Main Linac lattice design for TDR (KCS & DKS configurations)

V.Kapin, N.Solyak
Fermilab

LCWS12 Int. Workshop on Future Linear Colliders,
October 2012, 22-26 , Univ. of Texas at Arlington, USA

Outline

- The lattices for two layouts
  - **KCS - Klystron Cluster Scheme ("4-RFU" and "3-RFU")**
  - **DKS - Distributed Klystron Scheme ("3-RFU")**
- Treaty points:
  - **T(P/E)RTML2ML &**
  - **TPML2BDS/TEML2PS**
- Details of modified matching procedures

  (including optical functions, dispersion minimization and the linac reference orbit following the Earth's curvature)
- Summary & the present lattice status

ML lattices designed with MAD8 (a special version 51.15.s by M.Woodley) following to the approach.*

** A.Valishev, N.Solyak, M.Woodley, "Status of the ILC Main Linac Lattice Design", PAC'07,* ***2007****.*

Changes in TDR layout vs. RDR

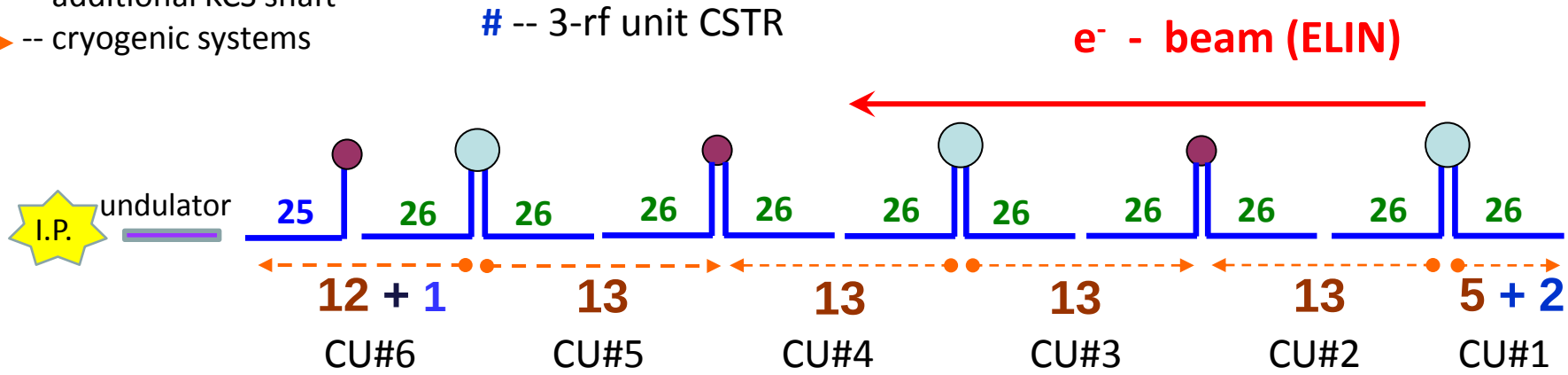
- Two configurations:
  - **KCS: new configuration of CryoUnits (CU) vs. DRFS**
    - CU contains long (4*RFunit) and short (3*RFunit) cryo-strings
    - Length of CU's are different: from 25 to 52 RF units.
    - Number of RF units are different for Electron (285) and Positron (282) Linacs
  - **DKS:**
    - All cryo-strings are short (3 RF units)
- Treaty points (from RTML and to Undulator/BDS) are modified
- Collimation system migrated from BDS to ML
    - Polarity of the last quad in ELIN and PLIN are different.

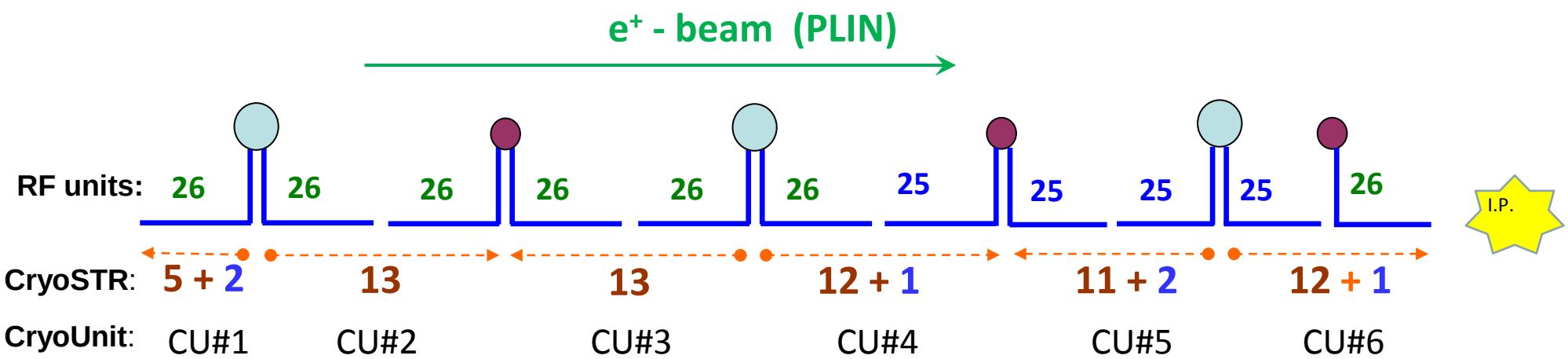
KCS version (ver. 6/26/2012, C.Nantista)

It allows to use most of existing RDR solutions and requires small number of re-matchings

-- main facilities shaft
-- additional KCS shaft
-- cryogenic systems

-- 4-rf unit CSTR
-- 3-rf unit CSTR





Basic lattice segmentations in ML

Name in Lattice	modules								Length (m)
		without quad	with quad	without quad			warm section (m)		7.652
RFU#	RF unit	12.652	12.652	12.652					
	(lengths in meters)	3 modules							37.956
		RF unit	RF unit	RF unit	RF unit	end-box			
CSTR#	"4" Long Cryo-String	37.956	37.956	37.956	37.956	2.50			
		12 CM's plus string end box							154.324
CSTR#	"3" Short Cryo-String	RF unit	RF unit	RF unit	end-box				
		37.956	37.956	37.956	2.50				
		9 CM's plus string end box							116.368
CUNIT #	Cryo-Unit	Service end-box 2.500	CSTR	CSTR	CSTR	CSTR	- - - -	CSTR	CSTR

KCS: Layout of Cryo-Units

Electron Main Linac: (72 CSTR = 285 RFunits = 855 CM's)

CUNIT1	7.65	CUNIT2	7.65	CUNIT3	7.65	CUNIT4	7.65	CUNIT5	7.65	CUNIT6

	CSTR "4"		CSTR "3"		RF units
CUNIT1 =	5		2		26
CUNIT2 =	13				52
CUNIT3 =	13				52
CUNIT4 =	13				52
CUNIT5 =	13				52
CUNIT6 =	12		1		51
Total:	**69**		**3**		**285**

Sbox	01	02	03	04	05	06	07						
Sbox	08	09	10	11	12	13	14	15	16	17	18	19	20
Sbox	21	22	23	24	25	26	27	28	29	30	31	32	33
Sbox	34	35	36	37	38	39	40	41	42	43	44	45	46
Sbox	47	48	49	50	51	52	53	54	55	56	57	58	59
Sbox	60	61	62	63	64	65	66	67	68	69	70	71	72

Legend: 7.65 Warm section 7.652m | Sbox Service box | ## Long (4-RFU) CSTR | ## Short (3-RFU) CSTR

Positron Main Linac: (72 CSTR = 282 RFunits = 846 CM's)

CUNIT1	7.65	CUNIT2	7.65	CUNIT3	7.65	CUNIT4	7.65	CUNIT5	7.65	CUNIT6

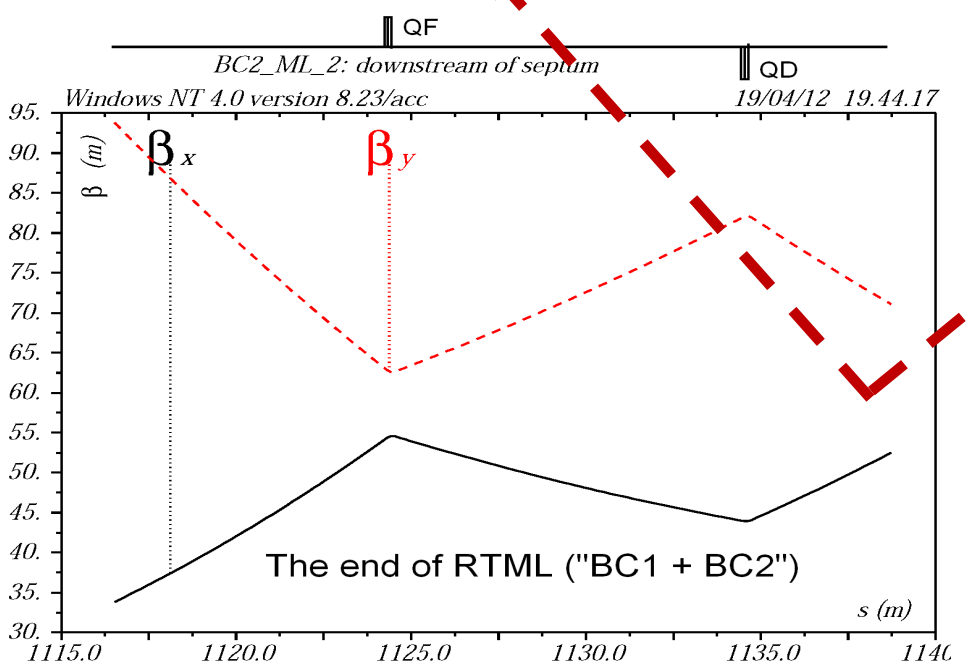
	CSTR "4"		CSTR "3"		RF unit
CUNIT1 =	5		2		26
CUNIT2 =	13				52
CUNIT3 =	13				52
CUNIT4 =	12		1		51
CUNIT5 =	11		2		50
CUNIT6 =	12		1		51
Total:	**66**		**6**		**282**

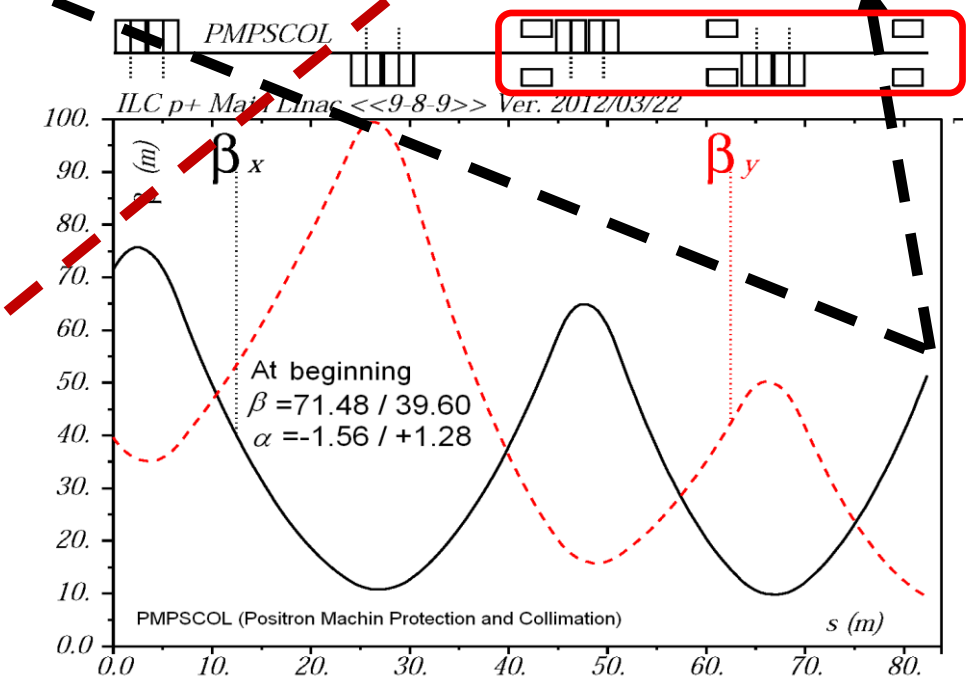
Sbox	01	02	03	04	05	06	07						
Sbox	08	09	10	11	12	13	14	15	16	17	18	19	20
Sbox	21	22	23	24	25	26	27	28	29	30	31	32	33
Sbox	34	35	36	37	38	39	40	41	42	43	44	45	46
Sbox	47	48	49	50	51	52	53	54	55	56	57	58	59
Sbox	60	61	62	63	64	65	66	67	68	69	70	71	72

