MADX and Aperture Studies for the BI Transfer Line

C. Bracco, E. Benedetto, B. Mikulec, G. Rumolo

Acknowledgment: C. Carli, A. Lombardi, A. Newborough, J. Borburgh, J. Hansen, T. Dobers, W. Weterings, M. Hourican

Reminder

https://indico.cern.ch/event/331610/

LIU-PSB Meeting 129

chaired by Klaus Hanke (CERN)

Thursday, 24 July 2014 from **10:30** to **11:35** (Europe/Zurich)
at **CERN (864-1-C02)**

Thursday, 24 July 2014

10:30 - 10:35	Approval of Minutes *5'* Speakers: Dr. Klaus Hanke (CERN), Bettina Mikulec (CERN)
10:35 - 10:45	Communications *10'* Speakers: Dr. Klaus Hanke (CERN), Bettina Mikulec (CERN)
10:45 - 10:50	Follow-up of Open Actions *5'* Speakers: Dr. Klaus Hanke (CERN), Bettina Mikulec (CERN)
10:50 - 11:10	Aperture Checks for Different Linac4 Transfer Line Optics *20'* Speaker: Dr. Chiara Bracco (CERN) Material: Slides
11:10 - 11:20	Status TDR *10'* Speakers: Dr. Klaus Hanke (CERN), Bettina Mikulec (CERN)
11:20 - 11:30	AOB *10'*

Checks for Different Linac4 Transfer Line Optics

C. Bracco

Acknowledgments: A. Lombardi, B. Mikulec, B. Goddard

Reminder

https://indico.cern.ch/event/331610/

Optics at End of BI-TL

Target

Case	$\beta_{T,H}$ (m)	$\alpha_{T,H}$	$\beta_{T,V}$ (m)	$\alpha_{T,V}$	D_T (m)	D_T'
All matched	5	0	4	0	-1.4	0
Zero disp.	5	0	4	0	0	0
D matched, small β's	2.5	0	2	0	-1.4	0
Zero dispersion, small β's	2.5	0	2	0	0	0
D matched, large β's	10	0	8	0	-1.4	0
Zero dispersion, large β's	10	0	8	0	0	0

$D_{TV} = D_{TV}'=0$
For all optics (ring 3)

A. Lombardi: https://edms.cern.ch/document/1391781/0.1

Optics parameters at PSB injection:

Case	$\beta_{T,H}$ (m)	$\alpha_{T,H}$	$\beta_{T,V}$ (m)	$\alpha_{T,V}$ (m)	D_{TH} (m)	D_{TH}'	D_{TV} (m)	D_{TV}'
All matched (medium)	5.5	6.5e-5	3.7	9.6e-5	-1.4	0	0	0

Reminder

https://indico.cern.ch/event/331610/

What's next?

- Alessandra and team performed full study with PATH for all the optics (https://edms.cern.ch/document/1391781/0.1):
  - Apertures checked (including errors) ➔ no losses
  - Flexible optics
  - All four rings considered? (Worst case for vertical dispersion, Ring 1)

- What is missing? Aperture cross-check?
  1. Use PATH output: Need all optics with H&V Dispersion!
  2. Fully independent check needed?
     - MAD-X (no space charge)
     - PTC + ORBIT (with space charge)
     - Need sequence, strength files, initial conditions for all optic (something already available)

Not ideal for non-experts!

Time and resources!

Goal of the Studies

- **MADX version of the BI-TL optics (from BHZ40): all optics and all 4 rings!**
  - Check layout (magnets positions)
  - Crosscheck with “PATH” optics
  - Define effect of SC
  - Provide MADX optics for quick checks (aperture, steering, etc.)

Optics “0 Dispersion”

- Lattice manually derived from “Path” output
- “s” coordinates rechecked wrt existing BI-TL

Quads strengths
(https://edms.cern.ch/document/1391781/0.1)

	L [m]	B [T/m]	B [T/m]	B [T/m]
		Large	Nominal	Small
QFN50	0.255	-1.1909	-1.1909	-1.1909
QDN55	0.255	1.3859	1.3859	1.3859
QFN60	0.255	-1.82279	-1.82279	-1.82279
QDN65	0.255	1.15105	1.15105	1.15105
QFW70	0.467	0.401532	0.401532	0.401532
QDN75	0.255	-1.46635	-1.46635	-1.46635
QFN10	0.255	1.0816	1.0816	1.0816
QDN20	0.255	-0.40911	-0.40911	-0.40911
QFW30	0.461	-1.40927	-1.40927	-1.40927
QDW40	0.461	1.65575	1.65575	1.65575
QFW50	0.461	-1.33639	-1.33639	-1.33639
QDW60	0.461	1.06024	1.06024	1.06024
BI.QN10	0.462	-1.04465	-1.28068	-1.04465
BI.QN20	0.462	1.01876	1.22486	1.01876
BI.QN30	0.462	-0.96627	-0.82535	-1.02548
BI-QN40	0.462	0.972508	0.914672	0.99931
BI-QN50	0.466	-1.84028	-2.13851	-1.6121
BI-QN60	0.466	2.015537	2.359182	1.781536

Change sign in MADX (H^-)

Initial conditions
(start of **BHZ40***, beginning of BI line)

(X,BGX') 100%-Emittance [m.rad]	**1.62E-05**
(X,BGX') 90%-Emittance [m.rad]	1.30E-06
(X,BGX') RMS-Emittance [m.rad]	3.11E-07
(Y,BGY') 100%-Emittance [m.rad]	1.54E-05
(Y,BGY') 90%-Emittance [m.rad]	1.45E-06
(Y,BGY') RMS-Emittance [m.rad]	3.34E-07
(PHI,dE) 100%-Emittance [deg.MeV]	7.58E+01
(PHI,dE) 90%-Emittance [deg.MeV]	1.09E+00
(PHI,dE) RMS-Emittance [deg.MeV]	3.13E-01
(X,X') Alpha [1]	**9.89E-01**
(X,X') Beta [m/rad]	**9.02E+00**
(Y,Y') Alpha [1]	**1.34E+00**
(Y,Y') Beta [m/rad]	**4.53E+01**
(PHI,dE) Alpha [1]	1.09E+01
(PHI,dE) Beta [deg/MeV]	4.09E+03
dx [m]	*0*
dxp	*0*
dy [m]	*0*
dyp	*0*

*Smallest SC effect

Optics “0 Dispersion”

- Lattice manually derived from “Path” output
- “s” coordinates rechecked wrt existing BI-TL

Quads strengths
(https://edms.cern.ch/document/1391781/0.1)

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		~~Large~~ Nom.	~~Nominal~~ Small	~~Small~~ Large
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Change sign in MADX (H^-)

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(start of **BHZ40***, beginning of BI line)

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(X,X') Alpha [1]	**9.89E-01**
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(Y,Y') Alpha [1]	**1.34E+00**
(Y,Y') Beta [m/rad]	**4.53E+01**
(PHI,dE) Alpha [1]	1.09E+01
(PHI,dE) Beta [deg/MeV]	4.09E+03
dx [m]	*0*
dxp	*0*
dy [m]	*0*
dyp	*0*

*Smallest SC effect

Main Magnet Positions

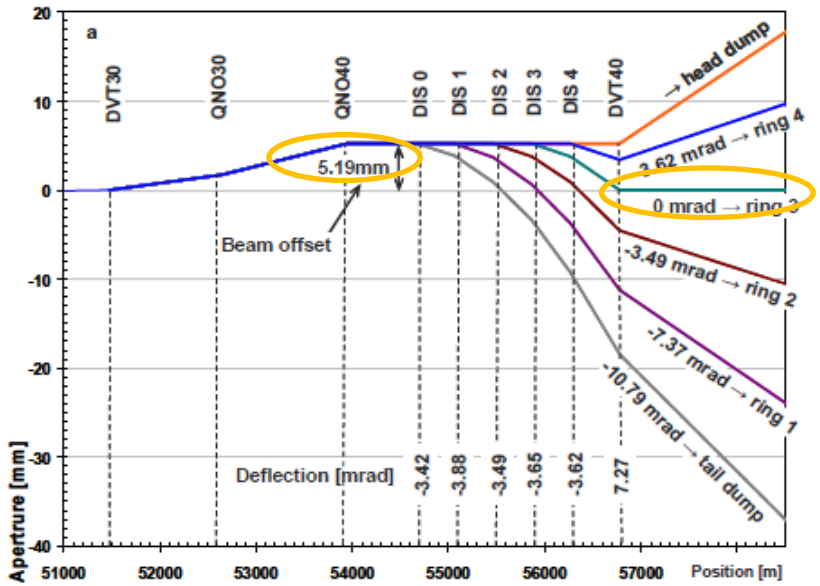
Compared magnets position with 2014 Linac2 layout.

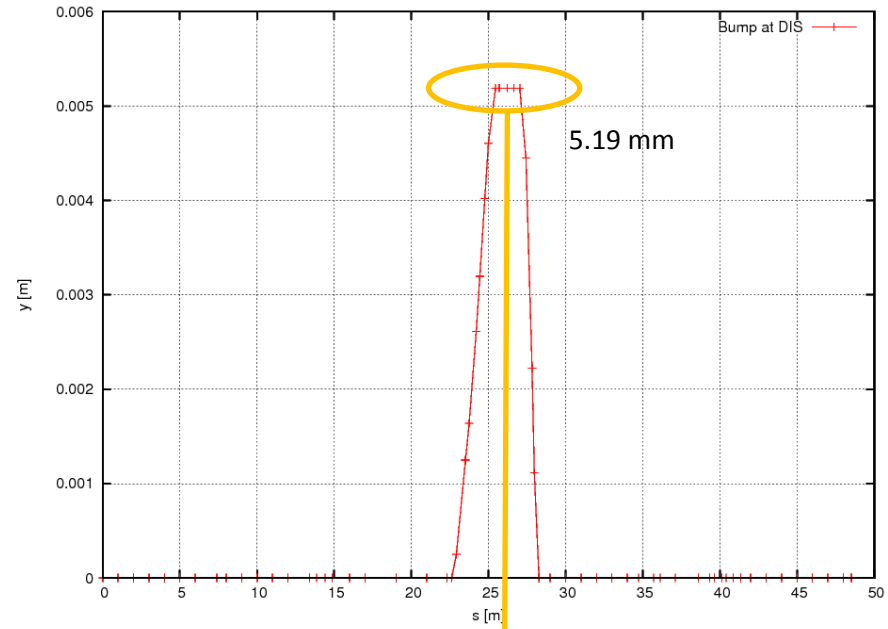
	Actual position [m]	Path position [m]	Difference [m]
BHZ40	0.45	0.45	0
BI.QNO10	13.624	13.636	-0.012
BI.QNO20	14.624	14.636	-0.012
BI.DVT30	22.766	22.532	0.234
BI.QNO30	23.9747	23.952	0.022697
BI.QNO40	25.22415	25.252	-0.02785
BI3.DIS1	26.42415	26.383	0.041154
BI3.DIS2	26.82415	26.783	0.041154
BI3.DIS3	27.22415	27.183	0.041154
BI3.DIS4	27.62415	27.583	0.041154
BI3.DVT40	28.10251	28.083	0.01951
BI3.SMV	35.22415	35.283	-0.05885
BI3.SMV	36.62415	36.603	0.021154
BI3.QNO50	39.87602	39.896	-0.01998
BI3.QNO60	40.62602	40.646	-0.01998
BI3.INJPT	48.50322	48.50322	0

