High-beta optics

- **Introduction**
- **Strategy to commission the intermediate 90 m optics**
- **Running scenario**
- **Required knowledge of beam-parameters**

in the spirit of a workshop --- for discussion

Acknowledgment :
M. Giovannozzi, W. Herr, O. Brüning, S. White (optics); R. Tomas (β-beat);
S. Redaelli, M. Lamont and G. Müller (on-line, commissioning)
P. Grafstrom, P. Puzo, S. Cavalier (ATLAS-ALFA)
V. Avati, M. Deile, K. Eggert, H. Niewiadomski (TOTEM)

Details : High-β* Optics for the LHC, H.B. & Simon White, LHC-Project-Note-431, May 2010

Introduction

As also discussed earlier this workshop, high-β optics are essential for

- forward physics and
- **cross section and absolute luminosity calibration**, where they are complementary to VdM scans and may ultimately achieve the best precision (BCT independent)

- Require **special optics** and **dedicated running time**

Challenges of **high-β optics**

- **tune change** in un-squeeze much larger than in squeeze - global optics change
- **additional constraints** between IP and roman-pots
- **aperture limitations** at very high-β^*
- need for **precision** and stability of **optics parameters**
- **insertion quadrupoles and power convertors at limits**

Strategy (for discussion)

- **Top priority is currently $\int L\,dt$**

- **Very high-β** (>> 90 m) **only relevant later**

The high-β* = 1535 m TOTEM optics was designed for 7 TeV, ε_N = 1μm (5 TeV still ok) and needs extra cables, installed during the 1st longer shutdown, see LMC#32

The current very high-β* = 2600 m ATLAS-ALFA optics requires Q4 polarity inversion with dedicated injection at β* = 200 m + ramp and squeeze; the hardware for polarity inversion is installed

not for the next year(s) -- and to be reviewed following the experience at 90 m

High-β in 2011 :

- **90 m optics commissioning** concentrate on one goal in 2011, which is the 90 m optics ; the commissioning should start in MD a.s.a.p. and will tell us a lot about the feasibility of these optics and the requirements in terms of commissioning and set up time
  if things go really well : commissioning in 5 shifts, simultaneously 2 beams and IP 1&5
  IP 2/8 left by default at 10m inj, r&s settings

- **Physics operation at 90 m** at the current physics energy, simultaneously in IP 1&5, in the 2nd part of the year, about a week, split in several parts

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)

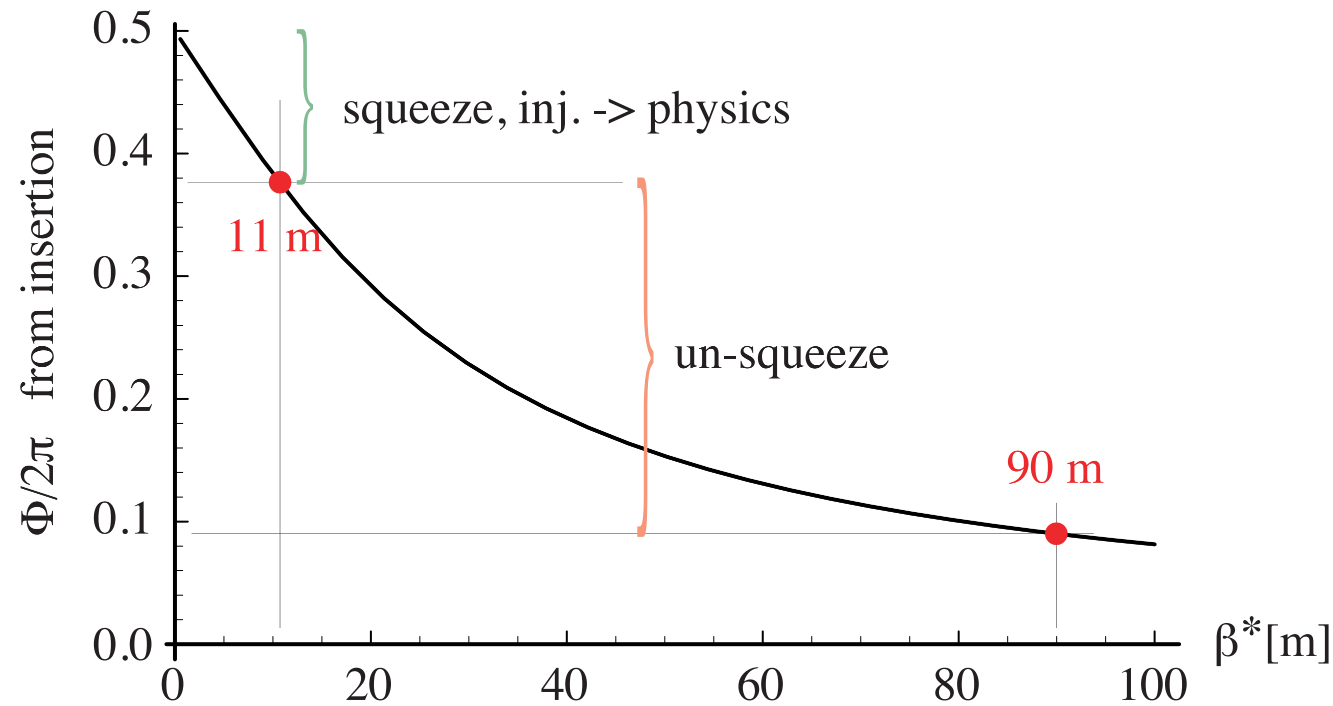
where low-β* means β* << ℓ

and **0** for high-β* β* >> ℓ

for the LHC with

ℓ = 26.15 m from

IP to centre of Q1



The tune change in the un-squeeze is much bigger than in the squeeze to low β

External tune compensation

three alternatives for the required tune adjust of $\Delta Qx = +0.222$, $\Delta Qy = +0.055$ / IP

