AFP - TCL collimator studies

LHC Collimation Study Group, 7-Sep-2009

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and
R. Assmann, I. Baichev, P. Bussey, F.Cerutti, S.Fartoukh, M.Giovannozzi, W.Herr, J.B.Jeanneret, E. Laface, D.Macina, S.Redaelli, V. Talanov, T.Weiler ... and others

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

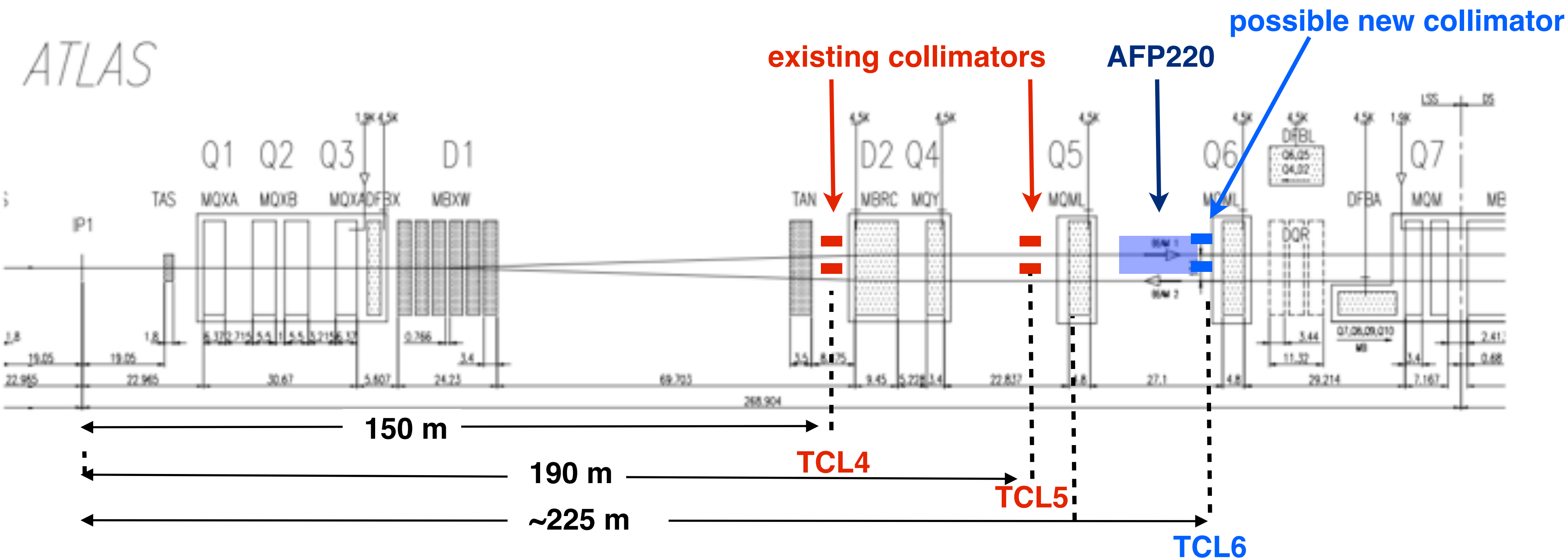
Proposed schedule: be ready for installation in 2010-2011 in compatibility with LHC sectors warm up

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.

TCL Collimator at 190 m from IP1



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)

QUENCH LIMIT: 8e6 p/s/m (in reality it's difficult to assess a value valid for all magnets)

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)

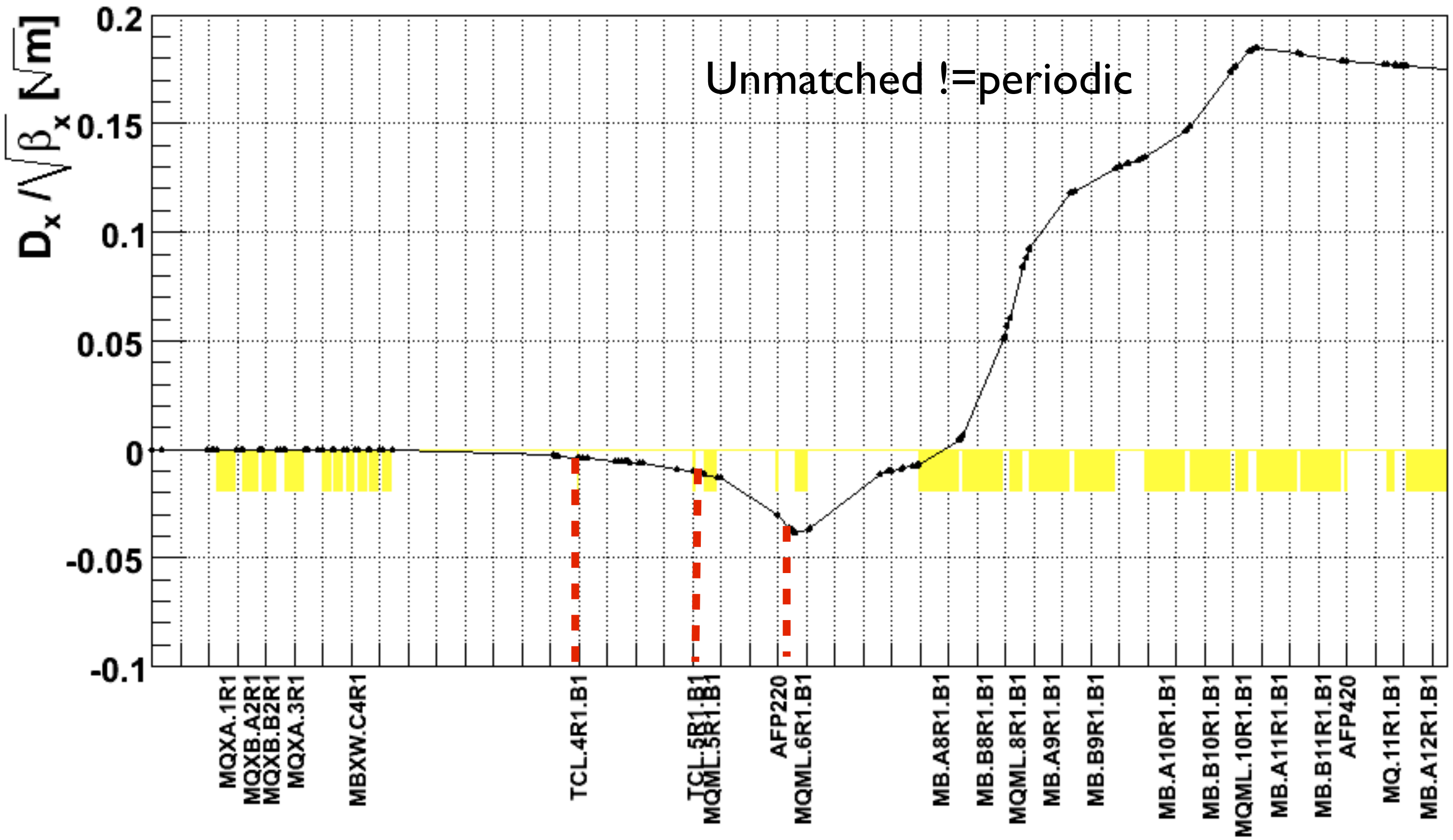
	WITHOUT COLLIMATORS	TCL5 AT 15 SIGMAS
1st highest peak [p/s/m]	4.2e7 in front of Q5	1.7e6 in front of Q5
2nd highest peak [p/s/m]	4.4e6 at MB.B8	0.8e6 at MB.B9
all other peaks well below quench limit		
losses integral (in p/s) for s>280 m (DS + ARC)	6.60E+07	1.70E+07

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

$$D_x^n(s) = \frac{D_x(s)}{\sqrt{\beta_x(s)}}$$



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

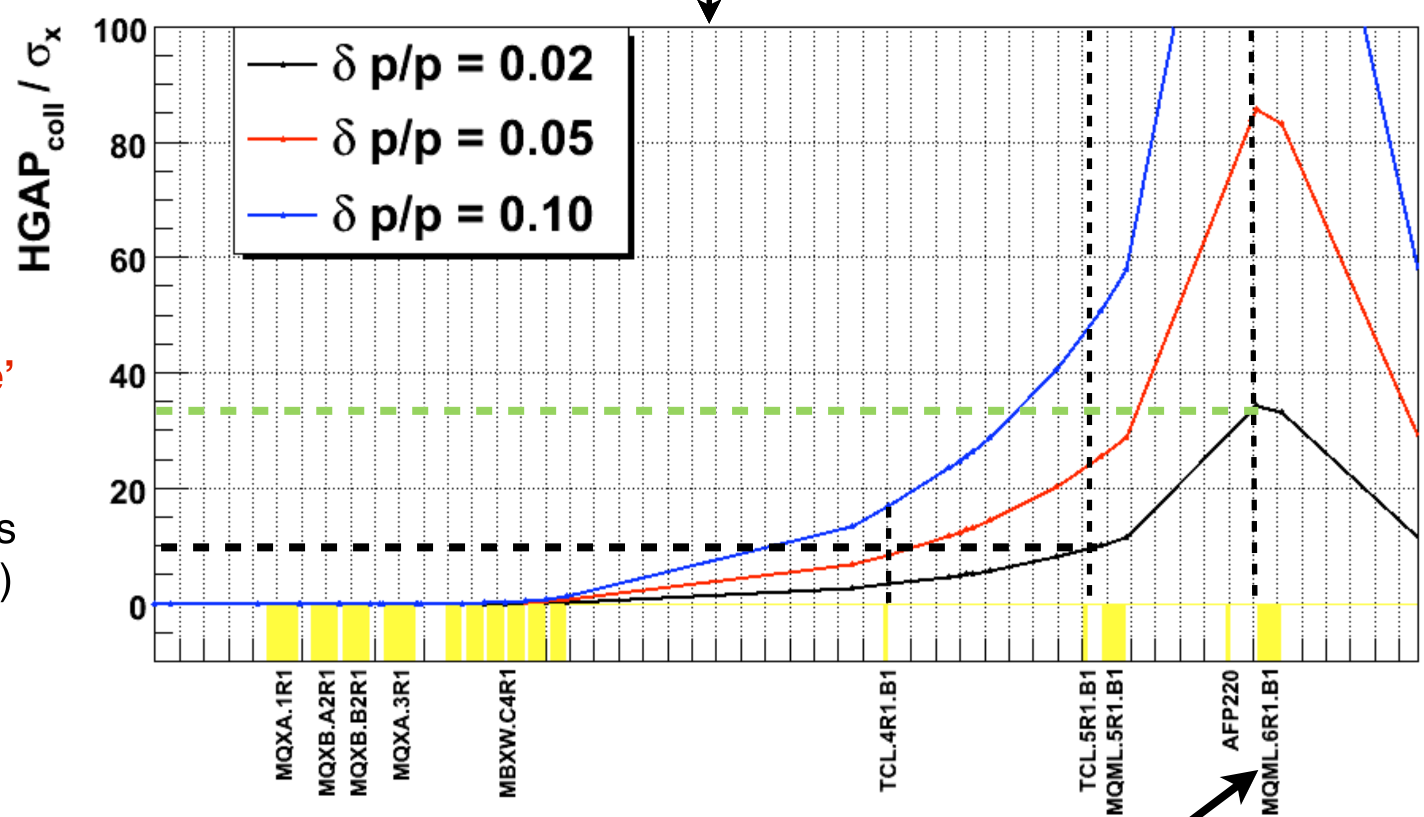
Collimator half-gap necessary to clean all particles with momentum offset >= dp/p0

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

See plot next slide

Optimal collimator location

Collimator half-gap necessary to clean all particles with momentum offset >= dp/p0, 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 ~220 m:

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

Loss maps of forward protons for different TCLs' settings

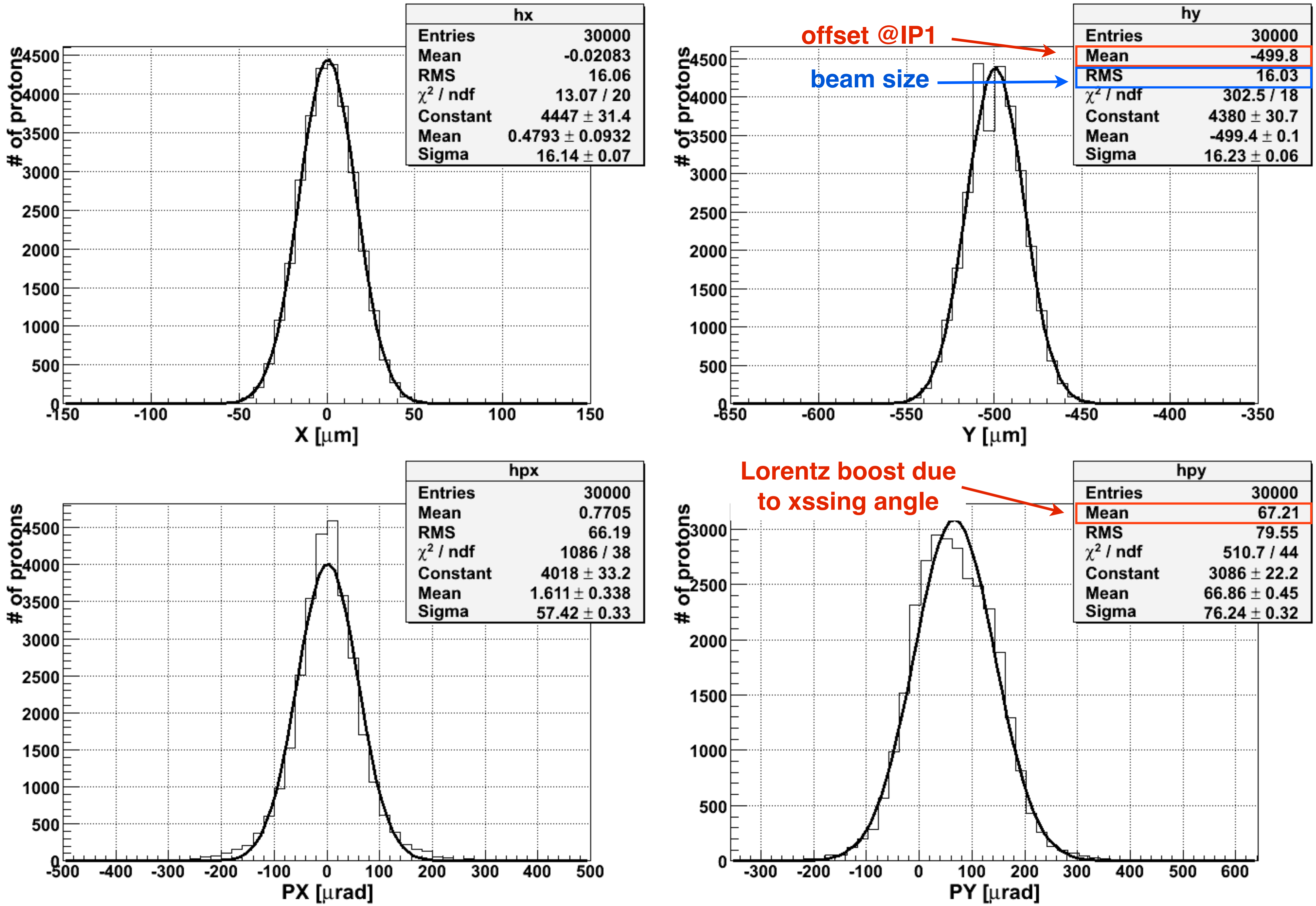
- Protons emerging from **p-p interaction** at IP1 generated with **DPMJET**
  - total cross section ~100mb
  - normalization to nominal luminosity L=1e34
  - smearing for nominal beam size and divergence at 7 TeV, nominal crossing angle

