INTERACTION REGION DESIGN: PRELIMINARY CONSIDERATIONS

M. E. Biagini, LNF-INFN

Workhop on e+e- in the 1-2 GeV Physics and Accelerator Prospects

OUTLINE

- IR design constraints & requirements
- Crossing angle
- Parasitic Crossings
- Tune shifts and luminosity with crossing angle
- IR design layout & parameters
- IR flexibility
- To do list

IR Design Requirements (Machine & Detector)

- Maximum detector solid angle, try to keep accelerator components far enough away from the IP (D)
- Large high-field solenoid (KLOE, FINUDA-like) (D)
- Push Q1 close to IP, to minimize IP spot size (M)
- Horizontal crossing angle (M) (DAΦNE experience)
- Small quadrupoles, embedded in detector field (M,D)
- Coupling correction (M) (DAΦNE experience)
- Adequate shielding from Touschek background (M,D)
- Ultra-vacuum (M,D)
- Impedance budget (M)
- Thin beam pipe (D)
- "Instrumented" IR (D)

The IR design is a common Machine & Detector business !!

Crossing angle

- The crossing angle option allows for larger collision frequency (smaller bunch spacing)
- It allows to have the beams "naturally" separated (no need of dipoles close to IP) and to be soon accomodated in 2 separate rings
- However this solution has some side effects:
  - Large angles can induce synchro-betatron resonances in the beams (Piwinski criterion)
  - Unwanted beam interactions at Parasitic Crossings
  - Effect of off-axis trajectories in quadrupoles and solenoids on the beam optics have to be evaluated
  - Luminosity and tune shifts are affected: $L \downarrow$, $\xi \downarrow$ (for same number of particles)

The crossing angle value has to be carefully chosen!!

Crossing angle (cont'd)

- Minimum crossing angle:

  to allow a 20 σ_x distance between the 2 beam cores at 1st PC (0.3 m from IP) ➔ 15 mrad

- Maximum crossing angle:

  dictated by the requirement of a ± 9° cone solid angle (present design at DAΦNE) ➔ 50 mrad (assuming a pm QD at 0.2 m from IP, with 2 cm thick material, and a 10 σ_x clearance)

- Piwinski angle: parameter of how harmful is the crossing angle:

$$\Theta = \theta \, \sigma_l / \sigma_x \qquad (\theta = \text{half crossing angle})$$

0.18 (θ = 15 mrad) ➔ 0.6 (θ = 50 mrad)

(DAΦNE = 0.29, KEK-B = 0.57)

Parasitic Crossings Effect

The unwanted beam interaction at the PCs has 2 effects:

- x and y tune shifts are induced, similarly to the main IP, depending on the beam separation at the PC
- beam lifetime is affected, if the separation is lower than 10 σ_x

$$\xi_x = -\frac{N r_e}{2\pi\gamma} \frac{\beta_x \left(x^2 - y^2\right)}{\left(x^2 + y^2\right)^2}$$

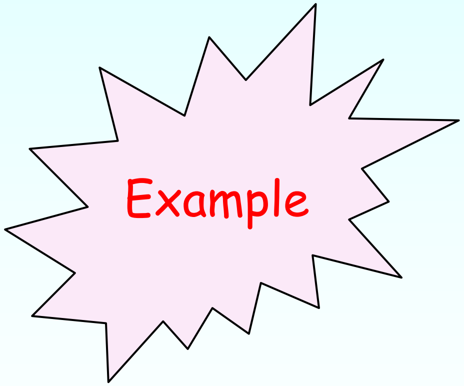
$$\xi_y = +\frac{N r_e}{2\pi\gamma} \frac{\beta_y \left(x^2 - y^2\right)}{\left(x^2 + y^2\right)^2}$$

