Intermediate β^* optics for ALICE

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Thanks to J.Jowett, H.Burkhardt

High β on IR2 and IR1/IR5

A brief overview

Requested for ALICE

- β^* of 30-50 m
- $\Delta\mu_{x,y}^{RP}$ close to 90°
- RP's position to be defined
- Consistent with high luminosity in other IPs
- 25 ns bunch spacing
- Crossing Angle
- **Long term runs**

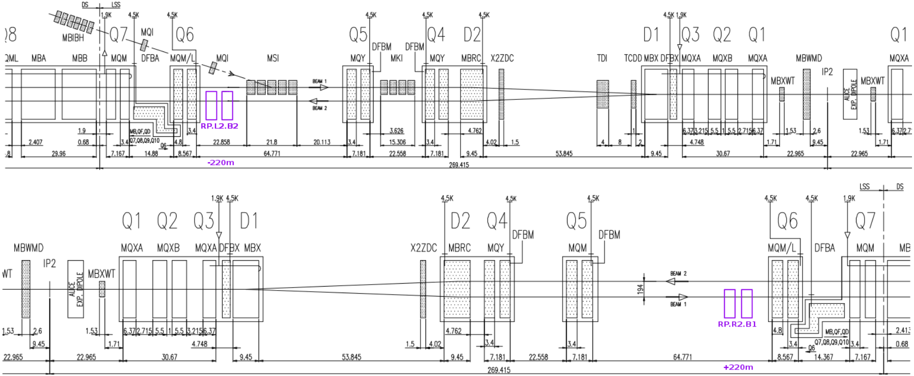
H. Burkhardt for IR1/IR5 :

- β^* =90 m, 500 m, 1000 m
- $\Delta\mu_x^{RP} \approx 180°$, $\Delta\mu_y^{RP} \approx 90°$
- RPs at $\pm$ 220/240 m from IP
- Low luminosity
- 525 ns bunch spacing
- Head-on Collisions, No Crossing Angle
- **Special runs ($\approx$ 8 days/year)**

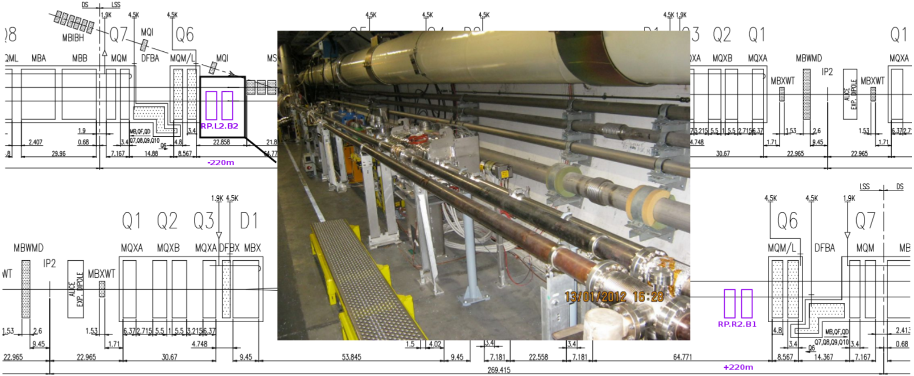
First Study - $\beta^* = 30\,\mathrm{m}$

- Start with intermediate value : $\beta^* = 30\,\mathrm{m}$
- Assume RPs at 220 m left and right of IP2
- Phase advance of 90° not feasible $\rightarrow$ Compromise 120°
  - Sufficiently far from point to point focusing (180°)
  - Reconstruction via multiple successive detectors
  - OK with experimentalists
- Rest : usual constraints - quad limitations, B1/B2 ratio limit, α, β, D, at IP and start/end of IR, aperture
- Matching with all bumps off

