PSB ejection lines

Modifications for the 2 GeV upgrade

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with many inputs from
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Review of the PSB Ejection Lines @2GeV, October 10th, 2013

Outline

- Upgrade motivation
- Optics
  - Optics requests
  - LHC, HI, Present optics at SMH42
  - BTM aperture bottlenecks
  - Trajectory correction
- HW upgrades/implications
  - Recombinaton septa and kicker
  - BT.BHZ10, BTM.BHZ10
  - Quadrupoles
  - Steerers
  - BPMs
  - Scraper

Aim of the PSB-PS transfer upgrade

- All beams to be transferred at 1.4 and 2 GeV (until LS2 also 1.0 GeV in BT and BTM/BTY for ISOLDE, no 1.0 GeV after LS2)
  - Magnet strength increased by 30% ($B\rho_{2GeV} / B\rho_{1.4GeV}$)
  - Can relax PS injection kicker fall time for LHC b
  - LHC beam can be injected with existing kicker … ne
  - HI beam injection at 2 GeV requires additional kicker in SS53

LHC inj w/out KFA53 possibly out for new HL parameters

- Match optics at PS injection to reduce emittance blow-up due to dispersion mismatch
  - Horizontal dispersion is presently not matched; install one additional quadrupole in BTP line to match the line to the PS injection optics
  - Vertical dispersion remains mismatched due to the vertical displacement of the four PSB rings (Dy < 0.5 m)

- Optimise optics for different beams
  - Requires ppm capability of HW (i.e. upgrade of BTP)

Optics studies

Optics requests

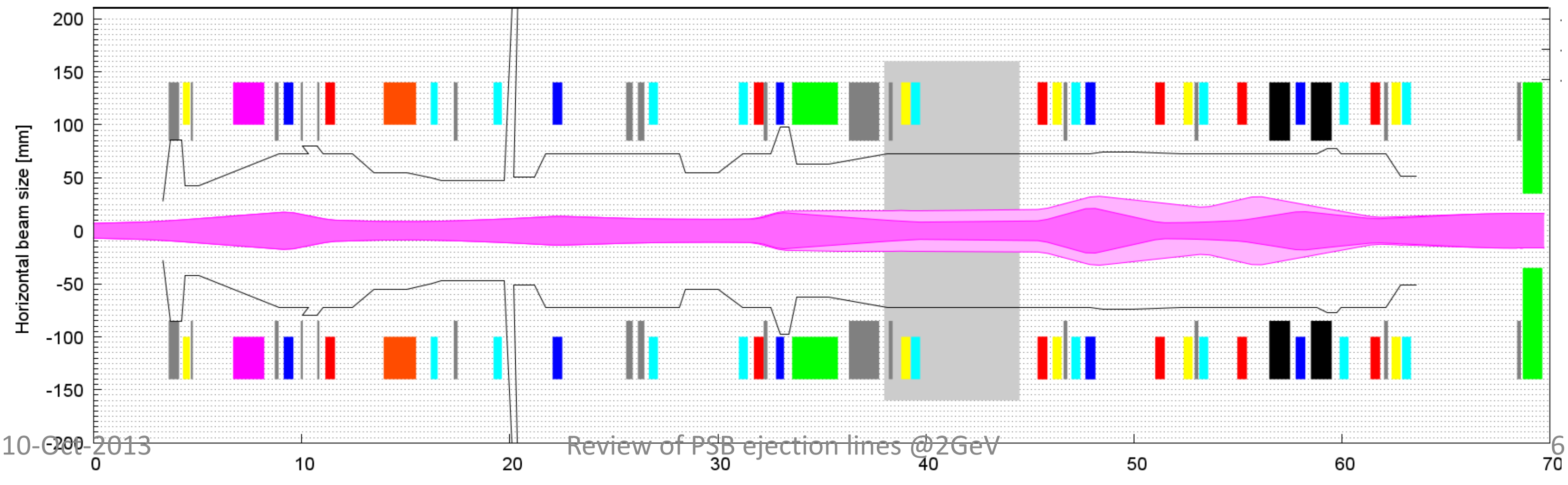
- Match horizontal dispersion to PS injection optics to reduce emittance blow-up
  - Improve luminosity for LHC beams
  - Reduce losses in PS for HI beams

- Squeeze beams at PS injection
  - Only for HI large emittance beams
  - Reduce radiation, equipment aging and beam loss
  - Requires a dedicated injection optics in the PS

- Preserve existing (mismatched) optics settings at PS injection
  - Fallback solution in case of too small beams (SC) in the PS due to missing emittance blow-up from mismatch

Madx Model

- Based on 2013 repository folder
- Changes for 2GeV upgrade model
  - BT.SMV10 and 20: longer and shifted
    - Marginal effect on optics, but rematching of recombination trajectory required (within 1.4 GeV limits feasible)
  - BT.BHZ10: longer, exit position remains
    - Marginal effect on optics
  - Complete reshuffling of all elements downstream of the wall
    - Quadrupole in wall not used as for present (non-MD) operation
    - One quadrupole added, one BPM added

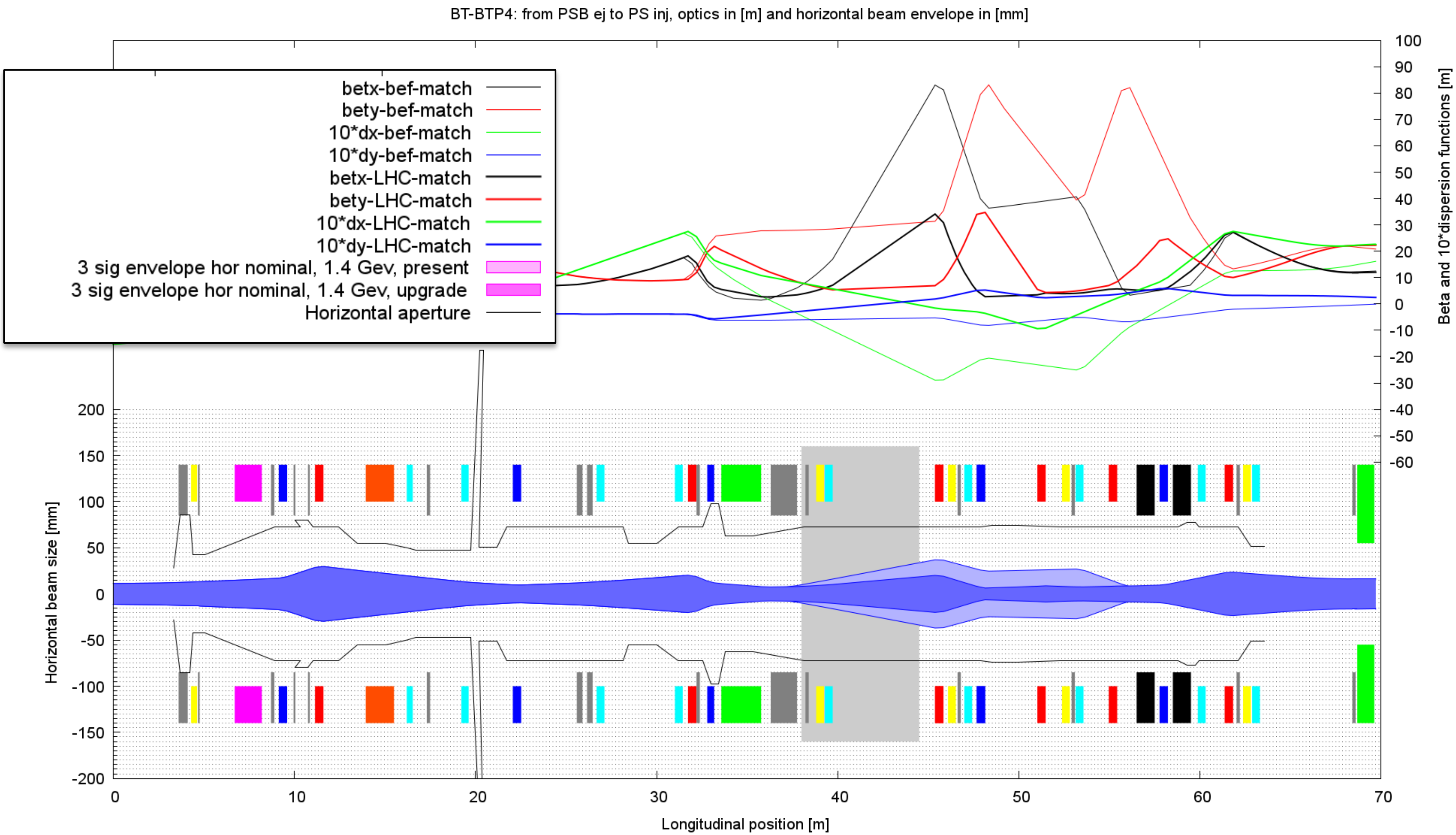


Apertures/gradients

- All magnets in BT-BTM-BTP need to work at 2 GeV
  - Gradients given for 2 GeV

- All elements need to accept beams at 1.4 GeV
  - Good field region (GFR) given at 1.4 GeV
  - $A_{x,y} = \pm n_{sig} \cdot \sqrt{k_\beta \cdot \beta_{x,y} \cdot \frac{\epsilon_{x,y}}{\beta\gamma}} \pm D_{x,y} \cdot k_\beta \cdot \frac{\Delta p}{p} \pm CO \cdot \sqrt{\frac{\beta_{x,y}}{\beta_{xmax,ymax}}}$
  - n_{sig} = 3, k_β = 1.2, CO = 3 mm
  - $\frac{\Delta p}{p}$ (1 sig, rms):
    - 1.07e-3 (LHC)
    - 1.35e-3 (HI)
  - Emittance(1 sig, rms):
    - 2/2 um (LHC)
    - 10/5 um (HI)

