LHC start-up
Season II

Cogging

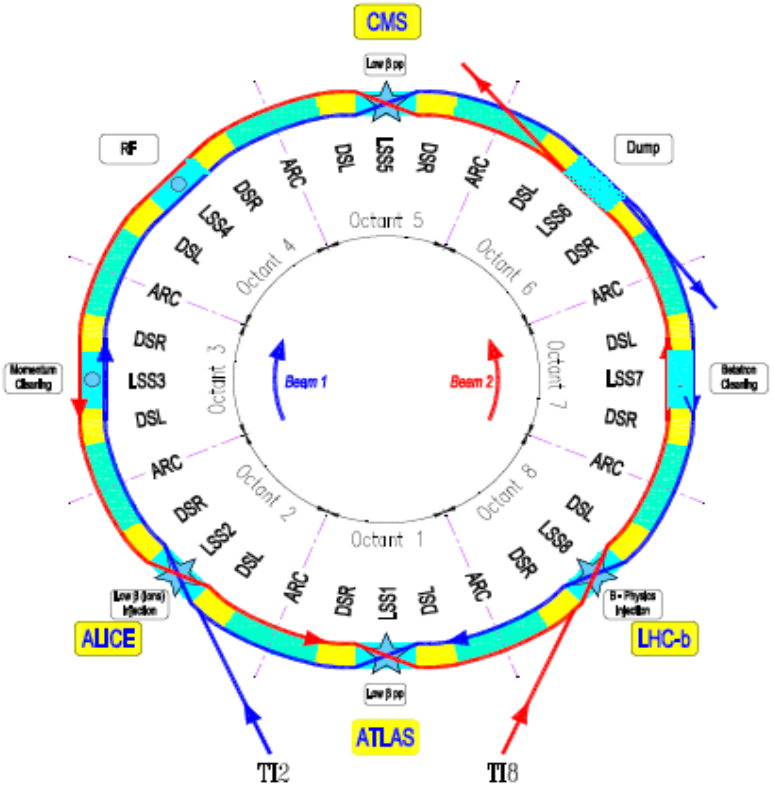
P. Baudrenghien BE/RF

Numerology

- For each ring:
  - The 400 MHz RF defines 35640 buckets, spaced by one RF period, and numbered from 1 to 35640
  - Bucket 1 is the first bucket after the 3 μs long abort gap (defined from bucket 34442 to 35640)
  - Bunches in bucket 1 of the two rings collide in IP1 (and IP5)

Bunch Numbering

- **Convention:** bunches in bucket 1 of the two rings collide in IP1
- **FAQ**
  - Q: Bunches in bucket 1 of both rings meet in IP1 (and IP5). Can this be changed ?
  - A: No…but if we want to have single bunch collisions in another IP we should **inject in a different bucket of ring 2**. For example for collision in IP2: Inject pilot in bucket 1 ring 1, and pilot in bucket 1 + 35640/4 = 8911 ring 2 .



By delaying the ring 2 injection bucket by ¼ turn we displace the collision point by 1 octant

Revolution Frequency or Orbit

- For each ring:
  - At a **given place** in the machine, and at a **given beam energy** (that is fixed RF frequency) the **delay between the pulse and the passage of a bunch in bucket 1 will be fixed from run to run**
  - Drift during the ramp: during the acceleration ramp due to the difference between signal transmission delay and the beam time of flight. For protons we have 6.5 ps/km, for ions 41.25 ps/km. Hopefully not a problem.

Bunch Clock

- For each ring:
  - At a given place in the machine, and at a **given beam energy** (RF frequency) the **delay between the edge of the Bunch Clock and the passage of a bunch will be fixed** from run to run
  - Drift during the ramp: At a given place, but varying energy (frequency) the edge will drift with respect to the bunch. (Same figures as for the Revolution Frequency pulses.)

