β*-reach

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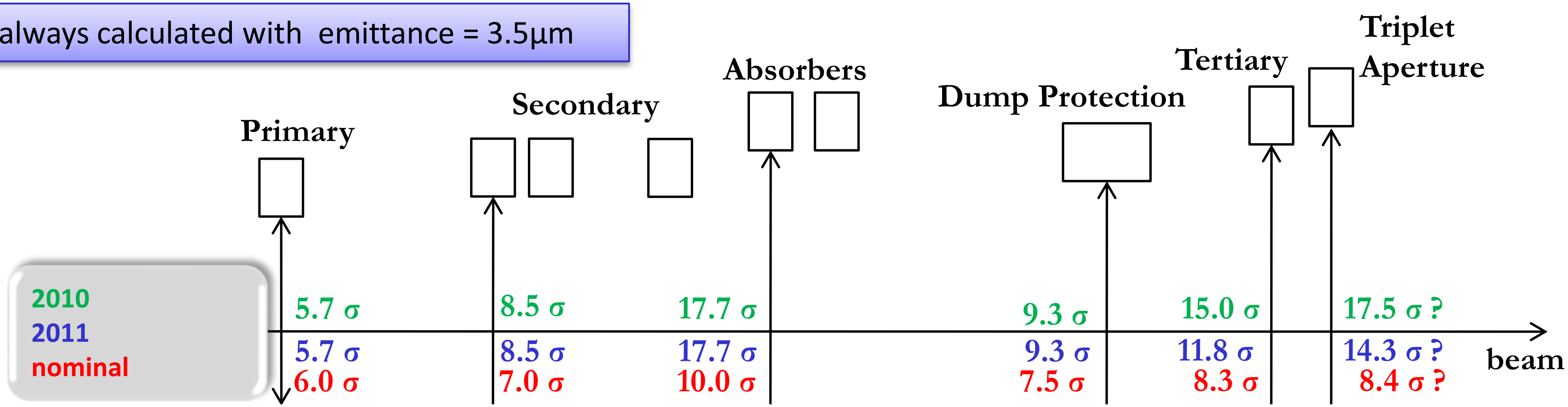
  - Impedance (E. Metral, N. Mounet, B. Salvant)
  - Optics (S. Fartoukh, M. Giovannozzi, R. de Maria)
  - Beta-beat (R. Tomas, G. Vanbavinckhove)
  - OP crew

Outline

- Overview of 2011 run
  - β* in 2011
  - Orbit stability
  - MDs: tight collimator settings and aperture measurements
- Outlook for 2012
  - Possible improvements in margins 2012
  - Aperture calculations
  - Scenarios for β* for 2012
  - Room for further gain
- Conclusions

Importance of collimation for β*

σ always calculated with emittance = 3.5µm

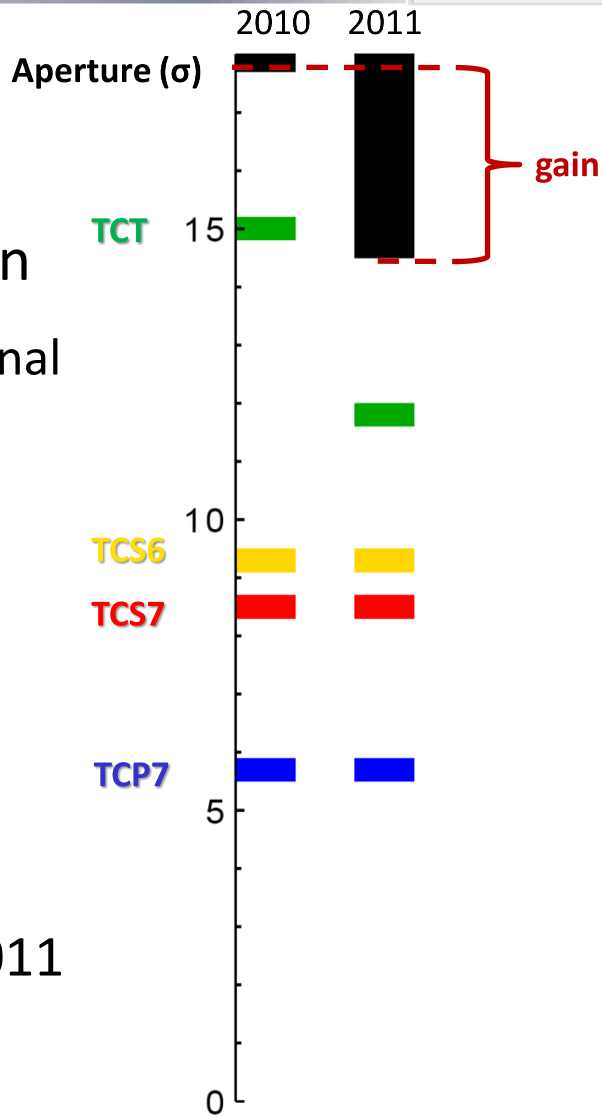


- Collimation system defines minimum aperture that can be protected
- Possible values of β* depend on the settings of all collimators and therefore on machine stability and frequency of collimation setups!
- To optimize β*, we have to investigate
  - Machine stability and necessary margins in collimation hierarchy (gives minimum value of triplet aperture that can be protected)
  - Triplet aperture
- Today's talk concerns only the collimation limit on β*

