Optics and Collimation Studies

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- Test scenario with a single global crab cavity
- Nominal LHC optics
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  - Dynamic aperture and orbit
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  - Preliminary collimation studies
- LHC upgrade optics (lowbetamax)
  - Optics, Dynamic aperture
  - Luminosity scan
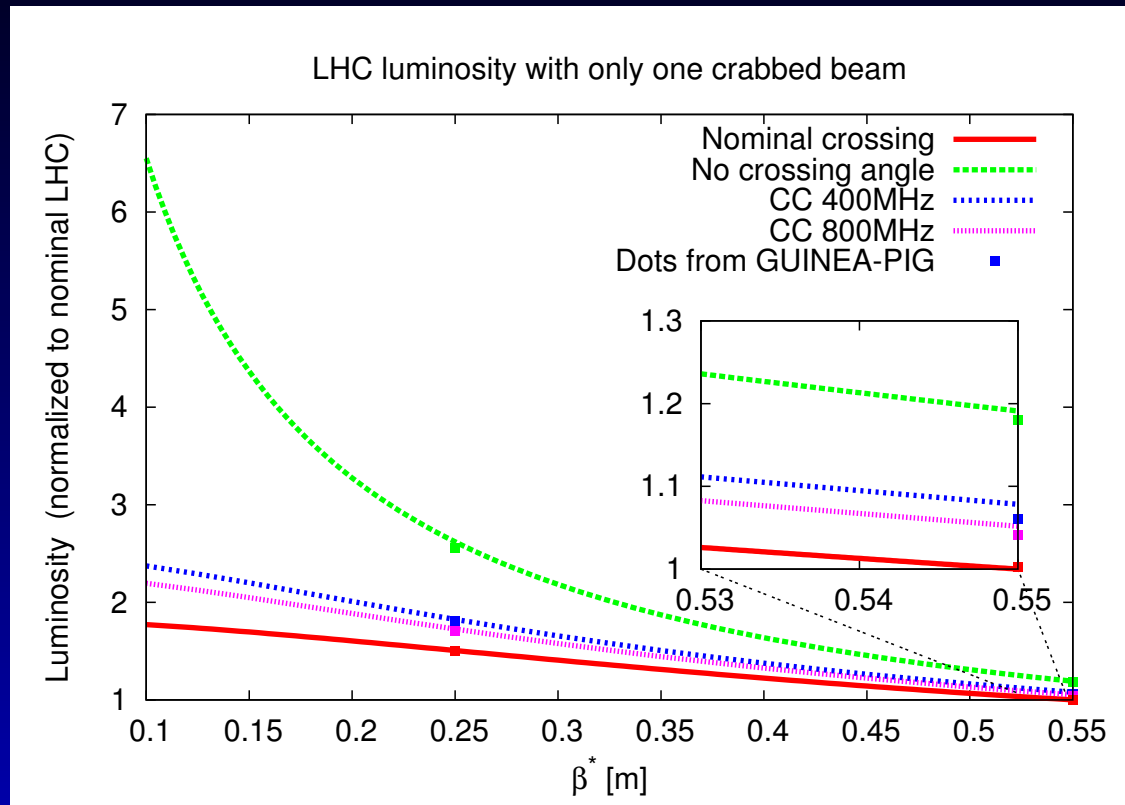 - Preliminary collimation studies
- Summary

Minimal test scenario: 1 CC
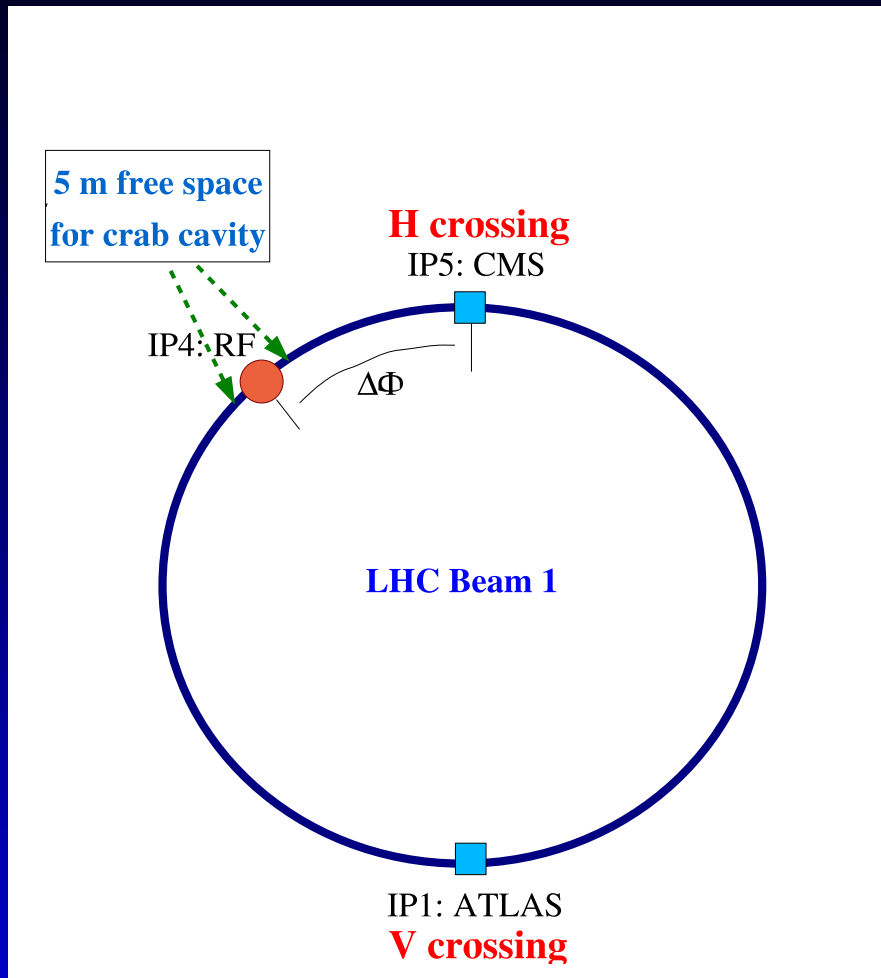
- A single global crab cavity at IR4 to benefit IP5

