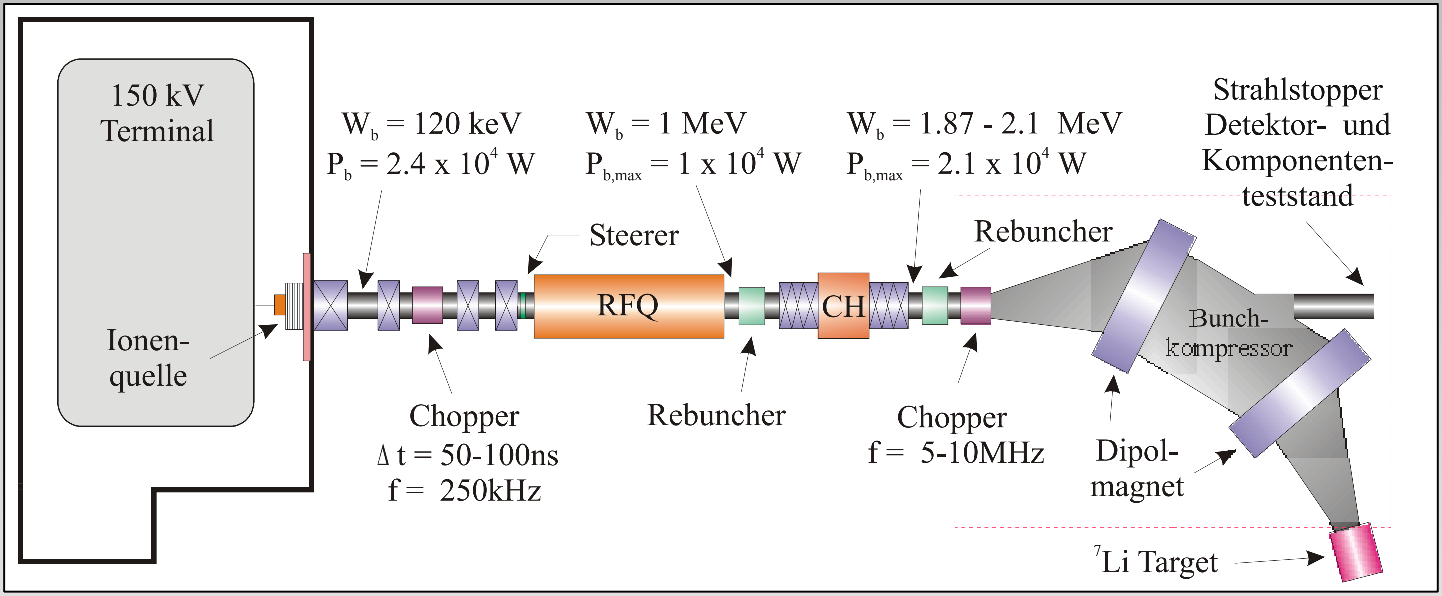
Buncher-System for FRANZ

- Concept
- Beam-Dynamics
- Chopper-System

Buncher-System for FRANZ

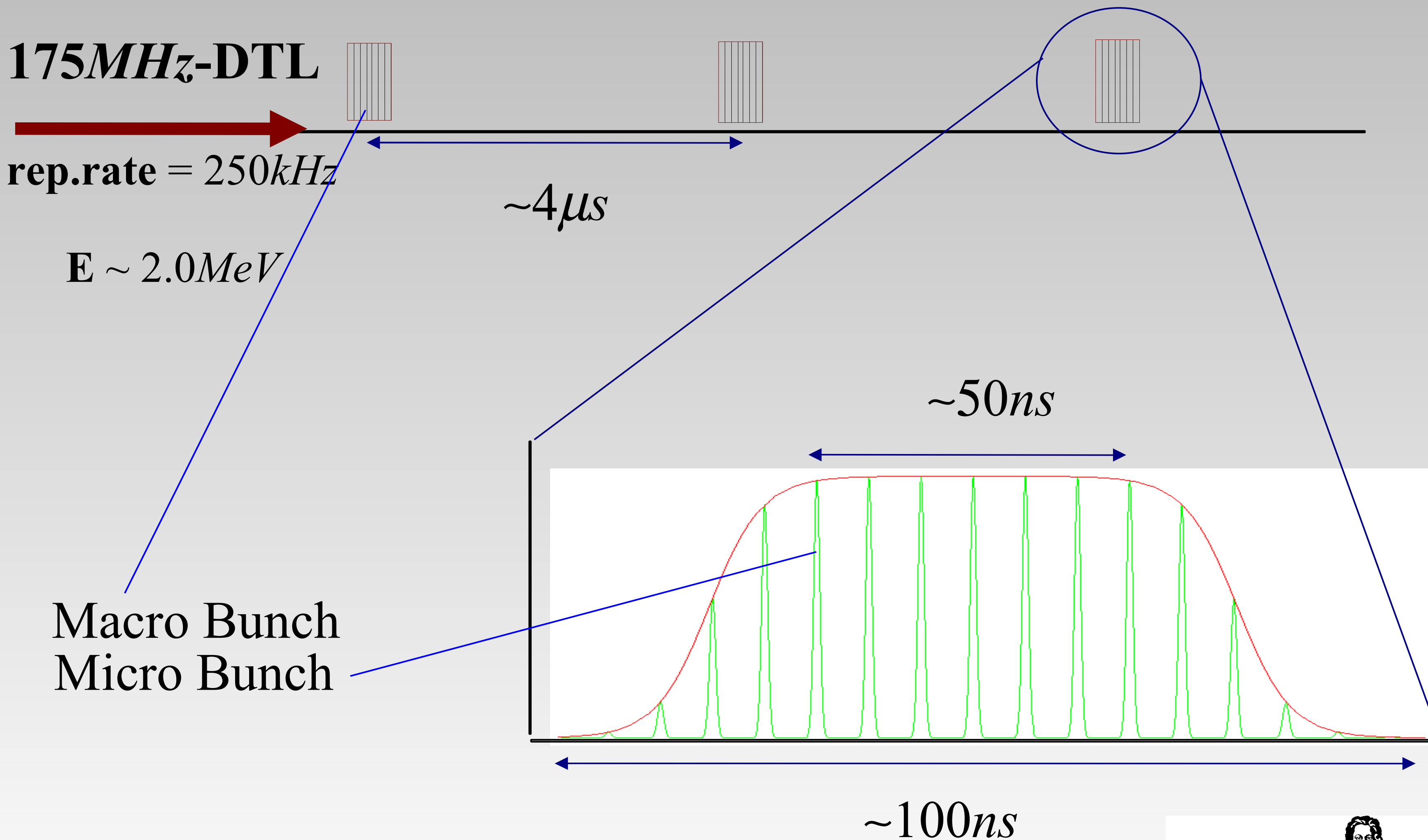


parameters at the Lithium-Target:

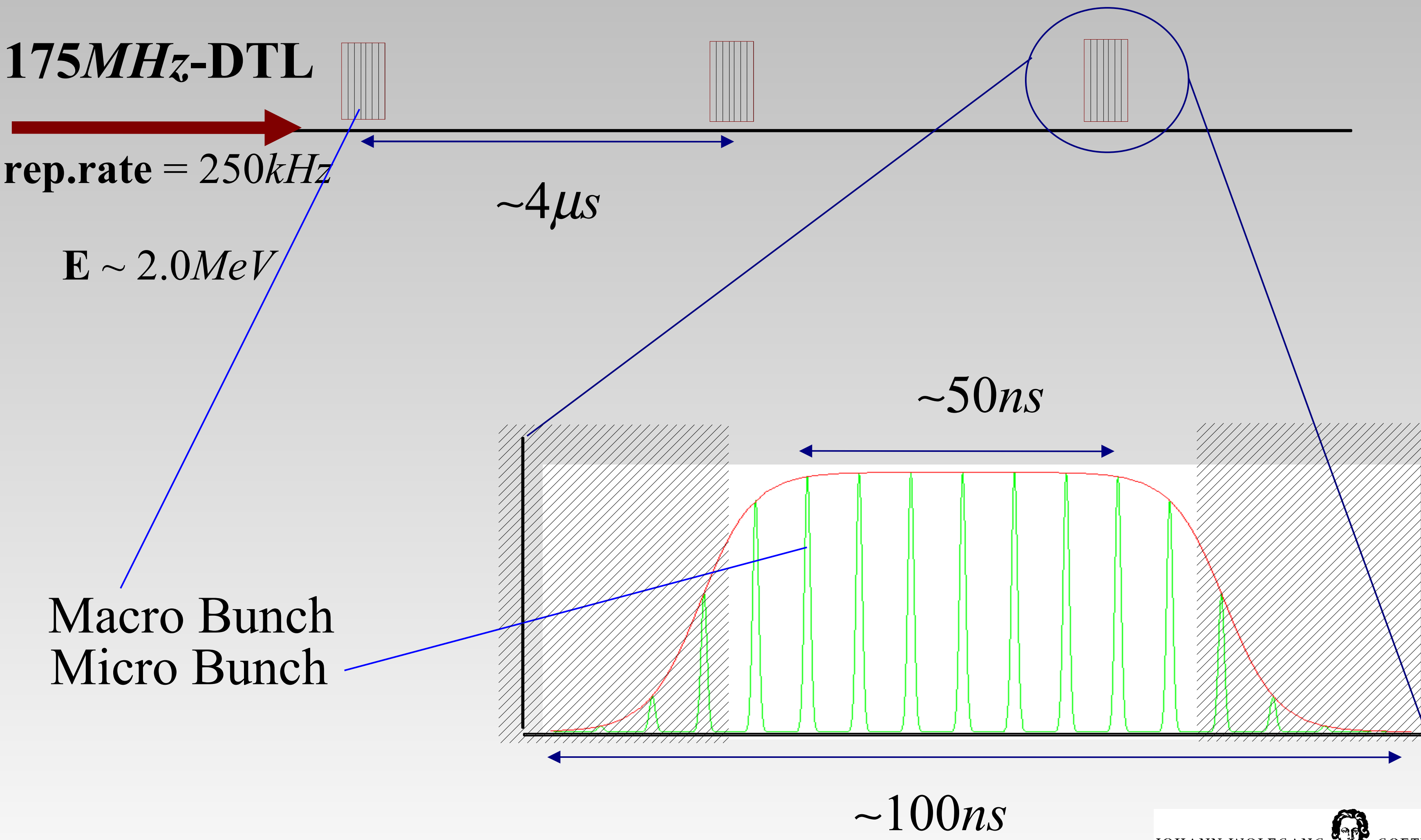
$$A = (2 \cdot X_{max}) \times (2 \cdot Y_{max}) < 3 \times 3 \; [cm^2]$$

$$\Delta T < 1 [ns]$$

Pulse-Structure after the DTL



Pulse-Structure after the DTL



Concept

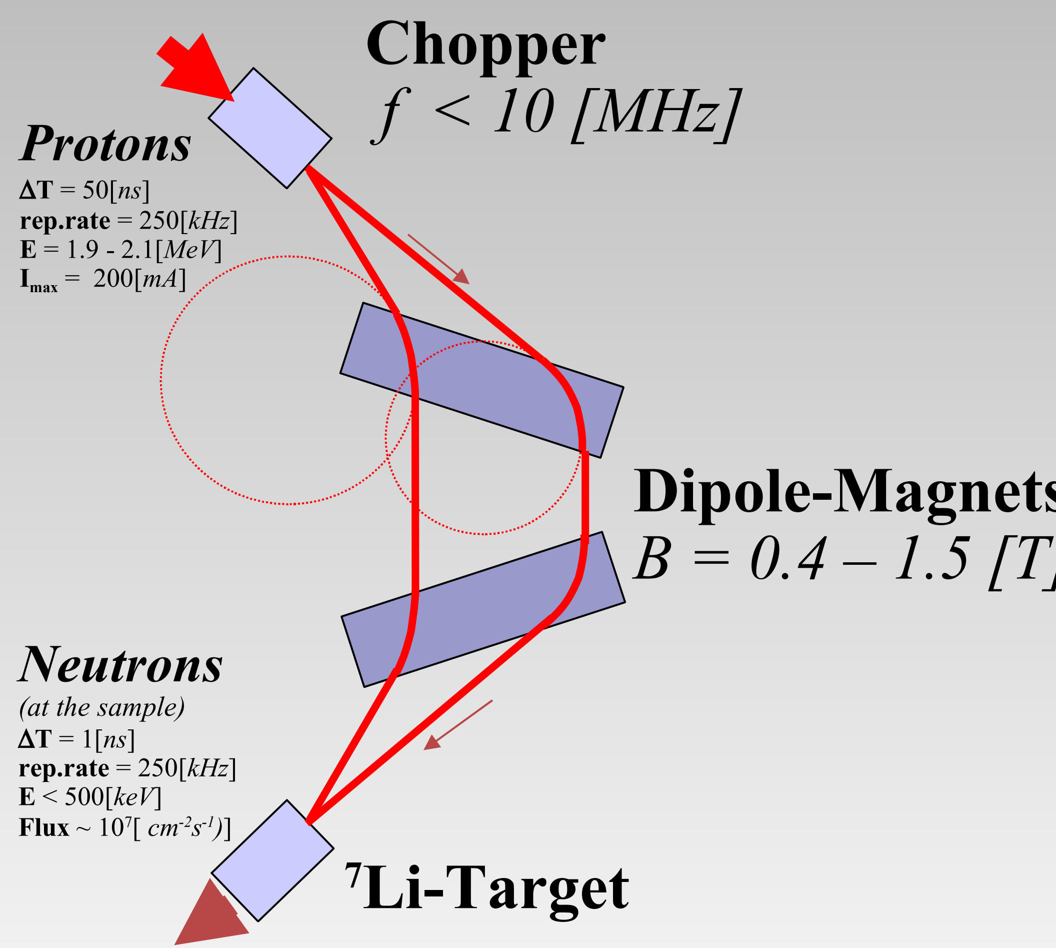
Inspired by [Phys. Rev. 88(2), 360-361 (1951)] a 1ns-Buncher-System composed of a rf-chopper and *two* skew magnets with spatial non-constant magnet fields is proposed.

