Squeeze Criteria & Requirements

- summary of luminosity optics and crossing parameters
- requirements during squeeze
- effect of gradient errors on beta−beat and closed orbit
- gradient transition during squeeze
- required actions for squeeze generation in operation
- time estimate for squeeze
- general comments and questions
- possible scenario for commissioning the squeeze

Nominal LHC IR Parameters

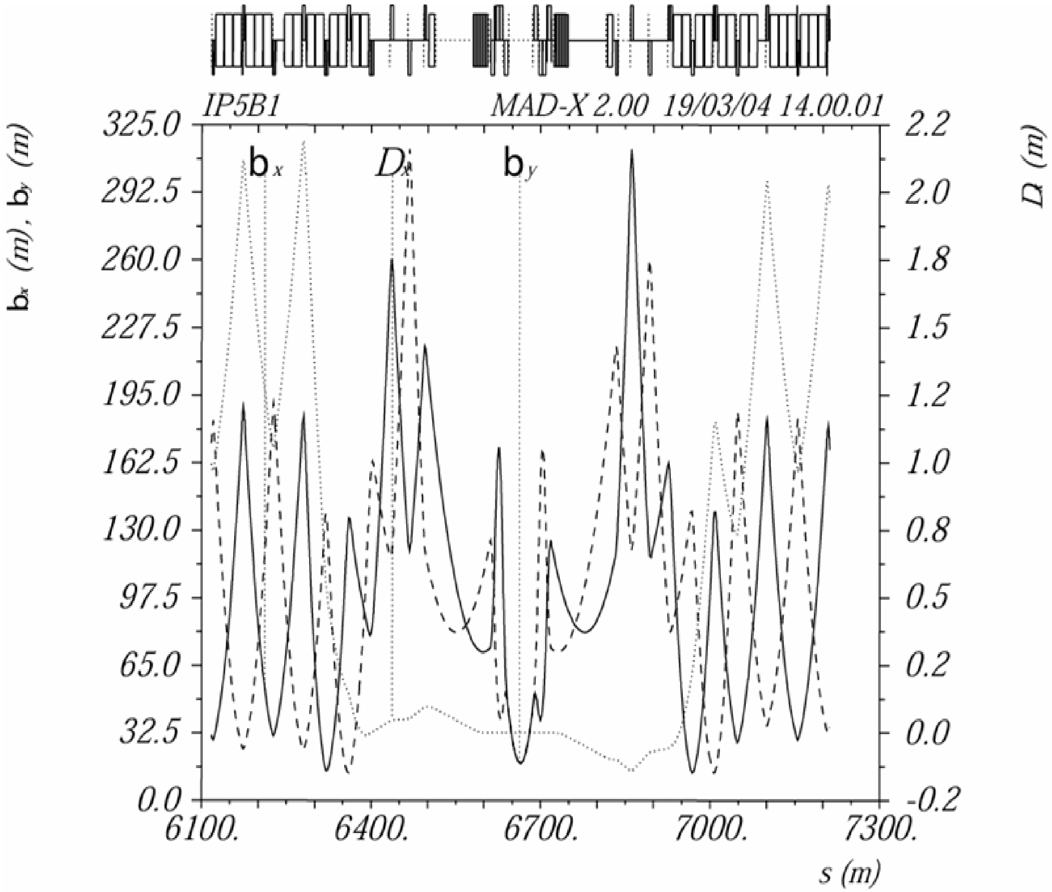
LHC Design Report Volume I; CERN−2004−003; 4 June 2004

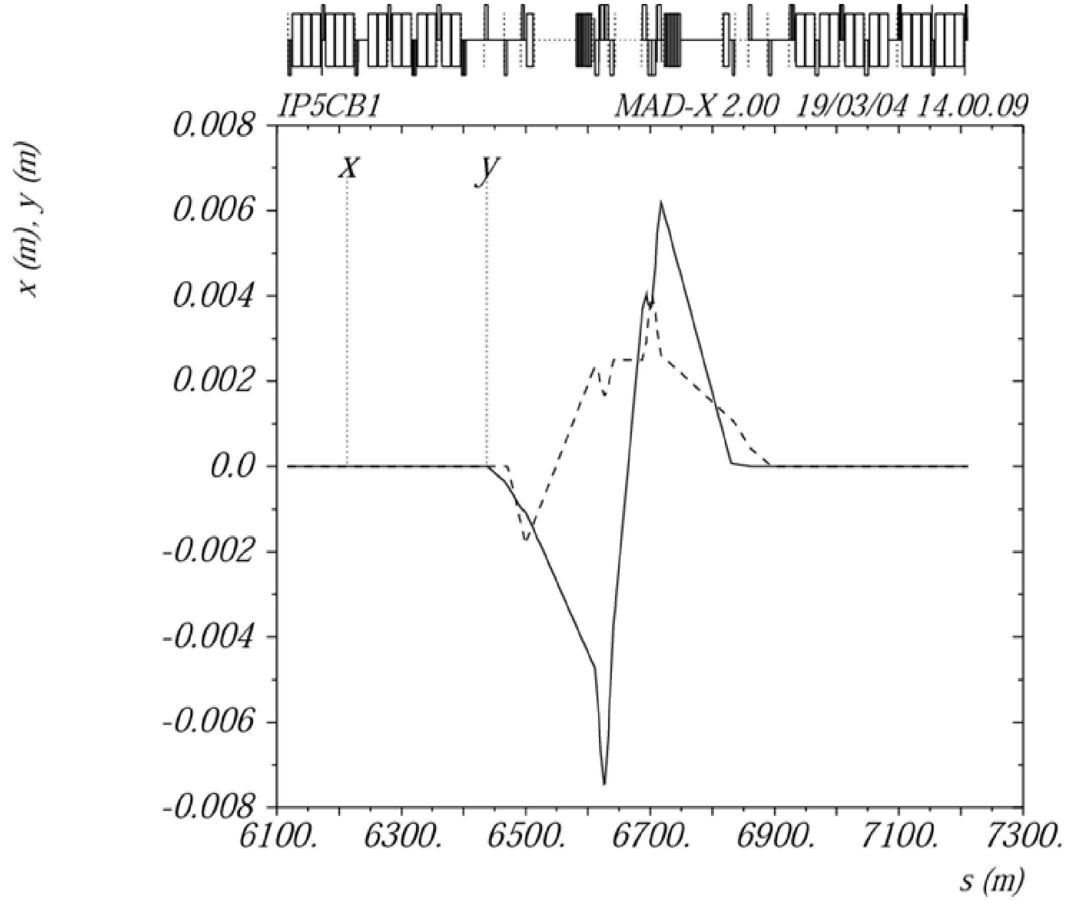
Insertion	proton − proton				ion − ion (Pb−Pb)			
	β* [m]	ϕ [μ rad]	Δ [mm]	L [$cm^{-2}s^{-1}$]	β* [m]	ϕ [μ rad]	Δ [mm]	L [$cm^{-2}s^{-1}$]
IR1	18.0 0.55	+/− 160 (V) +/− 142.5 (V)	+/− 2.5 (H) 0.0	10^{34}				
IR2	10.0 10.0	+/− 240 (V) +/− 150 (V) (80)	+/− 2.0 (H) +/−0.18	10^{30}	0.5	+/− 0.0 (V) +/− 80 (V)	0.0	10^{27}
IR5	18.0 0.55	+/− 160 (H) +/− 142.5 (H)	+/− 2.5 (V) 0.0	10^{34}				
IR8	10.0 1 / 35 (10)	+/− 300 (H) +/− 75 (H) +/− 200 (H)	+/− 2.0 (V) 0.0	10^{32}				

Injection Optics and Crossing Angle

[Stephane Fartoukh, 23. LTC 31. March 2004]

- optics and crossing scheme at injection (Beam1 IR5):



