Beam types and RF gymnastics in the PS

The CERN Proton Synchrotron (PS), can deliver a large variety of different beam types to several users in quick succession. Charged particles, mostly protons (p^+), but also ions (Pb^{54+} in particular), are accelerated in bunches, driven by radio frequency electromagnetic fields. The machine runs in cycles, each lasting 1200ms. For some operations, several 1200ms periods can be combined into a single cycle. Particle bunches are generally injected at 170ms after the beginning of a cycle.

Fig. 1: The PS accelerator complex

Positive particles run clockwise in the PS. Protons are injected from the Booster, while lead ions come from LEIR without passing through the Booster. The detailed structure of each beam is under perpetual evolution, in order to best adapt the beams to the requirements put upon it by the experiments and the limitations of the accelerators.

The diagrams below each represent one revolution period of the beam. The whole diagram can be thought of as repeating, or rotating, at the rate of F_{rev}.

AD

This p^+ beam is used to produce antiprotons for the Antiproton Decelerator (AD). Four bunches are injected at an energy of 1.4GeV, in four consecutive buckets on h=8. By convention, the first bunch in the group of four is assigned the number 1. The beam is accelerated to 26GeV and then subjected to bunch compression by inserting empty RF buckets diametrically opposite from the four bunches. The first harmonic change is from 8 to 10, inserting empty RF buckets number 7 and 8 in the h=10 line in Fig. 2. The procedure is repeated five more times, each time increasing h by 2, thus reaching h=20. The whole process takes about 60ms. The beam is ejected towards the AD some 10ms later, at C1075.

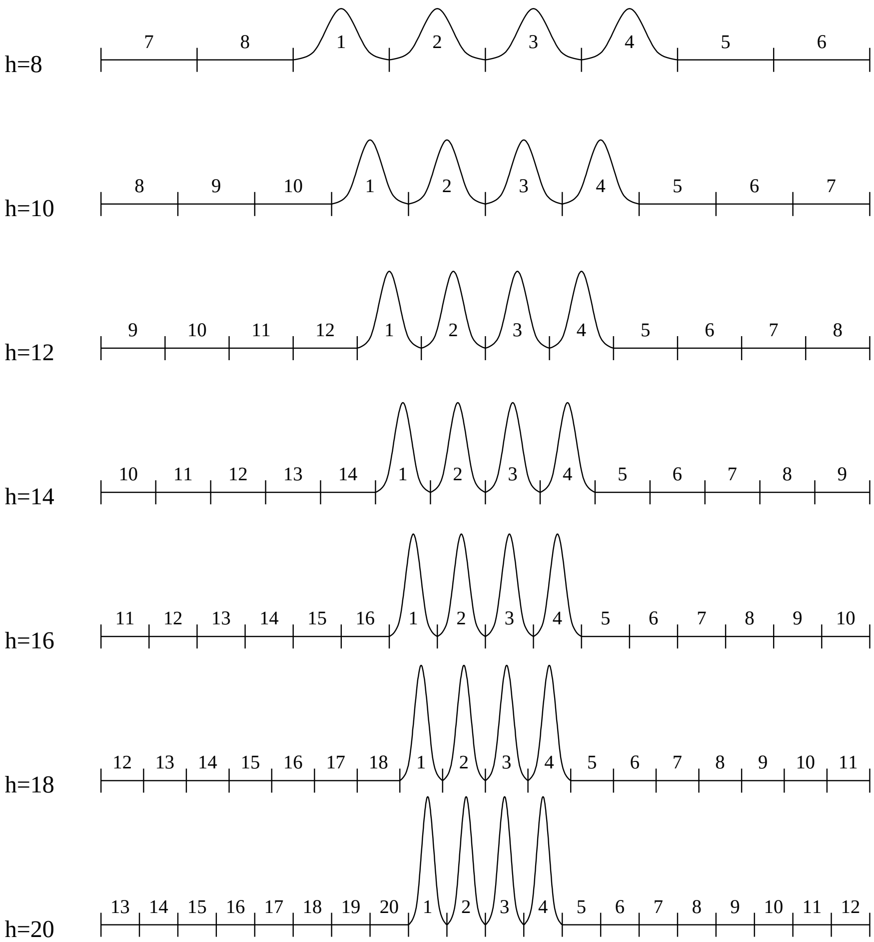

Fig. 2: Harmonic changes for AD

LHC

This p+ beam is intended for the Large Hadron Collider (LHC), currently under construction. Four bunches with an energy of 1.4GeV are injected in four consecutive RF buckets on h=7. By convention, the first bunch is assigned the number 1. (See Fig. 3.) The beam is kept circulating at constant energy for the next 1200ms, when two more bunches are injected into RF buckets 5 and 6. RF bucket 7 remains empty.

