Optics configurations from injection to collision

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Remark: design effort to analyse possible improvements to the IR optics on-going (S. Fartoukh).

- Status quo or evolution?
- Injection configurations
- Top energy configurations (IR1/5)
  - Flat beams
  - ATS
- High-beta
- Summary

Acknowledgements: R. Bruce, S. Fartoukh, session speakers and chairman, T. Risselada, R. Tomás.

Status quo or evolution? - I

- Out of LS1 with a new machine and new target energy:
  - Keep the injection optics configuration as in the 2012 run.
  - Incorporate improvements from MD and paper studies and commission them in 2015.
    - Possible options (never implemented during Run I) already discussed
      - Chamonix 2012 (M.G.)
      - Evian 2012 (R. Tomás)

For Alice and LHCb the quoted angles are the external ones.

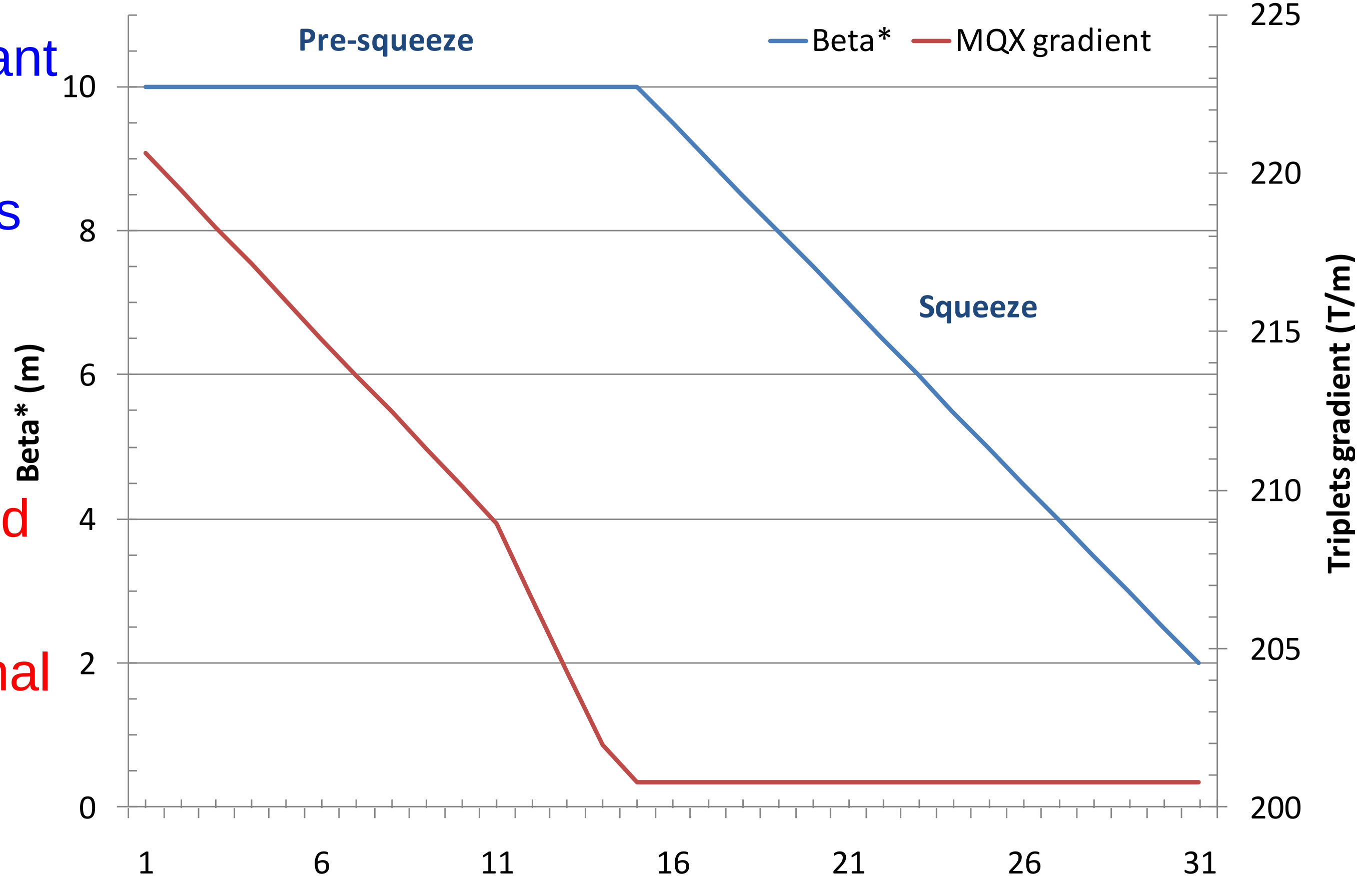
	ATLAS	Alice	CMS	LHCb
Beta* (m)	11	10	11	10
|half cross angle| (μrad)	170	170	170	170
|half parallel separation| (mm)	2	2	2	2