Idea:

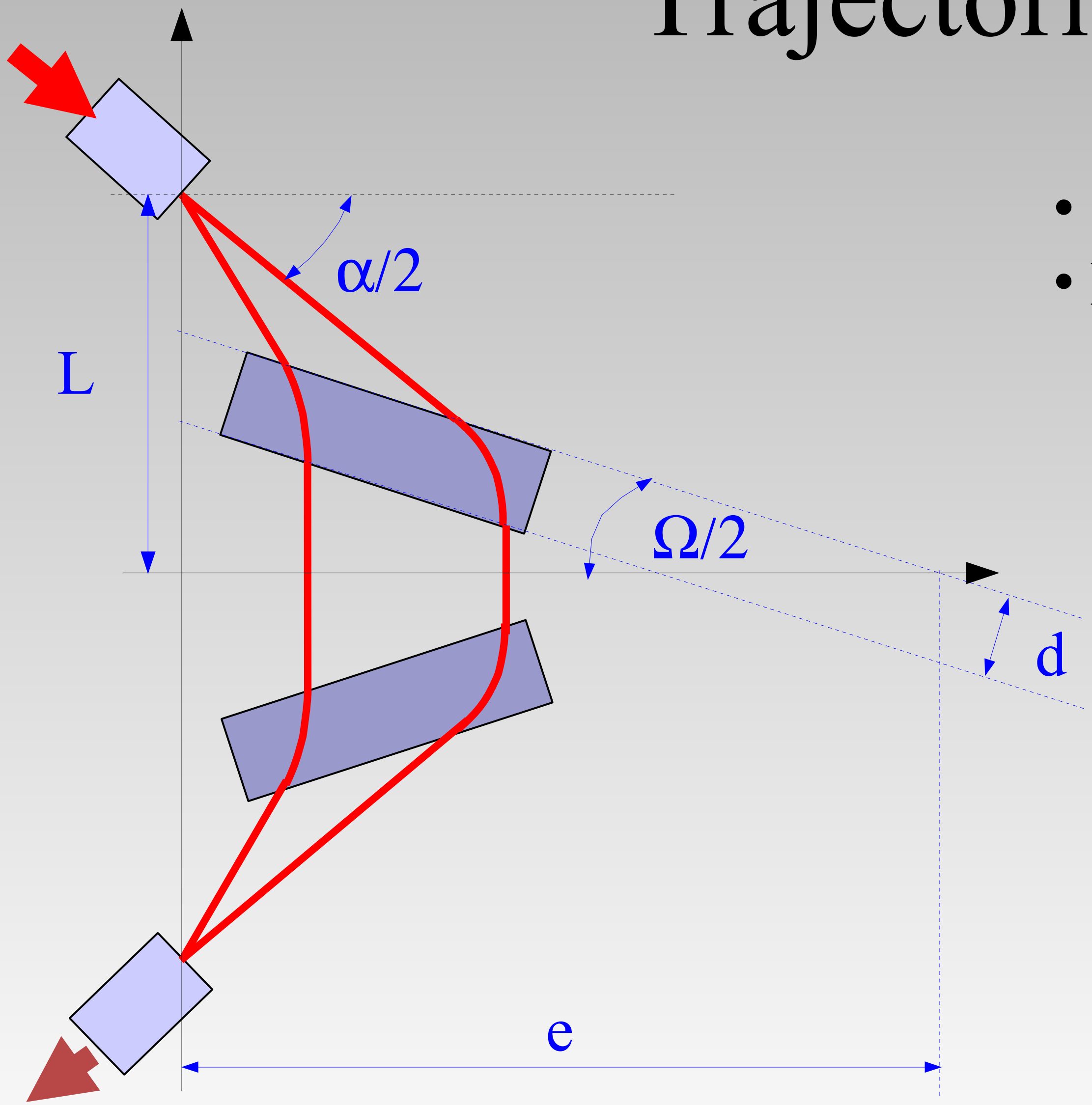
- About 7-9 micro bunches be deflected on different paths
- Arrive at the same time at the target

***Advantages of two skew magnets*:**

- More parameter to manipulate the beam dynamics
- Greater distance between the bunches
- More compact geometry

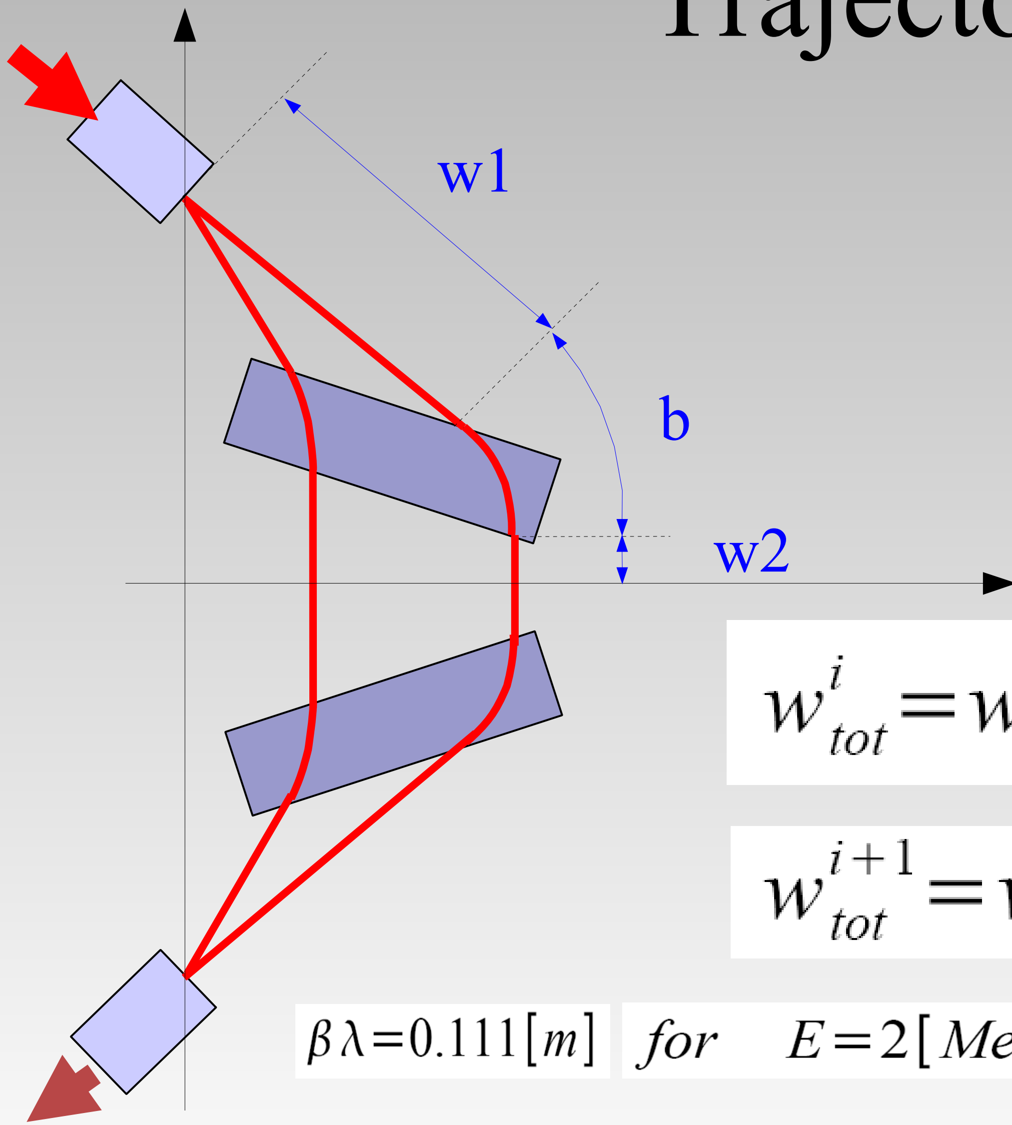


Trajectories



- Cartesian coordinate system
- Parameters: α, Ω, d, e, L

Trajectories



- Cartesian coordinate system
- Parameters: α, Ω, d, e, L
- w1(α, Ω, d, e, L)
- w2(α, Ω, d, e, L)
- b(α, Ω, d) --> R , B

$$w_{tot}^{i} = w_{tot}^{i}(\alpha_i, \Omega, d, e, L)$$

$$w_{tot}^{i+1} = w_{tot}^{i} + \beta\lambda$$

$\beta\lambda = 0.111[m]$ $\quad$ $for \quad E = 2[MeV/u] \quad , \quad f = 175[MHz]$

Bunch-Interaction

$$\ddot{\vec{r}}_j(t) = \frac{q}{m} \sum_{i \neq j}^{N} \vec{E}_{ji}(t)$$

$$q = q_i = q_j$$
$$m = m_i = m_j$$

N = total #bunchs (7 to 9)
j = #bunchs
k = #iteration

$$\ddot{\vec{r}}_j^{(k+1)\leftarrow k} = \frac{\Delta \vec{v}_j^{(k+1)\leftarrow k}}{\Delta t} = \frac{1}{\Delta t}\left(\vec{v}_j^{(k+1)\leftarrow k} - \vec{v}_j^{k\leftarrow (k-1)}\right) = \frac{1}{\Delta t}\left(\frac{\vec{r}_j^{k+1} - \vec{r}_j^{k}}{\Delta t} - \frac{\vec{r}_j^{k} - \vec{r}_j^{k-1}}{\Delta t}\right)$$

$$\ddot{\vec{r}}_j((k+1)\Delta t) \Rightarrow \quad \ddot{\vec{r}}_j^{(k+1)\leftarrow k} = \frac{\vec{r}_j^{k+1} - 2\cdot\vec{r}_j^{k} + \vec{r}_j^{k-1}}{(\Delta t)^2}$$

$$\vec{E}_{ji}((k+1)\cdot\Delta t) \Rightarrow \vec{E}_{ji}^{k+1\leftarrow k} \simeq \vec{E}_{ji}^{k} = q \sum_{i \neq j}^{N} \frac{\tilde{\vec{r}}_{ji}^{k}}{|\tilde{\vec{r}}_{ji}^{k}|^3}$$

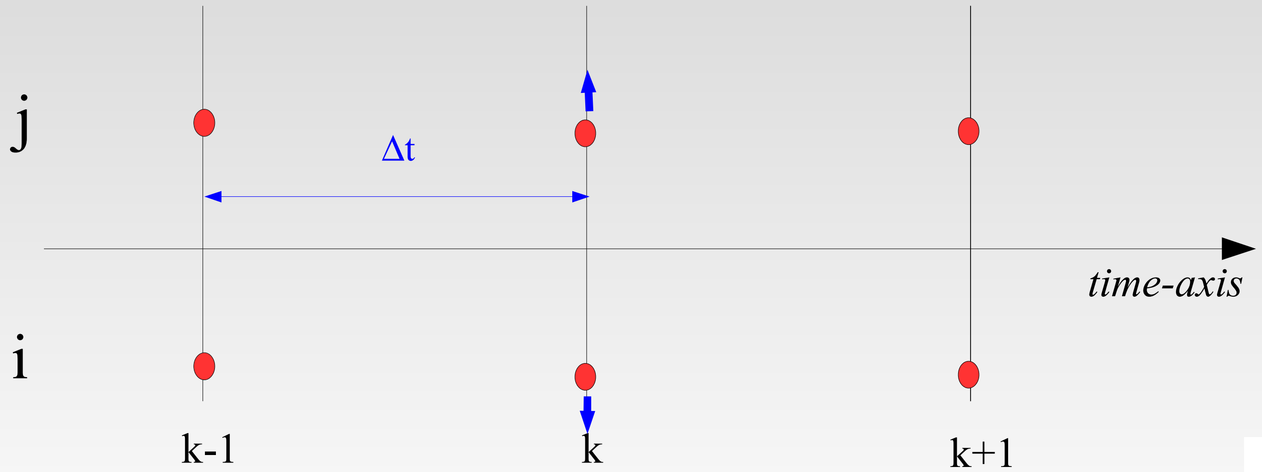
$$\tilde{\vec{r}}_{ji}^{k} = \vec{r}_j^{k} - \vec{r}_i^{k}$$

