Energy deposition with and without cryo-collimators in IR2 (ions) and IR7

R. Bruce, F. Cerutti, J. Jowett, A. Lechner, A. Marsili, S. Redaelli
E. Skordis, G. Steele, M. Schaumann

with valuable input from
M. Karppinen, T. Sahner, D. Ramos, V. Parma, V. Boccone

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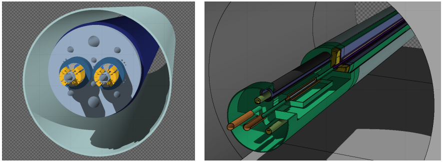
- Predictions of power density in dispersion suppressor (DS) magnets are presented
- Comparison of present layout with a layout including DS collimators (TCLDs)
- Considered integration option:
  MB $\rightarrow$ 11T dipole + TCLD + 11T dipole
- Two case studies:



FLUKA models of 11T dipole and TCLD

	DS next to IR2	DS next to IR7
Operation:	Pb@2.76 TeV/u	p@7 TeV
Heat load due to:	ion collision debris $\rightarrow$ secondary beams with changed rigidity due to EM processes	collimation leakage $\rightarrow$ off-momentum protons mainly due to single diffr. scattering
Considered layout:	1 $\times$ (11T + TCLD + 11T) (in DS cell 10)	2 $\times$ (11T + TCLD + 11T) (in DS cells 8 & 10)

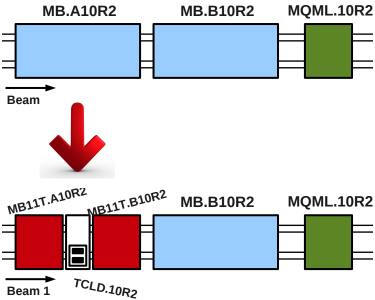
For reference, see also previous talks/publications:

[1] R. Bruce *et al.*, PhysRevSTAB **12**, 071002, 2009.
[2] G. Steele *et al.*, "DS Heat Load Scenarios in Collision Points and Cleaning Insertions", Collimation Review 2013.
[3] F. Cerutti, "Energy Deposition Studies for the LHC Phase II Collimation", CDR LHC Phase II Collimation , 2009.
[4] G. Steele *et al.*, "Status report on the TCLD FLUKA studies", 31st ColUS Meeting, 2013.

Contents

Studies of power deposition in DS magnets (next to IR2)

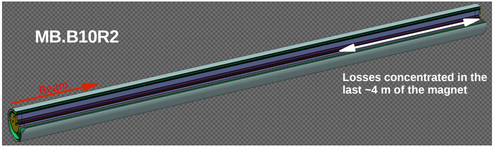
- **Pb@2.76 TeV/u**, beam 1
- Only consider bound-free pair production (BFPP1, see [1]) with secondary $^{208}\text{Pb}^{81+}$ beam
- Studied layouts (DS right of IR2) and vertical X-angles:
  - Present layout, external X-angle of 80 μrad (net 150 μrad), $^{208}\text{Pb}^{81+}$ impacts on MB.B10 beam screen [1]
  - Layout with 1 DS collimator + 2 11T dipoles replacing MB.A10, external X-angle of 4.6 μrad (net 74 μrad)
- Studied TCLD options:
  - TCLD half-gap arbitrarily set to 9.5 mm to allow for a 2 mm mean impact parameter of BFPP1 secondary beam
  - Different TCLD jaws (Cu 50 cm vs W 100 cm)
- All results presented in following are for an instantaneous luminosity of $6\times10^{27}\text{cm}^{-2}\text{s}^{-1}$ (6 × design, ALICE HL-LHC perform. goal [2])

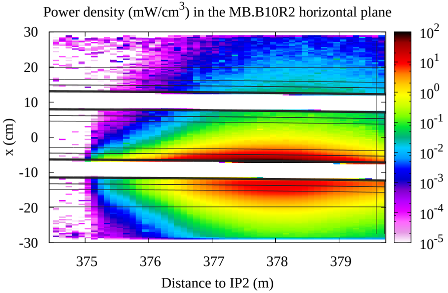


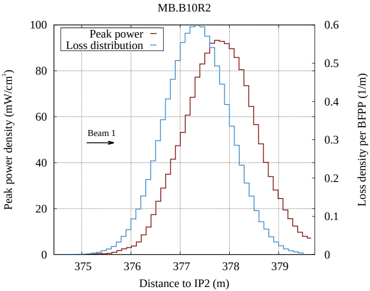
- Impact distributions from SixTrack (as described in [1] and [2])

[1] R. Bruce *et al.*, PhysRevSTAB **12**, 071002, 2009.
[2] J. Jowett and M. Schaumann, "Dispersion Suppressor Collimators for Heavy-Ion Operation", Collimation Review 2013.

