Proposal for the experimental scenario

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Workshop on Simulations and measurements of Long Range Effects in the LHC

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With input from

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Outline

- Principle of wire correction
- Wire embedded in collimators
  - Optics, wire distance and current
- Experimental conditions, observables and associated instrumentation needs
- SPS wires status
- Discussion

Wire compensation

- Considering round beams and crossing in both planes, the BBLR kicks are

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

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

- For an "infinite" round wire, the kicks are

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

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

- For cancelling the effect **for any position** (large separations) $x_W = x_c \ , \ \ y_W = y_c \ , \ \ I_W L_W = ecN_b$
- This gives **5.5 Am/encounter** for the nominal LHC and **10.6 Am** for HL-LHC

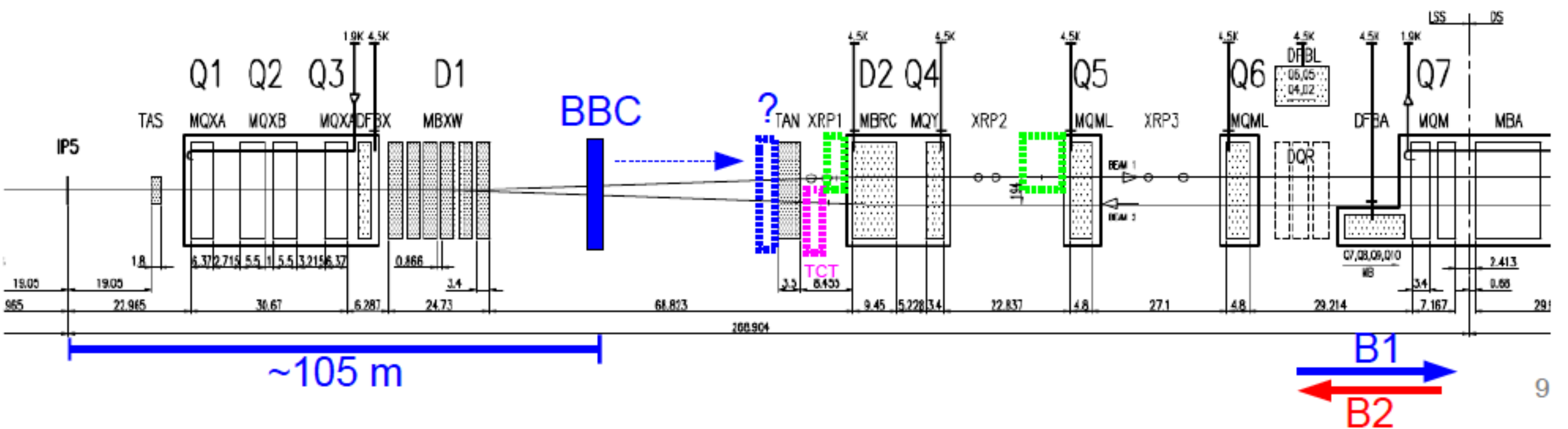
Basic considerations

J.P. Koutchouk, 2001

- **Locality** of the compensation
  - Close to the BBLR encounters which occur at ~π/2 from either IP side
  - A lot of space available between D1 and TAN but integration is difficult (idea of e-lens)
  - Phase advance still close to π/2 even up to Q5
- **Optics** considerations

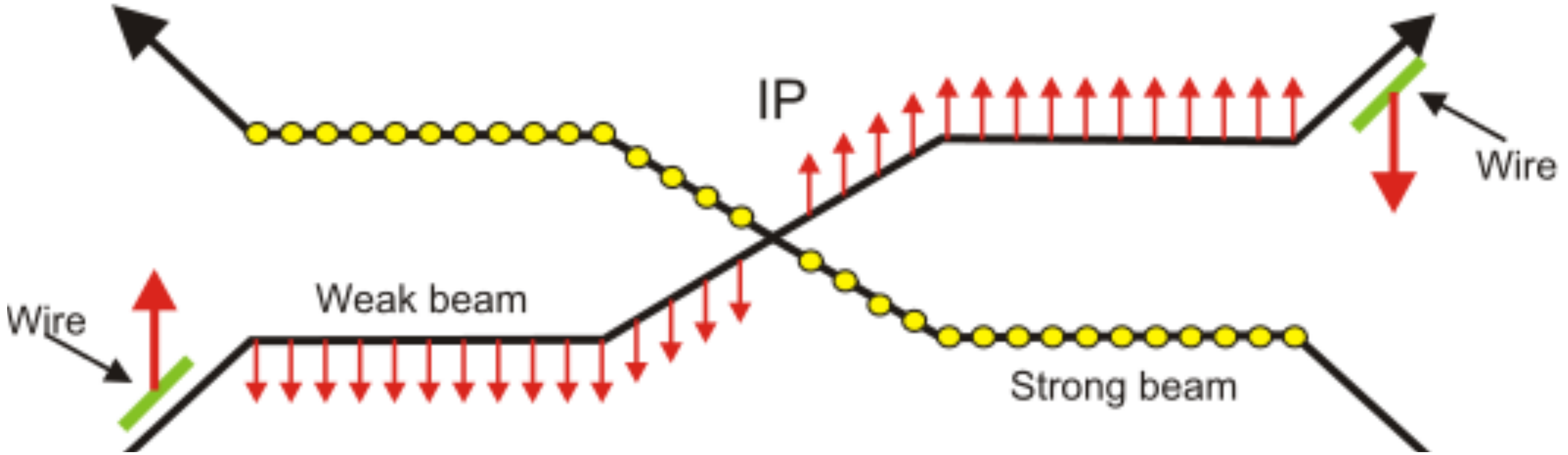
S. Fartoukh et al., PRSTAB, in press

  - Large beta functions for efficient tune-shift compensations
  - The optics functions equality is not optimal for resonance driving term compensation
    - Ratio of 2 or ½ is optimal for HL-LHC
- The absolute criterion should be **non-linear compensation**
  - Increase of Dynamic Aperture through combined reduction of non-linear resonances and tune-spread

