High-beta optics plans

- **introduction, schedule, constraints**
- **strategy for β* = 90 m and β* = 500 m**
- **longer term, studies required for LS1 and beyond**

Acknowledgment :
S. Redaelli, G. Müller, J. Wenninger (on-line, commissioning)
M. Giovannozzi, W. Herr, S. White, S. Cavalier (optics); R. Tomas, G. Vanbavinckhove (β-meas+corr)
Operations, TOTEM and ALFA teams

Planning and requests 2012

Priority : maximize Luminosity

double L_{peak} , $\int Ldt \geq 15\ fb^{-1}$

Baseline : 4 TeV, 50 ns

IP1/5 $\beta^* = 60$ cm (backup 70 - 90 cm)

ALICE & LHCB $\beta^* = 3$m

~ 129 proton running

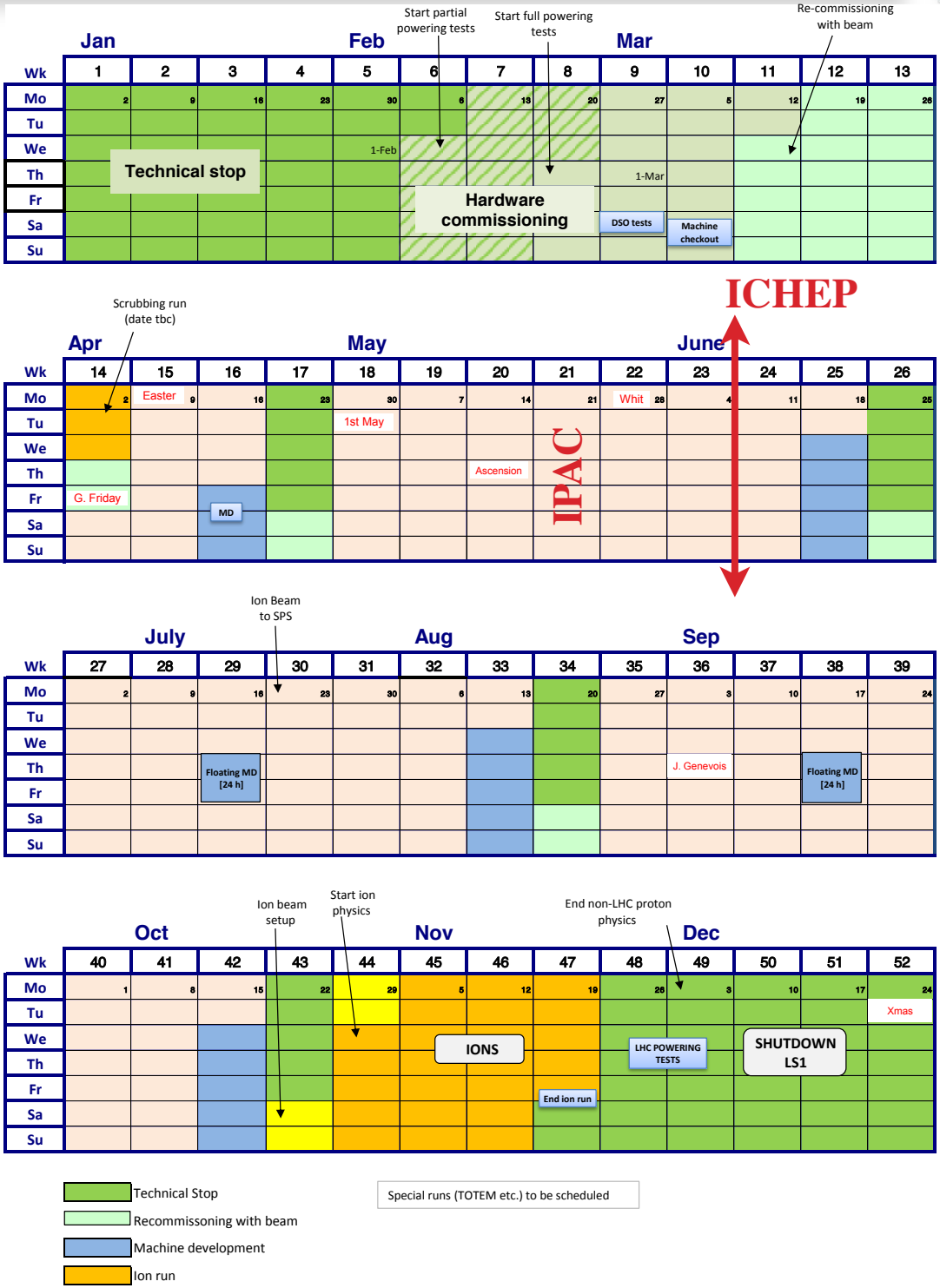
~ 18+4 days of MD

~ 8 days special runs

"to be scheduled"

VdM, Roman Pots and high-β^*

$\beta^* =$ 90 m and 500 m



β-function, phase advance and tune

relation between phase advance Φ(s), β(s) and **tune** of the ring Q = Φ / 2π

$$\Phi(s) = \int \frac{1}{\beta(s)}\, ds$$

integrated symmetrically around the minimum

$$\Phi(s) = \int_{s_0-\ell}^{s_0+\ell} \frac{1}{\beta(s)}\, ds = 2\arctan\left(\frac{\ell}{\beta^*}\right)$$

a low β insertion contributes **0.5 in tune** (π in phase)