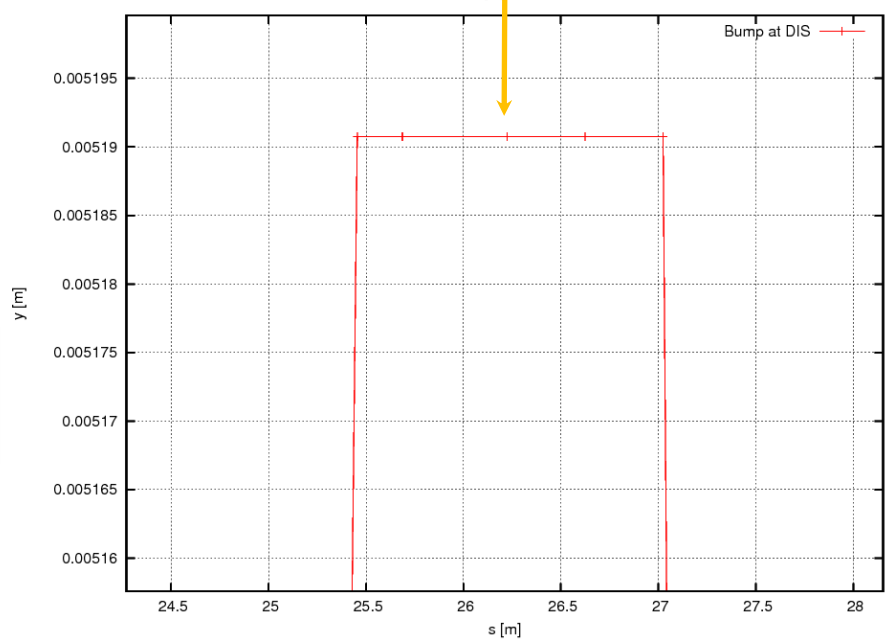
Few cm difference in longitudinal position.
Final check ➔ input for PATH

Bump to DIS

- QN30 and QN40 (off-centred ➔ SBENDS)





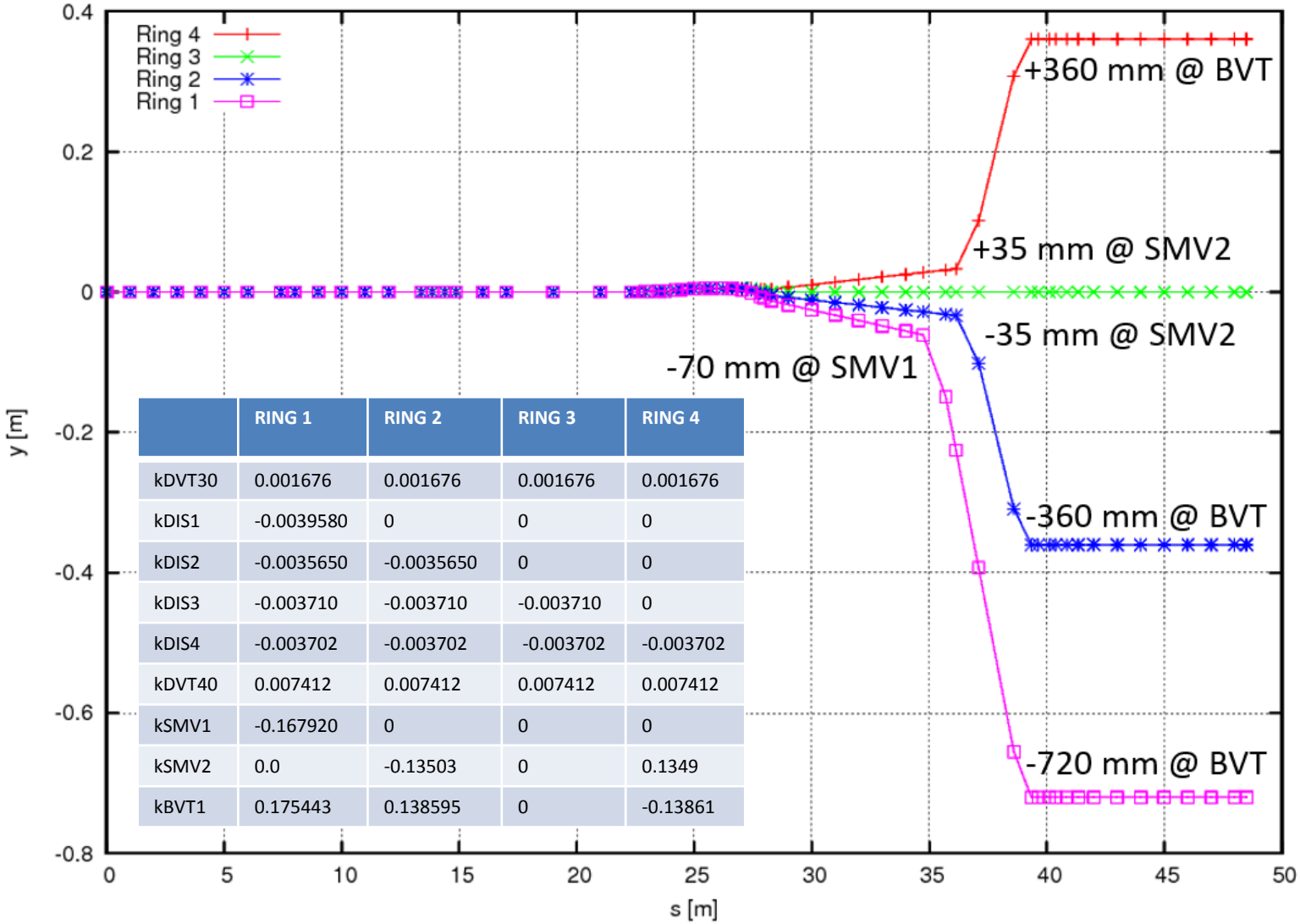


Kept Q30 and Q40 as in table from Alessandra➔ calculate DVT30 ➔ DIS and DVT40 strengths

kdvt30 := 0.001676;
kbiqn1_30 := 0.82535/brho ;
kbiqn1_40 := -0.914672/brho ;
kbiqn1_s30 := -0.000857;
kbiqn1_s40 := 0.002533;
kdis3 := 0.003710;
kdis4 := 0.003702;
kdvt40 := 0.007412;

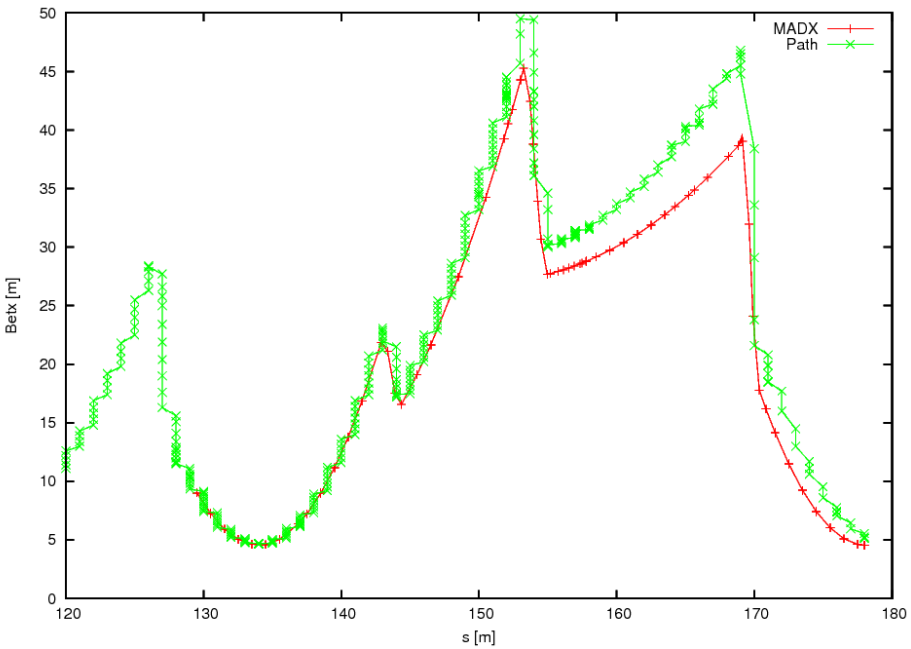
Agreement within few % wrt afs DB

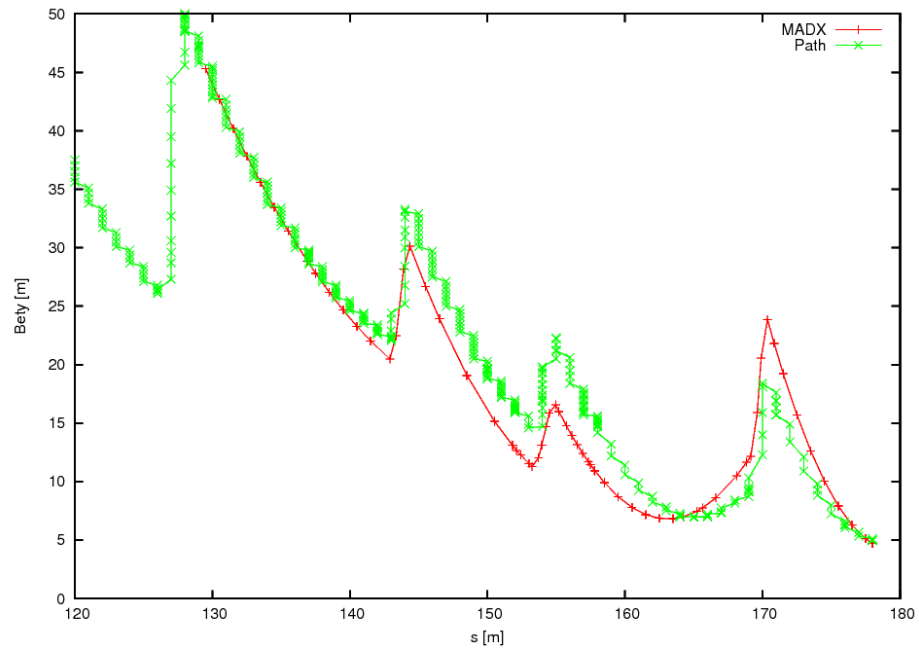
Ring 1 - 2 - 3 - 4



	RING 1	RING 2	RING 3	RING 4
kDVT30	0.001676	0.001676	0.001676	0.001676
kDIS1	-0.0039580	0	0	0
kDIS2	-0.0035650	-0.0035650	0	0
kDIS3	-0.003710	-0.003710	-0.003710	0
kDIS4	-0.003702	-0.003702	-0.003702	-0.003702
kDVT40	0.007412	0.007412	0.007412	0.007412
kSMV1	-0.167920	0	0	0
kSMV2	0.0	-0.13503	0	0.1349
kBVT1	0.175443	0.138595	0	-0.13861

Nominal Betax,y “0 Dispersion” Ring3

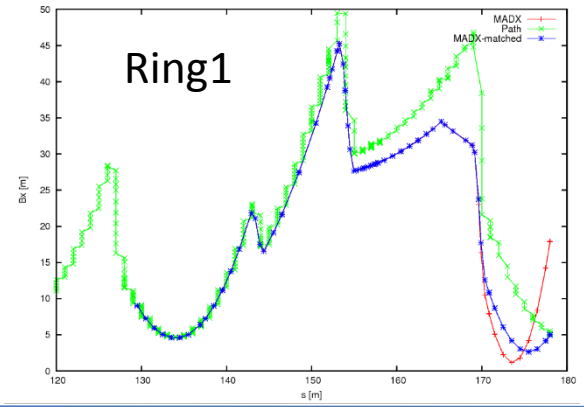


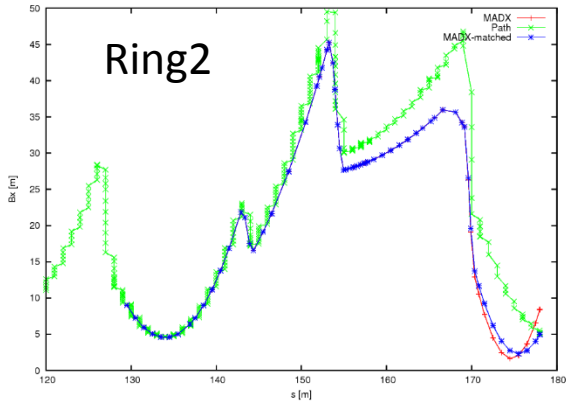


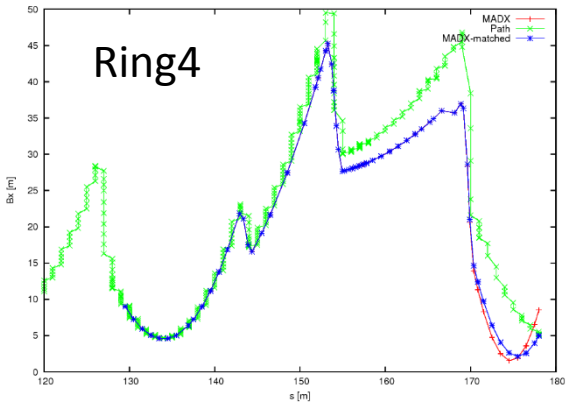
No MADX matching!
MADX-PATH agreement <15%
Difference likely due to SC!

