Design of pulsed synchrotrons for the high-energy acceleration chain of a muon collider

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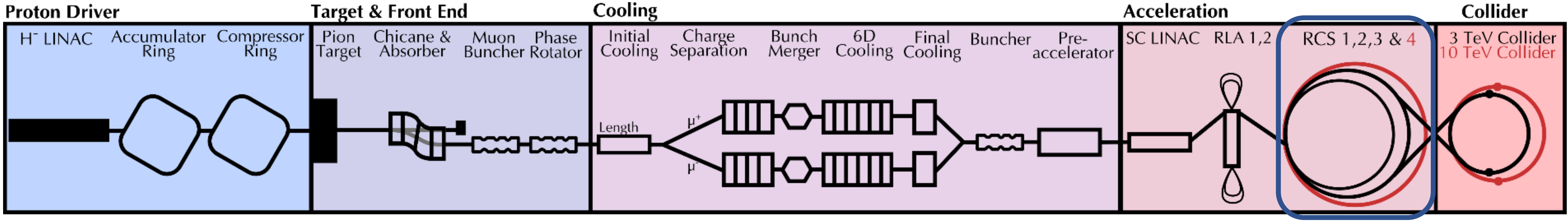
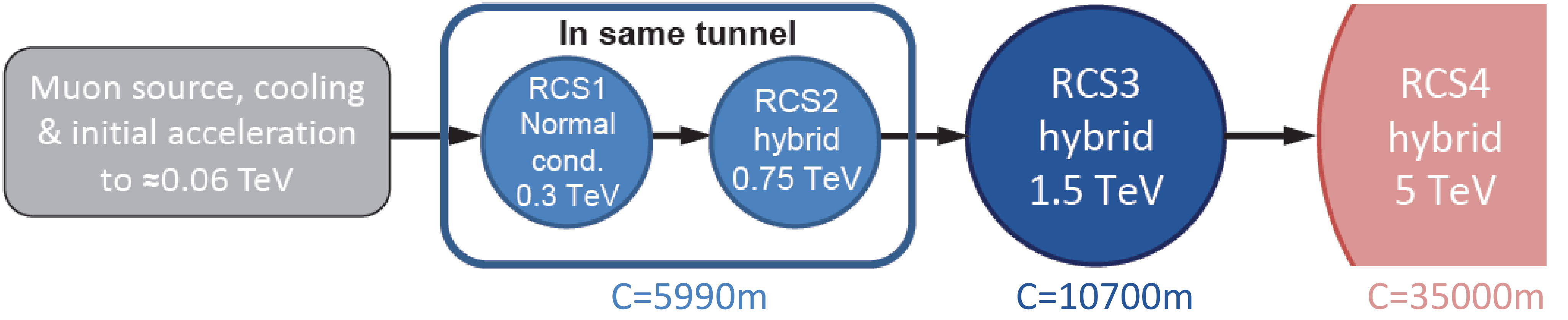
High-energy acceleration chain



Baseline: chain of Rapid Cycling Synchrotrons (RCS), with normal and hybrid machines.



Acceleration < **10 ms**

Normal and hybrid synchrotrons

Normal synchrotron

➢ « Conventional machine »

- The magnetic field of the bending magnets is ramped synchronously with the energy of the particles.
- The beam keeps the same loop-path during the acceleration.

