New design of ILC RTML in central integration region (“Ecentral” beamline)

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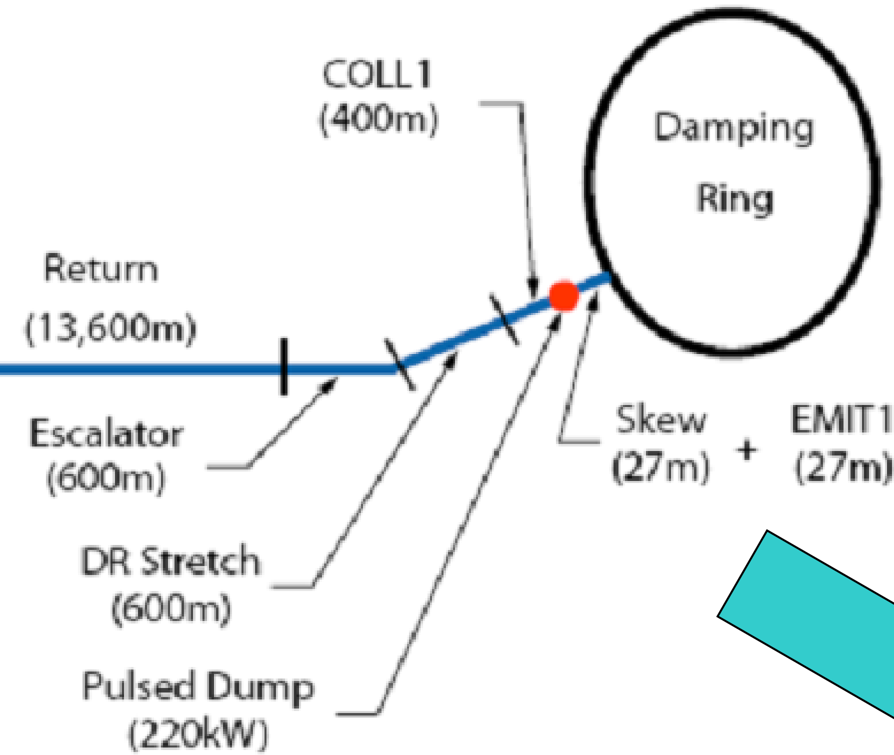
FERMILAB

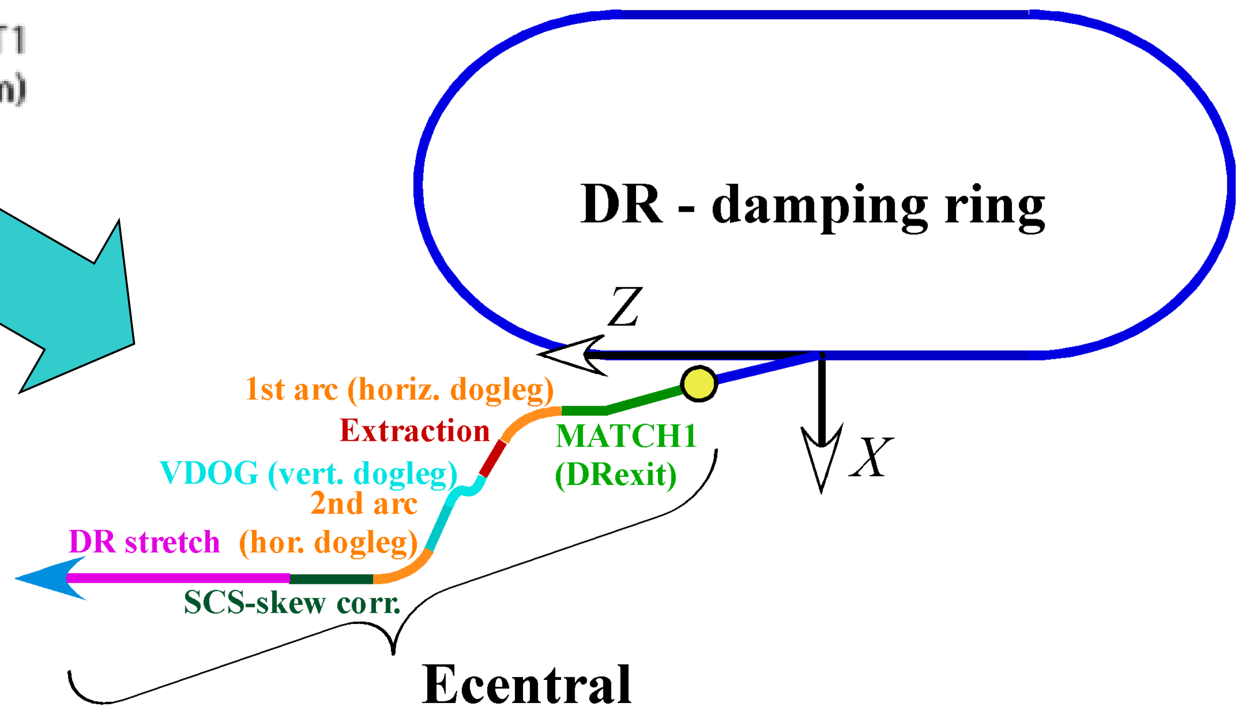
* CERN

Changes of RTML lattice in central area

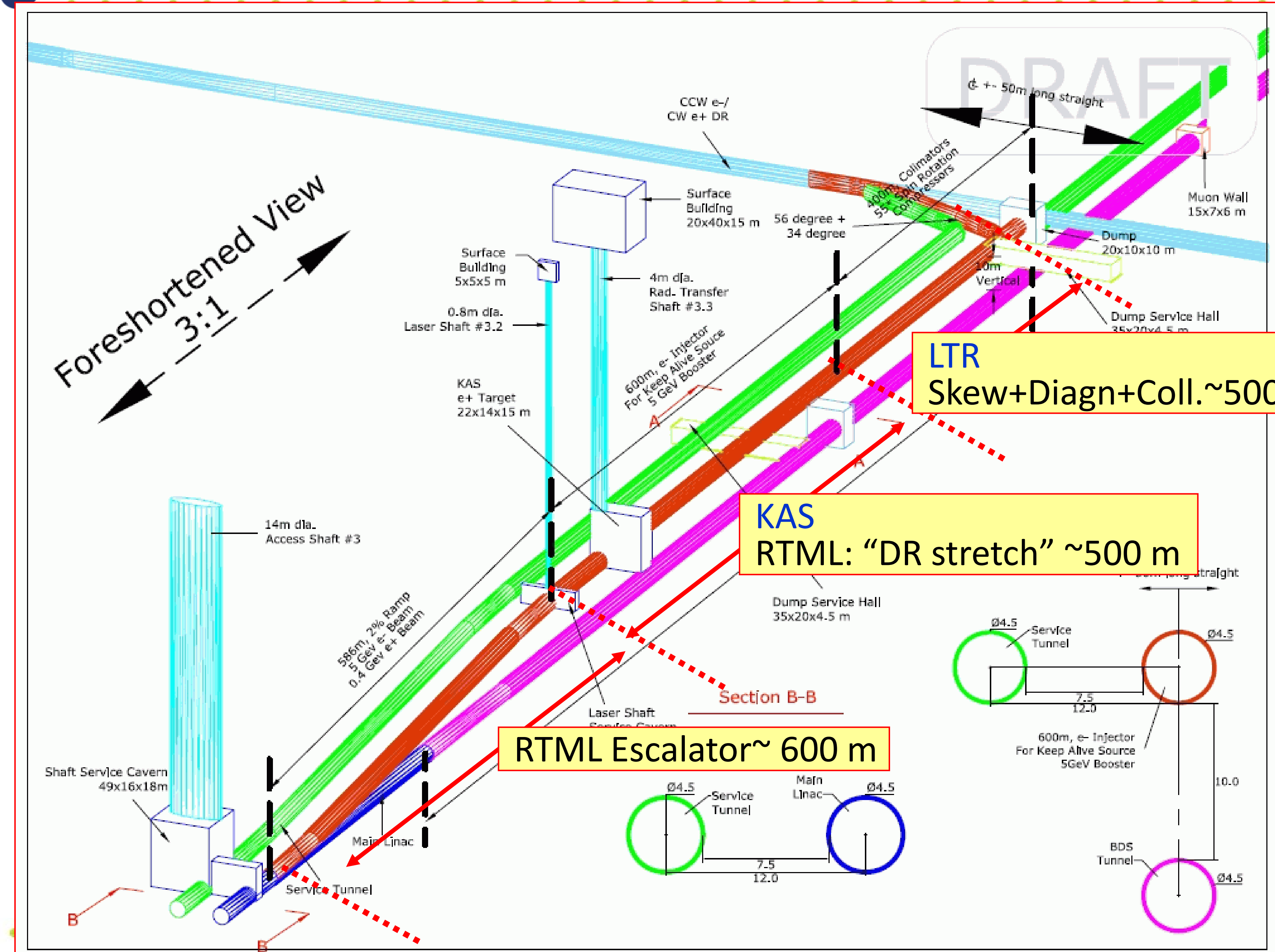


SB2009 baseline proposal:

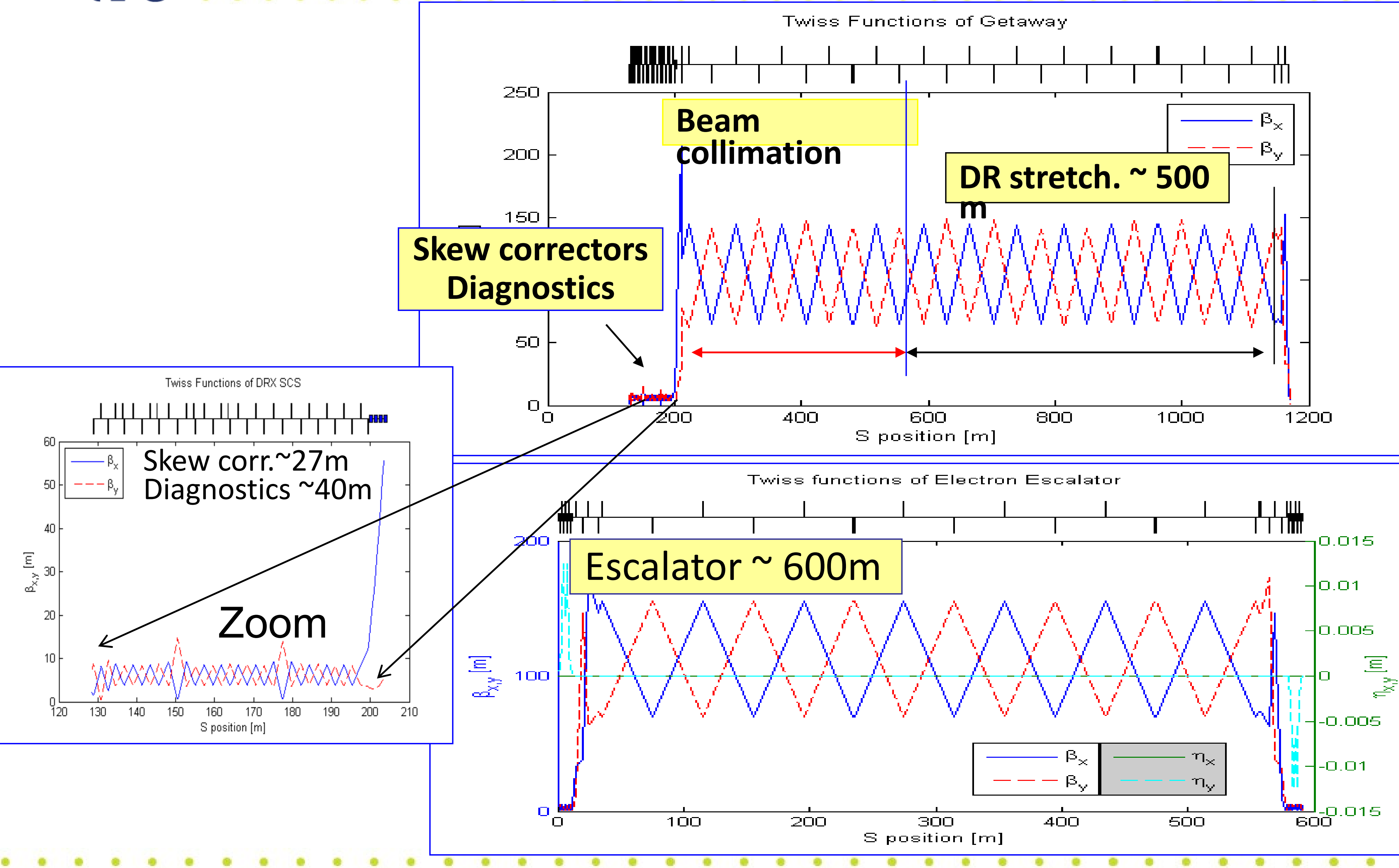
- New configuration of the DR
- DR has same elevation as ML



DR-to-RTML connection (RDR)



“Getaway” and “Escalator” in RDR



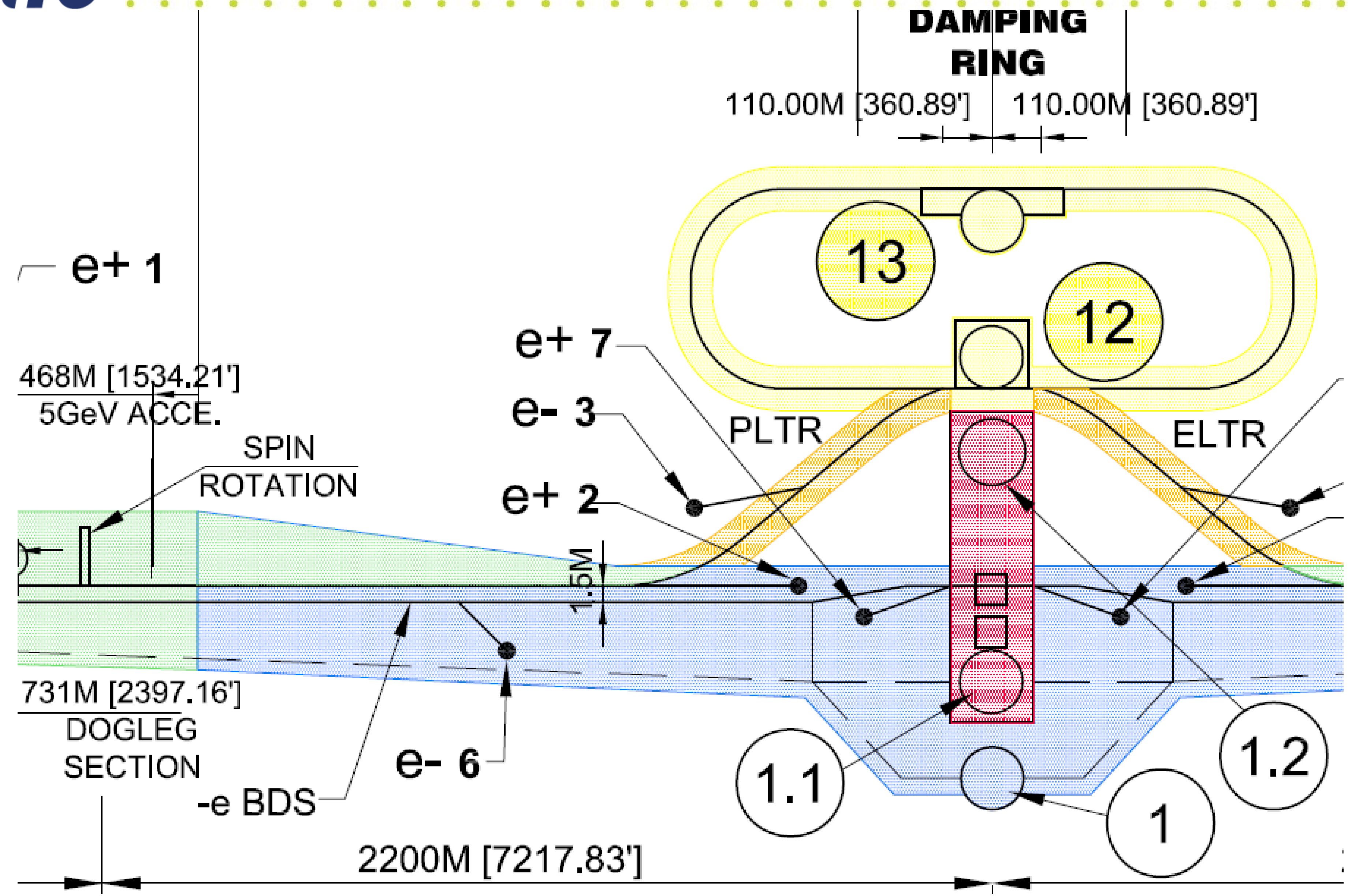
RTML lattice redesign in central area

Works for “ecentral” beam-line:

- Preserve all basic functionalities of RDR design
  - **The basic lattice modules forming the “ecentral” beam-line have been borrowed from the RDR 2007 baseline design**
- Geometry matching for a new RTML via appropriate arrangements of borrowed modules (done by A. Latina*)
- Matching of Twiss parameters between modules of “ecentral” line are presented here

