BBLR compensation simulations for SPS/LHC test

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HL-LHC workshop, October 30th, 2015

With input from

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Outline

- Wire compensation basic considerations
- Wire embedded in collimators
  - Optics and status
- Wire modeling
  - SIXTRACK implementation
  - Present simulation status
- Experimental conditions, observables and associated instrumentation needs
- SPS wires status
- Summary

Wire compensation

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

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

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

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

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

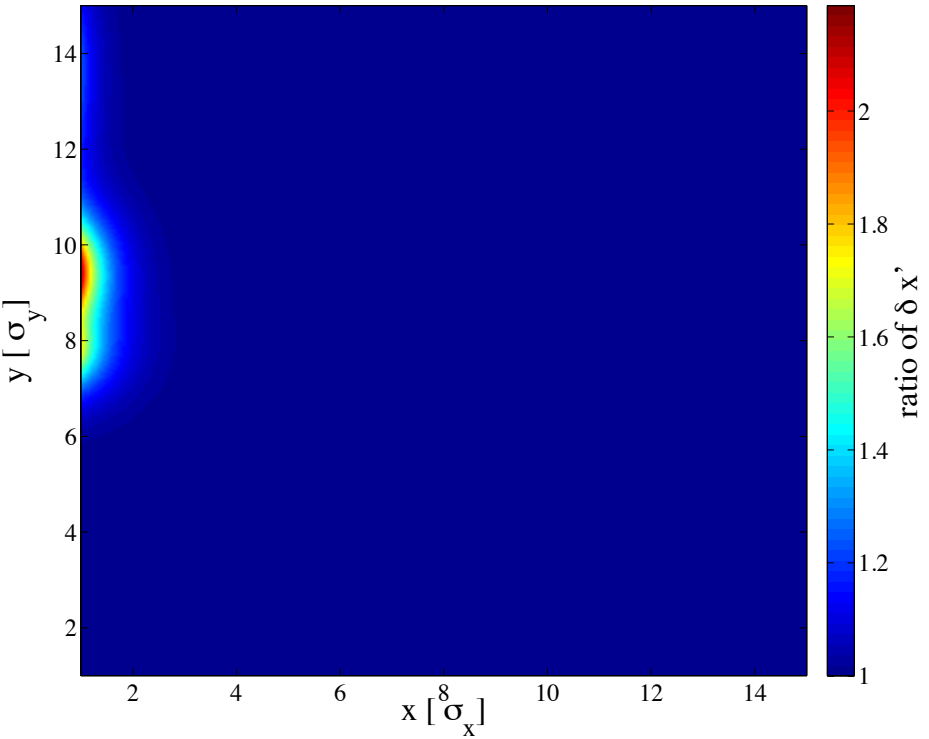
with $X_W = x + x_W\ ,\quad Y_W = y + y_W$

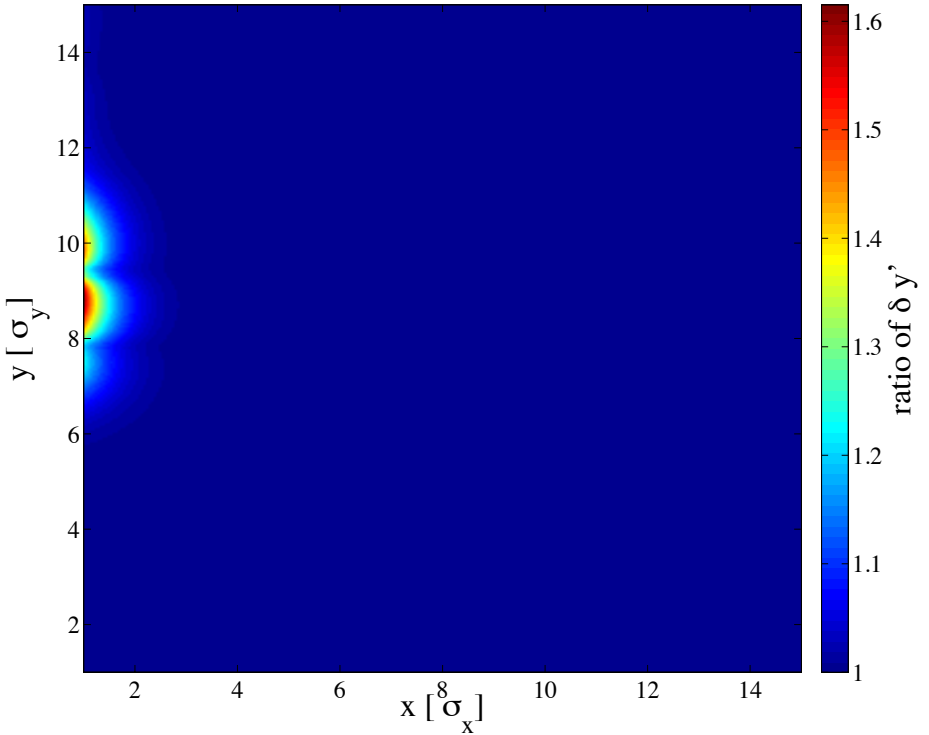
- For cancelling the effect **for any position** (large separations) $x_W = x_c\ ,\quad y_W = y_c\ ,\quad I_W L_W = ecN_b$
- This gives **5.5 Am/encounter** for the nominal LHC and 10.6 Am for HL-LHC

Round vs. 1/r

- Calculating the "lumped" beam-beam kick for a grid of horizontal and vertical positions, for B1 in IP1
- The ratio between the round and 1/r approximation is always very close to 1, apart for the areas that both coordinates are close to the origin, i.e. horizontal close to zero and vertical close to the separation
- Similar plots can be obtained for the exact force

