Longitudinal tracking studies for the entire RCS chain

Fabian Batsch, Rama Calaga,
Heiko Damerau, Ivan Karpov

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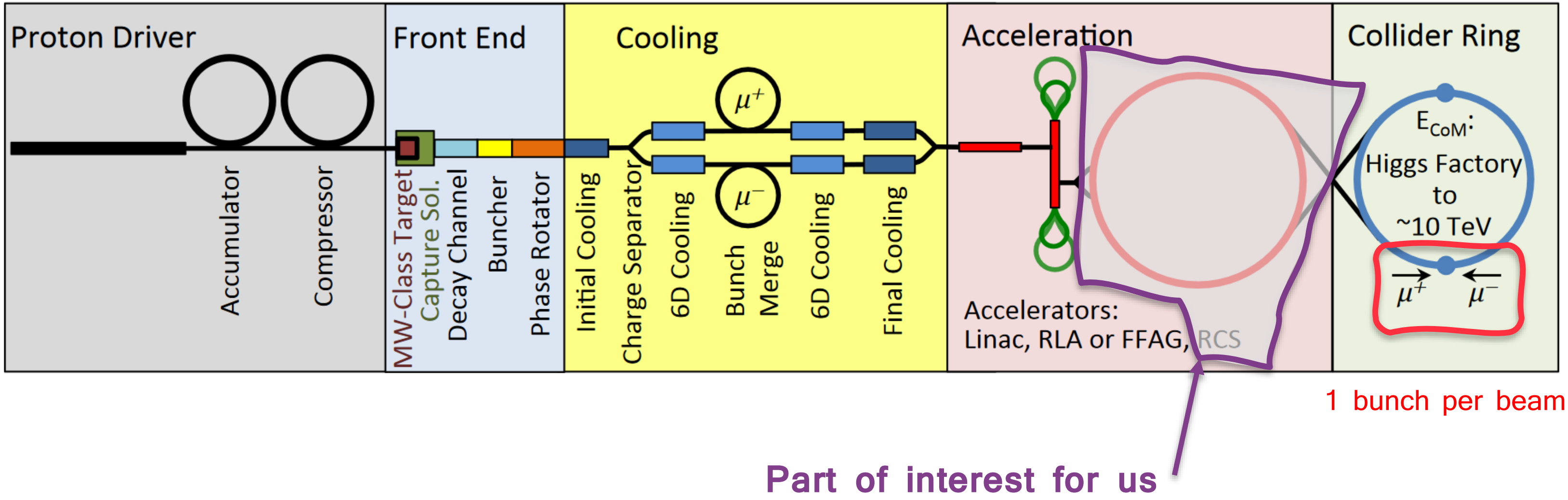
Outline

- Longitudinal emittance definitions
- Bunch length during acceleration
- Synchronous phase optimization
- Beam-induced voltages and HOM power estimates
- Outlook
  - emittance growth and budget
  - multi-turn effects and induced voltages calculations
- Summary

Reminder on design baselines

- Base for the work is the US [Muon Accelerator Program]() (MAP)
- High energy complex consist of a chain of rapid cycling synchrotrons (RCS)



The RF challenges: Voltage

- **Installed voltages in lepton rings:**

From talk by H. Damerau

	RCS1	LEP2	FCC-ee
Circumference, $2\pi R$ [m]	5990	26658	91106
Energy factor, E_{ej}/E_{inj}	5	4.8	n/a
Repetition rate, f_{rep} [Hz]	5 (asym.)	Slow (min.)	n/a
Number of turns	17	few 10^8	10^8
Max. RF voltage, V_{RF} [GV]	21	3.6	11.3
Energy gain per turn, ΔE [GeV]	14.8	3.49	10

→ **Even more RF voltage than any other circular collider**

→ **Much fewer turns**

The RF challenges: Intensity

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- **High bunch charge and current:**

From talk by H. Damerau

	ILC	RCS1 (and RCS2)
Number of bunches, n_b	1312	1 each μ^+ and μ^-
Bunch spacing, τ_{bs}	554 ns	T_{rev} = 20 μs
Bunch intensity, N_b	$2 \cdot 10^{10}$ p/b	$2.7\ (2.5) \cdot 10^{12}$ p/b
Average beam current, I_b	5.8 mA	2 x 20 mA

- **Average beam current more than three times (2×) above ILC**
- **Very strong transient beam loading**
- **During first turn in RCS1 energy gain is about 20% of beam energy**

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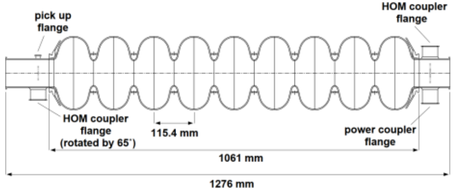
General parameter table

Detailed parameter table: https://cernbox.cern.ch/index.php/s/I9VpITncUeCBtiz

	RCS1→314 GeV	RCS2→750 GeV	RCS3→1.5 TeV
Circumference, $2\pi R$ [m]	5990	5590	10700
Energy factor, E_{ej}/E_{inj}	5.0	2.4	2.0
Repetition rate, f_{rep} [Hz]	5 (asym.)	5 (asym.)	5 (asym.)
Number of bunches	$1\mu^+, 1\mu^-$	$1\mu^+, 1\mu^-$	$1\mu^+, 1\mu^-$
Bunch population	$>2.5 \cdot 10^{12}$	$>2.3 \cdot 10^{12}$	$2.2 \cdot 10^{12}$
Survival rate per ring	90%	90%	90%
Acceleration time [ms]	0.34	1.04	2.37
Number of turns	17	55	66
Energy gain per turn, ΔE [GeV]	14.8	7.9	11.4
G_{acc} for survival [MV/m]	2.4	1.3	1.1
Acc. field in RF cavity [MV/m]	30 (45 optimistic)	30	30
Max. V_{RF} for ϕ_s=45° [GV]	20.9	11.2	16.1

				Stage 1		Stage 2		Stage 3
13				Stage 1		Stage 2		Stage 3
14	Basic data	Symbol	Unit	Value	Details	Value	Details	Value
15	Particles	-	-	μ		μ		μ
16	Costs	-	M€					
17	Type	-	-	RCS		hybrid RCS		hybrid RCS
18								
19	Dynamics							
20	Acceleration time	T_{acc}	[ms]	0.34		1.09704595		2.37
21	Injection energy	E_{inj}	[MeV]/u	63000		313830		750000
22	Ejection energy	E_{ej}	[MeV]/u	313830	defined by r	750000		1500000
23	Energy ratio	E_{ej}/E_{inj}	-	4.98		2.39		2.00
24	Momentum at e_i	p/c	MeV/c	63106		313935		750106
25	Momentum at e_j	p/c	MeV/c	313935		750106		1500106
26	Number of turns	n_{turn}	-	17		55		66
27	Planned Survival rate	N_{ej}/N_{inj}	-	0.9		0.9		0.9
28	Total survival rate	N_{ej}/N_0	-	0.9		0.81		0.729
29	Accel. Gradient, linear for survival	G	[MV/m]	2.44		1.33		1.06
30	Required energy gain per turn	ΔE	[MeV]	14755		7930		11364
31								
32	Transition gamma	γ_{tr}	-	20.41		20.41		~30
33	Injection relativistic mass factor	γ_{inj}	-	597		2971		7099
34	Ejection relativistic mass factor	γ_{ej}	-	2971		7099		14198
35	Injection v/c	β_{inj}	%	0.9999986		0.999999943		0.9999999901
36	Ejection v/c	β_{ej}	%	0.999999943		0.9999999901		0.9999999975
37								
38	Parameter Classical RCS							
39	Radius	R	[m]	953.3		953.3		1703.0
40	Circumference	$2\pi R$	[m]	5990		5990		10700
41	Circumference Ratio	R_{i+1}/R_i	-	-		1		1.79
42	Pack fraction	?	-	0.61		0.61		0.628
43	Bend radius	ρ_B	m	581.8		581.8		1070.2
44	Tot. straight section length	L_{str}	[m]	2334.7		2335.7		3975.7
45	Injection bending field (average)	B_{inj}	[T]	0.36		1.80		2.34
75	RF							
76	Systems	-	-	TESLA		TESLA		TESLA
77	Main RF frequency	f_{RF}	[MHz]	1300		1300		1300
78	Harmonic number	h	-	25957		25957		46367
79	Revolution frequency ej	f_{rev}	[kHz]	50.08		50.08		28.04
80	Revolution period	Trev	[μs]	20.0		20.0		35.7
81	Max RF voltage	V_{RF}	[GV]	20.87		11.22		16.07
82	Max RF power	P_{RF}	[MW]					
83	RF Filling factor	-	-	0.4		0.4		0.45
84	Number RF stations	-	-	Around 50		Around 50		Around 50
85	Cavities	-	-	9-cell		9-cell		9-cell
86	Number of cavities	?	-	696		374		536
87	Peak Impedance		[Ω]					
88	Gradient in cavity	$\Delta E/L$	[MV/m]	30		30		30
89	Average energy gain per total straight	$\Delta E/L$	[MeV/m]	6.3		3.4		2.9
90	Accelerating field per total straight	$\Delta E/L$	[MeV/m]	8.9		4.8		4.0
91	Accelerating field gradient, with FF	$\Delta E/L$	[MV/m]	22.3		12.0		9.0
92	Stable phase	ϕ_s	[°]	45		45		45
93	Conversion factor mm mrad – eVs	-	Vs/mm mra	69.40		165.86		331.72
94	Longitudinal emittance (σE * 4σz)	ε^L_n	[eVs]	0.025	7.5 MeV m	0.025		0.025
95	Longitudinal emittance (phase space area)	ε^L_n	[eVs]	0.079		0.079		0.079
96	Injection bucket area	$A_{b,inj}$	[eVs]	0.62		1.01		1.40
97	Ejection bucket area	$A_{b,ej}$	[eVs]	1.37		1.56		1.97
98	Bucket area reduction factor	$A_b/A_{B,st}$	-	0.172		0.172		0.172
99	Horizontal betatron tune	Q_h	-					
100	Vertical betatron tune	Q_v	-					
101	Average horizontal Twiss beta	βh	[m]	10		10		10
102	Average vertical Twiss beta	βv	[m]	10		10		10
103	Injection synchrotron frequency	$f_{S,inj}$	[kHz]	76.33		25.07		14.53
104	Ejection synchrotron frequency	$f_{S,ej}$	[kHz]	34.20		16.22		10.27
105	Injection synchrotron tune Q_s	$f_{S,inj}/f_{rev}$	-	1.52		0.50		0.52
106	Ejection synchrotron tune Q_s	$f_{S,ej}/f_{rev}$	-	0.68		0.32		0.37