Luminosity

LHC luminosity with only one crabbed beam
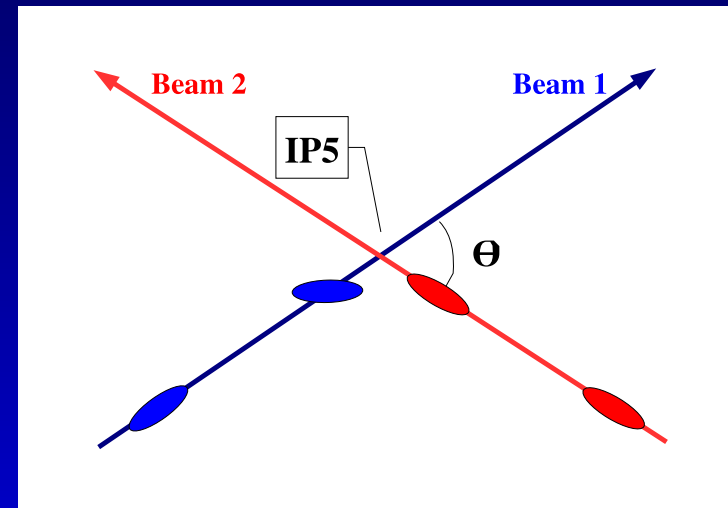
- Curves: analytical formulae; Dots: GUINEA-PIG
- Good agreement
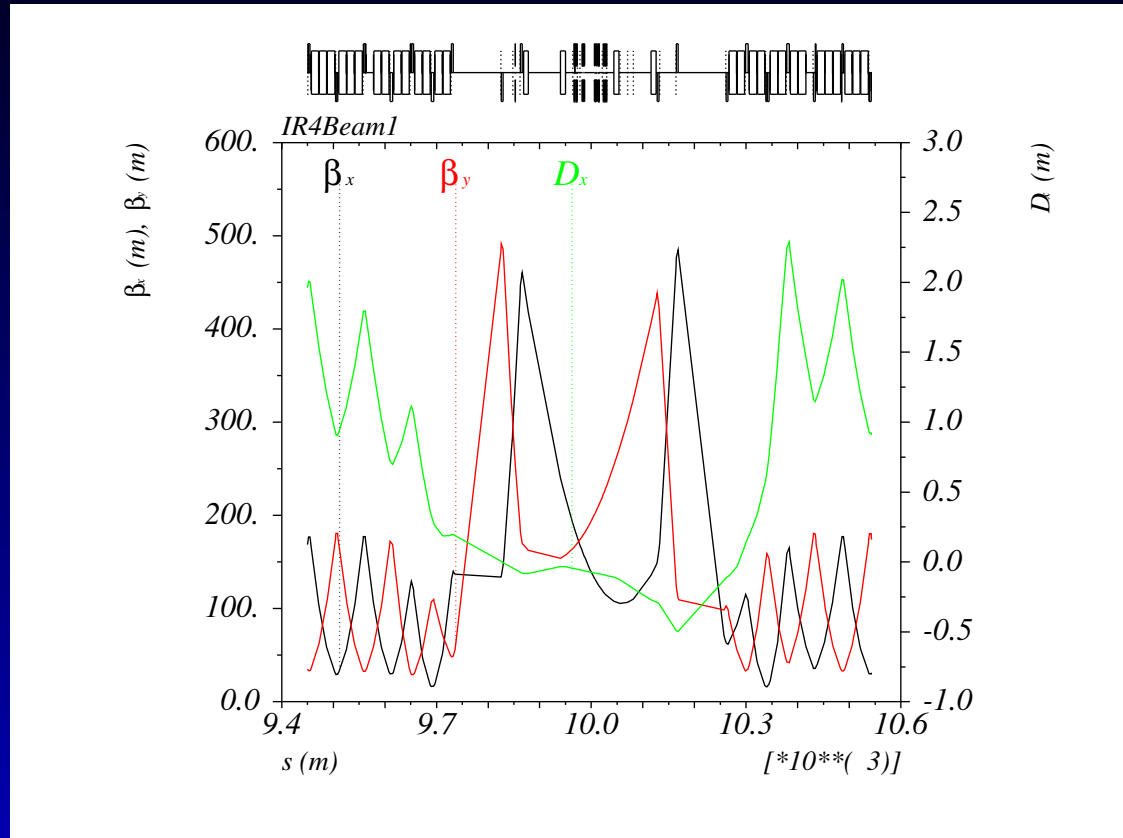- 5 percent gain at IP5, 5 percent loss at IP1, with $\beta^* = 0.55m$

Parameters (Nominal)

$$V = \frac{c \cdot E \cdot tan(\frac{\theta}{2})}{\omega \cdot \sqrt{\beta^* \cdot \beta_{crab}}} \cdot \left| \frac{2\sin(\pi Q)}{\cos(\Delta\varphi - \pi Q)} \right|$$