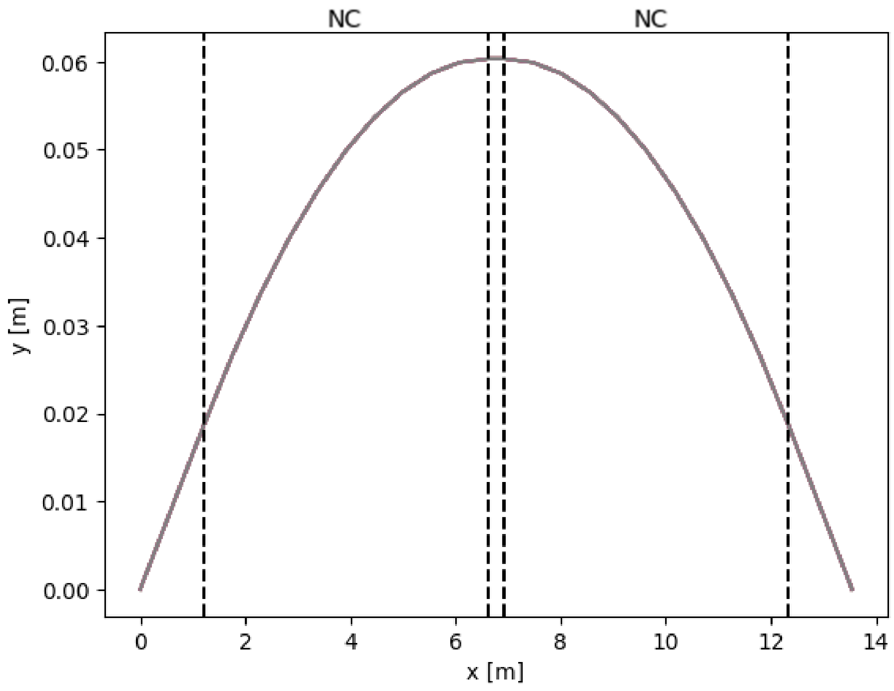
Hybrid synchrotrons

➢ Never operated configuration

- Interleave fixed-field superconducting dipoles and pulsed normal conducting dipoles
  - **Fixed-field SC dipoles:** achieve high-average bending field → compact ring (smaller footprint and use less RF)
  - **Pulsed NC dipoles:** synchronicity with beam energy
- The beam trajectory varies during the acceleration.

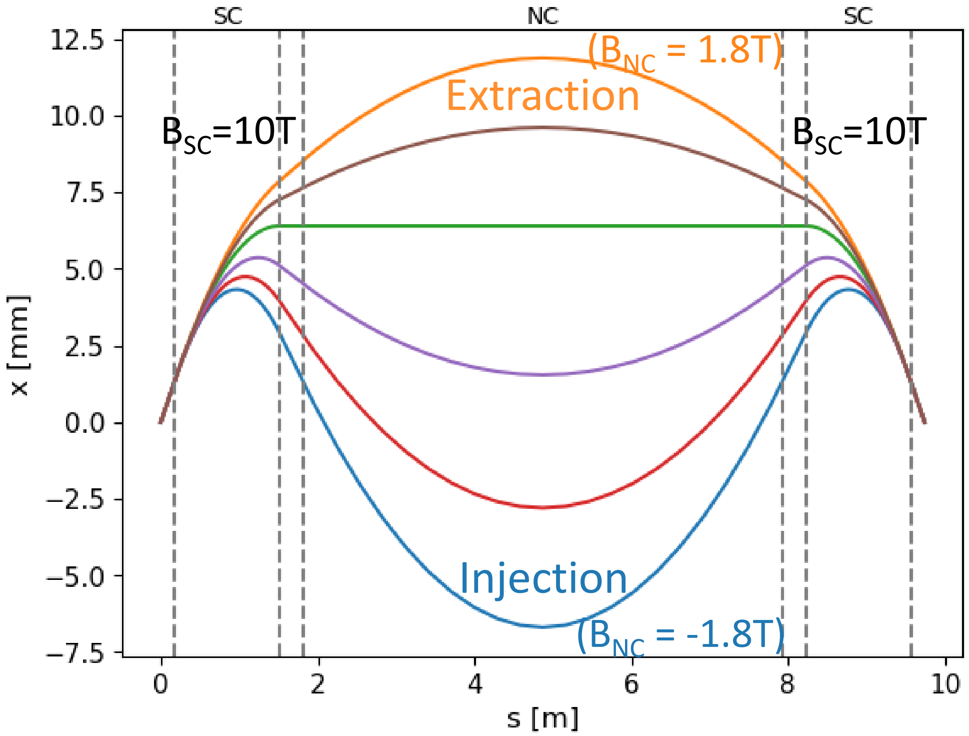
Normal and hybrid synchrotrons

Normal synchrotron: The magnetic field of the magnet is ramped synchronously with the energy of the particles.



