1. Official Setup

2. Increased Magnet Length (0.3m → 0.5m)  
   (full length = const)

3. Increased M2-M3 Drift  
   (0.5m magnets)  
   Movable BC Chamber  
   (Winni’s arguments)

4. Flat & Round Chamber for BC2  
   (0.5m magnets, increased M2-M3 drift)

5. Reduced M1-M2 & M3-M4 Drift  
   (0.5m magnets, flat chamber)

6. Conclusion
1. Official Setup

see FEL Beam Dynamics Group Talks: 18.12.2006 Bunch Compression System Review
http://www.desy.de/xfel-beam/data/talks/talks/bc_review/dohlus_-_bc_review_s2e_sim_20061218.pdf

Winni’s EXCEL table (Dec 2005)

Klaus’s gun & ACC0 settings: 1nC, 50A \rightarrow \varepsilon_{\text{slice}} \approx 0.58 \text{ \mu m}
(used for s2e simulations)

\rightarrow 6.9 \text{ MeV}
\rightarrow 130 \text{ MeV}, \text{ dog leg, laser heater}
\rightarrow 500 \text{ MeV}, 3r \text{ harm. rf, } 50A \rightarrow 1kA, r56 \approx 103 \text{ mm}
\rightarrow 2 \text{ GeV}, \text{ on crest, } 1kA \rightarrow 5kA, r56 \approx 14 (17) \text{ mm}
\rightarrow 17.5 \text{ MeV}
notation: magnet length

<table>
<thead>
<tr>
<th></th>
<th>drift M1→M2 &amp; M3→M4</th>
<th>drift M2→M3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC1</td>
<td>0.3_8.9_1.0</td>
<td></td>
</tr>
<tr>
<td>r56/mm</td>
<td>-0.103258</td>
<td></td>
</tr>
<tr>
<td>BC2</td>
<td>0.3_8.9_1.0</td>
<td></td>
</tr>
<tr>
<td>r56/mm</td>
<td>-0.0175798</td>
<td></td>
</tr>
</tbody>
</table>

maximal offset (x/m) | B/T bending radius/m

- BC1: $\max(\gamma) = 0.382$  
  $B(\gamma,\beta) = 0.417$  
  $R = 4$
- BC2: $\max(\gamma) = 0.386$  
  $B(\gamma,\beta) = 0.651$  
  $R = 9.66$

trajectory (x/cm)

<table>
<thead>
<tr>
<th>$\beta_x/m$</th>
<th>$\beta_y/m$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

optics for all following calculations unchanged

phase advance BC1 → BC2 increased by $\pi$ compared to EXCEL table
# peak current and projected x-emittance

<table>
<thead>
<tr>
<th>Flat Chamber</th>
<th>BC1</th>
<th>BC2</th>
<th>BC2, r56 tuned</th>
</tr>
</thead>
<tbody>
<tr>
<td>cu, h/mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;2x4&quot;</td>
<td>Ipeak/A=1005</td>
<td>Ipeak/A=5831</td>
<td>Ipeak/A=5054</td>
</tr>
<tr>
<td></td>
<td>emit_hor/um=1.13</td>
<td>emit_hor/um=2.24</td>
<td>emit_hor/um=1.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r56/mm=-0.016975</td>
</tr>
<tr>
<td>&quot;2x5&quot;</td>
<td>Ipeak/A=1004</td>
<td>Ipeak/A=5735</td>
<td>Ipeak/A=5.047</td>
</tr>
<tr>
<td></td>
<td>emit_hor/um=1.12</td>
<td>emit_hor/um=2.07</td>
<td>emit_hor/um=1.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r56/mm=-0.017034</td>
</tr>
<tr>
<td>&quot;2x8&quot;</td>
<td>Ipeak/A=1003</td>
<td>Ipeak/A=5603</td>
<td>Ipeak/A=5041</td>
</tr>
<tr>
<td></td>
<td>emit_hor/um=1.23</td>
<td>emit_hor/um=1.69</td>
<td>emit_hor/um=1.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r56/mm=-0.017119</td>
</tr>
<tr>
<td>&quot;2x10&quot;</td>
<td>Ipeak/A=1003</td>
<td>Ipeak/A=5571</td>
<td>Ipeak/A=5035</td>
</tr>
<tr>
<td></td>
<td>emit_hor/um=1.29</td>
<td>emit_hor/um=1.50</td>
<td>emit_hor/um=1.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r56/mm=-0.017141</td>
</tr>
<tr>
<td>&quot;inf&quot;</td>
<td>Ipeak/A=1001</td>
<td>Ipeak/A=5124</td>
<td>Ipeak/A=5009</td>
</tr>
<tr>
<td></td>
<td>emit_hor/um=1.39</td>
<td>emit_hor/um=1.16</td>
<td>emit_hor/um=1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r56/mm=-0.017474</td>
</tr>
</tbody>
</table>
peak current and projected x-emittance

