Losses in PS Booster

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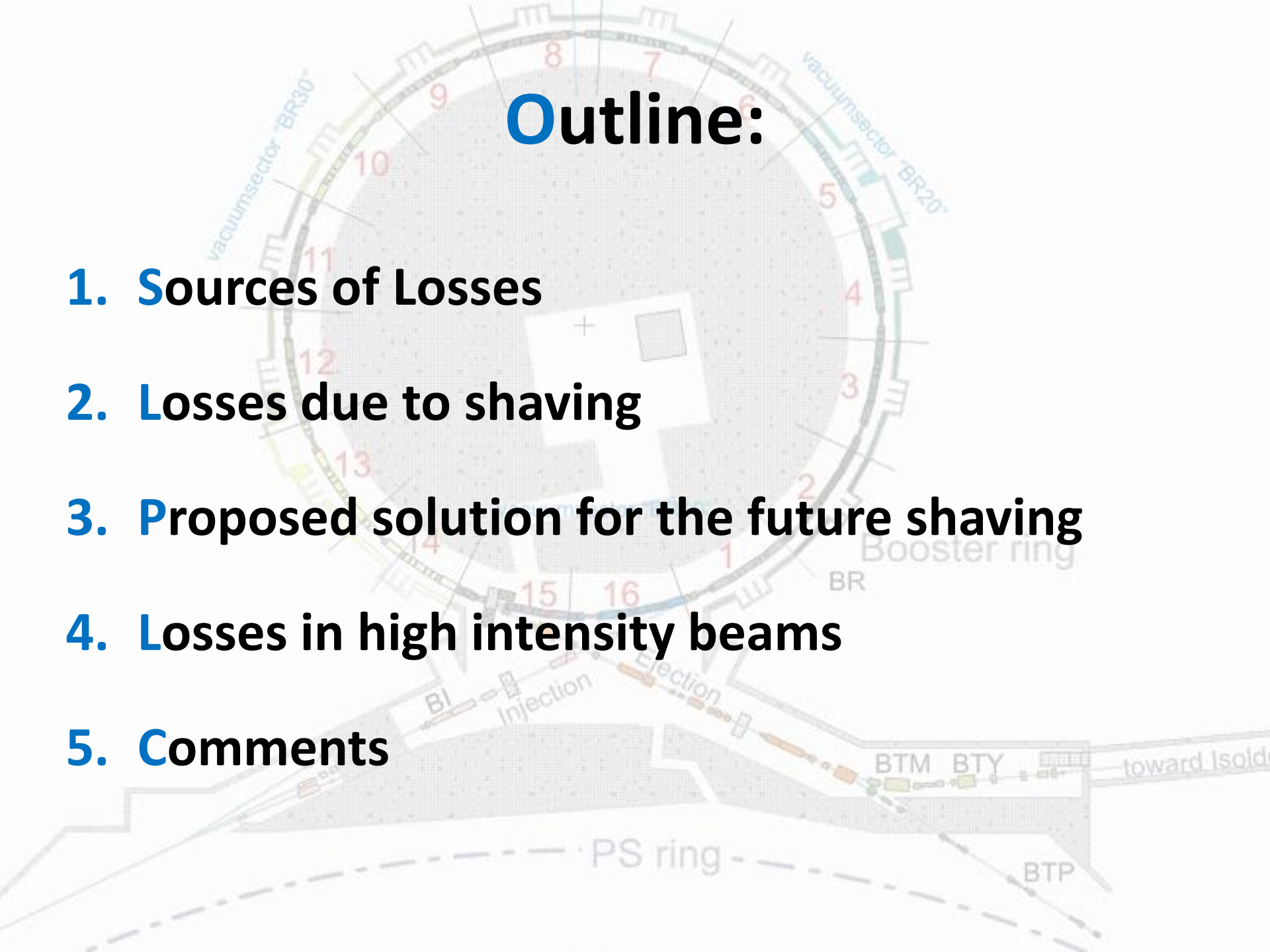
with the suport of Elena Benedetto, Christian Carli, Joao Pedro De Carvalho Saraiva, Bettina Mikulec, Giovanni Rumolo

LIU Meeting
12 June 2014

Outline:

1. Sources of Losses
2. Losses due to shaving
3. Proposed solution for the future shaving
4. Losses in high intensity beams
5. Comments



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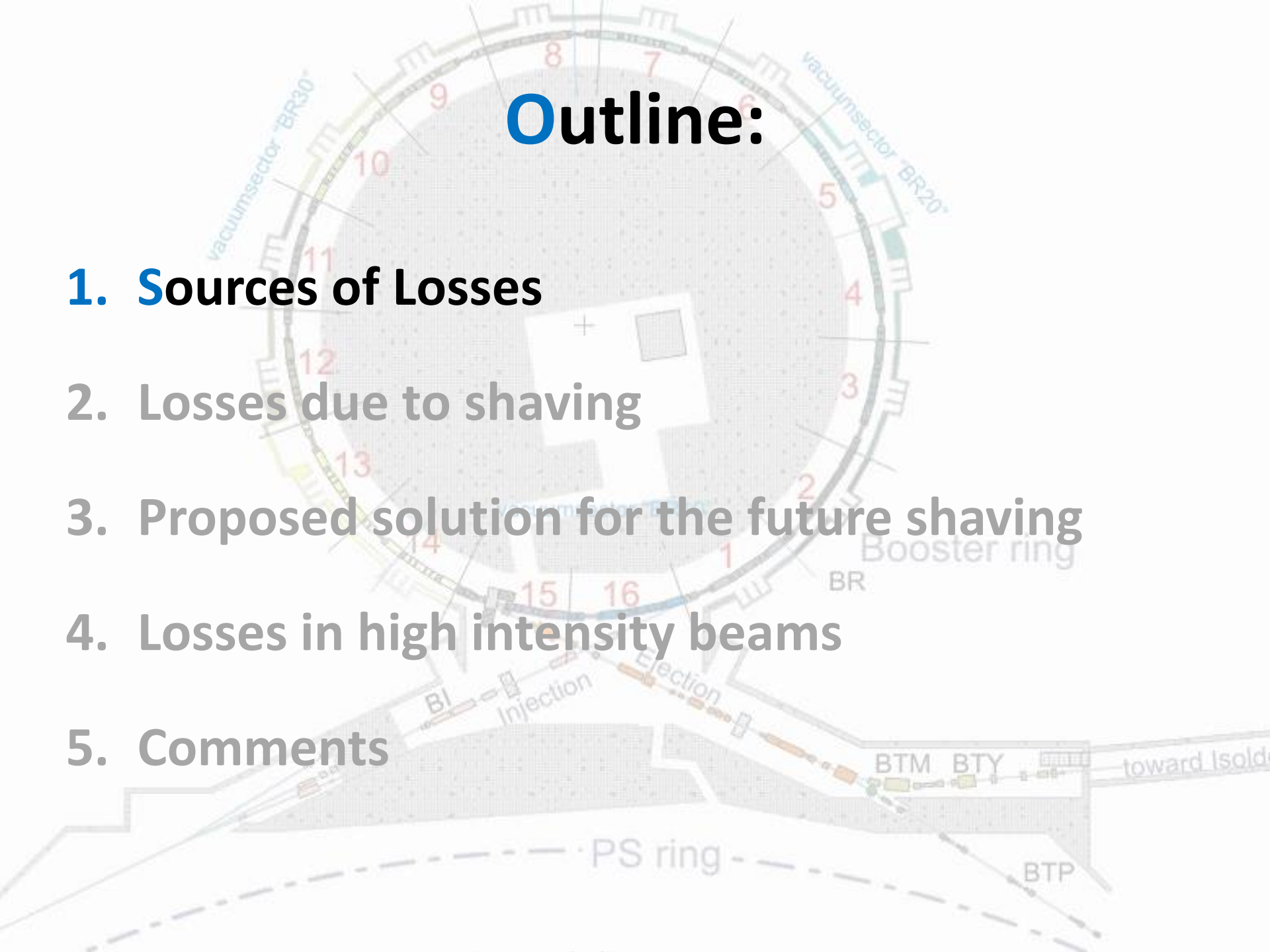
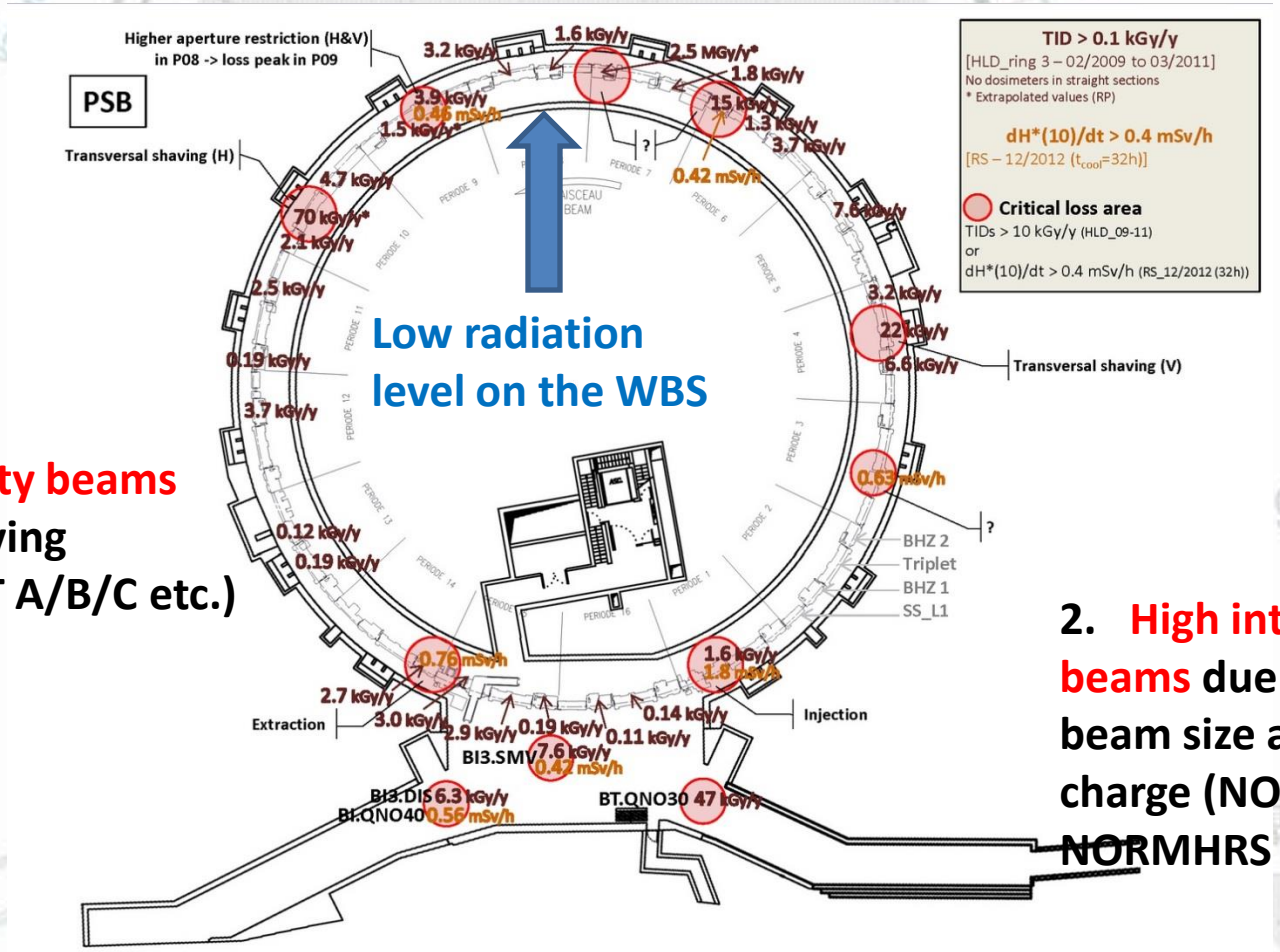


Sources of losses in PS Booster



1. **Low intensity beams due to the shaving (LHC50ns, EAST A/B/C etc.)**

2. **High intensity beams due to the big beam size and space charge (NORMGPS, NORMHRS etc.)**

Radiation level around the PS Booster ring

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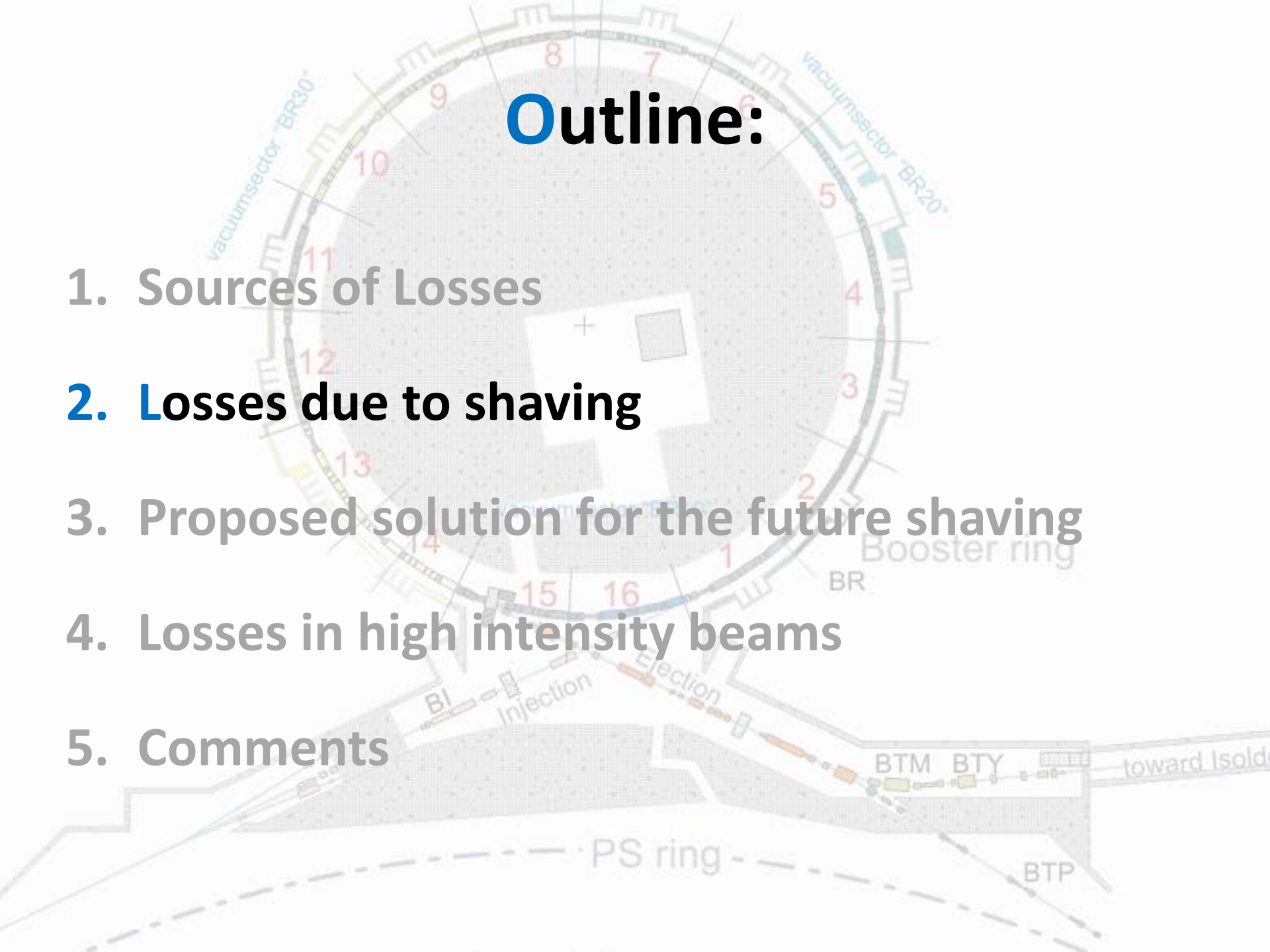
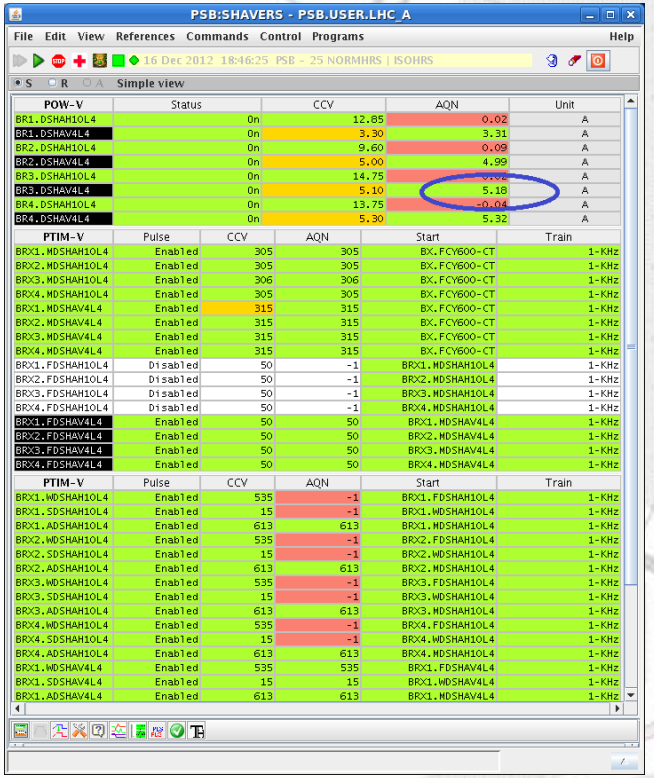


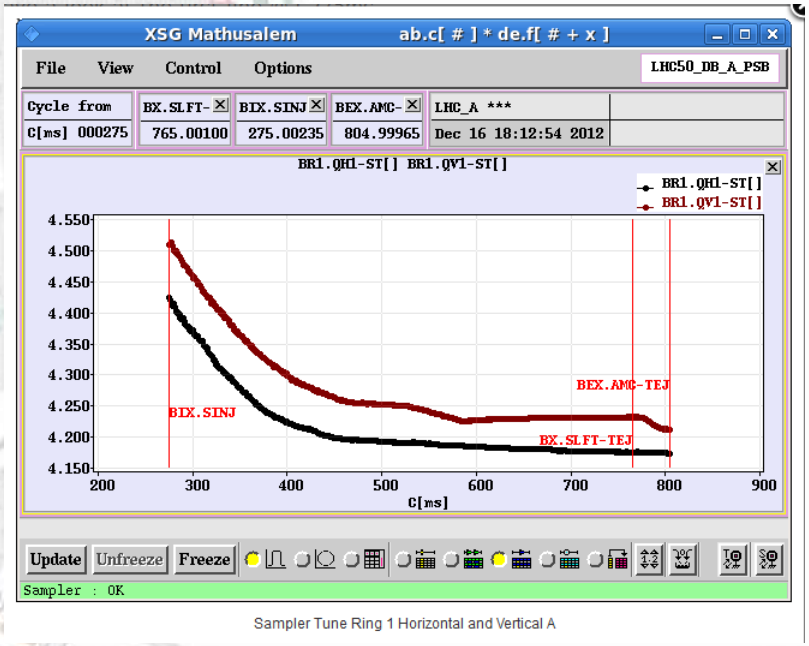
Current shaving in operation



Shaved beams:

EASTA
EASTB
EASTC
LHC50ns

(differs only in **kick strength** and slightly in shaving tune)



Sampler Tune Ring 1 Horizontal and Vertical A

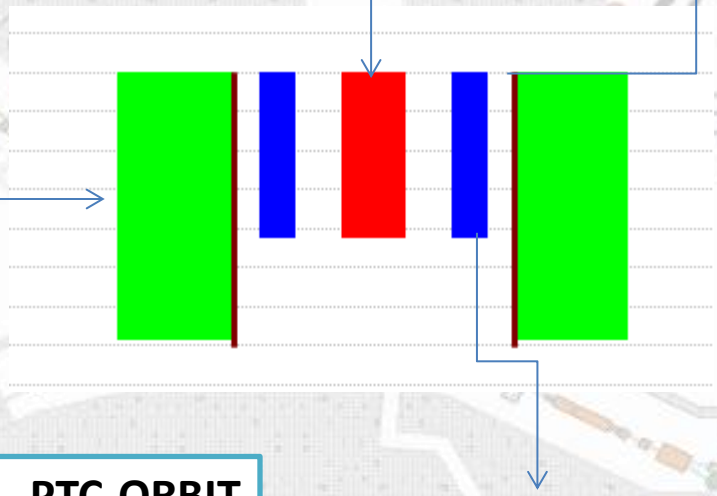
t = 305 ms
all the beams are shaved at
Qx = ~**4.37**
Qy = ~**4.45**
Energy of shaving = **65 MeV**

