Executive summary of LLRB workshop and MD plans

A. Rossi on behalf of (alphabetical):

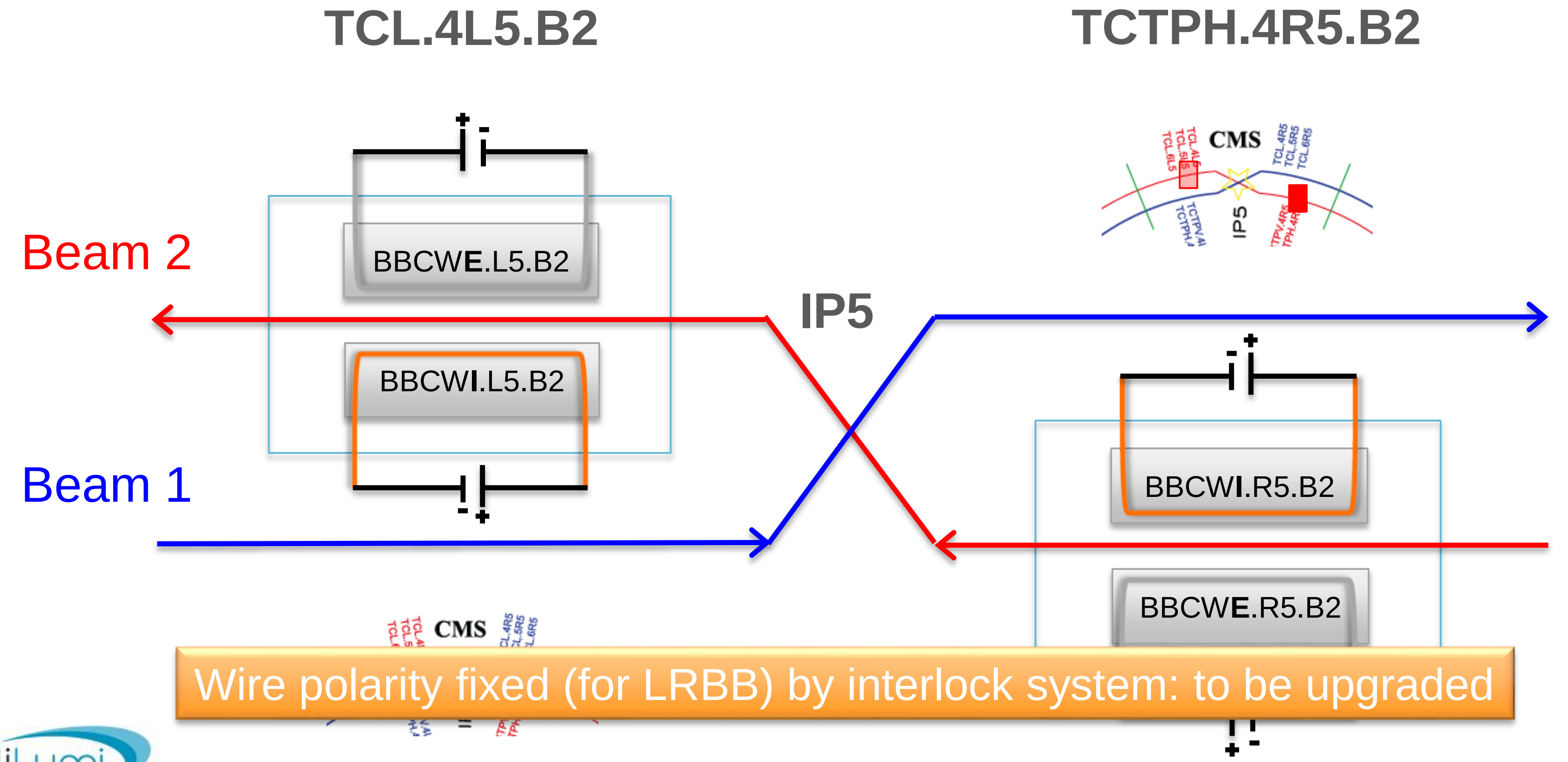
BE-ABP, BE-BI, BE-OP, EN-MME, EN-ACE, EN-STI, TE-EPC, TE-VSC

TCC 13th April 2017

Workshop outline

- Hardware:
  - TCTW
  - Instrumentation sensitivity and min beam requirements
- LRBB considerations with machine optics
- BB measurements and simulations
- MD plan outcome:
  - Wire impact on single beam
  - BBLR Compensation preparation
  - BBLR Wire Compensation
  - BBLR Compensation procedure

In-jaw wire collimators installed during EYETS 2016-17



Wire polarity fixed (for LRBB) by interlock system: to be upgraded

TCTW Summary

- 350A wire moving in crossing plane and perpendicular (5th axis + BPM V alignment)
- Wire tested in prototype jaw to define interlocks
- TCTW tested on surface successfully
- Collimators (H) installed in IR5:
  - HW commissioning including wire completed (11/04/2017)
  - HW interlock on wire commissioned
  - SW control + interlock still under commissioning
  - NOTE: interlock logic approved by MPP#144 (07 April 2017)

Will be presented at CWG 10/05

Instrumentation for BBLR

Observables

- Beam lifetime
- Losses at different collimator positions
- Tail diffusion
- Orbit
- Tune
- Chromaticity

Diagnostics

- BLM + BCT
- BSRT & Coronagraph
- Standard & DOROS BPM
- BBQ, BTF & Schottky
- Radial modulation & Schottky

Beam lifetime

Beam lifetime is a quick indicator of machine performance

Calculation from regular BLMs is possible with the cross-calibration with the BCT.

