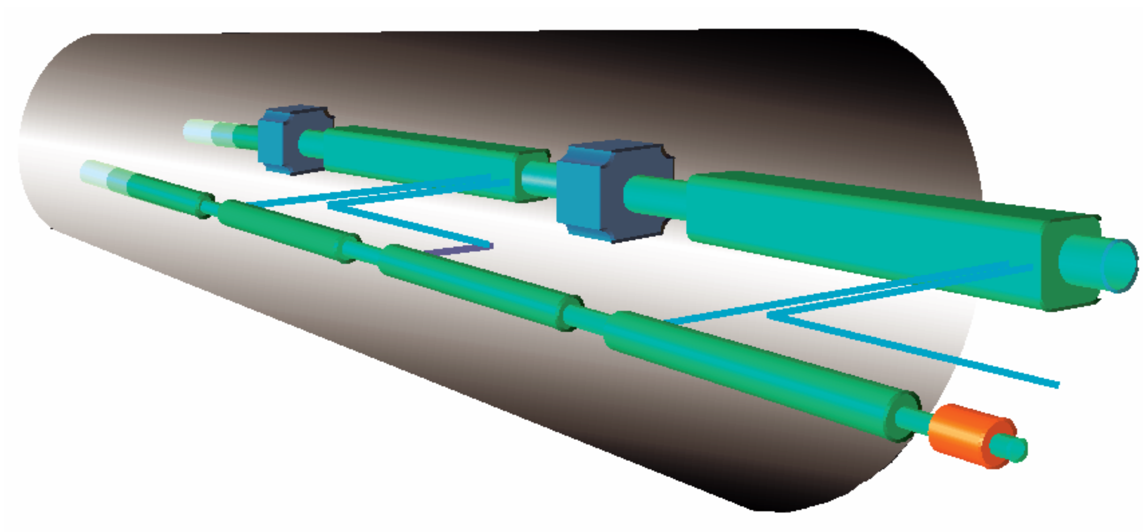
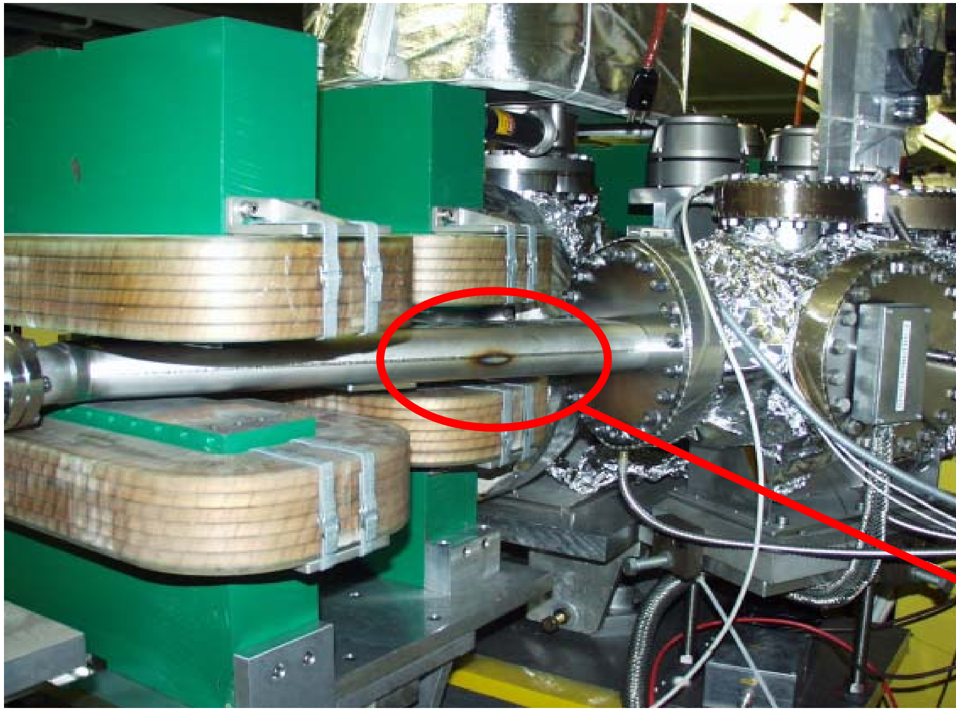
(Some thoughts about)