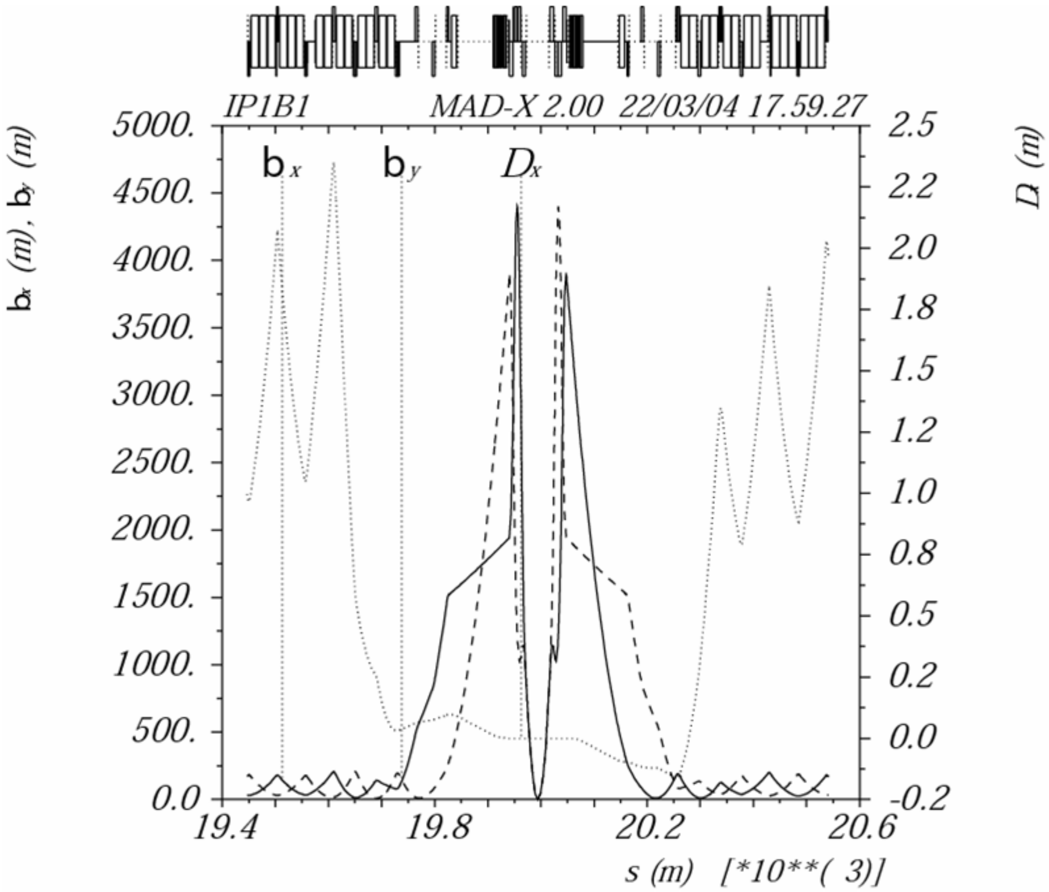


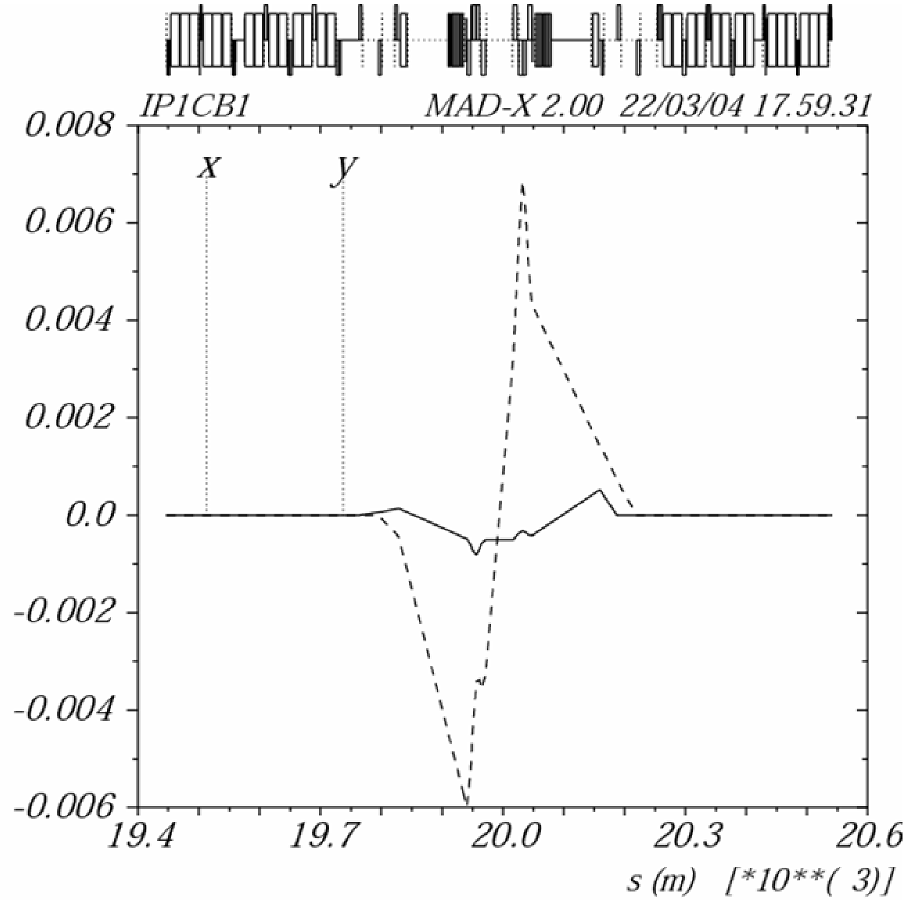
β^* = 18 m in IR1/IR5 (V / H); angle = +/− 160μ rad; separation = +/− 2.5mm

Collision Optics and Crossing Angle

[Stephane Fartoukh, 23. LTC 31. March 2004]

- optics and crossing scheme at collision (Beam1 IR1):





β^* = 0.55 m in IR1/IR5 (V / H); angle = +/− 142.5 μrad; separation = +/− 0.5mm

Squeeze Criteria & Requirements

- goal: maintain required minimum separation in common beam pipe

  → separation larger than: 9.0 σ at injection

  6.9 σ at collision

- goal: maintain margins for mechanical aperture and collimation system

- establish ´smooth´ transitions for magnet powering:

  avoid changes in the slope of the magnet ramp

- avoid zero crossings and small gradients where possible:

  delicate powering control near zero point

Tolerances during Squeeze

- gradient errors during squeeze change optics & beam separation:

- tolerances during squeeze:

  (triplet and IR3 & IR7)

  Δ Q < 0.01 (1/3 resonance)

  21% β−beat

  27% spurious normalized dispersion

  3 mm closed orbit error inside triplet

  < 1 σ relative closed orbit error for beam separation

→ requires excellent optics control during squeeze

- operation: → squeeze one IP at a time? (lattice correctors & time)

  → orbit feedback during squeeze is desirable

Tolerances for Gradient Errors: β

- β beat during squeeze with insertion magnet gradient errors:

$$\longrightarrow \quad \frac{\Delta\beta(s)}{\beta_0} \;\textrm{<=}\; \frac{-\beta_i}{2\cdot\sin(2\pi\cdot Q)}\cdot \Delta k_1 \cdot l$$

triplet magnet parameter: $k_1 = 0.0085\ m^{-2}$; $l = 2\cdot 5.5,\ 6.37$ m; $\beta = 4500$m

insertion magnet Q4: $k_1 = 0.0050\ m^{-2}$; $l = 3.4$ m; $\beta = 1500$m

insertion magnet Q7: $k_1 = 0.0085\ m^{-2}$; $l = 6.8$ m; $\beta = 200$m

assume: $\Delta k_1 = 10\cdot 10^{-4}\ k_1$ $\longrightarrow$ $\frac{\Delta\beta(s)}{\beta_0}$ <= 23%; 1.2%; 0.6%

$\longrightarrow$ $\frac{\Delta\beta(s)}{\beta_0}$ = 20% for one Q2 magnet or 50 insertion magnets (rms $-$ 3σ)

Tolerances for Gradient Errors: Q

- tune change during squeeze with insertion quadrupole gradient errors:

$$\longrightarrow \quad \Delta Q = \frac{\beta_i}{4\pi} \cdot \Delta k_1 \cdot l$$

triplet magnet parameter: $k_1 = 0.0085\ \mathrm{m}^{-2}$; $l = 2 \cdot 5.5,\ 6.37\ \mathrm{m}$; $\beta = 4500\mathrm{m}$

insertion magnet Q4: $k_1 = 0.0050\ \mathrm{m}^{-2}$; $l = 3.4\ \mathrm{m}$; $\beta = 1500\mathrm{m}$

insertion magnet Q7: $k_1 = 0.0085\ \mathrm{m}^{-2}$; $l = 6.8\ \mathrm{m}$; $\beta = 200\mathrm{m}$

assume: $\Delta k_1 = 10 \cdot 10^{-4} \cdot k_1$ $\longrightarrow$ $\Delta Q = 0.033;\ 0.002;\ 0.001$

$\longrightarrow$ $\Delta Q > 0.01$ for one Q2 magnet or 5 to 10 insertion magnets

Tolerances for Gradient Errors: CO

- orbit change during squeeze with crossing angle and gradient errors:

→ $$\Delta CO / \sigma = \frac{\sqrt{\beta_i / \varepsilon_n}}{2 \cdot \sin(\pi \cdot Q)} \cdot \Delta z \cdot \Delta k_1 \cdot l \; ; \; z=x,y$$

assume: $\Delta k_1 = 10 \cdot 10^{-4} \cdot k_1$

triplet magnet parameter: $\Delta z = 7$ mm → $\Delta CO = 1\sigma$

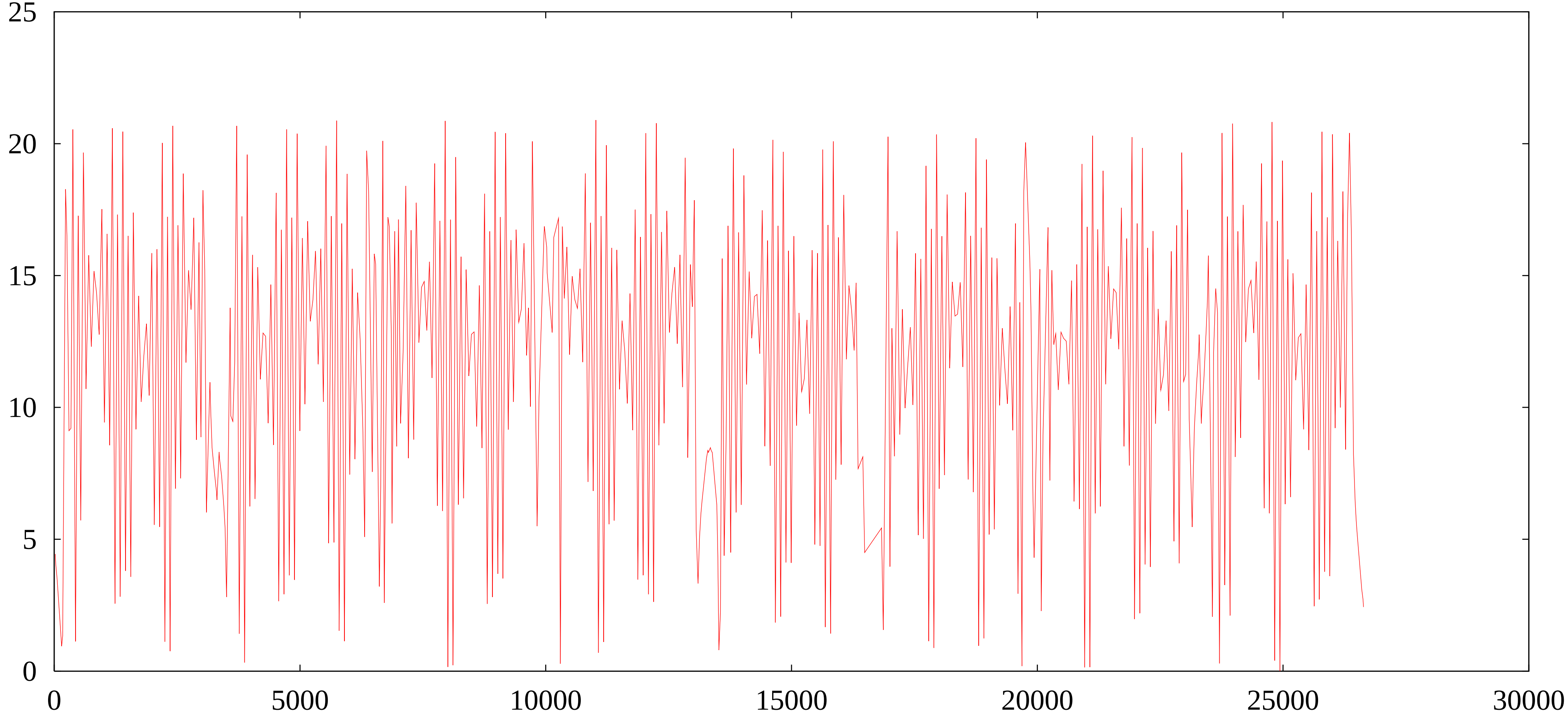
insertion magnet Q4: $\Delta z = 2$ mm → $\Delta CO = 0.3\sigma$

insertion magnet Q7: $\Delta z < 0.5$ mm → $\Delta CO = 0.01\sigma$

→ triplet and Q4 gradients are relevant for orbit control!

