CERN

Scenarios and timeline for wire compensation in the HL-LHC

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with contributions of

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9th HL-LHC Collaboration Meeting, Fermilab, 14-17 October 2019

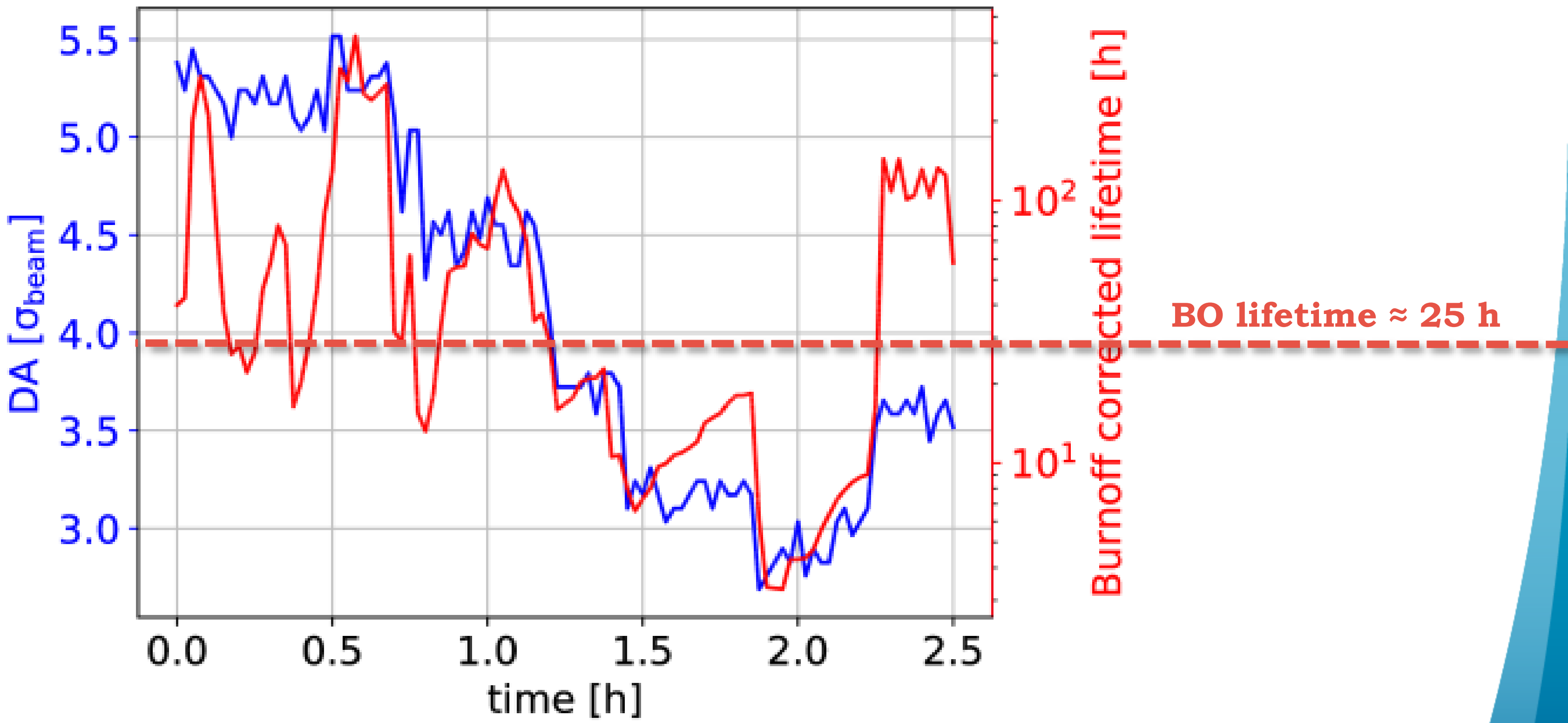
Motivation and Outline

- Review **Beam-Beam Long-Range** (BBLR) effect and its impact on HL-LHC **baseline operational scenario** during luminosity production (**β*-levelling**)
  - Some slides added for **correlation** of **DA** with **lifetime**
- Demonstrate **improvement** on performance of **BBLR wire compensation** for different configurations
  - Round/Flat optics with/without Crab
- Draw a **timeline** (milestones) for possible **implementation** of wire compensation in HL-LHC

Correlation of Dynamic Aperture versus beam-lifetime from LHC experience

Lifetime vs DA with 8b4e

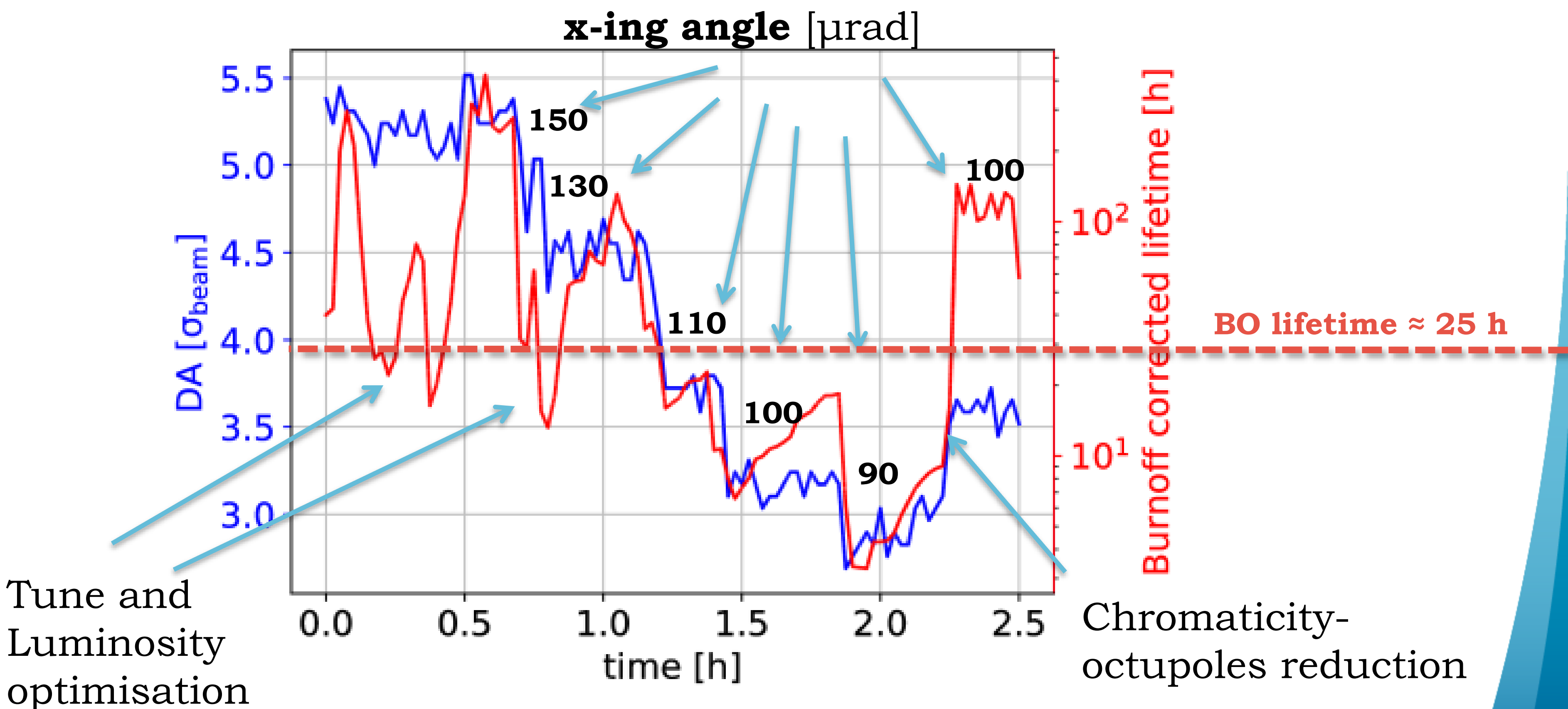
- Correlate **simulated DA** and measured burn-off (BO) corrected **lifetime** through x-ing angle scan **experiments** in the LHC



