Beam-Beam Long Range Compensation - Experimental plan for 2017

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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
- Summary

Wire compensation

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

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

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

- Neglecting form factor (sufficiently large separation), can be approximated by an "infinite" wire

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

with

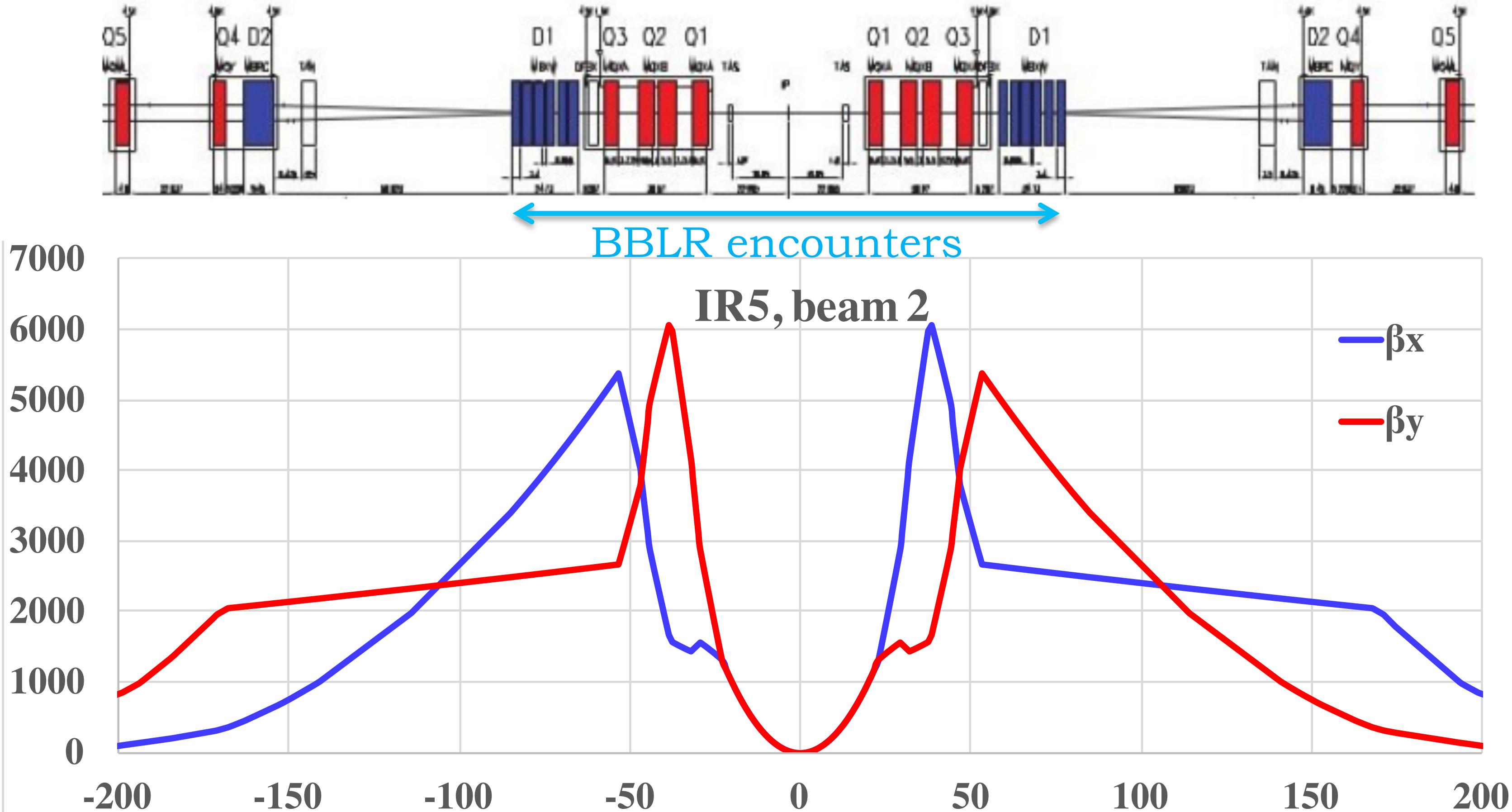
$$X_W = x + x_W\ , \quad Y_W = y + y_W$$

- The simple conditions for matching the effects are

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

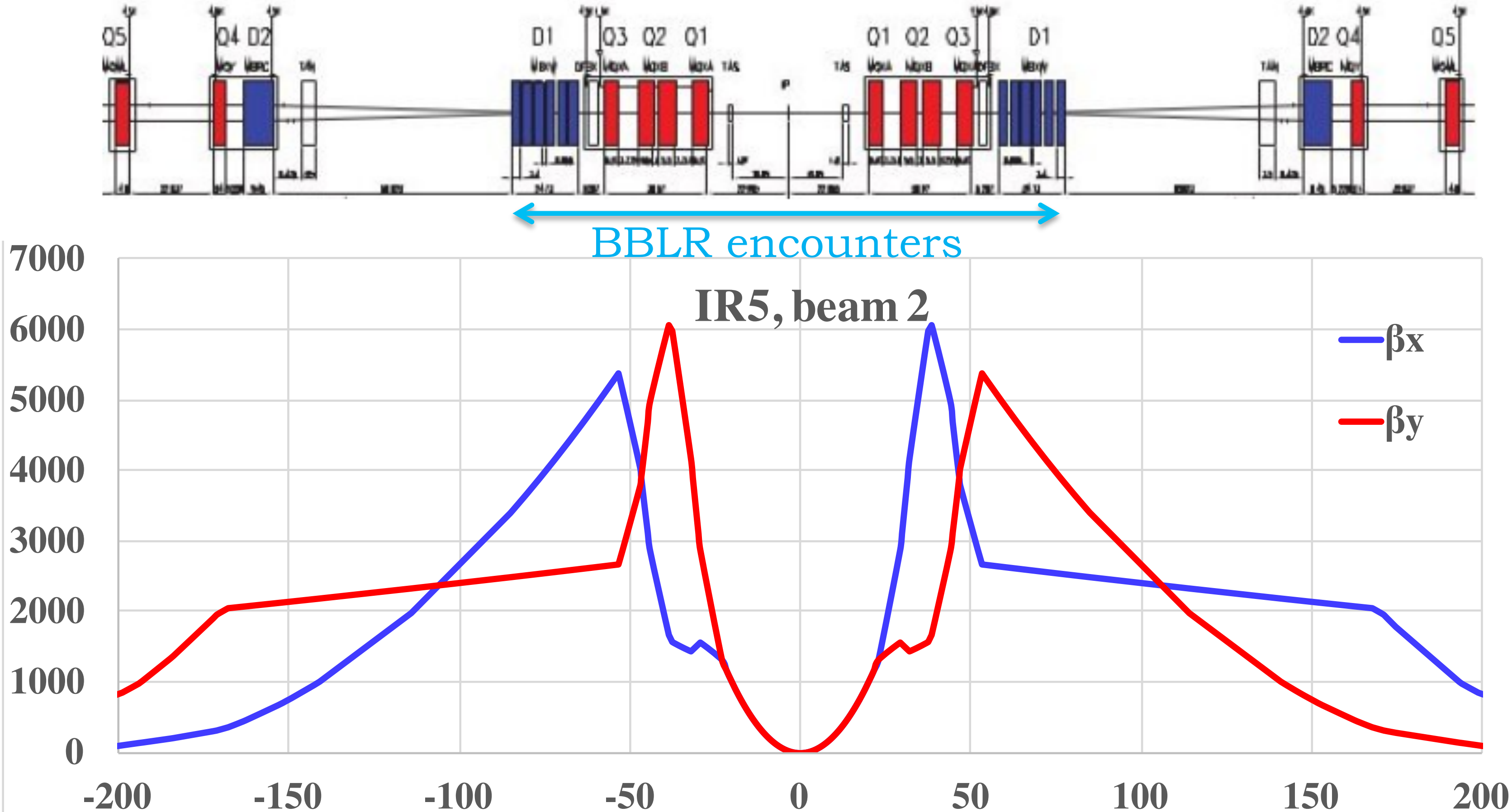
i.e. integrated current of **5.5 Am/encounter** for nominal LHC and **10.6 Am/encounter** for HL-LHC

