SUPER PLASTIC SYNCHROTRON

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Try to inject, accelerate and keep the steel ball circulating at "high energy". Will you reach the incredible 0.000 001 % of the speed of light? It's all in your hands!

CERN

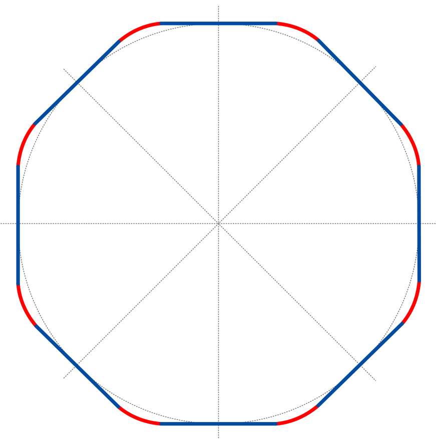
Fundamental building blocks of a particle accelerator

Bending magnets and the Beam orbit

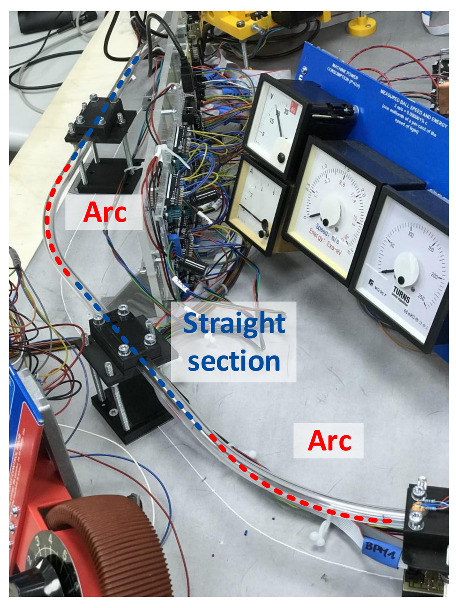
Trajectory the particles travel in a circular accelerator is called the **Beam orbit**. In order for beam to circulate in the machine for an indefinite amount of time, the beam orbit has to be perfectly **closed**.

Straight section – particles simply fly through by inertia. They do not change their direction. No external force is necessary. Straight sections are used to insert all kinds of instrumentation (experiments, acceleration system, collimators etc.).

Arc – is the curved part of the accelerator. Particles do change their direction by application of an external force, typically by magnetic field generated by "bending magnets".



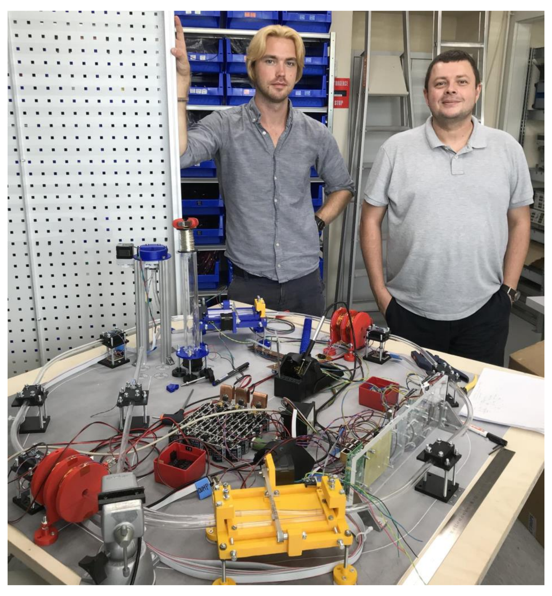
Super Plastic Synchrotron has 8 sectors (same as LHC), the straight sections are occupied by the following machine elements:
- two accelerating structures
- injection element
- extraction element
- beam position monitors



About the authors

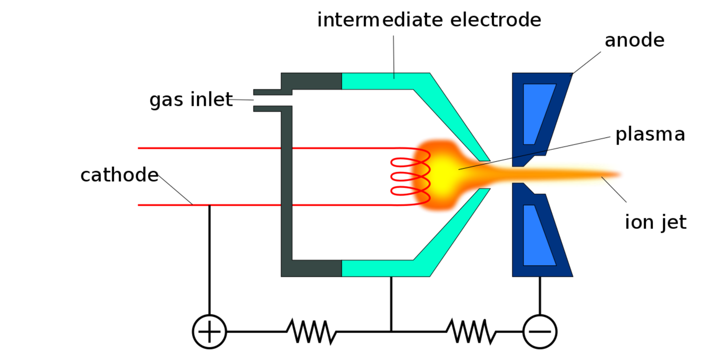
Martin Soderen (left) is a computer scientist in the Radio-frequency group of the Beams department. He specializes in high performance computing and real time, high throughput, data analysis from the Large Hadron Collider (LHC). He designed numerous computer and control systems for the LHC transverse feedback. Martin joined CERN in 2016.

