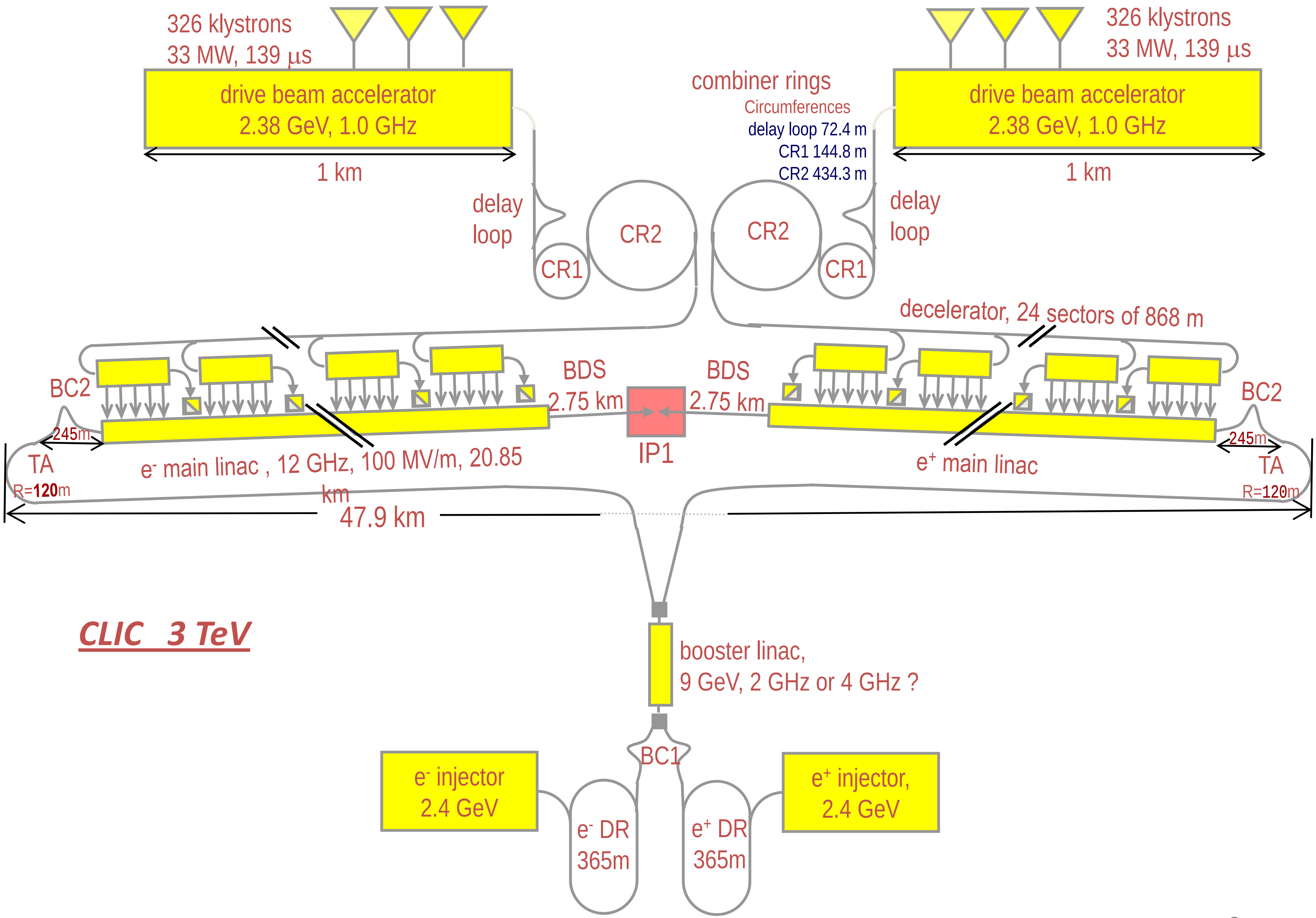
# Drive beam generation

B. Jeanneret
CLIC-ACE , may 2009
With material and advice from
E. Adli, C.Biscari, R. Corsini, D.Schulte, F. Stulle


326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
combiner rings
Circumferences
delay loop 72.4 m
CR1 144.8 m
CR2 434.3 m
delay loop
CR1
CR2
CR2
CR1
delay loop
decelerator, 24 sectors of 868 m
BC2
BDS 2.75 km
IP1
BDS 2.75 km
BC2
245m
TA
R=120m
e- main linac , 12 GHz, 100 MV/m, 20.85 km
e+ main linac
245m
TA
R=120m
47.9 km
CLIC 3 TeV
booster linac,
9 GeV, 2 GHz or 4 GHz ?
BC1
e- injector
2.4 GeV
e- DR
365m
e+ DR
365m
e+ injector,
2.4 GeV

