Beam Dump Synchronization

Not a proposition… Just the current status of our thinking

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The problem

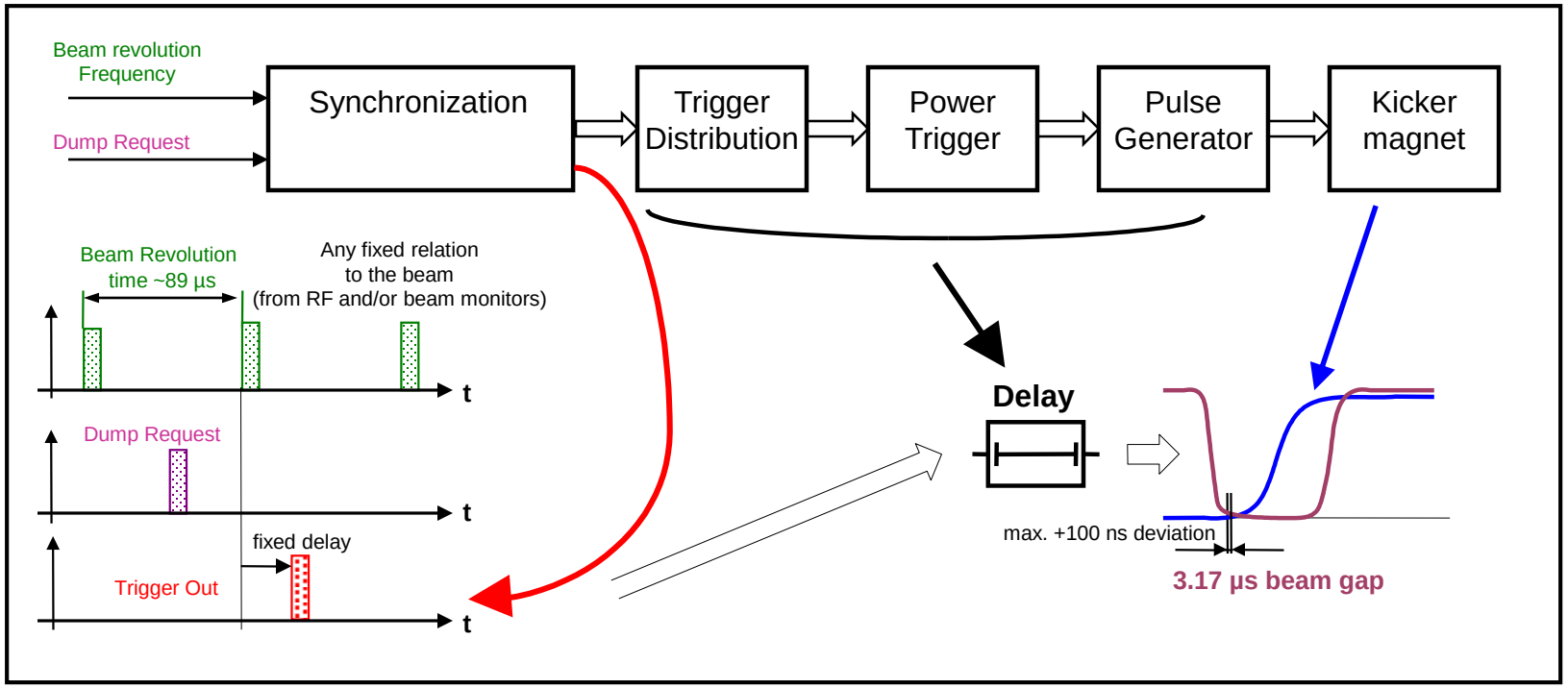
How to guarantee permanently a correct **phase** between the extraction kicker rising edge and the particle free gap ?

- Dump requests are issued spontaneously
  - The dump requests must thus be synchronised such that the requests and the gap coincide at the dump kicker magnets
    - The revolution frequency pulse train with a fixed relative phase offset to the particle free gap must be used for this
- The tolerance for the synchronisation is small (100ns)
  - Any delay or jitter in the transmission of the revolution frequency has severe consequences for the synchronisation of the extraction process (beam loss all around the LHC)
  - The absence of beam in the kicker magnets must be verified at the moment of each revolution frequency pulse (with phase offset)
    - What has to be done if a phase error is detected?
    - What has to be done if the expected particle free gap is filled with beam?

Definition…

- Revolution frequency
  - 11,2 kHz frequency synchronous with the circulating beam
- Particle free gap
  - 3us long (119 bunches) circulating beam particle free gap dedicated for the extraction kicker rising edge
- Beam abort frequency
  - Frequency in phase with the beginning of the particle free gap at the injection and extraction first magnet input. Re-phased revolution frequency.

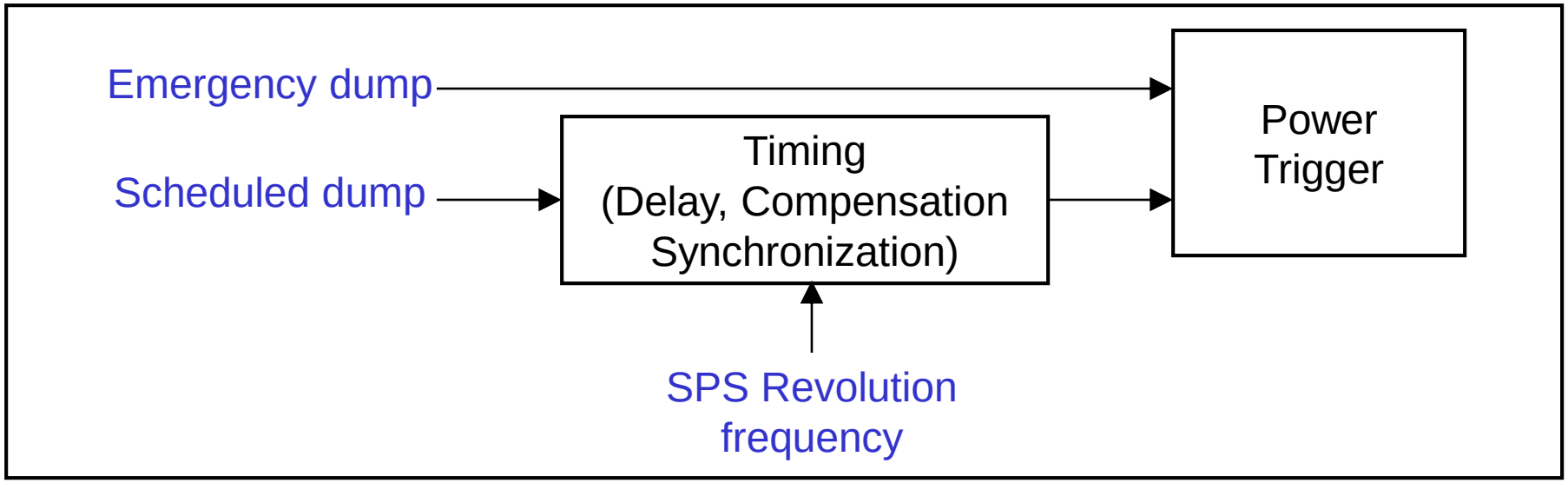
Synchronization



① Synchronizes the rise of the magnetic field of the extraction kicker magnets with the particle free gap