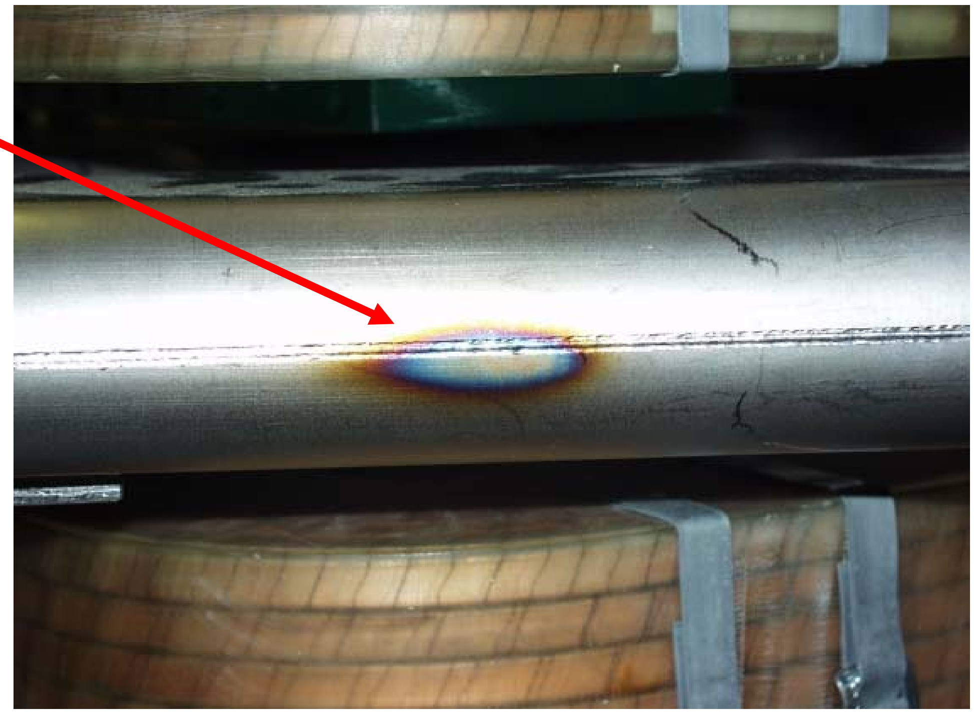
CLIC Drive Beam Failure Modes



(Only meant to stimulate discussion ...)