Treaty points: Optical Functions at ML boundaries

Electron side | Positron side

Treaty Point	TERTML2ML	TEML2PS	TPS2EBDS	TPRTML2ML	TPML2BDS
	Electron RTML to Main Linac	Electron Main Linac to Positron Source (Undulator Section)	Positron Source (Undulator Section) to Electron BDS	Positron RTML to Main Linac	Positron Main Linac to BDS
Optics Functions					
α_x	-1.142	-2.402	-2.402	-1.142	-2.402
β_x [m]	52.67	51.33	51.33	52.67	51.33
α_y	1.279	0.4888	0.4888	1.279	0.4888
β_y [m]	70.74	9.395	9.395	70.74	9.395





- The RTML ends with defoc. Q => **ML starts with focusing Q**
- ML proper ends at the entry of PMSCOL (p+ machine protection & collimation)

Quadrupoles in e⁻ ML (KCS) cells

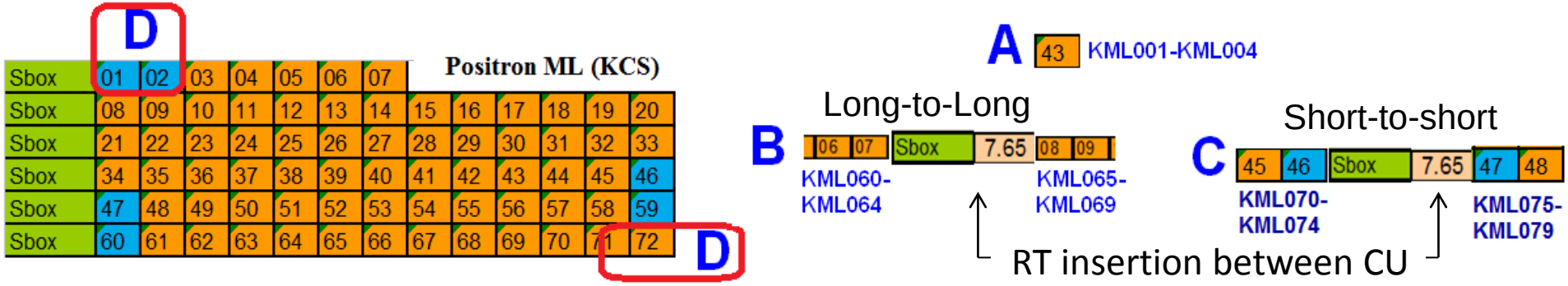
Basic configurations of focusing structure

A: Quasi-periodical "long" 4-RFU CSTR inside of regular part of CUNITs : 2 FODO quasi-periodical cells (phase advances ~75/60 degrees) => 4 quads with K1 denoted as K1=KML001, KML002, KML003, KML004

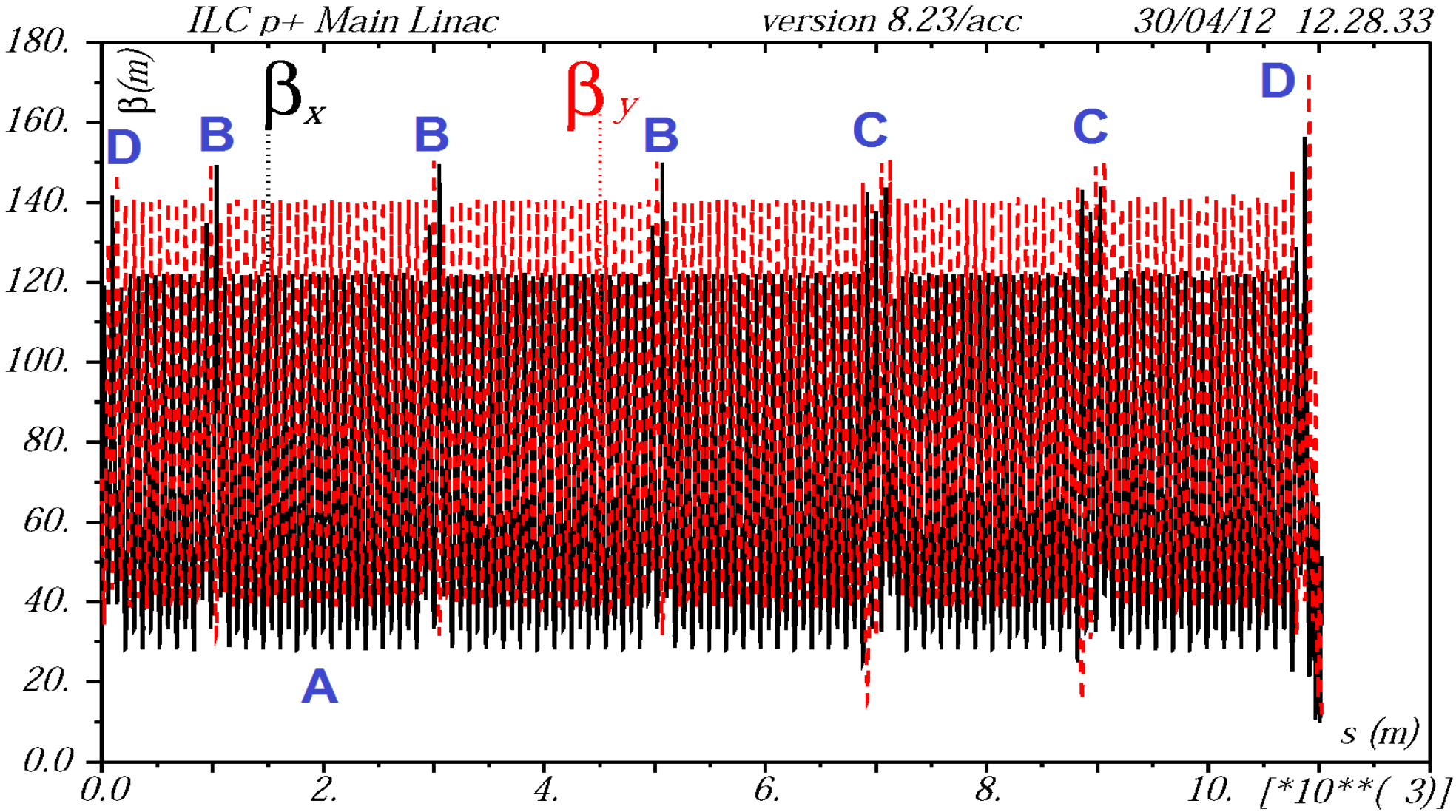
B: Long 4-RFU CSTR between CUNIT ends separated by warm sections: "5+5" quad configuration around warm sections with K1 denoted as KML060-KML064 and KML065-KML069

C: Two short 3-RFU CSTR at connections of CUNIT#4 with CUNIT#5, and CUNIT#5 and CUNIT#6 (for PLIN only): "5+5" quad configuration around warm sections with K1 denoted as KML070-KML074 and KML075-KML079

D: 6 quads at the ML beginning and 6 quads at the ML end are used for matching to the Twiss parameters b and a at ML boundaries.



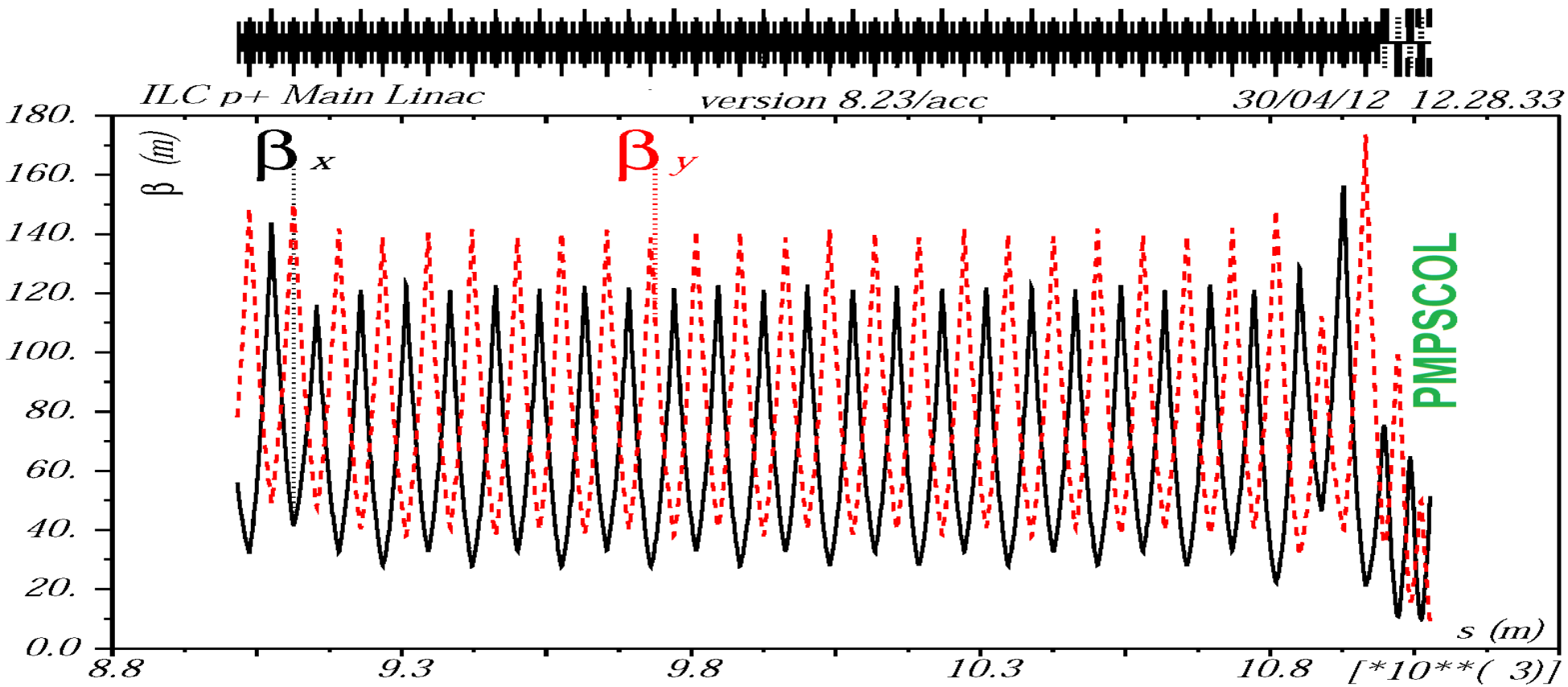
Matched β-functions in PLIN (KCS)



PLIN & PMPSCOL junction

- RTML ends with **defocusing** Quad => ML9 (e^+&e^-) starts with **focusing Quad**
- **Positron** ML with 282 Quads (= #RFU) ends with defocusing Quads
- ➔ PMSCOL starts with focusing Quad

