The LHC Nominal Cycle, Pre-cycle and Variations in 2015

J. Wenninger

M. Solfaroli, M. Lamont

FIDEL - general

- The core of the FIDEL TF data is already present in the LSA DB.
  - *At 6.5/7 TeV saturation becomes significant.*
  - *But saturation was always part of FIDEL – no surprises.*
- Some corrections / changes have to be made.
  - *Correct some TF errors, for example the MQY magnets,*
  - *Extend IT quadrupole TFs (+ some others?),*
  - *Update MB/MQ TFs (magnet exchanges).*
  - *Update missing magnets (also knobs, e.q. MQTs).*

FIDEL – decay & snapback

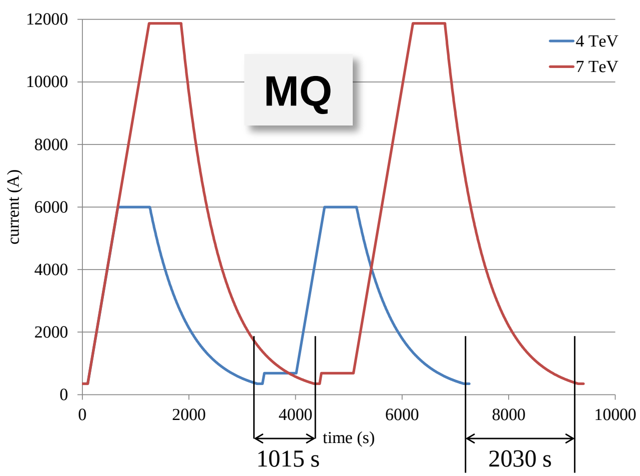
- Expectations for decays and snapback:
  - *The decay and snapback amplitudes @injection will increase ~ E.*
    - We keep the faster PELP at start of ramp – should be OK.
  - *The FT decay should decrease.*
- Measurements:
  - *Everything should be re-measured a few times (also on the FT !!),*
  - *From measurements fit b2 & b3 amplitudes and time constants,*
- Software should be OK.
  - *FIDEL server at injection,*
  - *Separate ramp BP for spools with decay at FT.*

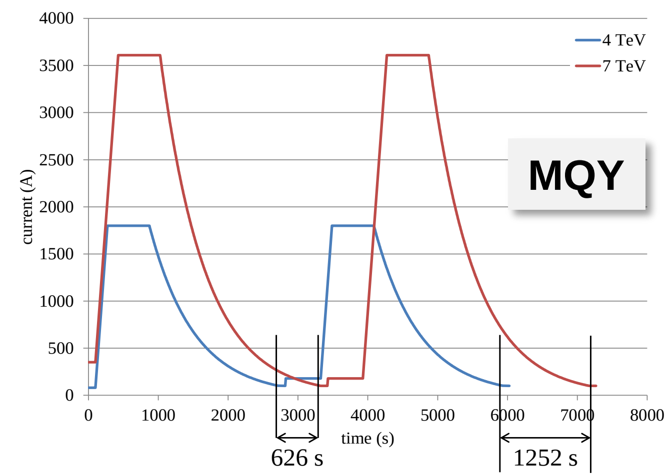
Note by N. Aquilina – to be published ⟺

	Decay amplitudes at ∞ (inj)	
	4 TeV	6 TeV
Tune	-0.022	0.035
b3	0.4	0.5-0.6

Pre-cycle

- No pre-cycle was generated so far for 6.5 TeV – need some work on the code and need update to LSA DB tables.
- Expected changes:
  - *The pre-cycle length increases of ~1000 s (dominated by MQs).*
    - Total pre-cycle duration ~4000 s ~ 1 hour.
  - *The ramp-down duration increases by ~500 s.*
    - Total duration ~2600 s.





Values from a note by N. Aquilina – to be published… and confirmed!

Collision configurations

- For 2015 we consider the 3 main collision configurations:
  - *Low β^* : 0.4 – 0.7 m,*
  - *Medium β^* : 20 m (30-40 m LHCb) for LHCf & VdM,*
  - *High β^* : 90 m – not discussed here → late summer.*

- Medium and low β^* must be prepared during the initial startup.
- All numbers and plots presented here refer to the 'classic' optics. But no significant difference is expected from the ATS-compatible optics.
- Up to a beam energy of 6.78 TeV there is no need to perform a pre-squeeze in IR2 and IR8 (triplet gradient limit). The injection optics can be scaled up.
  - ***Ramp and squeeze is not mandatory for 6.5 TeV.***

Some configuration details

Injection

(1) + parallel angle 30 μrad

IP	β* (m)	Ext ½ Xing angle (μrad)	Separation (mm)
1+5	11	±170	±2
2	10	±170	
8		-170	±3.5[1]