Daniel Valuch (right) is an electronics engineer and RF systems specialist in the Radio-frequency group of the Beams department. He designed and/or he is responsible of accelerating and transverse feedback systems for the Large Hadron Collider, Super Proton Synchrotron, High Intensity/ Energy ISOLDE, or Linac3. Daniel joined CERN in 2000.



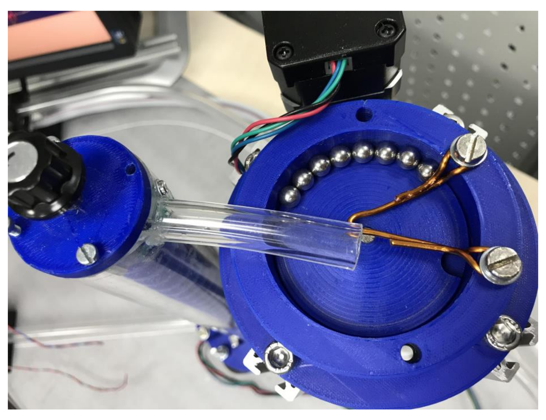
Particle source

Particles for acceleration in real machines are made out of ordinary materials, for example hydrogen gas, or lead pellets. The material needs to be "atomized" to obtain a gas of individual atoms, and ionized to make the neutral atoms electrically charged. This is usually achieved by lasers and strong electromagnetic fields.



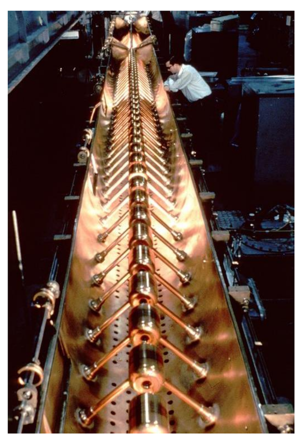
Picture author: Evan Mason
Source https://commons.wikimedia.org/wiki/File:Duoplasmatron.svg

The Super Plastic Synchrotron uses precision steel balls as particles. The ball has a diameter of d = 7 mm and weights m = 11 g. The steel ball material is ferromagnetic, so we can use magnetic fields to manipulate it (e.g. to accelerate).
Note in the real accelerator, only electric field can be used to accelerate the sub-atomic particles.



The linear accelerator

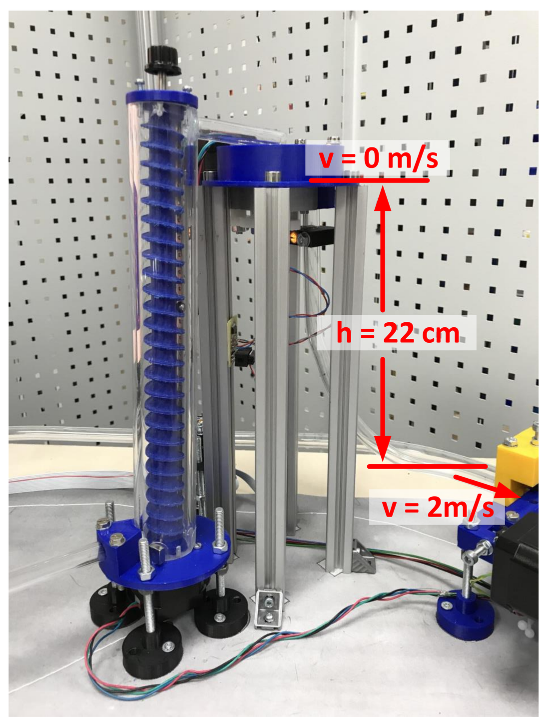
If we want to inject particles into a circular accelerator, they must be "moving" already. In other words we have to pre-accelerate them in a smaller machine. These are usually called Linear Accelerators, or LINACs.



The Super Plastic Synchrotron uses gravity to pre-accelerate the particles.

