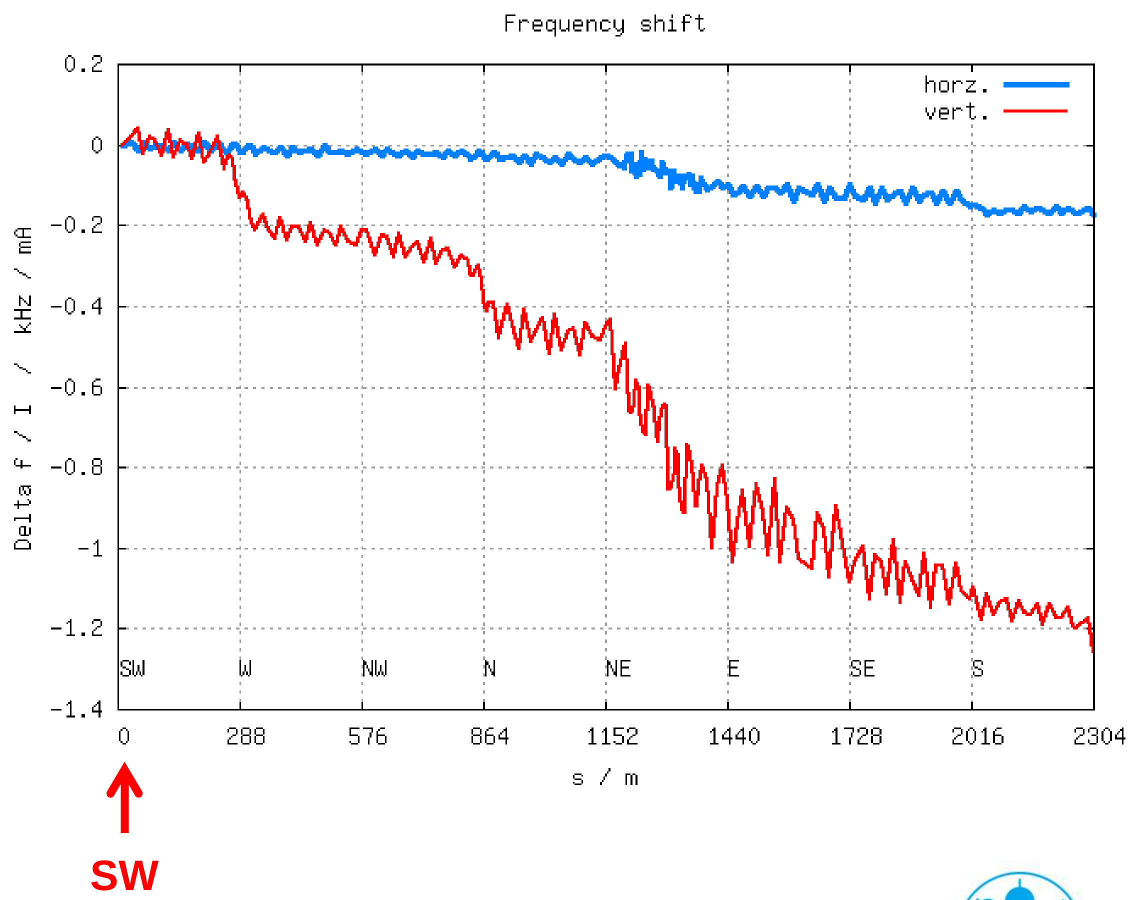
(measured fs = 5.2 kHz, ~ 15 MV total voltage)

Intensity Dependent Betatron Phase Advance

The betatron phase advanced is obtained from orbit response measurements (ORM).

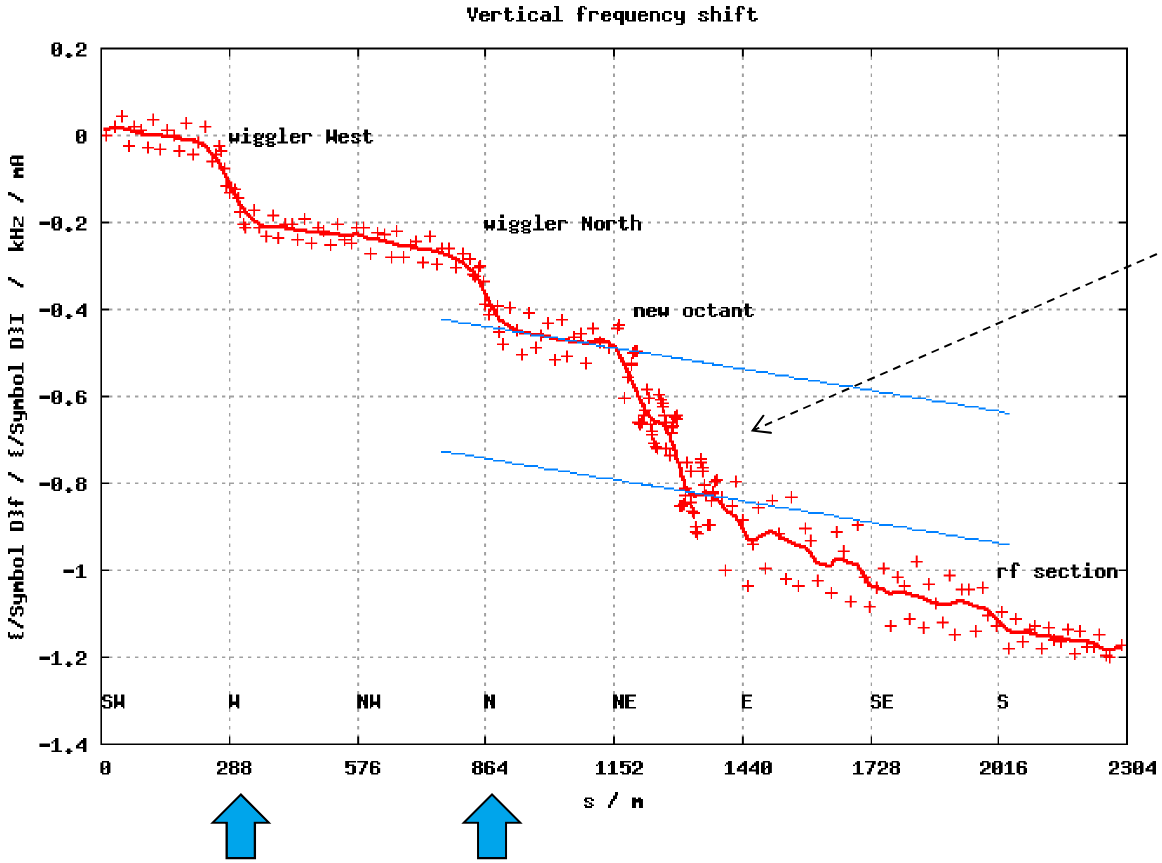
1) **Total current 20 mA, 240 Bunches**
2) **20 mA, 10 Bunches**
3) **Compare the results from step 1) and 2) and translate the data into a frequency shift**





