Measurements of Energy and Transverse Emittance of the 160 MeV Linac4 H⁻-Beam before Injection into the CERN PS Booster

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CERN Accelerator School 2009

Introduction to Linac4

- Upgrade project of the CERN accelerator complex (commissioning 2013/14)
  - Necessary for ultimate LHC beam
  - In PSB: $2.4 \cdot 10^{12}$ protons per bunch, normalised emittance 2.5 π mm mrad
- H^- beam at 160 MeV (kinetic energy)
  - Reduced space charge effects, incoherent tune shift smaller
- Charge-exchange injection mechanism (stripping foil) into PS Booster
  - More homogeneous painting of the PSB acceptance
  - Decrease of particle losses compared to present conventional injection with septum magnet
- Transfer between Linac4 and PSB via transfer line (length 177m)

Diagnostic Lines before PS Booster Injection

- Measurement of energy and transverse emittance in two dedicated diagnostic lines about 50m before the PS Booster injection point (Fig. 1)
- Lines already existing, but must be upgraded for 160 MeV H^--beam
  - Simulation studies with tracking and envelope programmes (Path and Trace3d)
- Energy Measurement Line (Fig. 2)
  - Determination of kinetic energy and energy spread
  - Measurement of systematic energy shifts (longitudinal painting)
- Emittance Measurement Line (Fig. 3)
  - Determination of transverse emittance values

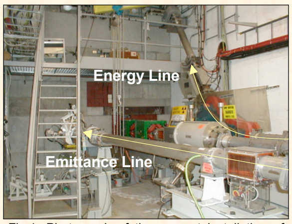

Fig.1: Photograph of the present installation of the two diagnostic lines.

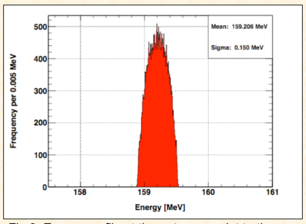

Fig.2: Energy profile at the entrance point to the energy measurement line.

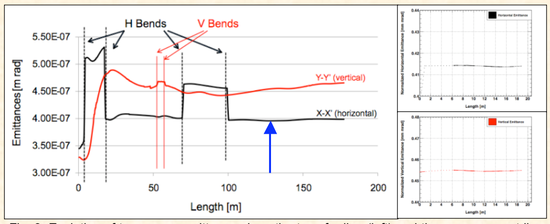

Fig. 3: Evolution of transverse emittance along the transfer line (left) and the measurement line (right). The blue arrow marks the point where the beam is deflected into the measurement line.

Simulation of the Energy Measurement Line

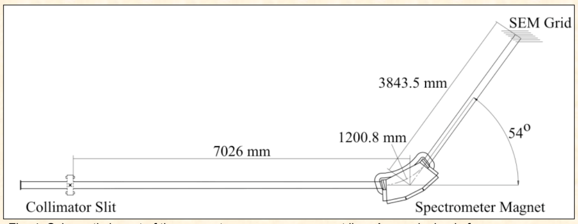

Fig. 4: Schematic layout of the present energy measurement line. A new design is foreseen.

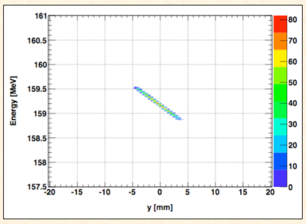

Fig. 5: Correlation between energy and vertical position for the nominal energy distribution.

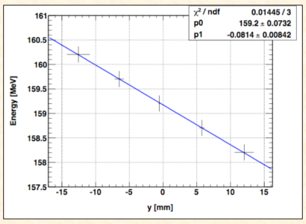

Fig. 6: Correlation between mean energy and fitted vertical position.

- **Measurement Method:** Beam slice selected by collimator slit, analysed by spectrometer magnet with edge angle focusing onto SEM grid (Fig. 4)
- Correlation between particle energy and vertical position on SEM grid (Fig. 5)
  - Spread on energy axis depending on slit dimension
  - Normalised energy resolution: $dE_{kin}/d \approx 80$ keV/mm
  - Projection to position-axis fitted by polynomial (2nd order) ⇒ mean energy
- Energy systematically shifted within ±1 MeV to account for energy painting
  - Linear correlation between central energy value and position (Fig. 6)
- Determine beam size to calculate energy/momentum spread

$$\frac{dp}{p} = \frac{1}{D}\sqrt{\sigma^2_{meas.} - (\varepsilon \cdot \beta)^2}$$

- Keep correction from second term small, here ≈ 0.5 % (relative to first one)
  - → Reduce emittance by slit
  - → Install SEM grid in minimum of vertical beta-function
- Get dispersion D from simulation

$$\frac{dE_{reco} - dE_{true}}{dE_{true}} \approx 1.3\%.$$

Simulation of the Emittance Measurement Line

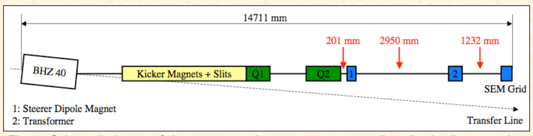

Fig. 7: Schematic layout of the present emittance measurement line. As the line must be kept for heavy ion operation it can only be modified in the red marked spaces. The available lengths are noted as well.

- **Measurement Method**: Modify beam evolution by pair of quadrupoles, measure beam sizes (x_j) before, close to and behind a beam waist (Fig. 7, 8)
- Solve linear equation system to get emittance and Twiss-parameters (β_j) with transfer matrix elements (M) between beam monitors from simulations

$$M \cdot \vec{\beta} - \vec{x}^2 = 0$$

- Results depend on resolution of beam size measurement
  - Aim at getting resolution better than 100 µm
  - Non-linear space charge effects sufficiently negligible for linear formalism

	10 µm	100 µm
horizontal	0.14%	- 4.99%
vertical	- 0.50%	- 1.01%

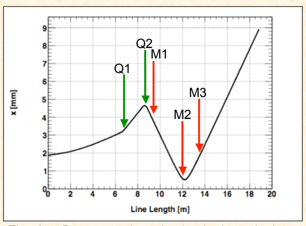

Fig. 8: Beam envelope in the horizontal plane (quadrupoles: green, beam monitors: red).

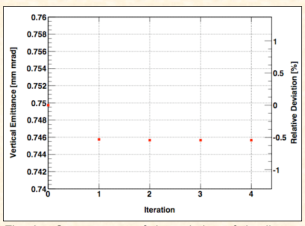

Fig. 9: Convergence of the solution of the linear equation system for the vertical emittance (reference value for iteration 0).

- Stability of solution tested by iteratively solving the equation system (Fig. 9)
- Systematic error controllable (quad. settings, alignment ⊕ transfer matrices)

$$\Delta\varepsilon_{hor.} \approx 2.15\% \oplus 0.65\%$$

$$\Delta\varepsilon_{ver.} \approx 0.78\% \oplus 0.19\%$$

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