Femtosource Advisory Committee Meeting

- Collective Effects -

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Vertical Emittance Preservation !

…with our present nominal parameters, but also:

Future upgrades

Is it possible to change something in the design for just an incremental cost ?

- Maximum bunch current
- Maximum repetition rate

Summary

- Single-bunch effects
  - Beam break up → CSR induced
  - Linac alignment
  - Resistive wall
- Multi-bunch effects
  - Beam break up
- "Decelerator"

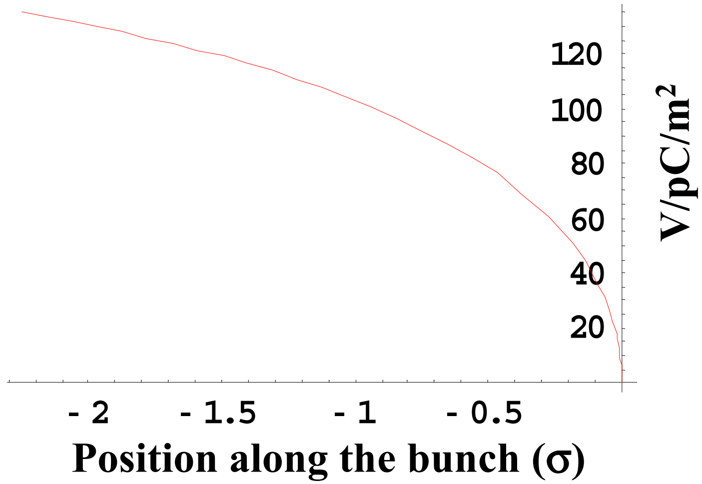
Max. bunch current (single-bunch effects)

Bunch trains ?
Higher rep. rate ? (multi-bunch effects)

Single-bunch BBU 1

Source: short range wake fields (transverse).
Effect: vertical emittance increase through variable displacement along the bunch.

Transverse wake field for the RF cavities *(from A. Mosnier)*:



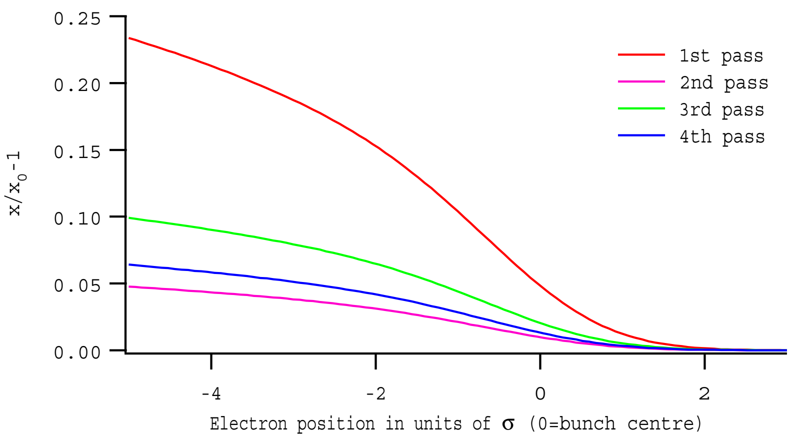
Analytic fit:

$$1290\sqrt{s} - 2600\ s\ \ (\mathrm{V/pC/m^2})$$

Single-bunch BBU 2

Since there are no focussing elements in the linac, the equation of motion can be solved by
successive iterations:

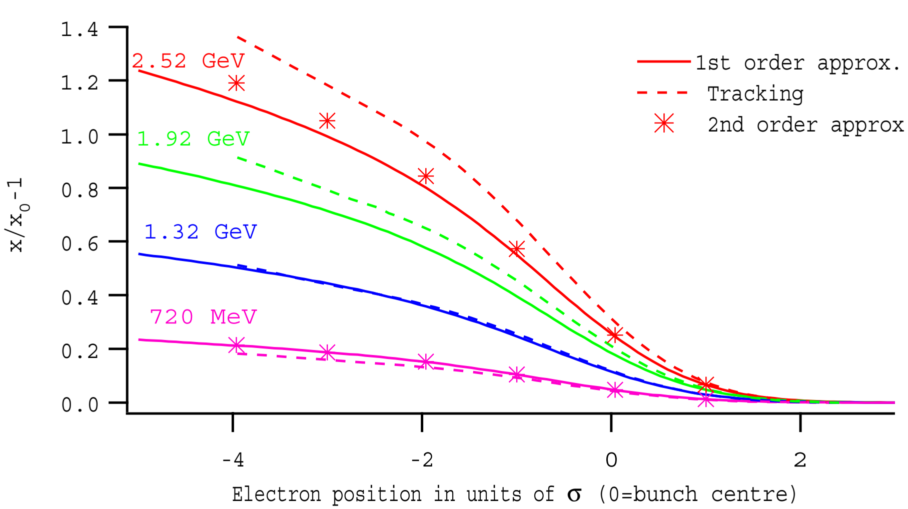
$$\frac{d}{ds}\left[\gamma(s)\frac{d}{ds}y_{(n)}(z,s)\right] = r_0\int_0^\infty \rho(z-z')W_\perp(z')y_{(n-1)}(z-z',s)dz'$$

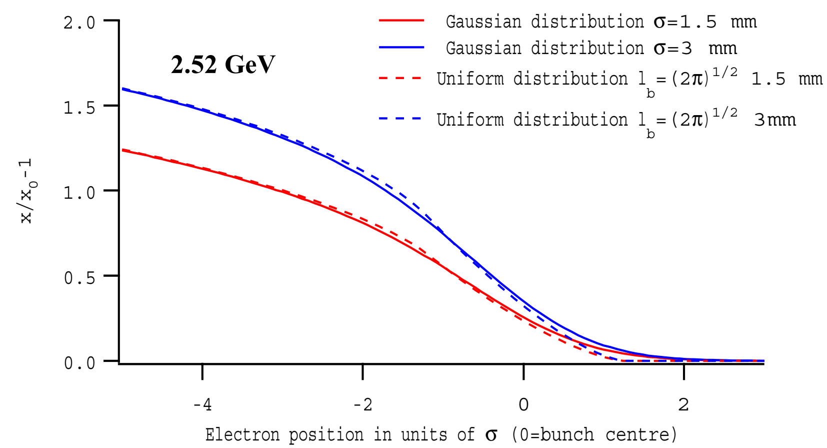


$$y_{(1)}(z,s=L) = y_0 + y_0\frac{r_0\gamma_i L^2}{(\Delta\gamma)^2}\int_0^\infty \rho(z-z')W_\perp(z')dz'\left[\frac{\Delta\gamma}{\gamma_i} - \ln\left(1+\frac{\Delta\gamma}{\gamma_i}\right)\right] + y_0' L\frac{\gamma_i}{\Delta\gamma}\ln\left(1+\frac{\Delta\gamma}{\gamma_i}\right)$$

Given our machine parameters, the first order solution is already good enough.

Single-bunch BBU 3





The analytical results have been compared to a tracking code output.
In the figure above, we assume no initial angle error.

The bunch distribution has a negligible effect on the displacement, which is strongly affected by the bunch length instead.

Main Linac Alignment

Main linac has 32 RF cavities divided in 4 cryomodules.

- Misalignments in RF Cavities: 500 µm rms value (from manifacturer, we can't change it).
- Misalignments in cryomodules: 150 µm rms value (estimate from ALS data).

$$\left\langle y^2\right\rangle^{1/2} = \frac{r_0\gamma_i L^2}{(\Delta\gamma)^2}\int_0^\infty \rho(z-z')W_\perp(z')dz'\sqrt{\sum_{i=0}^{N_{cav}-1}F_i^2(s)\left\langle d_c^2\right\rangle + \sum_{i=0}^{N_{\mathrm{mod}}-1}G_i^2(s)\left\langle d_m^2\right\rangle}$$

Displacement with no initial error ($y_0 = y_0' = 0$).

