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"

$\Rightarrow$ 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:

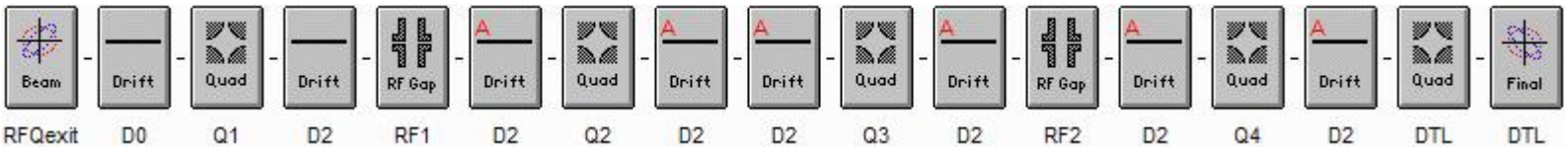
α_X	β_X (m/rad)	α_Y	β_Y (m/rad)	α_Z	β_Z (deg/kev)
0.0000	0.221706	0.0000	0.109947	0.0000	0.320636

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"

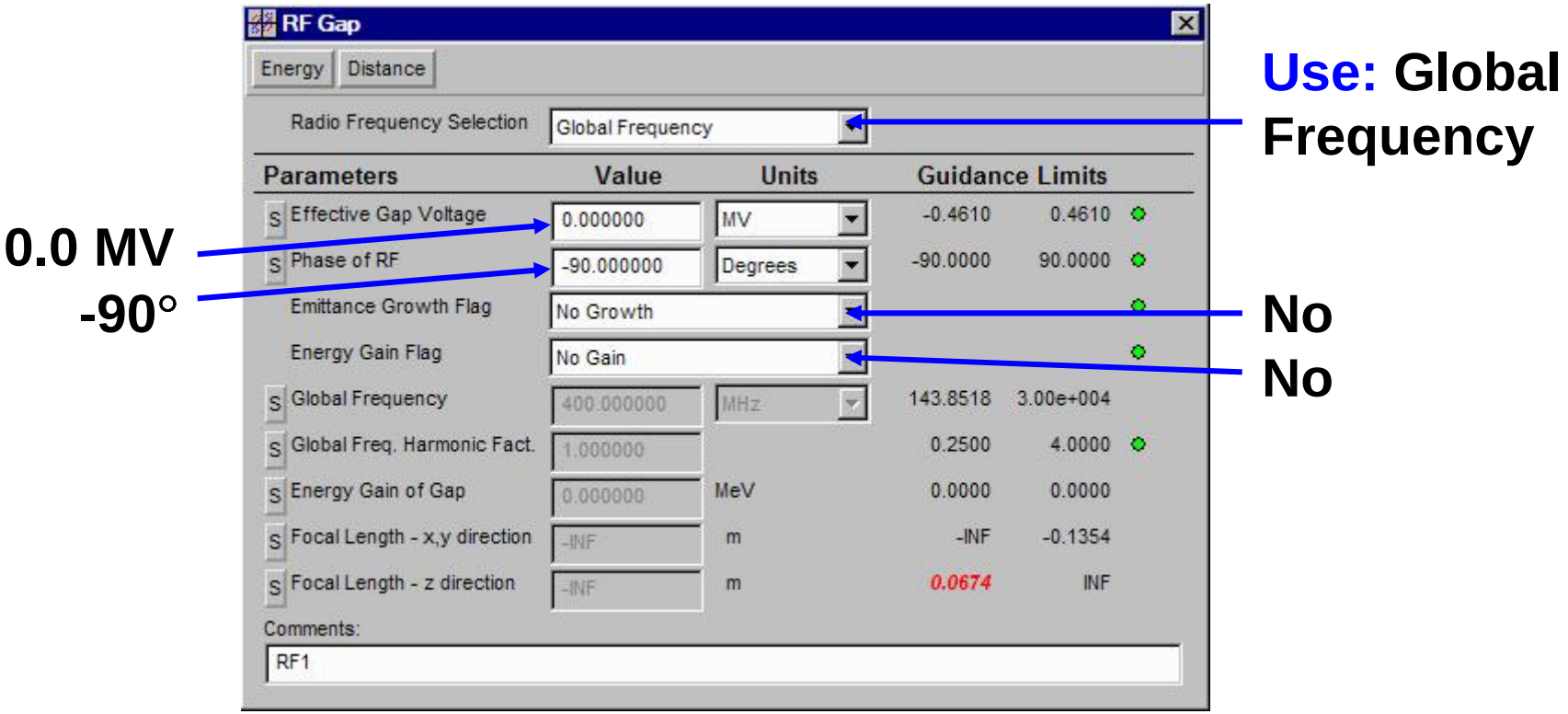
Add Two RF Gaps, Commented "RF1" and "RF2", Centered Between Quads Q1-Q2 and Q3-Q4 (Will Set Parameters Next)

The Model Should Look Like This:



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

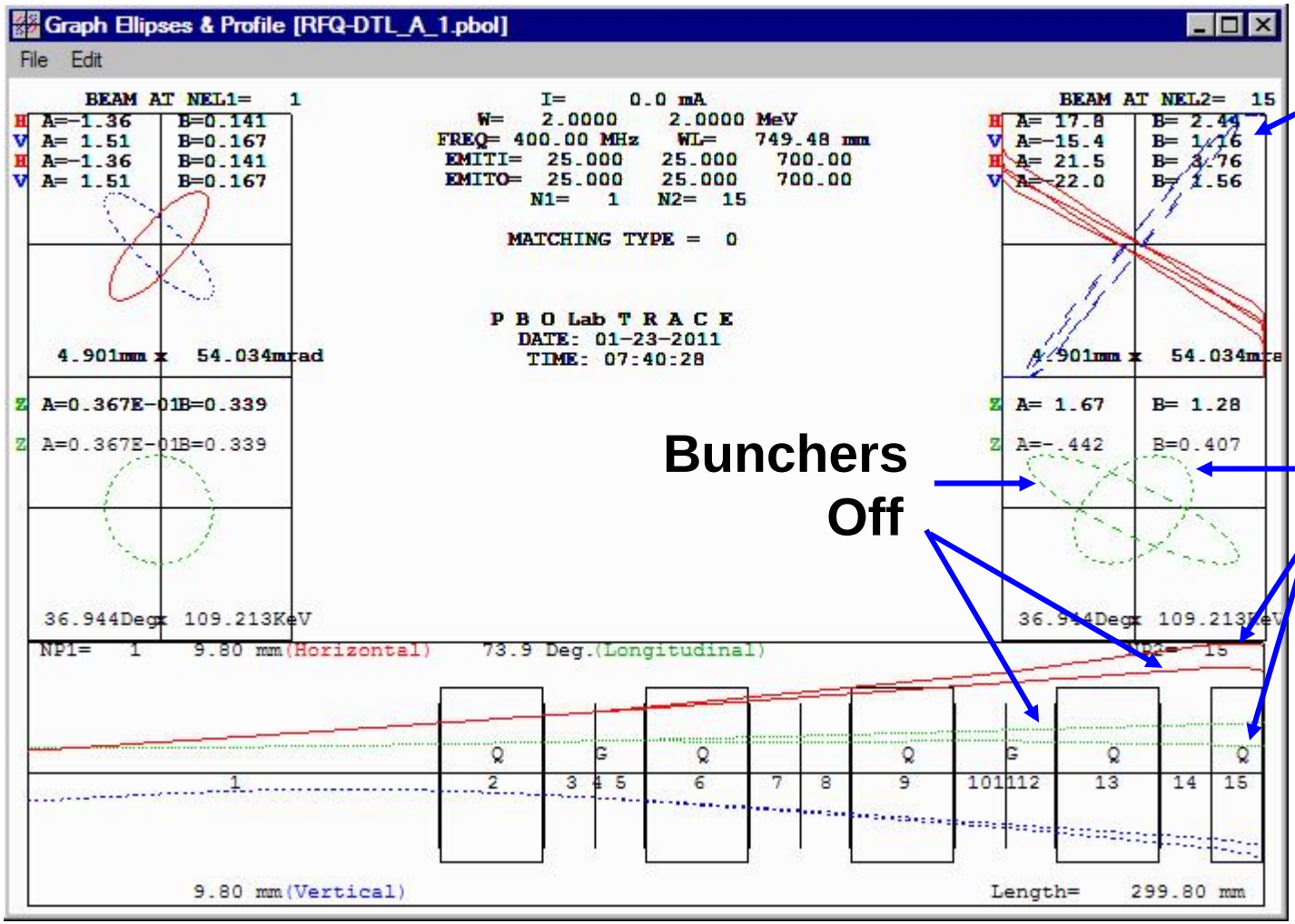
RF Gaps "RF1" and "RF2"



