Beam scenarios for a safe CLIC operation

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Beware!

This talk will mainly focus on the basic principles, without entering into too many details. The goal is to show what we want to do, and list some of the problems that have to be dealt with when we actually build CLIC and its Machine Protection system

Main Beam <-> Drive Beam: different problems, different dangers

Drive Beam(s)

- Lots of current
- (Relatively) low energy
- Large size
- Dangerous everywhere

Main Beam(s)

- Lots of energy
- (Relatively) low current
- Small (tiny) size == huge brilliance
- Already dangerous in the damping rings
- More dangerous towards the end, when it reaches max. energy

Our goal:

•Minimize the risk of beam-induced damage

Our strategy:

• Use a "small amount" of beam until we are confident that everything is OK

• Analyse the results at the end of the pulse

• If everything is OK, progressively increase this amount

• Step back to a safe beam (or to no beam at all) in case post-pulse analysis shows a problem

Q&A: What is a "safe" beam ?

- **It depends on our knowledge of the machine**

- **If we know nothing, a safe beam is one that could fully collide somewhere on an "obstacle" in the machine without making an unacceptable damage**

- **When we know that there are no direct obstacles or major problems, we can safely send a heavier beam**

- **As we proceed to exclude different kinds of problems, our "safe" beam will become more and more powerful**

- **We must ALWAYS send a beam which is safe**

Problems & Constrains:

•A small and safe beam might not be measured correctly by the instrumentation

• Some operations, like reducing the individual bunch current, may produce useless results (as they modify the beam behaviour)

• The total time to go from the first beam to the nominal one should be kept short (i.e. not larger than a minute).

• The machine settings should not be drastically changed just to produce a pilot beam (stability & reproducibility)

These arguments might impose restrictions on the kind of manipulations we can play with the beam generation

Drive beam and main beam are (semi-)independent

The drive beam and the main beam can be "commissioned" almost independently, but

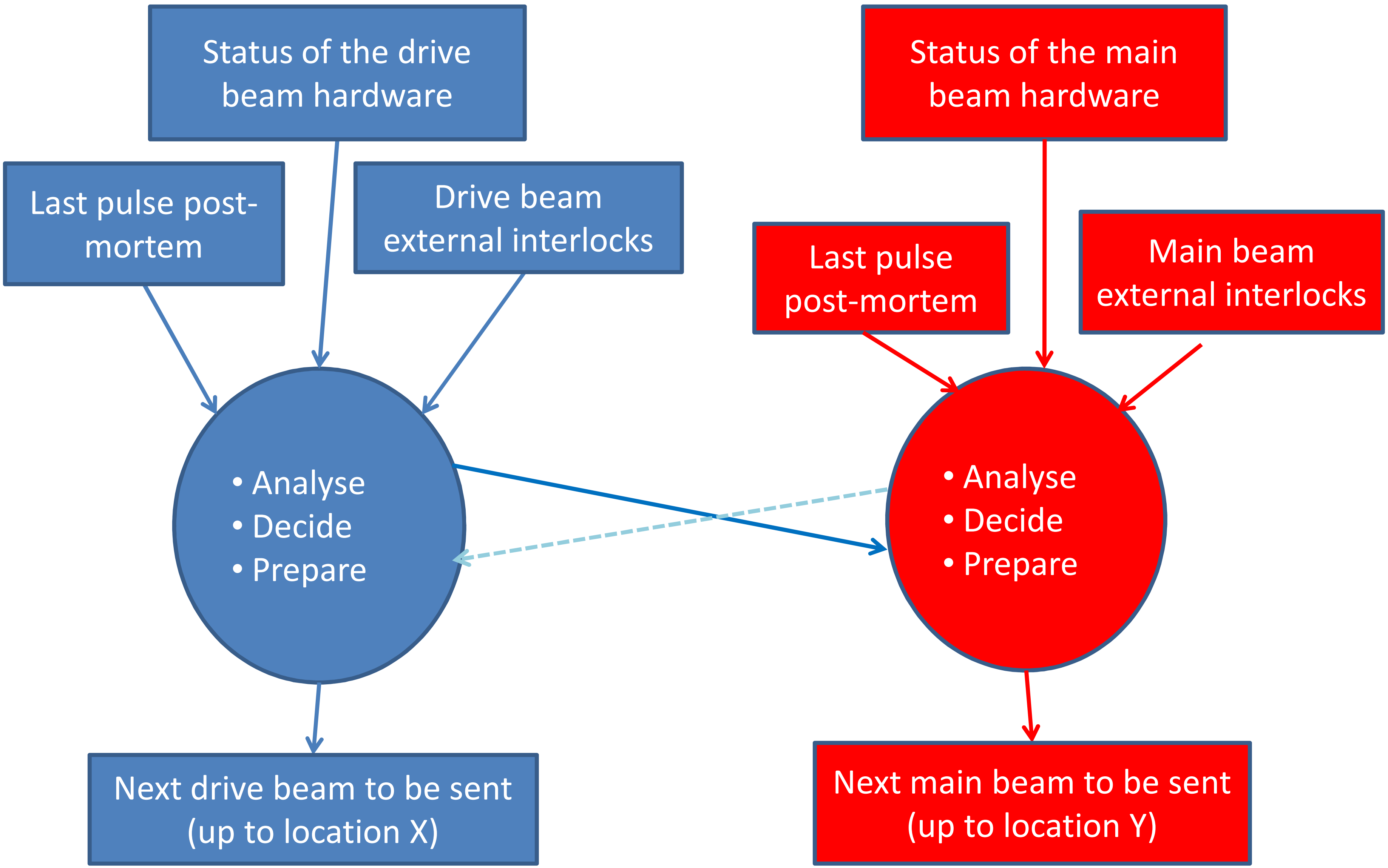
It might only make sense to routinely send the complete main beam to the main Linac if the drive beam