The 1.3 GHz TESLA cavity



(From design report)

- **Relevant beam parameter**
  - **Bunch population >2.2·10^{12}**→ large intensity effects
  - I_b = **20.4 / 18.8 / 10.0 mA** in RCS1/2/3 → **2x430 kW per cavity**
  - **700 / 370 / 530 cavities** distributed over n_{RF} RF stations
    (with G_{acc} = 30 MV/m)
  - ϕ_s **= 45°** (above transition: γ_{tr} = 20.41, 600 < γ < 14200)
- **Cavity parameter (9 cells, L=1.06 m):**
  - **Harmonic number h = 25957 to 46367**
  - R/Q **= 518 Ω**, total R_s = 306 GΩ
  - **Gradient of structure 30 MV/m**
  - Q_L **= 2.2e6** (for beam loading compensation with Δf = 320 Hz, [ref])

Table 2: TTF cavity design parameters.[a]

type of accelerating structure	standing wave
accelerating mode	TM_{010} , π mode
fundamental frequency	1300 MHz
design gradient E_{acc}	25 MV/m
quality factor Q_0	$> 5 \cdot 10^9$
active length L	1.038 m
number of cells	9
cell-to-cell coupling	1.87 %
iris diameter	70 mm
geometry factor	270 Ω
R/Q	518 Ω
E_{peak}/E_{acc}	2.0
B_{peak}/E_{acc}	4.26 mT/(MV/m)
tuning range	± 300 kHz
$\Delta f/\Delta L$	315 kHz/mm
Lorentz force detuning at 25 MV/m	≈ 600 Hz
Q_{ext} of input coupler	$3 \cdot 10^6$
cavity bandwidth at $Q_{ext} = 3 \cdot 10^6$	430 Hz
RF pulse duration	1330 μs
repetition rate	5 Hz
fill time	530 μs
beam acceleration time	800 μs
RF power peak/average	208 kW/1.4 kW
number of HOM couplers	2
cavity longitudinal loss factor $k_\parallel$ for $\sigma_z = 0.7$ mm	10.2 V/pC
cavity transversal loss factor $k_\perp$ for $\sigma_z = 0.7$ mm	15.1 V/pC/m
parasitic modes with the highest impedance : type	TM_{011}
$\pi/9$ $(R/Q)/$ frequency	80 Ω/2454 MHz
$2\pi/9$ $(R/Q)/$ frequency	67 Ω/2443 MHz
bellows longitudinal loss factor $k_\parallel$ for $\sigma_z = 0.7$ mm	1.54 V/pC
bellows transversal loss factor $k_\perp$ for $\sigma_z = 0.7$ mm	1.97 V/pC/m

From design report

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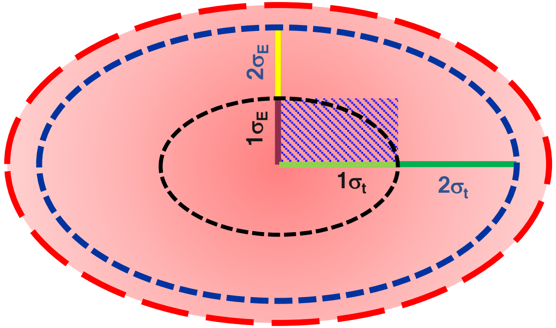
Longitudinal emittance

- **Different definitions of the longitudinal emittance and different units co-exist:**



Encircling, 1σ, 4σ, FWHM,…

Parameter table from webpage:

$\sigma_z \cdot \sigma_E = 7.5$ MeVm ≙ 0.025 eVs

$\rightarrow 4\pi \cdot \sigma_t \cdot \sigma_E = 0.31$ eVs **for 4*σ* ellipse**

Parameter	Unit	3 TeV	10 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20
N	10^{12}	2.2	1.8
f_r	Hz	5	5
<B> (average)	T	7	10.5
ε_L (norm, $1\sigma_z\sigma_E$)	MeV m	7.5	7.5
σ_E / E	%	0.1	0.1
σ_z	mm	5	1.5

- **[eV-s], [MeV-m], [mm] can be converted converted:**

$$[\text{MeV-m}] \cdot \frac{1}{c} = [\text{eV-s}] \qquad [\text{mm}] \cdot 10^{-3} \cdot \frac{E_{\mu,0}}{c} = [\text{eV-s}] \qquad [\text{mm}] \cdot 10^{-3} \cdot E_{\mu,0} = [\text{MeV-m}]$$

[see technical note on unit conversion]

$$E_{\mu,0} = 105.658\,\text{MeV}$$

The longitudinal profile definition

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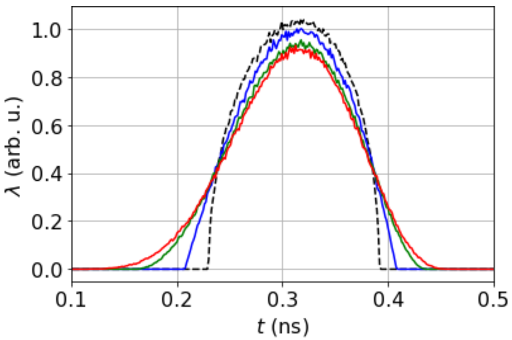
- The tails must be defined. Equal FWHM bunch lengths but different tail definitions give different encircling emittances:



μ = 0.5, τ_L = 4 σ_t
μ = 1 (parabolic)
μ = 2
μ = 3

$$\lambda(\tau) = \lambda_0 \left[1 - \left(\frac{\tau}{\tau_l}\right)^2\right]^\mu$$

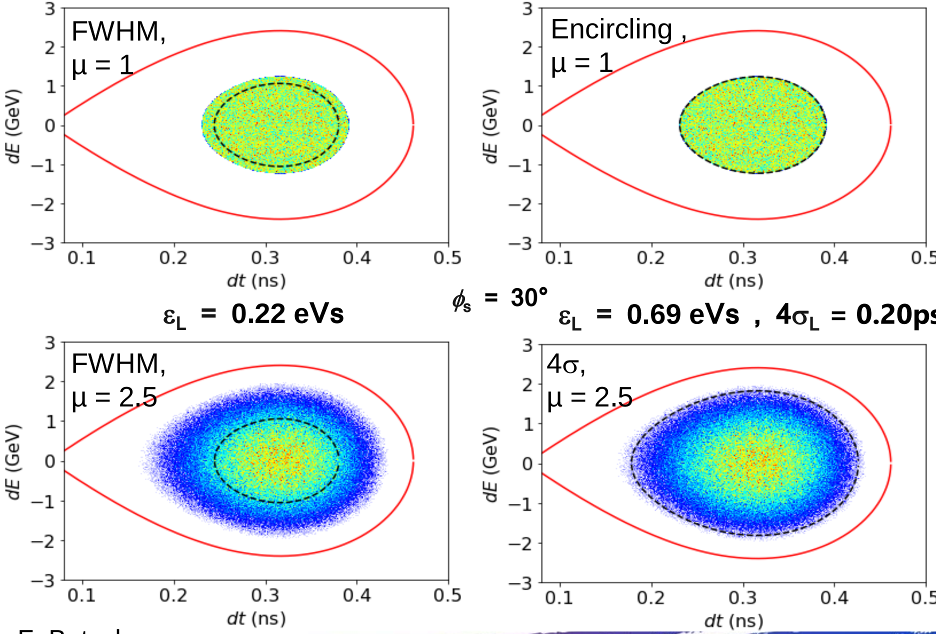
(^(μ+1/2) in BLonD)