Compensation constraints: locality



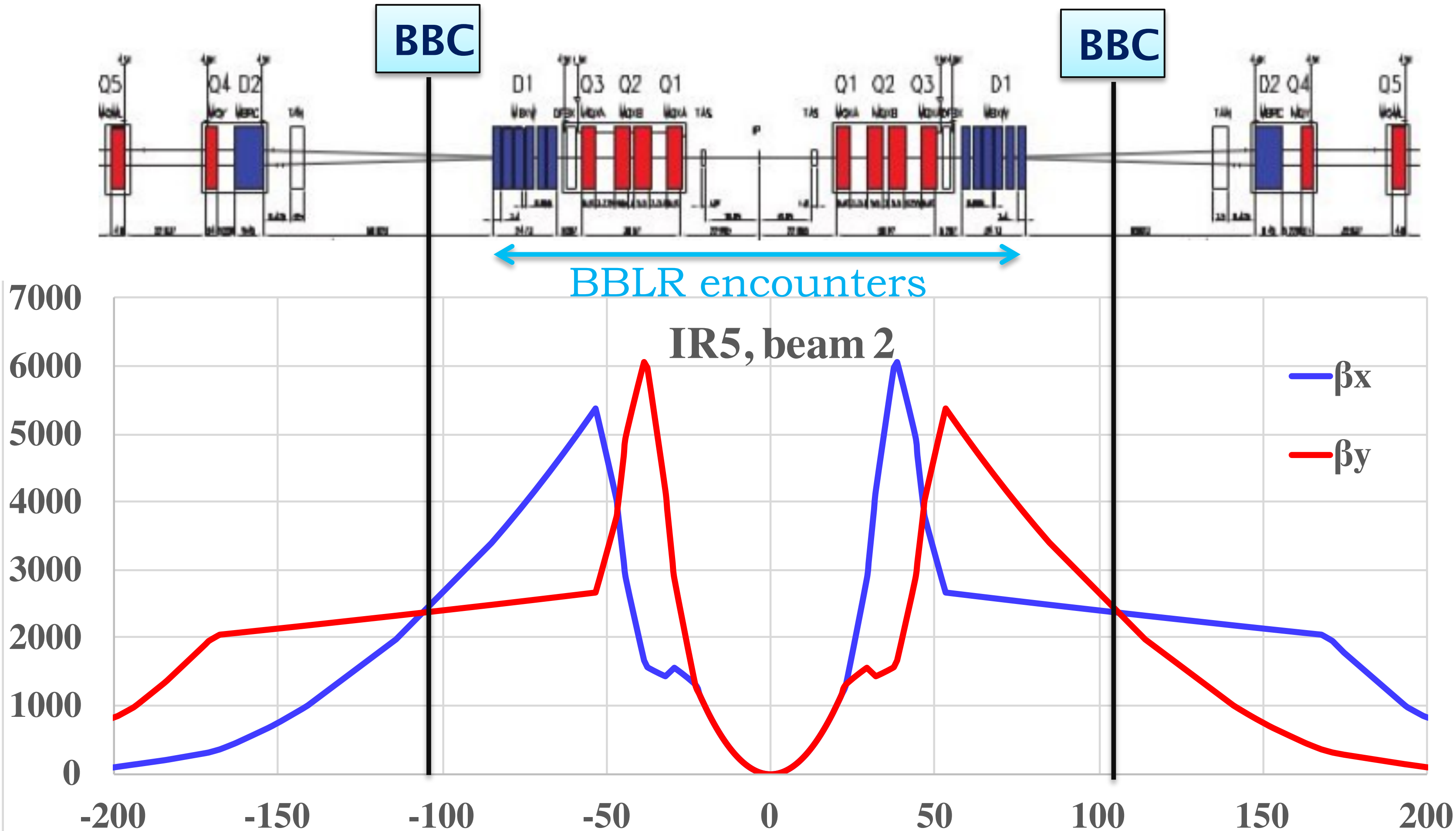
- BBLR encounters occurring at **~π/2** from either IP side
- Phase advance still ~ π/2 up to D2/Q4 (and the lower β*, the better)