↪ Useful for MD and sensitive to small losses.

BLMs downstream collimators could give additional information

↪ Location of the losses (IR3 vs IR7).

↪ Type of loss: vertical, horizontal, off-momentum.

dBLM in IR7: extremely fast, ns scale

↪ Provide bunch-by-bunch information, useful to distinguish bunches with LR interactions.

↪ On-going: calibration to protons per second and frequency analysis.

B. Salvachua BE-OP

Orbit

- DOROS on in-jaw BPMs allows wire alignment and sub-micron orbit measurement

Tune

- Unexcited ~1e^{-4}
- MKQA kicks ~1e^{-5}

Chromaticity

- Measurement via RF modulation

BTF

- Powerful tool with potential to measure stability diagram

Schottky

- Possibility for non-invasive tune/chromaticity measurements

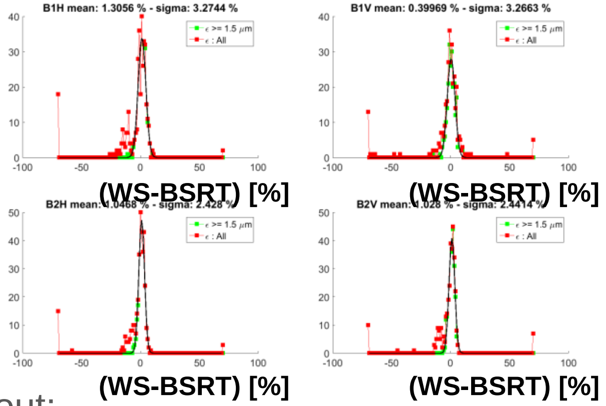
- BPM are optimised for very small offsets because they are very non liner systems.
- With the BBQ system, the tune can be measured for pilot up to a few nominal bunches. Precision depends on excitation method (ADT)
- BTF to measure tune shift and spread, but not linear
- Schottky: tune difficult to extract due to the strong synchrotron sidebands

Note that ultimate performance of instruments often requires special setup. Important to discuss MD plans with the experts in advance

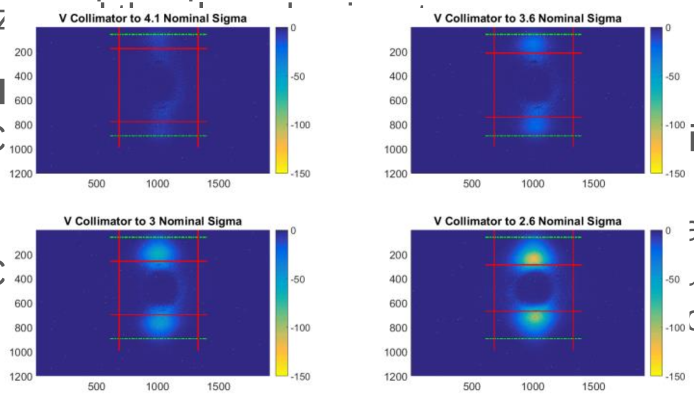
T. Levens BE-BI

Profile and halo measure

- **BSRT**
  - Energy dependent emission: SR at injection and collision wit
  - Emittance and profile measurements.
  - At flattop the profiles are diffraction limited, at injection the di siz



- **Coro**
  - C ies were carried out:



  - C already took place
    unexpected light observed
    operty of the SR source
    tested

- IN YETS the camera intensified allowing BbB gating was installed.
- BSRT and Coronagraph are installed in the same beam line, share the same mirror system and only one of them can be used at a time. The switch takes approximately 20 s.
- Future beam tests and lab tests will be requested

HiLumi HL-LHC PROJECT

G. Trad BE-BI

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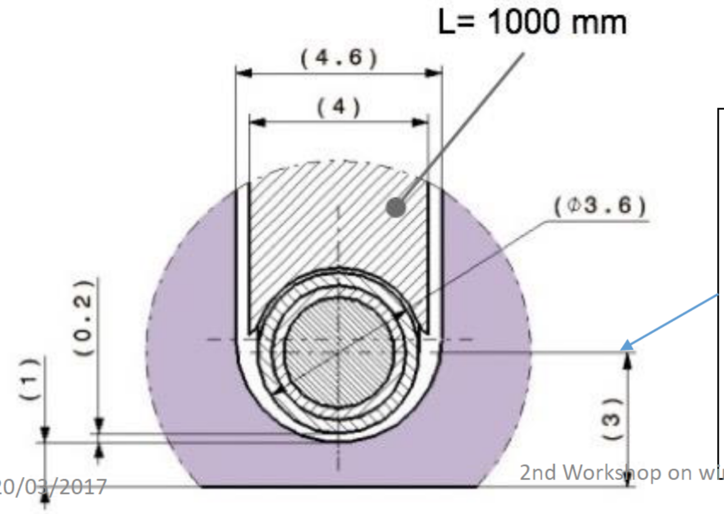
Optimal optics and HW conditions

- **Where are we with the present HW and which consequence?**

- ☺: Two wires at the TCT & TCL almost symmetric w.r.t. the IP
- ☺: β–aspect ratio at the wires not ideal but much better for ATS2017 than for the 2016 optics
- ☹: Wire in the H plane which rules out flat optics with very small (15-20 cm) horizontal beta*, not too large vertical beta* (~60 cm) and V crossing, as imposed by the IT aperture
- ☹: By far enough current (× 4 compared to LHC needs), **but which drove a specific HW solution with (too) many beam sigma's lost between wire and TCT edge** (see also next slide)

S. Fartoukh
BE-ABP



Round optics: 3 mm means already ~5 σ @ γε=2.5 μm and β^*=40 cm (β~900 m at the TCLW)

"Oval" optics: H crossing kept in CMS, β^* limited to ~ 35-40 cm in the V plane (parallel separation plane), and β^* ~ 1 m in the X-plane to keep a "decent" sizeable aspect ratio

3 mm becomes ~8 σ at β^*=1 m … (β shrinks to ~360 m at the TCLW)

→ Definitely the emittance of the weak beam has to be blown up.