$$\sigma_{\rm rms} = \frac{\tau_L}{2\sqrt{3+2\mu}}$$

ε_L = 0.22 eVs | **ε_L = 0.31 eVs, 4σ_L = 0.16ps**

ϕ_s = 30°

ε_L = 0.22 eVs | **ε_L = 0.69 eVs , 4σ_L = 0.20ps**



- Tails increase ε_L by factor of 2

→ **Increased voltage requirements to increase bucket area**

F. Batsch

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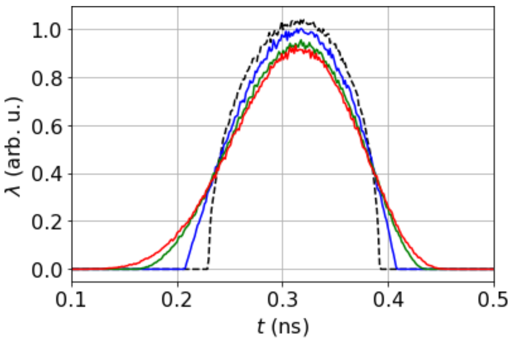

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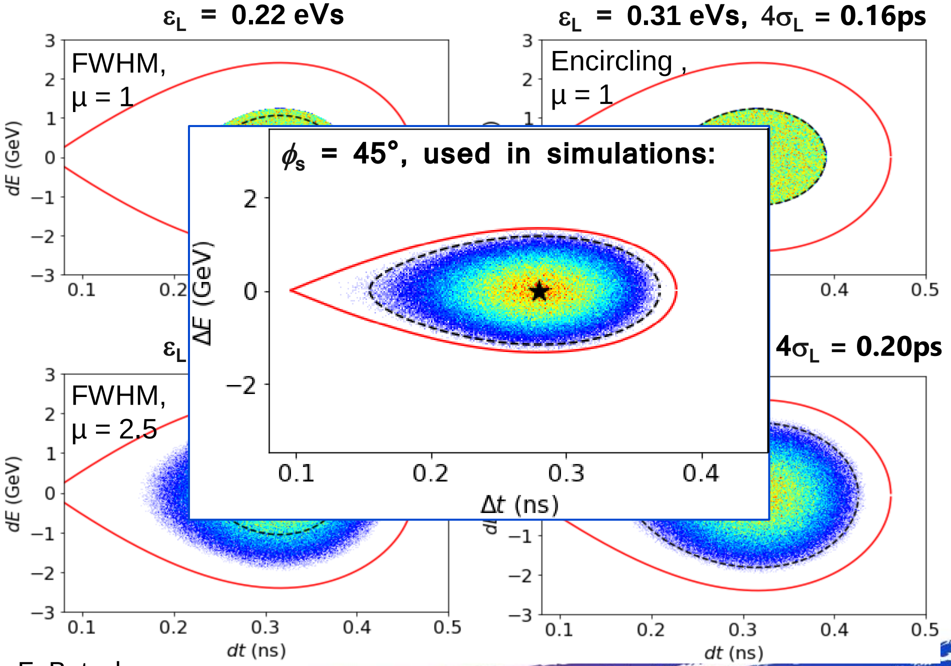

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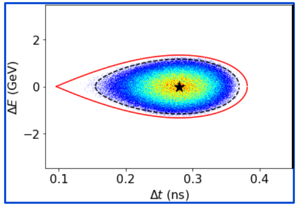
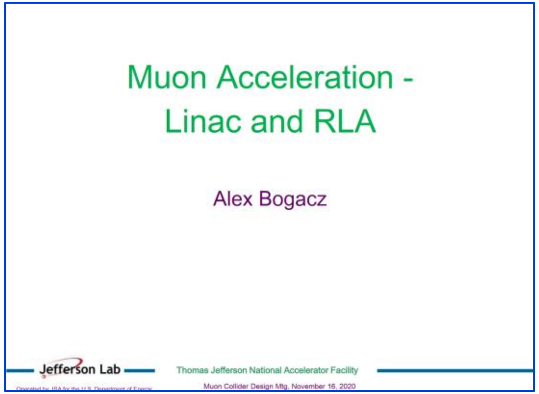
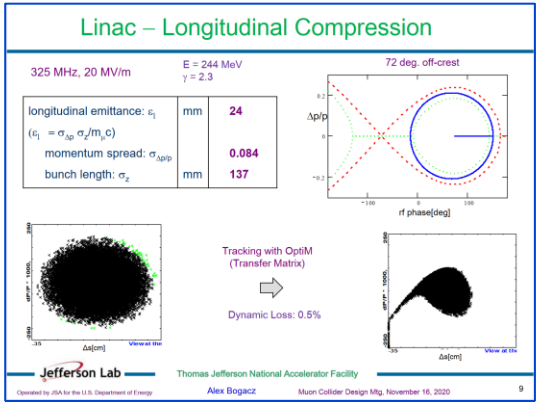
The longitudinal profile definition

Bucket at injection in RCS1



- From the dynamics point-of-view, muons behave more like protons → Chose μ = 2.5 for now:
- The longitudinal profile after cooling would be an important input
- Side note: examples for muons exist but <u>not</u> for a collider application:





$\varepsilon_L = \beta\gamma * \sigma_z * \sigma_{\Delta p/p}$ = 24 mm

[source]

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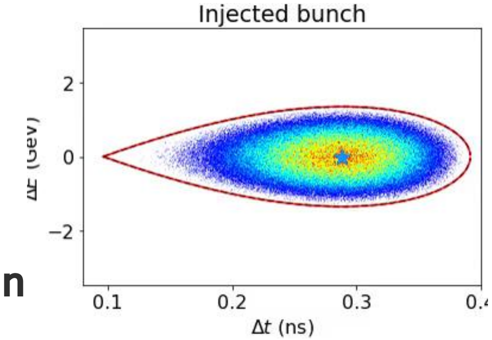
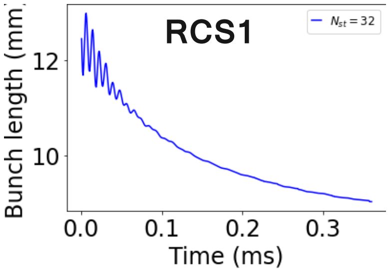
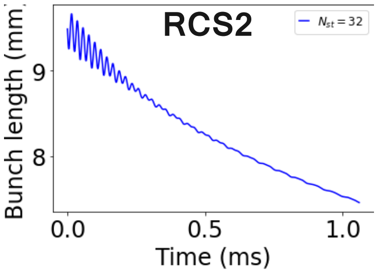
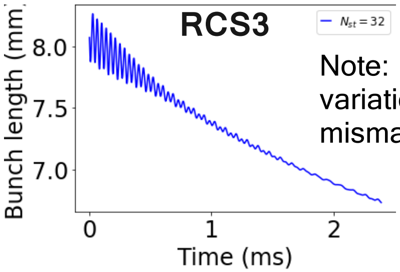
Bunch lengths during acceleration



- In the 1.5 TeV collider, bunch length σ_z = 5 mm
- In simulations, the bunch length at injection in RCS1 σ_z = 13 mm
- The 1 sigma bunch length decreases during acceleration in all 3 RCs:







Note: initial variations due to mismatched bunch

- Final bunch length is σ_z < 7 mm, bunch rotation might be required

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The synchronous phase and its influence

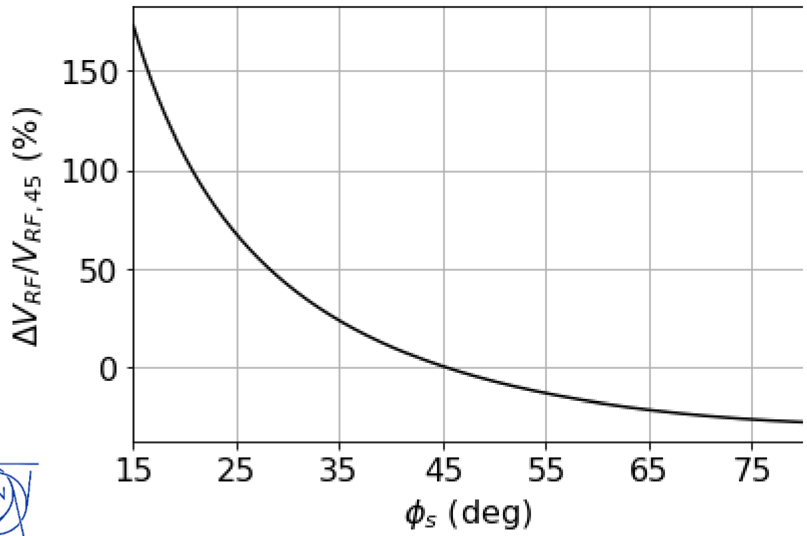
- Bucket filling factor defines stable phase ϕ_s
- The synchronous phase ϕ_s itself directly impacts the main RF requirements:
- Energy gain of the synchronous particle $\Delta E_s = V_{RF} * \sin\phi_s =$ 14.75 GeV per turn.
  For $\phi_s = 45°$ → $V_{RF} = 21$ GV, i.e., large overvoltage
- The bunch length changes with ϕ_s, which affects the HOM power to a small extend

