7th Evian Workshop

Evian, December 13-15th, 2016

Scenarios for 2017 and 2018

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with input from
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Hostettler, G.Iadarola, E.Metral, D.Pellegrini, M.Pojer,
S.Redaelli, G.Rumolo, C.Schwick and R.Tomas

Scenarios (in stable beams)

- Injectors' reach
    - Train composition
- Optics and collimation
    - β* choice, nominal vs ATS
- Heat-load and e-cloud
- Instabilities
    - Octupole and chromaticity
- Beam-beam
    - Crossing angle
- Scenarios for 2017 (and 2018)
    - Performance comparison
    - Standard vs BCMS

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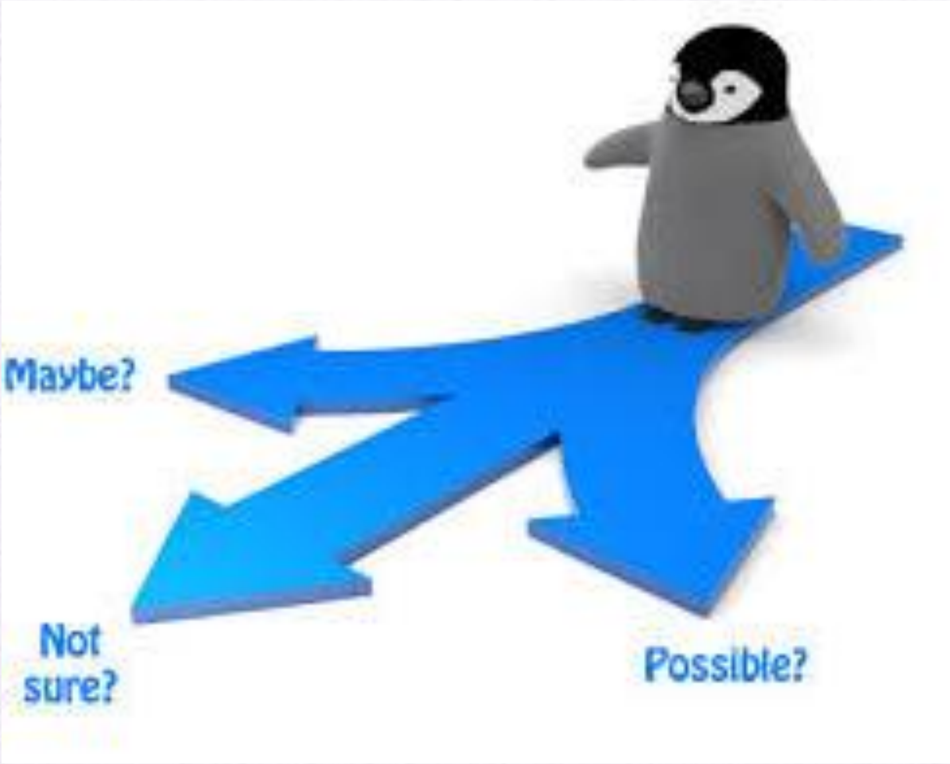
Evian preparation meetings 2016:
https://indico.cern.ch/event/591787/
https://indico.cern.ch/event/593347/



Injectors reach

H.Bartosik

- Intensity @ SPS extraction
  - Standard and BCMS: 1.15–1.30 x 10^{11} p ~4 % of losses → **1.25 x 10^{11} p** @ stable beams

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- ❑ Emittances @ SPS extraction
  - ❑ Standard: 2.5 (2.4) - 2.8 (2.7) μm → ~20-30 % of blow-up → [illegible] @ stable beams
  - ❑ BCMS: 1.7 (1.4) – 1.9 (1.6) μm → [illegible]**5 μm** @ stable beams

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  - BCMS: 1.7 (1.4) – 1.9 (1.6) µm → [illegible]**5 µm** @ stable beams
- ☐ Train composition @ SPS extraction
  - Min batch spacing **200 ns**
  - Standard: 4 x 72 = 288 b. → **2[illegible]** @ stable beams
  - BCMS: 3 (6) x 48 = 144 (288) b. → **[illegible]556 (2748) b.** @ stable beams

Collimation considerations

R.Bruce and S.Redaelli

- LR separation of **9 σ**
  - For **Standard**, β^* = **32 cm** (limited in X-plane, independent of CMS bump)
  - For **BCMS**, β^* of (limited in separation plane)
    - **32 cm**, with -1 mm CMS bump
    - **30 cm**, without CMS bump (or applying it after collapse of separation bump or reducing TCT aperture in vertical plane)

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- LR separation of **10 σ** and **BCMS**
  - **β^* = 32 cm**, with -1 mm bump of CMS (limited in separation plane)
  - **β^* = 31 cm**, without CMS bump (limited in X-plane)

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Target β^* = 31 cm

Nota bene: CMS bump considerations are pessimistic (IP shift when separation bump is already collapsed and -1 mm bump may be shared with magnet re-alignment)

Optics choice

- **(New) ATS**

R.De Maria, M.Giovannozi, S.Fartoukh, R.Tomas

  - **Superior chromatic properties**
  - Optics **ready** and **correctable** down to **21 cm**
  - **Margin** for high octupole and chromaticity operation and/or **low crossing angles** (see below)
  - Optics, beam-beam **MDs** for Run 3/HL-LHC and **new ideas** can be fulfilled
  - **Poorer performance** for **forward physics requirements** (mainly CT-PPS) and **recovery** at cost of **increased squeeze length**

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  - **Poorer performance** for **forward physics requirements** (mainly CT-PPS) and **recovery** at cost of **increased squeeze length**
- **(New) Nominal**
  - Squeezed **optics** down to **33 cm** with significant **reduction of squeeze time** and strength **margin** to continue to **lower β***
  - **Optics** solution for **forward physics preferred** by experiments. Realistic **minimum gap requirements** and **priority** with respect to main program has to be clarified

Optics choice

R.De Maria, M.Giovannozi, S.Fartoukh, R.Tomas

- **No significant difference** for nominal and ATS optics with respect to **aperture** collimation considerations
- Optics **commissioning** will take **similar time** (~3 shifts) for any new optics
- More **margin** in **nominal** optics with respect to optimal **phase advance** between **MKD-TCT** (but **no show-stopper** for **ATS**)
- **“Ramp and squeeze” towards lower β* (~1m)** to **mitigate** longer **squeeze length** due to forward physics constraints

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ATS with **β^* = 31 cm** (pre-squeeze to 40 cm) could be a **good choice,** paving the way towards **HL-LHC**

E-cloud

- **Limitation** imposed by **heat load** for standard and BCMS beams
  - **Stronger** for **standard** beam due to filling pattern
  - Assuming to reach **same situation** as **end of 2016**, after 1-2 months (provided Sector 1-2 behaves as in 2015)
  - **Significantly faster intensity ramp-up** with BCMS (2016-like) and easier Sector 1-2 recovery
  - Most likely **no more conditioning** than in 2016
    - **Heat loads not limiting** performance for **Run 2**, but **certainly** for **Run 3** and **HL-LHC**

G.Iadarola

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G.Iadarola

Scenario	Heat load [W/hcell]	N bunches within 160 W/hcell
Standard, 2760b, $1.25\text{x}10^{11}$ p/b	204	**2155** (22% reduction)
BCMS-144bpi, 2556b, $1.25\text{x}10^{11}$ p/b	171	2380 (7% reduction)
BCMS-288bpi, 2748b, $1.25\text{x}10^{11}$ p/b	188	2338 (15% reduction)

Instabilities (in stable beams)

