Sensitivity of integrated luminosity for beam parameter change

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WP2 meeting, 17/01/2017

Outline

- Xing angle choice during levelling
- Impact on levelling (β* vs. separation)
- Experience 2016:
  - Luminosity lifetime, blow-up, impact on estimated performance
  - Levelling tests
  - Availability
- Projection on integrated luminosity performance

Global DA scanning of parameters

- Tracking set-up:
  - HL-LHC optics v1.2, half available crab voltage
- Octupoles set to 0, chromaticity of 3, nominal tunes
- IP1, IP5 and IP8 head-on, IP2 seperated (halo collisions)
- Assuming constant (round) emittance of 2.5μm
- Tracking with SixTrack for 10^6 turns and estimating DA (minimum over 5 angles)
- Scanning of crossing angle vs. β* and vs. separation, for various intensities
- Superimposing luminosity curves for the various parameters

Global DA scanning of parameters

- Tracking set-up:
  - HL-LHC optics v1.2, half available crab voltage
- Octupoles set to 0, chromaticity of 3, nominal tunes
- IP1, IP5 and IP8 head-on, IP2 separated (halo collisions)
- Assuming constant (round) emittance of 2.5 μm along stable beams
- Tracking with SixTrack for 10^6 turns and estimating DA (minimum over 5 angles)
- Scanning of crossing angle vs. β* and vs. separation, for various intensities
- Superimposing luminosity curves for the various parameters
- Target DA of 6 σ, as simulation scenario is optimistic (no errors, no octupoles, low chromaticity,…)

Start of levelling N_b = 2.2 x 10^{11}

- Full crossing angle could be reduced to 440 µrad (~19.4 σ separation @ 65 cm β*), keeping the 6 σ DA and the luminosity at 5 x 10^{34} cm^{-2} s^{-1}
- Even for min. β* of 20 cm @ 510 µrad, DA ~5.5 σ
- For 7.5 x 10^{34} cm^{-2} s^{-1}, the leveling could start at 40 cm with a crossing angle of 480 µrad (16.6 σ)

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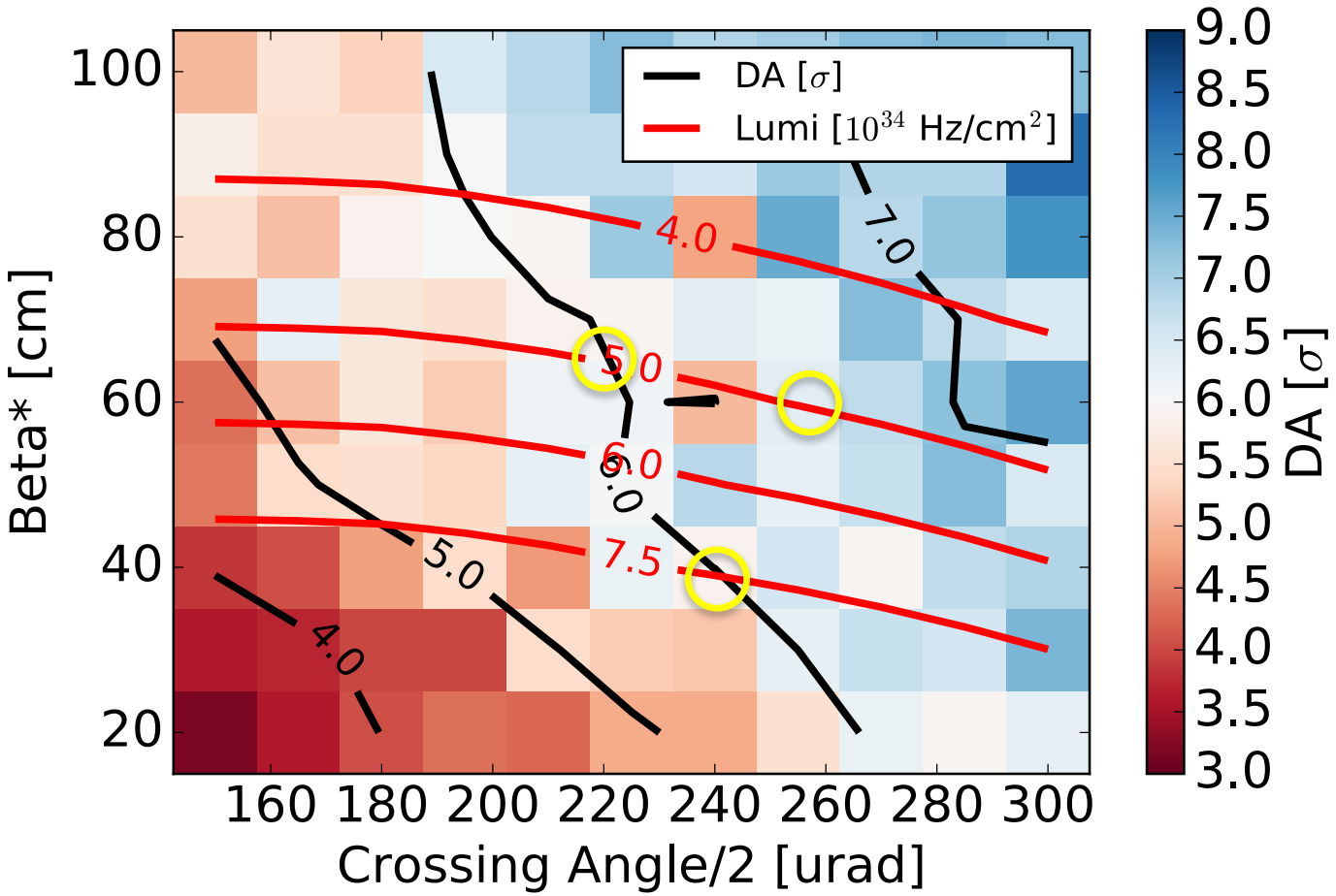

During levelling, N_b = 1.9 x 10^{11}

- Full crossing angle could be reduced to 340 µrad (~13.1 σ separation @ 50 cm β*), keeping the 6 σ DA and the luminosity at 5 x 10^{34} cm^{-2} s^{-1}
- For 7.5 x 10^{34} cm^{-2} s^{-1}, a DA of 6 σ is obtained with a crossing angle of 440 µrad (13.2 σ @ 30 cm)

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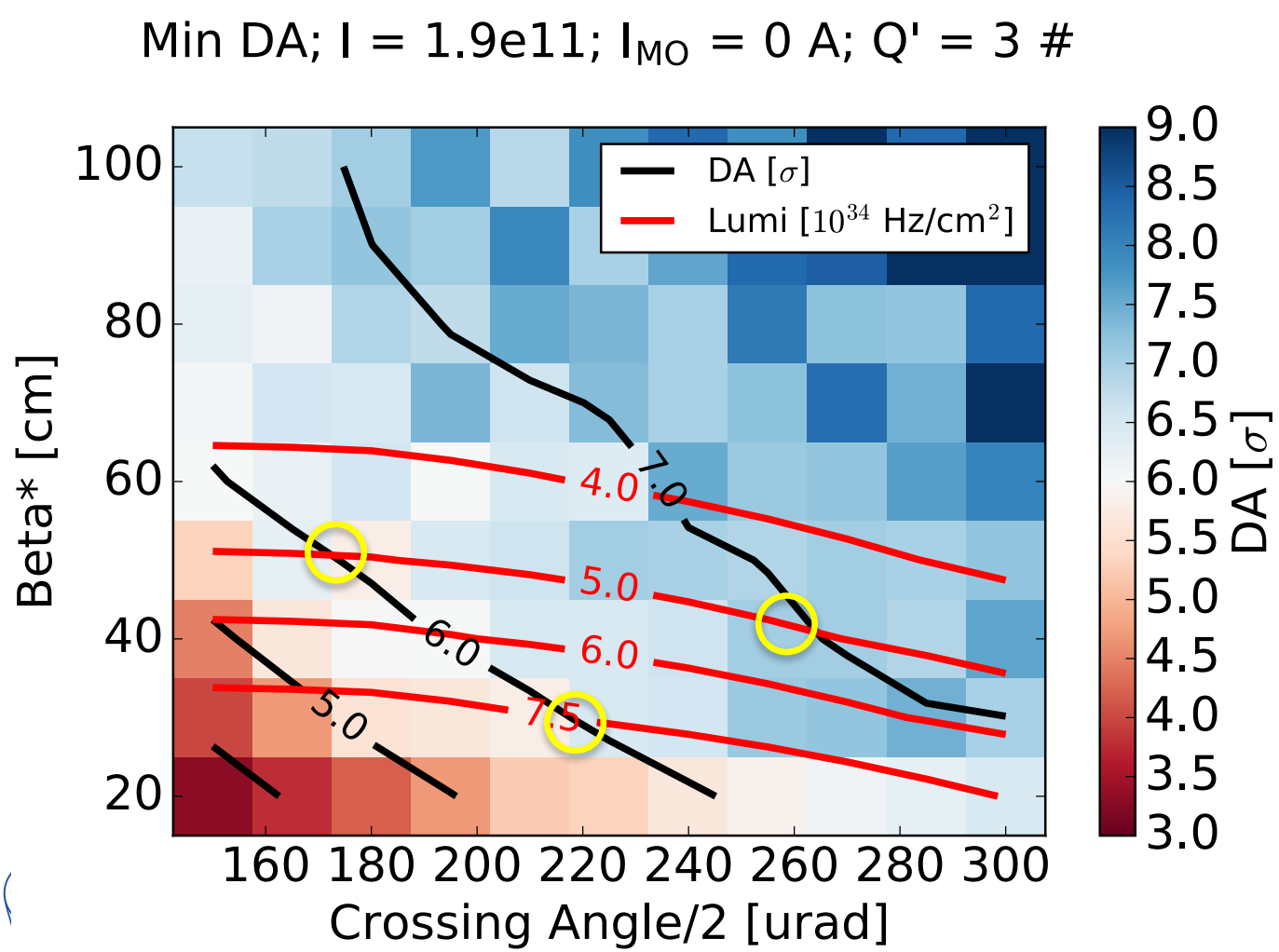

During levelling, N_b = 1.6 x 10^{11}

- Full crossing angle could remain at 340 µrad (~11 σ separation @ 35 cm β*), keeping the 6 σ DA and the luminosity at 5 x 10^{34} cm^{-2} s^{-1}
- For 7.5 x 10^{34} cm^{-2} s^{-1}, a DA of 6 σ is obtained with a crossing angle of 430 µrad (10.5 σ @ 20 cm, i.e. reaching the end of β* levelling)

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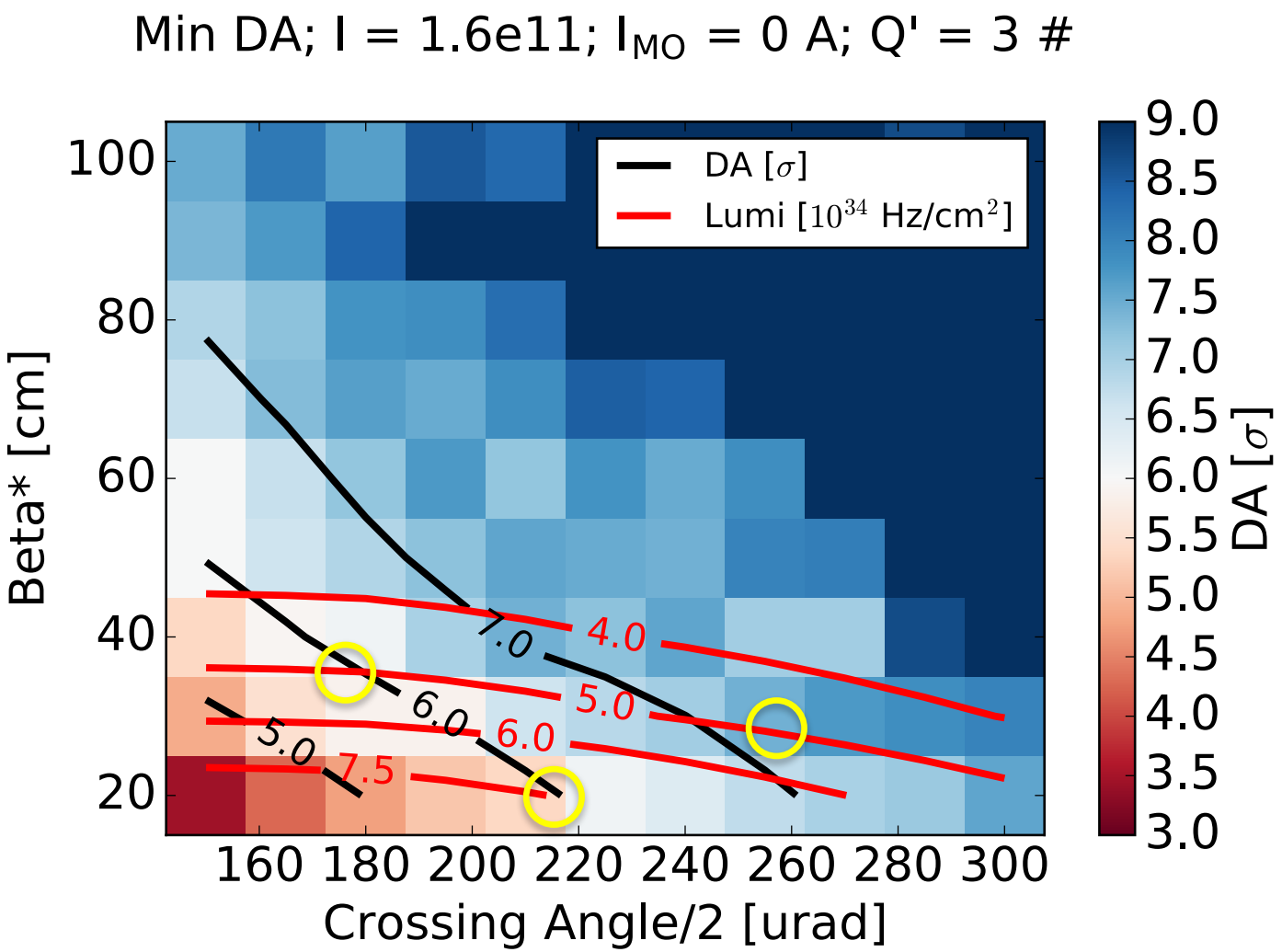

