Collimation Studies for ILC e^+ Source

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Collimation studies are done using STRUCT code:

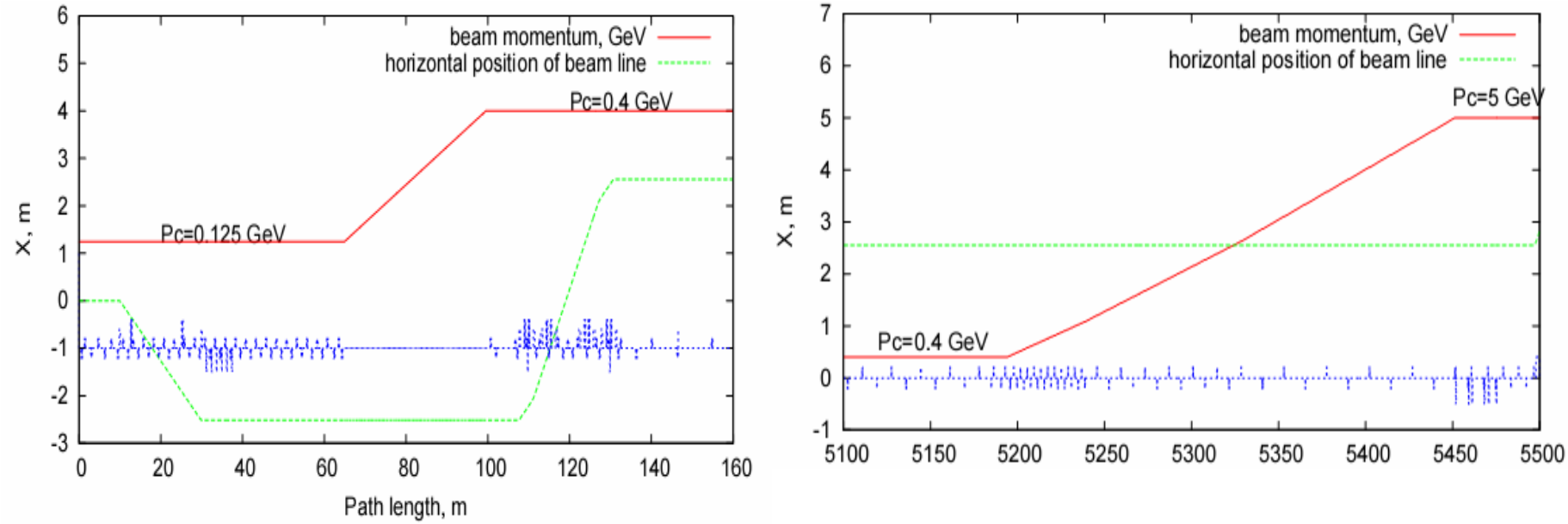
-- code may be used for performance analysis of already designed beam lines or accelerators, simulation of beam loss and other tracking studies.

-- proton interaction with material of scattering elements (collimators, masks and ..) is performed using Fortran modules of MARS14 code.

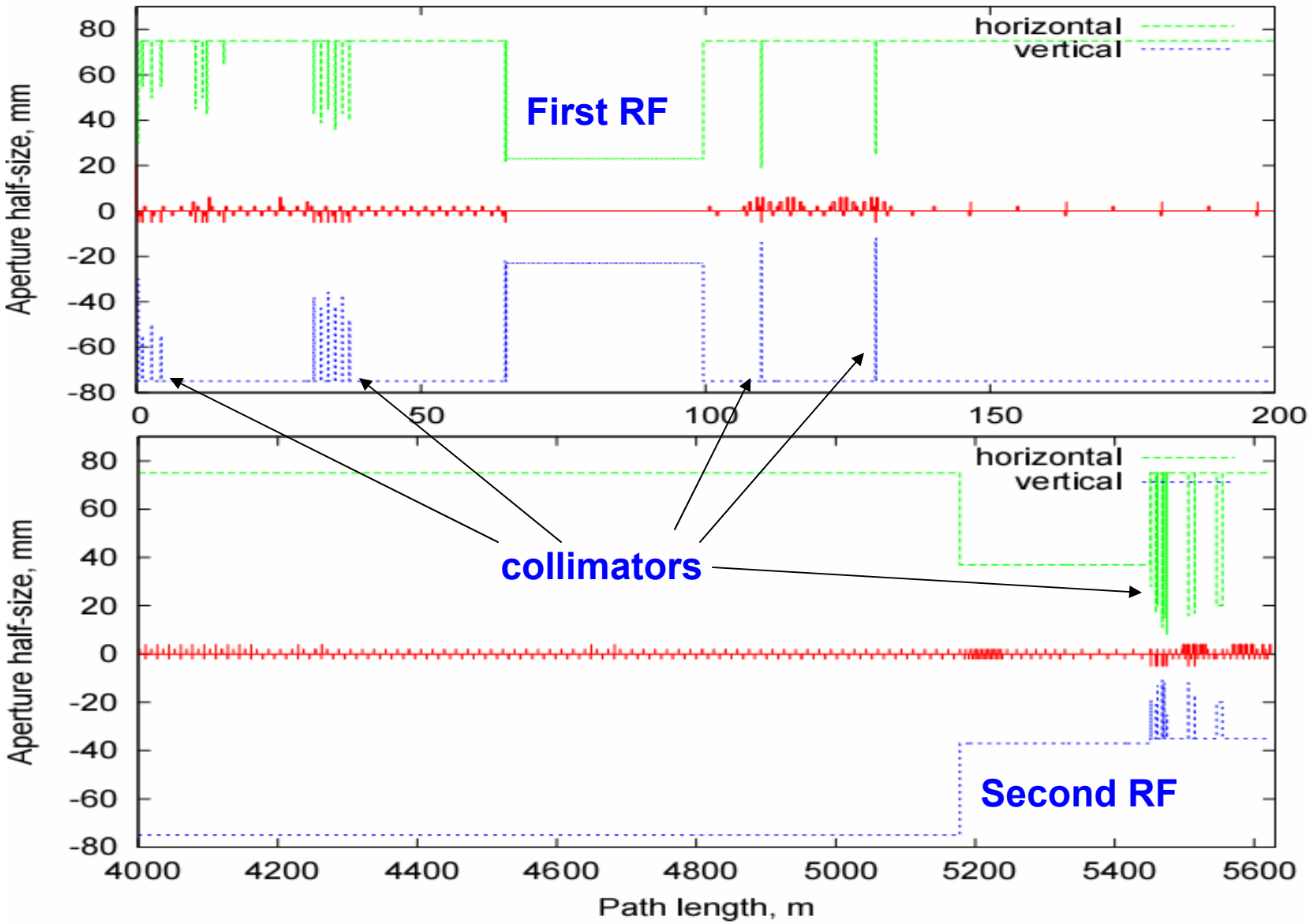
-- the GEANT code library is used for interactions of electrons with material of collimators and for synchrotron radiation generation in the magnetic elements of the beam line.

-- the first order approximation matrixes are used for beam line elements.

-- code will be improved to apply second order approximation matrix for dipole magnet in my next studies. It is necessary for e^+ source because of high divergence and large momentum spread of the beam, and also because of large bending angle of dipole magnets (125-150 mrad) used in the line.



Positron momentum gain along the beam line.



Aperture along the beam line.

MAD / STRUCT

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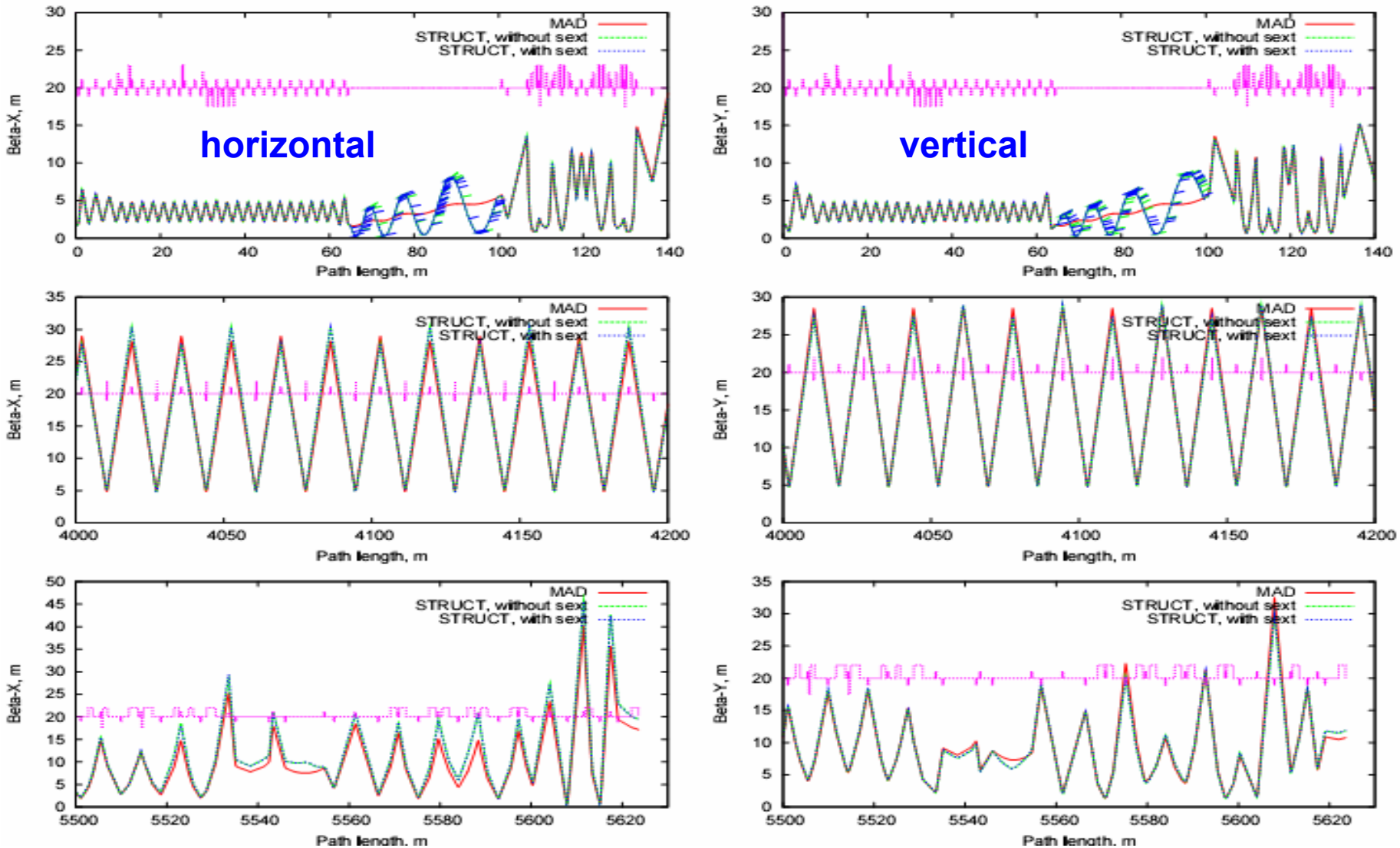

Calculated by MAD and STRUCT horizontal (left) and vertical (right) beta functions along the transport line. β-functions are calculated in STRUCT from beam size, assuming that phase shape of the beam is ellipse (for small beam size of 0.3σ).

