Using an Envelope and Matrix Code
PBO Lab TRACE 3-D Example Set 1

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Outline- Part II - Example Set 1

⇒ **Will use PBO Lab TRACE 3-D Module to work through some examples**

FODO Lattice

1. Setup a PBO Lab "template" with Global Parameters for the following beam:

Particle Mass:	**Protons**
Beam (Kinetic) Energy:	**2.5 MeV**
Frequency:	**402.5 MHz**

Add a "Beam" to the Model Space. Label it (Comment) "Beam_0"

Open the "Beam" and set the Beam Parameters switch to the setting "Courant-Synder (Twiss) - Beam 2"

Set the horizontal and vertical emittances both to:

0.0015 π-cm-mrad, rms

$\Rightarrow$ **Save this setup as "Setup_1" (File: Setup_1.pbol)**

We will use Setup_1 as the starting point for several examples

FODO Lattice

Starting with Setup_1 construct the following FODO lattice:

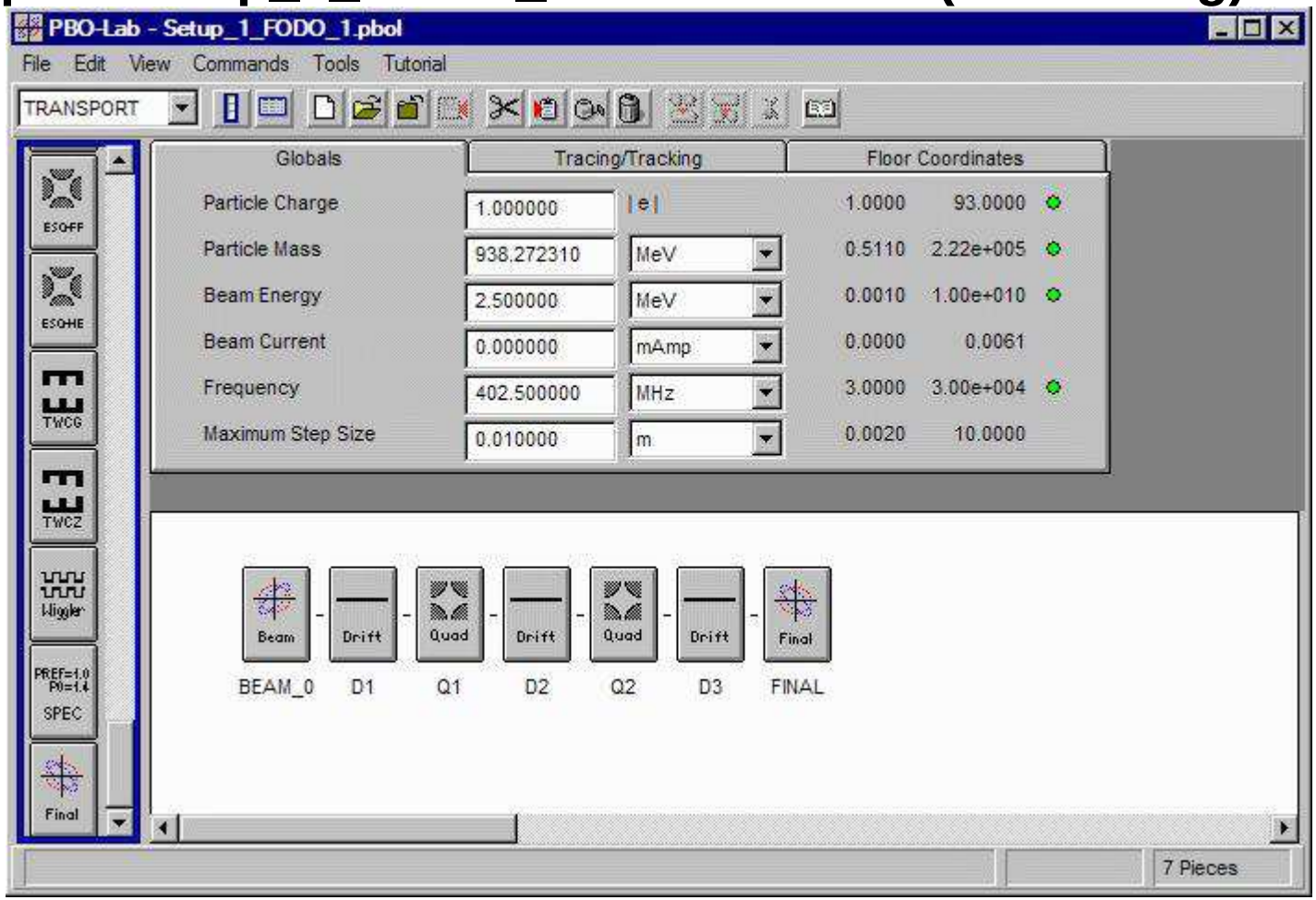
Drift "D1"	**20 cm long**	
Quad "Q1"	**10 cm long**	**20 T/m field gradient**
Drift "D2"	**40 cm long**	
Quad "Q2"	**10 cm long**	**-20 T/m field gradient**
Drift "D3"	**20 cm long**	