For example, after the first pass, at the bunch centre: $\left\langle y^2(z=0)\right\rangle^{1/2} \approx 0.017\sqrt{1.21\left\langle d_c^2\right\rangle + 9.30\left\langle d_m^2\right\rangle}$

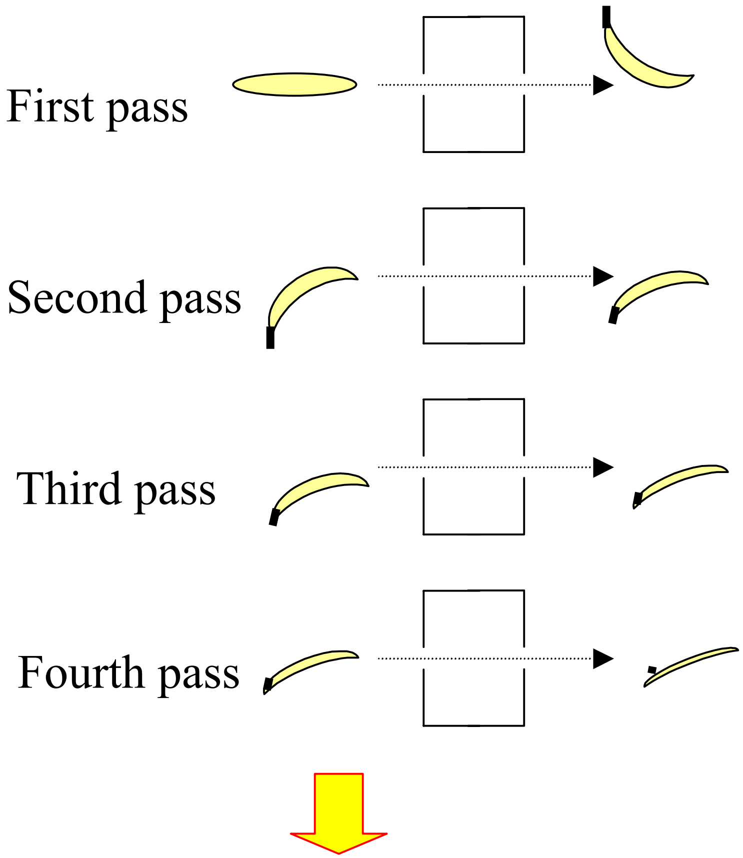
Main Linac Alignment: Cures 1

offset increases….tilt is canceled

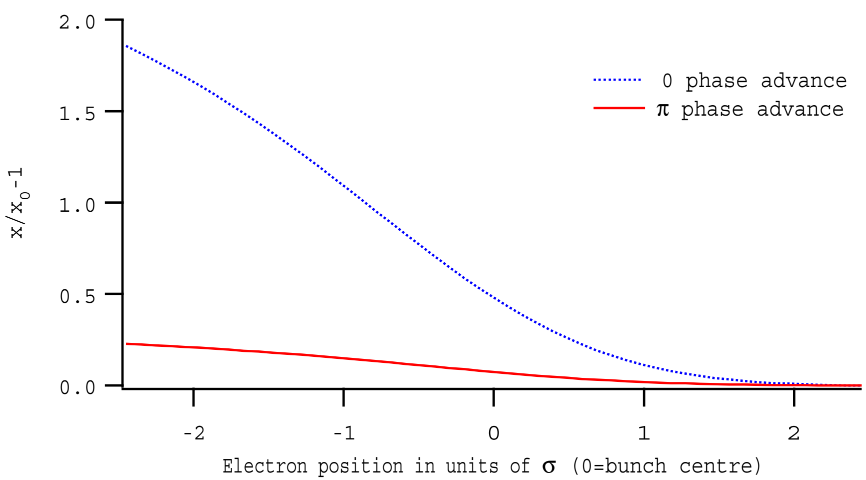
$$y(z) = y_0 + \underline{\underline{F(W_\perp, z, \gamma_i)}} \left\{ y_0 \left[\frac{\Delta\gamma}{\gamma_i} - \ln\left(1 + \frac{\Delta\gamma}{\gamma_i}\right) \right] + \sum F_i d_{ci} + \sum G_j d_{mj} \right\} + y_0' L \frac{\gamma_i}{\Delta\gamma} \ln\left(1 + \frac{\Delta\gamma}{\gamma_i}\right)$$

It is possible to cancel the displacement dependance on the particle position inside the bunch (no tilt) by introducing an appropriate initial offset. This requires accurate BBU measurement.