Beam damage in the CTF3 spectrometer line



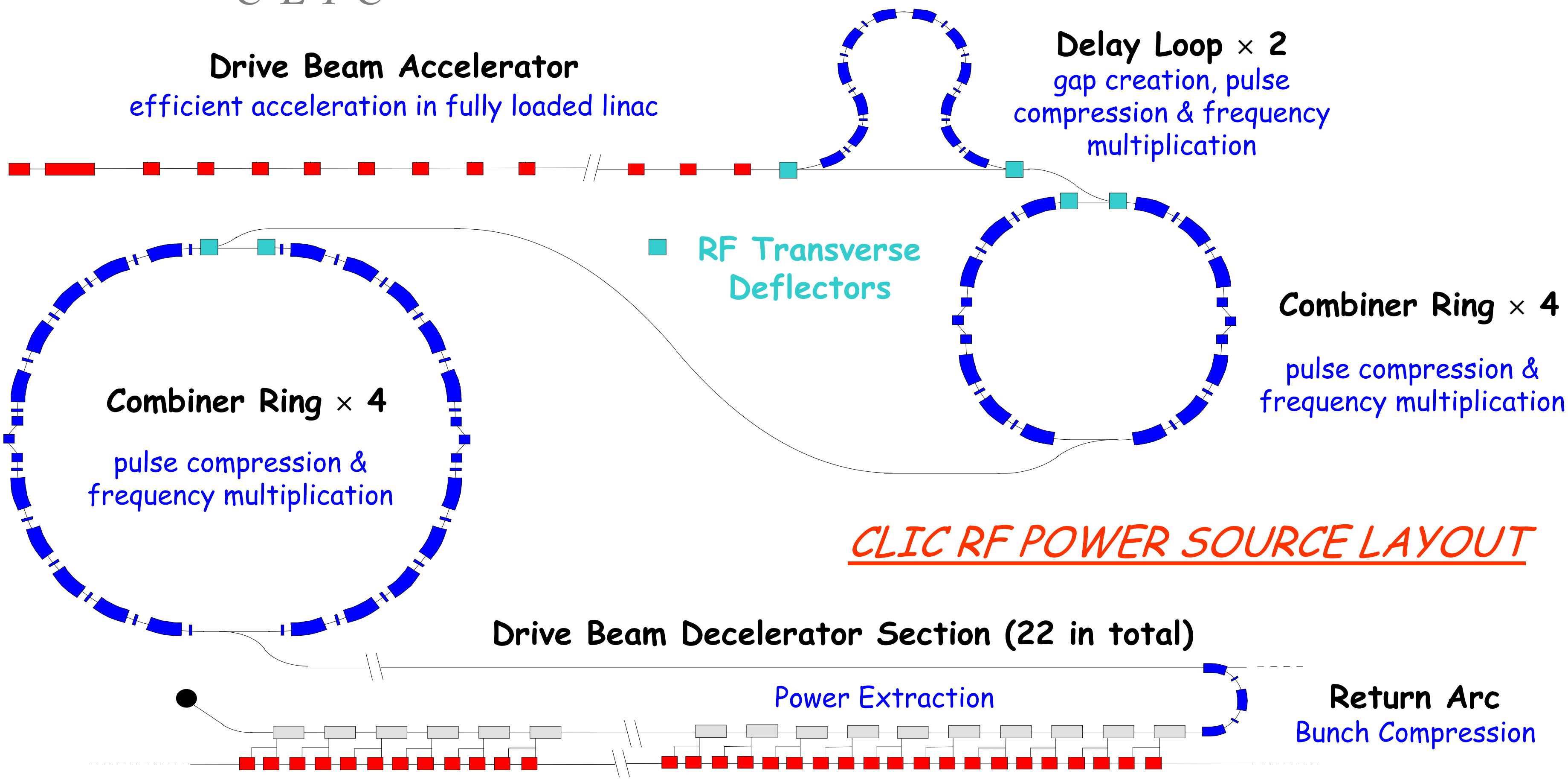


CTF3 beam in spectrometer:

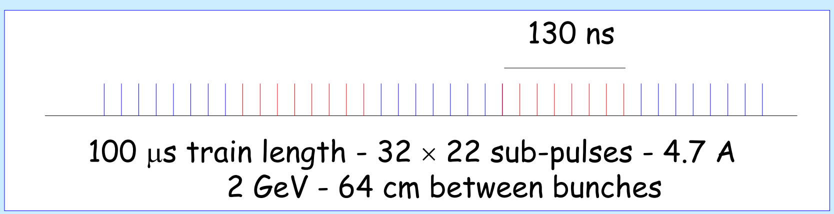
5 A, 1.5 μs, 20 MeV, 10 Hz

CLIC drive beam after the DBA:

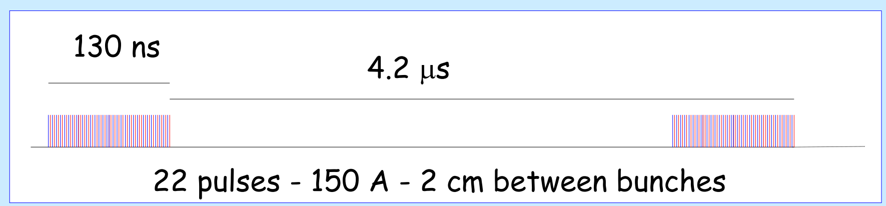
4.7 A, 100 μs, 2 GeV, 100 Hz



Drive beam time structure - initial



Drive beam time structure - final



What do we call a drive beam failure ?

In normal operation, we assume that the drive beam AND the main beam losses are kept at an acceptable level.

Normal drive beam cycle: the beam is accelerated to 2 GeV and manipulated to obtain the desired time structure. Each sub-pulse is sent to one decelerator section, decelerated to about 10% of the initial energy, and dumped.

Let's suppose that a component of the drive beam complex has a problem (it doesn't need a wild imagination…). Several possibilities:

1. The drive beam cannot follow its normal cycle – it is lost (or it's dumped) somewhere in the drive beam complex. Following pulses must be dumped or inhibited.

