Progress Report on the LHC Optics

The CERN SL Accelerator Group

+ TRIUMF / Canada collaboration (collimation)

+ U.S.A. / LHC collaboration (triplet magnets)

- summary of the LHC optics versions
- changes and developments from V6.0 (MAC6) to V6.4
- open issues for optics V6.4
- ongoing studies for V6

The LHC Optics Versions

- Version 1 (1987):
  - preliminary LHC design based on CERN 87-05 (May 1987)
  - MB, QF and QD powered in series -> true antisymmetry
  - 25 cells per arc -> $Q_x = 70.28$; $Q_y = 70.31$

- Version 2 (1994):
  - 24 cells per arc -> $Q_x = 68.28$; $Q_y = 68.31$

    → strong coupling problem

    → pairs of QS at each end of the arcs

The LHC Optics Versions

- Version 3 (1994):
  - study for dipole length of 15.574 meter -> 21 cells/arc
  - marginal dynamic aperture and mechanical problems

- Version 4 (1995-basis for the 'yellow book' CERN/AC/95-05):
  - crossings only in IR1, IR2, IR5 and IR8 (super-periodicity 1)
  - individual circuits for MQ and MB (but QF and QD still in series)
  - 23 cells per arc -> $Q_x = 63.28$; $Q_y = 63.31$ ($L_{dipole} = 14.2$ meter)
  - dedicated service insertions

The LHC Optics Versions

- Version 5 (1997):
  - optimised injection insertions
  - new dispersion suppressor plus left - right independent powering
  - integer tune split of 4 units: $Q_x = 63.28$; $Q_y = 59.31$
  - independent QF and QD circuits (ring1 and ring2 still coupled)
- Version 6 (1998):
  - L^*: 21 -> 23 meter
  - individualy powered dispersion suppressor quadrupoles
  - symmetric layout of insertion quadrupoles with respect to IP's
  - new correction circuits
  - new integer tune split (5)

The LHC Optics Version 6

- Version 6.0 (already presented at MAC6):
  - spool piece circuits for b_4 ; a_4 and b_5
  - different integer tune splits (4, 5, 7, 9)
  - new L^* : 21 -> 23 meter
  - individualy powered MQ in the dispersion suppressor
  - almost symmetric layout of the quadrupoles wrt the IP
  - Q4 aperture increased (crossing angle)
  - optimised protection for mis-injection in IR2 and IR8

The LHC Optics Version 6

Version 6.1 (1999):

- mixed triplet layout -> nested power converter *
- spectrometer compensation schemes
- new crossing angle scheme *
- second MQS family between Q6 and Q7
- open cryostat between Q4 and Q5 -> TOTEM
- spool piece circuits for b_4 and b_5 at every other MB *
- a_3 lattice corrector magnets *
- proper design for the momentum cleaning insertion

New Triplet Layout

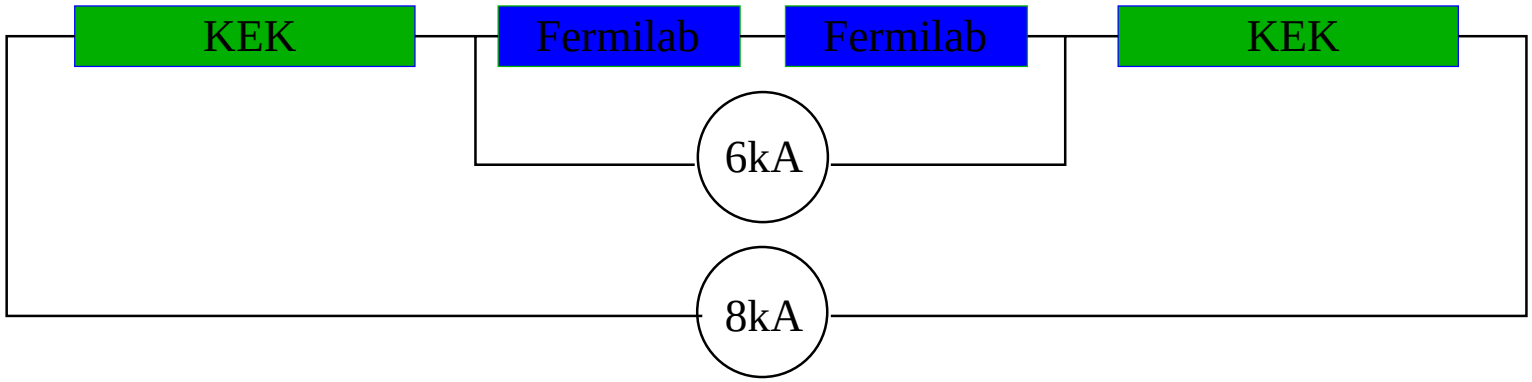
- *a short historic overview:*
  - *large b_{10} in KEK magnets*
    - → *do we need b_{10} correctors?*
    - → *'99 improved MQX design*
  - *quench performance for FNAL magnets*

→ *mixed triplet layout*

→ *optimisation of corrector magnets*

Powering Options

nested power converter:



→ ***no problems with power supply ripple expected***
(20ppm)

→ ***fall back solution with 2 or 3 PC still possible***

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- proper design for the momentum cleaning insertion
- cold Q6 in IR3 and IR7

Nominal Crossing Angle Parameters

W. Herr et al.

LHC Project Report 315

LHC Project Report 367

Insertion	proton - proton				ion - ion (Pb-Pb)			
	β^* [m]	ϕ [rad]	Δ [mm]	L [$cm^{-2} s^{-1}$]	β^* [m]	ϕ [rad]	Δ [mm]	L [$cm^{-2} s^{-1}$]
IR1	0.5	+/- 150 (V)	0.0	10^{34}				
IR2	10.0	+/- 170 (V) +/- 100 (V)	+/-0.17	10^{30}	0.5	+/- 170 (V) +/- 100 (V)	0.0	10^{27}
IR5	0.5	+/- 150 (H)	0.0	10^{34}				
IR8	1 / 35	+/- 150 (H) +/- 285 (H)	0.0	10^{32}				

