

Beam Matching with Space Charge (TRACE 3-D Matching Section Design)

Part 2 - 6-D Matching

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Chapter 8

Beam Matching with Space Charge

Matching Section Design - Some Basics

Single Phase Plane (2D) Matching (Mismatch Factor)

Transverse (4D) Matching (used for LEBTs, HEBTs)

Transverse Matching Solutions as a Function of Current

Transverse & Longitudinal (6D) Matching 

RFQ to DTL (MEBT) Matching

Transverse & Longitudinal Matching as a Function of Current

Particle Simulation of Matching Sections

⇒ **Will use the computer lab throughout the discussion**

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Open Saved File "**LEBT_1.pbol**" & **Change** Global Parameters:
(This is the "**Incoming Beam**")

Particle Mass: $+H^+$ (938.27231 MeV)
Beam (Kinetic) Energy: 2.00000 MeV
Frequency: 400.0 MHz

Change All Four Quad ("Q1", "Q2", "Q3", "Q4) Lengths to **2.54 cm**

Change Length of Drift D2 to **$0.25 \beta\lambda$** (All Aliases Will Adjust)

Change Emittances of Beam To:

ϵ_X (π -cm-mrad rms)	ϵ_Y (π -cm-mrad rms)	ϵ_Z (π -keV-deg rms)
0.5	0.5	140.0

Change Twiss Parameters of Beam To:

α_X	β_X (m/rad)	α_Y	β_Y (m/rad)	α_Z	β_Z (deg/keV)
-1.3649	0.1412	1.5125	0.1668	0.03670	0.3385

Change the Beam Piece Comment to "**RFQexit**"

⇒ **Save this setup as "RFQ-DTL_A" (File: RFQ-DTL_A.pbol)**

Open the Final Piece - **Change** the Comment to "**DTL**"

Button "Final Beam" to **Change** Fit Goals: Use "Copy from Initial"
Then Set (**Change**) Twiss Parameters To:

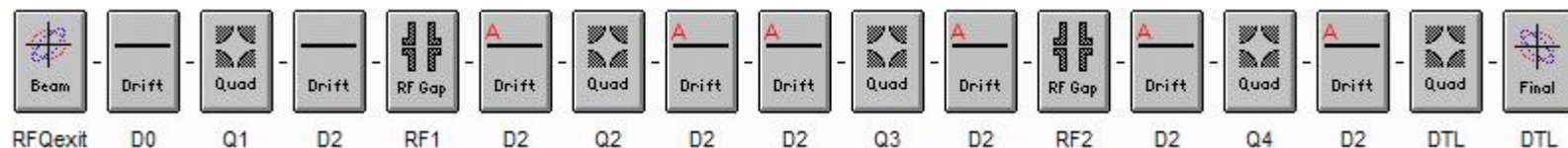
α_X	β_X (m/rad)	α_Y	β_Y (m/rad)	α_Z	β_Z (deg/kev)
0.0000	0.221706	0.0000	0.109947	0.0000	0.320636

Add a DTL Entrance Half-Quad Just Before the Final Piece
Quad "DTL" 1.27 cm Grad 160.0 T/m

Delete the Drifts "D1" and "D4"

Add Two RF Gaps, Commented "RF1" and "RF2", **Centered**
Between Quads Q1-Q2 and Q3-Q4 (Will Set Parameters Next)

The Model Should Look Like This:



⇒ **Save this setup as "RFQ-DTL_A_1" (File: RFQ-DTL_A_1.pbol)**

RF Gaps "RF1" and "RF2"

The screenshot shows the 'RF Gap' configuration window. Annotations include:

- 0.0 MV** and **-90°** pointing to the 'Effective Gap Voltage' and 'Phase of RF' fields respectively.
- Use: Global Frequency** pointing to the 'Radio Frequency Selection' dropdown.
- No** pointing to the 'Emittance Growth Flag' dropdown.
- No** pointing to the 'Energy Gain Flag' dropdown.