D. Pellegrini et al, Evian 2017

Lifetime vs DA with 8b4e

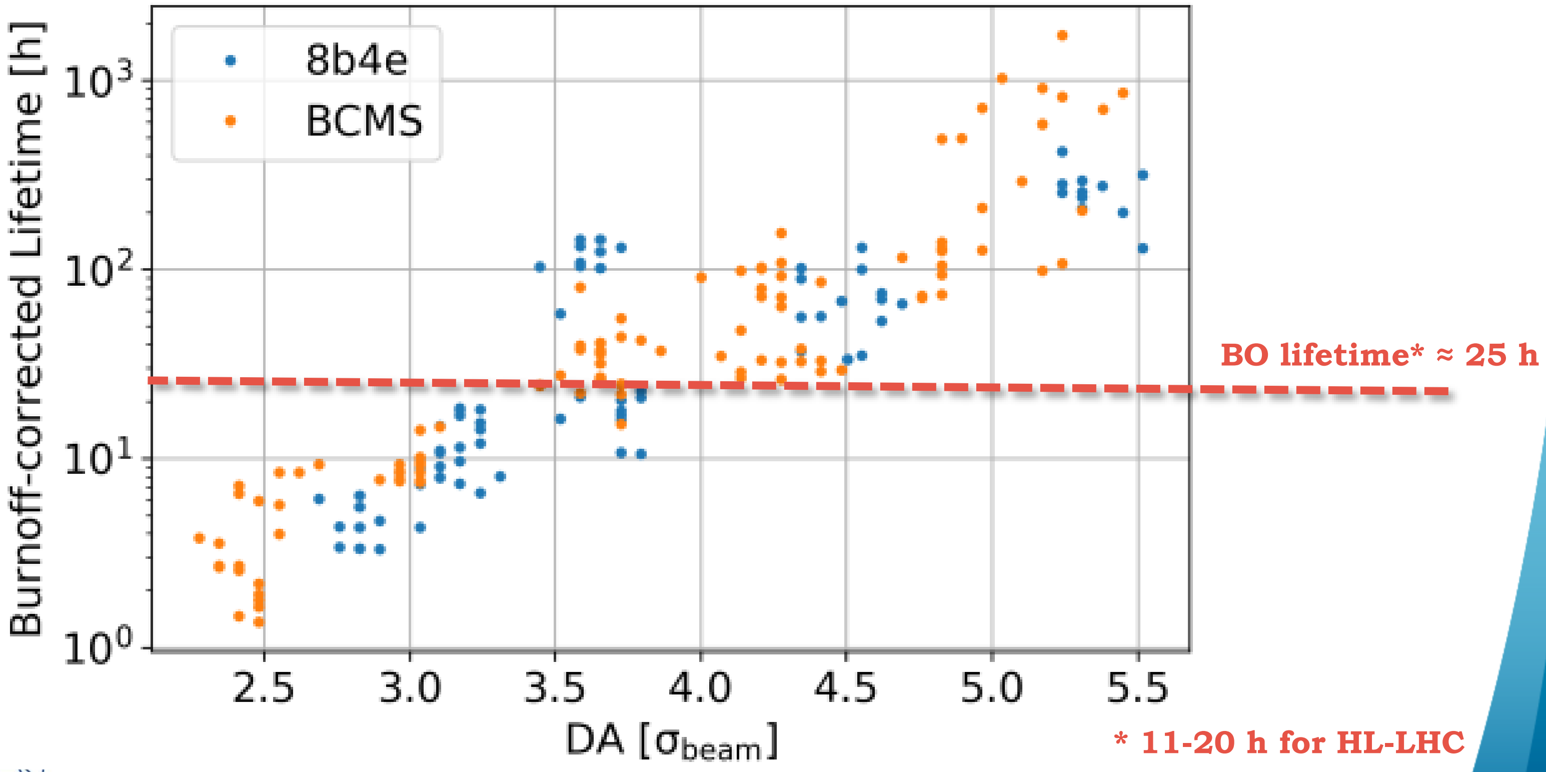
- Correlate **simulated DA** and **measured burn-off (BO) corrected lifetime** through x-ing angle scan **experiments** in the LHC
- Beam current decay follows $\frac{I(t)}{I_0} = -e^{-\frac{DA^2(t)}{2}}$ **M. Giovannozzi, PRST-AB, 2012**



D. Pellegrini et al, Evian 2017

DA vs Lifetime

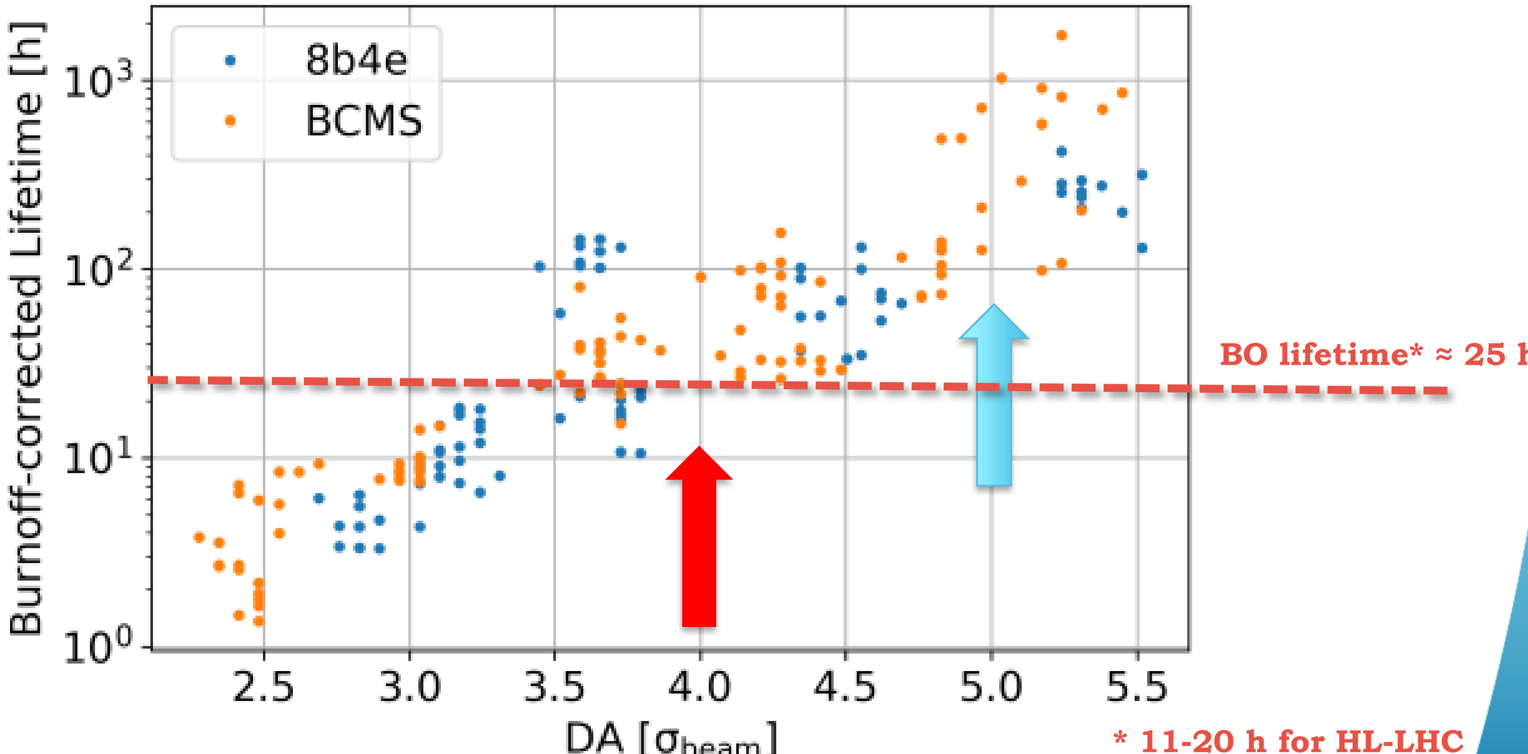
- Good **agreement** between high-intensity **8b4e** and **BCMS** (non-pacman):



