Operation with high luminosity LHCb

G.Arduini, R.de Maria, S.Fartoukh and Y.Papaphilippou

Thanks to
C. Bracco, R. Bruce, X. Buffat, P. Campana, F. Cerrutti, B. Di Girolamo, I. Efthymiopoulos, M. Fitterer, F. Galan, M. Giovannozzi, R. Lindner, E. Thomas, D. Tommasini, P. Schwarz, A. Valishev, G. Wilkinson.

Joint LARP CM26/HILUMI Meeting at SLAC, – May 19th, 2016

Content

- Luminosity scenarios with LHCb at 1-2 10^{34}.
- Machine configurations (reducing β*)
  - Optics flexibility
  - Aperture constraints and crossing angles
  - Beam-Beam aspects
- Conclusion.

HL-LHC Beam Parameters

Parameter [unit]	LHC	HL-LHC
Bunch Population [10^{11}]	1.1	2.2
Emittance [μrad/γ]	3.5	2.5
Min β* IP1/5 [m]	0.55[+]	0.15
Max Luminosity IP1/5 [10^{34} cm^{-2}s^{-1}]	1.0	5
Virtual Luminosity IP1/5 [10^{34} cm^{-2}s^{-1}]	1.0	20
Levelling time [h]	0	8
Min β* IP8 [m]	**3**	**3**
Max Luminosity IP8 [10^{34} cm^{-2}s^{-1}]	**0.2**	**1.1**

$$L \approx \frac{f_{rev} n_b N^2}{4\pi\epsilon\beta^*}$$

- Smaller β* needed to increase LHCb luminosity

[+]0.4 m in 2016

Integrated luminosities

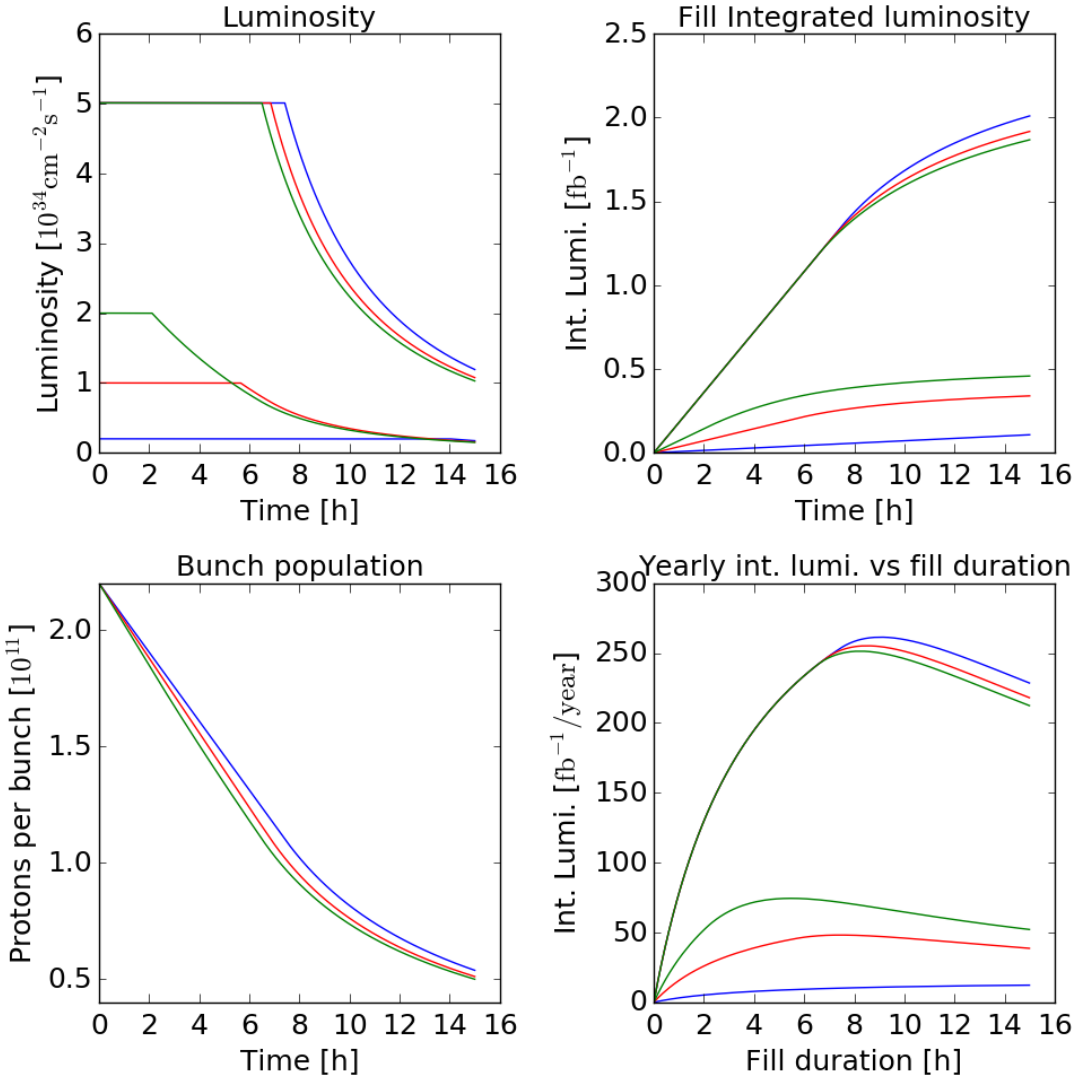
Levelled luminosity LHCb [10^{34} cm^{-2}s^{-1}]	Opt fill length (IP1/5) [h]	Integrated luminosity ATLAS/CMS [fb^{-1}/y]	Integrated luminosity LHCb [fb^{-1}/y]	β* IP8 [m]	Levelling time IP8 [h]
0.2 (nom.)	9.3	261	10.4	3	9
1	9.1	258	28	3	0.5
1	9	257	37	2	3
1	8.8	256	47	1	6
2	9.1	258	28	3	0
2	8.9	257	41	2	0
2	8.5	253	70	1	2

G. Arduini, Preliminary

- Integrated luminosity in ATLAS/CMS substantially independent from LHCb one.
- Assuming LHCb levelling with parallel separations.
- No levelling in LHCb without β* reduction

