Simulation Study of RFQ Injection Line: Update

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PIP General Meeting

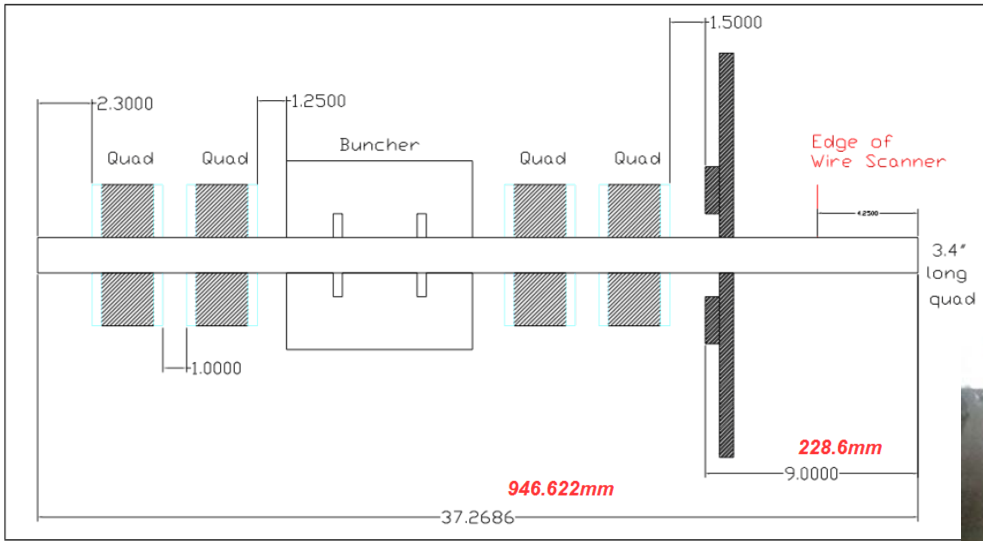
It is update to Reference:

[1] V.Kapin, “RIL Upgrade”, Beams-doc-6117-v1, 21-Feb-2018

The RFQ Injection Line - MEBT

RIL (RFQ Inj. Line) consists of:

1) H-minus ion Source;
2) 4rod RFQ;
3) LEBT (2 solenoids+E/S lense);
4) MEBT



MEBT consists of:

1 buncher (2-gap with grid->TTF);

2 sets of q-doublets (for matching)

4 sets of steerers in both planes

Study directions by C.Y.Tan (20/Jun/2017) [1]

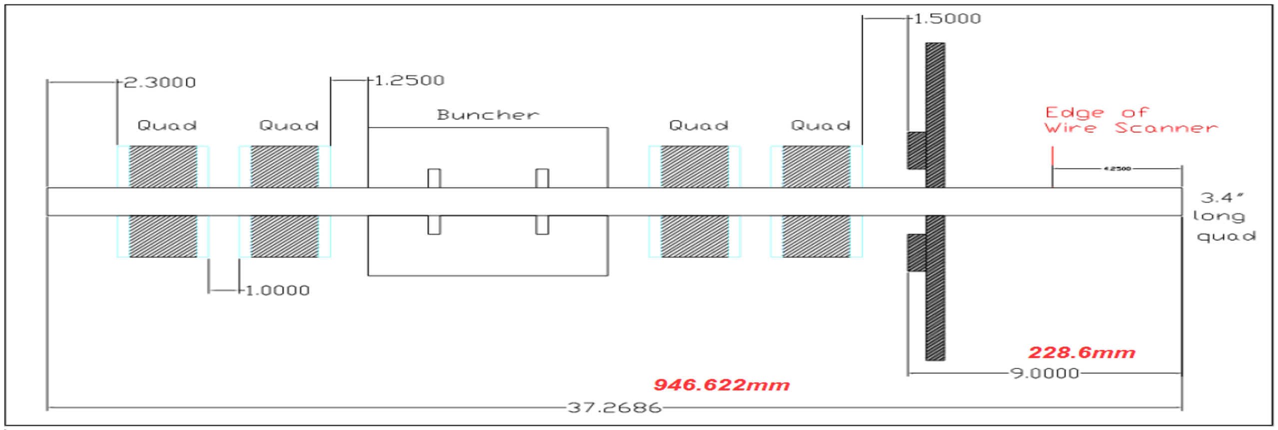
- Beam **transmission** in RIL is rather poor during normal ops.
- The goal is to improve transmission (at 28mA @L:TO1IN)
- Feb-2018 talk [1] discussion: "**beam quality**" (W.Pellico)

Configurations of MEBT to be considered:

1) present MEBT design (? if need for reinstallation of Dip. Correctors ?)

2) "RFQ+Tank1" (completely removing the MEBT)

3) New design - "RFQ+DS-doublet+Tank1" (no UpS Doublet & Buncher)



See options for RFQ in Ref.[1]

Simulation tools for problem resolving

Task:

- Create 3-level simulation models for MEBT of RIL using realistic beam distributions at RFQ exit after tracking throughout real fields in the Schempp's 4-rod RFQ in CST PS
- Four configurations (existing; without UpS Q-doublet; w/o MEBT keeping instrumentational drift in front of TANK1; w/o that drift)

Tools:

a) envelopes (ellipse tracking) with TRACE-3D => nominal Quad & RF-buncher parameters;

b) **multiparticle tracking** with old **PARMILA** in idealized (hard-edge) fields (also setup steering of beam centroid)

c) multiparticle tracking with CST in realistic fields (bell-shape fields => aberrations = r-dependent focusing lengths)

- PS – is not specialized beam dynamics code – all fields amplitudes & RF-phases must be defined by outside code; coordinate conversion etc.
- Time consuming (~24hrs for one RFQ pass at TD-server), license for PIC is busy frequently; => very restricted simulation conditions

Beam quality via I_{beam}=f (Emitt)

C.D. Curtis et al., “The operation of the 1st section **NAL** Linac”,Part.Acc, Vol.1, 1970

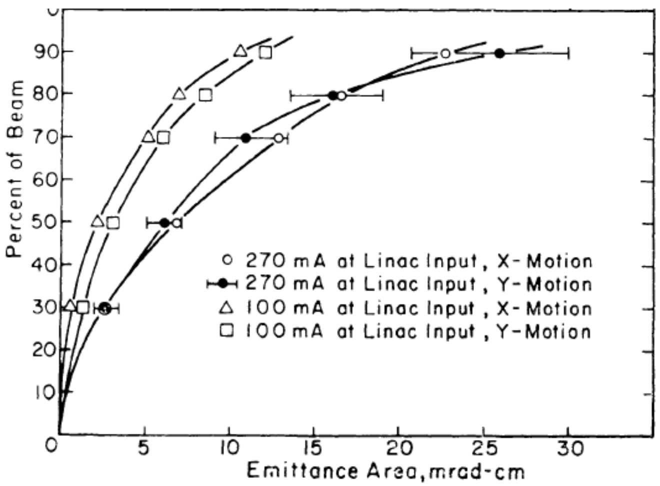
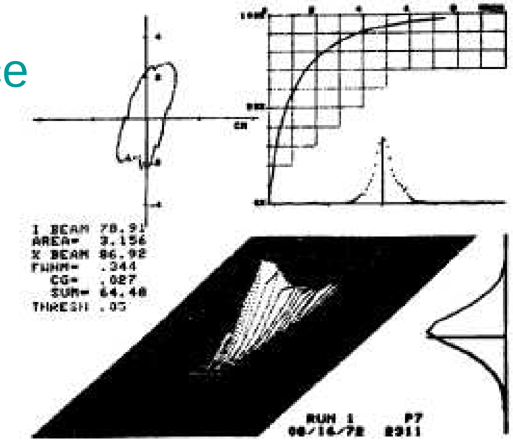


FIG. 13. Percentage of beam versus emittance area.

Data directly from emittance Mesurement Monitor :



Collect Ibeam=f(Enorm) on one plot at different energy (FNAL-linac !),

I.M.Kapchinsky, “Theory of Resonance Linear Accelerators, 1985(Eng)/1982(Rus)