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

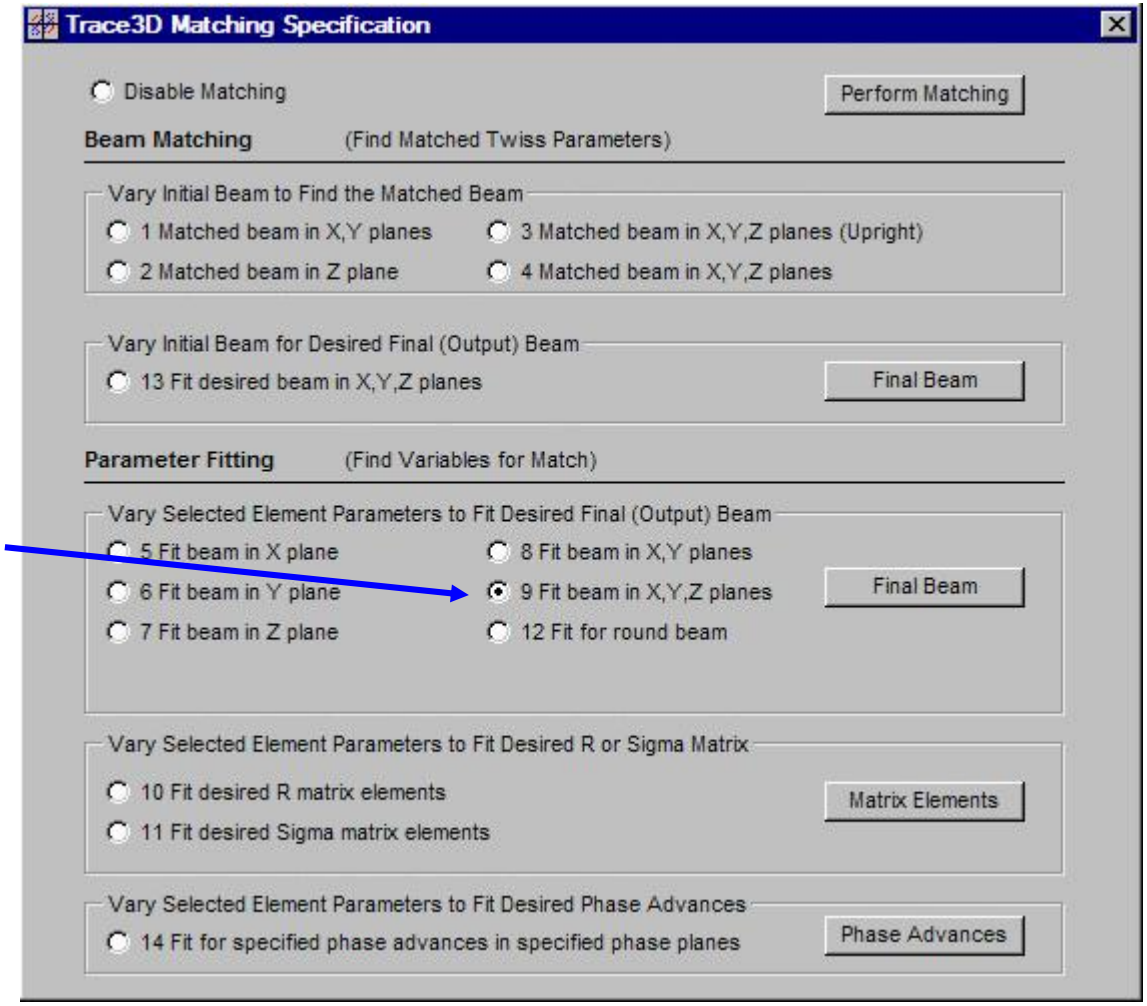


Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

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)**

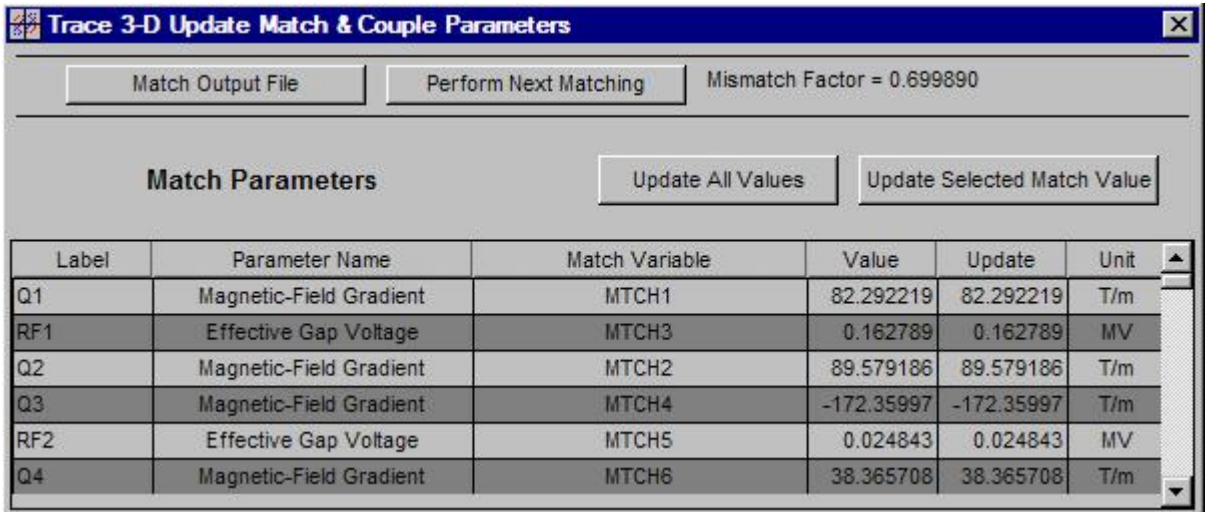
Transverse & Longitudinal (6D) Matching - RFQ-DTL Example

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 ⇒ Alternate Between 4-D & 2-D Matching

(Switch Between Transverse and Longitudinal Matching)