D. Pellegrini et al, Evian 2017

DA vs Lifetime

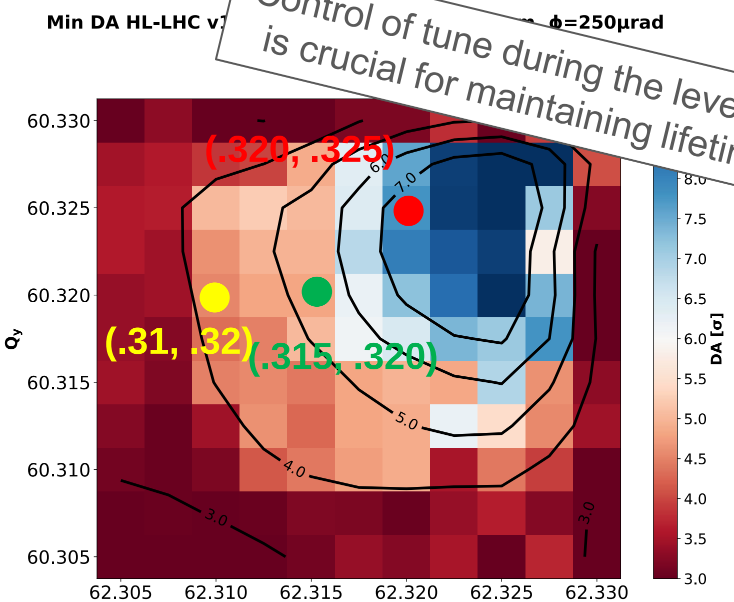
- Good **agreement** between high-intensity **8b4e** and **BCMS** (non-pacman):
  - **4 σ:** corresponds to **lifetime** close to **BO**
  - **5 σ:** grants **lifetimes** above **~100 h**: **Minimum target** for **LHC operation**
  - **6 σ:** **target** for **studies** (HL-LHC) in presence of larger **uncertainties** (e.g. multi-pole errors)

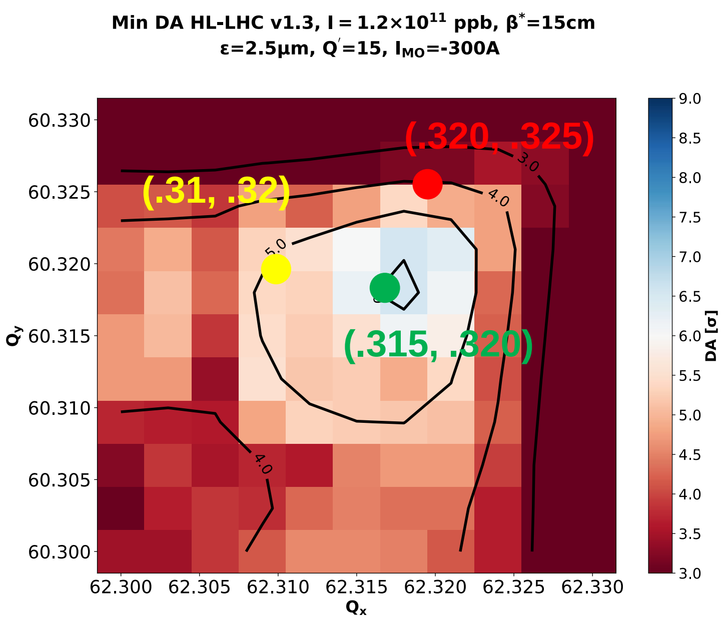


D. Pellegrini et al, Evian 2017

HL-LHC Baseline Operational Scenario

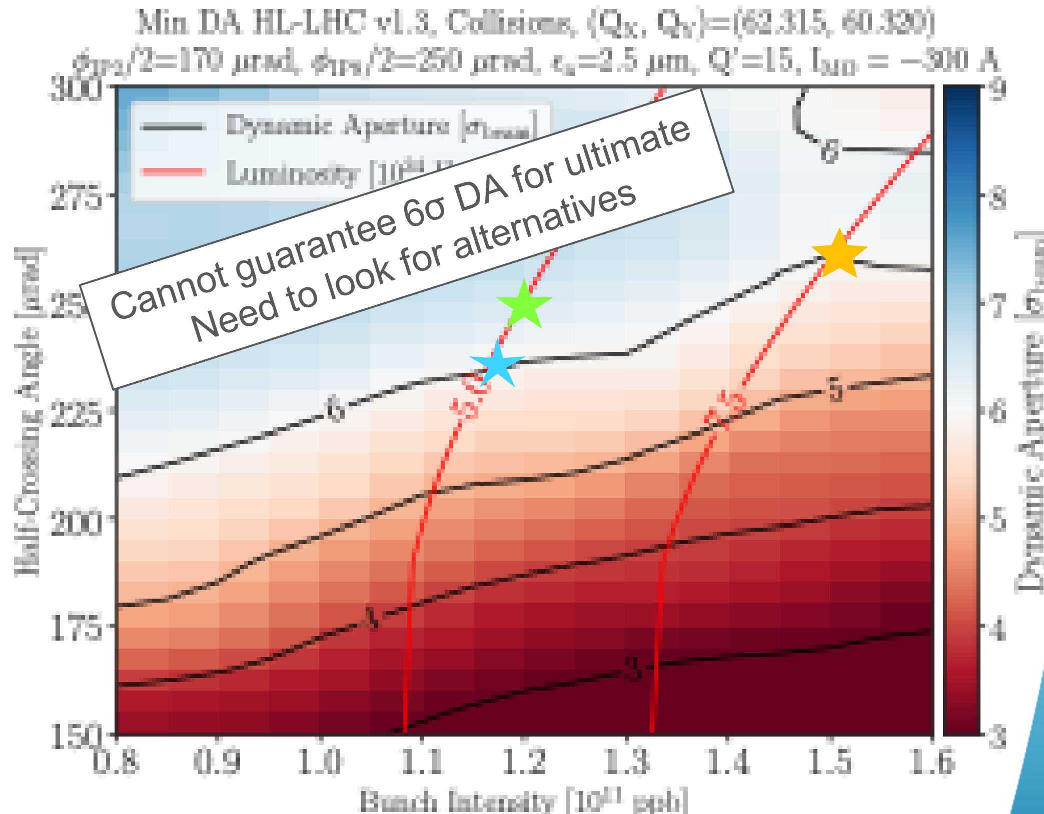
Operational Scenario @ collision





- DA [σ]
- Luminosity $[10^{34} Hz/cm^2]$
- ★ Baseline
- ★ Nominal (6σ)
- ★ Ultimate (6σ)

Scenario	Half-crossing angle [μrad]	I [ppb]
Baseline	250 (10.5σ)	1.22
Nominal (6σ)	235 (9.9σ)	1.19
Ultimate (6σ)	260 (11σ)	1.53

