The FNAL 400 MeV Linac in TRACEWIN (from Ion Source to Stripping Foil)

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FNAL/APC

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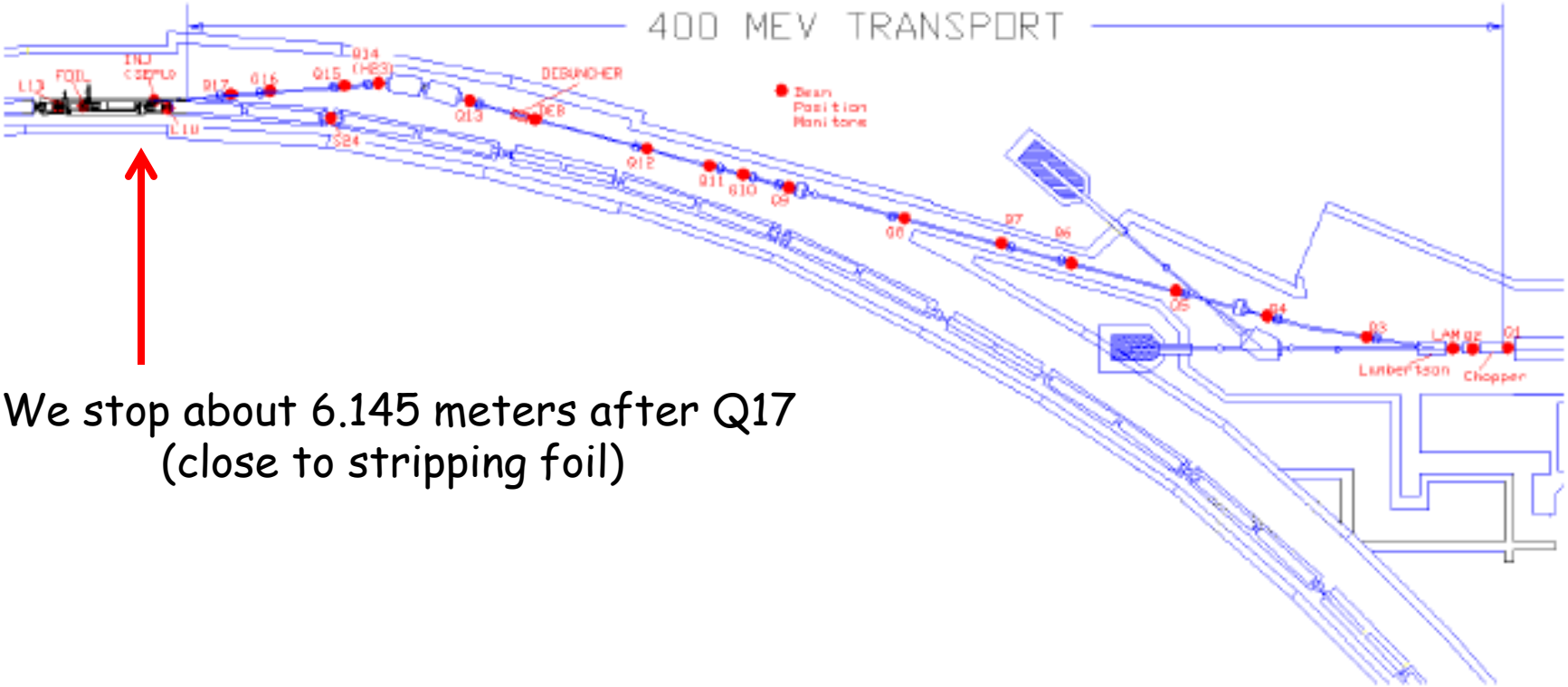
Start-to-end Model with TRACEWIN

- A start-to-end model of the FNAL 400 MeV Linac has been built using TRACEWIN and TOUTATIS
- TRACEWIN and TOUTATIS are codes from CEA/Saclay, France
- Where does the model start ? : from the Ion Source Exit
- Where does the model ends ?: 6.145 meters downsteam Q17 (see below)



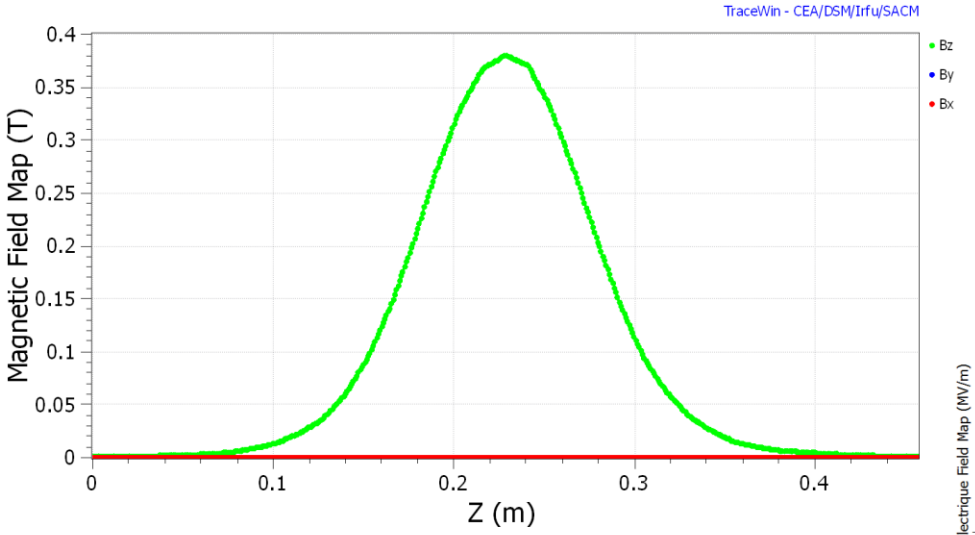
We stop about 6.145 meters after Q17
(close to stripping foil)

Start-to-end Model with TRACEWIN: How was the model built ?

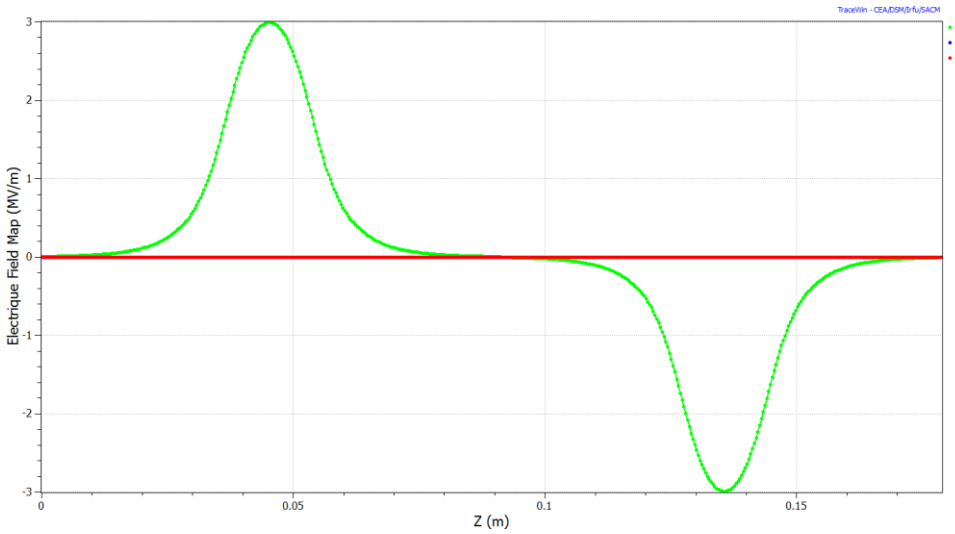
- LEBT (35 keV): from TRACE2D input file (CY Tan, D. Bollinger)
- RFQ (750 keV) : from PARMTEQM input file (CY Tan)
- MEBT +DTL (117 MeV) + CCL (400 MeV) : from PARMILA input file (H.J. Kim)
- Transfer Line : from MAD (F. Garcia)

- Field on axis were used (see below)

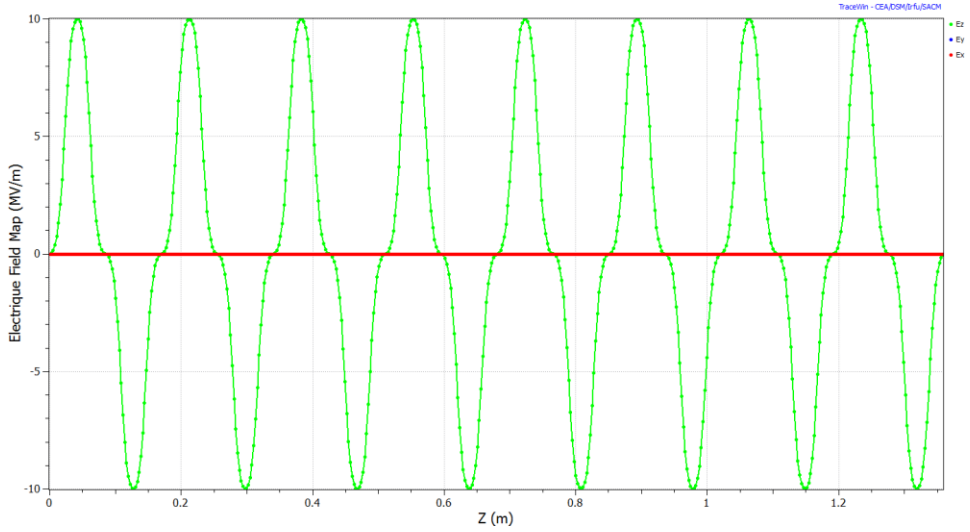
LEBT Solenoid

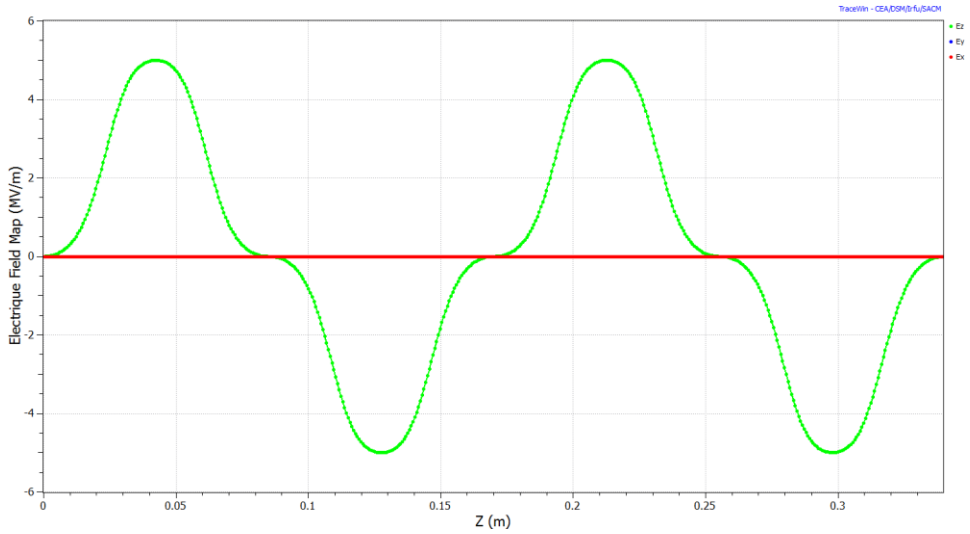


MEBT Buncher



BUNCHER + VERNIER FIELD ON AXIS





BUNCHER + VERNIER
(from Superfish)

