Effect of crab cavity non linearities with and without beam-beam: results of weak-strong simulations

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Acknowledgements: María Navarro Tapia, Rama Calaga

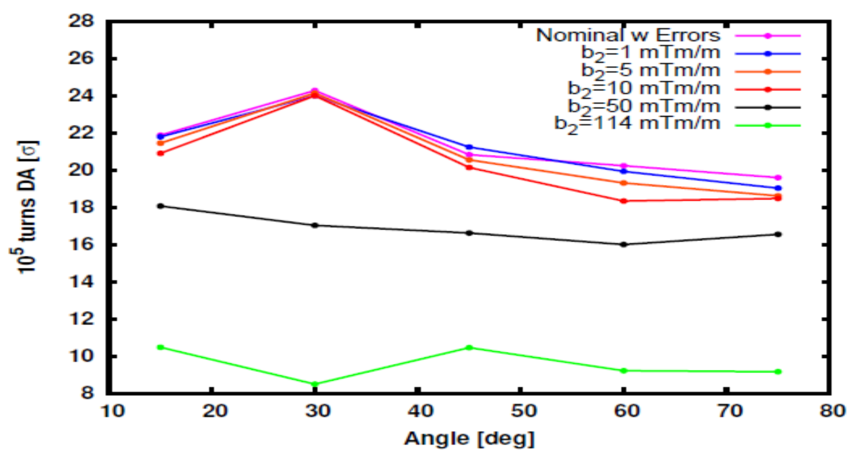
Introduction

- All CC designs are not axially symmetric thus giving rise to time varying high order multipoles in the form (for a normal quadrupole),

$$\Delta x' = -b_2 x \cos\left(\frac{\omega_{cc} z}{c} + \phi + \phi_{RF,quad}\right)$$

- These multipoles oscillate with f_{cc} not being possible to correct them with "traditional" techniques. Instead they should be minimized by design.
- In the HLLHC 2012 meeting some tolerances were given for a certain scenario (slhcv3.1b optics and magnets errors).
- The 2012 results presented a large initial dynamic aperture value made RF multipoles effect quite visible driving tight tolerances for 1σ DA decrease consideration. Nevertheless beam loading tolerance (< 1 mm) was the driving factor.

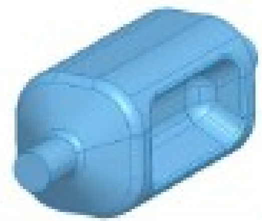
  - QWCAV (only HV) $|d_{x,y}| < 2$ mm
  - RWCAV (HH or HV) $|d_{x,y}| < 0.75$ mm
  - 4RCAV (HH or HV) $|d_{x,y}| < 2.7$ mm

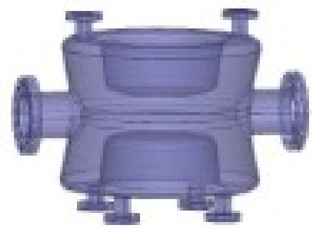


J. Barranco, R. Tomas *"RF multipoles: modelling and impact on the beam"*, *2nd Joint HLLHC-LARP meeting.*

Crab Cavities - RF Multipolar Kicks Simulations

- **Normal components:**





	Latest prototypes (as of 2012)		
bn [mT/m^{n-1}] *	RF-dipole cavity	Double QW cavity	4-rod cavity
b2	0	0	0
b3	4530	1080	1162
b4	0	0	0
b5	$-0.4\cdot10^6$	$-0.097\cdot10^6$	$-2.3\cdot10^6$
b6	0	0	0
b7	$-288\cdot10^6$	0	$-666\cdot10^6$

* Normalized to a nominal deflecting voltage of 10 MV

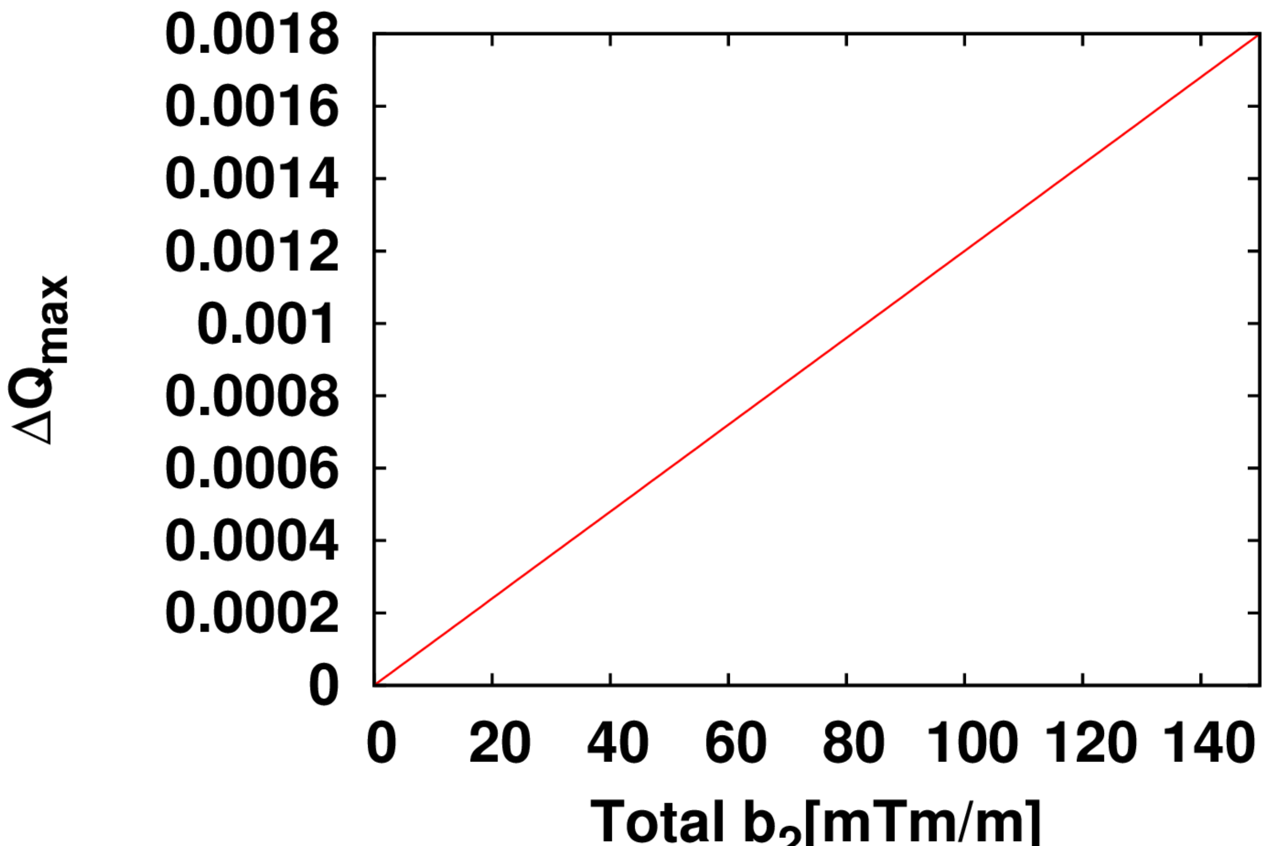
- **Skew components:** Ongoing simulations with realistic fabrication errors to assess the order of magnitude.