STRUCT: 3σ / 0.3σ

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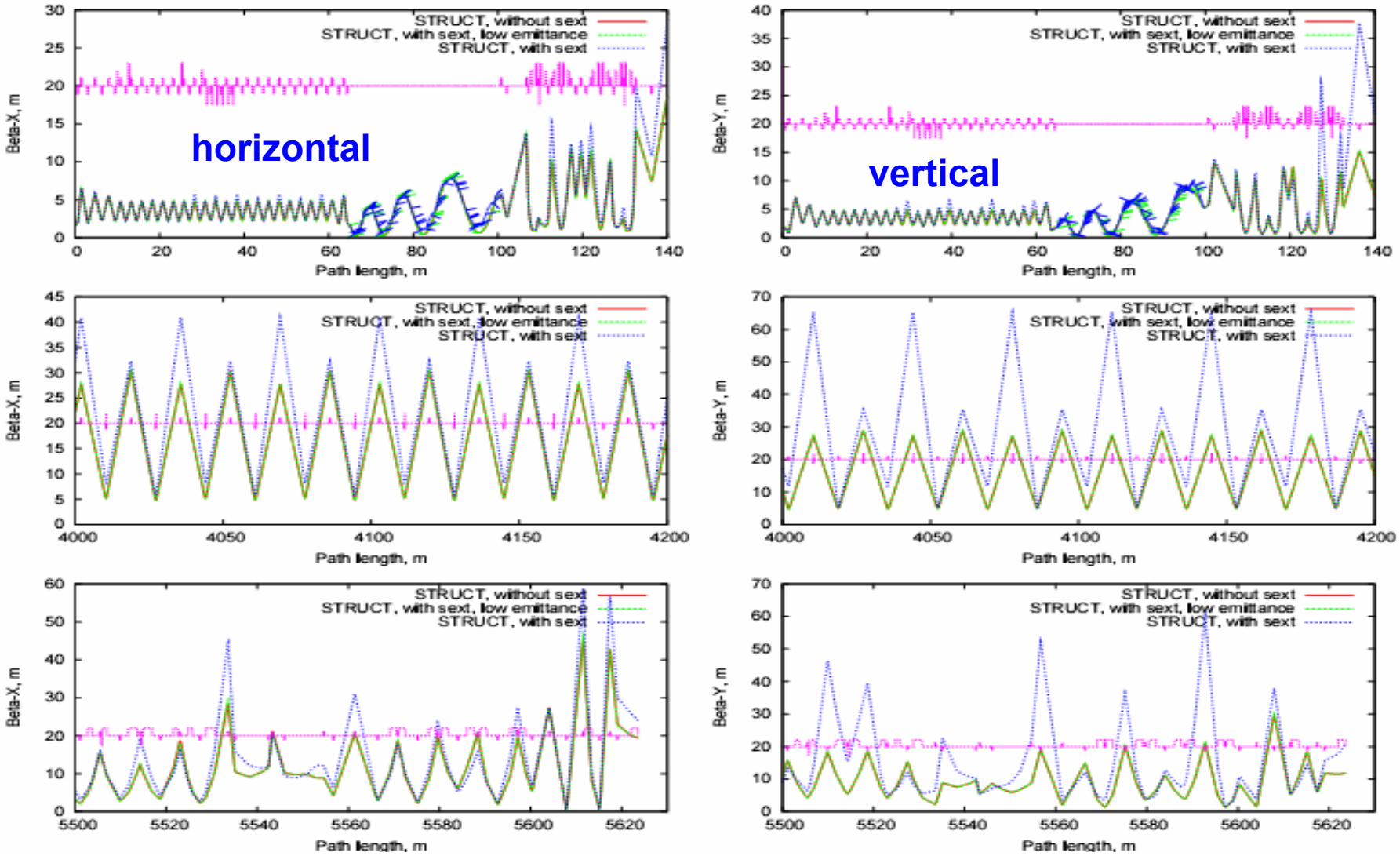

Calculated by STRUCT horizontal (left) and vertical (right) beta functions along the transport line for normal emittance of 245.28 mm-mrad (3σ) and low emittance of 2.45 mm-mrad (0.3 σ).

Positron beam distribution along beam line

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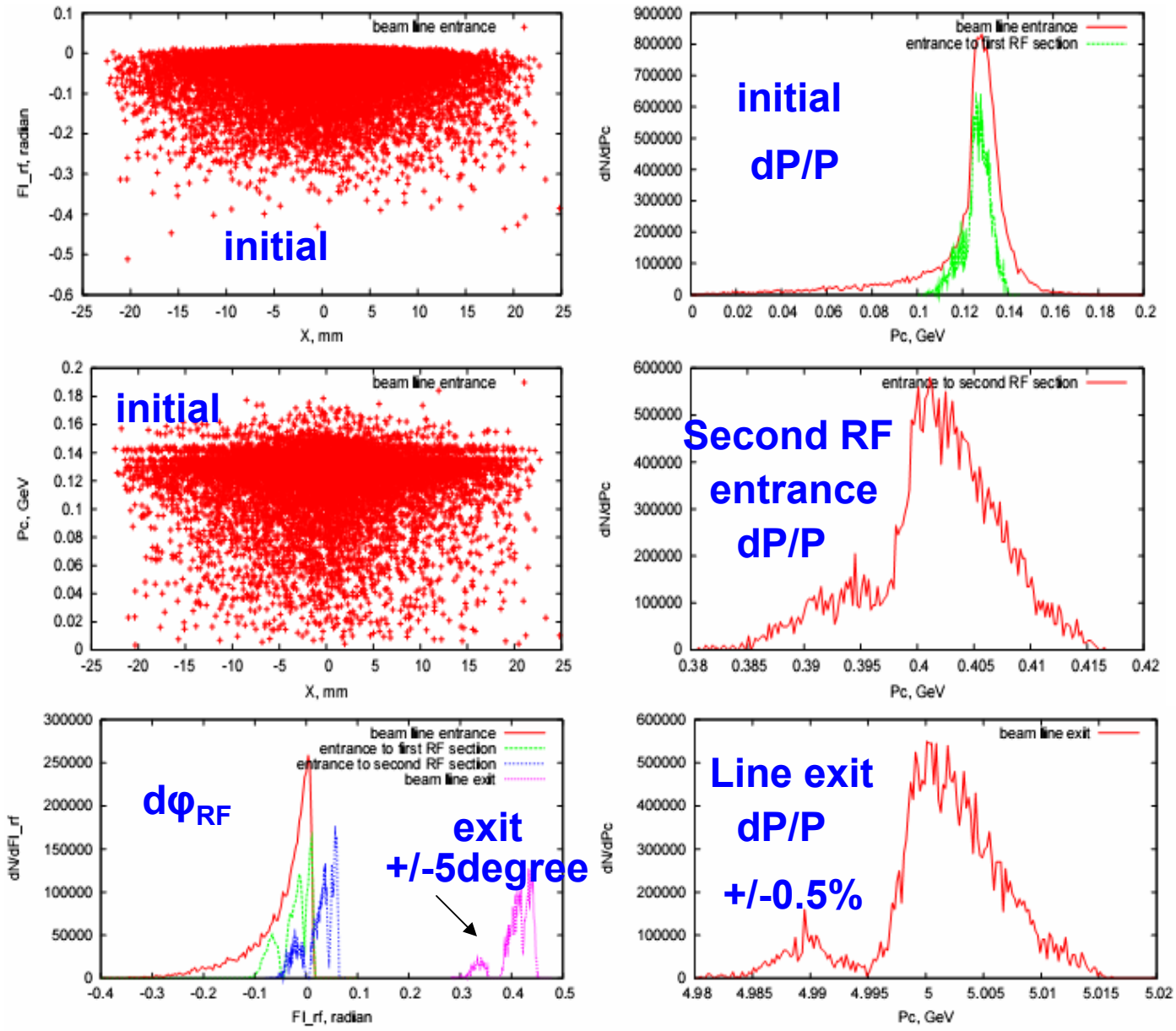


Positron distributions on RF phase (left) and momentum (right) along beam line.