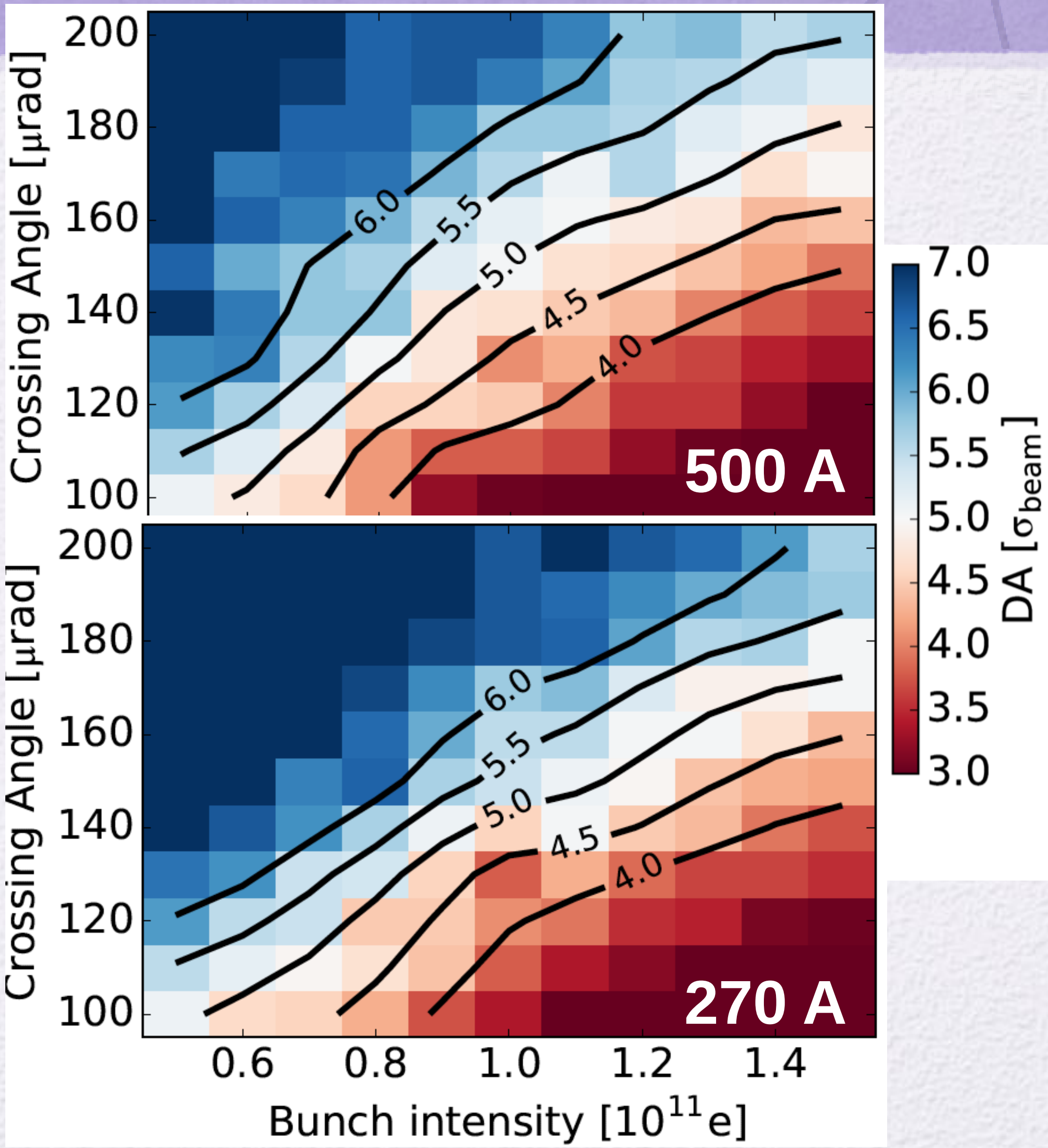
E.Metral et al.

- **Octupole** current
  - For **colliding bunches**: **No constraint** (zero or even negative), due to beam-beam head-on spread
  - For **non-colliding bunches**: Single beam stability limit at around **250 A**, but may be reduced due to other sources of non-linear tune-spread
- **Chromaticity**
  - Limited by e-cloud effects, but **10 units** seem reasonable
- **Coupling**
  - To be well corrected, especially when moving the WP towards the diagonal
- **ADT**
  - **Higher gain** (lower bandwidth) could help to mitigate emittance blow-up

Crossing angle choice 2016

D.Pellegrini

- **Min. DA** with **intensity** vs **X-angle**, for **nominal optics** (**β^*= 40 cm**) and **BCMS** beam (**2.5 µm** emittance), 15 units of chromaticity



Crossing angle choice 2016

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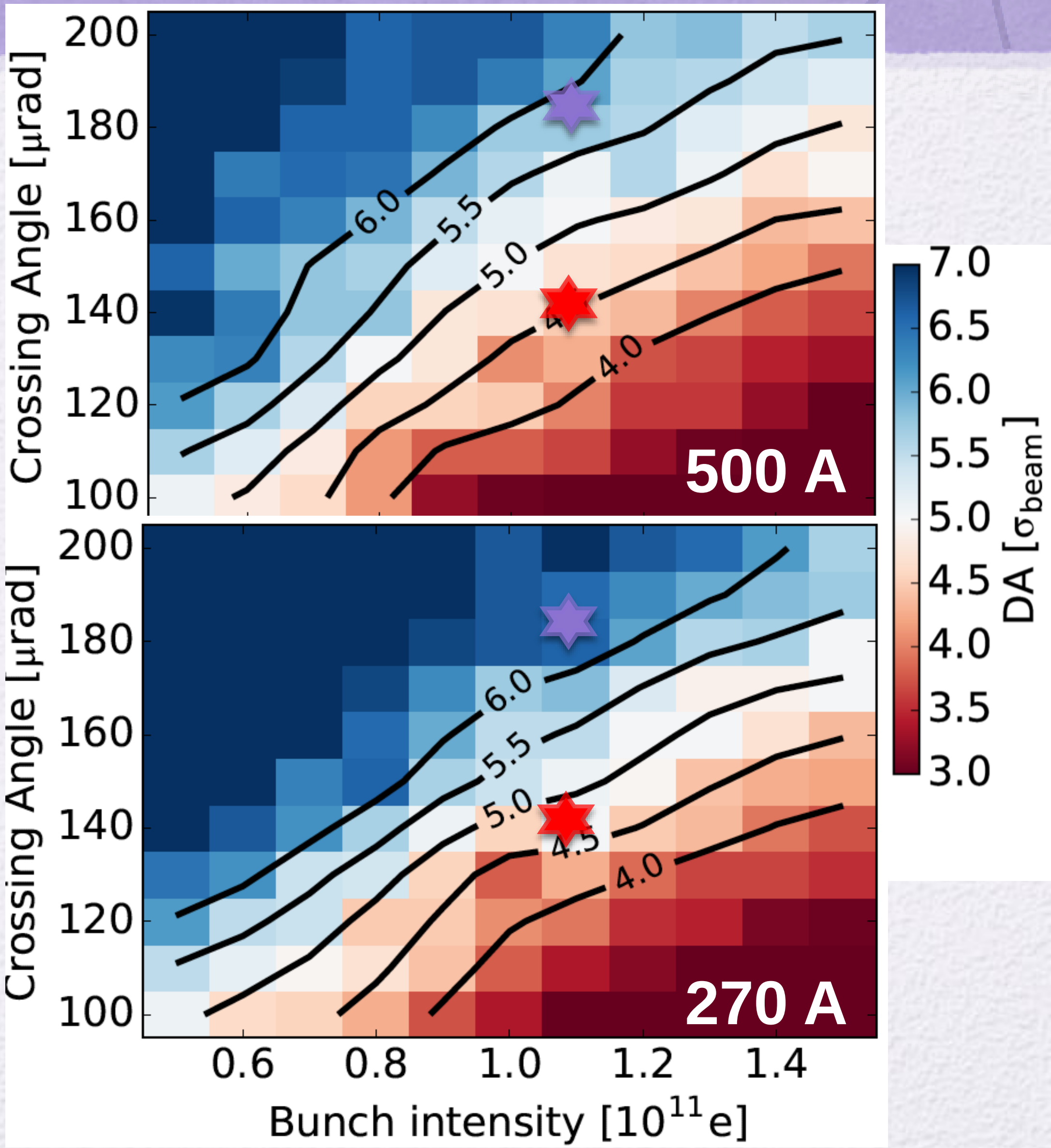
- **Min. DA** with **intensity** vs **X-angle**, for **nominal optics** (**β^*= 40 cm**) and **BCMS** beam (**2.5 µm** emittance), 15 units of chromaticity
- For **1.1×10^{11} p**
  - At **$\theta_c/2$ = 185 µrad** (~**12 σ** separation), DA around **6 σ**
  - At **$\theta_c/2$ = 140 µrad** (~**9 σ** separation), DA close to **5 σ**
  - **Slight improvement** for low octupoles