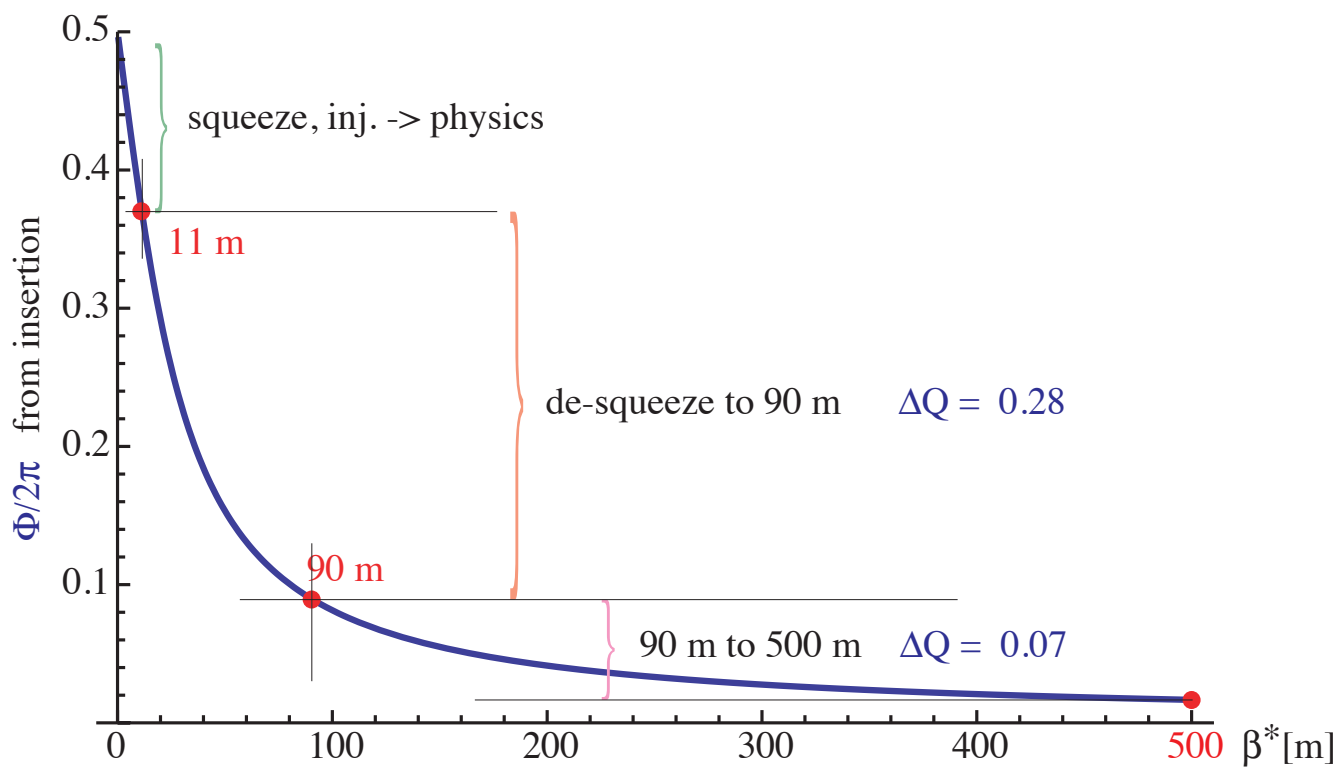
where low-β* means β* << ℓ

and **0** for high-β* β* >> ℓ

for the LHC with

ℓ = 26.15 m from

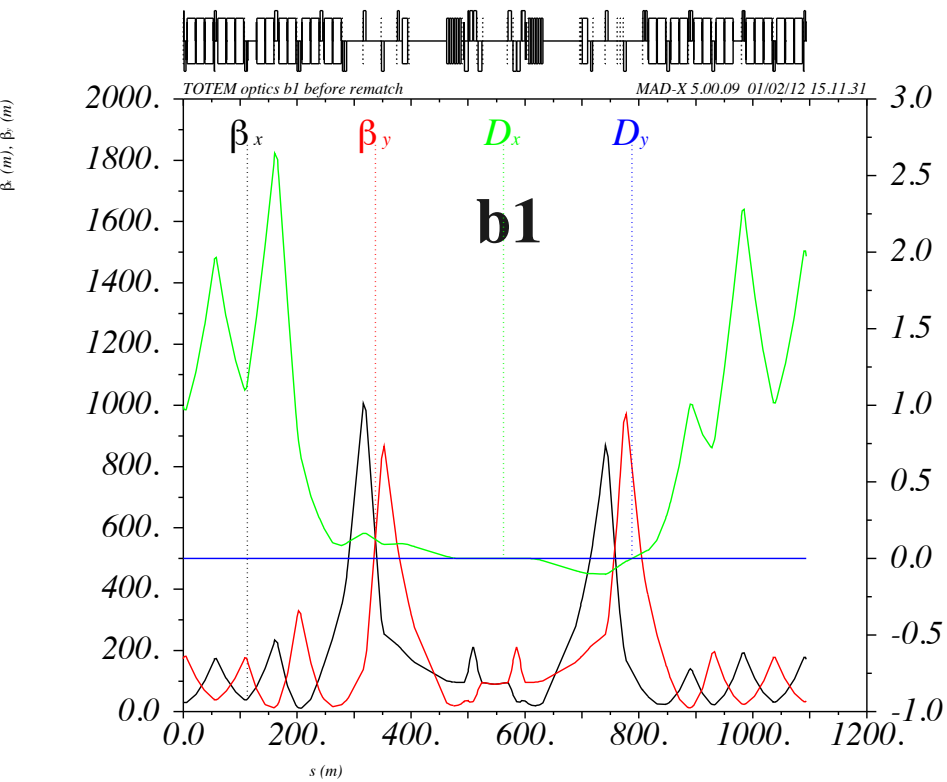
IP to centre of Q1

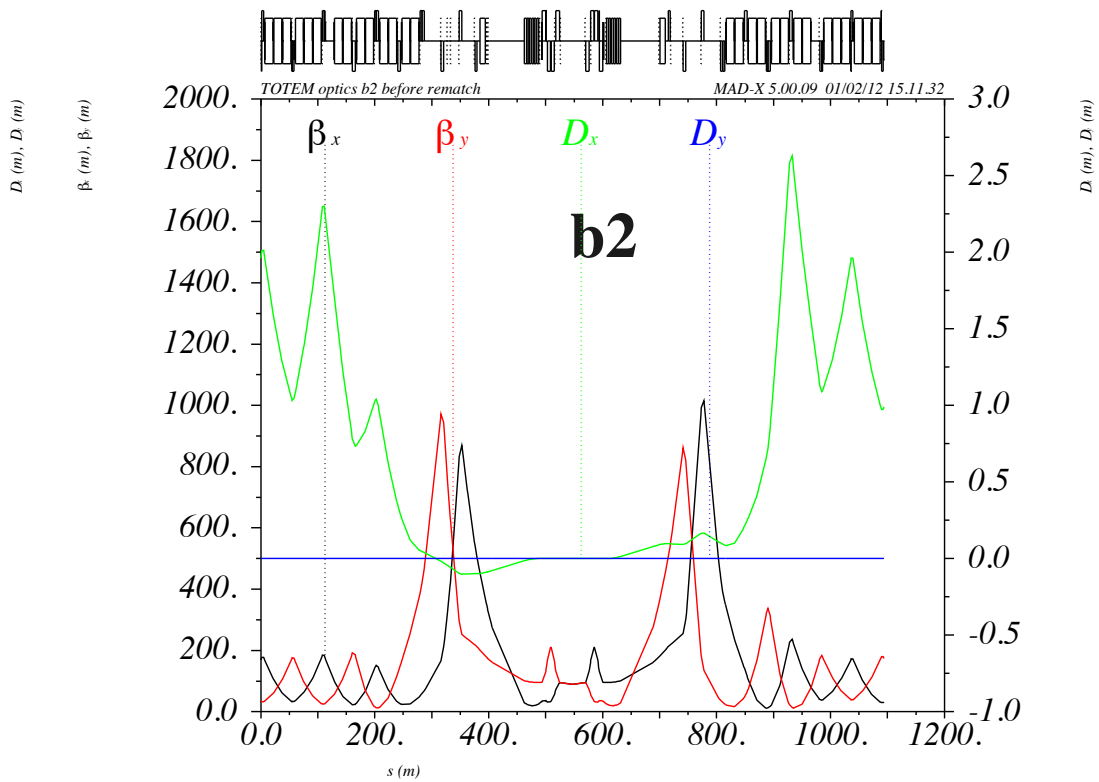


Major tune change in de-squeeze. **In triplet mostly between injection and 90 m**