→ Increase the synchronous phase and consequently reduce bucket area to possibly decrease V_{RF}

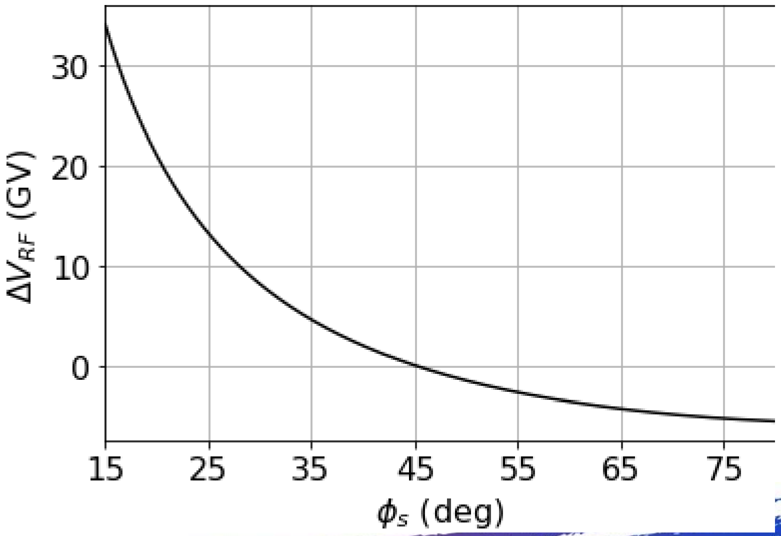
Over-voltages due to ϕ_s

- **Independent of the cavity frequency or RCS, the overvoltage in the RF voltage $V_{RF} = \Delta E_s/\sin(\phi_s)$, compared to $\phi_s = 45°$ is:**

Relative change in V_{RF}



Absolute change in V_{RF}



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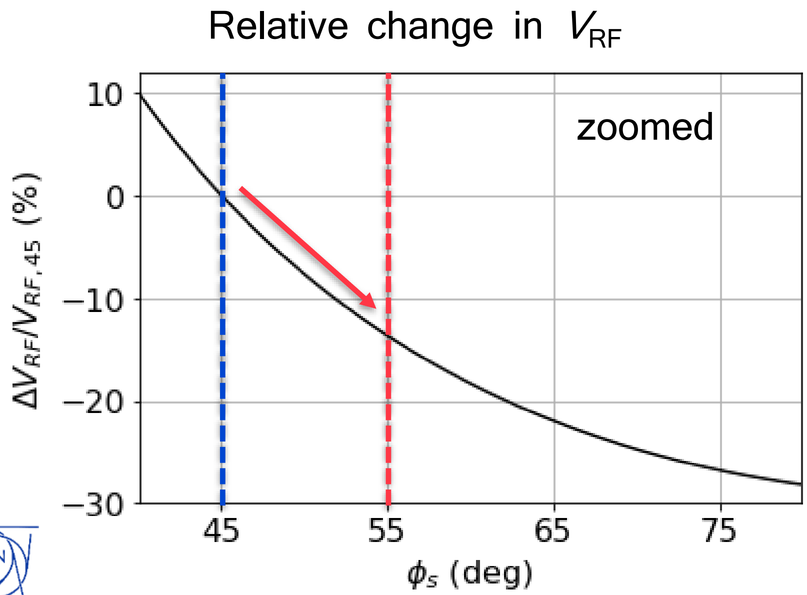
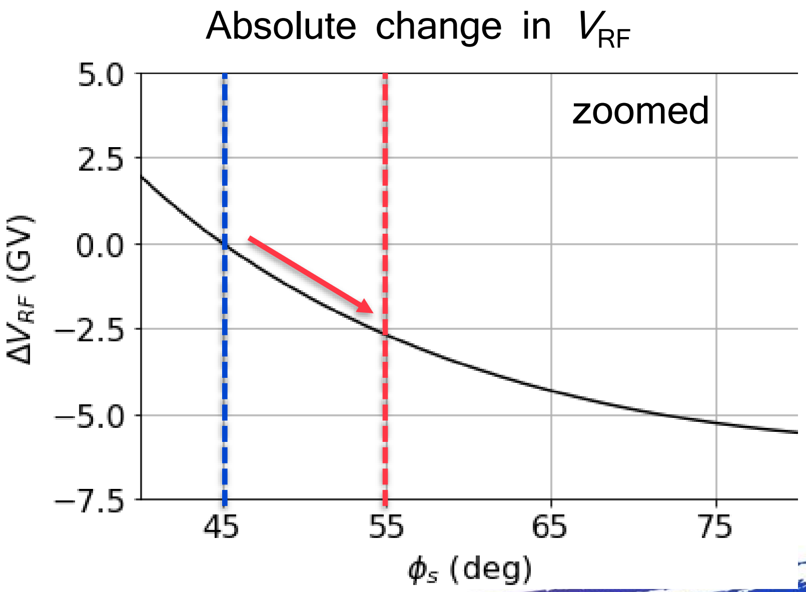
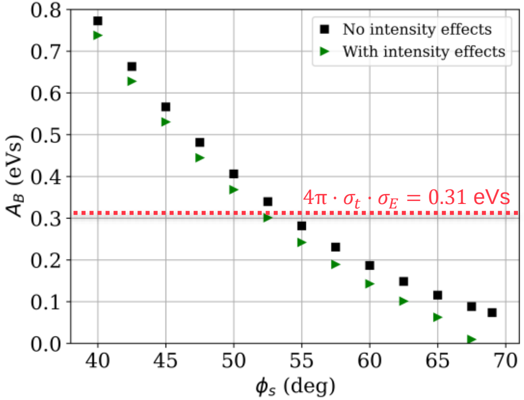




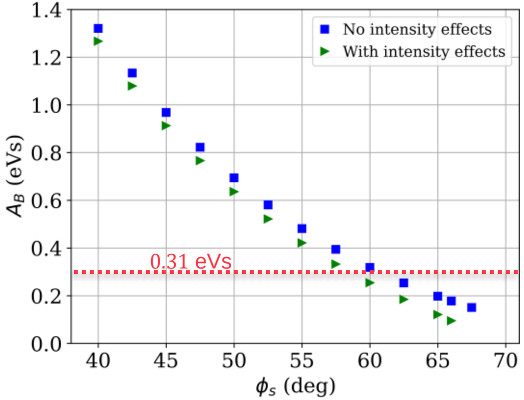
Synchronous phase optimization

- **Bucket areas for each RCS:**

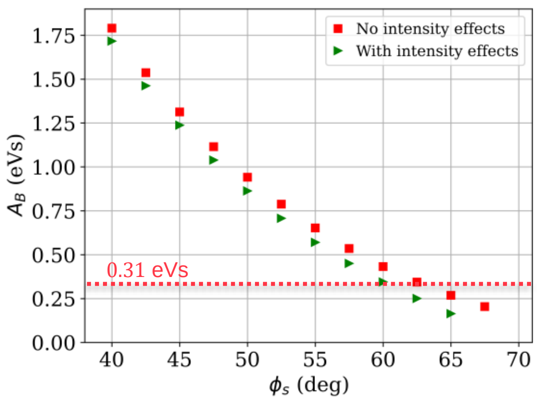
RCS1



RCS2



RCS3

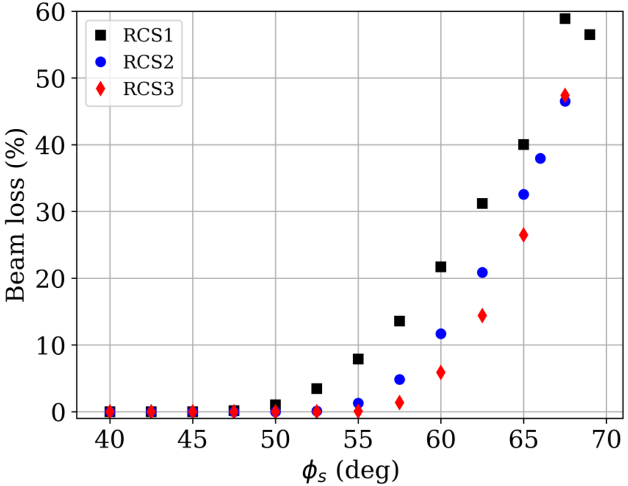


- **Intensity effects decrease the bucket area slightly**
- **Relaxed voltage requirements and longer bunches (reduces HOM power)**