Add a "Final" element to the end of the beamline

⇒ **Save this example as "Setup_1_FODO_1"**

FODO Lattice

Example "Setup_1_FODO_1" should look (something) like this:

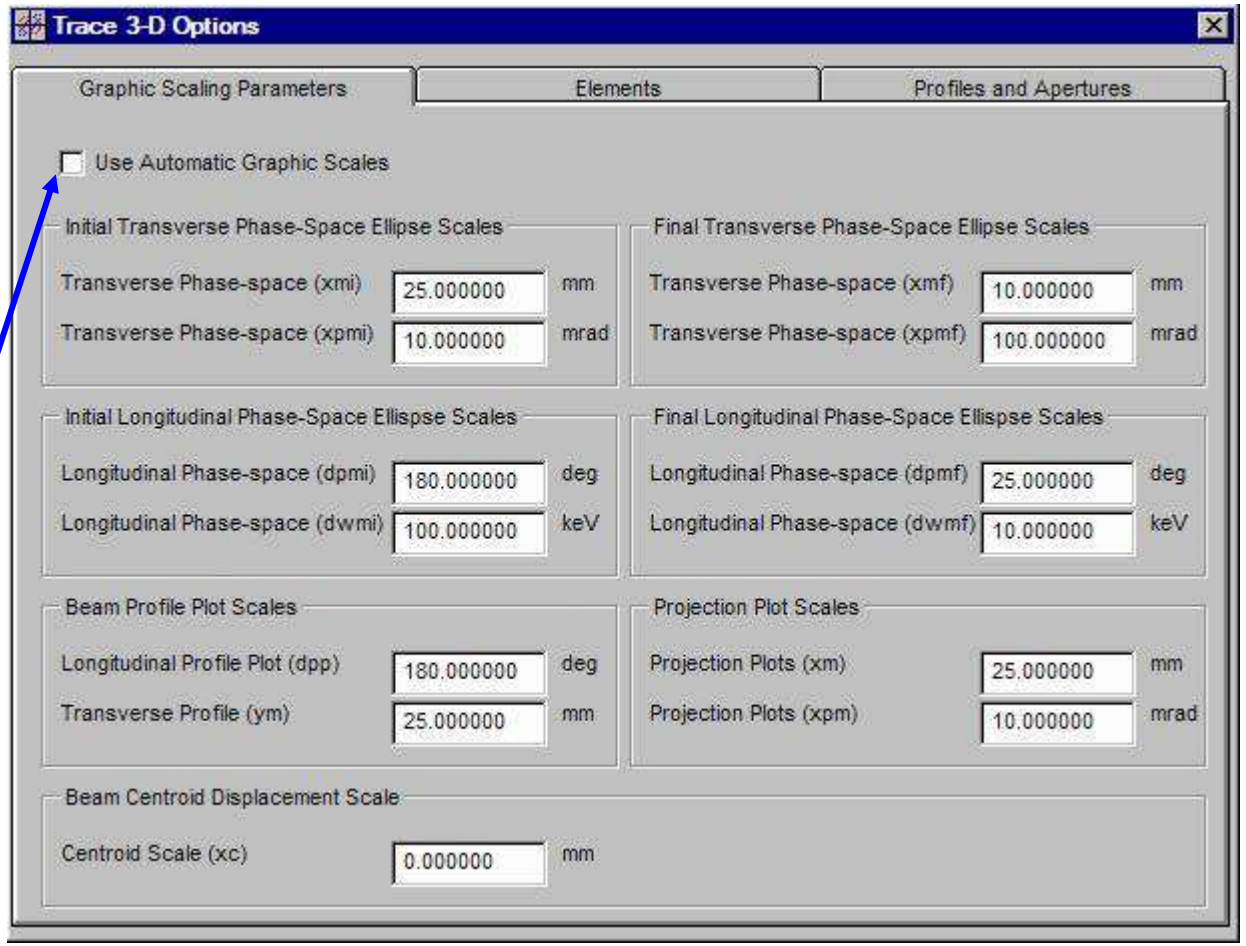


Use the menu chain: Commands->TRACE 3-D->Graph Beam Line

