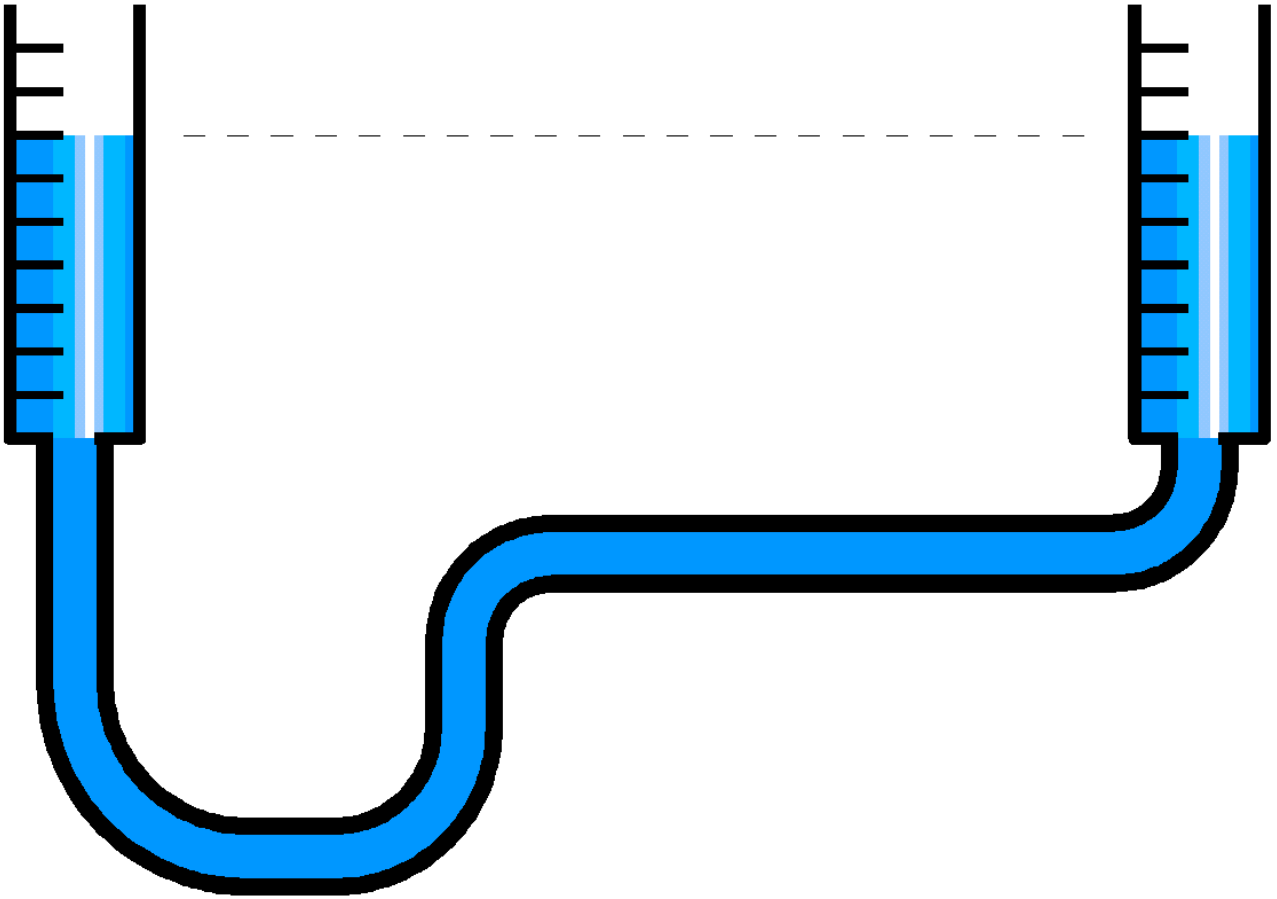
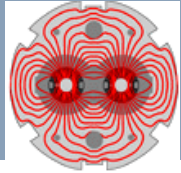
Colliding squeeze and b leveling*

J. Wenninger

X.Buffat, W. Herr, T. Pieloni,



Motivations - instabilities



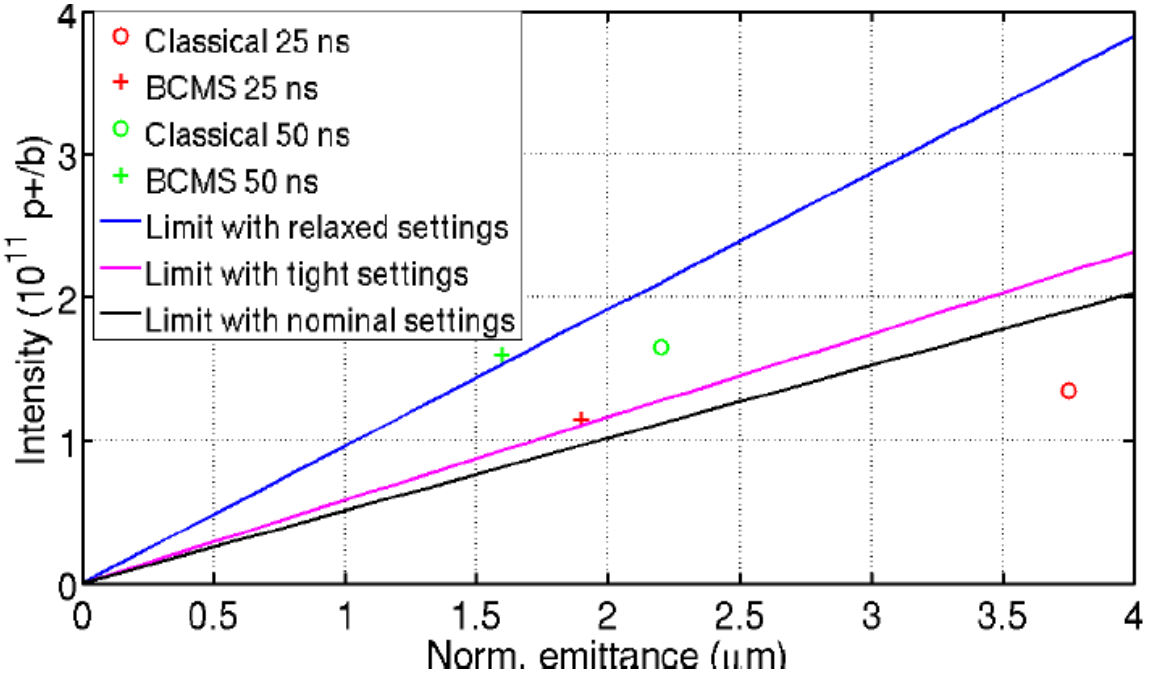
- As the bunch intensity was pushed in 2012, instabilities have started to plaque operation.
- Depending on sign and current of octupoles as well as Q', the problem appeared at different moments in the cycle.
  - *Still subject of studies and discussions.*
- Head-on beam-beam turned out to be an efficient → the most effective source of Landau damping.

  ⇒ *Idea to collide during (part of) the squeeze to stabilize beams.*
- At 6.5+ TeV the efficiency of our octupoles will go down further. And the low emittance BCMS beams will not improve the situation.

Evaluate options for colliding during the squeeze

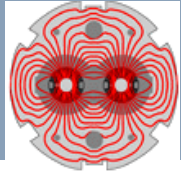
Stability & impedance

- Dependence on collimator settings ⇔ define β* reach.
  - *Tighter collimators → lower β* and lower instability threshold.*
  - *It would be nice to predict the optimum !*
- 50 ns BCMS critical, 25 ns ~ could be OK.