Synchronous phase optimization

- Possibility to use the muon loss as a criteria
- The beam losses increase gradually with the shrinking bucket

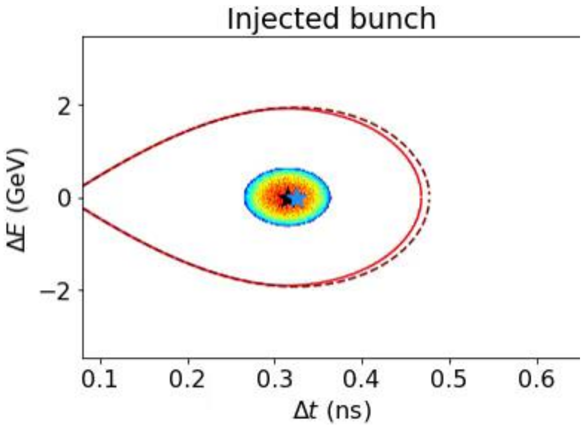
→ Used single bunch for ϕ_s = 45° and "injected" it in all cases to avoid that the matching routine shrinks the bunch:

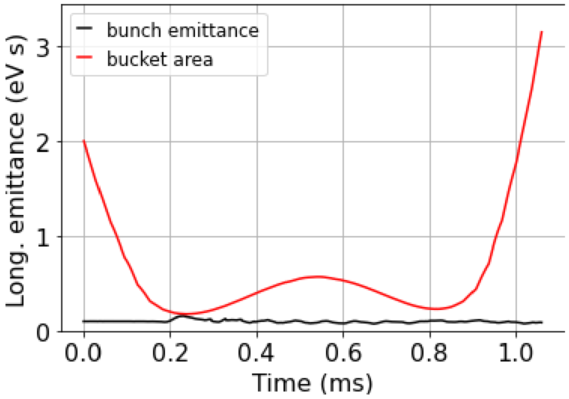


- Between ϕ_s = 50° and 55 seems to be the limit
- Further studies to come after optimization of the RF voltage and ramping

Synchronous phase for nonlinear ramping

- The same scan can be repeated for nonlinear ramping function
- Example of an older simulation for RCS 1, ϕ_s = 57.5°, input emittance 0.1 eVs:





→ 54% of the bunch lost

- This study will be repeated with updated values after optimization of the RF voltage and ramping

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Beam-induced power losses

- Question of possibly high HOM power for the TESLA cavity raised during collaboration meeting

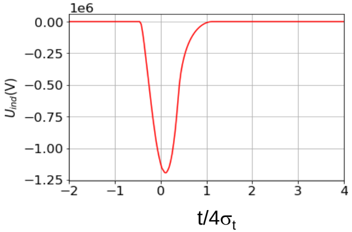
- HOM power in TESLA / ILC 1.3 GHz cavity calculated in two ways:

1. From power loss through loss factor $k_{||}$ from approximated wake potentials in macro-particle tracking simulations (BLonD), containing the information about all HOM:

$k_{||} = \int \lambda(t) W_{||,SR}(t) dt$, with bunch charge density $\lambda(t)$

↓

$P_{HOM} = k_{||} * \frac{Q^2}{T_B}$ with bunch charge Q and bunch spacing $T_B = T_{rev}$



short-range wakefield [ref, see appendix for details]

Beam-induced power from mode analysis

2. Using the output of ABCI code for detailed RF structure and an approximation for short Gaussian bunches to compute loss factor

$$k_{||} = \left|\frac{R}{Q}\right| \frac{\omega_r}{2} * e^{-(\omega_r \sigma)^2} \quad (\frac{\omega_r}{4} \text{ for Linac norm})$$

- This gives the loss factor per mode, for longitudinal modes, see here (TESLA) & paper (ILC LL)

→ Total HOM loss factor is sum over all HOMs:

$$k_{||} = \sum k_{||,i} \,, \qquad P_{HOM} = k_{||} * \frac{Q^2}{T_B}$$

Table 2 Values of Qext for the monopole modes

MODE		FREQ.	R/Q	2 welded couplers on asymmetric cavity Qext	2 demount. couplers on asymmetric cavity Qext	2 demount. couplers on symmetric cavity Qext	Qext Limit
		[MHz]	[Ω]	[1.0E+3]	[1.0E+3]	[1.0E+3]	[1.0E+3]
TM011	1	2379,6	0,00	350,0	1150	1600	
	2	2384,4	0,17	72,4	360	460	
	3	2392,3	0,65	49,5	140	220	
	4	2402,0	0,65	84,0	68	110	
	5	2414,4	2,05	32,0	70	97	
	6	2427,1	2,93	29,1	81	59	
	7	2438,7	6,93	20,4	66	49	1000
	8	2448,4	67,04	27,4	58	51	100
	9	2454,1	79,50	58,6	110	100	100
TM012	1	3720,0	1,26	3,0			
	2	3768,9	0,07	5,1			
	3	3792,2	0,75	5,2			
	4	3811,7	1,43	3,9			
	5	3817,5	0,18	15,2			
	6	3829,2	2,33	11,3			
	7	3839,8	0,77	40,0			
	8	3845,3	22,04	240,0			300
	9	3857,3	6,85	6,1			1000

From
"Higher order mode coupler for TESLA", J. Sekutowisz

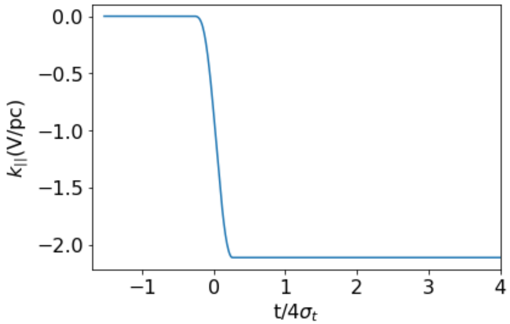
Beam-induced power losses: results

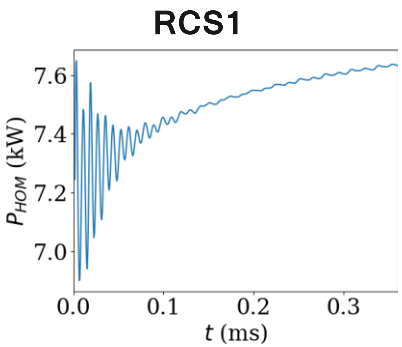
- **Parameters in BLonD: n_{RF} = 32 RF stations, 696 cavities, 90% survival, initial bunch length σ_z = 13 mm, 1 bunch, single-turn effects**

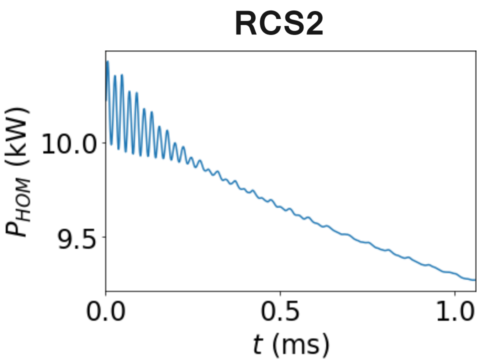
→ E.g. $k_{||,SR} = \int \lambda(t) W_{||,SR}(t) dt$ = -2.11 V/pC

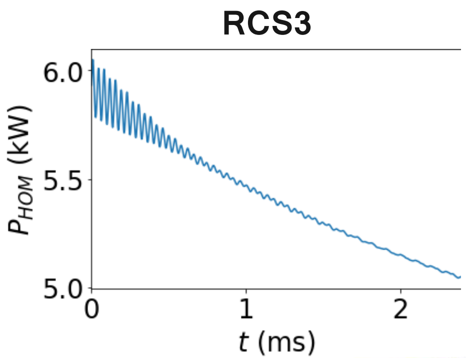
→ **The HOM power loss per cavity reaches 10.4 kW**

(Bunch population 2.54×10^{12}, T_{rev} = 20 μs → I = 20.4 mA as upper estimate)