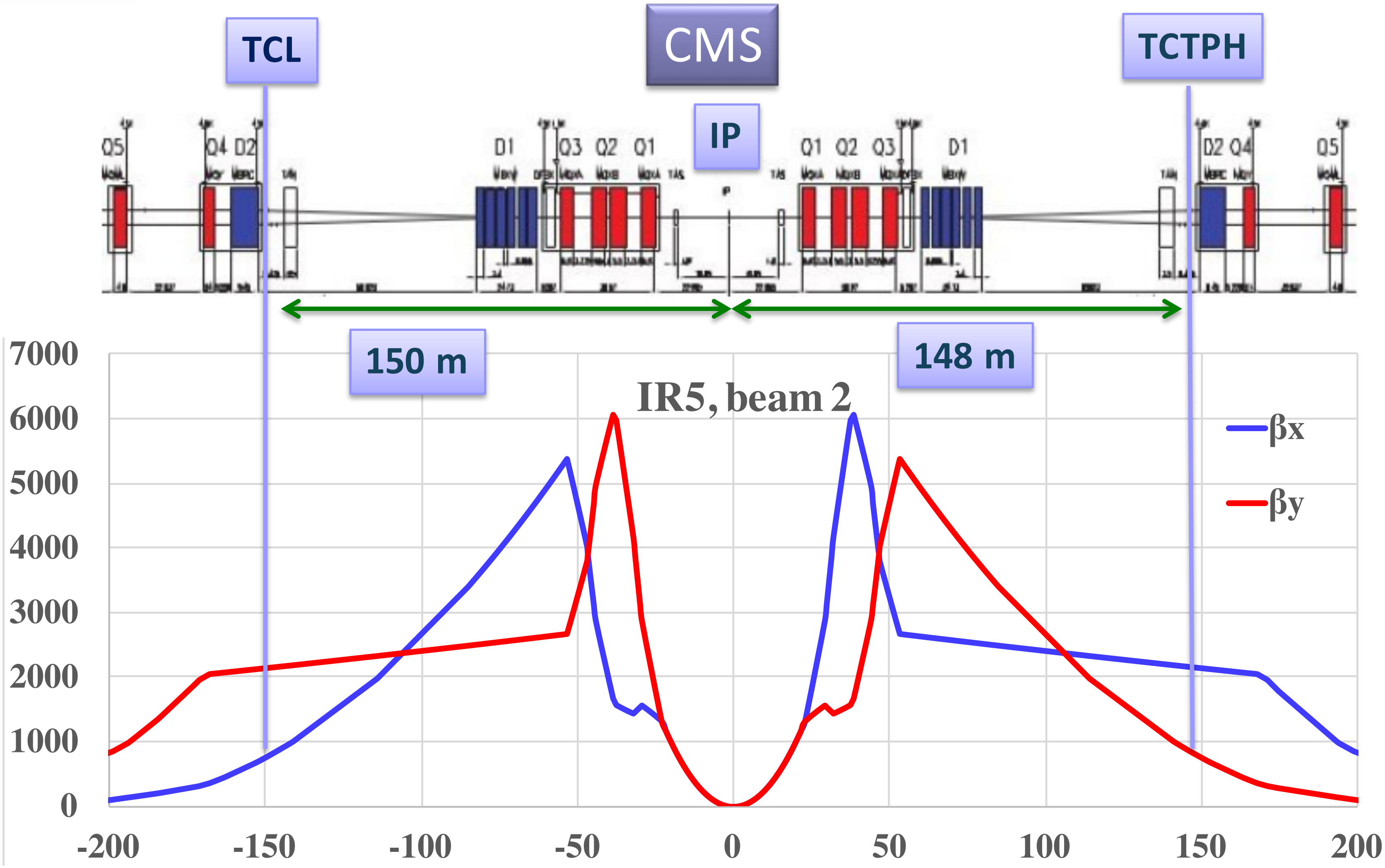


Two wires per IP

- **Integrated current** can be **reduced** for the same correction reach
- Due to optics anti-symmetry and different plane crossing, **effect of two wires** in the two planes is also **anti-symmetric** (if placed in symmetric locations wrt to the IP)
- **Powered independently** to fit better the integrated kick on either side
- **Beam 2** is presently considered being the one equipped with the test halo diagnostics (coronograph)
  - Are there any other constraints preventing this choice?

