Consideration on the Conceptual Phase Stabilisation System

D. Schulte for the phase stabilisation team

Special thanks to E. Adli, A. Aksoy, A. Andersson, Ph. Burrows, A. Dubrowskiy, B. Jeanneret, C. Perry, G. Sterbini, F. Stulle,...

IWLC2010, October 2010

Main to Drive Beam Tolerance

- Integrated simulations have been performed with PLACET and GUINEA-PIG of main linac, BDS and beam-beam
  - system is assumed to be perfectly aligned (to determine BDS bandwidth effect)
  - assuming target emittance at BDS
- Resulting luminosity loss is about 2% for

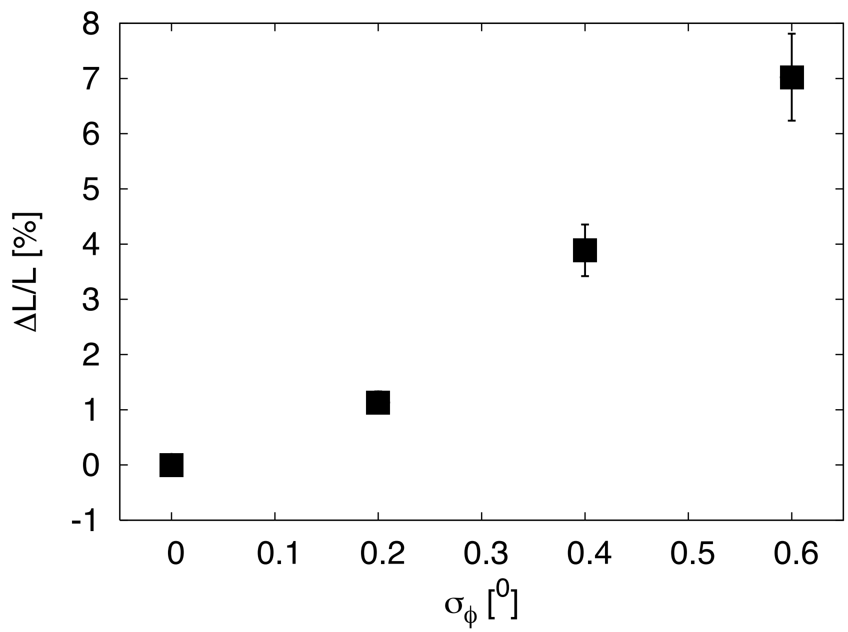
$$\frac{\sigma_G}{G} \approx 1 \times 10^{-3}$$

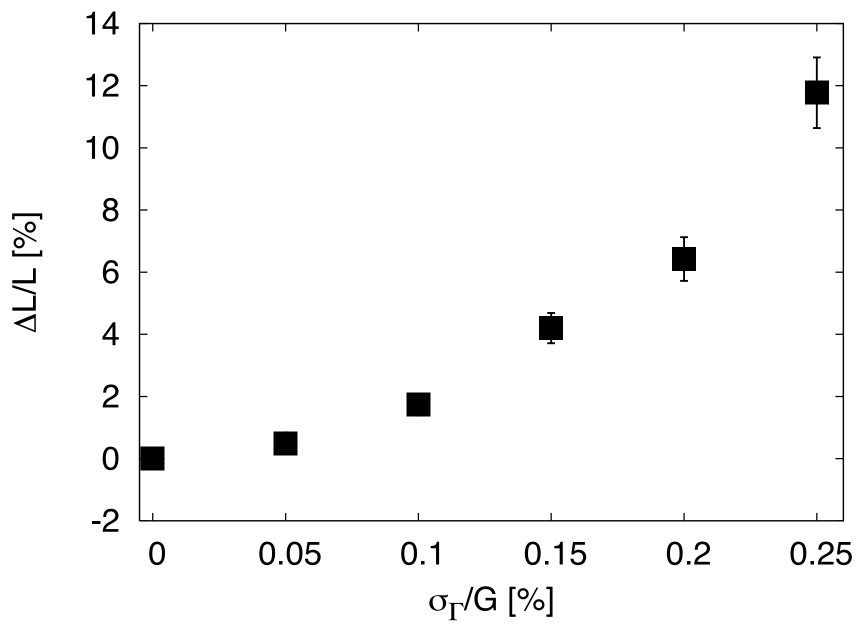
and

$$\sigma_\phi \approx 0.3^\circ$$

$$\frac{\Delta\mathcal{L}}{\mathcal{L}} \approx 0.01 \left[\left(\frac{\sigma_{\phi,coh}}{0.2^\circ}\right)^2 + \left(\frac{\sigma_{\phi,inc}}{0.8^\circ}\right)^2 + \left(\frac{\sigma_{G,coh}}{0.75 \cdot 10^{-3} G}\right)^2 + \left(\frac{\sigma_{G,inc}}{2.2 \cdot 10^{-3} G}\right)^2 \right]$$