- 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

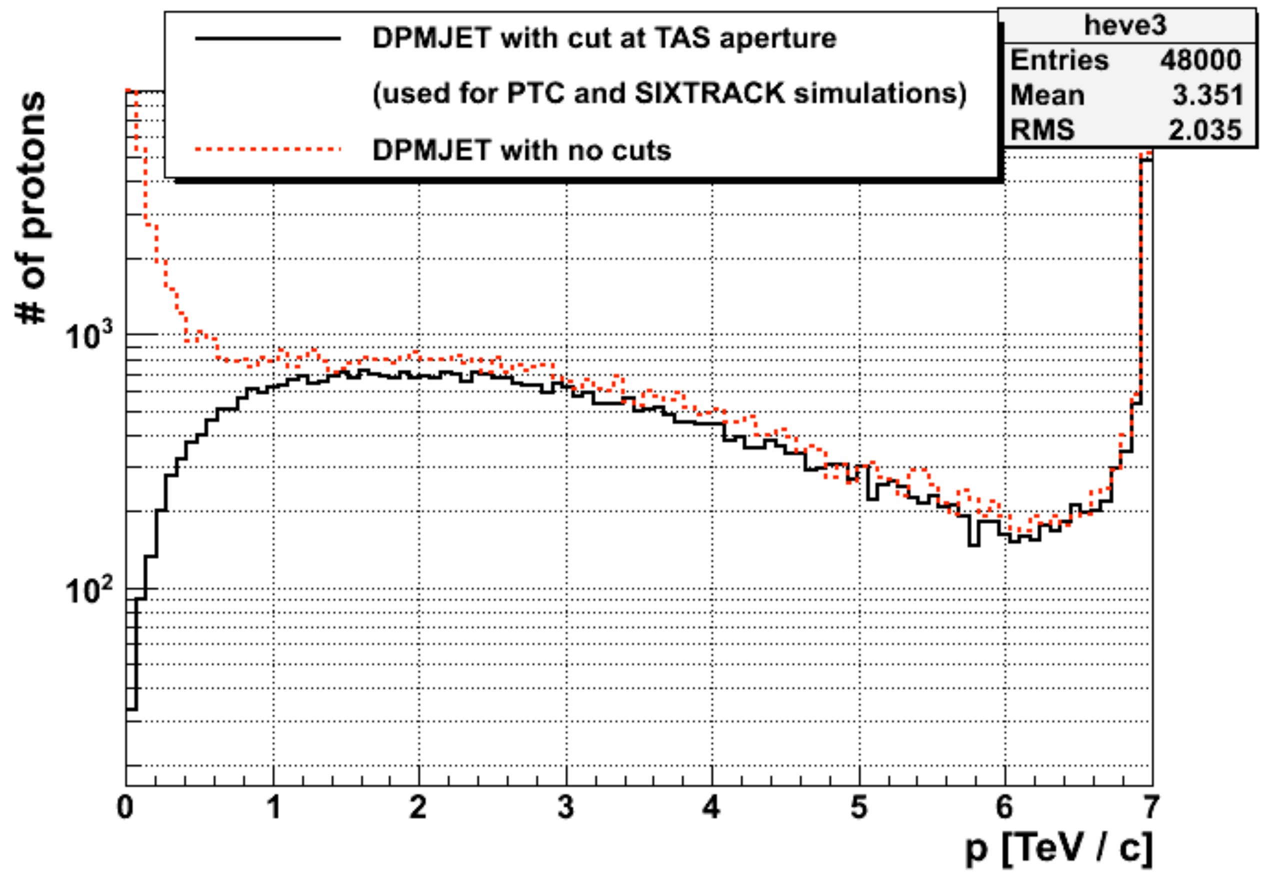
Initial distribution of protons



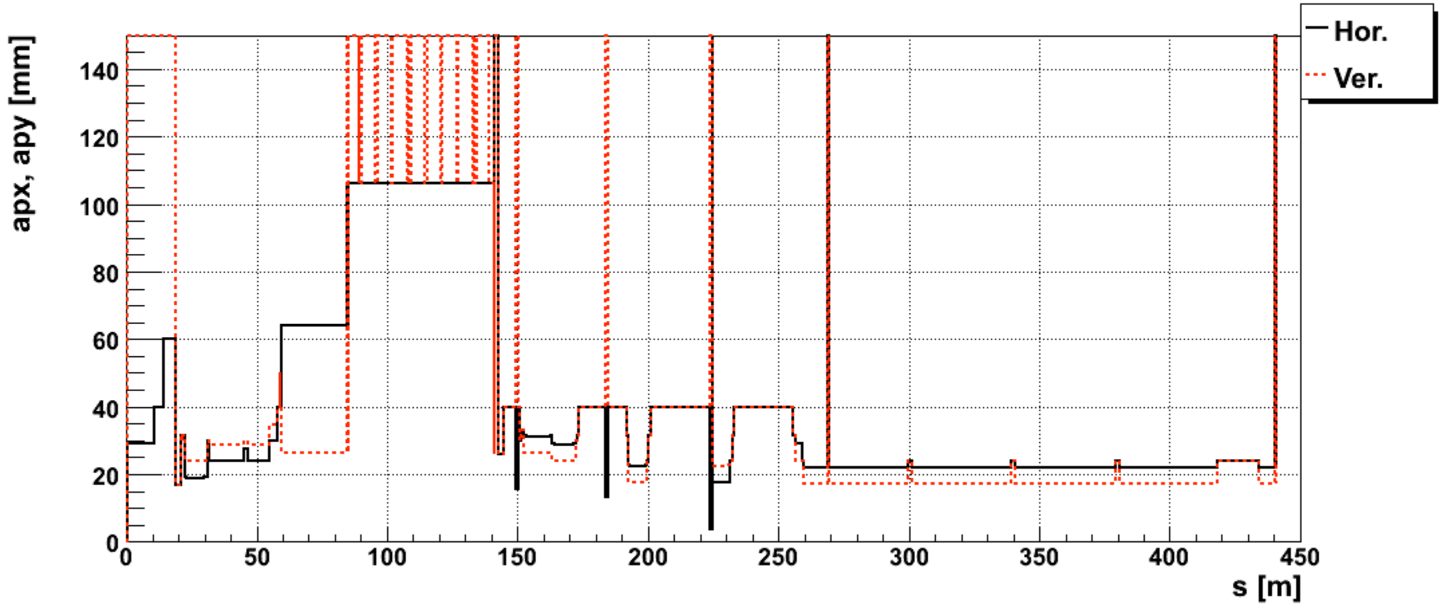
Initial distribution of protons

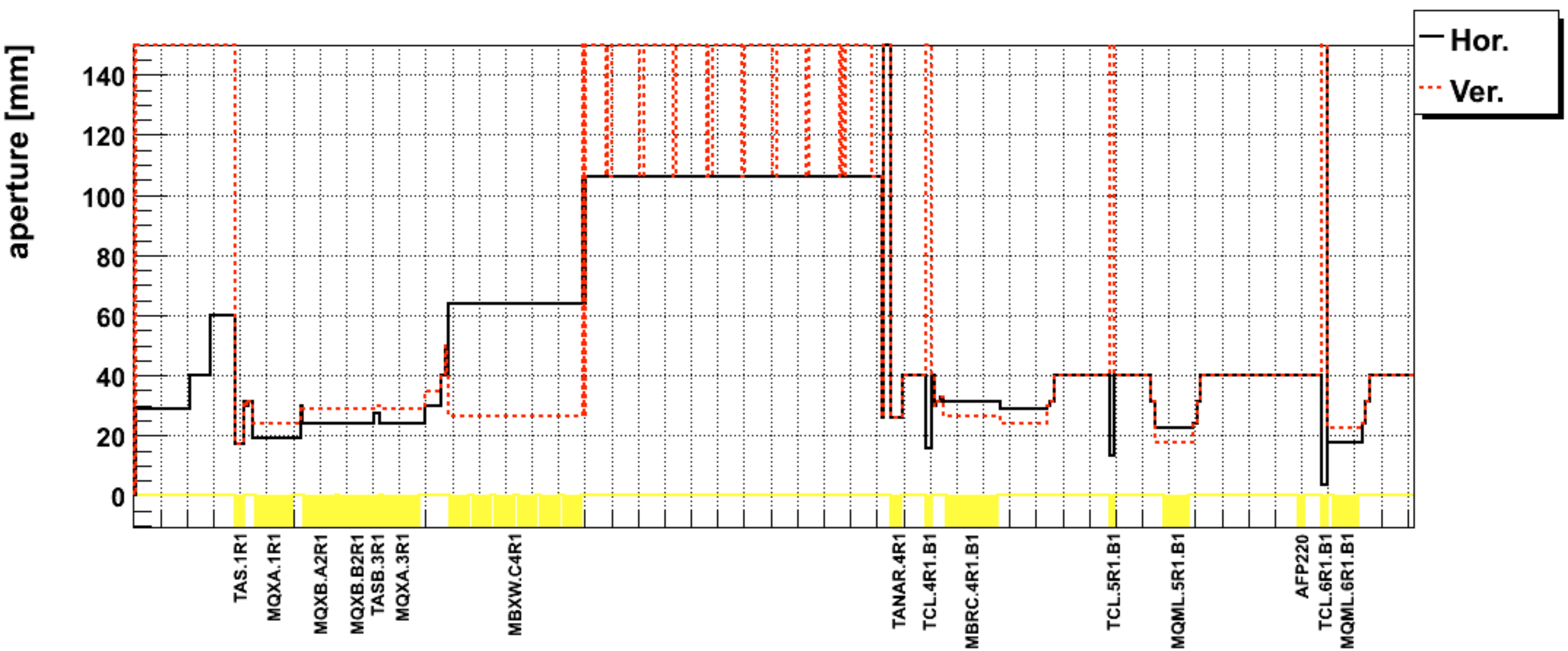
Black curve corresponds to energy distribution of protons used for both SIXTRACK and PTC

A cut has been applied inside DPMJET in order to have more statistics for all protons surviving after the first TAS



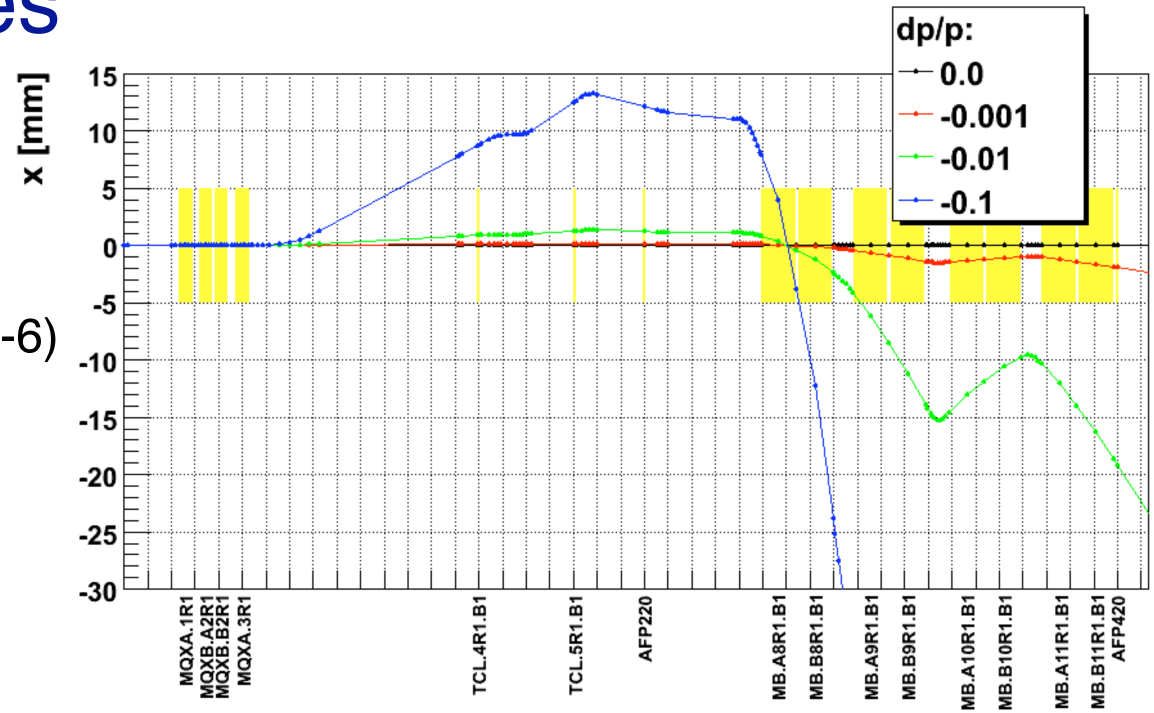
Aperture used for both PTC and SIXTRACK

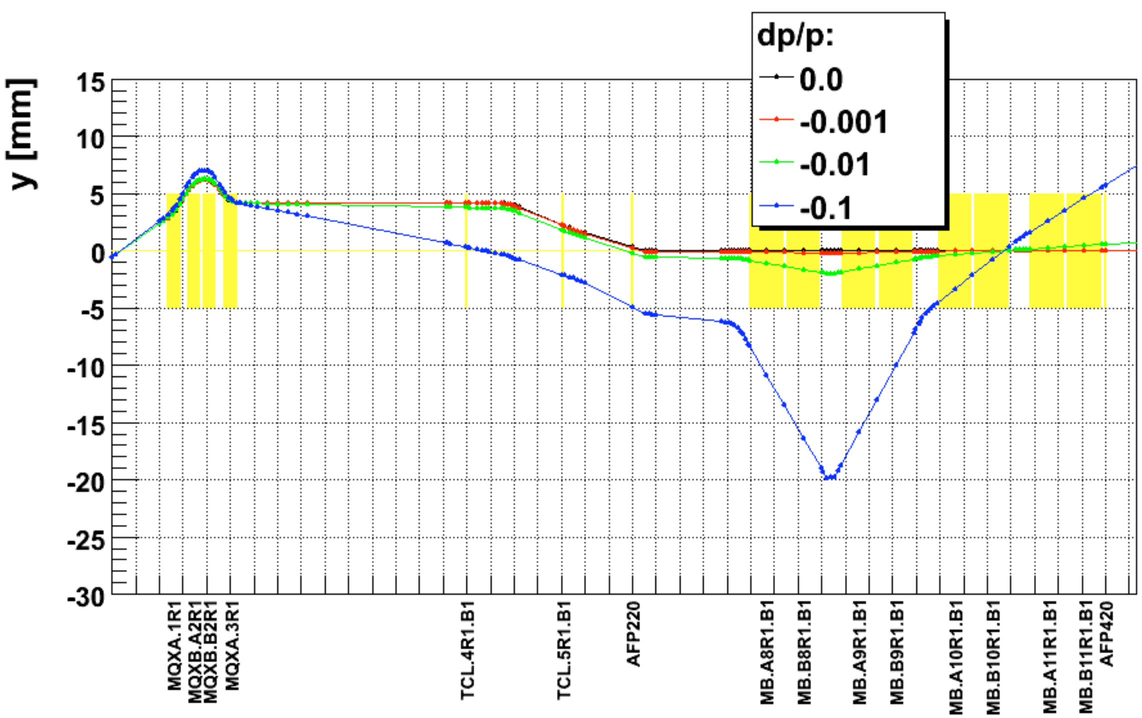




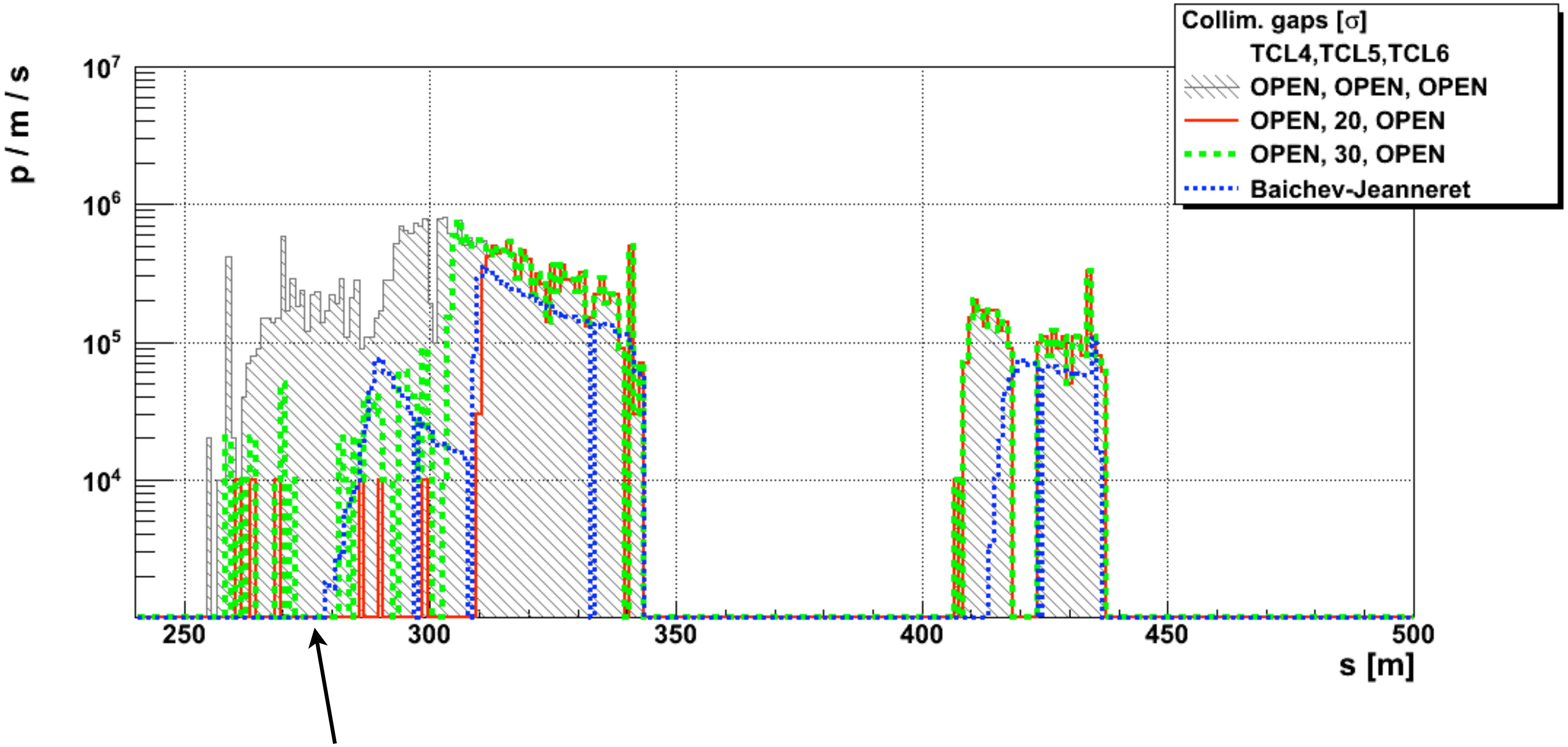
Reference trajectories

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

Comparison with published results

Coll.Gaps in sigmas (TCL4, TCL5, TCL6)	p losses for s > 280		
	PTC		Baichev-Jeanneret
	(1)	(2)	(3)
(OPEN, OPEN, OPEN)	2.80E+07	7.71E+07	6.60E+07
(OPEN, 15, OPEN)	9.80E+06	5.89E+07	1.70E+07
(30, 50, 40)	7.00E+06	5.61E+07	--
(30, OPEN, 30)	4.70E+06	5.38E+07	--
(30, 15, OPEN)	9.80E+06	5.89E+07	--

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

These settings result almost equivalent looking at losses in DS

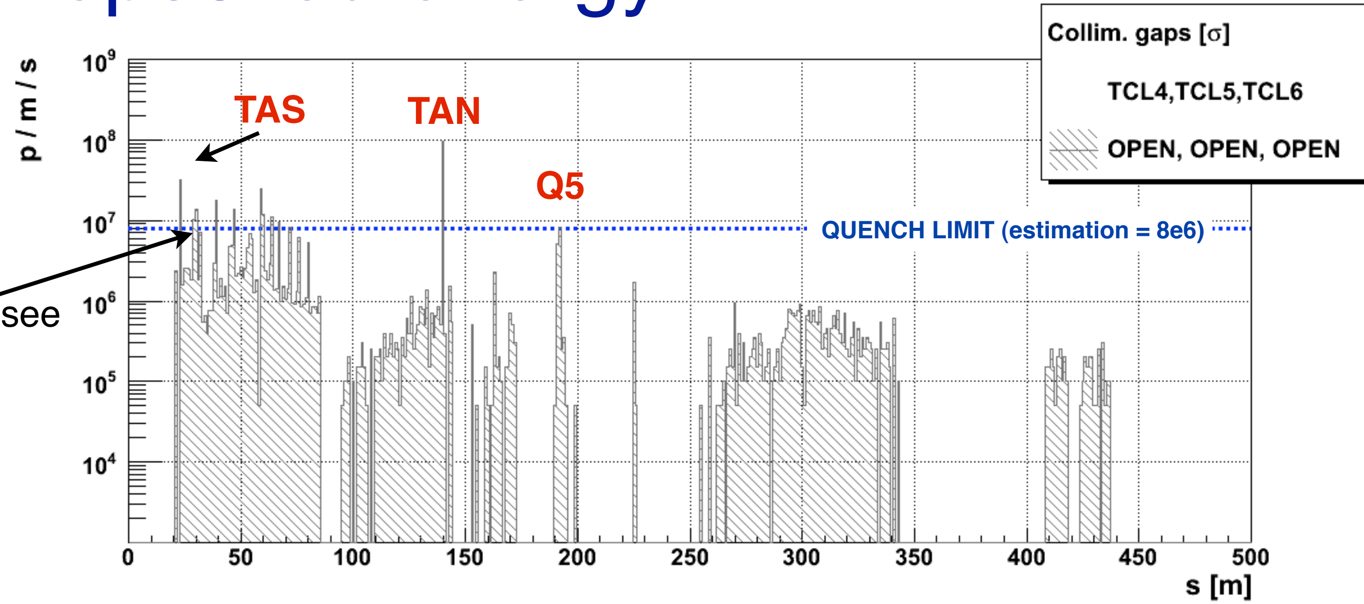
I did not score losses after 450m, therefore here I put →