Nominal Betax,y “0 Dispersion”

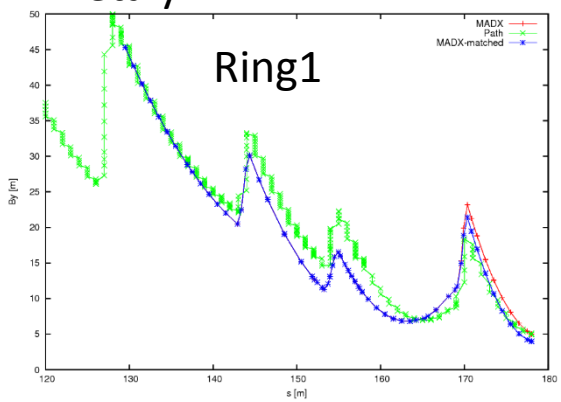
Beta x

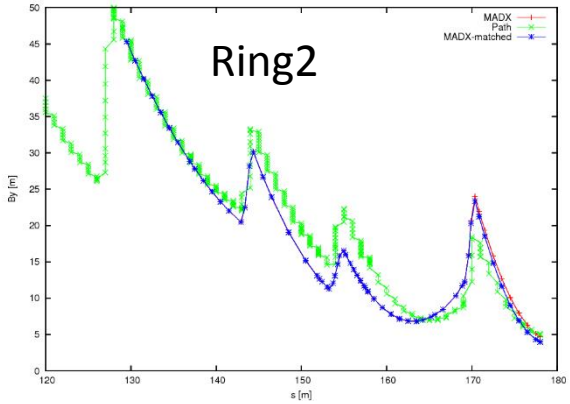


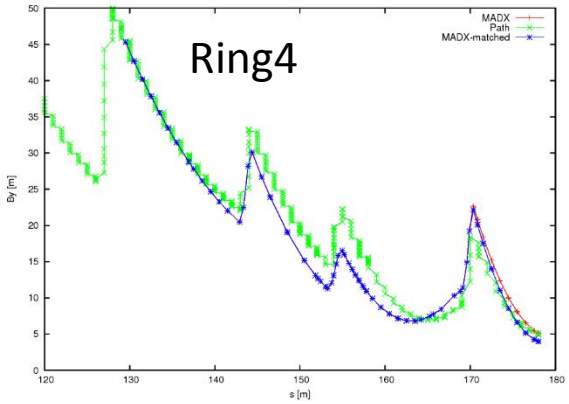




Beta y



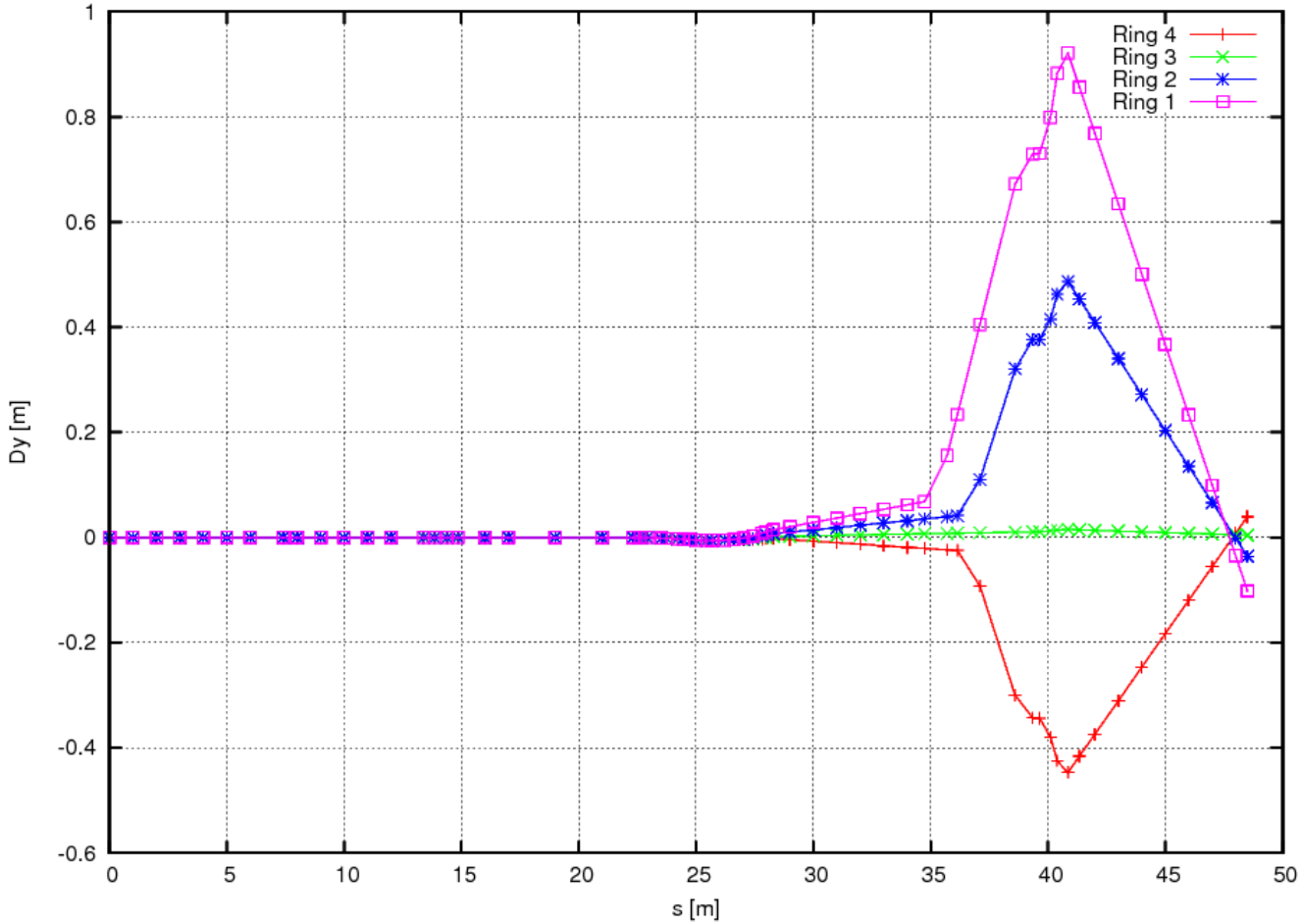




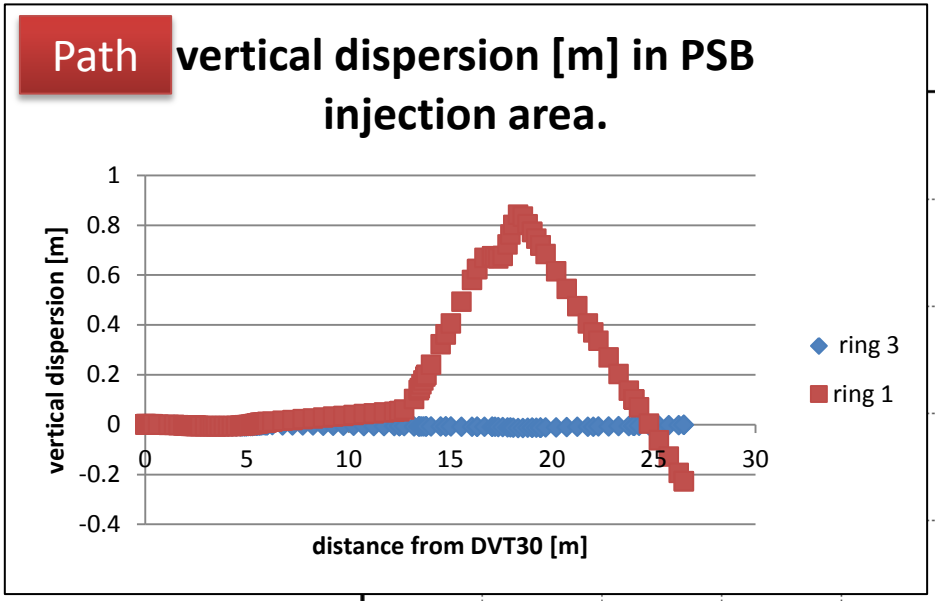
MADX matching for other rings (using QN50 and QN60)!
MADX-PATH agreement < 20%

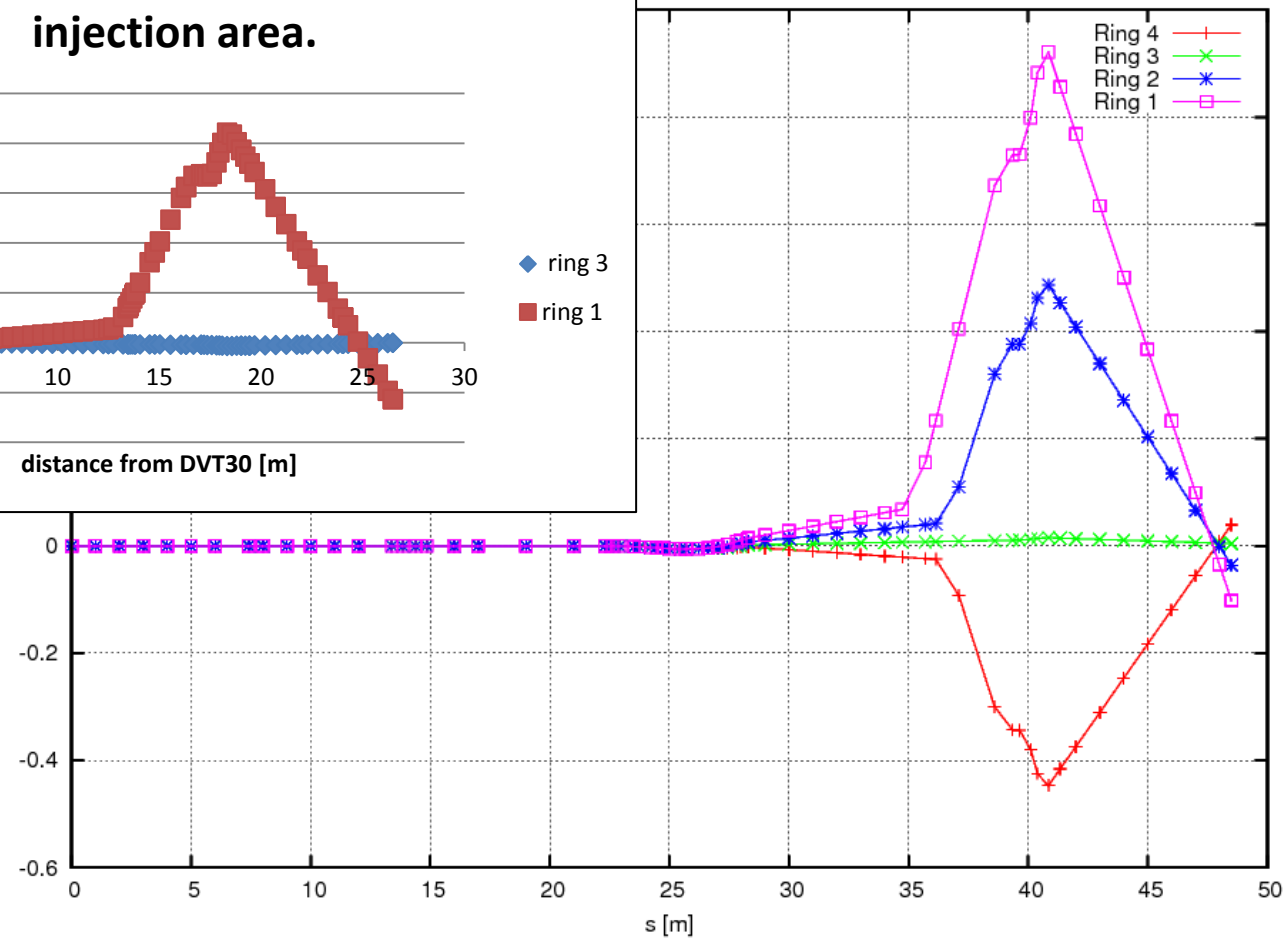
	Path [K1]	MADX [k1]			Max. Diff. [%]
	Ring3	Ring1	Ring2	Ring4	
BIQN50	0.967042	0.83154	0.923914	0.934228	14%
BIQN60	-1.05914	-1.00256	-1.04960	-1.06483	5%