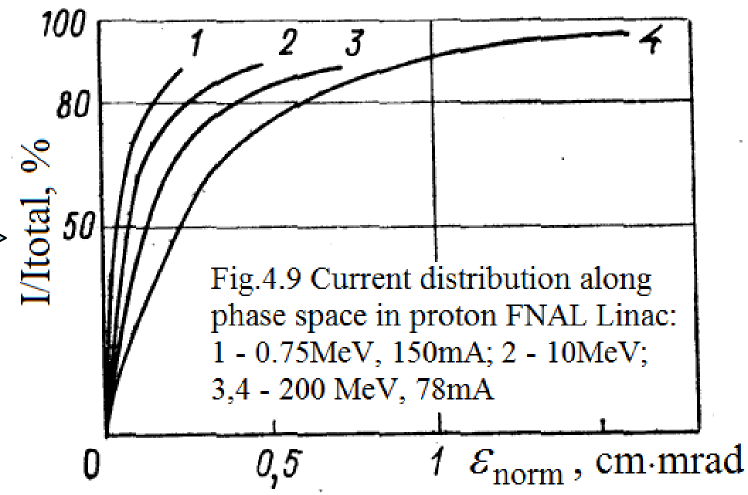
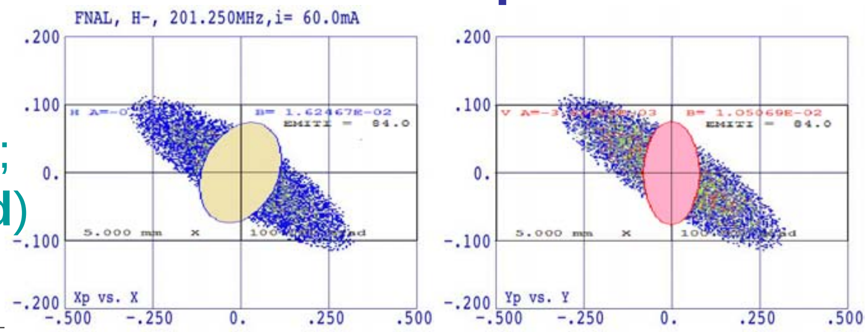
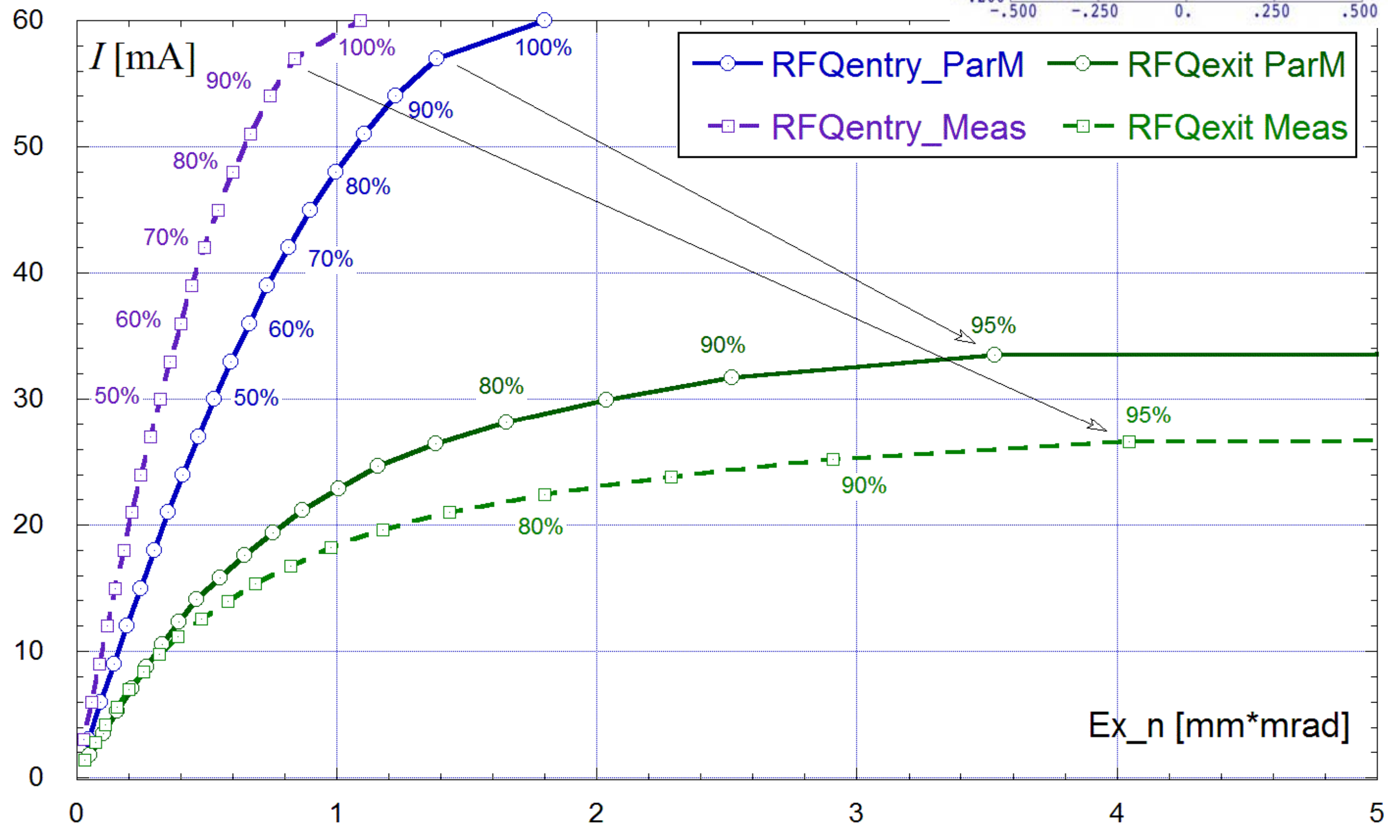


Fig.4.9 Current distribution along phase space in proton FNAL Linac: 1 - 0.75MeV, 150mA; 2 - 10MeV; 3,4 - 200 MeV, 78mA

Rerun PS in RFQ with Laser Notcher Aperture

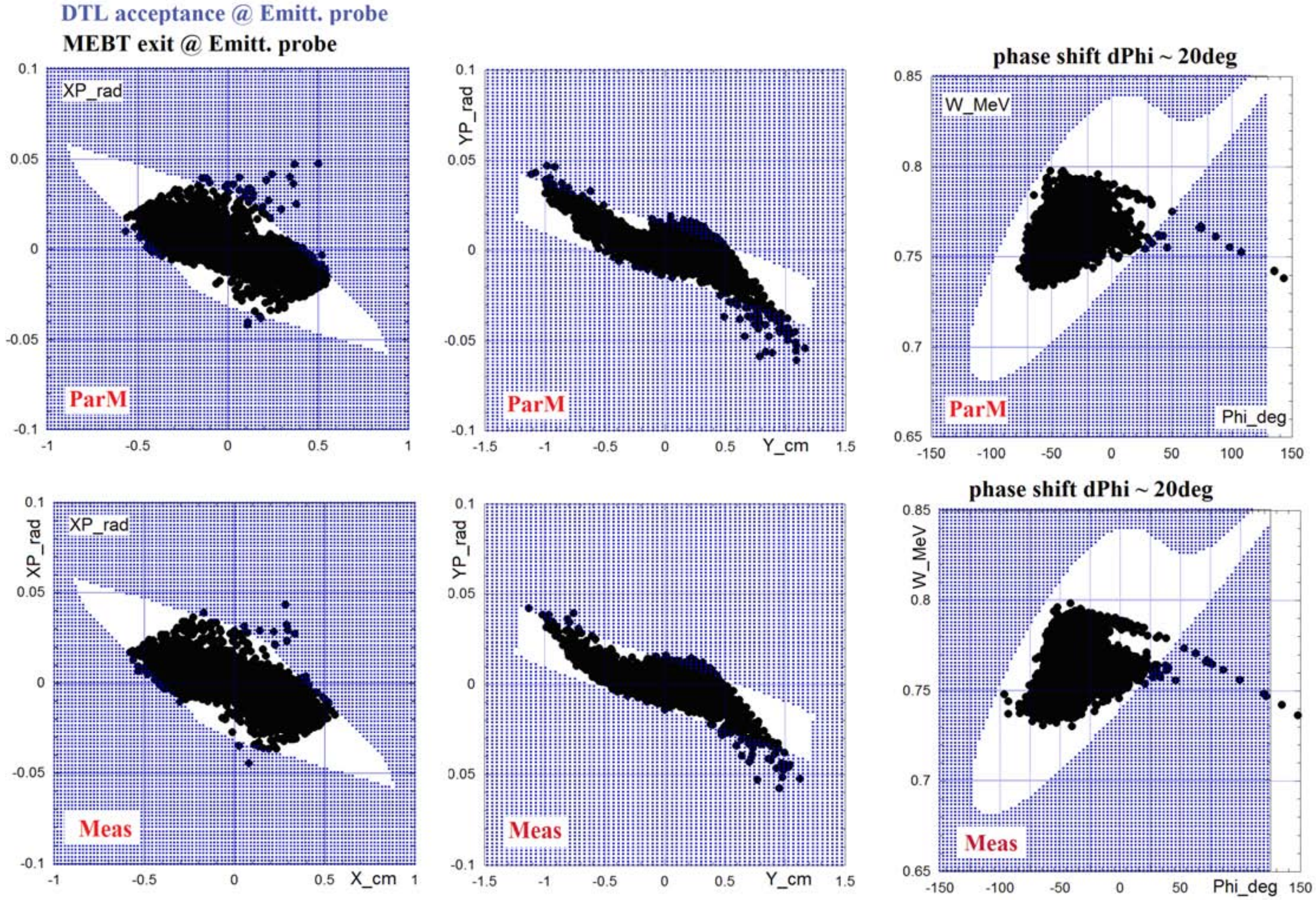
[1] 2 beam disrtributions @ RFQ-entry:
"ParM" =by Kress (ParmteqM) (**large-matched**);
"Meas" = meas. After LEBT (**small-mismatched**)





Matching MEBT beam emittance & DTL acceptance

MEBT exit beam is overlapped on DTL acceptance @ Em-probe (both by Parmila)

