

# HiLumi LHC

FP7 High Luminosity Large Hadron Collider Design Study

## Presentation

# Transition between injection optics and collision optics (including ATS squeeze)

Korostelev, M (CERN)

14 November 2013



The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

This work is part of HiLumi LHC Work Package 2: **Accelerator Physics & Performance**.

The electronic version of this HiLumi LHC Publication is available via the HiLumi LHC web site <<http://hilumilhc.web.cern.ch>> or on the CERN Document Server at the following URL: <<http://cds.cern.ch/search?p=CERN-ACC-SLIDES-2014-0084>>

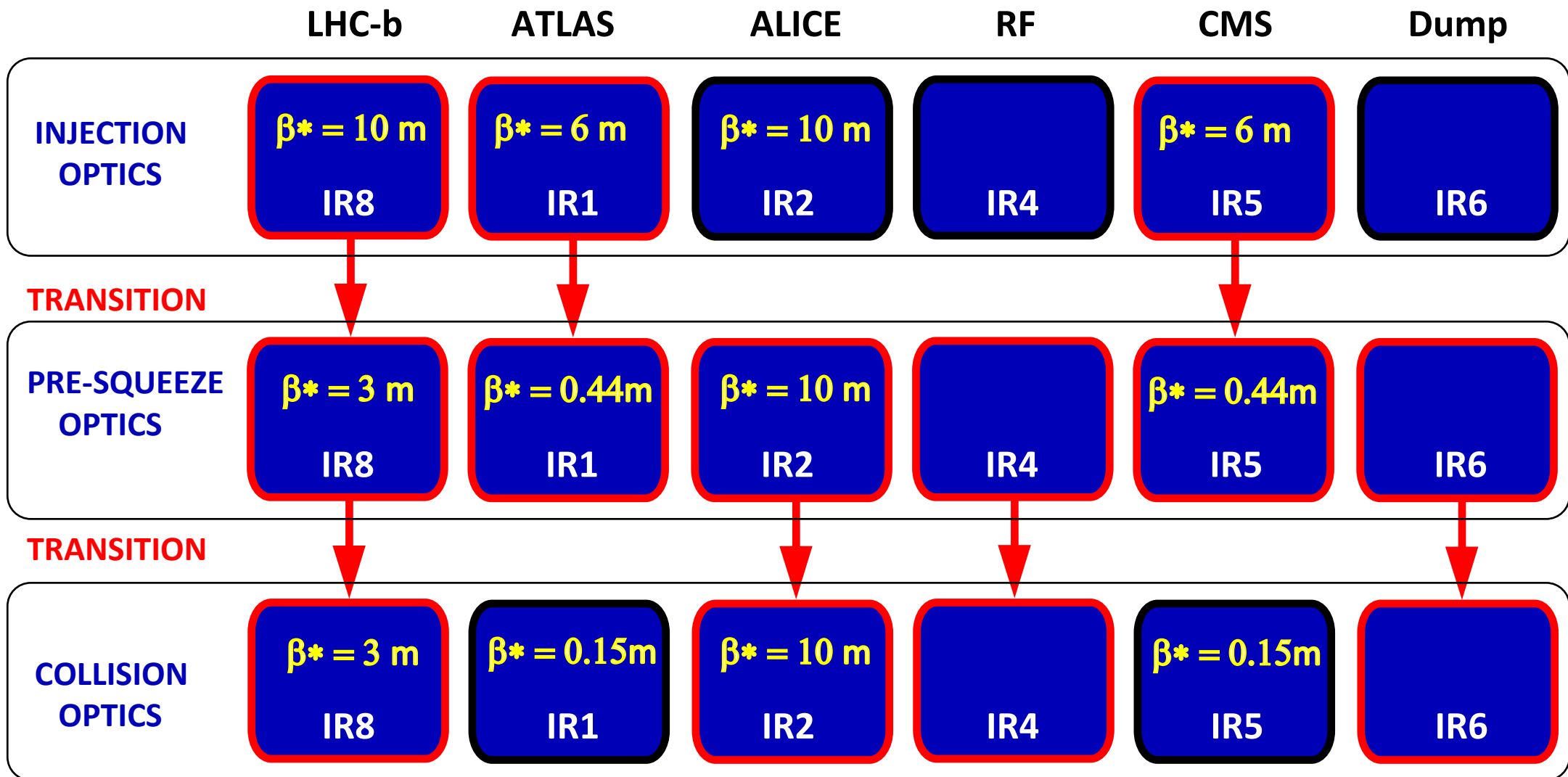
# Transition between injection optics and collision optics (including ATS squeeze)

Maxim Korostelev

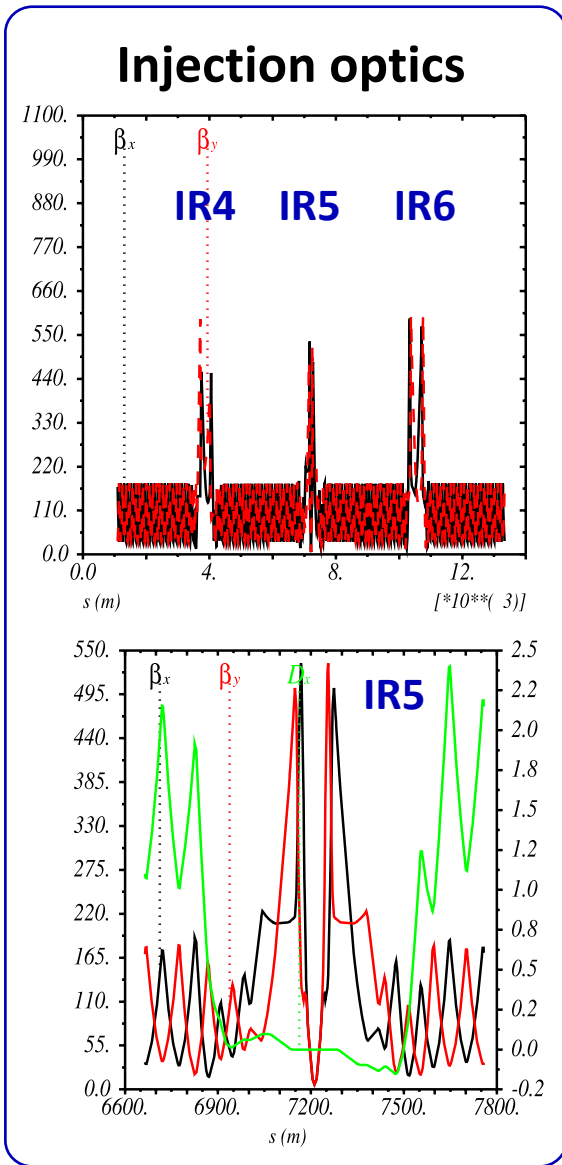
*University of Liverpool and the Cockcroft Institute*