Courtesy of M. Navarro Tapia, R. Calaga

Optical aberrations

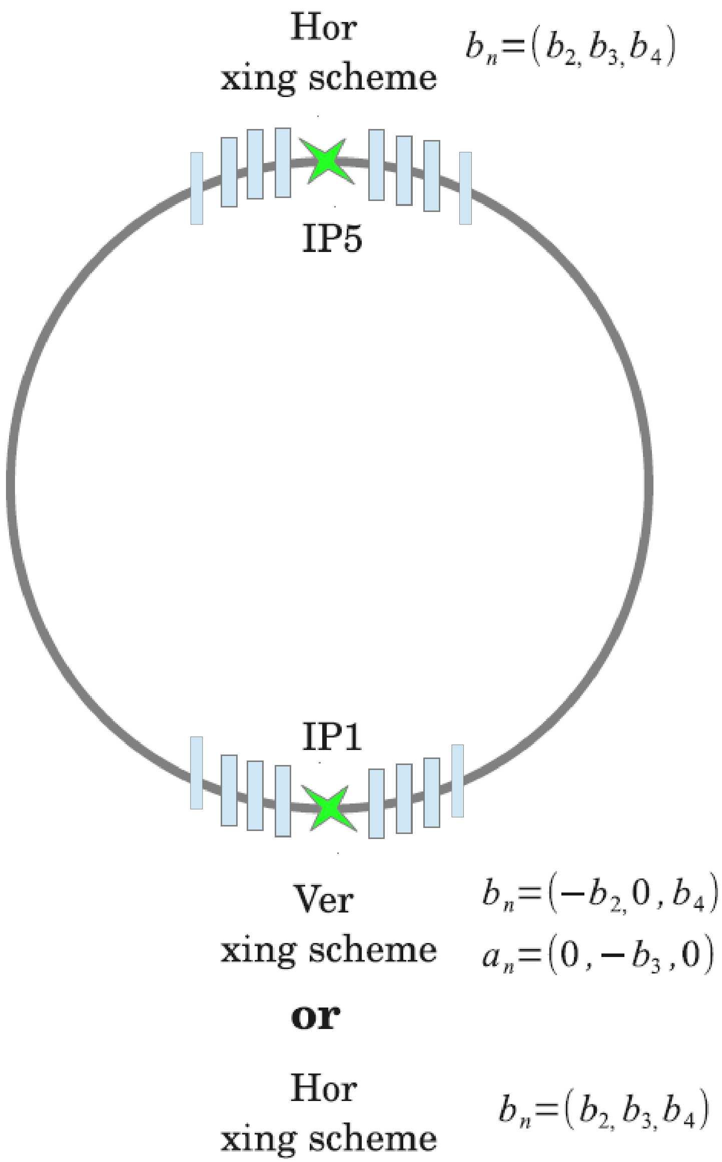
- A non-zero b2 could produce a non-neglilible tuneshift.

$$|\Delta Q_{x,y}| = \frac{1}{4\pi}\beta_{x,y}\frac{b_2}{B\rho}$$



- Other higher order multipole optical aberrations were studied in the past and showed not significant effect.

Reminder Crossing Schemes



- Symmetric horizontal CCs would present only normal components b_n.
- Baseline scenario is Horizontal crossing at IP5 and Vertical at IP1. This is preferred from the beam-beam point of view.
- For a 90° rotated cavity (V crossing) the multipolar content becomes,

$$b_n=\{-b_2, 0, b_4\}$$

$$a_n=\{0, -b_3, 0\}$$

- So in a HV scenario there is a **natural compensation of the b_2 effect.** While the HH case is a worst case scenario.