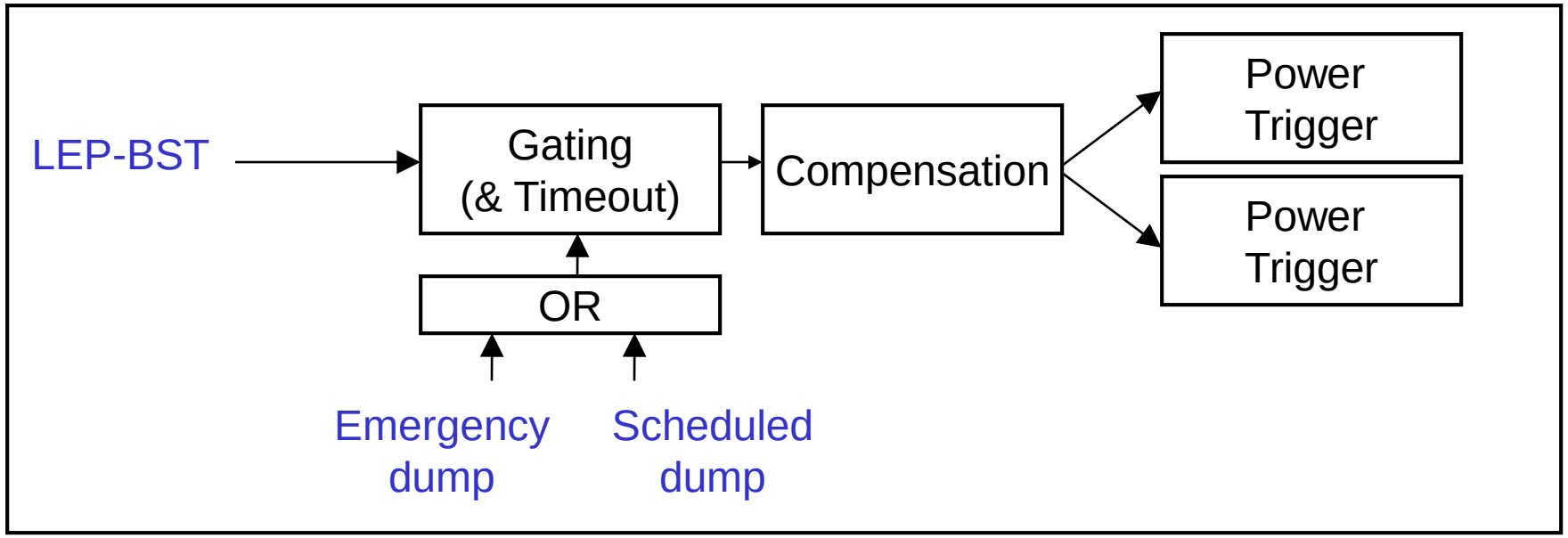
② Continues operation if the beam revolution frequency signal is failing

SPS Beam Dump



- Emergency dump requests are not synchronized with particle free gap (Request → Dump)
- Scheduled dump requests are synchronized with particle free gap through the SPS revolution frequency (43kHz clock)
- Cable and turn-on delays are compensated inside the timing system (20MHz clock)

LEP Beam Dump

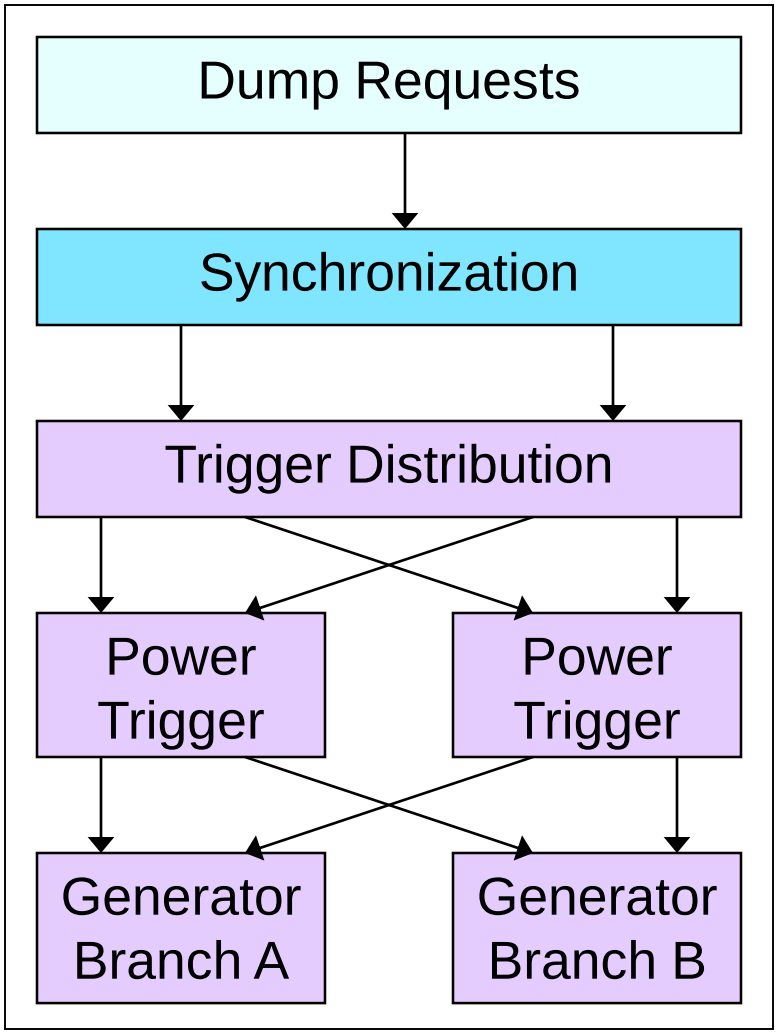


- Emergency and scheduled dump requests are synchronized with particle free gap
- Synchronization mechanism: gating-on of the LEP Beam Synchronous timing signal.
- Cable and turn-on delays are compensated through hardware passive delay lines (cable)

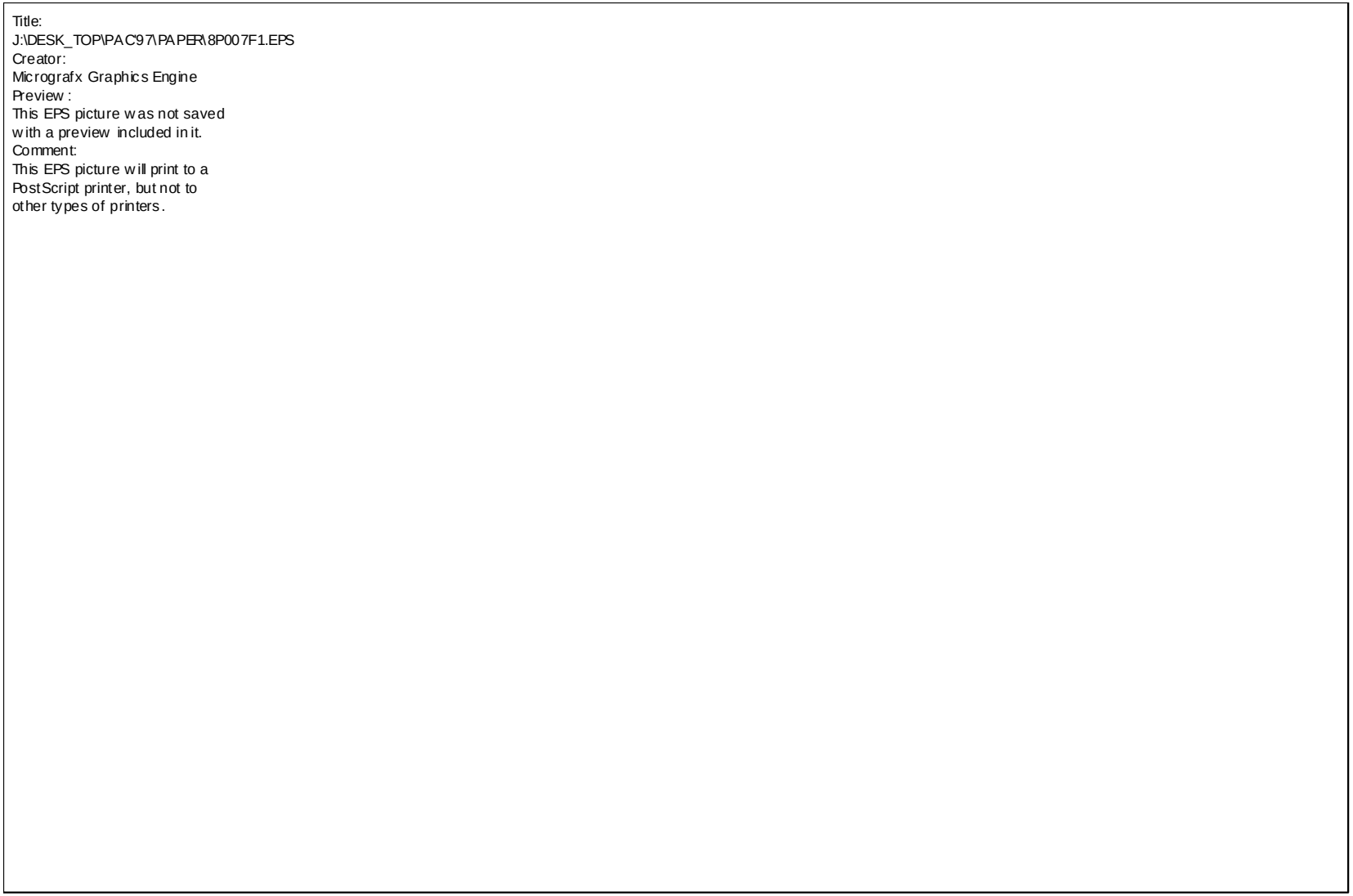
LHC Beam Dump

Three functional levels :