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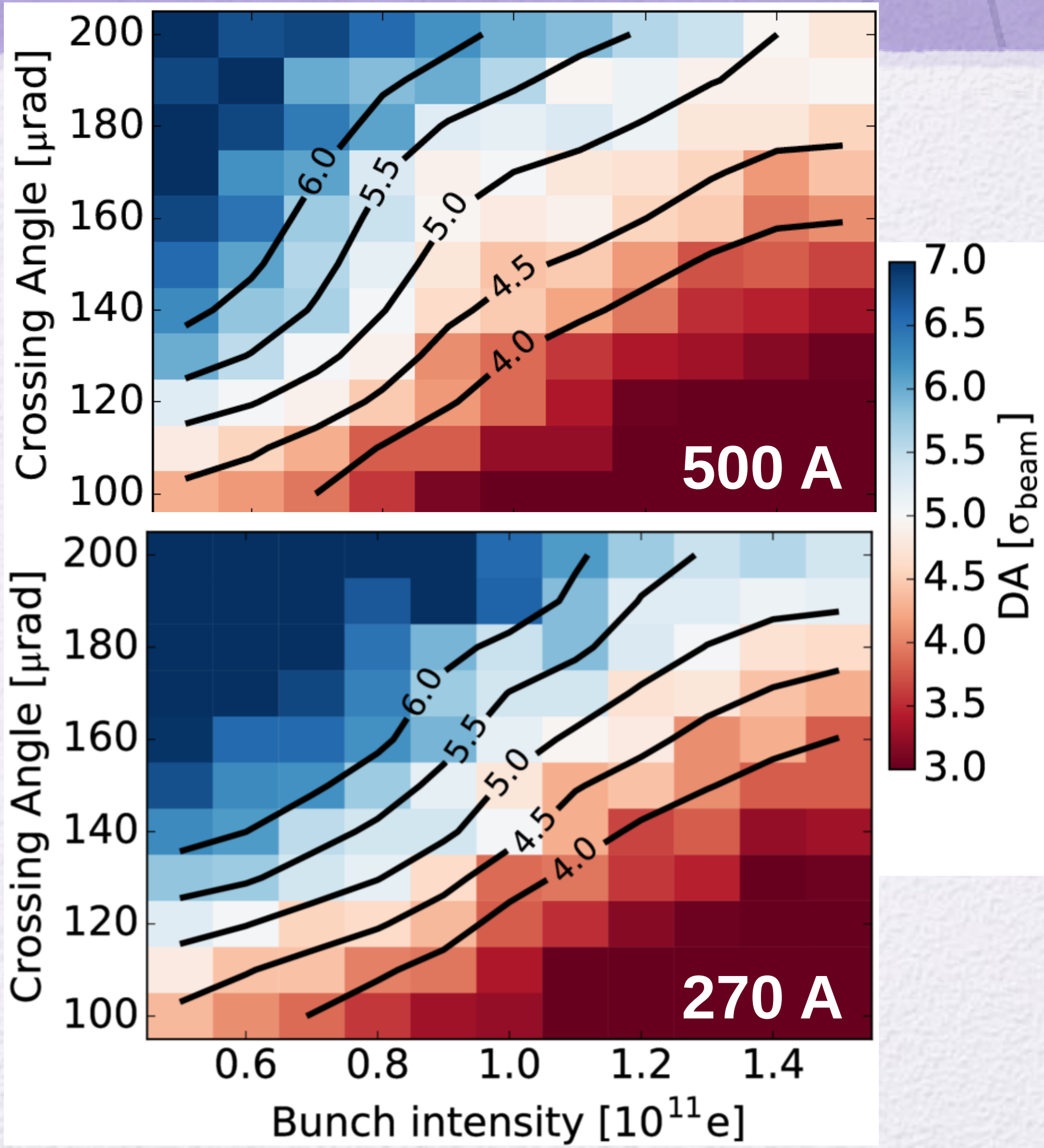
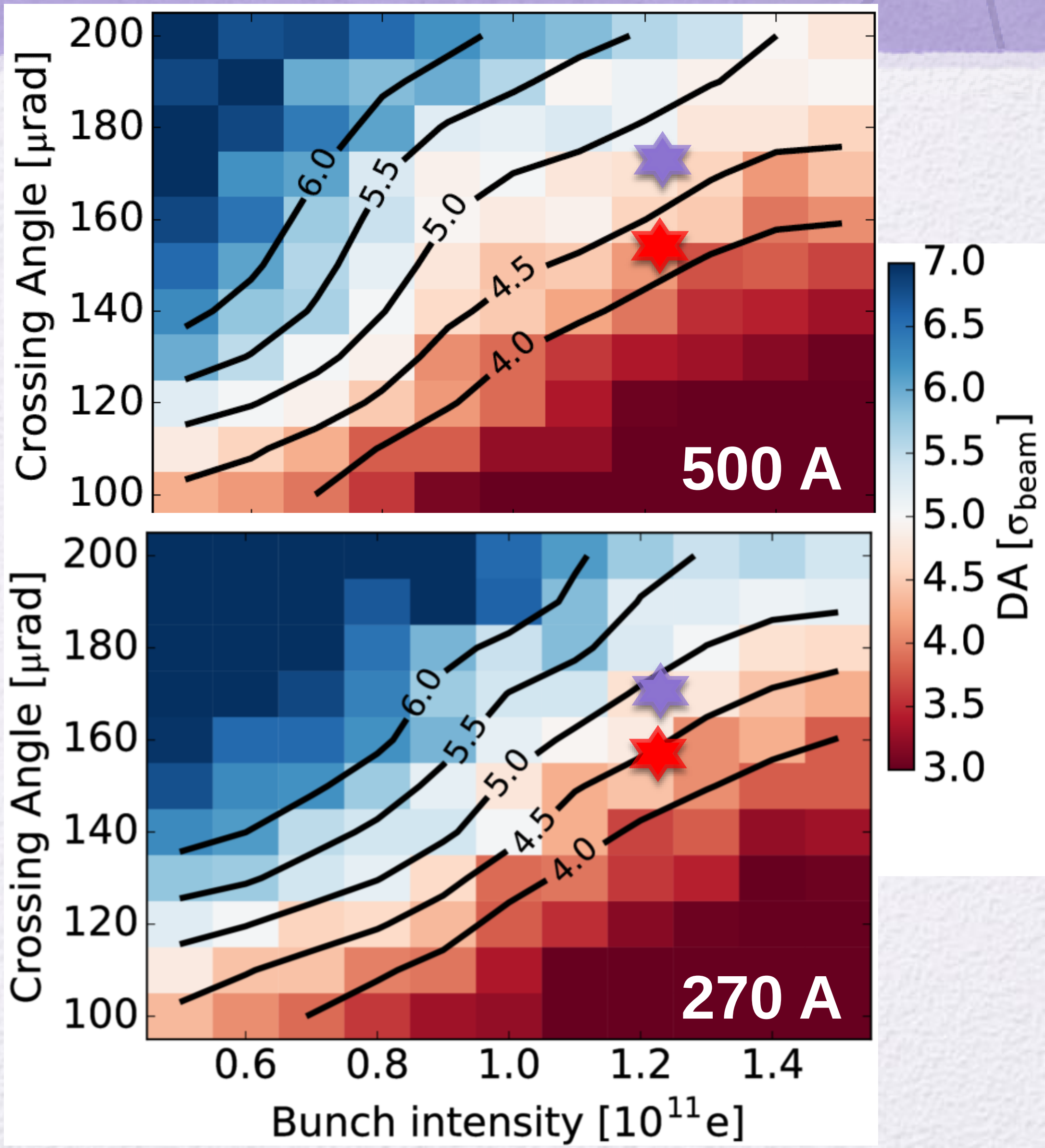


