HiLumi
HL-LHC PROJECT

Potential performance reach for the HL-LHC in case of a depleted beam halo

G. Arduini – BE/ABP

Review of the needs of a Hollow Electron Lens for HL-LHC – 7/10/2016

Mode of operation (nominal)

$$L = \frac{kN_b^{\ 2} f \gamma}{4\pi \beta^* \varepsilon^*} F$$

- Operation at pile-up/pile-up density limit (set by the experiments) by choosing parameters that allow higher than design pile-up (140 events) / pile-up density (<1.3 events/mm):
  - Beam brightness and in particular bunch population to sustain burn-off over long periods ➔ LHC Injector Upgrade
  - Maximize number of bunches to minimize pile-up ➔ 25 ns
  - Low β^* optics
  - Large crossing angle to minimize the beam-beam effects
  - Fight the reduction factor F by crab crossing

- Improve 'Machine Efficiency' ➔ minimize the number of unscheduled beam aborts

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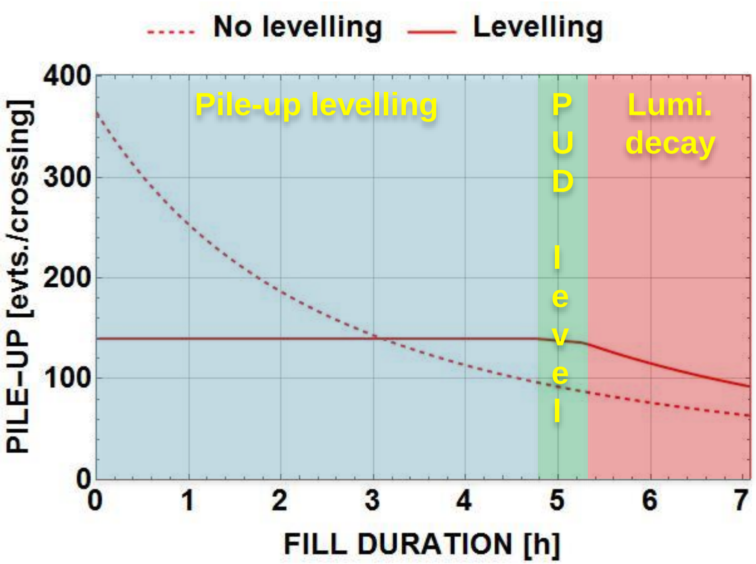
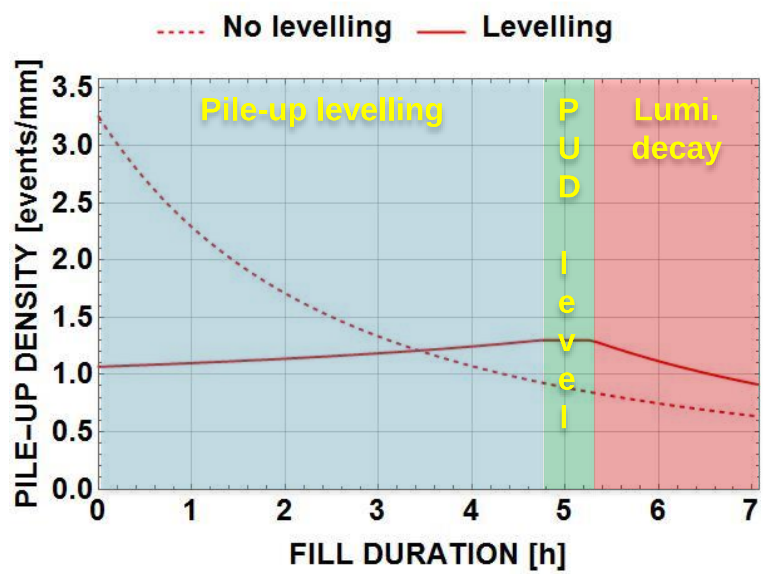
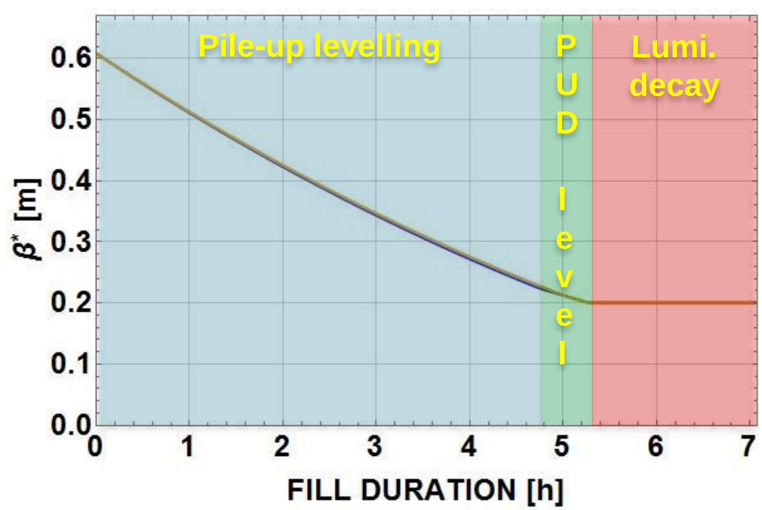
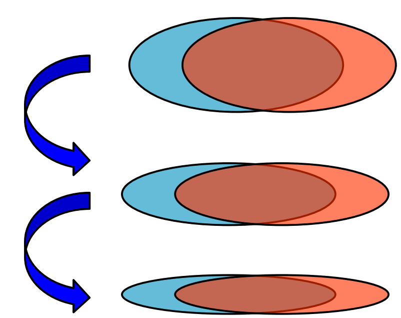
Mode of operation (nominal)