Bunch-Interaction

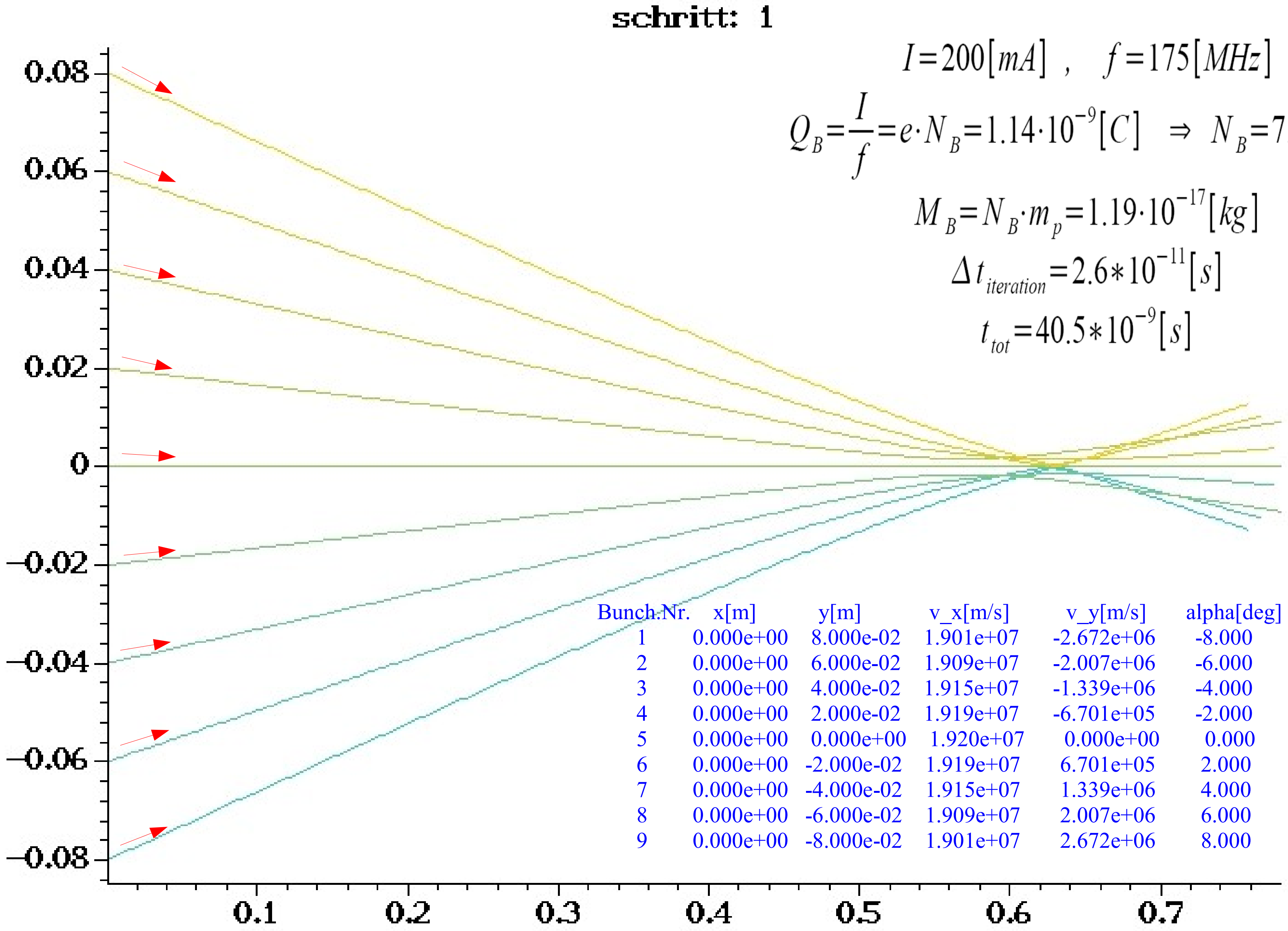
$$\ddot{\vec{r}}_j(t) = \frac{q}{m} \sum_{i \neq j}^{N} \vec{E}_{ji}(t)$$

N = total #bunchs (7 to 9)
j = #bunchs
k = #iteration

$$\Rightarrow \vec{r}_j^{\,k+1} = 2 \cdot \vec{r}_j^{\,k} - \vec{r}_j^{\,k-1} + \frac{q^2 (\Delta t)^2}{m} \sum_{i \neq j}^{N} \frac{\tilde{\vec{r}}_{ji}^{\,k}}{\left|\tilde{\vec{r}}_{ji}^{\,k}\right|^3}$$



Bunch-Interaction



$I = 200[mA] \quad , \quad f = 175[MHz]$

$Q_B = \frac{I}{f} = e \cdot N_B = 1.14 \cdot 10^{-9}[C] \quad \Rightarrow \quad N_B = 7.14 \cdot 10^{-9}$

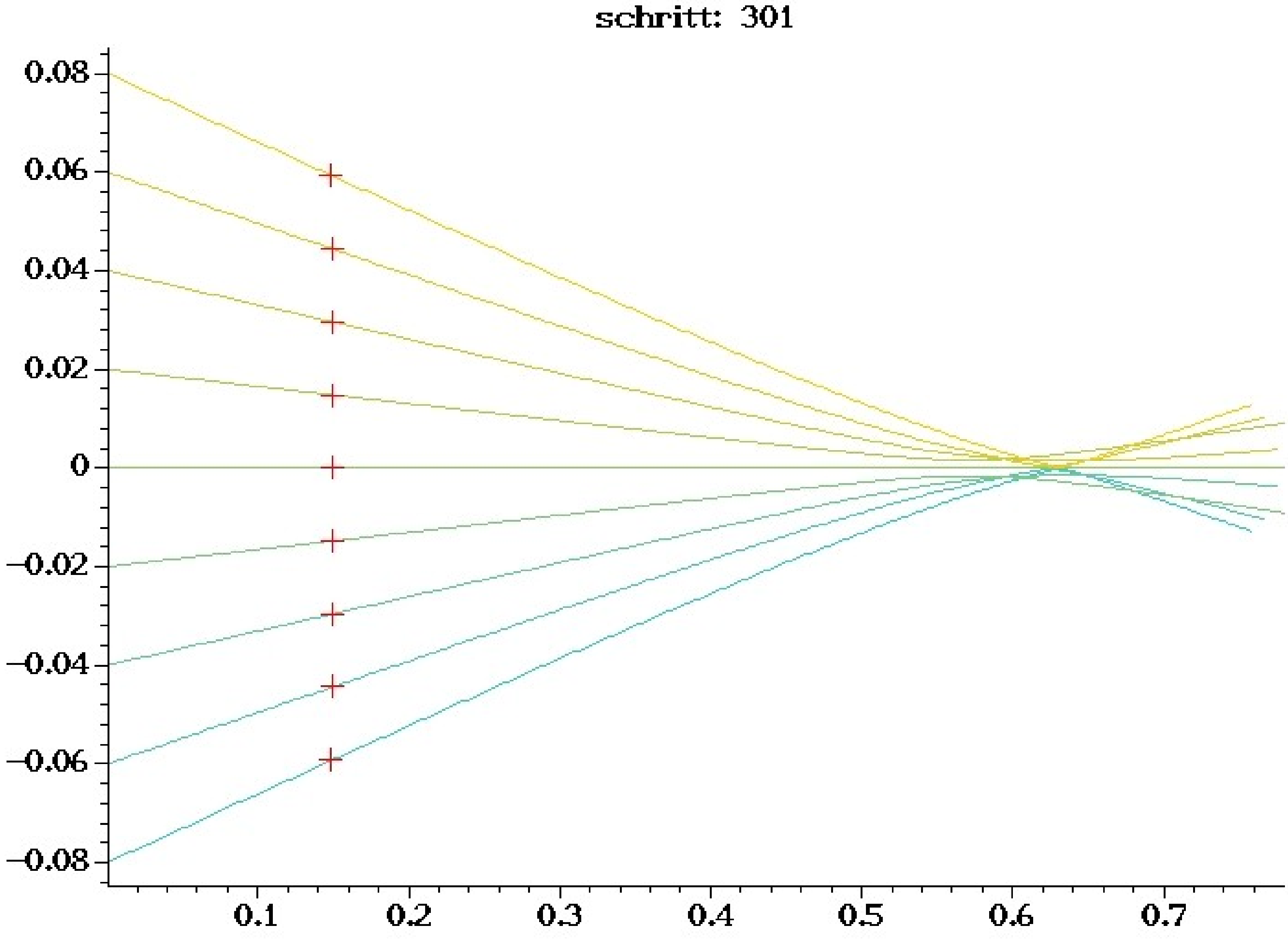
$M_B = N_B \cdot m_p = 1.19 \cdot 10^{-17}[kg]$

$\Delta t_{iteration} = 2.6 * 10^{-11}[s]$

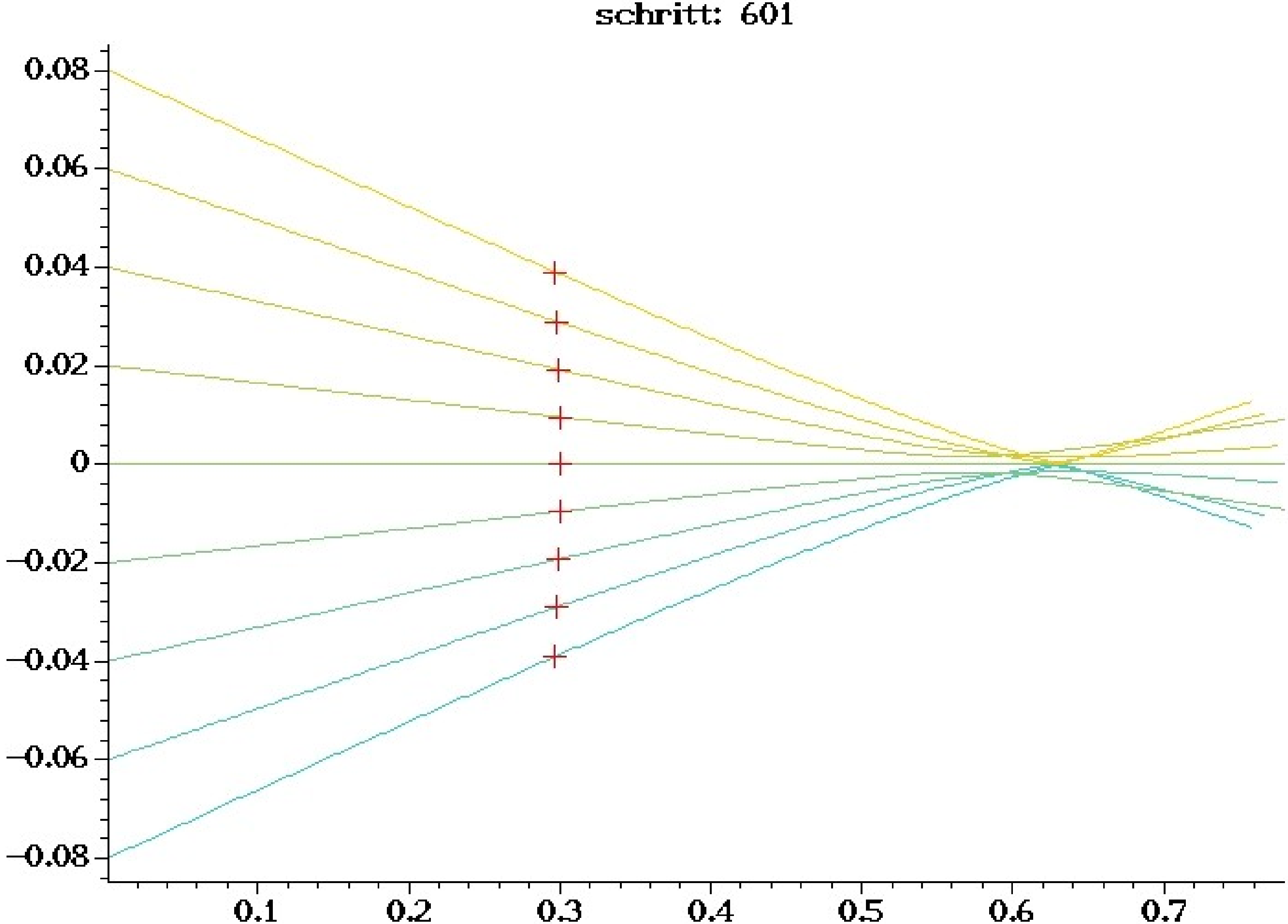
$t_{tot} = 40.5 * 10^{-9}[s]$

Bunch.Nr.	x[m]	y[m]	v_x[m/s]	v_y[m/s]	alpha[deg]	alpha[rad]
1	0.000e+00	8.000e-02	1.901e+07	-2.672e+06	-8.000	-0.140
2	0.000e+00	6.000e-02	1.909e+07	-2.007e+06	-6.000	-0.105
3	0.000e+00	4.000e-02	1.915e+07	-1.339e+06	-4.000	-0.070
4	0.000e+00	2.000e-02	1.919e+07	-6.701e+05	-2.000	-0.035
5	0.000e+00	0.000e+00	1.920e+07	0.000e+00	0.000	0.000
6	0.000e+00	-2.000e-02	1.919e+07	6.701e+05	2.000	0.035
7	0.000e+00	-4.000e-02	1.915e+07	1.339e+06	4.000	0.070
8	0.000e+00	-6.000e-02	1.909e+07	2.007e+06	6.000	0.105
9	0.000e+00	-8.000e-02	1.901e+07	2.672e+06	8.000	0.140