Integrated luminosities

- Simple luminosity model with burn-off, reproduces main features

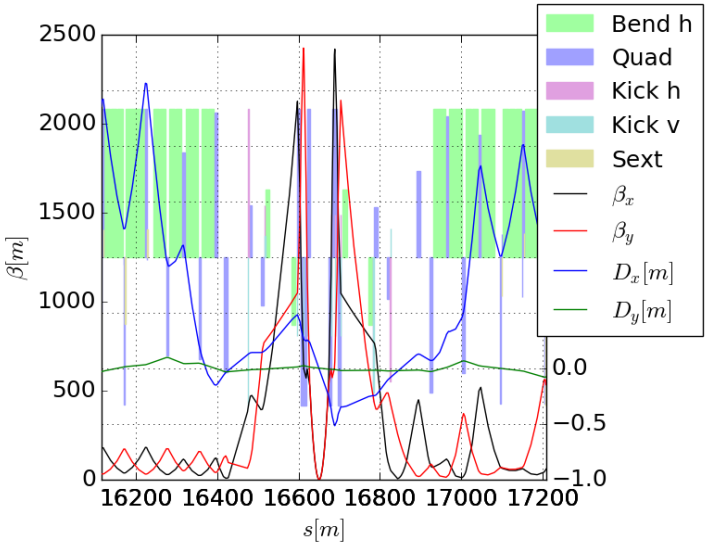


R. De Maria

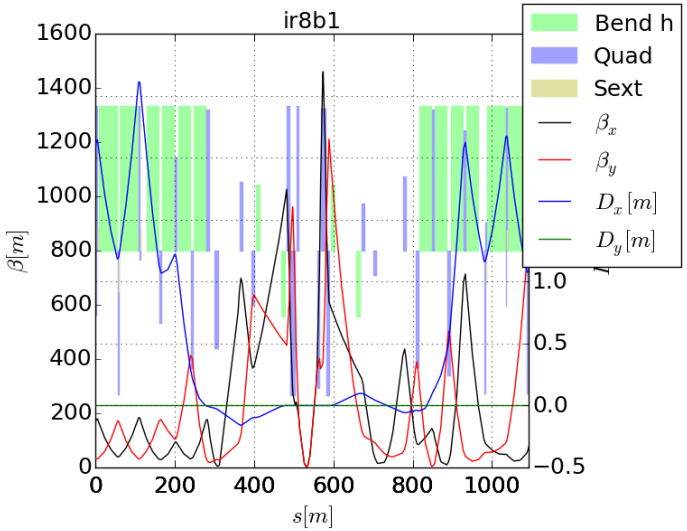
Optics flexibility

R. De Maria

- β* produced with IR8 quadrupoles.
- In HL-LHC IR8 contribute also to IP1 β* (ATS optics).
- Minimum β*≥1 m without IP shift
  - Optics transition to be found.
- With a shifted IP by 3.74 m, β* ≥ 2 m due to strong loss of symmetries limited by powering scheme of the triplets
  - Option dropped due to HW constraints



β*=1 m nominal IP



β*=2 m with IP shift

Aperture and crossing angles

- Minimum allowed crossing angle depends on beam-beam effects.
- Maximum allowed crossing angle depends (mainly) on aperture.
- Sign of the external crossing angle can be changed once per year.
- Constant spectrometer strength impose horizontal crossing angle and vertical separation at injection.
- Large horizontal crossing angle needed at flat top to compensate negative polarity (S.Fartoukh, LMC 167).

R. De Maria

β* [m]	Half Ext. angle [μrad]	Ap. IP nominal [$\sigma_{TCDDM}/\sigma_{MCBX}$]	Ap. IP shift [$\sigma_{TCDDM}/\sigma_{MCBX}$]
3	-250	18.6/22.5	18.0/18.2
2	-250	15.1/18.3	13.2/15.4
2	-300	12.2/14.9	10.0/11.9
1	-150	14.8/16.8	n/a
1	-200	12.7/15.3	n/a

Aperture limited by TCDDM and Triplets.
Study needed whether is possible to replace TCDDM with movable jaws.

Aperture and crossing angles

- Vertical crossing angle possible at flat top. Spectrometer polarity changes transparent (W. Herr, Y. Papaphilippou, LHC report 1009)
- Aperture bottlenecks in triplet only.
- Crossing angle gymnastic from horizontal to vertical needs to be demonstrated.

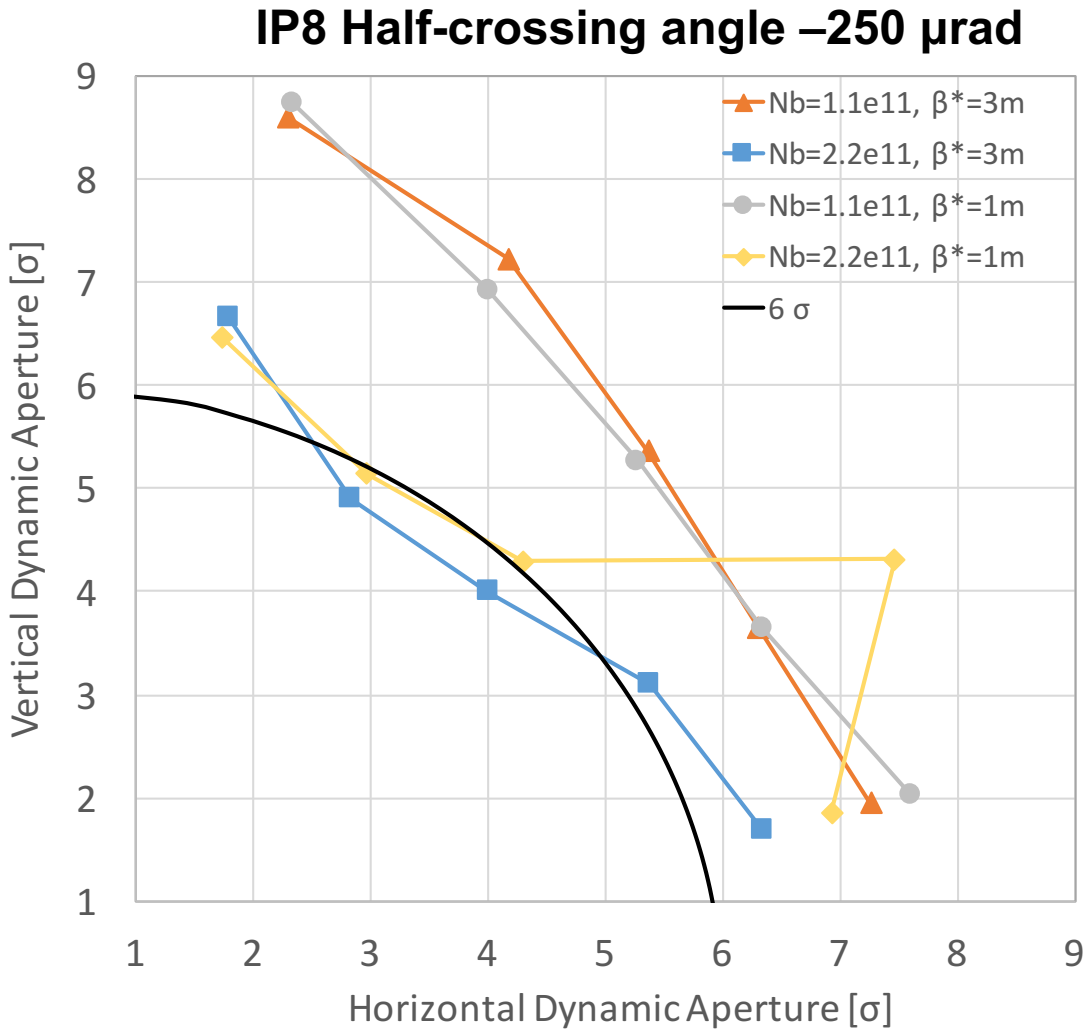
β* [m]	Ext. H. half-angle [μrad]	IP H half-angle Pos. Polarity [μrad]	Ap. IP nominal [$\sigma_{TCDDM}/\sigma_{MCBX}$]	V half-angle σ_{MCBX}=14.2 [μrad]
3	<-250	-115	18.6/22.5	±510
2	-250	-115	15.1/18.3	±430
2	-300	-165	12.2/14.9	
1	-150	-15	14.8/16.8	±260
1	-200	-65	12.7/15.3	