F. Batsch

Beam-induced power losses: results

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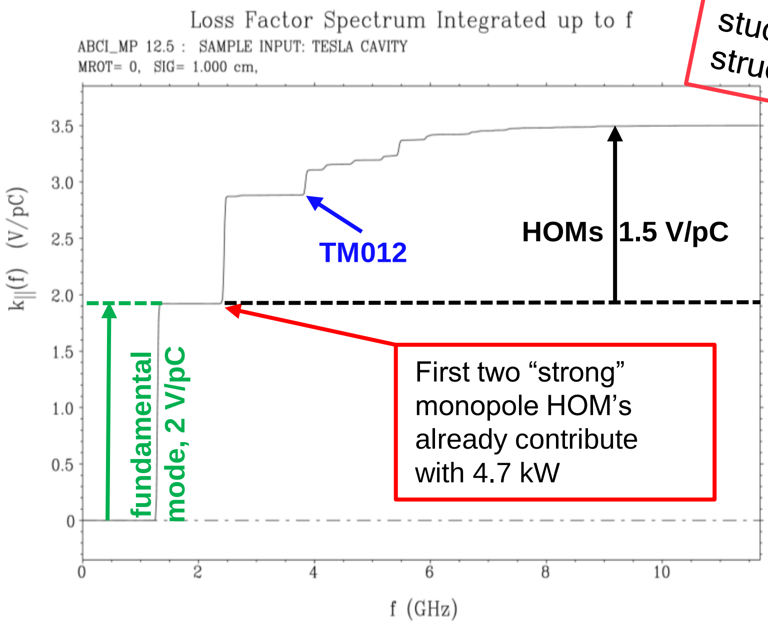
1. **From HOMs from ABCI: (ABCI file from S.-A. Udongwo): For RCS1:**



See talk by Sosoho U. [link], detailed studies of 1.3 GHz cavity types, structures, HOMs, other frequencies

1.5 V/pC results in 7.9 kW
→ Consistent with BLonD

Beam-induced power losses

- The induced power is very large, up to 10 kW for RCS1&2 per bunch and cavity

→ Bunch crossings inside the cavity increases power up to 4 times, to be avoided

- Central question: What is the CW value?
  10kW over 0.3 to 2.4 ms correspond to which CW power in 5Hz operation?

- Example: HOM power absorber capacity limit is 1 kW, 3-4 kW under development
  → up to 20 kW per cavity estimate

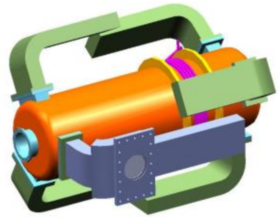


Figure 1: JLab Ampere class cavity with HOM loads and waveguide fundamental power coupler.

from [R.Rimmer]

See e.g. also PhD thesis by S. Zadeh

→ Detailed studies on HOM and high-capacity power absorbers
(or larger iris, wakefields scale with $1/a^2$, a the iris radius)

Outline

- **Longitudinal emittance definitions**
- **Bunch length during acceleration**
- **Synchronous phase optimization**
- **Beam-induced voltages and HOM power estimates**
- **Outlook**
  - **emittance growth and budget**
  - **multi-turn effects and induced voltages calculations**
- **Summary**

Emittance budget

- **The emittance budget was discussed in the Accelerator design meeting, see talk by D. Schulte:**

For the entire 5-GeV-to-1.5-TV acceleration chain!

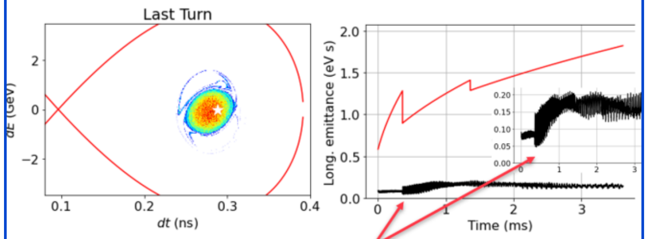
Rel. emittance blow-up	Relative tolerance	Relative luminosity
0.1%	0.03	0.999
1%	0.1	0.99
10%	0.3	0.9
100%	1	0.5

"Would assume **a total budget of 10%** (most relaxed acceptable tolerance)"

→ **Challenge assuming 4% per RCS and beam transfers**

→ **Beam transfer possible source of emittance growth**

See last annual meeting: [link]

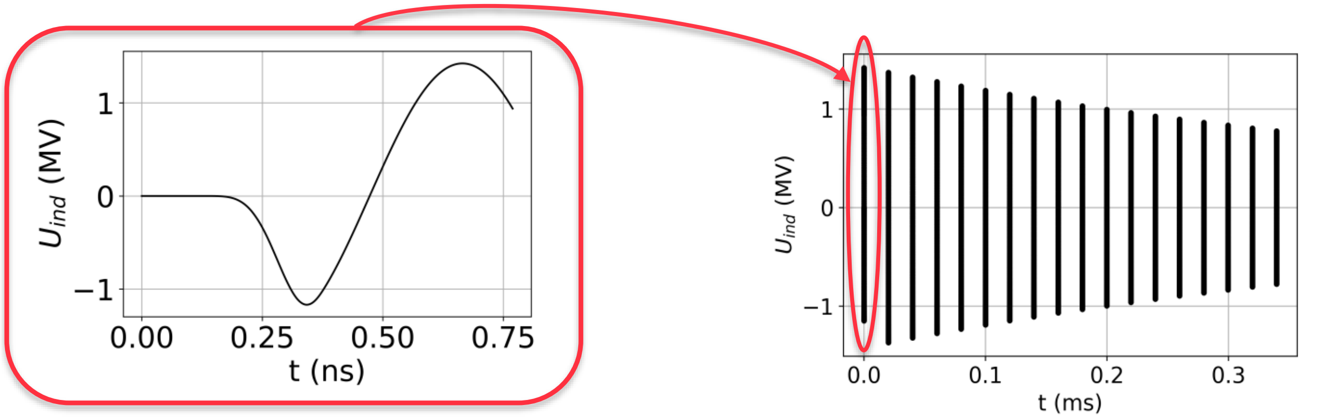


- Unmatched beam main problem, emittance growth 90%

→ **Beam transfer optimized with ramping functions after the HOM and multi-turn/bunch effects are determined**

Multiturn effects and mode analysis

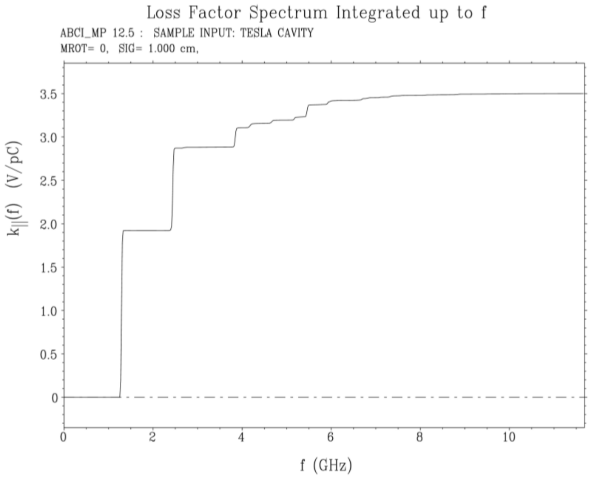
- Multi-turn effects computational challenge
- We compute the induced voltages only for the bucket one turn later



- Currently implementing this in our code, together with an improved calculation of the induced voltages

Multiturn effects and mode analysis

- Improved calculation of the induced voltages needed:
- K. Bane formulism only valid for short bunches with respect to the cavity cell
- We will not differentiate between short-range (K. Bane) and long-range effects, but use the mode analysis of ABCI and resonator models of the first 10 main HOMs:
- Add contributions from each mode, and later from the counterrotating bunches



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Summary

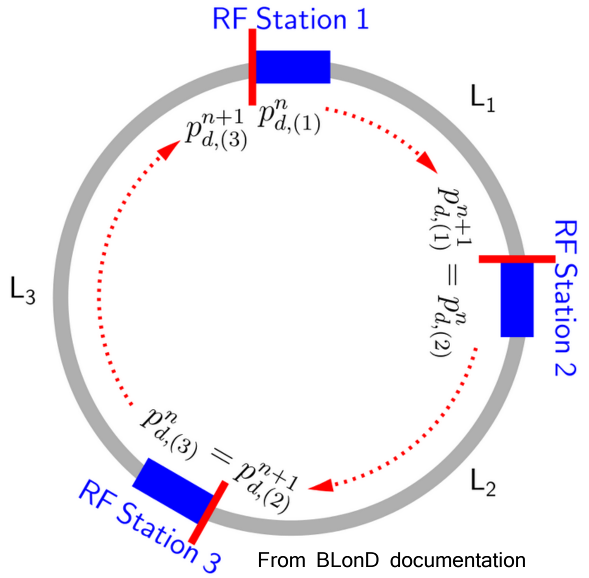
- Challenging target for longitudinal emittance, its budget and its growth
- Bunch length after acceleration below 7 mm to be expected
- Emittance after cooling and linac systems is essential input
- Synchronous phase baseline is $\phi_s = 45°$
- HOM power losses are on the 10 kW range during acceleration → CW level estimates and HOM coupler development important
- Working on a new calculation of the induced voltages and multiturn effects