2. The drive beam losses somewhere in the complex are unacceptable over a certain time scale – recovery actions may be attempted. In order to evaluate the loss level for a given failure, need knowledge of beam phase space distribution (6D), or make assumptions.

3. The RF power production process is affected, such that the main beam cannot follow its normal cycle, undergoes unacceptable losses, (or the luminosity loss is unacceptable).

➡ **Not covered here – possibly most critical**

What can go wrong ?

Magnets
- Main dipoles
- Quadrupoles
- Sextupoles
- Correctors

RF
- Modulator & klystrons
- Accelerating structures
- RF deflectors
- PETS

Kickers
Vacuum
(Controls – diagnostics - feedbacks)
…

Different time constants involved; e.g., magnets have field decay times of the order of 1 second, while RF can fail during a single drive beam pulse (e.g., breakdown)

Different effects on beam (orbit, beam size, energy and bunch length) depending on component and location

Again on failure types

- A component can fail completely or only partially. A partial failure can be worse than a complete one. For example:
    - short of one quad coil ⇒ can give a strong kick to a focused beam
    - partial kick from a fast kicker ⇒ beam lost in the vacuum chamber
- In the following, a total failure is in general assumed
- For magnets, a tolerance can be set on the allowed strength variation – given the field decay time, the available time to react can be calculated
- RF errors less straightforward. Can have both amplitude and phase errors, phase and amplitude can vary within one drive beam pulse, etc…

Some considerations

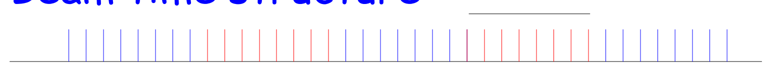
- The beam pulse energy is higher in the DBA (and in the loop and rings) with respect to the decelerator sections, but the aperture limitations are tighter there, and the beam is decelerated to low energy !
- The beam time structure at the location of the fault is important, especially if we want to react within one pulse

Typical reaction times & distances:

• Time between drive beam pulses (100 Hz)	10 ms	=	3000 km
• Drive beam pulse duration (DBA)	100 μs	=	30 km
• Time between sub-pulses (after DL)	130 ns	=	39 m
• Time between sub-pulses (after CR 1)	910 ns	=	273 m
• Time between sub-pulses (after CR 2)	4 μs	=	1.2 km

Drive beam accelerator (DBA)

Beam time structure 130 ns



100 μs train length - 32 × 22 sub-pulses - 4.7 A
Final energy 2 GeV

Injector Many components involved, large range of effects – but the beam energy is still low, and the distances involved are short (fast reaction time) with respect to the pulse duration (100 μs)

Accelerator Main component failures:

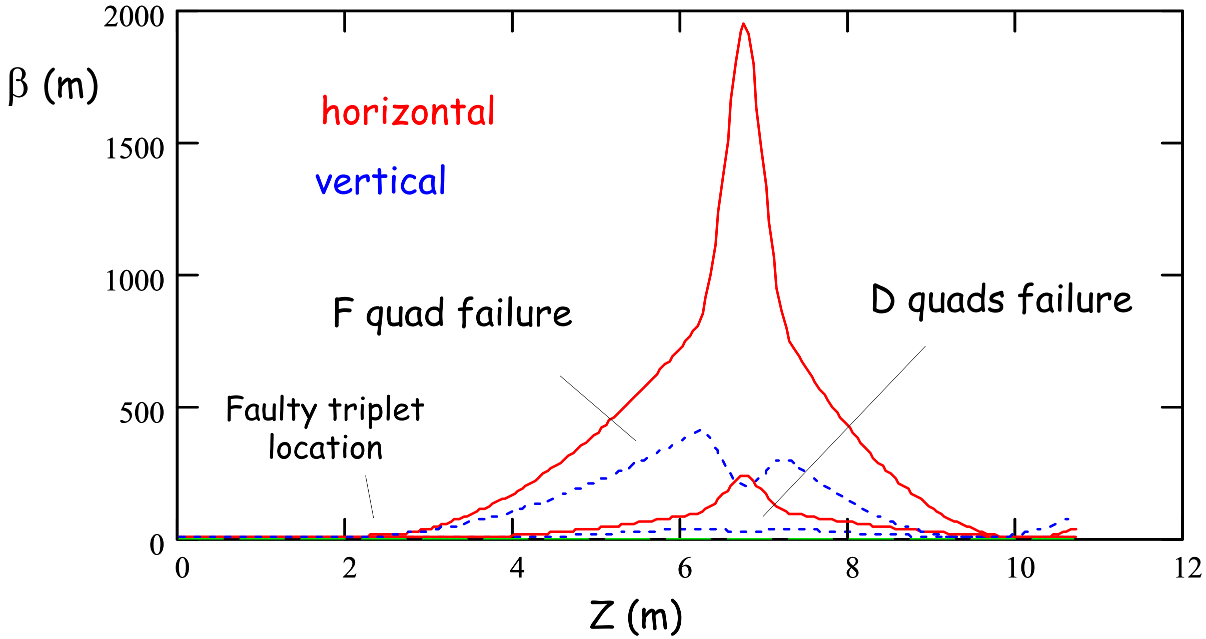
1. Quadrupole failure ⇒ beam lost over a relatively large area (slow)
   detection with beam loss monitors ?
   how to react ?

