Optimization of dynamic aperture for the ESRF upgrade

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on behalf of the
ASD Beam Dynamics Group

Workshop on Accelerator R&D for Ultimate Storage Rings
October 30-November 1, 2012 Huairou, Beijing

Outlines

- The Hybrid Multi-Bend (HMB) lattice
- Nonlinear optics: existing ESR SR Vs HMB lattice
- Optimizing dynamic aperture

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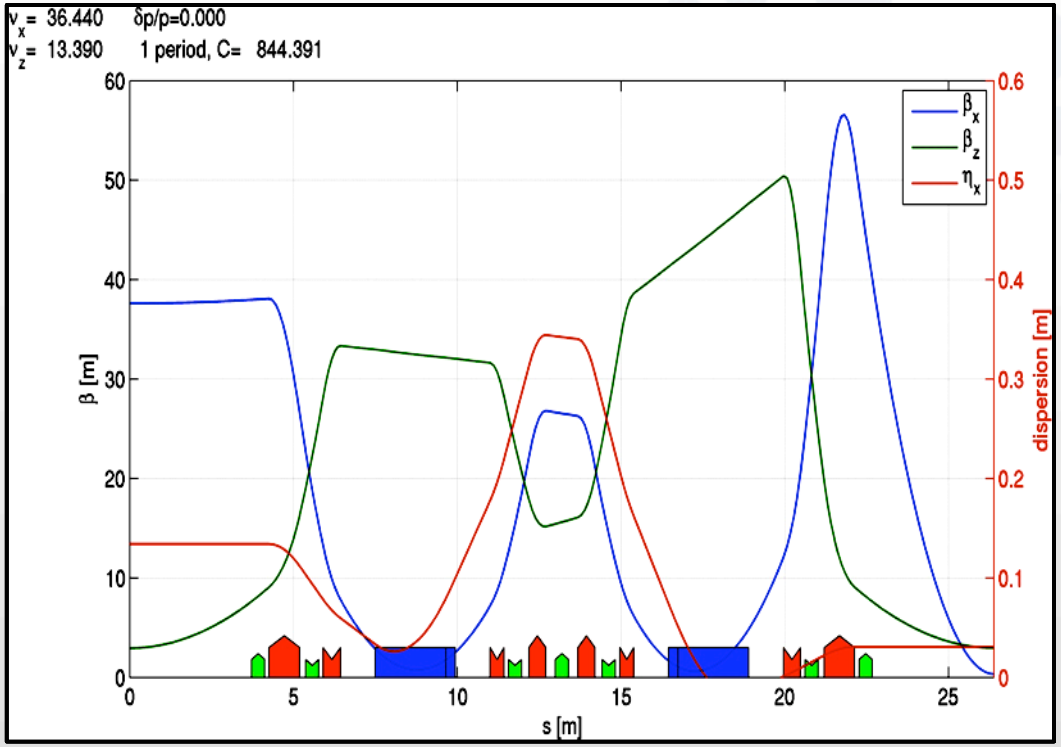
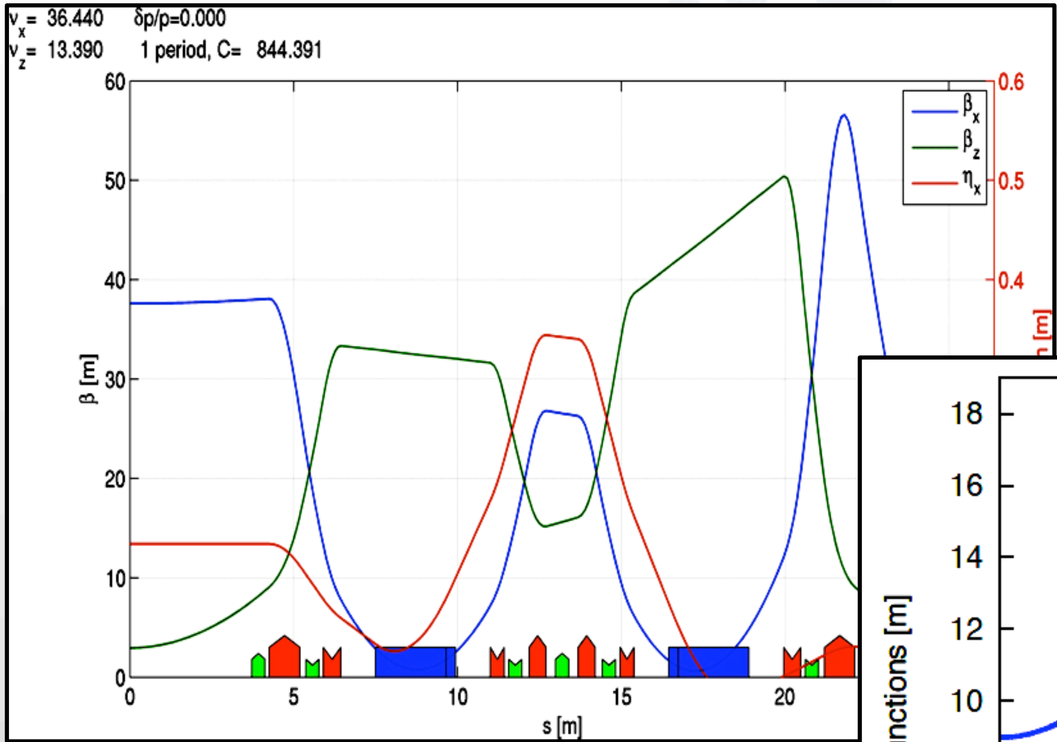


Double-Bend Achromat (DBA)

- Many 3rd gen. SR sources
- Local dispersion bump (originally closed) for chromaticity correction

The Hybrid Multi-Bend (HMB) lattice



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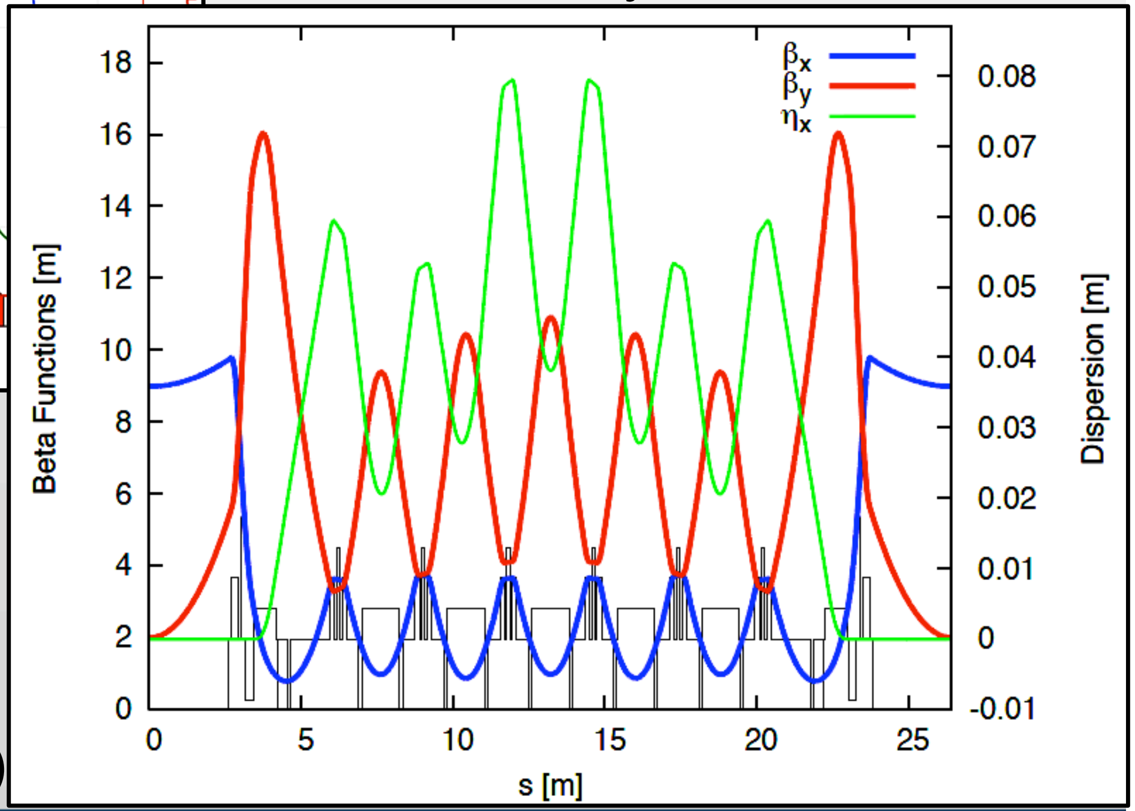
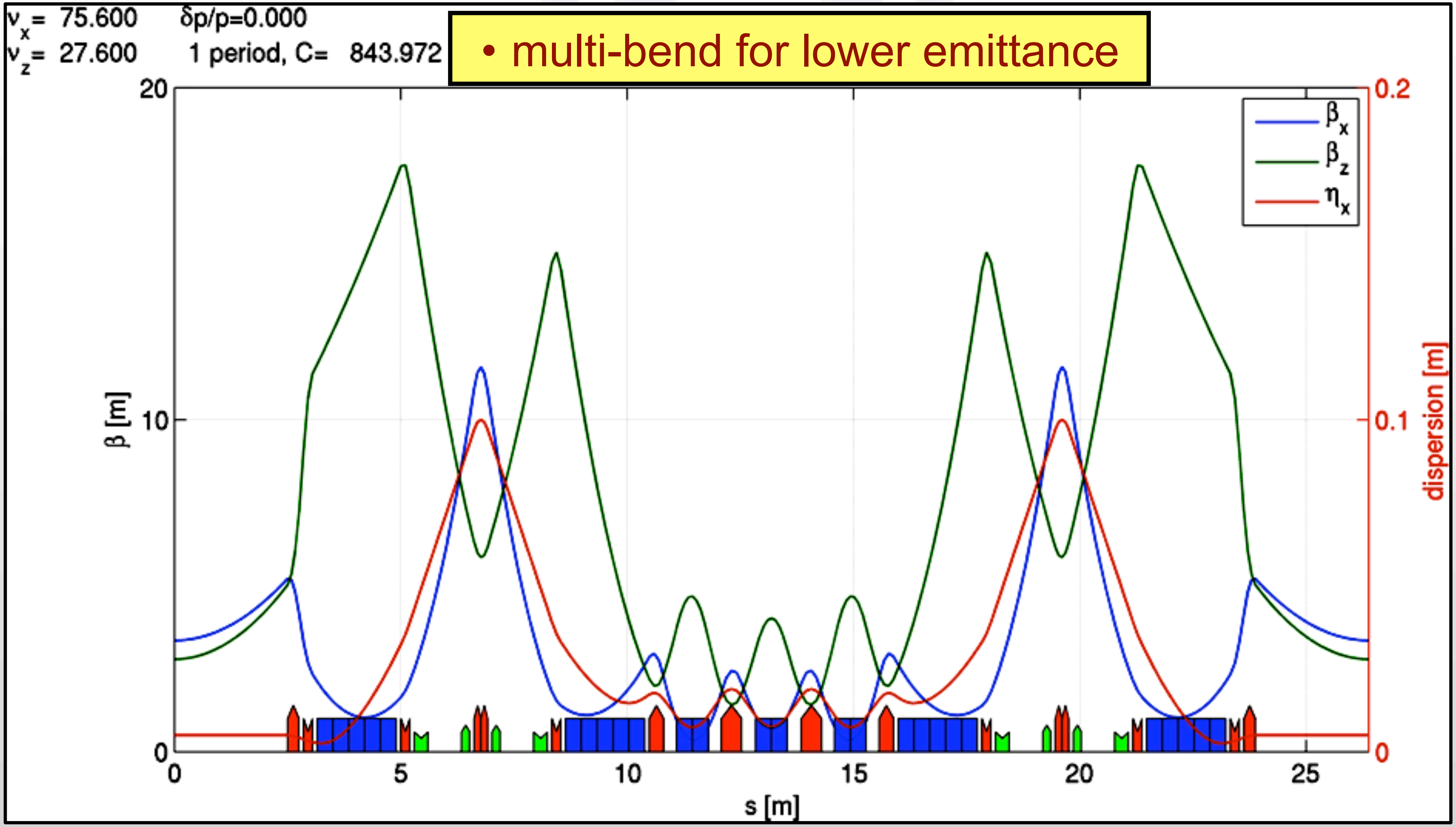


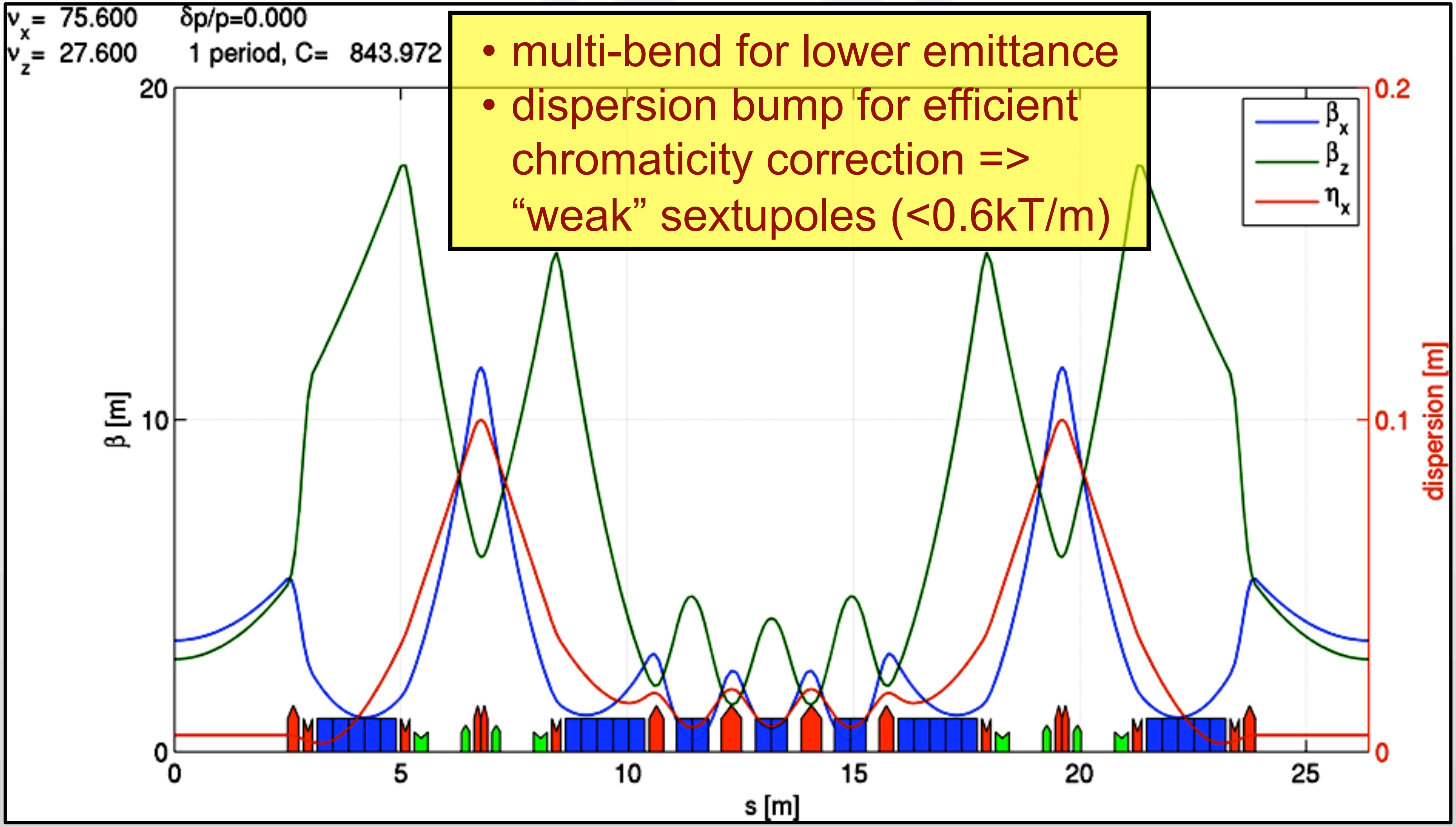
Multi-Bend Achromat (MBA)

