HiLumi
HL-LHC PROJECT

Beam-Beam Long Range Compensation Experimental plan

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CERN

6th HL-LHC Collaboration meeting, Paris, 14-16/11/2016

Outline

- Beam-bean long range (BBLR) wire compensation
  - BBLR in the LHC
  - Initial proposal and basic considerations
  - BBLR for HL-LHC and refined configuration
- Experimental conditions evolution and final proposal
- Simulations of beam lifetime evolution with BBLR compensation
- Alternative compensation with octupoles
- Summary

Wire compensation

- Beam-beam (LR) kick (round beams)

$$\Delta\{x', y'\} = -\frac{2N_b r_p}{\gamma} \frac{\{X, Y\}}{X^2 + Y^2} (1 - e^{-\frac{X^2+Y^2}{2\sigma^2}})$$

with $X = x + x_c, \quad Y = y + y_c$ beam separation

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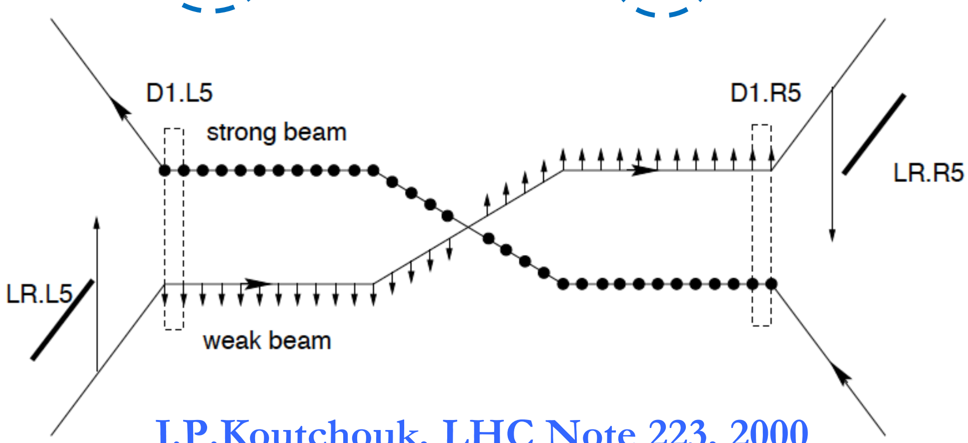
$$\Delta\{x',y'\}_W = \frac{\mu_0}{2\pi}\frac{I_W L_W}{B\rho}\frac{\{X_W,Y_W\}}{X_W^2+Y_W^2}$$

with $X_W = x + x_W$, $Y_W = y + y_W$ wire separation



J.P.Koutchouk, LHC Note 223, 2000

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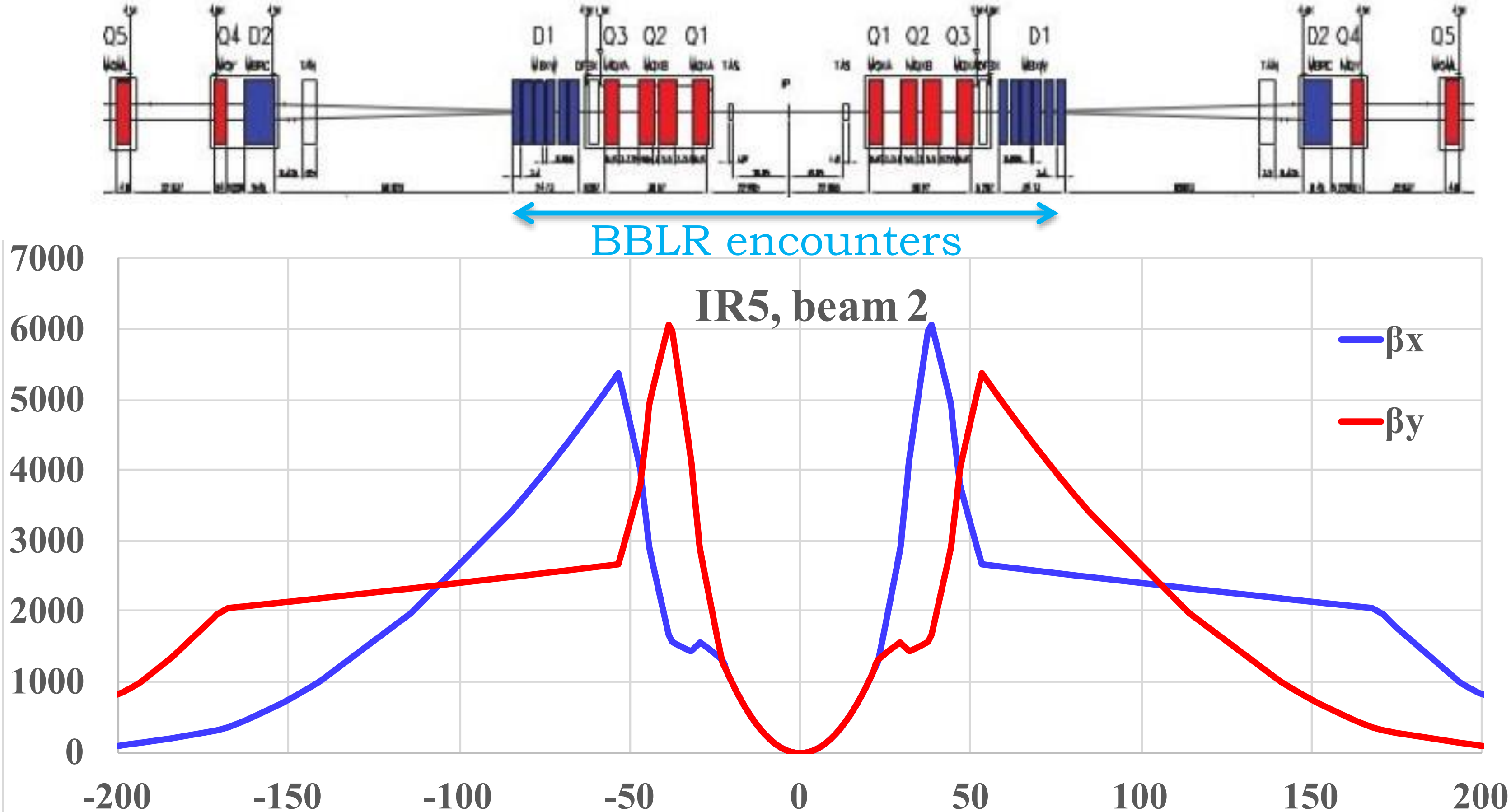
with $X_W = x + x_W \;, \;\; Y_W = y + y_W$

- The simple conditions for matching the effects are

$$x_W = x_c \;, \;\; y_W = y_c \;, \;\; I_W L_W = ecN_b$$

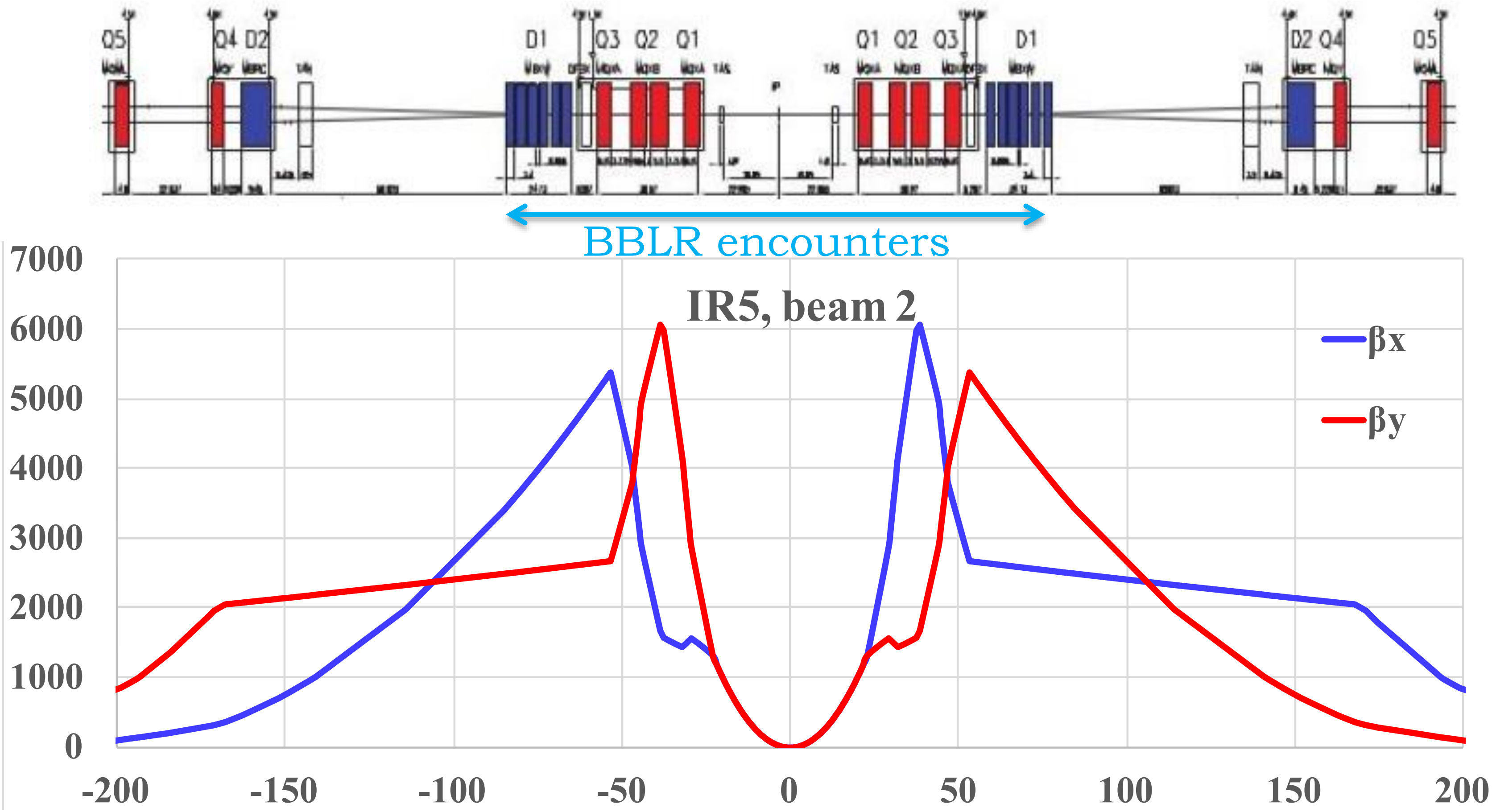
i.e. integrated current of **5.5 Am/encounter** for nominal LHC and **10.6 Am/encounter** for HL-LHC