# Optics transition from injection to collision optics with round proton beams at IPs

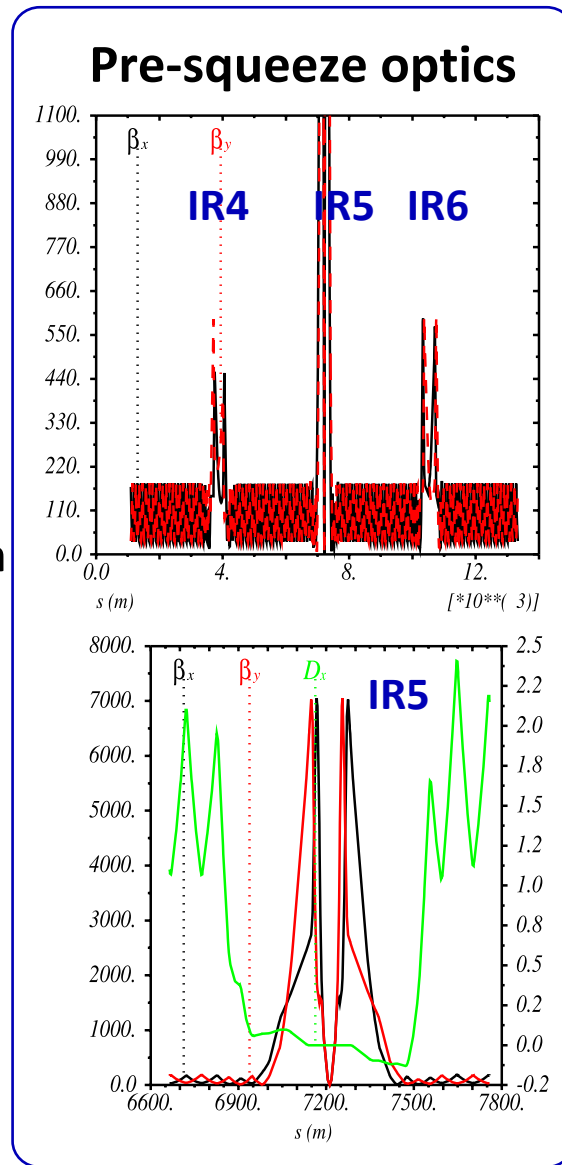


# Achromatic Telescopic Squeeze (ATS)



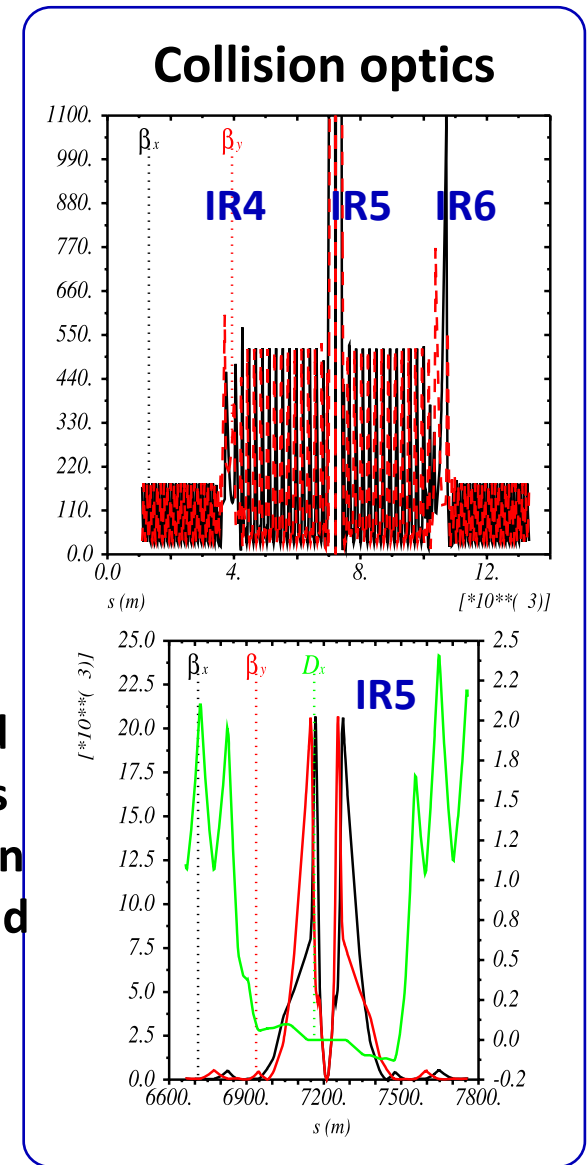
$$\beta_{x,y}^* = 6 \text{ m at IP5}$$

Optics  
Transition  
in IR5



$$\beta_{x,y}^* = 0.44 \text{ m at IP5}$$

ATS  
squeeze  
of IR5  
provided  
by optics  
transition  
in IR4 and  
IR6

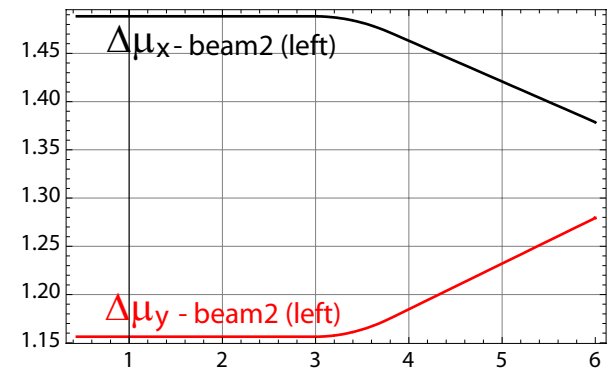
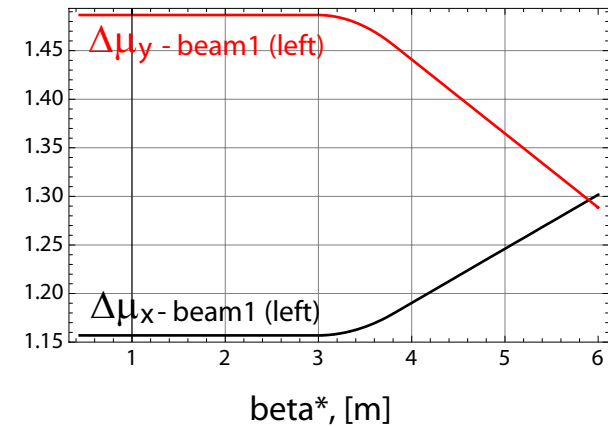
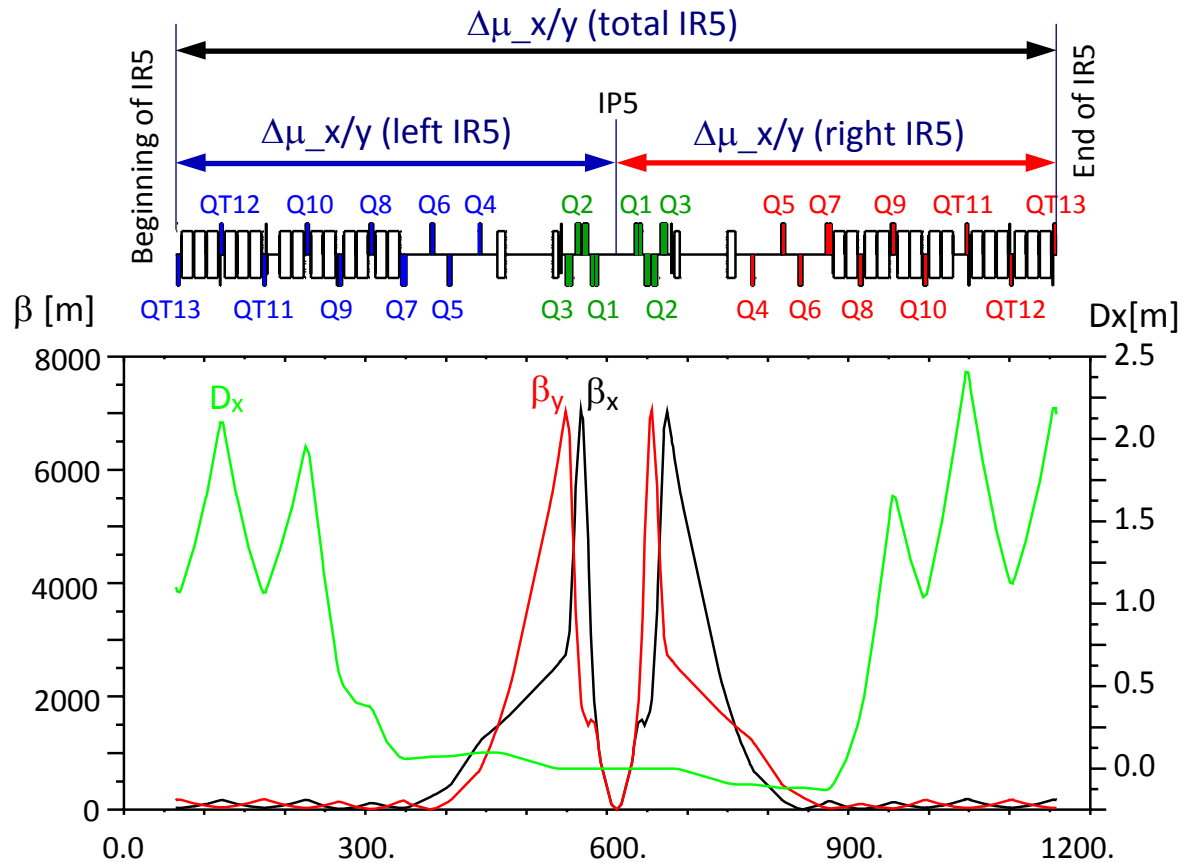


$$\beta_{x,y}^* = 0.15 \text{ m at IP5}$$

# Requirements during optics transition

- Twiss parameters throughout the IRs involved in the transition.
- Specified values for the phase advances over IRs.
- Specified minimum and maximum strengths of the quadrupoles.
- Variation of the quadrupole strengths should be as smooth as possible, especially for the strongest quadrupoles.
- Avoiding changes of slope of field gradient as much as possible.