$$L = \frac{kN_b^{\ 2} f \gamma}{4\pi \beta^* \varepsilon^*} F$$

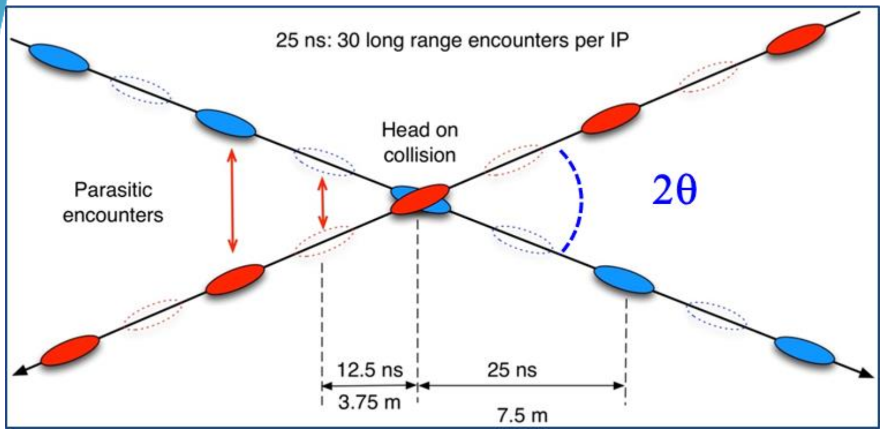


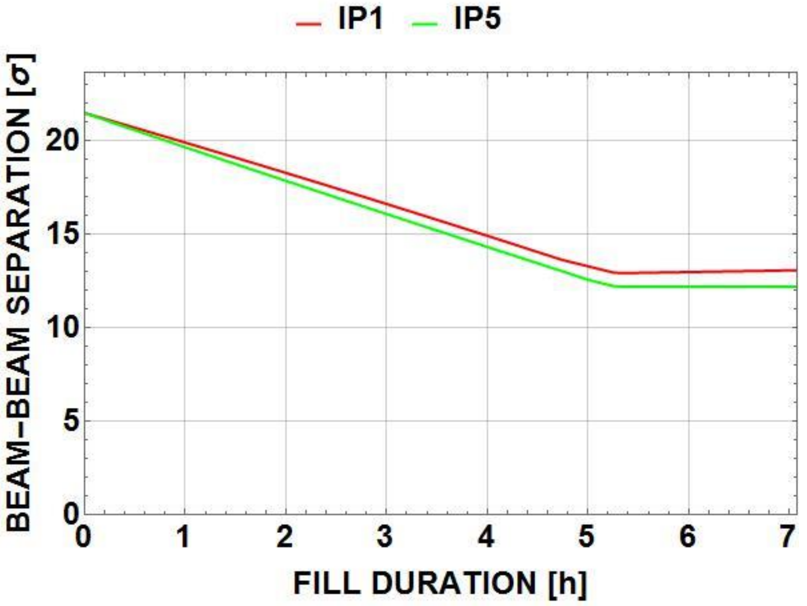




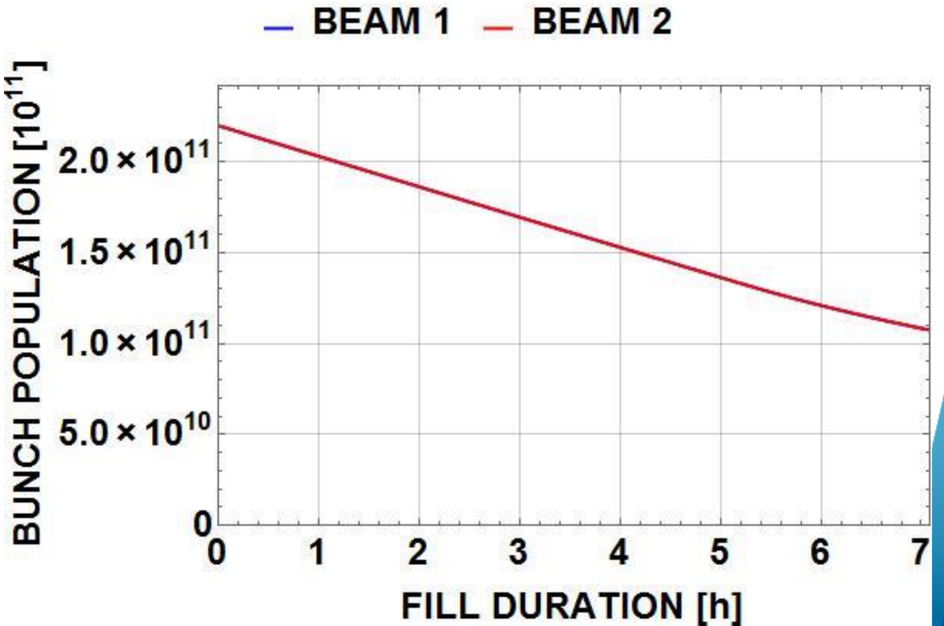


Beam-beam and β* levelling





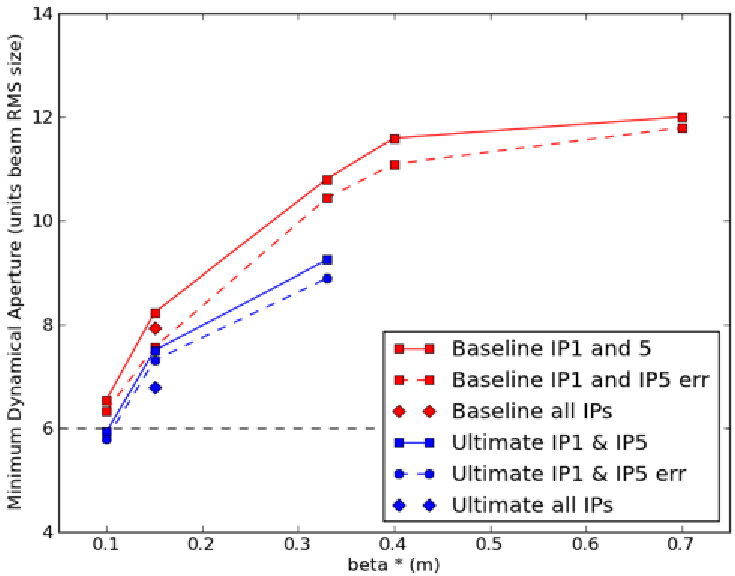
- β* levelling allows operating with larger long range beam-beam separation when the bunch population is larger



Beam-beam and β* levelling

- Soft way to go in collision initially with lower long range effects
- On the other hand it has not been proven in operation yet and the alternative (levelling by separation) might imply larger loss spikes.

Beam sigma (ε*=2.5 μm) !!



D. Banfi, J. Barranco, T. Pieloni, A. Valishev

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Potential performance reach with HEL

- Starting assumption:
  - Nominal HL-LHC collimator settings consistent with machine protection and operation with crab cavities
  - If not, opening of the collimators beyond the present values would impact the protected aperture and therefore performance and in that case halo control would become mandatory

- Looked for a rather aggressive scheme
- Assuming that the hollow electron lens can cut the tail down to 3 beam σ:
  - We can keep a margin of 1.5 sigma for crab cavity failures and therefore position the primaries at 4.5 σ
  - Keep the retraction of the secondary and tertiary collimators constant in mm

Potential performance reach with HEL

- Collimator settings in collision:

	Present (TDR) (ε_n=2.5 μm)	With HEL (ε_n=2.5 μm)
TCP (LSS7)	6.7	4.5
TCSG (LSS7)	9.1	6.9
TCSG (LSS6)	10.1	7.9
TCDQ (LSS6)	10.6	8.4
TCT (LSS1/5)	12.4	10.2
PROTECTED APERTURE	14.2	12