(1) = Losses scored for 280 < s < 440 m

(2) = (1) + all surviving protons

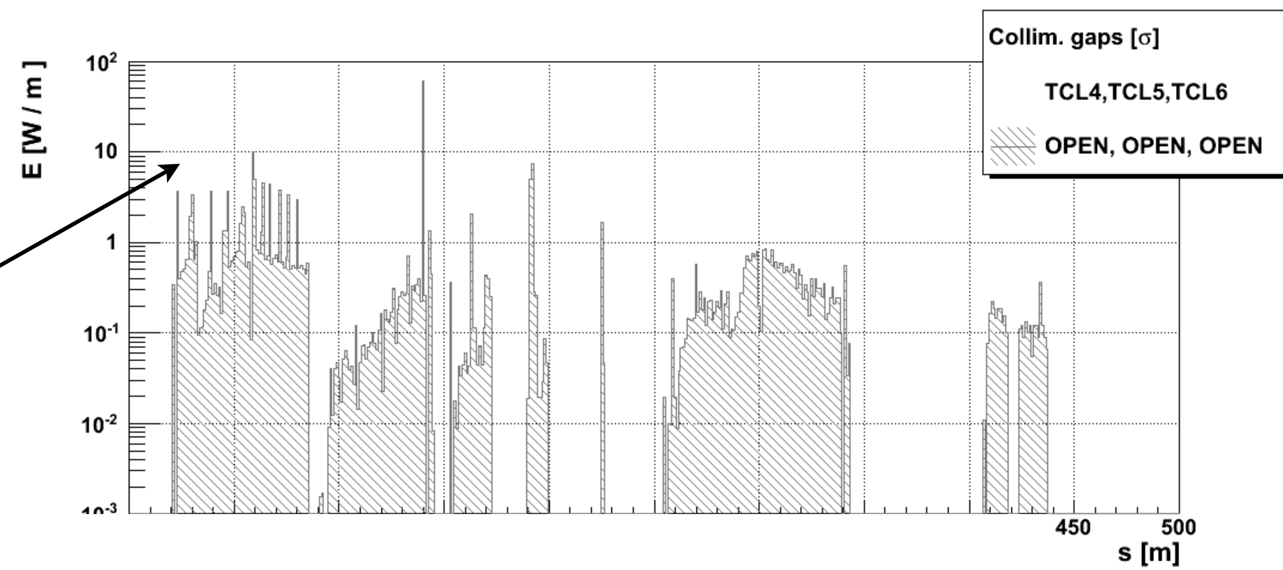
(3) = losses for 280 < s < ~ 700 m

Loss pattern and Deposited energy



Peaks triplets are high.
But those protons have low momentum, see next slide

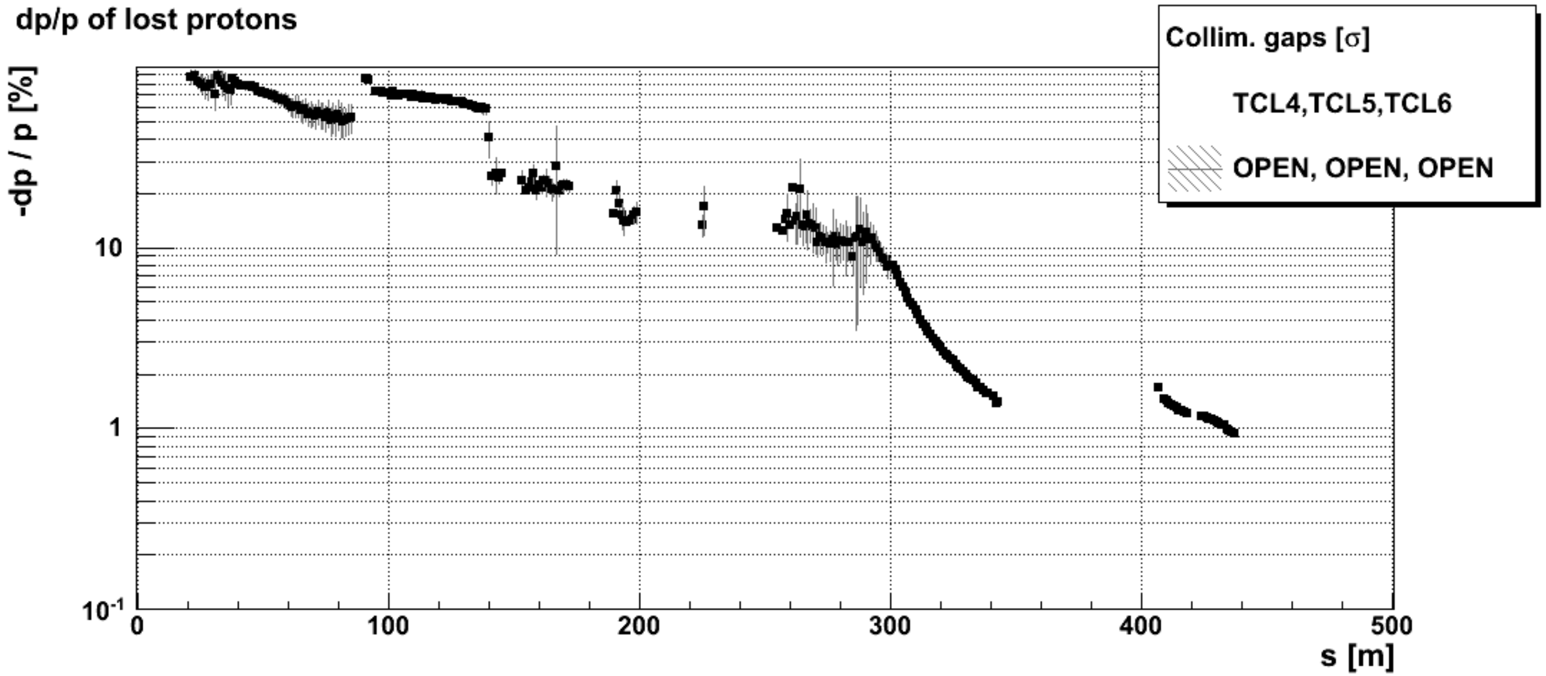
Peaks at Q5 close to estimated quench limit

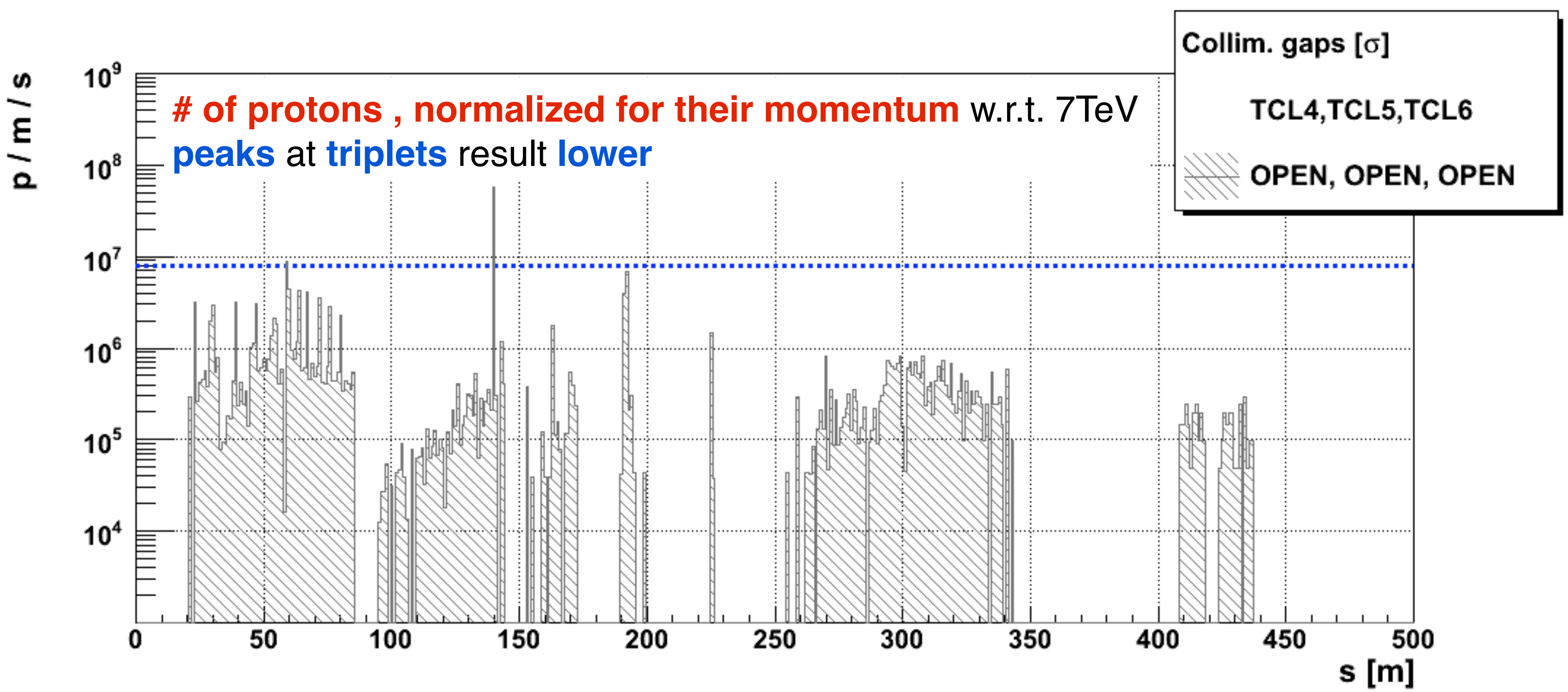


LHC Design Report:
deposited energy in the triplets can reach 10 W/m (--> consistent results)

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

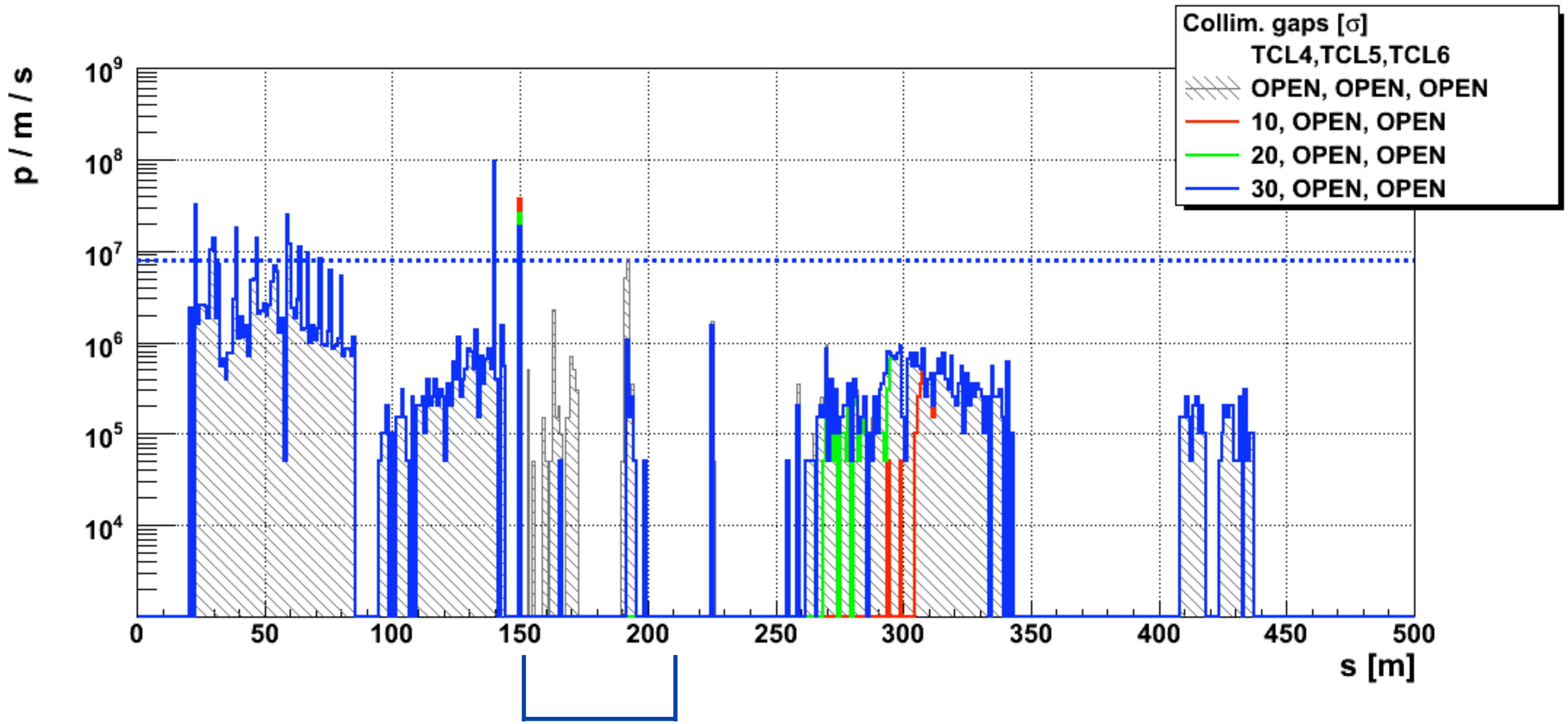
Energy of lost protons





LOSS MAP RESULTS (PTC)

Present settings Effectiveness of TCL4

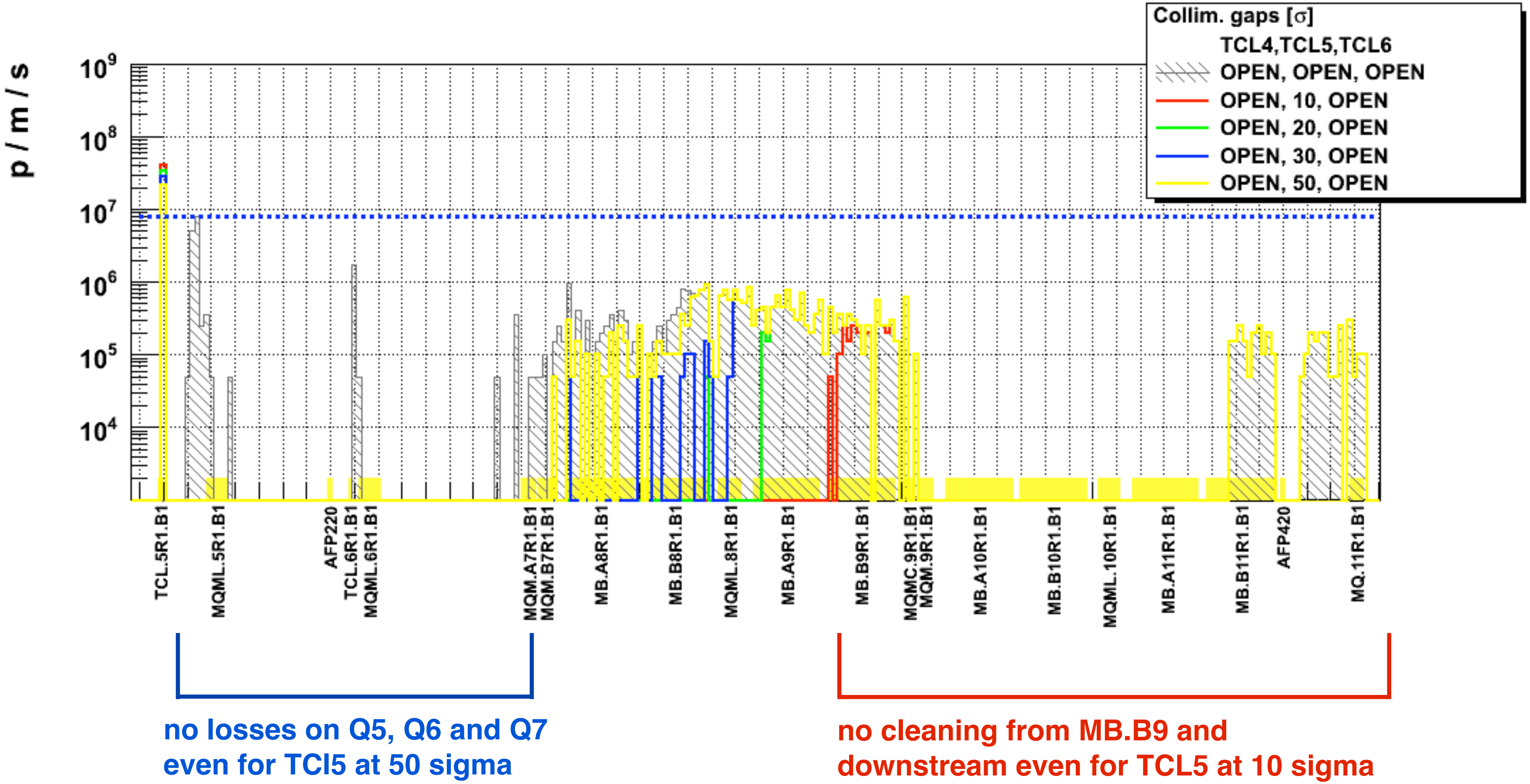


TCL4 at 30 sigma:

-no losses on Q4 and D2

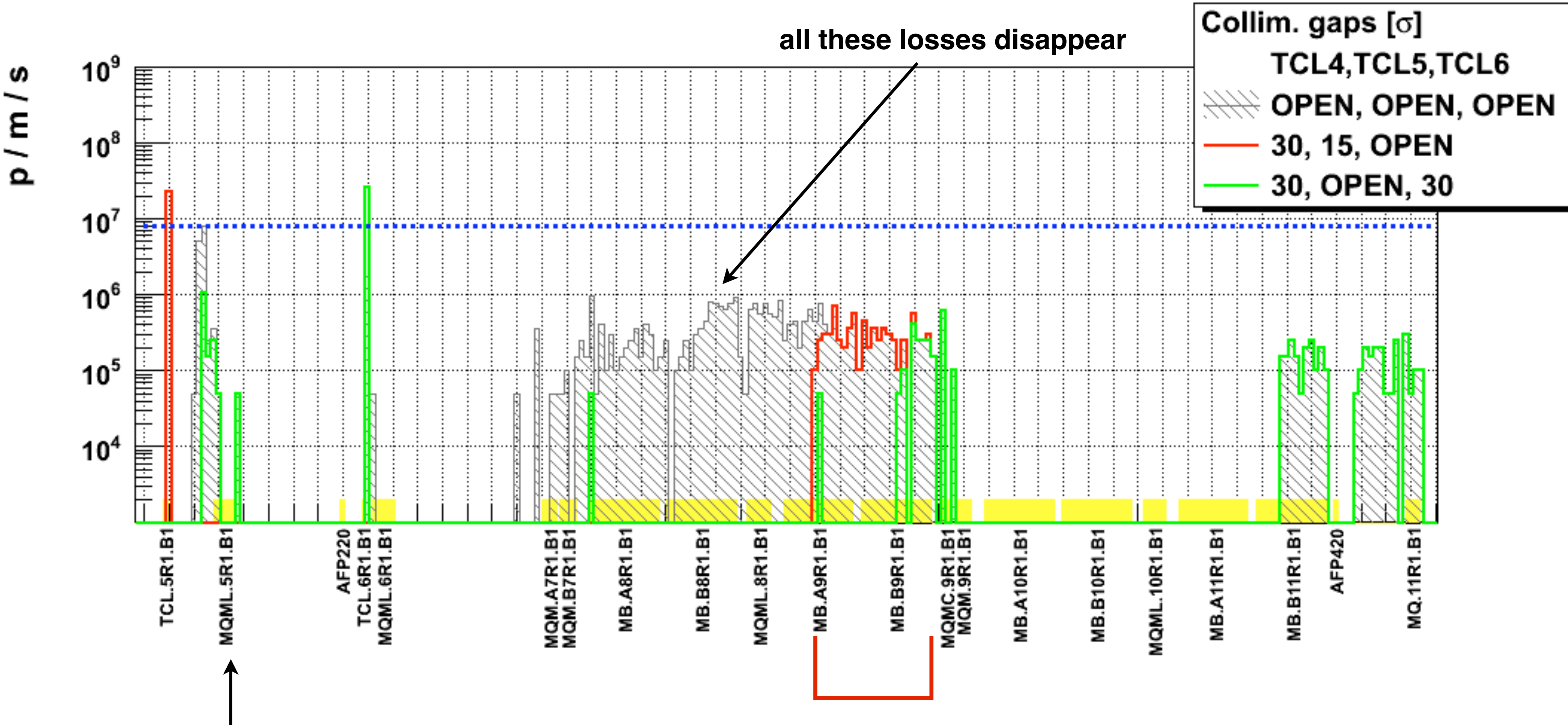
-reduced losses on Q5

Present settings Effectiveness of TCL5



ALTERNATIVE 1 Moving TCL5 in front of Q6 (after AFP220)