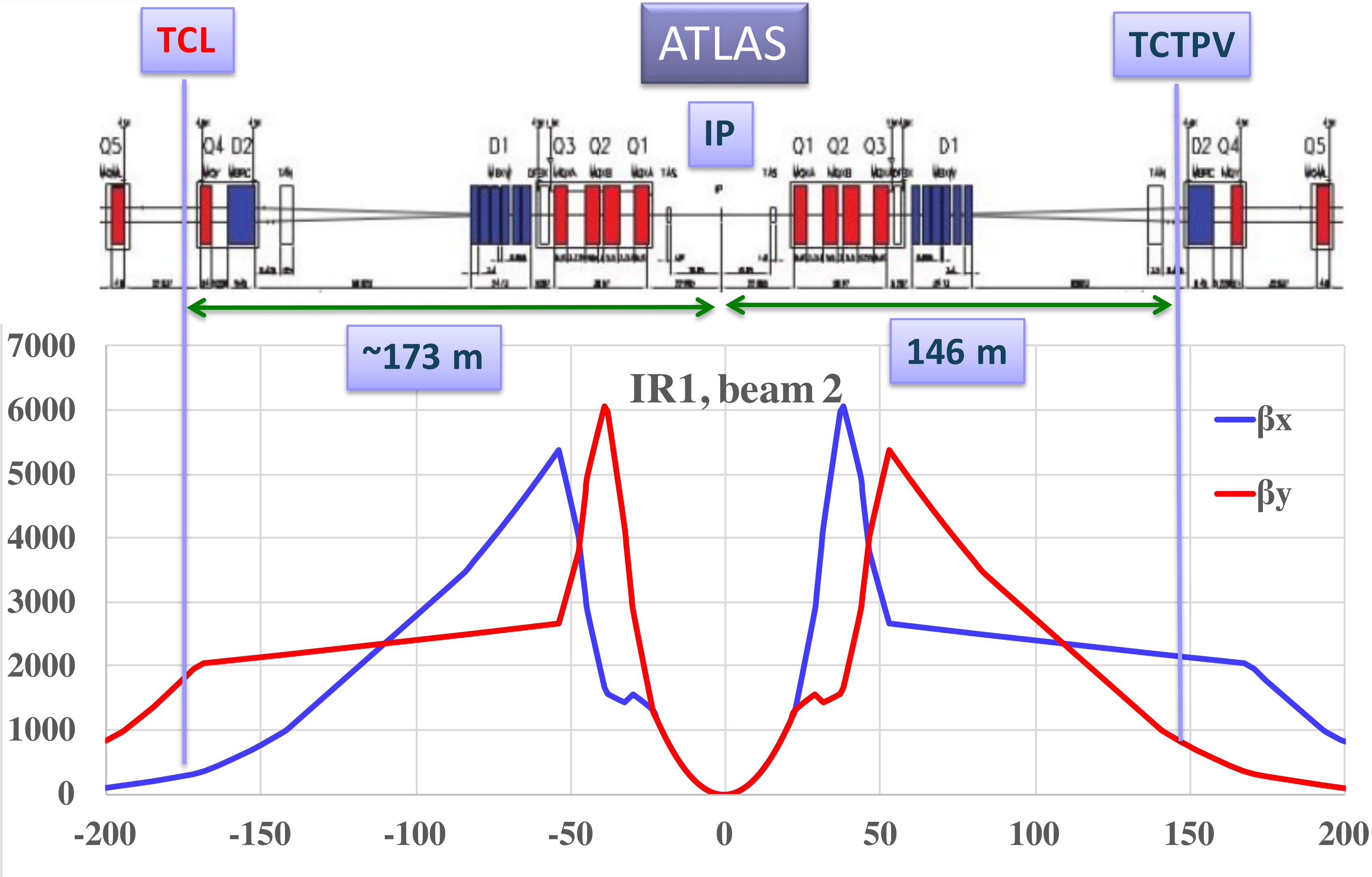


Optics at wire locations



- IR5: **Horizontal TCT** and **TCL** will be replaced with wire-embeded collimators
- **Optics** very close to **anti-symmetric** between the two locations (6.5TeV, 0.4m β* shown)

Optics at wire locations



- IR1: Vertical TCT will be replaced with wire-embeded collimator and **new TCL** installed downstream of Q4 (beam 2), as location next to D2 quite crowded
- Optics **not close to anti-symmetric** especially for the small corresponding β

Optics at wire locations

- In both IR1 and 5, wire location to almost **$\pi/2$** from IP (max deviation of 2.5^{o})
- For IR5, β-function ratios of around **0.36-2.61**, **almost anti-symmetric**
- For IR1, β-function ratios of around **2.48-0.16**, **far from anti-symmetric**
- Both optics are likely **far** from **optimal** β-function **ratio**
  - Around **1.7-0.6** for nominal LHC