Beam-beam tracking

- Optics configurations (beam 1):
  - Optics version HLLHCV1.2
  - β* of 15 cm in IR1/5, 10 m in IR2, 3 and 1 m in IR8
  - Tunes of 62.31 and 60.32
  - Crossing (half-)angles: 295 μrad in IR1/5, -170 μrad in IR2, -250 μrad, -200 μrad, -150 μrad and -50 μrad in IR8 (external)
  - LHCb Spectrometer polarity + and – (±135μrad, MADX convention)
  - Separation: 0 in IR1/5/8, 2 mm in IR2
  - Chromaticity of 3
  - Multi-pole errors and Landau octupoles switched off
- Emittance 2.5 μrad
- Intensities: 1.1×10^{11} and 2.2×10^{11}
- Crab cavities switched off and on
- 6D tracking, 10^6 turns
- 4D LR kicks, 4D and 6D HO kicks

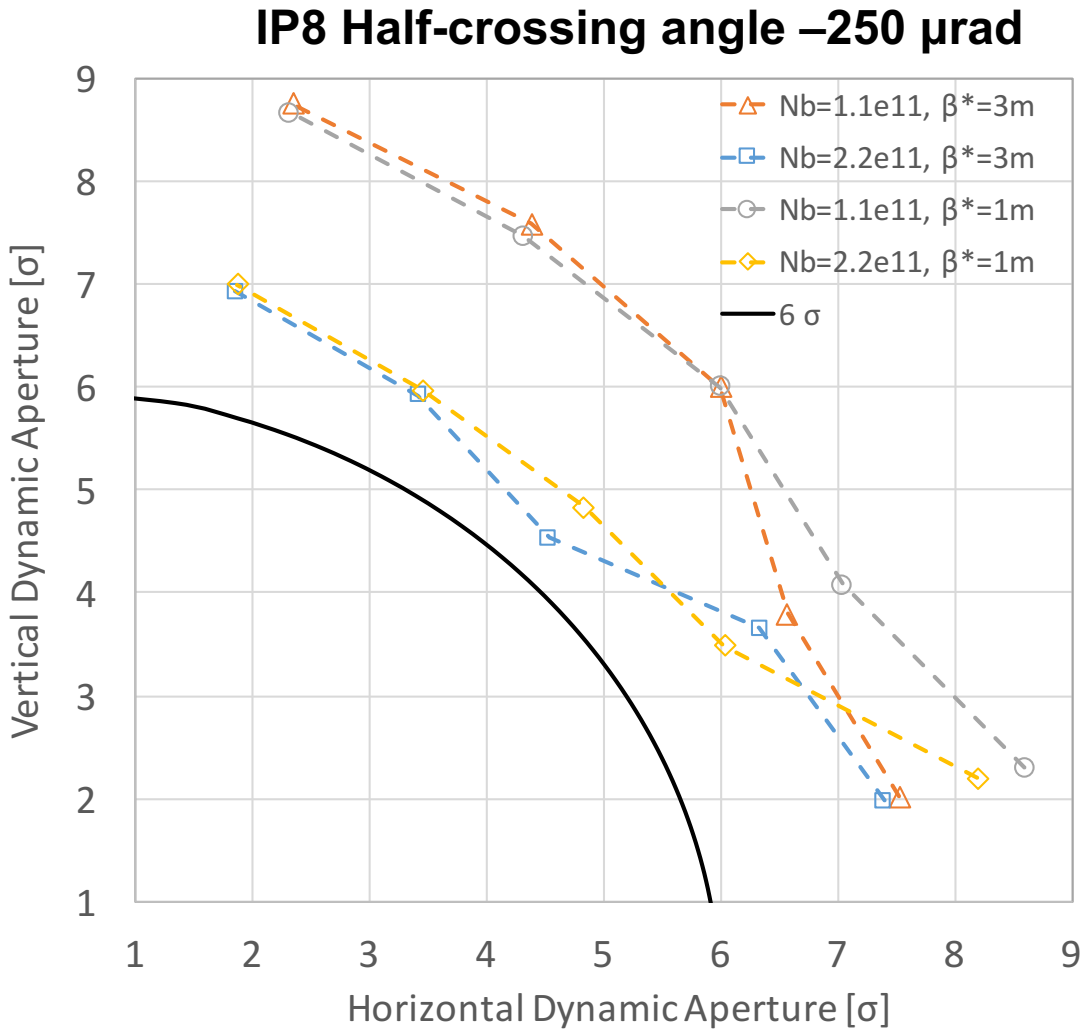
Crabs on - Positive polarity

- Different β* in IR8 does not affect significantly the DA
- Only for high-intensity of 2.2e11, DA < 6 σ