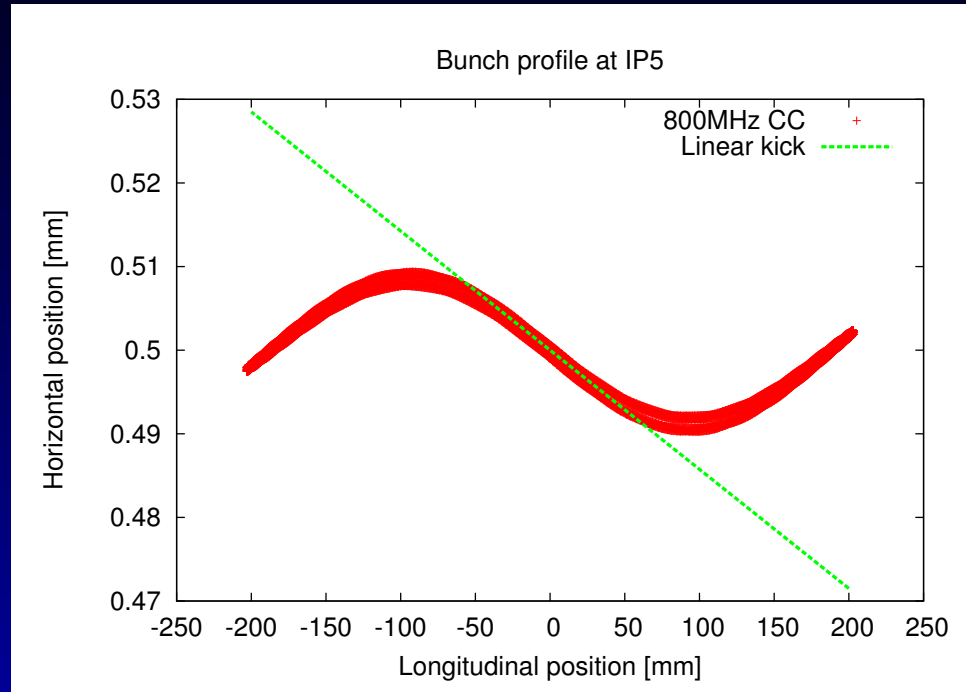|	s [m]	β_x [m]	β_y [m]	Phase x	Phase y
IP1	0	0.55	0.55	0	0
CC	9968	208	174	24.382	21.838
IP5	13329	0.55	0.55	32.047	29.609

- The betatron tune of LHC is (64.31, 59.32)
- The 800-MHz crab cavity voltage is calculated to be **9.3 MV**
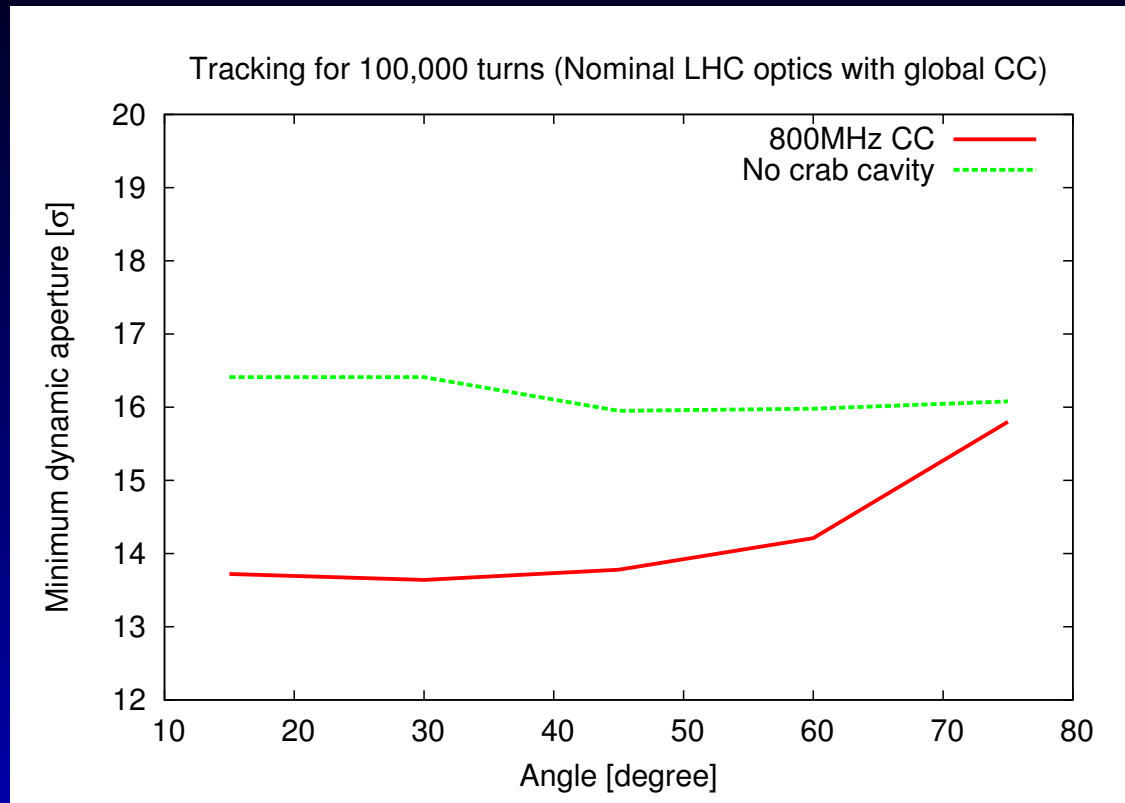
- **800** m -> 4.7 MV

Optics (Nominal)