Vertical Dispersion



Vertical Dispersion





Optics “Matched 1.4m Dispersion”

- Lattice manually derived from “Path” output
- “s” coordinates rechecked wrt existing BI-TL

Quads strengths
(https://edms.cern.ch/document/1391781/0.1)

	L [m]	B [T/m] Large	B [T/m] Nominal	B [T/m] Small
QFN50	255	-1.21153	-1.1909	-1.1909
QDN55	255	1.657855	1.3859	1.3859
QFN60	255	-1.57211	-1.48306	-1.48306
QDN65	255	0.935826	1.077851	1.077851
QFW70	467	0.508536	0.383437	0.383437
QDN75	255	-1.56731	-1.40174	-1.40174
QFN10	255	1.0816	1.0816	1.0816
QDN20	255	-0.40911	-0.40911	-0.40911
QFW30	461	-1.40927	-1.40927	-1.40927
QDW40	461	1.65575	1.65575	1.65575
QFW50	461	-1.33639	-1.33639	-1.33639
QDW60	461	1.06024	1.06024	1.06024
BI.QN10	462	-1.14711	-1.04465	-0.95114
BI.QN20	462	1.096658	1.01876	1.060401
BI.QN30	462	-1.02548	-1.04099	-1.04099
BI-QN40	462	0.99931	1.070225	1.070225
BI-QN50	466	-1.53973	-1.95651	-1.98625
BI-QN60	466	1.573803	2.209061	2.235629

Change sign in MADX (H^-)

Initial conditions
(start of **BHZ40***, beginning of BI line)

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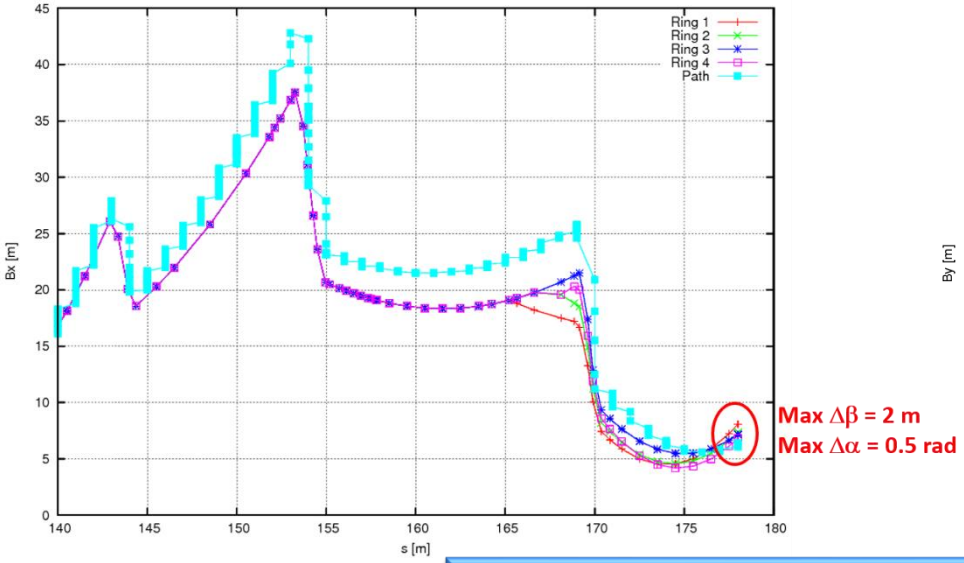
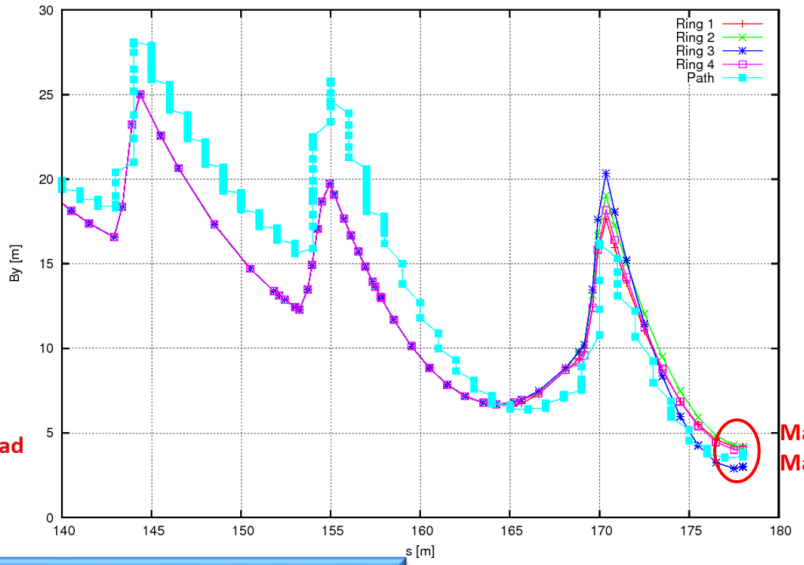
(PHI,dE) Alpha [1]	1.09E+01
(PHI,dE) Beta [deg/MeV]	4.09E+03
dx [m]	**1.13**
dxp	**-7.55e-3**
dy [m]	*0*
dyp	*0*

*Smallest SC effect

Nominal Betax,y “1.4 m Dispersion”

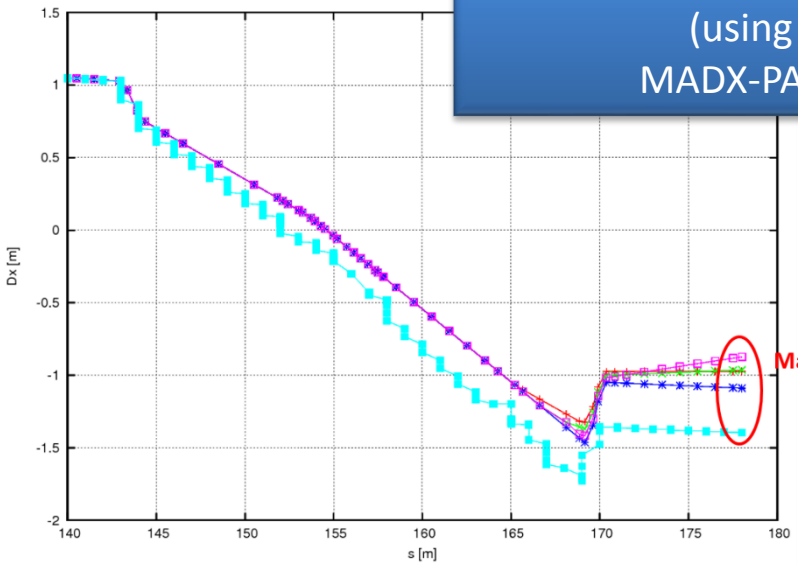


Max $\Delta\beta$ = 2 m
Max $\Delta\alpha$ = 0.5 rad

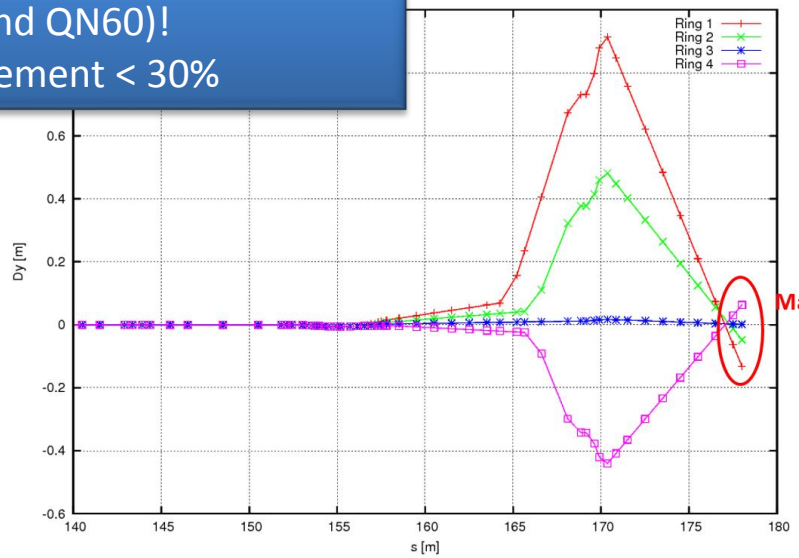


Max $\Delta\beta$ = 0.6 m
Max $\Delta\alpha$ = 0.5 rad

MADX matching for Ring 1-2-4
(using QN50 and QN60)!
MADX-PATH agreement < 30%



Max ΔD = 0.5 m



Max ΔD = 0.1 m

Strengths

	RING 1	RING 2	RING 3	RING 4
kDVT1	0.00174889	0.00174889	0.00174889	0.00174889
kDIS1	-0.0039580	0	0	0
kDIS2	-0.0035650	-0.0035650	0	0
kDIS3	-0.003710	-0.003710	-0.003710	0
kDIS4	-0.003702	-0.003702	-0.003702	-0.003702
kDVT3	0.007412	0.007412	0.007412	0.007412
kSMV1	-0.167920	0	0	0
kSMV2	0.0	-0.13503	0	0.1349
kBVT1	0.175443	0.138595	0	-0.13861
kQN10	0.548949027	0.548949027	0.548949027	0.548949027
kQN20	-0.535344193	-0.535344193	-0.535344193	-0.535344193
kQN30	0.547025748	0.547025748	0.547025748	0.547025748
kQN40	-0.562388334	-0.562388334	-0.562388334	-0.562388334
kQN50	0.801277	0.875123	1.028118760	0.900600
kQN60	-0.991892	-1.02530	-1.160830793	-1.05812

Conclusion I

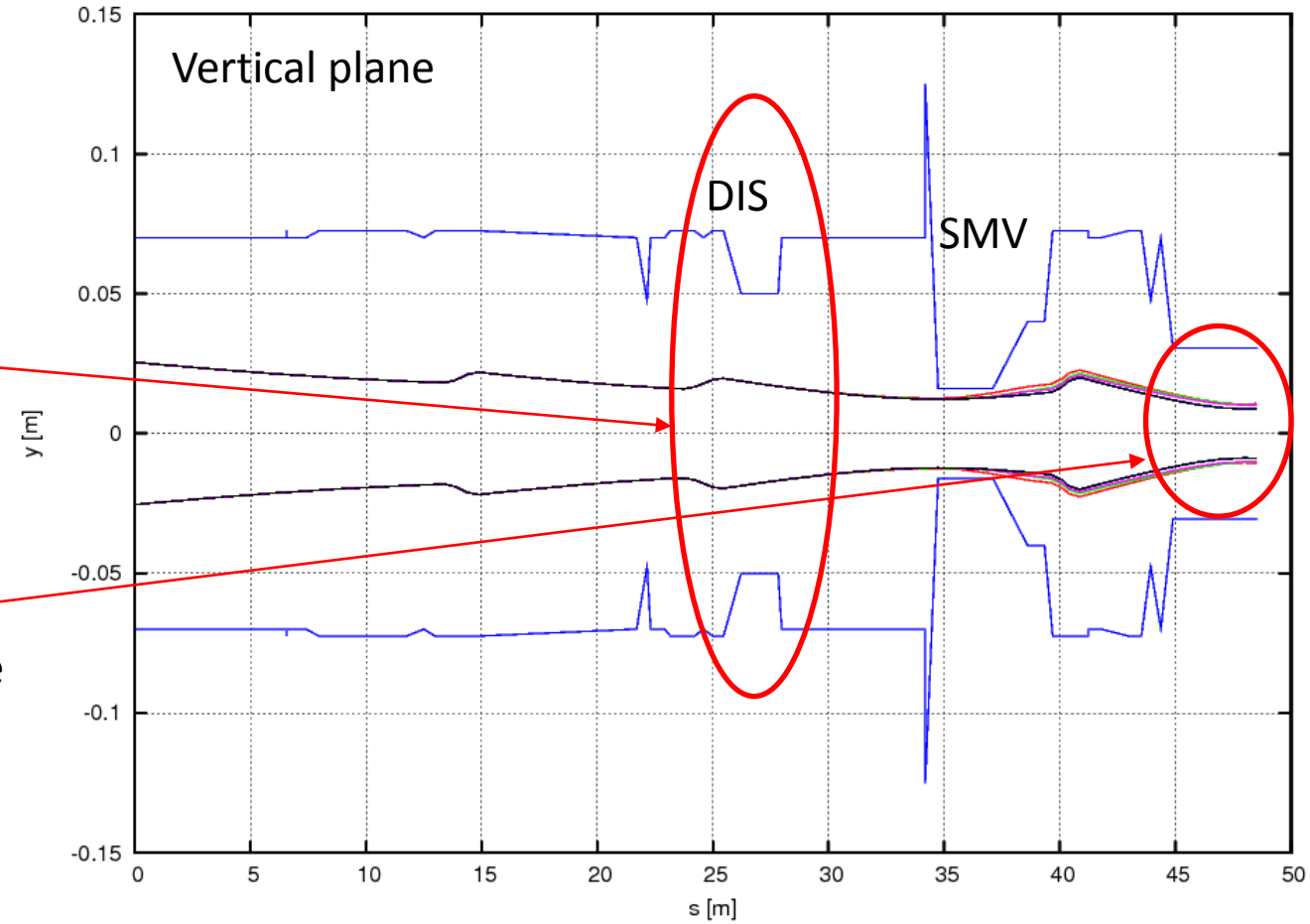
- A **MADX model** (without space charge) of the BI-TL has been prepared which agrees within **30%** with the PATH model (with space charge)
- Hint that Quads strengths for nominal, small and large beta in wrong order (tbc)
- Small **differences** (~cm) were found in the **longitudinal position of the main magnets** between the PATH model and the sequence in the afs DB (final checks needed)
- Some **geometric matching** of the line was needed to close the **bump** at the DIS for Ring3 and get the expected **offsets** at Ring 1,2 and 4 (magnets strengths change by **~%**)
- Some **optics matching** was also needed for Ring 1,2 and 4 (**QN50** and **QN60**, strengths changed by **< 15%**)
- This model was used for aperture checks!