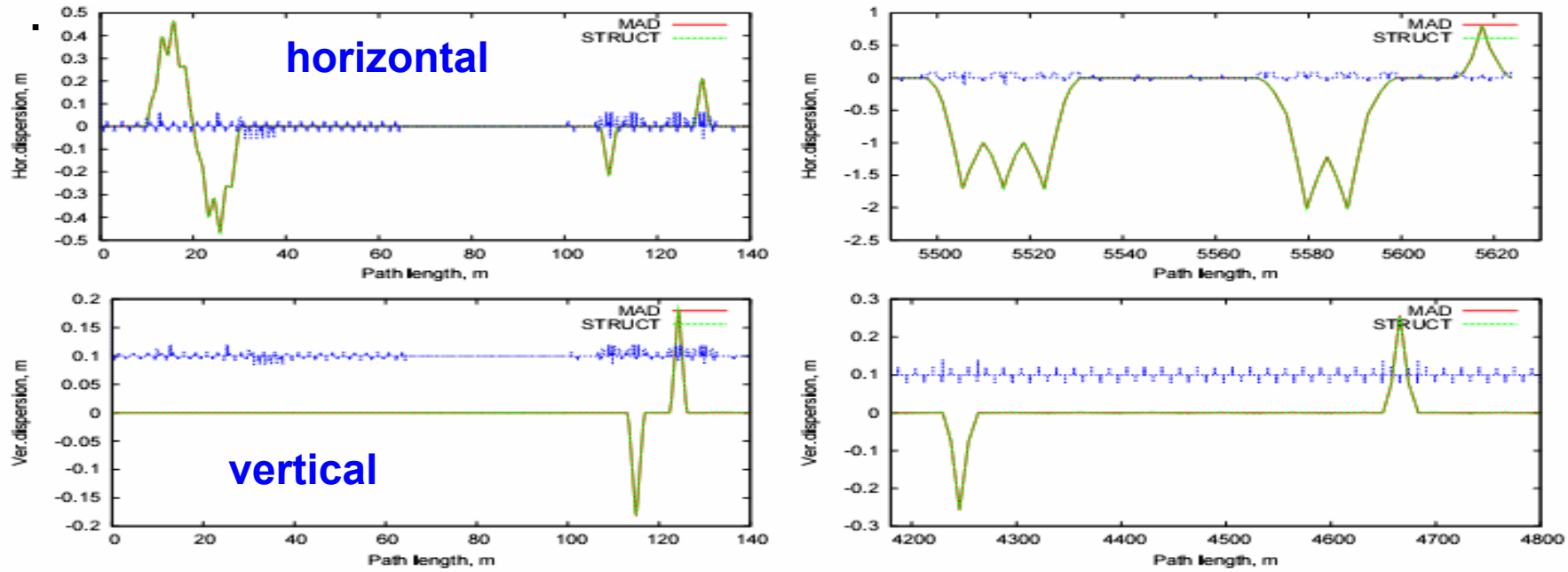
Beam line region	Aperture hor.	Aperture vert.	Acceptance
	mm	mm	$mm \cdot mrad$
PCAP	75	75	475
PPA	23	23	130
PBSTR	37	37	90

Calculated acceptance of beam line regions. If the aperture of PPA and PBSTR can not be increased, the only one solution to prevent losses at beam pipe is positioning of collimators at ε =130-90 mm-mrad.

Regions of beam line used for collimation:

Z=0:40 m for amplitude collimation at the beginning of beam line;

Z=5440:5485 m for amplitude collimation at the end of beam line before injection to the damping ring;



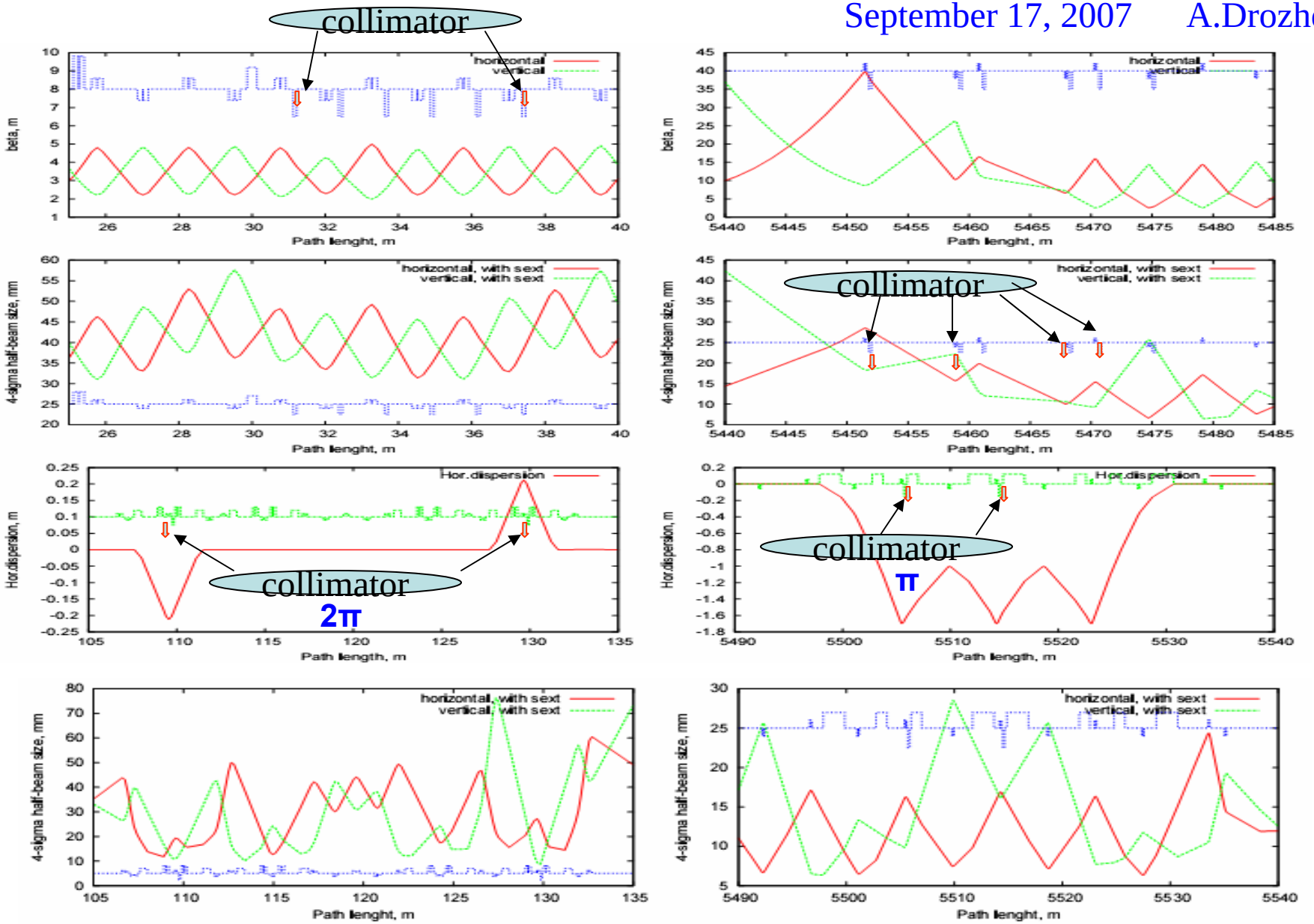
Z=105:135 m for momentum collimation with phase advance of 2π between different sign dispersion peaks;

Z=5500:5530 m for momentum collimation with phase advance of π between same sign dispersion peaks.

Dispersion region Z=10-30 m is not good for momentum collimation because phase advance between different sign dispersion peaks is π. This allows intercept only half of off-momentum particles.

collimator name	length	aperture half-size		reference beam line element	collimator entrance position		
					S	hor.	vert.
	m	mm	mm		m		
C1R	0.1	30.0	15.5	BEGINNING	0.200	0.0	0.0
C2R	0.1	47.0	13.5	QM1PCAPA	1.000	0.0	0.0
C3R	0.1	38.0	27.0	QM2PCAPA	2.600	0.0	0.0
C4R	0.1	50.0	21.5	QM3PCAPA	4.270	0.0	0.0
C5R	0.1	45.0	20.0	D1PCAPA	10.321	0.1	0.0
C6R	0.1	38.5	23.0	QFPCAPA	11.571	0.1	0.0
C7R	0.1	38.0	23.5	QDPCAPA	12.321	0.0	0.0
C8RMOM	0.1	46.0	20.0	QDPCAPA	15.320	0.0	0.0
C8RMOMa	0.1	46.0	20.0	QFPCAPA	26.120	0.0	0.0
ABL1	0.1	47.0	19.5	QS1PCAPA	31.121	0.0	0.0
ABL6	0.1	43.0	24.5	QSDPCAPA	37.371	0.0	0.0
ABLM1	0.1	20.5	7.5	Q1PPAT	109.750	0.0	0.0
ABLM2	0.1	28.0	7.0	Q1PPAT	129.850	0.0	0.0
ABH1	0.2	32.0	7.5	Q310PB	5451.809	0.0	0.0
ABH2	0.2	19.0	10.0	QMAT21PB	5459.201	0.0	0.0
ABH4	0.2	12.0	5.5	QMAT23PB	5468.244	0.0	0.0
ABH5	0.2	17.0	4.5	QEMIT1LT	5470.641	0.0	0.0
ABHM1	0.2	19.0	5.0	QARC13LTR	5505.688	0.0	0.0
ABHM2	0.2	19.0	7.0	QARC15LTR	5514.475	0.0	0.0

Rectangular collimator parameters. Collimator jaws are located at the envelope of the beam for ε_x=500 mm-mrad, ε_y=130 mm-mrad at Pc=0.125 GeV. This corresponds to ε_x=12.5 mm-mrad, ε_y=3.25 mm-mrad at Pc=5 GeV. Collimator displacement are not shown.



Lattice functions and 4σ beam size in the collimation system regions.