BTBTP: LHC optics



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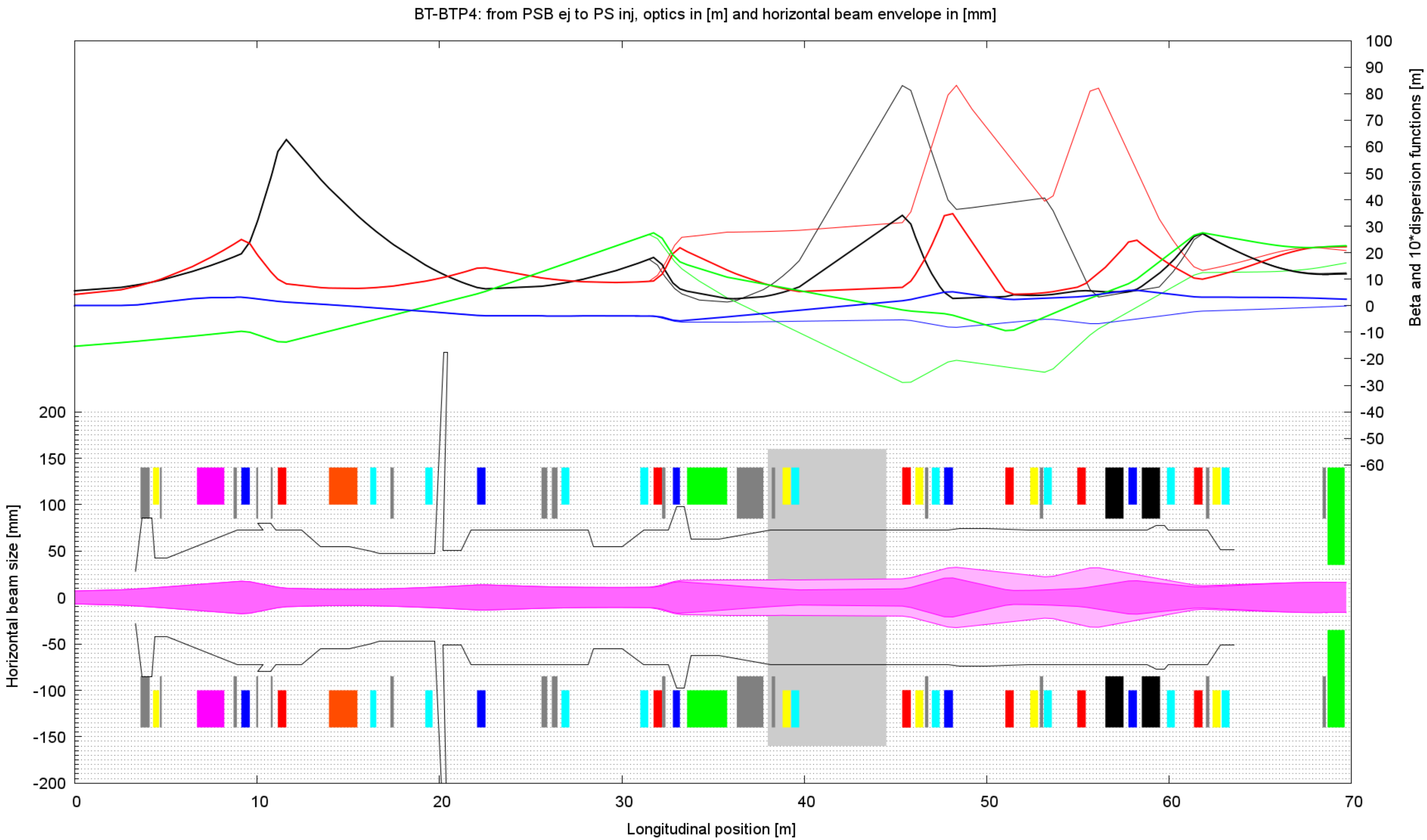
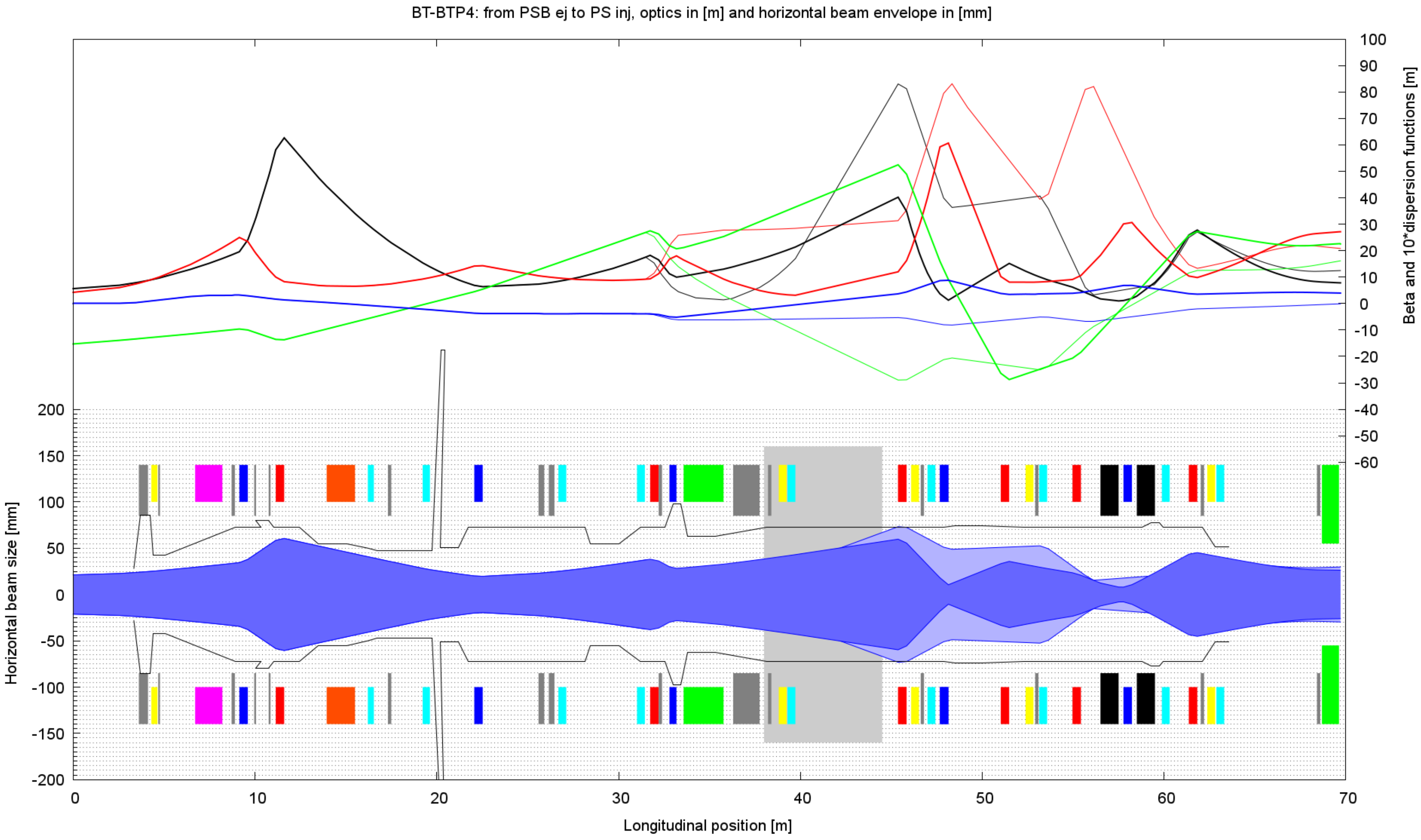


BTBTP: HI optics



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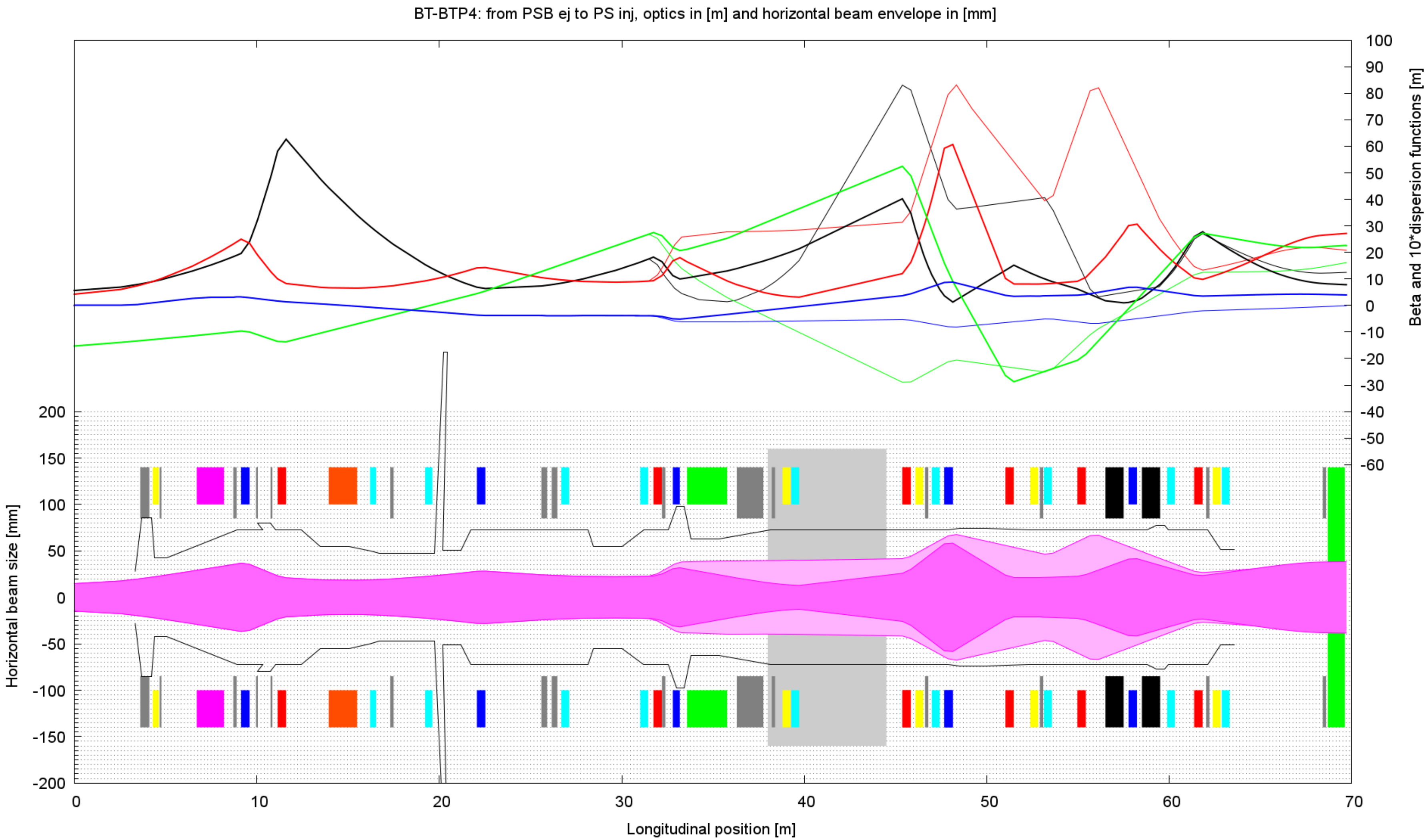
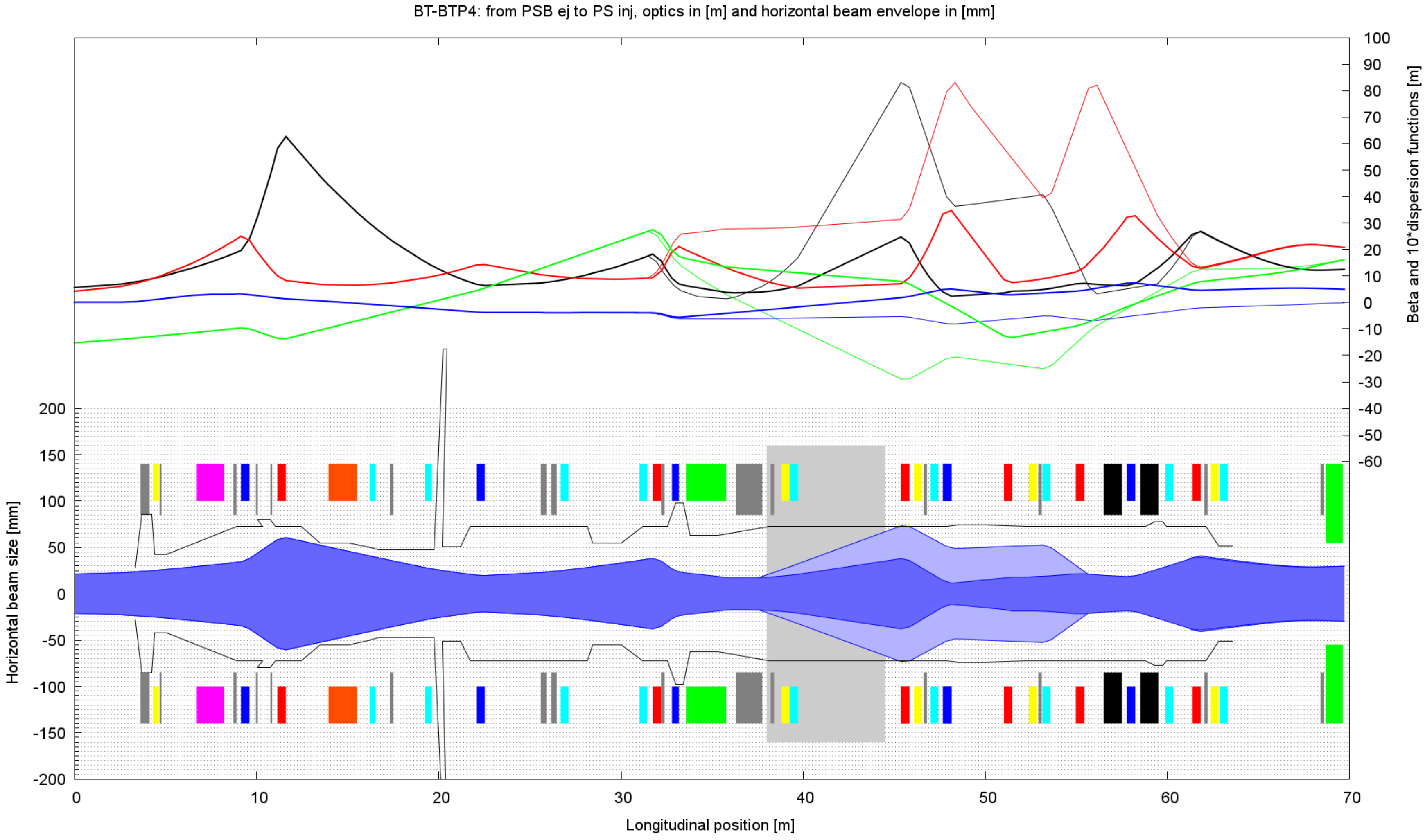