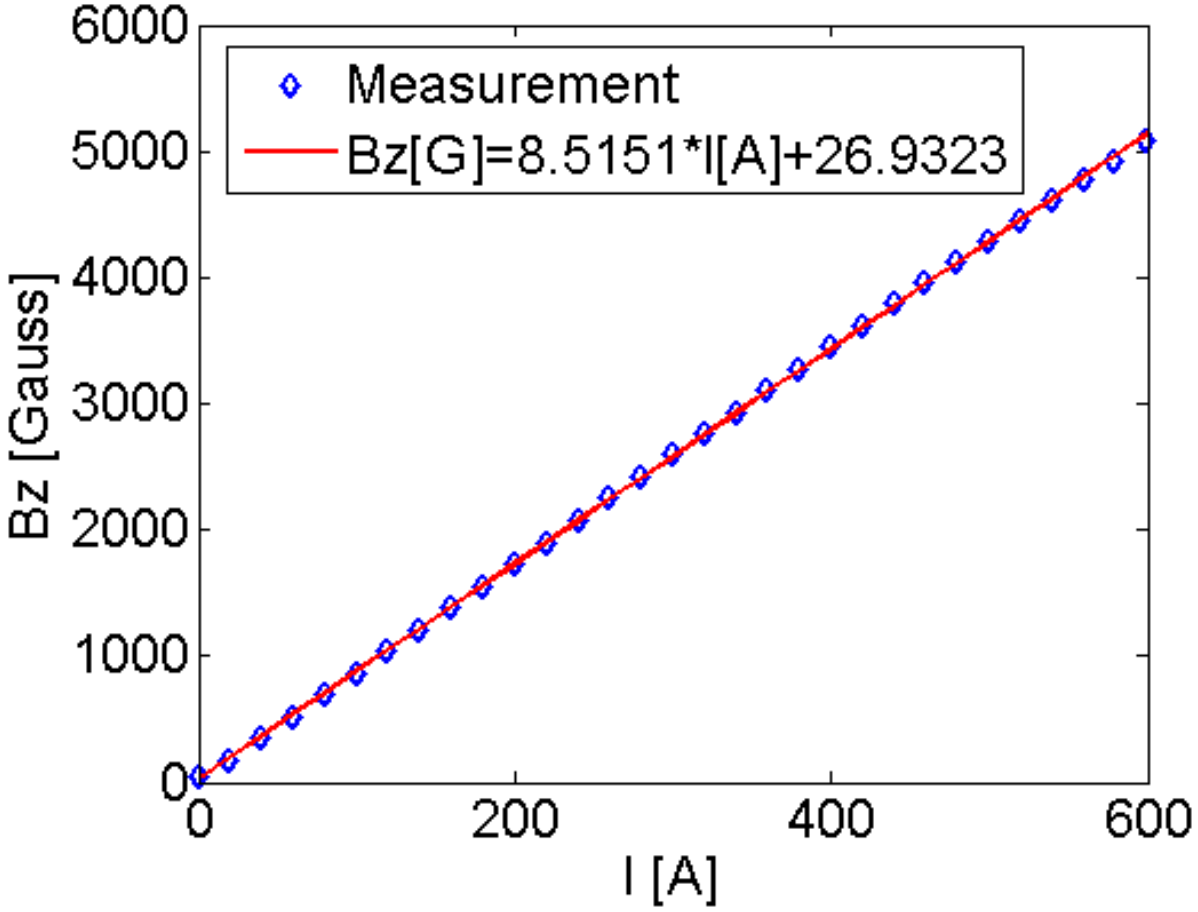
Start-to-end Model with TRACEWIN (LEBT + Start of RFQ part)

```
FREQ 201.24

DRIFT 1e-005 50 0
SPACE_CHARGE_COMP 0.5

DRIFT 172.09 50 0
FIELD_MAP 10 457.2 0 120 0.38 0 0 0 SOL-PIP
DRIFT 385.73 50 0
FIELD_MAP 10 457.2 0 120 0.41 0 0 0 SOL-PIP
DRIFT 29.4 50 0

SPACE_CHARGE_COMP 0.5

DRIFT 1e-005 50 0
DRIFT 1e-005 50 0
DRIFT 1e-005 50 0

;end

RFQ_GAP_RMS_FFS 8.5098 5.5087
RFQ_CELL 79200 5.001 0 1 25.72 -90 3 3.751 1 0 0 0 0
RFQ_CELL 79200 5.001 0 1 6.43 -90 4 3.751 -2.23445 0 0 0 0
lattice 2
RFQ_CELL 79200 4.981 0.000511145 1.0016 6.43 -90 -2 3.735 -12.6197 0 0 0 0
RFQ_CELL 79200 4.944 0.00139094 1.0043 6.43 -86.5707 2 3.708 -21.7853 0 0 0 0
```

Model starts about 398.19 mm from the middle of SOL01

File Map

Solenoids of LEBT



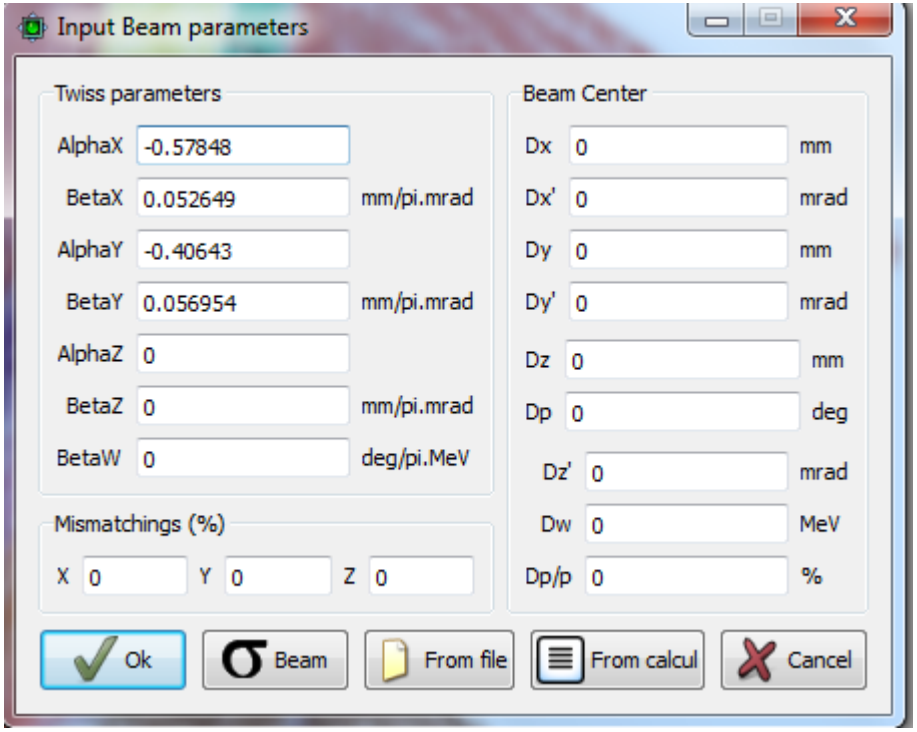
UPSTREAM SOLENOID: 445.4 Amps -> 3790.4 Gauss
DOWNSTREAM SOLENOID: 481.2 Amps → 4095 Gauss

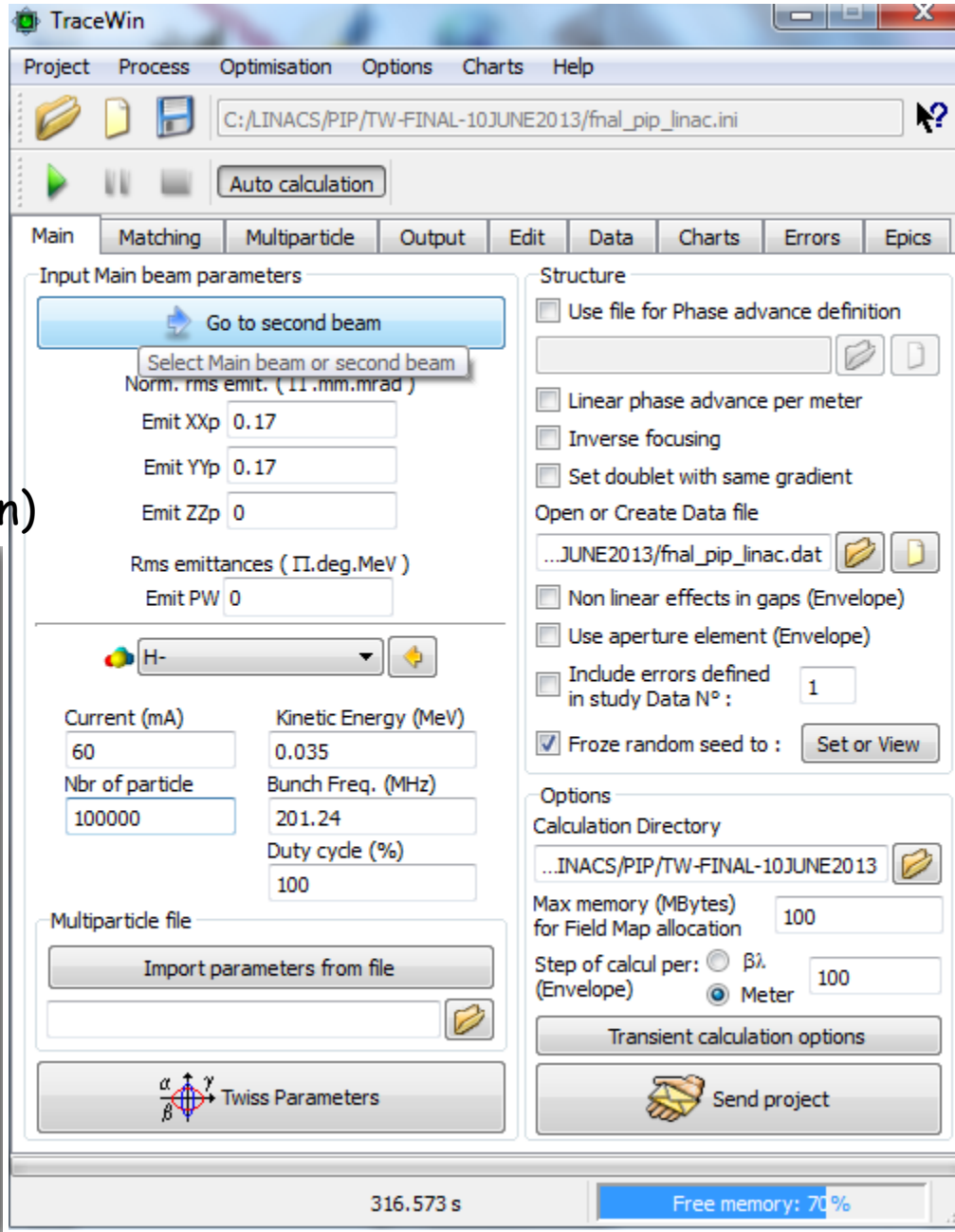
BIG !