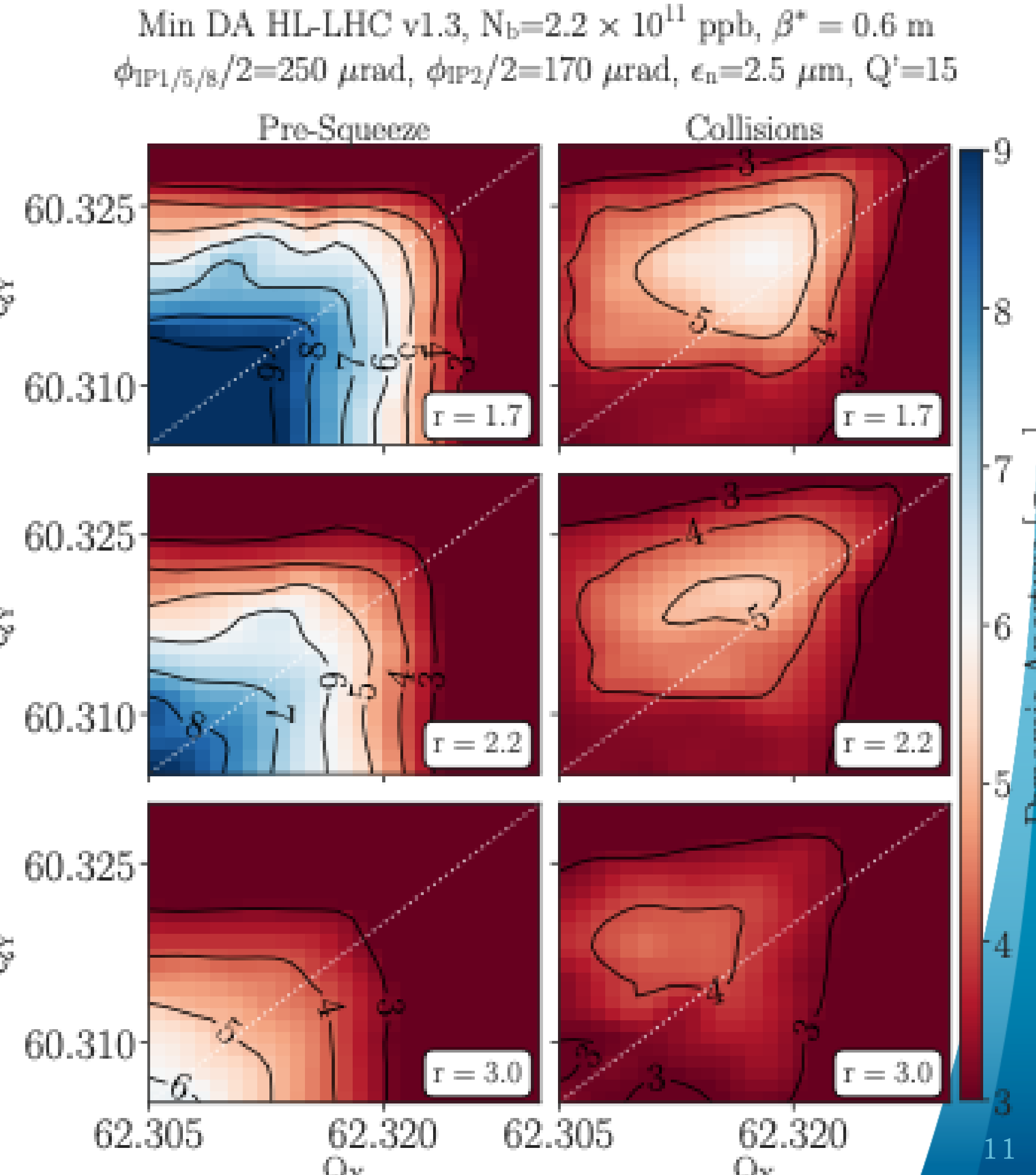


- E. Métral *et al.*, *"Update of the HL-LHC operational scenarios for proton operation"*, CERN-ACC-NOTE-2018-0002
- N. Karastathis *et al. "Refining the HL-LHC Operational Settings with inputs from Dynamic Aperture simulations: A Progress Report"*, 2018 J. Phys.: Conf. Ser. **1067** 022005

Pre-squeeze

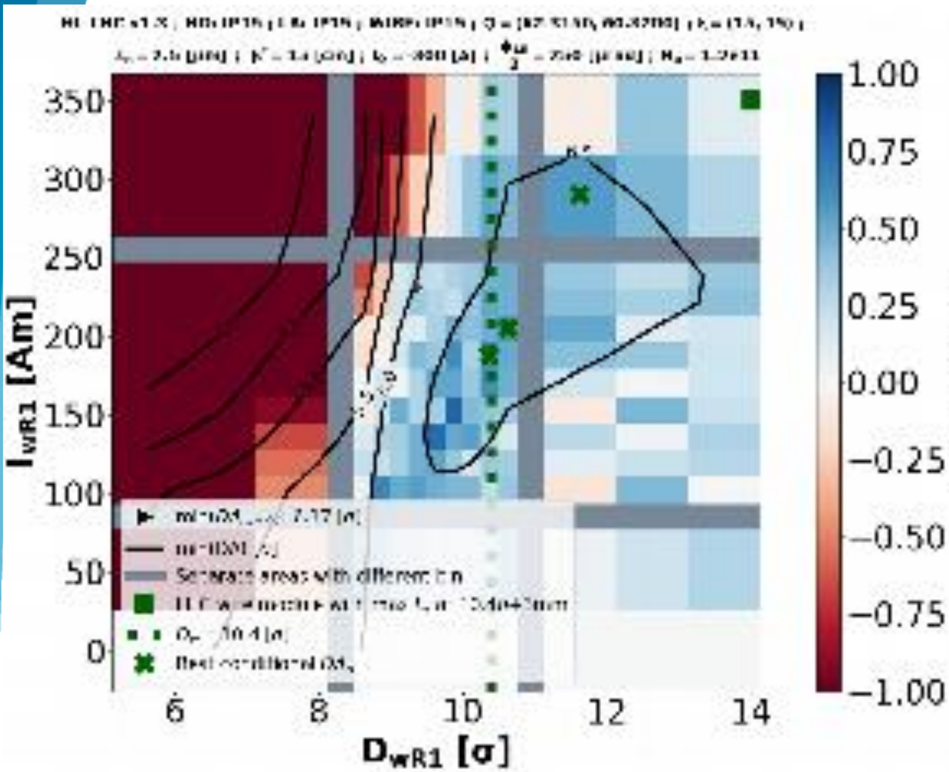
u - HL-LHC
wire meeting
2019

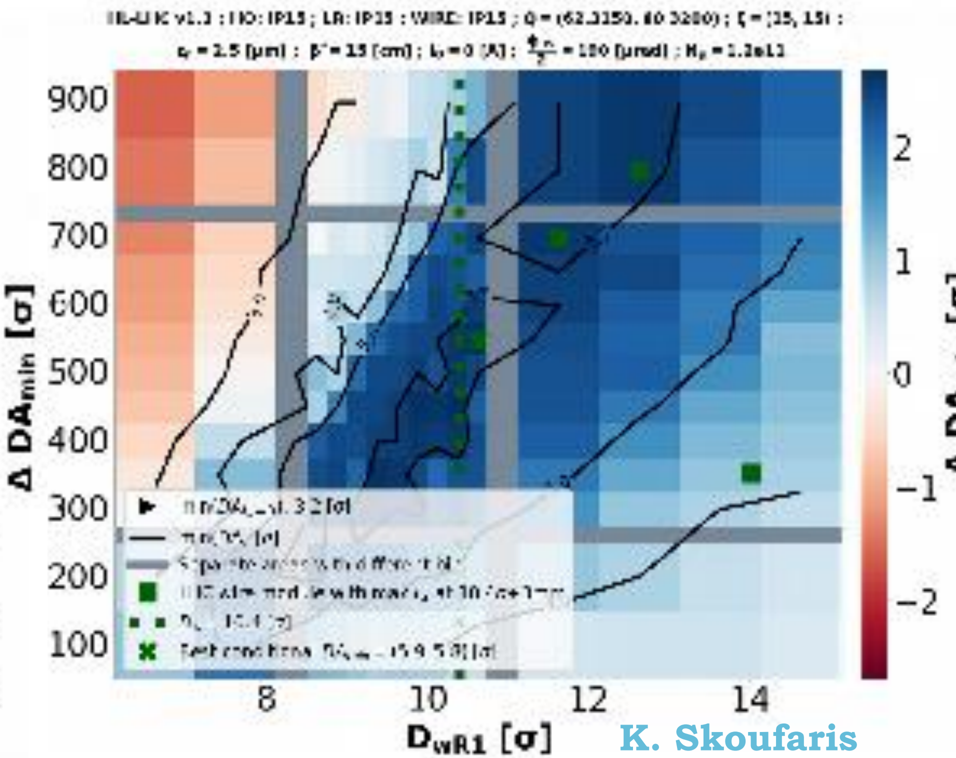
- **Increased telescopic index** necessary to guarantee stability during the pre-squeeze
  - Value depending on the collimator contribution to impedance (**upgrade** necessary)
- At collision, **telescope** (i.e. octupole strength) should be reduced (or even polarity reversed) for good lifetime