- Three dump request sources
  - Machine protection system, Access system, beam dump system itself (kickers, septa…)
- Synchronization
  - Synchronize extraction kicker rising edge in phase with particle free gap
- Trigger distribution
  - Fan-out and distribute trigger request to the power trigger units
  - Match cable, electronic and turn-on delays with time of flight of the beam



MKD Triggering Architecture



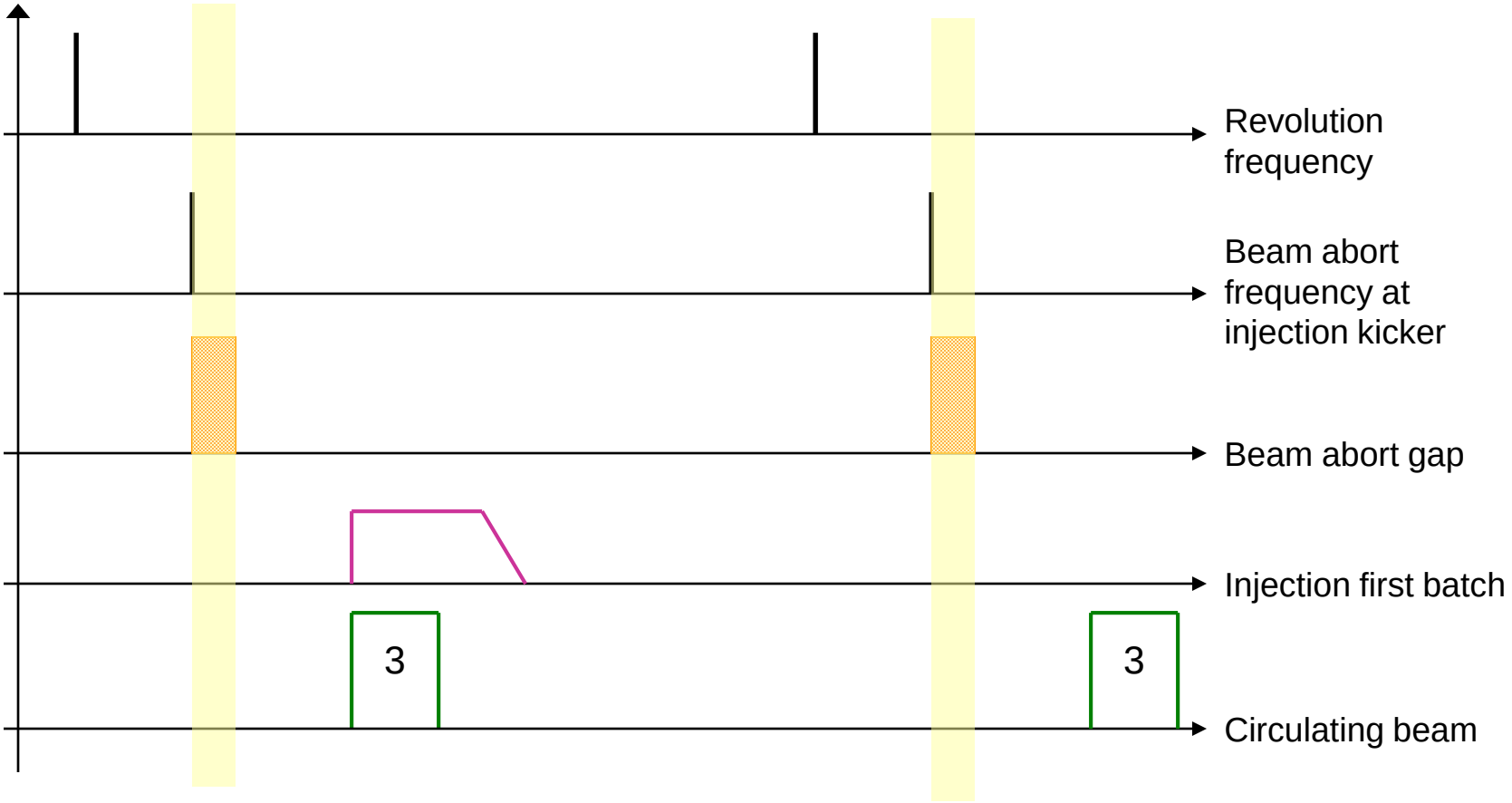
Possible Errors

- Bad phase relation between particle free gap and revolution frequency **(Type 1)**
  - Particle free gap is not correctly placed with respect to the revolution frequency
  - Offset in the revolution frequency
  - Modification of filling procedure
  - ….
- Particle free gap is filled with a wrong injection **(Type 2)**
  - First injection
  - Last injection
  - Any injection

Operation Modes

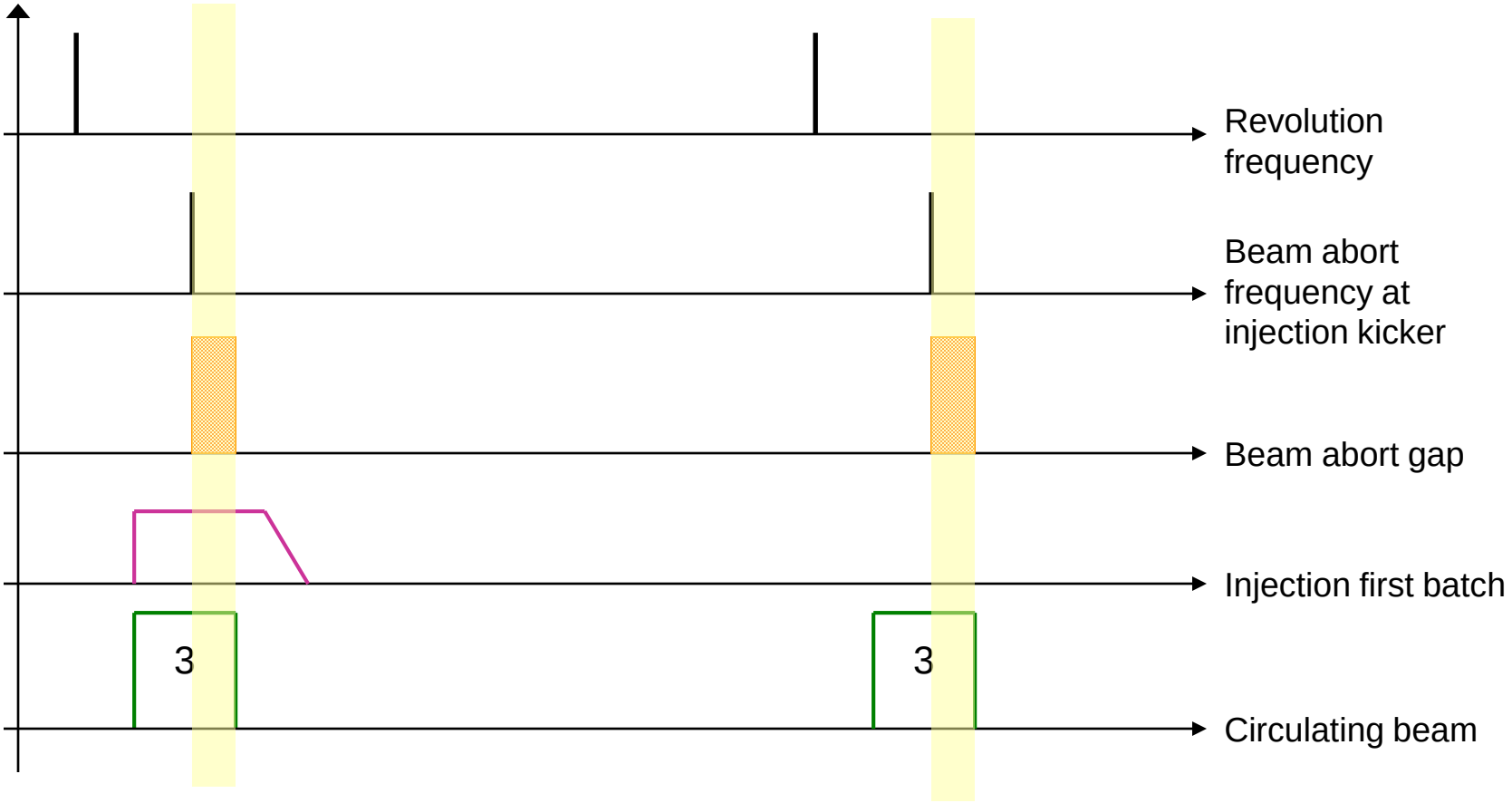
- Operation modes
  - Filling
  - Acceleration, Physics
- Major possible errors occur during filling
  - Synchronization has to be **performed** / **checked** / **locked** during this period
- Once acceleration has started, synchronization has to be **kept** and **controlled**
- All RF frequencies will be re-synchronized before the start of the filling.
  - Initial conditions are, a priori, well known and stable