- MAX IV and other USRs
- No dispersion bump, its value is a trade-off between emittance and sextupoles (DA)

The Hybrid Multi-Bend (HMB) lattice

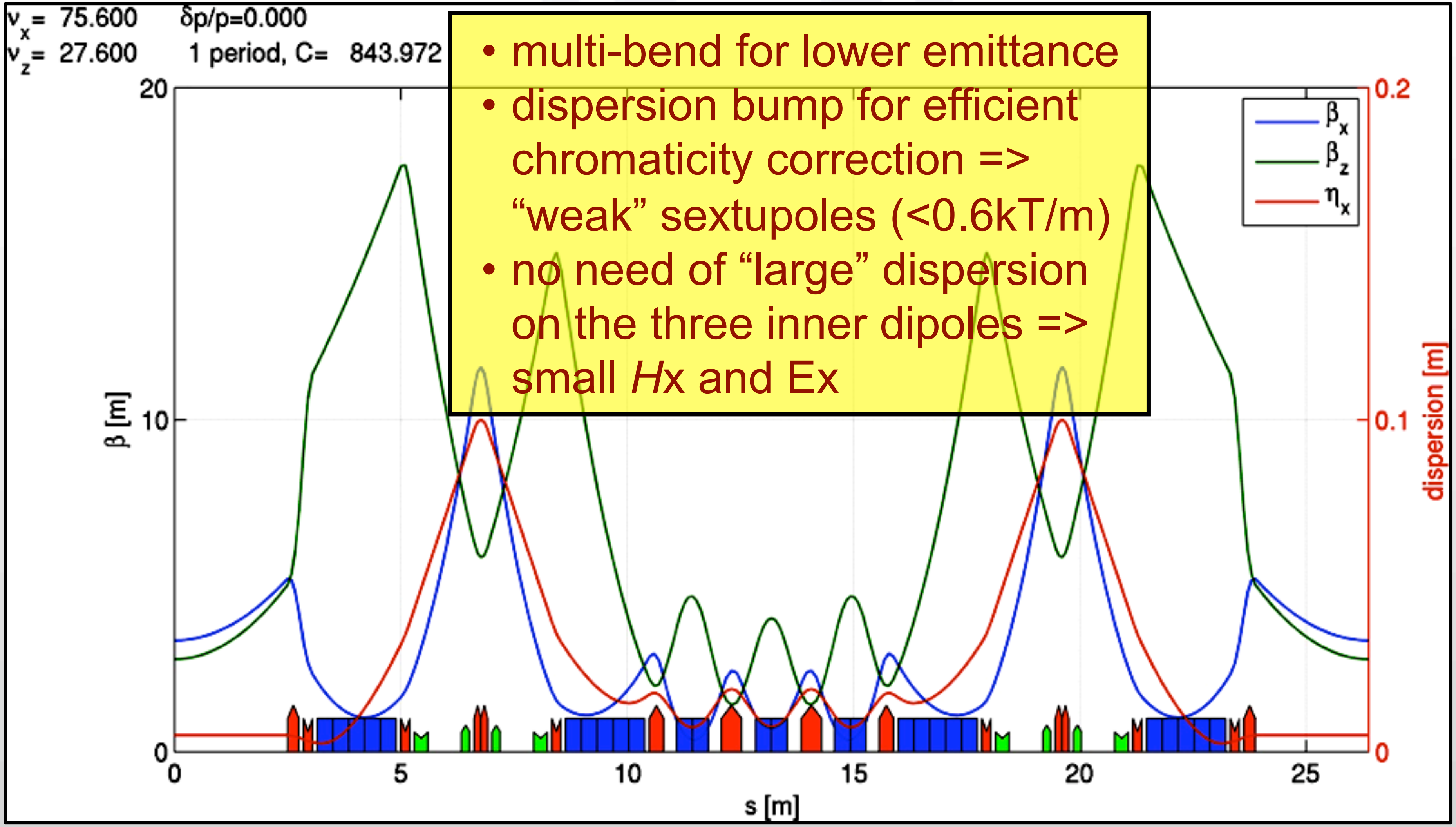


The Hybrid Multi-Bend (HMB) lattice



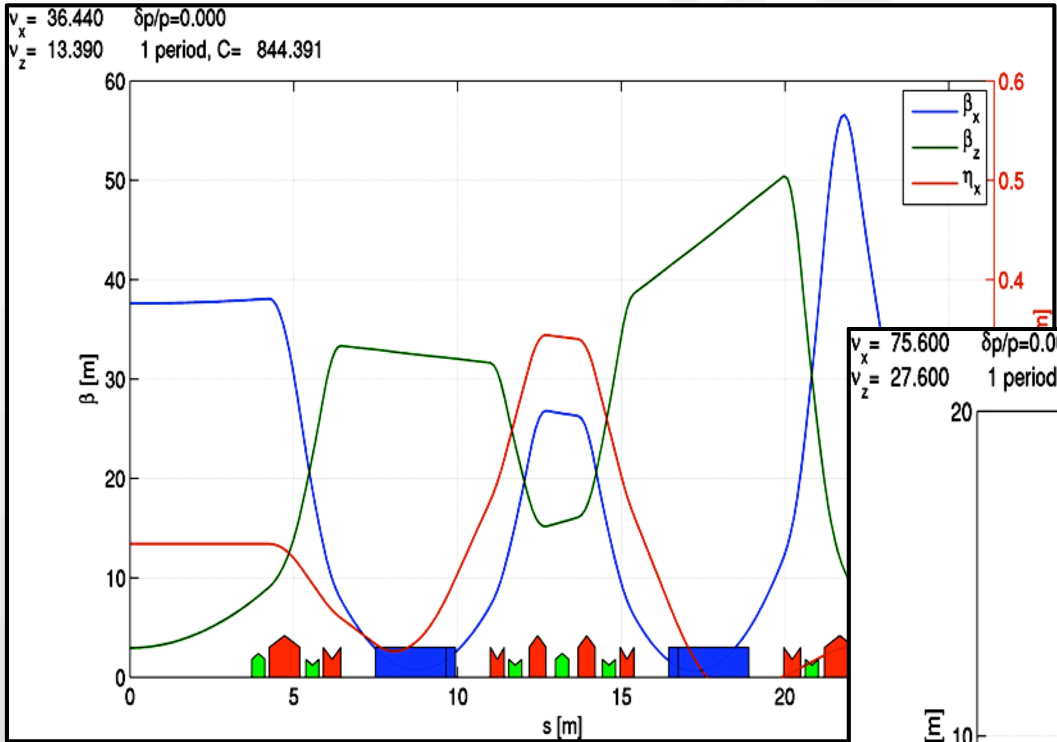
- multi-bend for lower emittance
- dispersion bump for efficient chromaticity correction => "weak" sextupoles (<0.6kT/m)

The Hybrid Multi-Bend (HMB) lattice



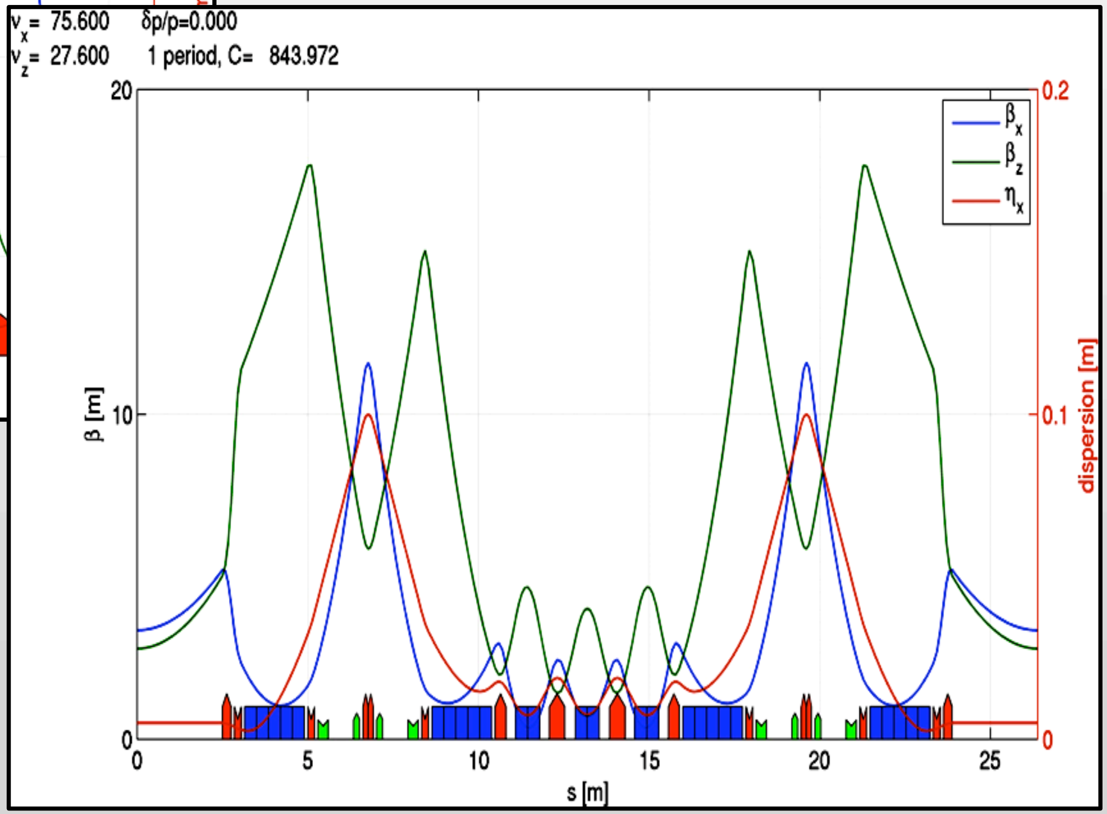
- multi-bend for lower emittance
- dispersion bump for efficient chromaticity correction => "weak" sextupoles (<0.6kT/m)
- no need of "large" dispersion on the three inner dipoles => small *Hx* and Ex

The Hybrid Multi-Bend (HMB) lattice



ESRF existing (DBA) cell

- Ex = 4 nm•rad
- tunes (36.44,13.39)
- nat. chromaticity (-130, -58)



Proposed HMB cell

- Ex = 160 pm•rad
- tunes (75.60, 27.60)
- nat. chromaticity (-97, -79)

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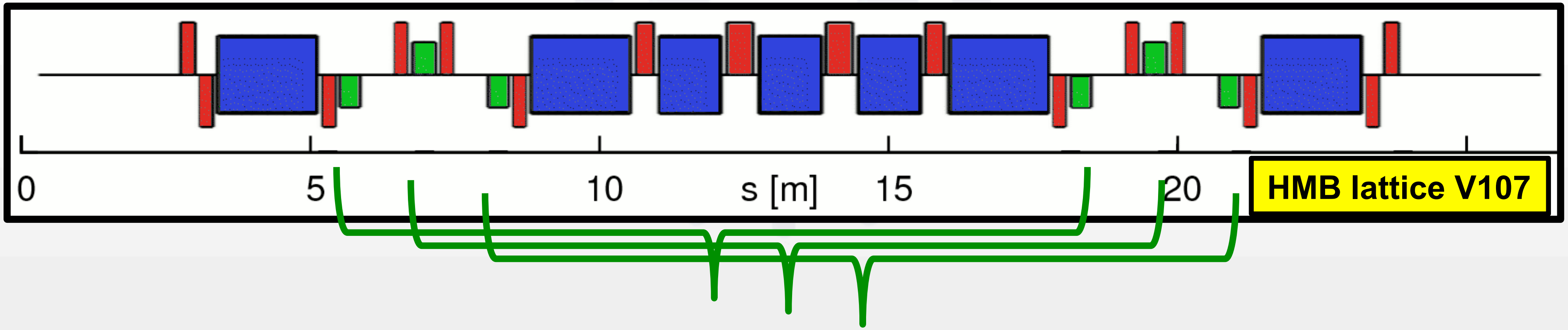
Nonlinear optics: the HMB lattice

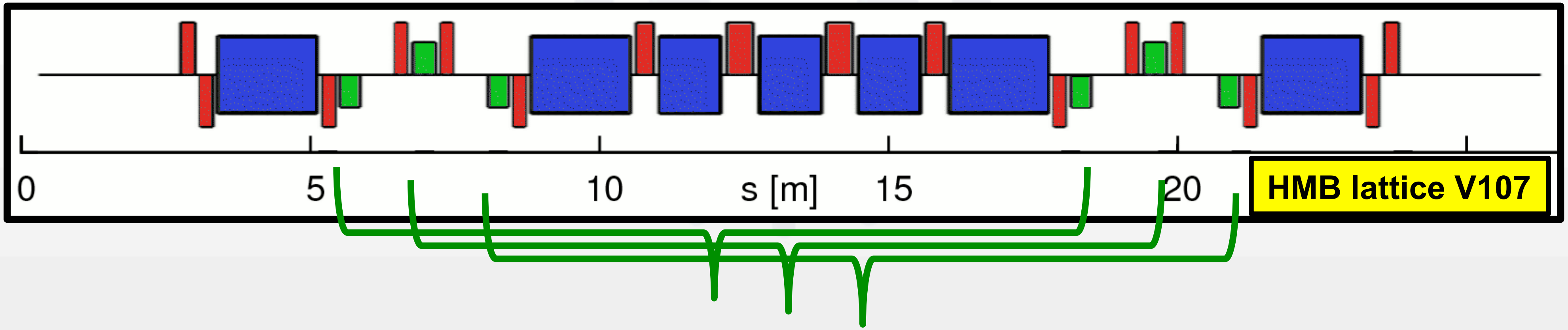


phase advance between pairs of (chrom.) sextupoles:

$\Delta\varphi_x=(2n+1)\pi \quad \Delta\varphi_y=n\pi$

$\Delta\varphi_x=(2n+1)\pi$ to minimize at the cell ends the Resonance Driving Terms from x^3 (f_{3000} and $f_{1200} \approx 0$) => elliptical horizontal phase space

Nonlinear optics: the HMB lattice



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$\Delta\varphi_y=n\pi$ minimize those from xy^2 (f_{1020} and $f_{0120} \approx 0$) rendering vertical phase space elliptical too [$f_{0111} \approx 0$ from $\Delta\varphi_x=\pi$] …