Potential performance reach with HEL

- Potential gain in β^*:
  - 20 ➔ 16 cm
  - down to 13 cm if we reduce margin TCT/TCDQ as for LHC with appropriate phase advance MKD/TCT – but this is independent of electron lens
- In addition we could imagine to keep the crossing angle constant in sigma instead of keeping it constant in μrad given the expected lower sensitivity to loss spikes (short time scales) in the presence of HEL when going in collision (provided that dynamic aperture remains larger than the halo-cleaned aperture)

Potential performance reach

- Collimator settings in collision:

	Present (LHC) (ε_n=2.5 μm)	With HEL (ε_n=2.5 μm)
TCP (LSS7)	6.7	4.5
TCSG (LSS7)	9.1	6.9
TCSG (LSS6)	10.1	7.9
TCDQ (LSS6)	10.1	7.9
TCT (LSS1/5)	11	8.8
PROTECTED APERTURE	12.2	10

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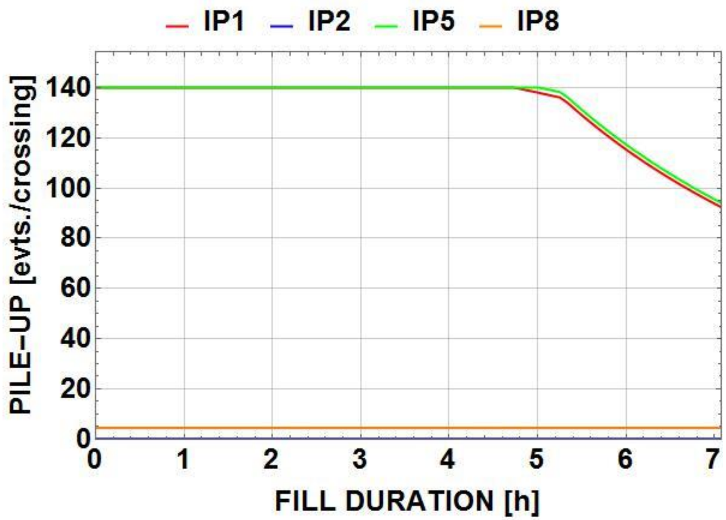
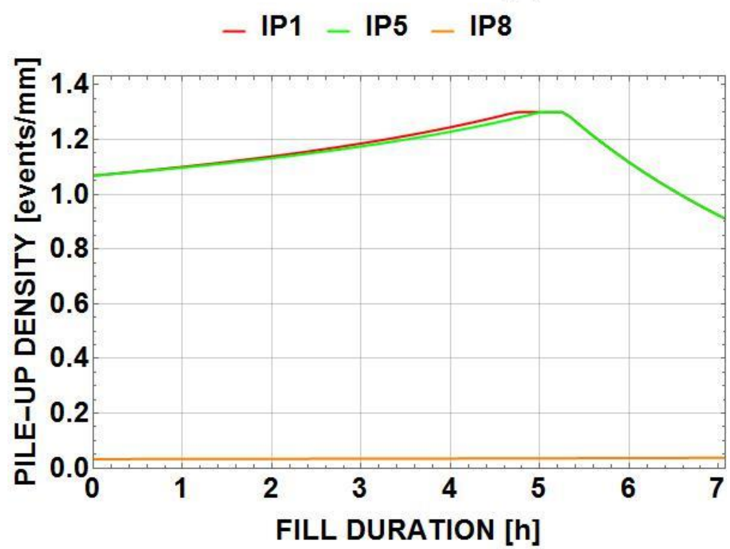
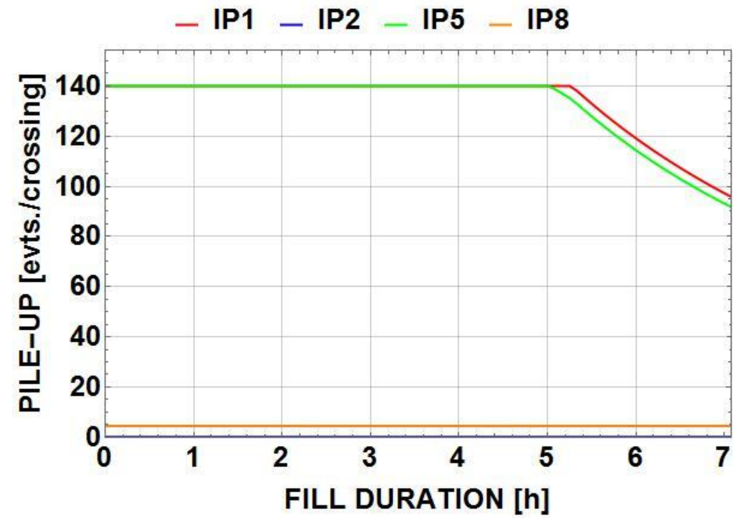
Round Optics