Injection Error – Case 1



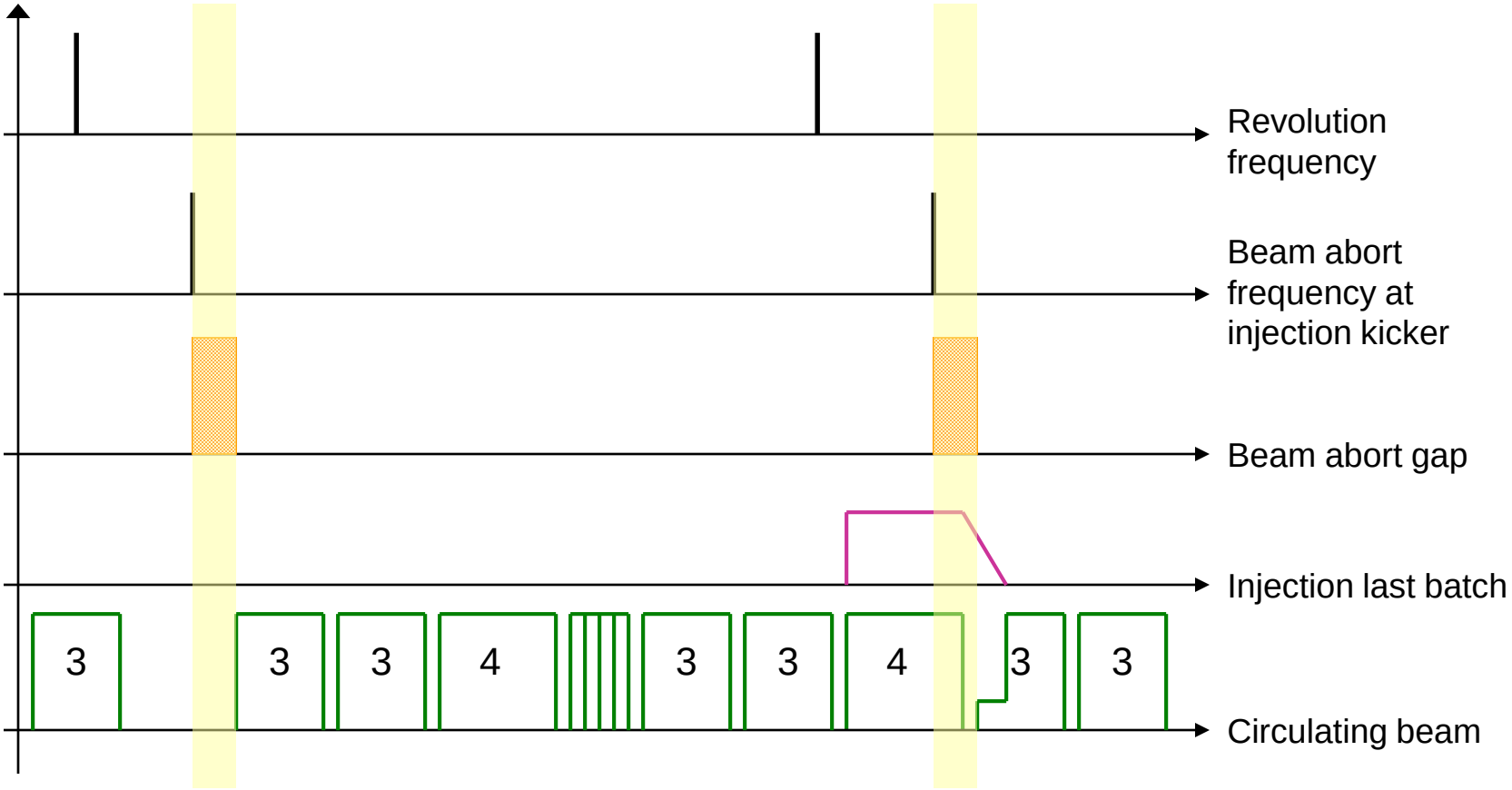
Injection first batch: Type 1 error

Injection Error – Case 2



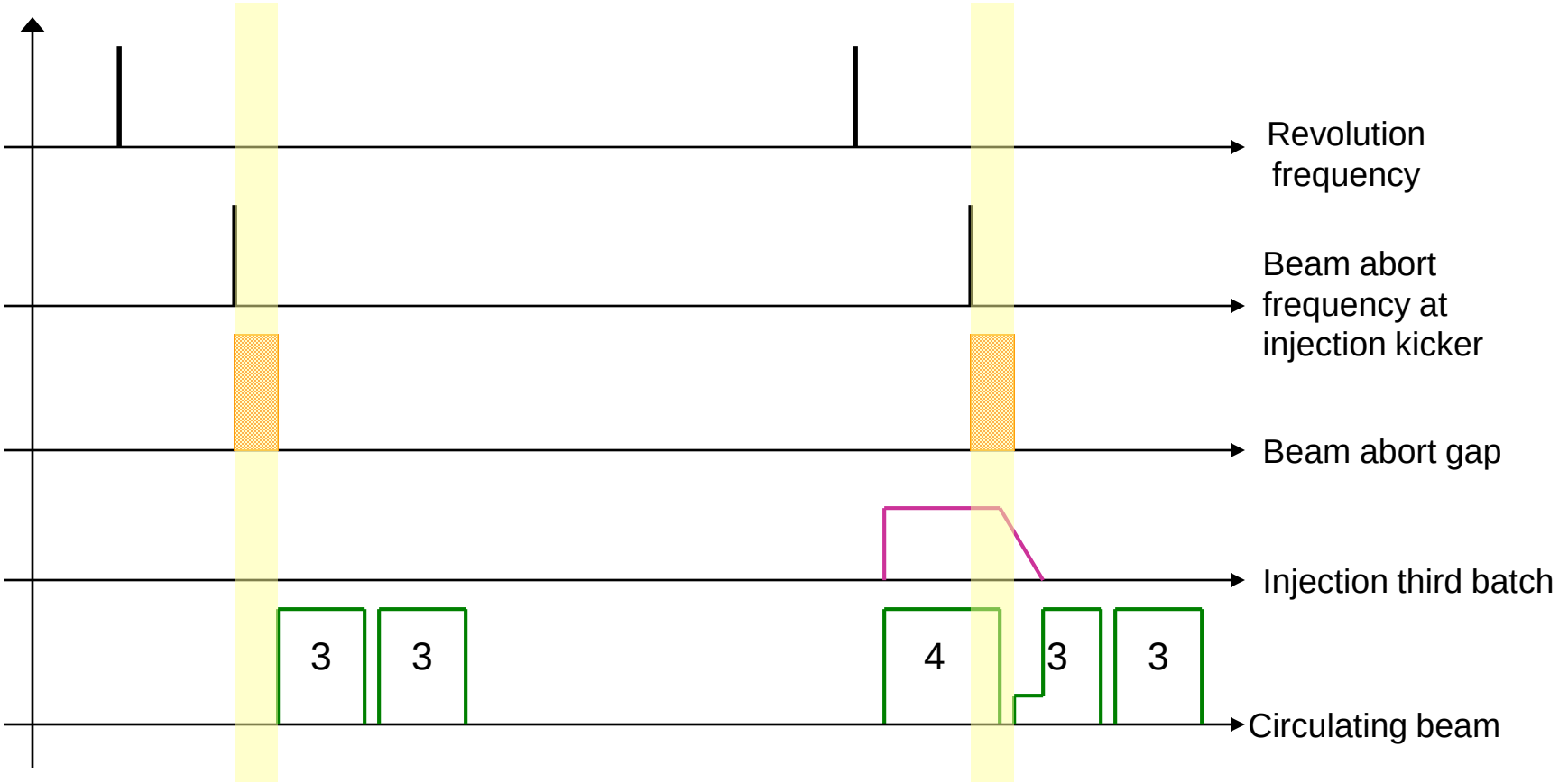
Injection first batch: Type 1 & Type 2 errors