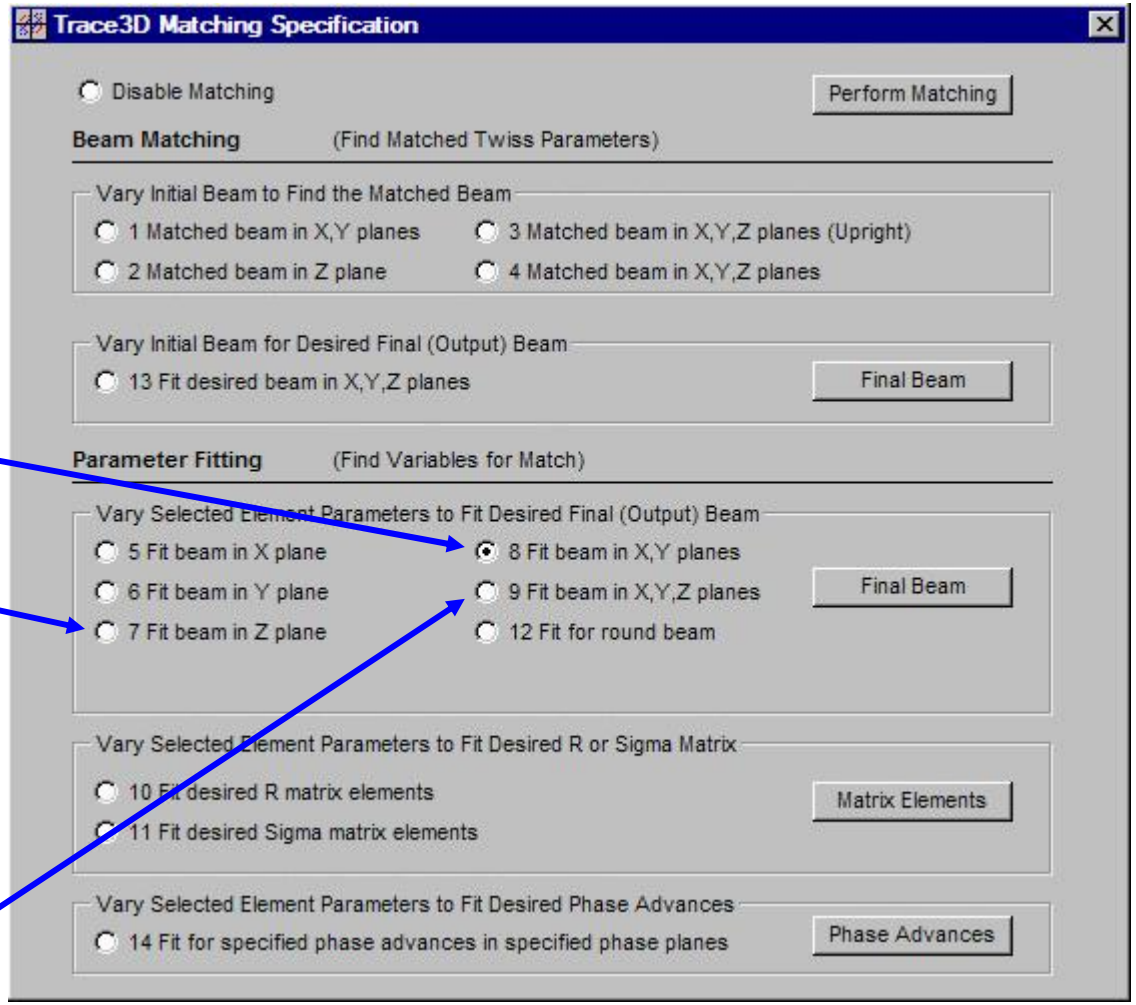
Alternate Between:

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

Type 7 "Fit beam in Z plane"

Check Results with

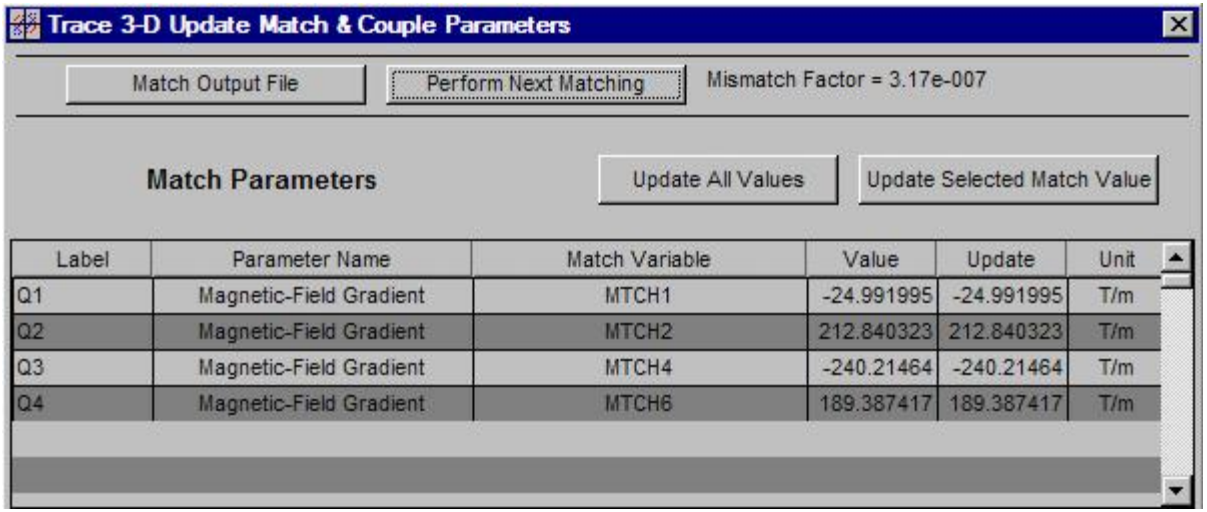
Type 9 "Fit beam in X, Y, Z planes"