Beam Envelope & Aperture Checks

$4\ \sigma_{\beta x,y(+20\%)}$ + $D_{x,y}$*$\Delta p/p$ + Orbit
(nominal $\beta_{x,y}$, normalized r.m.s. $\varepsilon_{x,y}$ =0.5 mm mrad)
Dp/p = 0.0044 (1.13 MeV longitudinal painting)
Orbit = ±2 mm

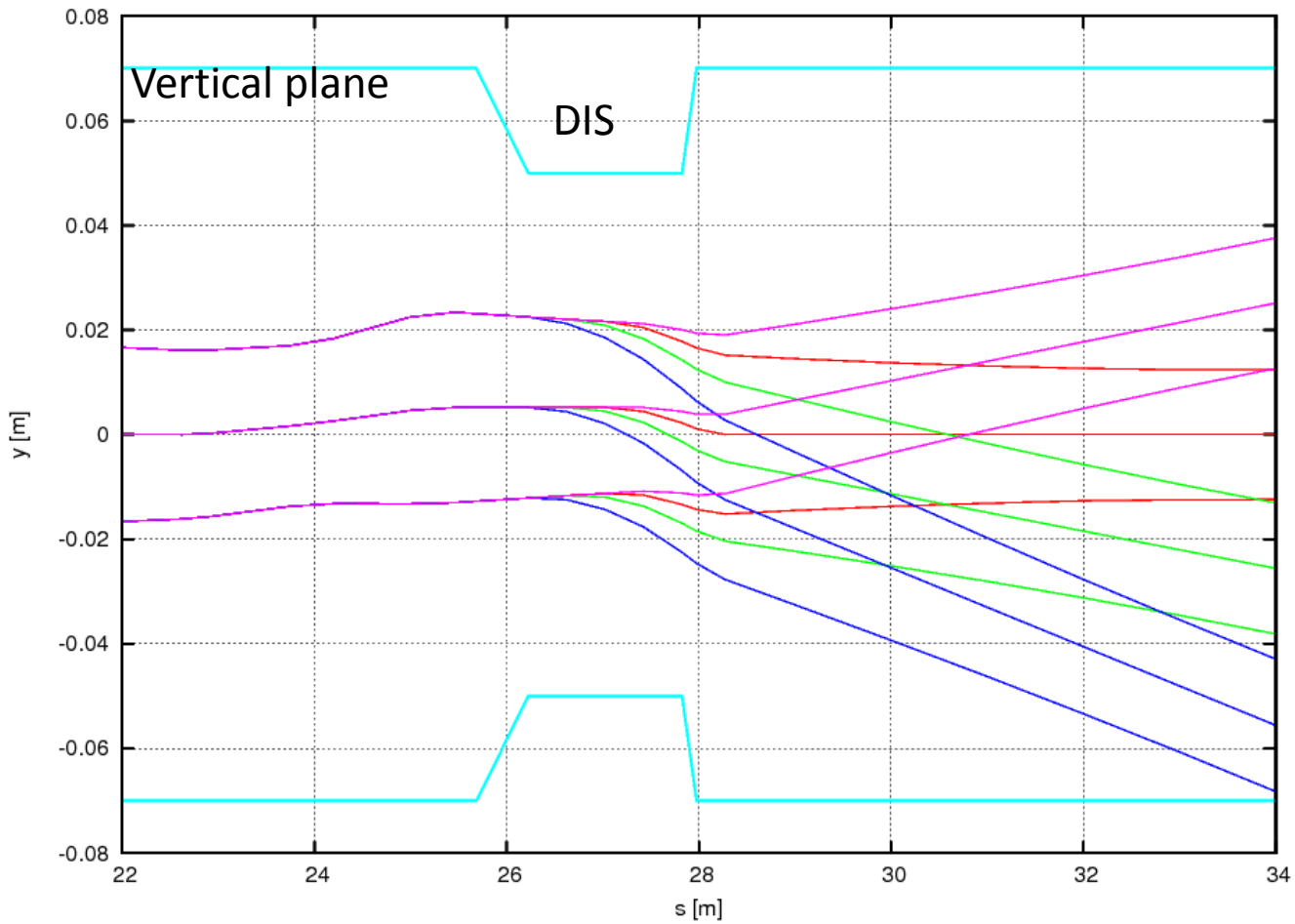
Assuming all beam on the same vertical axis!! In reality @ DIS there is a common chamber + vertical separation.

A maximum vertical offset of ±10 mm can be applied at the end of the line for the large emittance beams (i.e. ISOLDE)



Beam Envelope & Aperture Checks

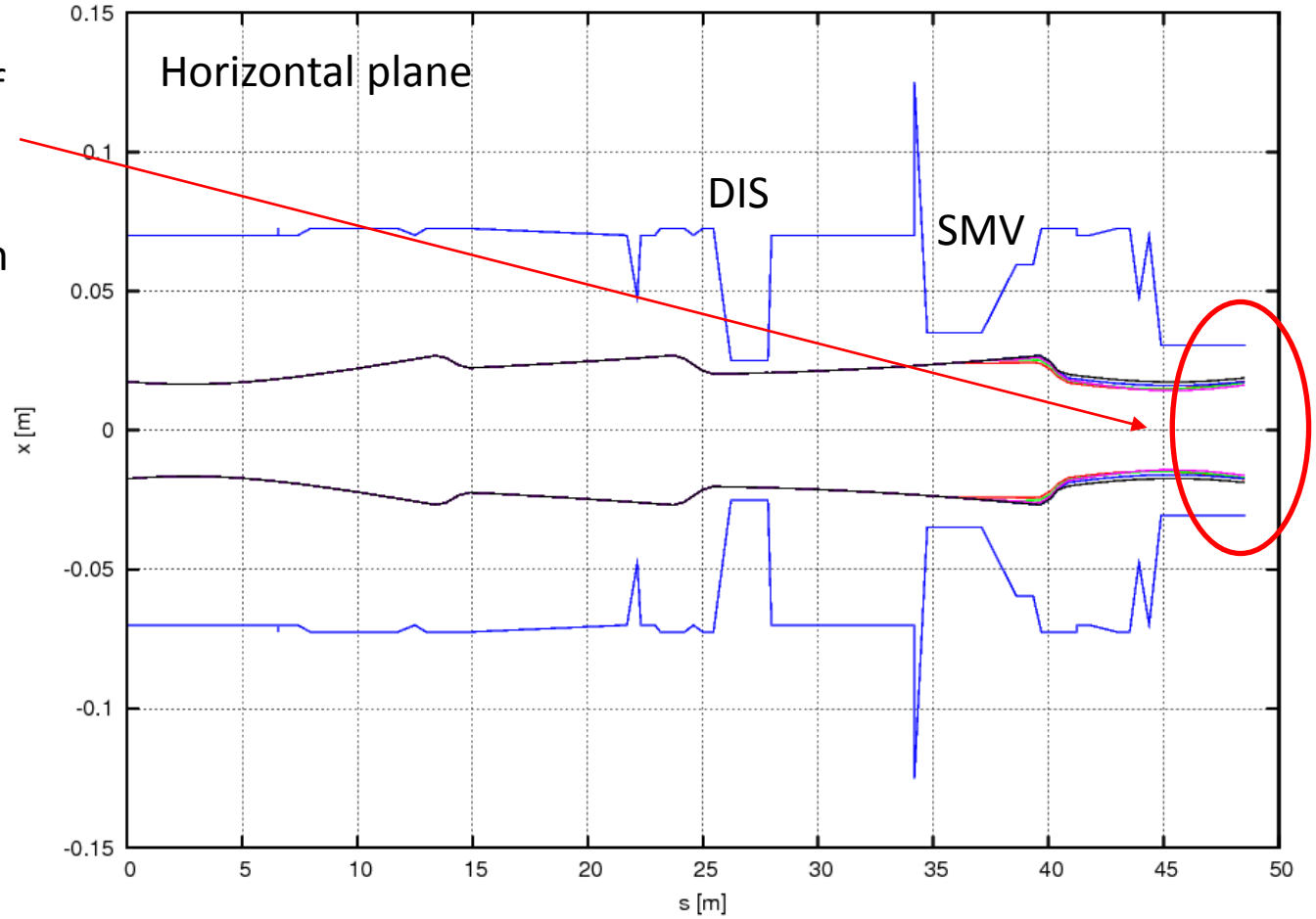
$4\ \sigma_{\beta x,y(+20\%)}$ + $D_{x,y}$*$\Delta p/p$ + Orbit
(nominal $\beta_{x,y}$, normalized r.m.s. $\varepsilon_{x,y}$ =0.5 mm mrad)
Dp/p = 0.0044 (1.13 MeV longitudinal painting)
Orbit = ±2 mm



Beam Envelope & Aperture Checks

$4\ \sigma_{\beta x,y(+20\%)} + D_{x,y} * \Delta p/p$ + Orbit
(nominal $\beta_{x,y}$, normalized r.m.s. $\varepsilon_{x,y}$ =0.5 mm mrad)
Dp/p = 0.0044 (1.13 MeV longitudinal painting)
Orbit = ±2 mm