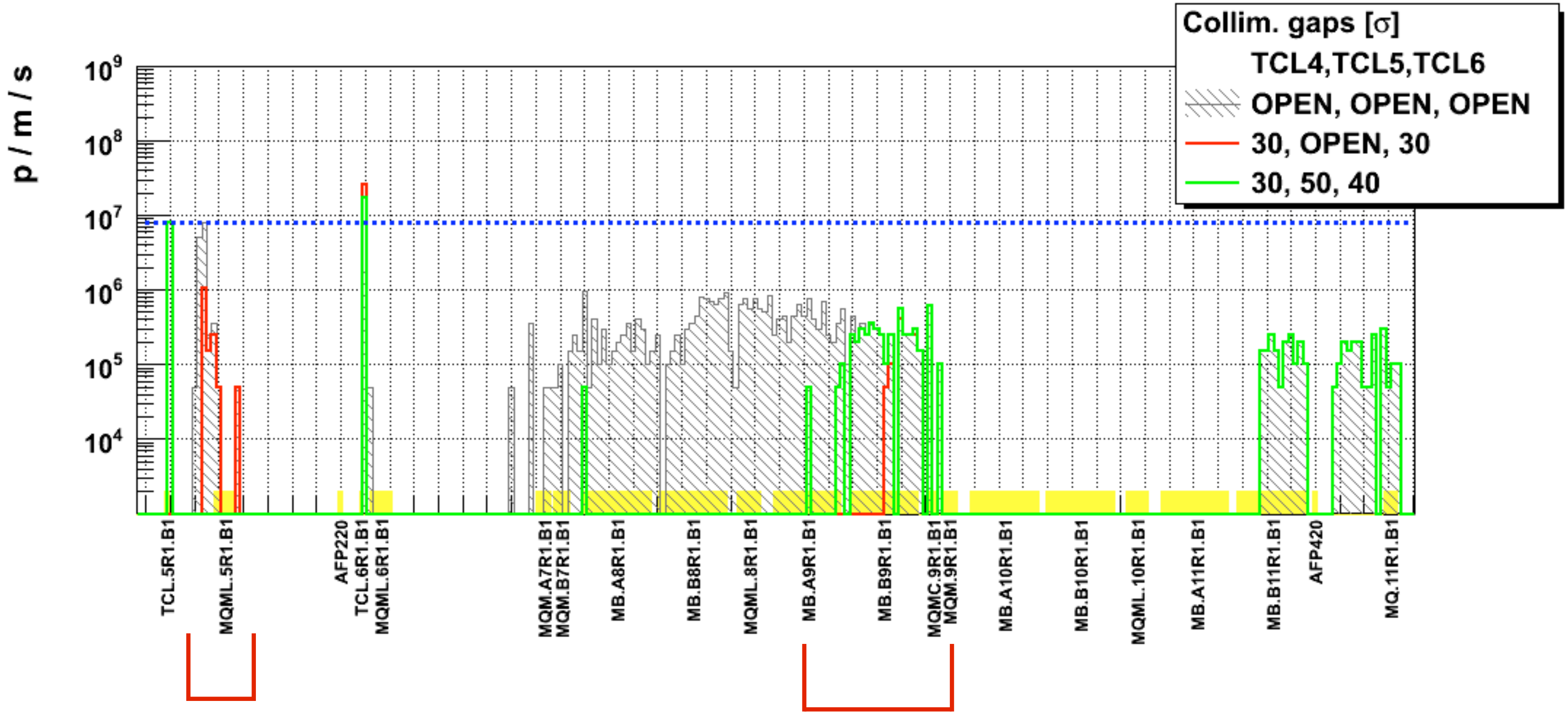
TCL6 at 30 sigma vs TCL5 at 15 sigma:



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)



TCL5 at 50: all losses on Q5 disappear

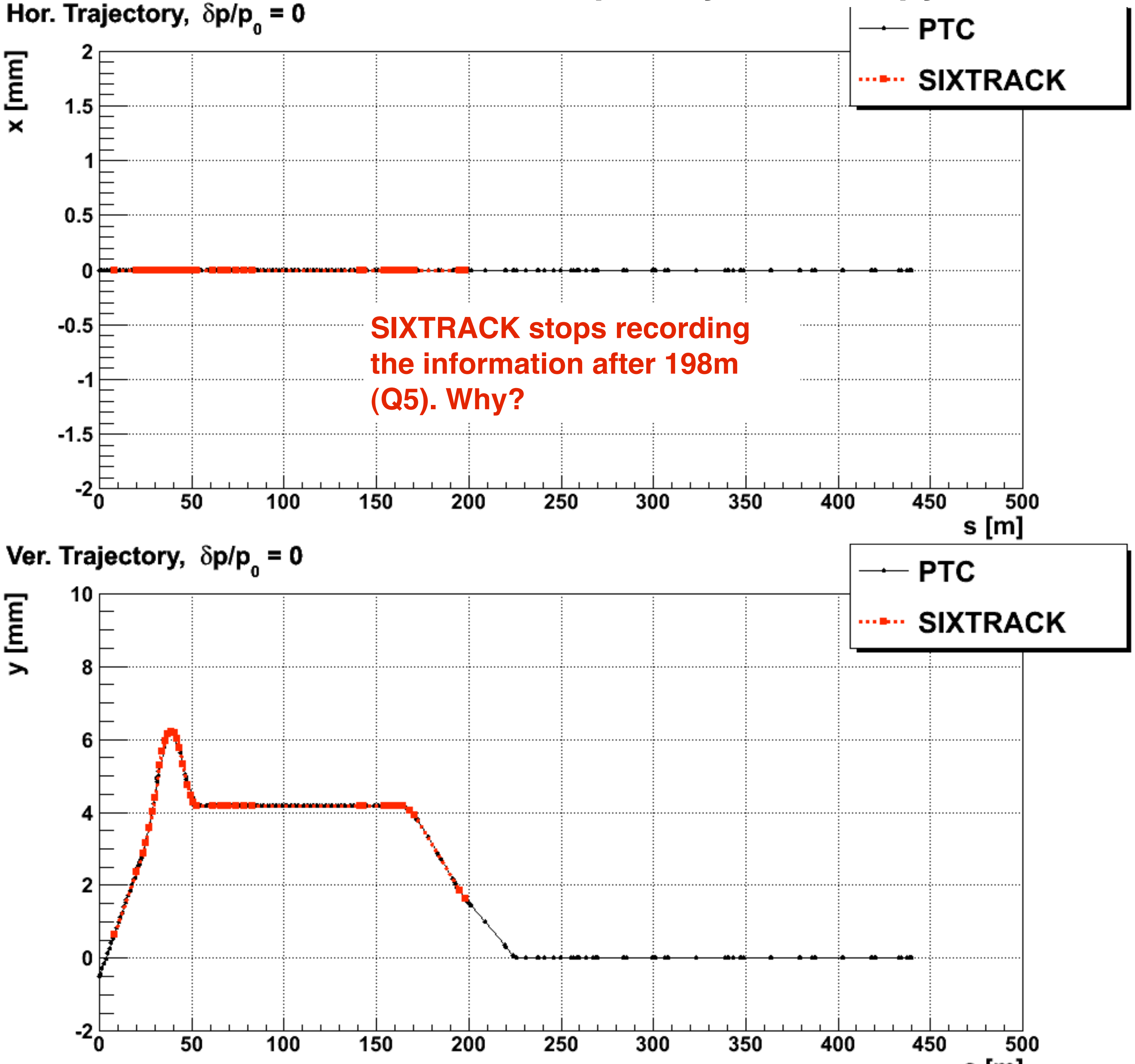
TCL5 at 50 and **TCL6 at 40**: worse than 'Alternative 1' but **better than TCL5 at 10** at MB9 (see slide 15, 'Effectiveness of TCL5')