- Main beam current needs to be stable to ≈ 0.1–0.2%





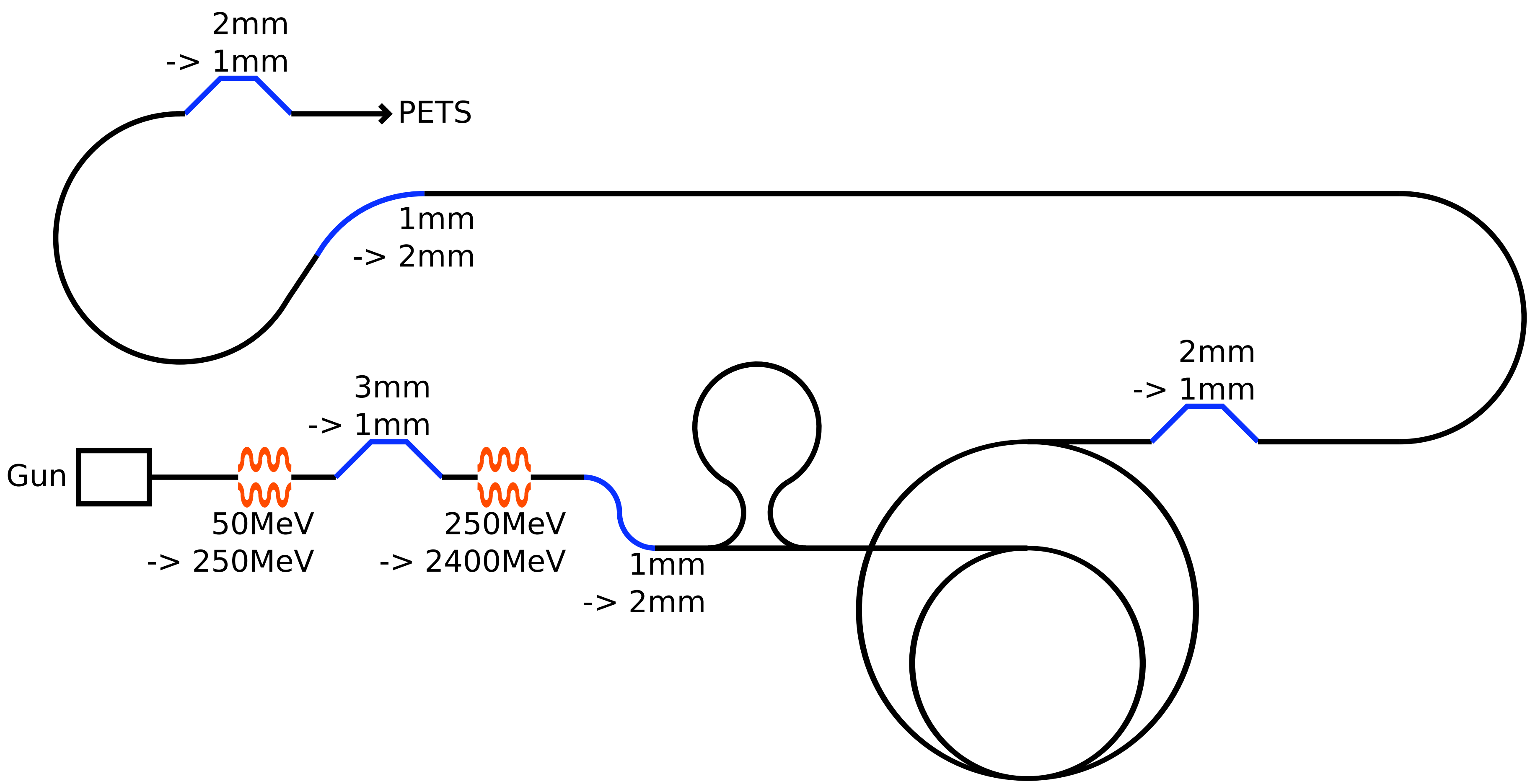
Drive Beam Tolerances

- We can re-write the tolerance for the RF amplitude and phase as tolerance for the drive beam phase, current and bunch length

$$\frac{\Delta\mathcal{L}}{\mathcal{L}} \approx 0.01\left[\left(\frac{\sigma_{\phi,coh}}{0.2^\circ}\right)^2 + \left(\frac{\sigma_{\phi,inc}}{0.8^\circ}\right)^2 + \left(\frac{\sigma_{I,coh}}{0.75\times 10^{-3}I}\right)^2 + \left(\frac{\sigma_{I,inc}}{2.2\times 10^{-3}I}\right)^2 + \left(\frac{\sigma_{\sigma_z,coh}}{1.1\times 10^{-2}\sigma_z}\right)^2 + \left(\frac{\sigma_{\sigma_z,inc}}{3.3\times 10^{-2}\sigma_z}\right)^2\right]$$

- We want to stabilise the parameters separately
  - drive beam phase
  - drive beam current
  - drive beam bunch length
- Phase tolerance is driving other tolerances
  - e.g. current errors can lead to phase errors