2011 run, part 1

- 2010: safe margins in collimation hierarchy based on conservative assumptions
- Detailed analysis in Evian 2010 of the 2010 run
  - Calculation of margins based on data and operational experience
  - Detailed analysis allowed to decrease margins, in particular TCT/IR6
  - Scaling of triplet aperture from measurements at injection energy

  ⟹ Allowed to decrease β* from 3.5m to 1.5m
- Comfortable running at β*=1.5m in first half of 2011

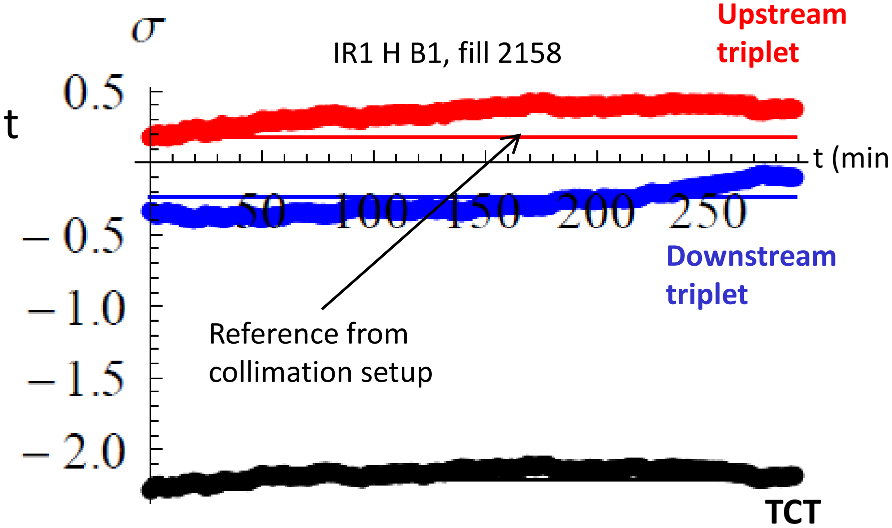


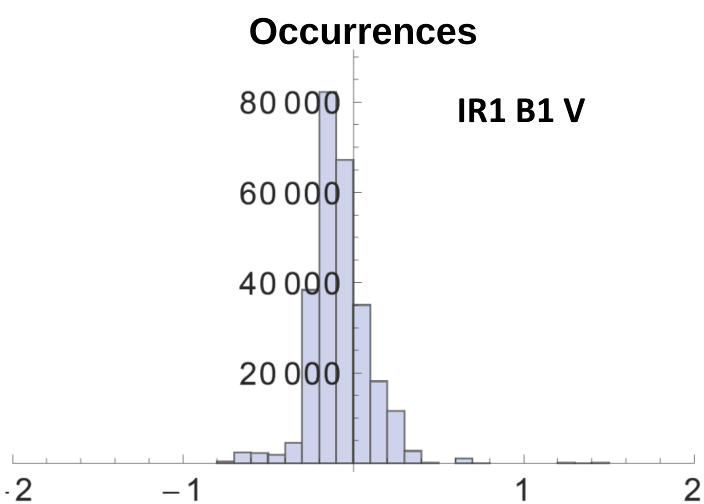
2011 run, part 2

- So far: aperture based on measurements at injection, with tolerances added for orbit and beta-beat
- Measurements done only in crossing plane. In separation plane, aperture pessimistically determined from global aperture limit
- August 2011: Local aperture measurements in IR1/5 triplets at top energy and squeezed optics *(see talk S. Redaelli and CERN-ATS-Note-2011-110 MD)*
- Outcome: aperture close to ideal mechanical aperture in squeezed configuration
  - Extrapolating injection aperture in crossing plane as in Evian 2010 *without* tolerances gives similar result. Including tolerances resulted in pessimistic aperture
- With the same collimator settings, enough room for β^*=1m without change in settings *(see presentation S. Redaelli, J. Wenninger et al. in LMC)*

2011 orbit stability triplets/TCTs

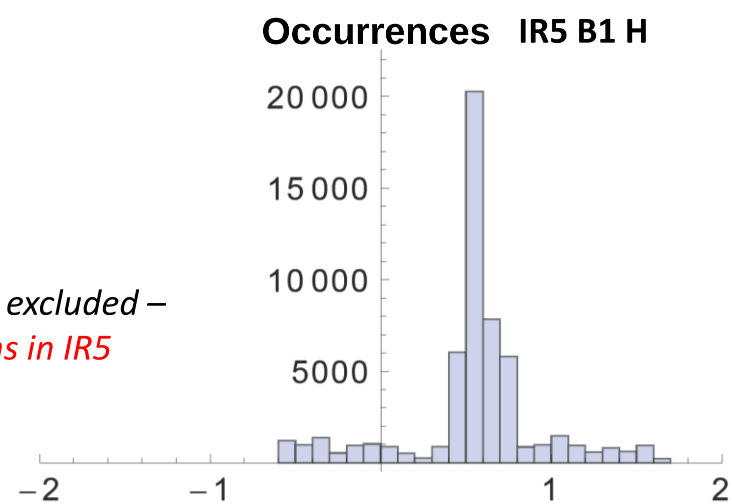
- Very good stability within fills
- In many cases better than 2010 in σ. Consistent with larger beam size from smaller β*
- IR1 now stable within 0.6 σ for 99% coverage. For IR5, 1.1 σ still needed in spite of β*=1m
- Possibly part of margin due to temperature effects. Still room for improvement?