Crossing angle choice 2017

D.Pellegrini

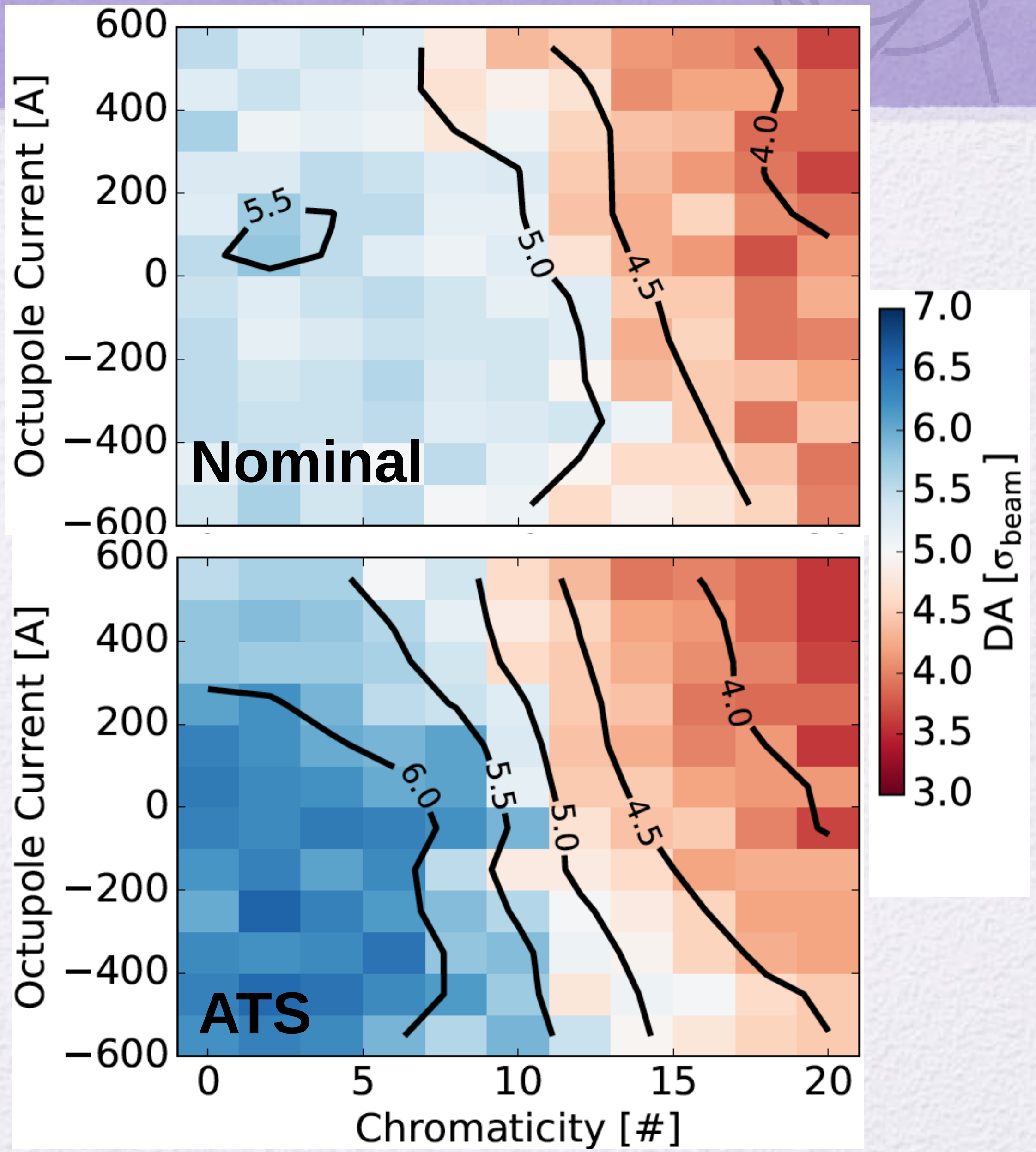
- **Min. DA** with **intensity** vs **X-angle**, for **nominal optics (β^*= 33 cm)** and **BCMS beam (2.5 μm** emittance), 15 units of chromaticity
- For **1.25 x10^{11} p**
  - At **9 σ** separation (**θ_c/2 = 155 μrad**), DA close to **4 σ**
  - Need > **10 σ** separation (**θ_c/2 = 170 μrad**), for DA approaching **5 σ**
  - **Slight improvement** for low octupoles



Crossing angle choice, nominal vs ATS

D.Pellegrini

- **Min. DA** with **octupoles** vs **chromaticity**, **nominal** vs **ATS** optics (**β^*= 33 cm**) and **BCMS** beam (emittance of **2.5 μm** and intensity of **$1.25\text{x}10^{11}$ p), $\theta_c/2$ = 155 μrad**



Crossing angle choice, nominal vs ATS

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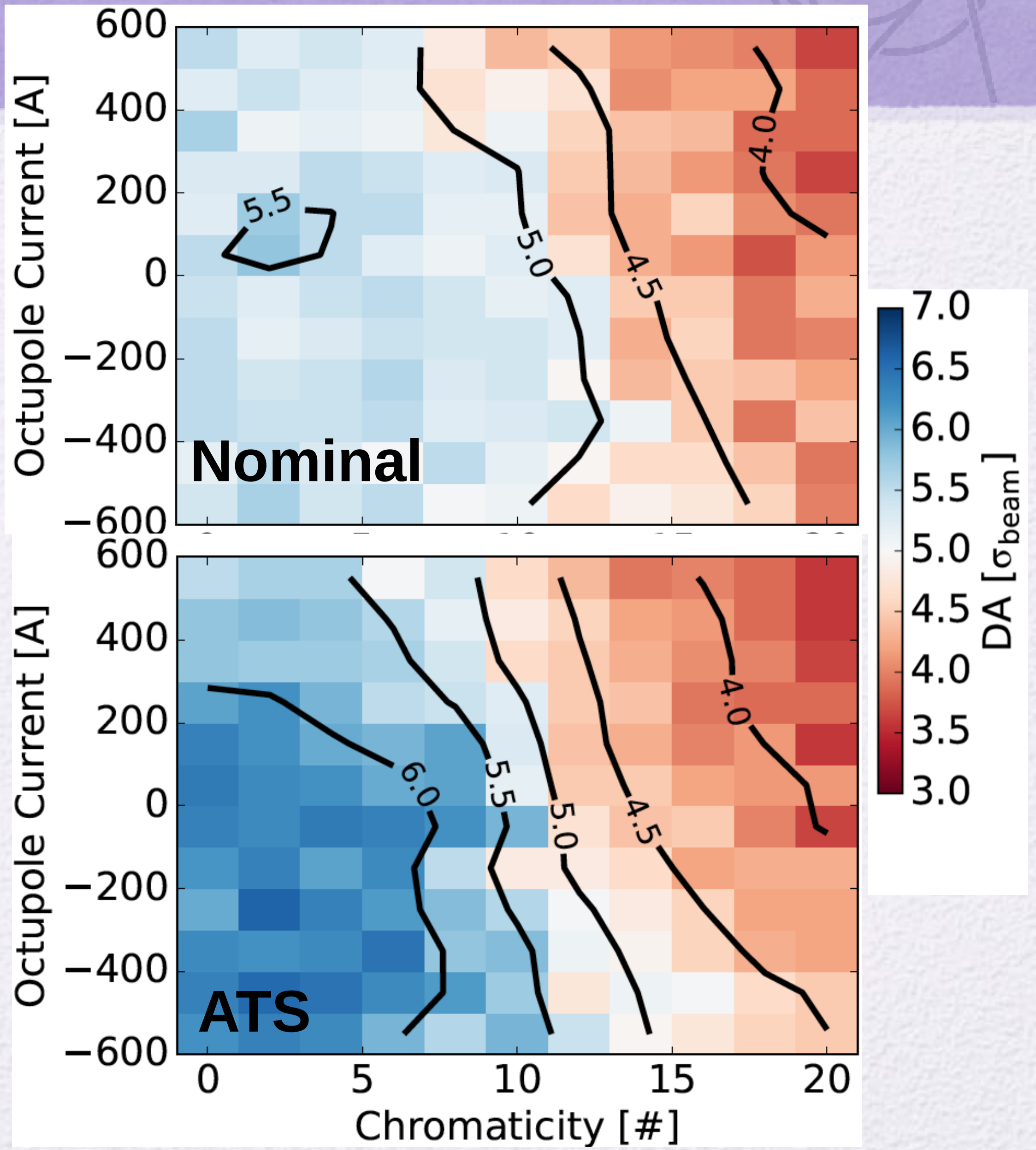
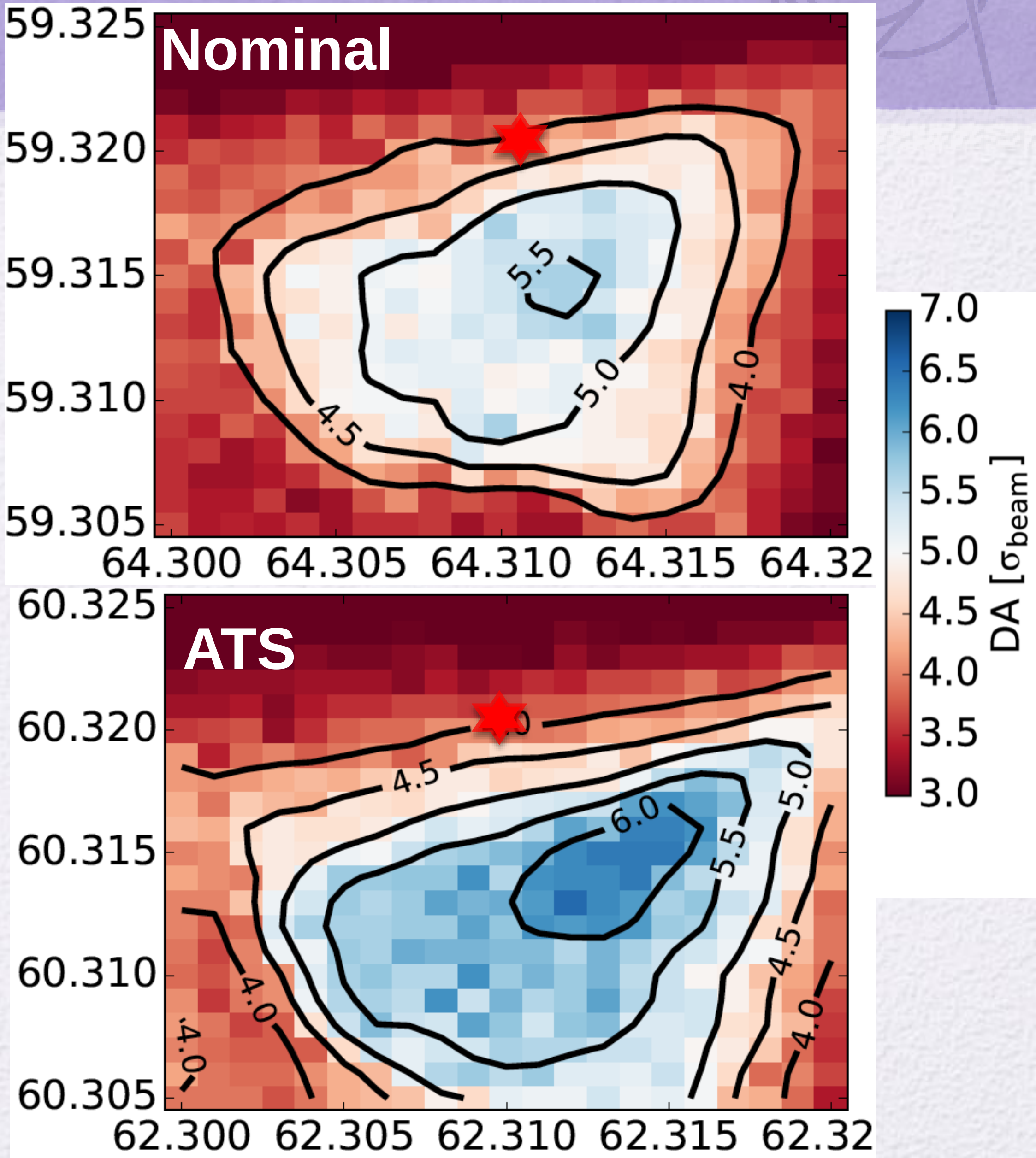
- **Min. DA** with **octupoles** vs **chromaticity**, **nominal** vs **ATS** optics (**β^*= 33 cm**) and **BCMS** beam (emittance of **2.5 μm** and intensity of **1.25×10^{11} p), $\theta_c/2$ = 155 μrad**
  - **DA > 5 σ**, only for **chromaticities < 10** units and **moderate octupole**
  - ATS opens the route for increasing DA, for **negative octupoles** (partial BBLR compensation) and even **high chromaticity**



