Collimator settings and performance

R. Bruce

on behalf of the LHC collimation team

Acknowledgement

- Collimation team: R. Assmann, F. Burkart, M. Cauchi, D. Deboy, L. Lari, S. Redaelli, A. Rossi, B. Salvachua, G. Valentino, and D. Wollmann

- Aperture team: C. Alabau-Pons, R. Assmann, M. Giovannozzi, G. Muller, S. Redaelli

- β* calculations: collaboration with R. Assmann

- Other input and discussions:
  R. de Maria, S. Fartoukh, M. Giovannozzi, B. Goddard, W. Herr, R. Tomas, G. Vanbavinckhove, J. Wenninger,
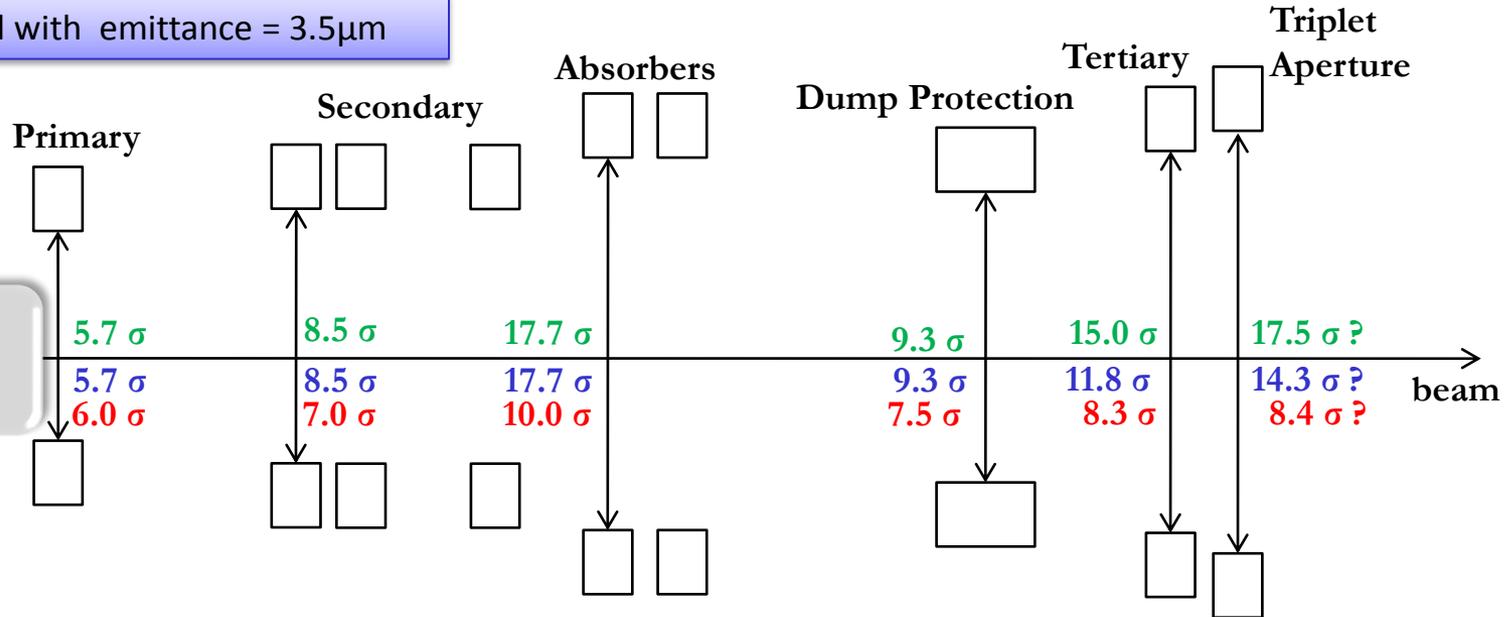
Outline

- Reminder: importance of collimation for machine performance

- 2011 Highlights

  - Tight collimator settings

  - Aperture measurements

  - Quench test

- Outlook for 2012

  - Proposed collimator settings for 2012

  - Scenarios for β^* for 2012 from collimation point of view

  - Room for further gain

- Conclusions

Importance of collimation for performance

σ always calculated with emittance = 3.5μm

|	Primary	Secondary	Absorbers	Dump Protection	Tertiary	Triplet Aperture
2010	5.7 σ	8.5 σ	17.7 σ	9.3 σ	15.0 σ	17.5 σ ?
2011	5.7 σ	8.5 σ	17.7 σ	9.3 σ	11.8 σ	14.3 σ ?
nominal	6.0 σ	7.0 σ	10.0 σ	7.5 σ	8.3 σ	8.4 σ ?

beam

- Collimation system defines minimum aperture that can be protected

- Therefore, limit on β* from collimation (beam blows up in triplet in squeeze)

- Inefficiency (leakage fraction) in cold region depends on collimation system

- Together with the beam lifetime and the quench limit, the collimation system thus defines the maximum allowed intensity

See early predictions: R. Assmann Chamonix 2002

MD on tight collimator settings
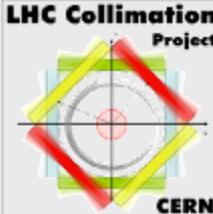
- Collimators in IR7 and IR6 driven to tighter settings (TCP @ 4 nominal σ, TCS@6, TCLA@8)