change in min margin (σ)

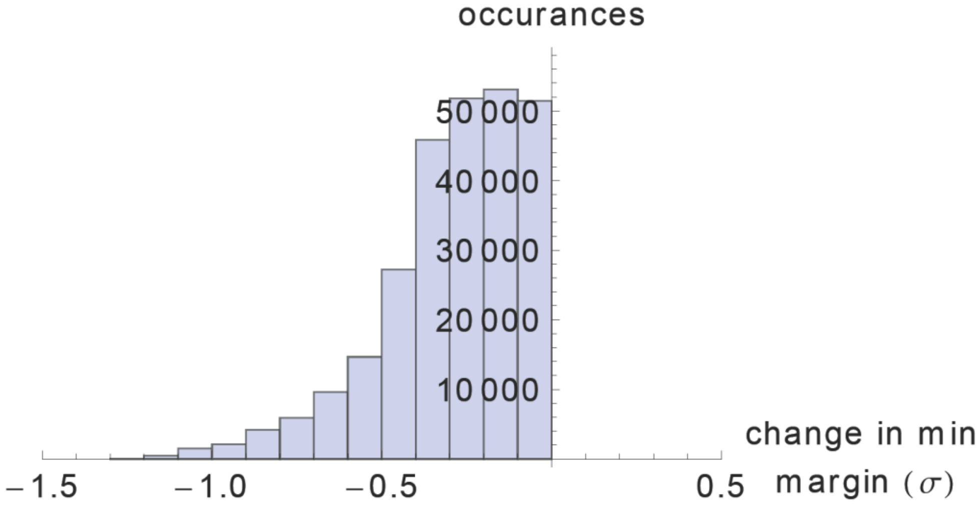
BPMS.2L5.B1 excluded –
BPM problems in IR5



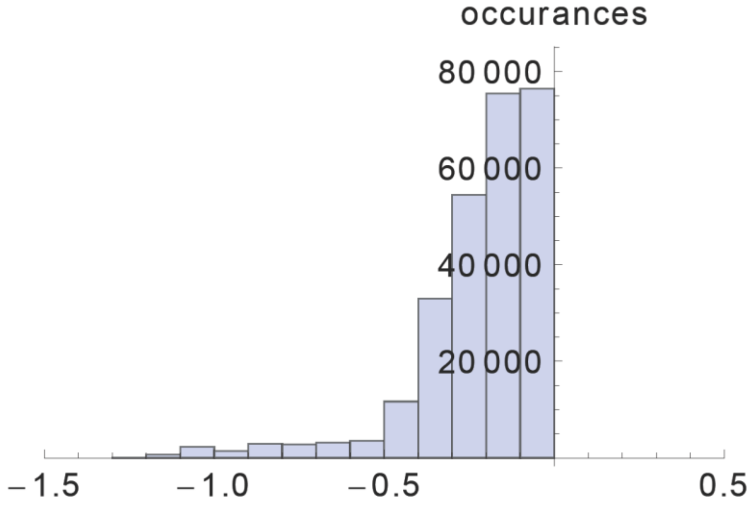
2011 orbit stability TCTs/IR6

- For orbit margin between TCTs and IR6, 1.1 σ needed and allocated (no reduction possible) for 99% coverage