Effect of sextupole magnets

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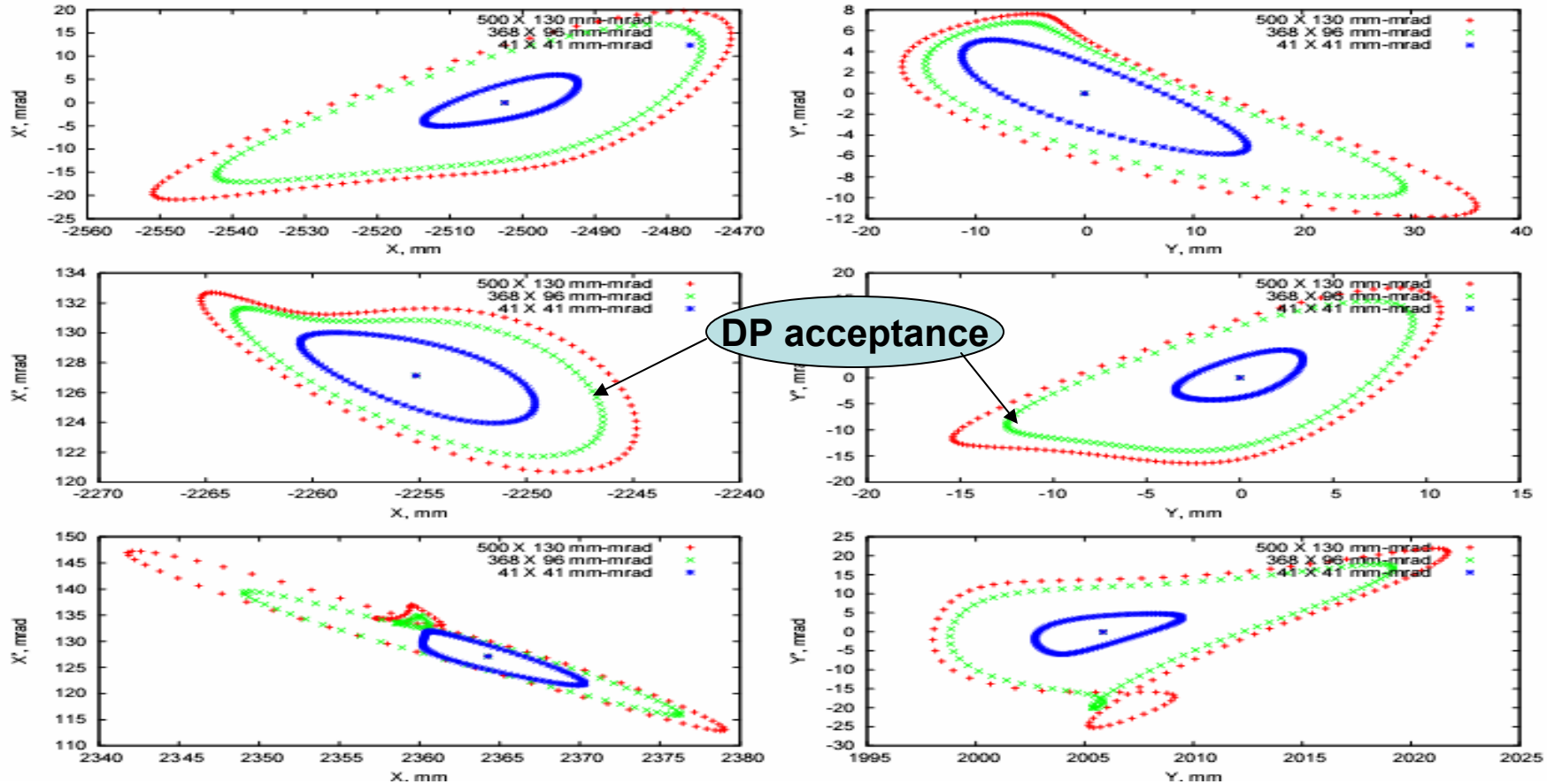

Horizontal (left) and vertical (right) phase plane in the collimator ABL6 (top), ABLM1 (middle) and ABLM2 (bottom) for betatron amplitudes of 500 X130 mm-mrad, 368 X 96 mm-mrad, and 41 X 41 mm-mrad.

Amplitudes of 368 mm-mrad at Pc=0.125 GeV corresponds to emittance of 9.2 mm-mrad at Pc=5 GeV what is an acceptance of the Damping Ring.

Effect of sextupole magnets

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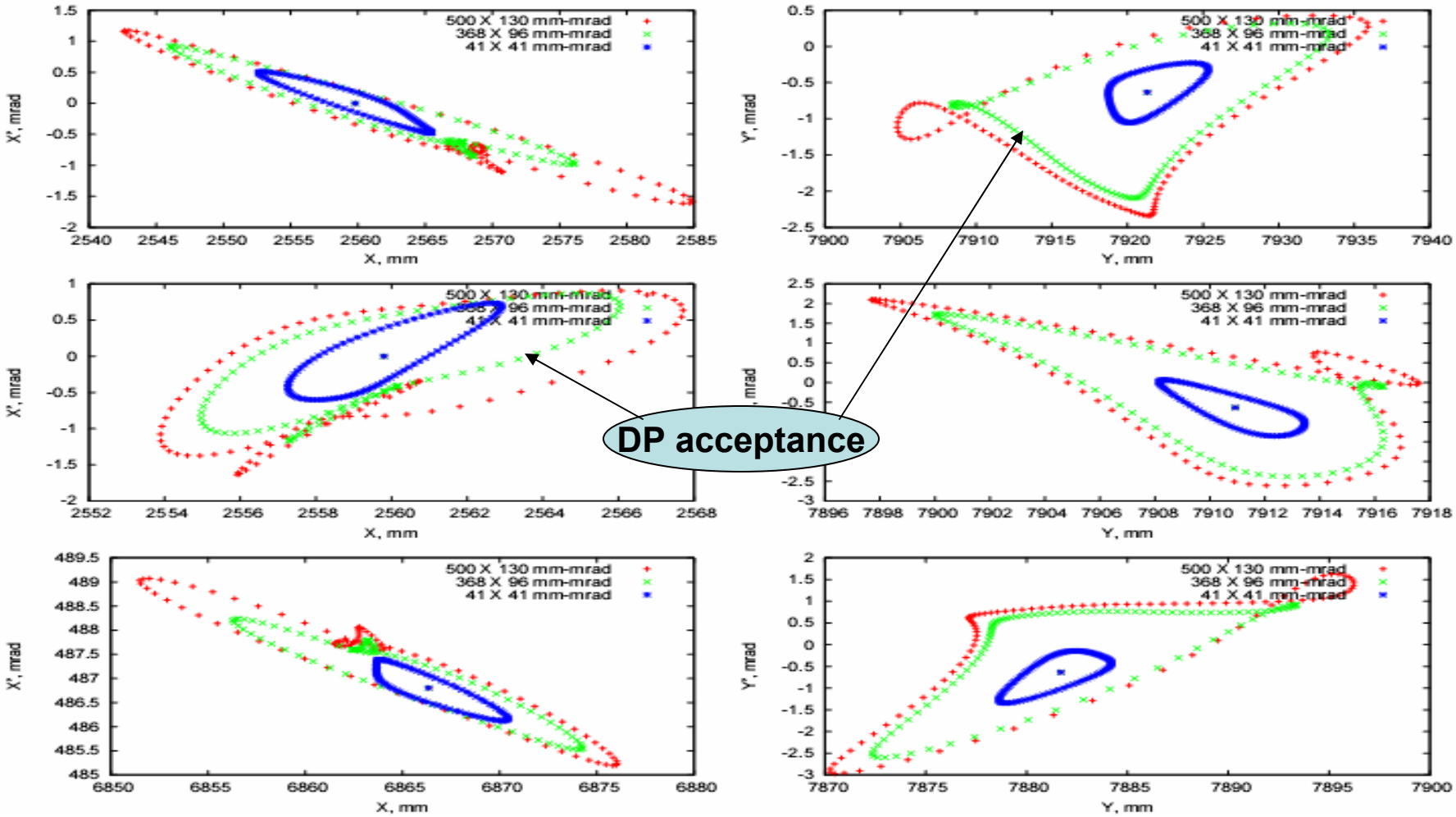

Horizontal (left) and vertical (right) phase plane in the collimator ABH1 (top), ABH4 (middle) and ABHM2 (bottom) for betatron amplitudes Of 500 X130 mm-mrad, 368 X 96 mm-mrad, and 41 X 41 mm-mrad.

Positron loss ELEGANT / STRUCT

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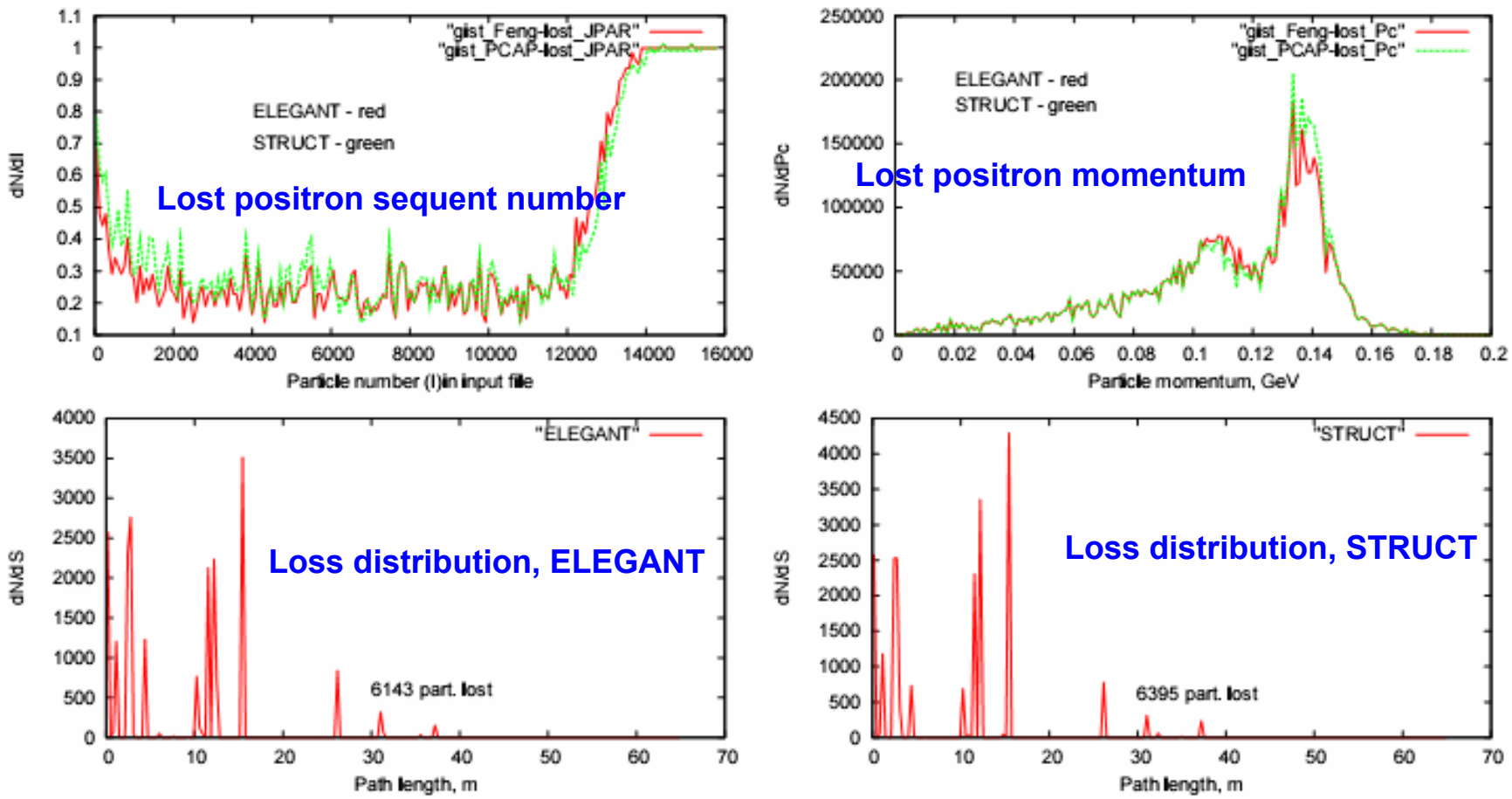

Comparison of primary positron loss distributions in the PCAP line calculated with ELEGANT and STRUCT codes.