End of levelling, N_b = 1.275 x 10^{11}

- Full crossing angle should be increased to 380 µrad (~9.3 σ separation @ 20 cm), keeping 6 σ DA and luminosity of 5 x 10^{34} cm^{-2} s^{-1}

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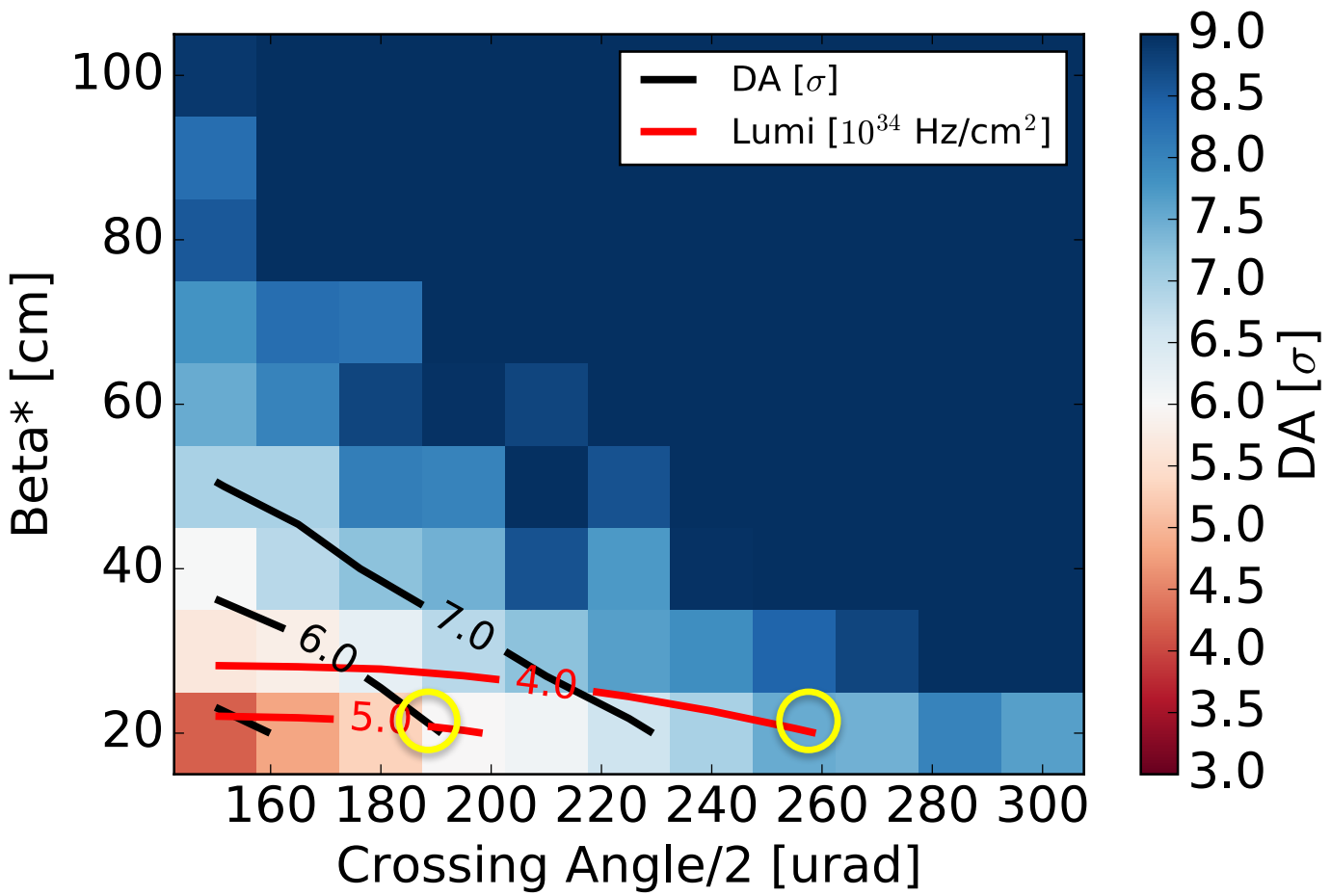
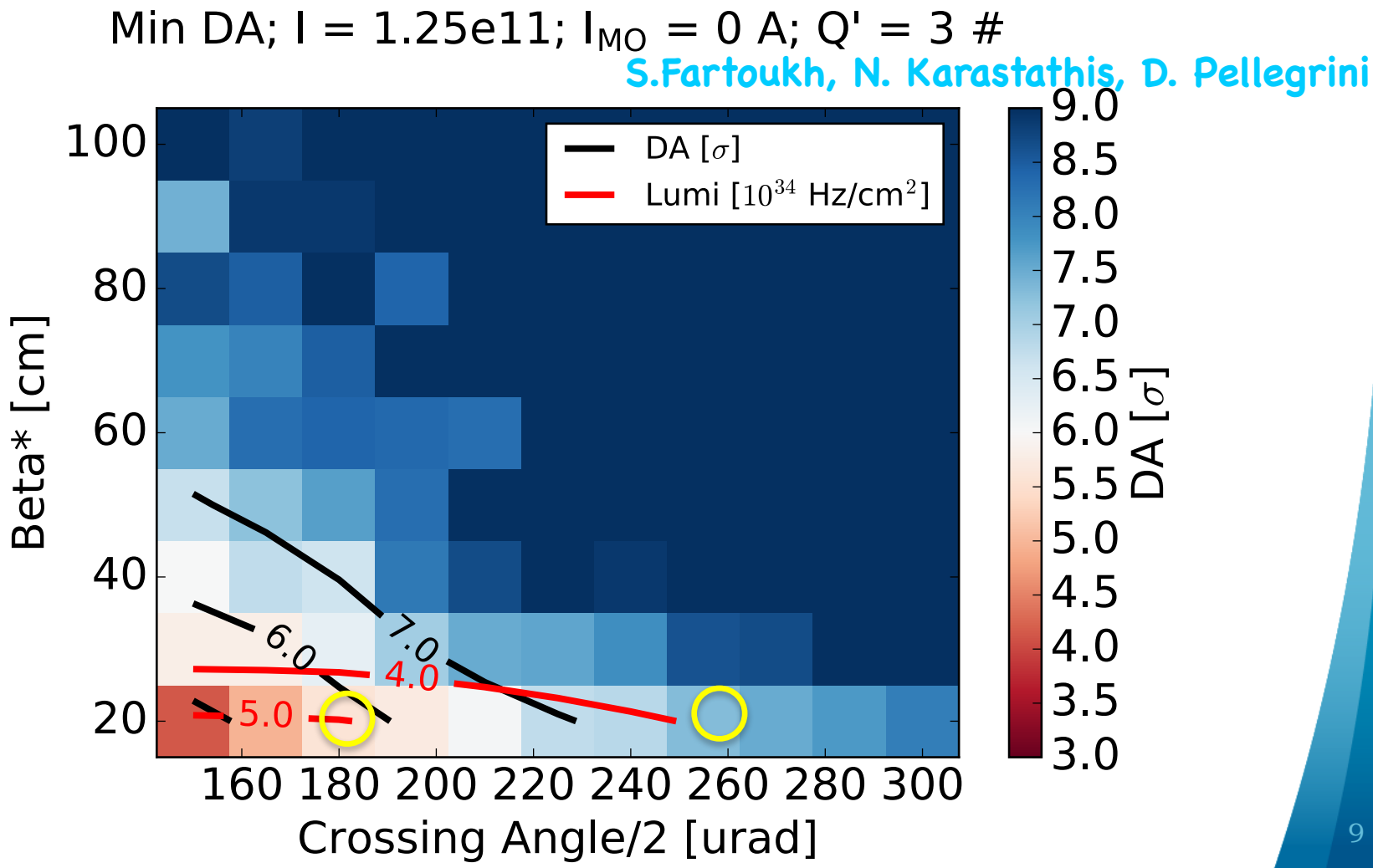


Extra levelling, N_b = 1.25 x 10^{11}

- Some extra levelling time can be gained by levelling with the crossing angle at DA close to 6 σ and constant β* of 20 cm



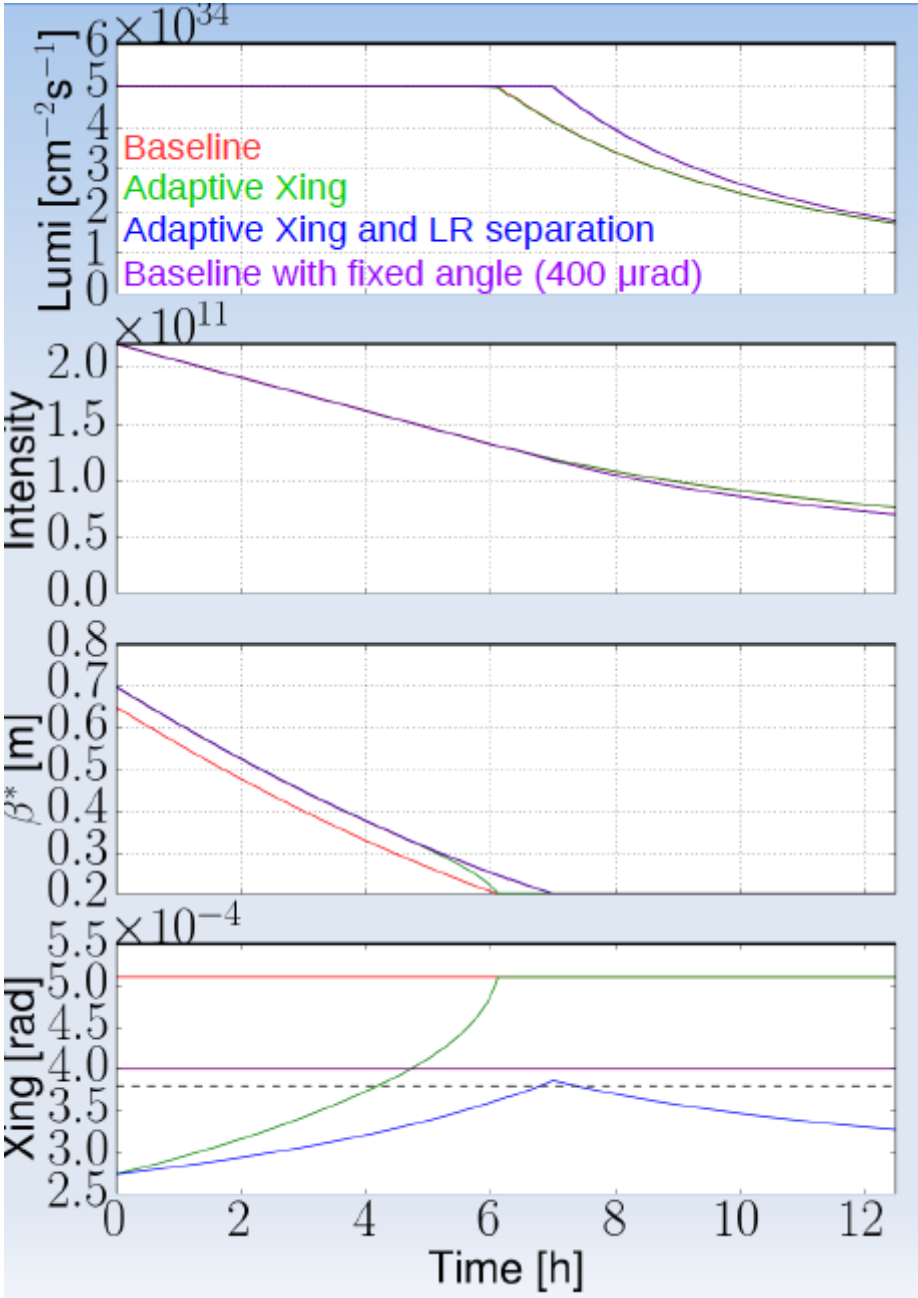
A few remarks

- Crossing angle can be reduced during levelling to 6 σ DA, reducing pile-up density and triplet irradiation
- Full crabbing can be achieved with two cavities (max kick of 380 μrad) for currents < 2 x 10^{11} almost through the whole levelling process
- Some small leveling time (and performance) can be gained @ 20 cm, by levelling with the crossing angle
- Need to complement the DA simulations down to 15 cm especially for the ultimate scenario and span also lower crossing angles