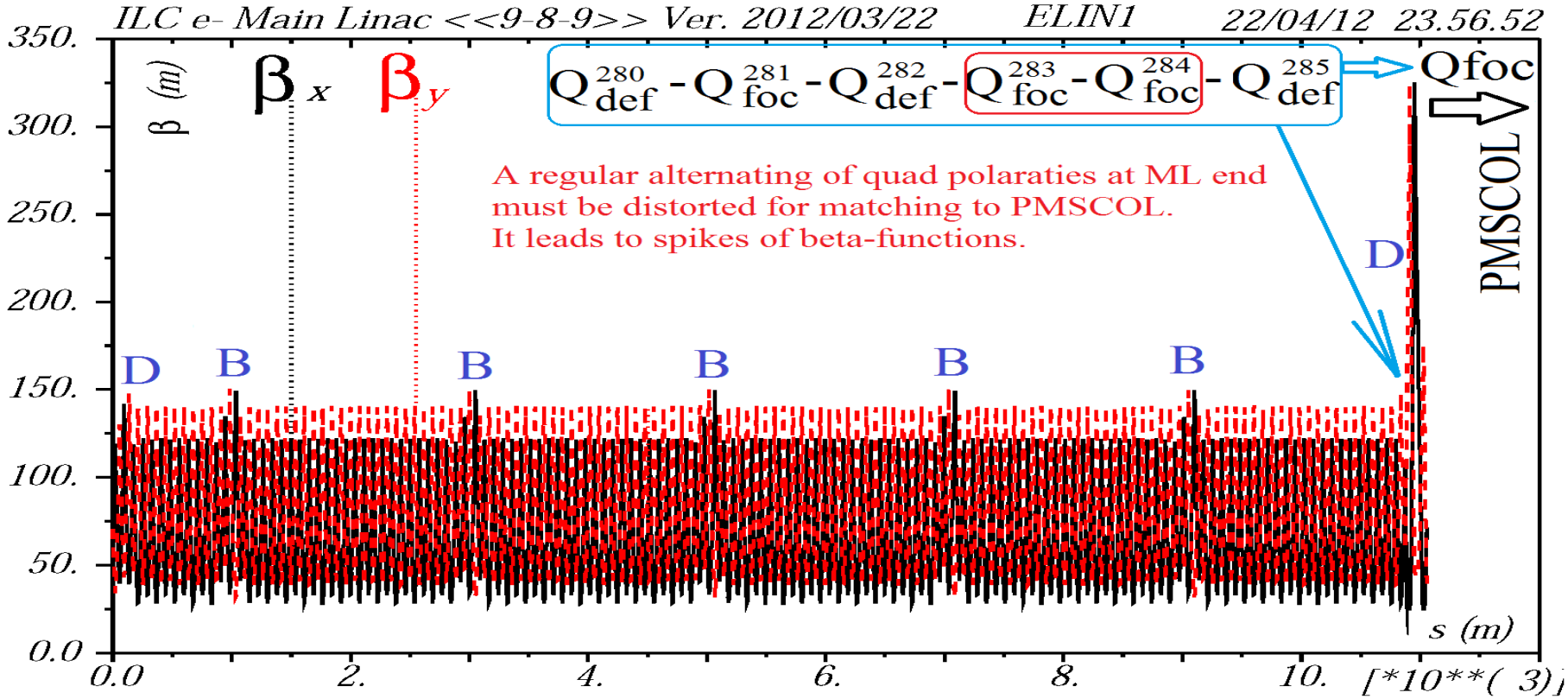
=> Alternative polarity of Quads is kept throughout total Positron ML



Matching features for ELIN

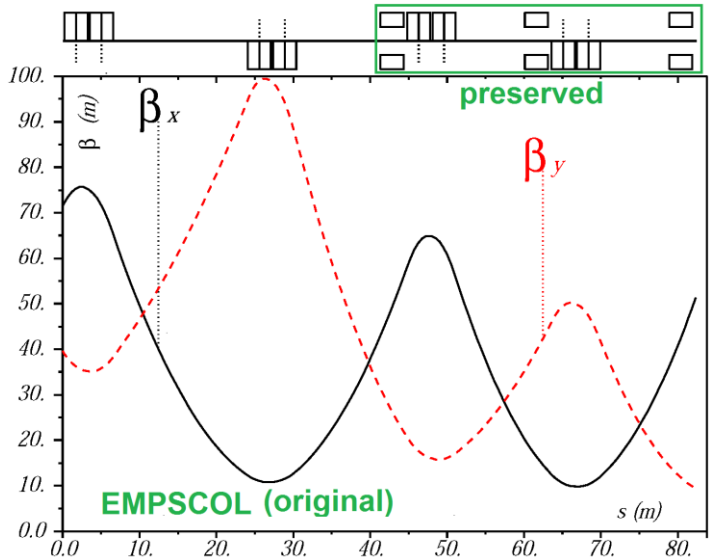
- ELIN has a regular structure inside; no need for “C”- type matching quads
- **Electron** ML with 285 Quads starts and ends with **focusing Quads**
- PMSCOL starts with **Q-foc** => the same Q-polarities at ELIN & COL junction

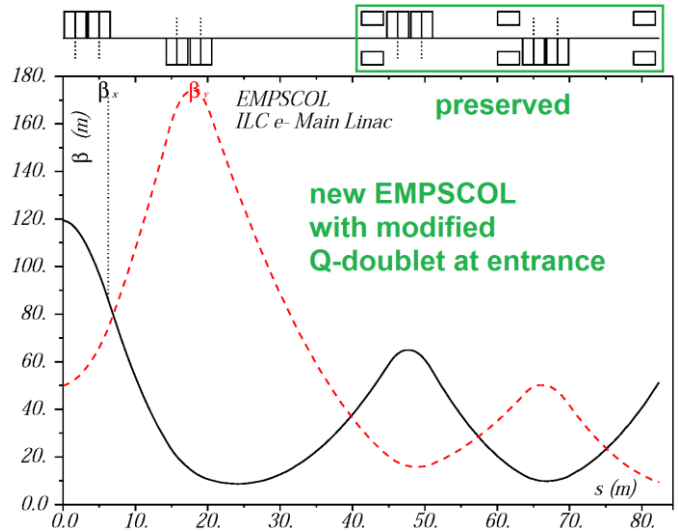
=> Difficult matching with COLL structure resulting in large β-functions

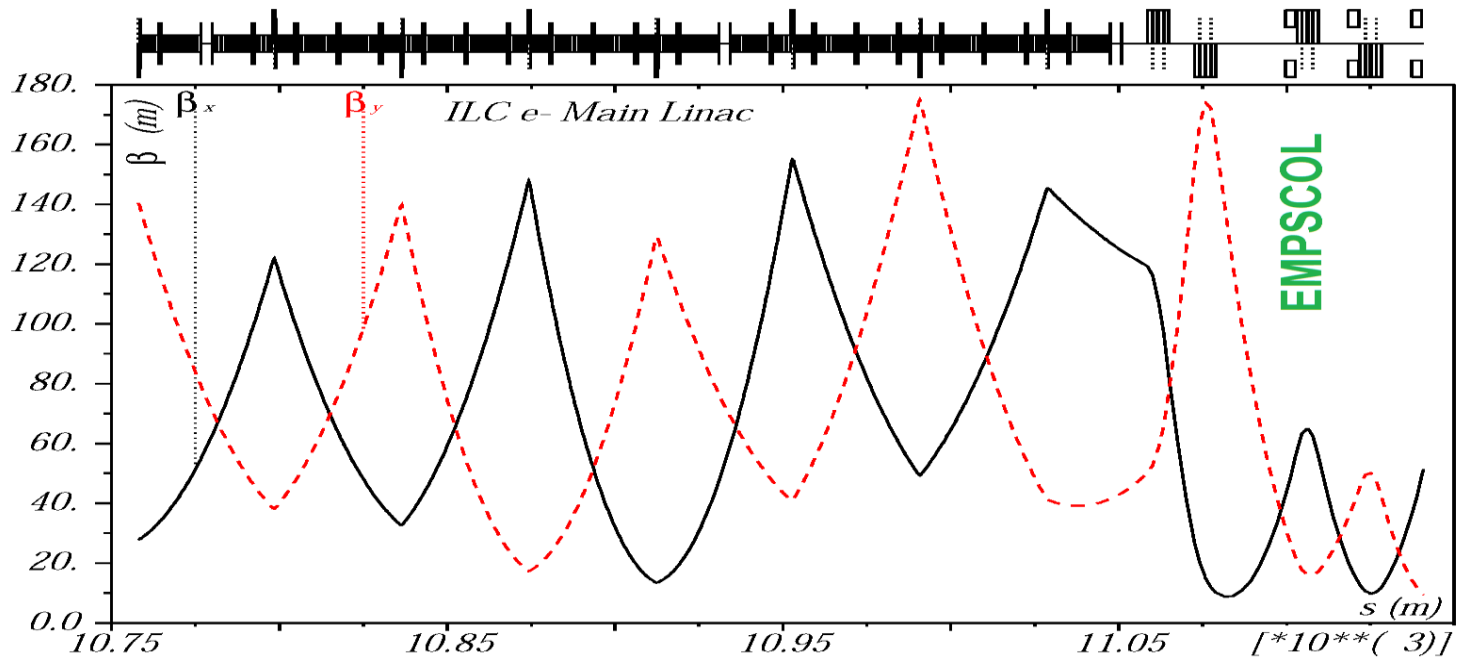


A bad matching at ELIN-end with **original** COL-structure (large β-function)

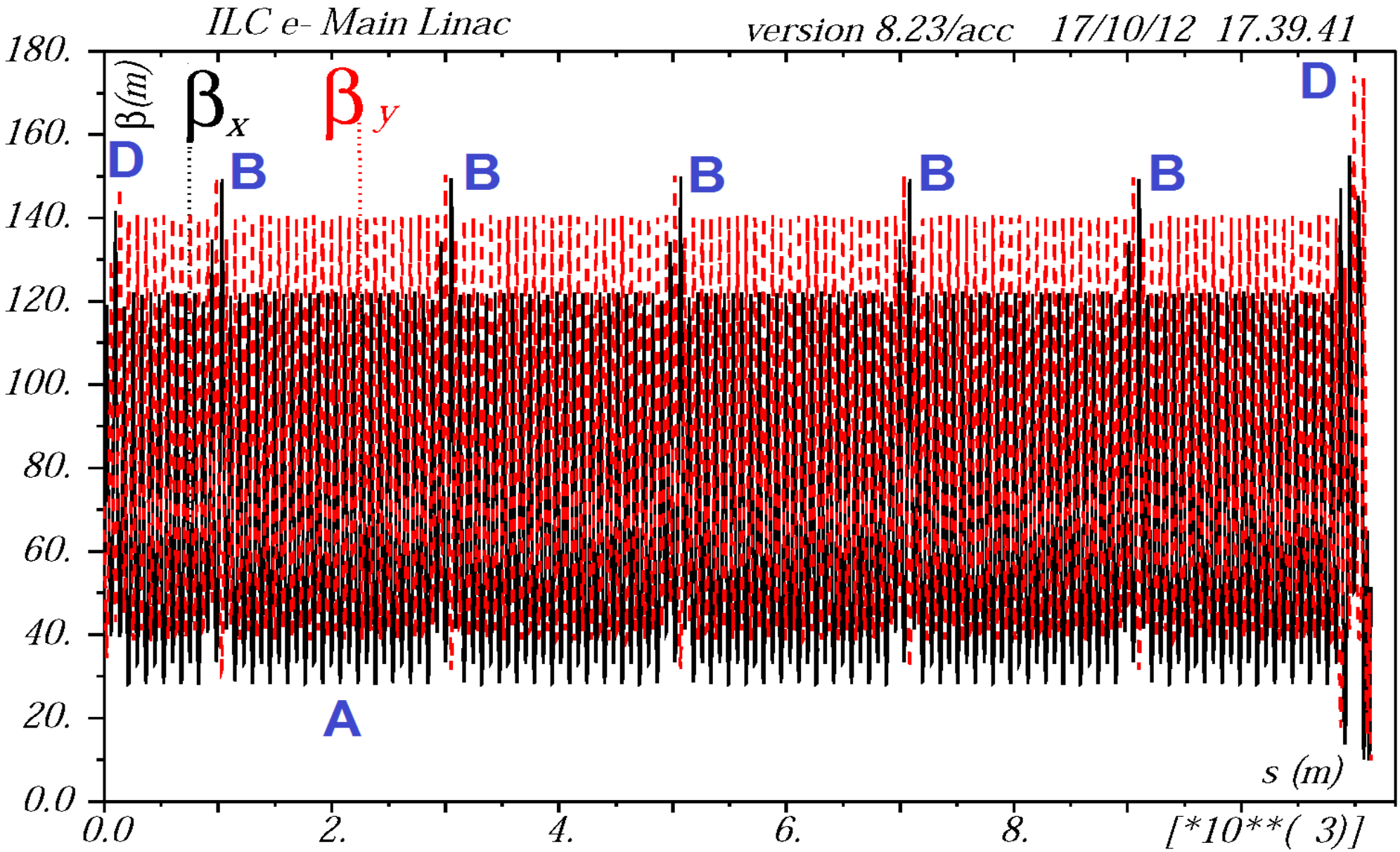
Improved ELIN & EMPSCOL junction







Matched β-functions in ELIN (KCS)