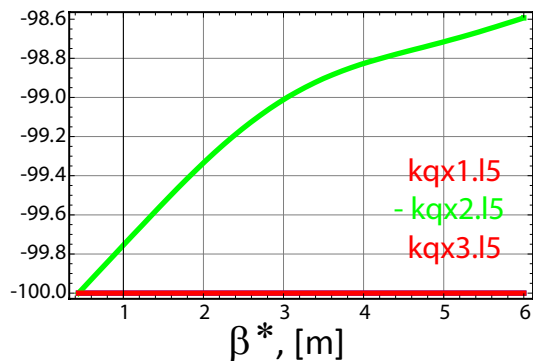
# IR5 matching conditions



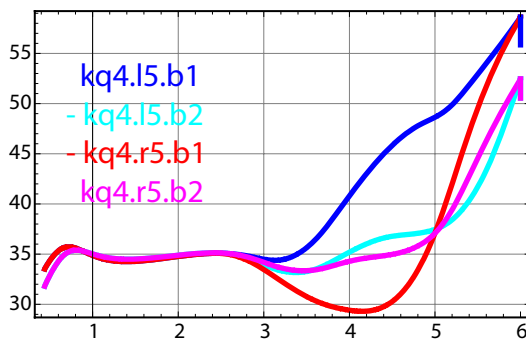
- Twiss parameters at the beginning and at the end of IR5
- Twiss parameters at the IP5:  $\alpha_{x/y} = 0$ ,  $D_x = 0$ ,  $D'_x = 0$
- Fixed horizontal and vertical phase advance  $\Delta\mu_{x/y}$  (total IR5) during the optics transition
- Fixed horizontal and vertical phase advance  $\Delta\mu_{x/y}$  (left IR5) between the beginning of IR5 and IP5 in the range of  $\beta^*$  from 3.2 m to 0.44m

# IR5 optics transition

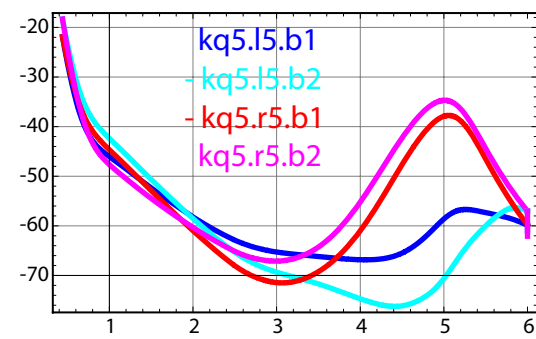
Q1, Q2, Q3, [% of 140 T/m]



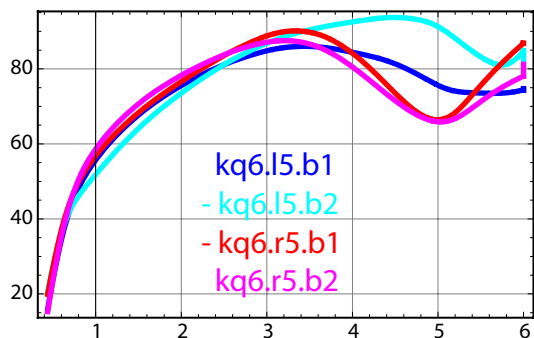
Q4, [% of 125 T/m]



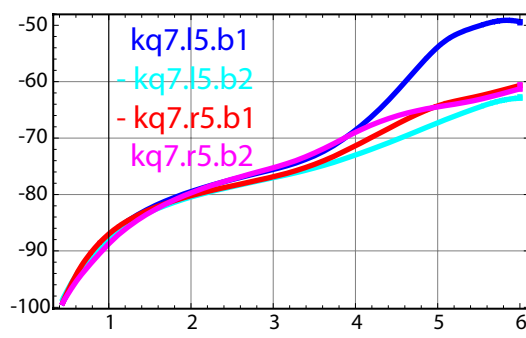
Q5, [% of 160 T/m]



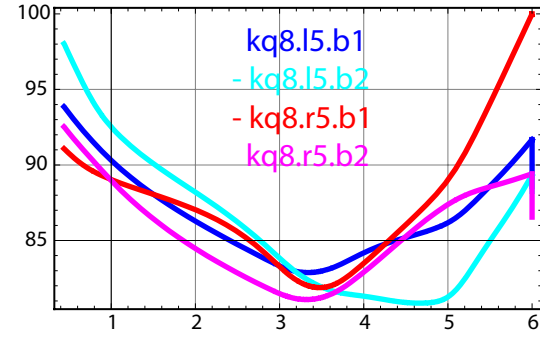
Q6, [% of 160 T/m]



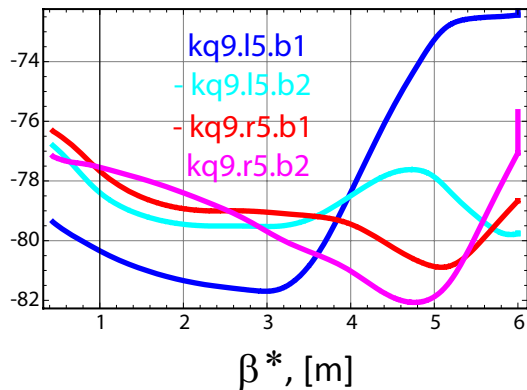
Q7, [% of 200 T/m]



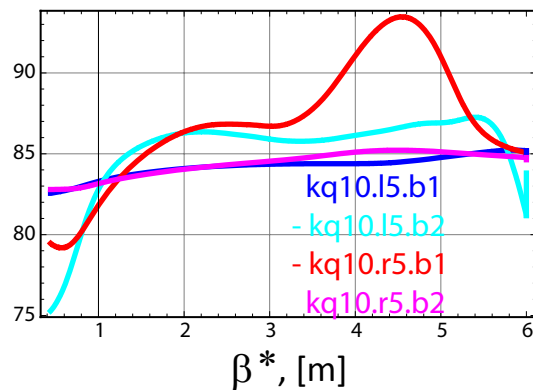
Q8, [% of 200 T/m]



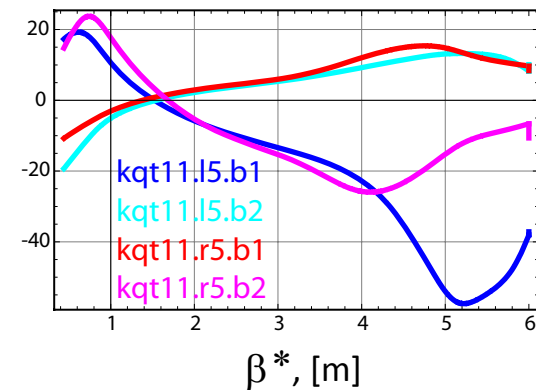
Q9, [% of 200 T/m]