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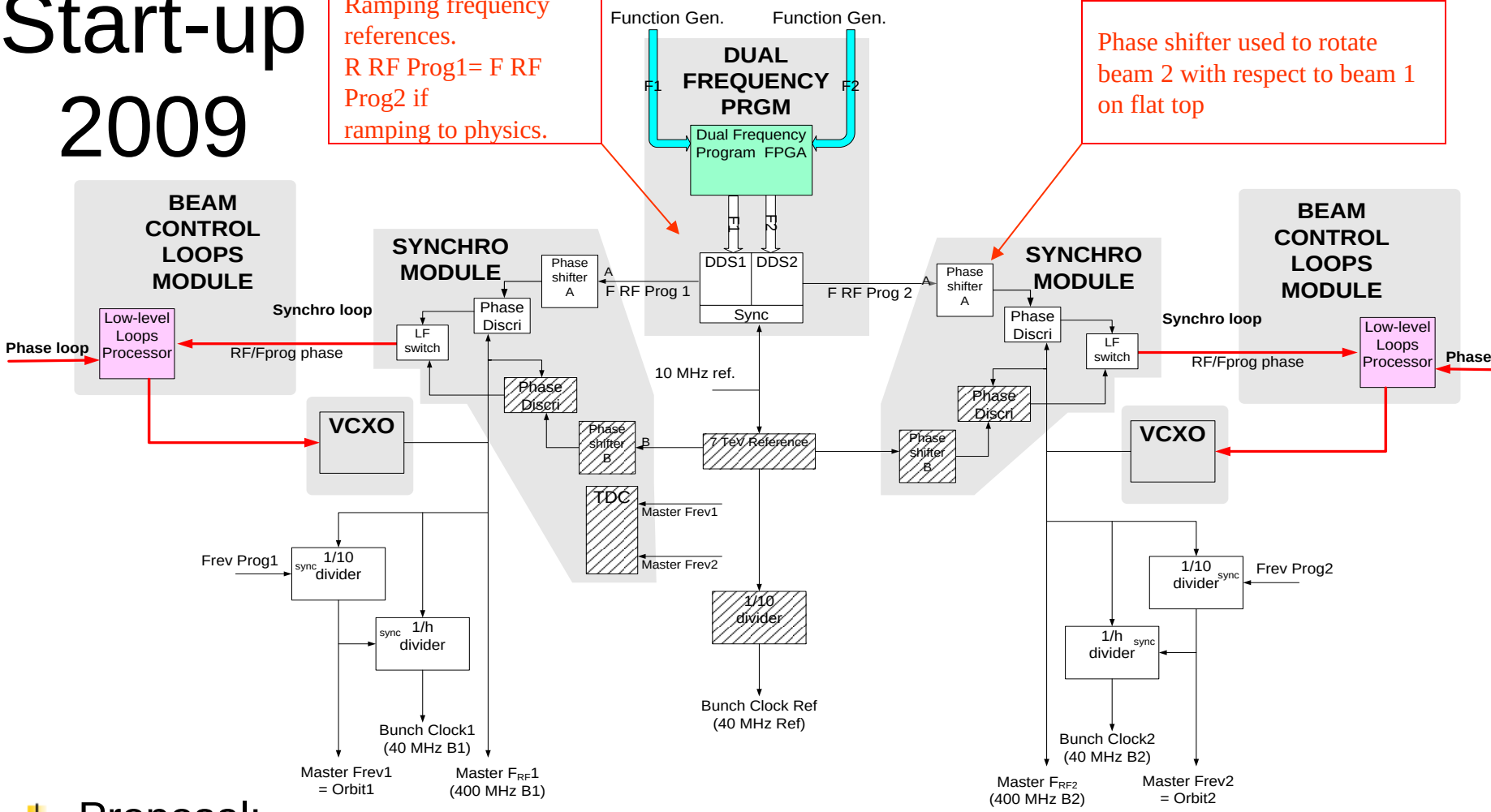
Ramping frequency references.
R RF Prog1= F RF Prog2 if
ramping to physics.

