MULTI-TURN INJECTION OF 50 MEV PROTONS INTO THE CERN PROTON SYNCHROTRON BOOSTER

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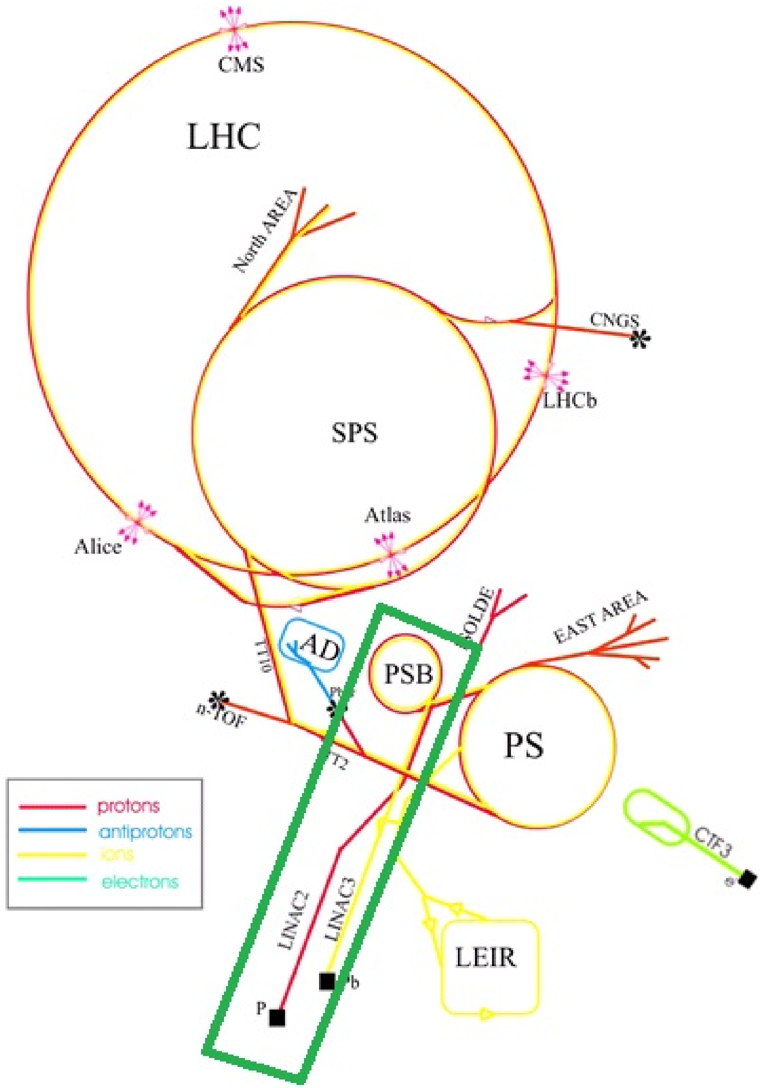
NA-PAC'13, Pasadena

CERN Injector Complex



- Actual layout
  - **Linac2** produces beams of **50 MeV protons** with a current of around **160 mA** injected into the PSB using a **conventional multi-turn injection.**
  - **PSB** consists of four superposed rings and it is boosting protons from 50 MeV to 1.4 GeV.

- Future layout
  - Linac2 will be replace with **Linac4, a new H^- linac injecting into the PSB at higher energy, i.e. 160 MeV,** using the **charge-exchange principle.**

Motivations of the study

- General planning of CERN foresees the **connection Linac4-PSB** not before the end of the second LHC long run.
- Linac2 is ageing and showing weaknesses in terms of vacuum tightness
- ➢ **In case of serious breakdown of Linac2, it is envisaged to inject 50 MeV proton beams from Linac4 into the PSB using the current multi-turn injection.**

- ➢ **Is it possible to produce beams useful for the LHC injecting 50 MeV protons from Linac4 into the PSB?** (Linac4 current 40/50 mA and emittance of 0.4 π mm mrad).