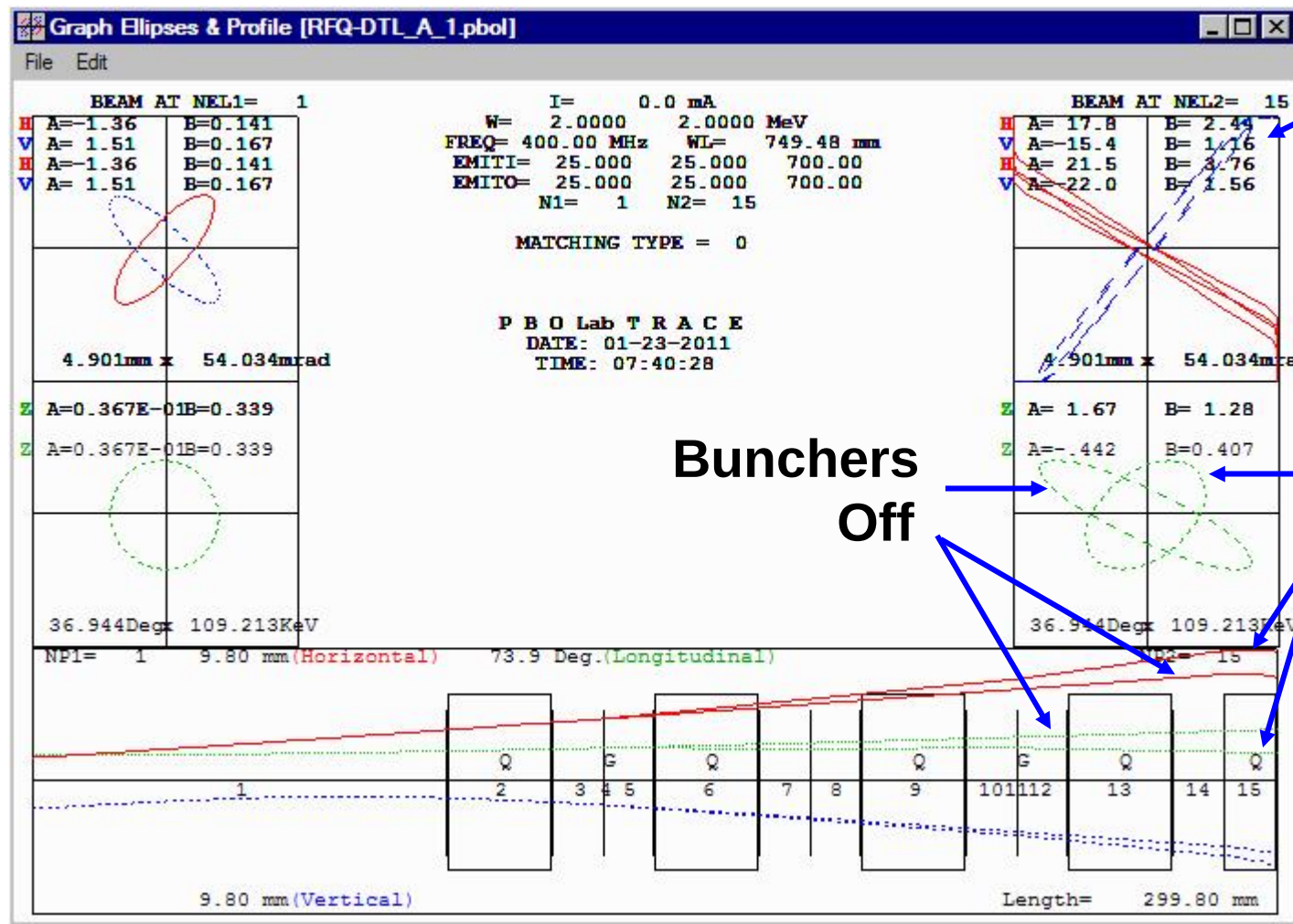
Parameters	Value	Units	Guidance Limits
Effective Gap Voltage	0.000000	MV	-0.4610 0.4610
Phase of RF	-90.000000	Degrees	-90.0000 90.0000
Emittance Growth Flag	No Growth		
Energy Gain Flag	No Gain		
Global Frequency	400.000000	MHz	143.8518 3.00e+004
Global Freq. Harmonic Fact.	1.000000		0.2500 4.0000
Energy Gain of Gap	0.000000	MeV	0.0000 0.0000
Focal Length - x,y direction	-INF	m	-INF -0.1354
Focal Length - z direction	-INF	m	0.0674 INF

Comments:
RF1

Reduce Global Parameters Maximum Step Size to: 0.001 m

⇒ **Save this setup as "RFQ-DTL_A_1" (same name)**

Use the TRACE 3-D **Graph Beam Line Command** (Bunchers Off)
 Turn On Bunchers: Change the **Effective Gap Voltage** to **0.1 MV**
 Use the TRACE 3-D **Trace on Background** Command to Compare