Dynamic Aperture Simulations

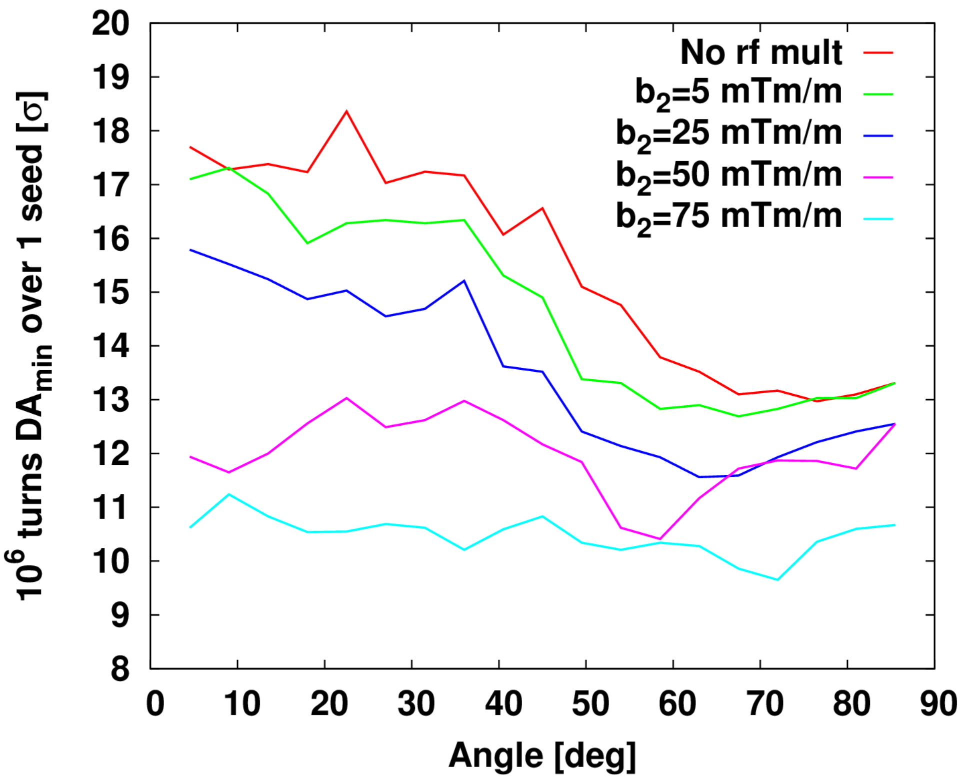
- Studies done using the **SixDesk environment** running in both LSF and BOINC queues.
- The HLLHCv1.0 optics are used with main parameters,

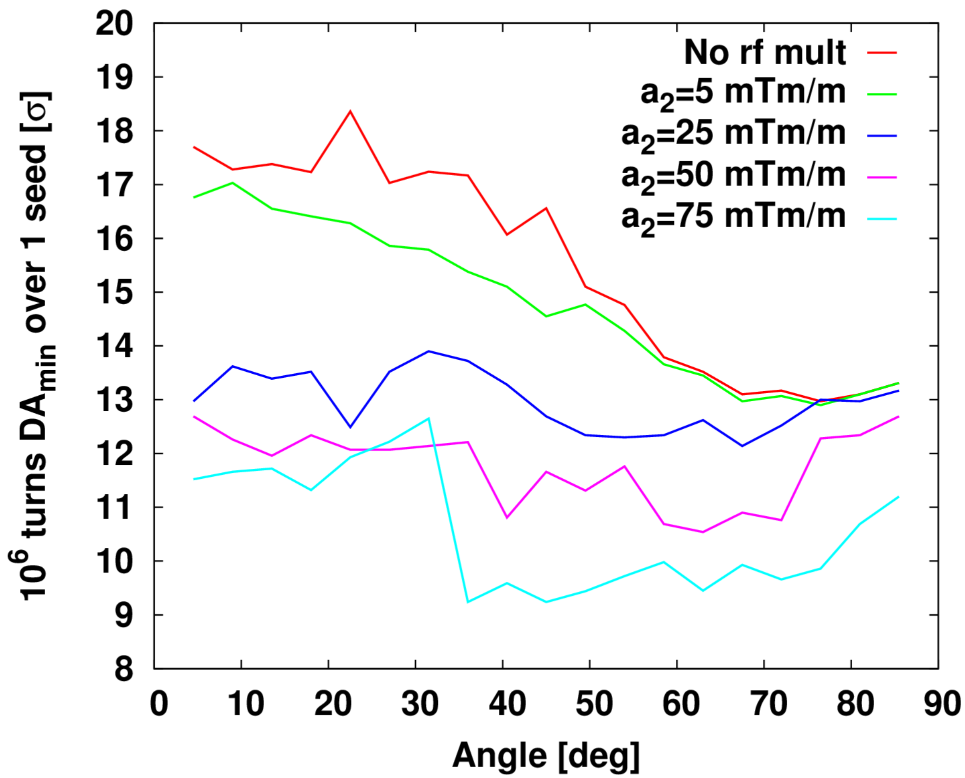
Parameter	Value
$\beta^*_{x,y}$[cm] IP1/5	15
σ_z[cm]	7.5
θ[μrad]	590
I[ppb]	$1.1\ 10^{11}$ ← β^* levelling
f_{cc}[MHz]	400
f_{RF}[MHz]	400
$\varepsilon_{n,x,y}$[μrad]	2.5

- Beam-beam effects HO(6D)+LR at IP1&5.
- Latest magnets errors included but only 1 seed evaluated due to time constraints.