Low β*

(2) Scaled 0.65 mm to 6.5 TeV

Medium β*

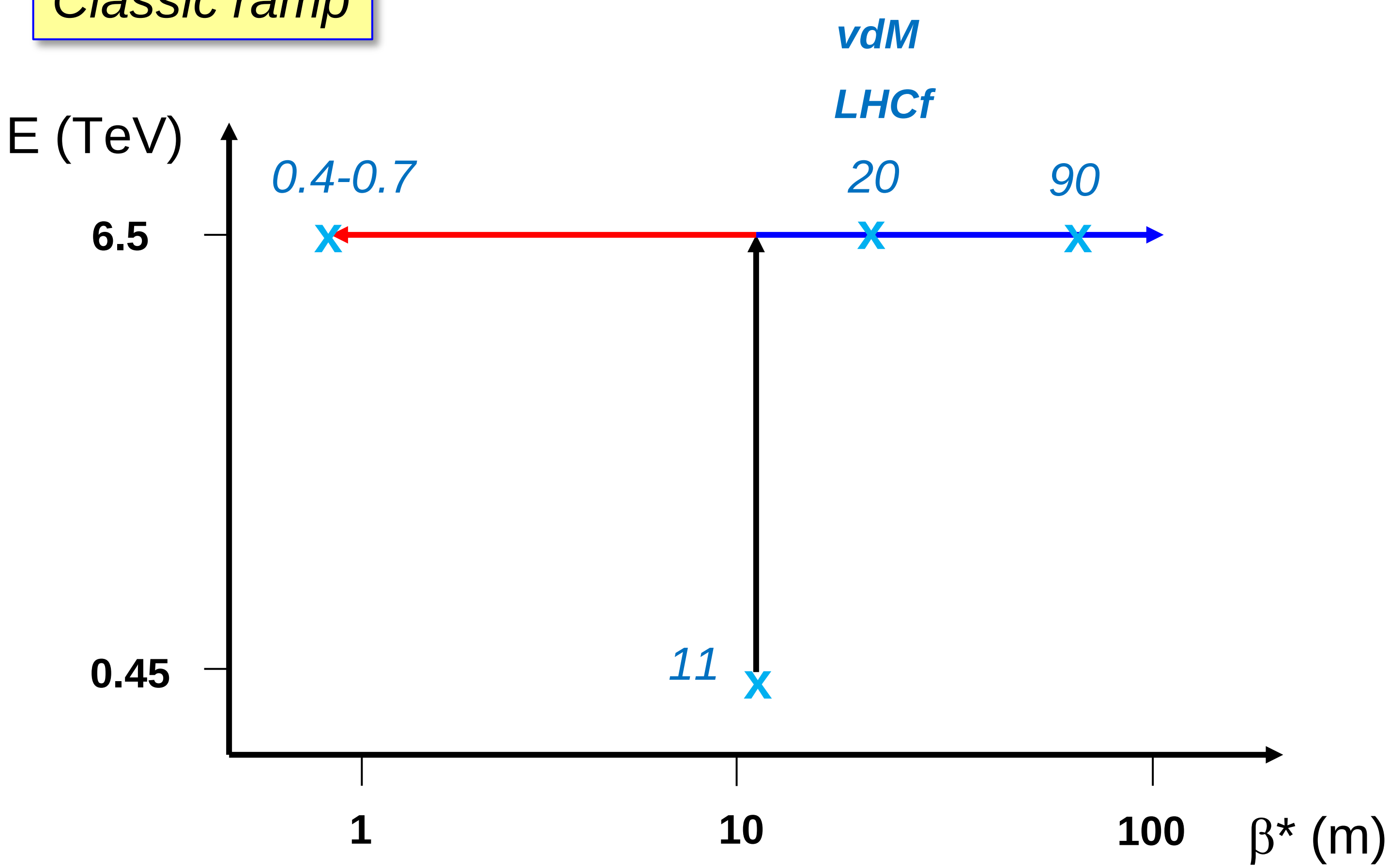
Collapse Xing before colliding

(3) xing angle ≈ -140 μrad during initial phase in IR1 for LHCf

IP	β* (m)	Ext ½ Xing angle (μrad)	Separation (mm)
1+5	0.65	±170	±0.55[2]
1+5	0.4	±155	
2	10	±120 ??	
8	10 - 3	-250	
1+5	20	0[3]	±0.55
2	20	0 ??	
8	30-40	0 ??	

Ramp – then – squeeze IR1+5

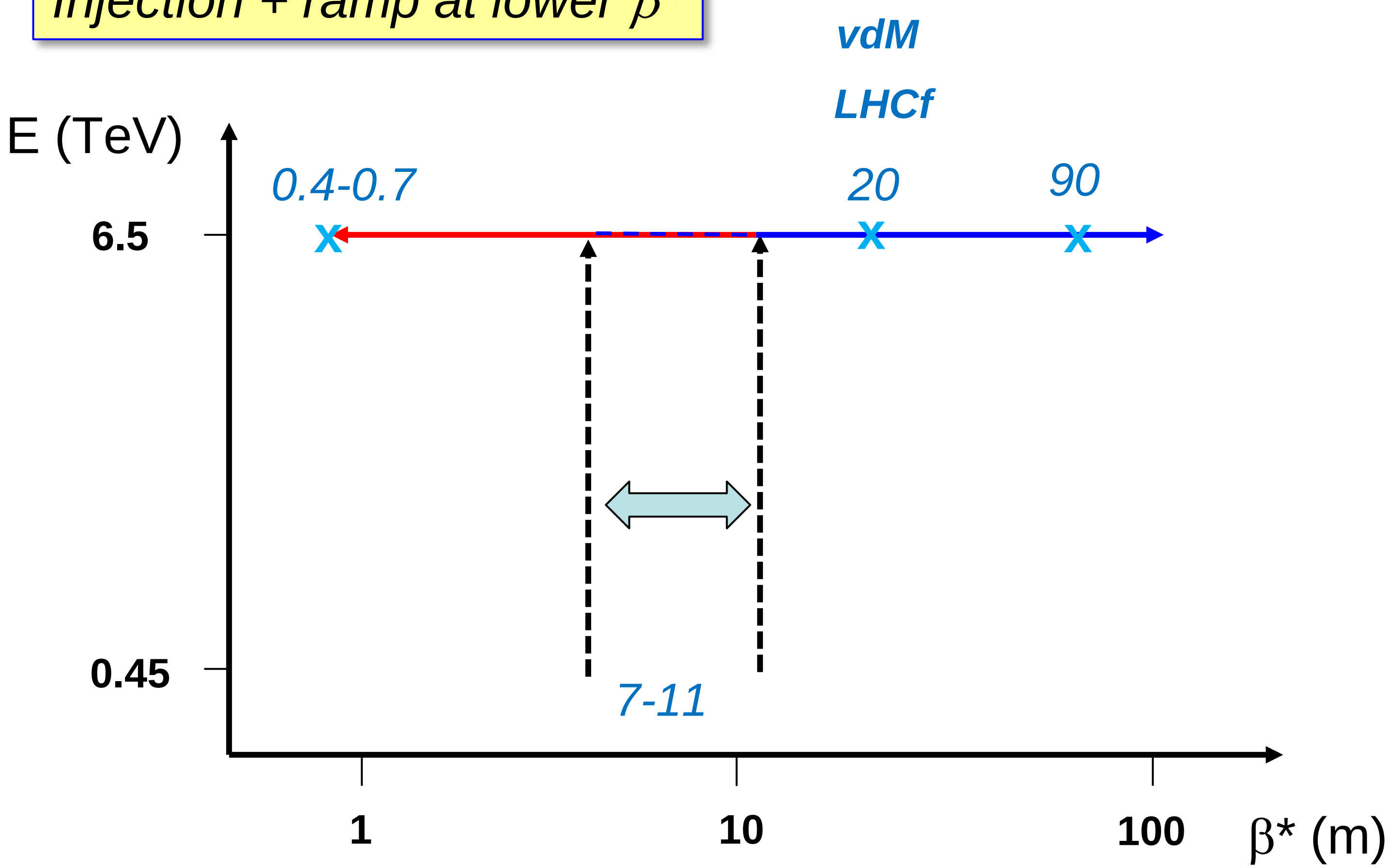
Classic ramp



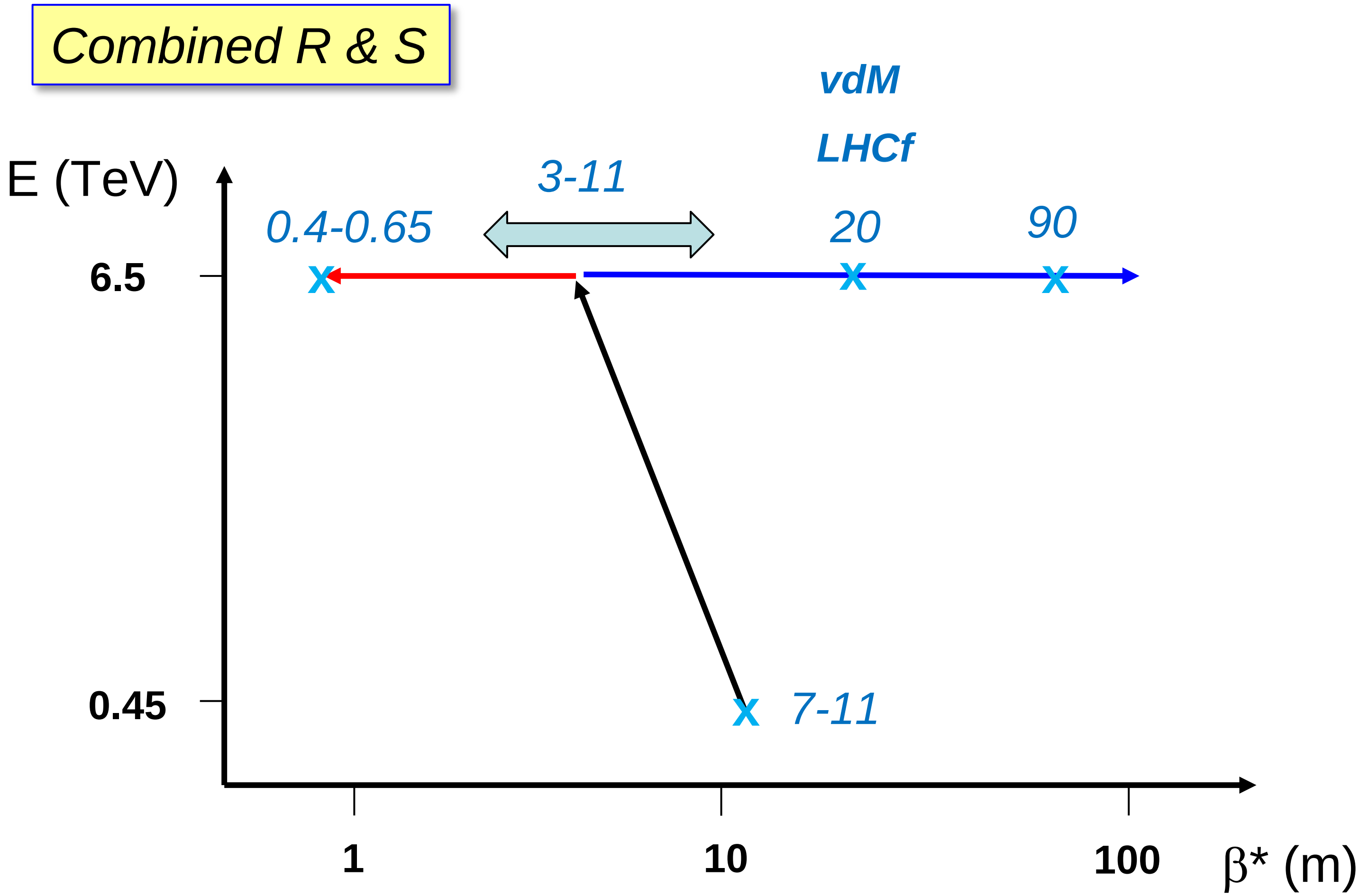
- IR8(and IR2) β* values to be mapped – depends on operation mode (collide & squeeze, β* leveling, standard…).