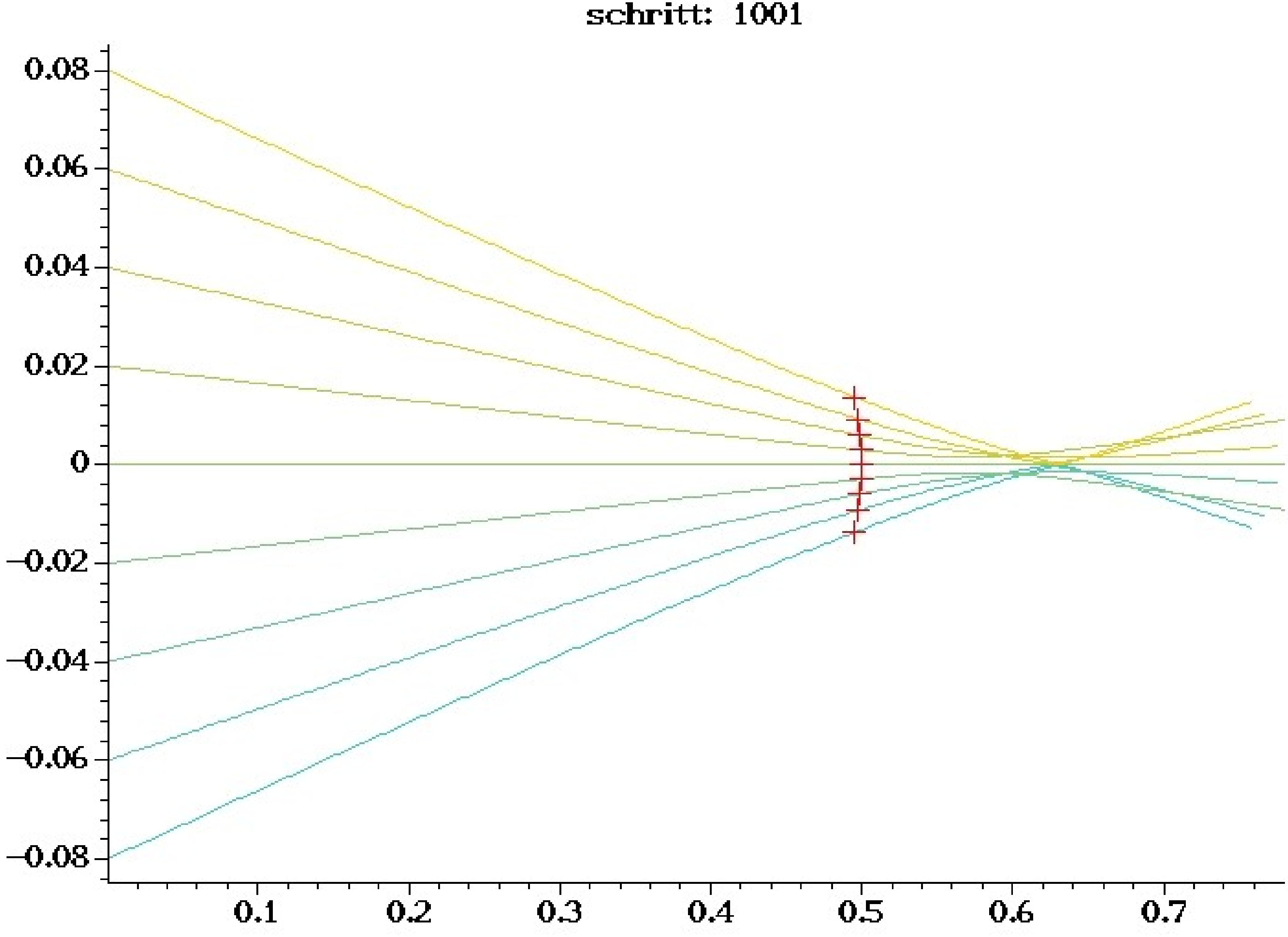
Bunch-Interaction



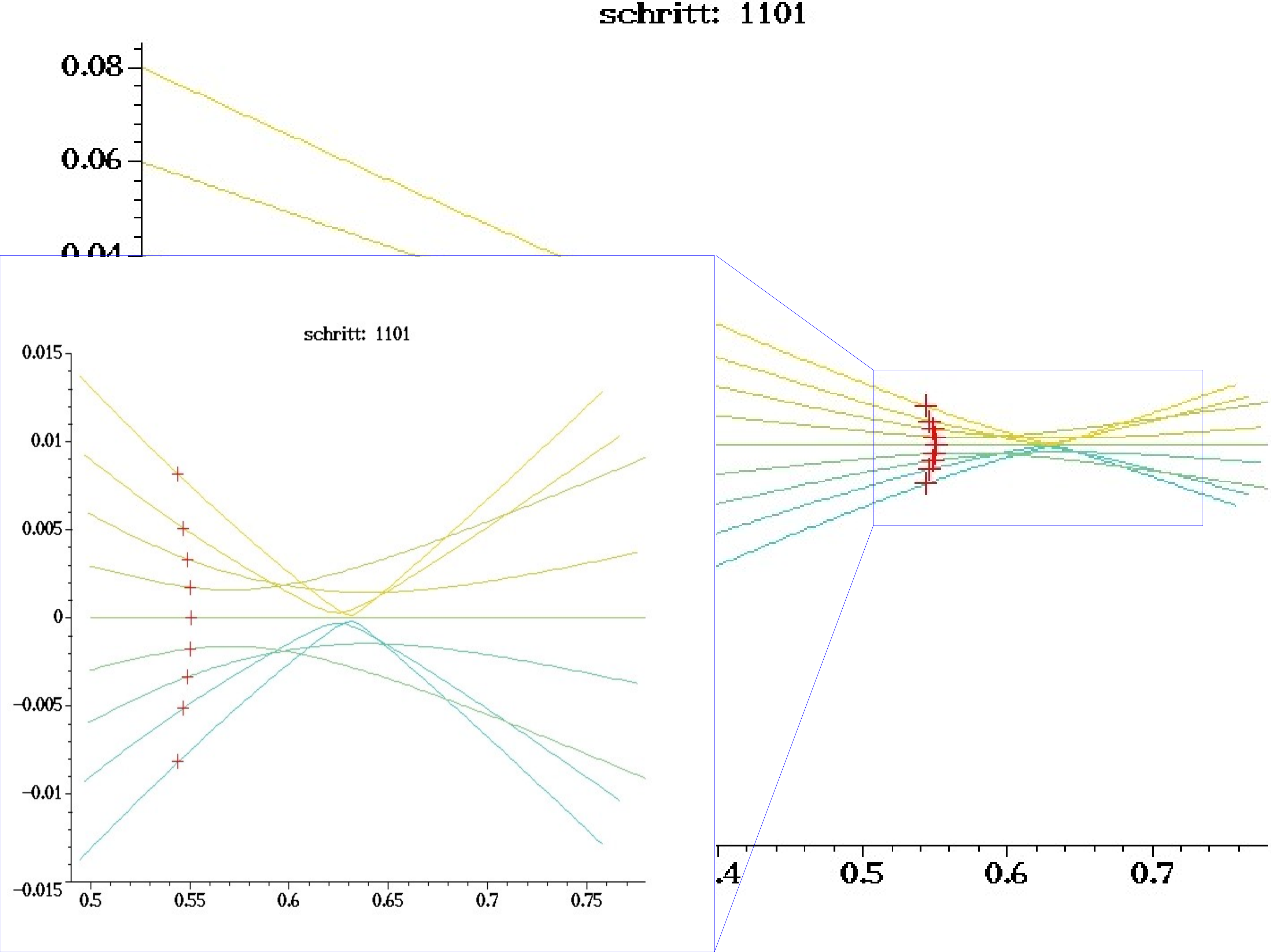
Bunch-Interaction



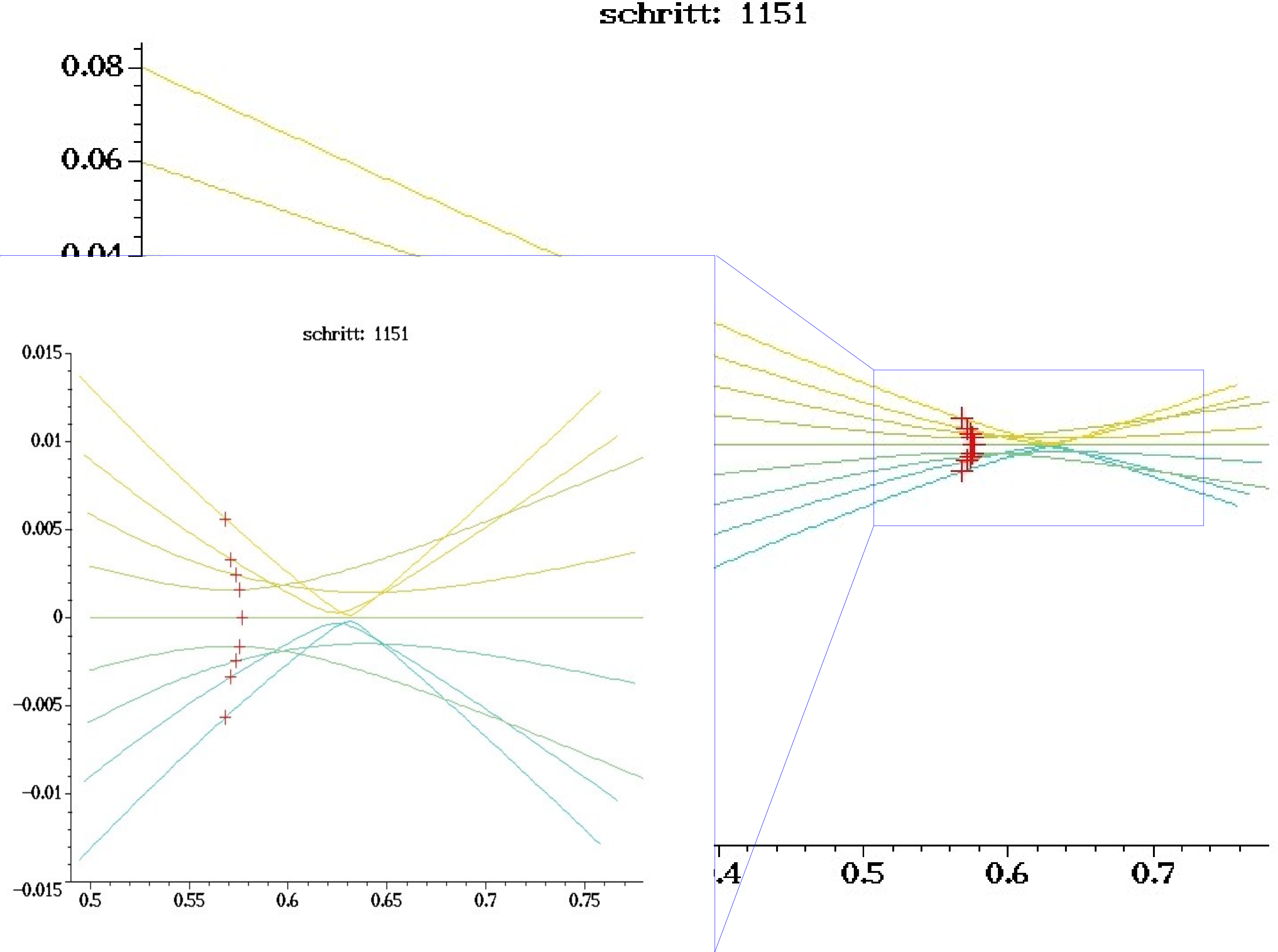
Bunch-Interaction



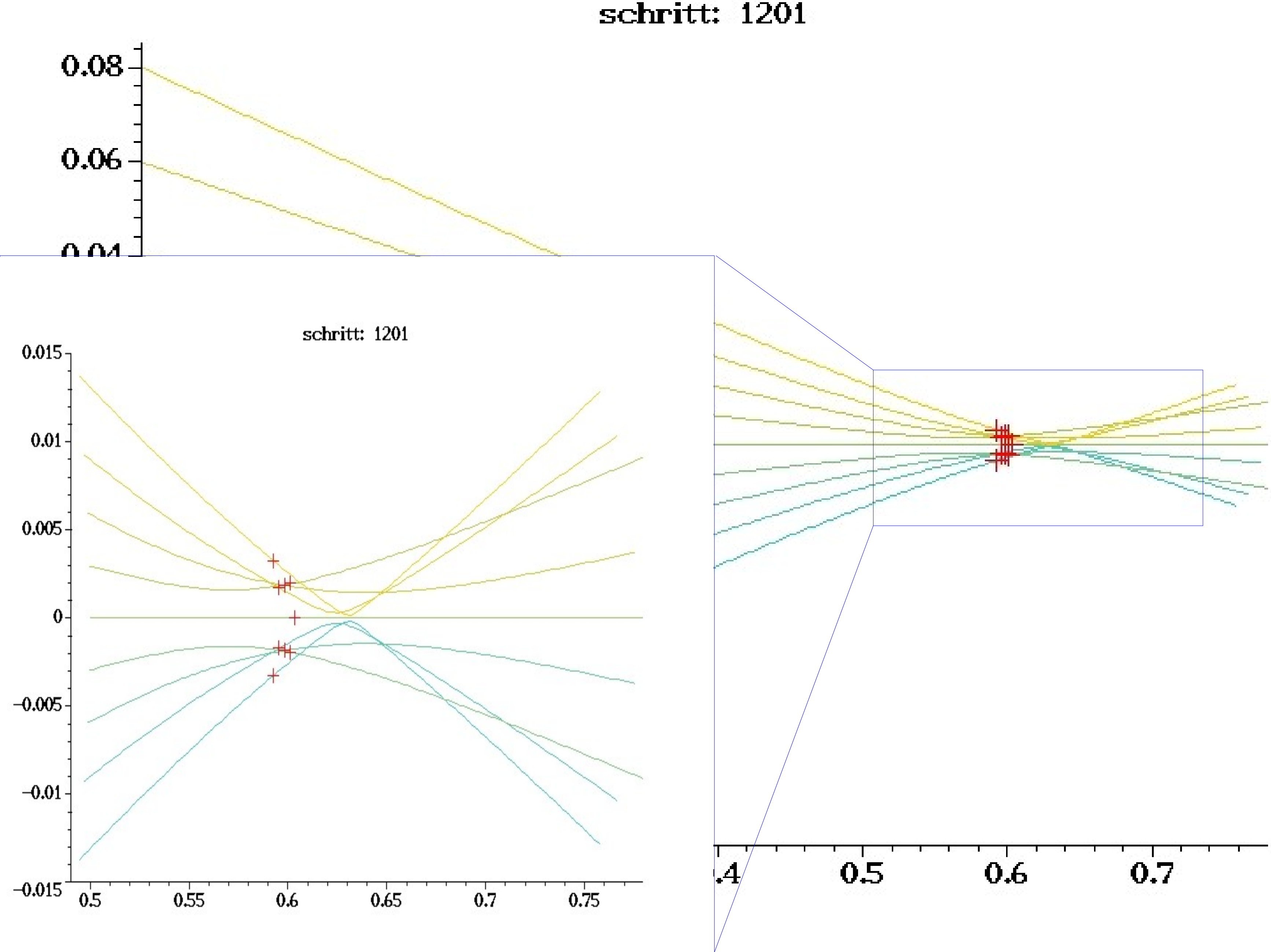
Bunch-Interaction



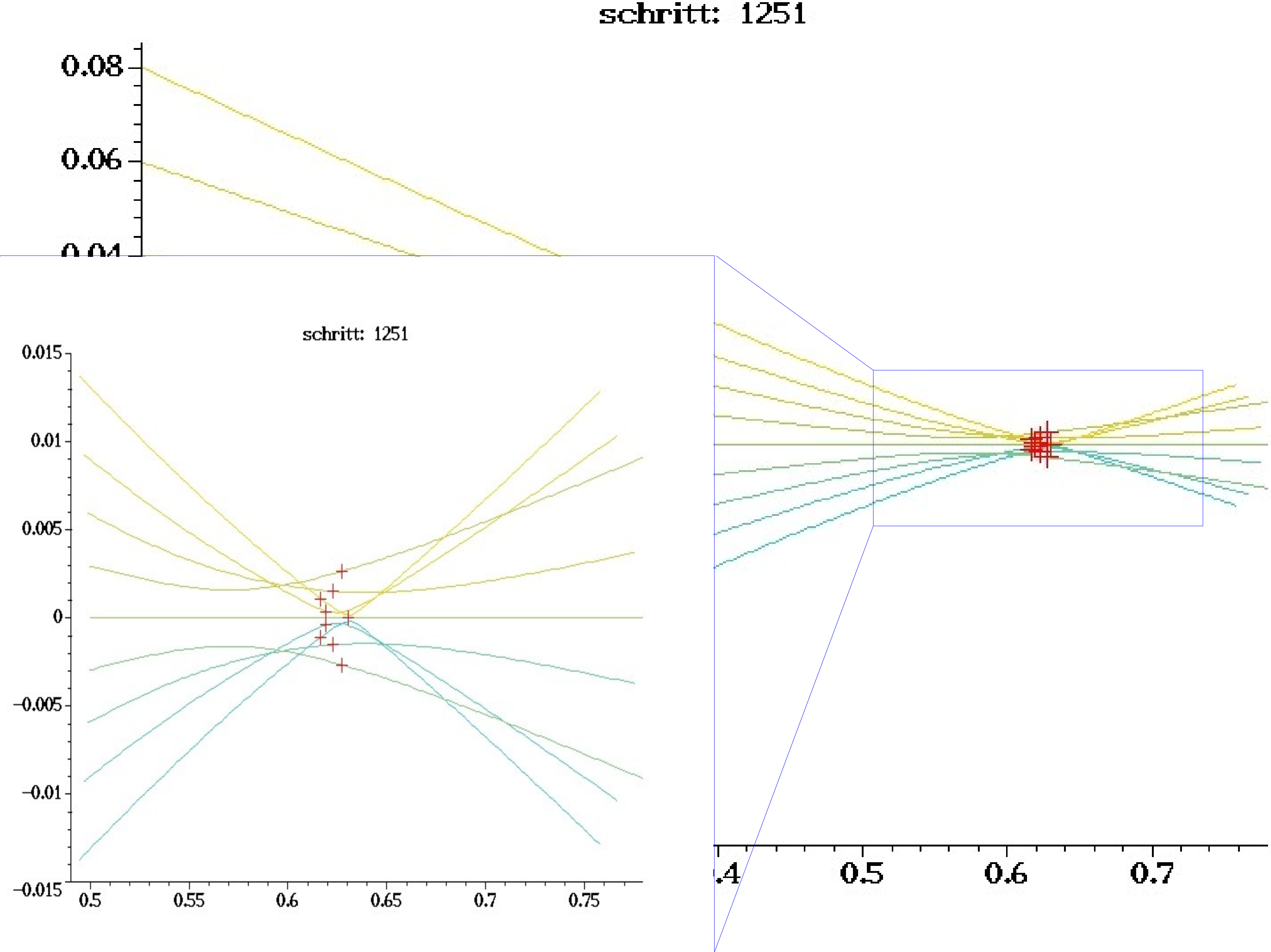
Bunch-Interaction



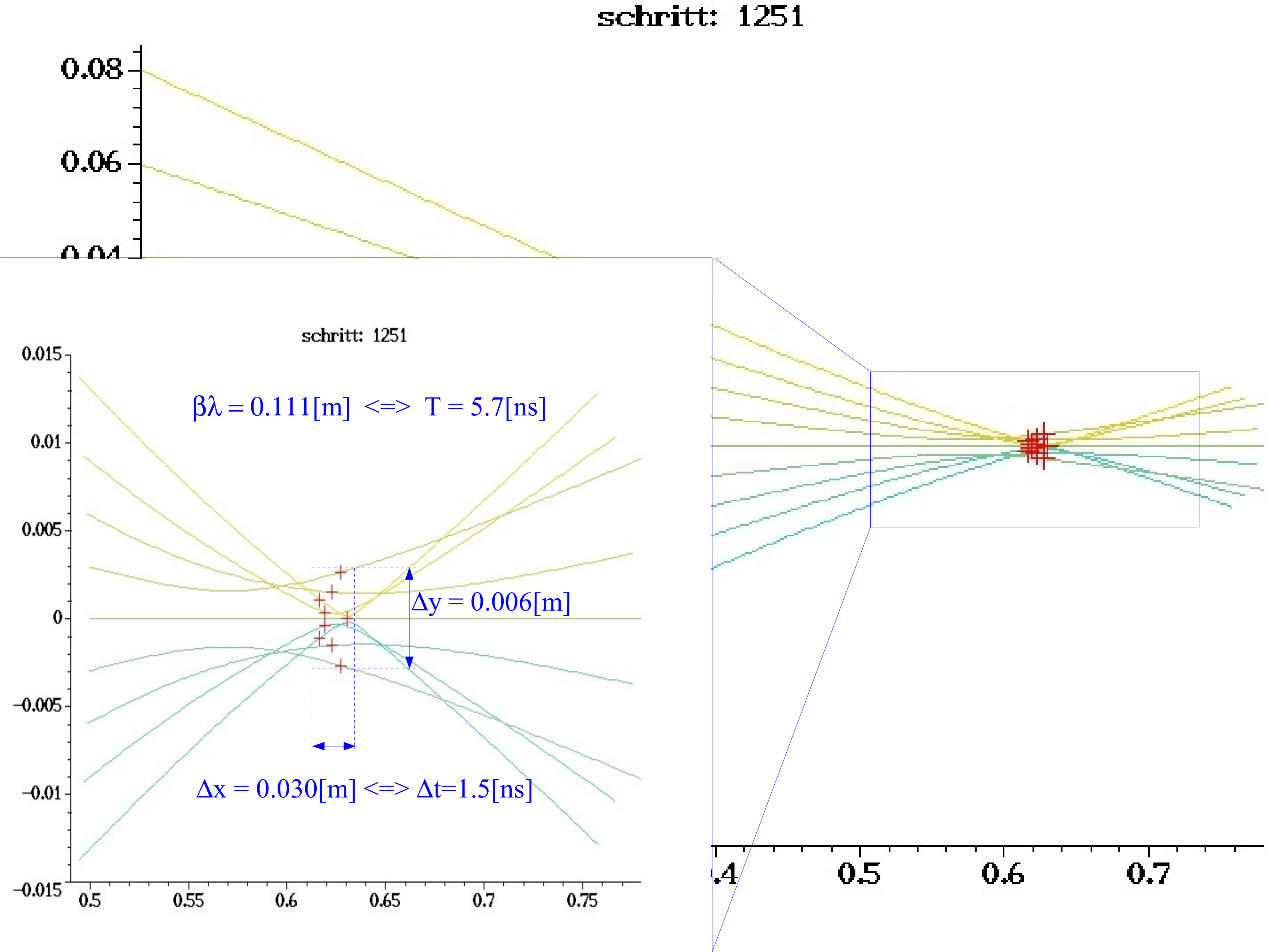
Bunch-Interaction



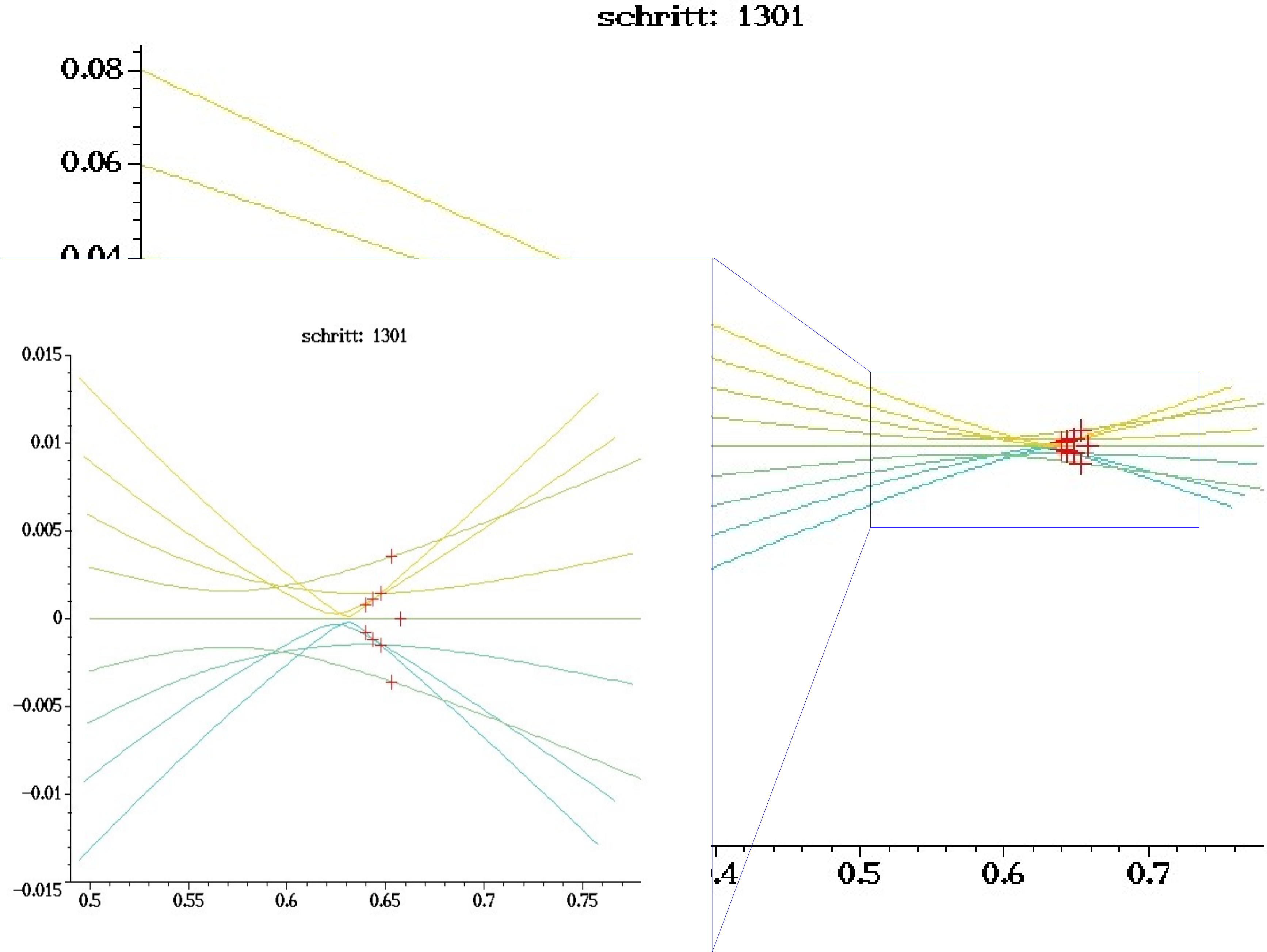
Bunch-Interaction



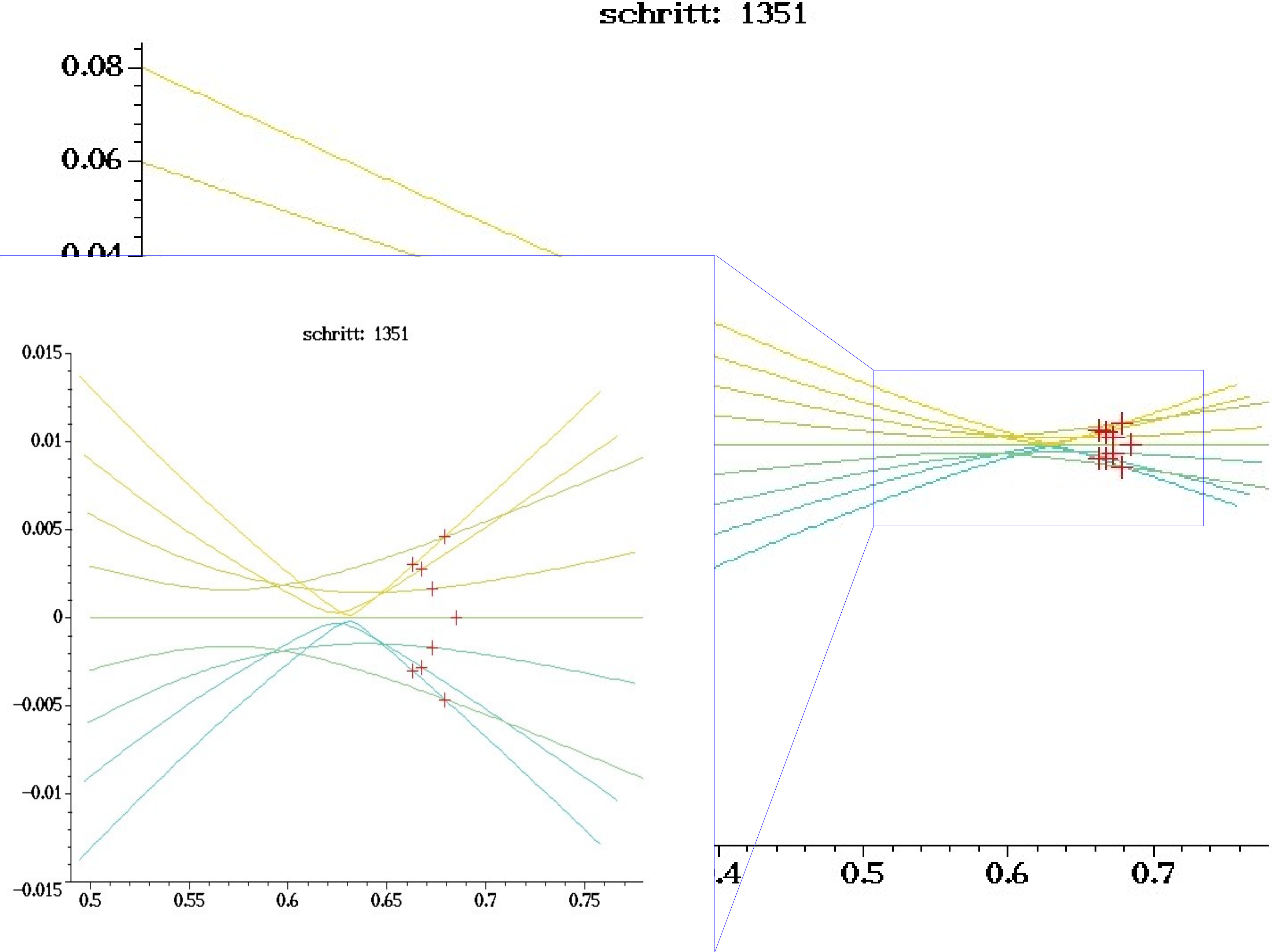
Bunch-Interaction



Bunch-Interaction



Bunch-Interaction



Beam-Dynamics

Available Parameters: 2 edge angle, rf-voltage

TRACE3D

•Envelope
•Space-charge calc.:
- approximation: electrical field of an uniformly charged ellipsoid

=>improper for transport through dipole! First order estimation for Envelope

PARMILA(SCHEFF)

• Multi-Particle
• Space-charge calc.:
  - PIC
  - radiale Symmetry
  - 2D-Solver (r, z)

=> fast calculation

PARMILA(PICNIC3D)

• Multi-Particle
•Space-charge calc.:
  - PIC
  - grid: 3.5*(X/Y)_rms
  - gauß distributed charges on gridpoints
  - 3D-Solver