# Drive beam parameters

R. Corsini,
ACE sep08

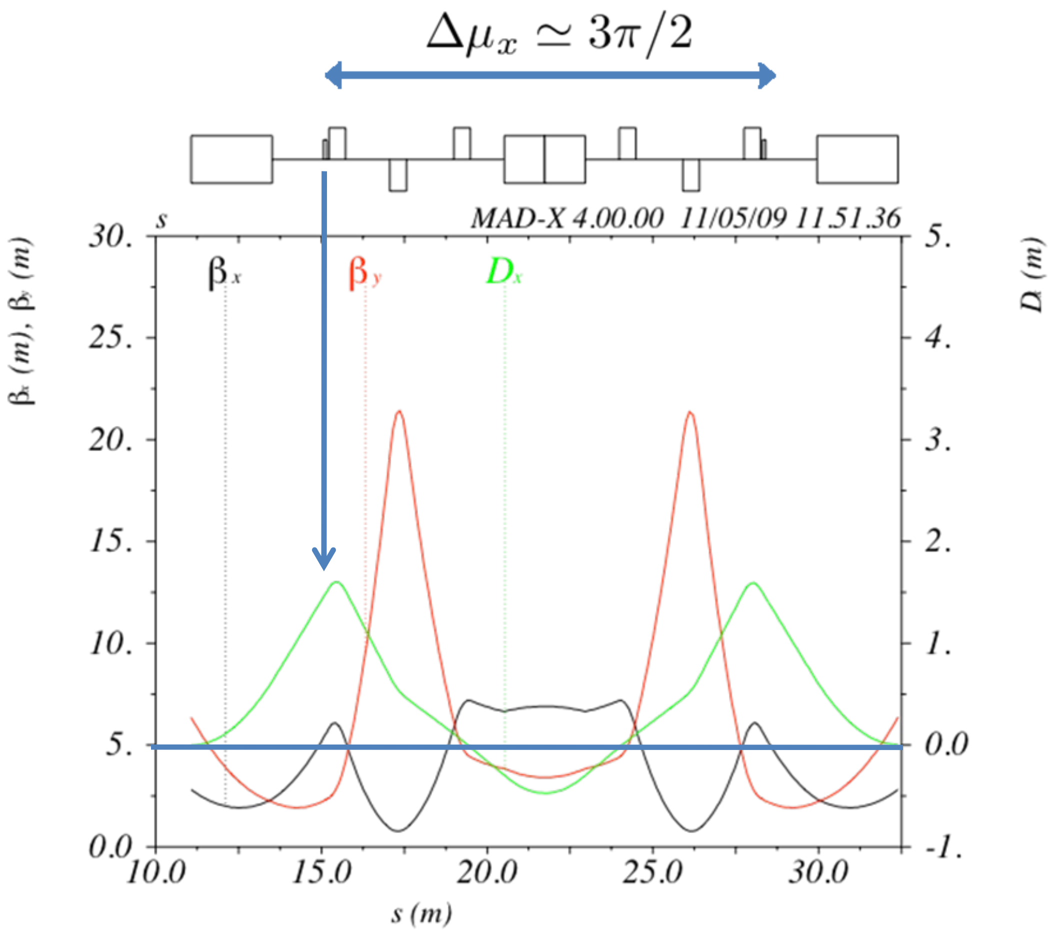
| | 3 TeV | 500 GeV |
|---|---|---|
| Drive beam current initial | 4.2 A | |
| Drive beam current final | **100 A** | 106 A |
| DB bunch charge | 8.4 nC | |
| Drive beam energy | **2.35 GeV** (⇒ 240 MeV) | 2.54 GeV |
| DB acceleration frequency | 1 GHz | |
| DB bunch frequency initial | 0.5 GHz | |
| DB bunch frequency final | 12 GHz | |
| DB pulse length initial | 140 μs | |
| DB pulse length final | 240 ns | |
| Combination factor | $2 \times 3 \times 4 = 24$ | |
| Number of sectors/linac | 24 | |
| Sector length | 868 m | |
| Length delay loop/line | 72 m | |
| Length combiner ring 1 | 145 m | |
| Length combiner ring 2 | 434 m | |
| Rms bunch length final | 1 mm | |
| Power per PETS | 136 MW | |

# Frequency multiplication, transfer, compression

- OPTICS : DL, CR1, CR2, DBTL, TAs
- BEAM DYNAMICS
- GRADIENT AND BUNCH POPULATION
- PHASE ERROR, PHASE CONTROL

# CR1 arc cell

C. Biscari, BJ
PAC09




Quad-triplet :

$$R_{56} = \int \frac{D(s)}{\rho(s)} ds = 0$$

Sextupoles :

$$T_{566} = 0$$
$$Q'_{x,y} = 0$$
$$\partial\beta/\partial\delta = 0$$

All this would ideally requires
3 families of sextupoles at well
Defined phase advances (x and y)

In practice :

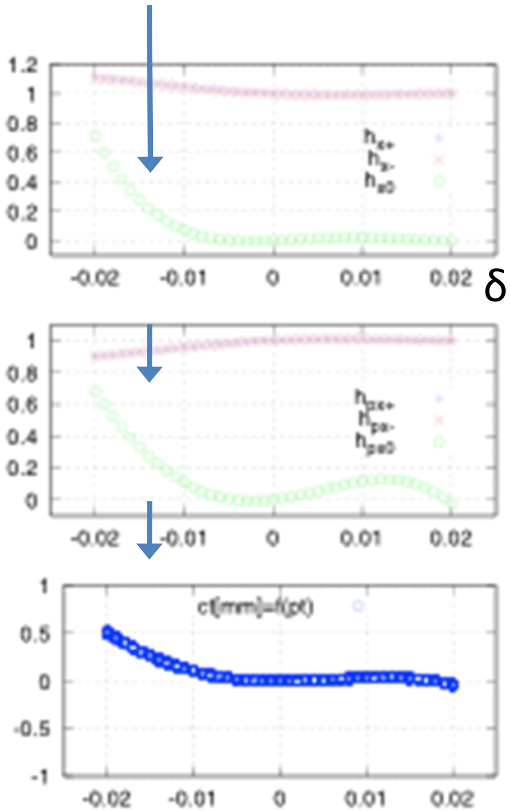
- Not enough Δμ/per cell , ratio D/ß inadequate ,…
- dp = 0.02 → large higher-order effects with many sextupoles
- → presently, explore with 1 family only

# CR1 optics and 6D-tracking

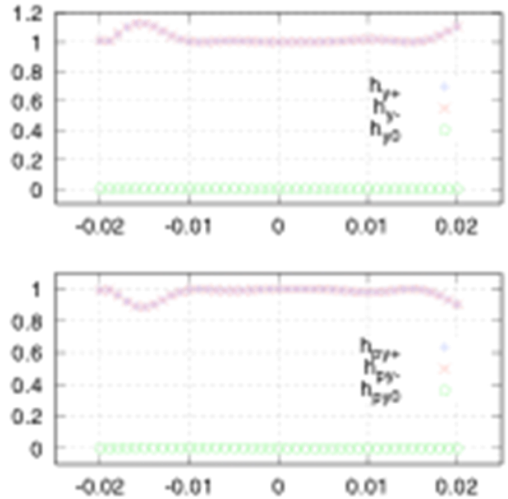
$$+\delta \text{ error} \quad : \quad \frac{1}{1+\delta} = 1 - \delta + \delta^2 - \delta^3 + \cdots$$

$$-\delta \text{ error} \quad : \quad \frac{1}{1-\delta} = 1 + \delta + \delta^2 + \delta^3 + \cdots$$