Drive Beam Compression and Phase Stabilisation Concept

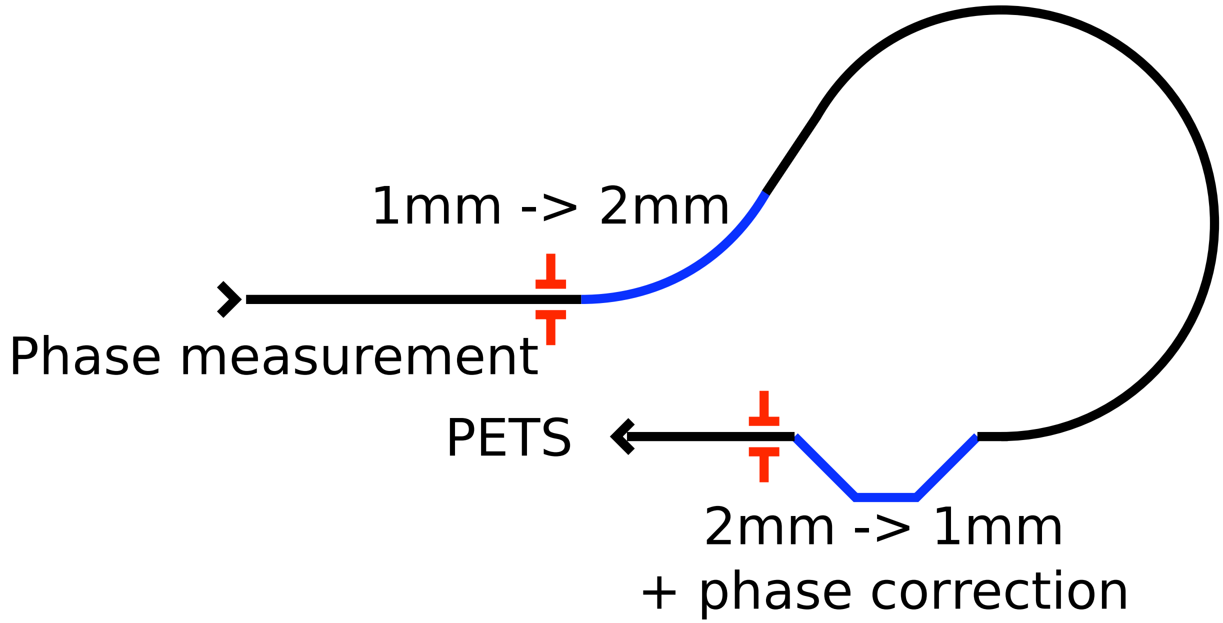


Feedforward at Final Turn-Around

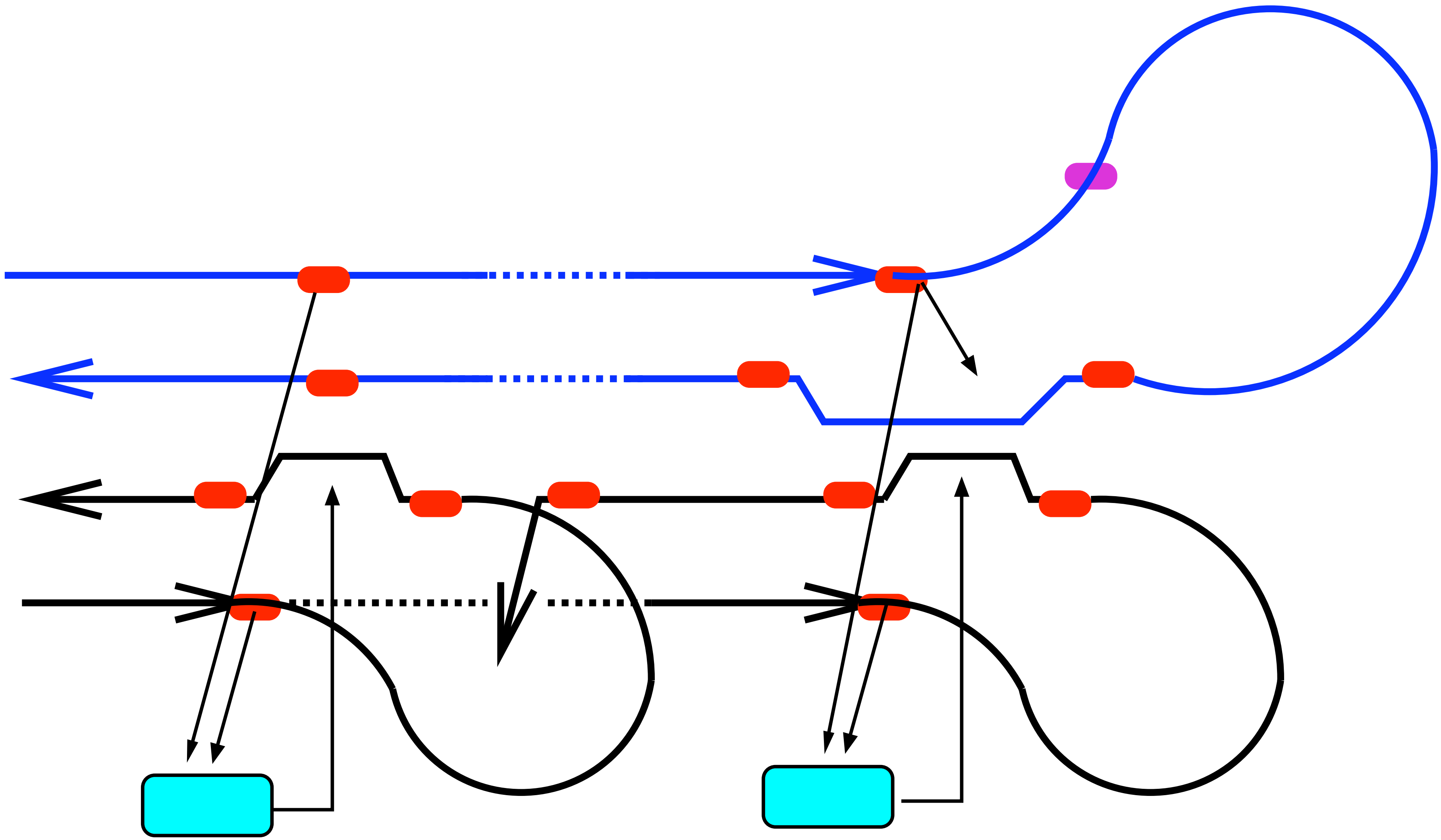
- Phase driven tolerance (DBA)
  - $\Delta I/I = 10^{-4} \Rightarrow \Delta I/I = 2 \times 10^{-3}$
  - $\Delta G/G = 1 \times 10^{-4} \Rightarrow \Delta G/G = 1 \times 10^{-3}$
  - $\Delta\Phi = 0.01^\circ \Rightarrow \Delta\Phi = 0.035^\circ$