BTBTP: Present optics



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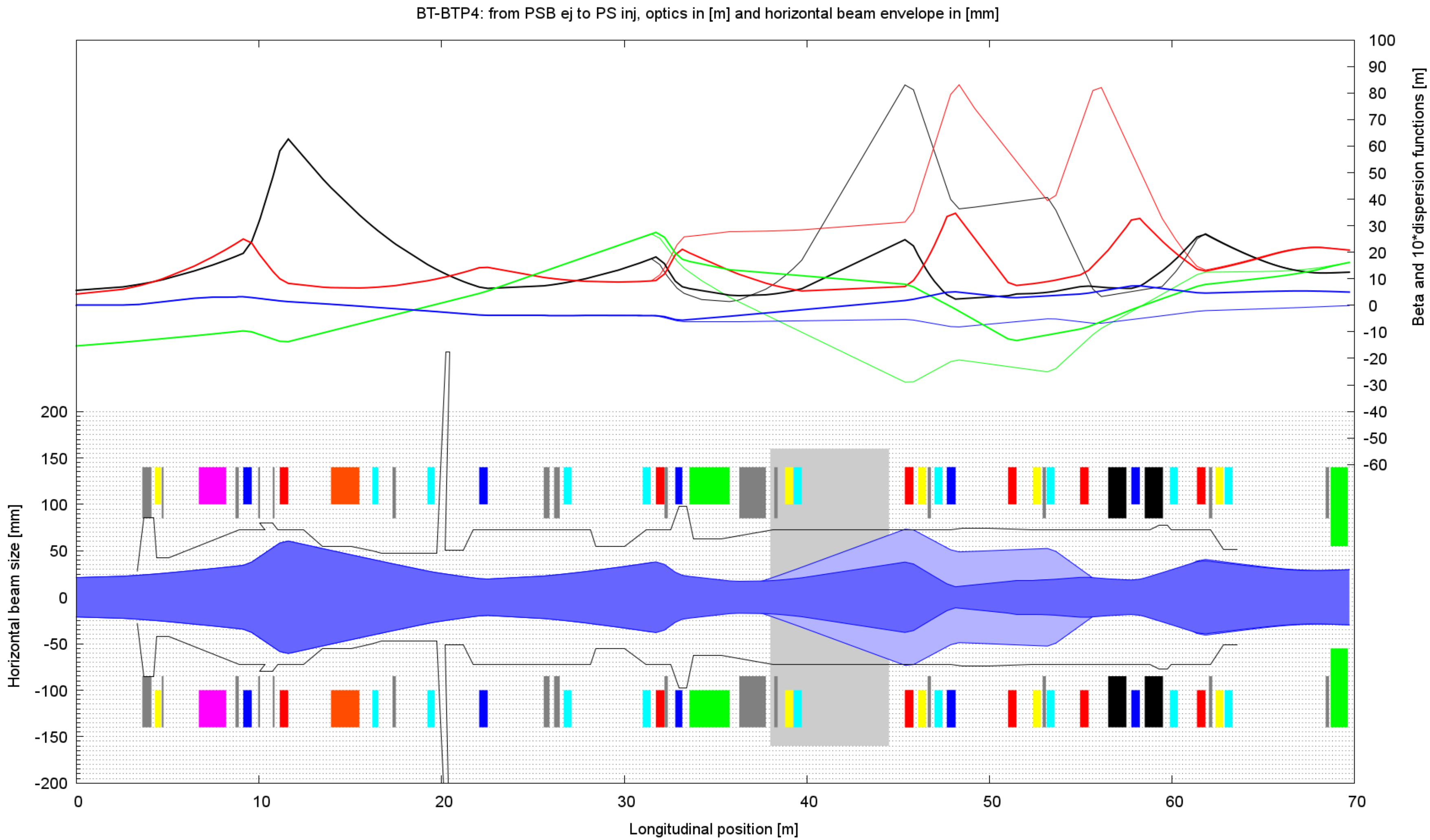

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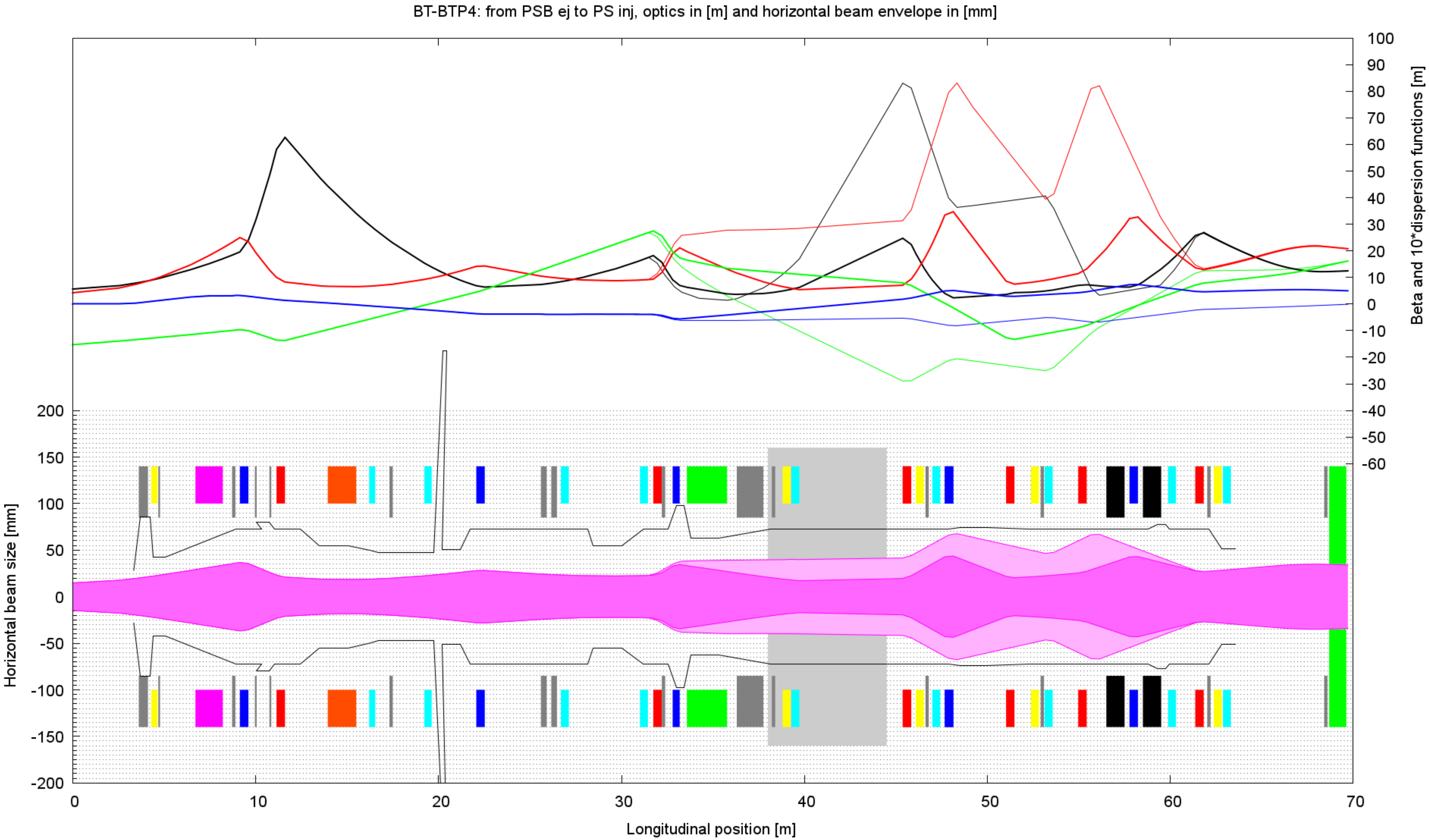


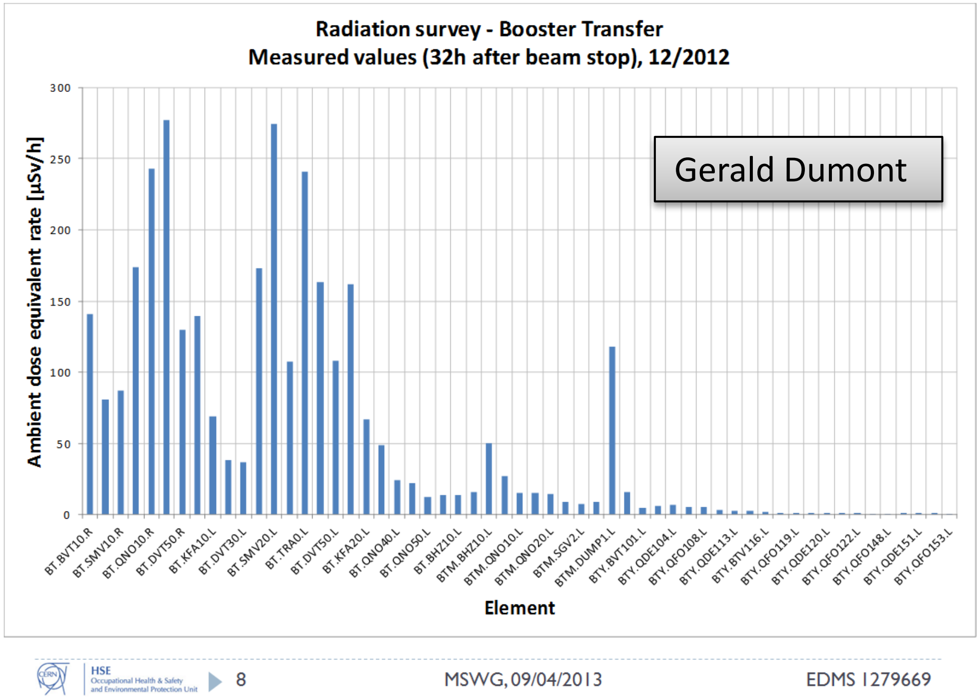
BT-BTM

Measurement line

- 4 optics settings:
  - Dump, ISOLDE
  - Hor. Emittance (Large Dispersion)
  - Hor. Emittance (Small Dispersion)
  - Vertical Emittance

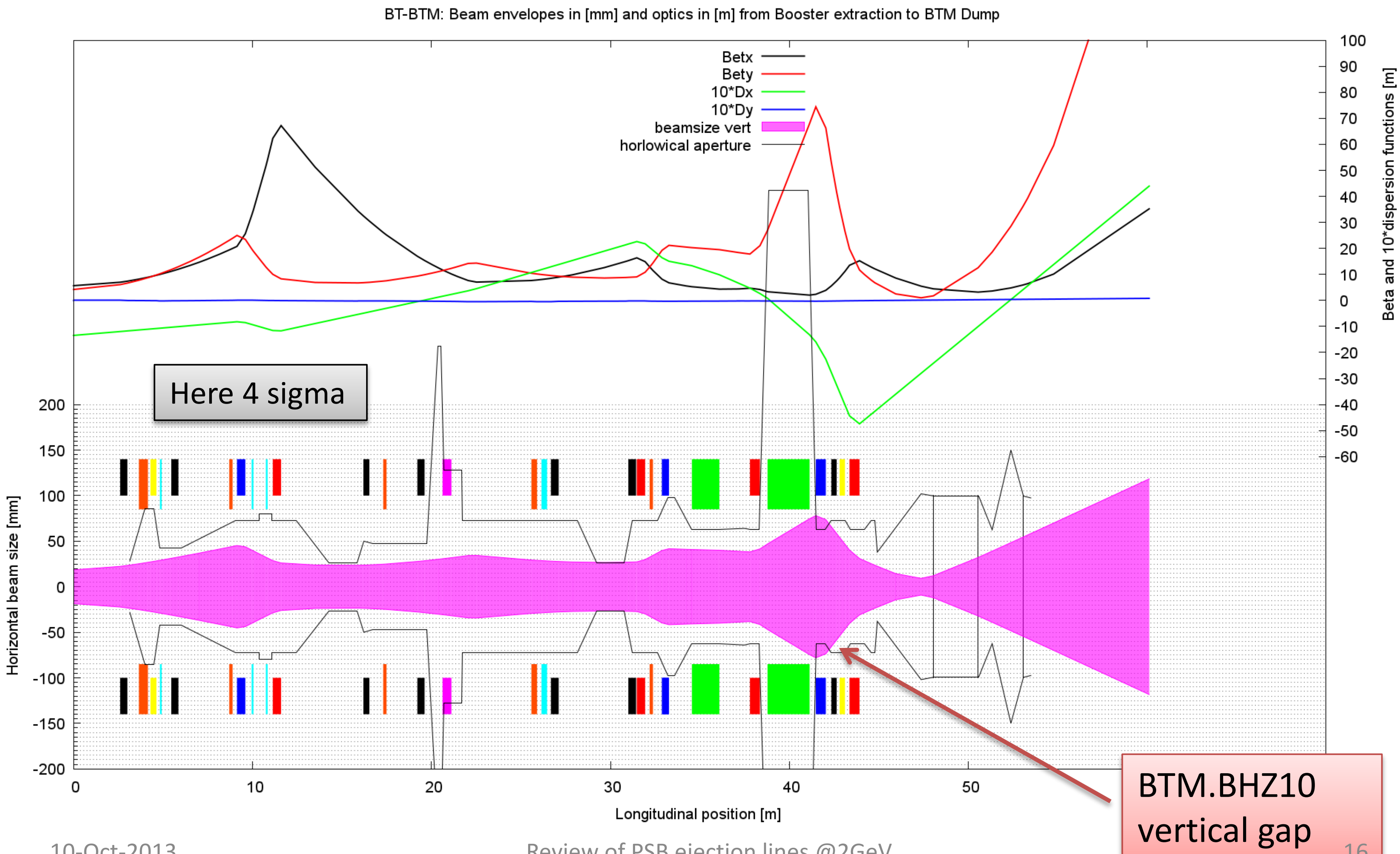
- Potential issue with losses in area of BTM.BHZ10
  - Rematch for beam size?