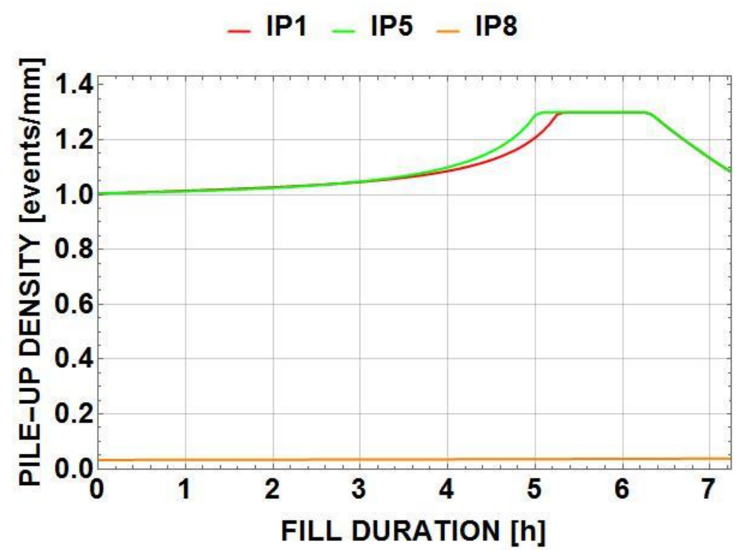
β*=20 cm
Constant crossing angle





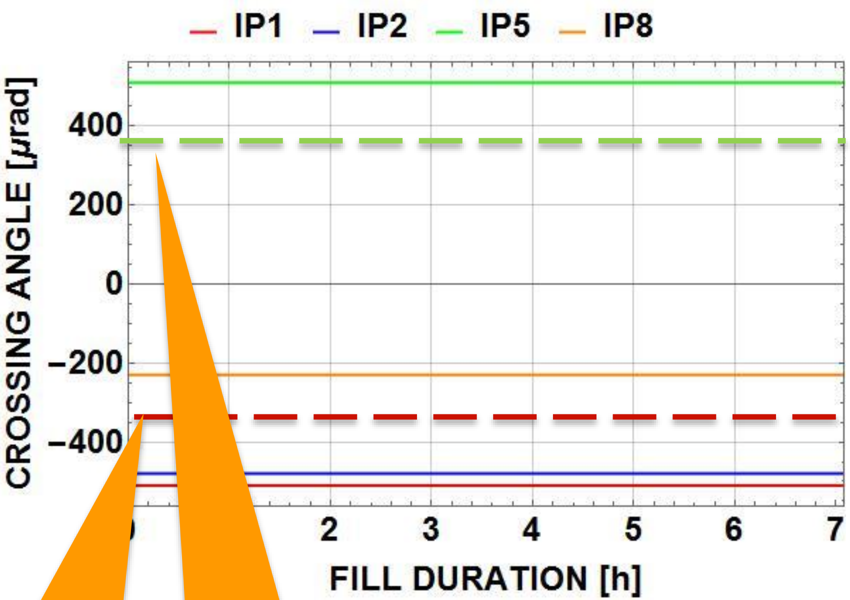
β*=16 cm
Constant normalized BB separation





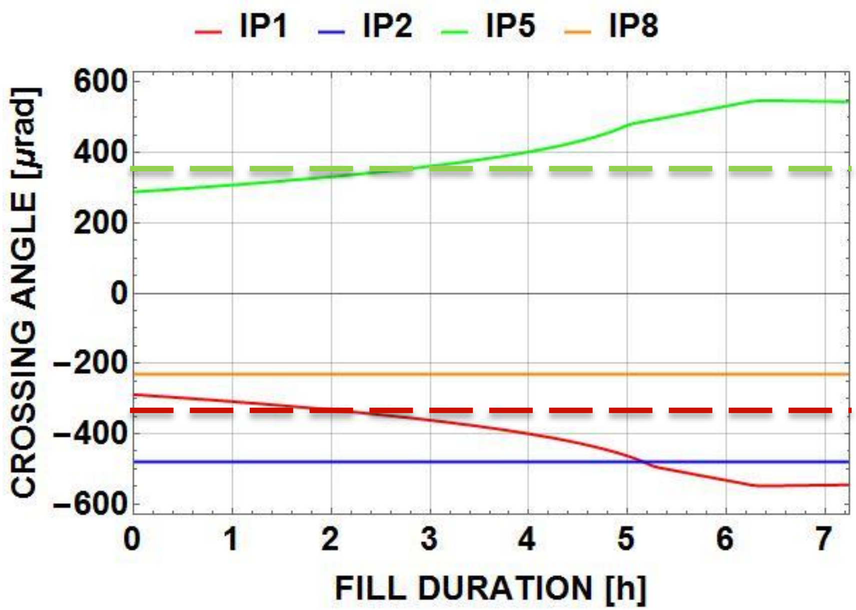
Round Optics

β*=20 cm



Crabbing angle

β*=16 cm

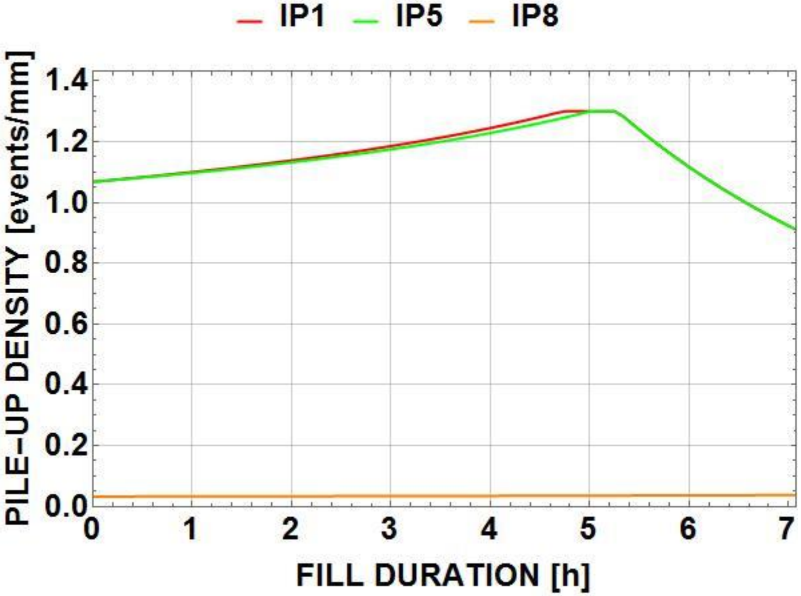


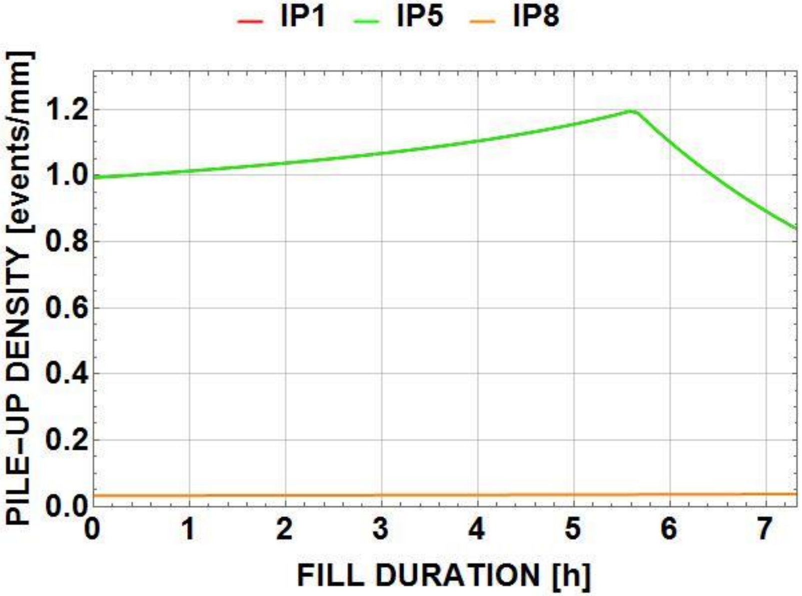
- Reduction of the pile-up density at the beginning of the fill
- Modest increase in integrated luminosity for the nominal/ultimate scenario ~ 2%

Other scenarios

- The possibility of closing the TCTs down to <9 BEAM sigma could open the possibility to the use of wire collimators for beam-beam long range compensation:
  - e.g. flat optics 40/10 cm (compatible with present baseline for 10 sigma protected aperture) studied in S. Fartoukh, A.Valishev, I. Papaphilippou, D. Shatilov (PRSTAB 18, 121001)
- We could have full compensation of the crossing angle with the available crab cavities or use them in the orthogonal plane for crab kissing

