Status of the SPS collimation system design

M. Patecki, A. Mereghetti, D. Mirarchi, S. Redaelli

Outline

- Beam losses in the SPS
- Objectives for the SPS collimation system
- Simulation tools
- Reminder of the collimation system in the arc
- Baseline: Primary collimator in the arc, TIDP used as an absorber
- Error study:
  - Orbit bump amplitude error
  - Initial distribution error
  - Orbit error
  - Beta and dispersion beating
  - Aperture
- Summary

Losses in the SPS

- Injection and extraction losses
- Off-momentum losses
  - Capture (bunch S-shape)
  - Flat bottom (full bucket)
  - During E ramp
  - In high dispersion regions
- Transverse losses
  - Due to large beam size at injection energy
  - At aperture restrictions
- Scraping
- 10% of losses are allocated within HL-LHC budget with intensity of ~2.5e11

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Objectives and challenges

- **Objectives:**
  - Passive machine protection against off-momentum losses
  - Concentration of losses in chosen and prepared locations
  - Reduction of machine equipment irradiation and activation
  - Possibly functional for all SPS beams and optics (priority to HL-LHC beams)
- **Challenges:**
  - Fitting into (very limited) empty spots
  - Protecting the machine without consuming the usefull beam
  - Avoiding the movement of collimators between the cycles (common gap or small adjustment with orbit bump)

Simulation tools

- SixTrack + FLUKA coupling:
  - SixTrack for tracking protons through the accelerator;
  - FLUKA for interactions of protons with collimators;
- Simulation starts at the primary collimator front face:
  - 100k protons per case.
  - 0.1 um impact parameter
  - Initial protons distribution:
    - Betatron amplitude is randomly assigned following a double Gaussian distr. (90% 1σ, 10% 3σ)
    - dp/p value is calculated to reach the collimator jaw
- Aperture:
  - Ideal (from madx model) ideal aper.
  - Measured by V.Kain in 2017 + 5mm (expected improvement when fixing the flange issue) meas aper.

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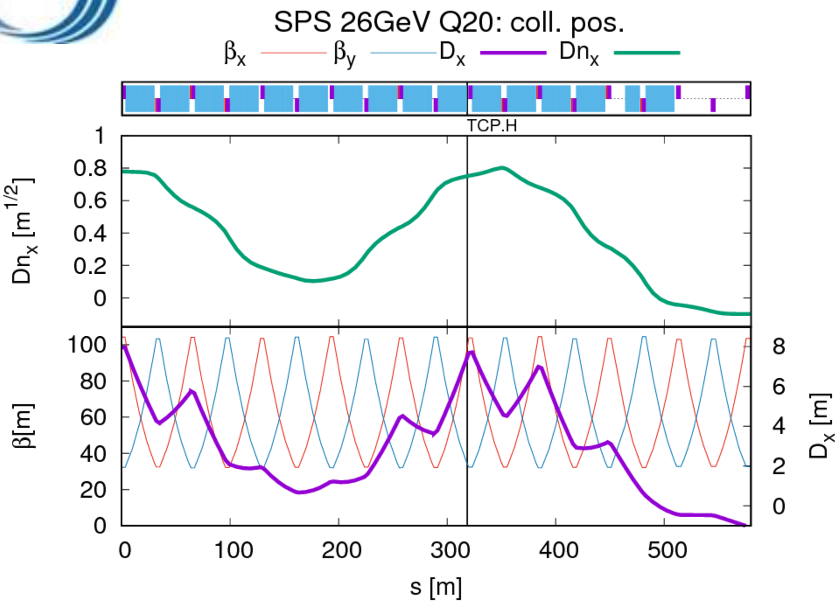
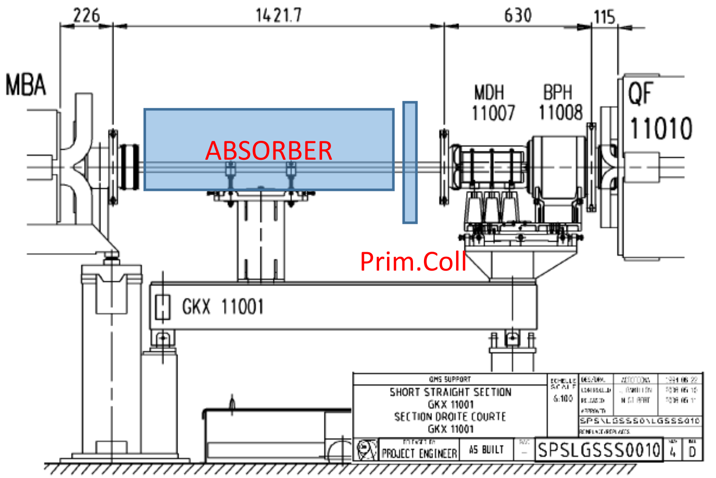
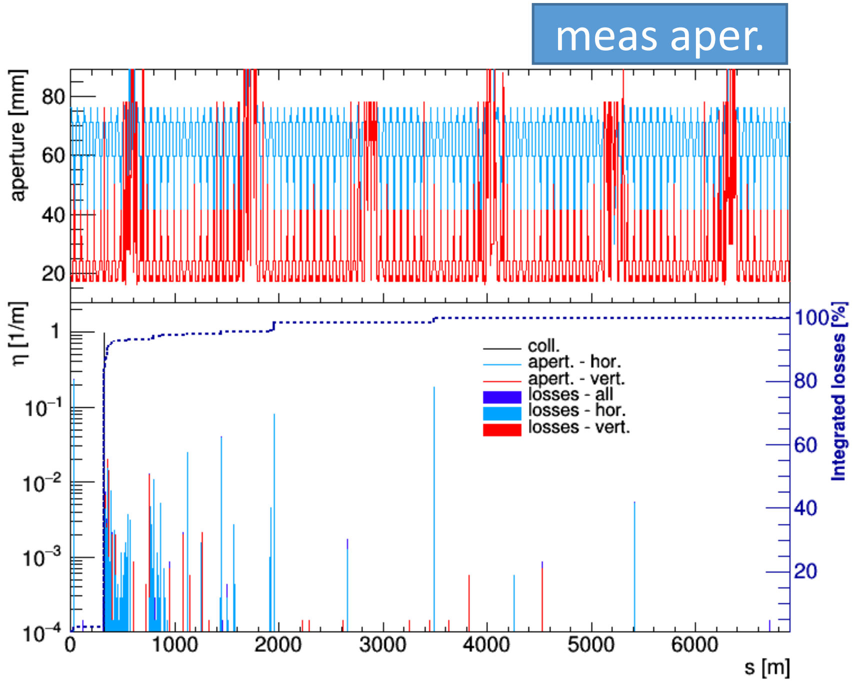
Prim.Coll + Absorber @ Dx max



- Compact design at the maximum of the dispersion;
- Optimized for off-momentum cleaning;
- Prim.Coll increases dp/p of halo particles, send them to the absorber;
- Protons hit the absorber front face with a large impact parameter (a few mm) and a large spread (a few mm);
- Tight space conditions;
- Only one collimation insertion.

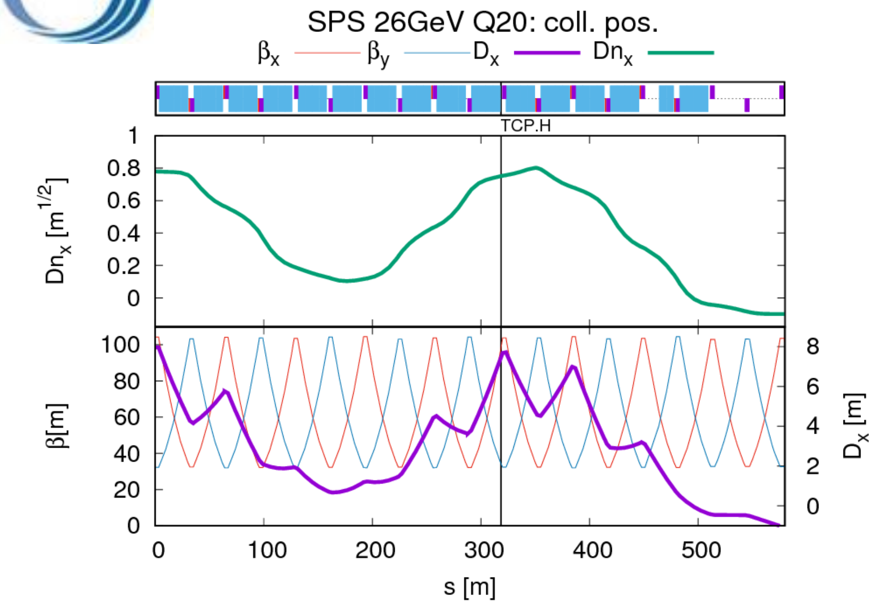




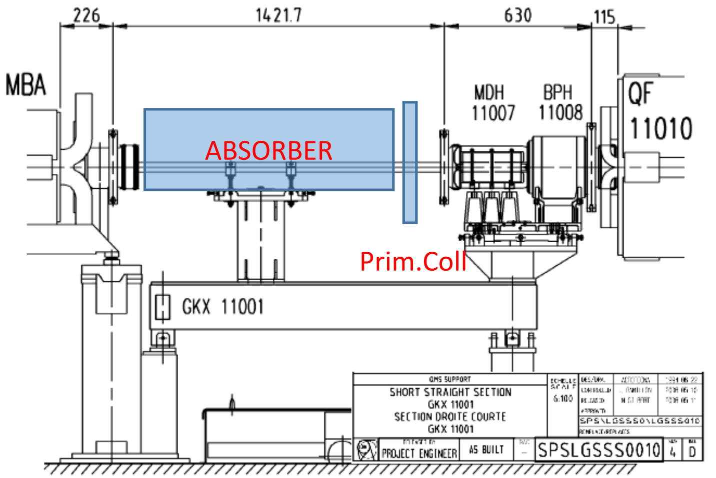
meas aper.