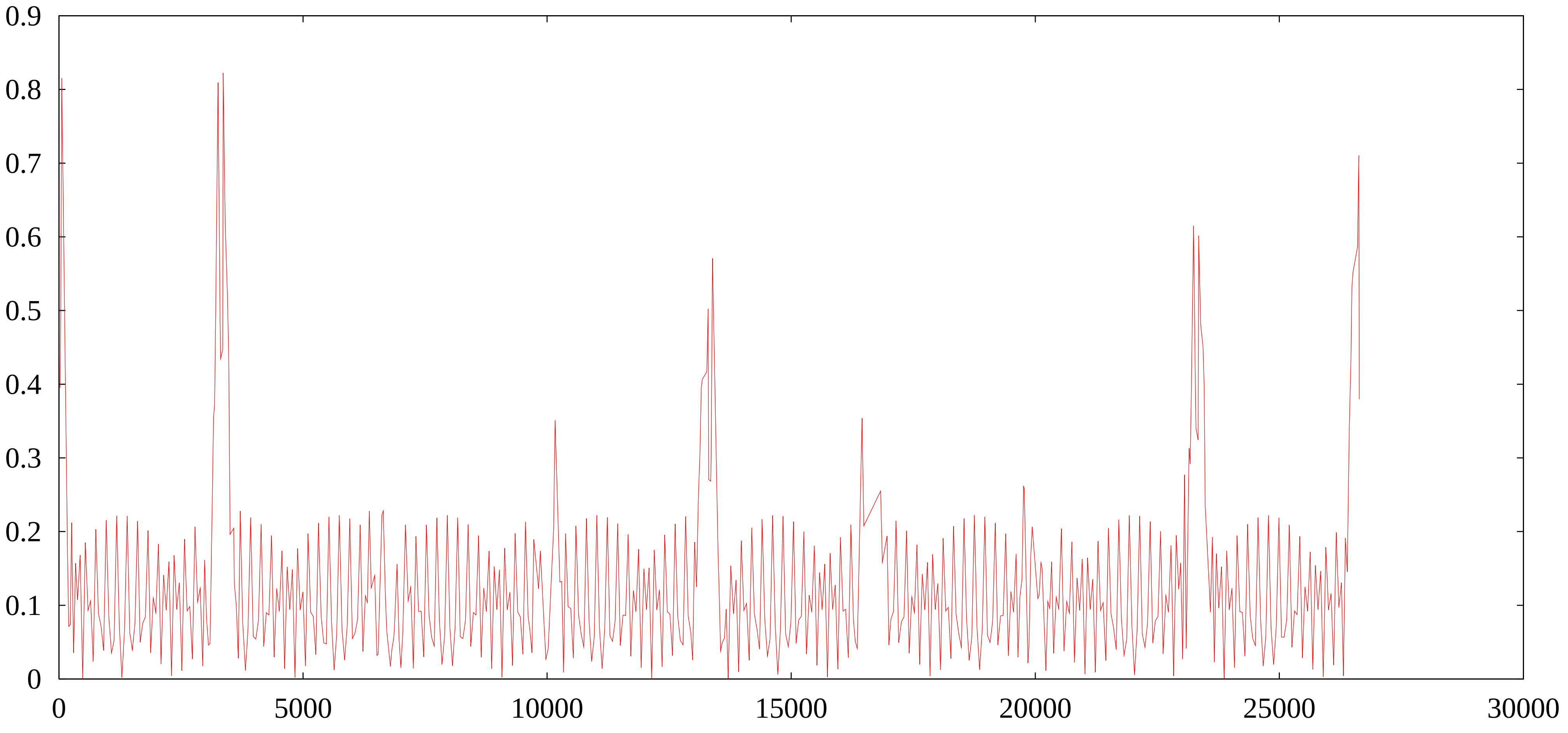
Tolerances for Gradient Errors: triplet left IP5

- β −beat for 10 units triplet error left in IR5:



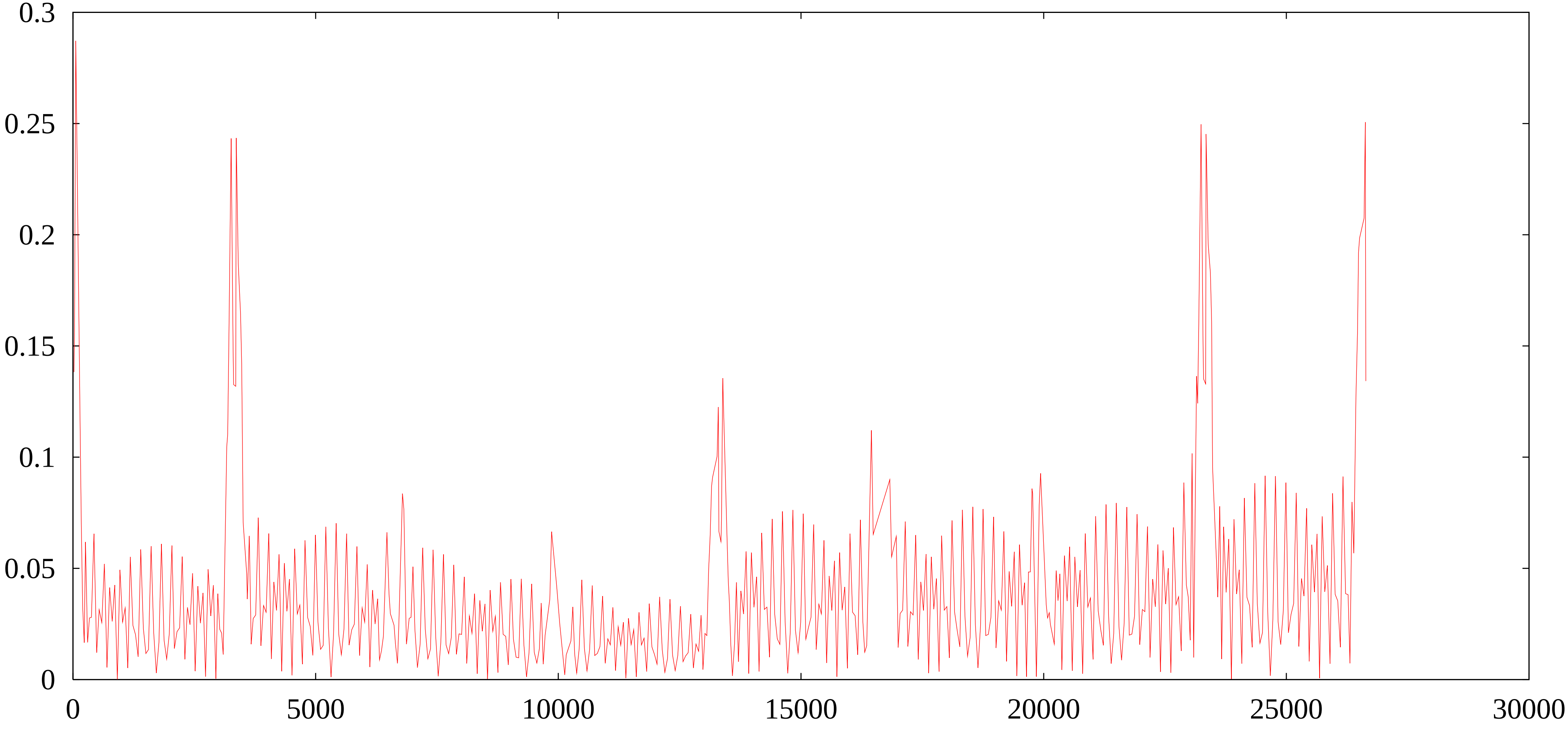
Tolerances for Gradient Errors: triplet left IP5

- CO for 10 units triplet error left in IR5:



Tolerances for Gradient Errors: triplet left IP5

- horizontal dispersion for 10 units triplet error left in IR5:

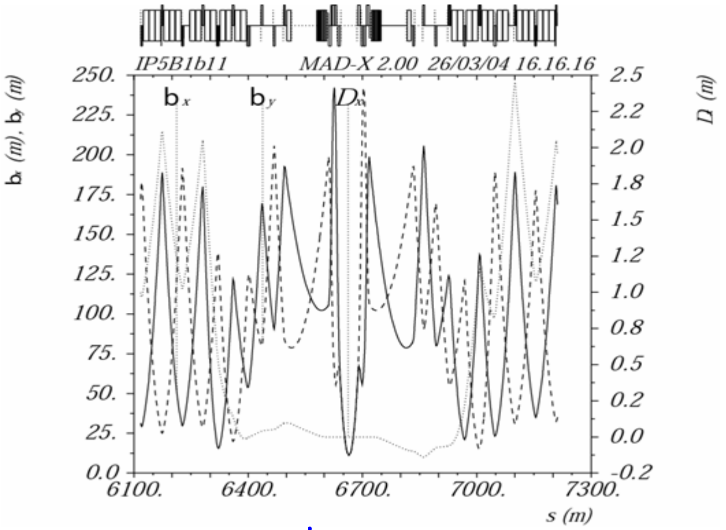


Collimation During the Squeeze

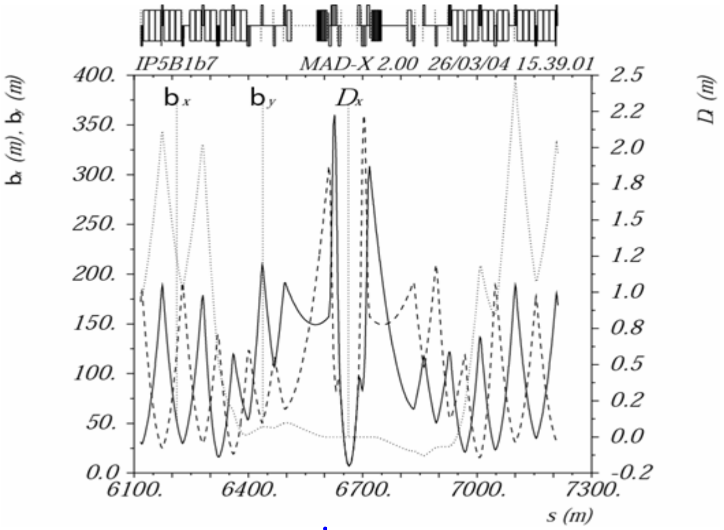
- the collimator jaws define a shadow for the cold aperture:
  - → primary collimator jaws at 7 (6) σ; [n_1]
  - → secondary collimators at 8.4 (7.2) σ
  - → cold bore protection up to 9.8 σ (radially) / 8.4 σ (h/v)
- radiation damping: σ (450 GeV) = 4• σ (7 TeV)
  - → collimator jaw opening must change at top energy for same n_1
  - → collimators must move before squeeze
- constant collimator opening is possible if n_1 (7 TeV) = 4• n_1 (450 GeV)
  - → no crossing angle and $\beta^* > 5$ meter!