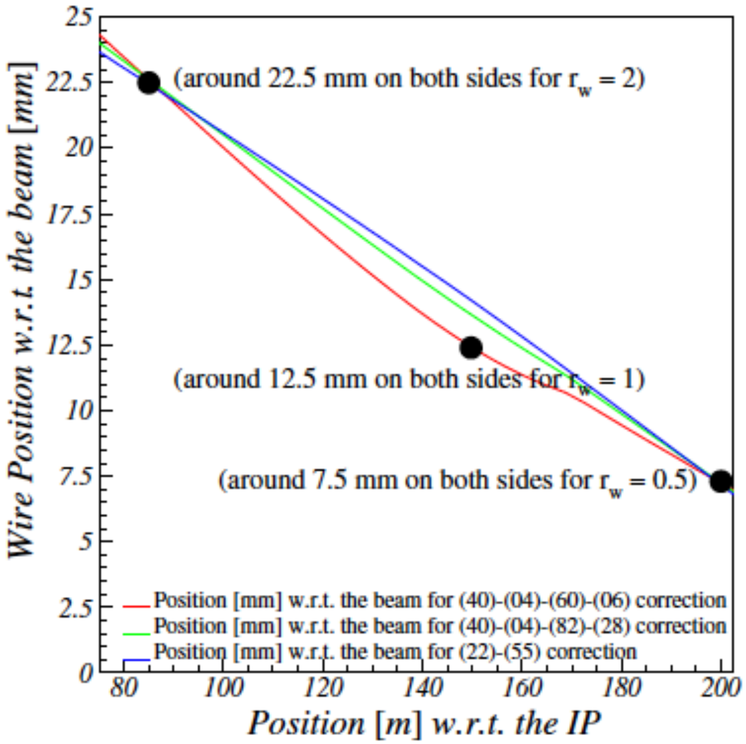
S. Fartoukh et al., PRSTAB, in press

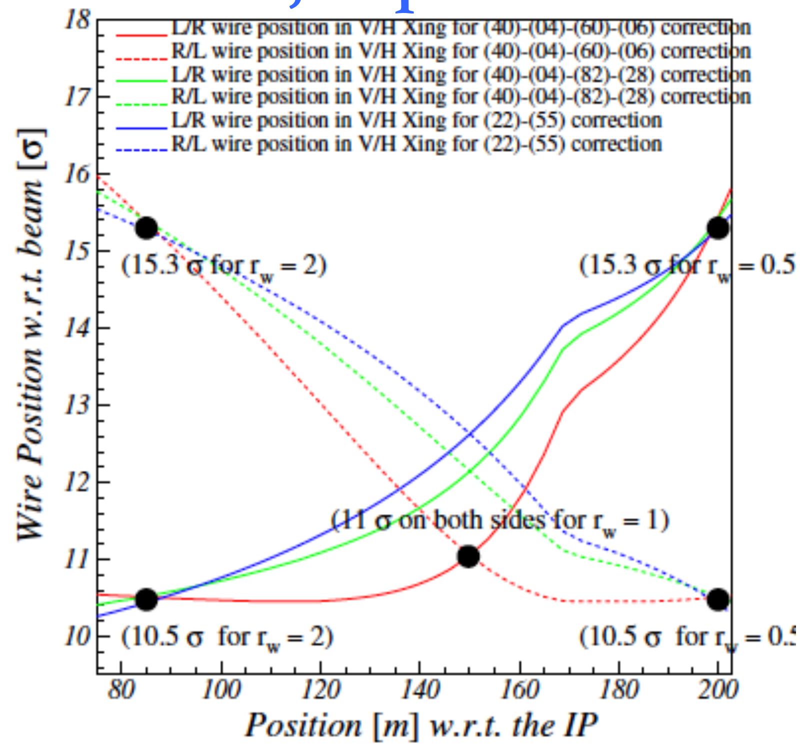
- **Optics adjustments** are desirable for the experiment, at least for left side of IR1

Wire-beam distance

- For strict optics anti-symmetry (round optics), and for equal wire currents matching the number of long range encounters (~**90A** for the nominal LHC), physical distance of wire to the beam should be the same (but not the normalised one)
- This is independent on the resonances corrected
- For the "ideal" aspect ratio (2 and ½ for HL-LHC), all resonances are corrected with the same wire distance to the beam

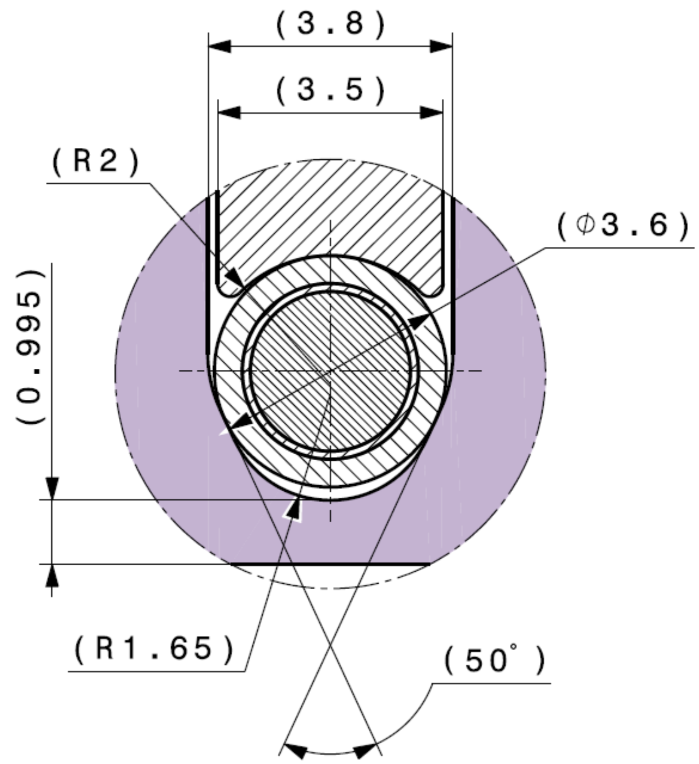
S. Fartoukh et al., PRSTAB, in press





Wire-beam distance

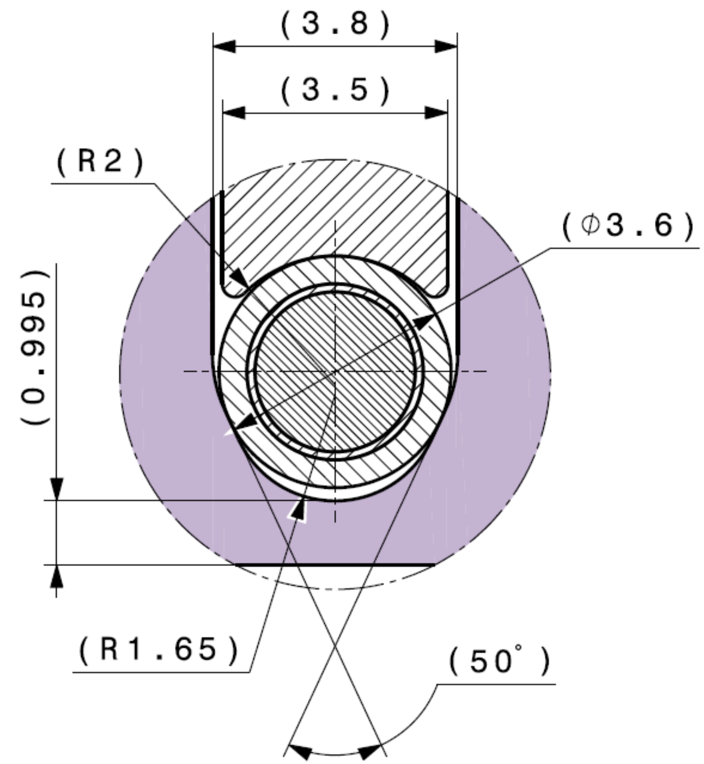
- Distance of wire for the test depends on optics at that location
  - For ideal aspect ratio (**modified** optics), a unique distance at either side cancels all LR driven resonances
- The wire center is positioned at around 2.8 mm from the collimator jaw edge, corresponding to around **2.6 - 4.3 σ** (0.4m-β* optics @ 6.5 TeV, for the **almost symmetric locations** and 3.75 μm emittance)
- For nominal TCT-TCL collimator settings (~9.5 σ), the wire position will be at 12.1 σ for high-β aspect ratio, and at **13.8 σ** for low-β aspect ratio