=> more accurate output

$$A = (2\cdot X_{max})\times(2\cdot Y_{max}) < 3\times 3 \; [cm^2]$$

$$\Delta T < 1[ns]$$

Beam-Dynamics

TRACE3D-Input

```
ER=  938.28000   Q= 1.   W=    1.90000   XI=  200.000
EMITI=     25.0000     25.0000    700.0000
BEAMI =     0.0000      5.0000      0.0000      5.0000      0.1000      0.3000
BEAMCI=     0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
BEAMC =     0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
BEAMF =     1.9000      2.9000      1.1000      2.5000      0.1000      0.3000
FREQ=  175.000,  PQEXT=  2.50, ICHROM= 0, IBS= 0 XC=  0.00
XM= 60.0,  XPM= 15.0000,  YM= 60.0,  DPM=180.,  DWM=  100.,  DPP= 180.
N1=    1,  N2=     9,   SMAX=  5.0,  PQSMAX=  2.0
NEL1 =   1,  NEL2 =   9,  NP1 =   1,  NP2 =   9
MT=  8   NC=  4   LOC=   0   0   0

     MP(1,N)  MP(2,N)   VALUE        MVC       VALUE
        1        2     -4.000

        1        4      20.00

        1        6      20.00

        1        8     -4.000

            n  NT(n)   A(1,n)      A(2,n)      A(3,n)      A(4,n)      A(5,n)