- $\beta_{x,CC} = 208$ m
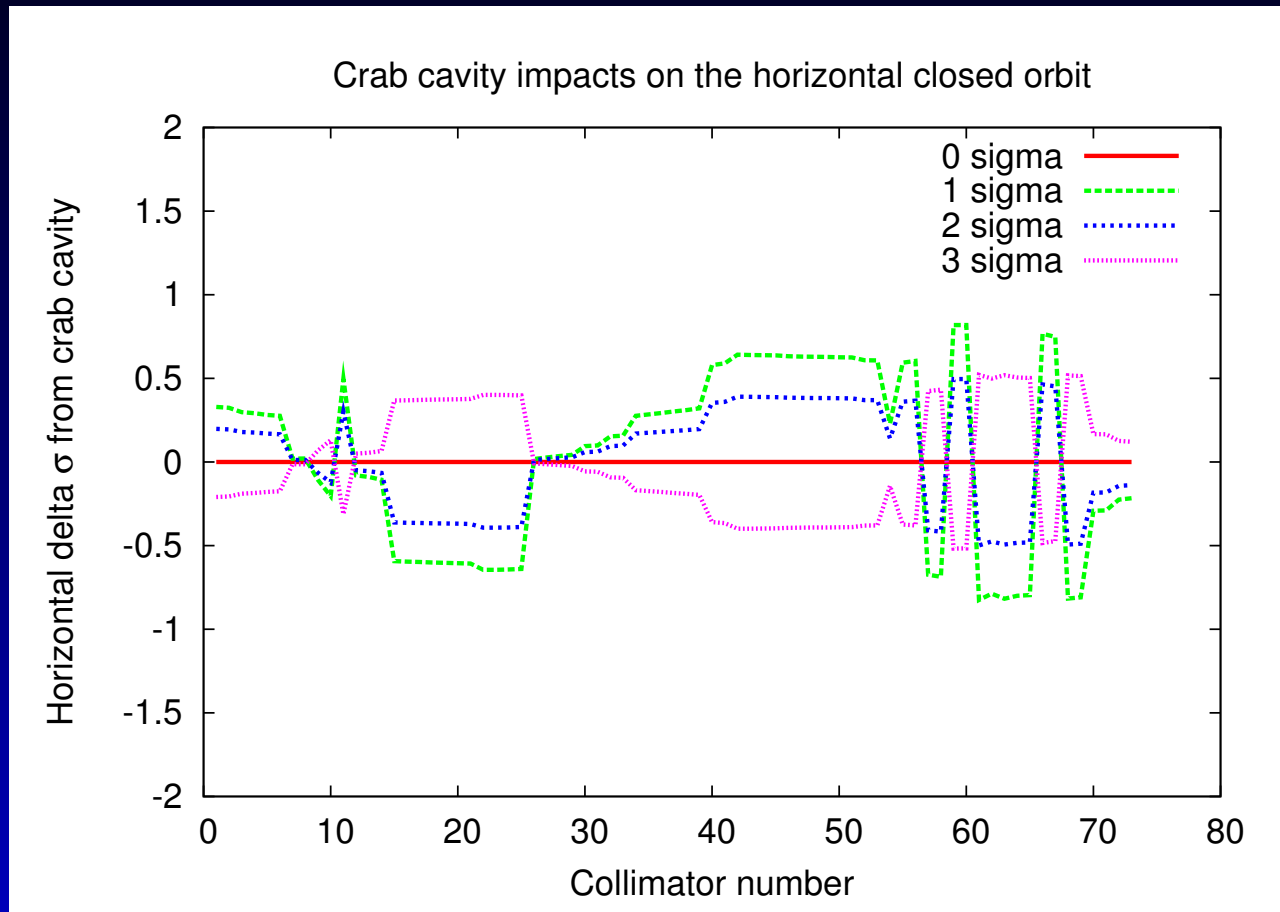- Under investigation: Increase $\beta_{x,CC}$ to $800m$

Bunch shape at IP5 (Nominal)

- 800-MHz crab cavity and linear kick crab cavity RF slope case ($\sigma_z = 75.5mm$)
- Zero transverse and longitudinal offset, and $2.5\sigma_p$ energy offset
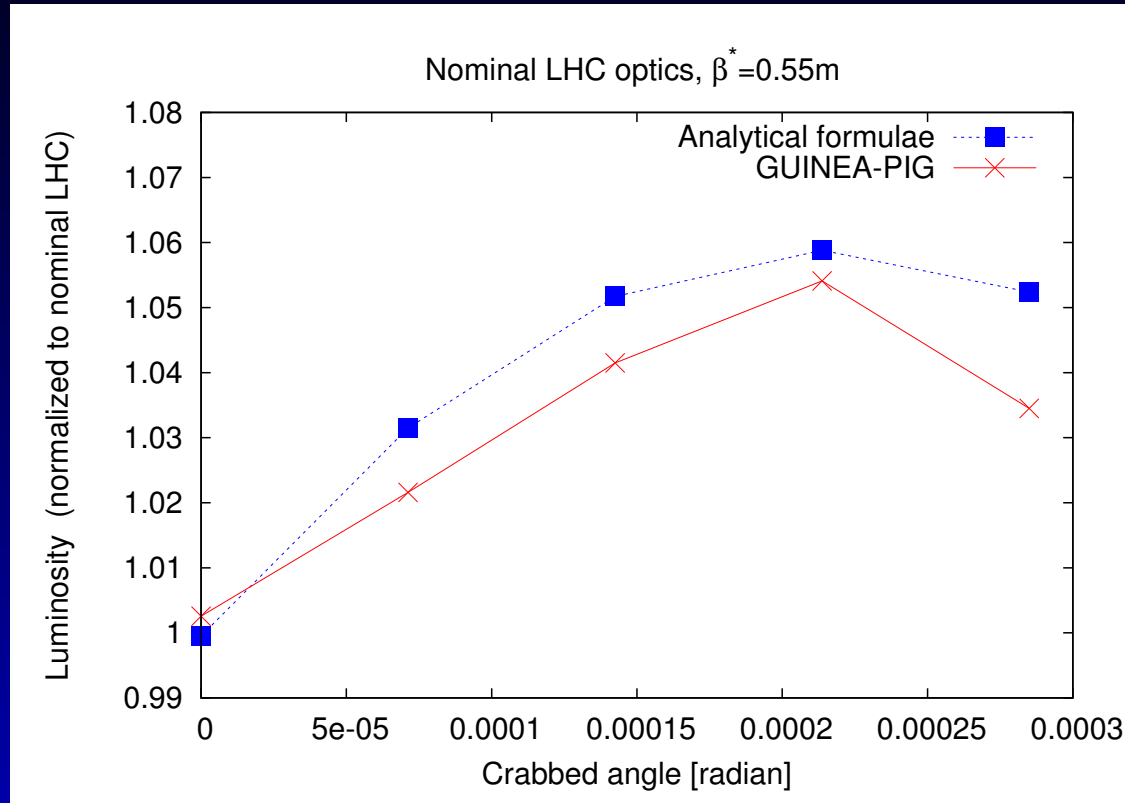
Dynamic aperture (Nominal)