TRACKING RESULTS

PTC versus SIXTRACK

7 TeV proton starting at

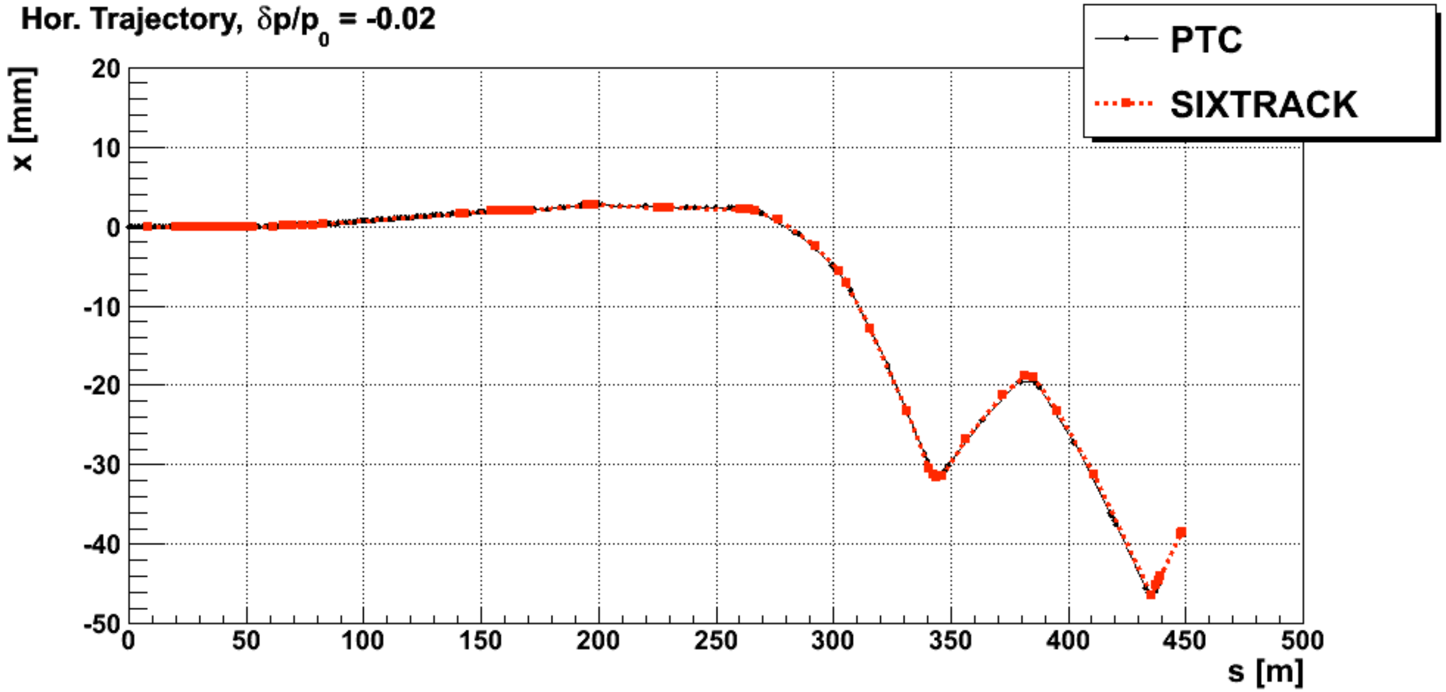
x=0, px=0, y=-0.5mm, py=142.5urad

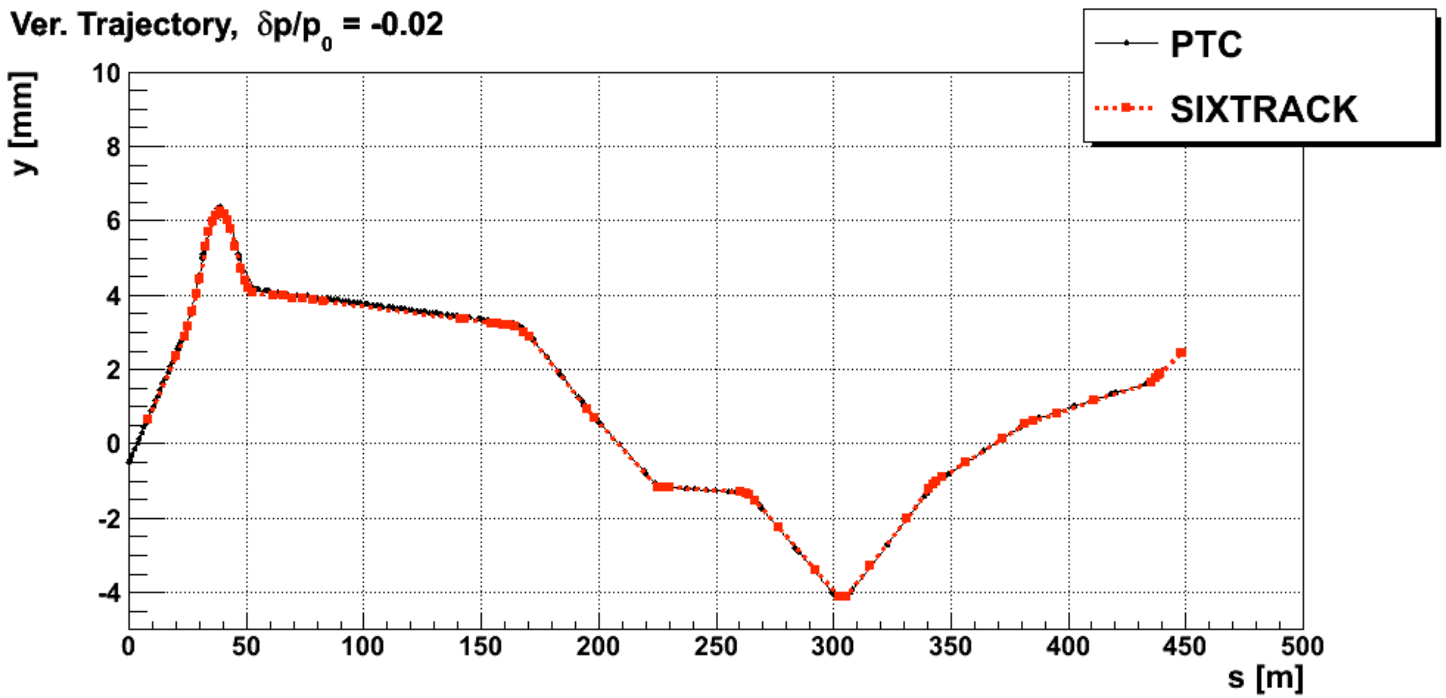


TRACKING RESULTS

PTC versus SIXTRACK

dp/p0 = -0.02 proton starting at
x=0, px=0, y=-0.5mm, py=142.5urad



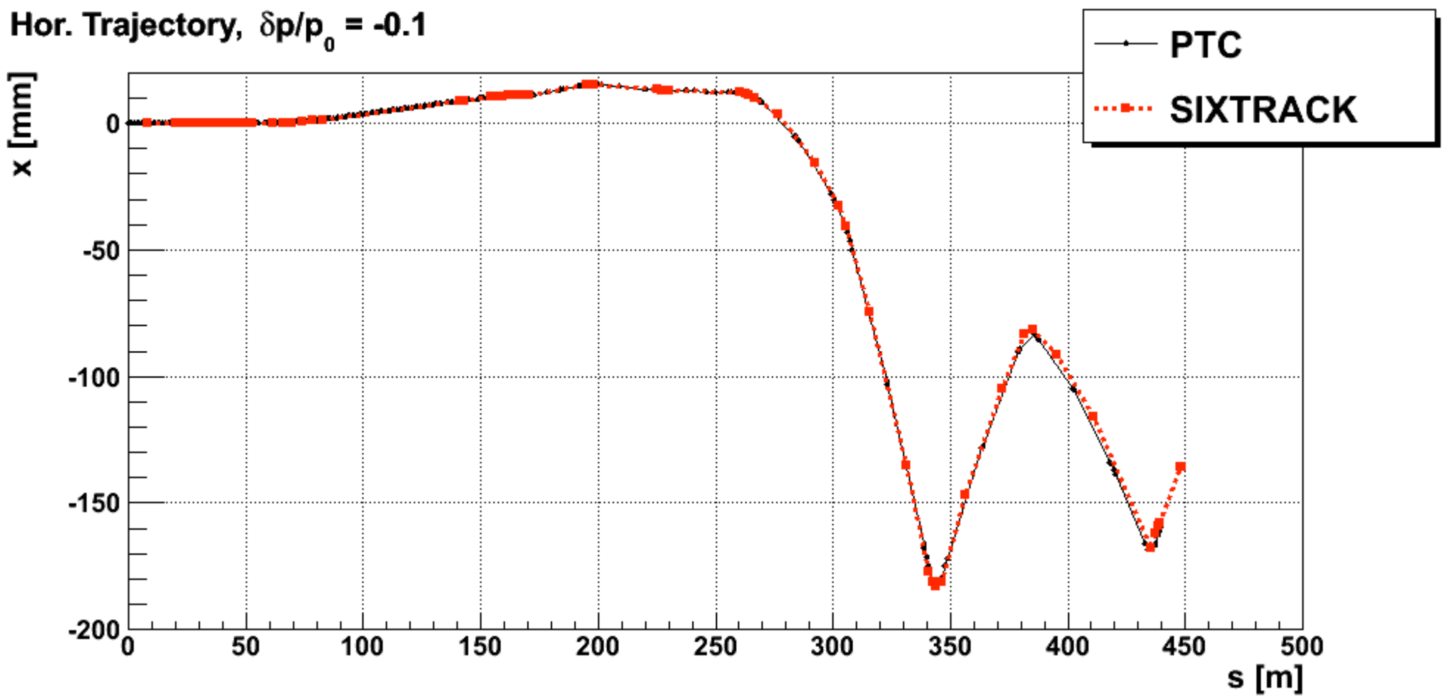


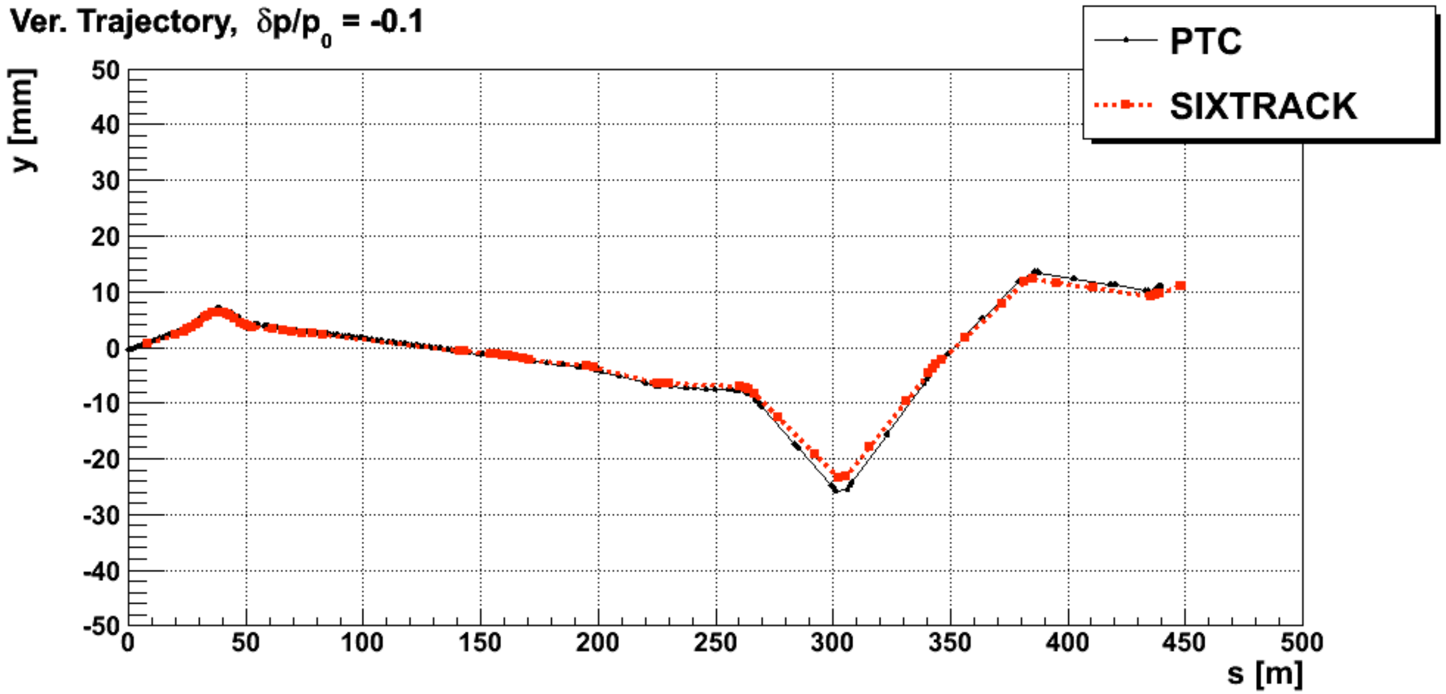
TRACKING RESULTS

PTC versus SIXTRACK

dp/p0 = -0.1 proton starting at

x=0, px=0, y=-0.5mm, py=142.5urad



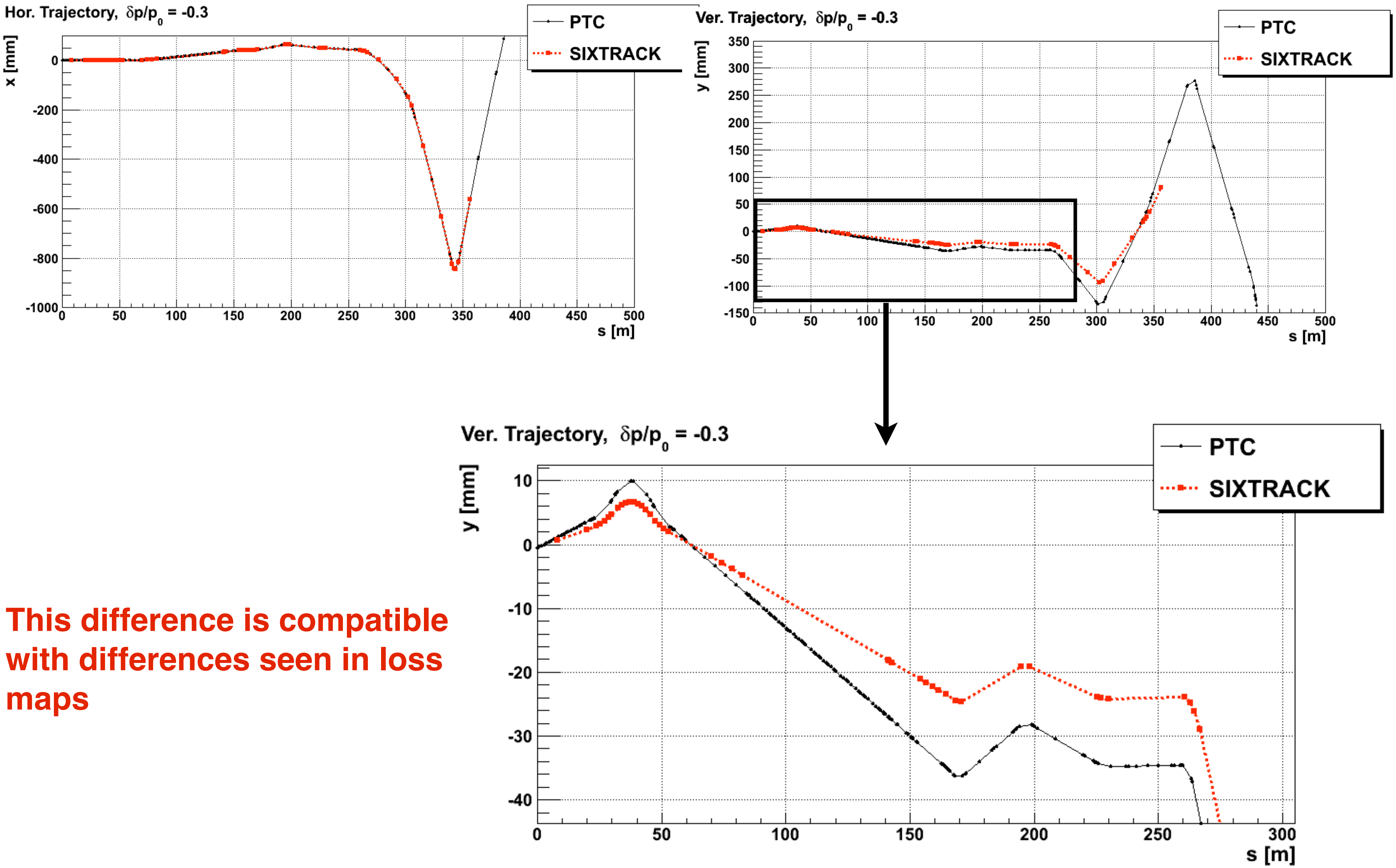


TRACKING RESULTS

PTC versus SIXTRACK

dp/p0 = -0.3 proton starting at

x=0, px=0, y=-0.5mm, py=142.5urad



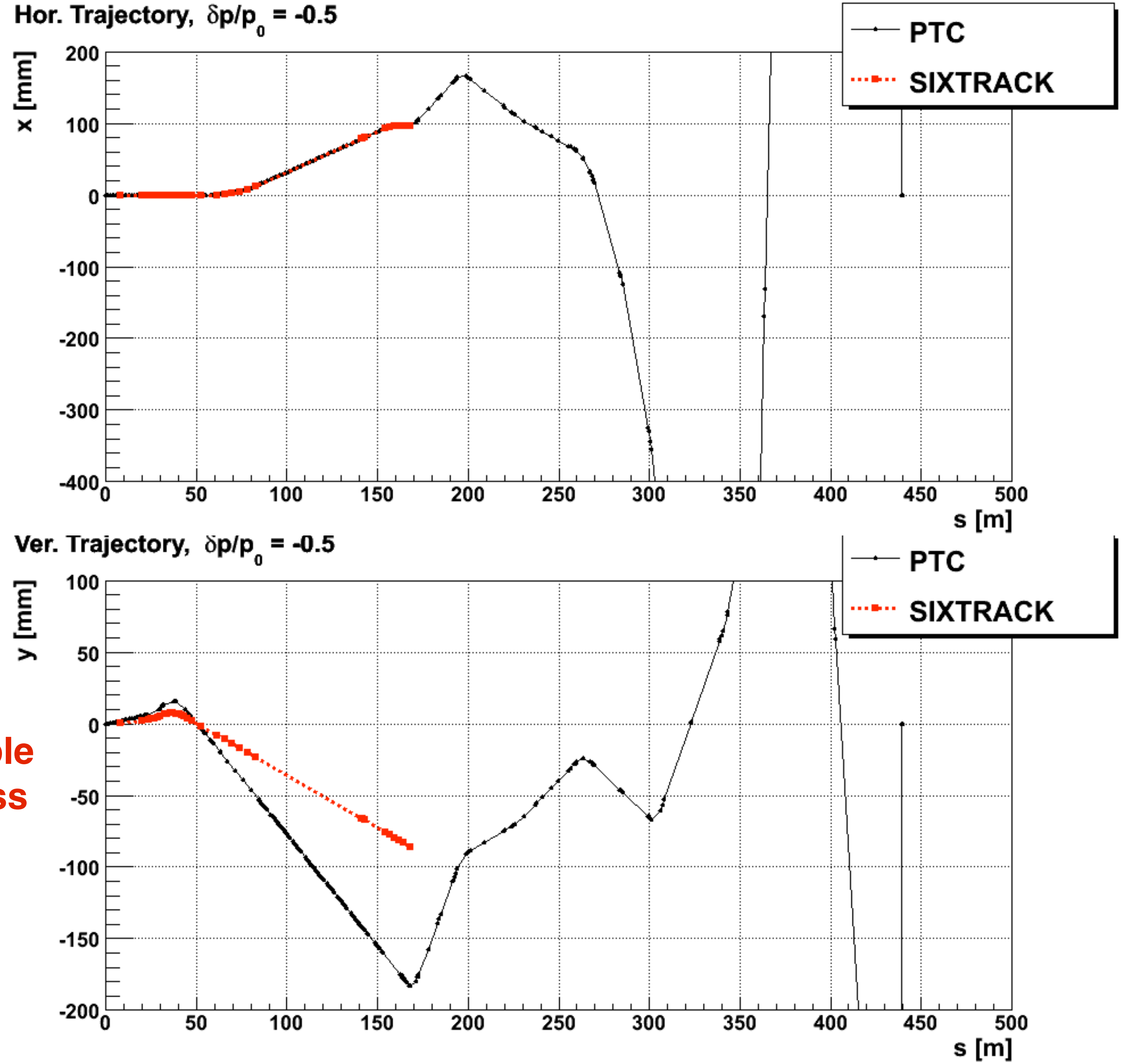
This difference is compatible with differences seen in loss maps

TRACKING RESULTS

PTC versus SIXTRACK

dp/p0 = -0.5 proton starting at

x=0, px=0, y=-0.5mm, py=142.5urad

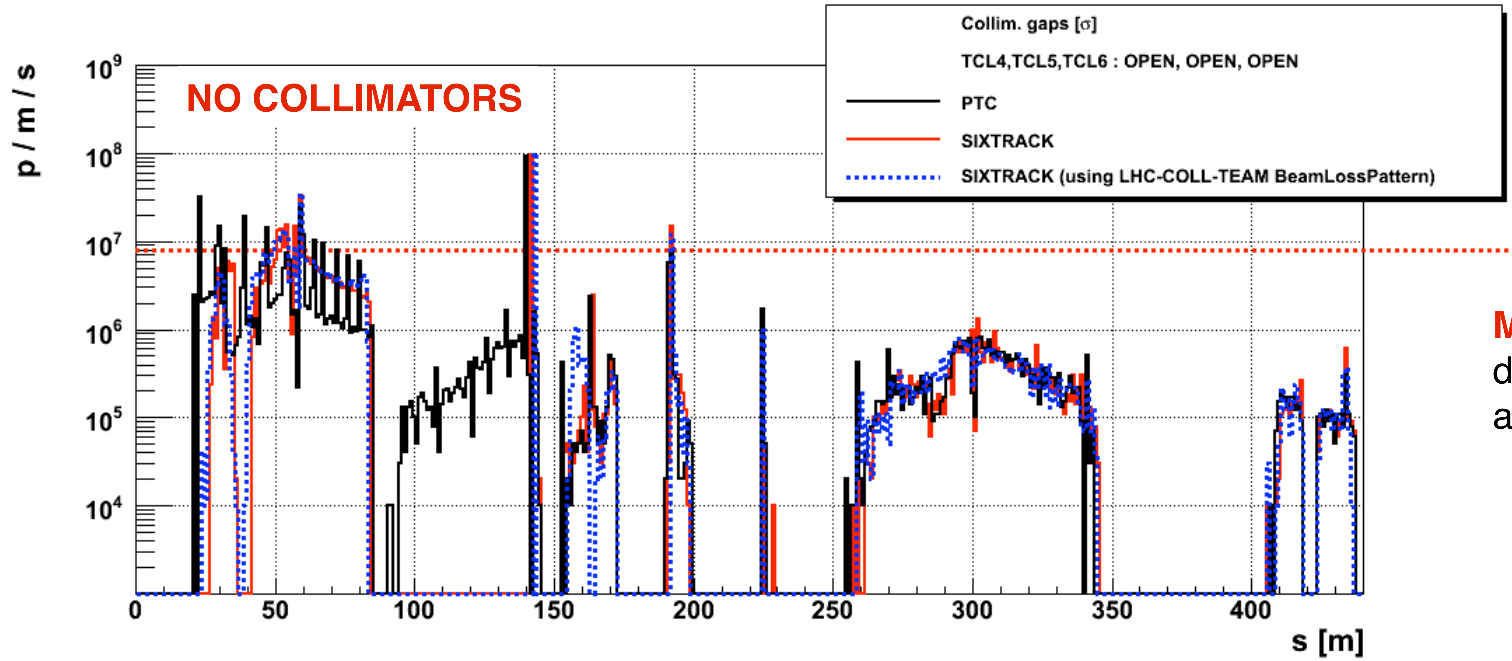


SIXTRACK stops at 168m (Q4)