Performance

- Estimate impact in integrated luminosity and pile-up density for nominal and ultimate, for mentioned “crossing adaptive levelling”

X. Buffat, HL-LHC meeting 2016



Separation levelling N_b = 2.2 x 10^{11}

- β* kept constant while levelling the luminosity by separation
- For 5 x 10^{34} cm^{-2} s^{-1}, the leveling could start at 1.8 σ separation with a large crossing angle of 550 µrad (13.4 σ)
- For 7.5 x 10^{34} cm^{-2} s^{-1}, the leveling could start at 1.2 σ with a crossing angle of 580 µrad (14.2 σ)

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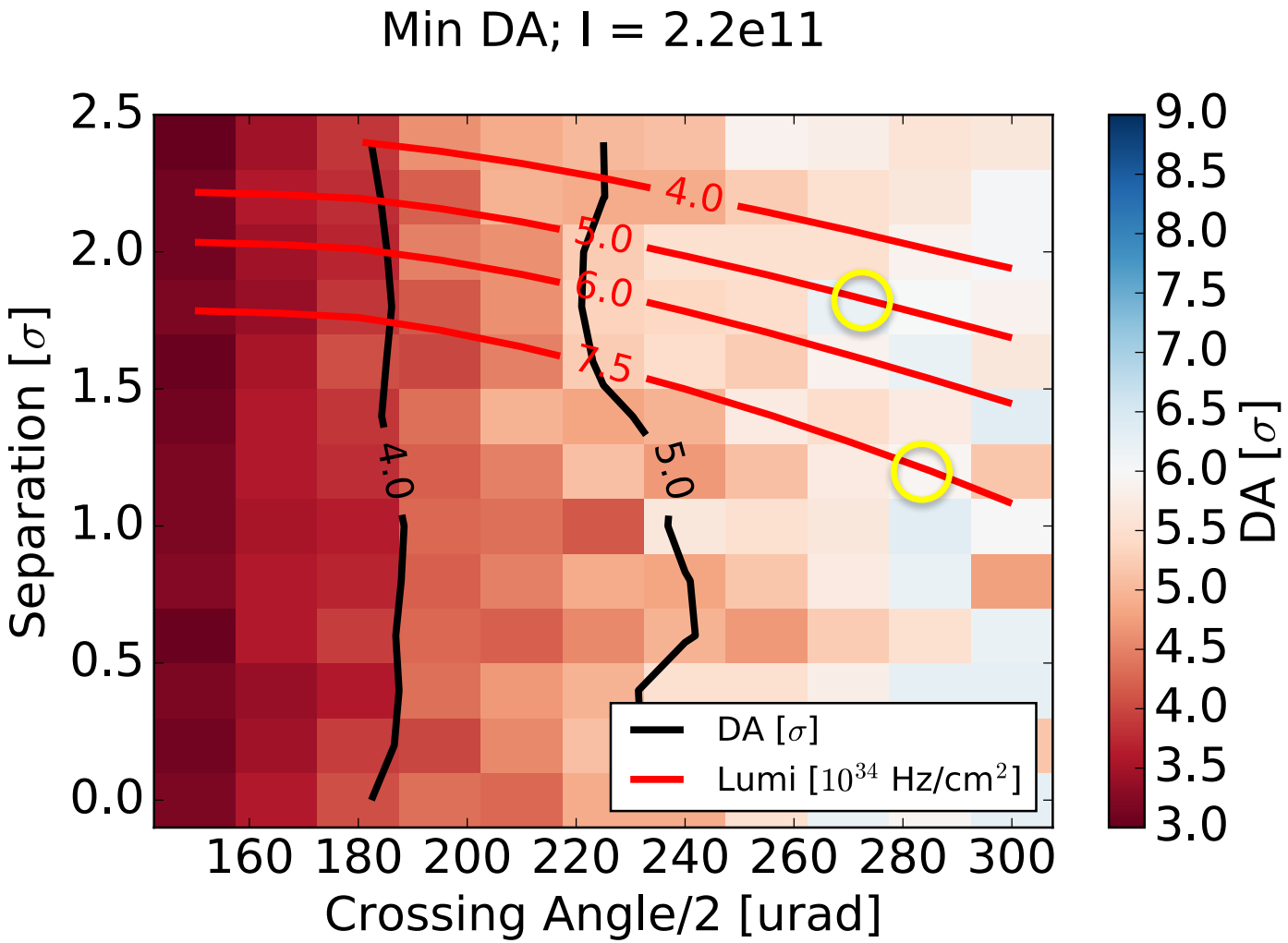

Separation levelling N_b = 1.9 x 10^{11}

- DA seems quite independent on separation
- For both nominal (1.6 σ separation) and ultimate (1 σ separation), a crossing of 500 μrad (12.2 σ) maintains DA

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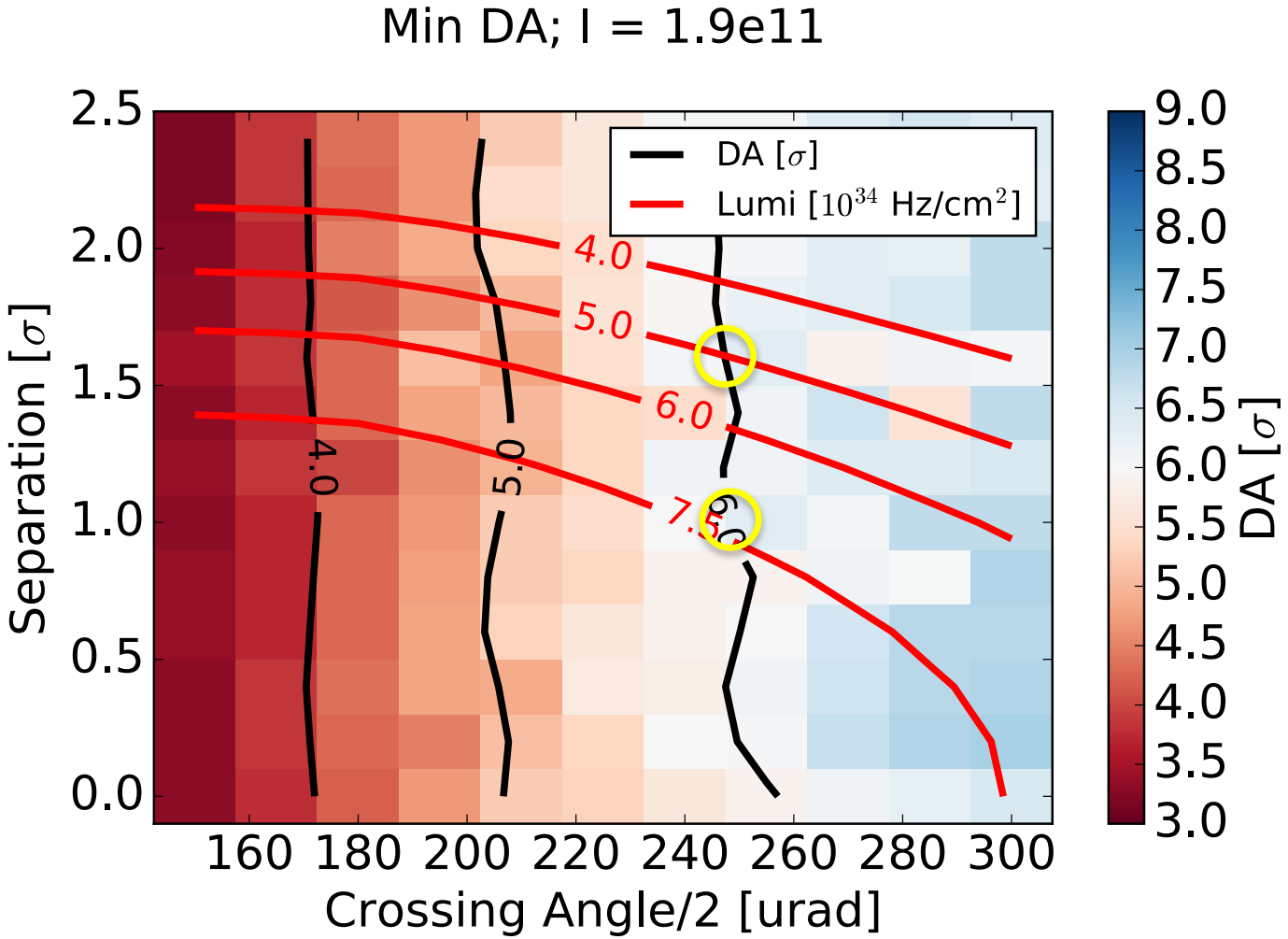

Separation levelling N_b = 1.6 x 10^{11}

- DA seems again quite independent on separation
- For 5 x 10^{34} cm^{-2} s^{-1}, the leveling could continue with a 1.2 σ separation with a crossing angle of 450 μrad (11 σ)
- For 7.5 x 10^{34} cm^{-2} s^{-1}, the leveling can stop @ a crossing angle of 440 μrad (10.8 σ)

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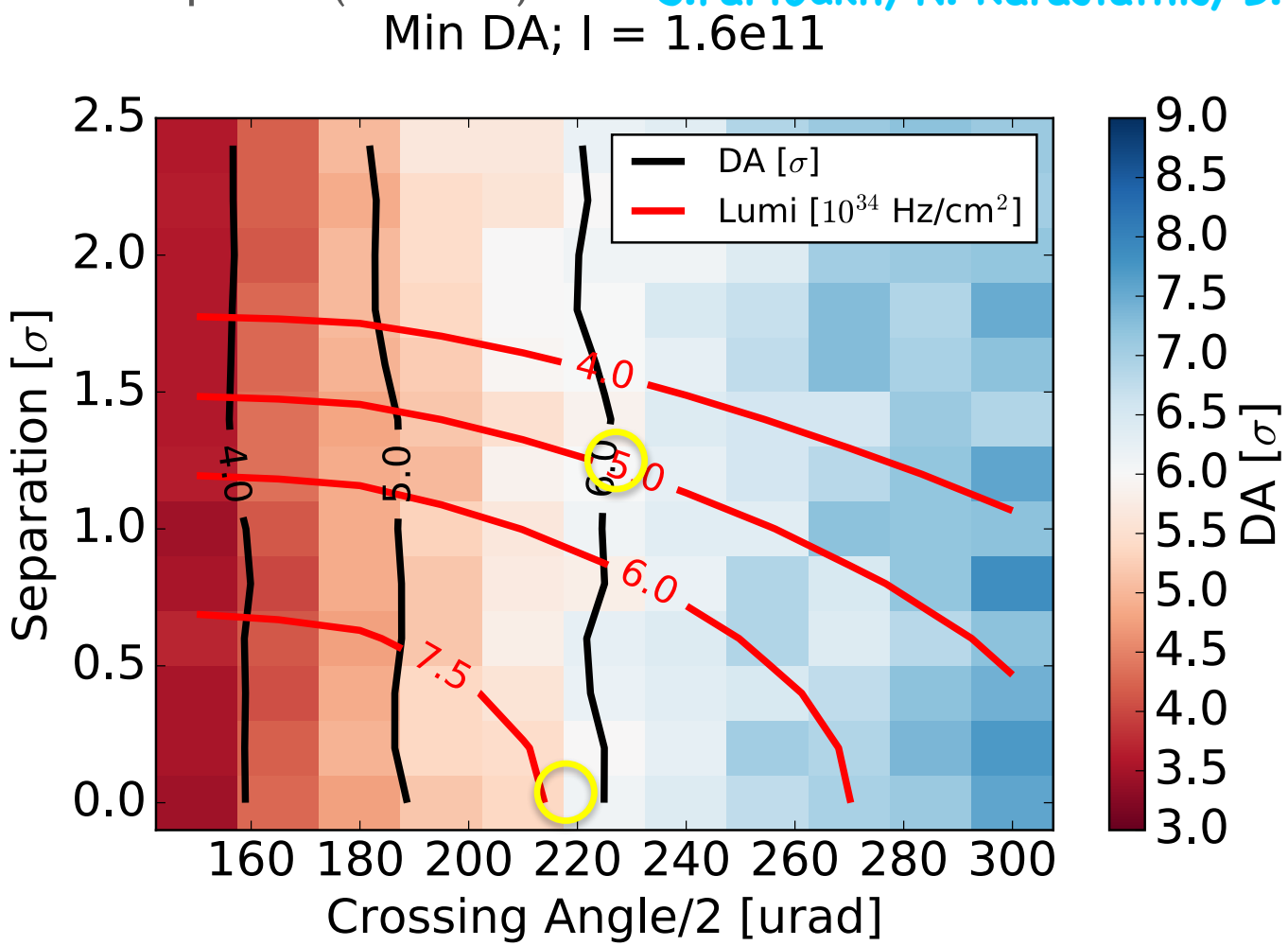