Compensation constraints: locality



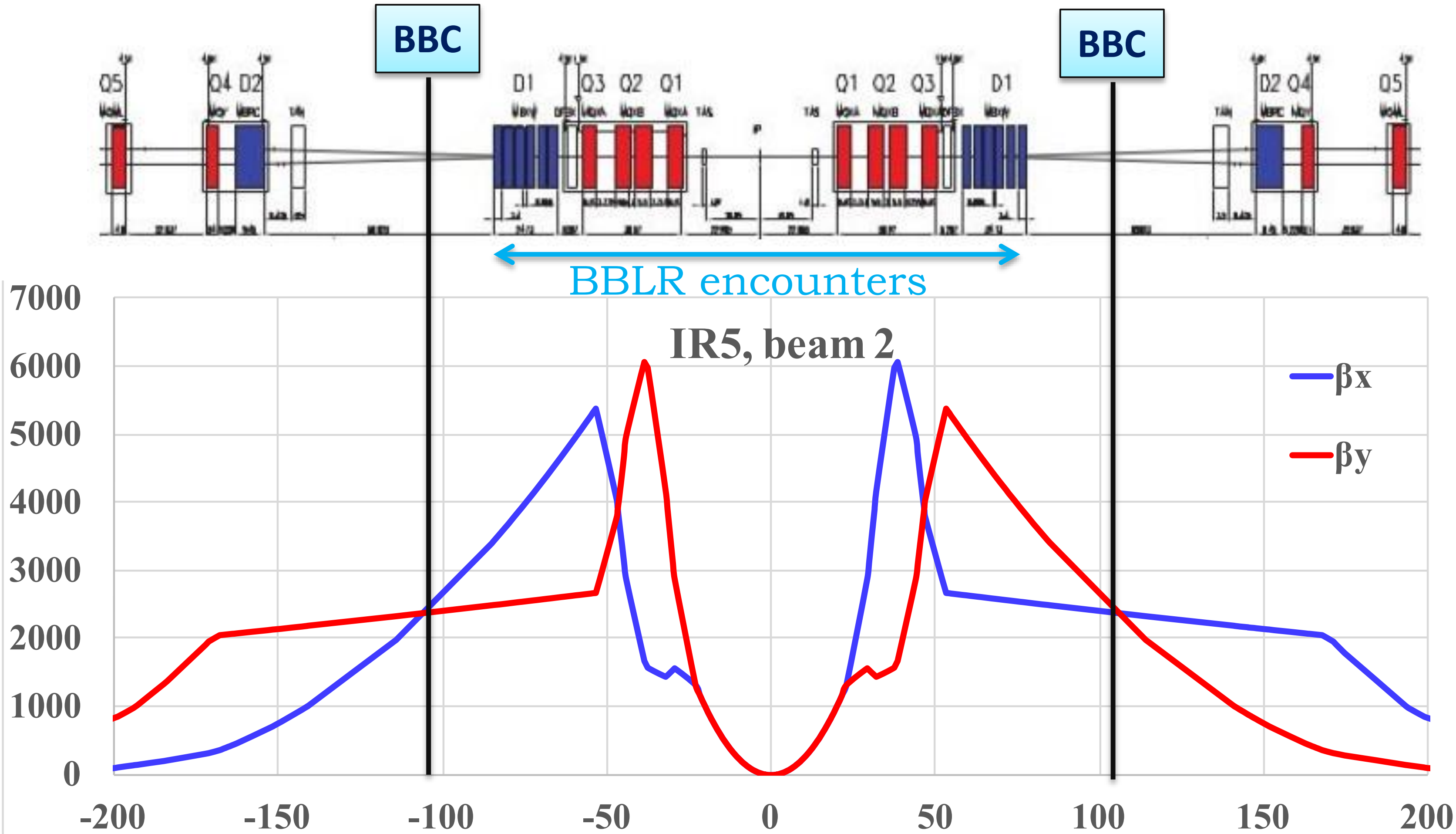
- BBLR encounters occurring at **~π/2** from either IP side
- Phase advance still ~ π/2 up to D2/Q4 (and the lower β*, the better)

Compensation constraints: optics



- Optics strictly anti-symmetric L/R of the IP
- Optics symmetric between Q1s, where 50% of encounters occur

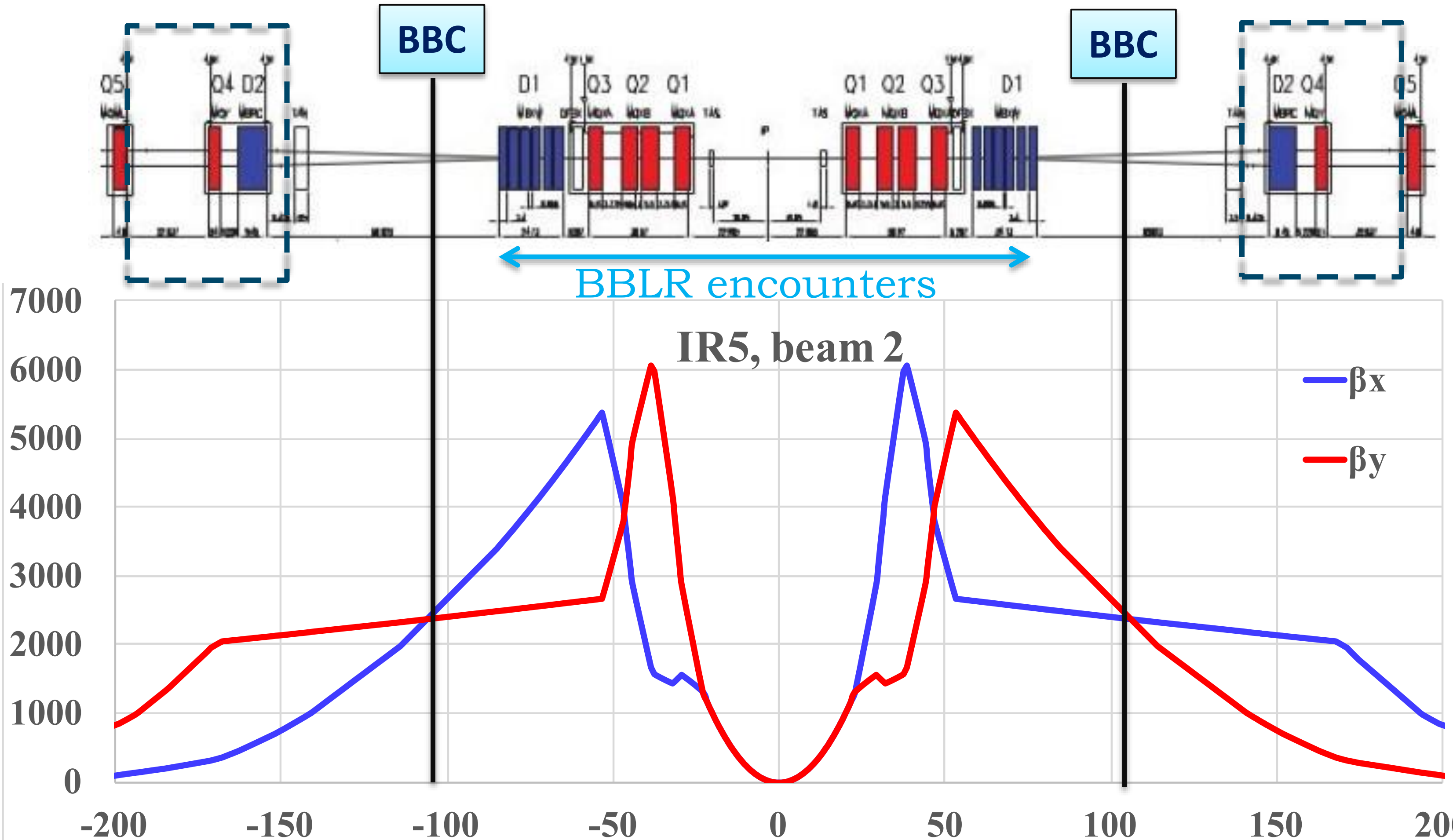
Compensation constraints: optics



- Initial idea of **BBC** wire location, where β-functions are large and with aspect ratio $r_w = \beta_x/\beta_y \approx 1$
- In principle, one wire from one IP side (and double the current) will have the same compensation effect (compensating LR encounters near IP)