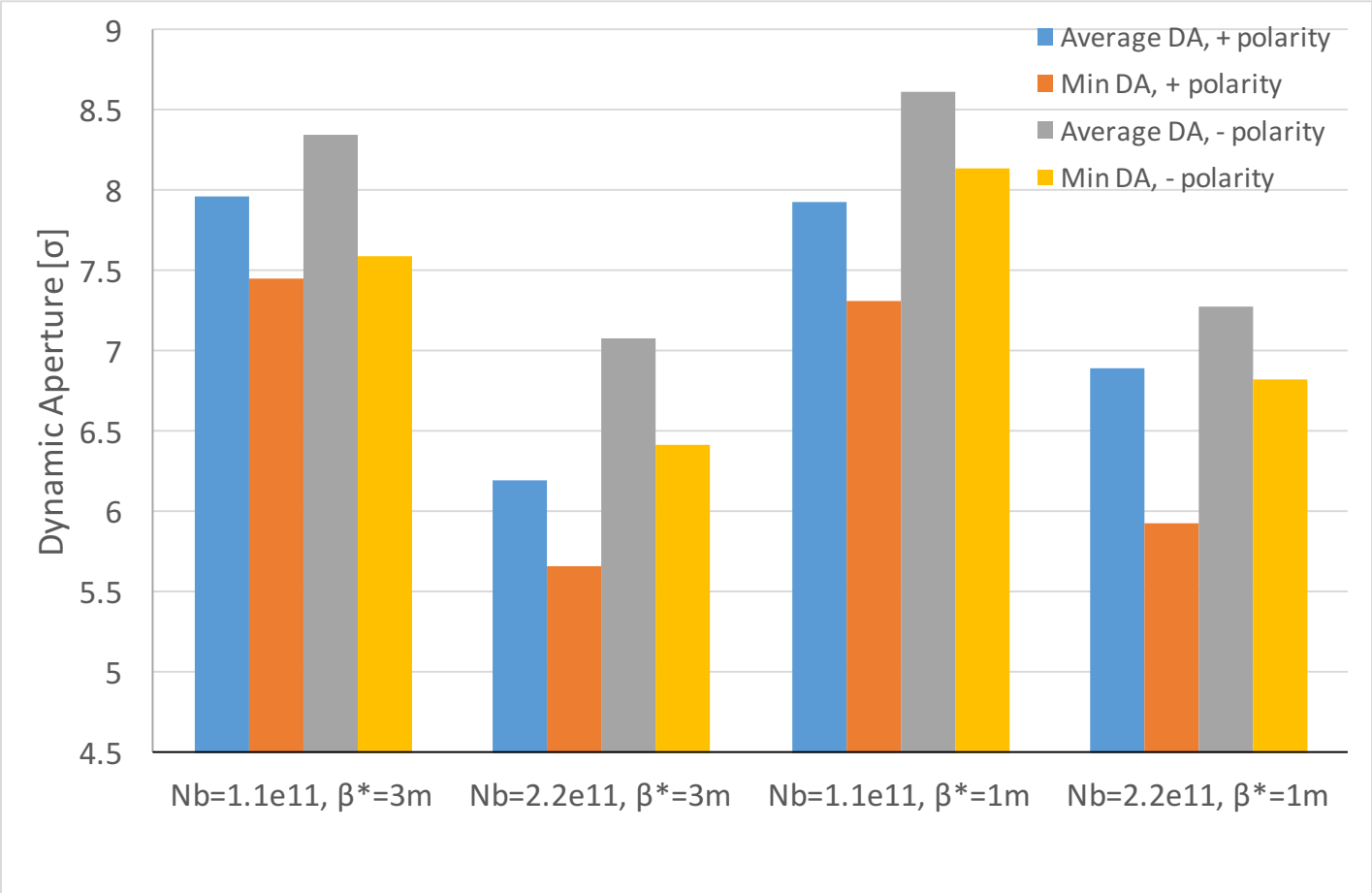
Crabs on– Negative polarity

- For negative spectrometer polarity, DA> 6 σ for all intensities



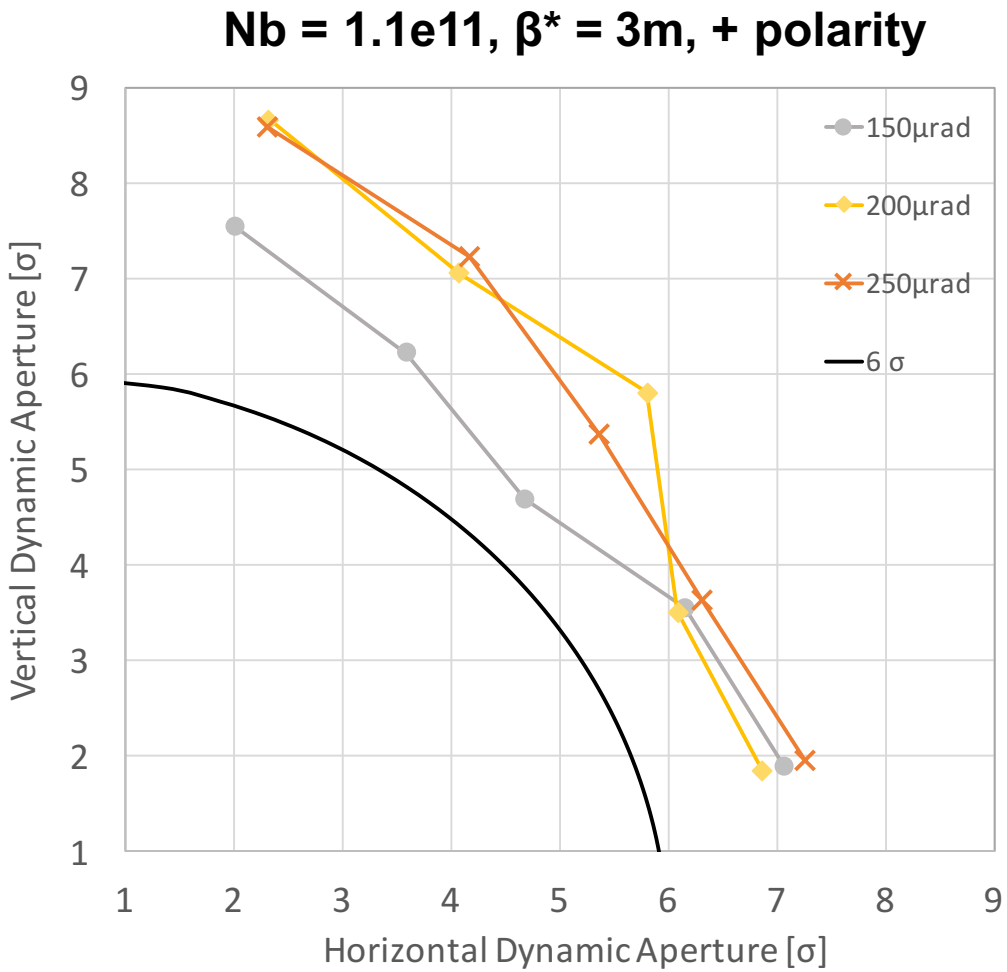
Crabs on - summary

- Overall higher DA (average and minimum) for negative polarity



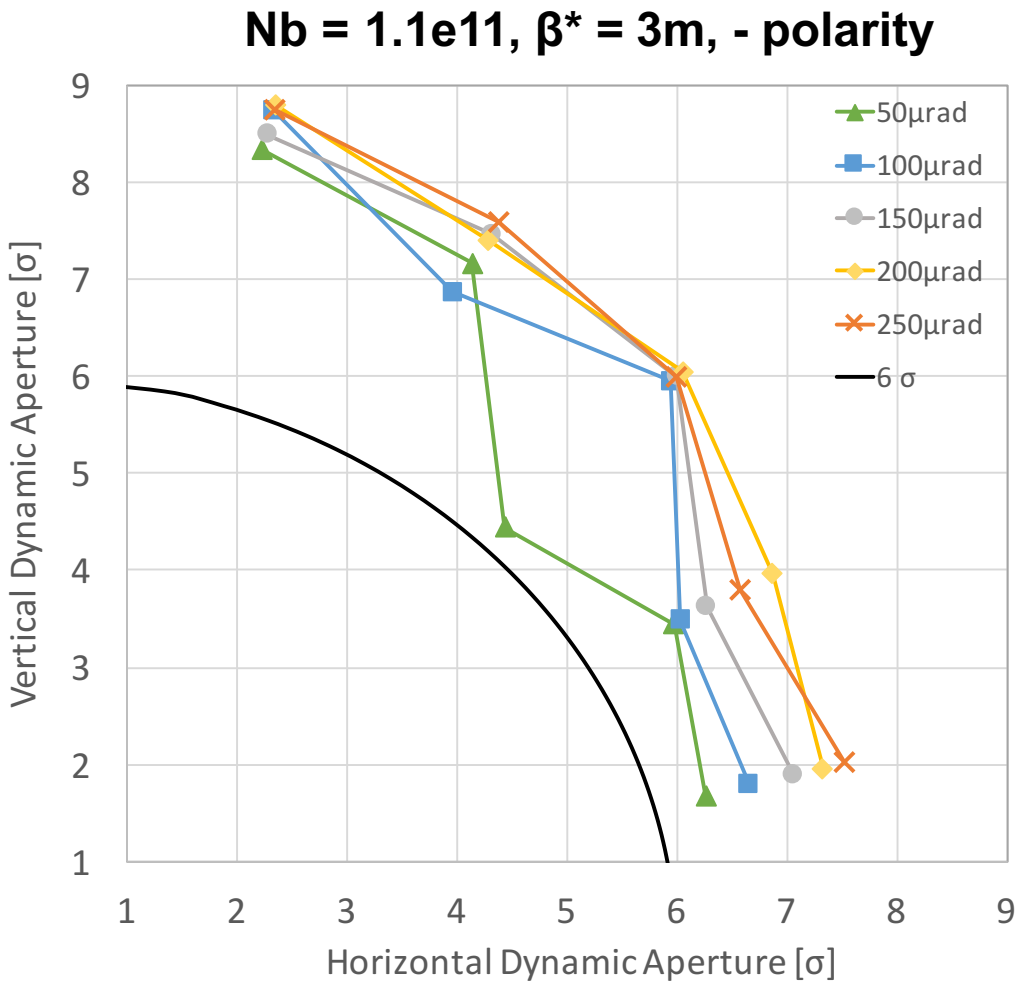
Crossing-angle scan

- Clear degradation of DA below -150 μrad (-15 μrad total)
- Lower crossing angles will suffer from collision points away from the IP



