# Machine Protection for SPS Crab Cavity MDs

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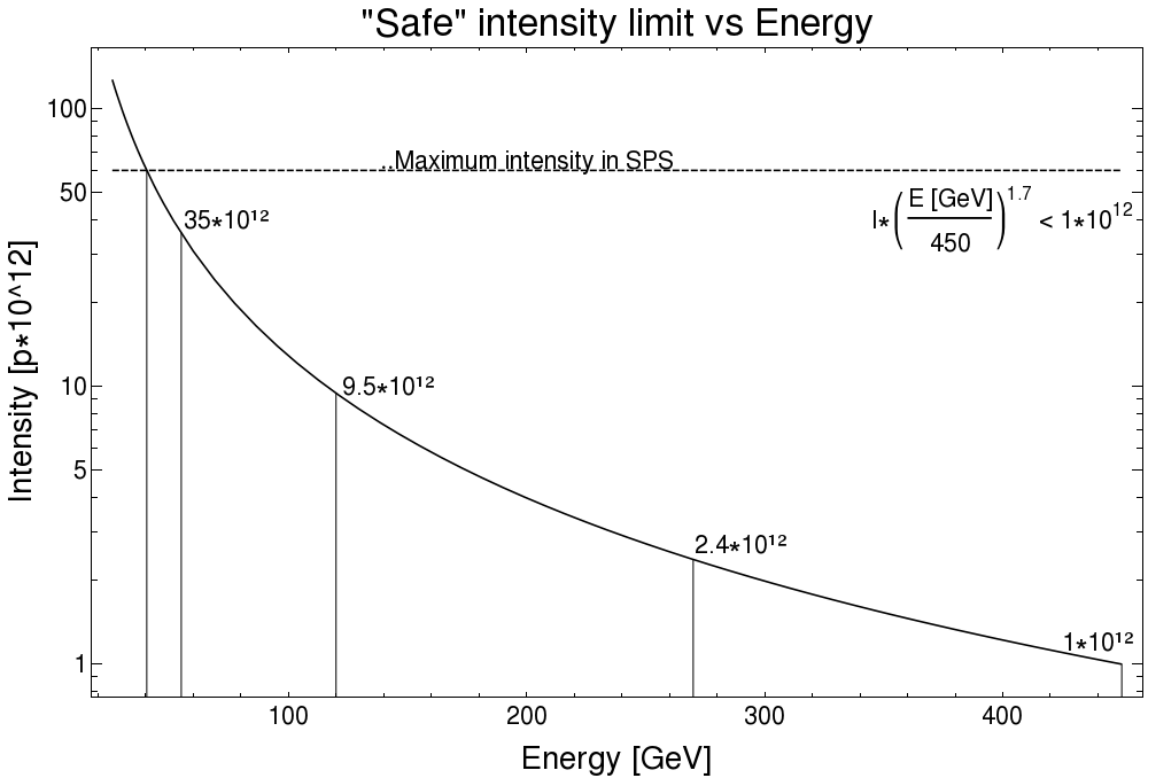
# Outline

- Re-cap crab cavity failures cases
- Re-cap of criticality of CC failures in the SPS
- Experiments requested for Machine Protection (SPS and HL-LHC)
- Requirements before first CC operation with beam in SPS
- Requirements after RF commissioning
- Requirements before CC operation with higher intensity beams in SPS

# Re-cap Crab Cavity failure cases

- Crab cavities can potentially cause **fast orbit distortions** (>1.5 sigma within 1 LHC turn) leading to high losses into the aperture
- Full simulation model of crab cavities missing → **estimate criticality of failures** for HL-LHC by studying 'corner cases' (see A. Santamaria Garcia's PhD thesis):
  - **Voltage decay**: sudden drop of crab cavity voltage
  - **Phase jump**: sudden change of crab cavity phase
  - **Phase slip**: continuous change of crab cavity phase
- **Combined failures** are under study (see IPAC18 paper by B. Lindstrom et al.)
- **Criticality** of crab cavity failures has also been studied **for the SPS**