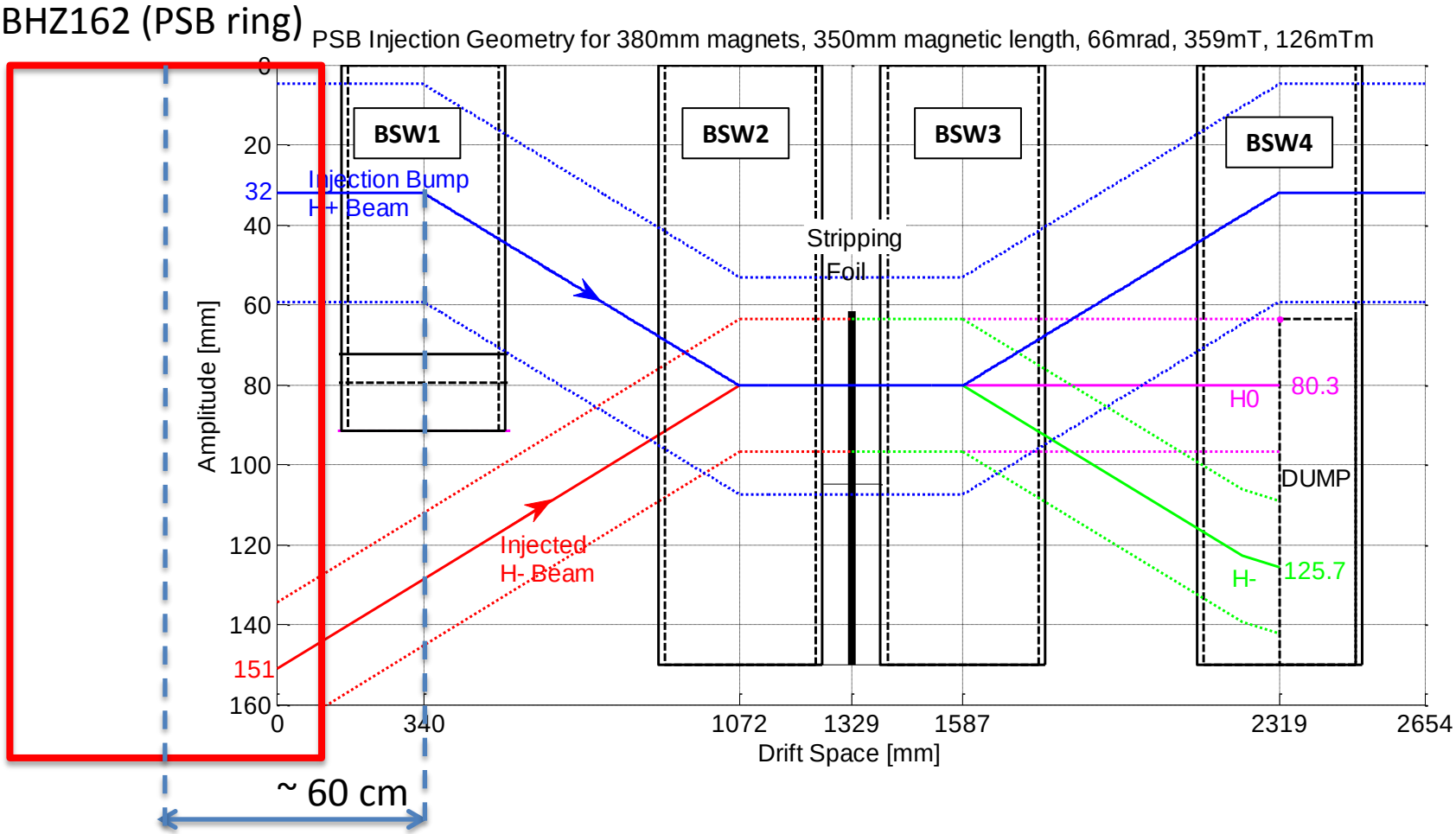
The beam at the end of the BI-TL has a **10 mm horizontal offset towards the PSB ring** in order to be injected exactly on the circulating beam orbit when the chicane (46 mm) and the injection bump (35 mm) are on.



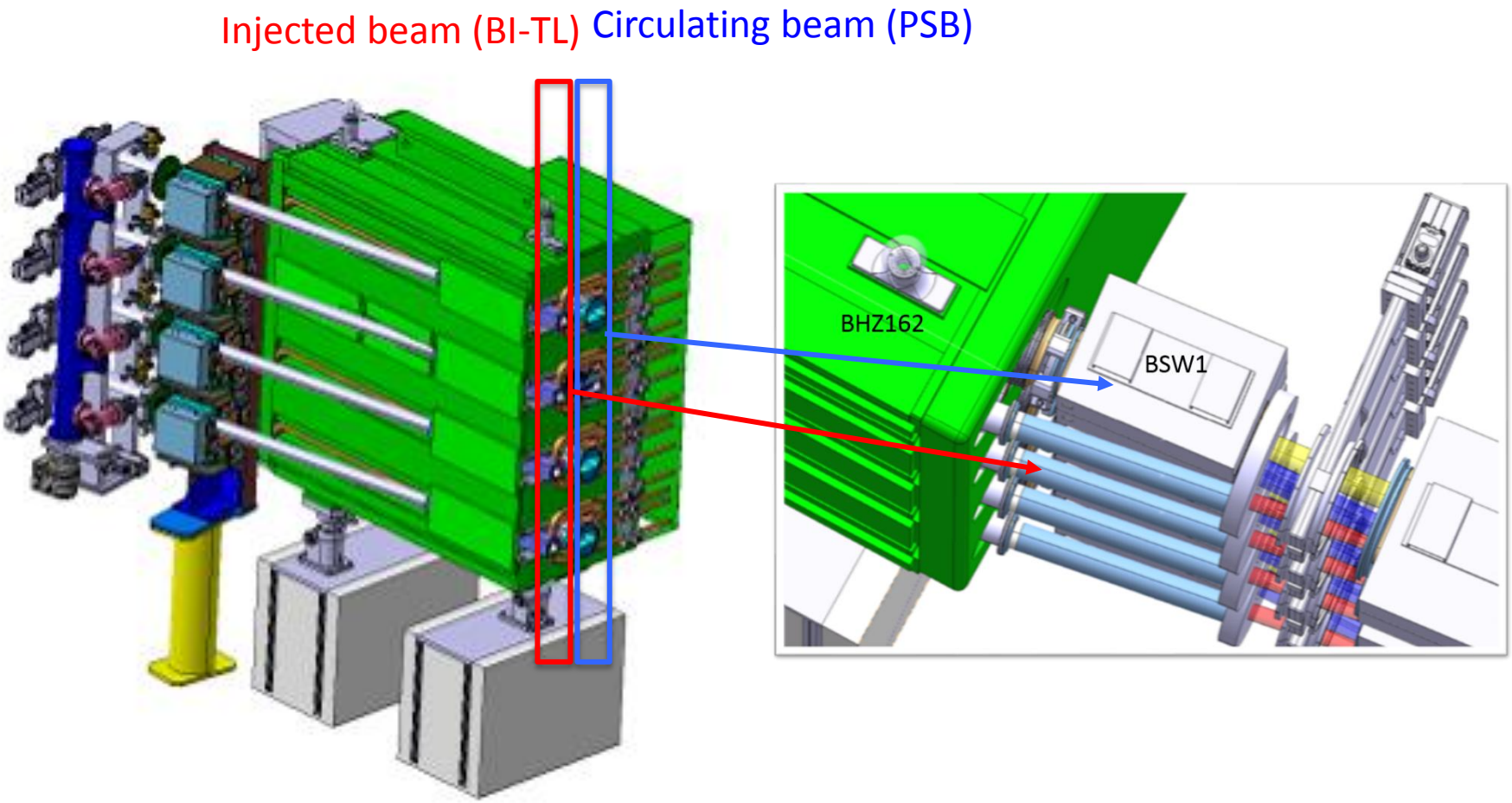
PSB Injection Region

Aperture checks over last 3 m of BI line where inner diameter = 60 mm (@ BHZ162) and 57.1 mm (@ BI.BSW)

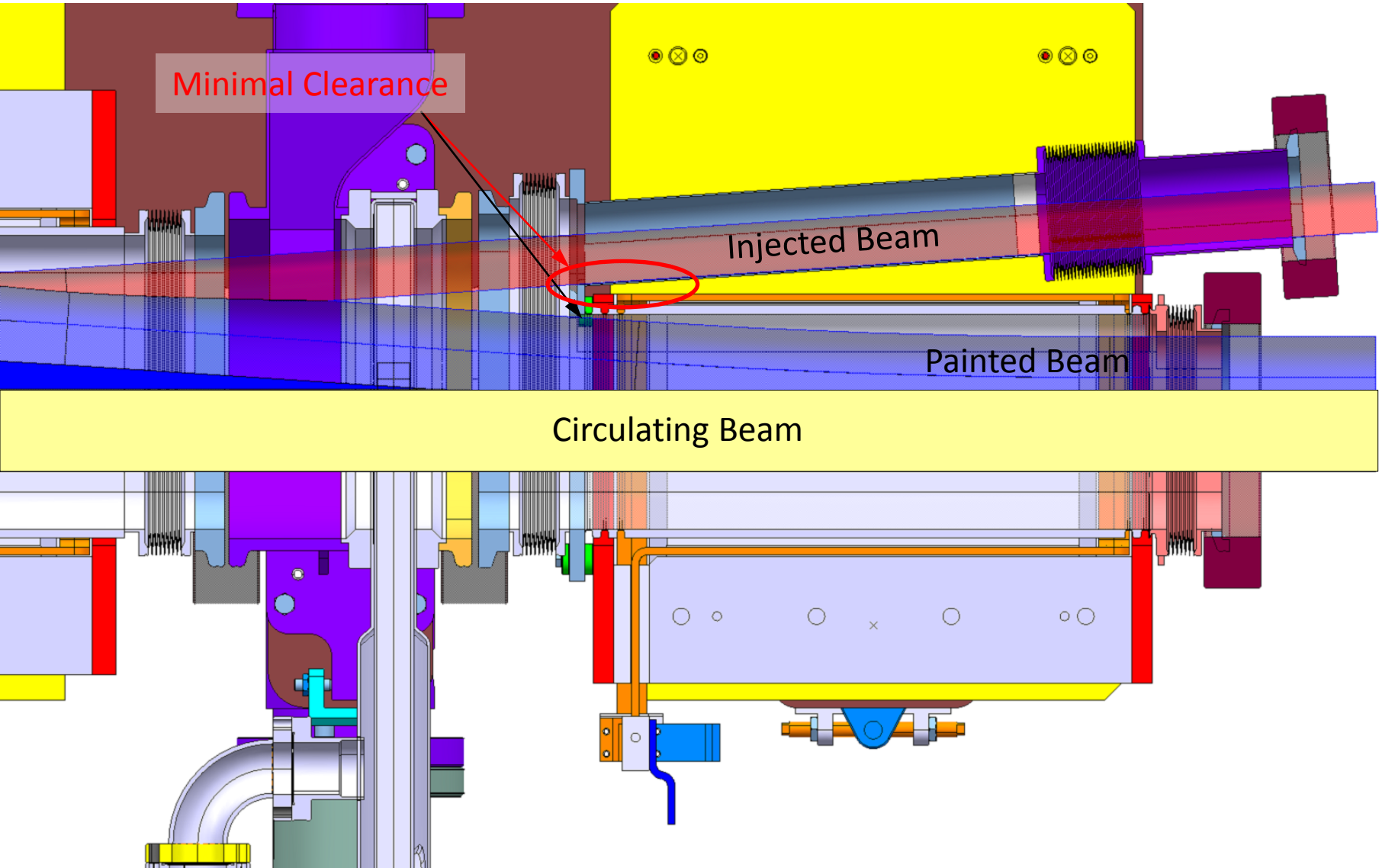
BHZ162 (PSB ring)



BHZ162

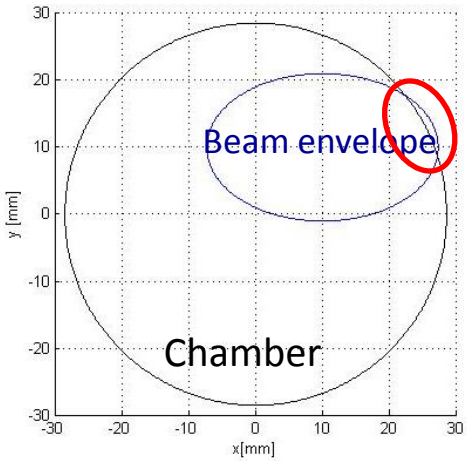


BSW1


Minimal Clearance
Injected Beam
Painted Beam
Circulating Beam

Beam Envelope & Aperture Checks

28.55 mm radius @ BSW1



Extreme case:

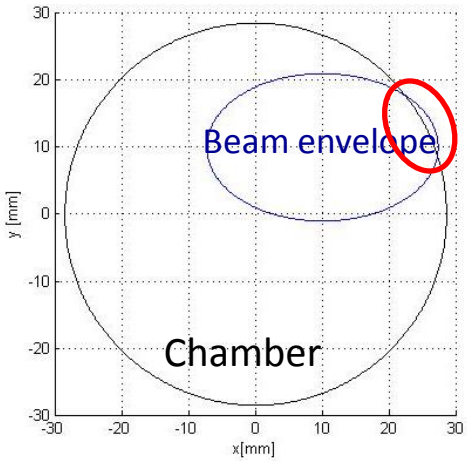
Longitudinal painting
+
10 mm beam horizontal offset
+
10 mm beam vertical offset

↓

Beam scraping the chamber!

