Impedance Budget Database

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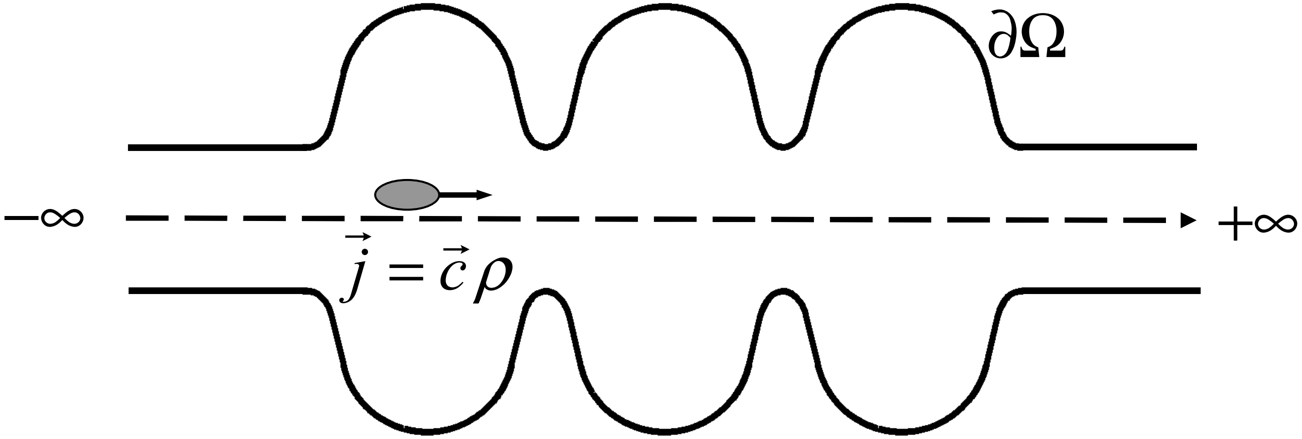
14.04.08

BD meeting, DESY

Wake field calculation – estimation of the effect of the geometry variations on the bunch



Maxwell's Equations

$$\nabla \times \mathbf{E} = -\frac{\partial}{\partial t}\mathbf{B}, \qquad \nabla \cdot \mathbf{B} = 0,$$

$$\nabla \times \mathbf{H} = \frac{\partial}{\partial t}\mathbf{D} + \mathbf{j}, \qquad \nabla \cdot \mathbf{D} = \rho,$$

$$\mathbf{H} = \mu^{-1}\mathbf{B}, \qquad \mathbf{D} = \varepsilon\mathbf{E},$$

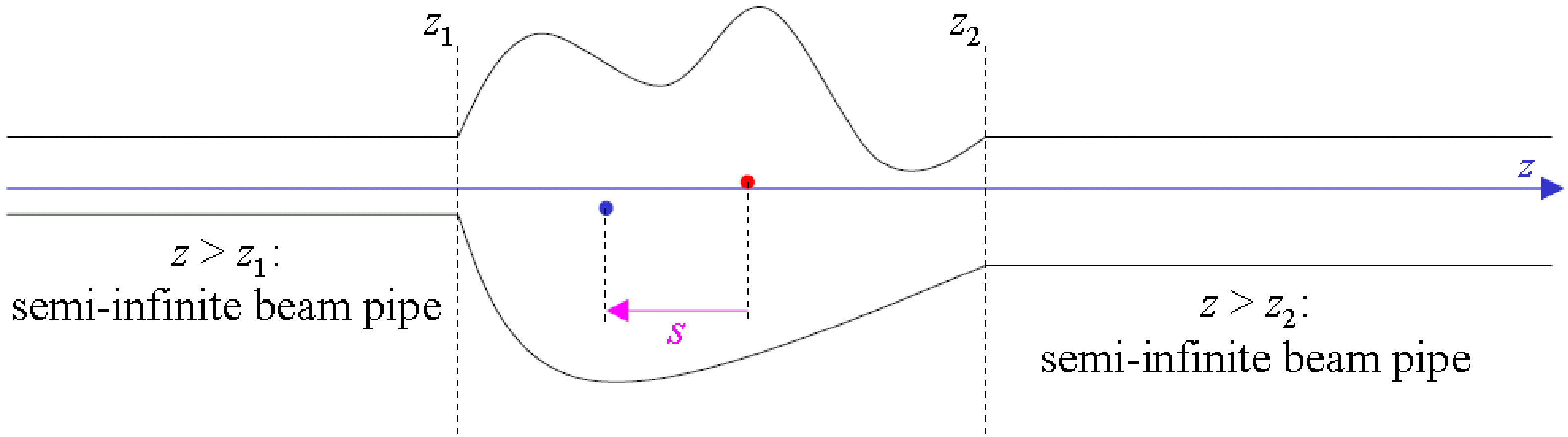
$$\mathbf{n} \times \mathbf{E} = 0 \quad on \quad \Omega$$

First codes in time domain
~ 1980
A. Novokhatski (BINP),
T. Weiland (CERN)

Used at DESY now:
MAFIA, ABCI,
CST Microwave Studio,
ECHO

wake fields and impedances

much more: Weiland, Wanzenberg DESY M-91-06



source particle q_s: $\mathbf{r}_s(t) = x_s \mathbf{u}_x + y_s \mathbf{u}_y + c(t - t_0)\mathbf{u}_z$

test particle q_t: $\mathbf{r}_t(t) = x_t \mathbf{u}_x + y_t \mathbf{u}_y + \left(c(t - t_0) - s\right)\mathbf{u}_z$

