Separation, crossing, β^*, performance

from first experience: what can we do in 2010 ?

(proposals for discussion)

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Objectives for LHC running in (2009) 2010

- Minimum risk operation
- Deliver luminosity to experiments
- Understand limitations and behaviour of machine and beams
- Establish/improve procedures for operation and optimization

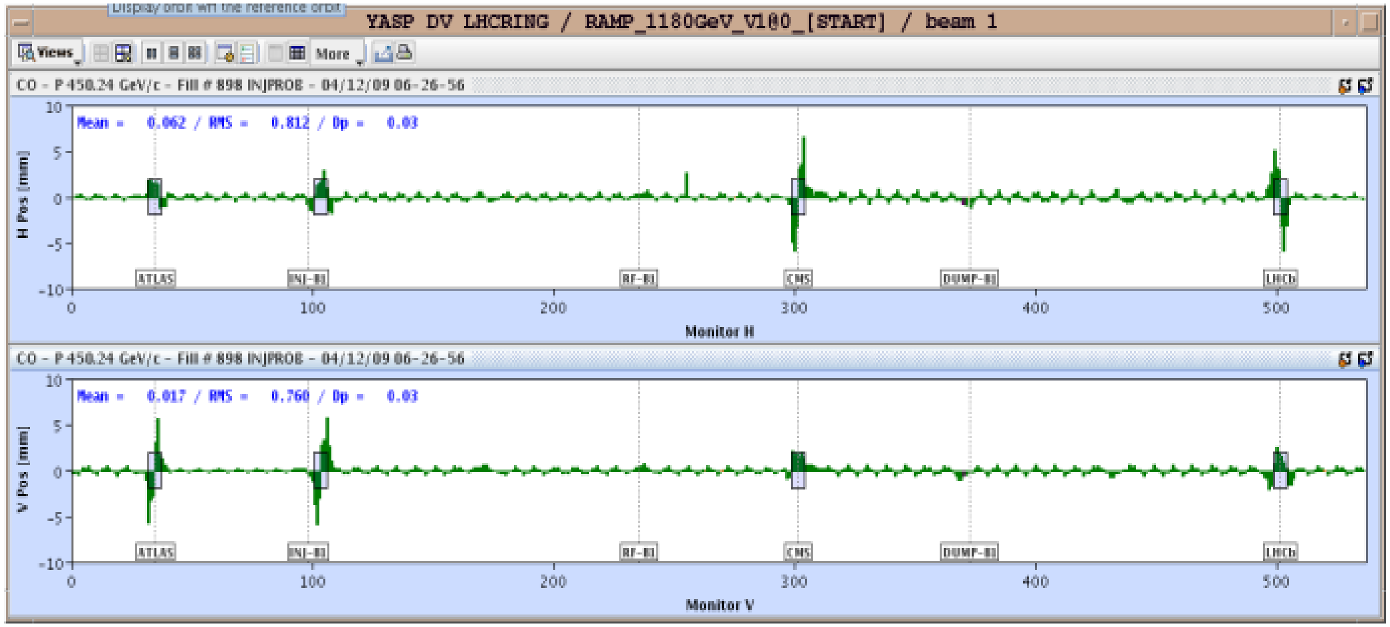
Question:

What is the worst thing for the (luminosity) performance of a hadron collider ?

What has changed since Chamonix 2009 ?