Wire Impact

Wire @ nominal intensity

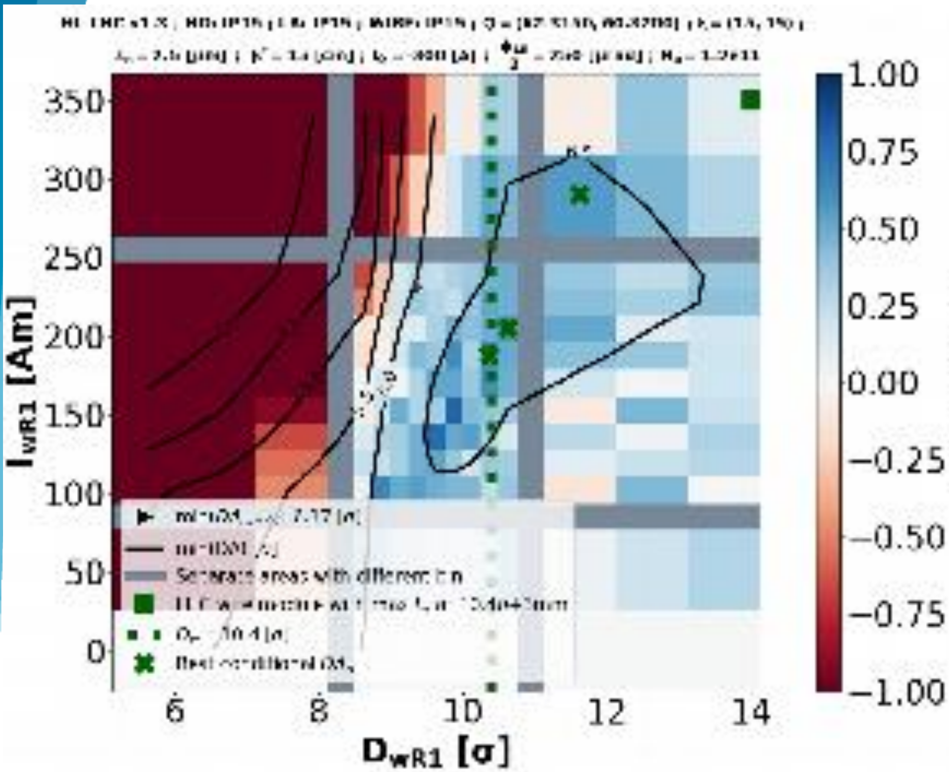


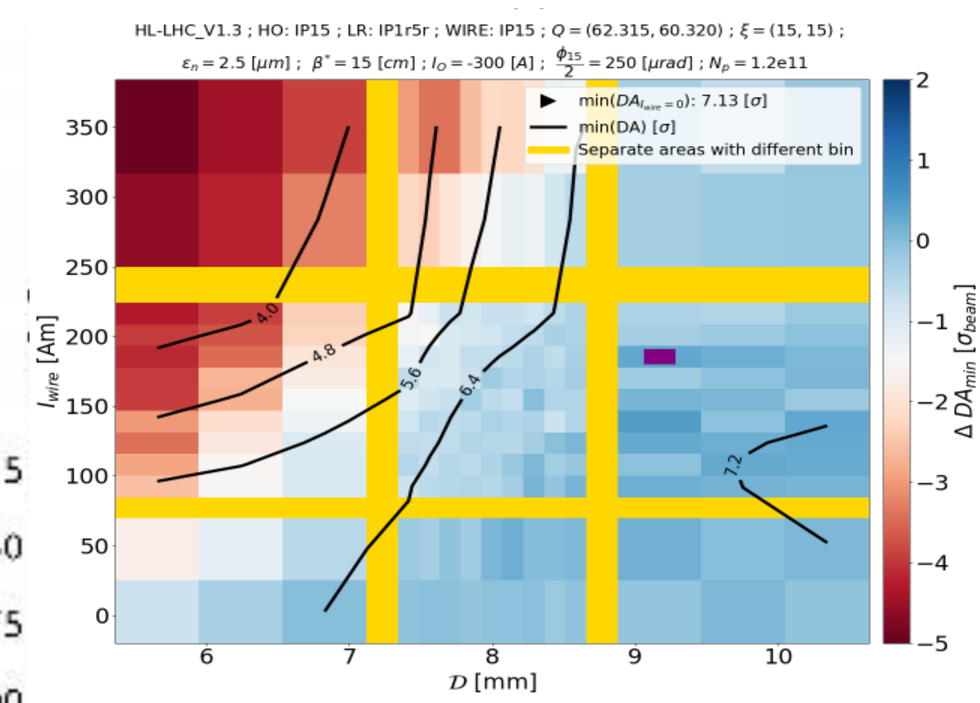


K. Skoufaris

- Wires located at **beam distance beyond TCTs** (>10.4 σ) enable to reduce half **x-ing angle to 190 μrad** (by 25 %), while maintaining **6 σ DA**
  - Enhance **min. β* reach** to **13 cm**
  - Reduce **triplet irradiation** i.e. increase their lifetime and overall integrated luminosity by around **15-20 %** **F. Cerutti**
  - Allow **full crabbing** during the whole levelling period (or minimise impact of reduced CC voltage)

