LHCb at High Luminosity: Update

R. De Maria
Thanks to G. Arduini, D. Banfi, C. Bracco, R. Bruce, X. Buffat, P. Campana, B. Di Girolamo, I. Efthymiopoulos, S. Fartoukh, M. Fitterer, F. Galan, M. Giovannozzi, R. Lindner, Y. Papaphilippou, T. Pieloni, E. Thomas, D. Tommasini, P. Schwarz, A. Valishev, G. Wilkinson.

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Motivation

Evaluate how LHCb can run at $1\text{-}2\cdot10^{34}$ $cm^{-2}s^{-1}$ after LSS4 without degrading ATLAS and CMS luminosities and with minimal machine changes.

Issues to address:

- Low beta* with sufficient beam-beam separation
- Layout changes for protection (evaluate whether a full TAS + TAN option can directly replace the mini TAN one)
- Determine:
  - maximum integrated luminosity with a limit at $2\cdot10^{34}$ $cm^{-2}s^{-1}$
  - Maximum integrated luminosity with constant levelled luminosity within a typical fill length

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

- Scaling and impact of additional burn-off without aperture constraints
- Integrated luminosity in Atlas/CMS substantially independent from LHCb one
- No levelling in LHCb if low β* not reachable.

G. Arduini

Recap

emittance =2.5 μm
Ap target 14.2 σ

First proposal:

- include also a new spectrometer and shift the IP
- Keep a frequent change of spectrometer polarity

Implications:

- New hardware needed to close the bump
- No coupling between polarity change and external crossing angle
- Larger β*/less luminosity for the same aperture target

β* [m]	Ext. angle [μrad]	Ap. IP nominal [$\sigma_{TCDDM}/\sigma_{MCBX}$]	Ap. IP shift [$\sigma_{TCDDM}/\sigma_{MCBX}$]
3	-500	18.6/22.5	18.0/18.2
2	-500	15.1/18.3	13.2/15.4
2	-600	12.2/14.9	10.0/11.9
1	-300	14.8/16.8	n/a
1	-400	12.7/15.3	n/a

High Luminosity LHC

Update from LHCb

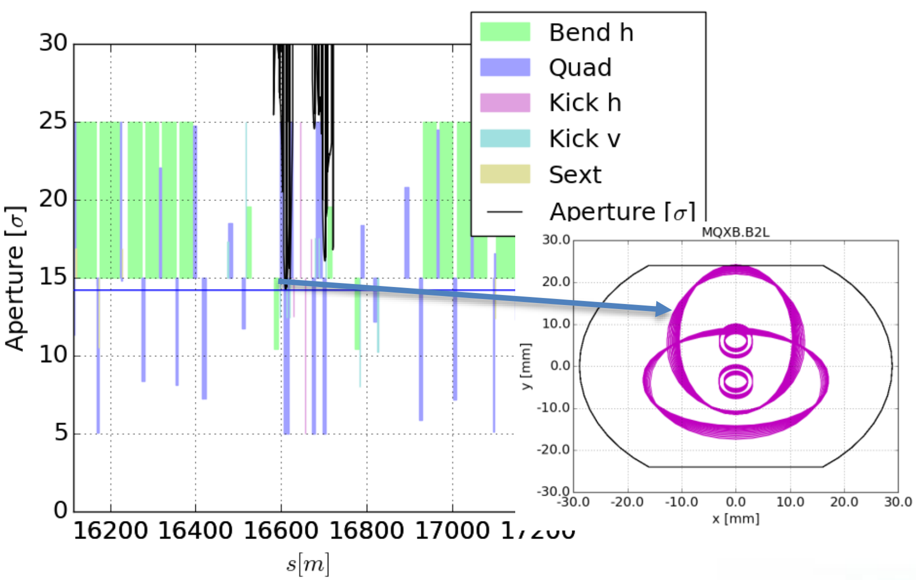
- The advantages the IP shift would bring do not payoff the loss in luminosity
- A scenario with a change of spectrometer polarity per year can be proposed if brings more luminosity

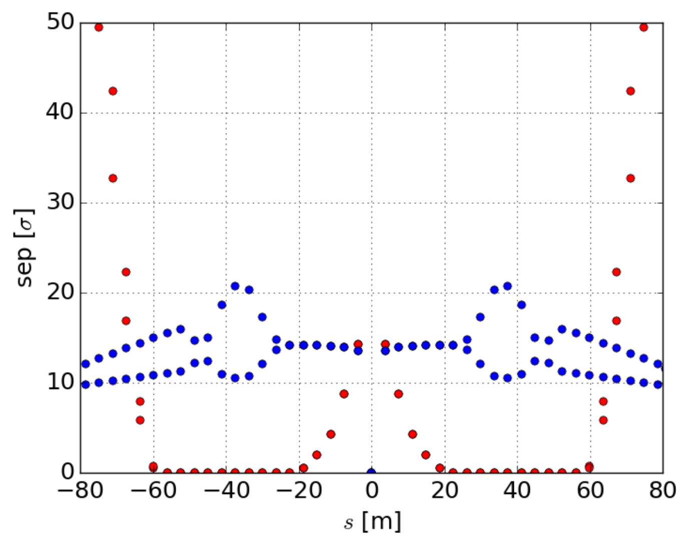
Implications:

- No need of new corrector dipole, more room for protection devices
- Additional freedom in the external crossing angle choices

Vertical crossing

- β* as low as 1 m found compatible with ATS optics.
- Vertical crossing angle 130 μrad compatible with 14.2 σ aperture (14.2 σ is the right (vertical) target for IR8 ?) and provides min. 10 σ BB separation.
  - V sign can be changed to spread radiation every year.
  - Neg. V offset can further improve aperture
  - Still room in H plane for additional ext. crossing angle and β_x reduction.
  - TCDDM not a bottleneck as with large H crossing angle.