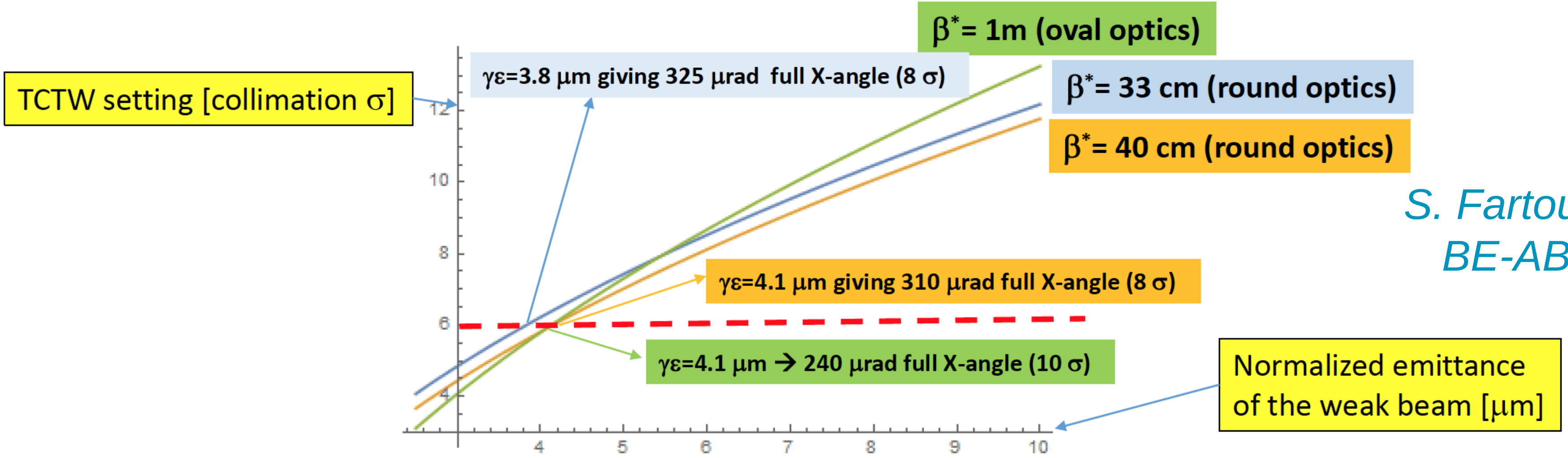
Can we find any configuration for 2017 to test the full correction?

.. Assuming

(i) Minimum allowed TCTW gap of 6 collimation σ (i.e. calculated for γε=3.5 μm)

(ii) Targeting a X-angle of 8 (10) beam σ in round (oval) optics to see convincing life time drops (.. and recovery), i.e. ~ 10 (12) beam σ for the wire at the smallest β.

(iii) Trying β*=33 - 40 cm for round optics, β*= 1 m in the X-plane for "oval" optics



S. Fartoukh BE-ABP

It looks really tricky in all cases, and round optics still seems to be the most promising (easy) way to go

Collimator settings

- Collimator settings on the strong beam
  - For intensities above 3E11, no interlocks can be masked. MP qualification needed
  - Use standard collimator settings qualified for physics operation
  - Consider same procedure as in previous MDs on BBLR to decreasing crossing angle at constant gap + shift in central orbit at TCTs
- Collimator settings on the weak beam
  - For intensities below 3E11, interlocks can be masked
  - More freedom to change settings
  - No real inner limit on setting, as long as the TCSP is 1 σ further in. Example: TCTs at 6 σ (ε_n=3.5 μm)
  - Will scrape the beam if collimators are too close
- Collimator TCTW impedance
  - Very small down to 2 σ gaps