Compensation constraints: optics



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

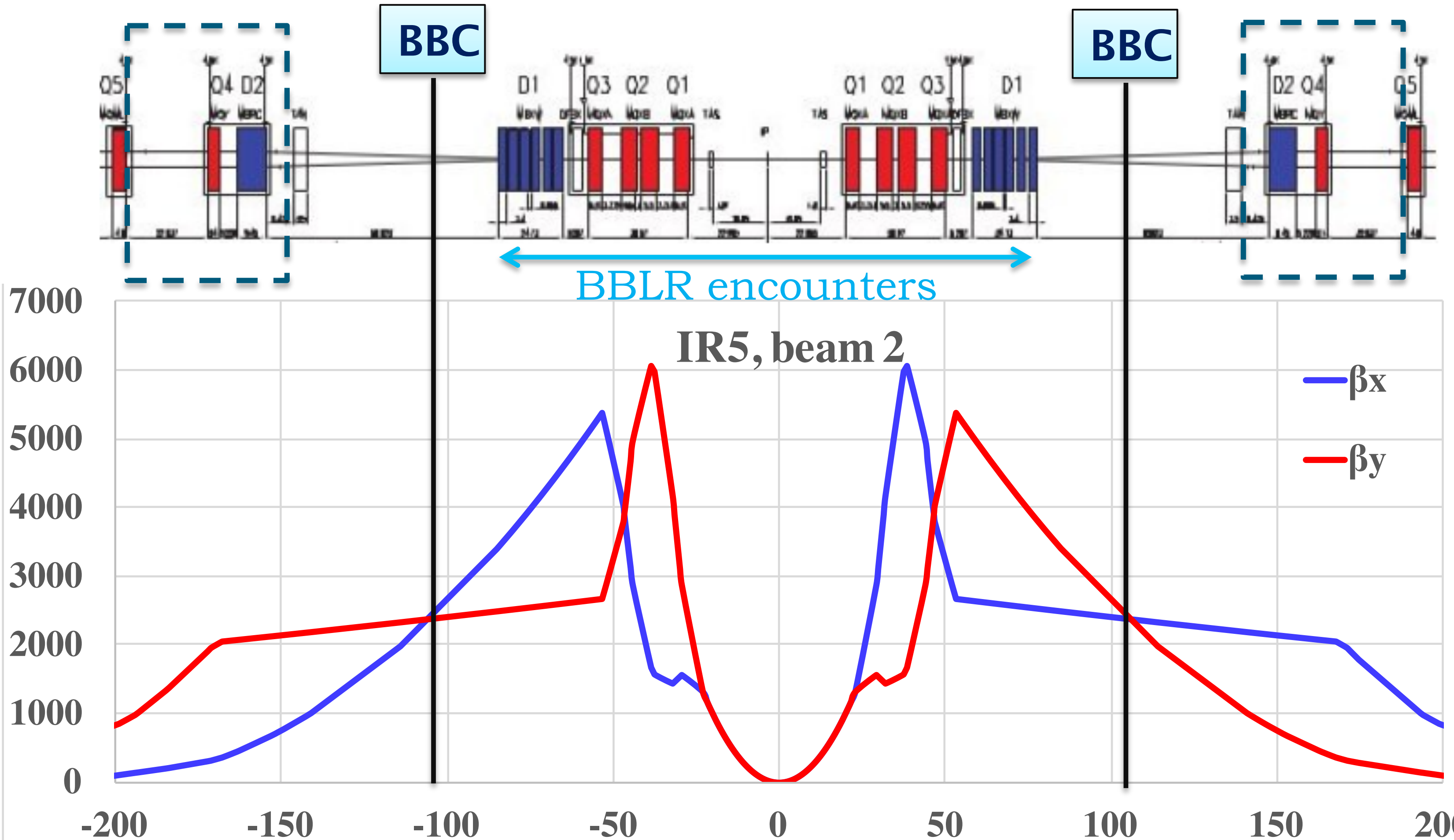
Compensation constraints: optics



- 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



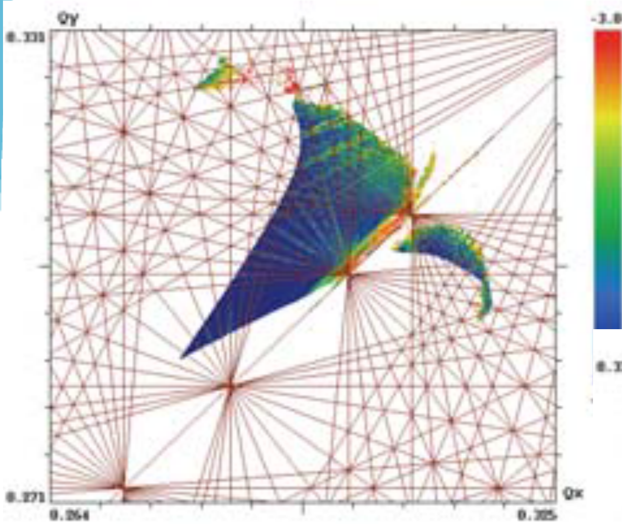
- Integration between D1 and TAN quite **challenging**
- Use wires embedded in tertiary collimators between D2 and Q5 for **proof-of-principle** tests

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

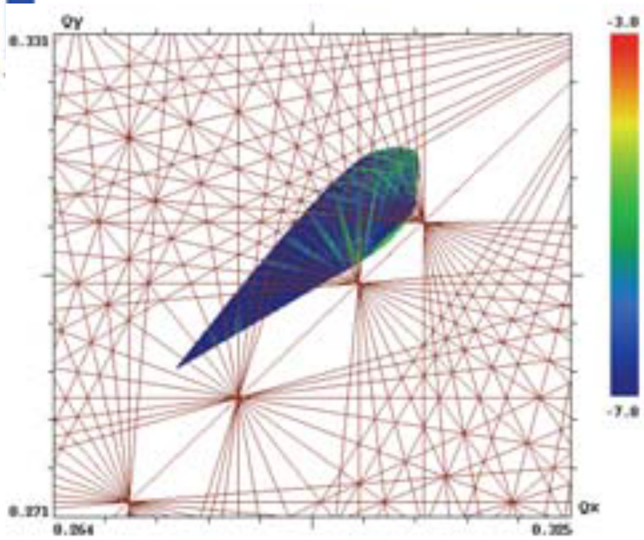
Optimal β aspect ratio

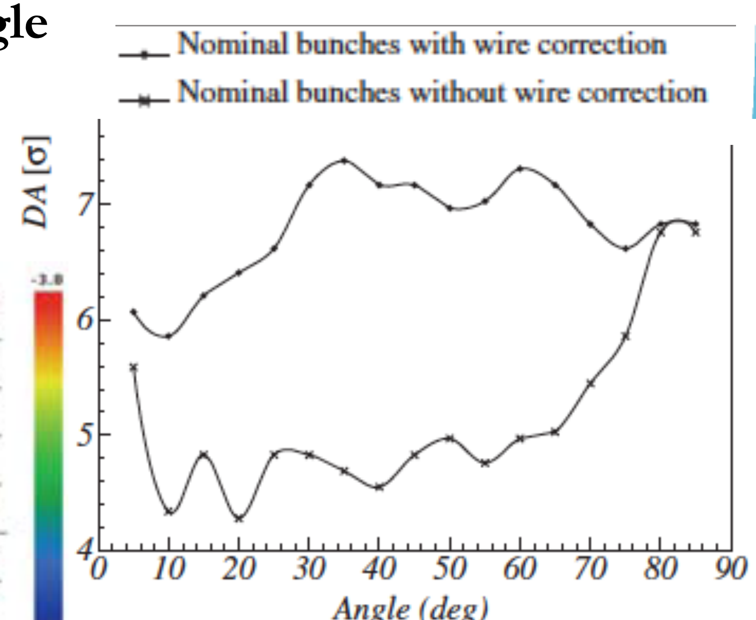
- Recent studies for HL-LHC revealed that optimal compensation can be achieved for unique β aspect ratio (strictly depending on triplet layout)
  - For HL-LHC optimal $r_w \approx 2$ or 1/2
  - For nominal LHC, $r_w \approx 1.7$ or 0.6