- **use another IP,** for example IP4
  advantage : local to IPs , no β-beating in arcs
  disadvantage : limited to ~ 0.2, no way to compensate 90 m in several IPs
  implications for instrumentation and damper in IP4

- **use the trim quadrupoles,** the tune adjust (of a single IP)
  results in up to 8.5% β-beat in x and 4.5 % in y / IP

- **ramp up the main quads during the un-squeeze to compensate the loss in tune**
  proposed first by O. Brüning in LCCWG#4 on 19/4/2006
  results in up to 4.5% β-beat in x and 1.6 % in y / IP

Start with the 3rd alternative which is the most promising
and should allow to run with 90 m in two IPs
Files are prepared for this for IP5 and will be cloned + optimized in last step to 90 m
for ATLAS (ALFA) with help from Sophie Cavalier

Only switch to the other methods or a combination of them if really needed

Steps in Commissioning

1st. goal : demonstrate the feasibility of the un-squeeze in β* from 11 m to 90 m with external tune compensation using the main quads

Detailed steps:

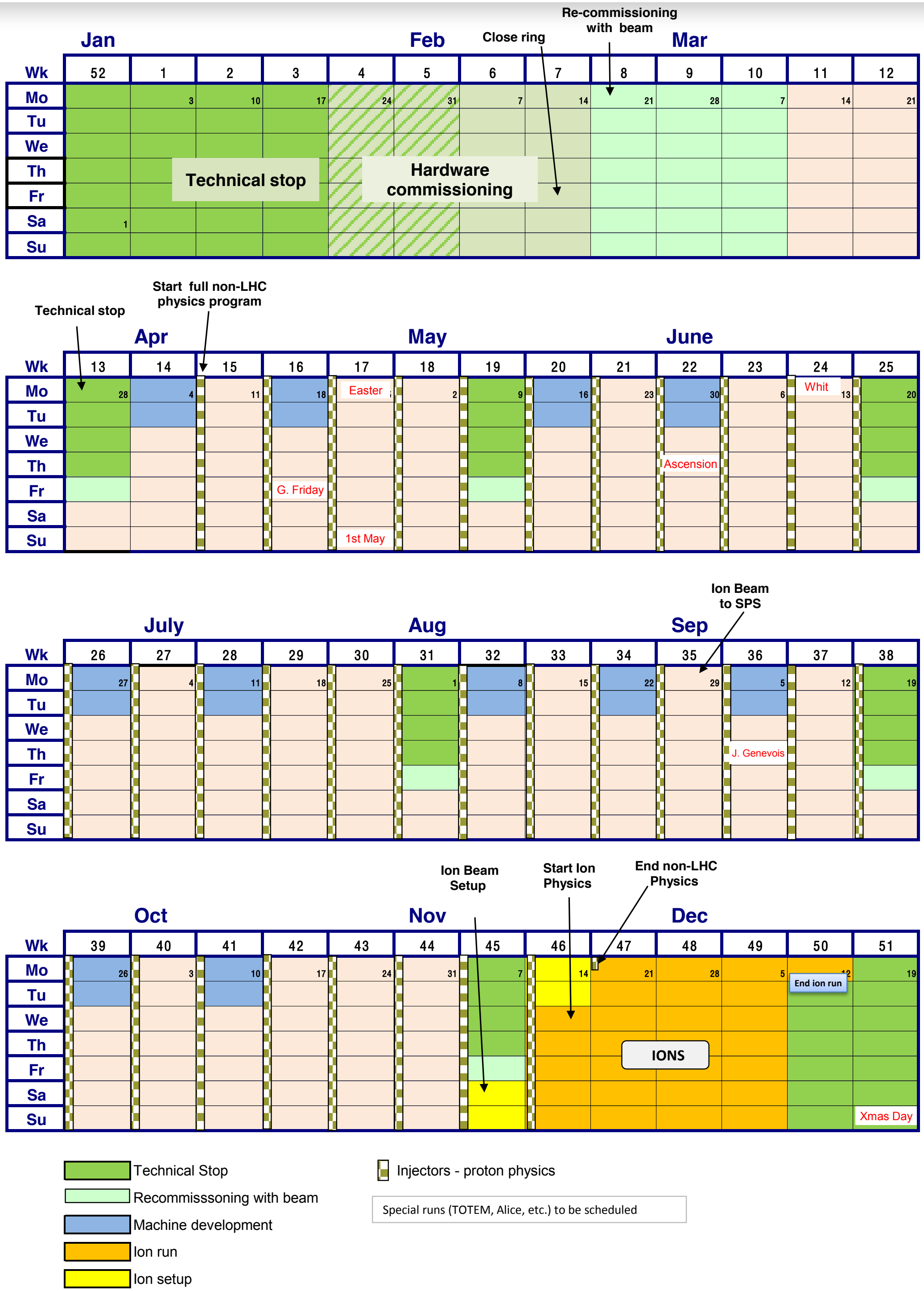
1. Full consistent set of optics files for IP5 from 11m to 90m in 19 intermediate steps with external tune compensation using the arc quadrupoles. ✔
2. Transfer of these files into the control system and global checks using the online model. in collaboration with Stefano Redaelli and Gabriel Müller ✔ extend this to IP1