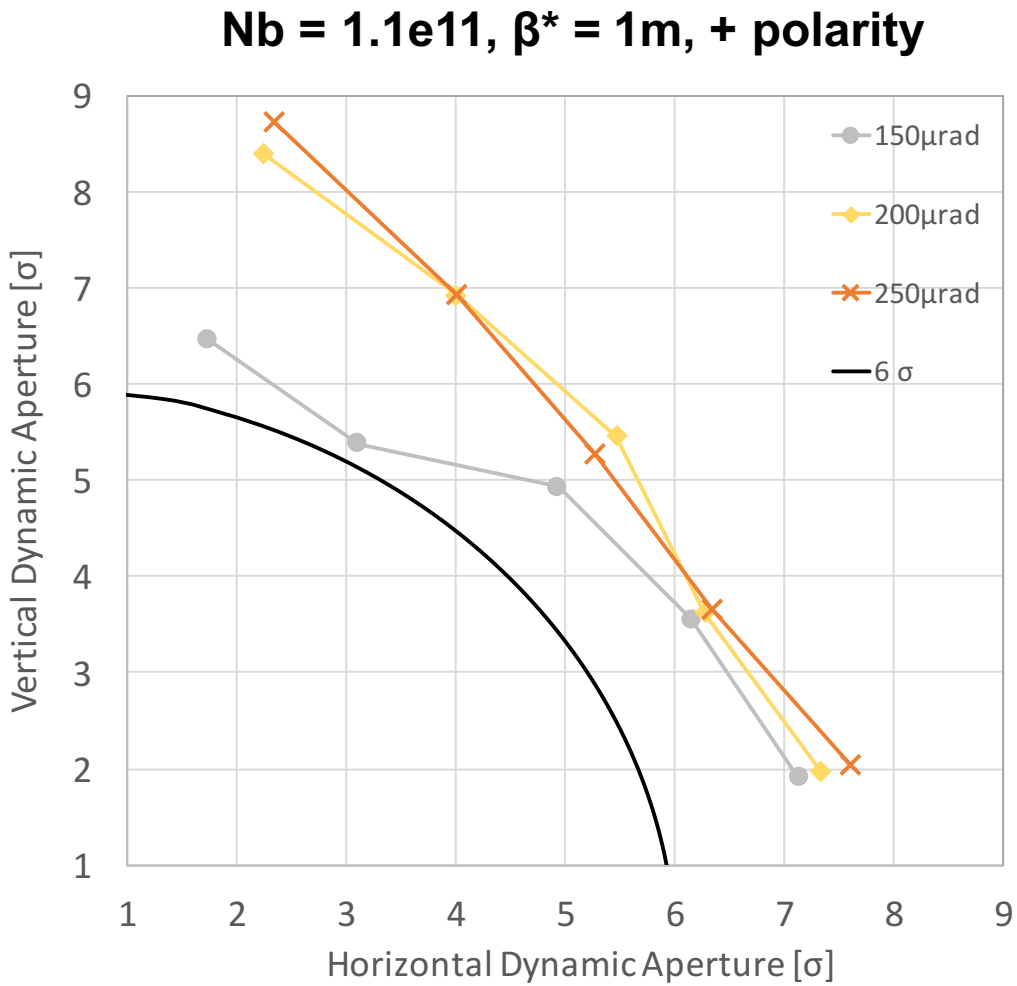
Crossing-angle scan

- DA not affected until external crossing angle of 50 μrad, (i.e. -185 μrad of total crossing angle)
- Only for crossing angle below 50 μrad, DA close to 6σ



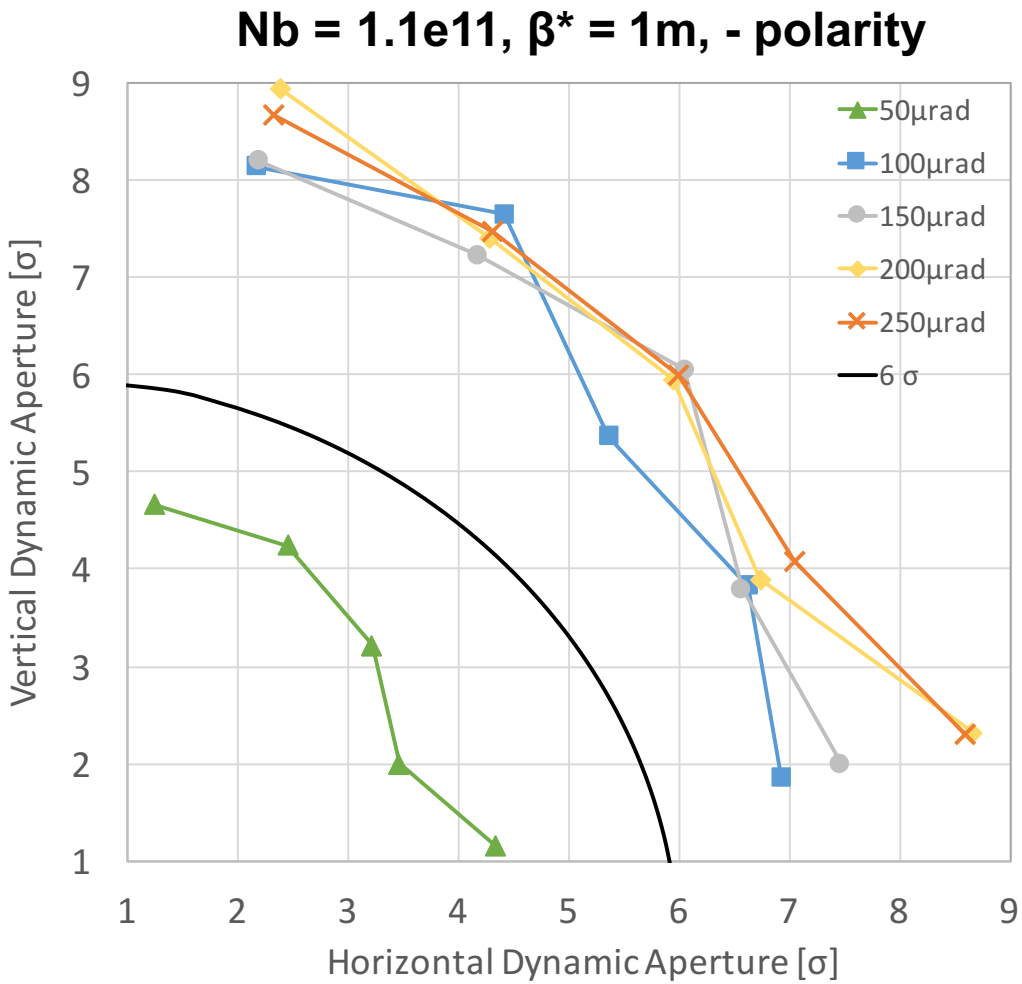
Crossing-angle scan

- Clear degradation of DA below -150 μrad (total crossing angle of -15 μrad)