X. Buffat BE-ABP

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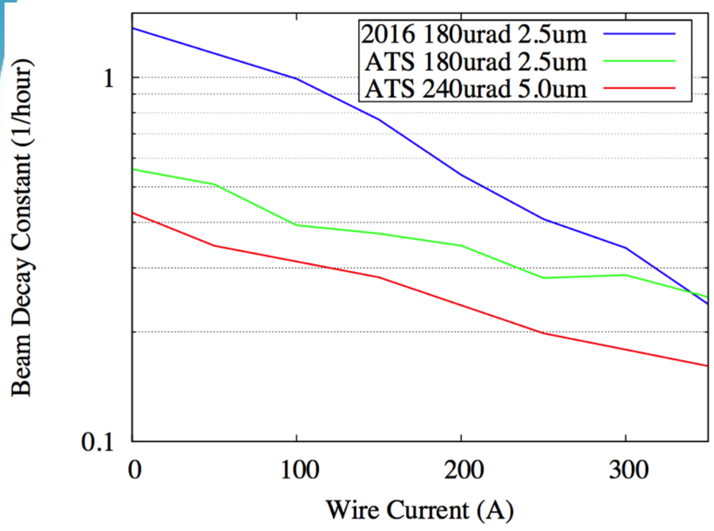
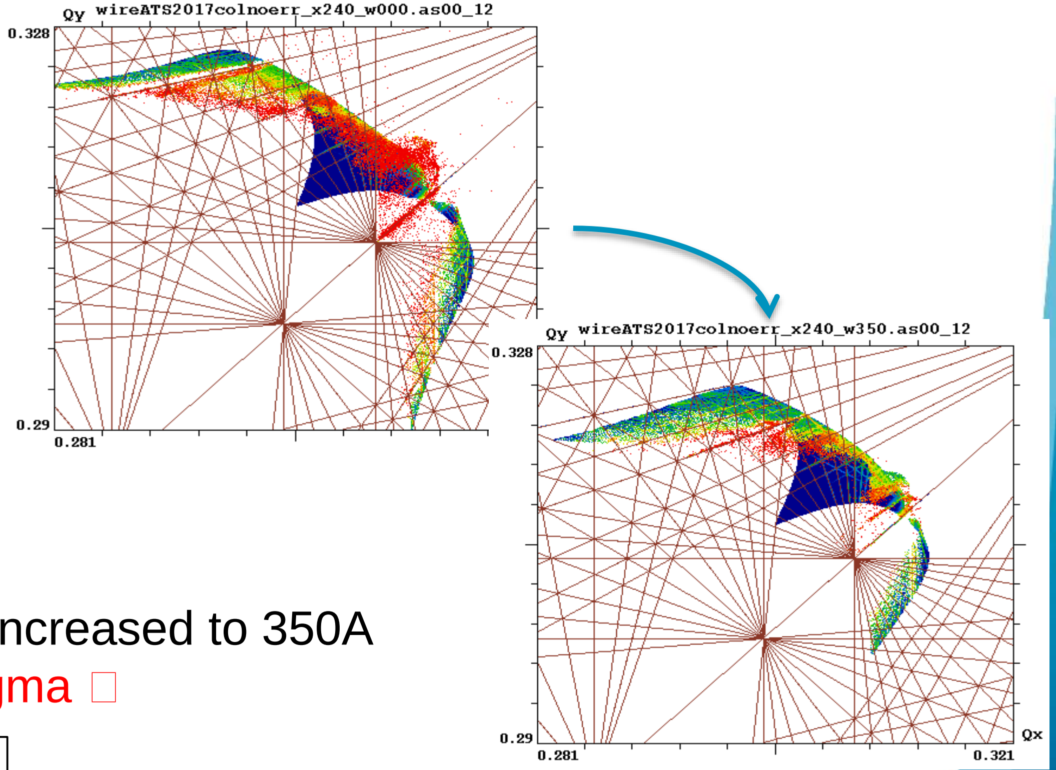
Impact of 2 IP5 Wires at ◡=240urad (5.6 ∕sep.)
Increased Wire Distance





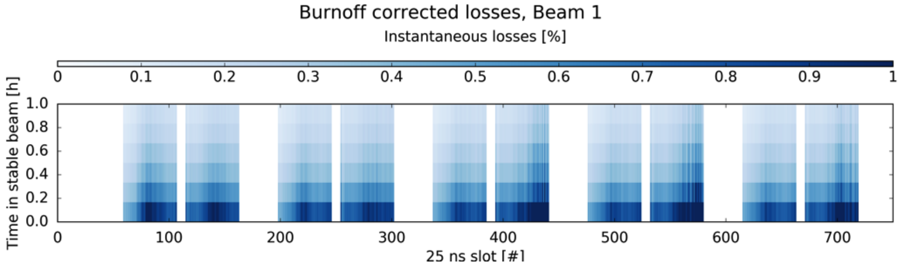
- Wires at 8.8 beam sigma – current increased to 350A
- L5 collimator jaw at 6 collimation sigma □

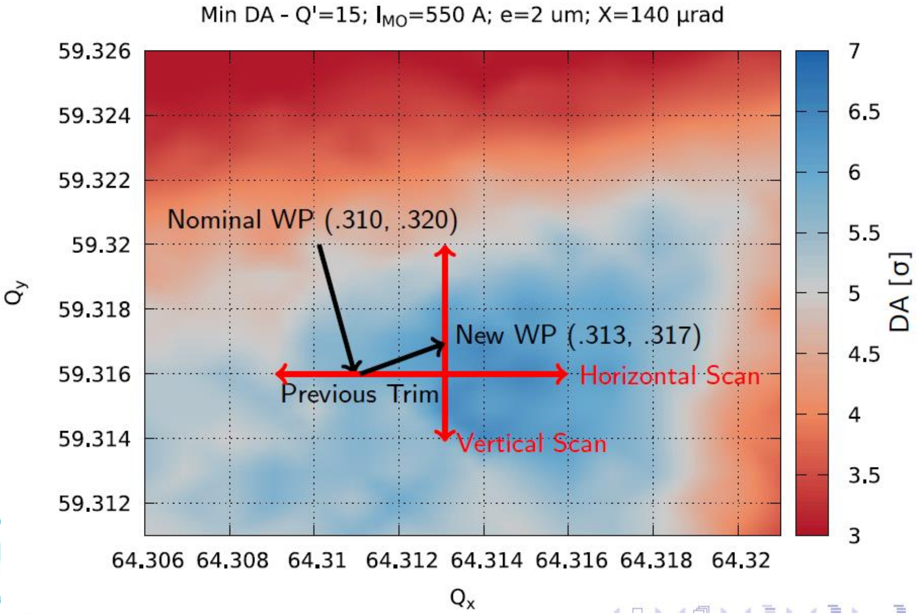
Lifetrac simulation
ATS optics, ∑=5um

Impact of 2 IP5 Wires

- Without major changes to machine configuration, simulations show **severe beam lifetime degradation (down to below 1h)** due to long-range begins at separations of <6 ʃ.
- Even with the present HW limitation, a 2-wire scheme can show measurable benefit to lifetime
  - 4x in 2016 optics at ∪=180urad
  - 2x in 2017 ATS optics and ∪=180urad
  - 2x in 2017 ATS optics, ∑=5um and ∪=240urad
  - Complementary simulations are under way to further optimise L/R wire impact