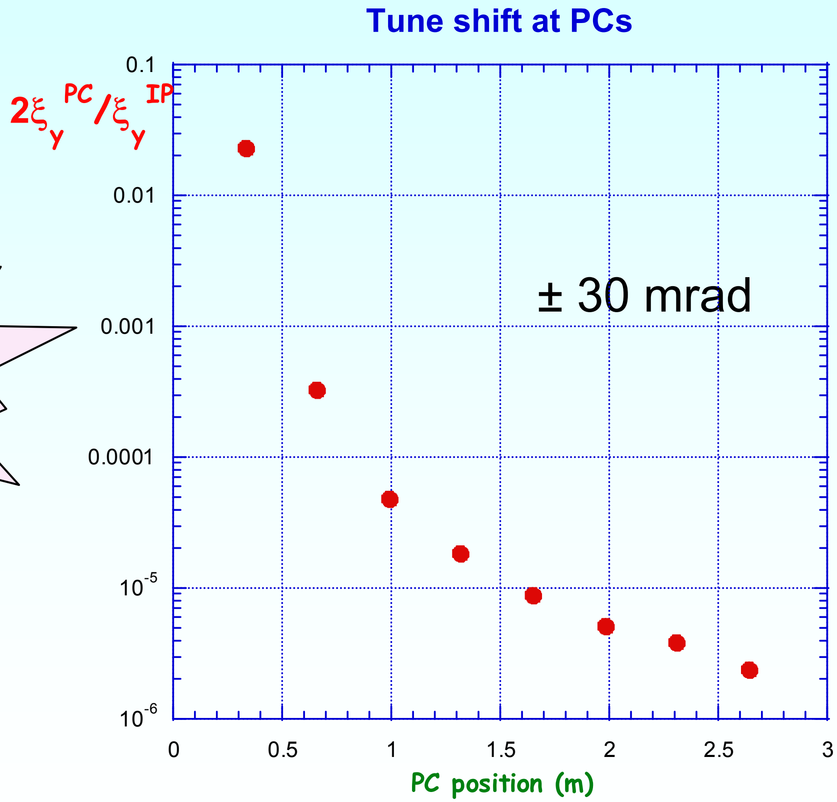
x, y = beam separation at PCs
Gaussian beam distribution

J. Jowett, Handbook of Accelerator Physics and Engineering:
Beam-beam tune shifts for gaussian beams

Parasitic Crossings (cont'd)

Vertical tune shift due to PCs for a 30 mrad half crossing angle:
the 1st PC tune shift is 1% of the IP tune shift. The other PCs have no effect.
The horizontal tune shift is a factor 20 lower. The separation at the 1st PC is 20 σ_x





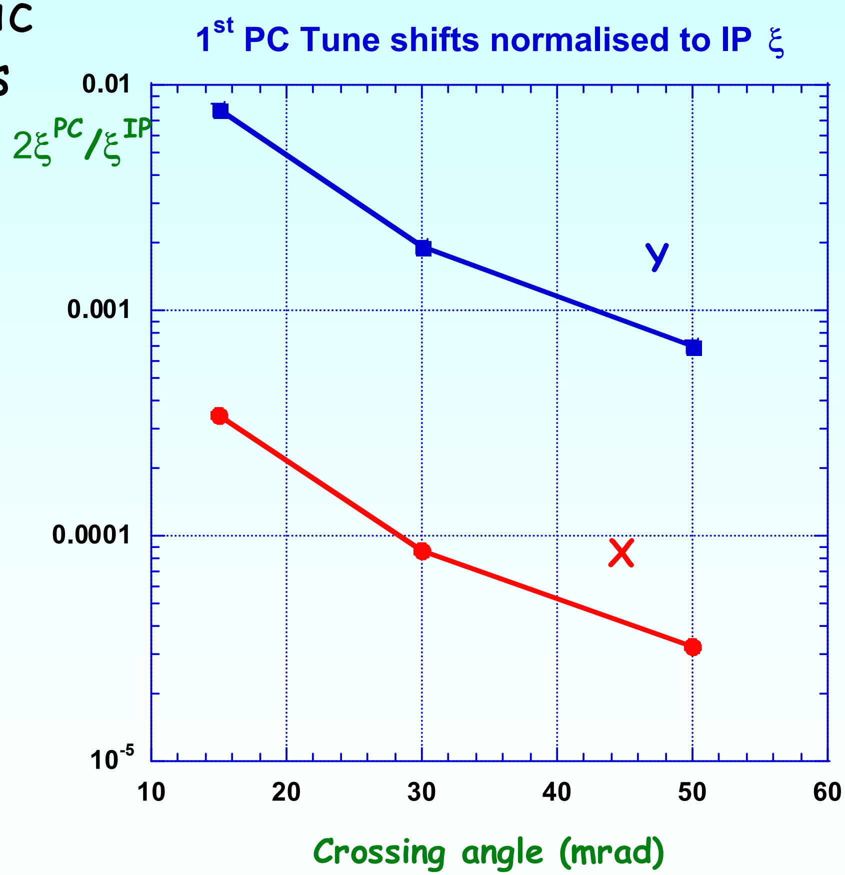
Note: y scale is logaritmic!

PC tune shift normalised to IP tune shif. The PC tune Shift counts twice!