3. Cold checkout - driving magnets based on these files without beam, will be tried early this year

4. Actual MD. Beam conditions : End of ramp at physics energy, 1+1 bunch, about 1.e10 intensity.
Un-squeeze towards 90 m in IP1 & 5, orbit + tune feedback on
when successful - beta-beating measurements and adjust
several iterations, adjust tertiary collimators and check hierarchy
Requires the help & presence of a number of people -- schedule accordingly

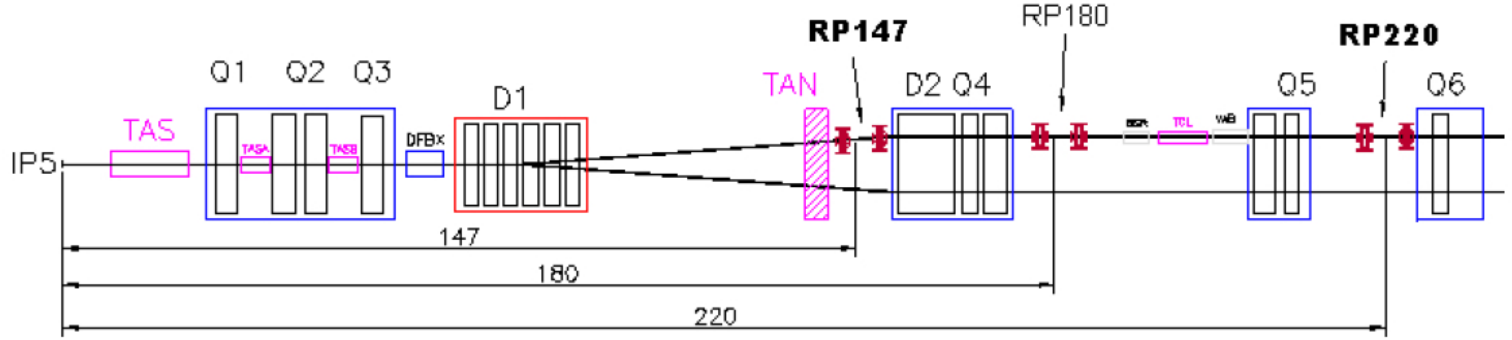
MD request for 2011 is to start the 90 m commissioning in MD a.s.a.p.
high-β is different, going to some extend in the opposite direction of what the insertions were designed for, and relying for the first time on triplet power convertors
to allow for time to react in case of problems

2011 schedule with MD periods

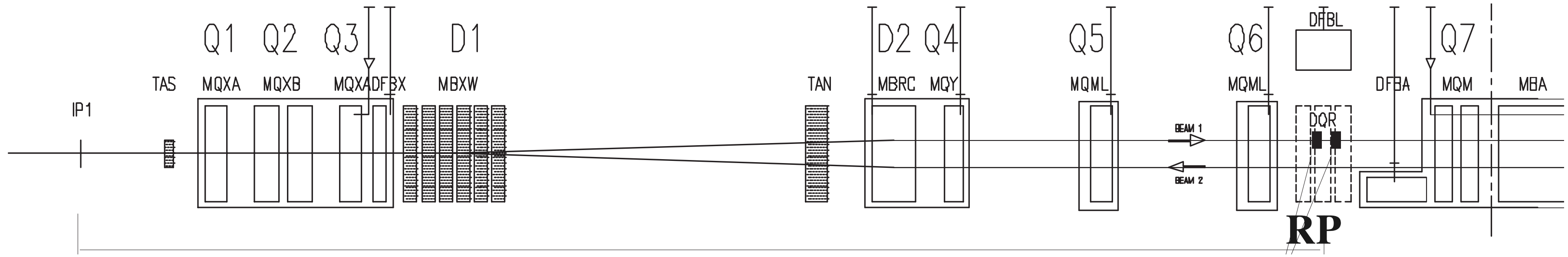


Ref. https://espace.cern.ch/be-dep/BEDepartmentalDocuments/BE/2011-LHC-schedule_v1.0.pdf from 16/12/2010

Layout and optics



Schematic layout with roman pots for TOTEM. Phase matching refers to the RP at 220 m