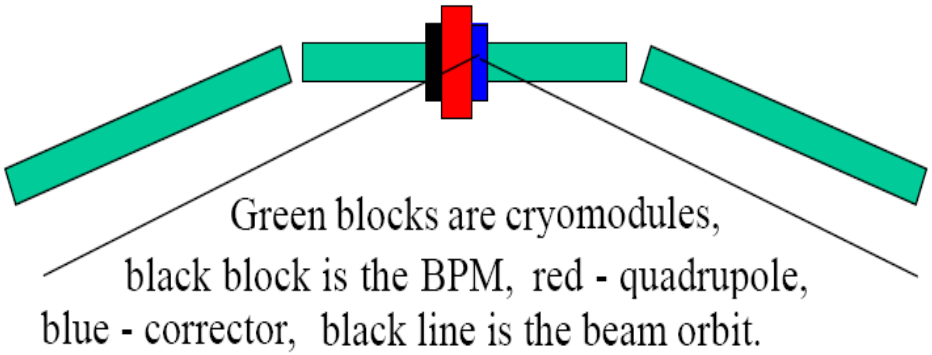
Earth Curvature implementation

- ML follows curvature of the Earth ‘s surface
- Each CM is straight and aligned along the Earth horizon and the beam-line is kinked at the ends of CMs
- Kinks between CM’s are implemented in MAD8 as a thin KML-lines consisting of a dipole (MULT, K0L=p) & a vert. corrector (VKICK): (The former changes both ref. frame and beam trajectory, the latter cancel the trajectory change)
- In MAD8 curvature (KMLs) are switched ON/OFF by “SET, CURVE, 1” & 0
- KML-lines are set at both ends of every CM. Several types:
  - ***KML1 – between CMs inside of RFUs***
  - ***KMLQ – at the ends of CM with quads***
  - ***KML2 – between CMs at CSTRs ends***
  - ***KML4 – between CMs at CUNITs ends***
  - ***KML5 – at the end of the last CM (at ML exit)***
  - ***KML8 – at the beginning of the first CM (ML entrance)***

Steering to the Earth's curvature

Constrains:

- The beam trajectory is steered by vertical correctors through the centers of quads, i.e. only at every 3rd CM.
- Steering can be switched "ON/OFF" by "SET, STEER,1" or 0



Match corrector strengths along ML:

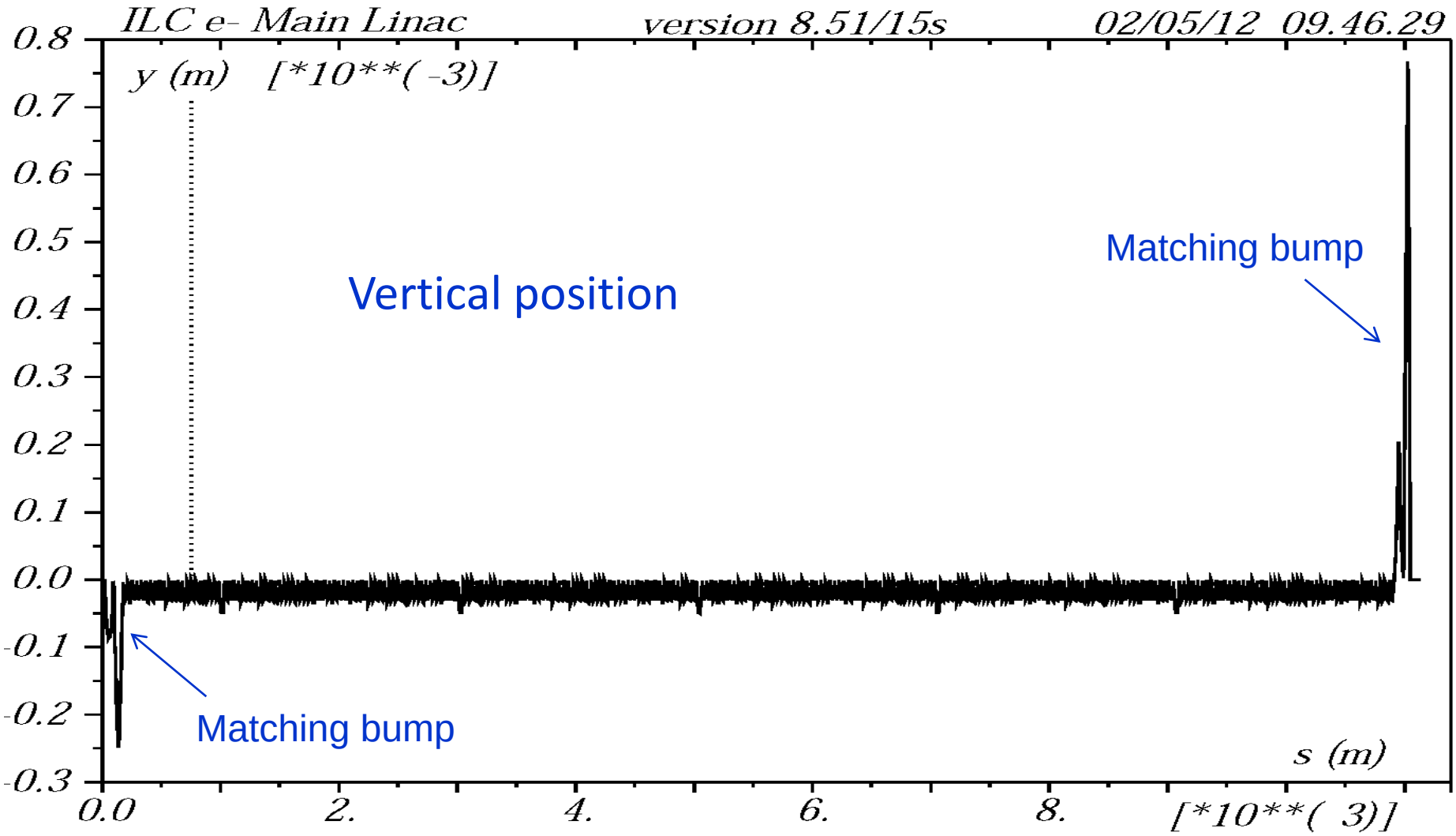
```
MATCH, BETA0=TWSS0
  VARY, AMLY#  (# = 10, 11,13,15,22,23,25)
  ……————————————————
  CONSTR, PATTERN="YML...", Y=0
   LMDIF, TOL=1.E-20,…
   MIGRAD, TOL=1.E-20, …
ENDMATCH
```

Match AML26, AML27 at exit:

```
MATCH, BETA0=TWSS0
    VARY, AMLY26, STEP=1.E-9
    VARY, AMLY27, STEP=1.E-9
    CONSTR, #E, Y=0, PY=0
    LMDIF, TOL=1.E-20, CALLS=5000
    MIGRAD, TOL=1.E-20, CALLS=5000
  ENDMATCH
```

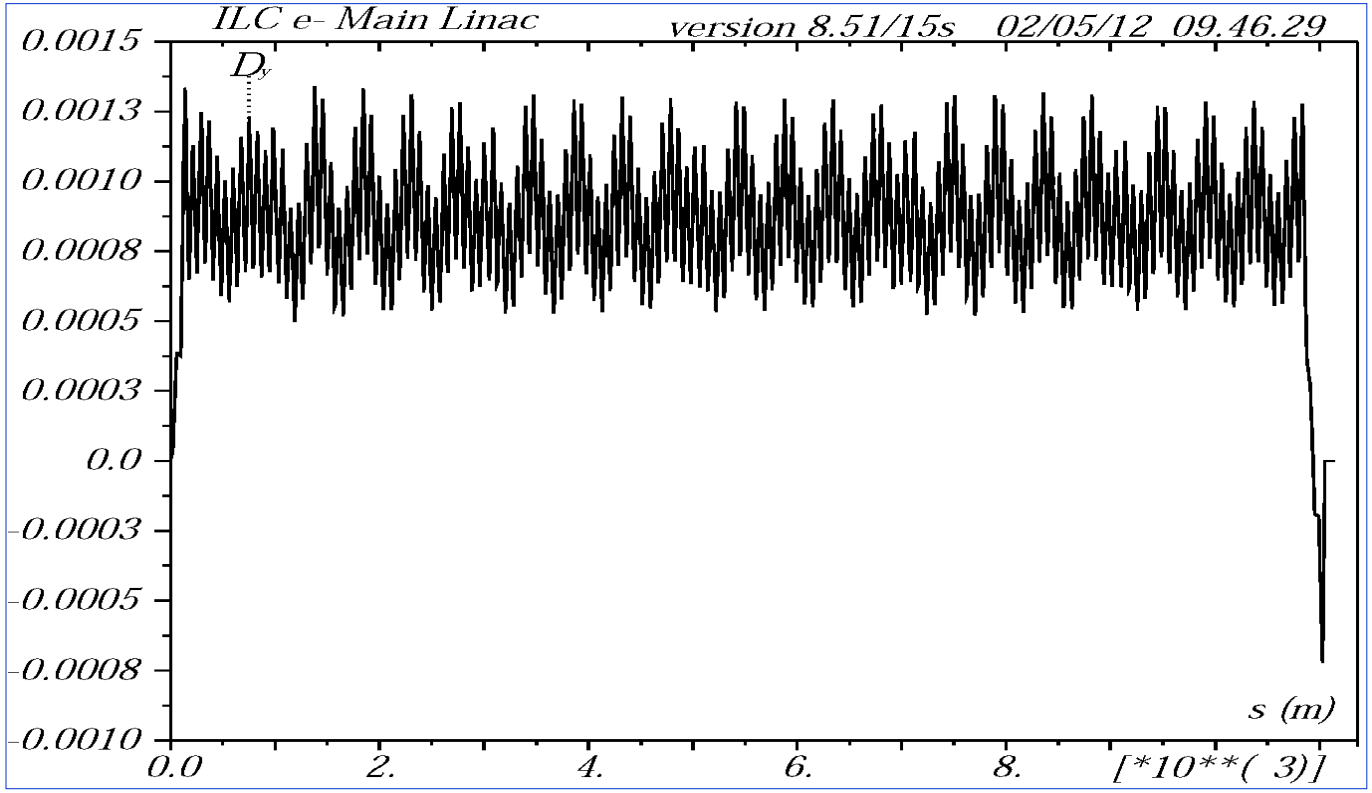
Notice: Another possible constraint with Y> 0 (instead of Y=0) minimizing wake-field effects (Kubo's proposal) is not realized yet in the present ML lattice.

Beam orbit after steering (KCS)



Dispersion minimization (KCS)

- The beam injected into ML must be matched to the periodic dispersion in curved lattice
- The optimal dispersion at injection (TDY & TDPY) is found by minimizing D_y at every defocusing quad.




```
! Find TDY & TPDY
SET, CURVE, 1; SET, STEER, 1;
SET, BUMPS, 0; USE, PLIN1

MATCH, BETA0=TWSS0
   VARY, TDY; VARY, TDPY
   WEIGHT, WX=1.E-9
   CONSTR, PATTERN="MQD.*", DY=0
   LMDIF, TOL=1.E-20;
ENDMATCH

! Save solution at the 6th RFU
SET, MDY,  TWSS_QML006[DY]
SET, MDPY, TWSS_QML006[DPY]
```

Matching D_y & ref. orbit at ML entrance

- RTML end with DY=0 & w/o curvature is matched into ML beginning with DY ≠0 &CURVE=>1
- 5 additional vertical kicks (AMLYi+AMLDY##**i**) for 5 first correctors at ML beginning are switched on by "SET, BUMPS,1"

SET, CURVE, 1; SET, STEER, 1

SET, BUMPS, 1; USE, PLIN1

SAVEBETA, **TWSS1, YML003**

SAVEBETA, **TWSS2, YML005**

TWISS, BETA0=TWSS0

MATCH, BETA0=TWSS0

VARY, AMLDY11i (12i, 13i, 14i, 15i);