Nominal Crossing Angle Parameters

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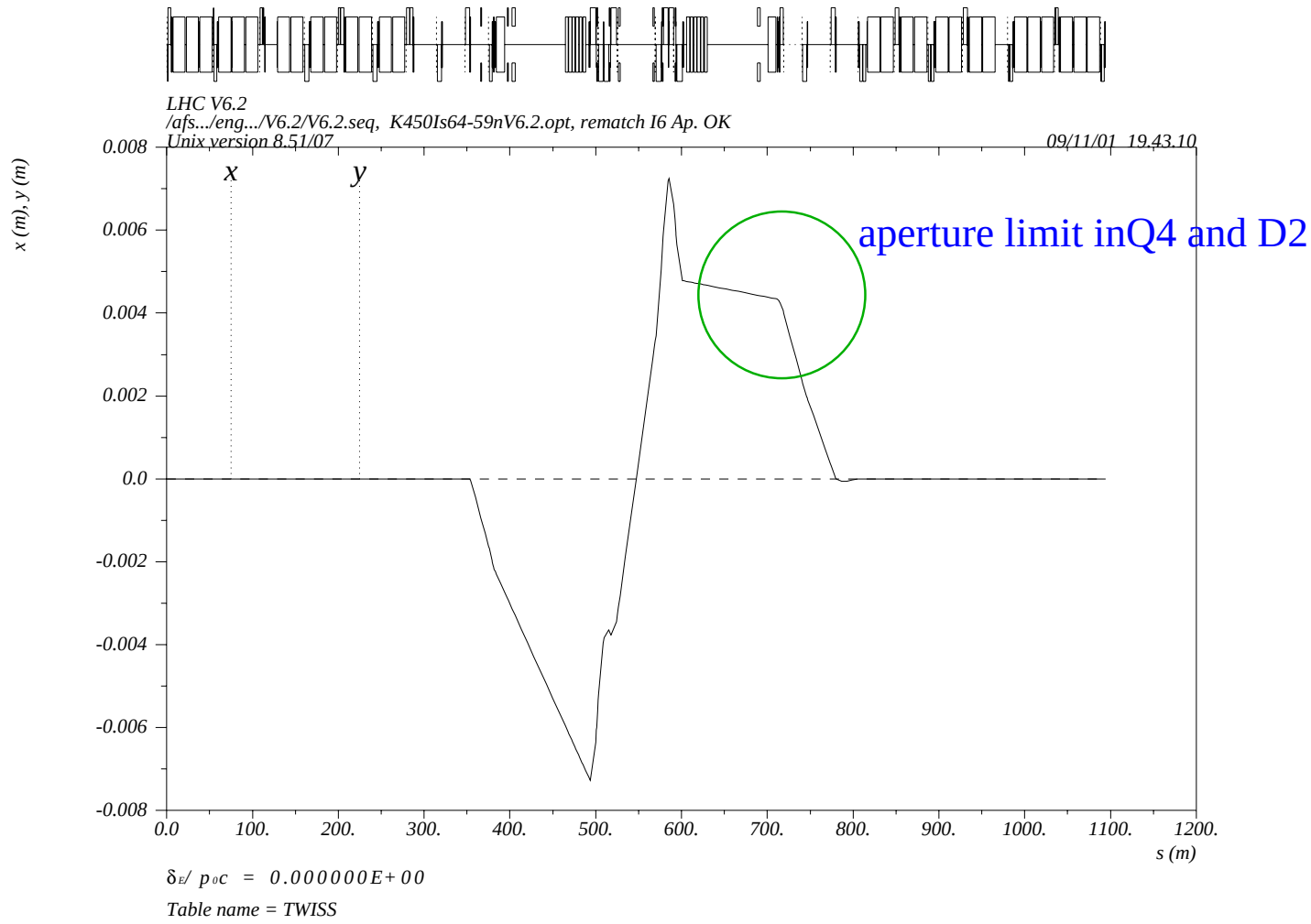
- old crossing angle scheme:
  - separate corrector magnets for Ring1 and Ring2
    - → orbit corrector magnets next to Q4 and Q5
    - → large angles and large bump amplitudes
- new crossing angle scheme:
  - use orbit corrector elements next to Q1
    - → smaller angles and bump amplitudes

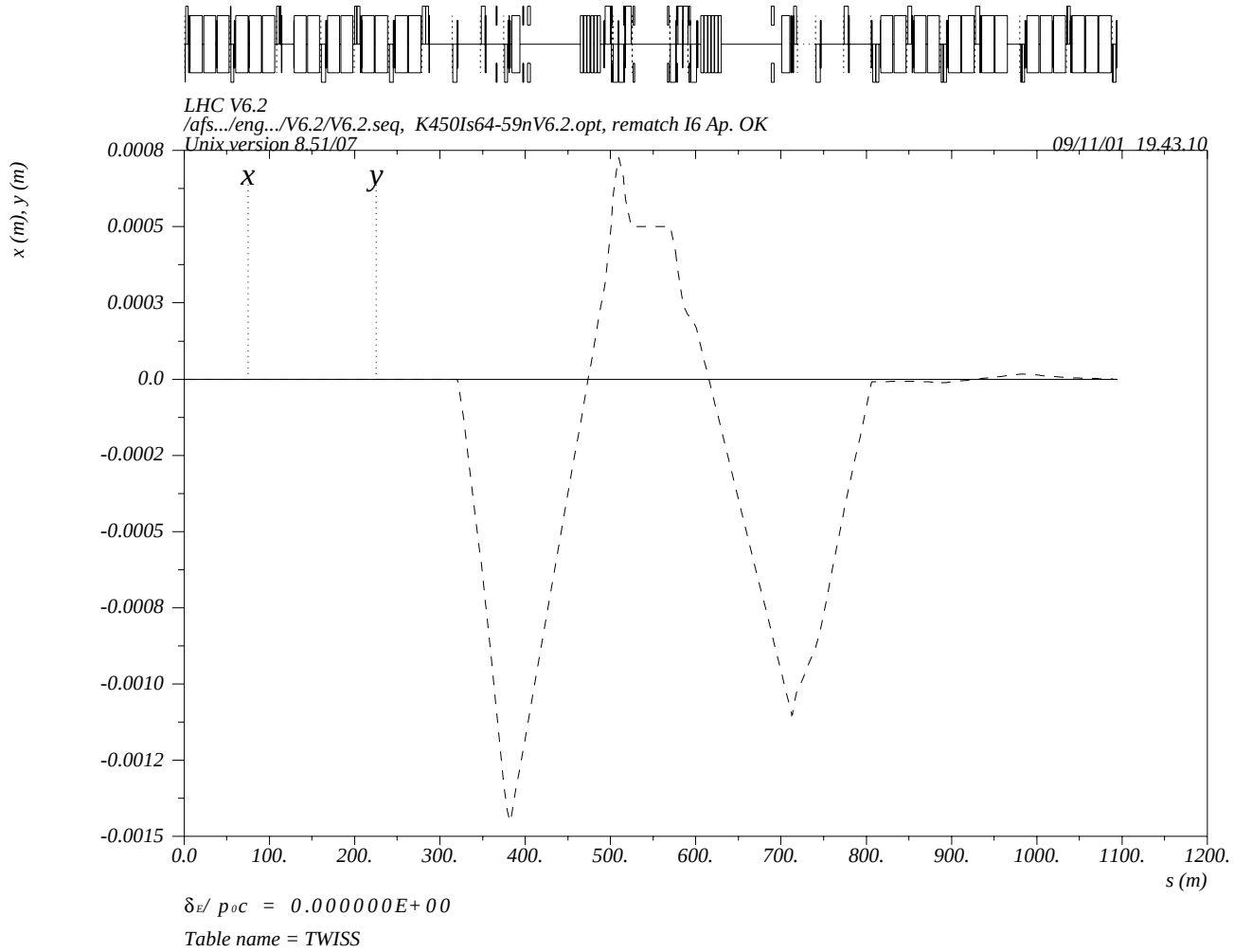
IR5 Crossing Angle Bump

old crossing angle scheme:



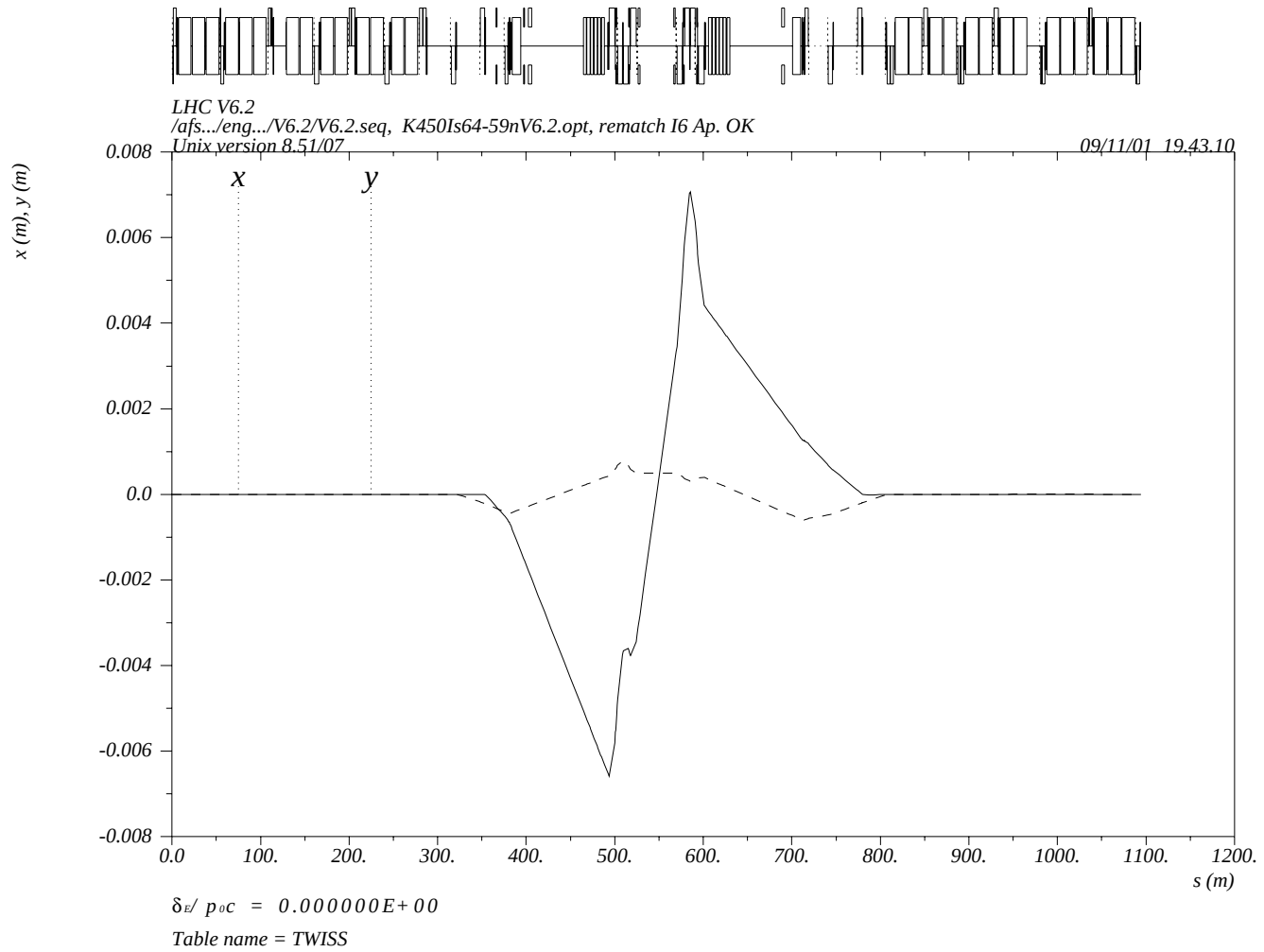
IR5 Crossing Angle Bump

old crossing angle scheme parallel bump:



IR5 Crossing Angle Bump

new crossing angle scheme: 30% + 70%



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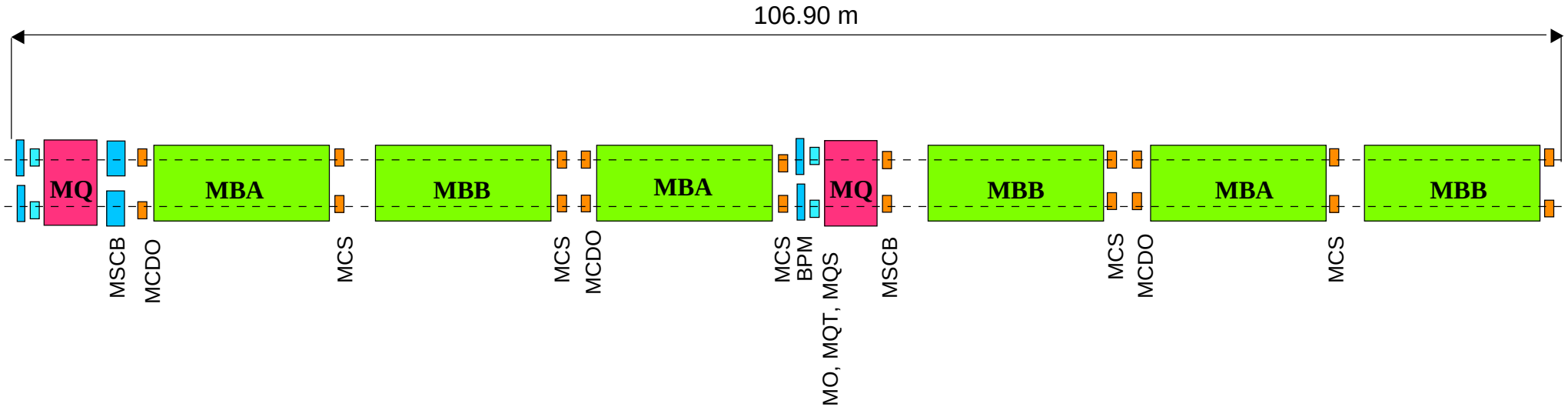
- cold Q6 in IR3 and IR7

Correction Circuits

Schematic layout of one LHC cell (23 periods per arc)



