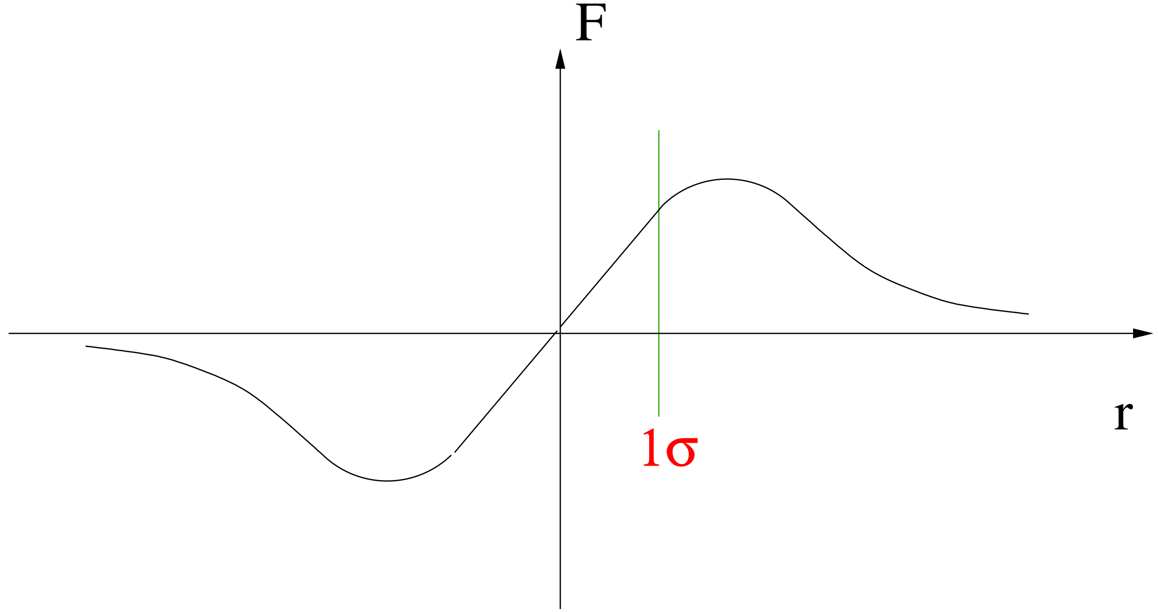
Triplet Issues Discussed at the LCC

overview:

- summary of beam-beam tune shifts
- optimum value for the crossing angle and its limits
- orientation of the crossing angle planes
- overview of the current baseline separation scheme
- options for the triplet beam screens
- adjustments of the transverse collision point

Beam-Beam Interaction



- small amplitudes:

$$\frac{F}{v \cdot p} \approx \frac{N_2 \cdot r_p}{\gamma} \cdot \frac{r}{\sigma^2} \longrightarrow \text{quadrupole}$$

- intermediate amplitudes ($r \approx \sigma$): $\longrightarrow$ strong non-linearity

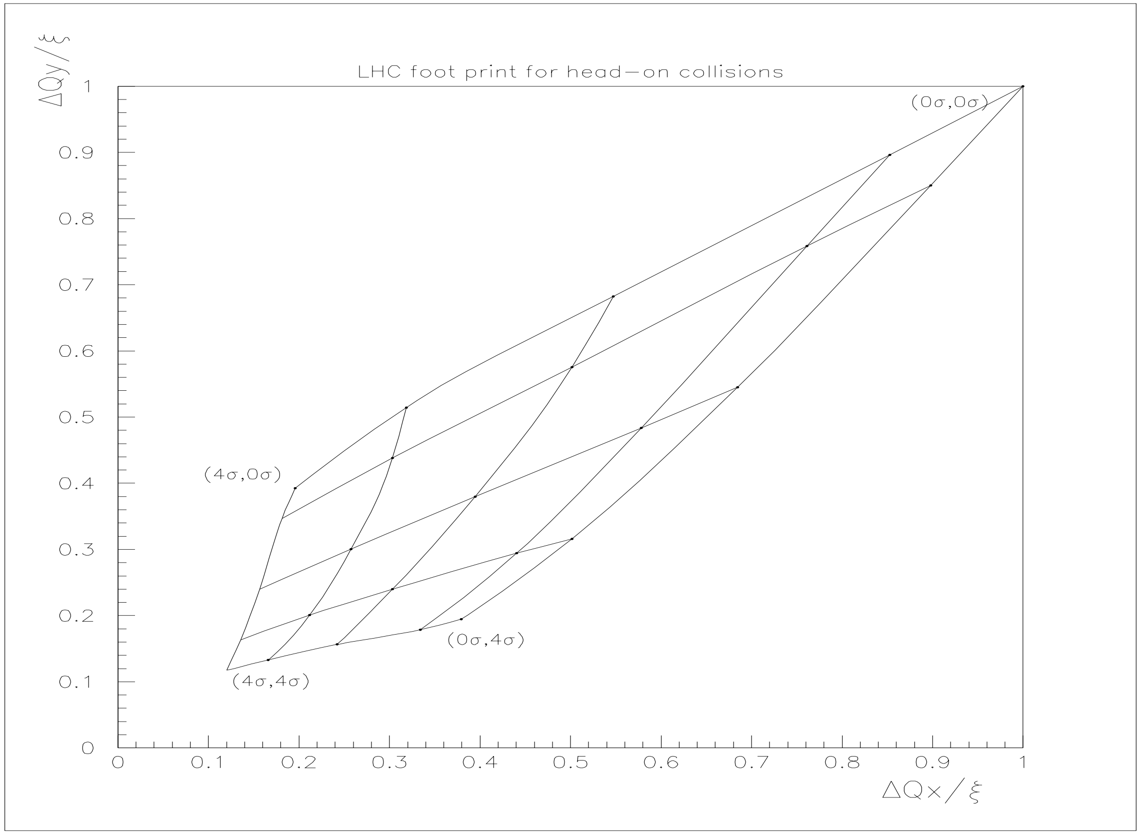
- large amplitudes: $\frac{F}{v \cdot p} \propto \frac{2}{r}$ $\longrightarrow$ charged wire

Beam-Beam Parameter

- tune shift with head-on collisions:

$$\Delta Q = \frac{N_2 \cdot r_p}{4\pi \cdot \gamma \cdot \varepsilon} \longrightarrow \xi_{\text{beam-beam}}$$

- foot print:

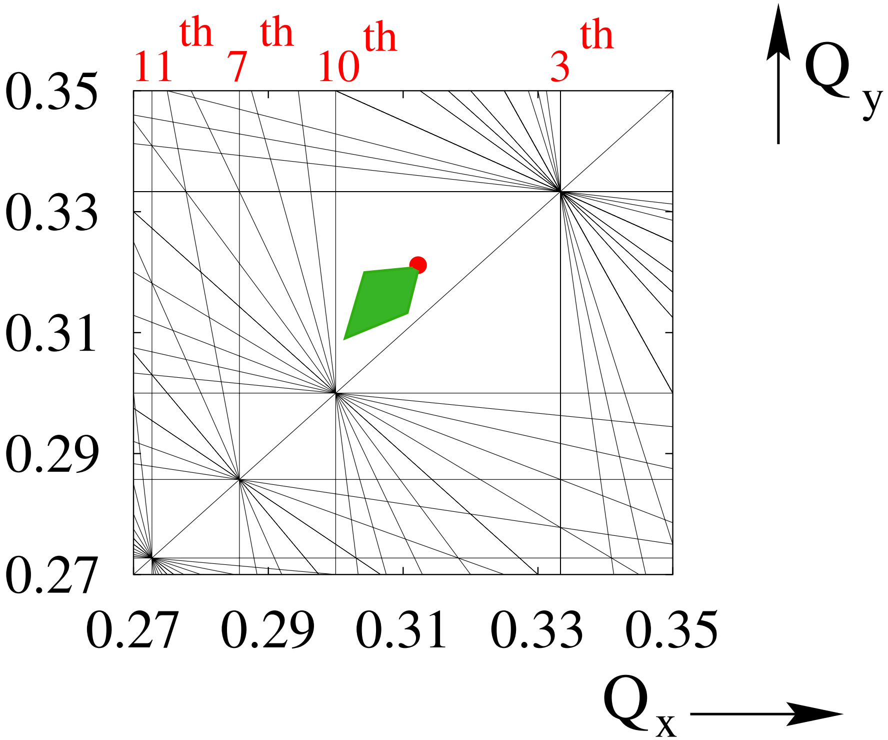


→ particle tune depends on particle amplitude

Beam-Beam Limit

- LHC working point:

$Q_x = 64.31; \quad Q_y = 59.32$



n + m < 12 (SppS)

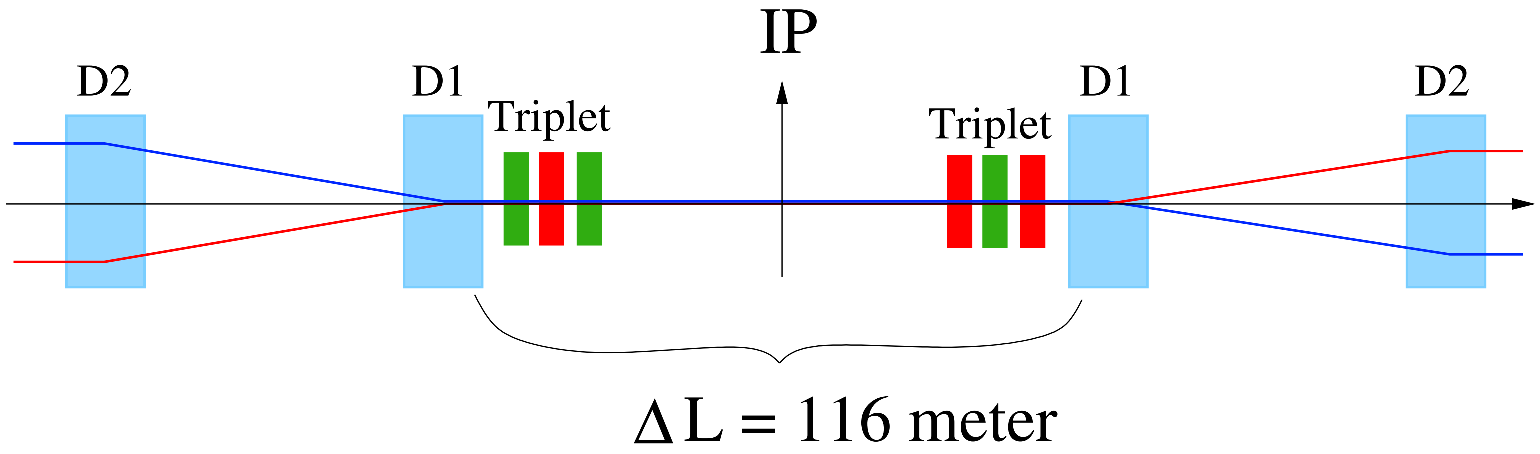
→ total beam-beam tune shift must be smaller than 0.015!

- the LHC features 3 proton experiments with head on collisions:

→ $\xi_{tot} = 0.01$ → only $\Delta Q = 0.005$ tolerance for lattice and operation!

Long Range Beam-Beam

IR layout:



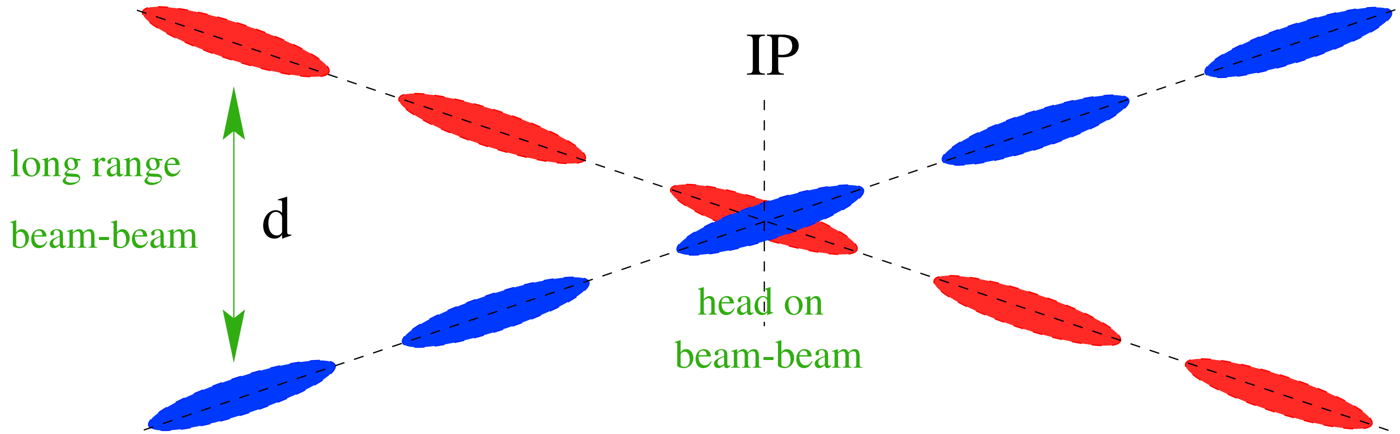
→ additional head on collisions for a bunch separation of less than 232 meter

crossing angle:

→ separate the two beams left and right from the IP with additional orbit bumps

Long Range Beam-Beam

- crossing angle:

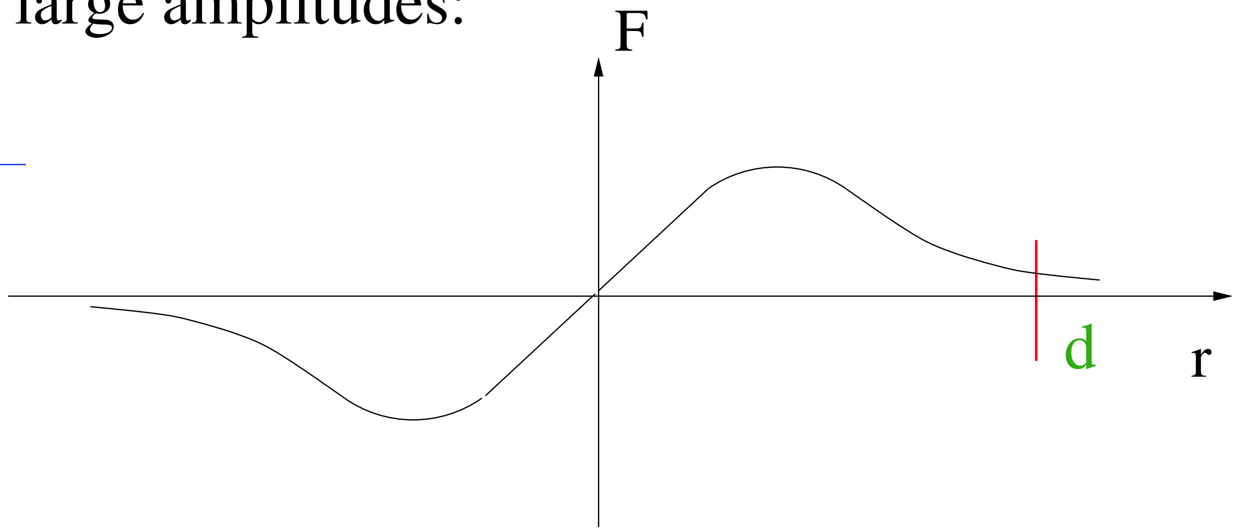


- additional features: → generates additional tune shift
  → requires larger triplet magnet aperture
  → breaks the bunch symmetry (pacman bunches)
  → generates additional orbit perturbations
  → breaks symmetry between x,y planes
  → odd order resonances are exited
  → couples longitudinal and transverse motion

Long Range Beam-Beam

- beam-beam force for large amplitudes:

$$\frac{F}{v \cdot p} \approx \frac{N_2 \cdot r_p}{\gamma} \cdot \frac{2}{r}$$



- orbit and tune shift (opposite sign for tune shift compared to head-on)
- tune spread
- total tune change depends on number of long-range collisions
  - → non-uniform filling pattern creates different collision patterns
  - → ca 135 different collision classes; (> 200 super pacman bunches)

Beam-Beam Parameter

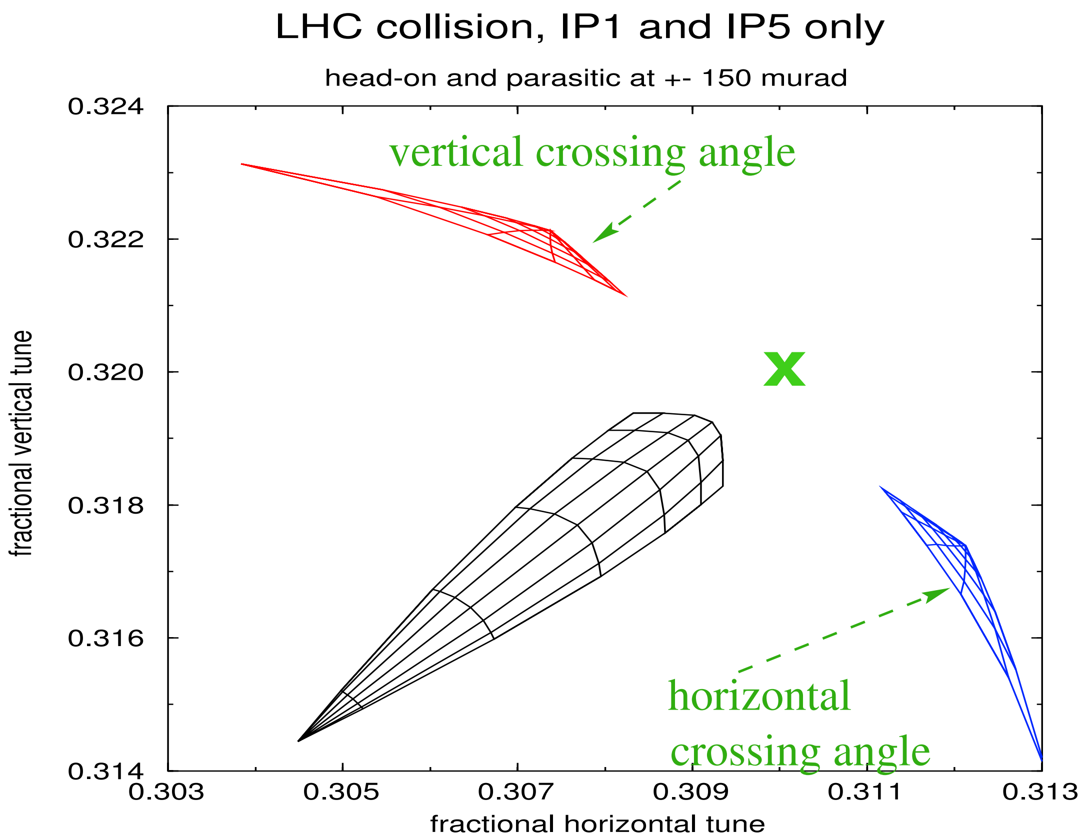
- tune change for long range interaction: $\Delta Q_{lr} = \frac{N_2 \cdot r_p}{2\pi \cdot \gamma} \cdot \frac{1}{\phi^2 \cdot \beta^*}$

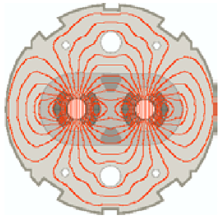
  with: $d = 2 \cdot \tan(\phi/2) \cdot s$ (ϕ = total crossing angle)

- foot print:

  tune shift depends on crossing angle plane!