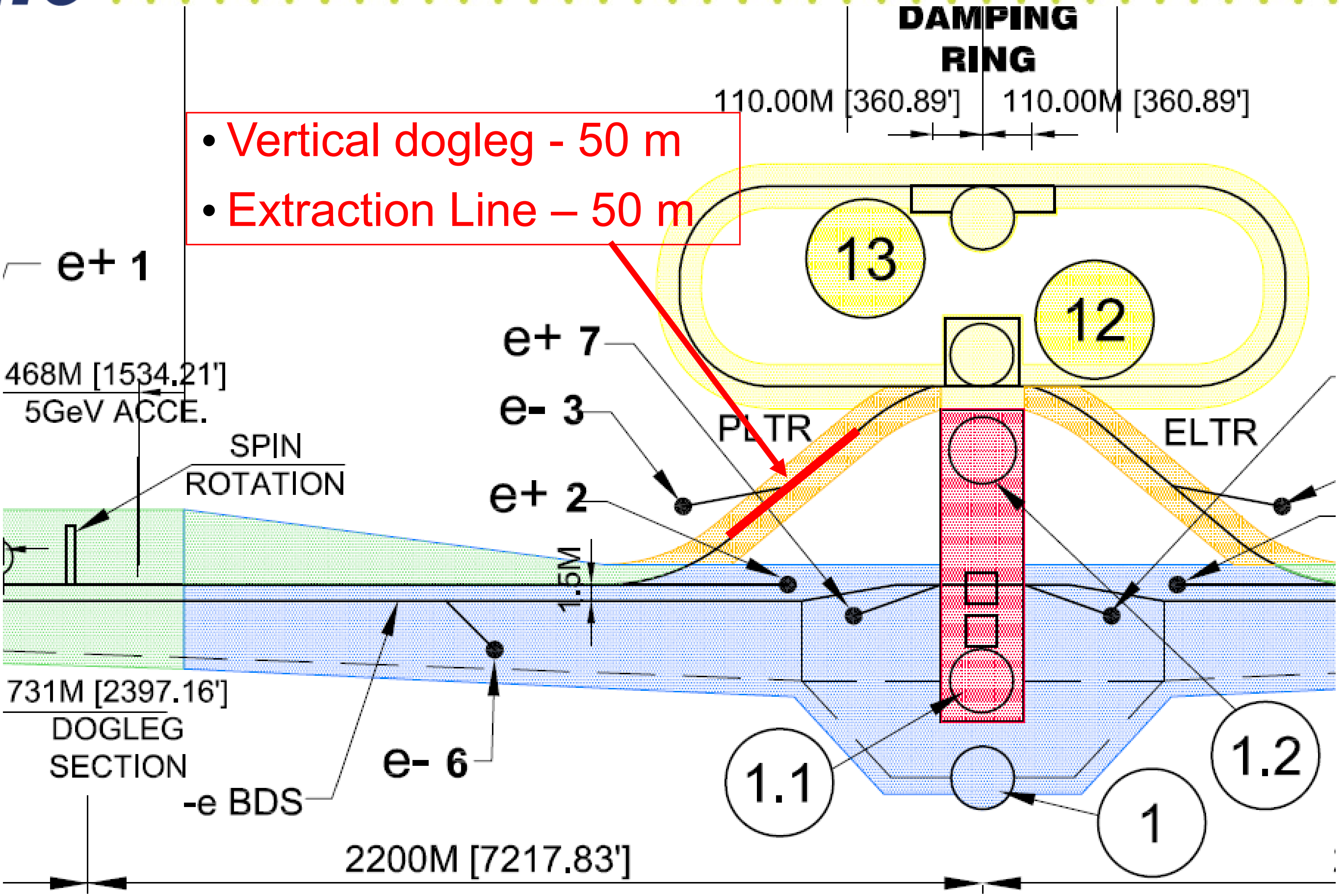
* A. Latina, archive file “RTML_Central_Lattice.tgz”, 2-Nov-2010

RTML configuration in Central Area



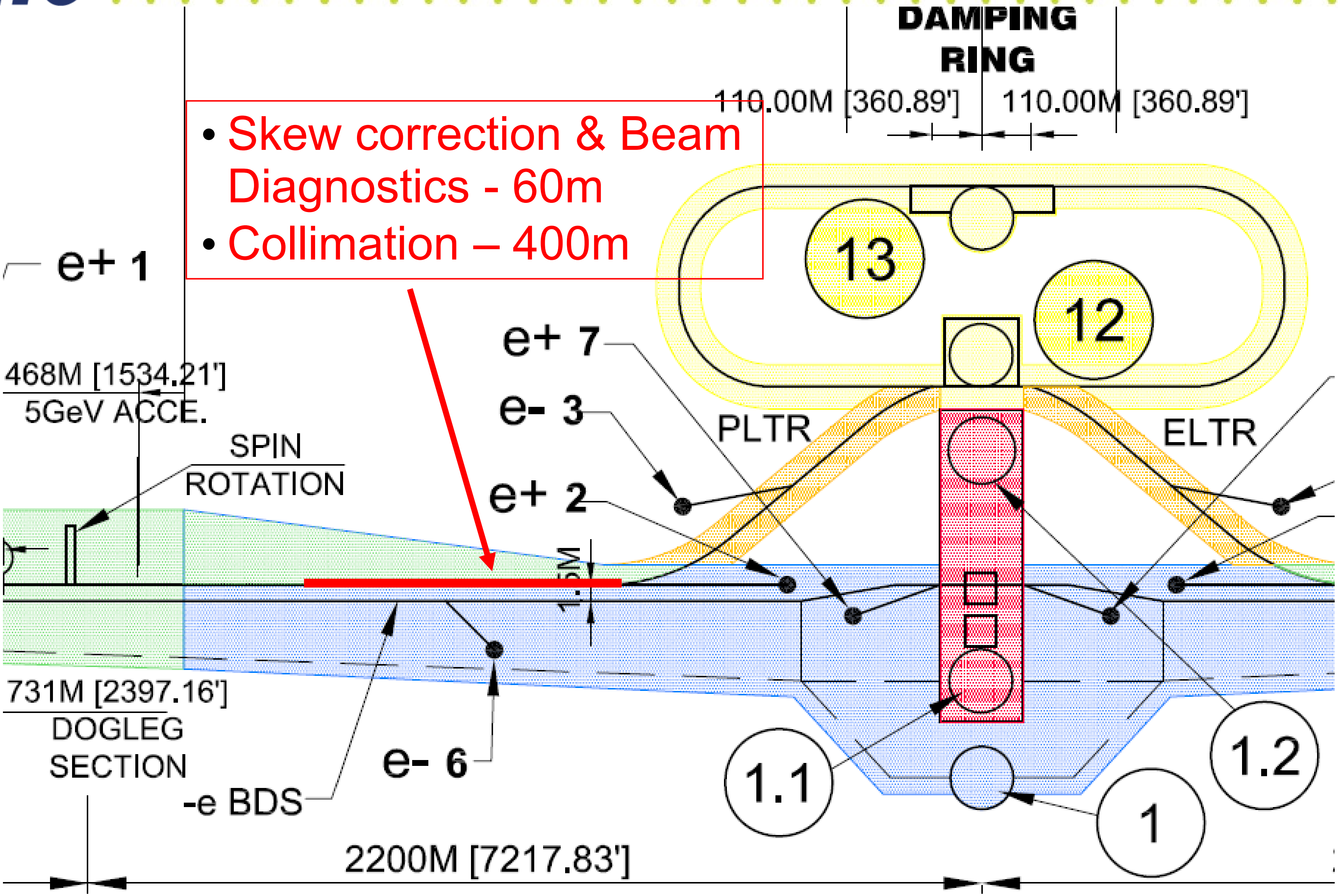
RTML configuration in Central Area

- Vertical dogleg - 50 m
- Extraction Line – 50 m

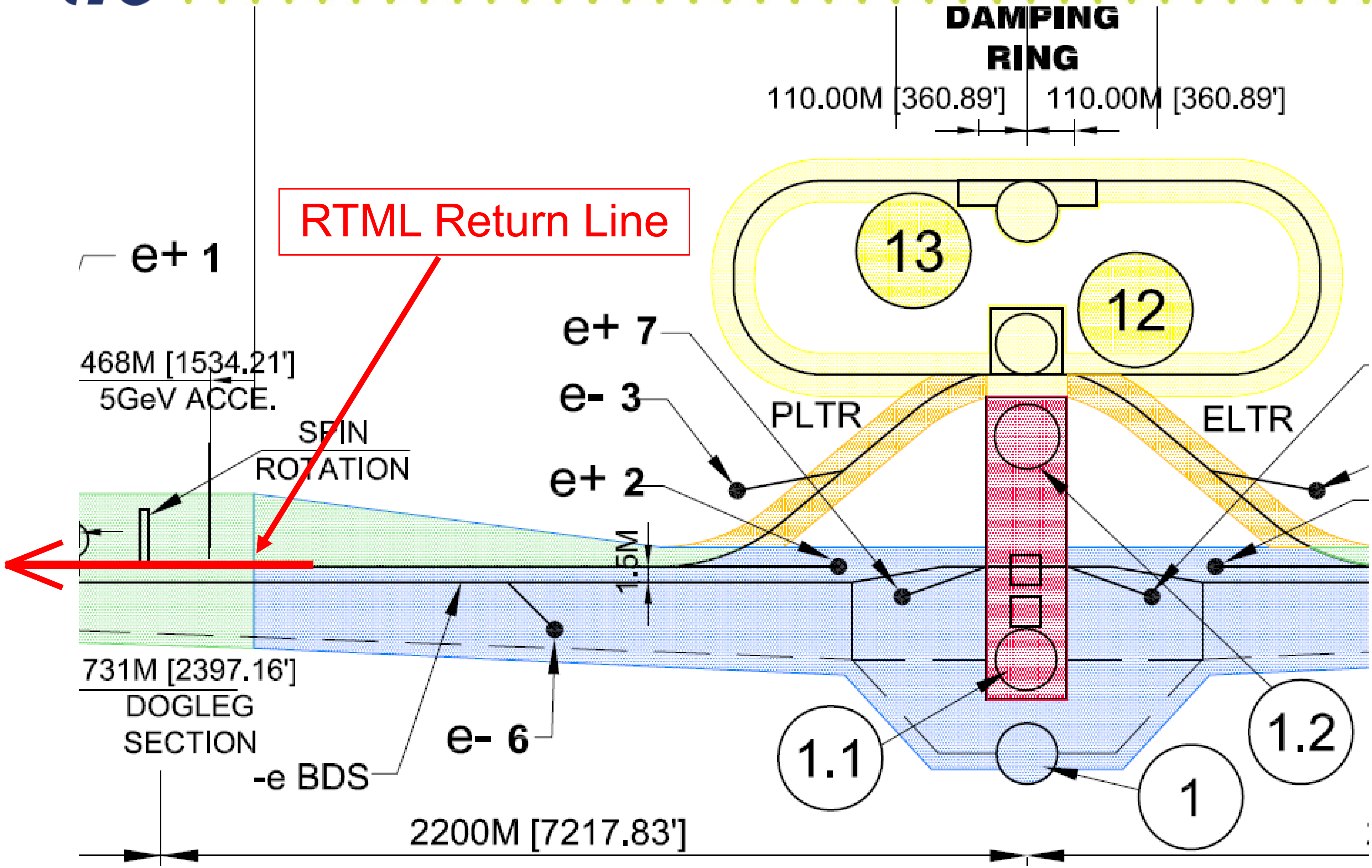


RTML configuration in Central Area

- Skew correction & Beam Diagnostics - 60m
- Collimation – 400m



RTML configuration in Central Area

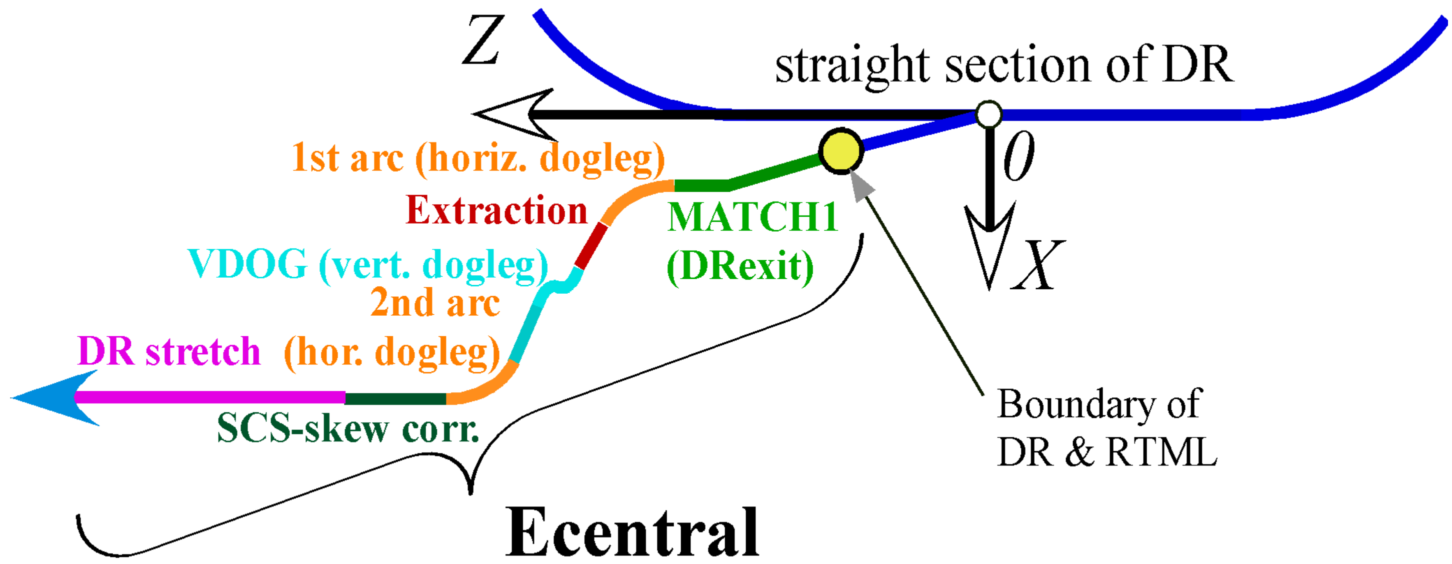


Steps for Twiss matching

- Extraction of Twiss parameters at boundaries of borrowed modules using MAD8 lattices for 2007 design of “getaway”, “TURNaround” and “ELBC1” extraction lines .
- Most of matching sections are Quad. Doublets
- Approximate doublet parameters via a numerical implementations of semi-analytical solutions* for quadrupole doublets
- Refined solutions via numerical optimizations using MAD8 matching commands
- Global coordinates of modules via MAD8 survey

** Ph.J.Bryant, K.Johnsen, "The principles of circular accelerators and storage rings", Cambr. Univ. Press, 1993*

DR exit & global coordinate system



DR-end: MAD8 file:

"EXT_RTML: S=87.90;

β_x=73.77; α_x=-0.1132;

DX=-0.49; DPX=0.20E-02;

β_y=17.18; α_y=-1.33;

DX=-0; DPX=0.