Status quo or evolution? - II

- Is it really possible to keep optics configuration unchanged? Not quite!
  - IR2/8:
    - Injection process imposes a number of constraints on phase advance (kicker/septum, kicker/TDI).
    - Solution presented in LHC PR Notes 188 (IR2) and 193 (IR8) by O. Brüning.
    - The gradient for injection optics is 220 T/m.
  - Nominal solution:
    - Pre-squeeze at constant beta*

Status quo or evolution? - III

- Acceptance tests were performed up to 230 T/m.
- The nominal gradient can be exceeded provided the beams are not in collision. Hence:
  - Optics is kept constant from injection to top energy.
  - Triplets strength is decreased at constant beta*
  - Beta* squeeze starts afterwards.
  - However: due to hardware constraints at around 6.2 TeV the triplets Have to be at nominal strength.

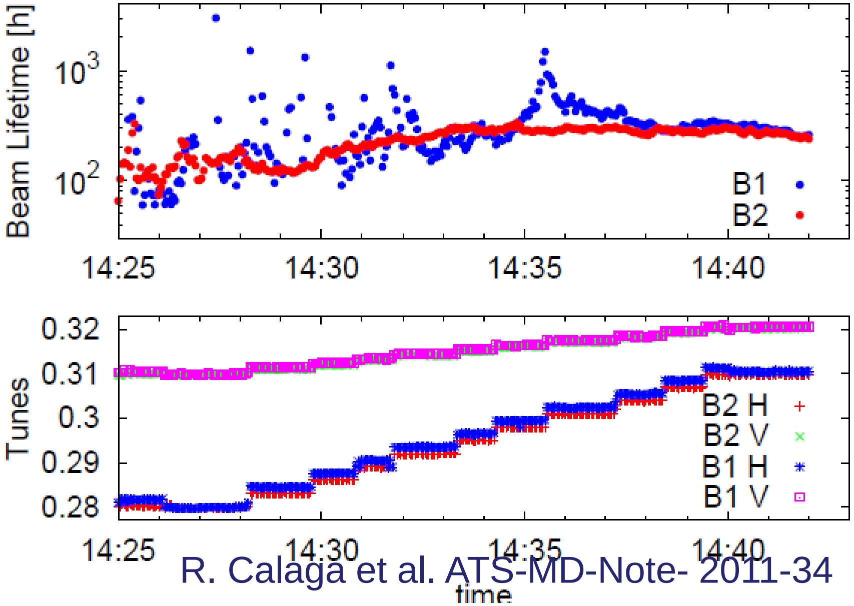


Status quo or evolution? - IV

- In Run II the change of strength of triplets should be performed before reaching the nominal collision energy.
- It is proposed to remove the constraint on performing the pre-squeeze at constant beta*
  - Already during Run I the triplets in IR2/8 where changed during squeeze together with beta*.
  - This would allow reaching the nominal beta* in IR2/8 (in particular if un-squeeze is required).
- Two options possible:
  - Perform the pre-squeeze after the end of the injection process (but still at injection energy) -> moderate change
  - Perform the pre-squeeze during the ramp -> bold change!
  - It opens up the Pandora box of more complex ramp and squeeze gymnastics!

Injection configurations - I

- Collision tunes at injection:
  - Successfully tested in 2011 in MD.
  - Some gain in beam lifetime.
    - Change of tune too violent at the first step of the squeeze.
    - 19 s gained (from current squeeze sequence)
  - Less manipulations at top energy.
  - As an alternative, the change could be performed more adiabatically than in Run I.

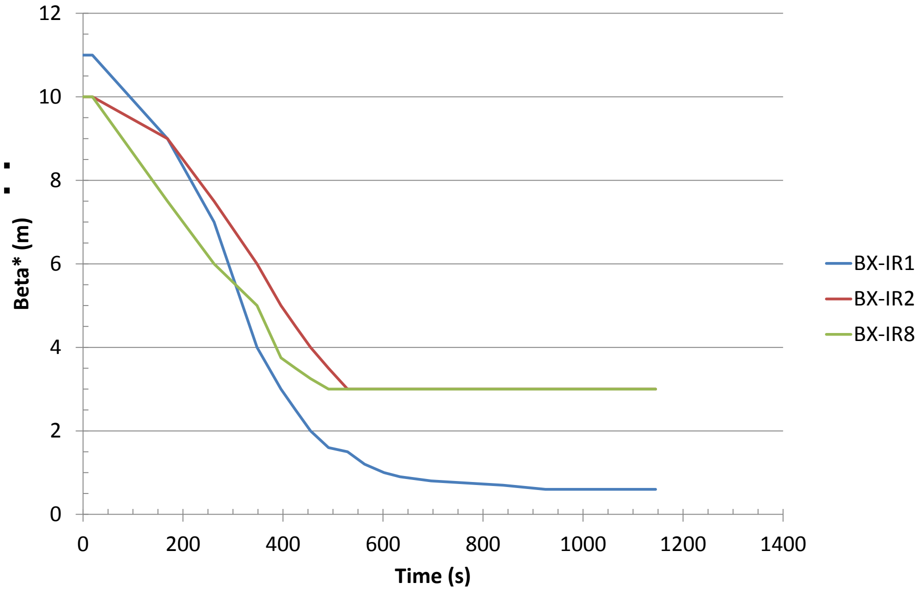


R. Calaga et al. ATS-MD-Note- 2011-34

Interesting option, but not fundamental!