- Any change of the BTM line should not hinder the possible 2 GeV upgrade of BTY for ISOLDE



- Best to look at both upgrades simultaneously

BTM aperture bottlenecks



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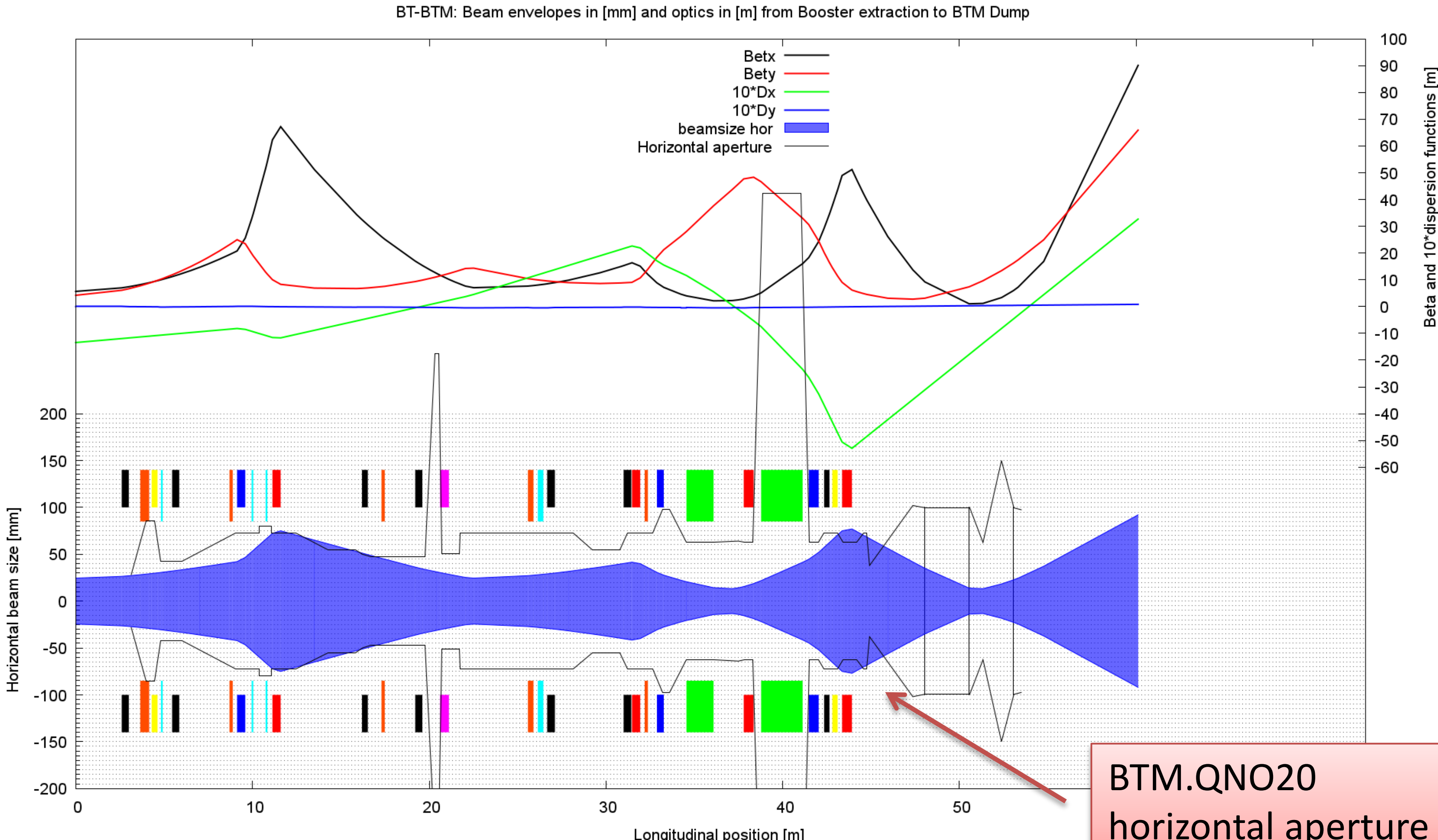


BTM.QNO20 horizontal aperture

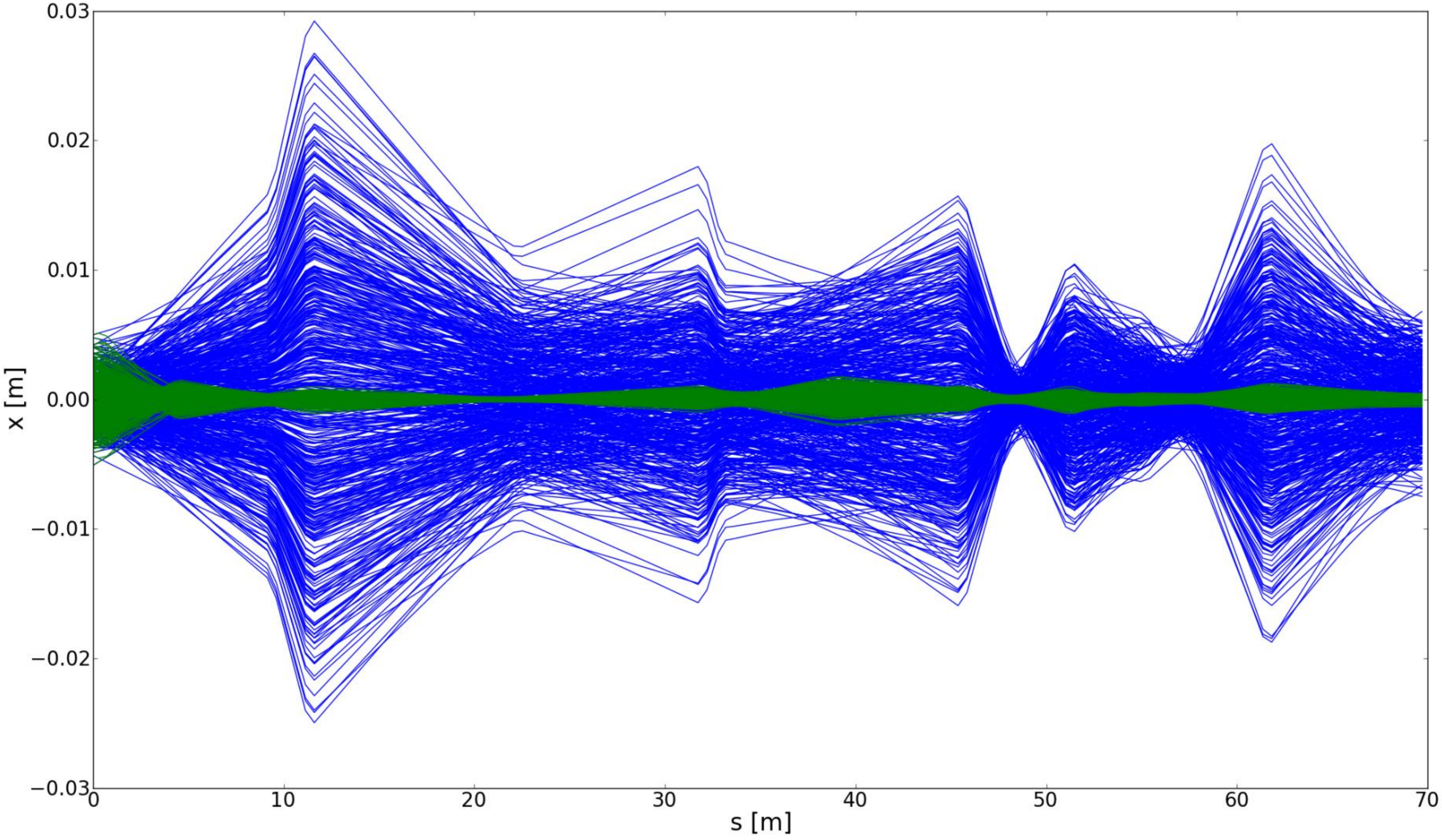
Trajectory correction

- Positions and angles at start of the line according phase space distribution
- Error assignment

	DS, DX ,DY 1 σ rms, cutoff 2σ [mm]	DPHI, DTHETA, DPSI 1 σ rms, cutoff 2σ [mrad]	Rel. error of integr. field along axis 1 σ rms, cutoff 2σ
Quadrupole	0.2	0.3	1e-3
Dipole	0.3	0.3	4e-3
Corrector	0.3	0.3	4e-5
Monitor	0.3	0.3	

- Installed additional Hkicker at beginning of line to simulate correction effect of extraction septum
- Results shown for HI beam optics, 500 machines

Trajectory correction: HOR



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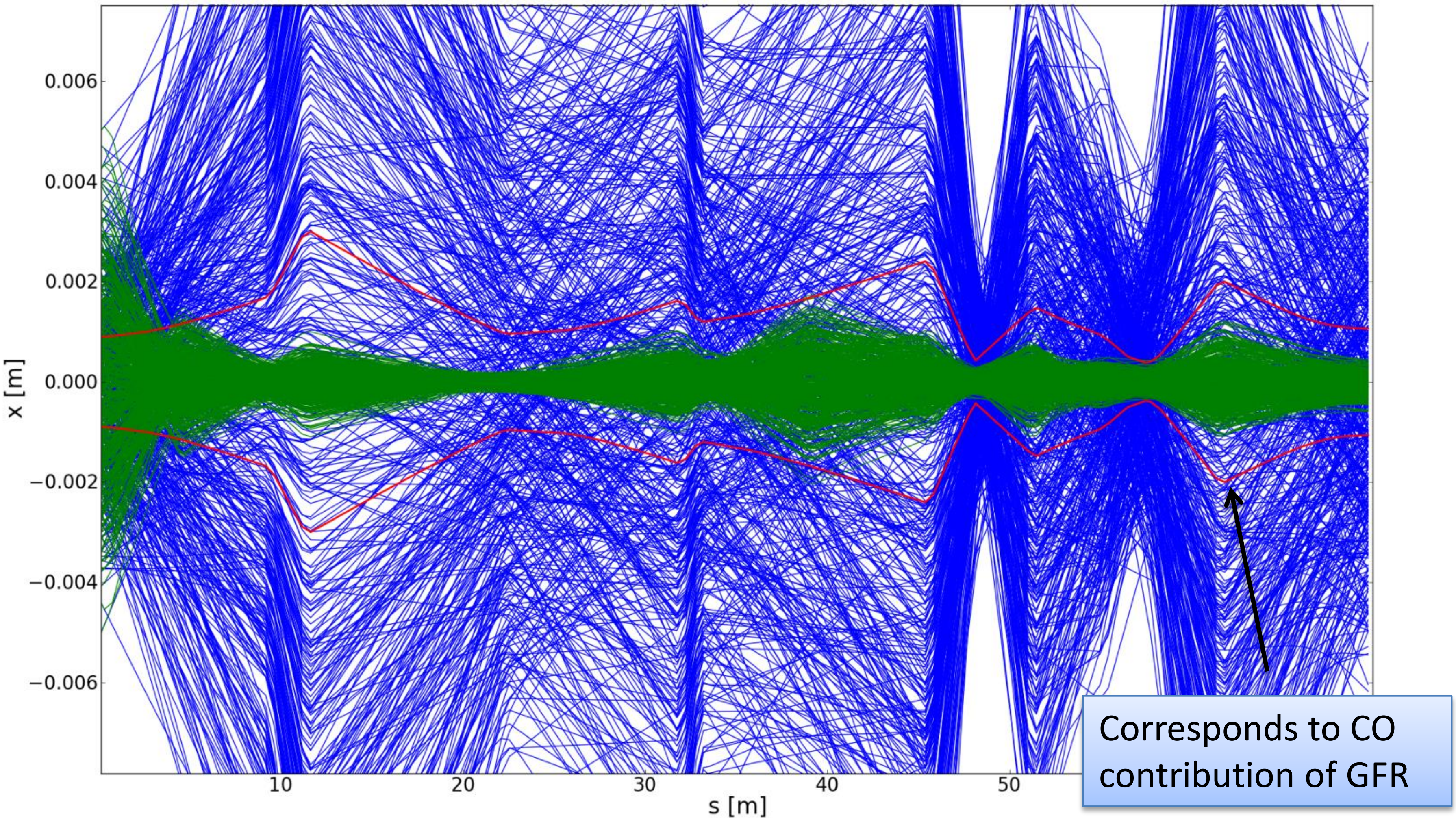