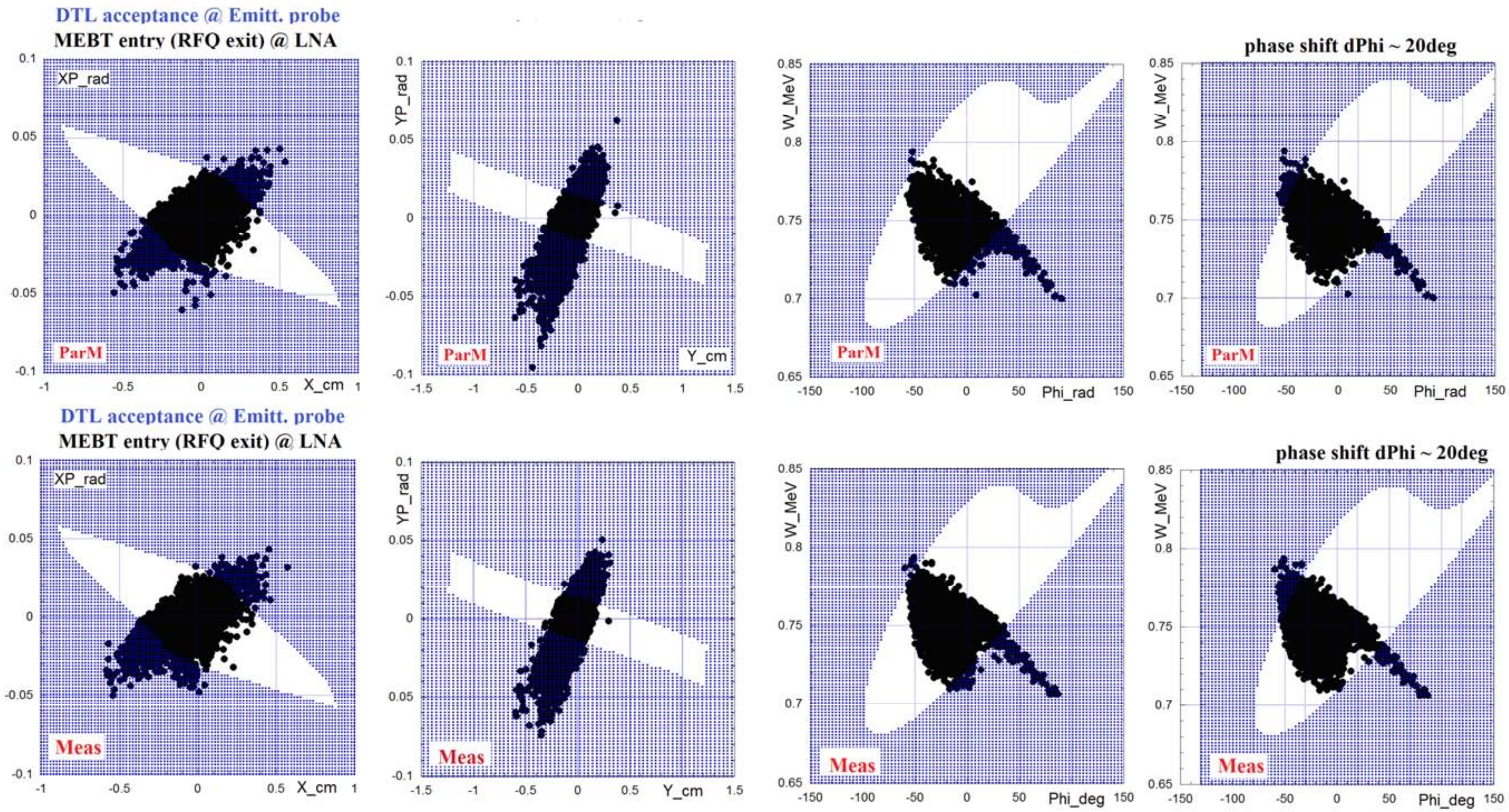


MEBT design (Trace&Parmila) ensures good matching by MEBT => good transmission

Note. Acceptances shown are maximum phase spaces when no distributions in other planes.

Option “RFQ+Tank1” (removing the MEBT)

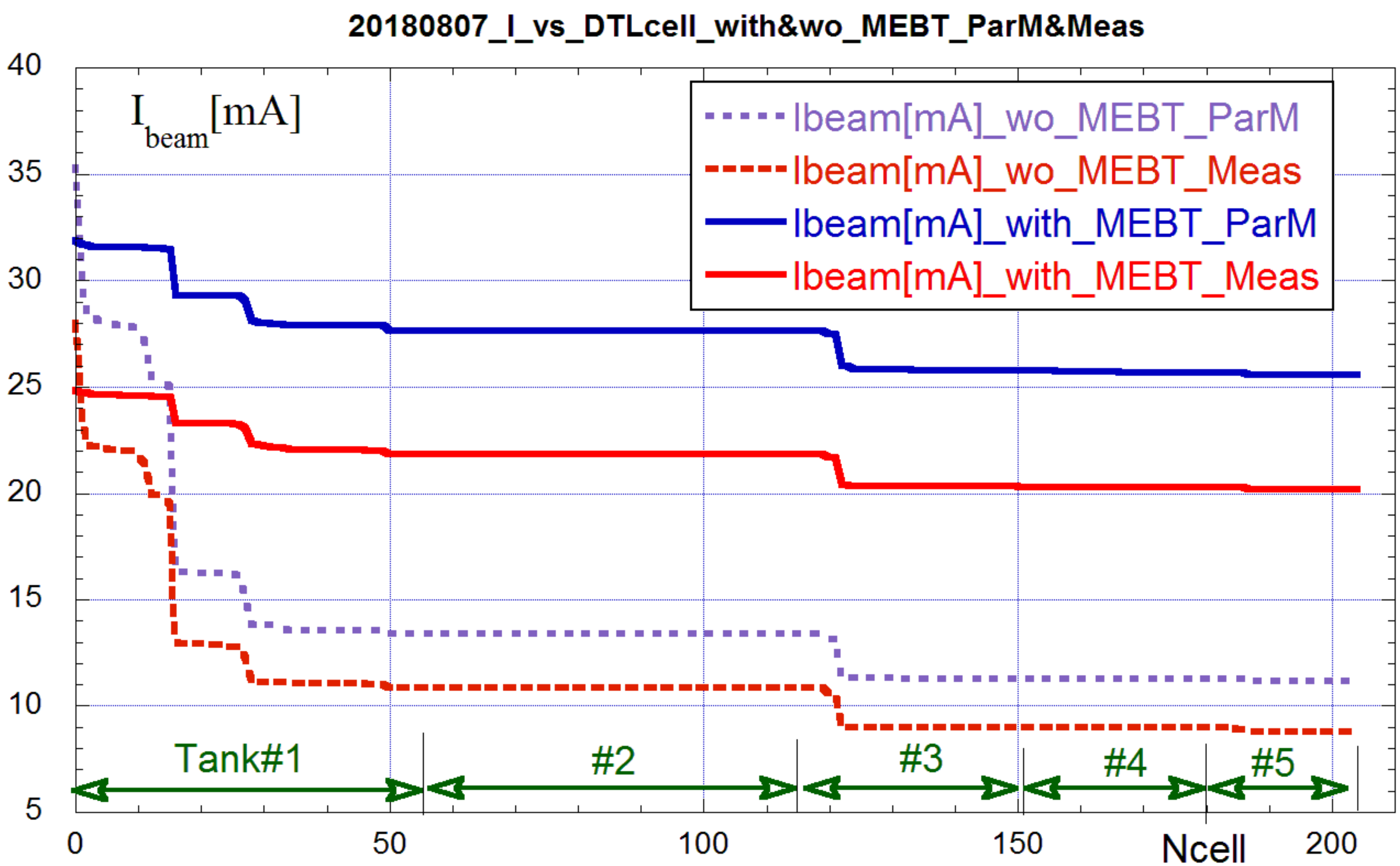
RFQ exit beam by PS CST is overlapped on DTL acceptance by Parmila @ Em-probe



Bad overlap =>
bad transmission

Note. Acceptances shown are maximum phase spaces when no distributions in other planes.

Beam Transmission by Parmila for “w/o MEBT”



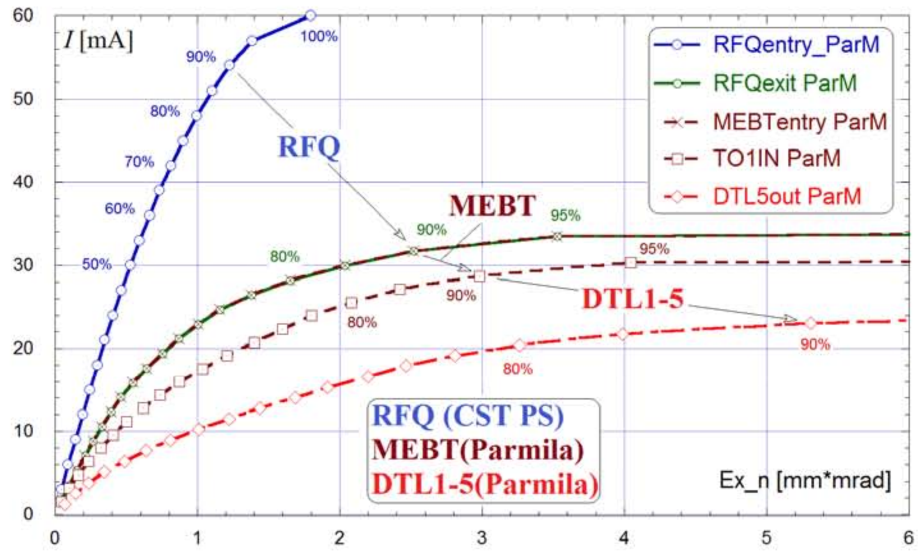
***I*out DTL 20-25mA**

Without existing MEBT transmission along DTL1-5 drop down to < ~30% !

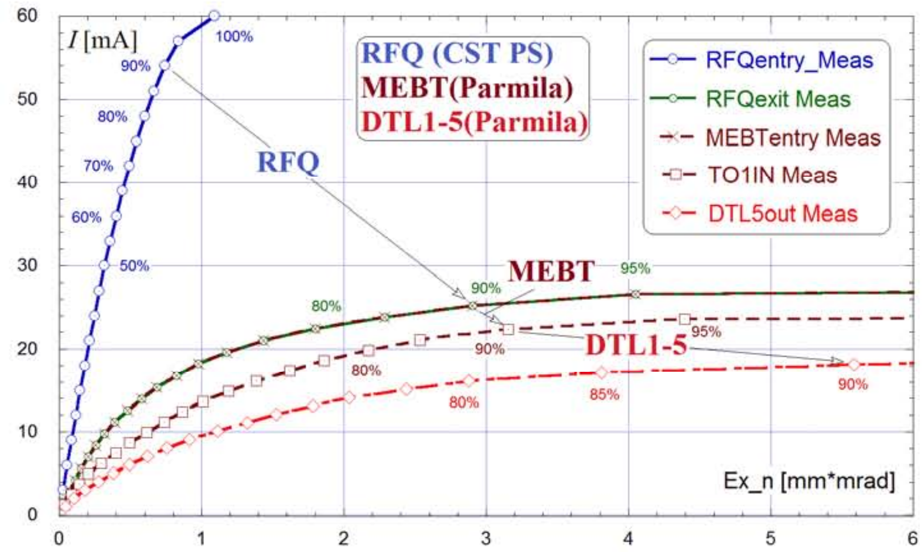
=> Existing MEBT perform a usuful job !!!