Wire @ nominal intensity

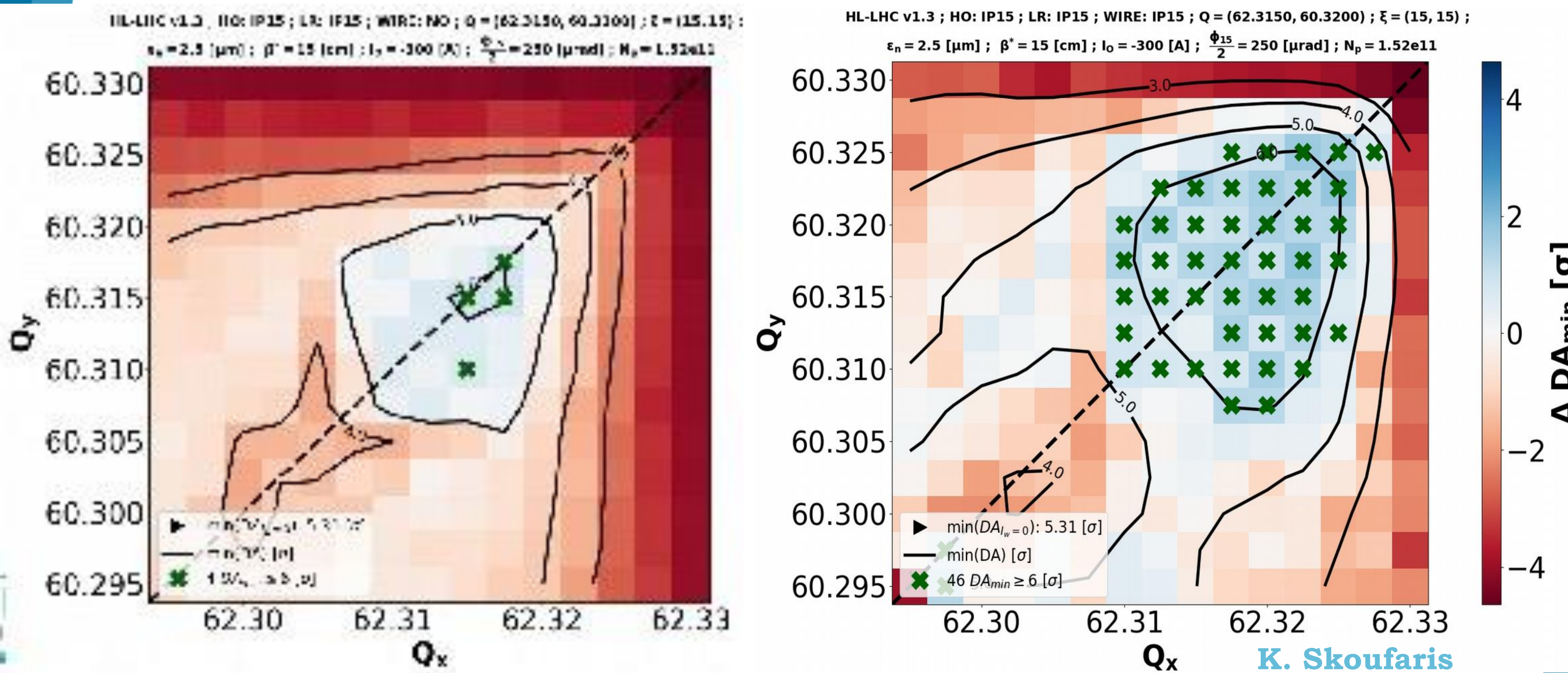




K. Skoufaris

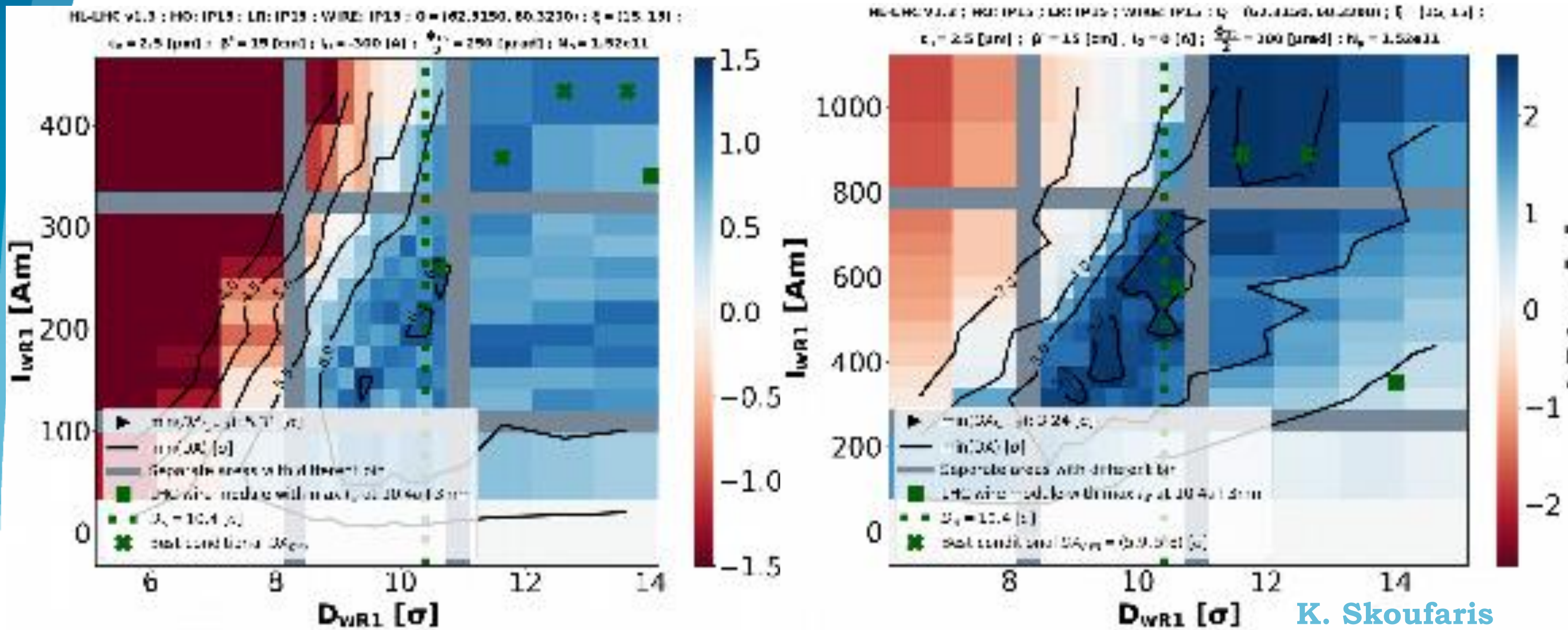
- **DA** of “pacman” bunches is **not degraded** by DC wire due to “overcompensation” (actually slightly improved)
  - Compatible with **experimental observations** in the LHC
  - **No need** for complicated **“pulsed” wire** HW

Wire @ ultimate intensity



- Wires open-up **WP area** ensuring **6 σ DA**, in particular for the ultimate intensity
  - Even in the presence of negative octupole current assisting BBLR tune-spread reduction
- Allow full **flexibility** on **WP choice** during levelling

Wire @ ultimate intensity



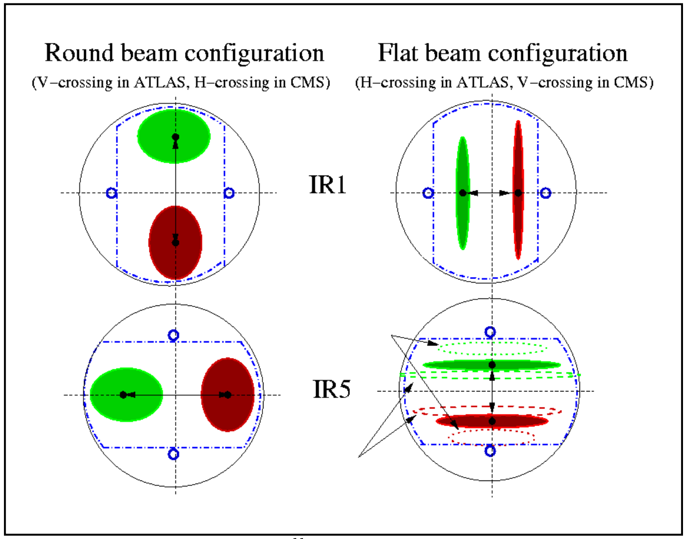
K. Skoufaris

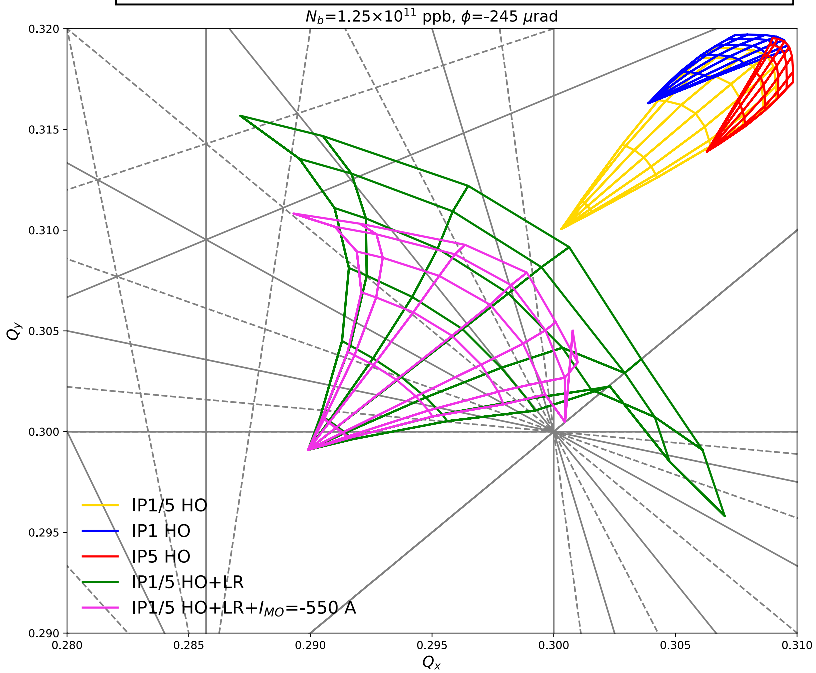
- Wires at beam distance beyond TCTs (>10.4 σ) enable to reduce half x-ing angle to **200 μrad** (by 20 %), while maintaining **6 σ DA**
  - Enhance min. β* reach to **13.4 cm**
  - Reduce **triplet irradiation** i.e. increase their lifetime and overall integrated luminosity by around **15 %** F. Cerutti
  - Allow **almost full crabbing** during the whole levelling period (or minimise impact of reduced CC voltage)