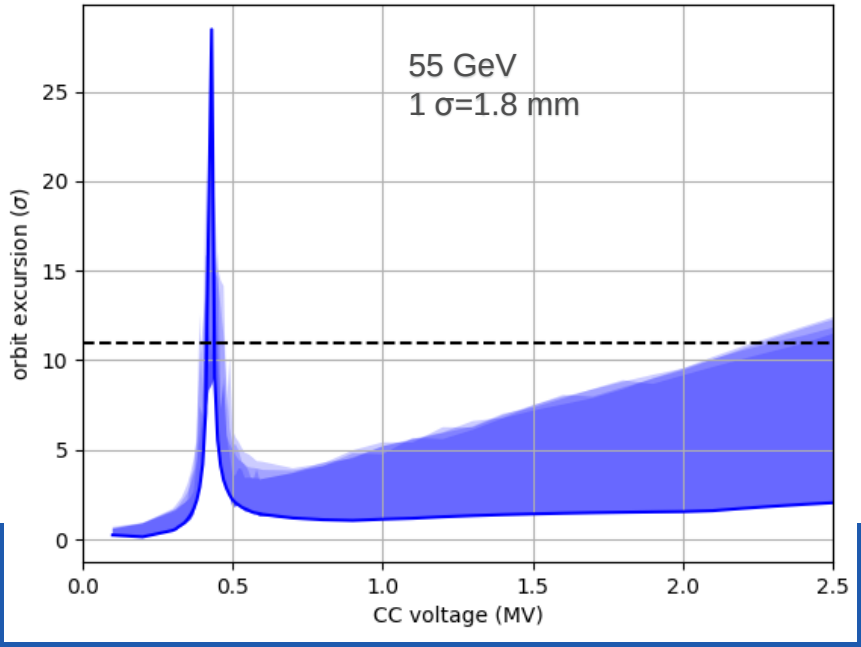
# Re-cap Safe intensity in SPS

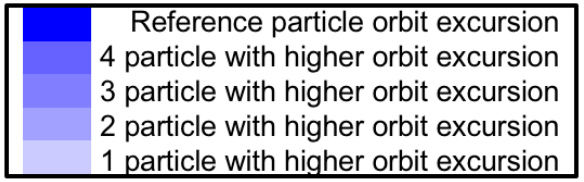



- Crab cavity MDs in early stage should be performed with total beam intensities **factor 10 below** the 'safe intensity' limit, i.e.:
  - @ 26 GeV: < 6 x $10^{12}$; @ 55 GeV: < 3.5 x $10^{12}$ ; @ 120 GeV: < 9.5 x $10^{11}$
  - @ 270 GeV: < 2.4 x $10^{11}$; @ 450 GeV: < 1 x $10^{11}$
- Experimental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

# Re-cap criticality of CC failures in SPS

- Voltage drop: non – critical for SPS
- Phase jump: non – critical for SPS
- Phase slip: **critical** especially for energies <450 GeV → potentially driving of resonance if phase slip close to tune




- Simulation with 5 particles with different $J_z$ and $J_x$=$J_y$=0 in phased mode, assuming a worst case continuous phase slip
- Ideal machine, no misalignments etc.

# Requested Experiments with CC in the SPS for Machine Protection

| | Voltage drop | Voltage drop with LLRF* | Phase jump | Phase jump with LLRF* | Phase slip on resonance | Phase slip High voltage | Cavity Quench |
|---|---|---|---|---|---|---|---|
| **Phased 55, (120), 270 GeV** | X | X | X | X | X | X | X |
| **Transparent (26), 55, (120), 270 GeV** | X | X | X | X | X | X | X |

*With the LLRF trying to compensate for the failure by matching the voltage/phase of the other cavity.

- Machine protection experiments are required to **validate** simulation models and **verify** existence and **criticality of failure cases**
  - **Pre-requisite** for SPS high intensity operation of CC
  - **Essential** input for CC interlocking requirements in HL-LHC
- Need to be **integral part** of test plan
- Will be performed with **low intensity** beam, **details** to be defined

# Before first CC tests with beam

In dedicated Machine Protection Panel meeting **before first** crab cavity **operation with beam**:

- Test stand **interlock specification** document EDMS document 1843638 released.
- **Verification** of correct functioning of interlock matrix for test stand (see. G. Vandoni's presentation in 153rd MPP)
  - Test procedures?
  - Results of tests documented?
- Thresholds agreed for additional BLMs and triggering tested?
- OK to take beam with crab cavities?

# After RF beam commissioning (MD1/2) and first beam tests

In dedicated MPP meeting (**before MD3/4** )

- Review of **status and functioning** of CC interlock matrix, additional BLMs incl. thresholds and triggering history
- Status of **low-level RF controls** in respect to machine protection – reliability of operation, protection of change of critical parameters etc.
- **Availability and exploitation** of beam instrumentation to assess failure cases
- **Detailed beam test procedures** in view of machine protection requirements.

# Before High Intensity CC Operation in SPS

In **Machine Protection Panel** meeting (Before MD6/7)

- Review of **status and functioning** of CC interlock matrix, additional BLMs incl. thresholds and triggering history
- Status of **low-level RF controls** in respect to machine protection – reliability of operation, protection of change of critical parameter etc.
- Review of **beam tests** (ramp, etc.) and results in view of machine protection
- Ready for **unsafe intensities**?
- Review of results of **failure case studies with beam** (voltage drop, phase slip, phase jump, quench)
- Availability and exploitation of **beam instrumentation** to assess failure cases
- Definition of **operational window** of coming intensity steps, additional tests etc.

# Conclusion

- Three dedicated MPP meetings (before first beam operation, after RF commissioning and before higher intensity operation) to ensure readiness from machine protection point of view.
- Machine protection experiments need to be an **integral part** of beam experiments
  - HL-LHC interlocking requirements for crab cavities
  - SPS criticality of failures with high intensity beam

# List of documents on CC failures

- B. Lindstrom: *First results from crab cavity failure studies for the SPS*, 6th Meeting on Crab Cavities Failure Studies (17.02.2017)
- M. Valette: *Failure cases for the Crab Cavities in the SPS*, 7th HL-LHC Annual meeting (Madrid, 13.-16.11.2017)
- B. Lindstrom, M. Valette: *Discussion on Machine Protection MDs in the SPS*, 8th Meeting on Crab Cavities Failure Studies (07.04.2017)
- A. Santamaria Garcia: *Experiment and Machine Protection from Fast Losses caused by Crab Cavities in the High Luminosity LHC*, PhD thesis 2018

# Discussion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