Scans of the DA and their applications and confirmations during the 2016 run

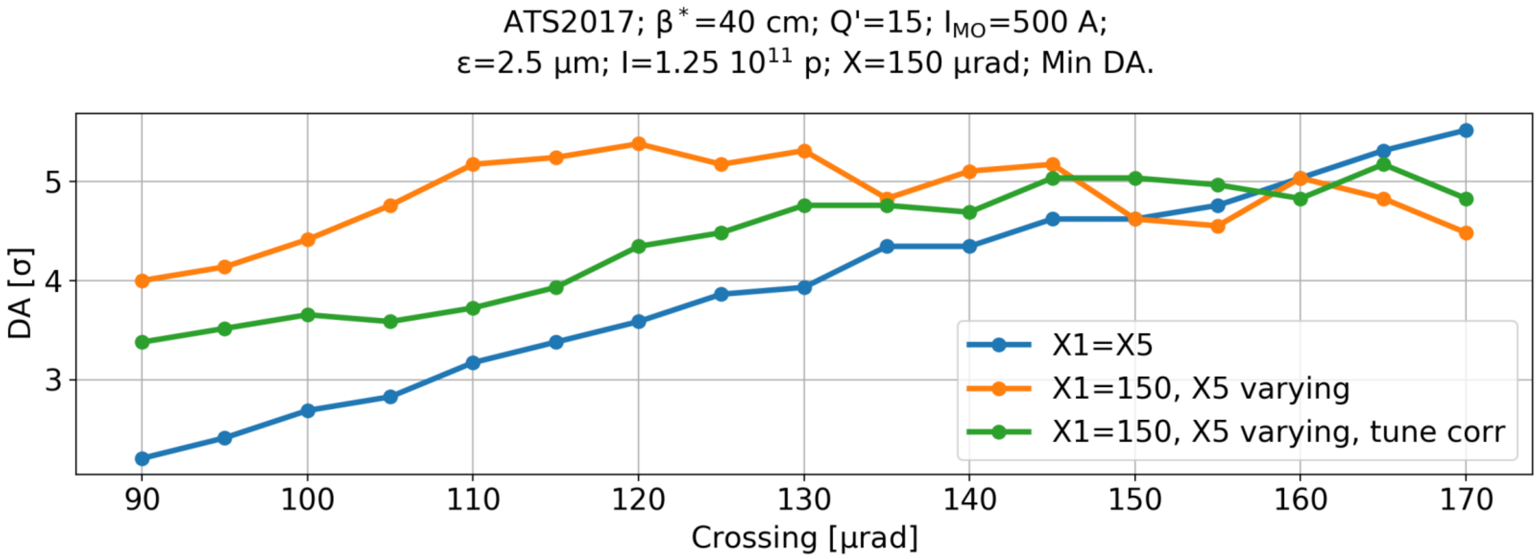




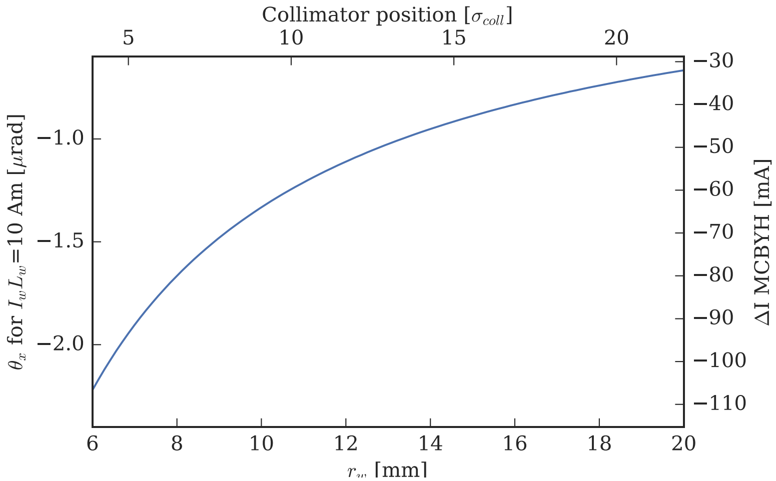
- Additional, but acceptable losses appeared when half crossing angle reduced from 185 to 140 urad.
- Lifetime or DA are also sensitive to the working point choice
- Clear dependence of lifetime on LR BB encounters was also observed in B1 and slight less in B2