Beam TWISS at Ion Source

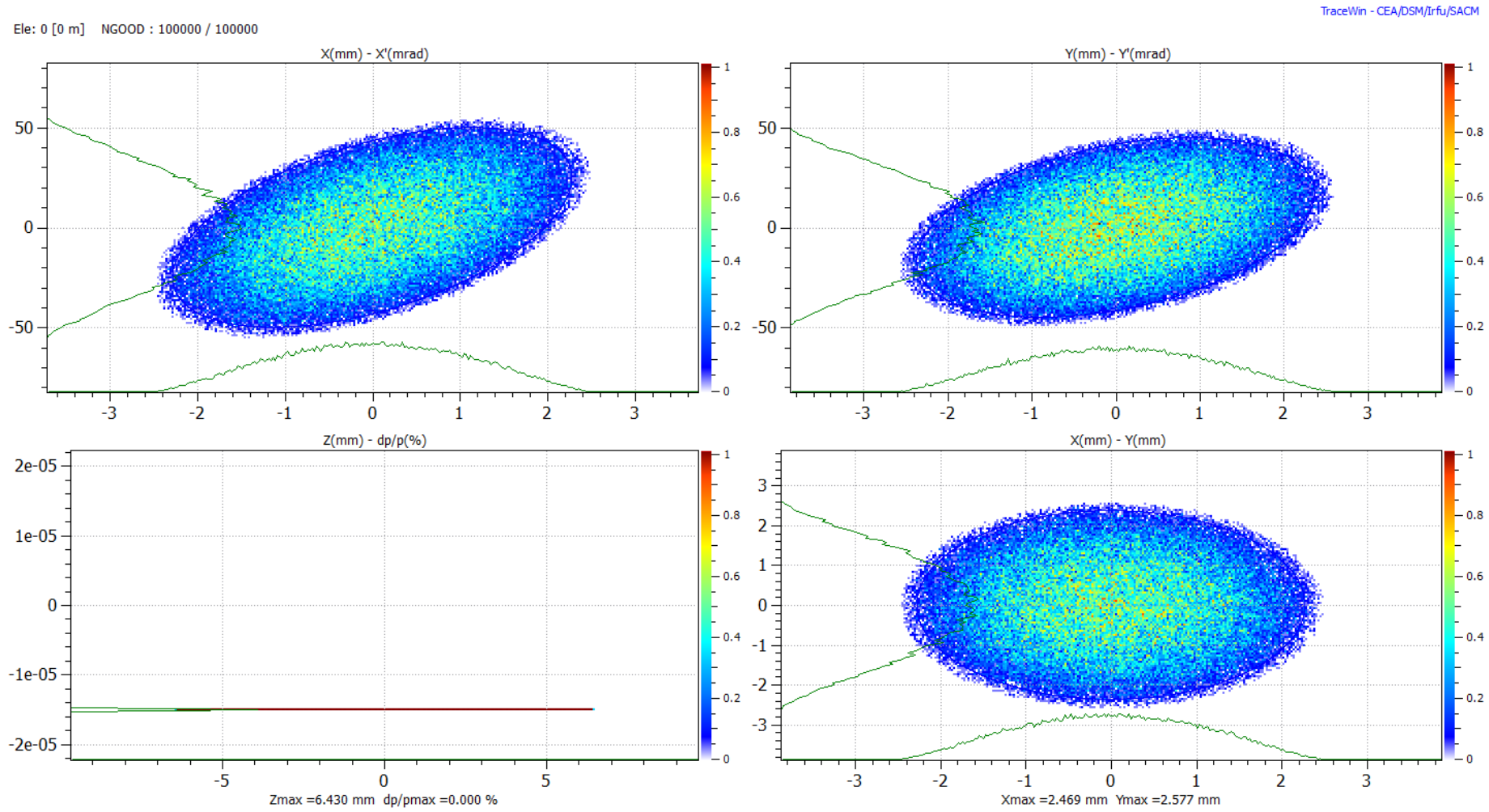
- 0.17 mm-mrad transverse emittance
- 60 mA
- 100 k
- 4D Ellipse – Uniform Distribution

Beam TWISS
(from probes2RFQ.t2d back propagation)





Beam Output Ion Source (from TRACEWIN)



Beam Output Ion Source : Important Questions for the Model

- What is the degree of space-charge neutralization in the LEBT ?
- Is the beam properly matched at the RFQ entrance ?

(MATCHES **SYMMETRIC** TWISS AT RFQ ENTRANCE : 1.5 and 0.051 mm/mrad)

Is the beam symmetric at the RFQ entrance (Paper from HB2012, China)

- Is the beam symmetric at the RFQ entrance ?

No ! from HB2012 paper

11-FEB-2013

The beam is asymmetric because the source is asymmetric by construction. There is a dipole field inside the source. This is a feature not a bug.

Tan

LEBT Commissioning Instrumentation

A number of beam measurements have been made in order to commission the ion source and LEBT portion of the injector system. These include

- beam current transmission and beam centroid steering through the two-solenoid LEBT, and
- beam size and transverse emittance near the entrance of the RFQ.

Figure 3 shows the various beam diagnostics setups used to make these measurements.

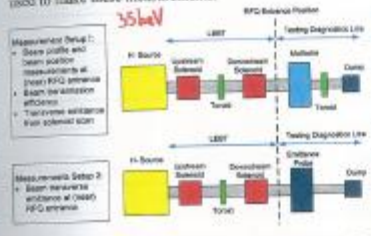


Figure 3: Schematic of measurements setups for commissioning through the LEBT

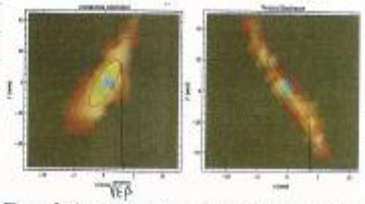


Figure 5: A measurement of the horizontal (left) and vertical (right) transverse phase space near the entrance of the RFQ. Red ellipses are one and two sigma fits.

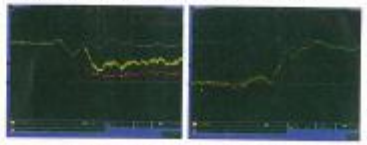


Figure 6: A beam toroid measurement of the leading-edge (left) and trailing-edge (right) of the Einzel lens beam chopping performance. The yellow curve is with-beam, the white curve is without-beam and the red curve is the difference.

$\beta\gamma \sim 0.0867$ (35 keV)

HORIZONTAL DIVERGING

VERTICAL CONVERGING

$x_{max} = 15$ mrad

$= \sqrt{18\varepsilon}$

~ 15 mrad

$\beta_x = 0.3715$ mm/mrad

$\alpha_x = -1.5857$

$y'_{rad} \sim 20$ mrad

$\beta_y = 0.816$

$\alpha_y = 3.95$

~ 3 mm

~ 4 mm

$x_{max} = 3\text{ mm} = \sqrt{\beta_x \varepsilon_x}$

$y_{max} = 1$ mm

How important is the beam matching at the RFQ entrance ?

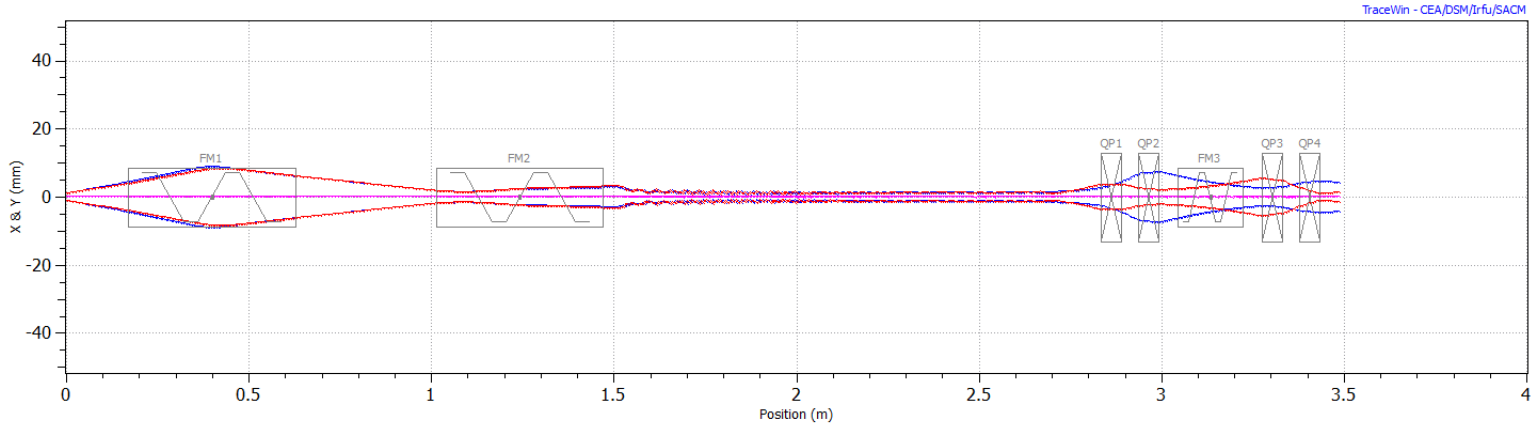
LA-UR-13-21653

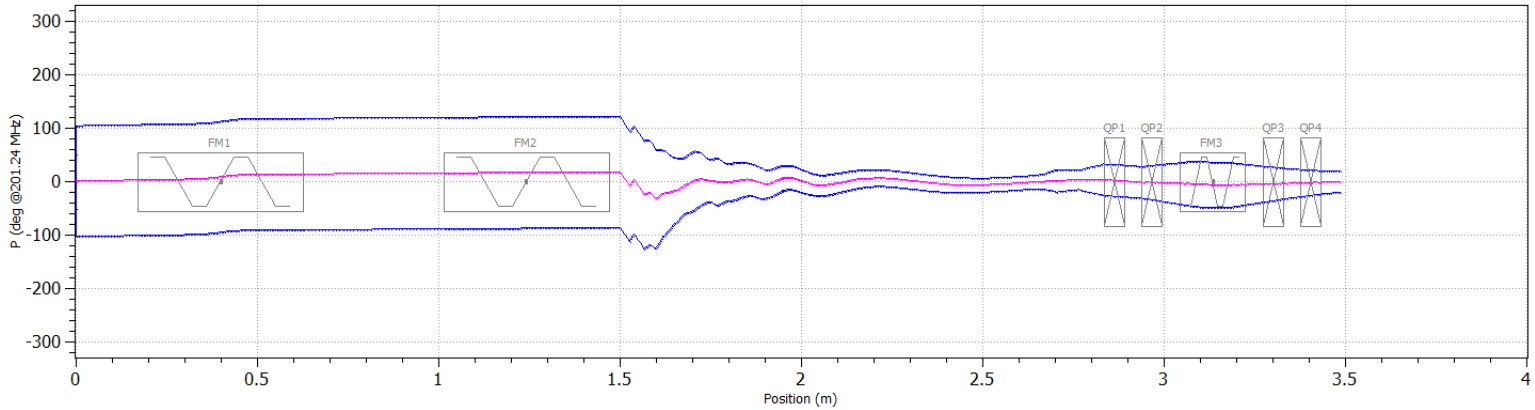
Approved for public release; distribution is unlimited.