  → alternate crossing angle plane!



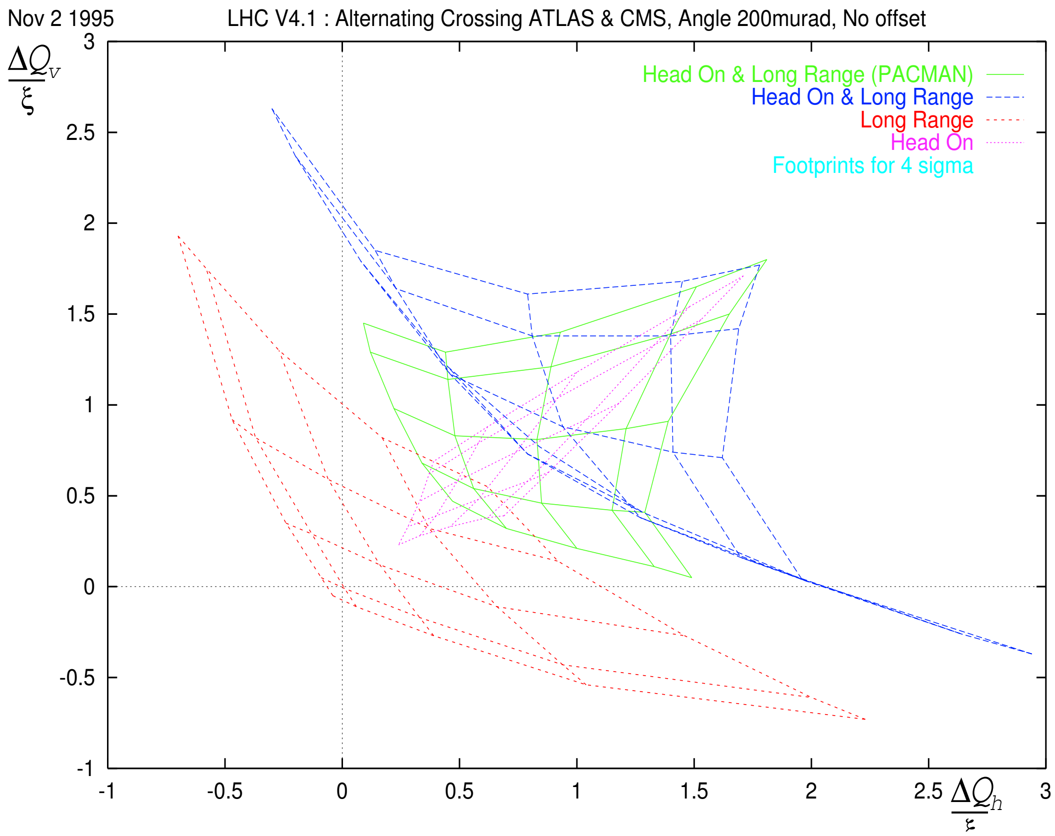


Beam-Beam Parameter

- alternate crossing angle planes in IR1 and IR5:

  → partial compensation of the long range tune shift

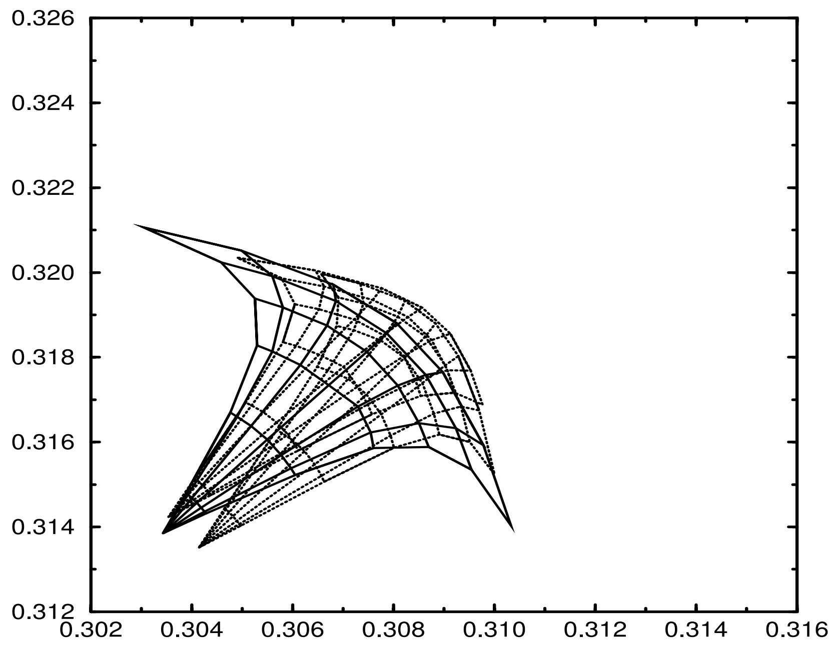
- foot print:



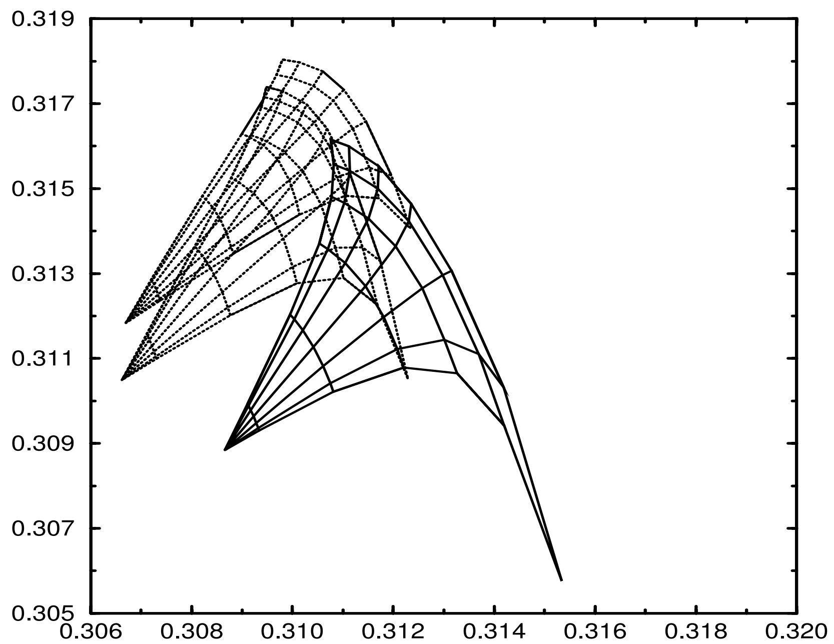
Tune Footprints

H. Grote et al LHC Project Note 161

- vertical / horizontal crossing in IR1 and IR5



- horizontal / horizontal crossing in IR1 and IR5



Long Range Beam-Beam

- avoid long range beam-beam tune shift by large separation:

  → limited by mechanical aperture in triplet magnets

  → limits imposed by corrector strength

- compensate the long range beam-beam effects:

  → alternate crossing angle planes in the IR's

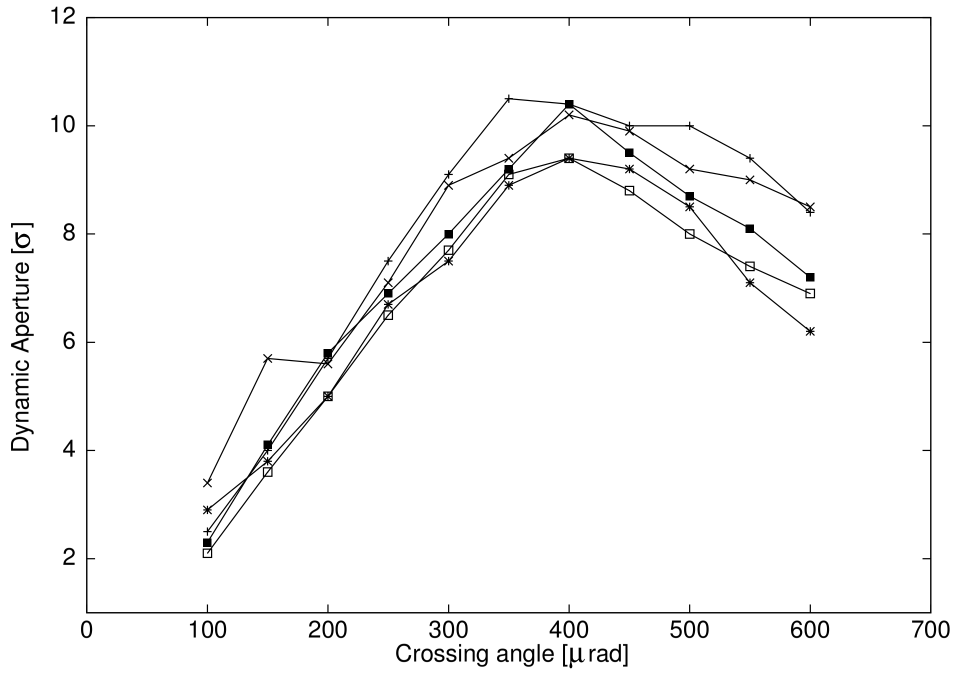
  → summary of the LHC base line separation scheme

  → nominal LHC crossing scheme is barely sufficient

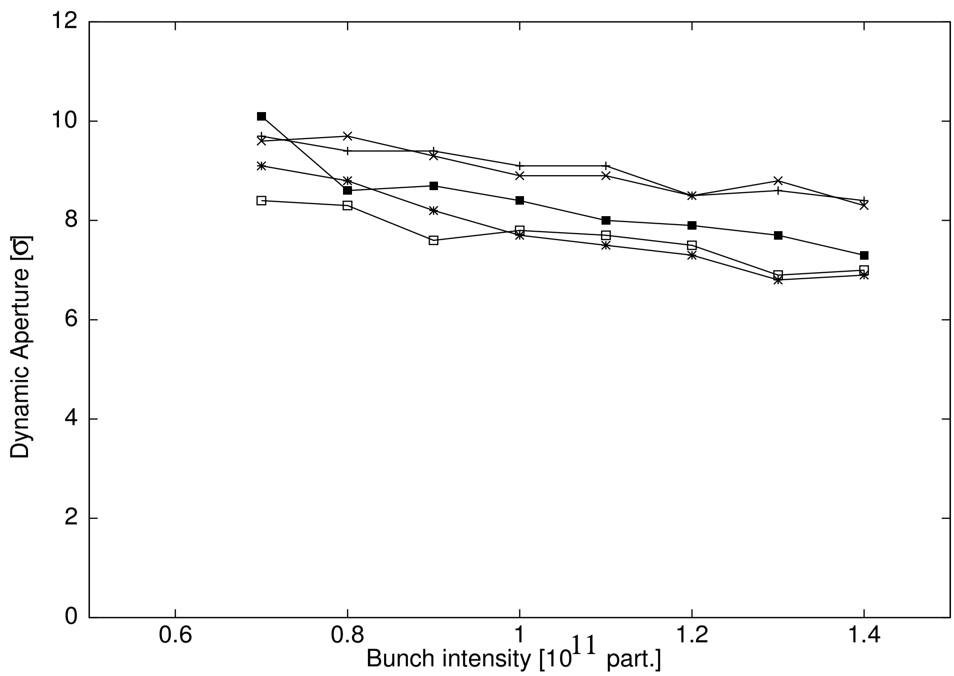
DA Studies

Leunissen et al LHC Project Report 405

DA versus crossing angle



DA versus bunch intensity



Maximum Beam Separation

tolerances for the mechanical acceptance:

- β-beat (10% beam size increase)
- 27% spurious dispersion (normalised by $\sqrt{\beta}$)

  (no possibility to correct vertical dispersion in LHC)
- 3mm closed orbit tolerance