MQT: trim quadrupole

MQS: skew trim quadrupole

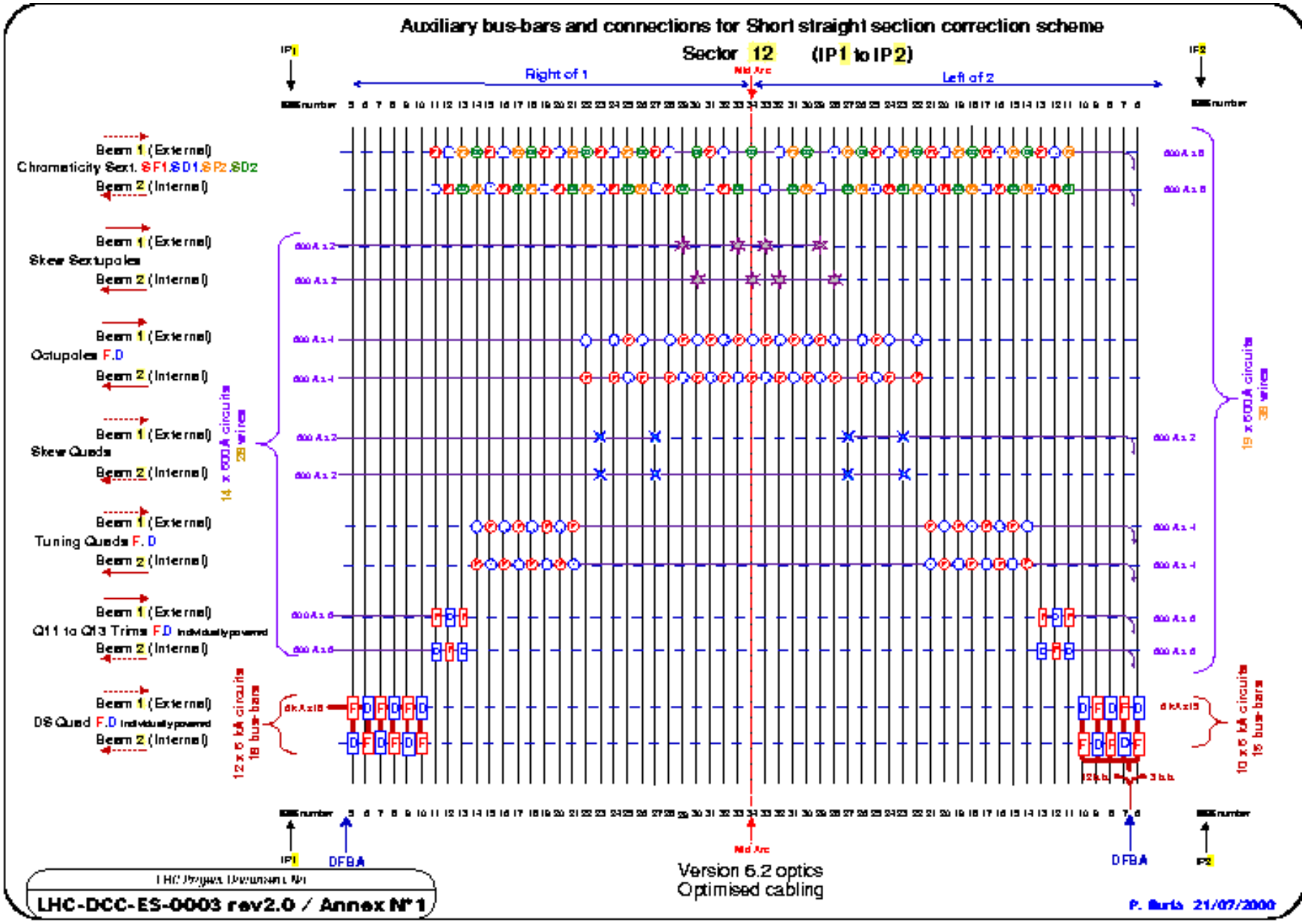
MO: lattice octupole

MSCB: sextupole (skew sextupole) + orbit corrector

MCS: spool piece sextupole

MCDO: spool piece octupole + decapole

Powering of the LHC Correction Circuits

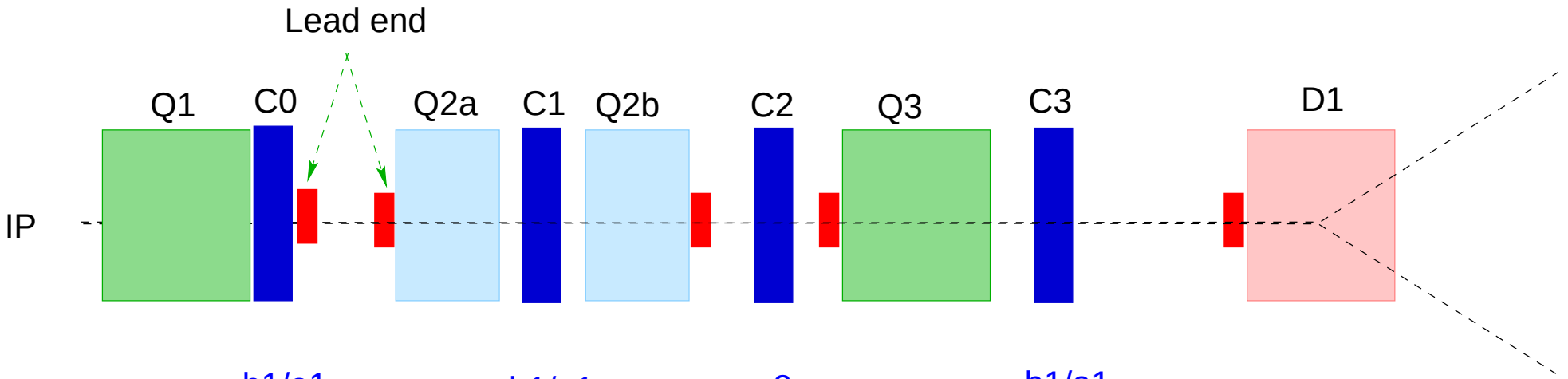


The LHC Optics Version 6

- Version 6.2 (2000):
  - auxiliary collimators next to Q5 and D2 in IR1 and IR5
  - MCBL replaced by MCBC
  - MQT: 110 T/m -> 120 T/m
  - new corrector package for the triplet magnets (smaller random) *
  - new layout and optics including collimators in IR3 and IR7 *
  - new layout of the skew quadrupole correction circuits *
  - shielding infront of D1 and auxilliary collimators in IR2 and IR8 *

Triplet Correction Schemes

- ***two possible schemes:***



b1/a1	b1/a1	a2	b1/a1	
	b4	a3	b3	
	b5	a4	b6	: scheme 1
	a5	a6		
		a3	b3	
		b4	b6	: scheme 2
		a4		

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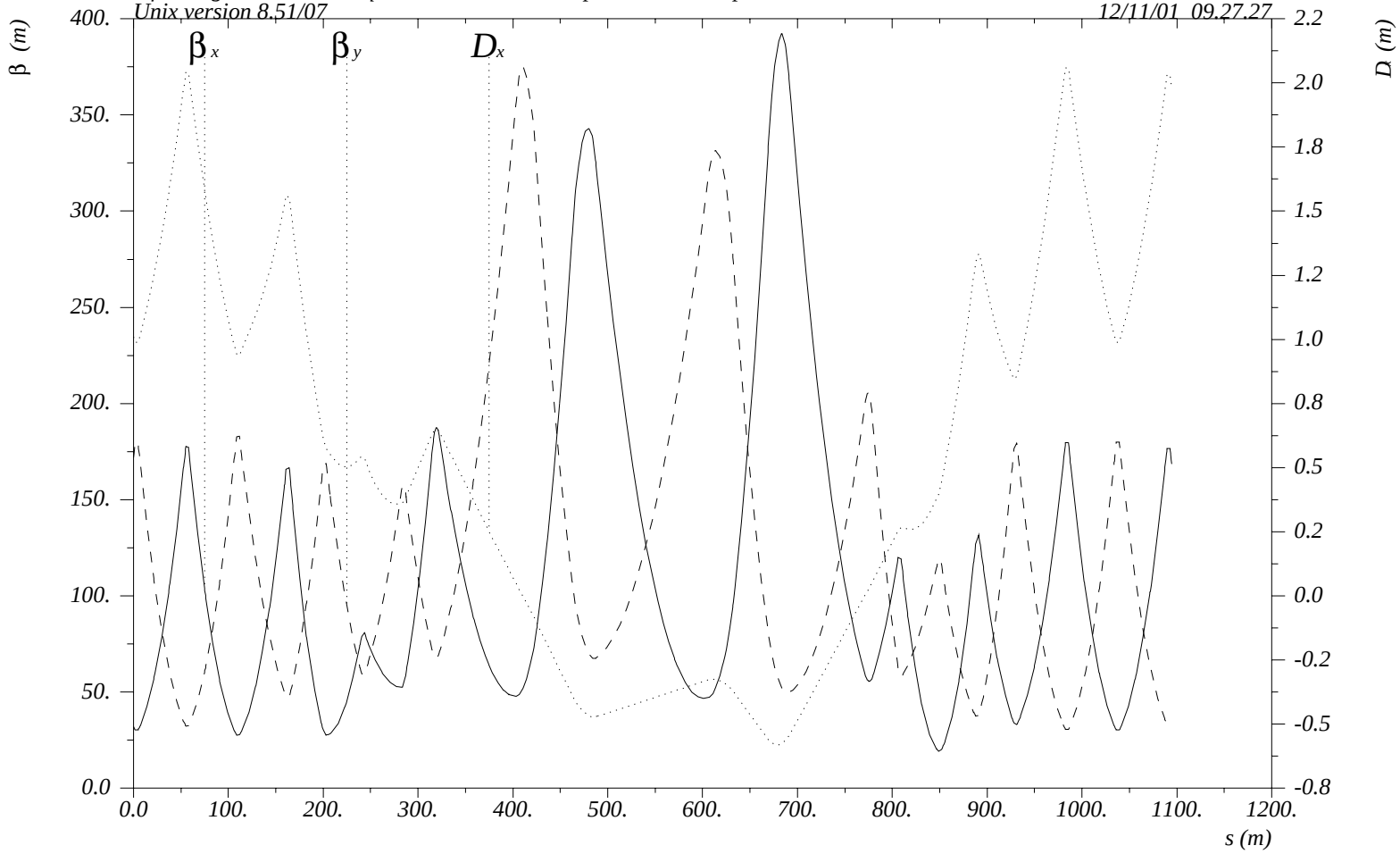
β-cleaning in IR7: Optics for Ring1

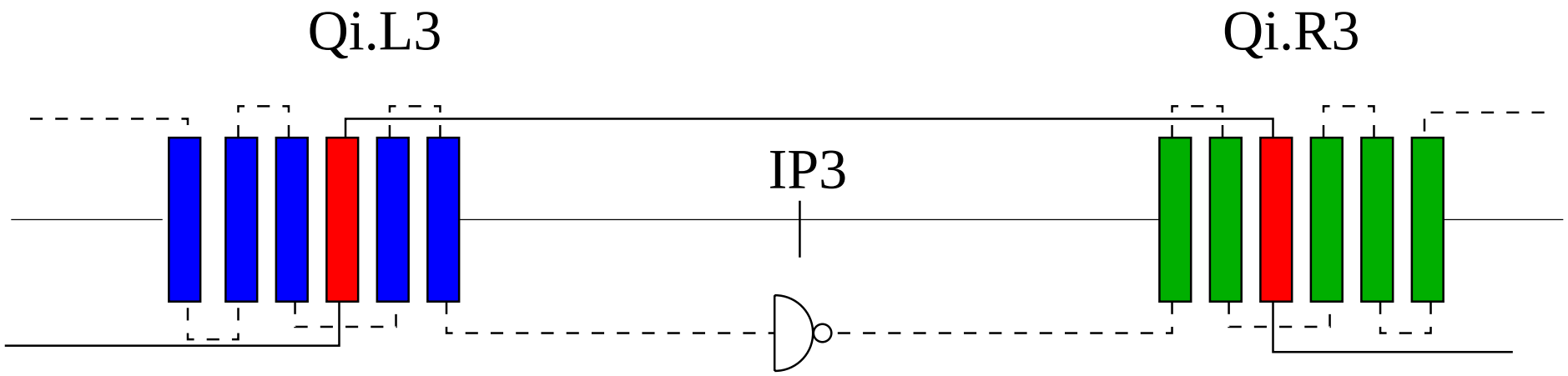
Dobrin Kaltchev
Bernard Jeanneret



Momentum Cleaning in IR3

requires large $D_x / \sqrt{\beta_x}$ at the position of primary collimator:

- goal: $D_x / \sqrt{\beta_x} > 0.19 \sqrt{\text{meter}}$
- break the antisymmetry:



Momentum-cleaning in IR3: Ring1

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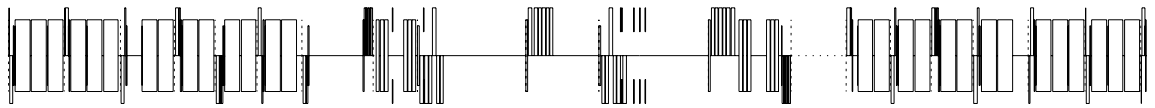

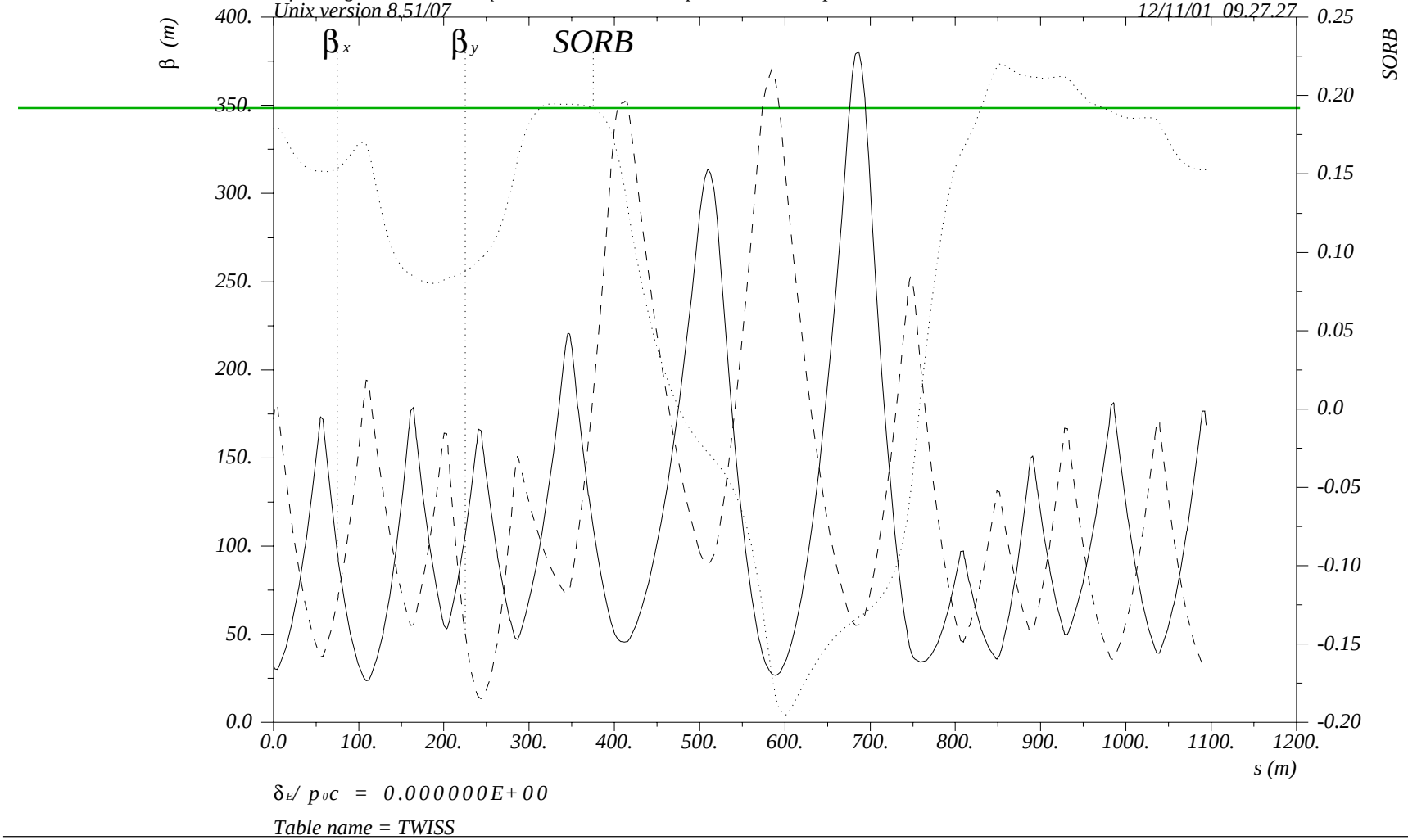

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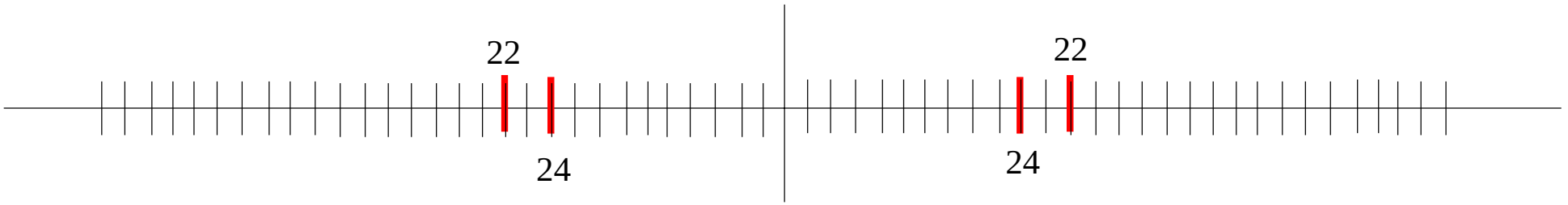
Correction of Systematic Error per ARC

- ***4 skew quadrupole corrector magnets per arc:***



correction of uncertainty → B = 75 T/m

- ***correction of random error requires additional knobs:***
  - powering of different arcs -> depends on integer tune split
  - additional MQS -> V6.1
  - left-right independent powering of the arcs MQS's