drift       1    1   600.0000
edge        2    9    -4.0000   220.0000     30.0000      0.4500      2.8000
BEND        3    8    70.0000   220.0000      0.0000      0.0000
edge        4    9    20.0000   220.0000     30.0000      0.4500      2.8000
drift       5    1   300.0000
edge        6    9    20.0000   220.0000     30.0000      0.4500      2.8000
BEND        7    8    70.0000   220.0000      0.0000      0.0000
edge        8    9    -4.0000   220.0000     30.0000      0.4500      2.8000
drift       9    1   600.0000

            FRANZ-Test
```

Twiss-Parameter

$$\alpha_{x,y} = 0.0$$

$$\beta_{x,y} = 5.0 \left[\frac{mrad}{mm}\right]$$

$$\epsilon_{x,y} = 25.0 \; [\pi \cdot mm \cdot mrad]$$

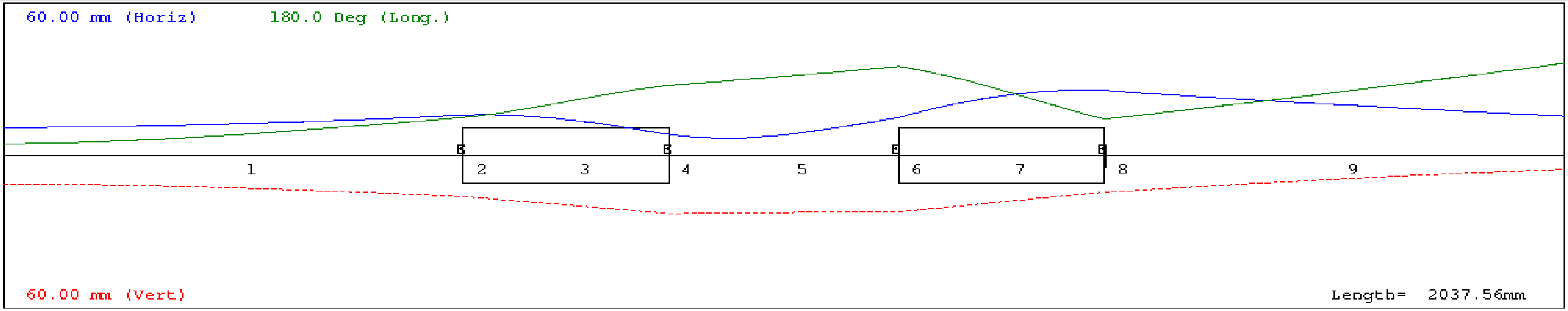
$$\epsilon^n_{x,y} = 1.6 \; [\pi \cdot mm \cdot mrad]$$

$$\alpha_z = 0.1$$

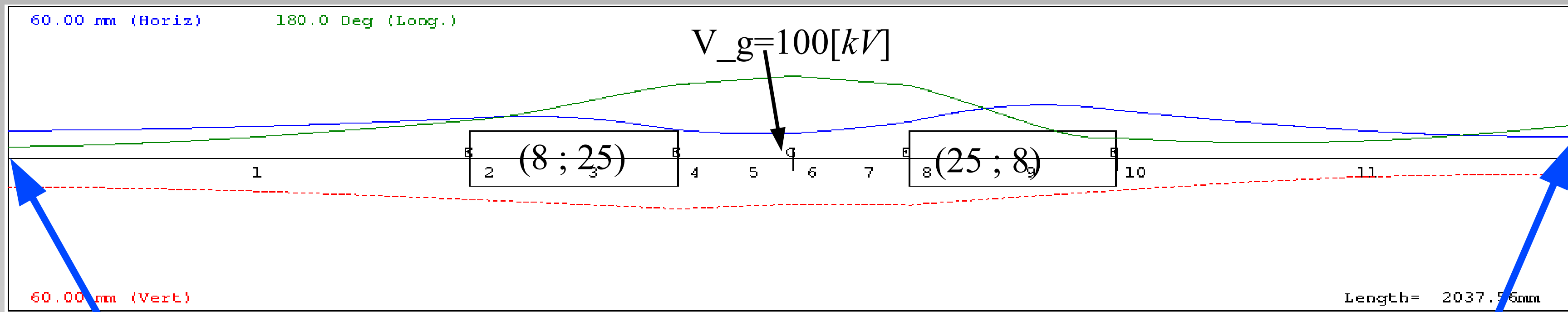
$$\beta_z = 0.3 \left[\frac{keV}{deg}\right]$$

$$\epsilon_z = 700.0 \; [\pi \cdot deg \cdot keV]$$

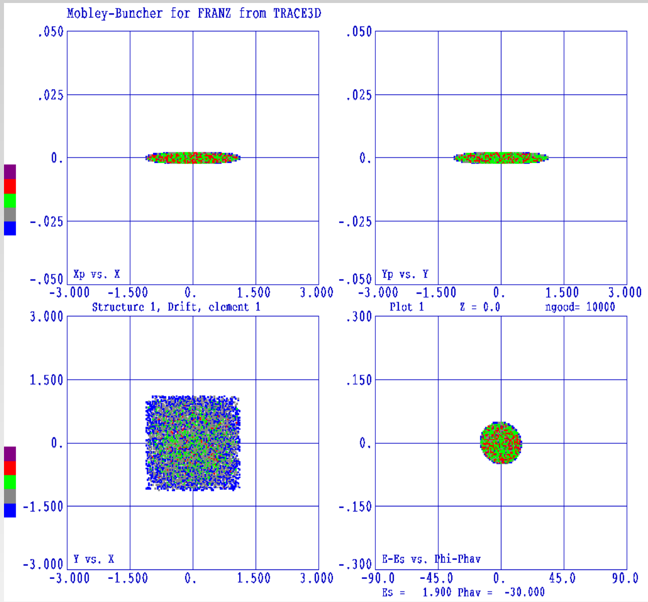
$$\epsilon^n_z = 44.8 \; [\pi \cdot deg \cdot keV]$$