X=508.8mm; PX=54 mrad

- S.Guiducci, Sept. 2010: Boundary DR & RTML should be relocated to the exit of the extraction septa.
- Global coord. origin -> center of DR straight section
- "DR-exit" with D_x compensation are included in RTML
- RTML start (in MAD8 conventions):

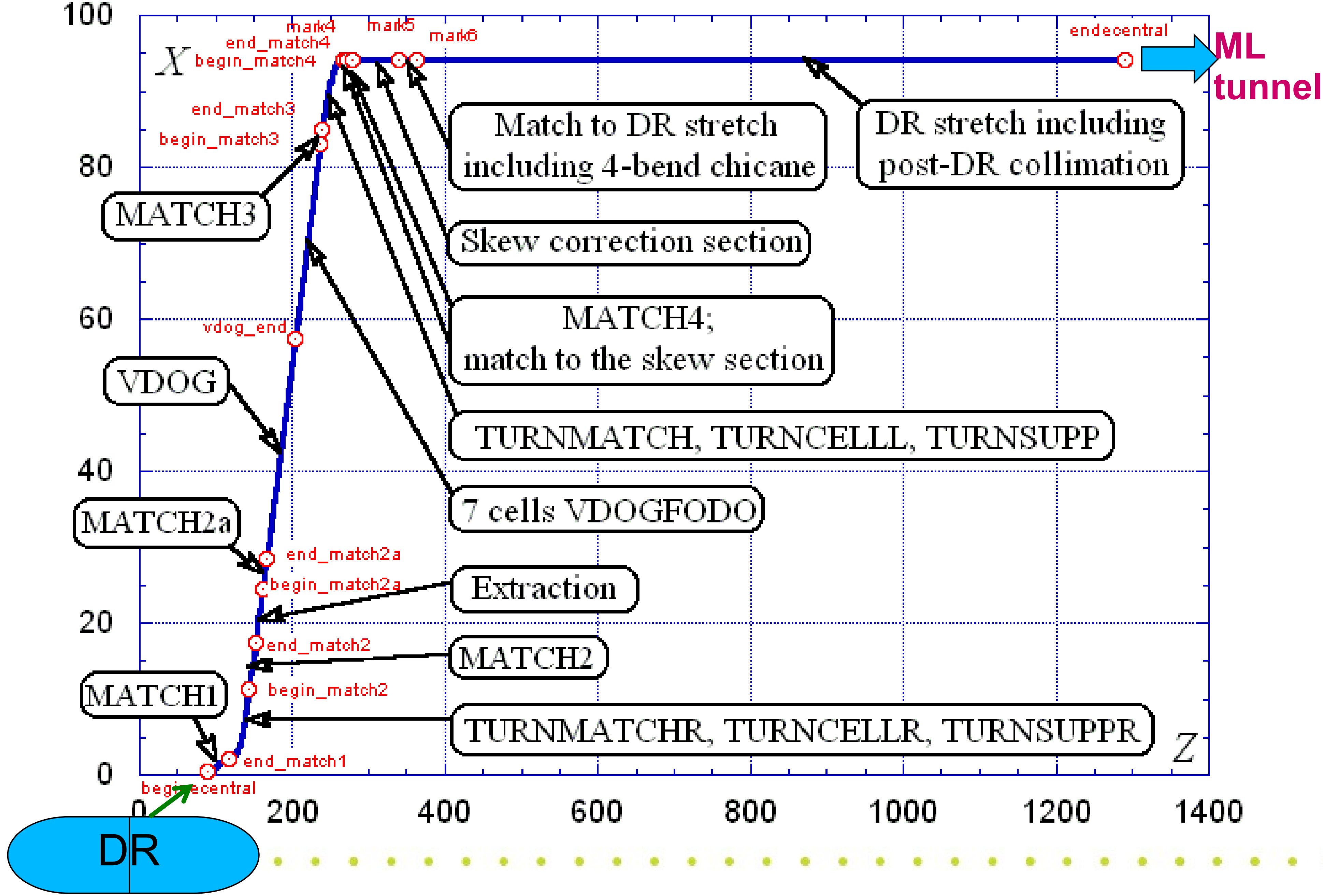
$$\{X,Y,Z\}=(0.508;0;87.9);\ \{\Theta_{xz};\Phi_{yz};\Psi_{xy}\}=\{0.054;0;0\}$$

"Ecentral" modules & matching sections

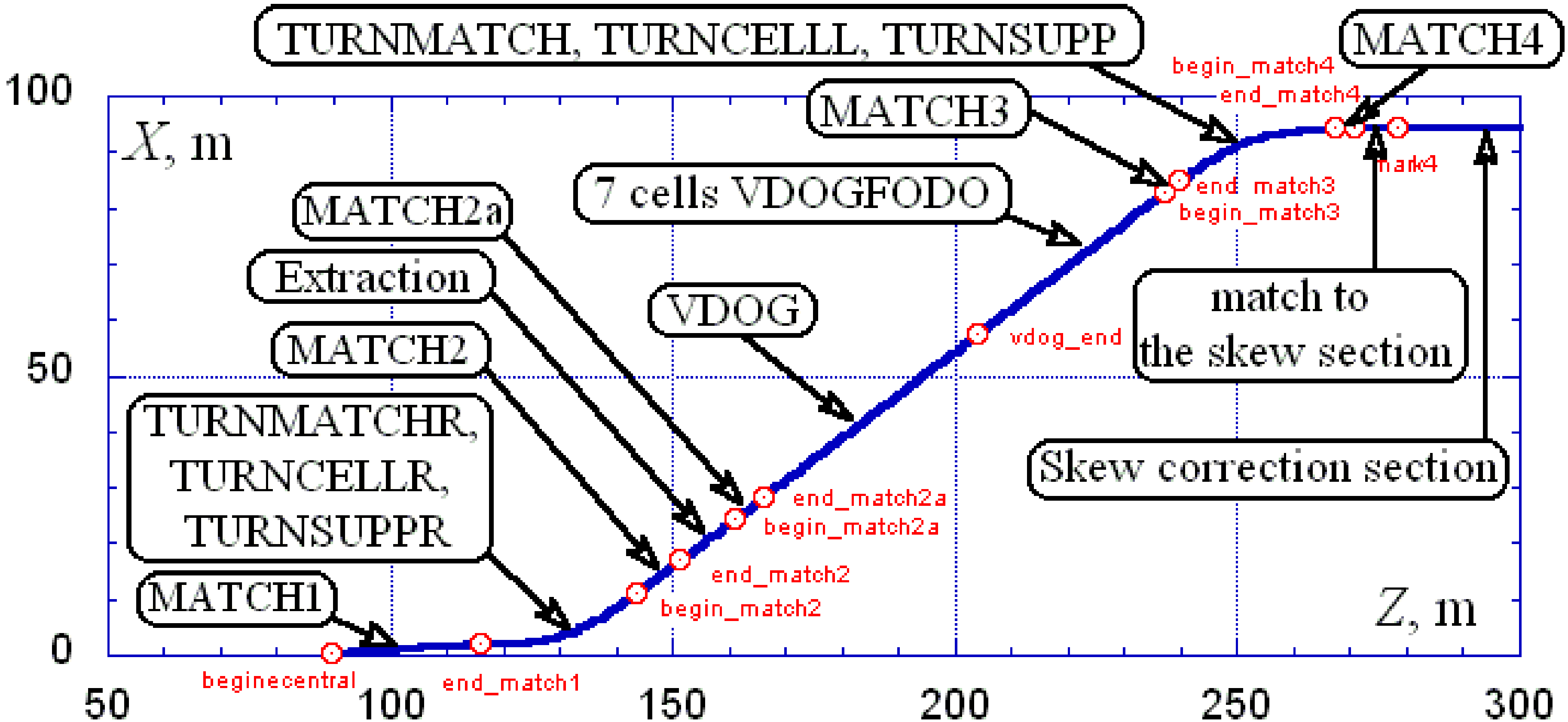
MATCH1	"DRexit" (Dx→0)+ "Q-dblt"+ "oppos_line" (Θ→ 0)
1st hor. arc	H-Dogleg*: "TURNMATCHR"+ "TURNCELLR"+"TURNSUPPR"
MATCH2	Matching quadrupole doublet ("Q-dblt")
EXTRACTION	from "BC1_EXT"
MATCH2a	Matching quadrupole doublet ("Q-dblt")
VDOG	VDOG(2 arcs of vert. dogleg*) ; 7cells of VDOGFODO
MATCH3	"QF" (continuation of VDOGFODO)+ "Q-dblt"
2nd hor. arc	H-Dogleg*: "TURNMATCH"+ "TURNCELL"+"TURNSUPP"
MATCH4	Matching quadrupole doublet ("Q-dblt")
Match to SCS ♣	4 matching quadupoles
Skew corr.sec.♣	with "4 skew corr. Quads" + "4 wire scanners"
Match to DRS ♣	Match to DR stretch including 4-bend chicane
DR stretch ♣	including post-DR collimation of halo

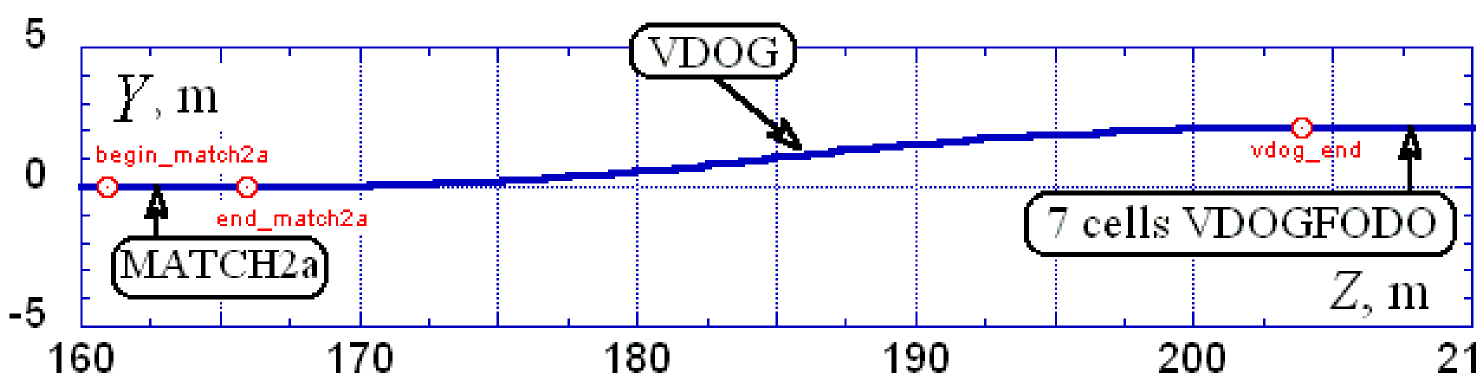
* Borrowed from TURNAROUND RDR; ♣ borrowed from "egetaway"

“ecentral” layout (via MAD-8 survey)



“ecentral” layouts in details





The global coordinates of the section boundary markers.

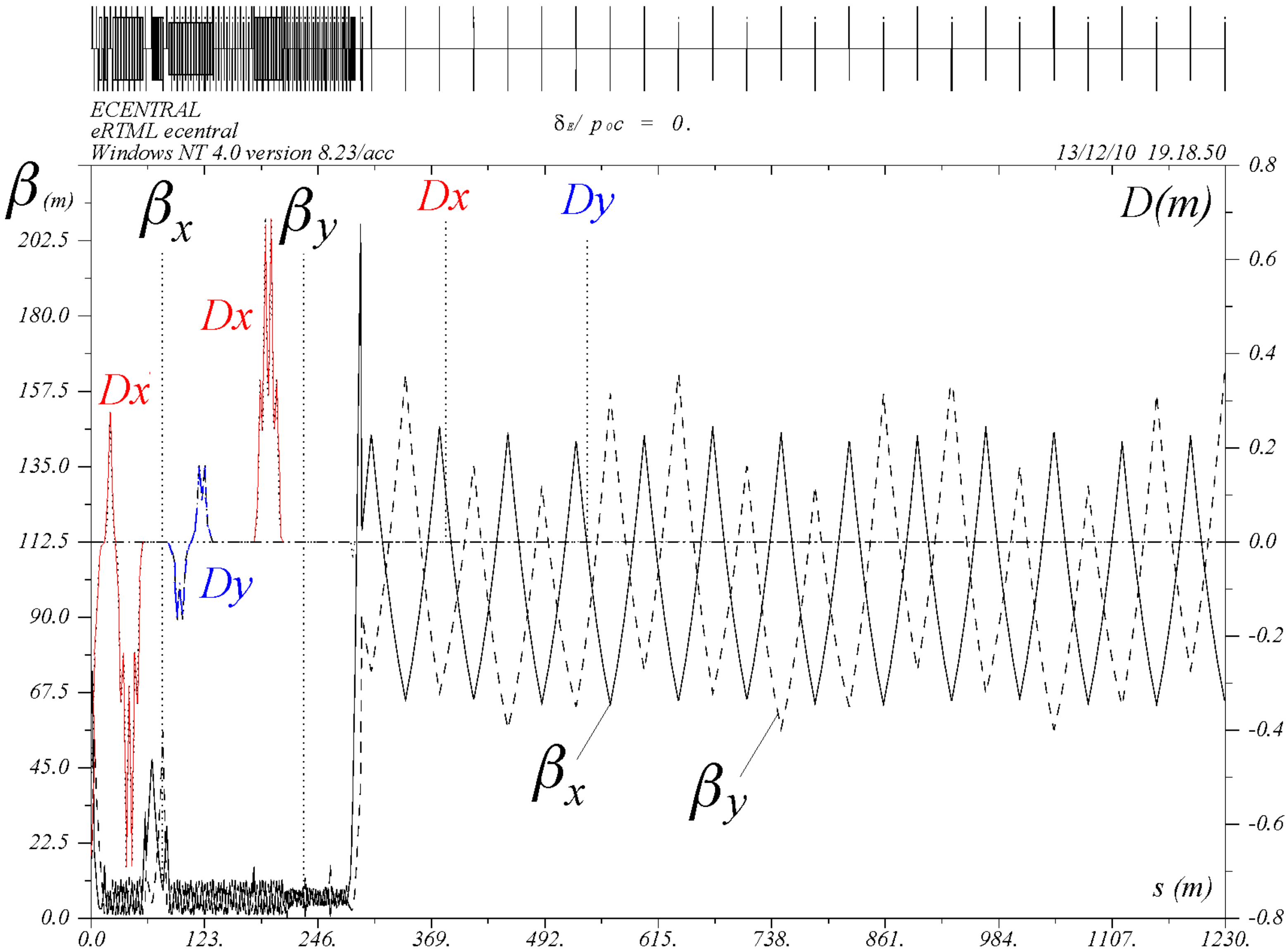
Ψ=0

No.	elem_label	type	X	Y	Z	sumL	Theta	Phi	Psi
1	BEGINECENTRAL	MARK	0.5088E+00	0.0000E+00	0.8970E+02	0.0000E+00	0.5400E-01	0.0000E+00	0.0000E+00
2	END_MATCH1	MARK	0.2028E+01	0.0000E+00	0.1161E+03	0.2644E+02	-0.2082E-16	0.0000E+00	0.0000E+00
3	BEGIN_MATCH2	MARK	0.1138E+02	0.0000E+00	0.1437E+03	0.5624E+02	0.6538E+00	0.0000E+00	0.0000E+00
4	END_MATCH2	MARK	0.1735E+02	0.0000E+00	0.1514E+03	0.6606E+02	0.6538E+00	0.0000E+00	0.0000E+00
5	BEGIN_MATCH2A	MARK	0.2459E+02	0.0000E+00	0.1609E+03	0.7796E+02	0.6538E+00	0.0000E+00	0.0000E+00
6	END_MATCH2A	MARK	0.2848E+02	0.0000E+00	0.1660E+03	0.8435E+02	0.6538E+00	0.0000E+00	0.0000E+00
7	VDOG_END	MARK	0.5751E+02	0.2143E+01	0.2039E+03	0.1321E+03	0.6538E+00	0.1041E-16	-0.4348E-29
8	BEGIN_MATCH3	MARK	0.8306E+02	0.2143E+01	0.2372E+03	0.1741E+03	0.6538E+00	0.1041E-16	-0.4348E-29
9	END_MATCH3	MARK	0.8491E+02	0.2143E+01	0.2396E+03	0.1772E+03	0.6538E+00	0.1041E-16	-0.4348E-29
10	BEGIN_MATCH4	MARK	0.9425E+02	0.2143E+01	0.2674E+03	0.2072E+03	0.6245E-16	0.8262E-17	0.6331E-17
11	END_MATCH4	MARK	0.9425E+02	0.2143E+01	0.2708E+03	0.2106E+03	0.6245E-16	0.8262E-17	0.6331E-17
12	MRK4	MARK	0.9425E+02	0.2143E+01	0.2784E+03	0.2182E+03	0.6245E-16	0.8262E-17	0.6331E-17
13	MRK5	MARK	0.9425E+02	0.2143E+01	0.3395E+03	0.2793E+03	0.6245E-16	0.8262E-17	0.6331E-17
14	MRK6	MARK	0.9425E+02	0.2143E+01	0.3639E+03	0.3037E+03	0.6592E-16	0.8262E-17	0.6331E-17
15	ENDECENTRAL	MARK	0.9425E+02	0.2143E+01	0.1289E+04	0.1229E+04	0.6592E-16	0.8262E-17	0.6331E-17

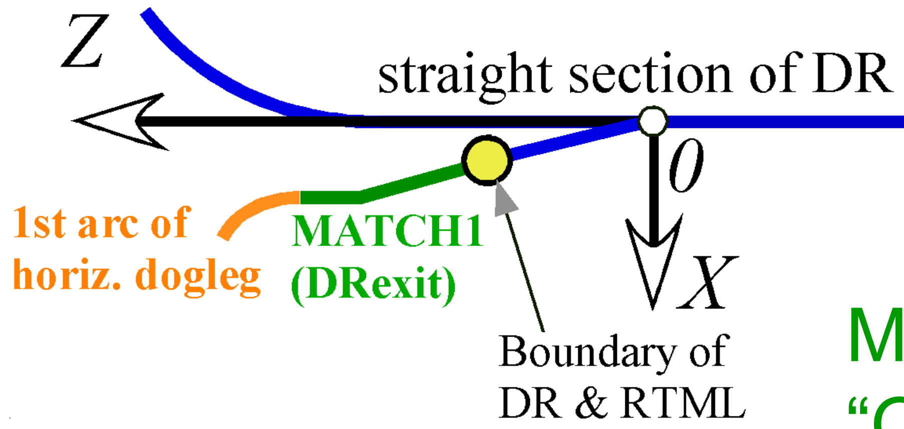
Global coordinates in MAD-conventions: Θ – angle of rotation about the vertical Y-axis; Φ – elevation angle; Ψ - roll angle.