Simulations w/o beam-beam interactions

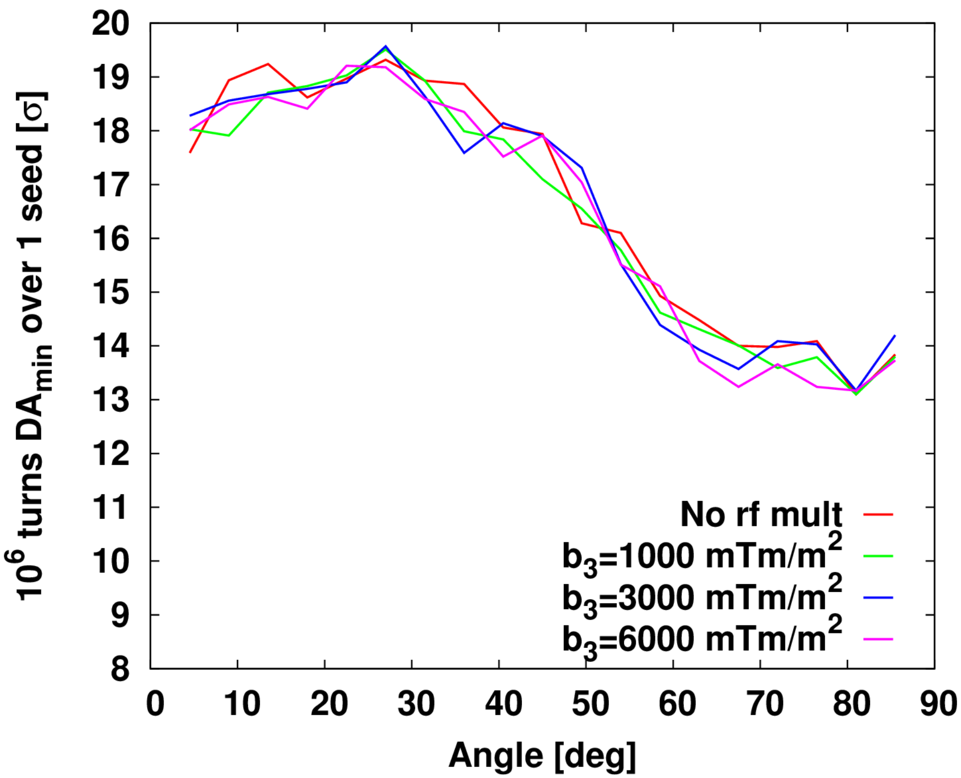
Right plot is an actual realistic scenario H_{IP5}-V_{IP1} with symmetric CCs (only b3).

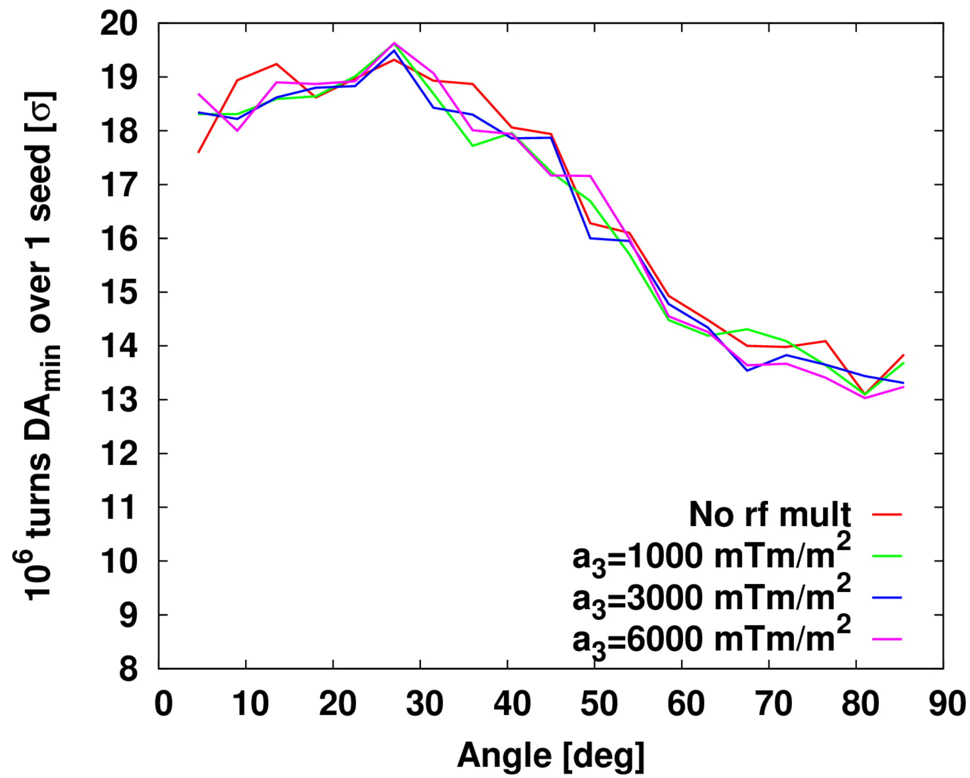




- Tracking over 10^6 turns and scanning 19 phase space angles.
- The b_2 value quoted is normalized per 10MV deflecting voltage.
- Only magnets errors (1 seed) → $DA_{min} \sim 13\sigma$.
- Similar DA evolution for b_2 and a_2.