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" ⇒ Good 4-D Fit Obtained But Only After *Many* "Perform Next Matching" Commands:



Label	Parameter Name	Match Variable	Value	Update	Unit
Q1	Magnetic-Field Gradient	MTCH1	-24.991995	-24.991995	T/m
Q2	Magnetic-Field Gradient	MTCH2	212.840323	212.840323	T/m
Q3	Magnetic-Field Gradient	MTCH4	-240.21464	-240.21464	T/m
Q4	Magnetic-Field Gradient	MTCH6	189.387417	189.387417	T/m

The Longitudinal Match Was Generally Maintained:

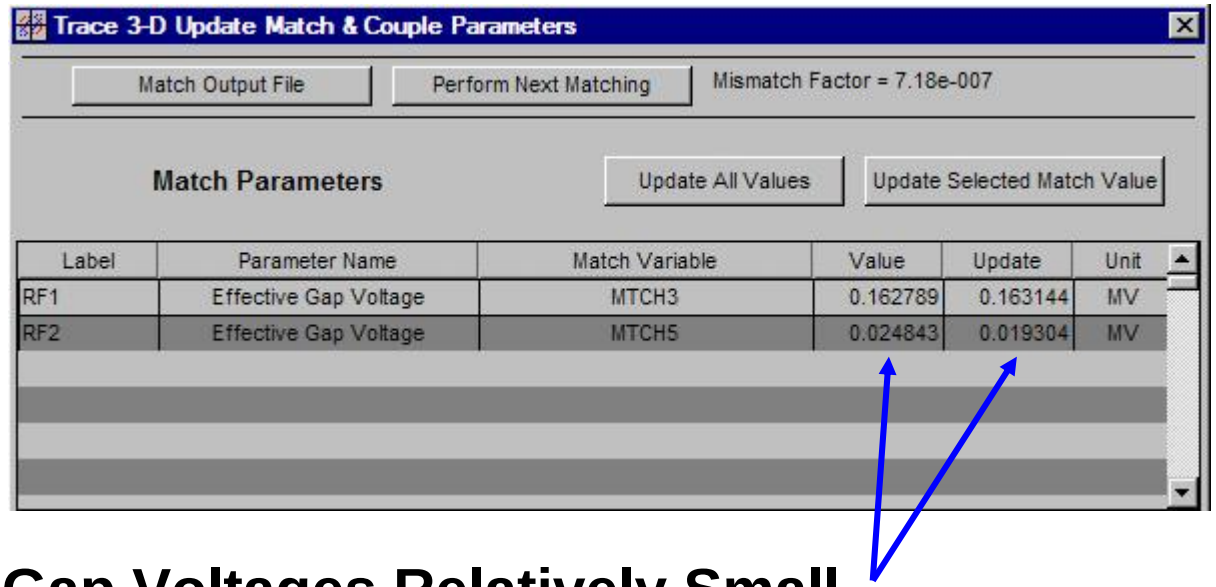
MMFx= 3.16803083e-007, y= 2.05938166e-007, z= 1.65737045e-002

⇒ Save the Fit as "RFQ-DTL_A_2_Fit_2"

⇒ 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" ⇒ Good 2-D Fit Obtained After Only *One* "Perform Next Matching" Command:



Change in Gap Voltages Relatively Small

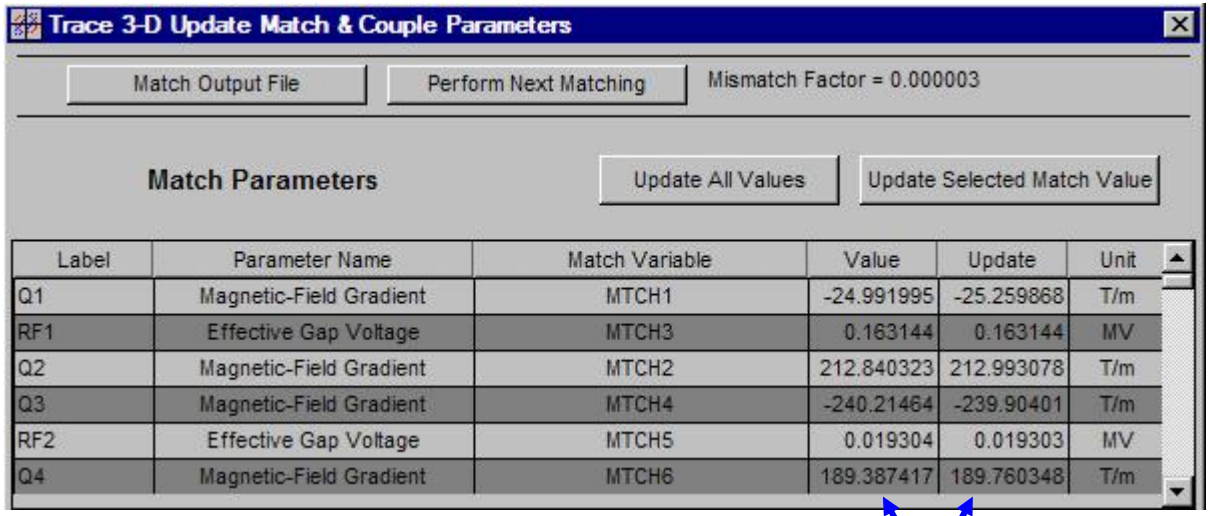
The Transverse Match Was Generally Maintained:

MMFx= 3.29375359e-003, y= 3.11636536e-002, z= 7.17967214e-007

⇒ **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" ⇒ 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:

MMFx= 4.55278742e-007, y= 2.80753852e-006, z= 0.00000000e+000

⇒ **Save the Fit as "RFQ-DTL_A_2_Fit_4"**

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

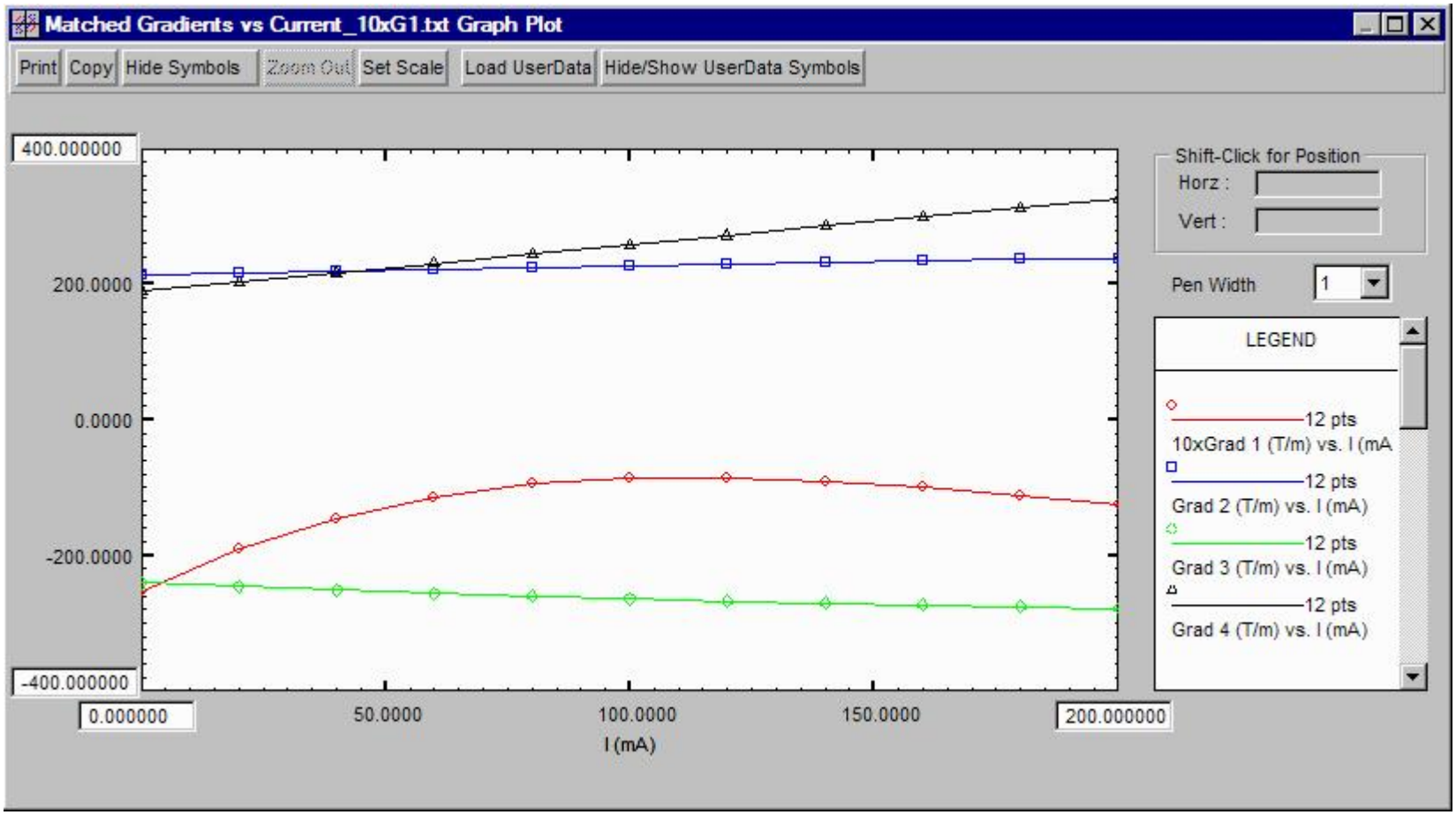
- **Space Charge Can Strongly Couple X, Y, Z Phase Planes**
- **Start with Good Match for "0" Current and Increase Current**
- **Increase Current So that Starting MMF is Less Than ~0.2**
- **Try Match Type 9 "Fit beam in X, Y, Z planes" (6-D Matching)**
- **May Need to Alternate 4-D / 2-D Similar to "0" Current Example**