N. Mounet

Motivations – pile-up

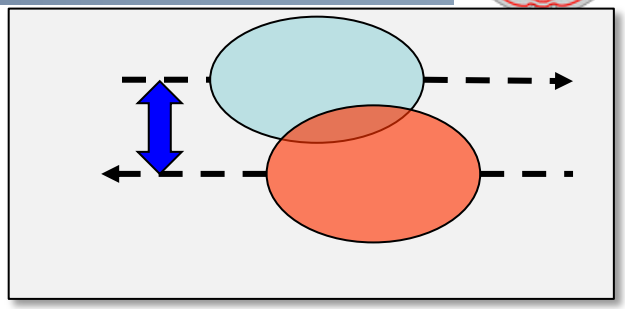


Two out of many possible scenarios @ 6.5 TeV

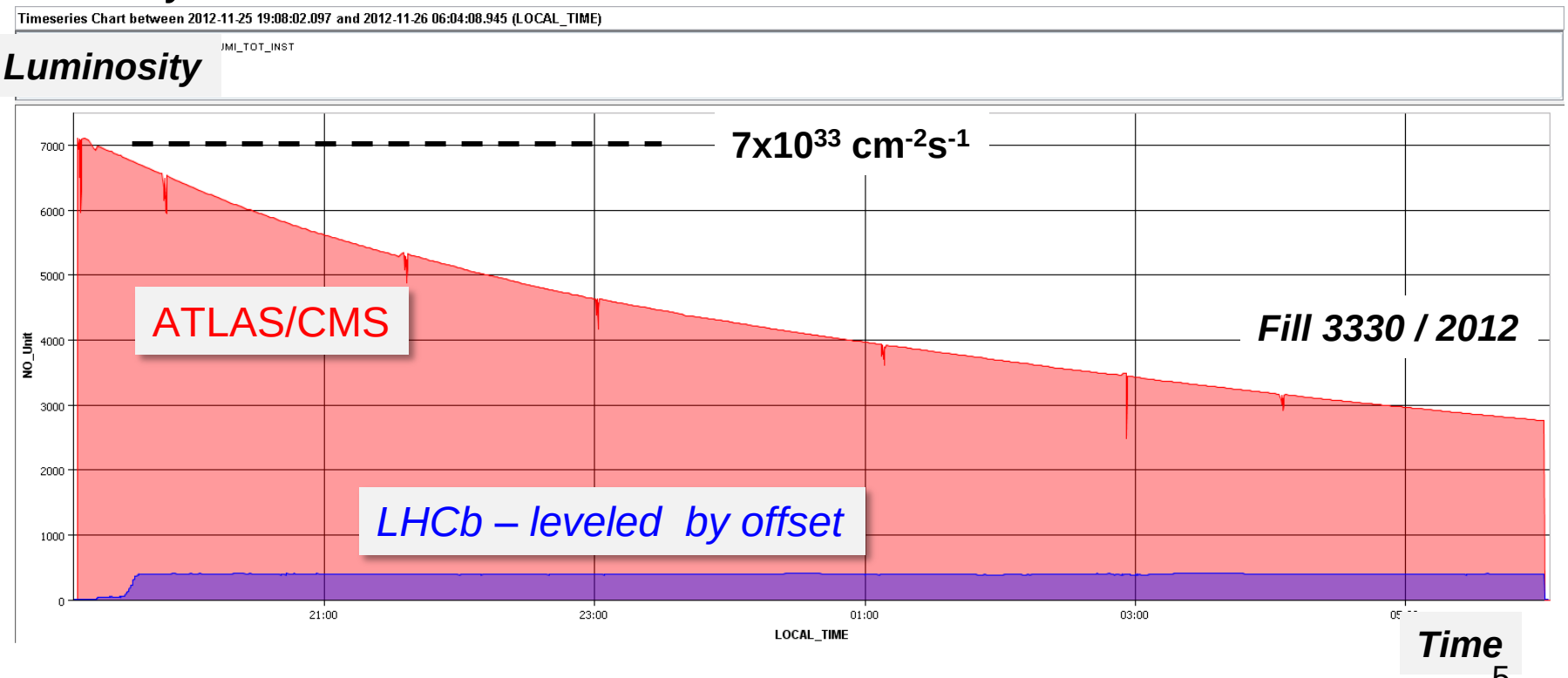
Beam	k	N_b [10^{11} p]	ε [μm]	β* [m]	L [10^{34} cm^{-2}s^{-1}]	Event pile-up	Int. L [fb^{-1}]
50 ns	1260	1.70	1.6	**0.4**	**2.0**	110*	~30
25 ns low ε	2520	1.15	1.9	**0.4**	**1.5**	42*	~50
25 ns standard	2760	1.15	3.7	**0.5**	**0.85**	23	~30

- Optimists would say that we could get 50% higher peak L…
- 50 ns : pile-up way to high → leveling needed.
- 25 ns: at the limit for ATLAS / CMS? Wait and see.

