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Static and dynamic beam dynamic effects in the e-, common and HE-linacs

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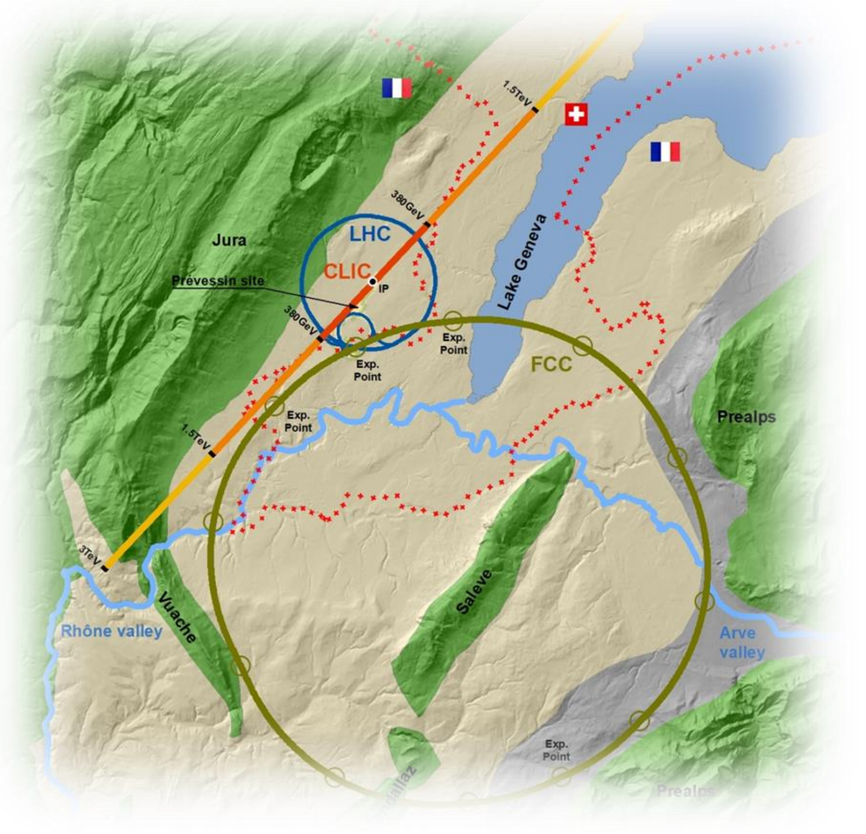
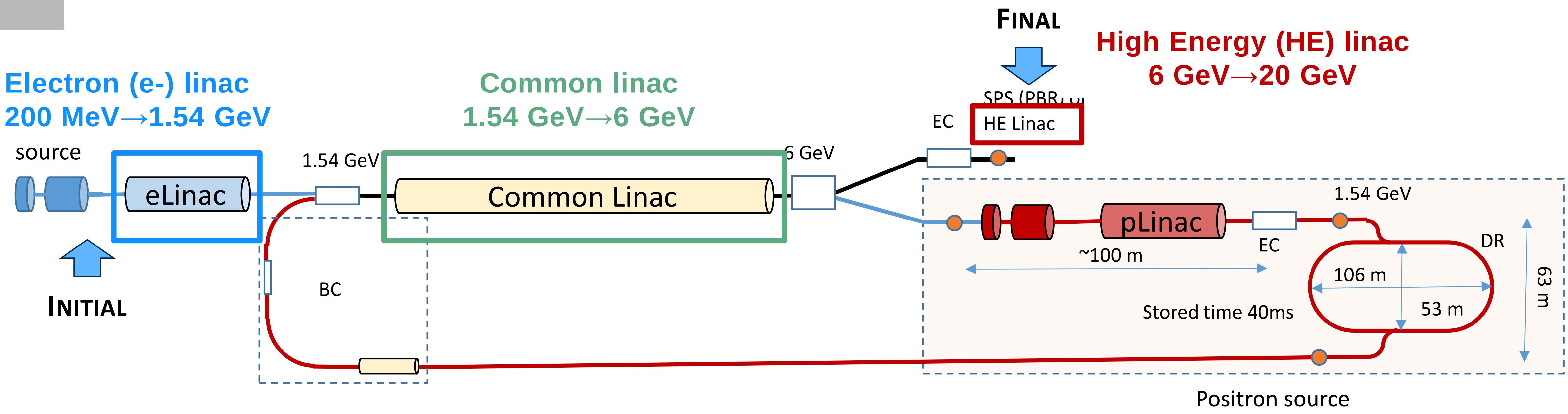
Outlook

- **Machine layout, inputs, and targets**
- **Static effects:**
  - Longitudinal phase space optimization
  - Emittance growth due to elements misalignments and mitigation strategies
- **Energy compressor: why and where?**
- **Dynamic effects: jitter amplification**
  - Single bunch
  - Multi-bunch
- **Implications of the 2.86 GeV damping ring for e^- e^+**
- **Conclusions**



Layout, inputs, and acceptance



Electron (e-) linac
200 MeV→1.54 GeV

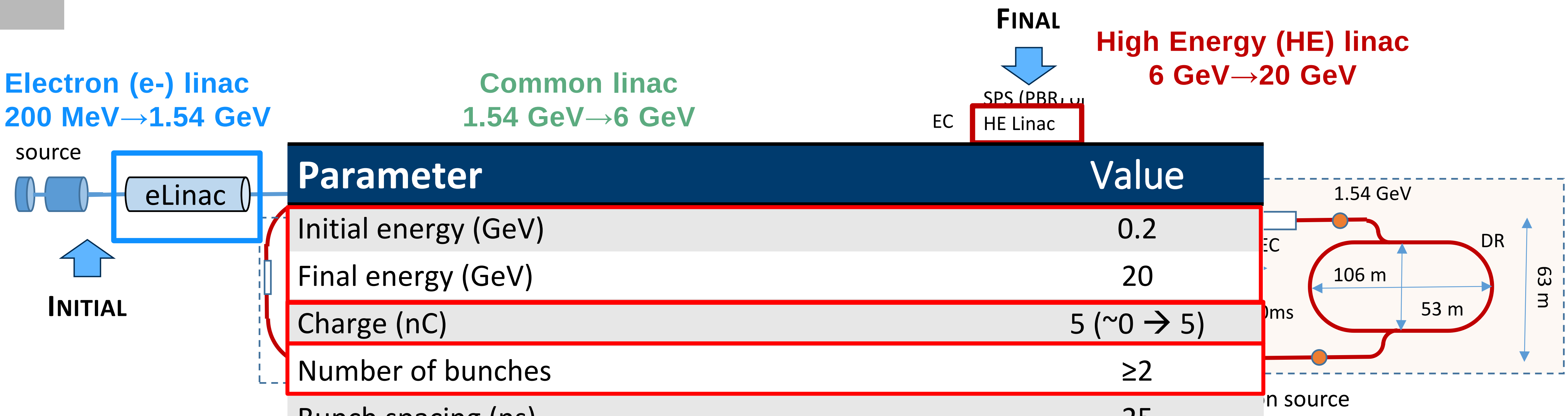
Common linac
1.54 GeV→6 GeV

High Energy (HE) linac
6 GeV→20 GeV

INITIAL

FINAL

Layout, inputs, and acceptance



Electron (e-) linac
200 MeV→1.54 GeV

Common linac
1.54 GeV→6 GeV

FINAL

High Energy (HE) linac
6 GeV→20 GeV

INITIAL

Parameter	Value
Initial energy (GeV)	0.2
Final energy (GeV)	20
Charge (nC)	5 (~0 → 5)
Number of bunches	≥2
Bunch spacing (ns)	25
Initial transverse rms emittance (mm.mrad)	3.2
Final maximum transverse rms emittances (mm.mrad)	10
Final rms bunch length (mm)	~4
Final rms relative energy spread	~0.1-0.15%

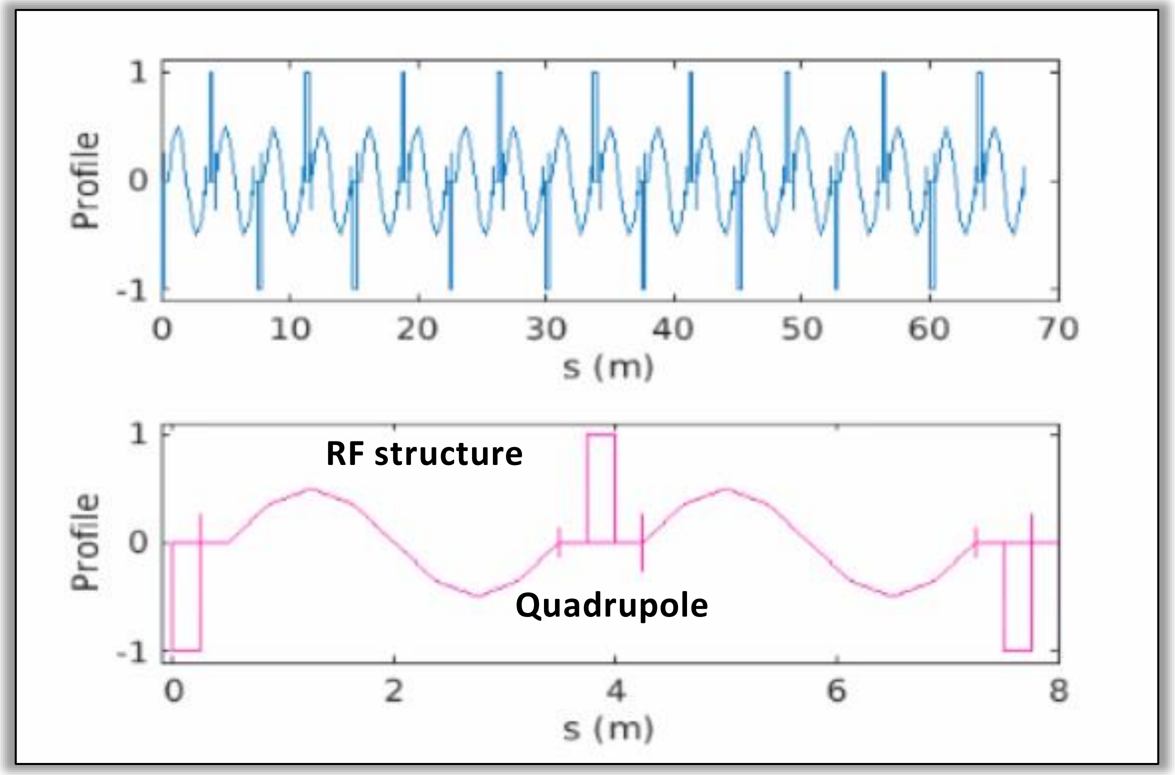
Linacs' modeling and simulation codes

Lattice modeling:

- FODO lattice with **90 degs** phase advance/cell
- One quadrupole/RF structure: distance among the quadrupoles **~3 m**

Very important for the single bunch jitter amplification

- RF structures' wakefield: Bane model (a in the following is the iris radius)
- 90 degrees of the RF cavity corresponds to on-crest operation
- a/λ corresponds to the mean a/λ



Simulation codes:

- **MAD-X**: optics matching
- **Elegant**: single bunch tracking simulations longitudinal plane (verified agreement with RF-Track)
- **RF-Track**: single and multi-bunch tracking simulations transverse plane (reached agreement RF-Track vs Elegant after that M. Borland modified Elegant-see FCC week 2023 presentation)

PAUL SCHERRER INSTITUT

Most promising layouts

More reported at previous FCC Weeks

f (GHz)	G (MV/m)	a/λ	a (mm)	Maximum σ_z (mm)		Maximum phase (deg)	
				δ_E = 0.1 %	δ_E = 0.15 %	δ_E = 0.1 %	δ_E = 0.15 %
2.8	25	0.15	16.1	0.8	1	79	82
5.6	25	0.2	10.7	0.5	0.6	74	66
5.6	40	0.2	10.7	0.4	0.5	67	72
2.0	25	0.1	15	1	1.2	78	81

- With **all these configurations** we reach an **energy spread** ~ 0.1-0.15%
- The RF aperture (a/λ), operating phase, and **bunch length**, given the bunch charge, are optimized to obtain the target energy spread:
  - Optimal bunch length is of the order of **few mm** (from ~1 mm up to about 2 mm with the linearizing cavity)
  - Bunch decompressor needed

σ_{z0} >~ 1 mm, ϕ~80 deg

e- LINAC — **COMMON LINAC** — **HE LINAC** — **σ_{z0}**

f1 = 2.0 GHz | **f1 = 2.0 GHz** | **f1 = 2.0 GHz**

Larger aperture → lower gradient

σ_{z0} ~ 1 mm, ϕ~80 deg

e- LINAC — **COMMON LINAC** — **HE LINAC** — **σ_{z0}**

f1 = 2.8 GHz | **f1 = 2.8 GHz** | **f1 = 2.8 GHz**

Selected

σ_{z0} ~ 0.5 mm, ϕ~70 deg

e- LINAC — **COMMON LINAC** — **HE LINAC** — **σ_{z0}**

f1 = 5.6 GHz | **f1 = 5.6 GHz** | **f1 = 5.6 GHz**

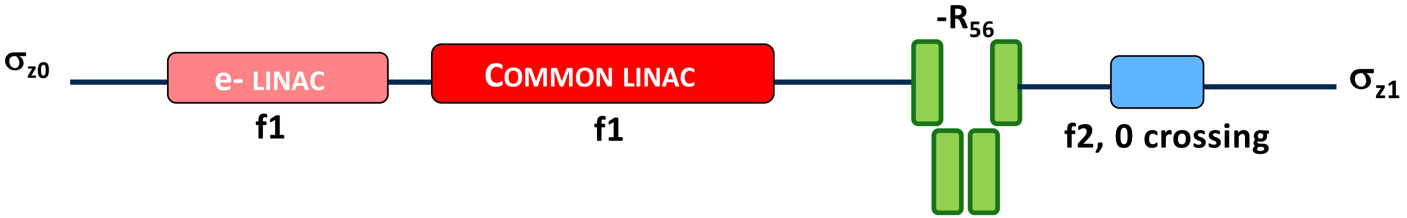
More off-crest operation

↓ Low energy gain

↓ Larger Δemittance

The energy compressor “a la SuperKEKB”

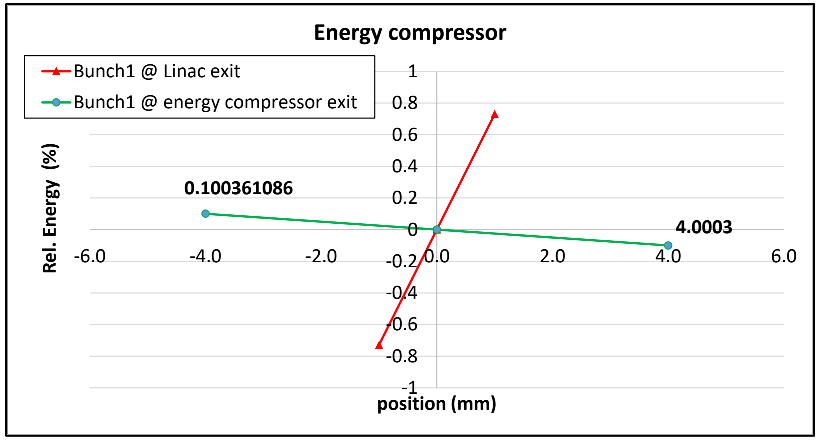
Goal: manipulate the bunch longitudinal phase space → change the energy spread and the bunch length



$$V_{f2} = \frac{\lambda_2 E_{TARGET}}{2q\pi R_{56}}$$

Method:

- Chicane transforms energy difference → arrival time difference
- RF cavity transforms the arrival time difference → phase difference
- RF cavity compensates the incoming energy difference (inside the bunch or bunch-to-bunch) by applying the appropriate voltage downstream of the chicane



Procedure:

1. Chirp determined by the upstream linacs (operating phase+beam loading at a given bunch length and charge) → increased on purpose
2. Determine R_{56} to have the target bunch length
3. Given R_{56}, compute the voltage to have the desired energy spread
4. Verify the results with tracking simulations. Necessary, because the energy-time distribution may be non-linear

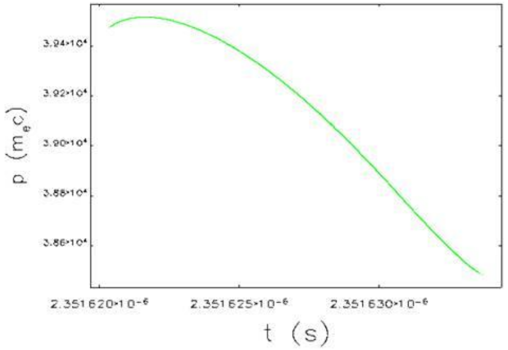
Advantages:

- Bunch length and energy spread match the **booster requirements**
- **Tunability** of the bunch length and energy spread separately and without modifying the upstream linacs
- Bunch energy spread variation compensation due to **charge scan**

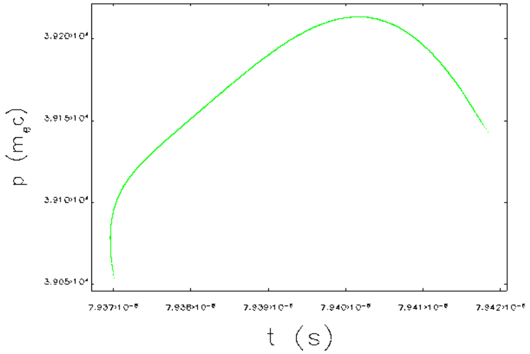
Energy compressor: results

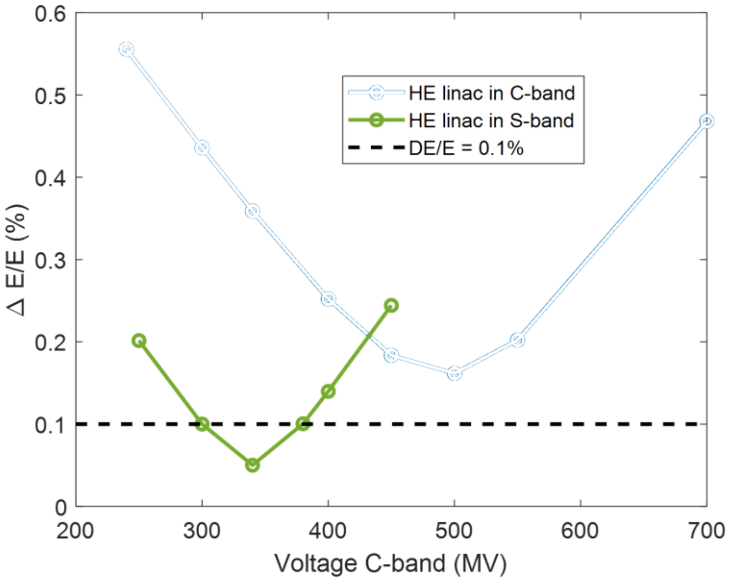
START-TO-END SIMULATIONS

At the HE Linac exit



At the EC exit





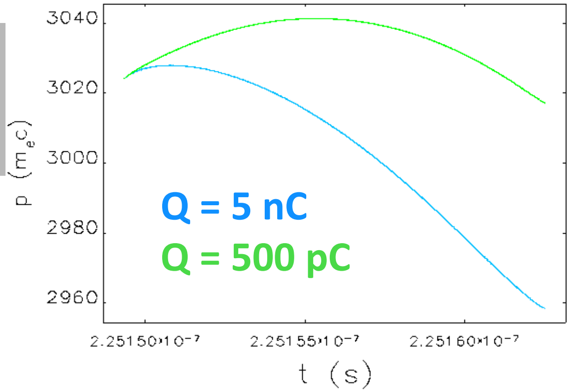
Initial HE Linac δE/E (%)	0.75
R_{56} (m)	0.41
Voltage X δE/E = 0.15% (MV)	135
Voltage C δE/E = 0.15% (MV)	270
Voltage X minimum δE/E (MV)	170
Voltage C minimum δE/E (MV)	340
Length X-band cavities min (m)*	3.4
Length C-band cavities min (m)*	11.8
Minimum δE/E	5.1e-4
Energy spread reduction	14
Initial bunch length (mm)	1
Final bunch length (mm)	4

* Assuming one module/structure: C-band: 28.8 MV/m, X-band: 50 MV/m

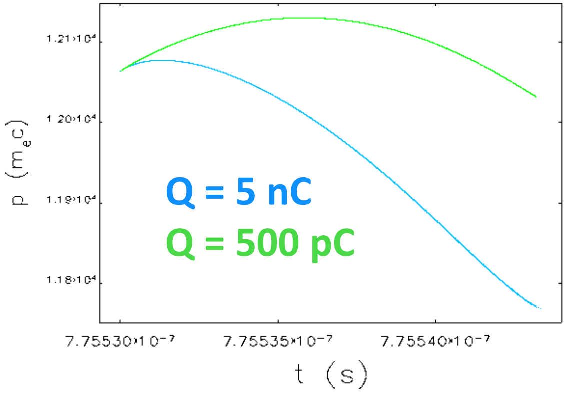
More than a factor 2 margin in <15 m (C-band) < 5 m (X-band) length allocated for the RF structures

Impact of the different bunch charges: scan of the charge

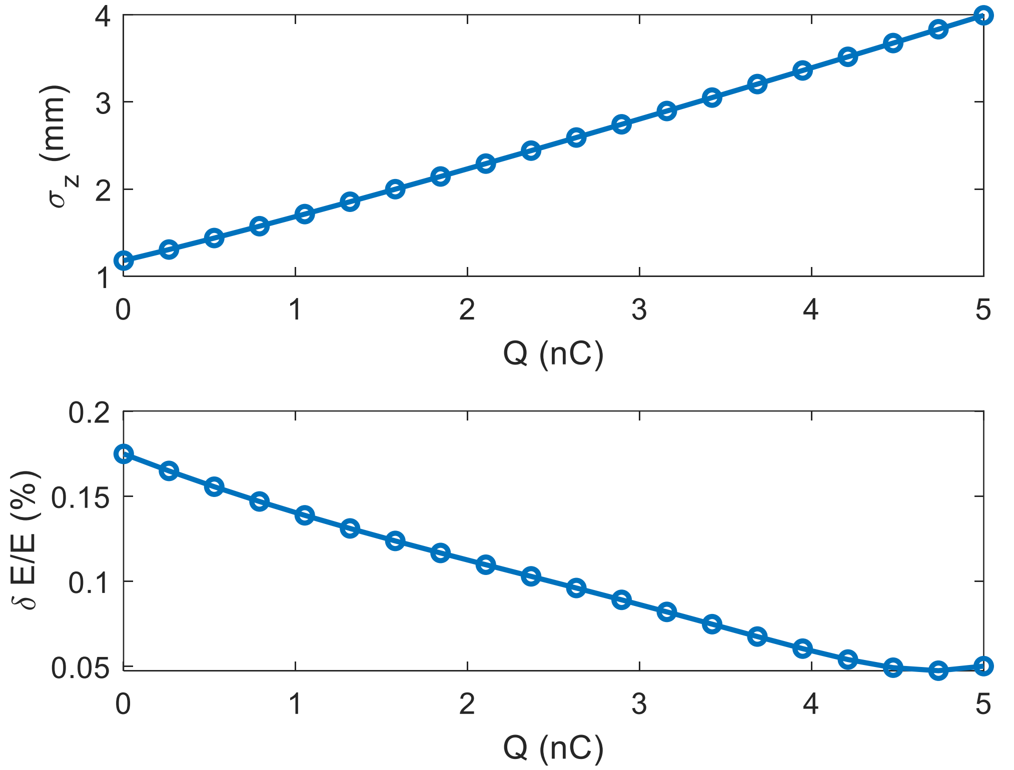
e- Linac exit (1.54 GeV)



Common Linac exit (6 GeV)



HE Linac exit
(energy compressor tuned for the minimum $\delta E/E$ at 5 nC)

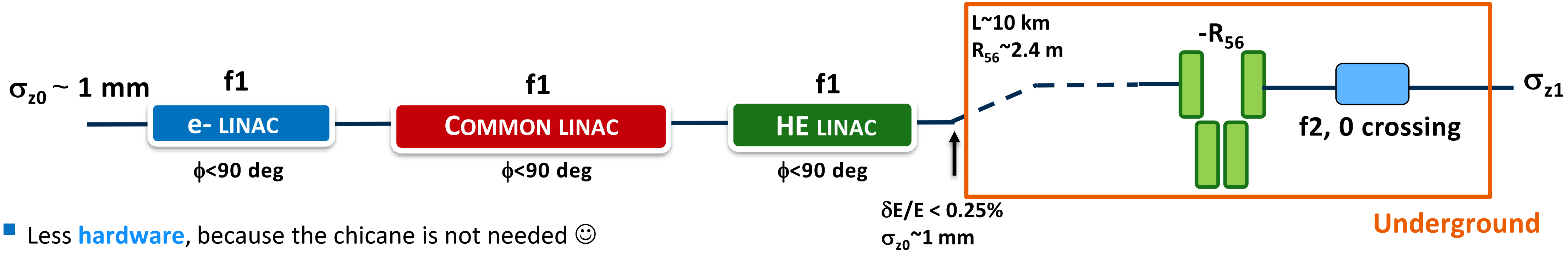


Energy spread at the exit of	Q = 5 nC	Q = 0.5 nC
Gun section (E = 200 MeV)	1.97e-3	1.97e-3
e- Linac (E = 1.54 GeV)	6.41e-3	1.74e-3
Common Linac (E = 6 GeV)	7.22e-3	1.76e-3

Energy spread from 0.05% to 0.2%,
bunch length ~few mm (shorter only for lower charge beams)

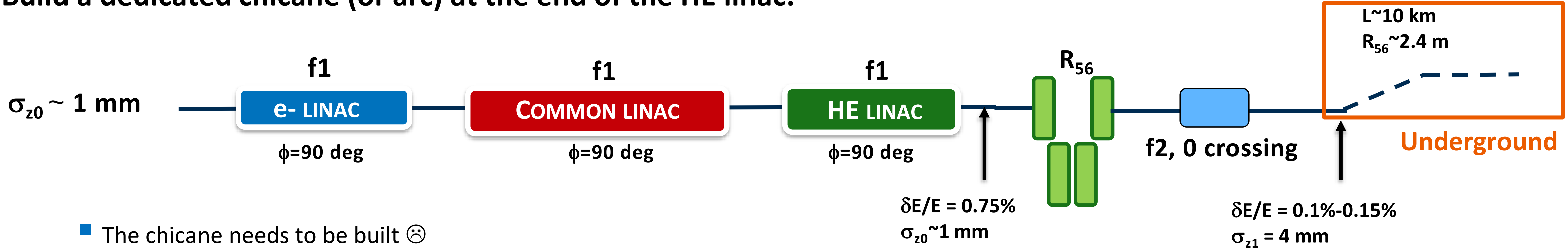
Energy compressor: where?

Use the R_{56} in the transfer line to the booster:



- Less **hardware**, because the chicane is not needed ☺
- RF power needs to be brought ~100 m **underground** ☹
- **Dispersion** in the transfer line sets a limit on the maximum energy spread (off-crest operation or another energy compressor), and after chirp must be added to decompress the beam 😐

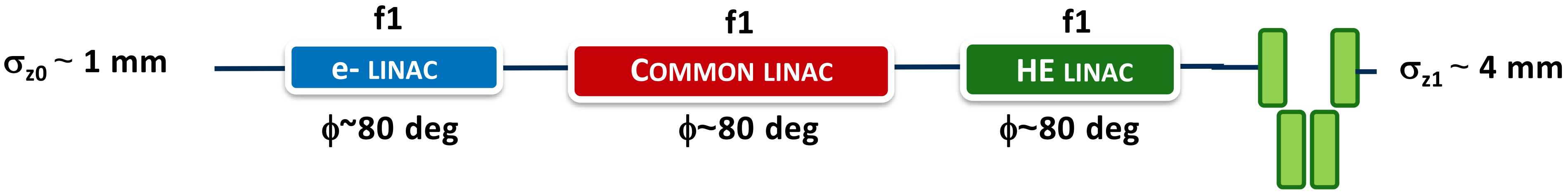
Build a dedicated chicane (or arc) at the end of the HE linac:



- The chicane needs to be built ☹
- RF power at **"surface"** ☺
- The linacs may be operated on-crest → better for **emittance** preservation and **energy efficiency** ☺
- Smaller beam size with the same dispersion → smaller aperture **magnets** (cost) ☺
- Less **CSR** (longer bunch length) and **chromaticity** (smaller energy spread) related effects along the transfer line ☺

Static effects longitudinal: summary

Layout <u>without</u> the energy compressor:



$\sigma_{z0} \sim 1$ mm

f1 **e- LINAC** $\phi\sim80$ deg

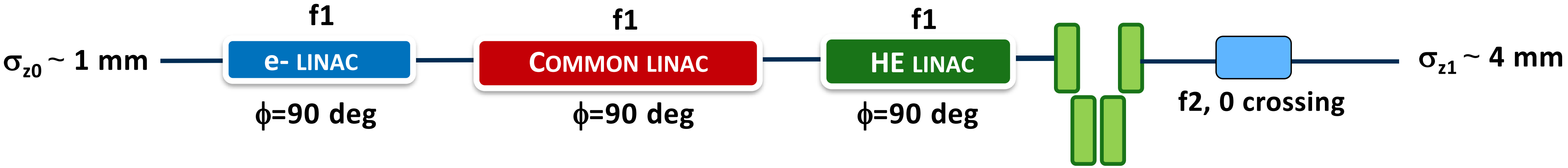
f1 **COMMON LINAC** $\phi\sim80$ deg

f1 **HE LINAC** $\phi\sim80$ deg

$\sigma_{z1} \sim 4$ mm

- Determined **an optimal combination** of bunch length, RF operating frequency, phase and geometry to obtain the target energy spread
  - Optimal bunch length and phase @ 2.8 GHz -> ~1 mm
  - Optimal bunch length and phase @ 5.6 GHz -> ~0.5 mm
- Both are far from the required 4 mm → bunch must be **decompressed** upstream of the booster injection

Layout <u>with</u> the energy compressor:



$\sigma_{z0} \sim 1$ mm

f1 **e- LINAC** $\phi=90$ deg

f1 **COMMON LINAC** $\phi=90$ deg

f1 **HE LINAC** $\phi=90$ deg

f2, 0 crossing

$\sigma_{z1} \sim 4$ mm

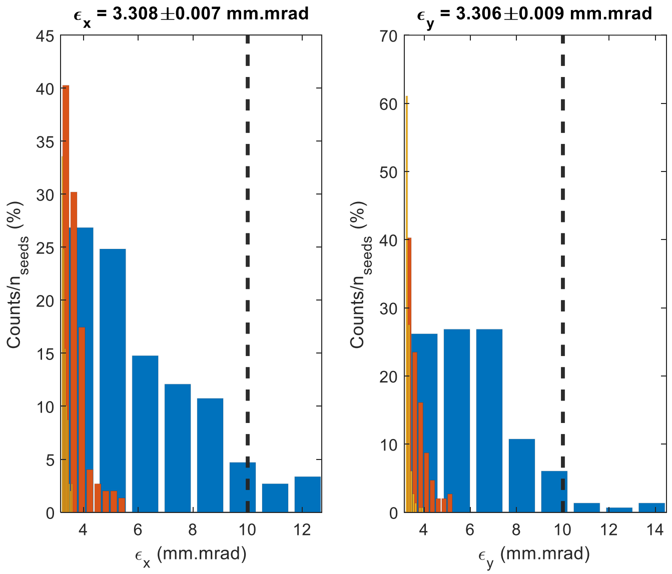
- We use the energy compressor to reach the target bunch length and energy spread (with a margin factor 2-3)
- We can operate the linacs on-crest → better for **emittance** growth and energy efficiency
- The bunch **energy jitter** is reduced
- Added **tunability** for the bunch length and the energy spread

