Machine protection requirements for crab cavity MDs with unsafe beam intensities

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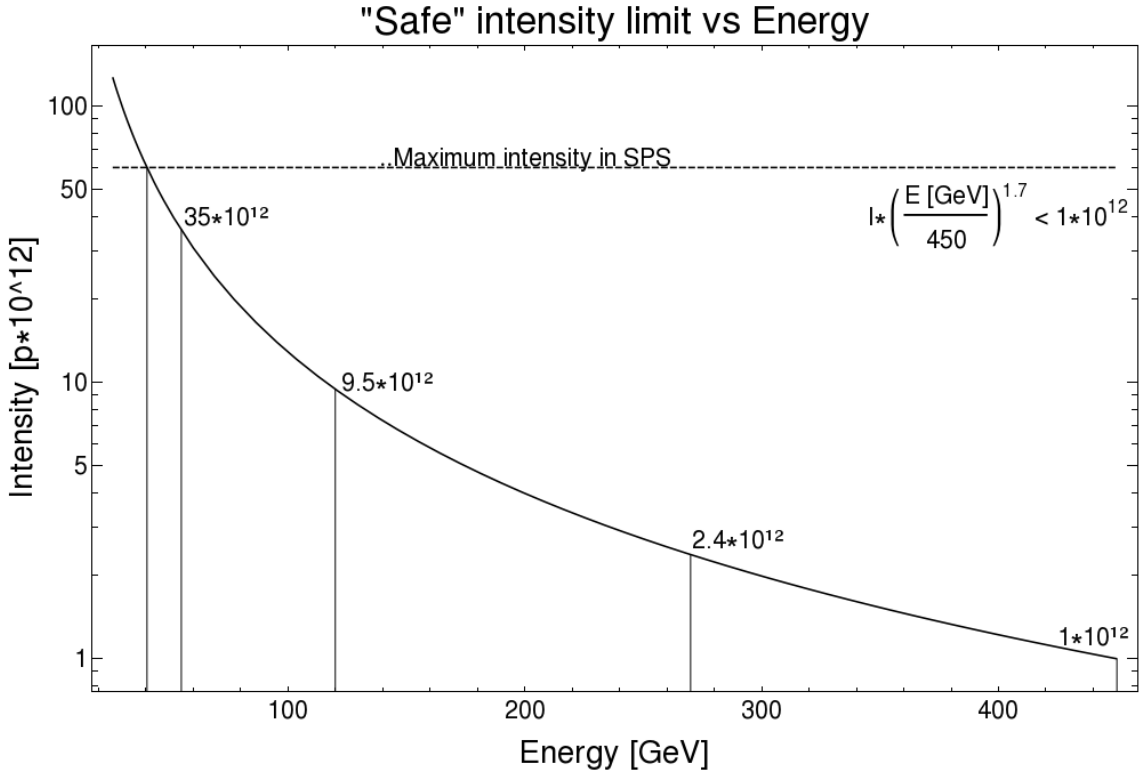
Re-cap Safe intensity limits for Crab Cavity MDs in SPS



- Crab cavity MDs in early stage should be performed with total beam intensities **factor 10 below** the 'safe intensity' limit, i.e.:
  - @ **26 GeV: < 6 x 10^{12}**; @ 55 GeV: < 3.5 x 10^{12} ; @ 120 GeV: < 9.5 x 10^{11}
  - @ **270 GeV: < 2.4 x 10^{11}**; @ 450 GeV: < 1 x 10^{11}

Overview of criticality of failures (simulations / observed during MDs)

- **Crabbed beam** entering aperture in case of fast voltage ramp (> 3.2 MV @ 26 GeV) → only **critical at 26 GeV → limit total** crabbing **voltage** at 26 GeV
- **Static dipole** kick on beam center → only **critical @ 26 GeV** (at 270 GeV aperture cannot be reached) → **limit voltage** in single crab cavities @ 26 GeV
- **Resonant excitation** of beam by crab cavities (frequency shift between SPS-RF and CC-RF) → beam lost in aperture within **<1 ms** → interlock successful **re-phasing** / interlock **frequency difference** between SPS-RF and CC-RF / limit **CC voltage** during non-phased operation
- Note: SPS ring BLMs have 20 ms reaction time

Proposal of required sanity checks and interlocks for high intensity operation

- Implement **consistency check** of crab cavity low level RF **set-parameters** → define as machine critical settings in LSA and ensure keeping operational envelope
- Implement **fast interlock channel** from RF interlock → beam dump in case of switch off of low level RF
- Interlock successful **re-phasing** of SPS-RF and CC-RF (BA3) – keep CC voltage **below 50kV** until confirmed re-phasing at 270 GeV
- Interlock **frequency difference** between SPS-RF and CC-RF (BA3)
- Validate (fast) interlocks as far as possible before high intensity MD.

Proposal of required beam tests before high intensity operation

- Measurement of **delay of IOT fast interlock** through table interlock matrix to BIC
- Verify triggering and reaction time of **SPS ring BLMs** and **identify loss location** during failure cases
- Measure **rise time of losses** for resonant excitation at 26 GeV and 270 GeV with different crab cavity voltages (0.5 MV – 2 MV) and the two cavities and **compare to simulations**
- Measure **static crab cavity kick** at 26 GeV and 270 GeV with different crab cavity voltages (0.5 MV – 2 MV) and **compare to simulations**

Conclusion

- **Resonant excitation** of beam via crab cavities has been observed and is (so far) most critical failure case for test campaign in the SPS.
  - further measurement of rise time of losses required
- SPS ring BLMs cannot catch any problem **< 20 ms**
- Use of crab cavities with high intensity beam requires the implementation of **fast interlocks** (RF IOT, re-phasing, frequency difference)

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