A. Bertarelli

Wire-beam distance

- An optimal aspect ratio optic can reduce it by ~**1 σ,** but still far from average beam-beam separation of **10 σ**
- At the nominal separation, lifetime is not dominated by BBLR, so wire tests should be done while reducing the crossing angle (TCT settings can be slightly relaxed)
- In conclusion, from one side the wire location is not an issue but from the other side, the internal collimator jaw should be pushed towards ~ **6 σ**
- This may be a machine protection issue, apart from **pilot beams**



A. Bertarelli

Current vs. wire distance

- The effect of the wire or BBLR (RDTs or tune spread) is linear with integrated current but scales as the inverse wire distance to the beam to a power equal to the resonance order, i.e.

$$c_{p,q} \propto \frac{IL}{d_W^{p+q}}$$

- If the optics and layout conditions (β-aspect ratios, wire distance,…) cannot be met, wire currents and distances, should be used for cancelling the LR leading order effect, i.e. **octupole-like tune-spread**
- Wire distance is scaled as the inverse 4^{th} power, so the max wire current (~**350A**), can be used to relax the wire distance by **40%**

Experimental set-up - Train composition

- **"Strong"** (non-compensated) beam1 composed by nominal 25ns trains with sufficient number of bunches to cover all long ranges, i.e. with at least (16x2)+1 = 33 bunches, neglecting the long-ranges inside D1
  - Usual train with 72 bunches from PS covers all long ranges even inside D1
- **"Weak"** (compensated) beam2 composed of (at least 4) single bunches, with
  - **Low intensities** (pilots), allowing the wire to approach in "optimal" distance
  - **Large emittances**, for enhancing the effect on the tails
  - **One bunch** positioned by e.g 12.5ns from nominal bucket for **avoiding HO**
  - **One bunch** on nominal bucket for testing the effect **with HO**
  - **One "PACMAN" bunch** positioned in a way to receive **only half LR kicks**
  - **One non-colliding bunch** (not HO nor LRs) for reference
- Beams should be initially separated in IP2 and 8
- Colliding in only 1 IP can be used to test correction separately

Experimental set-up - conditions

- **Optics** need to be adjusted at least for new collimator in IR1, but also modified optics with optimal aspect ratio should be considered
  - **MD time** for optics **validation** already **during 2016**
- Effect is weak with nominal crossing angle, so reduction is necessary
  - Sufficient **time** to **long range MDs** should be given for quantifying the effect
- Doing the tests at injection energy should be also considered
  - Large gain in time and machine protection restrictions
  - Optics conditions are not optimal for enhancing the long range effect (squeezed optics)

Main observables

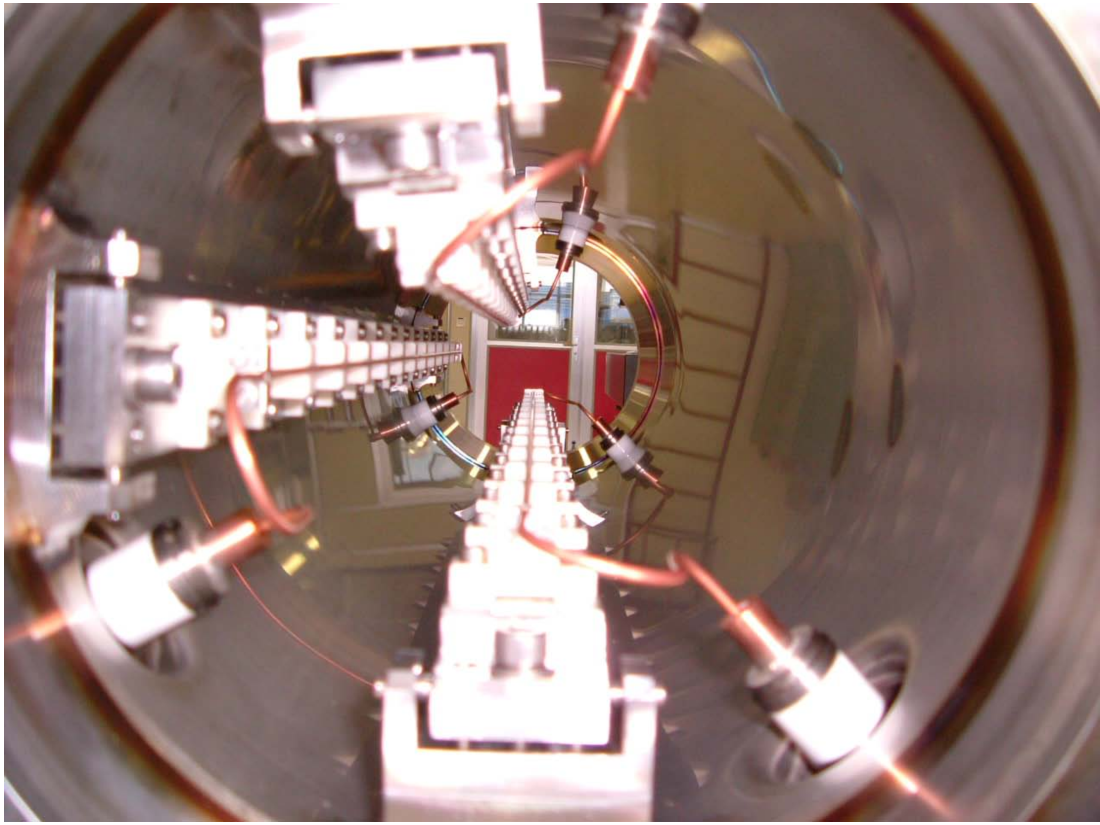
- Lifetime (bunch-by-bunch)
  - Need simulations to benchmark the experiments, i.e. track distributions with BBLR + compensation
  - Disentangle BBLR with respect to other effects such as head on, burn-off, vacuum, IBS, noise,… (on going work of F. Antoniou for LHC luminosity modelling)
- Tails evolution
  - Losses on different collimator positions
  - **Halo diagnostics**
- Beam transfer function
  - Damper effect?
- Orbit, tune, tune-spread (coupling, chromaticity)
  - Last three are difficult to measure, while in collision