$\Rightarrow$ Current stability given by gradient in ML

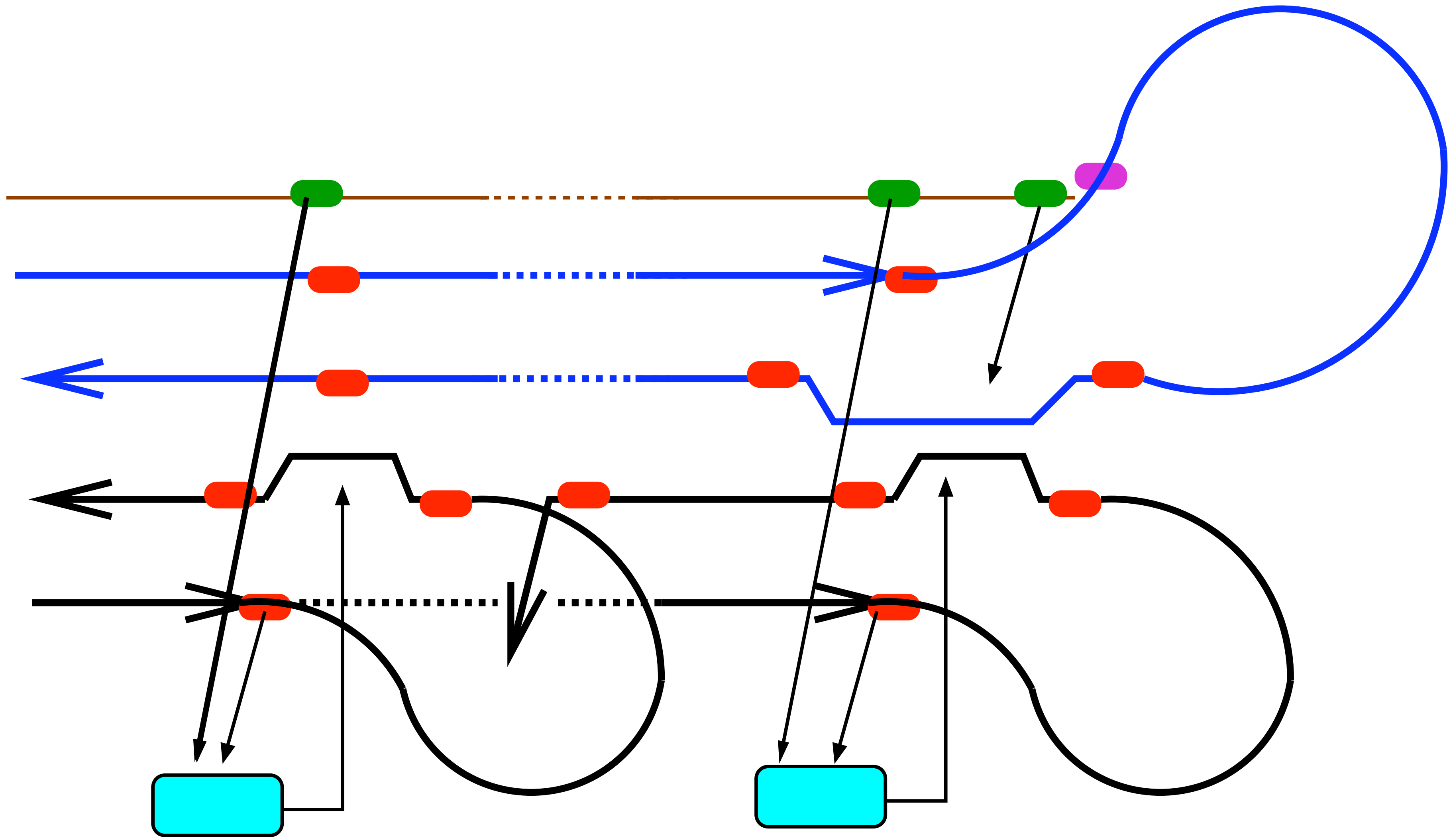
(Timing reference: A. Andersson; phase monitor F. Marcellini, I. Syratchev; BC design A. Aksoy; loop design F. Stulle; kickers Ph. Burrows, M. Barns)