	S [m]	W 60cm	Cu 100cm	MoGr 100cm
All colls	**-**	**87.8**	**84.7**	**73.0**
Absorber	318.4	86.5	83.2	71.2
Prim.Coll	319.0	1.3	1.5	1.8
MDH.11007	319.3	0.4	0.5	1.2
BPH.11008	319.6	-	0.7	1.7
QF.11010	320.0	1.8	1.9	3.9
MBA.11030	323.4	3.3	3.5	3.5
MBA.11050	330.0	0.5	1.7	1.8
MBB.11090	343.0	0.2	1.0	1.0
QD.22510	1952	0.2	0.4	1.9
QD.40110	3488	0.2	0.4	1.7
QD.10110	32.0	0.5	0.8	2.5

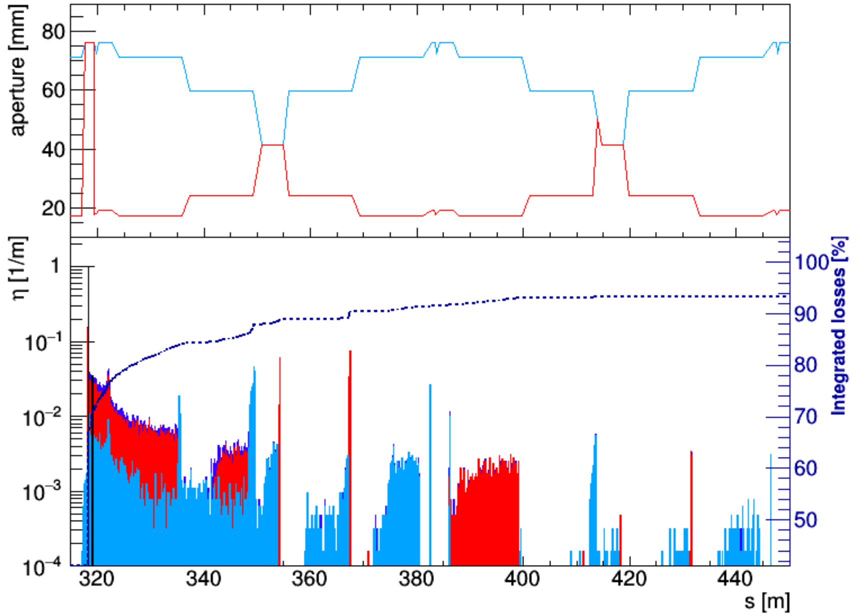
Prim.Coll + Absorber @ Dx max



- Compatible with all optics
- Very robust, no bump or extra control needed
- Downstream elements exposed to secondary particles
- Challenging integration into the machine



meas aper.



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MBA.11030	323.4	3.3	3.5	3.5
MBA.11050	330.0	0.5	1.7	1.8
MBB.11090	343.0	0.2	1.0	1.0
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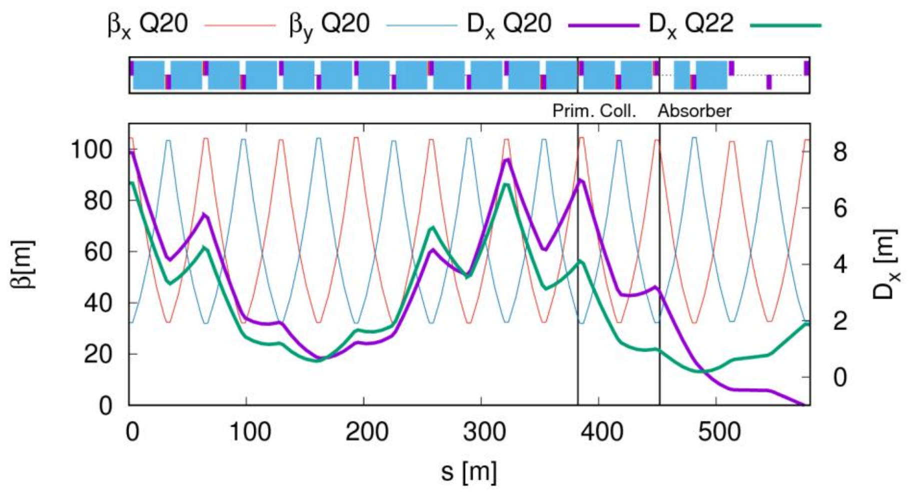
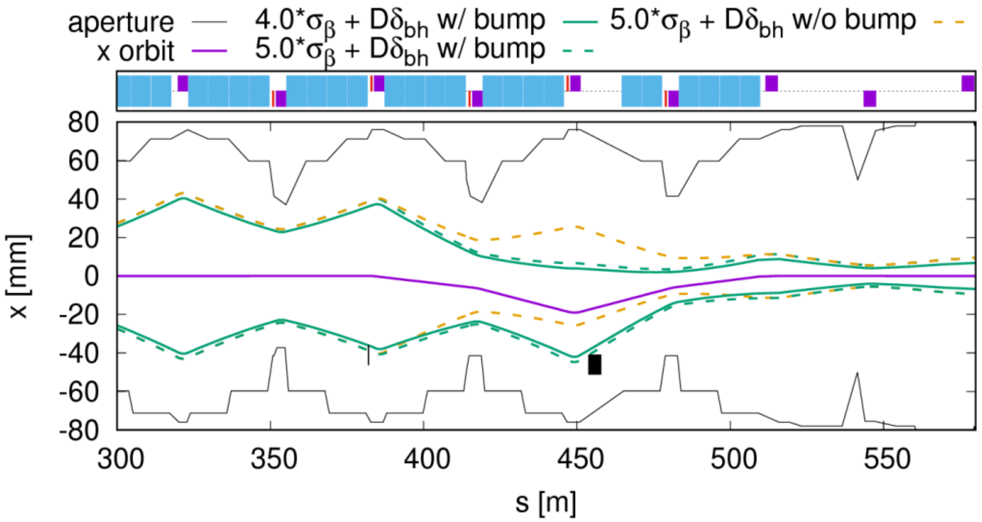
TIDP as absorber reached with an orbit bump, Q20

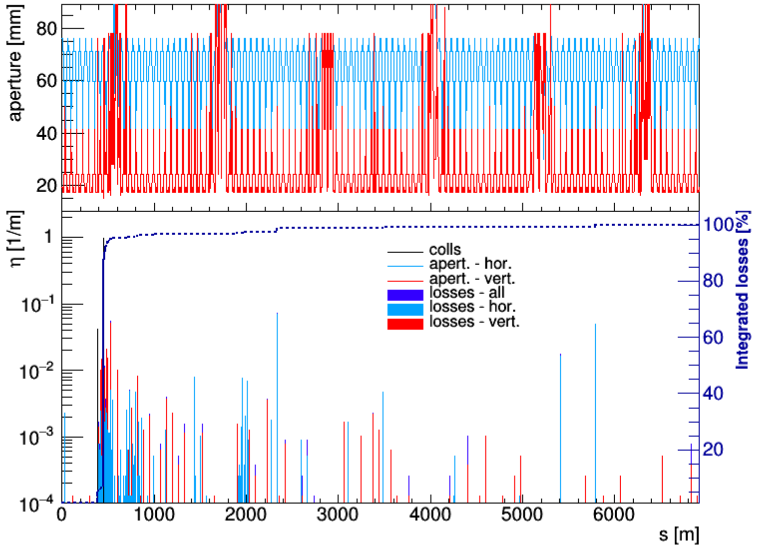


- Prim.Coll gap: $4.0\sigma_\beta + D_x\,\delta_{bh}$ = -36.1 mm
- Orbit bump needed to reach the TIDP
- TIDP inner gap: $5.0\sigma_\beta + D_x\,\delta_{bh}$ + 17.5mm= **-41.0 mm**