90 m optics

shown for IP5 with π in *x* and π / 2 in *y* to roman pot at 220 m






```
muxrpvb6r5b1 =  180°
muyrpvb6r5b1 =   90°   Ly = 263 m
```
ΔQx = 0.222 ΔQy = 0.055 βy = 769.53 m @ RP 220 m

```
muxrpvb6l5b2 =  180°
muyrpvb6l5b2 =   90°    Ly = 263 m
```
ΔQx = 0.220 ΔQy = 0.053 βy = 769.49 m @ RP 220 m

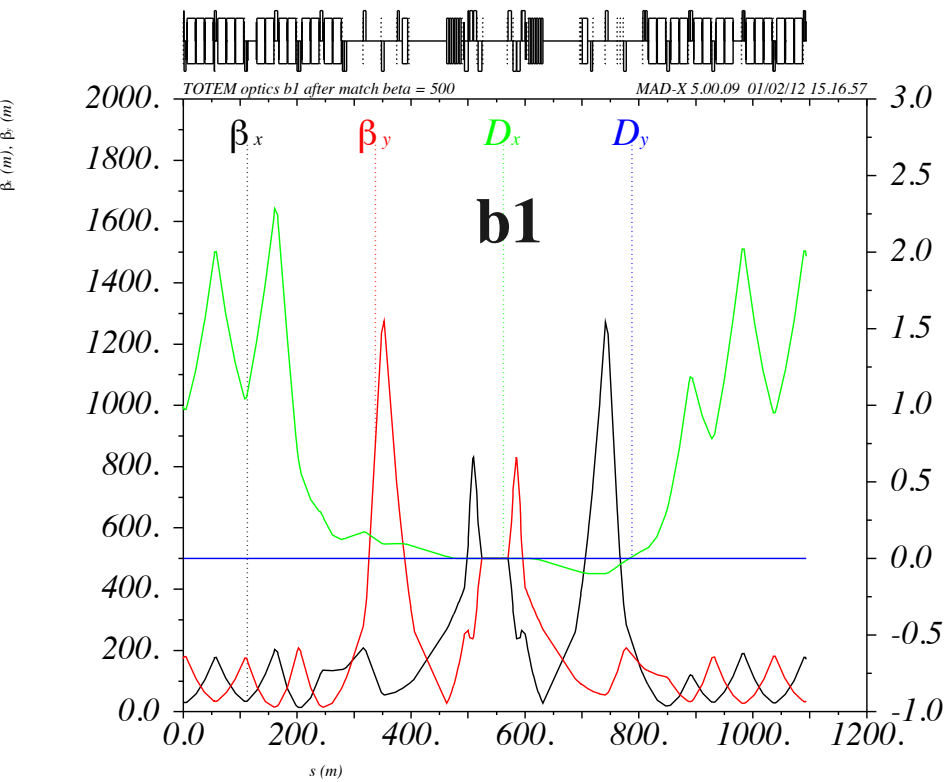
With current cabling required to have quad strength ratios within **0.5 < b1/b2 < 2.0**

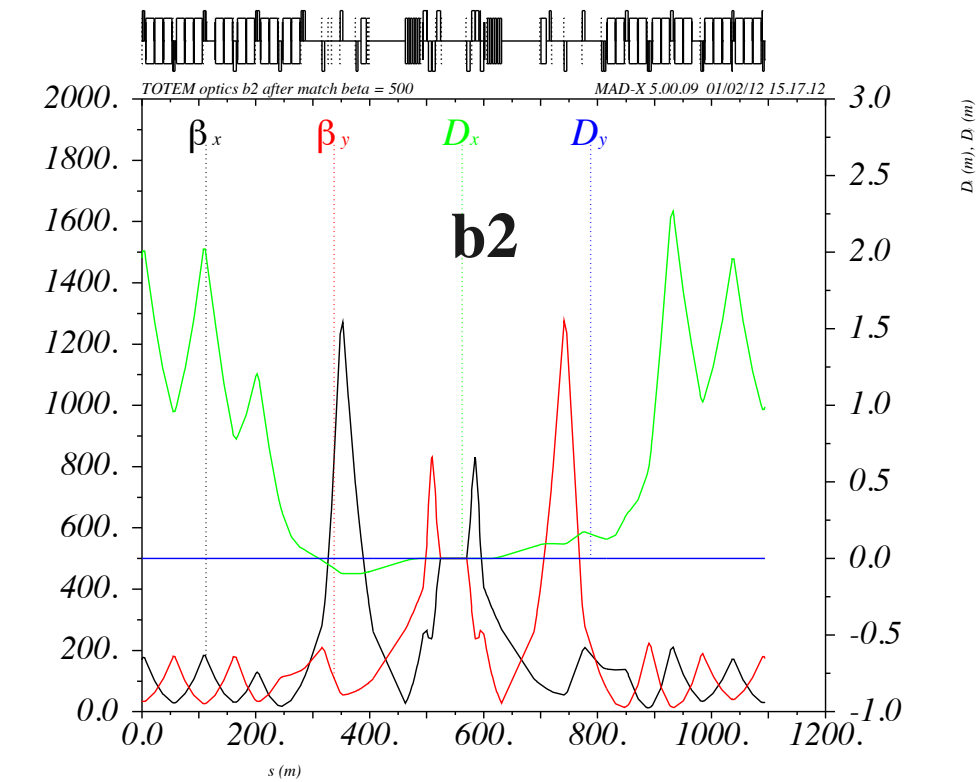
kq4.l5b1/	kq4.l5b2=	0.970945
kq5.l5b1/	kq5.l5b2=	1.04019
kq6.l5b1/	kq6.l5b2=	1.05394
kq7.l5b1/	kq7.l5b2=	1.58160
kq8.l5b1/	kq8.l5b2=	1.33077
kq9.l5b1/	kq9.l5b2=	1.03071
kq10.l5b1/	kq10.l5b2=	0.94919

kq4.r5b1/	kq4.r5b2=	1.10542
kq5.r5b1/	kq5.r5b2=	0.961367
kq6.r5b1/	kq6.r5b2=	0.938599
kq7.r5b1/	kq7.r5b2=	0.525421
kq8.r5b1/	kq8.r5b2=	0.571775
kq9.r5b1/	kq9.r5b2=	0.964224
kq10.r5b1/	kq10.r5b2=	1.05372