- Qualified with loss maps

R.W. Assmann, R. Bruce, F. Burkart, M. Cauchi, D. Deboy, L. Lari, E. Metral, N. Mounet, S. Redaelli, A. Rossi, B. Salvachua, B. Salvant, G. Valentino, D. Wollmann CERN-ATS-Note-2011-036 MD CERN-ATS-Note-2011-079 MD

betatron losses B1 3500GeV hor norm IR7 (2011.11.05, 00:57:51)
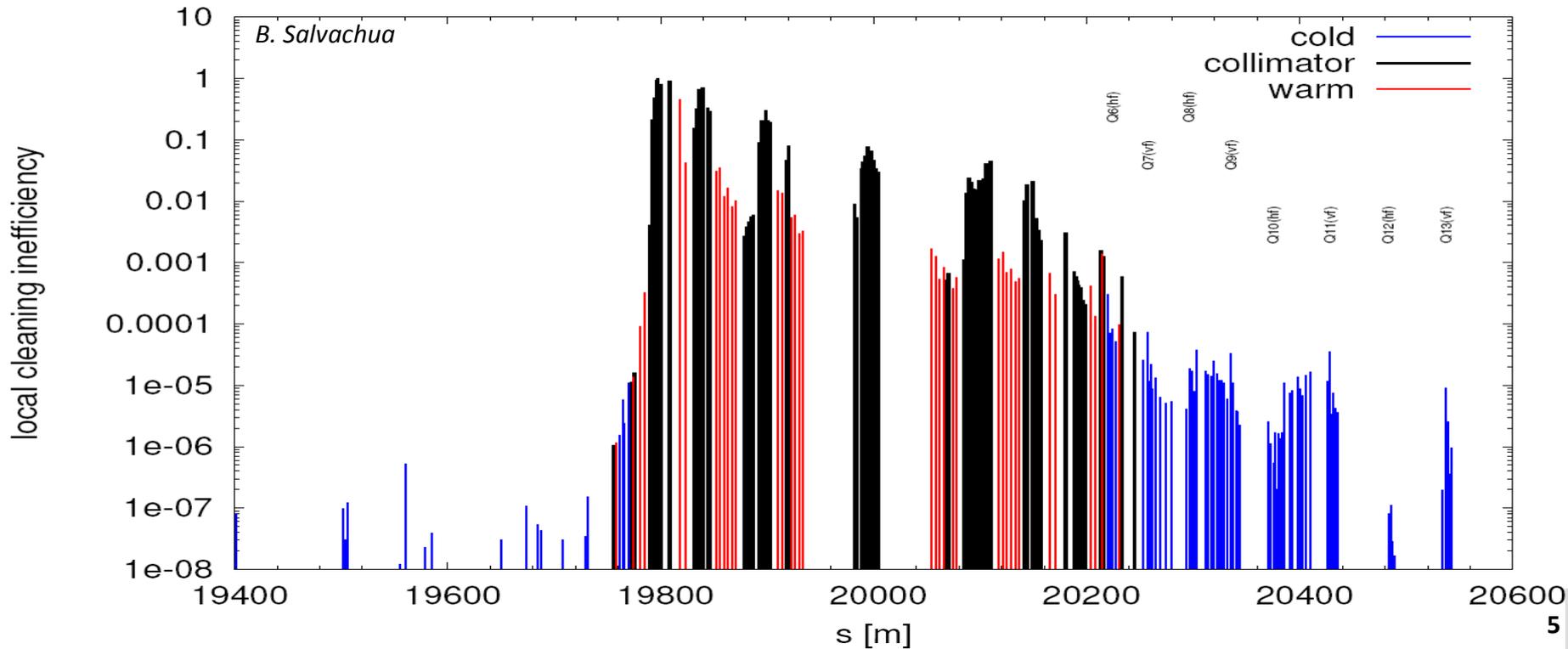
**Norway**

Iberian peninsula

Intermediate settings (2011): ~3.1 mm gap of primary collimator

**Tight settings: ~2.2 mm gap of primary collimator**

- Gain factor 3.3-10 in efficiency compared to intermediate settings

- Loss maps with tight settings in 3 MDs over the year: May, August, November

- Keeping old centers from setup in March

- All loss maps OK ⇒

  - Demonstrates stability of collimation setup. Tight settings still valid 8 months after alignment

- Using tight settings gives more room to squeeze β* (less aperture in triplet)
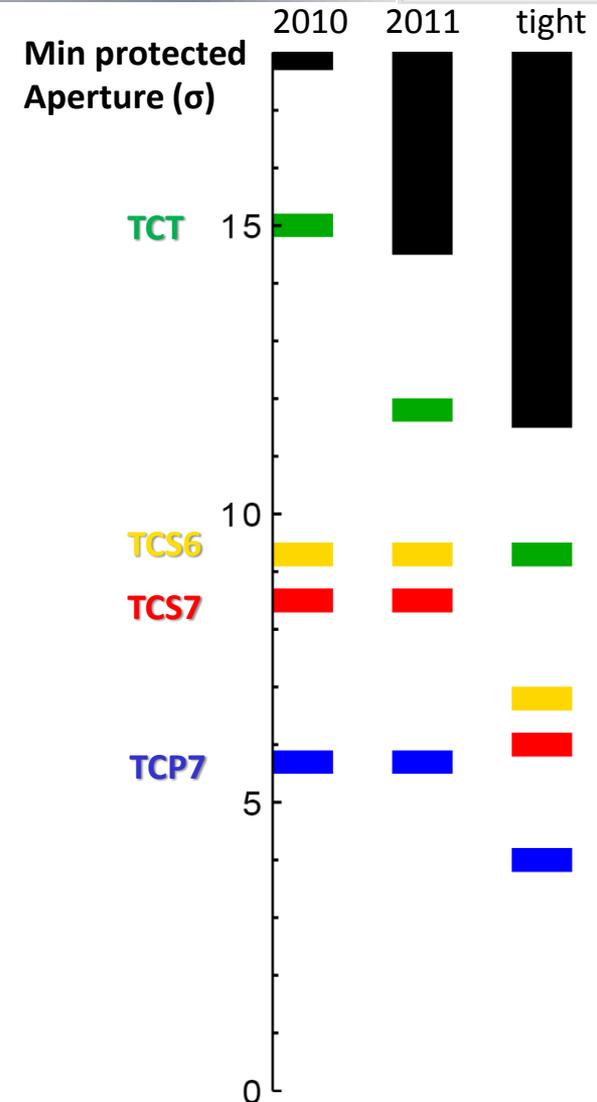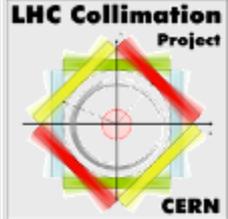
Beam losses with tight settings