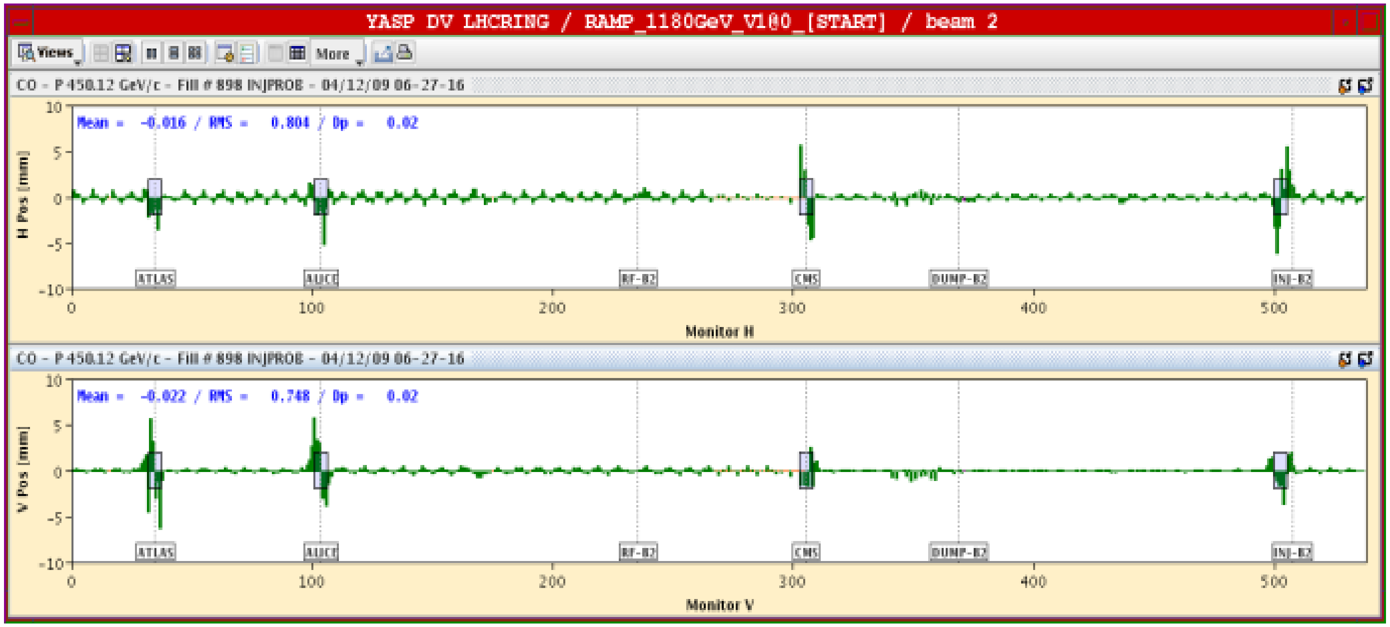
- **First target energy 3.5 TeV (5 TeV)**
- **We assume intermediate collimator settings**
- **We had first experience with:**
  - **Colliding beams**
  - **"multi-bunch" operation**
  - **Established crossing and separation schemes**
  - **Initial squeeze**
  - **Experimental magnets**

Crossing and separation scheme



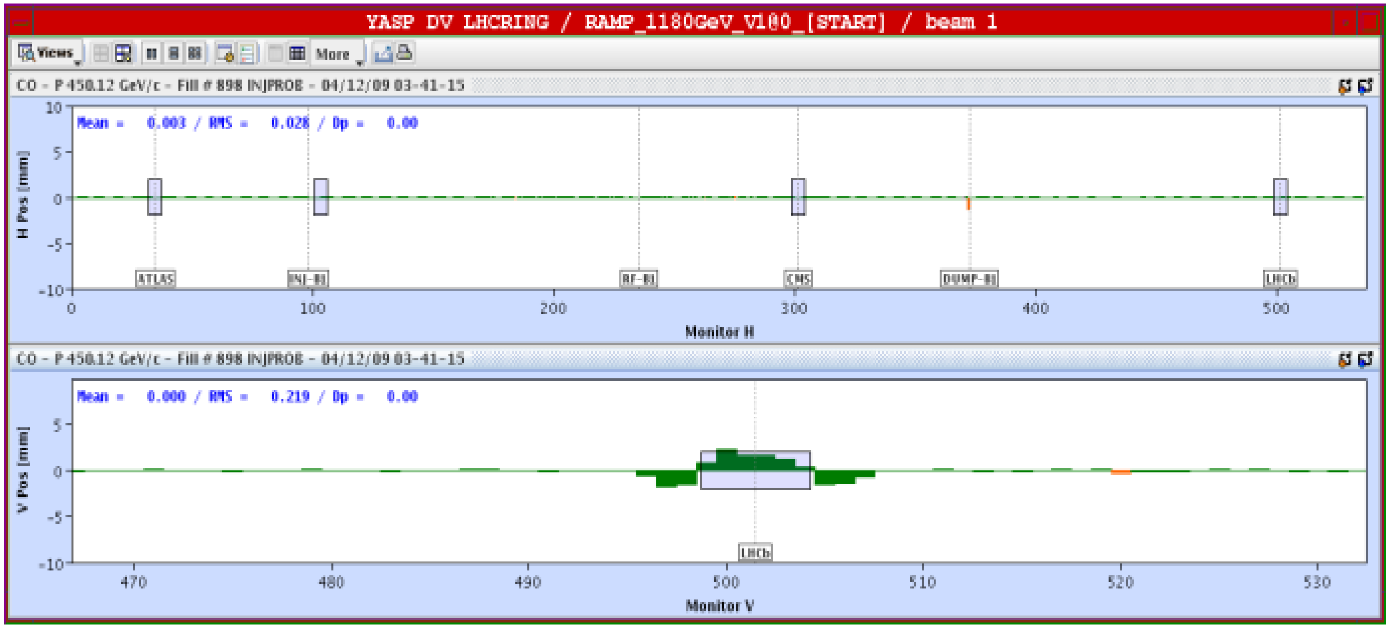
- Crossing and separation beam 1 (injection settings)
- Not corrected, required adjustment small