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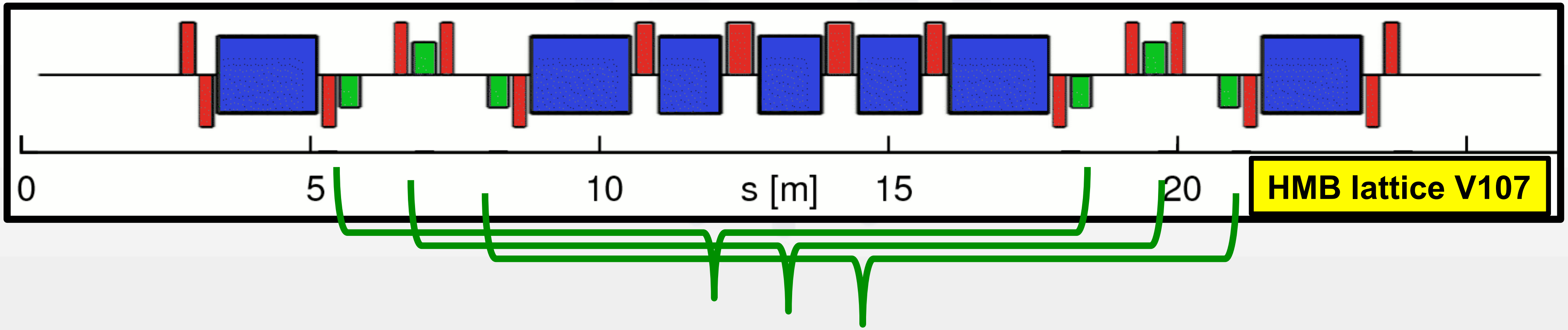

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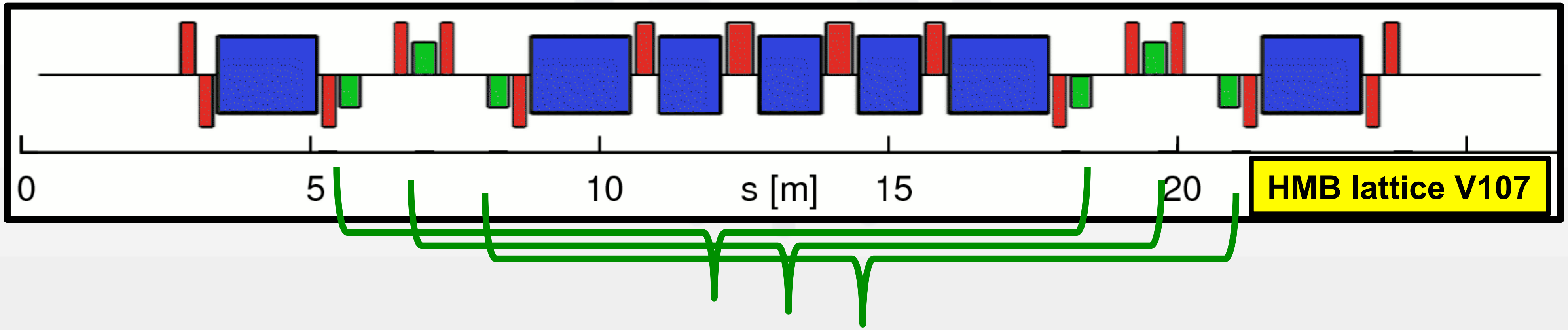
… provided that second-order (octupolar-like) RDTs are kept low

no harmonic sextupoles

Nonlinear optics: the HMB lattice



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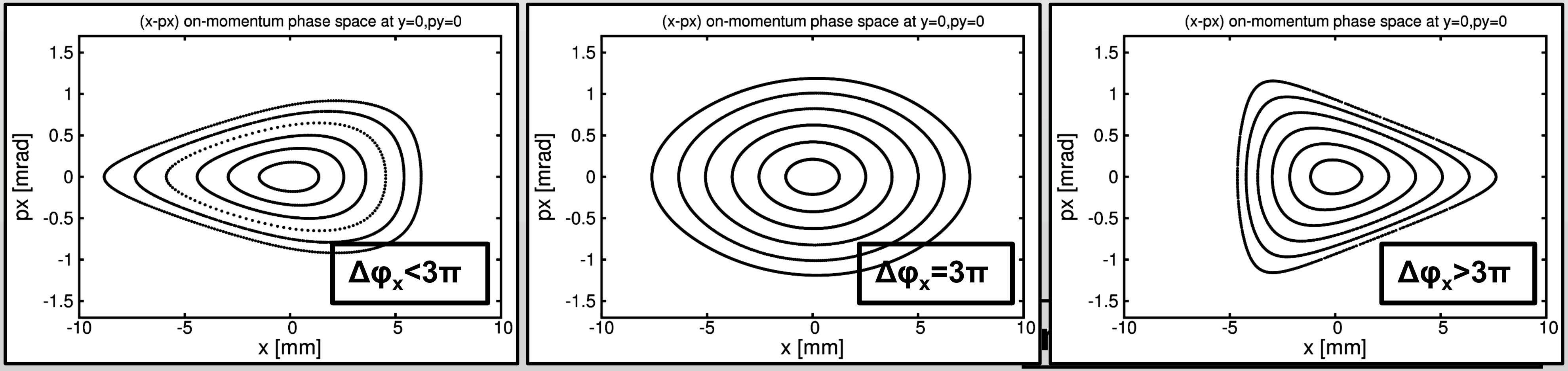
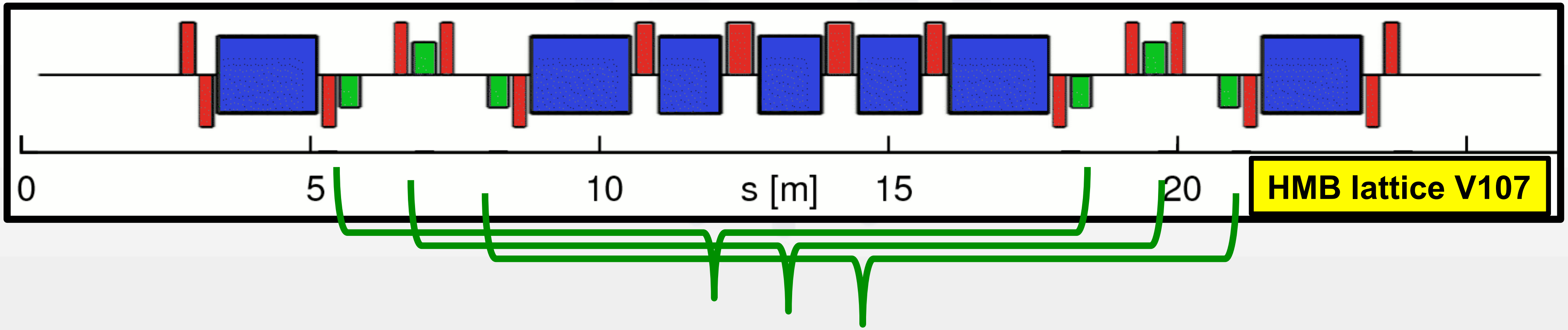


Nonlinear optics: the HMB lattice



phase advance between pairs of (chrom.) sextupoles:

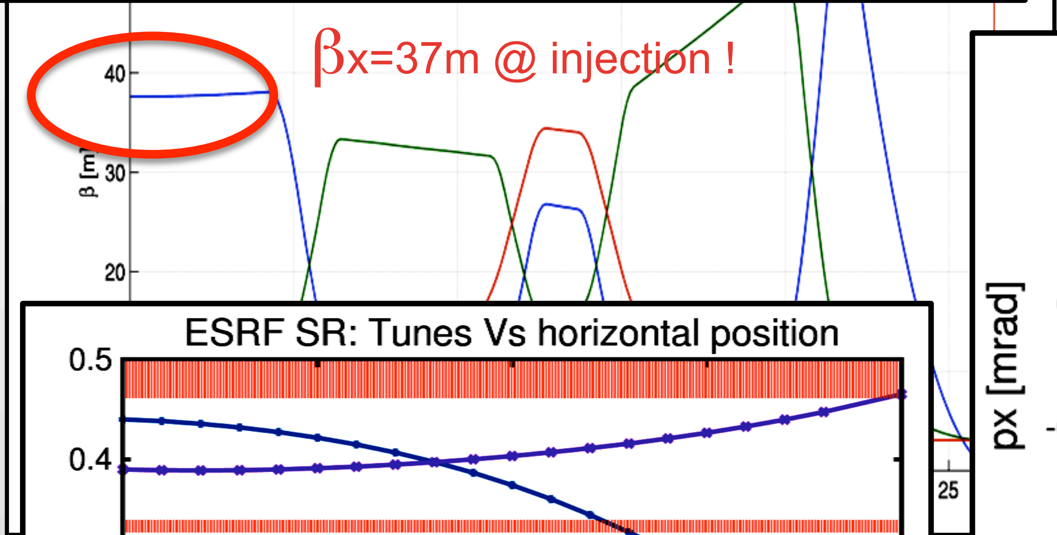
$\Delta\varphi_x=(2n+1)\pi \quad \Delta\varphi_y=n\pi$

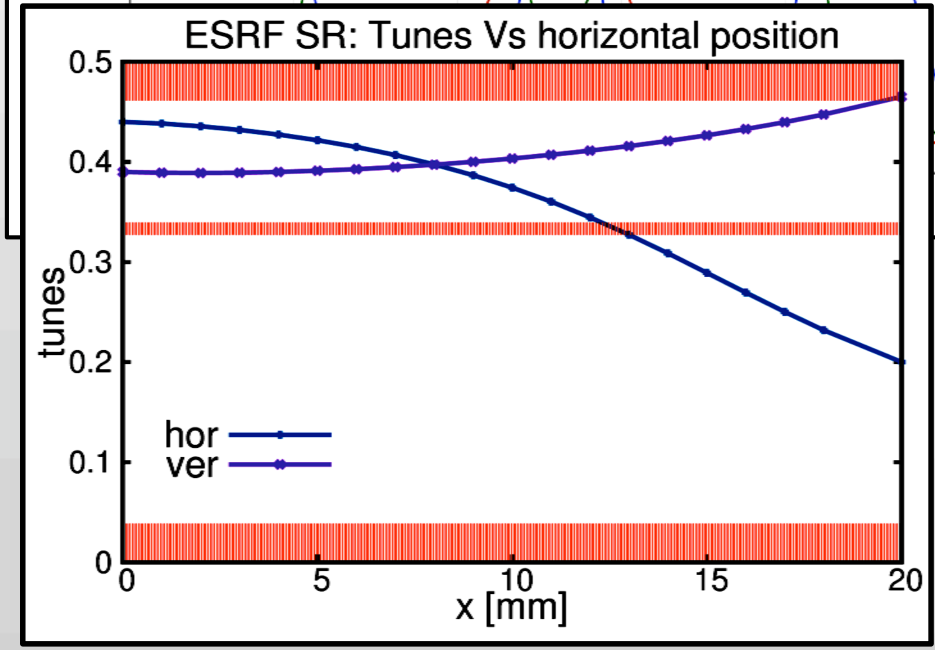
This constraint does not help minimize amplitude-dependent detuning generated by second-order cross-products of sextupolar terms within the cell [$\propto \cos(\Delta\varphi_x), \sin(3\Delta\varphi_y), \ldots$] and across other cells.

no harmonic sextupoles

Nonlinear optics: existing ESR SR Vs HMB lattice

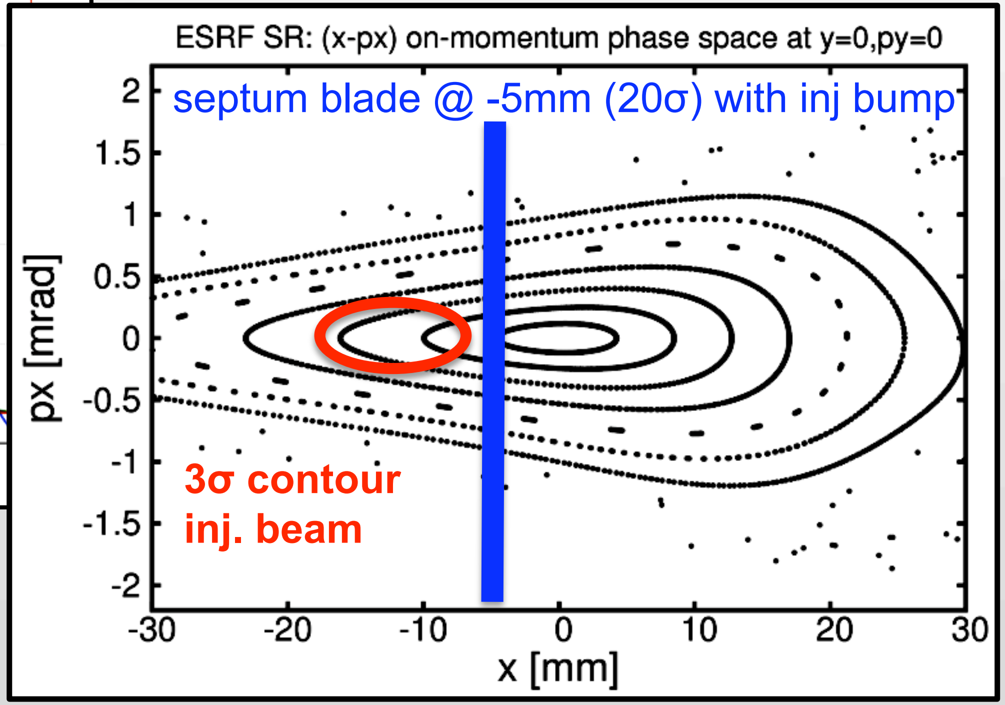
$dQx/dJx = -15\times10^3 \quad d^2Qx/dJx^2 = 0.3\times10^9$
$dQy/dJx = -11\times10^3 \quad d^2Qy/dJx^2 = 0.2\times10^9$
$dQy/dJy = 12\times10^3 \quad d^2Qy/dJy^2 = 0.2\times10^9$





ESR (DBA) Storage Ring

- 3 chromatic and 4 harmonic sextupoles

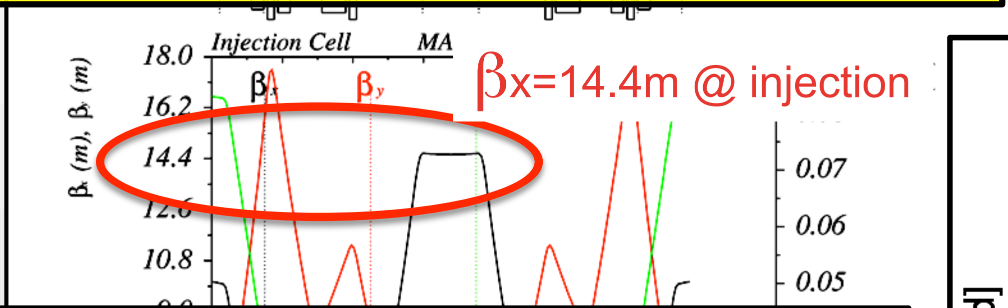


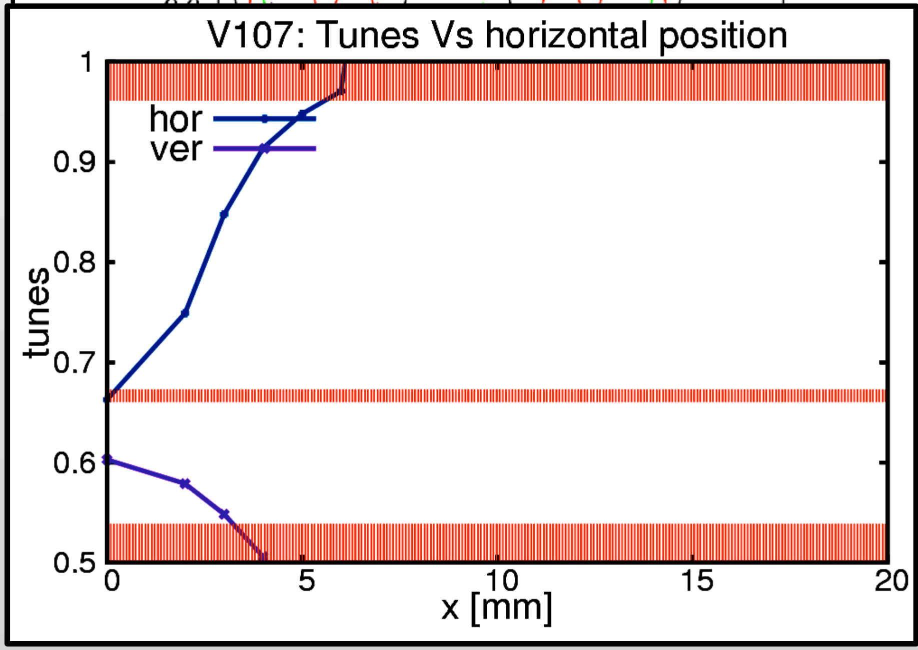
Nonlinear optics: existing ESR SR Vs HMB lattice