Power density for present layout





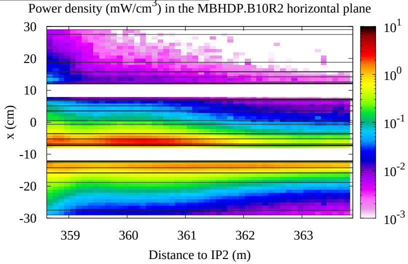


- Results use an improved MB model geometry with respect to [1] but are nonetheless consistent
- Estimated peak power density in MB coils for 6× design lumi: 95 mW/cm^3
- If averaged radially over the cable, one gets about half this value

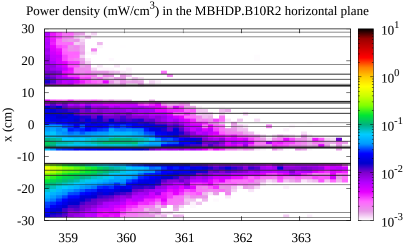
[1] R. Bruce *et al.*, PhysRevSTAB **12**, 071002, 2009.

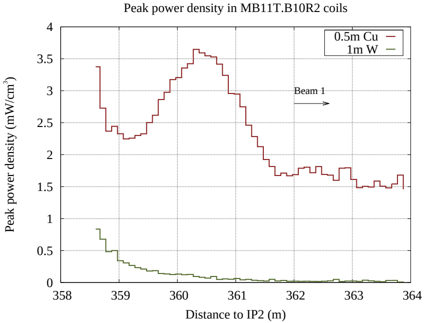
Power density with DS collimator

TCLD jaws: 50 cm Cu



TCLD jaws: 100 cm W





- 11T dipole downstream of TCLD: peak power density in coils for 6× design lumi ranges from 0.8 mW/cm^3 (1 m W) to 3.7 mW/cm^3 (50 cm Cu)
- Heat deposition in magnet evidently depends on assumed half gap (rather large gap assumed in this study)

Contents

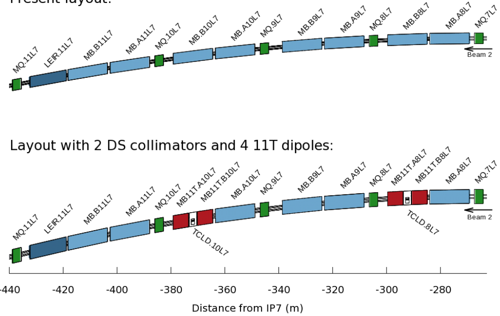
Studies of power deposition in DS magnets (next to IR7): layout and collimator settings

- **p@7 TeV**, beam 2
- Nominal optics
- Only horizontal losses considered
- Studied layouts (DS left of IR7):
  - Present layout *vs* layout with 2 DS collimators (cells 8&10) – see illustration
- Studied options:
  - Different collimator settings (relaxed *vs* nominal) – see table
  - TCLD: W 80 cm jaws
- All results presented in following are normalized to 0.2 h beam lifetime (4.5×10^{11} p/sec lost)

	TCP7	TCS7	TCLA7	*TCLD*	TCSG6	TCDQ6	TCT
relaxed	7.0	10.3	13.0	*13.0*	11.0	11.6	13.2
nominal	6.0	7.0	10.0	*10.0*	7.5	8.0	8.3

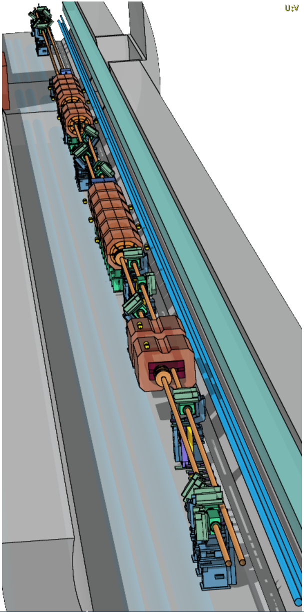
Table: settings in 3.5 μm·rad emittance, as shown in [1]

Present layout:



[1] R. Bruce *et al.*, "SixTrack studies of new TCLD", 29th ColUS Meeting.