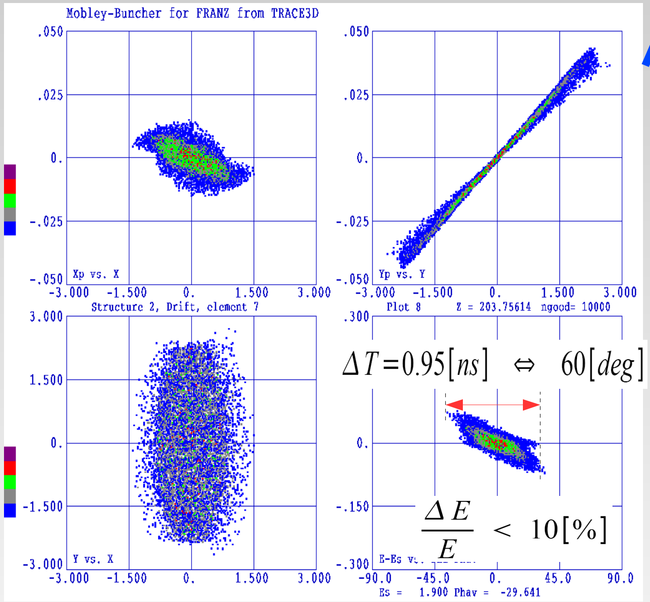


Beam-Dynamics

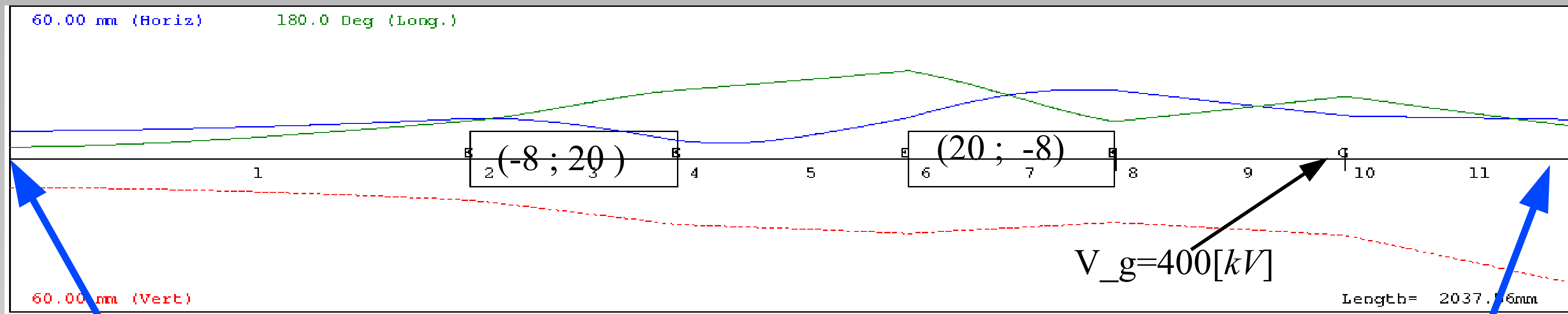


PARMILA(PICNIC3D): I=200[mA],10000 [particle], 100[calls/m]

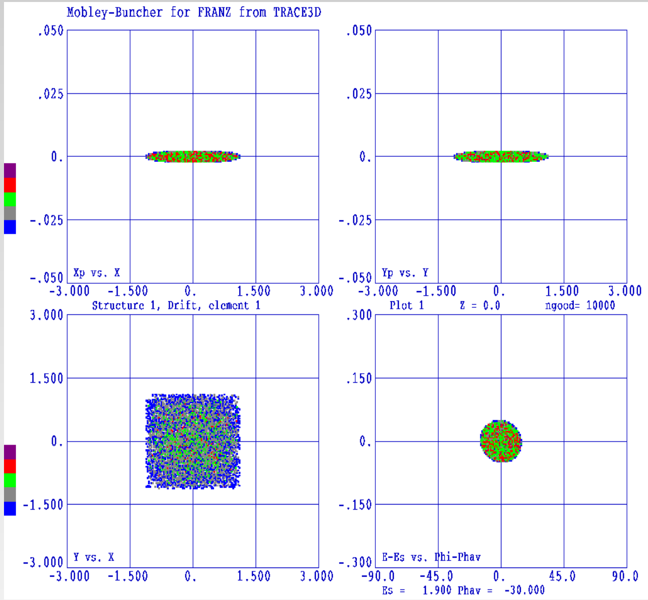


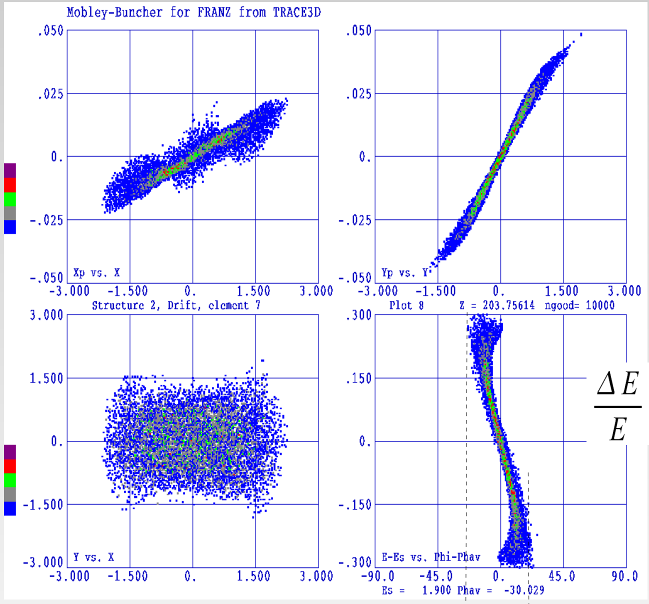


Beam-Dynamics



PARMILA(PICNIC3D): I=200[mA],10000 [particle], 100[calls/m]



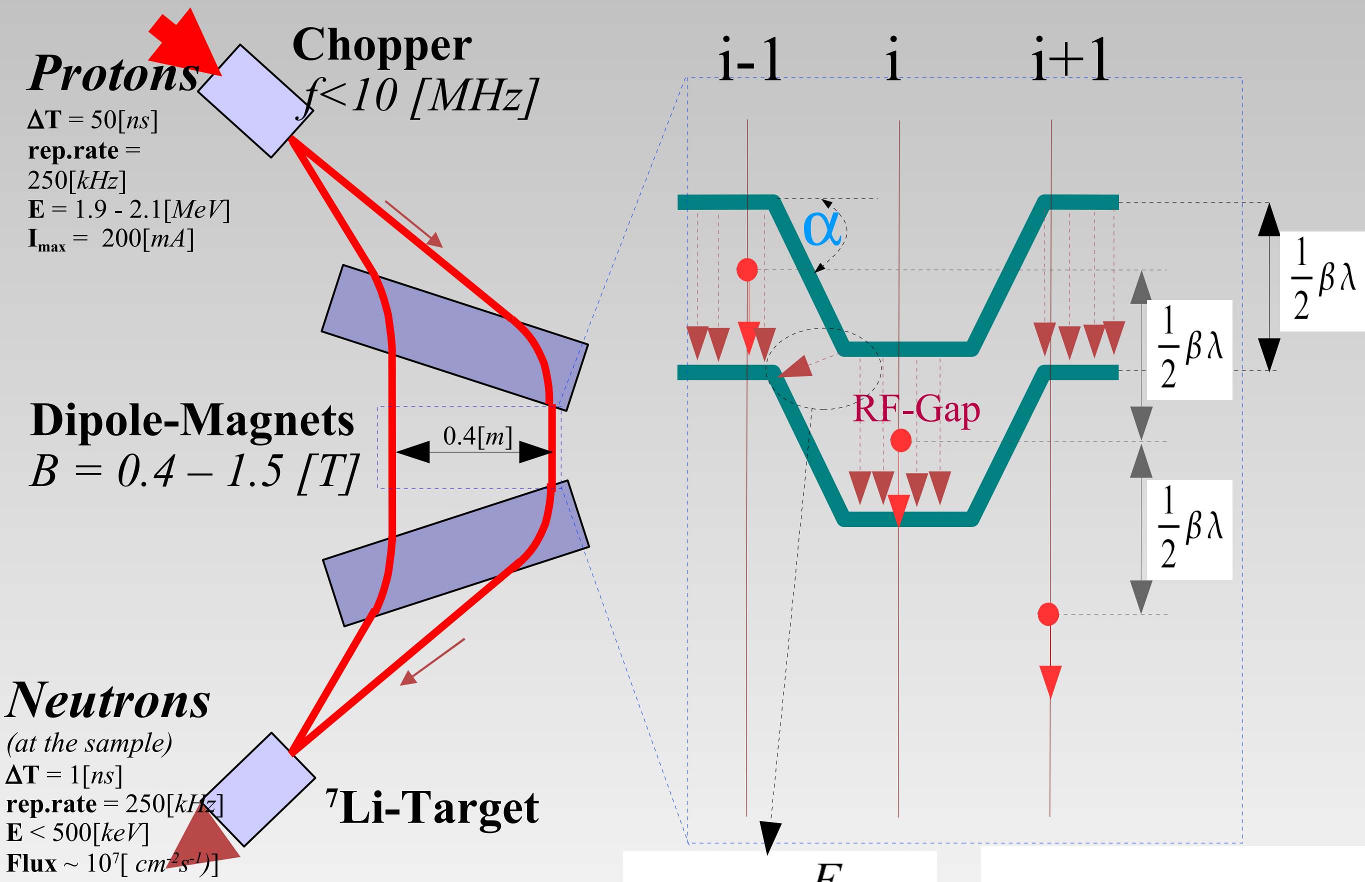


$$\frac{\Delta E}{E} = 30[\%]$$

$$\Delta T = 0.71[ns] \Leftrightarrow 45[deg]$$

RF-Gap: Config1

Mikro-Bunche



$$f = 175[MHz]$$

$$\beta = 0.064$$

$$V_{gap} = 100[kV]$$

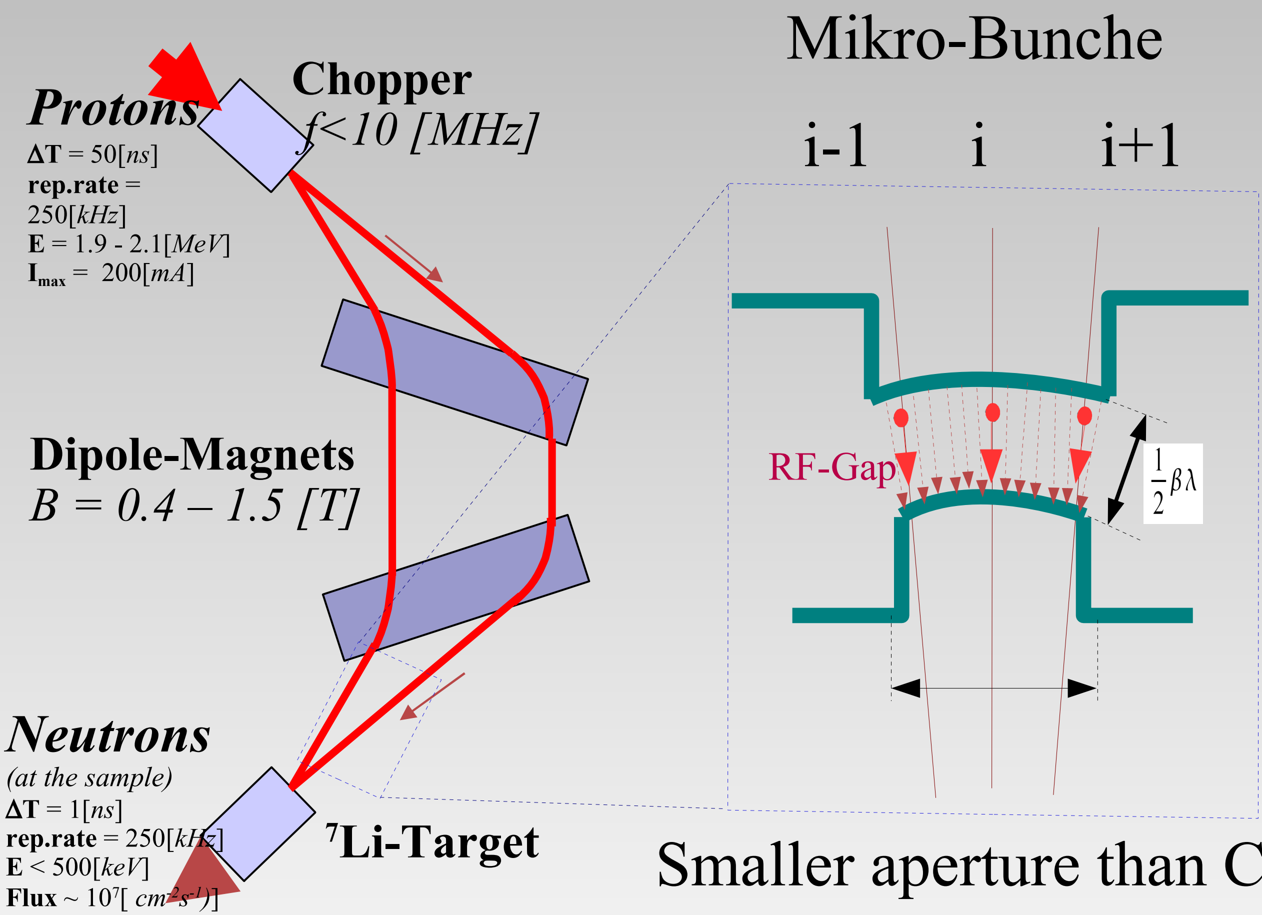
$$\Rightarrow \quad \beta\lambda = 0.111[m]$$

$$\Rightarrow \quad E_{gap} = \frac{V_{gap}}{\frac{1}{2}\beta\lambda} = 1.8\left[\frac{MV}{m}\right]$$

$$E_{gap}^{peak} = \frac{E_{gap}}{\cos(\alpha)}$$

$$Killpatrick: \quad 175[MHz] \Rightarrow \quad E_{max} = 13\left[\frac{MV}{m}\right]$$

RF-Gap: Config2



$$V_{gap} = 400[kV]$$

$$E_{gap} = 7.2\left[\frac{MV}{m}\right]$$

Smaller aperture than Config1

Gap-Geometry => transversal *and* longitudinal focussing per bunch!