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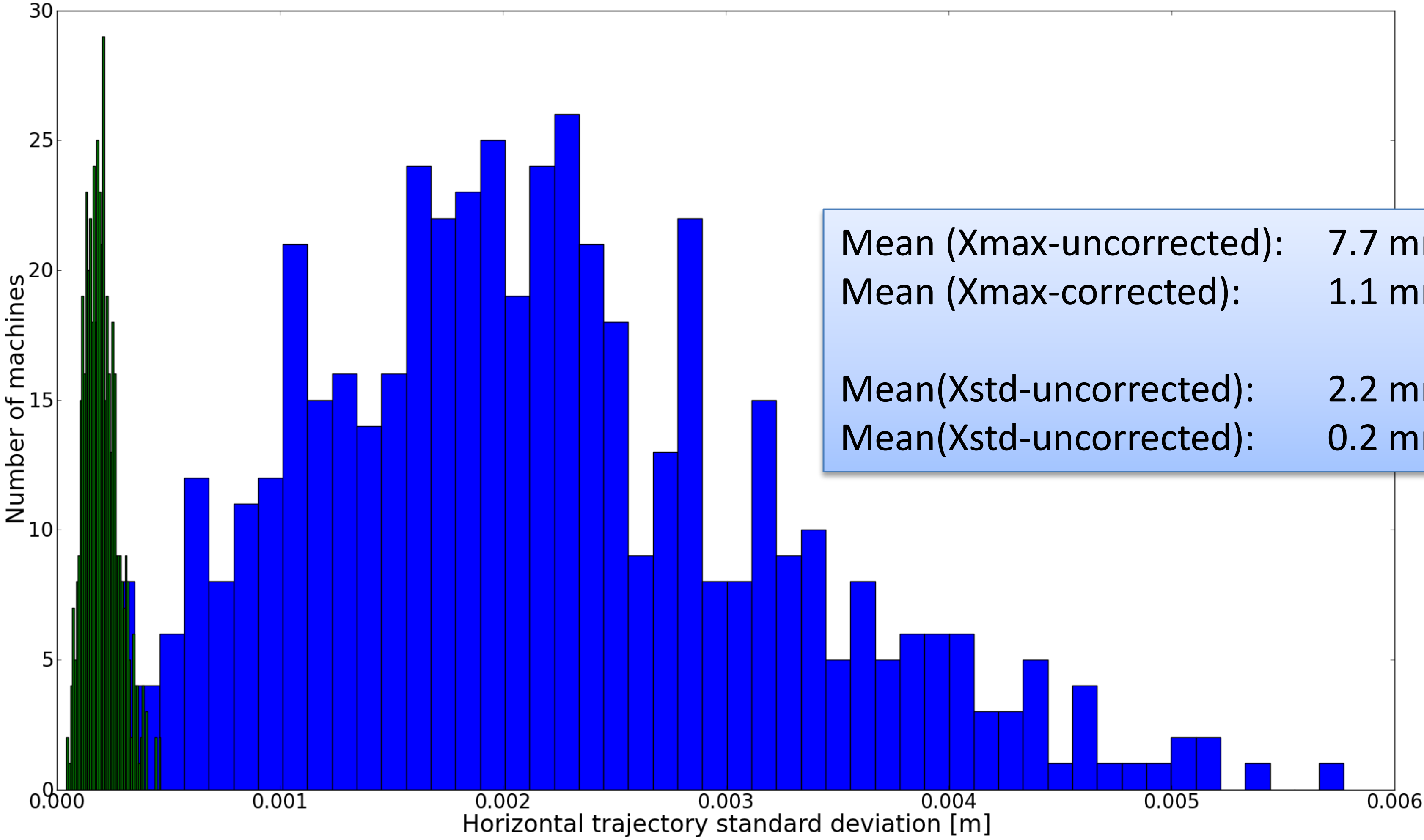
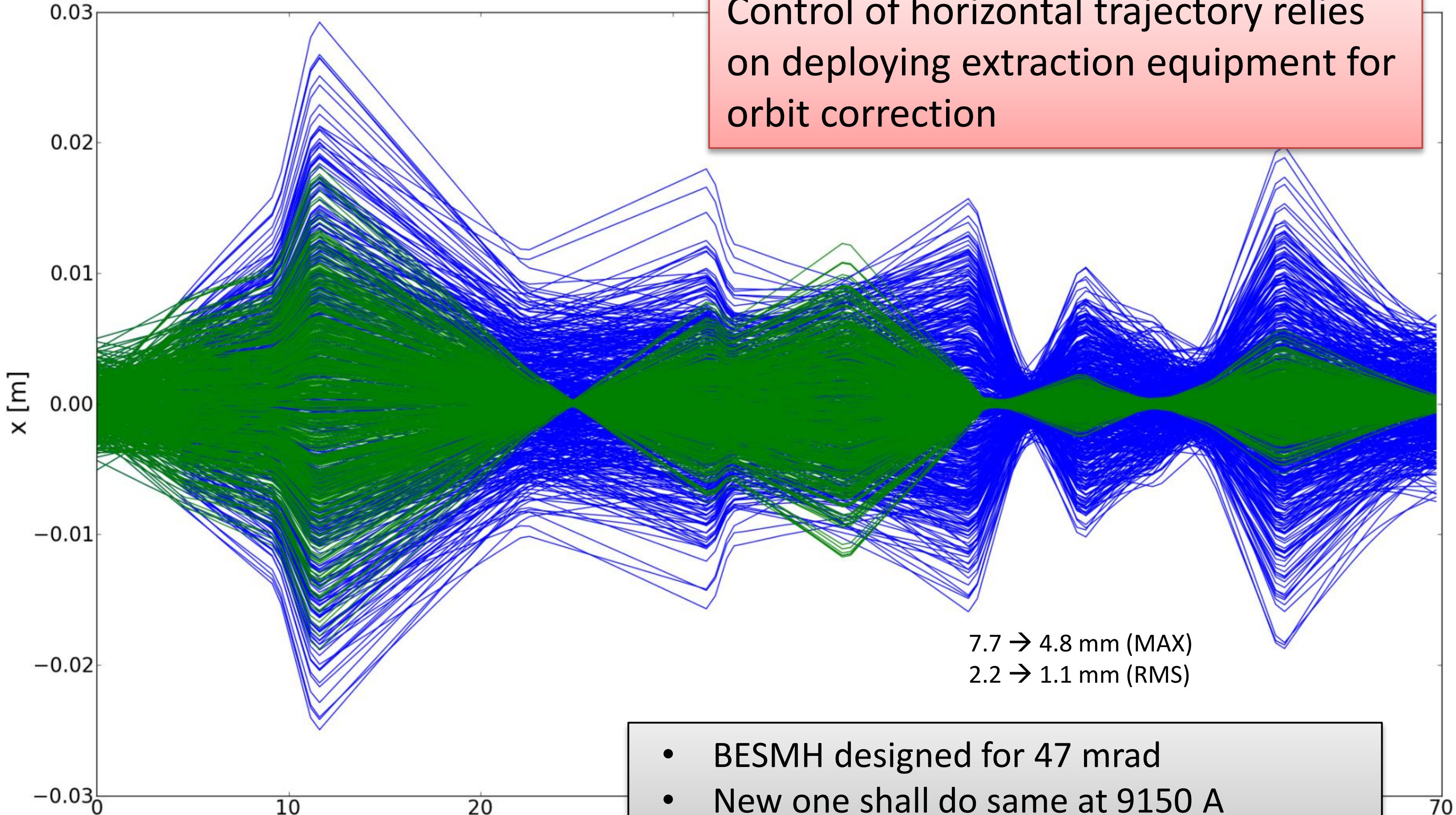


Mean (Xmax-uncorrected):	7.7 mm
Mean (Xmax-corrected):	1.1 mm
Mean(Xstd-uncorrected):	2.2 mm
Mean(Xstd-uncorrected):	0.2 mm

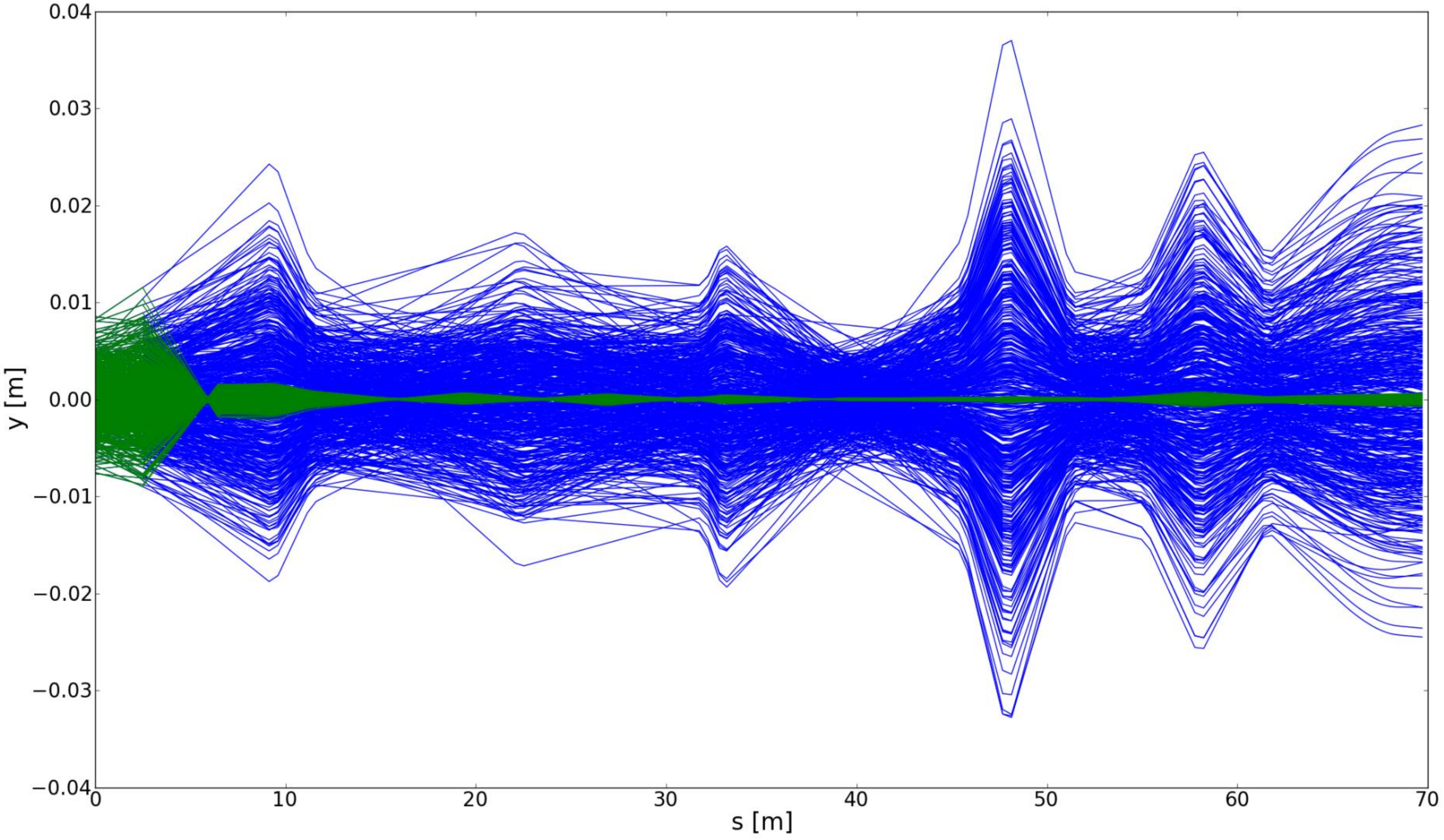
Trajectory correction HOR without septum knob

Control of horizontal trajectory relies on deploying extraction equipment for orbit correction