J.P.Koutchouk, LHC Note 223, 2000

Experimental test constraints: hardware



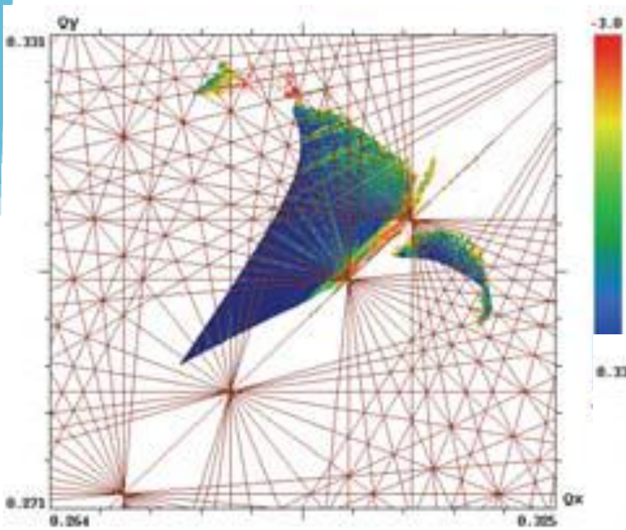
- Integration between D1 and TAN quite **challenging**
- Use wires embedded in tertiary collimators between D2 and Q5 for **proof-of-principle** tests

T.Rijoff, CERN-THESIS-2012-377
R.Steihagen, 3rd HI-LUMI Meeting, 2013

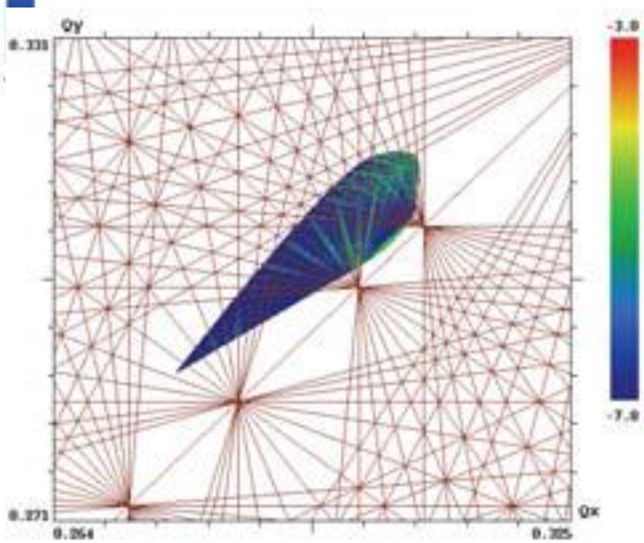
Optimal β aspect ratio

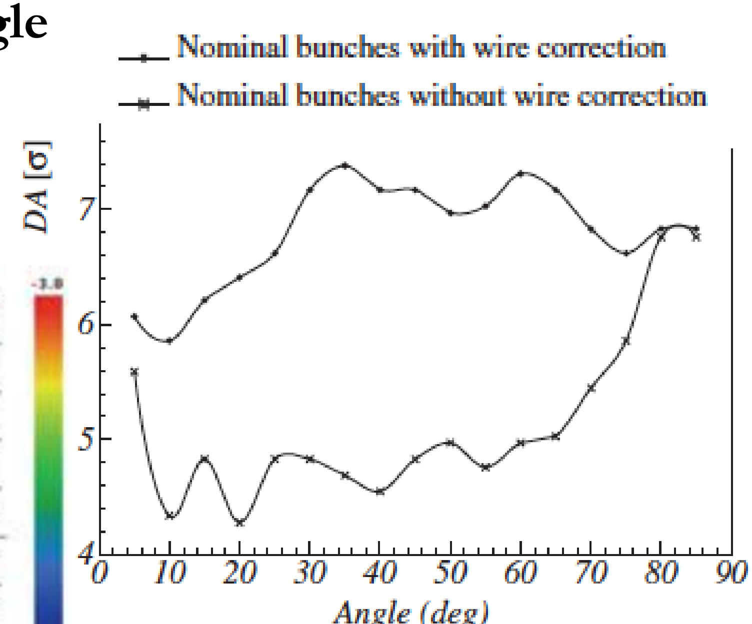
- Recent studies for HL-LHC revealed that optimal compensation can be achieved for unique β aspect ratio (strictly depending on triplet layout)
  - For HL-LHC optimal $r_w \approx 2$ or 1/2
  - For nominal LHC, $r_w \approx 1.7$ or 0.6

S. Fartoukh et al., PRSTAB, 2015



Reduced crossing angle of 450μrad @ 15cm





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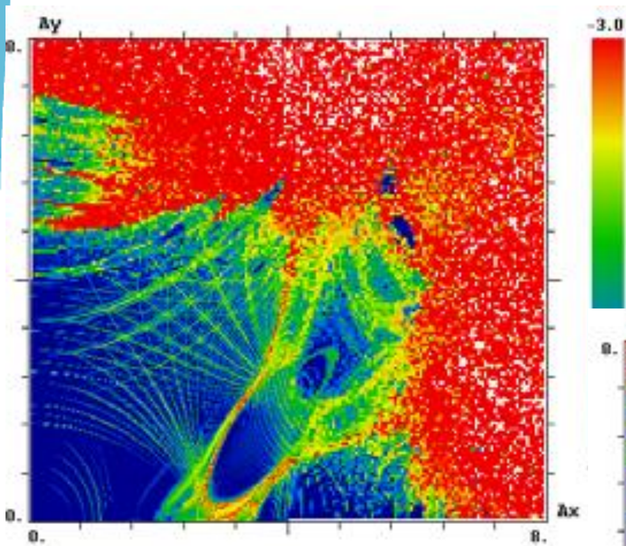