Main Linac Alignment: Cures 2



If the first arc has a phase advance of π, subsequent passes through the linac tend to cancel the effect of the first pass (there is no total cancellation because of the different energies).



Pre-accelerator

Single cryomodule linac accelerating the beam from 10 to 120 MeV

- Analytical study is more difficult because of the large energy relative change.
- Since higher energy are beneficial, we made conservative estimates considering a constant energy beam of 10 MeV.
- RF focussing effect taken into account ($\sim G/\gamma$).

$$\frac{\Delta y(z=0)}{y_0} \leq 3\ 10^{-3}\ !$$

Resistive Wall

Transverse wake:

$$W_{RW}(z) = \frac{c\,L}{\pi\, b^3}\sqrt{\frac{Z_0}{\pi\,\sigma_{Al}}}\int_z^{\infty}\frac{\rho(z')}{\sqrt{|z-z'|}}\,dz'$$

- Bunch length
- Beam pipe material
- Beam pipe diameter

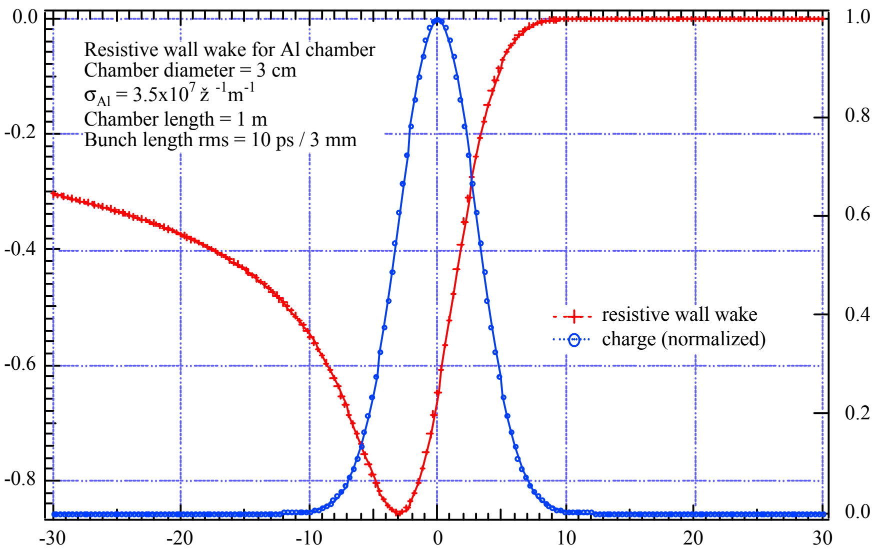
Vertical kick:

$$\Delta y'(z) = \frac{Q_b\, y(z)}{E/e}\, W_{RW}(z)$$

- Beam energy
- Charge per bunch

- Focussing and betatron motion
- Coherent synchrotron radiation
- Energy spread
- Flat beam pipe (+ 20%)