Crossing and separation scheme



- **Crossing and separation beam 2 (injection settings)**
- **Not corrected, required adjustment small**

Separation bump IP8



- **Well closed and follows expectations**
- **Also for other bumps and other IPs**

Generation of crossing and separation schemes

- Generation of knobs with online model
- Efficient and fully appropriate
- Possible improvements .. ?
  - Maybe some templates for alternative schemes
  - Should known imperfections/limitations be part of the underlying model ?

Crossing and separation

- **Knobs available for all IPs (in mm and μrad)**
  - **Closure already good without correction, not optimized**
  - **For closure: orbit correction procedure sufficient**
  - **Should have "standard" settings available**
- **For luminosity knobs: see S. White presentation**

→ **Suggestion: tuning knobs for single beams**

(Interlude ...)

- **Regularly problems with MCBX (in triplet)**
- **Used for crossing and separation scheme !**
  - **Vital only for small β^* and high energy**
  - **In case of severe problems or for operational efficiency → make bumps without MCBX**
  - **Alternatively: use another one, there are three of them**
  - **On-line model can do that for you**

Experimental magnets commissioning and operation

- **Solenoids (IP1, IP5, IP2) and dipoles (IP2, IP8)**
  - **Need corrections: orbit closure and coupling (H.Burkhardt)**
- **Closure of bumps:**
  - **Done with standard orbit tools**
  - **No active elements inside, corrections should be static**

Experimental magnets commissioning and operation

- **Solenoids coupling correction:**
  - **Important: CMS at injection energy**
  - **ALICE and ATLAS small effects, probably in noise of coupling measurement**
  - **Compensation is global, i.e. sensitive to imperfections, optical errors**
  - **Computed correction works well, empirical fine tuning necessary (and sufficient)**
  - **Probably separate corrections needed for the two beams**

Experimental magnets commissioning and operation

- **For operation of experimental magnets:**
  - **(Careful) setting up of the corrections, should be part of the settings**
  - **Minor adjustments may be necessary over time, otherwise should be o.k., once set up**
  - **Preferred scenario: keep them at full field all the time with all corrections, if possible*)**

***) not possible for LHC*b* spectrometer with unhealthy polarity (+) and crossing angle: energy ramp required (see Chamonix 2006)**

”Multi-bunch” operation in 2009

- **Limited number of bunches and only single bunch injection**
- **Demonstrated:**
  - **Flexible injection process**
  - **Single bunch diagnostics**
- **In 2009: used 2x2, 4x4, 16x16 bunches, no problems encountered (but always single bunches transferred)**