Next Steps

- Perform BB DA simulations and evaluate Pacman effects to find minimal crossing angle H&V for β^*=1 m, 2 m, 3 m.
- Decide on a target aperture.
- Define a crossing angle gymnastic from injection to collision to rotate the crossing angle.
- Depending on the results iterate on
  - β^* and crossing angle values , as further optimizations are still possible.
  - apertures of protecting devices.

define a levelling strategy

High Luminosity LHC

References

W. Herr, Y. Papaphilippou, LHC report 1009

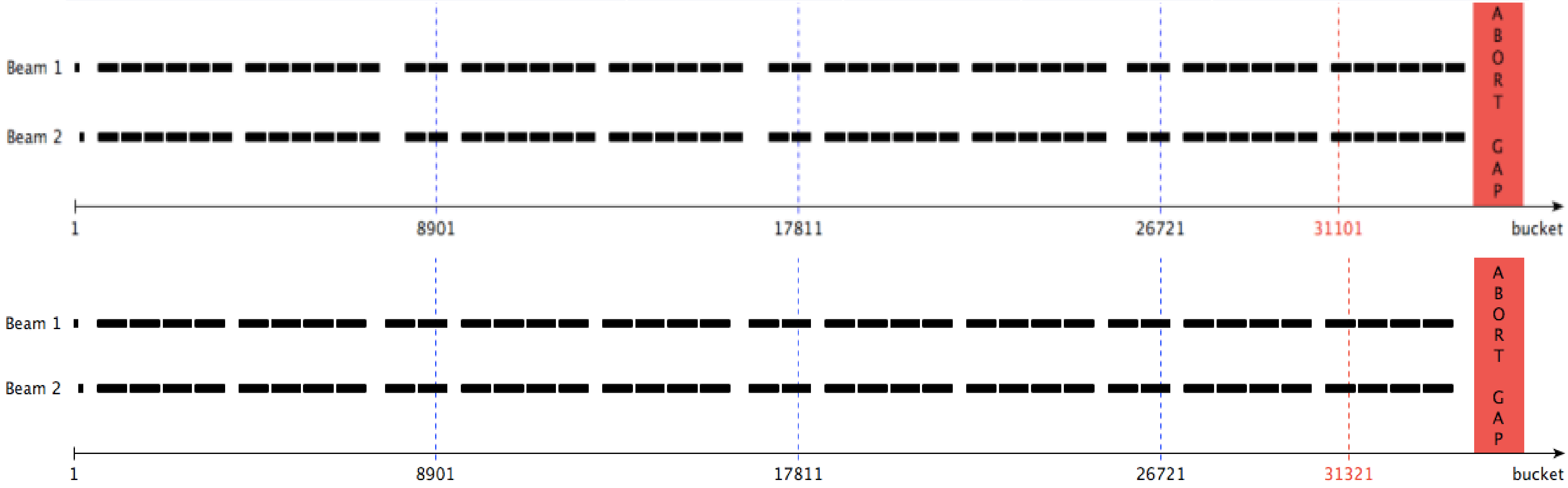
S. Fartoukh, LMC 167

Backup

Filling schemes

- Filling schemes 12 SPS injections:
- 2808-72 colliding bunches in IP1 and IP5, 12 non colliding bunches;
- Non colliding bunches or IP8/IP2 private bunches will be lost if have the same population of the other and not enough tune spread.

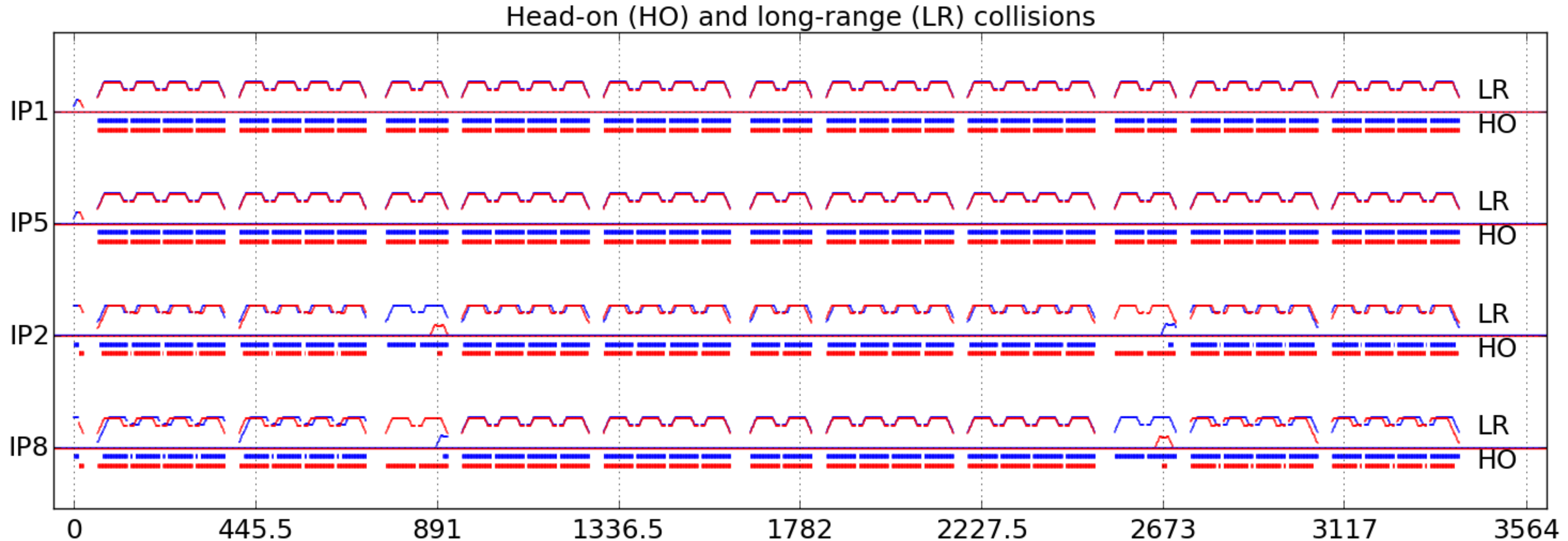
Filling scheme	Total	IP1-5	IP2	IP8
BCMS: 48b 6 Ps inj, 12 SPS inj	2604	2592	2288	2396
Standard: 72b 4 Ps inj, 12 SPS inj	2748	2736	2452	2524