“ecentral”: Twiss parameters

- Matched Twiss parameters along the matched “ecental” beam-line



MATCH1: Twiss parameters at boundaries

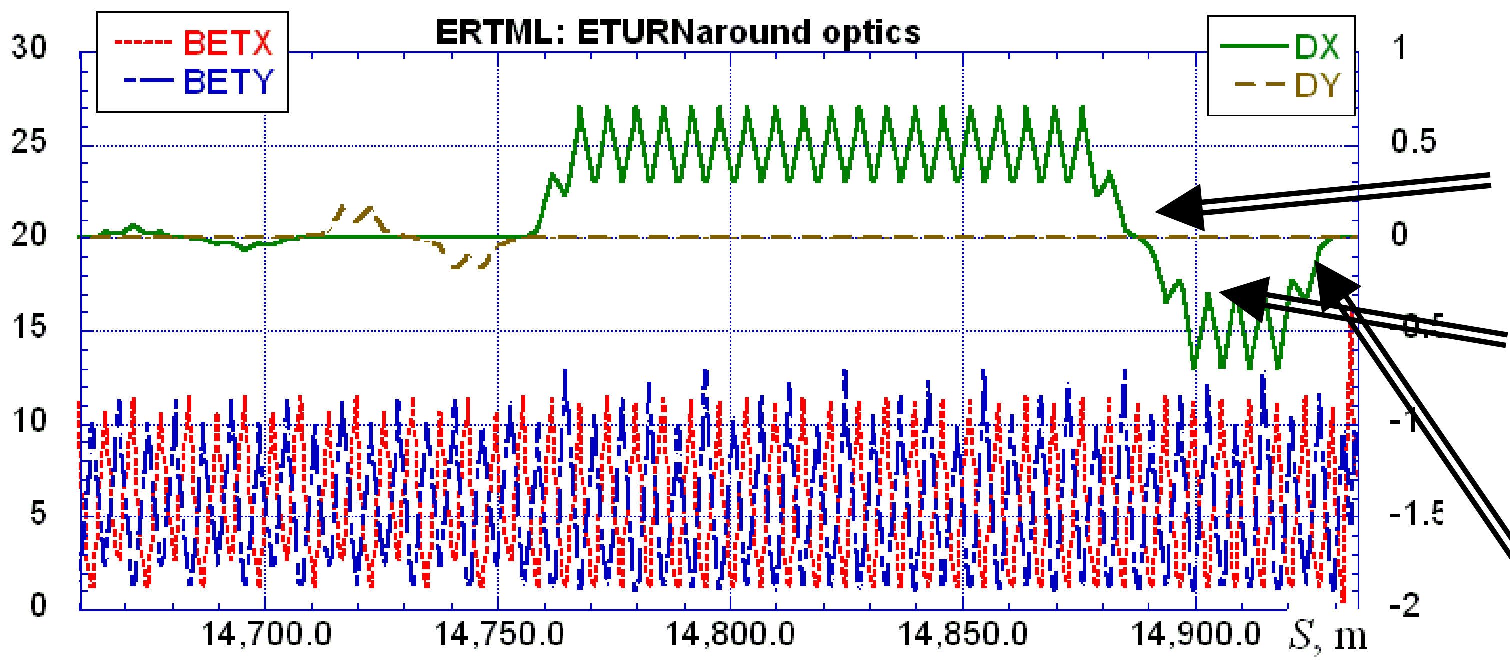


DR-end: MAD8 file: "EXT_RTML: S=87.90;

β_x=73.77; α_x=-0.1132; **DX=-0.49; DPX=0.20E-02;**

β_y=17.18; α_y=-1.33; X=508.8mm; **PX=54.0mrad**

MATCH1: "DRexit" (Dx→0)+ "Q-dblt"+ "oppos_line" (Θ→ 0)



1st arc H-Dogleg:

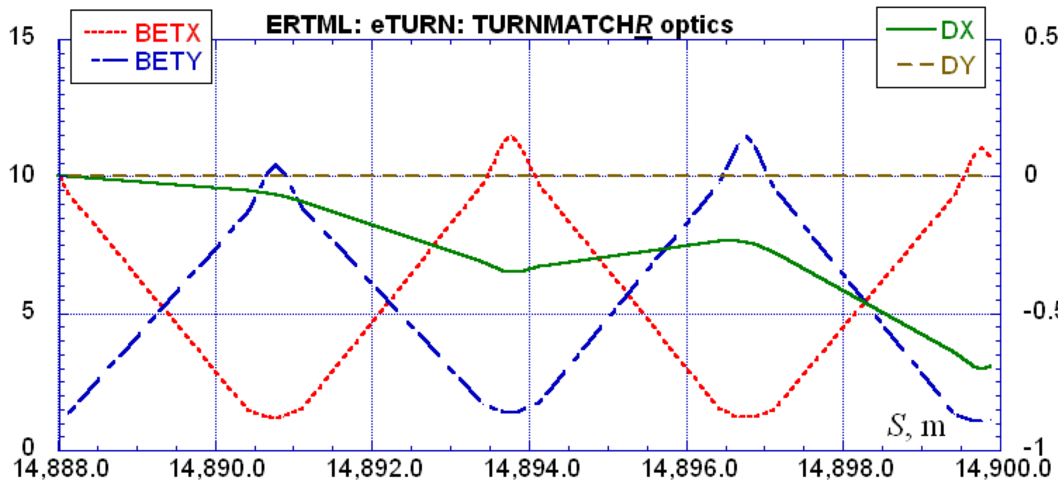
"TURNMATCHR" (S=14887.8-14899.8)

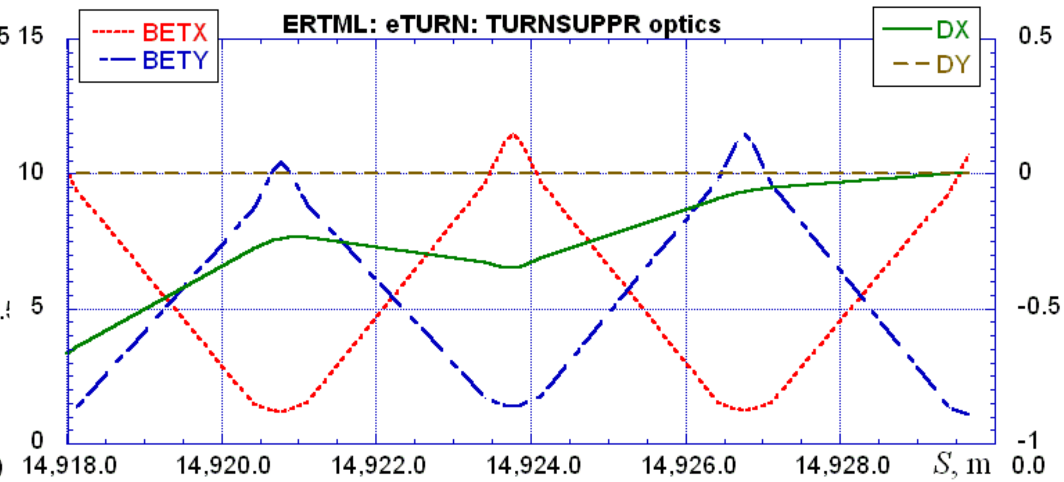
"TURNCELLR" (S=14899.8-14905.8)

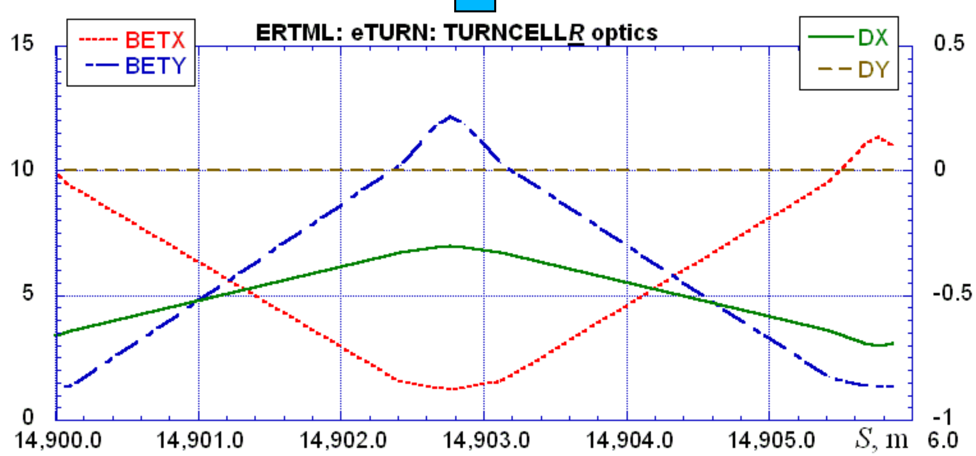
"TURNSUPPR" (S=14917.8-14929.6)

20101120_ETURNaround_summary_VK.doc

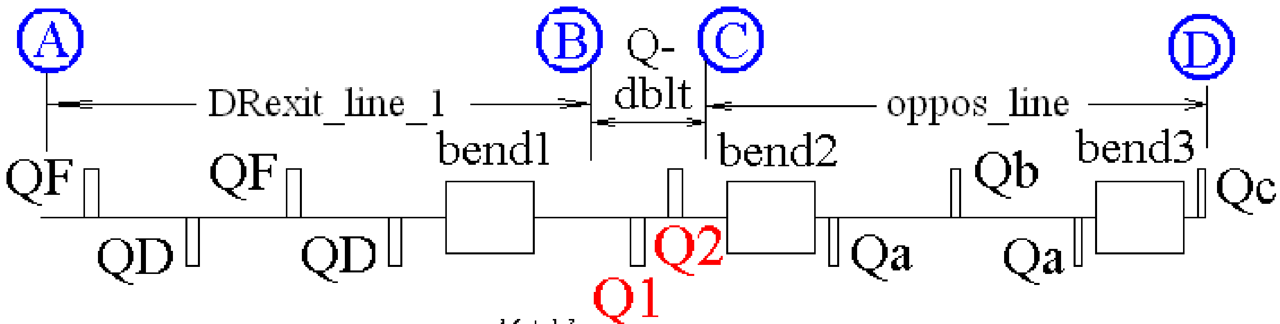
“TURNMATCHR”+“TURNCELLR”+”TURNSUPPR” from “ETURNaround” line





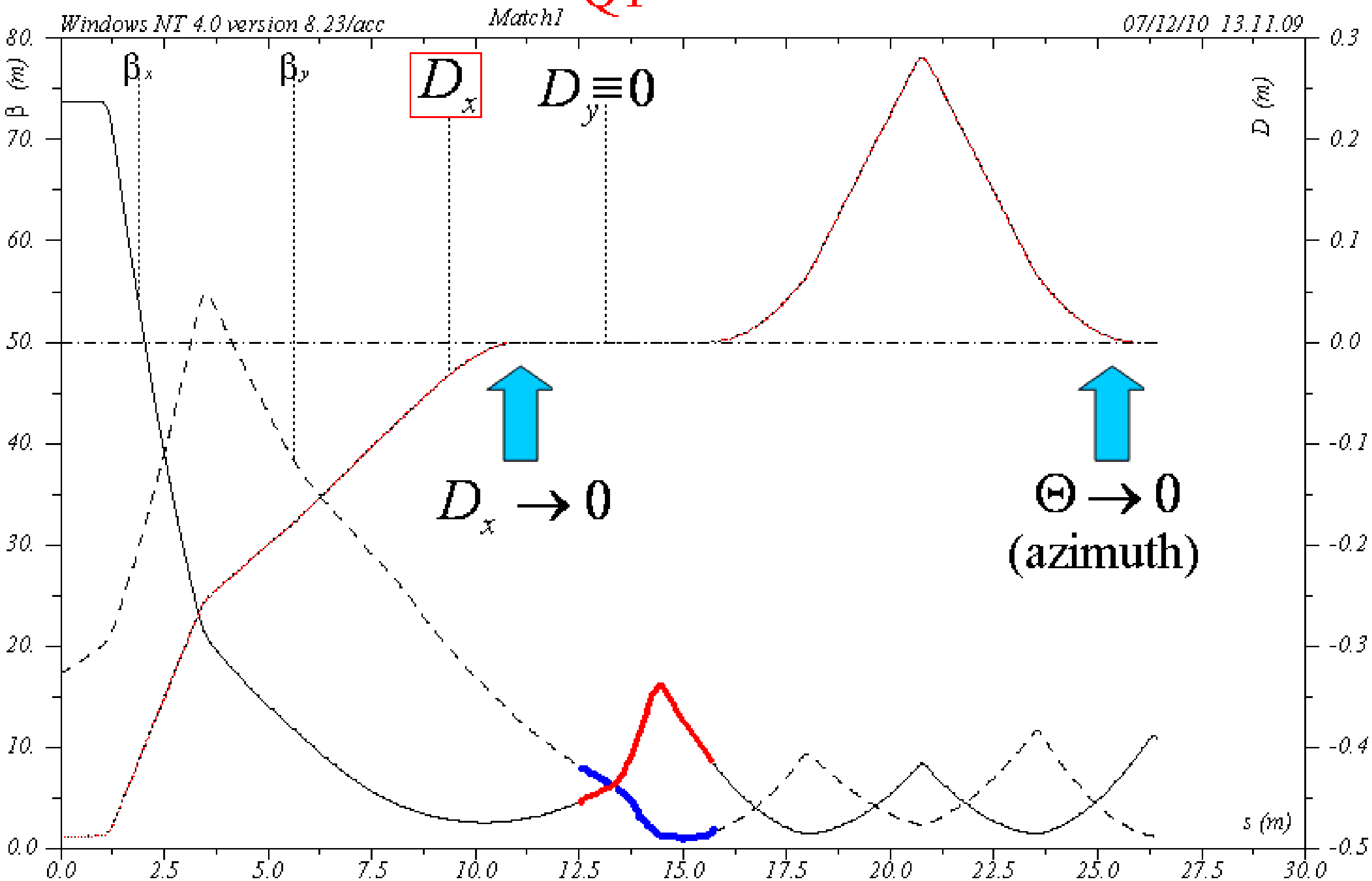


MATCH1: Twiss parameters



AB: 4Quad+Bend => Dx, D'x->0

BC: Q-doublet (α,β-matching)

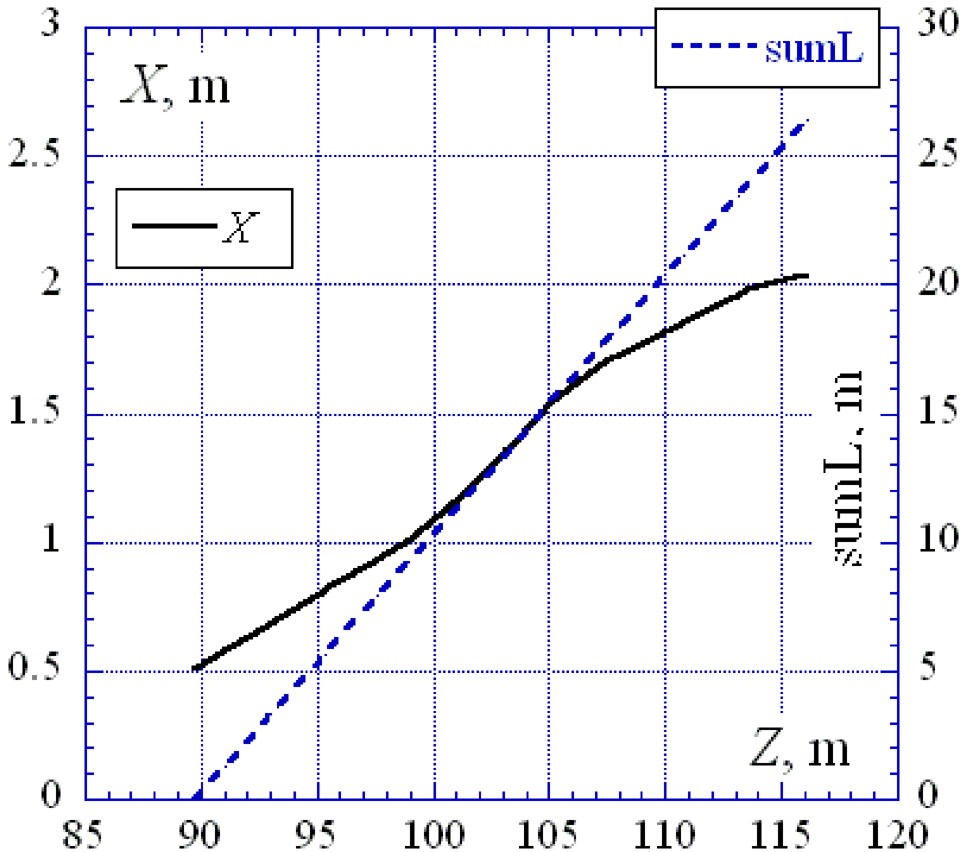


CD:
a) make beam-line line parallel to DR straight section (azimuth Θ→0)
b) translate α, β – values