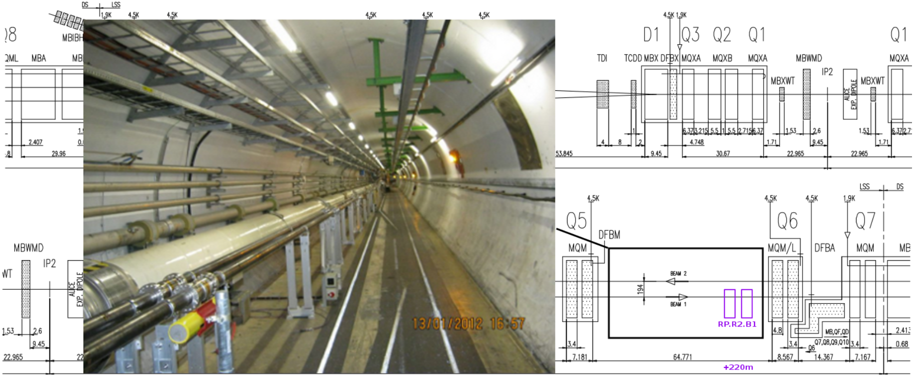
Roman Pot Placement



Roman Pot Placement

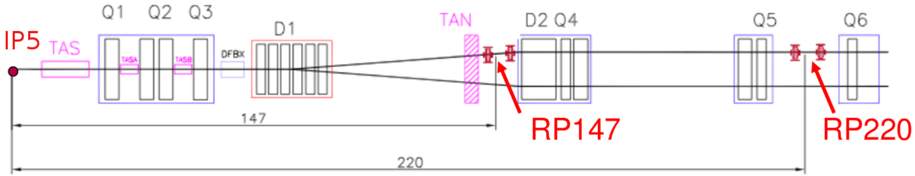


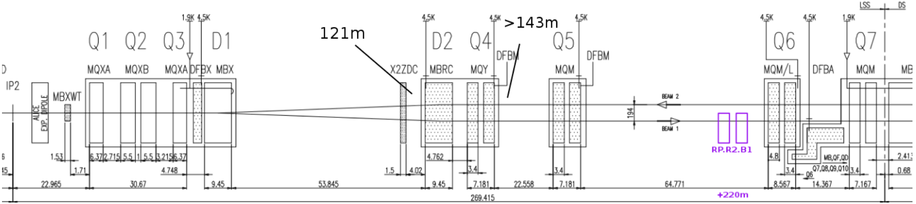
Roman Pot Placement



Roman Pots

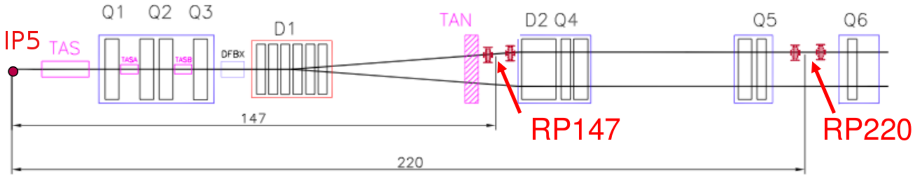
Positioning for TOTEM & ALICE

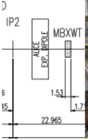


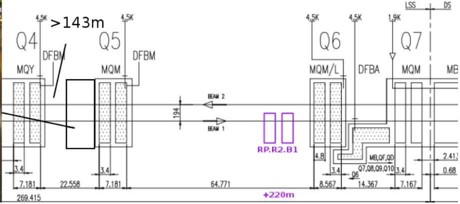


Roman Pots

Positioning for TOTEM & ALICE - right hand side

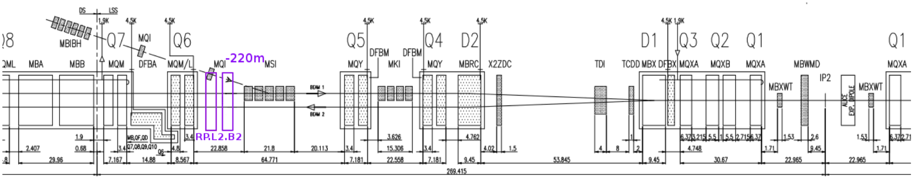






Roman Pots

Positioning - left hand side

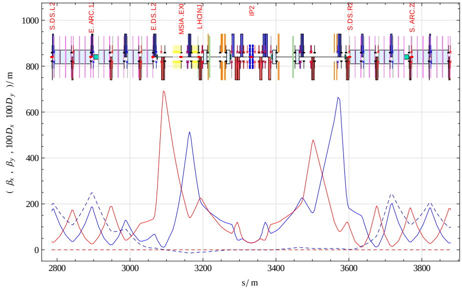


- Q4-Q5 area blocked by injection kicker
- RP left of Q5 ?