Tracking for 100,000 turns (Nominal LHC optics with global CC)

- Two error seeds
- Momentum offset 0.00027, 100,000 turns
- 2 to 2.5 σ degradation

Z-dependent Closed orbit (Nominal)

Crab cavity impacts on the horizontal closed orbit

Legend:
- 0 sigma (red solid)
- 1 sigma (green dashed)
- 2 sigma (blue dashed)
- 3 sigma (magenta dotted)

Y-axis: Horizontal delta σ from crab cavity
X-axis: Collimator number

Crab cavity replaced by a corrector in the sequence
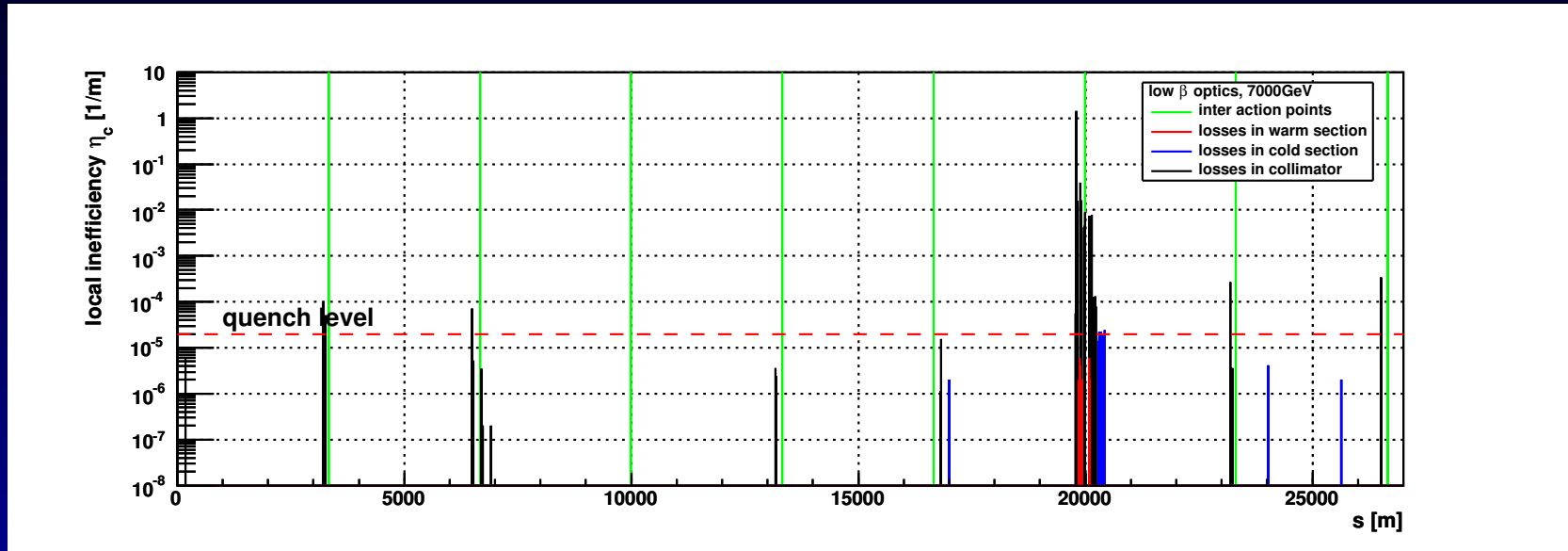
Luminosity scan (Nominal)