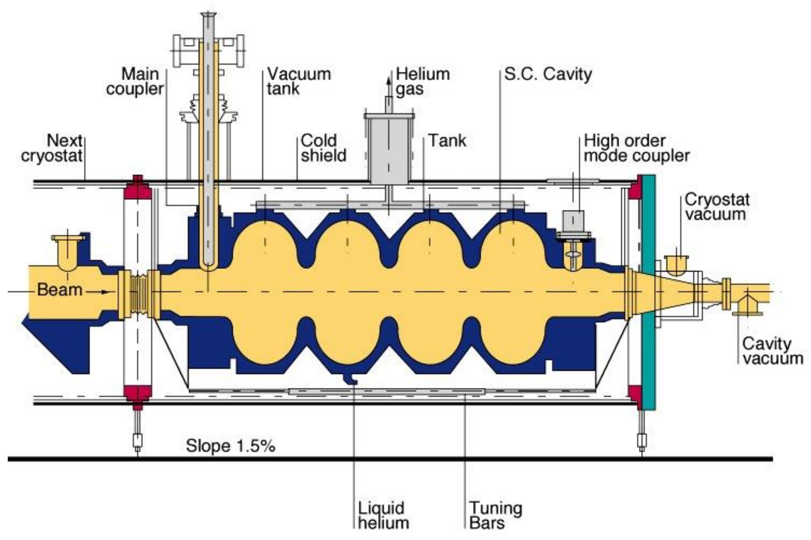
The steel ball is lifted to a height of h = 22 cm, gaining potential energy of $E_{potential}$ = 0.033 Joules.

When dropped, this is converted by gravity into a kinetic energy giving the ball an approximate injection velocity of $v_{injection}$ = 2 m/s.

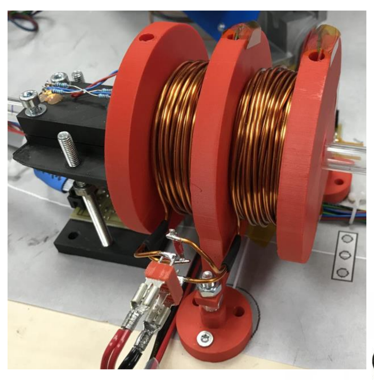


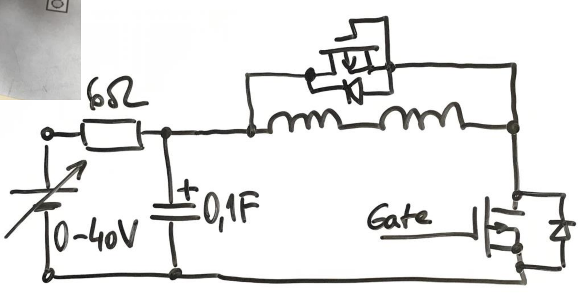
Acceleration system

Charged sub-atomic particles are accelerated in real machines by very strong electric fields. For example, the accelerating system of the Large hadron Collider, you are about to visit underground, produces a voltage of 16 MegaVolts (16 million Volts) to accelerate and keep the beams under control. Often a superconducting radio-frequency resonators are used to produce such high voltages.
An ultra precise synchronization and extreme frequency stability is required for acceleration too, the particles have to pass the accelerating structure within 7 pico-seconds (7 millionth of a millionth of a second) time window.



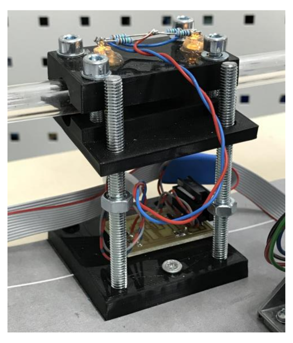
The Super Plastic Synchrotron uses a ferromagnetic ball as its particles, so we can cheat a bit and we use electromagnets to accelerate the balls.
The perfect timing is achieved by two sensors installed within the accelerating coil body. When the ball enters the coils, the coil is switched on and the ball is sucked in. When the ball passes exactly the coil center, the current polarity is reversed and ball is pushed out.
The energy is controlled by the amount of current within the accelerating pulse. A power supply voltage is altered by the control knob, giving you a possibility to increase the ball velocity by about factor two (but quadruple the energy).