Schematic layout for ATLAS

RP at 240 m

For the machine side : identical magnet layouts for IP1 & IP5

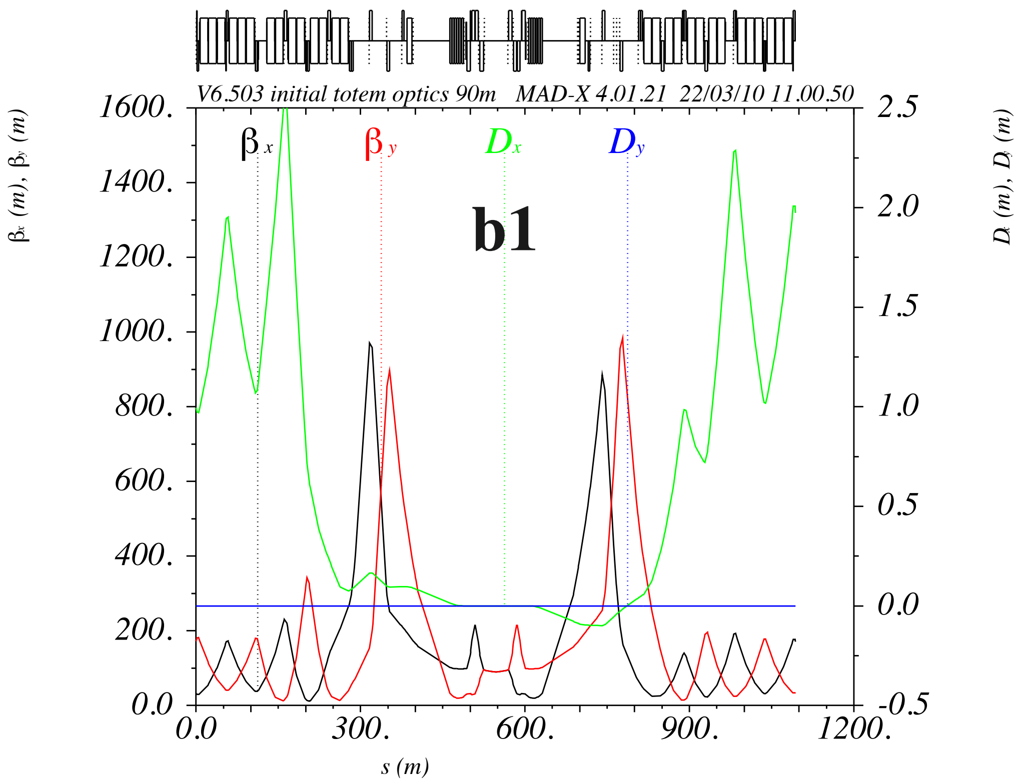
Differences only from experimental requirements

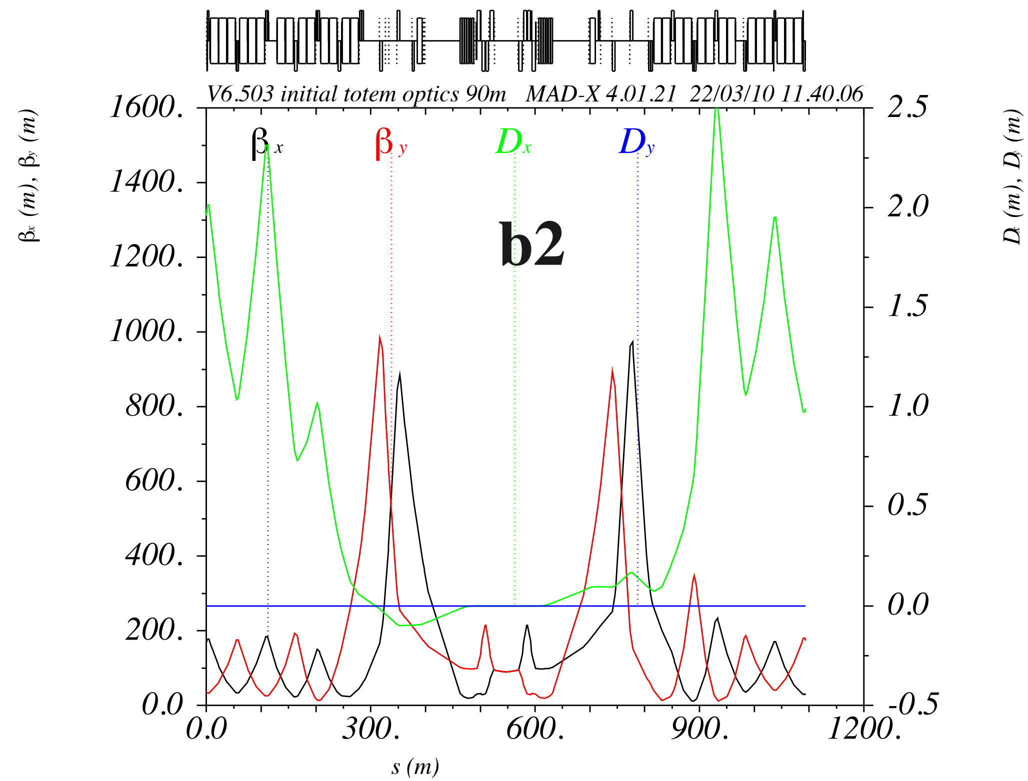
TOTEM $\Delta\mu_y = \pi/2$, $\Delta\mu_x = \pi$ at 220 m from IP (90 m)