Flat optics with BBLR compensator





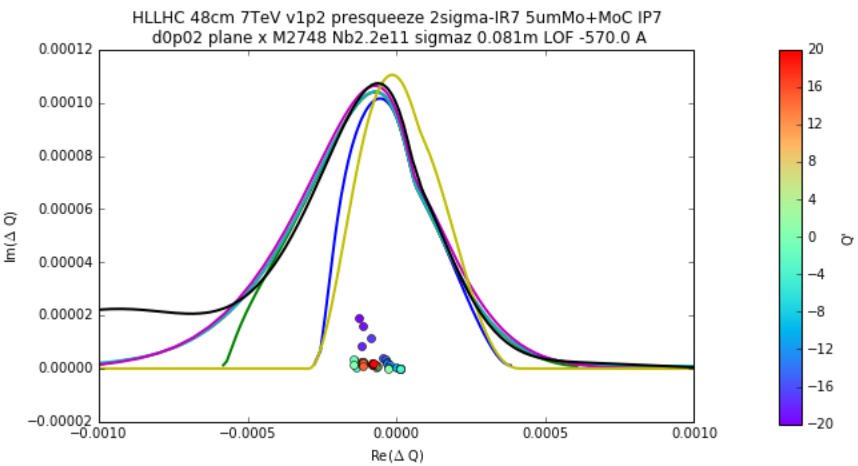
Round β*=20 cm

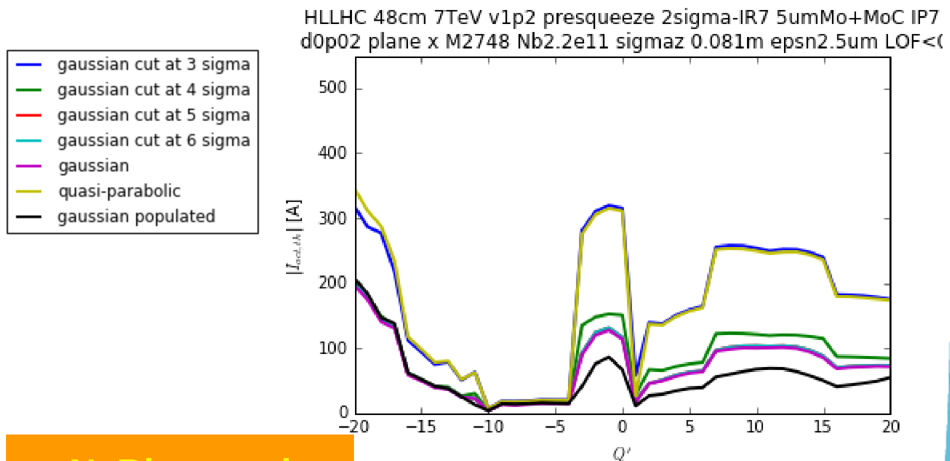
Flat optics β*=40/10 cm – 300 μrad crossing angle – BBLR Compensation

- Marginal gain wrt integrated performance (+2%) but visible reduction of the pile-up density

Beam Stability Considerations

Negative Octupole polarity
Negative detuning with amplitude





N. Biancacci

- Nominal collimator settings for HL-LHC parameters and machine components for the present baseline: 2 CC/beam/IP side and low-impedance collimators in LSS7. Assumed here DQW cavities and machine at the end of the pre-squeeze ➔ Further work is ongoing to reduce the impedance of a remaining HOM at 920 MHz
- Negative Octupole polarity can provide stability for lower values of the octupole currents but more sensitive to distributions

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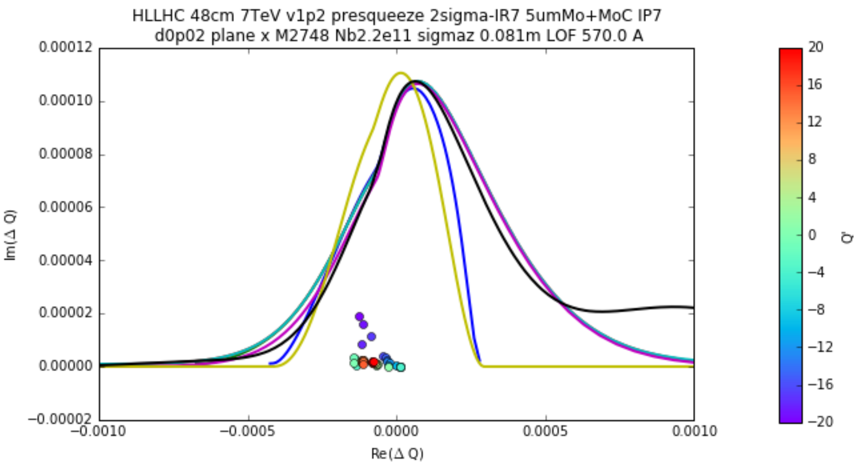
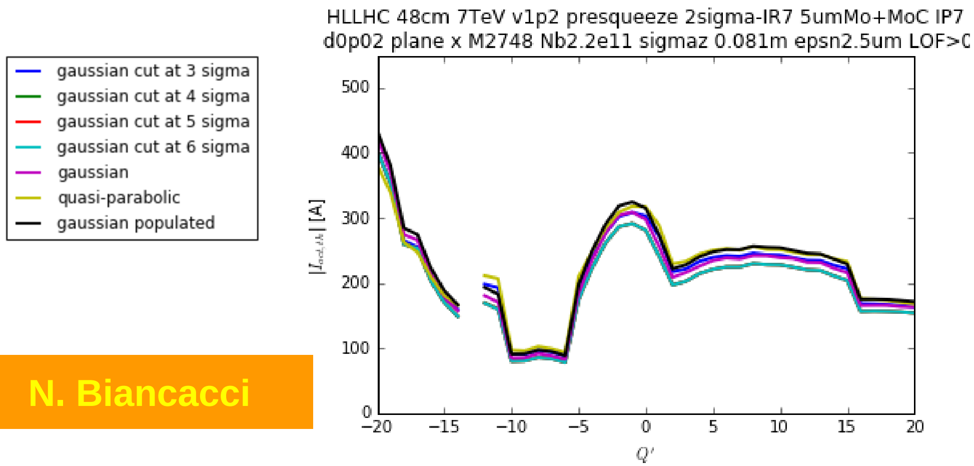
Beam Stability Considerations

Positive Octupole polarity
Positive detuning with amplitude





N. Biancacci

- Nominal collimator settings for HL-LHC parameters and machine components for the present baseline (2 CC/beam/IP side) with low-impedance collimators in IP7. Assumed here DQW cavities and machine at the end of the pre-squeeze.
- Positive Octupole polarity requires stronger octupoles but less sensitive to distributions.
- Beam is stable in all cases for both octupole configurations for nominal collimator settings (design choice as for LHC: we cannot rely on tail distribution) for LOF<300 A ➔ thanks to the impedance reduction