Summary QS in IR1 and IR5

- efficiency depends on total tune split

  → O.K. for tune split of 4 and 5

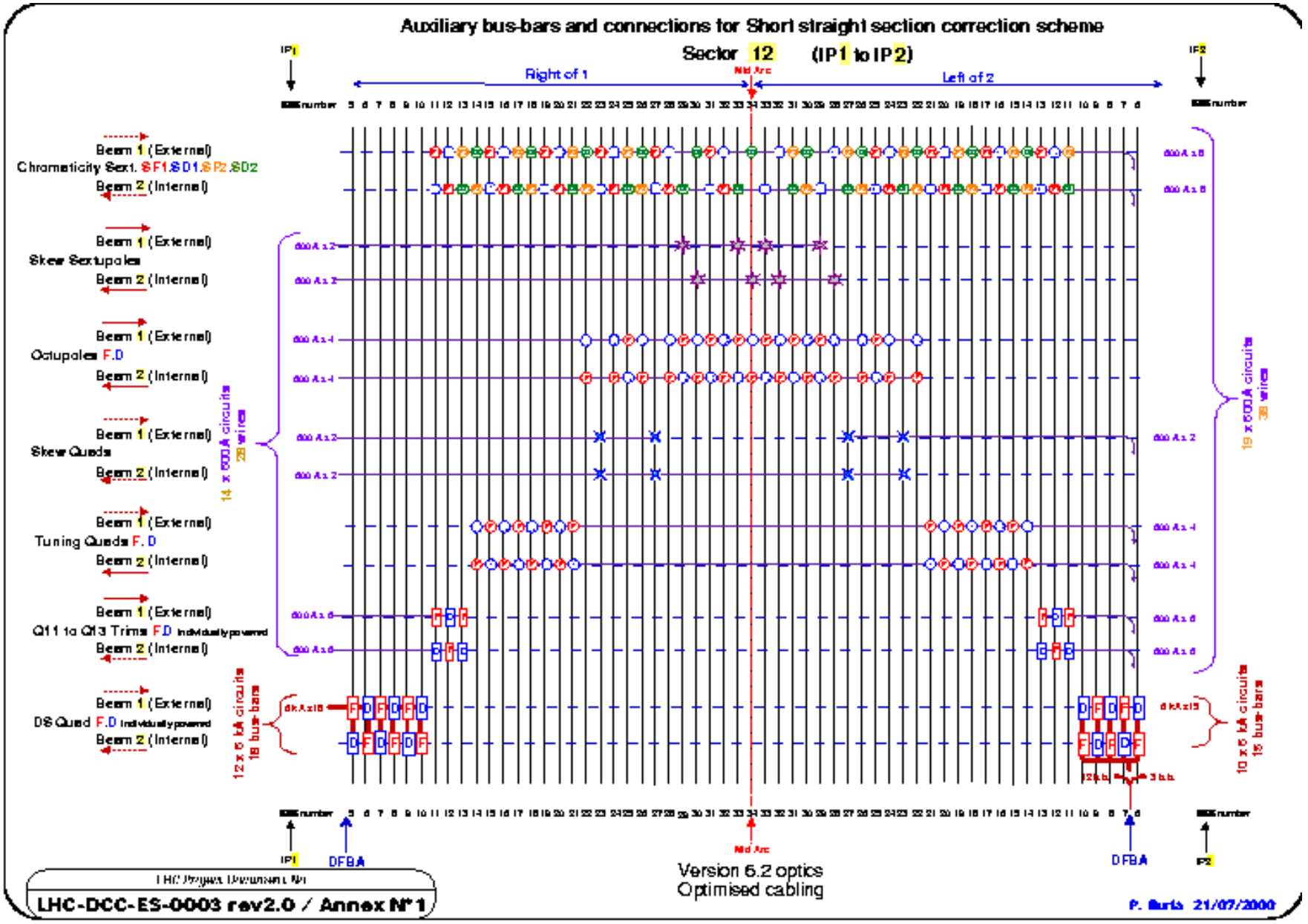
- efficiency depends on phase advance over IR1 / IR5

  → O.K. but asymmetric for version 6

- change between injection and collision optics

  → effect of triplet magnets!

Powering of the LHC Correction Circuits



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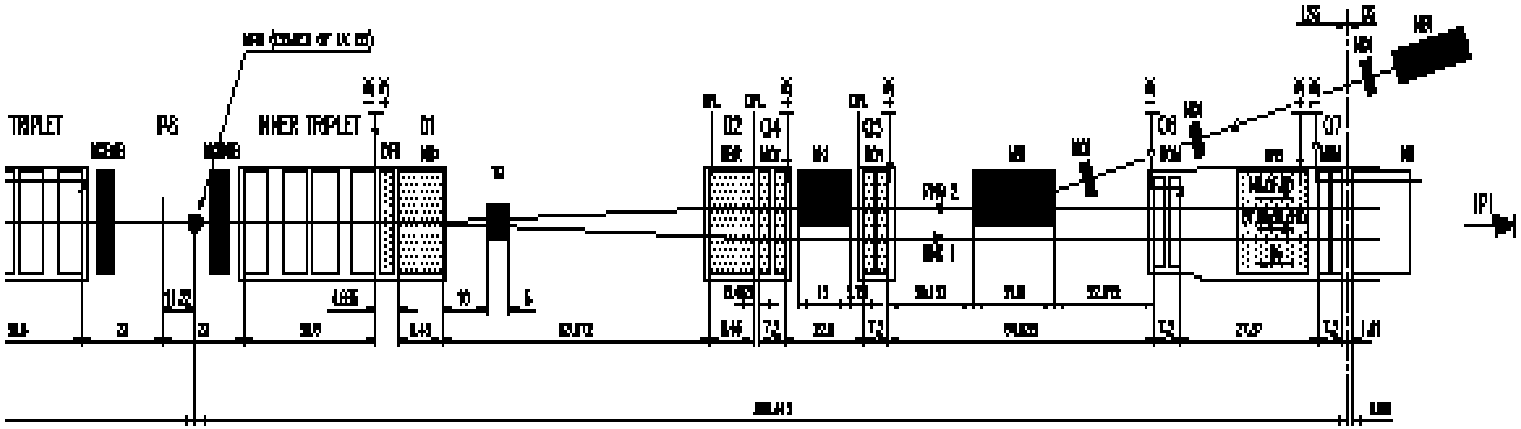
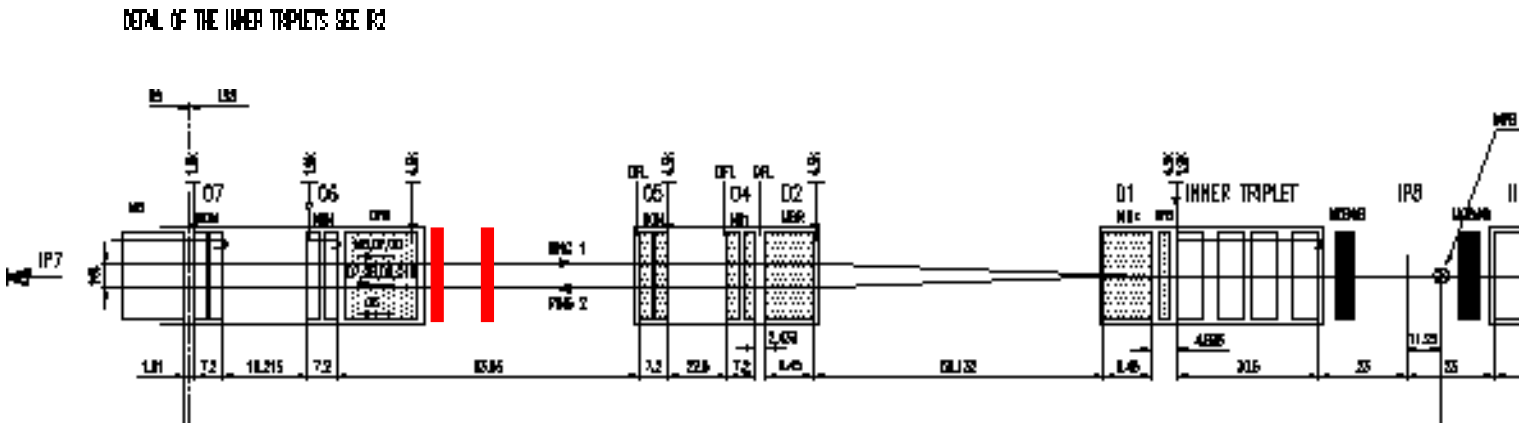
Insertion Region Layout