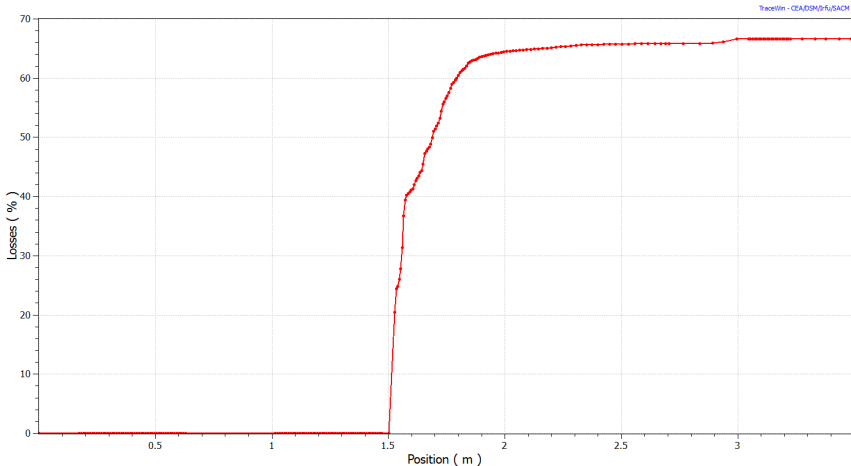
Title:	Beam dynamics modeling in RFQ with CST Particle Studio
Author(s):	Kurennoy, Sergey S.
Intended for:	Distribution to external collaborators

For these cases, the initial transverse normalized rms emittances were 0.11 π mm·mrad in the vertical plane and 0.15 π mm·mrad in the horizontal one (0.3 π mm·mrad in the matched case), but the beam parameters that we inferred from the measurements were different from the design values. In the last case in Fig. 21, marked "V3, mism1", the initial distribution was additionally rotated 45° in the transverse plane plus the initial energy was 37 keV instead of 35 keV. The transmission in the case "V3, mism" was 37% for 5 central bunches, and much lower in the last case. This comparison suggests that matching the initial distribution to the RFQ is very important, while the voltage profile has some influence but not critical for transmission. It is worth mentioning that the FNAL RFQ transmission achieved in operation so far has been around 60-70% [8].

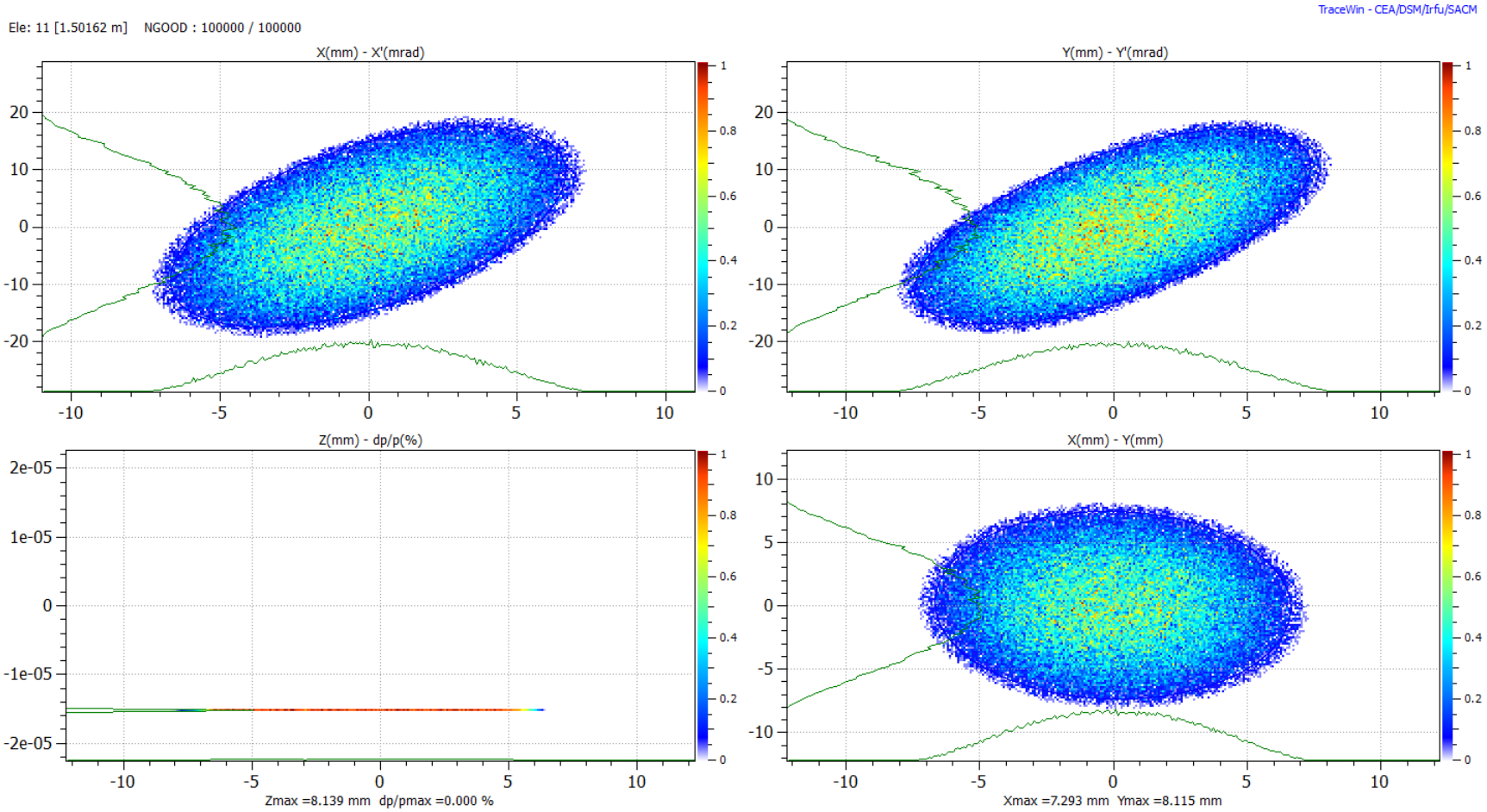
Zero Space Charge in LEBT (k=1 in TRACEWIN)
Beam is divergent at the RFQ input. ~60% losses at the RFQ exit.



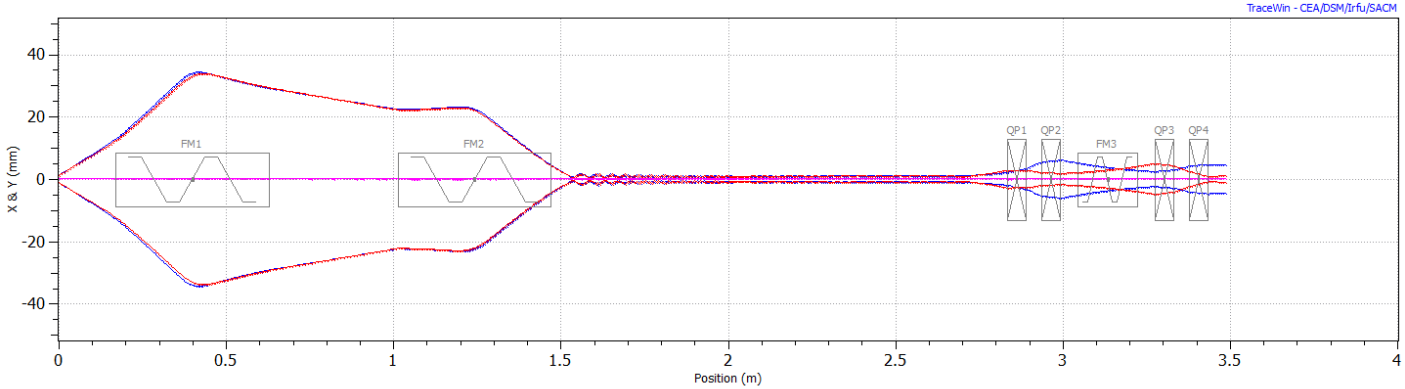


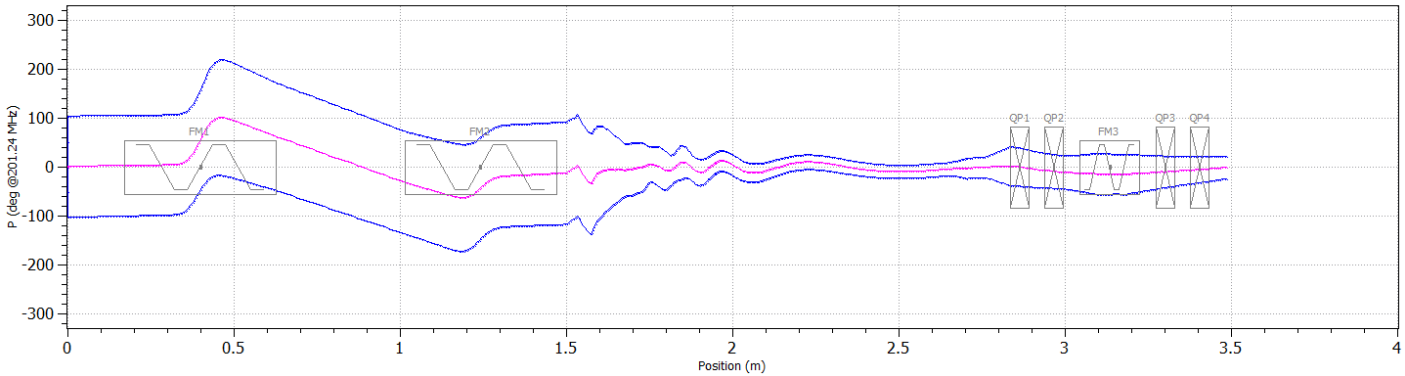


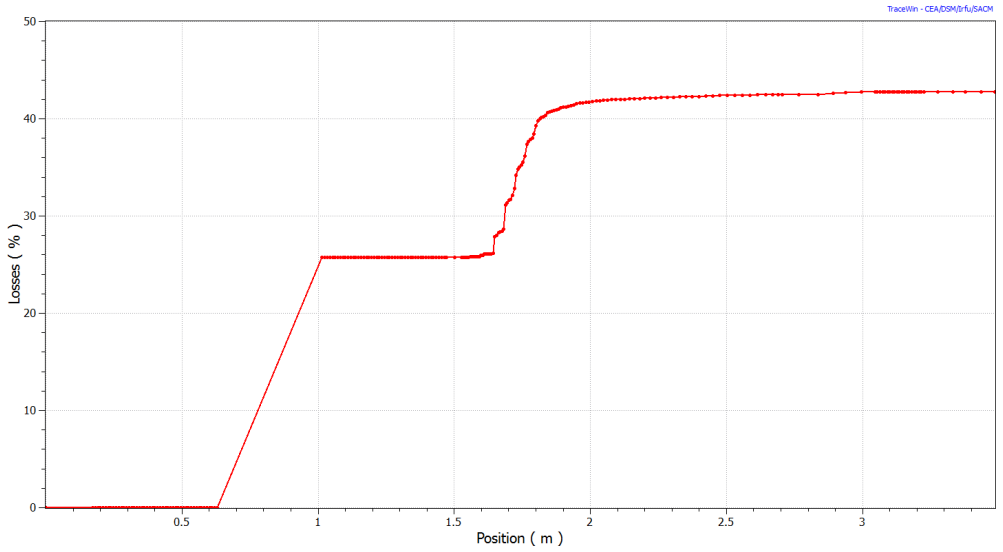
Zero Space Charge in LEBT (k=1 in TRACEWIN)
Beam distribution at the RFQ input.