Transverse distribution of the beam

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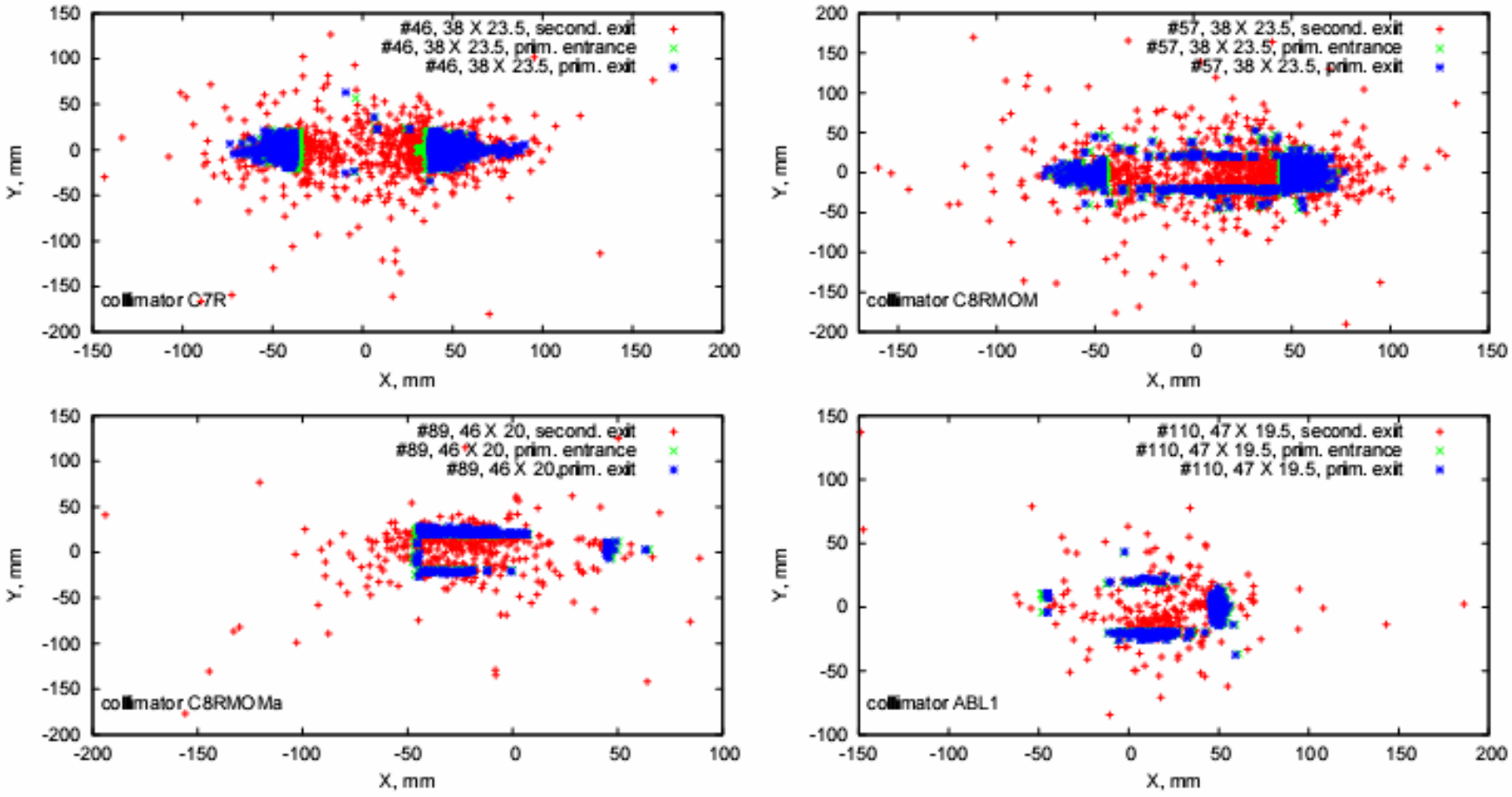

Primary (green and blue) and secondary (red) particle distributions in the collimators C7R (top, left), C8RMOM (top, right), C8RMOMa (bottom, left) and ABL1 (bottom, right).

Secondary beam distribution example

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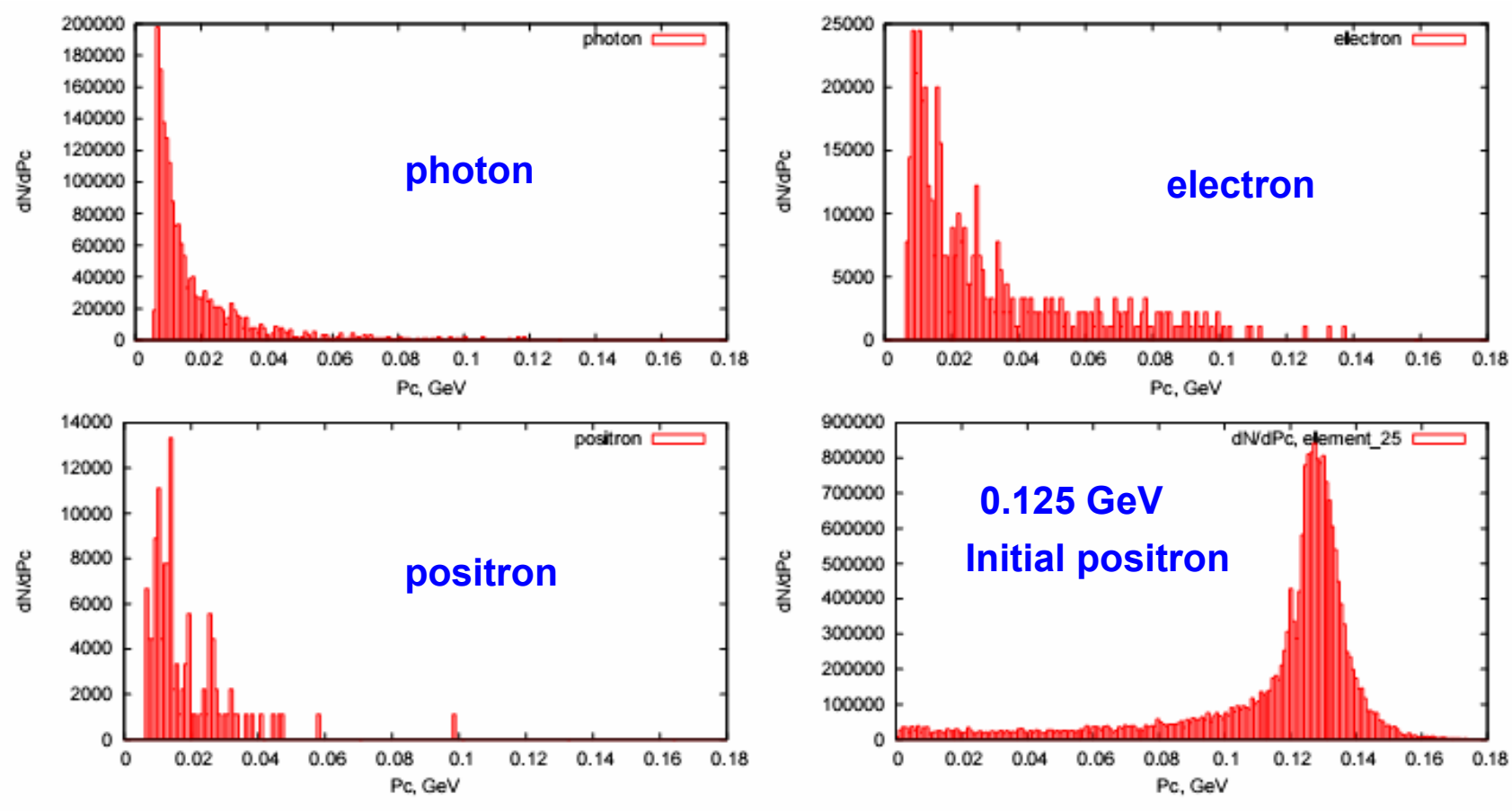

Photon (top, left), electron (top, right) and positron (bottom, left) energy (momentum) spectrum at the 100 mm length copper collimator exit, and initial positron beam momentum distribution (bottom, right).