IR1, B1

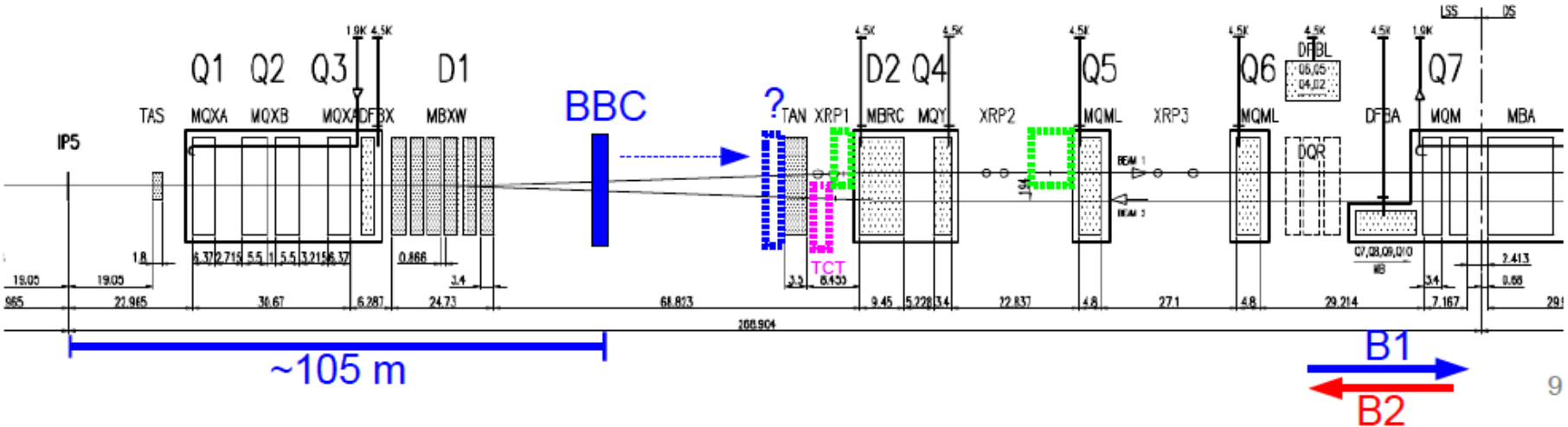




Basic considerations

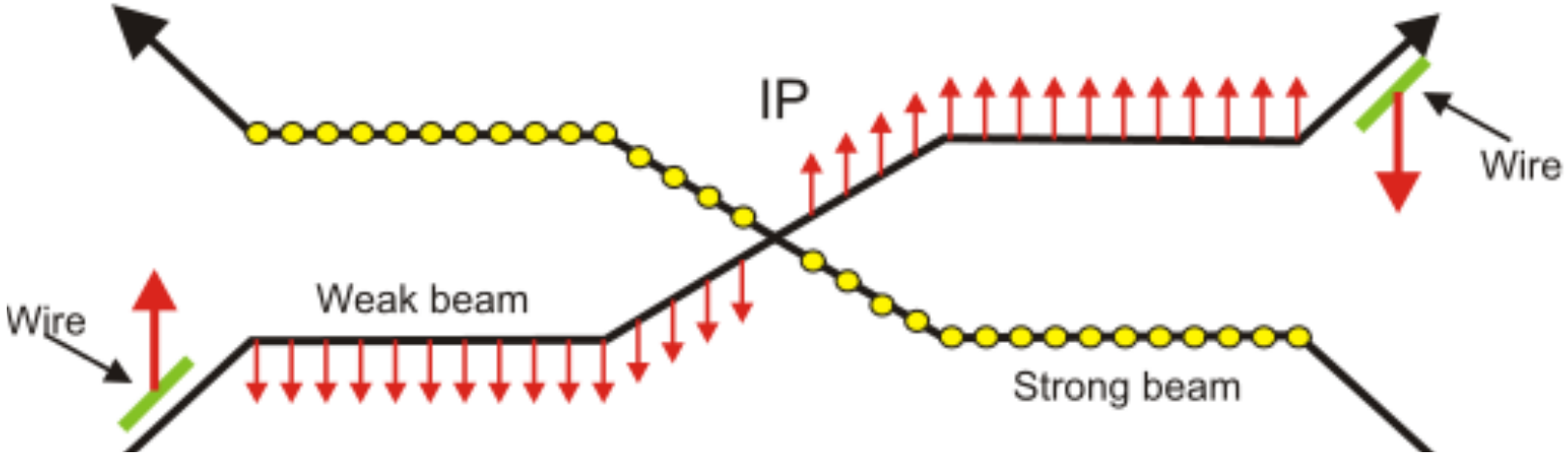
J.P. Koutchouk, 2001

- **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 may be 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 may be 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 DA, i.e. lifetime, through combined reduction of non-linear resonances and tune-spread)

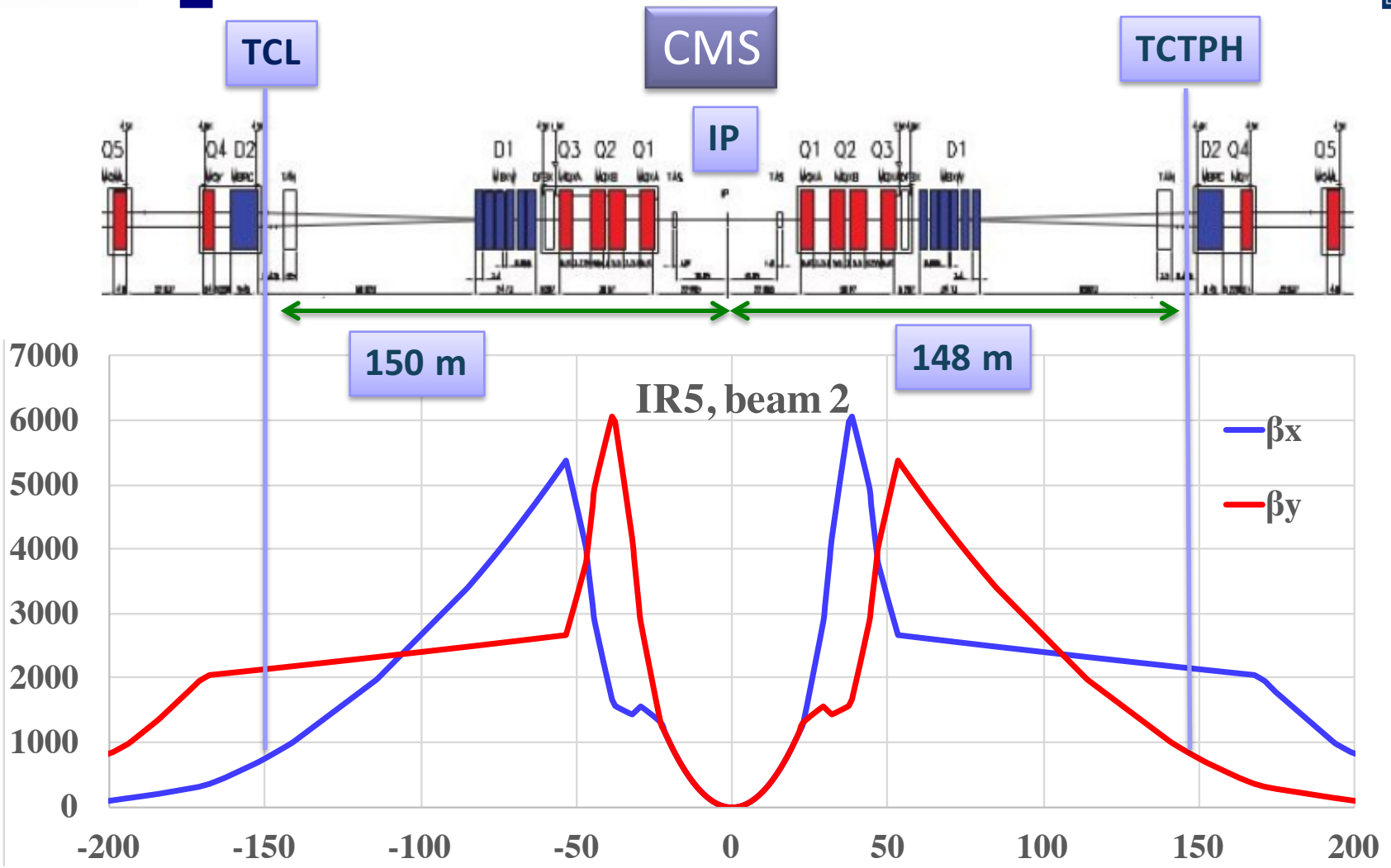


Two wires per IP

- 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)
- Powered independently to fit better the integrated kick on either side
- Beam 2 was chosen being the one equipped with the test halo diagnostics (coronograph)