1σ relative retraction — bump amplitude



meas aper.



		ideal aper.	meas. aper.
	S [m]	Loss[%]	Loss [%]
Prim.Coll+TIDP	**-**	**86.3**	**84.2**
Prim.Coll	382	3.5	3.5
TIDP	455	82.3	80.7
QF.11210	384	0.6	0.7
MBA.11230	390	0.7	0.7
MBB.11470	467	1.9	1.8
MBB.11490	474	0.9	1.0
QD.30110	2336	<0.2	1.3
QD.60110	5793	<0.2	0.8

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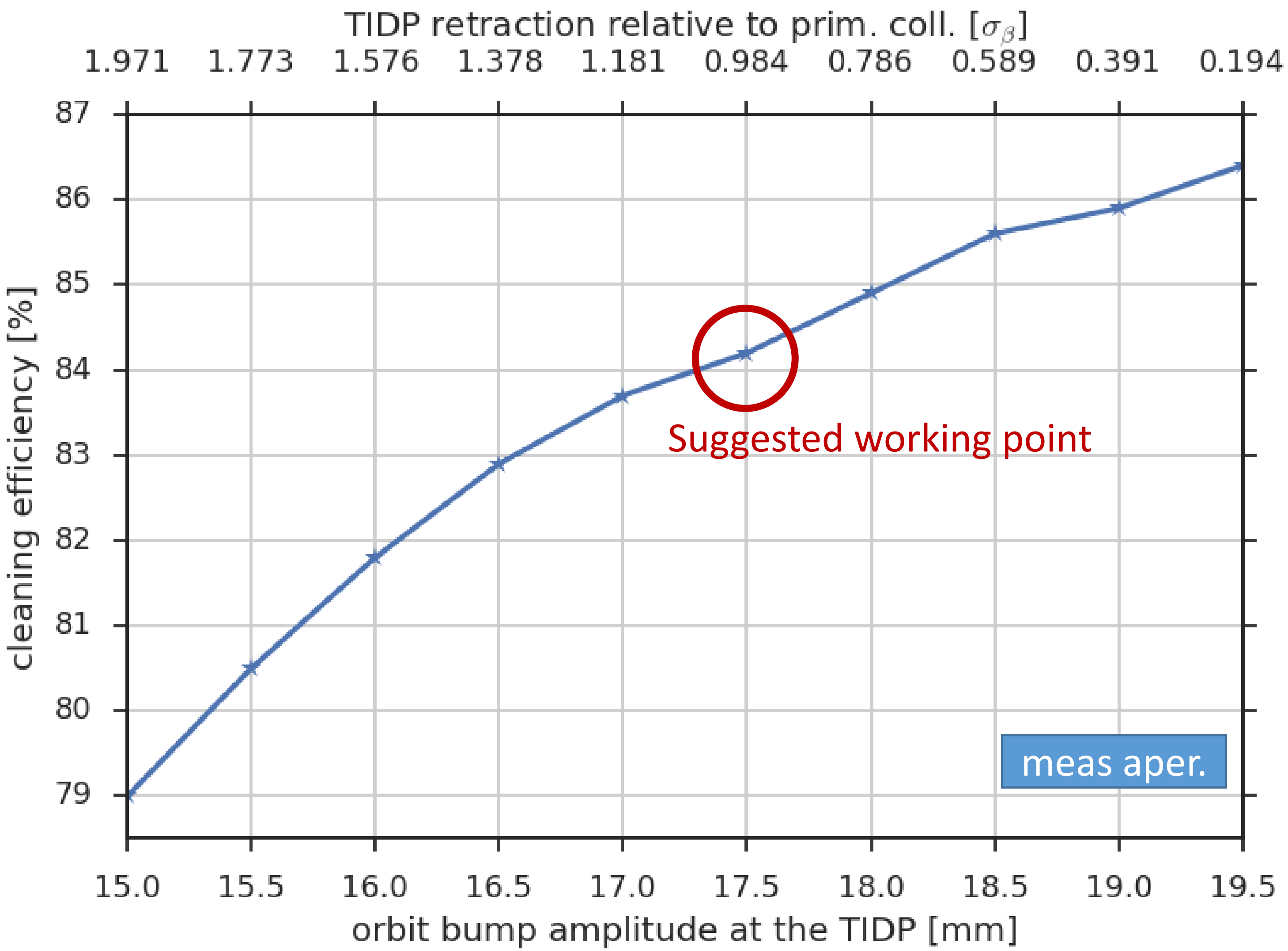
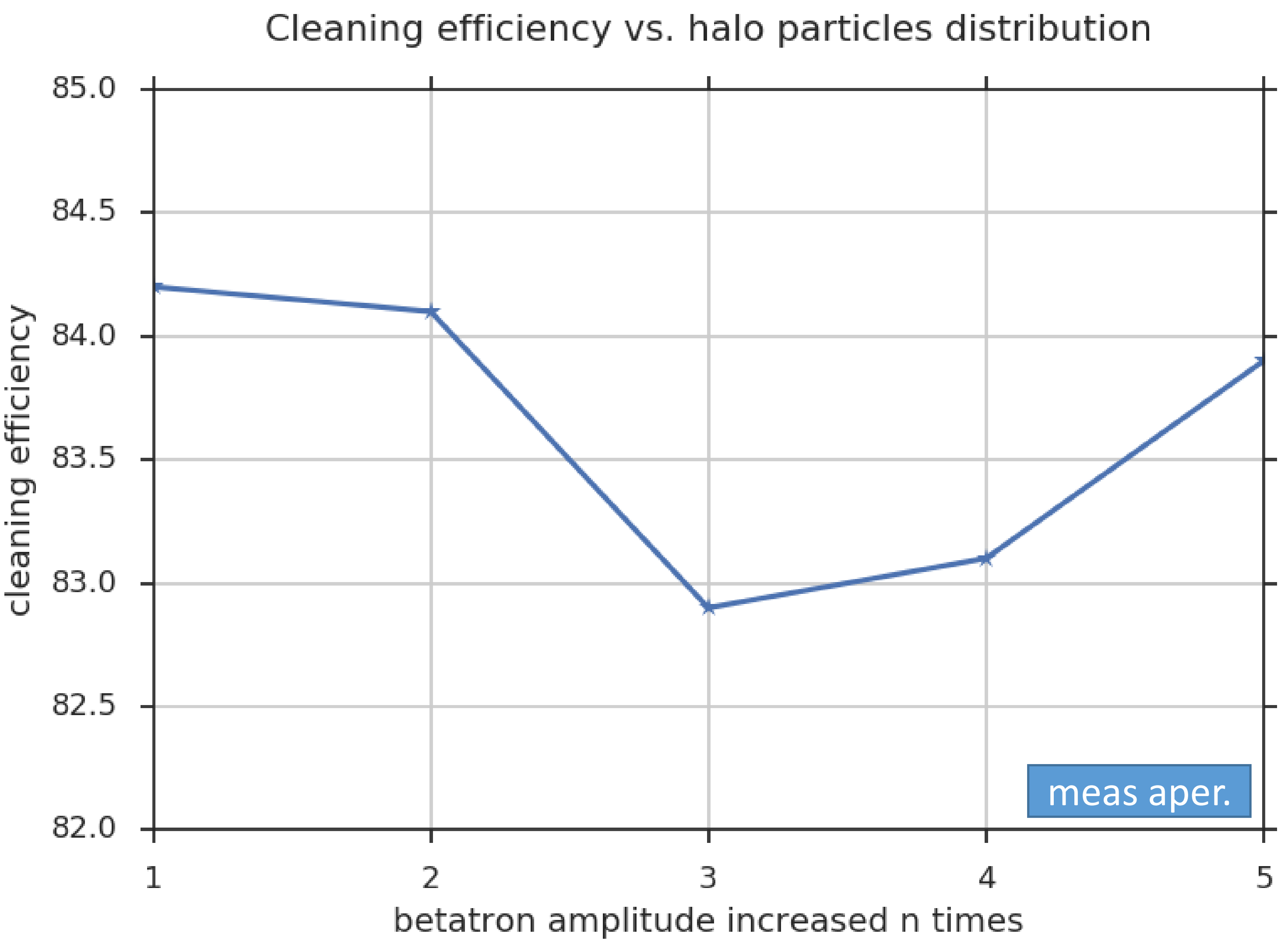
Cleaning efficiency vs. bump amplitude