Transverse
Less Focus

Bunchers
Off

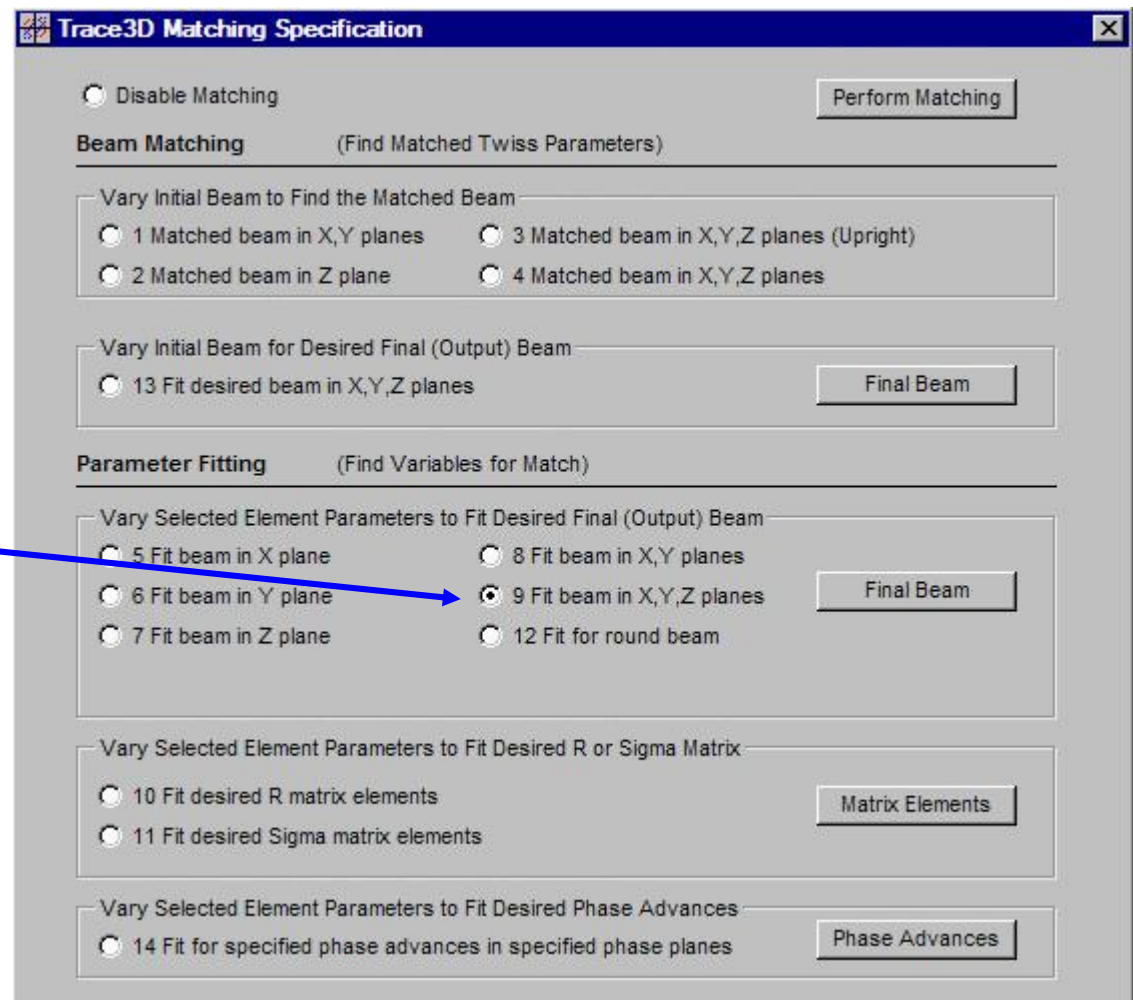
Bunchers
On

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Set 4 Quad ("Q1", "Q2", "Q3", "Q4) Gradients as Match Variables

Set 2 RF Gap ("RF1", "RF2") Gap Voltages as Match Variables

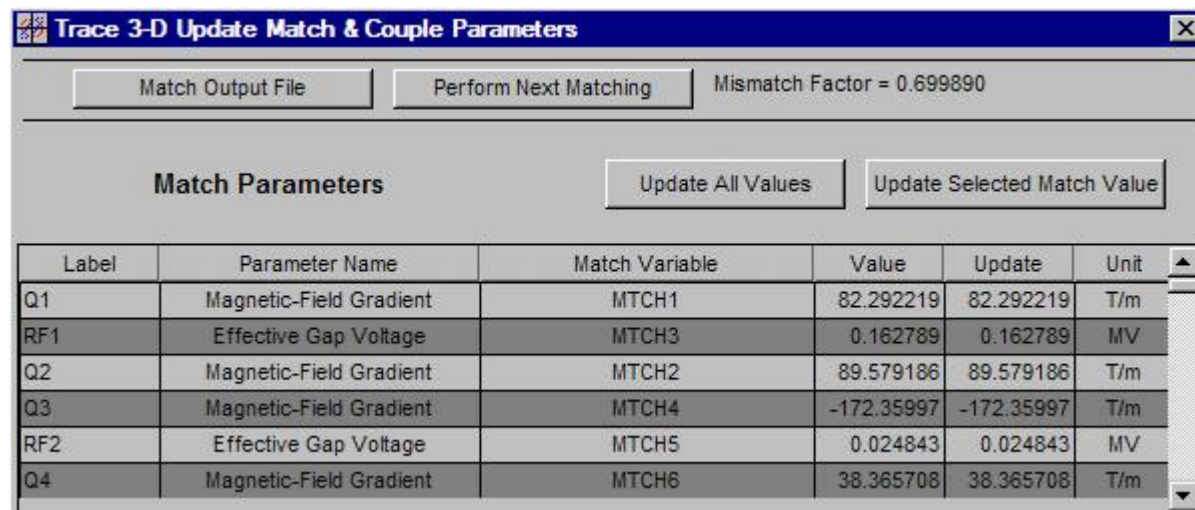
Set Trace 3D Matching Specification To Type 9 "Fit beam in X, Y, Z planes"



⇒ **Save this setup as "RFQ-DTL_A_2" (File: RFQ-DTL_A_2.pbol)**

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Execute the TRACE 3-D Command "Perform Matching"
"Perform Next Matching" Until the MMF Stops Decreasing
You May, but Probably Won't, Get a "Great" Match
One Example MMF Went from ~ 5.95 to ~ 0.700



Label	Parameter Name	Match Variable	Value	Update	Unit
Q1	Magnetic-Field Gradient	MTCH1	82.292219	82.292219	T/m
RF1	Effective Gap Voltage	MTCH3	0.162789	0.162789	MV
Q2	Magnetic-Field Gradient	MTCH2	89.579186	89.579186	T/m
Q3	Magnetic-Field Gradient	MTCH4	-172.35997	-172.35997	T/m
RF2	Effective Gap Voltage	MTCH5	0.024843	0.024843	MV
Q4	Magnetic-Field Gradient	MTCH6	38.365708	38.365708	T/m

Results Can Depend Upon: Starting Value of Match Parameters,
Random Number Initialization,
Order Match of Parameter Selection,
Match Tolerance Used, ...