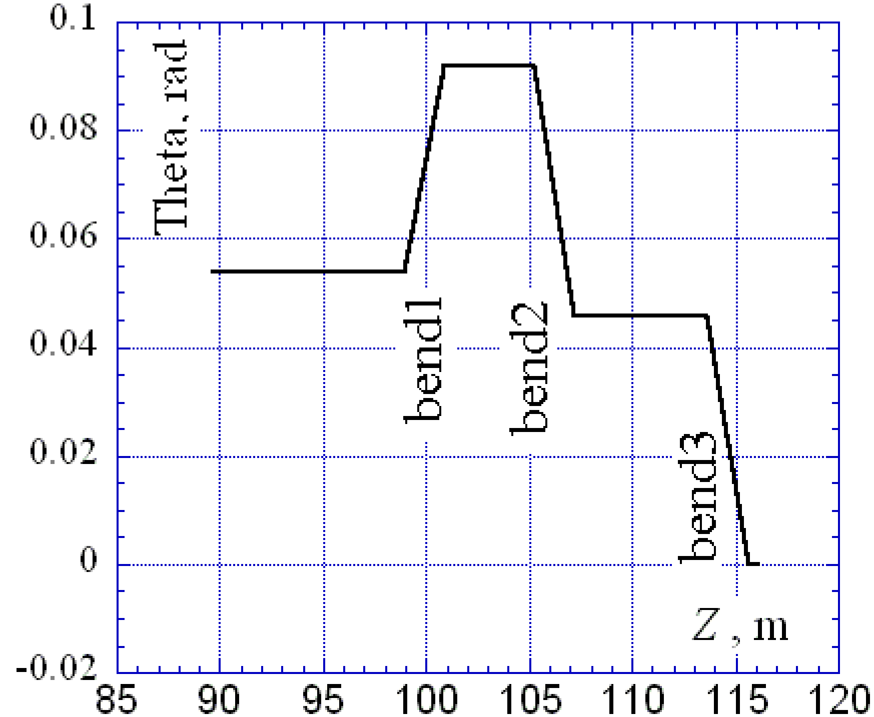
	A	B	C	D
β_x	73.8	6.03	10.8	10.8
α_x	-0.017	-1.18	3.02	3.02
β_y	17.2	6.36	1.16	1.16
α_y	-1.33	+1.08	-0.29	-0.29
D_x	-0.490	0	0	0
D'_x	0.002	0	0	0

MATCH1 layouts

Projection of MATCH1 on horizontal plane X0Z and cumulative length sumL



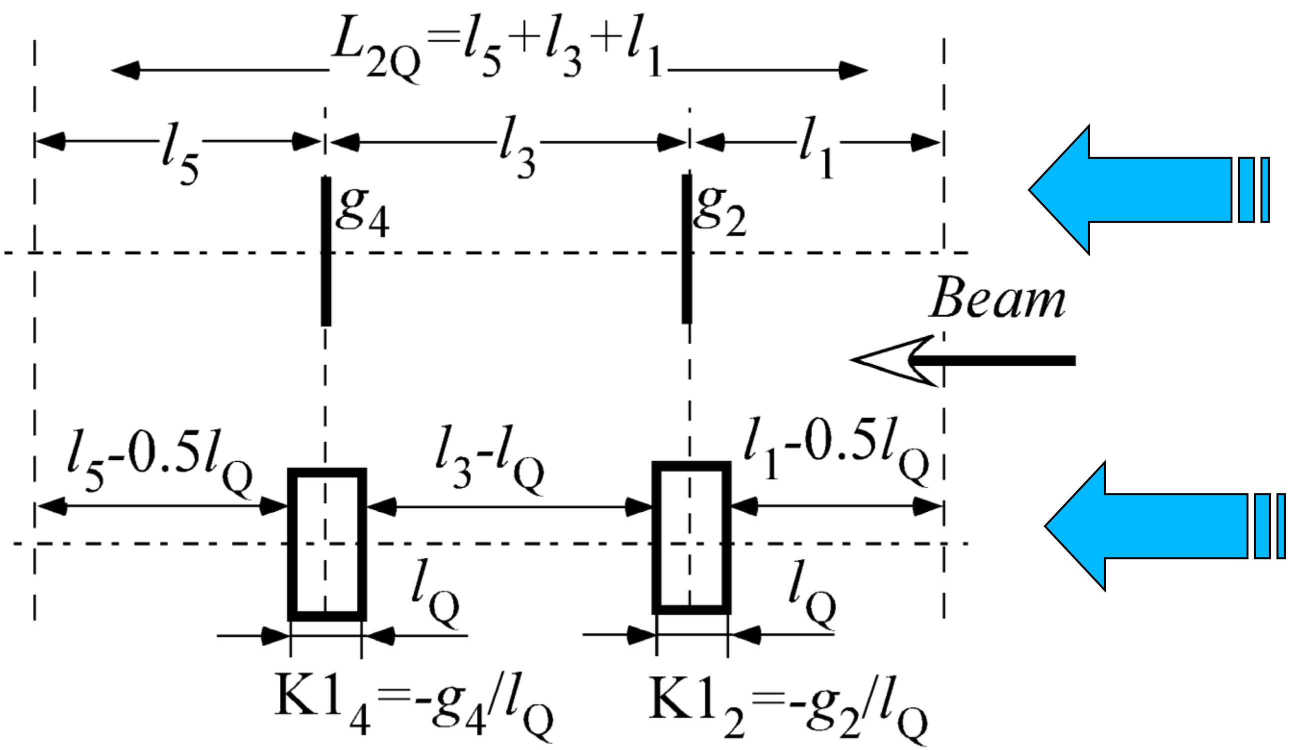
Dependence of Θ (rotation about the vertical Y-axis) on the Z-coordinate.



Bend1: Initial Θ=54mrad is increased
Bend2 & Bend3: Θ →0 in two steps
=> Beam line becoms || to
DR's straight section

Matching methods

- The matching of the "DRexit_line_1"(Dx→0, D'x→0) and "Oppos_line" (Q-triplet & 2 bends) performed purely numerically with minimization algorithms (MAD8 matching);
- 2 steps matching for "DRexit_line_2" (quadrupole doublet):



a) approximate semi-analytical solutions* for Q-doublet (thin quadrupoles);

b) refined numerical solutions using MAD8 matching commands (thick quadrupoles)

* Ph.J.Bryant, K.Johnsen, "The principles of circular accelerators and storage rings", 1993.

Q-doublet: analytical solution

- The pure numeric matching with the MAD code may require a lot of efforts and can not guarantee optimum results
- The analytic solutions act as design guides.

The analytic solution for Q-doublet is formulated using the "mismatch factor" Eq. (4.97)*:

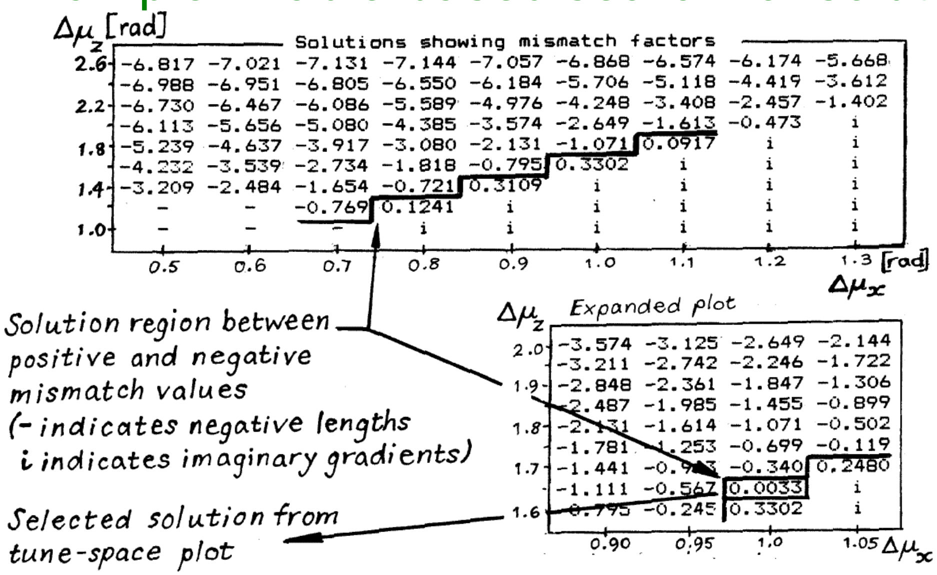
$$\Phi_{(4.97)}(\Delta\mu_x, \Delta\mu_y) = 0$$

phase advances in x,y planes

Search for solution with contour-plot (computer algebra software Maple-V) for modified "mismatch factor":

$$F_{(4.97)}(\Delta\mu_x, \Delta\mu_y) = \begin{cases} 4(\text{if } l_1 < 0); \quad 3(\text{if } l_5 < 0); \quad 2(l_3 < 0) \\ 1, \quad \text{if } \mathrm{Im}(g_{2,4}) \neq 0 \\ \Phi_{(4.97)}(\Delta\mu_x, \Delta\mu_y), \quad \text{otherwise} \end{cases}$$

Example*: Table-based search for solution.



Solutions showing mismatch factors

Δμz [rad]	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
2.6	-6.817	-7.021	-7.131	-7.144	-7.057	-6.868	-6.574	-6.174	-5.668
	-6.988	-6.951	-6.805	-6.550	-6.184	-5.706	-5.118	-4.419	-3.612
2.2	-6.730	-6.467	-6.086	-5.589	-4.976	-4.248	-3.408	-2.457	-1.402
	-6.113	-5.656	-5.080	-4.385	-3.574	-2.649	-1.613	-0.473	i
1.8	-5.239	-4.637	-3.917	-3.080	-2.131	-1.071	0.0917	i	i
	-4.232	-3.539	-2.734	-1.818	-0.795	0.3302	i	i	i
1.4	-3.209	-2.484	-1.654	-0.721	0.3109	i	i	i	i
	–	–	-0.769	0.1241	i	i	i	i	i
1.0	–	–	–	i	i	i	i	i	i

Δμx [rad]

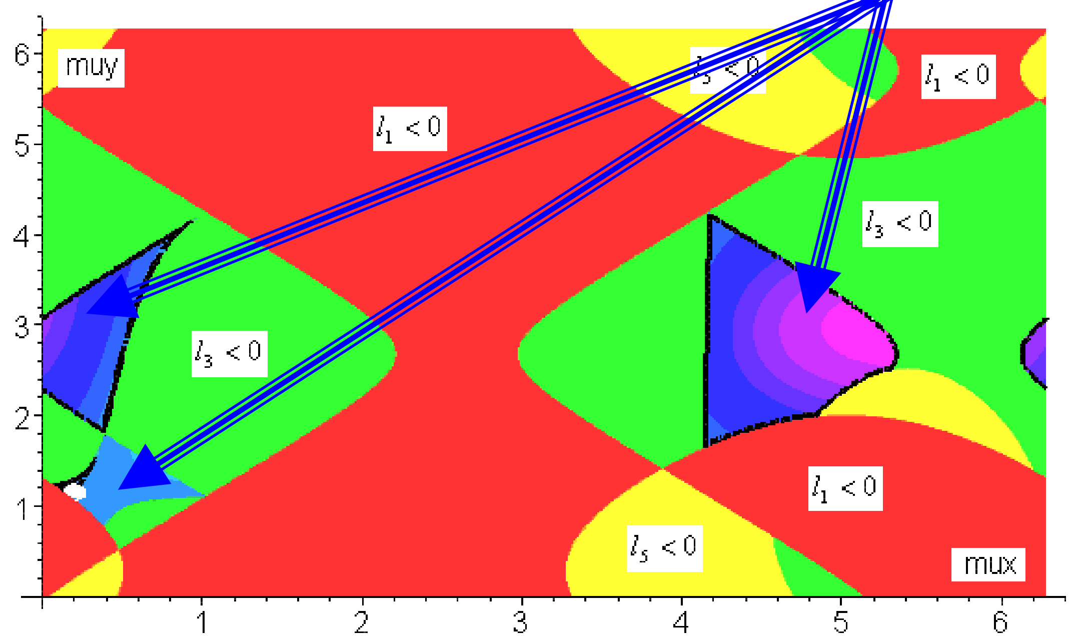
Solution region between positive and negative mismatch values
(- indicates negative lengths
i indicates imaginary gradients)

Expanded plot

Δμz				
2.0	-3.574	-3.125	-2.649	-2.144
	-3.211	-2.742	-2.246	-1.722
1.9	-2.848	-2.361	-1.847	-1.306
	-2.487	-1.985	-1.455	-0.899
1.8	-2.131	-1.614	-1.071	-0.502
	-1.781	-1.253	-0.699	-0.119
1.7	-1.441	[illegible]	-0.340	0.2480
	-1.111	-0.567	0.0033	i
1.6	-0.795	-0.245	0.3302	i

Δμx: 0.90, 0.95, 1.0, 1.05

Selected solution from tune-space plot

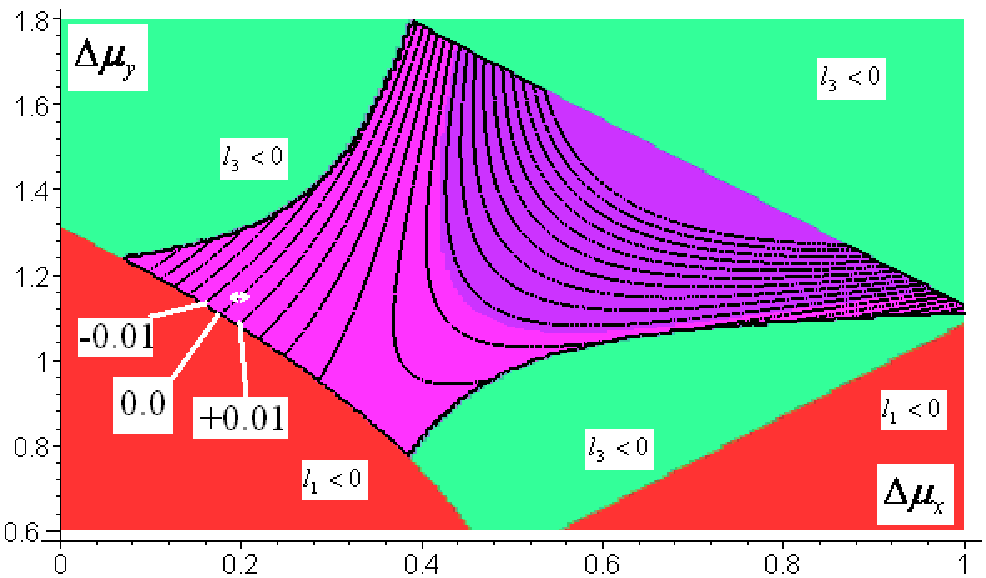


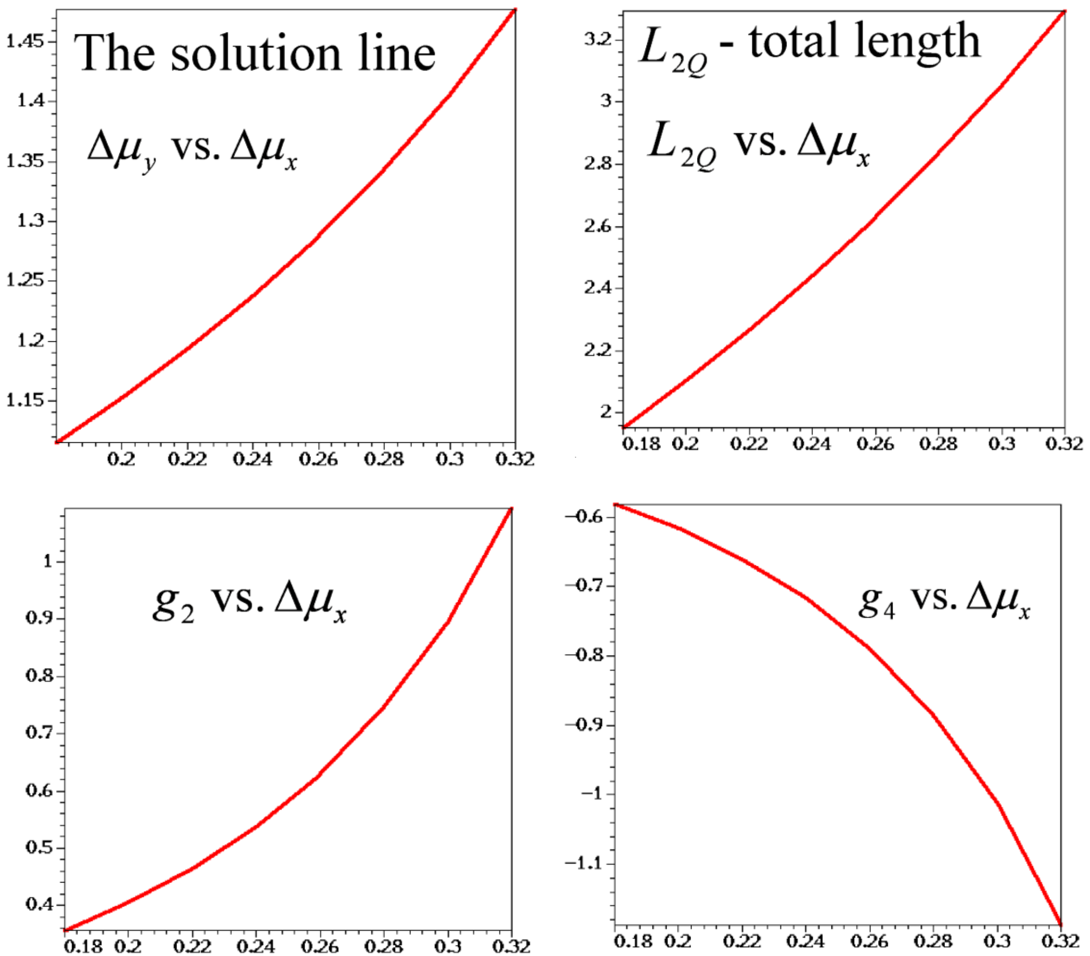
* Ph.J.Bryant, K.Johnsen, "The principles …", p.79-82.