Beam quality drop in chain: RFQ->MEBT->DTLs

"ParM"-beam



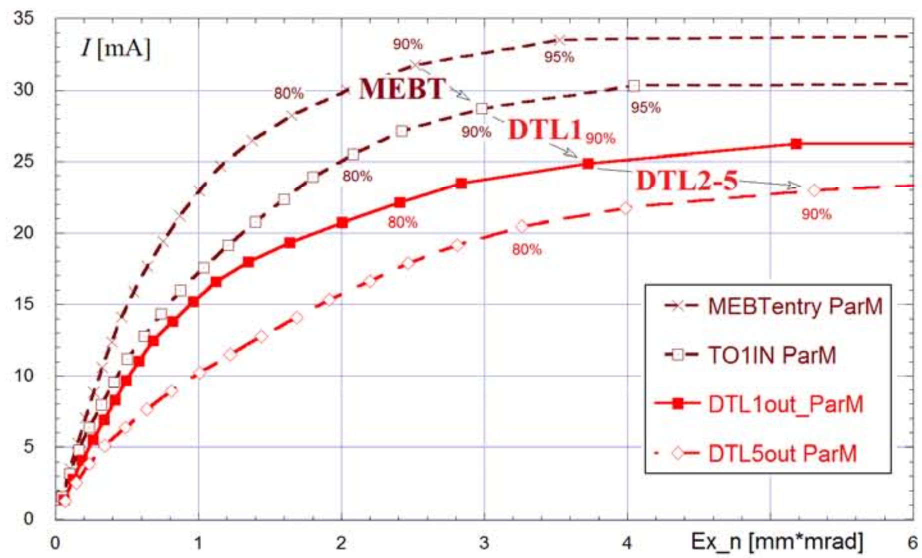
"Meas"-beam



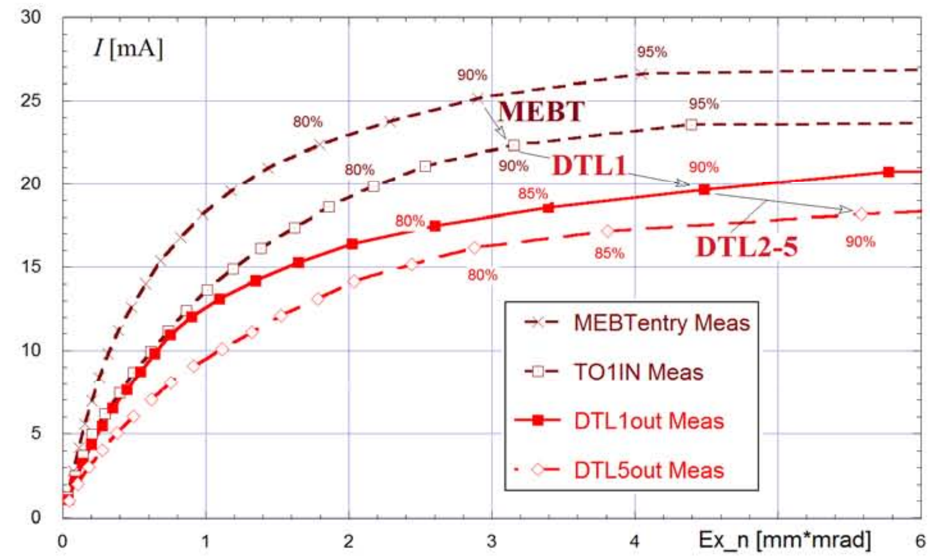
- ❖ Essential *I*-drop & E-increase within RFQ for both ParM & Meas beams
- ❖ MEBT (Parmila with hard-edge ideal fields) – keeps *I* (a large aperture ?)
- ❖ DTL – further *I*-drop (due to previous in Emit-spread from RFQ & MEBT)
- ❖ worse "Meas" beam (small unmatched-to-RFQ emittance)

Beam quality in chain: MEBT -> DTL1 -> DTL2-5

"ParM"-beam



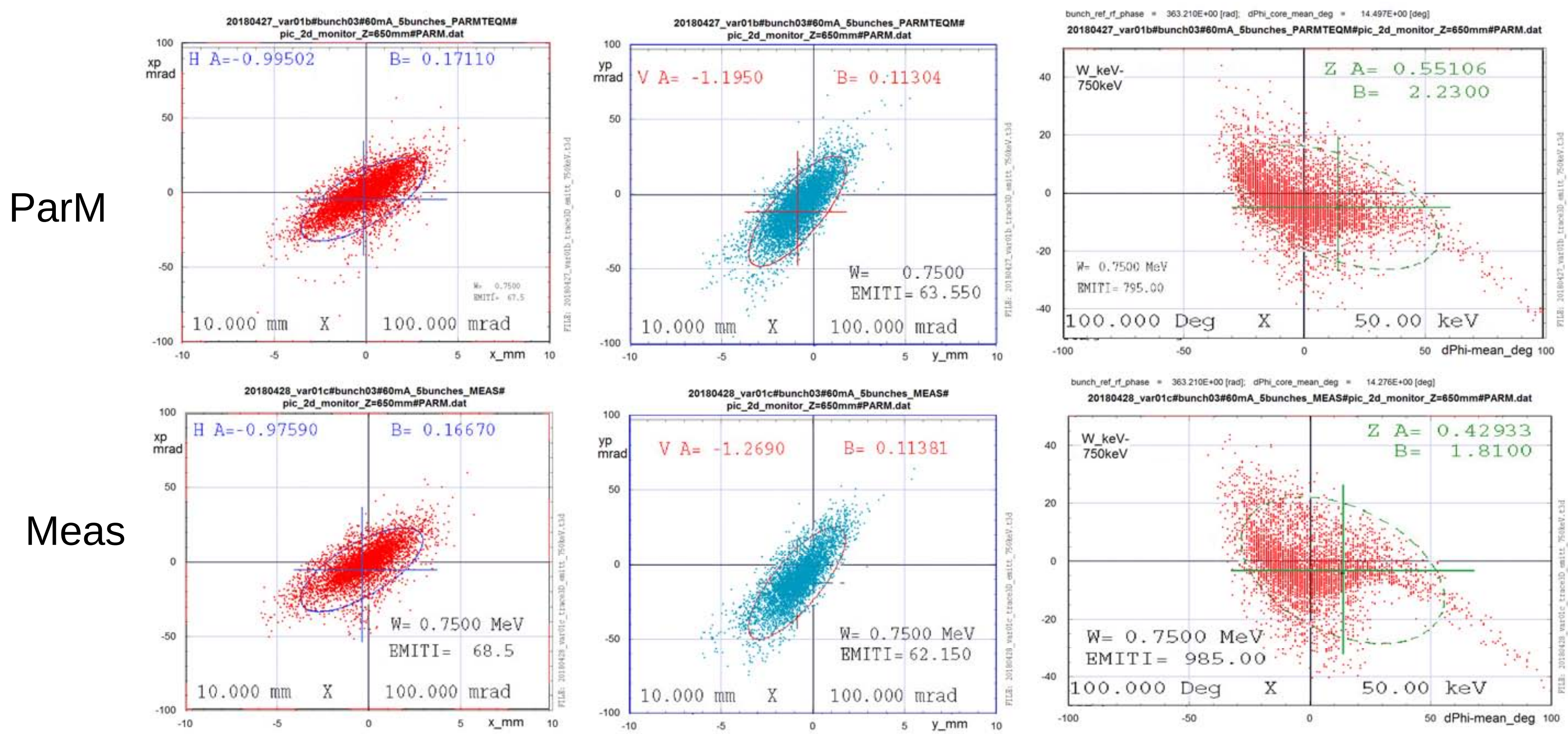
"Meas"-beam



❖ Essential *I*-drop & E-increase within MEBT and Tank#1 (also due to bad beam throuout of MEBT ?)

❖ DTL2-DTL5 – *I*-drop of the same order as for MEBT and DTL1

MEBT tuning: initial ellipses @ RFQ-exit (CST PS)



Procedure steps:
1) CST PS distributions; 2) RMS ellipse parameters & centroids;
3) Trace-3D ellipses; 4) overlap each other

Sparse phase-spaces.

MEBT tuning: ellpises matching with Trace-3D

Only ellipses (assuming zero centroid shifts)
Example: ParM (left = RFQ-exit ellipses; right = DTL acceptance ellipses)