Legend

(red) defocusing quadrupole

(green) bending magnet

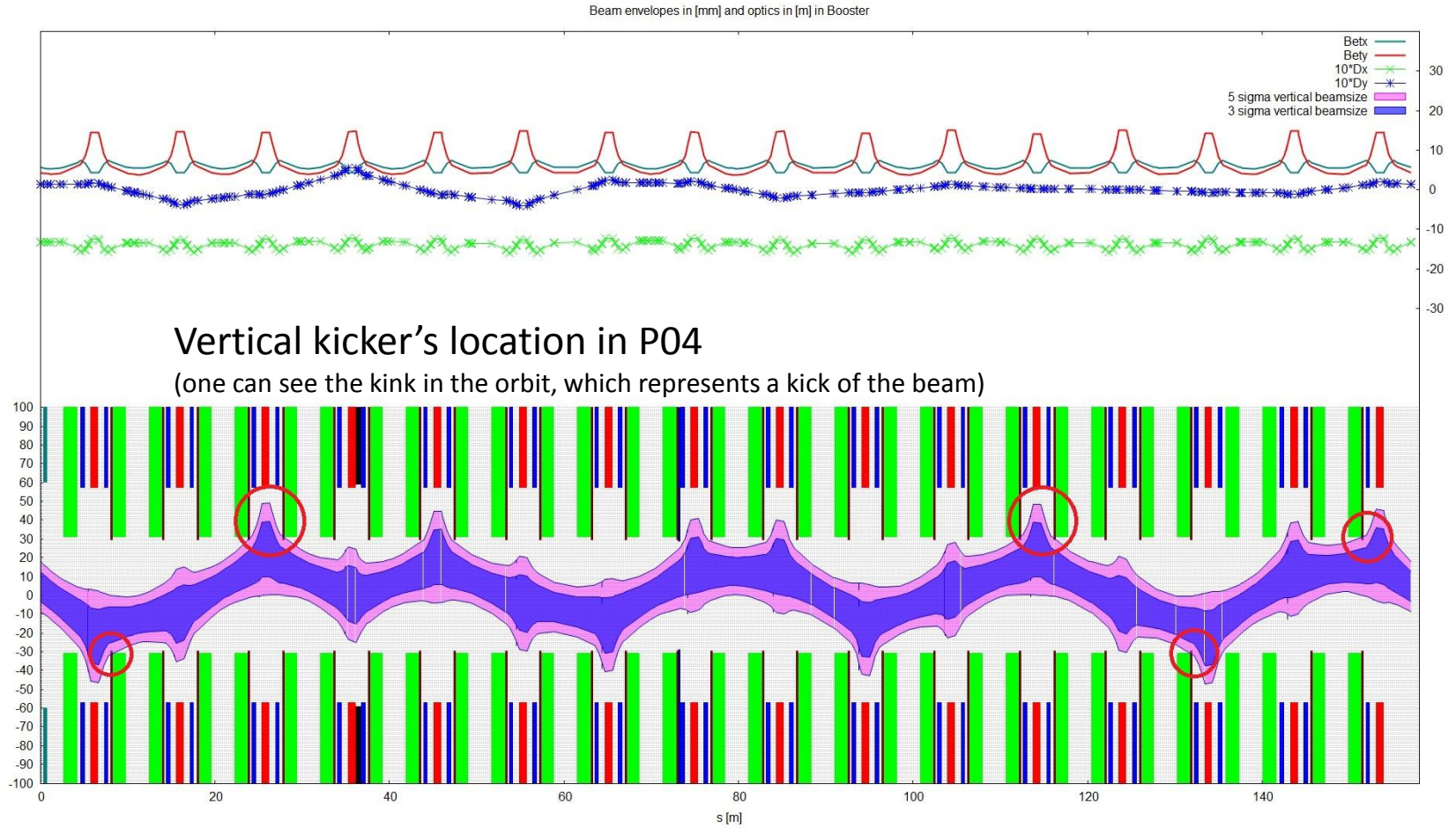
(maroon) scraper



(blue) focusing quadrupole

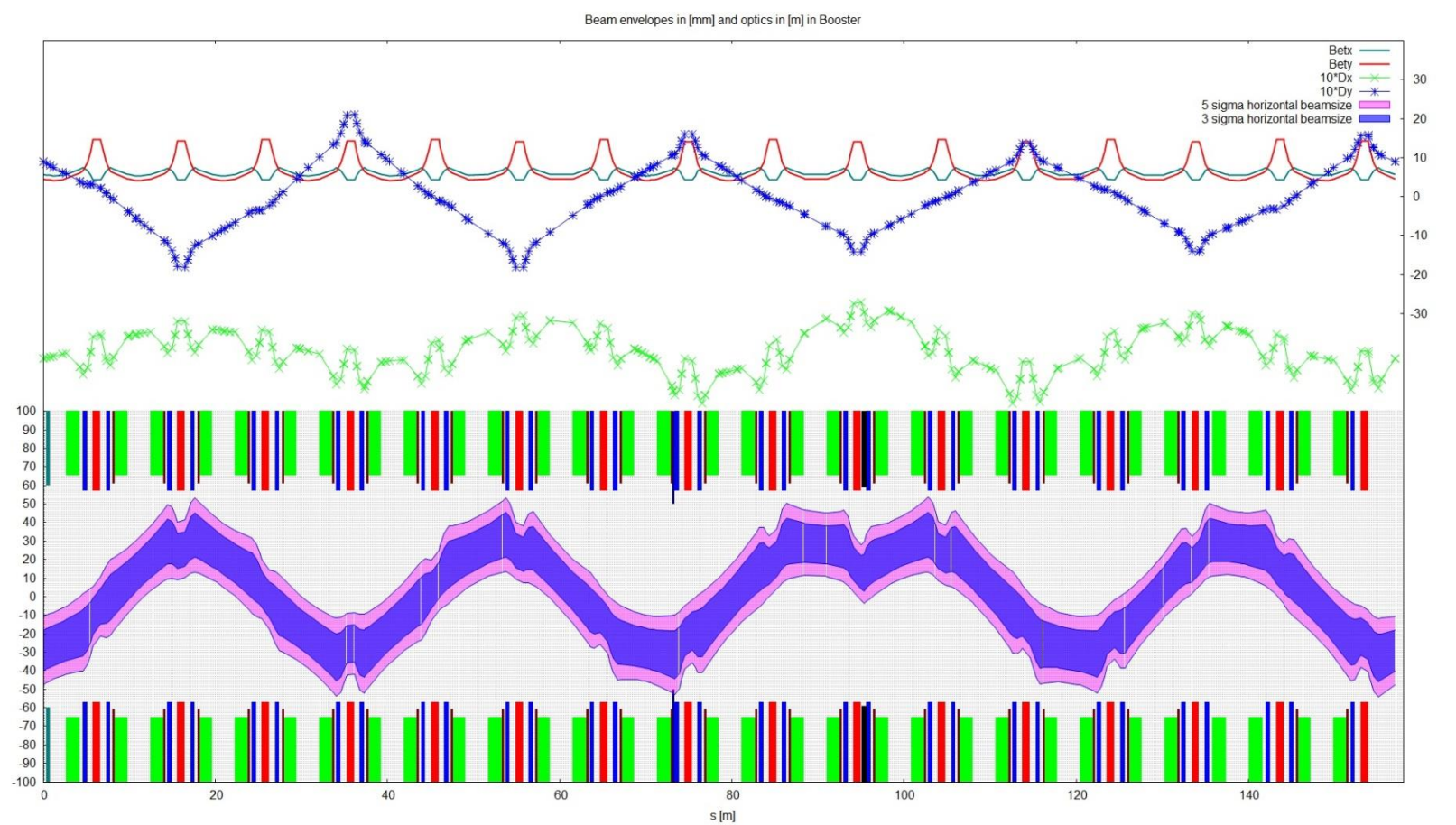
All the MAD-X and PTC-ORBIT simulations were performed including misalignments and field errors computed by Meghan

Example of vertical shaving



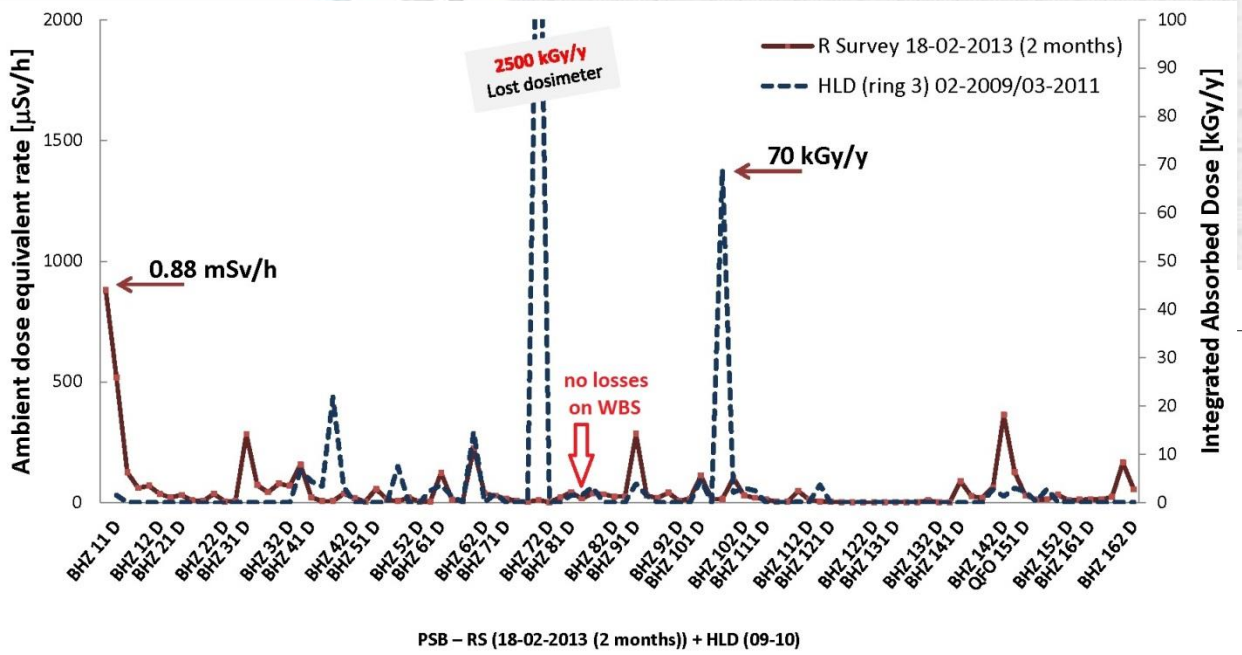
Losses occur in multiple locations – not only (and in this case even do not occur) at the aperture restriction

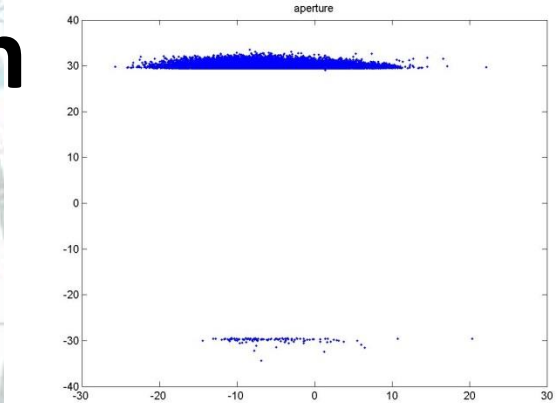
Example of horizontal shaving

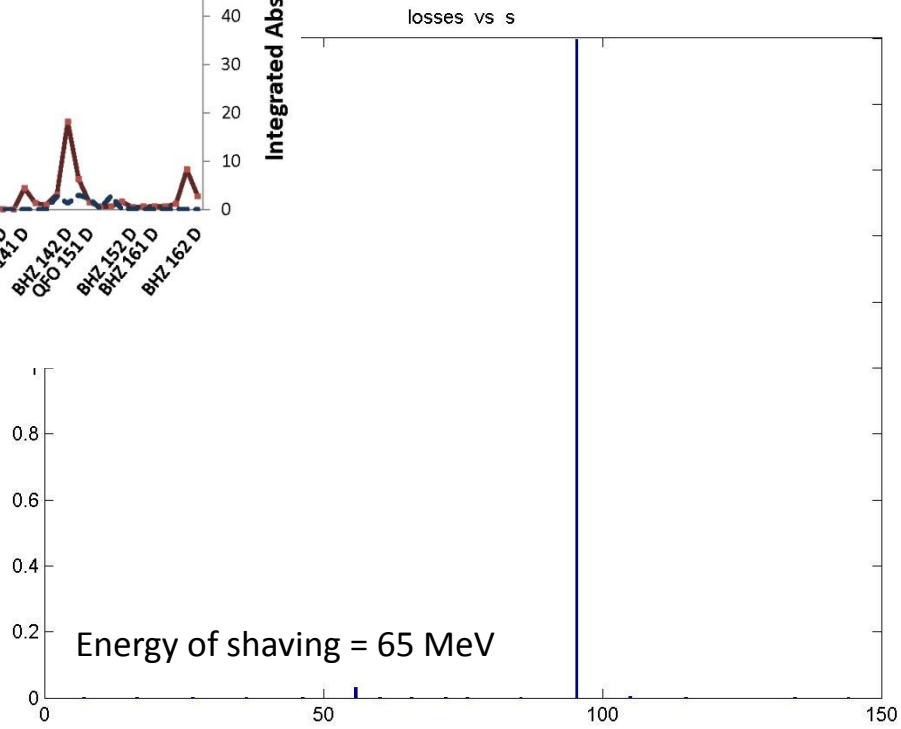


Losses occur at the aperture restriction in P08 (magnet's yoke in horizontal plane is big enough to avoid losses on elements)

Current shaving in operation losses vs position







Peak detected at
s = 95.23 m
(BR.BHZ102)

* which overlap with the results of the HLD **(peak in period 10 + no losses on WBS)**

LHC 50ns A beam ring 3/EASTB – same pattern of losses

Comments:

- The peak of 70 kGy/y has been detected during HLD measurements in 2009-2011 in period 10.
- According to the MADX and PTC-ORBIT simulation, the beam is not shaved on the Window Beam Scope as it was designed. **The beam hits the second bending magnet in period 10 (BR.BHZ102),** which reflects in the dosimetry measurements.
- **New proposal of shaving is needed.**

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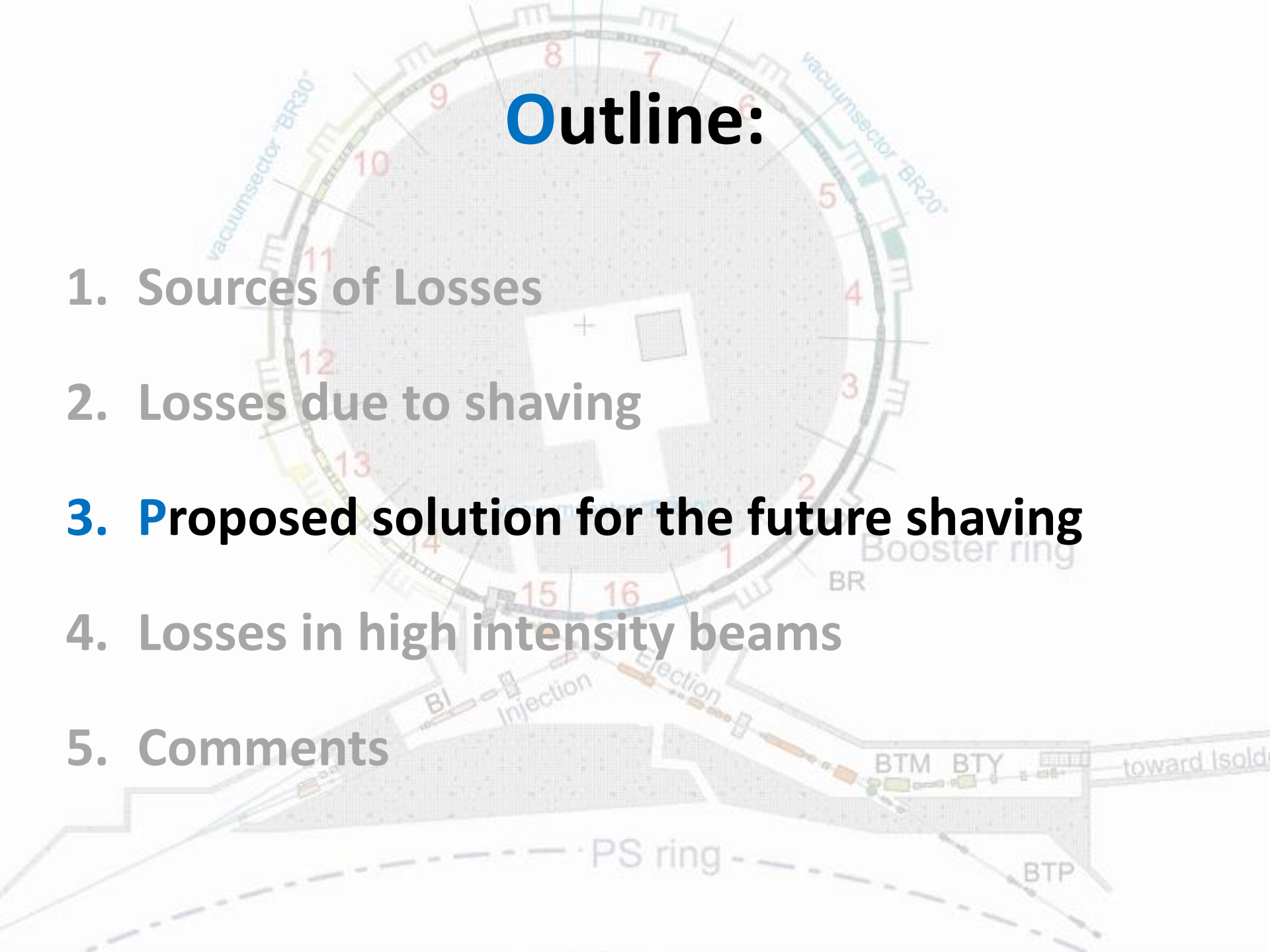


Proposal of the new shaving:

Currently we have **15** vertical correctors in PS-Booster
with assumed maximum current = **15 A**, which corresponds to

Max angle (@ 65MeV) = 10 mrad
Max angle (@ 170MeV) = 6 mrad

Two designs were considered:

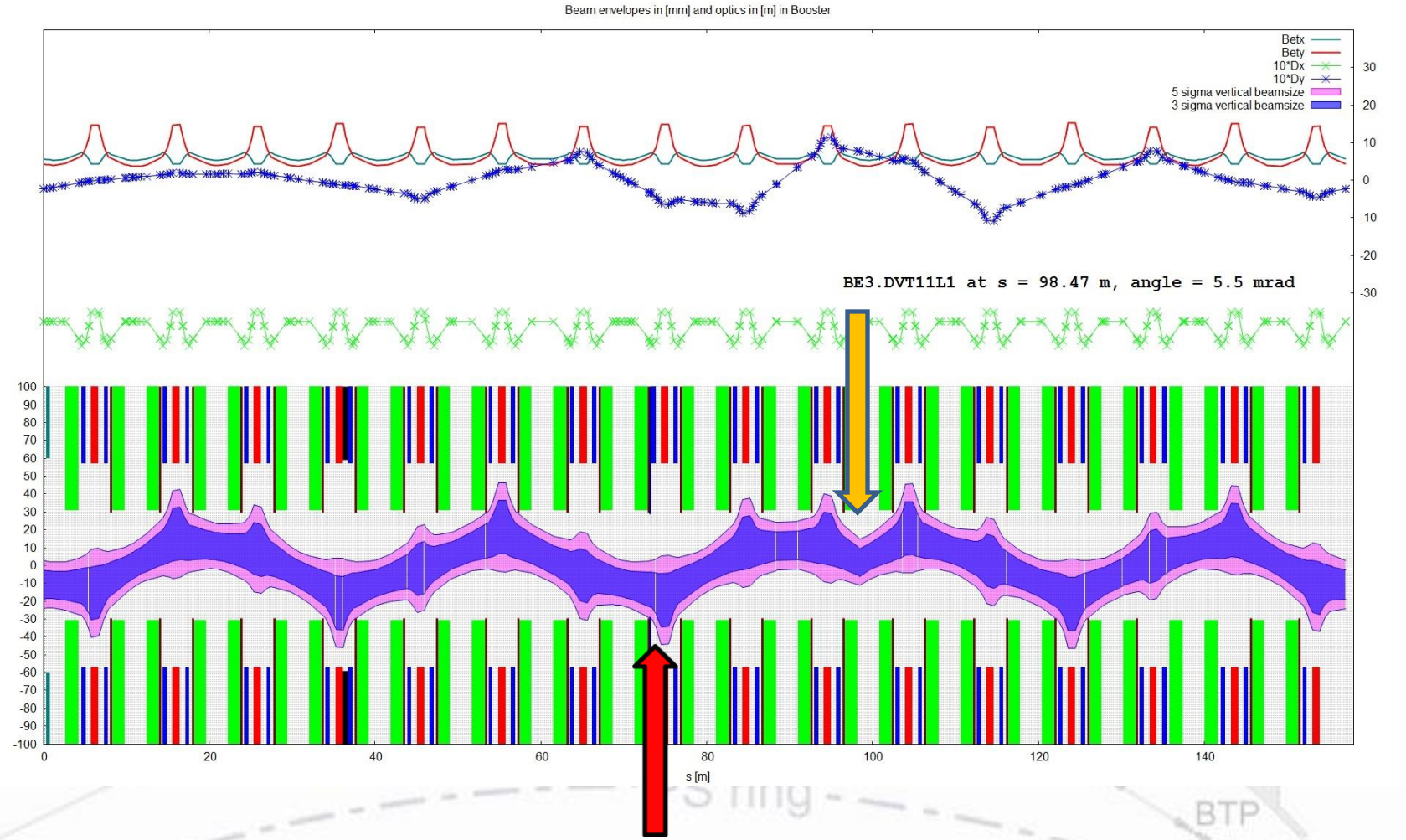
1. Single kick (2 suitable correctors found)

- Global distortion produced
- Possible losses on multiples elements
- Only **one corrector** needed