Nominal LHC optics, $\beta^{*}=0.55$m

- Only beam 1 is crabbed • Peak luminosity at $\frac{3\theta_c}{4}$
- Measurement resolution 0.01 (Courtesy Simon White) https://edms.cern.ch/file/347396/1.1/LHC-B-ES-0007-10-00.pdf
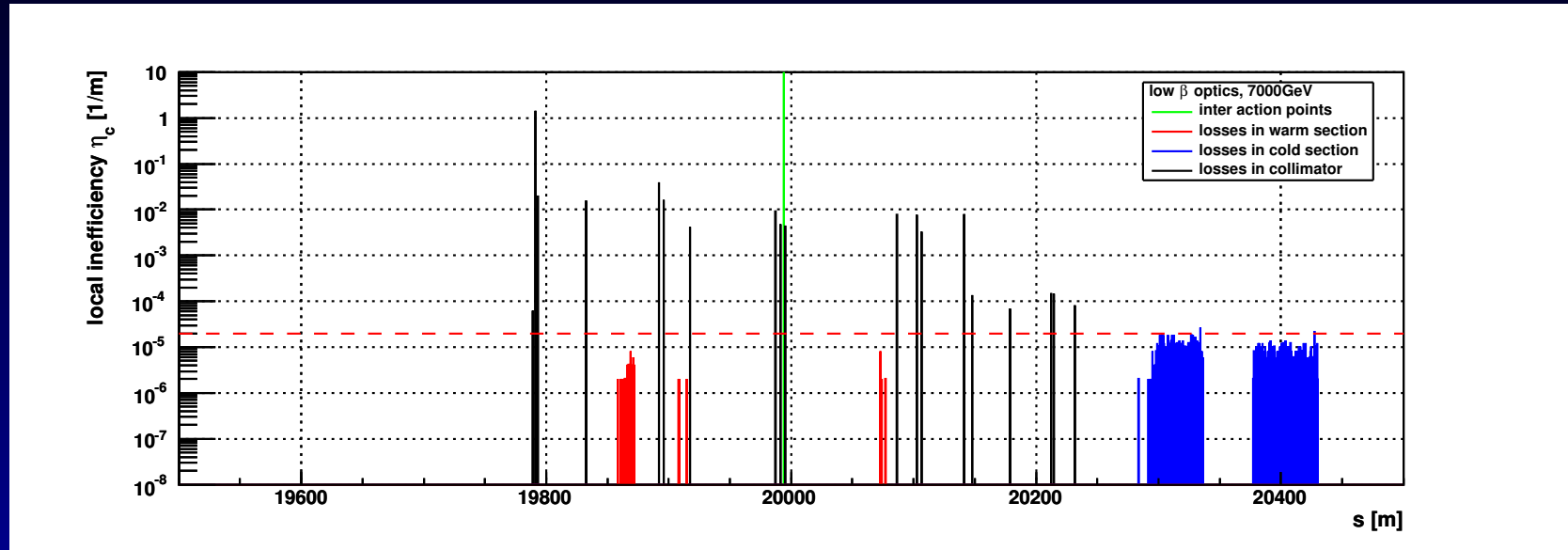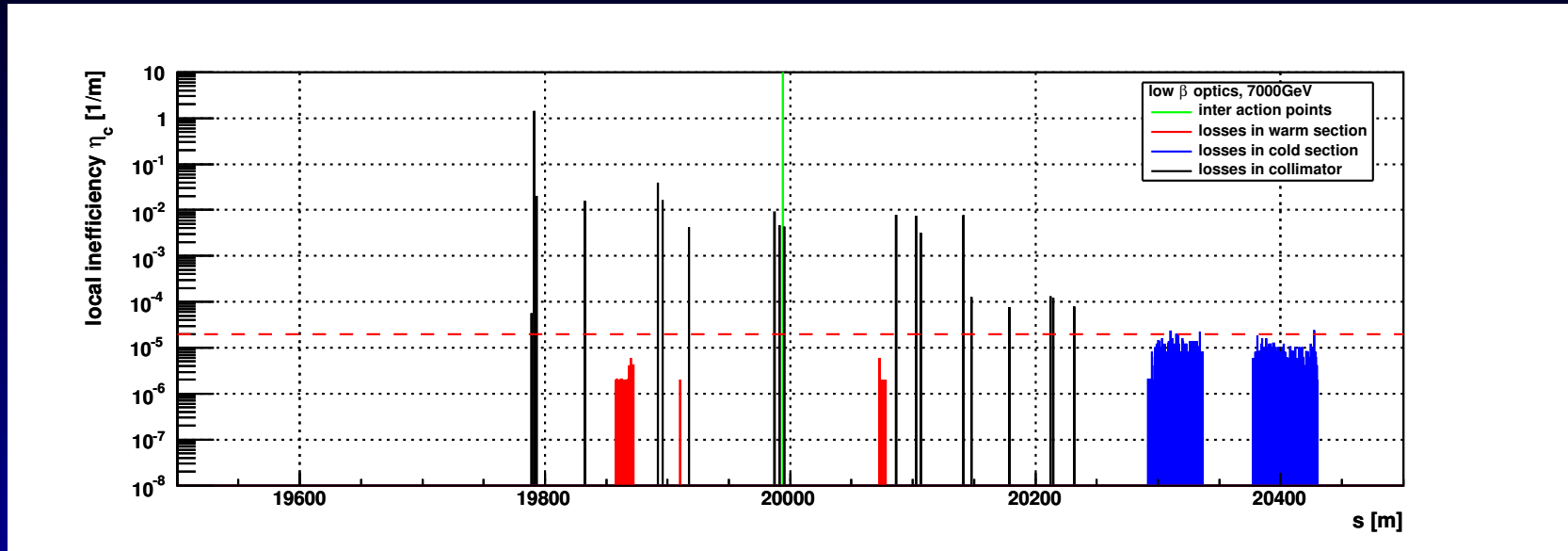
Loss map (1)

Loss map for Nominal LHC at IR7 (top energy, $\beta^*_{IP1,5} = 0.55m$), <u>without crab cavity</u> and with horizontal halo

Loss map (2)

- **Loss map for Nominal LHC (top energy, $\beta^*_{IP1,5} = 0.55m$), with crab cavity and horizontal halo**
- **Preliminary**

Loss map (3)

low β optics, 7000GeV
- inter action points
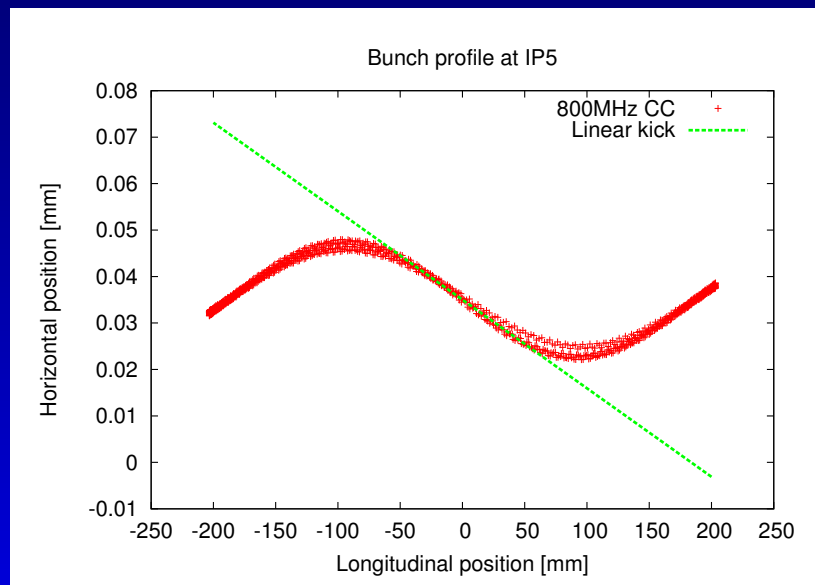- losses in warm section
- losses in cold section
- losses in collimator

