AFP - TCL collimator studies

LHC Collimation Study Group, 7-Sep-2009

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Many thanks to C. Bracco, K. Potter, R. Appleby and
INTRODUCTION

AFP proposal

AFP = Atlas Forward Physics

In addition to Roman Pots at 240 m (ALFA project, installed, run with special optics at low luminosity-low emittance), the AFP collaboration is proposing to install detectors at 220 and 420 m on both sides of ATLAS

Proposed physics: mainly forward proton tagging, with nominal optics, both at intermediate and high luminosity

Proposed schedule: be ready for installation in 2010-2011 in compatibility with LHC sectors warm up

ATLAS internal review started in February 09

Referees rose up questions including impact of collimation system on proposed physics

After a couple of iterations (AFP --ATLAS reviewers) a decision (TDR --> Approval) is expected during the ATLAS week in Barcelona, Oct 09.
TCL4 and TCL5 are designed to protect D2, Q4, Q5, Q6 (and possibly other downstream elements down to the beginning of the arc) and RR regions from physics debris particles during high luminosity runs (L > 2e33)

- setting of both TCLs is negligible on AFP420 acceptance and backgrounds from secondary showers (TCL are very far)
- setting of TCL4 has little impact on AFP220 acceptance
- impact of TCL5 on AFP220 is not negligible

See plots in SPARE slides
TCL5 available studies

LHC-Project Note 208 (Jeanneret-Baichev, 2000), Using LHC optics V6.1

Need for protecting Q5 (at ~190 m) + MB.B8 (at ~ 280m)

They proposed the installation of TCL5 between Q4 and Q5, and looked at losses on Q5, MB.B8 and all the region downstream (up to ~ 700 m)

<table>
<thead>
<tr>
<th></th>
<th>WITHOUT COLLIMATORS</th>
<th>TCL5 AT 15 SIGMAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st highest peak [p/s/m]</td>
<td>4.2e7 in front of Q5</td>
<td>1.7e6 in front of Q5</td>
</tr>
<tr>
<td>2nd highest peak [p/s/m]</td>
<td>4.4e6 at MB.B8</td>
<td>0.8e6 at MB.B9</td>
</tr>
<tr>
<td>all other peaks</td>
<td>all other peaks well below quench limit</td>
<td></td>
</tr>
<tr>
<td>losses integral (in p/s) for s&gt;280 m (DS + ARC)</td>
<td>6.60E+07</td>
<td>1.70E+07</td>
</tr>
</tbody>
</table>

Later they discovered that also D2 and Q4 needed protection and the TCL4 was proposed
Optimal collimator settings

It is often convenient to look for locations where there is a **maximum normalized dispersion**

\[ D^n_x(s) = \frac{D_x(s)}{\sqrt{\beta_x(s)}} \]

Similarly, willing to **clean particles** for a certain \( \frac{dp}{p} \), one can look at the **necessary collimator gap** (in terms of sigma) at different locations \( s \):

**Collimator half-gap necessary to clean all particles with momentum offset \( \geq \frac{dp}{p_0} \)**

\[
\frac{x_c(s)}{\sigma_x(s)} = \frac{D_x(s)}{\sigma_x(s)} \cdot \frac{\delta p}{p_0} = \frac{D_x(s)}{\sqrt{\beta_x(s)\varepsilon_x}} \cdot \frac{\delta p}{p_0}
\]

See plot next slide
Optimal collimator location

Collimator half-gap necessary to clean all particles with momentum offset $\geq dp/p_0$, in the momentum region of losses at $250m < s < 350 m$ (critical region)

This ‘prove of principle’ is consistent with the results of the tracking studies for different TCLs settings (presented later).

Given that TCL4 provides enough protection down to $\sim 220 m$:

Could think of putting a collimator (or moving TCL5) in front of Q6
TRACKING STUDIES

Loss maps of forward protons for different TCLs’ settings

- Protons emerging from **p-p interaction** at IP1 generated with **DPMJET**
  - total cross section \( \sim 100 \text{mb} \)
  - normalization to nominal luminosity \( L=1e34 \)
  - smearing for nominal beam size and divergence at 7 TeV, nominal crossing angle

- Tracking with **MadX PTC TRACK** (thick lens)
  - LHC optics V6.503
  - aperture model July 09, including last information on ATLAS beam pipe (drifts from 0 to 150m)
  - loss maps with on purpose written **python routine**
  - any aperture -including collimators- treated as black absorber

- Tracking with **MadX SIXTRACK** (thin lens, includes scattering on collimators)
  - starting from C. Bracco’s templates
  - LHC optics V6.503
  - aperture model July 09, including last information on ATLAS beam pipe loss maps, beam loss patterns crosschecked with 2 routines:
    - same routine used for PTC
    - routine used by LHC collimation team
DPMJET PROTONS