- **High losses in ramp and squeeze** – orbit oscillations scrape beam at primary collimators

  - 1% loss in ramp, 5% loss in squeeze: not acceptable for high-intensity operation

  - Improved orbit correction underway (S. Redaelli, J. Wenninger). No show-stopper expected

B. Salvachua
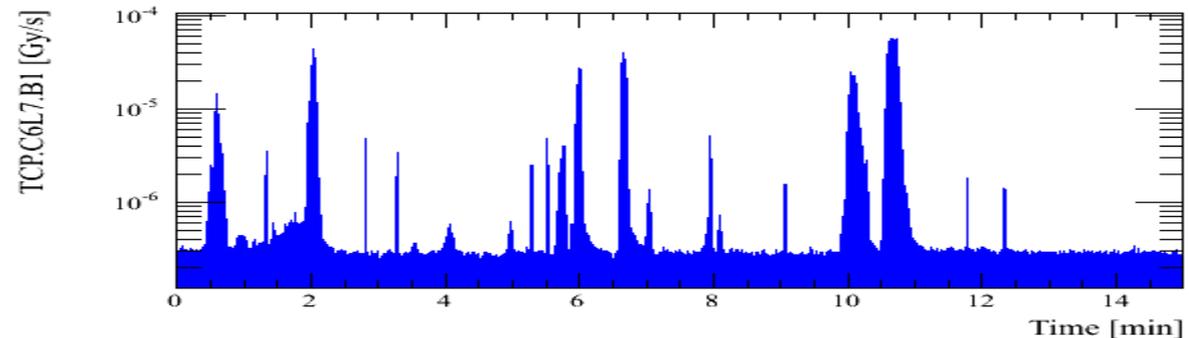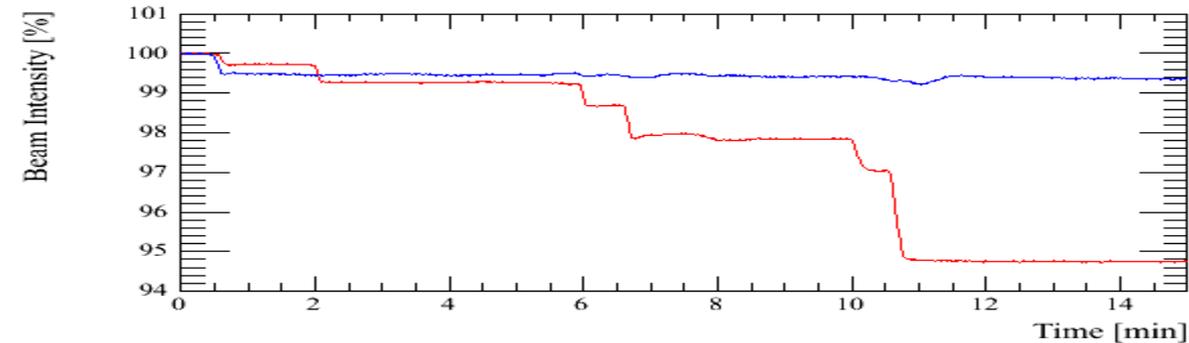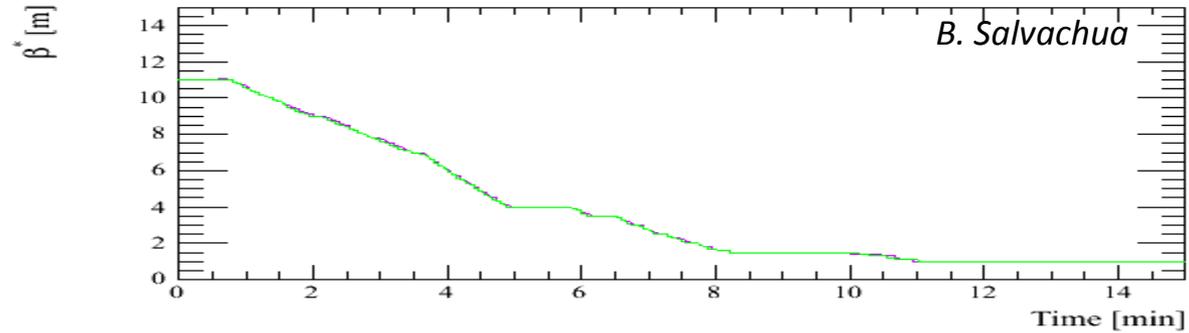
- Large beam losses observed with tight settings, 84 bunches at end of squeeze on August 29 2011 (*see talk talk J. Wenninger , LMC 2011.08.31, N. Mounet in Evian, talk E. Metral, LBOC 2011.08.30 and W. Herr, HiLumi workshop, 2011.11.17*)

- Cause believed to be interplay between several effects: impedance and a low beam-beam separation

- Studies in impedance team (*see N. Mounet in Evian*):

  - Possible cure: well-controlled chromaticity close to 0 or even negative, and octupoles at 450 A

 - Effect on beam from octupoles to be investigated

Tight settings summary

- Advantages:

  - Protection of a smaller triplet aperture => more squeeze in β*

  - Better efficiency => higher intensity reach

  - Maintain full protection and operational margin for van der Meer scans

  - Gain experience for 7 TeV

    - Tight gap of TCP in mm similar to nominal gap at 7 TeV, while secondary collimators are further retracted. **Tight settings at 3.5 TeV in mm = relaxed settings at 7 TeV**.