Injection configurations - II

- Lower beta* in ATLAS, CMS at injection
  - Target beta* at injection: 7-9 m (current 11 m).
  - Some gain for the squeeze time: 262-169 s (current squeeze).
  - Pros:
    - Simple, no dynamic change, positive impact on squeeze duration.
  - Cons:
    - With 25 ns beams, e-cloud might have a negative impact on transverse beam emittance: reducing beta* at injection might not be the best strategy.
    - Lower powering of insertion quadrupoles…



- Alternatively, β^* could be reduced during ramp (optics change needed anyway): what is the added complexity?

Interesting option, to be explored in more details!

Injection configurations - III

- New optics in IR6 (proposal by S. Fartoukh):
  - Improved phase advance between MKD and TCSG.
  - Positive impact on protection of TCSG and retraction of TCDQ/TCT.
  - Discussed at LBOC (31/01/2012).

Interesting option, to be explored in more details!

- Crossing scheme in IR8 (to be presented at next LMC meeting 19/06/2013)
  - Injection (S. Fartoukh): optimised horizontal crossing scheme to overcome small amplitude beam-beam encounters.
  - Collision (B. Holzer): review of gymnastics to tilt the crossing plane and avoid systematic differences between spectrometer polarities.

Mandatory option!

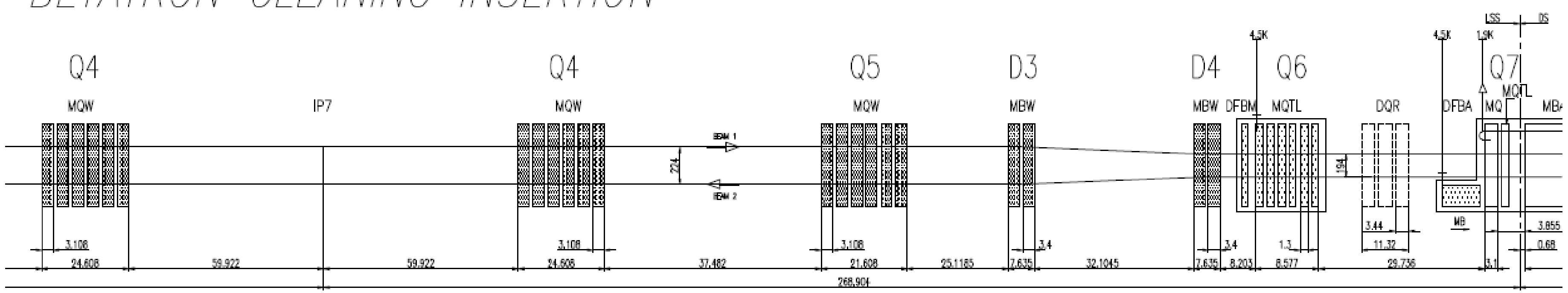
Injection configurations - IV

- New optics in IR3/7?
  - Trigger: recuperate warm magnets to increase the number of spares. Preliminary conclusions:
    - In IR3 no MQWB can be removed without changing the optical conditions at the collimators.
    - In IR7 the MQWB modules in the two Q5 may be removed without changing the optical conditions at the collimators (2 spare magnets).
    - Any other change in the layout will generate a difference of optical condition at the location of the collimators -> Detailed validation of the optics with simulations is required before taking any decision.

Analysis made by T. Risselada

Option to be explored in more details!