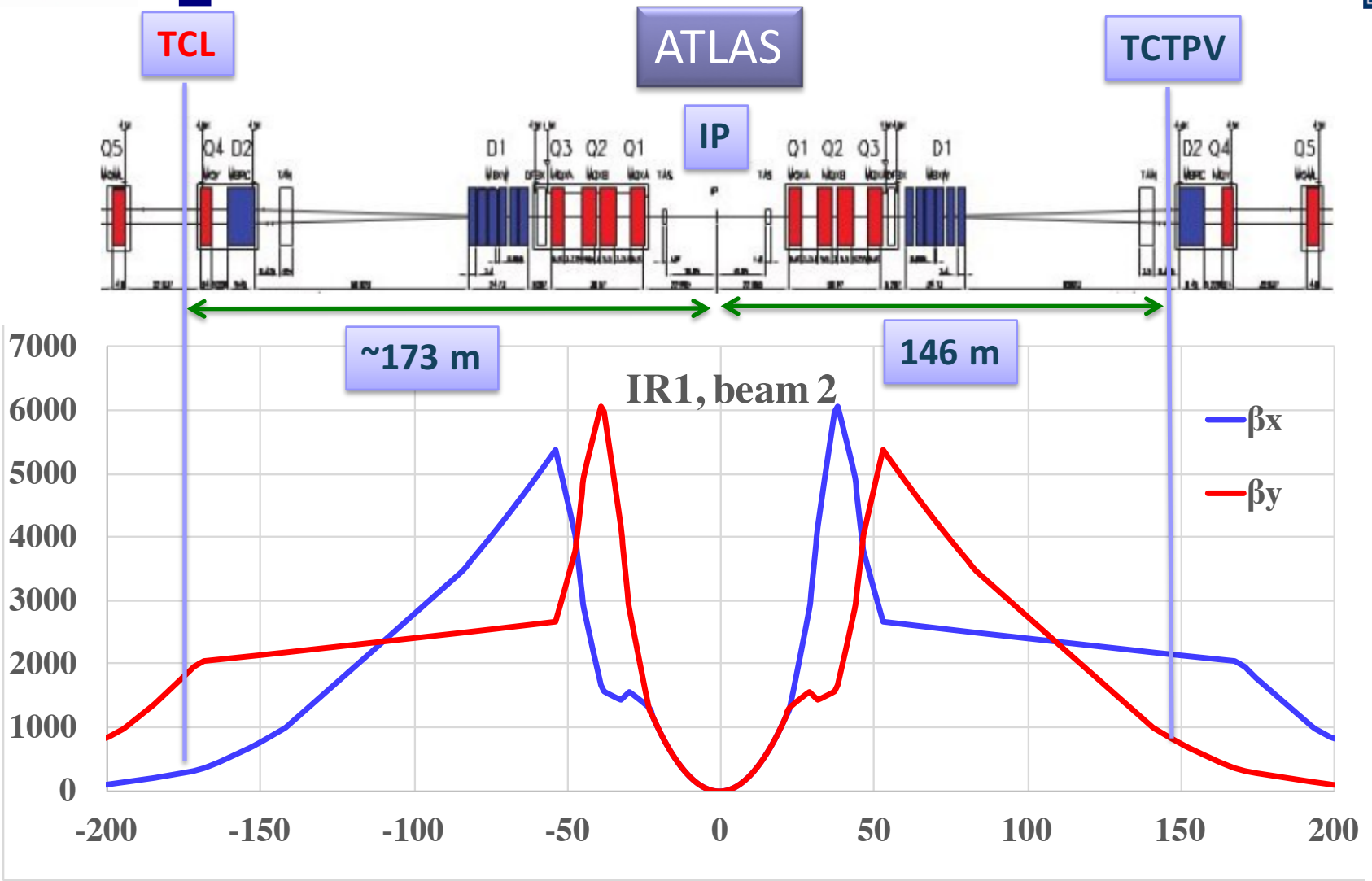


Optics at wire locations



- 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)

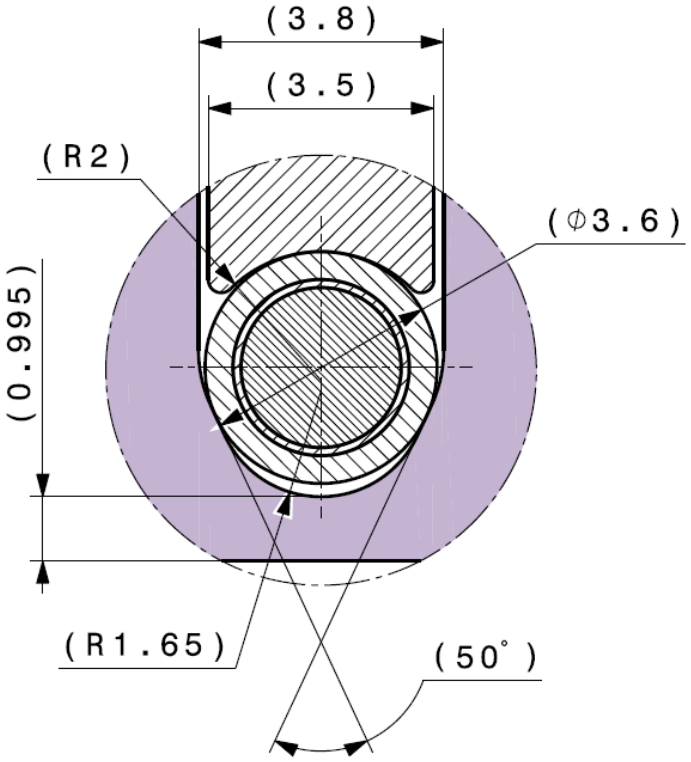
Optics at wire locations



- IR1: Vertical TCT will be replaced with wire-embeded collimator and **new TCL** installed downstream of Q4 (beam 2)
- Optics not close to anti-symmetric especially for the smaller corresponding β

Position of wire wrt beam

- As close as average BBLR separation (9.5σ for actual LHC)
- Integrated kick scaled inversely with distance
- Difficulty with wire-in-jaw collimator to approach the beam closer to ~12-13σ (for nominal TCT-TCL collimator settings)
- Some strength can be recovered by wire current but dependence is not uniform depending on resonance order



A. Bertarelli

Status of wire-in-jaw collimators

- 4 "wire-in-jaw" collimators ordered from CINEL
  - Cost covered by HL-LHC
  - Design finished in late 2014
  - Delivery, although originally planned, will be impossible during 2015 (new estimated date 04/2016)
  - Installation in winter stop 2016/2017 (vacuum group approval)
    - Installing during a Technical Stop may not be easy but under investigation
  - Cabling to be finalised for 4 individual power supplies
  - Integration details to be finalised **A.Rossi**
- Full compensation of beam2: 2 collimators/IP

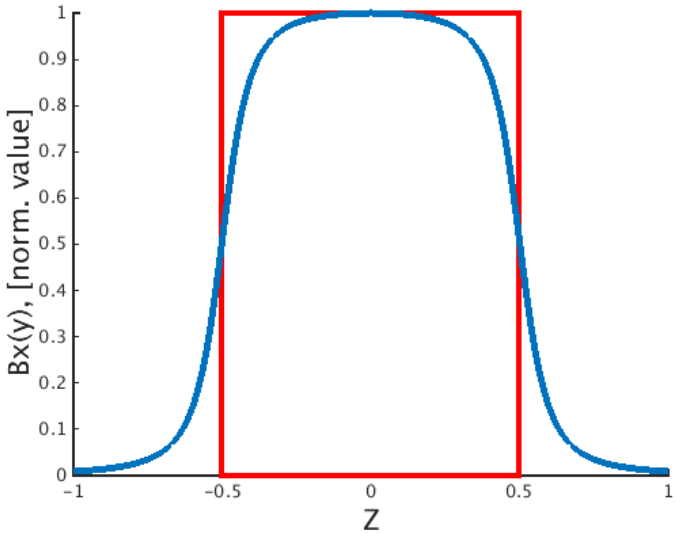
Wire modelling

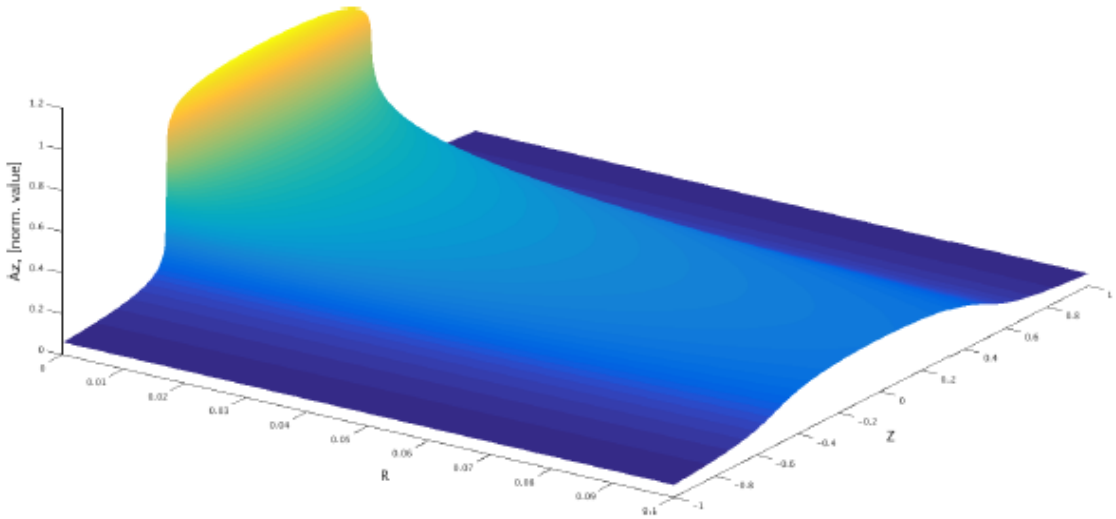
A. Patapenka

- Derived 3D vector potential for **finite** straight wire, including potential tilts
  - For parallel wire, only one longitudinal component (z-dependent, with central symmetry), integrated to give (thin lens)

$$A_z(x,y,z) = \frac{\mu_0 I}{2\pi}\,\mathrm{asinh}\left(\frac{L}{2\sqrt{x^2+y^2}}\right)$$