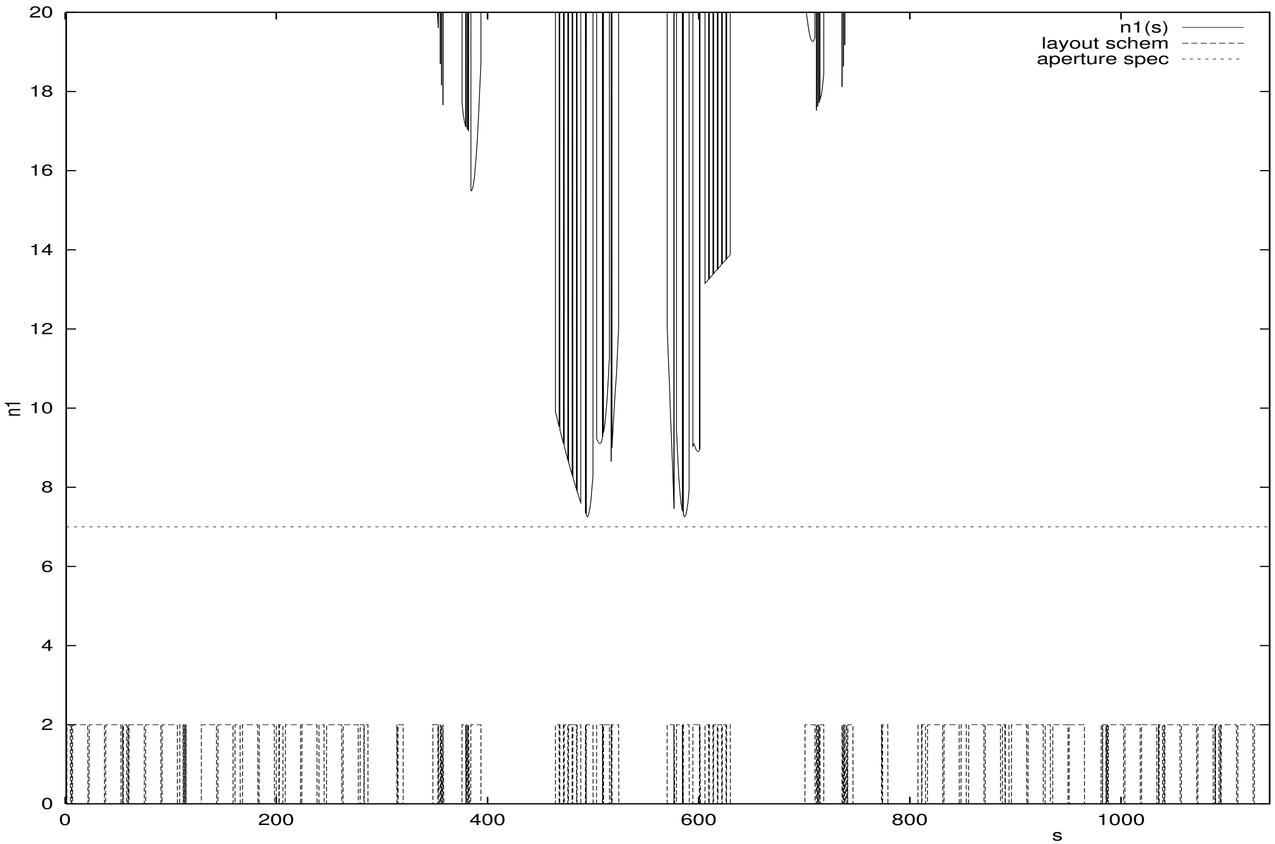
  x-ing angle partially generated by offset in triplet

  orbit errors during squeeze
- mechanical tolerances of the triplet components

Maximum Beam Separation

- express mechanical acceptance by required collimator position:

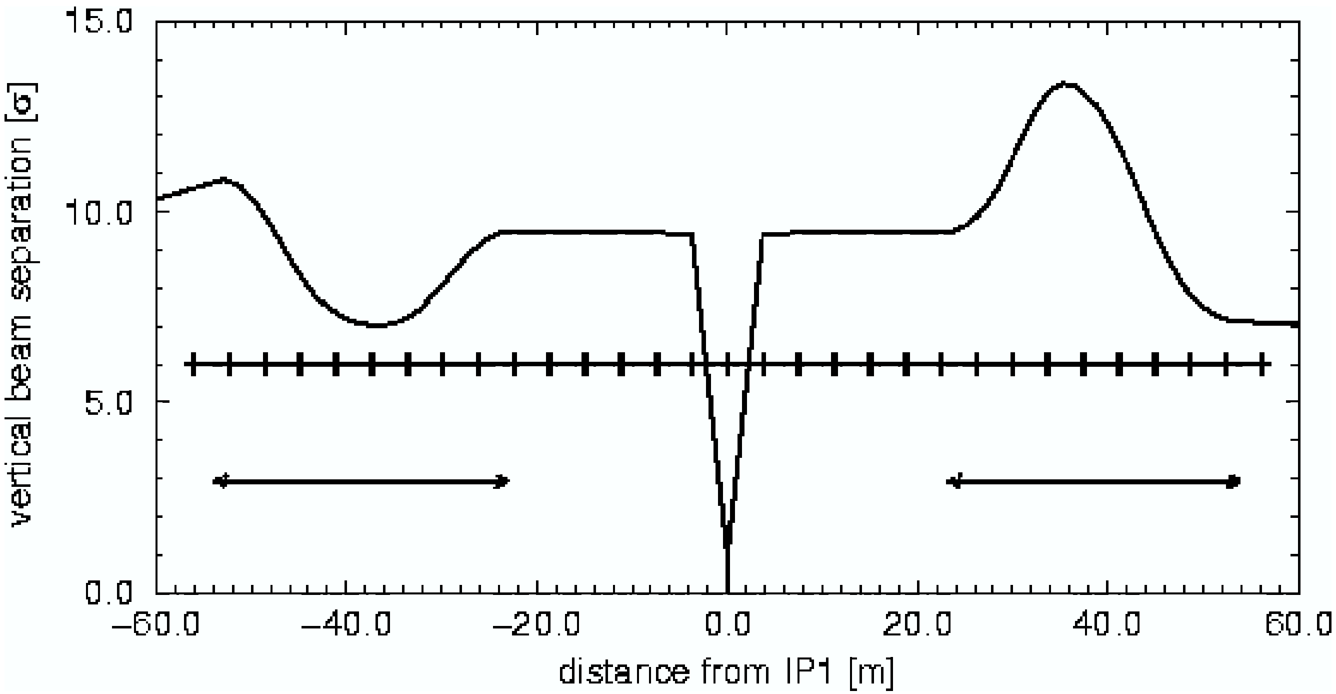
→ required primary collimator position for protection



Parasitic Beam-Beam Encounters

- ***beam separation in IR5:*** (300 μrad)

Leunissen et al. LHC Project Report 405



The scale with the tick marks indicates positions of beam-beam encounters

Options for Long Range Compensation

- rely on compensation of alternate crossing angle planes

  -IR2 requires vertical crossing angle

  -IR8 requires horizontal crossing angle

- vertical / horizontal or horizontal / vertical

  → requires simultaneous operation in IR1 / IR5

- crossing angle planes at 45^{o} / 135^{o} or 135^{o} / 45^{o}

  → long-range tune shift transforms into coupling

  → orbit effects still require alternate crossing

  → more complex crossing angle bumps

Nominal LHC Collision Parameters

Bruning, Herr and Ostojic

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}				

Other Considerations for the Crossing Plane

- correction of dispersion requires horizontal crossing plane

  $D_{max} = 1.26$ meter → 0.6 mm in triplet ($5 \cdot 10^{-4}$)

  → however: horizontal / horizontal crossing provides no correction of long range beam-beam effects

- correction of long-range beam beam effects with wire

  applicability in operation not yet demonstrated

  installation simplified for vertical crossing

  → no correction for pacman bunches!