Outline of the study

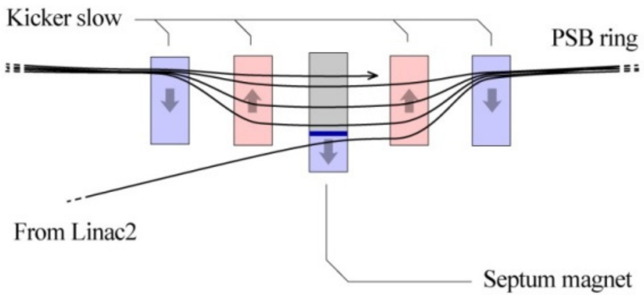
Simulations done with ORBIT.

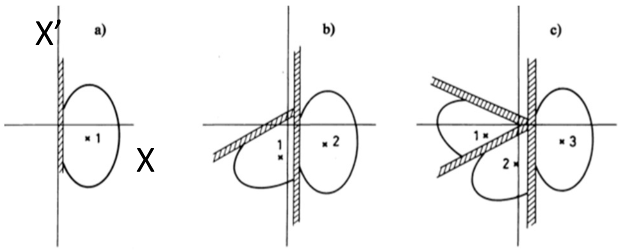
1. **Test the PSB model** using the reference parameters of the **PSB injection with Linac2 to produce a LHC-25 beam**. Comparison to measurements.

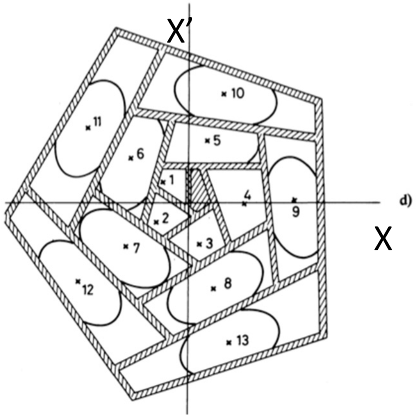
2. **Simulations are performed with Linac4 parameters**. An optimization of the injection process is done to obtain an estimate of the highest reachable intensity for the LHC-25 beam.

PSB Multi-turn Injection

- During the PSB conventional multi-turn injection, the beam is stacked in horizontal betatron phase-space:
  - **Magnetic septum** deflects the injected beam.
  - **Four slow kickers** generate a closed orbit bump to approach the circulating beam closely to the injection septum to minimize the transverse emittance of the resulting beam.
  - The bump decreases and the beam moves to the closed reference orbit.
- **Losses on the septum blade due to betatron oscillations.**
- The following parameters can be tuned to optimize the injection: working point at injection, injection timing wrt the bump and horizontal and vertical positions and angles of the injected beam.