2. RF failures ⇒ wrong energy (and/or time/energy correlation – can be fast)
   detection in dispersive sections ? bunch length monitoring ?
   the energy acceptance of the accelerator and of the transfer lines could be large enough for most cases (~ 200 klystrons)
   beam dumped afterwards(eventually) and energy correction on following pulses

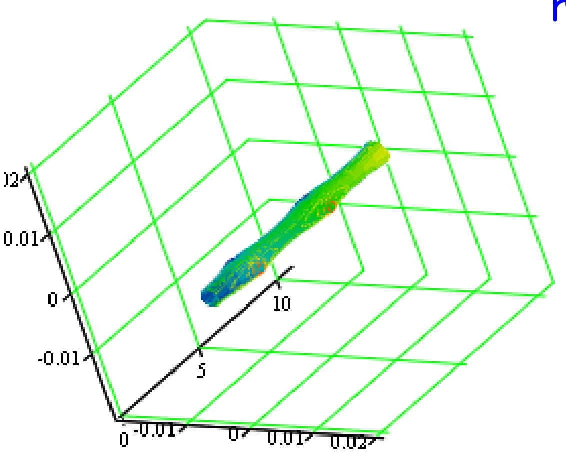
3. Dipole (bunch compressors) ⇒ beam lost (relatively large horiz. area ?) (slow)

4. Correctors ⇒ ? wakefields - can be bad (focused beam lost) (slow)

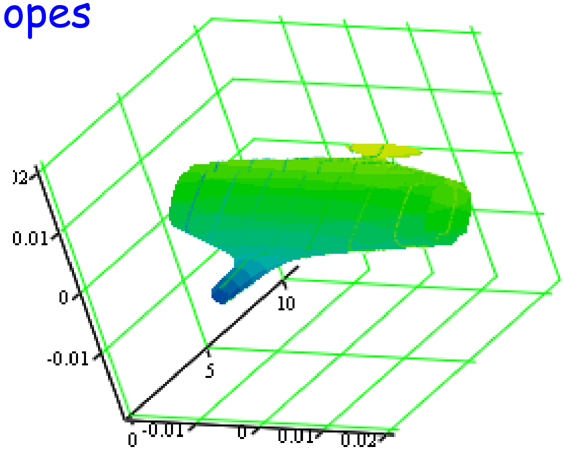
Example: failure of F quad or D quad couple in CTF3 drive beam accelerator triplet lattice (50 MeV)