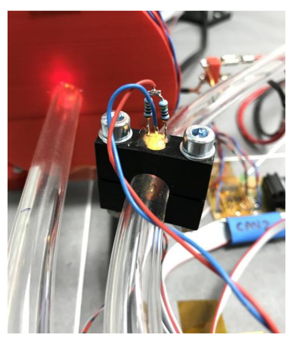


Beam diagnostics and measurements

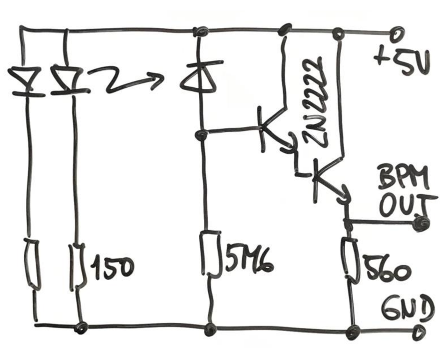
The beam position and velocity is measured by means of Beam Position Monitors (BPM). There is more than 4000 of them in the Large Hadron Collider. The Super Plastic Synchrotron needs precise timing and beam passage detection too, therefore we are using multiple Ball Position Monitors. They are based on photo-elements, the microcontroller then calculates all important parameters, like the time of flight, ball velocity, the accelerating structure timing...



Dual sensor integrated in the support for time of flight measurement



Single sensor for beam injection and dump detection

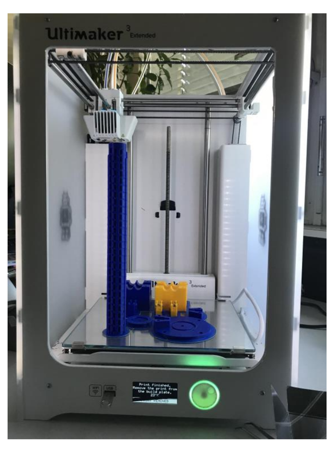


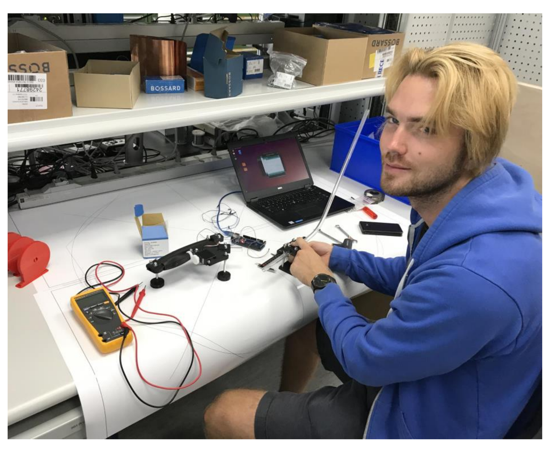
Design and building

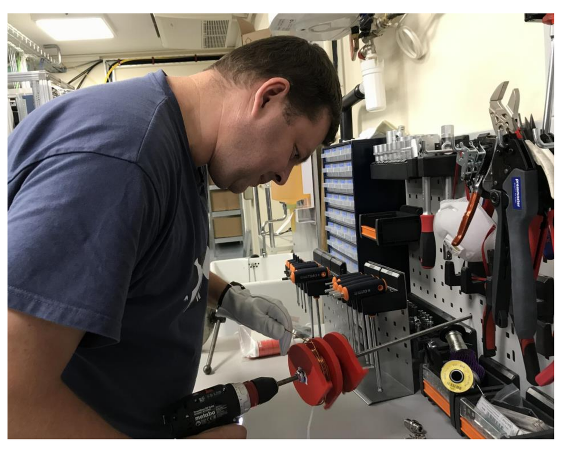
The Super Plastic Synchrotron as you see it, had taken about four weeks of full time work to design and build.

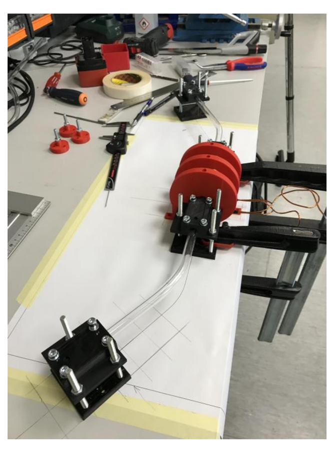
All mechanical parts, including the whole integration were designed in FreeCAD and printed on Ultimaker 3 Extended 3D printer. We have used about 3kg of filament, the printer was running non-stop for more than two weeks.