Chopper-System

Electrical Deflector:

- E(t), capacitor
- LC-oscillator
- sine-pulse

Pro:
- technical realisation

Contra:
- longitudinale Energy-shift(?), first estimation without fringe-fields
- max. deflection<=> Gap (!)
- max. deflection<=> E_max, sparking(!)
- f > 5[*MHz*], air-coil(!)
- rf-amplifier
- skin-Effekt
- EM-radiation

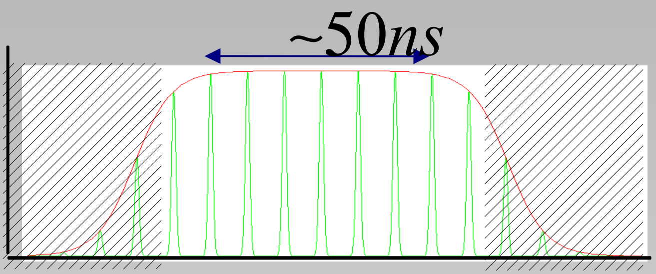
Electro-magnetic Deflector:

- B(t), dipole with ferritic yoke (*J.-C. Sun*)
- triggering by high-voltage-switchs
- variable pulse(!)

Pro:
- *no* Energy-shift
- max. deflection independent from gap (!)
- pulse-repetition ~ 250[kHz] (!)

Contra:
- material costs
- Ferrite: small gradient, B_max (!!)
- technical realisation of the trigger-system
- eddy current, powerloss

Chopper-Frequency (el.Deflector)



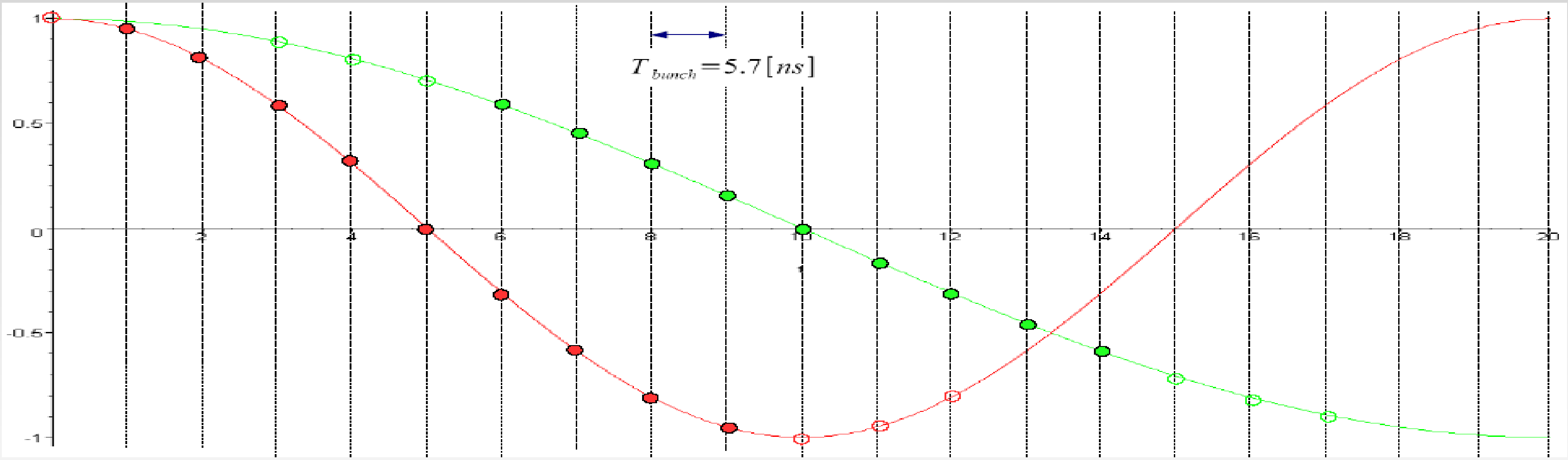
9 Bunche => 1/2 T :

9 Bunche => 1/4 T :

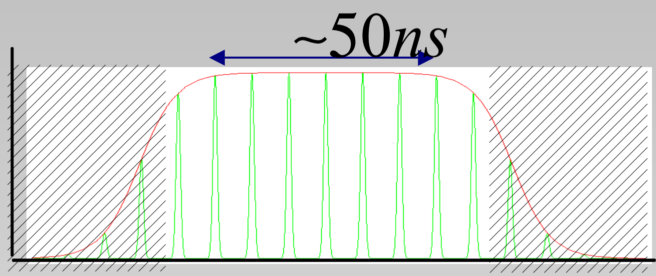
$$f_{bunch} = 175[MHz] \Leftrightarrow T_{bunch} = 5.7[ns]$$

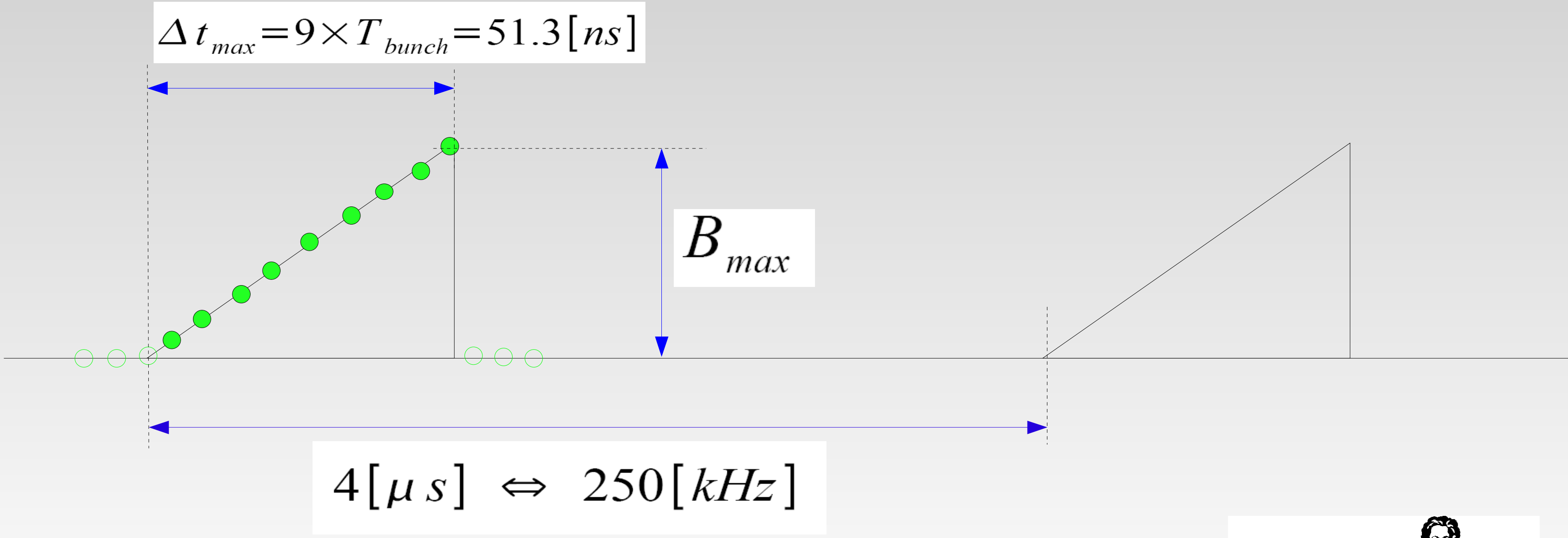
$$(9+1) \times T_{bunch} = 57.0[ns] = \frac{1}{2} T_{chopper} \Leftrightarrow f_{chopper} = 8.75[MHz]$$

$$(9+1) \times T_{bunch} = 57.0[ns] = \frac{1}{4} T_{chopper} \Leftrightarrow f_{chopper} = 4.38[MHz]$$

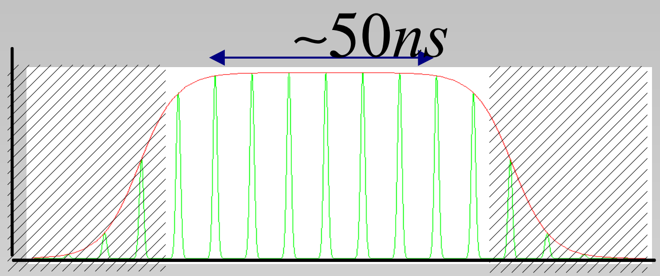


Chopper-Frequency (el.mag.Deflector)



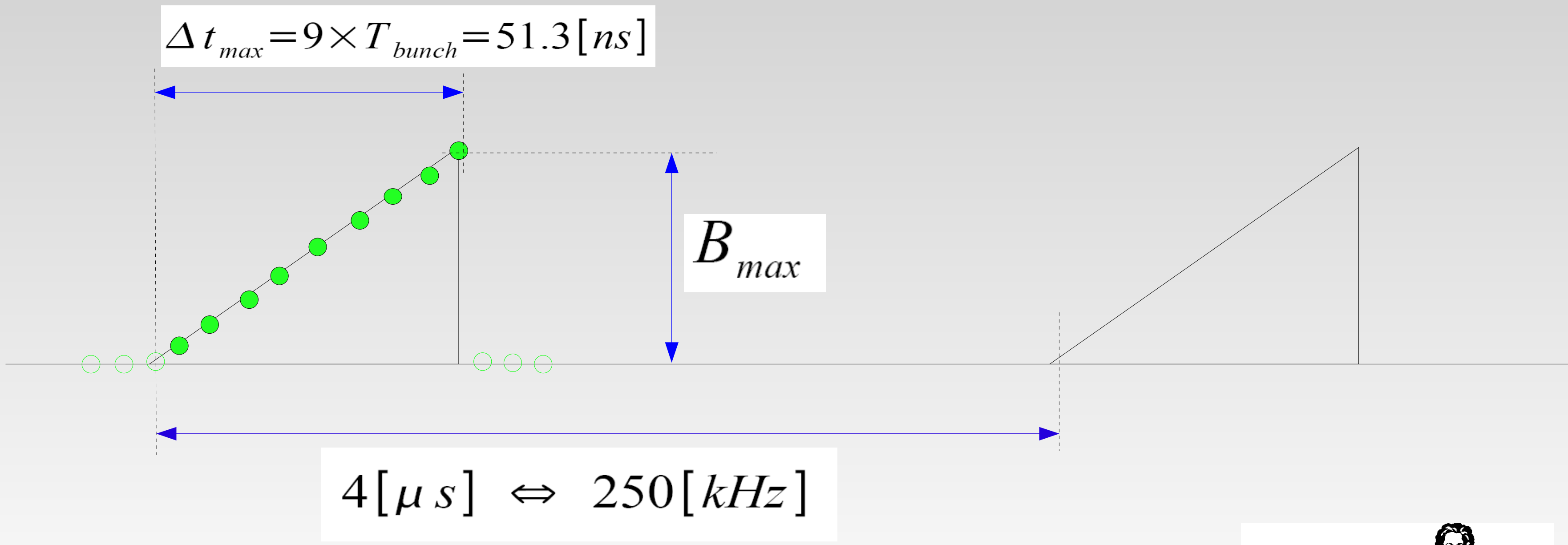


Chopper-Frequency (el.mag.Deflector)



Max. performance factor(f *B_max/[Hz T])
at PV=500[mW/cm^3] <=> 100[°C]:

80[kHz T]: $B_{max} = 80 \cdot 10^3 [Hz \;\; T] \times 51.3 \cdot 10^{-9} [s] = 4.1 [mT]$



TO DO

Beam-Dynamics

- LORASR, dispersion function, achromate design
- Twiss-paramters and emittances after Chopper [E(t), B(t)]

Chopper

- effect of fringe fields for both chopper concepts,
  energy shift due to the el.chopper
- E_max, B_max

RF-Gap (LINAC-AG)

- design
- optimisation