Optics During Squeeze in IR1 & IR5

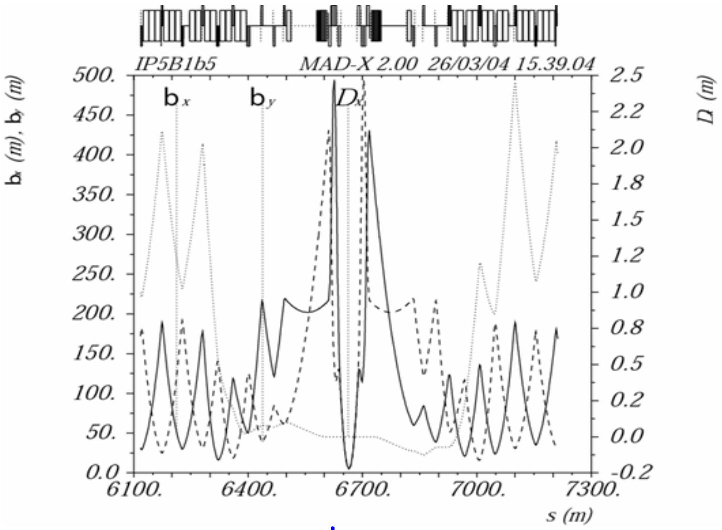
[Stephane Fartoukh at 23. LTC; 31. March 2004]