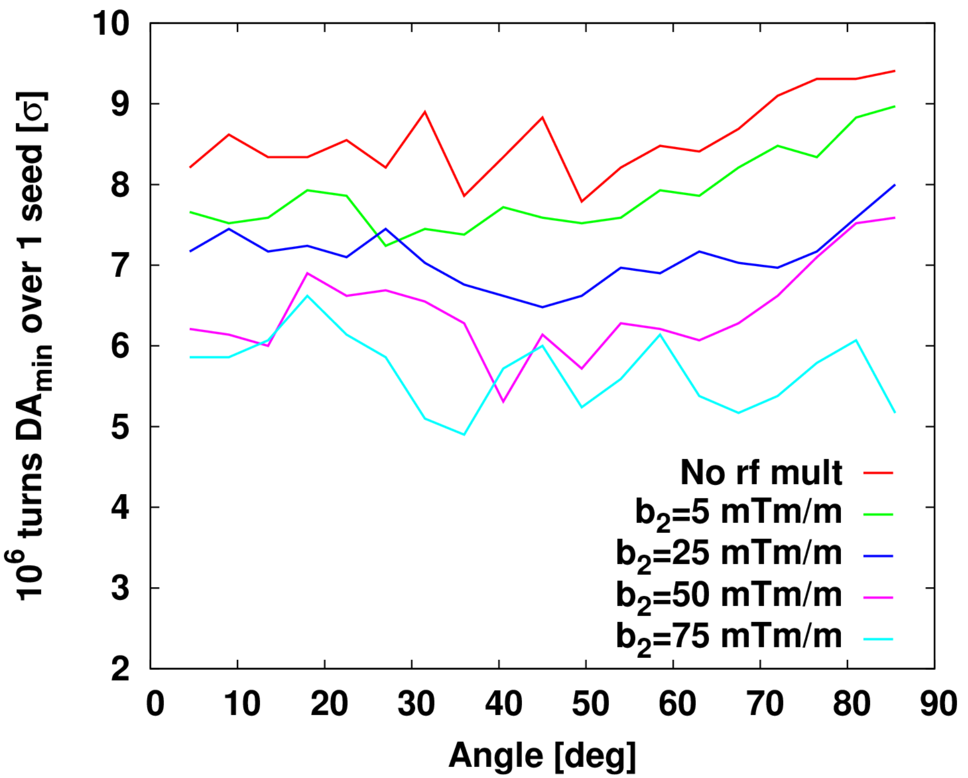
Simulations w/o beam-beam interactions

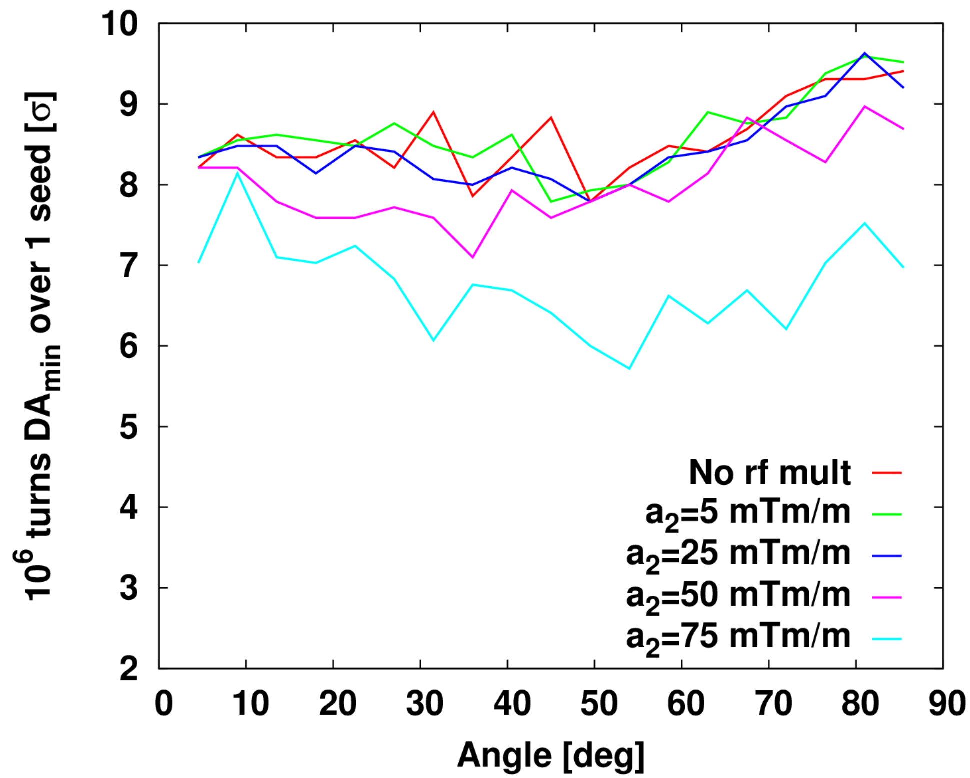




- Tracking over 10^6 turns and scanning 19 phase space angles.
- The b_3 value quoted is normalized per 10MV deflecting voltage.
- Only magnets errors (1 seed) → DA_{min} ~ 13σ.
- No DA impact observed in both cases b_3 and a_3.