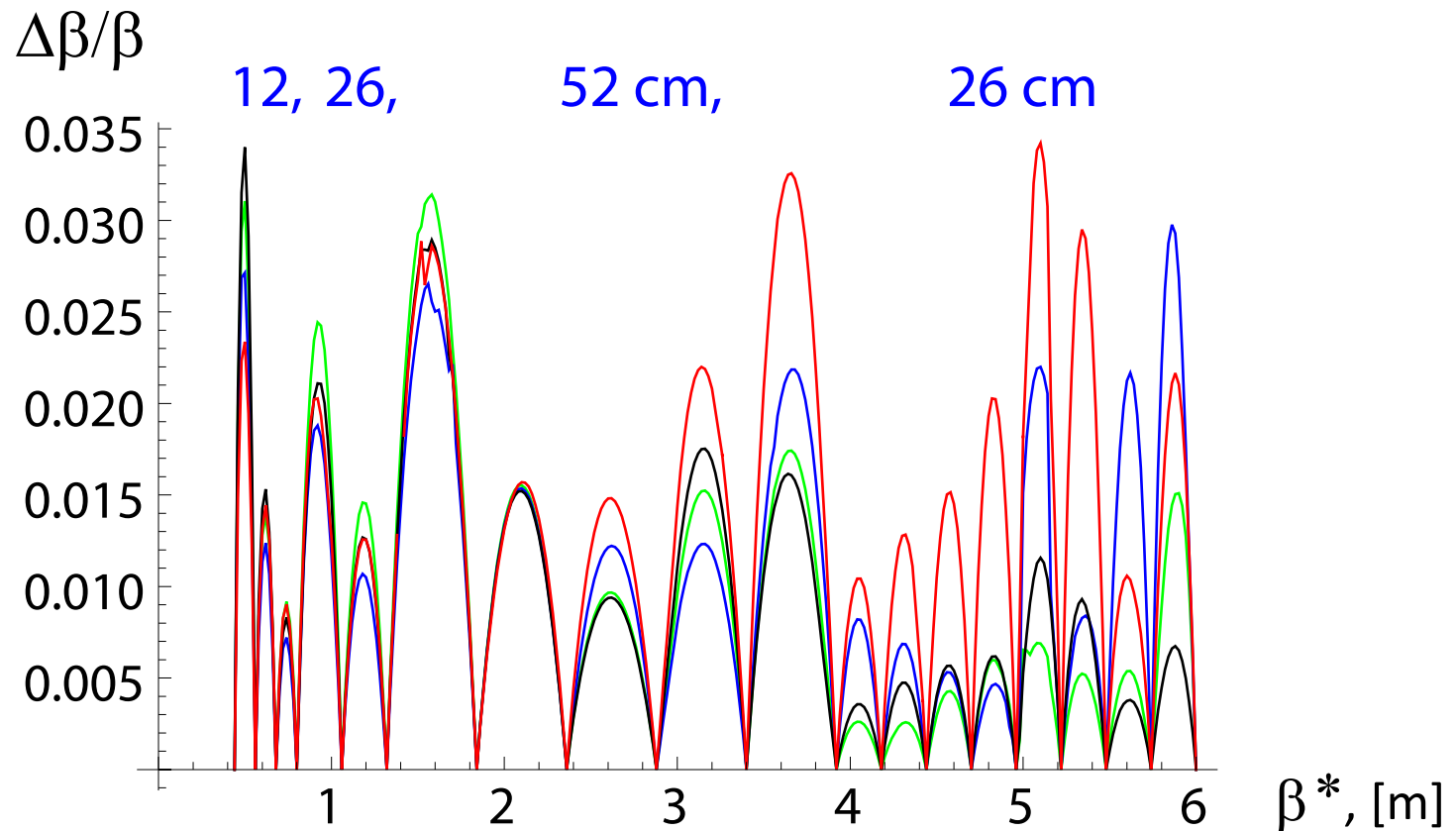
Q10, [% of 200 T/m]



QT11, [% of 125 T/m]



# Beta-beating



The maximum beta-beating can be kept below 3.5% by making linear interpolations of the optics transition as follows:

steps of 26 cm from  $\beta^* = 6$  m to  $\beta^* = 3.92$  m;  
steps of 52 cm from  $\beta^* = 3.92$  m to  $\beta^* = 1.32$  m;  
steps of 26 cm from  $\beta^* = 1.32$  m to  $\beta^* = 0.8$  m;  
steps of 12 cm from  $\beta^* = 0.8$  m to  $\beta^* = 0.44$  m.



# IR4 matching conditions

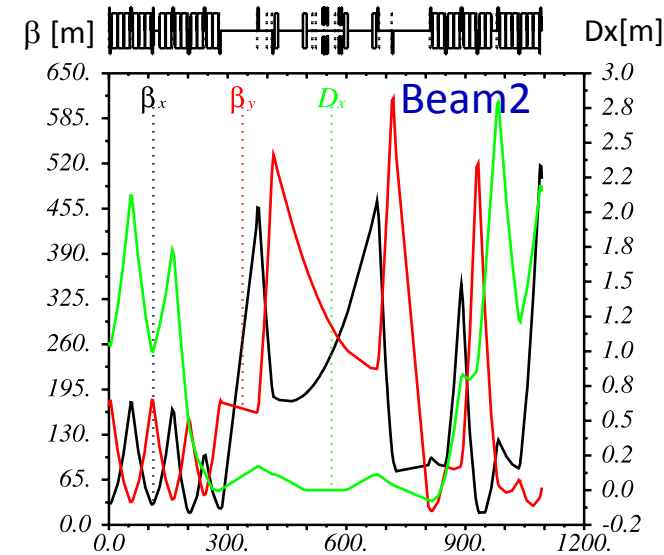
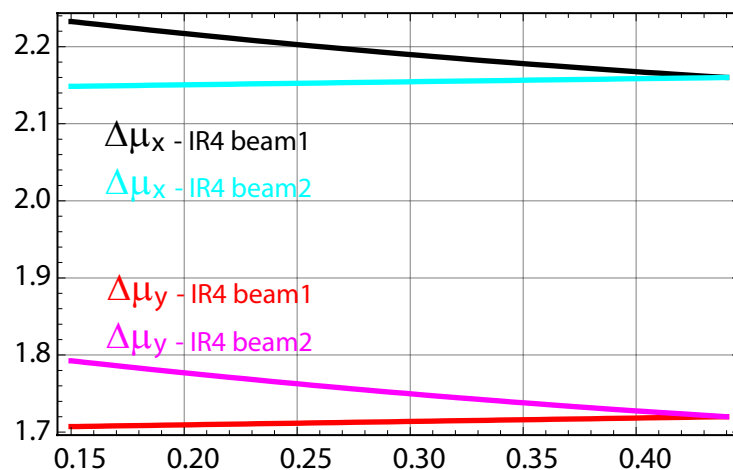
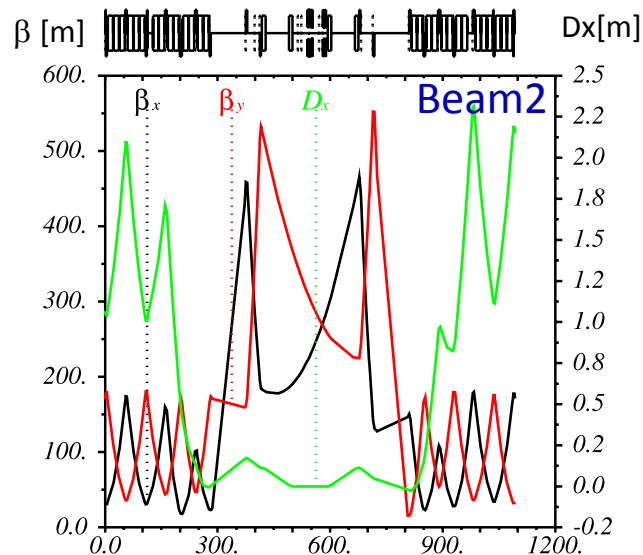
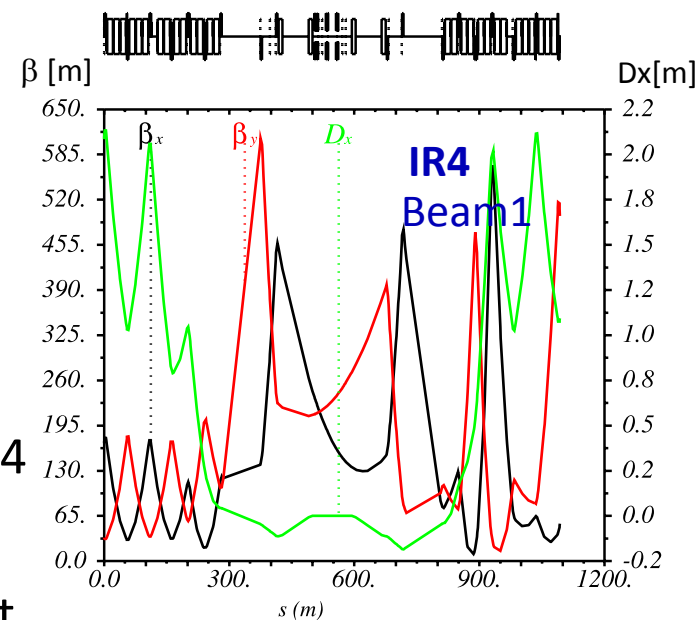
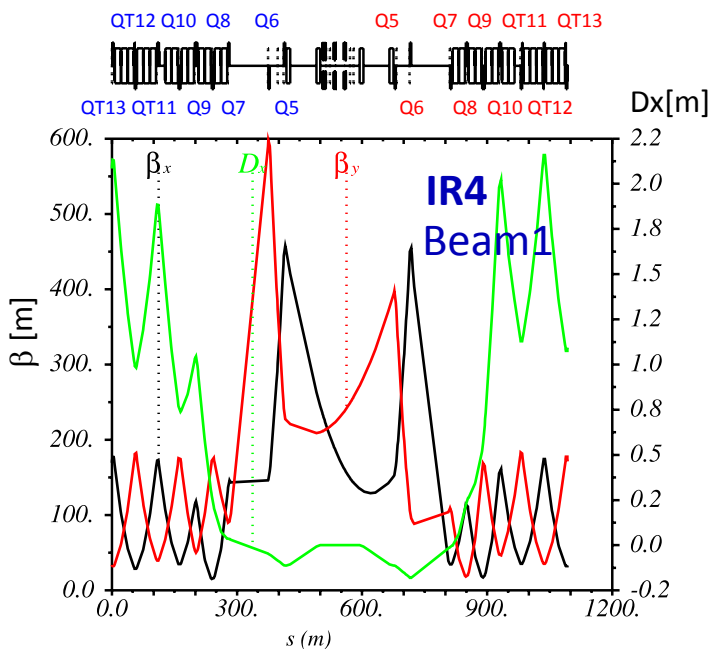
## Constraints for Beam1 and Beam2:

Twiss parameters at the end of IR4 as a function of beta\* at IP5 during the optics transition

Fixed Twiss parameters at the beginning of IR4

Fixed Twiss parameters at the IP4

Horizontal and vertical phase advance as a function of beta\* at IP5 during the optics transition



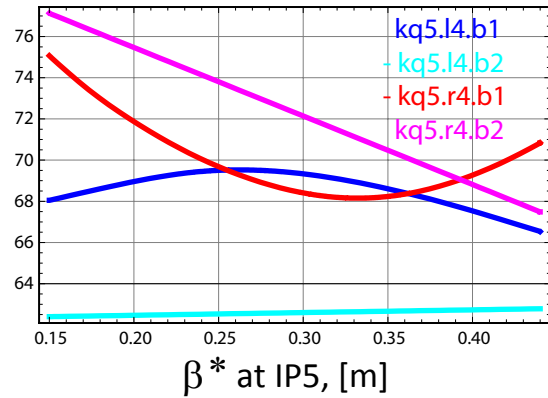
pre-squeeze optics

beta\* at IP5, [m]

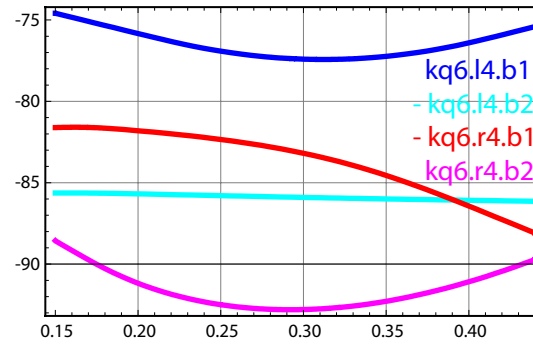
collision optics

# IR4 optics transition

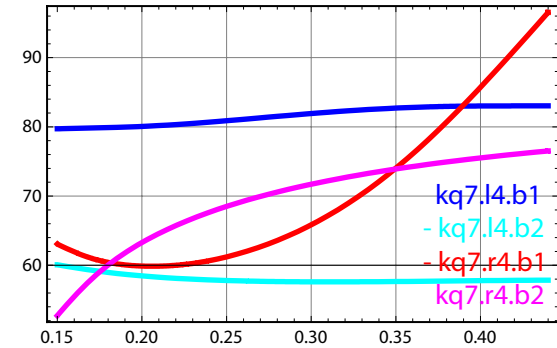
Q5, [% of 160 T/m]



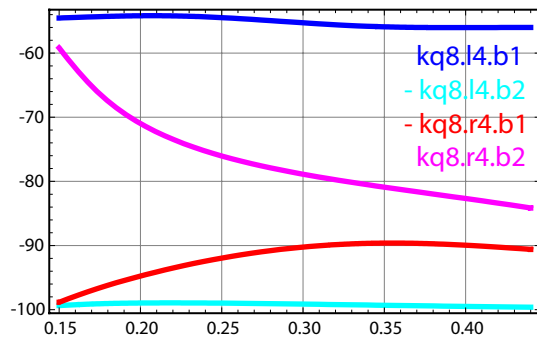
Q6, [% of 160 T/m]



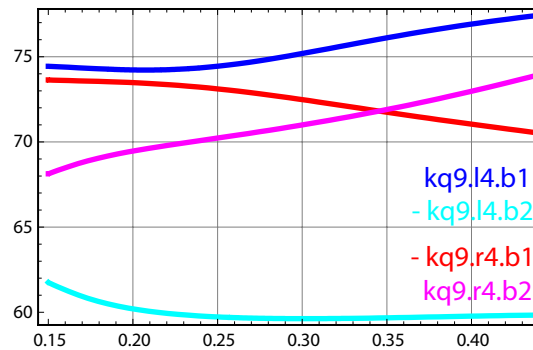
Q7, [% of 200 T/m]



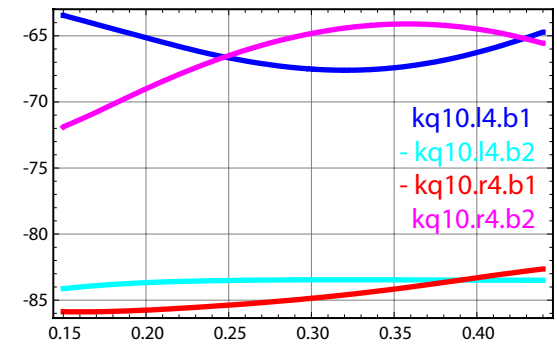
Q8, [% of 200 T/m]



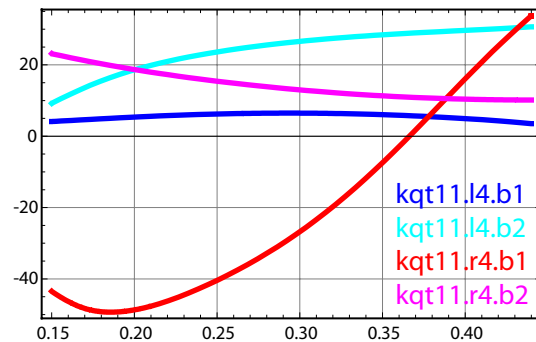
Q9, [% of 200 T/m]



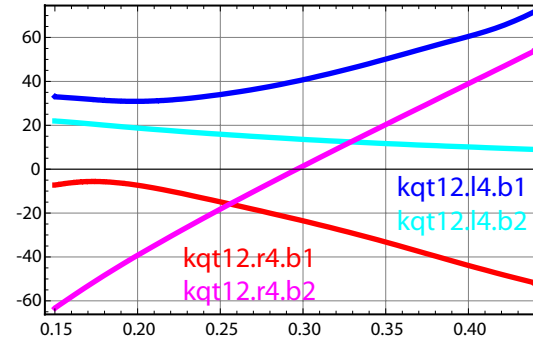
Q10, [% of 200 T/m]



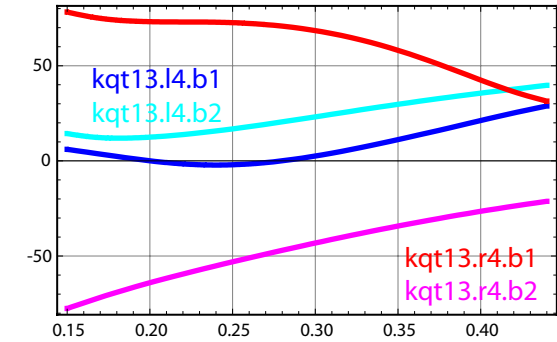
QT11, [% of 125 T/m]



QT12, [% of 120 T/m]



QT13, [% of 120 T/m]

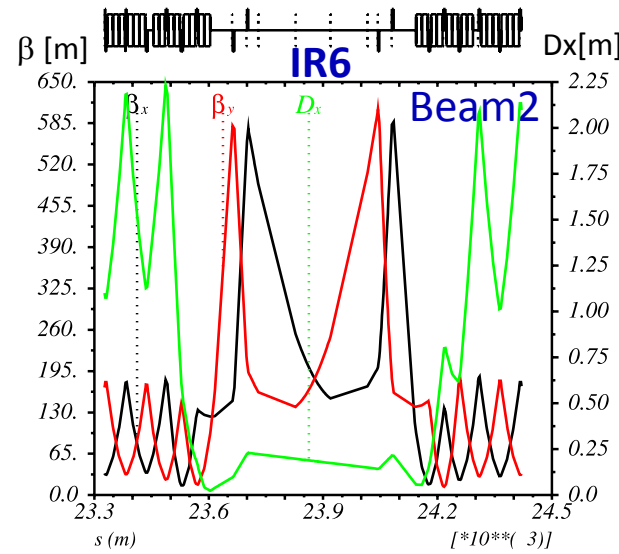
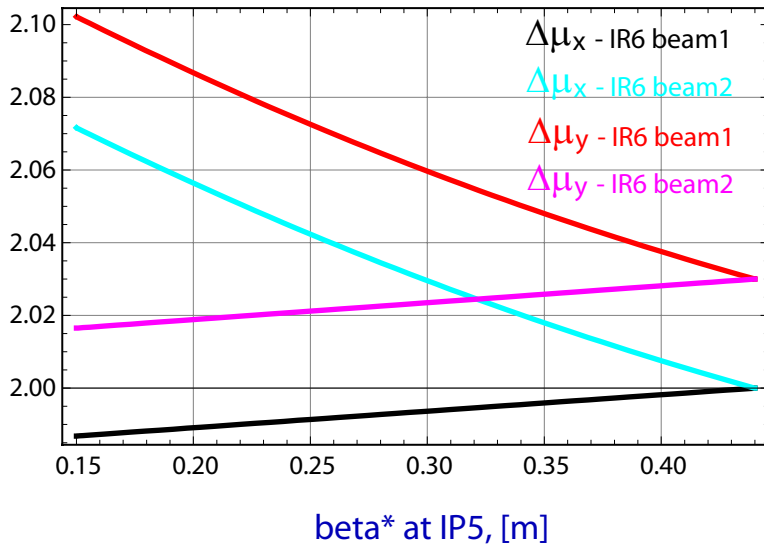