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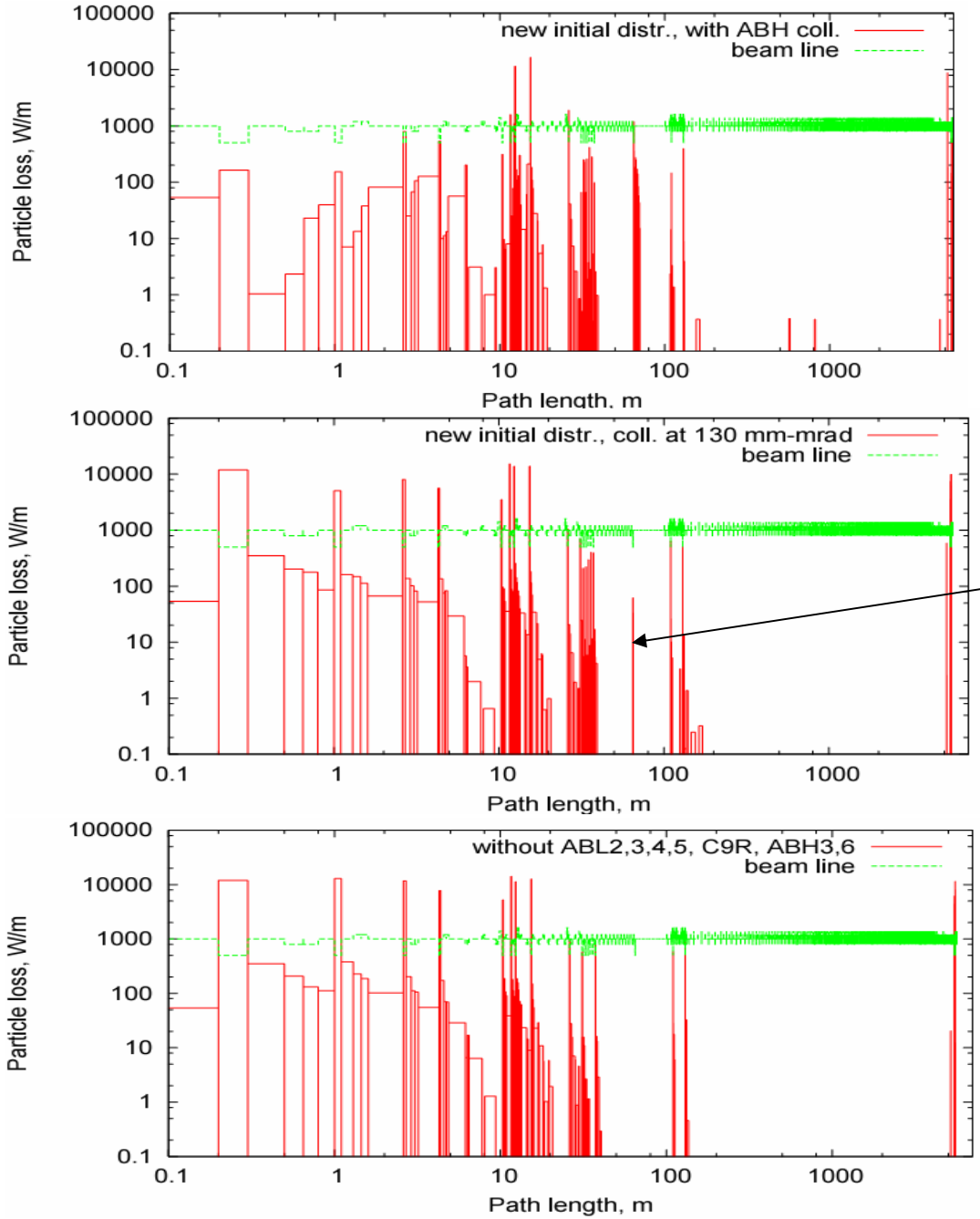

Primary and secondary beam loss distribution with all collimators at

ε=500 mm-mrad (top),

ε=130mm-mrad (middle)

(Positioning of collimators at 130 mm-mrad allows to eliminate losses in the first RF regin)

and ε=90 mm-mrad (bottom)

Beam line exit phase plane

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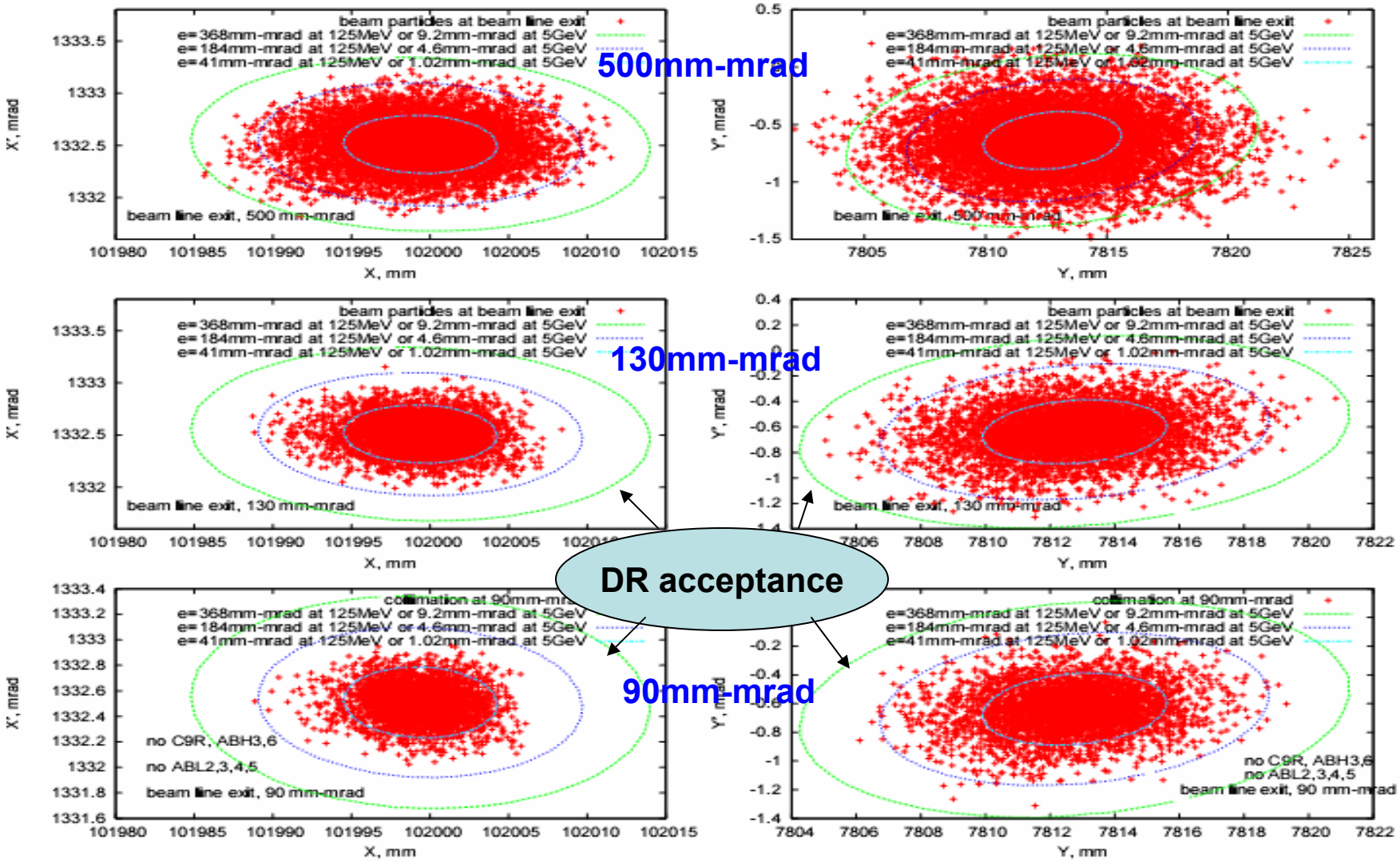

Horizontal (left) and vertical (right) phase plane at the exit of beam line for beam collimated at 500 mm-mrad (top), 130 mm-mrad (middle) and 90 mm-mrad (bottom).

Beam line exit phase plane

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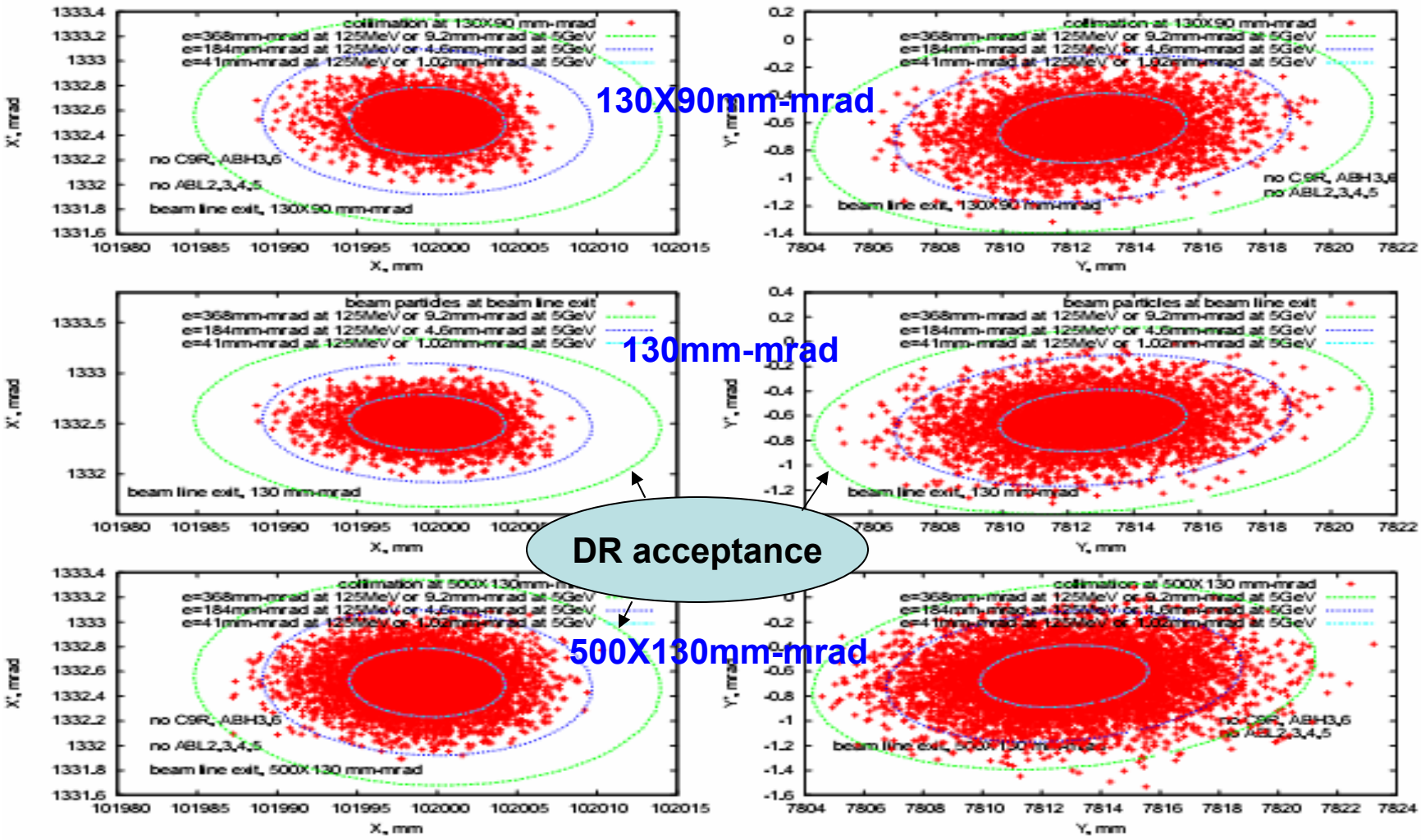

Horizontal (left) and vertical (right) phase plane at the exit of beam line for beam collimated at ε_x=130 mm-mrad, ε_y=90 mm-mrad, (top), at $\varepsilon_{x,y}$=130 mm-mrad (middle) and at ε_x=500 mm-mrad, ε_y=130 mm-mrad (bottom).