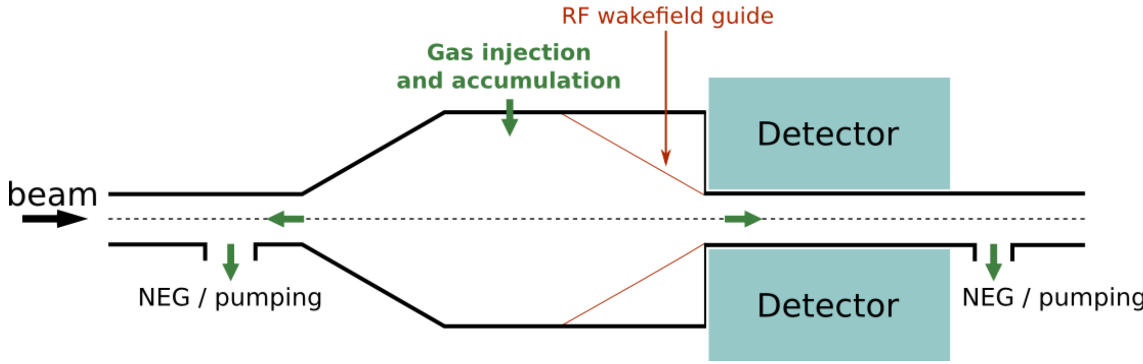
BETATRON CLEANING INSERTION

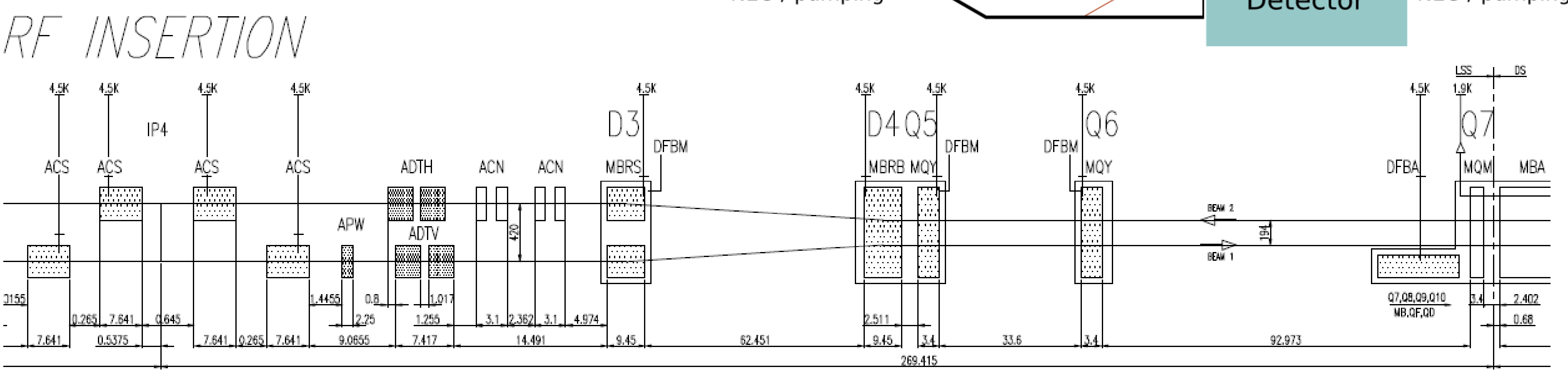


Injection configurations - V

- New optics in IR4?
  - Trigger: improve optical conditions for instruments (e.g., new BGV).
  - Constraints:
    - IR4 is used to tune the LHC: at injection mechanical aperture is the limiting factor.
    - Extended optics flexibility at top energy -> change of optics between injection/top energy.

Option to be explored in more details!