2. Closed bump

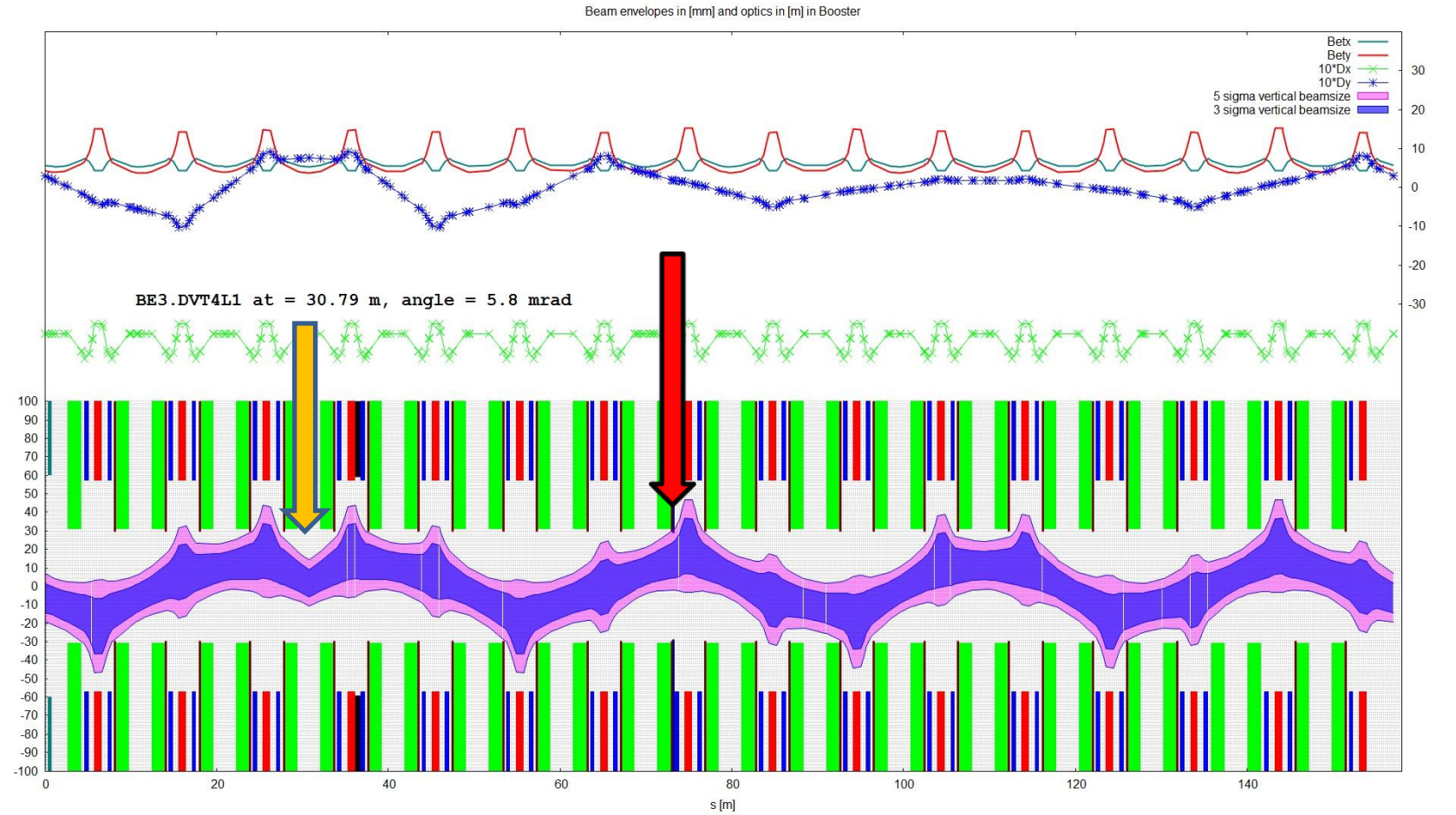
- Using **2 correctors** (i.e.. DBSV7L4 & DBSV9L4)
- Local orbit distortion produced
- Global orbit distortion can be suppressed to the negligible values (no more losses on elements due to shaving)

First option: single kick (BE3.DVT11L1)



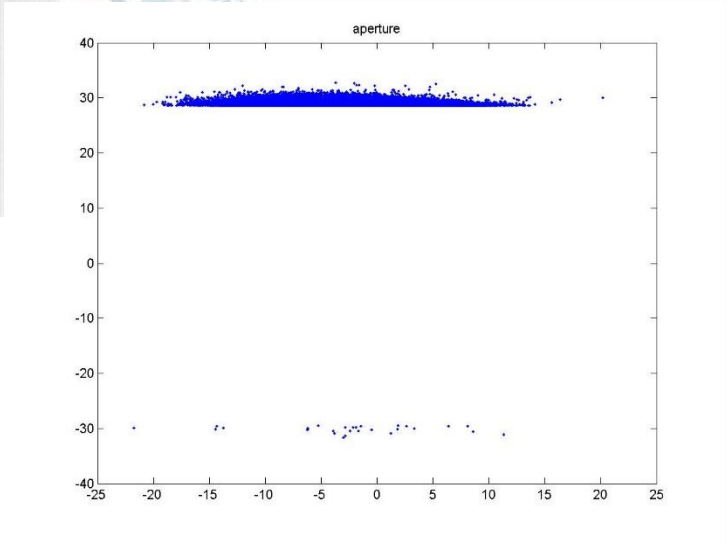
What is the maximum current for BE3.DVT11L1? Are we within the limits for 170 MeV shaving?

Second option: single kick (BE3.DVT4L1)

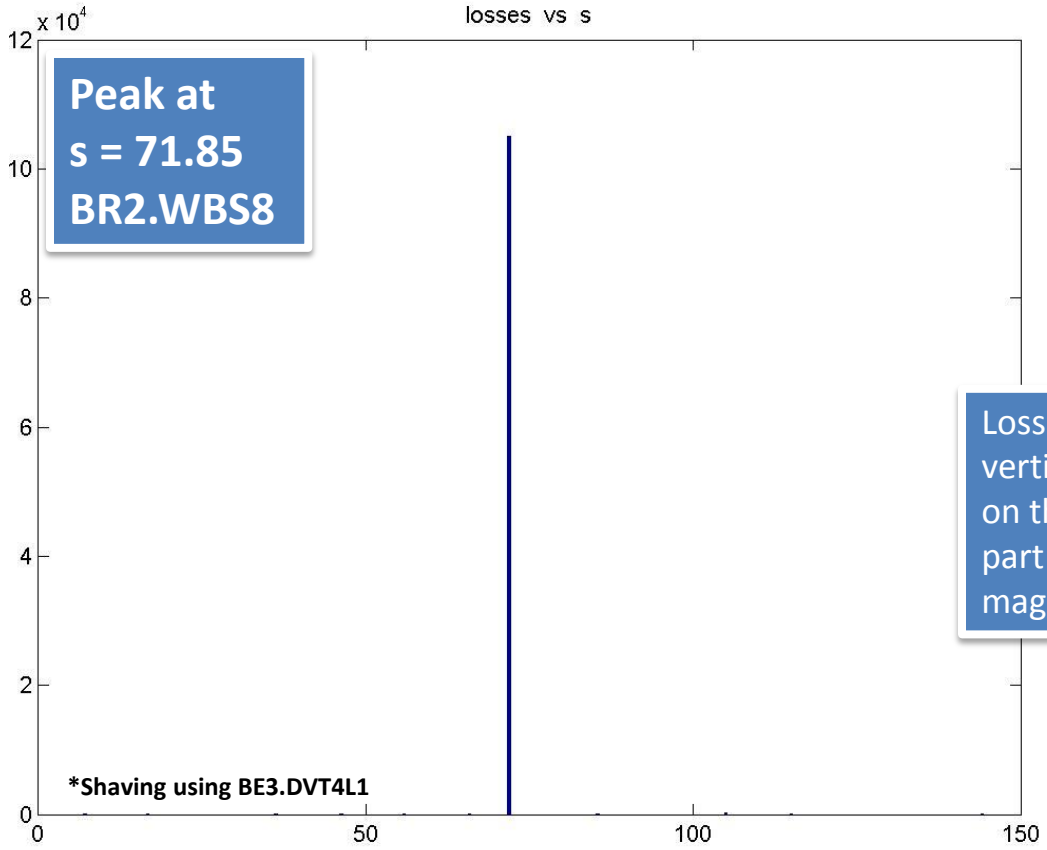


What is the maximum current for BE3.DVT4L1? Are we within the limits for 170 MeV shaving?

Losses vs s position



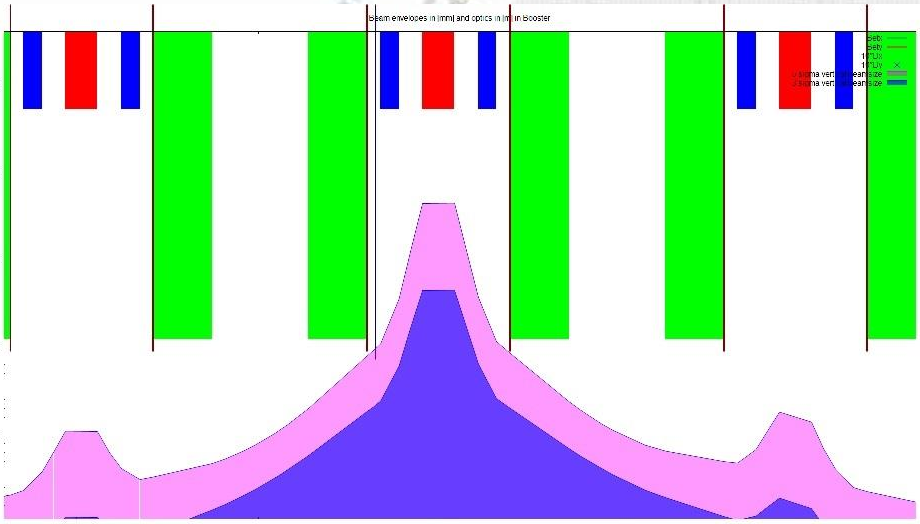
Aperture for proposed shaving

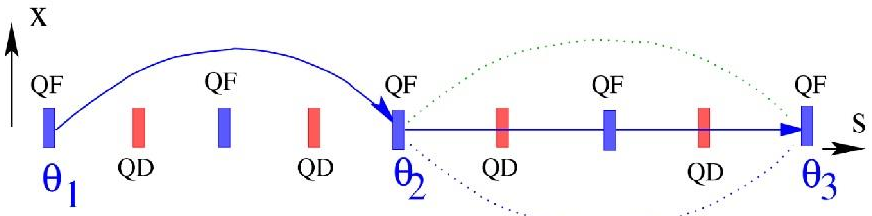


Losses only in vertical plane on the upper part of magnet yoke

Energy of shaving = 65 MeV

Third option: “closed bump”





2-bump: Only good for phase advance equal π between correctors

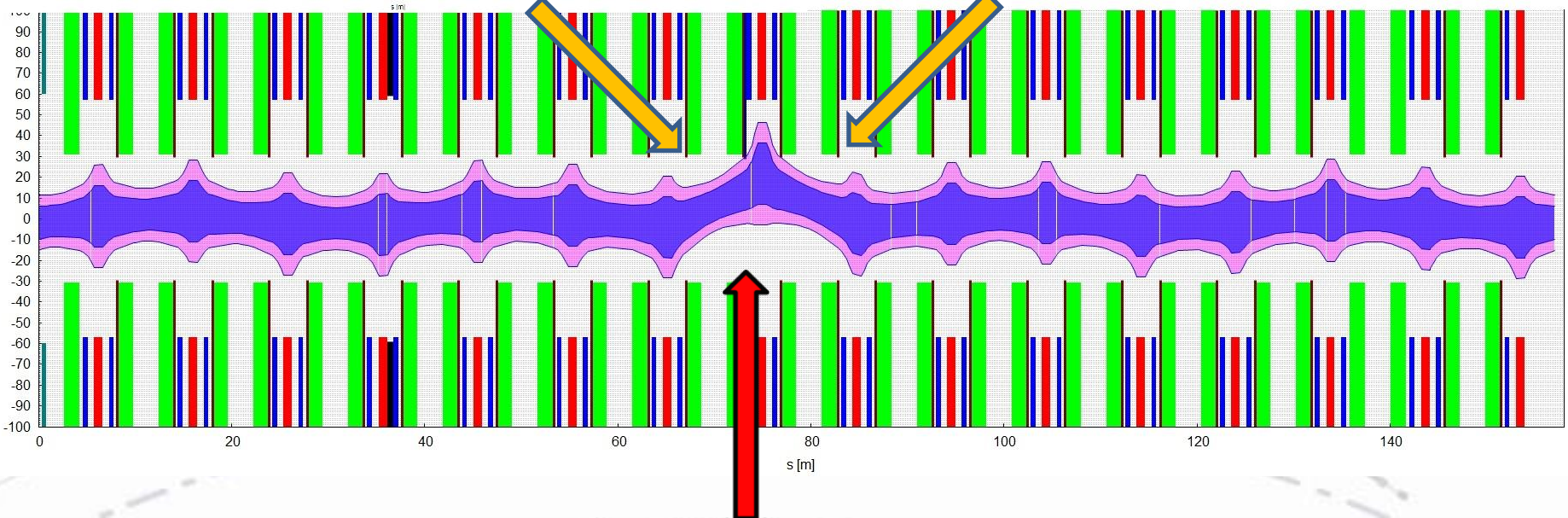
Sensitive to lattice and BPM errors

Large number of correctors

$$\theta_2 = \frac{\sqrt{\beta_1}}{\sqrt{\beta_2}}\theta_1$$

```
BR3.DBSV7L4 at s = 65.90 m, angle = 1.7 mrad
BR3.DBSV9L4 at s = 85.55 m, angle = 1.8 mrad
```

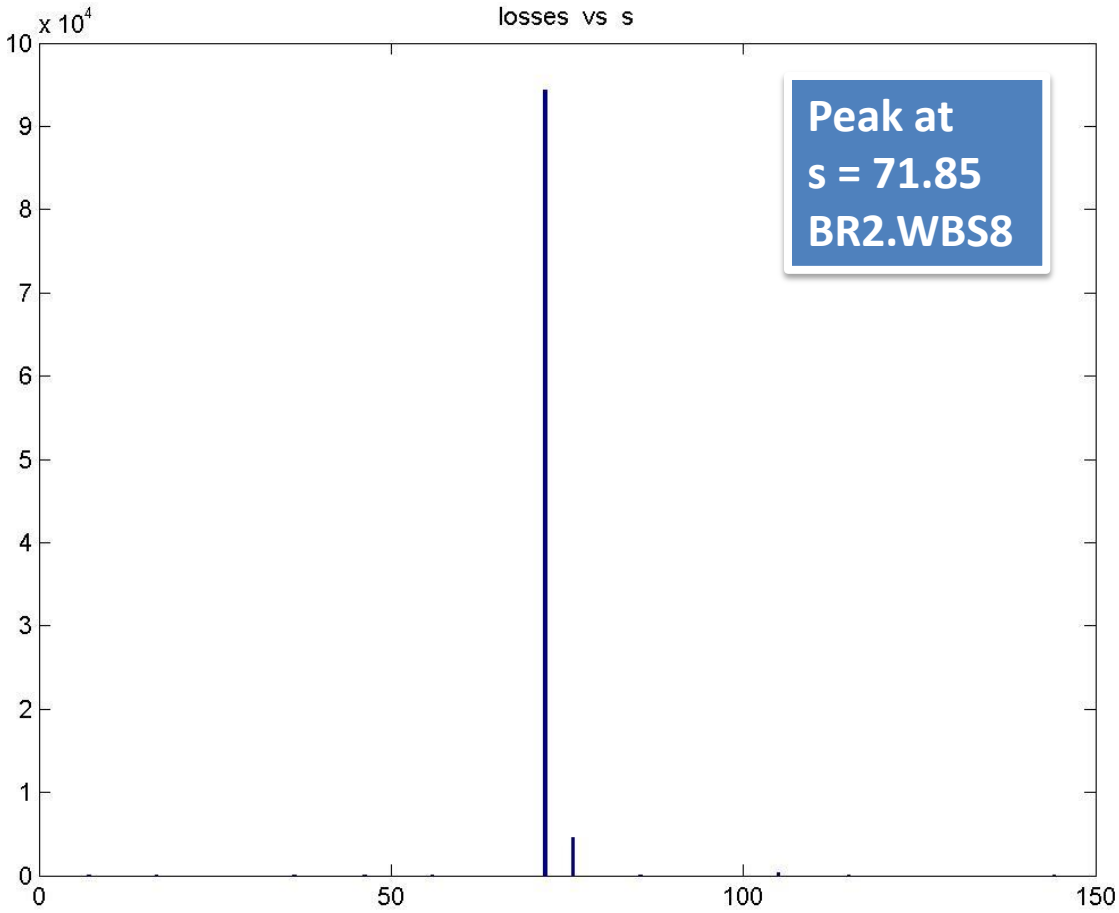
steerers for WBS measurements



Losses vs s position

Steerers for WBS measurements

Are they planned to be removed?



Summary

- All the kick strengths were “rough guess” – so they can be adjusted if needed

	H emittance [mm mrad]	V emittance [mm mrad]	Intensity
Default initial	2.5	2.5	1.70 e+12
Default final	< 2 (usually < 1.8)	< 2 (usually < 1.8)	0.85-1.25 e+12
Shaving in OP	**1.60**	**1.40**	**1.01 e+12**
Single kick	**2.03**	**1.83***	**1.34 e+12***
Closed bump	**2.03**	**1.78**	**1.36 e+12**

LHC 50ns A beam

** Smaller intensity (bigger losses), but bigger emittance blow up in comparison to the closed bump option*

Comments:

- For the moment, shaving is a source of the losses in PS Booster (to be quantified).
- This year we hope not to be blind and to be able to see where actually we lose when applying shaving:
  - Turn-by turn pickups
  - New BLMs (where we can expect to have them working?)
- Shaving can be very efficient if we change the shaving routine.
  - Applying a „single kick”, but change the shaver to either BE3.DVT11L1 or BE3.DVT4L1
  - A second proposal is to use the kickers dedicated to the Beam Scope measurements to produce a closed bump.
- We are checking now the robustness with respect to a random distribution of misalignments and errors.
- Also crosscheck if the required kickers can be used in operation (maybe they are some other issues (e.g. shielding)? **Your comments are welcome☺**).

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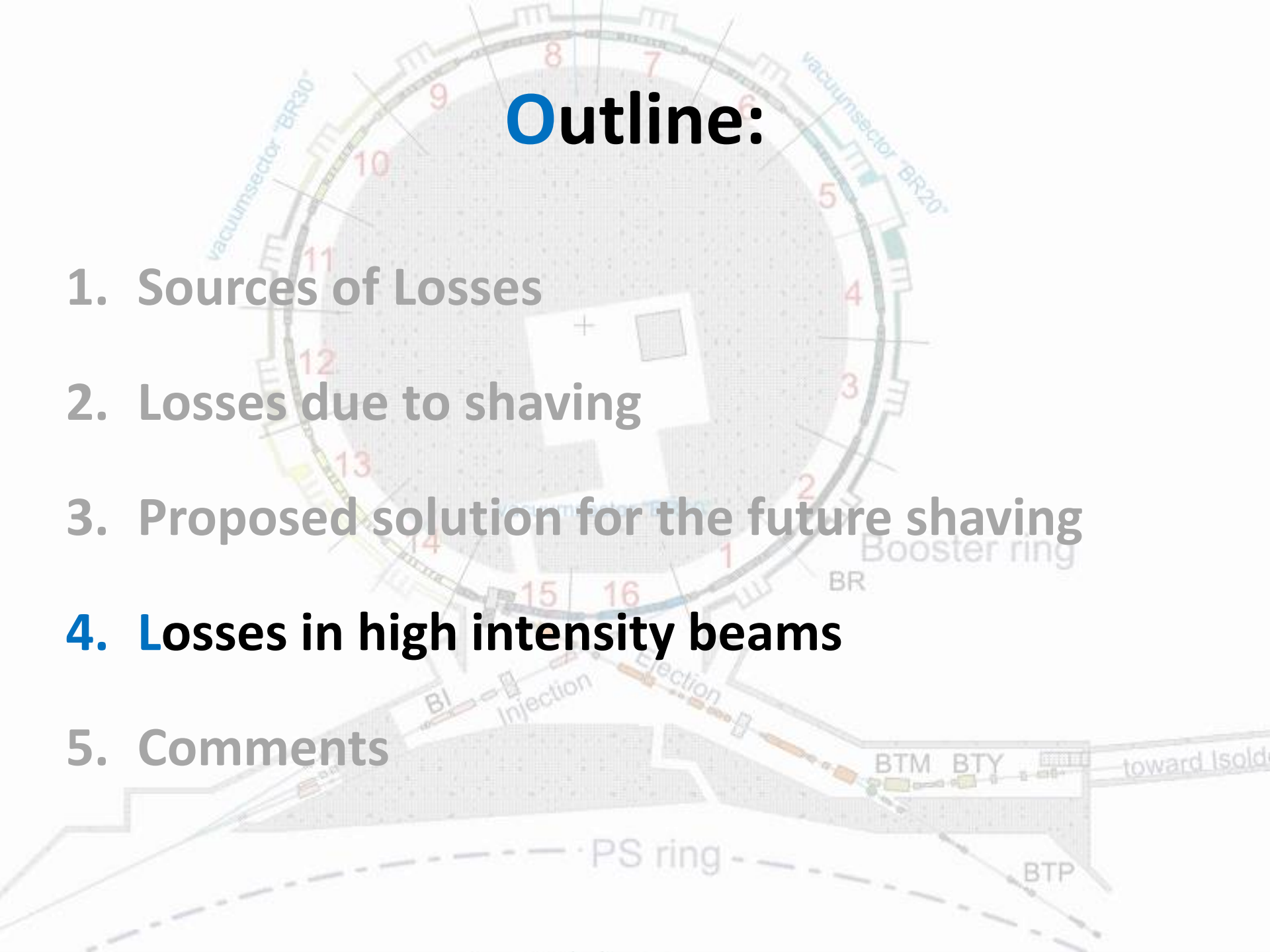
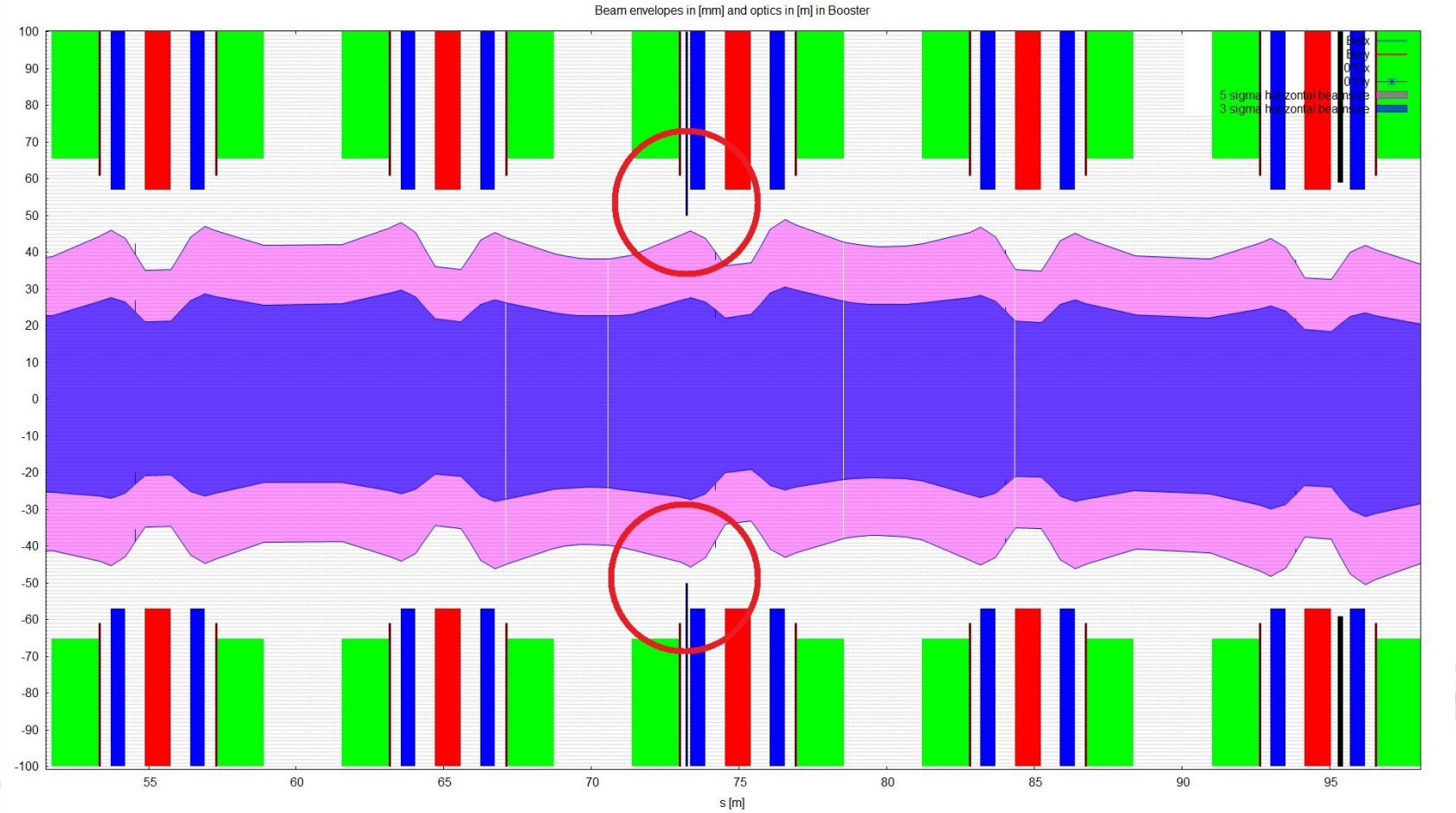