$$h_{x+} = (\hat{x} - \overline{x})/\sigma_{\beta x} \ , \ \ldots$$

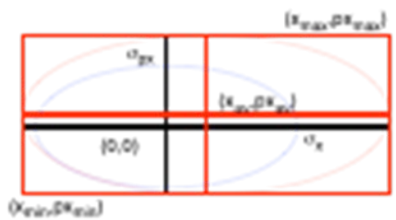


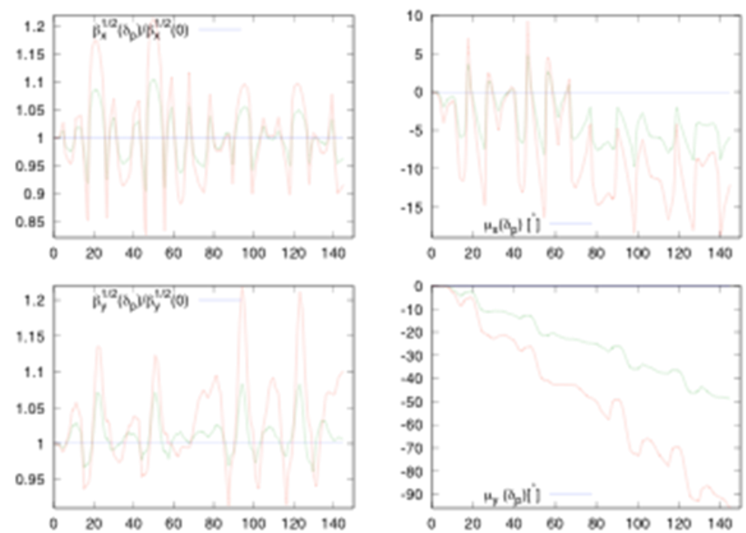
$\delta_p$



With only one family of sextupoles
Spaced by $\Delta\mu_x$=3π/2

$$T_{566} = 0$$
$$Q'_x = -2 \ \ (= -10 \text{ w/o SX})$$
$$Q'_y = -13.5 \ \ (= -10 \text{ w/o SX})$$

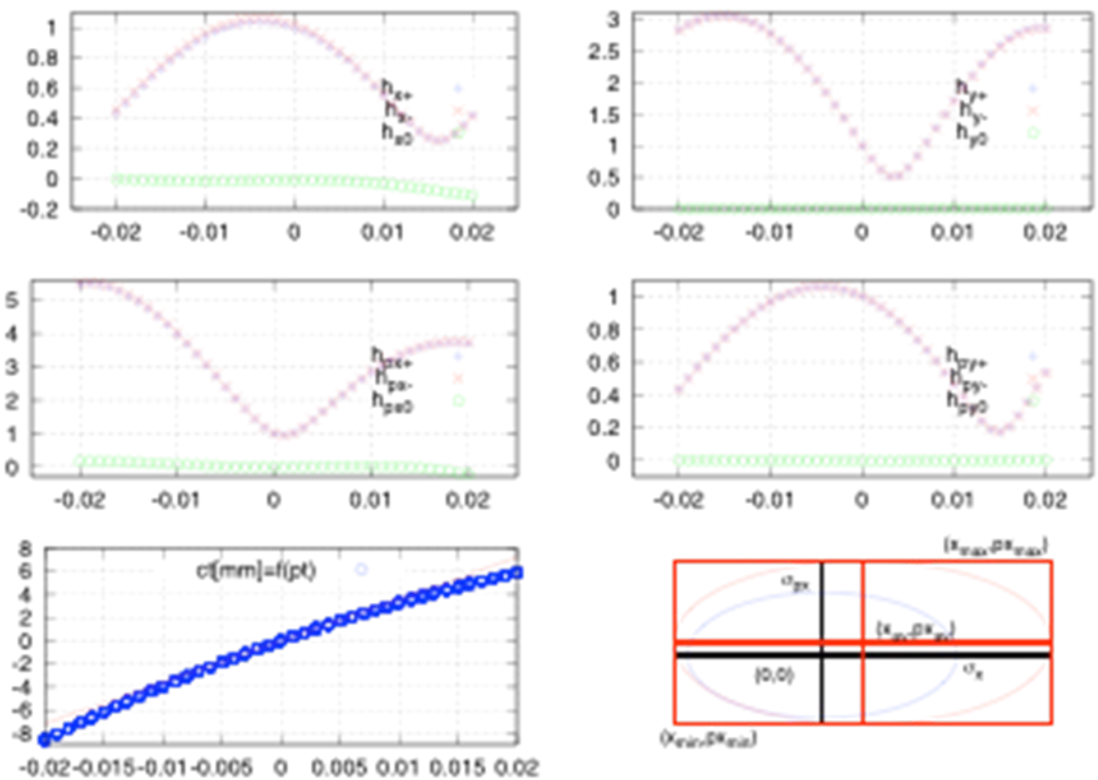




OK up to $J_{x,y}$ = 3

Further work :
- Work off-energy to avoid large ∂p <0
- Full 6D tracking with errors, etc

# Present Turn-Around




- 80m-long vs. 146m/CR1
- Twice more dipoles (accept. CSR)
- Larger D/ρ
  - stronger quads
  - More aberrations, …
- Correcting longitudinal and transverse phase space simultaneously not possible