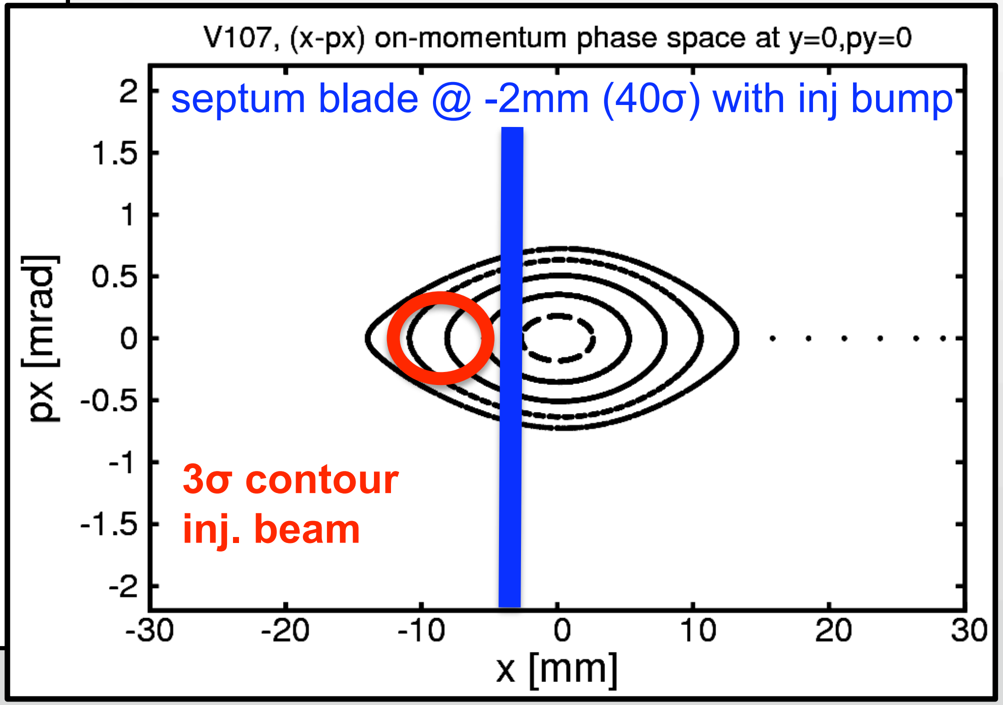
$dQx/dJx = 100\times10^3$ $d^2Qx/dJx^2 = 5.9\times10^9$
$dQy/dJx = -80\times10^3$ $d^2Qy/dJx^2 = 29.3\times10^9$
$dQy/dJy = 40\times10^3$ $d^2Qy/dJy^2 = 0.9\times10^9$

HMB lattice (V107)

2+4 chromatic sextupoles, no harmonic sextupoles







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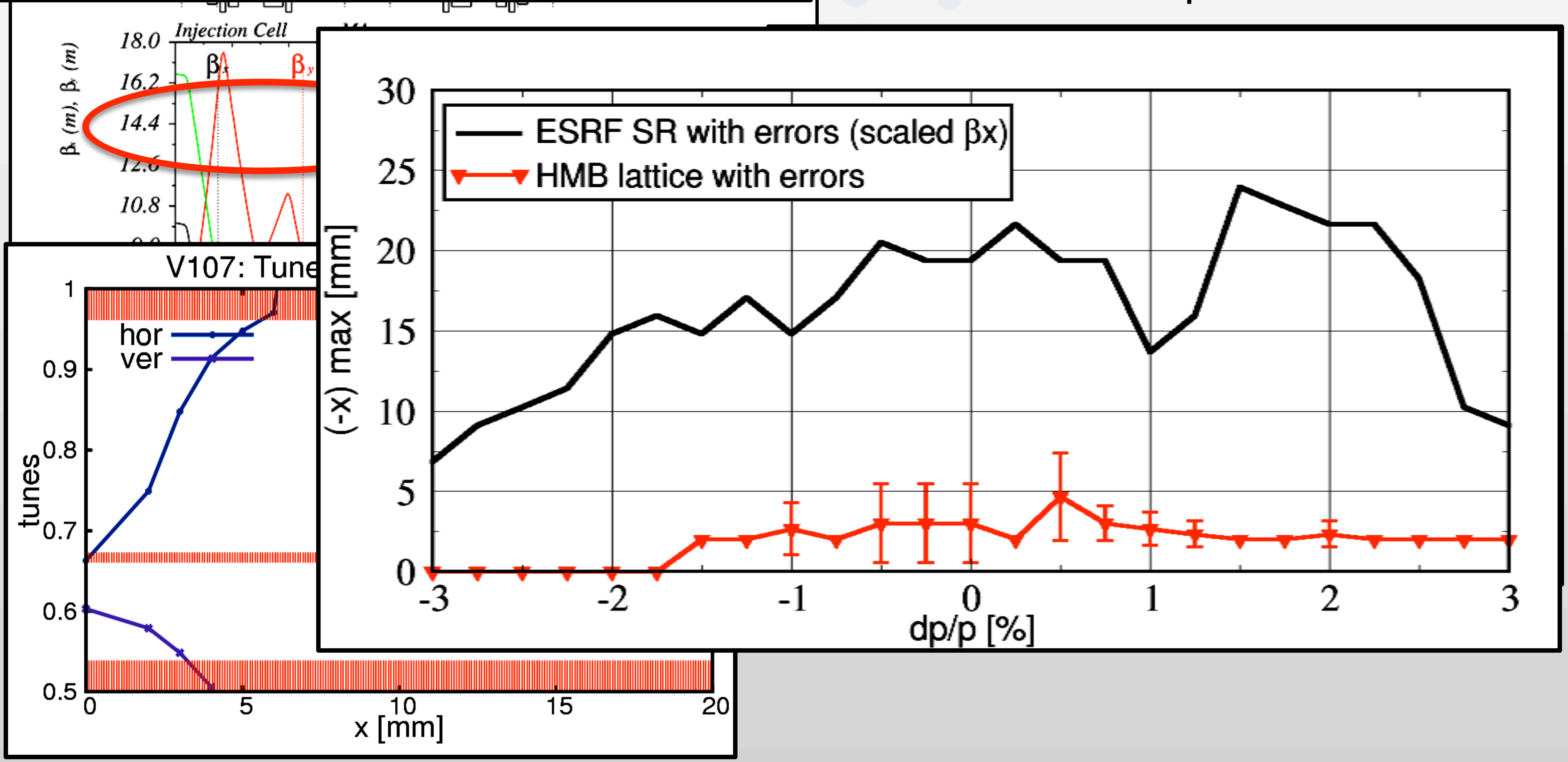

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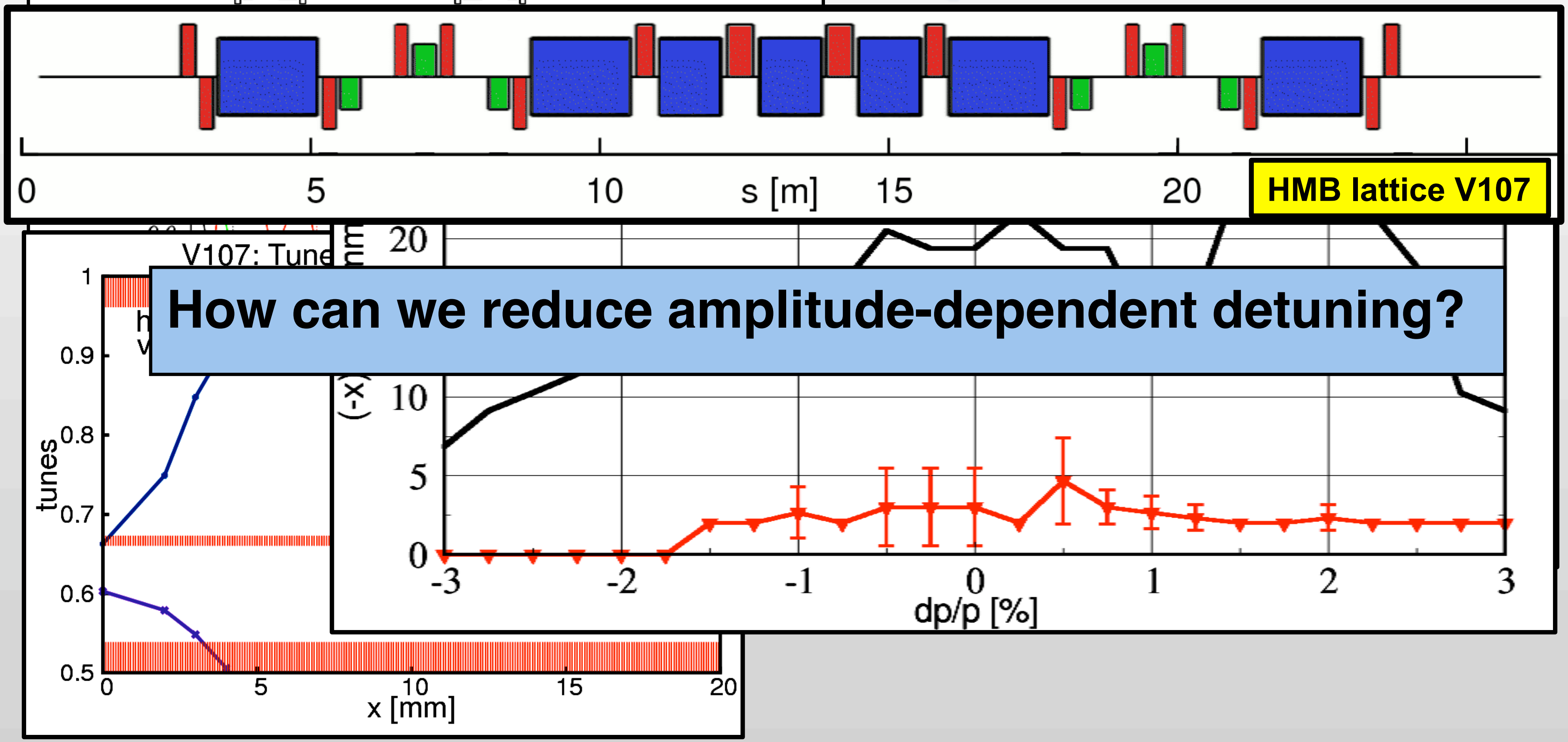

How can we reduce amplitude-dependent detuning?

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very preliminary, focused on horizontal DA only, not yet optimized in vertical plane and energy deviation.

Lattice errors: focusing errors from H & V (6μm RMS) displacement of sextupoles generating ~2% peak beta-beating & 5% coupling, no sext. field errors, orbit corrected.

Optimizing dynamic aperture

HMB lattice (V107)

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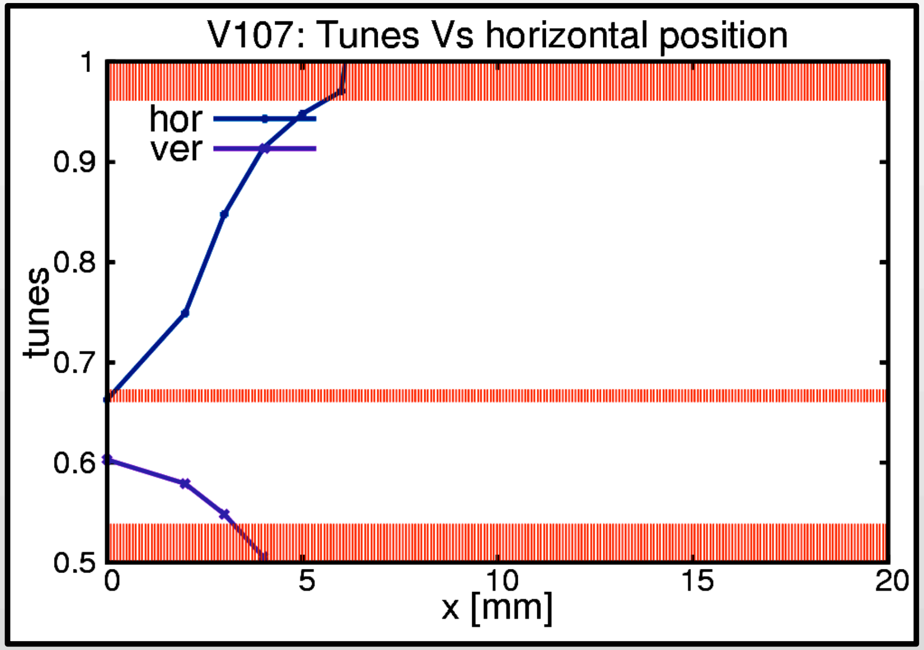
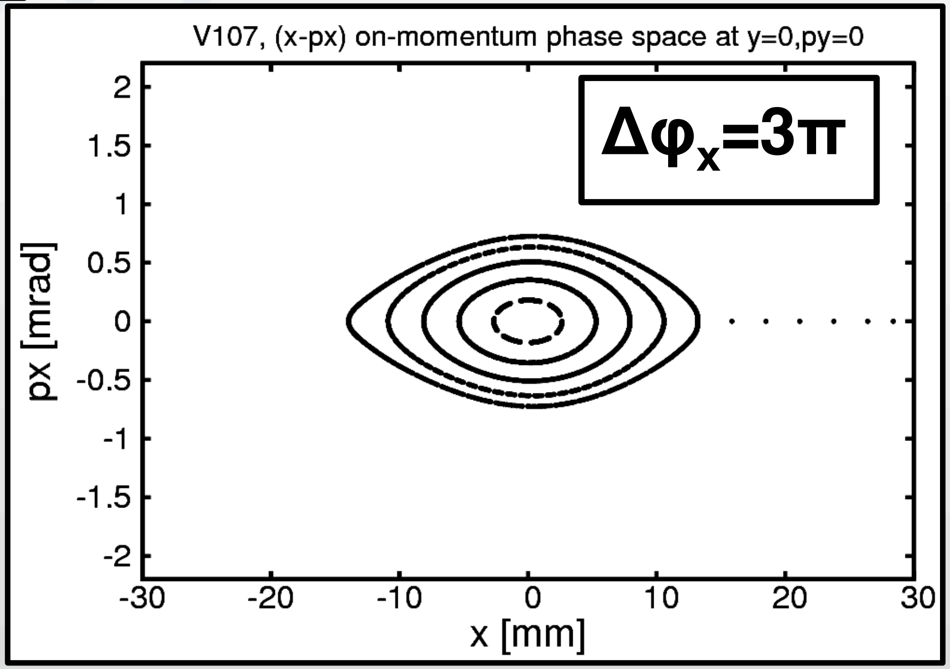
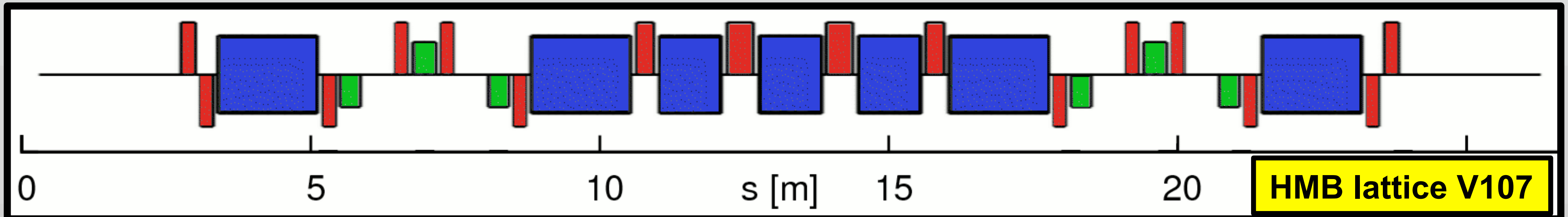