Phase shifter used to rotate beam 2 with respect to beam 1 on flat top



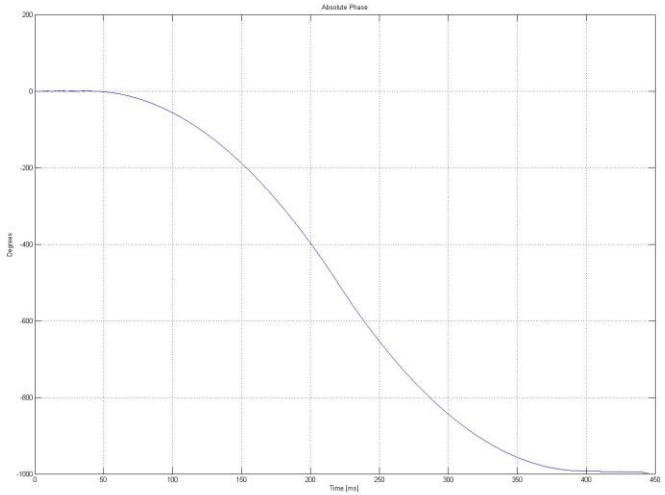
- Proposal:
  - Use only BC1 and BC2
  - **NO rephasing to BCref**
- Before physics, fine phasing of BC2 to get collision in detectors

Cogging strategy (1)

- Step1: Coarse adjust position of bucket 1, beam 2 so that buckets 1 collide in IP1/IP5
  - Done by adjusting FrevProg2 delay BEFORE injection
  - Transparent to the experiments (effect during the Sequencer RF Resync)
  - Need coarse measurement from experiments. Observe time difference in beam 1-2 passing by IP1 or IP5 (or other IPs). Calls for ~ 2.5 ns resolution

Cogging strategy (2)

- Step2: **Fine adjust**. On flat top, before physics, rotate beam 2 so that buckets 1 collide in the middle of the detectors IP1/IP5 (or other)
  - Done by Phase Shifting beam 2 (and BC2) w.r.to beam 1 (see page 6).
  - Seen by experiments, but very smooth. NO DRIFT of bunch with respect to corresponding BC during rotation
  - Need fine measurement from the experiments IP1 /IP5 (or other). ~ 100 ps resolution



Parabolic-Linear-Parabolic phase step. Max 25 ns/second. Corresponds to 10 Hz @ 400 MHz (-0.1 mm or $\Delta p/p = -8 \times 10\text{-}5$). No limit on the amplitude: Rephasing ¼ turn (= 8910 buckets) would take 891 seconds (~ 15 min)! Expect less than 2.5 ns.

Additional material if needed

Numerology (2)