IR6 – TCT IR1 B2 H



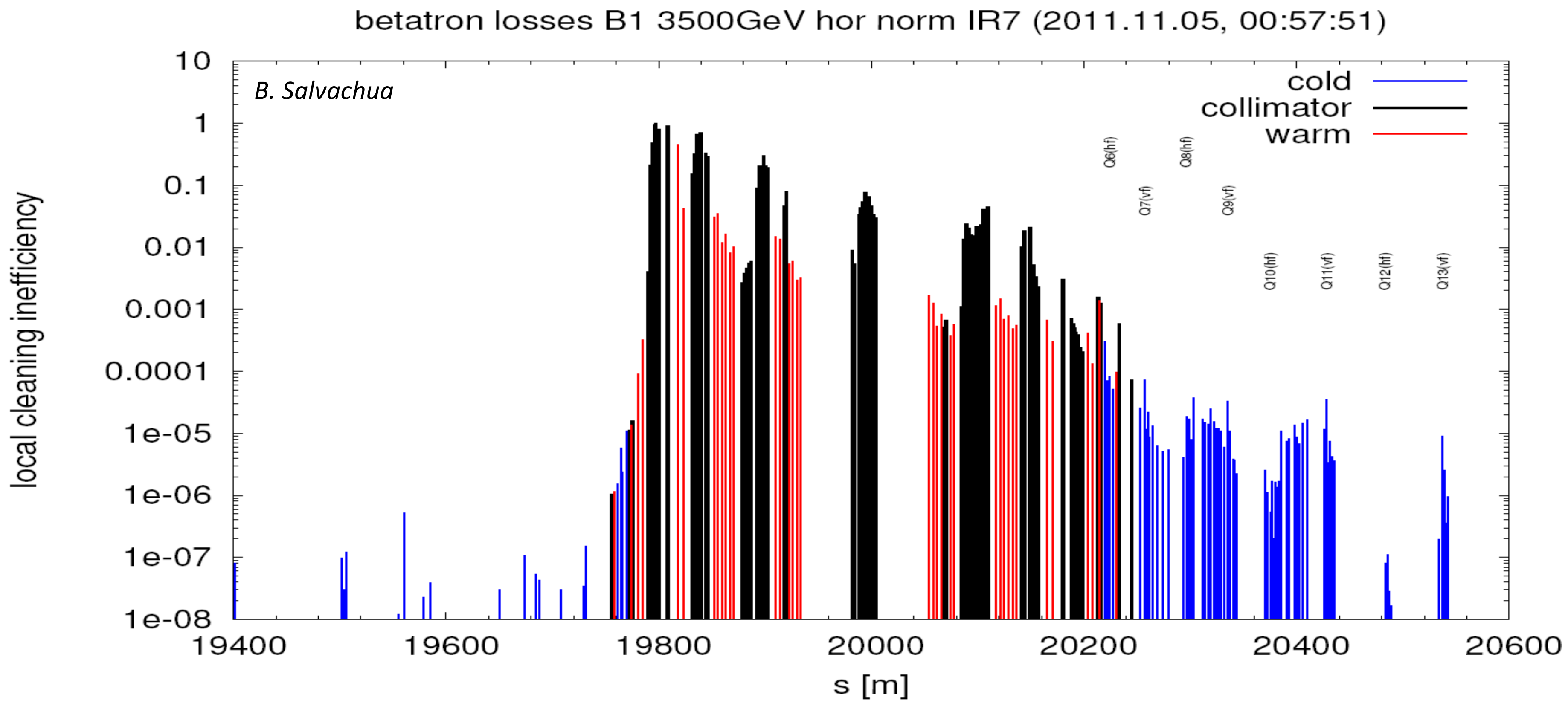
IR6 – TCT IR5 B1 H



MD on tight collimator settings

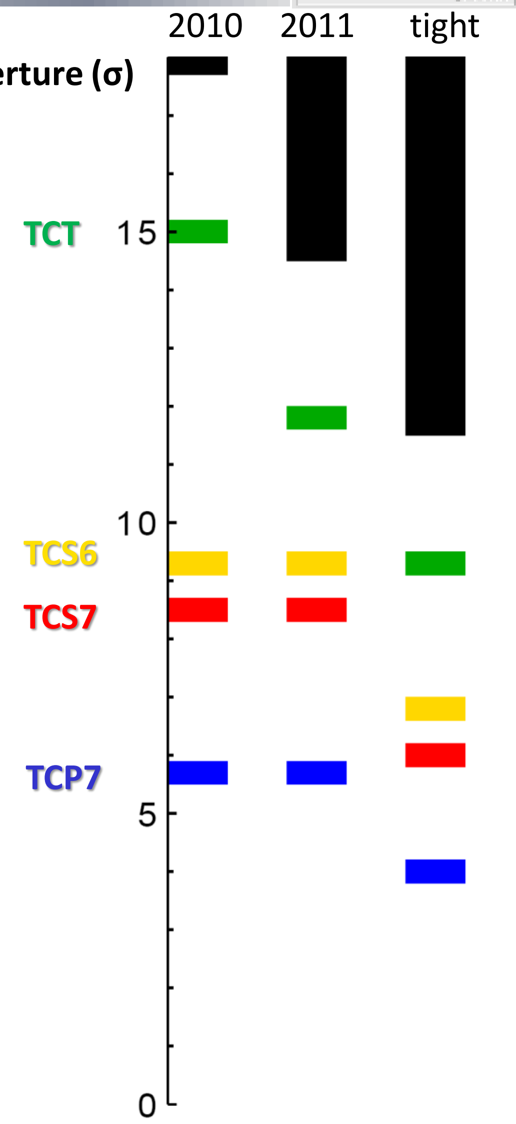
- Collimators in IR7 and IR6 driven to tighter settings (TCP @ 4 nominal σ, TCS@6, TCLA@8)
- Qualified with loss maps