Separation levelling N_b = 1.275 x 10^{11}

- Separation levelling for nominal scheme ends @ 380 µrad (~9.3 σ)

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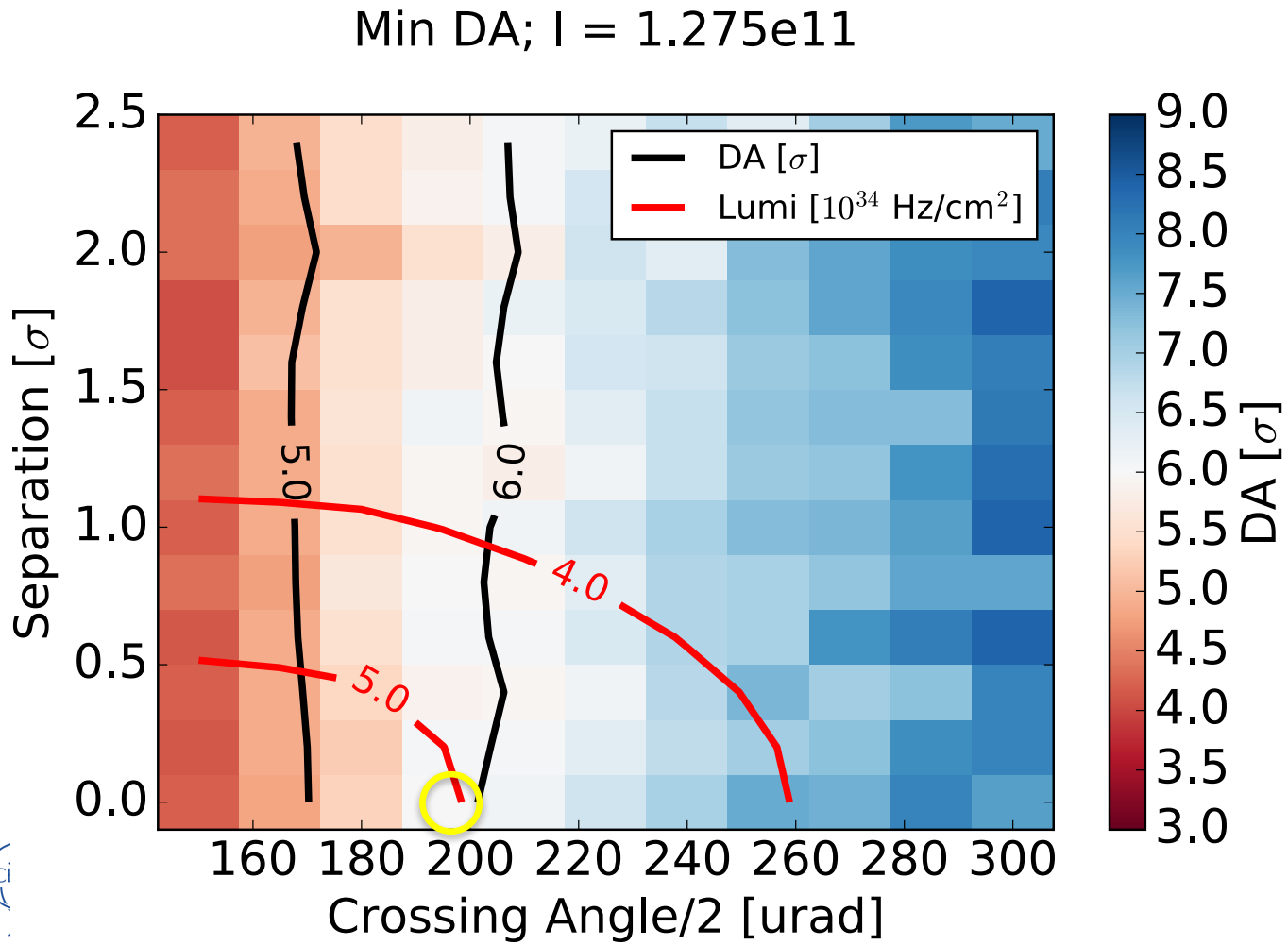

Separation levelling N_b = 1.2 x 10^{11}

- The same crossing angle levelling scheme can be pursued as before to gain some extra levelling time and optimize performance

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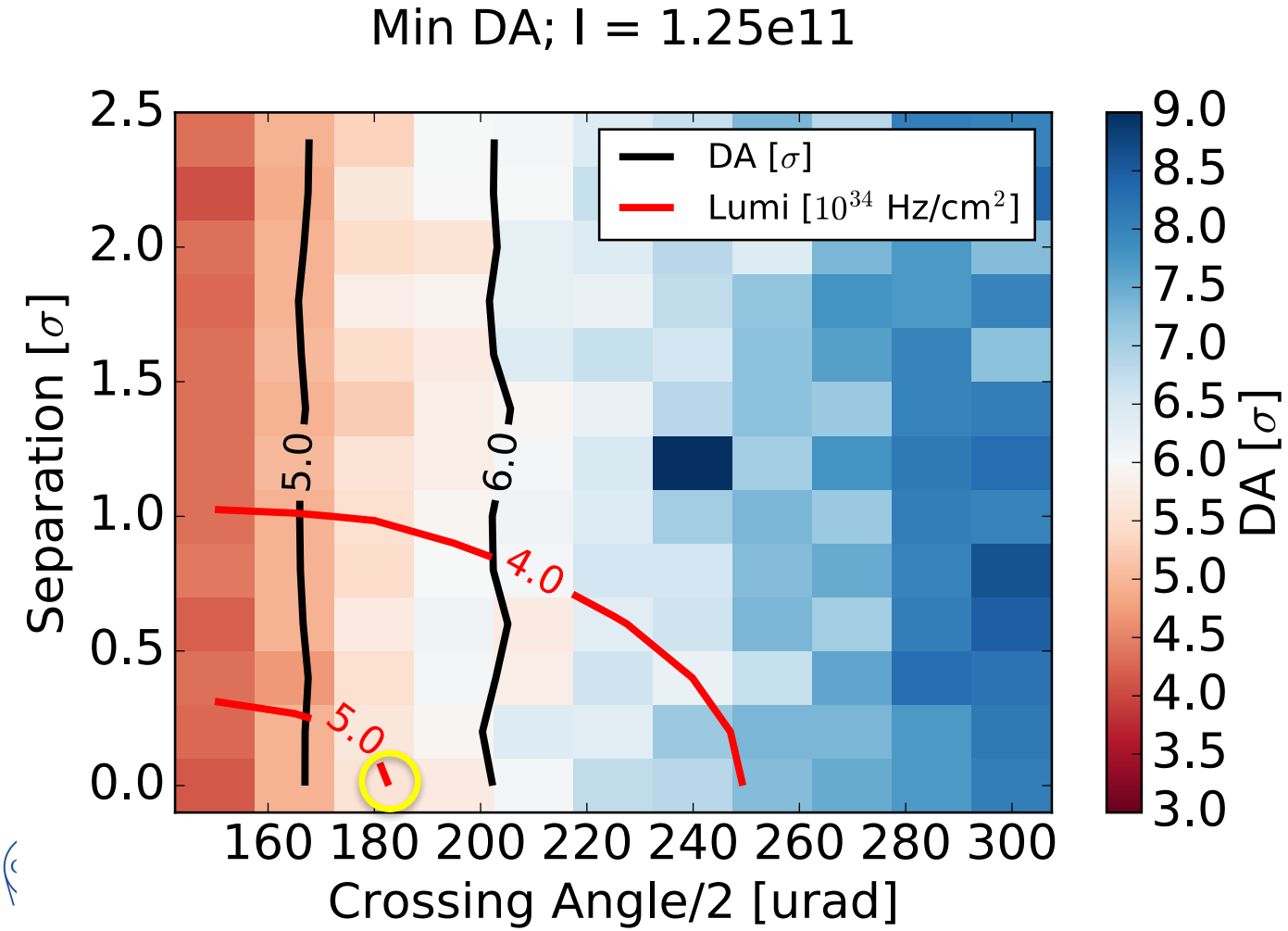
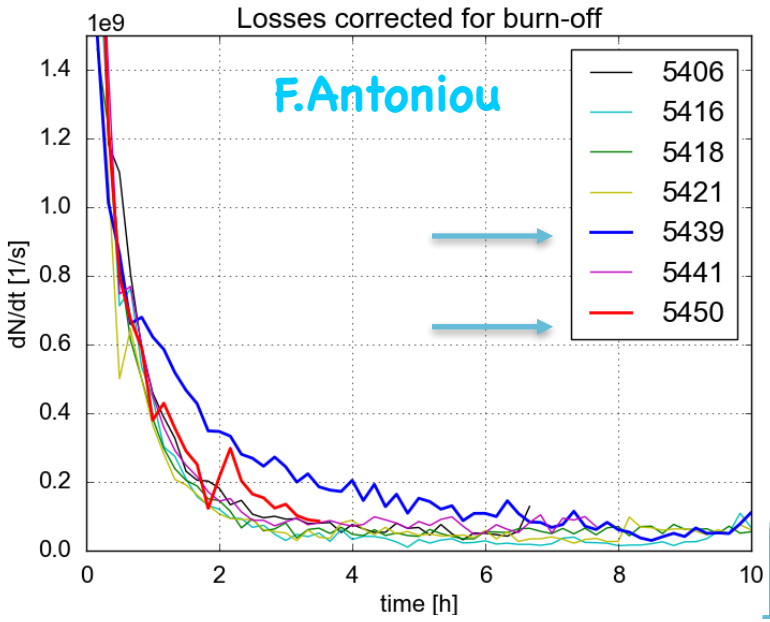
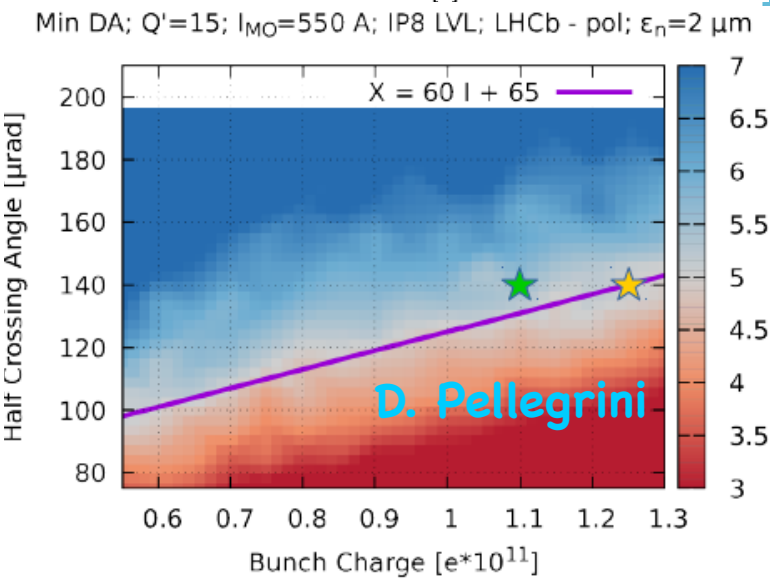