Wire effect in single beam

- Need to benchmark effect of wire
- Calibrate position and current with observables:
  - Orbit, tune, tunes-spread, coupling (alignment), resonance driving terms, effect on distribution (tails)
- Could be done even at injection energy and conditions (only 1 beam)
  - Experimental conditions and instrumentation as for LHC optics measurements
    - BPMs in orbit and TBT mode, BSRT, wire scanners, Q-Kicker, AC-dipole, etc…
  - A lot of information can be already gained with existing wires in SPS

Wires at SPS

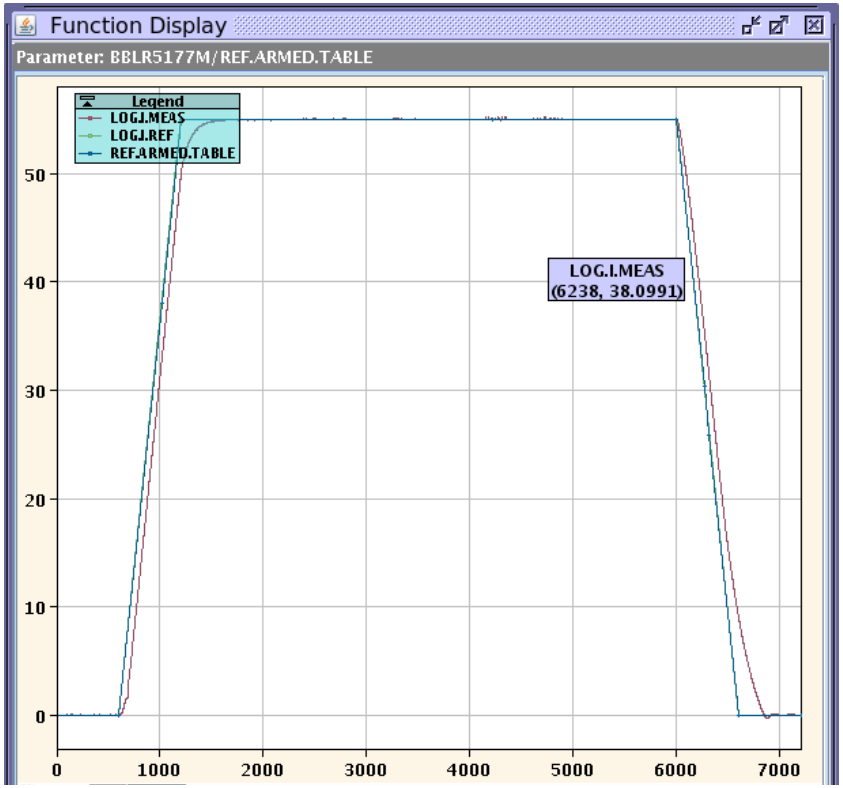
- Two 60cm long 3-wire compensators installed in the CERN SPS
  - Different "crossing" plane and even @ 45deg
- Movable in vertical by +/- 5mm (remote controlled)
- Water cooled



- Powered with integrated DC current of up to 360A m (~60 LR collisions in LHC)
- About equal beta functions in the transverse planes (~50m)

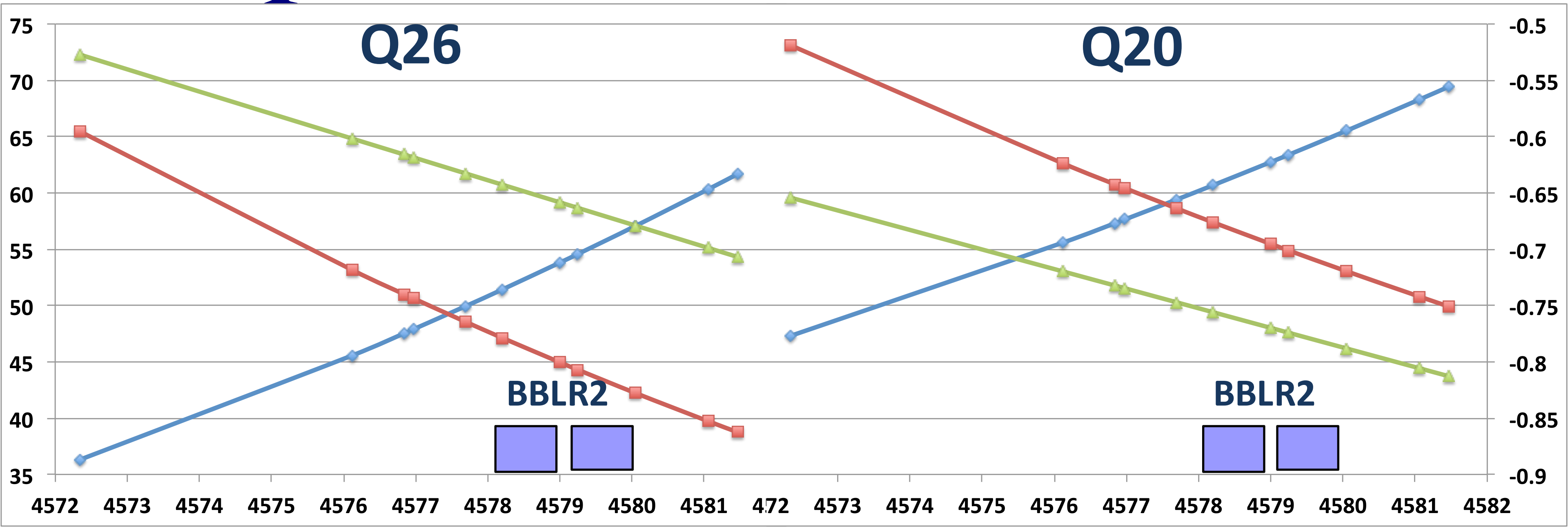
Wires at SPS

- Set-up re-evaluated
  - New power convertor able to pulse in PPM mode Powering H or V wire, with a switch
  - Step motors verified and controller in good shape
  - Vacuum integrity checked
  - Fine tuning of the PC performed during this summer (interlock, polarity switch)