⇒ Save the Fit as "RFQ-DTL_A_2_Fit_1"

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

To Improve the Match $\Rightarrow$ **Alternate Between 4-D & 2-D Matching**

(Switch Between Transverse and Longitudinal Matching)

Alternate Between:

Type 8 "Fit beam in X, Y planes" and

Type 7 "Fit beam in Z plane"

Check Results with

Type 9 "Fit beam in X, Y, Z planes"

Trace3D Matching Specification

☐ Disable Matching Perform Matching

Beam Matching (Find Matched Twiss Parameters)

Vary Initial Beam to Find the Matched Beam

☐ 1 Matched beam in X,Y planes ☐ 3 Matched beam in X,Y,Z planes (Upright)

☐ 2 Matched beam in Z plane ☐ 4 Matched beam in X,Y,Z planes

Vary Initial Beam for Desired Final (Output) Beam

☐ 13 Fit desired beam in X,Y,Z planes Final Beam

Parameter Fitting (Find Variables for Match)

Vary Selected Element Parameters to Fit Desired Final (Output) Beam

☐ 5 Fit beam in X plane ☒ 8 Fit beam in X,Y planes Final Beam

☐ 6 Fit beam in Y plane ☐ 9 Fit beam in X,Y,Z planes

☐ 7 Fit beam in Z plane ☐ 12 Fit for round beam

Vary Selected Element Parameters to Fit Desired R or Sigma Matrix

☐ 10 Fit desired R matrix elements Matrix Elements

☐ 11 Fit desired Sigma matrix elements

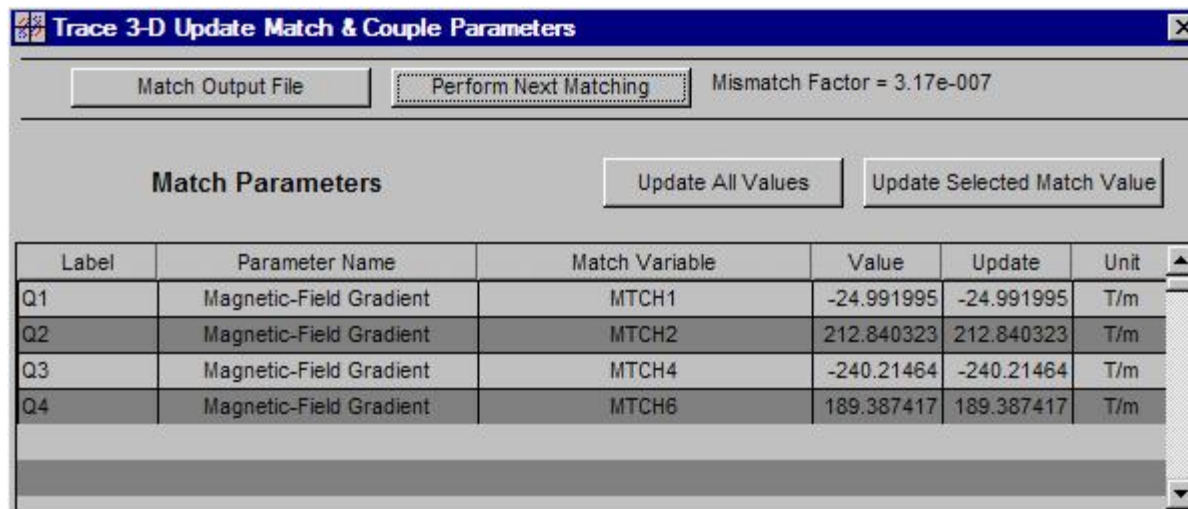
Vary Selected Element Parameters to Fit Desired Phase Advances

☐ 14 Fit for specified phase advances in specified phase planes Phase Advances

Turn Off Match Variables for Unrelated Planes (e.g. no RF for 8)

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Starting from Fit "**RFQ-DTL_A_2_Fit_1**" $\Rightarrow$ Good 4-D Fit Obtained
But Only After *Many* "Perform Next Matching" Commands:



The Longitudinal Match Was Generally Maintained:

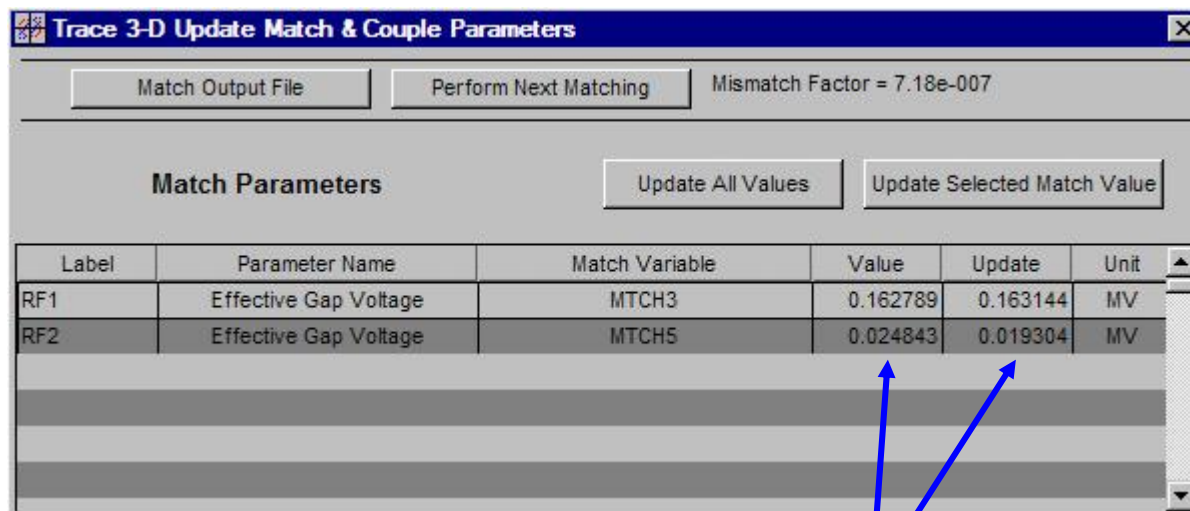
MMF_x = 3.16803083e-007, y = 2.05938166e-007, z = 1.65737045e-002

$\Rightarrow$ **Save the Fit as "RFQ-DTL_A_2_Fit_2"**

$\Rightarrow$ **4-D Iterations May Be Reduced with Better Initial Gradients**

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Starting from Fit "**RFQ-DTL_A_2_Fit_2**" $\Rightarrow$ Good 2-D Fit Obtained After Only **One** "Perform Next Matching" Command:



Label	Parameter Name	Match Variable	Value	Update	Unit
RF1	Effective Gap Voltage	MTCH3	0.162789	0.163144	MV
RF2	Effective Gap Voltage	MTCH5	0.024843	0.019304	MV

Change in Gap Voltages Relatively Small

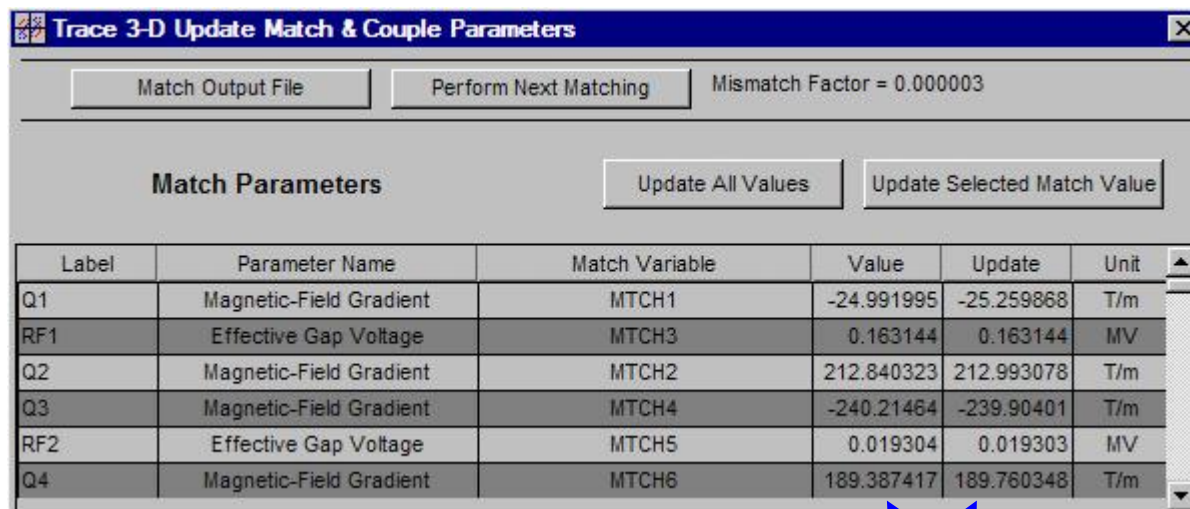
The Transverse Match Was Generally Maintained:

$\text{MMF}_x = 3.29375359\text{e-}003$, $y = 3.11636536\text{e-}002$, $z = 7.17967214\text{e-}007$

$\Rightarrow$ Save the Fit as "**RFQ-DTL_A_2_Fit_3**"

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

Starting from Fit "**RFQ-DTL_A_2_Fit_3**" $\Rightarrow$ Good 6-D Fit Obtained After Only **One** "Perform Next Matching" Command:



Label	Parameter Name	Match Variable	Value	Update	Unit
Q1	Magnetic-Field Gradient	MTCH1	-24.991995	-25.259868	T/m
RF1	Effective Gap Voltage	MTCH3	0.163144	0.163144	MV
Q2	Magnetic-Field Gradient	MTCH2	212.840323	212.993078	T/m
Q3	Magnetic-Field Gradient	MTCH4	-240.21464	-239.90401	T/m
RF2	Effective Gap Voltage	MTCH5	0.019304	0.019303	MV
Q4	Magnetic-Field Gradient	MTCH6	189.387417	189.760348	T/m

Changes in All Parameters Relatively Small

Rarely Any Need for This Kind of Precision in LINAC Design:

MMF_x= 4.55278742e-007, y= 2.80753852e-006, z= 0.000000000e+000

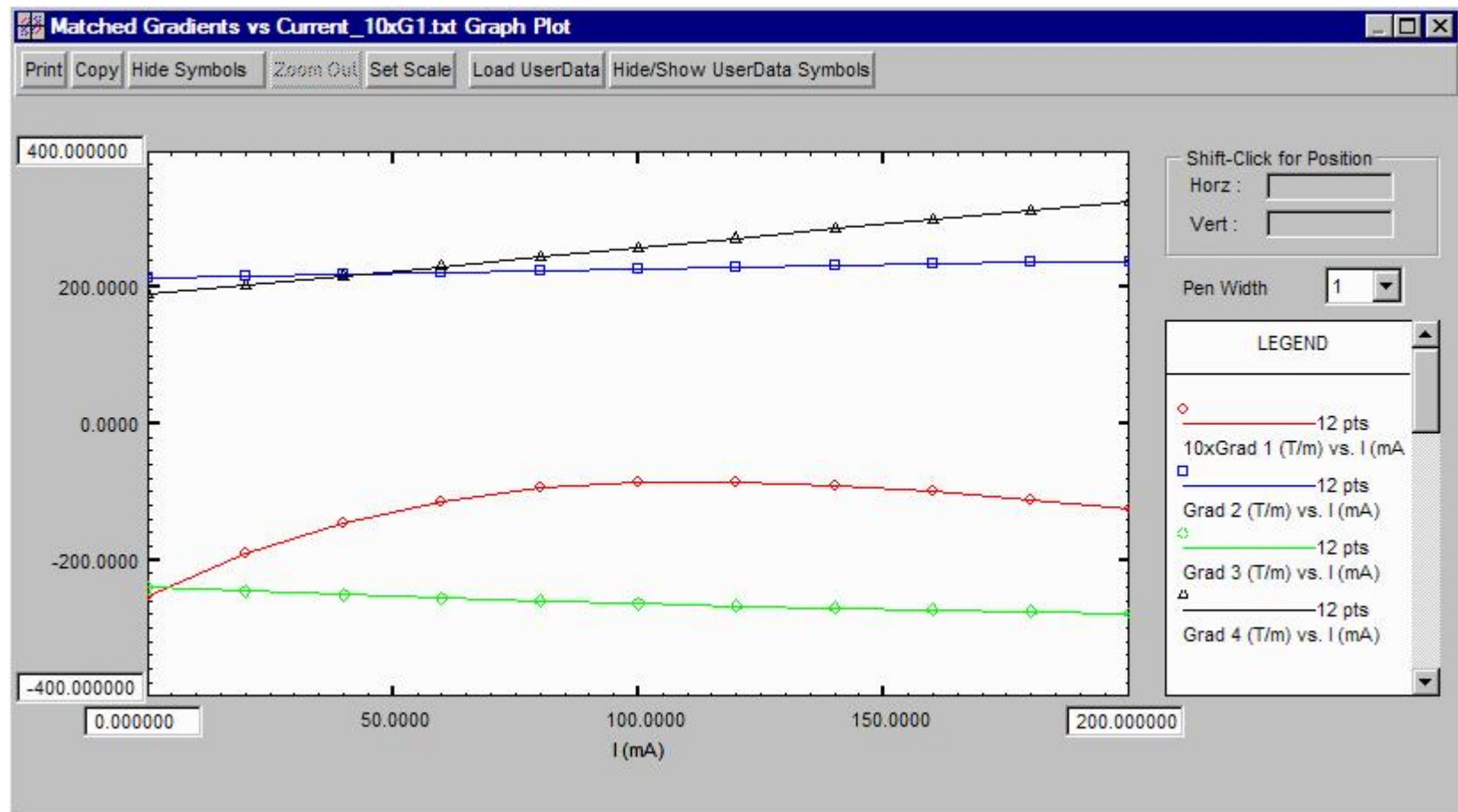
$\Rightarrow$ **Save the Fit as "RFQ-DTL_A_2_Fit_4"**

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

- Space Charge Can Strongly Couple X, Y, Z Phase Planes
 - Start with Good Match for "0" Current and Increase Current
 - Increase Current So that Starting MMF is Less Than ~ 0.2
 - Try Match Type 9 "Fit beam in X, Y, Z planes" (6-D Matching)
 - May Need to Alternate 4-D / 2-D Similar to "0" Current Example
- ⇒ Start with "RFQ-DTL_A_2_Fit_4" and Increase Current
Find a Matched Beam for a Current of 100 mA
Watch Changes in the Quad Gradients & RF Gap Voltages
- ⇒ Save the Fit as "RFQ-DTL_A_100_mA_Fit"