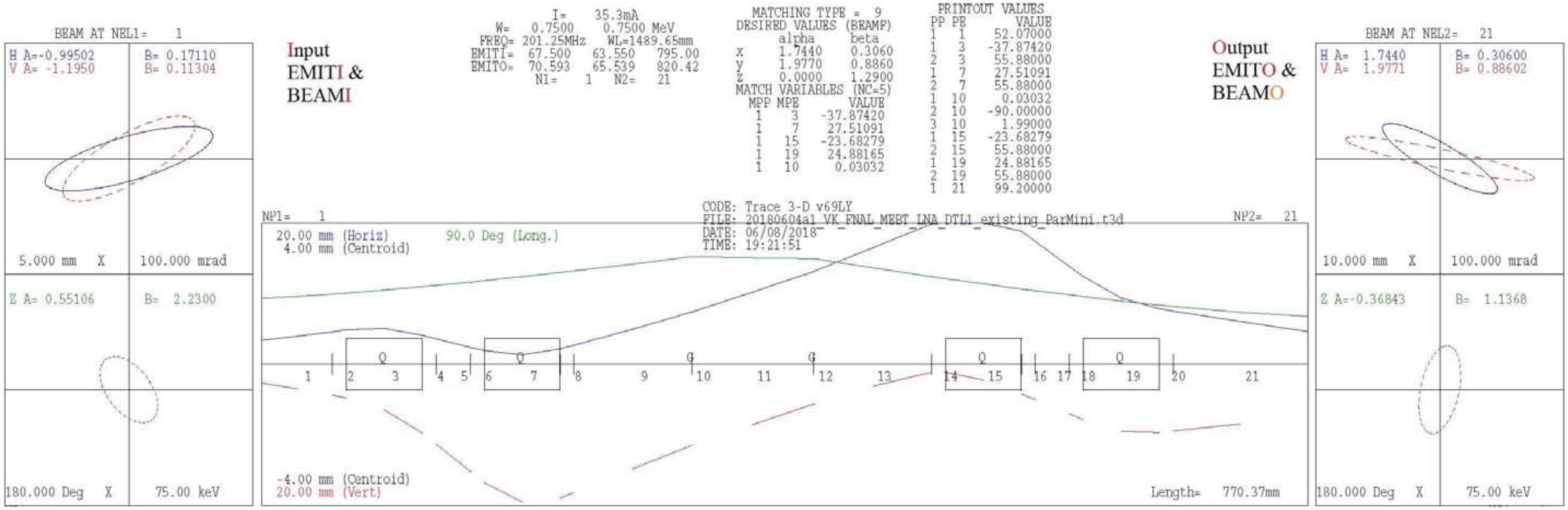


Table. Final Trace3D field strengths for FNAL MEBT

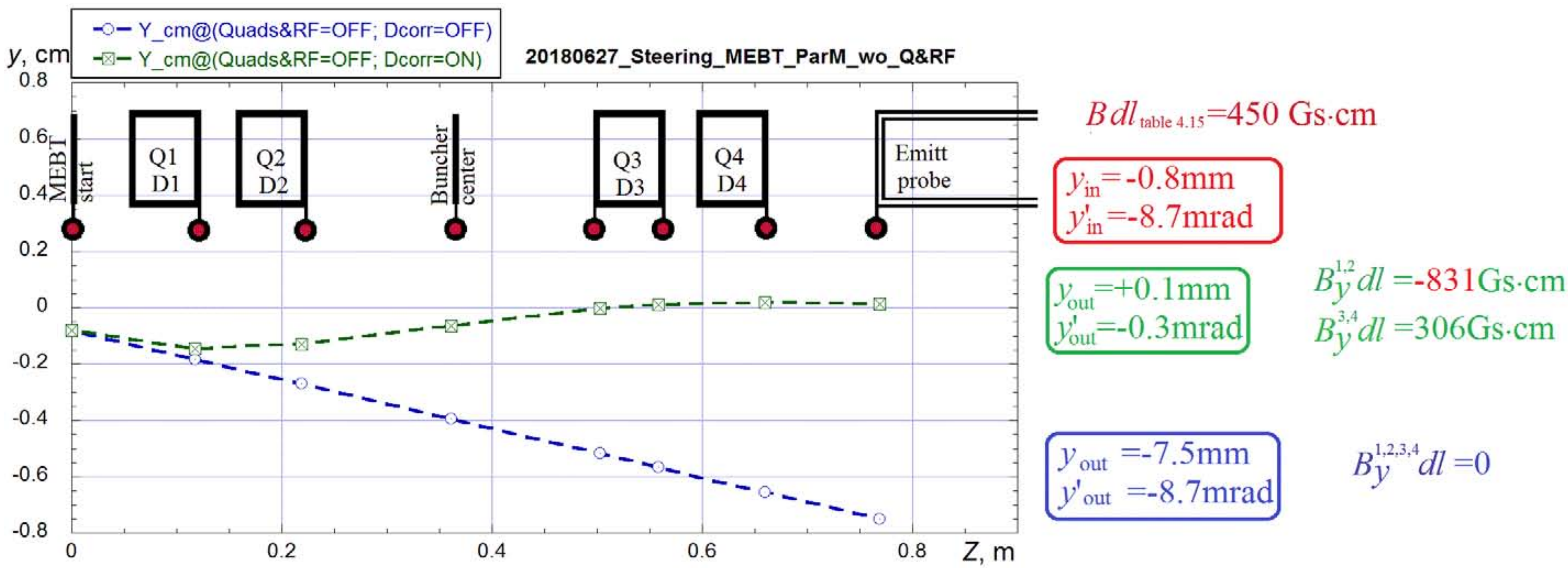
Table 4.13 in Tan's report.				Tbl.4.13	fig.4.83 before matching	VK for fig4.83: (MT=9) x10 + (MT=8)x1	PS CST "ParM-ini"	PS CST "Meas-ini"
Trace3D Elem ID	**Element**	**Gradient (T/m)**	**Integrated Field (T)**					
3	Quad	–32.8	–2.0	-32.8	-32.754	-34.043	–37.874	-37.680
7	Quad	27.5	1.5	27.5	+27.531	+27.683	+27.511	+27.348
15	Quad	–23.4	–1.3	-23.4	-23.433	-22.982	-23.683	-23.534
19	Quad	21.6	1.2	21.6	+21.630	+22.277	+24.882	+24.820
15,17	Buncher	31.6 kV = E_0TL		31.6	+0.0316	0.0342	+0.03032	+0.02944

MEBT tuning: steering tuning with Parmila

RFQ exit – beam centroid shift: vertical (y) >> horizontal (x)

Different shifts for “ParM” & “Meas” => different setting for Dipole correctors

1) Correction w/o Quad & RF fields => **High Dipole** fields

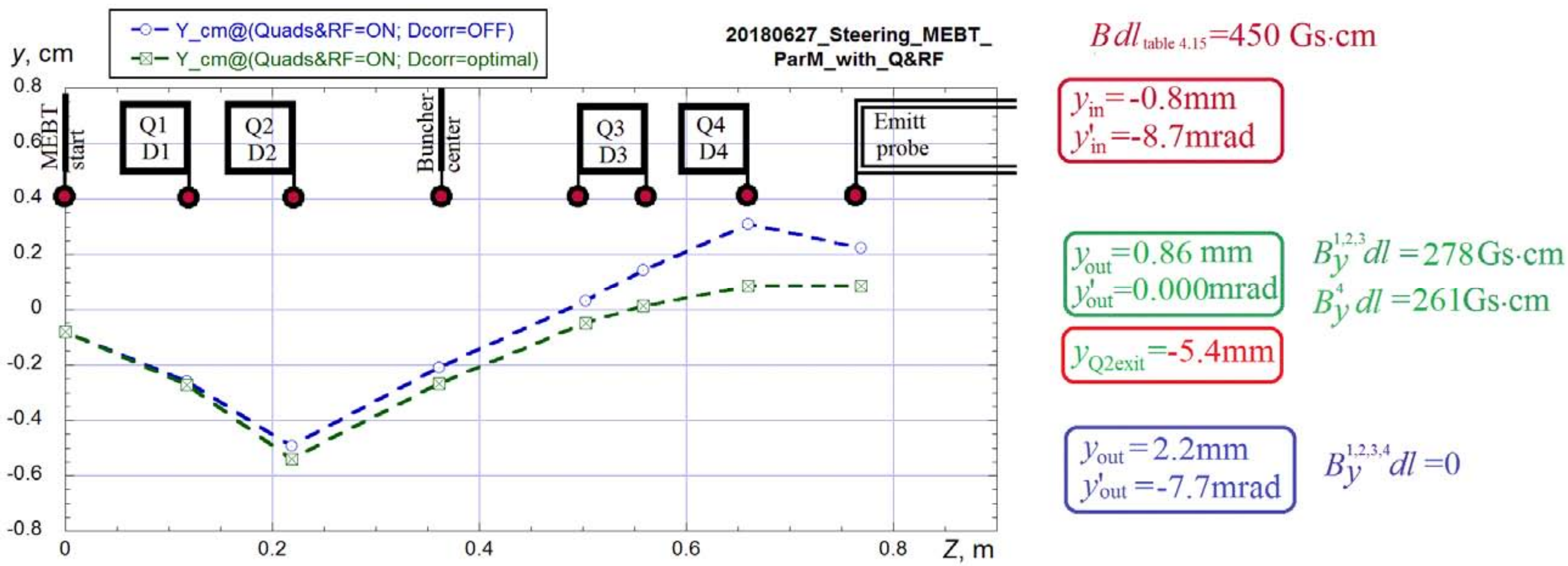


MEBT: steering tuning with Parmila

2) Correction with Quad & RF fields = ON

=> centroid is focused w/o dipole fields (blue) !

Moderate dipole corrector fields are needed to correct the exit coordinates of the beam centroid (green) => answer=NO (question about reinstalling D- correctors)



Essential centroid shift within MEBT (-5.4mm @ Q2-exit) =>

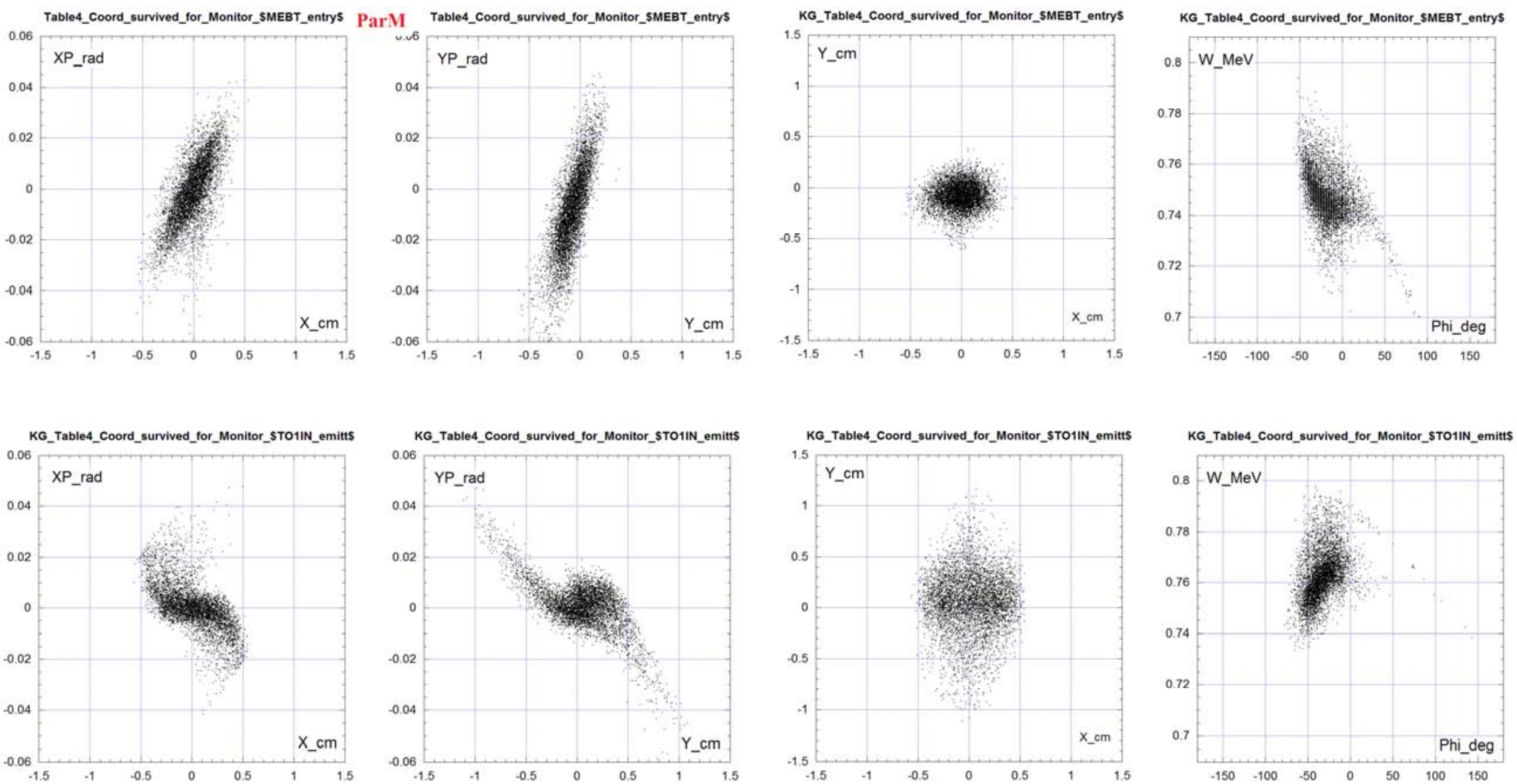
beam may suffer from non-linear fields !