B. Gorini

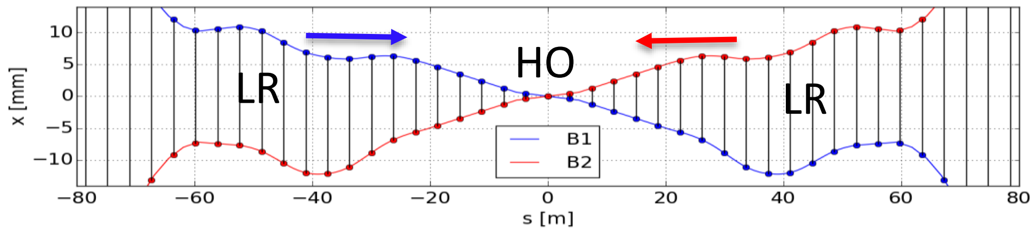
Filling schemes with IP8 shift

X. Buffat



	IP1&5	IP2	IP8 (shifted)
72b	2736	2466	2544 (2513)
72b+	2808	2255	2186 (2163)
80b	2800	2727	2626 (2592)
80b+	2880	2380	2350 (2342)

No big difference for IP8 shift.



Not possible to fully avoid strong pacman and super-pacman effects in IP2 and 8 (regardless of the shift)

Beam-beam effects

HO interactions create:

- tune spread beneficial for instabilities
- when coupled strong with nonlinearities (LR effects, triplet field imperfections, residual arc sextupole/octupoles aberrations) and Q’ beam current/luminosity lifetime reductions
- when coupled with noise, increased emittance growth,
- β -beating and dynamic β effects
- Parallel separation reduces head-on effects as luminosity

LR interactions create

- tune spread: important without HO collision
- nonlinearities: stronger with small β* (large β at the interactions point) and small crossing angle,
- tune shifts, orbit effects and chromaticity effects
- and those effects are bunch dependent due to pac-man.

Levelling strategies

β* and parallel separations (to extent bunches are stables) are effective levelling mechanism however:

- β* leveling important to reduce the effect of the LR in IP1/IP5
- β* leveling is operationally difficult for keeping IP orbit stable during optics transitions (solvable with effective IP orbit feedback).
- simultaneous β* leveling in IP8 and IP1 is even more complicated since ATS scheme couples the two insertion (needs to commission N^2 optics transition or anticipate luminosity evolutions and freeze β* steps in both IP1 and IP8).

After LS4 LHCb might need to run full head-on from the beginning, differently from the nominal scenario.

Can this change the overall preferred levelling strategy?

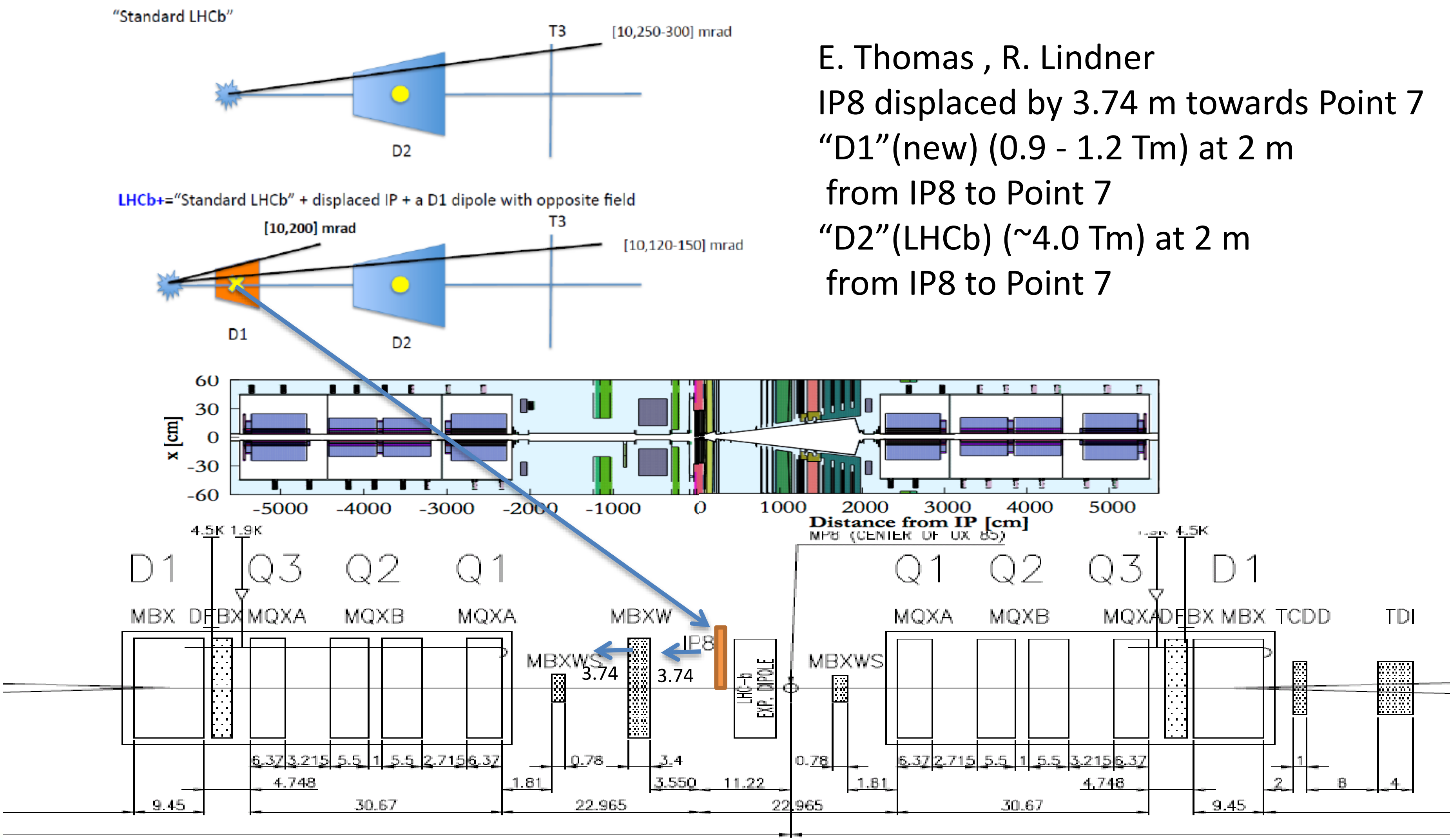
If head-on limited, separation leveling can helps.