Reference:
CERN-ATS-Note-2011-036 MD
CERN-ATS-Note-2011-079 MD



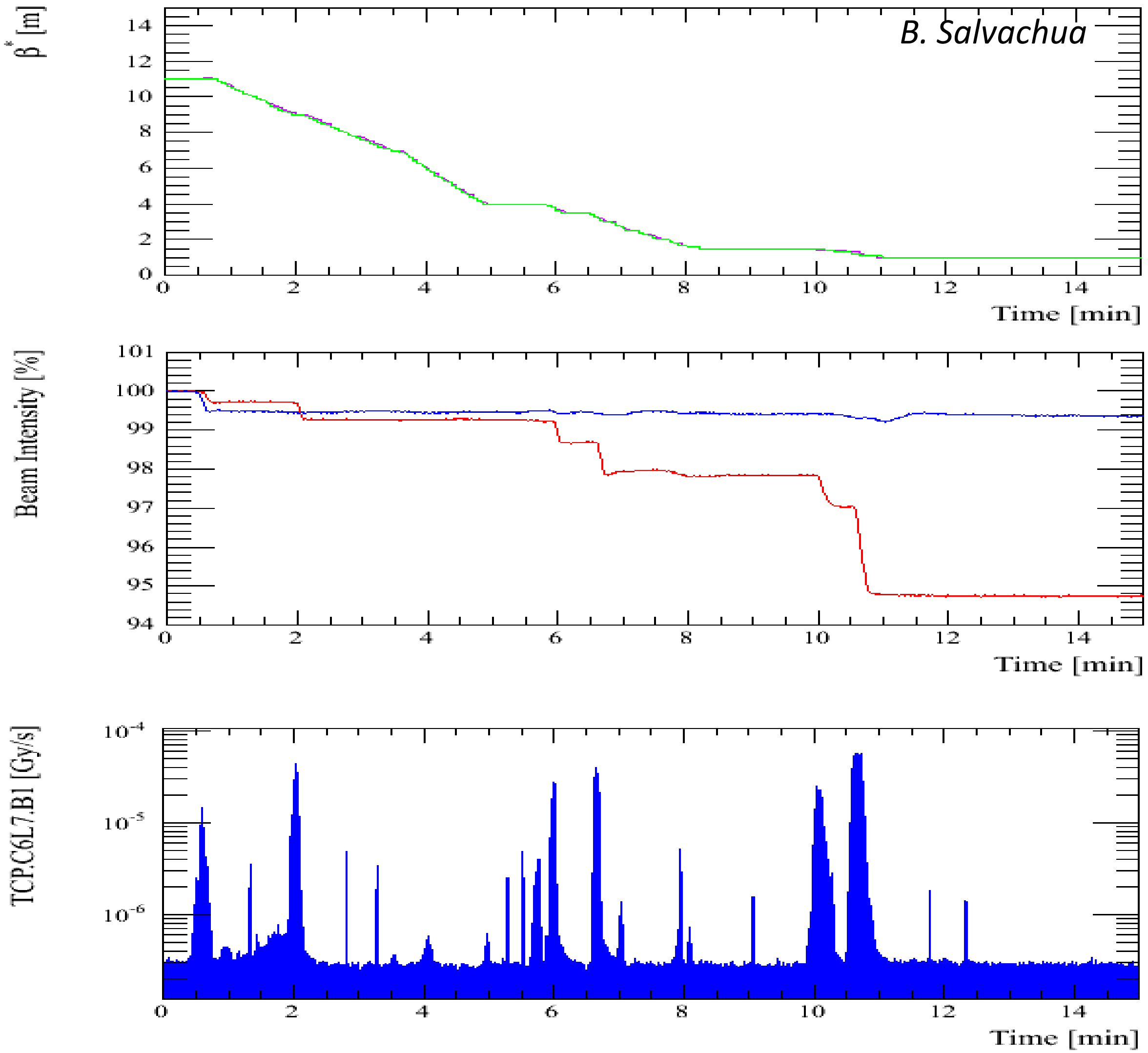
Conclusions from MD

- Gain factor 3.3 in efficiency compared to 2010 average ⇒ Higher intensity reach
- Loss maps with tight settings in 3 MDs over the year: May, August, November
- Keeping old centers from setup in March
- All loss map OK ⇒
  - Demonstrates stability of collimation setup. Tight settings still valid 8 months after alignment
- Using tight settings gives more room to squeeze β*



Losses in ramp and squeeze

- 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



Instability observations

- Impedance from tight settings under study - *see talk N. Mounet*
  - Instability observed during intensity ramp-up (*see talk E. Metral, LBOC 2011.08.30 and W. Herr, HiLumi workshop, 2011.11.17*)
  - Probable cause: combination of impedance and beam-beam. Possibly mitigated by octupoles at 550A and chromaticity control. No show-stopper expected
  - Tight gap of TCP in mm similar to nominal gap at 7 TeV, while secondary collimators are further retracted
  - 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

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Possible improvements in margins 2012

- Based on 2011 operation, we conclude
  - 2011 assumptions kept for orbit, beta-beat: not likely that we can gain more.
    - Study of margins required for asynchronous dump protection consistent with present margins
  - Tight collimator settings $\Rightarrow$ 2.5 σ gain in margin
- Beam size increasing at triplet and TCT $\Rightarrow$ gain in σ when going to smaller β* for margins constant in mm
- Gain in β-beat margin from tighter setting (total error depends on half-gap)
- Only small gain 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.