Other Considerations for the Crossing Plane

- luminosity monitor can be simplified for fixed crossing planes

- losses in triplet magnets smaller for horizontal crossing plane

  → however horizontal / horizontal crossing does not provide compensation for long range beam beam effects

  → triplet design includes these losses:

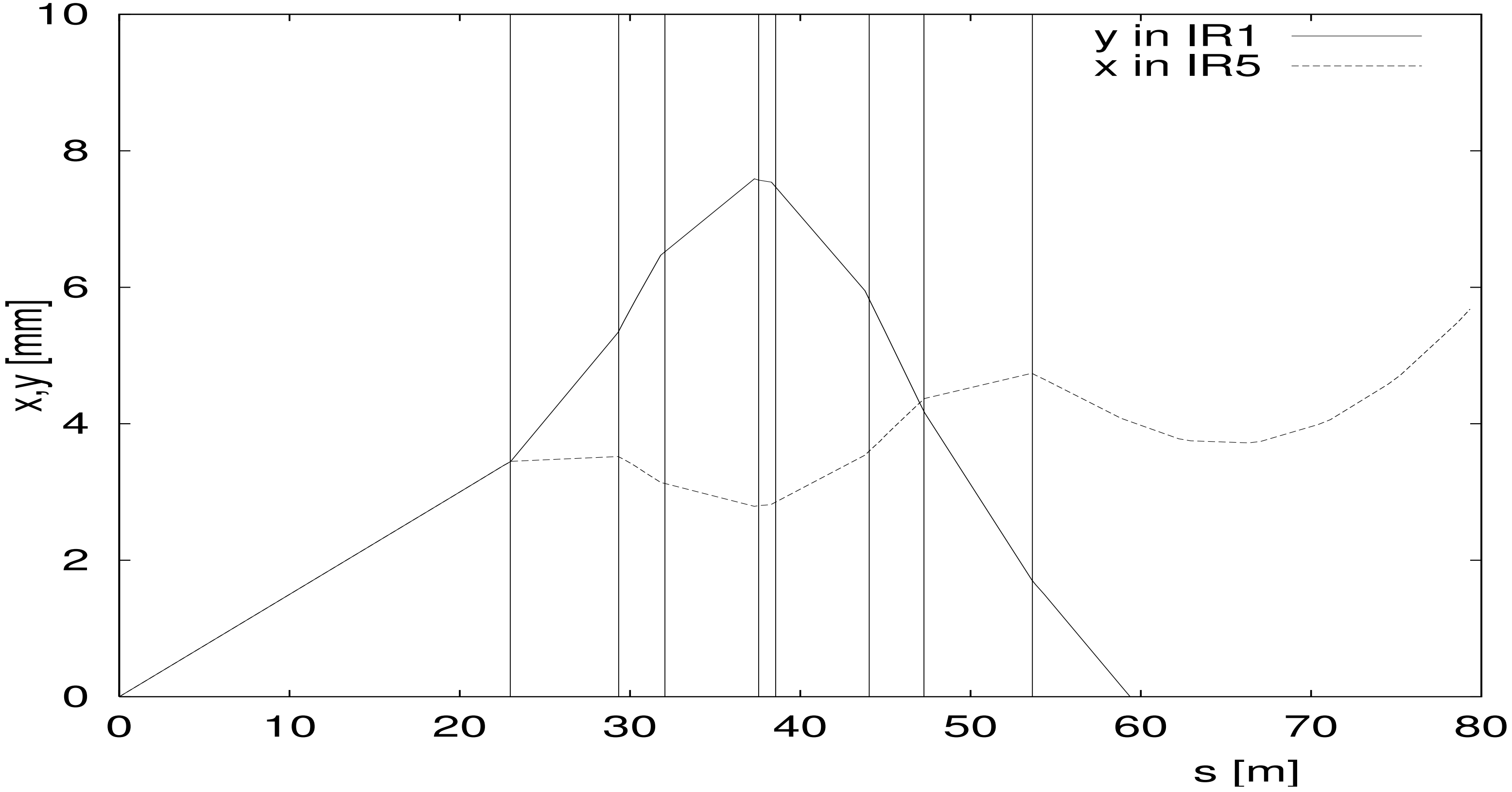
  maximum gradient limited to 200 T/m compared to design value of 240 T/m

- impact on detector background difficult to predict

Other Considerations for the Crossing Plane

- losses in triplet magnets smaller for horizontal crossing plane

30% of nominal energy [I. Baishev, JB Jeanneret]



Off Momentum Losses and Triplet Quench Limit

- 0.6 mW/gr in IR1
- 0.3 mW/gr in IR5

→ no impact on relative performance!

- estimated quench limit in triplet: 1.2 mW/gr

→ factor 2 safety margin

factor 3 safety required for other cold elements

→ how confident are we in the quench limit estimate?

can we increase the quench limit via increased cooling?

Summary Crossing Planes

- crossing angle value barely sufficient (limited by aperture)

  → maximise triplet aperture!

- base line crossing scheme works well for long range beam-beam compensation

- crossing angle planes at 45^{o} has not been demonstrated be beneficial

- crossing scheme without alternate crossing does not compensate long range effects (pacman tune shift) and features larger orbit at IP

  → impact on background and beam lifetime?

Summary Crossing Planes

- all crossing angle planes are possible for larger β^*

  → discussion only relevant for maximum performance!