Ramp – then – squeeze IR1+5

*Injection + ramp at lower β**



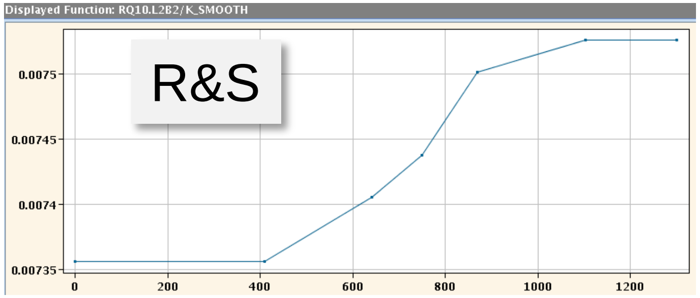
Ramp & squeeze – then – squeeze IR1+5



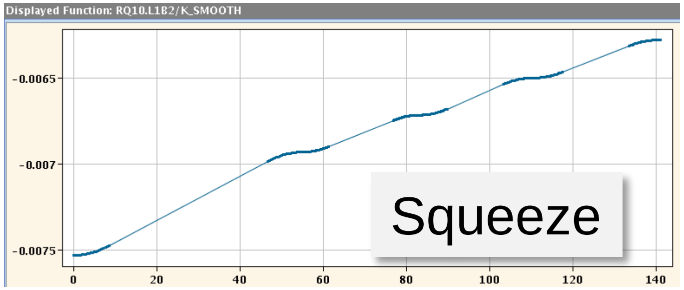
- Gain in time with R&S to **3 m** (for low β*): **~430 s** (½ the duration).

Ramp-squeeze development

- Currently the design of the combined R&S is clumsy because the smoothing of the quadrupole gradients is not applied.
  - *Distance between matched points must be tuned* ***manually*** *until the 'kinks' in the functions become tolerable.*



- For combined R&S we have to use smoothing as it is done for the squeeze design with parabolic segments.
  - *We may initially use the same principle than for squeeze, and apply the energy ramping on top of it.*

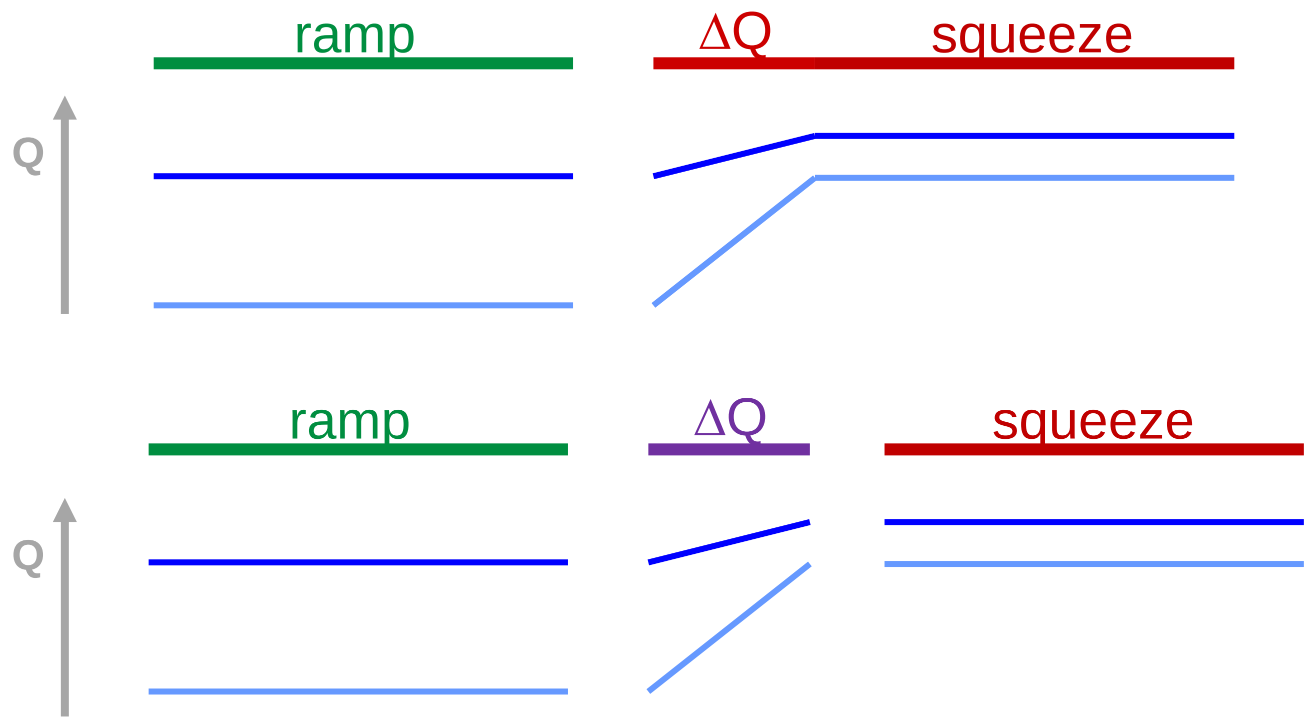


- <u>Proposal</u>: proceed with standard ramp for the moment, but initiate development and testing of improved R&S software.
  - *To be ready when we want it.*

Ramp / squeeze : tune (1)