Beam Phase Spaces at MEBT ends

Example: “ParM” beam at MEBT entry (RFQ exit) by PS CST(real RFQ fields) and at MEBT exit (Emit. probe) by Parmila tracking (ideal fields)

MEBT entry

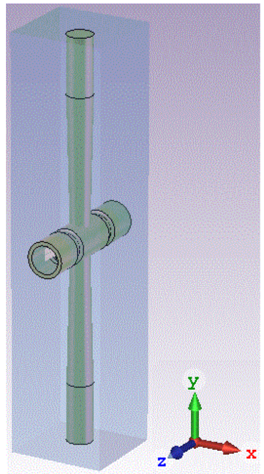
MEBT exit

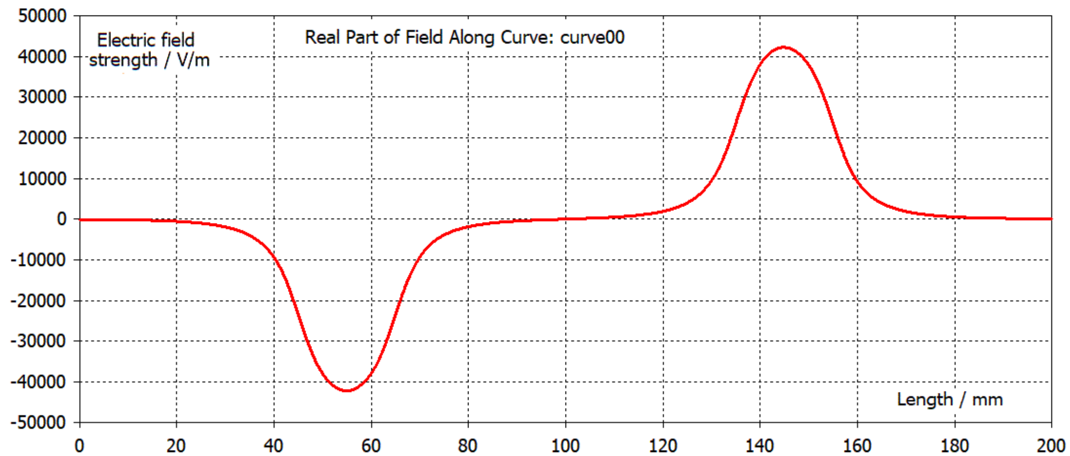


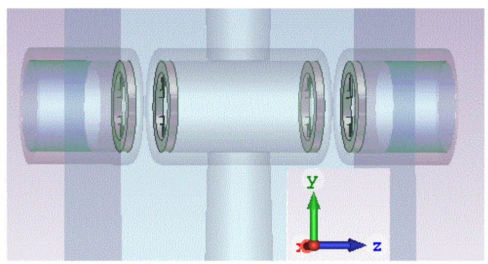
Prepare CST model for MEBT (real fields => aberrations)

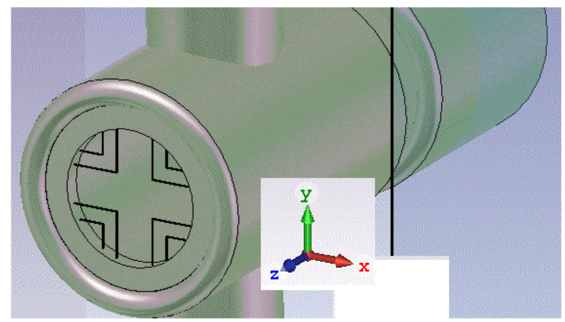
CST E/S
Model for Buncher

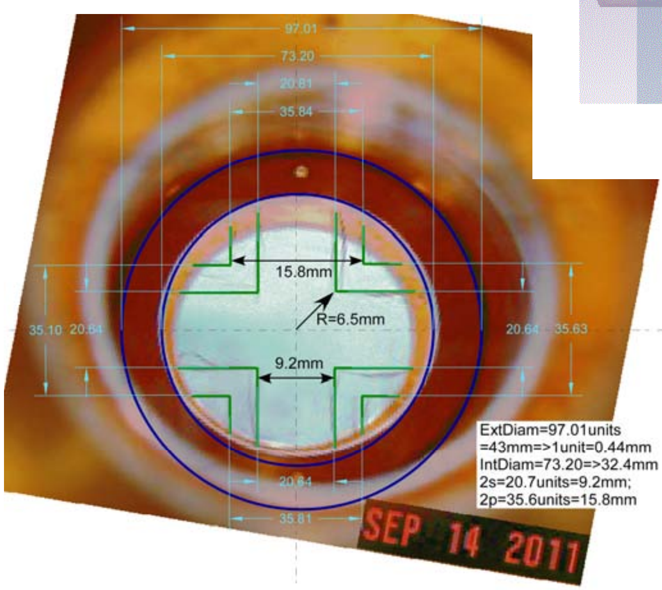
E-Fields imported
in MEBT model









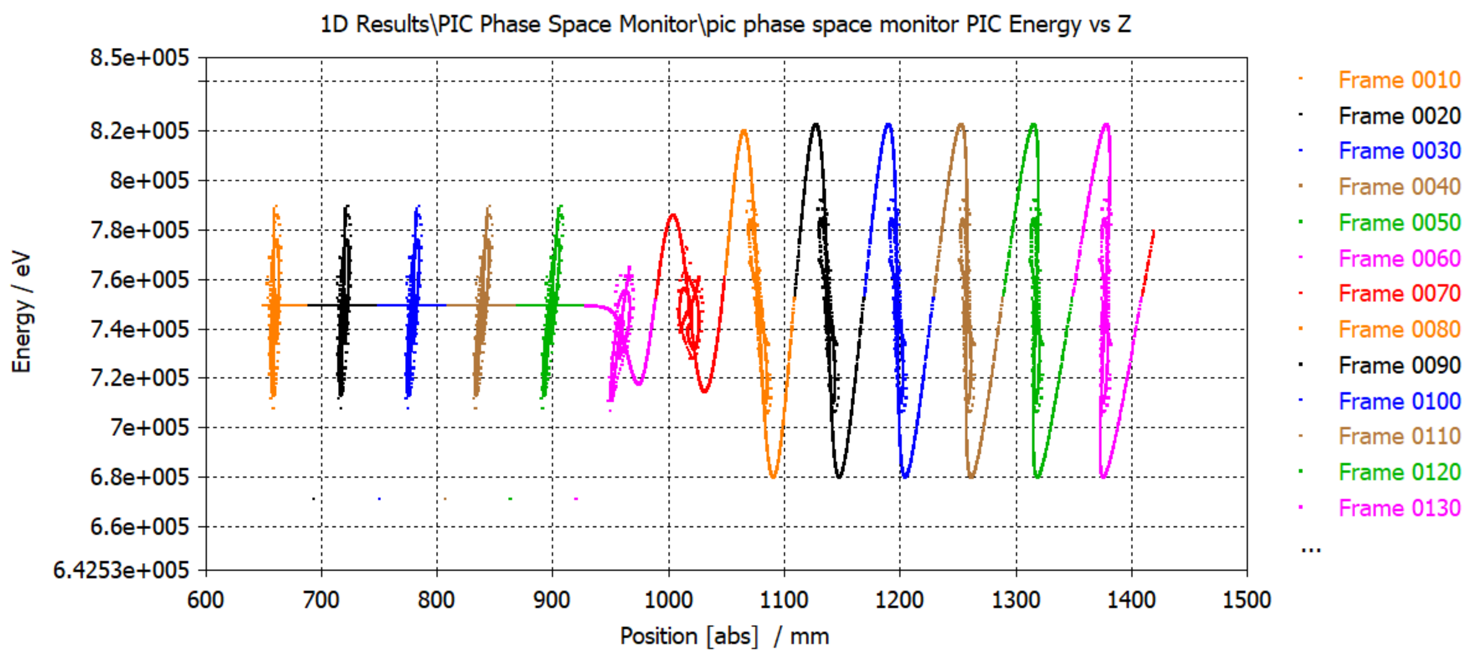


Prepare CST model for MEBT – magn. Fields D &Q

B fields imported into MEBT model from “Opera” (by V.Kashikin - thanks!!!):

1) Quads – (for doublet) Q1, Q2, Q3, Q4 - text files of 1mm mesh
2) Dipole – (stand along) D1, D2, D3, D4 - text files of 1mm mesh

Example of the on-axis bunching in MEBT: “bunch from RFQ + 360-deg dW=0”