→Need new TA optics similar to CR1 with $L_{TA} \approx 150$m

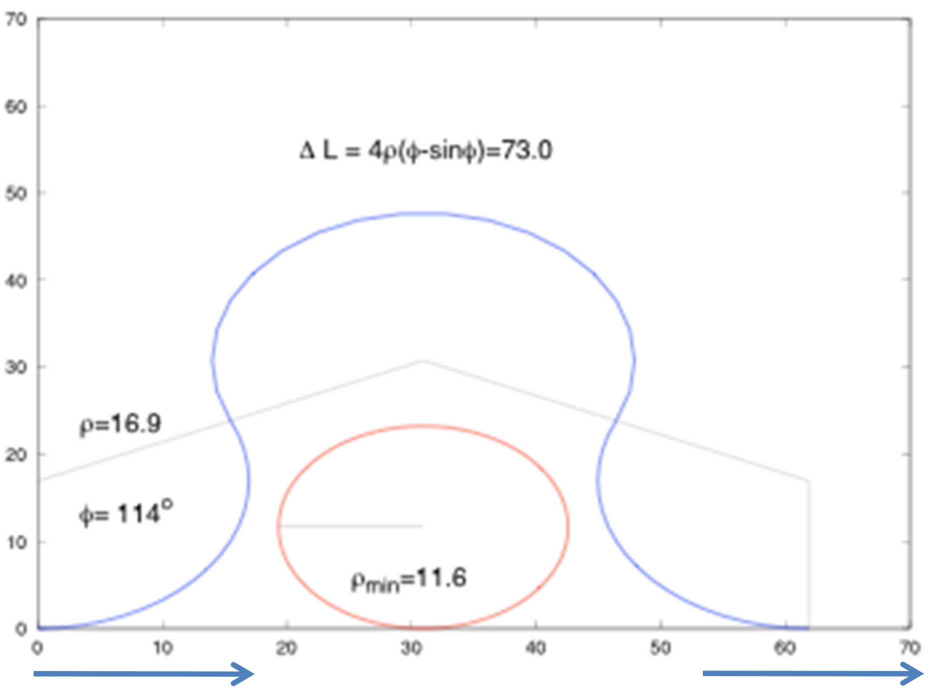
COST :

Presently DBTL + 48 TA : 3% of total

$L_{TA} \rightarrow 2L_{TA}$ : 3.7% of total

# Delay Line

- Presently : Layout is a ring
  - Constraint : $L_{DL}$ = 73 m (beam train length)
  - As with TA : transverse chromatic effects
  - SAME CURE : longer length
- Go to a 'Ω' – shape




From Linac

To CR1

$L_{loop}$ = 135m

$L_{straight}$ = 62 m

Total extra-length :

$L_{loop}+L_{straight}-\Delta L$ = 123 m

(small extra-cost )

Straight segment :
Very useful for beam diagnostics
After Linac

# CR2 / Down to tunnel /DBLongTL Optics

- CR2
  - $L_{CR2}$ = 438 m
  - Not studied at 2$^{nd}$ order
  - But length comfortable → a priori not problematic

- Down to tunnel
  - No studied
  - Common tunnel with Main Beam
  - Main beam more critical (vertical bends vs. Small $\varepsilon_y$, may require $\varepsilon_y \Leftrightarrow \varepsilon_x$ )
  - A priori, not critical for Drive Beam

- Long Transfer line
  - L= 20 km, simple FODO
  - Long cells  avoids large chromatic detuning and filamentation
  - Needs limited beam based alignment
  - No critical issues, see CLIC Note 760

# Beam dynamics from DL → DECEL

- Presented by R. Corsini at ACE-sep08, see also CLIC Note 761
- N-bunch resistive wall instabilities
  - Large effect (3000 bunches, 5 $10^{10}$ $e^-$ (8 nC), spaced by 2.5 cm
  - $W_\perp \sim a^{-3}$ → CURE : use vac. Chamber with large radius (copper)
  - Long transfer line (L= 20 km, large β's) : a = 100 mm
  - Other lines : : a = 25 mm
- Vacuum
  - $e^-$ ionise and confine +ions
  - Δμ between head and tail of trains → correctability, filamentation
  - Beam/ion instabilities
  - CURE : $p < 10^{-10}$ Torr . Reachable with getter + bake-out
- ISSUE : "not more than" COST (budgeted already)
- Emmitance growth small

# RF deflectors in DL,CR1,CR2

- OK in CTF3
- But larger current in CLIC 100 A vs. 12A, while higher energy helps
- Need more work in order to fix a ‘level of criticality’ vs. Collective effects
- optimize ring tune for min. transverse excitation by deflector (R.Corsini, D. Schulte)

Transverse position error at the entrance of the Decelerator

- $\Delta x/\sigma_\beta$ =0.3 for <5% increase of amplitude at the DECEL exit (E. Adli)
- At deflectors ( $\beta$=15m, $\varepsilon=2\cdot10^{-8}$ m) , $\sigma' = 4\cdot10^{-5}$ rad
- Deflector kick $K_d = 5\cdot10^{-3}$ rad
- Beam will pass through $n_{defl}$ = 9 deflectors (DL 2, CR1 3, CR2 4)

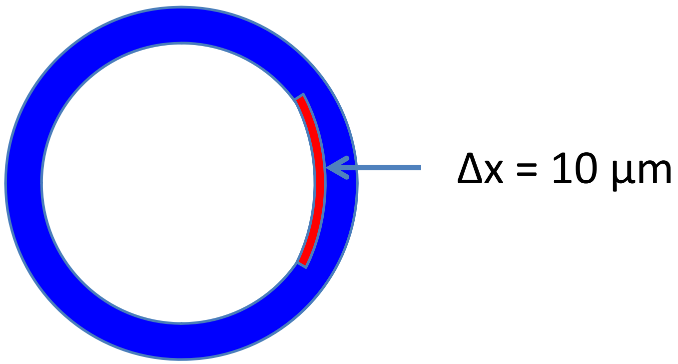
$$\frac{\delta K_{defl}}{K_{defl}} = \frac{0.15\sigma'}{n_{defl}^{1/2} K} = 0.4 \cdot 10^{-3}$$

Similarly, with $n_{kick}$ kickers (CR1,CR2,in-TA) :