S. Fartoukh et al., PRSTAB, 2015



Reduced crossing angle of 450μrad @ 15cm





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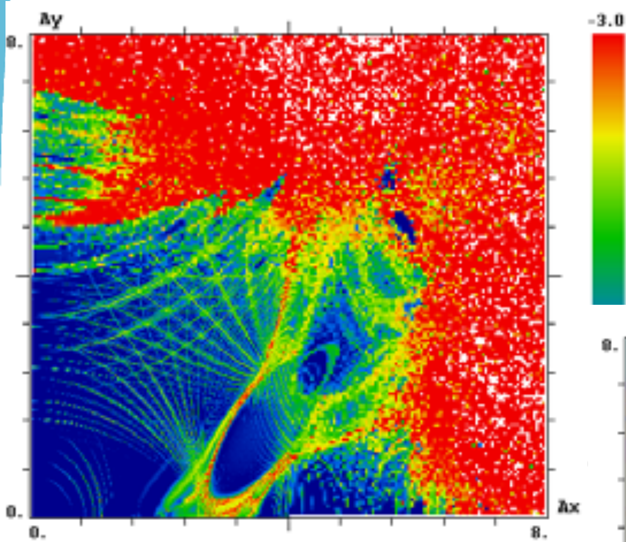

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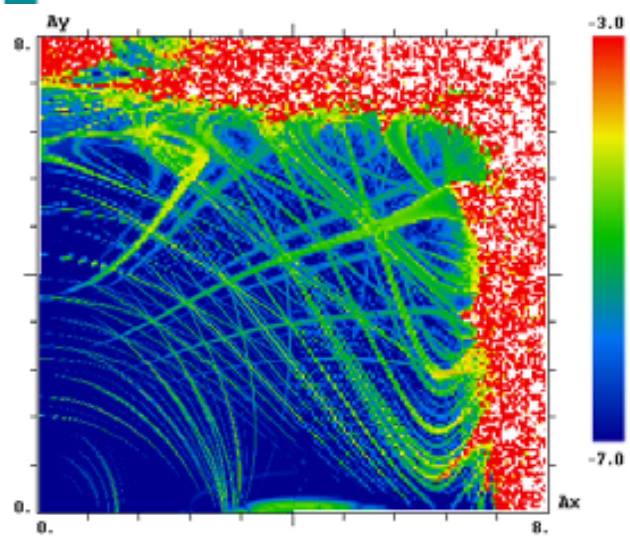
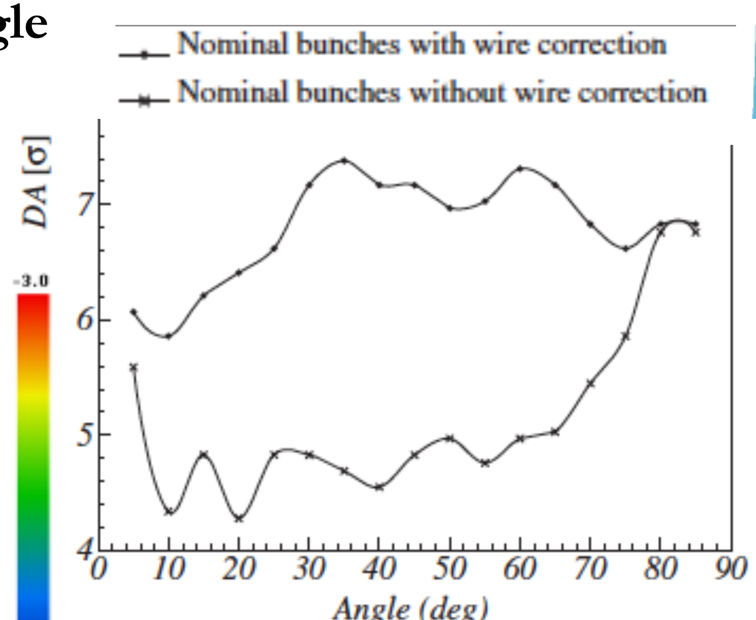
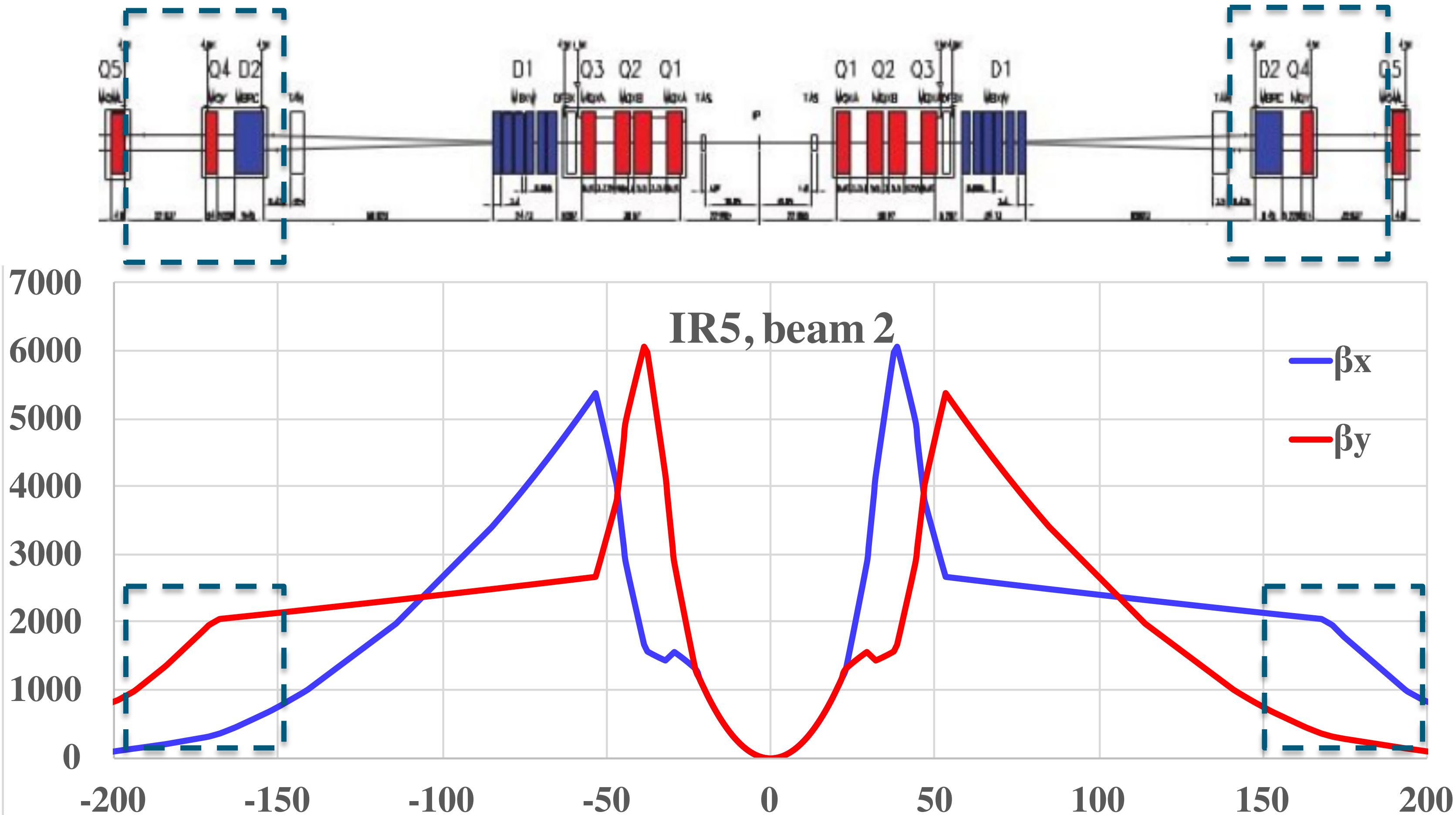