BC1=0.3_8.9_1.0
BC2=0.3_8.9_1.0
2. Increased Magnet Length (0.3m → 0.5m)
(full length = const)

BC1=0.5_8.5_1.0
r56/mm=-0.103258

BC2=0.5_8.5_1.0
r56/mm=-0.0175798

![Graph BC1](image)

BC1  \[Y(0) = 0.287\]  B(R,γ1) = 0.254  R = 6.569

![Graph BC2](image)

BC2  \[Y(0) = 0.284\]  E(R,γ2) = 0.421  R = 15.863
peak current and projected x-emittance

BC1=0.5_8.5_1.0
BC2=0.5_8.5_1.0

gray = official setup
3. Increased M2-M3 Drift

(0.5m magnets)

C1=0.5_8.5_3.3
r56/mm=-0.103258

C2=0.5_8.5_2.0
r56/mm=-0.0175798
peak current and projected x-emittance

BC1 = 0.5_8.5_3.3
BC2 = 0.5_8.5_2.0

gray = official setup

h = 4cm
cu, st

grey = official setup
Arguments for movable bunch compressors

Variable R56

The compression scenario of the XFEL incorporates 2 bunch compressor chicanes. The nominal setting requires a compression by a factor of 100. The compression can be varied by varying the R56 (the ratio of path length variation with varying energy), which in turn is done by varying the angle (or offset) of the chicane.

The compression scenarios for the XFEL have been laid out such that a broad range of parameters (different bunch length or peak currents) can be obtained. The exact balance of the compression factors depends on many parameters which are not well defined yet. That requires a large variation of the R56 in the two chicanes.

The first bunch compression chicane requires the smallest variation in R56, because even a small compression factor of 4 requires an R56 of at least 75 mm (assuming a correlated energy spread of 2% and 2 mm initial bunch length). The maximum R56 is about 105 mm for a compression of 20. Consequently, the 2nd chicane requires a larger tuning range.

Assuming a constant total compression of 100, the extreme cases are an R56 of 20 mm for the compression factor 5 and an R56 of 80 mm for the factor 20 compression (assuming an energy of 2 GeV at BC3).

The following table summarizes the values - note that this is only one possible scenario and for instance the chicane offset depends strongly on the exact geometry of the chicane.

<table>
<thead>
<tr>
<th></th>
<th>Compression Factor</th>
<th>R56 [mm]</th>
<th>Chicane Angle [deg]</th>
<th>Chicane Offset [mm]</th>
<th>Full Beam Width [mm]</th>
<th>Beam Pipe Width for +/-10% R56 variation [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>4</td>
<td>75</td>
<td>3.7</td>
<td>590</td>
<td>4</td>
<td>-30, +30</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>105</td>
<td>4.4</td>
<td>690</td>
<td>4</td>
<td>-35, +32</td>
</tr>
<tr>
<td>B2</td>
<td>20</td>
<td>80</td>
<td>3.8</td>
<td>600</td>
<td>1</td>
<td>-35, +32</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>20</td>
<td>1.9</td>
<td>300</td>
<td>0.25</td>
<td>-15, +15</td>
</tr>
</tbody>
</table>
Winni's Arguments ...