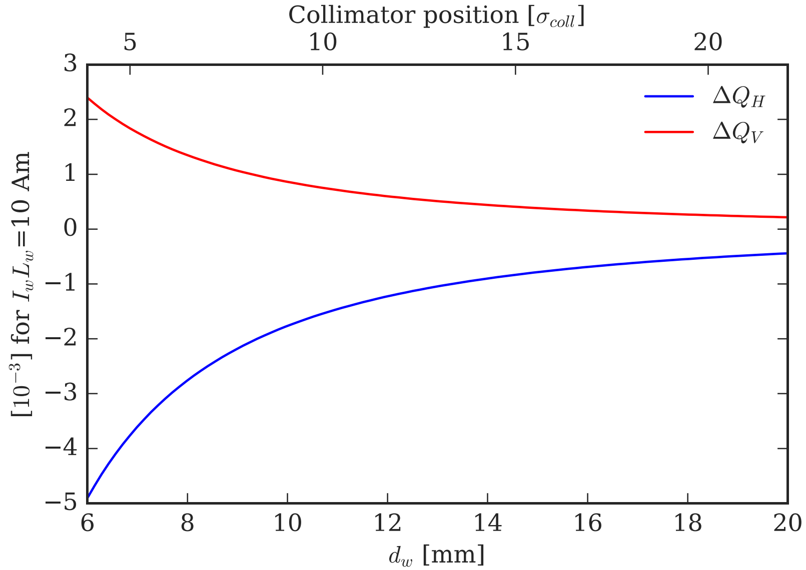
D. Pellegrini BE-ABP

Measurements with wire for 2017



- Scenario with only IP5 crossing reduced + wire
  - With and without tune correction : case with tune correction worse but not understood why.
- Better to go from large DA to small DA = first operate with wire – then switch it off and observe a degradation in lifetime.





Wire tests at injection energy

1. **Calibrating the wires** → 1 beam and 1 wire
2. Compensation btw wires → 1 beam and 2 wires
3. Mimic the LR → 1 beam and 1 wire
4. LR compensation → 2 beams and 1 wire

Most of these tests (1,2,3) can be done with 1 PILOT at 450 GeV <u>if</u> compatible with the required BI precision.

Feedforward of wire impact on orbit and Q and Q'

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Wire impact on single beam

- **Goal:** Test and calibrate the effect of the wires in a single beam (first at injection, then at flat top)
  - **Align wires** with respect to the beam by measuring vertical orbit (or coupling)
  - Measure impact of wires on beam orbit and tune and calibrate theoretical **feed-forward functions**

G.Sterbini, A.Rossi, et al.

Commissioning 2X8h already scheduled

  - Other **optics measurements** (linear and non-linear **chromaticity**, **beta-beating**, **tune-spread**, **RDTs**)
  - Repeat the test using the wires in **external jaw**
  - Estimate impact in **lifetime** and **emittance** (tails, halo?) with one wire and compensate with other wire (**lower priority**)

If time permits

- **Energy**: All can be done at **450 GeV.** Qualification of tune and orbit feed-forward at **6.5 TeV**
- **Beams** required: Only **beam 2.** Compatible with **parallel** studies using beam 1
- Beam **composition** and **intensity**: Single nominal bunches of 1.3 x 10^{11} ppb
  - Some tests can function already with probe
- **Emittances**: Nominal BCMS, i.e. ~1.5-2.0 μm.rad
- **Optics**: Nominal @ injection with nominal injection tunes, octupoles and chromaticity settings
  - More **exotic options** if testing compensation or lifetime impact can be foreseen

BBLR Compensation preparation

J.Wenninger et al.

- **Goal:** Measure the crossing angle reduction impact on lifetime
- Ideally, part of the **intensity ramp-up**
  - Synergy with **crossing angle levelling setting-up**
- Energy: **6.5 TeV**
- **Beam** composition: 2-3 colliding trains in beam1 and 2 (without/with IR8), a few single bunches in beam 2
  - With **full long-range, PACMAN-L/R**, **non-colliding**
- **Intensity**: Nominal @ 1.25 x 10^{11} ppb
- **Emittances**: Nominal for trains i.e. **2.5 μm.rad** for BCMS, some nominal single bunches and some blown up by ADT to **4-5μm**
  - Optics measurements can be done with pilot
- **Optics**: Nominal @ collision with nominal tunes, octupoles and chromaticity settings
  - β* of **40 cm**, but probably **33 cm** when commissioned
- **Procedure:**
  - **Reduce crossing angle** in steps
  - Measure impact on **lifetime** of different bunches, while keeping **constant orbit** and **tune**
  - Monitor impact in **emittances**, **luminosity**, **halo**, **losses**
  - **Measure optics** if time permits

BBLR Wire Compensation

- **Goal:** Prove **BBLR compensation** with powering wire when crossing angle reduction impacts beam lifetime
  - Leading order octupole effect compensation possible with present hardware
- **Energy**: **6.5 TeV**
  - Partially squeezed optics @ injection could be envisaged (simulation work to be done and optics commissioning overhead)
- **Beam composition**
  - A **few single bunches** (around 3-4) in beam 2 (weak beam) spaced far enough for machine protection (abort gap kicker rise time)
  - With **full long-range, 1 non-colliding**
  - As many trains in beam 1
- **Intensity**: Nominal of **1.25×10^{11}** ppb for beam 1 (or highest possible from SPS)
- **Emittances**: Nominal for trains i.e. **2.5 μm.rad** for BCMS, some nominal single bunches and some blown up by **ADT** to **4-5μm**
- **Optics**: Nominal @ collision with nominal tunes, octupoles and chromaticity settings
  - β^* of **40 cm**, but probably **33 cm** if commissioned
  - Un-squeezed optics in IR1 (only if commissioned for IR compensation MD)
- **Crossing angle:**
  - Start with nominal in both IR1 and 5, no collisions in IR2 and 8
  - Moving only one IR crossing angle could be **envisaged**