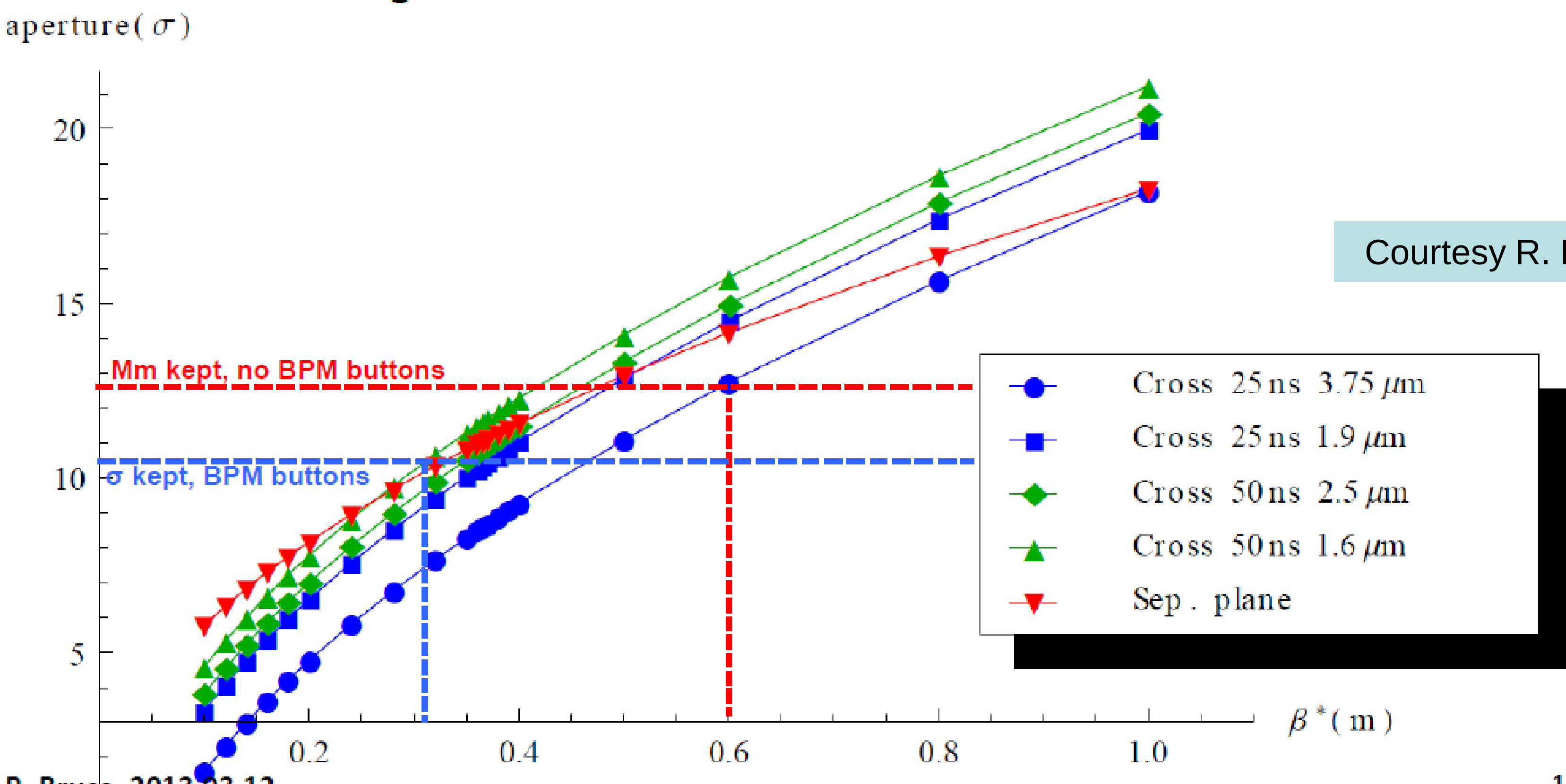




Top energy configurations IR1/5 - I

Preliminary β*-reach

- Crossing plane aperture scaled from most pessimistic 2011/2012 measurements (11 σ at 4 TeV, 60cm, 145 μrad) to 6.5 TeV configurations
- Reach in β* between ~31cm and ~60cm in crossing plane unless reverting to relaxed settings



Courtesy R. Bruce

Top energy configurations IR1/5- II

Summary: preliminary β^*-reach

LHC Collimation Project CERN

50 ns, 2.5 um	beta* crossing (cm)	beta* separation (cm)	Half crossing angle (urad)	BB sep (sigma)
mm scaled, no BPM	47	49	129	9.3
mm scaled, BPM	39	39	141	9.3
2 sig retraction, no BPM	42	43	136	9.3
2 sig retraction, BPM	35	33	150	9.3

50 ns, 1.6 um	beta* crossing (cm)	beta* separation (cm)	Half crossing angle (urad)	BB sep (sigma)
mm scaled, no BPM	43	49	108	9.3
mm scaled, BPM	35	39	119	9.3
2 sig retraction, no BPM	38	43	115	9.3
2 sig retraction, BPM	31	33	127	9.3

$31\text{ cm} < \beta^* < 60\text{ cm}$

25 ns, 3.75 um	beta* crossing (cm)	beta* separation (cm)	Half crossing angle (urad)	BB sep (sigma)
mm scaled, no BPM	60	49	180	12
mm scaled, BPM	52	39	194	12
2 sig retraction, no BPM	55	43	189	12
2 sig retraction, BPM	46	33	205	12

Courtesy R. Bruce

25 ns, 1.9 um	beta* crossing (cm)	beta* separation (cm)	Half crossing angle (urad)	BB sep (sigma)
mm scaled, no BPM	49	49	141	12
mm scaled, BPM	42	39	154	12
2 sig retraction, no BPM	45	43	149	12
2 sig retraction, BPM	37	33	163	12

Top energy configurations IR1/5- III

- Assume a conservative value of beta* of 60 cm.
  - Status quo with respect to Run I.
  - Review of impact of hysteresis for squeeze at 6.5 TeV.
- Assume a beta* of 40 cm.
  - Nominal optics (round beams):
    - Settings available and successfully tested in MD in 2012.
    - Few quadrupoles are running out of strength at 7 TeV, but this can be fixed.

Better situation in terms of hysteresis

Q6 - IP1 and IP5 - 7 TeV

β* (m)	k (m-2)	Gradient (T/m)	Current (A)	Error (units)
11.00	0.005068	118.4	3188	1
9.00	0.005292	123.6	3329	1
7.00	0.005393	126.0	3392	1
5.00	0.005288	123.5	3326	1
4.00	0.005094	119.0	3204	1
3.50	0.004933	115.2	3103	1
2.50	0.004362	101.9	2744	1
2.00	0.003823	89.3	2405	1
1.50	0.003385	79.1	2129	2
1.10	0.002754	64.3	1732	3
0.80	0.001866	43.6	1174	5
0.65	0.001203	28.1	757	10
0.55	0.000617	14.4	388	26