- **Is fully produced ***
- **Comes with the right phase relative to the main beam ****

***perhaps it also could be useful to check the acceleration in the main Linac sector by sector**

****to find initially the right phase the pilot beam will be used**

Every 20 msec the CLIC Machine Protection will ...



Q&A: Can’t we reduce the danger by sending a “safer” beam ?

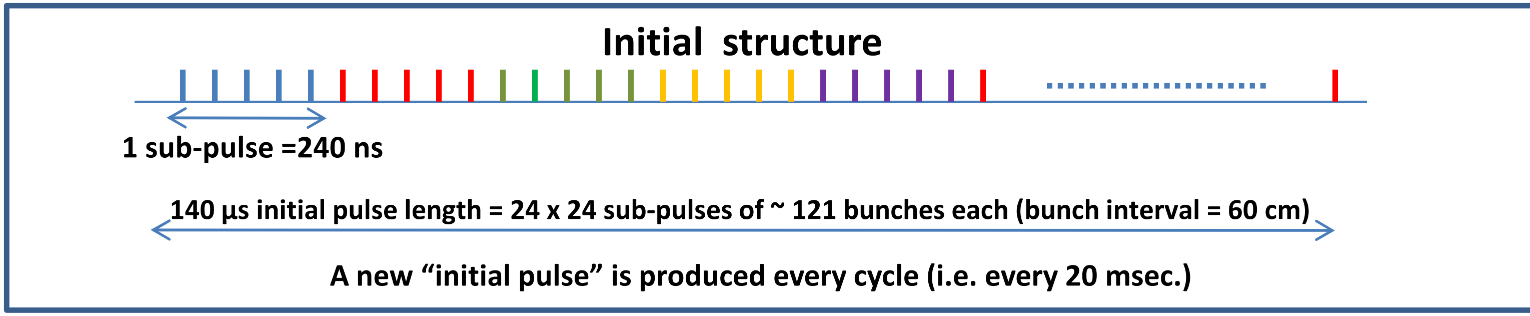
Yes, but

- **Beam should be measurable by instrumentation**

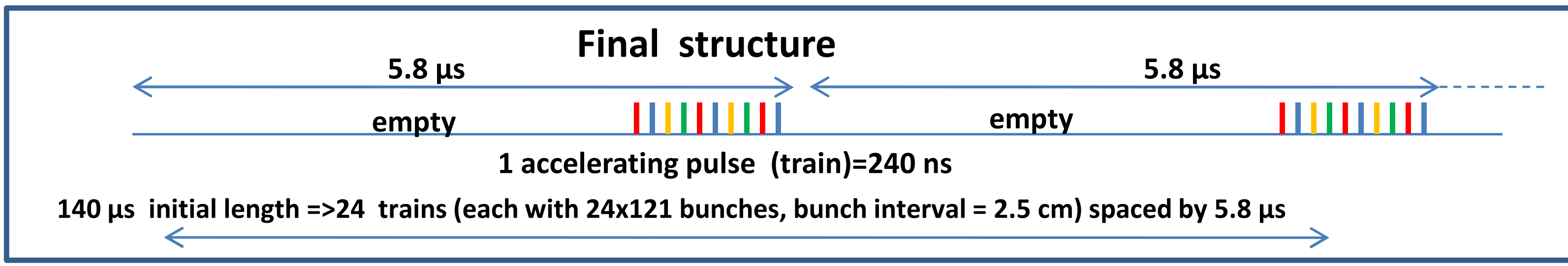
- **Beam should be representative of complete beam (or else its different behaviour should be predictable)**