- Loss map for Nominal LHC at IR7 (top energy, $\beta^*_{IP1,5} = 0.55m$), with crab cavity and horizontal halo
- Preliminary

Optics (Upgrade)
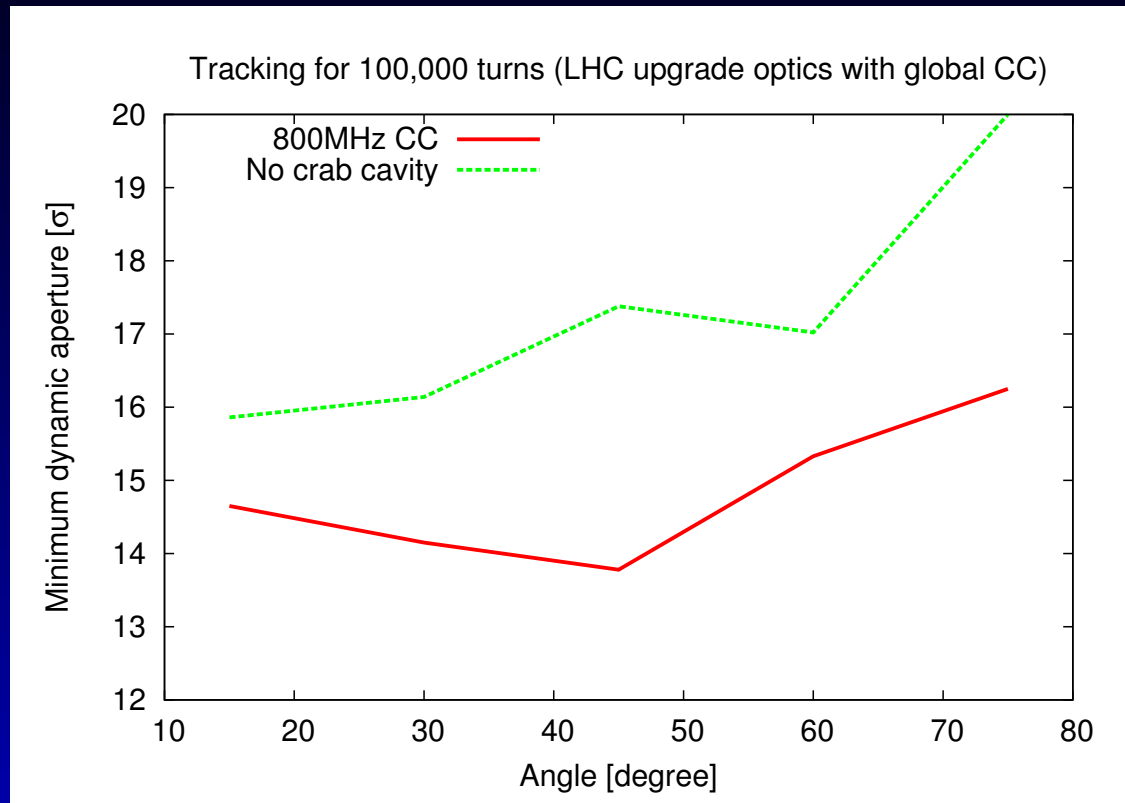
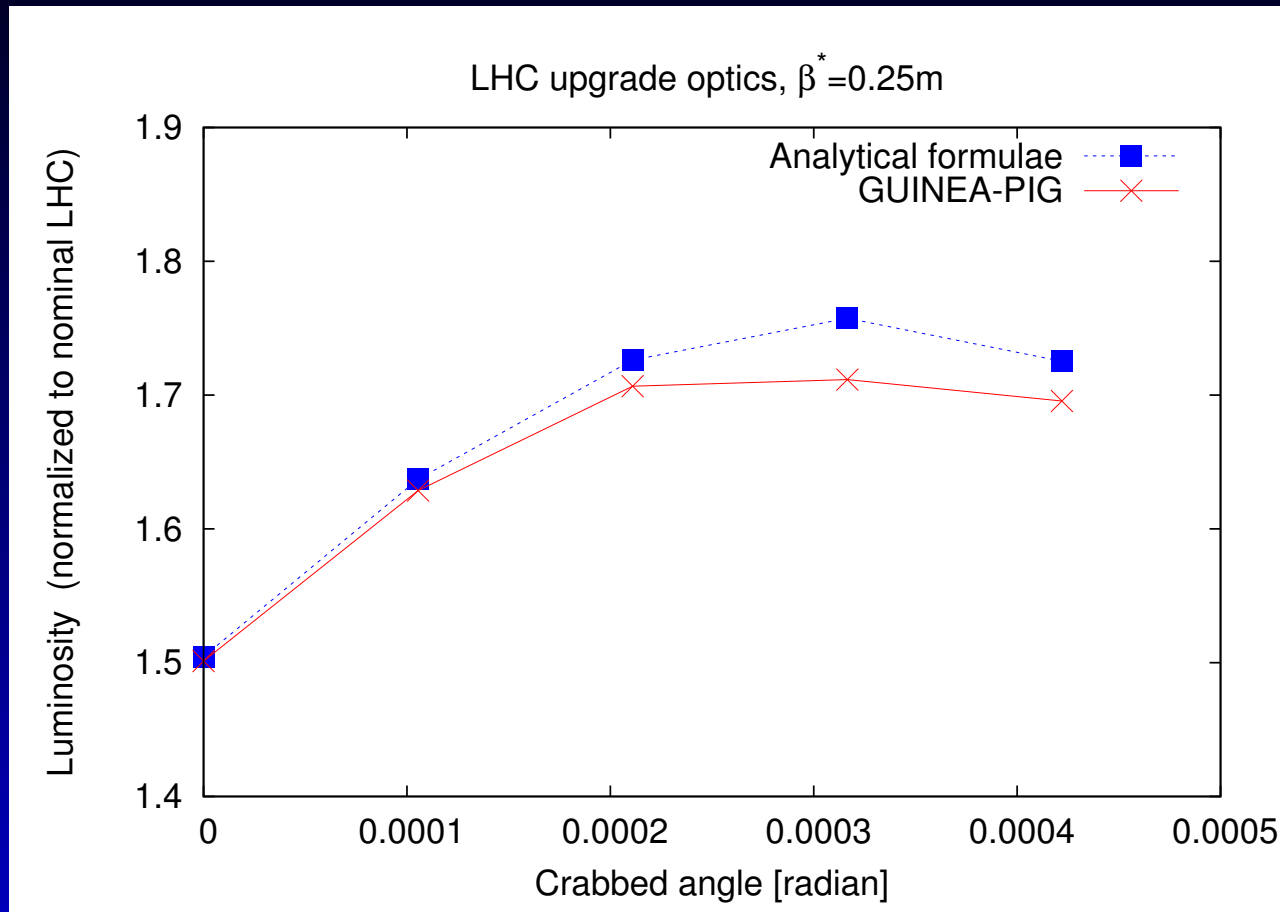|	s [m]	β_x [m]	β_y [m]	Phase x	Phase y
IP1	0	0.25	0.25	0	0
CC	10028	113	250	24.557	22.379
IP5	13329	0.25	0.25	32.253	29.736