Studies of power deposition in DS magnets (next to IR7): simulation methodology



Step 1 (SixTrack, data©Collimation team [1])

- Calculation of the spatial distribution of inelastic nuclear interactions in collimator jaws by means of SixTrack

Step 2 (FLUKA)

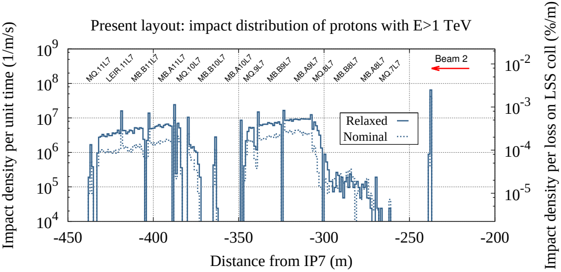
- Generation of inelastic nuclear collision products in LSS collimators (incl. single diffractive protons)
- Shower development and transport of (secondary) particles with high production and transport cut in LSS and DS
- Calculation of impact distribution in DS (magnet aperture and DS collimators)

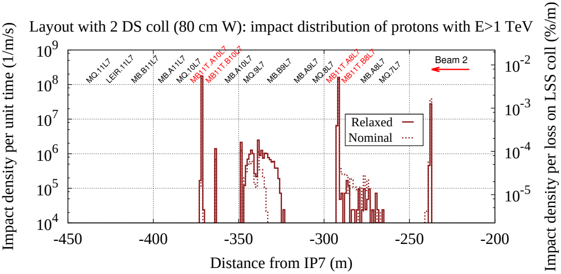
Step 3 (FLUKA)

- Detailed energy deposition simulation in DS using low production and transport cut

[1] R. Bruce and S. Redaelli, "SixTrack studies of new TCLD", 29th ColUS Meeting.

[Single diffractive] proton impact distribution in the DS with and without DS collimators





relaxed and nominal settings

TCLD jaws: 80 cm W

- Present layout (top figure):
  - Clusters across cells 9 and 11 (due to dispersion function)
- Layout with 2 DS coll 80 cm W (bottom figure):
  - Proton impacts are largely concentrated on DS coll
  - Towards end of cell 9, direct proton losses on aperture remain, however with significantly reduced loss density

[Single diffractive] proton spectra

relaxed and nominal settings

TCLD jaws: 80 cm W

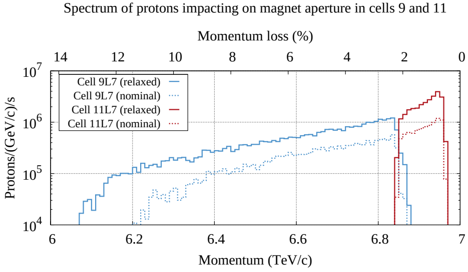
- Present layout (top figure):

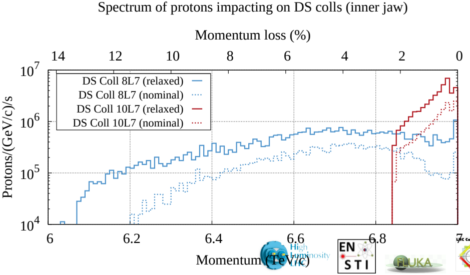
$\Delta p/p$	impacts on magn. apert.
>2.3%	primarily around cell 9
∼0.5%-2.3%	primarily around cell 11
0.5%<	escape DS

- Layout with 2 DS coll (bottom figure):

$\Delta p/p$	impacts on DS coll.
2.3%<	primarily intercepted by DS collimator in cell 10 but also in cell 8
0.5%<	both collimators (primarily the one in cell 10) also intercept protons with smaller momentum loss which would otherwise escape the DS

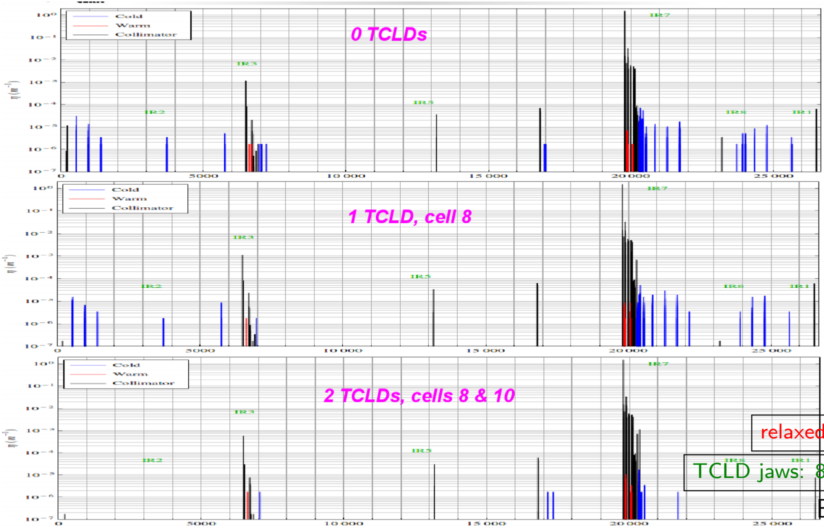
→ indicates importance of collimator in cell 10 for global cleaning *(as also shown by tracking studies [1])*