"Multi-bunch" operation in 2009

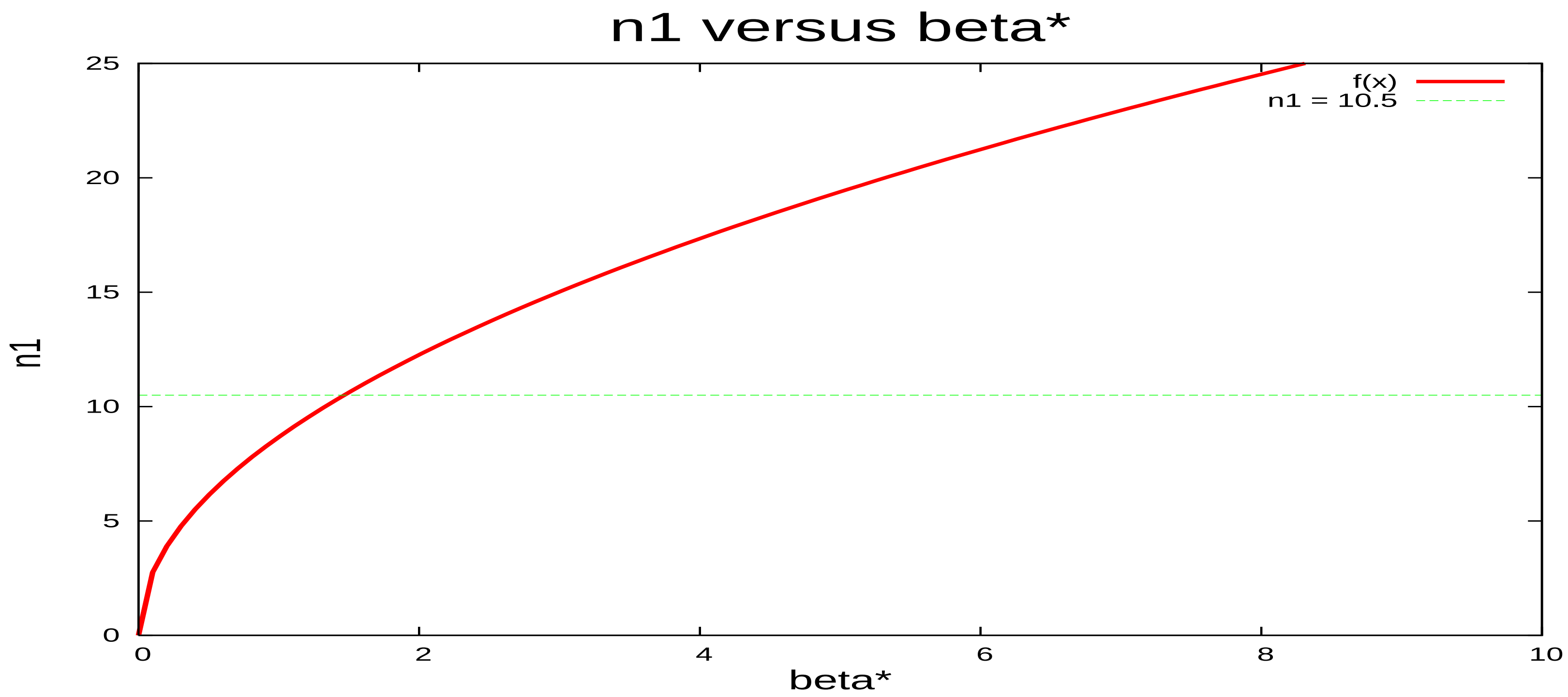
- **Special: equal number of collisions in all IPs (unequal filling schemes), becomes difficult (rather: inefficient) for large number of bunches:**
  - **For 4x4 only 2 collisions maximum per IP**
  - **For 16x16 only 8 collisions maximum per IP**
  - **In general: get only (maximum) n/2 collisions for n bunches per beam**
- **For 43 or 156: can optimize number of collisions in IP1/IP5 at the expense of IP2/IP8 (e.g.: 43-4-43-19)**
- **For injection: multi bunches from SPS to LHC**