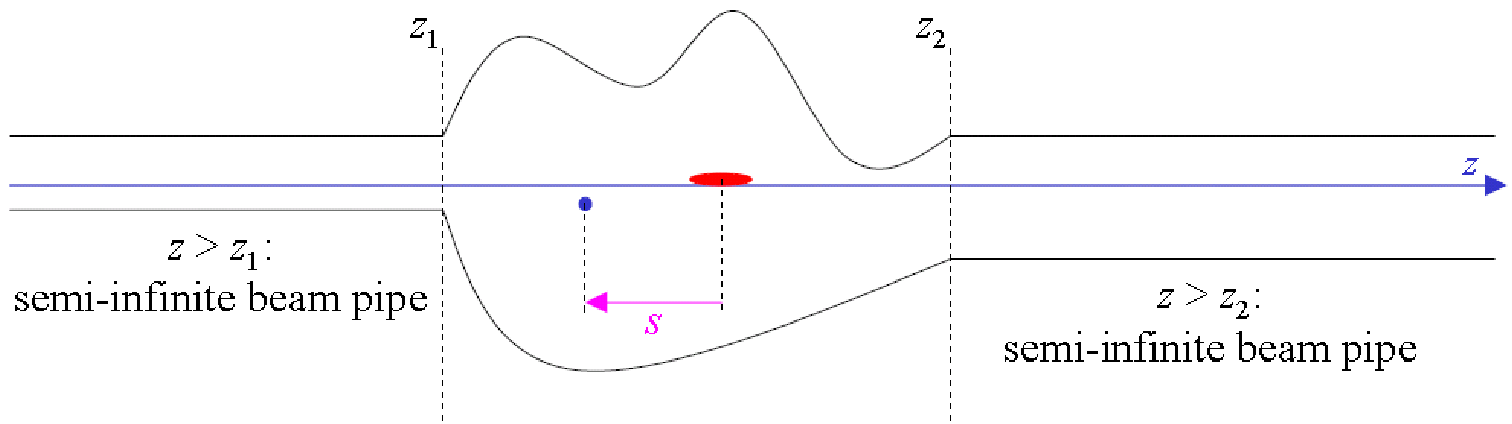
wake function: $\mathbf{W}(x_s, y_s, x_t, y_t, s) = \dfrac{1}{q_s} \int_{-\infty}^{\infty} (\mathbf{E} + \mathbf{v} \times \mathbf{B})\, dz \quad \rightarrow \Delta\mathbf{p} = q_s q_t \mathbf{W}$

impedance: $Z_{\parallel}(x_s, y_s, x_t, y_t, \omega) = c^{-1} \int_{-\infty}^{\infty} \left(W_{\parallel}(x_s, y_s, x_t, y_t, s) \exp(-j\, s\omega/c)\right) ds$

$$Z_{\perp}(x_s, y_s, x_t, y_t, \omega) = -jc^{-1} \int_{-\infty}^{\infty} \left(W_{\perp}(x_s, y_s, x_t, y_t, s) \exp(-j\, s\omega/c)\right) ds$$

http://www.desy.de/~dohlus/2004/2004.09.holgers_seminar/asym&kick_sep2004.pdf

wake potential



source particle → source distribution

$$W_{||}(s) = -\int_{-\infty}^{s} w_{||}(s - s')\lambda(s')ds'$$

wake (Green) function

Motivation

$$W_{||}(s) = -\int_{-\infty}^{s} w_{||}(s-s')\lambda(s')ds'$$

wake potential

wake (Green) function

If we know wake function then we can calculate wake potential
for any bunch shape. For beam dynamics simulations we need the wake function.

The numerical codes can calculate only wake potentials
(usually the Gaussian bunch shape for relatively large rms width is used).
But the real bunch shape is far not Gaussian one.

How to obtain the wake function?

Motivation

$$W_{||}(s) = -\int_{-\infty}^{s} w_{||}(s-s')\lambda(s')ds'$$

wake potential

wake (Green) function

How to obtain the wake function?
The deconvolution is bad poised operation and does not help.

Well developed analytical estimation for short-range wake functions of different geometries are available.
Hence we can fit our numerical results to an analytical model and define free parameters of the model.

Such approach is used, for example, in

A. **Novokhatsky**, M. **Timm**, and T. **Weiland**, Single bunch energy spread in. the **TESLA** cryomodule, Tech. Rep. DESY-**TESLA**-99-16

T. **Weiland**, I. **Zagorodnov,** The Short-Range Transverse Wake Function for **TESLA** Accelerating Structure, DESY-TESLA-03-23

Motivation

There are hundreds of wakefield sources in XFEL beam line.

The bunch shape changes along the beam line.

Hence, a database with wake functions for all element is required.

The wake functions are not functions but distributions (generalized functions).

How to keep information about such functions?

We need a model.