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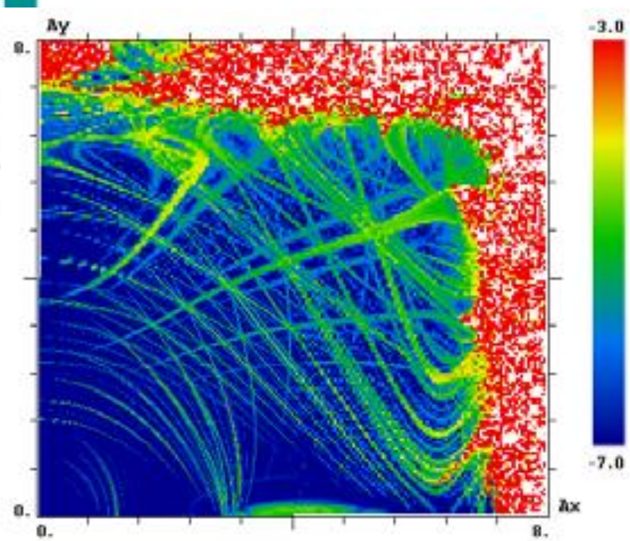
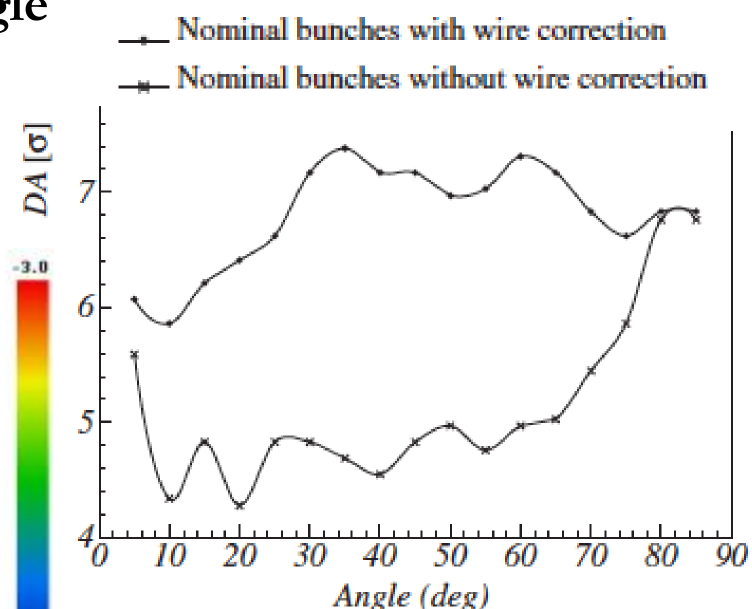
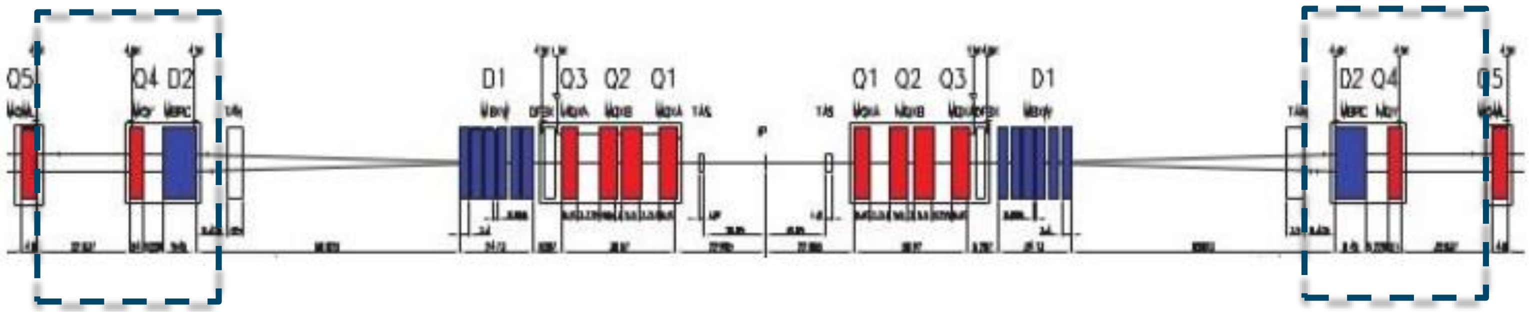
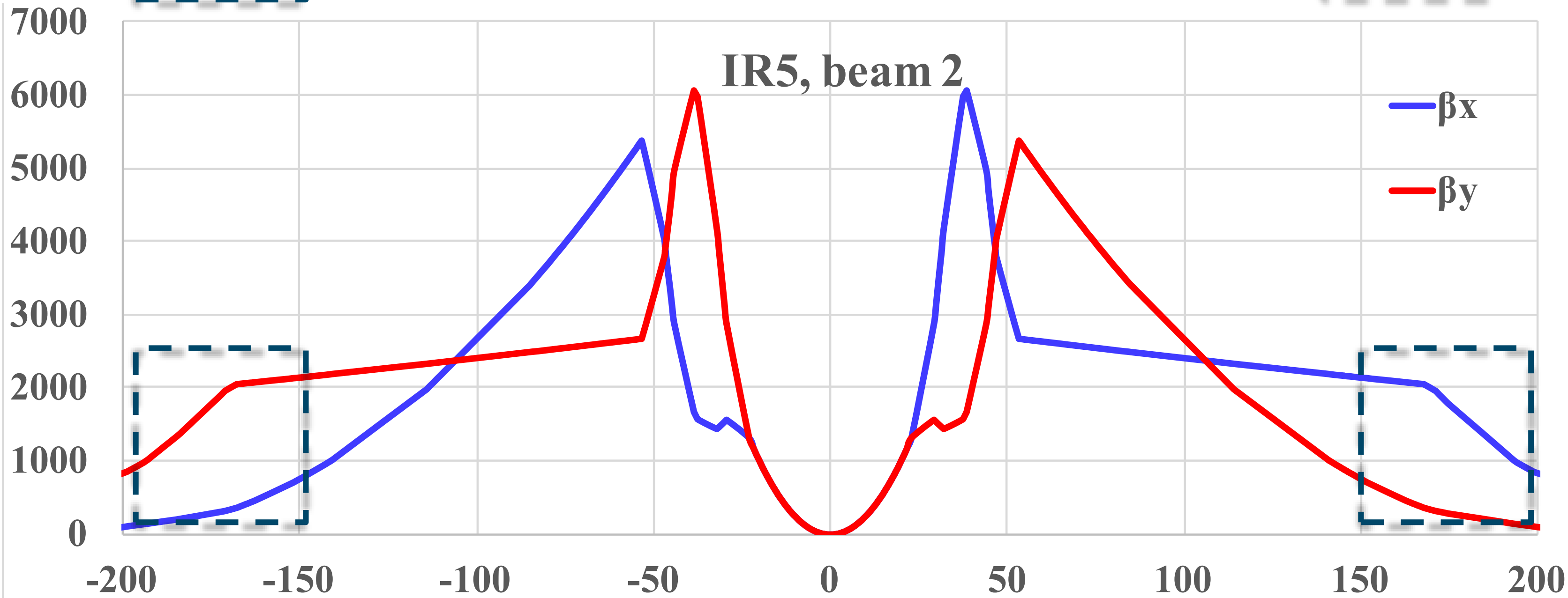