- **Beam should be easy to produce**

Reducing the Drive Beam



Recombination (delay loop, CR1, CR2): the first 24 sub-pulses (5.8 μs) will be compacted together to produce the 240 ns "accelerating pulse", or "train", for the first decelerator sector. The compaction is achieved by making earlier sub-pulses following a longer path.
The second 24 sub-pulses will produce the train for the second decelerator sector, etc.



Within a train, bunches with different colours have followed different paths through the "recombination complex" (delay loop, CR1 and CR2**). If we can decide which bunches are initially produced, or else if later we can get rid of unwanted bunches**

- we can probe the different paths one by one
- we can produce the train for an individual deceleration sector
- we can produce a train with less bunches (i.e. less current == limited damage)

Reducing the Drive Beam (2)

What is a "safe" drive beam when we do not know how the machine behaves?

- We need to reduce the intensity of the Drive Beam by a factor ~100

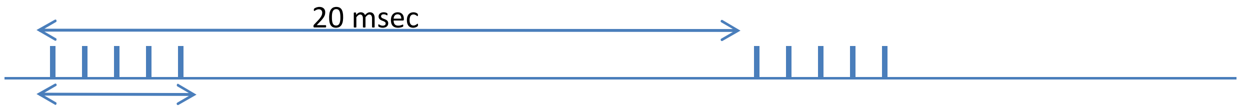
- More specifically, the intensity of each train must be reduced by a factor 100

- We can get a factor 24, for example, by selecting one out of the 24 recombination paths. This will be done by selecting just one among the first 24 sub-pulses, one among the second 24 sub-pulses, etc.

- By changing the sub-pulse selection, we can probe the different paths

- We can get another factor of 4 by only keeping every fourth bunch inside the sub-pulse (alternatively, we could cut the tail and produce a shorter train, to be able to accelerate a shortened main beam pulse)

Reducing the Main Beam



1 pulse = 156 ns, 312 micro-bunches spaced by 500 ps

A new pulse is produced every 20 msec.

We can send around a single "pilot" pulse, with a reduced number of micro-bunches (ideally 1). There are, however, limitations due to the measurement instruments. For instance, the BPMs have to see a signal for at least 10 ns to be able to measure correctly. This sets a minimum number of 20 consecutive micro-bunches. If the BPMs are able to measure a signal produced by 10 micro-bunches spaced by 1 ns each, **and if we get full control on the micro-bunches production, or else if we later can get rid of any unwanted bunch,** we can gain another factor 2.

We can also increase the emittance of the "pilot" pulse, to reduce its brilliance. This requires changing some setting in the machine.

Reducing the Main Beam (2)

Is there such a thing like a "safe" main beam?

- We need to reduce the brilliance of the main beam by a factor ~10000 (?)
- A factor 30 can be gained if we move from 156 ns pulse to 10 ns pulse and we eliminate every second bunch (312 -> 10)
- We could perhaps reach a factor ~50 if we eliminated even more bunches
- Can we reduce the bunch current by a factor 3 ?
- Can we enlarge the beam size by 3 (horiz) x 20 (vertic) ?
- If we can, we are not too far from a "safe pilot beam"

Dynamic range of the different beam diagnostic instruments

What we can do to reduce the beam depends also on the beam diagnostic instrumentation capability to correctly measure an amount of beam much smaller than the nominal one.

Implementing this capability might require more money, or simply could be impossible (in which case we have a problem).

Getting rid of the unwanted bunches: why, how, where ?

- To be able to send a less harmful beam around

- To be able to look at a given beam (drive beam, different paths in the recombination complex; also useful when diagnosing problems with the phase synchronization)

- Ideally we would like to have a complete control of the production of the individual bunches. It would be nice if the beam production complex was equipped with a “programmable bunch selection mechanism”, with a possibility to change “filling” schema between two consecutive cycles.

- alternatively we can probably use rf deflectors to “extract” (i.e. dump) undesired bunches
    - possibly at the beginning of the Linac (Drive Beam)
    - possibly before the Damping Rings (Main Beam)

What will determine/limit the kind of beam we can send ?