"High luminosity" operation in 2010

- **"High luminosity": $\mathcal{L} \geq 10^{32} \text{cm}^{-2}\text{s}^{-1}$**
- **Needs:**
  - **High bunch intensities**
  - **Small beam size, i.e. small β^***
  - **Larger number of bunches**
  - **Up to 156 bunches without, later with crossing angle**
  - **Adjust relative luminosities in IP1/IP5 and IP2, IP8**
- **Which β^* is possible ?**
  - **Dictated by machine protection requirements**

Minimum n1 versus β^*- without crossing angle

- **Minimum $n1$ versus β^* for 3.5 TeV**



Constraints - no crossing angle

- **Respect $n1$ larger than 10.5**
- **Respect maximum intensity I_{max} $5 \cdot 10^{13}$ per beam**
- **Minimum $\beta^* \approx 2$ m is comfortable, slightly lower not excluded**
- **Maximum 156 bunches, all collisions in IP1 and IP5, IP2 and IP8 adjusted (suggestion: 156 - 12 - 156 - 68)**

➤ **Numbers for luminosity therefore approximate**

Going to larger number of bunches

- **Probably start with 4x4, 16x16 etc. to increase intensity**
- **From 4x4 to 43x43 (156x156): single bunches to multiple bunches injection**
- **From 156x156 to more: injection of multiple trains**

First parameter set - no crossing angle

number of bunches	N_b p/bunch)	β^* (m)	angle (μrad)	$\mathcal{L}_{peak}^{IP1,5}$ ($cm^{-2}s^{-1}$)	% I_{max} stored
43	3 10^{10}	4	-	8.6 10^{29}	2.6
43	5 10^{10}	4	-	2.4 10^{30}	4.3
43	5 10^{10}	2	-	4.8 10^{30}	4.3
156	5 10^{10}	2	-	1.7 10^{31}	16
156	7 10^{10}	2	-	3.4 10^{31}	22
156	10 10^{10}	2	-	6.9 10^{31}	31

Conclusions - no crossing angle

- Always well below maximum intensity limit
- To get close to a luminosity 10^{32} cm^{-2}s^{-1}
  - Close to nominal bunch intensity
  - But well away from total intensity limit
  - → For lower energies: incentive to go to crossing angle quickly (i.e. from equidistant bunches to <u>trains</u>)
  - → For the proposed parameters: luminosity loss very small ($\leq$ 3%)
- Do not waste your time optimizing this configuration (except correction of linear machine, β-beating !)

Operation with many bunches (≥ 156)

- This means going from equidistant bunches to trains
- Number of long range interactions increases with number of bunches per train and not the total number of bunches in the beam
- Adding trains does not change the beam-beam effects
- Probably start with very few trains (see later)

Towards larger stored energy

- Basically two options:
  - Many (all) bunches and in steps increase intensity per bunch
  - Large (maximum) intensity per bunch and in steps increase number of bunches (i.e. trains)
- Consequences for:
  - Beam-beam effects
  - Luminosity control in experiments
  - Operation