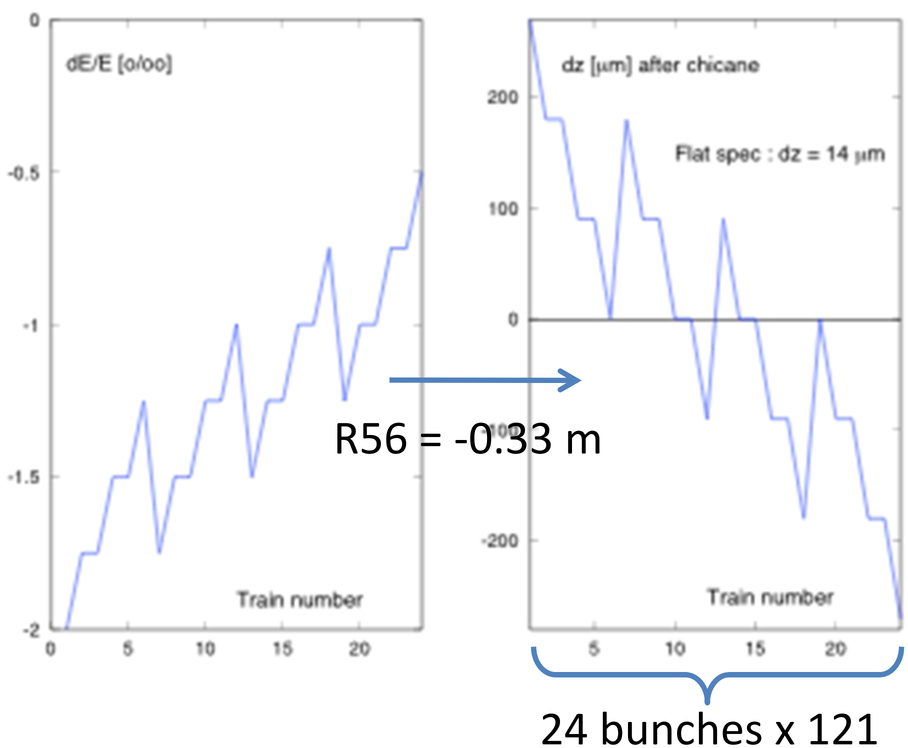
$$\frac{\delta K_{kick}}{K_{kick}} = \frac{0.15\sigma'}{n_{kick}^{1/2} K} = 0.7 \cdot 10^{-3}$$

Remains to translate this
Into detailed specification

# Incoherent synchrotron radiation




- X-ray @ 6 keV : $L_{\_absorption}$ = 50 µm (Aluminium)
- Impact angle : ~ 0.2 rad
- ΔT = 80 °K @ 50 Hz
- Risk of rapid ageing




## TIME STRUCTURE

Overall dE/E of ISR varies between Trains travelling :

- MIN : No DL, 1×CR1, 1×CR2
- MAX : 1×DL, 3×CR1, 4×CR2
- Max dE/E = 2 o/oo
- Converts to dz after last chicane before DECEL
- 1% longitudinal z-pitch modulation

Cure :

- make the DL, CR1,CR2 longer accordingly
- complicates the feed-forward ϕ–correction (see slide 20)

# Tolerance on Phase and Gradient

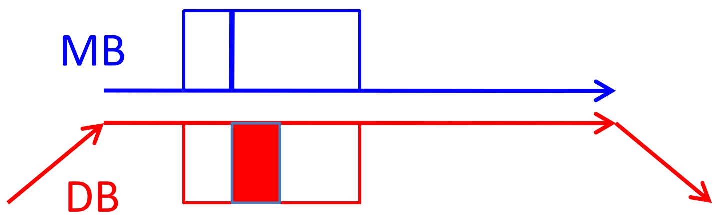
- Luminosity and understanding/adjustment of the Beam Delivery and of the Final Focus

$$\left\langle \frac{\Delta\mathcal{L}}{\mathcal{L}} \right\rangle = 0.01 \left[ \left( \frac{\sigma_{\phi,coh}}{0.2^o} \right)^2 + \left( \frac{\sigma_{\phi,inc}}{0.8^o} \right)^2 + \left( \frac{\sigma_{G,coh}}{0.75 \cdot 10^{-3} G} \right)^2 + \left( \frac{\sigma_{G,inc}}{2.1 \cdot 10^{-3} G} \right)^2 \right]$$

D.Schulte & R.Tomas, PAC09

$\delta\mathcal{L} \sim \delta_\phi^2 \text{ and } \delta_G^2$ → Not much margin on these

# Gradient error for MB




A bunch of the main beam see always the gradient as built-up by the same $n_b = 0.5 f_0 \cdot \tau_{fill\text{-}MBAS} \cong 400$ DB bunches ahead of it

With N the bunch population ,
And 'inc' as for 'per sector'

$$\Rightarrow \frac{1}{\sqrt{n_b}} \frac{\sigma_N}{N} = \left(\frac{\sigma_G}{G}\right)_{\text{inc}} \stackrel{spec}{=} 2 \cdot 10^{-3}$$

$$\Rightarrow \frac{\sigma_N}{N} \simeq 4 \cdot 10^{-2}$$

At the entrance of the DECEL

Stability of the DB in the DECEL :
An overcurrent of 1% over $\tau_{fill\text{-}PETS} \equiv 10$ b. makes the last bunch of these unstable Before the end of the DECEL

$$\left.\frac{\delta N}{N}\right|_{n_b=5} < 1\% \quad \Rightarrow \quad \frac{\delta N}{N} < 2.2\% \text{ random}$$

$$\Rightarrow \quad \frac{\sigma_N}{N} < 0.7\% \text{ random}$$

Stability over a whole cycle :

$$\left(\frac{\sigma_I}{I}\right)_{\text{coh}} = \left(\frac{\sigma_G}{G}\right)_{\text{coh}} = 0.75 \cdot 10^{-3}$$

# Tolerance on DB bunch population

$$\left(\frac{\sigma_N}{N}\right)_{\mathrm{DECEL,inc}} = \left[\left(\frac{\sigma_N}{N}\right)^2_{\mathrm{loss}} + \left(\frac{\sigma_N}{N}\right)^2_{\mathrm{source}}\right]^{1/2} \simeq 7 \cdot 10^{-3}$$

- Losses : constant part is harmless (adjust $N_{source}$ )
- Erratic part :
  - transverse n-poles in RF structures, RF deflectors, magnets
  - Badly understood optics (chromatic errors)
  - Time dependent error in kickers
- Not explored as yet.
- Until we know more about loss control :

$$\left(\frac{\sigma_N}{N}\right)_{\mathrm{loss}} = \left(\frac{\sigma_N}{N}\right)_{\mathrm{source}} \simeq 4 \cdot 10^{-3}$$

Maybe still optimistic
Need a more elaborate
Statistical model

Together with :