$\Rightarrow$ **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

$\Rightarrow$ **Save the Fit as "RFQ-DTL_A_100_mA_Fit"**

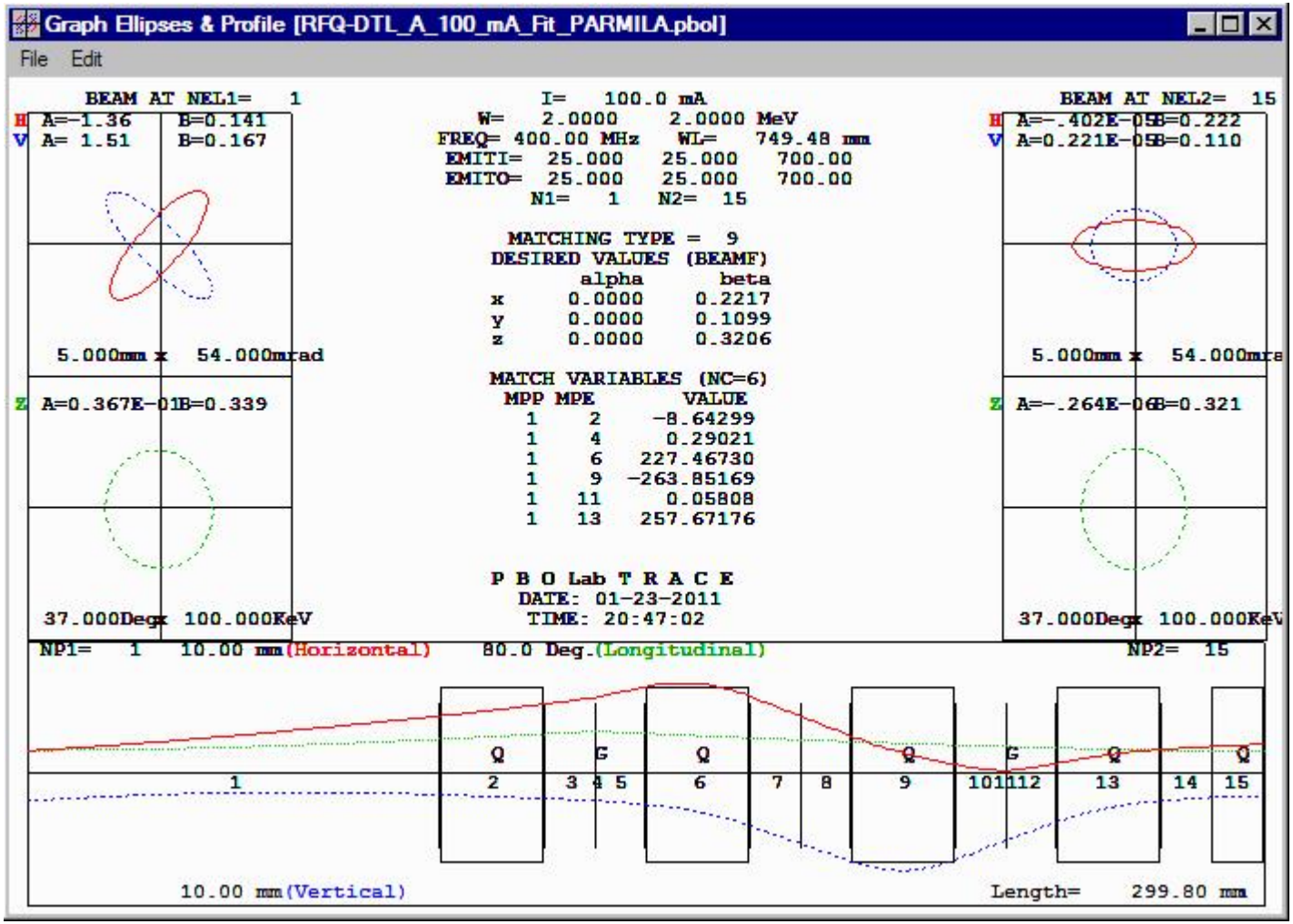
Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