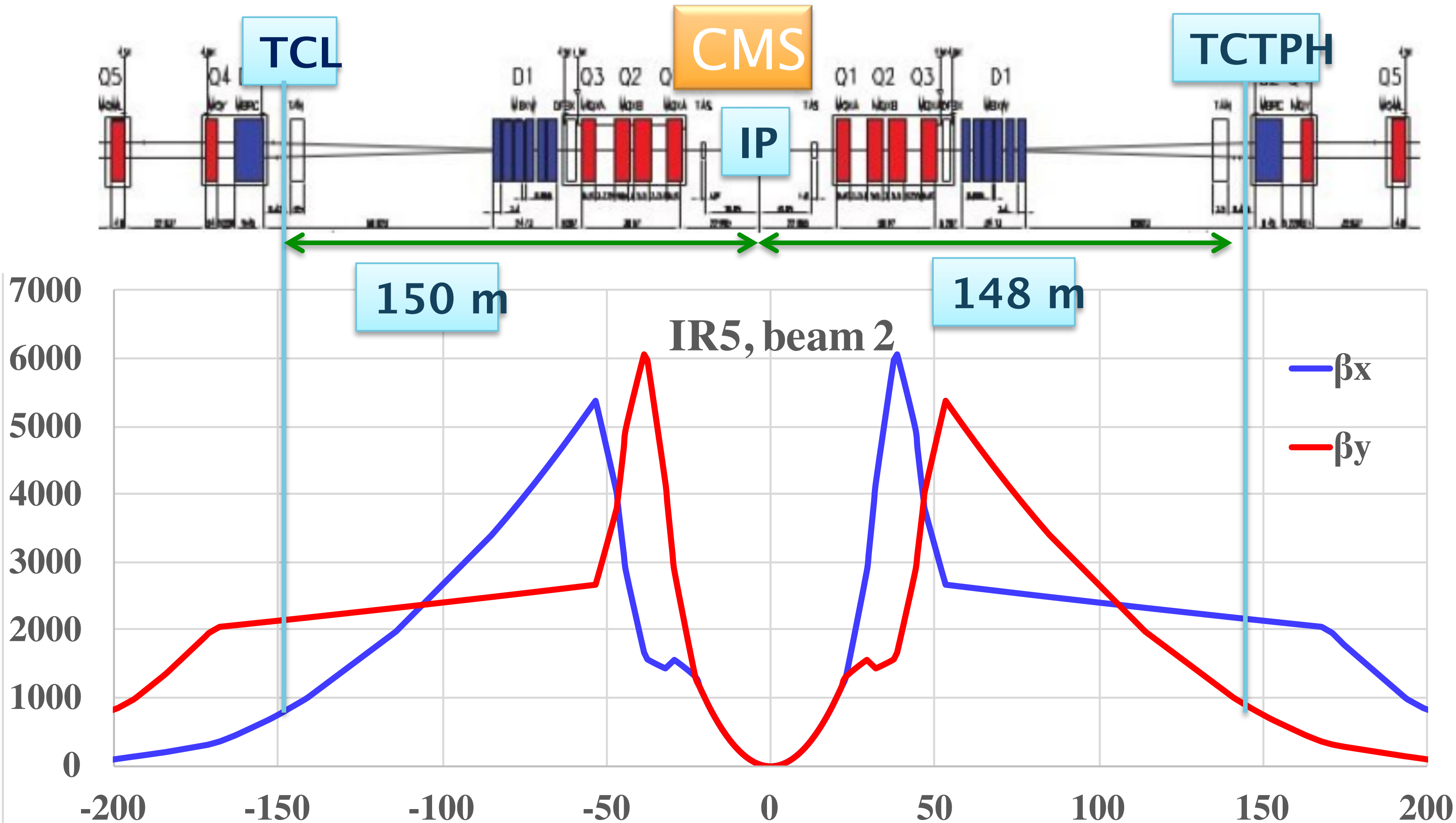


Experimental test constraints: optics



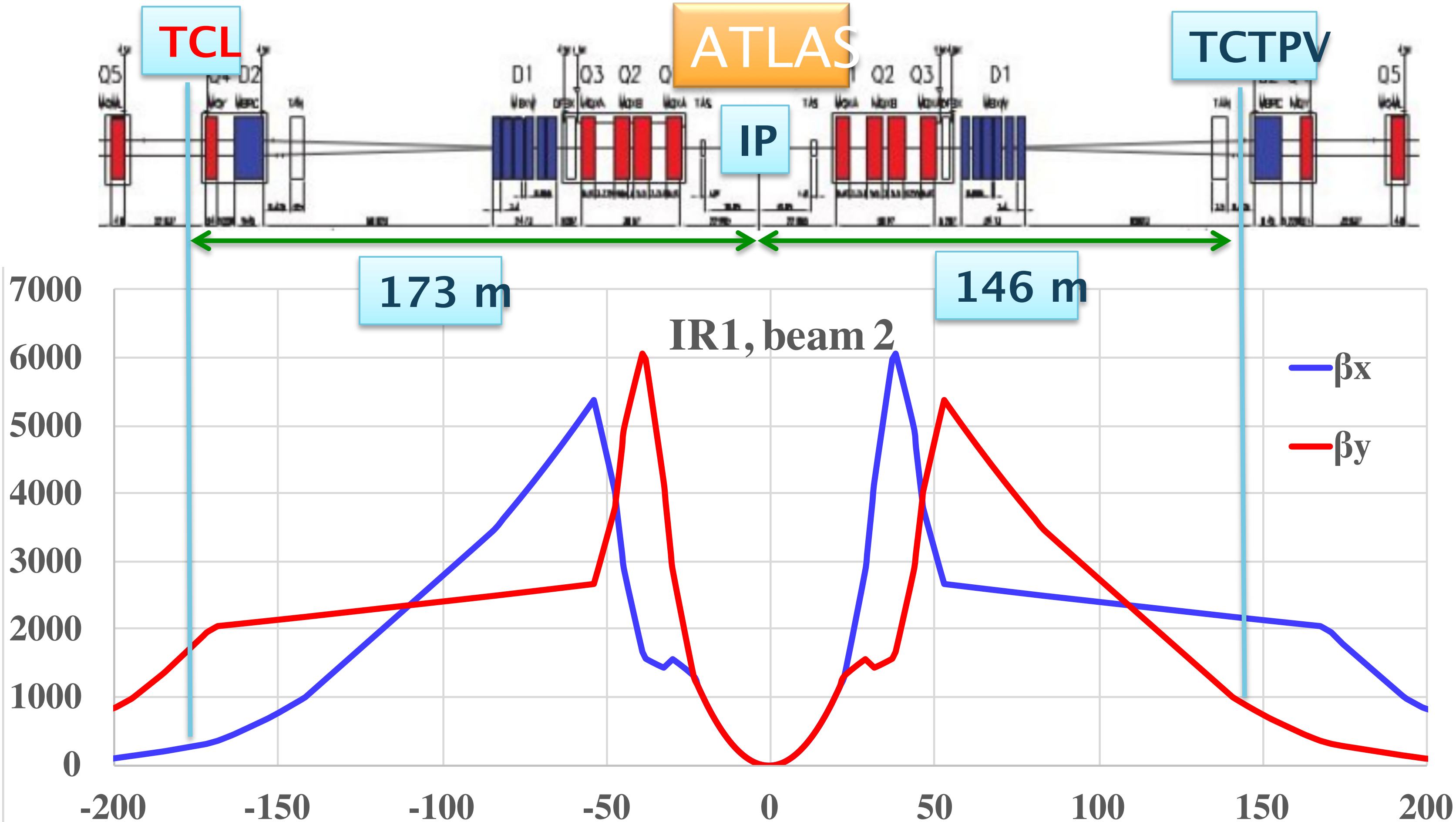
- Between TAN and Q5, ($r_w \neq 1$), one wire per IP does not provide good compensation (optics anti-symmetry)
- Need **two wires** per IP, powered individually in symmetric locations