- **Right from IP8:**

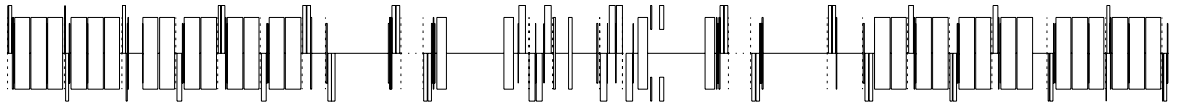


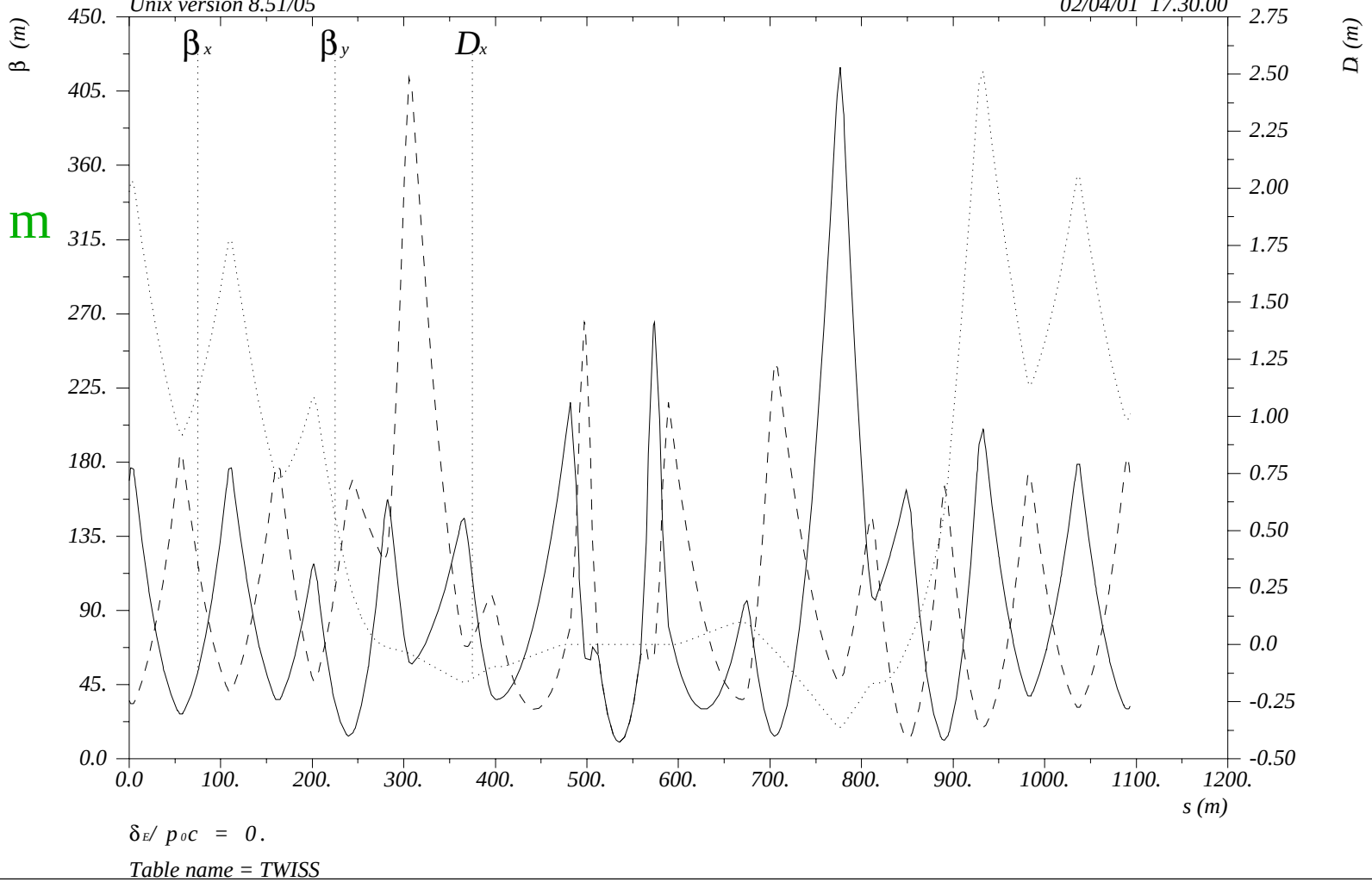
- **Left fron**



Injection optics for Ring1

$\beta^* = 10$ m

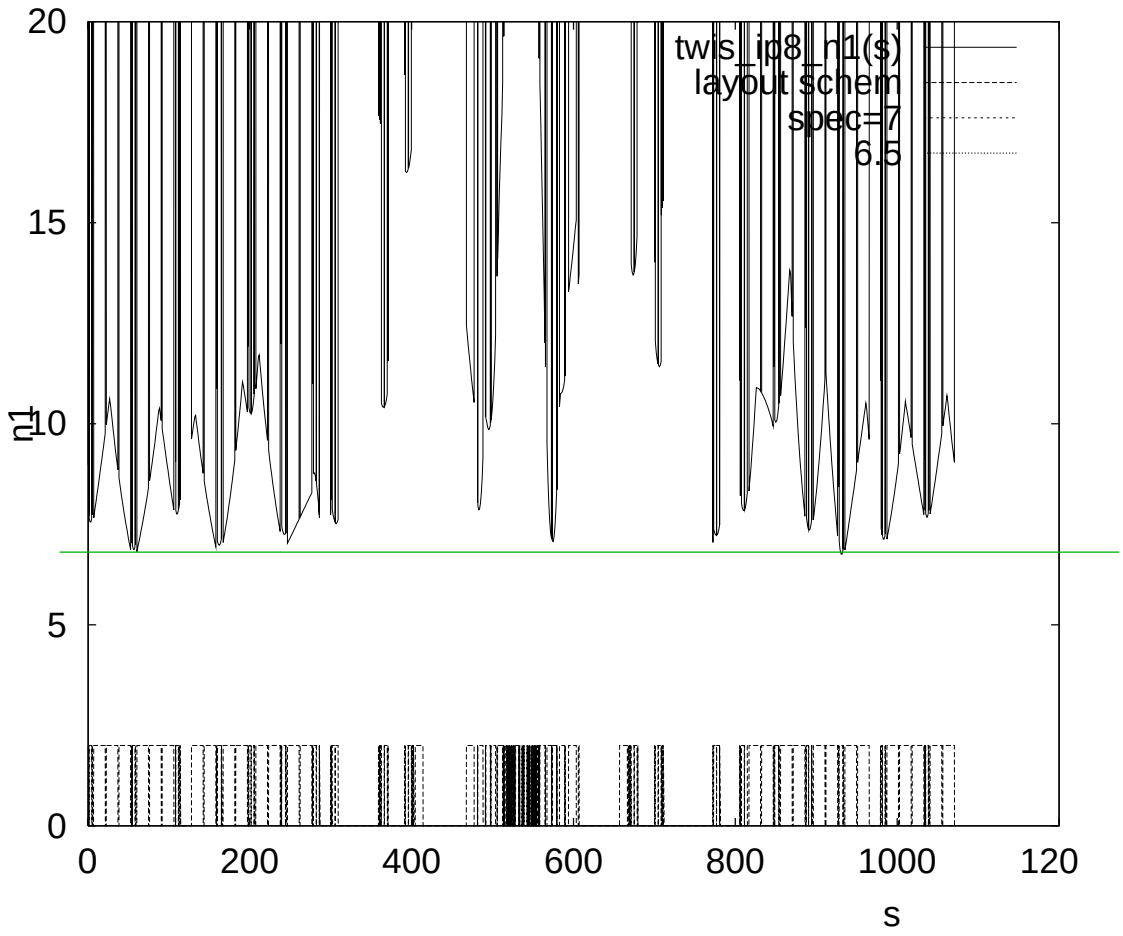




IR8 Optics Parameter

- +/– 150μrad crossing angle and +/- 2mm parallel separation:

aperture at injection



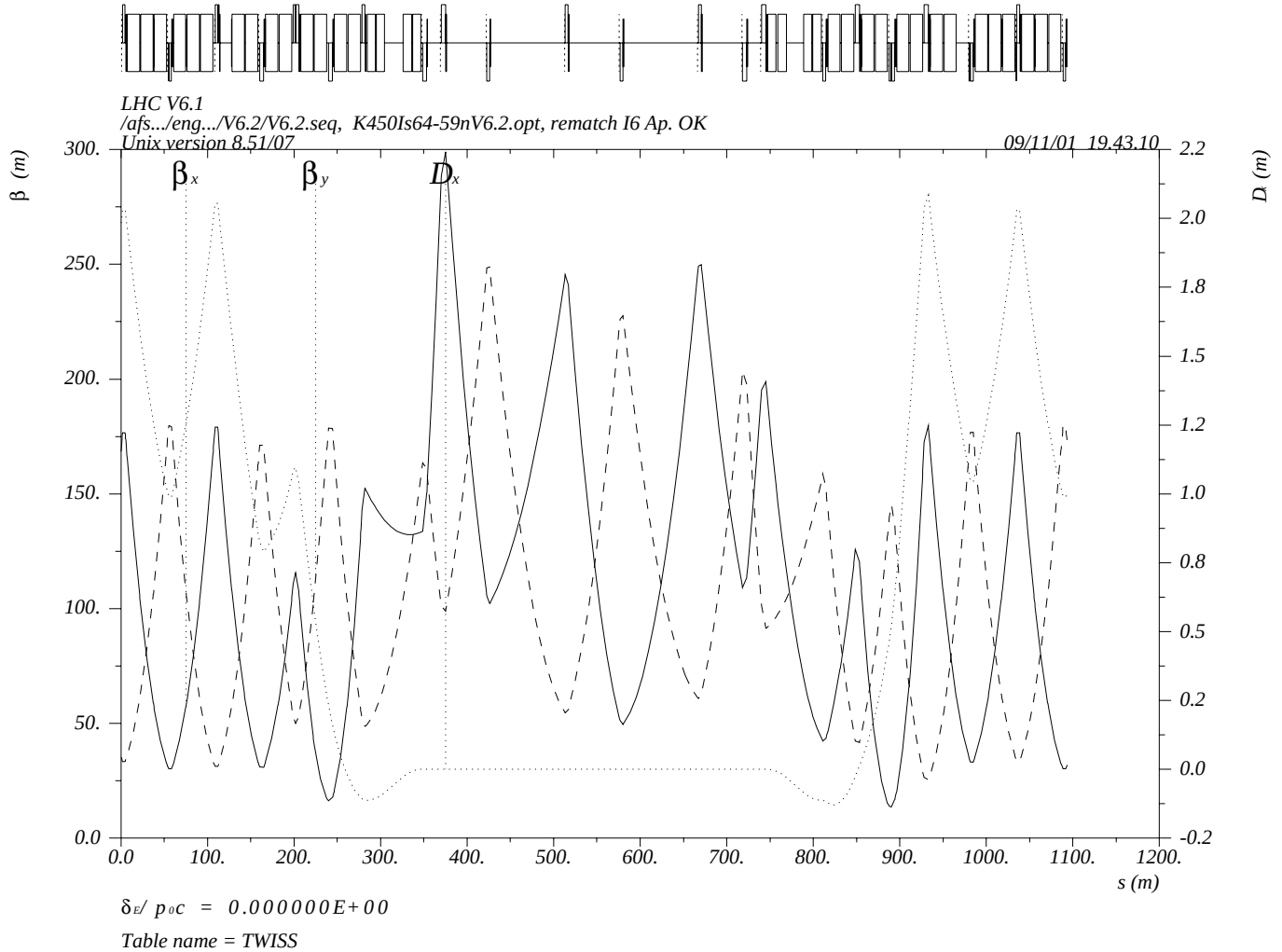
The LHC Optics Version 6

- Version 6.3 (2001):
  - new layout of C11R: MQTL moves to the right of Q11
  - additional MQTL module in Q6 of IR3 and IR7
  - new magnet distance between Q6 and Q7
  - warm BPM at Q1
- Version 6.4 (2002):
  - new layout and optics in IR4 *

IR4 Modifications for V6.4

A. Verdier

- old optics:



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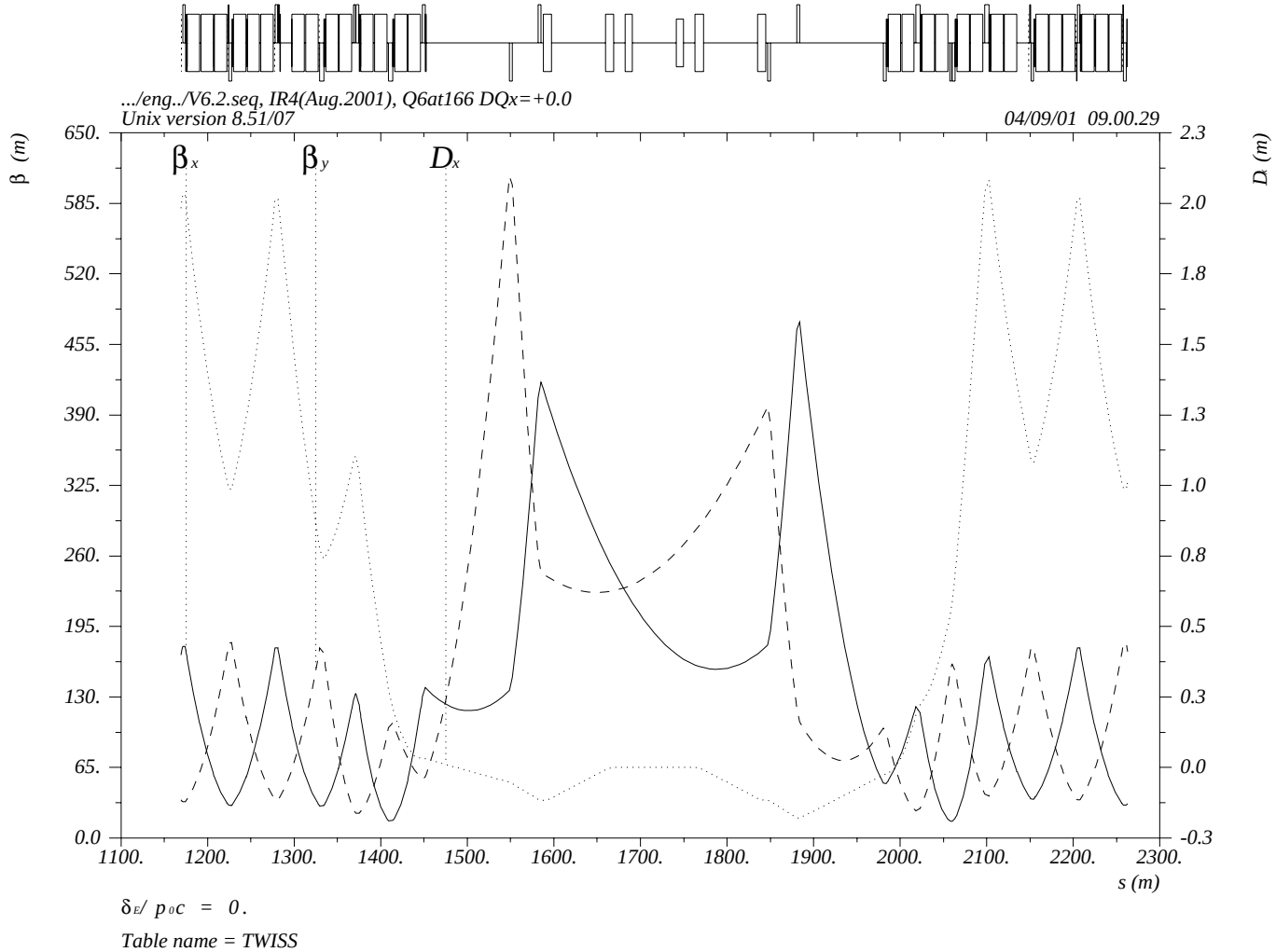

IR4 Modifications for V6.4

summary:

- standardised dogleg magnets
- economise half dogleg magnets
- supress quads with special bore distance
- economise 4 insertion quadrupoles
- maintain tuneability of: $\Delta\mu = +/- 0.15$

Summary V6.4

- optics available for wide range of configurations:
  - IR1 / IR5: $\beta^* = 0.25 <\!\!-\!\!> 18$meter
  - IR2: $\beta^* = 0.5 <\!\!-\!\!> 50$ meter
  - IR8: $\beta^* = 1.0 <\!\!-\!\!> 50$ meter
- all sequence and optics files are maintained for both rings
  - modified MAD version (since V6.1)
  - aperture evaluation + tuneability analysis for both rings
  - maintain tuneability of: $\Delta\mu = +/- 0.12$ in IR1 / IR5

    $\Delta\mu = +/- 0.15$ in IR4

    $\Delta\mu = +/- 0.10$ in IR6

Open Issues for V6.4

- gradient of Q7 in IR1 / IR5
- do we need a4 corrector spool pieces?

  → alignment strategy in the tunnel?

- concept of uncertainty versus installation procedure
- DA with beam-beam and linear imperfections
- collimation efficiency with time dependent effects
- aperture in the long straight sections (beam screen)