Parasitic Crossings (cont'd)

- 1st PC tune shifts (logaritmic y scale, PC tune shift counts twice)

- 15 mrad: ξ_y^{PC} 9% of ξ_y^{IP}
- 30 mrad: ξ_y^{PC} 2% of ξ_y^{IP}
- 50 mrad: ξ_y^{PC} 1% of ξ_y^{IP}



Luminosity &tune shifts with crossing angle

$$L = \frac{N^2}{4\pi\sigma_y\sqrt{\left(\sigma_z^2 tg^2(\theta/2)+\sigma_x^2\right)}}$$

$$\xi_{xp} = \frac{r_e N}{2\pi\gamma}\frac{\beta_x}{\sqrt{\left(\sigma_z^2 tg^2(\theta/2)+\sigma_x^2\right)}\left(\sqrt{\left(\sigma_z^2 tg^2(\theta/2)+\sigma_x^2\right)}+\sigma_y\right)}$$

$$\xi_{yp} = \frac{r_e N}{2\pi\gamma}\frac{\beta_y}{\sigma_y\left(\sqrt{\left(\sigma_z^2 tg^2(\theta/2)+\sigma_x^2\right)}+\sigma_y\right)}$$

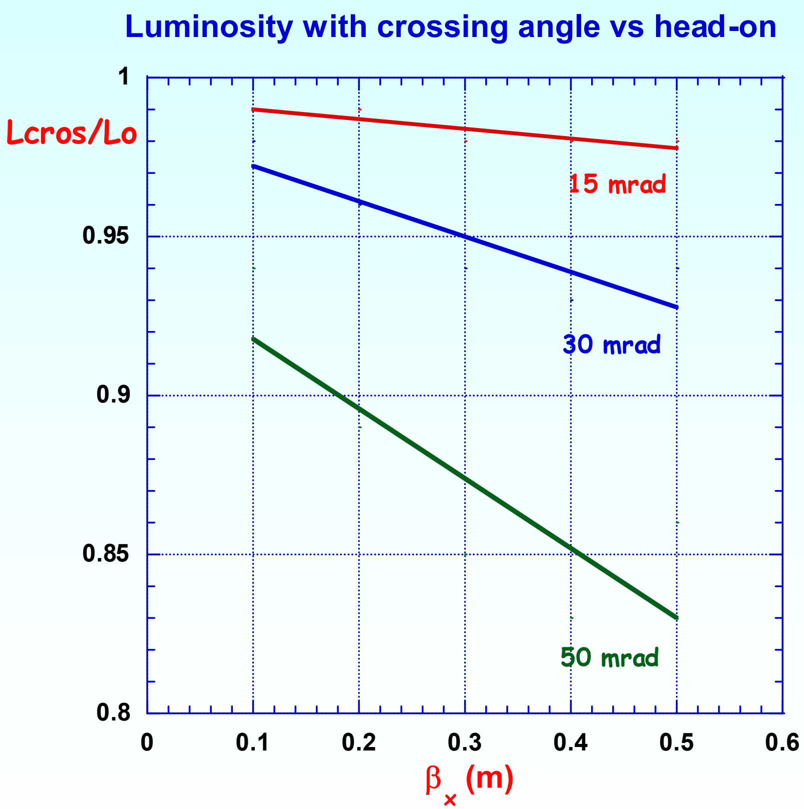
For γ >> tg (θ/2). σ_z = bunch length, θ = crossing angle

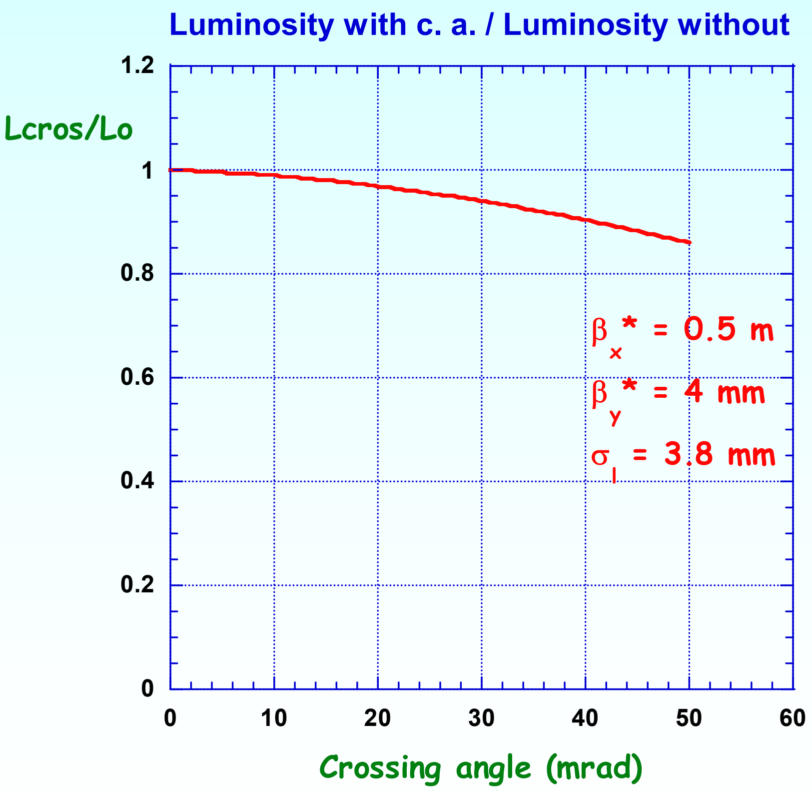
P. Raimondi, M. Zobov, “Tune shift in beam-beam collisions with a crossing angle”, DAFNE Tech. Note G-58, Apr. 2003

Luminosity with crossing angle

Luminosity reduction, due to the crossing angle, versus β_x.