New method for adding margins

- Adding in square
  - Assuming errors are statistically independent random variables
  - Selecting a margin corresponding to ~99% confidence level for each error source
  - To arrive at a total 99% confidence level, margins should be added in square

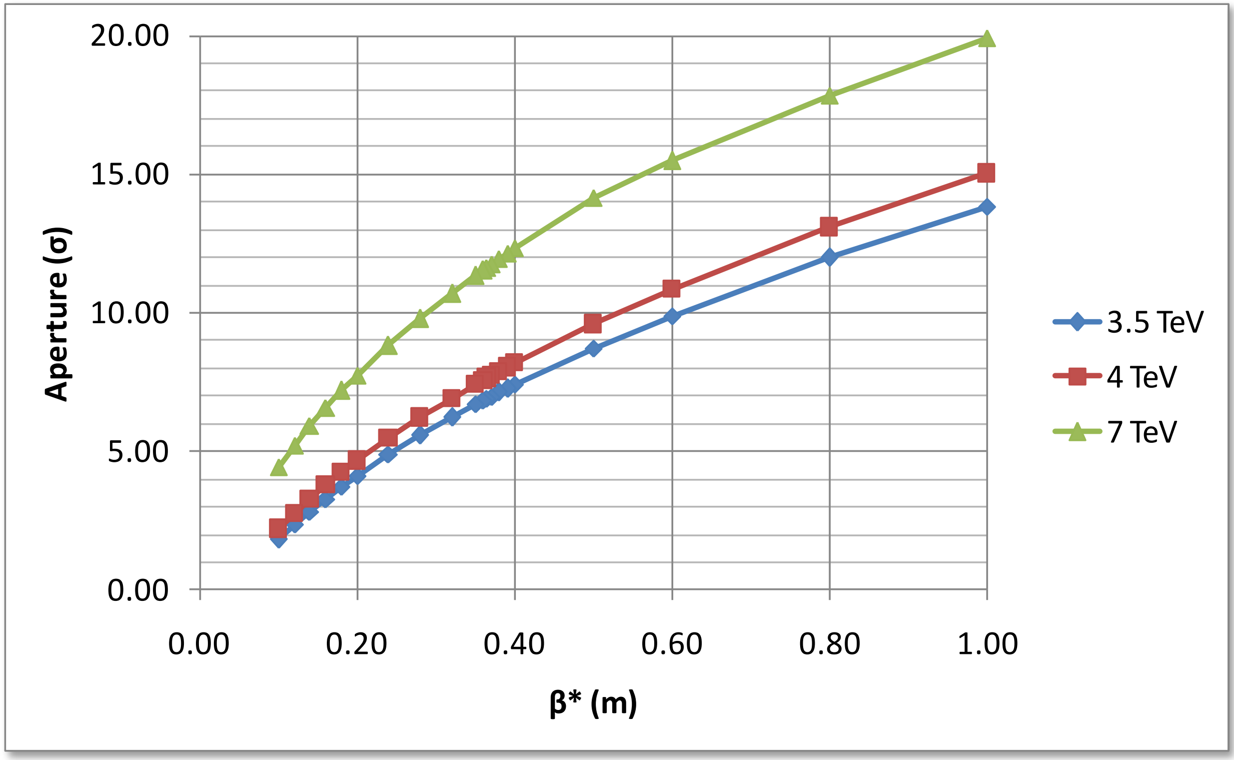
Old: $$\Delta_{total} = \sum_i |\Delta_i|$$ → New: $$\Delta_{tot} = \sqrt{\sum_i \Delta_i^2}$$

  - Logical extension of the already deployed strategy for orbit and already accepted risk levels, but should be discussed in MPP
- Risk level:
  - Assuming one asynchronous dump per year, spending 1/3 of time in stable beams
    - 2011: zero asynchronous dumps, 2010: 1 asynchronous dumps
  - With violation of margin 1% of time, expect 1 dump dangerous for TCT in 300 years and for triplet in 30000 years if independent
  - Same risk level as presently assumed in orbit analysis

Aperture calculations

- 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. Possible with 25ns? ***(see talk G. Papotti)***
- 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

Reach in β* with tight settings

old	3.5 TeV	4 TeV	7 TeV
gamma	3730	4263	7461
TCP 7	4	4.3	5.7
TCSG 7	6.0	6.4	8.5
TCLA 7	8.0	8.6	11.3
TCSG 6	6.8	7.3	9.6
TCDQ 6	7.3	7.8	10.3
TCT	9.1	9.6	12.6
aperture	10.9	11.6	15.0
Φ (μrad)	143	134	110
β* (m)	0.7	0.7	0.6

new	3.5 TeV	4 TeV	7 TeV
gamma	3730	4263	7461
TCP 7	4	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	8.2	8.6	10.4
aperture	9.4	9.9	12.1
Φ (μrad)	155	145	126
β* (m)	0.6	0.6	0.45