Vacuum Chamber

A movable vacuum chamber can be positioned according to the required R56. A certain R56 range should be reachable without moving the chamber, thus a full width of 70 to 80 mm is necessary. A large aperture chamber has to span the complete movable range, yielding a total width of 450 mm.

<table>
<thead>
<tr>
<th>Inner Dimensions</th>
<th>Movable Chamber</th>
<th>Fixed Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80 x -40 mm</td>
<td>450 x -40mm</td>
</tr>
</tbody>
</table>

**Advantages**
- dipole gap can be small
- energy resolving bpm is easier
- damage risk smaller

**Disadvantages**
- moving bellows are always a potential risk for operation
- flexible bellows cannot be shielded due to the dust-free requirements
- complicated vacuum design
- large dipole gap required
- energy resolving bpm difficult
4. Flat & Round Chamber for BC2
(0.5m magnets, increased M2-M3 drift)

BC1=0.5_8.5_3.3
r56/mm=-0.103258
flat (2x20mm)

BC2=0.5_8.5_2.0
r56/mm=-0.0175798
flat (2x20mm), round (d=100mm)
impedance:

\[ Z \approx 71 \Omega \]

flat to round &
round to flat

\[ |Z| \text{ small} \]
impedance ... flat to round
& round to flat

Igor's mathematica:

Z/\Omega

"flat to round"
Z = 81.7406 \Omega

"round to flat"
Z \approx 0.829439 \Omega

Impedance Calculations of Non-Axisymmetric
Transitions Using the Optical Approximation*

SLAC-PUB-12370
K.L.F. Bane, G. Stupakov
DESY-07-023
Stanford Linear Accelerator Center.
February 2007
Stanford University, Stanford, CA 94309

I. Zagorodnov
Deutsches Elektronen-Synchrotron, Notkestrasse 85, 22607 Hamburg, Germany
\[ Z_f \rightarrow r \approx 80 \Omega \]
\[ Z_r \rightarrow f \approx 0 \Omega \]

**BC1: flat chamber in BC1**

- "2x20" cu
  - I\(_{\text{peak}}/A = 1002\)
  - emit\(_{\text{hor/um}} = 1.56\)

- "inf"
  - I\(_{\text{peak}}/A = 996\)
  - emit\(_{\text{hor/um}} = 1.61\)

- "2x20" st
  - I\(_{\text{peak}}/A = 1001\)
  - emit\(_{\text{hor/um}} = 1.31\)

**BC2: flat & round**

- I\(_{\text{peak}}/A = 5076\)
  - emit\(_{\text{hor/um}} = 1.36\)

- I\(_{\text{peak}}/A = 5005\)
  - emit\(_{\text{hor/um}} = 1.12\)

- I\(_{\text{peak}}/A = 5065\)
  - emit\(_{\text{hor/um}} = 1.59\)
magnitudes of effects:

- \( V \frac{1}{nC \cdot m} = \sigma \)
- \( \mu m \ 25 = \sigma \)

Graphs show the wake per length (V/μC/m) for different scenarios:
- copper \( H=2\times 20mm \), round and flat pipe
- \( \sigma = 25 \mu m \)

Additional graph:
- wake for impedance \( Z=80 \text{Ohm} \)
long. field along BC2:

\[ \text{resistive wall (cu flat)} \]

\[ \mu \text{m} = 25 \text{ \mu m} \]

\[ \sigma \approx 80 \text{ \Omega} \]

\[ Z_f \rightarrow r \approx 80 \text{ \Omega} \]

\[ \text{step f } \rightarrow r \]

\[ \text{long field vs position} \]

\[ \text{change of energy vs position} \]

\[ \text{(cu flat)} \]
5. Reduced M1-M2 & M3-M4 Drift
(0.5m magnets, flat chamber)