Injection Error – Case 3



Injection last batch: Type 2 error

Injection Error – Case 4



Injection first batch n: Type 2 error

Operation Mode (cont.)

Filling

1. Filling particle free gap with the first injection
   - Can it be avoided by gating-off injection kicker ? →
   - Pilot beam (see “scenario II”) can be used to check the correct synchronization before injecting an intense batch
2. Filling the particle free gap with a wrong 4 batches injection
   - Still place to re-phase the beam abort frequency
   - Beam can not be dumped with injection kicker (falling edge)
   - Re-phase beam abort frequency with another empty gap ???
3. Filling of the particle free gap with the last injection
   - Very bad situation: particle free gap will be filled & first circulating batch will be touched
   - Beam has to be dumped with un-correct synchronization

Beam Injection Inhibition at kicker level

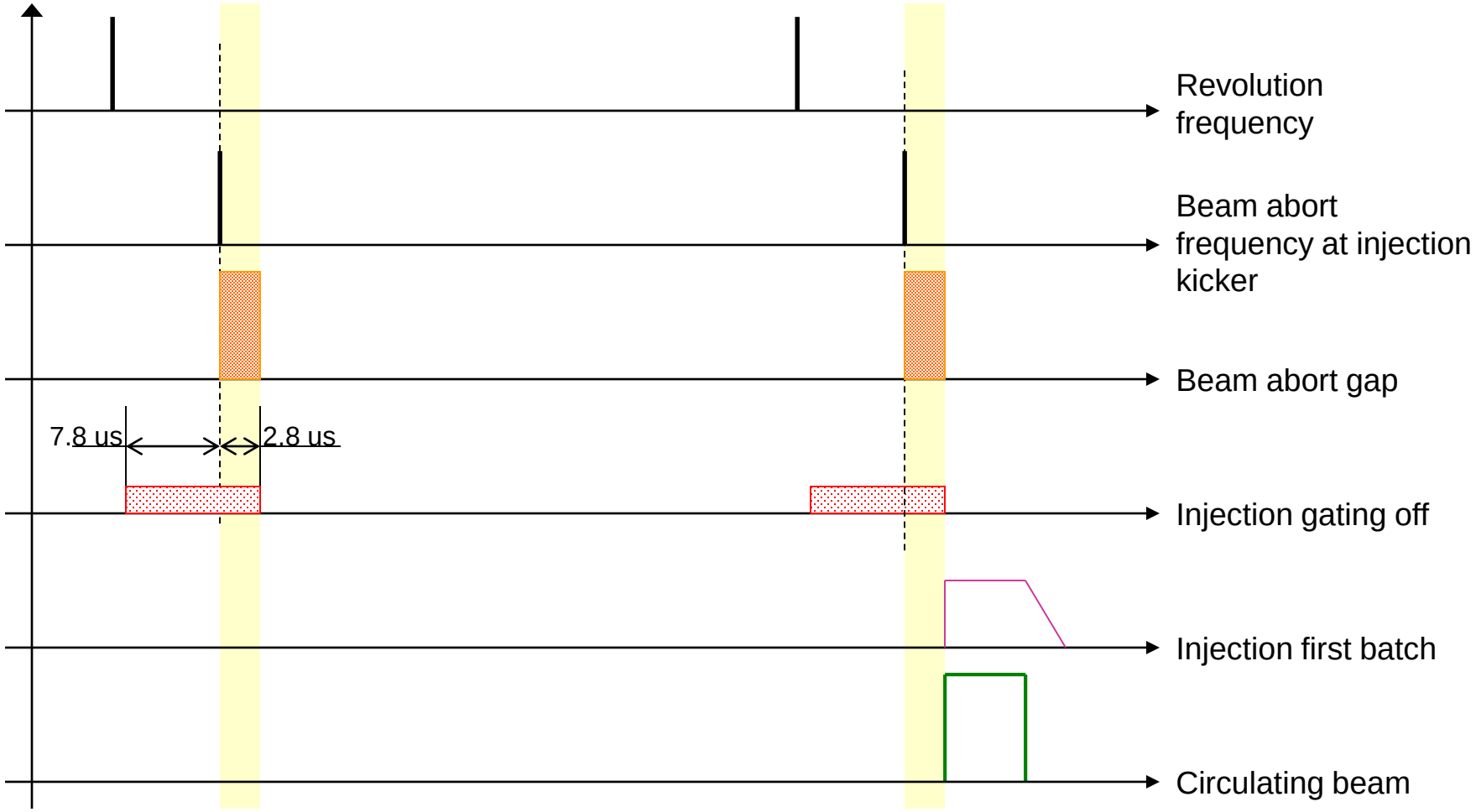
- Injection kicker (MKI)
  - Adjustable kick length: up to 7.8us
  - Falling edge: 2.8us
  - No clipper switch… It is not possible to stop rapidly (~100ns) the injection kick
- Injection is triggered by the injection prepulse received from the LHC-RF
- Prepulse is bind to the SPS/LHC common frequency but the final position in the LHC depends of the selected SPS extraction turn

Beam Injection Inhibition at kicker level

- Authorization to inject can be gated-off → injection prepulse inhibition
- Due to the 3.3.4… injection pattern different inhibition durations exist
- Inhibition durations
  - 3 batches injection: 5.8us before and 2.8us after beam abort frequency → **8.6us**
  - 4 batches injection: 7.8us before and 2.8us after beam abort frequency → **10.6us**
- Injection inhibition can be set to 10.6us (4 batches injection) up to the last injection where it has to be reduced to 8.6us