- Map constructed for thin lens but also "integrated-kick"
- Benchmarked against numerical integration

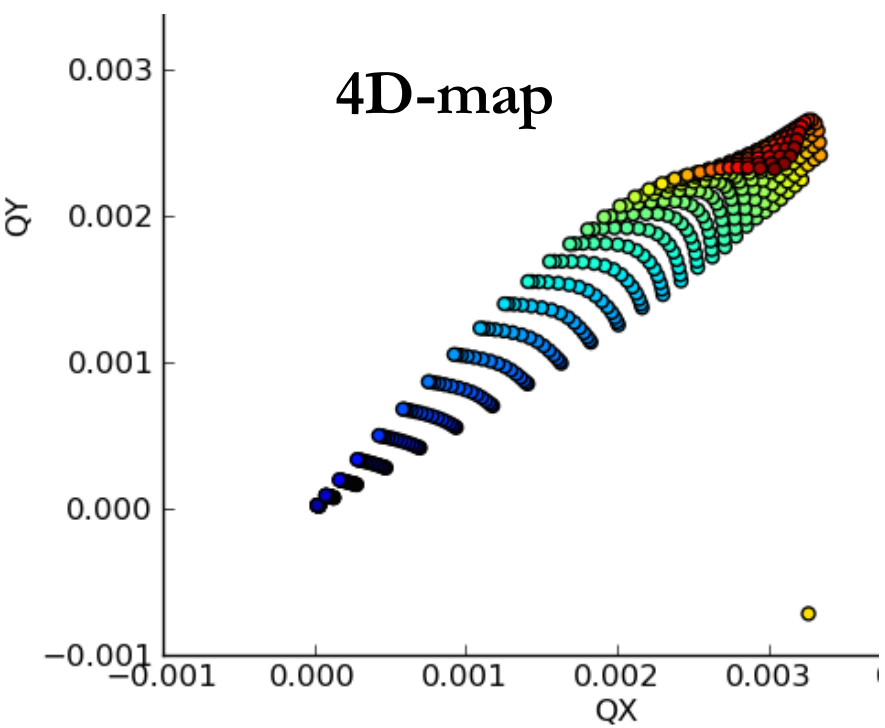


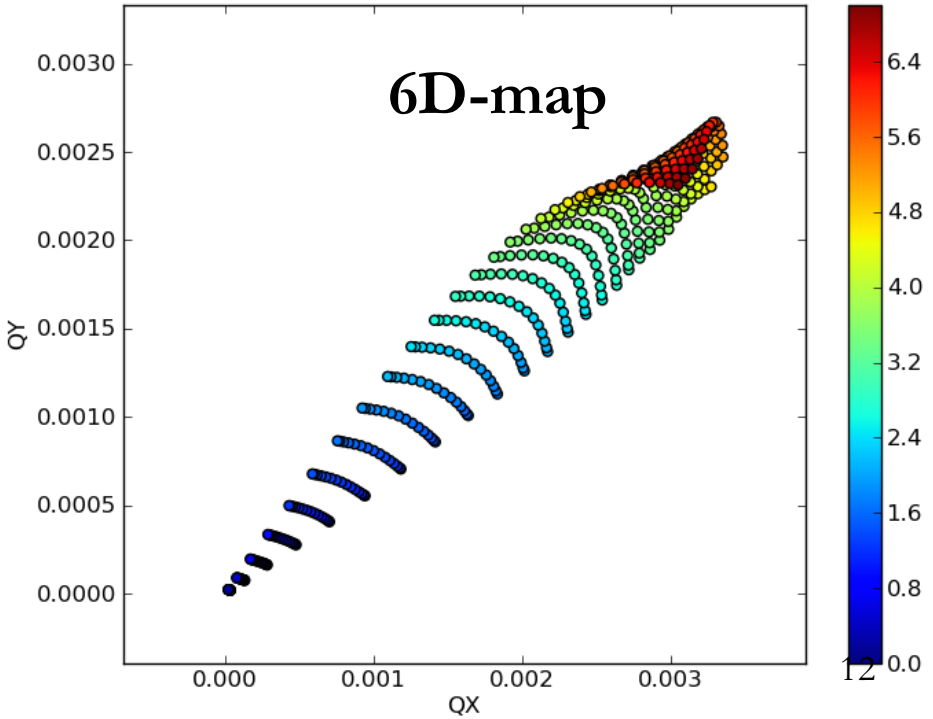


SIXTRACK implementation

A. Patapenka

- Two models in SIXTRACK
  - Existing one debugged and fixed see Erdelyi and Sen
  - Implementation of a map for an arbitrary 3D vector potential, based on Euler integration method
    - Ability to integrate a generic field coming from a model or magnetic measurements
  - Tilts of the wire are treated as coordinate transformations before and after the element
  - The two models produce identical results for the wire element