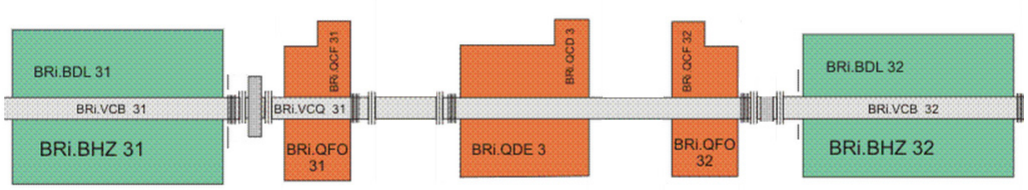






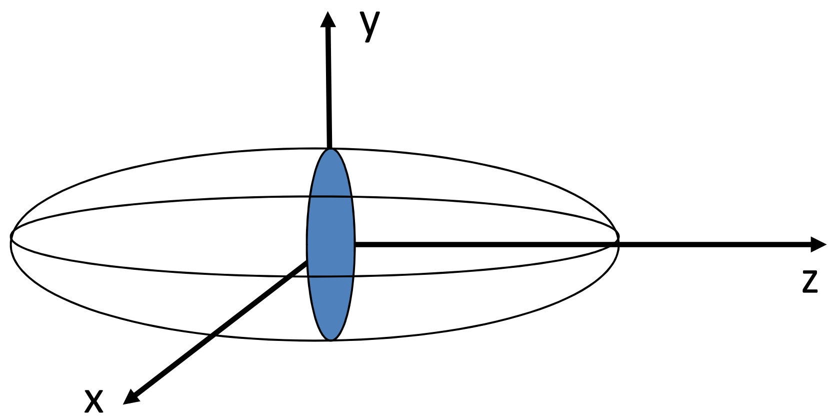
PSB Model

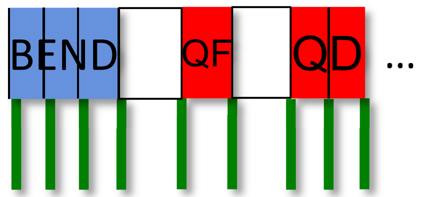
- The MAD-8 model of the PSB is a linear lattice (bending and quadrupole magnets). The injection tune is fixed in the MAD-8 model.
- A Python script is used to import MAD-8 lattice files to ORBIT.
- The injection kickers are modeled in ORBIT with the ideal bump module.
- As ORBIT does not contain a septum module, a foil of thickness null as first element of the lattice and an aperture as last element of the lattice are used. The foil simulates the septum blade seen by the injected particles whereas the aperture simulates the septum blade seen by the circulating particles.



ORBIT Space Charge Modules

- **Transverse Space Charge FFT-PIC** without boundary condition(s) :
  - Macroparticles are binned to a 2D grid.
  - The force distribution on the grid is calculated using a FFT method.
  - Particle kicks are obtained by interpolation from the grid to each macroparticle. The kicks are weighted by local longitudinal density (longitudinal profile).
  - Transverse space charge nodes are inserted after each transfer matrix of the lattice.
- **Longitudinal Space Charge FFT** with only one node, as the longitudinal profile does not change much during a single turn.





Linac2 Simulations

- **Reference parameters** of Linac2 50 MeV proton beam and of the PSB injection:

Parameters	Symbol	Value
Linac2 normalized rms beam emittance	$\varepsilon^*_h = \varepsilon^*_v$	1.2 π mm mrad
Linac2 beam current		155 mA
Bump Collapse Time	TIKS	50 µs
Horizontal Tune	Q_h	4.42
Vertical Tune	Q_v	4.49
Number of injected turns		2

- Injection timing, horizontal and vertical positions and angles of the injected beam are optimized to reach maximum intensity within the required emittance.
- **Real case LHC-25 beam: ε^*_h= 1.90 π mm mrad, ε^*_v= 1.75 π mm mrad, injection efficiency ~57% and intensity of 1.85×10^{12}.**

➢ **The most optimized simulation => ε^*_h= 1.88 π mm mrad, ε^*_v= 1.70 π mm mrad, injection efficiency ~61% and intensity of 1.98×10^{12} protons.**