500 m optics for 2012, preliminary

shown for IP5 with $\pi / 2$ in y to roman pot at 220 m





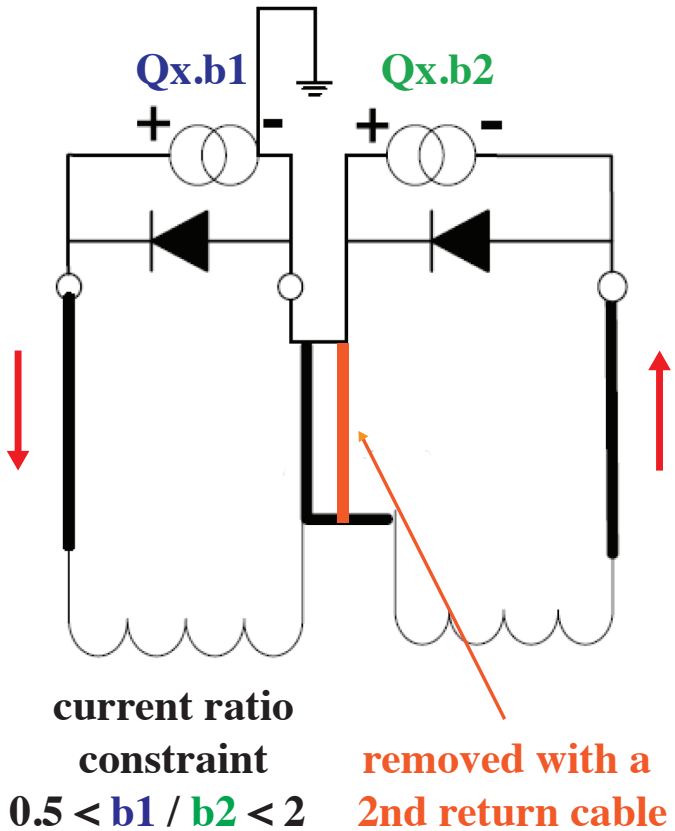

```
muxrpvb6r5b1 =  176°
muyrpvb6r5b1 =   90°   Ly = 284 m
```
$\Delta Qx = 0.222$ $\Delta Qy = 0.229$ $\beta y =$ 160.88 m @ RP 220 m

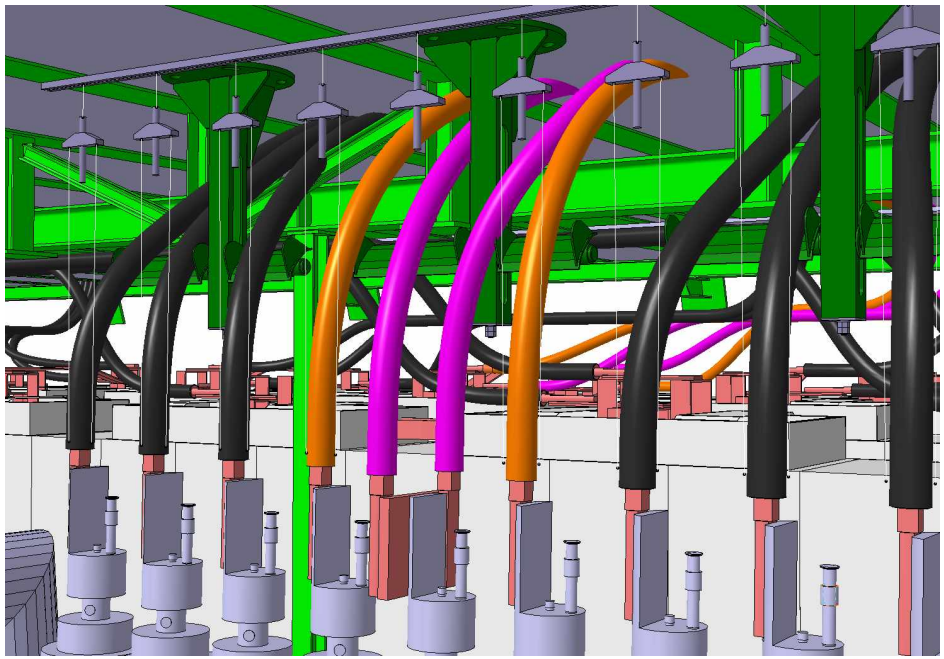
```
muxrpvb6l5b2 =  176°
muyrpvb6l5b2 =   90°   Ly = 284 m
```
$\Delta Qx = 0.212$ $\Delta Qy = 0.229$ $\beta y =$ 160.996 m @ RP 220 m

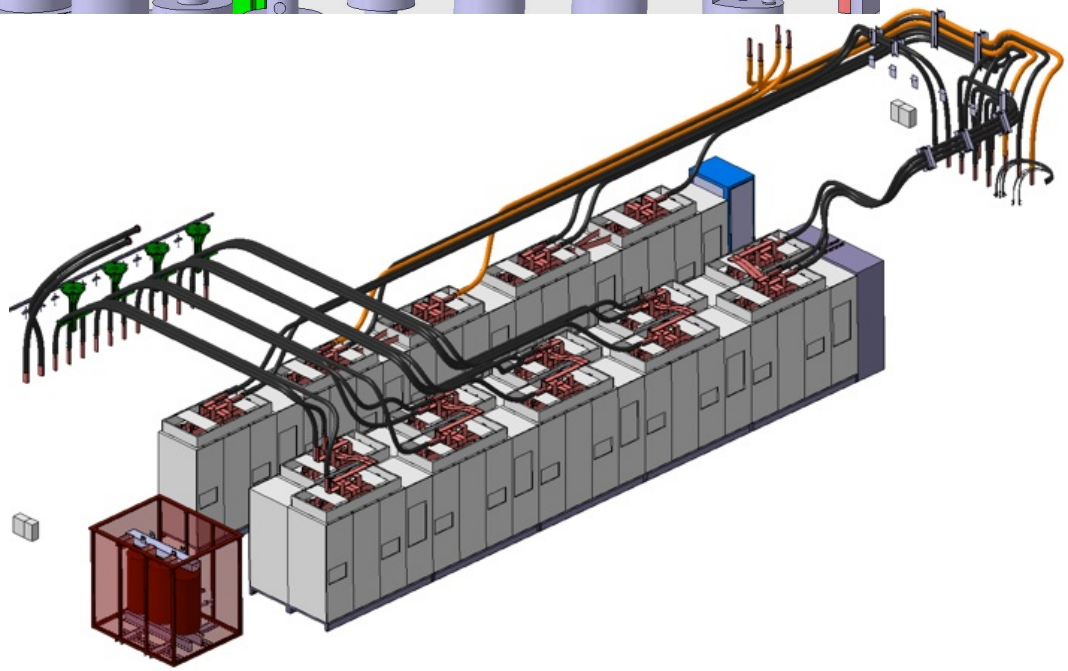
With current cabling required to have quad strength ratios within **0.5 < b1/b2 < 2.0**