    - Sooner or later we have to use (at least) these settings in mm to reach nominal. Problematic for 7 TeV if tight settings can not be used now

- Detrimental effects:

  - Beam losses in ramp and squeeze caused by orbit variations (solution underway)

  - Impedance and beam-beam effects (cure proposed)

  - We give up a little margin between primary and secondary collimator

Aperture measurements at 3.5 TeV
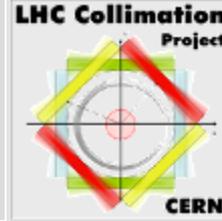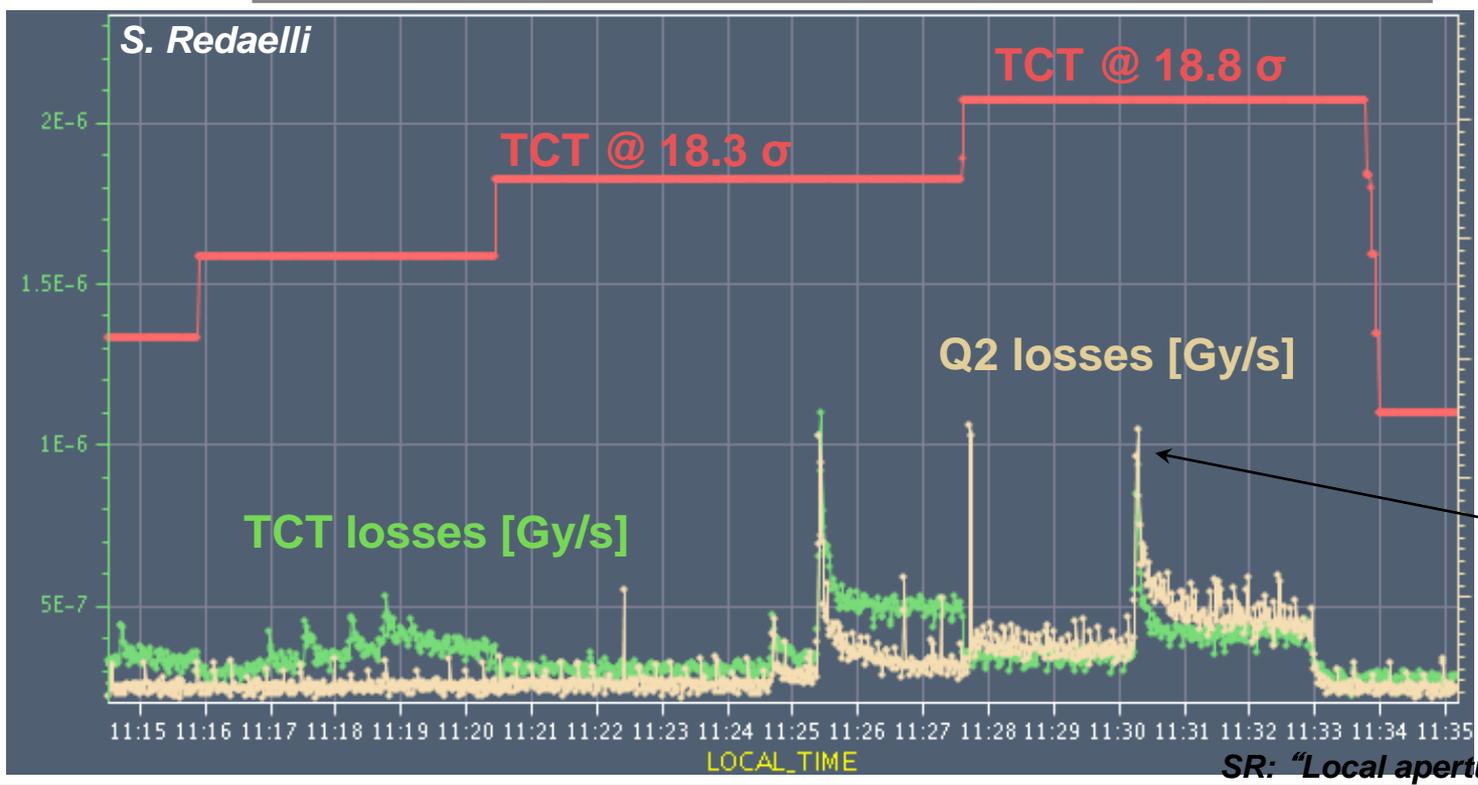
CERN-ATS-Note-2011-110 MD

August 2011
Stefano.Redaelli@cern.ch

IR1 and IR5 aperture at 3.5 TeV

C. Alabau Pons, R. Assmann, R. Bruce, M. Giovannozzi, E. MacLean, G. Müller,
S. Redaelli, F. Schmidt, R. Tomás, J. Wenninger

- **Measured triplet aperture close to mechanical design aperture!**

- **Allowed β* to be reduced to 1m with intermediate collimator settings** (see J. Wenninger et al., CERN-ATS-Note-2012-005 MD)

S. Redaelli

TCT @ 18.8 σ

TCT @ 18.3 σ

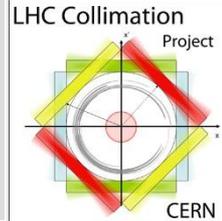Q2 losses [Gy/s]