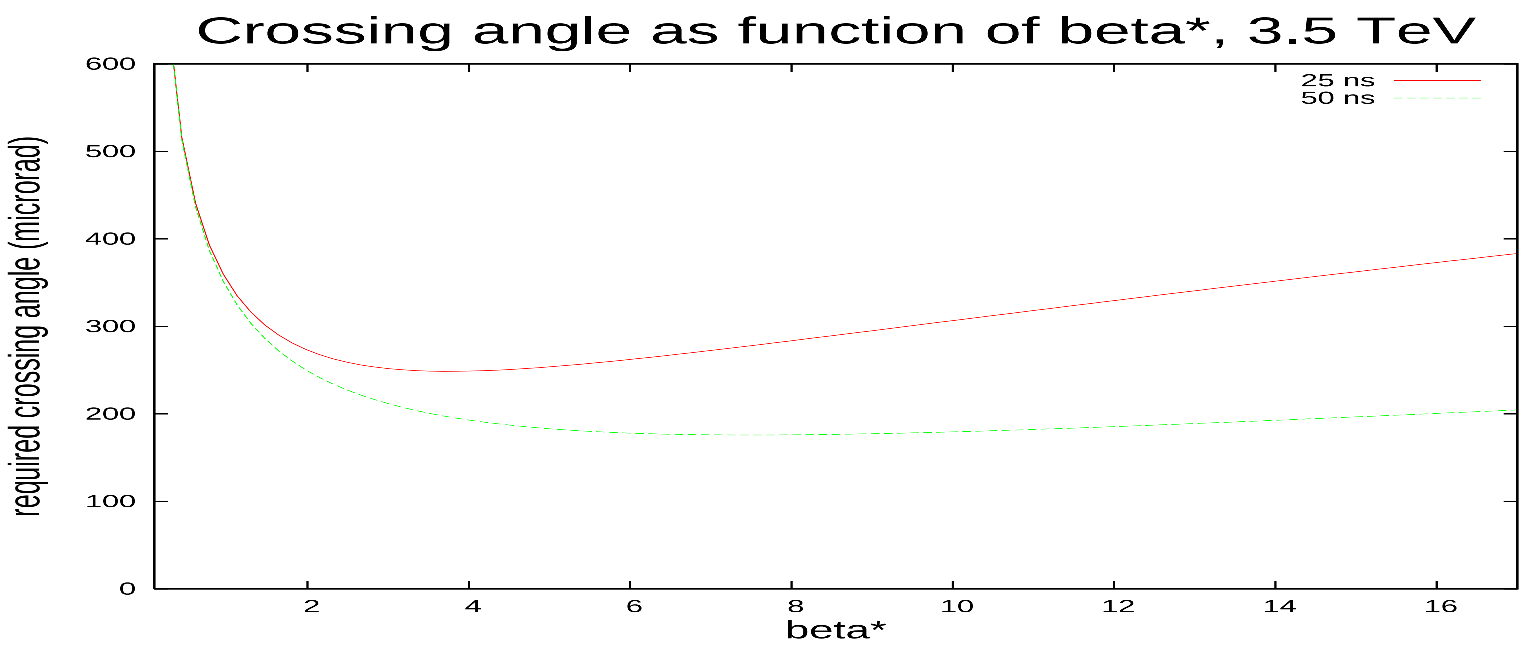
Towards larger stored energy

- **Beam-beam effects:**
  - **Additional bunches behave as bunches already in the machine (for second option)**
- **Luminosity control**
  - **More flexible to share between experiments**
- **Operation**
  - **Changing filling pattern proved to be very easy**

Limits with crossing angle ?

- **With crossing angle:**
  - $\beta^* = 3$ **m is comfortable,** $\beta^* = 2$ **m near limit**
  - **Crossing angle close to nominal, small long range effects, but get operational experience**
  - **Select simple filling schemes (50 ns spacing)**
- **How large is the crossing angle ?**

β^* and crossing angle in 2010



- **Total crossing angle required for 3.5 TeV (for 'sufficient' separation)**

Operation with crossing angle

- **What is needed:**
  - **Generate squeeze with crossing angle (down to 1 m, just in case)**
  - **Closure during squeeze should be sufficient**
  - **Good correction of β-beating**
  - **Good correction of orbit in interaction region**
  - **Luminosity scan knobs for different β^* needed**
  - **Angle should be large enough. For proposed β^* and limited intensity: can keep it constant during squeeze**