Initial distribution error

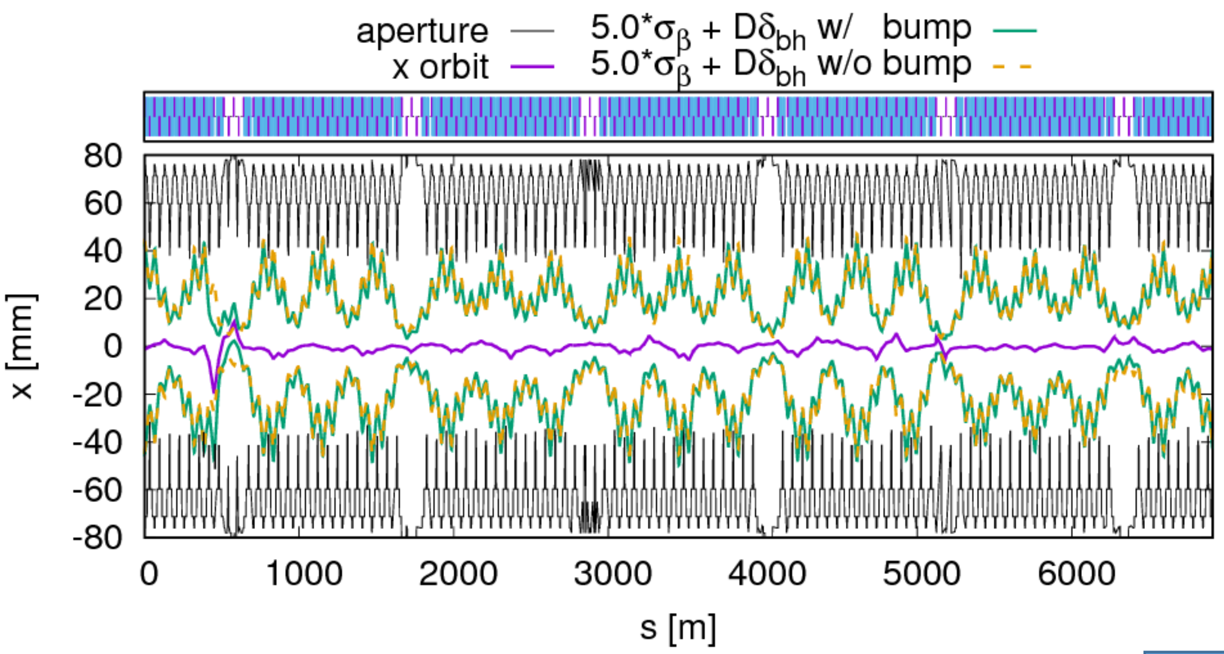
- Initial protons distribution:
  - Betatron amplitude is randomly assigned following a single Gaussian distr. (100% 1σ)
  - Betatron amplitude is increased n times, n={1,2,…,5}
  - dp/p value is calculated to reach the collimator jaw
- Lower dpp value;
- Initial angle changed;

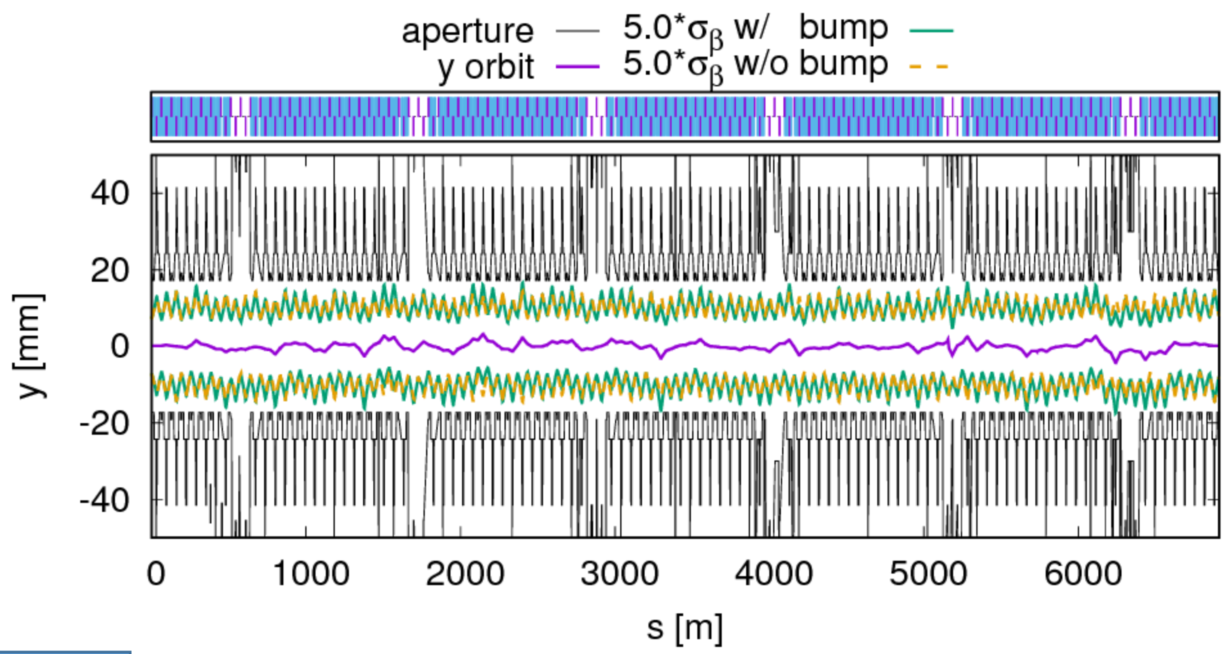
- No evident effect on efficiency;
- Small difference within statistical fluctuation.



Global orbit

- Orbit matched to the same target as in the real operation (courtesy H. Bartosik)
- Orbit bump at the TIDP
- Additional constraint x=0 at the primary collimator

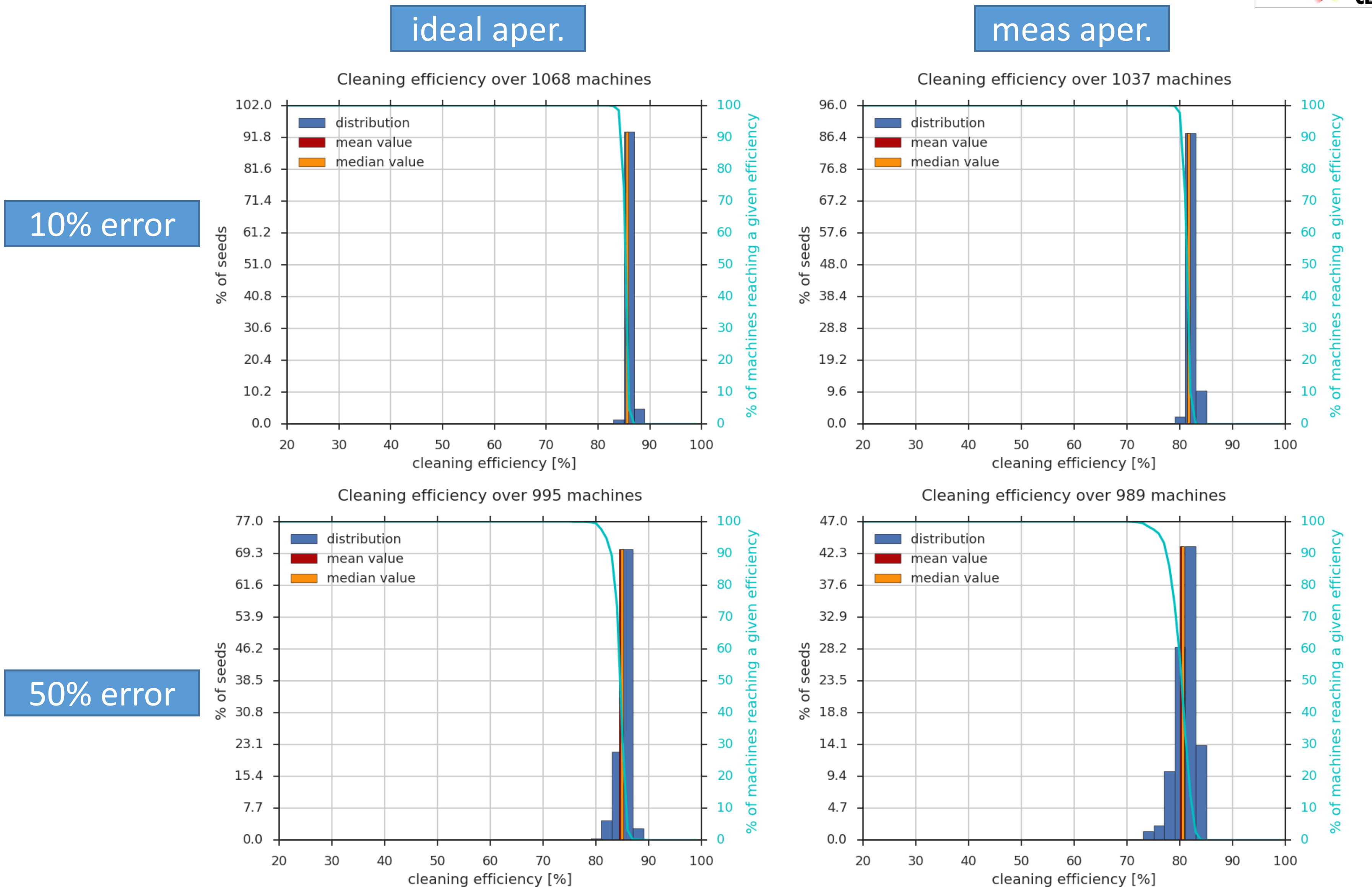




meas aper.