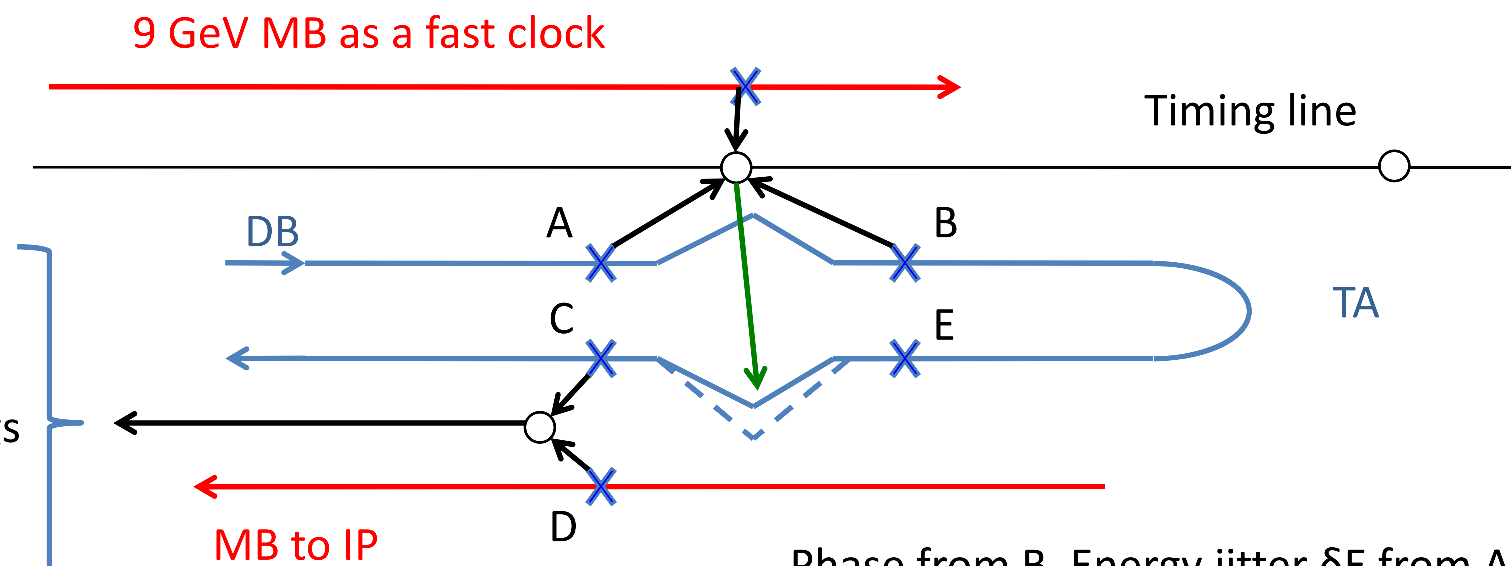
$$\left(\frac{\sigma_I}{I}\right)_{\mathrm{coh}} = \left(\frac{\sigma_G}{G}\right)_{\mathrm{coh}} = 0.75 \cdot 10^{-3}$$

# Timing and feed-back strategy in the tunnel

- To relax on δϕ : feed-forward & back before entering the DECEL

Notional, as for now

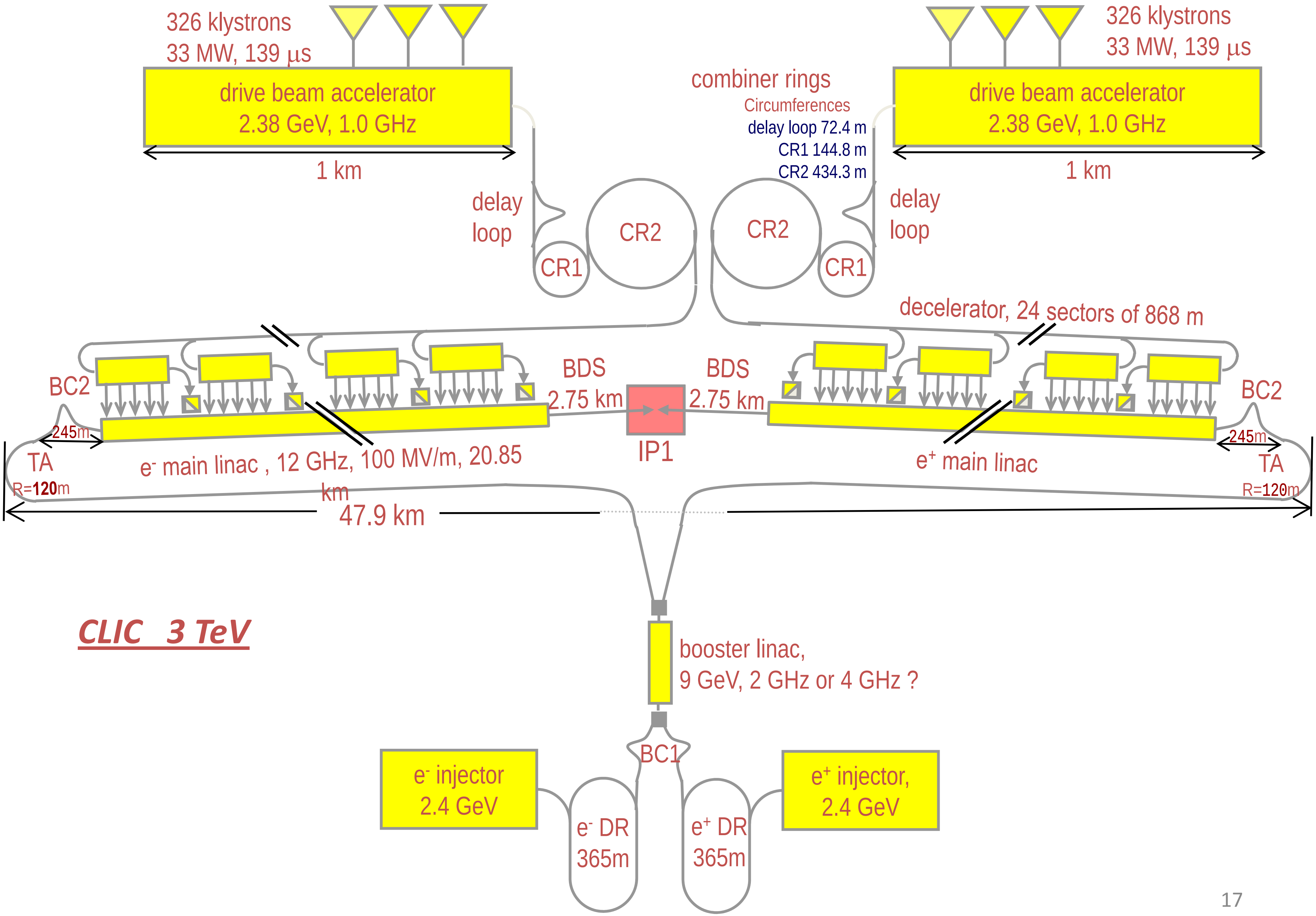
Δt to:
injectors
DB & MB
Damp. Rings
MB TA
DB TAs
@50 Hz