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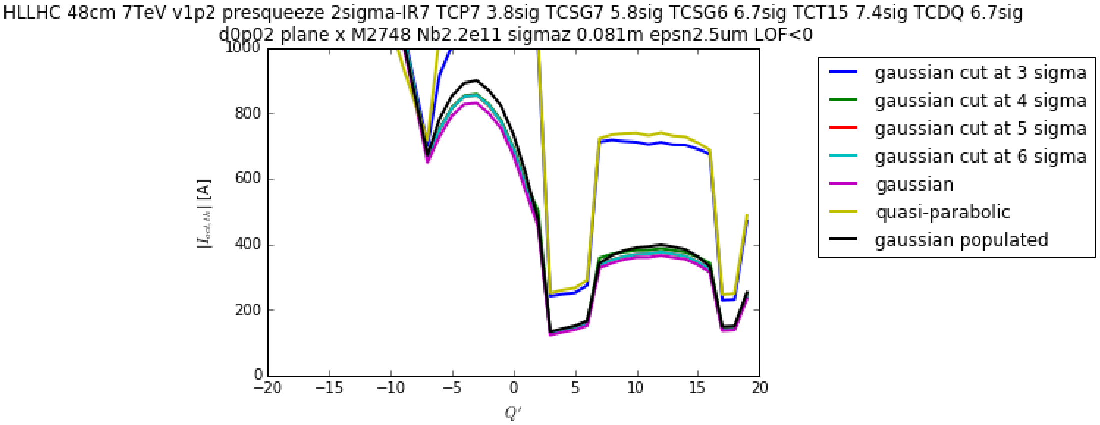
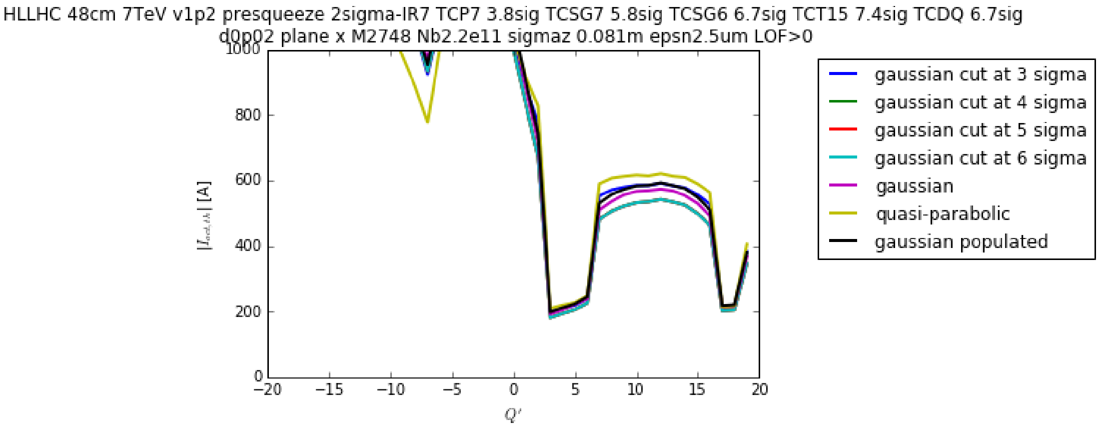
Beam stability considerations

- The situation is of course more difficult if we close the collimators...



Negative Octupole polarity



Positive Octupole polarity

N. Biancacci

Beam stability considerations

- Operation with the tightest collimators settings would possible
  - Provided that reduction of the impedance of the DQW cavities (ongoing) is successful and no additional or unidentified sources of impedance are present
  - But smaller margin for accommodating other effects affecting beam stability (e.g. electron cloud)

Other potential issues

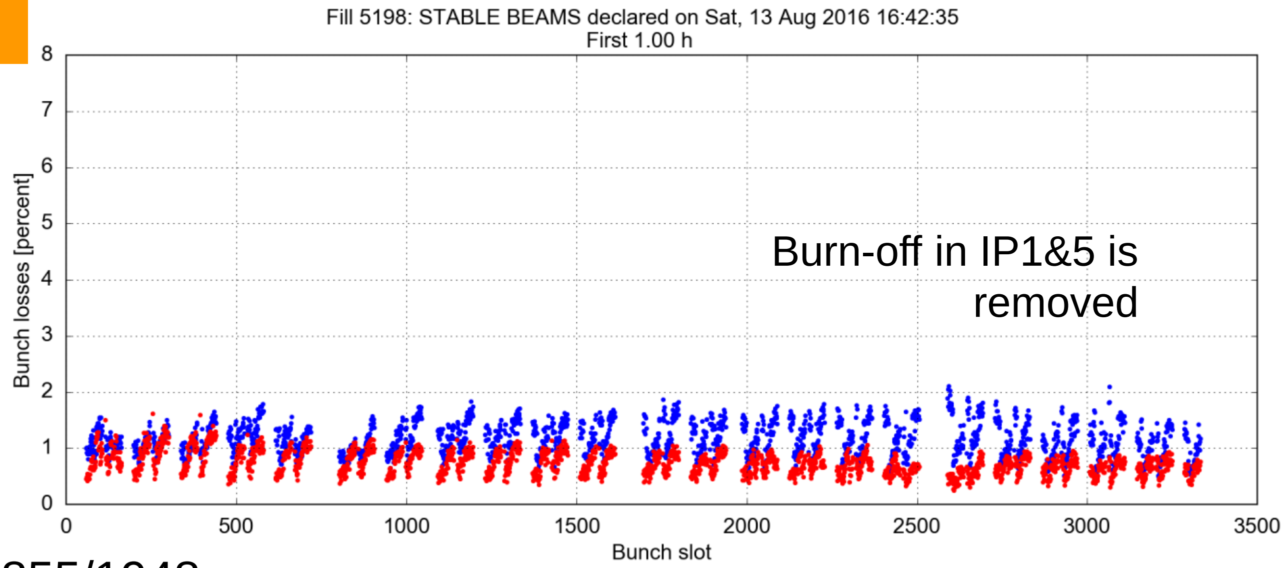
- Possible instabilities generated by coupling of the electron and proton beam (impedance equivalent of the electron beam): seem to be negligible (see also BNL experience)
- Impedance of the electron lens components need to be studied

Other potential advantages

- Deterministic halo control is likely not a luxury for a machine with 670 MJ beam power:
  - Could help in particular during the ramp-up phase
  - Would reduce the sensitivity to injected beam parameters
  - Could make levelling processes smoother - these occur during stable beams!
  - Could help in making configuration changes more transparent and provide some time to understand unexpected features