Cleaning efficiency vs. orbit error

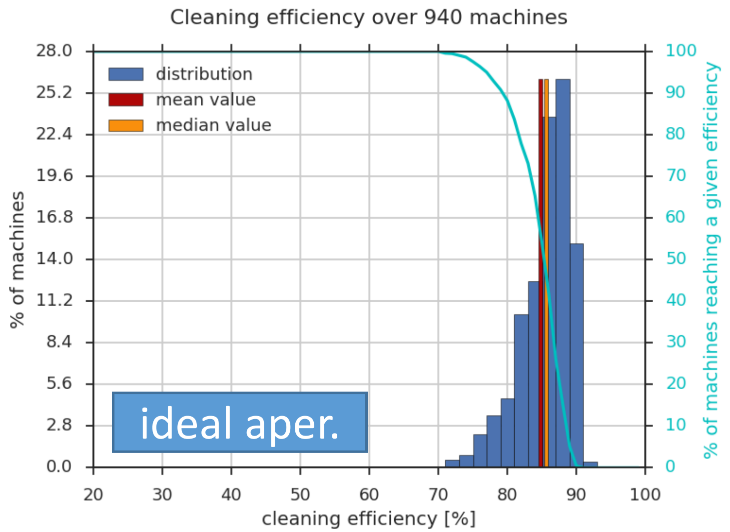
- Random Gaussian error applied to target orbit:
  - 2 cases studied: 10% and 50% of error
  - error applied at every BPM from the target
- Effectively equivalent to random aperture decrease
- No effect on cleaning efficiency

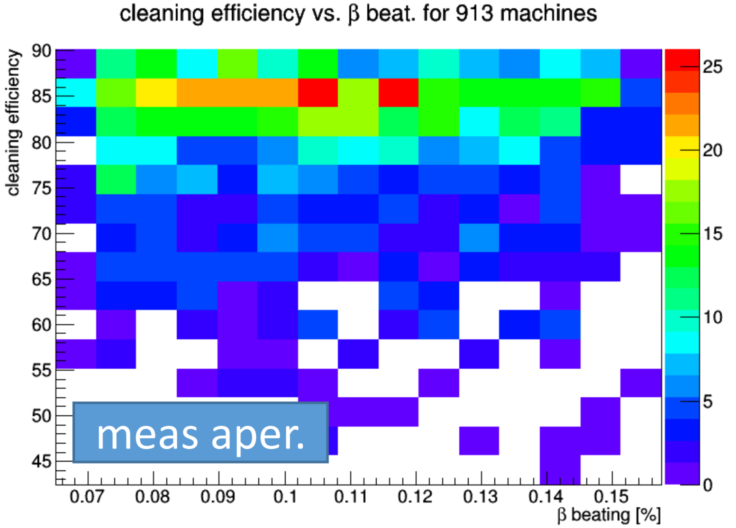


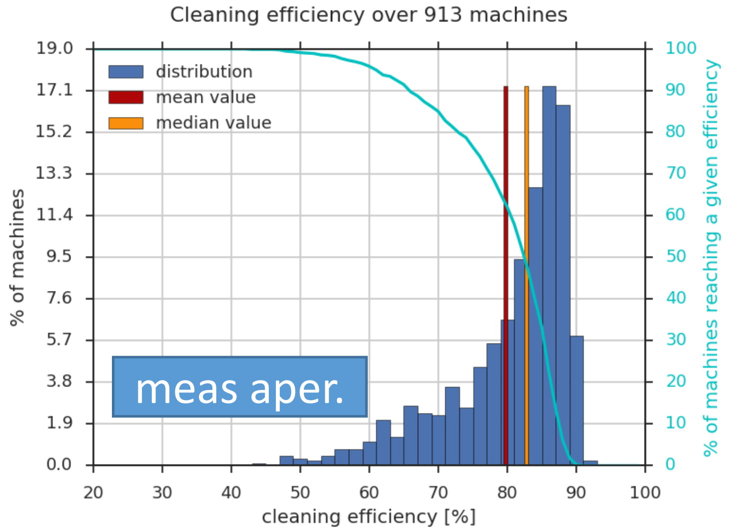
Cleaning efficiency vs. optics error

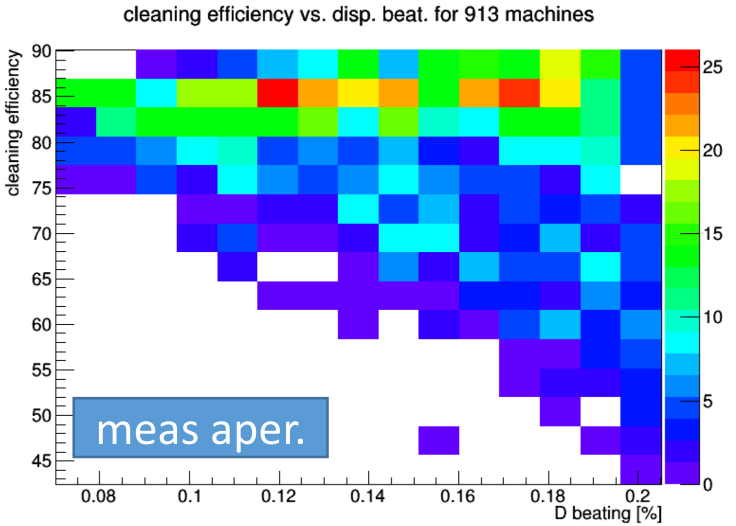
- Random quad strength error;
- Machine accepted if:
    - Beta beat 7-15%
    - Disp beat 7-20%

- No effect of beta beat;
- Disp beat spoils the cleaning efficiency;
- No issue for ideal aperture;
- Degraded performance for measured aperture;



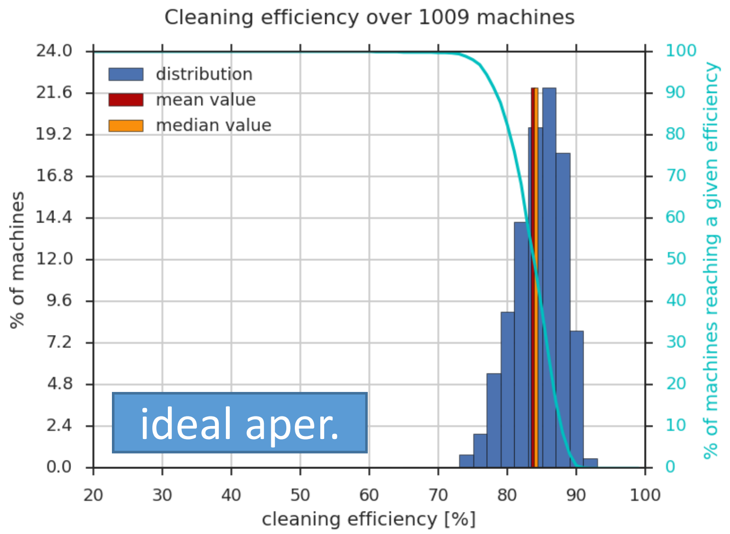


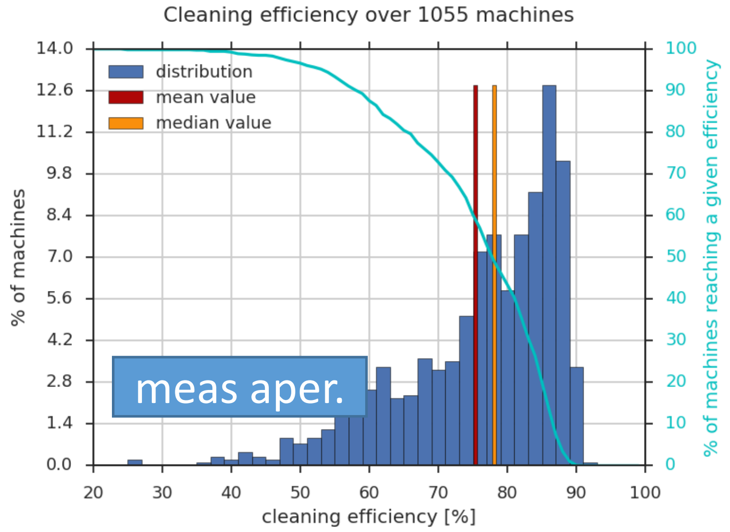




Cleaning efficiency vs. optics & orbit errors

- Acceptable performance for ideal aperture;
- Degraded performance for measured aperture;





Summary

- An off-momentum collimation system can be effectively deployed with the TIDP as an absorber.
- A 5mm thick carbon primary collimator must be added one cell upstream (cell 111/112) of the TIDP (cell 114), 80cm of space available.
- Assets:
  - >80% of global cleaning efficiency.
  - Rather insensitive to common machine errors, dispersion beating must be carefully controlled.
  - Efficient for Q20 and Q22 optics, no limitation for Q26.
  - TIDP shielding efficient for suppressing the effects of secondary showers and activation:
    - E deposition study done by L. Salvatore (LIU-SPS Beam loss-Protection-Transfer Lines meetings).
    - Activation study done by D. Bjorkman (LIU-SPS Beam loss-Protection-Transfer Lines meetings).
- Liabilities:
  - Relies on an orbit bump, orbit correctors strength limited to flat bottom and beginning of ramp
  - Usage of TIDP for collimation purpose must be carefully investigated.