⇒ Result Does Not Look So Pretty! Let's Find Some Scales

FODO Lattice

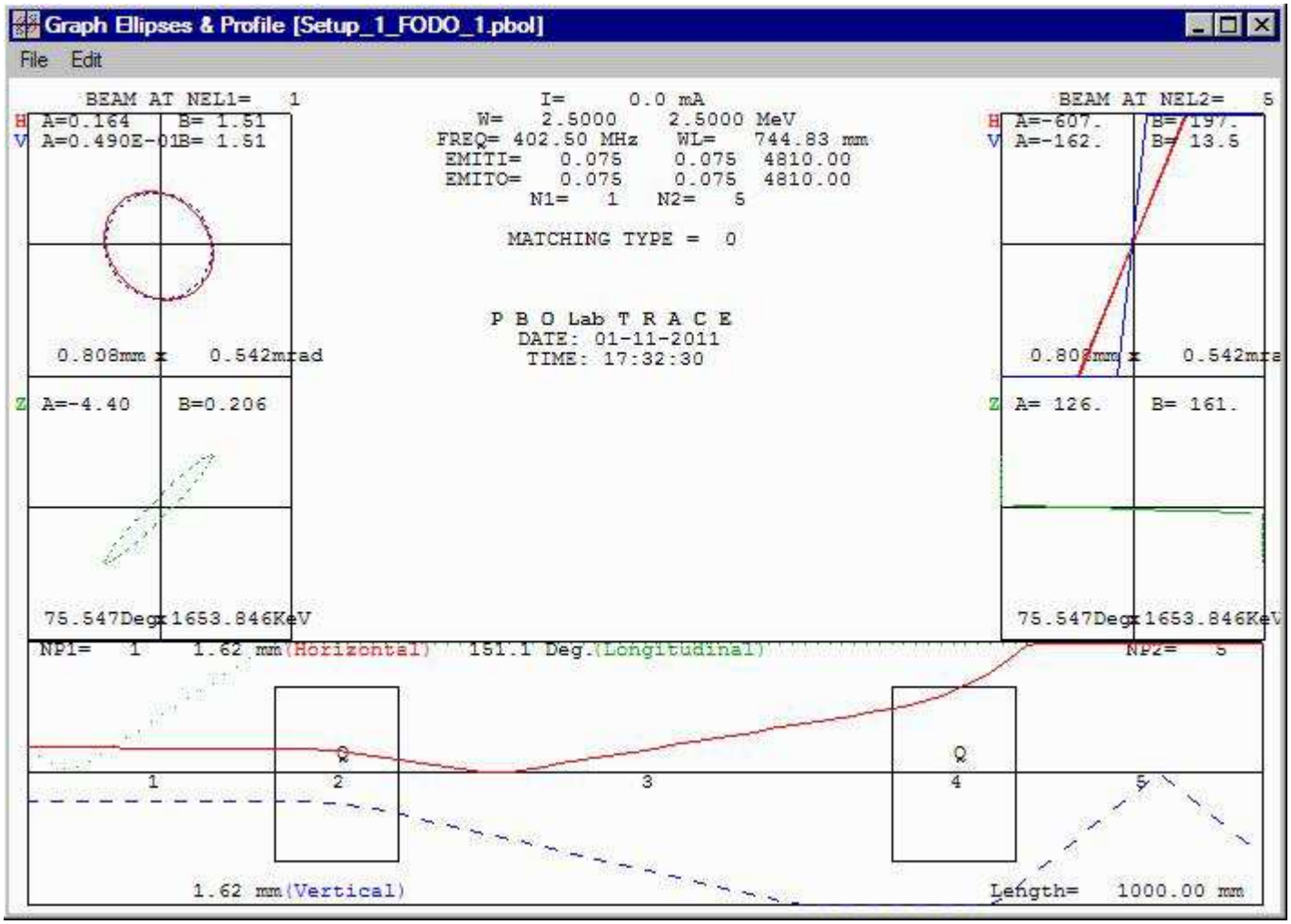
Use the menu chain: Commands->TRACE 3-D->Options
A window titled "Trace 3-D Options" should open:



Check box "Use Automatic Graph Scales" ⇒ numbers change

FODO Lattice

Use the menu chain: Commands->TRACE 3-D->Graph Beam Line



⇒ **Well, Still Not "Pretty," But Most Data Now Visible**

⇒ **Save this updated example (same name "Setup_1_FODO_1")**

FODO Lattice

Go back to the "Trace 3-D Options" window and
uncheck the box "Use Automatic Graph Scales"

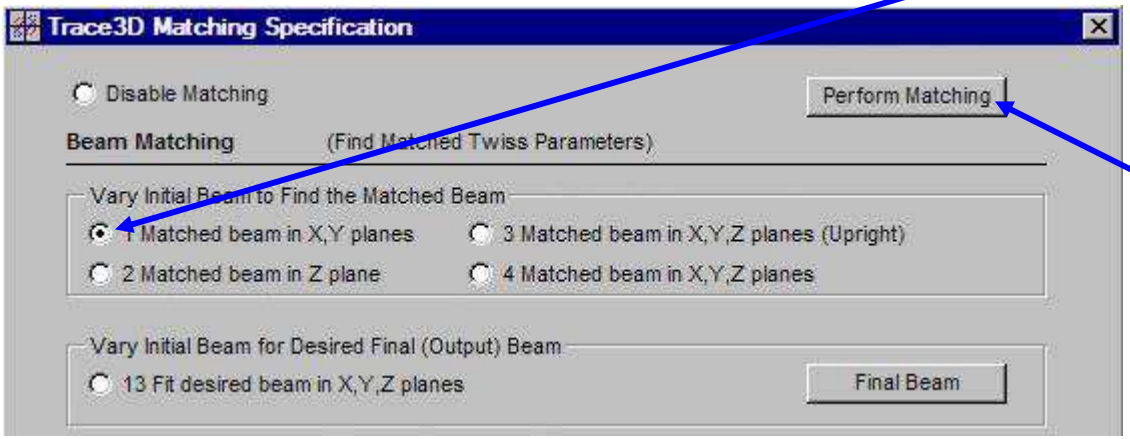
⇒ **Don't want the plot scales changing every time we run!**

Finding Matched Beam for a FODO Lattice (1st Attempt)

2a. If Necessary Set the Context Switch to TRACE 3-D

Open the Final Piece
Use the "Open" button under the Constraints panel

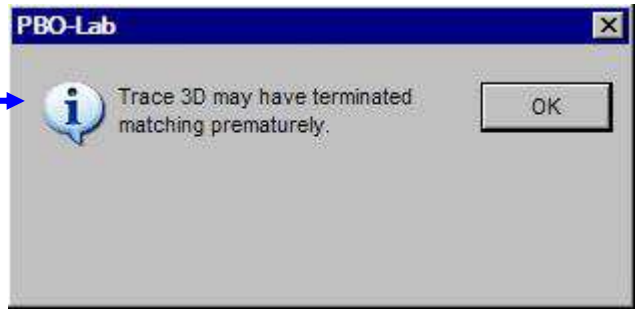
For "Beam Matching" - "Vary Initial Beam to Find Matched Beam"
Select the Option: "1 Matched beam in X, Y planes"