J. Keil, Analysis of ORM Data

Intensity Dependent Betatron Phase Advance (cont.)



Analysis of the vertical data:

Between the blue lines: New Octant with Tapered Transition

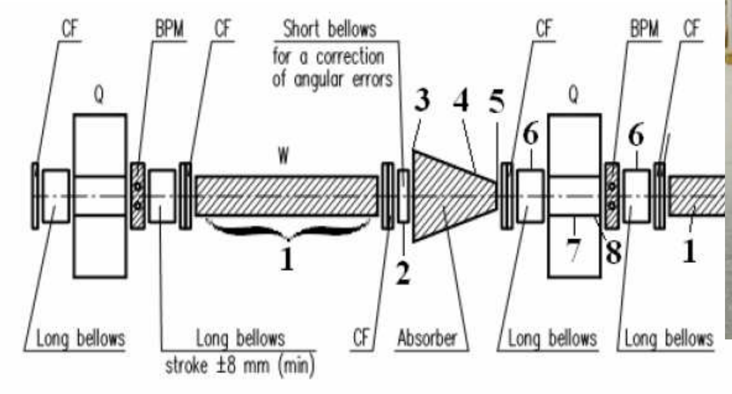
Measured local tune Shift: -0.325 kHz / mA

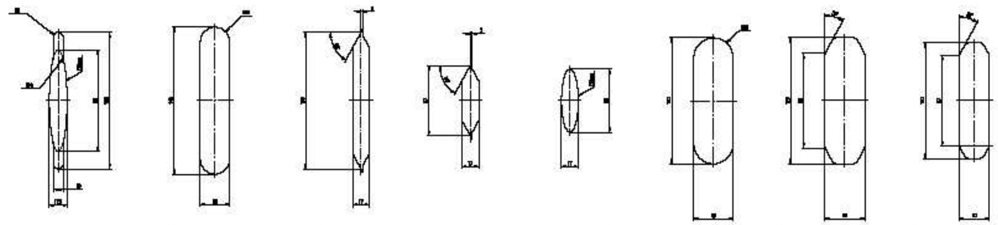
Impedance model -0.265 kHz / mA

There are two section with 2 x 10 damping wigglers (4 m long) which also contribute significantly to the impedance budget. (-0.175 kHz / mA for one section)
There are small gap chambers and several synchrotron light absorber blocks.

Wiggler Section

Absorber: 9 mm und 17 mm gap





1 2 3 4 5 6 7 8

Wake field calculations: V. Smaluk, BINP, Novosibirsk

Summary

Impedance model $\frac{\Delta f_x}{\Delta I} = -0.2\ \frac{\text{kHz}}{\text{mA}}$ $\frac{\Delta f_y}{\Delta I} = -0.7\ \frac{\text{kHz}}{\text{mA}}$

Impedance budget $\frac{\Delta f_{x,y}}{\Delta I} = -1.28\ \frac{\text{kHz}}{\text{mA}}$

Measurements PETRA III

Aug 14, 2009 $\frac{\Delta f_x}{\Delta I} = -0.228\ \frac{\text{kHz}}{\text{mA}}$ $\frac{\Delta f_y}{\Delta I} = -1.046\ \frac{\text{kHz}}{\text{mA}}$

Oct 21, 2010, ORM based $\frac{\Delta f_x}{\Delta I} = -0.17\ \frac{\text{kHz}}{\text{mA}}$ $\frac{\Delta f_y}{\Delta I} = -1.2\ \frac{\text{kHz}}{\text{mA}}$

Oct 10, 2012 $\frac{\Delta f_x}{\Delta I} = -0.26\ \frac{\text{kHz}}{\text{mA}}$ $\frac{\Delta f_y}{\Delta I} = -1.24\ \frac{\text{kHz}}{\text{mA}}$

In Oct. 2010 and Oct. 2012 the measued vertical tune shift is 0.2 kHz larger than in Aug 2009 !

Conclusion

- The tapered transition of the small gap undulator chambers dominate the (vert.) impedance of the PETRA III
- But the contribution from the two wiggler sections together is even a bit larger
- The horz. impedance model is in very good agreement with the Measurements
- The vert. impedance model differs noticeably from the measurements (factor 1.48 … 1.77), but the is within the impedance budget.
- The results for the kick parameters of the tapered transitions depend on the step size of the mesh
- There is a not understood differrence between the measured tune shift from 2009 and 2010
  (change of the resitivity of the NEG coating in the Wiggler chambers ?)

Thank you for your attention !