Initial distribution of protons

- **hx**
  - Entries: 30000
  - Mean: -0.02083
  - RMS: 16.06
  - $\chi^2$/ndf: 13.07/20
  - Constant: 4447 ± 31.4
  - Mean: 0.4793 ± 0.0932
  - Sigma: 16.14 ± 0.07

- **hy**
  - Entries: 30000
  - Mean: -499.8
  - RMS: 16.03
  - $\chi^2$/ndf: 302.5/18
  - Constant: 4380 ± 30.7
  - Mean: -499.4 ± 0.1
  - Sigma: 16.23 ± 0.06

- **hpz**
  - Entries: 30000
  - Mean: 0.7705
  - RMS: 66.19
  - $\chi^2$/ndf: 1086/38
  - Constant: 4018 ± 33.2
  - Mean: 1.611 ± 0.338
  - Sigma: 57.42 ± 0.33

- **hpz**
  - Entries: 30000
  - Mean: 67.21
  - RMS: 79.55
  - $\chi^2$/ndf: 510.7/44
  - Constant: 3086 ± 22.2
  - Mean: 66.86 ± 0.45
  - Sigma: 76.24 ± 0.32

- **Lorentz boost due to xssing angle**
  - Offset @IP1
  - Beam size
DPMJET PROTONS

Initial distribution of protons

Black curve corresponds to energy distribution of protons used for both SIXTRACK and PTC.

A cut has been applied inside DPMJET in order to have more statistics for all protons surviving after the first TAS.
Aperture used for both PTC and SIXTRACK
Protons starting with \((x, x', y, y') = (0,0,-0.0005,142.5e-6)\) and different off-momentum
Comparison with published results

- In the case I managed to rebuild, Baichev-Jeanneret did not score losses before 280 m
- I’m more pessimistic from 300 to 350 m

Remember differences in LHC optics, tracking model, p-p protons model

- LHC optics (V6.503 vs V6.2) and aperture model
- scattering on collimators (PTC no, J-B yes)
- p-p interaction source file
  - I used DPMJET with 100mb cross section, that I transform to ~ 12 forward protons / bunch crossing
  - They quoted a rate of 3.5e8 inelastic events per sec that I assume gives 8.75 protons/bunch crossing
## Loss Map Results

### Comparison with Published Results

<table>
<thead>
<tr>
<th>Coll. Gaps in Sigmas (TCL4, TCL5, TCL6)</th>
<th>$p$ Losses for $s &gt; 280$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTC</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>(OPEN, OPEN, OPEN)</td>
<td>2.80E+07</td>
</tr>
<tr>
<td>(OPEN, 15, OPEN)</td>
<td>9.80E+06</td>
</tr>
<tr>
<td>(30, 50, 40)</td>
<td>7.00E+06</td>
</tr>
<tr>
<td>(30, OPEN, 30)</td>
<td>4.70E+06</td>
</tr>
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</tbody>
</table>

Remember differences in LHC optics, tracking model, p-p protons model.

These settings result almost equivalent looking at losses in DS:

- **(1)** = Losses scored for $280 < s < 440$ m
- **(2)** = **(1)** + all surviving protons
- **(3)** = Losses for $280 < s < \sim 700$ m

I did not score losses after 450m, therefore here I put...
Peaks triplets are high. But those protons have low momentum, see next slide.

Peaks at Q5 close to estimated quench limit.

LHC Design Report: deposited energy in the triplets can reach 10 W/m (--> consistent results).

N.B.: this is energy deposited by IP protons on the elements’ aperture (no showers, no penetration through the coils).
Energy of lost protons

LOSS MAP RESULTS (PTC)

dp/p of lost protons

Collim. gaps [$\sigma$]
- TCL4, TCL5, TCL6
- OPEN, OPEN, OPEN

# of protons, normalized for their momentum w.r.t. 7TeV
peaks at triplets result lower

Collim. gaps [$\sigma$]
- TCL4, TCL5, TCL6
- OPEN, OPEN, OPEN
Present settings Effectiveness of TCL4

TCL4 at 30 sigma:
- no losses on Q4 and D2
- reduced losses on Q5
Present settings Effectiveness of TCL5

- No losses on Q5, Q6, and Q7 even for TCL5 at 10 sigma.
- No cleaning from MB.B9 and downstream even for TCL5 at 10 sigma.
ALTERNATIVE 1 Moving TCL5 in front of Q6 (after AFP220)

TCL6 at 30 sigma vs TCL5 at 15 sigma:

all these losses disappear

TCL6 at 30: residual losses on Q5

TCL5 at 15: residual losses on MB9
ALTERNATIVE 2 Relaxing TCL5 settings and add a TCL6 in front of Q6 (after AFP220)