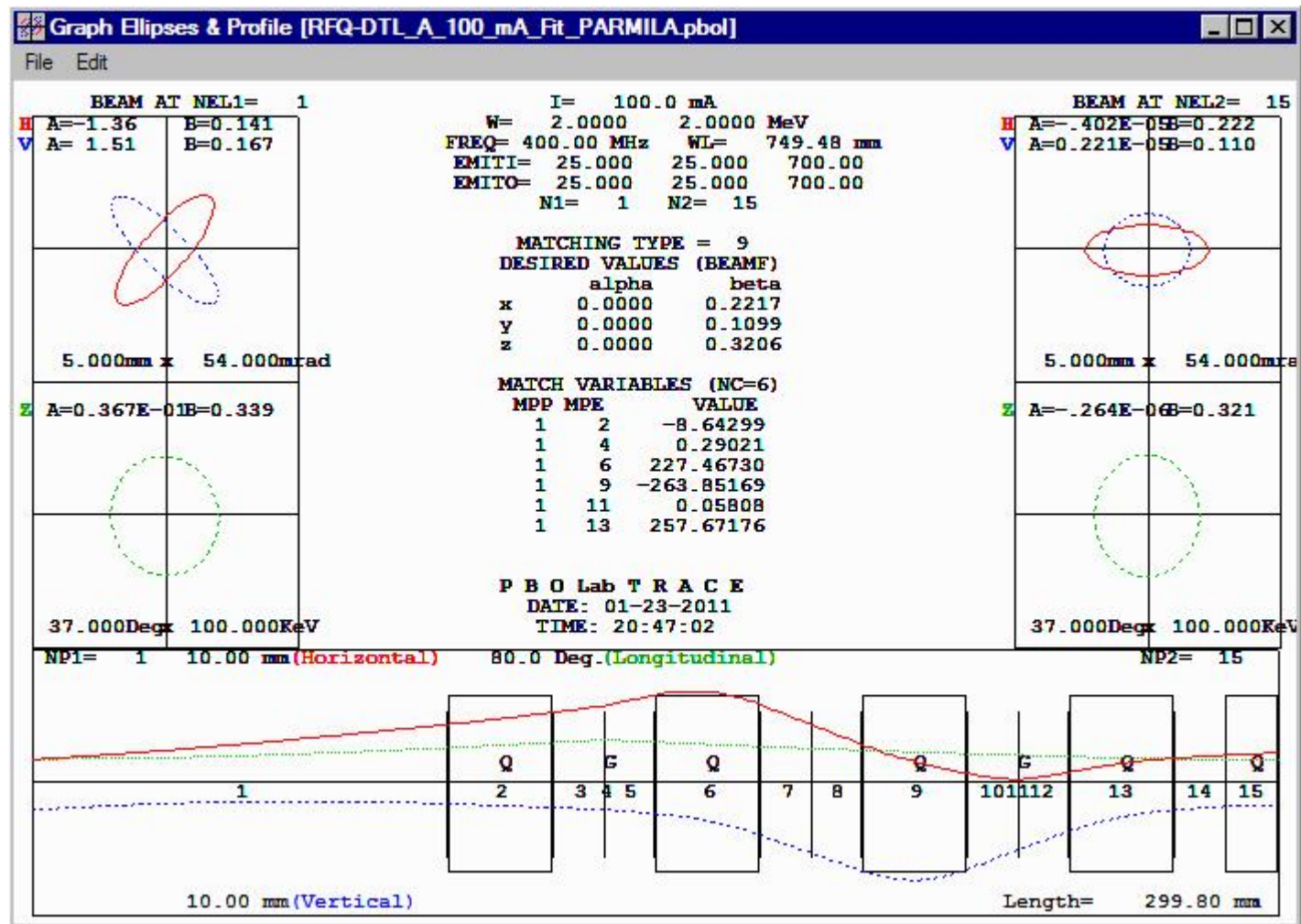
Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