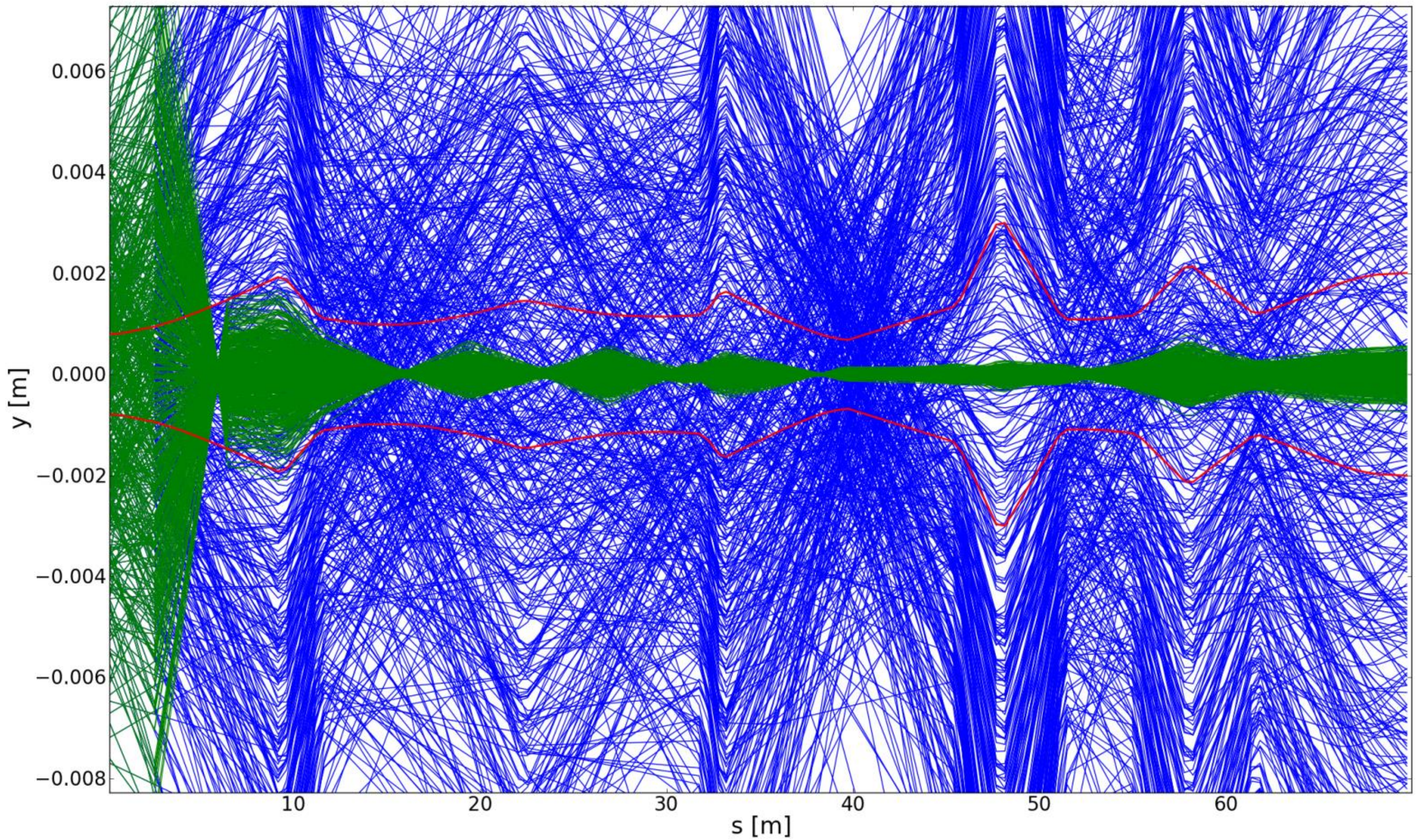


- BESMH designed for 47 mrad
- New one shall do same at 9150 A
- 2 mrad for steering are feasible (9.6 kA)

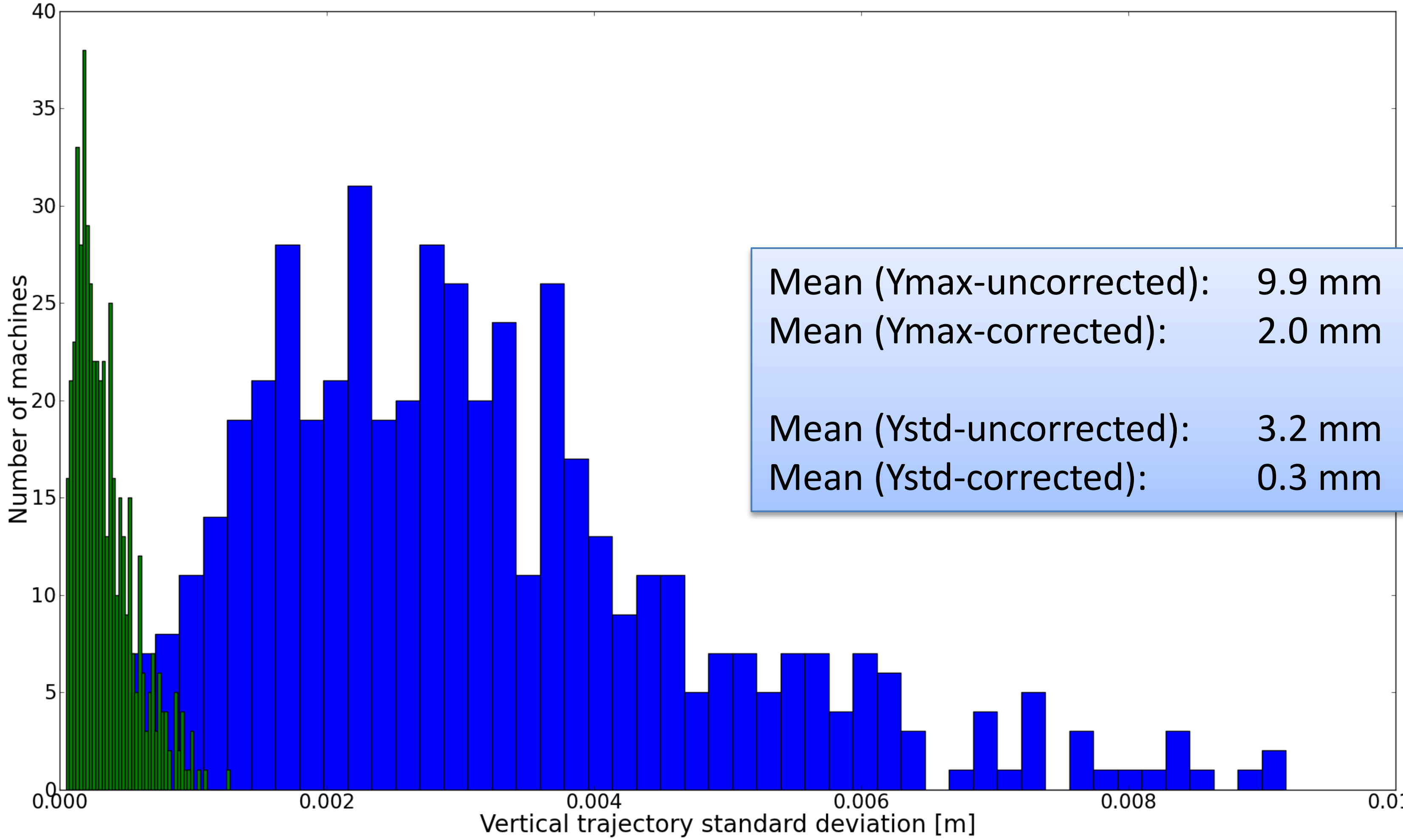
Trajectory correction: VERT



Trajectory correction: VERT



Trajectory correction: VERT

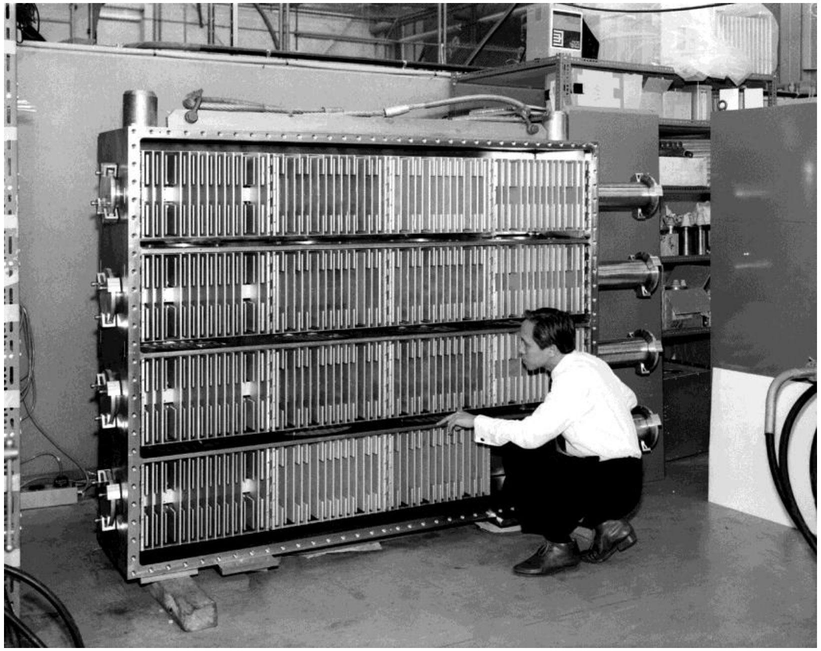


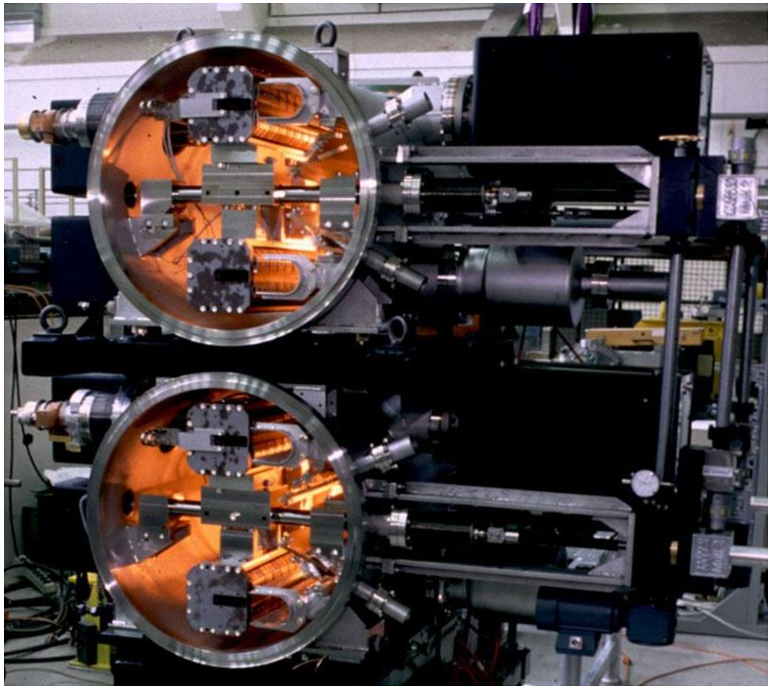
Mean (Ymax-uncorrected):	9.9 mm
Mean (Ymax-corrected):	2.0 mm
Mean (Ystd-uncorrected):	3.2 mm
Mean (Ystd-corrected):	0.3 mm

HW upgrades/implications

PSB extraction

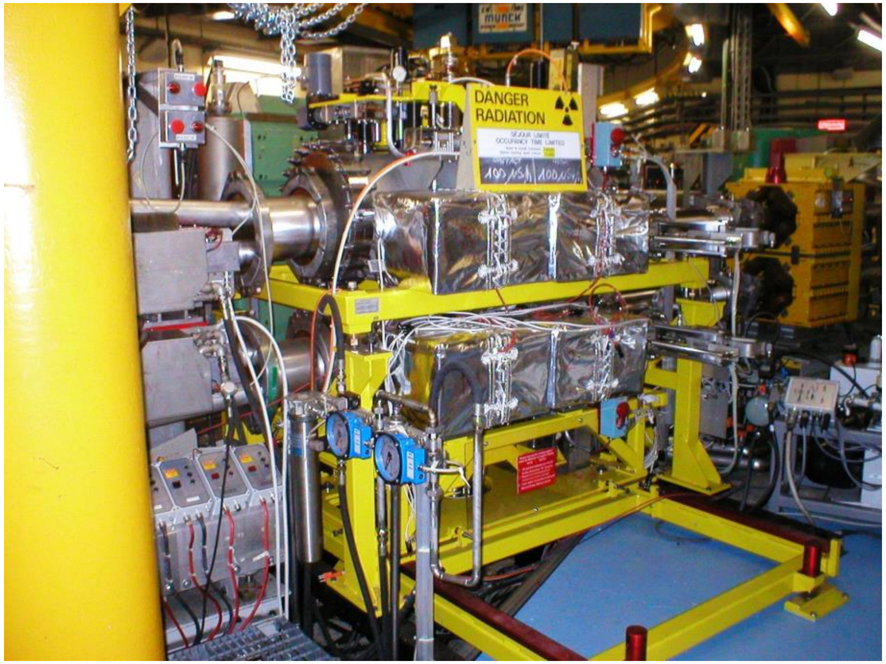
- PSB extraction bumpers → OK with present system
- PSB extraction kickers → on the limit – to be measured which field can be reached in ferrites
- PSB extraction septa: bus bars to be reinforced, magnets to be cooled in parallel to deal with increased RMS current