Wake function model

$$w(s) = \underbrace{w^{(0)}(s) + \frac{1}{C}}_{\text{regular part}} + \underbrace{Rc\delta(s) - c\frac{\partial}{\partial s}\left[Lc\delta(s) + w^{(-1)}(s)\right]}_{\text{singular part (cannot be tabulated directly)}}$$

regular part

singular part
(cannot be tabulated directly)

$$Z(\omega) = Z^{(0)}(\omega) - \frac{1}{i\omega C} + R + i\omega\left[L + Z^{(-1)}(\omega)\right]$$

capacitive: $W \sim \int \lambda(s)ds$

resistive: $W \sim \lambda(s)$

inductive: $W \sim \lambda'(s)$

$$\frac{\partial}{\partial s} w^{(-1)}(s) = o(s^{-1}), \qquad s \to 0.$$

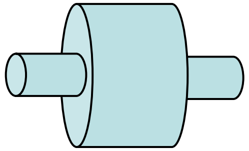
it describes singularities $s^{-\alpha}$, $\alpha<1$

Examples

$$w(s) = w^{(0)}(s) + \frac{1}{C} + Rc\delta(s) - c\frac{\partial}{\partial s}\left[Lc\delta(s) + w^{(-1)}(s)\right]$$

Pillbox Cavity

$$w(s) = \frac{Z_0 c}{\sqrt{2}\pi^2 a}\sqrt{\frac{g}{s}}$$

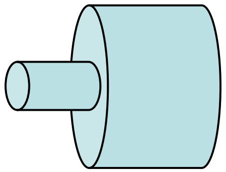


$$w^{(-1)}(s) = -\frac{Z_0}{\sqrt{2}\pi^2 a}\sqrt{sg}$$

Step-out transition

$$w(s) = c\frac{Z_0}{\pi}\ln\left(\frac{b}{a}\right)\delta(s)$$

$$w(s) = cR\delta(s)$$

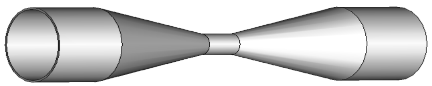


$$R = \frac{Z_0}{\pi}\ln\left(\frac{b}{a}\right)$$

Tapered collimator

$$w(s) = -c^2\left(\frac{Z_0}{4\pi c}\int r'dr\right)\frac{\partial}{\partial s}\delta(s)$$

$$w(s) = -c^2 L\frac{\partial}{\partial s}\delta(s)$$



$$L = \frac{Z_0}{4\pi c}\int r'dr$$

Wake potential for arbitrary bunch shape

$$W(s) = -\int_{-\infty}^{s} w^{(0)}(s-s')\lambda(s')ds' - \frac{1}{C}\int_{-\infty}^{s} \lambda(s')ds' - Rc\lambda(s) -$$

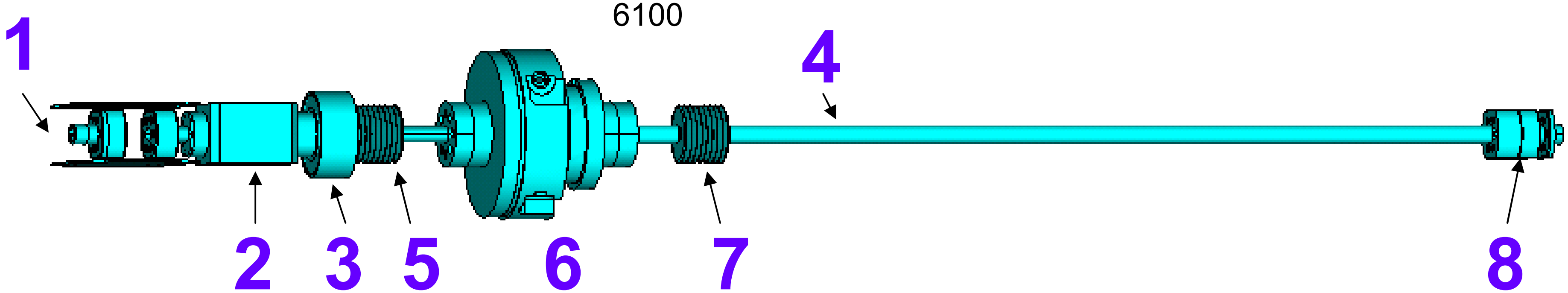
$$-c^2 L\lambda'(s) - c\int_{-\infty}^{s} w^{(-1)}(s-s')\lambda'(s)ds'$$