Transverse dynamics

Single and **multi-bunch** effects are dominated by long and short-range wakefield, elements misalignment, and incoming jitter

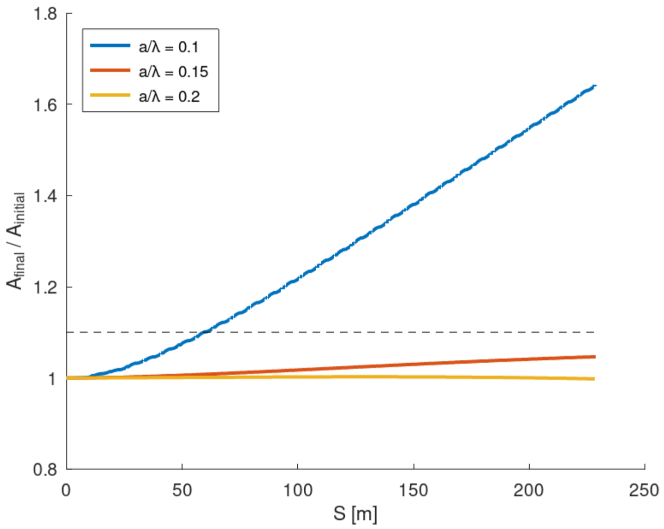
SINGLE BUNCH

Static misalignments



Source: misalignments of the lattice elements
Effect: emittance growth
Cures: trajectory correction schemes

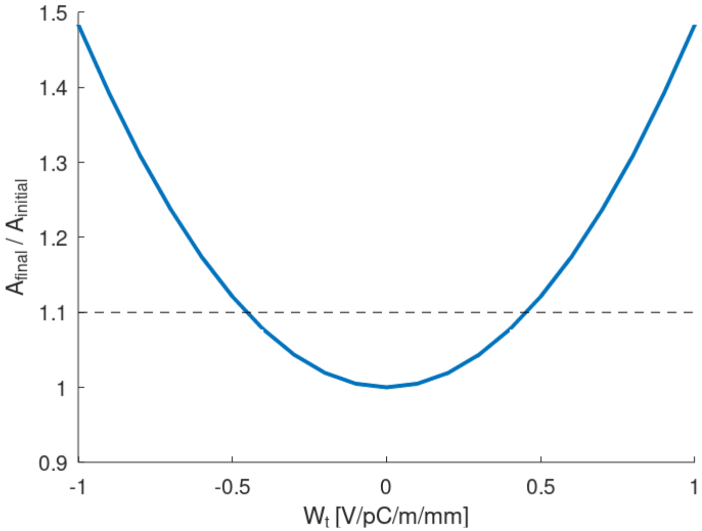
Bunch jitter



Source: off-axis incoming orbit and short-range wakefield
Effect: bunch jitter amplification
Cures: lattice and RF aperture

MULTI-BUNCH

Bunch-to-bunch jitter



Source: preceding bunch and long range wakefield
Effect: bunch-to-bunch jitter amplification
Cures: RF high order mode mitigation

Static single bunch: errors and mitigation strategy

Elements misalignments

Quadrupoles
Offset x, y = 50 μm rms

Gaussian distribution

RF cavities
Offset x, y = 100 μm rms

Gaussian distribution

BPM
Offset x, y = 30 μm rms
Resolution x, y = 10 μm
Gaussian distributions

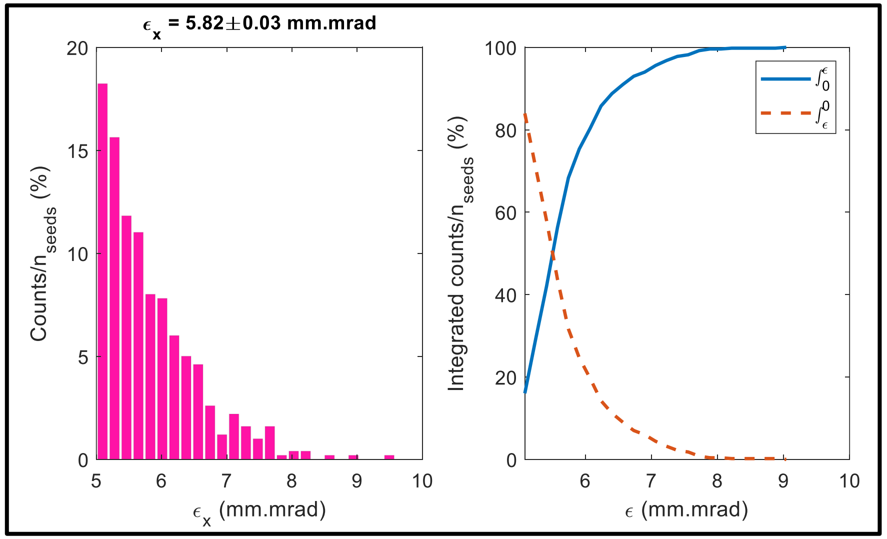
Steering algorithms

- **One-to-one orbit correction**
  1. Orbit x_i with errors computed
  2. Response matrix computed
  3. Correctors strengths calculated (SVD) to steer the beam

- **Dispersion Free Steering (DFS)**
  1. Orbit x_i with errors computed
  2. Response matrix computed
  3. Off-energy beam (different RF phase) orbit $x_{\Delta E,i}$ computed
  4. Response matrix computed
  5. Correctors strengths calculated, minimizing X^2 defined as:

$$\chi^2 = \sum_{\text{bpms}} x_i^2 + \omega^2 \sum_{\text{bpms}} (x_{\Delta E,i} - x_i)^2 + \beta^2 \sum_{\text{corrs}} \theta_j^2$$

Parameters for the simulations

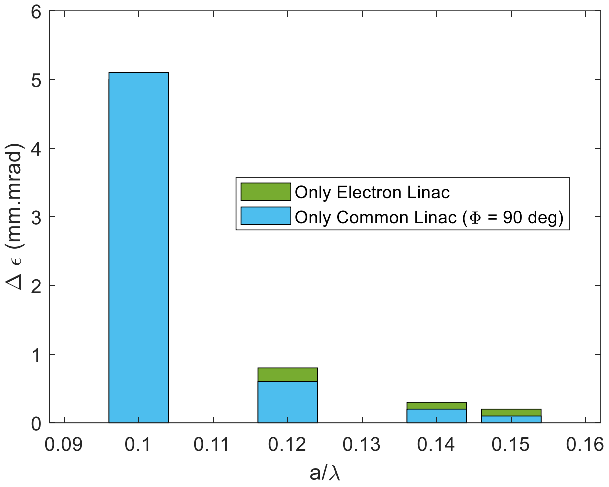


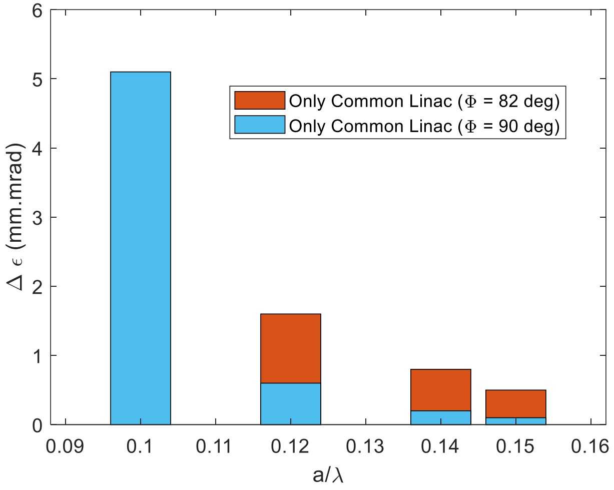
- Between few hundreds and 1000 seeds
- Initial emittance is **3.2 mm.mrad** at 5 nC with 1 mm rms laser pulse length (Z. Vostrel and S. Doebert)
- Very **pessimistic assumption**: 99% of the good seeds (CLIC for example uses 90% of the seeds)

Static single bunch: results

LOWER ENERGY

a/λ	a (mm)	e- Linac	Common Linac (82 deg)	Common Linac (90 deg)
0.10	10.7	5.0	/	5.1
0.12	12.9	0.8	1.6	0.6
0.13	13.9	/	/	/
0.14	15.0	0.3	0.8	0.2
0.15	16.1	0.2	0.5	0.1



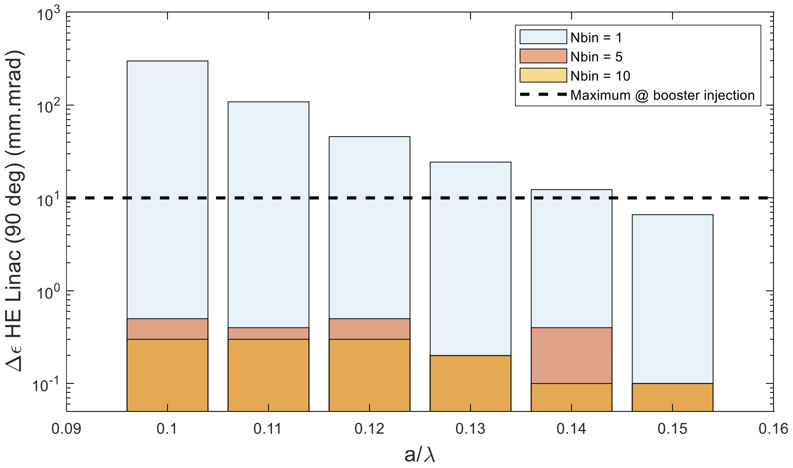


Outcomes:

- Largest emittance growth/length at the low energy section→ important reduction in case of the **<u>e- damping ring</u>** option
- Emittance growth strongly depends on the RF operating phase

HE LINAC

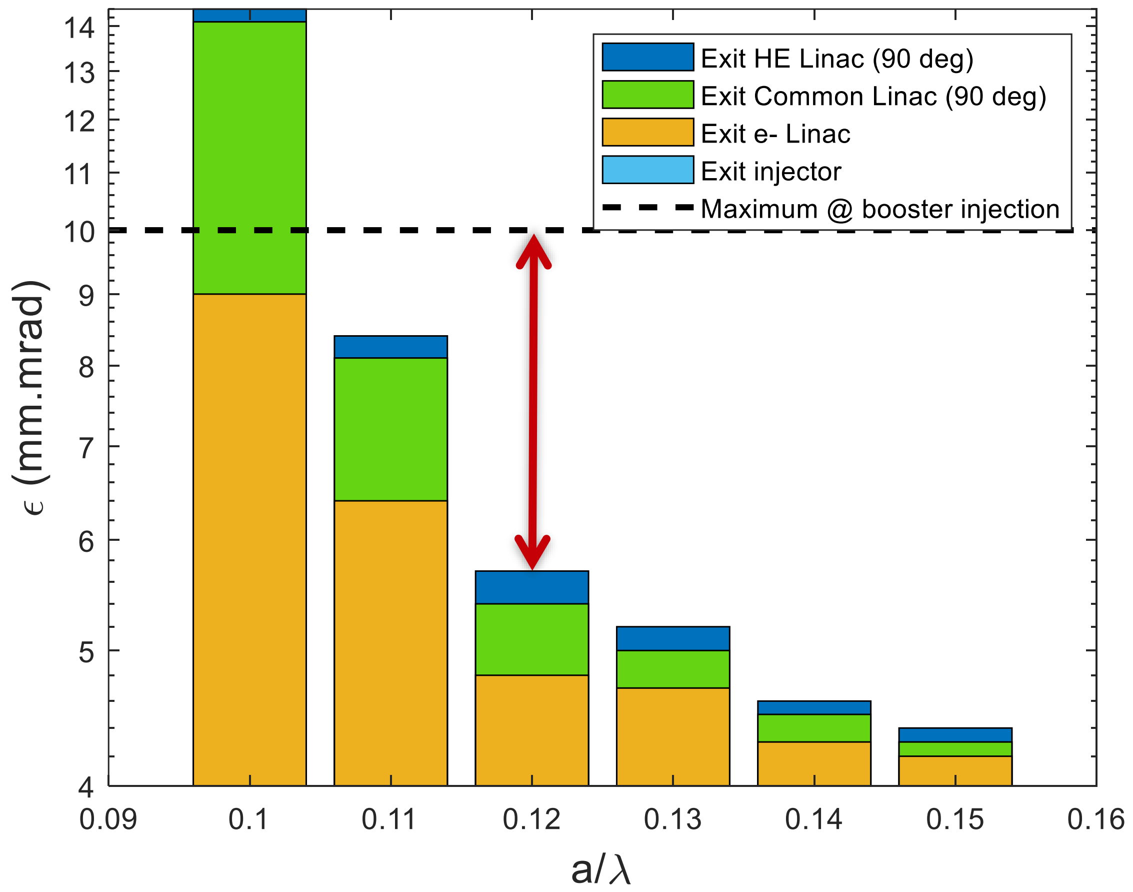
a/λ	a (mm)	e- linac	Common linac (90 deg)	HE linac, Nbins = 10
0.10	10.7	5.0	5.1	0.3
0.11	11.8	2.4	1.7	0.3
0.12	12.9	0.8	0.6	0.3
0.13	13.9	0.7	0.3	0.2
0.14	15.0	0.3	0.2	0.1
0.15	16.1	0.2	0.1	0.1



Outcome:

- Essential to separate the orbit steering/DFS in several sections (what we defined bins)

Static single bunch: summary



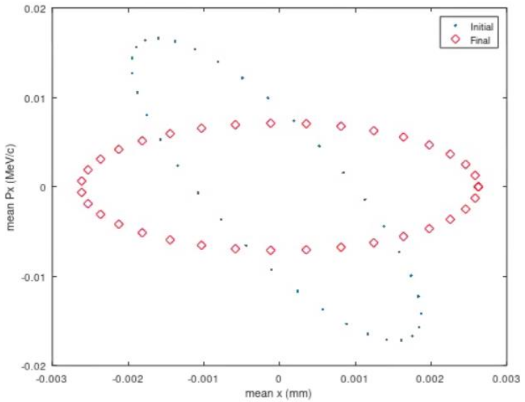
Outcomes:

- Relatively small emittance growth in the HE linac compared to the lower energy sections → important in case we go to the **e- damping ring**
- Quite an important impact of the **RF operating phase** on the emittance growth

About a factor 2 margin for a/λ ≥ 0.12

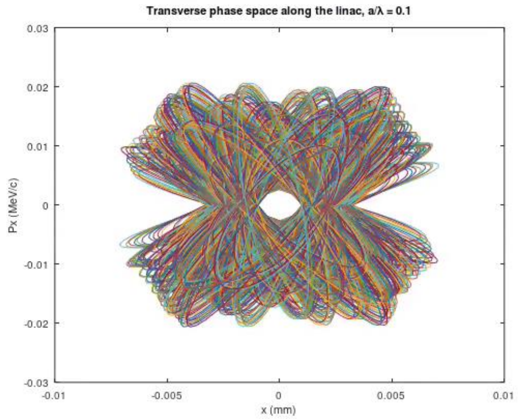
Orbit jitter

Definition Non-correctable (shot-to-shot) incoming offset



Evolution In a linear system, the relative amplitude of the oscillation w.r.t. the beam size is preserved along the lattice.