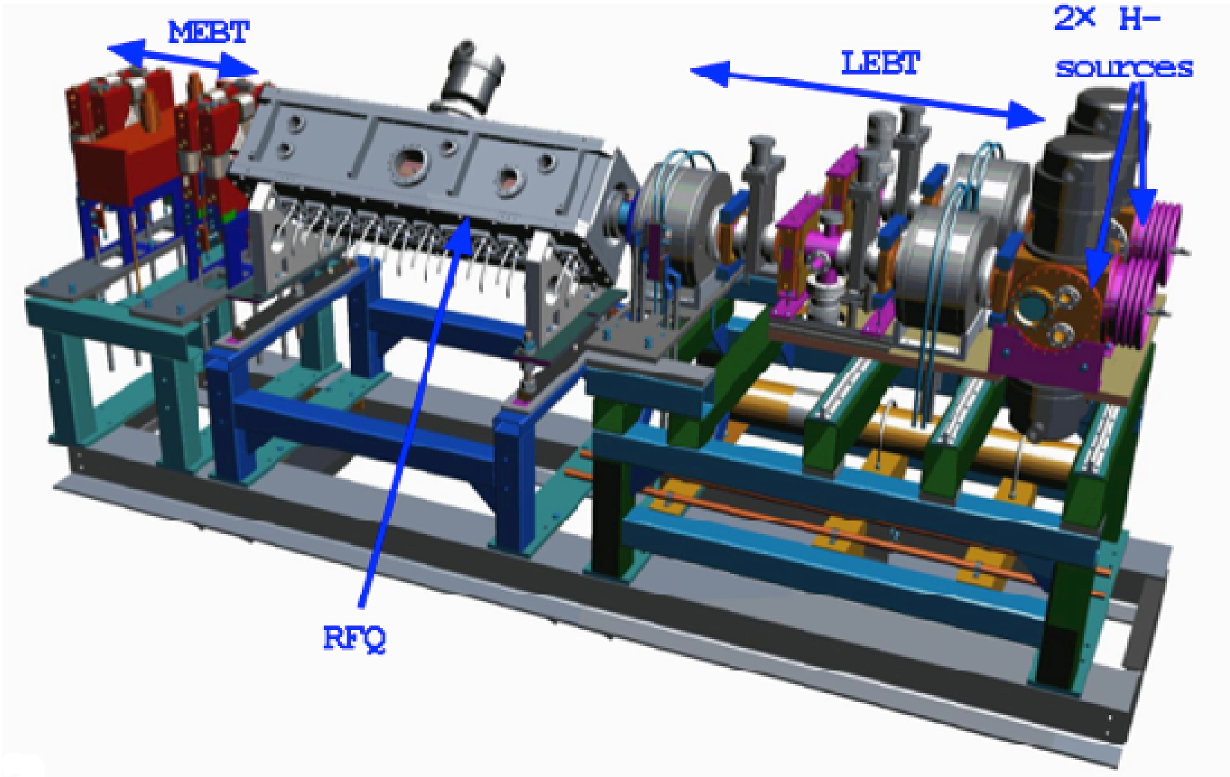


Status

- Simulations for existing MEBT with Trace-3D & Parmila are completed => nominal field setting for CST model
- Beam current drop along Linac is close to realistic
- CST model for existing MEBT: realistic RF, B-quad, B-dipole fields are imported; RF-phase for bunching is set
- “I-beam vs Enorm” are obtained by Parmila and will be refined with CST PS – “reference bottom line” for a modified MEBT (demonstrate “potential improvement room” for MEBT; recent Kurennoy studies on LANL MEBT with PS)
- Configuration without MEBT does not work well (Transm drop)
- New modified MEBT: a) one “doublet”; b) set of small-aperture quadrupoles to keep periodical focusing from RFQ-to DTL

Some additional slides

The RFQ Injection Line Configuration & References



Parameter	Value	Units
Input energy	35	keV
Output energy	750	keV
Frequency	201.25	MHz
Number of cells	102	
Length	120	cm
Minimum radial aperture	0.3	cm
Maximum peak surface field	25.18	MV/m
Peak cavity power+beam power	~140	kW
Duty factor (80 μs, 15 Hz)	0.12	%
Design current	60	mA
Modulation m	$1 \leq m \leq 1.95$	
Intervane voltage	72	kV
Transmission efficiency	98	%

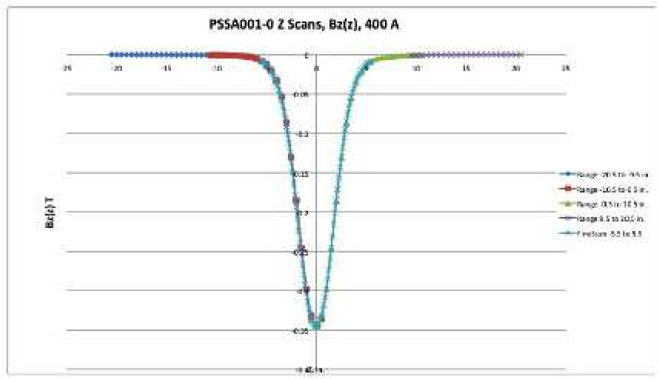
[1] C.Y. Tan et al, “The 750 keV RFQ Injector Upgrade”, (final writeup) 11/Dec/2013 BeamDoc#3646-v16 (154p.)

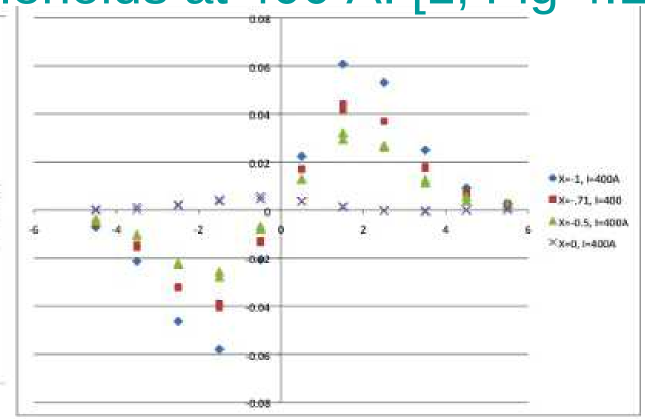
[2] C.Y. Tan et al, “PIP I: RFQ Injector”, talk, Acc seminar, BeamDoc 4563-v2 (48pp)

[3] C.Y. Tan, ”Pre-Injector Upgrade Updates”, **(>75)** talks on the current status (BeamDocs 8/Dec/2008÷10/Sep/2014)

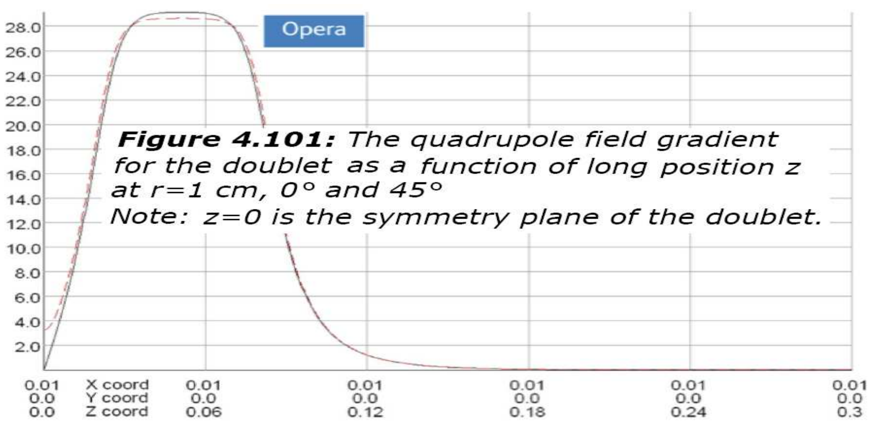
Illustration of non-ideal fields in LEBT & MEBT

Measured Bz & Bx fields of solenoids at 400 A. [1, Fig 4.18]

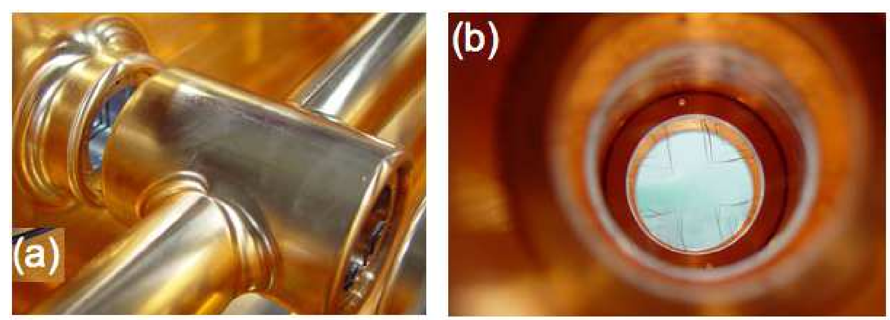




Q-field gradient at r=1cm vs z [1, Fig 4.101]
z=0 is simmetry plane of doublet

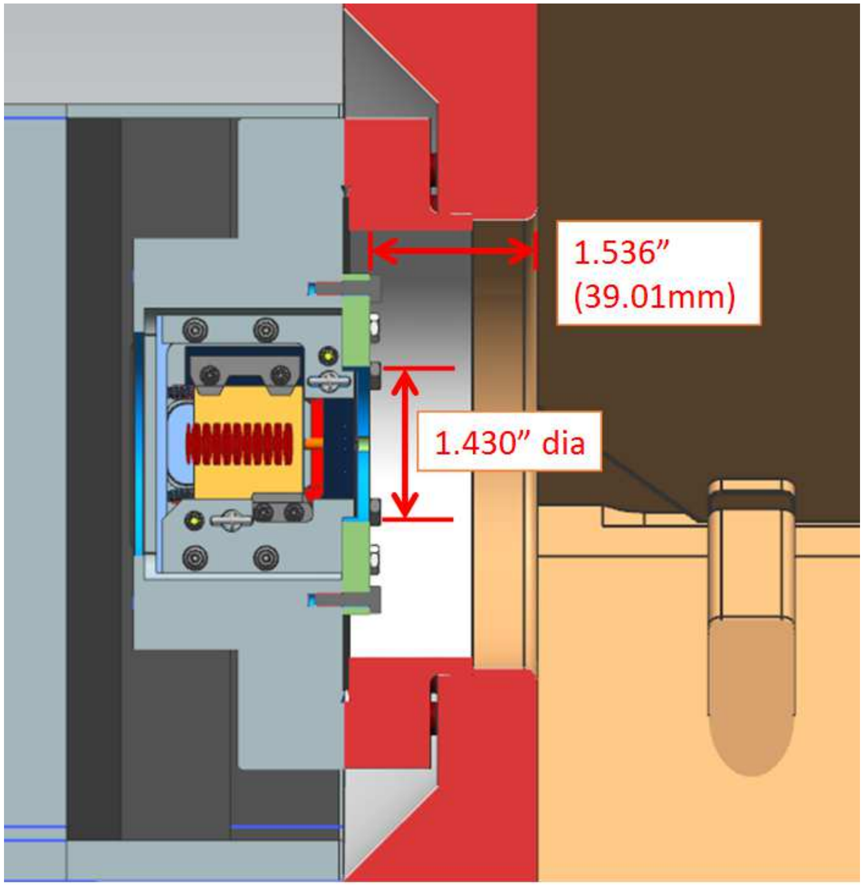


Buncher DT with grids. [1, Fig 4.92]