Simulations with beam-beam interactions

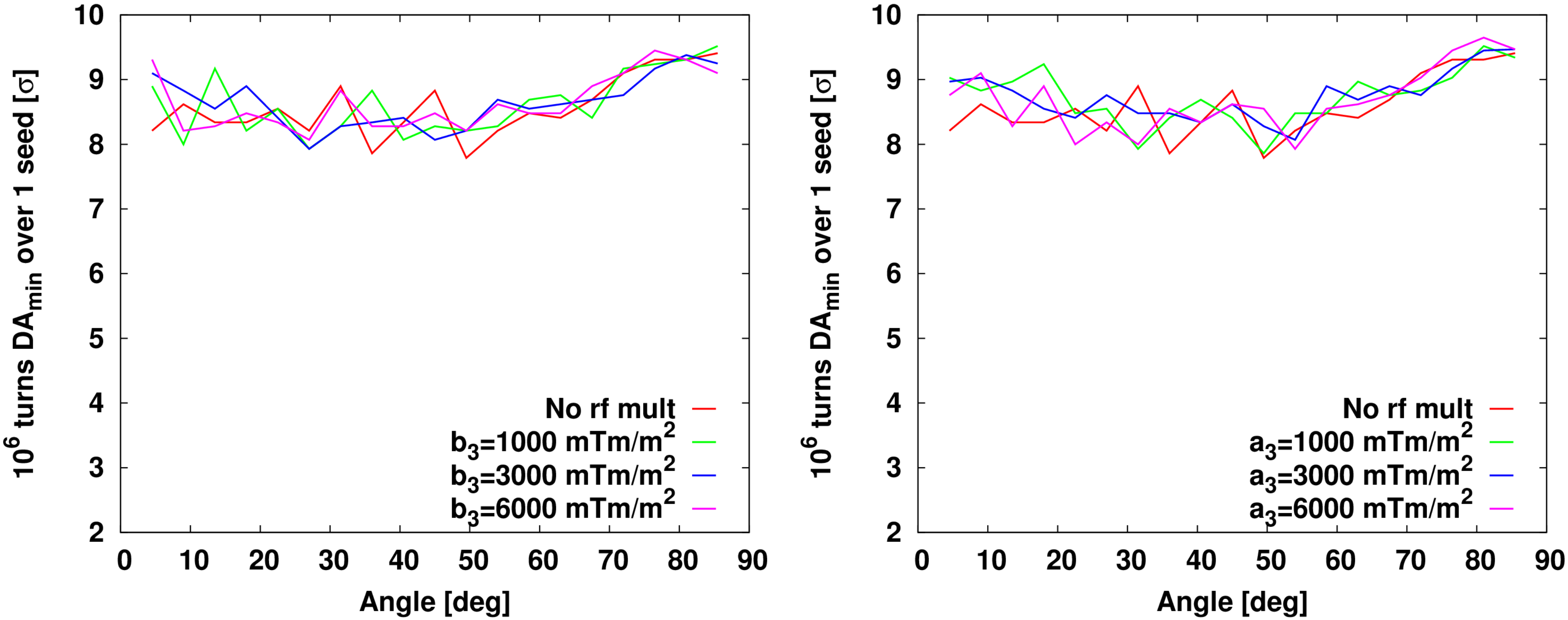




- Tracking over 10^6 turns and scanning 19 phase space angles.
- The b_2 value quoted is normalized per 10MV deflecting voltage.
- Only magnets errors (1 seed) → $DA_{min} \sim 8\sigma$.
- Faster DA decay for b_2 than for a_2 (related to coupling?).

Simulations with beam-beam interactions

Right plot is an actual realistic scenario H_{IP5}-V_{IP1} with symmetric CCs (only b3).

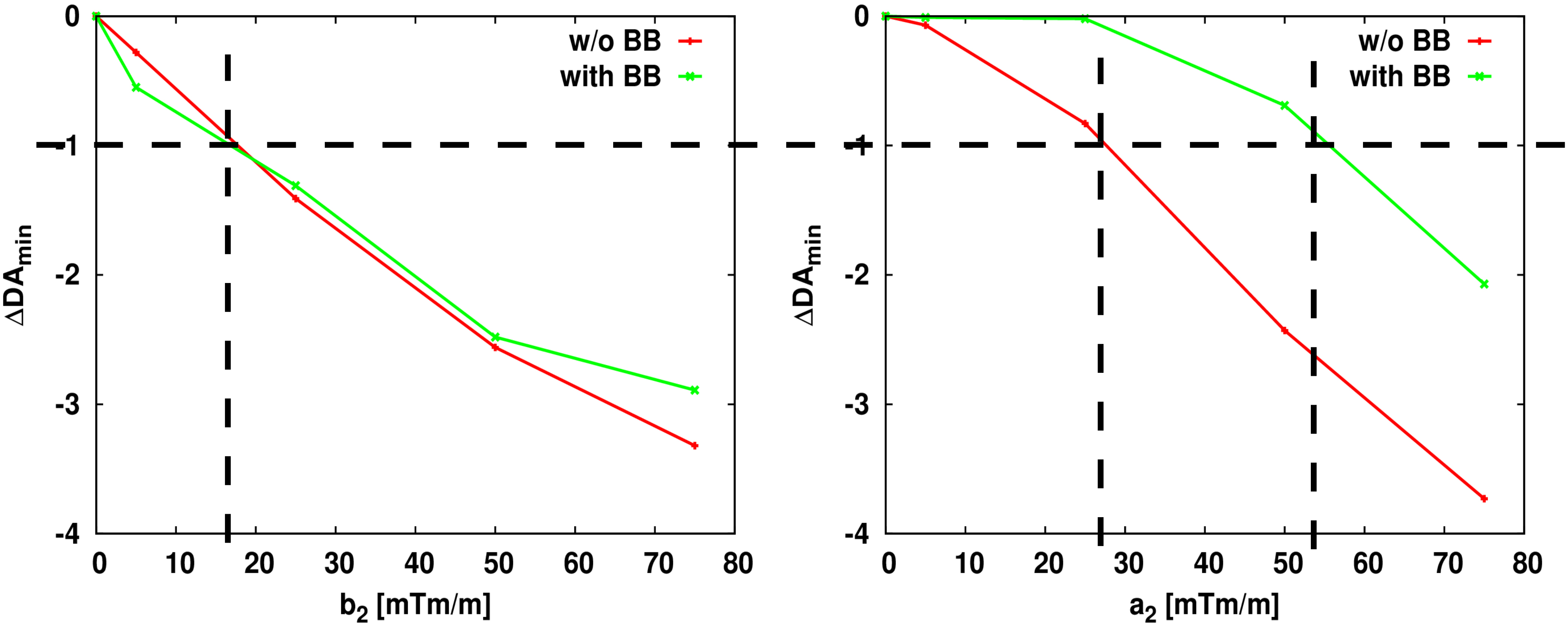


- Tracking over 10^6 turns and scanning 19 phase space angles.
- The b_3 value quoted is normalized per 10MV deflecting voltage.
- Only magnets errors (1 seed) → $DA_{min} \sim 8\sigma$.
- No DA impact observed in both cases b_3 and a_3.