ATLAS $\Delta\mu_y = \pi/2$ at 240 m from IP

Current 90 m optics

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





ΔQx = 0.222 ΔQy = 0.055

ΔQx = 0.220 ΔQy = 0.053

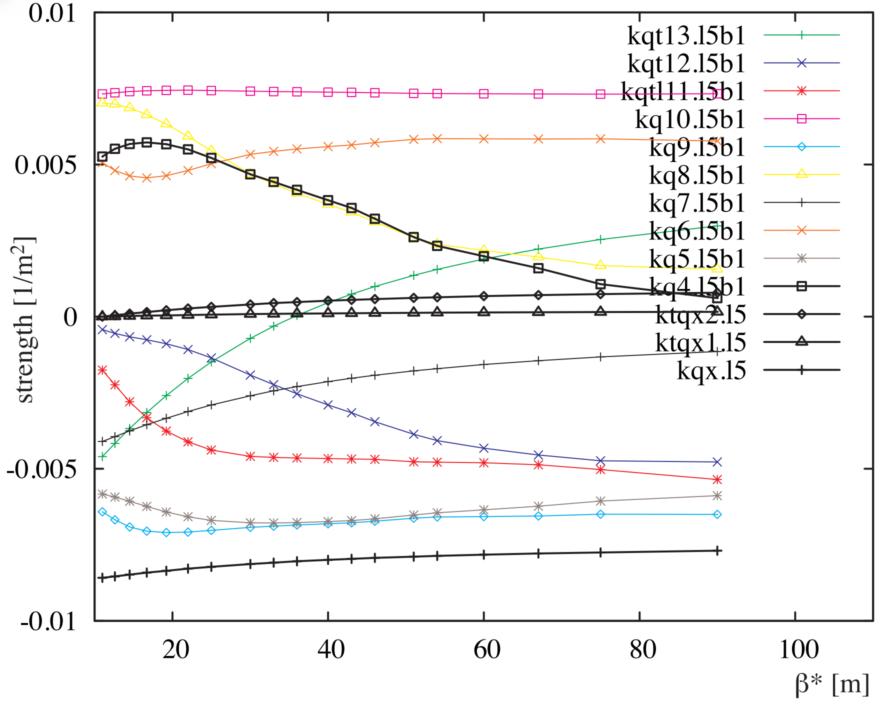
With current cabling required to have quad strength ratios within **0.5 < b1/b2 < 2.0**

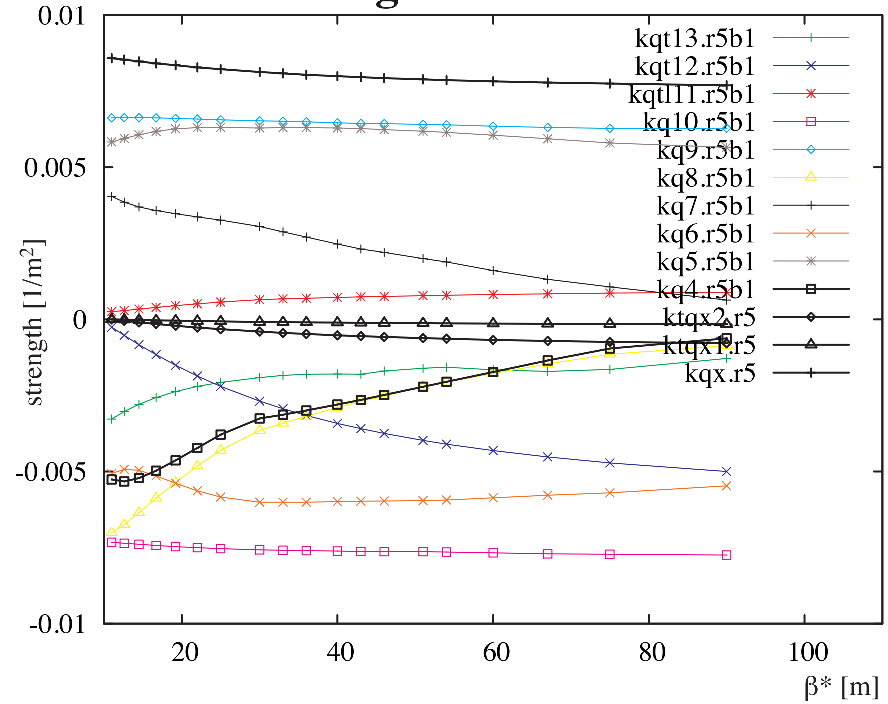
kq4.l5b1/	kq4.l5b2=	0.970945	kq4.r5b1/	kq4.r5b2=	1.10542
kq5.l5b1/	kq5.l5b2=	1.04019	kq5.r5b1/	kq5.r5b2=	0.961367
kq6.l5b1/	kq6.l5b2=	1.05394	kq6.r5b1/	kq6.r5b2=	0.938599
kq7.l5b1/	kq7.l5b2=	1.5816	kq7.r5b1/	kq7.r5b2=	0.525421
kq8.l5b1/	kq8.l5b2=	1.33077	kq8.r5b1/	kq8.r5b2=	0.571775
kq9.l5b1/	kq9.l5b2=	1.03071	kq9.r5b1/	kq9.r5b2=	0.964224
kq10.l5b1/	kq10.l5b2=	0.94919	kq10.r5b1/	kq10.r5b2=	1.05372