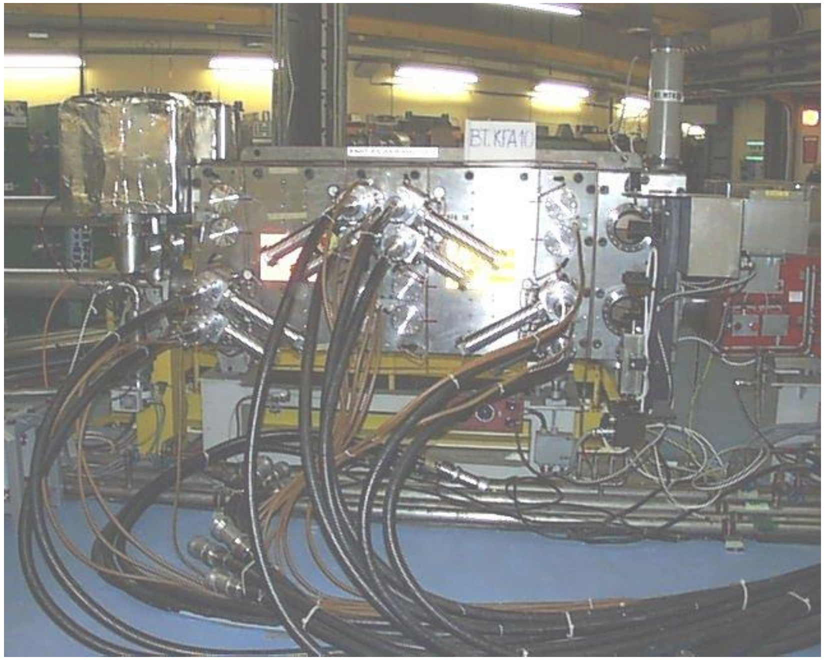
Recombination Septa

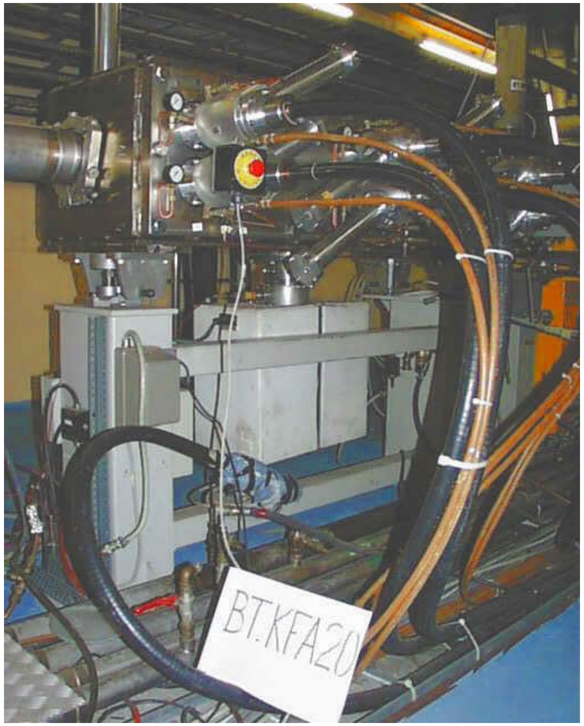
- BT recombination septa (BT.SMV10 and BT.SMV20):
  - new magnets (from 1060 to 1300 mm) to be inserted into existing vacuum vessel
  - BI equipment to be moved outside vessel to provide space for longer magnets
  - Baseline accepts vacuum degradation (longer magnet,but smaller laminations)



Recomb. Kickers

- BT recombination kicker (BT.KFA10 and BT.KFA20)
  - 202 mT required vs 200 mT max in the KFA10 ferrite
  - Ferrite replacement for KFA.10 recommended because of poor vacuum peformance of present type
  - KFA.20 OK





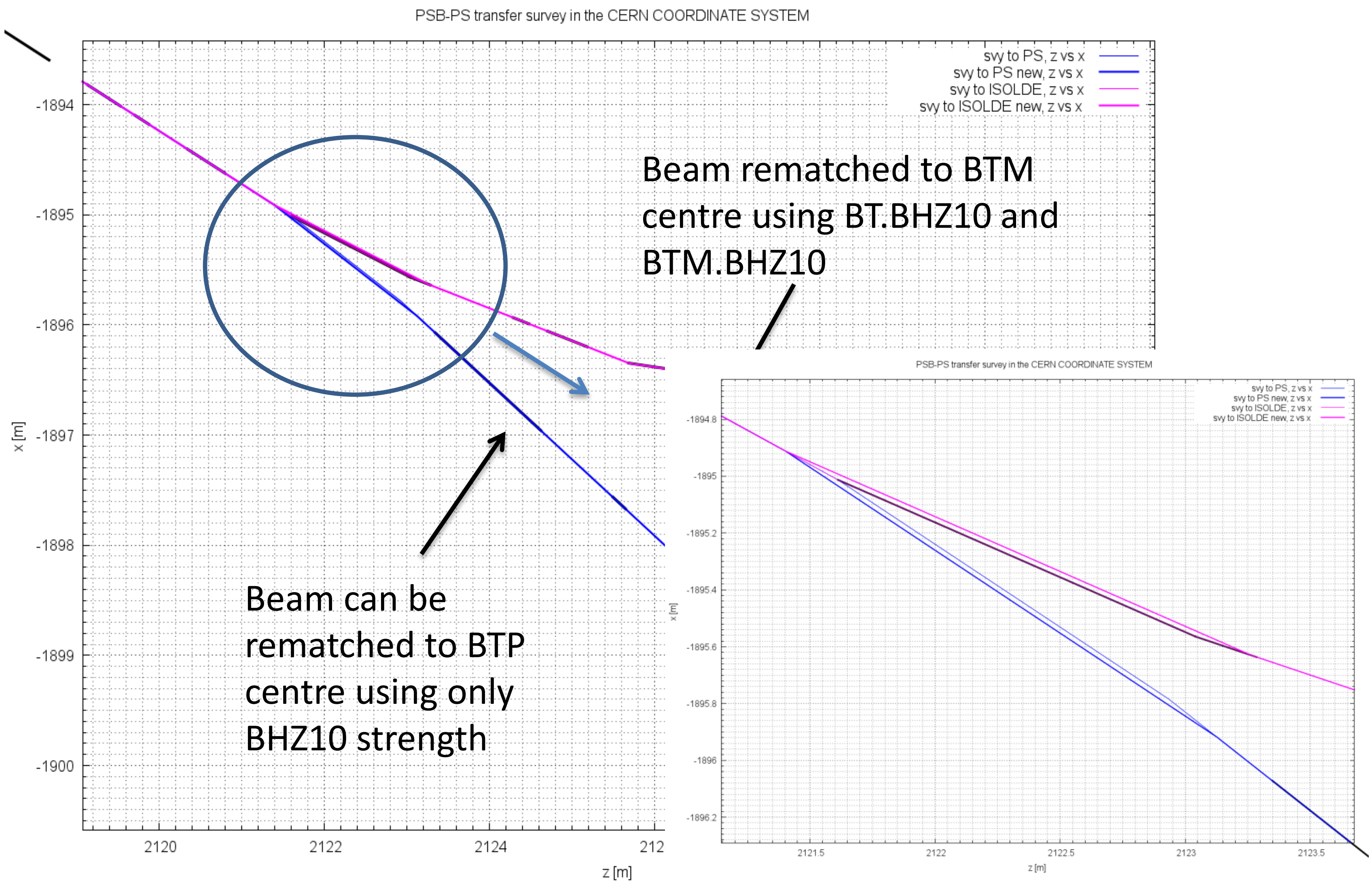
BT.BHZ10

Switching dipole between measurement line and PS

- Several options studied and presented
- Choice (IEFC meeting) for longer magnet with existing power supply
- In case of replacement before LS2 (no spare) the line geometry and optics can be rematched
- Magnet design ongoing
- Effect of field errors simulated by tracking particles through Opera field model and feeding back into Madx

	Option	Technically feasible	Effect on TL geometry	Spare policy	Cost/Manpower
0	Baseline: build spare magnet (Consolidation) and 2 power supplies (PSB-LIU 2GeV)	Issues with higher fields/Saturation and a faster ramp required are difficult to predict – no spare exists to measure!	No effect	1+1 magnet	200kCHF for spare magnet 750 kCHF for 2 power supplies
1	Longer BHZ10+ existing PS	Feasible; Integration of vacuum chamber to be studied	minimal	1+1 magnet	275 kCHF per magnet 50 kCHF for PS controls update
2	Split C-shaped magnets	Horizontal gap reduced; if existing PS used need to reduce vert gap by 6 cm; Difficult because same field in 1m length; lot of turns needed; more hardware (reliability)	More severe because different deflection point for at least one line	Have to build 2+1 magnets; maybe reduced # PS if switching possible	New magnets and PS needed if gap stays the same and switching not preferred, 500kCHF per PS; 200kCHF per magnet;
3	Existing BHZ10 + opposite field septum	Opposite field septum seems difficult; Takes more space for integration, almost full 3m available; more hardware (reliability)	Due to inflexibility in positioning effect on TL geometry expected	BHZ10 spare could be built immediately; Septum + spare; Reuse existing PS but new ones for septum needed	Dominated by septum and its PS cost, > 1 MCHF; Budget for spare BHZ10 is already available
4	Kicker + septa	Integration in lattice very difficult, a lot of space needed; more hardware (reliability)	TL geometry strongly affected	Kicker +1, first septum +1, second septum +1, power supplies, lifetime?	~3 MCHF in 2000 for 1.4 GeV

BHZ10 upgrade – TL geometry



BTM.BHZ10

Strong horizontal bend in measurement line

- Several options studied to cover 2 GeV upgrade
- Choice (PSB-LIU meeting) for building a new magnet with same length as present and new power supply
- Assuming the present optics, the required GFR is:
  - Width: 86 mm, Height: 124 mm
- Magnet design ongoing

J. Cole, A. Newborough, S. Pittet

Option 1	Present magnet with no modifications	0	kCHF
	B8 power supply + spare	750	kCHF
	Total	750	kCHF
Option 2	Present magnet with additional coils +spare	120	kCHF
	New S500 + spare	170	kCHF
	Existing B1/IEP	0	kCHF
	Total	290	kCHF
Option 3	Present magnet with additional coils + spare	120	kCHF
	New power supply + spare	450	kCHF
	Reuse of existing power supply	-240	kCHF
	Total	330	kCHF
Option 4	New magnet + spare	500	kCHF
	Existing B1/IEP with additional extraction system	50	kCHF
	Total	550	kCHF
Option 5	New magnet + spare	500	kCHF
	New power supply + spare	300	kCHF
	Reuse of existing power supply	-240	kCHF
	Total	560	kCHF