➢ **PSB model matches well reality for the LHC-25 beam.**

Linac4 Simulations

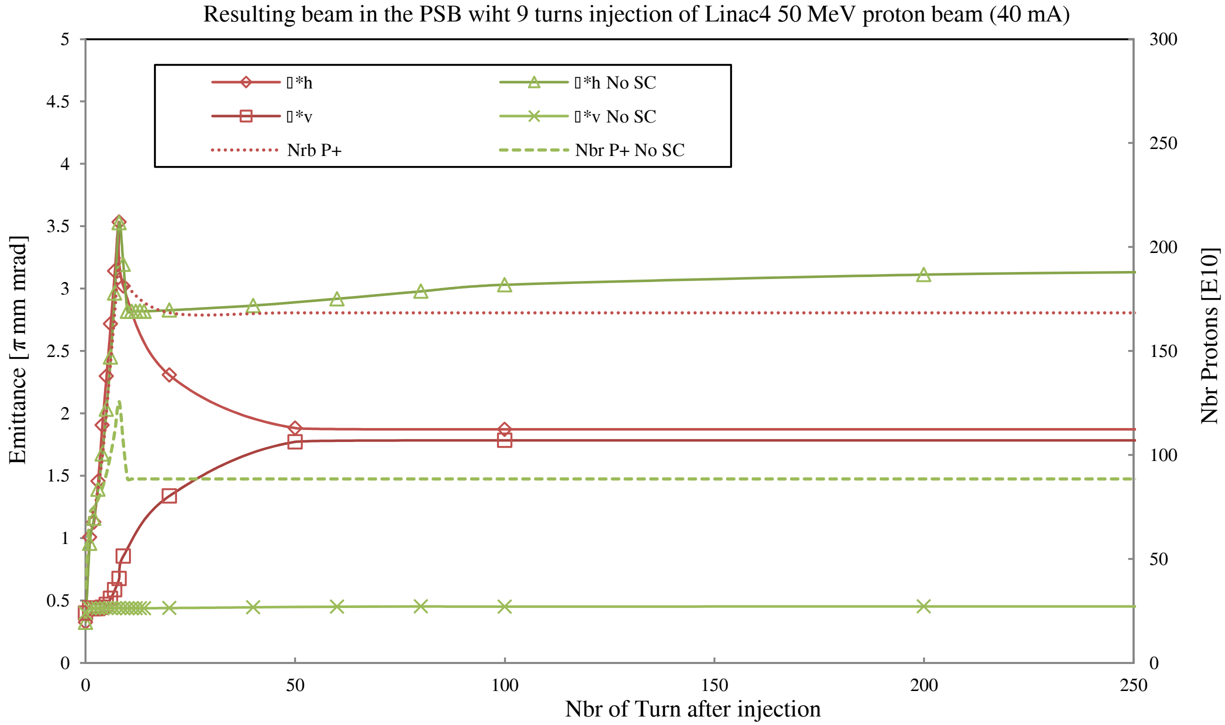
- **Linac4 50 MeV proton beam parameters**:
  - **Nominal current 40 mA and maximal current 50 mA (klystron power limitation)**
  - **$\varepsilon^*_h = \varepsilon^*_v = 0.4\ \pi$ mm mrad**
- Parameters for optimization: Injection bump collapse time, the injection timing, the number of injected turns and horizontal and vertical positions and angles of the injected beam.

➢ **Optimum results for both currents with an injection of 9 turns and a bump collapse time of 90 µs (compared to the 50 µs for Linac2).**

	40 mA case	50 mA case
Beam intensity	1.68×10^{12}	2.19×10^{12}
Normalized rms emittance horizontal [π mm mrad]	1.87	1.81
Normalized rms emittance vertical [π mm mrad]	1.78	1.91
Injection efficiency	44.9%	46.6%