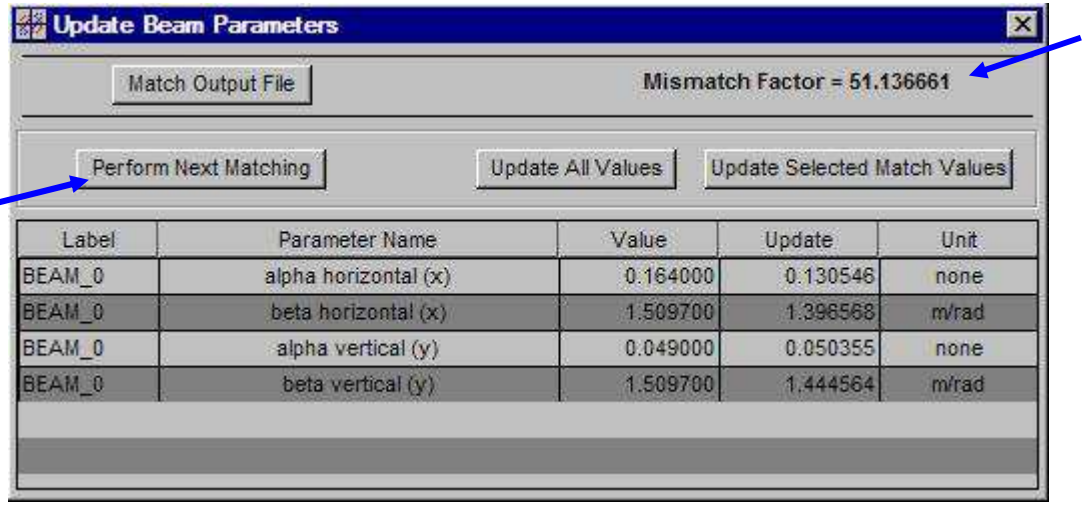
Then use the button "Perform Matching"

Finding Matched Beam for a FODO Lattice (1st Attempt)

You may get something that looks like an error dialog
Just click OK!



You can continue to ask TRACE 3-D to search for a solution, using the "Perform Next Matching" button. The Mismatch Factor will improve, but won't get below about 13.5 or so.



What's happening here?

This FODO lattice does *not* have a matched beam solution.