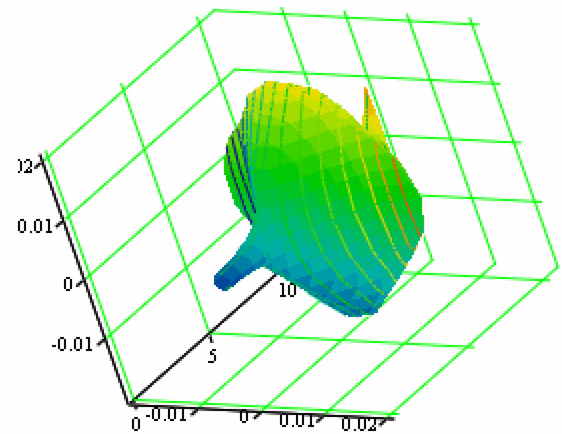
rms envelopes



nominal

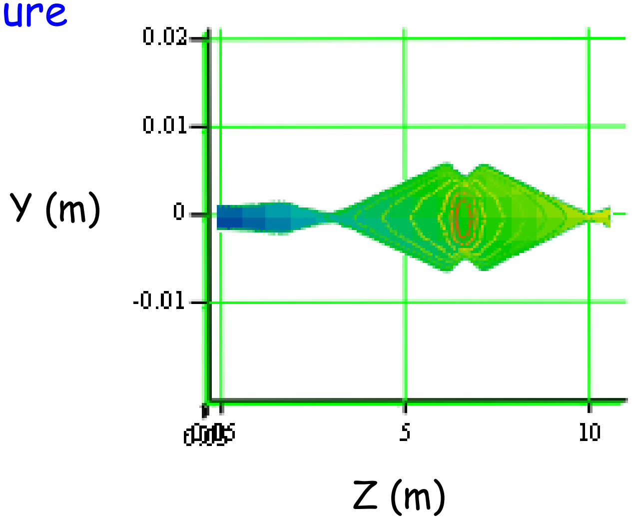


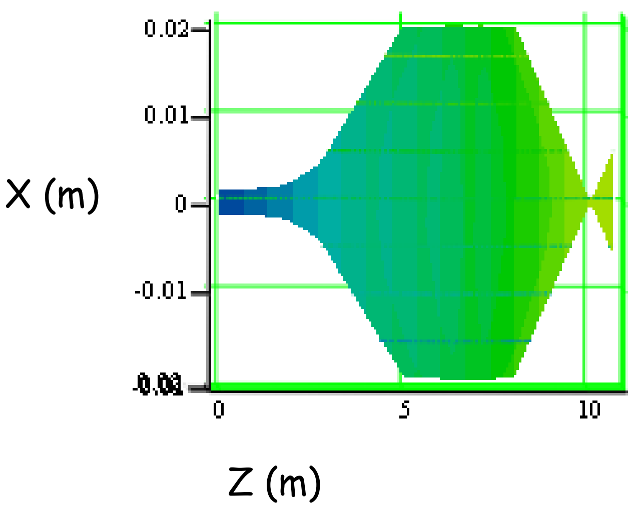
F quad failure



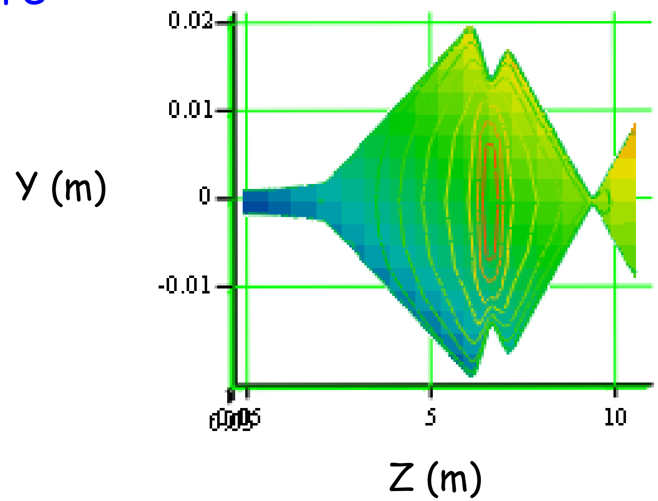
D quads failure

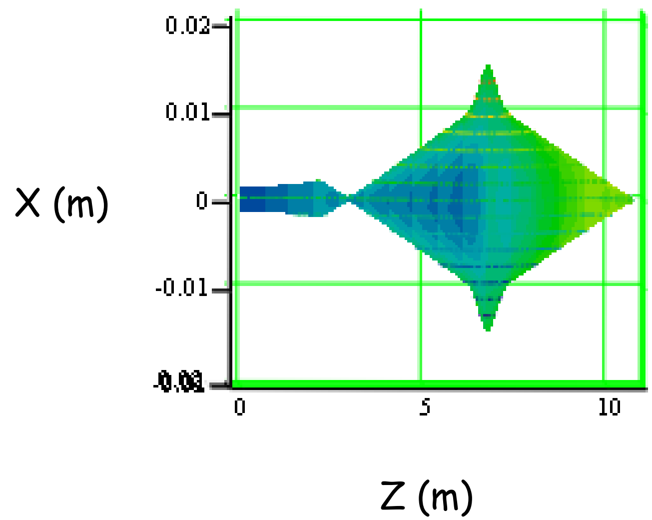
F quad failure





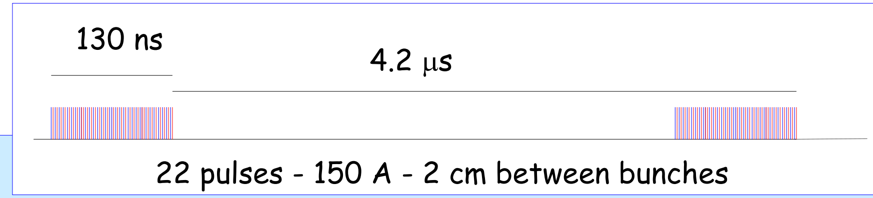
D quads failure





Delay loop & combiner ring

Final beam time structure

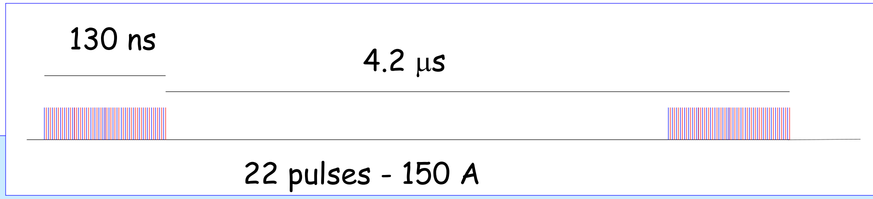


The peak current is higher than in the DBA, but there are "holes" in the beam time structure (allows for fast kicker rise time) & the beam is bent around (time to react with a downstream kicker)

1. RF failures (deflectors) ⇒ orbit error
   acceptance could be large enough to transport beam to a proper kicker location – to be included in design – can be a strong constraint
2. Ring extraction kickers ⇒ pulses will hit septum after ½ turn !
   worse if partial failure - fast reaction on deflector ?
3. Quadrupole ⇒ similar to DBA
   but a small error in F quads located in dispersive regions can have a larger effect on the longitudinal phase space than on the transverse (true also in transfer lines – bunch compressors/stretchers)