TCT losses [Gy/s]

Loss spikes while the orbit is increased, touching TCT or MQX

SR: "Local aperture measurements of the triplet magnets in IP1/5 at 3.5 TeV", MP document

CERN-ATS-Note-2011-042 MD (LHC)

May 24, 2011
Stefano.Redaelli@cern.ch

Collimator losses in the DS of IR7 and quench test at 3.5 TeV

R.W. Assmann, R. Bruce, F. Burkart, M. Cauchi, D. Deboy, B. Dehning,
E.B. Holzer, E. Nebot del Busto, A. Priebe, S. Redaelli, A. Rossi, R. Schmidt,
M. Sapinski, G. Valentino, J. Wenninger, D. Wollmann, M. Zerlauth,
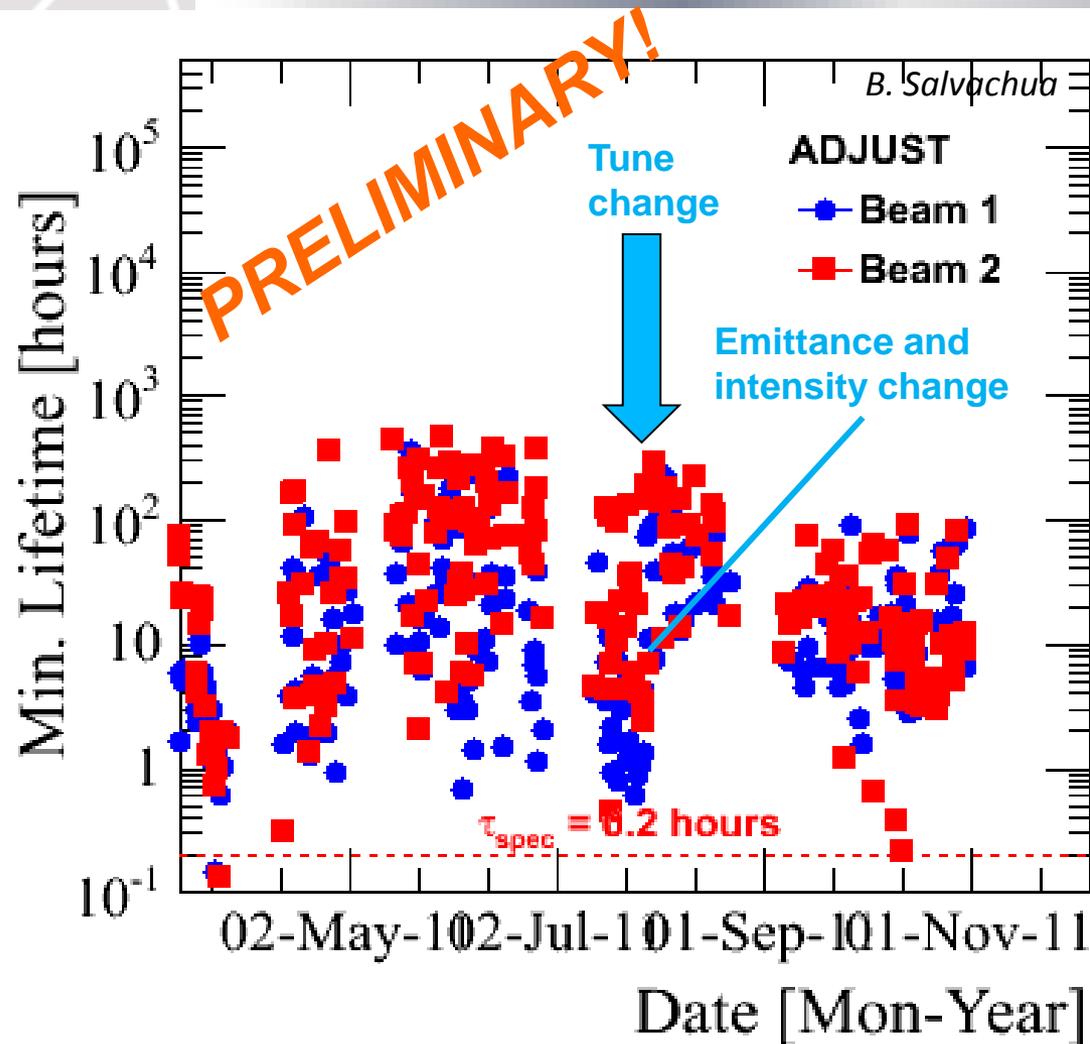CERN, Geneva, Switzerland

Keywords: Collimation, beam losses, quench, dispersion suppressor

- 16 bunches, 3.5 TeV

- Provoked beam loss: beam blow up on 1/3 resonance

- Achieved loss rate: 9e11 p/s at 3.5TeV => 505 kW over 1 s

- No quench!