$\beta^*$  at IP5, [m]

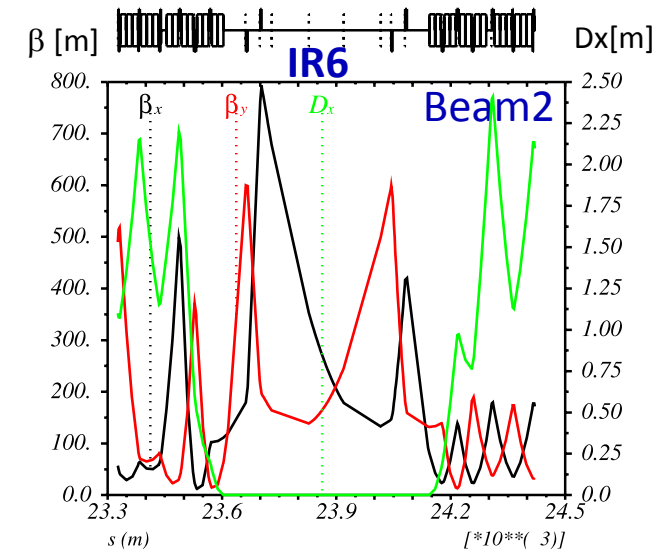
$\beta^*$  at IP5, [m]

$\beta^*$  at IP5, [m]

# IR6 matching conditions



pre-squeeze optics



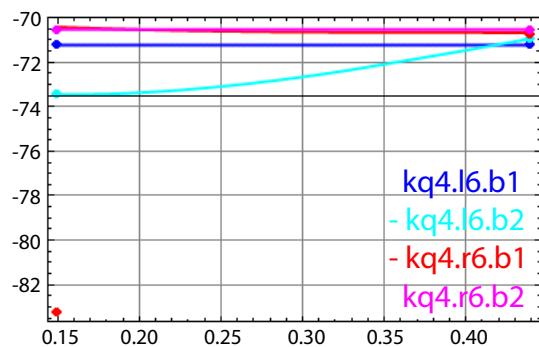
collision optics

- Twiss parameters at the beginning of IR6 as a function of  $\beta^*$  at IP5 during the optics transition
- Fixed Twiss parameters at the end of IR6
- Horizontal and vertical phase advance as a function of  $\beta^*$  at IP5 during the optics transition
- Horizontal and vertical beta functions at the dump
 

for Beam1:	$\beta_x > 5012$ ,	$\beta_y > 3955$
for Beam2:	$\beta_x > 5052$ ,	$\beta_y > 3698$
- Phase advance between the kicker and septum magnet is 90 degree when  $\beta^*$  at IP5 is 0.15 m

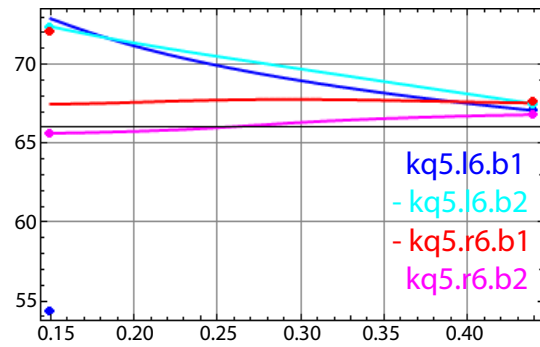
# IR6 optics transition

Q4, [% of 160 T/m]

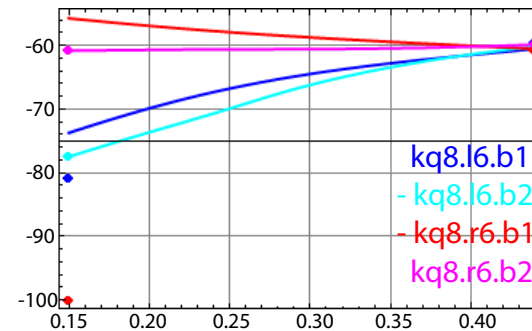


$\beta^*$  at IP5, [m]

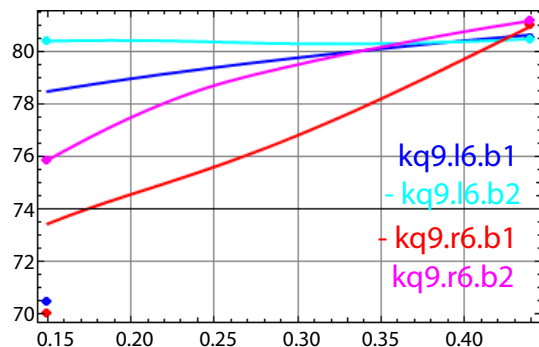
Q5, [% of 160 T/m]



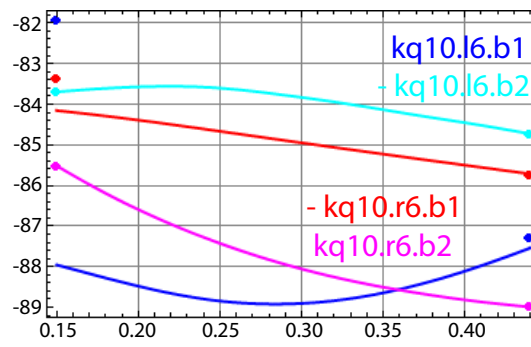
Q8, [% of 200 T/m]



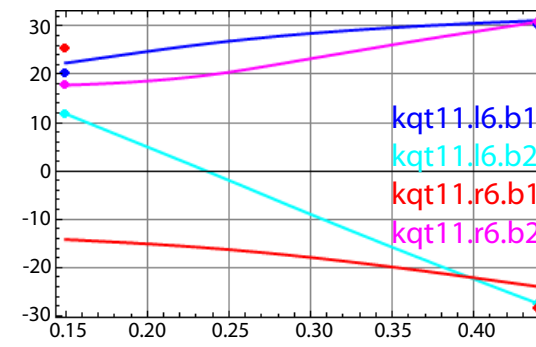
Q9, [% of 200 T/m]



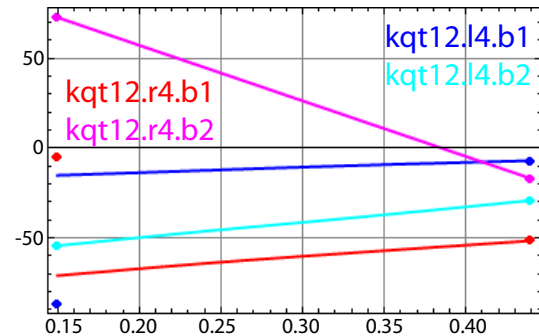
Q10, [% of 200 T/m]



QT11, [% of 125 T/m]

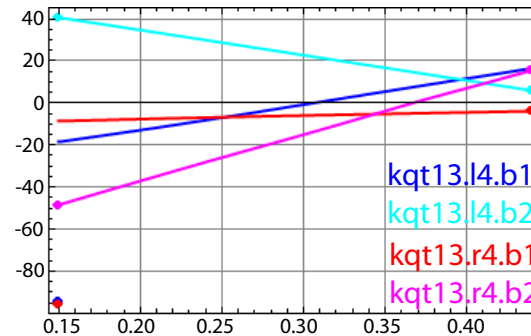


QT12, [% of 120 T/m]