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
- On-going discussion (collimation team) for moving it in a **more favorable position**

Status of wire-in-jaw collimators

- 4 “wire-in-jaw“ collimators ordered from CINEL
  - Cost covered by HL-LHC — O.Aberle, BBLR Mini-workshop, 2015
  - Design finished in late 2014
  - Delivery of 2+2 collimator expected in 06-07/2016, followed by acceptance (wire functionality) tests
  - Installation in EYETS 2016/2017 (vacuum group approval)
  - Cabling to be finalized for 4 individual power supplies
  - Integration details are worked out — A.Rossi, BBLR Mini-workshop, 2015
- Full compensation of beam 2: 2 collimators/IP
  - Schedule is tight!
  - “Murphy’s Law” approach: Anticipate any delays on delivery or acceptance tests
- Devise **scenario with 2 collimators** in IP5 for testing already in 2017

Experimental set-up - energy

- Tests to be done at **6.5 TeV**
- **Flat bottom** presently **disregarded**
  - Cannot provide similar LR effect (i.e. kicks occurring at ~π/2 phase advance) without squeezed optics.
  - Can be used for **calibrating** wires (optics measurements)
  - Should be part of the standard **commissioning**

Experimental set-up – strong beam composition

- **"Strong"** (non-compensated) beam (B1)
  - A few **nominal 25 ns** trains with at least **33** bunches (neglecting the long-ranges inside D1)
    - Usual 72 bunches train from PS covers all long ranges even inside D1 (also 48 bunches train with BCMS scheme)
  - As **high intensity** as possible (ultimately **1.7e11 p/ bunch** presently limited at **1.3e11 p/bunch** in the SPS)
    - May be limited by instability considerations (chromaticity, octupole settings, ADT)
  - **Emittance** small enough to guarantee that long range kick identical to 1/r field corrected by wire for all LRs

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Experimental set-up – weak beam composition

- **"Weak"** (compensated) beam (B2)
  - **Few bunches** (at least two) spaced by >15x25 ns for machine protection
    - **One bunch** with **full LRBB + HO**
    - **One bunch** with **full LRBB** but **without HO**
    - **Two bunches** with **half LR** (PACMAN-L and PACMAN-R) and **without HO**
    - **One bunch without HO nor LRs** for reference, calibrating wire effect and impact on non-colliding bunches
    - Schemes without HO are incompatible with schemes with HO due to the BPM resolution
  - **As high intensity** (and number) as machine protection permits, ideally **1.e11 p/bunch**
    - Technically feasible but **pending approval** of MP
  - **Large emittances**, for enhancing the effect on the tails, and at the same time reducing impact of wire distance to collimator edge

Experimental set-up - optics

- Fully **commissioned** and **validated** optics (correction, collimator positions, machine protection,…)
- Presently **round optics** with **β^*=~33cm** is the choice (ATS or nominal) enabling the enhancement of the LR effect, but flat optics could be used (if **commissioned**)
- **IP1**
  - Fully squeezed but beams **separated**
  - **Not fully squeezed** (e.g. with β^*=2m), below which triplet settings are not modified (**to be commissioned**)
- Nominal **collision working point** or one that could enhance lifetime reduction due to LR effect
- **IR beam separations**
  - Beams should be separated in IP2 and 8
  - **Scenario 1** (2017?)
    - **IP1** with **large separation** (> 20 σ) of weak beam (**to be worked out**)
    - **IP5** with separation for which lifetime is affected (**to be identified** by tracking and experiments in 2016)
  - **Scenario 2** (2018?)
    - **IP5** and **IP1** with separation for which lifetime is affected

Experimental set-up

- **Wires**
  - Only **two wires** left and right of **IP5** in **scenario 1 (2017)**, **four wires** in **scenario 2 (2018)**
  - **Distance** and **current** optimized for correcting **leading order LR tune-spread** (compensation of the weak beam with full LR)
  - Finding **compromise** (for wire current and/or distance) for **compensating** also weak beam with half LR (**PACMAN**)
- **Observables**
  - **Lifetime**
  - Tails **diffusion**
    - Losses on different collimator positions, BSRT, **halo diagnostics**
  - Orbit, tune, chromaticity, **tune-spread**, RDTs
  - Beam transfer function, Schottky