Beam Envelope & Aperture Checks

28.55 mm radius @ BSW1



Extreme case:

Longitudinal painting
+
10 mm beam horizontal offset
+
10 mm beam vertical offset

↓

Beam scraping the chamber!

Realistic operational scenarios

LHC beams:

- No longitudinal painting and maximum Dp/p = **0.0031 (0.8 MeV)** ➔ **10% smaller beam envelope**

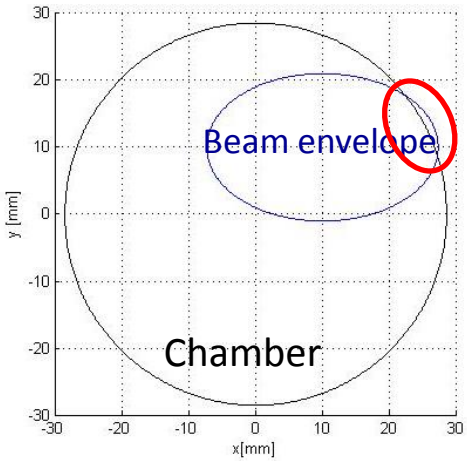
Large emittance beams:

- A 2 mm horizontal offset between injected and circulating beam is allowed ➔ **8 mm horizontal offset**.
- Simulations show that a maximum **vertical offset** of **8 mm** allows reaching reasonably large vertical emittance (6 mm mrad)

Possible to off-centre the vacuum chamber by 1 mm at least in the horizontal plane?

Beam Envelope & Aperture Checks

28.55 mm radius @ BSW1

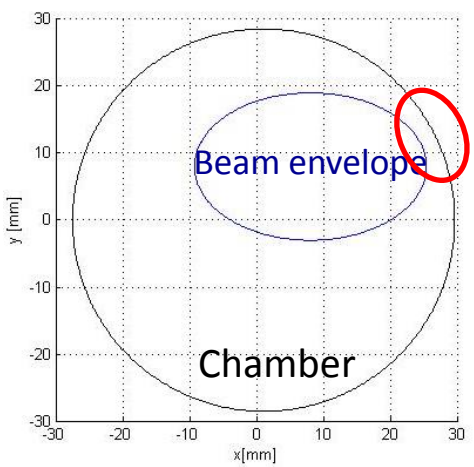


Extreme case:

Longitudinal painting
+
10 mm beam horizontal offset
+
10 mm beam vertical offset

↓

Beam scraping the chamber!



Operational case:

Longitudinal painting
+
8 mm horizontal offset
+
8 mm vertical offset
+
1 mm horizontal offset vacuum chamber

↓

> 2 mm margin

Realistic operational scenarios

LHC beams:

- No longitudinal painting and maximum Dp/p = **0.0031 (0.8 MeV)**
  ➔ 10% smaller beam envelope

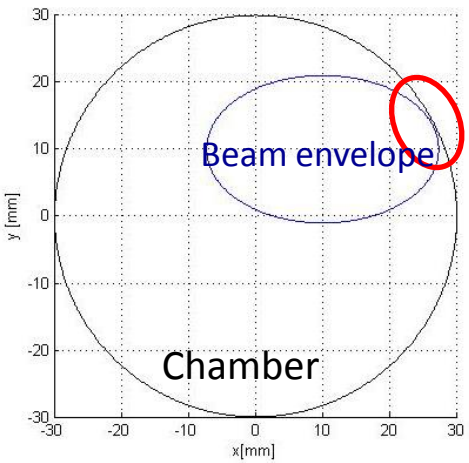
Large emittance beams:

- A 2 mm horizontal offset between injected and circulating beam is allowed **➔ 8 mm horizontal offset**.
- Simulations show that a maximum **vertical offset** of **8 mm** allows reaching reasonably large vertical emittance (6 mm mrad)

Possible to off-centre the vacuum chamber by 1 mm at least in the horizontal plane?

Beam Envelope & Aperture Checks

30 mm radius @ BHZ162

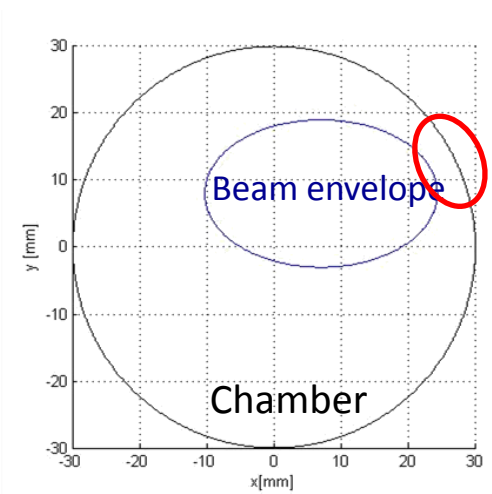


Extreme case:

Longitudinal painting
+
10 mm beam horizontal offset
+
10 mm beam vertical offset

↓

0 margin



Operational case:

Longitudinal painting
+
8 mm horizontal offset
+
8 mm vertical offset
+
1 mm horizontal offset vacuum chamber

↓

> 3 mm margin

Realistic operational scenarios

LHC beams:

- No longitudinal painting and maximum Dp/p = **0.0031 (0.8 MeV)** ➔ **10% smaller beam envelope**

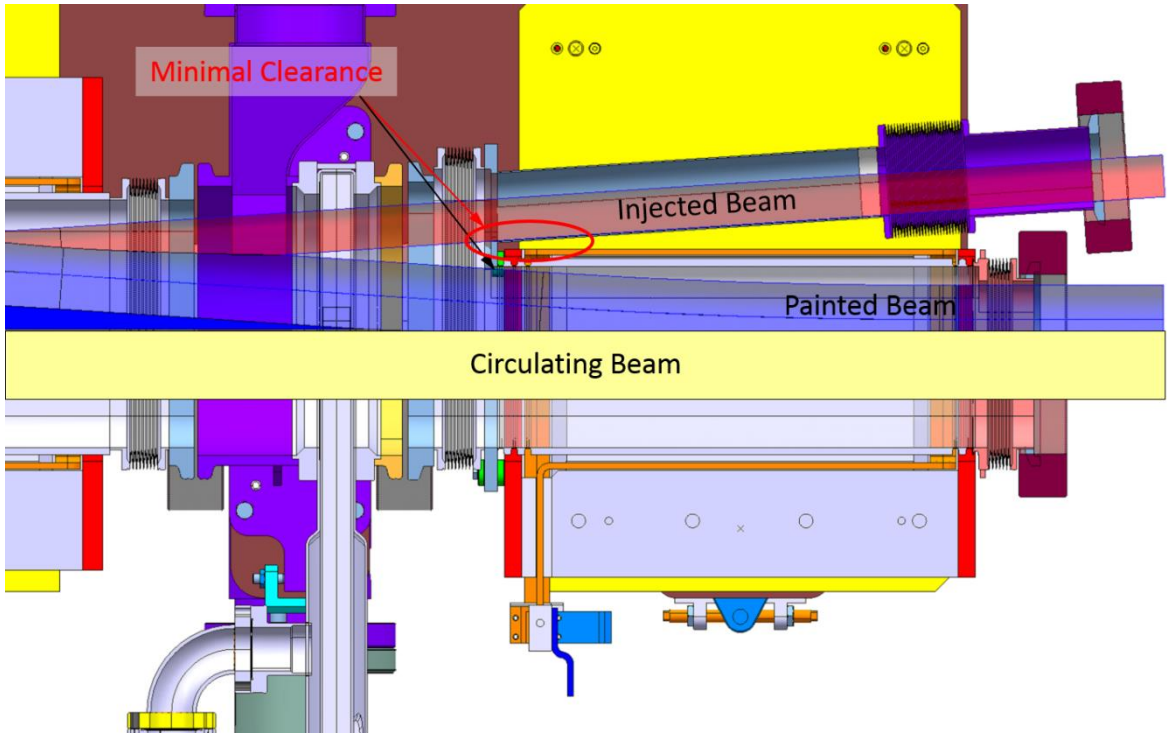
Large emittance beams:

- A 2 mm horizontal offset between injected and circulating beam is allowed ➔ **8 mm horizontal offset**.
- Simulations show that a maximum **vertical offset** of **8 mm** allows reaching reasonably large vertical emittance (6 mm mrad)

Possible to off-centre the vacuum chamber by 1 mm at least in the horizontal plane?

Can we off-center the chambers?

- BSW: the chamber can be off-centered by 1 mm by displacing the septum plate and tightening the tolerances (no impact on reliability or performance, only more expensive) ➔ **OK!!**

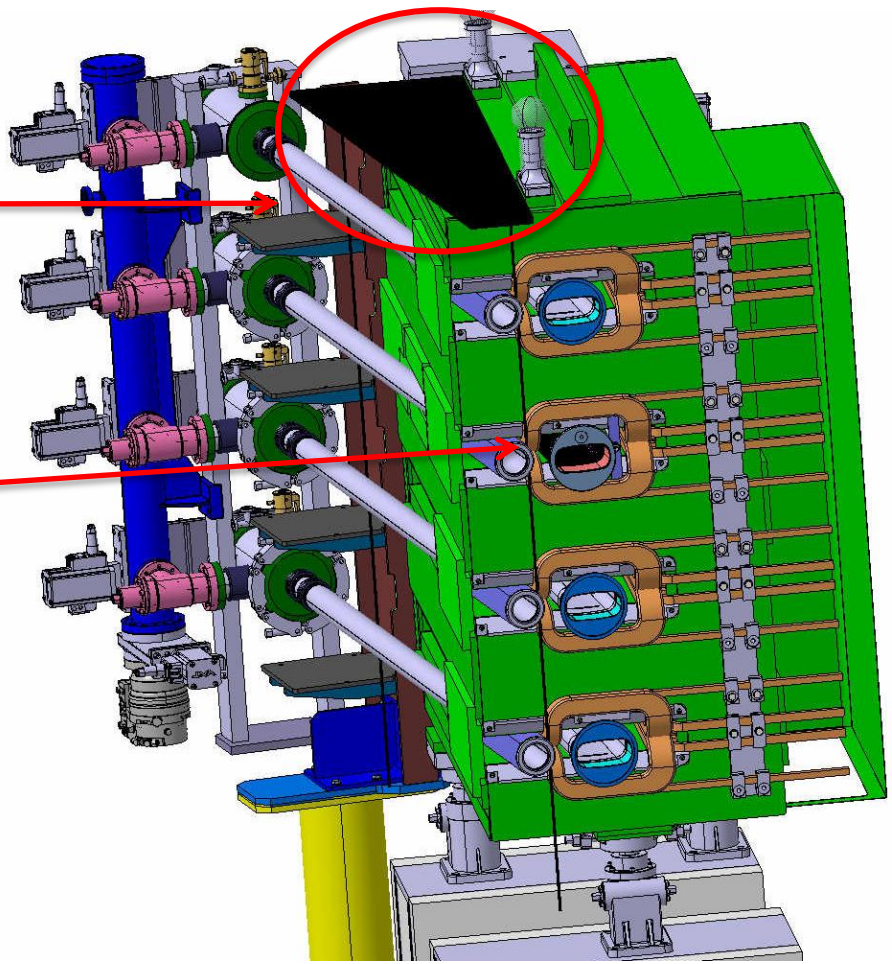


Can we off-center the chambers?