derivative of the bunch shape

Undulator intersection

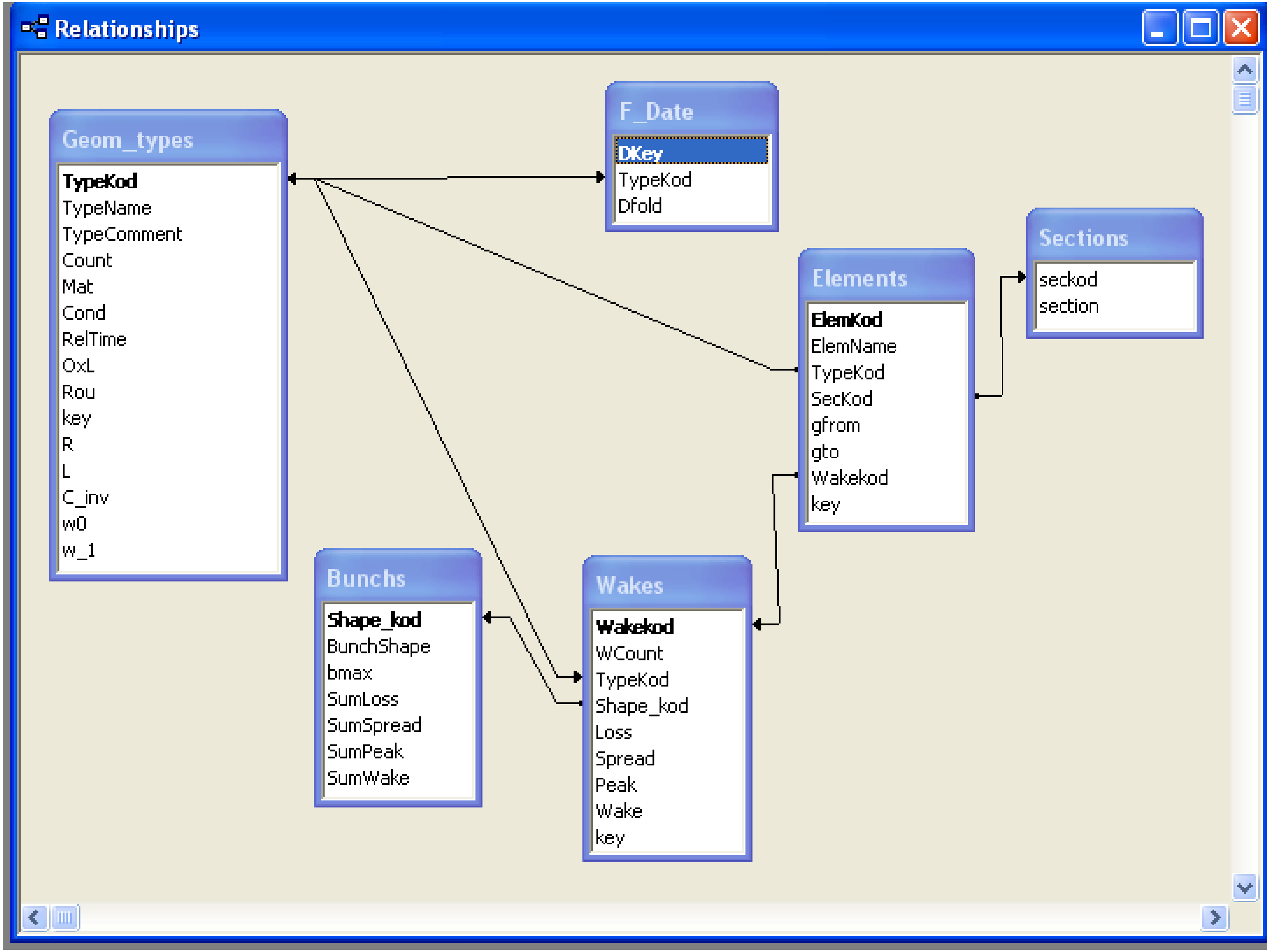
N	Element	from	to	Effective Length	Material	Conduct.	Relax. Time	Oxid layer	Rough ness
		mm	mm	mm		1/Omm/m	sec	nm	nm
1	Elliptical pipe	0	5288	5161	Aluminium	3,66E+07	7,10E-15	5	300
2	Pump	5161	5266	105	Aluminium	3,66E+08	7,10E-15	5	300
3	Absorber/Round transition	5266	5288	22	Copper	5,80E+07	2,46E-14	5	300
4	Round pipe	5288	6100	652	Copper	5,80E+07	2,46E-14	5	300
5	Bellow	5288	5318	30	BeCu 174	2,78E+07	2,46E-14	5	300
6	BPM	5373	5473	100	Stainless Steel 304	1,40E+06	2,40E-15	5	300
7	Bellow	5513	5543	30	BeCu 174	2,78E+07	2,46E-14	5	300
8	Round/Elliptical transition	6100	6100	0					