Main Beam as Phase Reference



External Phase Reference



Main Beam to Main Beam Phase Tolerance

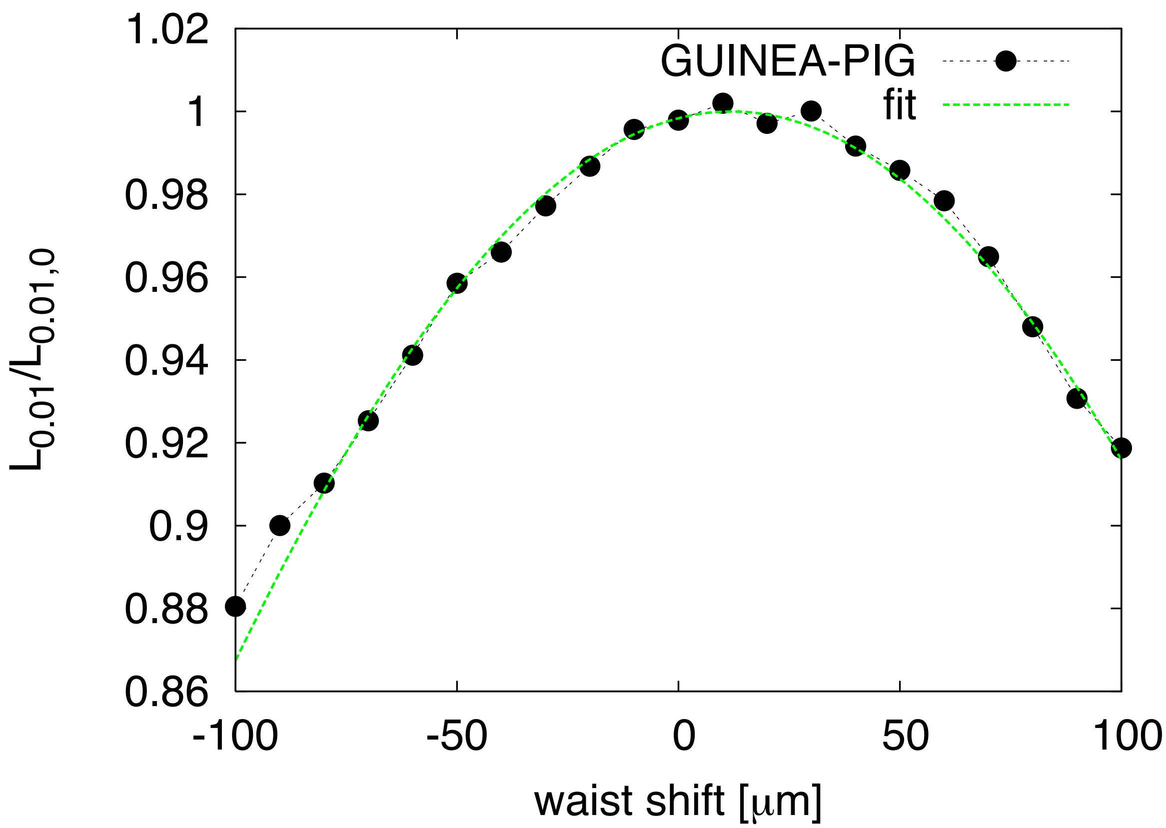
- RMS collision timing shift

  1% loss for shift of $21\,\mu\mathrm{m}$

$$\frac{\Delta\mathcal{L}_{0.01}}{\mathcal{L}_{0.01,0}} \approx 0.01\left(\frac{\sigma_{IP,z}}{21\,\mu\mathrm{m}}\right)^2$$