Crossing angle choice, working point

D.Pellegrini

- **Min. DA** for **working point scan** of **nominal** vs **ATS** optics (**β^*= 33 cm**), chromaticity of **15** units, octupoles of **500 A** and **BCMS** beam (emittance of **2.5 μm** and intensity of **$1.25\mathrm{x}10^{11}$ p**), **$\theta_c/2$ = 155 μrad**



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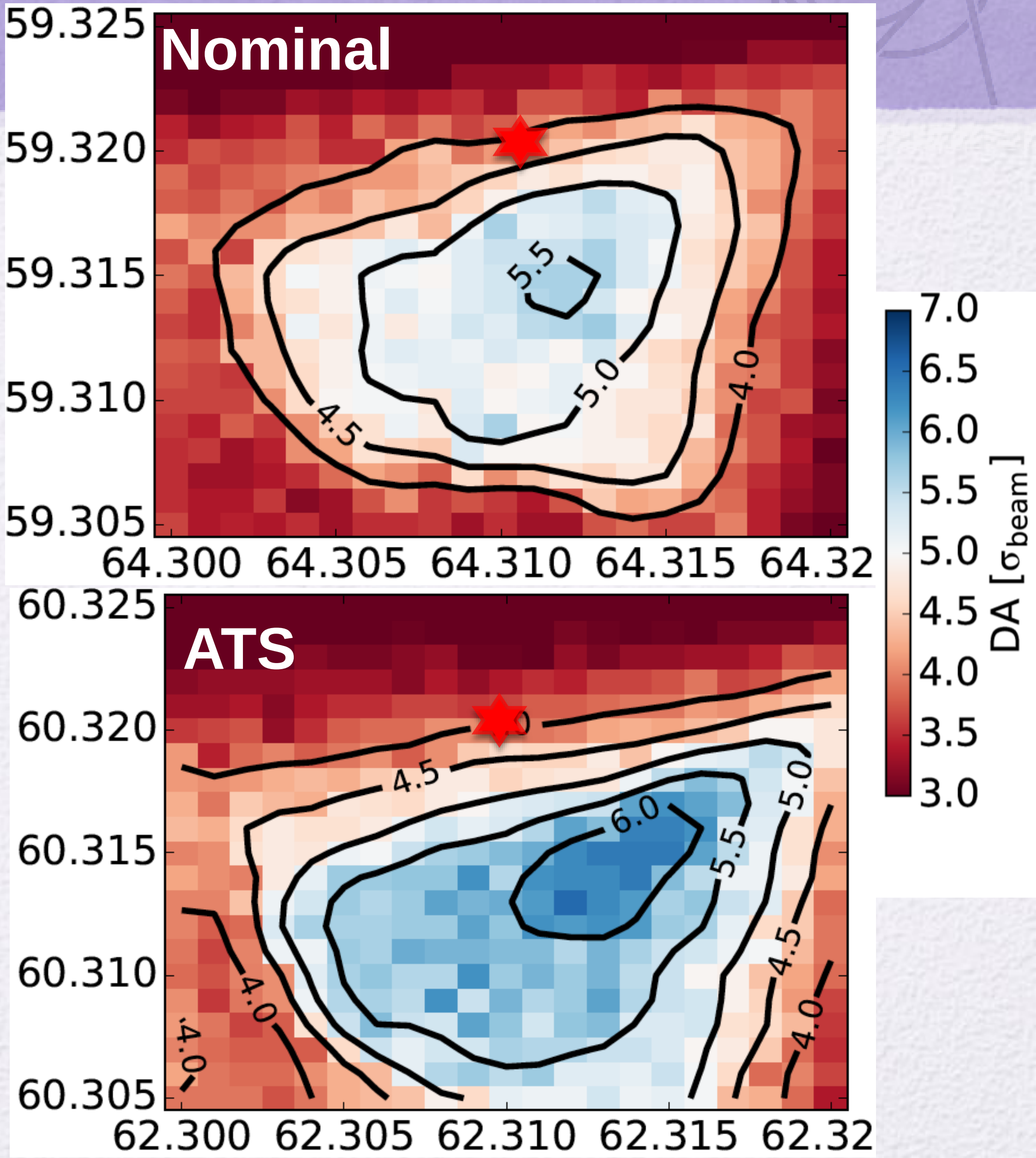
  - **DA increased** by moving **WP** towards the **diagonal** (proved in operation during 2016 run)
  - **ATS** provides **larger margins**



Luminosity performance

Parameter	BCMS 144b 40 cm 300 urad	BCMS 144 31 cm 340 urad	BCMS 288 31 cm 340 urad
Beam energy in collision [TeV]	6.5	6.5	6.5
Particles per bunch, N [10^{11}]	1.25	1.25	1.25
Number of bunches per beam	2556	2556	2748
Number of collisions in IP1 and IP5*	2544	2544	2736
Number of collisions in IP2/IP8	2205/2308	2205/2308	2258/2378
Maximum number of bunches per injection	144	144	288
Crossing angle in IP1 and IP5 [µrad]	300	340	340
Minimum normalized LRBB separation [σ]	10	10	10
Minimum β* [m]	0.40	0.31	0.31
e_n [µm]	2.5	2.5	2.5
ε_L [eVs]	2.2	2.2	2.2
R.M.S. bunch length [cm]	8.3	8.3	8.3

F.Antoniou and G.Iadarola

Per day integrated luminosity estimation for optimal fill length, and **6h turn-around-time**

- **β^* = 31 cm**
- Batches with **144/288 bunches** of **BCMS** beams **(2.5 µrad** emittance)
- **X-angle** of **340 µrad (10 σ)**
- **Intensity** of **1.25x1011 p/b, bunch length** of **8.3 cm**
- **Luminosity levelling @ 1.7x1034 cm^{-2} s^{-1} when necessary**
- With/without **heat-load limit @ 160 W/hcell**