6100

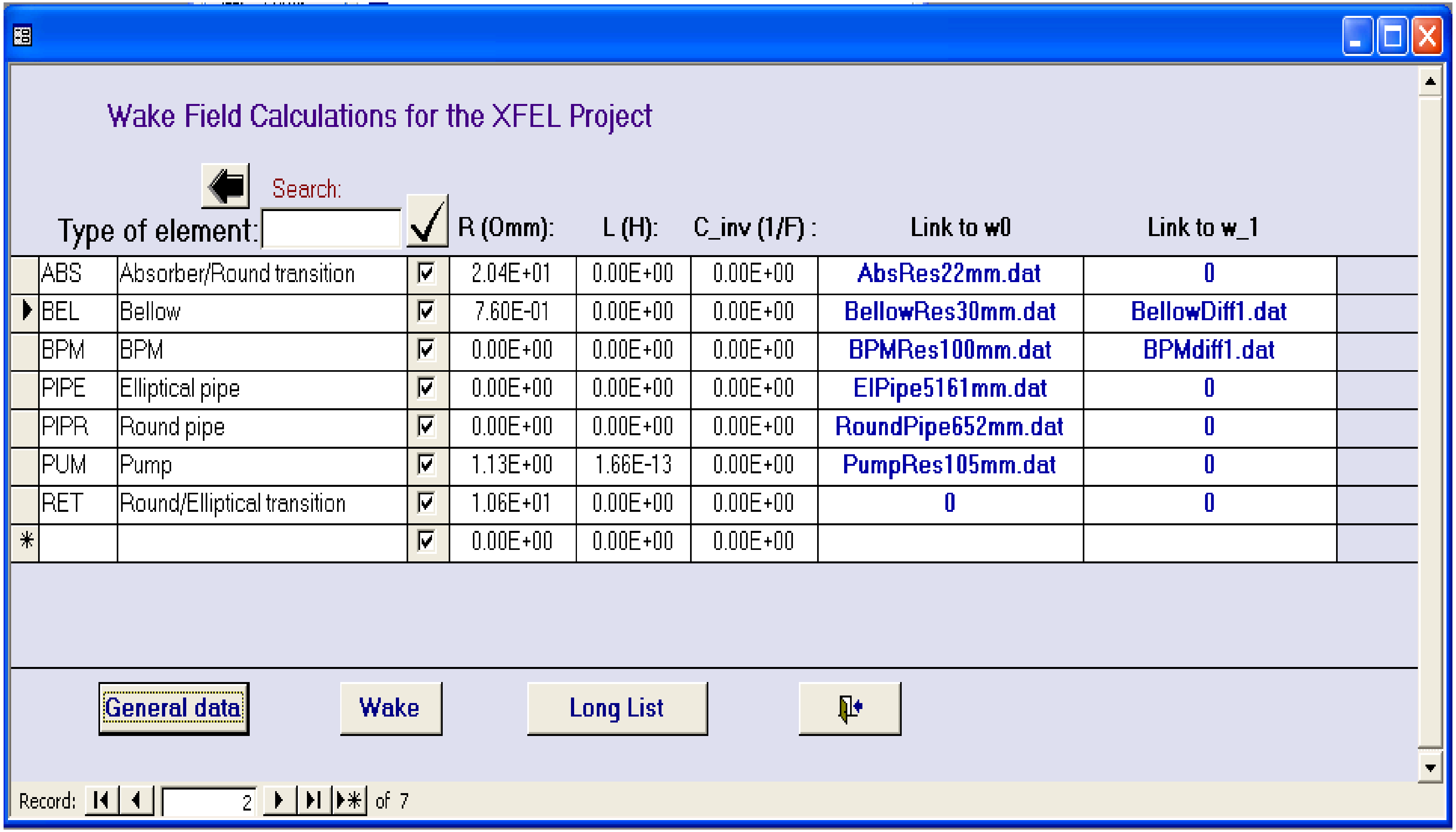


Katrin Schuett, ZM1
Dirk Lipka, MDI

The main structure of DB



The main form of data base application contains a list of element types, parameters R, L, C and links to tables w0 and w_1.



Wake Field Calculations for the XFEL Project

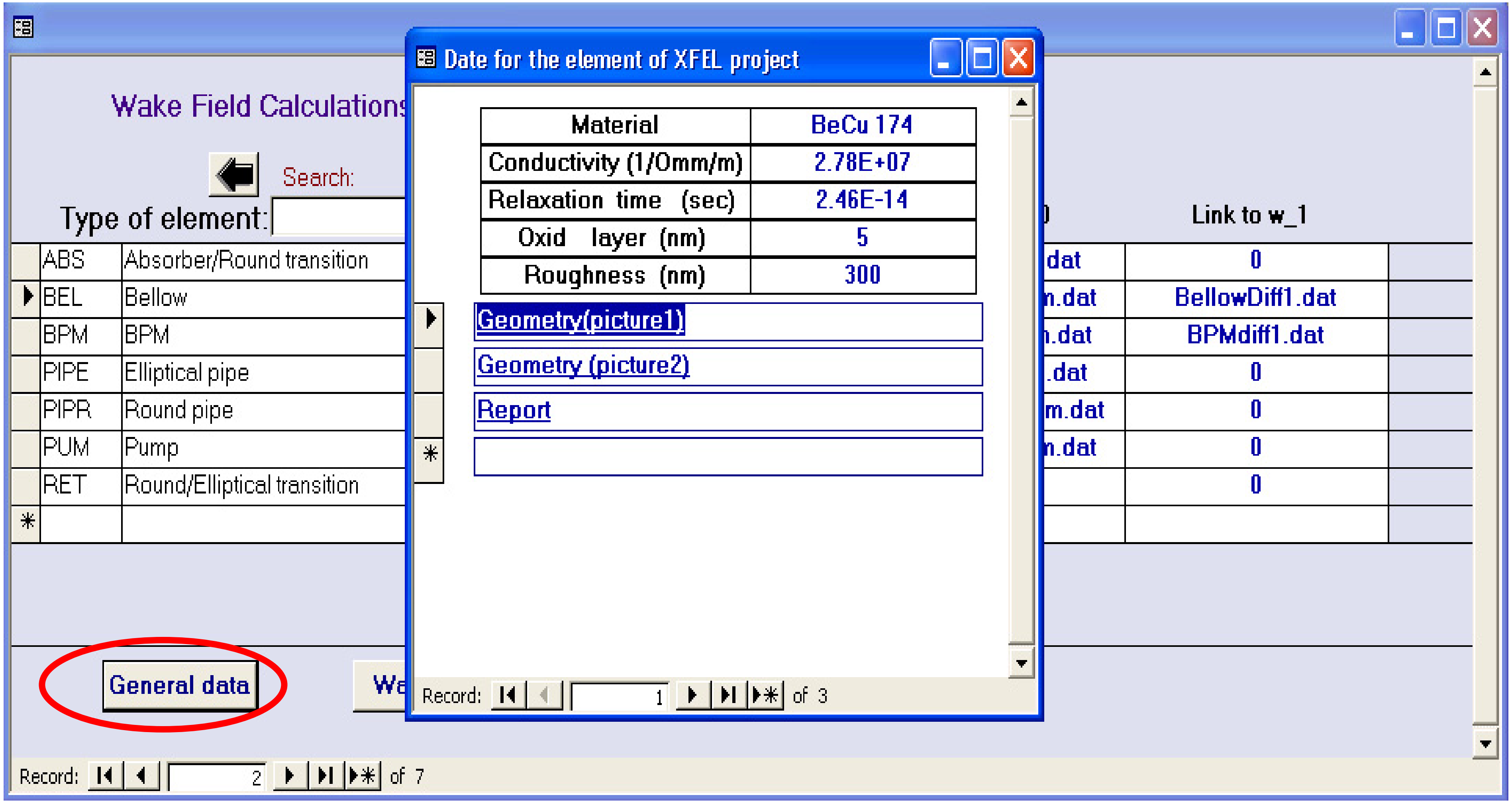
Search:

Type of element:			R (Omm):	L (H):	C_inv (1/F) :	Link to w0	Link to w_1
ABS	Absorber/Round transition	☑	2.04E+01	0.00E+00	0.00E+00	AbsRes22mm.dat	0
BEL	Bellow	☑	7.60E-01	0.00E+00	0.00E+00	BellowRes30mm.dat	BellowDiff1.dat
BPM	BPM	☑	0.00E+00	0.00E+00	0.00E+00	BPMRes100mm.dat	BPMdiff1.dat
PIPE	Elliptical pipe	☑	0.00E+00	0.00E+00	0.00E+00	ElPipe5161mm.dat	0
PIPR	Round pipe	☑	0.00E+00	0.00E+00	0.00E+00	RoundPipe652mm.dat	0
PUM	Pump	☑	1.13E+00	1.66E-13	0.00E+00	PumpRes105mm.dat	0
RET	Round/Elliptical transition	☑	1.06E+01	0.00E+00	0.00E+00	0	0
*		☑	0.00E+00	0.00E+00	0.00E+00		

General data | Wake | Long List

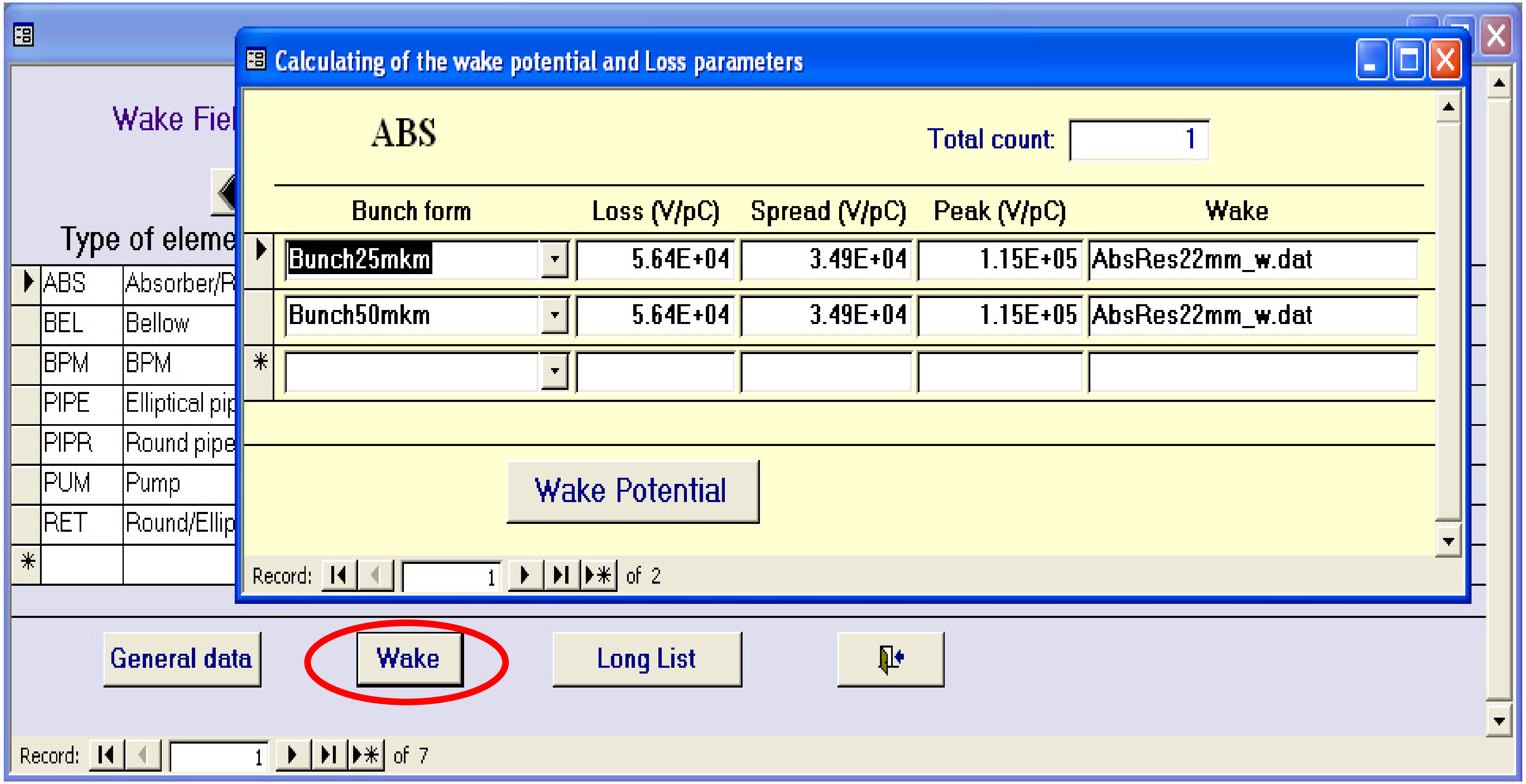
Record: 2 of 7

The click on button „General data” opens a description of the current element. This table can contain a reference to additional material: geometry description, input files for wakefield calculations, reports.