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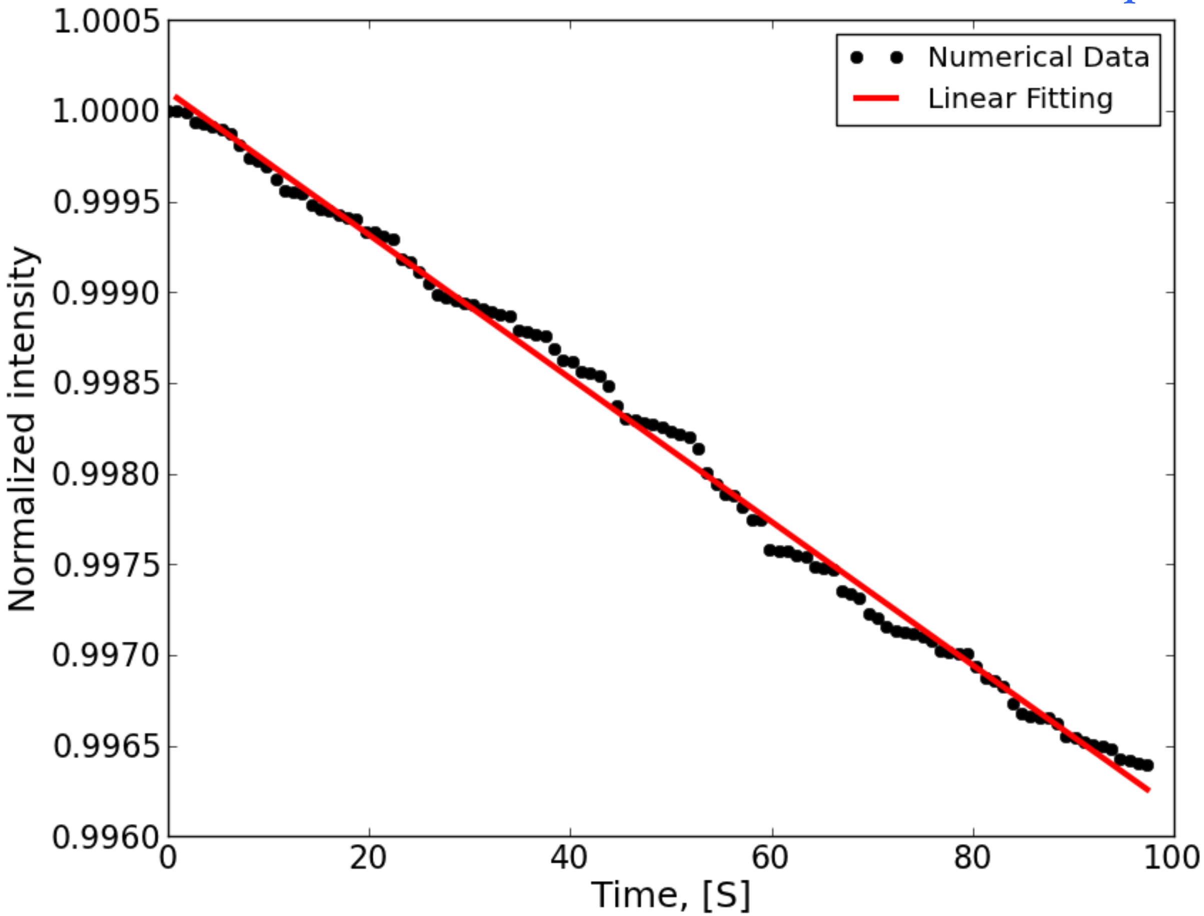
Tracking and compensation parameters

- Beam intensity 1.2×10^{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

A.Patapenka, S. Valishev et al.

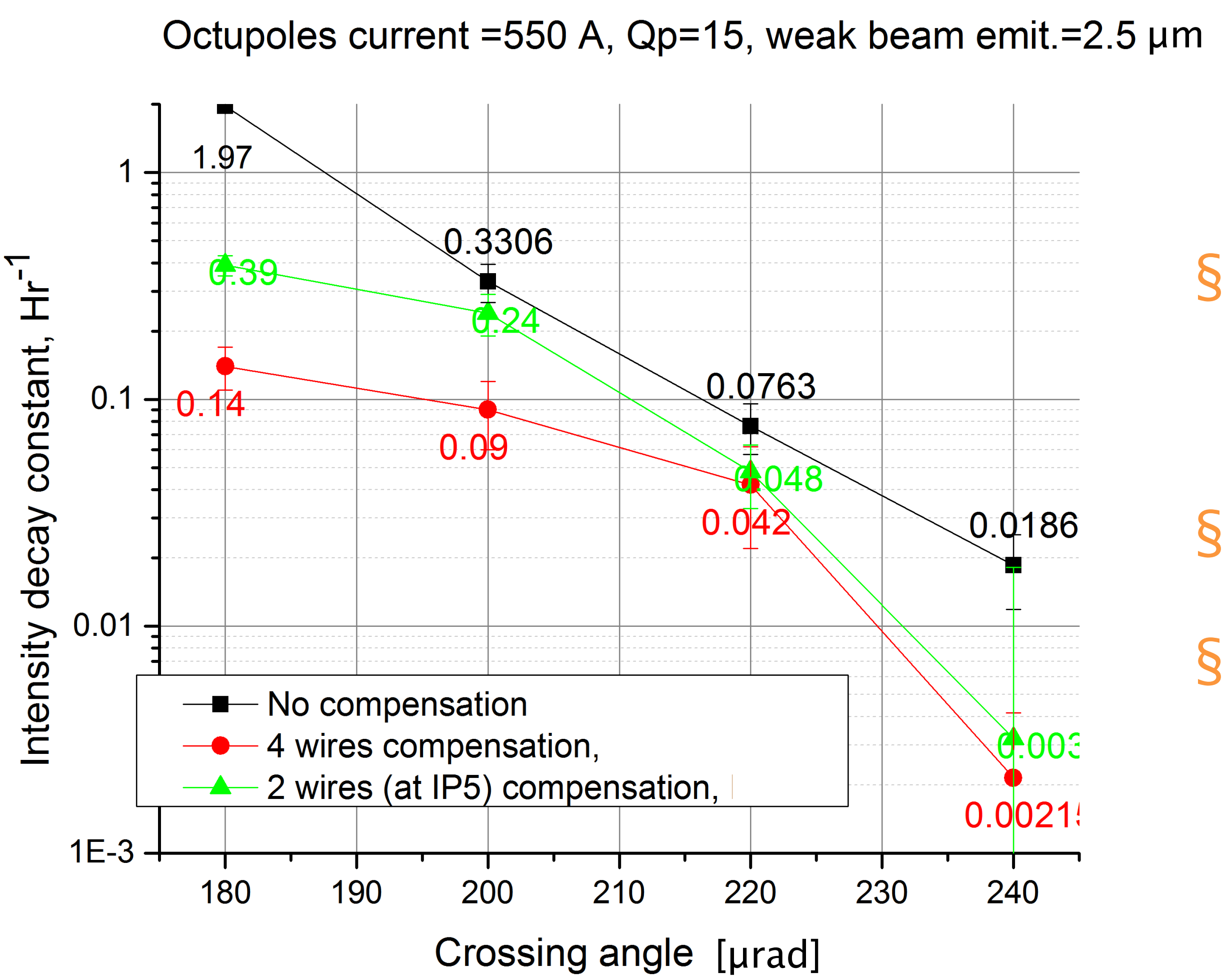
Beam intensity decay

A.Patapenka, S. Valishev et al.