Crossing-angle scan

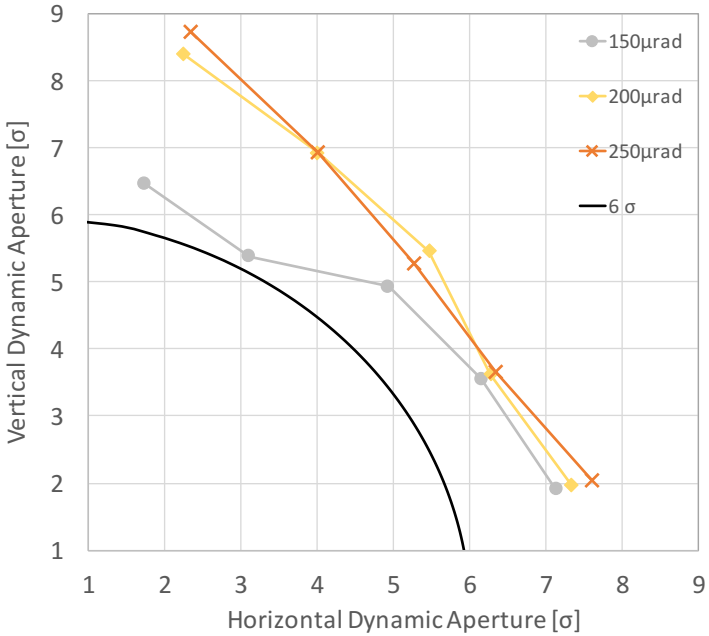
- Clear degradation of DA below -100 μrad (total crossing angle of -235 μrad)

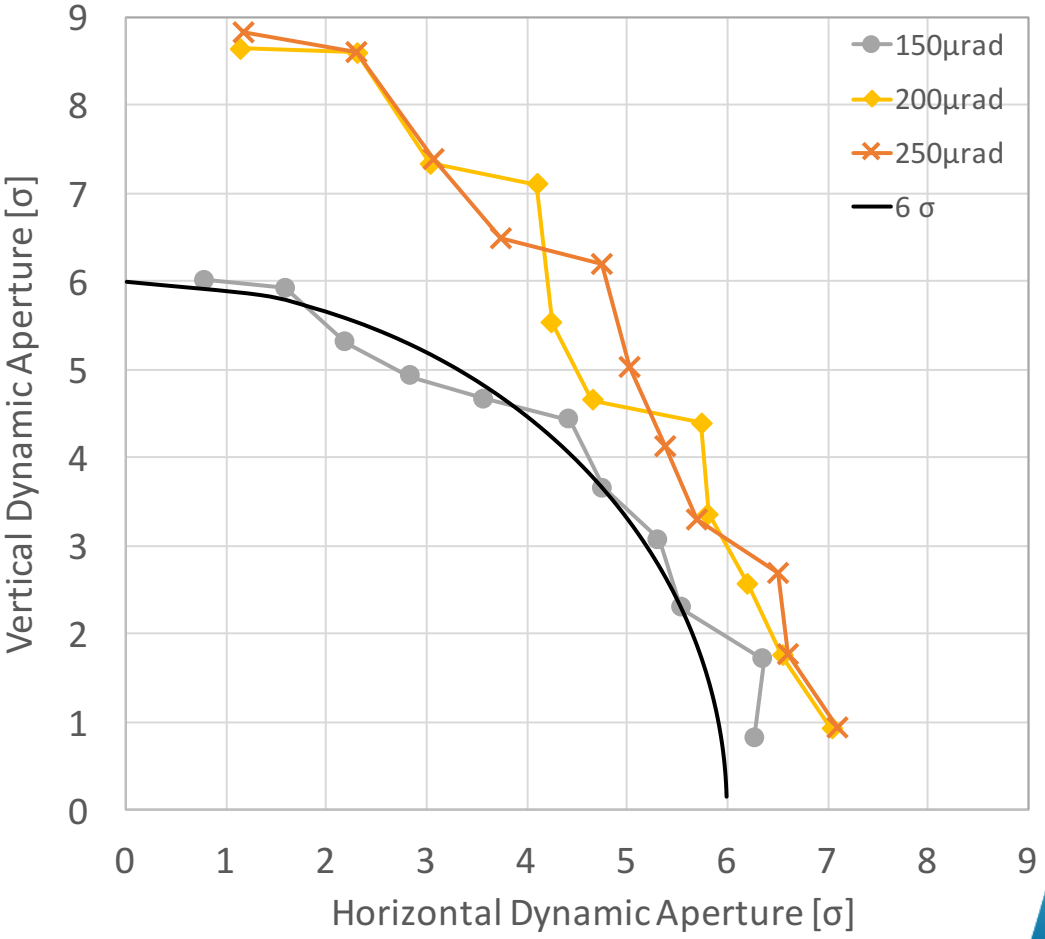


Crossing-angle scan – 6D BB

- Degradation of DA below -150 μrad (total crossing angle of -15 μrad) is confirmed