CERN

The BLonD code

(Beam Longitudinal Dynamics code)

- BLonD: macro-particle tracking code, developed at CERN since 2014
- Links: documentation and github
- MuC-specific to multiple RF stations & muon decay
- Studies of today with only one bunch, 2nd to follow

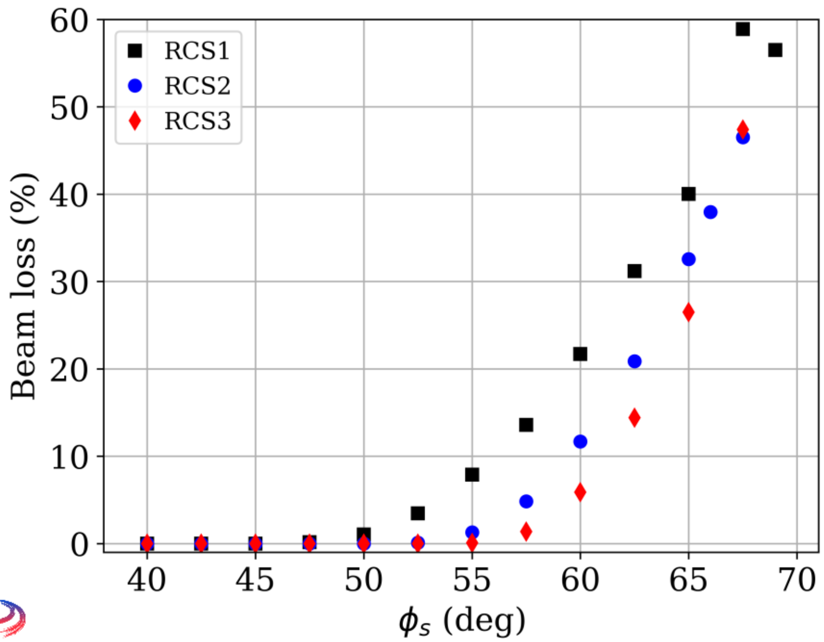


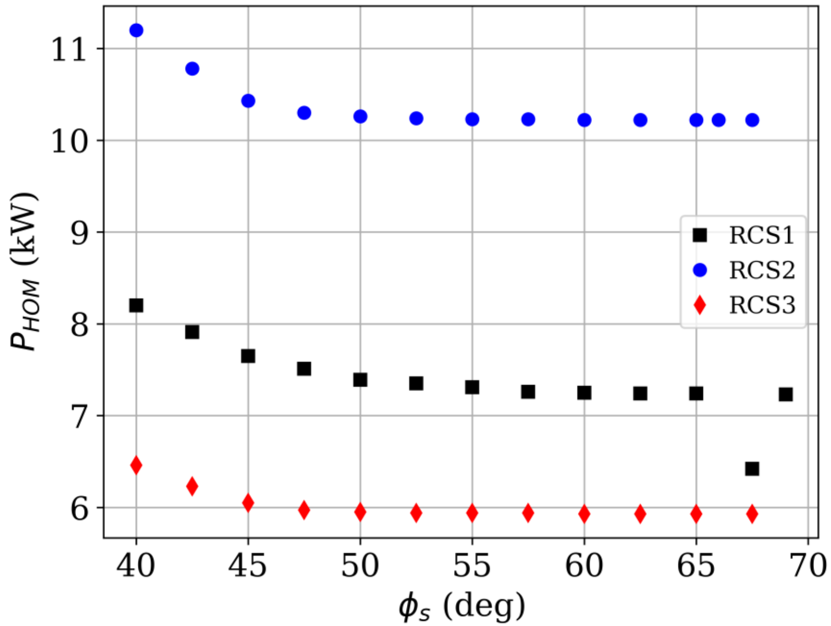
From BLonD documentation

Extra

- The beam losses increase gradually with the shrinking bucket

→ Used single bunch for ϕ_s = 45° and "injected" it in all cases to avoid that the matching routine shrinks the bunch,





Induced voltages: Short-range wakefields

Based on K. Bane et al., '[Calculation of the short-range longitudinal wakefields in the NLC linac]', ICAP98, 1998

$$W_L \approx \frac{Z_0 c}{\pi a^2} \exp\left(-\frac{2\pi \alpha^2 L^2 s}{a^2 g}\right) \operatorname{erfc}\left(\frac{\alpha L}{a}\sqrt{\frac{2\pi s}{g}}\right) \quad [s \text{ small}] \qquad (3)$$

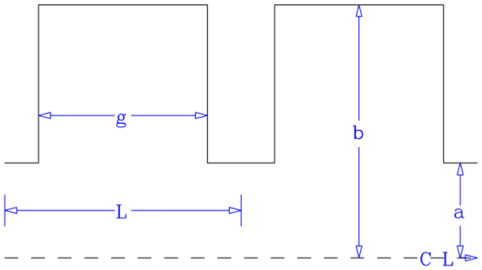
One can approximate this by a semi-analytically expression, valid for small bunch length *s* and *s/L* < 0.15:

$$W_L = \frac{Z_0 c}{\pi a^2} \exp\left(-\sqrt{s/s_0}\right)$$

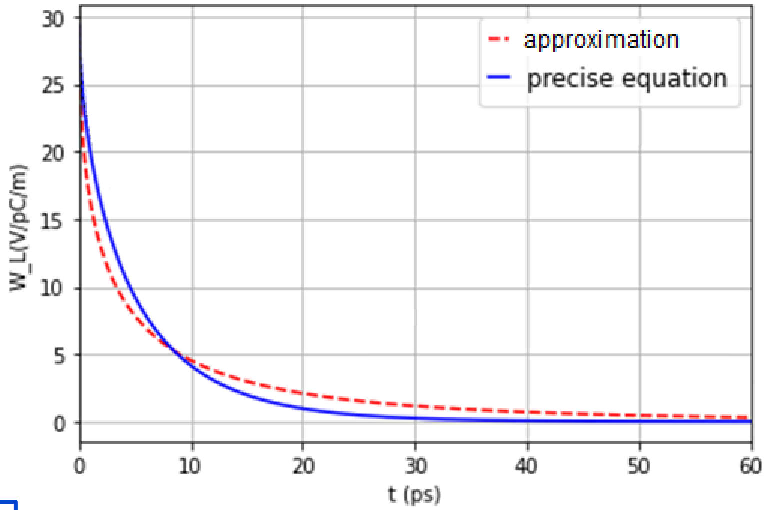
$$s_0 = 0.41 \frac{a^{1.8} g^{1.6}}{L^{2.4}}$$

Adjusting inner diameter can be a powerful tool to mitigate wakefields!

The parameters for the Tesla cavity[1] gives long. wake functions on the order of 30 V/pC/m:



L= 115.4 mm
g= 82 mm
a= 35 mm
b= 103.3 mm

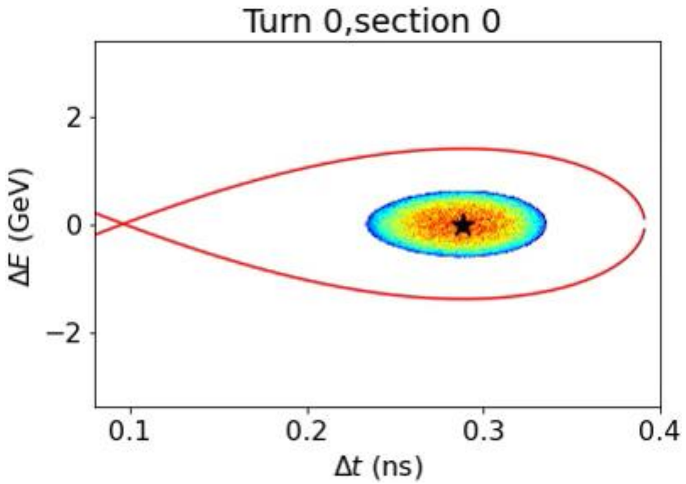


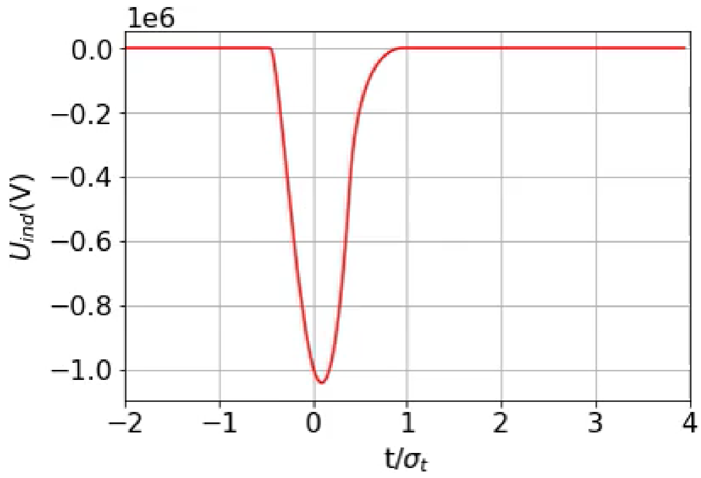
The BLonD code convolutes this wake function with the beam profile to obtain the induced voltage