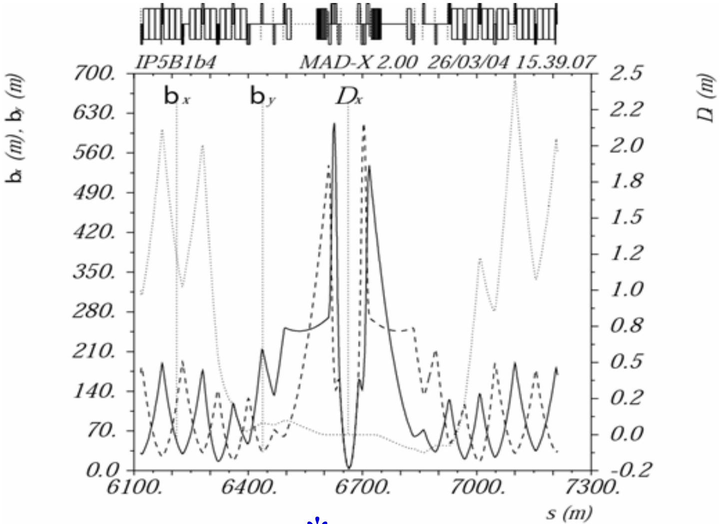
$\beta^* = 11$ m



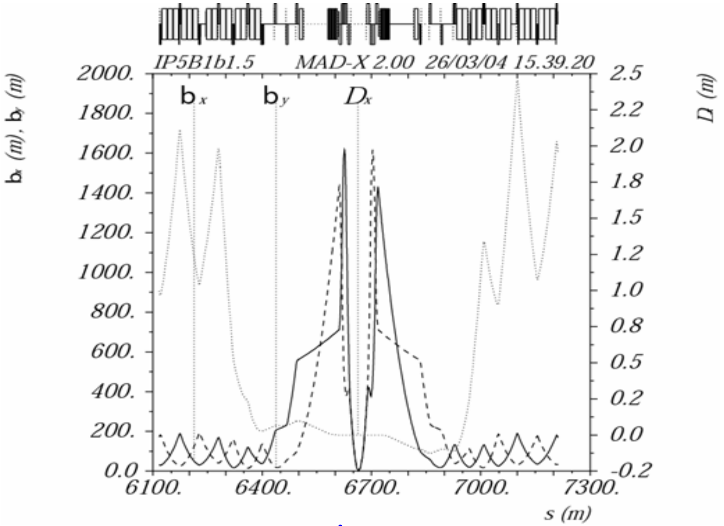
$\beta^* = 7$ m



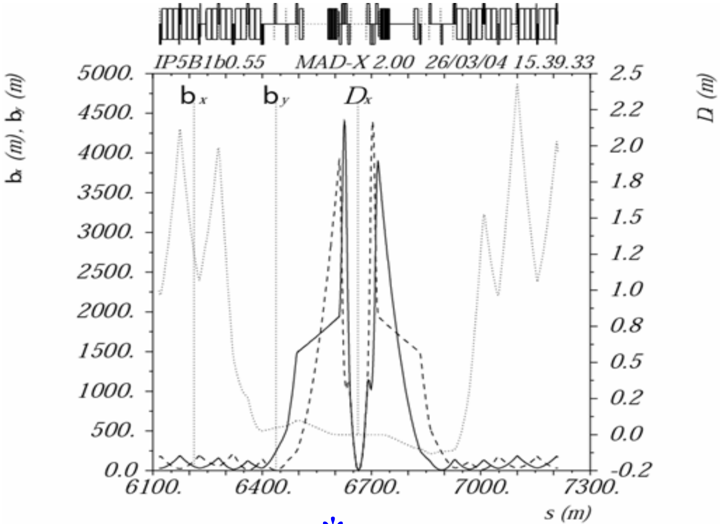
$\beta^* = 5$ m



$\beta^* = 4$ m



$\beta^* = 1.5$ m

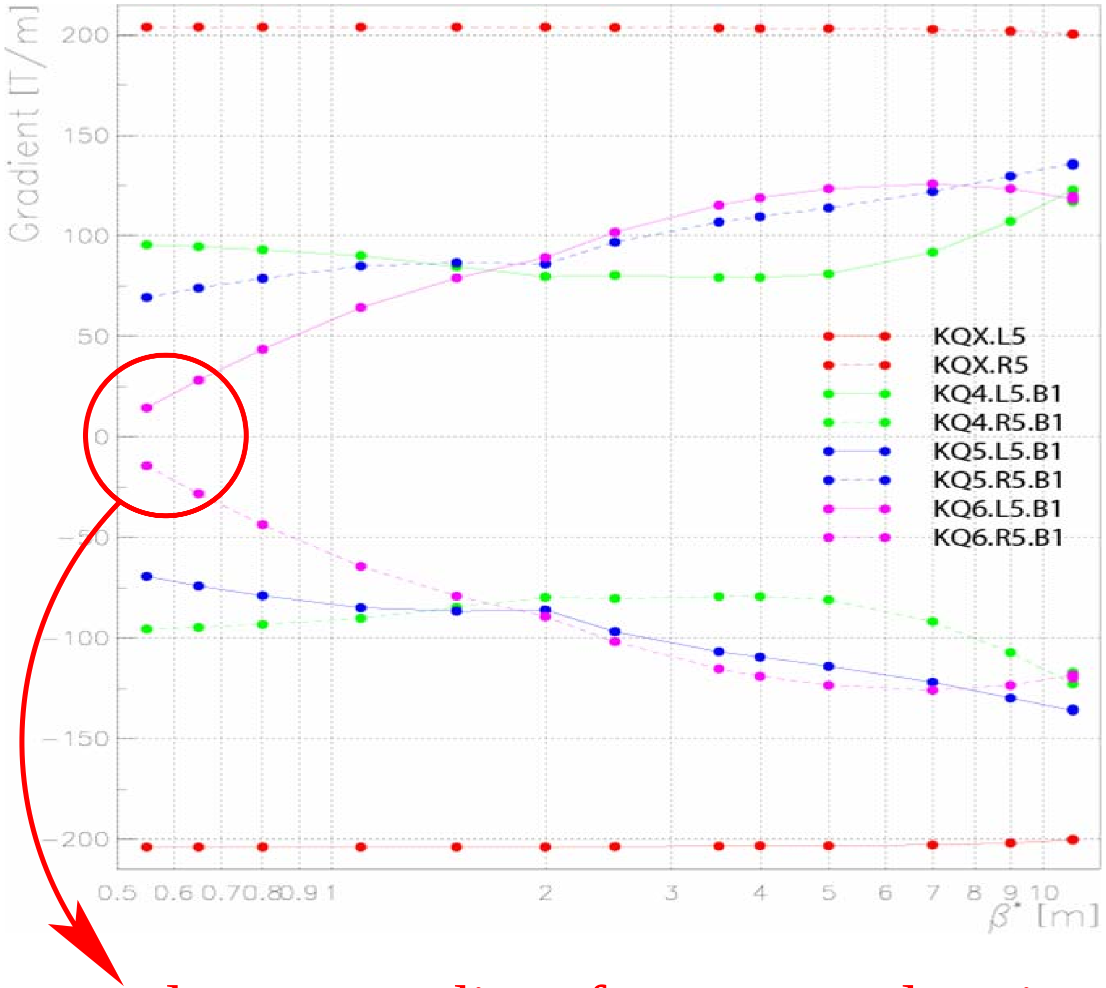


$\beta^* = 0.55$ m

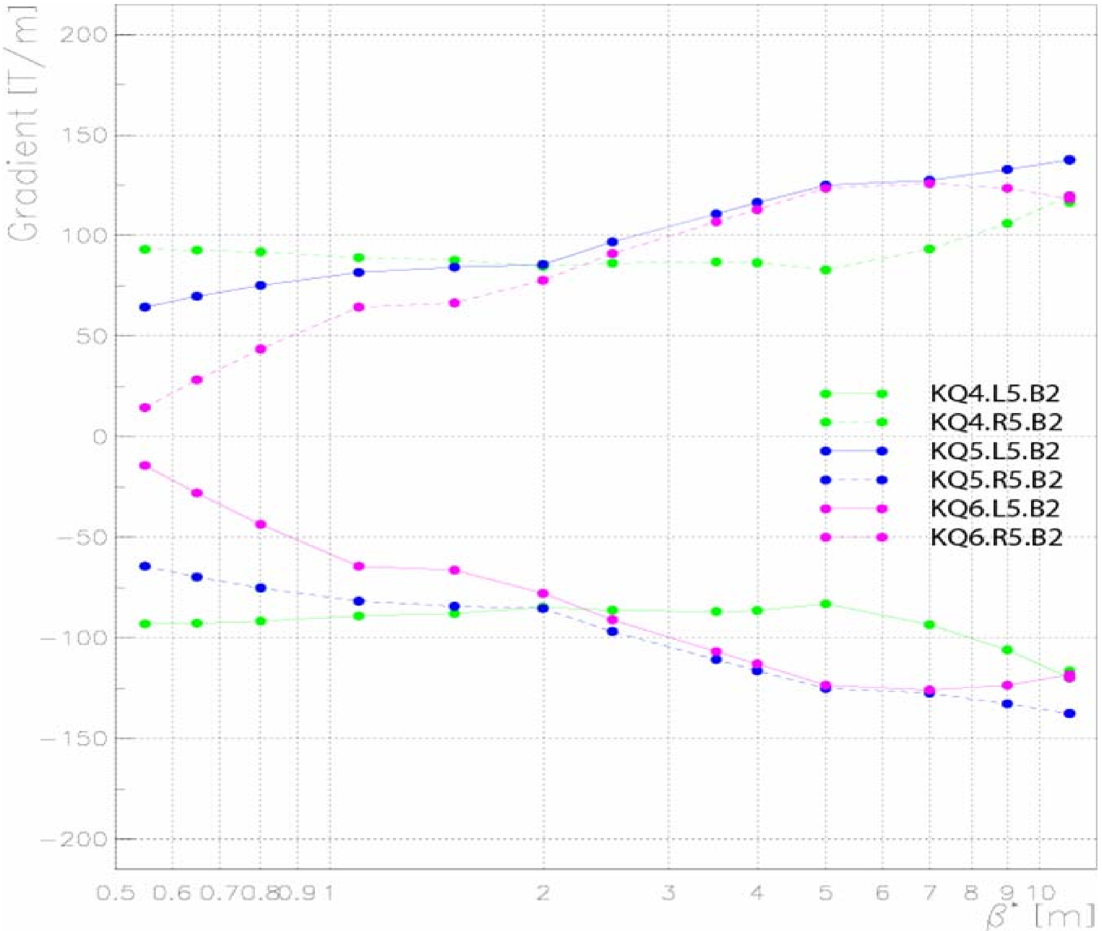
Gradients During Squeeze in IR1 & IR5

[Stephane Fartoukh at 23. LTC; 31. March 2004]

Beam1:



Beam2:



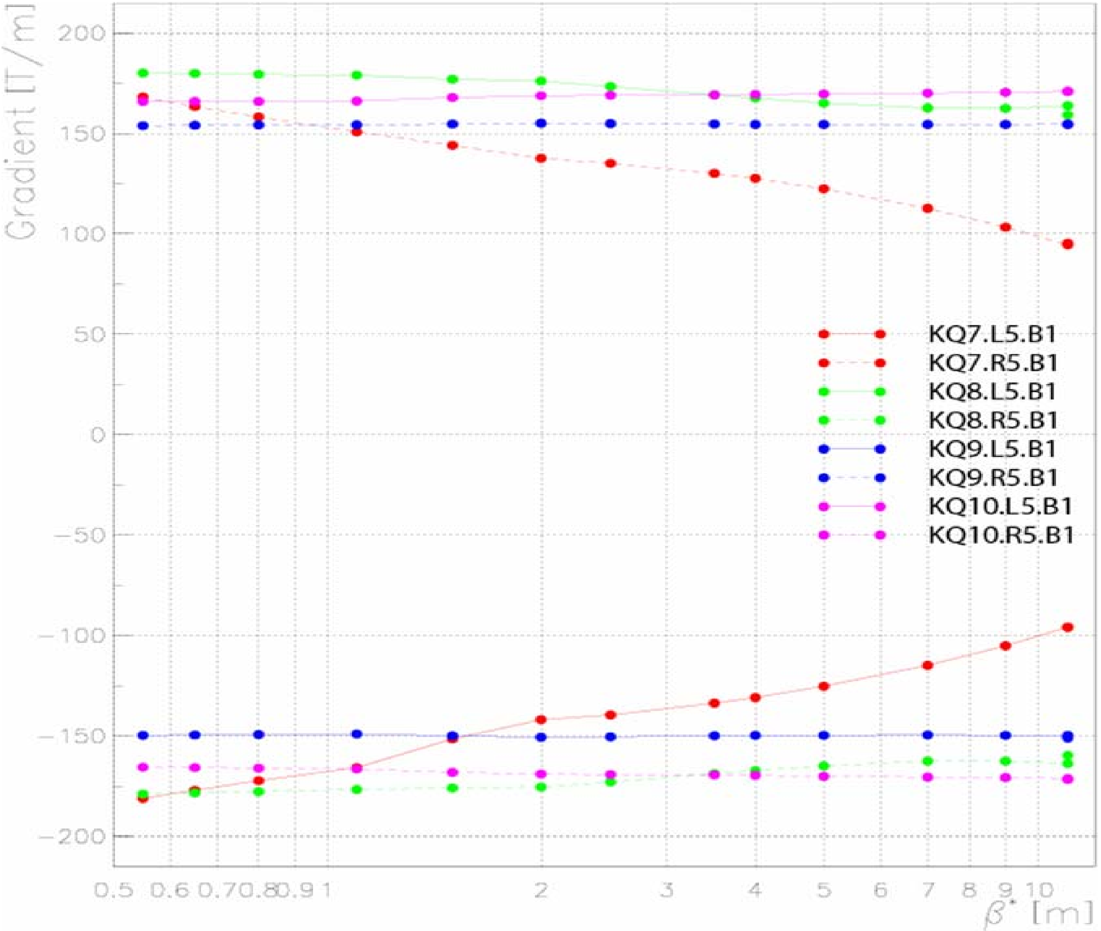
lowest gradient for squeezed optics is approximately only 5% of nominal!

→ squeeze potentially challenging for $\beta^* < 1$ m

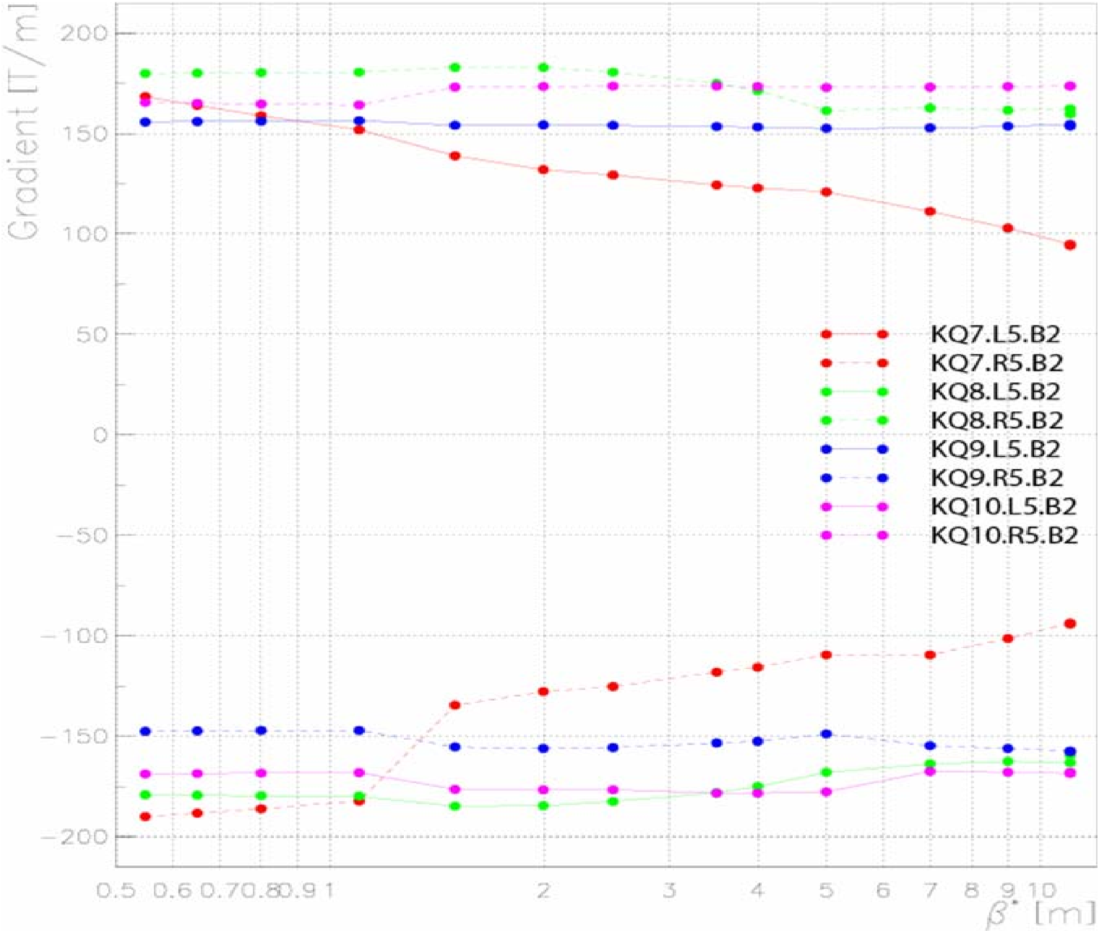
Gradients During Squeeze in IR1 & IR5

[Stephane Fartoukh at 23. LTC; 31. March 2004]

Beam1:



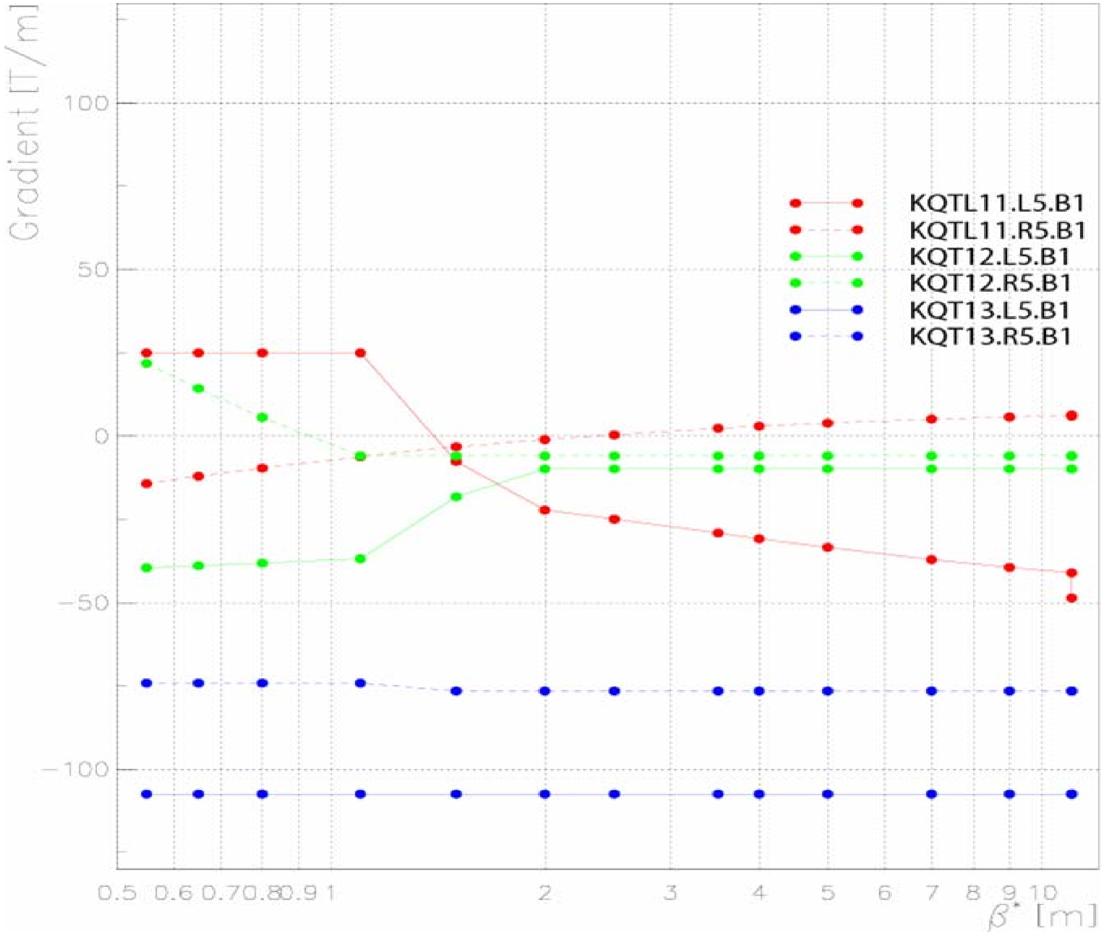
Beam2:



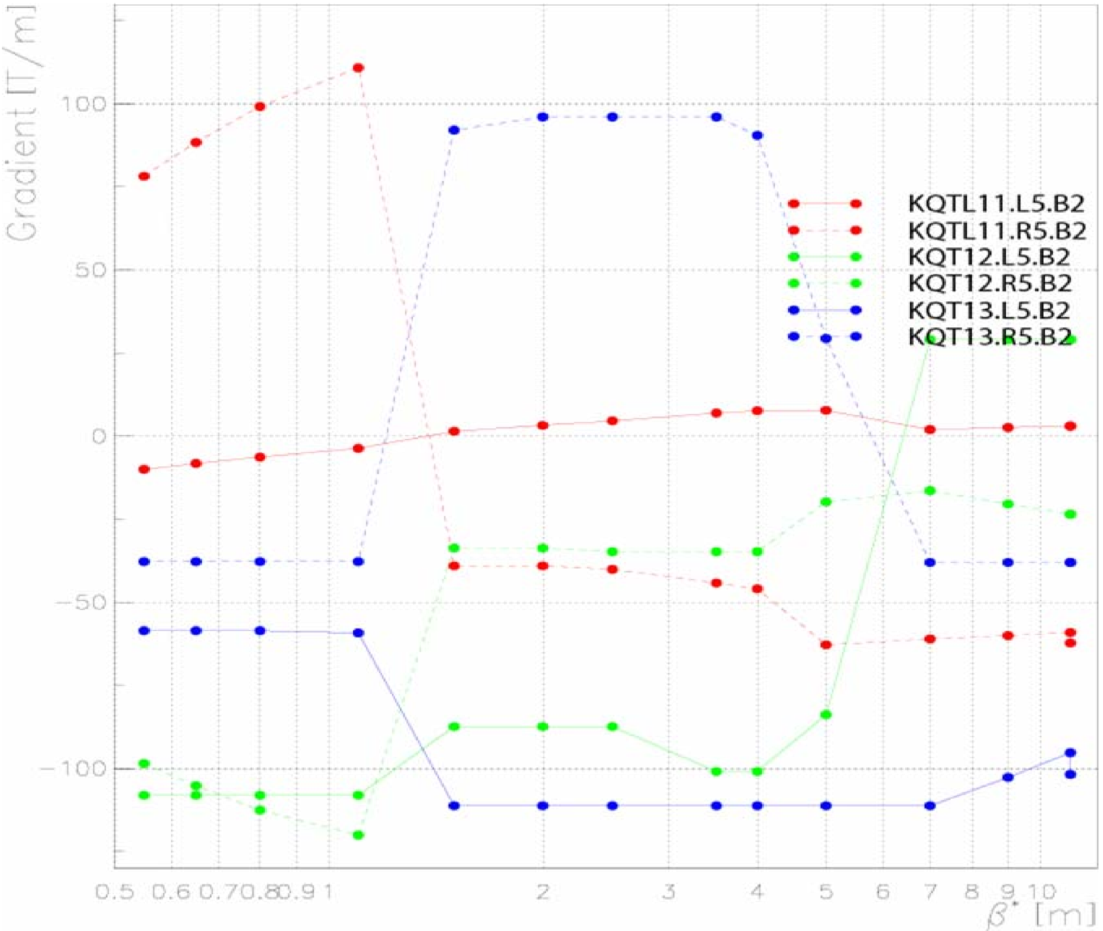
Gradients During Squeeze in IR1 & IR5

[Stephane Fartoukh at 23. LTC; 31. March 2004]

Beam1:



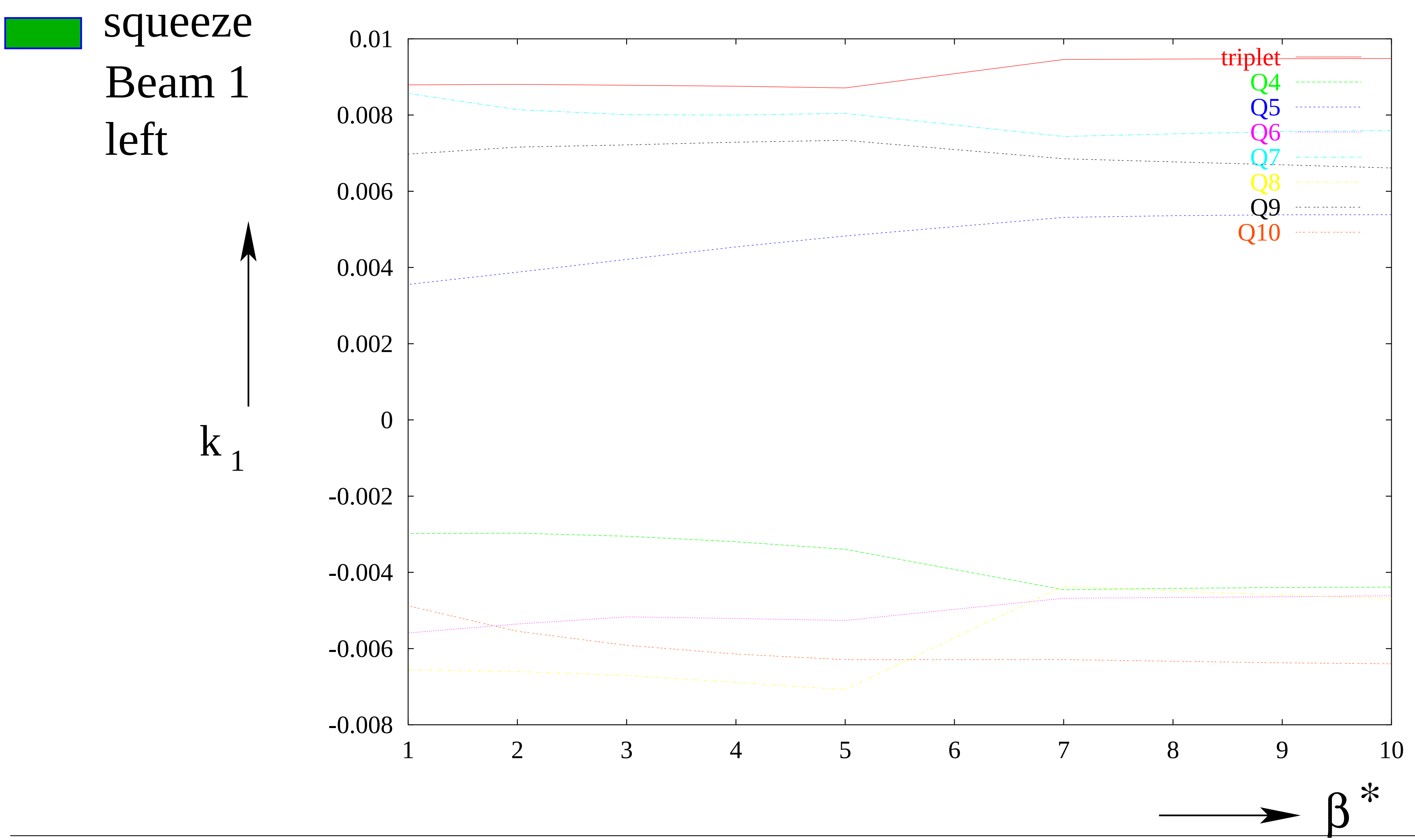
Beam2:



→ zero crossings for the corrector circuits can not be avoided!