Leveling luminosities

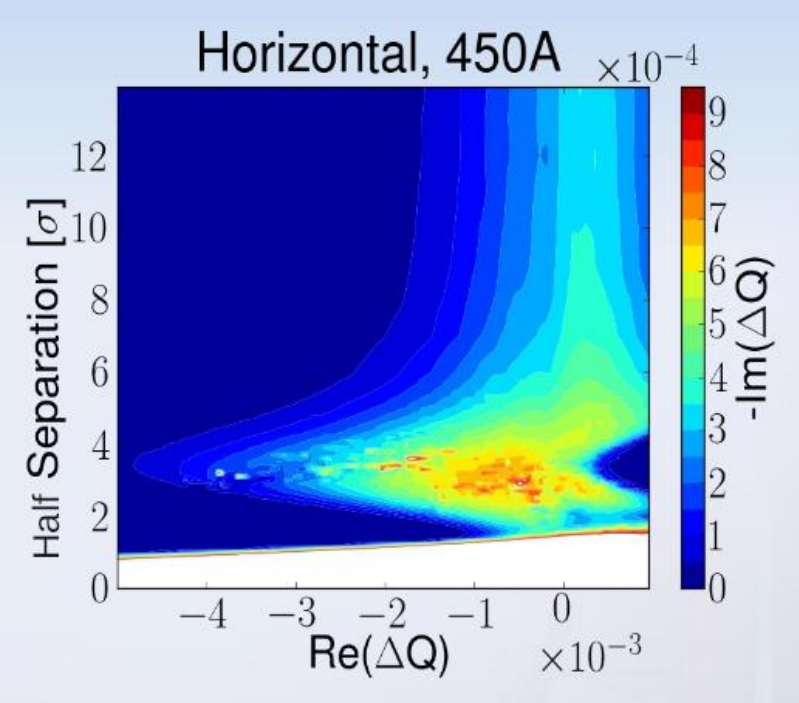


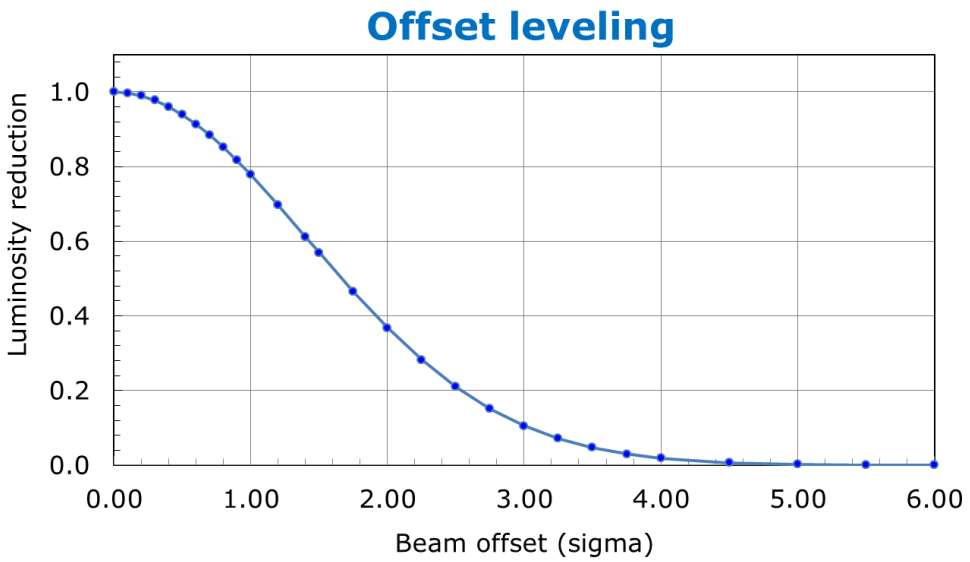
- In run 1 we have leveled the luminosity of LHCb (and ALICE) by adjusting the *offsets between the beams*.
  - *Smooth, local and easy to operate.*
- In run 2 we have to consider β* leveling for stability reasons.



Offset leveling

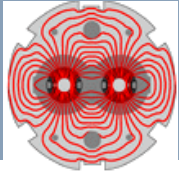
- Offset leveling by a factor ~2 – as required for IR1+IR5 with 50 ns – brings us into an unfavorable region for beam stability.
- Offset leveling in H for ATLAS and V for CMS (separation planes) could be envisaged taking advantage of head-on from other IP.
  - *Issue of luminosity optimizations – instability triggered during scans.*





X. Buffat

Two operation modes



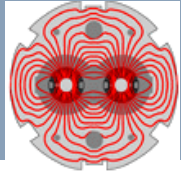
Squeezing with colliding beams and beta* leveling are similar operations – squeezes – but with different boundary conditions.

- **Colliding squeeze**: experiments are off/on standby (could be ON!!)
  - *As fast as possible,*
  - *Large / minimum number of steps in beta* (‘one go desirable’),*
  - *Fixed beta* sequence.*
- **Beta* leveling**: experiments are taking data
  - *As smooth as possible,*
  - *Small steps,*
  - *Ideally fully flexible beta* sequence*.

Compared to a simple squeeze the added challenge is to keep the beams in collision during the process

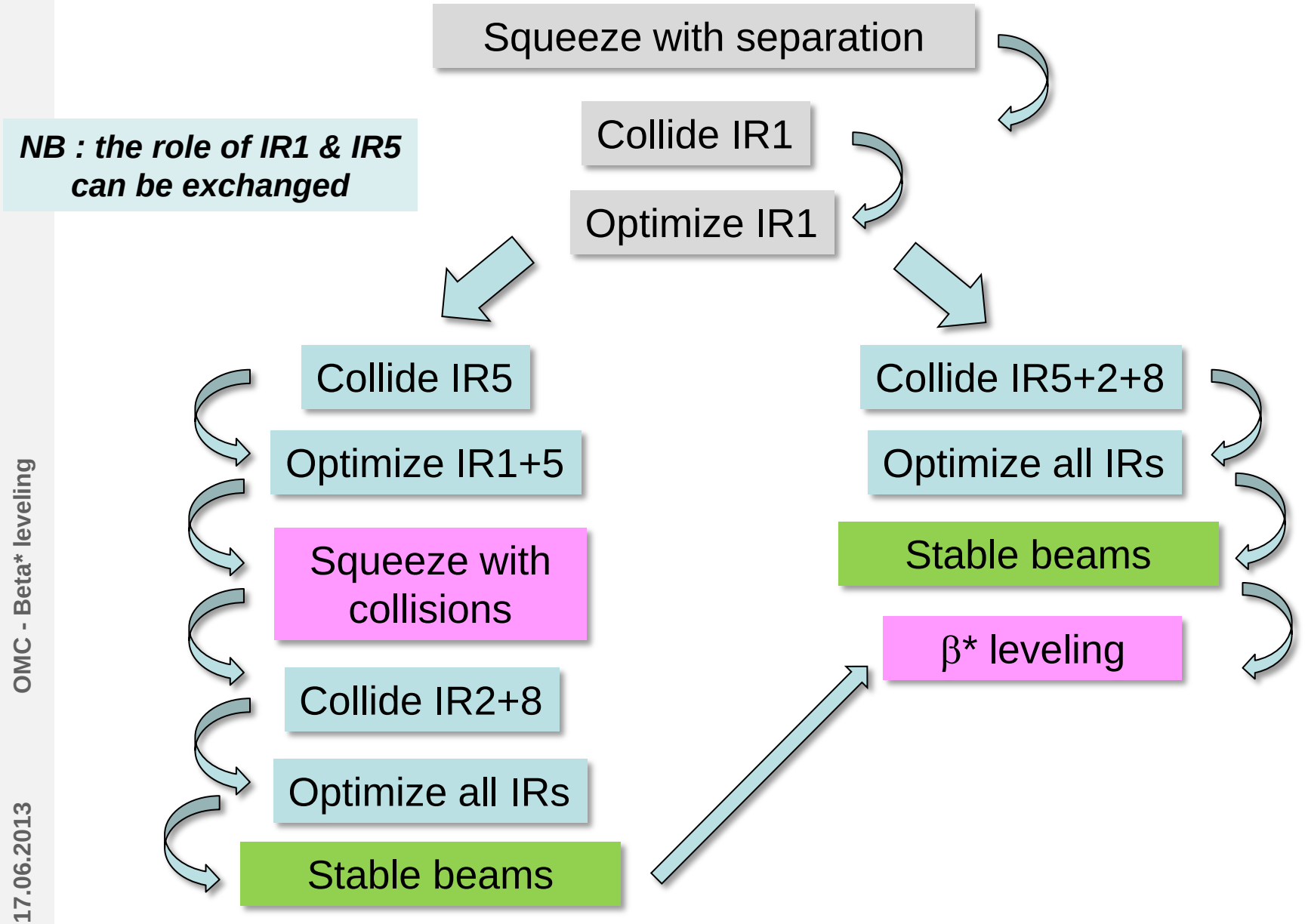
(ignoring controls aspects here)