Luminosity performance

Parameter	BCMS 144b 40 cm 300 urad	BCMS 144b 31 cm 340 urad	BCMS 288b 31 cm 340 urad
Peak luminosity L_{peak} [10^{34} cm^{-2} s^{-1}]	1.7	1.9	2.1
Max pile-up	48	54	54
Levelling time [h] for levelling at 1.7x10^{34} cm^{-2}s^{-1}	0.	2.5	4.25
L_{int} with levelling (1.7x10^{34}) [fb^{-1}/day] – no heat load lim.	0.79	0.85	0.91
L_{int} without levelling [fb^{-1}/day] – no heat load lim.	0.79	0.86	0.92
L_{int} with levelling (1.7x10^{34}) [fb^{-1}/day]–heat load lim. (160 W)	0.74	0.80	0.78
L_{int} without levelling [fb^{-1}/day] – heat load limited (160 W)	0.74	0.80	0.78

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Per day integrated luminosity estimation for optimal fill length, and **6h turn-around-time**

❑ **Peak luminosity > 1.7x1034 cm^{-2} s^{-1}**, **peak pile-up < 60** events

❑ Levelling time from **2.5 to 4.25 h** (but no performance impact when heat load limited)

❑ **8 %** more **integrated luminosity/day**, as compared to 2016 scenario

❑ **Longer batches** enhance performance (extra **7 %**) when not limited by heat load

Luminosity performance X-angle lowering

Parameter	BCMS 144b 40 cm 300 urad	BCMS 144b 31 cm 310 urad	BCMS 288b 31 cm 310 urad
Peak luminosity L_{peak} [10^{34} cm^{-2} s^{-1}]	1.7	2.0	2.2
Max pile-up	48	57	57
Levelling time [h] for levelling at 1.7×10^{34} $cm^{-2}s^{-1}$	0.	3.5	5.25
L_{int} with levelling (1.7×10^{34}) [fb^{-1}/day] – no heat load lim.	0.79	0.88	0.93
L_{int} without levelling [fb^{-1}/day] – no heat load lim.	0.79	0.89	0.95
L_{int} with levelling (1.7×10^{34}) [fb^{-1}/day]–heat load lim. (160 W)	0.74	0.83	0.81
L_{int} without levelling [fb^{-1}/day] – heat load limited (160 W)	0.74	0.83	0.81

F.Antoniou and G.Iadarola

Per day integrated luminosity estimation for optimal fill length, and **6h turn-around-time**

- **Peak luminosity > 2x10^{34} cm^{-2} s^{-1}**, **peak pile-up < 60** events
- Levelling time from **3.5 to 5.25 h** (but no performance impact when heat load limited)
- **11 %** more **integrated luminosity/day**, as compared to 2016 scenario
- **Longer batches** enhance performance (extra **6 %**) when not limited by heat load

Luminosity performance - Standard

Parameter	BCMS 144b 40 cm 300 urad	BCMS 144b 31 cm 310 urad	BCMS 288b 31 cm 310 urad	Standard 288b 31 cm 340 urad
Peak luminosity L_{peak} [10^{34} cm^{-2} s^{-1}]	1.7	2.0	2.2	1.63
Max pile-up	48	57	57	42
Levelling time [h] for levelling at 1.7x10^{34} $cm^{-2}s^{-1}$	0.	3.5	5.25	0.
L_{int} with levelling (1.7x10^{34}) [fb^{-1}/day] – no heat load lim.	0.79	0.88	0.93	0.82
L_{int} without levelling [fb^{-1}/day] – no heat load lim.	0.79	0.89	0.95	0.82
L_{int} with levelling (1.7x10^{34}) [fb^{-1}/day]–heat load lim. (160 W)	0.74	0.83	0.81	0.64
L_{int} without levelling [fb^{-1}/day] – heat load limited (160 W)	0.74	0.83	0.81	0.64

F.Antoniou and G.Iadarola

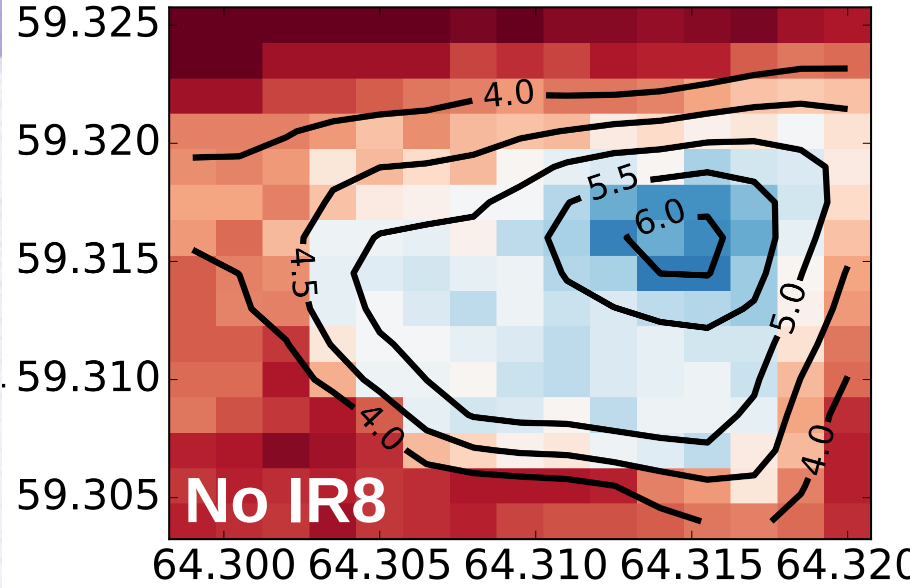
- **Standard** scheme with **low X-angle (8.4 σ)** can be considered at the end of run for further **lowering SEY**
- No need of levelling
- **23 (7) %** of **luminosity loss** if **(not) heat load** limited

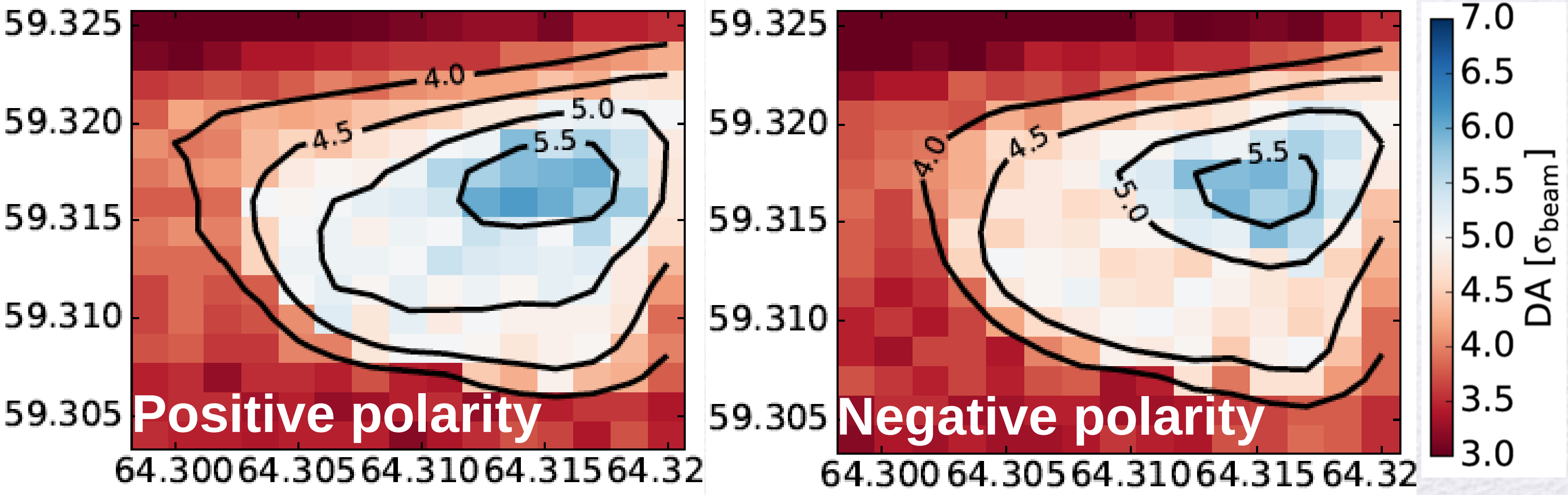
LHCb operation

- ❑ LHCb spectrometer **polarity** impact beam lifetime in 2016
  - ❑ **Confirmed** by **DA** simulations
  - ❑ **Mitigated** in operation by **WP tuning** (B1)
- ❑ Due to **head-on** with different X-angles
- ❑ **LRs smaller** (but non-negligible) **impact**
- ❑ Need careful **choice** of **working point**