Y.Papaphilippou BE-ABP

BBLR Compensation procedure

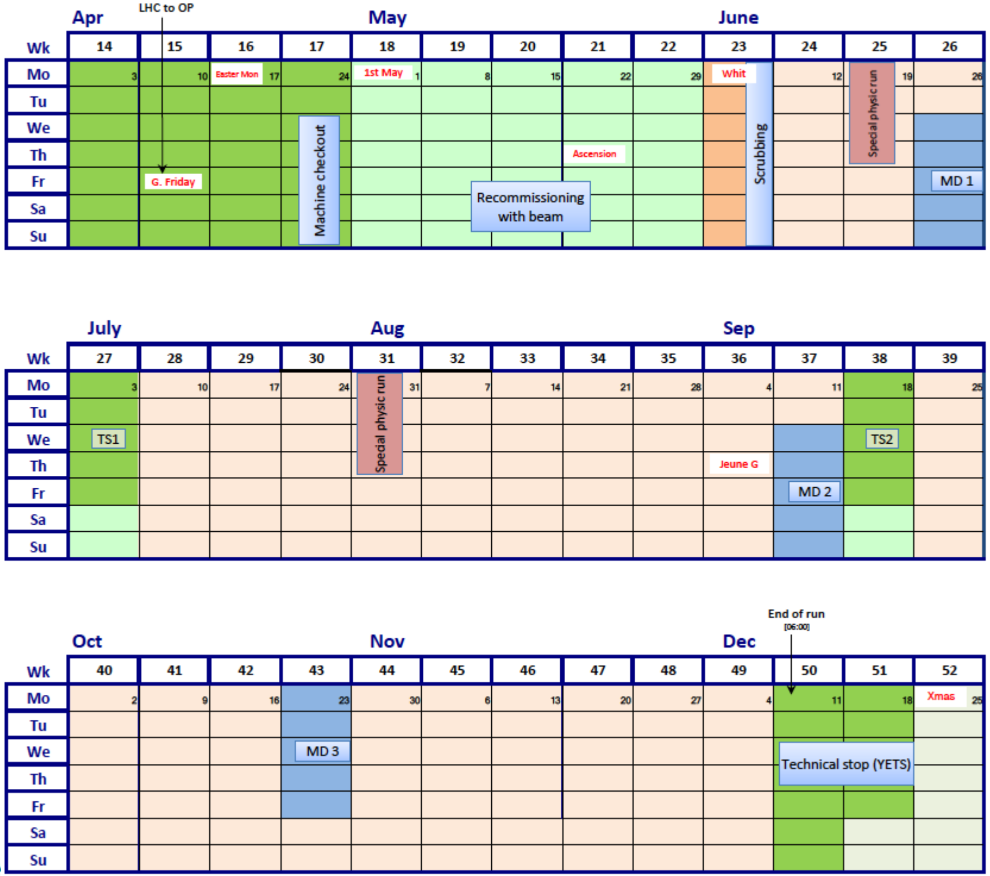
- Inject and ramp up a few bunches in beam 2 to commission **orbit** and **tune** feed-forward with wire (ideally during commissioning phase) and **blow-up** effect of ADT
  - Compatible with parallel tests in beam 1
- Inject, ramp-up and collide strong (beam 1) and weak beam (beam 2)
- Set **internal TCT/L jaw** at **5-6**σ_{col} (including other collimation adjustments enabling this)
- **Reduce crossing angle** in steps, while keeping orbit and tune constant
- Observe **lifetime reduction** and ramp-up the current of each wire in steps, observing lifetime **recovery** in colliding weak beam
- Monitor **emittance**, **luminosity**, **halo**, **losses**
- Repeat the test with different weak beam flavours (**Pacman-L**, **Pacman-R**, **without HO** and **non-colliding**)

- **Measure optics,** e.g. **beta-beating**, **coupling**, **chromaticity**, **tune spread**, **RDTs,** with wire compensation
- Repeat the test with **IR1 crossing angle fixed** and/or separated in IR1
- Repeat the test using the wires in **external jaw**

If time permits

HL-LHC PROJECT

MD schedule and time-line



- Only 15 MD block days
  - MD1 may be moved towards mid-July
  - Possibility for additional days after TS2 if LHC lumi goal reached
- Wire calibration will profit from **commissioning** time in May (2x8h)
- Crossing angle scan may profit from intensity ramp-up
- Wire compensation MD requests **3x8h** for strict minimum
- Ideally Would like to profit already from the **1st MD block**