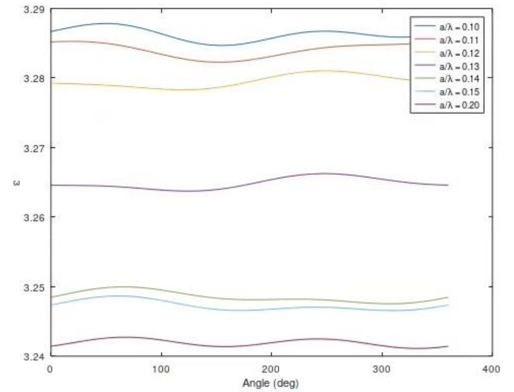
In the presence of nonlinear effects, such as nonlinear elements or short- and long-range wakefields, the relative amplitude tends to increase.



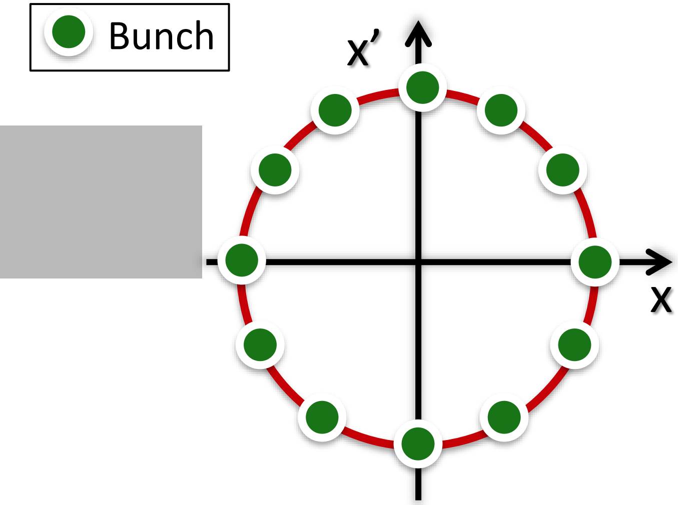
Wakefield

- The <u>short-range</u> depends on *cell geometry*
- The <u>long-range</u> depends on *high-order modes damping*

The total jitter amplification factor is the product of the two.



"Painting" of the transverse phase space



Jitter amplification computation:

- Single bunches distributed on a circle (in 10 degrees step size) injected to the line with different (x,x')
- Computed the area in the initial beam transverse phase space → A_0
- Computed the area in the final beam transverse phase space → A_F
- Jitter amplification, JA, is defined as the ratio of the areas → A_F / A_0

Advantages of this approach (already applied to the CLIC design):

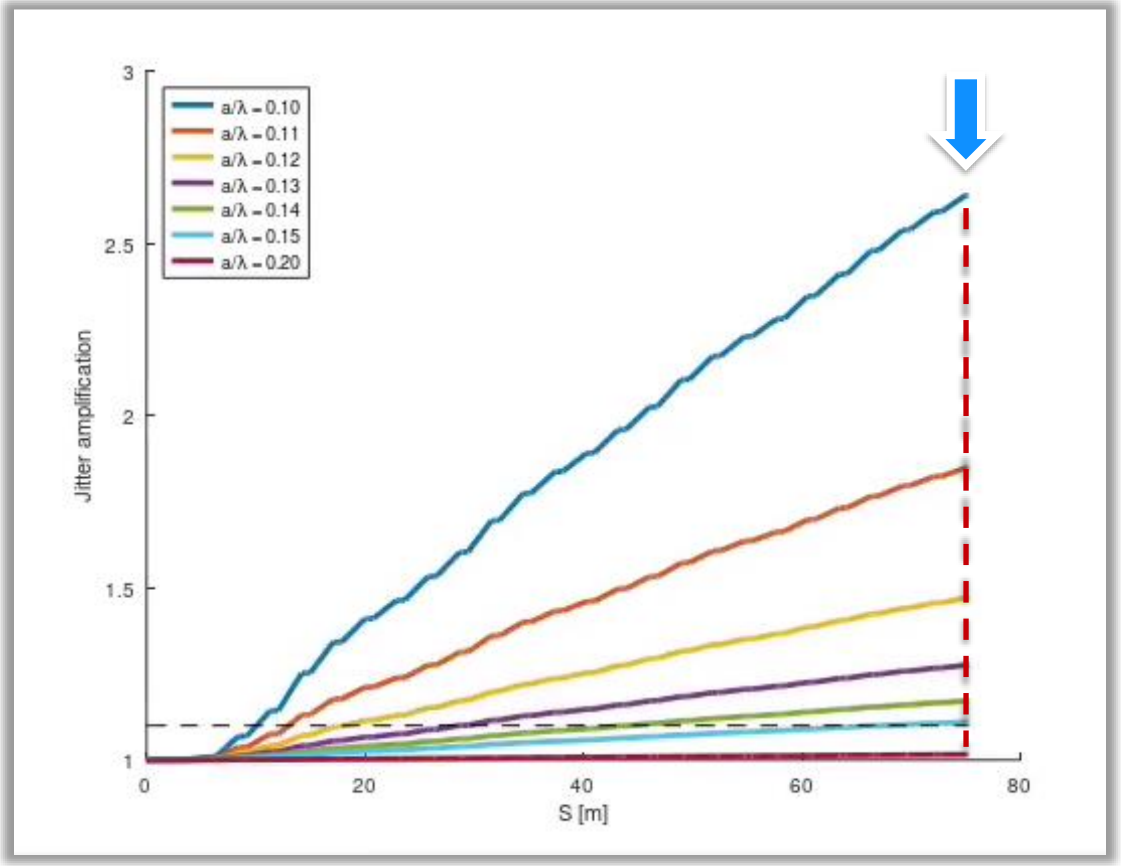
- JA is **independent** on the initial jitter
- JA considers the effect on the transverse phase space, and not only in x **OR** x' (y or y') → it does not depend on the location where it is determined
- The impact of jitter is largely on the orbit. The **emittance** is mostly **unaffected** (orbit much on-axis than that corresponding to the static error studies)
- Given JA of a generic kth section, JA_k, the **total jitter amplification** JA_{tot} is given by the product of all of them:

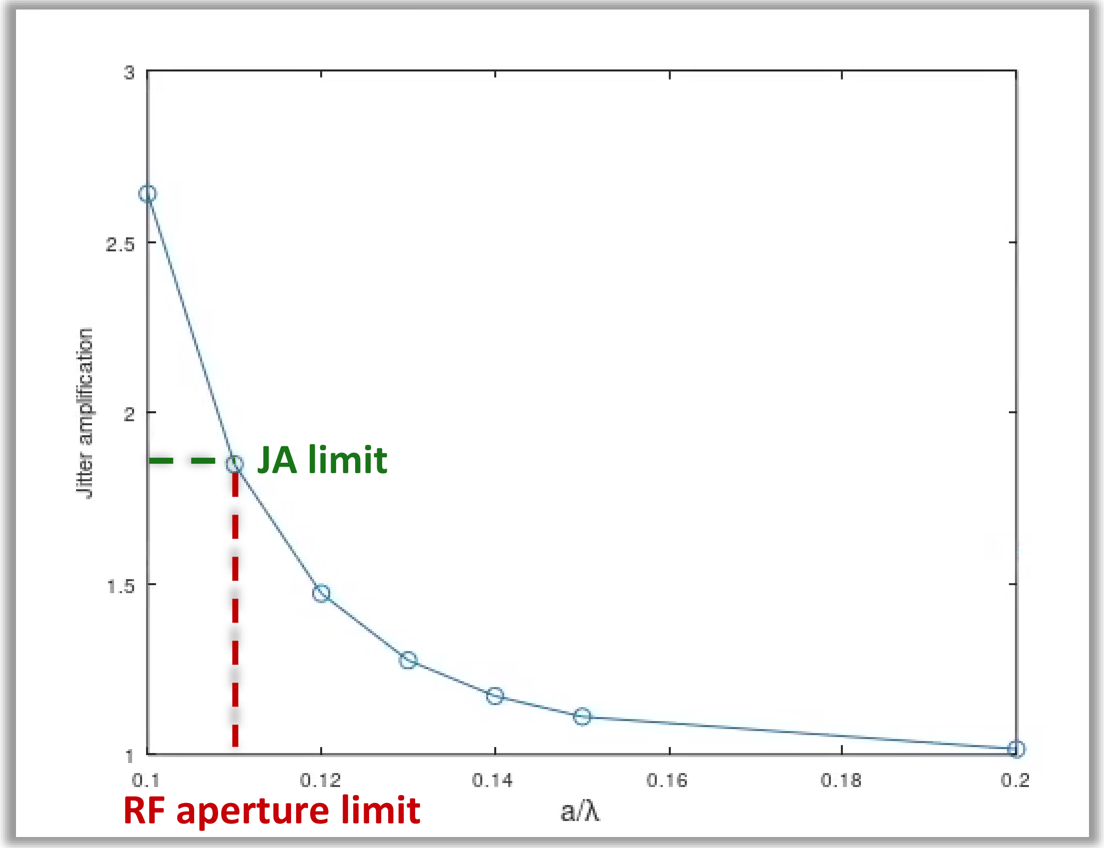
$$JA_{tot} = \prod_{k=1}^{N} JA_k$$

Jitter amplification: procedure

Simulation setup:

- Compute the JA along the considered linac
- Determine the JA at the end of the considered linac
- Given the maximum acceptable jitter, determine the specifications for the RF design





JA limit

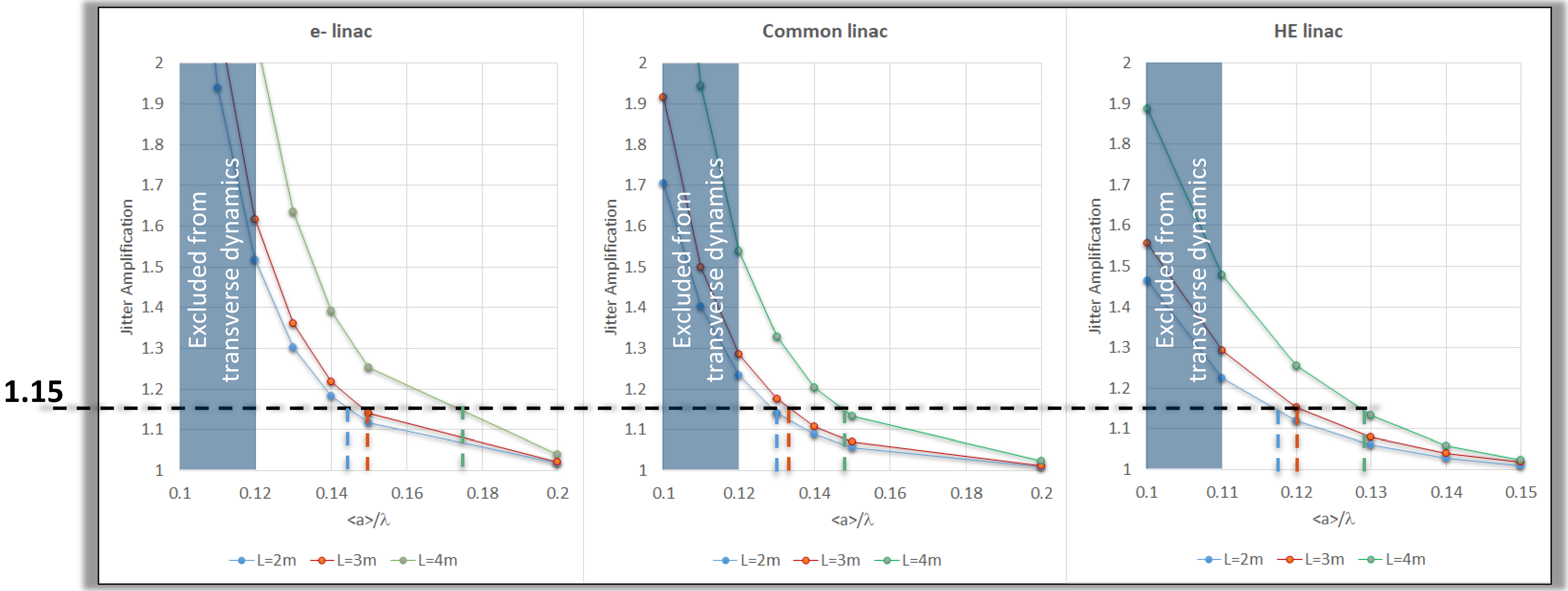
RF aperture limit

Jitter amplification: results

Assumed full linacs chain jitter amplification: $A_k = \mathbf{1.15}$/linac → $A_{tot\ single} = 1.15 * 1.15 * 1.15 = 1.52$

Optimal RF structure length = 3 m (compromise between shunt impedance and aperture-**see A. Kurtulus' talk**)

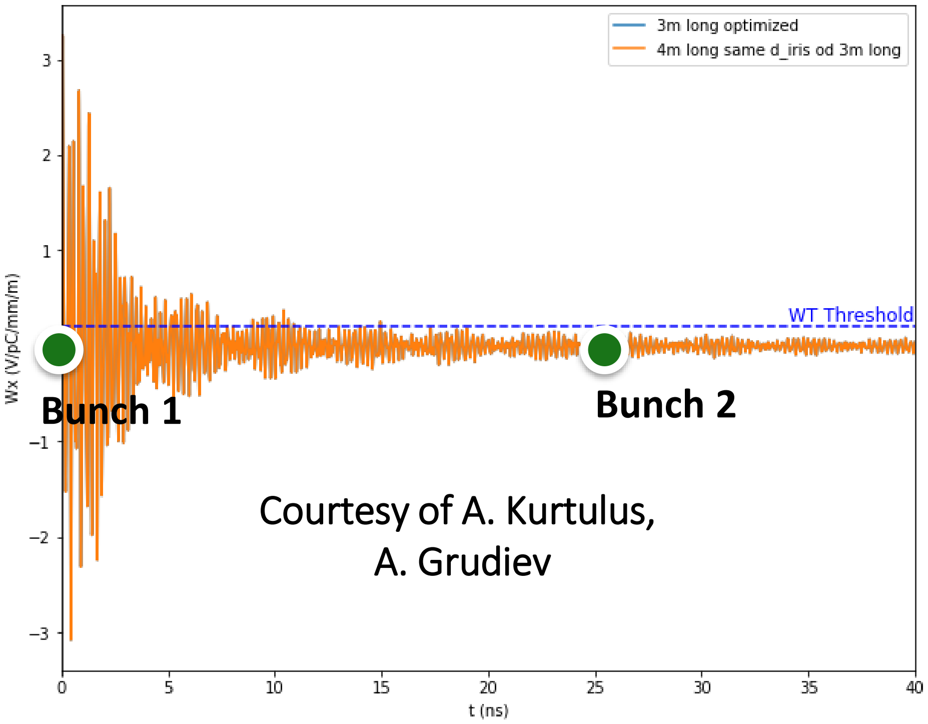
	e- linac	Common linac		HE linac
Energy range	[0.2,1.54) GeV	[1.54,2.8) GeV	[2.8,6) GeV	[6,20] GeV
<a>/λ	0.15	0.15	0.12	0.12