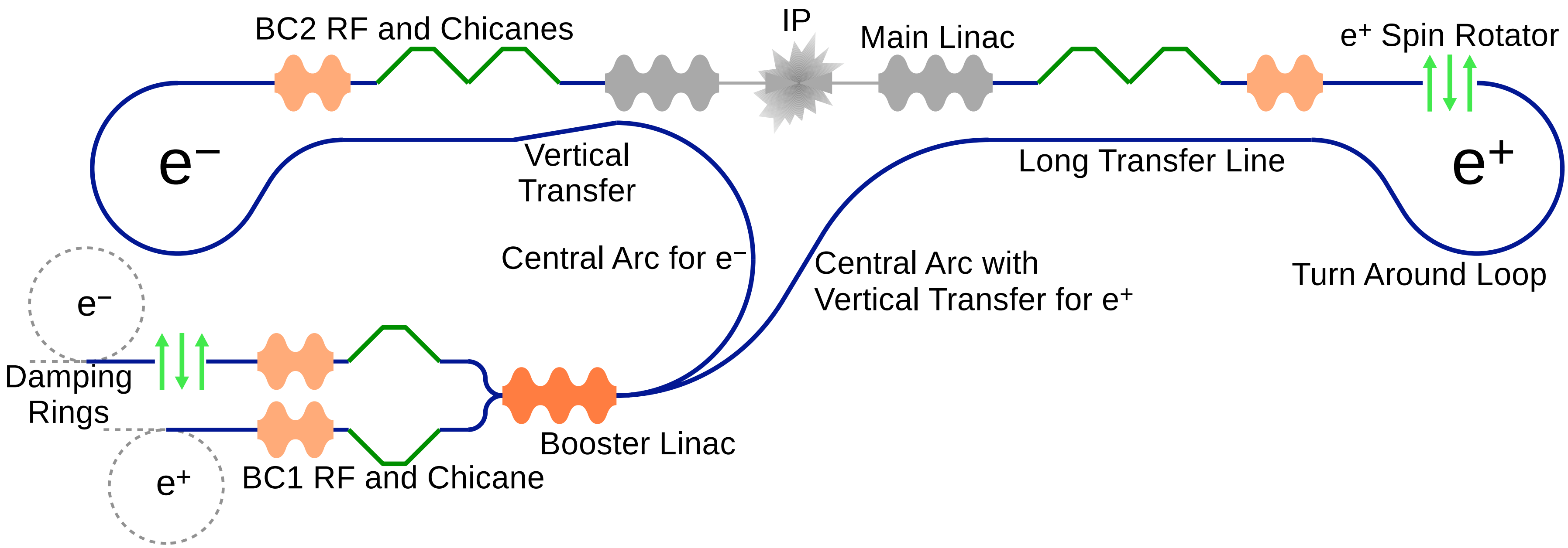
$$\Delta_{IP} = \frac{\Delta z_1 - \Delta z_2}{2}$$

$\Rightarrow$ Independent timing jitter of beams can be $30\,\mu\mathrm{m}$ for 1% luminosity loss



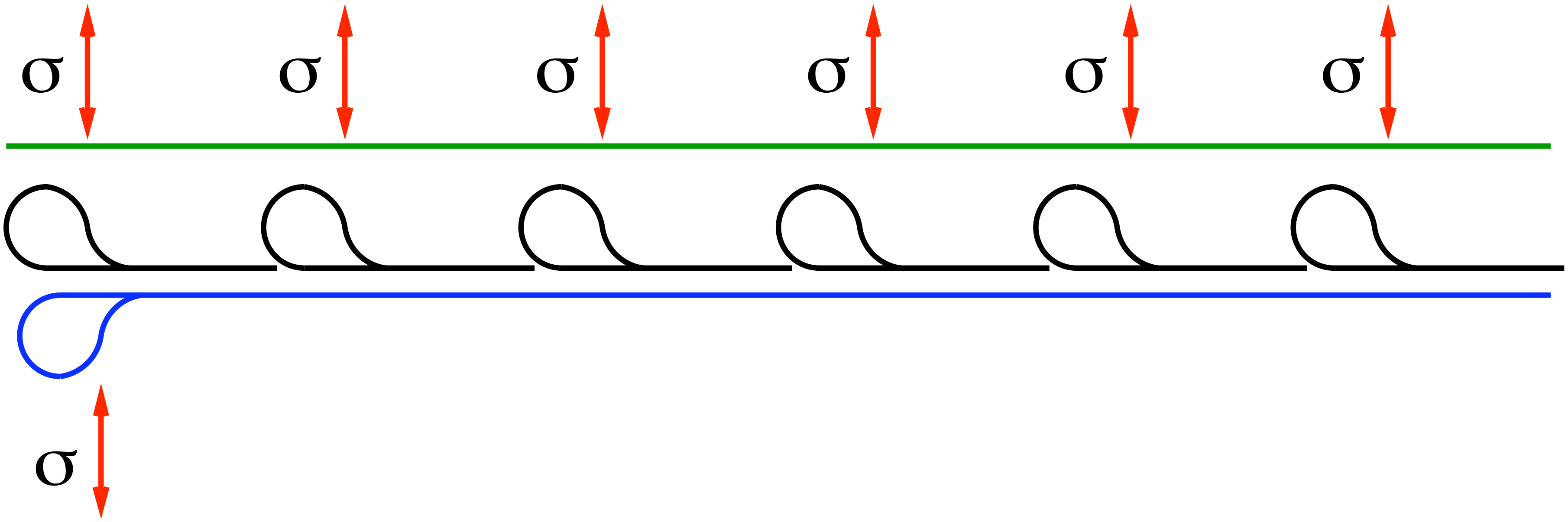
- Shift of collision point with respect to waist

Main Beam Phasing



- In central complex external timing reference assumed
- Along the main linac
  - distributed timing system
  - use of main beam as timing reference