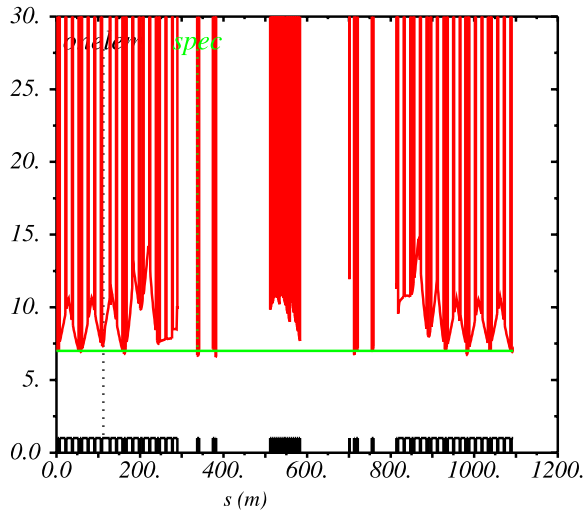
$\beta^*$  at IP5, [m]

QT13, [% of 120 T/m]

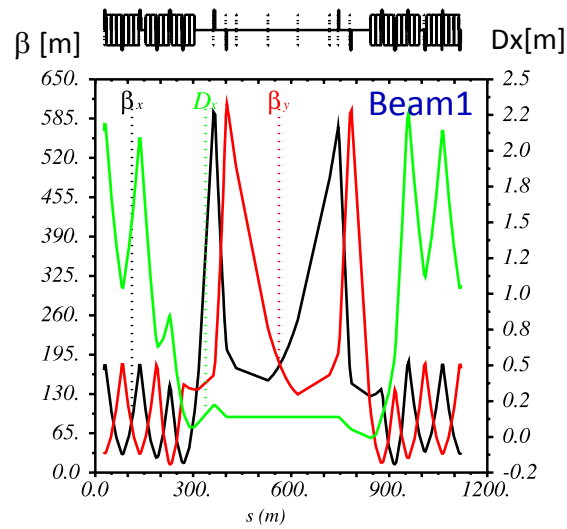


$\beta^*$  at IP5, [m]

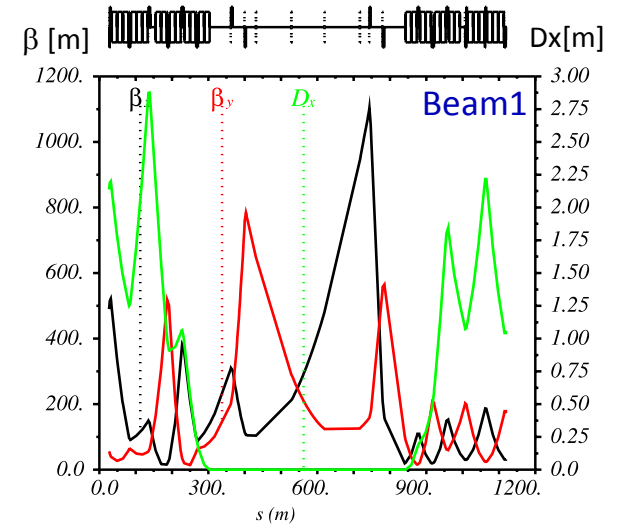
# New optics in IR6 for beam1



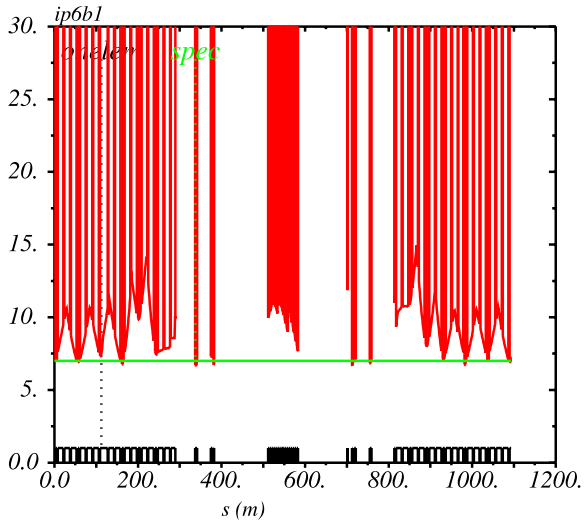
Aperture at injection (450 GeV) for predefined pre-squeeze/injection optic



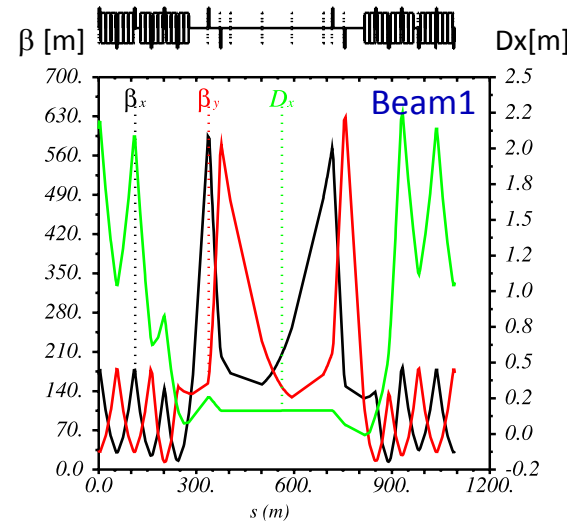
predefined pre-squeeze optics



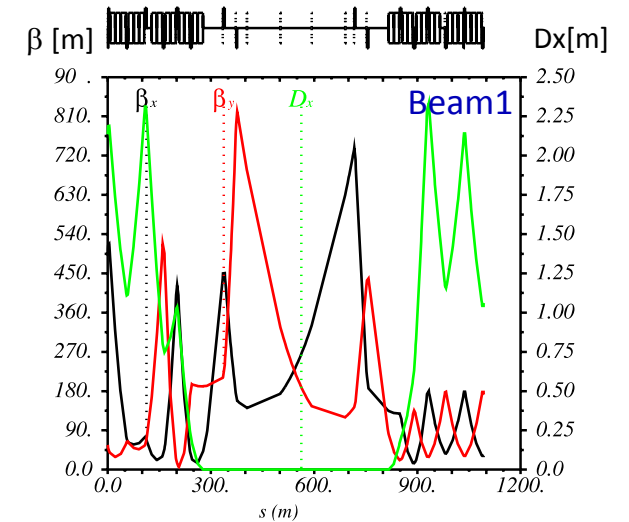
predefined collision optics



Aperture at injection (450 GeV) for new pre-squeeze/injection optic



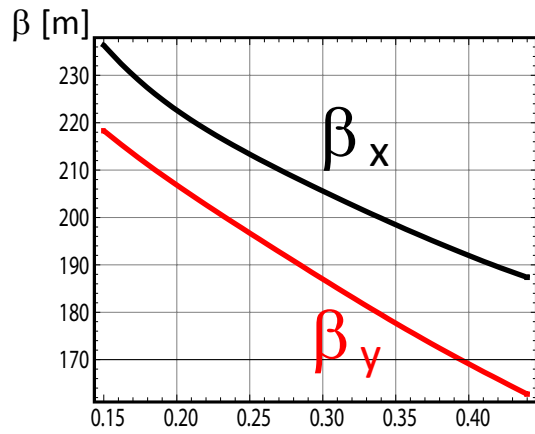
new pre-squeeze optics



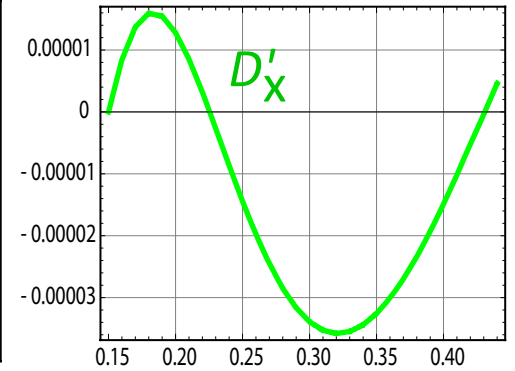
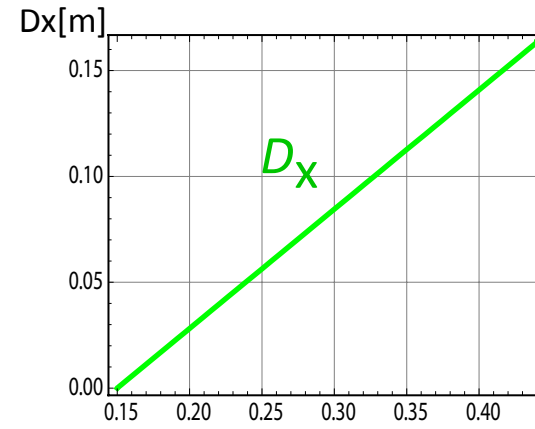
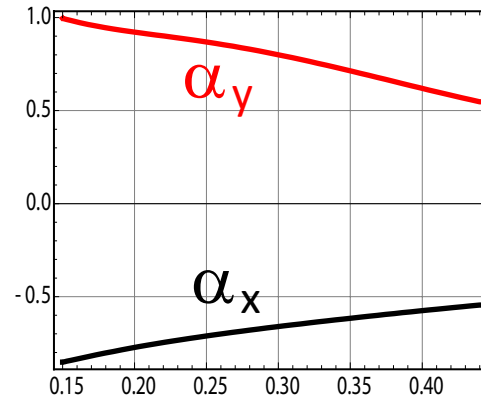
new collision optics