The beam keeps the same loop-path during the acceleration.

Hybrid synchrotrons: Interleave fixed-field superconducting dipoles and pulsed normal conducting dipoles



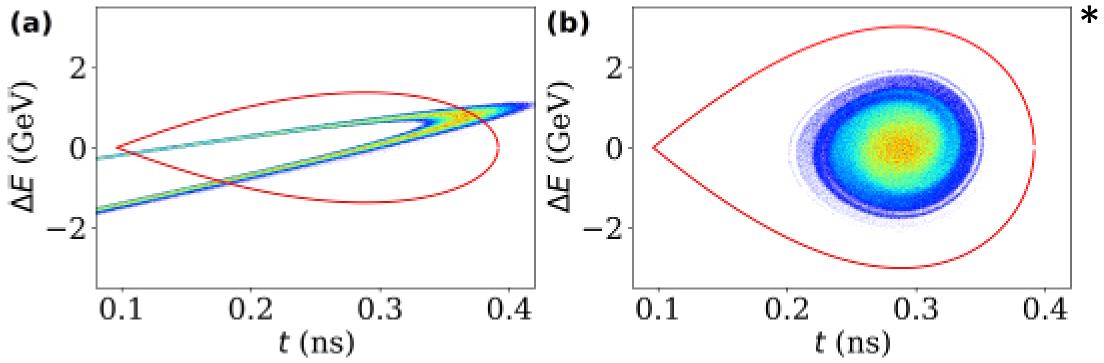
The beam trajectory varies during the acceleration.

Distribution of the RF cavities

	RCS 1	SPS
Circumference	5990 m	6912 m
Injection energy	60 GeV	26 GeV
Extraction energy	313 GeV	450 GeV
Total RF Voltage	21 **GV**	≈ 2 **MV**
Energy gain per turn	14.8 **GeV** (25% of E_{inj})	≈ 1.3 **MeV**
Acceleration time	0.34 **ms**	7.5 **s**

- Accelerate much faster than a conventional ring → require high total RF Voltage.
- Conventional ring: $n_{RF} \approx 1$ accelerating station.
- For the RCS of a muon collider, need to distribute the RF : $n_{RF} >> 1$.

$n_{RF} = 4$ $n_{RF} = 32$



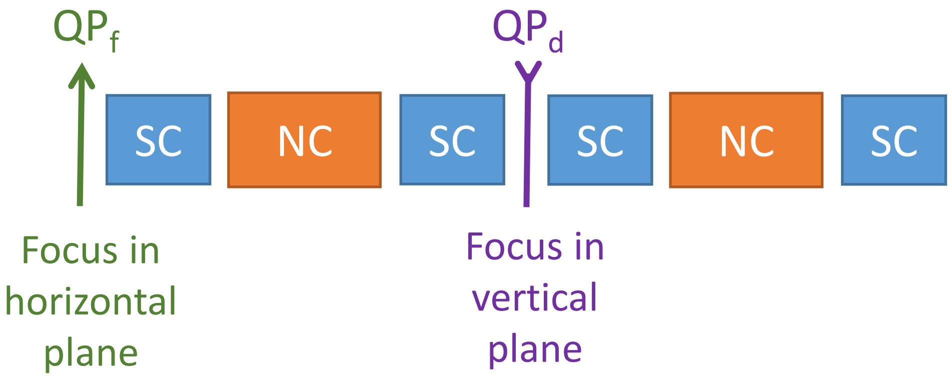
De-bunching, 82% of particles are lost after 1 turn

No particle loss!