If LR limited, β*leveling helps, besides it would also allow savings in pick dose if geometrical crossing angle can be reduced during the first part of the fill .

LHCb new layout

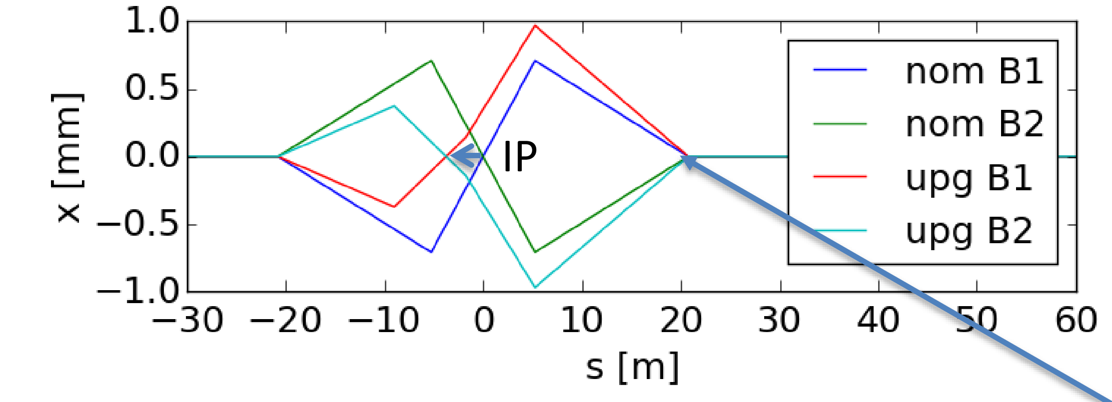
A previous scenario with 3.74 m and 7.48 m shift, no additional dipole was developed by B. Schmidt and S. Fartoukh.

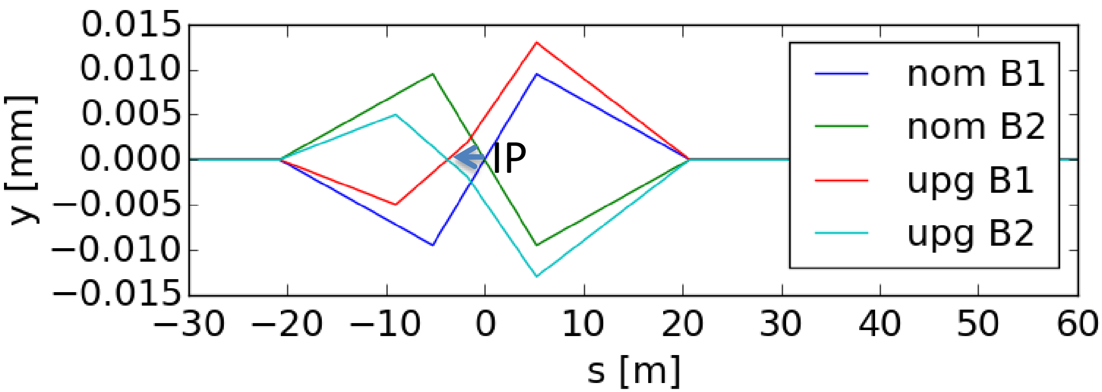
E. Thomas , R. Lindner
IP8 displaced by 3.74 m towards Point 7
“D1”(new) (0.9 - 1.2 Tm) at 2 m from IP8 to Point 7
“D2”(LHCb) (~4.0 Tm) at 2 m from IP8 to Point 7



Internal Bump

Orbit at top energy





Crossing angles for flat machine

	Nom	Upg.
x' [μrad]	±135	±118
y' [μrad]	±1.81	±1.58

Based on MBNW of 1.1 Tm
Range allowed 0.9-1.2 Tm.

Stronger MBXWS.R8 (+37%):
+10% possible at the cost of field quality (P. Schwarz).
Can it be replaced with stronger one?

Other options: not closed bump or shifted IP crossing to be recovered with external bumps can save replacing MBXWS -> may complicate operations.