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

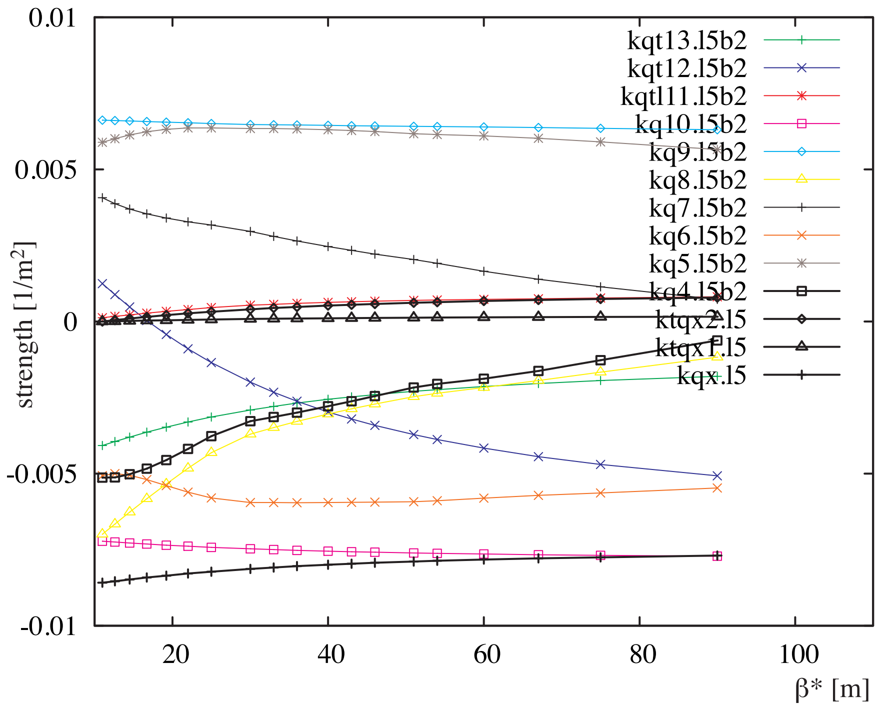
left of IP5 | right of IP5

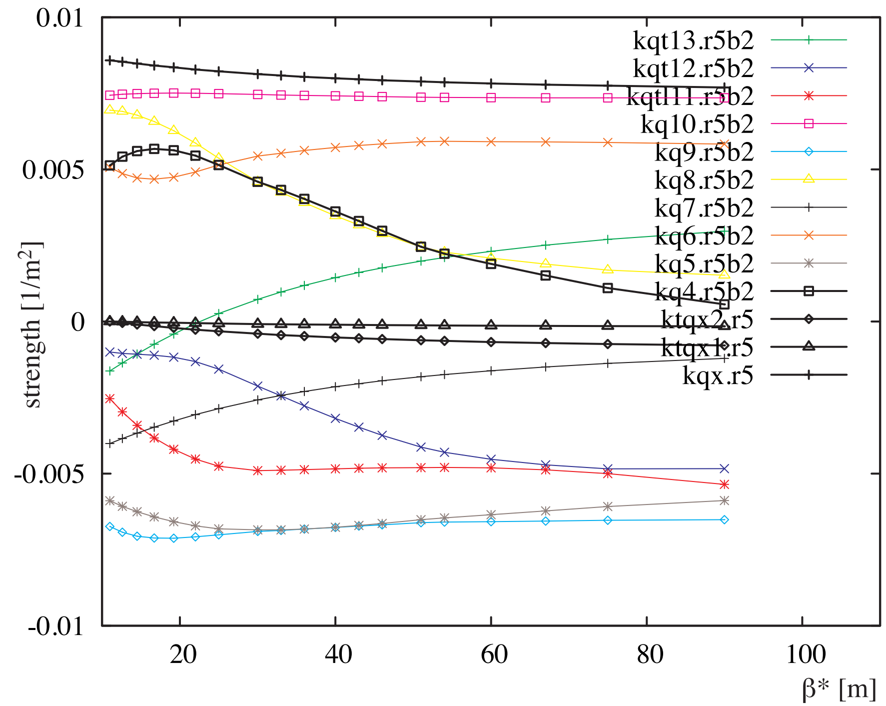
beam 1