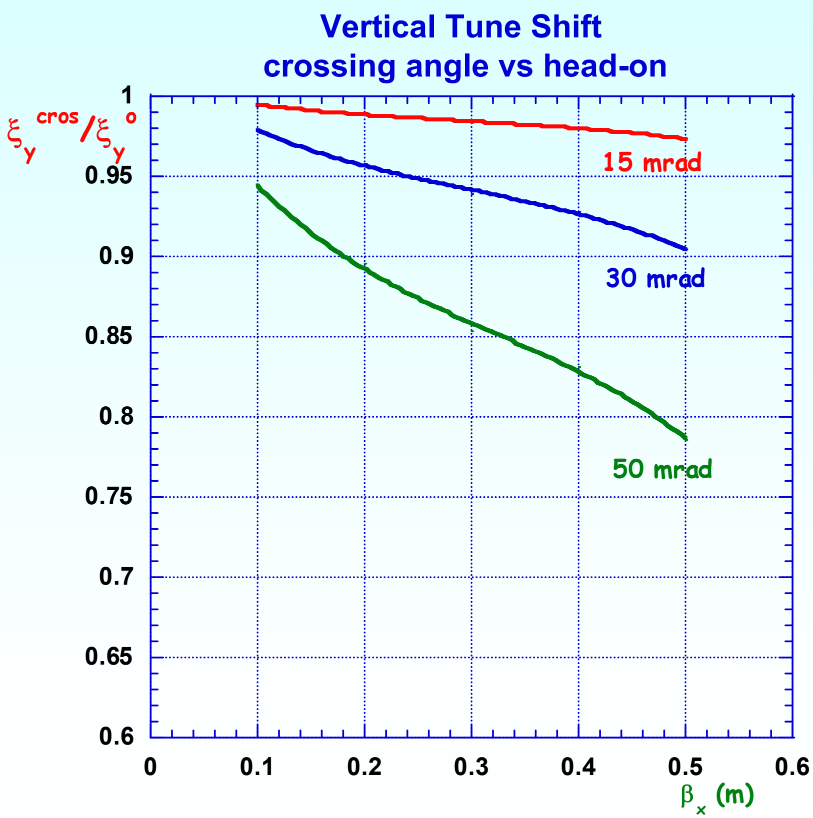
Y scale : L^{cros} over $L^{head\ on}$, with $L^{head\ on} = 10^{34}$

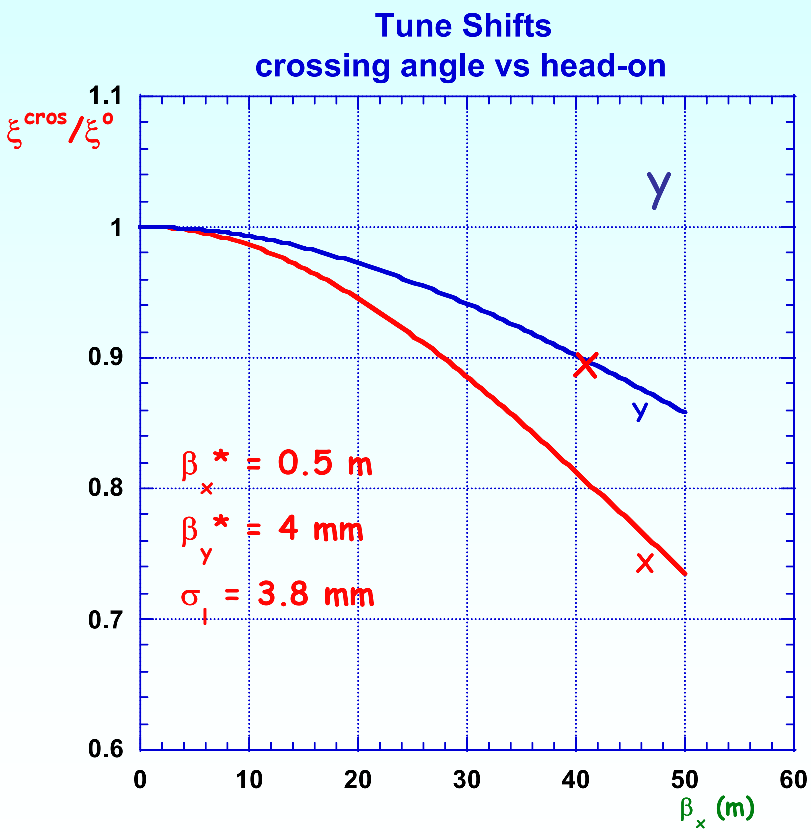




Tune shifts with crossing angle (cont'd)