Beam line exit positron beam emittance

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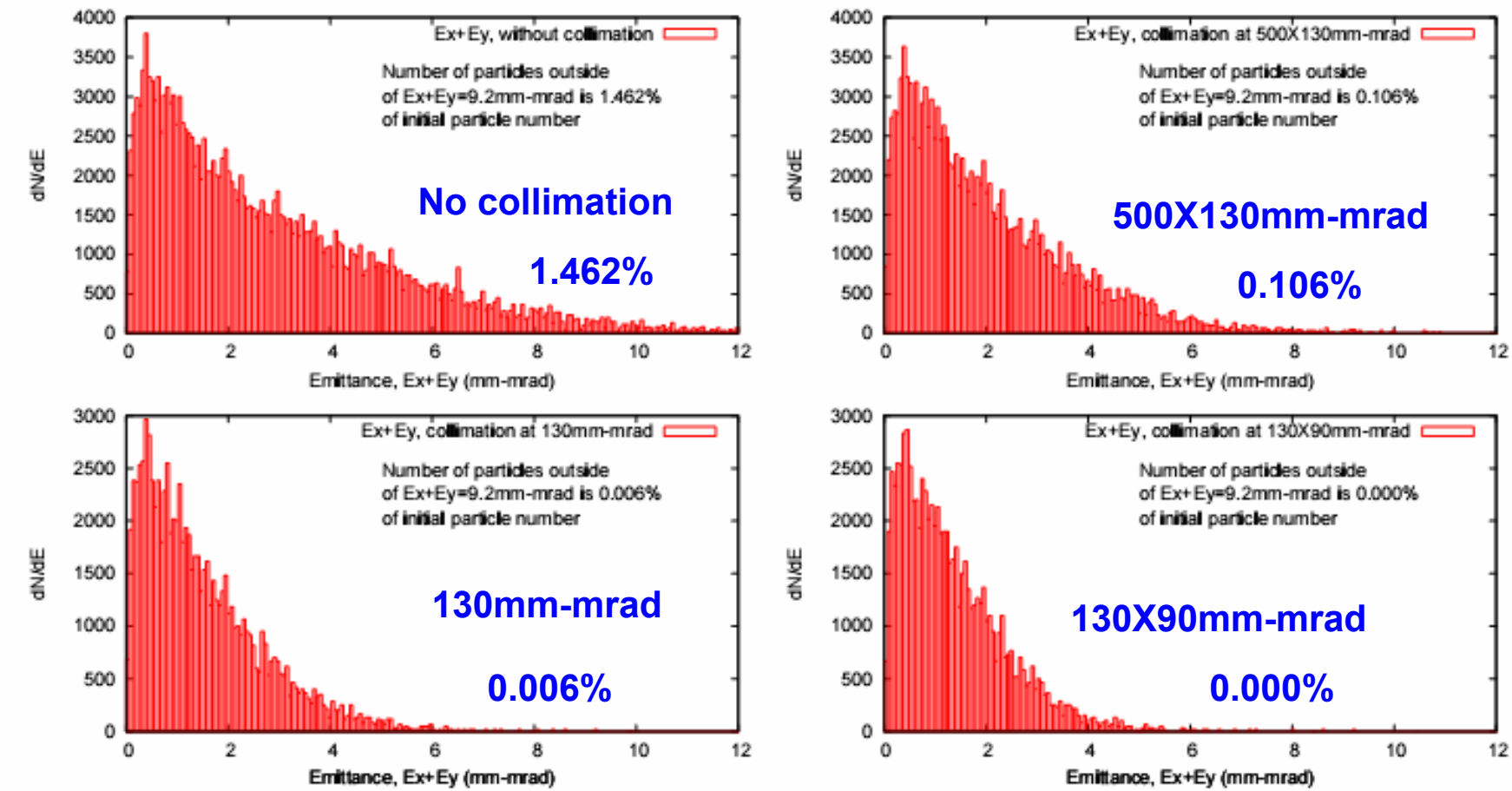

Positron beam ``emittance'' $\varepsilon_{x,y} = \varepsilon_x + \varepsilon_y$ distribution at the exit of beam line without collimation (top, left) and with collimation at ε_x=500 mm-mrad, ε_y=130 mm-mrad (top, right), and with collimated at $\varepsilon_{x,y}$=130 mm-mrad (bottom, left) and at ε_x=130 mm-mrad, ε_y=90 mm-mrad (bottom, right).

Beam loss and transfer efficiency

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Beam loss				beam transfer efficiency	particle number at line exit with $\varepsilon_{x,y} > 9.2 mm \cdot mrad$
C1R-C8aR 0-30 m	ABL collim. 30-140 m	ABH collim. 5170-5520 m	Total 0-5630 m		
W	W	W	W	%	%
without collimators					
0.710E+04	0.549E+04	0.809E+04	0.207E+05	11143/50000=22.3%	731/50000=1.462%
collim. at $\varepsilon = 130\ mm \cdot mrad$					
0.264E+05	0.142E+04	0.252E+05	0.534E+05	5242/50000=10.5%	3/50000=0.006%
collim. at $\varepsilon = 90\ mm \cdot mrad$					
0.305E+05	0.121E+04	0.239E+05	0.552E+05	3968/50000=7.9%	0.000
collim. at $\varepsilon_x = 130\ mm \cdot mrad$, $\varepsilon_y = 90\ mm \cdot mrad$					
0.276E+05	0.210E+04	0.219E+05	0.518E+05	4832/50000=9.7%	0.000
collim. at $\varepsilon_x = 500\ mm \cdot mrad$, $\varepsilon_y = 130\ mm \cdot mrad$					
0.161E+05	0.618E+04	0.375E+05	0.600E+05	8237/50000=16.5%	53/50000=0.106%

Calculated beam power lost along beam line. Positron number at the source is 50,000. Initial number of positrons at PCAP entrance in calculations is 15823. The calculations of particle number outside of emittance $\varepsilon_{x,y} = \varepsilon_x + \varepsilon_y$

at the beam line exit are done using

$$\alpha_x = 0.119018,\ \beta_x = 17.1647m,\ \gamma_x = (0.119018^2 + 1)/17.1647,$$
$$\alpha_y = -0.11505,\ \beta_y = 10.7784m,\ \gamma_y = (0.115050^2 + 1)/10.7784,$$
$$\text{and } \varepsilon_x = \gamma_x X^2 + 2\alpha_x X \cdot X' + \beta_x \cdot X'^2,$$
$$\varepsilon_y = \gamma_y Y^2 + 2\alpha_y Y \cdot Y' + \beta_y \cdot Y'^2.$$