High Intensity and Emittance Beams

Horizontal aperture in present (50 MeV) case

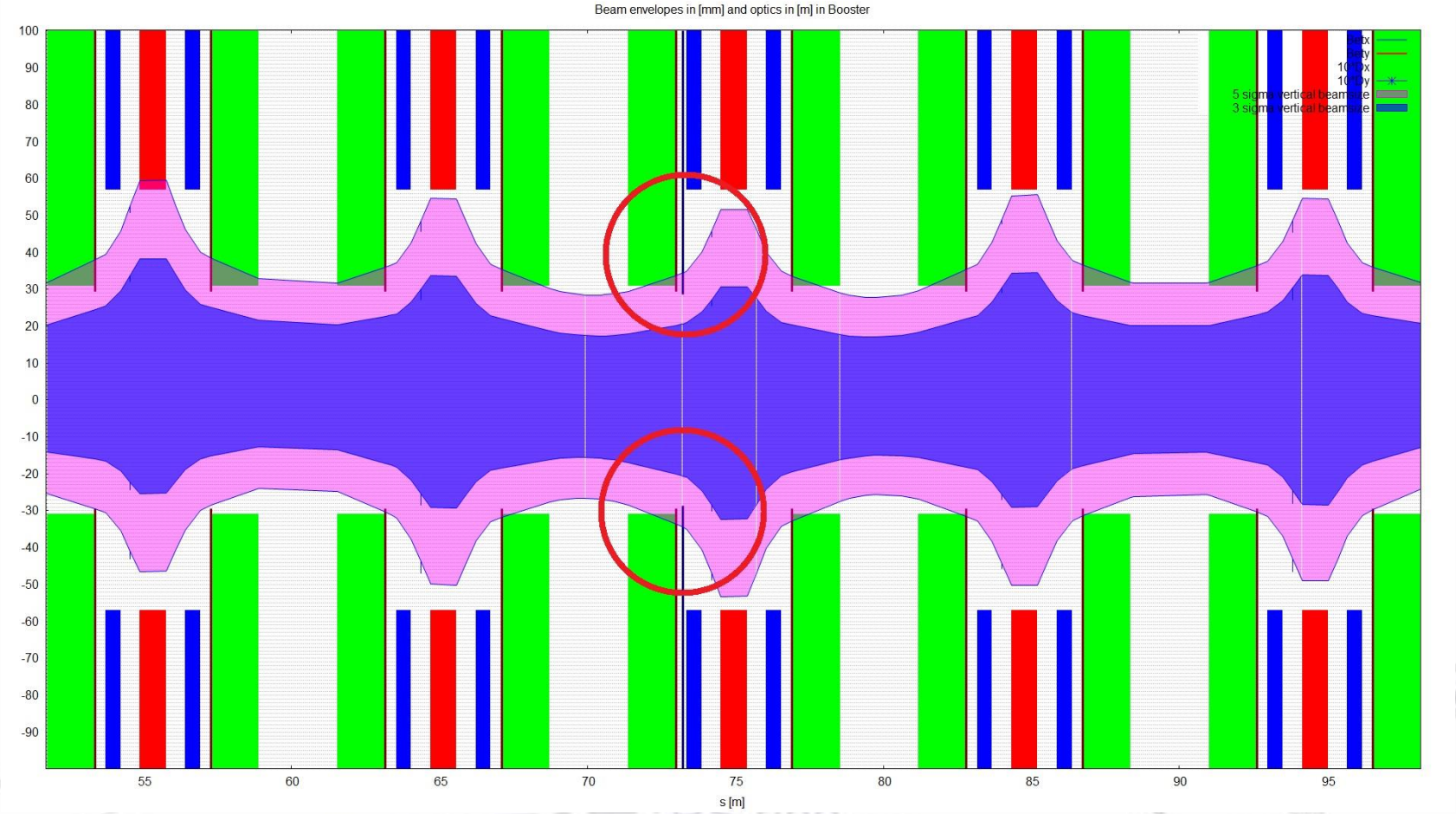


Horizontal 3 and 5 sigma beam passing through PS Booster lattice with misalignment and field errors *calculated by Meghan McAteer* (MAD-X).

Losses are not foreseen in horizontal plane. (5 sigma) beam size is much smaller then the aperture restriction

High Intensity and Emittance Beams

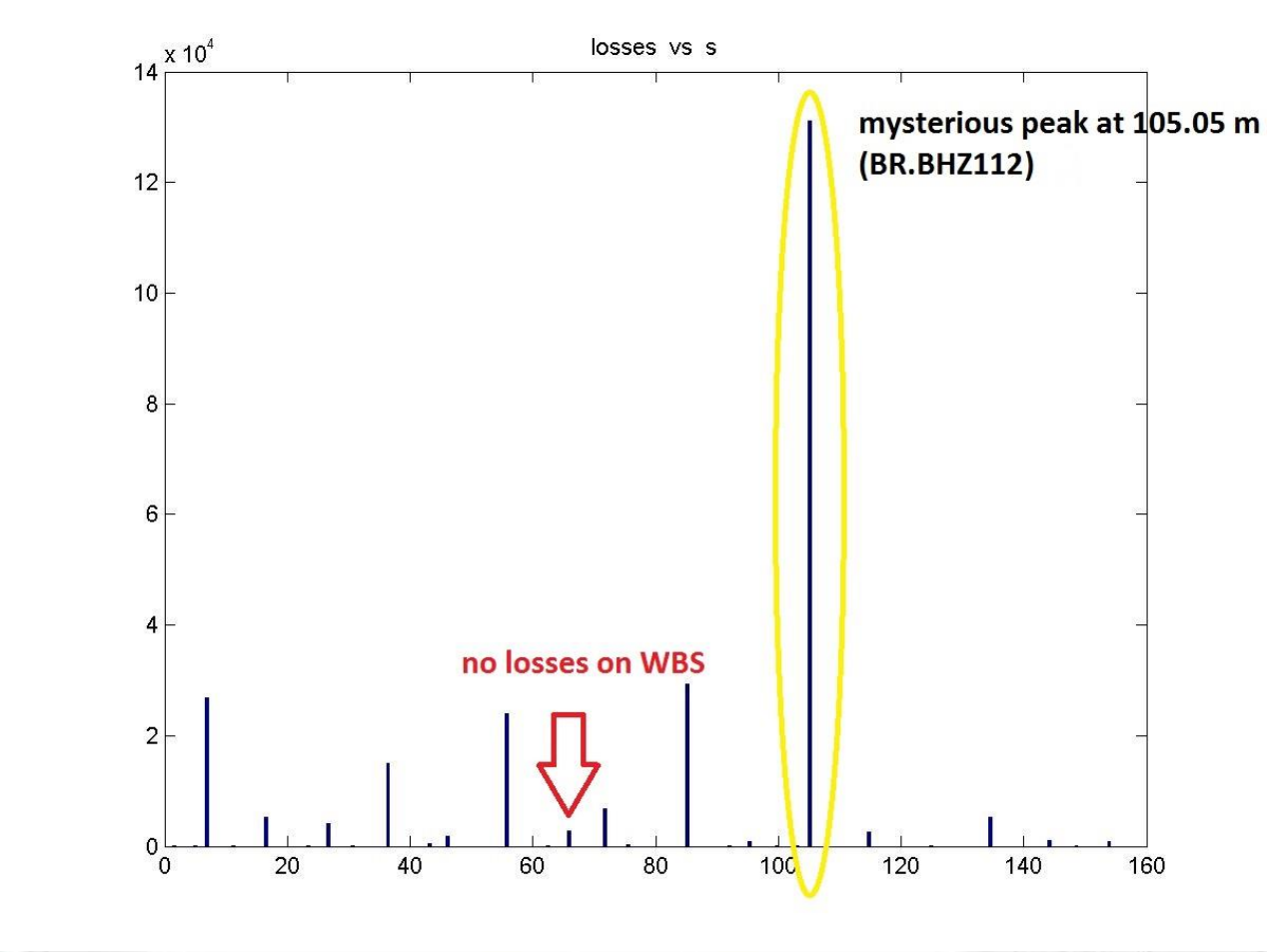
Vertical aperture in present (50 MeV) case



Horizontal 3 and 5 sigma beam passing through PS Booster lattice with misalignment and field errors *calculated by Meghan McAteer* (MAD-X).

Losses are expected at many locations only in vertical plane due to the similar size of the bend's scrapper and Window Beam Scope.

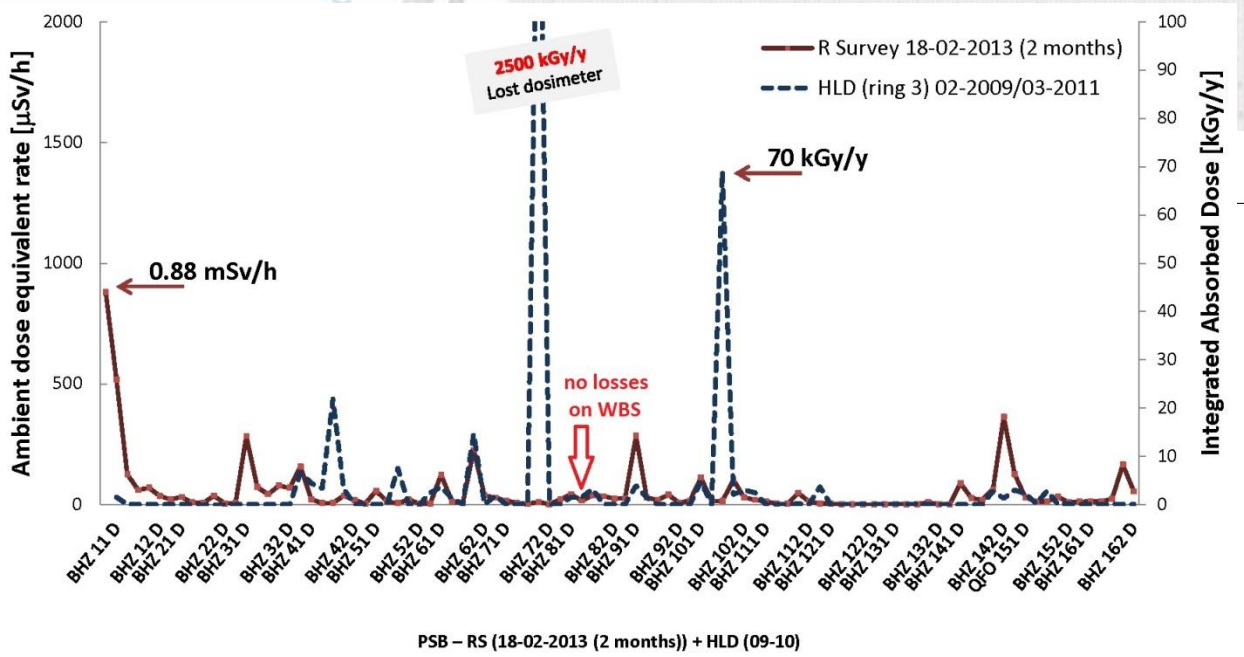
Expected losses pattern (ring 3)

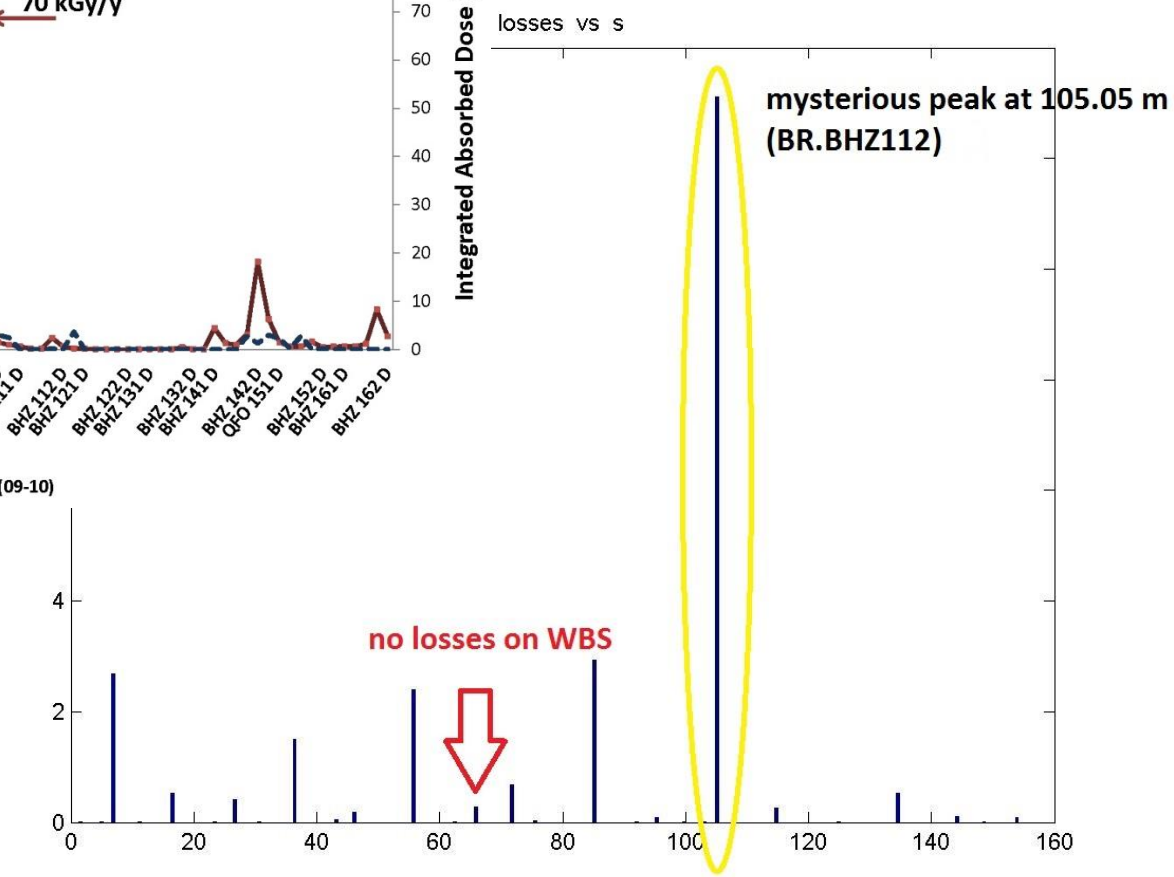


Studies made using PTC-ORBIT (*intensity = 1100 e10, number of macro particles = 500 000, transverse bin = 256x256, longitudinal bin = 128)* taking into account misalignment and field's errors, 10000 first turns at 50 MeV investigated assuming no acceleration.

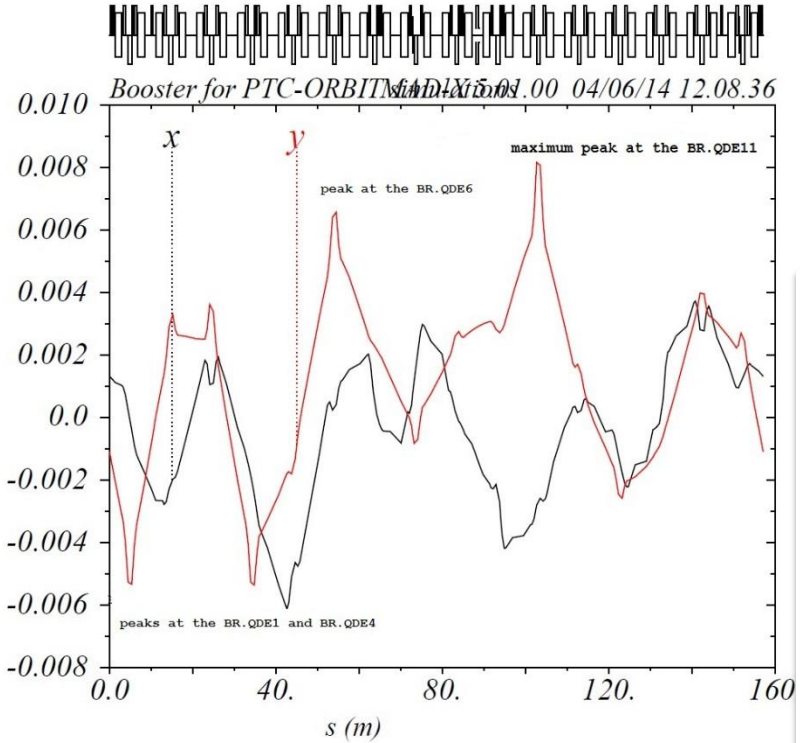
Super Gaussian transverse distribution (N=10) in use with normalized horizontal and vertical emiitances equal to *15 mm mrad and 10 mm mrad respectively.*

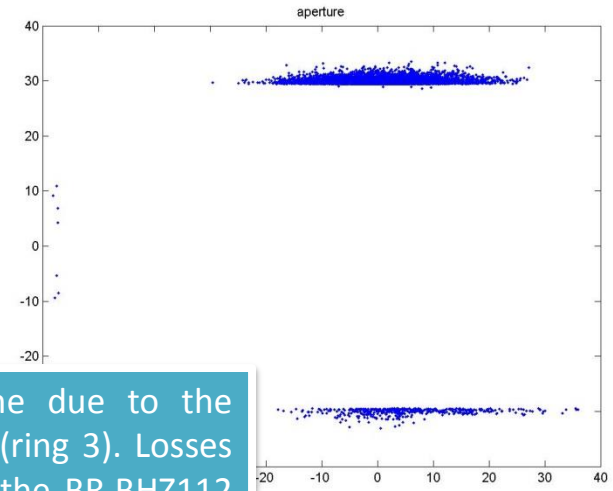
Expected losses pattern (ring 3)



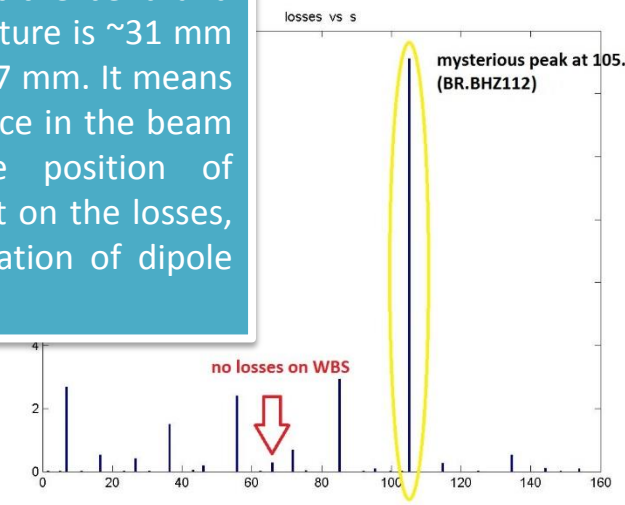


Explanation of losses at the s = 105 m





We lose in vertical plane due to the lattice errors distribution (ring 3). Losses occur at the entrance of the BR.BHZ112 where orbit deviation is ~ 4.5 mm in V plane . Even it is not the maximum, one need to take into account the bend and quad aperture. Bend aperture is ~31 mm while quad aperture is ~57 mm. It means that 8 mm of the difference in the beam centre position at the position of quadrupole has no impact on the losses, while 4.5 mm at the location of dipole makes it significant.