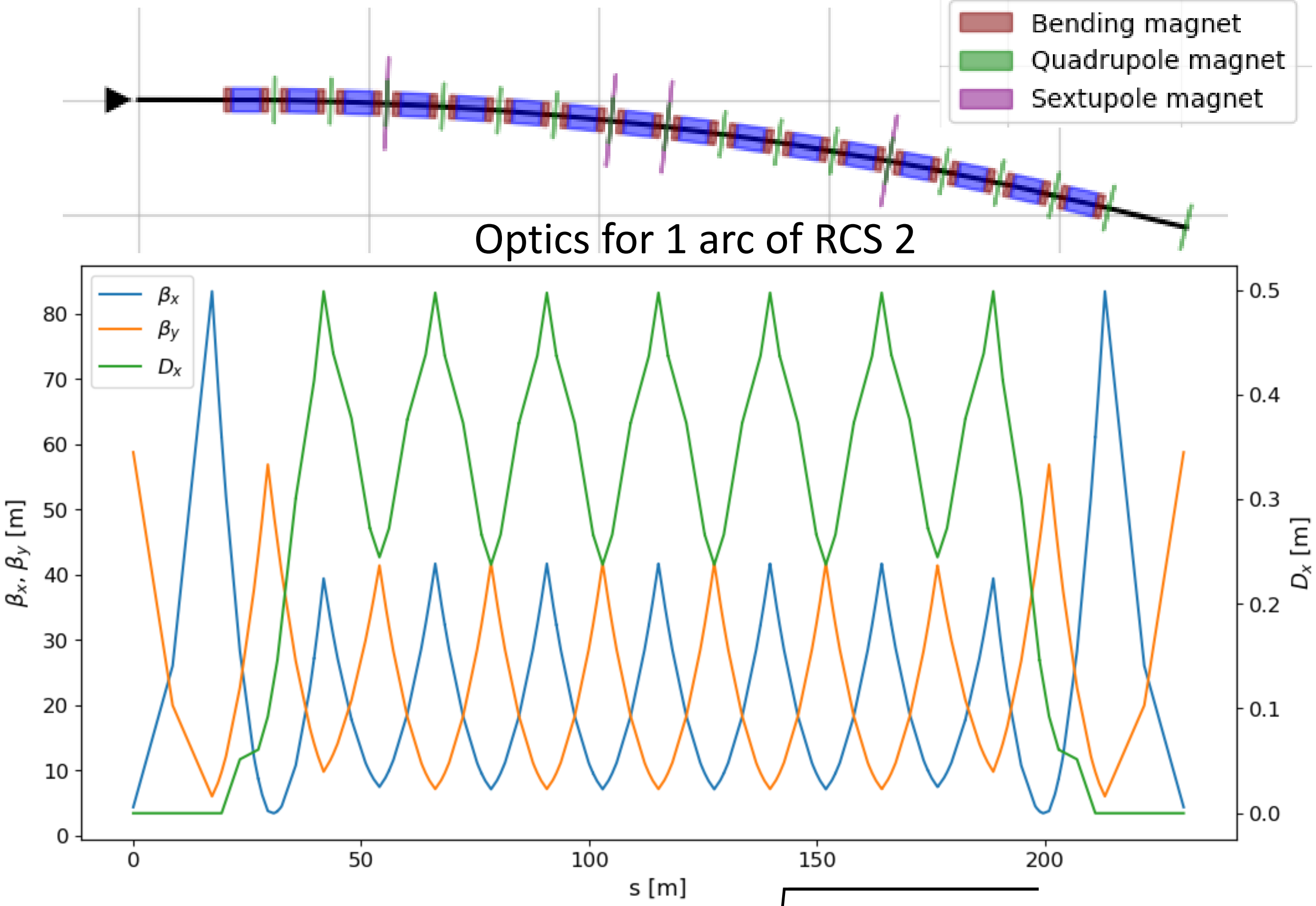
* Longitudinal beam dynamics and RF requirements for a chain of muon RCSs (inspirehep.net) (F. Batsch et al.)

Preliminary RCS optics

- A lattice is the way we organize:
  - Dipoles: bending magnets
  - Quadrupoles: focusing elements
  - RF cavities: accelerating stations
  - …
- Most basic lattice is called FODO:



Repetition of FODO cells + RF insertions = 1 arc



Size of the beam: $\sigma_x = \sqrt{\epsilon_x \beta_x + D_x^2 \sigma_\delta^2}$

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