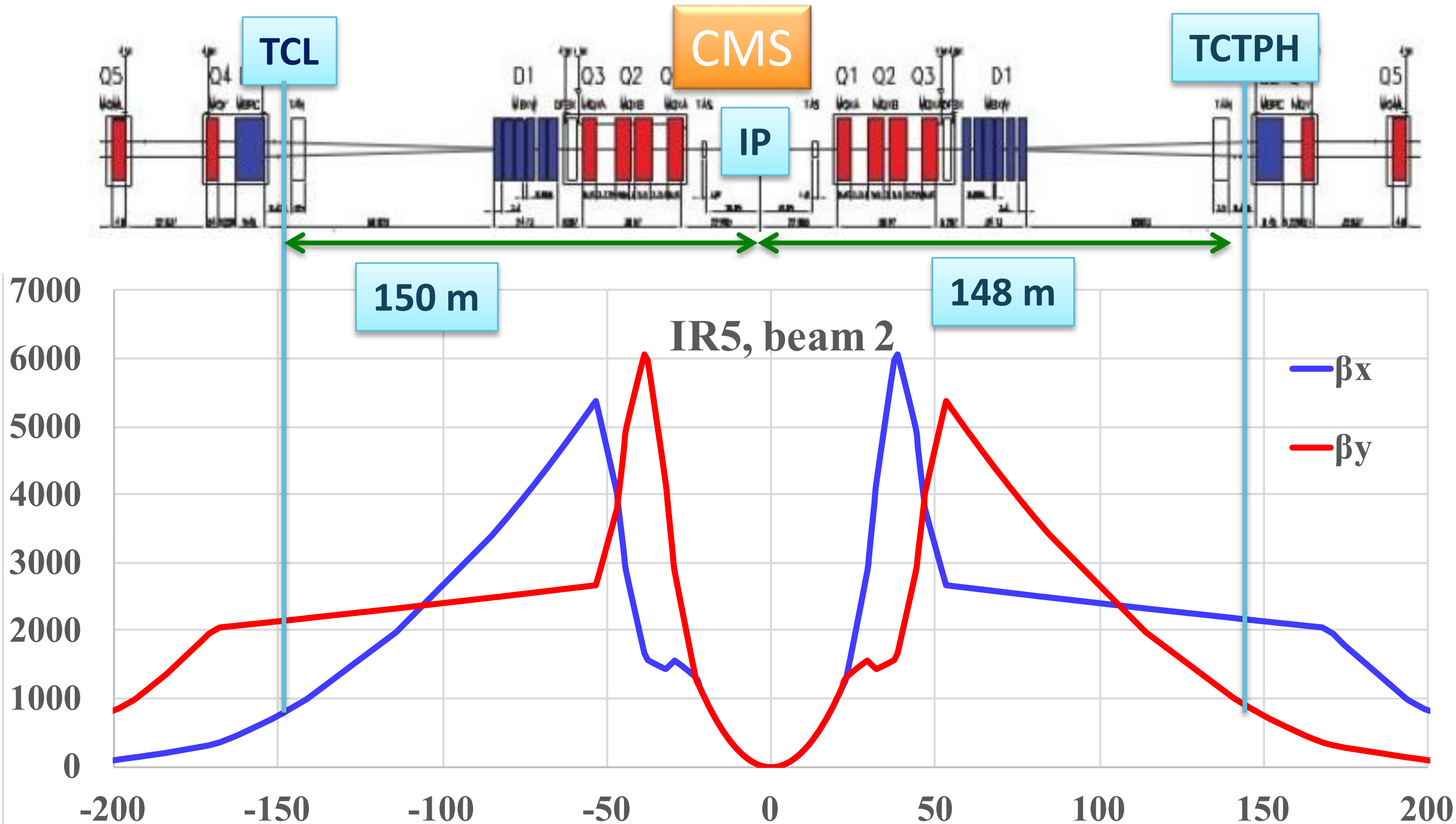
Experimental test constraints: optics





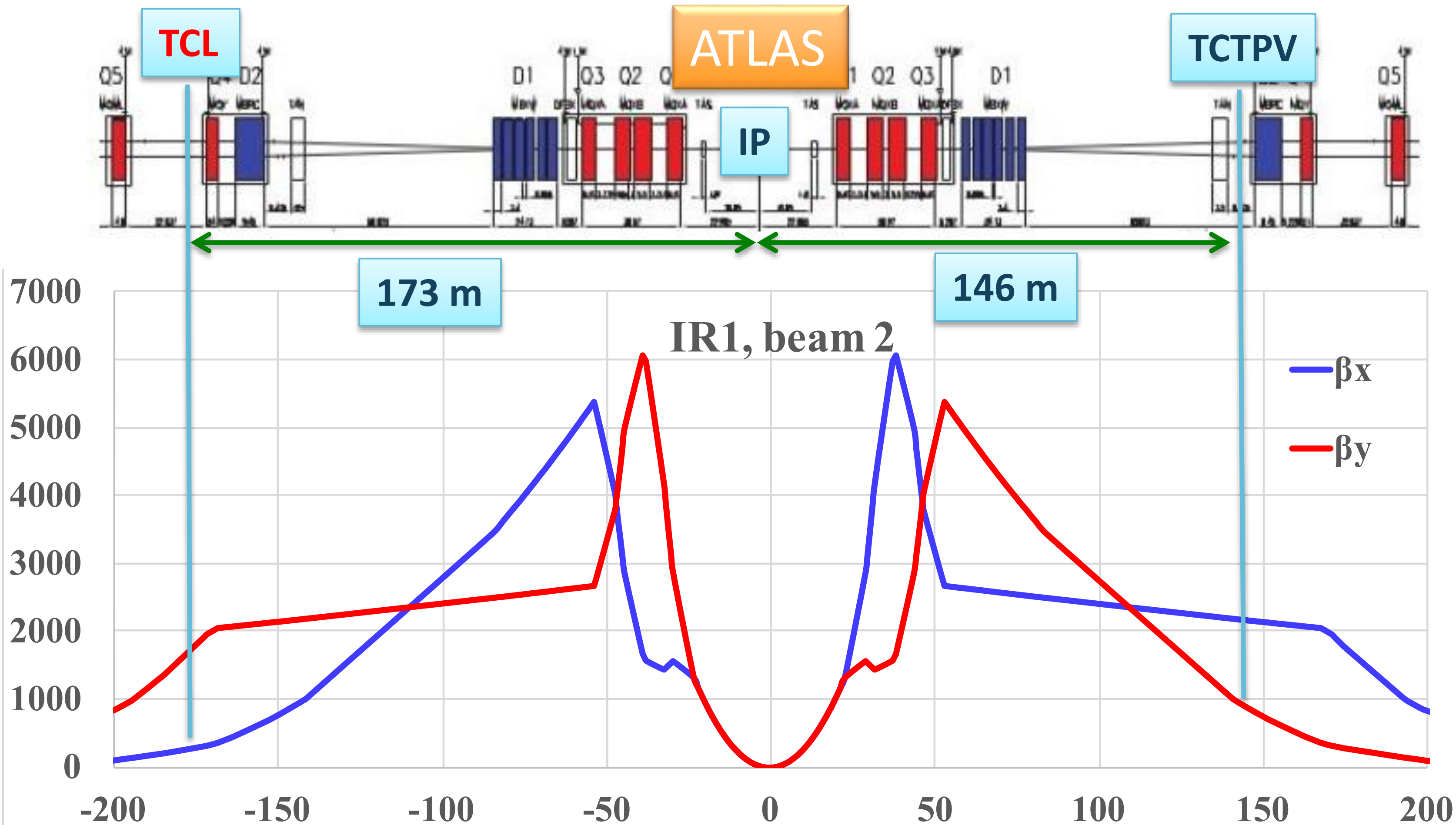
- Between TAN and Q5, ($r_w \neq 1$), one wire per IP does not provide good compensation (optics anti-symmetry)
- Need **two wires** per IP, powered individually in symmetric locations

Optics at TCT locations: IP5



- IR5: **Horizontal TCT** and **TCL** replaced with wire-embedded collimators
- Optics very close to anti-symmetric between the two locations

Optics at TCT locations: IP1



- IR1: **Vertical TCT** replaced with wire-embedded collimator
- **New TCL** downstream of Q4 (for beam 2), as location next to D2 crowded
- Optics not close to anti-symmetric especially for small corresponding β

Experimental scenarios

Conclusions of the Lyon workshop

- In both IR1 and 5, wire location to almost **π/2** from IP (max deviation of 2.5^{o})
- Both optics are **far** from **optimal** β-function **ratio** and IR1 **far from anti-symmetric**
  - For IR5, β-function ratios of around **0.4-2.6**
  - For IR1, β-function ratios of around **2.5-0.2**

Experimental scenarios

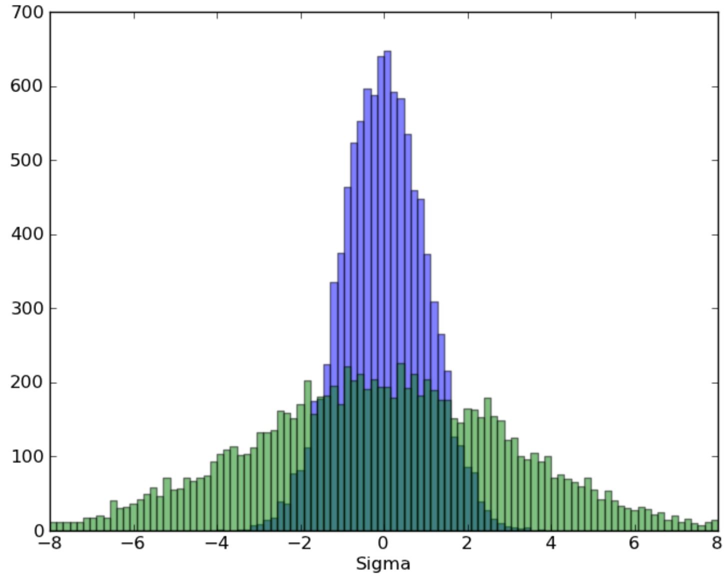
Conclusions of the Lyon workshop

- In both IR1 and 5, wire location to almost **π/2** from IP (max deviation of 2.5^{o})
- Both optics are **far** from **optimal** β-function **ratio** and IR1 **far from anti-symmetric**
  - For IR5, β-function ratios of around **0.4-2.6**
  - For IR1, β-function ratios of around **2.5-0.2**
- **Two experimental scenarios** considered
  - I. With **optics adjustments**
    - Optics to achieve strict anti-symmetry for left side of IR1 and/or more optimal beta aspect ratio in both
    - Compensating only one IP (IP5), with the other IP not-squeezed and non-colliding (synergy with optics MDs)
    - Necessitate **commissioning time**
  - II. With **commissioned** 2017-2018 machine optics (nominal or ATS)
    - Use all 4 wires and adjust distance/current for **best** compensation
- All experiments in a **Weak-strong** regime, i.e. a few low-current blown-up bunches in beam2 (machine protection) against a full train in beam1

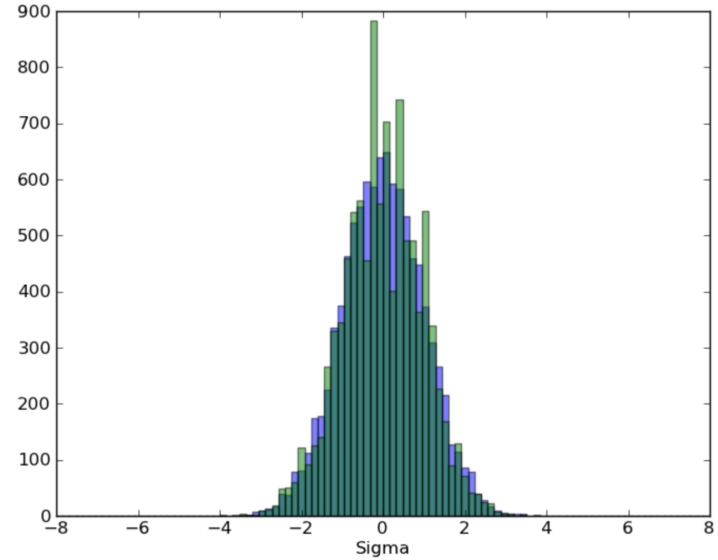
"Lifetime" simulations with SIXTRACK

A.Patapenka, S. Valishev et al.