- no strong arguments to change baseline crossing from machine point of view

  (except the argument that it is good to have flexibility)

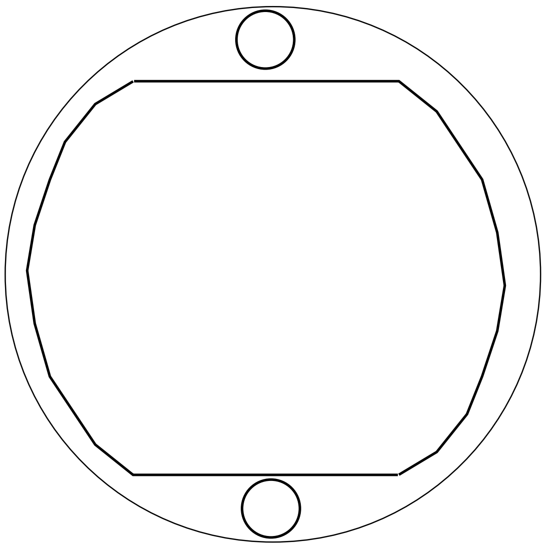
  → what do we do if the operation conditions in IR1 and IR5 are very different?

Beam Screen in Triplet Magnets

- there is no beam screen in the LHC base line design!

  → only recently required by LHC-VAC to ensure vacuum stability

- proposed beam screen layout similar to arc beam screen



-can be oriented along crossing plane

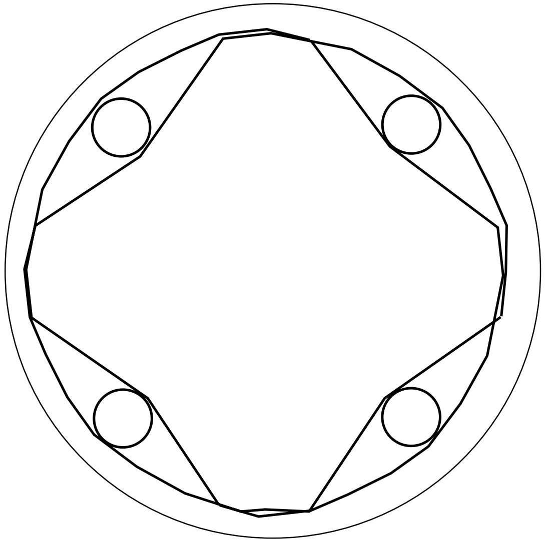
-orientation fixed after installation

-0.6mm net aperture loss (->11% in L)

-crossing at 45 ^{o} still possible (loss in aperture)

Beam Screen in Triplet Magnets

- proposed alternate beam screen (Ranko Ostojic)



-crossing angle plane can be changed during operation

-net aperture loss comparable to race track

-crossing at 45^{o} still possible but with reduced aperture at 45^{o}

- the LHC-VAC group considers this design as too demanding

(no manufacturer at hand that could produce this beam screen)

Current Situation for Beam Screen

- use race track type beam screen

  → beam screen must be ordered now

- decide on beam screen orientation when magnets are installed

  → the crossing angle planes are locked in 2004

- any change from the above scenario requires strong reaction from the experiments!

Adjustment of the Collision Point

- types of parallel bumps:
  - -common correctors for beam1 and beam2 (triplet corrector):
    - -most efficient use of corrector
    - -anti symmetric for beam1 and beam2
    - -no independent control for both beams
  - -independent correctors for beam1 and beam2:
    - -independent control for both beams
    - -requires large corrector strength
    - -reduces aperture in D1 and insertion

→ vertex adjustments require independent corrector elements!

Oliver Bruning/CERN

Parallel Vertex Displacement

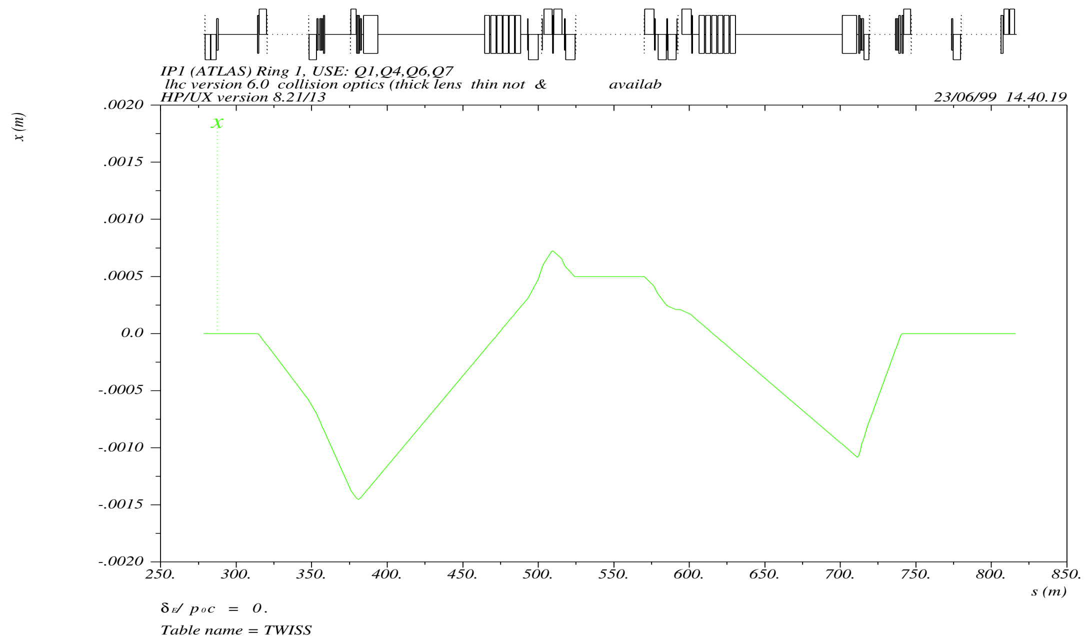
- independent orbit correctors for beam1 and beam2:

0.5mm parallel bump:

-60% of corrector strength

-0.75mm orbit error in Q2

-1.5mm orbit error in Q4



→ 0.5mm parallel bump is the limit for transverse adjust-ability

Parallel Vertex Displacement

- corrector strength limit: 40% margin -> 0.8mm parallel bump

  → start bump in DS requires corrector strength

- aperture limit in Q4: have approximately 7mm margin

  → not a strong limit

- aperture limit in triplet: we need all aperture that is available

  → aperture limits maximum crossing angle

  0.7mm orbit error in Q2

→ offsets > 0.5mm require realignment of the triplet and TAS

→ offsets > 0.8mm require realignment of whole insertion + DS

Parallel Vertex Displacement

- capability to align the detector would be desirable

- remote controlled triplet alignment is delicate and the use questionable

  7.5μm offset in Q2 generate 1σ offset at the IP!

  (TAS aperture and 0.8mm bump limit from corrector elements)

- time required to realign?

  → LEP experience: need 16 quadrupoles for 10mm

  → realignment of insertion + DA + 1 half cell