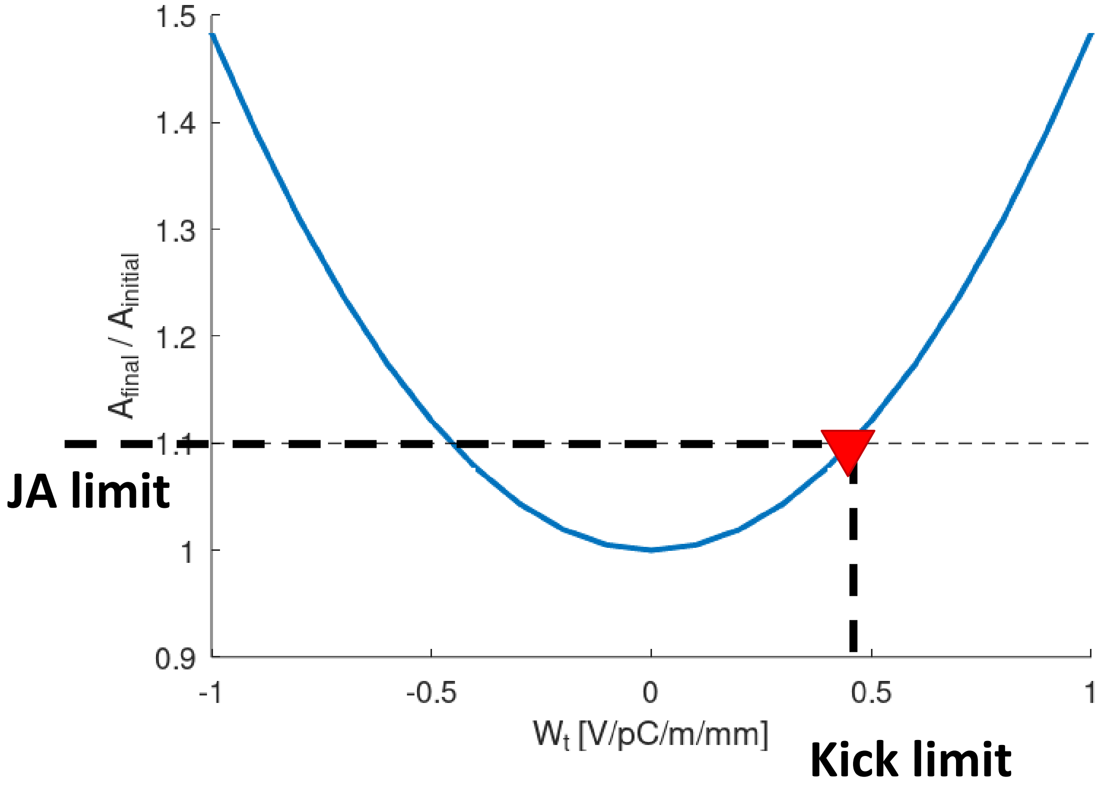
Multi-bunch jitter amplification: procedure

Simulations’ strategy: provide specifications for the RF design

- Imposed a kick to the second bunch to simulate the long-range wakefield generated by the first bunch to the following one: independent on the bunch time separation
- Determined the tolerable kick to maintain the JA below the defined threshold
- RF design aims to produce transverse wakefield below this value
- This method is independent on the minimum bunch separation

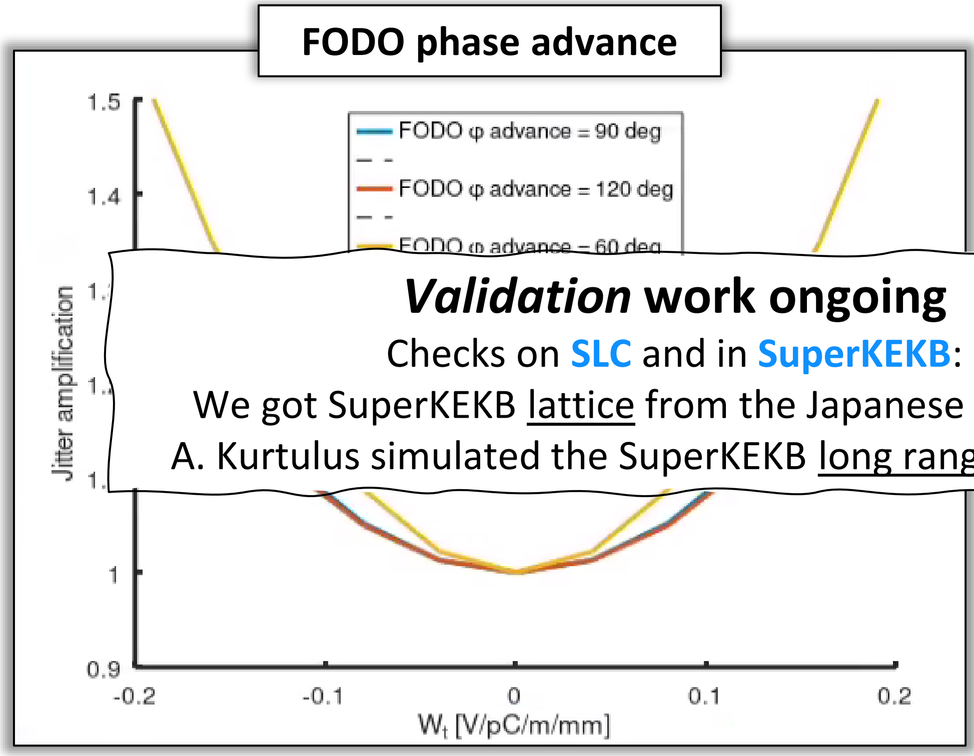


Courtesy of A. Kurtulus,
A. Grudiev



Multi-bunch jitter amplification: dependences

Simulations → full linac chain from 200 MeV (gun section exit) to 20 GeV



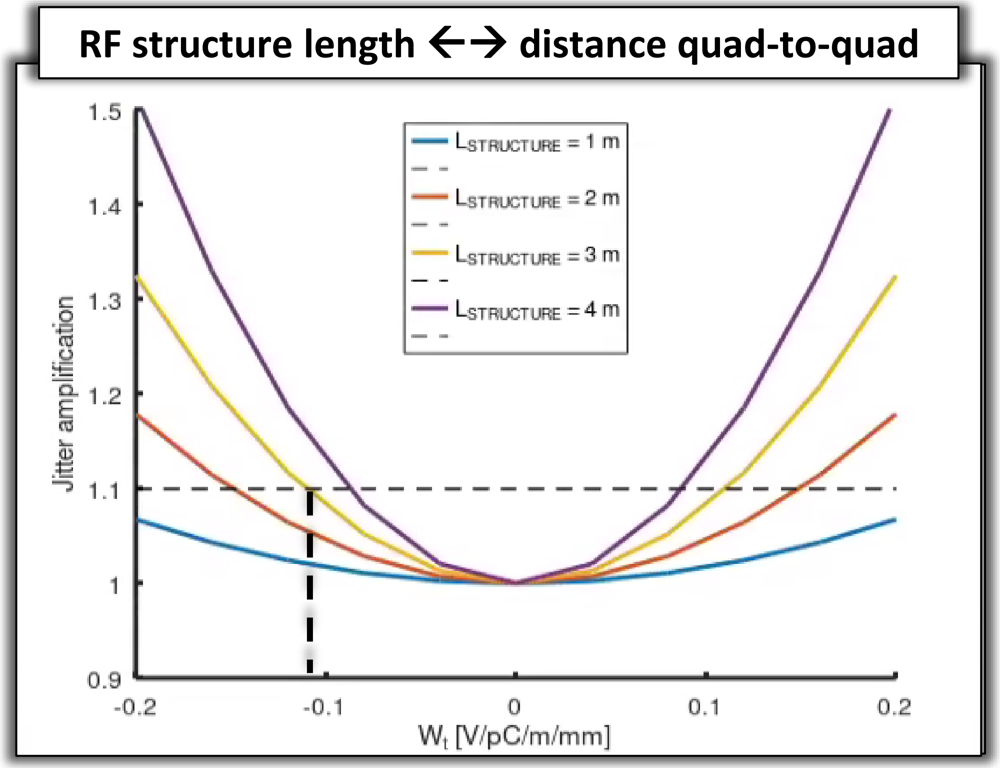
FODO phase advance

Validation work ongoing

Checks on **SLC** and in **SuperKEKB**:

We got SuperKEKB lattice from the Japanese colleagues

A. Kurtulus simulated the SuperKEKB long range wakefield



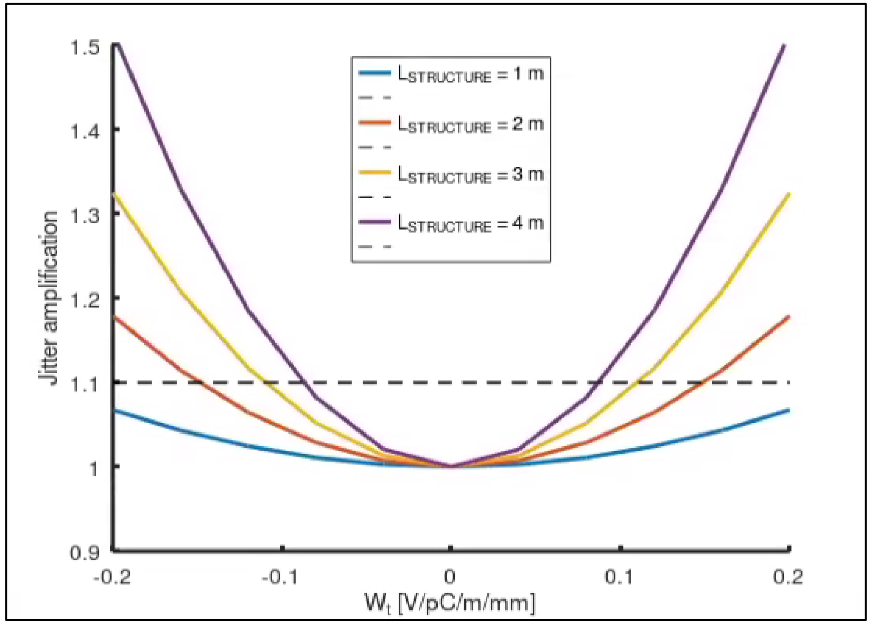
RF structure length ←→ distance quad-to-quad

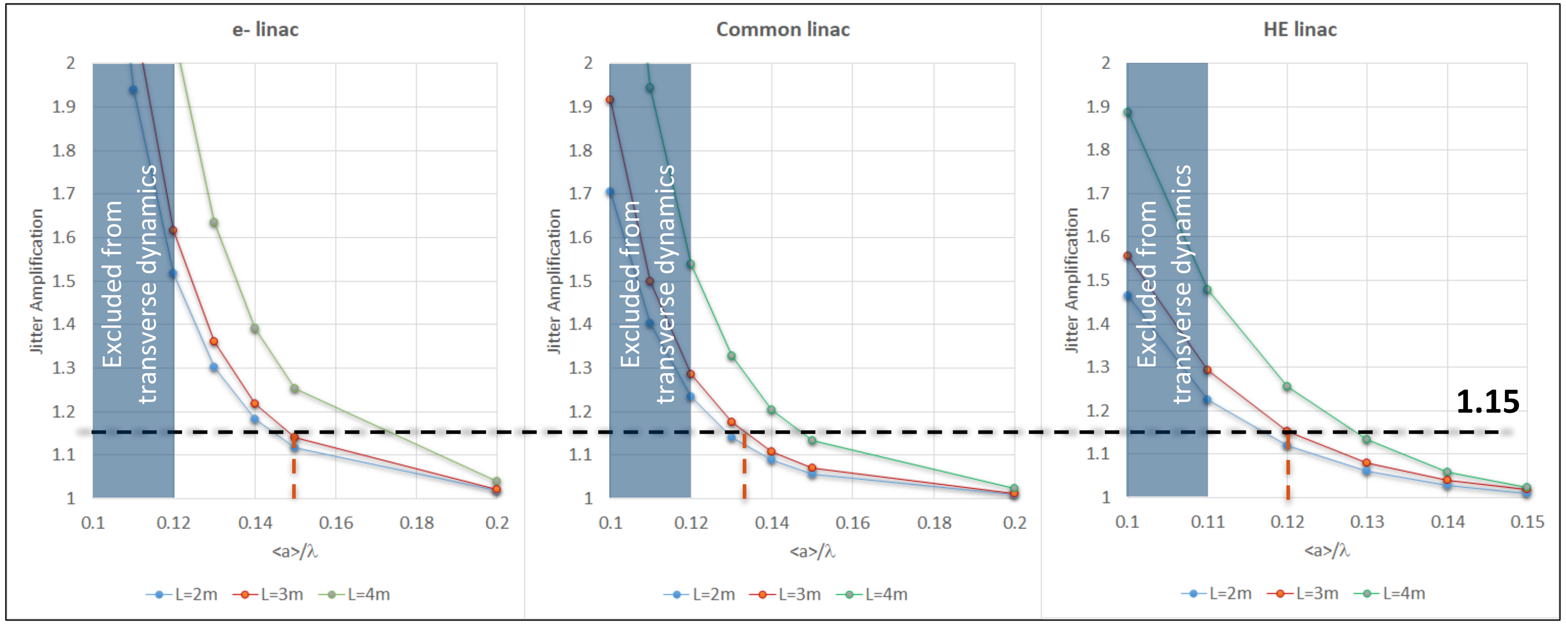
RF structure length = 3 m

Maximum tolerated kick = 0.11 V/pC/m/mm

Dynamic effects transverse: summary

Effect	JA	Optimization knob	Settings
Single bunch	1.52	RF aperture	<a>/λ = [0.15,0.12]
Multi-bunch	1.1	RF structure length (←→ distance quad-to-quad)	3 m



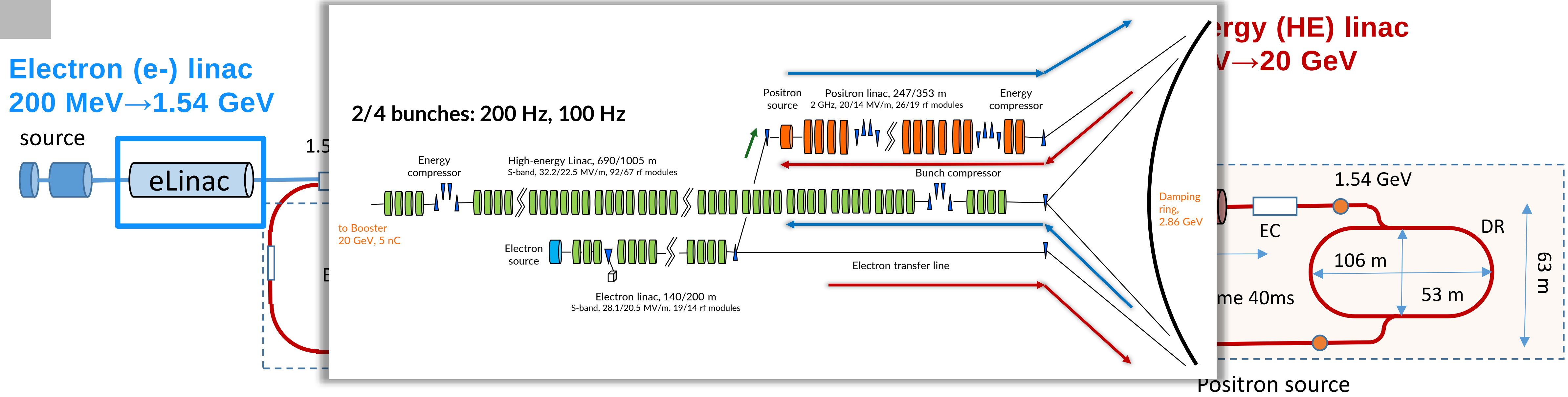


$$\boxed{A_{tot} = 1.52x1.1{\sim}1.70}$$

Total jitter amplification~30% margin

Impact of the 2.86 GeV DR on the e- beam

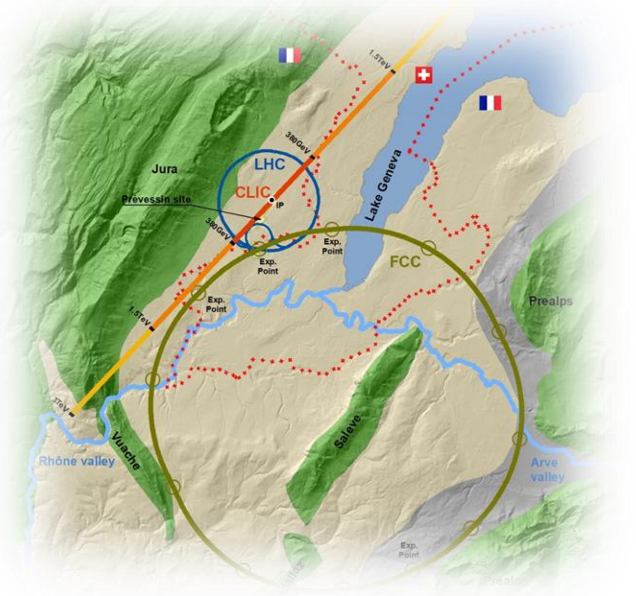
The proposed use of the DR for e+ at 2.86 GeV instead of 1.54 GeV gives also the possibility to use the damping ring for the e- as well