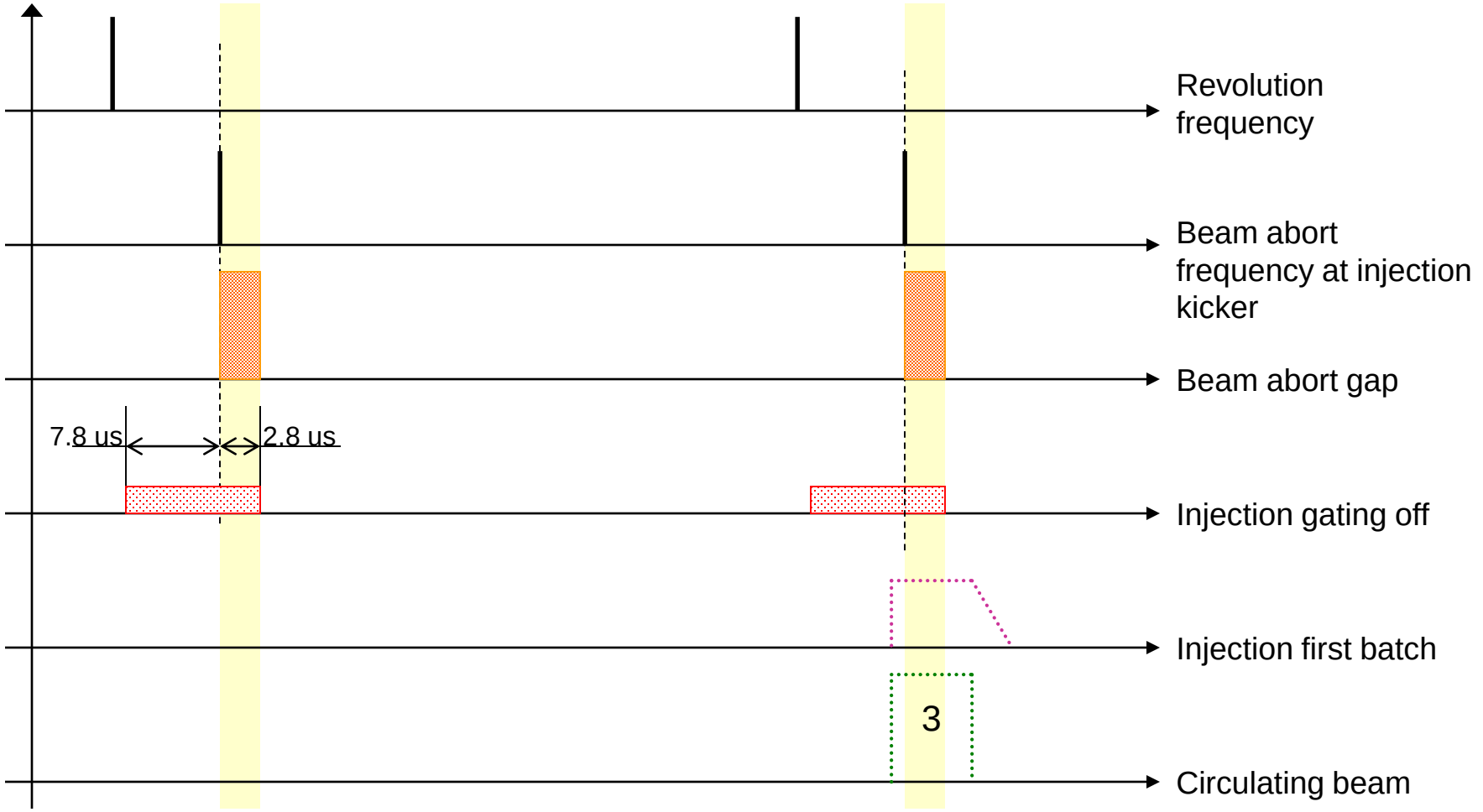
  → LHC injection inhibition is SPS elementary cycle dependent

Injection Inhibition – Case 1



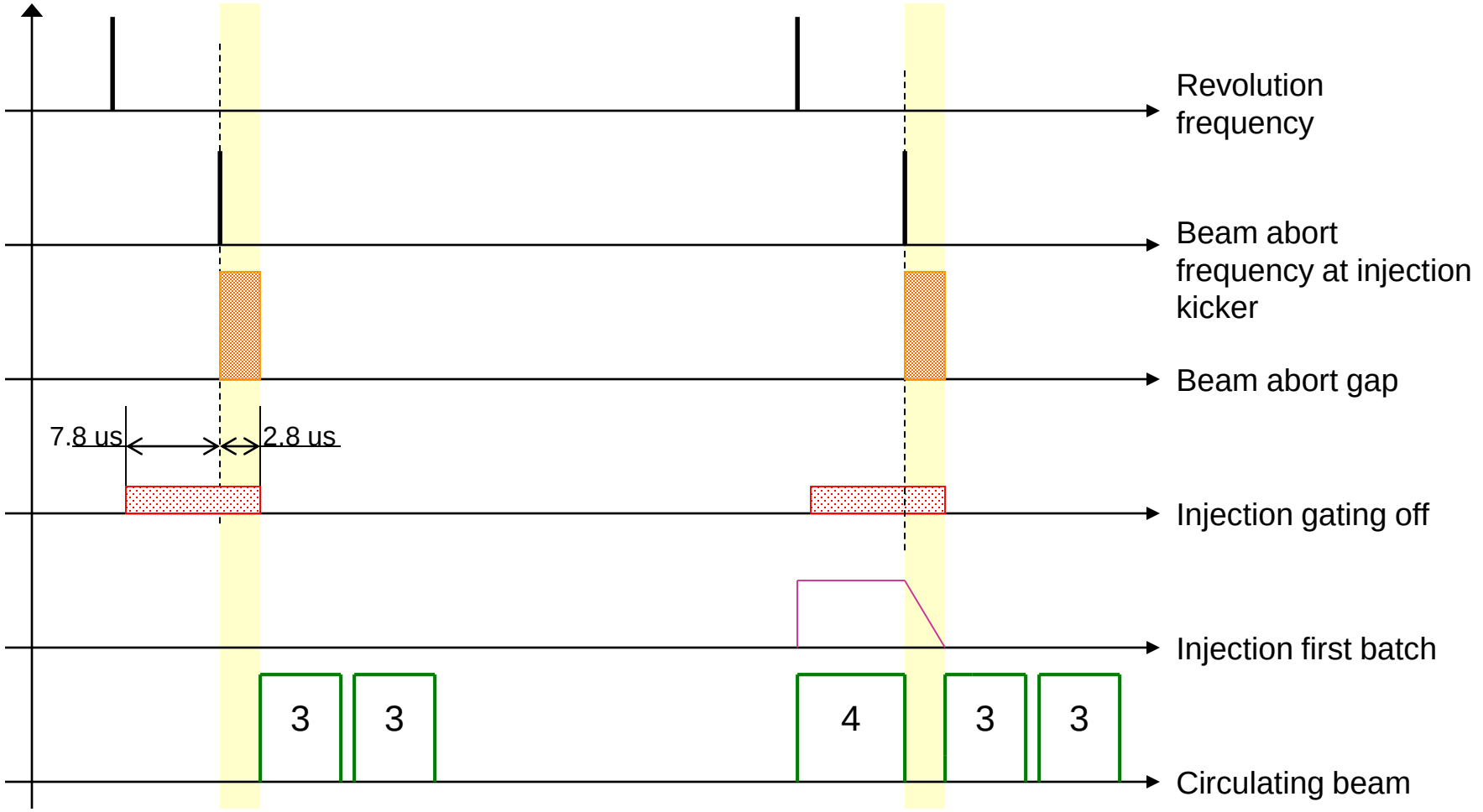
Injection first batch, prepulse correctly synchronized → beam correctly injected