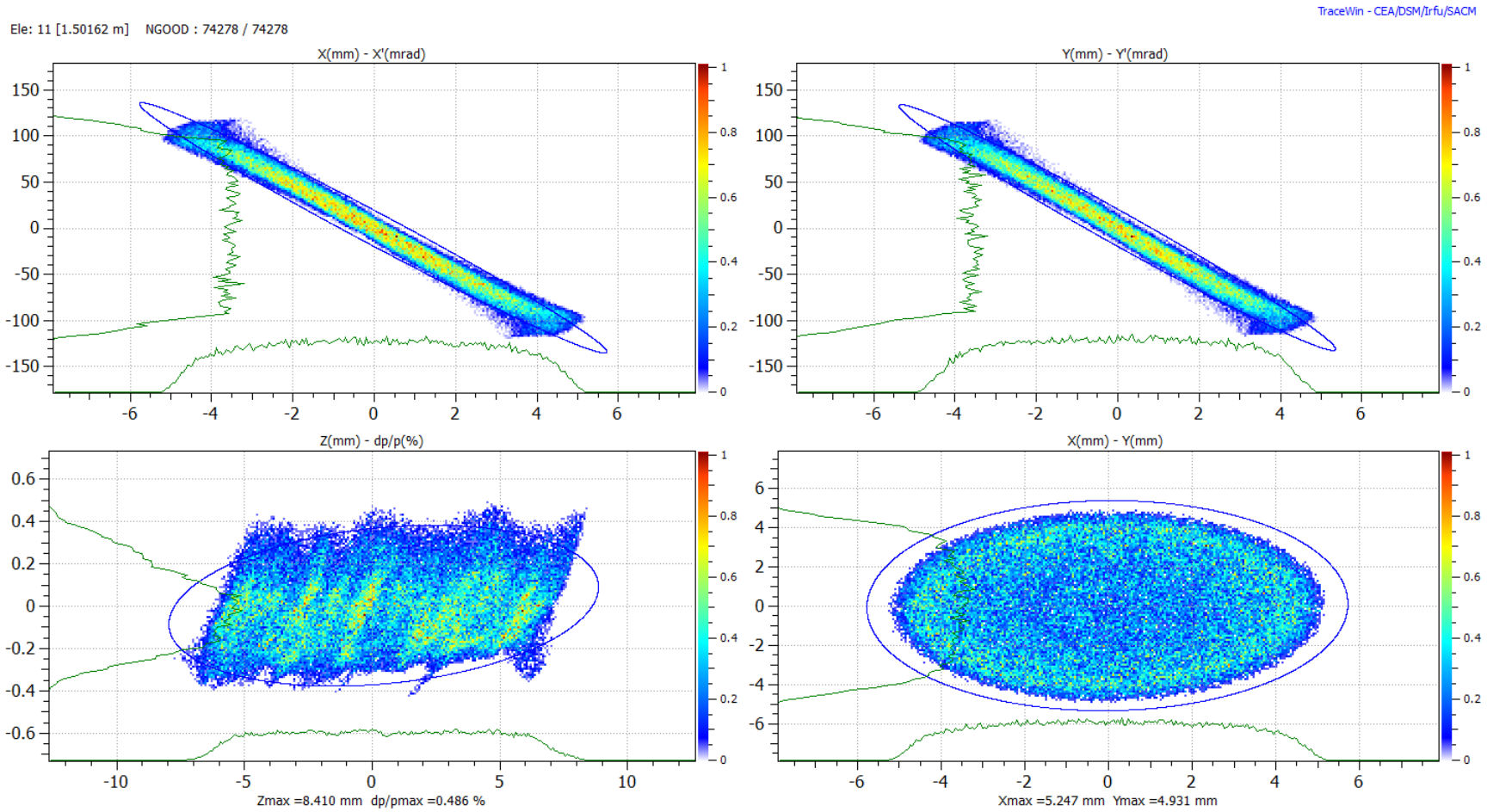
Full Space Charge in LEBT (k=0 in TRACEWIN)
Beam is convergent at the RFQ entrance. Losses in LEBT + RFQ. ~40 % losses



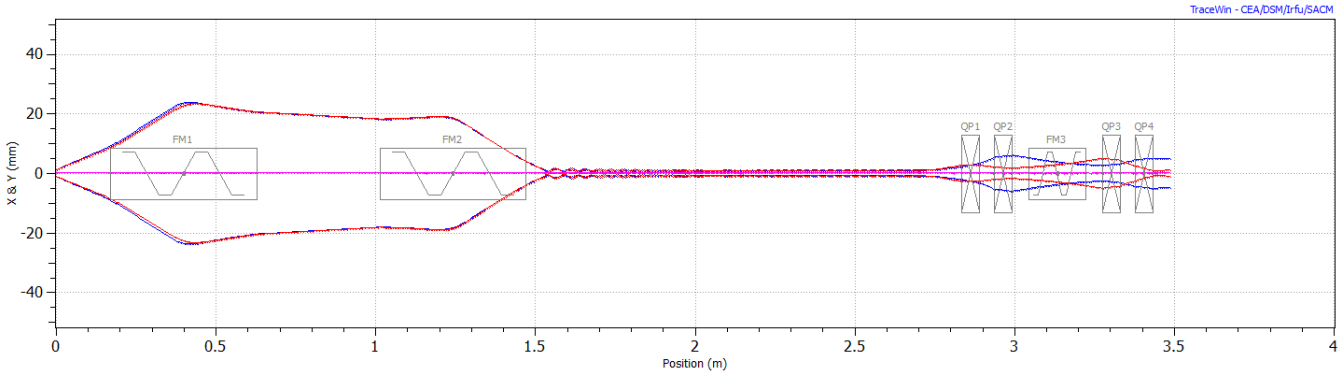


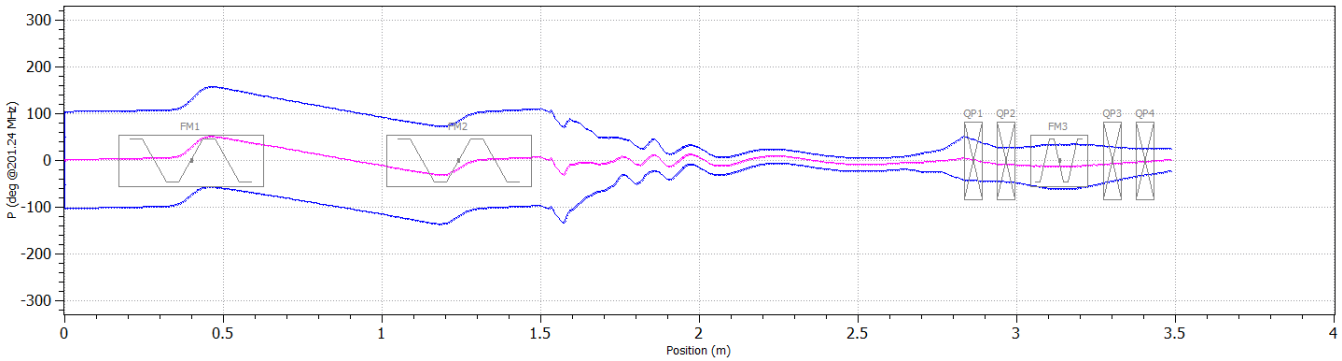


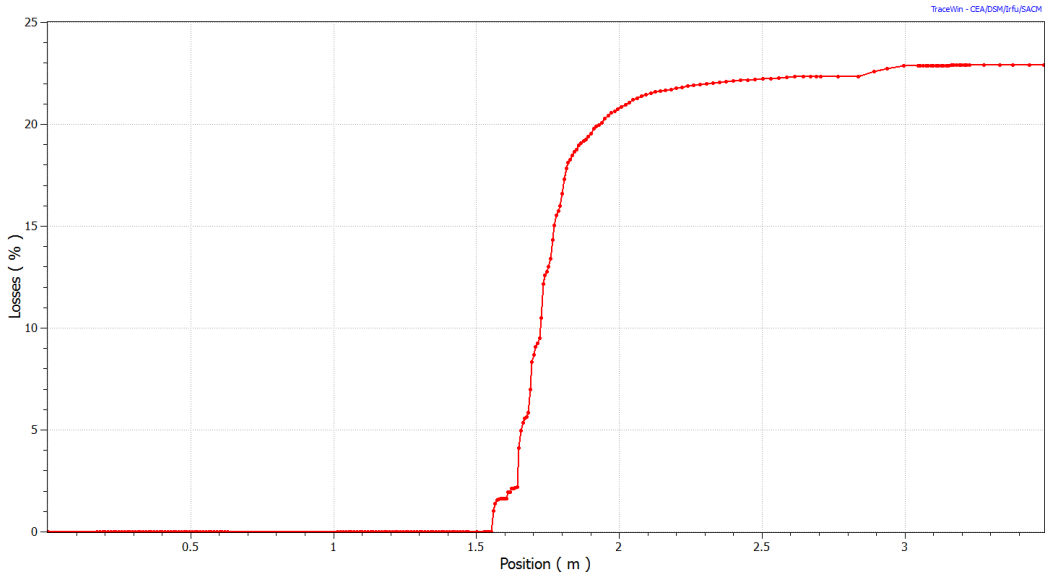
Full Space Charge in LEBT (k=0 in TRACEWIN)
Beam is distribution at the RFQ entrance.