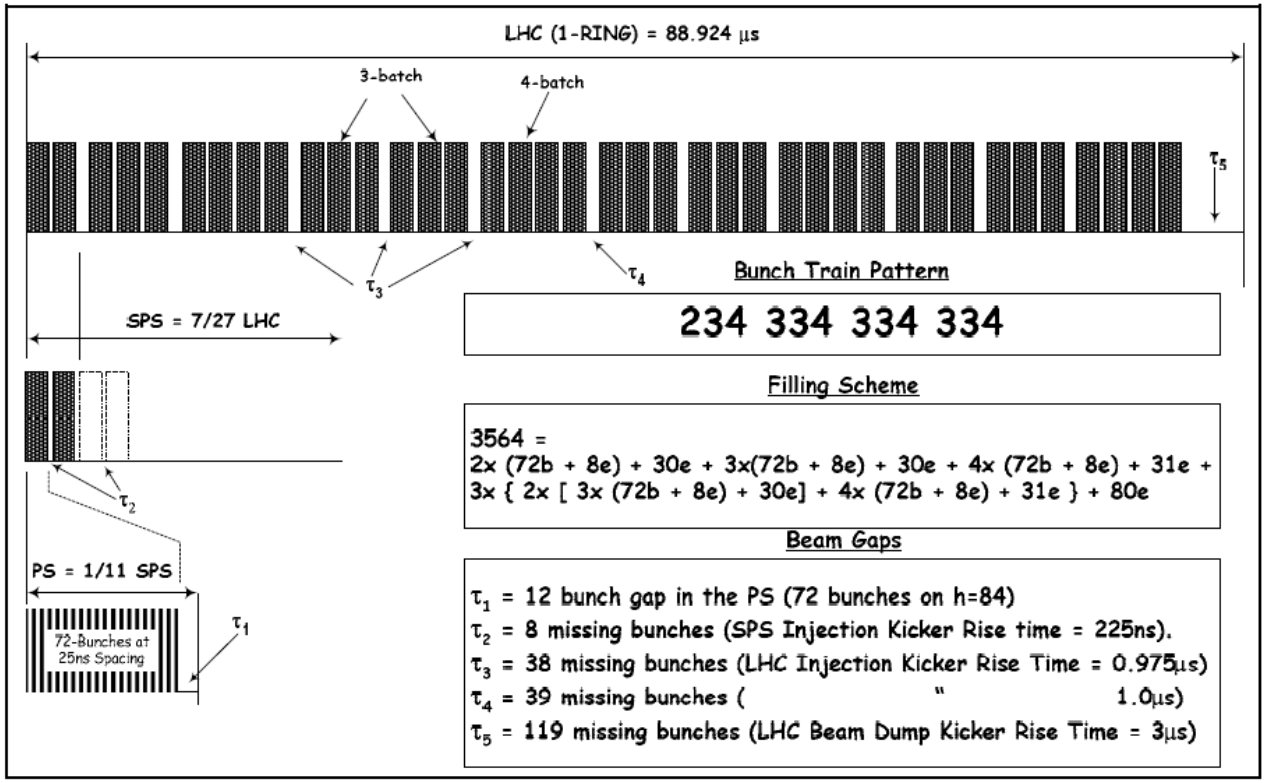


Figure 1: Schematic of the Bunch Disposition around an LHC Ring for the 25ns Filling Scheme (2808 Bunches/Ring).

- For 25ns operation the bunches will occupy buckets 1, 11, 21 etc. with gaps occurring every PS or SPS kicker gap. (see Figure 1 above reproduced from *LHC-OP-ES-0003 rev 1.0*).

Numerology (3)