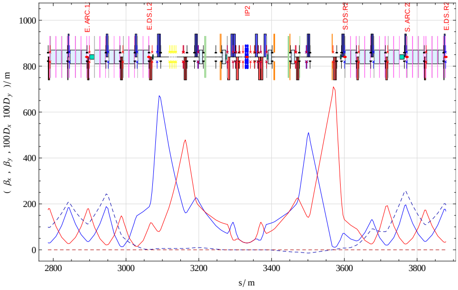
30 m optics for IR2

Beta functions

Beam 1



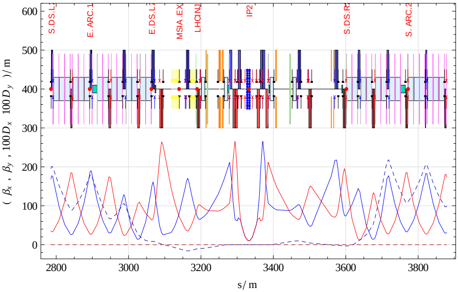
Beam 2



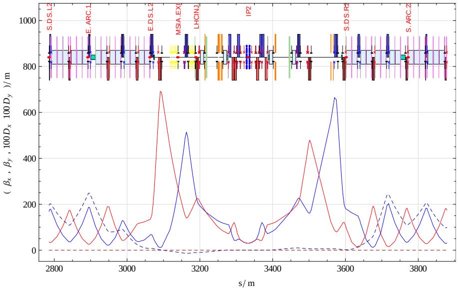
30 m optics for IR2

Beta functions

Beam 1 at 10 m



Beam 1 at 30 m



30 m optics for IR2

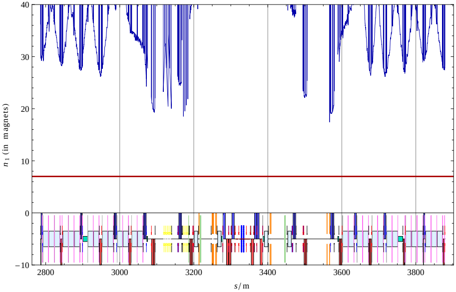
Optics Parameters

IP			RPs		
Parameter	Unit	Value	Parameter	Unit	Value
ϵ_N	μm	3.75	β_x	m	496.2
$\beta^*_{x,y}$	m	30	β_y	m	155.8
$\alpha^*_{x,y}$		0	σ_x	μm	499
$D^*_{x,y}$	m	0	σ_y	μm	280
$\sigma_{x,y}$	μm	123	$\Delta\mu_{x,y}$	$2\,\pi$	1/3

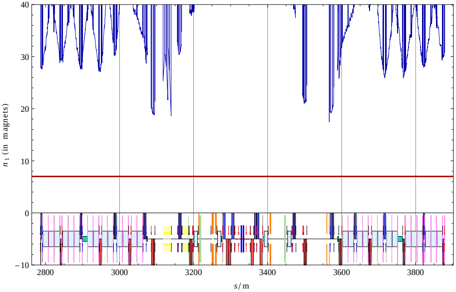
30 m optics for IR2

Aperture for a flat machine

Beam 1



Beam 2



- Min. value around 17.4 for both Beams
- Re-check with new ALICE beam pipe

Tune compensation

TABLE: Phase shifts between IP and Q6 (230 m right of IP for Beam 1)

TOTEM			ALICE		
β^* (m)	$\Delta\mu_x$	$\Delta\mu_y$	β^* (m)	$\Delta\mu_x$	$\Delta\mu_y$
0.55	0.54	0.28	10	0.55	0.52
90	0.51	0.25	30	0.34	0.34
Difference	0.03	0.03		0.21	0.18
Compensation	0.23	0.06		0.47	0.41

- Need for higher compensation for IR2 is evident
- IR1/IR5 : Good experience with ramping the arc quads (globally)
- Comparable compensation for 500 m on ALFA and TOTEM
- For high luminosity : phase advance constraints between IR1/IR5

Crossing Angle

- Vertical crossing angle, max. $\pm 150\,\mu$rad
- Results from external bumps and ALICE spectrometer bump
  Half crossing angle for protons at 7 TeV :

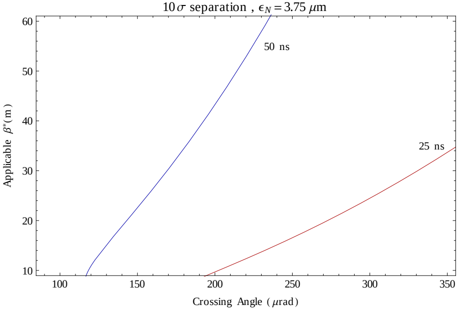
$$\theta_{yc} = \pm 70\,\mu\text{rad} + \theta_{y,\text{ext}} \tag{1}$$

- Required angle for high β depends on :
  - bunch spacing,
  - required separation at first parasitic beam encounter,
  - emittance

Crossing Angle and β^*

What is the highest applicable β^* value in function of crossing angle ?

