Status of transfer line collimation and LHC protection at injection

- Reference numbers. Intensities, number of sigma

- Detailed look at transfer line Ti8

- Possible protection system and its expected performance
reference numbers  collimation should be at least ok for nominal SPS (450 GeV)
• 1.1e11 protons per bunch,  ε = 7.82 nm (ε_N = 3.75 µm),  σ_e = 4.68 x 10^{-4}
• 72 bunches per batch
• 3 or 4 batches,  max. intensity 4x72x1.1e11 = 3.2e13
  (and 4x72x1.7e11 = 4.9e13 or about 5e13 ultimate),  4/11 of an SPS turn or 7.2 µs

LHC, 450 GeV (injection)
• 1.1e11 per bunch
• 2808 bunches,  in total 3.1e14 protons  (2x12 SPS pulses)

Extraction done in single SPS turn at 450 GeV.  For fast losses
• Damage level ~ 2e12 protons  and  Quench level ~ 1e9 protons

Attenuation factor for passive protection in the transfer lines:
> 20 to avoid damage  (better of order 100, Brennan)
From the SPS to the LHC

under standard running conditions, well adjusted, high intensity

• SPS shave the beam before extraction to $4\sigma$ in V and H injection tolerances:
  SPS c.o., SPS extraction, transfer line ripple and drifts, injection kicker ripple and drifts, all together $1.5\sigma$ (LHC Report 208)
or $5.5\sigma$ filled with incoming beam in the LHC

• LHC: injected beam with tolerances and injection oscillations after about 1/2 turn:
  primary collimators at $6-7\sigma$, secondaries at $8.5-10\sigma$
  TDI, prim. and secondary collimators can survive full batch $3-5\times10^{13}$ possible failures, and protection
  SPS LSS4 fast $1.1\,\mu$s extraction kicker MKE, $0.5$ mrad in H followed by DC septum MSE, protected by TPSG ($4m, C + Al + Cu$)
  Vertical Injection kicker MKI at end of Ti2/8
  TDI protection against kicker failures $8-10\sigma$ in V
  wrong bending fields in pulsed transfer lines
Injection Region, here IP2  (IP 8 injected beam comes from the bottom)

- MSI thin, tight septum magnets with horizontal deflection
- MKI vertical kicker, brings beam in LHC plane
- TDI + secondary coll. downstream IP, to protect in V against kicker failures

- the transfer line (warm magnets) is turned off when no injection is needed and pulsed horizontal extraction from SPS (MKE) and many horizontal + some vertical bends, wrong bending could result in local loss of full intensity 
  most critical: end of line with tight septum

--> passive protection for septum needed. At the same time limit injection oscillations.
Septum MSI Ti8, seen from the side

Circulating LHC Beam 2

Injected Beam 1.192 mrad

Ø 13 mm
β_x = 99 m, β_y = 116 m
7.4 \sigma_x, 6.9 \sigma_y

Ø 17 mm for beam
β_x = 59 m, β_y = 202 m
13 \sigma_x, 7 \sigma_y
Septum MSI Ti8, seen from the top, in the plane of the circulating beam
Proposal

1) H  momentum cleaning at beginning of the line
2) V  about 90° from Septum and 180° in H, in front of TED
3) H  about 90° from Septum
4) Septum protection

with number for optics in Ti8:

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$5\sigma$ collimation would imply rather narrow apertures

H $\pm 2.3$ mm at QI15
V $\pm 2.8$ mm at QI14
abs(s-1816.12).lt.1.and.1.gt.0

final x and y when lost at collqi14

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Transfer Line Collimation Performance Estimate

- momentum collimation  \( D_X = 3.5 \text{ m}, r_X = +/- 3.2 \text{ cm}, \sigma_X = 2 \text{ mm} \).
  \[ \text{max. momentum acceptance arc } \Delta E/E = +/- 2.8 \text{ cm}/3.5 \text{ m} = +/- 0.8 \% \]
  \[ \text{mom. collimation at } D_X = 3 \text{ m}, \beta_X = 100 \text{ m}, 1\sigma = 1.7 \text{ mm}, \text{ set to } 5\sigma \text{ or } +/- 8.5 \text{ mm} \]
  \[ \Delta E/E = +/- 8.5 \text{ mm} / 3.5 \text{ m} = +/- 0.24 \% \]

- betatron collimation estimate,
  \[ \text{critical thickness in carbon at } 450 \text{ GeV } b_c = 12 \mu\text{m} \]
  \[ \text{for flat losses over } 5 \text{ mm } \text{collimation by } 5 \text{ mm}/12 \mu\text{m} = 420 \]
  \[ \text{worst full impact of small beam } s = 0.5 \text{ mm}, \text{ still collimation by about } 40 \]

  \[ \theta_0 = \frac{13.6 \text{ MeV}}{\beta cp} \sqrt{x/X_0} \left[1 + 0.038 \log(x/X_0)\right] \approx 53 \mu\text{rad} \]

Graphite  \( \rho = 2.3 \text{ g/cm}^3 \); nuclear interaction length \( \lambda = 26.6 \text{ cm} \), \( 2\lambda \) as distance \( x \), \( X_0 = 18.8 \text{ cm} \)