β* ranges – round beams

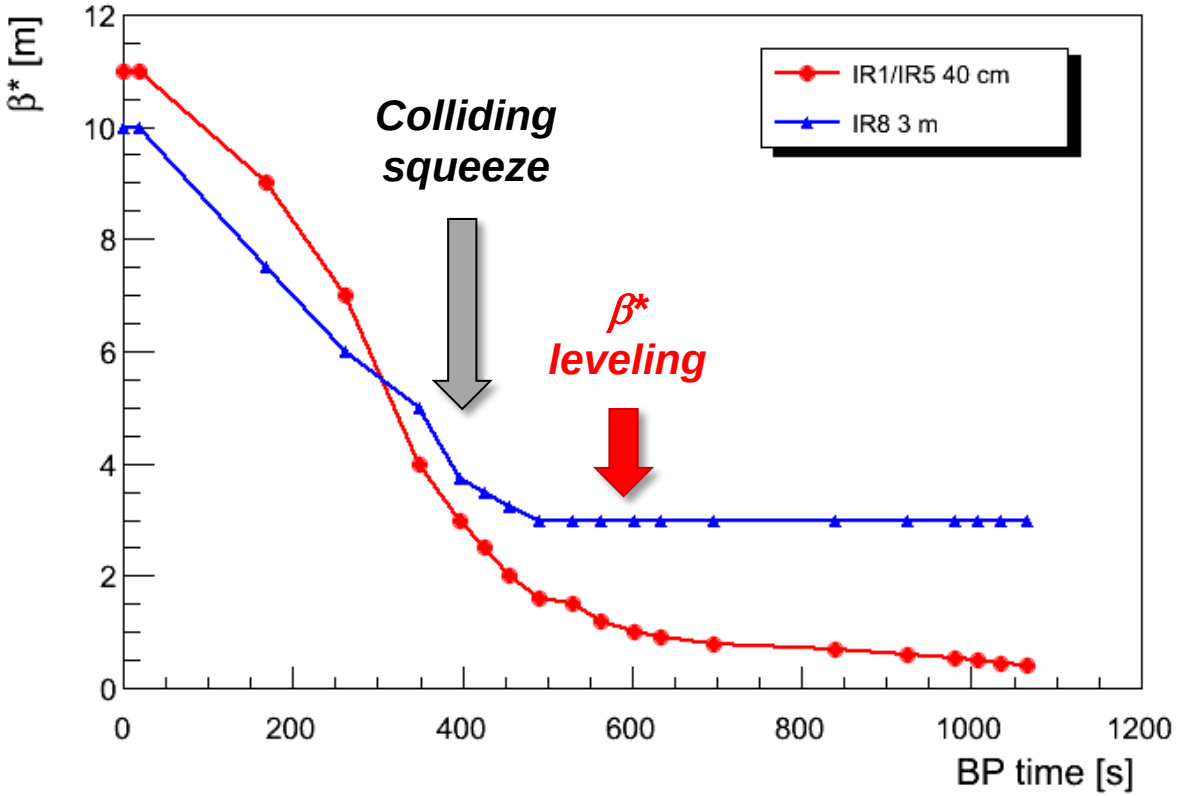


- **IR1 and IR5**:
  - *Expected β* range:*
    ~3 m (coll. squeeze) / ~1.5-1.0 m (β level) ⇒ min. β* ~0.4 m.*
- **IR2:**
  - *No β* leveling possible – L reduction ≥ 100 needed (β* 10m).*
  - *Only offset leveling is an option, required offset: ~4-5 sigma.*
- **IR8**:
  - *Required β* range: from ~20-40 m to 3-5 m.*
  - *Depends on beam (50 / 25 ns) and brightness.*
  - *De-squeeze and/or larger injection β* required !*
- The ranges are increased for flat beams in IR1 and IR5.
  - *No flat beams in IR8: excessive β range and tilted crossing !*

Flow chart

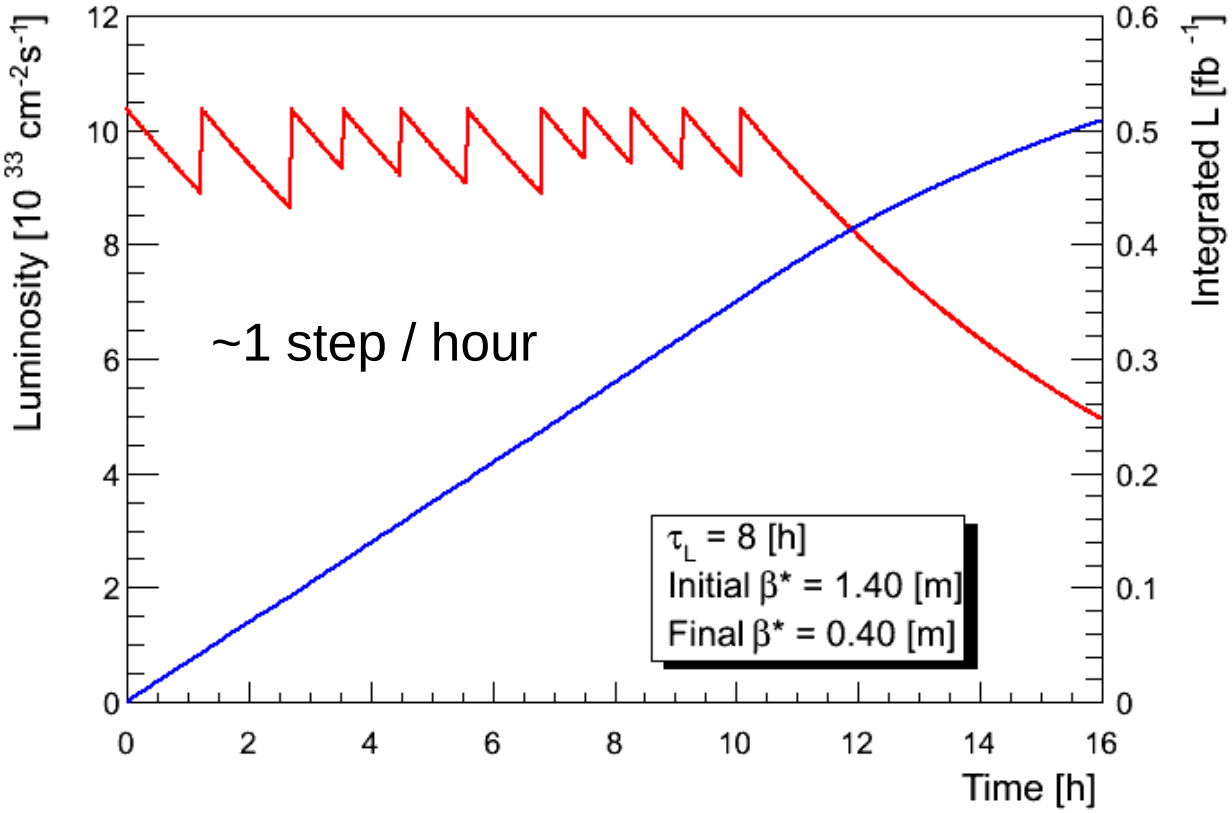

Squeeze with separation
Collide IR1
Optimize IR1
NB : the role of IR1 & IR5 can be exchanged
Collide IR5
Optimize IR1+5
Squeeze with collisions
Collide IR2+8
Optimize all IRs
Stable beams
Collide IR5+2+8
Optimize all IRs
Stable beams
β* leveling