- MDs for benchmarking wire models
  - At SPS flat bottom in parallel MD cycle (single LHC-type bunches)
  - Beam brought close to the wire with closed bump (already checked)
  - Effect of wire on orbit, tune, tunes-spread, coupling (alignment), resonance driving terms, beam distribution (tails)

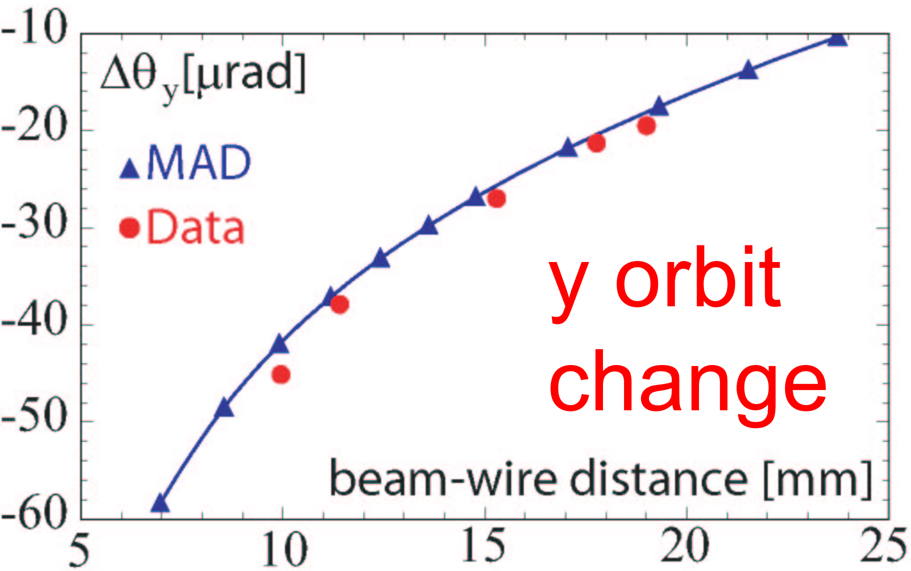
Optics at the SPS wires



- Q26 optics (nominal for FT beam)
  - β_x ~53m, β_y ~45m, D_x~-0.65m
- Q20 optics (nominal for LHC beam)
  - β_x ~63m, β_y ~55m, D_x~-0.75m

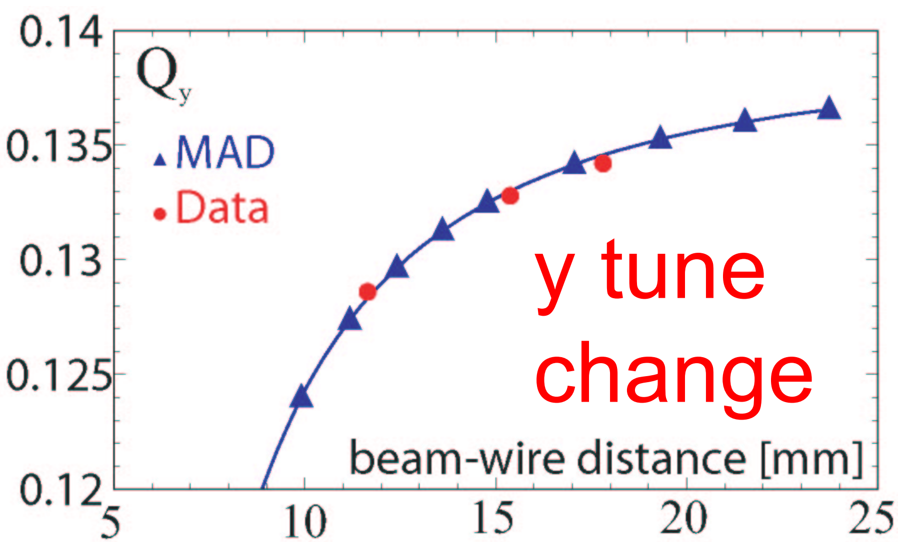
SPS wire calibration

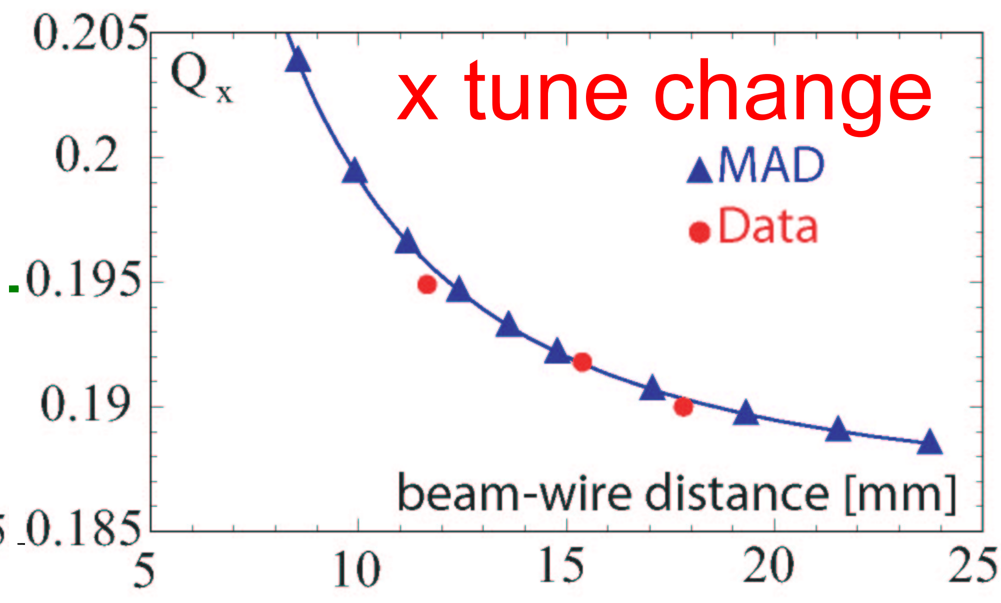
F. Zimmermann et al.