Nb = 1.1e11, β* = 1m, + polarity

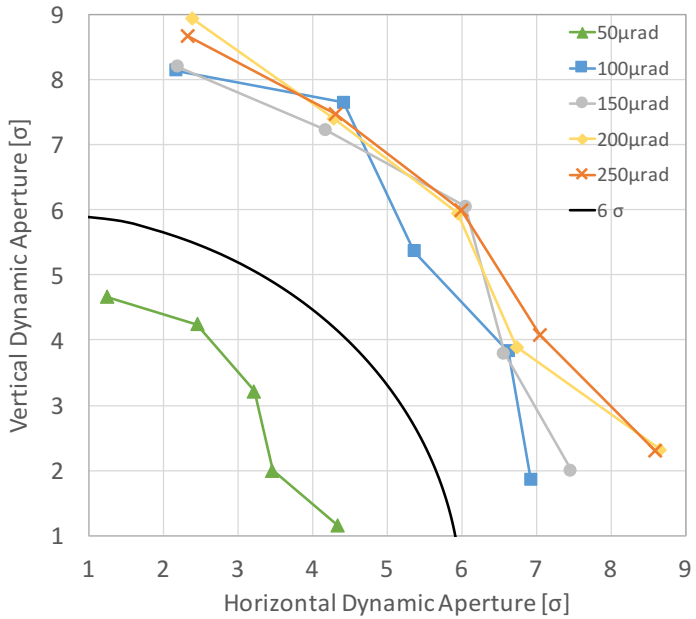


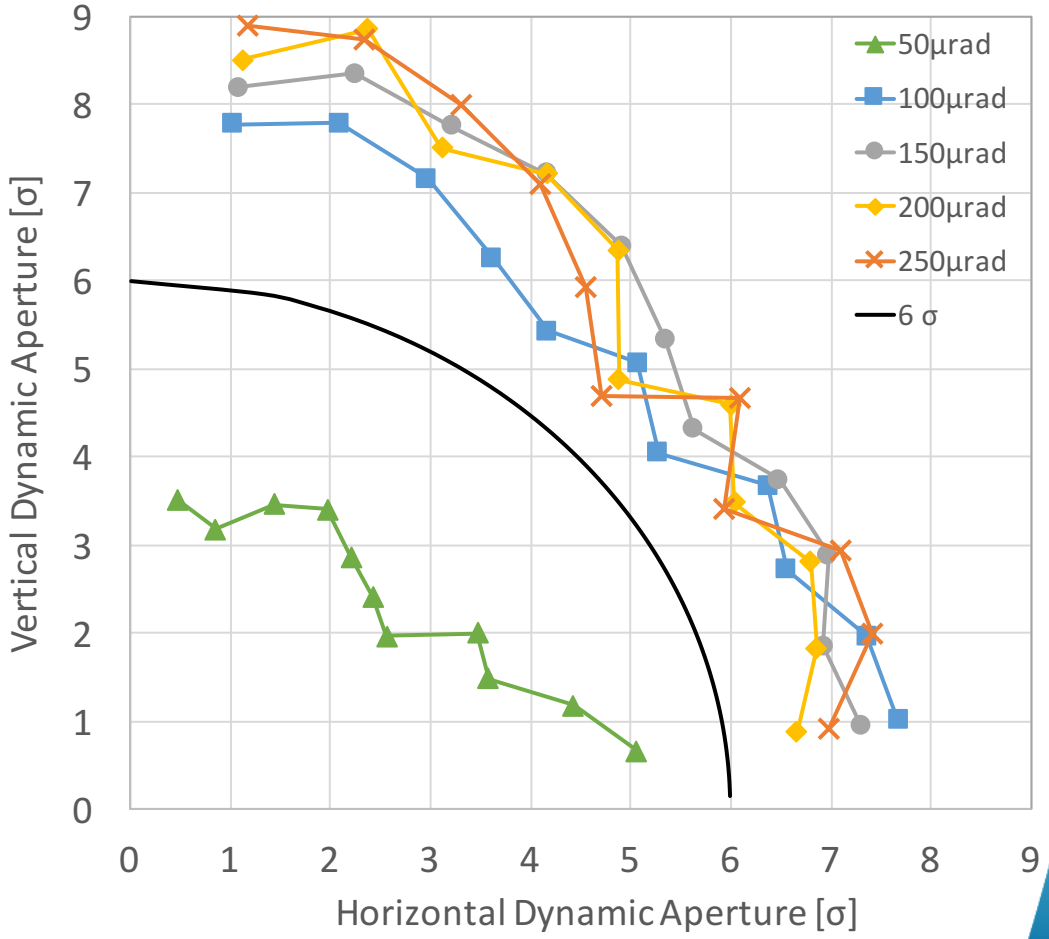


Crossing-angle scan – 6D BB

- Degradation of DA below -100 μrad (total crossing angle of -235 μrad) confirmed

Nb = 1.1e11, β* = 1m, - polarity





Conclusion and next steps

- Substantially more luminosity in LHCb have a limited impact in Atlas/CMS luminosities when burn-off only is considered as an additional source of lifetime reduction (beam-beam effects being addressed).
- Preliminary studies do not exclude $\beta^* = 1$ m and crossing angle below ~200 μrad for both polarities
- Hardware changes may be limited to TAS (magnetic shielding of MBXWS), additional TAN, TCL, TCDDM (fixed to movable) and additional shielding.

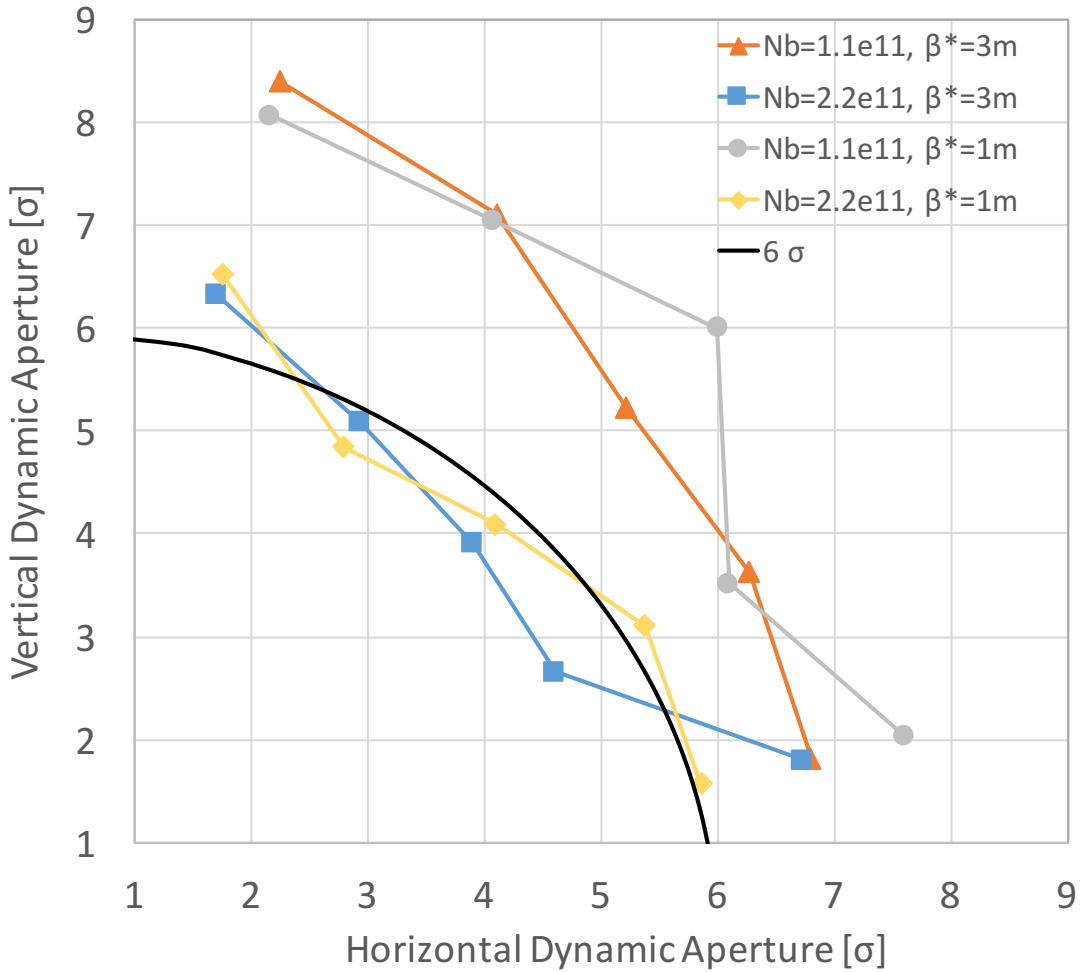
- Critical next steps to consider scenarios feasible:
  - Update luminosity and levelling scenarios with latest models.
  - Detailed optics and orbit scenarios.
  - Full evaluation of beam-beam effects: DA, pacman, coherent effects.
  - Collimation studies to confirm minimum aperture targets.
  - Energy deposition studies to confirm magnet lifetime.