- Outlook:
  - check losses in case of hierarchy breakage;
  - check other materials for TIDP core.

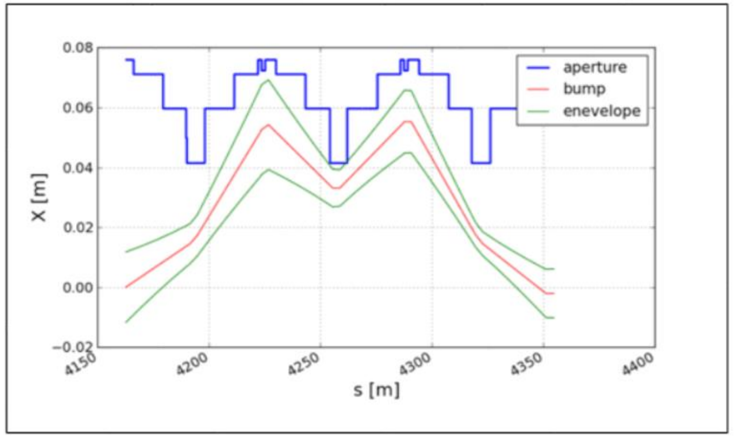
Extra slides

Measured horizontal aperture

V. Kain, Measured Q20 aperture limits at QDs and possible physical explanation/solution, https://indico.cern.ch/event/673312/:

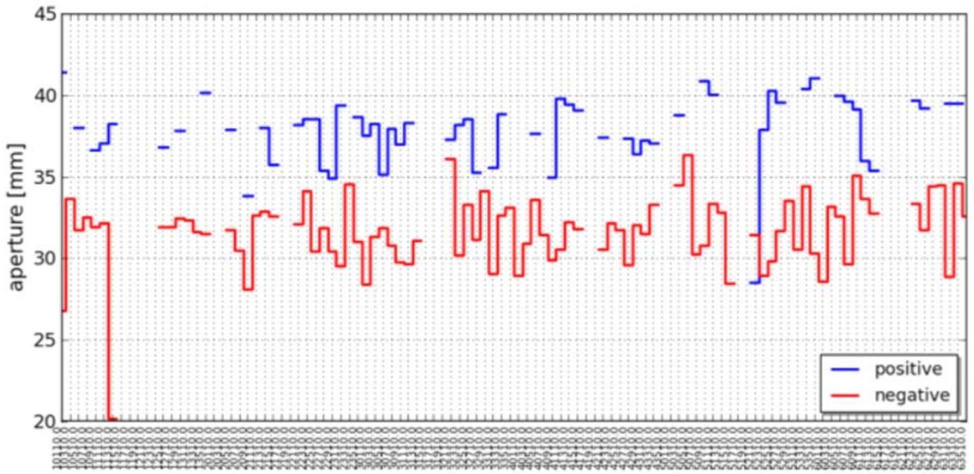
Measurement of mechanical aperture at QDs in H

- Measured at all QDs except locations *17 and *19
- Measurement at 14 GeV, Q26 with 4C bump
- Interpolate orbit at QD location and correct measured max. bump amplitude



Result in mm

- Systematically smaller aperture towards the inside than towards the outside. Aperture on paper 41.5 mm



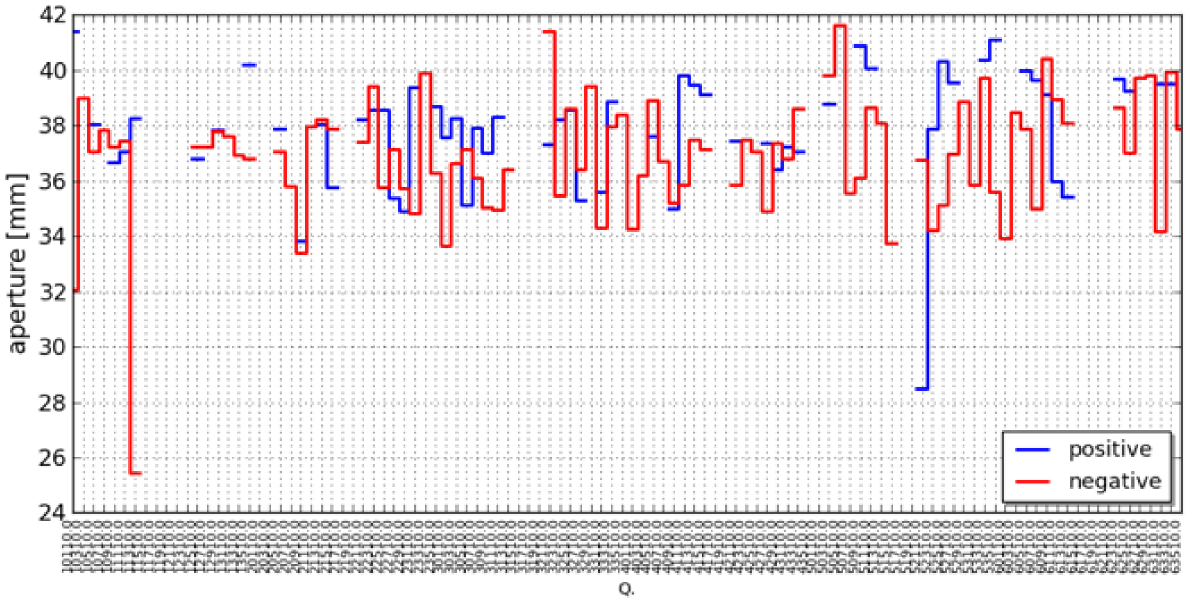
If there is no line, either no measurement or aperture never reached. Max. possible 4C bump = 40 mm @ QD.

Measured horizontal aperture +5mm

V. Kain, Measured Q20 aperture limits at QDs and possible physical explanation/solution, https://indico.cern.ch/event/673312/:

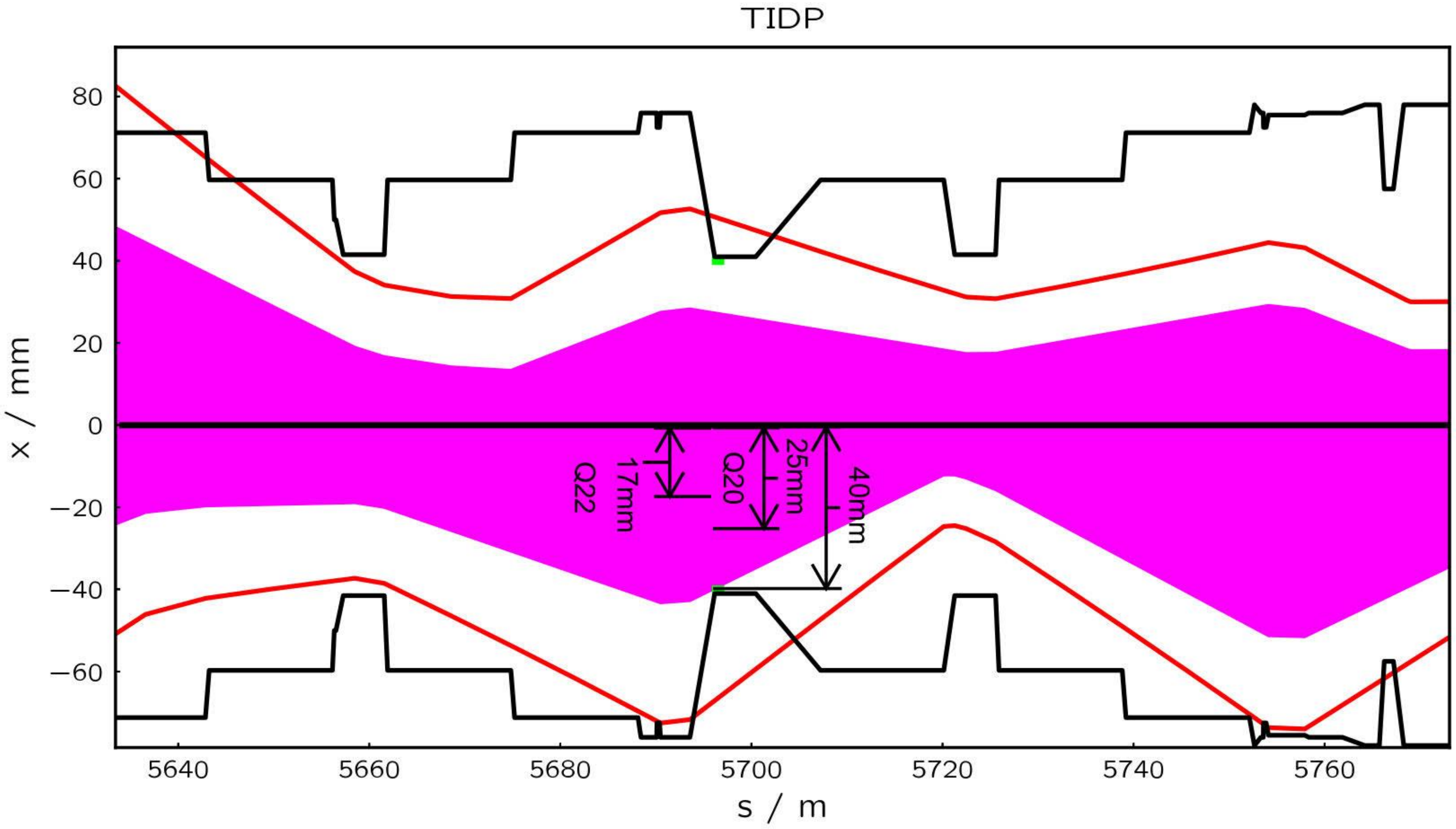
Aperture measurements correcting for 5.3 mm

- Difference between negative and positive aperture less pronounced
- Possibly a few locations with pumping port shield flange on QD-MBB transition installed wrongly

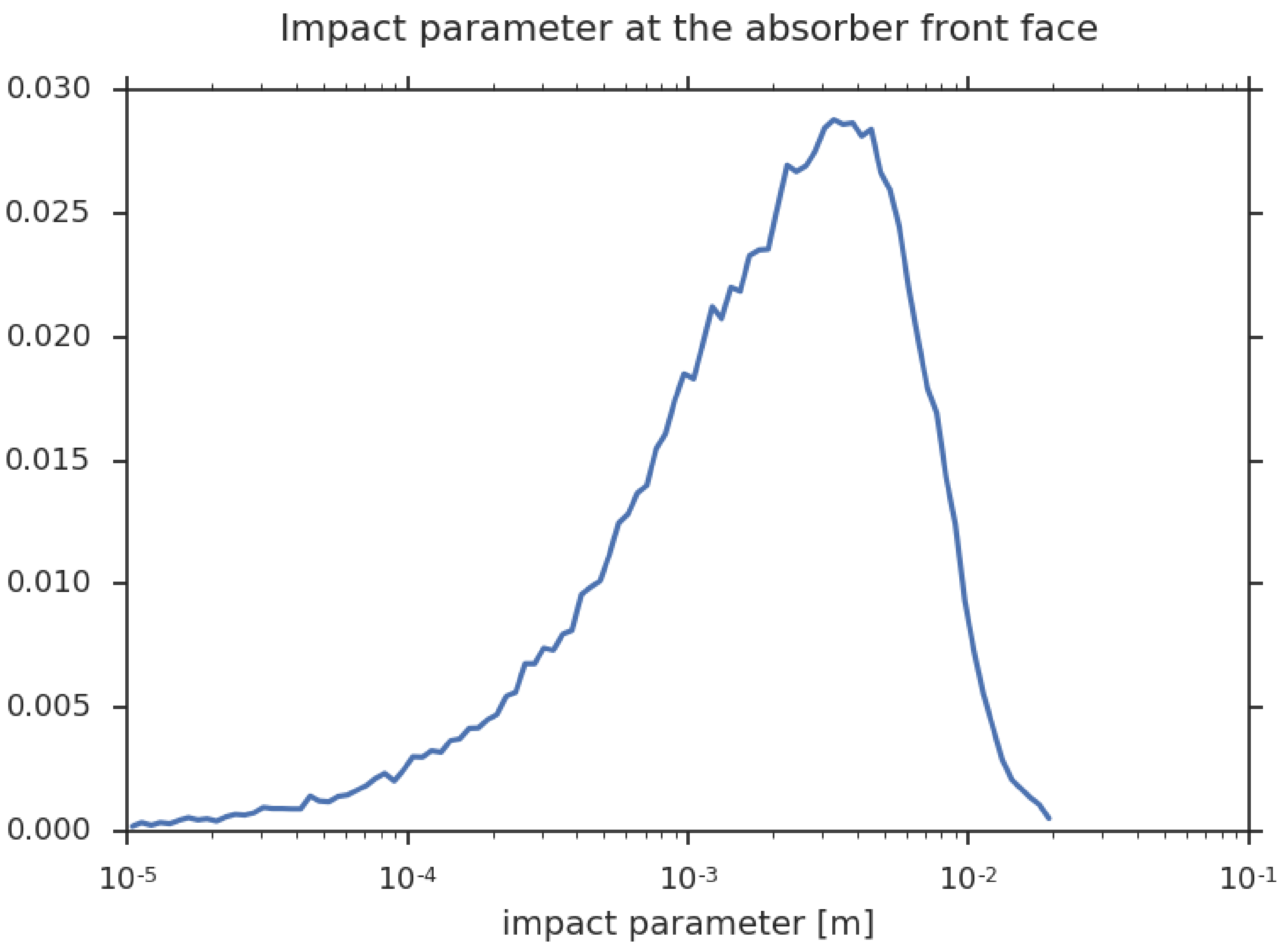


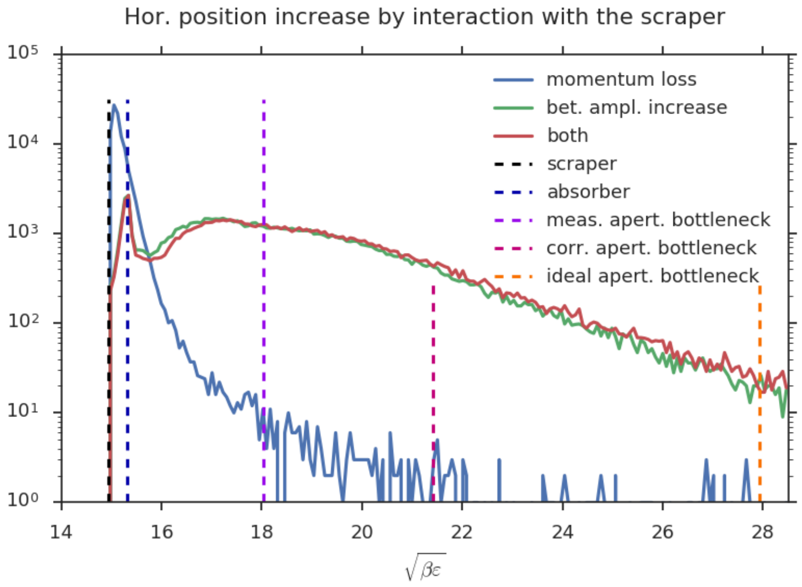
Requirement of the fixed target beam during the slow extraction

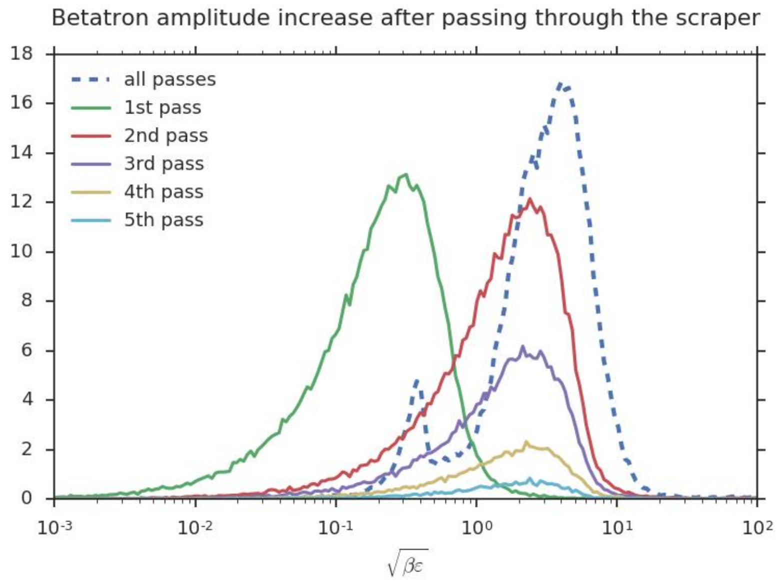
- Beam is blown-up during the slow extraction.
- Absorber must be placed outside the beam envelope.
- An orbit bump can be used:
  - 17mm for Q20
  - 25mm for Q22
  - Both feasible, at least at flat bottom