Scenario IR1+R5 β* leveling / colliding squeeze



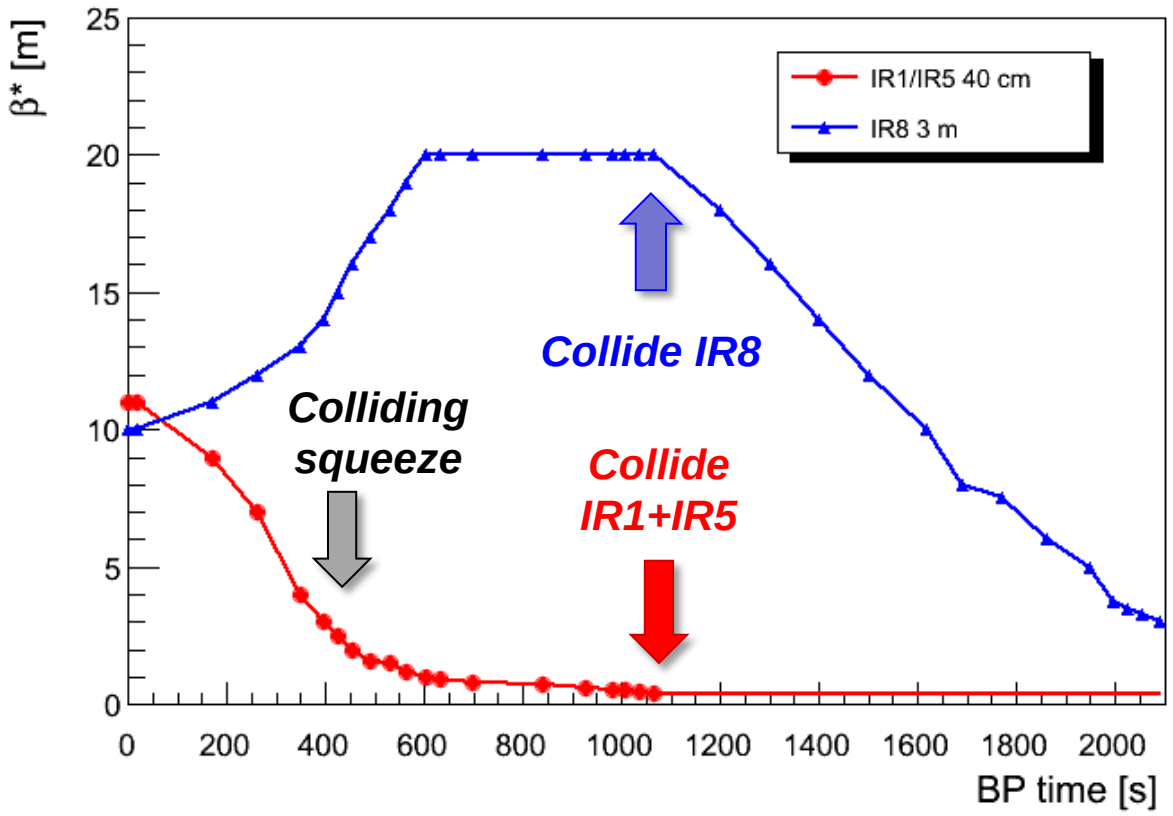
- **Colliding squeeze or β* leveling IR1+IR5.**
  - *Essentially the same machine settings / setup.*
  - ***Assumes the same β* in IR1 and IR5.***
  - *Offset leveling in IR8.*
  - *'Easy' to revert to squeeze with separation followed by collisions.*

Example of a leveled fill IR1/5



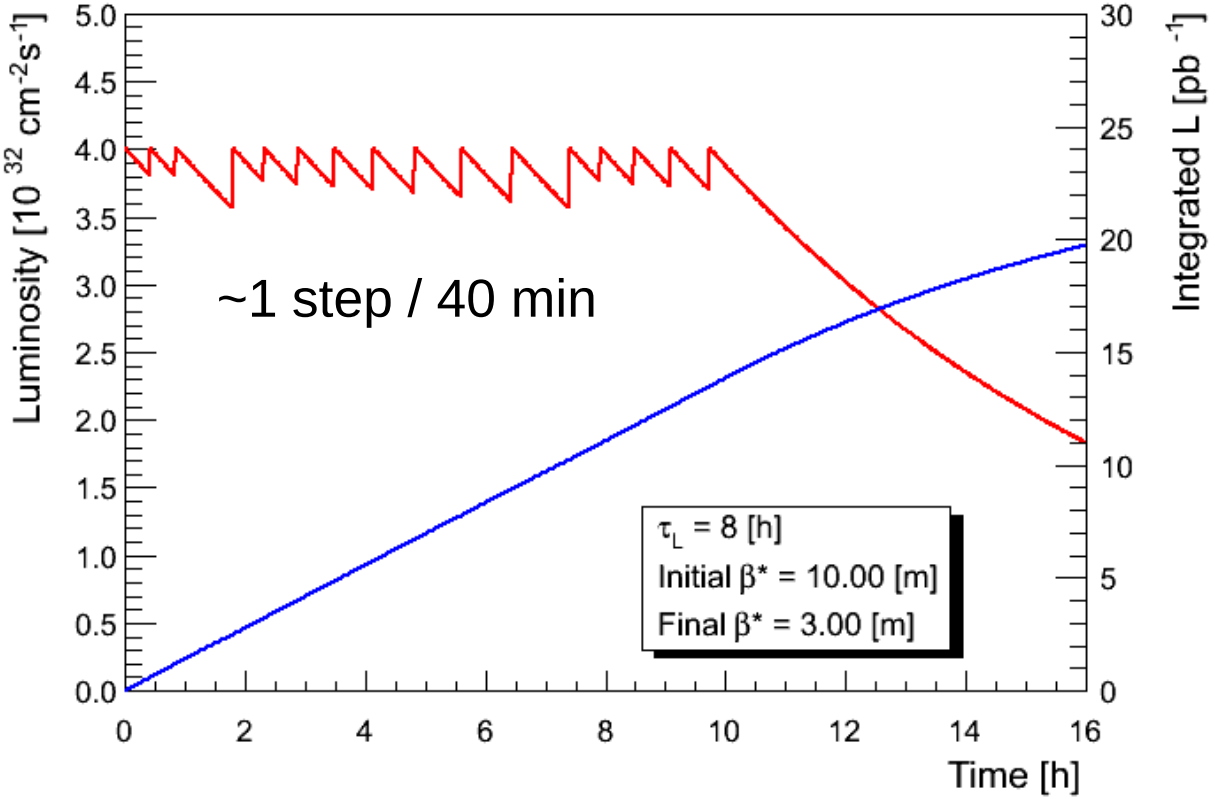
- 50 ns leveled down to 10^{34} $cm^{-2}s^{-1}$.
- Steps correspond to the 2012 squeeze points. Luminosity is constant within 10% until we run out of β^* points.

Scenario IR8 β* leveling



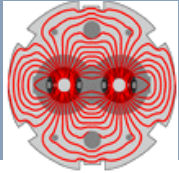
- **β* leveling in IR8** – if no issue with pile-up in IR1&IR5.
  - *Squeeze IR1/5 to 0.4m, IR8 β* ~20 m (max?).*
    - *→ need an un-squeeze in IR8, or start with offset leveling.*
  - *To revert to offset leveling: redo squeeze (IR8) → need smaller β* in IR8.*

Example of a leveled fill IR8



- 25 ns beam with ~3.5 μm emittance and 10^{11} p/b leveled to 4×10^{32} $cm^{-2}s^{-1}$.
- The steps correspond to all currently available matched points/optics. Luminosity is constant within 10% until we run out of β* points.

More scenarios

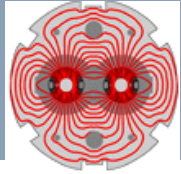


- **Collide in IR2 during the 'squeeze'**
  - *Since there is no squeeze in ALICE/IR2 → stable conditions – much easier !*
  - *Collide in IR2 during squeeze, as soon as beams collide in IR1+IR5 → re-separate for stable beams.*
  - *But ALICE must be OFF,OFF,OFF – not sure ALICE will accept this…*
- **Fully flexible beta* leveling in IR1+IR5+IR8** (à la HL-LHC?)
  - *Every experiment can choose its β^* at any time in any fill…*
  - *To do it properly requires (significant) changes in the LHC control system.*
  - *The commissioning is much longer: 3-5 times?*
    - *Squeeze each IR alone → collect all corrections.*
    - *Test flexible squeeze – N times.*

Change of paradigm: we are NOT reproducing the same sequence in every fill as we did so far.

Not considered (so far) for post LS1

Constraints?