[1] R. Bruce and S. Redaelli, "SixTrack studies of new TCLD", 29^{th} ColUS Meeting.

Global loss maps (from SixTrack, by courtesy of R. Bruce and S. Redaelli [1])



relaxed settings

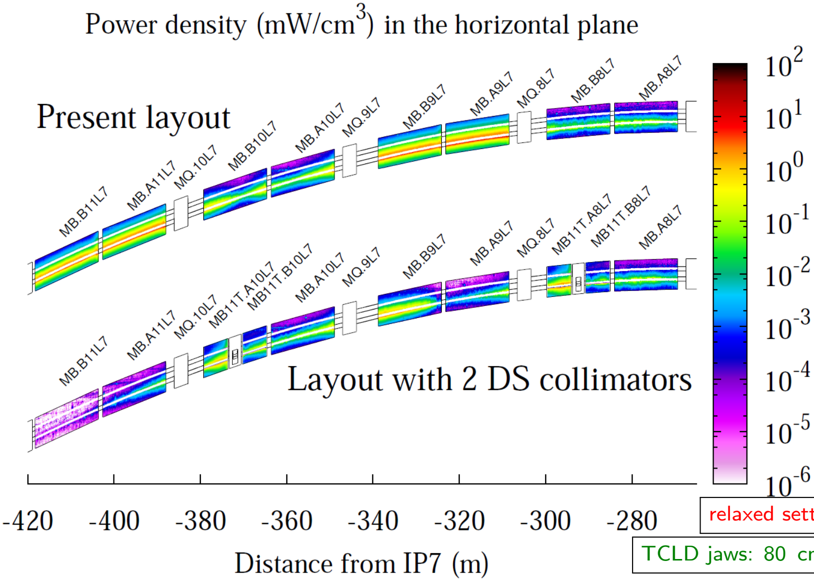
TCLD jaws: 80 cm W

Beam →

[1] R. Bruce and S. Redaelli, "SixTrack studies of new TCLD", 29th ColUS Meeting.

Power density distribution with and without DS collimators

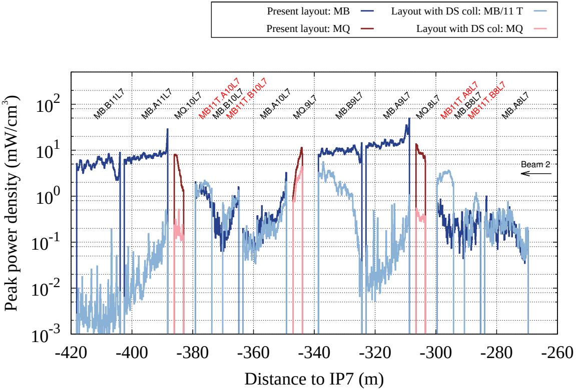
← Beam 2



relaxed settings

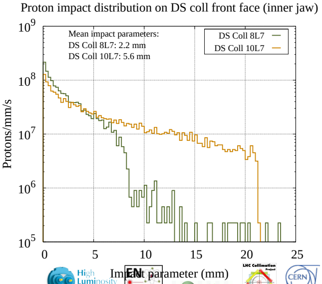
TCLD jaws: 80 cm W

Peak power density in DS magnet coils with and without DS collimators



relaxed settings

TCLD jaws: 80 cm W



- With DS colls: overall reduction of maximum peak power density by about a factor 10
- For nominal settings one gets a comparable reduction (see summary page for peak energy densities)
- Local increase of peak power in dipole downstream of TCLD in cell 8 (less in cell 10) → mean impact parameter is significantly larger in cell 10