In function of bunch spacing



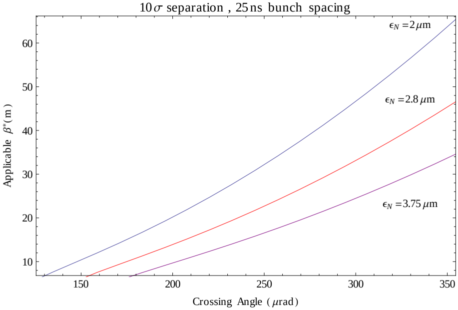
- 25 ns much harder than 50 ns
- quadratic dependancy
- For 30 m and 10 σ separation :

$$\theta_{yc} = \begin{cases} \pm 165.4\,\mu\text{rad} & \text{for } 25\,\text{ns} \\ \pm 84.6\ \ \mu\text{rad} & \text{for } 50\,\text{ns} \end{cases} \tag{2}$$

Crossing Angle and β^*

What is the highest applicable β^* value in function of crossing angle ?

In function of emittance



- β^* increases with decreasing emittance
- For 30 m and 10 σ separation :

$$\begin{cases} \pm 165.4\,\mu\text{rad} & \text{for } 3.75\,\mu\text{m} \\ \pm 143.0\,\mu\text{rad} & \text{for } 2.8\,\mu\text{m} \\ \pm 120.8\ \ \mu\text{rad} & \text{for } 2\,\mu\text{m} \end{cases} \tag{3}$$

Crossing Angle and β^*

Most conservative consideration

- Normalized Emittance 3.75 μm rad
- Bunch Spacing 25 ns
- Separation at first parasitic beam encounter $> 10\,\sigma$

- Required half-crossing angle for 30 m :

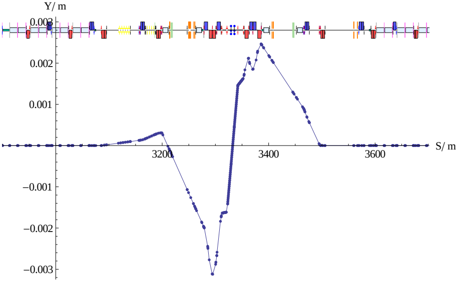
$$\theta_{yc} = \pm 165.4\,\mu\text{rad} = \pm(\theta_{\text{spec}} + 95.4)\,\mu\text{rad} \tag{4}$$

- Not feasible with present magnets
- Let's check the separation for $\pm 150\,\mu$rad