kq4.l5b1/	kq4.l5b2=	1.09461	kq4.r5b1/	kq4.r5b2=	0.90464
kq5.l5b1/	kq5.l5b2=	1.00453	kq5.r5b1/	kq5.r5b2=	0.992453
kq6.l5b1/	kq6.l5b2=	0.99592	kq6.r5b1/	kq6.r5b2=	1.00846
kq7.l5b1/	kq7.l5b2=	1.79995	kq7.r5b1/	kq7.r5b2=	0.555572
kq8.l5b1/	kq8.l5b2=	1.67941	kq8.r5b1/	kq8.r5b2=	0.587201
kq9.l5b1/	kq9.l5b2=	1.12708	kq9.r5b1/	kq9.r5b2=	0.874162
kq10.l5b1/	kq10.l5b2=	1.11807	kq10.r5b1/	kq10.r5b2=	0.889277

The current ratio constraint



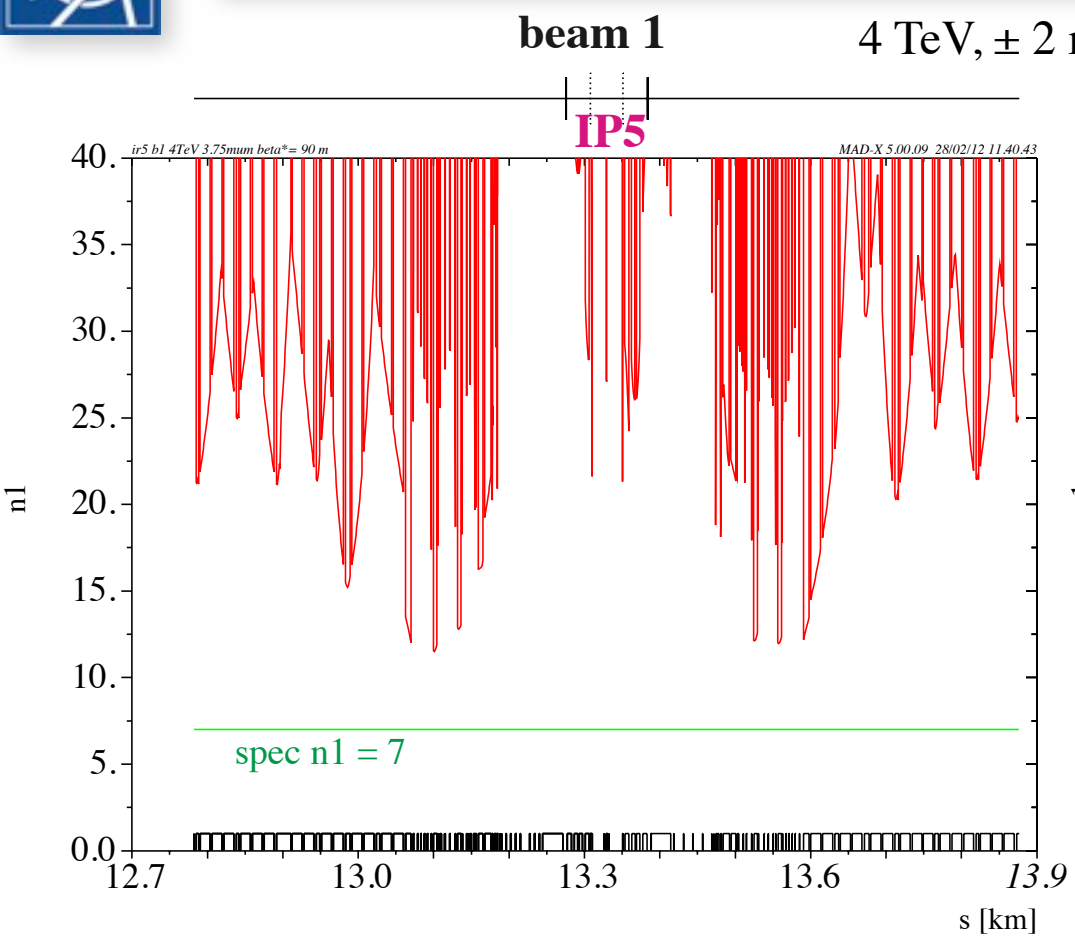


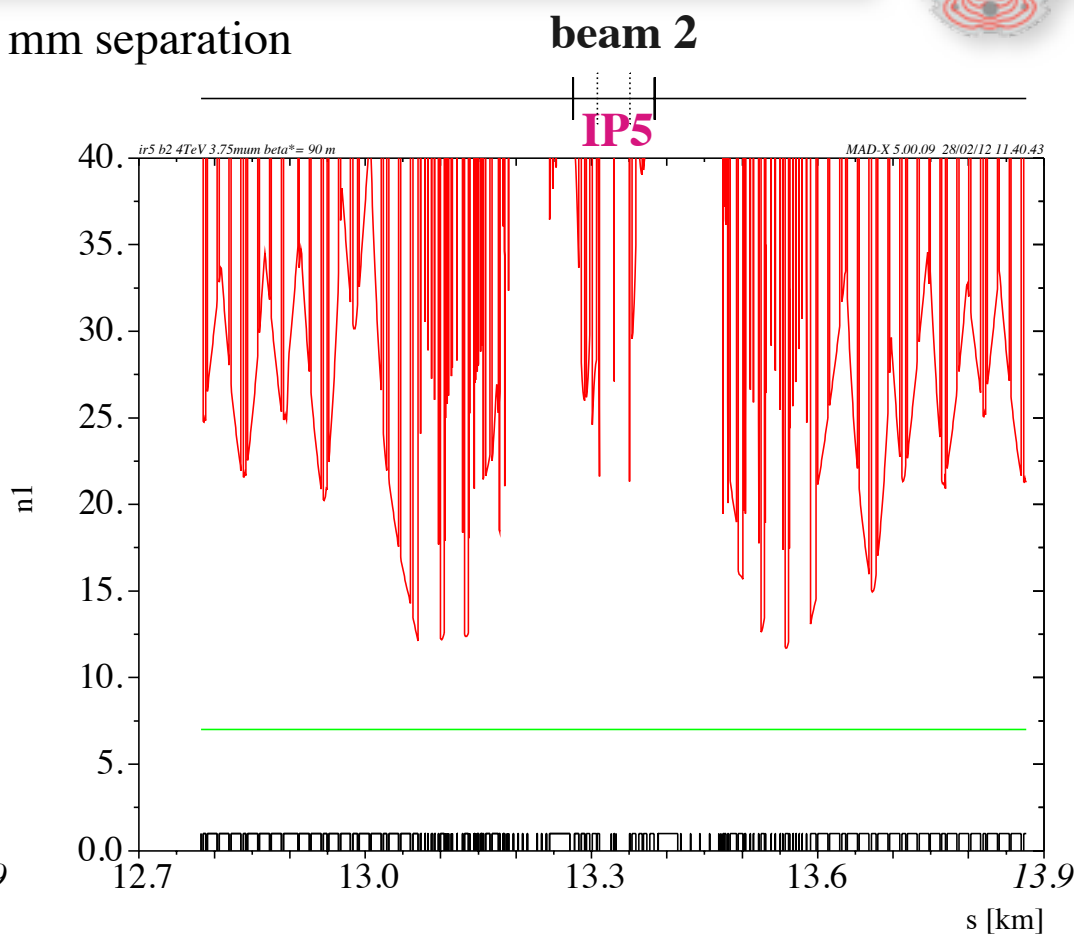


D. Nisbet LMC 15/4/2009
F. Duval LMC#31 October 2009; cost ~ 100 kCHF
my proposal, do for Q4, Q7, Q8 L/R, LMC#32 10/2009

Installation in LS1 : implies to buy cables by June 2012 latest

Aperture at β* = 90 m





beam 1 $n1_{min} = 11.506$ at Q6.L

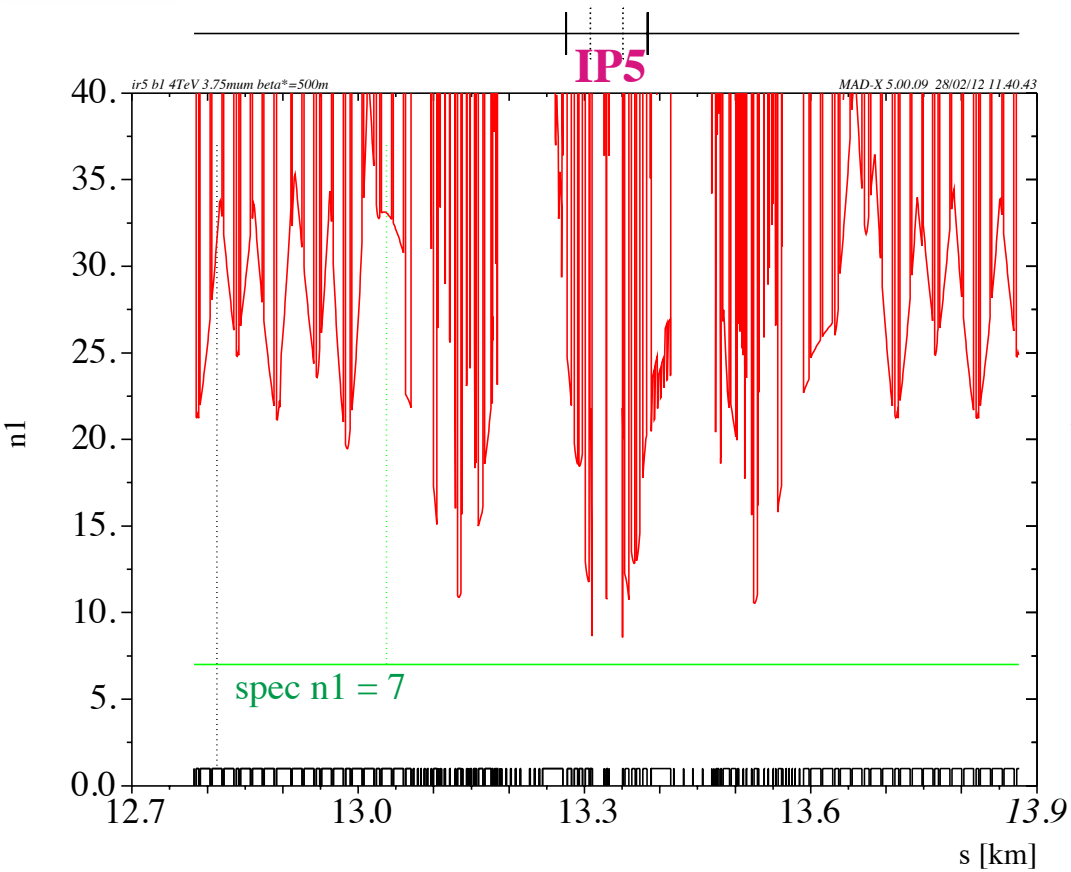
beam 2 $n1_{min} = 11.7$ at Q6.R

Aperture at 90 m not critical