Of course, orbit deviation in horizontal plane is negligible since the aperture is much more big than in vertical plane

Comments:

- According to beam size calculations based on MADX PTC-TWISS output with existing aperture restriction (50 mm x 28.86 mm) ISOLDE 50 MeV p+ beam induces the losses in vertical plane. No losses are expected in horizontal plane.

- PTC-ORBIT simulations detected a “mysterious peak” around **s = 105 m**. No special aperture restriction is declared at this position.

-> losses locations depend on the misalignment and field errors of the Booster magnets

Hopefully this situation will be cured after the re-align campaign ☺

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To sum up…

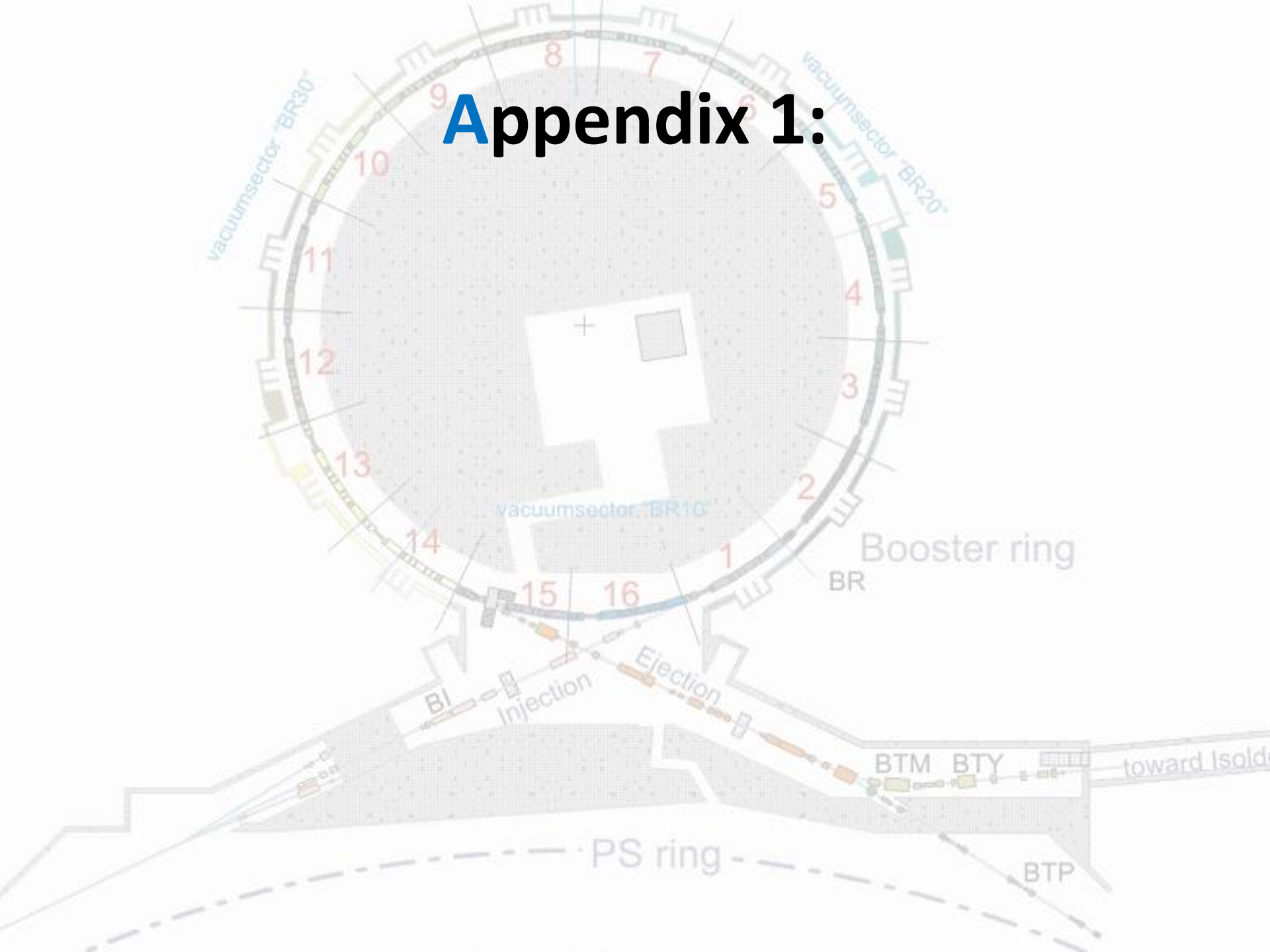
1. According to the MADX and PTC-ORBIT simulation and radiation survey, the beam is not shaved on the Window Beam Scope as it was designed. Peak obtained in the computer simulations corresponds to the existing measurements. Changes in shaving routine are needed not to lose the beam on other elements.

2. High intensity beams is another source of losses. Simulations were performed for ISOLDE beam and are planned to be done for the other high emittance beams. Quantitative analysis is needed.

3. In parallel there is a work on the situation at 160 Mev, both for:
   - the shaving: is it feasible?
   - modifying the beam scope window aperture restriction (dimension, thickness, material) to collimate beam at injection energy (in appendix)

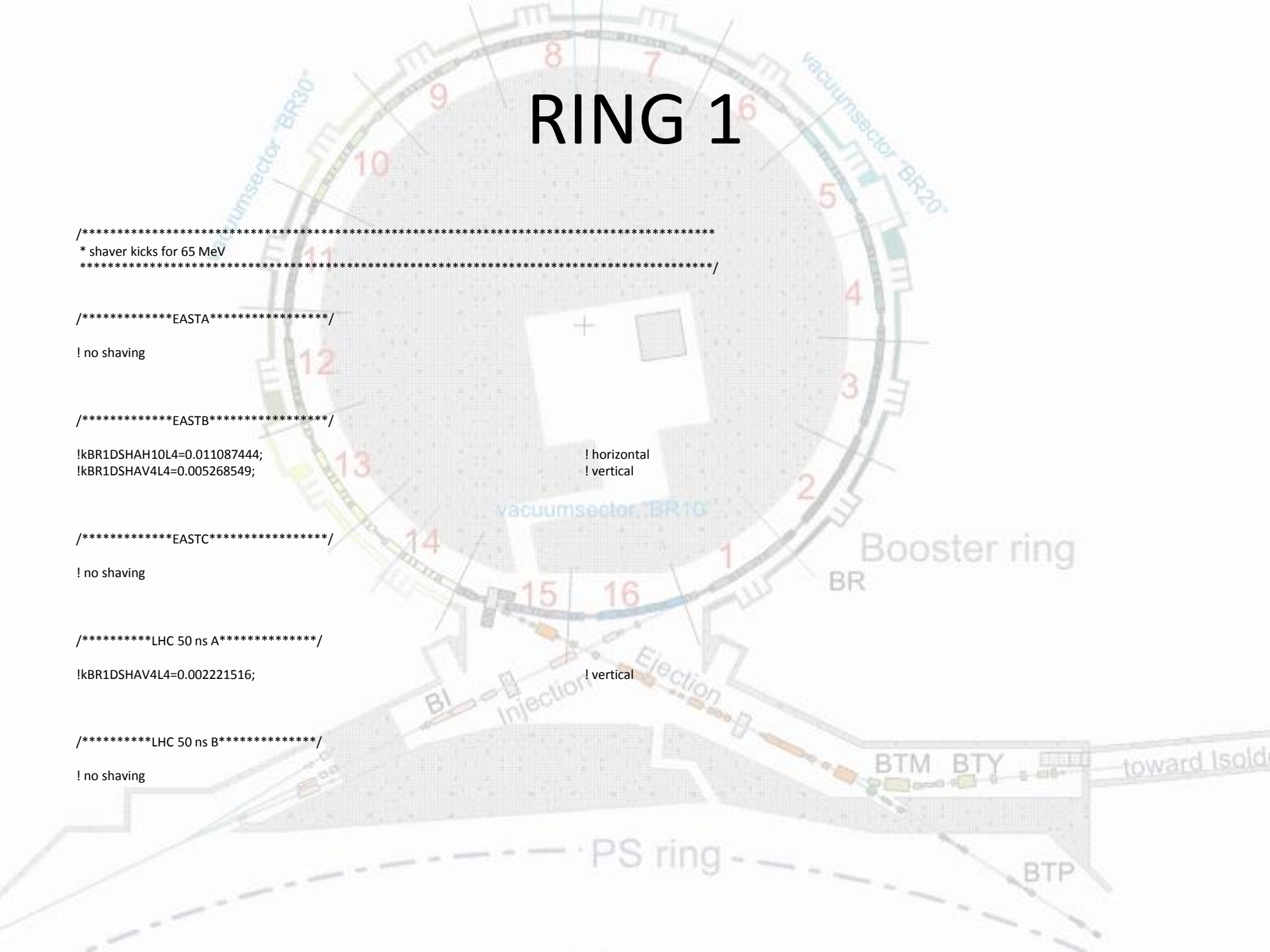
4. Your comments are very welcome☺ Thank you for your attention.

Appendix 1:

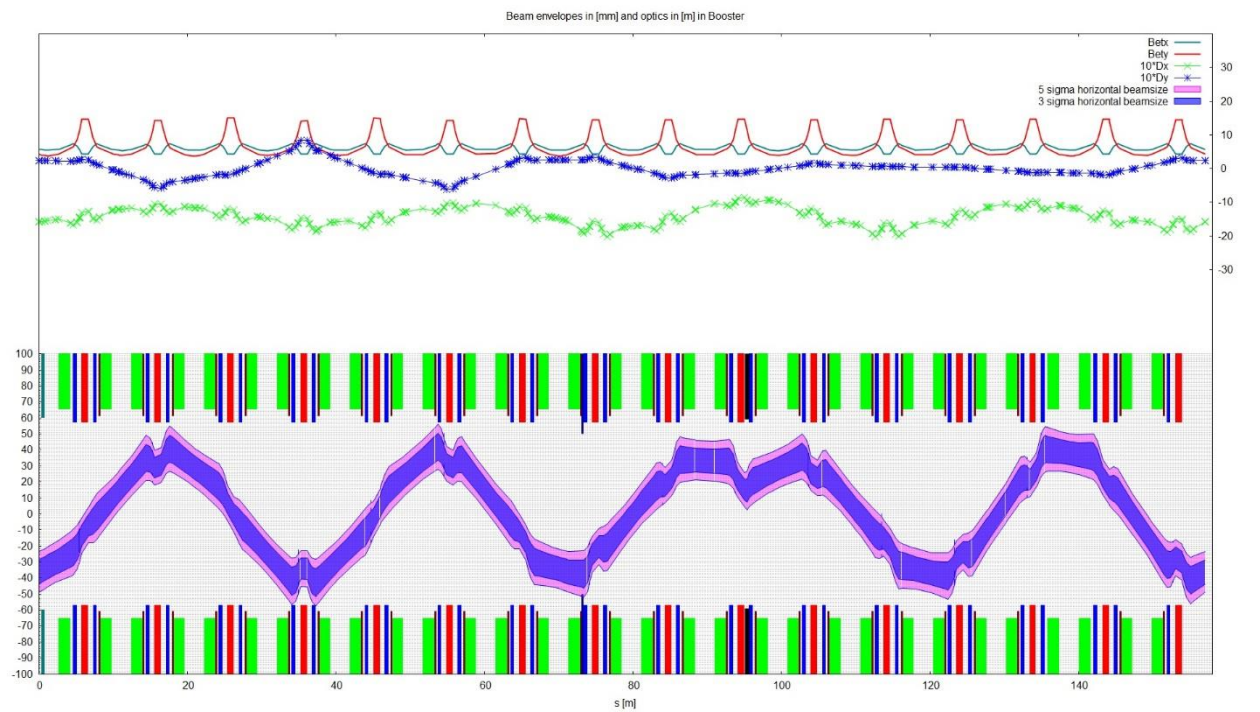

vacuumsector "BR30"
vacuumsector "BR20"
vacuumsector "BR10"
Booster ring
BR
BI
Injection
Ejection
BTM
BTY
toward Isold
PS ring
BTP

RING 1

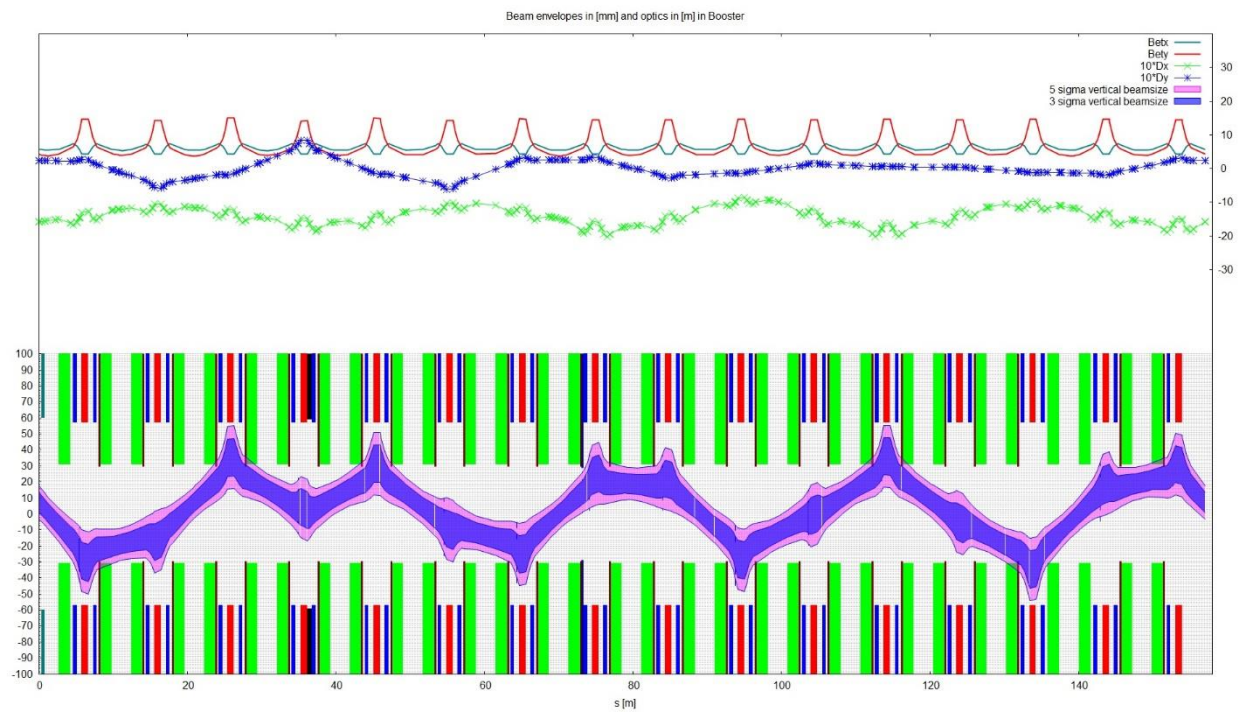
```
/*****************************************************************************************
 * shaver kicks for 65 MeV
 *****************************************************************************************/


/*************EASTA*****************/

! no shaving


/*************EASTB*****************/

!kBR1DSHAH10L4=0.011087444;                    ! horizontal
!kBR1DSHAV4L4=0.005268549;                     ! vertical


/*************EASTC*****************/

! no shaving


/**********LHC 50 ns A**************/

!kBR1DSHAV4L4=0.002221516;                     ! vertical


/**********LHC 50 ns B**************/

! no shaving
```