Levelling experience in 2016

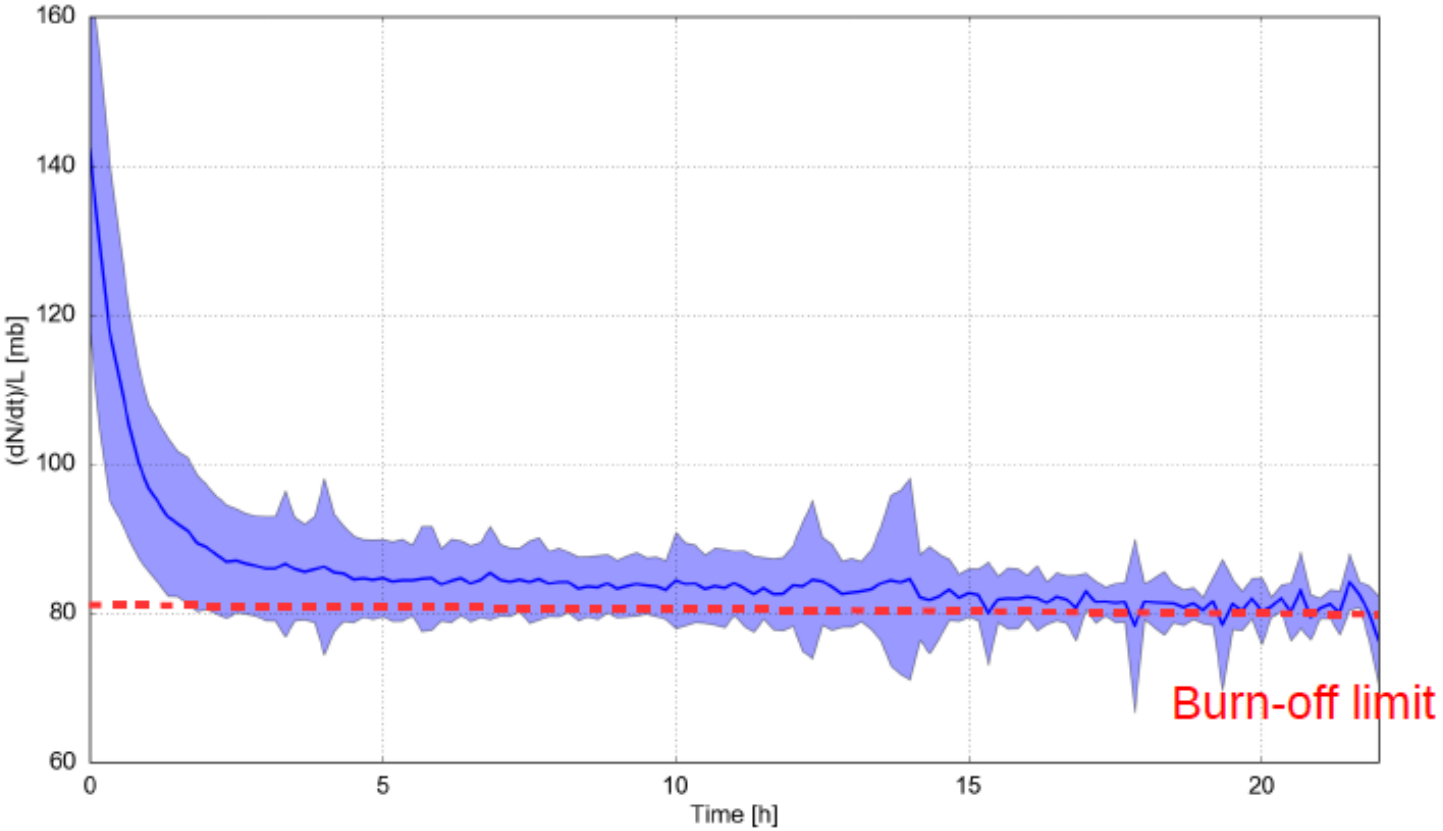
- **Levelling** by **separation** demonstrated in test fills during 2016
  - **Fine tune** adjustments and **reduction** of **octupoles/chromaticity** necessary to improve lifetime during levelling
- Satisfying possible request of **experiments** or when reaching **cryogenics' limit**
- **Changing X-angle** from fill-to-fill (adapt **H/V emittance ratio** or **increase** peak **luminosity**) or **levelling** during stable beams (range of 60 µrad in X/2-angle)





Beam losses

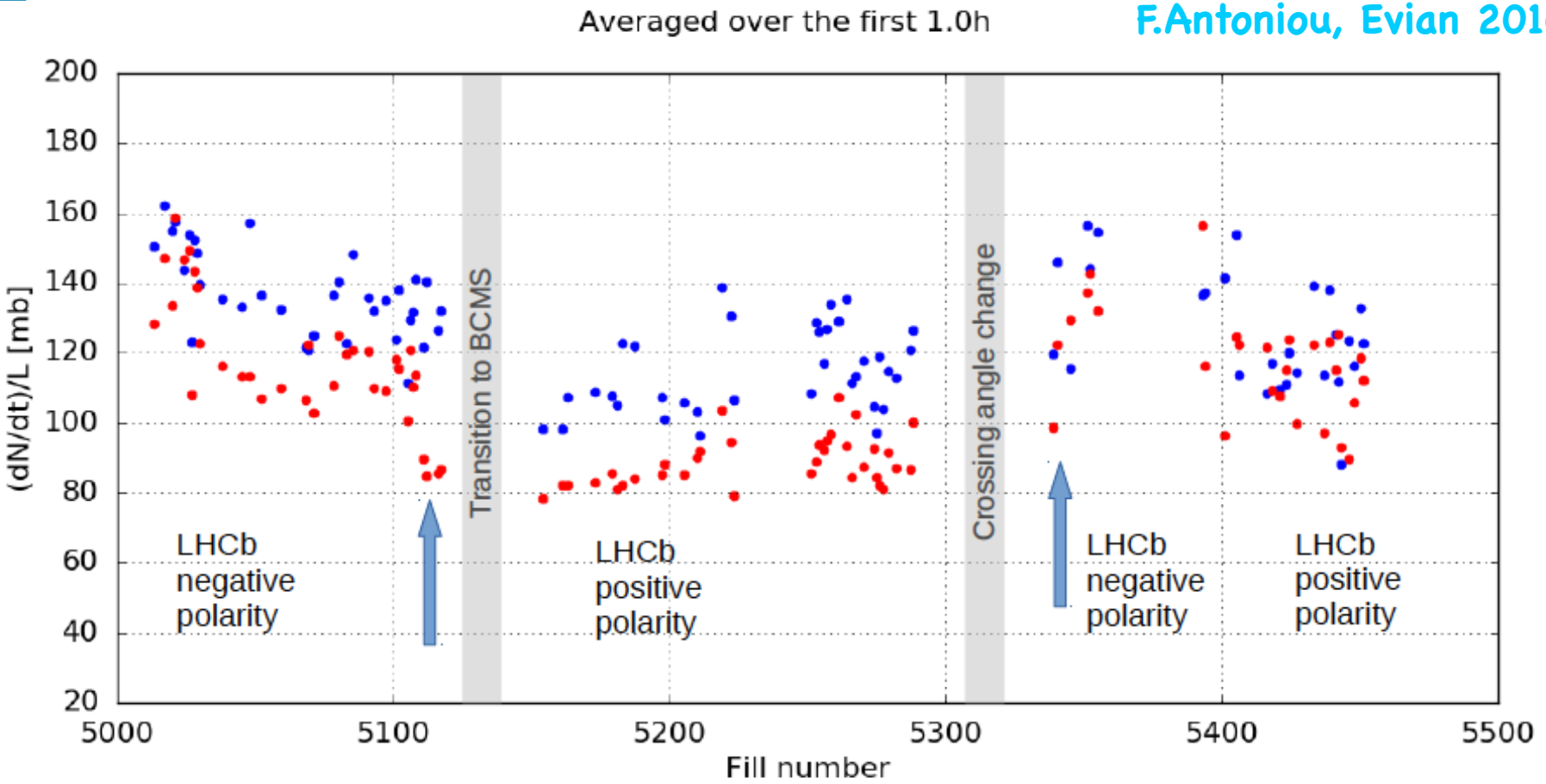
F.Antoniou, Evian 2016



- Normalized loss rate for all fills
- Losses on-top of Burn-off were observed for many fills
- Mainly the first 3h and then become burn off dominated

Beam losses

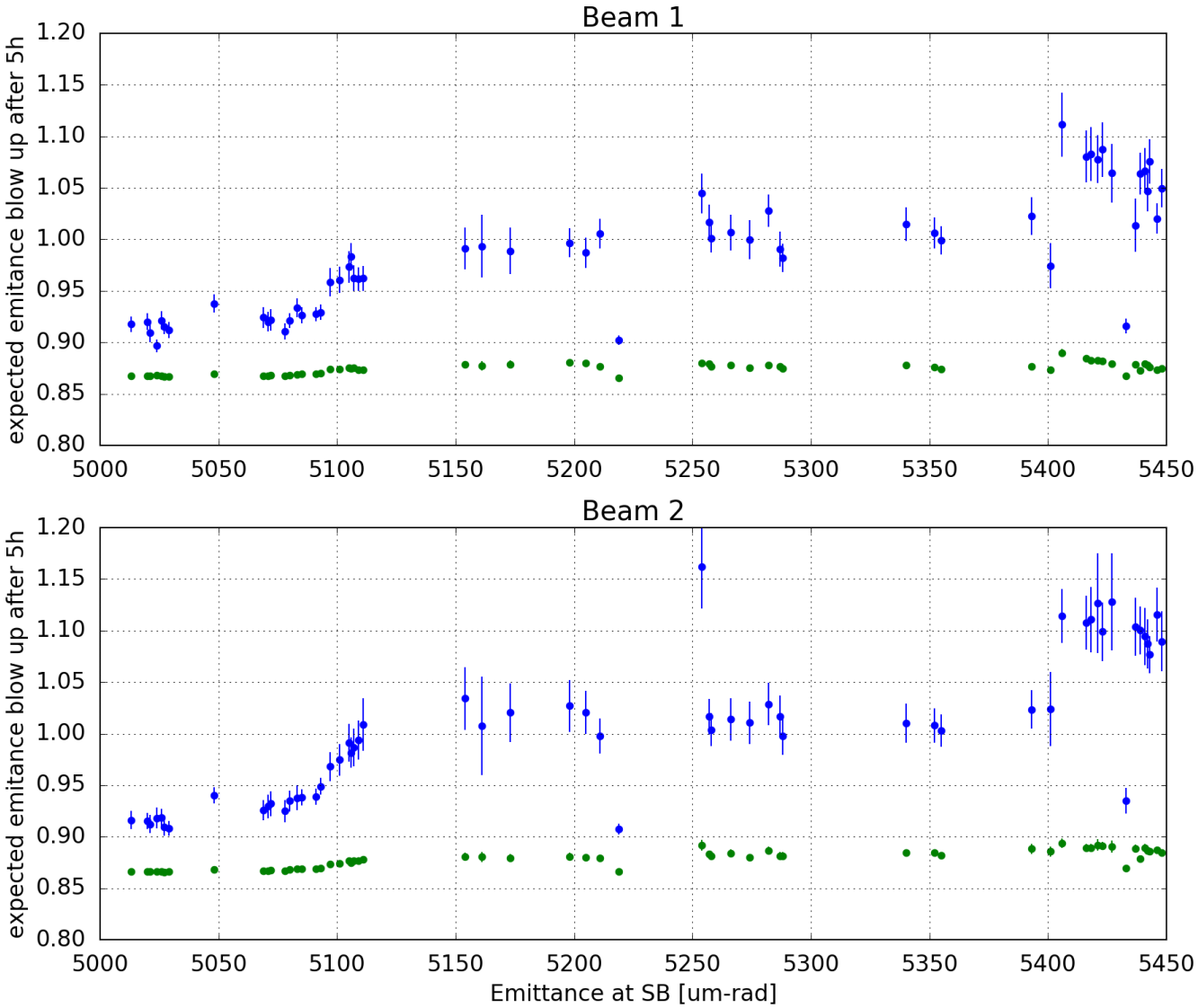
F.Antoniou, Evian 2016



- Evolution of the average normalized losses (after one hour in SB) along the run
- Beam 1 losses higher than Beam 2 losses
- Minimum losses after the transition to BCMS (Beam 2 losses become burn-off dominated)
- Increase of losses after the crossing angle change followed by an improvement trend
- Clear impact of the LHCb polarity changes