- Initial distribution composition
  - **Matched** 6D Gaussian tracked for 10^6 turns
  - "Beam Core" + "Beam Halo" (2 times 10^4 macro-particles) with 3 times bigger beam size, statistically weighted with the "core"



Beam core (in blue) + beam halo (transverse size ~ 3 times bigger)



"Halo" statistically weighted with the "Core"

Tracking and compensation parameters

- Beam intensity $1.2x10^{11}$, with nominal 25~ns bunch separation and $\beta^* = 40$cm
- Transverse emittances: 2.5 (weak and strong beam) & 4.0 μm (weak beam)
- Energy 6.5 TeV, energy spread 1.12E-4, bunch length of 7.5 cm
- Chromaticity of 3 & 15 units, Octupole current of 0 & 550 A, no multi-pole errors
- Beam-beam interactions at IP1 & 5
- **Compensation** with 4 wires per beam (2 per IP) at TCT locations
  - Preliminary results for 2 wires in IP5
- **Wire separation** matching the average BBLR separation given by the crossing angle
- **Wire current** estimated with optimization procedure minimizing ($\Delta p_{wire} - \Delta p_{BBLR}$) for the given optics
- Linear tune shift due to wires corrected back to nominal working point

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Beam intensity decay

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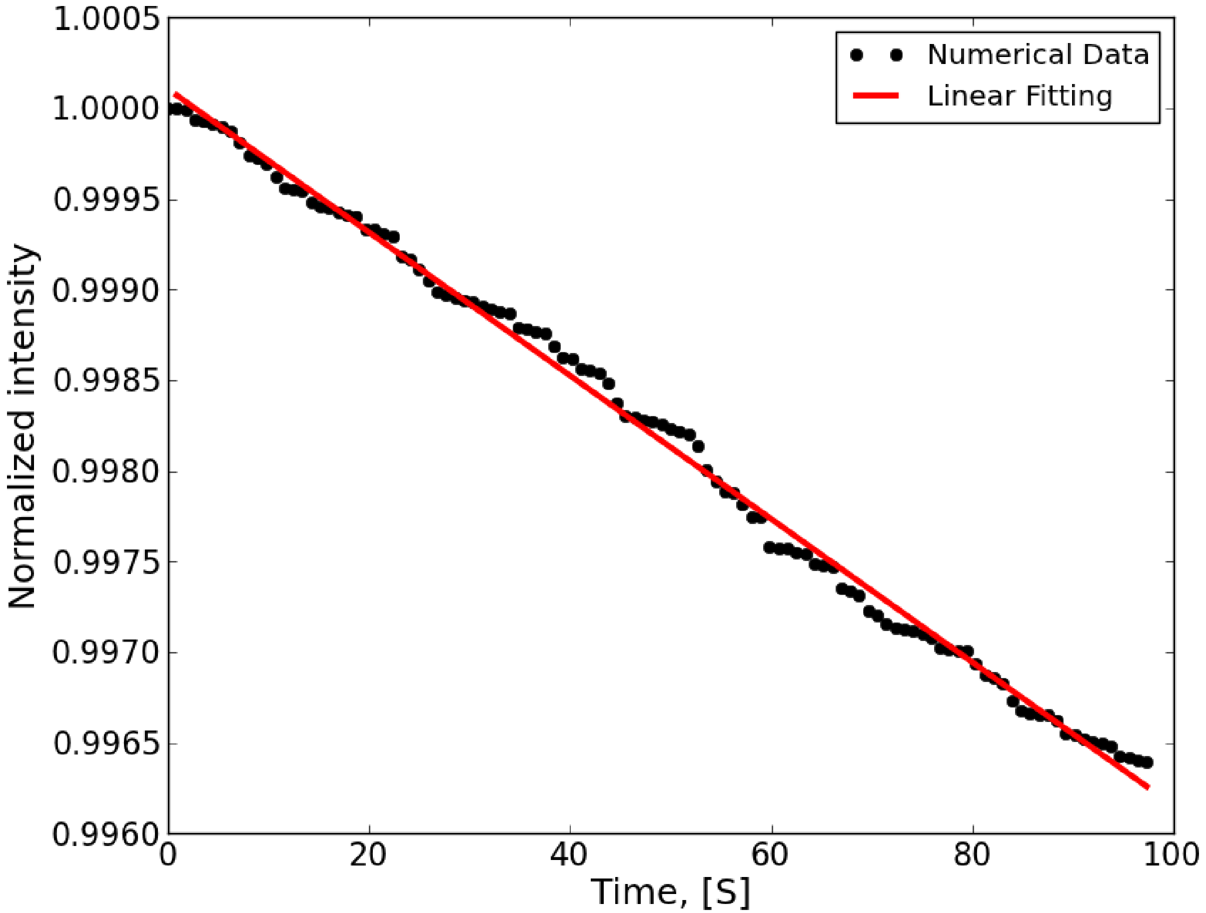
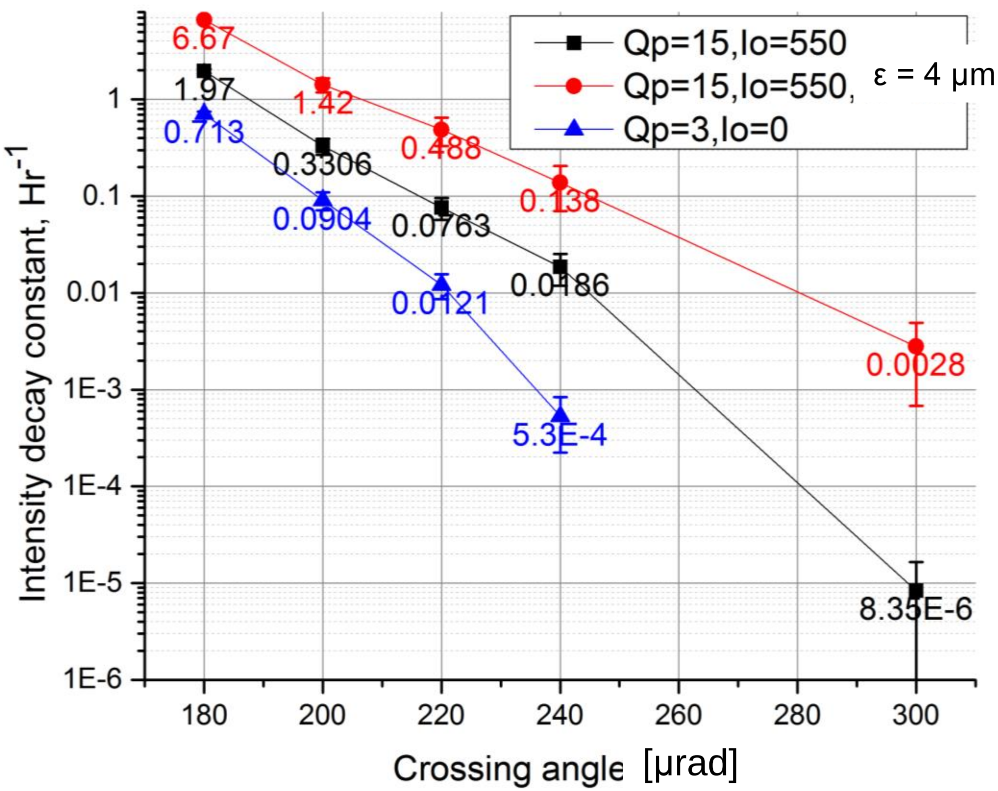


- Tracking for 10^6 turns and estimation of beam intensity decay constant λ (either from liner fit, for slow decay, or from direct fit to exponential for fast decay)

Impact of Octupoles and Chromaticity



Stat. error >30-50%

- Decay constant as a function of full crossing angle:
- **Black:** Chromaticity of 15, octupole current of 550 A, emittance of weak beam of 2.5 μm
- **Red:** Chromaticity of 15, octupole current of 550 A, emittance of weak beam of 4.0 μm
- **Blue:** Chromaticity of 3, zero octupole current, emittance of weak beam of 2.5 μm