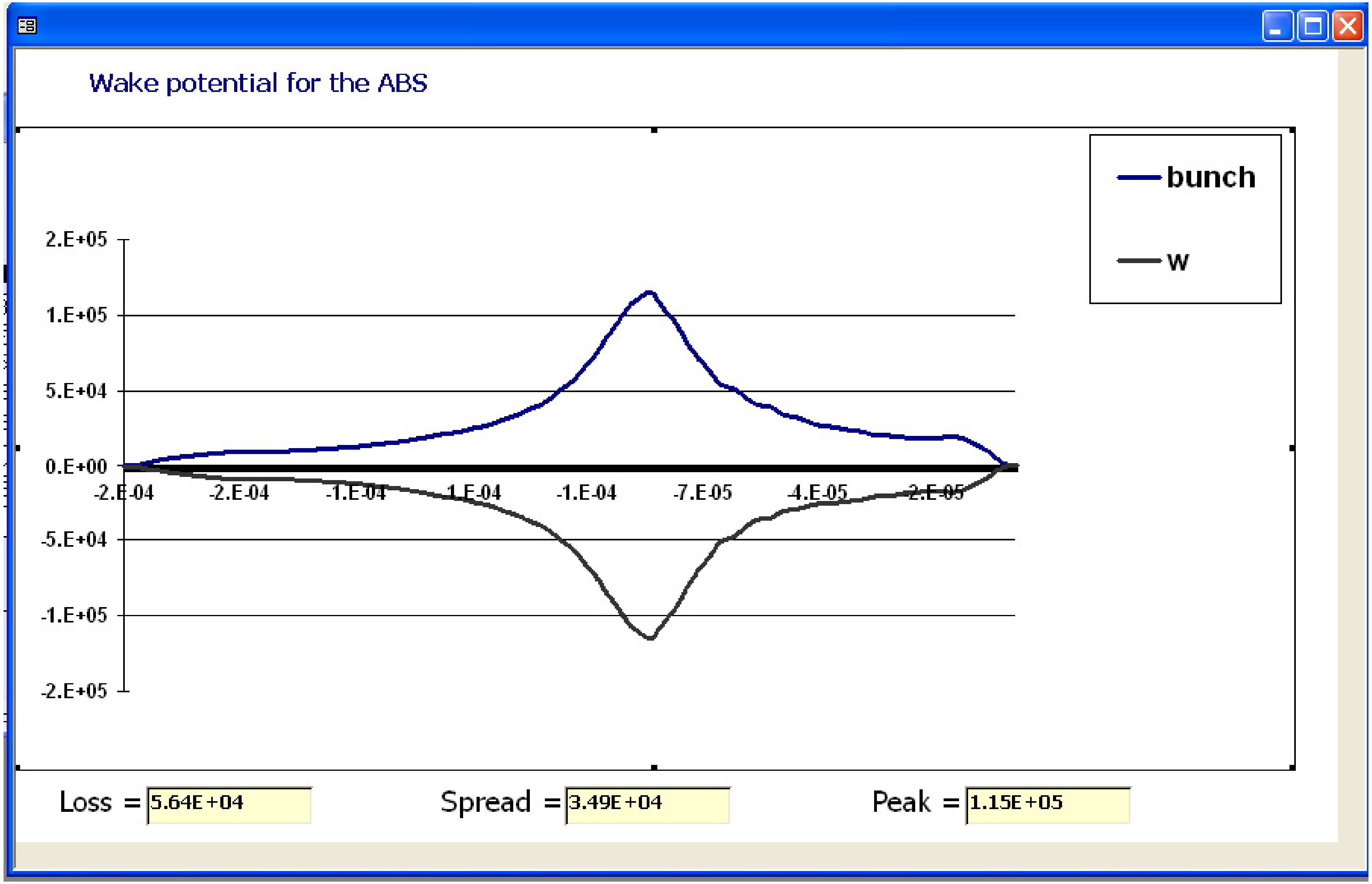


The same element type can appear several times along the beam line. Hence, we need to have all combinations of this element with different bunches.

The click on button „Wake" opens a form to assign a bunch to the current element and to calculate the wake potential for all possible combinations



Plot with wake potential of the current element with selected bunch shape can be seen.



The next table shows a long list of unique elements and integrated wakefield parameters for each of them.