<table>
<thead>
<tr>
<th>L / m</th>
<th>L_tot / m</th>
<th>max(x1) / cm</th>
<th>B1 / T</th>
<th>max(x2) / cm</th>
<th>B2 / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5</td>
<td>20</td>
<td>69</td>
<td>0.278</td>
<td>28</td>
<td>0.421</td>
</tr>
<tr>
<td>7.0</td>
<td>17</td>
<td>63</td>
<td>0.000</td>
<td>26</td>
<td>0.461</td>
</tr>
<tr>
<td>5.5</td>
<td>14</td>
<td>56</td>
<td>0.312</td>
<td>23</td>
<td>0.517</td>
</tr>
<tr>
<td>4.0</td>
<td>11</td>
<td>49</td>
<td>0.361</td>
<td>20</td>
<td>0.600</td>
</tr>
<tr>
<td>2.5</td>
<td>8</td>
<td>40</td>
<td>0.445</td>
<td>17</td>
<td>0.741</td>
</tr>
</tbody>
</table>
BC1 = 0.5_7.0_1.0
r56/mm = -0.103258

BC2 = 0.5_7.0_1.0
r56/mm = -0.0175798
BC1=0.5_5.5_1.0
r56/mm=-0.103258

BC2=0.5_5.5_1.0
r56/mm=-0.0175798
BC1 = 0.5_4.0_1.0  
r56/mm = -0.103258

BC2 = 0.5_4.0_1.0  
r56/mm = -0.0175798
BC1 = 0.5_2.5_1.0
r56/mm = -0.103258

BC2 = 0.5_2.5_1.0
r56/mm = -0.0175798
peak current and projected x-emittance

<table>
<thead>
<tr>
<th>L / m</th>
<th>L_tot / m</th>
<th>max(x1) / cm</th>
<th>B1 / T</th>
<th>max(x2) / cm</th>
<th>B2 / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>17</td>
<td>63</td>
<td>0.000</td>
<td>26</td>
<td>0.461</td>
</tr>
</tbody>
</table>

gray = official setup
peak current and projected x-emittance

<table>
<thead>
<tr>
<th>L / m</th>
<th>L_tot / m</th>
<th>max(x1) / cm</th>
<th>B1 / T</th>
<th>max(x2) / cm</th>
<th>B2 / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>14</td>
<td>56</td>
<td>0.312</td>
<td>23</td>
<td>0.517</td>
</tr>
</tbody>
</table>

![Graph showing peak current and projected x-emittance](image)
peak current and projected x-emittance

<table>
<thead>
<tr>
<th>L / m</th>
<th>L_tot / m</th>
<th>max(x1) / cm</th>
<th>B1 / T</th>
<th>max(x2) / cm</th>
<th>B2 / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>11</td>
<td>49</td>
<td>0.361</td>
<td>20</td>
<td>0.600</td>
</tr>
</tbody>
</table>
peak current and projected x-emittance

<table>
<thead>
<tr>
<th>L / m</th>
<th>L_tot / m</th>
<th>max(x1) / cm</th>
<th>B1 / T</th>
<th>max(x2) / cm</th>
<th>B2 / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>8</td>
<td>40</td>
<td>0.445</td>
<td>17</td>
<td>0.741</td>
</tr>
</tbody>
</table>

![Graph showing peak current and projected x-emittance](image)
6. Conclusions

shielding vs resistive wall wake:
  avoid rww → no or weak shielding
  high and wide chamber
  copper

increased magnet length (0.3 → 0.5m) ok

increased drift length (M2→M3):
  projected emittance growth slightly increased
  after BC1 but compensated in BC2

BC2 with movable chamber **(operation different from 20x5 design!)**

BC2: bellows & round pipes for drift (M1→M2, M3→M4)
  projected emittance increased from ~1.15 to ~1.35
  → more work, better ideas

reduced drift length (M1→M2, M3→M4)
  projected emittance after BC1 increased
  essentially compensated in BC2 for Ltot > 11m

do not believe too much in compensation of effects in BC1 and BC2
  (depends on optics, idealized particle dynamics, 20x5 compression with design parameters …)
  only with design parameters!