Expected Emittance blow-up

F.Antoniou



Observed Emittance blow-up

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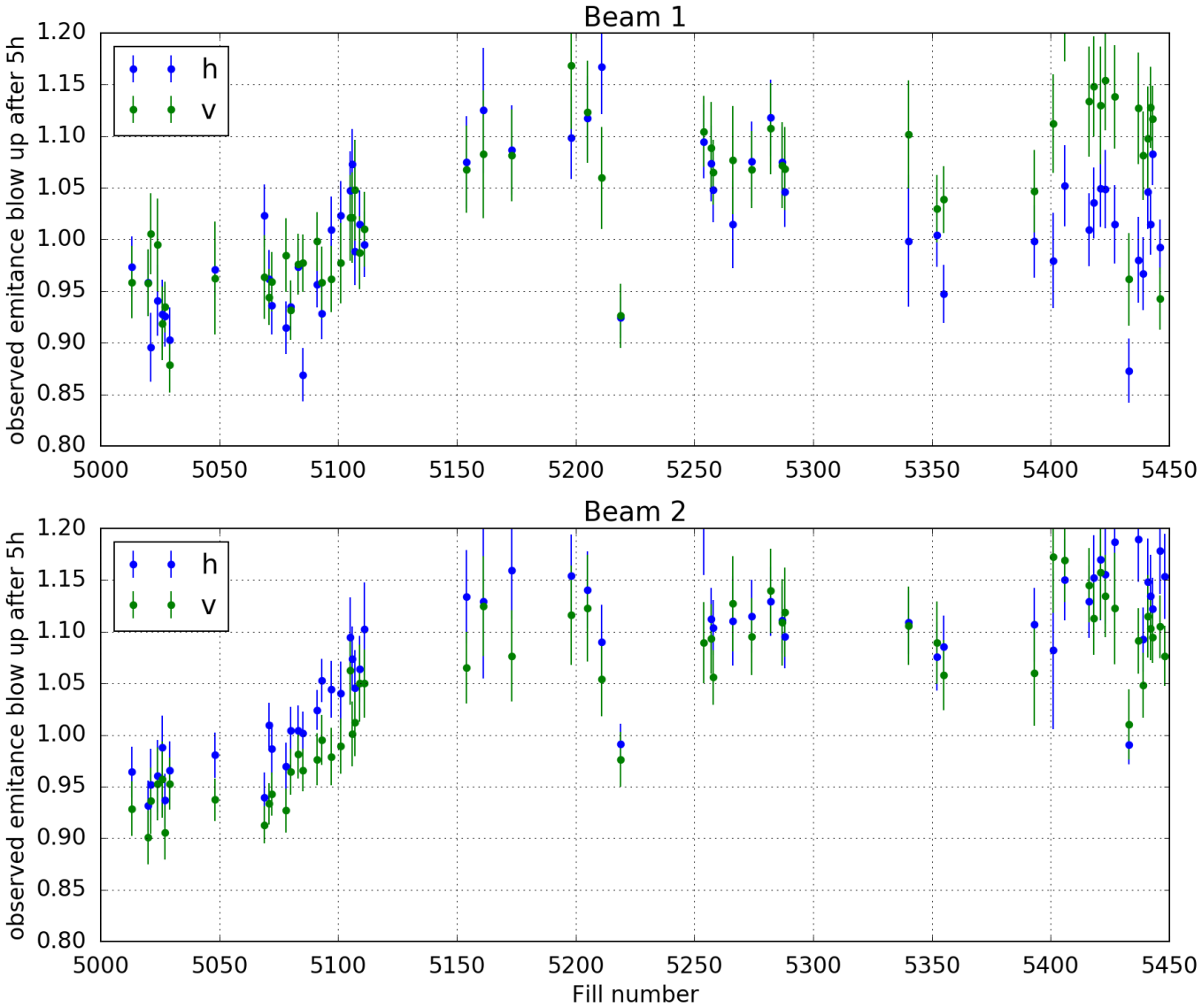

Observed Emittance blow-up

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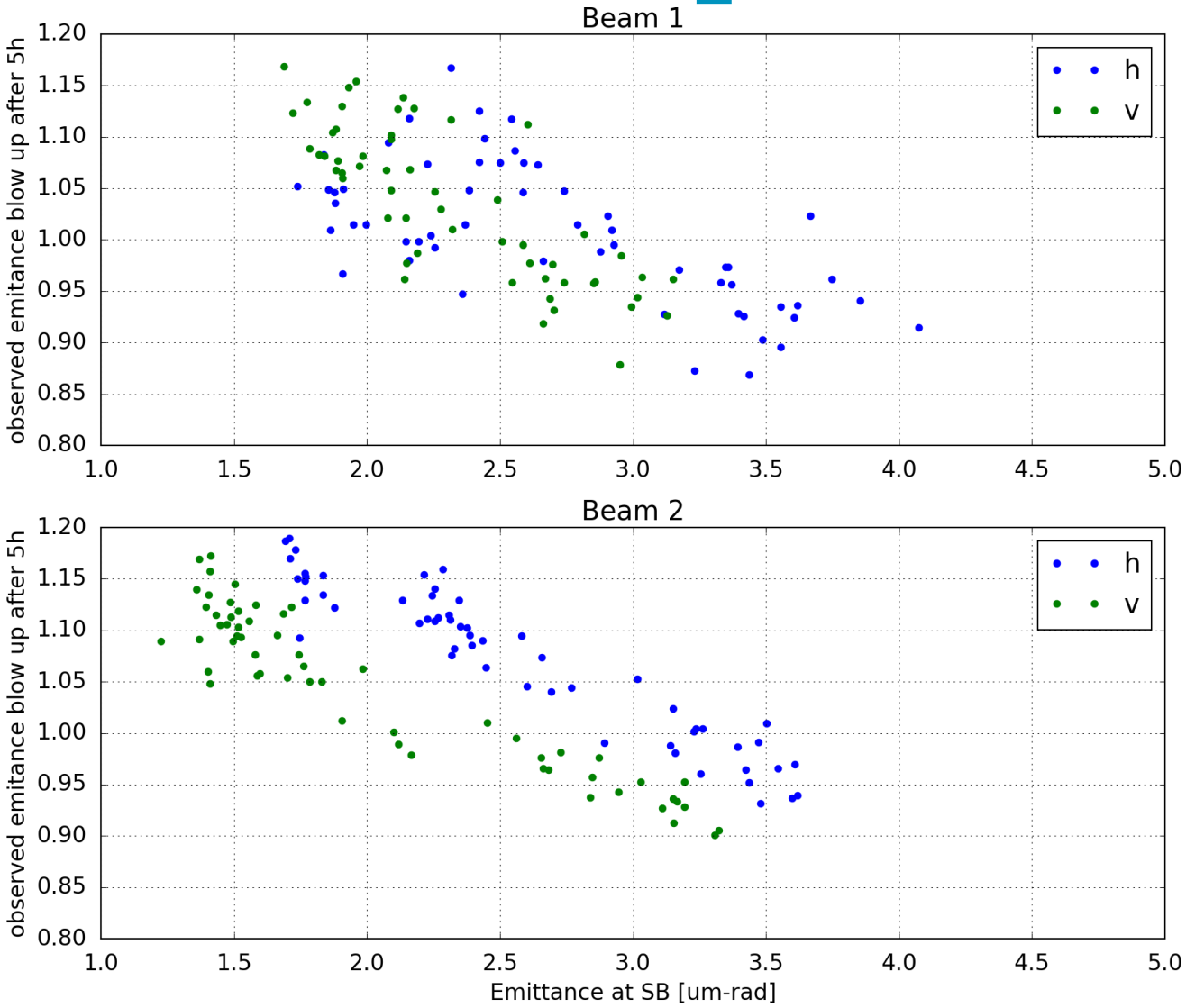
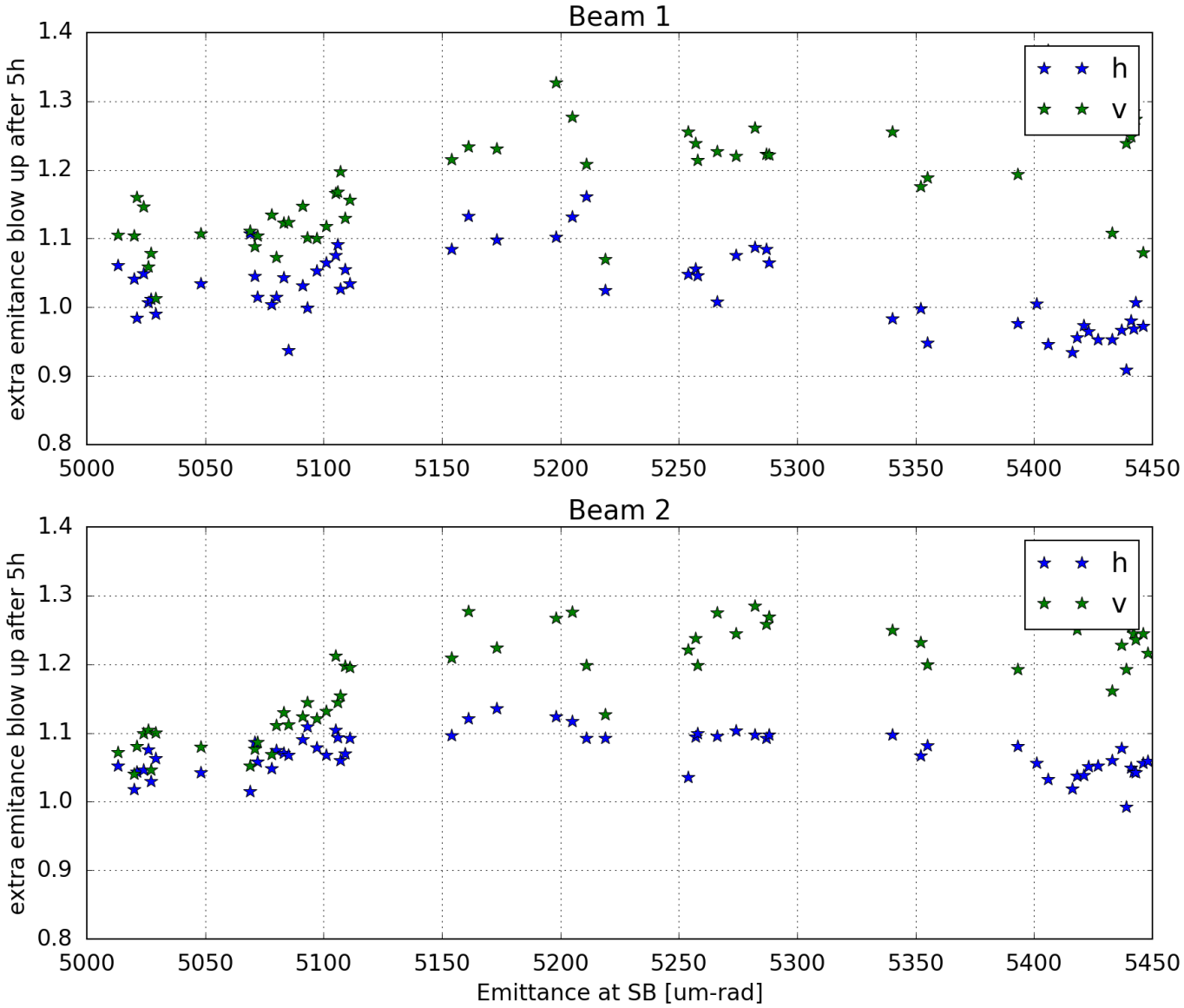