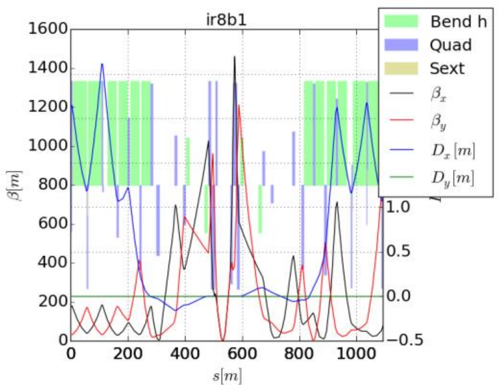
Update Layout

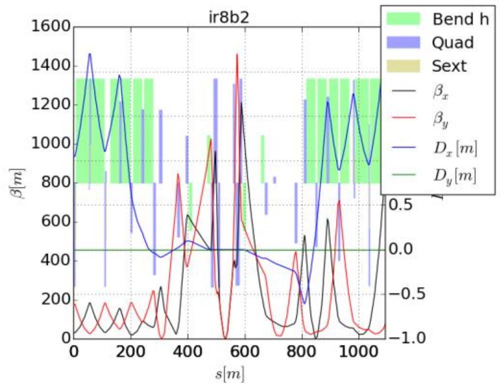
Element	Specification	Pos. nominal	Pos. "upgrade"
MQXA.1L8	205 T/m, 6.37m	-26.15 m	-26.15 m
L*		-22.965 m	-22.965 m
BPMSW.1L8		-21.595 m	-21.595 m
MBXWS.1L8	1.41 T, 0.78 m	-20.765 m	-20.765 m
MBXWH.1L8	1.24 T, 3.4 m	-5.25 m	-5.25-3.74 m
IP8N		n/a	-3.74 m
MBNW ("D1")	0.9-1.2 Tm	n/a	2-3.74 m
IP8		0 m	0 m
MBLW.1R8 ("D2")	3.636 T, 1.1m	5.25 m	5.25 m
MBXWS.1R8	1.9 T, 0.78 m	20.765 m	20.765 m
BPMSW.1R8		21.595 m	21.595 m
MQXA.1R8	205 T/m	26.15 m	26.15 m

High Luminosity LHC

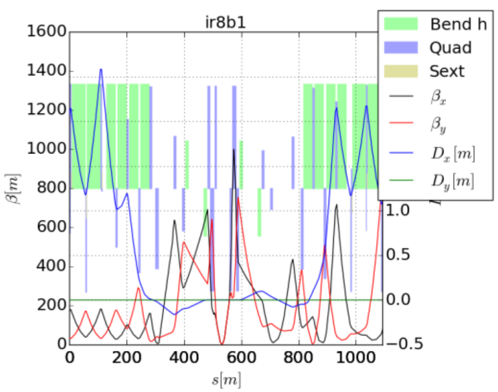
Optics with IP shift

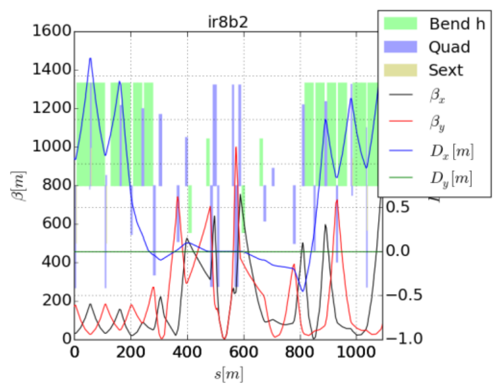
2m, ATS round





3m, ATS round





Beam 1

Beam 2

Difficult to reduce it below 1.8 m.
Right triplet not well matched
-> aperture bottleneck could be smoothed with triplet strength.

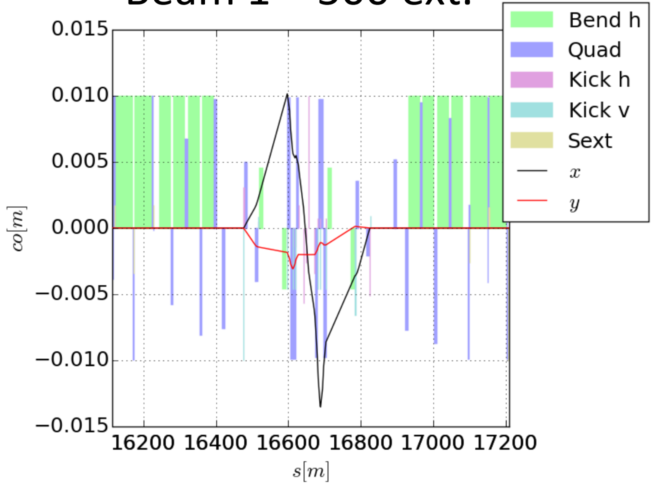
Triplet powering scheme has a limited range for Q1 Right (6450A@ 205T/m):
For <185 T/m and 600 A Q1 trim not sufficient

Is it worth change/double trim power converter?

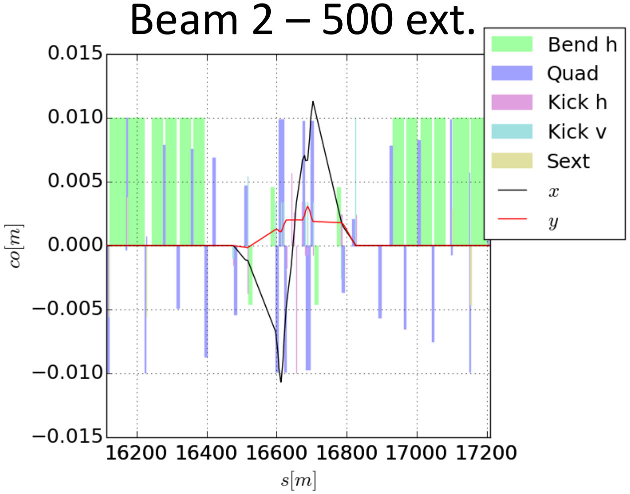
For injection aperture we need detail on the new vacuum chambers.

Crossing scheme

Beam 1 – 500 ext.



Beam 2 – 500 ext.



Used same philosophy of present operation to control the LR:

at injection with parallel separation

at collision use large H crossing angle with bad polarity

For the good polarity possible to reduce the angle or reduce β* for higher luminosity and higher pile-up the beginning of the fill.

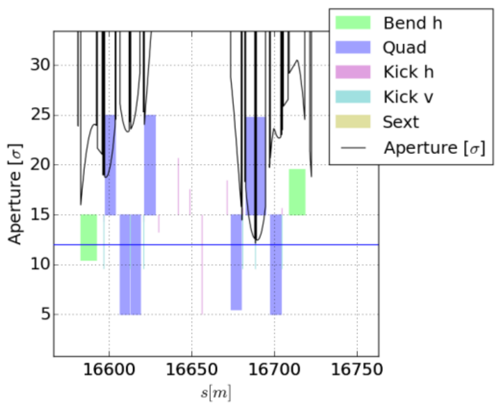
Is it worth/desirable?