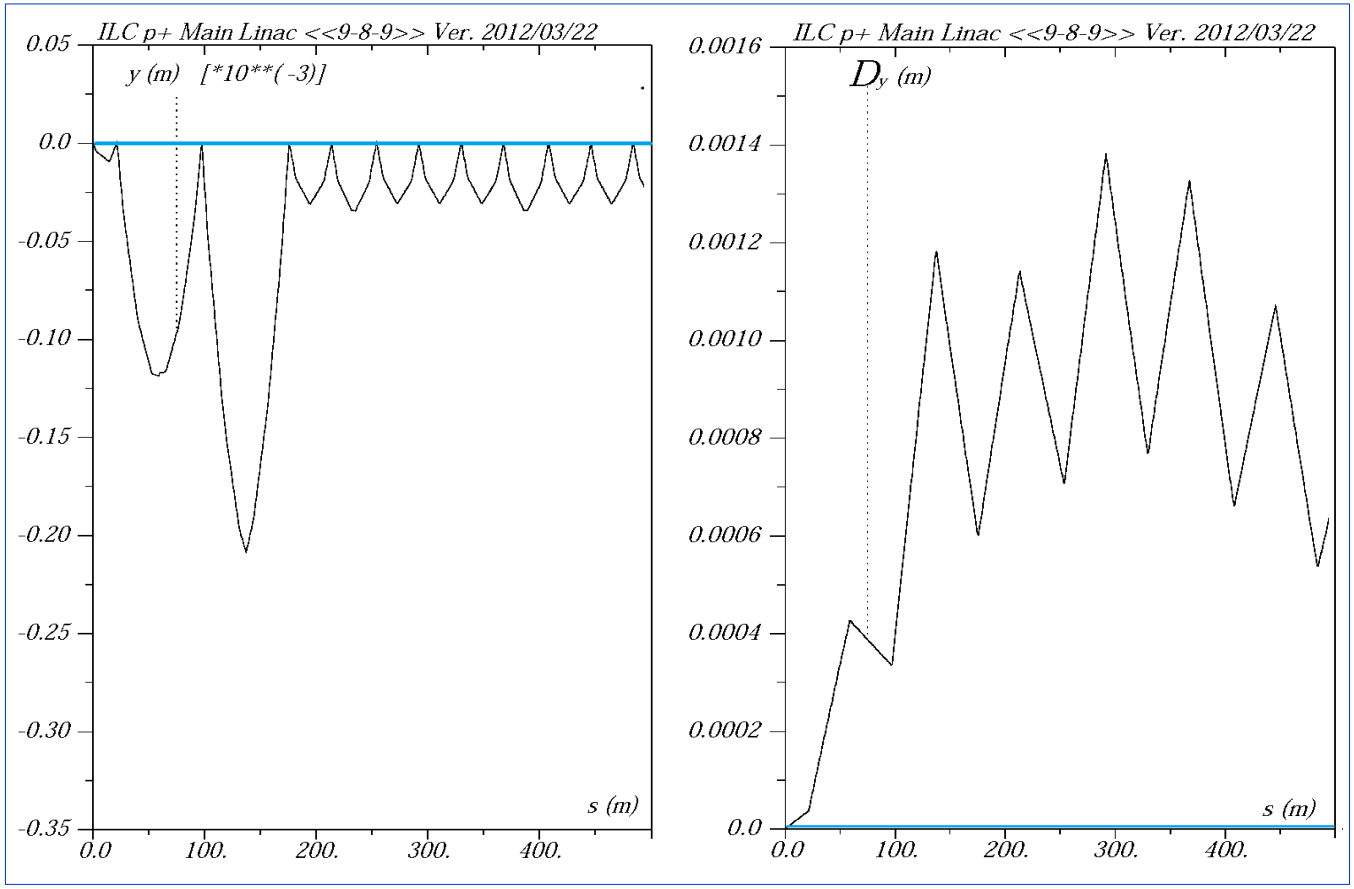
CONSTR, YML003, Y=TWSS1[Y]

CONSTR, YML005, Y=TWSS2[Y], PY=TWSS2[PY]

CONSTR, QML006[1], DY=MDY, DPY=MDPY

LMDIF (MIGRAD), TOL=1.E-20;

ENDMATCH



Matching DY & ref. orbit at the ML end

- ML end with DY ≠0 & CURVE=>1; is matched PMSCOL end with DY=0 & w/o curvature
- 5 additional vertical kicks (AMLYi+ AMLDY##o) for the last correctors at ML end are switched on by “SET, BUMPS,1”

!PLIN example:

SET, CURVE, 1; SET, STEER, 1

SET, BUMPS, 1; USE, PLIN1

SAVEBETA, **TWSS1_YML281, YML281 !next-to-last**

TWISS, BETA0=TWSS0

MATCH, BETA0=TWSS0

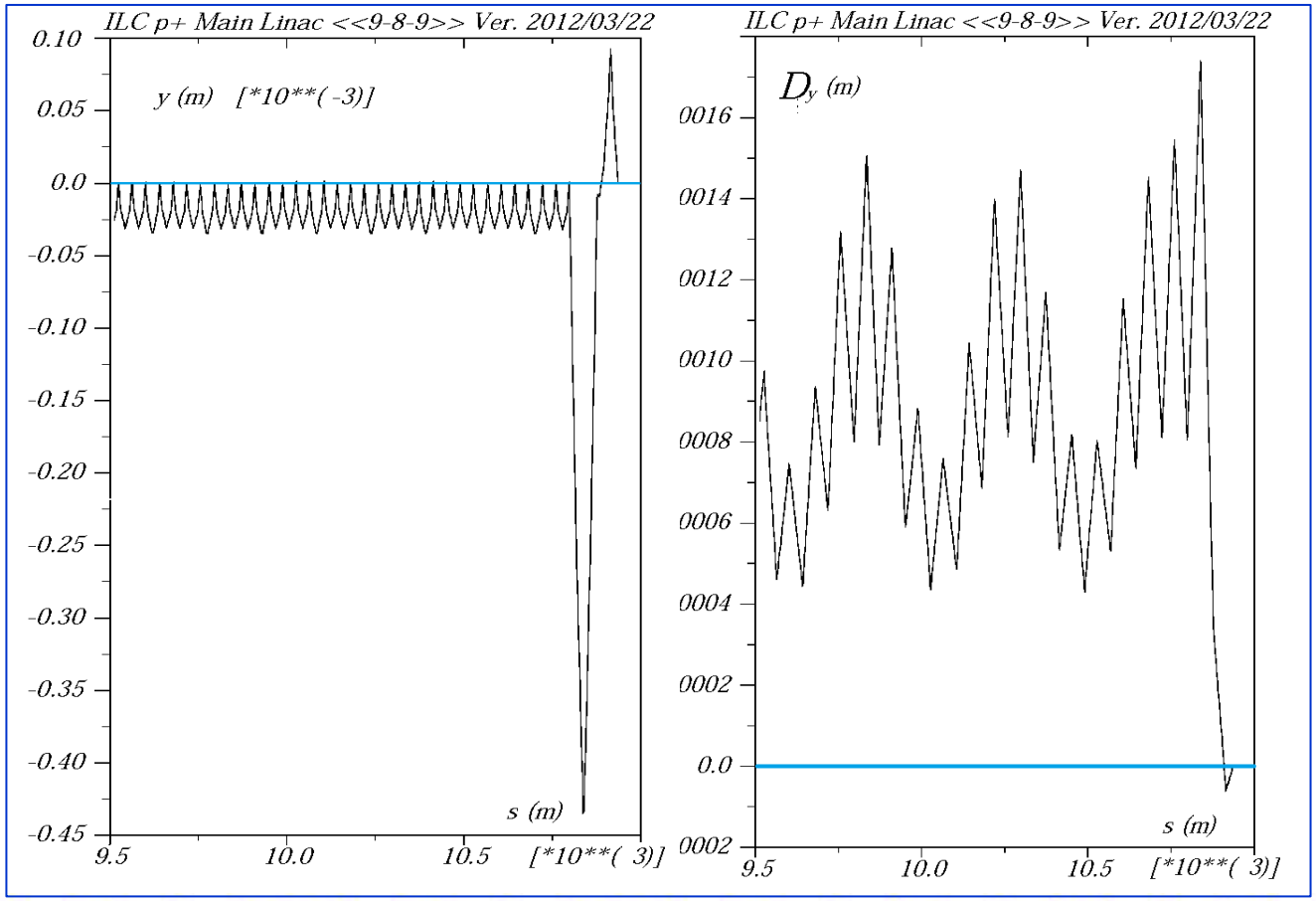
VARY, AMLDY21o (22o, 23o, 24o, 25o);

CONSTR, YML281, Y=TWSS1_YML281[Y]

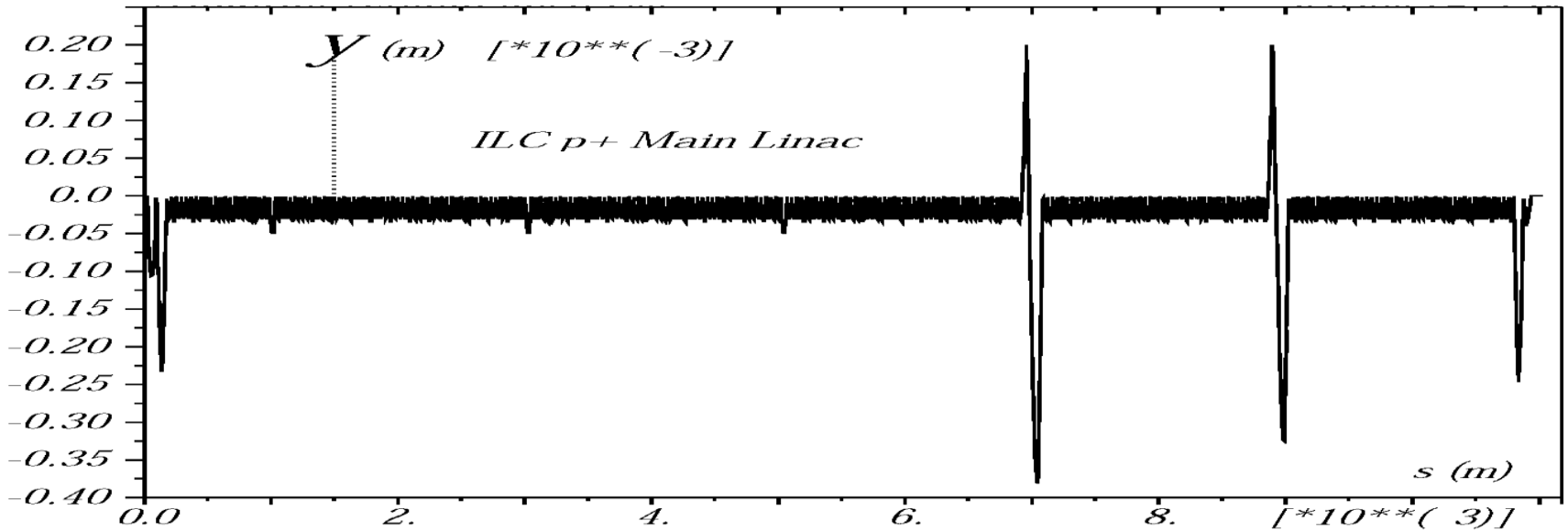
CONSTR, YPLIN2o, Y=0, PY=0, DY=0, DPY=0

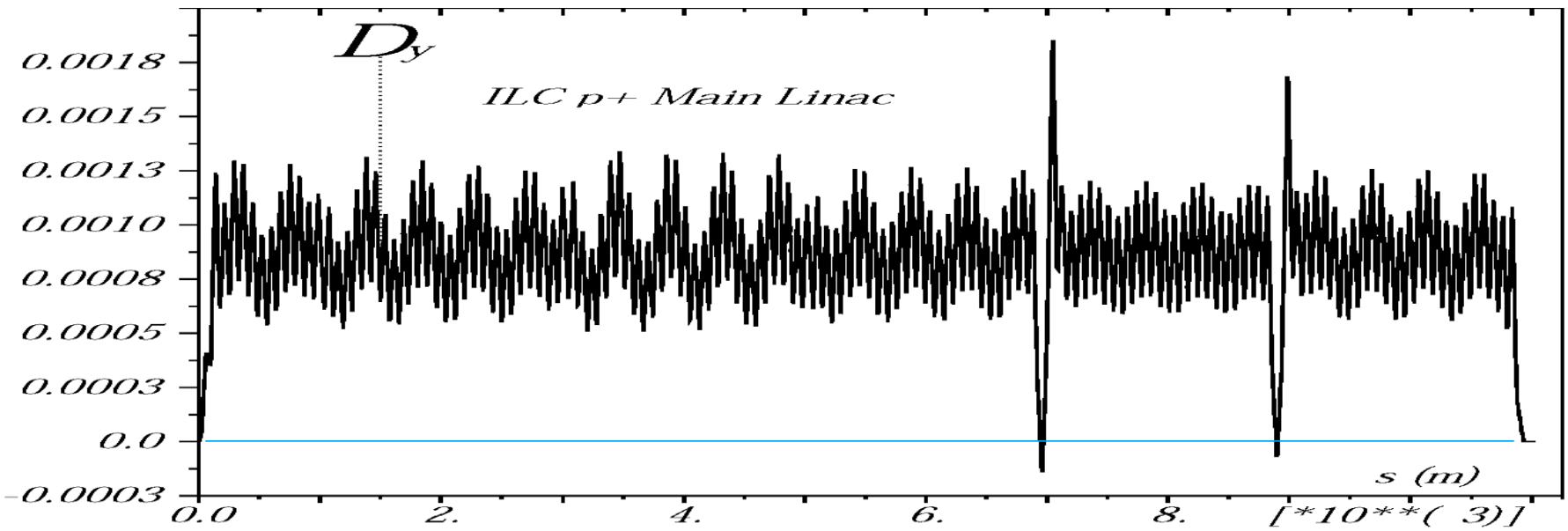
LMDIF (MIGRAD), TOL=1.E-20;

ENDMATCH



Matched DY & Y throughout PLIN (KCS)





Summary for KCS-lattice status

- Main Linac lattices (9+4Q4+9 configuration) for TDR version have been re-designed, tuned and matched
- Tuning and matching subroutines previously created for RDR in 2007 are checked and adaptively modified for TDR-2012 version
- Presented outlook of lattice tuning is a helpful reference in a future, since the CM length can be slightly changed in the final designs
- ML lattices are ready for a further non-optical “text-information” polishing (like MAD8 “TYPE” statements)
- ML lattices are documented and will be posted at ILC EDMS.