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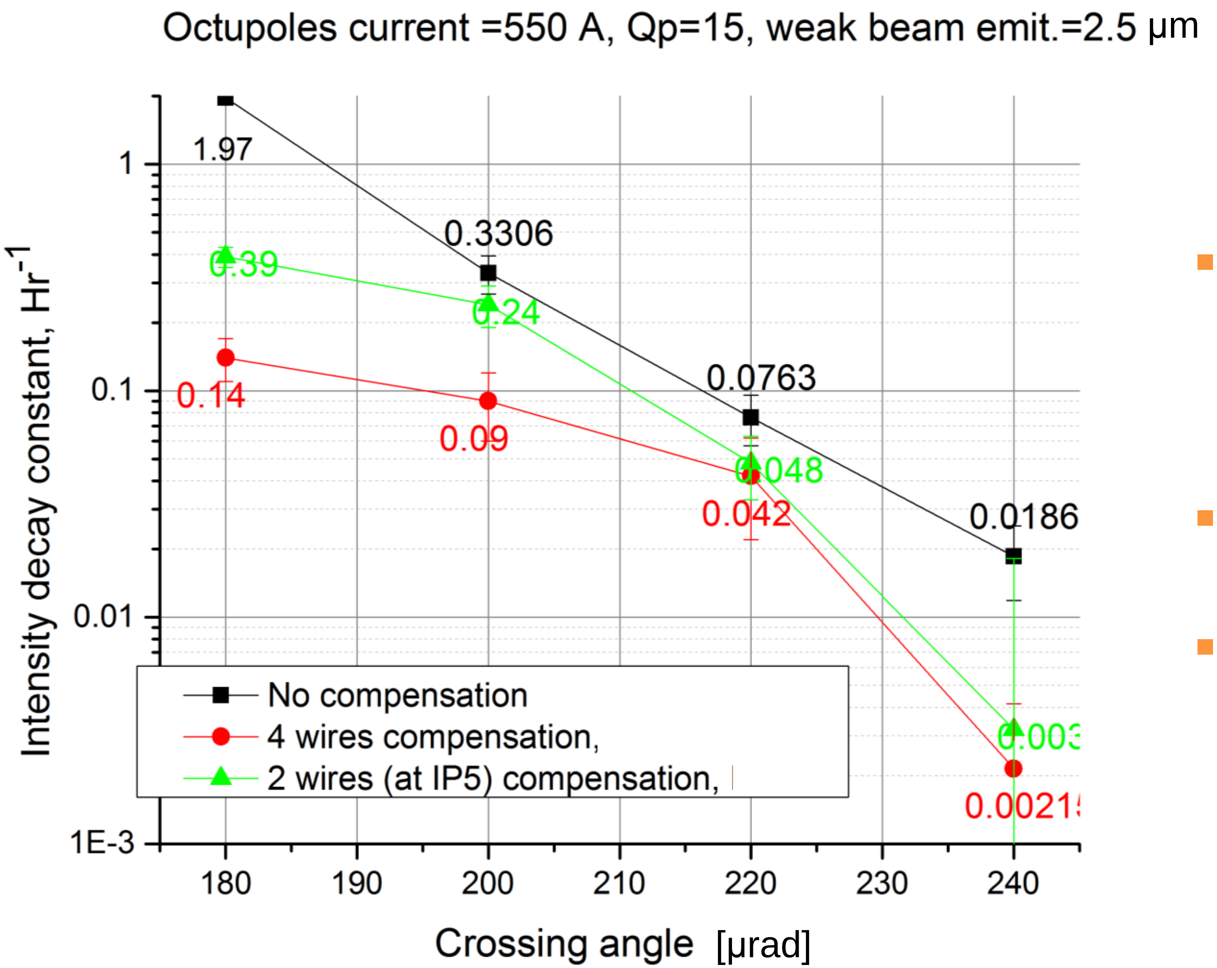
Impact of compensation



- **Black:** No compensation, weak beam emittance of 2.5 µm
- **Red:** Compensation with 4 wires
- **Green:** Compensation with 2 wires in IP5

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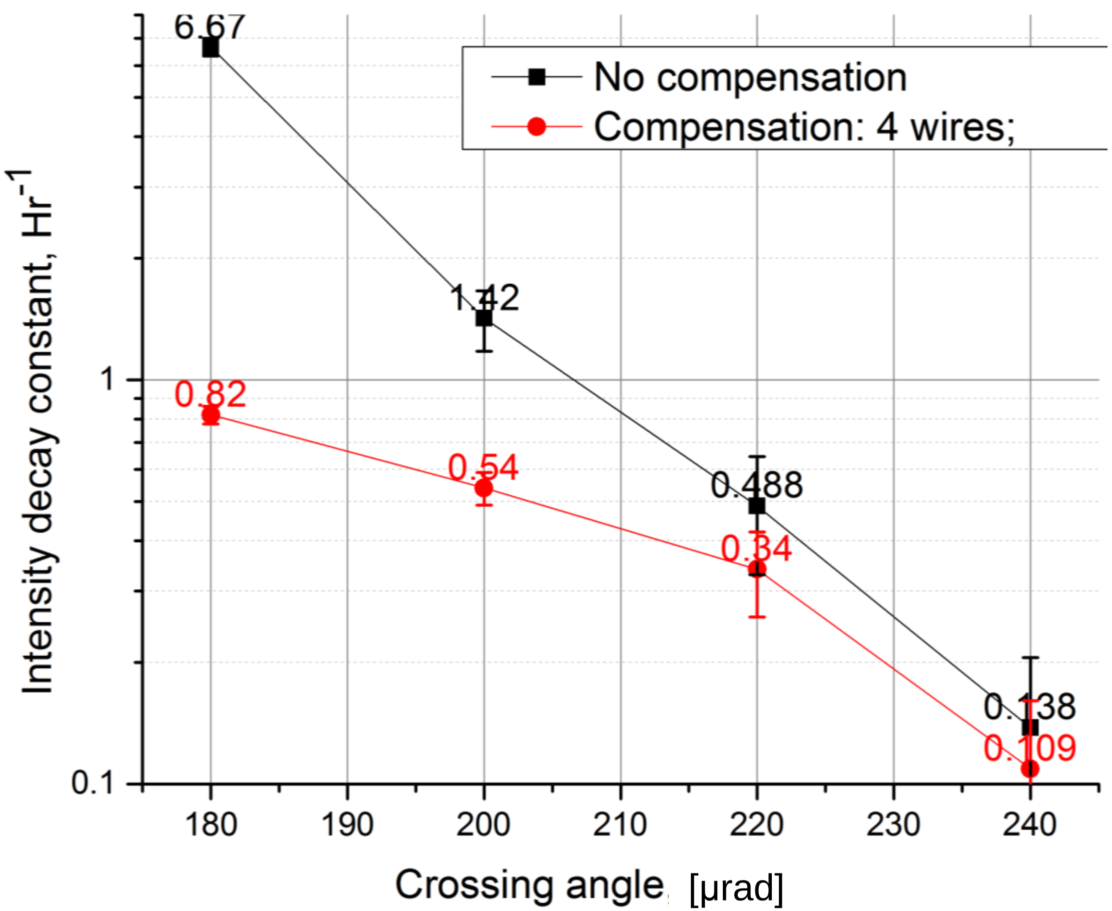
Impact of compensation

Octupoles current =550 A, Qp=15, weak beam emit.=4.0 μm



- **Black:** No compensation, weak beam emittance of 4 μm
- **Red:** Compensation with 4 wires

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Beam profile evolution

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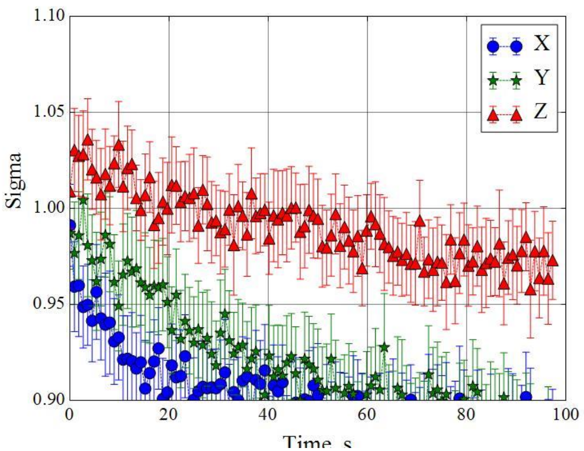
Beam Gaussian shape as a function of time: I_O=550A, Q'=15, ε = 4.0 μm

180 μrad, compensation is OFF



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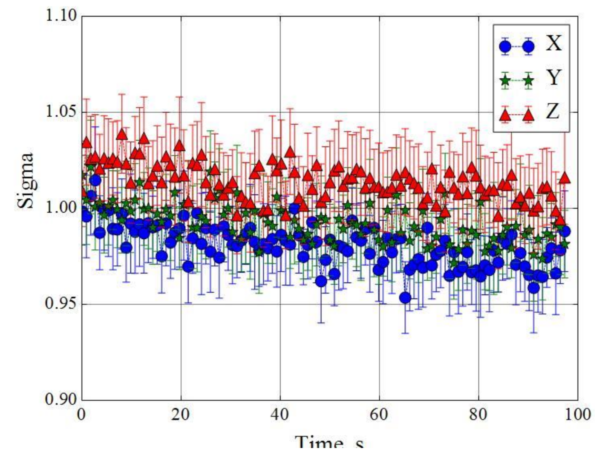
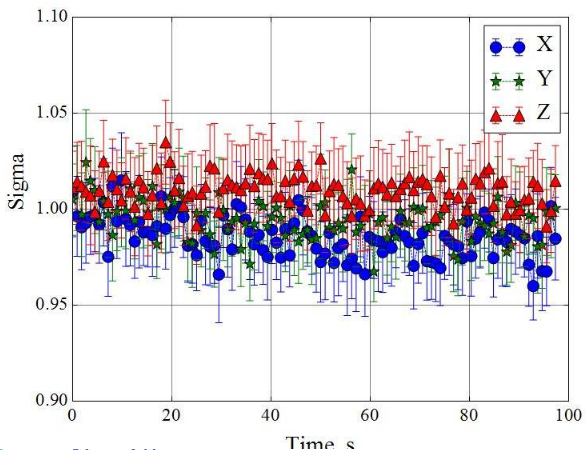
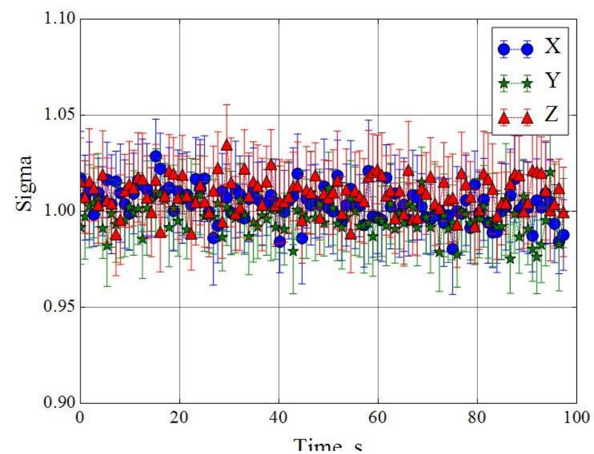