About 5ms later, still at the injection energy, each of the bunches is split into 3, and we end up with 18 bunches on h=21, with RF buckets 19, 20 and 21 empty. The beam is then accelerated up to 26GeV.

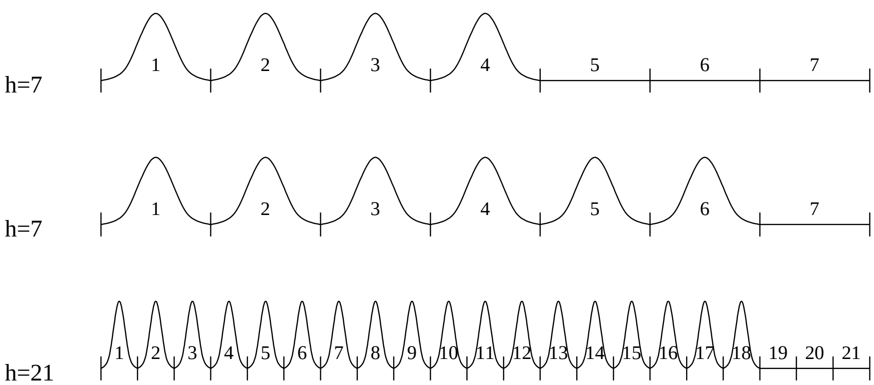

Fig. 3: LHC type beam

On the 26GeV plateau, each bunch is then further split into two twice consecutively, taking it to h=84 with 72 bunches. This takes it beyond the bandwidth of the trajectory PUs and therefore no trajectory can be measured anymore. The beam is ejected towards the SPS at C2369.

EASTA

The EASTA beam is a p^+ beam produced for detectors and experiments in East Hall, and possibly also for the neutron Time Of Flight (nTOF) experiment at the end of the TT2 ejection line. Two bunches, with an energy of 1.4GeV but differing in intensity by a factor of almost ten, are injected at C170 on h=8. The smaller of the two is designated as bunch number 1. The taller bunch normally sits in RF bucket 7 and the others are empty.

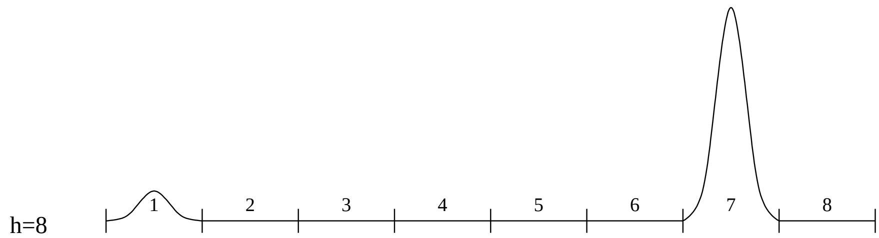

Fig. 4: EASTA type beam

Both bunches are accelerated together up to 20GeV, when the taller of the two is ejected into TT2, with destination nTOF. The remaining bunch is further accelerated to 24GeV and then finally ejected towards the East Hall.

EASTB

One, possibly two, p^+ bunches are injected on h=16. They are accelerated to 24GeV and then de-bunched, to form a DC beam. The trajectory measurement system cannot see DC beams. Slow extraction towards the EAST Hall then occurs over about 400ms starting at C980.

LHCION

Two bunches of lead ions (Pb^{54+}) are injected on h=16. The initial revolution frequency F_{rev}=178kHz, which is very low (Fig. 5). The beam is then accelerated up to F_{rev}=420kHz. On a constant energy plateau, the harmonic number is successively changed from 16, via 14 to 12. Both bunches are then split into two, with the machine then running on h=24, and then the harmonic number is changed to h=21, thus forcing the bunches somewhat further apart. The beam is then further accelerated to high energy. On the final high energy plateau, the beam is recaptured on h=169 without significantly changing the bunch spacing, but greatly narrowing the bunches. Finally, it is then ejected into TT2.