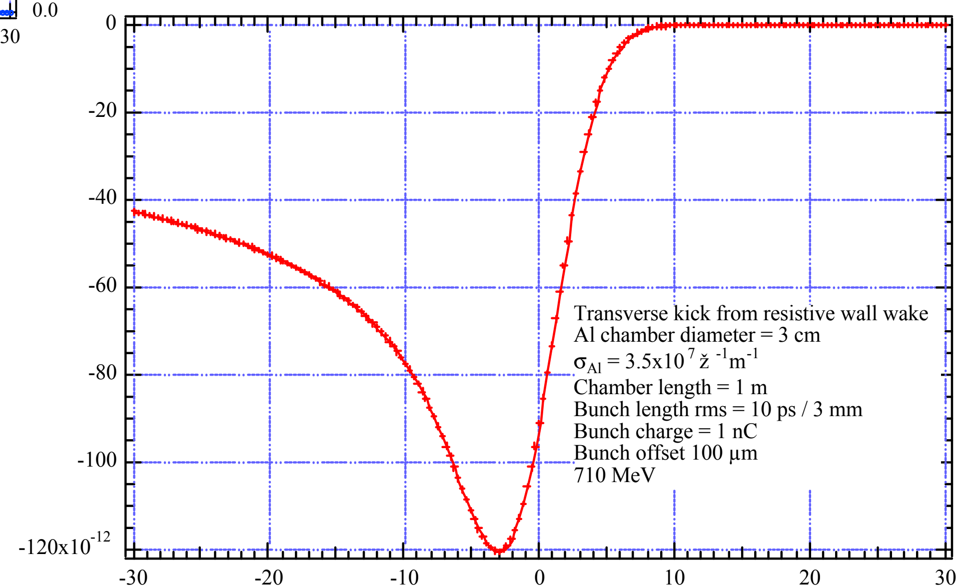
Resistive Wall: Lower Energy



Position relative to bunch center, mm

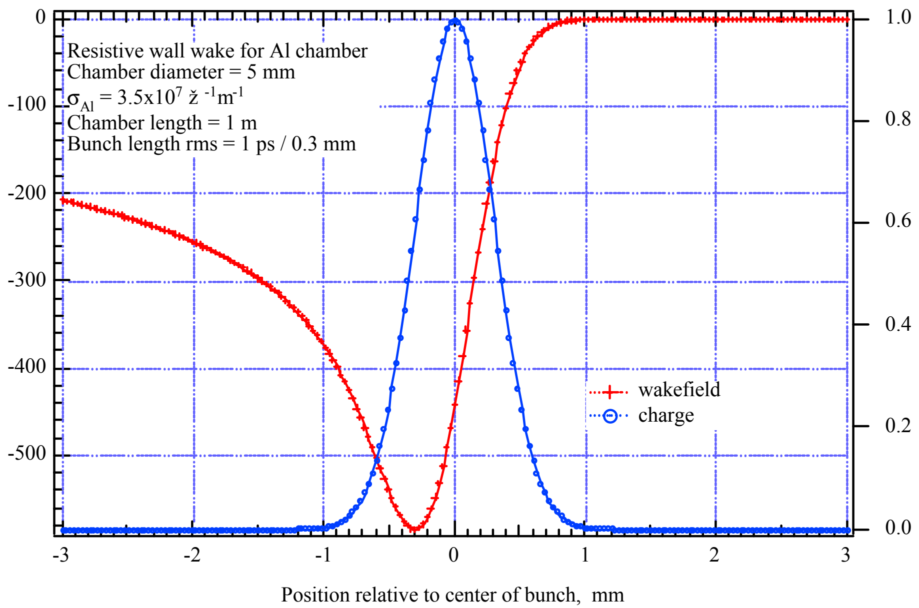
Initial offset: 100 μm
Bunch length: 10 ps
Beam pipe radius: 15 mm
Length: 1 m (Al)
Energy: 710 MeV

The deflection is small: only 12 nm over 100 m of beam pipe.