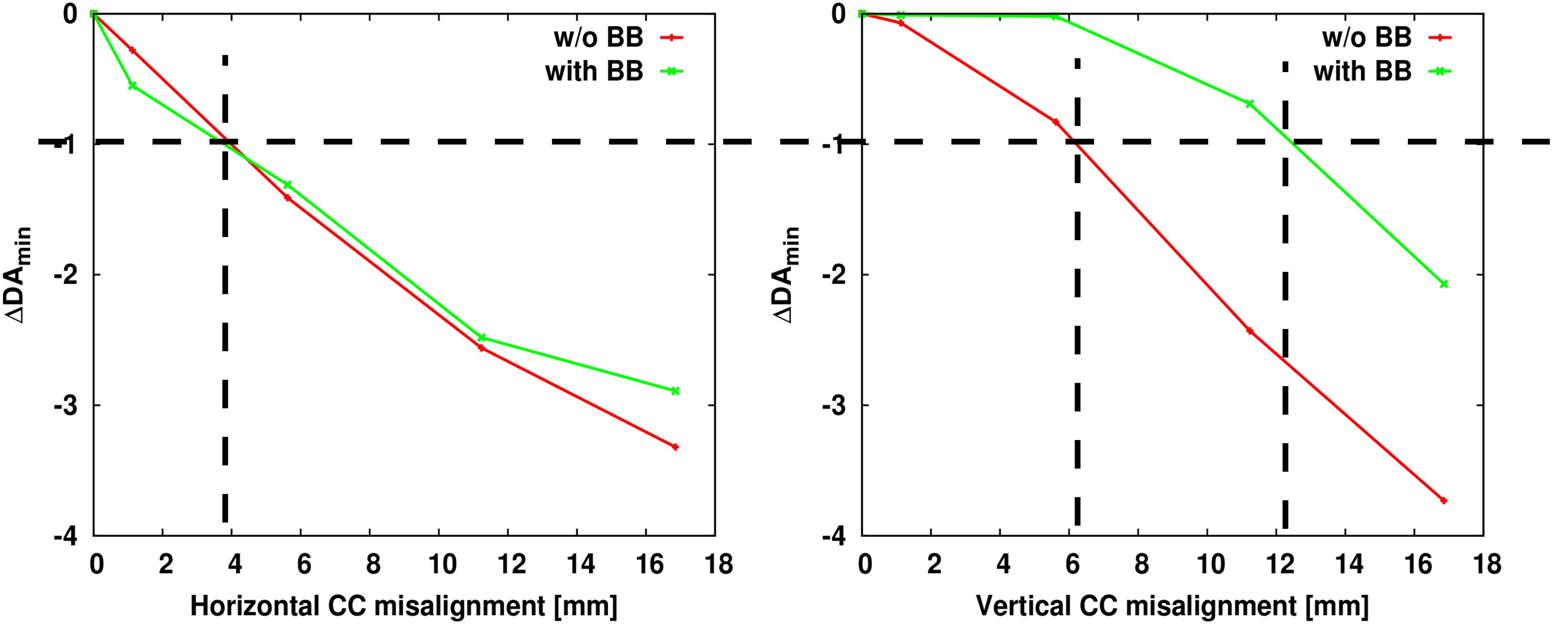
Tolerances criteria

- These simulations aims not to set hard limits for tolerances but rather orders of magnitude.
- As in the past an **arbitrary** maximum DA decrease allowed of 1σ is considered for all scenarios.
- Three tolerances are given,
  - Maximum b_2 and a_2.
  - Maximum displacement (d_x, d_y) of b_3,a_3. (for a worst case of RF Dipole Cavity b_3=4530 mTm/m^2).
  - Maximum b_3,a_3 for a displacement d_x=$d_{y=}$1 mm (beam loading tolerance).