220 μrad, compensation is OFF



220 μrad, Compensation is ON



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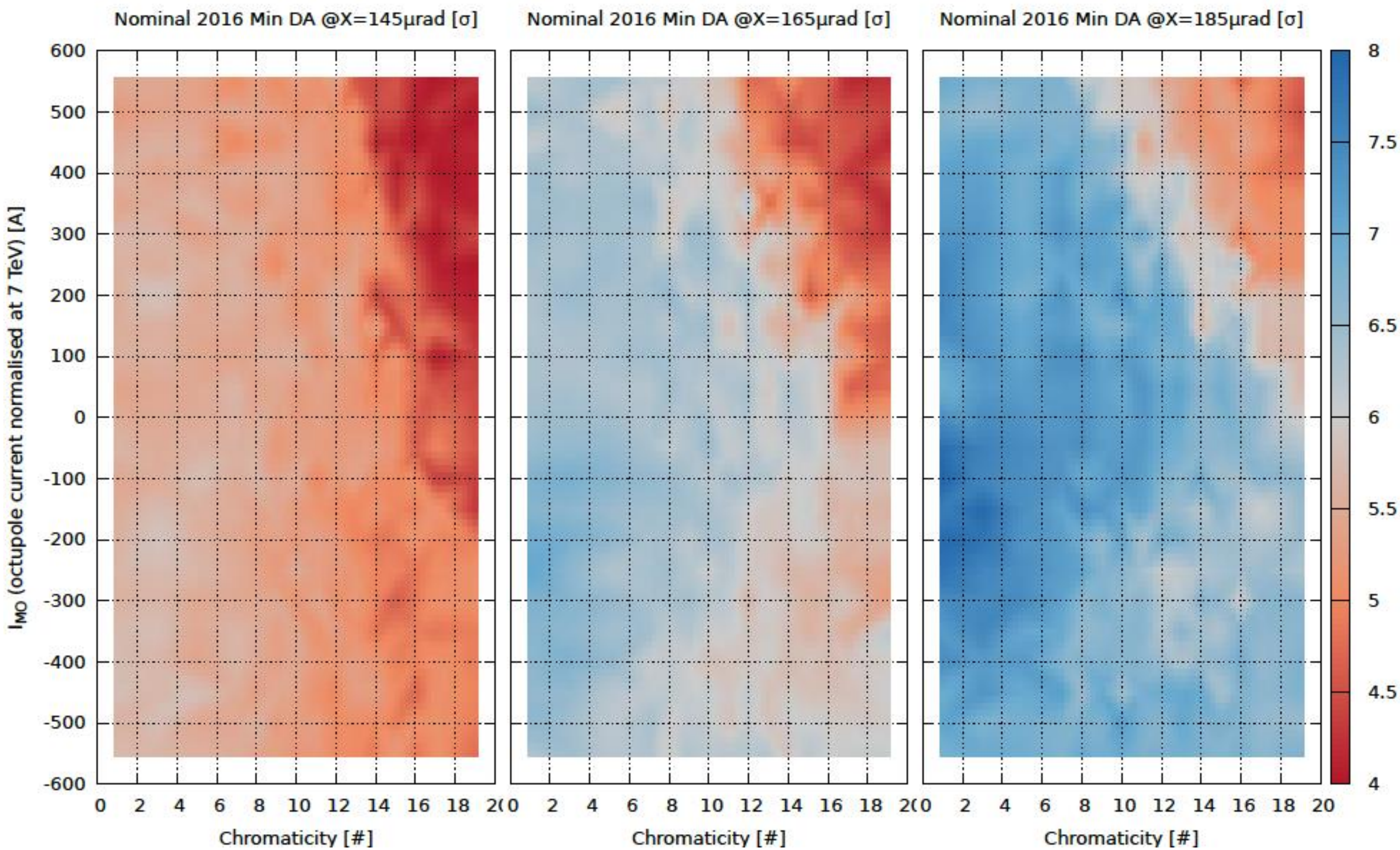
Alternative compensation

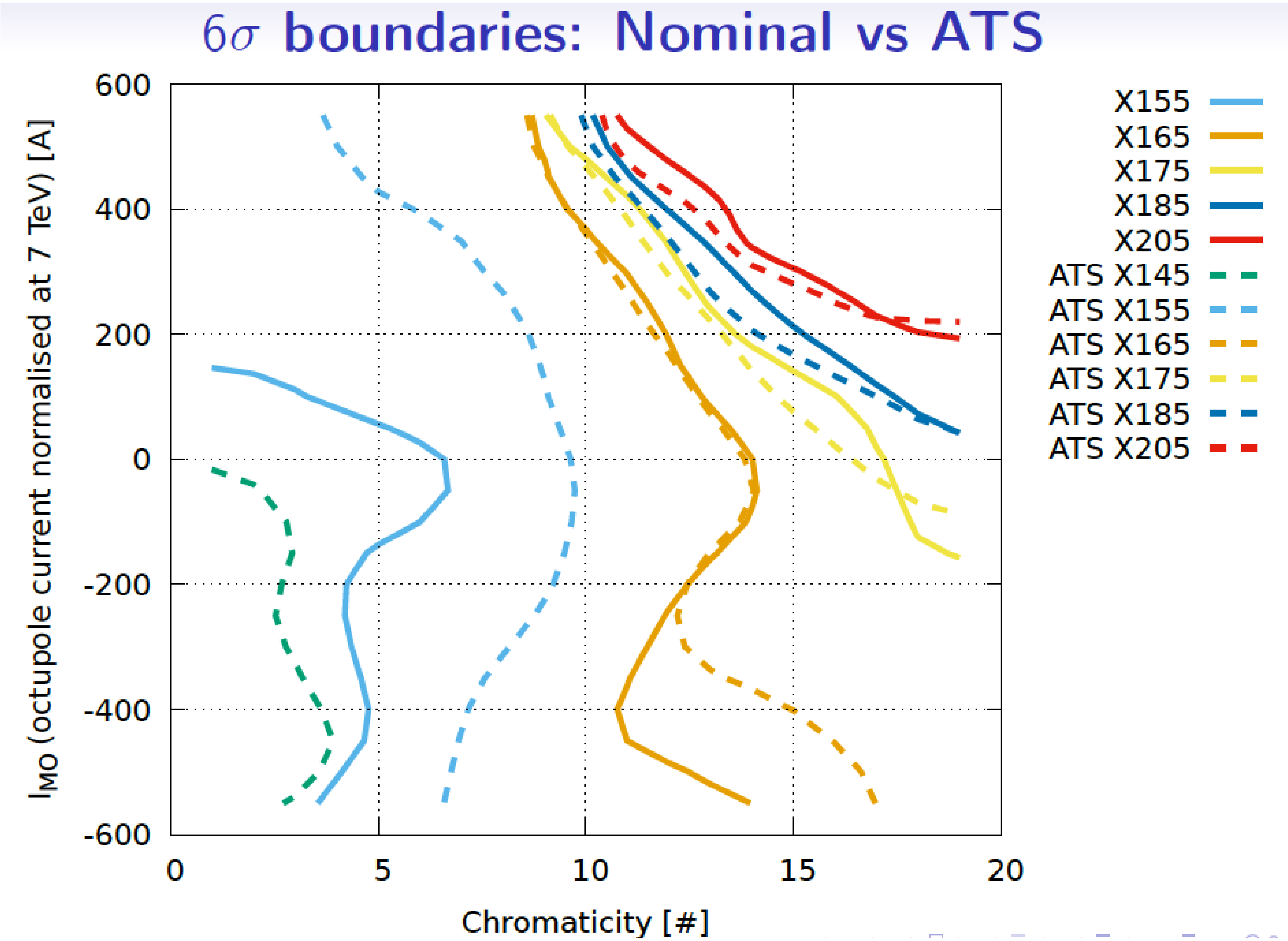
D.Pellegrini et al.



- Octupoles with negative polarity increase DA (reduce BBLR octupole-like tune-spread

Alternative compensation

D.Pellegrini et al.



- Effect of octupoles is more pronounced with ATS, (lower crossing angle reach)

Summary

- BBLR Compensation concept evolved significantly since its first proposal
- Experimental plan for BBLR devised taking into account:
  - Layout, optics constraints and schedule
- Initiated beam distribution simulations (lifetime, profile evolution) reflecting experimental scenarios
  - On-going work for simulating scenario 1 with one IP (IP5)
- Alternative compensation with octupoles (and ATS optics) is being observed in simulations
  - Tests to be done in MD in 2017-2018

Thanks for your attention