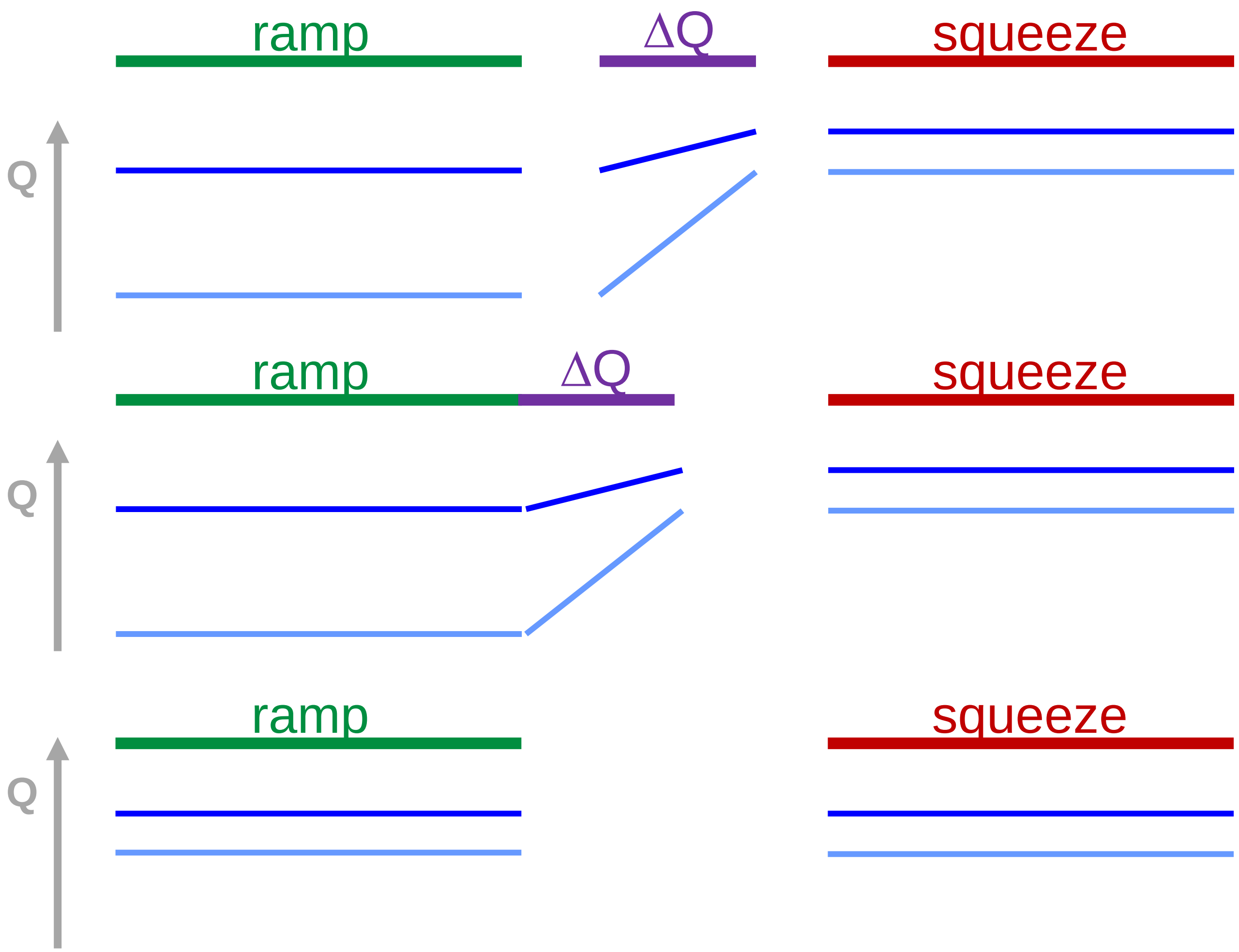
- For the entire pre-LS1 period, the tune change was made at the start of the squeeze with the matching quads in IR1 and IR5.
  - *Some proposal to change tunes at injection (better?).*

- Proposal: to gain flexibility the tune change should be decoupled from the squeeze.



Ramp / squeeze : tune (2)

- Options and possible evolution. With the ΔQ decoupled from the squeeze, it is easier to evolve without impact on the squeeze BP.



Squeeze BP not affected !

Injection & collision tunes

- Q change with the MQTs instead of matching quadrupoles in 1+5:
  - *Q change could be faster and would lead to smaller orbit perturbations,*
  - *The induced beta-beating would at the level of max. 1% - OK,*
  - *It would be easier to switch from one WP to another:*
    - Use tune trim knob,
    - Update of optics id/name (mainly steering).
- Practical reasons to use injection tunes Q_{inj} (0.28/0.31) instead of collision tunes Q_{col} (0.31/0.32) at 450 GeV :
  - *Mainly related to Q signal quality and feedback performance. With Q_{col} the peak search windows are tighter → more delicate peak search, risk of QFB to lock on wrong tune or switch off.*
- Proposal:
  - *Start with Q_{inj}, review the choice at a later stage.*
  - *Decouple Q change from squeeze.*
  - *Use MQTs to apply tune change wrt collision tunes.*

Squeeze duration estimates

- All durations *WITHOUT* tune change and starting with β* = 10/11 m.
- Difference 0.6 – 0.65 m : ~ 40 s.

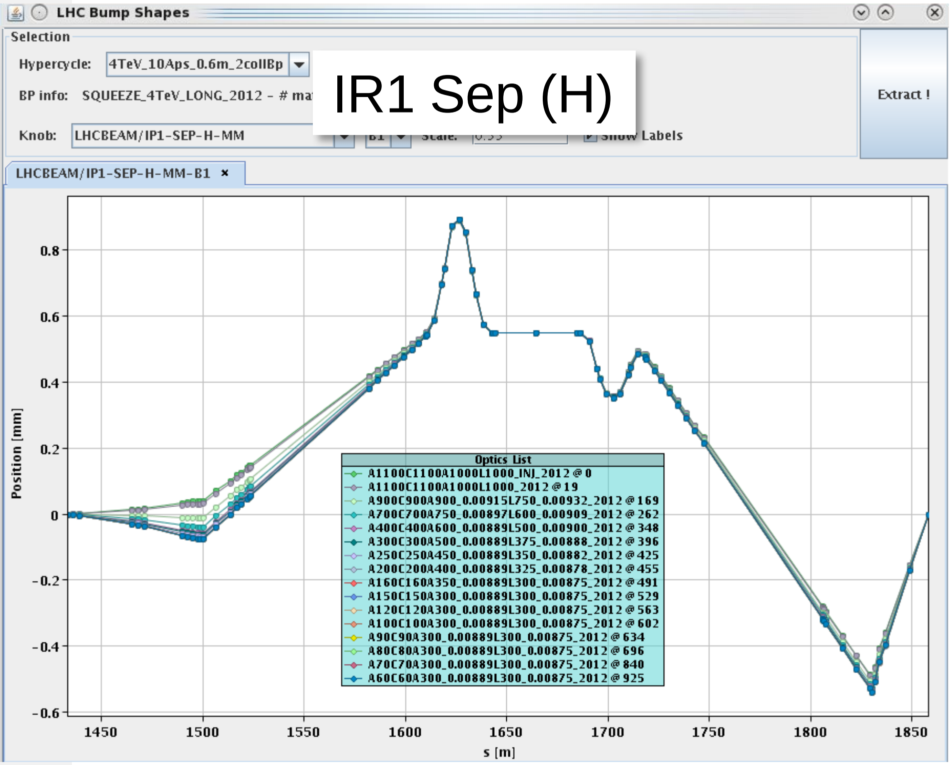
Energy	Type	Target β* (m)	Duration (s)
4 TeV	Squeeze 2012	0.6	906
6.5 TeV	Squeeze IR1/5	0.6	955
6.5 TeV	Squeeze IR1/5	0.4	1154
6.5 TeV	De-squeeze IR1/5	19	453
6.5 TeV	De-squeeze IR1/5	40	1138
6.5 TeV	De-squeeze IR1/5	90	2415