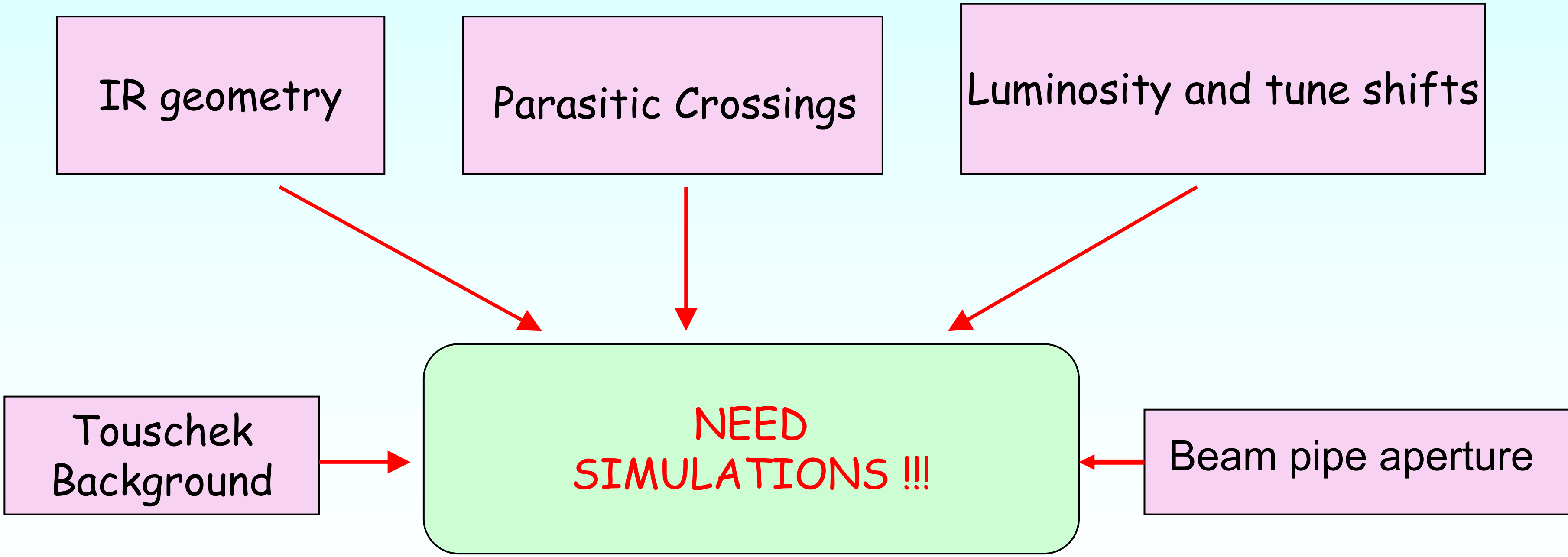
Tune shifts reduction, due to crossing angle, vs. β_x* for different crossing angles. Horizontal ξ drops faster. Beam footprint is smaller, we can increase L by increasing the current.





Conclusions on crossing angle choice

The crossing angle should be chosen by considering:



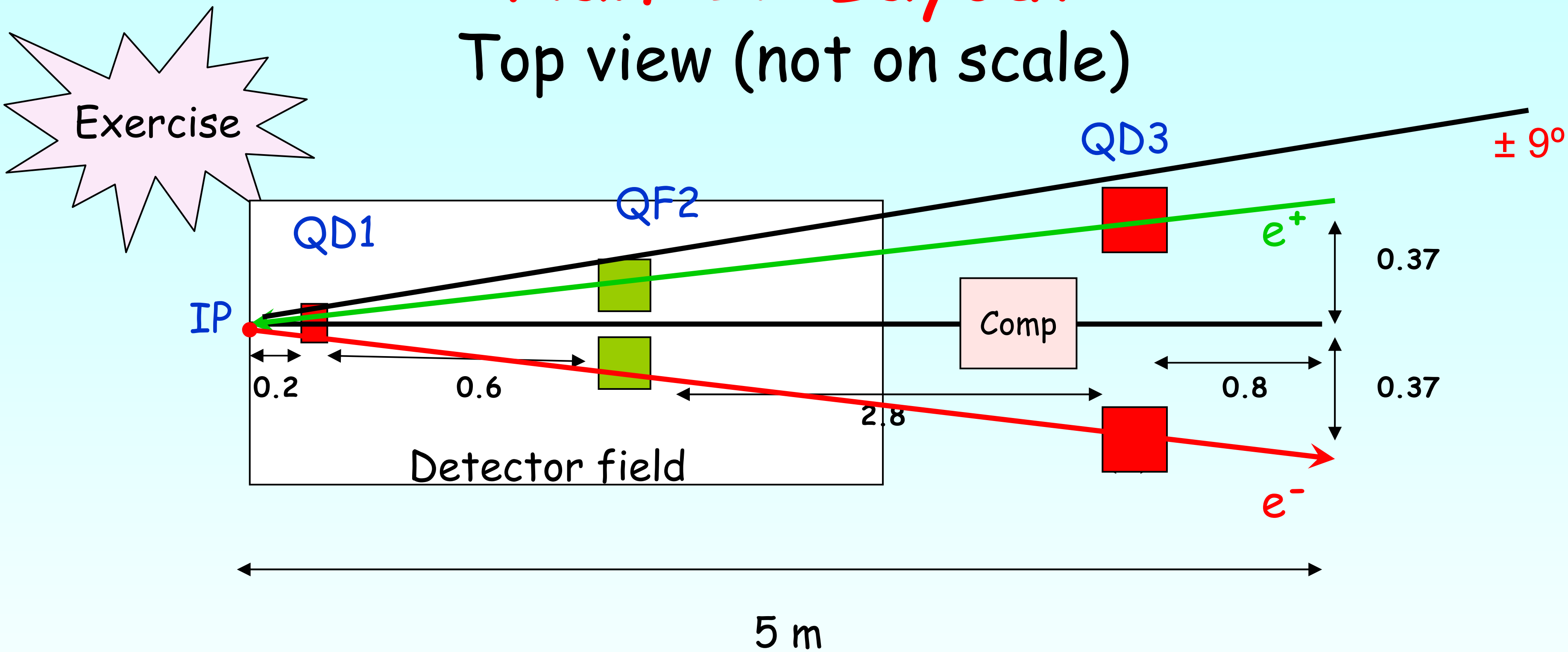
IR Layout

- Try to separate the beamlines asap
- Whole IR is 10 m long, quads are 0.2 m long
- IR solid angle: cone ± 9°
- QD1 and QF2 need to be pm type, QD3 could be em
- SC quads ???

- Preliminary design with:
  - horizontal half crossing angle: 30 mrad
  - two quadrupole triplets DFD
  - QD1 at 0.2 m from IP, shared by both beams (beams are off-axis in this quad)
  - QF2 : on separate beamline (x_{sep} ~ 14. cm, beam is on-axis)
  - QD3 : on separate beamline (x_{sep} ~ 60. cm, beam is on-axis)

Half-IR Layout

Top view (not on scale)



With ± $10\sigma_x$ clearance, ± 9° cone, ±30 mrad angle:

QD1: L= 20 cm, pole radius = 1.5 cm, R_{ext} = 3 cm, pm thickness= 1.5 cm

small

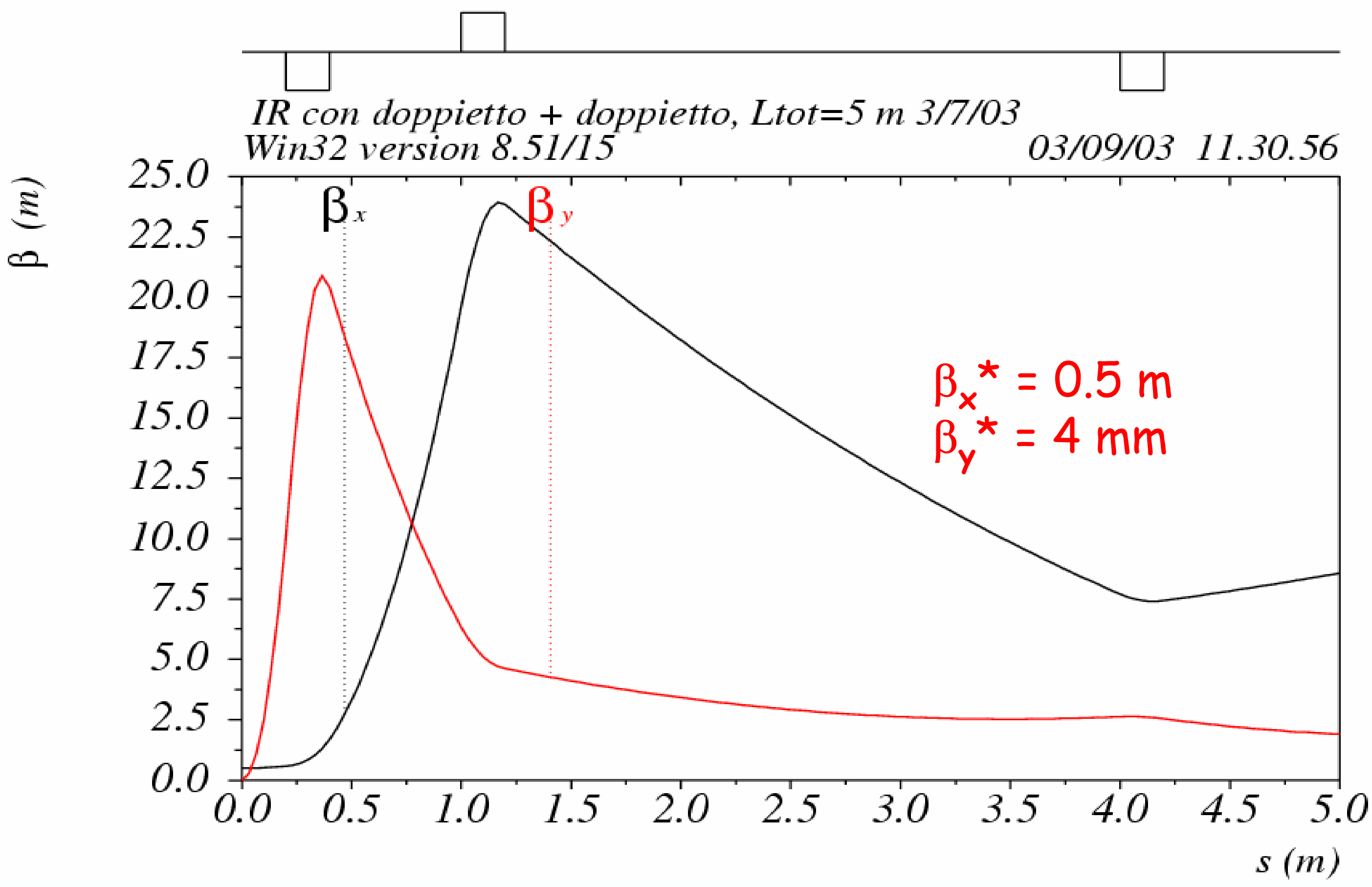
QF2: L= 20 cm, pole radius = 11 cm, R_{ext} = 16 cm, pm thickness= 1.5 cm, 4 cm space between 2 quads

QD3: L= 20 cm, pole radius = 15 cm , R_{ext} = 63 cm, 25 cm space between 2 quads

IR Beam Parameters (preliminary)

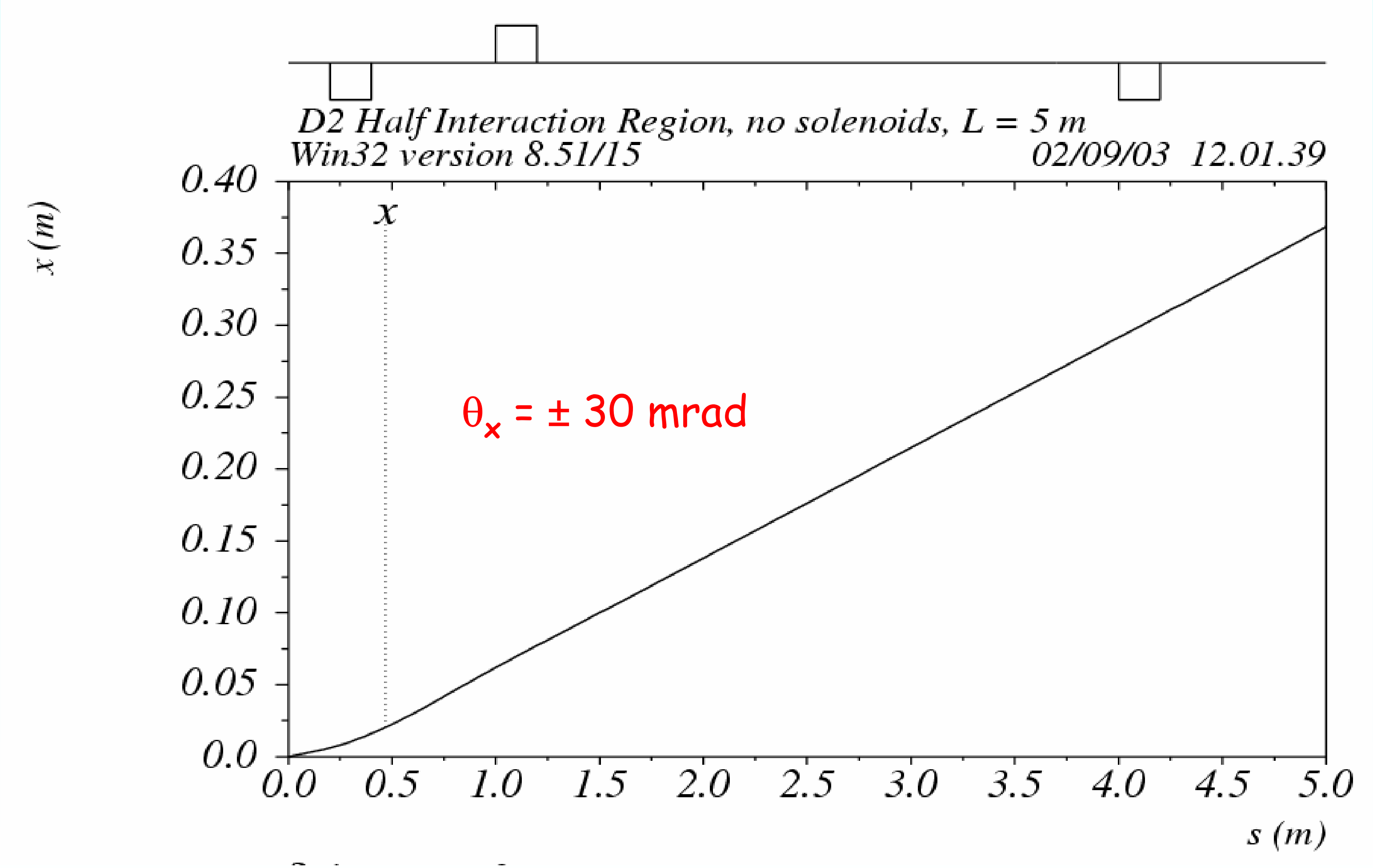
- Horizontal β^* = 50 cm
- Vertical β^* = 4 mm, given the present estimate on the bunch length (3.8 mm)
- Horizontal crossing angle = ± 30 mrad
- First parasitic crossing at 30 cm from IP
- Beams separation at the IR end is 74 cm