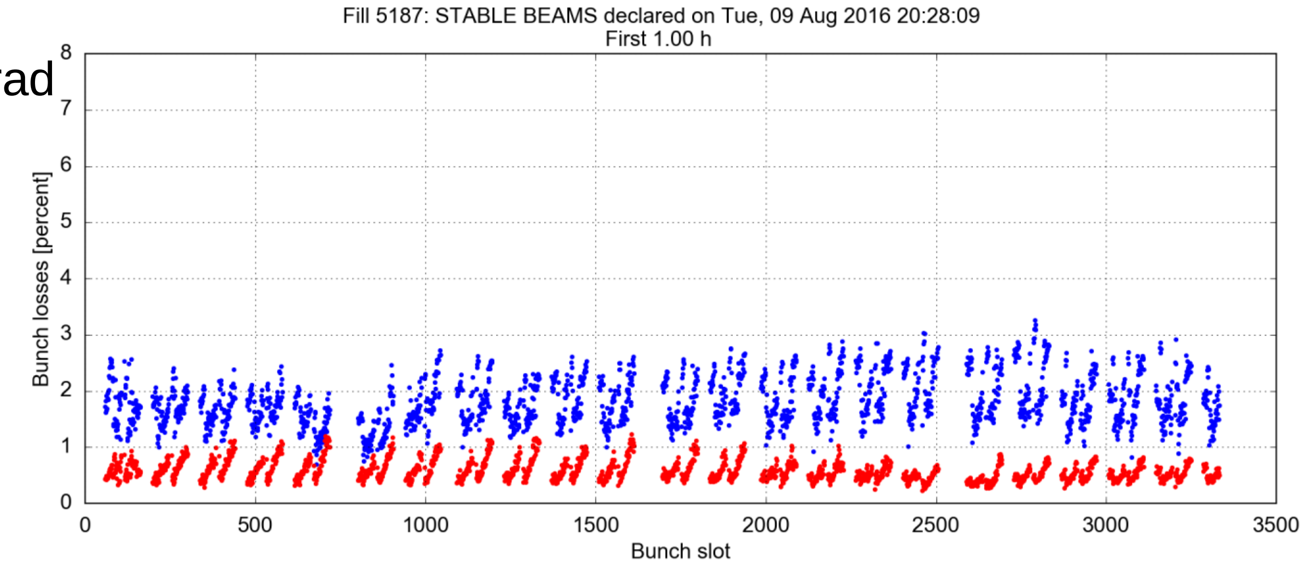
Fill to fill variations are still observed beam lifetime variations of a factor 2!!

Other potential advantages



Collision scheme: 2160/1855/1948

Xing angle IP1/5: 185 urad
BCMS beam
LHCb polarity: positive



G. Iadarola

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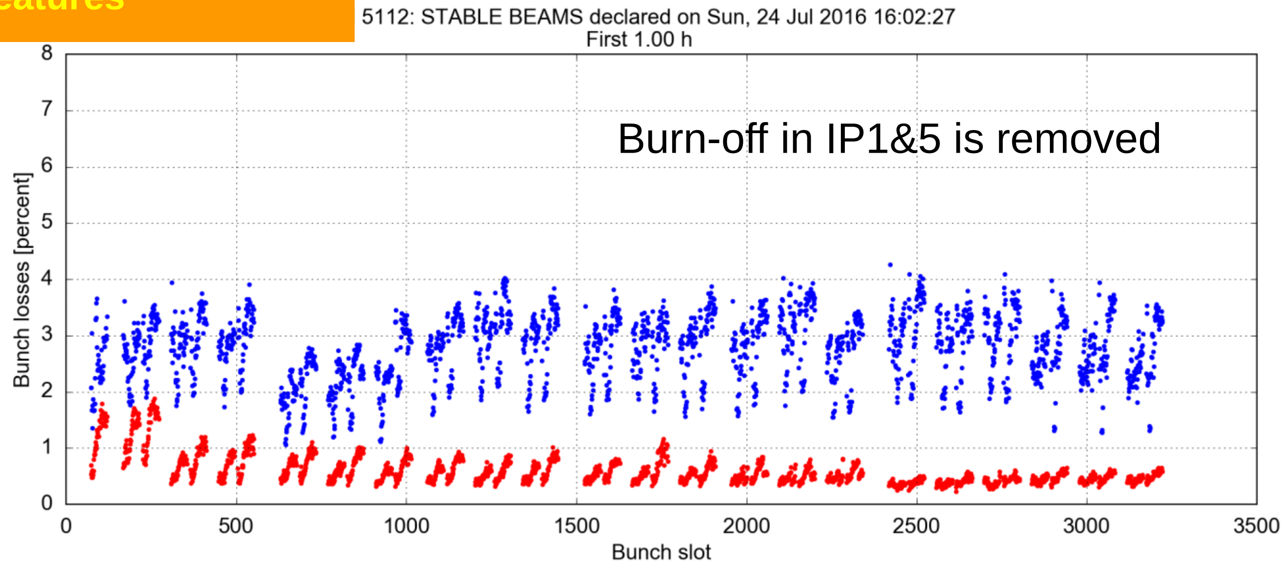
Other potential advantages