Q6 - IP1 and IP5 - 4 TeV

Courtesy E. Todesco

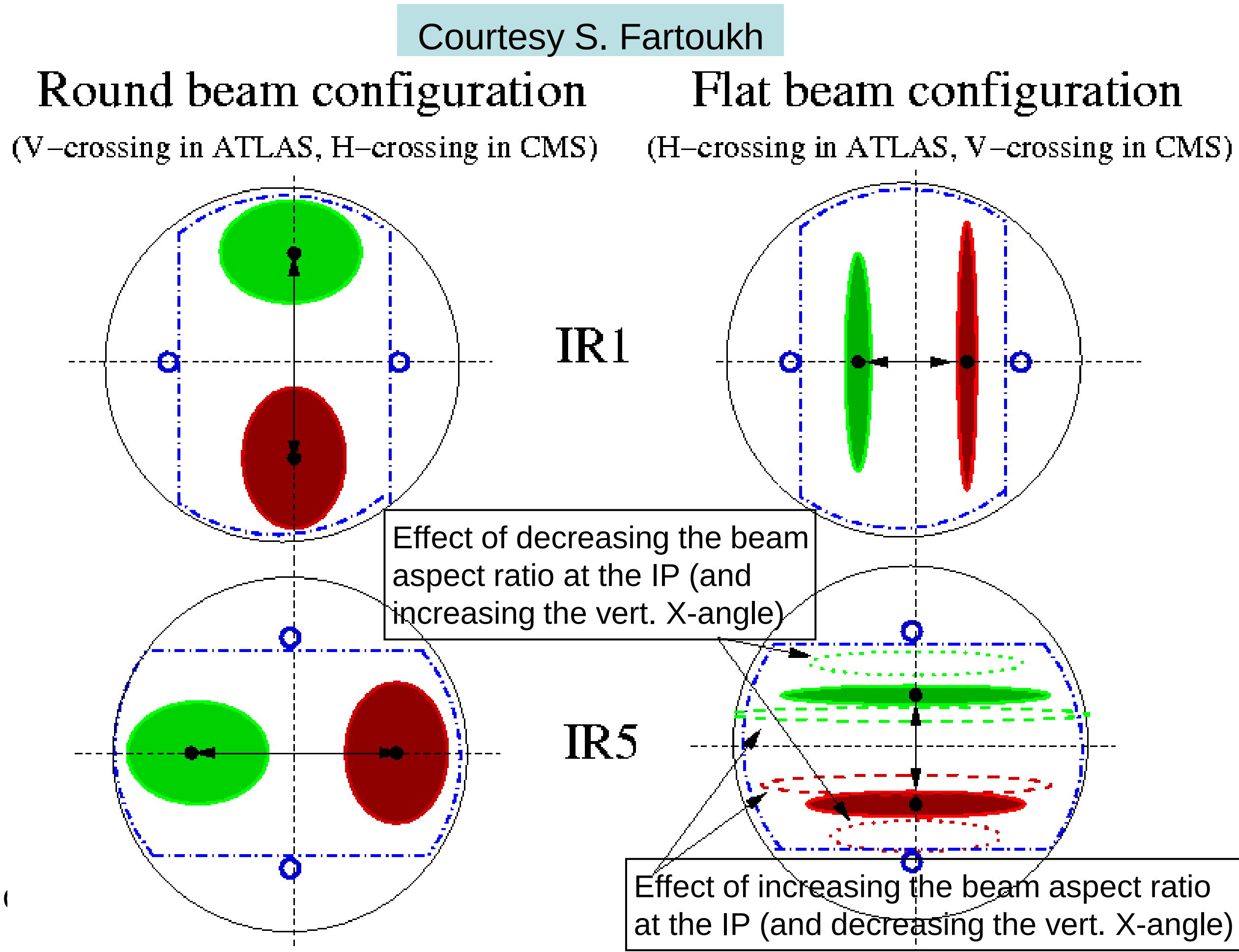
β* (m)	k (m-2)	Gradient (T/m)	Current (A)	Error (units)
11.00	0.002896	67.6	1821	0
9.00	0.003024	70.6	1902	0
7.00	0.003082	72.0	1938	0
5.00	0.003022	70.6	1901	2
4.00	0.002911	68.0	1831	3
3.50	0.002819	65.8	1773	3
2.50	0.002493	58.2	1568	3
2.00	0.002185	51.0	1374	4
1.50	0.001934	45.2	1217	5
1.10	0.001574	36.8	990	7
0.80	0.001066	24.9	671	12
0.65	0.000688	16.1	432	21
0.55	0.000352	8.2	222	60

Flat beams - I

– Performance reach of a flat optics (based on S. Fartoukh presentation a LHC MAC – June 06)

Remark:

- Alternating plane of crossing angle is kept, but orientation has to be changed with respect to round optics configuration.
- Larger beta* in the crossing plane.
- Smaller beta* in the separation plane.
- Beta*x=r Beta*
- Beta*y=1/r Beta*



Flat beams - II

- ***Summary table*** (note case 5 further split into 2 sub-cases)