$$\delta y_0' = \frac{\mu_0 I L}{2\pi r_W B\rho}$$

$$\delta \nu_{x,y} = \mp \frac{\mu_0 I L}{8\pi^2 B\rho} \frac{\beta_{x,y}}{r_W^2}$$





Questions for discussion

- Is beam 2 the final choice?
  - Beam instrumentation and machine protection considerations
- Optics adjustments (full or partial)
  - Are they possible? Can we schedule them already in 2016?
- Wire-collimator installation schedule
  - Is it possible to install even one wire-collimator during a technical stop in 2016, allowing wire calibration MDs earlier then the full installation
- Wire tests at injection energy
  - Do we have an experimental set-up where the LR effect can be enhanced at injection (e.g. squeezed optics for weak beam)
  - Is injection energy good for halo measurements
- Beam intensity of the week beam
  - Are pilot bunches enough for all type of measurements, in particular halo, losses, lifetime, BTF,…
  - Is there a possibility to move the jaws further close to the beam for higher intensities

Back up slides

Orbit effect due to wire

- The wire induces an orbit shift due to a "dipole" kick expressed as

$$\delta x'_0 = \frac{\mu_0 I L}{2\pi B\rho}\frac{\cos\phi_W}{r_W} \quad \text{and} \quad \delta y'_0 = \frac{\mu_0 I L}{2\pi B\rho}\frac{\sin\phi_W}{r_W}$$

- For only horizontal or vertical positioning of the wire, there is only an orbit kick in the corresponding plane
- In either side of the IP, powering the wires accordingly (opposite sign and with current following the square root of beta functions ratio), orbit effect (π-bump)
  - To be used for calibration purposes

Coupling due to wire

- The minimum tune-split due to wire-induced coupling is

$$\delta\nu_{\min} = \frac{\mu_0 I L}{4\pi^2 B\rho}\sqrt{\beta_x\beta_y}\frac{\sin 2\phi_W}{r_W^2}$$

- If the wire is positioned in one plane, there is no coupling
- Maximum coupling is induced for φ_W=45°, giving around 6e-3 tune-shift for wire in **BBC** position
- Global coupling can be cancelled, between wires in the two IPs , if wire is positioned in complementary phase φ_W=135°, in the opposite IP (and current follows square root of the product of beta functions)

Tune-shift due to wire

- The linear tune-shift induced by a wire is expressed as

$$\delta\nu_{x,y} = \mp \frac{\mu_0 I L}{8\pi^2 B\rho}\beta_{x,y}\frac{\cos 2\phi_W}{r_W^2}$$

- Equal beta functions in both planes chosen for having the same impact in both planes (**BBC** location)
- Induced tune-shift between wires in two IPs cancelled, if wire is positioned in equal distance but different planes, and integrated current follows beta function change
    - Alternating crossing idea for cancelling BBLR tune-shift
- For equal distance of the wire in both planes at the same IP (ϕ_W=45°), tune shift is suppressed (true also for BBLR)

Tune spread due to wire

- The first order tune-spread (octupole-like effect) is

$$\begin{pmatrix}\delta\nu_x\\ \delta\nu_y\end{pmatrix} = -\frac{3\mu_0 IL}{16\pi^2 B\rho}\frac{\cos(4\phi_W)}{r_W^4}\begin{pmatrix}\beta_x^2 & -2\beta_x\beta_y\\ -2\beta_x\beta_y & \beta_y^2\end{pmatrix}\begin{pmatrix}J_x\\ J_y\end{pmatrix}$$

- For alternating crossing in optically symmetric IPs, tune-spread adds up (same polarity)
- It can be cancelled for wire angle (or crossing) at π/8
- Because of triplet optics symmetry, diagonal terms of anharmonicity matrix for BBLR are equal
  - True also for the effect of two wires placed symmetrically in either side of the IP
- Ratio of beta functions at wire position can be chosen as to cancel completely tune-spread

Resonance driving terms

- The first order resonance driving terms are

$$\mathcal{H}_{n_x,n_y} \propto \left| \int_0^C \frac{b_n}{r_W^n} \beta_x^{n_x/2} \beta_y^{n_y/2} e^{i} \left(n_x\mu_x + n_y\mu_y\right) ds \right|$$

- For phase advances $\mu_x \approx \mu_y \approx \pm\pi/2$

$$\Re\left[e^{i}\left(\pm(2k+1)\pi/2\right)\right] \approx 0 \qquad \Im\left[e^{i}\left(\pm 2k\pi/2\right)\right] \approx 0$$

$$\Re\left[e^{i}\left(\pm 4k\pi/2\right)\right] \approx 1 \qquad \Im\left[e^{i}\left(\pm(4k-3)\pi/2\right)\right] \approx \pm 1$$

$$\Re\left[e^{i}\left(\pm(4k-2)\pi/2\right)\right] \approx -1 \qquad \Im\left[e^{i}\left(\pm(4k-1)\pi/2\right)\right] \approx \mp 1$$

- Due to the IP optics anti-symmetry, the contribution to purely H/V even resonances, from either side, is symmetric