Matched Quad Gradients as a Function of Beam Current



Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

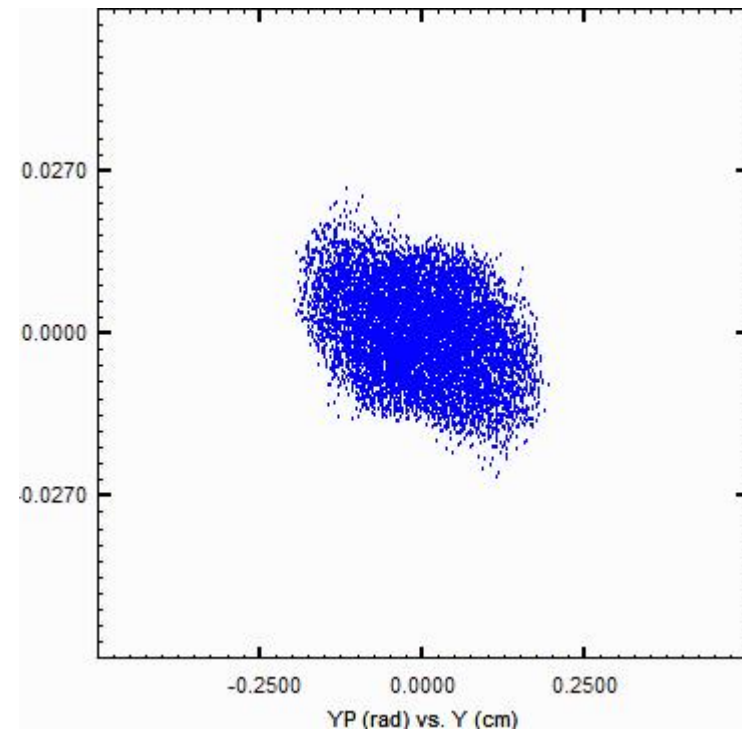
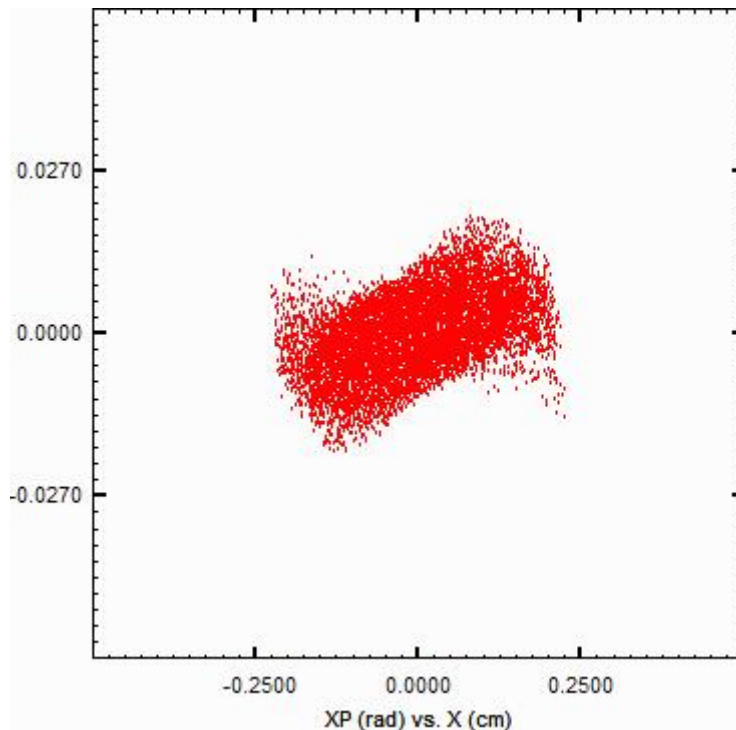
Comparison of PARMILA-2 Particle Simulation with TRACE 3-D



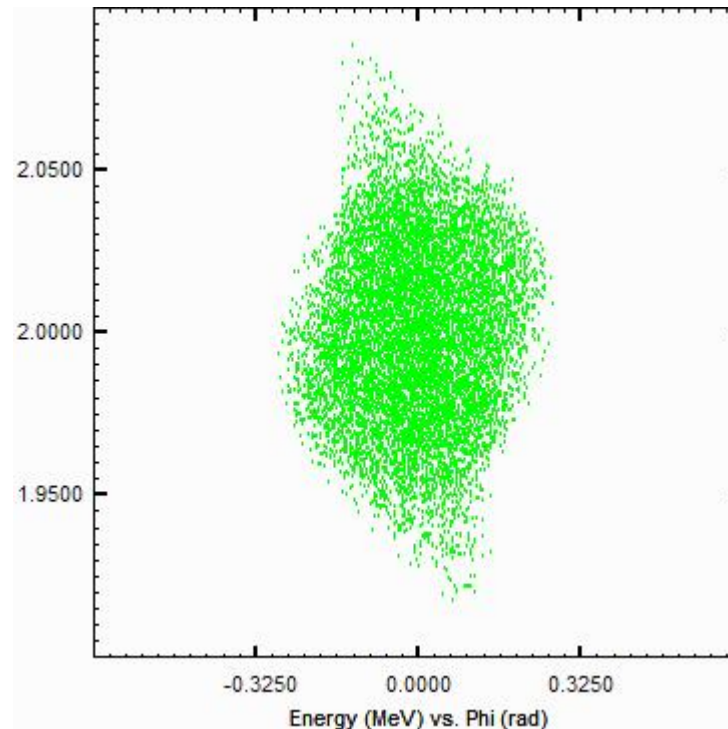
Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

PBO Lab PARMILA-2 Particle Simulation of the Matching Section

- Add PrtBeam and SCHEFF Pieces - adjust Scheff parameters
- Set PARMILA-2 Options - OutputFlag, Use_PICNIC_3D
- Add LinGraf Piece - select plots and set parameters



Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge



- **Particle Simulation Improvements Possible with PARMILA-2**
 - More Accurate Simulation by Segmenting Drifts
 - More Accurate Simulation by Splitting Quads
- **Simulation Indicates TRACE 3-D Results Only Provide a Guide**

Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