Local Error Model



- Phase error at each point is independent of each other point

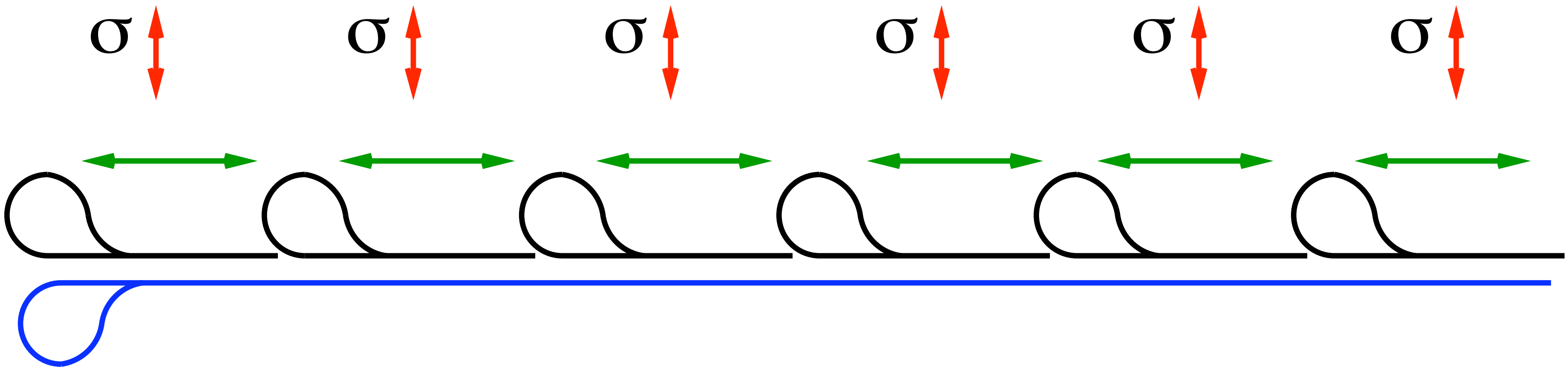
Simple Calculation for Local Control Error

- Let us assume that all errors are local
  - main beams have no phase jitter when going into transfer line
  - external timing system has the right signal in the fibers everywhere
- Local timing errors will occur due to
  - picking up the signal from the main beam
  - or picking up the signal from the fibers
  - error in controling the main beam bunch compressor RF
  - or error in controling the drive beam feed-forward

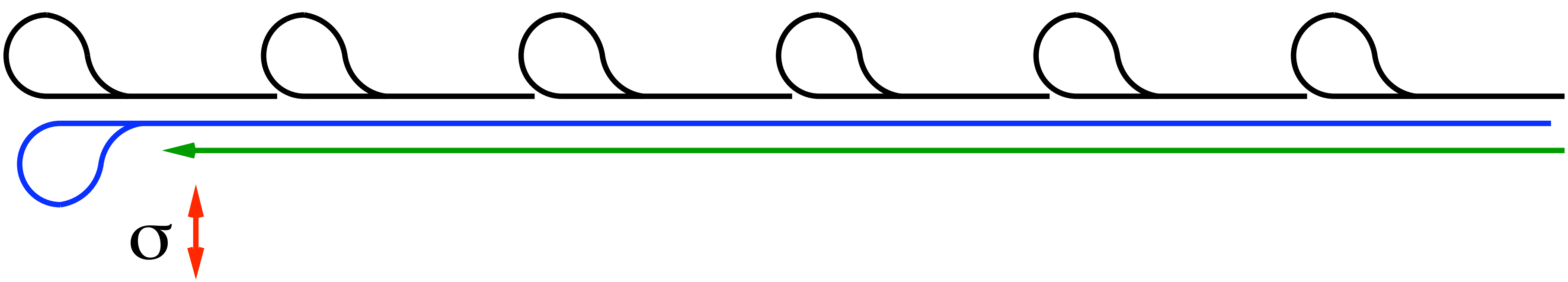
⇒ In this case tightest tolerance comes from main beam error

- $14\,\mu\mathrm{m} = 0.2^{\circ}$ lead to 1% luminosity loss due to incorrect main beam energy
- tolerance on main to incoherent drive beam phase is more relaxed (0.8°)

Global Error Models



- Timing error exists between each pair of points



- Timing of main beam is wrong with respect to reference time
- Timing of drive beam feedforward is correct for main beam

Simple Calculation for Global Control Error

- The only error considered is
  - a phase jitter of the outgoing beam
  - or a random walk-like error of the external timing

⇒ The jitter of the outgoing main beam can be $0.4^\circ = 30\,\mu\mathrm{m}$, limited by IP jitter

- The total difference between the two ends of the BC timing references is $\sigma \approx \sqrt{50}\sigma_\phi$, σ_ϕ the RMS drift from one sector to the next

⇒ $\sigma_\phi \approx 4\,\mu\mathrm{m} \approx 0.05^\circ$ from IP jitter tolerance

- On top will have phase errors between main and drive beam sectors, roughly doubling the luminosity loss