BCT_DC PLOTS

Legend
- LHC.BCTDC.A6R4.B1
- LHC.BCTDC.A6R4.B2
- LHC.BCTDC.B6R4.B1
- LHC.BCTDC.B6R4.B2
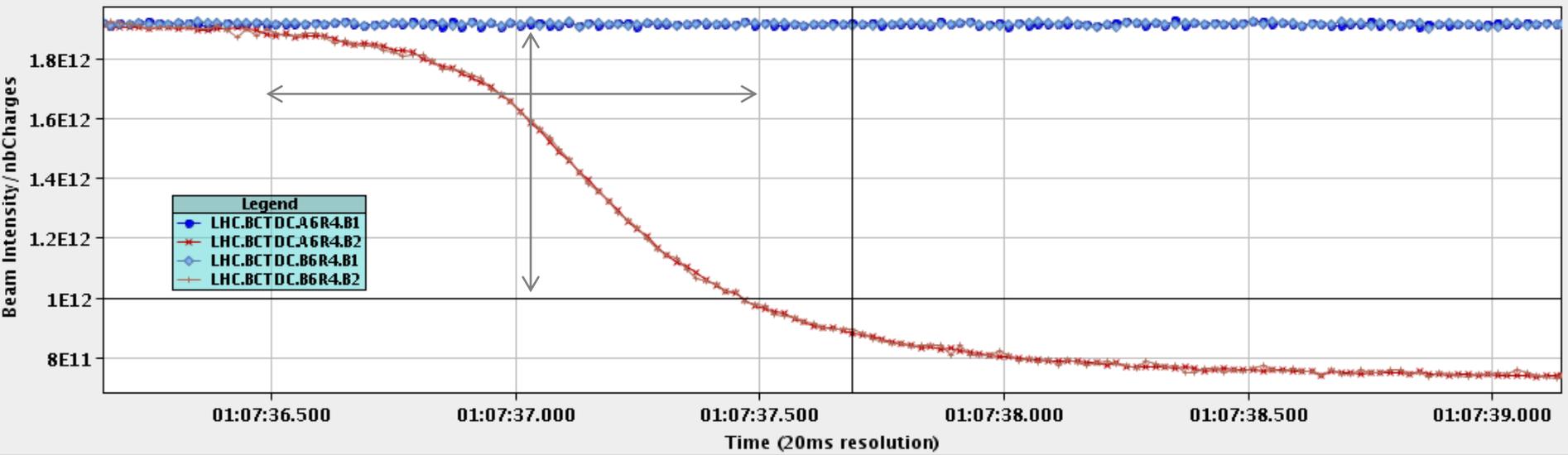
Beam lifetime in adjust over the year

- Analysis of lifetime from BLMs at primary collimator by F. Burkart, B. Salvachua, D. Wollmann

- Some calibration with BCT still to be done and low-lifetime points to be examined and possibly removed

- Most fills show excellent lifetimes, some up to 100 hours!

- Tune change boosted lifetime to >10 hours

Proton Performance Reach from MD: 3.5 TeV
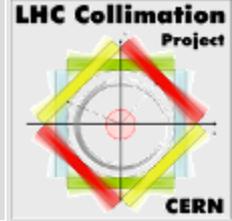
$$N_p^{\max} \geqslant 3.3 \times t \times R_{loss}^{prim} = 1.1 \times 10^{16}\, p$$

Factor 3.3 better inefficiency from tight settings compared to MD (most pessimistic estimate!)

3600 s   **9e11 p/s**

- 30 times nominal intensity at 3.5 TeV
- Enough for nominal and ultimate intensity at 7 TeV

(*see talk R. Assmann and S. Redaelli, this Chamonix, and D. Wollmann, R. Assmann in collimation review*)

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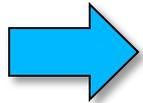
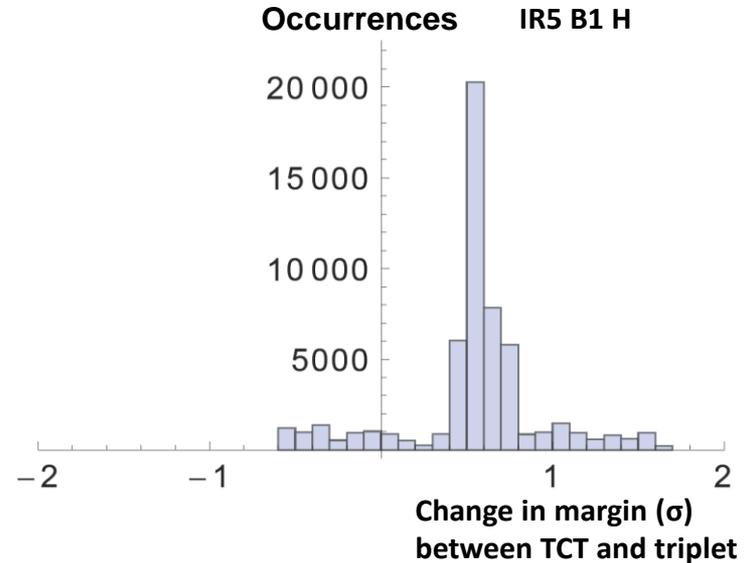# Proposed collimator changes for 2012

- Based on 2011 operation, we conclude

  - No risk of intensity limit at 3.5 TeV and 4 TeV

  - 2011 assumptions kept for orbit, beta-beat

  - Tight collimator settings $\Rightarrow$ 2.5 σ gain in margin. (moving in primaries, secondaries, absorbers – TCTs and IR6 follow)

- Only small gain in margins by going to 4 TeV

  - BPM systematic not expected to improve

  - Most of the errors stay constant in mm, but also the aperture $\Rightarrow$ both aperture and errors increase in σ.