Position relative to center of bunch, mm

Resistive Wall: Production Arc

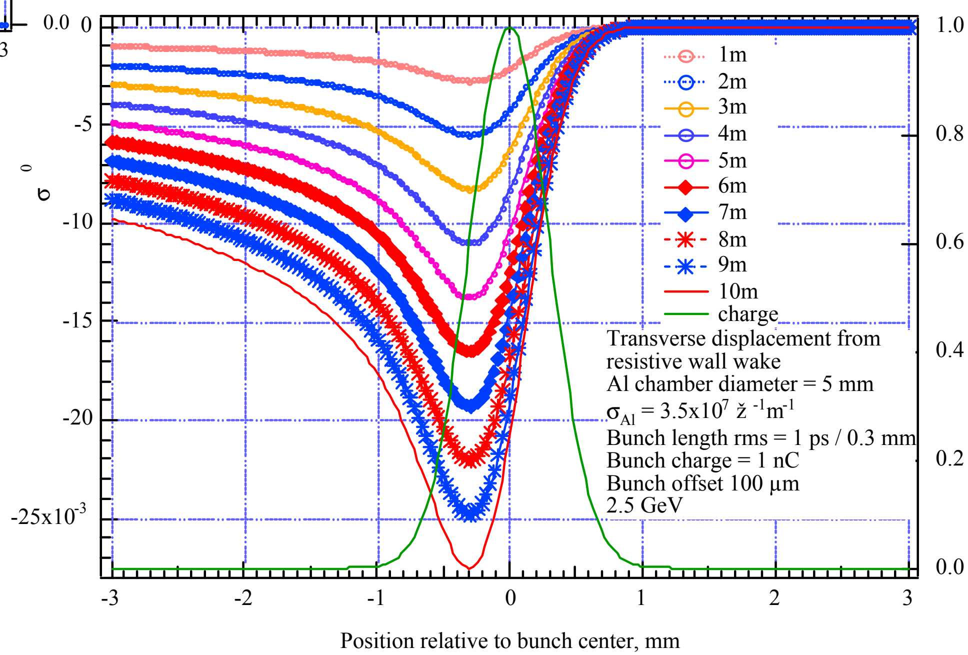


Initial offset: 100 μm
Bunch length: 1 ps
Beam pipe radius: 2.5 mm
Energy: 2.52 GeV

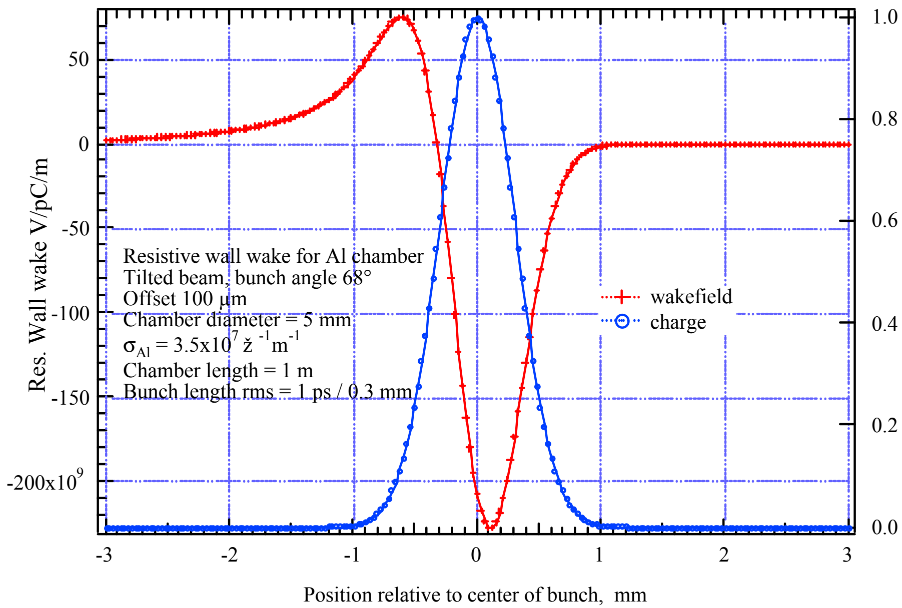
To maintain a 1% max. bunch distortion over a 10 m long chamber:

50 μm max. offset (5 mm Ø pipe)

100 μm max. offset (6.3 mm Ø pipe)