This difference is compatible with differences seen in loss maps

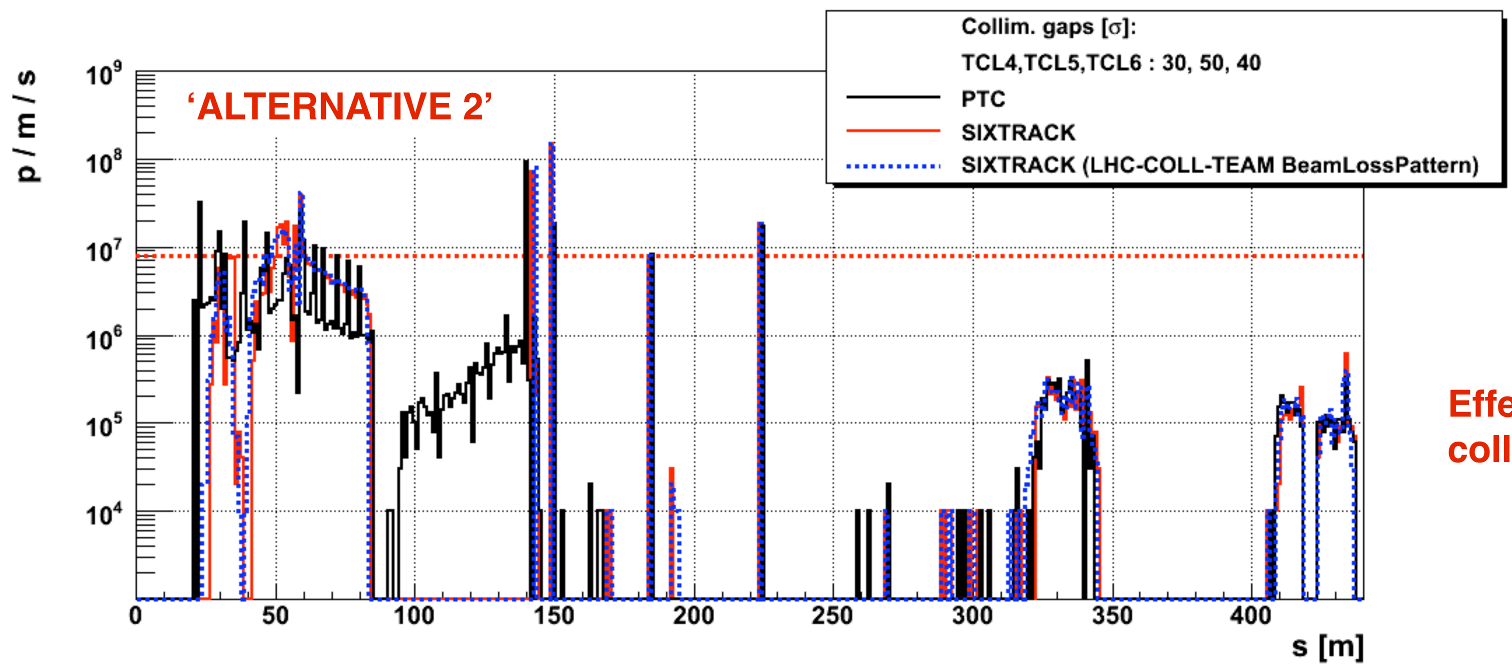
LOSS MAP RESULTS

PTC versus SIXTRACK



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

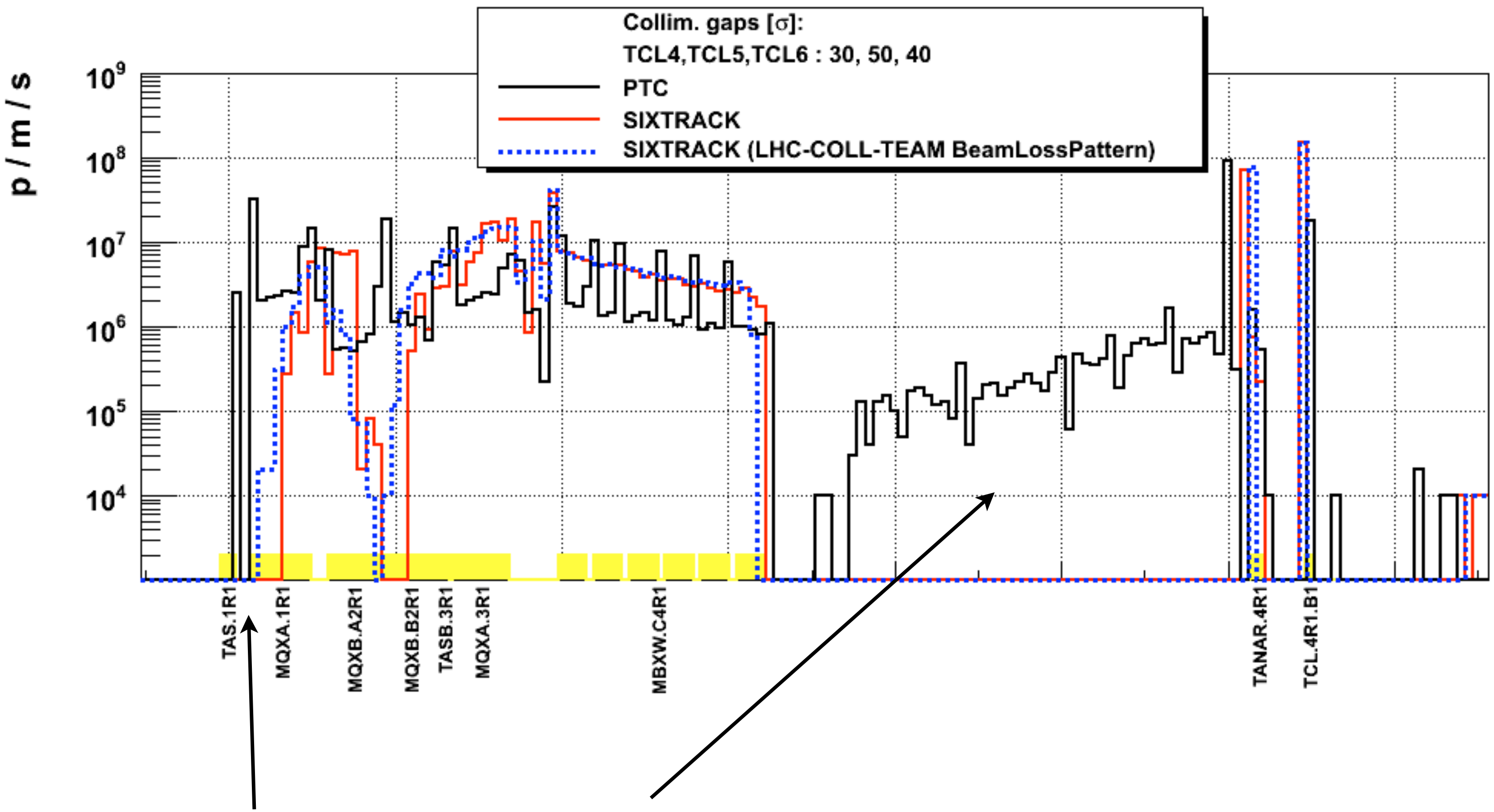
SEE NEXT SLIDE



Effect of scattering on collimators: looks negligible

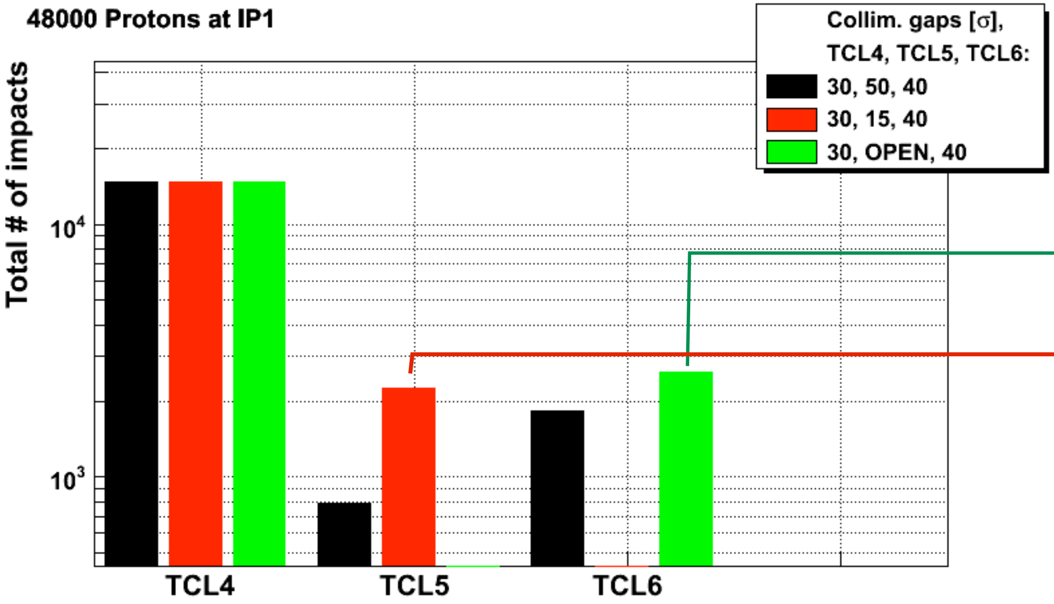
LOSS MAP RESULTS

PTC versus SIXTRACK



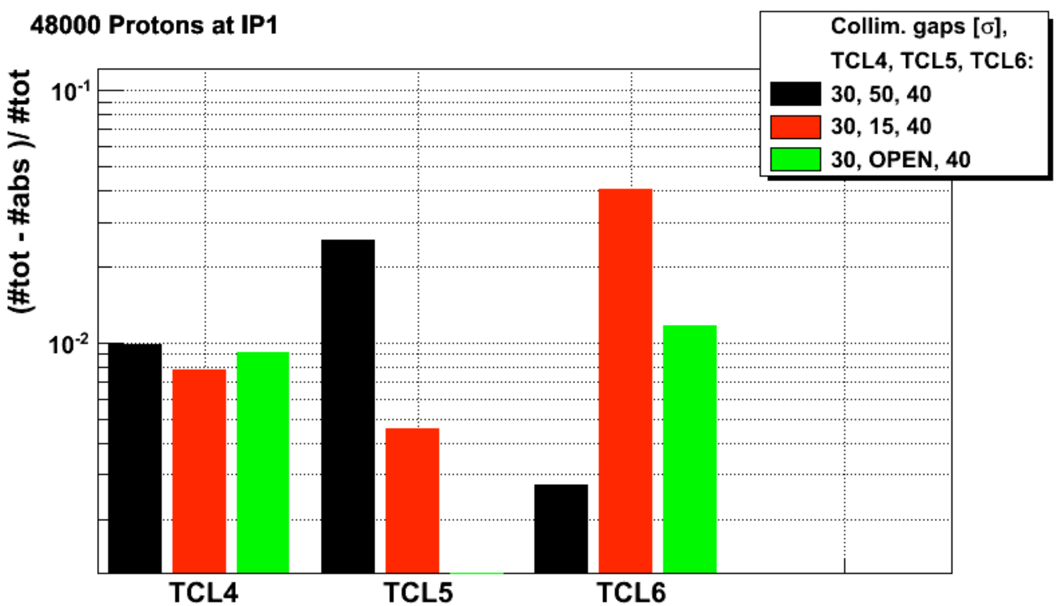
Chromatic effect of drifts?
Thick lens-Thin lens difference?

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 %

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

Open questions

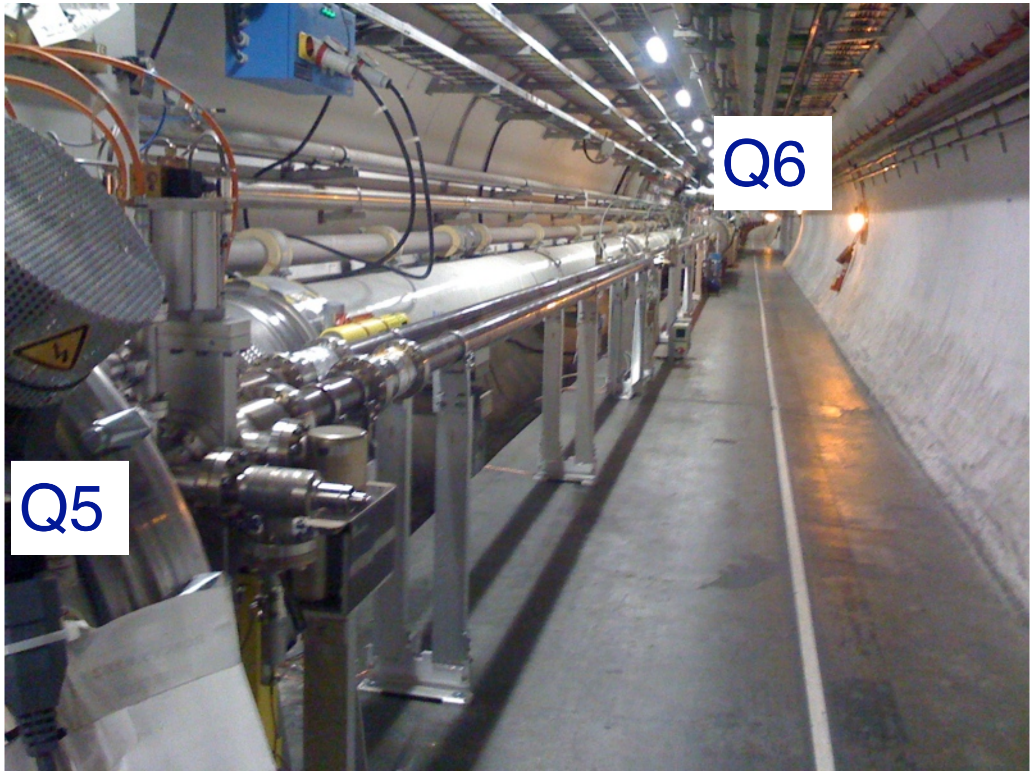
I went down in IR1 - right side and there seems to quite a lot of space between Q5 and Q6

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

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.

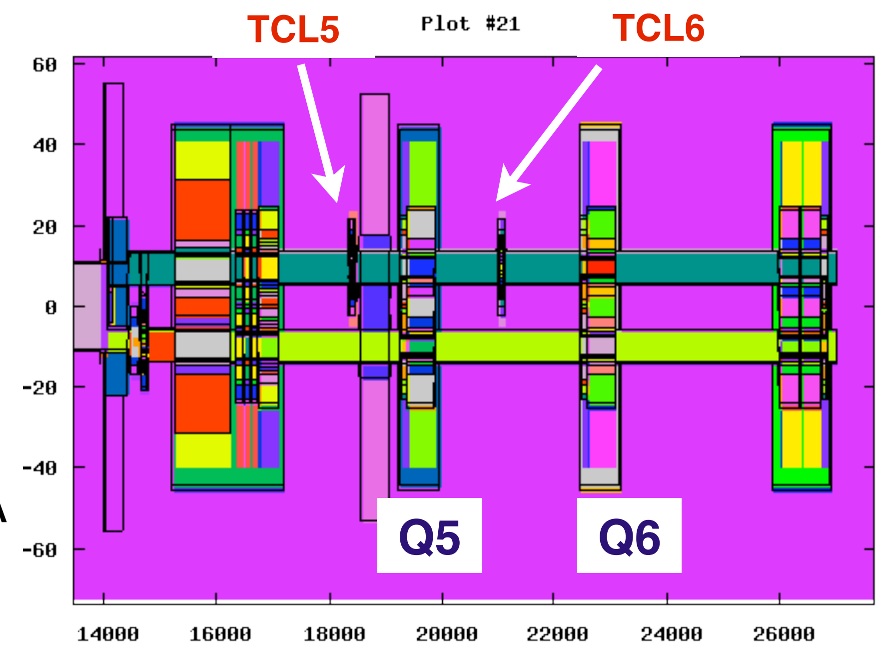
Now:

-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,



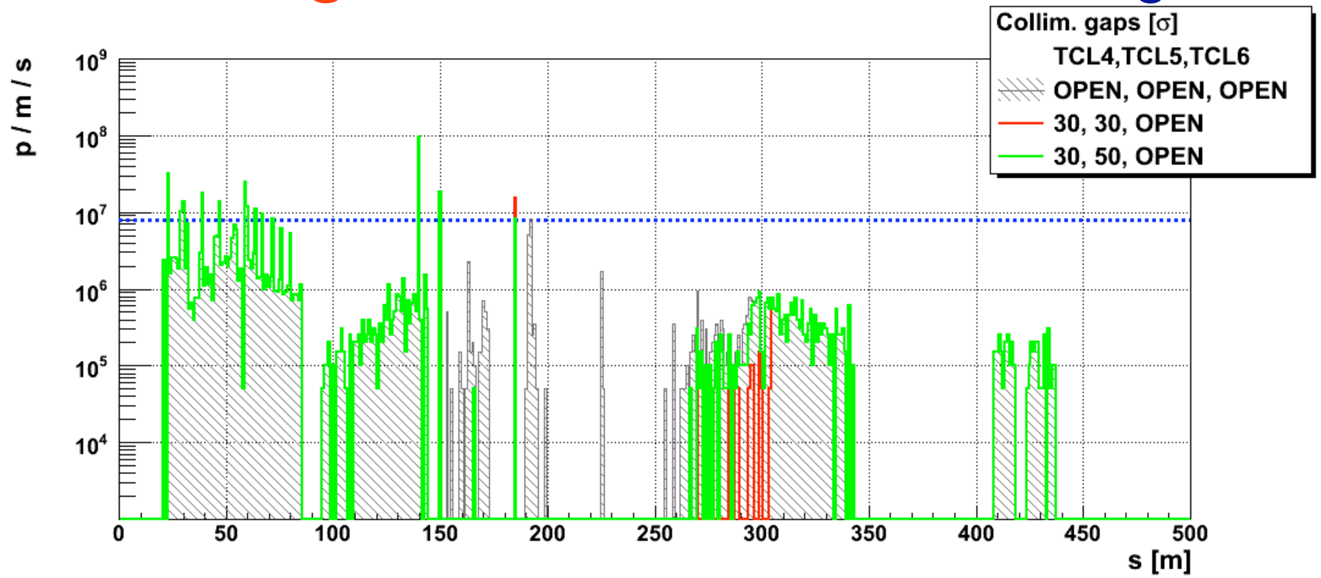
FLUKA model, (R.Appleby)

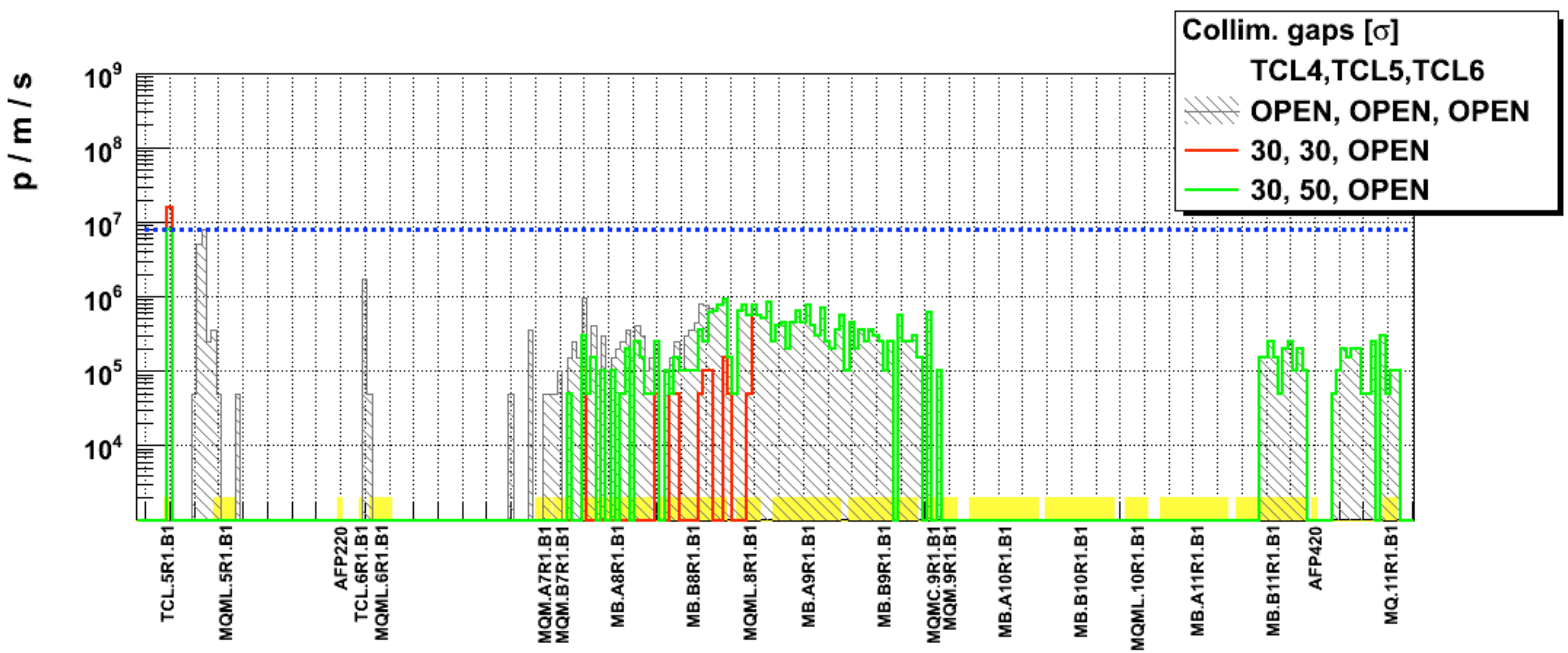
is enough ?

A very similar problem applies to CMS too. (see SPARE slides)

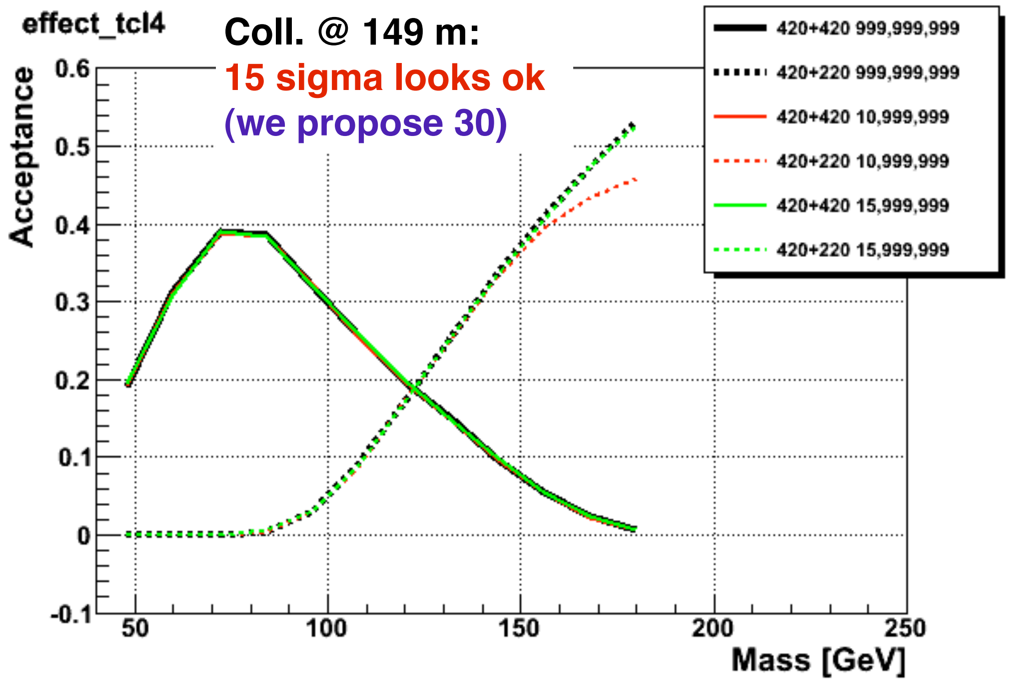
SPARE

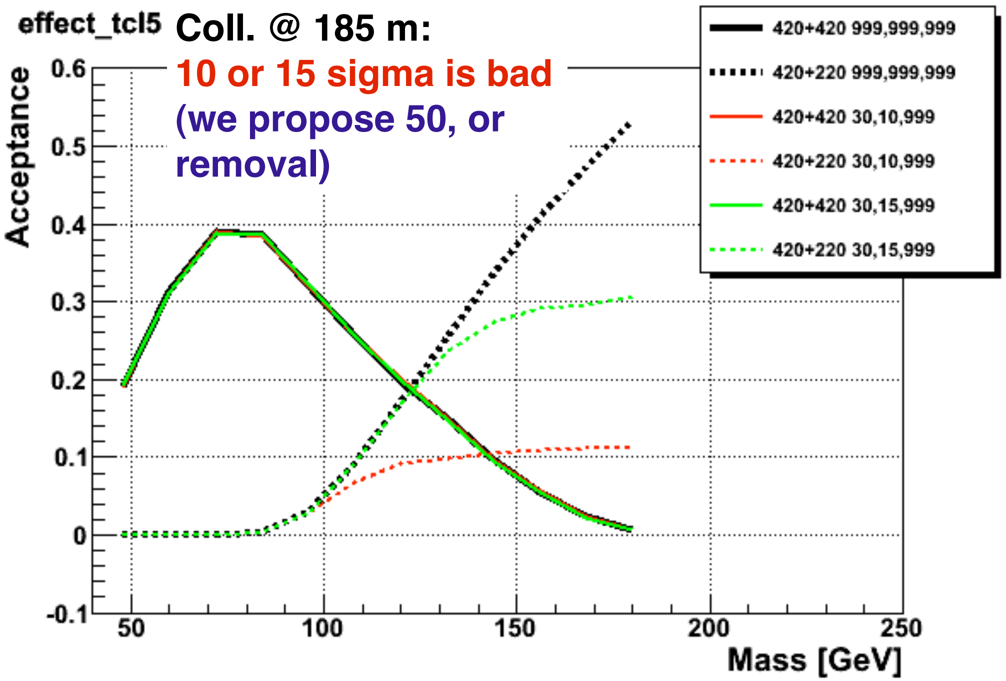
Present settings TCL4 and TCL5 at XXX sigma