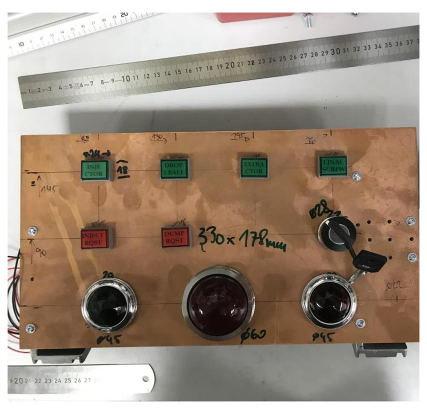
The control software runs in a single ATMega 2560 microcontroller in a form of Arduino MEGA board. Many routines require very critical timings, so part of the code is written directly in assembly language. The microcontroller controls full functionality of the machine. It communicates with the Raspberry-Pi computer, which can run sophisticated automatic sequences, similar to the operators in the CERN Control Center.

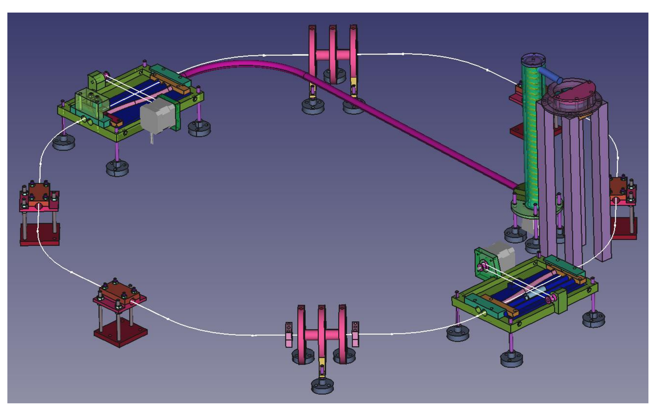