BHZ162

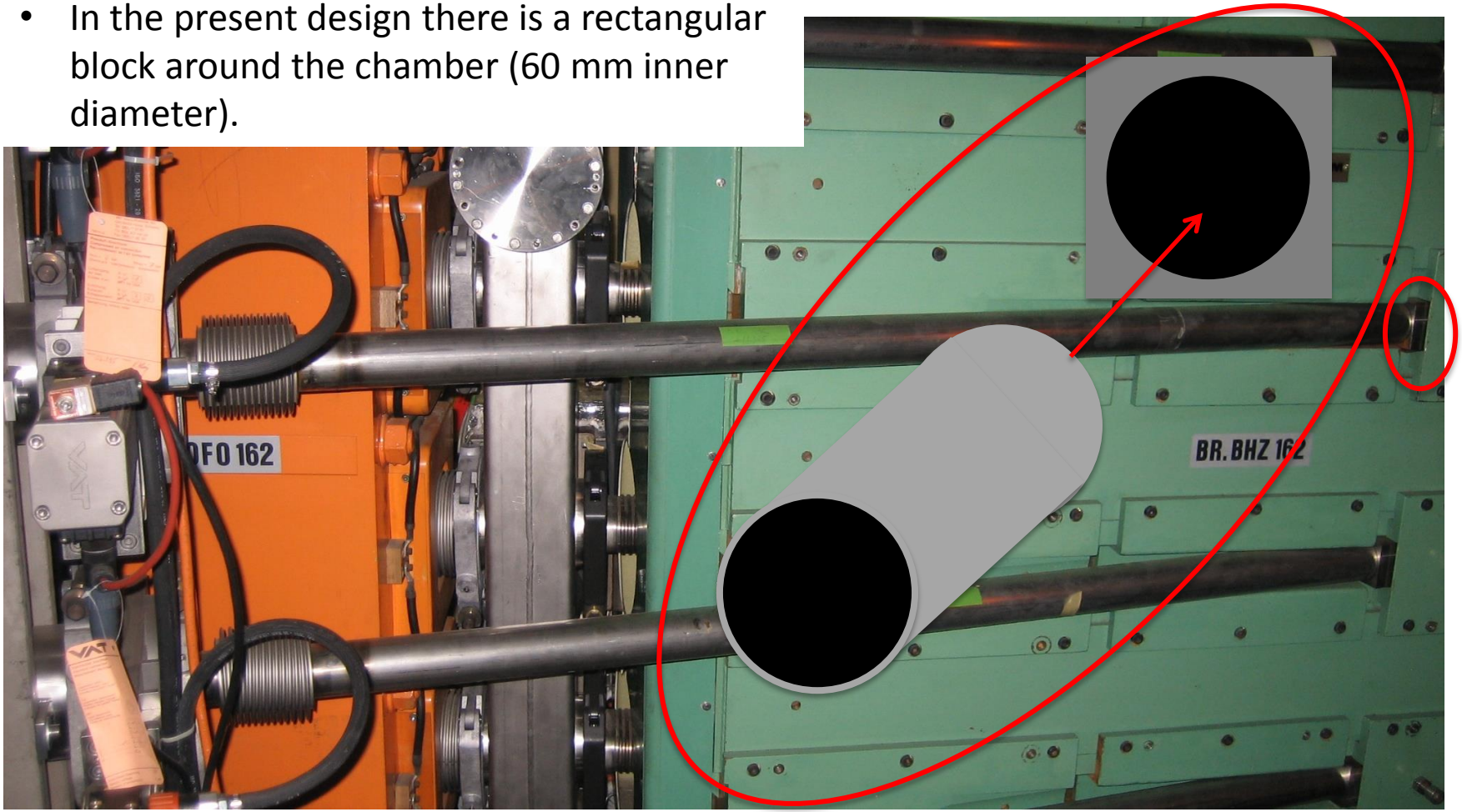
- An horizontal alignment (< 1 mm) of the vacuum chambers for the injected beam in the magnet BHZ162 can be done installing a metallic plate on the top of the magnet and using the "fil a plomb”

- An additional coil has to be added to allow operation at 160 MeV. We measured 12 mm for shimming, assuming that we have to count for 9 mm for the additional coil we could still move the chamber further in by 1-2 mm.



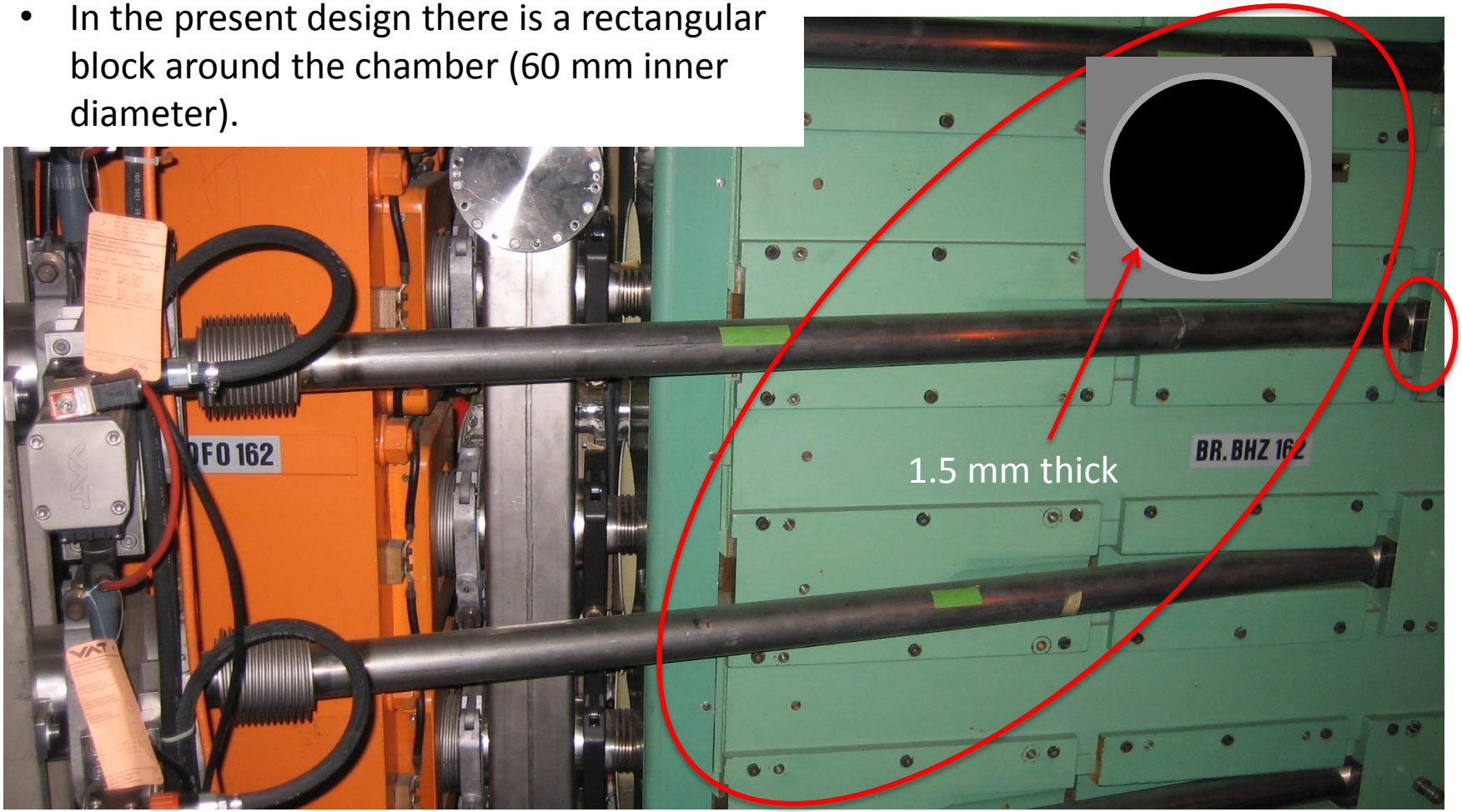
Can we off-center the chambers?

- In the present design there is a rectangular block around the chamber (60 mm inner diameter).



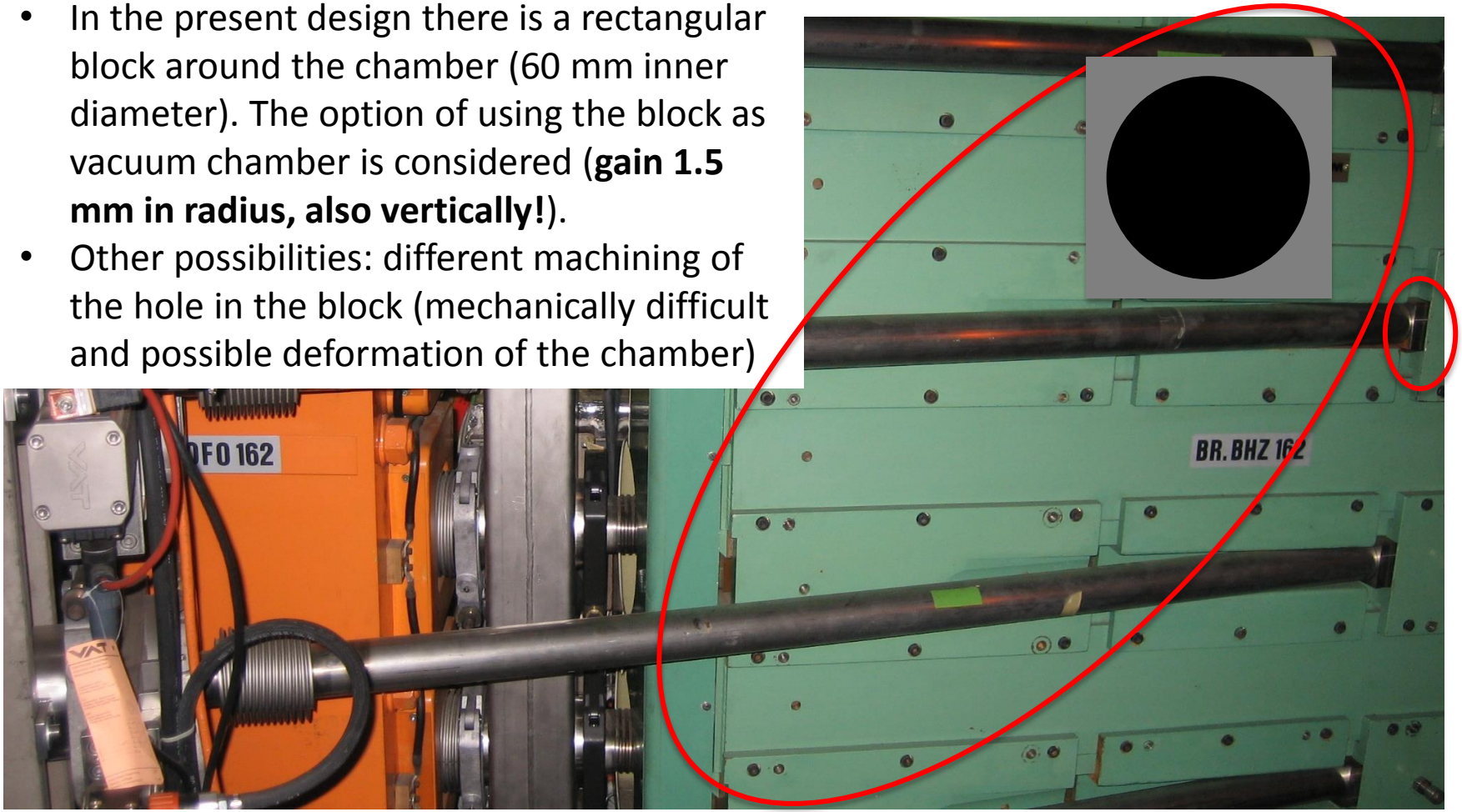
Can we off-center the chambers?

- In the present design there is a rectangular block around the chamber (60 mm inner diameter).



Can we off-center the chambers?

- In the present design there is a rectangular block around the chamber (60 mm inner diameter). The option of using the block as vacuum chamber is considered (**gain 1.5 mm in radius, also vertically!**).
- Other possibilities: different machining of the hole in the block (mechanically difficult and possible deformation of the chamber)



Conclusions II

- **Aperture checks** for the **BI-TL** were performed for the **nominal matched optics** (nominal beta and matched dispersion), for the 4 PSB rings (new MADX model)
- **Bottlenecks** were identified at the end of the **BI-TL** (BHZ162 and BSW1)
- Some **margin** can be operationally gained **by reducing the horizontal and vertical offset**.
- The chamber at the **BSW** can be **off-centered by 1 mm** by displacing the septum plate and tightening the tolerances
- An **alignment system** can be implemented at the BHZ162 magnet to align the vacuum chambers with an **accuracy < 1 mm**. An **aperture gain** between **1 and 3 mm in horizontal plane and ~1 mm in the vertical plane can be envisaged** (ECR to be written and approved by all involved experts).
- **Achievable optics flexibility** (maximum allowed beta at injection point**) t.b.d**.