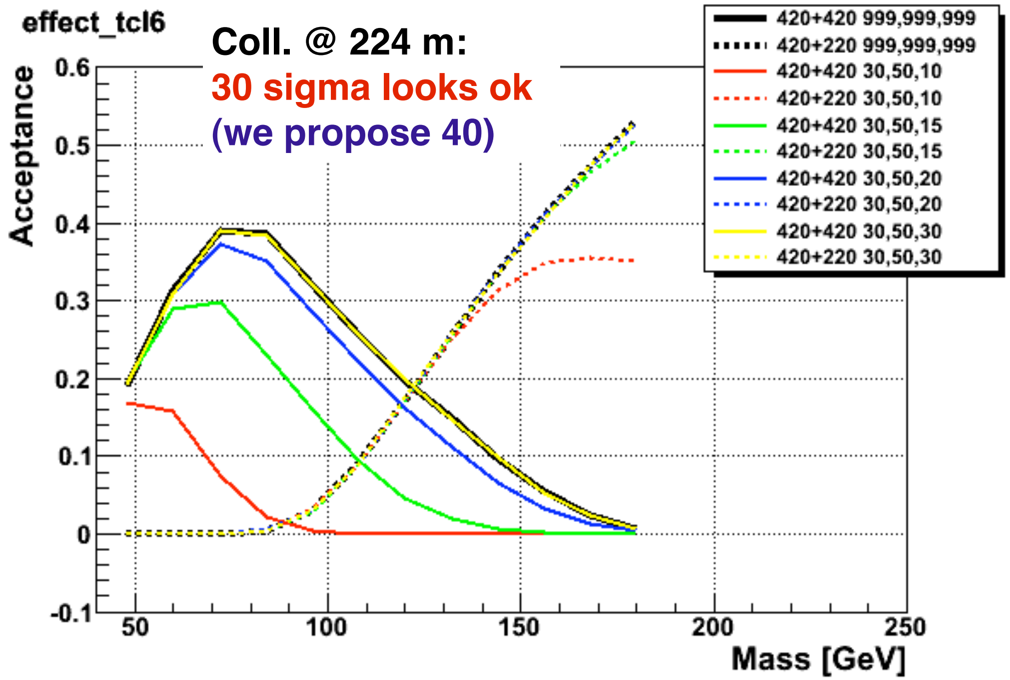




Effect of collimator settings on acceptance



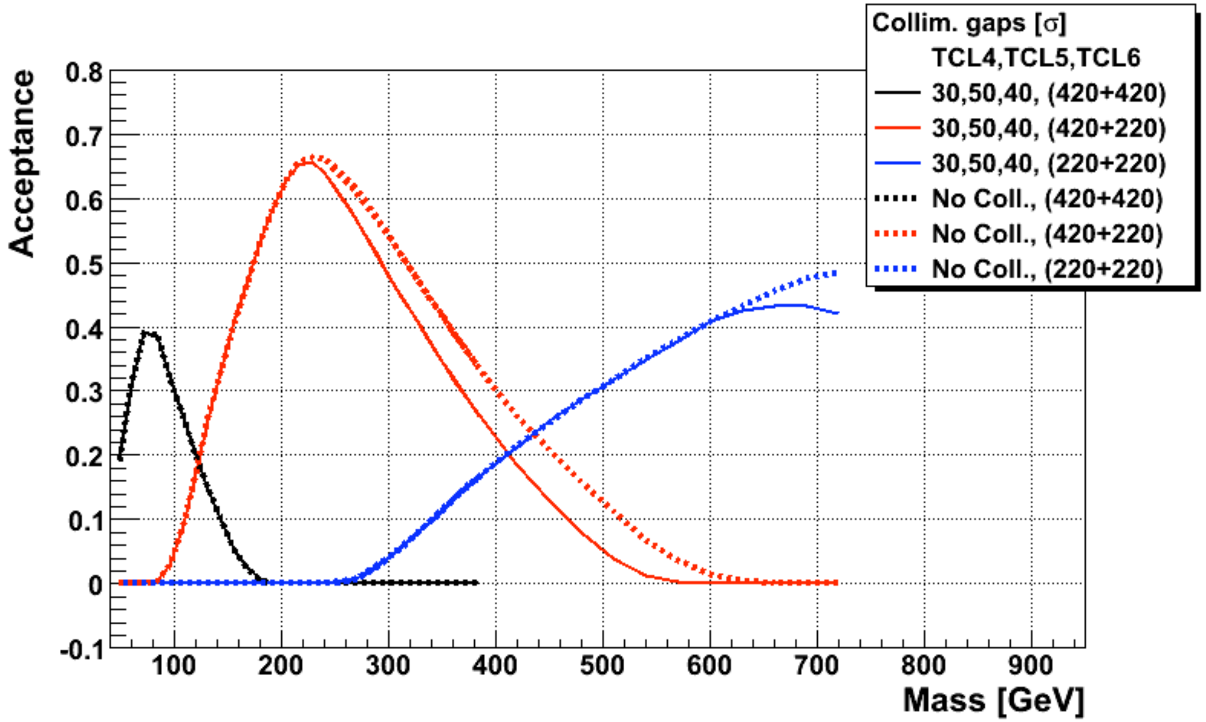




Data from P. Bussey

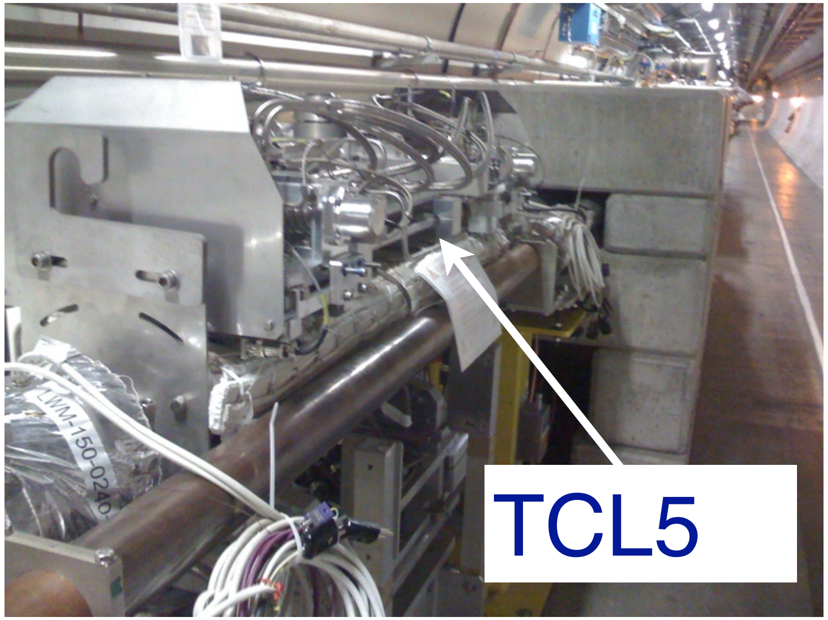
Effect of collimator settings on acceptance

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



Data from P. Bussey

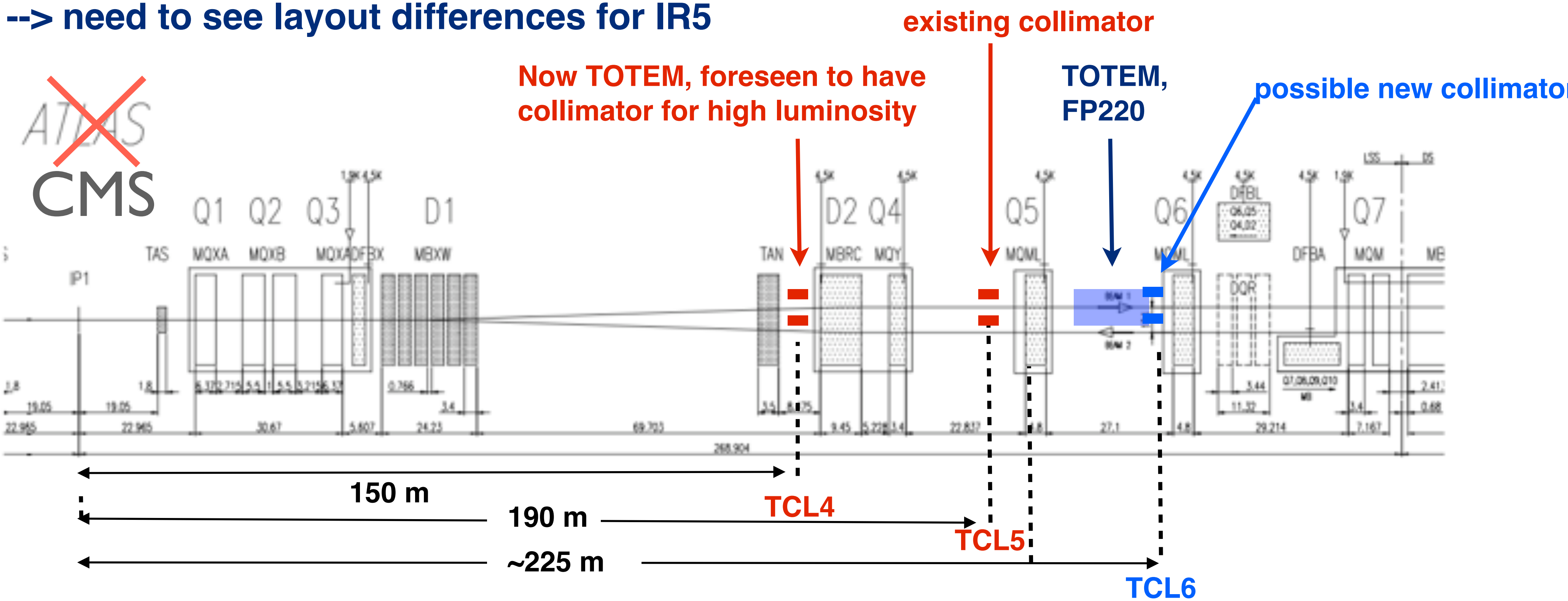
PICS


TCL5
LWM-150-0240


Q6
some installation
(compressor? for
vacuum?)

TCL Collimators at CMS

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

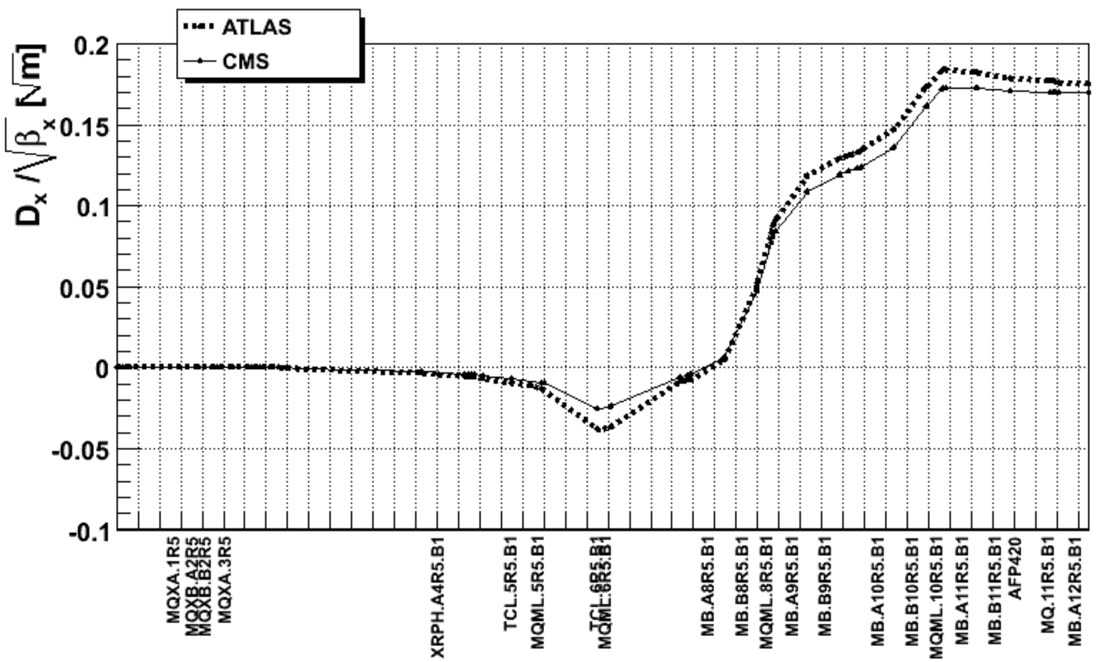


At **CMS**:

TCL4 collimator slot is occupied by TOTEM.

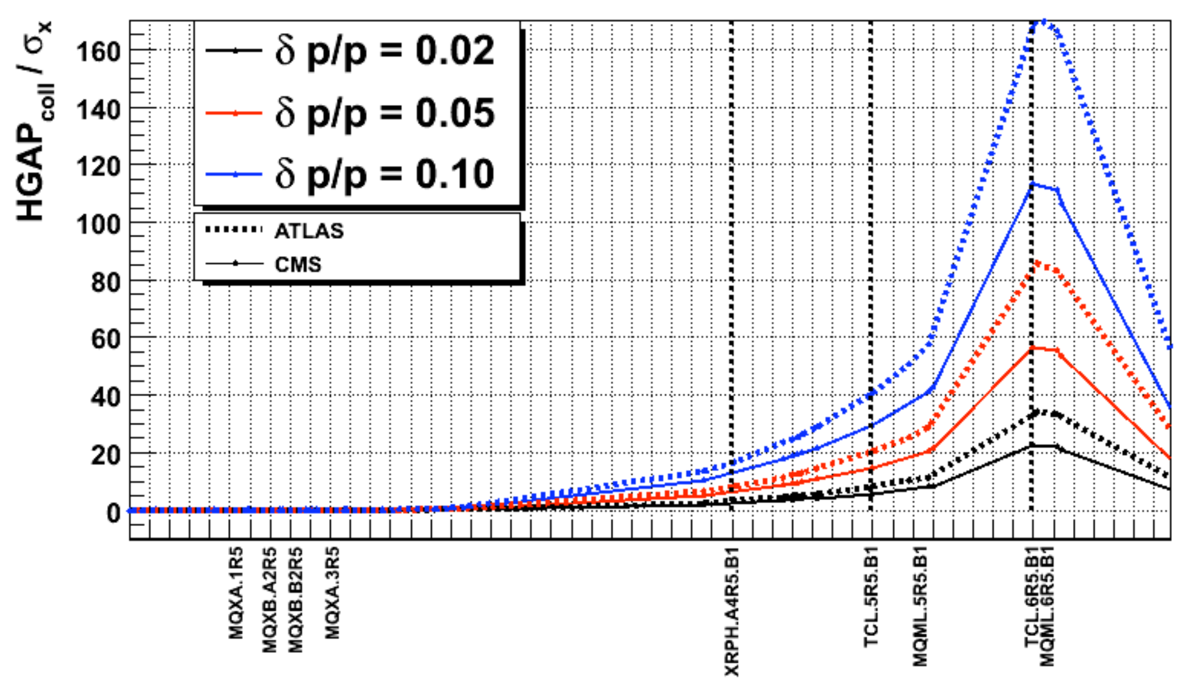
Official statement is: TOTEM will operate until when **high luminosity will require the installation of TCL4** --> TOTEM pot at 147m removed

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)



Physics debris particles downstream ATLAS (and CMS)

Any p-p interaction has a probability to generate a forward proton with momentum offset dp/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 dp/p > ~0.25 are intercepted by the TAN at 140 m

2- All protons with dp/p < ~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 < dp/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

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)

TCL5 available studies

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

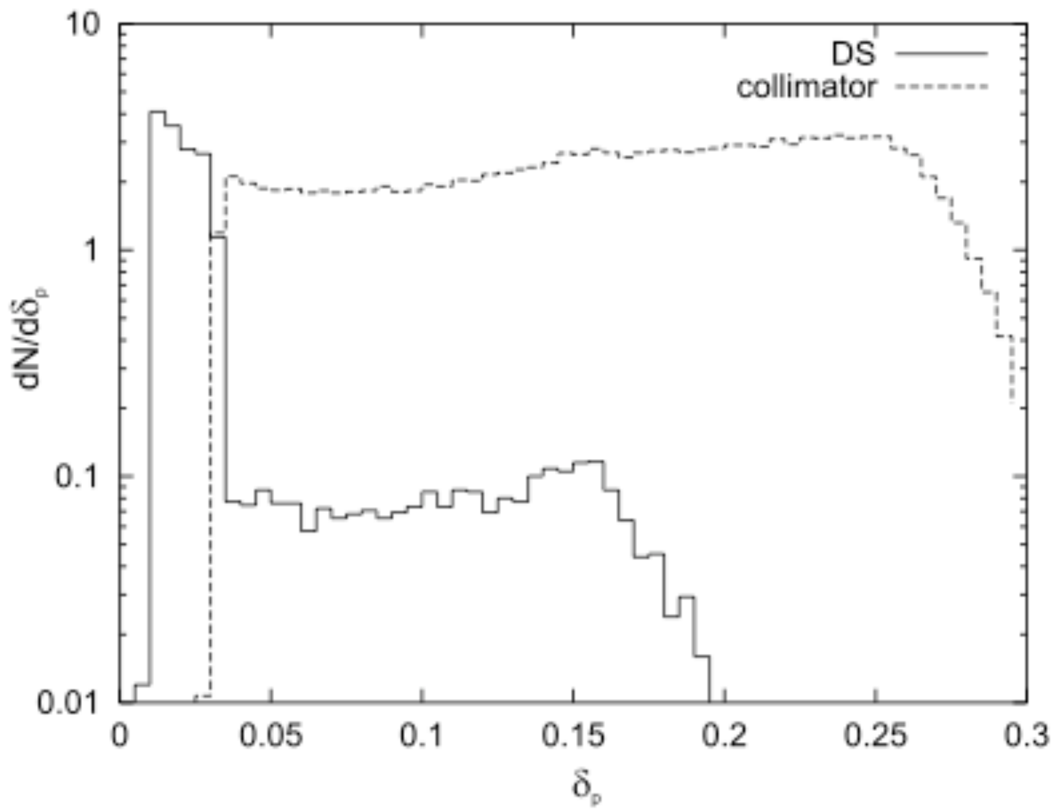
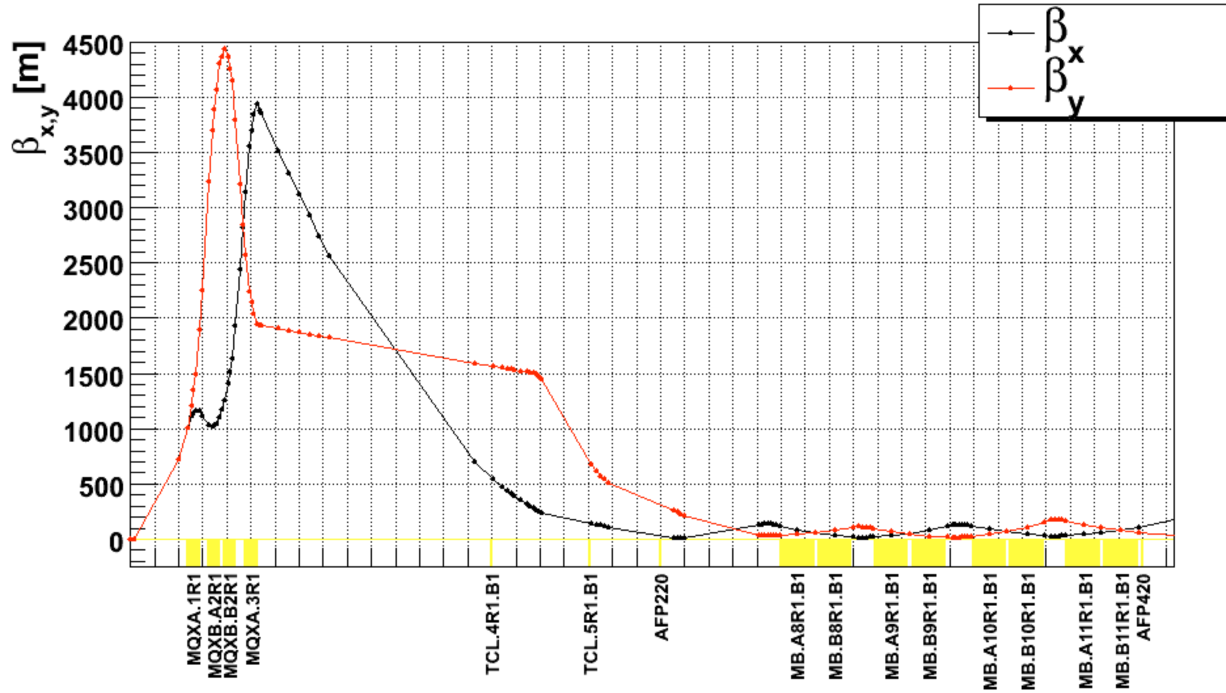


Figure 3: The momentum distributions of the lost protons. Dashed histogram - the protons intercepted by the collimator, solid one - those one lost in the dispersion suppressor and in the arc cells, including the protons which are reemitted by the collimator.