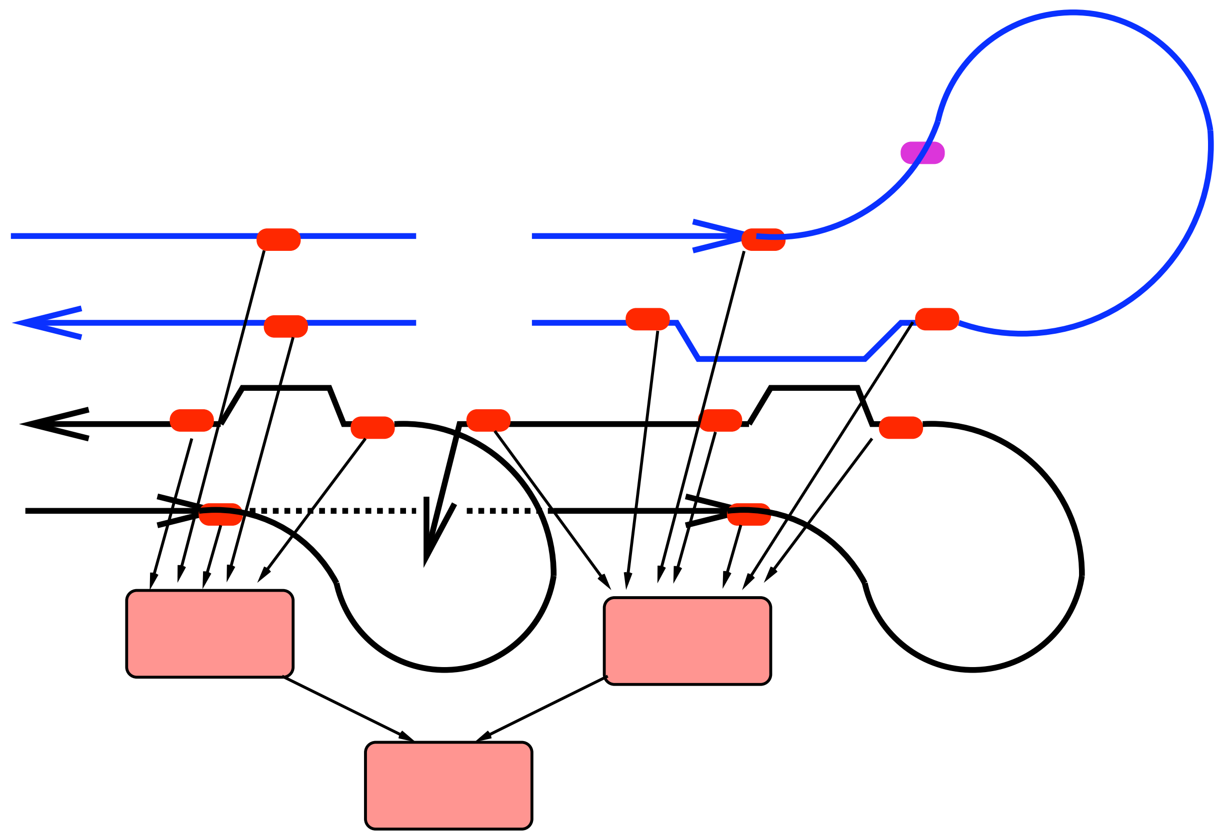
⇒ $\sigma_\phi \approx 3\,\mu\mathrm{m} \approx 0.03^\circ$

- at DESY $\sigma_\phi \approx 3\,\mu\mathrm{m}$ has been achieved over $300\,\mathrm{m}$, not far

Feedback and Tuning Strategy

- Feedback to deal with slow variations
- Path length tuning system for each turn-around
  - in drive beam and main beam
- Adjustment of path length from one drive beam turn-around to the next
- Similarly for the combiner rings, the delay loop and the drive beam accelerator complex

⇒ Slow drifts of relative phasing of the beams do not appear to be an feasibility issue



Sensitivity

- No active compensation assumed, each value results in $\Delta\mathcal{L}/\mathcal{L} = 0.01$ or an energy jitter of $0.2\,\%$ at linac entrance (external timing)
- Note: the tolerances will be tighter
- Energy jitter from damping ring: 2×10^{-4} (4×10^{-4}) for main beam (external) timing reference
- Phase jitter from damping ring: 0.2° (0.35°) at $1\,\mathrm{GHz}$
- Drive beam accelerator
  - 0.05° at $1\,\mathrm{GHz}$ klystron phase (0.035° at $3\,\mathrm{GHz}$ for average achieved, see A. Dubrowskiy)
  - 10^{-3} amplitude stability in drive beam accelerator (achieved, see A. Dubrowskiy)
- Phase error of first bunch compressor (BC1) at $4\,\mathrm{GHz}$:
  - 0.08° (0.14° for main beam as timing reference
- Gradient error in booster linac (without energy feedforward):
  - 1×10^{-3}
- BC2 phase jitter tolerance: 0.2° at $12\,\mathrm{GHz}$
- drive beam current stability: 0.75×10^{-3} (0.6×10^{-3} achieved, see G. Sterbini)

Conclusion

- We have two options to provided a distributed phase reference system in the main linac
  - use the outgoing main beam
  - X-FEL-like system
  - or a combination
- Decision needs to be based on further input from hardware performance
  - both seem to not be too far
- We seem to have a concept for drive beam generation and transport complex that leads to acceptable tolerances
  - demonstration of hardware

  ⇒ close to becoming a performance and cost issue
  - ready for improvements (cost, performance)
  - e.g. one central feedforward
- The effective loop and transfer line lengths are measured and can be corrected with feedback
- We need to look further into effects within the drive beam accelerator pulse
- More work to be done

Experiments in CTF3