Extra Emittance blow-up



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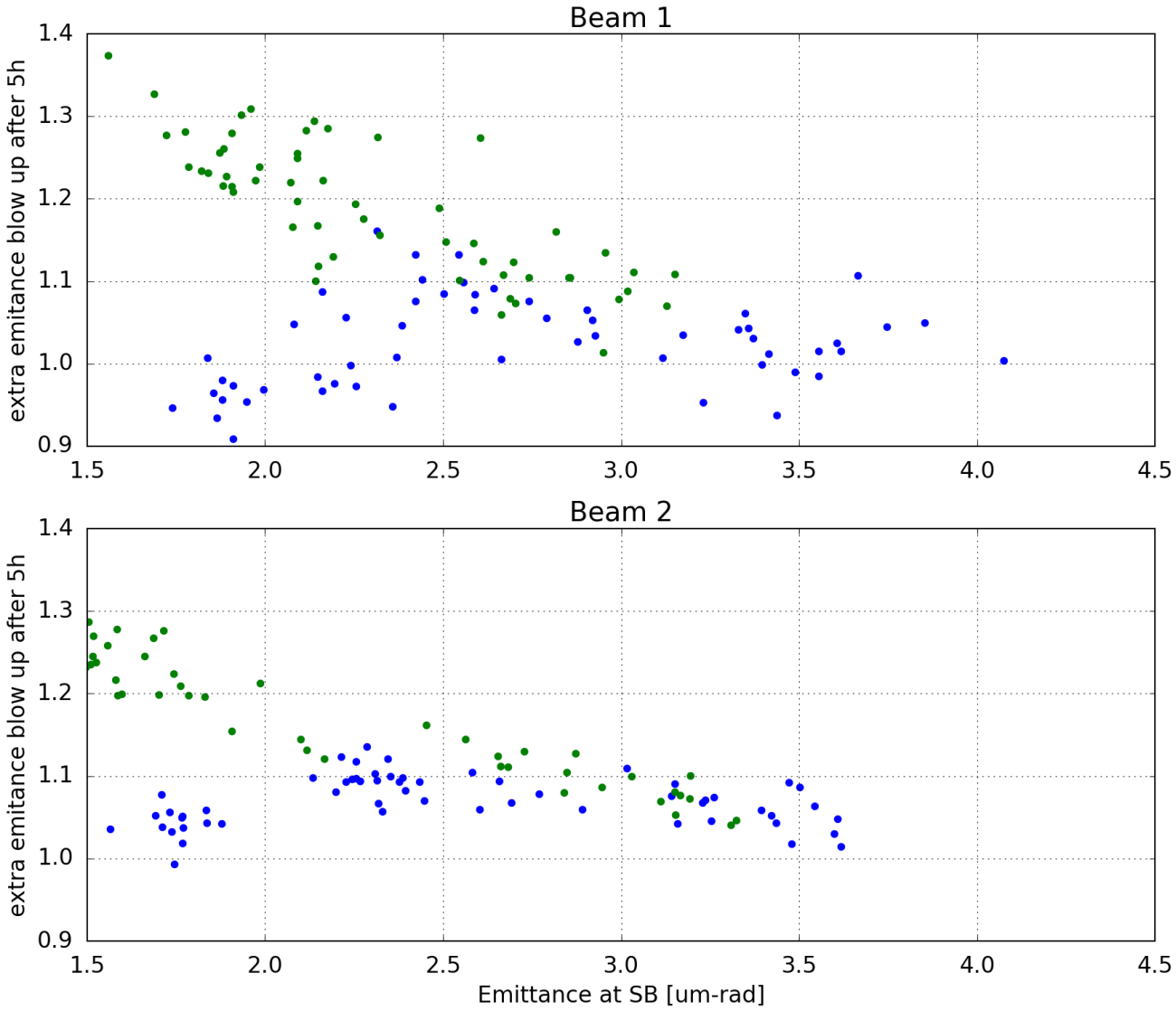
Extra Emittance blow-up



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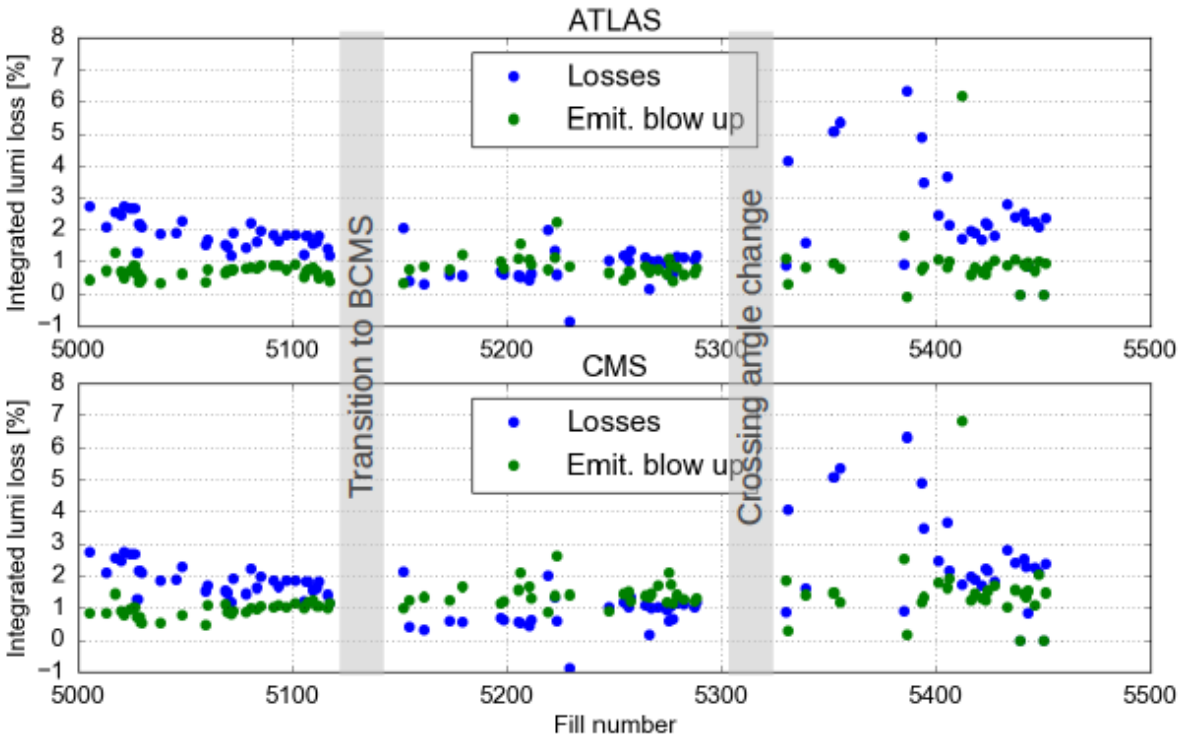
Luminosity loss



- The integrated luminosity over the first 3h is calculated for each model assumption
- Integrated luminosity loss due to:
  - **extra losses**:
  - **extra emittance blow up**

➔ Contribution of the extra **emittance blow-up** is **constant** over the year

➔ Contribution of extra **losses** is **sensitive to changes in the machine**

Availability

Remarks

- Based on observation from 2016
  - Estimate luminosity evolution for HL-LHC scenarios by assuming an extra blow-up growth rate based on the data
    - Correlated with brightness?
  - Including realistic evolution from injection to stable beams
  - Including availability observed in 2016

Impact of LHCb polarity - octupoles

Effect of octupoles and LHCb

- Tune scans for **550A octupole** and LHCb on with good polarity, end of levelling parameters, nominal scheme
- DA quite limited…

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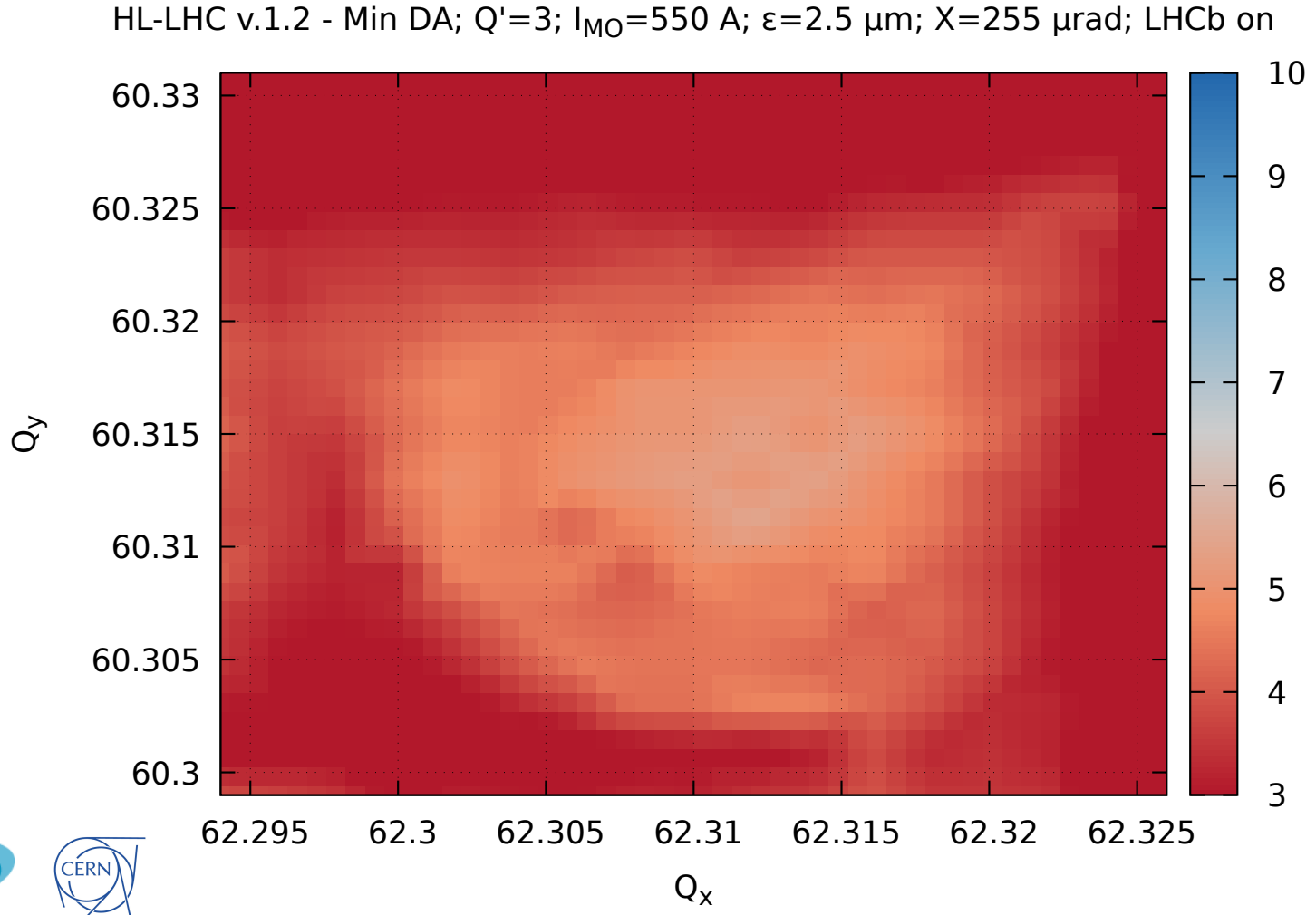

Effect of octupoles and LHCb

- Tune scans for **0 octupole** and LHCb on with good polarity, end of levelling parameters, nominal scheme
- Recovering DA towards the diagonal

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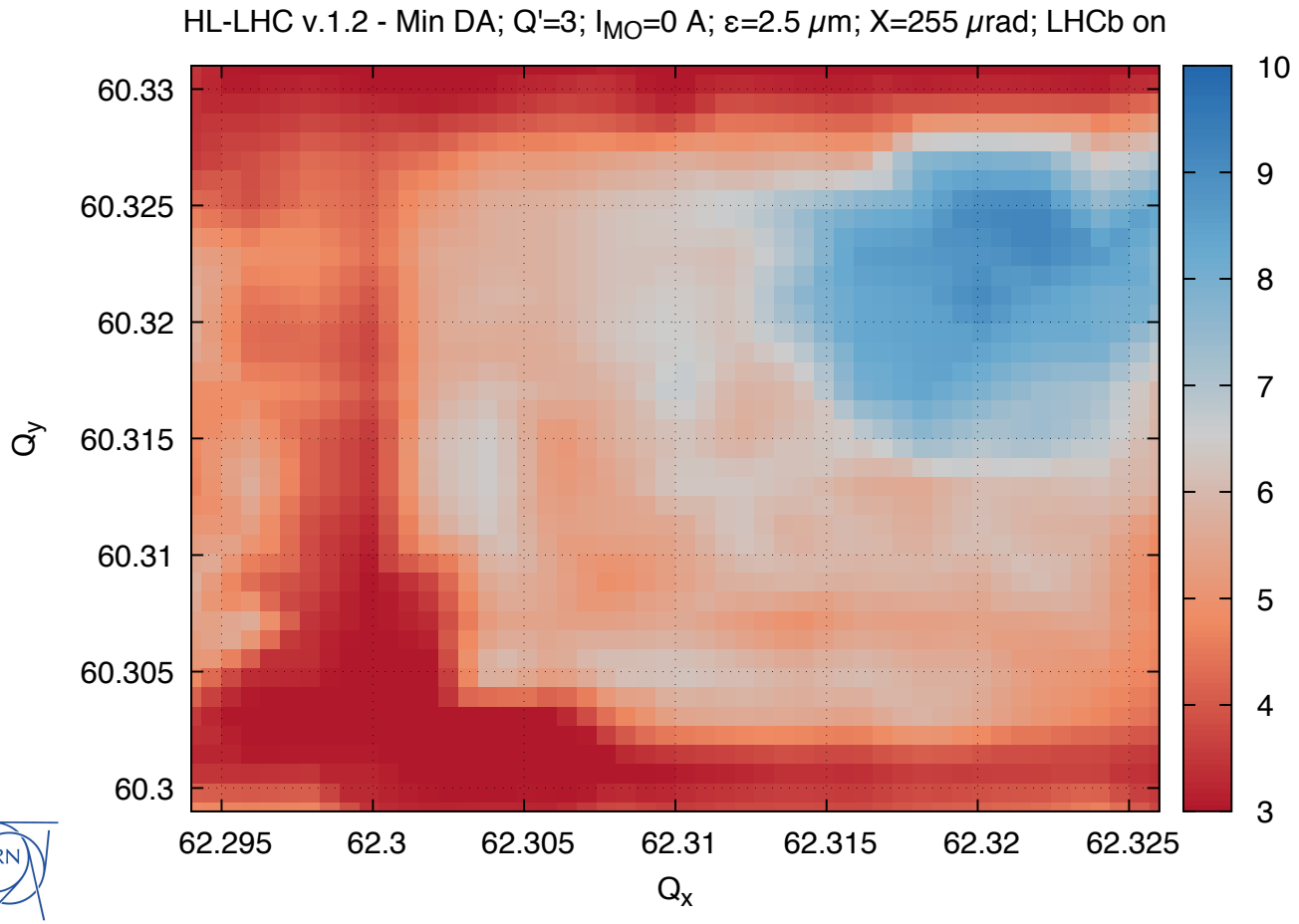