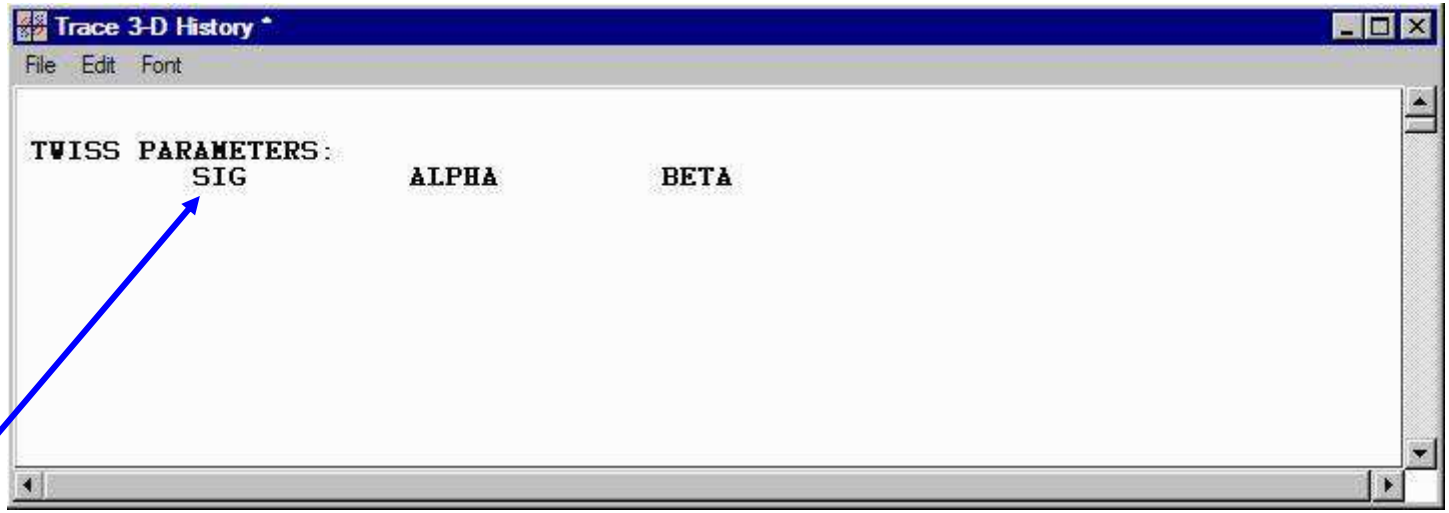
⇒ **the lattice is "unstable" - an "unmatchable" FODO lattice**

⇒ **Is there a quick way to know this in advance?**

Finding Matched Beam for a FODO Lattice (1st Attempt)

Use menu: Commands->TRACE 3-D->Calculate Phase Advance

You will a text file output window named "Trace 3-D History" that will have virtually nothing in it:



TRACE 3-D first attempts to calculate the phases advances, called "SIG" in this text output. TRACE 3-D "SIG" is in degrees.

The lack of data means that the phases advances are complex, i.e., the lattice for the beamline is unstable (all 3 phase planes).

⇒ **Leave the "Trace 3-D History" file window OPEN**

Finding Matched Beam for a FODO Lattice (2nd Attempt)

2b. Start over from the Setup_1_FODO_1, but now reduce the strengths of the quads. Try these

Quad "Q1" 10 cm long +10 T/m field gradient
Quad "Q2" 10 cm long - 10 T/m field gradient

First: Use the TRACE 3-D Command to Graph Beam Line.
Next: Use the TRACE 3-D Calculate Phase Advance.
Do you think you can find a matched beam now?

2c. Reduce the strengths of the quads further:

Quad "Q1" 10 cm long +5 T/m field gradient
Quad "Q2" 10 cm long - 5 T/m field gradient

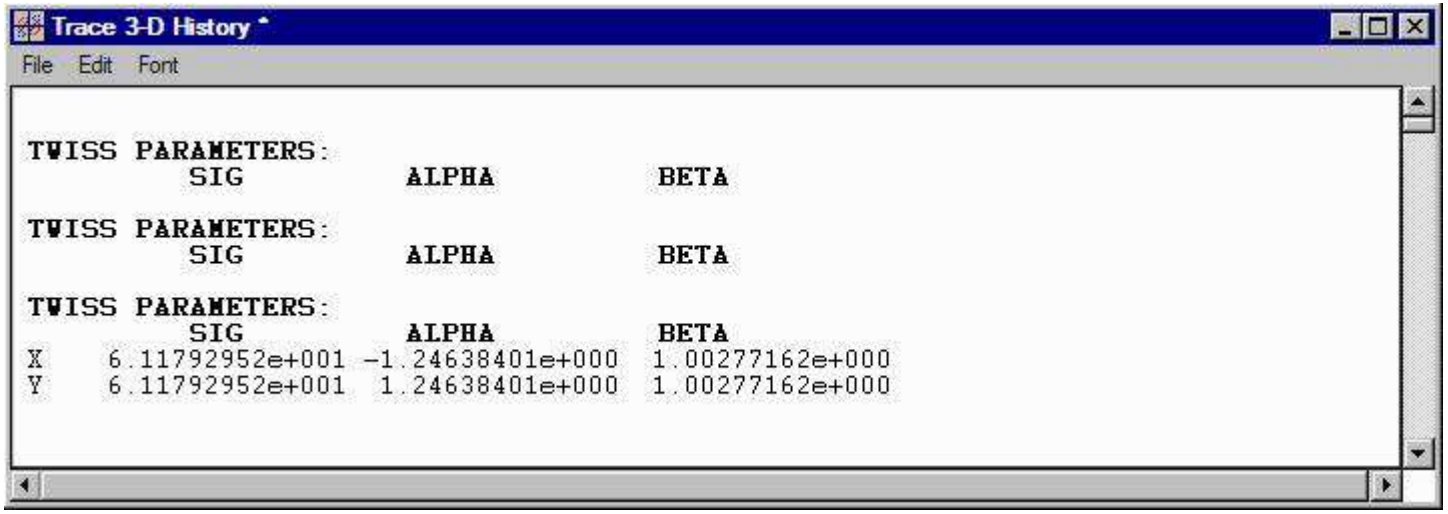
First: Use the TRACE 3-D Command to Graph Beam Line.
Next: Use the TRACE 3-D Calculate Phase Advance.
Do you think you can find a matched beam now?