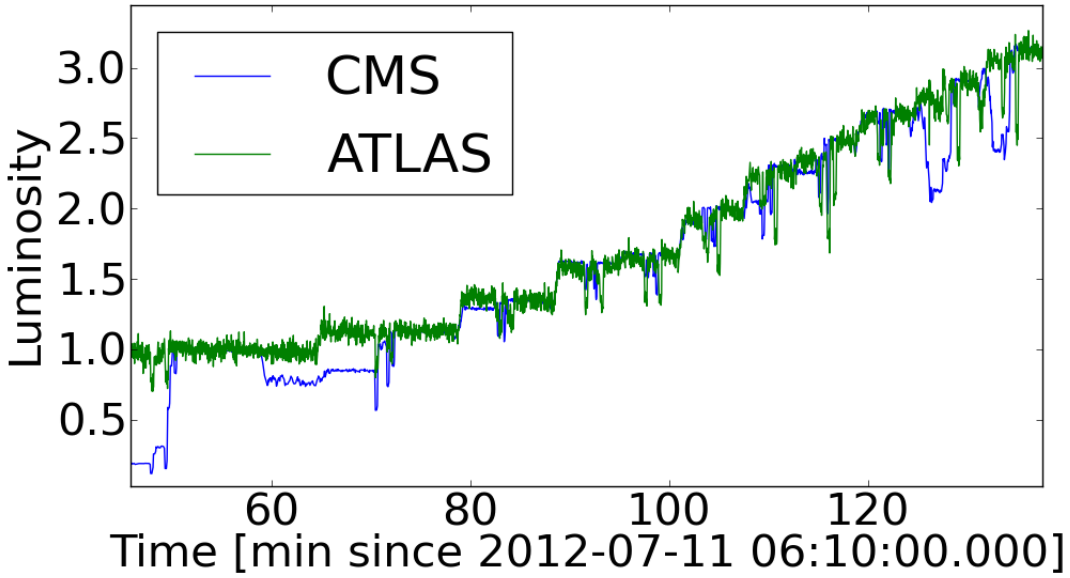


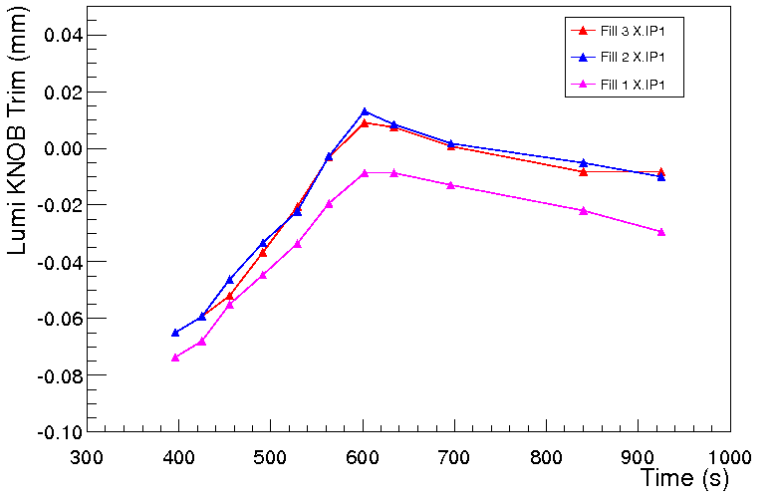
- **Colliding squeeze**: driven by beam stability considerations.
  - *The beams should remain in collision within ~ 1 sigma.*

- **Beta* leveling**: driven by luminosity considerations.
  - *Excluding beam stability, no hard constraints on stability.*
    - *If leveling in IR8, stability not too critical ⇔ head-on for 1+5.*
  - *But it is better if the beams are kept colliding head-on.*
  - *Steps should not be too large 5-10% seems a reasonable compromise between stable periods and squeezing periods.*

MDs in 2012

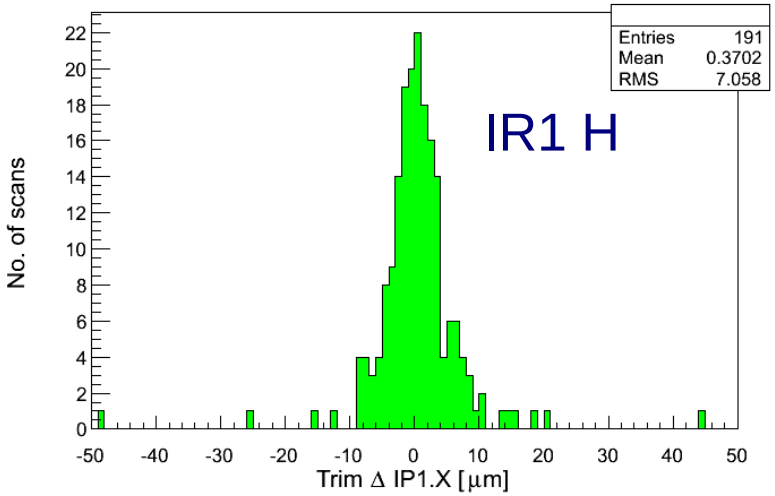
- Principle was tested with success in 2012 from 11m and 3m → 0.6m.
- Luminosity corrections remained valid for an interval of 3 weeks.
  - *Only overall offset change → established with going into collision.*
- Orbit reference management was a bit tricky.
  - *Lumi knobs were not part of reference orbit system – 'easy' to fix.*
  - *Need a very clean setup of the orbit from the start.*

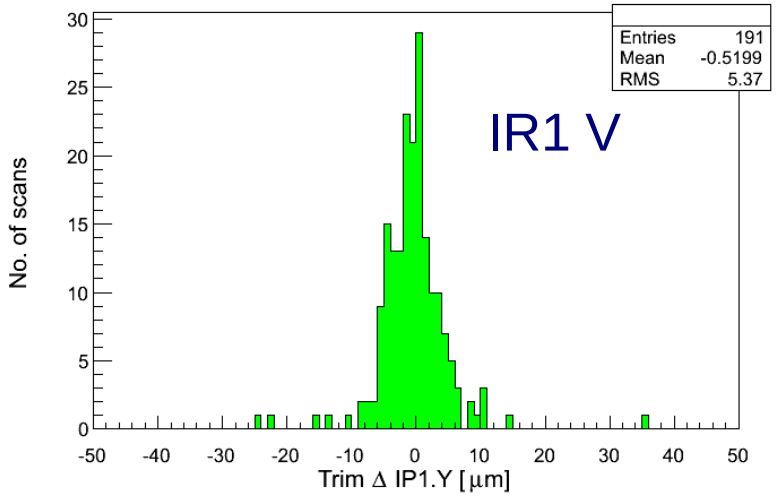




Stabilize collisions (1)

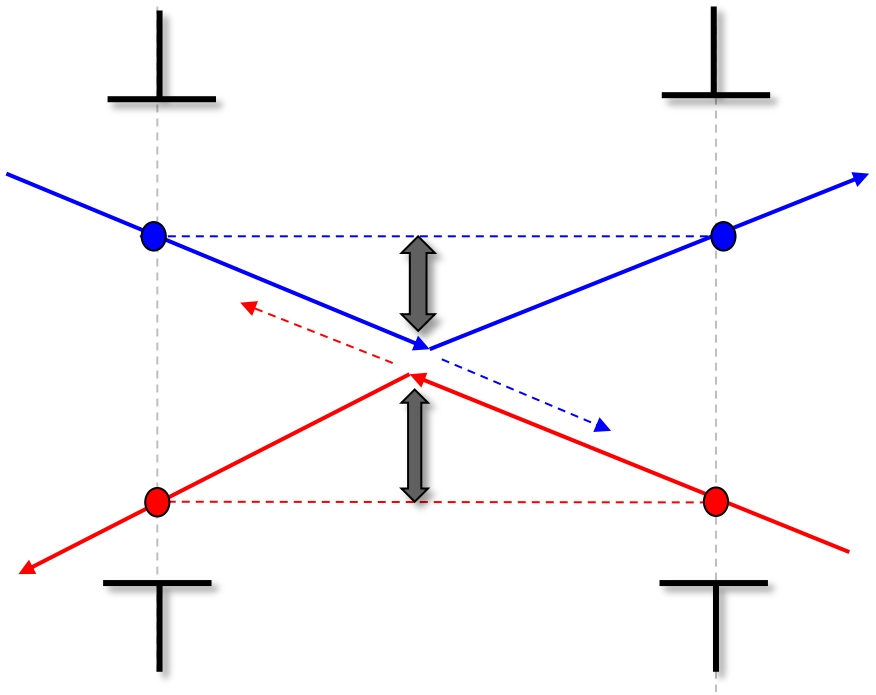
- Stabilization of the collision point during the process is more difficult for large colliding squeeze β* steps than for small β* leveling steps.
- Technique 1: Just correct the orbit well (to the reference) with all available BPMs - what we did so far.
  - *Worked very well in 2012 for the last point of the squeeze.*
  - *Fill-2-fill reproducibility of 0.5σ for more than 95% of the fills.*
  - *After LS1 on could try to tune no. of SVD eigenvalues for orbit correction.*