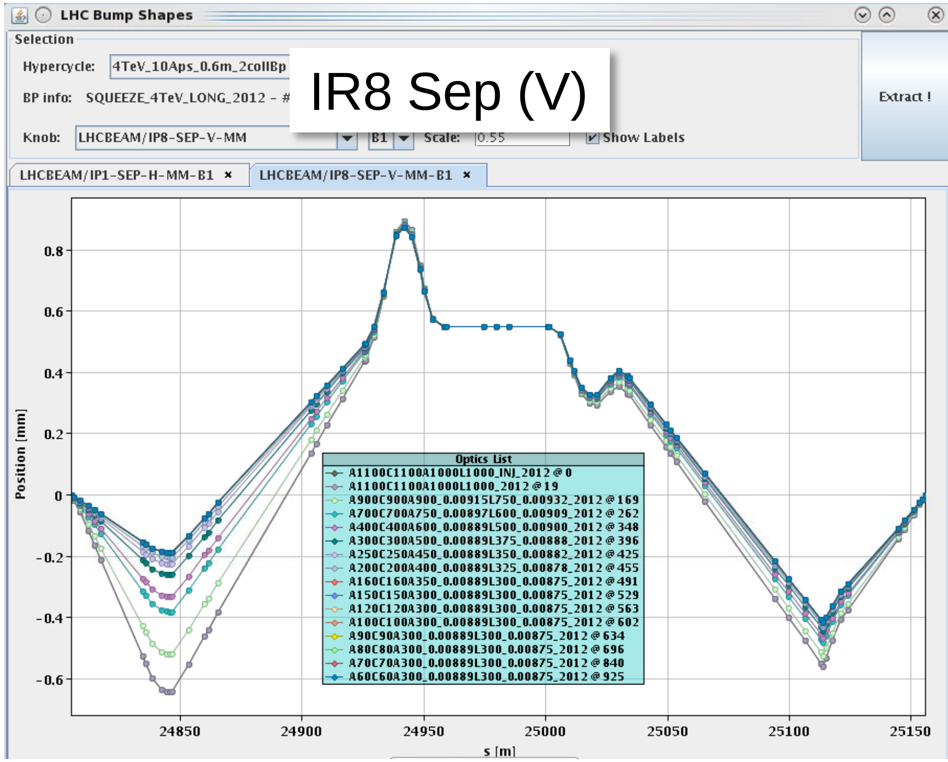
- There would be enough time to **de-squeeze IR2 to ~20 m** for regular operation without lengthening the squeeze – if judged useful and possible(*) : aperture + LR beam-beam.

(*) P. Hermes, CERN-ATS-2013-001

Bump evolution - separation

- The bump shapes change more in IR8 (and IR2) than they do in IR1 and IR5.
  - *The matched points at the start of the squeeze were a bit to coarse for the IR2/8 bumps – over-optimized wrt Q and Q'.*

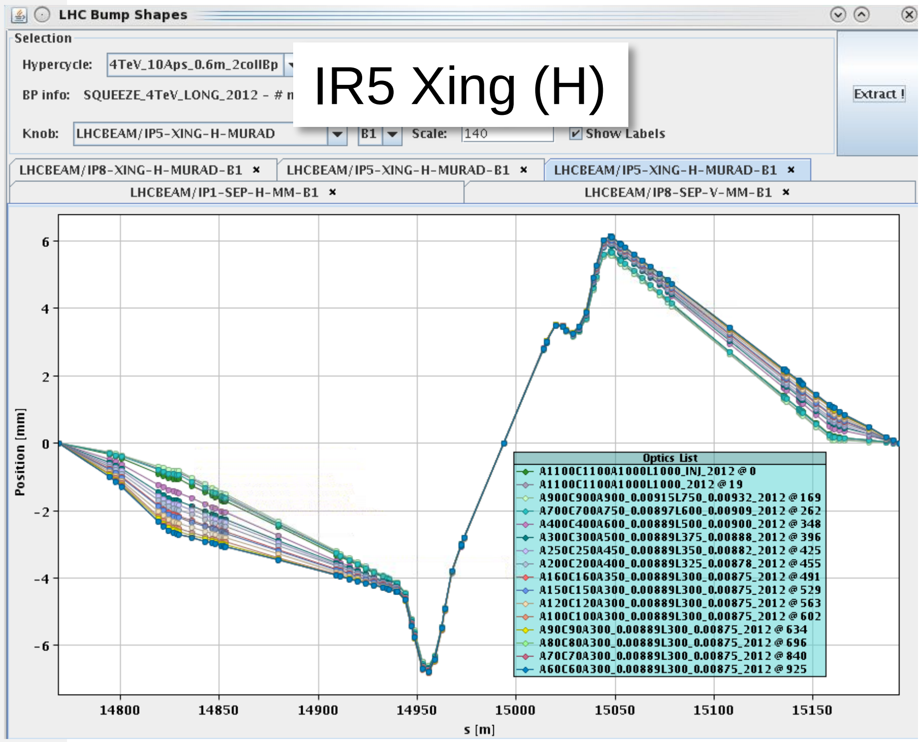


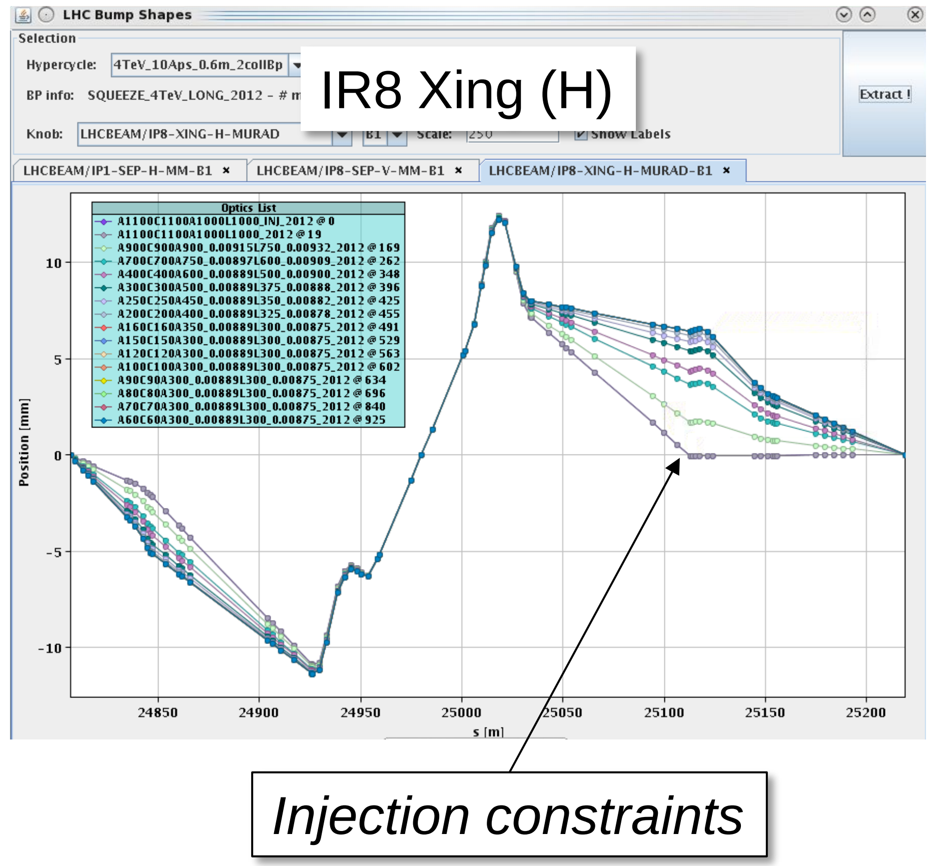


Display available under CCM : LHC Control → LHC Beam Control → LHC Bump Shapes

Bump evolution - Xing

- The bump shapes change more in IR8 (and IR2) than they do in IR1 and IR5.
  - *Constraints from injection. Very coarse at start of squeeze.*





Bumps, matched points and CODs

- **Recommendation** for bumps – valid for standard squeeze:
  - *For the classic optics, we should add one matched point for IR8 between 10 m and 7.5 m, and one between 7.5 m and 6 m.*
  - *For ATS-compatible – complete analysis for Q, Q' & orbit required.*