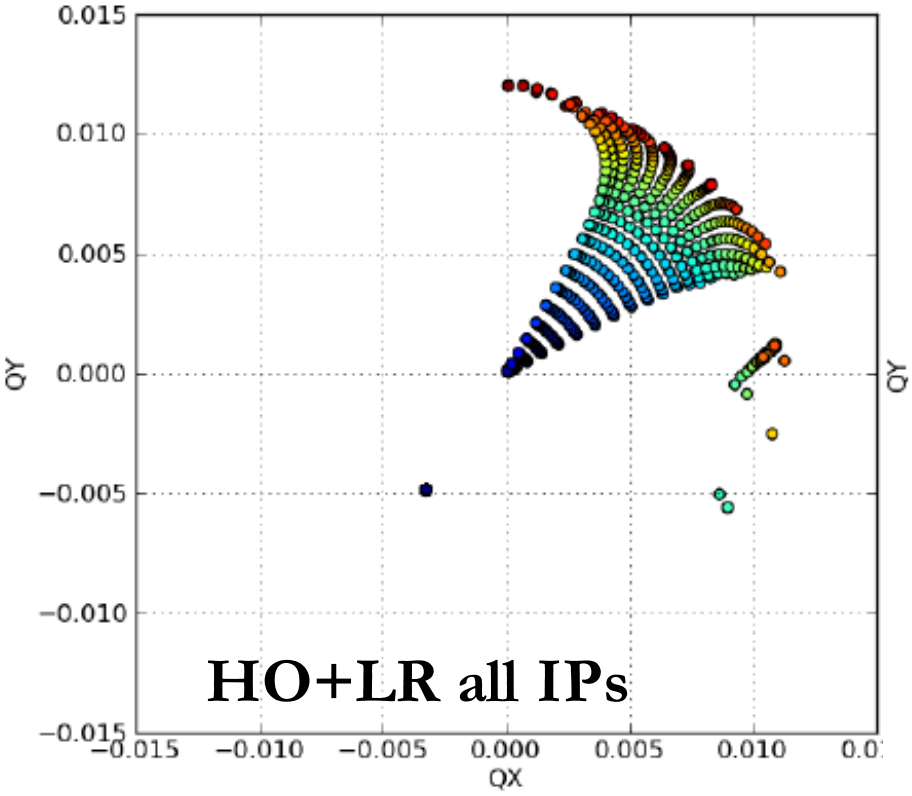


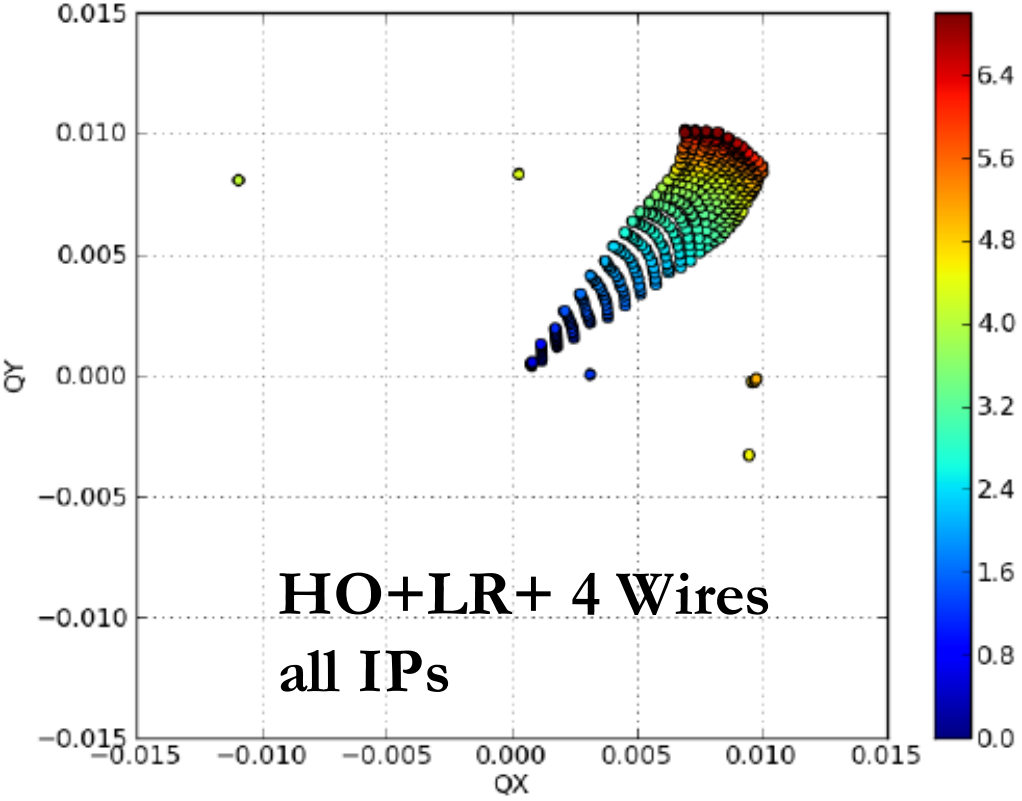


Wire compensation - footprints

A. Patapenka

- Optics version 6.503, 7TeV, nominal LHC beam parameters
- Compensation in IP1 and IP5 with 4 wires of ~90A in the BBC location (~105m from IP)