Gradients During Squeeze in IR8

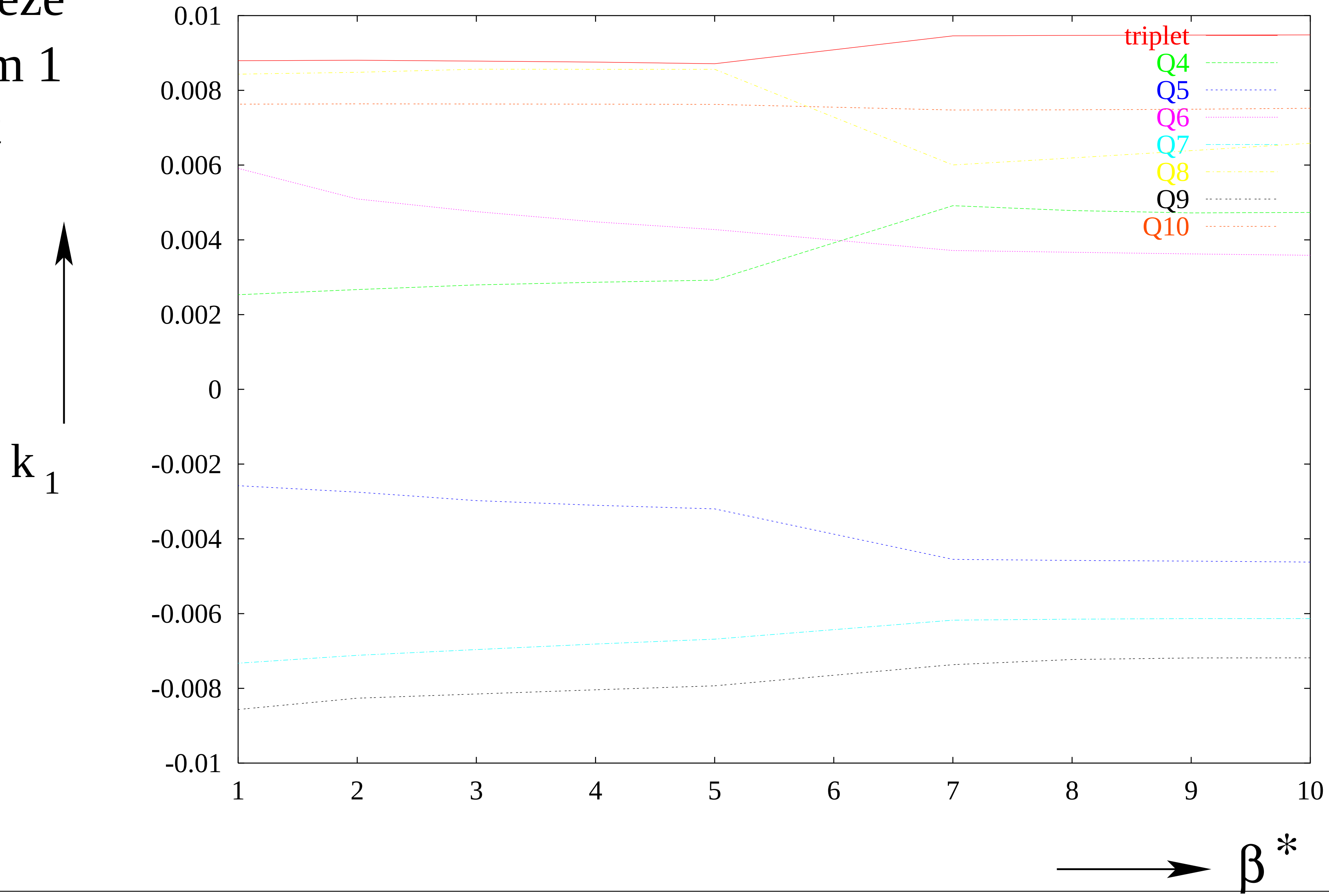
[Oliver Bruning at 23. LTC; 31. March 2004]



Gradients During Squeeze in IR8

[Oliver Bruning at 23. LTC; 31. March 2004]

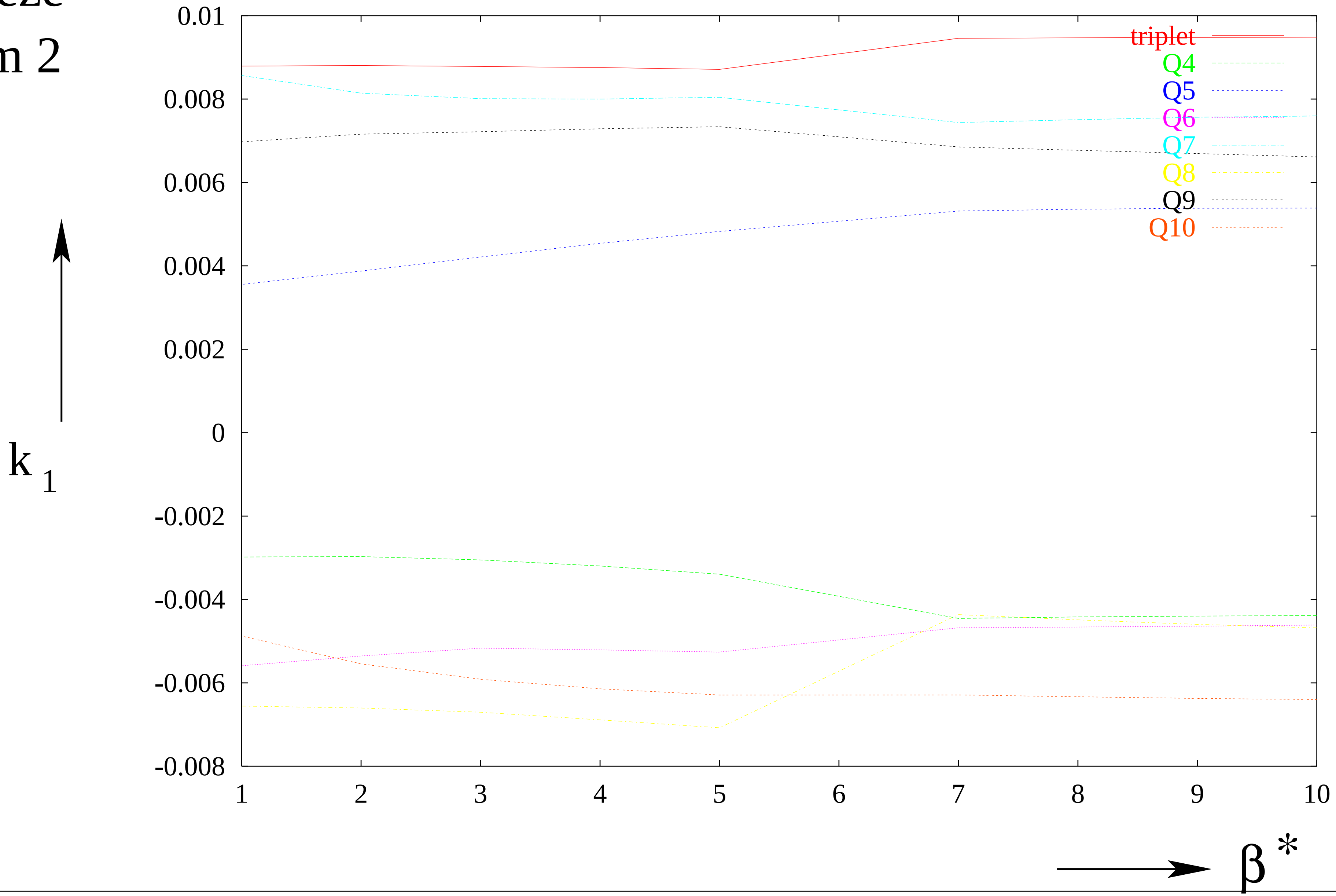
squeeze
Beam 1
right



Gradients During Squeeze in IR8

[Oliver Bruning at 23. LTC; 31. March 2004]

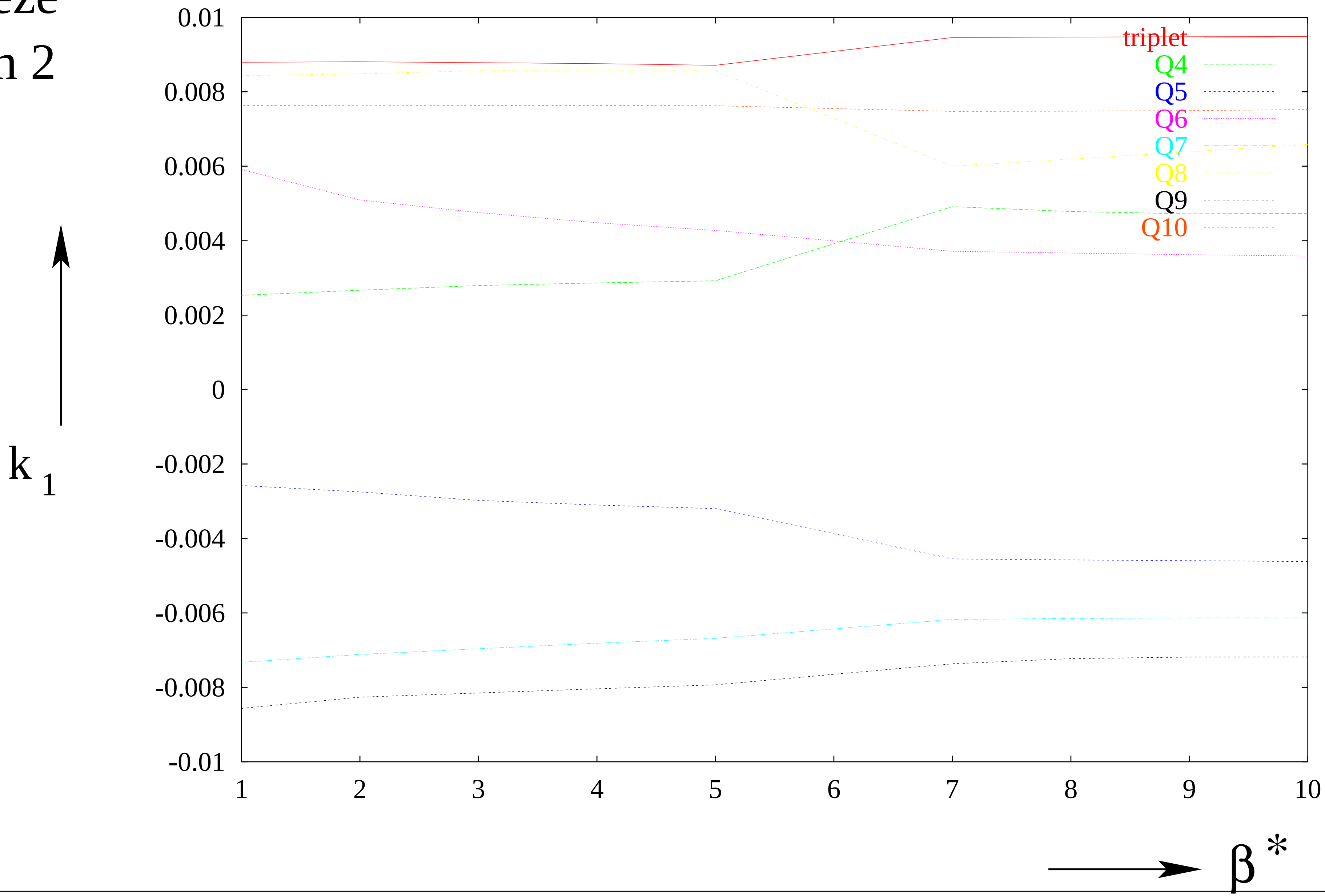
squeeze
Beam 2
left



Gradients During Squeeze in IR8

[Oliver Bruning at 23. LTC; 31. March 2004]