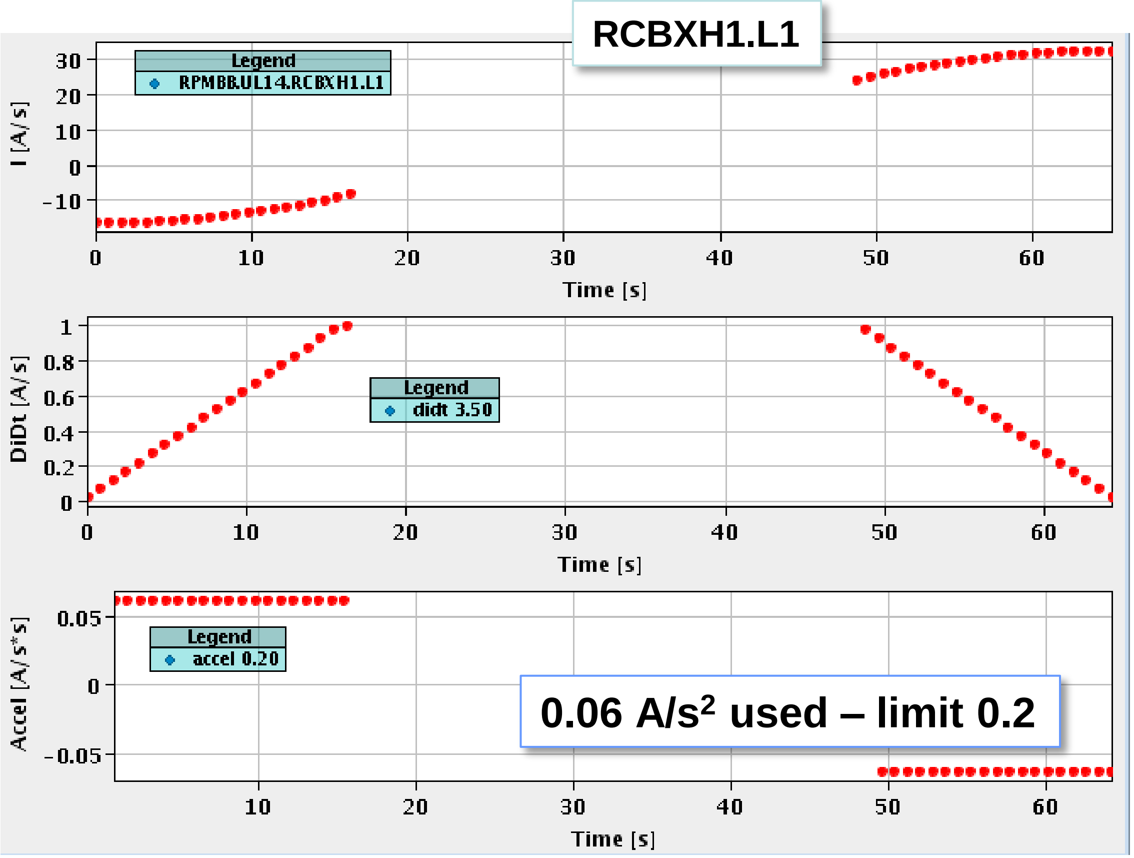
- A probable origin of (some of) the orbit spikes near matched points observed in 2012 is the different smoothing methods for orbit correctors (sep & xing knobs versus 'the rest').
  - *After LS1 all CODs will be smoothed in the squeeze with parabolic rounding (same ad quads etc),*
  - *Feed-forward of reproducible OFB trims → corrections on top of the smoothed functions.*

Collision BP

- From the beam-beam team: we can collapse IR1 and IR5 together since no problem was ever observed.
- Since the VALUE of the separation knob is not a ‘static’ part of the optics (can be adjusted), the design of the collision BP depends on the target value (+ margin) that is selected.
  - *The length of the parabolic sections at both ends are set manually.*
  - *The required BP length is adjusted by trial and error (and with time also experience).*
- Due to lack of diagnostics software, it was difficult to judge the ‘efficiency’ of the BP design.
  - *New application that analyses all COD functions I, dI/dt and acceleration → eases optimization of BL parameters.*

2012 Collision BP (IR1+5)

- The dI/dt was pushed to ~80% of the maximum – OK.
  - *Limit at the Q4/5 correctors.*
- But only ~25% of the acceleration potential was used !
  - *Limit at the MCBX.*



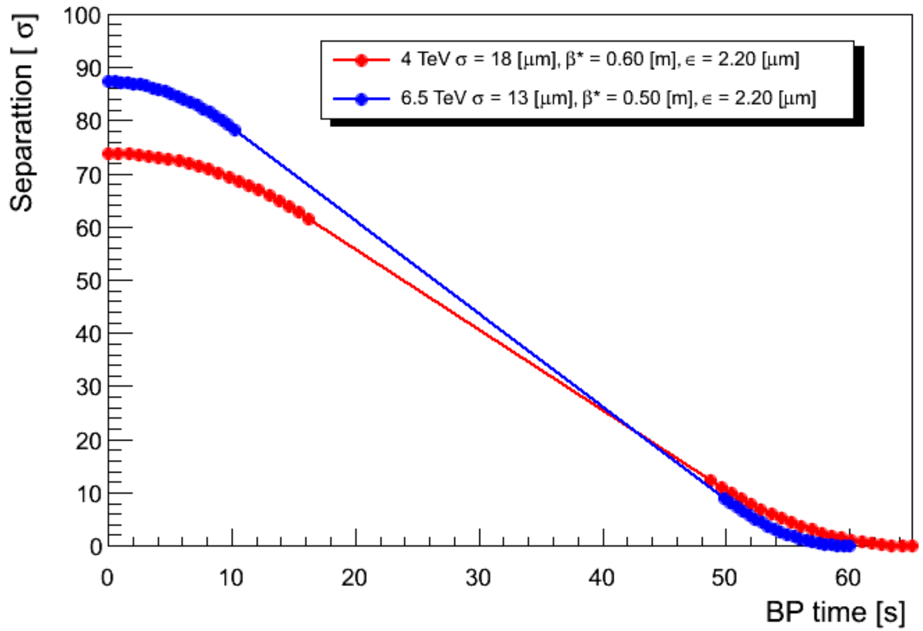
Display available under CCM : LHC Control → LHC Beam Control → LHC COD Di/dt

Collision BP optimization

- Optimized collision BP.
  - *Table for β* = 60 cm at 4 TeV, β* = 50 cm at 6.5 TeV*

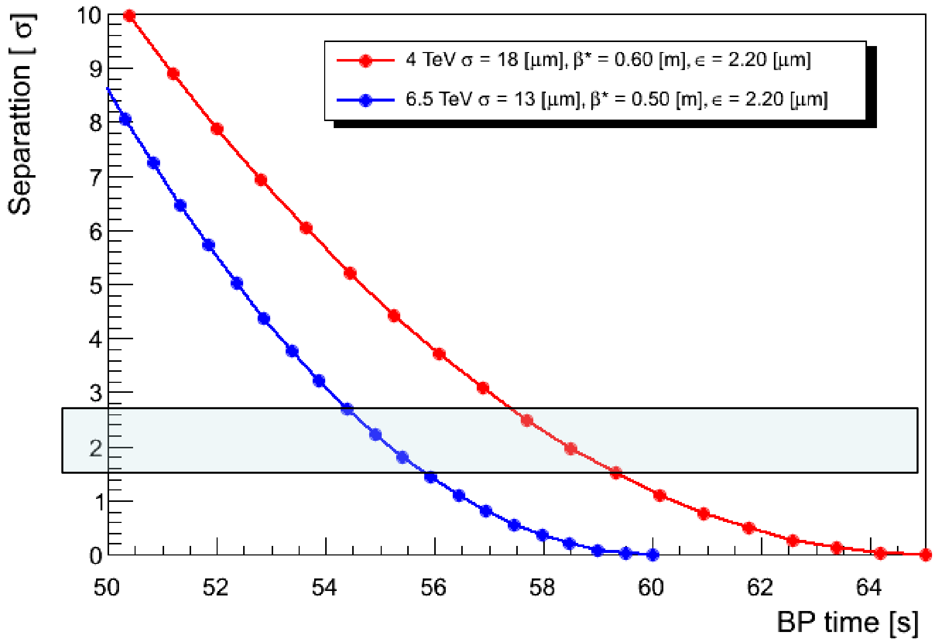
Energy (TeV)	Nominal Separation (mm)	Separation range (mm)	BP length (s)	Max dI/dt	Max d^2I/dt^2
4	0.65	0.9	**65**	~90%	~25%
6.5	0.55	0.7	**60**	~90%	~90%