D. Pellegrini

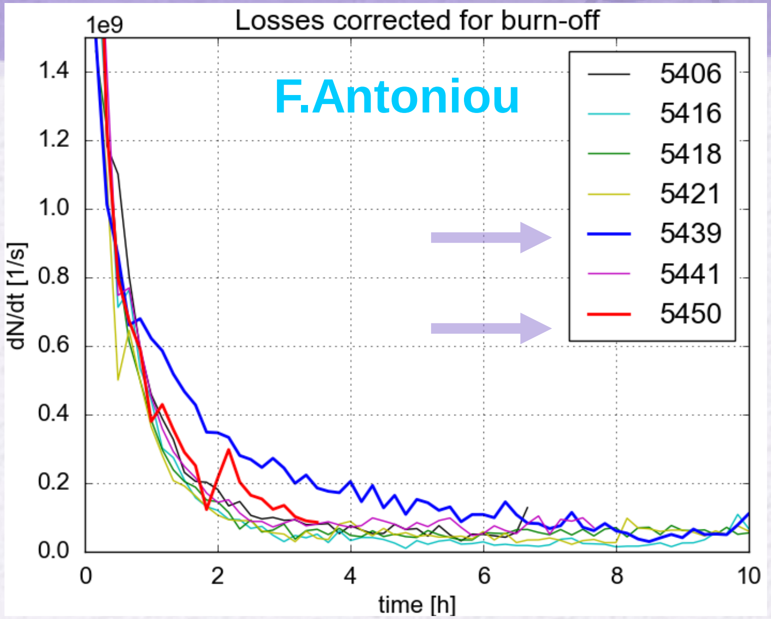
TuneScan_LHCb_off; Min DA; β^*=40 cm; ε=2 μm; I=1.15 10^{11} e; Q'=15; I_{MO}=500 A; X=140 μrad.





Levelling

- **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**



F.Antoniou

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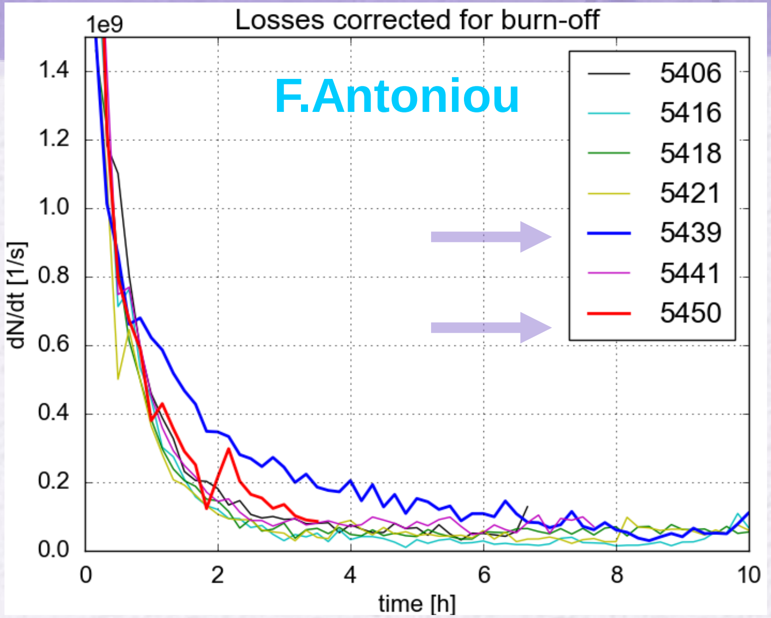
- **Changing X-angle** from fill-to-fill (adapt **H/V emittance ratio** or **increase** peak **luminosity**) or **levelling** during stable beams (range of 60 μrad in X/2-angle)
    - Tolerance of 10-20 μrad in X/2-angle is ok with TCT orbit interlock (no need to change SIS references)
    - Investigate possibility of having functions and sequences for moving X-angle and TCTs
    - Change on losses in per mille range observed for proposed TCP settings (probably acceptable)



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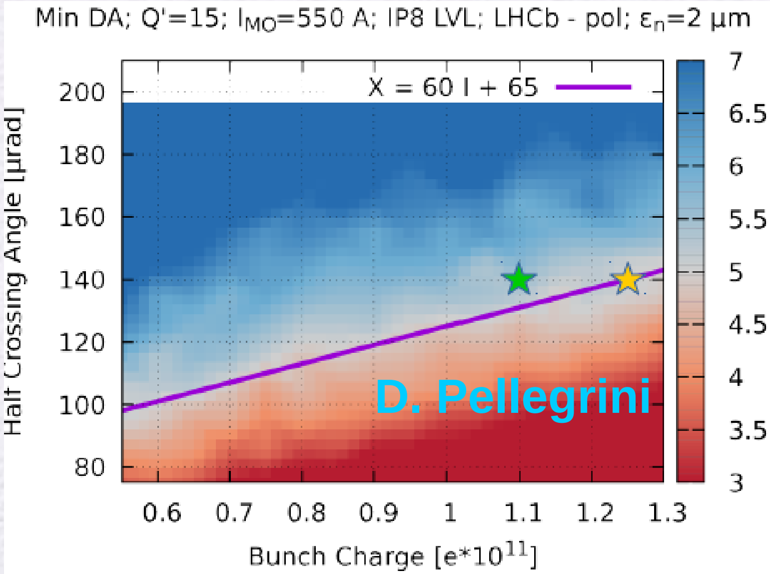

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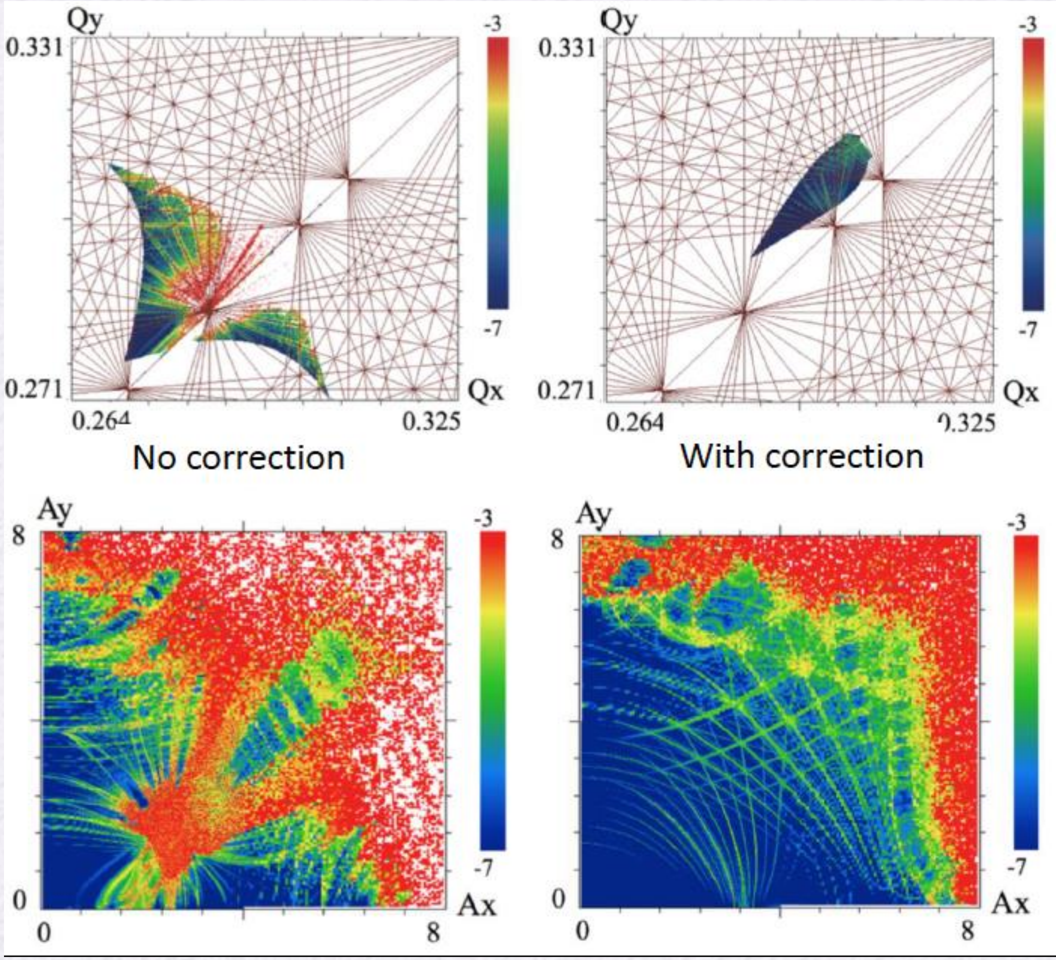
Scenarios for 2018 - Flat optics