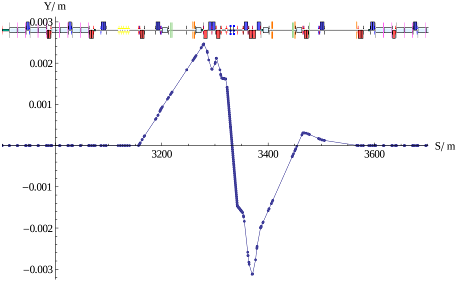
Crossing Angle for the 30 m optics

Crossing Scheme for $\theta_{yc} = \pm 150\,\mu$rad

Beam 1



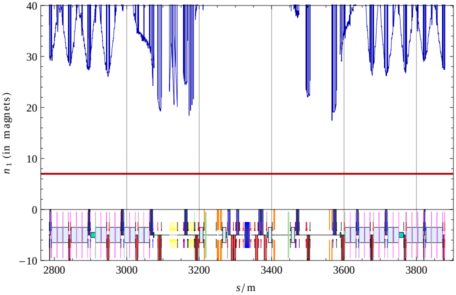
Beam 2



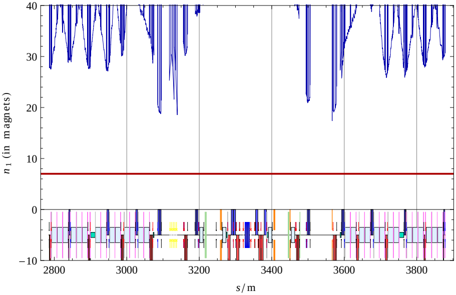
Crossing Angle for the 30 m optics

Aperture with crossing angle

Beam 1

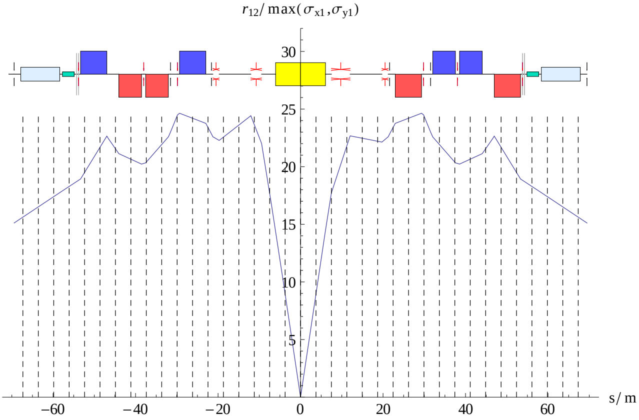


Beam 2



Crossing Angle for the 30 m optics

Separation for $\theta_{yc} = \pm 150\,\mu$rad and $\epsilon_N = 3.75\,\mu$m



- Around $9\,\sigma$ separation at first parasitic beam encounter

Crossing Angle
Validation

Use a more optimistic model

- Separation of $9\,\sigma$ for DR emittance
- For 50 ns the LHC runs with emittances down to $2\,\mu$m
- Assuming to reach the same at 25 ns, separation lies in between 9σ (for $3.75\,\mu$m) and more than $12\,\sigma$ (for $2\,\mu$m)
- Limit for $10\,\sigma$ is $\epsilon_N = 3.1\,\mu$m

Higher β^*

- Higher β^* might be reachable
- Phase advance will be closer to $\frac{\pi}{2}$
- But : Crossing angle must be higher or emittance smaller
- With $\theta_{yc} = \pm 150\,\mu\text{rad}$, separation of $10\,\sigma$ and $\epsilon_N = 2\,\mu\text{m}$:

$$\beta^*(\text{max}) = 46\,\text{m} \tag{5}$$

- Additional horizontal crossing angle ?

Diffractive physics

The aim of high β

We want to measure :

- Diffraction angle on IP $\theta^*_{x,y}$
- Momentum loss $\xi = \frac{\Delta p}{p}$

At position s (e.g. at the RPs), we have

$$\begin{pmatrix} x \\ \theta_x \\ y \\ \theta_y \\ \xi \end{pmatrix} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & D_y \\ 0 & 0 & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \theta^*_x \\ y^* \\ \theta^*_y \\ \xi \end{pmatrix} \tag{6}$$

Diffractive physics

Matrix Elements

In our special case we have (in one transverse direction)

$$\begin{pmatrix} v & L \\ v' & L' \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta}{\beta^*}} \cos \Delta\mu & \sqrt{\beta^* \, \beta} \sin \Delta\mu \\ -\frac{1}{\sqrt{\beta \, \beta^*}} (\alpha \cos \Delta\mu + \sin \Delta\mu) & \sqrt{\frac{\beta^*}{\beta}} (\cos \Delta\mu - \alpha \sin \Delta\mu) \end{pmatrix} \tag{7}$$

- Fully determined by the optics
- We know all the matrix elements

Diffractive physics
Transfer Matrix

	RP1 (150m)		RP2 (220 m)	
	x	y	x	y
L(m)	75.8	90.0	105.6	59.2
L'	-0.60	1.31	0.82	-1.10
v	-0.59	-0.89	-2.03	-1.14
$10^2 \cdot v'$ (m^{-1})	-0.84	-2.4	2.5	-0.43
$10^2 \cdot D$(m)	8.33	-2.87	5.82	-1.59
$10^4 \cdot D'$	-12.97	-4.14	-0.06	3.47

- v and v' are 0 for $\Delta\mu = \pi/2$
- We will have to consider x^*, since we don't have $\pi/2$

Diffractive Physics

Acceptance Plots

$$\begin{pmatrix} x \\ \theta_x \\ y \\ \theta_y \\ \xi \end{pmatrix} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & D_y \\ 0 & 0 & v'_y & L'_y & D'_y \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \theta^*_x \\ y^* \\ \theta^*_y \\ \xi \end{pmatrix} \tag{8}$$

- Acceptance plots will show the detectable range of ξ and θ for the given optics, defined by the transition matrix
- With two RP stations we can reconstruct the parameters
- Reconstruction algorithm will be developed

De-Squeeze

- Injection at 10 m
- De-Squeeze from nominal optics to high β
- Several intermediate steps for smooth transition
- Not matched yet

Summary

- First study on high β optics for IR2
- Machine is compatible to 30 m
- High luminosity running possible (with low emittance)
- Two roman pot stations, prospectively at 150 and 220 m left and right of IP
- De-squeeze and acceptance plots will follow
- Check tune compensation

Open questions

Tune compensation strategy

- What should be the phase advance between IR1 and IR5 ?

Crossing angle

- Horizontal crossing angle ?