Flat optics

Introduction to Flat Optics

S. Fartoukh et al, CERN-ACC-2018-0018



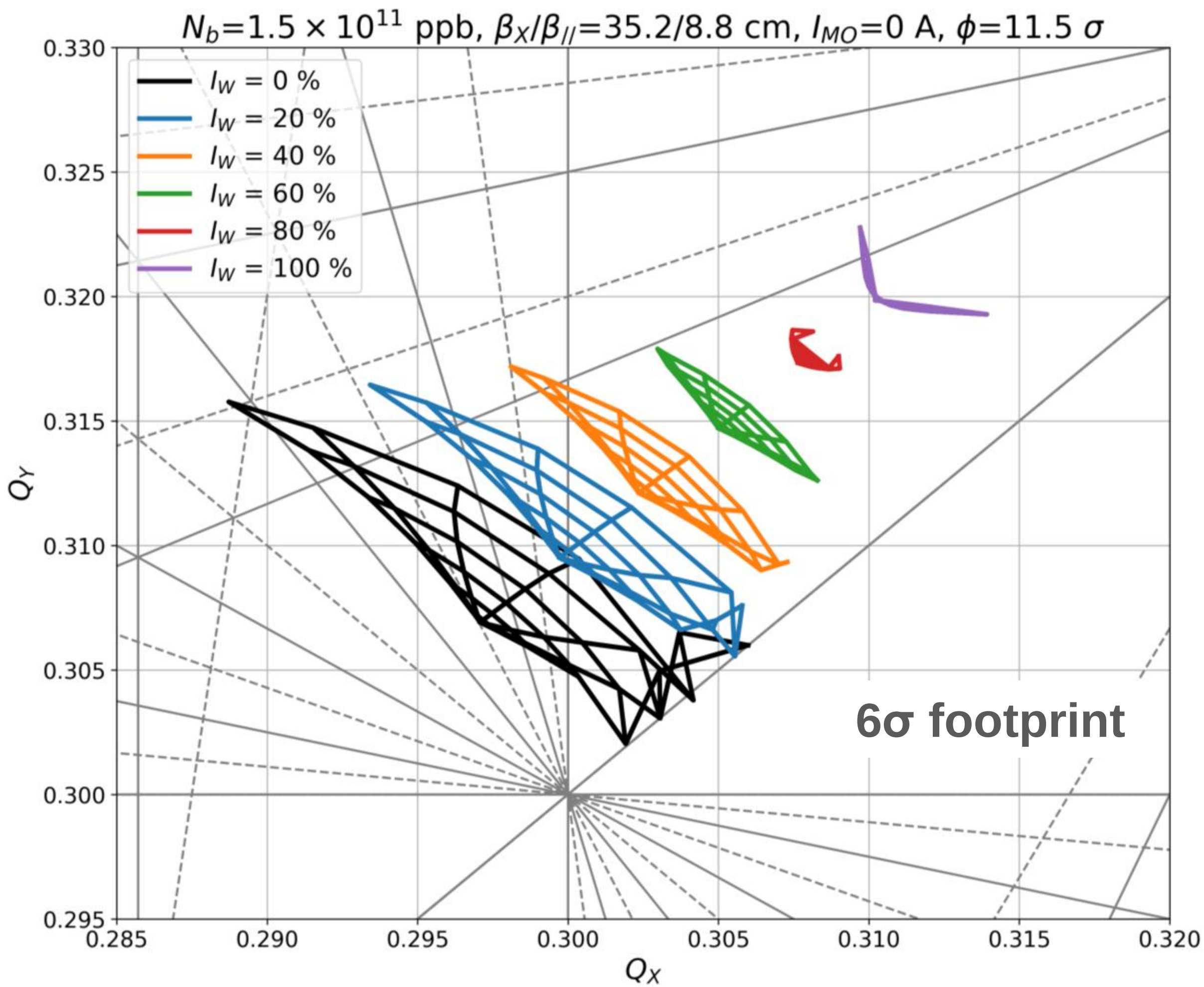


- Flat Optics proposed as "**plan B**" of HL-LHC without CC, due to increased virtual luminosity performance
- Contrary to LHC case, **HL-LHC** triplet beam screens allow **beam flattening** in IP1/5 **without** crossing **plane restriction**
- By alternating crossing planes, the flat optics **reduces HO** beam-beam **tune shift** (and spread) at constant peak luminosity
- **BBLR** induced **tune shift not** fully **compensated** (and similar to HO)
- Feasibility of scheme strongly depends on **BBLR compensation**
- **Detailed operational scenario** to be defined, e.g. start colliding at round and then flatten β* more in the parallel plane while intensity decays.

Wire Compensation for flat optics

S_{WIRE}: 198.04m from the IP

I_w [%]	I_w [A m]
20	26.84
40	53.68
60	80.53
80	107.37
100	134.21

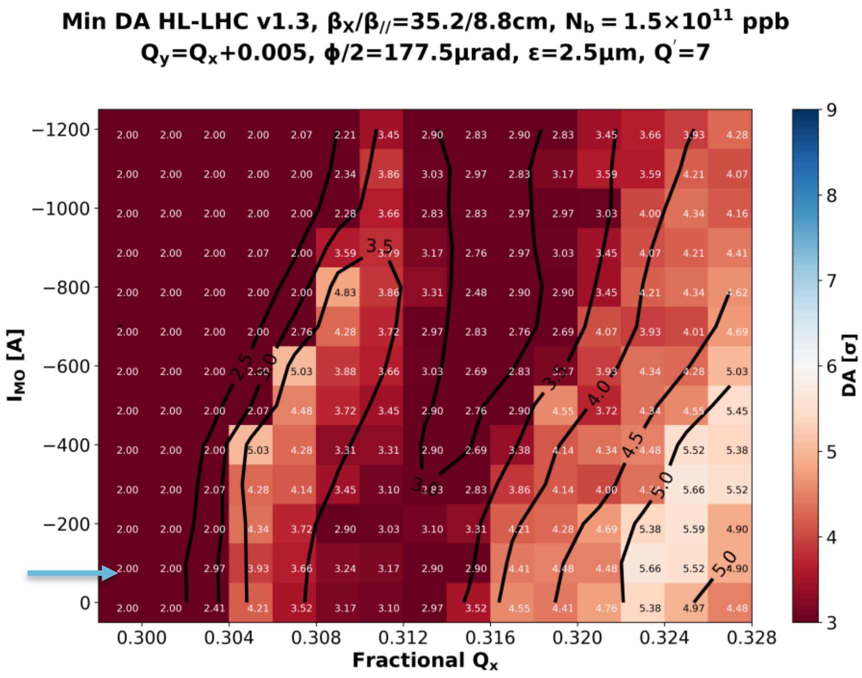


S. Fartoukh, et al., "Compensation of the long-range beam-beam interactions as a path towards new configurations for the high luminosity LHC", PRAB 18 121001 (2015)

BBLR Compensation

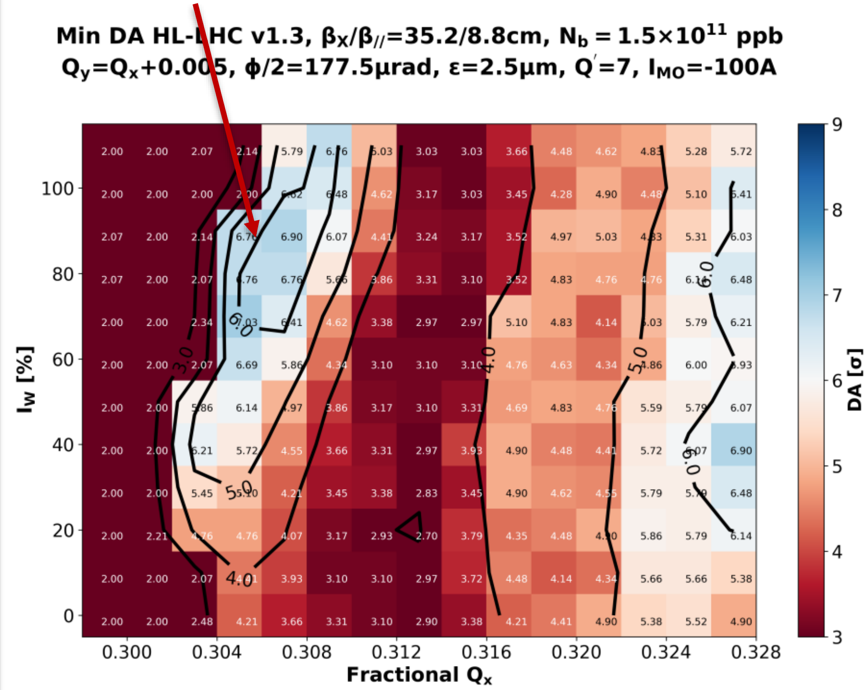
11.5σ – No CC

Octupoles



Wire [IMO=-100A]