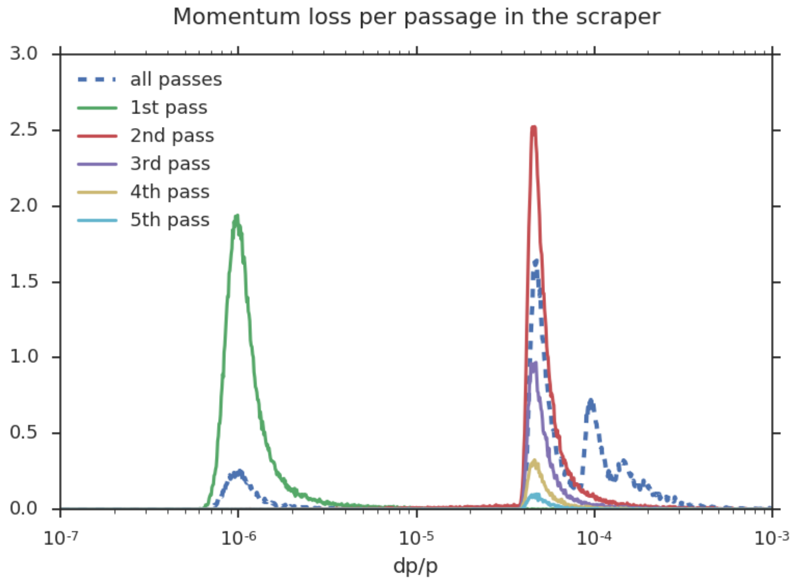


Plot courtesy of F. Velotti


Impact parameter at the absorber front face
0.030
0.025
0.020
0.015
0.010
0.005
0.000
10-5
10-4
10-3
10-2
10-1
impact parameter [m]


Hor. position increase by interaction with the scraper
momentum loss
bet. ampl. increase
both
scraper
absorber
meas. apert. bottleneck
corr. apert. bottleneck
ideal apert. bottleneck
$\sqrt{\beta\varepsilon}$

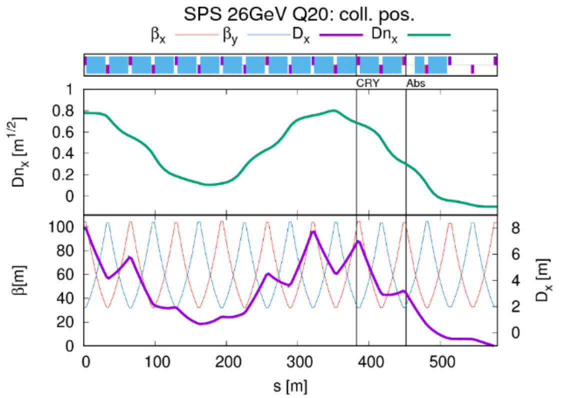

Betatron amplitude increase after passing through the scraper
all passes
1st pass
2nd pass
3rd pass
4th pass
5th pass
$\sqrt{\beta\varepsilon}$


Momentum loss per passage in the scraper
all passes
1st pass
2nd pass
3rd pass
4th pass
5th pass
dp/p

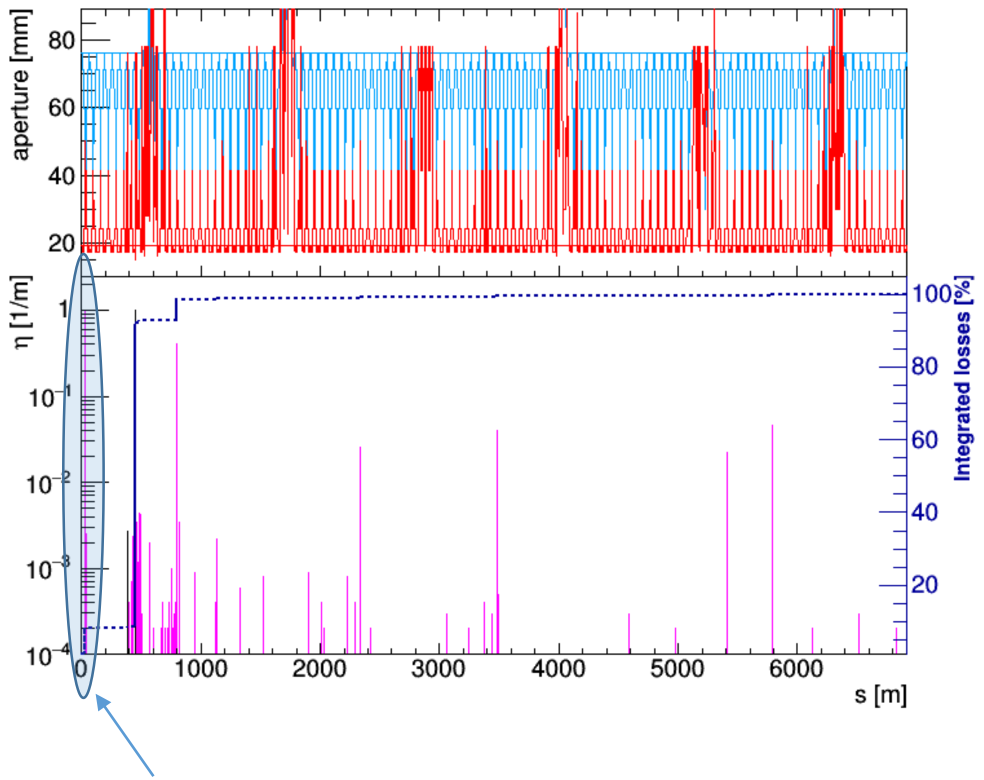
Bent crystal as a primary collimator

- Absorber upstream of the TIDP
  - **Gap: 41mm = 11.15σ_β + $D_x\,\delta_{bh}$** - compatible with fixed target beam (injection and extraction)
- Bent crystal as a primary collimator:
  - **Gap: 4.0σ_β + $D_x\,\delta_{bh}$ = 36.1 mm**
  - 300 urad kick -> 8σ_β growth at the absorber

length [mm]	3	1.5
bending/critical radius [m]	10/0.9	5/0.9
angular acceptance 26/450 GeV [urad]	37.0/8.1	36.8/7.2
single-pass efficiency [%]	70.6	76.6



Measured hor. aperture +5mm, crystal: 1.5mm, absorber: 1m Cu



Large localized loss at QD.10110 – to be understood and mitigated.

Bent crystal instead of Prim.Coll
cleaning efficiency

Measured hor. aperture +5mm, crystal 3mm					
	S [m]	MoGr 100cm	MoGr 180cm	Cu 100cm	W 100cm
All colls	**-**	**63.1**	**72.7**	**76.7**	**77.4**
Crystal	382	0.5	0.5	0.5	0.5
Absorber	452	62.6	72.2	76.2	76.9
drift	452.5-453.6	6.5	2.2	0.3	-
TIDP	455	4.2	2.7	1.0	0.8
MBB.11470	468	1.0	0.7	0.3	0.2
BPCN.12508	799.6	3.8	2.5	3.6	3.6
QD.12510	800	2.5	2.0	2.4	2.4
QD.30110	2336	1.3	1.3	1.2	1.3
QD.10110	**32**	**11.0**	**10.4**	**10.7**	**10.7**

Measured hor. aperture +5mm, crystal 1.5mm					
	S [m]	MoGr 100cm	MoGr 180cm	Cu 100cm	W 100cm
All colls	**-**	**67.8**	**78.1**	**82.2**	**83.0**
Crystal	382	0.2	0.2	0.2	0.2
Absorber	452	67.6	77.9	82.0	82.8
drift	452.5-453.6	6.9	2.4	0.3	-
TIDP	455	4.4	2.8	0.9	0.8
MBB.11470	468	1.1	0.7	0.3	0.2
BPCN.12508	799.6	3.7	2.3	3.4	3.3
QD.12510	800	2.3	1.9	2.3	2.3
QD.30110	2336	0.4	0.3	0.4	0.3
QD.10110	**32**	**8.5**	**7.9**	**8.2**	**8.2**