Solution lines (Match1 Q-dblt)

The solution line $F_{(4.97)}(\Delta\mu_x, \Delta\mu_y) = 0$ defines a continuous solution set for all doublet parameters: $L_{2Q}, l_{1,3,5}, g_{2,4}$

Contour plot for the left-bottom blue island with $F_{(4.97)}(\Delta\mu_x, \Delta\mu_y) \approx 0$





Working point (Match1 Q-dblt)

Possible prescriptions for choice of working point:
minimal phase advances; minimal Q-gradients;
optimal total length; solution sensitivity:
a) lowest density of counters;
b) optimal ratio "output/input" for some Twiss parameters

Presently, working point has minimal phase advances (0.20; 1.15). It is featured: a) near low density counters; b) small total length L_{2Q}; c) small gradients modules;

Working point:

l_1 =0.27483 m

l_3 =0.96094 m

l_5 =0.84977 m

l_{2Q} =2.0855 m

g_2 =+0.39930 m^{-1}

g_4 =-0.61215 m^{-1}.

Elements of sensitivity matrix (1-input; 2-output)

$$\delta = \begin{Vmatrix} \delta_{\beta_2}/\delta_{\beta_1} & \delta_{\beta_2}/\delta_{\alpha_1} \\ \delta_{\alpha_2}/\delta_{\beta_1} & \delta_{\alpha_2}/\delta_{\alpha_1} \end{Vmatrix}$$

$$\Delta\beta_{2,x} \approx 0.8\cdot\Delta\beta_{1,x},\ \Delta\beta_{2,x} \approx -4.1\cdot\Delta\alpha_{1,x},$$

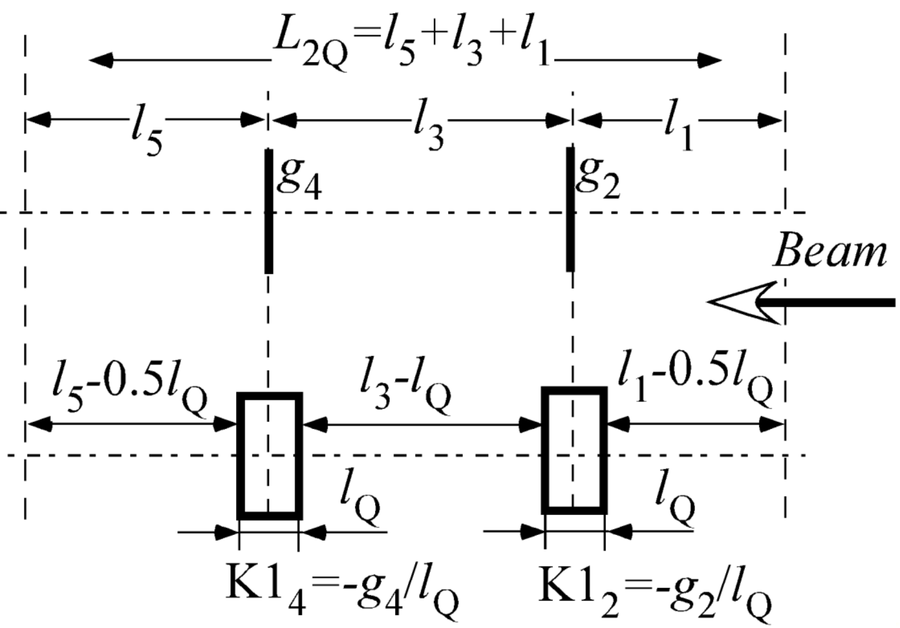
$$\Delta\alpha_{2,x} \approx 0.05\Delta\beta_1,\ \Delta\alpha_{2,x} \approx -0.26\cdot\Delta\alpha_{1,x},$$

$$\Delta\beta_{2,y} \approx 0.03\cdot\Delta\beta_{1,y},\ \Delta\beta_{2,y} \approx -0.8\cdot\Delta\alpha_{1,y},$$

$$\Delta\alpha_{2,y} \approx 0.22\cdot\Delta\beta_{1,y},\ \Delta\alpha_{2,y} \approx -0.46\cdot\Delta\alpha_{1,y}.$$

Solution refining with MAD8 matching

- The doublet parameters from approximate analytical solutions (for thin Qs) – are refined with MAD-8 matching commands (for thick-quadrupoles).
- Constant parameters:
  the total length of doublet *L*2Q and distance between their centers *l*3
- 4 variable parameters: two lengths and two gradients
- The refining matching with MAD-8 did not meet any difficulties providing small corrections to initial values (< 30%).
- Similar situation for other doublets: Match2, Match2a, Match3, Match4.



Refining results with MAD8 matching

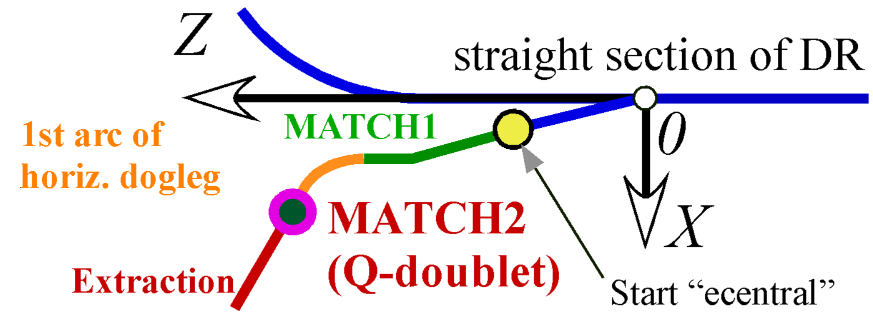
Constant parameters:	
L_{2Q}	2.086 m
l_Q	0.3 m
l_3	0.961 m

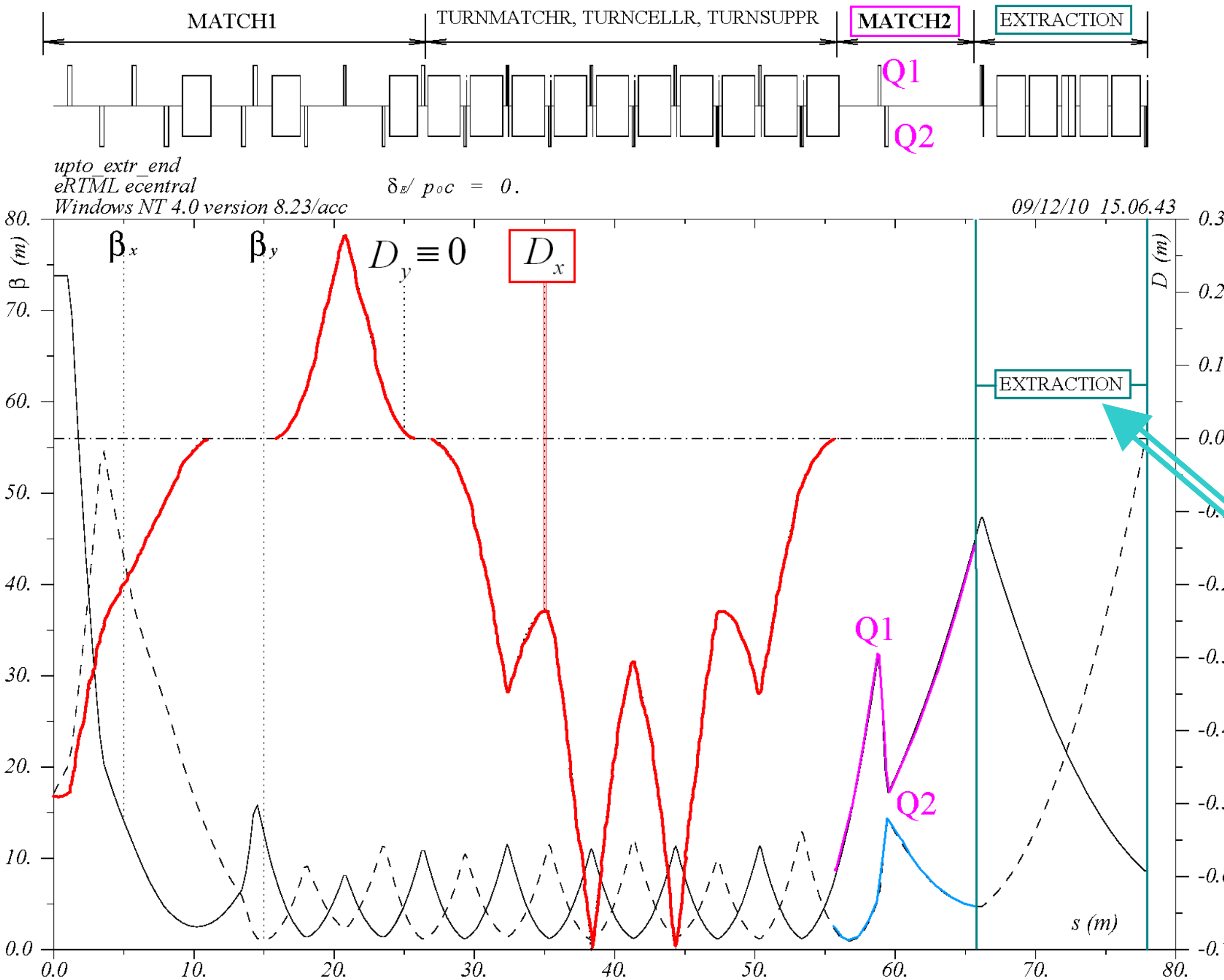
Variable parameters:			
	before	after	δ, %
l_1, m	0.275	0.350	27
l_5, m	0.850	0.892	4.9
g_2, m^{-1}	0.399	0.466	17
g_4, m^{-1}	-0.612	-0.682	11

MATCH2: Q-doublet before EXTRACTION

Twiss parameters at boundaries of MATCH2.

position	β_x	α_x	β_y	α_y	D_x	D'_x
start	10.843	-2.993	1.206	0.533	0	0
end	47.06	-2.94	4.7	0.02	0	0

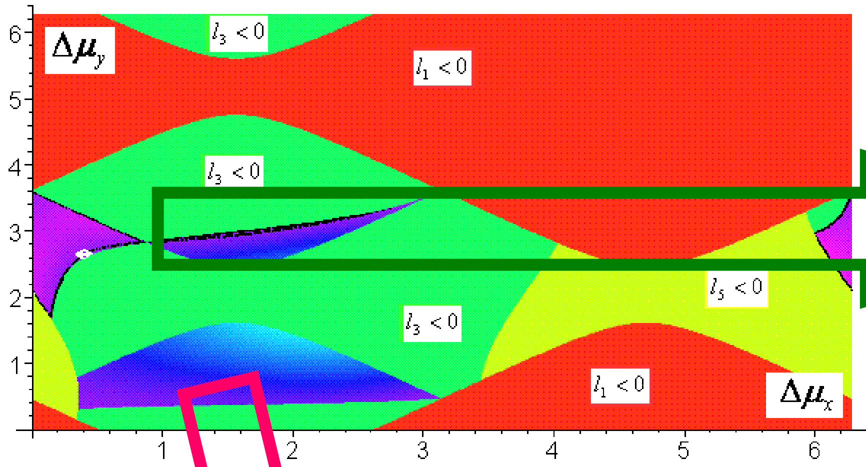


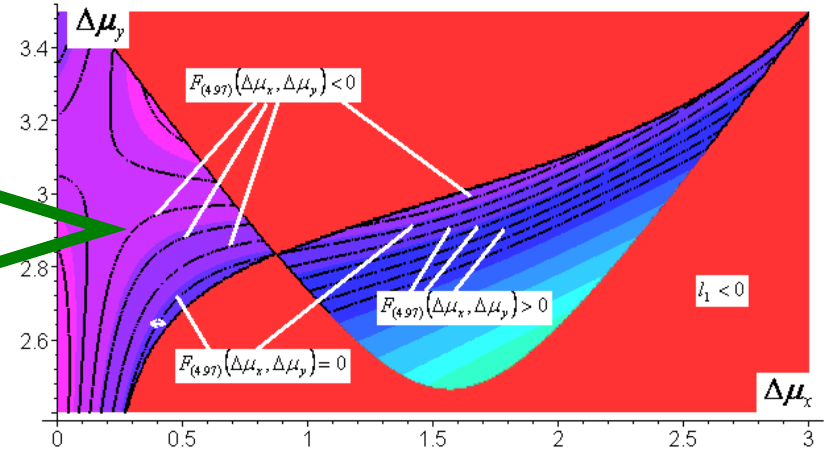


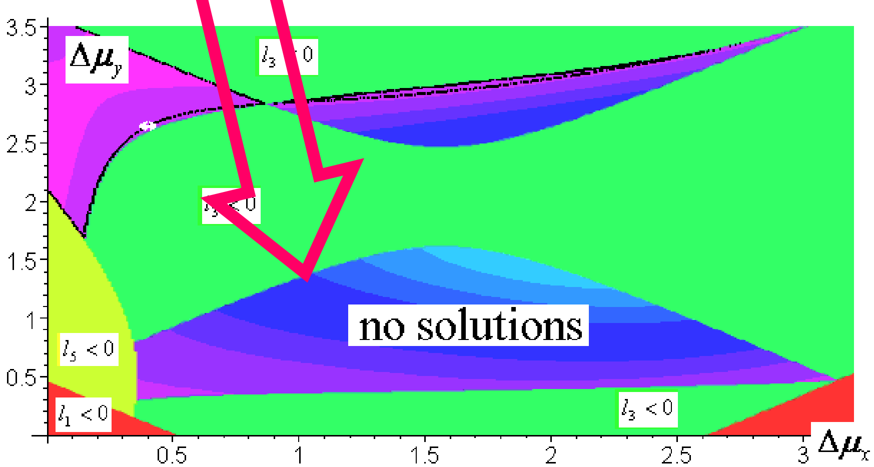
"EXTRACTION" borrowed from "BC1_EXT" RDR (S=15256.472552-15268.372552 m)*

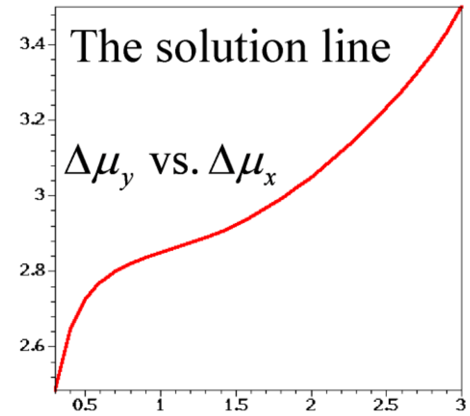
* 20101120_ETURNaround_summary_VK.doc

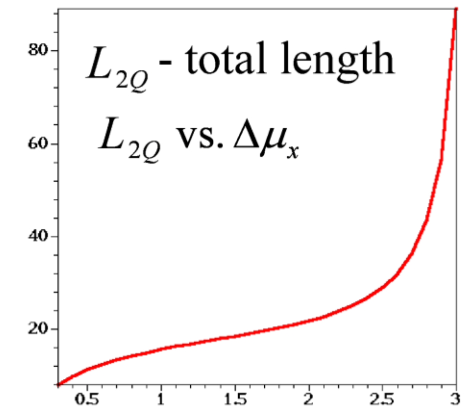
MATCH2: solution for Q-dblt

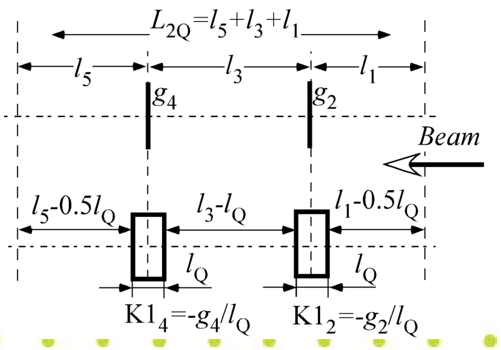








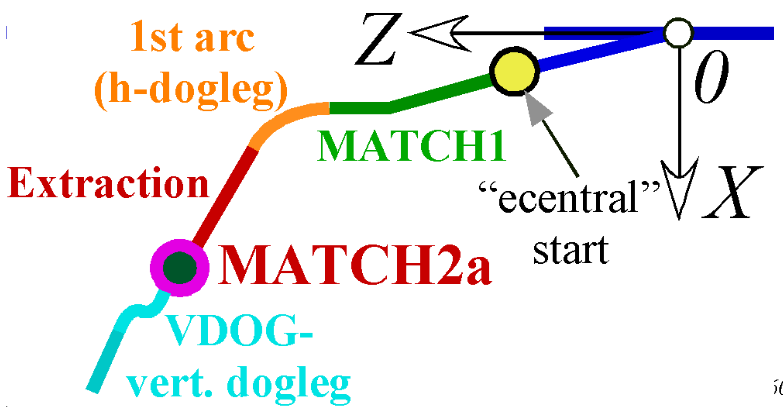




Constant param.	
$\Delta\mu_{x,y}$	0.4/2.64
l_{2Q}, m	9.815
l_3, m	0.574
l_Q, m	0.3