- 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 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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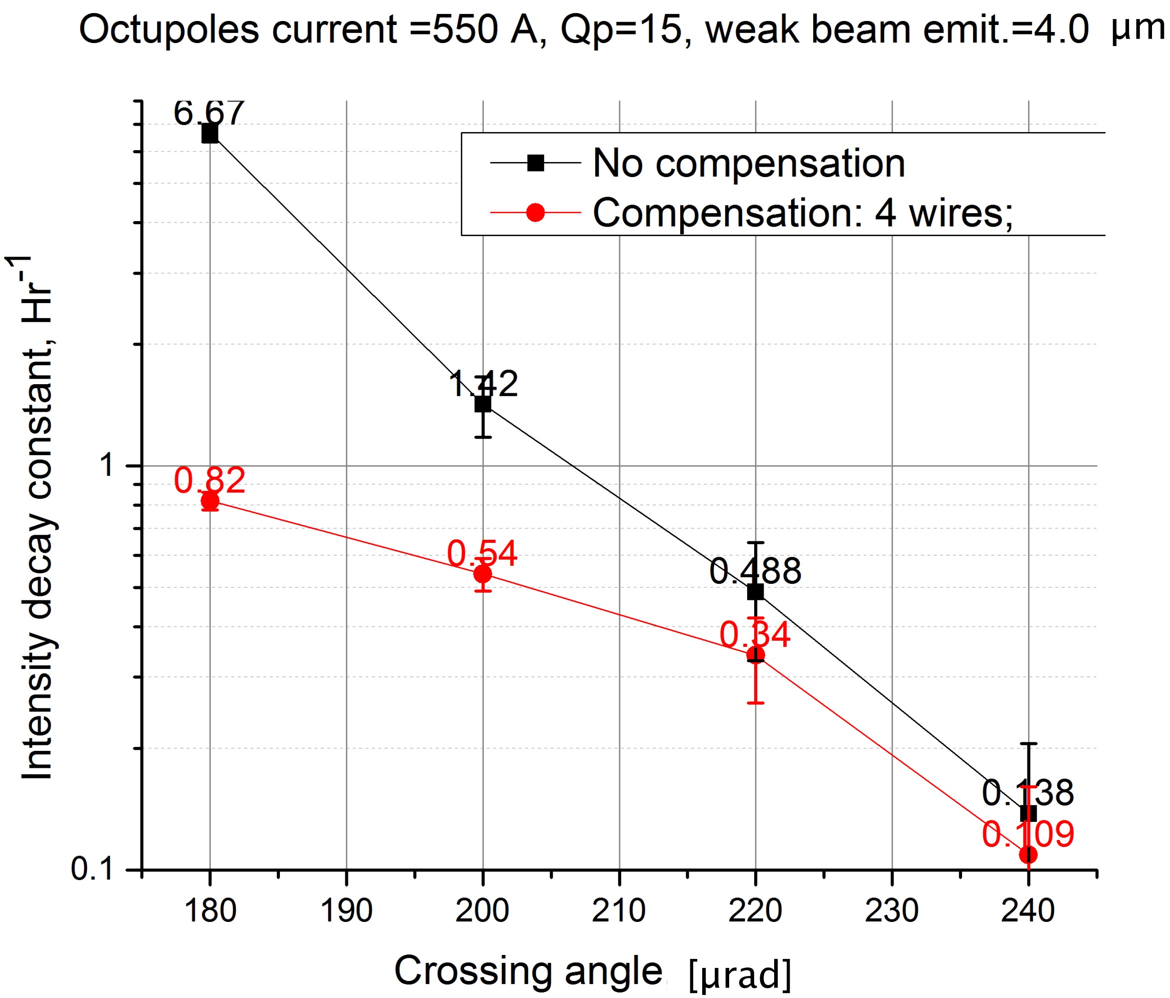
Impact of compensation



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

A.Patapenka, S. Valishev et al.

Summary

- BBLR Compensation concept evolved significantly since its first proposal
- Experimental plan for BBLR devised taking into account:
  - Layout and optics constraints
  - Hardware delivery schedule
- Scenario 1 (only IP5 squeezed) part of the MD planning since 2016
  - Synergy with IR optics correction MDs
  - Final planning to be discussed during 1-day workshop in March

R.Tomas, Chamonix 2016

- Initiated beam distribution simulations (lifetime, profile evolution) reflecting experimental scenarios
  - On-going work for simulating scenario 1 with one IP (IP5)
- Tight MD schedule for 2017 (scenario 1) and even more for 2018 (scenario 2)

Thanks for your attention

Beam profile evolution

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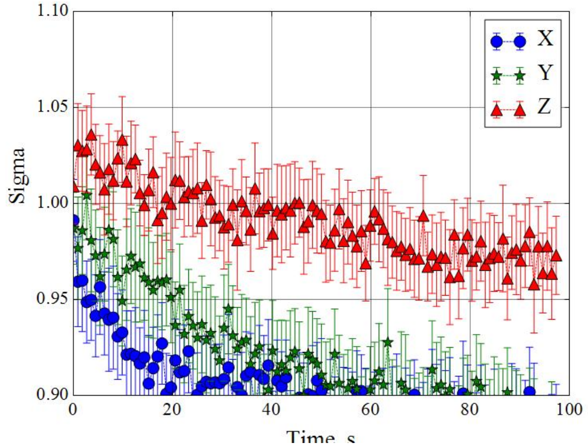
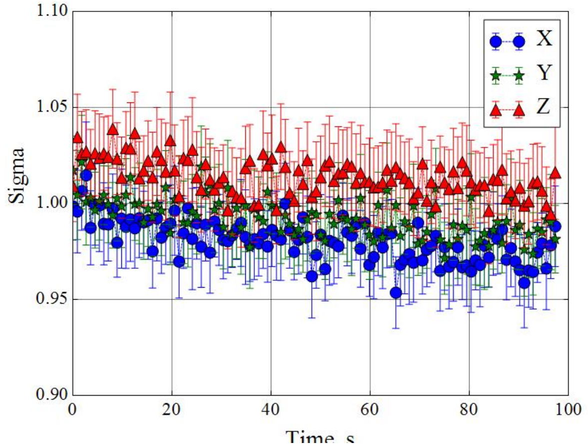
Beam Gaussian shape as a function of time: I_O=550A, Q'=15, ε = 4.0 μm

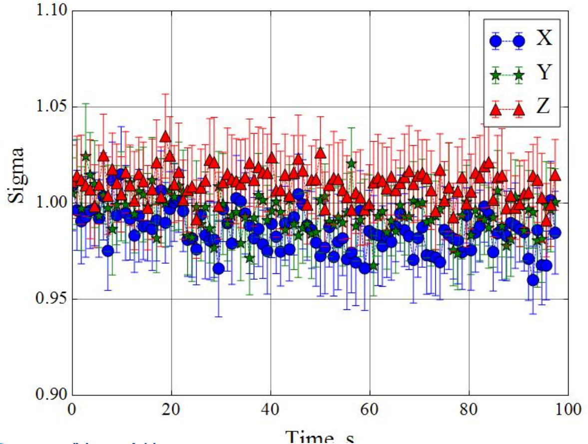
180 μrad, compensation is OFF



180 μrad, Compensation is ON



220 μrad, compensation is OFF



220 μrad, Compensation is ON