# Twiss parameters at IP6

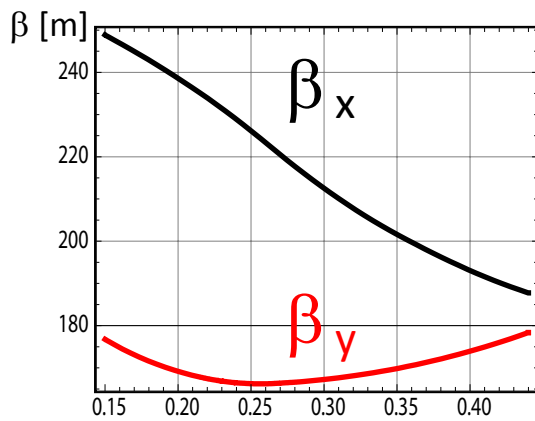
## BEAM 1



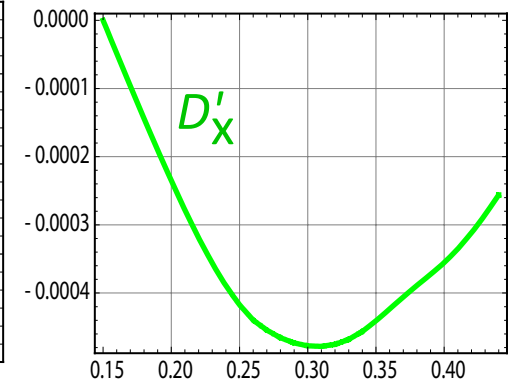
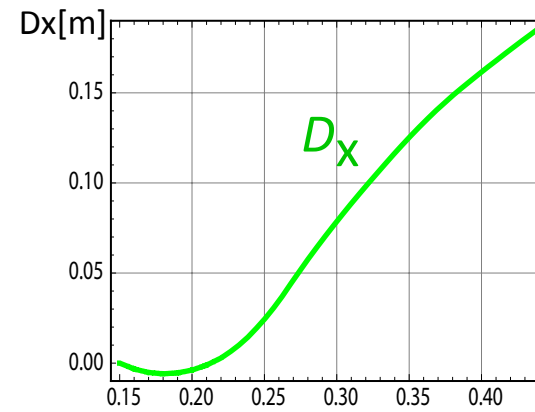
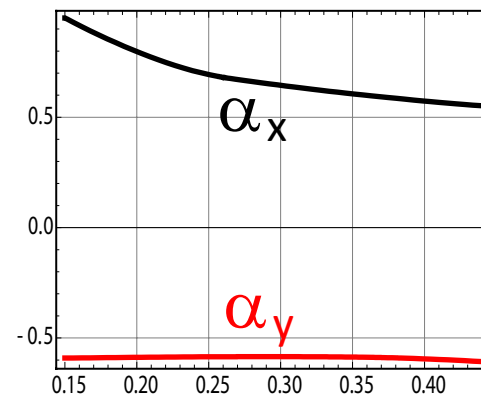
$\text{Beta}^*$  at IP5, [m]



## BEAM 2

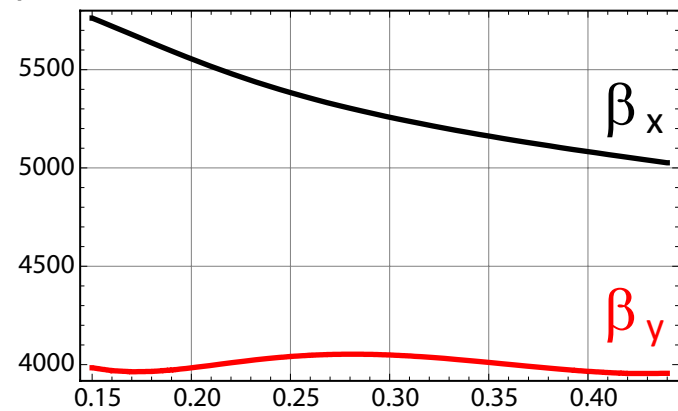


$\text{Beta}^*$  at IP5, [m]



# Beta functions at the beam dump and phase advance between the kicker and septum magnet in IR6

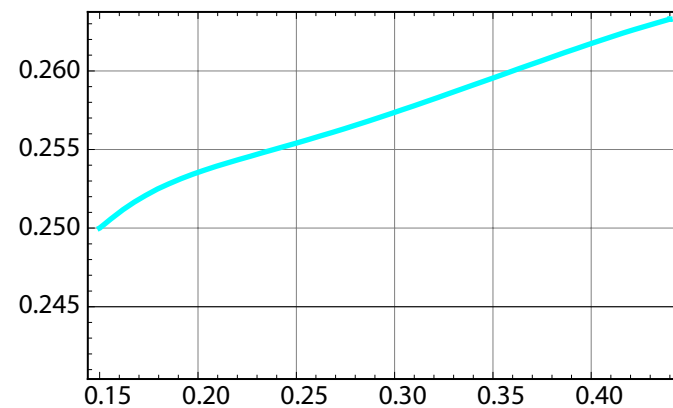
$\beta$  [m] Beta functions at the beam dump



Beta\* at IP5, [m]

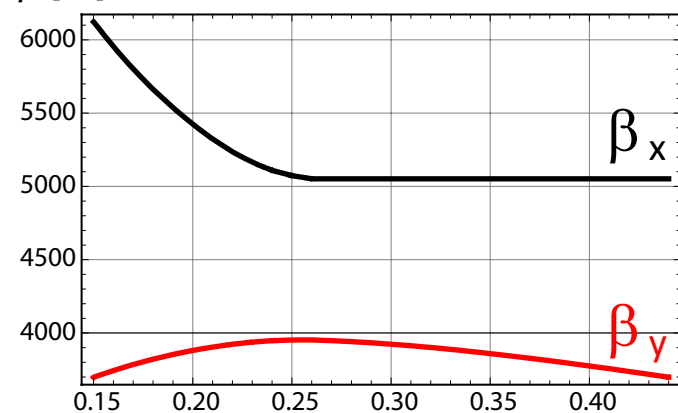
Beam 1

Phase advance between the kicker and septum



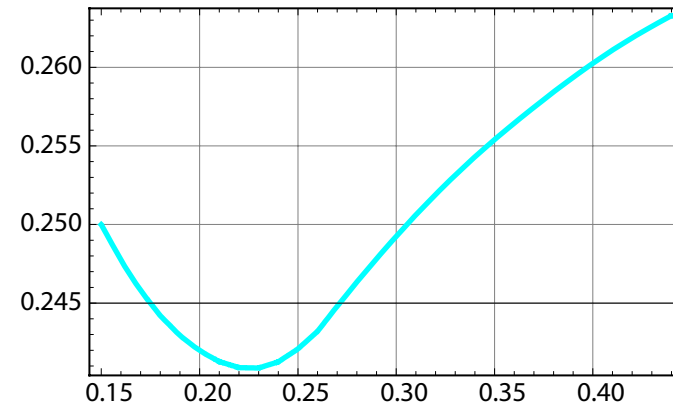
Beta\* at IP5, [m]

$\beta$  [m] Beta functions at the beam dump



Beam 2

Phase advance between the kicker and septum



# Conclusions

- Solutions for the optics transitions in IR5, IR1, IR4 and IR6 which meet all required matching constraints have been found.
- Optics transition in IR5 and IR1 provides ATS pre-squeeze optics in the range of  $\beta^*$  from 3.2 m to 0.44 m. Any changes of slope of field gradient take place far from the low-field domain.
- Optics transition in IR6 results in the new optics for the beam1 at collision.
- Next steps: to find solutions for the optics transition in IR8 and IR2