- **Flat optics** for gaining **luminosity** (pushing geometric loss factor to 1), within the aperture limits in the triplet
  - Exchange X-plane in ATLAS/CMS
  - Absence of passive BBLR tune-shift elimination
  - **Active compensation scheme** may be necessary (wires, octupoles,…)
  - Opens the route for satisfying other optics requirements
- Development and **experimental validation** of flat telescopic optics in 2017 (and possibly synergy with BB compensation MDs)
  - Ultimately **60/15 cm** starting from 60 cm pre-squeezed optics



No correction

With correction

S.Fartoukh

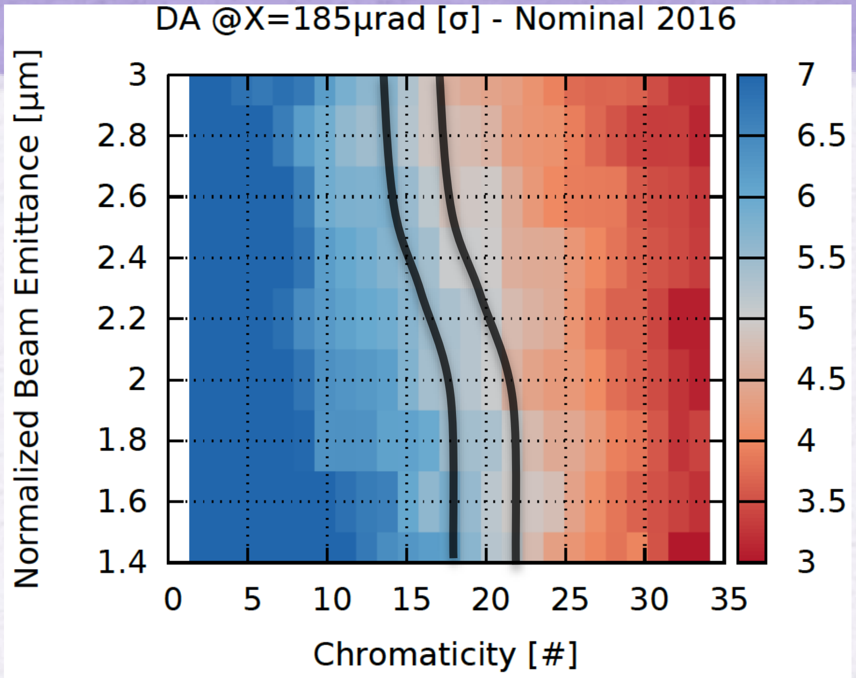
Summary

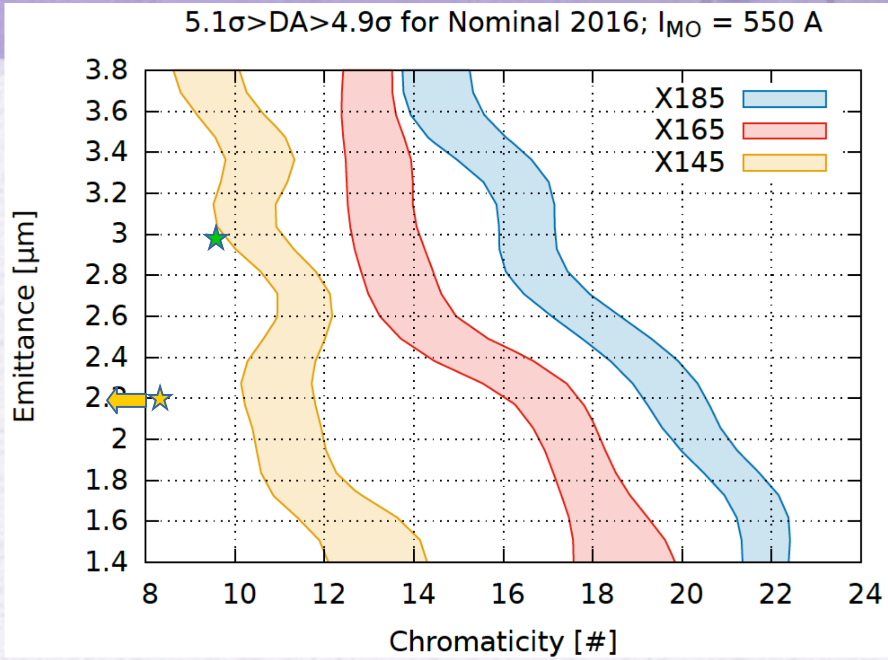
- **β* of 31cm** within reach for both ATS and nominal optics
- **ATS** seems the choice, building operational experience for the future
    - Some potential margin in chromaticity, octupole, WP choice and/or crossing angle reach
    - Nominal optics able to reach the same β* and more margin to deal with AFP/CT-PPS
- **BCMS beams** are a natural choice for luminosity performance (boosted by 200 ns batch spacing)
    - Standard beam could be used towards end of the run for enhancing scrubbing efficiency (SEY reduction) for Run 3 and HL-LHC
- Crossing angle of **10 σ -> safe choice** for intensity of 1.25x10^{11}
    - Can be lowered during the run to **9 σ** when reduction of octupoles and chromaticity is proved possible (as in 2016)
    - **WP optimisation** is essential for minimising losses in the first few hours (and also mitigate impact of LHCb polarity switch)
    - Keeping the **same crossing angle in σ** for ATLAS and CMS may be essential to mitigate luminosity differences
    - Consider (crossing angle) **levelling**
- **Flat optics** would be an attractive scenario for 2018 (BBLR compensation?)
    - **MD time** would be essential for qualifying these optics (quite limited in 2017)

Thanks you for your attention

Appendix

BCMS vs Standard





- Smaller emittance comes with additional DA (beam sigma), by reducing the crossing angle we seem to pay some margin for chromaticity, with some extra margin required for the intensity increase.
- The fluctuations of the bands show some uncertainty in the study (~2 units of chroma).
- From experience: BCMS with reduced crossing caused comparable losses as Standard (slide 2).

D.Pellegrin

Luminosity performance Nominal vs BCMS

Parameter	BCMS 144b 40 cm 300 urad	BCMS 144b 31 cm 340 urad	BCMS 288b 31 cm 340 urad	BCMS 144b 31 cm 310 urad	BCMS 288b 31 cm 310 urad	Standard 288b 31 cm 340 urad
Beam energy in collision [TeV]	6.5	6.5	6.5	6.5	6.5	6.5
Particles per bunch, N [10^{11}]	1.25	1.25	1.25	1.25	1.25	1.25
Number of bunches per beam	2556	2556	2748	2556	2748	2760
Number of collisions in IP1 and IP5*	2544	2544	2736	2544	2736	2748
Number of collisions in IP2/IP8	2205/2308	2205/2308	2258/2378	2205/2308	2258/2378	2494/2572
Maximum number of bunches per injection	144	144	288	144	288	288
Crossing angle in IP1 and IP5 [μrad]	300	340	340	310	310	340
Minimum normalized LRBB separation [σ]	10	10	10	9	9	8.4
Minimum β^* [m]	0.40	0.31	0.31	0.31	0.31	0.31
e_n [μm]	2.5	2.5	2.5	2.5	2.5	3.5
ε_L [eVs]	2.2	2.2	2.2	2.2	2.2	2.2
R.M.S. bunch length [cm]	8.3	8.3	8.3	8.3	8.3	8.3
Peak luminosity L_{peak} [10^{34} cm^{-2} s^{-1}]	1.7	1.9	2.1	2.0	2.2	1.63
Max pile-up	48	54	54	57	57	42
Levelling time [h] for levelling at 1.7×10^{34} cm^{-2}s^{-1}	0.	2.5	4.25	3.5	5.25	0.
L_{int} with levelling (1.7×10^{34}) [fb^{-1}/day] – no heat load lim.	0.79	0.85	0.91	0.88	0.93	0.82
L_{int} without levelling [fb^{-1}/day] – no heat load lim.	0.79	0.86	0.92	0.89	0.95	0.82
L_{int} with levelling (1.7×10^{34}) [fb^{-1}/day]–heat load lim. (160 W)	0.74	0.80	0.78	0.83	0.81	0.64
L_{int} without levelling [fb^{-1}/day] – heat load limited (160 W)	0.74	0.80	0.78	0.83	0.81	0.64