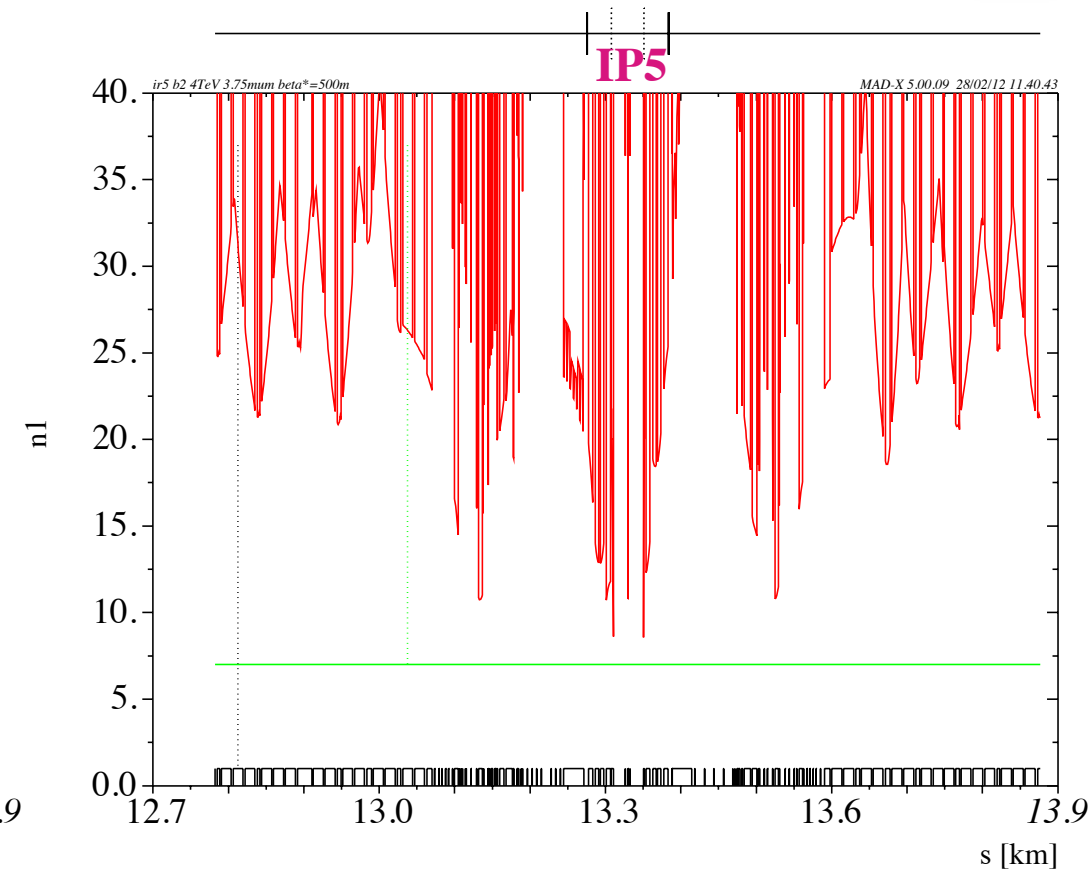
IP region in shadow of roman pot / Q6 region and arc

Aperture at β* = 500 m

beam 1 — 4 TeV, ± 2 mm separation — beam 2



beam 1 $n1_{min} = 7.869$



beam 2 $n1_{min} = 7.865$

At β* = 500 m, the aperture limit is moved in to the triplet region close to TAS
Still within the standard specification of n1 = 7

at β* = 1000 m n1 ≈ 5.2 with and n1 ≈ 6.3 without separation

Strategy

Basic strategy : **keep (re-commission cleanly) the de-squeeze to 90 m** (during re-commissioning)
and extend it with extra files for higher β^*, above 90 m all matched for $\Delta\mu_y = 90^o$

"Same optics" in IP1 & 5 except for :

match the vertical phase advance to $\Delta\mu_y = 90^o$ for TOTEM for RP at 220m, ALFA RP at 240 m

parallel separation : IP1 in x, IP5 in y

Preliminary files exist for $\beta^* =$ 90 - 500 m, appear to fulfill all constraints,