Advantages	Disadvantages
Relax the constraint on the emittance growth up to 2.86 GeV	Bunch will need to be compressed at the DR extraction
Reduce emittances	
Produce flat beam ($\varepsilon_y \ll \varepsilon_x$)-recent booster wish	
Relax the jitter amplification constraint up to 2.86 GeV	

Conclusions

Complete beam dynamics design of the full FCCee linac chain has been shown



Longitudinal dynamics (single bunch): energy spread and bunch length

- Design *without energy compressor*: booster requirements on energy spread fulfilled, but the bunch needs to be decompressed to reach the target bunch length
- Design *with energy compressor*: all *booster requirements fulfilled* in terms of energy spread and bunch length with an improved bunch energy stability (charge scan)

Transverse dynamics (static single bunch): emittance growth

- Defined a range of RF aperture ($a/\lambda \geq 0.12 \rightarrow a \geq 12.9$ mm) giving a *factor 2 margin* in emittance growth

Transverse dynamics (dynamic single and multi-bunch): jitter

- Determined the optics, RF structures aperture (from $a/\lambda = 0.15$ to 0.12) and length (3 m) to control the bunch jitter
- Determined the maximum kick to control the bunch-to-bunch jitter (0.11 V/pC/m/mm)
- The jitter amplification fulfills the transfer line/booster injection requirements with a *30% margin*
- More work ongoing to *validate* our modeling with other machines (*SLC* and SuperKEKB)

Ready to optimize the “new baseline design” (2.86 GeV damping ring) having fruitful interactions with the damping ring , transfer line and booster groups

RF structure design requests from beam dynamics

From the other sections’ requirements to the linacs’ beam dynamics: requirements and achievements

Parameter	Transfer line request	Booster request	Achieved
Bunch length (mm)	-----	4	4 tunable from <1 mm to few mm
Energy spread	<0.25%	0.1-0.15%	0.15% tunable from 0.05% to % level
Jitter amplification	2	-----	1.7
Maximum emittances x, y (mm.mrad)	-----	<10	<6
Maximum emittances x,y (mm.mrad)-recent	-----	Smaller in y (2), ok in x (20)	Probably possible with the e- DR option

From the linacs’ beam dynamics to the RF design

Effect to control/parameter to match	Effect	RF specification	Value
Bunch length (mm)	Short range longitudinal wakefield	a/λ, for given bunch length (and charge)	Between 0.1 and 0.2. More flexibility and energy stability adding the energy compressor
Energy spread			
Jitter amplification (single bunch)	Short range transverse wakefield	Length, a/λ	3 m, <a>/λ = 0.12 and 0.15
Jitter amplification (multi-bunch)	Long range transverse wakefield	HOM damping	Max kick = 0.11 V/pC/m/mm
Emittances (mm.mrad)	Short range transverse wakefield and misalignments	a/λ	>0.12

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Acknowledgments…

···to the entire WP1,

the booster and the transfer line and

booster WPs ···

···CHART* and you for your attention

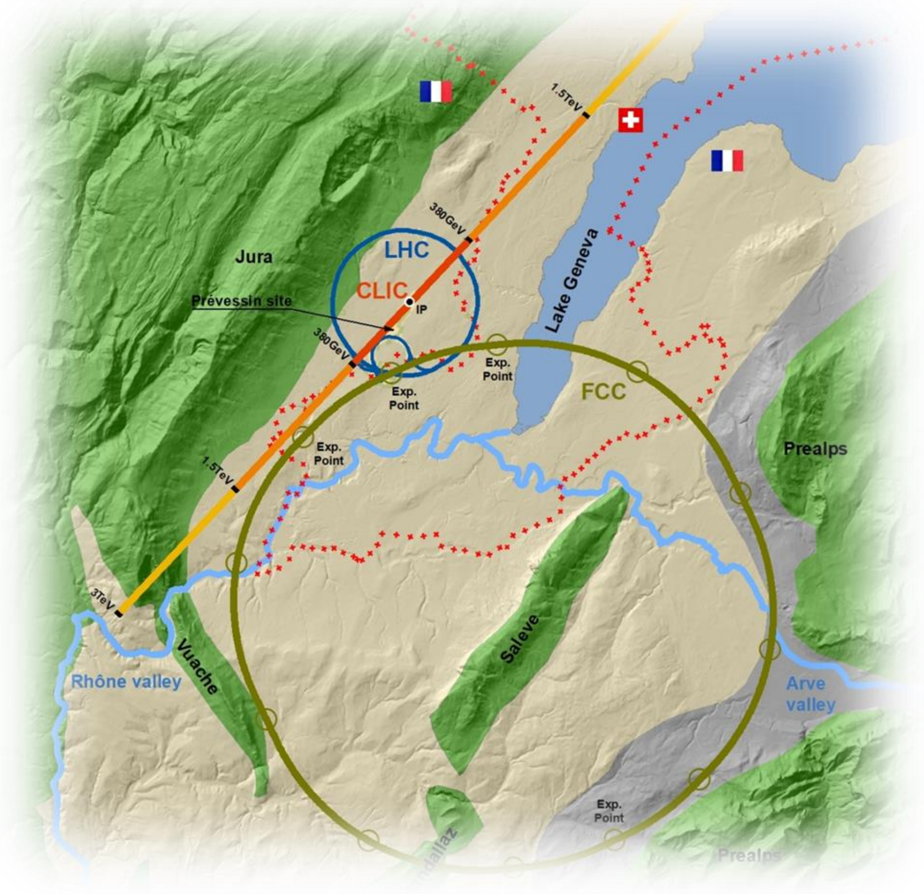

CHART Swiss Accelerator Research and Technology

*This work was done under the auspices of CHART (Swiss Accelerator Research and Technology) Collaboration

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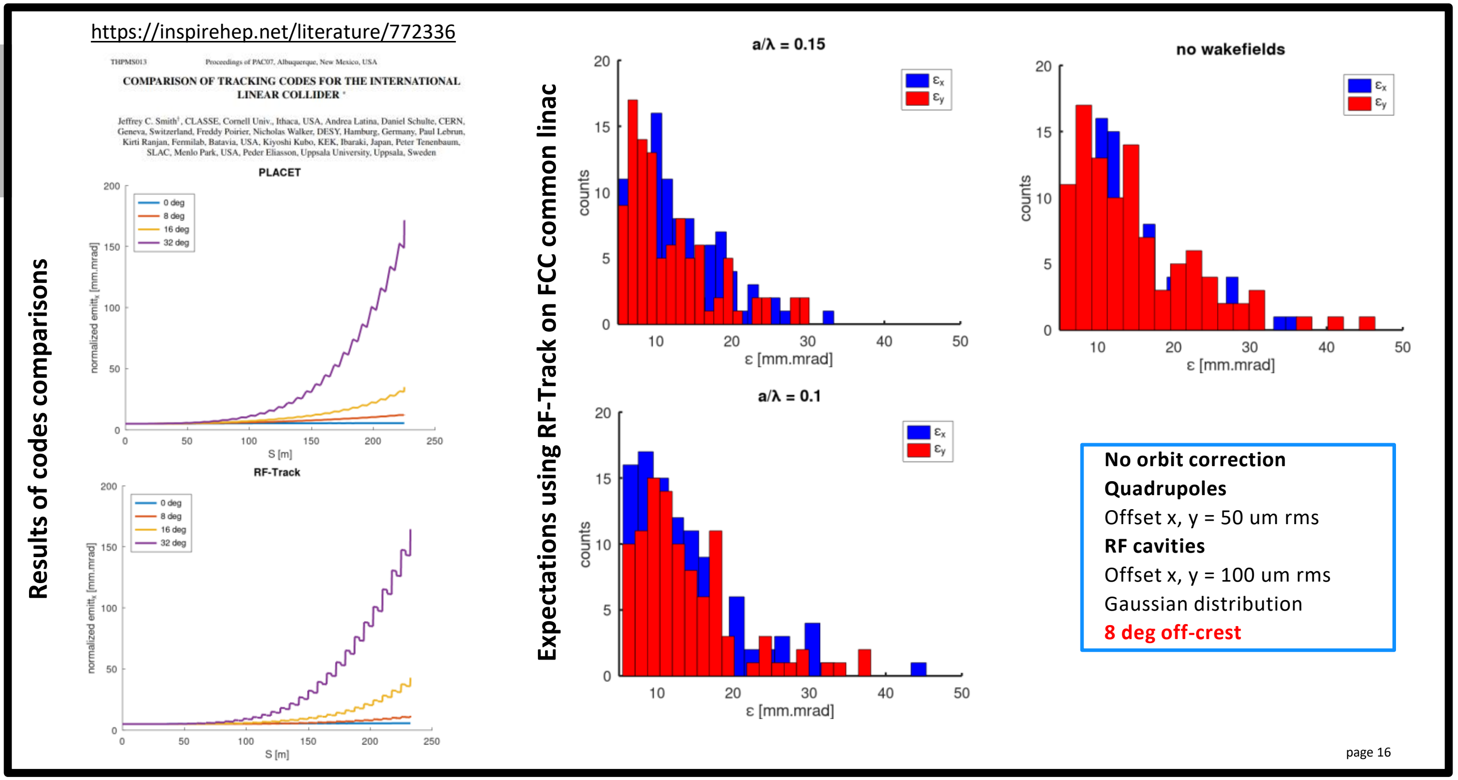
FCCIS: 'This project has received funding from the European Union's Horizon 2020 research and innovation programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754.'

Simulation code: RF-Track vs Elegant

From the Orsay Mini-workshop presentation



https://inspirehep.net/literature/772336

THPMS013 Proceedings of PAC07, Albuquerque, New Mexico, USA

COMPARISON OF TRACKING CODES FOR THE INTERNATIONAL LINEAR COLLIDER *

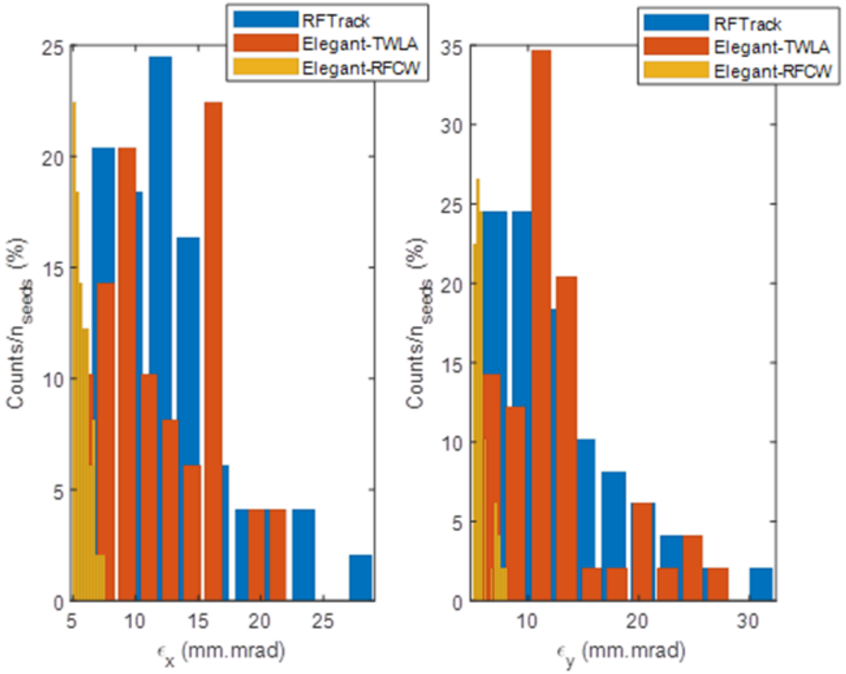
Jeffrey C. Smith†, CLASSE, Cornell Univ., Ithaca, USA, Andrea Latina, Daniel Schulte, CERN, Geneva, Switzerland, Freddy Poirier, Nicholas Walker, DESY, Hamburg, Germany, Paul Lebrun, Kirti Ranjan, Fermilab, Batavia, USA, Kiyoshi Kubo, KEK, Ibaraki, Japan, Peter Tenenbaum, SLAC, Menlo Park, USA, Peder Eliasson, Uppsala University, Uppsala, Sweden

Results of codes comparisons

Expectations using RF-Track on FCC common linac

No orbit correction
Quadrupoles
Offset x, y = 50 um rms
RF cavities
Offset x, y = 100 um rms
Gaussian distribution
8 deg off-crest

page 16



Codes benchmarking

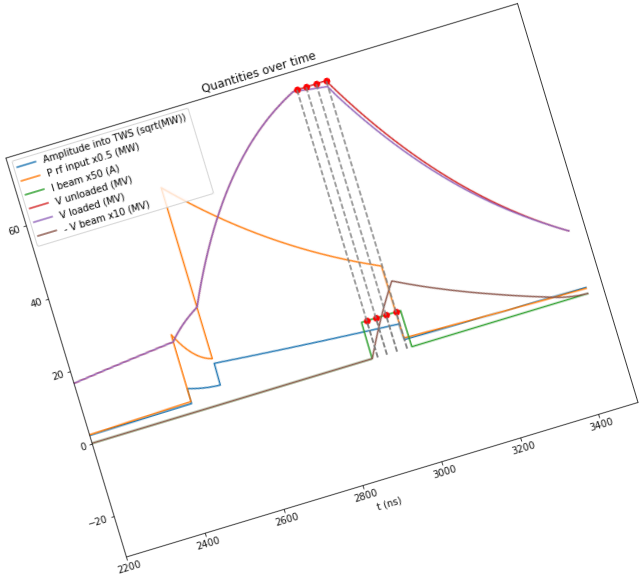
- Elegant foresaw a very small emittance increase
- Disagreement Elegant vs RF-Track
- Agreement RF-Track vs other codes, like Placet (verification by A. Latina)
- Problem pointed to M. Borland, new Elegant release in Feb 2023 to simulate the correct emittance growth in RF structure with also wakefield included

Important change in the design considerations!