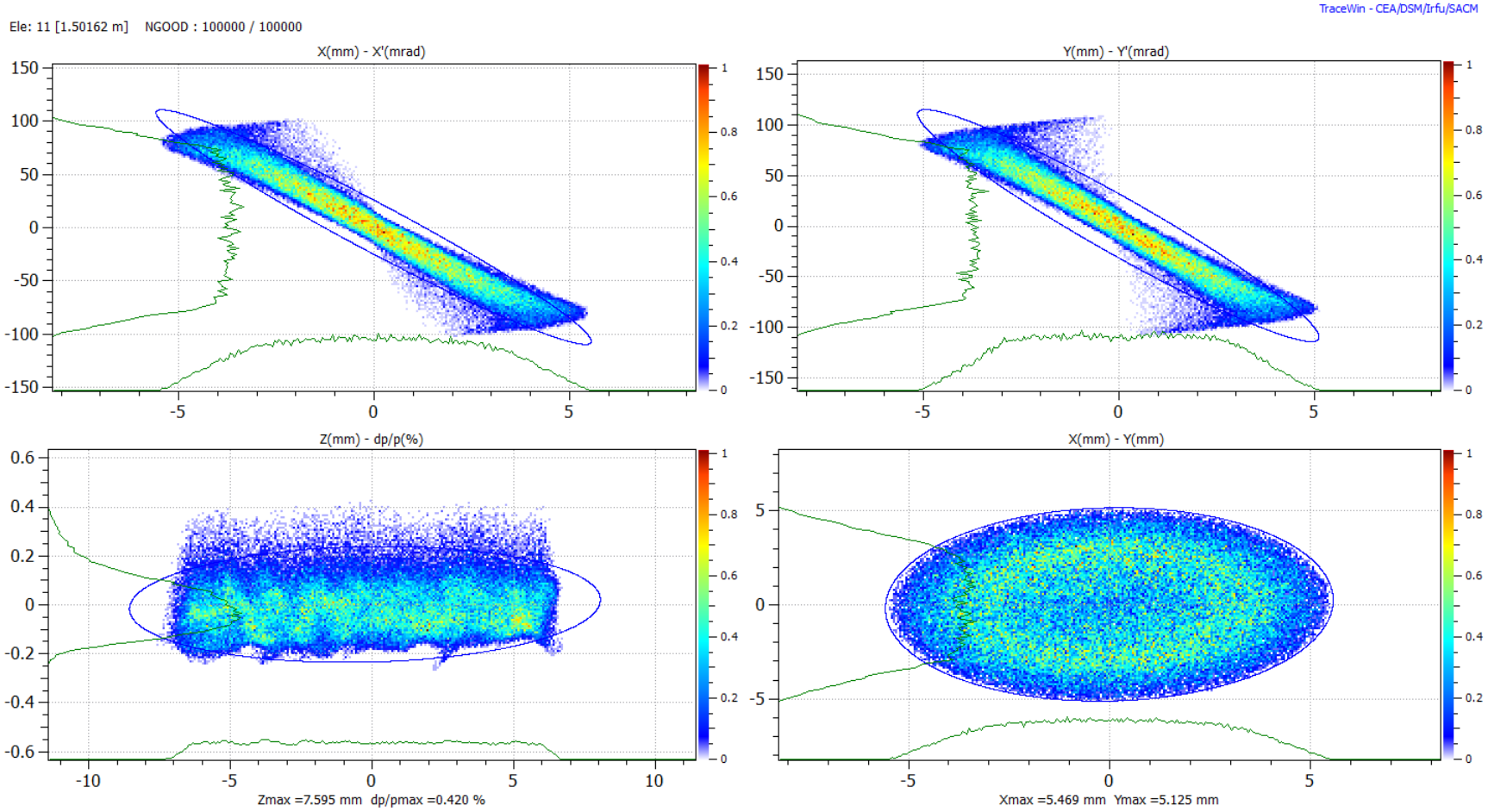
Half Space Charge in LEBT (k=0.5 in TRACEWIN)
Beam is convergent at the RFQ entrance. Losses in RFQ. ~20 % losses







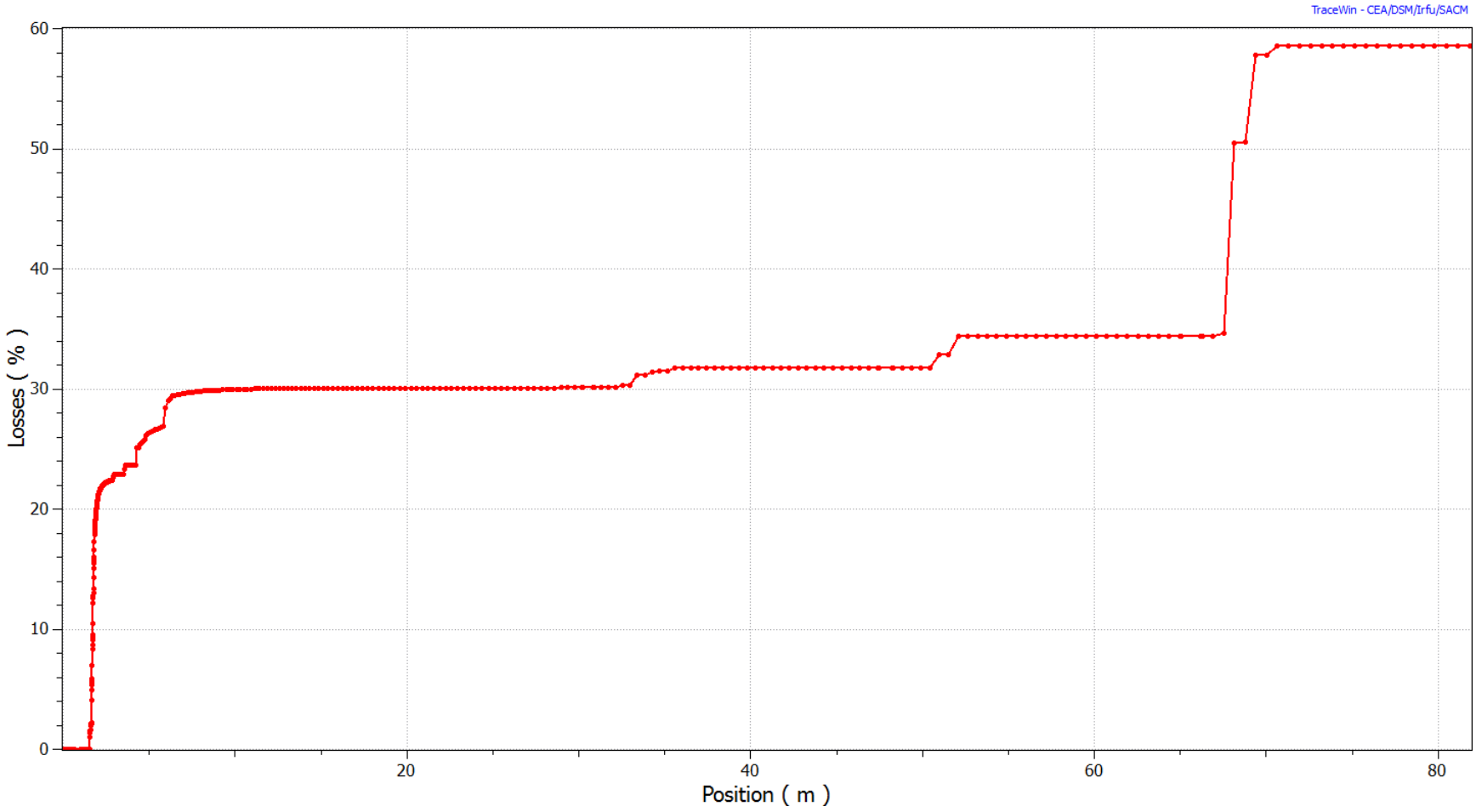
Half Space Charge in LEBT (k=0.5 in TRACEWIN)
Beam distribution at the RFQ entrance.



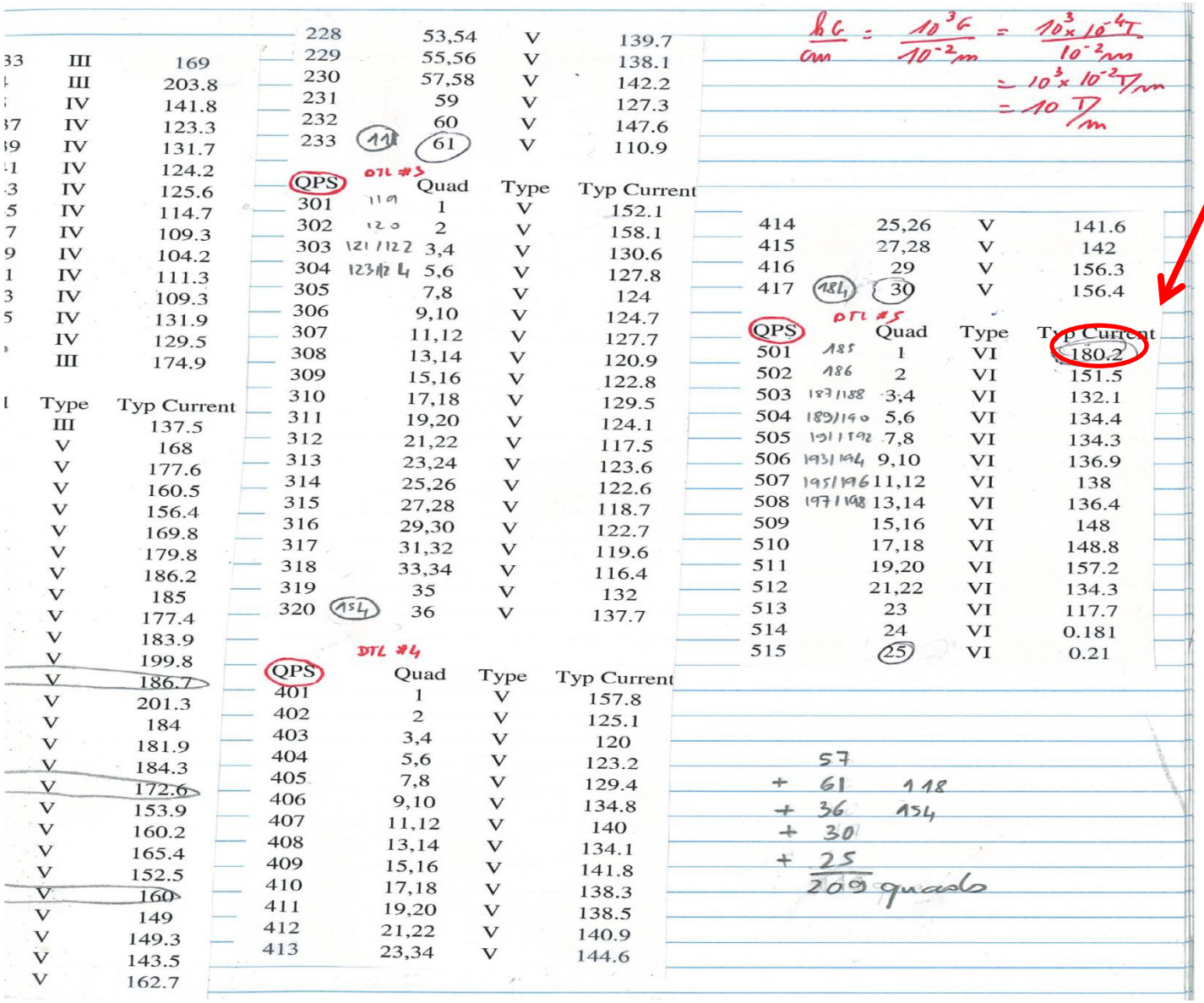
Losses up to the DTL exit. Large losses between DTL#4 and DTL#5.

MEBT Quads: 300.8 / 248.6 / 271.6 / 169.8 Amps
28.08 / 23.21 / 25.36 / 15.85 T/m

From Velev Gueorgui



Losses up to the DTL exit. Large losses between DTL#4 and DTL#5.
First Quad of DTL#5 is big compared to other quads.
Why? Probably to break an asymmetry (my guess !)