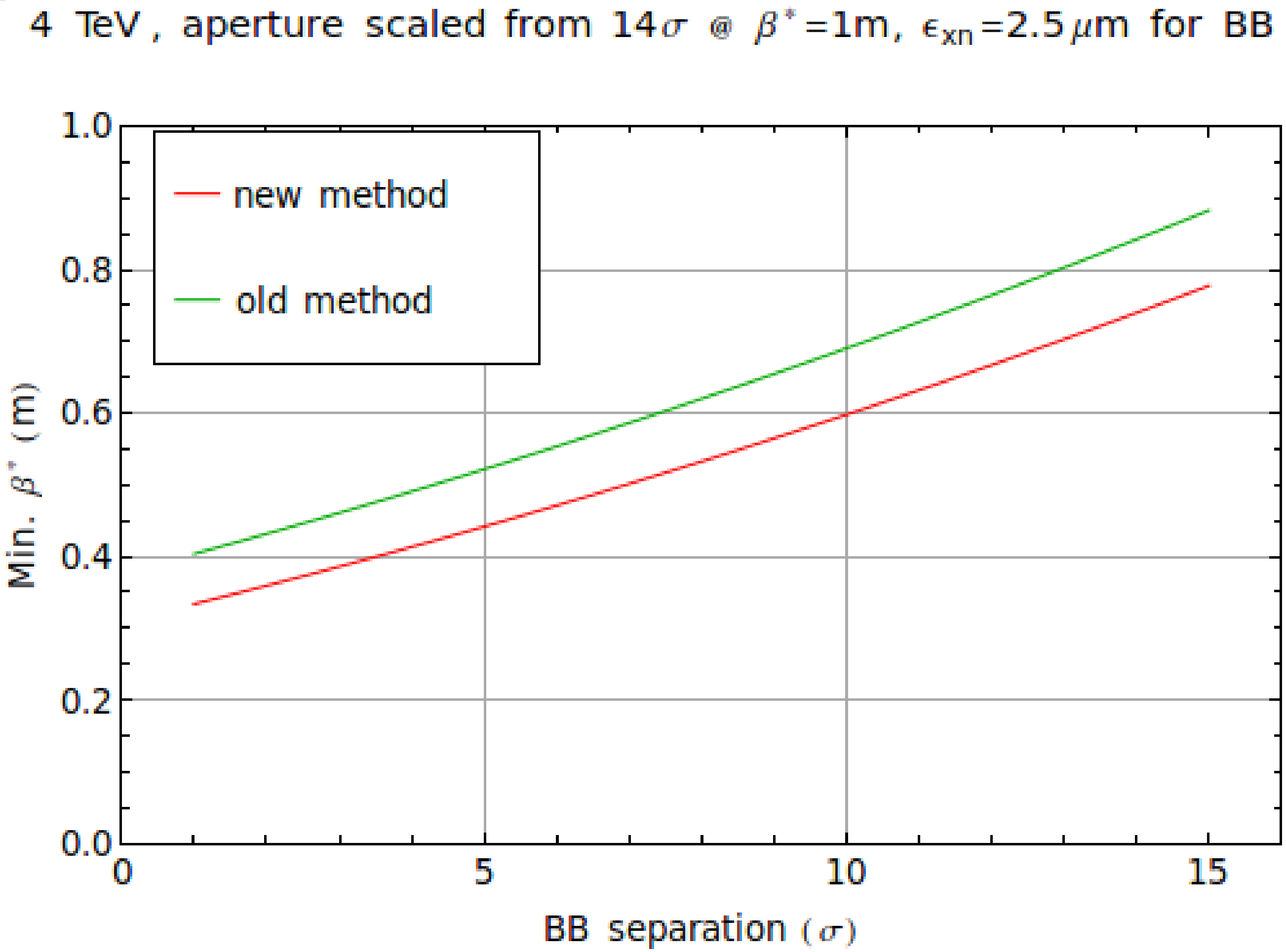
- Tight settings, old method:
  - IR6 and IR7 fixed in mm at the 3.5 TeV tight settings
  - Adjusting other margins IR6-TCT-aperture with expected beam size
- Tight settings, new method:
  - primary collimator stays at 4σ 3.5 TeV position in mm, but using σ at 4 TeV for margins in IR7 and IR6-IR7

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

Operational challenges

- Orbit correction in squeeze
- Non-linear triplet correctors
  - Possibly needed for smaller β*
  - Study needed - See MD request R. Tomas et al.
- IR6 orbit interlock at 1.5σ – same as margin with new method (comment J. Wenninger)
- Operational strategy to check that limits are not violated
- Mitigate beam-beam induced instabilities with tight settings
  - Larger beam-beam separations needed?

β* vs beam-beam separation



- Larger BB separation could be needed at 25 ns
- Increasing to 12σ BB separation: we lose about 10cm in β*

Future improvements in β* present machine

- Ways to reach smaller β* with the present machine
  - Reduce margin TCP-TCS7-TCS6 - no catastrophic damage if hierarchy breaks, but risk for dumps and/or high radiation to DS magnets
  - Move in primary collimator closer to beam – challenge for impedance and orbit correction. 4σ TCP at 4 TeV gives small gain
  - Investigate BPMs in experimental IRs. Which drifts are real? Can the orbit margin be reduced? (comment S. Fartoukh)
  - Decrease beam-beam separation (gains aperture)
  - Updated IR6 optics with 90 deg phase advance MKD-TCDQ (S. Fartoukh). Reduces dangerous time window during asynchronous dump (or increases the acceptable TCDQ error). Can allow for reduced margin IR6-TCTs.
- We are probably not at the limit yet – more studies required