Contents

Summary of estimated power values and reduction factors

DS next to IR2 (Pb@2.76 TeV/u), instant. lumi. 6×10^{27} cm^{-2}s^{-1}

Layout	TCLD jaws	Coll sett	Peak power density coils	Reduction factor	Tot. power on magnet[(b)]	Total power TCLD jaws
Present layout	–		95 mW/cm^{-3}	–	105 W	–
With 1 TCLD	Cu 0.5 m	TCLD: 2 mm mip[(a)]	3.7 mW/cm^{-3} (MB11T.A8)	∼25	46 W (MB11T.A8)	42/7 W
With 1 TCLD	W 1 m	TCLD: 2 mm mip[(a)]	0.8 mW/cm^{-3} (MB11T.A8)	∼100	8 W (MB11T.A8)	77/13 W

DS next to IR7 (p@7 TeV), 0.2 h beam lifetime

Layout	TCLD jaws	Coll sett	Peak power density coils	Reduction factor	Tot. power on magnet[(b)]	Total power TCLD jaws
Present layout	–	relaxed	50 mW/cm^{-3} (MB.A9)	–	141 W (MB.A9)	–
With 2 TCLDs	W 0.8 m	relaxed	5 mW/cm^{-3} (MQ.9)	∼10	41 W (MB11T.A8)	198/71 W & 255/53 W (TCLD.8&10)
Present layout	–	nominal	17 mW/cm^{-3} (MB.A9)	–	61 W (MB.A9)	–
With 2 TCLDs	W 0.8 m	nominal	1.6 mW/cm^{-3} (MQ.9)	∼10	14 W (MB11T.A8)	82/30 W & 100/23 W (TCLD.8&10)

[(a)]mip=mean impact param.; [(b)]incl. beam screen; stat. error <5% on total power and <12% on peak power

Conclusions

Simulation predictions on heat deposition in DS magnets were presented:

IR2 (heat deposition in DS due to ion collision debris from BFPP1 for ALICE HL-LHC goal)

- Depending on half gap and jaw material, a DS collimator in cell 10 allows to reduce the peak energy density in coils by at least a factor 25
  - maximum peak density of less than $\sim$3.7 mW/cm^3 (in 11T dipole) compared to $\sim$95 mW/cm^3 (in MB) w/o DS coll

IR7 (heat deposition in DS due to proton collimation leakage - nominal case)

- A layout with 2 DS collimators (cell 8&10) with 80 cm W jaws allows to reduce the peak energy density in coils by about a factor 10 (for considered coll hirarchy)
  - maximum peak densities of $\sim$1.6–5 mW/cm^3 (in MQ), depending on settings, compared to $\sim$17–50 mW/cm^3 (in MB) w/o DS colls
- The mean impact parameter of [single diffractive] protons is significantly larger for TCLD.10 than for TCLD.8
  - local increase of power deposition in 11T dipole downstream of TCLD.8 compared to MB.B8 in present layout $\rightarrow$ peak of $\sim$1.3–3.5 mW/cm^3 in 11T dipole
- The TCLD.10 (less TCLD.8) intercepts [single diffractive] protons with small momentum loss ($\Delta p/p<0.5\%$) which would otherwise escape DS
  - underlines importance of TCLD.10 for global cleaning (as seen in tracking studies)

Points to be studied

Quench limits

- Evidently, peak power densities have to be seen relative to quench limits
- Requires extrapolation from proton quench tests@4 TeV to 7 TeV
  - Recent estimates of steady-state quench limits of MBs at 7 TeV range from 27 mW/cm^3 [1] to 47 mW/cm^3 [2] (**these values are the radial cable average!** $\rightarrow$ results shown in this study are peak values, which are roughly a factor two of average)
  - Older estimates were generally lower (5 mW/cm^3 [3] to 12–17 mW/cm^3 [4], again radially averaged)
- Quench limit of 11T dipole?
  - Calculated power density distributions will be passed to experts for quench limit calculations

Other DS heat load scenarios to be studied?

- Ion collision debris from ATLAS, CMS
- Ion collimation losses in IR7

[1] A. Verweij and B. Auchmann, "Quench limits: extrapolation of quench tests to 7 TeV", Collimation Review 2013.
[2] P.P. Granieri, "Deduction of steady-state cable quench limits for the LHC main dipoles", Collimation WG Meeting 164, 2013.
[3] J.B. Jeanneret *et al.*, "Quench levels and transient beam losses in LHC magnets", LHC Project Report 44, 1996.
[4] D. Bocian *et al.*, "Entalpy Limit Calculations for transient perturbations in LHC magnets", CERN note AT-MTM-IN-2006-021, 2006.