HMB lattice V107

Optimizing dynamic aperture

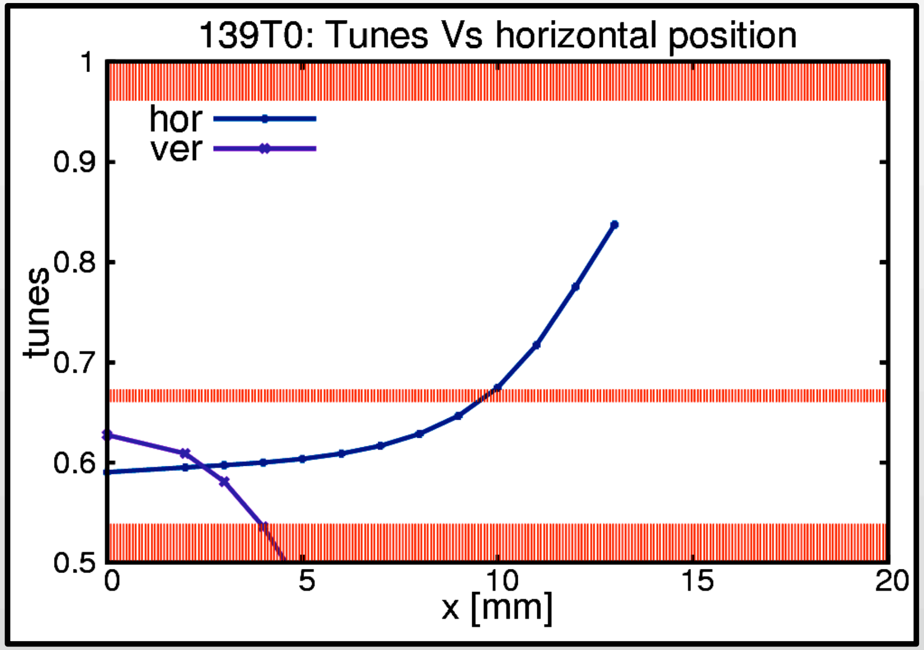
$dQx/dJx = -2\times10^3$ $\quad d^2Qx/dJx^2 = 2.7\times10^9$

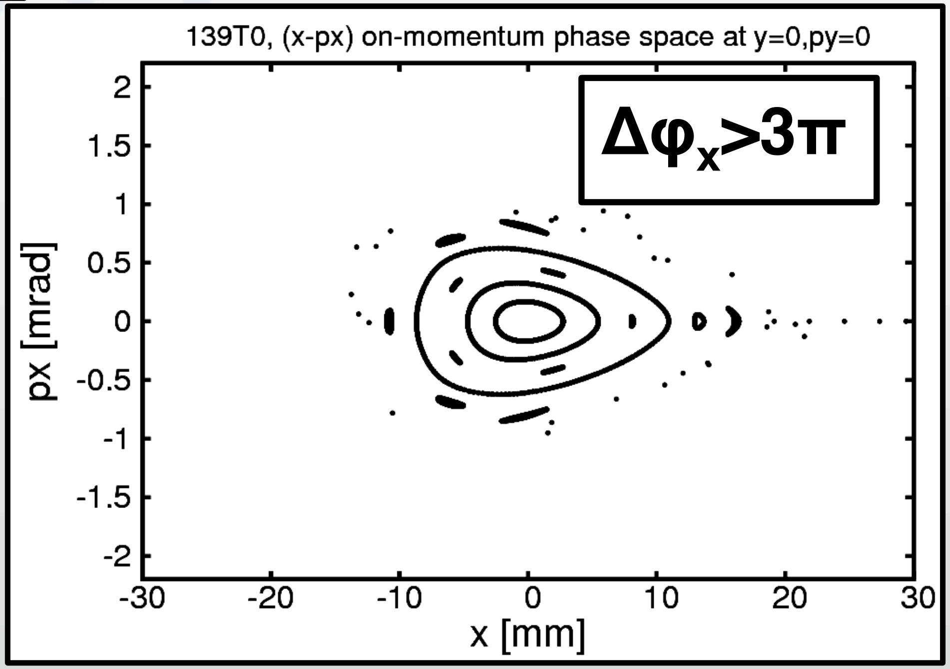
$dQy/dJx = -82\times10^3$ $\quad d^2Qy/dJx^2 = 30.6\times10^9$

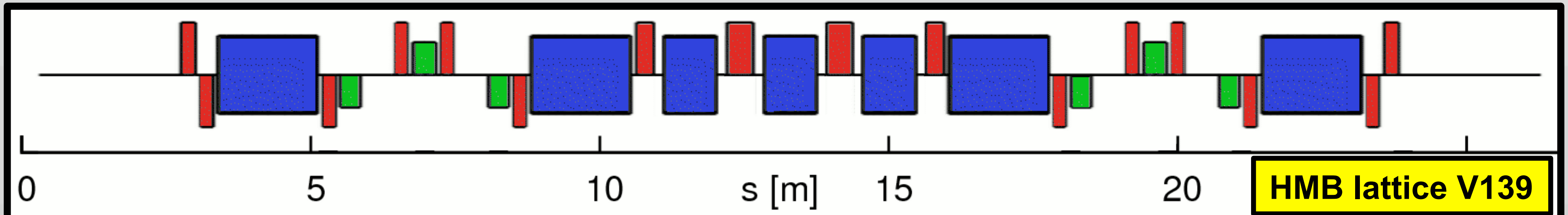
$dQy/dJy = -1\times10^3$ $\quad d^2Qy/dJy^2 = 0.6\times10^9$

HMB lattice (V139)

- **shorter bends for equipment**
- **lower hor. and ver. detuning**
- **cross-term detuning still too large**



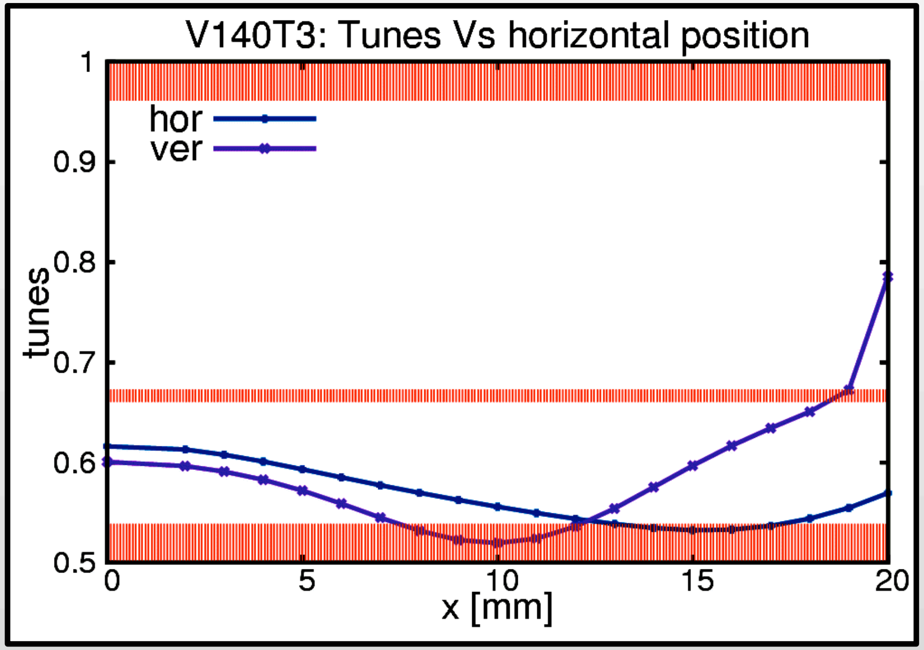


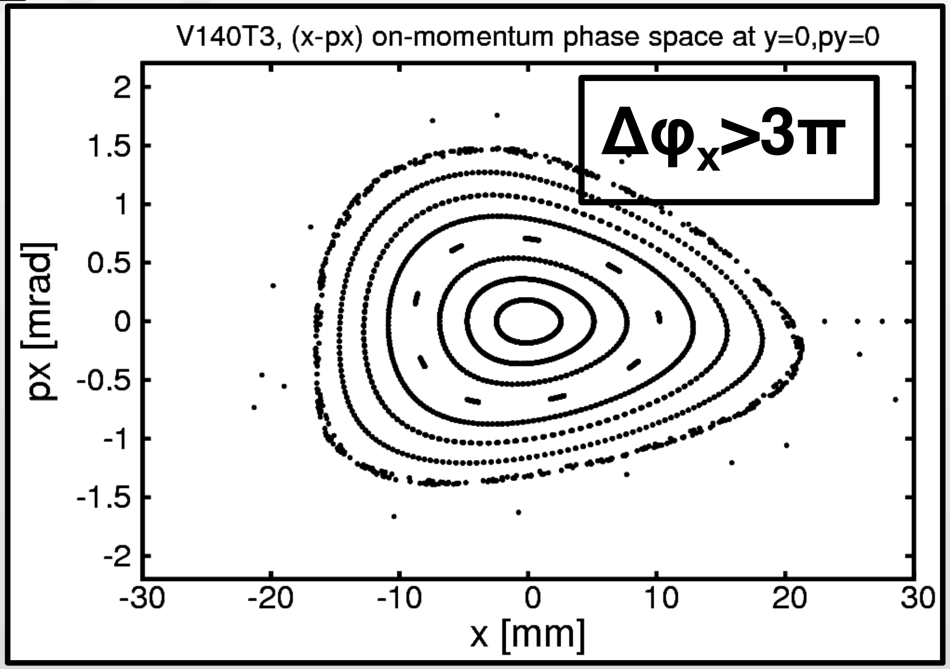


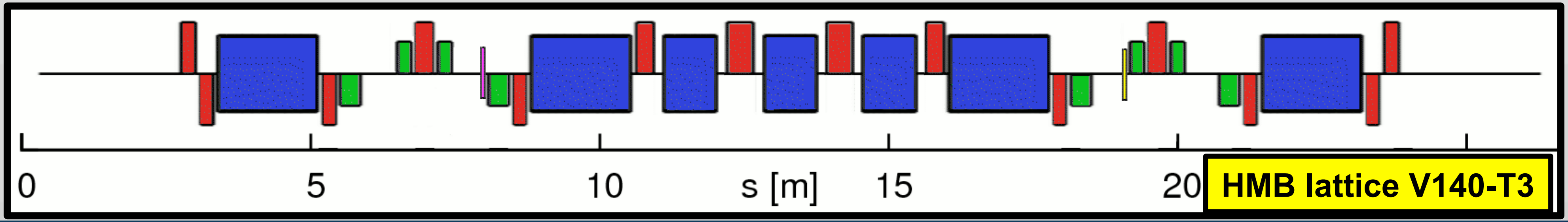
Optimizing dynamic aperture

$dQx/dJx = -11x10^3$ $d^2Qx/dJx^2 = 0.6x10^9$
$dQy/dJx = -15x10^3$ $d^2Qy/dJx^2 = 19.3x10^9$
$dQy/dJy = -9x10^3$ $d^2Qy/dJy^2 = 4.1x10^9$

HMB lattice (V140-T3)
- **swapped centre quad <-> sext.**
- **added thin octu- and dodeca-pole**
- **lower cross-term detuning**