Bunch profile at IP5

- 30 m downstream of IP4

- 25.7 MV -> adjust optics

- 800 m -> 9 MV

Dynamic aperture (Upgrade)

- Two error seeds
- Momentum offset 0.00027, 100,000 turns
- 2 to 4 σ degradation

Luminosity scan (Upgrade)

LHC upgrade optics, $\beta^{*}=0.25$m

- Only beam 1 is crabbed
- Peak luminosity also at $\frac{3\theta_c}{4}$

LHC nominal with larger Crab angle
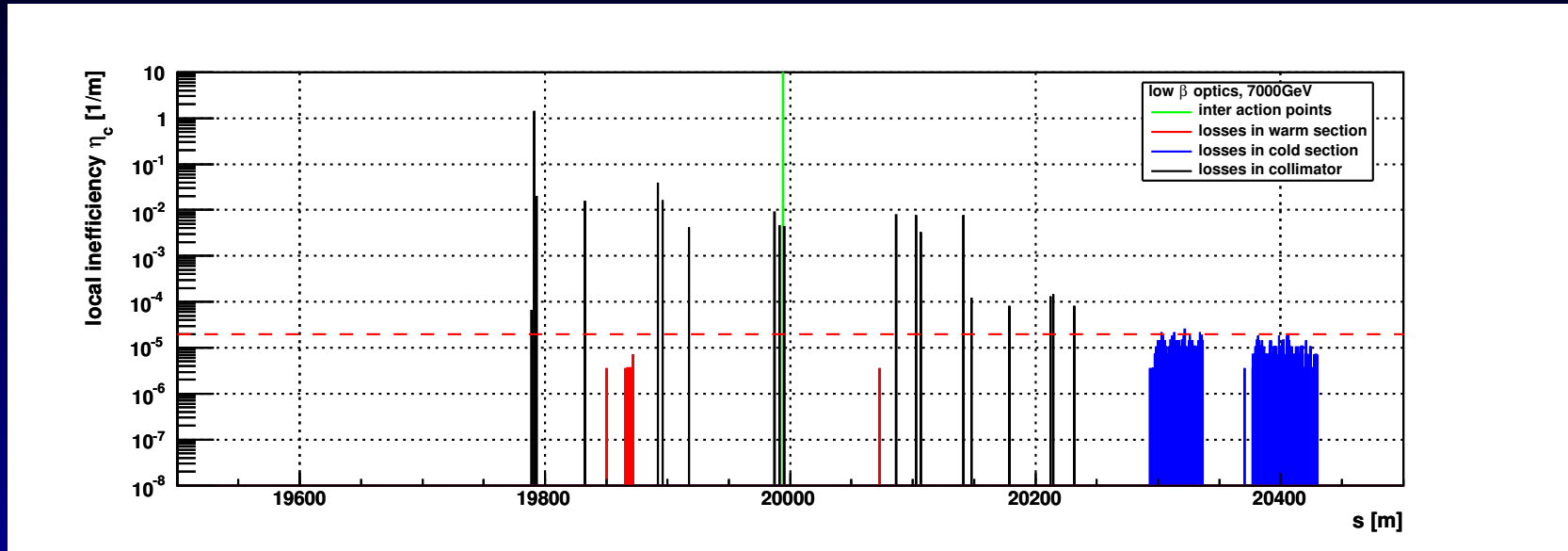
- Loss map for Nominal LHC at IR7 (top energy, $\beta^*_{IP1,5} = 0.55m$), with crab cavity and horizontal halo
- Increase crossing angle from $285\mu rad$ to $500\mu rad$, to mimic conditions expected for upgrade optics
- Work in progress

Summary

- CC performance can be validated with one CC in the LHC nominal (luminosity, lifetime, ...)

- LHC optics need adjustments (increase β_{cc}, optimize phase...)

- Luminosity gain 5% (12%) for nominal LHC, with one (two) global CCs

- Luminosity gain 14% (43%) for LHC upgrade, with one (two) global CCs

- Dynamic aperture OK

- Collimation (OK?)