Filling schemes

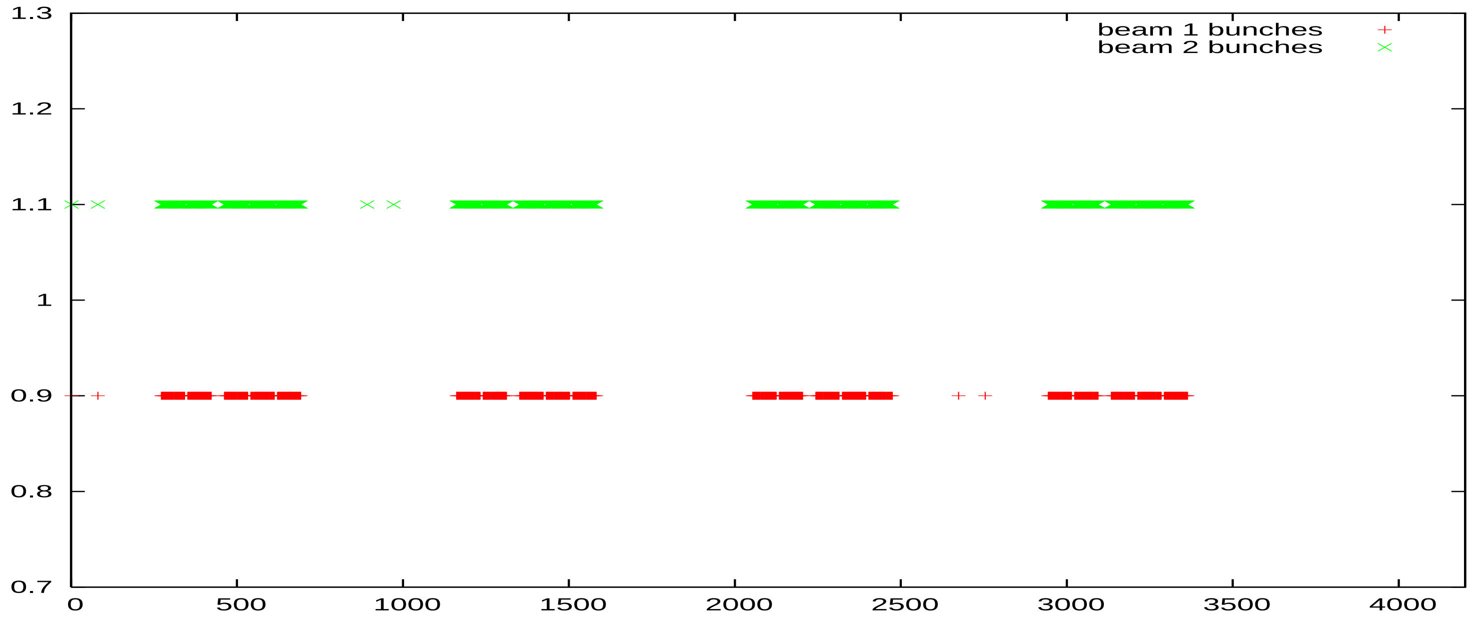
- **"Simple" filling schemes:**
  - **50 ns spacing (no 100 or 150 ns spacing)**
  - **Standard number of trains (2, 3, 4) in the SPS**
  - **Must respect the intensity limit, i.e. total number of particles less than 5 10^{13}**
  - **Number of bunches given all collide in IP1/5**
  - **Number of special bunches for IP2: 1 to 4 with large spacing are possible (or a train, 50 ns spacing)**

Parameter set with crossing angle

number of bunches	N_b p/bunch)	β^* (m)	half angle (μrad)	$\mathcal{L}_{peak}^{IP1,5}$ ($cm^{-2}s^{-1}$)	% I_{max} stored
156 (-)	10 10^{10}	2	-	6.9 10^{31}	31
144 (4)‡	7 10^{10}	3	$\pm$140	2.0 10^{31}	20
288 (8)‡	7 10^{10}	3	$\pm$140	4.1 10^{31}	40
432 (12)‡	7 10^{10}	3	$\pm$140	6.2 10^{31}	60
720 (20)‡	7 10^{10}	3	$\pm$140	10.2 10^{31}	100

$\ddagger$  **LHC*b*,**  **ALICE**

Example: filling scheme with 720 bunches



- **Filling scheme for 720 bunches per beam, extra bunches for IP2**

Possible strategy

- **Start with few bunches and move up to 156 per beam**
- **Push bunch intensity towards nominal (i.e. above $7 \cdot 10^{10}$)**
- **Start operation with crossing angle**
- **Replace equidistant bunches by trains**
- **Add trains until E_{tot} limited or luminosity sufficient (choice of trains to tailor the relative luminosities)**
- **Do not waste your time to optimize the machine before you hit a limit, and thanks for all the fish**