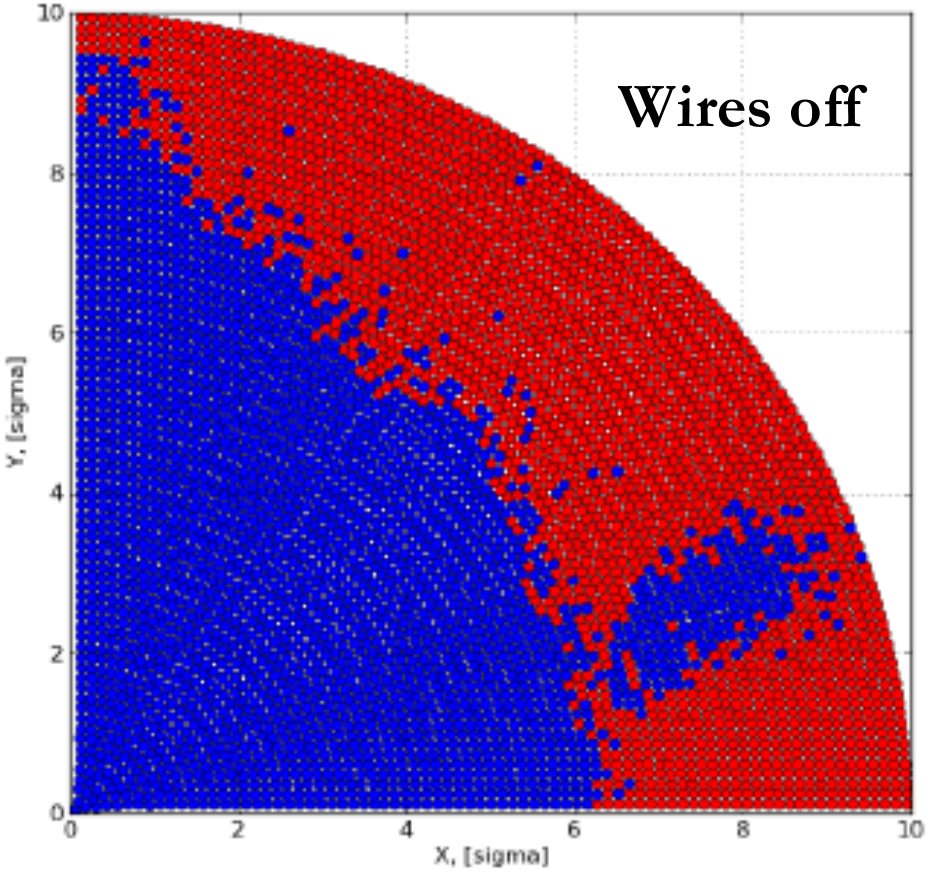


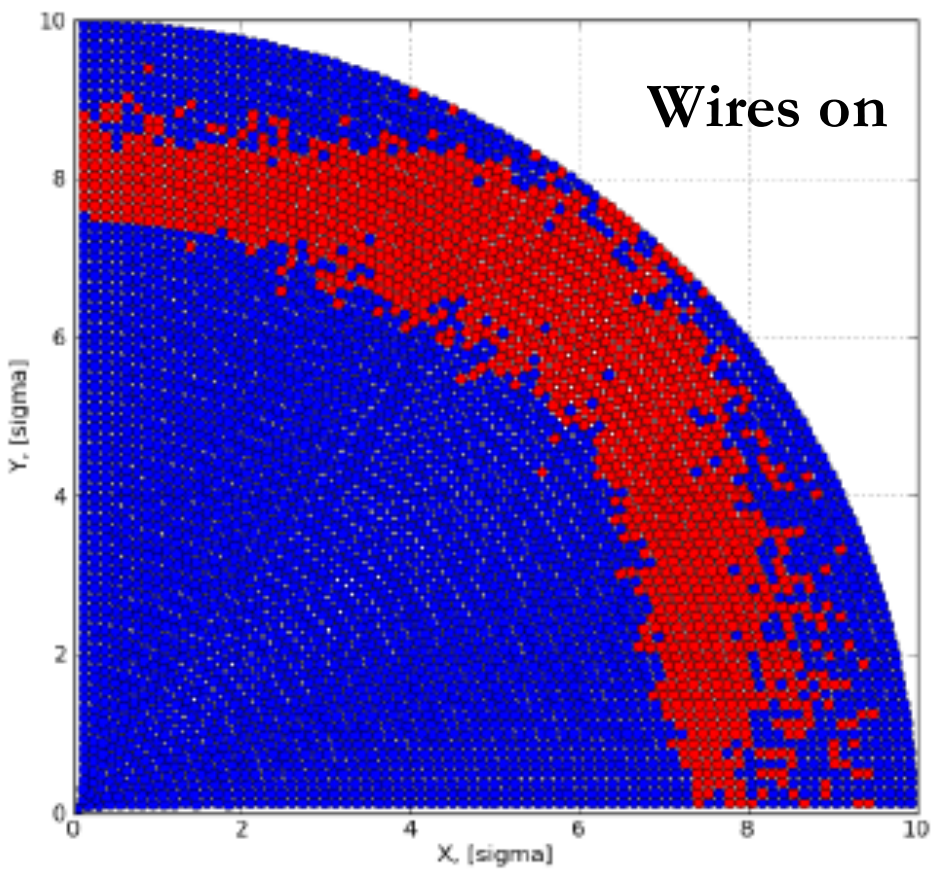


Wire compensation - DA

A. Patapenka

- 6D tracking for 3e6 turns
- DA min increased from 6 to 7.5σ



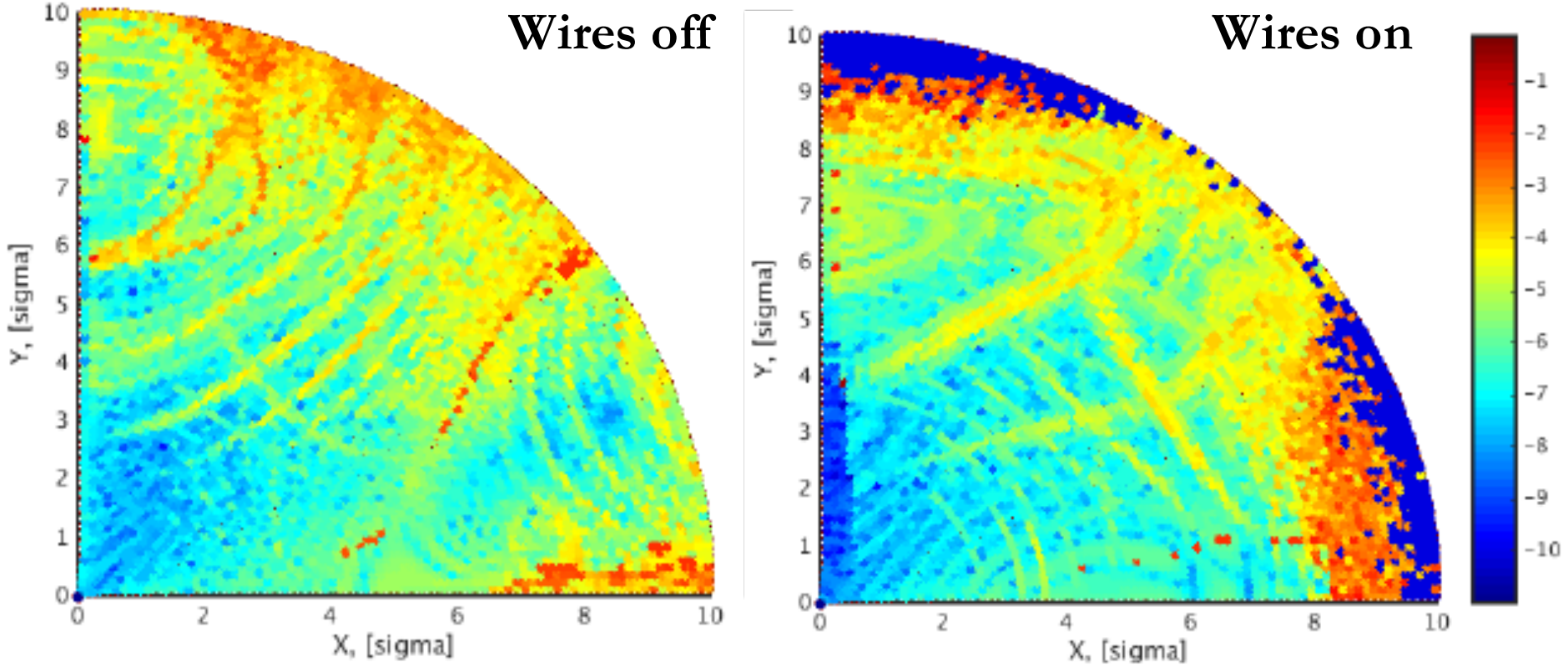


Wire compensation – frequency diffusion maps

- 5D tracking with δp/p=2.7e-4

A. Patapenka

- Frequency vectors of motion computed with NAFF for two consecutive 1000-turn spans and compared

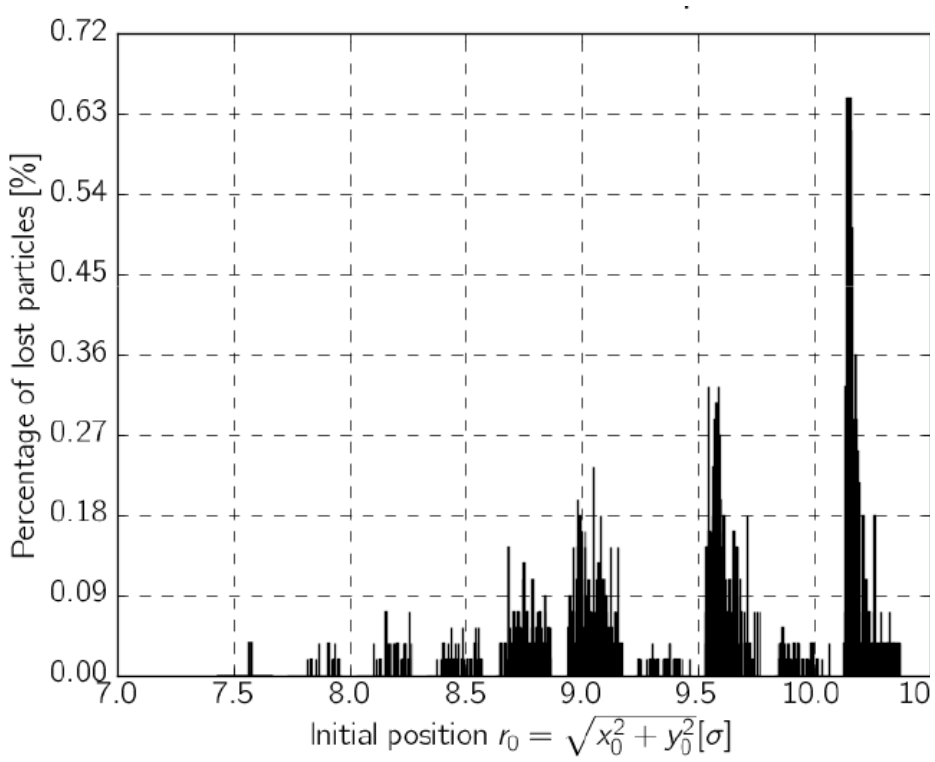


Wire simulations on-going work

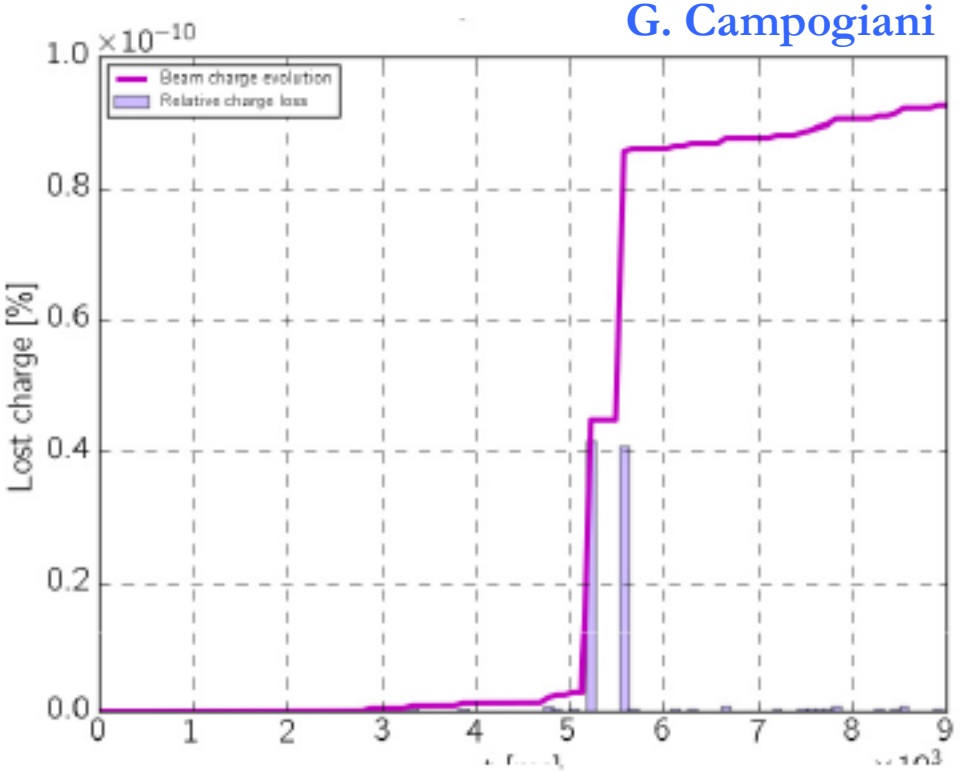
- Create MADX mask files with "fake" wires (BB long range elements with infinite separation) in the TCT/L locations
  - Eventually write a wire module for MADX
- Run SIXTRACK simulations for LHC@6.5TeV
  - For nominal but also BCMS beams
  - Nominal but also reduced crossing angles to enhance LR effect
  - Different wire separations and currents (average BB separation and larger separation taking into account collimator nominal settings)
  - With/without HO, with/without IP2 and IP8
  - Nominal and ATS optics
  - All magnetic non-linearities, sextupoles @ nominal chromaticity, with/without Landau octupoles
  - Different working points