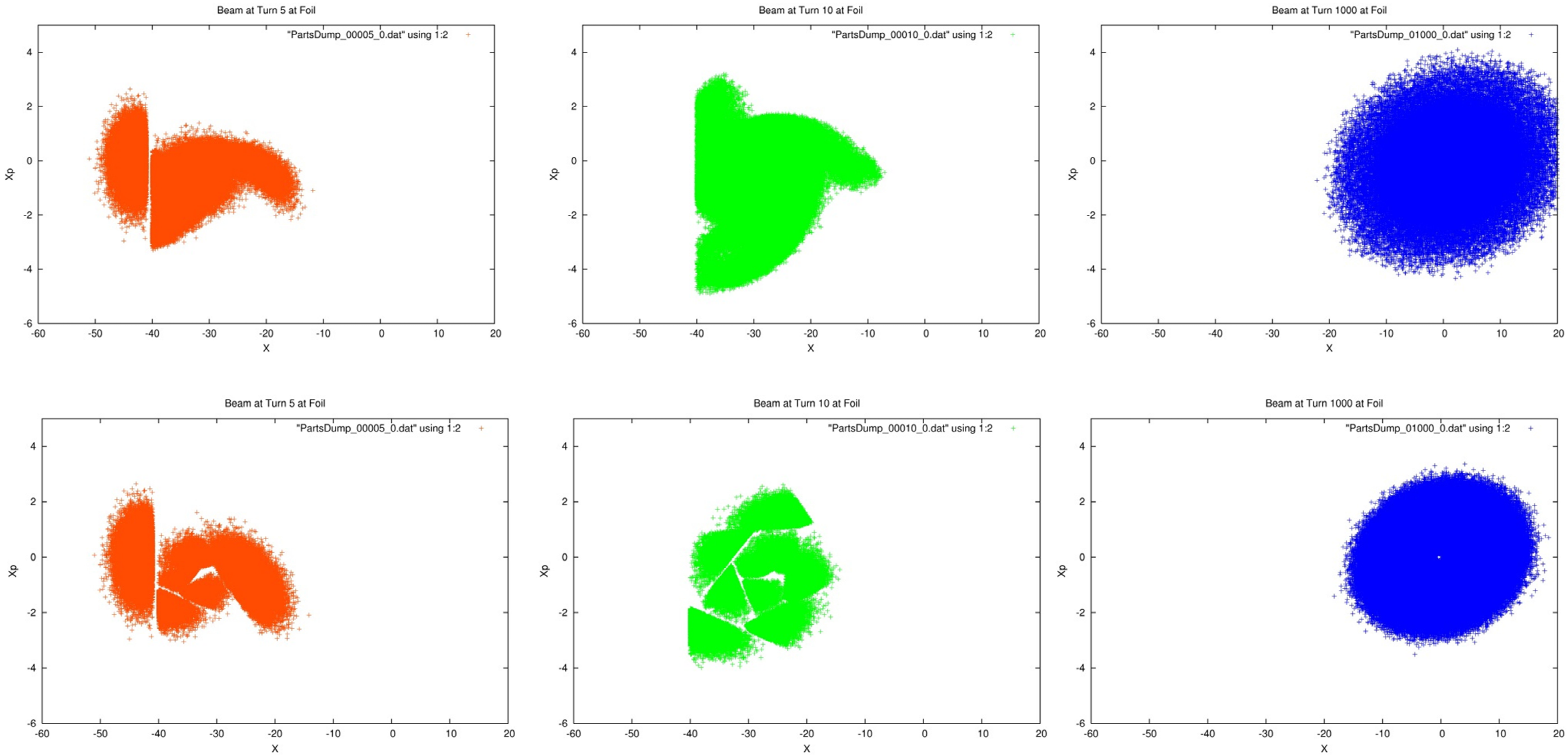
Space Charge Influence for Linac4 Case

- Due to space charge particles have different tunes depending on their position inside the bunch. The rotation in phase-space of the particles with the strongest detuning close to the centre of the bunch will be slowed down and eventually they will not interact with the septum , because when they would be in the critical position, the painting bump would have already fallen enough to carry them away from the septum blade.
  - **Space charge is helping to reduce the amount of losses with Linac4**



Space Charge Influence for Linac4 Case

- Space charge made possible the mixing of the beamlets and smoothing of the distribution.
  - **Space charge is helping in producing beam with smaller horizontal emittance with Linac4.**



Linac4 as backup for Linac2

- **PS Booster model** gives **coherent** results for the production of LHC-25 beam with **the present multi-turn injection of Linac2 50 MeV protons**.
- Comparing simulations results of Linac2 and Linac4 cases:
  - **With a 40 mA Linac4 50 MeV protons beam, max ~83% of today's LHC-25 beam brightness could be achieved in the PSB.**
  - **With a 50 mA Linac4 50 MeV protons beam, max ~106% of today's LHC-25 beam brightness could be achieved in the PSB.**
- **Linac4 with a 50 MeV proton beam with 50 mA beam current could be used as backup solution in case of major failure of Linac2**, at least to provide usable production beams for the LHC.

Thanks for your attention

Q & A?