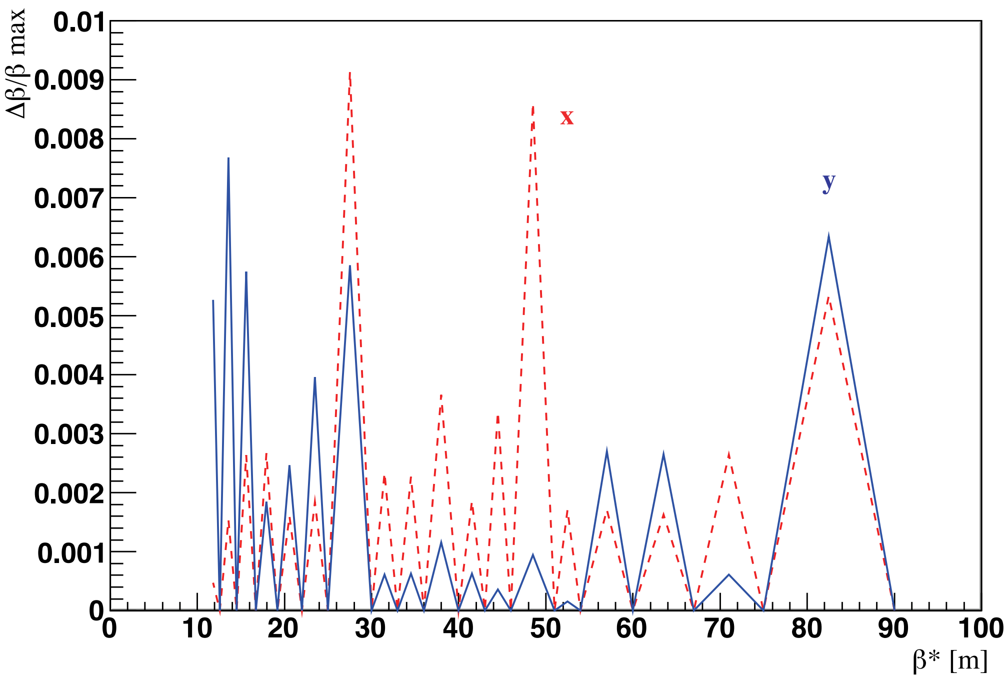
beam 2

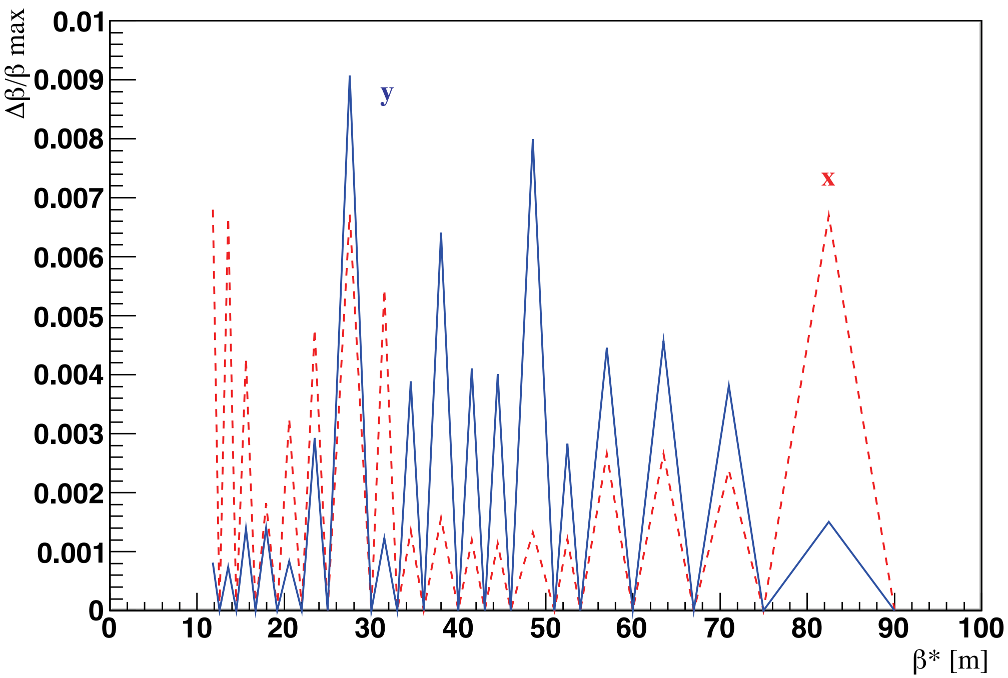




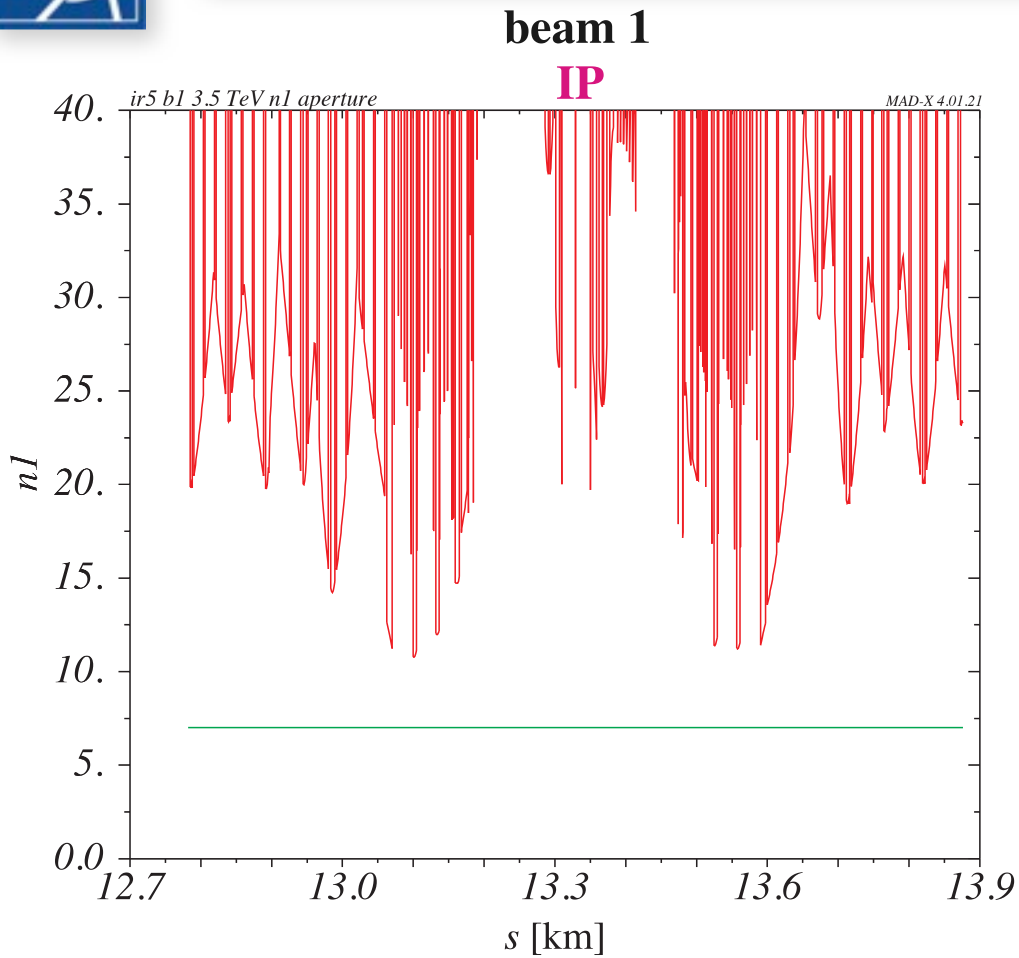
β-beating from interpolation between intermediate points