Wire simulations analysis

- Dynamic aperture
- Frequency maps
- Resonance driving term estimation
- Track distributions and correlate them with lifetime (diffusion of tails)
  - Include IBS, burn-off, emittance blow-up (noise), synchrotron radiation



G. Campogiani



Main observables

- Lifetime (bunch-by-bunch)
  - Need simulations to benchmark the experiments, i.e. track distributions with BBLR + compensation (on-going work of G. Campogiani)
  - 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 **see Kim et al., HB2008**
  - Damper may not allow to have any relevant measurement (gating ?)
- Orbit, tune, tune-spread (coupling, chromaticity)
  - Last three are difficult to measure, while in collision

Workshop

Simulations and Measurements of Long Range Beam-beam Effects in the LHC

In Lyon, Hotel Metropole, 30.11.2015 – 1.12.2015

Dear Collegue,

CERN is organizing the above mini-workshop with the following aim:

In the winter shutdown 2016/2017 four collimators will be installed into the LHC, which have insulated copper wires embedded into their jaws. Placing these wires at an appropriate distance to one proton beam and powering these wires to high DC currents, a compensation of the long-range beam beam effect will be attempted during machine development sessions in the years 2017 and 2018.

During the workshop the details of the LHC configuration for these experiments will be discussed. Furthermore simulations for expected observables shall be presented. And last not least experts of the beam instrumentation community will present to what level of resolution the simulated effects can be measured.

Since the workshop will be on invitation only I am sending this invitation letter specifically to you hoping for your active contribution. An indico based agenda will be produced by Yannis Papaphillipou and myself and you might be asked to give a presentation.

CERN will cover financially during the two days half board for you (excluding evening dinner) and a hotel room for two nights. Any transport cost to and from the workshop will have to be covered by your home institute. For CERN participants a bus transport will be organized and no other transport will be refunded.

Yours sincerely

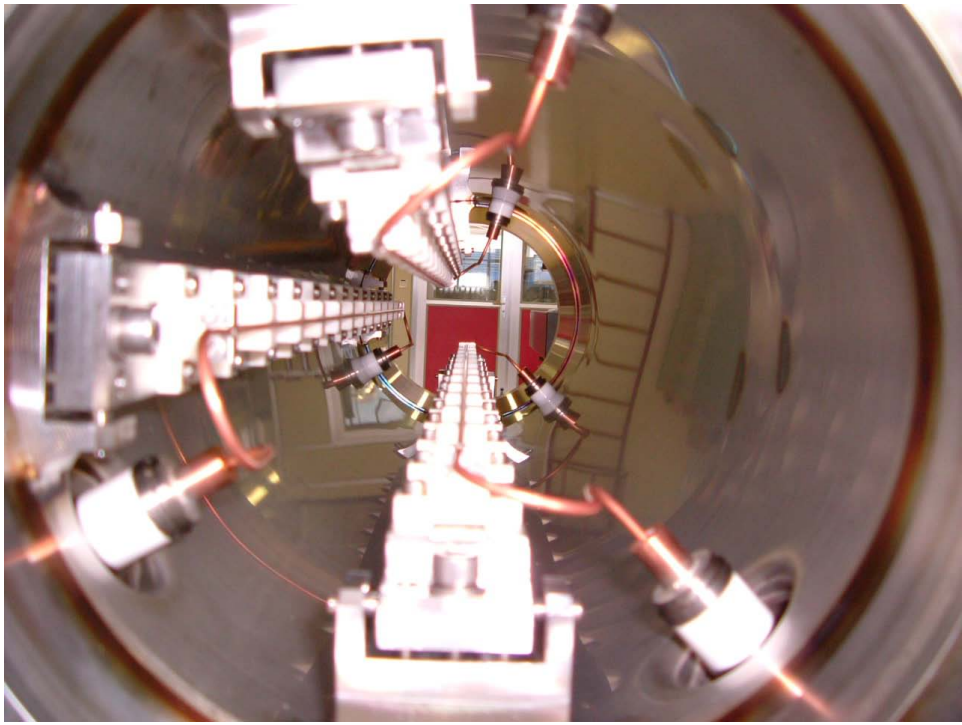
Hermann Schmickler

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

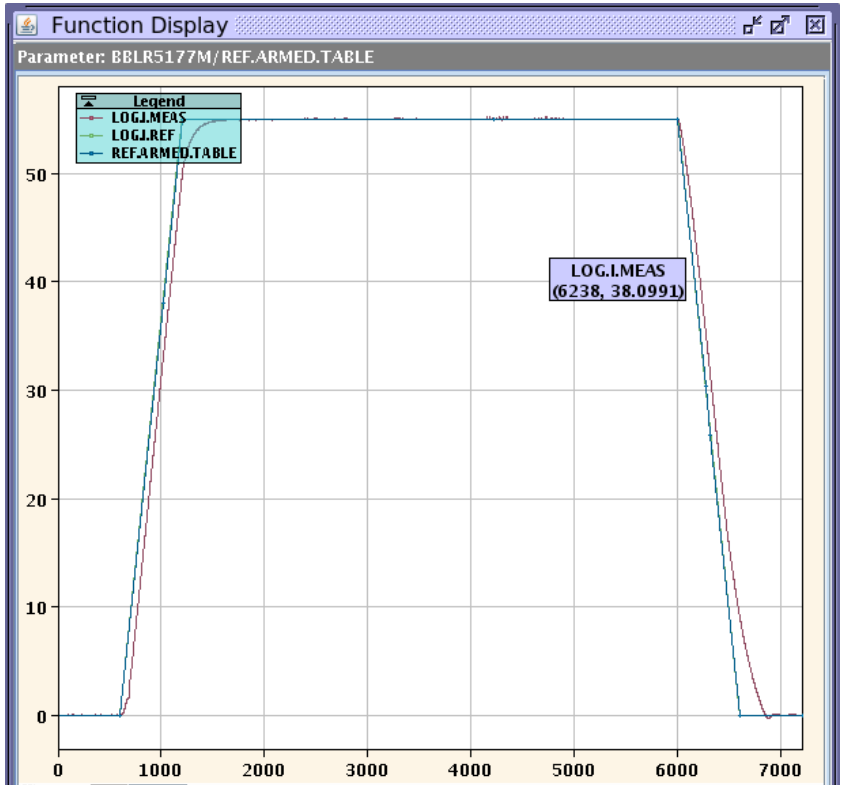
- Two 60cm long 3-wire compensators installed in the CERN SPS
  - Different "crossing" plane and even @ 45deg
- Movable in vertical by +/- 5mm (remote controlled)
- Water cooled
- About equal beta functions in the transverse planes (~50m)



- Separated by a phase advance of 3deg (similar between BBC and long range interactions in LHC)
- Powered with integrated DC current of up to 360A m (~60 LR collisions in LHC)