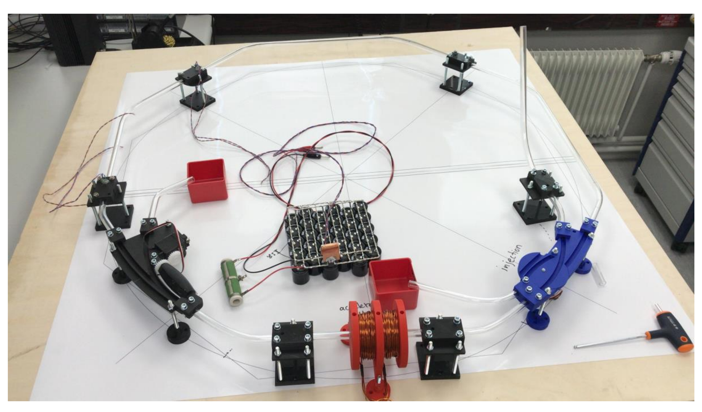






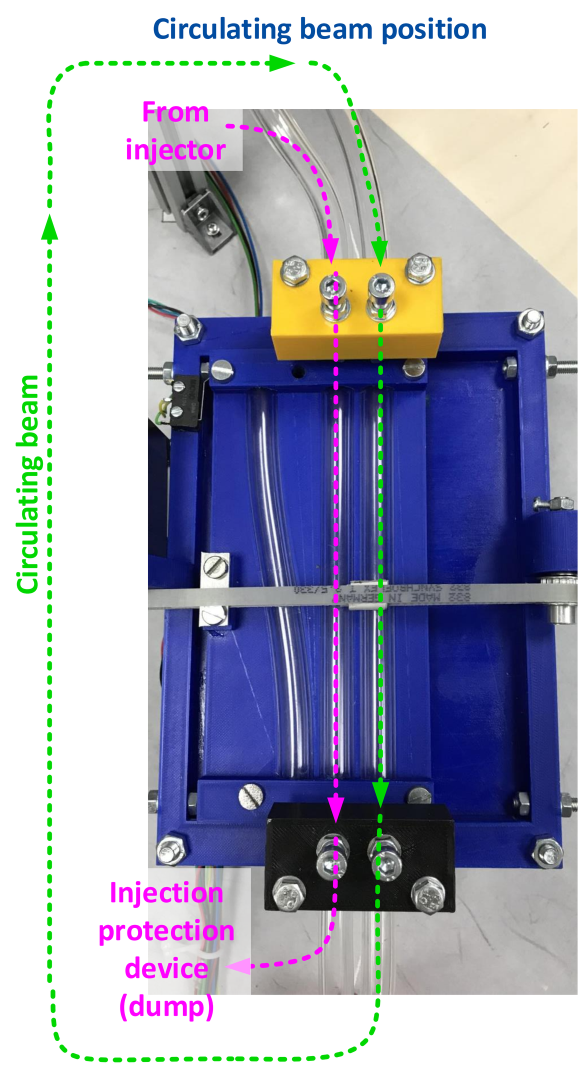




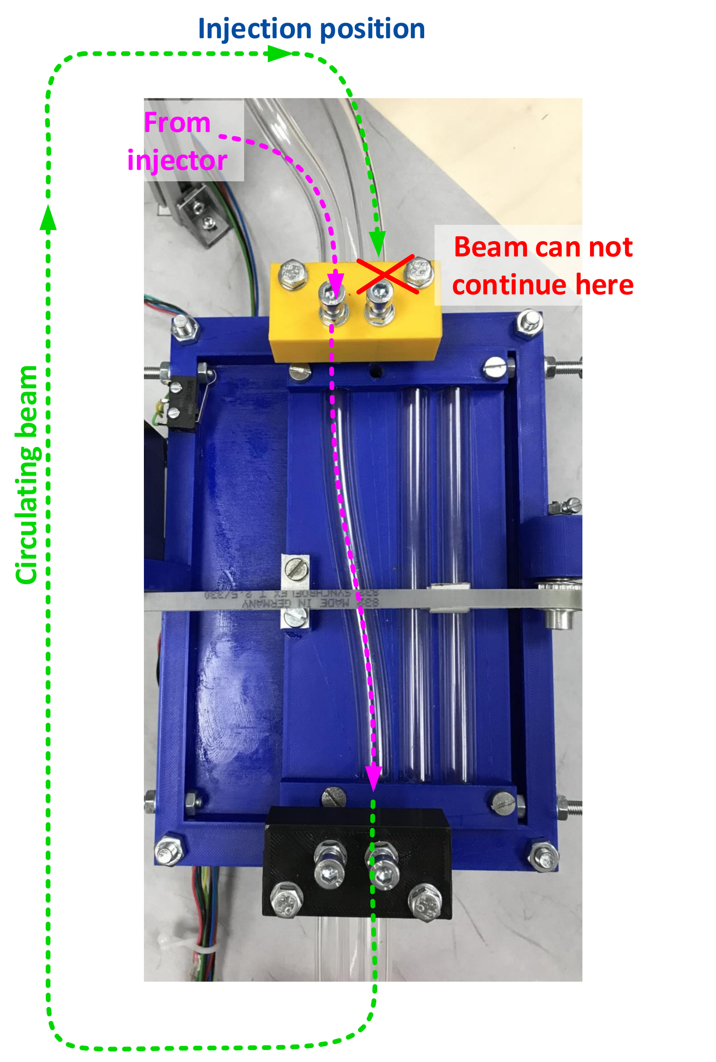


Injection system

Injection element is like a switch in the railway. It momentarily opens the perfect circular closed orbit **to allow injection** of particles from the pre-accelerator. It has to close the orbit immediately after the injection, before the beam makes its first turn. The Super Plastic Synchrotron uses a purely mechanical injection element, but with the same functionality as in the real machine.