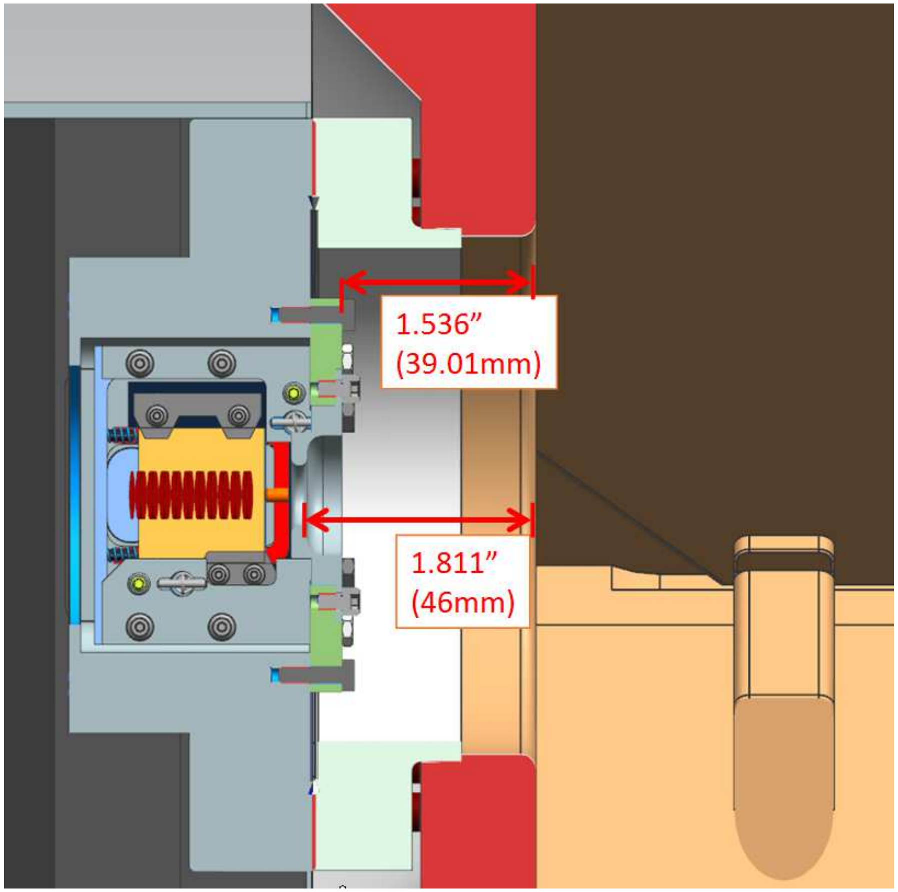


New Laser Notcher Aperture (drawing by Kevin Duel)

Notcher was installed
~ in summer of 2014



New diaphragm with i.d. 12mm has
been installed recently (Feb of 2018)

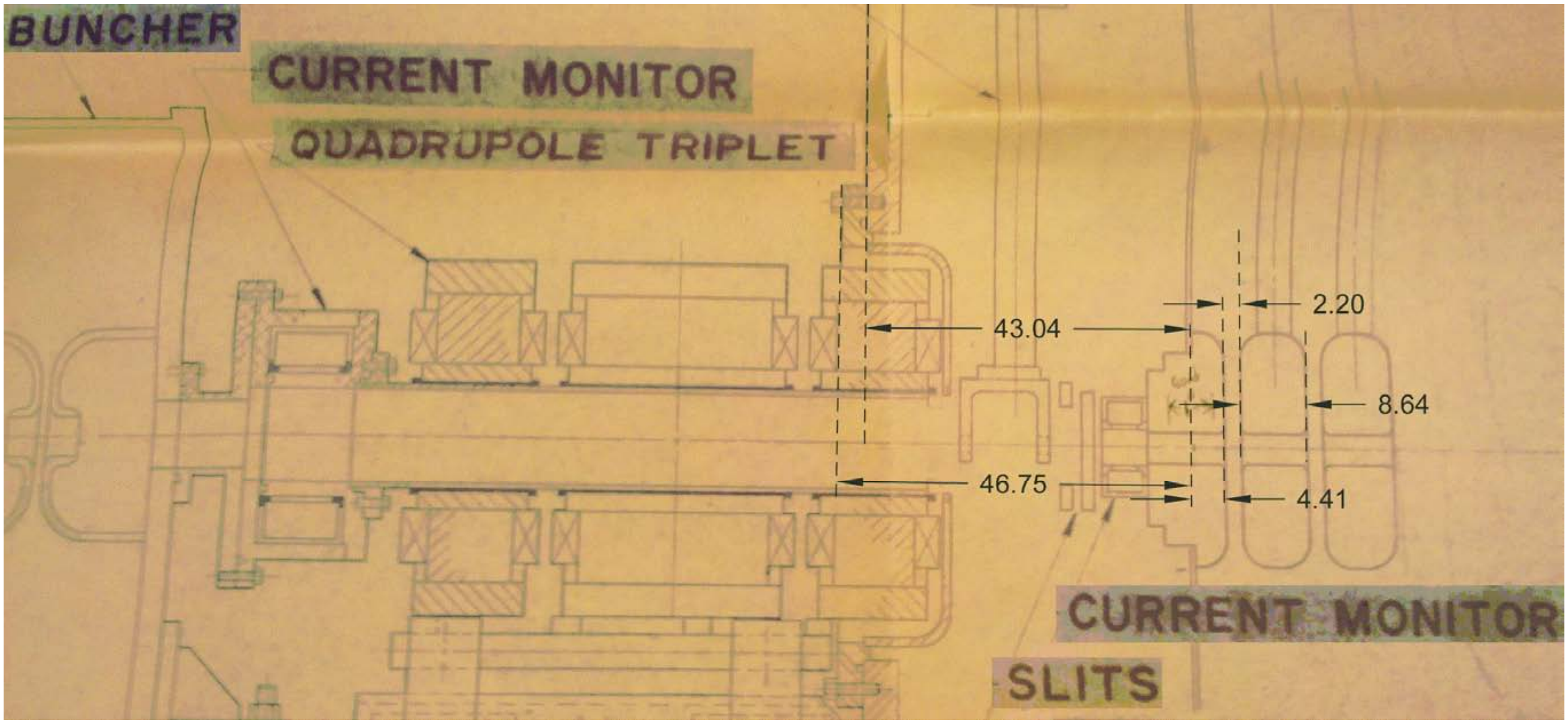


The notcher is inserted inside of exit pipe with length of 100mm assumed in CST model

Exit field distortion ?

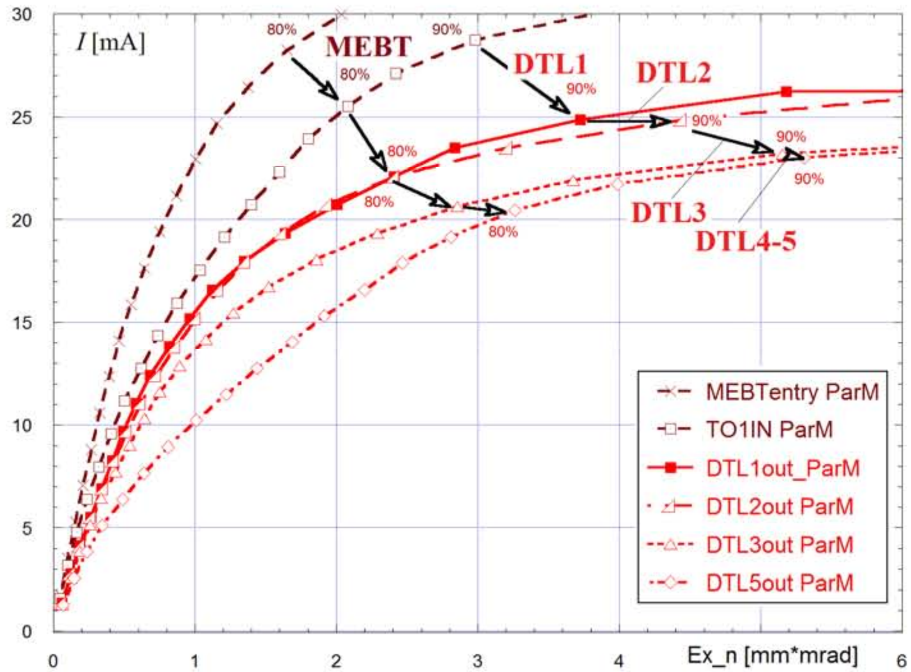
MEBT- DTL

Long drift between MEBT and the first quadrupole of DTL (~27mm)



Beam quality: MEBT -> DTL1-DTL2-DTL3-DTL4&5

"ParM"-beam



"Meas"-beam