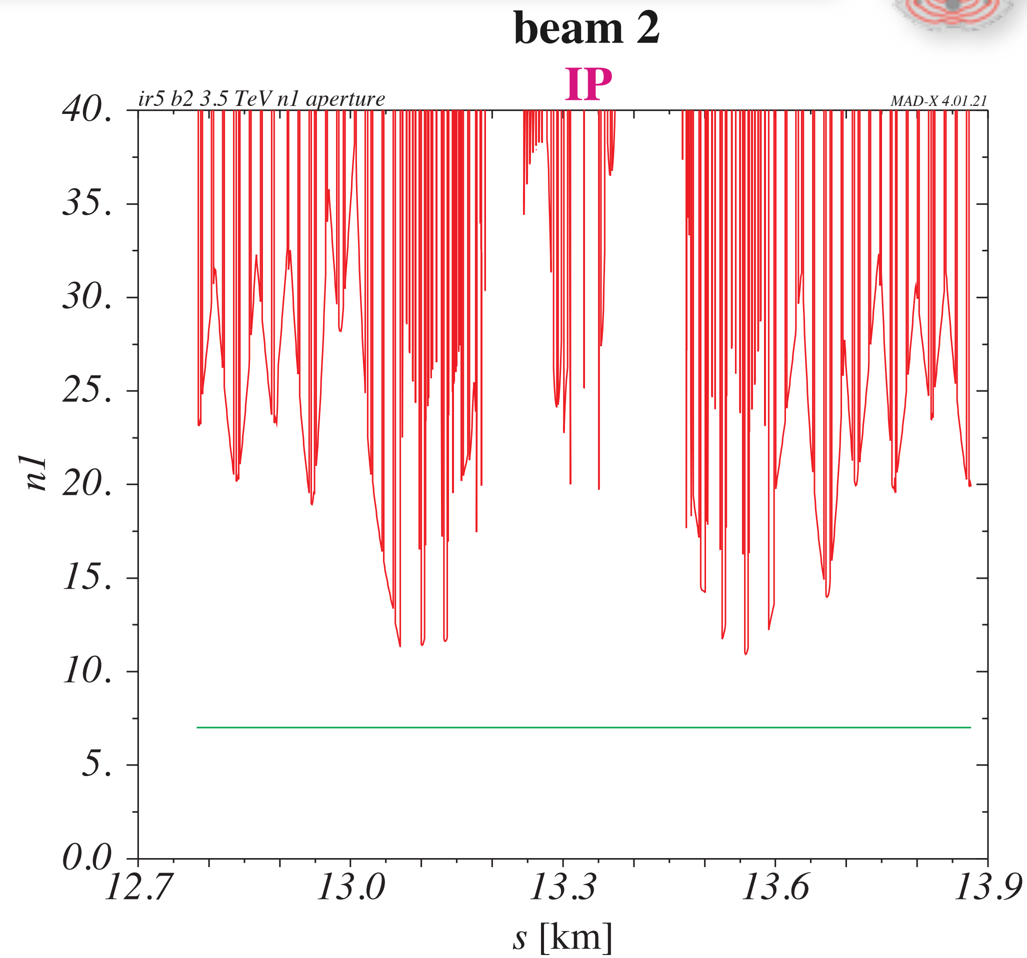
of intermediate points and spacing adjusted for $\Delta\beta/\beta < 1\%$





Aperture at 90 m





No problem with aperture at 90 m, even in the most conservative case shown here :

3.5 TeV, nominal emittance, ±7 σ vertical separation

for design tolerances (which, as we know now, are rather generous)

Aperture at 90 m not critical

No problem to run the 90 m with the standard emittance

Will however aim to run with the lowest emittance available

Running scenario and accuracy

~5 shifts will be required to get the optics ready in "MD" / commissioning conditions before providing physics ; followed by running at 90 m + if needed further optics measurements / adjustments

good knowledge and stability of beam parameters is important, mostly transfer matrix IP to roman pot; here with some preliminary numbers from H. Niewiadomski et al. / TOTEM :

$\Delta\beta_x / \beta_x < 1$ % should be feasible, requires dedicated measurements (strongly kicking the beams, AC-dipoles) by R. Tomas et al.

$\Delta D_x / D_x < 1$% @RP looks tough, may require input from experiment

90 m also important to learn more about precision needs and possibilities

Luminosity, # of bunches

TOTEM : prefers 6-7e10 protons in 1-2 bunches

ATLAS, prelim disc. with P. Grafstrom et al. : aim for maximum luminosity (~1.e30 cm-2s-1) and maximum #bunches compatible without crossing angle (which is 156, 50 bunches would also be ok)

Aim for ~ 1 week of physics operation at 90 m in 2nd half of 2011, split in several parts

At 4+4 TeV, 2μm, 8.e10 p/bunch, L = 1.4e28cm-2s-1 / bunch, μ< 0.1; L=2.e30 for 156 bunches $\sigma_{x,yIP}$ = 205 μm

90 m as intermediate step (last slide)

We can potentially learn a lot from 90 m - both in physics (not much discussed here) and for the **future of high-β operation** ---> TOTEM 1.5km / ATLAS 2.6 km optics

Hardware : the (approved) TOTEM optics $\beta^* = 1535$ m requires **extra cables** on insertion quadrupoles Q4-Q10 (more flexibility, allows potentially un-squeeze from standard ramp) or polarity inversion on Q4

the experience from 90 m will be **essential input** to decide which way to go and which and how many cables to add

If 90 m and un-squeeze goes well in 2011 and we run in 2012 :

potential to squeeze in 2012 well beyond 90 m

MD studies should start soon to allow for time to react and implement what was learned