- We know damage will be made (ex. A magnet is off) (**I** = Interlock)

- We know damage could be made (ex. A Dump system is broken) (**I**)

- We think there is a good possibility that damage could be made (ex. There is a trend showing a problem is developing) (**P** = Post-pulse analysis)

- We do not know how to check if damage will be made (ex. Some diagnostic system is not fully operational) (**I**)

- We do not know in which state is the machine, or part of it (ex. First time; ex. Recovery from a problem)

How do we know when everything is Ok ?

- **External interlocks**
  - **Access system**
  - **Detector**

- **Equipment status (at t-2)**
  - **Equipment needed to produce and deliver the beam**
  - **Equipment needed to measure the beam**

- **Results from last pulse (post-mortem) : the trickiest part**
  - **Absolute measurements (beam loss monitors, radiation monitors,...)**
  - **Difference with reference**
  - **Difference with previous measurement (stability, reproducibility)**

Measurements, and post-mortem analysis

- Measurements indicating something is wrong
  - ex. Beam loss monitors
  - ex. Beam current is lost somewhere
  - ex. Totally wrong phase between Main beam and Drive beam

- Measurements indicating something is not stable
  - ex. Trajectory changes more than threshold
  - ex. Position of piezo-stabilizers moves too much
  - ex. Phase is drifting

- Missing measurements
  - to stay on the safe side, should be considered as a bad measurement
  - instrumentation redundancy: how much?

Possible (re-)commissioning scenario

- Commission in parallel the drive and the main beam up to a certain stage;
  - DB: Probe all different paths through the recombination complex
  - DB: Probe the production of each of the 24 final pulses
  - MB: Probe the beam line up to the final turn-around with the pilot beam
  - MB: Gradually increase the number of micro-bunches, up to 312
  - MB: With the pilot beam, probe the control on the emittance blow-up
- Before sending the main beam in the main Linac, check and correct the phase
  - MB+DB: With the blown-up pilot beam, try acceleration in first sector
  - MB+DB: Gradually add sectors
  - MB+DB: With all sectors, use pilot beam and nominal emittance
  - MB+DB: Gradually increase the number of micro-bunches, up to 312

How long will it take? (if everything is OK)

50 cycles/second

Drive Beam/ draft

•Second 1: test the 24 recombination paths, one by one, with reduced sub-pulses (1 bunch out of 4). Send beam to farthest turn-around.

• Second 2 : produce a reduced "accelerating" pulse, with bunches from the different recombination paths, and send it to every deceleration sector.

• Second 3 : double the number of bunches inside each accelerating pulse.

• Second 4 – 9 : double (every sec) the number of bunches.

• Second 10 : increase the number of accelerating pulses produced to 24, and send them to every decelerating sector.

Failure scenario

Where has the damned beam gone ?

Failure scenario: general prescriptions to minimize the recovery time

- As long as it is not clear how long the problem will last, if possible try to maintain a “safe beam” running. In this way we can continue to measure things and prevent the accumulations of drifts.

- Depending on where the failure occurs, keep on producing a reduced beam up to the last “dumping” point before the failure.

- Once we know that the intervention will be long, we can consider stopping the beam. In this case, when we restart we will go through all the stages like for the initial commissioning.

Failure scenarios

- CASE 1: Drive beam is partially lost during recombination
  - Abort main beam (ideally)
  - Switch main beam to pilot mode (send it also to main linac?)
  - Switch phase feedback into monitor-only mode
  - Produce sequence of reduced drive beams to try and identify the problem
  - Correct the problem
  - Re-establish full drive beam
  - Re-enable phase feedback
  - Re-establish full main beam

- CASE 2: Beam loss monitors report a signal “too high”
  - Switch to pilot beam
  - Measure and try to understand and correct the problem
  - Gradually increase the number of micro-bunches, to check if problem persists

Where do we restart from after a failure?

It depends

- **On the failure, and on how we know it is fixed**
- **On how long it took to fix it (drifts in the machines)**

Examples

- **Beam Loss monitors give signals above the threshold**
- **A magnet power supply readout returned a wrong value**
- **The phase between the drive beam and the main beam is significantly wrong**

Conclusions: what we need

- Fine control on the "production" of both drive beam and main beam
- Instruments which can measure correctly the reduced beams
- (Re)commissioning procedures, defining the sequences of beams to be sent around
- Post-pulse detailed analysis of the measurements and of the different failure scenarios, to determine what kind of beam we can safely use for next cycle

Thank you