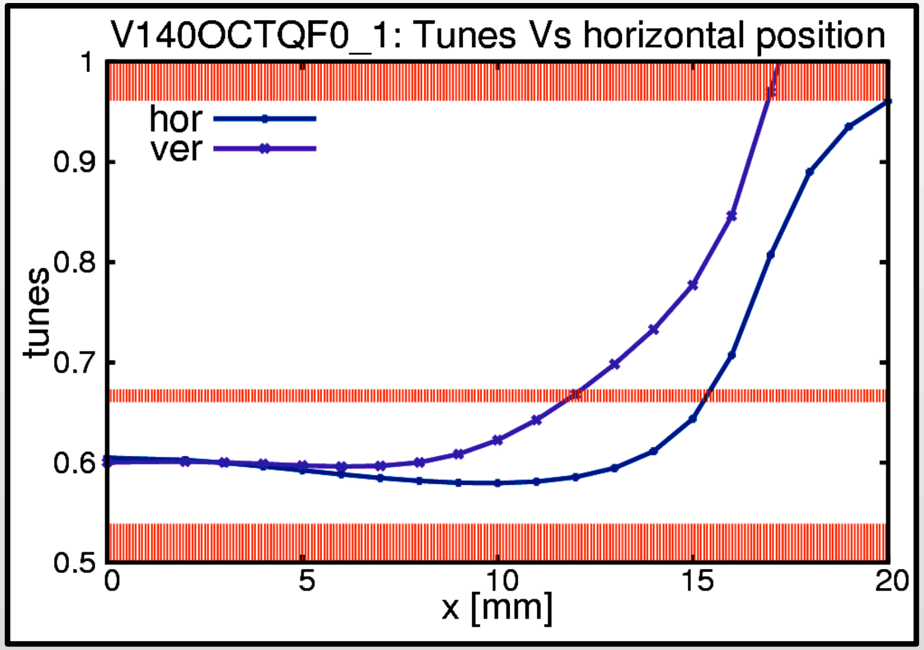


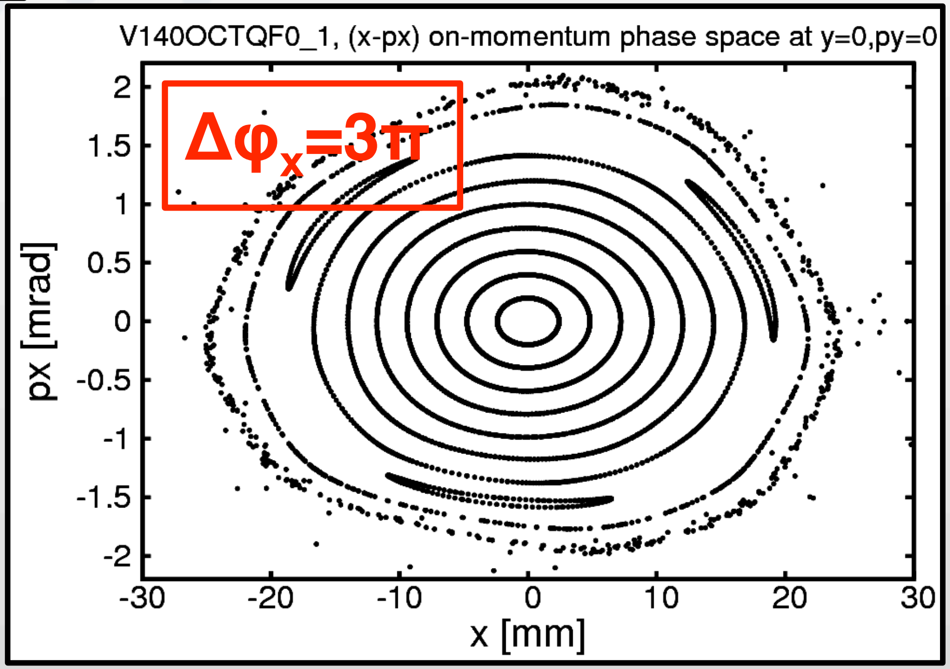
Optimizing dynamic aperture

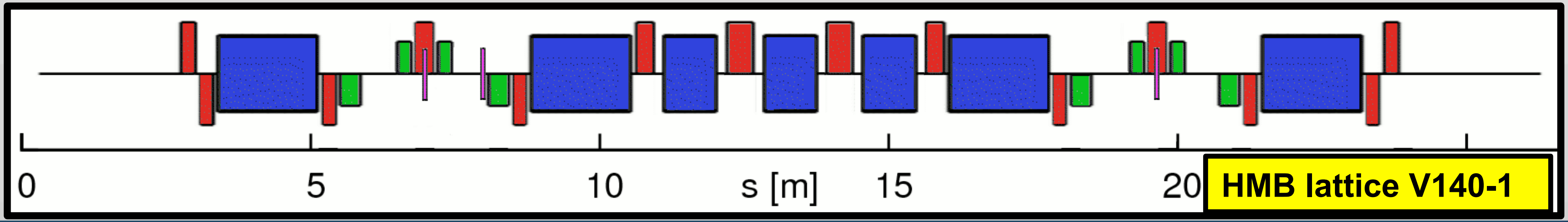
$dQx/dJx = -5x10^3 \quad d^2Qx/dJx^2 = 0.6x10^9$
$dQy/dJx = -3x10^3 \quad d^2Qy/dJx^2 = 17.7x10^9$
$dQy/dJy = -6x10^3 \quad d^2Qy/dJy^2 = 3.8x10^9$

HMB lattice (V140-1)

- **octupole component in QF0 added**
- **dodecapole removed**
- **lower cross-term detuning**







Optimizing dynamic aperture

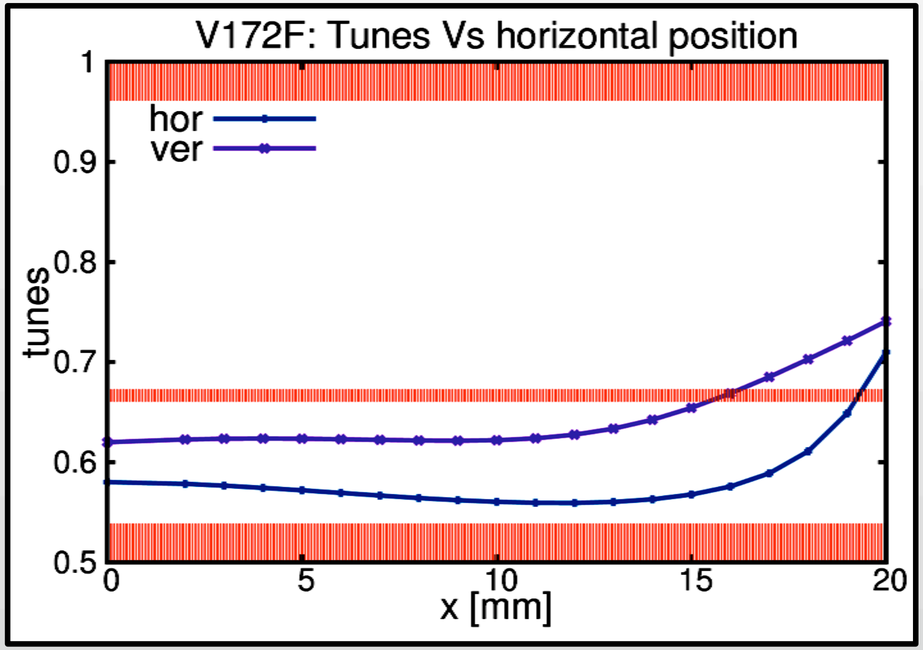
$dQx/dJx = -4\times10^3 \quad d^2Qx/dJx^2 = 0.5\times10^9$

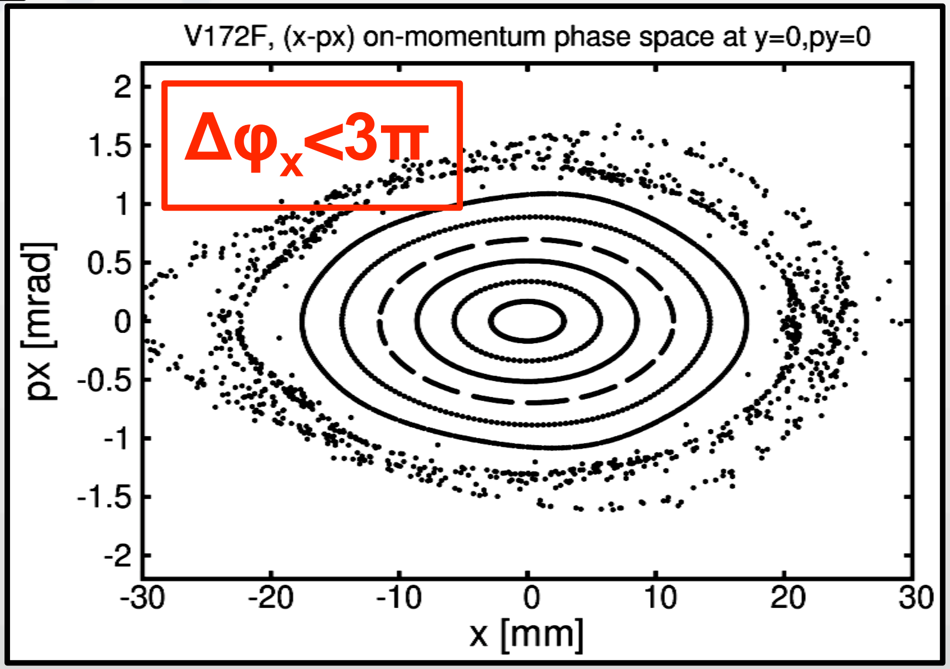
$dQy/dJx = -3\times10^3 \quad d^2Qy/dJx^2 = 0.1\times10^9$

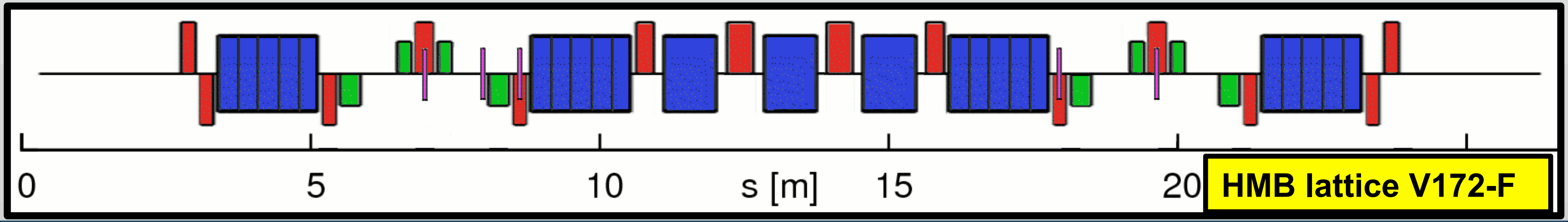
$dQy/dJy = -5\times10^3 \quad d^2Qy/dJy^2 = 1.0\times10^9$

HMB lattice (V172-F)

- **octupole component in QD0 added**
- **long. gradient in dipoles**
- **lower cross-term detuning**







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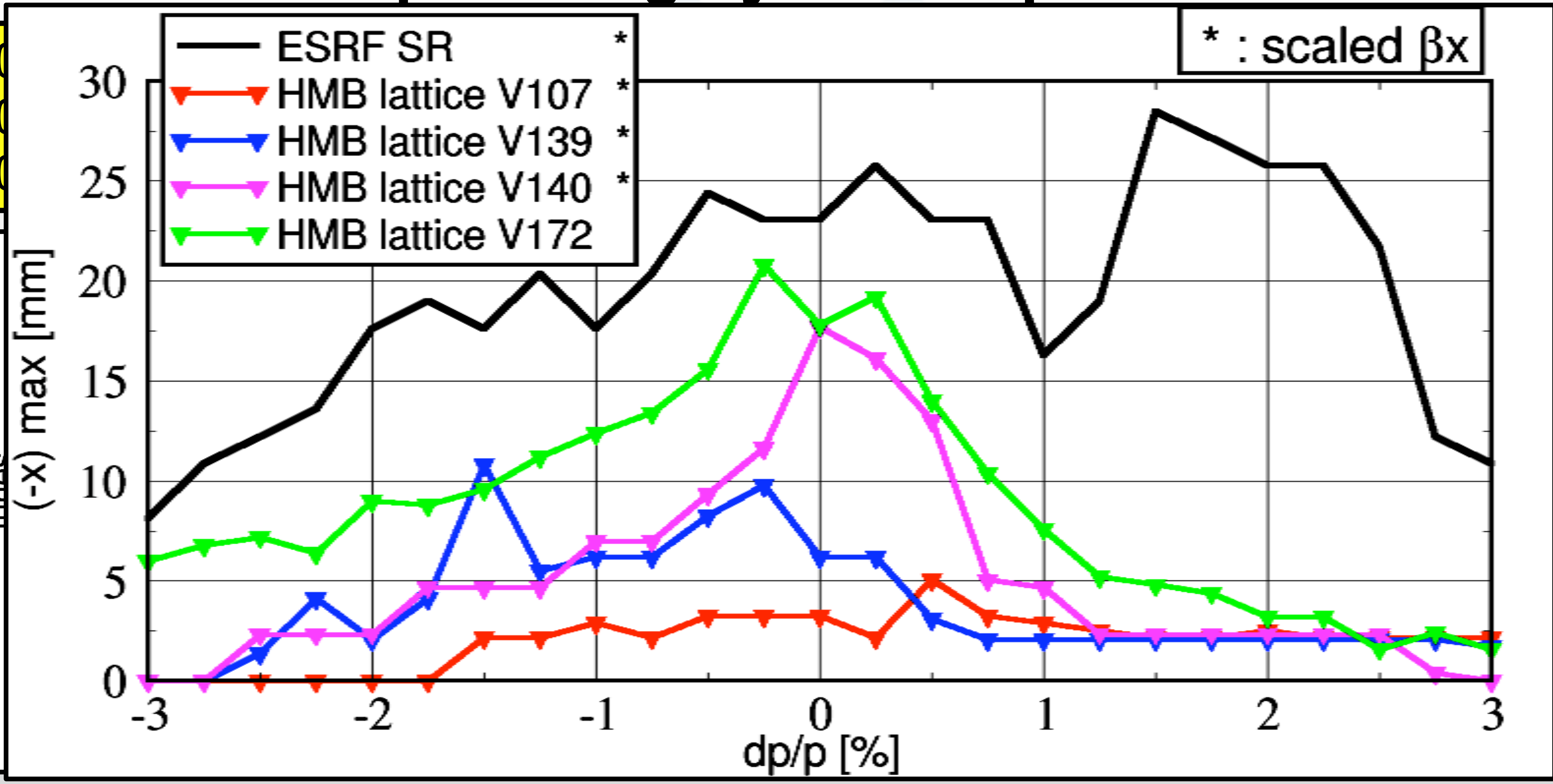