require a bit more smoothing + transfer to control system

Keep ± 2mm separation during de-squeeze

no constraint on $\Delta\mu_x$, naturally just a bit below ~ 175°

$L_{yeff} = \sqrt{\beta^*\beta_{RP}}$ not constraint, typically ~ 250 - 300 m

matching to ~ 200 m rather straightforward, 400 m reached with few iterations

500 m and more getting difficult, main reasons :

- **control of b1/b2 ratios of in particular Q8, Q7 and Q4 --- remove this in LS1**
- **parallel separation, kicks up to 113 µrad, outside the range allowed at 7 TeV, ok @ 4 TeV**
- **aperture**

How to get to the Coulomb interference region ?

Getting down to $-t \approx 6.5\times10^{-4}$ GeV^2 is known to be extremely challenging at LHC energies

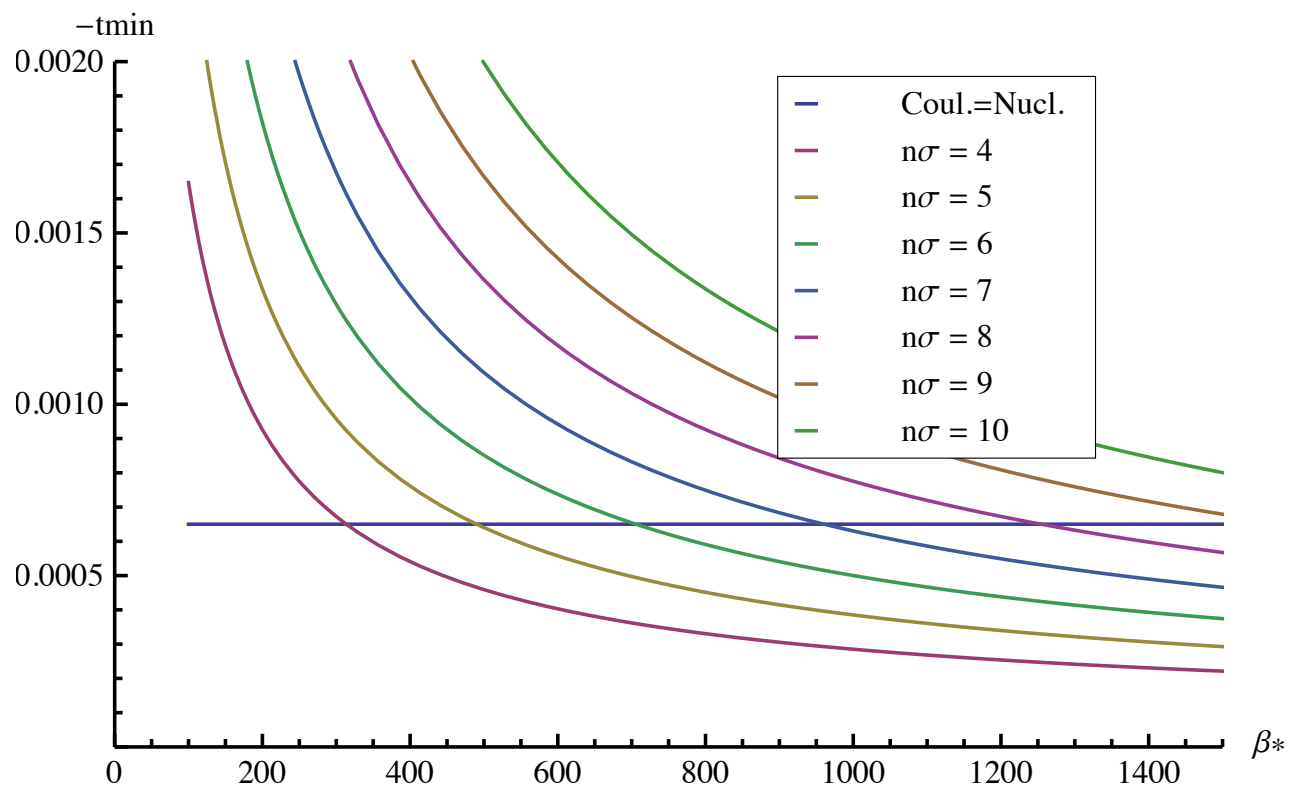
original ALFA request : $\beta^* = 2450$ m, Q4 inverted and 200 m injection , $\varepsilon_N = 1$ μm (7 TeV)