Q4/5 CODs **MCBX**



Collision BP optimization

- Comparison of the last seconds of the collision BPs



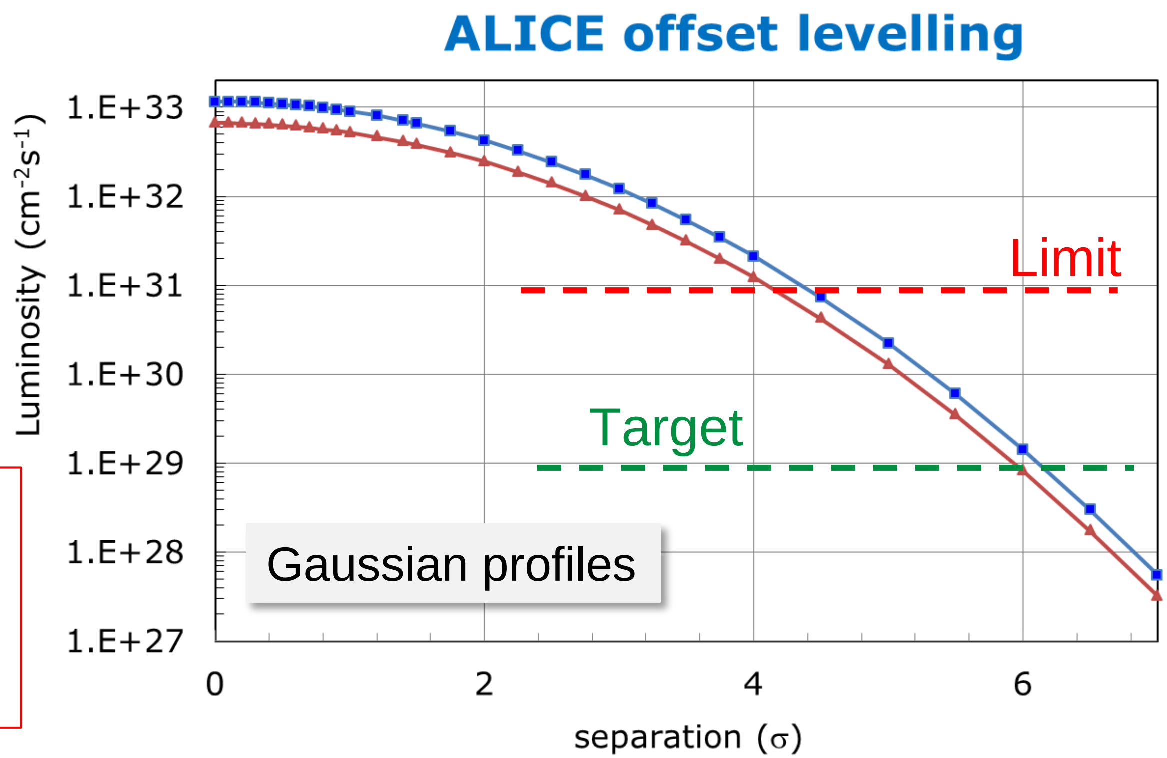
Cross the critical region in ½ the time !

- Additional improvements: the parabolic part could be shortened further if we spread the kick strength over 2 or 3 MCBX instead of just one magnet.
  - *Plus 2-3 lower currents ⇔ QPS.*
  - *Plus potential gain from powering tests.*

ALICE offset

- Luminosity in ALICE versus total separation of the 2 beams, 6.5 TeV.
  - *Parameters: N=1.2$\times$10^{11} p, ε = 2 μm, β* = 10 m $\Rightarrow$ σ = 54 μm*
  - *Parameters: N=1.2$\times$10^{11} p, ε = 3.5 μm, β* = 10 m $\Rightarrow$ σ = 71 μm*

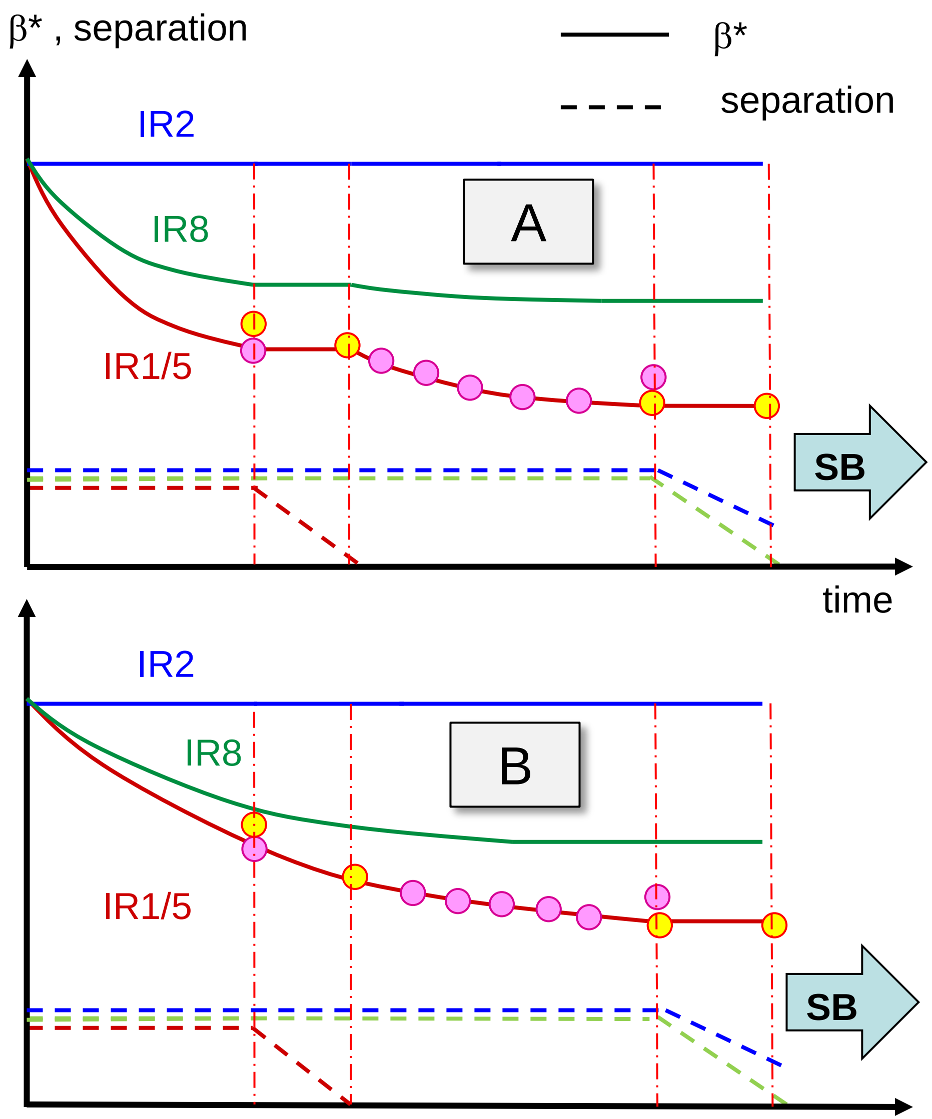
But we know that the tails are not Gaussian!