squeeze
Beam 2
right



Required Actions for Squeeze Generation

- downloading of functions for the collimator jaw motors
  - → what needs to be measured during the adjustment?
  - → can we ´just´ reduce the insertion settings by a given fraction?
- downloading of functions for the insertion region and lattice corrector circuit power converters
  - → power converter ramp round off at transition points
  - → corresponds to a ´stop´ and ´re−start´ of the ramp
    - → time and magnetic field quality?
- online monitoring of key parameters (tune and closed orbit and β^*)
- online correction of key parameters −> feedback for tune + closed orbit

Time Estimate for Squeeze Generation

- maximum power converter ramp rates:

  10 A / sec for corrector quadrupole circuits → 2 min for full swing

  10 A / sec for main 4kA quadrupole circuits

  5 A / sec for main quadrupole circuits near 500A

- maximum power converter ranges during squeeze:

  4.5 K circuits (Q6 IR1 & IR5): 75% of nominal −> 5% of nominal

  1.8 K circuits (Q7 IR1 & IR7): 50% of nominal −> 100% of nominal

  → 1.8K: 5 min for 50% −> 100%; 4.5 K: 4 min for 70% −> 30%

  5 A / sec near 500A → 4.5 K: 3.5 min for 30% −> 5%

→ 5.0 min for β^* > 1m + 3.5 min for β^* = 1m −> 0.55m = 8.5 min / IP

→ plus additional time for ramp round off and collimator adjustments!

Chamonix 2003

- D1 transfer function and triplet alignment have strong effect on closed orbit:
  - → 10 units TF in warm D1 changes closed orbit in triplet by 3σ (4 mm)
  - → 10μm alignment error in Q2 changes CO by 1σ (1.2mm in triplet)

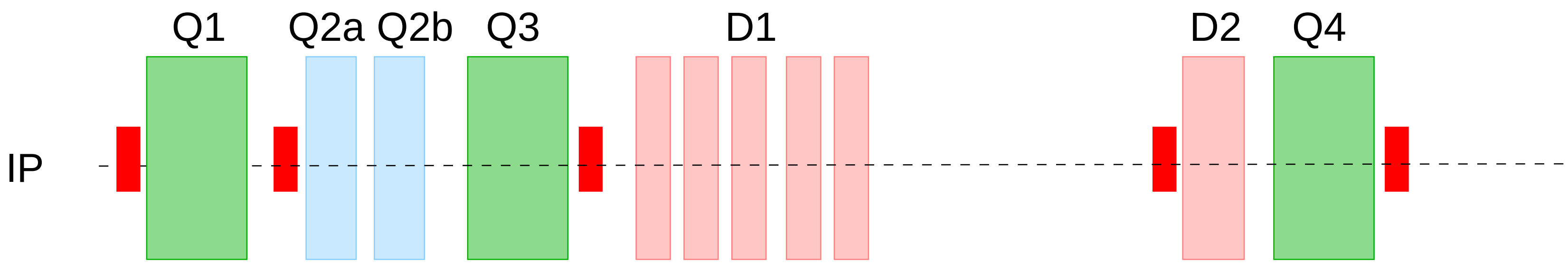
- verify triplet quadrupole alignment (orbit + coupling)

- verify D1 / D2 transfer functions and roll error
  - → correct linear field errors (orbit + coupling)

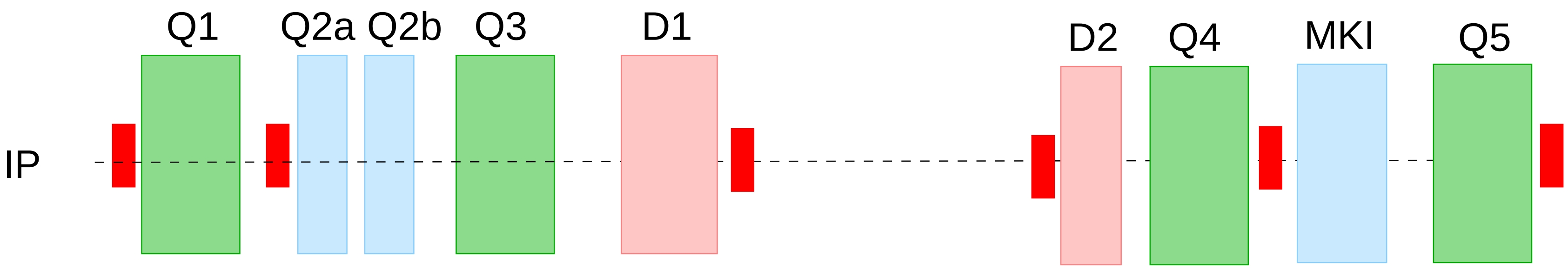
- k−modulation and special alignment optics (at 7 TeV!)

IR BPM Systems

BPM's in IR1 and IR5:

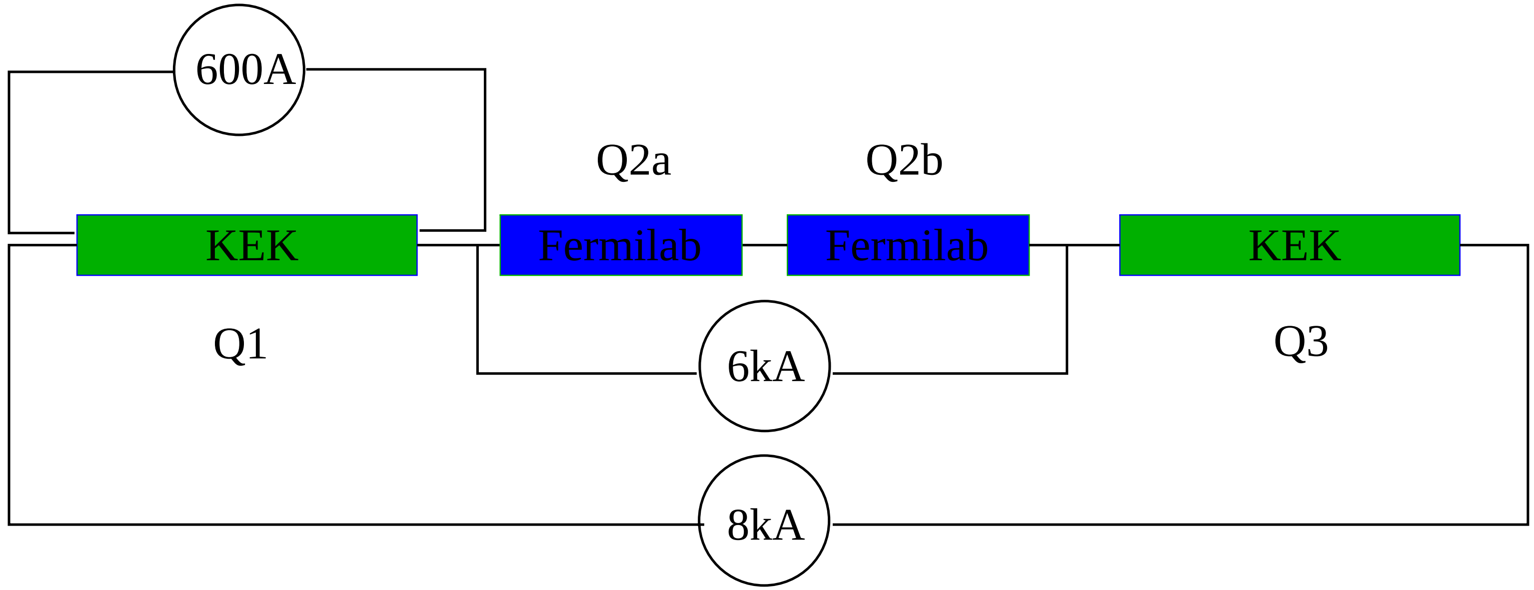


BPM's in IR2 and IR8:



Triplet Powering

- nested power and trim power converter



- possibility for different powering in Q1/Q3 and Q2
- possibility for measuring beta function by modulation of Q1

Questions & Comments for Discussion

- the triplet field error correction is only relevant for $\beta^* < 0.7$ m
- phase advance between triplet left and right = π -> local CO feedback?
- β^*–knob for independent adjustments in Beam 1 and Beam 2

  [Walter Wittmer]
- what is the reproducibility of the TF for 5% powering at top energy?
- how many matched intermediat steps are required?

  → available beam instrumentation and feedback loops?

  → total time for squeeze with smooth transitions and jaw adjustments?

One Scenario for Squeeze Commissioning

- squeeze first one IP at a time without crossing angle:
  - → separate D1 TF error from triplet alignment errors
  - → establish matched intermediate solutions & minimize beta−beat
  - → implement collimator movement for intermediate solutions
- squeeze one IP at a time with crossing angle:
  - → correct closed orbit for each intermediate solution
  - → implement and verify triplet corrector setting ($\beta^* < 0.7$ m)
  - → implement closed orbit feedback during transitions
- minimize the number of intermediate solutions: time!
  - → feedback loops and partial squeeze during ramp?
- establish parallel squeeze in more than one IP: time!