Case	β_x^* [cm]	β_y^* [cm]	α *[μrad]	Triplet aperture (n1)	Geometric loss factor [%]	L/L_{nom}
Case 1 : Nominal r=1.0, β*=55cm	55.00	55.00	285 (9.5σ)	~7	83.9	1.00
Case 2: Flat r=2.0, β*=55cm	110.00	27.50	201 (9.5σ)	~7	95.1	1.13
Case 3: Flat r=1.6, β*=55cm	88.00	34.37	225 (9.5σ)	~7.5	92.7	1.10
Case 4: Flat r~1.7, β*~51cm	88.00	30.00	225 (9.5σ)	~7	92.7	**1.18**
Case 5a: Flat r~1.45, β*~61cm	88.00	42.00	225 (9.5σ)	**~ 8**	92.7	1.00
Case 5b: Flat r~1.45, β*~61cm	88.00	42.00	**263 (~11σ)**	~7	90.4	**0.97**

→ **All these configurations are achievable with the nominal LHC hardware** (layout, power supply, optics antisymmetry, b.s. orientation in the MQX'triplets).

→ **The last 3 cases will be studied in more detail.**

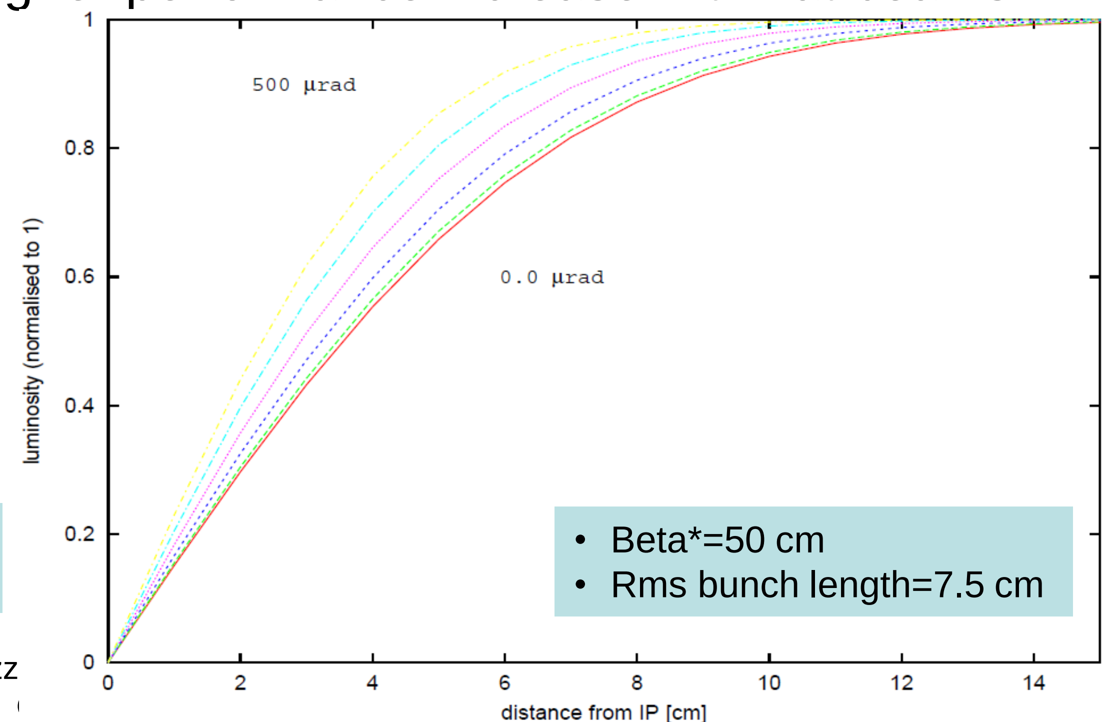
S. Fartoukh, LHC-MAC, 16 June 2006, p. 10/20

Courtesy S. Fartoukh

Flat beams - III

- Additional remarks:
  - Previous table based on nominal beta*=55 cm.
  - If beta*=40 cm is considered feasible, then performance can be reviewed (upwards).
  - Flat beams recover the performance loss of the geometric factor (at best, nothing more).
  - Previous performance table assumed 7.5 cm rms bunch length.
  - Longer bunches allow a higher performance increase with flat beams.
  - Luminous region: smaller crossing angle implies a larger luminous region and a lower density of vertices.

$$L(r,\beta^*) = \frac{L_0}{\sqrt{1+\left(\frac{\alpha\,\sigma_z}{2r\beta^*}\right)^2}}$$