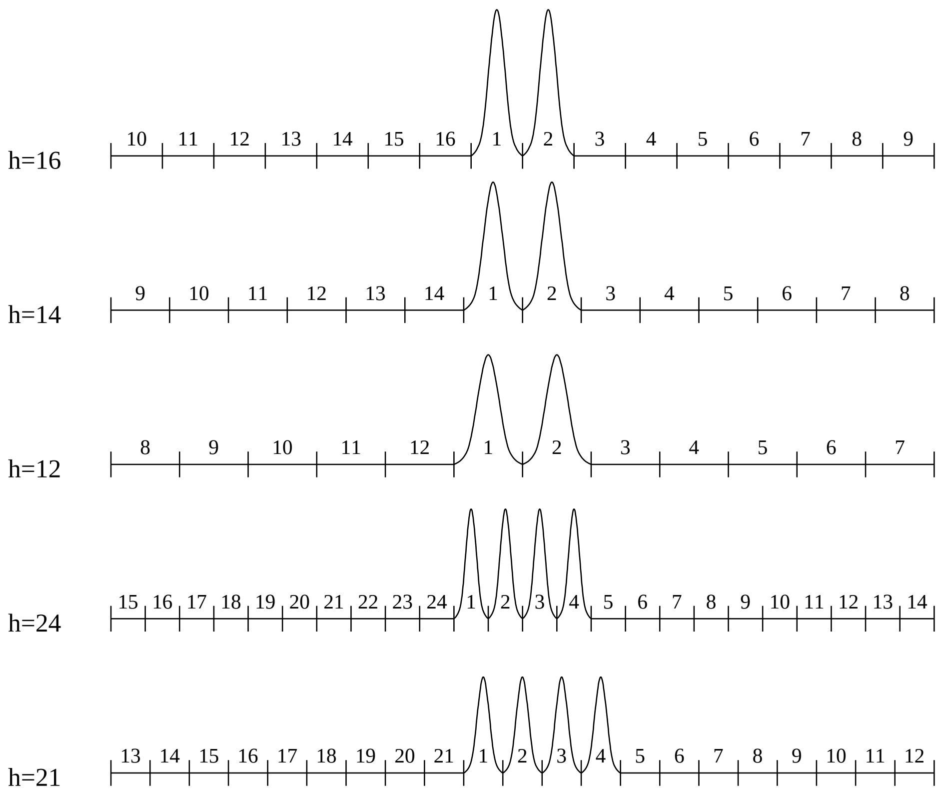

Fig. 5: LHCION type beam

SFTPRO

This is the SPS Fixed Target PROduction beam. Eight bunches are injected at an energy of 1.4GeV on h=8. The beam is then accelerated to 3.5GeV. Then, on a constant energy plateau, each bunch is split into two, yielding 16 bunches on h=16 (Fig. 6). The beam is then further accelerated to 14GeV, debunched and then rebunched at 200MHz (h=420, not shown), and finally ejected over five consecutive turns into TT2. From the moment the beam is debunched, it can no longer be seen by the trajectory measurement system.

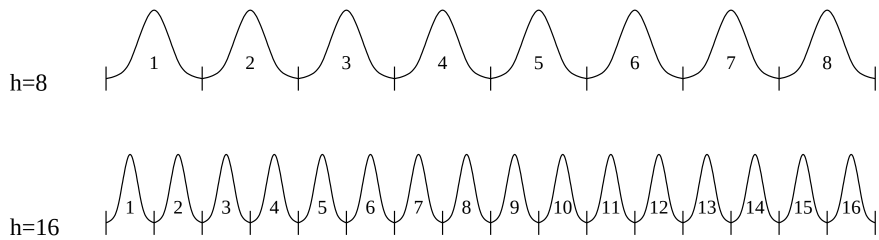

Fig. 6: SFTPRO beam

MD3

MD stands for 'Machine Development'. In practice, this beam setup is currently used for the CNGS experiment. (CERN Neutrinos for Gran Sasso). The beam is directed into an underground target oriented such that the neutrinos produced traverse detectors installed in the Italian laboratory of Gran Sasso, on the other side of the Alps. The beam is very intense, to obtain the highest neutrino yield possible. It is otherwise very similar to the SFTPRO beam.