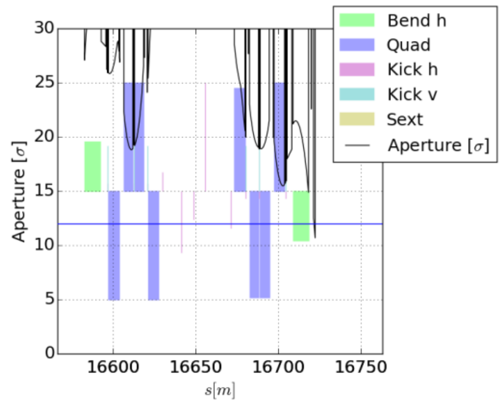
Alternative strategy, e.g. 45°, 90° crossing plane not considered at the moment.

Any preference from the experiment side?

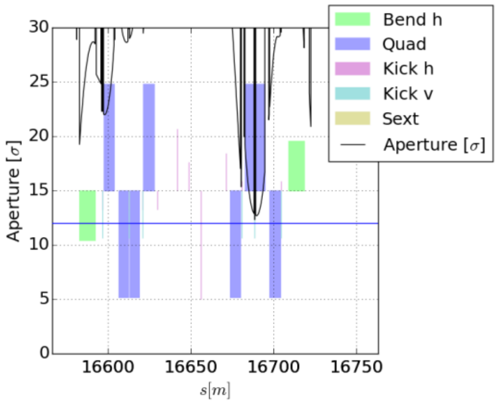
Apertures with IP shift

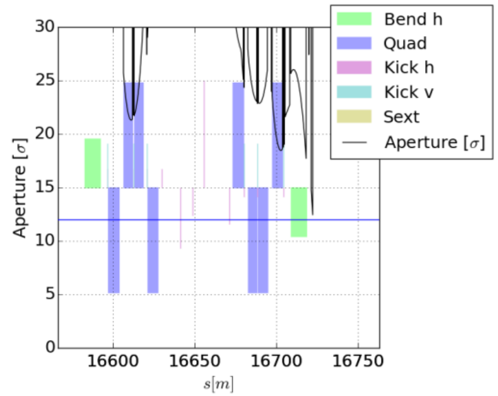
2m, 390 µrad





3m, 600 µrad





Beam 1 Beam 2

With worst (for aperture) spectrometer polarity and no IP transverse shift.

For β*=2 m: 350 µrad limit full crossing due to TCDDM for Beam 2 and 380 µrad limited in triplet for Beam 1.

For β*=3 m: 600 µrad limit full crossing due to TCDDM for Beam 2 and triplet for Beam 1.

Can we have a movable jaw for the TCDDM?

Aperture and optics with IP shift allow smaller β* reach.

Maximum allowed ext. crossing angle

β* [m]	Ext. angle [μrad]	Ap. IP nominal [$\sigma_{TCDDM}/\sigma_{MCBX}$]	Ap. IP shift [$\sigma_{TCDDM}/\sigma_{MCBX}$]
3	-500	15.7/19.0	15.2/15.4
2	-500	12.8/15.5	11.2/13.0
2	-600	10.3/12.6	8.5/10.1
1	-300	12.5/14.2	n/a
1	-400	10.7/12.9	n/a

- IP shift has larger β* for the same aperture.
- The mask TCCDM should replaced with a movable device if possible.
- For injection, no change with respect to the baseline if bump is closed. Details of the new vacuum chambers are needed.

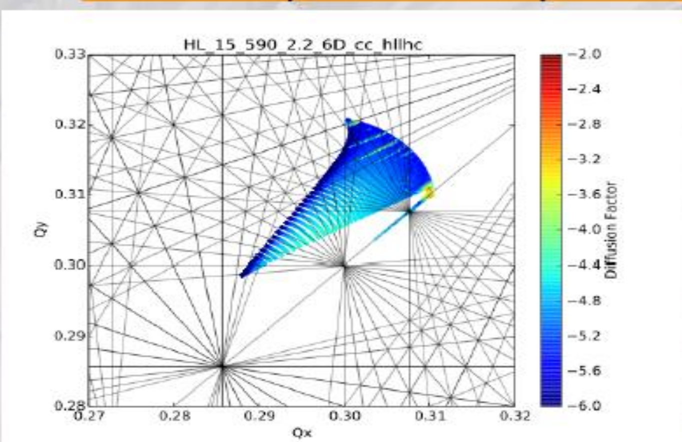
Shall we aim at 12σ in IR8 like in IR1 and IR5?
Minimum crossing angle to be found looking at beam-beam LR effects.

IP8 Crossing angle scans

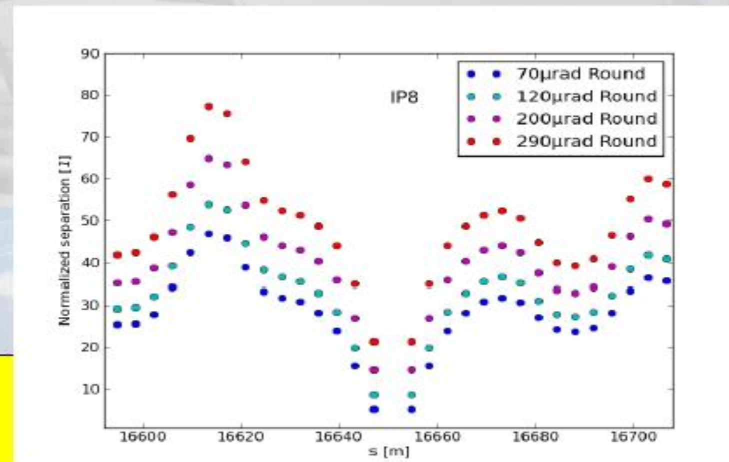
HLLHCV1.0: effect of IP8

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

IP1 & IP5 only HLLHCV1.0 optic



Int ppb 10	DA No Err No IP8
1.0	8.41
2.2	6.42



Full head-on from IP8 DQ = - 0.01

Three cases for IP8 LRs at 3m β^*:

- α_{IP8} = 610 μrad → all LR d_{sep} > 43 σ
- α_{IP8} = 290 μrad → 2 LR with d_{sep} 20σ all others LR d_{sep} > 38 σ
- α_{IP8} = 70μrad → 2 LR with d_{sep} 5σ all others LR d_{sep} > 15 σ

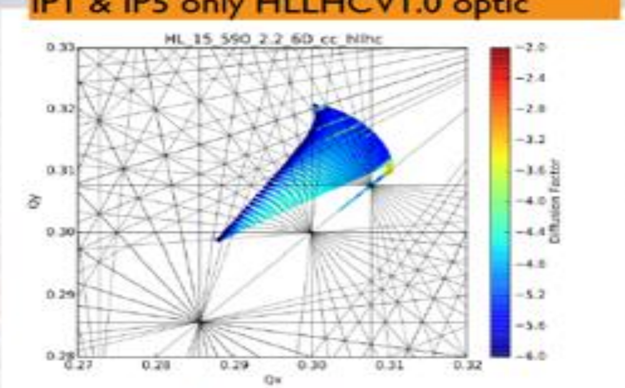
9

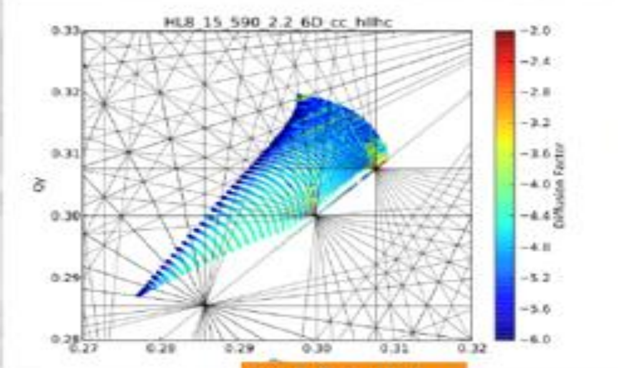
D. Banfi, J. Barranco, T. Pieloni
WP2 meeting 20/3/2015

IP8 Crossing angle scans

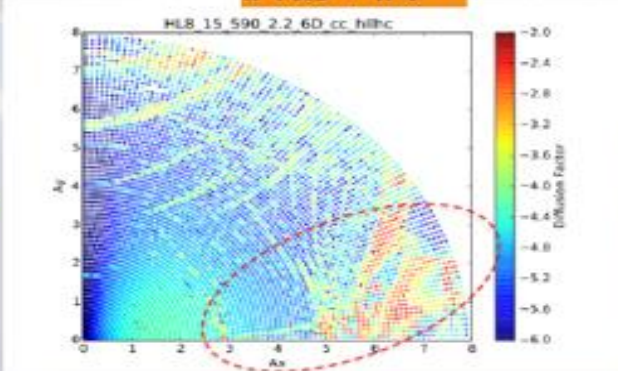
HLLHCV1.0: effect of IP8

IP1 & IP5 only HLLHCV1.0 optic





IP1&5 + IP8



	No IP8	IP8 610μrad (neg spectr)	IP8 290μrad (pos spectr)	IP8 70μrad (pos spectr)
1.0	8.41	8.07	7.93	7.72
2.2	6.42	6.28	6.06	5.86

LHCb spectrometer add +/- 270 μrad, depending on polarity

Full head-on from IP8 DQ = - 0.01
Three cases for IP8 LRs at 3m β*:

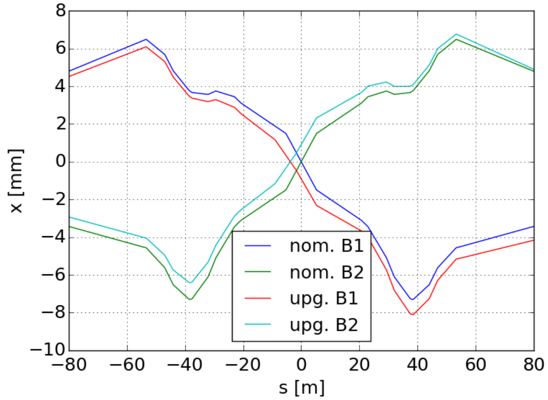
- α_{IP8} = 610 μrad → ΔDA = -0.35@2.2e11 (0.14@1.0e11) σ
- α_{IP8} = 290 μrad → ΔDA = -0.5@2.2e11 (0.36@1.0e11) σ
- α_{IP8} = 70μrad → ΔDA = -0.7@2.2e11 (0.56@1.0e11) σ

10

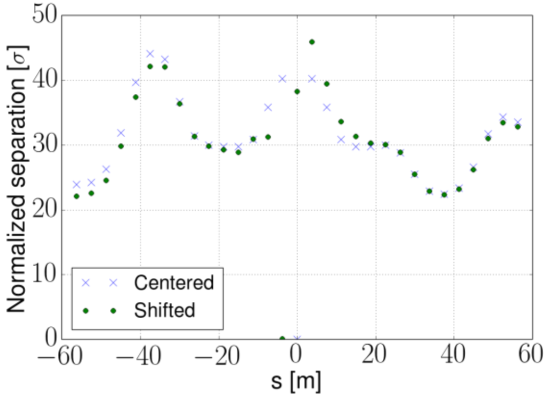
D. Banfi, J. Barranco, T. Pieloni
WP2 meeting 20/3/2015

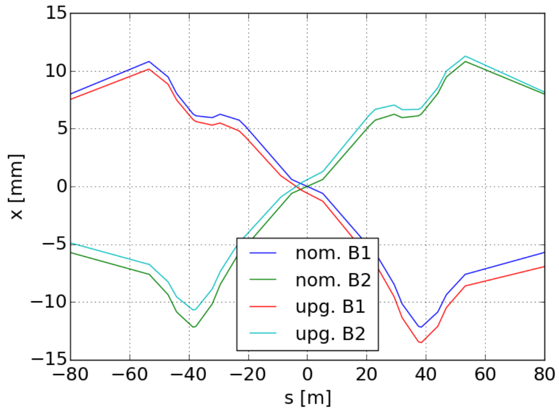
Margins in DA available w.r.t. baseline in IP8 crossing angle if not taken by Q', MO, pacman.