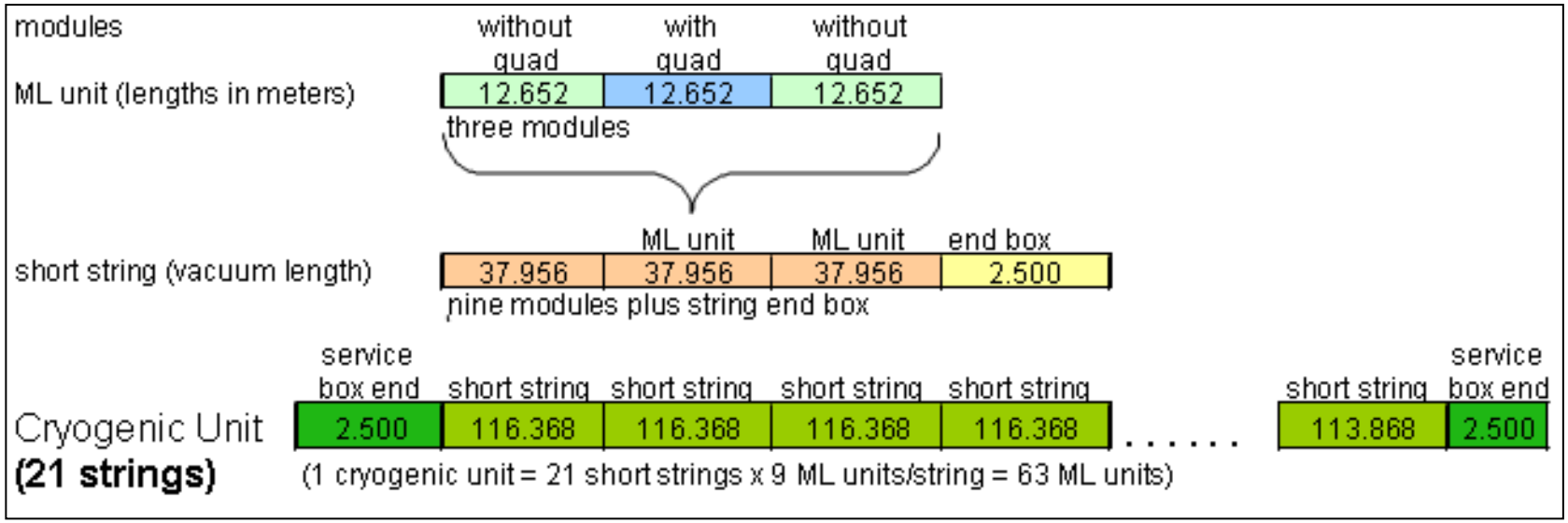
ML DKS version (Ver. 25/6/2012)

11 long str short str 33 ML units	warm drift space	21 long str short str 63 ML units	warm drift space	0 21 long str short str 63 ML units	warm space	21 long str short str 63 ML units	drift space	0 21 long str short str 63 ML units	drift space	collimation section	undulator protection section	66 undulators	Source
1282.5	7.652	2446.2	7.652	2446.2	7.652	2446.2	7.652	2446.2	7.652	82.4	295.9	318.0	BDS
													DR

Electron ML 285 RF units

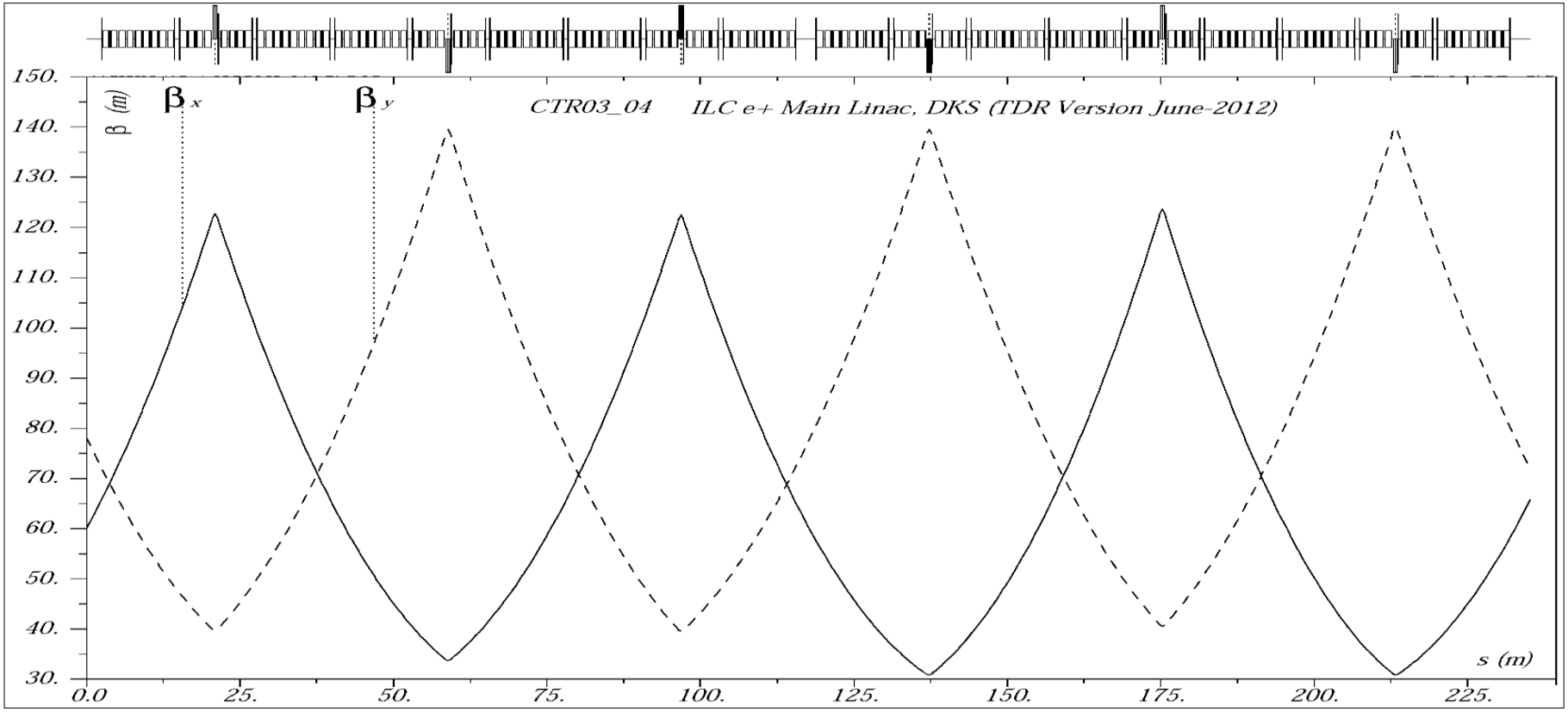
0 11 long str short str 33 ML units	warm drift space	0 21 strings 63 ML units	warm drift space	0 21 strings 63 ML units	warm space	0 21 strings 63 ML units	warm drift space	0 20 strings 60 ML units	warm drift space	collimation section	Source
1282.5	7.652	2446.2	7.652	2446.2	7.652	2446.2	7.652	2446.2	7.652	82.340	BDS
											DR

Positrion ML 282 RF units

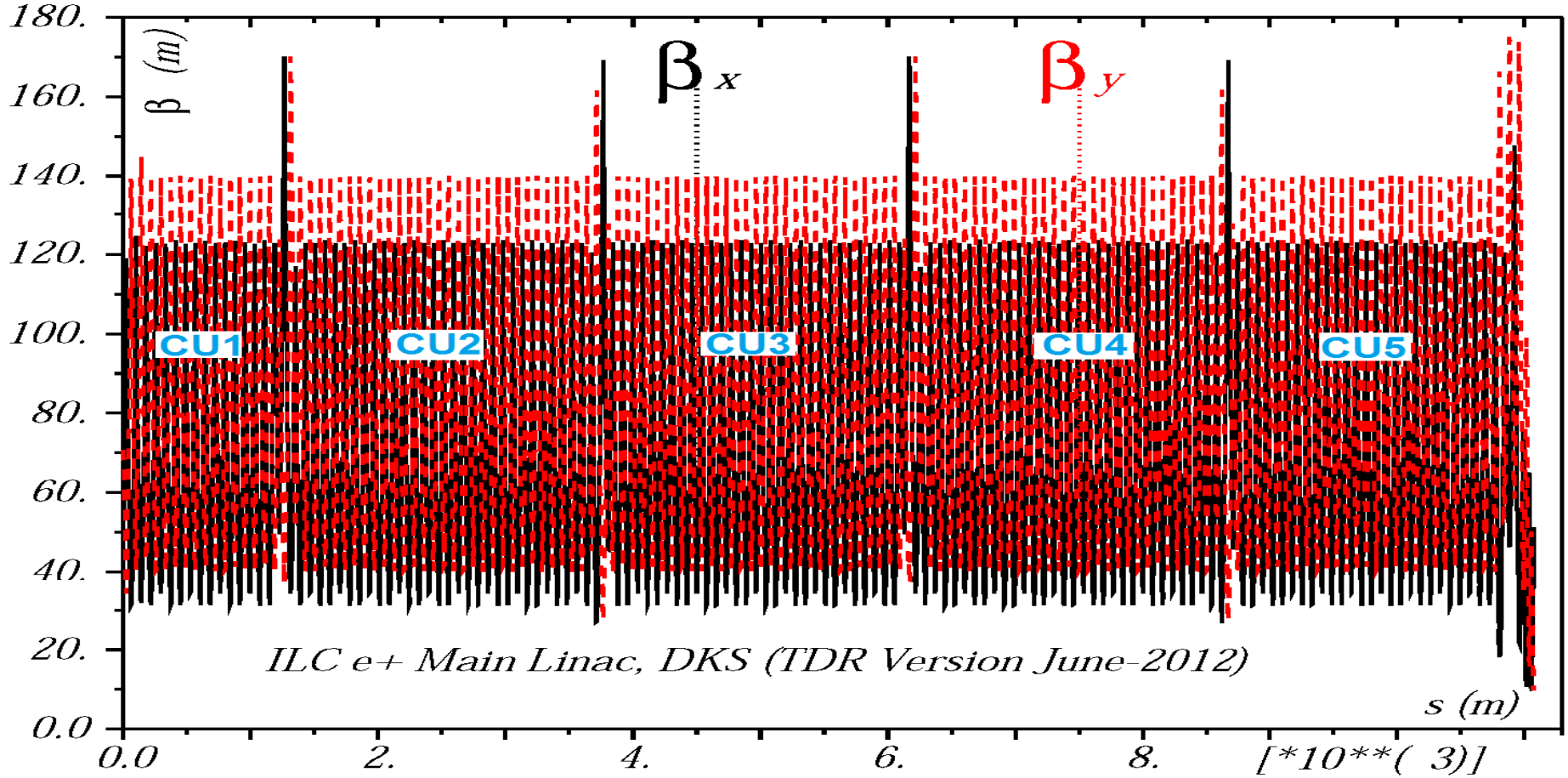


Matched β-functions in PLIN (DKS)