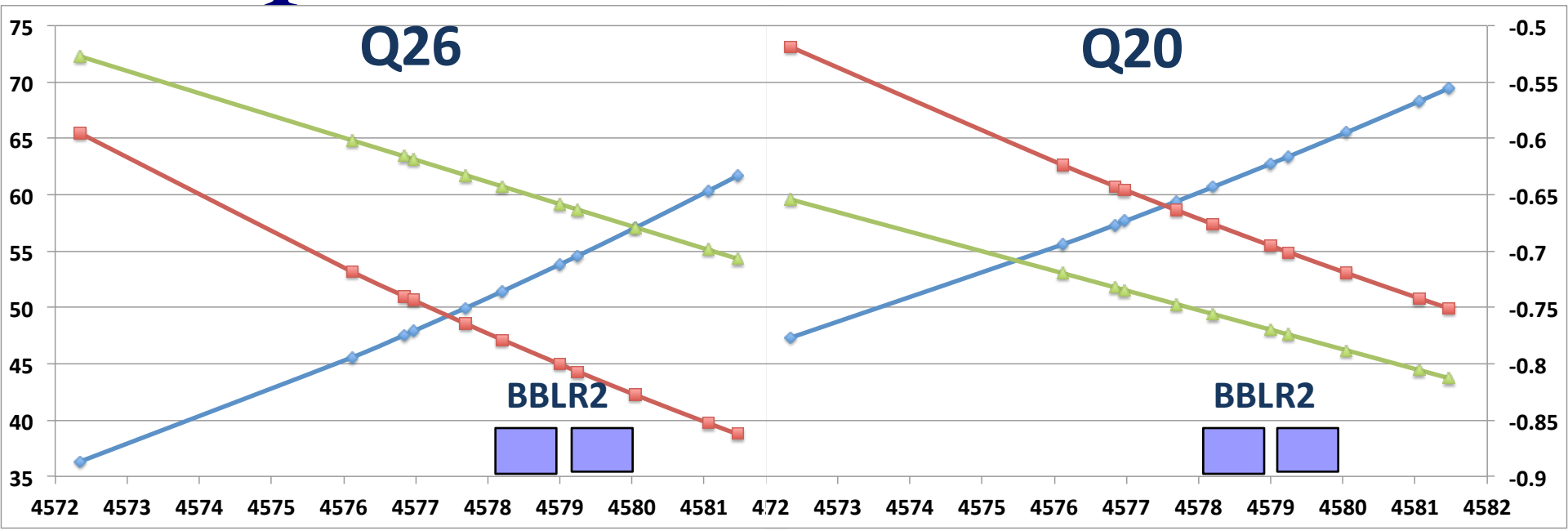
Wires at SPS

- 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 in 2015 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)

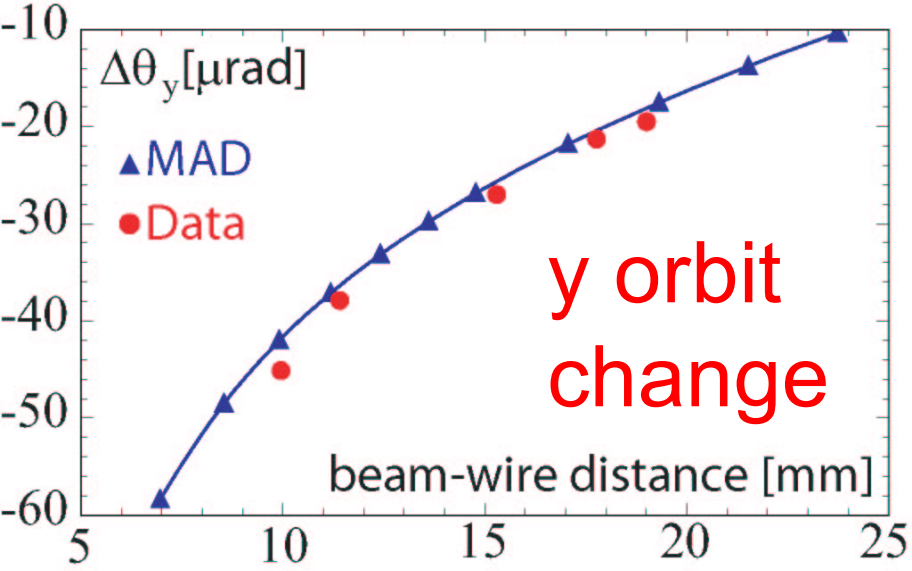
Optics at the SPS wires



- 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

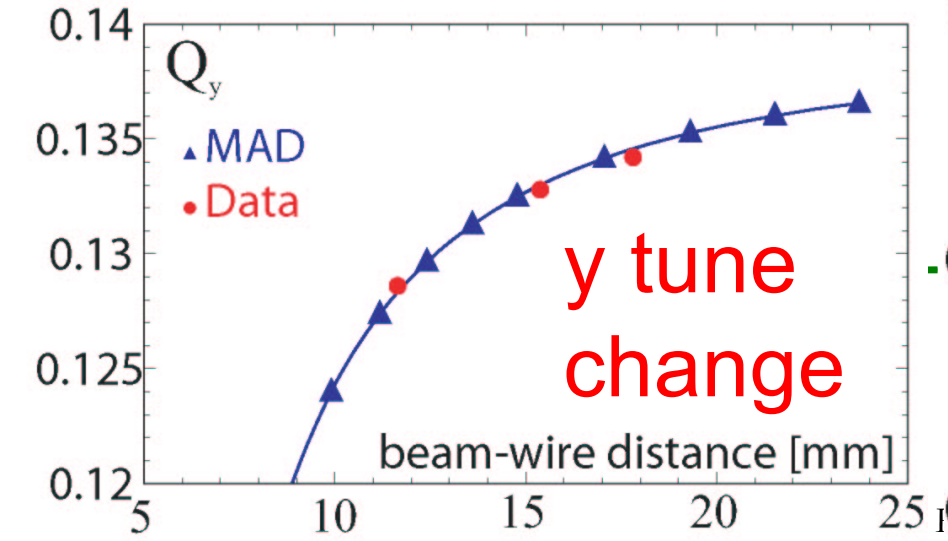
SPS wire calibration

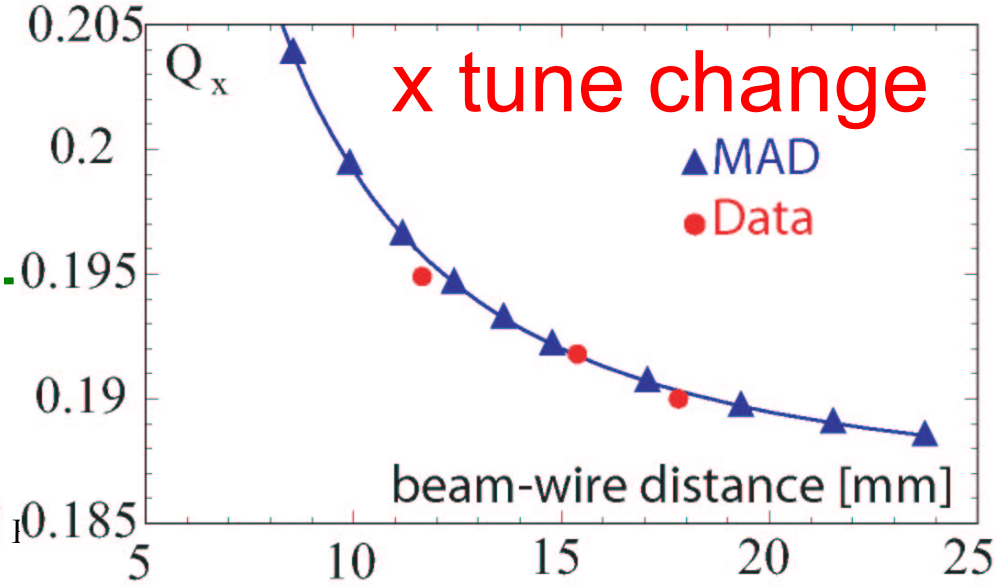
F. Zimmermann et al.



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

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





Summary

- Experimental set-up for wire test is being finalised
- Implementation of wire model in SIXTRACK completed
- First simulations matching experimental conditions (collimator locations, LHC machine parameters during RUNII) are in progress
- Experimental plan has being worked-out, including ideas about observables and diagnostics (more during the workshop next month)
- SPS wire revived and ready for first MDs