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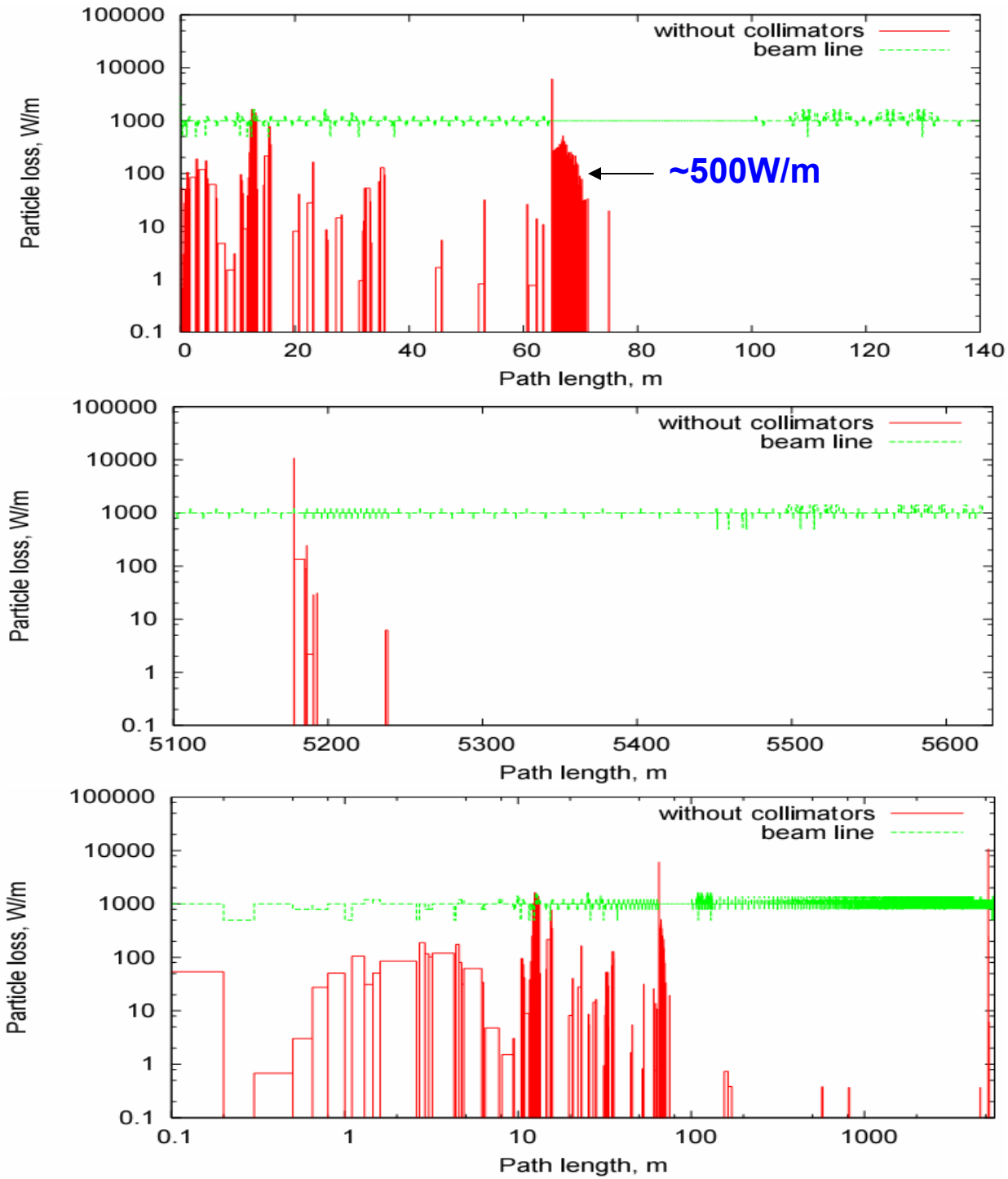
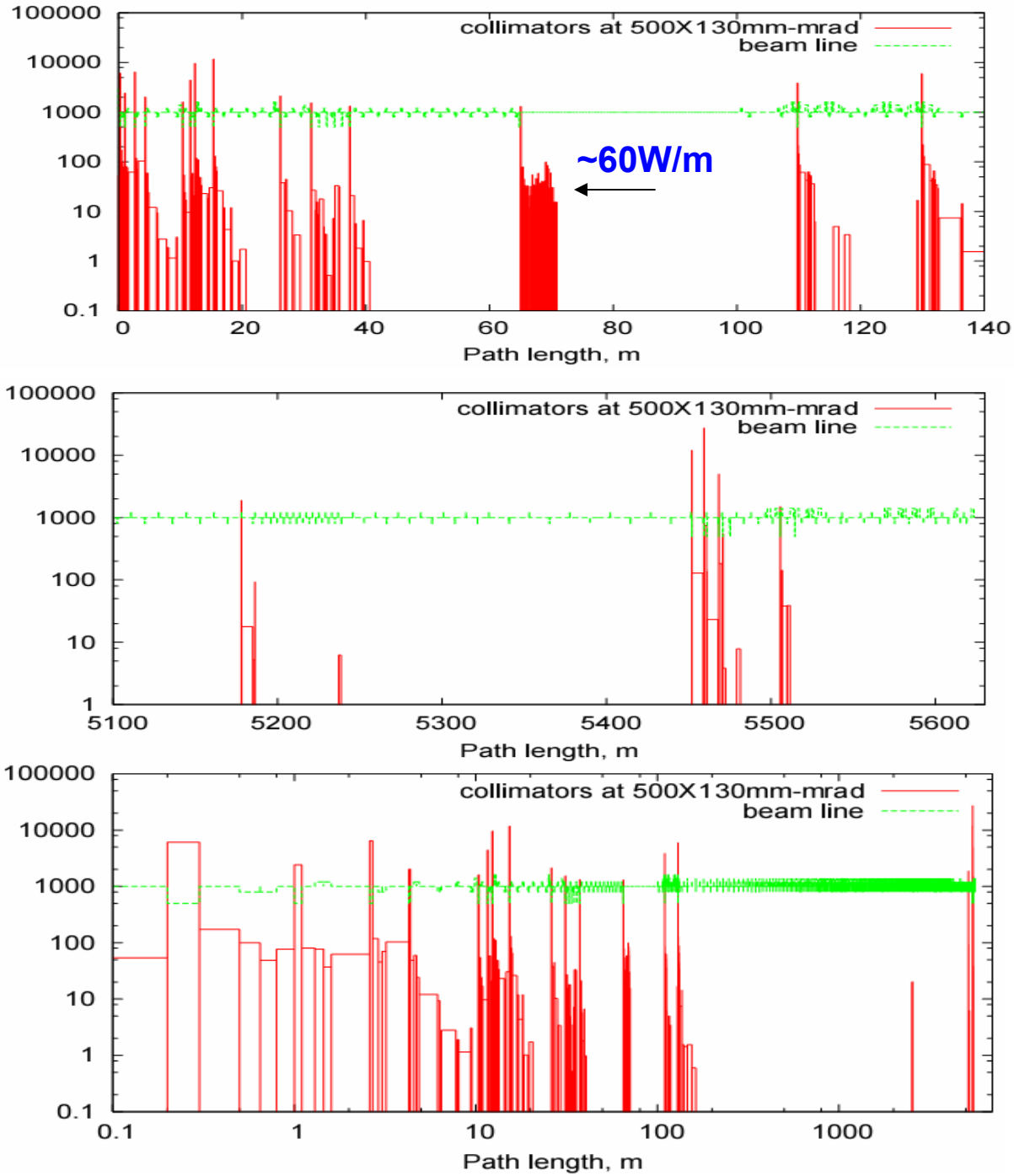
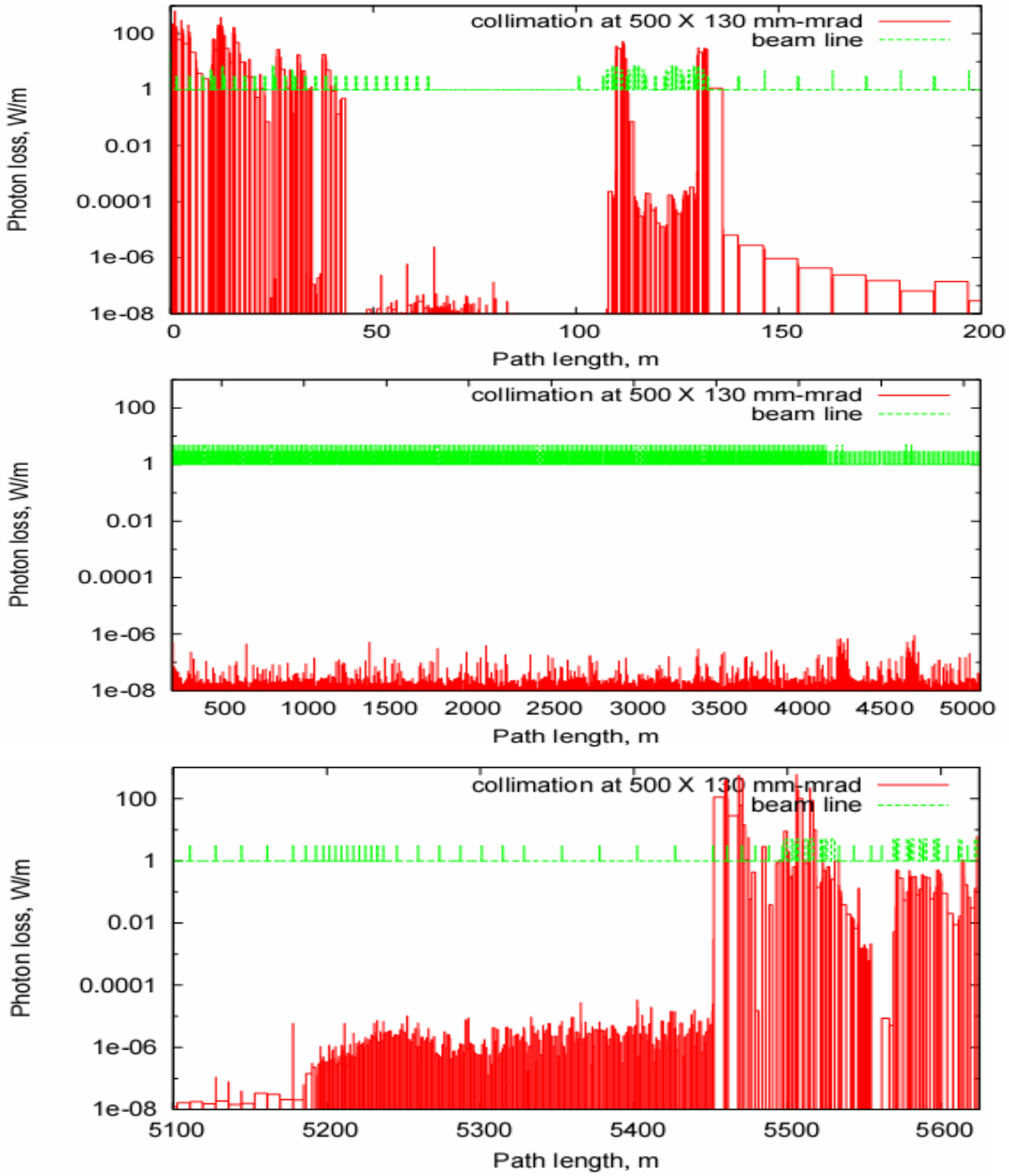


Positron loss distribution without collimation.



Primary and secondary beam loss distribution with collimators at ε_x=500 mm-mrad, ε_y=130 mm-mrad. Beam loss power at the beginning of PPA section (S=65-71m) is about 300W with high peak at the first element.



Photon loss distribution with collimators at ε_x=500 mm-mrad, ε_y=130 mm-mrad. Photon loss in the regions 0-40 m, 110-140 m and 5460-5624 m are mostly defined by bremsstrahlung radiation in the collimators, in the rest part of beam line they are defined by synchrotron radiation.

Summary

- Beam and synchrotron power loss in the beam line with collimation system is below 100 W/m.

- Power loss in the collimators are:

  C1R-C6R – 0.6-1.8 kW, C7R – 2.7 kW,

  C8M – 3.6 kW, ABL1-ABLM2 – 0.6-1.8 kW,

  ABH1- 7.2 kW, ABH2 – 16.7 kW, ABH4 – 3 kW,

  ABH5 – 0.3 kW, ABHM1 – 0.9 kW

- Beam loss in the RF section may be eliminated with collimation at 130 mm-mrad.

- Work is in a progress.