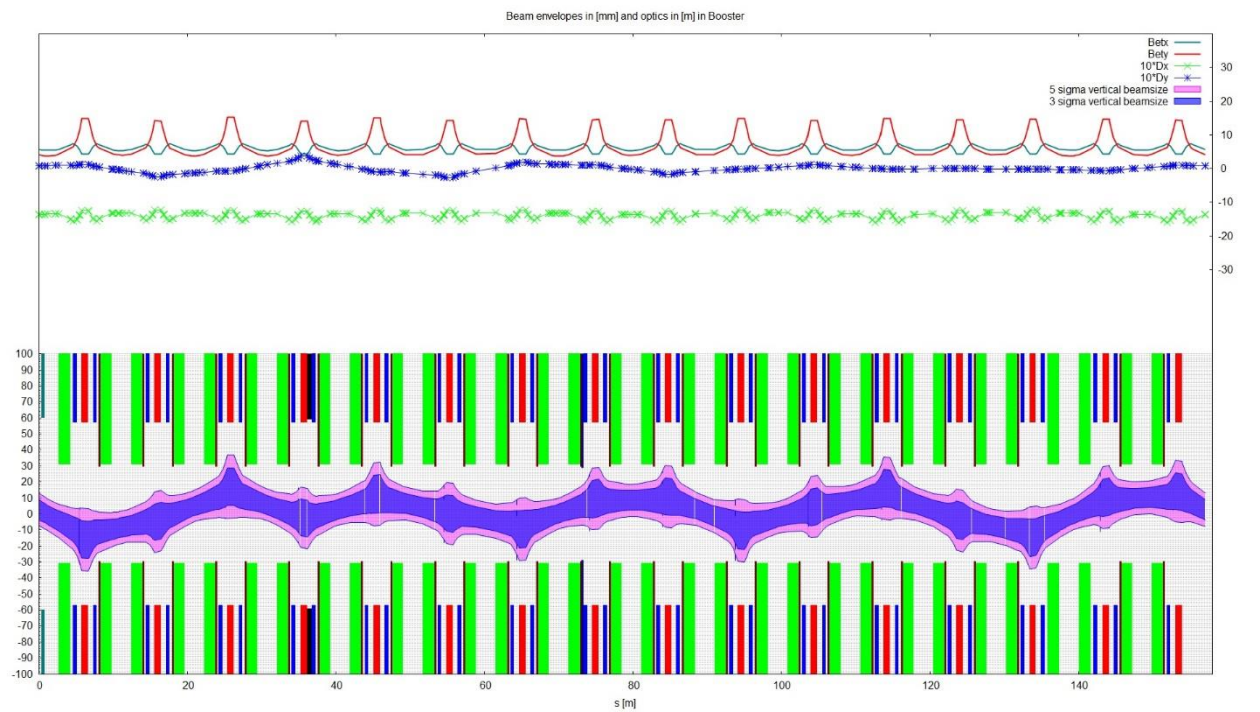
horizontal shaving for EAST B



vertical shaving for EAST B



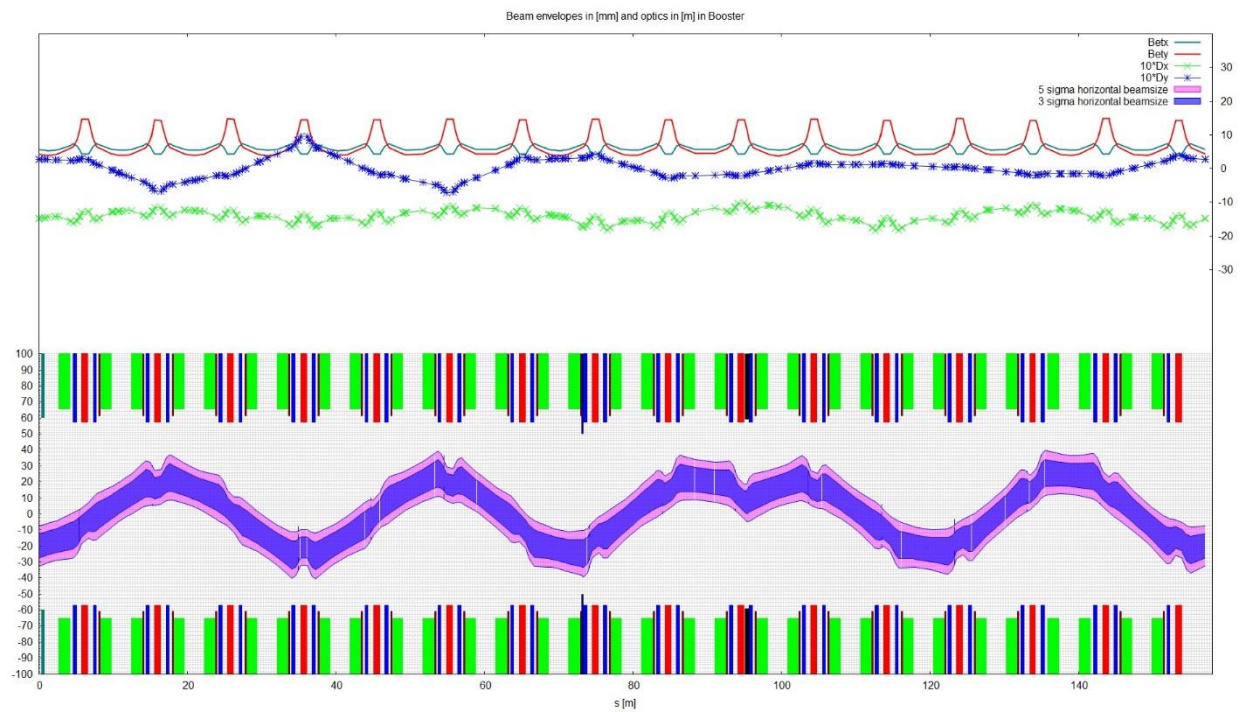
vertical shaving for LHC50ns A



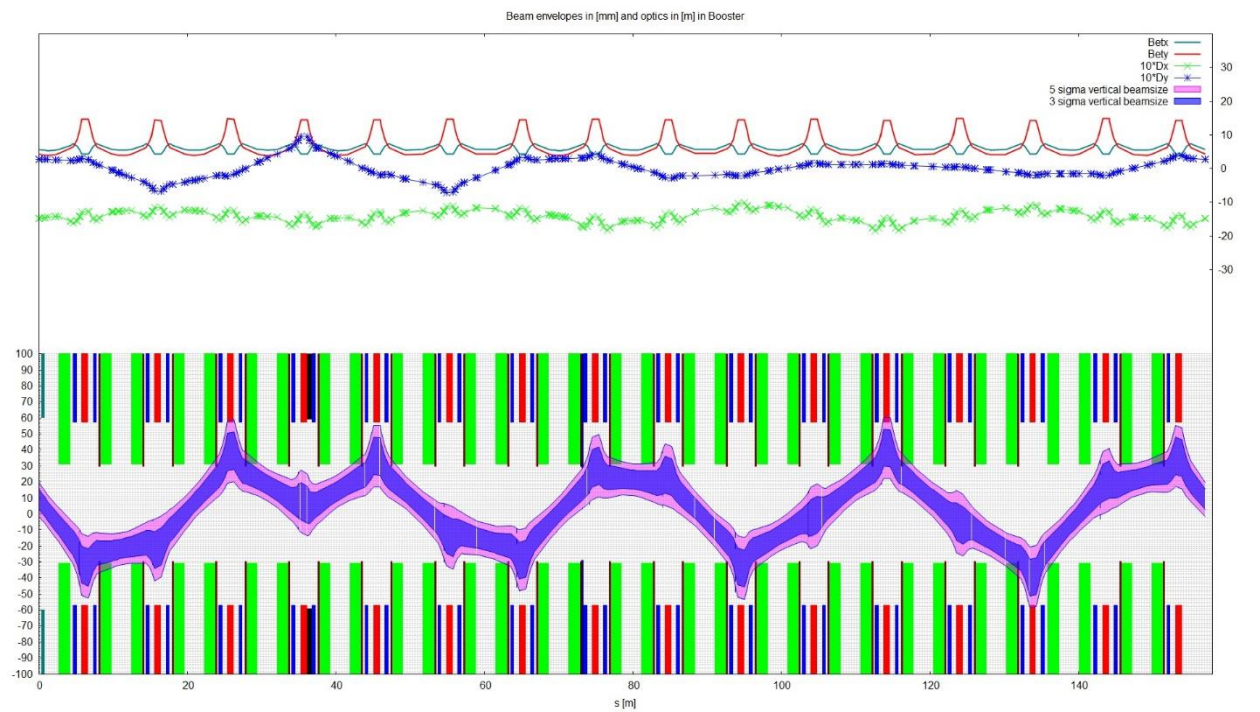
RING 2

```
/*****************************************************************************************
 * shaver kicks for 65 MeV
 *****************************************************************************************/


/*************EASTA*****************/

! no shaving


/*************EASTB*****************/

!kBR2DSHAH10L4=0.007094085;                    ! horizontal
!kBR2DSHAV4L4=0.006047086;                     ! vertical


/*************EASTC*****************/

! no shaving


/**********LHC 50 ns A**************/

!kBR2DSHAV4L4=0.003349052;                     ! vertical


/**********LHC 50 ns B**************/

! no shaving
```

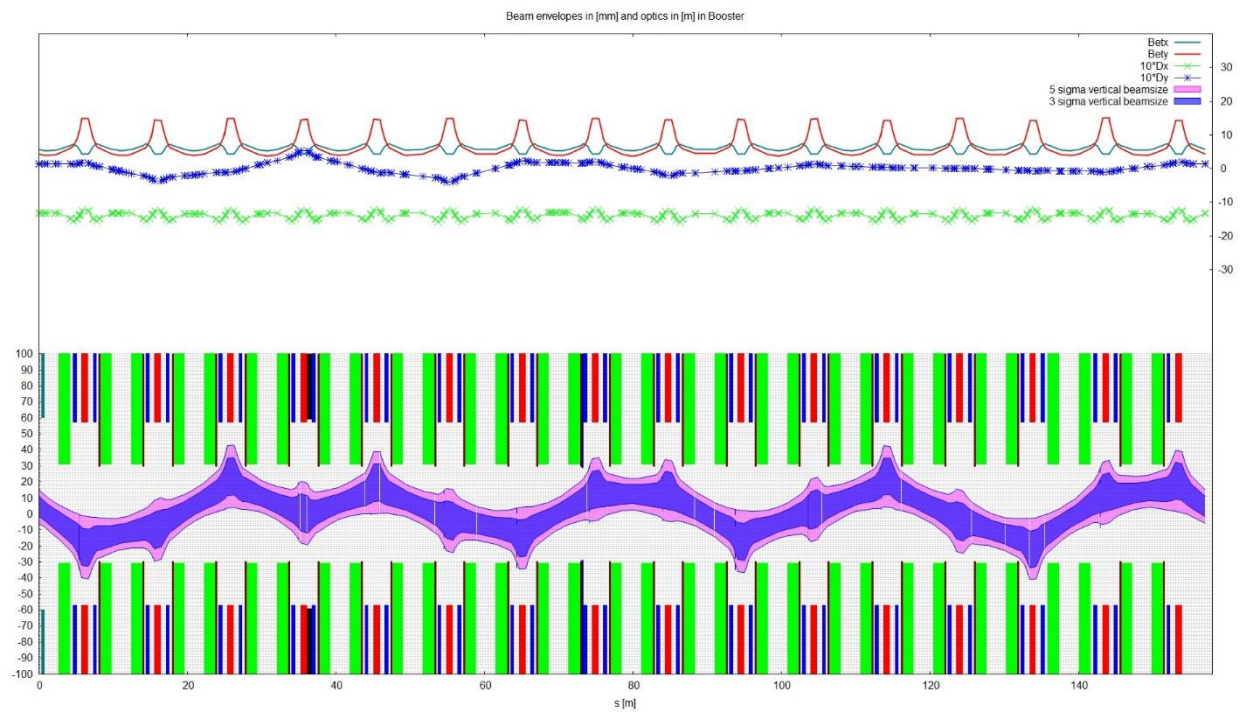
horizontal shaving for EAST B



vertical shaving for EAST B



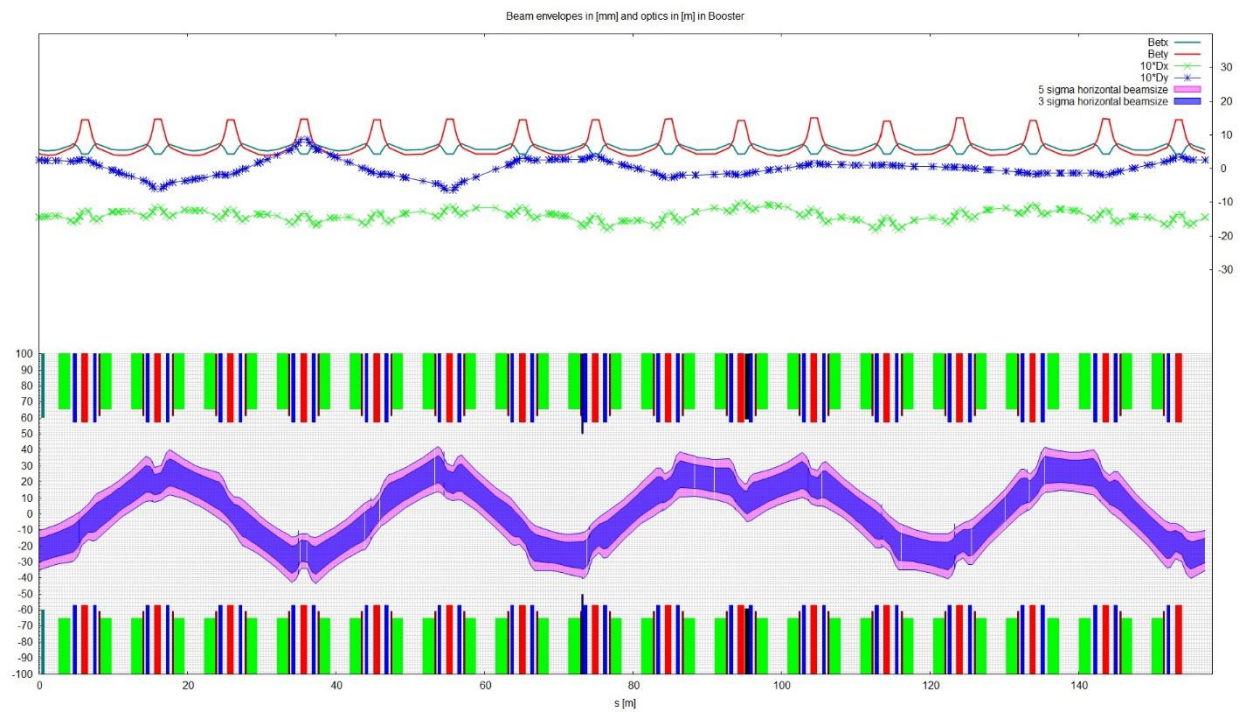
vertical shaving for LHC50ns A



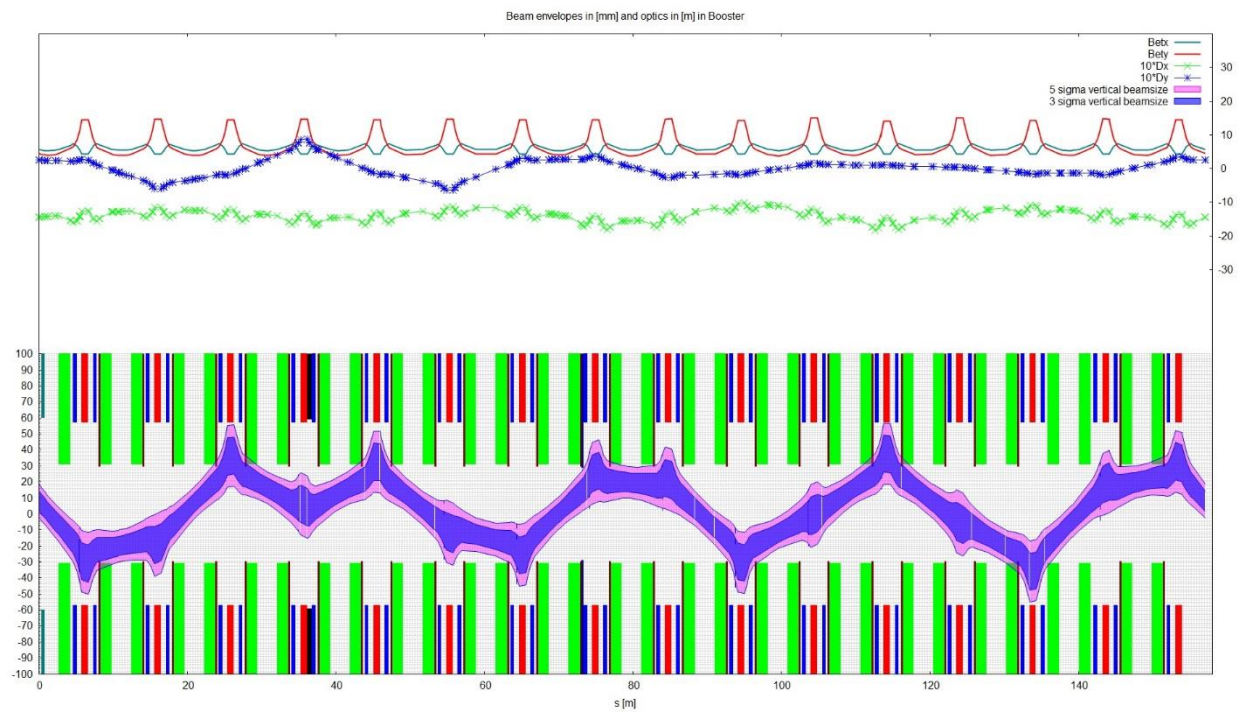
RING 3

```
/*****************************************************************************************
 * shaver kicks for 65 MeV
 *****************************************************************************************/


/*************EASTA*****************/

!kBR3DSHAH10L4=0.007939737;                                    ! horizontal
!kBR3DSHAV4L4=0.005483318;                                     ! vertical


/*************EASTB*****************/

!kBR3DSHAH10L4=0.006094067;                                    ! horizontal
!kBR3DSHAV4L4=0.006114202;                                     ! vertical


/*************EASTC*****************/

!kBR3DSHAH10L4=0.007711545;                                    ! horizontal
!kBR3DSHAV4L4=0.005194722;                                     ! vertical


/**********LHC 50 ns A**************/

!kBR3DSHAV4L4=0.003476571;                                     ! vertical


/**********LHC 50 ns B**************/

!kBR3DSHAV4L4=0.003503417;                                     ! vertical
```