[1]Wakefield studies for the Tesla cavity shown in TESLA Report 2003-19

Induced voltages: Short-range wakefields

- The induced voltage from the short-range wakefield is as large as 1.5 MV per cavity, i.e., also 1.5 MV/m
- The total induced voltage per turn is around 400 MV, thus 3-4% of the accelerating voltage





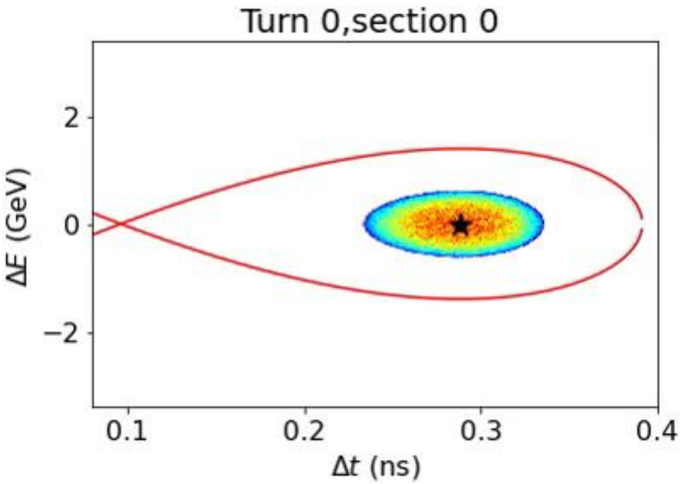
From design report

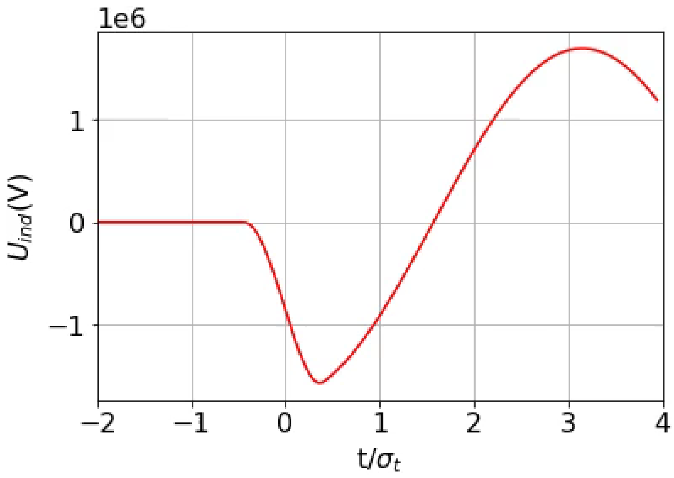
Simulation for RCS1, $n_{\mathrm{RF}} = 48, \varepsilon_L =$ 0.1 eVs

Induced voltages: Long-range wakefields

- The induced voltage from fundamental beam loading for a single turn is 1.5 MV per cavity
- So far for a single turn

Important cavity parameters :
Gradient in cavity: 30MV/m
L=1.04m
R/Q = 518 Ω
Δf = 320 Hz ⎫ for beam loading
Q_L=2.2e6 ⎭ compensation

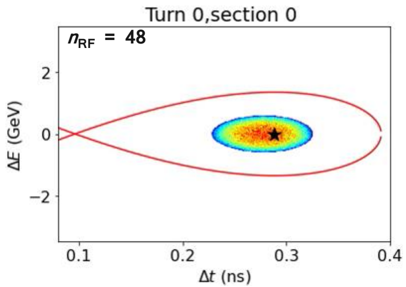


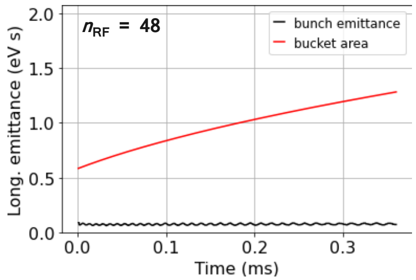


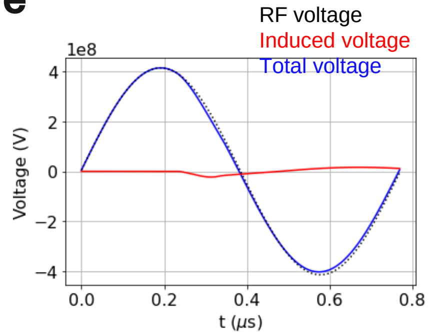
Simulation for RCS1, $n_{\mathrm{RF}} = 48, \varepsilon_L =$ 0.1 eVs

Induced voltages: Combined wakefields

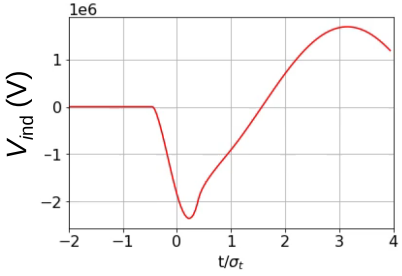
- **Both effects combined: total induced voltage in a cavity is around 2.2 MV per cavity / per meter, i.e. 10-11% of the RF voltage**

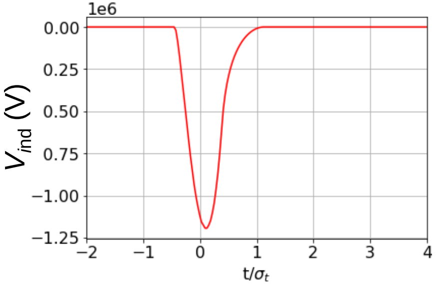


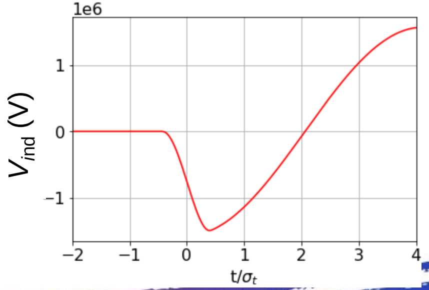




Total induced voltage = short-range wakefield + long-range wakefield



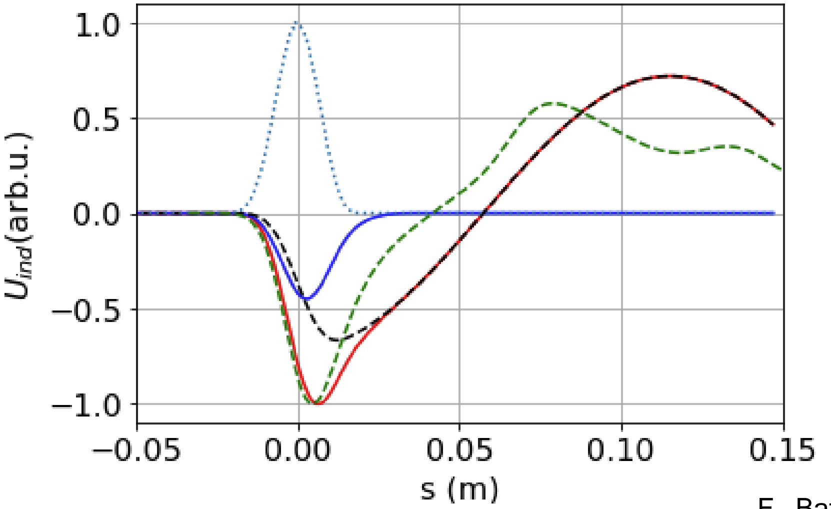




Beam-induced power with BLonD

- The geometry of the cavity defines all HOM, i.e. for single-bunch cases, the short-range wakefield from K. Bane [ref, see appendix for details] includes these, but not the long-range fundamental mode

→ Use short-range wake potential $W_{||,SR}$ to compute power



Plot shows:

bunch charge density, σ = 6.6mm

U_{ind}, short-range

U_{ind}, fundamental mode

Total U_{ind}

Wake potential from ABCI

(for RCS1, n_{RF} = 32, parameter in appendix)

F. Batsch

Studies for 801.58 MHz cavities

- **Some RCS parameter that change with the FCC-ee 5-cell cavity:**

	TESLA/ILC	FCC-ee
Frequency f_{RF} [MHz]	1300	801.58
Cells	9	5
Active length L_{active} [mm]	1038	935
Cavity length L_{cav} [mm]	1276	1291
Gradient [MV/m]	30 (conservative)	25
Number of cavities RCS1	696	835
Straight length RCS1	2334	2334
Straight length with RF	**38 %**	**46 %**

46% instead of 38% use of straight section, feasible!