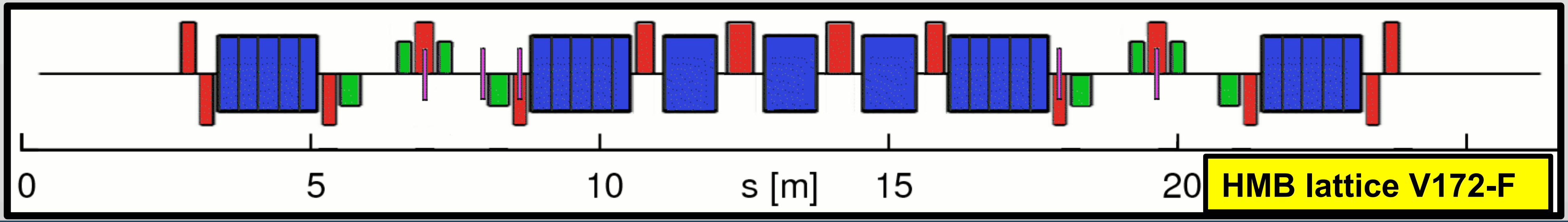

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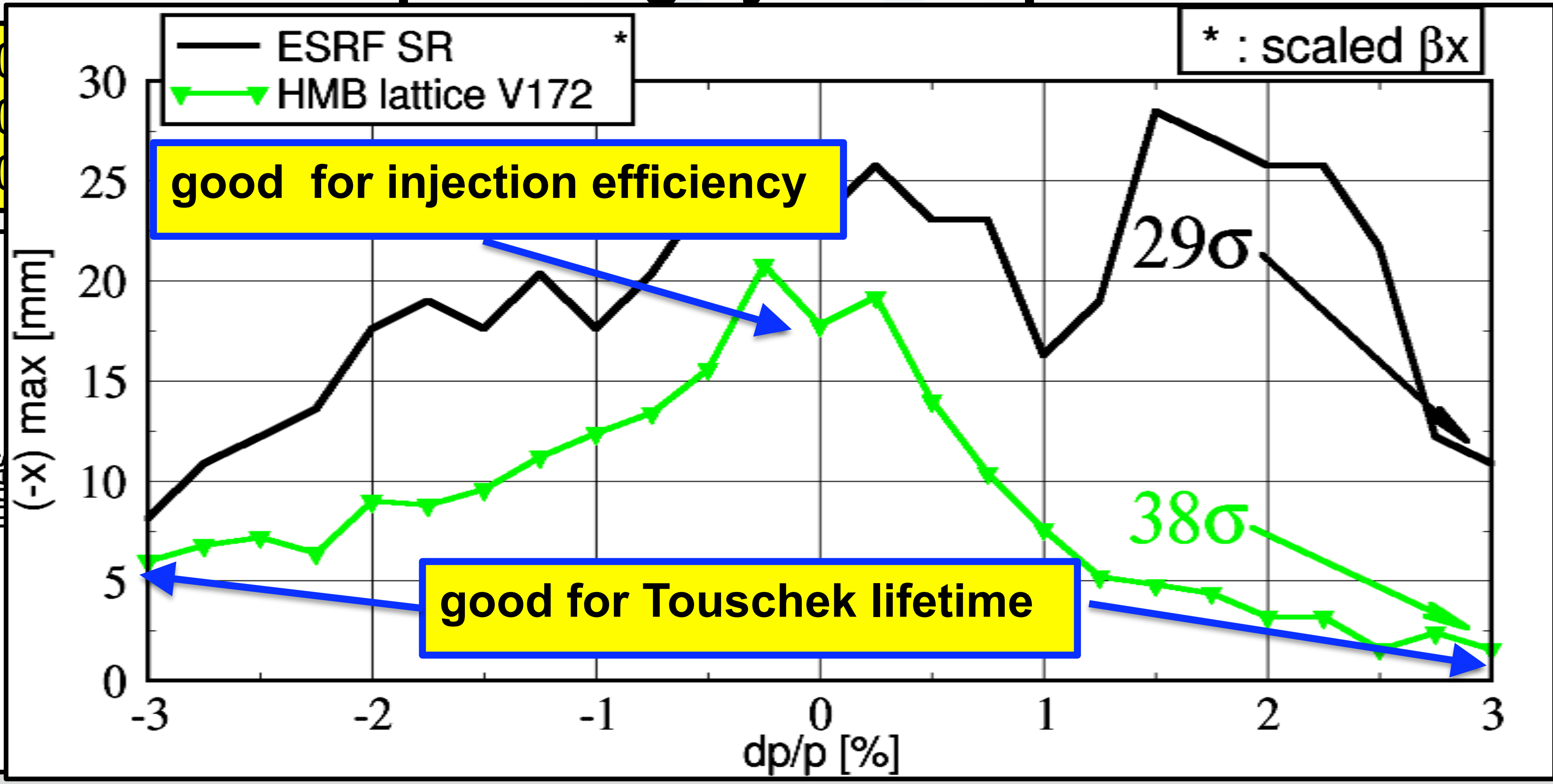
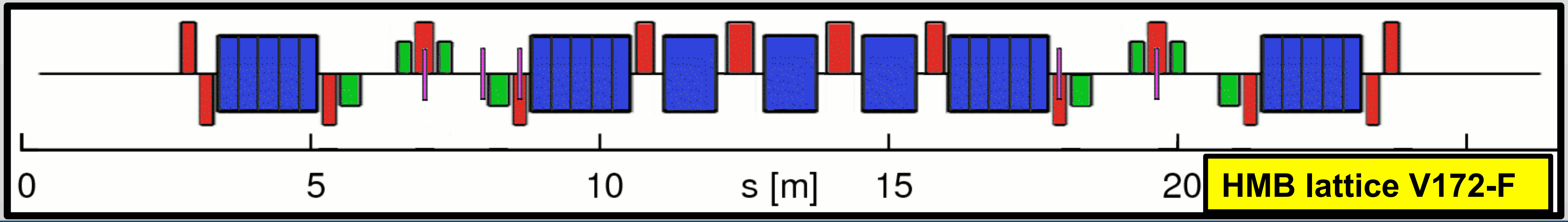




Conclusion

- lattice design in advanced status of development
- (standard) magnet requirements within reach of existing technology (100 T/m for quads, 2kT/m^2 for sexts)
- dynamic properties already compatible with present injection system
- good energy acceptance
- lattice still evolving to further improve its performances and to match hardware constraints (diagnostic, vacuum, front ends, etc…)

Parameter	Existing Lattice	New Lattice
Energy, E [GeV]	6.03	6.03
Circumference, C [m]	844	844
Tune, ν_x, ν_y, ν_s	36.44 , 13.39, 0.0054	75.60 , 25.60 , 0.0034
Emittance, ϵ_x , ϵ_y [pm ·rad]	4000 , 5	160 , 5
Bunch length, σ_z [ps]	15.6	11
Energy spread, σ_δ	1.06 10^{-3}	1.06 10^{-3}
Momentum compaction	17.6 10^{-5}	8.7 10^{-5}
Damping time, τ_x, τ_y, τ_s [ms]	7 , 7 , 3.5	7 , 11 , 7.9
Natural chromaticity, ξ_{x0} , ξ_{y0}	-130 , -58	-97, -79
Energy loss per turn, U_0 [MeV]	4.9	3.05
RF voltage, V_{RF} [MV]	8	6
RF frequency, f_{RF} [MHz]	352	352
Harmonic number	992	992
Beta at ID center, β_x , β_y [m]	37.6 , 3.0 (high β) 0.35 , 3.0 (low β)	3.35 , 2.79
Beam size at ID center, σ_x , σ_y [μm]	413 , 3.9 (high β) 50 , 3.9 (low β)	24, 3.7
Beam div. at ID center, $\sigma_{x'}$, $\sigma_{y'}$ [μrad]	10 , 1.3 (high β) 107, 1.3 (low β)	6.8 , 1.3

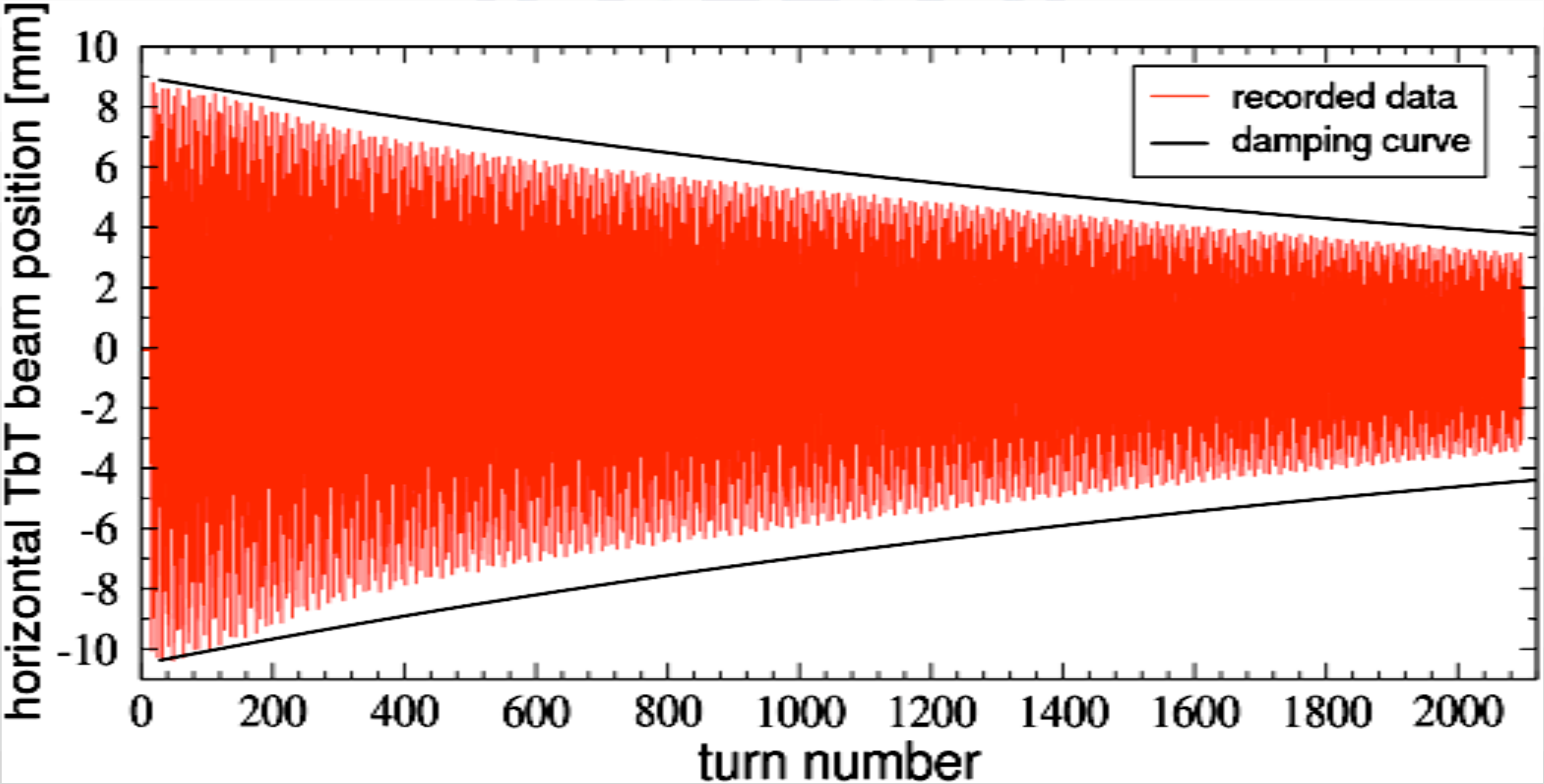
HMB lattice

# NAME	L	ANGLE	R0	B0	G1	G2	G3L	BETX	BETY	DX
#	[m]	[mrad]	[m]	[T]	[T/m]	[T/m^2]	[T/m^2]	[m]	[m]	[mm]
"QFMA"	0.25				93.71			4.16	7.21	4.3
"QDMA"	0.20				-87.77			2.33	11.39	2.9
"BPI1E"	0.35	9.89	35.38	0.57				1.52	12.67	3.4
"BPI1D"	0.35	6.89	50.76	0.40				1.16	13.73	7.2
"BPI1C"	0.35	5.40	64.86	0.31				1.03	14.85	13.1
"BPI1B"	0.35	4.20	83.40	0.24				1.15	16.03	20.6
"BPI1A"	0.35	3.60	97.30	0.21				1.50	17.27	29.6
"QDID"	0.20				-38.35			2.13	17.04	39.1
"SD1A"	0.30					-1808		3.84	13.44	55.4
"SF1A"	0.18					1885		10.05	6.87	92.9
"QF0"	0.15				55.29			11.59	5.86	100.0
"OCF0"	0.00						-13215	11.59	5.86	100.0
"QF0"	0.15				55.29			10.85	6.16	97.0
"SF1A"	0.18					1885		8.43	7.50	85.7
"OCF"	0.10						-11646	4.30	10.92	61.5
"SD1B"	0.30					-1808		2.17	13.99	43.1
"QD0"	0.20				-57.82			1.39	14.52	33.0
"BPI1A"	0.35	3.60	97.30	0.21				1.11	10.58	24.5
"BPI1B"	0.35	4.20	83.40	0.24				1.16	7.98	19.4
"BPI1C"	0.35	5.40	64.86	0.31				1.42	5.76	15.9
"BPI1D"	0.35	6.89	50.76	0.40				1.91	3.94	14.7
"BPI1E"	0.35	9.89	35.38	0.57				2.61	2.52	16.3
"QF1"	0.32				102.68			2.24	2.33	15.8
"BPI2E1"	0.35	12.74	27.47	0.73	-44.04			0.36	4.68	7.4
"BPI2E2"	0.35	12.74	27.47	0.73	-44.04			0.74	3.40	10.9
"QF2"	0.45				96.52			2.06	1.75	16.7
"BPI2E1"	0.35	12.74	27.47	0.73	-44.04			0.68	4.02	7.5

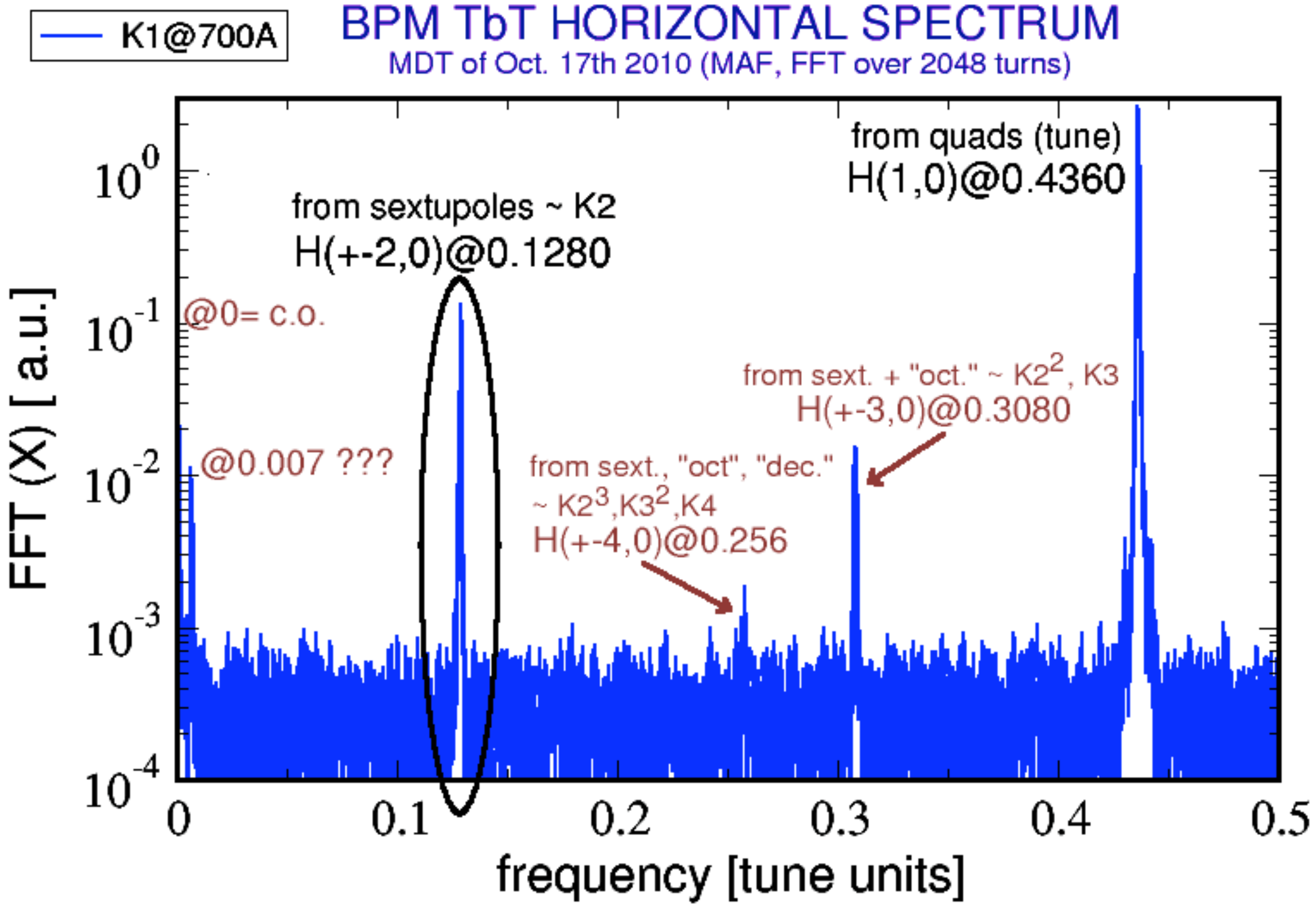
# NAME	L	ANGLE	R0	B0	G1	G2	BETX	BETY	DX
#	[m]	[mrad]	[m]	[T]	[T/m]	[T/m^2]	[m]	[m]	[mm]
SBEND	2.45	98.00	24.96	0.86			1.77	32.16	79.40
g1.qf2	0.94				7.86		26.48	16.34	111.60
g1.qd3	0.53				-12.14		7.81	33.34	59.54
g1.qd4	0.42				-12.10		10.87	28.24	219.10
g1.qf5	0.52				14.78		26.81	15.17	344.30
g1.qd6	0.52				-16.47		20.53	41.27	9.45
g1.qf7	0.92				13.71		52.41	9.08	30.79
g2.s04	0.40					124.31	38.00	8.16	134.30
g2.s06	0.40					-165.15	18.85	22.20	93.90
g2.s13	0.40					-88.02	15.39	23.32	260.90
g2.s19	0.40					443.32	26.53	15.61	342.30
g2.s20	0.40					-419.43	14.37	27.19	250.60
g2.s22	0.40					-95.81	30.47	30.16	15.43
g2.s24	0.40					132.33	44.47	8.15	30.80