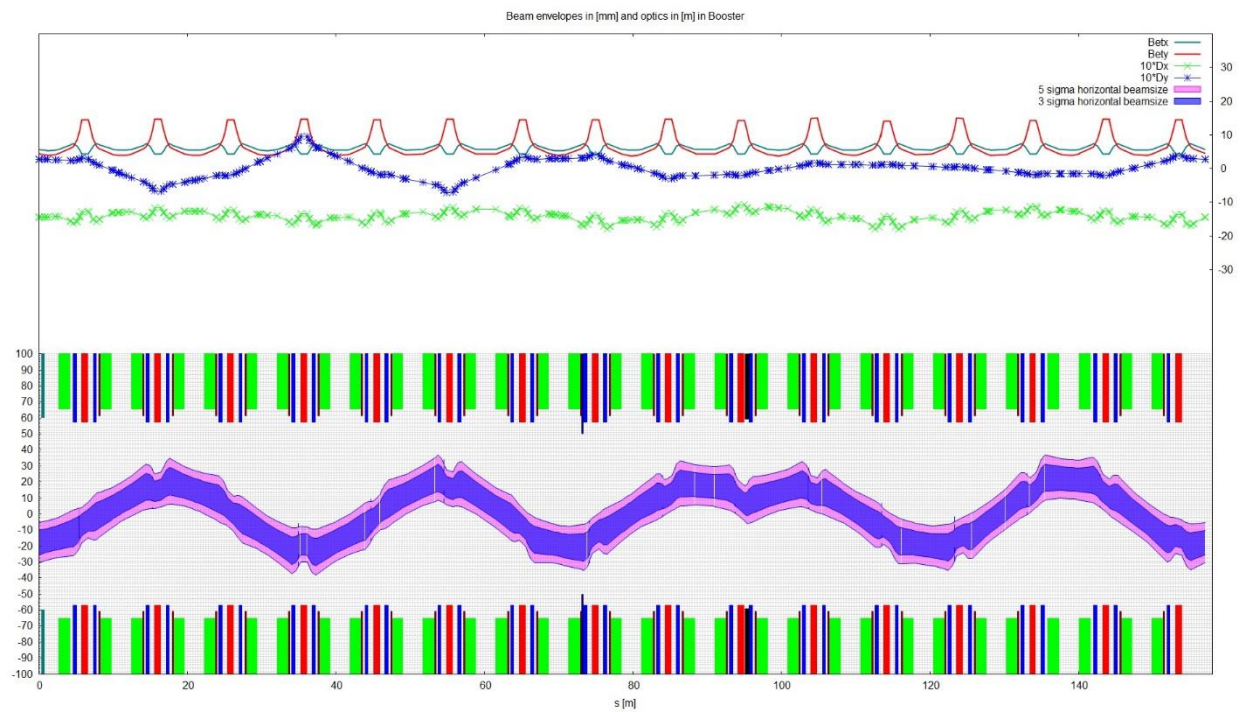
horizontal shaving for EAST A



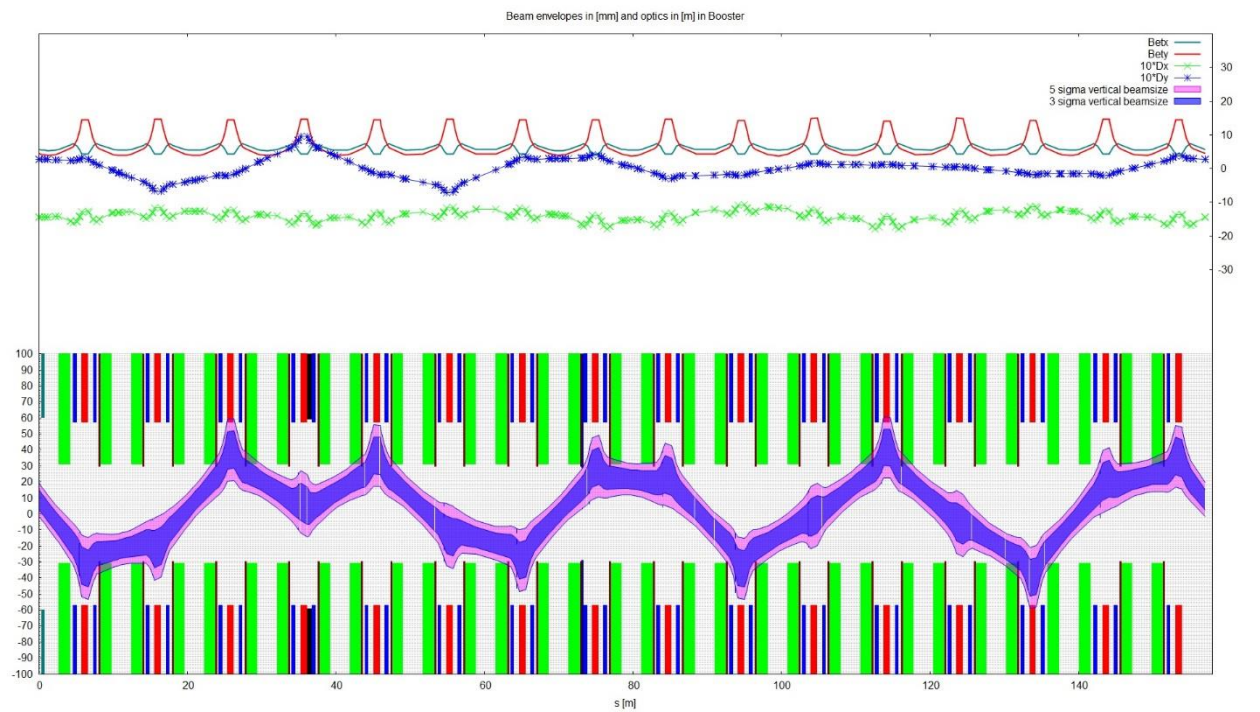
vertical shaving for EAST A



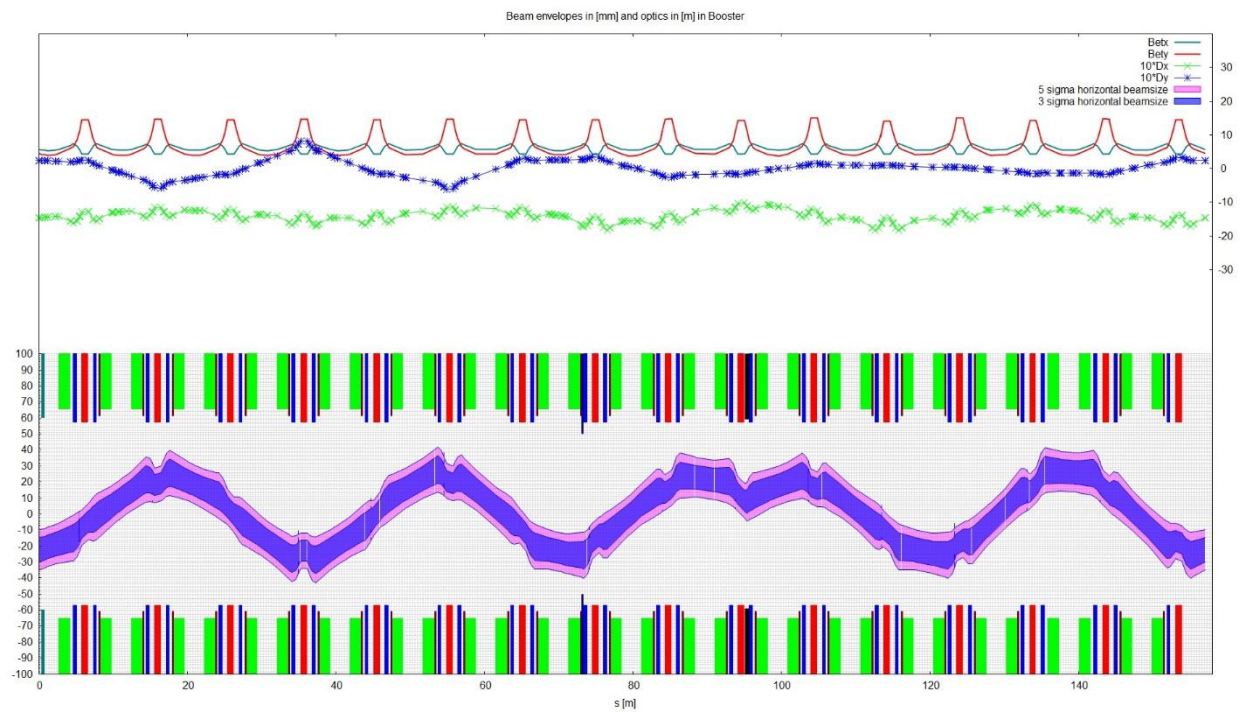
horizontal shaving for EAST B



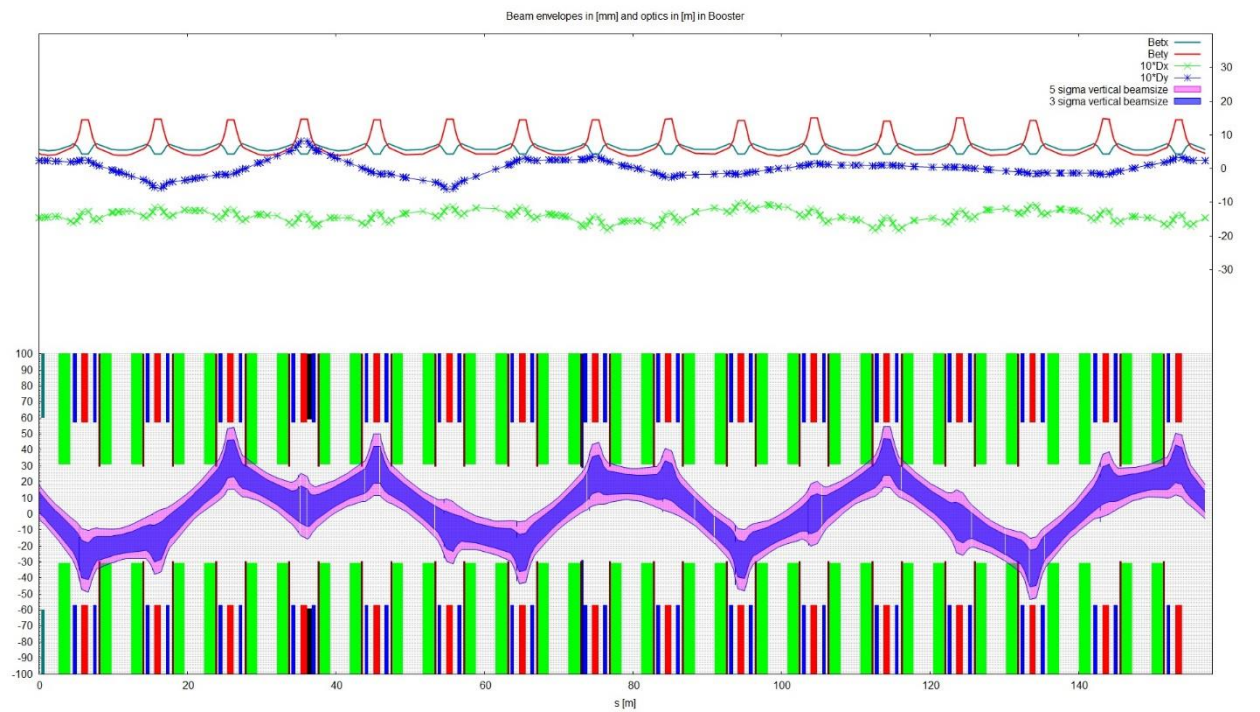
vertical shaving for EAST B



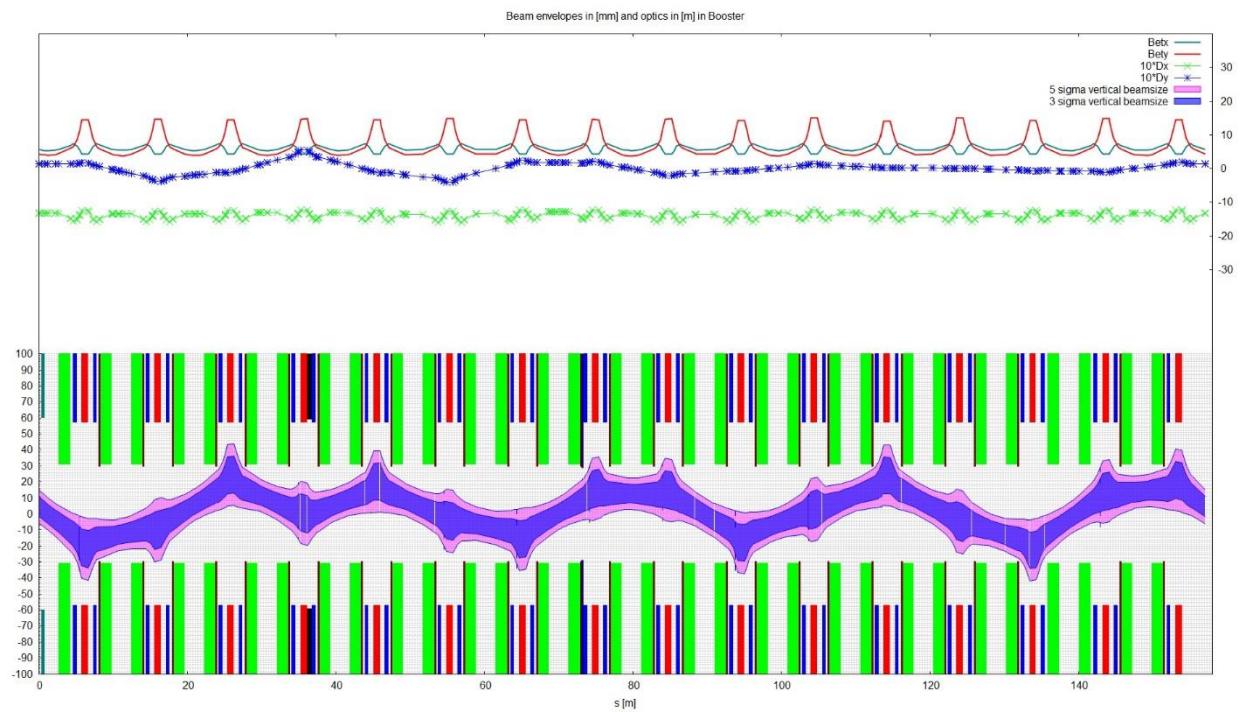
horizontal shaving for EAST C



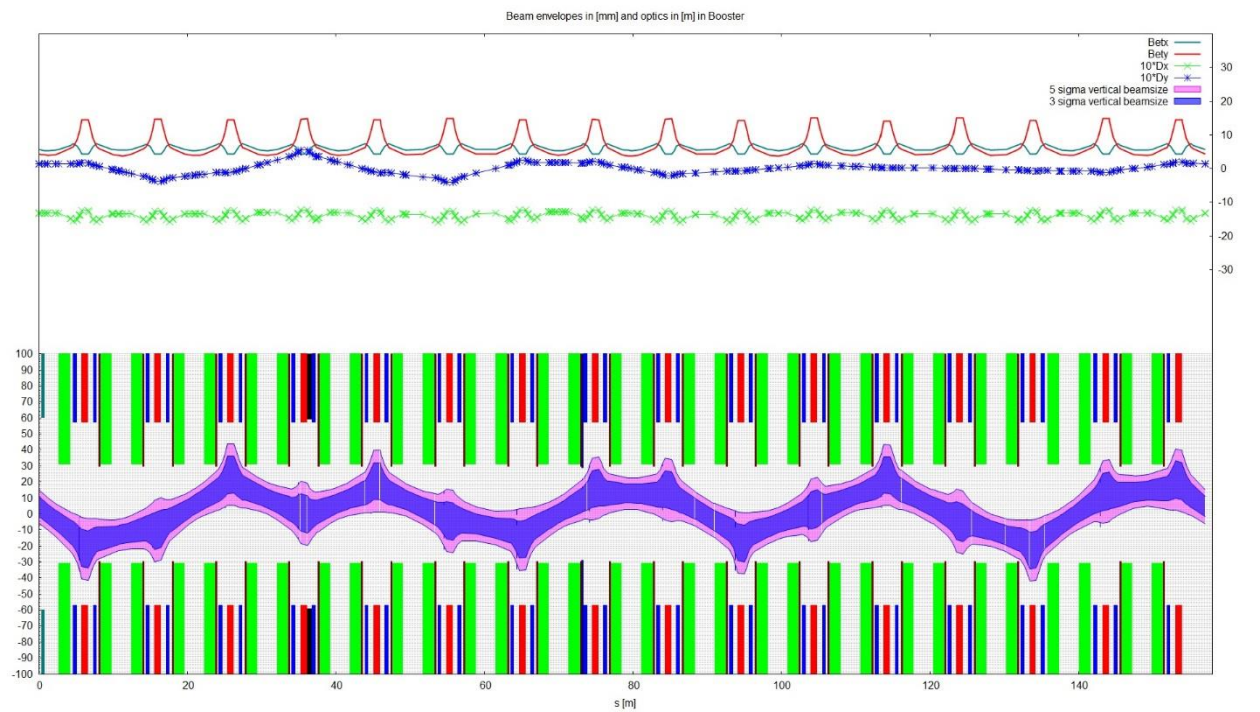
vertical shaving for EAST C



vertical shaving for LHC50ns A



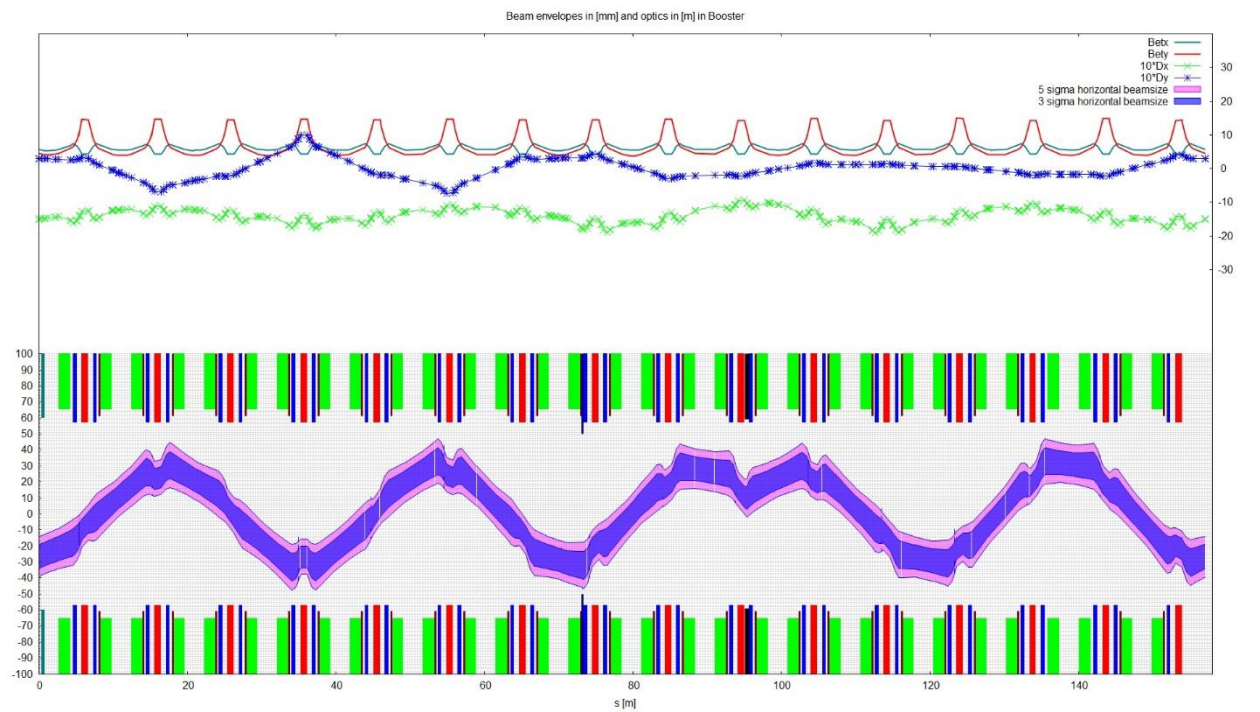
vertical shaving for LHC50ns B



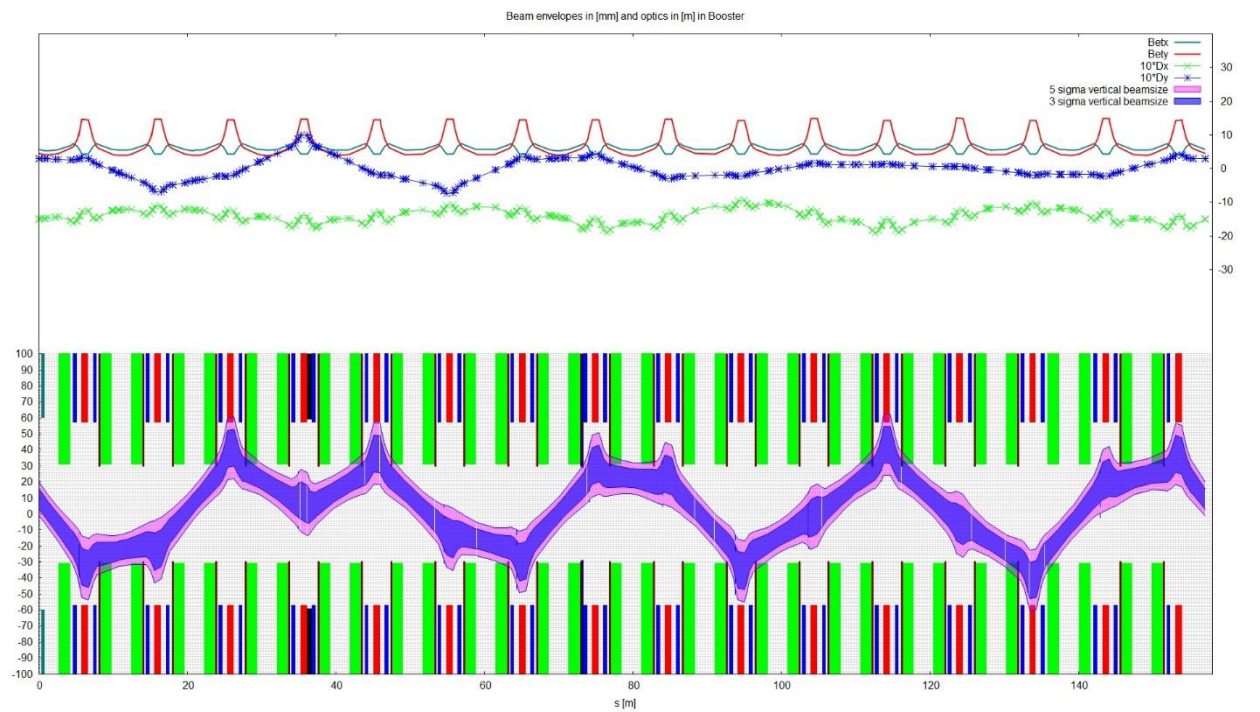
RING 4

```
/*********************************************************************************************
 * shaver kicks for 65 MeV
 *********************************************************************************************/


/*************EASTA*****************/

! no shaving


/*************EASTB*****************/

!kBR4DSHAH10L4=0.009342446;                    ! horizontal
!kBR4DSHAV4L4=0.006322259;                     ! vertical


/*************EASTC*****************/

! no shaving


/**********LHC 50 ns A**************/

!kBR4DSHAV4L4=0.003570533;                     ! vertical


/**********LHC 50 ns B**************/

!kBR4DSHAV4L4=0.003906109;                     ! vertical
```