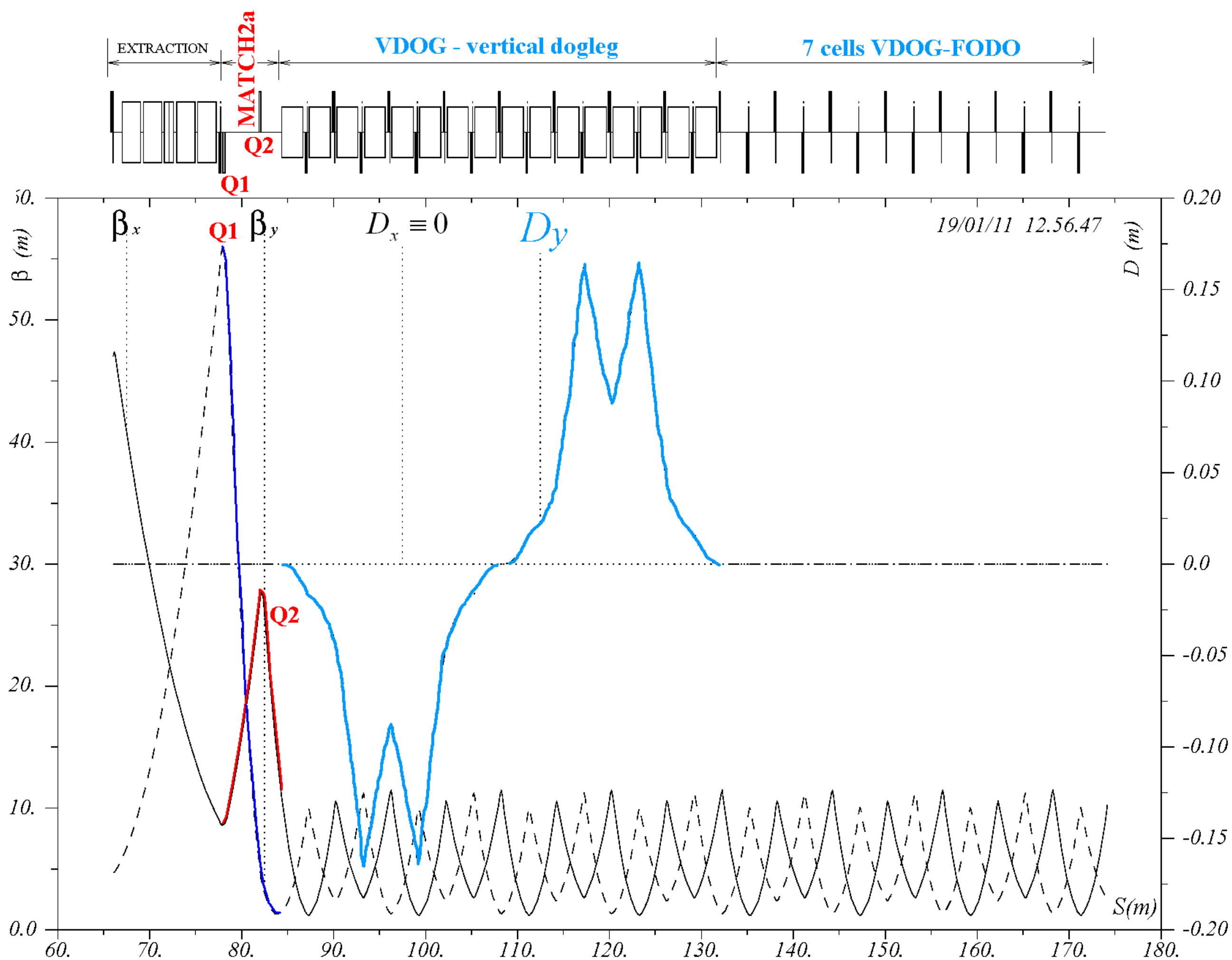
MAD8 matching:			
Var.:	before	after	δ, %
l_1, m	2.591	2.635	1.7
l_5, m	6.650	6.684	0.5
g_2, m^{-1}	-0.647	-0.757	17
g_4, m^{-1}	+0.757	+0.869	15

MATCH**2a**: Q-doublet between Extraction & VDOG



Twiss parameters at boundaries of MATCH2a.

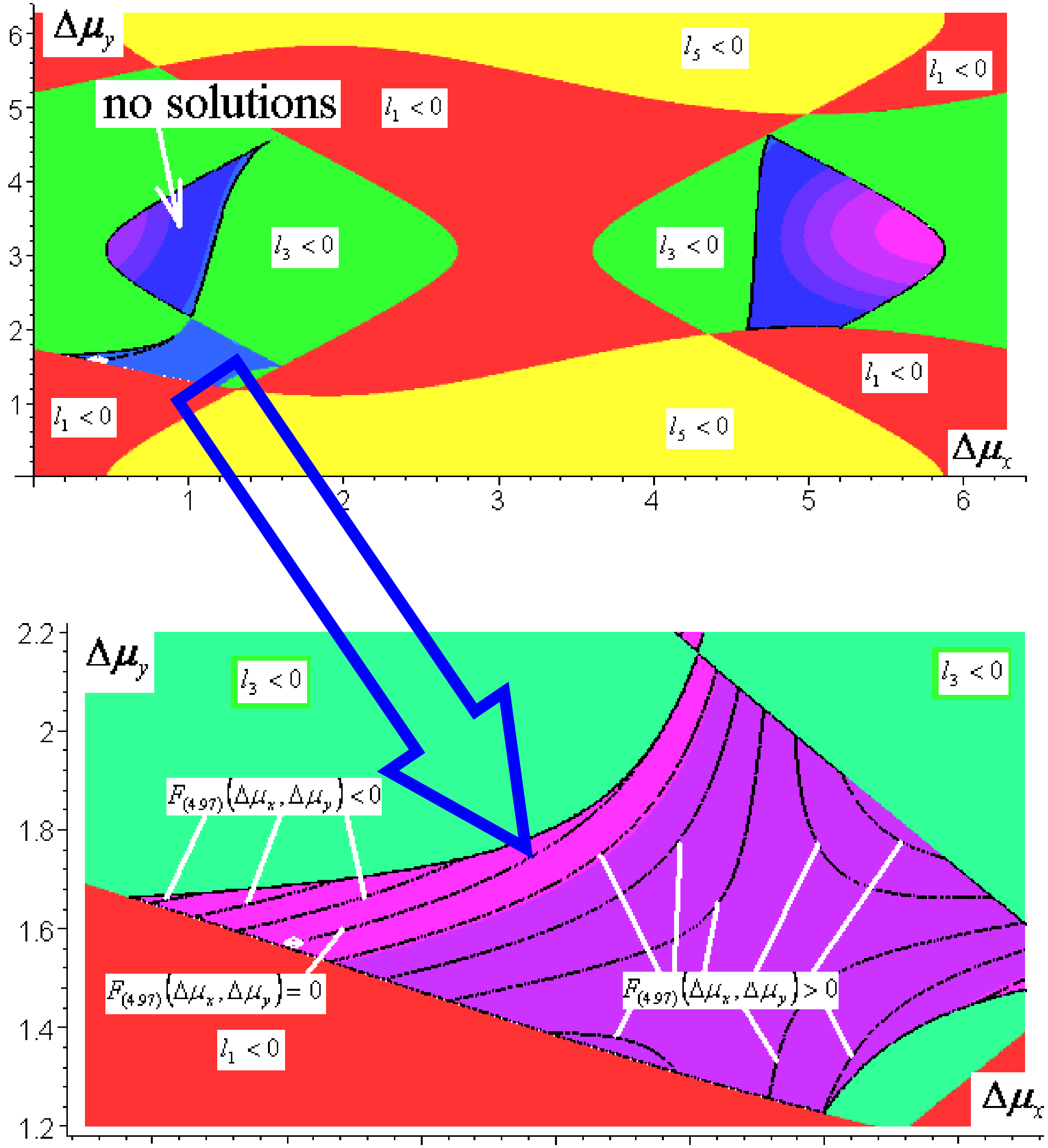
position	β_x	α_x	β_y	α_y	D_x	D'_x
start	8.604	-0.294	55.627	2.384	0	0
end	11.040	3.079	1.359	-0.340	0	0

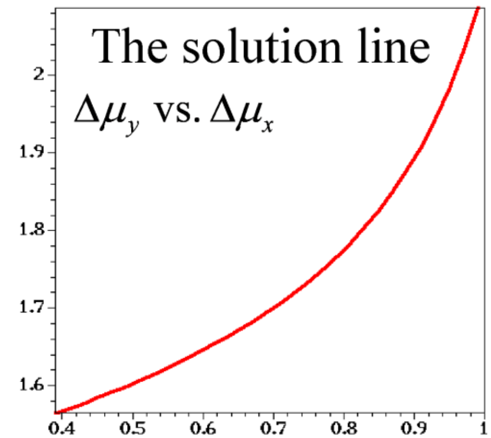


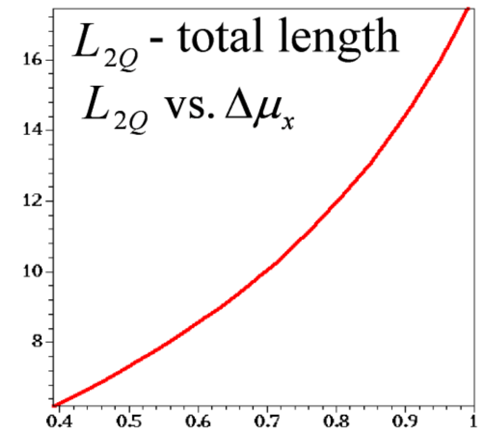
"VDOG" borrowed from "ETURNaround" S=14707.868241-14755.868241 m;

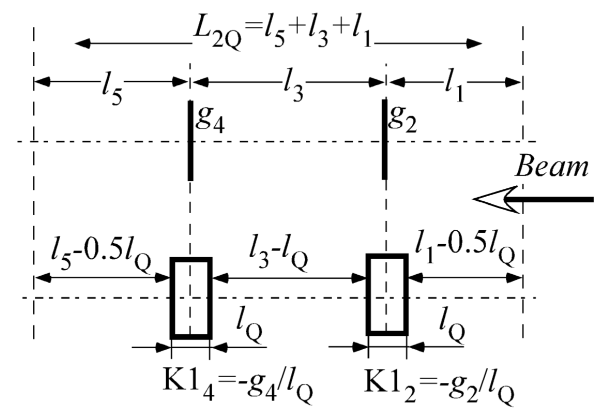
VDOGFODO – periodical structure generated by A.L.

MATCH2a: solution for Q-dblt









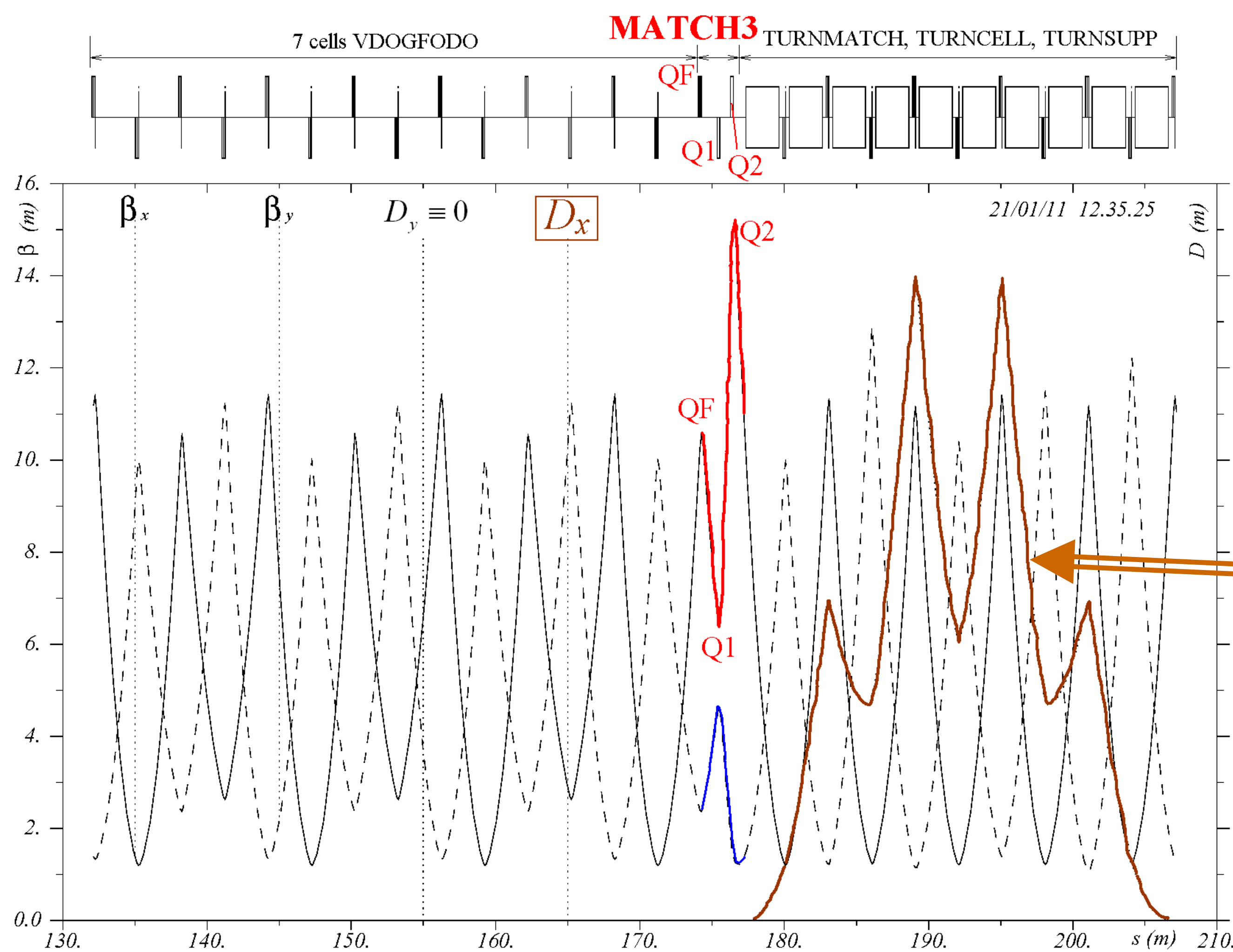
Constant param.	
$\Delta\mu_{x,y}$	0.41/1.57
l_{2Q}, m	6.394
l_3, m	4.00
l_Q, m	0.3

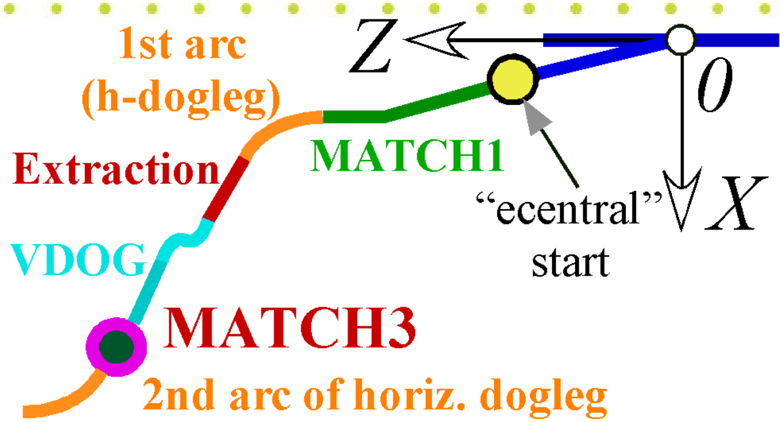
MAD8 matching:			
Var.:	before	after	δ, %
l_1, m	0.290	0.348	20
l_5, m	2.102	2.122	1.0
g_2, m^{-1}	+0.145	+0.149	2.8
g_4, m^{-1}	-0.295	-0.300	1.7

MATCH3: Q-doublet before 2nd arc of H-dogleg

Twiss parameters at boundaries of MATCH3.

position	β_x	α_x	β_y	α_y	D_x	D'_x
start	10.368	2.104	2.440	-0.685	0	0
end	11.040	3.079	1.359	-0.340	0	0