$-t \approx p^2\theta^2$ $\theta = 6.4$ μrad at 4 TeV, $\theta = 3.6$ μrad at 7 TeV

$t \propto n_\sigma^2 / \beta^*$ roman pots can be put to 5 σ or less, or ~2 times closer than early estimates

Opens the way to get to the Coulomb region at more practical β* in the range of

500 m this year and ~1 km after LS1 (with cable constraints removed and higher energy)



Estimate for Eb = 4 TeV, $\varepsilon_N = 2$ μm, δgap = 0.4 mm , $n_\sigma = 5$, Coulomb region reached at b* = 490 m

(MD) Subjects in 2012 with beam for high-β*

General aims

- **define the 2012 high-β physics optics**
- **explore limits to define the required hardware modifications in LS1 (extra cables) for the high-β program at the design beam energy after LS1**

Tasks (MD-sessions)

- **de-squeeze to β* ~ 500 m in IP1&5** **+ recommission 2012 new energy, modified ramp + squeeze ?**
- **scraping to ~ 1 μm normalized emittance at top energy**
- injection at 90 m optics in IP1&5 -- to speed up operation with high-beta*
- squeeze with colliding beams
- test Q4 inversion, with injection at 200 m
- longitudinal separation using RF
- maximum β* without extra cables

Summary / Conclusion

- **Get to $\beta^* \approx 500$ m by de-squeeze in 2012 starting a.s.a.p**
  approach the interference region by minimizing n_σ $t_{min} \sim n_\sigma^2 / \beta^*$
  with reduced emittance and going closer with RPs to beam
  all bunches same intensity $\sim 3\times10^{10}$ $\varepsilon_n < 2$ µm
  also test higher intensity and further emittance reduction by scraping

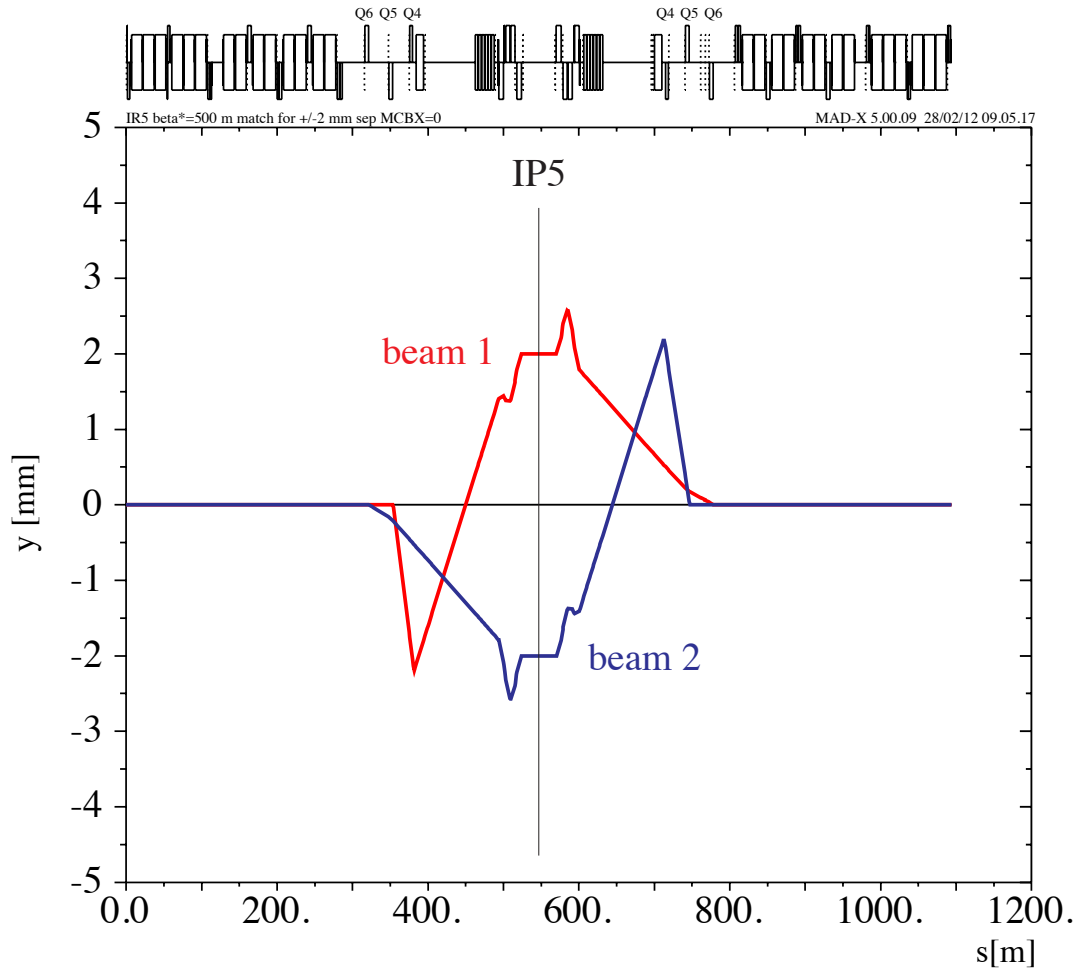
- **2012 also crucial for modifications in LS1, required to fully exploit high-β at the nominal LHC energy after LS1**
  Good potential to reach Coulomb region without Q4 inversion at full energy
  Requires the installation of the missing cables, most important for Q4, Q7, Q8
  (was in principal agreed in LMC 31, 32)
  in LS1, apply to both IP1 & IP5 and left and right of the IPs

to be efficient : we need at least a rough schedule for the special runs soon

with several sessions, separated in time

Backup

Separation bump at 500 m




```
MCBX off - have wrong phase advance for parallel separation at high β
acbyvs4.l5b1 :=     0.000113450750 *on_sep5 ;   ! kmax = 96 murad at 7 TeV
acbcv5.l5b1  :=    -0.000079352759 *on_sep5 ;
acbyvs4.r5b1 :=     0.000000837063 *on_sep5 ;
acbcv6.r5b1  :=     0.000005866063 *on_sep5 ;

acbyvs4.l5b2 :=    -0.000000435499 *on_sep5 ;
acbcv6.l5b2  :=    -0.000006223428 *on_sep5 ;
acbyvs4.r5b2 :=    -0.000098589908 *on_sep5 ;
acbcv5.r5b2  :=     0.000070288777 *on_sep5 ;
```

de-squeeze 11 m to 90 m in 19 intermediate steps