**LOSS MAP RESULTS (PTC)**

- TCL5 at 50: all losses on Q5 disappear
- TCL5 at 50 and TCL6 at 40: worse than ‘Alternative 1’ but better than TCL5 at 10 at MB9 (see slide 15, ‘Effectiveness of TCL5’)

Collim. gaps [σ]
- TCL4, TCL5, TCL6
- OPEN, OPEN, OPEN
- 30, OPEN, 30
- 30, 50, 40
TRACKING RESULTS

PTC versus SIXTRACK

7 TeV proton starting at
x=0, px=0, y=-0.5mm, py=142.5 urad

SIXTRACK stops recording
the information after 198 m
(Q5). Why?
TRACKING RESULTS

PTC versus SIXTRACK

Hor. Trajectory, $\delta p/p_0 = -0.02$

Ver. Trajectory, $\delta p/p_0 = -0.02$

$dp/p_0 = -0.02$ proton starting at $x=0$, $px=0$, $y=-0.5\text{mm}$, $py=142.5\text{urad}$
TRACKING RESULTS

PTC versus SIXTRACK

$dp/p_0 = -0.1$ proton starting at
$x=0$, $px=0$, $y=-0.5\text{mm}$, $py=142.5\text{urad}$
This difference is compatible with differences seen in loss maps.
TRACKING RESULTS

PTC versus SIXTRACK

\[ \frac{dp}{p_0} = -0.5 \] proton starting at
\[ x=0, \ px=0, \ y=-0.5\text{mm}, \ py=142.5\text{urad} \]

SIXTRACK stops at 168m (Q4)

This difference is compatible with differences seen in loss maps.
LOSS MAP RESULTS

PTC versus SIXTRACK

Main difference: SIXTRACK does not see losses between 90 and 140m

SEE NEXT SLIDE

Effect of scattering on collimators: looks negligible
PTC versus SIXTRACK

Chromatic effect of drifts?
Thick lens-Thin lens difference?
Information on impacts on collimators

TOTAL NUMBER OF IMPACTS

TCL6 at 40 sigma intercepts more protons than TCL5 at 15 sigma

SCATTERED PROTONS / TOTAL IMPACTS

All below 4 %
CONCLUSIONS

Tracking studies results

PTC and SIXTRACK give similar results, apart from additional losses scored by PTC in some drift spaces. The following conclusions apply not forgetting remaining uncertainties (machine imperfections, FLUKA for secondary showers, uncertainty on p-p cross-sections at 7TeV)

PRESENT TCL SCHEME (TCL4 + TCL5)
- Will TCL5 needed at 10-15 sigma (=no AFP possible) ?
- losses on Q5 are already reduced of a factor 10, for TCL4 at 30 sigma
- TCL5 at 50 sigma completely screens Q5, Q6 and Q7 from primary protons
- TCL5 at 10 sigma is not effective on DS

POSSIBLE ALTERNATIVES
- If one believes the absolute scaling of the results: there is little quench probability in Q5 and DS even without TCL5 and with a TCL6 at > 30-40 sigma
- If one does not believe the absolute scaling, indeed TCL5 (at ~40 sigma) or TCL4 (at 20 sigma) would protect Q5
- in any case a TCL6 seems more efficient than a TCL5 for protection of the DS in the ~350m region
OUTLOOK

Open questions

I went down in IR1 - right side and there seems to quite a lot of space between Q5 and Q6

1- is it conceivable the installation of a new TCL6 collimator in front of Q6?
   - how much would it cost?
   - who would pay for it?

2- concerning the DS protection: could a TCL6 do the job of (or be considered as) cryo-collimators around IP1 and IP5?

3- If FLUKA simulations will confirm loss pattern results:
   - in case a new TCL6 is not conceivable, would be possible to move TCL5 in front of Q5?

4- With the present settings, observing that:
   - Q5 is protected with TCL5 at 50 sigma
   - TCL5 doesn’t help much for the DS protection,
   what would be the tightest setting required for TCL5?

5- How does the TCL5 setting affect the RR radiation levels?
   Would a TCL6 affect the RR?

The ATLAS green light to go for a TDR (that means a very likely ATLAS approval to go to the LHCC) depends on proving to have a possible solution to avoid interference between the TCL collimators and the AFP acceptance.
AFP approval

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Now:

- the results presented here
- the fact that our case was mentioned during the April’s collimation review
- the plan for FLUKA simulations
- the plan for collaborating with Coll.team, FLUKA team, RR radiation team,

is enough?