33	III	169
	III	203.8
	IV	141.8
37	IV	123.3
39	IV	131.7
41	IV	124.2
43	IV	125.6
45	IV	114.7
47	IV	109.3
49	IV	104.2
51	IV	111.3
53	IV	109.3
55	IV	131.9
	IV	129.5
	III	174.9

	Type	Typ Current
	III	137.5
	V	168
	V	177.6
	V	160.5
	V	156.4
	V	169.8
	V	179.8
	V	186.2
	V	185
	V	177.4
	V	183.9
	V	199.8
	V	186.7
	V	201.3
	V	184
	V	181.9
	V	184.3
	V	172.6
	V	153.9
	V	160.2
	V	165.4
	V	152.5
	V	160
	V	149
	V	149.3
	V	143.5
	V	162.7

228		53,54	V	139.7
229		55,56	V	138.1
230		57,58	V	142.2
231		59	V	127.3
232		60	V	147.6
233	118	61	V	110.9

DTL #3

QPS		Quad	Type	Typ Current
301	119	1	V	152.1
302	120	2	V	158.1
303	121/122	3,4	V	130.6
304	123/124	5,6	V	127.8
305		7,8	V	124
306		9,10	V	124.7
307		11,12	V	127.7
308		13,14	V	120.9
309		15,16	V	122.8
310		17,18	V	129.5
311		19,20	V	124.1
312		21,22	V	117.5
313		23,24	V	123.6
314		25,26	V	122.6
315		27,28	V	118.7
316		29,30	V	122.7
317		31,32	V	119.6
318		33,34	V	116.4
319		35	V	132
320	154	36	V	137.7

DTL #4

QPS	Quad	Type	Typ Current
401	1	V	157.8
402	2	V	125.1
403	3,4	V	120
404	5,6	V	123.2
405	7,8	V	129.4
406	9,10	V	134.8
407	11,12	V	140
408	13,14	V	134.1
409	15,16	V	141.8
410	17,18	V	138.3
411	19,20	V	138.5
412	21,22	V	140.9
413	23,34	V	144.6

$\frac{kG}{cm} = \frac{10^3 G}{10^{-2} m} = \frac{10^3 \times 10^{-4} T}{10^{-2} m}$
$= 10^3 \times 10^{-2} \frac{T}{m}$
$= 10 \frac{T}{m}$

414		25,26	V	141.6
415		27,28	V	142
416		29	V	156.3
417	184	30	V	156.4

DTL #5

QPS		Quad	Type	Typ Current
501	185	1	VI	180.2
502	186	2	VI	151.5
503	187/188	3,4	VI	132.1
504	189/190	5,6	VI	134.4
505	191/192	7,8	VI	134.3
506	193/194	9,10	VI	136.9
507	195/196	11,12	VI	138
508	197/198	13,14	VI	136.4
509		15,16	VI	148
510		17,18	VI	148.8
511		19,20	VI	157.2
512		21,22	VI	134.3
513		23	VI	117.7
514		24	VI	0.181
515		25	VI	0.21

57
+ 61 118
+ 36 154
+ 30
+ 25
209 quads

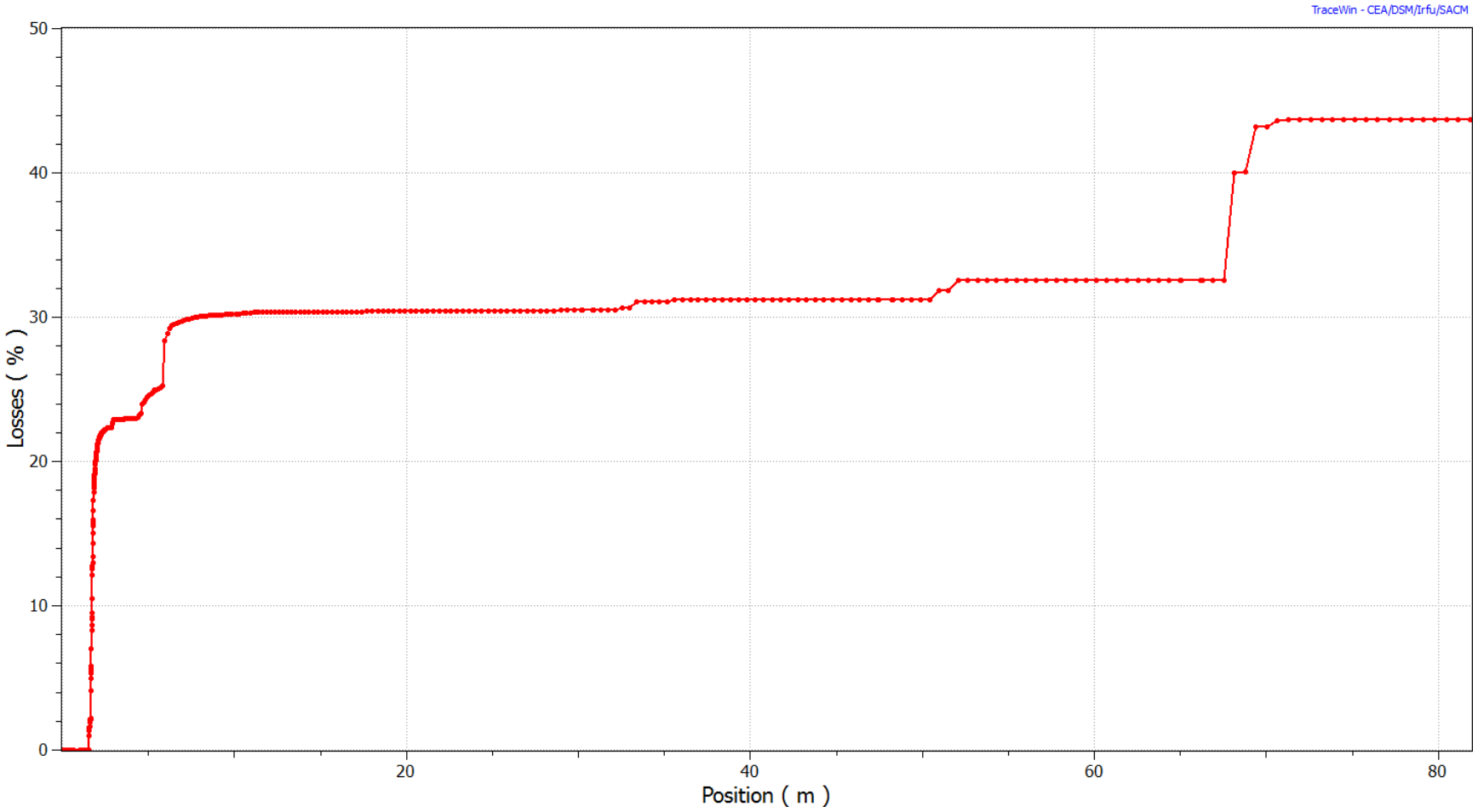
BIG !

Losses up to the DTL exit. Large losses between DTL#4 and DTL#5.
First Quad of DTL#5 is big compared to other quads.
Why? Probably to break an asymmetry (my guess !)

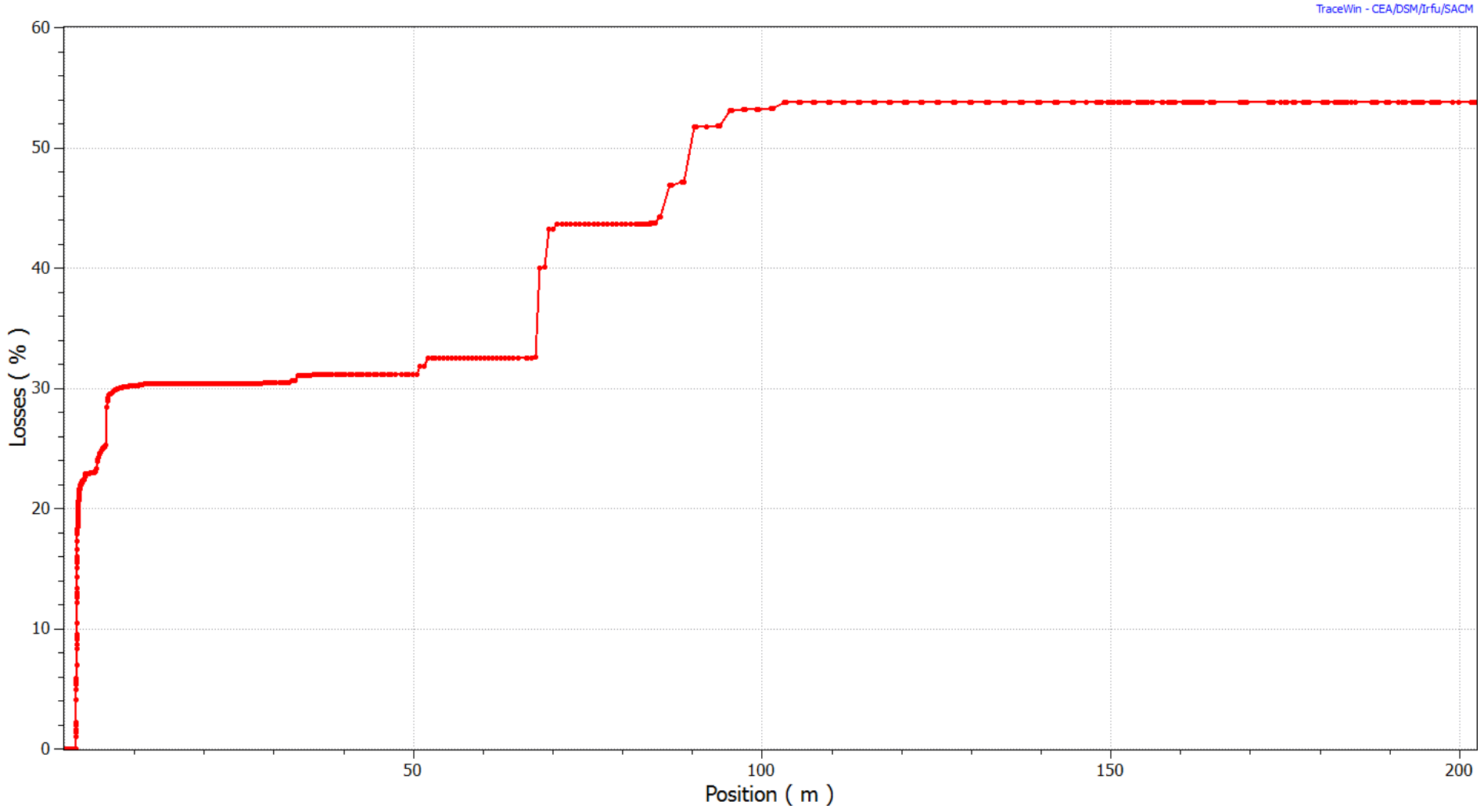
- What does this mean ? My guess is that the beam enters DTL#01 not symmetric and Q5 brings the symmetry back in DTL#05

- What if Q4 of MEBT goes to -30 T/m i.o -15.85 T/m?