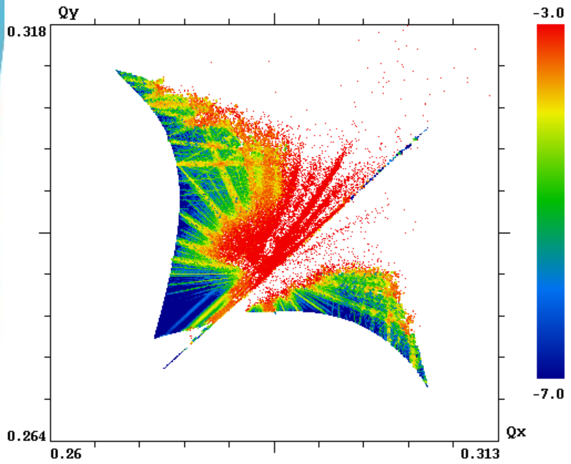
R.Tomas

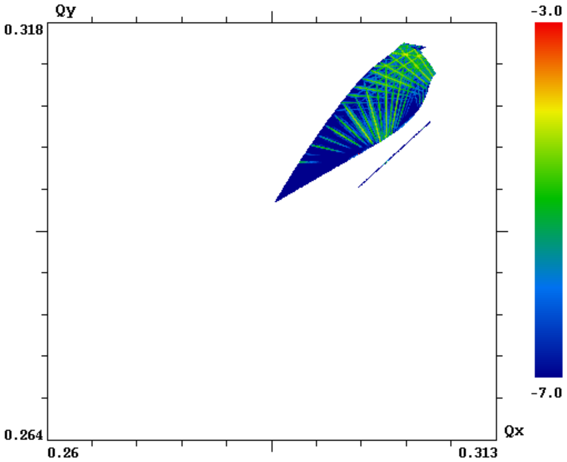
Appendix

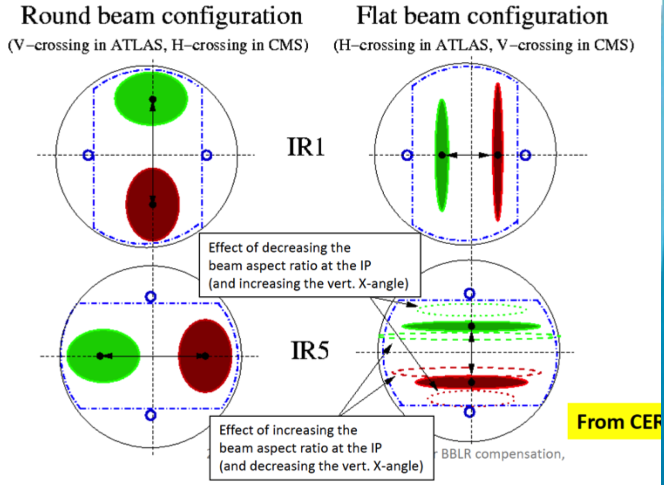
Introduction to flat optics and potential of wire compensation

- **Flat optics example: HL-LHC plan B for 10^{35} virtual luminosity w/o crab-cavities**
  (HL-LHC Coordination Group, May 2013, and ***PRSTAB 18-121001, 2015***)

→ ®*=40/10 cm at IP1&5 (i.e. *r=4*), $◡_c$=300 μrad, i.e. about halved vs. baseline but still 10.5σ at ®*=40 cm in the X-plane, ho collision at full current in 3 IPs







From CER

Wire on the right plane?

A ``monster'' before correction (ΔQ_{ho}=0.025, ΔQ_{LR}=0.015)

A regular HO footprint after correction (ΔQ_{ho}=0.025, ΔQ_{LR}=0.0) with wire installed at optimal position (see later)

Principle of the wire correction and wire specification

$$B_k + i\,A_k = \frac{\mu_0 [IL]_{\text{eq}}}{2\pi} \times \frac{1}{z_0^k}$$

Proposed by Koutchouk

1. H crossing ($z_0 = x_0$ real) induces only normal harmonics (A_k=0).
2. V crossing ($z_0 = iy_0$ purely imaginary) induces both skewed harmonics when k is odd (B_{2k+1}=0) and normal harmonic when k is even (A_{2k}=0).
3. An **alternated <u>HV Xing scheme in 2 low-β IRs with</u>** <u>identical round optics</u> compensates all $(4n+2)$-pole tune shift and tune spread (B_2, B_6,…) but combine additively the $(4n)$-pole tune spread (B_4, B_8,…). …That is why the LR tune spread is close to that of a **pure octupole in the LHC**, and was easy to compensate with octupole magnets, at least at 4 TeV ….
4. The compensation is only **partial for alternated HV Xing in <u>2 low-β IR's with</u>** **<u>flat optics of aspect ratio r and 1/r</u>**

$$r = b_x / b_y$$

S. Fartoukh
BE-ABP

Effects of wire on tails at injection

- effect of wire on lifetime is small at injection even at minimal separation of $d_{jaw<->beam} = 5.7\ \sigma$ and current of $I_{wire} = 350$ A
- effect of WIRE RIGHT is small compared to WIRE LEFT due to different ratio in beta function
- wire contributes considerably to the tune spread

⇒ tune spread generated by octupoles might be compensated by wire (e.g. thin line for $I_{wire} > 0$)

- without octupoles, wire cleans in horizontal plane (1/r potential)
- with octupoles, the effect of the wire on the tail particles depends on:
  - the non-linearities present
  - the working point

⇒ effect of wire on tail particles depends strongly on machine configuration (mainly tune and octupoles)

⇒ **wire does not necessarily deplete particles uniformly in x and y**

M. Fitterer
FNAL

HiLumi HL-LHC PROJECT

Considerations on impedance and beam stability

- The TCTW impedance is similar to the TCTPH's
- The increase of the impedance due to the reduced gaps (>2 nominal σ → >~7 beam sigma for the wire) of the TCTW does not affect significantly the beam stability. The cut tails also have marginal impact with the positive polarity of the octupole
- For a single bunch, operation without ADT should be possible
- The variation of the tune shift due to the impedance when moving the wire can be in the order of few 10^{-4} with 10^{11}p per bunch
- Beam transfer function measurements provide a measurement of the amplitude detuning, mixed with the particle distribution
  - Detailed studies usually needed to fully understand the measurements
  - Relative impact of the wire (tune shift and spread) should be visible