Thanks for your attention

Additional slides

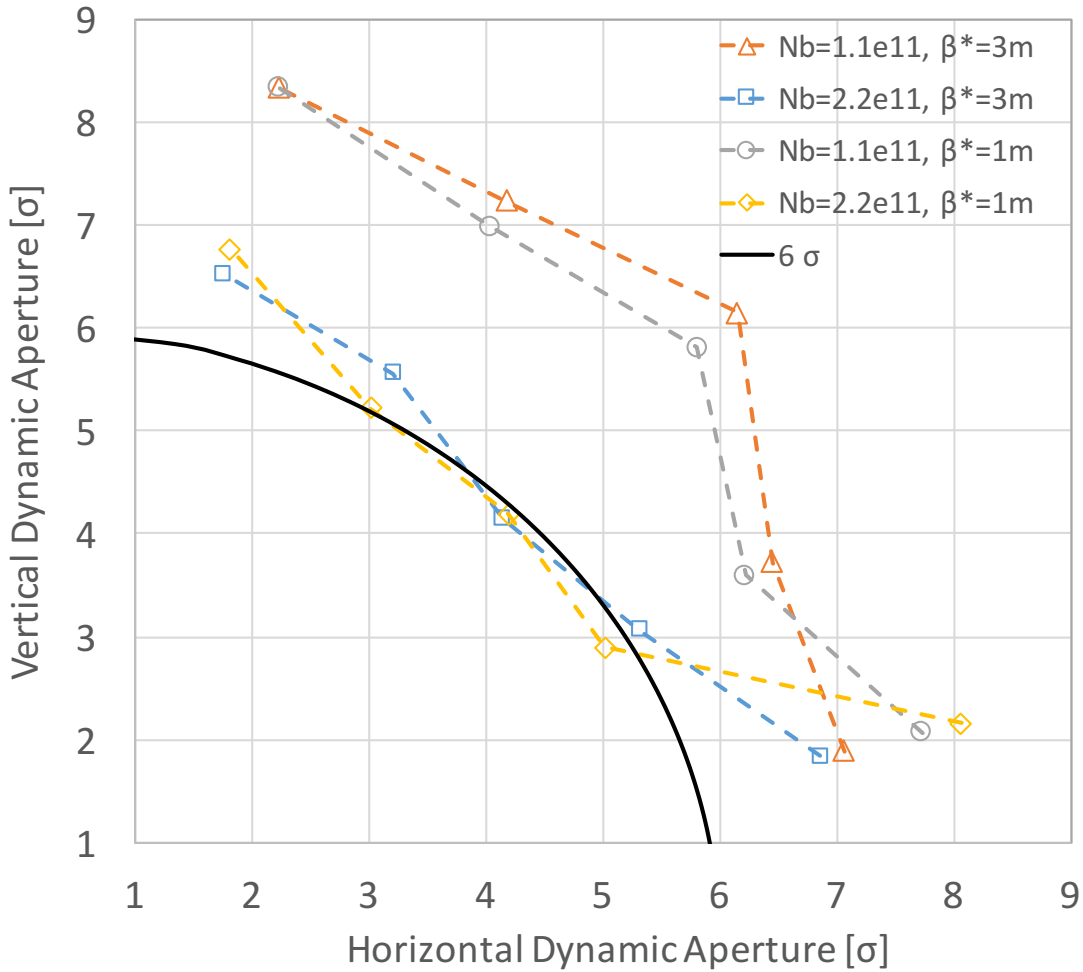
Crabs off - Positive polarity

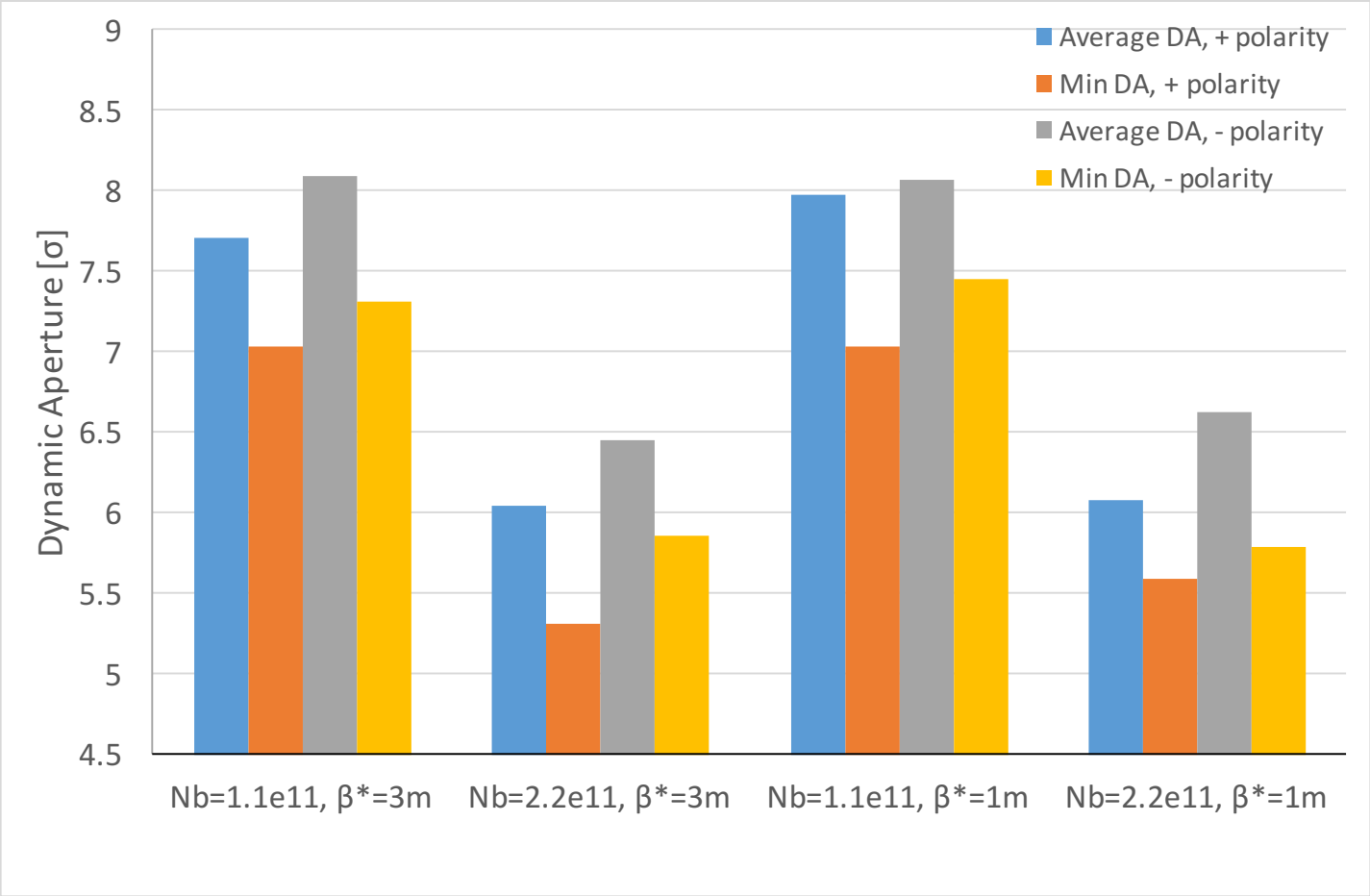
- Different β* in IR8 does not affect significantly the DA
- Only for high-intensity of 2.2e11, DA < 6 σ



Crabs off – Negative polarity

- Different β* in IR8 does not affect significantly the DA, for negative spectrometer polarity as well
- Only for high-intensity of 2.2e11, DA < 6 σ



Crabs off - summary

- Overall, slightly higher DA from negative spectrometer polarity (IR8 total crossing angle increase)