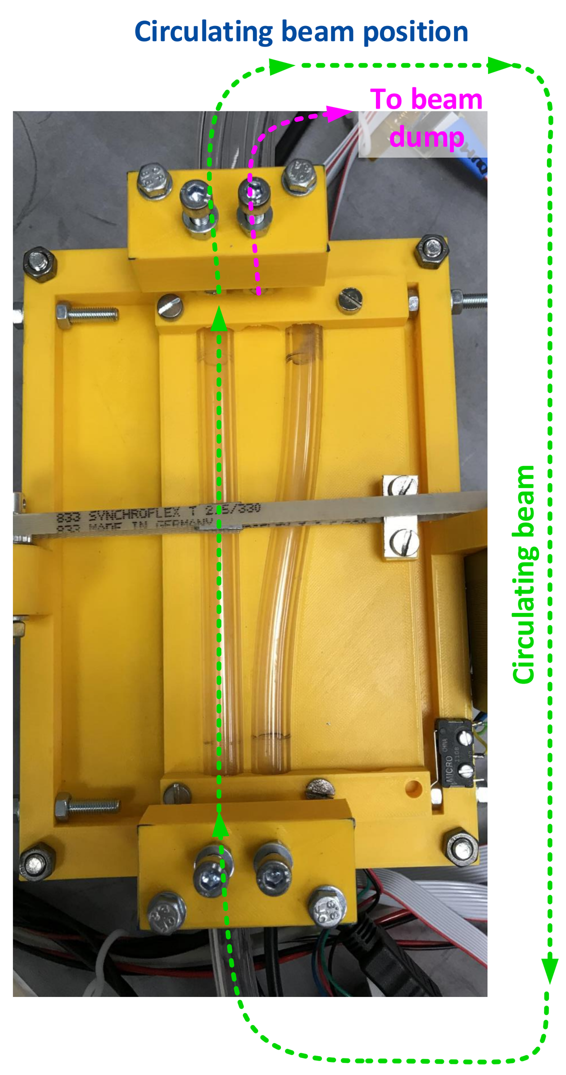
Injector is transparent to the beam, the orbit is perfectly closed and the beam is circulating.
Any attempt to inject in this position will send the beam to the injection protection device (dump)



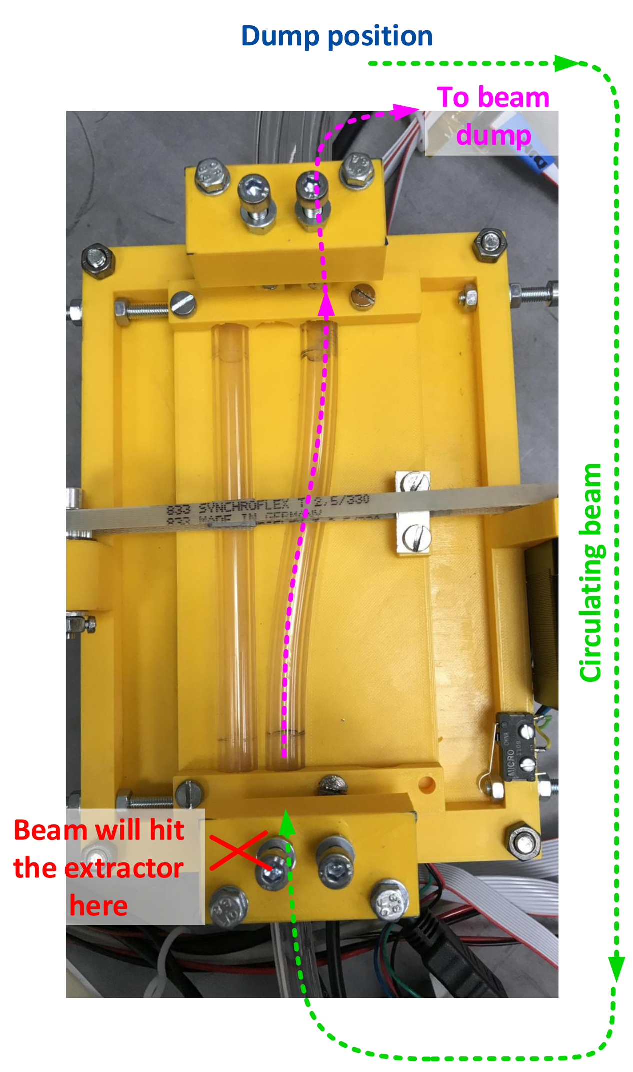
Injector opens the orbit and the beam can enter the machine, but it **can not circulate.**
The injection element has to be switched back to the closed orbit position immediately after the injection, otherwise the beam will hit the injection magnet (and damage it).

Extraction system and Beam dump

The extraction element acts also like a switch in the railway. It momentarily opens the closed orbit to allow **a controlled beam disposal** into the beam dump block. As the extraction magnet requires some time to ramp to its full strength, triggering this magnet has to be extremely carefully synchronized with the circulating beam. The Super Plastic Synchrotron uses a purely mechanical injection element, but with the same functionality as in the real machine.



Extractor is transparent to the beam, the orbit is perfectly closed and the beam is circulating.
The extractor needs time to reach the full position. Correct timing to call the beam dump is extremely critical.



Extractor opens the orbit and the beam is sent to the dump.
Any attempt to move the extractor when the beam is passing will result in the beam hitting the extractor with possible damage (asynchronous dump).