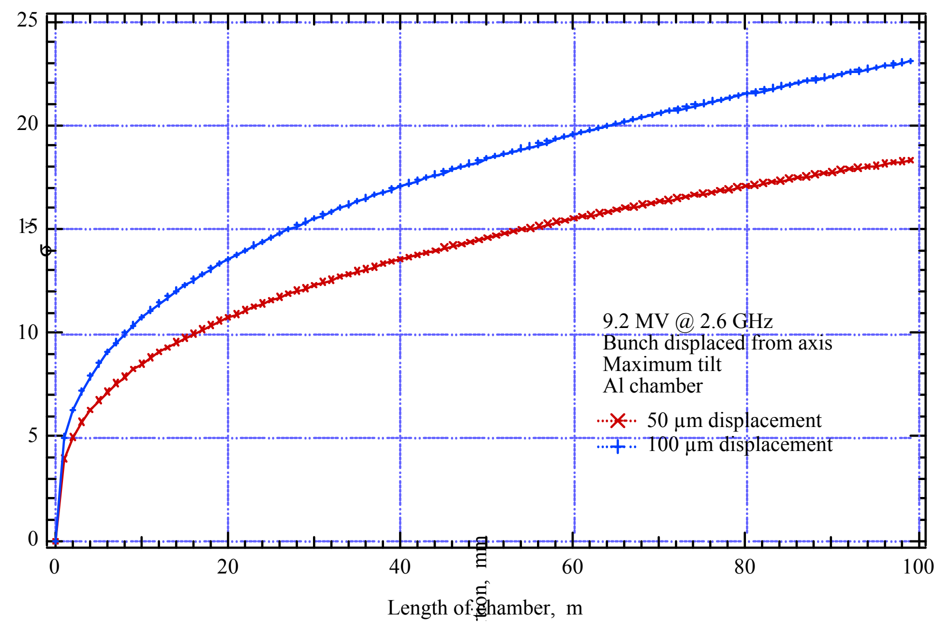


Resistive Wall: 2T Dipoles



Bunch tilt: 1.2 rad
Bunch length: 1 ps
Bunch offset: 100 µm
Beam pipe radius: 2.5 mm
Energy: 2.52 GeV

Minimum beam pipe diameter to maintain a distortion of $\sigma_y/100$



Cooled beam pipe ?
Tapers ?

S. De Santis

Multi-bunch BBU 1

Can we increase the total current ?

Long range wake

↓

High order modes

Frequency (ave. meas.) [GHz]	Loss factor (simulation) [V/pC/m^2]	R/Q (simulation) [Ω/cm^2]	Q (meas.)
TE_{111}-like			
1.6506	19.98	0.76	$7.0\cdot10^4$
1.6991	301.86	11.21	$5.0\cdot10^4$
1.7252	423.41	15.51	$2.0\cdot10^4$
1.7545	59.86	2.16	$2.0\cdot10^4$
1.7831	49.20	1.75	$7.5\cdot10^3$
TM_{110}-like			
1.7949	21.70	0.77	$1.0\cdot10^4$
1.8342	13.28	0.46	$5.0\cdot10^4$
1.8509	11.26	0.39	$2.5\cdot10^4$
1.8643	191.56	6.54	$5.0\cdot10^4$
1.8731	255.71	8.69	$7.0\cdot10^4$
1.8795	50.80	1.72	$1.0\cdot10^5$
TE-like			
2.5630	42.41	1.05	$1.0\cdot10^5$
2.5704	20.05	0.50	$1.0\cdot10^5$
2.5751	961.28	23.80	$5.0\cdot10^4$

(From N. Baboi)

Multi-bunch BBU 2

Threshold current for regenerative BBU:

$$I_{th} = -I_0 \frac{\lambda_{HOM}/2\pi}{Q_{HOM} L_{eff} \sum_{m=1}^{2N-1} \sum_{n=m+1}^{2N} \frac{R_{nm} \sin\left[\frac{2\pi c}{\lambda}(T_n - T_m)\right]}{\gamma_m}}$$

Worst case:

$$-\sqrt{\beta_m \beta_n \gamma_m / \gamma_n}$$

We are far below it, at a first estimate.

It is also possible to study the multi-bunch effects with the same method used for the single-bunch:

$$W_\perp(t) = \omega_r \frac{R_\perp}{Q_{HOM}} e^{-t/T_f} \sin(\omega_r t)$$

Single HOM wake

"Decelerator"

- Is it really necessary ? -

- Low energy beam dump
  - Lesser constraints on beam quality.
  - It is enough to keep losses to a minimum.
- Lower energy beam lines
  - Previous analysis must be extended to more passes.
  - We already have the tools, but constraints for earlier passes are likely to increase.

Conclusions and Future Plans

- No show stoppers, up to now.
- Multi-bunch analysis.
- Decelerating passes.
- CSR effects.
- Comprehensive instabilities analysis.
  - *Ions, etc.*