Injection Inhibition – Case 2



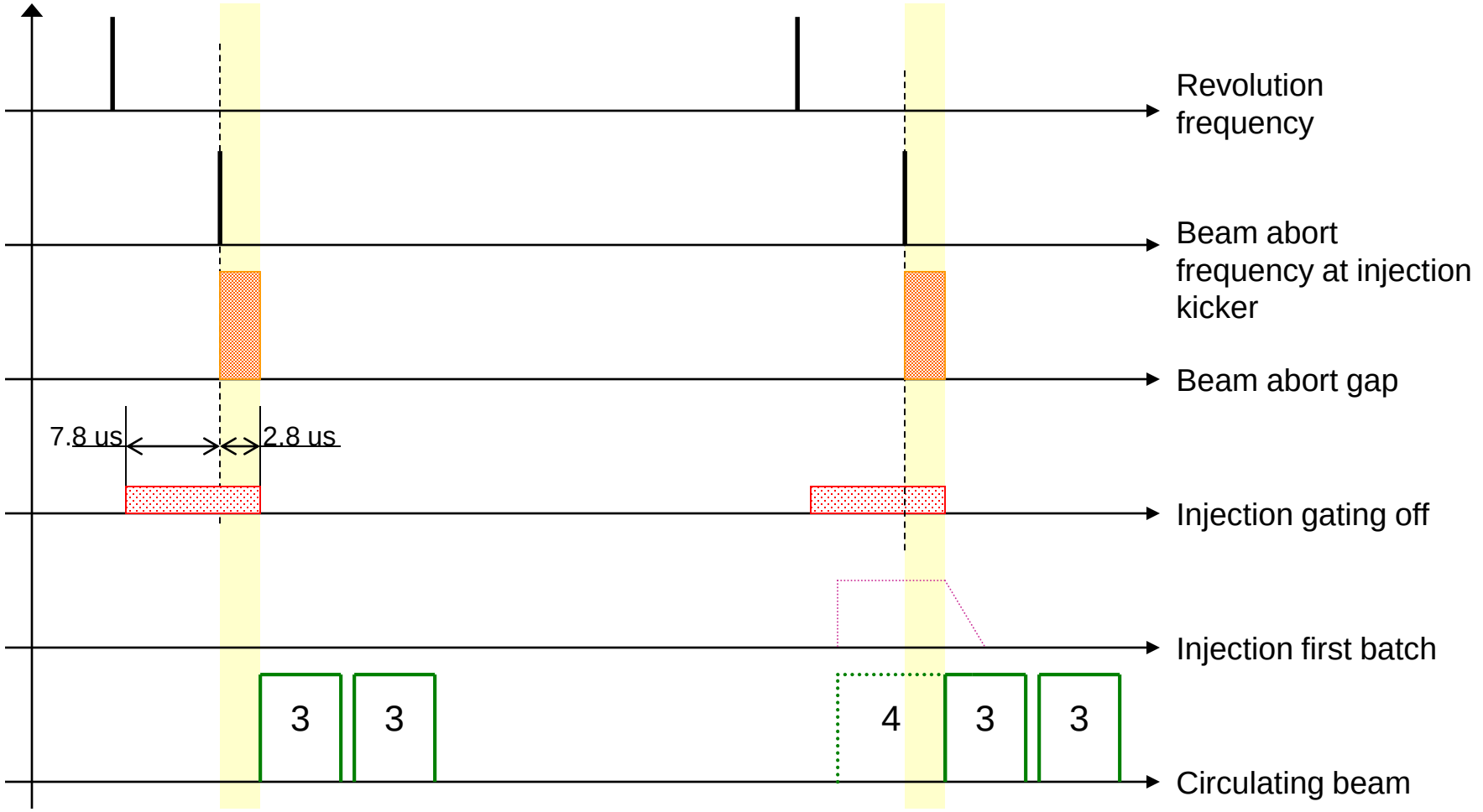
Injection first batch, prepulse not correctly synchronized (inside inhibit windows)
→ injection inhibited and beam on TDI

Injection Inhibition – Case 3



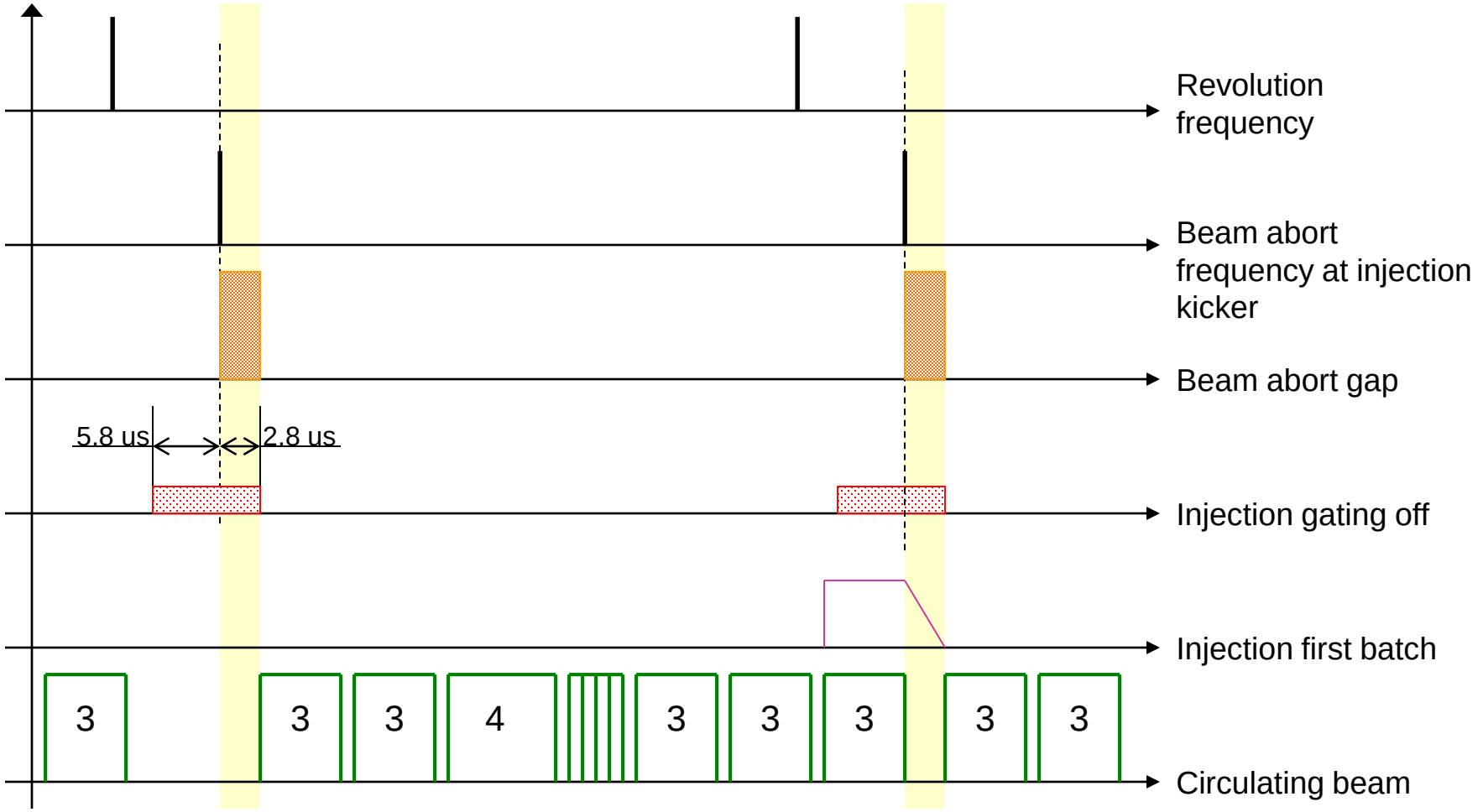
Injection third batch, prepulse not-correctly synchronized w.r.t filling pattern but outside the inhibition windows → beam injected at the wrong position, but particle free gap is still available

Injection Inhibition – Case 4



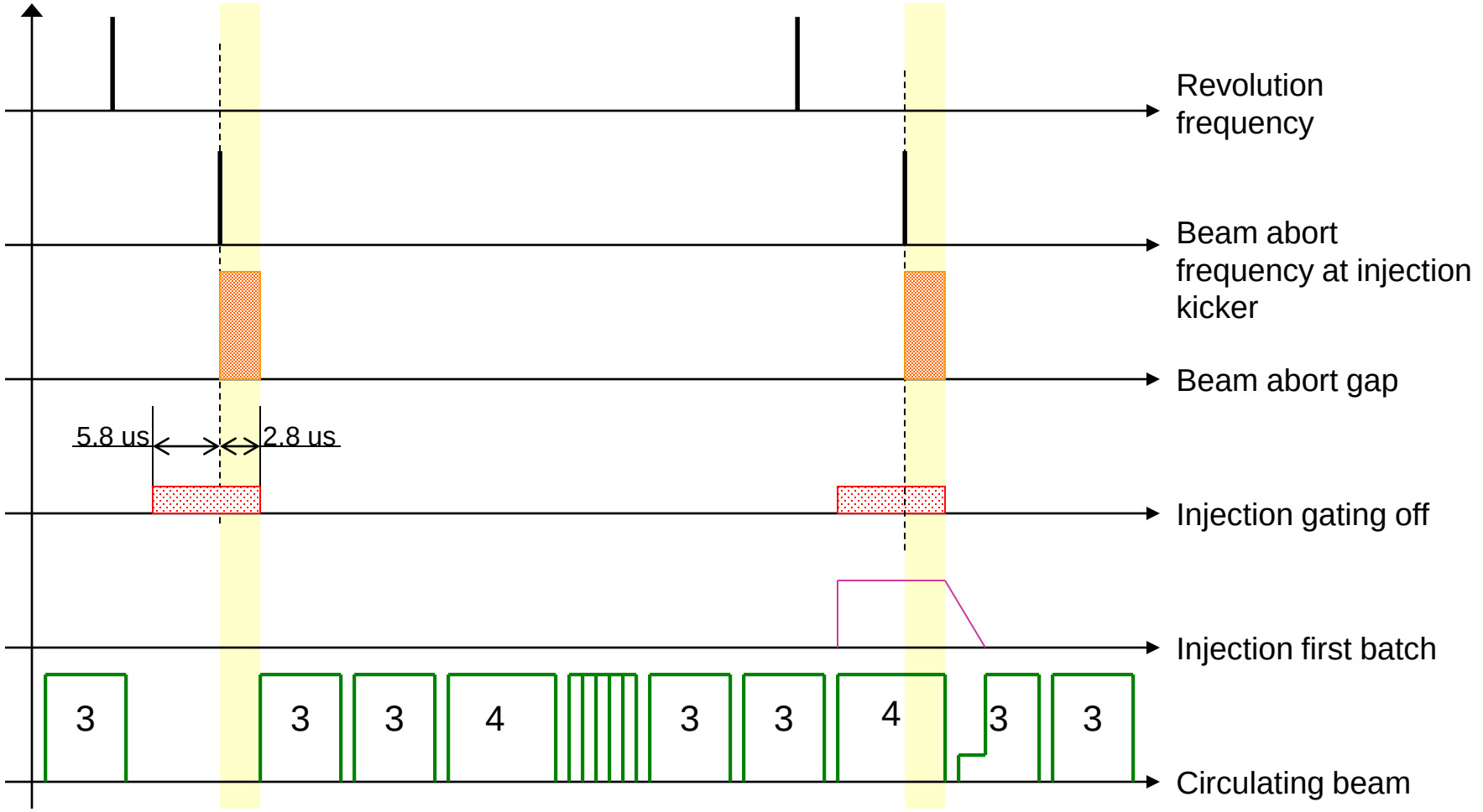
Injection third batch, prepulse not-correctly synchronized w.r.t filling pattern but inside the inhibition windows → injection inhibited and beam on TDI