BT/BTP Quadrupole Gradients

Magnet	Length [m]	k1 [1/m**2]	Gradient@2GeV [T/m]	Max gradient [T/m]	GFR radius h/v [mm]
FIXED TARGET BEAM SETTINGS					
"BT4.QNO10"	0.466	0.66749	6.20	7.44	39 / 27
"BT4.QNO20"	0.466	-0.63160	-5.87	-7.04	62 / 16
"BT3.QNO30"	0.466	0.28709	2.67	3.20	20 / 21
"BT.QNO40"	0.466	0.77414	7.19	8.63	38 / 19
"BT.QNO50"	0.388	-1.06415	-9.88	-11.86	30 / 24
"BTP.QNO20"	0.465	0.86720	8.05	9.67	59 / 23
"BTP.QNO30"	0.465	-0.98315	-9.13	-10.96	11 / 44
"BTP.Q35"	0.466	1.11613	10.37	12.44	38 / 16
"BTP.QNO50"	0.465	0.54924	5.10	6.12	22 / 19
"BTP.Q55"	0.466	-0.66216	-6.15	-7.38	11 / 31
"BTP.QNO60"	0.465	0.69688	6.47	7.77	47 / 18
LHC BEAM SETTINGS					
"BT4.QNO10"	0.466	0.66749	6.20	7.44	20 / 18
"BT4.QNO20"	0.466	-0.63160	-5.87	-7.04	31 / 11
"BT3.QNO30"	0.466	0.28709	2.67	3.20	10 / 15
"BT.QNO40"	0.466	1.04156	9.67	11.61	20 / 14
"BT.QNO50"	0.388	-1.15395	-10.72	-12.86	13 / 18
"BTP.QNO20"	0.465	0.89488	8.31	9.97	20 / 12
"BTP.QNO30"	0.465	-0.99915	-9.28	-11.14	7 / 23
"BTP.Q35"	0.466	1.11518	10.36	12.43	9 / 8
"BTP.QNO50"	0.465	0.39606	3.68	4.41	9 / 11
"BTP.Q55"	0.466	-0.62347	-5.79	-6.95	11 / 20
"BTP.QNO60"	0.465	0.50982	4.74	5.68	25 / 12
PRESENT BEAM SETTINGS					
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"BT.QNO50"	0.388	-1.11999	-10.40	-12.48	25 / 27
"BTP.QNO20"	0.465	0.87258	8.10	9.73	37 / 17
"BTP.QNO30"	0.465	-0.91801	-8.53	-10.23	12 / 34
"BTP.Q35"	0.466	0.83747	7.78	9.33	19 / 16
"BTP.QNO50"	0.465	0.37048	3.44	4.13	22 / 21
"BTP.Q55"	0.466	-0.57546	-5.34	-6.41	20 / 33
"BTP.QNO60"	0.465	0.47763	4.44	5.32	40 / 21

- BT quads in recombination area not changed for any of the optics variants; need to provide 30% increase in Brho (2GeV)
- Present limit of 10.07 T/m just at the edge of saturation
- Last 3 quadrupoles in BTP can reach the specified gradient without change in length
- Last two BT quads (BT.QNO40 and 50) and first three BTP quads (BTP.QNO20,30 and 35) need an increase of the magnetic length from 466 to ~570 mm

Even if length stays the same: New laminated magnets for ppm

BT/BTP Quadrupole GFR

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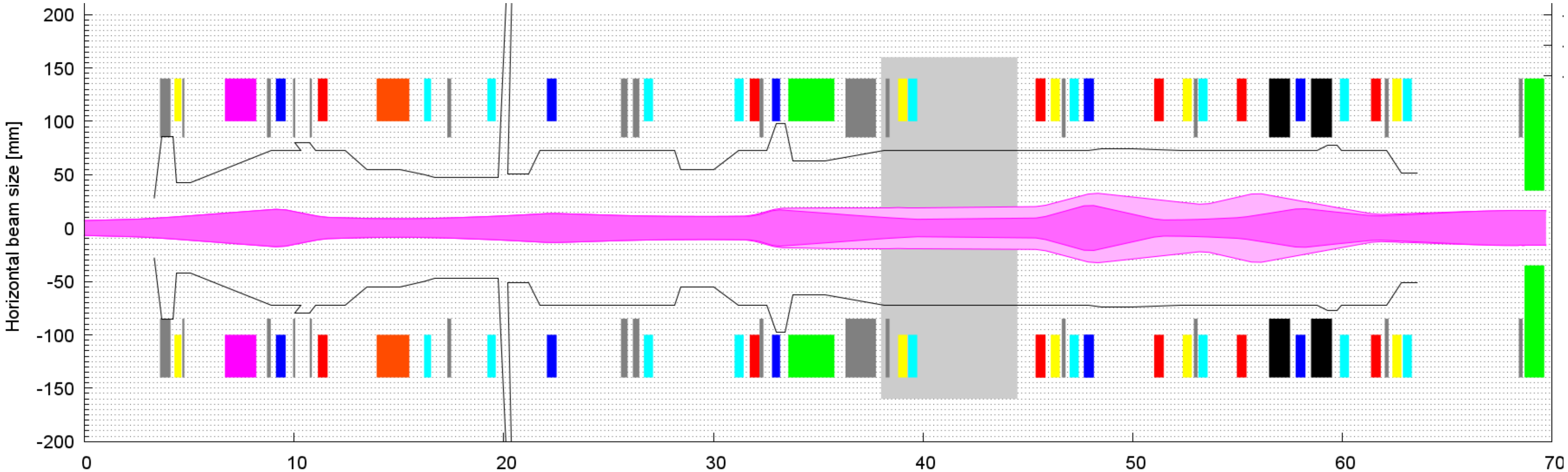
- Present quad opening is 150 mm
- 2/3 for GFR comfortable
- ¾ for GFR possible
  - 56 mm
- BT.QNO20 requires 62 mm, but not foreseen to be changed
- BTP.QNO20 requires 59 mm – on the limit

Only one quadrupole length

- Need 570 mm magnetic length (for at least 4 quadrupoles)
  - now 466 mm
- Envelope ~700 mm
  - Now 590 mm
  - Need extra 660 mm in line after wall – looks feasible
  - Need extra 220 mm upstream BT.BHZ10 – looks feasible as well
  - 3D model of integration required



BT/BTM Quadrupoles

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"BT3.QNO30"	0.466	0.28709	2.67	3.20	25 / 27
"BT.QNO40"	0.466	0.73355	6.81	8.18	41 / 24
"BT.QNO50"	0.388	-0.71408	-6.63	-7.96	28 / 33
"BTM.QNO05"	0.560	0.62599	5.81	6.98	19 / 33
"BTM.QNO10"	0.560	-0.81000	-7.52	-9.03	25 / 58
"BTM.QNO20"	0.560	0.84011	7.80	9.36	50 / 24
HORIZONTAL EMITTANCE SETTINGS - LOW DISPERSION					
"BT3.QNO10"	0.466	0.66749	6.20	7.44	47 / 35
"BT3.QNO20"	0.466	-0.63160	-5.87	-7.04	76 / 21
"BT3.QNO30"	0.466	0.28709	2.67	3.20	25 / 28
"BT.QNO40"	0.466	0.68125	6.33	7.59	41 / 24
"BT.QNO50"	0.388	-0.89763	-8.34	-10.00	30 / 32
"BTM.QNO05"	0.560	0.67236	6.24	7.49	32 / 19
"BTM.QNO10"	0.560	-0.75464	-7.01	-8.41	18 / 31
"BTM.QNO20"	0.560	0.93745	8.71	10.45	44 / 15
HORIZONTAL EMITTANCE SETTINGS - LARGE DISPERSION					
"BT3.QNO10"	0.466	0.66749	6.20	7.44	47 / 35
"BT3.QNO20"	0.466	-0.63160	-5.87	-7.04	76 / 21
"BT3.QNO30"	0.466	0.28709	2.67	3.20	25 / 28
"BT.QNO40"	0.466	0.67782	6.30	7.55	41 / 24
"BT.QNO50"	0.388	-0.32477	-3.02	-3.62	29 / 34
"BTM.QNO05"	0.560	-0.19195	-1.78	-2.14	19 / 51
"BTM.QNO10"	0.560	-0.29569	-2.75	-3.30	54 / 36
"BTM.QNO20"	0.560	0.63928	5.94	7.13	80 / 18
VERTICAL EMITTANCE SETTINGS					
"BT3.QNO10"	0.466	0.66749	6.20	7.44	47 / 35
"BT3.QNO20"	0.466	-0.63160	-5.87	-7.04	76 / 21
"BT3.QNO30"	0.466	0.28709	2.67	3.20	25 / 28
"BT.QNO40"	0.466	0.60386	5.61	6.73	42 / 24
"BT.QNO50"	0.388	-0.39158	-3.64	-4.36	31 / 32
"BTM.QNO05"	0.560	-0.22342	-2.08	-2.49	20 / 42
"BTM.QNO10"	0.560	0.74961	6.96	8.35	35 / 30
"BTM.QNO20"	0.560	-0.60803	-5.65	-6.78	22 / 39

- No change in optics in BTM
- All quadrupoles need to provide 30% increase in Brho (2GeV)

Steerers

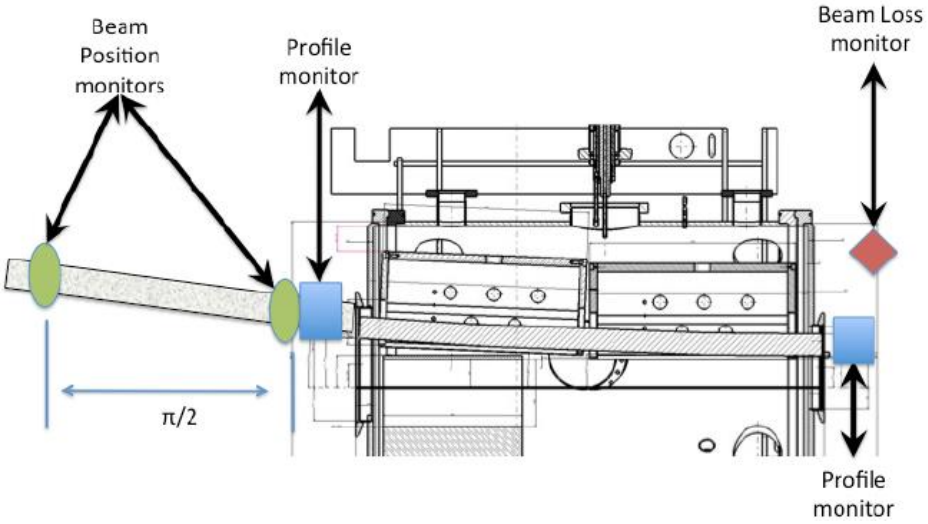
- Vertical recombination magnets (DVT, BVT)
  - 30% increase Brho
- Trajectory correction steerers
  - Additional H/V pair in the wall (air-cooled) to be able to use the existing pair even if one fails
  - Due to recombination a lot of vertical correction possibilities
  - Essential to deploy extraction septum as horizontal correction knob (include in YASP as suggested by Vivien)

Power supplies

- Based on outcome of review, detailed list of magnets/supplies will be checked by Serge
- Power supplies which can probably stay:
  - First three BT quads: BT.QNO10, 20 and 30
  - Steerers
  - BT.BHZ10

Beam position monitors

- Functional specification for PS injection instrumentation: https://edms.cern.ch/document/1207510/1
  - 90 deg in H (upstream BTP.QNO55)
  - 90 deg in V (upstream BTP.QNO20)
  - HI optics
- Additional BPM and profile monitors at the end of BTP just upstream the septum



- Reshuffling of monitor positions according to quadrupole positions in BTP

Scrapers

- Motivation:
  Reduce losses at PS injection with HI beams to mitigate radiation hot spot
- H and V scraper, moveable
- Position according HI beam optics
- To be studied if ‘relocation’ of losses is improving the radiation situation
- Beam distribution as input for FLUKA studies

Summary I

- 3 different sets of optics requirements
  - Matched in betx, alfx, bety, alfy, dx, dpx
  - Dy kept below 50 cm at PS inj
  - Tunability range mostly given by horizontal dispersion matching (1.61 m to 2.25 m)
  - Keep a margin of at least 20% in quadrupole gradient
  - GFR OK with existing quad opening apart from BT.QNO20 (already ppm) and BTP.QNO20 (59 vs 56 mm)

- Trajectory correction
  - OK in vertical plane
  - Need extraction kicker/septum as knob in horizontal plane
  - Envelope of corrected trajectories defines CO contribution for GFR specification

Summary II

- Recombination septa/kicker, BT.BHZ10, BTM.BHZ10 listed for completeness
- All dipoles not specifically mentioned (e.g. recombination steerers) need to provide kick strength at 2 GeV
- BTBTP quadrupoles:
  - 5 out of 8 need increase in magnetic length 466 → 570 mm (590 → 700 mm phys.)
  - 3 out of 8 could stay with present length (but new HW due to laminations)
  - If only one type of quads, should fit but integration model required
- BTBTP steerers
  - Additional H/V pair in the wall for redundancy (maintenance difficult)
- Power supplies
  - List to be checked in detail
  - Probably OK: First three BT quads, steerers, BT.BHZ10
- BTBTP position monitors
  - Functional specification for PS injection requires BPM upstream of SMH42 and another pair 90 deg upstream (depending on the optics this pair overlaps with already foreseen monitors)
- Scrapers
  - Position according HI beam optics
  - Beam distribution as input for FLUKA studies