  - Rescaling errors where suitable with energy and β-function

  - For details: see R. Bruce in Evian 2011

Occurrences   **IR5 B1 H**

Change in margin (σ) between TCT and triplet

Proposed collimator changes for 2012

- Further gain by assuming that orbit errors, β-beat errors, collimator jaw positioning errors, and setup errors are uncorrelated at critical locations

- Statistically independent => adding errors in squares instead of linearly

$$\Delta_{total} = \sum_i |\Delta_i|$$

$$\Delta_{total} = \sqrt{\sum_i \Delta_i^2}$$

- Gain: 1.4 σ

- In the unlikely case that errors would add linearly, count on detection of abnormal behaviour in loss maps and asynchronous dump tests
  - We have to carefully monitor the losses from beam in the abort gap during regular dumps! If problems are detected, try to correct, and in worst case step back and increase margins

- Margins for van der Meer scans added linearly

- still to be approved by MPP

Proposed collimator changes for 2012
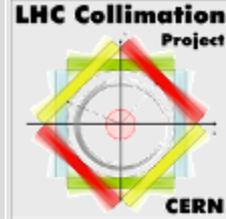
- **Faster setup**
  - 9 Hz collimator movement with semi-automatic setup – improvement from present 1 Hz *(G. Valentino et al.)*

- Set up and move in TCLP during physics at 10 σ, behind the TCTs.
  - Copper collimators on outgoing beam from the experiments in IR1 and IR5
  - Protection against luminosity debris.
  - Could mitigate high losses around the experiments
  - So far fully retracted
  - Proposed test: retraction during physics will tell if they are useful

- Putting it all together, we calculate new collimator settings (tight settings, adding errors in square)

|	3.5 TeV	4 TeV
gamma	3730	4263
TCP 7	4.0	4.3
TCSG 7	6.0	6.3
TCLA 7	8.0	8.3
TCSG 6	6.8	7.1
TCDQ 6	7.3	7.6
TCT	8.5	9.0
aperture	9.9	10.5

- 3.5 TeV or 4 TeV. Showing some 7 TeV results but not main focus

- Keeping beam-beam separation constant at 9.3σ for ε=2.5μm – probably not possible with 25ns

- Scaling 14σ aperture at β*=1m, 120μrad.

  - No additional margins added, similar to the switch to β*=1m

  - Spurious dispersion not included – assuming main beam stays on-momentum. Momentum cut of tails still in IR3

  - Aperture has to be re-measured and cleaning qualified at new β*.

  - In case of unexpected problems, step back
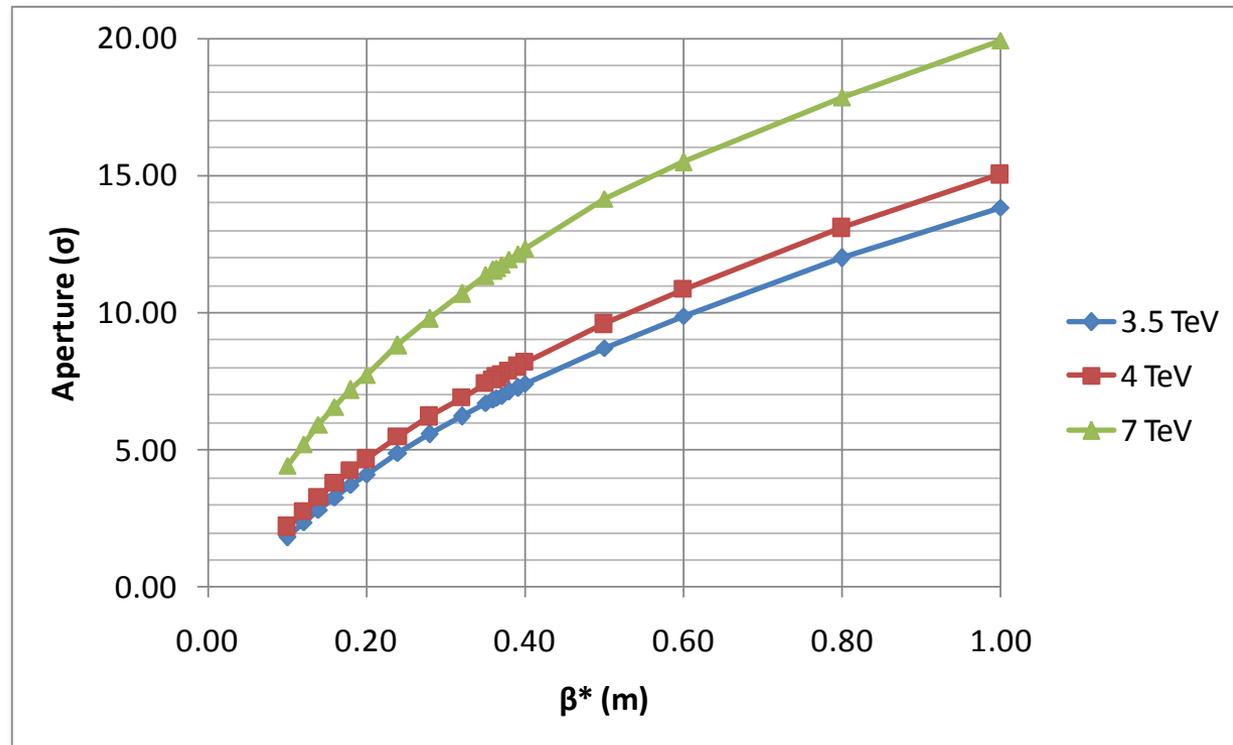
Aperture scaled from 14σ at β*=1m, 120 μrad half angle, keeping BB separation constant, using ATS optics from S. Fartoukh

Proposal for collimator settings and β*, 50 ns
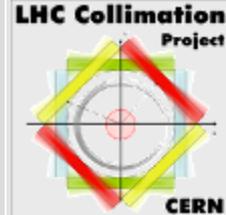
- **Tight settings, square margin:**
  - primary collimator stays at 4σ 3.5 TeV position in mm, but using σ at 4 TeV for margins in IR7 and IR6-IR7

- **These settings work only if we assume**
  - Beam losses in ramp and squeeze mitigated
  - Instabilities observed with tight settings alleviated
    - Larger beam-beam separations needed?
  - We have the same excellent aperture (to be re-measured)

- Must be demonstrated operationally!