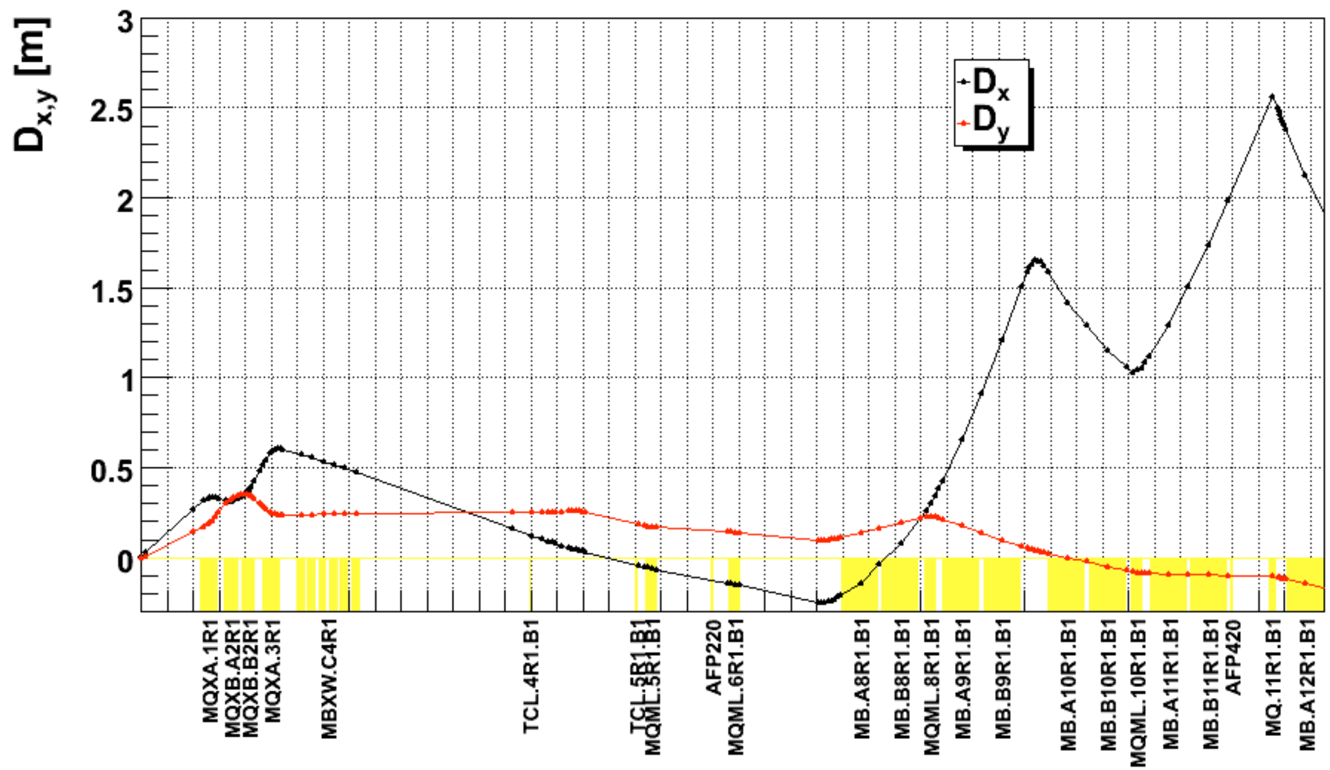
To me this says: less than 10% of protons scattered on collimator are lost in DS

OPTICS

Periodic optics



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

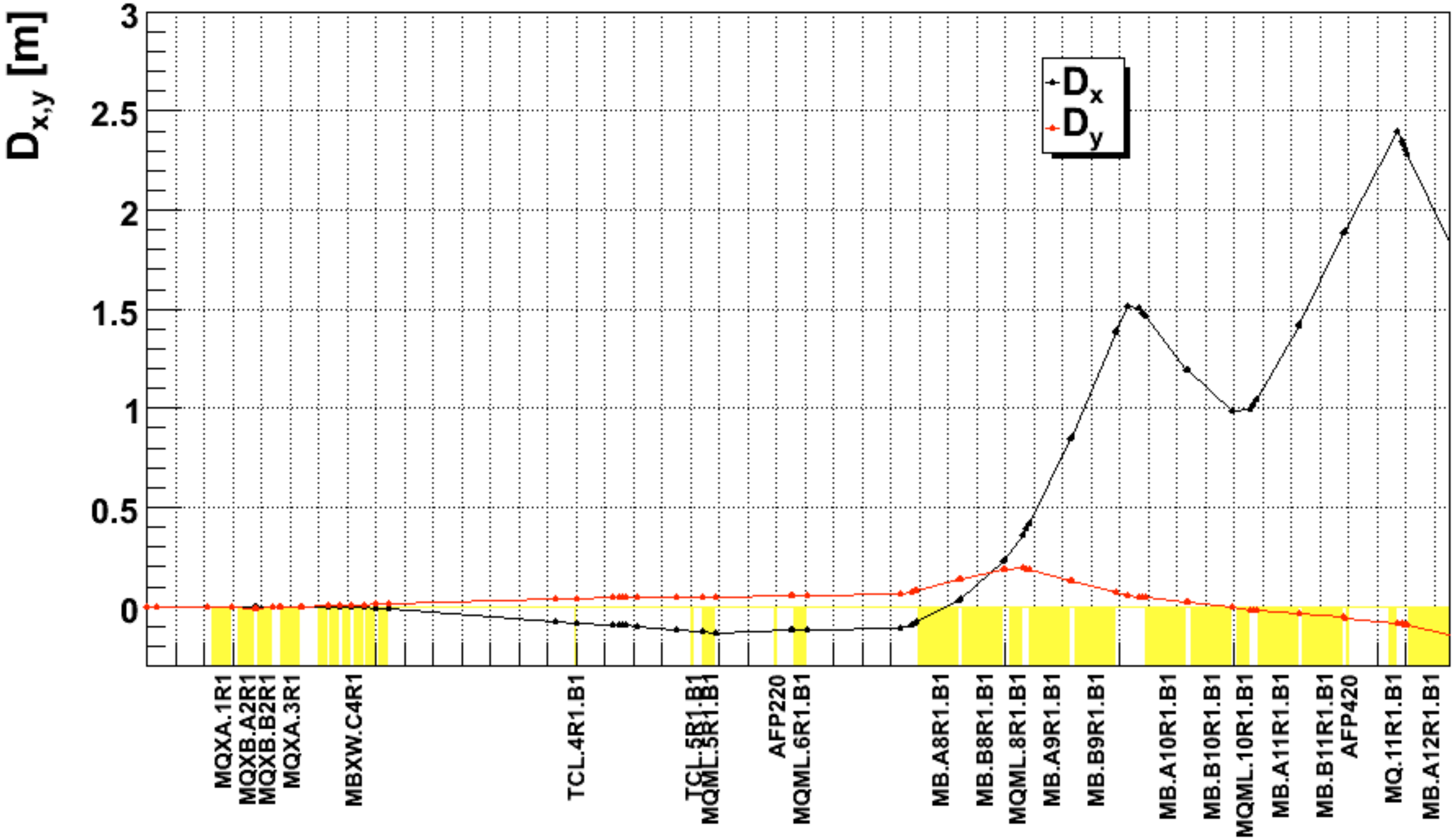


BEAM SIZES AT COLL

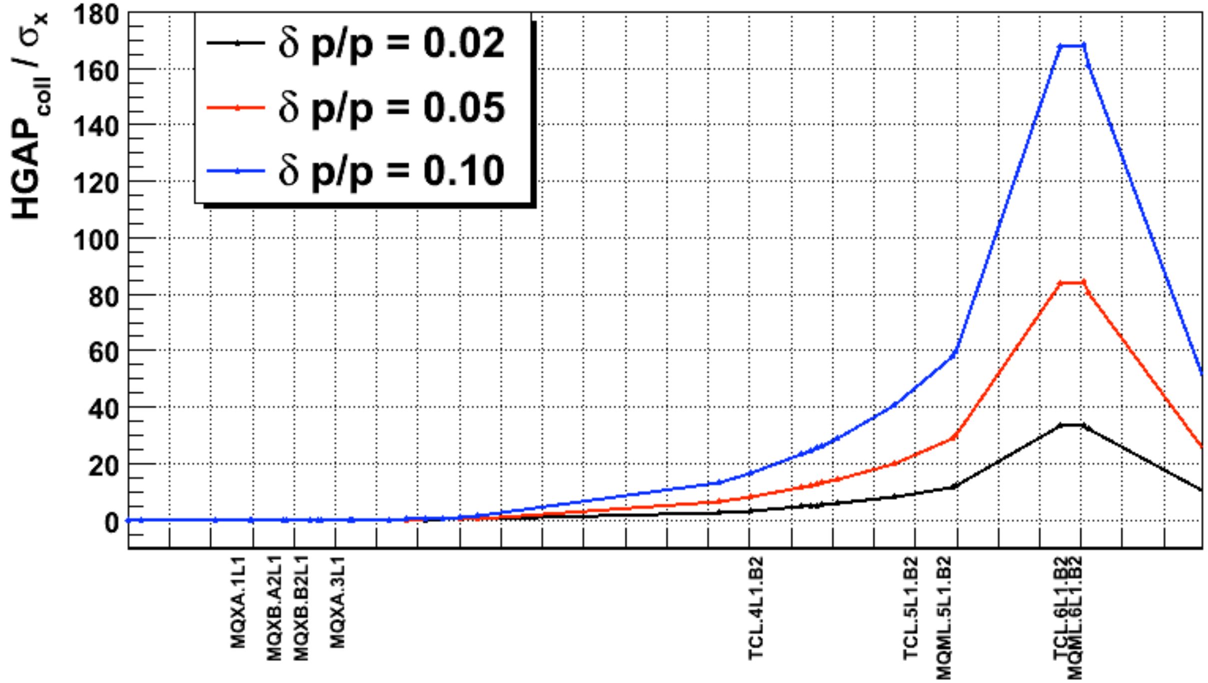
	s [m]	σx [mm]	10*σx [mm]	50*σx [mm]	betx [m]	Dx [m]	Dx/sqrt(betx)
TCL.4R1.B1	150.345	0.524	5.240	26.200	546.873	-0.022	-0.000954
TCL.5R1.B1	184.857	0.291	2.910	14.550	168.714	-0.110	-0.008460
TCL.6R1.B1	224.800	0.071	0.710	3.550	10.147	-0.165	-0.051893

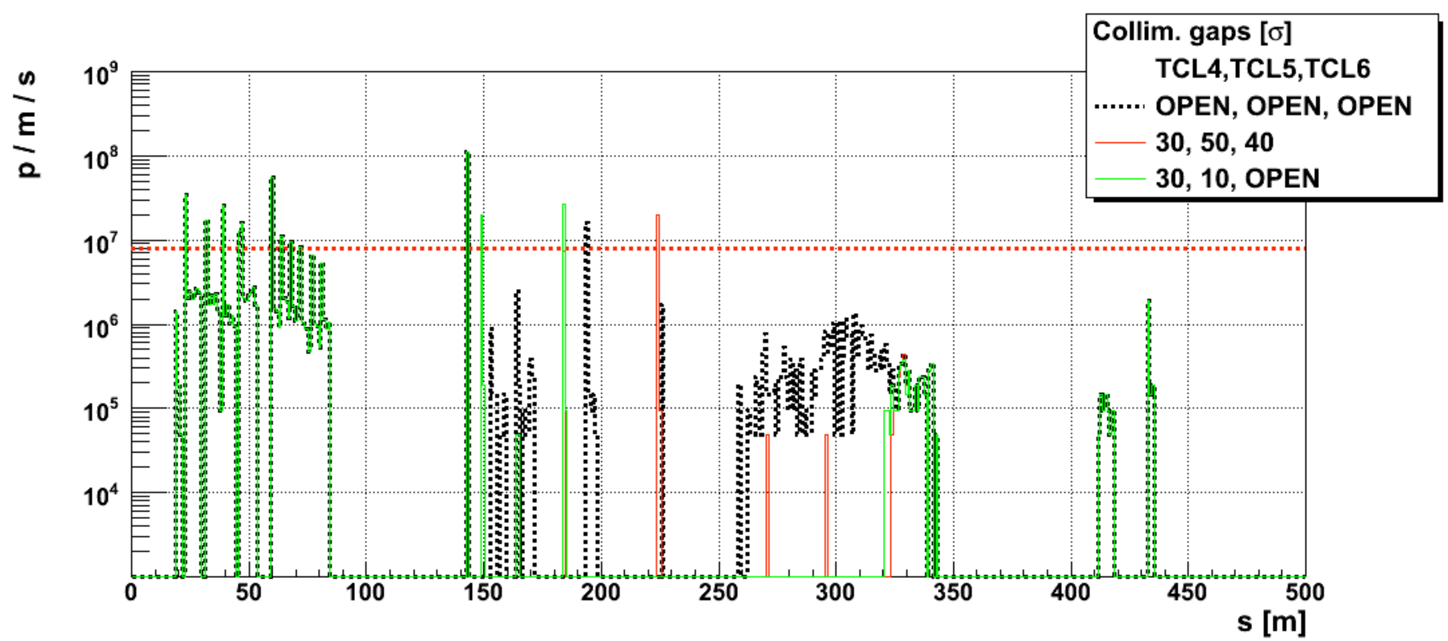
Mismatched optics

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: Dx and Dy at the IP are == 0 for our distributions
--> to be used for tracking

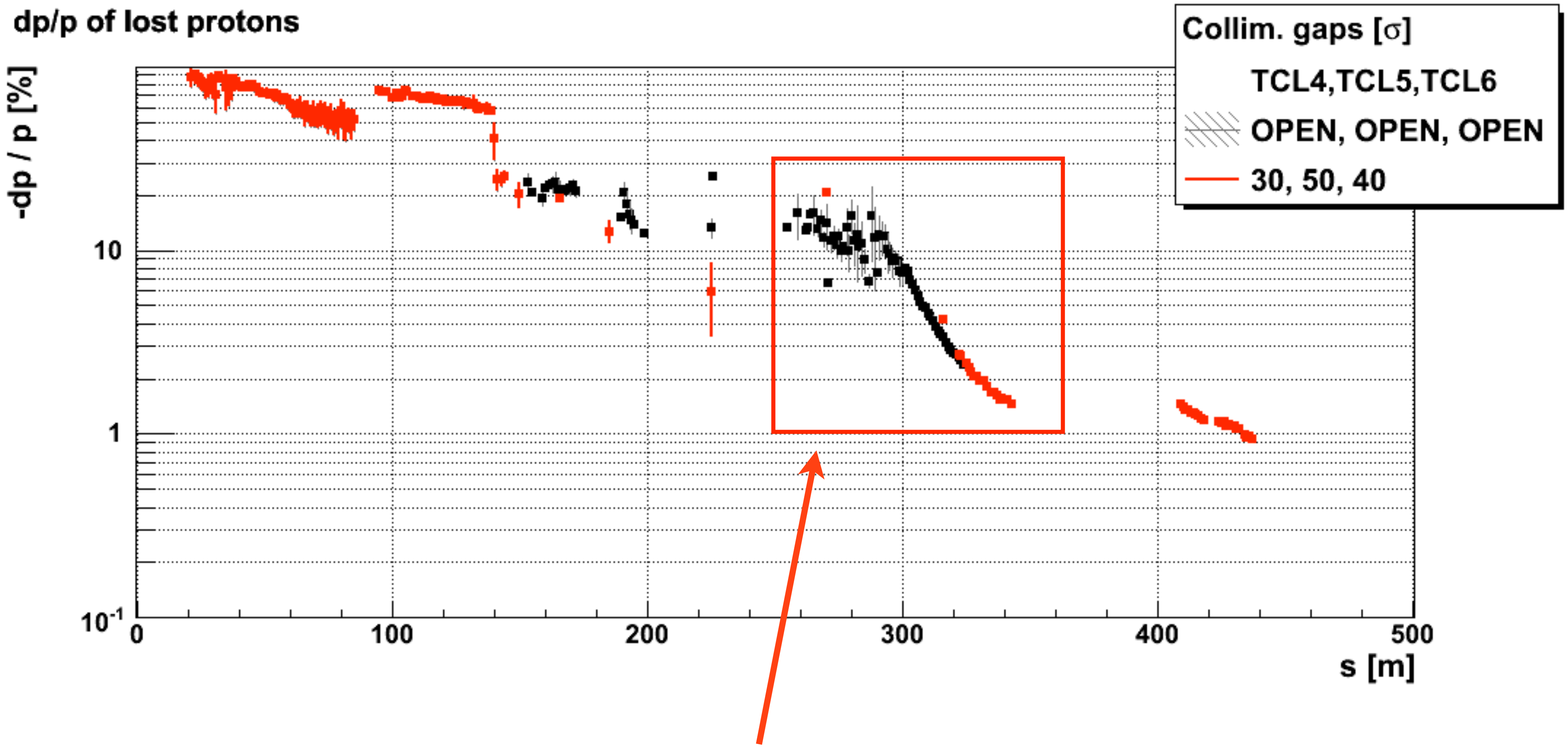


Beam2


HGAP$_{coll}$ / σ_x
δ p/p = 0.02
δ p/p = 0.05
δ p/p = 0.10
0
20
40
60
80
100
120
140
160
180
MQXA.1L1
MQXB.A2L1
MQXB.B2L1
MQXA.3L1
TCL.4L1.B2
TCL.5L1.B2
MQML.5L1.B2
TCL.6L1.B2
MQML.6L1.B2


p / m / s
10^9
10^8
10^7
10^6
10^5
10^4
0
50
100
150
200
250
300
350
400
450
500
s [m]
Collim. gaps [σ]
TCL4,TCL5,TCL6
OPEN, OPEN, OPEN
30, 50, 40
30, 10, OPEN

Energy of lost protons



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.