Effect of octupoles and LHCb

- Tune scans for **-550 octupole** and LHCb **off**, end of levelling parameters, nominal scheme
- DA even more improved

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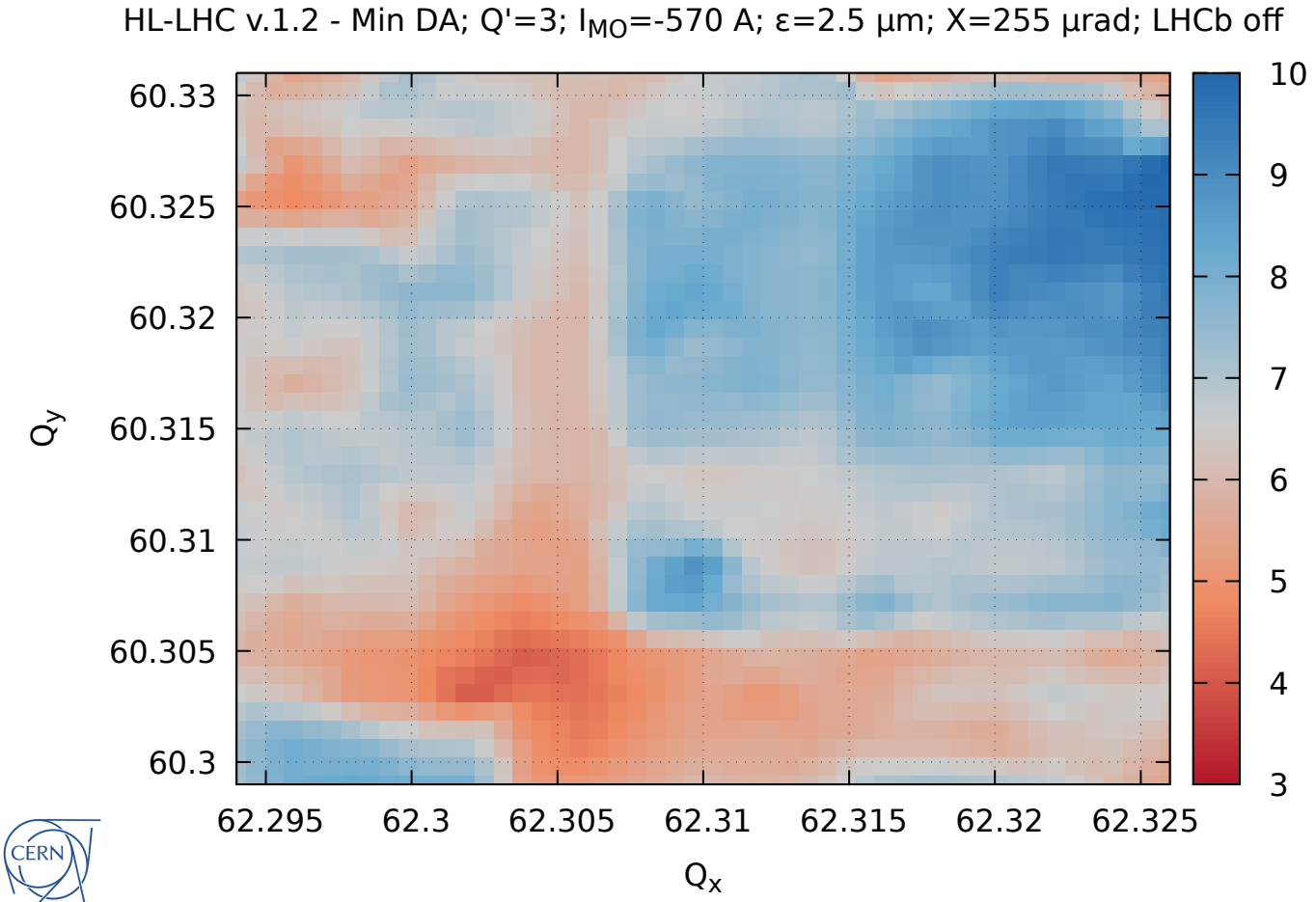
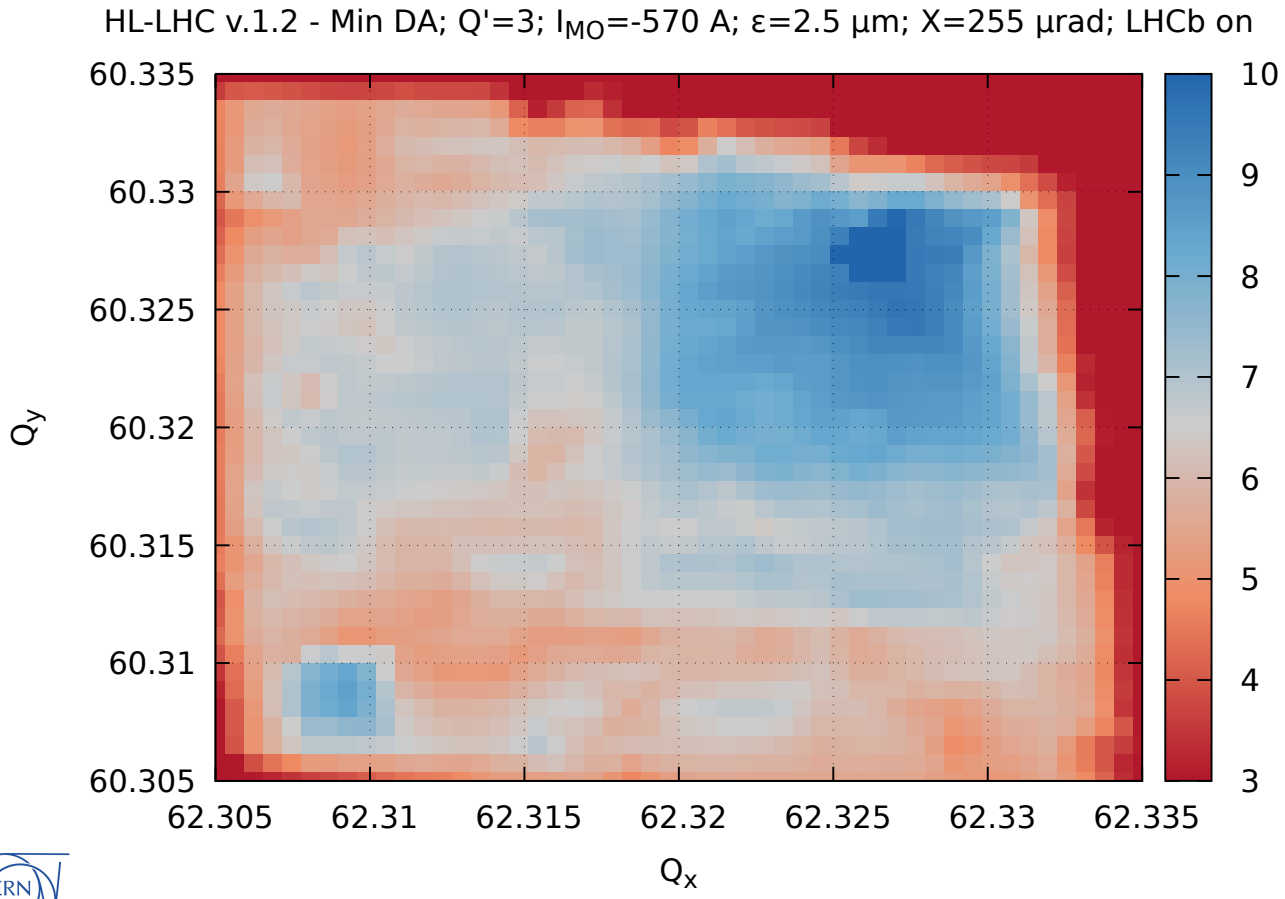


Effect of octupoles and LHCb

- Tune scans for **-550 A octupole** and LHCb **on**, with "**good polarity**" end of levelling parameters, nominal scheme
- DA degraded especially close to 3rd and 10th order resonances

N. Karastathis, D. Pellegrini



Effect of octupoles and LHCb

- Tune scans for **-550 A octupole** and LHCb **on**, with "**bad polarity**" end of levelling parameters, nominal scheme
- DA degraded mostly close to 10th order resonances

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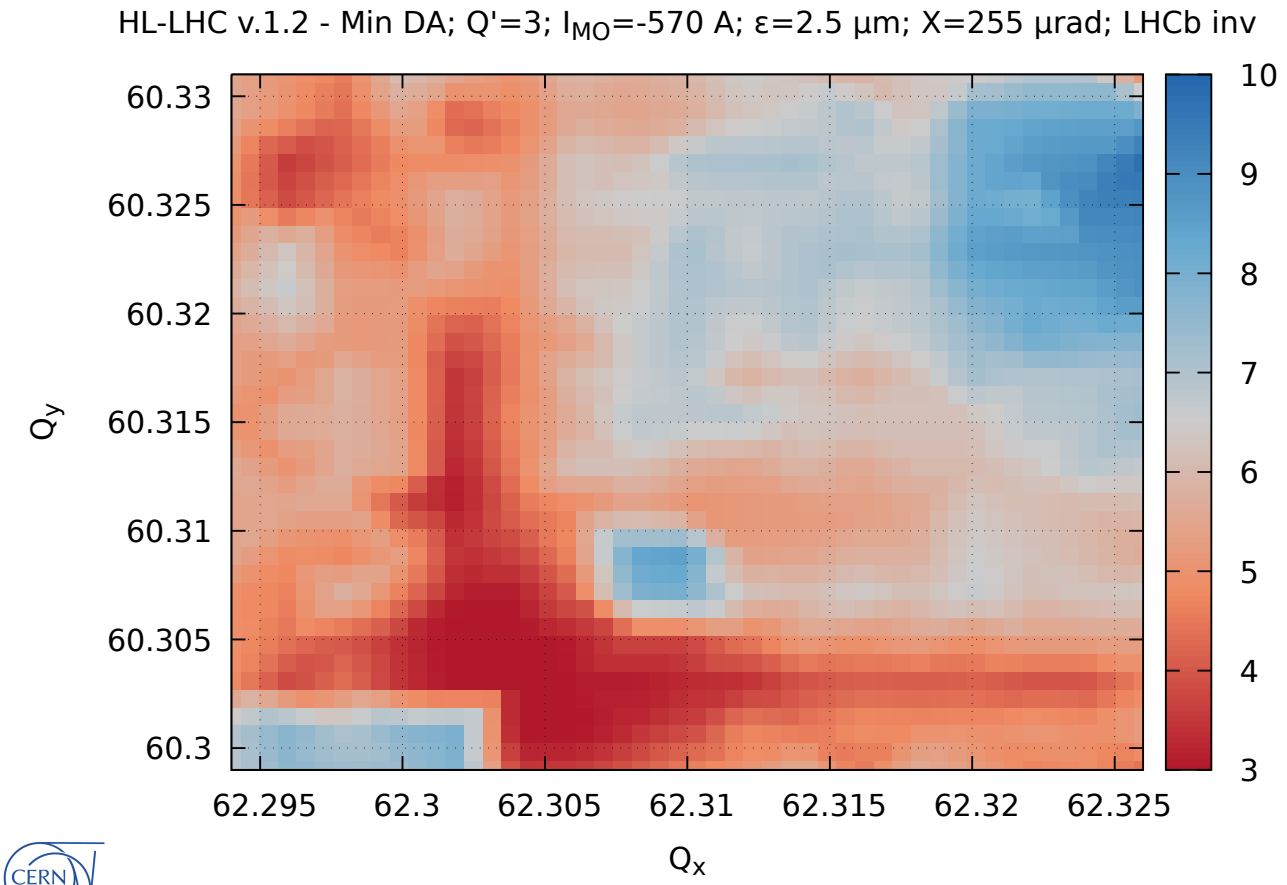

Summary

Thanks for your attention