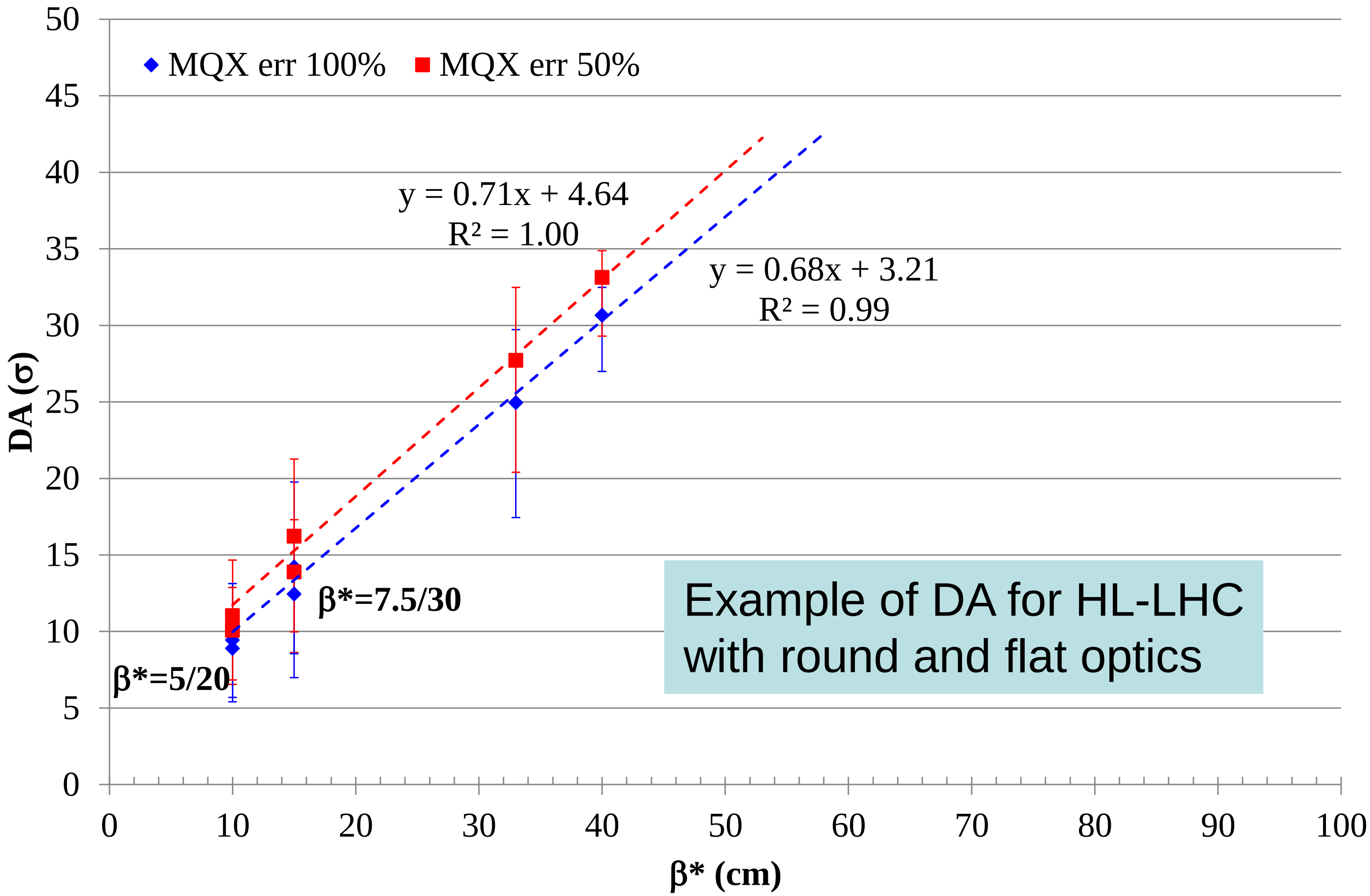


- Beta*=50 cm
- Rms bunch length=7.5 cm

B. Muratori, LHC Project Note 301

Flat beams - IV

- Performance of flat beams:
  - DA not too much different than for round optics
  - HO tune shift independent of “r”.
  - Parasitic beam-beam effects dependent on “r” and enhanced with respect to round beam optics.



ATS - I

- ATS (by S. Fartoukh)
  - Offers the possibility of achieving very small beta* and correcting chromatic effects.
  - Two stages at top energy:
    - Pre-squeeze: from beta* at injection to about 40 cm.
    - Squeeze: arc optics changed in neighbouring arcs of IR1 and 5.
  - Given beta* reach estimated for post LS1, only pre-squeeze should be used
  - A very mild squeeze might be needed in case of pushed performance.
  - Flat beams options available.
  - Successfully tested in MD down to beta* of 10 cm.

High-beta optics - I

- Estimate of performance post LS1:
  - Even higher beta* than in Run I.
  - Exact estimate of beta* reach depends on installation of additional cables.
  - Rather independent on optics choices for the rest of the machine in case of nominal optics:
    - High-beta optics are local to IR1/5 apart from the tune compensation (using main quadrupoles).
  - In case of ATS
    - Develop a high-beta optics compatible with ATS -> additional commissioning efforts.
    - Keep the same overall machine configuration as in Run I and develop further the IR1/5 optics solution to achieve higher beta* values.

Summary

- Probably, it will not be possible to keep exactly the same optical configuration of Run I.
- Change of triplets' strength in IR2/8 might impose ramp and squeeze.
- A number of improvements are being studied (S. Fartoukh) for the IRs optics: trade off between adding new features, while keeping changes to the minimum necessary should be found.
- At top energy, flat optics options will bring performance improvements or additional margins.
- ATS is a very interesting candidate for post LS1 operation.