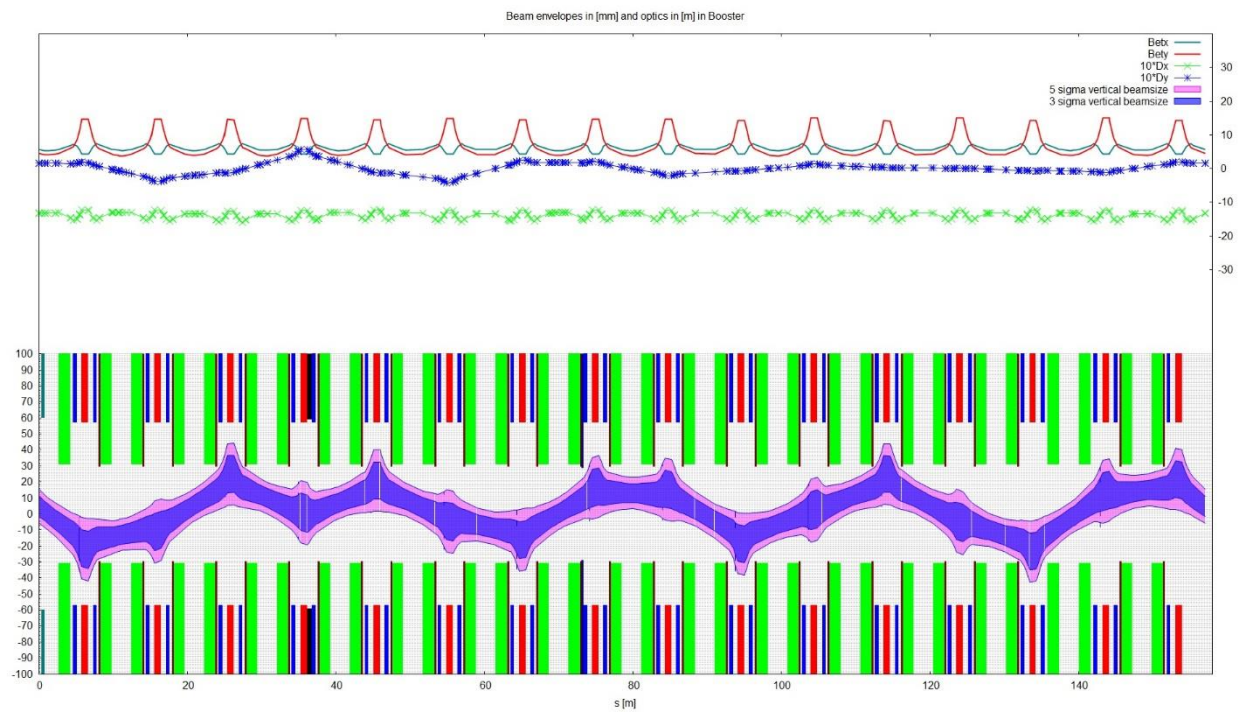
horizontal shaving for EAST B



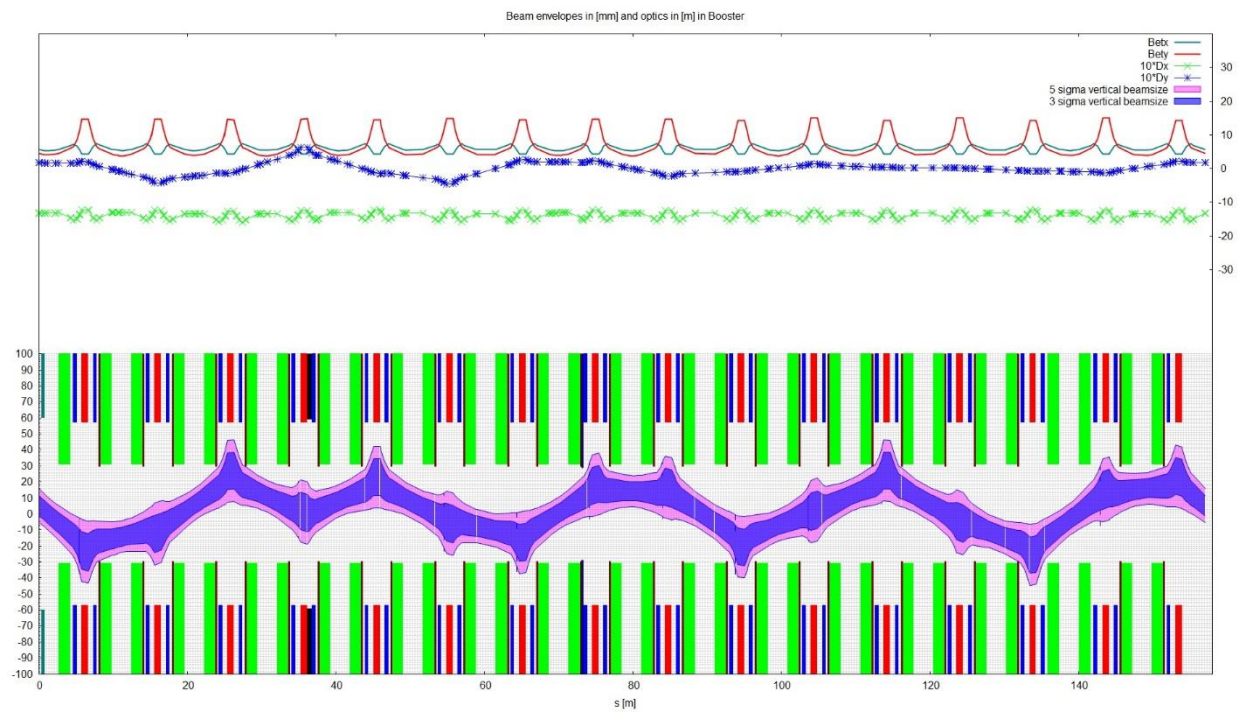
vertical shaving for EAST B



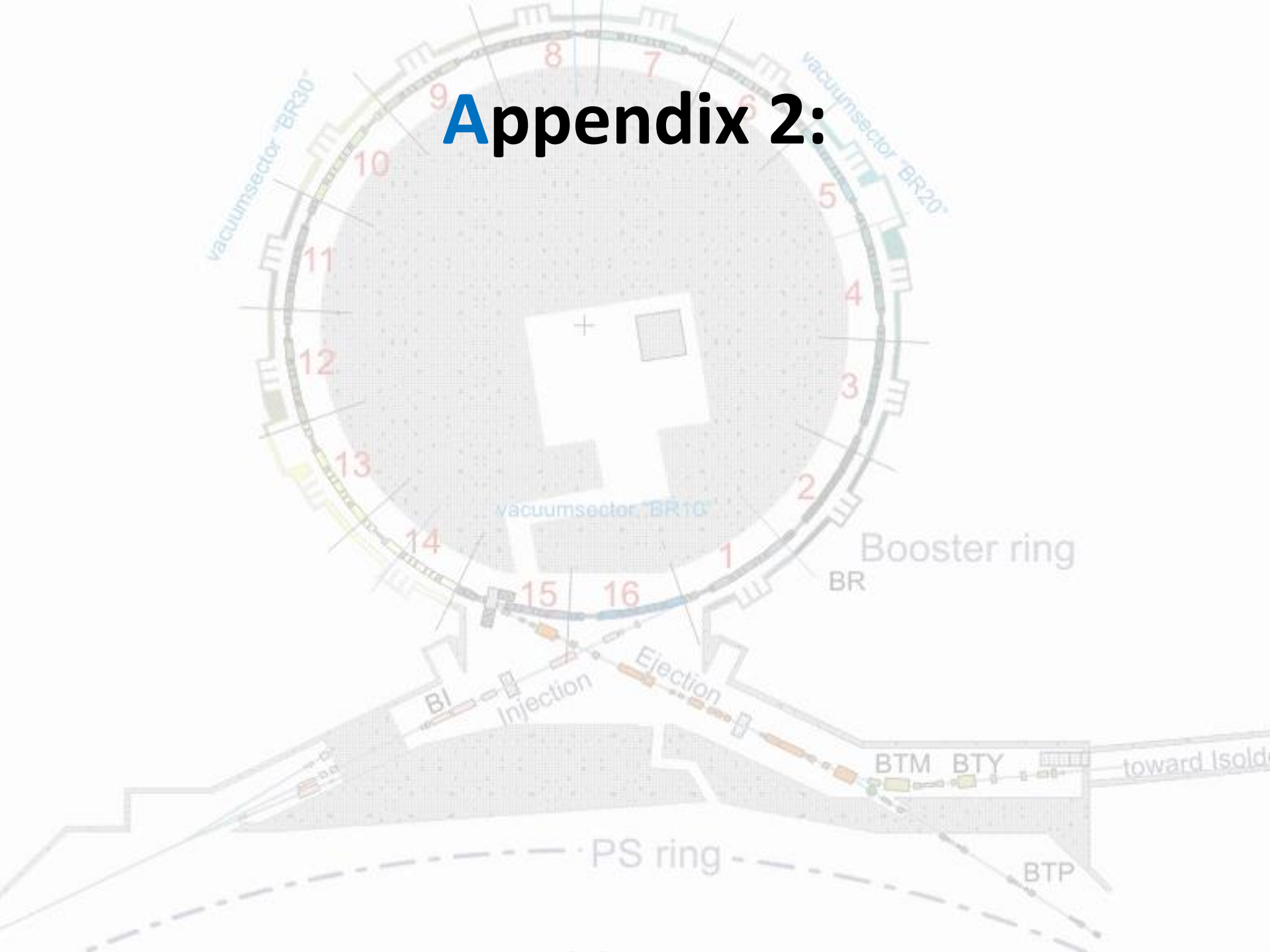
vertical shaving for LHC50ns A



vertical shaving for LHC50ns B

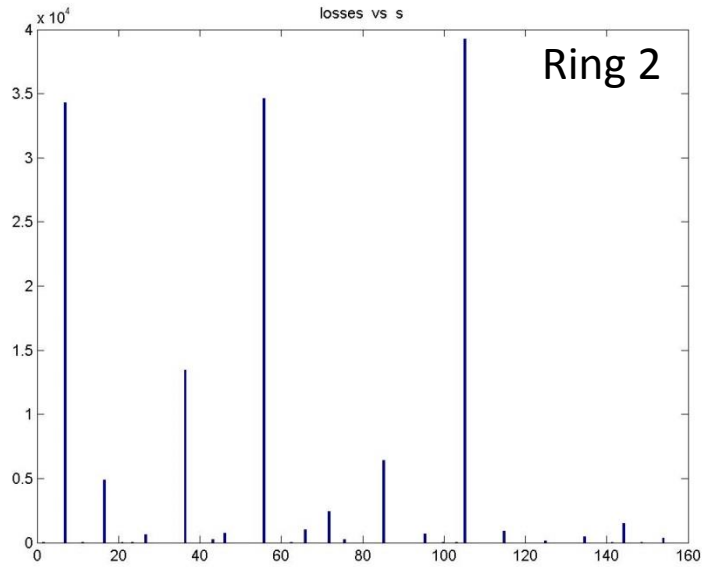


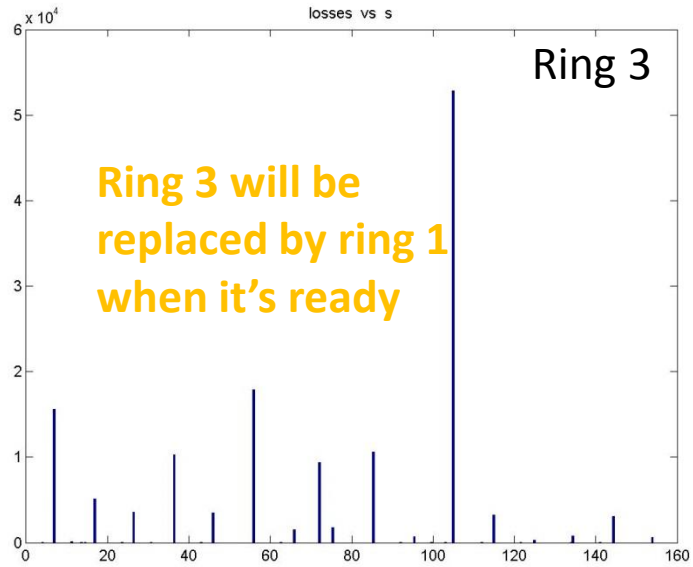
Appendix 2:


vacuumsector "BR30"
vacuumsector "BR20"
vacuumsector "BR10"
Booster ring
BR
BI
Injection
Ejection
BTM
BTY
toward Isold
PS ring
BTP

Expected losses pattern for Isolde

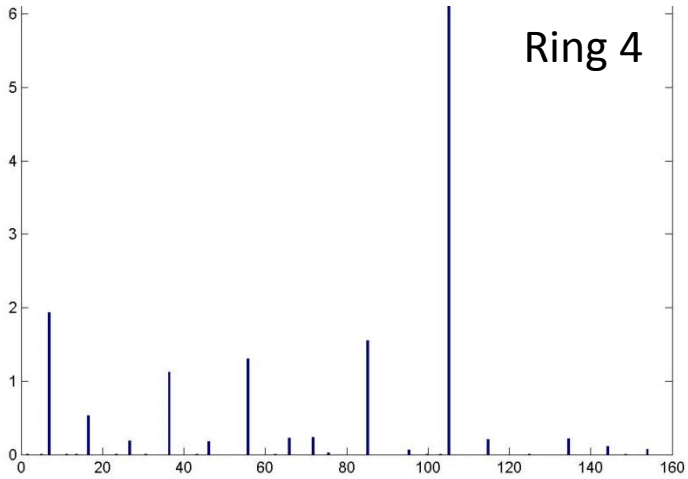
depends on the error distribution





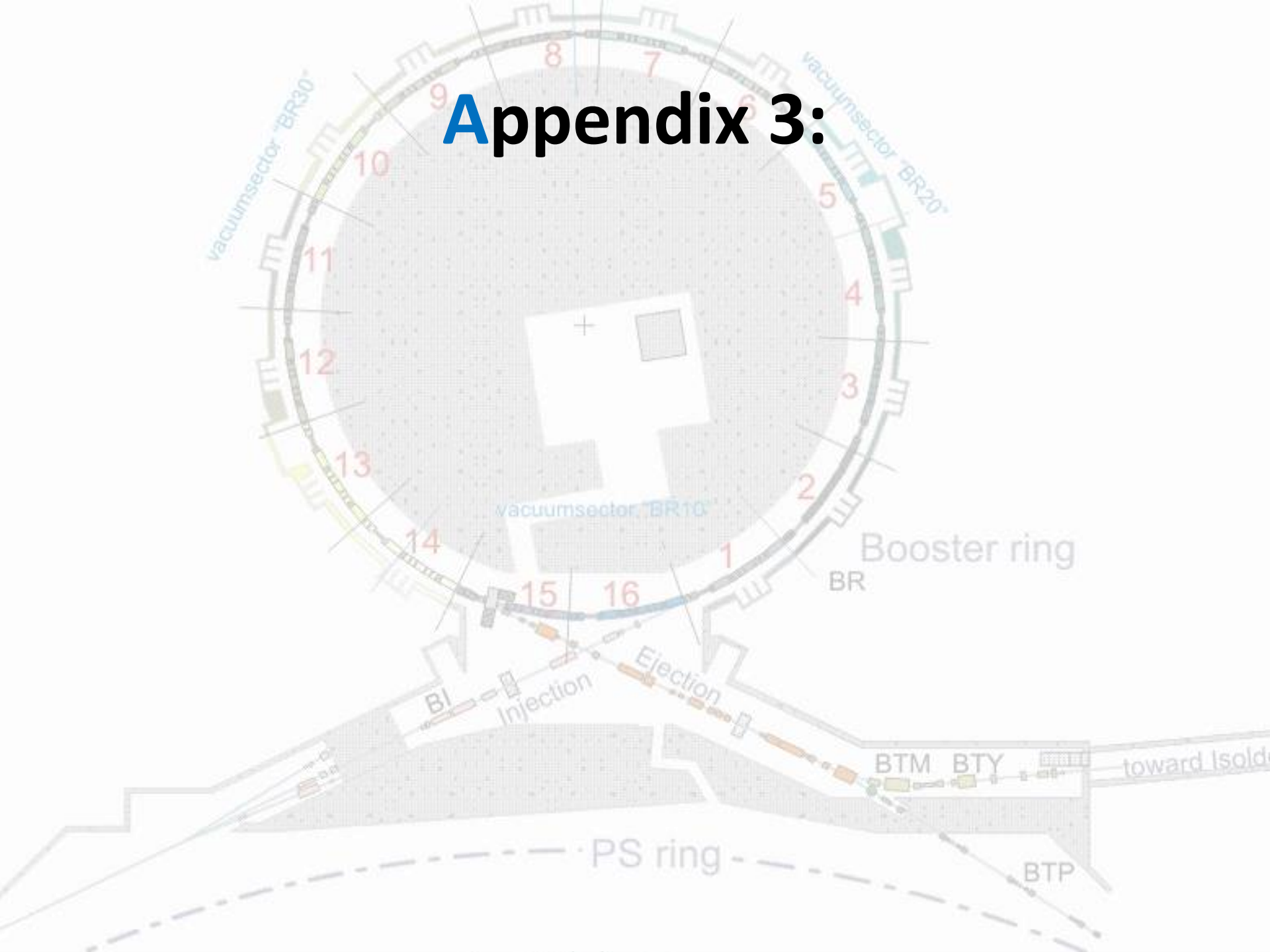
Ring 3 will be replaced by ring 1 when it's ready

losses vs s



First 1000 turns investigated

Appendix 3:


8
7
9
6
10
5
11
4
12
3
13
2
14
1
15
16
vacuumsector "BR30"
vacuumsector "BR20"
vacuumsector "BR10"
Booster ring
BR
BI
Injection
Ejection
BTM
BTY
toward Isold
PS ring
BTP

New Window Beam Scope dimensions for 160 MeV

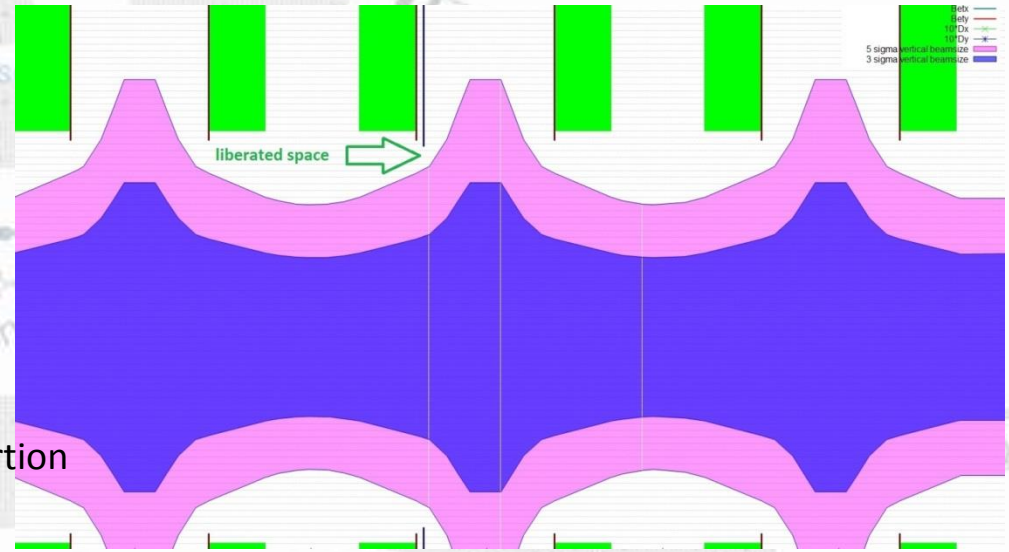
Window Beam Scope is an aperture restriction in PS Booster designed in the past to perform beam profile measurements.

In current operation its main role is to shave the beam in order to have a controlled value of the intensity and emittances.

With injection energy upgrade…

physical size **50mm x 28.6mm**
should be scaled as

$\sqrt{(\beta\gamma_{160}/\ \beta\gamma_{50})}$ ~= 1.35



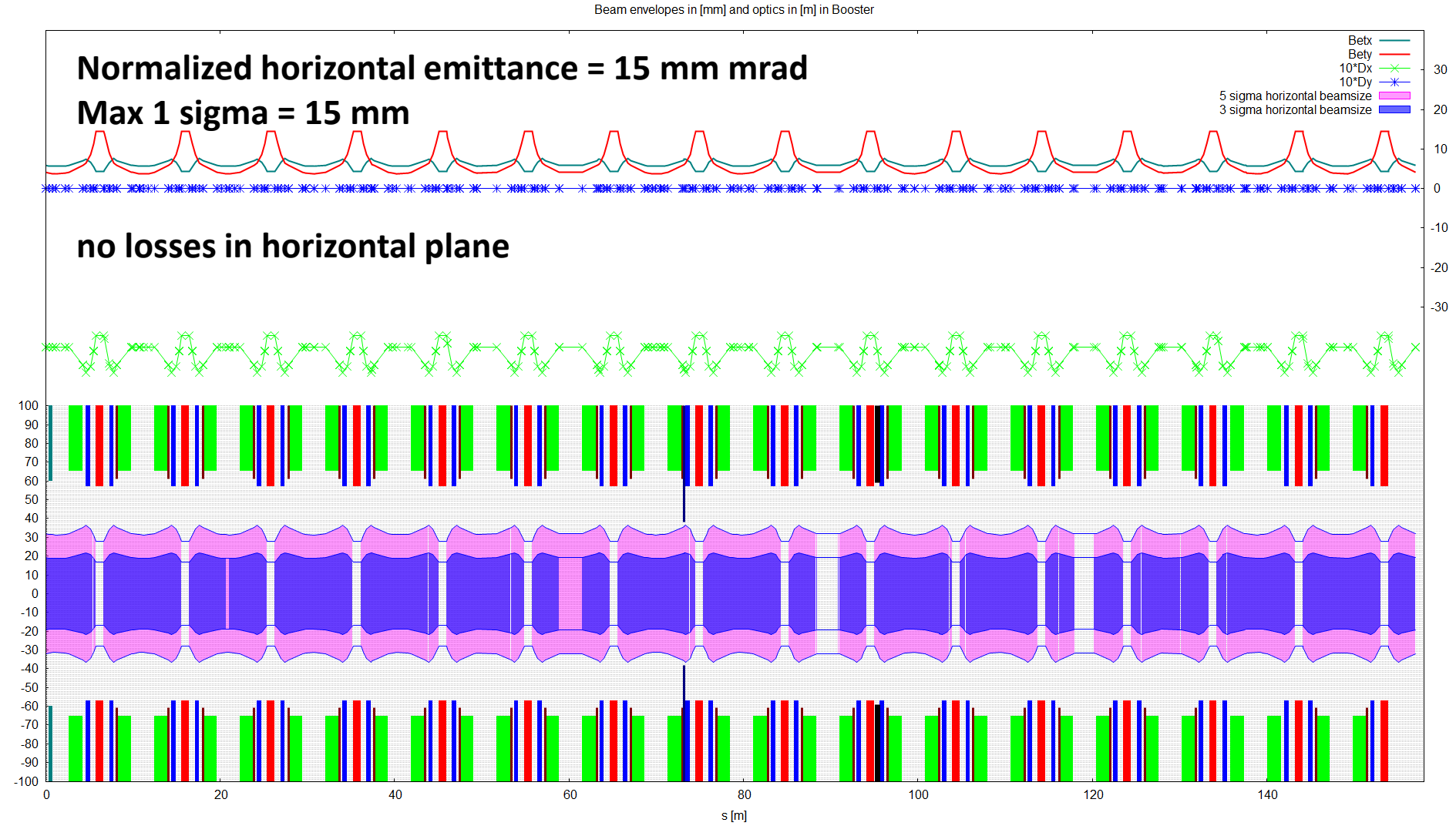
Taking into account 5 mm of closed orbit distortion

the new WBS aperture should be
38.18mm x 22.40mm **

* * Matthias Scholz "Simulationen zur H- Charge Exchange Injection in den CERN Proton Synchrotron Booster mit Linac4"

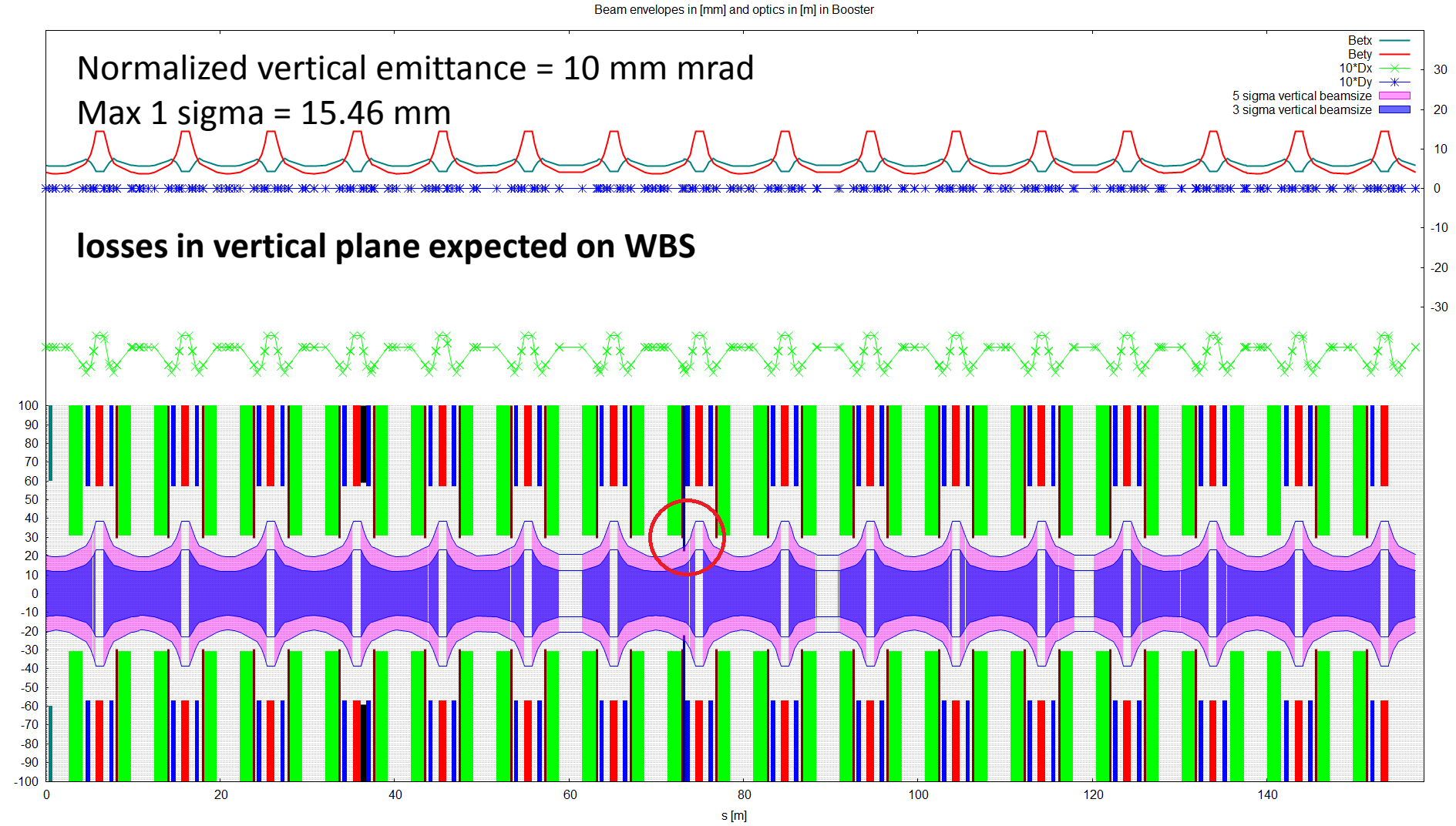
Isolde beam

passing through the PSB lattice with reduced WBS (no errors), horizontal plane



Isolde beam

passing through the PSB lattice with reduced WBS (no errors), vertical plane



Comments:

- Forecast for future ISOLDE 160 MeV p+ beam and reduced aperture restriction to 38.18 mm x 22.40 mm, losses are not foreseen in horizontal plane and they are expected to occur only in vertical plane (at WBS position).

- Expected losses will be smaller than the present ones.

Thank you for your attention.