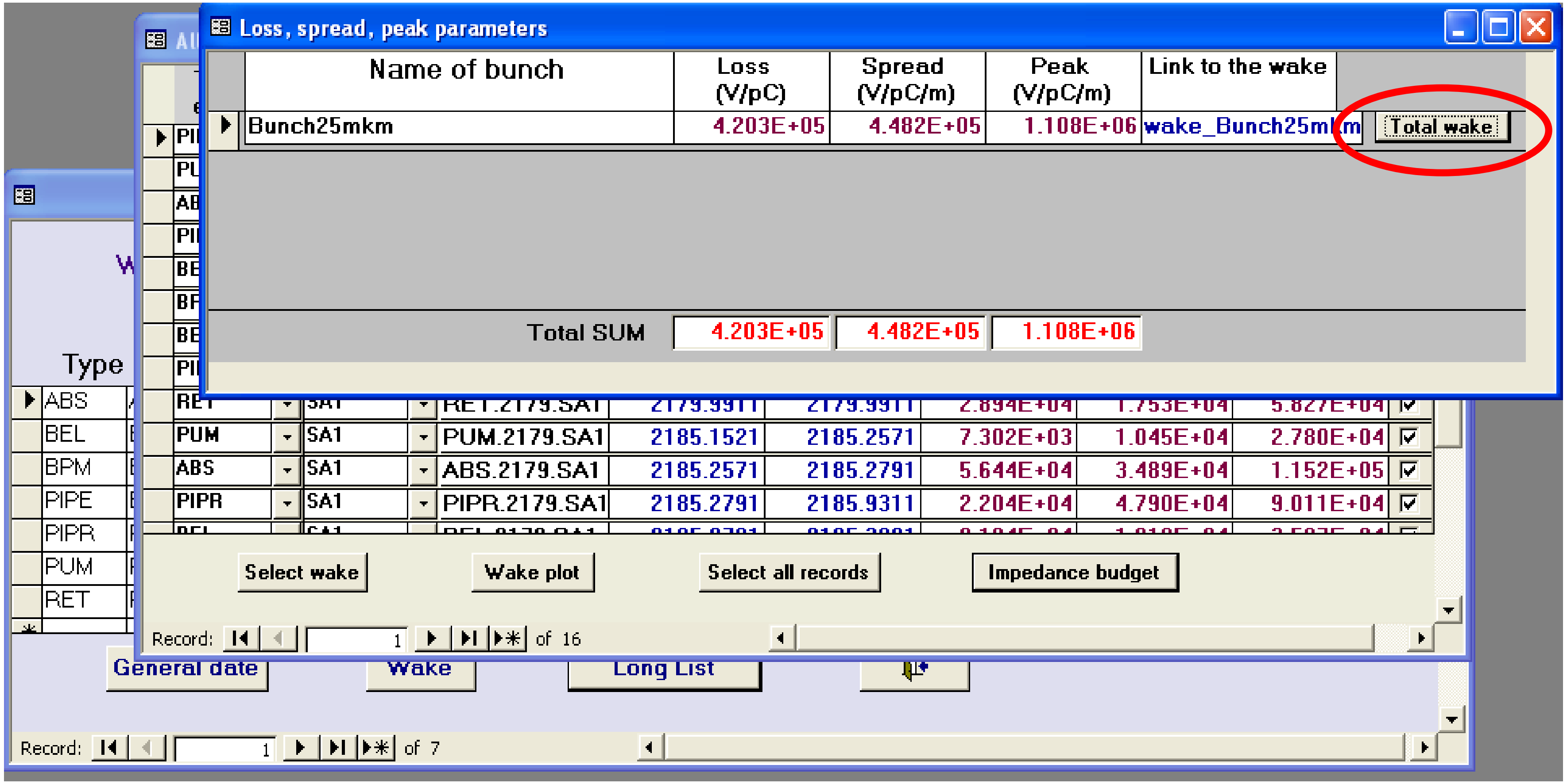
All elements

Type of element	Section	Name of element	from (m)	to (m)	Loss (V/pC)	Spread (V/pC/m)	Peak (V/pC/m)	✓
PIPE	SA1	PIPE.2173.SA1	2173.8911	2179.0521	2.079E+05	3.249E+05	6.835E+05	☑
PUM	SA1	PUM.2179.SA1	2179.0521	2179.1571	7.302E+03	1.045E+04	2.780E+04	☑
ABS	SA1	ABS.2179.SA1	2179.1571	2179.1791	5.644E+04	3.489E+04	1.152E+05	☑
PIPR	SA1	PIPR.2179.SA1	2179.1791	2179.8311	2.204E+04	4.790E+04	9.011E+04	☑
BEL	SA1	BEL.2179.SA1	2179.1791	2179.2091	2.194E+04	1.019E+04	3.597E+04	☑
BPM	SA1	BPM.2179.SA1	2179.2641	2179.3641	5.561E+04	3.050E+04	9.812E+04	☑
BEL	SA1	BEL.2179.SA1	2179.4041	2179.4341	2.194E+04	1.019E+04	3.597E+04	☑
PIPE	SA1	PIPE.2173.SA1	2179.9911	2185.1521	2.079E+05	3.249E+05	6.835E+05	☑
RET	SA1	RET.2179.SA1	2179.9911	2179.9911	2.894E+04	1.753E+04	5.827E+04	☑
PUM	SA1	PUM.2179.SA1	2185.1521	2185.2571	7.302E+03	1.045E+04	2.780E+04	☑
ABS	SA1	ABS.2179.SA1	2185.2571	2185.2791	5.644E+04	3.489E+04	1.152E+05	☑
PIPR	SA1	PIPR.2179.SA1	2185.2791	2185.9311	2.204E+04	4.790E+04	9.011E+04	☑
BEL	SA1	BEL.2179.SA1	2185.2791	2185.3091	2.194E+04	1.019E+04	3.597E+04	☑
BPM	SA1	BPM.2179.SA1	2185.3641	2185.4641	5.561E+04	3.050E+04	9.812E+04	☑
BEL	SA1	BEL.2179.SA1	2185.5041	2185.5341	2.194E+04	1.019E+04	3.597E+04	☑
RET	SA1	RET.2179.SA1	2186.0911	2186.0911	2.894E+04	1.753E+04	5.827E+04	☑

Select wake | Wake plot | Select all records | Impedance budget

Record: 1 of 16

The click on button „Impedance Budget” opens a report with total impedance budget of the selected elements. The wakes are given for each bunch shape separately.



The click on button „Total Wake“ opens a plot with the total wake of all elements with current bunch shape.