Injection Inhibition – Case 5



Injection last batch, prepulse correctly synchronized w.r.t filling pattern, injection inhibition windows reduced to 8.6us and injection kick length reduced to 6us → beam injected and availability of particle free gap is kept

Injection Inhibition – Case 6



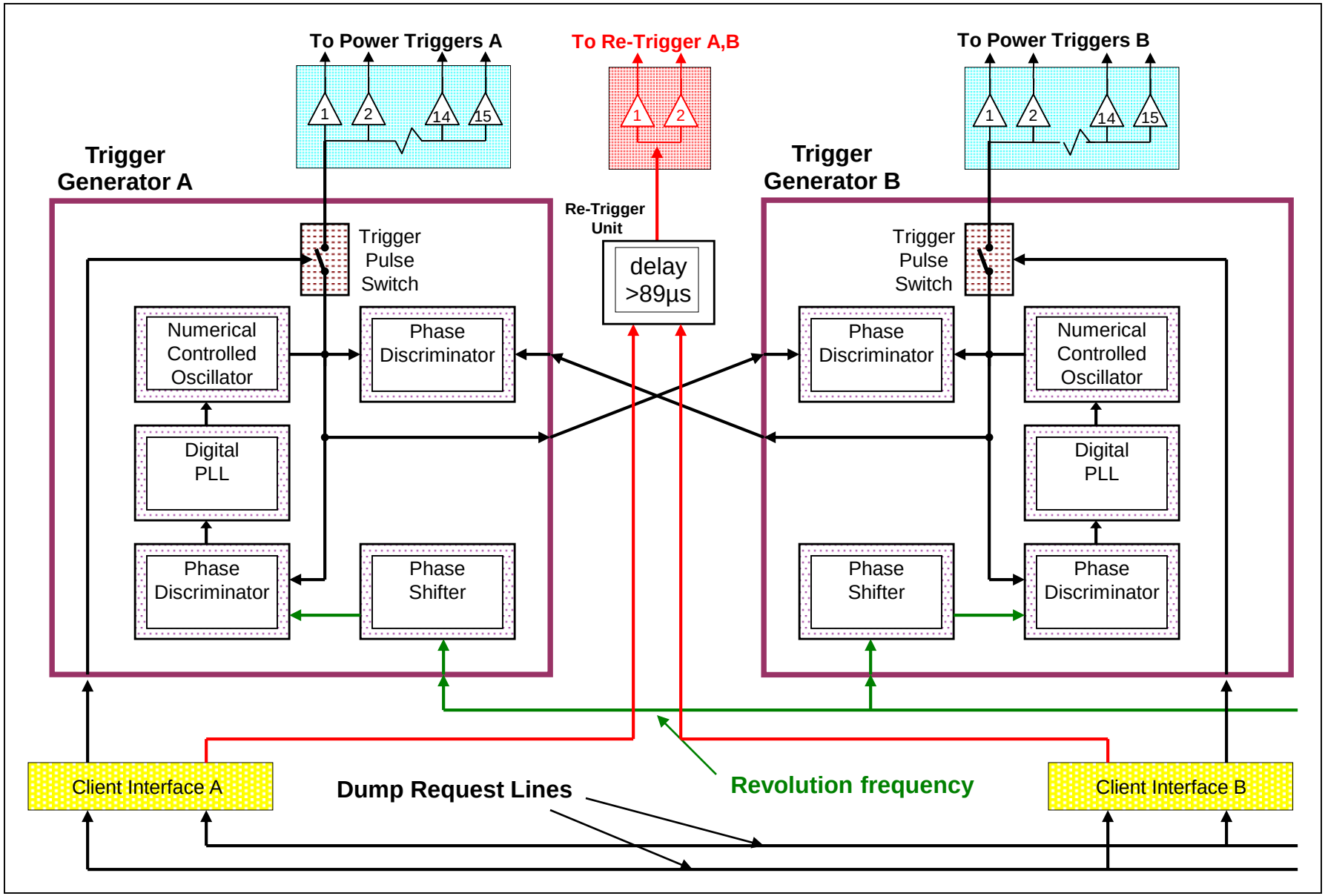
Injection last batch, prepulse correctly synchronized w.r.t filling pattern, injection inhibition windows reduced to 8.6us but, injection kick length maintained at 7.8us and 4 batches beam → beam injected, no particle free gap anymore, beam losses

Operation Mode (cont.)

Acceleration	Physics

1. Beam abort frequency is locked with the correct phase w.r.t the beam before start of acceleration
2. Synchronization between frequencies (beam abort and revolution) is maintained & guaranteed through a digital PLL redundant logic system →
   - Revolution frequency is continuously measured
   - Generation of the beam abort frequency signal is guaranteed if the revolution frequency is failing
   - Any loss or jump of the revolution frequency will issue a synchronous dump request.
3. Any deviation of the beam abort frequency with respect of the particle free gap will be detected and a synchronous dump request will be issued

Synchronization



Status - Signals availability

- Revolution frequency
  - Direct connections requested between LHC-RF Point 4 & LHC-Beam dump Point 6
  - No request for a direct connection to injection kicker in LHC Point 2 and LHC Point 8 has been made up to now, but TTC system will be available
- Circulating beam measurements
  - Beam pick-ups (BCT or BPM) requested in Point 6 (ring 1 & ring 2), in Point 2 (ring 1) & in Point 8 (ring2)

Status - Prototype

- Prototype for a synchronization and trigger system has been studied, developed and tested in SL/BT
  - Martin RAMPL & Johan DIEPERINK
  - Digital PLL and Numerical Controlled Oscillator (NCO) based on a 50MHz base clock appears to be stable enough to guarantee a correct synchronization for at least 5 turns without reception of the revolution frequency

Conclusion / Remark

- Technical solutions exist to guarantee a correct synchronization during acceleration and physics if initial condition are fulfilled at the end of injection
- Particle free gap filling during acceleration and physics has not to be taken into account by the dump synchronization system
- Tracking the particle free gap during injection appears to be a more difficult challenge. Injection kicker can be used to inhibit wrong injection pattern, but can not cover all the possible errors (…mainly because it don’t have a clipper switch)

Conclusion / Remark

- Who is the guardian of the particle free gap during injection
  - RF: generates the revolution frequency and the injection prepulses
  - BT: can inhibit injection if wrong prepulses are received with respect to the received revolution frequency
  - Both… (BT & RF)