Phase from B, Energy jitter δE from A&B,
Phase correction for δE

C&D, Phase error MB/DB , to synchronize the injector linacs

Open issue:
frequency band of δE correction



326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
combiner rings
Circumferences
delay loop 72.4 m
CR1 144.8 m
CR2 434.3 m
326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
delay loop
CR2
CR1
CR2
CR1
delay loop
decelerator, 24 sectors of 868 m
BC2
BDS
2.75 km
BDS
2.75 km
BC2
245m
245m
TA
R=120m
e- main linac , 12 GHz, 100 MV/m, 20.85 km
IP1
e+ main linac
TA
R=120m
47.9 km
booster linac,
9 GeV, 2 GHz or 4 GHz ?
BC1
e- injector
2.4 GeV
e- DR
365m
e+ DR
365m
e+ injector,
2.4 GeV


**CLIC 3 TeV**

# Phase control - I

$$\delta\phi_{\mathrm{MB/DB}} = 0.2^o \ / \ 0.8^o \quad [\mathrm{coh, inc}]$$ At 12 GHz

$$\delta\phi = 0.2^o \ @\mathrm{f}_0 = 12\mathrm{GHz} \ \equiv \ \delta z_{\mathrm{tol}} = 14 \ \mu \ \equiv \ \delta t_0 = 46 \ \mathrm{fs}$$

Scheme : correct the phase with fast feed-forward in the final chicane and slow feed-back to the injectors.

Ingredients :

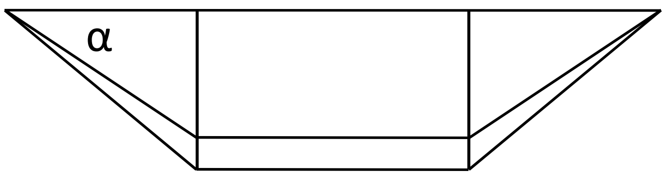
- measurement of the 9 GeV MB ( keep in memory for T = [0..23] × 6 μs] )
- error in the 9 GeV MB from Injector and in the MB-TA
- DB TA length must be very stable ⇔ magnet stability to be specified
- measurement of the DB
- error of the feed-forward adjustement of the chicane
- transmission error in the timing system
- bandwidth limit for correction
- periodic dE/E structure complicating the measurement (slide 13)
- Path-lengths variations to be worked-out everywhere

J.Sladen proposed a Solution,down to 20 fs → cost

# Phase control – II : data

$$\delta\phi = 0.2^o \ @\mathrm{f}_0 = 12\mathrm{GHz} \ \equiv \ \delta z_{\mathrm{tol}} = 14 \ \mu \ \equiv \ \delta t_0 = 46 \ \mathrm{fs}$$

$L_0$ Chicane after TA




$L_0$ = 8m α = 0.1 rad

Tolerance on α :
- 1/10 $\delta z_{tol}$
- 4 magnets

$$\Delta z_{\mathrm{chicane}} = \alpha^2 L_0$$
$$dz = 2\alpha L_0 d\alpha$$
$$d\alpha = \frac{\delta z_{\mathrm{tol}}}{10\sqrt{4} \times 2\alpha L_0} = 4 \cdot 10^{-7}$$

Use static magnets + variable deflectors for range $\delta\phi_r$=10°

$$\Delta\alpha_{\mathrm{defl}} = \frac{c}{2 f_0 \alpha L_0} \frac{\phi_r}{360} = 5 \cdot 10^{-4}$$

$$\Rightarrow \frac{\sigma_{\alpha,\mathrm{defl}}}{\Delta\alpha_{\mathrm{defl}}} = \frac{d\alpha}{3\Delta\alpha_{\mathrm{defl}}} = 3 \cdot 10^{-4} \ @ \ 1/\tau_{\mathrm{fill,MBAS}} = 30 \ \mathrm{MHz}$$

$$\Rightarrow \frac{\sigma_{\alpha,\mathrm{static}}}{\alpha_{\mathrm{static}}} = \frac{d\alpha}{3\alpha_{\mathrm{static}}} = 10^{-6}$$

Erk will say ‘red’ or ‘black’

With feed-forward : relax for linac

Range inside which correction applies

$$\delta z_{\mathrm{Linac}} \simeq 10 \, \delta z_{\mathrm{decel}} \ \Rightarrow \ \delta\phi_{\mathrm{Linac}} = \frac{10}{12} \delta\phi_{\mathrm{decel}} \simeq 0.2^o \ @ \ 1\mathrm{GHz}$$

(Need room for feed-forward overall error → keep 0.2° for coh & inc in DB Linac)

# Decelerator : conclusions (from E. Adli, last ACE)

- Simulations gives **reasonable confidence for minimum-loss transport of the decelerator beam**
- **Beam-Based Alignment is needed**, and **Dispersion-Free Steering** seems to be an excellent alternative
- Dispersion-Free Steering comes almost "**for free**" with the use of delayed switching
- **Tune-up procedures** must be applied
- Simulations need to be benchmarked and technology needs to be proven: **TBTS and TBL**

PETS Internal tolerances, perf,... : not discussed here

$r_0$ = 3.5 mm :
nominal max beam enveloppe
$R_{iris}$ = 11.5 mm

| Tolerance | Value | Comment |
|---|---|---|
| PETS offset | 100 $\mu$m | $r_c < 1$ mm fulfilled |
| PETS angles | ~ 1 mrad | $r_c < 1$ mm fulfilled |
| Quad angles | ~ 1 mrad | $r_c < 1$ mm fulfilled |
| Quad offset | 20 $\mu$m | Must be as small as possible to be able to transport alignment beam |
| BPM accuracy (incl. static misalignment and elec. error) | 20 $\mu$m | Must be as small as possible to be able to do initial correction |
| BPM precision (diff. measurement) | ~ 2 $\mu$m | Allows efficient suppression envelope growth due to dispersive trajectories |