A very similar problem applies to CMS too. (see SPARE slides)
SPARE
Present settings **TCL4 and TCL5 at XXX sigma**

**Loss Map Results (PTC)**
Effect of collimator settings on acceptance

Coll. @ 149 m: 15 sigma looks ok (we propose 30)

Coll. @ 224 m: 30 sigma looks ok (we propose 40)

Coll. @ 185 m: 10 or 15 sigma is bad (we propose 50, or removal)

Data from P. Bussey
Effect of collimator settings on acceptance

For higher Higg’s masses: the proposed scheme affects $420 + 220$ acceptance. One should relax more the collimator settings.

Data from P. Bussey
TCL5

some installation (compressor? for vacuum?)
INTRODUCTION

TCL Collimators at CMS

NB: this is a copy and paste of IR1
--> need to see layout differences for IR5

At CMS:

TCL4 collimator slot is occupied by TOTEM.

Official statement is: TOTEM will operate until when high luminosity will require the installation of TCL4 --> TOTEM pot at 147m removed
CMS optics/prove of principle (no tracking yet)

For CMS: normalized dispersion is a bit smaller --> need to close more collimators to clean the same dp/p proton
But: as for ATLAS, a TCL6 (after 220) looks to be more effective than a TCL5 (installed now)
INTRODUCTION

Physics debris particles downstream ATLAS (and CMS)

Any p-p interaction has a probability to generate a forward proton with momentum offset $\frac{\delta p}{p}$. The protons will be intercepted (with a good approximation) by the first aperture restriction for which

$$x(s_a) \leq D_x(s_a) \cdot \frac{\delta p}{p_0}$$

1- All protons with $\frac{\delta p}{p} > \sim 0.25$ are intercepted by the TAN at 140 m

2- All protons with $\frac{\delta p}{p} < \sim 0.01$ potentially remain in the beam envelope and will be intercepted by IR3 collimators

3- (In between 1 and 2) protons with $0.01 < \frac{\delta p}{p} < 0.25$ are likely to be lost in the region from 150m to the first arc included and need to be cleaned to avoid quenches
INTRODUCTION

Optimal collimator settings

Basic constrains:

- collimator gap can’t be smaller than 8-10 sigma: to avoid interfering with main cleaning system (IR3, IR7)

- collimator operation must avoid quenches on the downstream magnets due to secondary showers (the smaller the gap the larger the showers)

- collimator operation must avoid excessive irradiation of downstream electronics due to secondary showers (the smaller the gap the larger the showers)

Favorable locations for off-momentum protons cleaning are where

- Dx large : to enhance the off-momentum orbit excursion and therefore minimize relax the collimator gap

- Betax is small : to have a collimator gap in mm that corresponds to a larger number of betatron sigmas

REMARK: if the gap in mm results too small: --> it may introduce problems with alignment and sensitivity to orbit errors (i.e. a small orbit error can result in loosing the beam on the collimator)
INTRODUCTION

TCL5 available studies

LHC-Project Note 208 (Jeanneret-Baichev, 2000), Using LHC optics V6.1

![Graph showing distribution of lost protons]

Figure 3: The momentum distributions of the lost protons. Dashed histogram - the protons intercepted by the collimator, solid one - those one lost in the dispersion suppressor and in the arc cells, including the protons which are reemitted by the collimator.

To me this says: less than 10% of protons scattered on collimator are lost in DS
OPTICS

Periodic optics

To be used for calculating beam size
--> collimator gaps in sigmas
## OPTICS

### BEAM SIZES AT COLL

<table>
<thead>
<tr>
<th></th>
<th>s [m]</th>
<th>$\sigma_x$ [mm]</th>
<th>$10^*\sigma_x$ [mm]</th>
<th>$50^*\sigma_x$ [mm]</th>
<th>betx [m]</th>
<th>$D_x$ [m]</th>
<th>$D_x/\sqrt{\text{betx}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCL.4R1.B1</td>
<td>150.345</td>
<td>0.524</td>
<td>5.240</td>
<td>26.200</td>
<td>546.873</td>
<td>-0.022</td>
<td>-0.000954</td>
</tr>
<tr>
<td>TCL.5R1.B1</td>
<td>184.857</td>
<td>0.291</td>
<td>2.910</td>
<td>14.550</td>
<td>168.714</td>
<td>-0.110</td>
<td>-0.008460</td>
</tr>
<tr>
<td>TCL.6R1.B1</td>
<td>224.800</td>
<td>0.071</td>
<td>0.710</td>
<td>3.550</td>
<td>10.147</td>
<td>-0.165</td>
<td>-0.051893</td>
</tr>
</tbody>
</table>
Mismatched optics

p-p forward protons (FP signal and background) don’t follow the periodic optics, their initial distribution is not matched to the colliding beams distributions. In particular: $D_x$ and $D_y$ at the IP are $== 0$ for our distributions

--> to be used for tracking
This is the region for which one can argue that TCL5 needs to stay very closed (even < 10 sigma) to be effective. A TCL6 at 224 m is more effective.