4. Main dipole ⇒ similar to DBA
5. Correctors ⇒ " "
6. Sextupoles ⇒ emittance increase (chromaticity) + bunch lengthening (slow)

Transfer lines - turnaround

Beam time structure



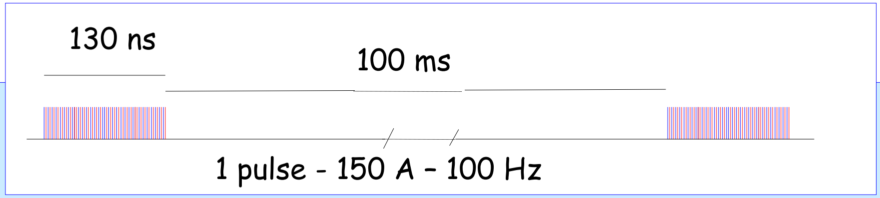
Most issues are similar to the ones in the combiner rings and delay loop, one important element:

Fast kickers – one per each turn-around - used to inject the selected pulses in the decelerator sections

$\Rightarrow$ if one fails completely, a decelerator section will not be powered

Drive beam decelerator

Beam time structure



Lower energy per pulse and no (fast) active components BUT high peak current, restricted aperture, deceleration to low energy, large momentum spread, wake-fields.

1. Quadrupoles
2. RF failures (PETS) ⇒ breakdown ! – effect on drive beam ?
3. Effects of upstream errors ⇒ failures that are not critical in the drive beam generation complex can be critical here – need collimation system ? betatron + momentum ?

➡ **If protected by a collimation system, could be less critical than other parts of the RF power source**