- Tune ALICE L with Q', octupoles, LRBB?
  - *Tail diagnostics with ALICE?*

Initial collision offset > 6σ → offset: > 0.15-0.2 mm / beam

Collide & Squeeze (1)



- Collide at constant β* (A) or while squeezing (B).
- Regular stops.
  - *Every fill (lumi scans…).*
- Occasional stops (setup, fix, loss maps…).

- Cutting the C&S in 4 BPs covers the regular stops.
- But the collimator intlk function (MCS!) implementation does not allow intermediate stops!
  - *Either we spilt the C&S into many short BPs,*
  - *Or we revisit the collimator intlk fcts & MCS.*

Collide & Squeeze (2)

- Extra complexity of C&S: head-on collisions will probably make life of the tune peak finder for the QFB even more difficult.
  - *QFB + Q' measurements.*
    - Not possible with colliding beams?
    - Procedure to separate beams with low intensity? How do we handle (once more) collimators and their interlocks?

- An operational C&S requires more 'thinking' (design) and work on the controls (MCS functions) side.
  - *Unless we cut it up in many small pieces.*

Software, setup

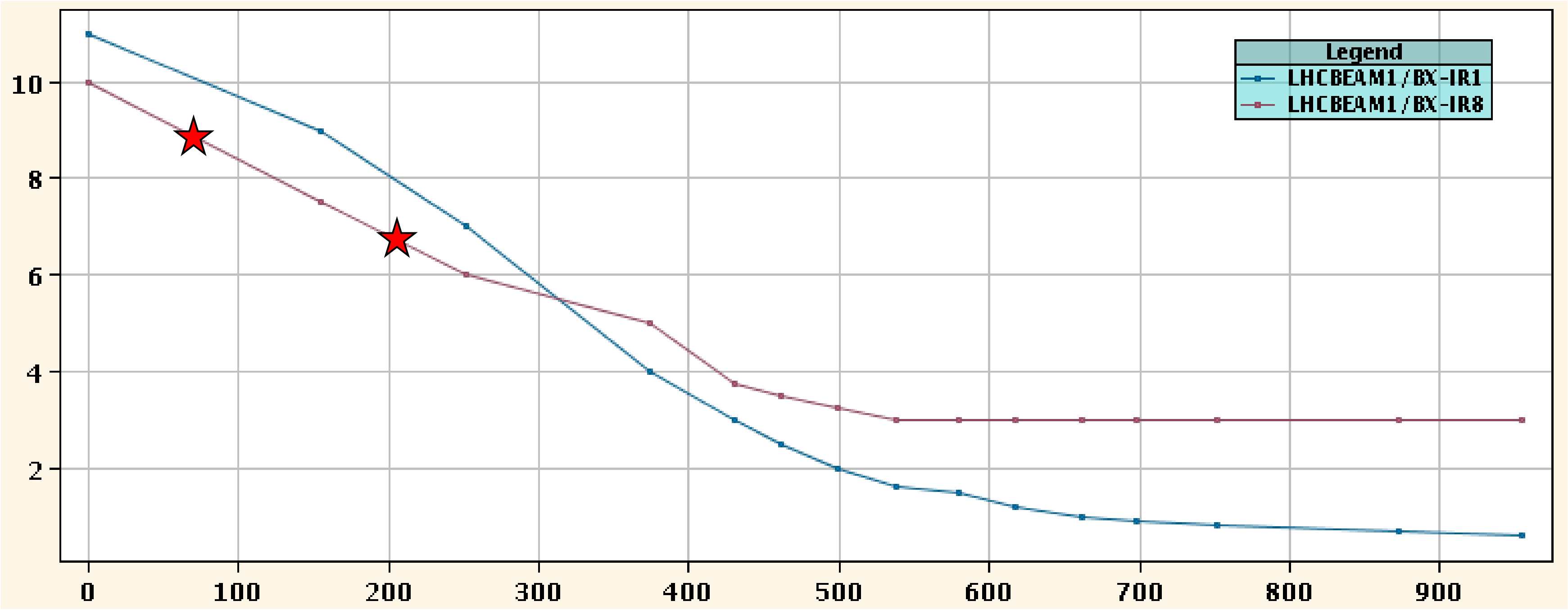
- The settings generation and FIDEL software will (or have) received some face-lifting.
- If we want to switch configurations between pure squeeze, C&S, R&S etc we will have to improve our setting copy tools:
  - *From longer to shorter BP, the reverse,*
  - *Merge 2 BPs, split one BP into 2,*
  - *…*
- For C&S we have to work on collimator functions / MCS.
- To enhance the flexibility for switching ‘β* combinations’, it is recommended to maintain corrections (optics, orbit) as local as possible.
  - *During commissioning CODs in arcs and in IRs that are not squeezed will be de-activated for OFB and manual steering.*
  - *Recommend to split beta-beating corrections in a similar way.*

Summary

- Forecast for process durations:
  - *Pre-cycle ~ 70 min,*
  - *Ramp-down ~45 min,*
  - *Ramp-squeeze-collide ~40 min,* β^* *= 65 cm*
- Proposals:
  - *Maintain simple ramp for 2015 startup, but prepare R&S,*
  - *Split off Q change from squeeze BP,*
  - *Start with injection tunes, decide later for collision tunes (injection),*
  - *Use MQTs for Q trim between injection and collision tunes,*
  - *Share separation knob over all MBCX to speed up parabolic end of collision BP.*
- Collide and squeeze requires SW work and/or a more detailed design study.

Squeeze duration

- Squeeze: classic optics, 60 cm, no tune change, 6.5 TeV.
  - *Dos not include 2 additional pts for IR8.*



Time estimates : change of β*

- Assumption: operation at 65 cm with β* leveling IR8.
  - *Optics corrected down to 40 cm during initial commissioning.*
- Two options:
  - *Build a single squeeze BP to 40 cm,*
  - *Add extra squeeze BP from 65 to 40 cm – see 2011 for 1m (simpler).*
- Steps:
  - *Offline:*
    - propagate/merge corrections of 65 cm and 40 cm.
    - β* leveling BP at 40 cm. Same corrections for IR8!
  - *1 or 2 cycles with probes.*
    - Orbit with all bumps on to 40 cm, optics check at 40 cm.
      - Adjust crossing angle value between 65 and 40 cm.
    - Run through all IR8 β* leveling steps for β* 40 cm, optics checks.
  - *1 cycle for collisions and TCT setup.*
  - *MPS validation campaign.*

From IR8 β^* leveling to C&S

- Offline: build new combined squeeze (1+5+8) with colliding part, build collision BP for IR2 and IR8.
  - *Copy IR1+5 settings, zero separation where desired.*
  - *Map IR8 matched points new squeeze.*
    - Copy corrections for IR8 (orbit, optics), take into account separation, remove lumi scans.
    - Quality of optics less critical than for β^* leveling.
- Steps:
  - *Cycle with probes to check orbit and optics.*
  - *If problem (not expected if IR8 corrections are local !) one cycle to correct optics.*
  - *Cycle to setup collisions and align collimators.*
  - *Cycle to check collisions with direct C&S (no stops).*
  - *MPS validations – details to be defined.*

From C&S to squeeze

- Simple transition, only the separation is restored.
- Steps:
  - *One cycle with probes to check orbit and OFB (reference).*
  - *One cycle for collimator alignment at end of squeeze (all IPs separated).*
  - *MPS validation at end of squeeze.*