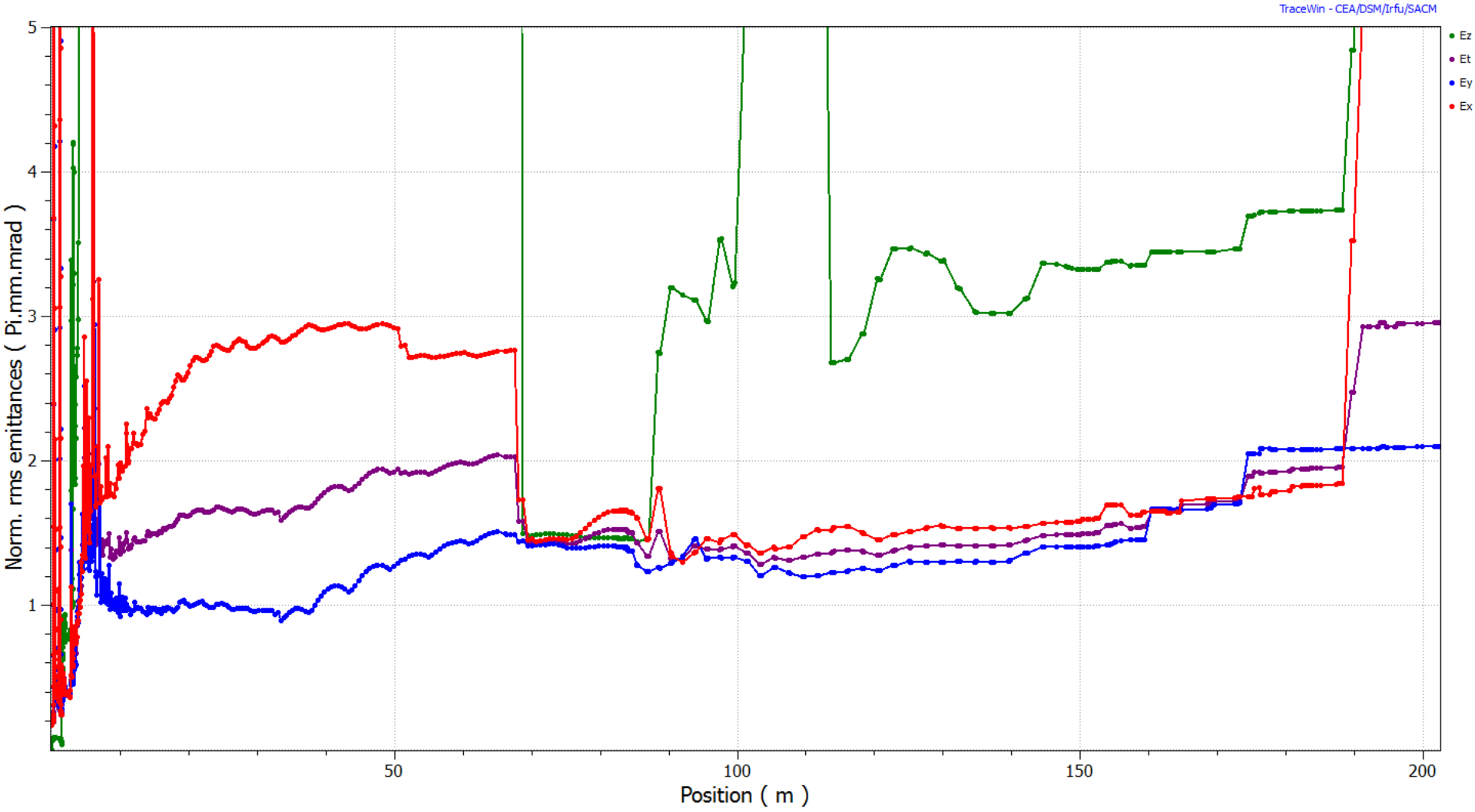
LEBT with half space charge (k=0.5) and q4=-30 T/m (i.o -15 T/m)
Losses up to the end of the DTL (Much Better !)



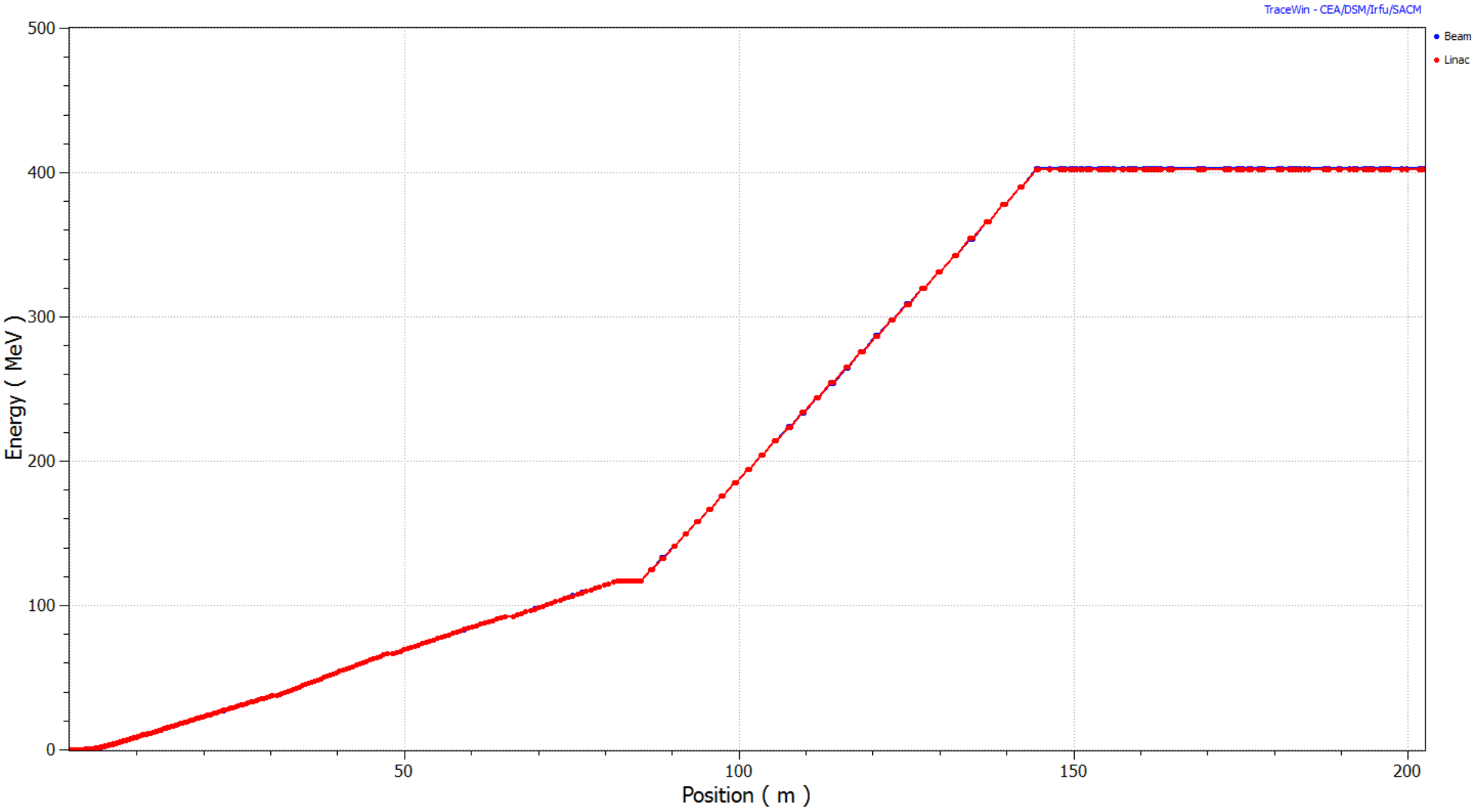
LEBT with half space charge (k=0.5) and q4=-30 T/m (i.o -15 T/m)
Losses up to the end of the Transfer Line



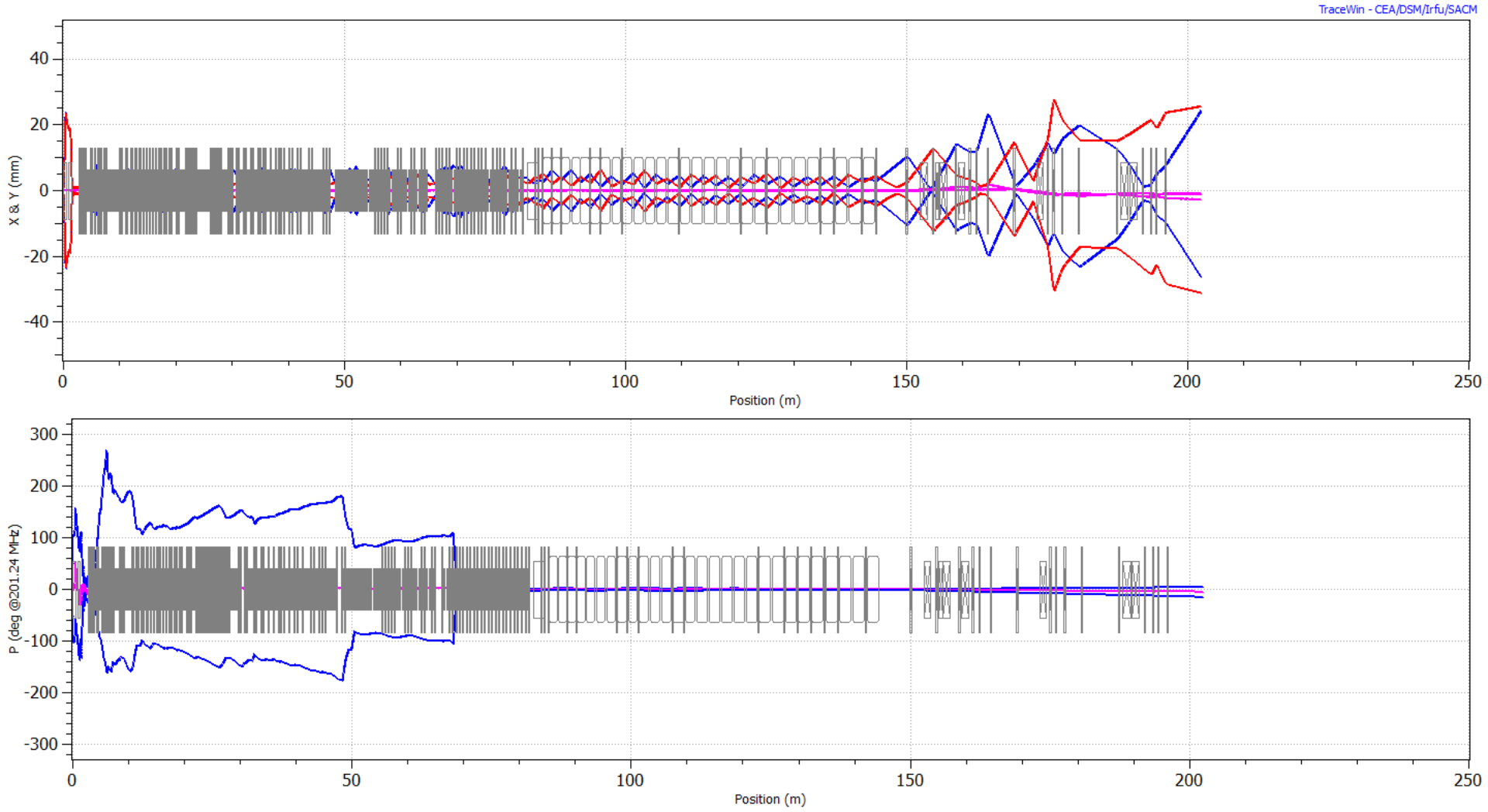
LEBT with half space charge (k=0.5) and q4=-30 T/m (i.o -15 T/m)
Emittance along the linac + transfer line



LEBT with half space charge (k=0.5) and q4=-30 T/m (i.o -15 T/m)
Energy along the linac + transfer line



LEBT with half space charge (k=0.5) and q4=-30 T/m (i.o -15 T/m)
Envelopes along the linac + transfer line



Conclusion

- A start-to-end simulation model is now available in TRACEWIN for the FNAL 400 MeV Linac

- From IS exit to the upstream of the Stripping Foil of the Booster

- Reasonable beam losses from the IS to the stripping foil
  (~60 mA at start and ~30 mA at the end)

- Two assumptions were taken
  1/ k=0.5 (half neutralization in the LEBT)
  2/ beam not symmetric at the entrance of the DTL#01