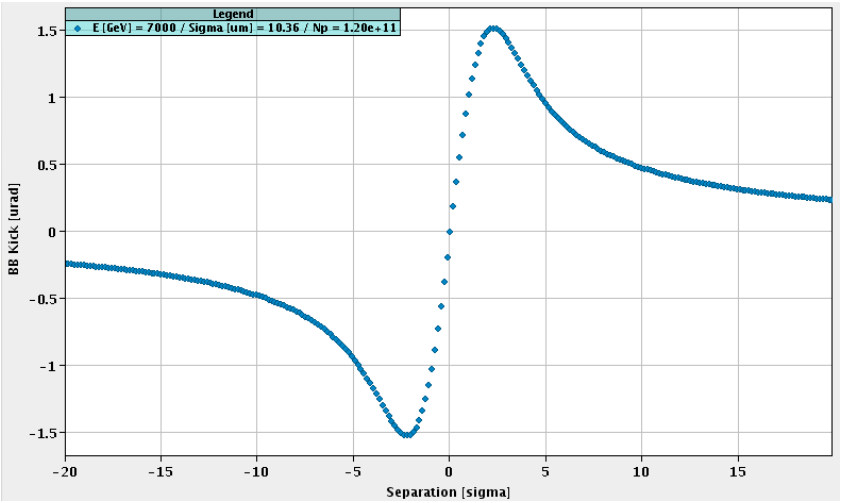


Stabilize collisions (2)

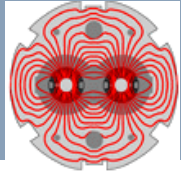
- Technique 2: Integrate more precise BPMs around the IP – 'DOROS'.
  - *We should get one more accurate (!) BPM at Q1 after LS1.*
  - *Wait and see how it works, if we use it for precise steering → possible redundancy issue – what if the BPM is 'broken'?*
  - *Note that the measurement is biased by beam-beam kicks when the beams are not head-on !*



Interpolation error can exceed ~1σ / beam



Stabilize collisions (3)

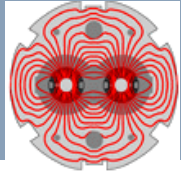


- Luminosity – scan the beams
  - *Multi-point scans, 2D scans, back and forth one step one plane at a time.*
  - *Need fast and accurate relative luminosity values. Issue when there are few bunches…*
  - *Scan procedure is not stable with drifts in both planes, can easily be biased:*
    - *Example: drift of V separation while scanning H plane → wrong result !*
    - *'Large' drift as compared to scan range → need 2σ scan range?*

      Large range is in contradiction with stability requirements.

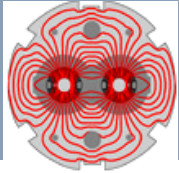
To be looked at more carefully…

Setup and optics measurements



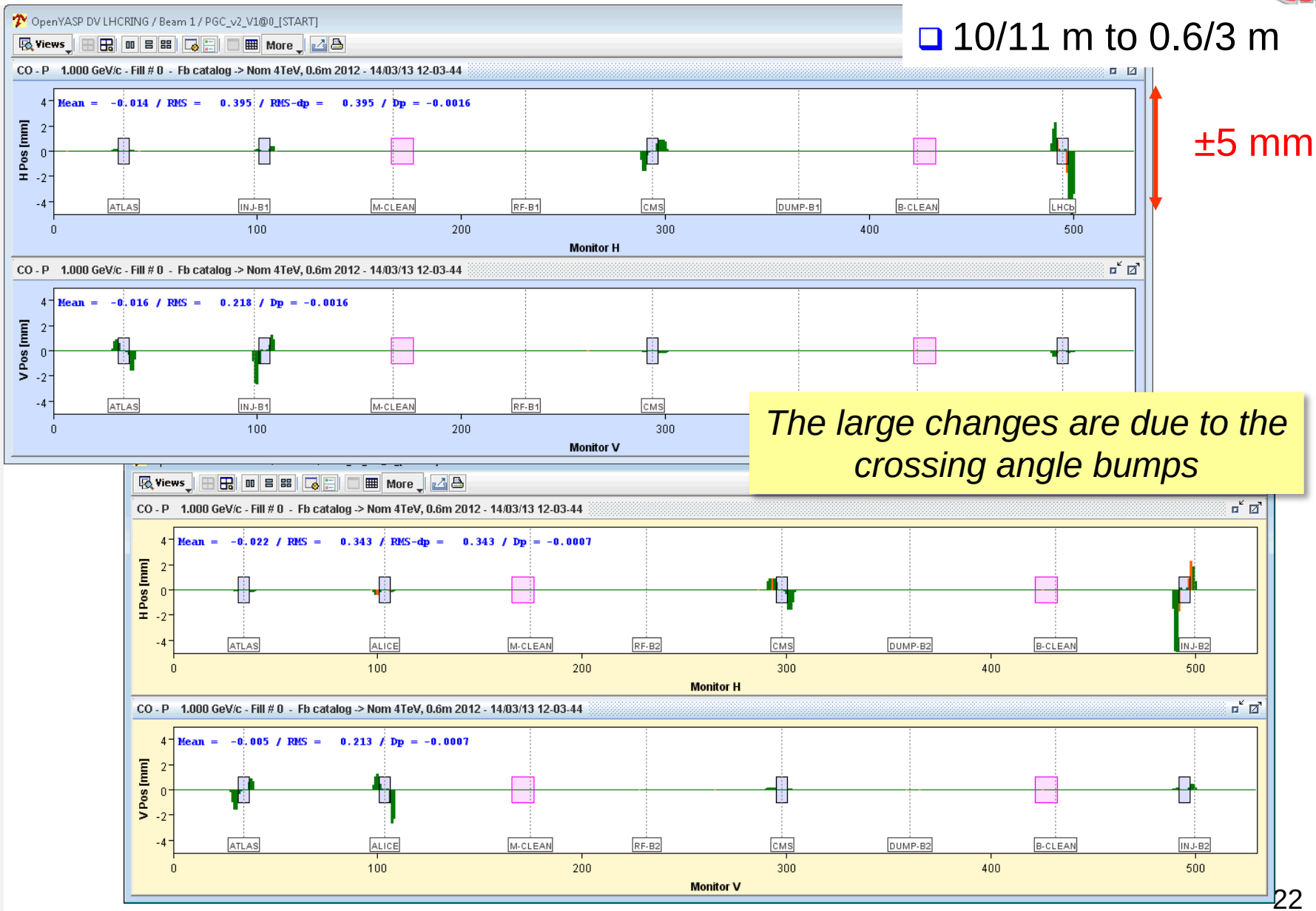
- Processes must be setup from the start with beams in collision.
  - *One could of course consider switching on separation for certain measurements...*
- Optics measurements and other diagnostics (Q,Q', coupling) are easier to perform with non-colliding beams.
- Setup fills & commissioning: no problem – add/use non-colliding bunch(es).
  - *Watch out for the Safe Beam Limit ⇔ masking of certain interlocks.*
  - *Measurement and correction of beam parameters: no change wrt past (exclude fully flexible scheme).*
- With high intensity Q diagnostics (and everything that depends on it) may be an issue due to beam-beam.
  - *Feed-forward will be important – as it was in 2012 for the squeeze.*