Sometimes set-up changes present some unexpected features

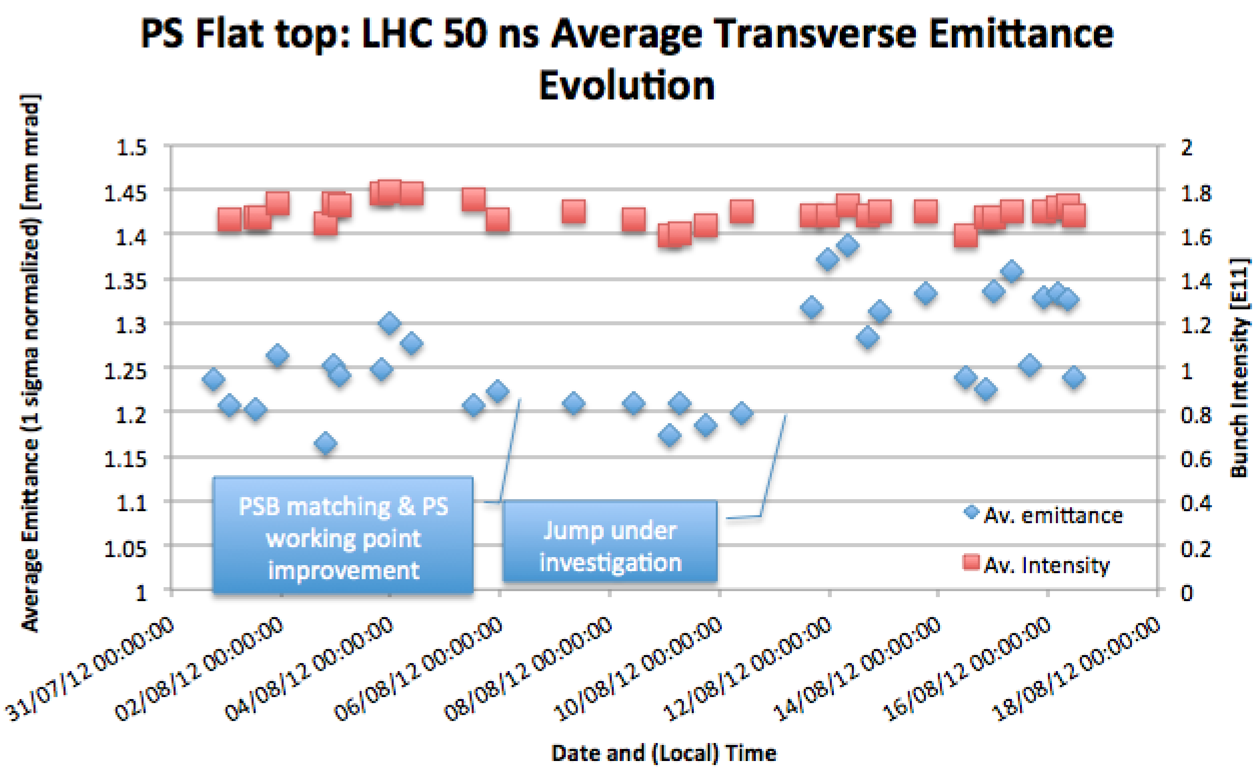


Collision scheme: 2064/1681/1772

Xing angle IP1/5: 185 urad
Beam type: BCMS
LHCb polarity: negative

Emittance at injection

- Emittances in the LHC larger than last Sunday for similar intensity. PS sees fluctuations since the week-end.

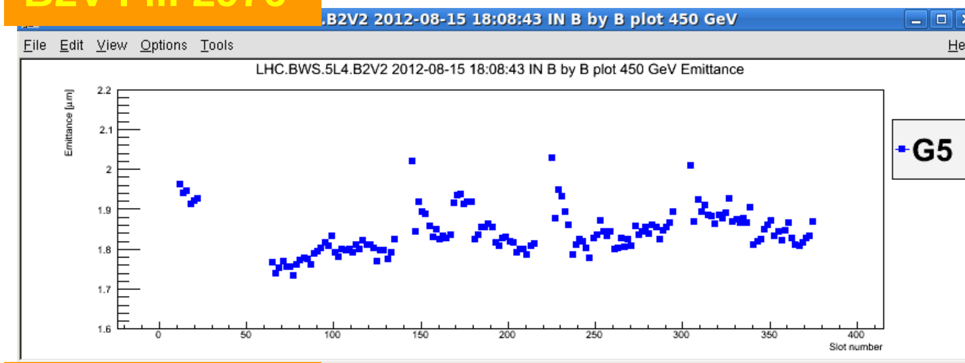


R. Steerenberg

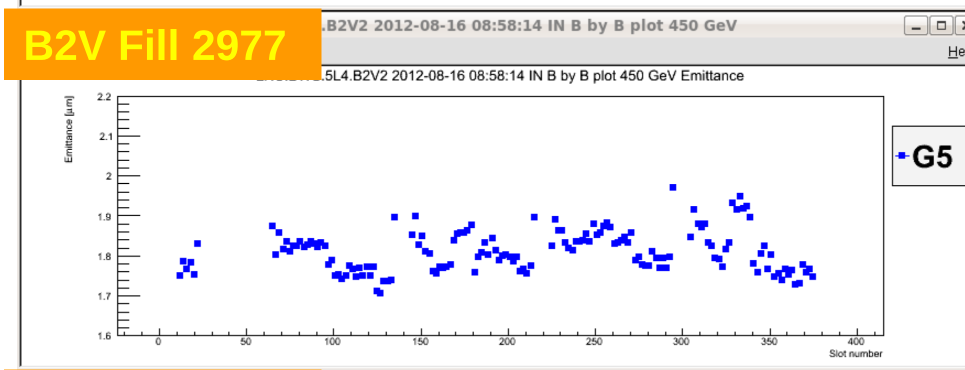
Emittance at injection

- Further deterioration during Thursday
- Some improvement after SPS inj. Kicker timing adjustment

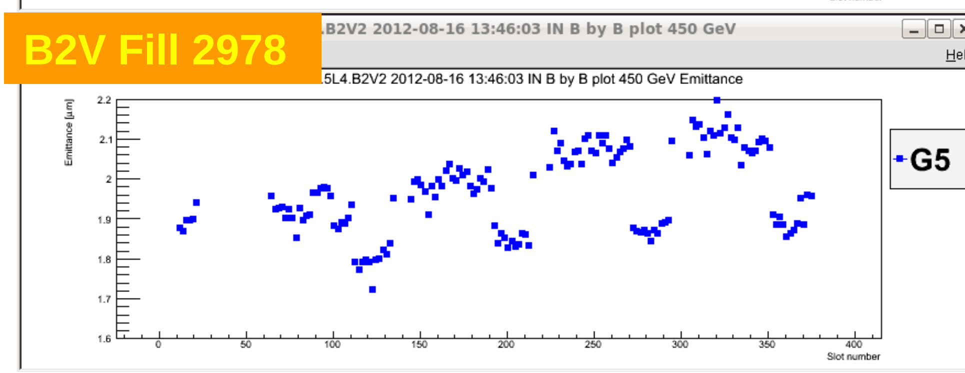
B2V Fill 2976



B2V Fill 2977



B2V Fill 2978



E. Bravin

Summary

- Halo control can open the way to tighter collimator settings and therefore reduced β^* with:
  - limited increases in integrated luminosity but a visible reduction on pile-up density
  - A back up scenario in case of issues with crab cavities (requires beam-beam wire compensator) with flat optics
- The proposed scenarios rely on a further reduction of the impedance of the DQW cavities HOM (ongoing) but with reduced margins available for stabilizing other sources of instabilities other than impedance (e.g. electron cloud)
- For the HL-LHC nominal scenario we do not rely on tails for beam stabilization (as for the LHC) as experience tell us that they are not reproducible ➔ we rely on impedance reduction

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Summary

- In addition to this potentialities halo control can provide more margin during all the operational phases and to handle ramp-up phases and configuration changes that inevitably HL-LHC will face.
- Synergies for other potential developments like long range and head on beam-beam compensation should be also considered

Thank you for your attention!

Acknowledgements: N. Biancacci, R. Bruce, H. Burkhardt, R. De Maria, S. Fartoukh, G. Iadarola, E. Métral, Y. Papaphilippou, S. Redaelli, A. Santamaria, G. Stancari, R. Tomas, A. Valishev