*Static tolerances*

| Tolerance | Value | Comment |
|---|---|---|
| Quadrupole position jitter | 1 $\mu$m | $\delta r/r_0 < 5$ % |
| Quadrupole field ripple | $1 \cdot 10^{-3}$ | $\delta r/r_0 < 5$ % |
| Current jitter | < 1% | Stability req. only – RF power constraints might be tighter. |
| Beta mismatch, $d\beta/\beta$ | ~10 % | $\delta r/r_0 < 5$ % |

*Dynamic tolerances*

# Critical issues, injector → end TA

| System | Baseline design | Critical issues | Criticality 1..3 | Cost 1..3 | status |
|---|---|---|---|---|---|
| Injector | NA | **dI/I** | **2** | | See E. Jensen |
| Linac | Under work | **dϕ , dE/E**<br>**Klyst./modul.**<br>**optics** | **3?** | **2** | Feasability ?<br><br>NA |
| DL+CR1+CR2 OPTICS | CR1 exists | ISR absorbtion<br>6D-chrom<br>RF deflectors | **2**<br><br>**2** | | Need study<br>~OK, need refined study<br>Coll. effects, under work |
| Transfer to tunnel | NA | - | **-** | | |
| DBTL | exists | - | **-** | | |
| Decelerators | exists | See summary above | **3** | **3** | |
| Dumps | Proof of feas. | - | **-** | | Need effective layout |
| Collective effects CR→TA | | N-bunch resist. wakes, vacuum | | **1** | OK (cost) |
| DL→TA → DECEL chicanes | | **dø, dN/N, dE** | **3** | | **Still much work**<br>**Overall timing strategy**<br>RF, Instrumentation |
| | | Emittance growth | **1** | | Full tracking with error needed |
| | | Beam loss control, melting/radiation | **?** | | See M. Jonker |

# Summary and close future (CDR)

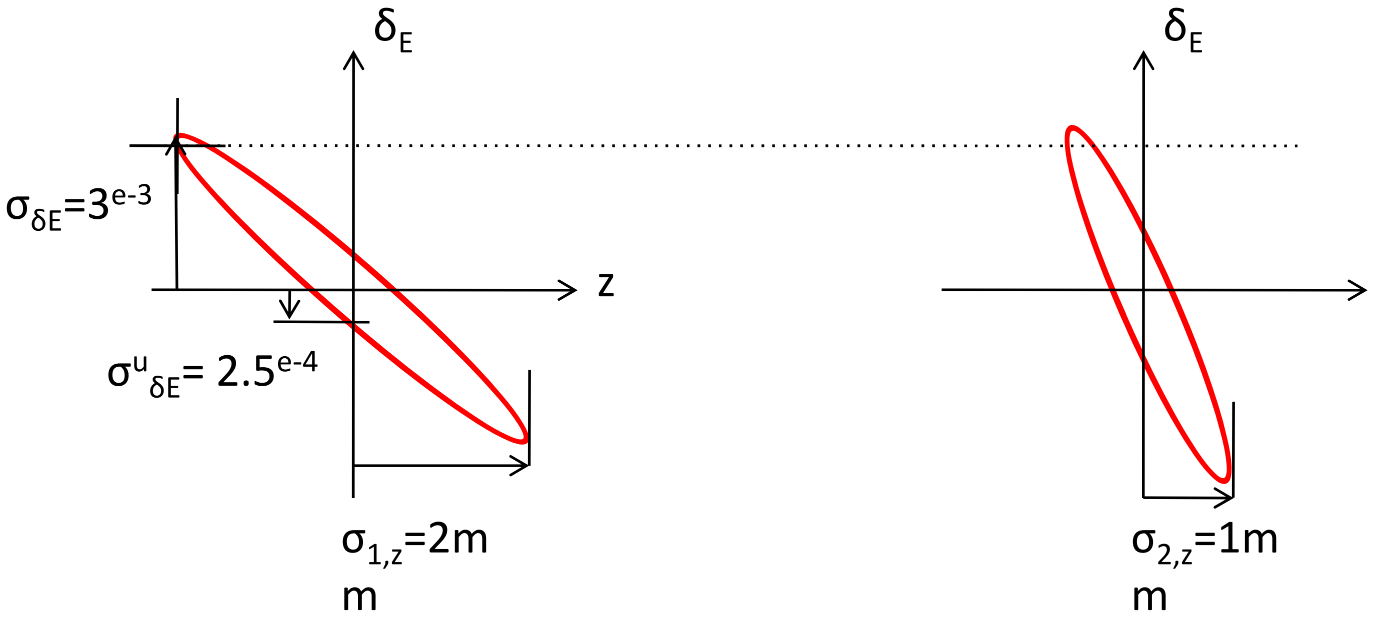
- Most critical issues
  - Phase control $d\phi = 0.2^{o}$ ↔ chicane / feed-forward / timing strategy
  - Bunch current ↔ source and loss control
  - RF deflectors ↔ design, tolerance, beam instabilities
  - ISR absorption ↔ thermal stress, materials

- For CDR (proposal)
  - Full optics study of CR1 ↔ 6D chrom, Length adjustment
    (If OK : DL, CR2 , TA granted)
  - Coordinated effort for $d\phi$ by RF/CO/BI/ABP
  - Better statistical model for $I_{bunch}$, sources, losses

# Reserve slides

# Chicanes and compression at the end of the Turn-around

F. Stulle




Presently : $R_{56} = (\sigma_{2,z}-\sigma_{1,z})/\sigma_{\delta E} = -0.33$ m

This value is large and converts energy jitters into large phase errors

→Make use of the larger possible momentum window of $\Delta E = \pm 2\%$

→ $\sigma_{\delta E}=3^{e-3}$ → $\sigma_{\delta E}=6^{e-3} \Rightarrow R_{56} = -0.16$ m

More comfortable, but a new study is needed (both chicane and chirp in DB Linac)