Matched Quad Gradients as a Function of Beam Current



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

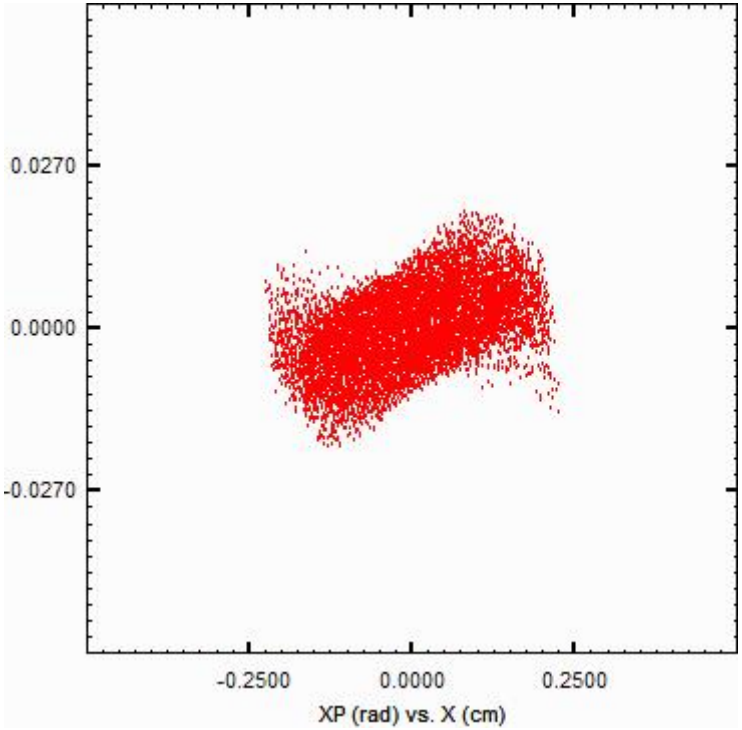
Comparison of PARMILA-2 Particle Simulation with TRACE 3-D

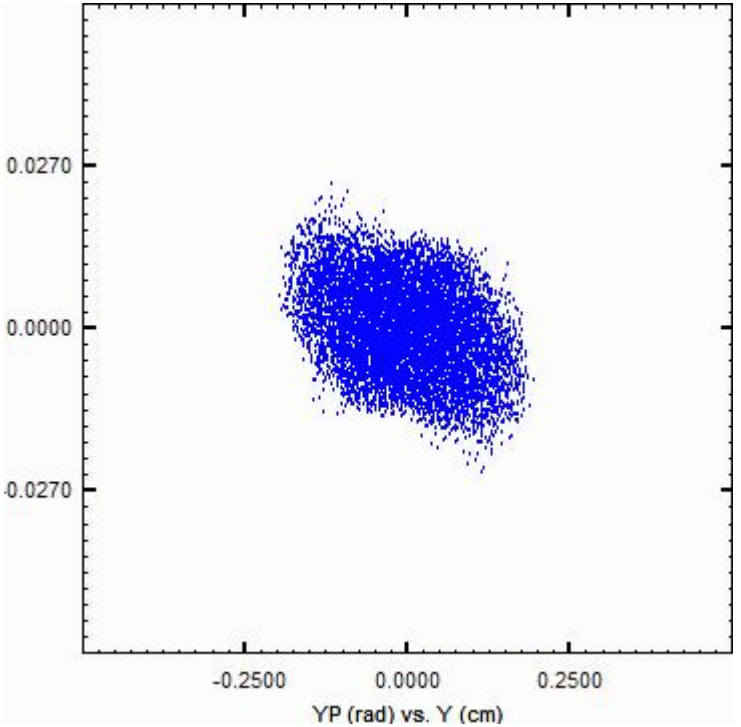


Transverse & Longitudinal (6D) Matching - RFQ-DTL Example With Space Charge

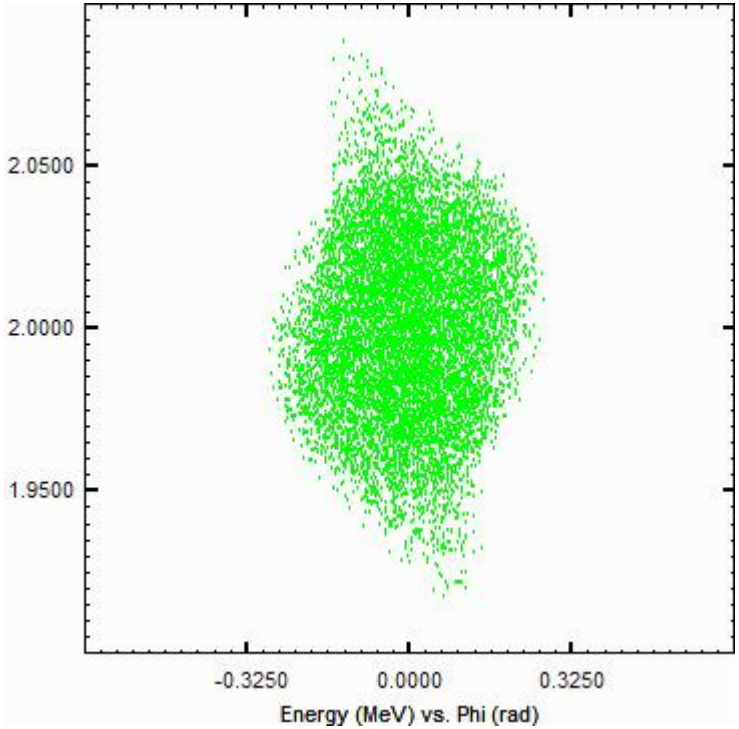
PBO Lab PARMILA-2 Particle Simulation of the Matching Section

- 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