Half-IR Optical Functions



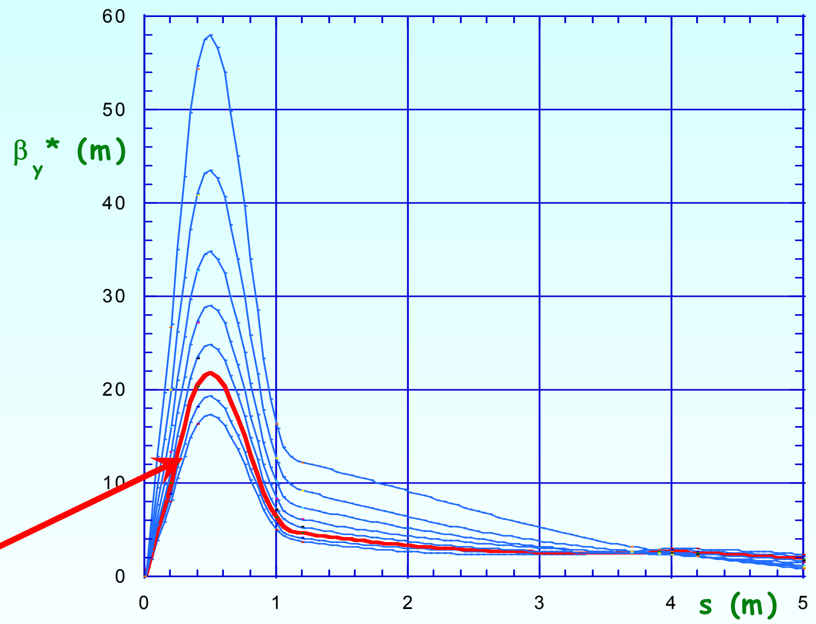
$\beta_x^* = 0.5$ m
$\beta_y^* = 4$ mm

Half-IR One Beam Trajectory



IR Flexibility

- Checked IR flexibility versus β_y* change (1.5 mm to 5 mm)
- Low-β: keeping same quads strengths. β_y at the IR end (0.7 to 2 m), easily matchable with cell quads or with QD3.



β_y* = 4 mm is red line

Coupling correction

- Depends on detector field. Needs 8 parameters to decouple whole IR matrix.

- DAΦNE scheme (all 6 IR quads embedded in B_s):
  2 compensating solenoids + 6 quadrupole tilts +
  skew quadrupoles outside IR (fine adjustments)

- New IR scheme (4 IR quads embedded in B_s):
  2 compensating solenoids + 4 quadrupole tilts +
  1 skew quadrupole in IR (can be a tilt in QD3) +
  skew quadrupoles outside IR (fine adjustments)

To Do List (practically everything...)

- Technical design
- Engineering studies of pm quads
- Chromaticity correction study
- Coupling correction scheme
- Background evaluation
- Beam pipe design
- Vacuum design
- Impedance budget
- Trapped HOM study
- Temperature control
- ......