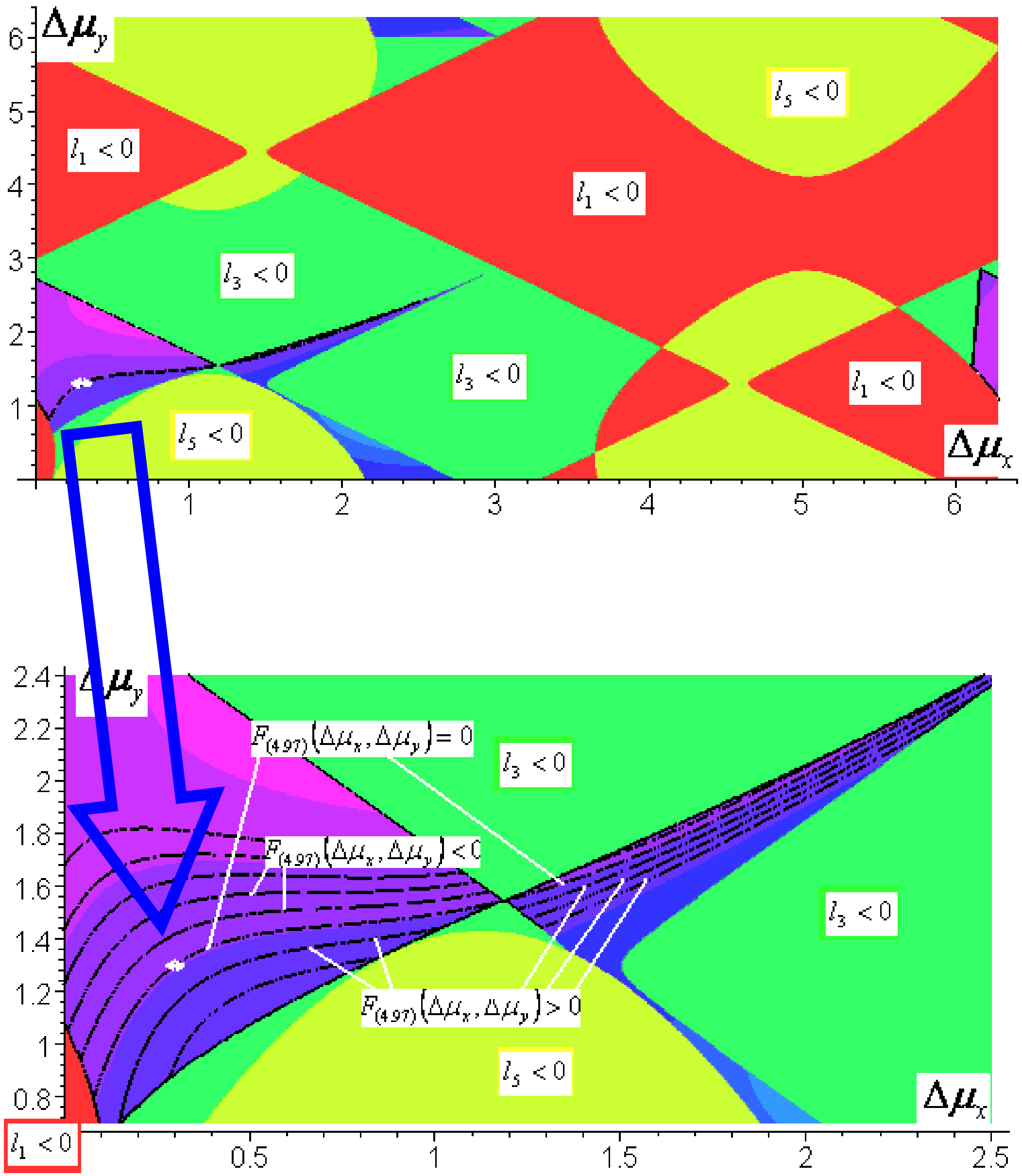


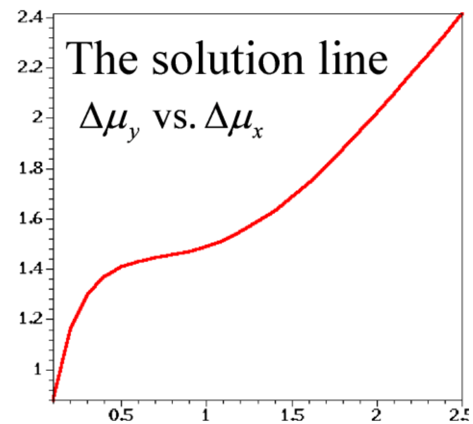


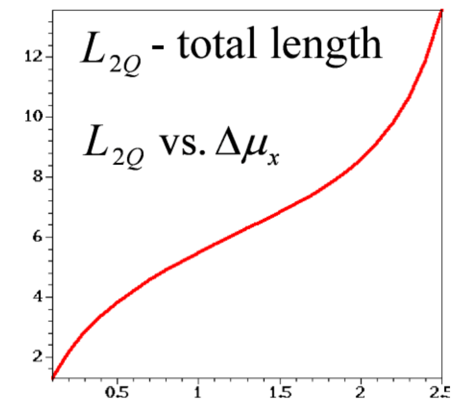
MATCH3: "QF" (added to end of VDOGFODO)+ +"Q-dblt"

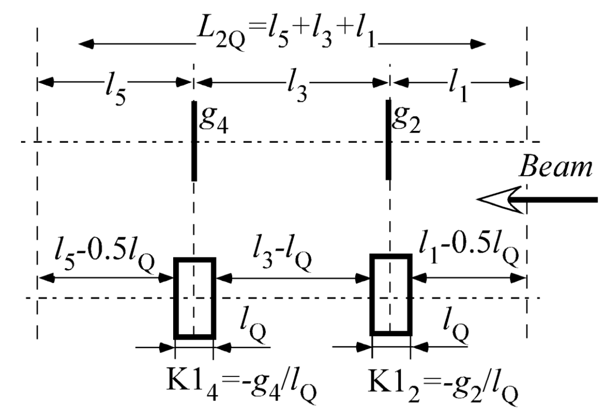
"2nd arc of H-dogleg" borrowed from "aTURNaround" (S=14755-14767m; 14767-14773m; 14875-14887m)

MATCH3: solution for Q-dblt









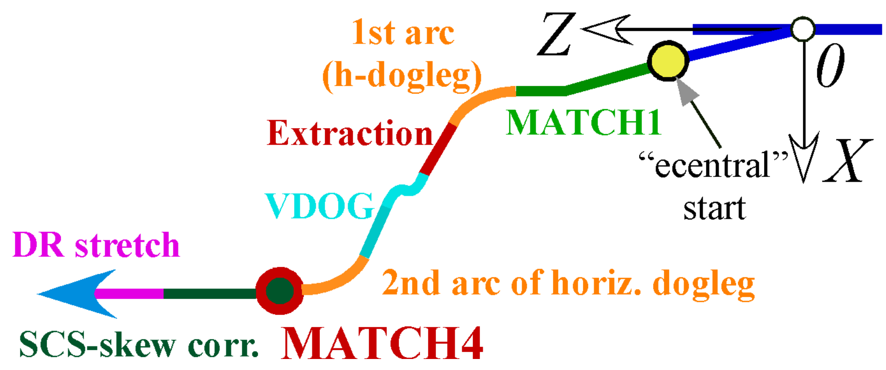
Constant param.	
$\Delta\mu_{x,y}$	0.30/1.30
l_{2Q}, m	2.842
l_3, m	1.014
l_Q, m	0.3

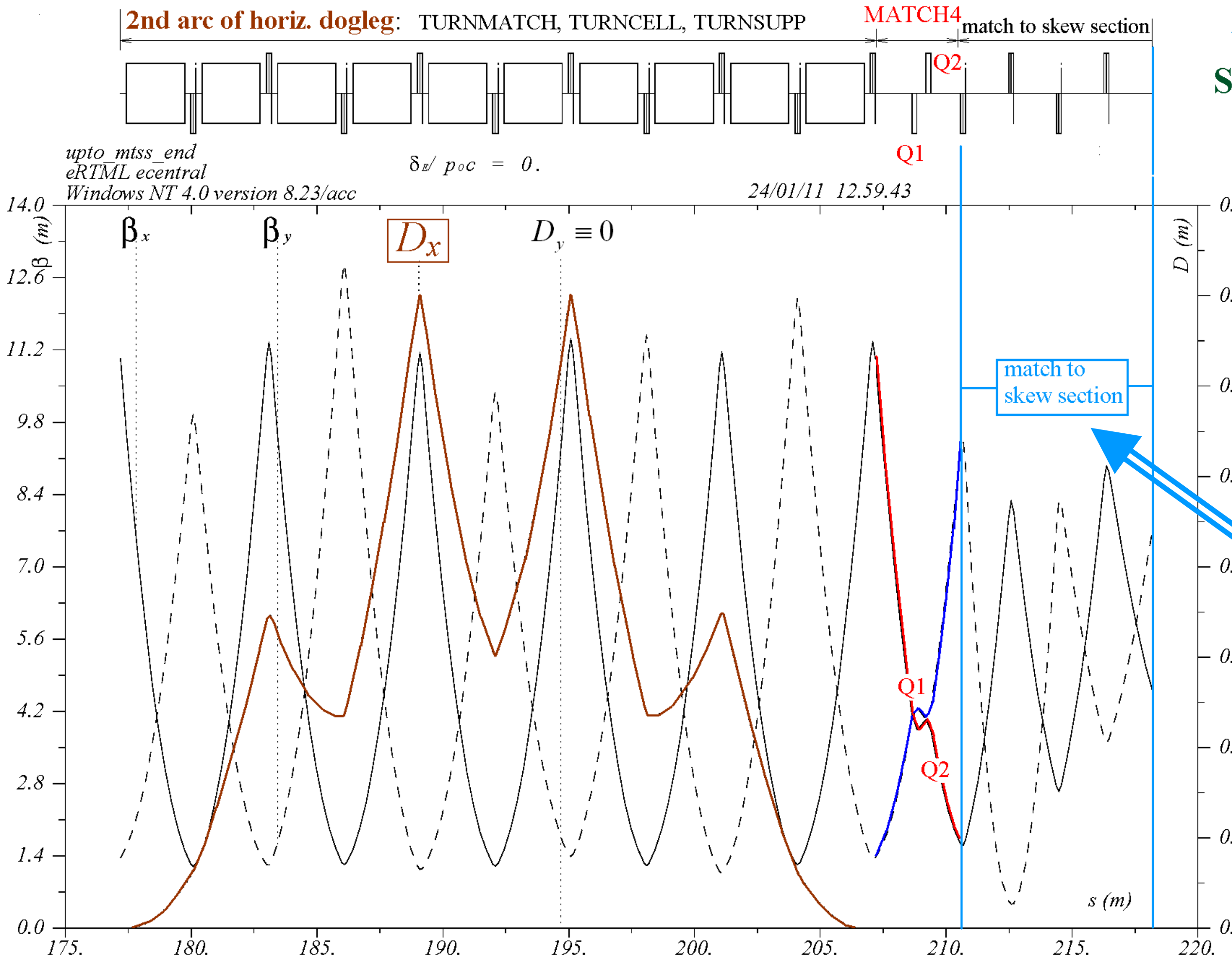
MAD8 matching:			
Var.:	before	after	δ, %
l_1, m	1.160	1.189	2.5
l_5, m	0.667	0.721	8.0
g_2, m^{-1}	+0.810	+0.871	7.5
g_4, m^{-1}	-0.606	-0.662	9.2

MATCH4: Q-doublet after 2nd arc of H-dogleg

Twiss parameters at boundaries of MATCH4.

position	β_x	α_x	β_y	α_y	D_x	D'_x
start	11.040	3.078	1.360	-0.342	0	0
end	1.630	0.481	9.341	-2.626	0	0



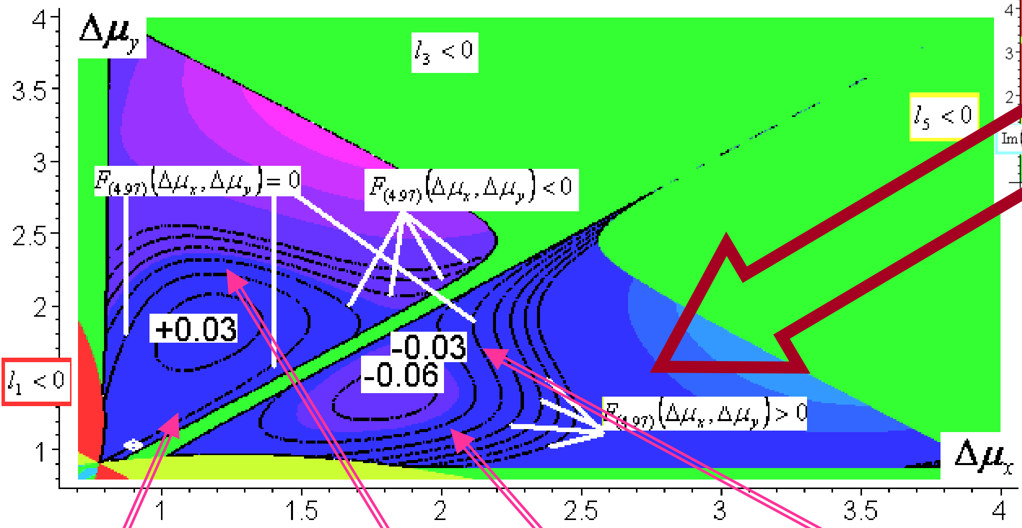


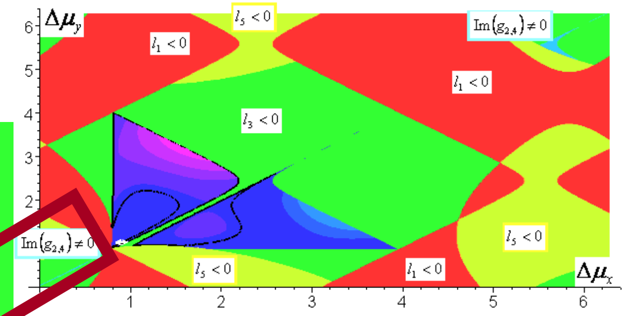
MATCH4: "Q-dblt"

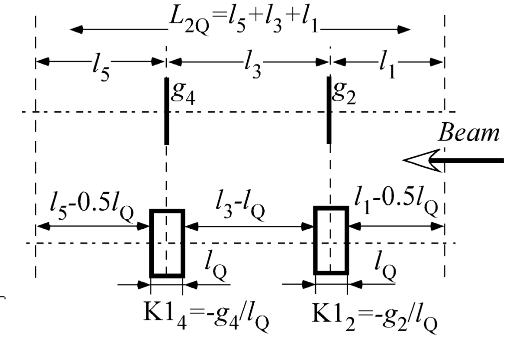
"Match-to-skew section" borrowed from "eGETAWAY"

MATCH4: solution for Q-dblt

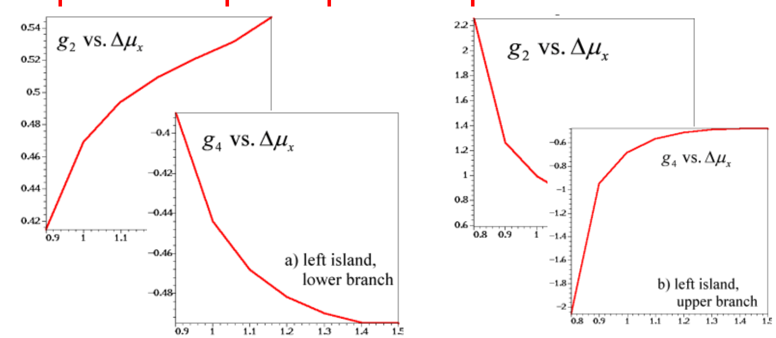
Solution lines: 2 double valued curves => the function with 4 branches

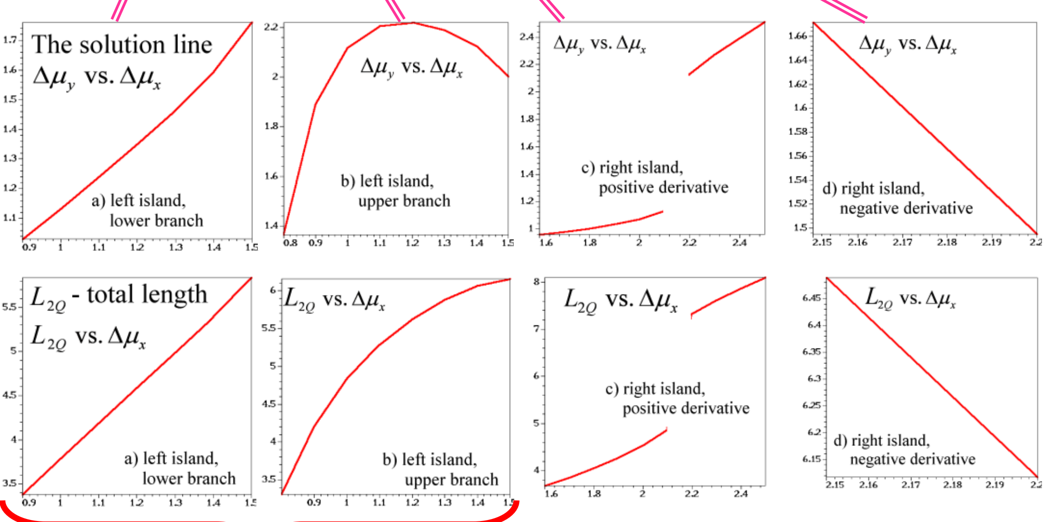






Curve on the left blue island:
Lower branch => lower gradients
|0.40-0.5| vs. |1.0-2.0|





similar L_{2Q} ~ 3.5-5.5m

Constant param.	
$\Delta\mu_{x,y}$	0.90/1.03
l_{2Q}, m	3.382
l_3, m	0.663
l_Q, m	0.3

MAD8 matching:			
Var.:	before	after	δ, %
l_1, m	1.505	1.542	2.5
l_5, m	1.244	1.284	3.2
g_2, m^{-1}	+0.414	+0.470	14
g_4, m^{-1}	-0.389	-0.445	14

Summary

Lattice design for RTML line in central area:

- **Most of modules have been adopted from RDR lattice ("eTURNaround", "eGetaway")**
- **Initial part of RTML at DR exit (MATCH1) has been redesigned**
- **Geometry of "ecentral" matches to overall RTML dimensions**
- **Geometry should be further refined in terms of geometry neighboring beam-lines and DRs.**
- **Matching of TWISS parameters between neighboring modules has been performed**
- **Most of matching section is based on quadrupole doublets**
- **Analytical method for evaluation of doublet parameters is implemented.**
- **Parameters of doublet are refined using matching routines of MAD8**