- ~50% higher lumi and pile-up than 2011

	3.5 TeV	4 TeV	7 TeV
gamma	3730	4263	7461
TCP 7	4.0	4.3	5.7
TCSG 7	6.0	6.3	7.7
TCLA 7	8.0	8.3	9.7
TCSG 6	6.8	7.1	8.5
TCDQ 6	7.3	7.6	9.0
TCT	8.5	9.0	10.4
aperture	9.9	10.5	12.3
Φ (μrad)	155	145	126
β* (m)	0.6	0.6	0.45

Fall-back solution in case linear addition of errors margins must be used or larger crossing angle needed:
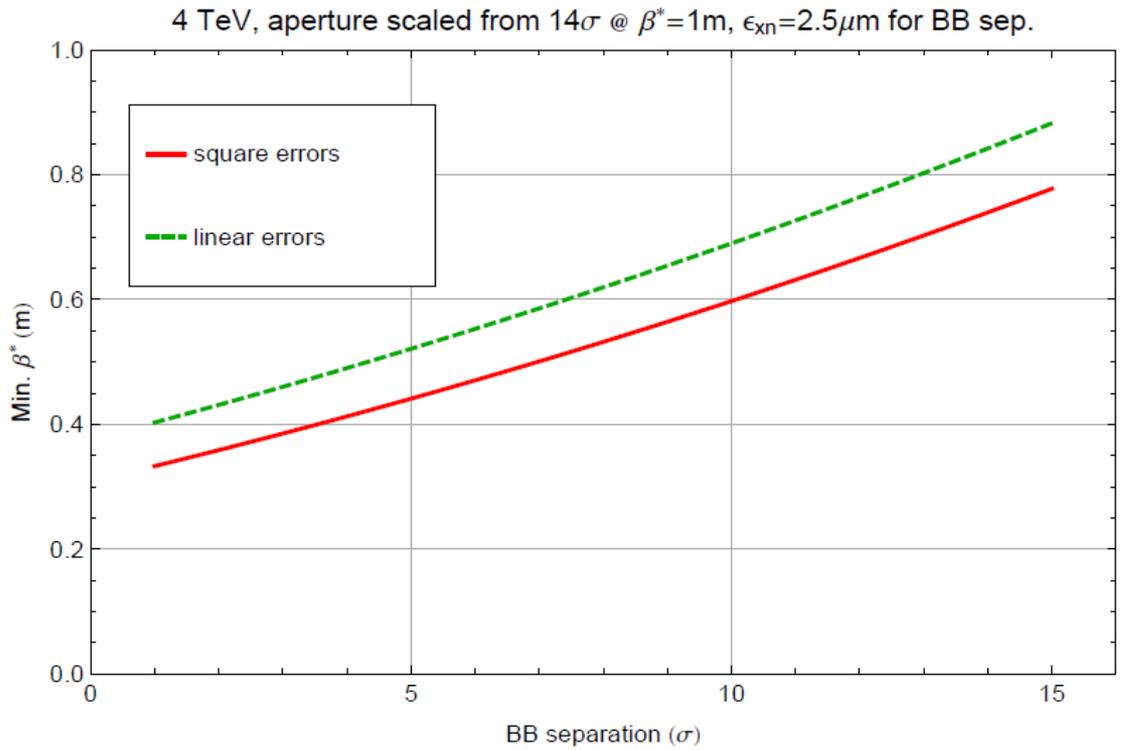Tight settings, β *=0.7 m

Fall-back solution in case of unexpected problems with tight settings:
intermediate settings, linear margins, β *=0.9 m

Our analysis concerns only collimation limit on β*
For optics considerations, see talk M. Giovannozzi

- Larger 12 σ BB separation could be needed at 25 ns (*see G.Papotti in Evian*) => We lose ~10cm in β*

- Larger emittance from the injectors

- With ε=3.5μm, we lose another ~10cm in β*

- Possible settings, 4 TeV: β*=80cm, 192 μrad half crossing angle

- Tight settings become more challenging (orbit correction in ramp and squeeze)

4 TeV, aperture scaled from 14σ @ $\beta^{*}=1m$, $\epsilon_{xn}=2.5\mu m$ for BB sep.

- square errors
- linear errors

Min. β^{*} (m)

BB separation (σ)

More info: see talk G. Arduini

Improvements

- Several improvements possible – we are not yet at the limit! (see R. Bruce in Evian 2011 for details)

- Some highlights:

  - Further analysis of the orbit margins in the IRs – which drifts are real? (proposal S. Fartoukh)

  - Decrease of margins in IR7 towards nominal

  - Flat beams (S. Fartoukh, W. Herr et al.)

  - BPM button collimators

- Dream scenario opens for very small β*

  - TCP 4σ at 7 TeV (significant challenge for orbit correction and impedance)

  - BPM button collimators – orbit margin drastically reduced. Almost at nominal collimator retractions?

  - Significant reduction below nominal β*

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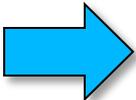
- Conclusions

Conclusions

- We routinely collimate 110 MJ beams through the whole cycle without quench

- With tight settings: achieved target cleaning efficiency of 99.995 % and maintained stability of collimation setup over a full operational year while demonstrating 7 TeV gaps for primary collimators

- Demonstrated the design loss rate at primary collimators of 0.5 MW without quench

- As a consequence, system should be ready for nominal and ultimate intensities both at 4 TeV and 7 TeV beams

- Collimation limit on β* pushed in 2012 proposal with tight settings and β*=60cm. **Relies on assumptions:**

  - Error margins added in squares

  - BB separation can be kept constant and instabilities mitigated

  - We have the same excellent aperture

  - Orbit correction in ramp and squeeze improves

Experience during startup will tell!