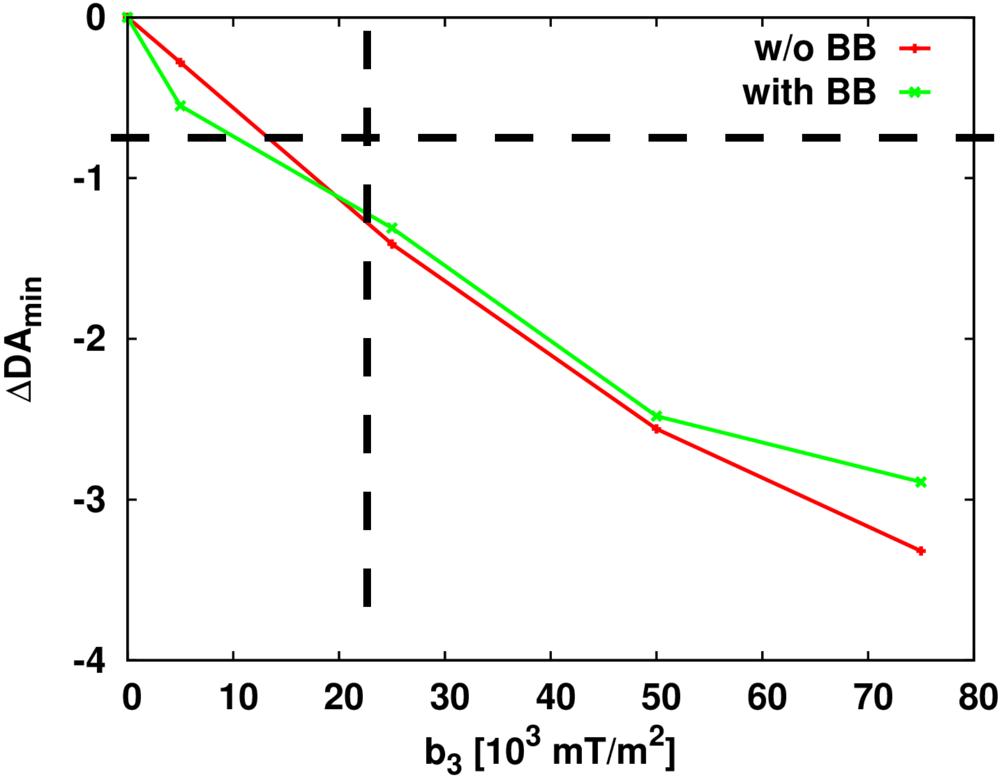
Maximum b_2,a_2 tolerance

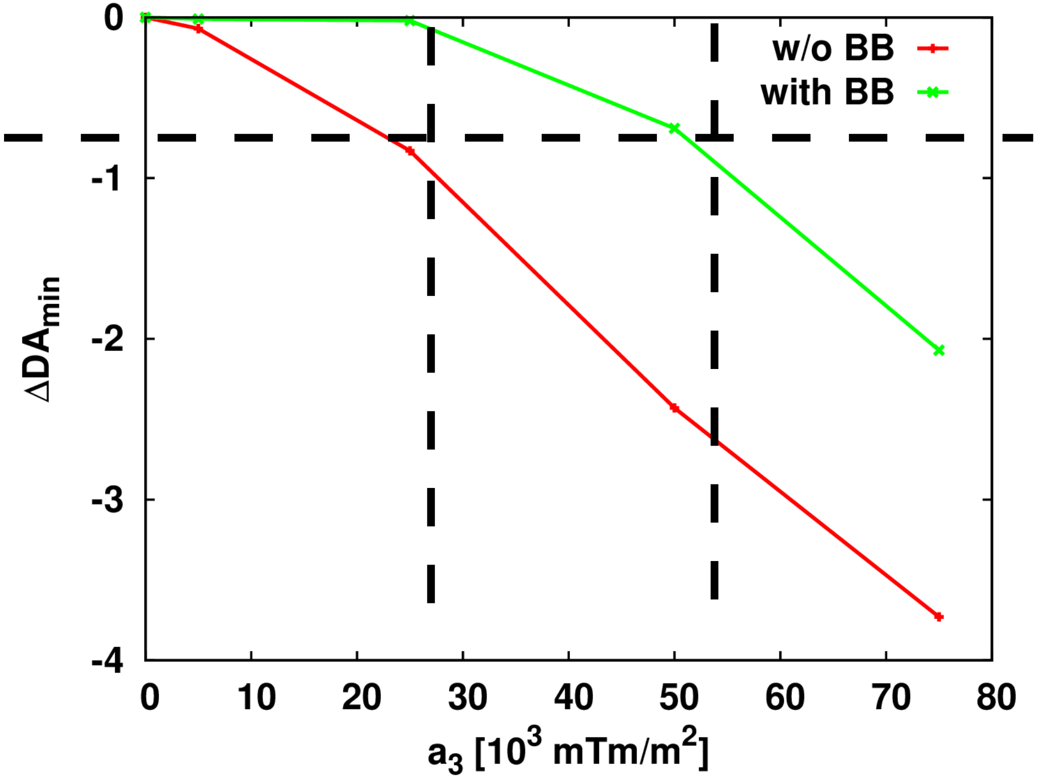


Maximum CC misalignment tolerance



Maximum b_3,a_3 tolerance





Conclusions

- The ideal baseline scenario V_{IP1}-H_{IP5} and symmetric cavities (i.e. only b_3) **is OK with and w/o BB.**
- Summary tolerances for 1σ drop for the 3 criteria,

	w/o BB	with BB
b_2[mTm/m]*	16	16
b_3 (d_x=1mm) [mTm/m^2]*	18 10^3	18 10^3
d_x(b_3=4530 mTm/m^2) [mm]	4	4
a_2[mTm/m]*	27	53
a_3 (d_y=1mm) [mTm/m^2]*	28 10^3	55 10^3
d_y(a_3=4530 mTm/m^2) [mm]	6	12

* Normalized to Vcc=10 MV

- Simulations performed for 1 error seed. Full 60 seeds study might tighten tolerances, however not below beam loading tolerances .
- All the tolerances are assuming an arbitrary criteria and should be adapted to a particular scenario.

Back Up Slides

Crab Cavities - RF Multipolar Kicks Measurements

- **A bead-pull** setup has been built for the purpose.
  - Versatile workbench to host the 3 different crab cavities.
  - String in a closed loop (4 pulleys).
  - Vertical movement of the bead (1 motor).
  - Horizontal movement of the bead (2 motors + 2 linear units).

- **Latest progress:**
  - Installation of a security stop mechanism for the linear units.
  - Design and fabrication of two weakly coupled antennas.

- **Ongoing work:** code writing in LabVIEW (graphical programming platform).
  - Centralize the control of the vectorial network analyzer.
  - Control de movement of the 3 motors.
  - Synchronize the measurements.

Courtesy of M. Navarro Tapia, R. Calaga