~7σ island

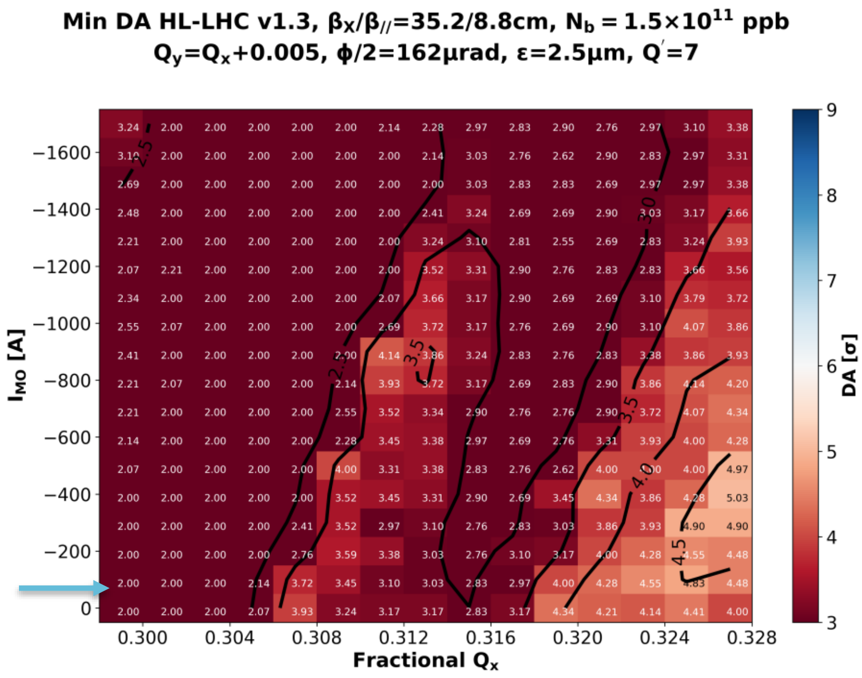


- The addition of the wire increases **DA** by **~1.5σ** DA at constant normalized crossing angle

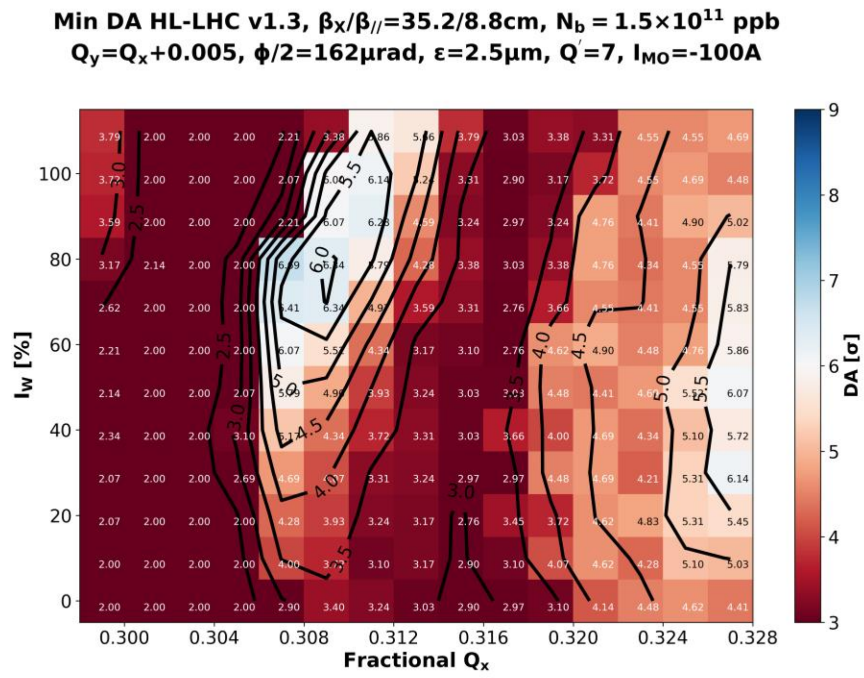
BBLR Compensation

10.5σ – No CC

Octupoles



Wire [I_{MO}=-100A]

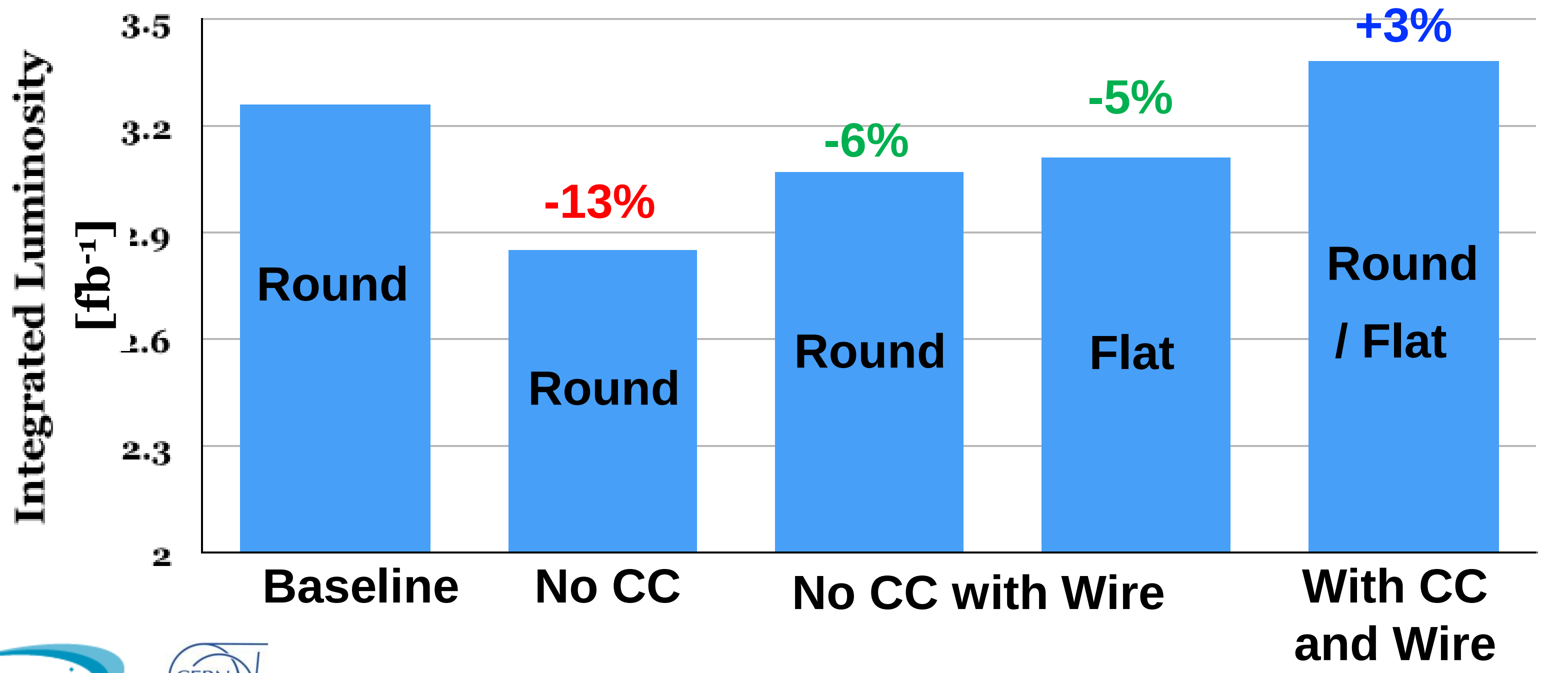


- Field of wire can create all possible multipoles making it feasible to target all the RDTs
- The octupoles only target the b4 component → can be washed out if other multipoles are dominating.

Performance summary and Timeline

Wire impact on luminosity

- Without CC, integrated luminosity (per day) is reduced by **13 %**
- Wires **partially restore** lost **performance**
- In the presence of CC and wire a slight **increase** of **integrated luminosity** is **guaranteed**



Summary of wire impact

- **DC solid wires** at distances compatible with collimation hierarchy are able to partially **restore integrated luminosity** in the absence of CC
- Slightly **increase luminosity** in the baseline scenario
- Wires provide a series of **positive side effects,** e.g.
  - Relax **WP choice** through levelling
  - Recover **6 σ DA** for **ultimate scenario** (round optics)
  - Enhance **β* reach**
  - **Reduce triplet radiation**, increasing significantly (up to 20%) triplet lifetime
  - Increase luminous region leading to **peak pile-up density reduction**
  - **Enable** running with **full crabbing** through levelling, or reduce impact of limited crab voltage

Timeline

- **Experimental verification** achieved with demonstrator (2016-2018)
- **Simulations** proved potential at present LHC but also for HL-LHC, with a **solid DC wire solution** (2017-2019)
  - Refining flat optics operational scenario (2020)
- **Wire operation** during **run3** will clarify operational and machine protection issues (2021-2023)
- **Hard-ware design** and short prototype HW tests for HL-LHC (2020)
- **Technical review** (including budget) for using wire compensation in the HL-LHC era (2020)
- Prepare **locations** for integration (during LS3)
- Wire **installation** and **operation for HL-LHC** (during Run4)

Wire is not (only) Plan B…

It is Plan… A+ !

Thank you for your attention