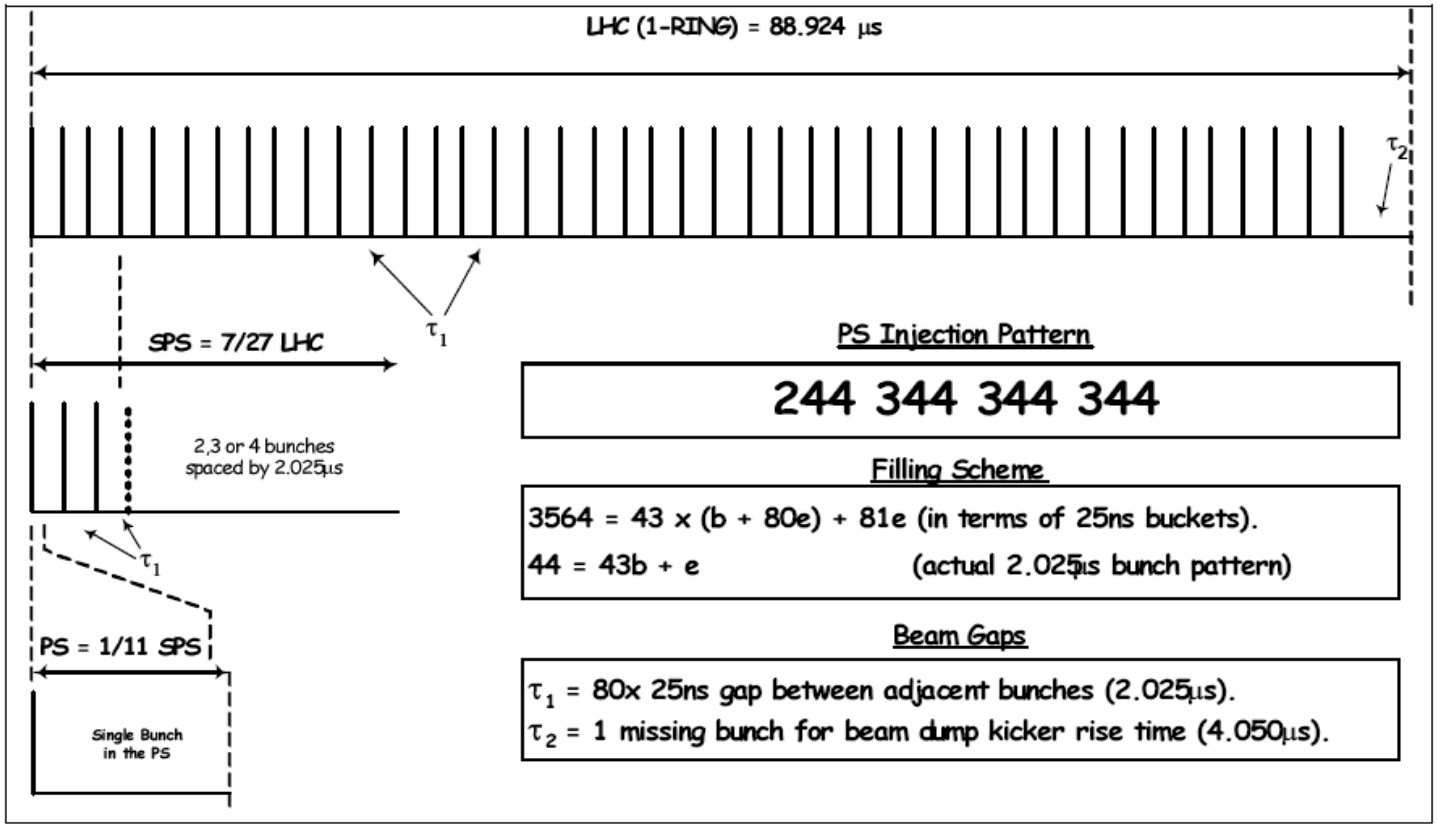
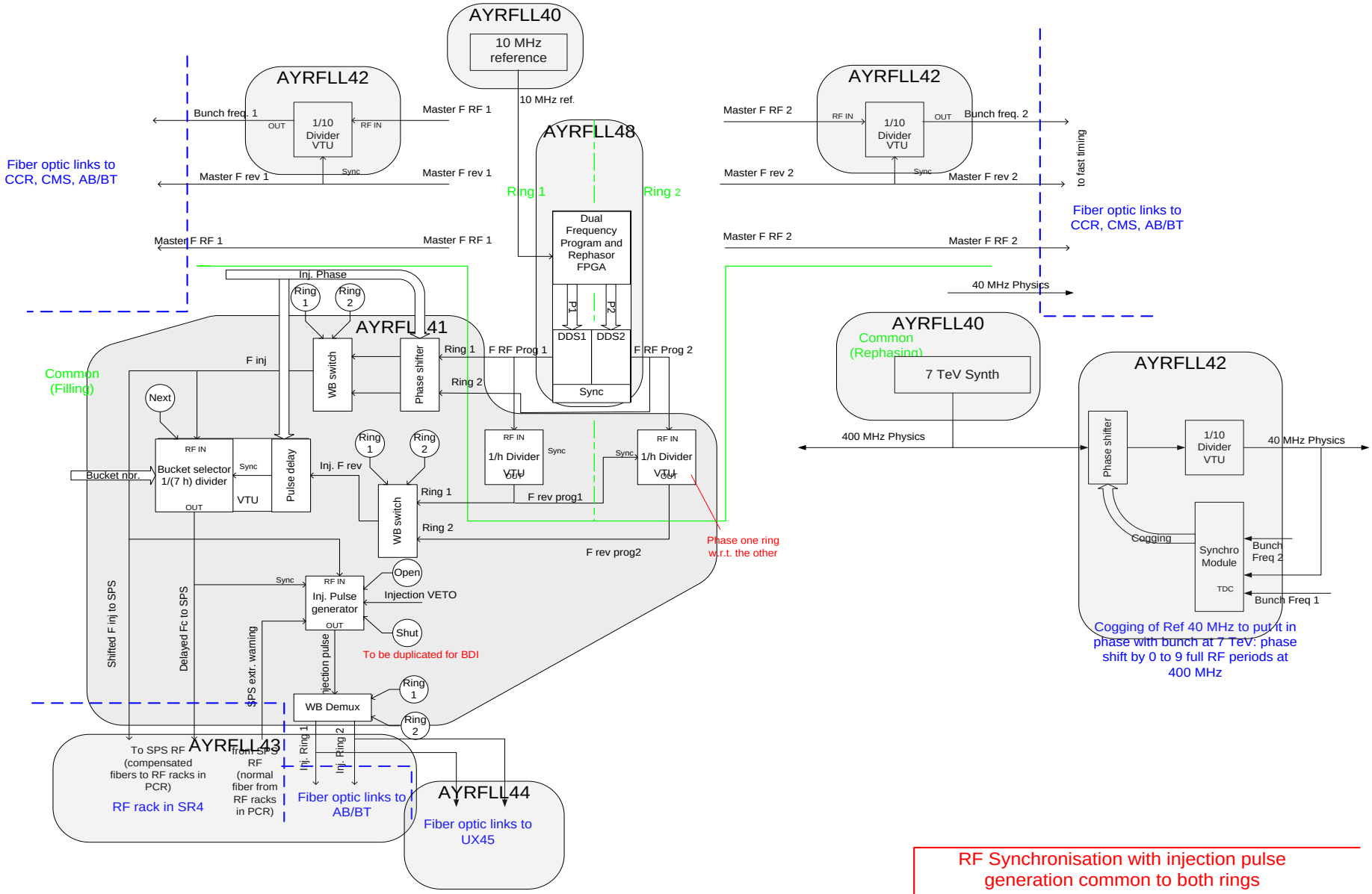