Driving the process



- A β* leveling / colliding squeeze step is similar to a standard squeeze step with separation.
  - *Functions, feed-forward of Q, Q', orbit…*
  - *Orbit FB on (+ reference change as needed),*
  - *Unclear if we can use Q FB – quality – wait and see.*
  - *Tertiary collimators moving (a priori).*
- Since β* leveling is more invasive than offset leveling, and in some cases the experiments will be coupled (ATLAS/CMS), the control of the leveling has to be revised ⇔ comm. with experiments.
  - *With offset leveling each experiment is free to drive the steps (see LHCb), with β* leveling the process is too heavy (at least in the beginning).*
- Forward detectors (TOTEM, ALFA) must change positions during data taking with β* leveling to maintain distance constant (in σ).
  - *Requires settings functions !*
  - *Or we set them to the most conservative distance. But this means that the distance in sigma varies along the fill.*

Example: ref. orbit change in 2012 pp squeeze

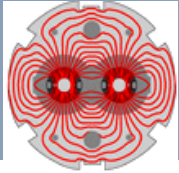


- 10/11 m to 0.6/3 m

±5 mm

The large changes are due to the crossing angle bumps

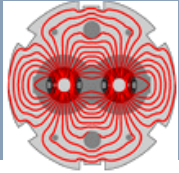
Controls changes?



- For simple leveling / colliding squeeze (fixed and reproducible β* sequence) all the ingredients are available.
- Things to improve/change:
  - *We have to take into account luminosity knobs in the reference orbit.*
  - *It must be possible to incorporate lumi knob trims in the reference 'on the fly'.*
  - *We should aim to keep all corrections as local as possible – prepare for the future (orbit, beta-beating).*
  - *….*
- Sequencing the colliding squeeze.
  - *To be analyzed.*
  - *If it is a problem to perform it in one step → small automated steps:*

    Load & execute a step, if luminosity OK → next step, if not OK fast luminosity optimization, incorporate changes (trim + orbit ref) before step.

Ultimate leveling – à la carte



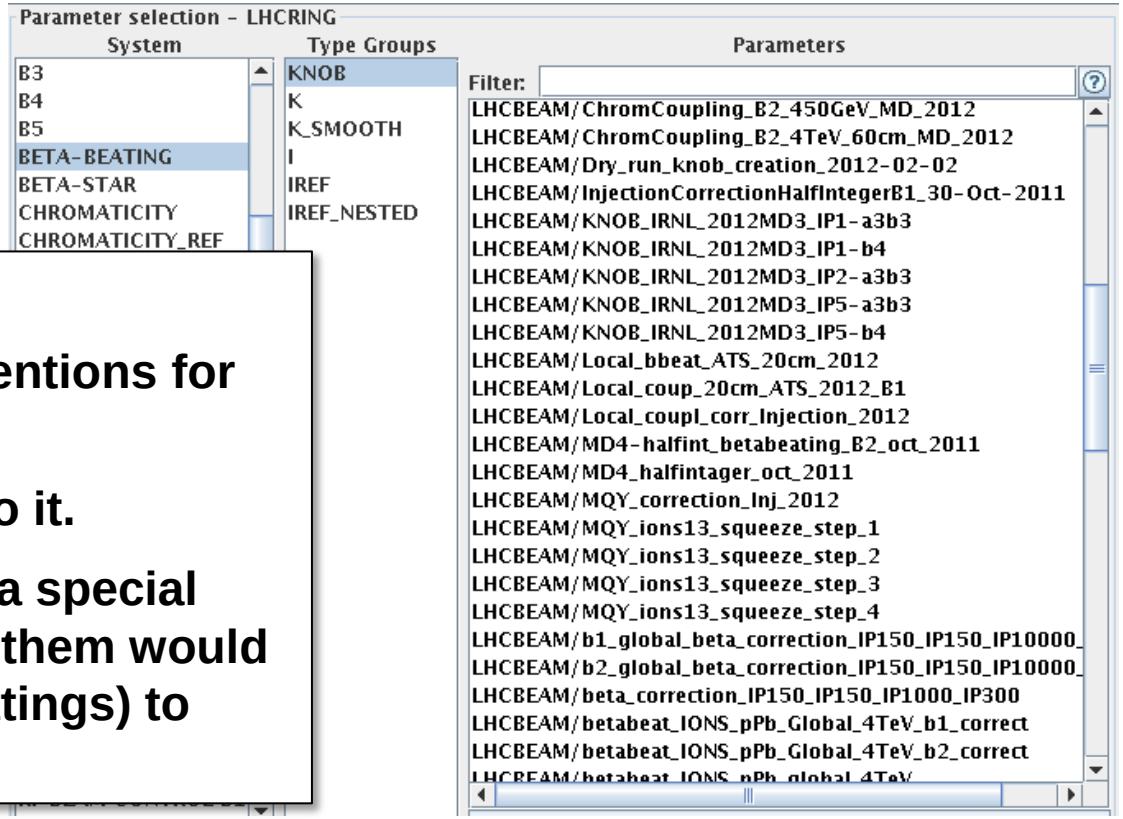
- To get leveling 'à la carte' in all IRs (except IR2) we need to change habits and structure.
- Commission the leveling (squeeze sequence) one IR at a time.
  - *Keep corrections local (as far as reasonable) – orbit, beta-beat.*
  - *Collect all corrections and store as a function of β^* for each IR separately.*
- Execute the leveling – to move from one β^* configuration to the next:
  - *Collect and add together the changes for all IRs involved in a step (including all corrections for orbit, Q, Q', beta-beat, etc).*
  - *Build the functions to drive to the end points dynamically.*

Change of paradigm: we are NOT reproducing the same sequence in every fill !

Clean-up !

- Knobs are nice, but they accumulate.
- And there is a tendency for chaos and absence of naming conventions….

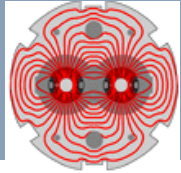
A subset (!) of beta-beat knobs



In the future:

- **We will define naming conventions for knobs.**
- **You are requested to stick to it.**
- **Old knobs will be parked in a special parameter group (removing them would require to delete all their settings) to avoid cluttering the GUIs.**

Summary



- There are number of options for colliding squeeze or β* leveling.
- Input from the experiments needed to define parameters (average & peak pile-up, granularity) and control of β* leveling.
- We could try β* leveling in IR8 if IR1+IR5 need no β* leveling.
  - *With IR1+IR5 in collision, there are no issues with stability – relaxes requirements on position control at IP8 – good training for the future.*
- Ultimate β* à la carte requires LSA changes (to be done cleanly).
  - *Study all implications – for the future. Not justified for 2015.*
- Small working group looking at the leveling options and issues for post LS1 – just started.
  - *Updates and results reported at LBOC.*