Two strings (6-RFU) forms quasi-periodical 6-Q strong focusing cell (phase advances ~ 3 x (75/60) degrees) =>
6 quads with K1 denoted as K1=KML001-KML006



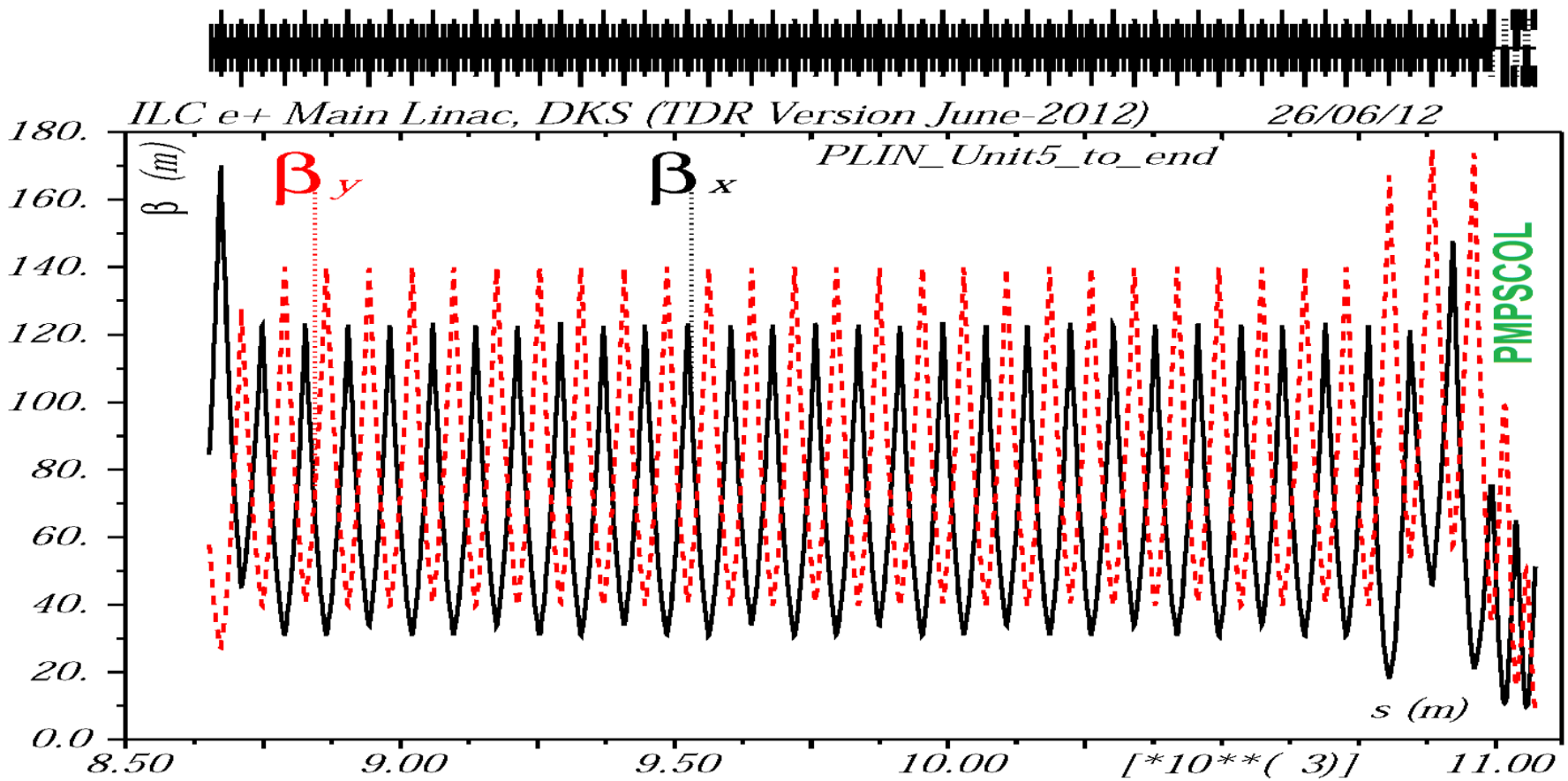
Matched β-functions in PLIN (DKS)



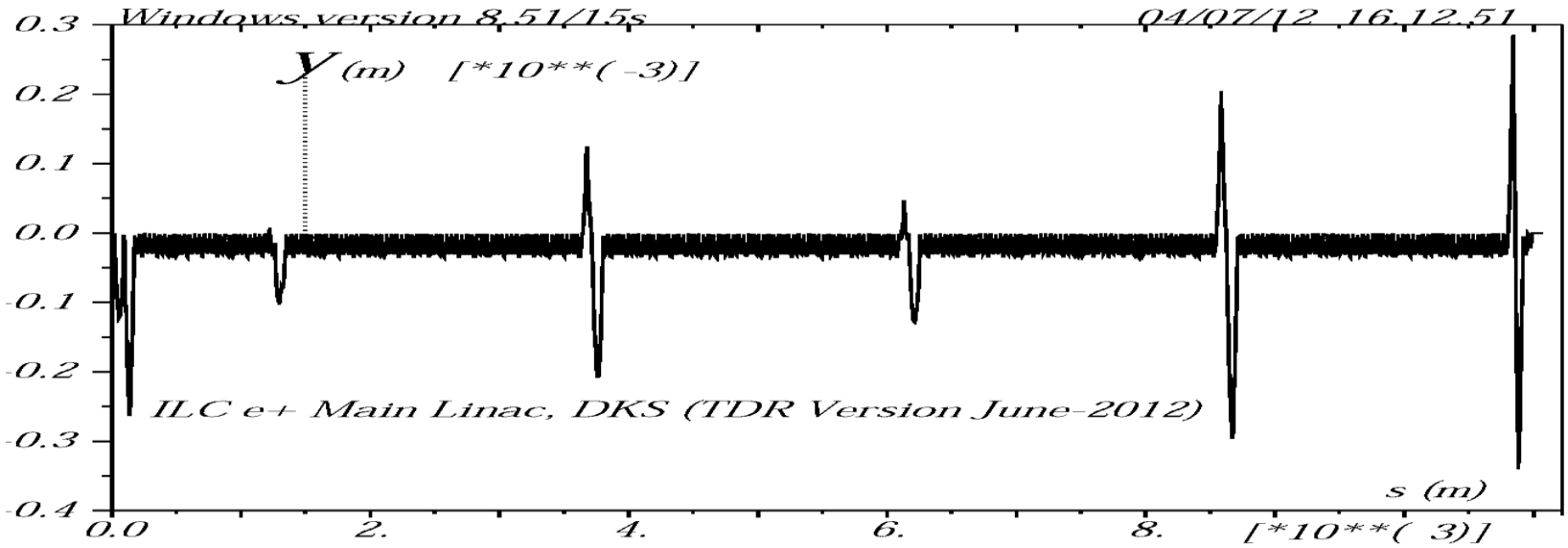
matching at ML entry (after RTML) with 6 quads KML031-KML036;
matching between CU1 & CU2 and CU3 & CU4 with 6 quads KML051-KML056;
matching between CU2 & CU3 and CU4 & CU5 with 6 quads KML041-KML045.

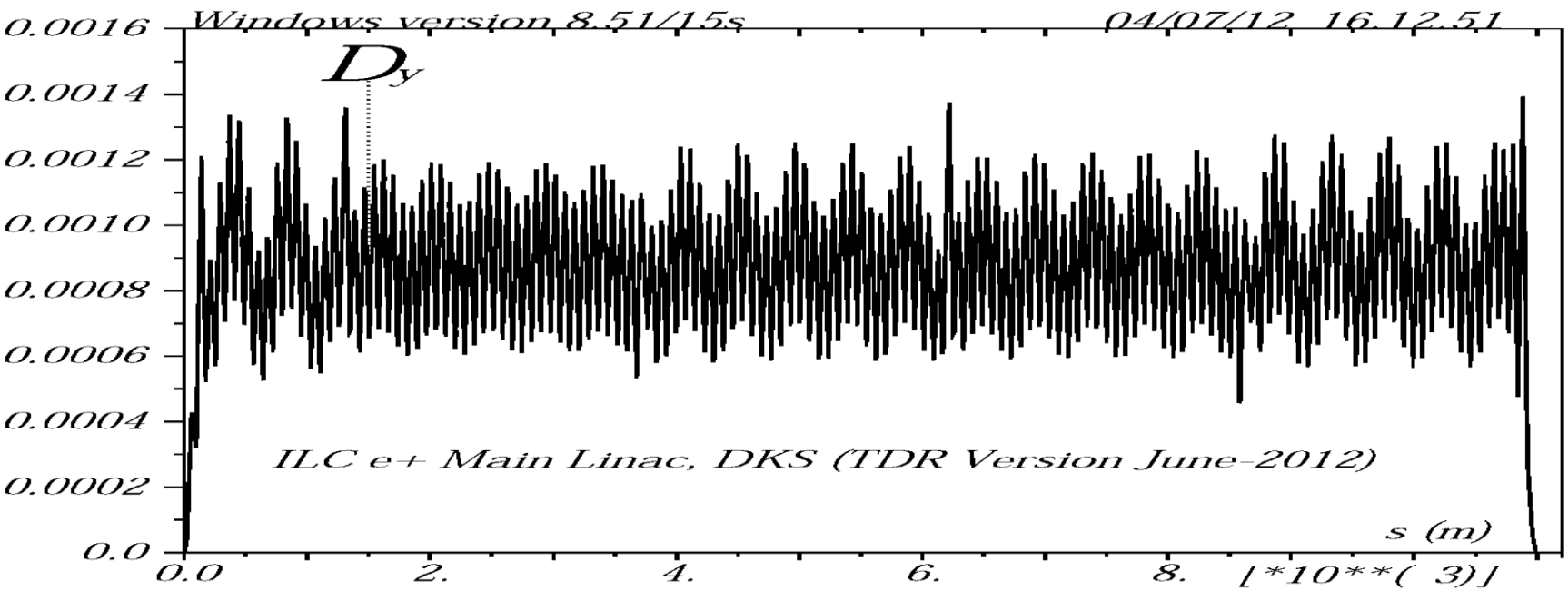
PLIN & PMPSCOL junction (DKS)

Alternative polarity of quads is kept throughout total Positron ML
=> easy matching at the junction with PMPSCOL (original)



Matched DY & Y throughout PLIN (DKS)