Long range with new layout

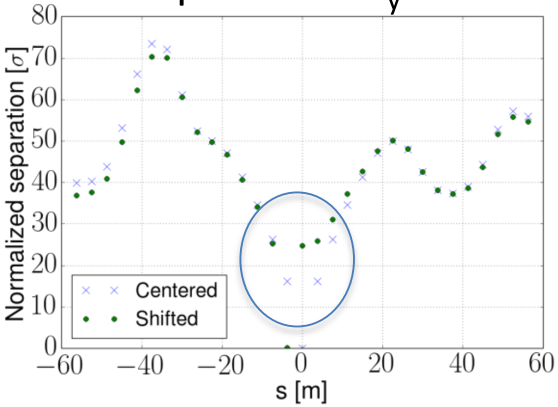


-300 μrad ext. $B_y>0$





-500 μrad ext. $B_y<0$



X. Buffat

Beneficial effect of the new dipole

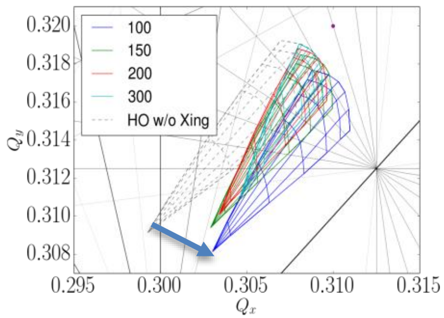
Minimum crossing angle due to LR

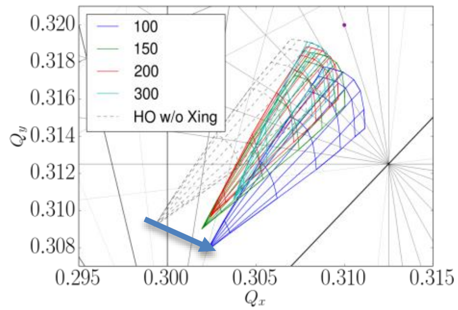
β*= 3 m
Without shift

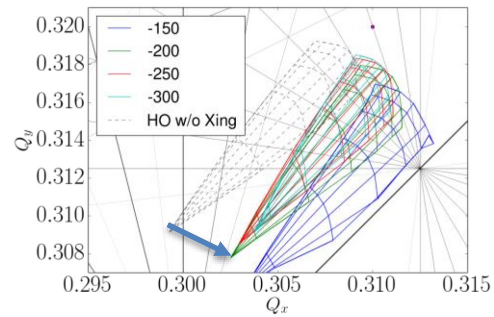
β*=3 m
With IP shift

β*=2 m
With IP shift

$B_y>0$

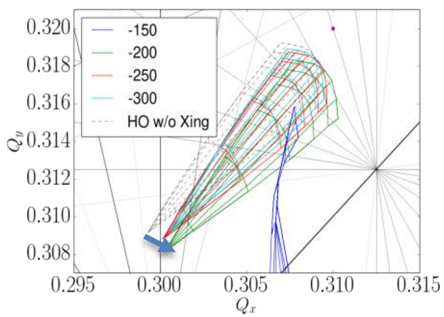


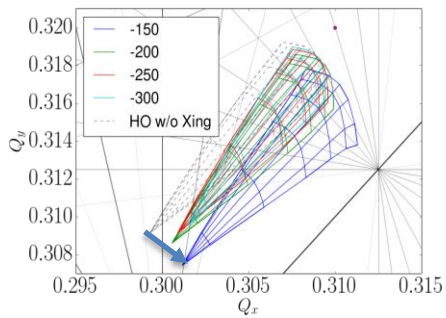


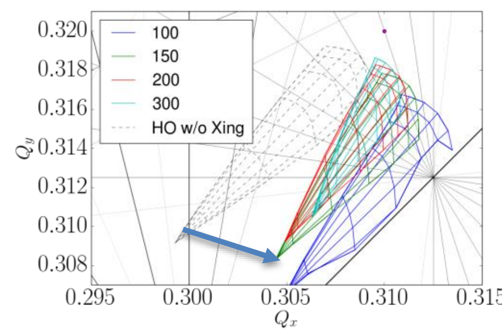


Legend:
half external crossing angle

$B_y<0$







X. Buffat

Pacman dependent shift is the dominant issue for reducing β*.
Footprint give first indications, DA simulations with crossing angle scan and impact of pacman necessary to formulate a specification.

Wrap-up

- Assuming substantially more luminosity in LHCb have a limited impact in Atlas/CMS luminosities.
- The new LHCb experimental scheme can be implemented in the machine, with stronger MBWXS on the right.
- The TCDDM on the right limits the β* reach of IP8 before the triplets, a movable device would be beneficial.
- Increasing range in the Q1 trim, will allow more optimal optics.
- The β* reach and therefore expected integrated luminosity depends:
  - on the minimum crossing angle allowed by beam-beam effects
  - the minimum aperture allowed by collimation system.
- Next step:
  - evaluation of the pacman effects on orbit, tune shift, Q' shifts and noise
  - weak-strong simulations for several pacman classes to estimate the minimal crossing vs β*
  - collimation studies with additional aperture bottleneck