Future improvements in β* upgraded machine

- Upgraded collimators with built-in BPM buttons allow collimators to be quickly re-centered without touching beam ⇒ decreased orbit margins
  - Prototype installed in the SPS. Promising MD results (D. Wollmann et al in IPAC11)
- 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
  - Significant reduction below nominal
- Upgraded magnets and new ATS optics (flat beams?) allow much smaller β* (L. Rossi, S. Fartoukh et al)

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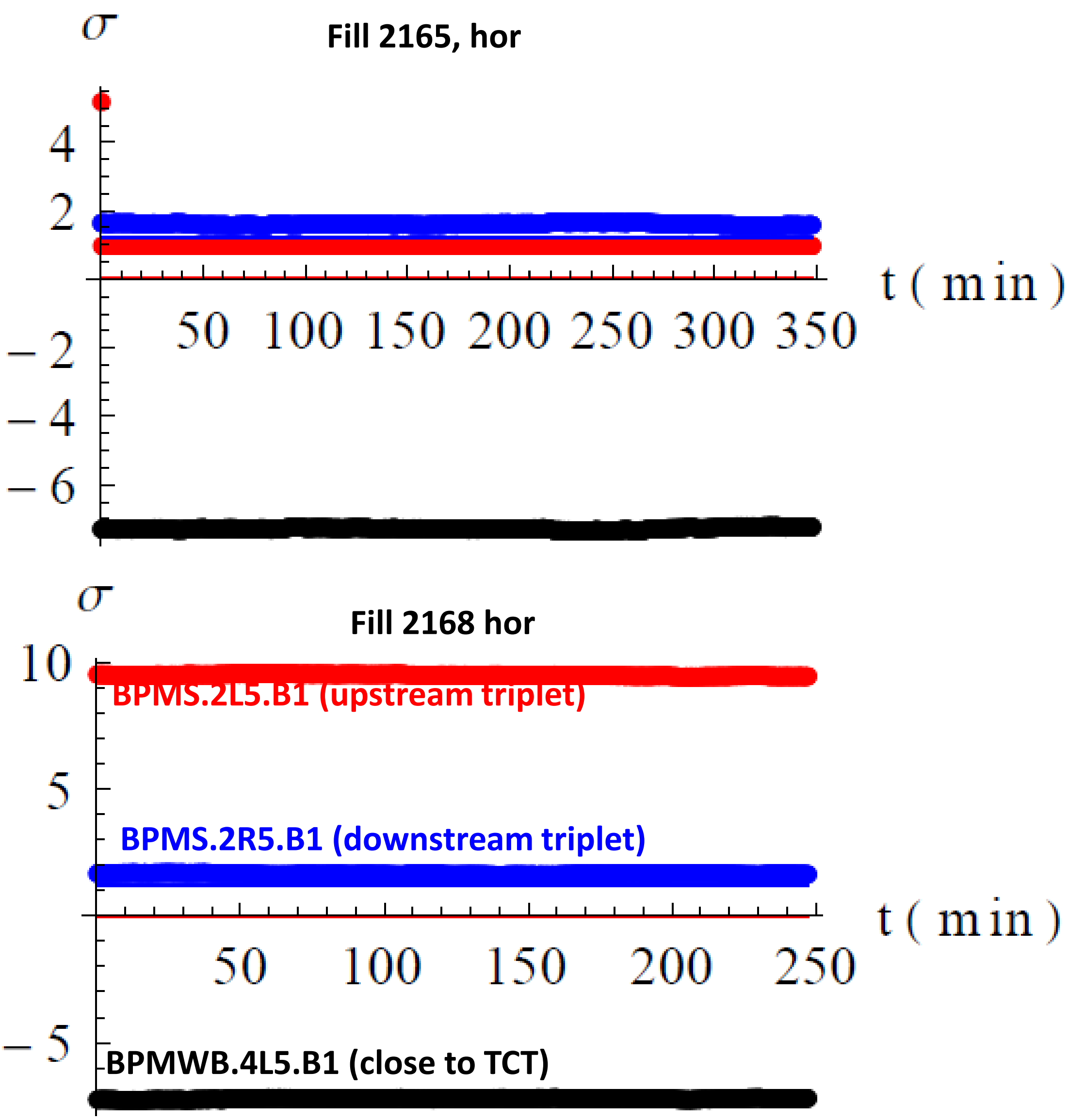
Conclusions

- β* is dependent on settings and margins in collimation and protection system. Present limitation on β* in the LHC.
- Important 2011 operational results
  - Measured aperture close to mechanical at top energy, squeeze
  - Tight collimator settings show excellent long-term stability. Instabilities and orbit oscillations in squeeze must be controlled.
  - No reduction of margin for orbit and β-beat
- Gain in β* from new statistical method for calculating margins, summing squares
- With tight settings, we can now go to β*=70cm with old method, β*=60cm with new method **if we assume**
  - 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!
- There is still some room improvement – studies to be done

Backup slides

IR5 B1: BPM problems



- BPMS.2L5.B1 jumps by >10mm between fills.
- Both planes affected
- Excluding this BPM from analysis
- BPMS.2L5.B1 and BPMS.2R5.B1 both flagged with error during TCT setup
- Less complete analysis in IR5 than in IR1 due to lack of reliable data