Figure 3: Schematic of the Bunch Disposition for the 43-Bunch Filling Scheme (43 Bunches/Ring).

- For 43 bunch operation the bunches will occupy buckets 1, 811, 1621, etc. (see Figure 3 above reproduced from *LHC-OP-ES-0003 rev 1.0*).


AYRFLL40
10 MHz reference
10 MHz ref.
AYRFLL42
Bunch freq. 1
OUT
1/10 Divider VTU
RF IN
Sync
Master F RF 1
Master F rev 1
Fiber optic links to CCR, CMS, AB/BT
AYRFLL48
Ring 1
Ring 2
Dual Frequency Program and Rephasor FPGA
P1
P2
DDS1
DDS2
Sync
Master F RF 1
Inj. Phase
AYRFL 41
Common (Filling)
F inj
WB switch
Phase shifter
F RF Prog 1
F RF Prog 2
Next
Bucket nbr.
RF IN
Bucket selector 1/(7 h) divider
VTU
Pulse delay
Inj. F rev
1/h Divider VTU
F rev prog1
F rev prog2
Phase one ring w.r.t. the other
Open
Injection VETO
Inj. Pulse generator
Shut
To be duplicated for BDI
Shifted F inj to SPS
Delayed Fc to SPS
SPS extr. warning
Injection pulse
WB Demux
AYRFLL43
To SPS RF (compensated fibers to RF racks in PCR)
RF rack in SR4
From SPS RF (normal fiber from RF racks in PCR)
Inj. Ring 1
Inj. Ring 2
Fiber optic links to AB/BT
AYRFLL44
Fiber optic links to UX45
Master F RF 2
Bunch freq. 2
to fast timing
Fiber optic links to CCR, CMS, AB/BT
40 MHz Physics
AYRFLL40
Common (Rephasing)
7 TeV Synth
400 MHz Physics
AYRFLL42
Phase shifter
1/10 Divider VTU
Cogging
Synchro Module
TDC
Bunch Freq 2
Bunch Freq 1
Cogging of Ref 40 MHz to put it in phase with bunch at 7 TeV: phase shift by 0 to 9 full RF periods at 400 MHz
RF Synchronisation with injection pulse generation common to both rings
Diagnostics signals:
signal
Technology:
DSP
CPLD (40 or 80 MHz)
Analog RF