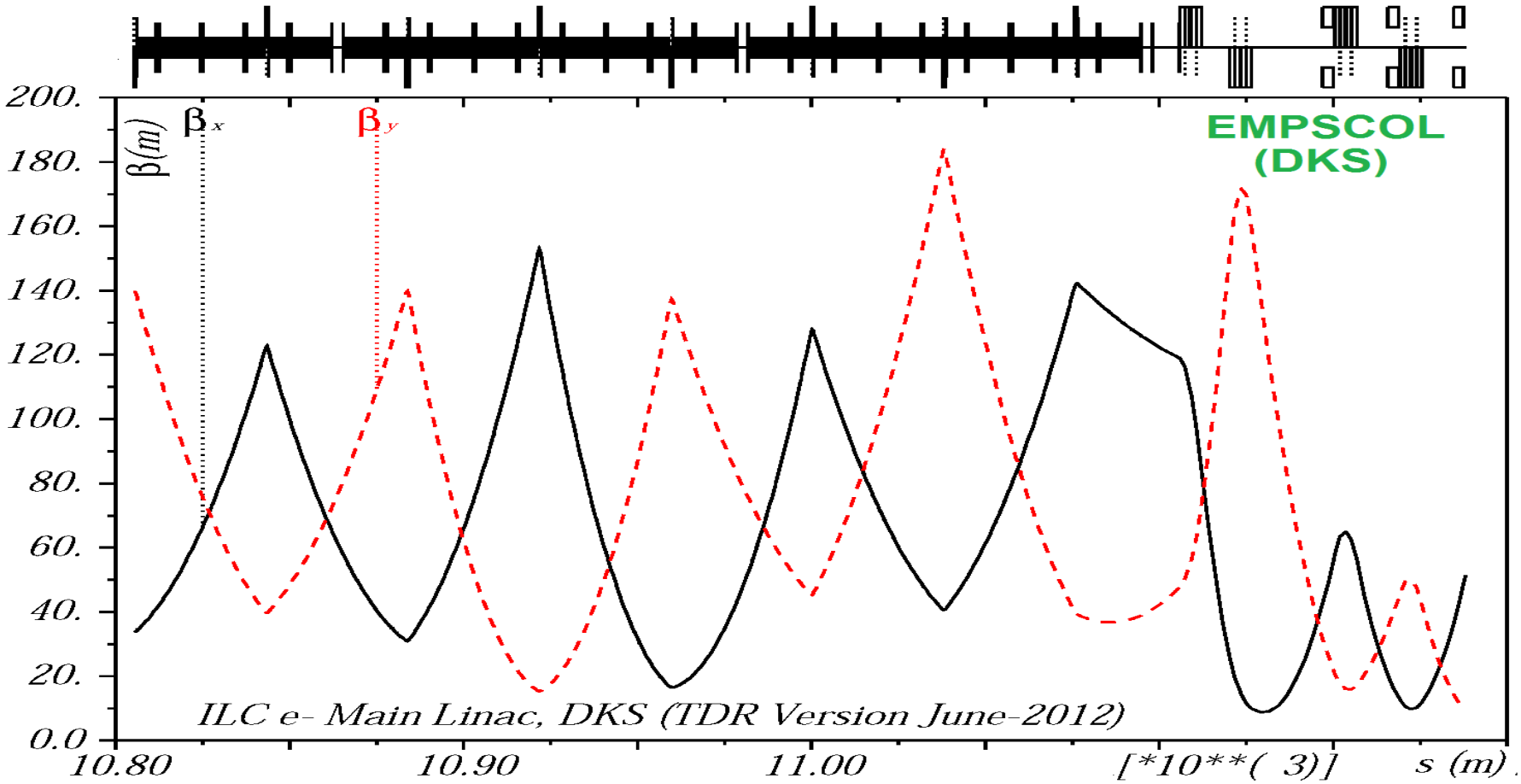


ELIN & EMPSCOL junction (DKS)

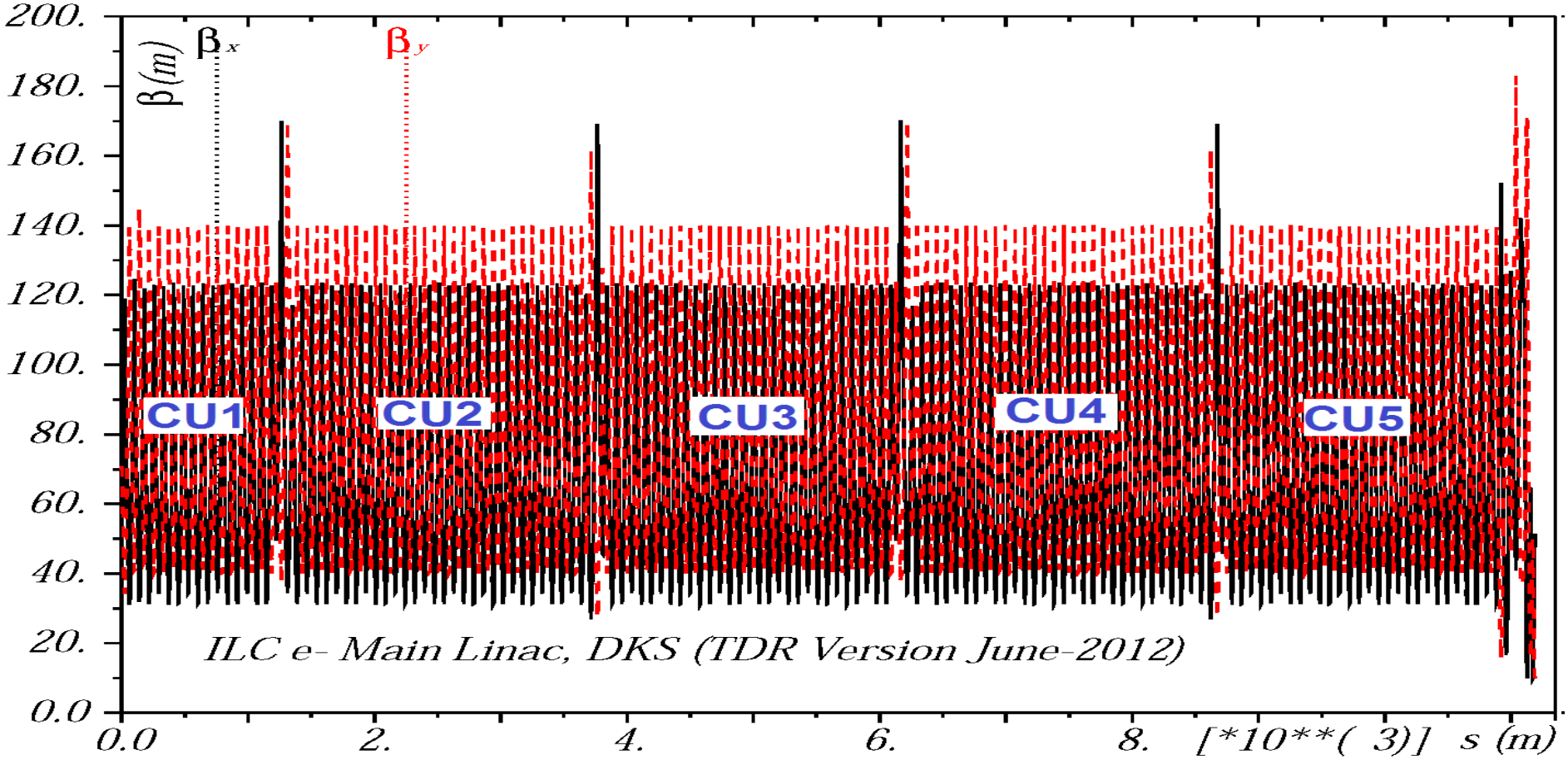
A regular alternating polarity of quads is distorted at the junctions with EMPSCOL.

➔ It leads to large spikes of β-function.

To avoid spikes Q-doublet at the EMPSCOL entrance is modified (similar to KCS)

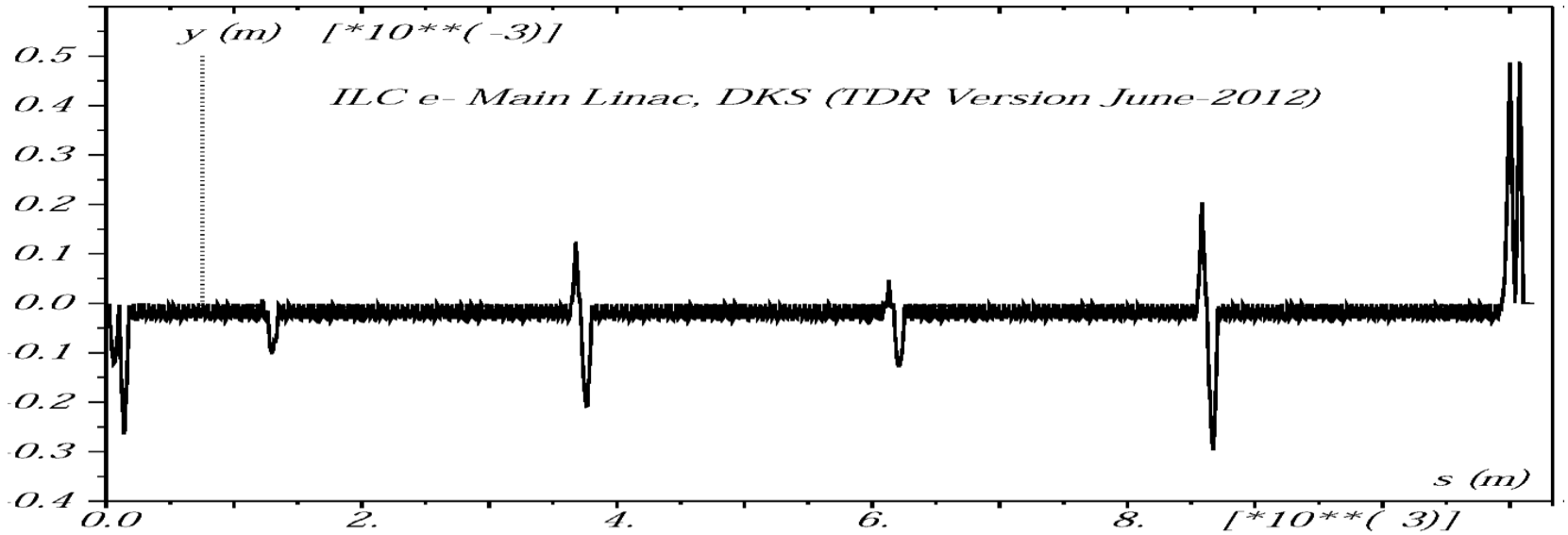


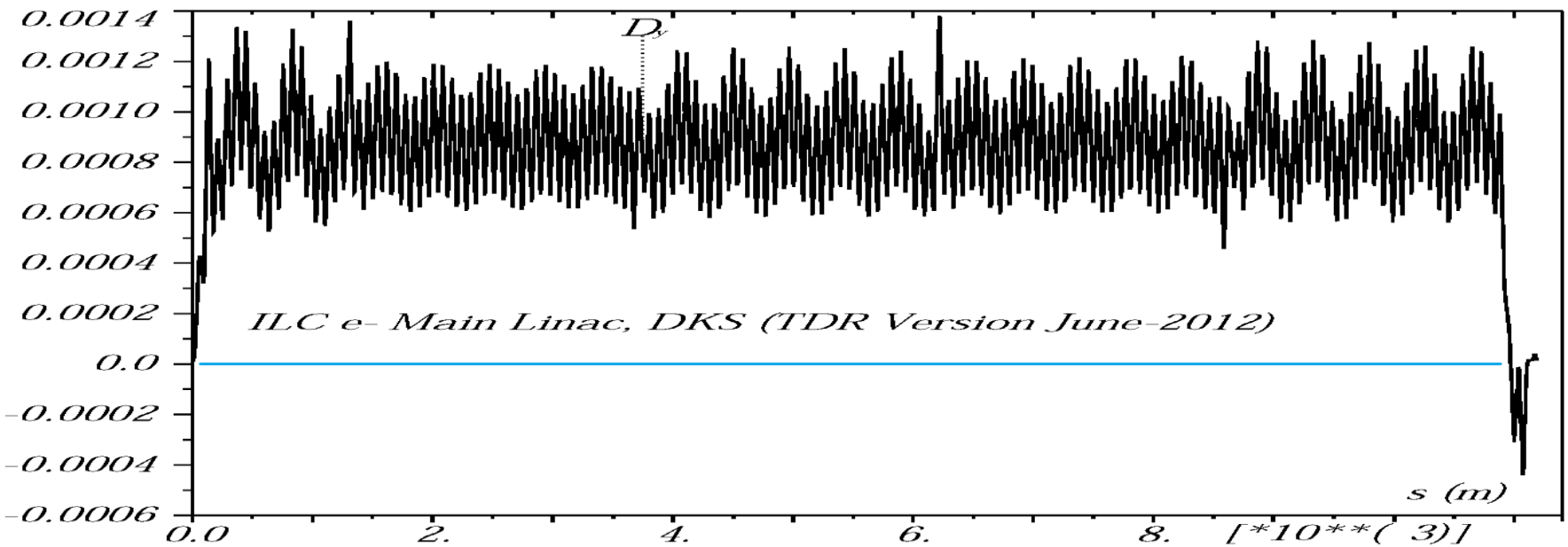
Matched β-functions in ELIN (DKS)



matching at ML entry (after RTML) with 6 quads KML031-KML036;
matching between CU1 & CU2 and CU3 & CU4 with 6 quads KML051-KML056;
matching between CU2 & CU3 and CU4 & CU5 with 6 quads KML041-KML045.

Matched DY & Y throughout ELIN (DKS)





Conclusion

- Two Lattices for KCS and DKS Main Linac layouts were designed, based on approach developed for RDR design
- Earth curvature was incorporated in design. Beam reference orbit and dispersion were optimized.
- Tuning and matching subroutines previously created for RDR in 2007 are checked and adaptively modified for TDR-2012 version
- Both ML lattices are documented and will be posted at ILC EDMS.