ESRF SR

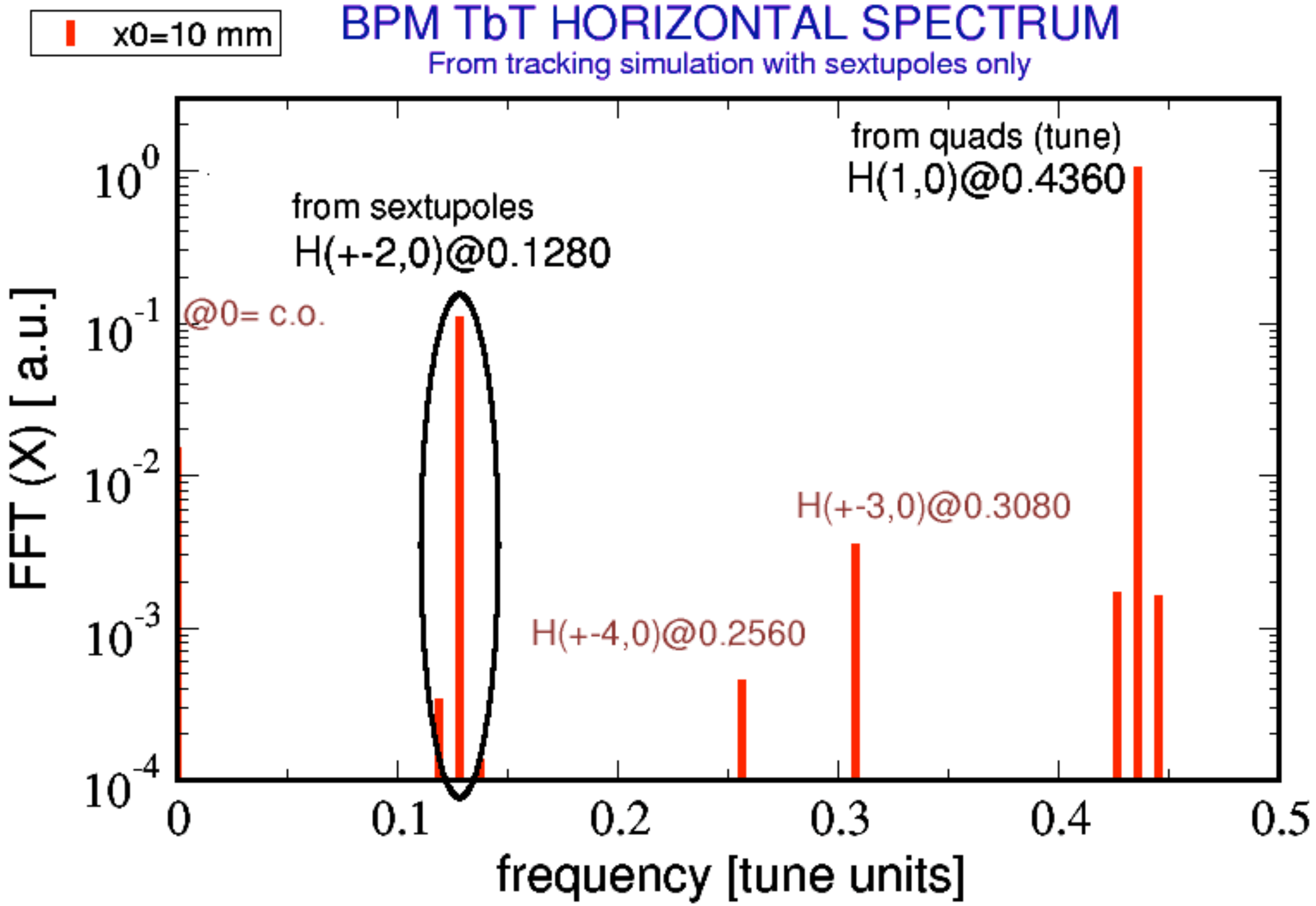
Beam response after horizontal kick …



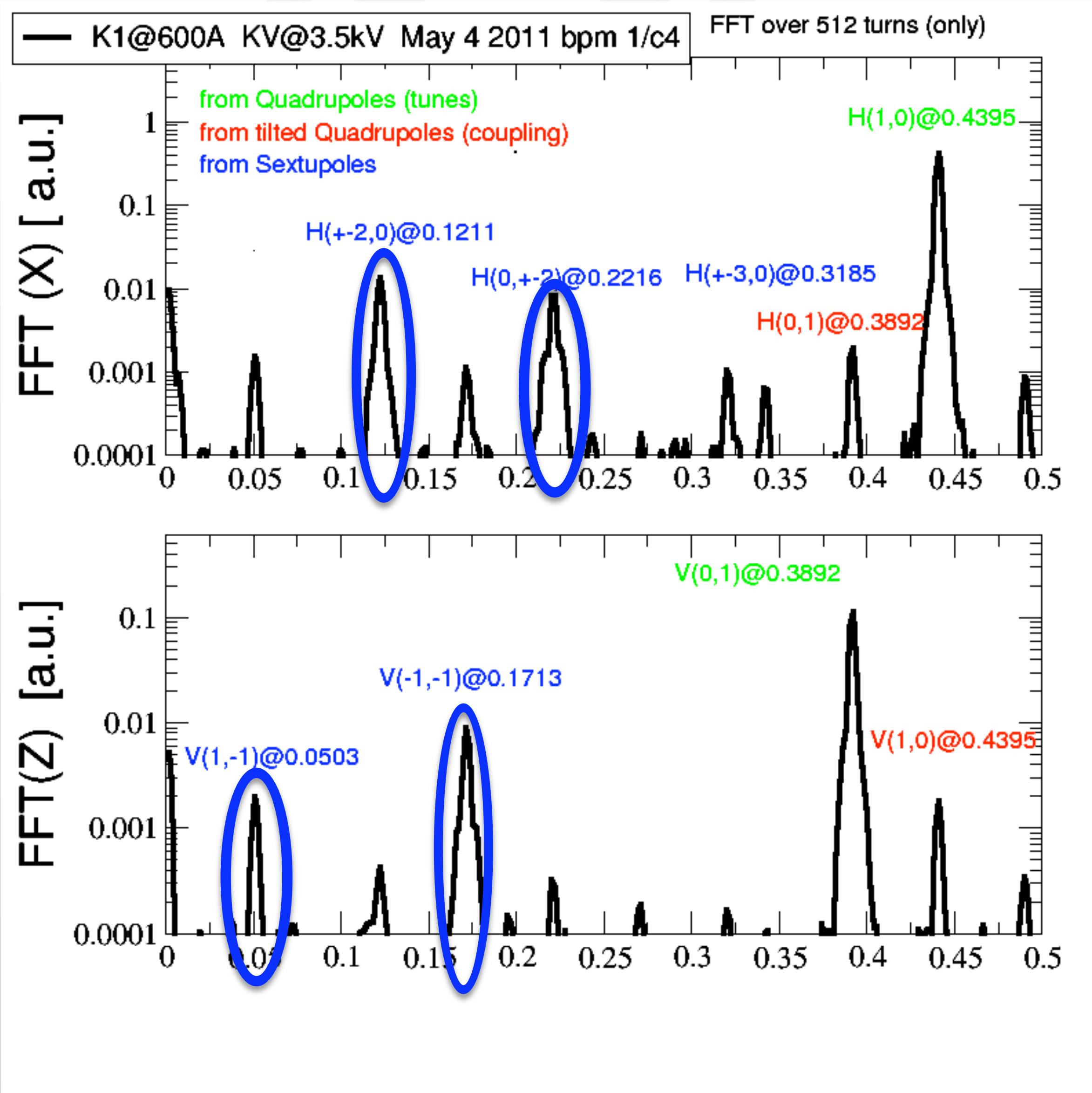
… and its spectrum (FFT) *measured*



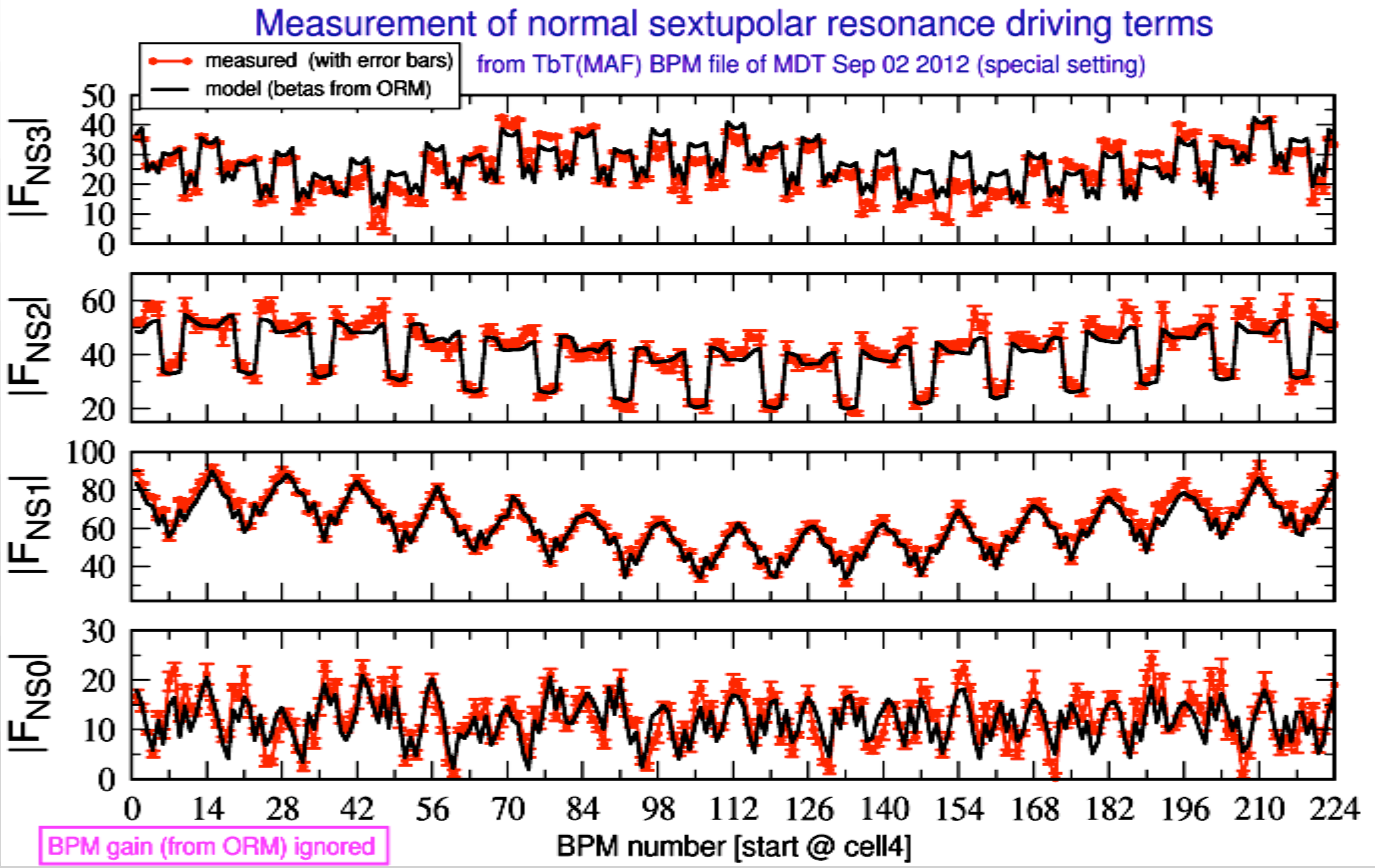
… and its spectrum (FFT) *simulated*



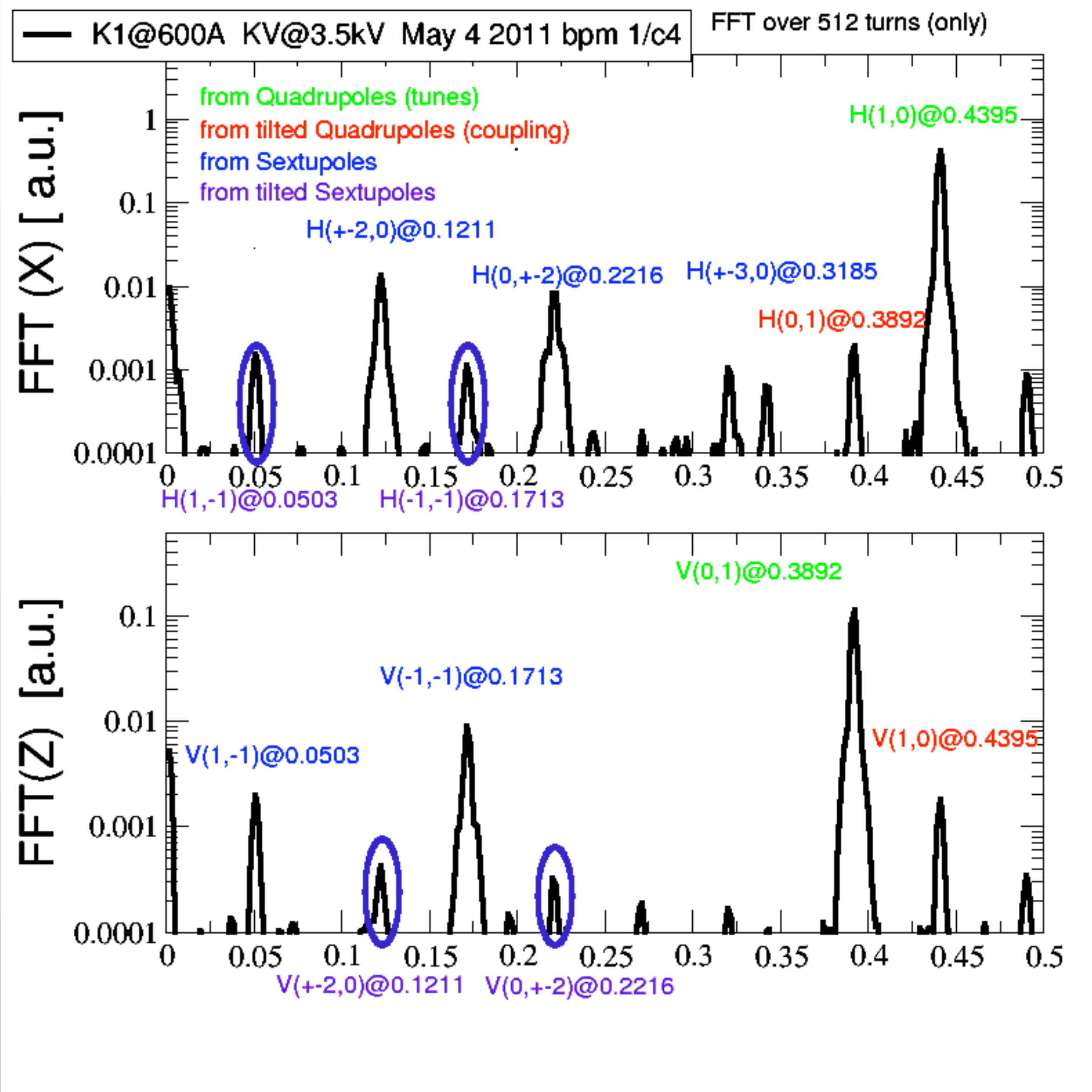
… and its spectrum (FFT) *measured*



its normal sextupolar RDTs *measured*



… and its spectrum (FFT) *measured*



its skew sextupolar RDTs *measured*