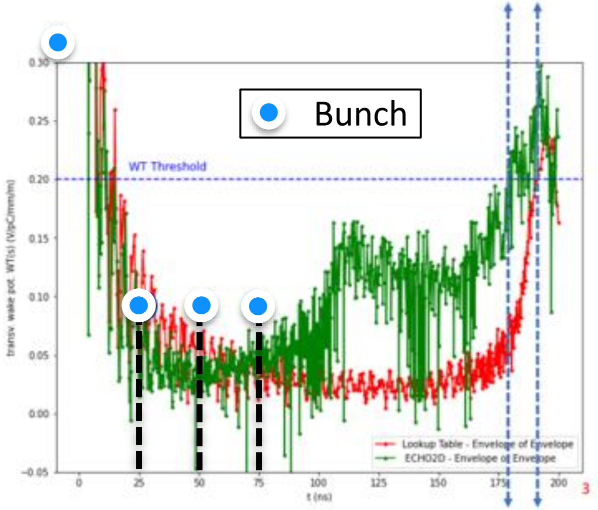
Toward 4 bunches operation mode

Go to 4 bunches operation mode to reduce the linacs operating frequency

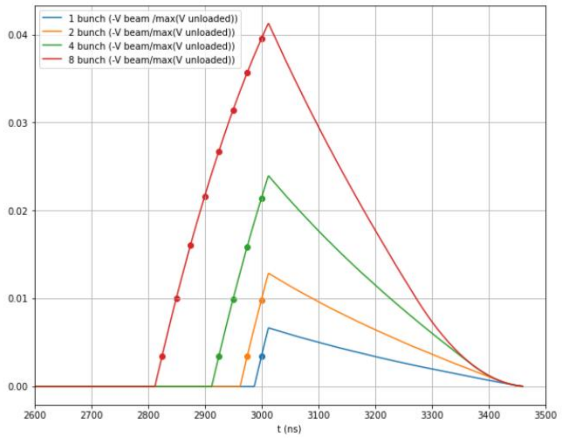
The bunches see a different beam loading



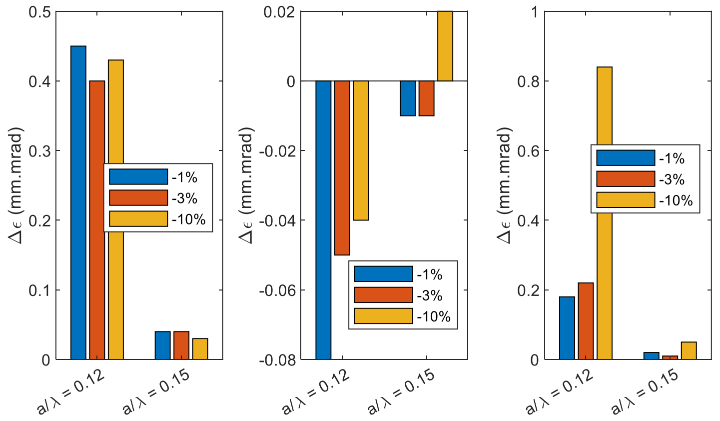
See A. Kurtulus talk

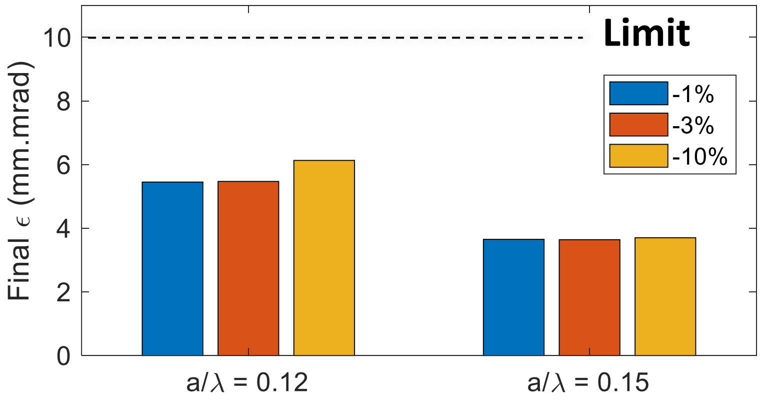


Courtesy A. Kurtulus, A. Grudiev



The bunches see Δenergy→ optics mismatch → Δemittance





Optimized scenarios

More reported at previous FCC Weeks

Goal: optimize the bunch length, the RF parameters (phase and aperture) to match the target energy spread and final bunch length

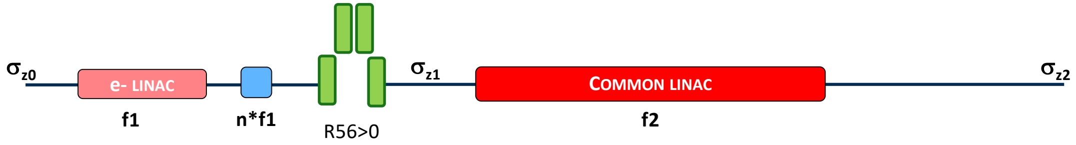
Considered scenarios:

1. Short bunch from the gun

- ✓ Fixed bunch length, and necessary bunch decompression at the end to match the final bunch length (large R_{56} if the energy chirp is small)
- ✓ Minimal hardware request
- ✓ No CSR emittance degradation

f = 2.8 GHz	a/λ = 0.10	a/λ = 0.15	a/λ = 0.20
Phase range (deg)	73…74	<75…80	<80…85
Min δE/E	1e-3	5e-4	4e-4
Rms bunch length (mm)	0.8	0.4…0.65	<0.4…0.7

2. Bunch compressor at the exit of e- Linac



- ✓ More hardware necessary
- ✓ Possible emittance degradation due to CSR
- ✓ Very small values of energy spread achievable

f = 2.8 GHz	a/λ = 0.10	a/λ = 0.15	a/λ = 0.20
Phase range (deg)	<70…75	86…>90	<80…85
Min δE/E	1e-4	1e-4	1e-4
Rms bunch length (mm)	0.457		

3. Shorter bunch from the gun and linearization

- ✓ Same advantages and disadvantages as 1., but a smaller value of energy spread (or equivalently longer bunch lengths) achievable
- ✓ Energy loss at the linearization

f = 2.8 GHz	a/λ = 0.10	a/λ = 0.15	a/λ = 0.20
Phase range (deg)	66…70	77…80	81…85
Min δE/E	2e-4	3e-4	3e-4
Rms bunch length (mm)	0.650		

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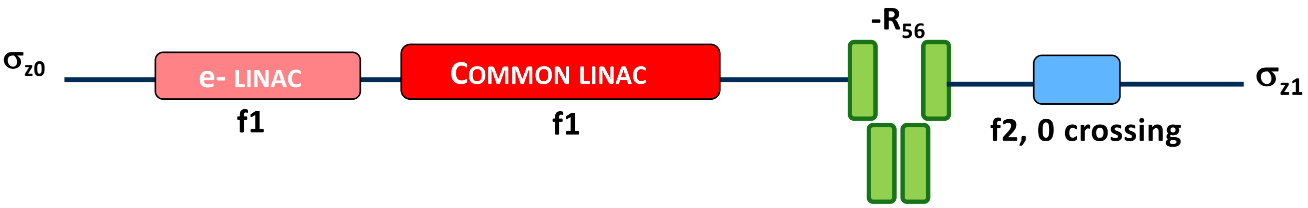
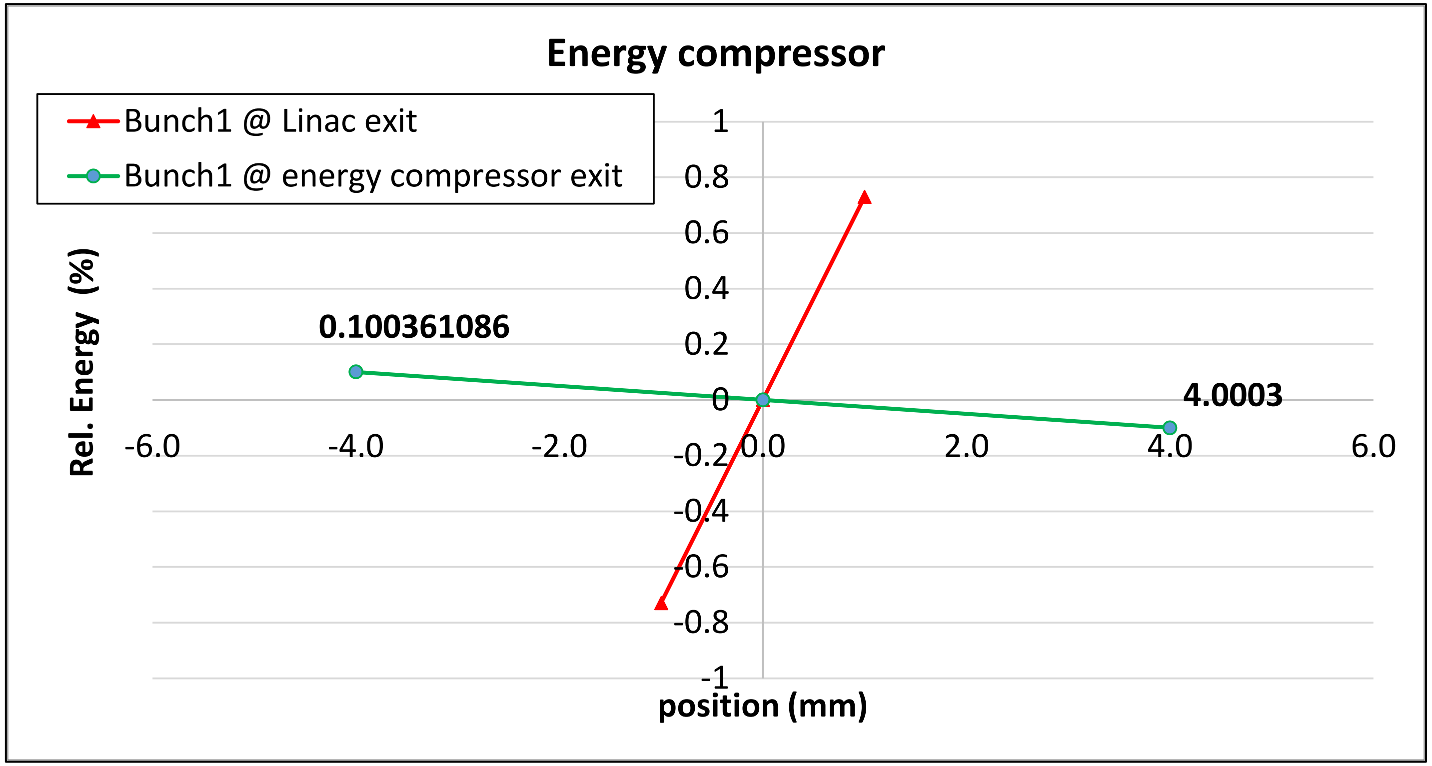
Energy compressor à la SuperKekB (a special thank to R. Zennaro)



Method:

- Chicane: energy difference → arrival time difference → phase difference
- Compensate the energy difference by applying the appropriate voltage downstream of the chicane (cavities at f2)

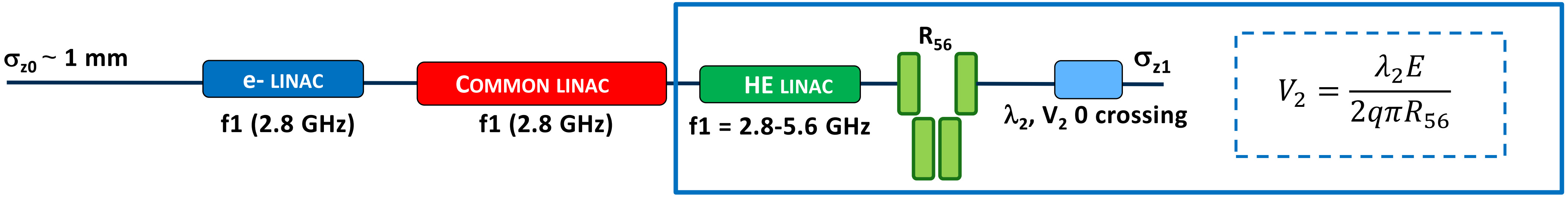


$$V_2 = \frac{\lambda_2 E}{2q\pi R_{56}}$$

Advantages:

- Final energy spread and bunch length are not independent but separately adjustable
- Possible to use the R_{56} in the transfer line to the ring (transfer line group)

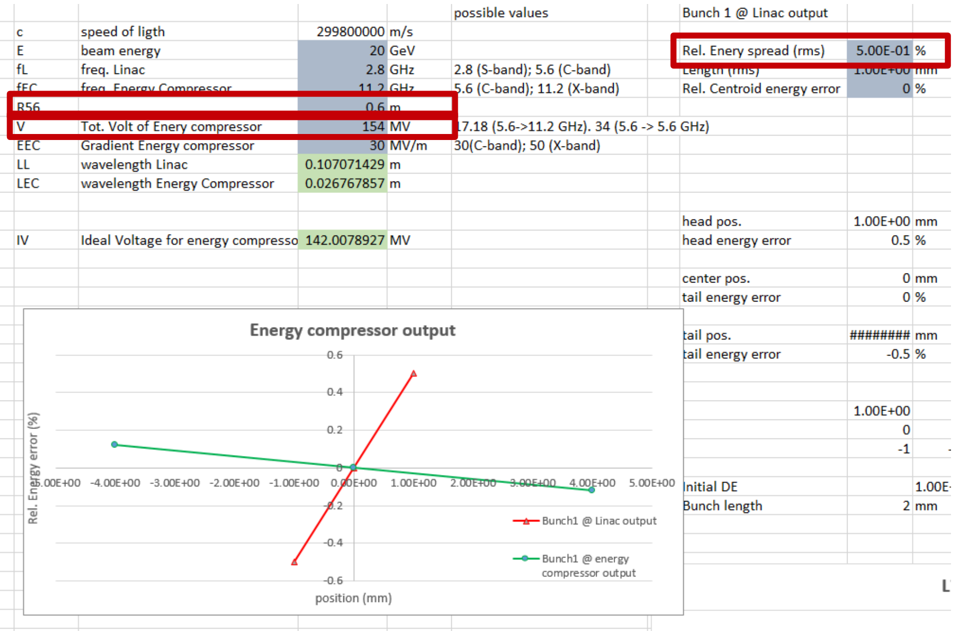
Optimization steps



$$V_2 = \frac{\lambda_2 E}{2 q \pi R_{56}}$$

Procedure:

1. **Chirp** determined by the upstream linacs (operating phase+beam loading at a given bunch length and charge)
2. Determine **R_{56}** to have the target bunch length
3. Given R_{56} compute the **voltage** to have the desired energy spread
4. Verify the results with **tracking** simulations. Necessary, because the energy-time distribution may be non-linear



				possible values
c	speed of ligth	299800000	m/s	
E	beam energy	20	GeV	
fL	freq. Linac	2.8	GHz	2.8 (S-band); 5.6 (C-band)
fEC	freq. Energy Compressor	11.2	GHz	5.6 (C-band); 11.2 (X-band)
R56		0.6	m	
V	Tot. Volt of Enery compressor	154	MV	17.18 (5.6->11.2 GHz). 34 (5.6 -> 5.6 GHz)
EEC	Gradient Energy compressor	30	MV/m	30(C-band); 50 (X-band)
LL	wavelength Linac	0.107071429	m	
LEC	wavelength Energy Compressor	0.026767857	m	
IV	Ideal Voltage for energy compresso	142.0078927	MV	

Bunch 1 @ Linac output		
Rel. Enery spread (rms)	5.00E-01	%
Length (rms)	1.00E+00	mm
Rel. Centroid energy error	0	%
head pos.	1.00E+00	mm
head energy error	0.5	%
center pos.	0	mm
tail energy error	0	%
tail pos.	########	mm
tail energy error	-0.5	%
	1.00E+00	
	0	
	-1	
Initial DE		1.00E
Bunch length	2	mm

Target values:

- Final energy spread ~0.1-0.15%. Determined the minimum achievable
- Final bunch length up to 4 mm. Less implies a smaller R_{56} and a larger RF voltage, more a larger R_{56} and a smaller RF voltage

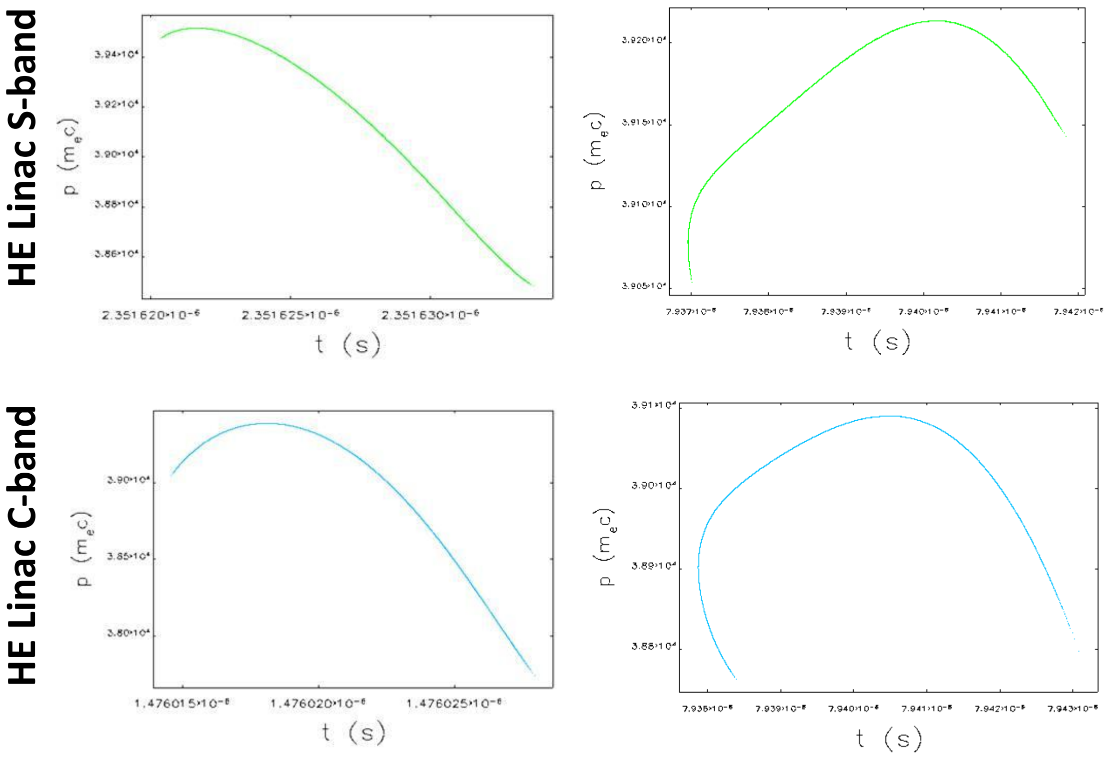
Comments:

- Different linac(s) RF structures' settings correspond to only different initial energy chirp: more R_{56} smaller voltage V_2
- For the time being simulated a four dipoles chicane. In reality the $R_{56} \neq 0$ element will be the line to the ring (transfer line WG)

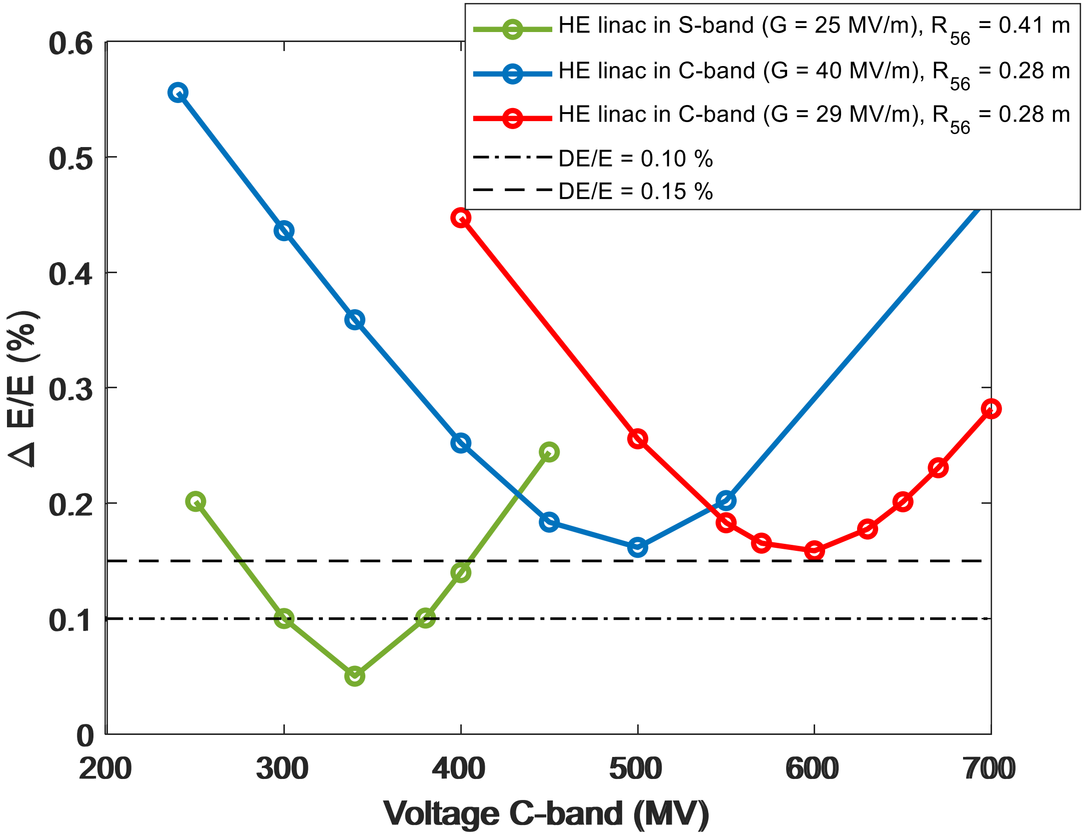
Setting Common (S-band) and HE Linac **on-crest**

$$V_2 = \frac{\lambda_2 E}{2 q \pi R_{56}}$$

At the HE Linac exit **At the EC exit**



	HE linac S-band (G = 25 MV/m)	HE linac C-band a/λ = 0.20 (G = 40 MV/m)	HE linac C-band, a/λ = 0.19 (G = 29 MV/m)
Exit HE Linac δE/E (%)	0.74	1.1	1.3
R_{56} (m)	0.41	0.28	0.28



Assumed target bunch length = 4 mm (longer is even better for RF)

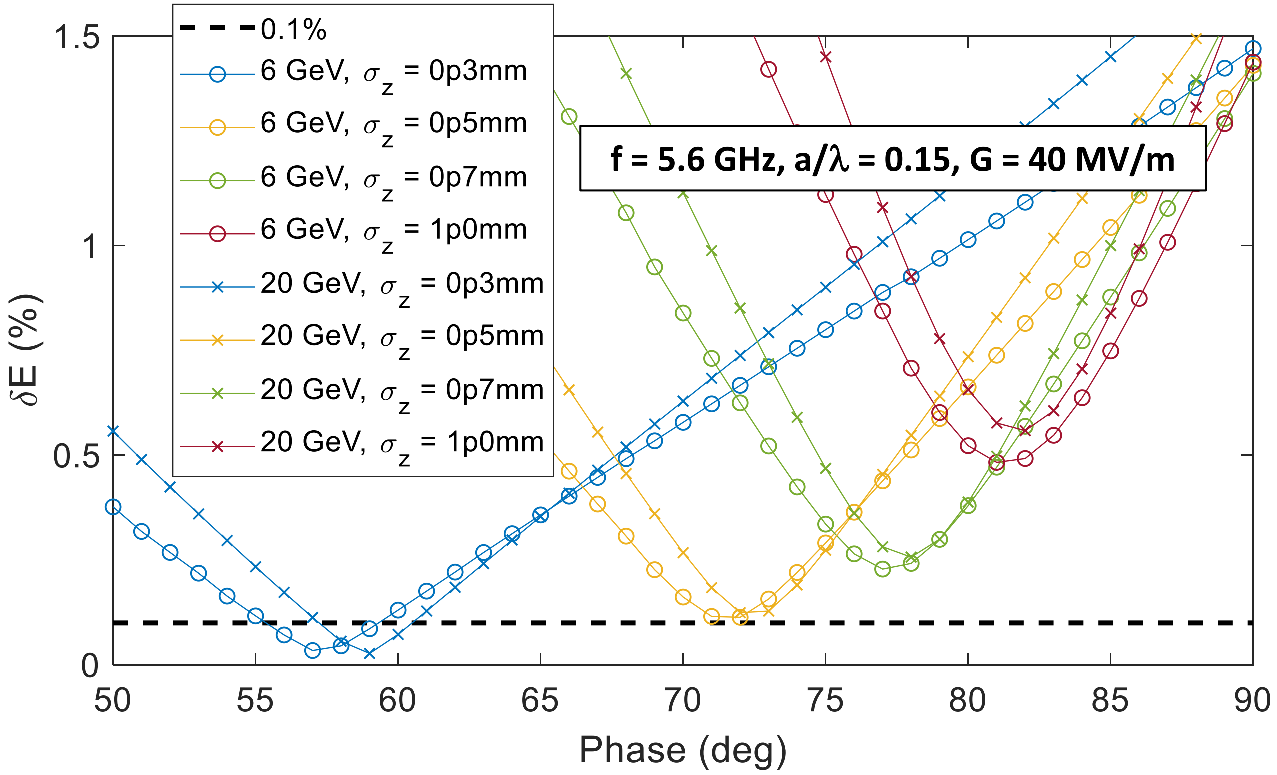
S-band HE Linac on-crest: δE/E = 0.05% achievable with 340 MV in C-band and 170 MV in X-band

C-band HE Linac on crest: minimum of δE/E limited to ~0.15% with 600 MV in C-band, 300 MV in X-band

Toward the High Energy (HE) linac (E = 6 GeV → 20 GeV)

Alternative

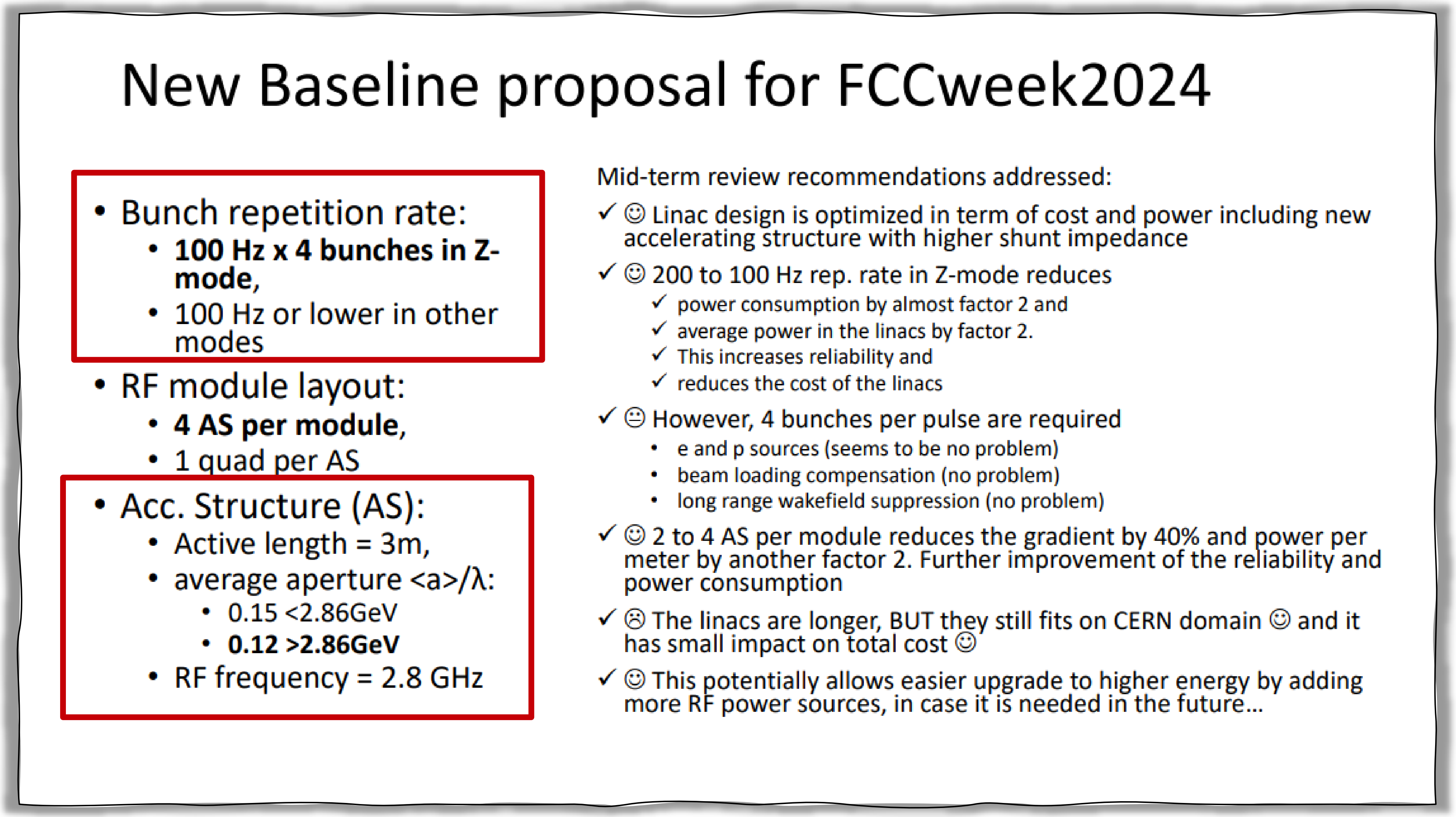
Baseline



20 GeV vs 6 GeV linac:

- Minimum of the energy spread and corresponding working point (bunch length and operating phase) similar for the two cases → we can use the same table of the previous slide
- Strong impact on the linearizing cavity amplitude (in case we want to move to another scenario): alternative solutions must be considered

From A. Grudiev, 6th June 2024 coordination meeting



New Baseline proposal for FCCweek2024

- Bunch repetition rate:
  - **100 Hz x 4 bunches in Z-mode**,
  - 100 Hz or lower in other modes
- RF module layout:
  - **4 AS per module**,
  - 1 quad per AS
- Acc. Structure (AS):
  - Active length = 3m,
  - average aperture <a>/λ:
    - 0.15 <2.86GeV
    - **0.12 >2.86GeV**
  - RF frequency = 2.8 GHz

Mid-term review recommendations addressed:

- ✓ ☺ Linac design is optimized in term of cost and power including new accelerating structure with higher shunt impedance
- ✓ ☺ 200 to 100 Hz rep. rate in Z-mode reduces
  - ✓ power consumption by almost factor 2 and
  - ✓ average power in the linacs by factor 2.
  - ✓ This increases reliability and
  - ✓ reduces the cost of the linacs
- ✓ 😐 However, 4 bunches per pulse are required
  - e and p sources (seems to be no problem)
  - beam loading compensation (no problem)
  - long range wakefield suppression (no problem)
- ✓ ☺ 2 to 4 AS per module reduces the gradient by 40% and power per meter by another factor 2. Further improvement of the reliability and power consumption
- ✓ ☹ The linacs are longer, BUT they still fits on CERN domain ☺ and it has small impact on total cost ☺
- ✓ ☺ This potentially allows easier upgrade to higher energy by adding more RF power sources, in case it is needed in the future…

https://indico.cern.ch/event/1402911/