⇒ **When you get "SIG" values, save as "Setup_1_FODO_2"**

Finding Matched Beam for a FODO Lattice (2nd Attempt)

"Setup_1_FODO_2"

The "Trace 3-D History" file should look something like this:



In addition to the X and Y Phase Advances (SIG), TRACE 3-D also computes the X and Y Twiss Parameters for the matched beam (ALPHA, BETA).

Why no data for Z ?

Have the matched beam parameters, but the data are not yet in the Beam Piece for other calculations ⇒ Copy & Paste numbers?

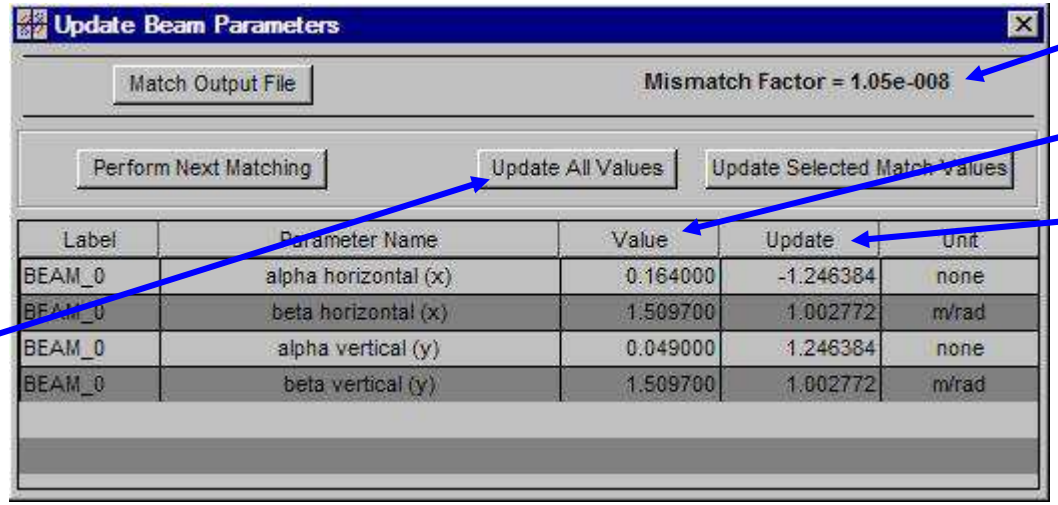
Finding Matched Beam for a FODO Lattice

"Setup_1_FODO_2"

(Quad "Q1" 10 cm long +5 T/m field gradient)
(Quad "Q2" 10 cm long - 5 T/m field gradient)

2d. Use the TRACE 3-D Command: Perform Matching

You should get these matched beam parameters:



Note MMF

Start Values

Solutions

Update All Values

α_X	β_X (m/rad)	α_Y	β_Y (m/rad)
-1.246384	1.002772	1.246384	1.002772

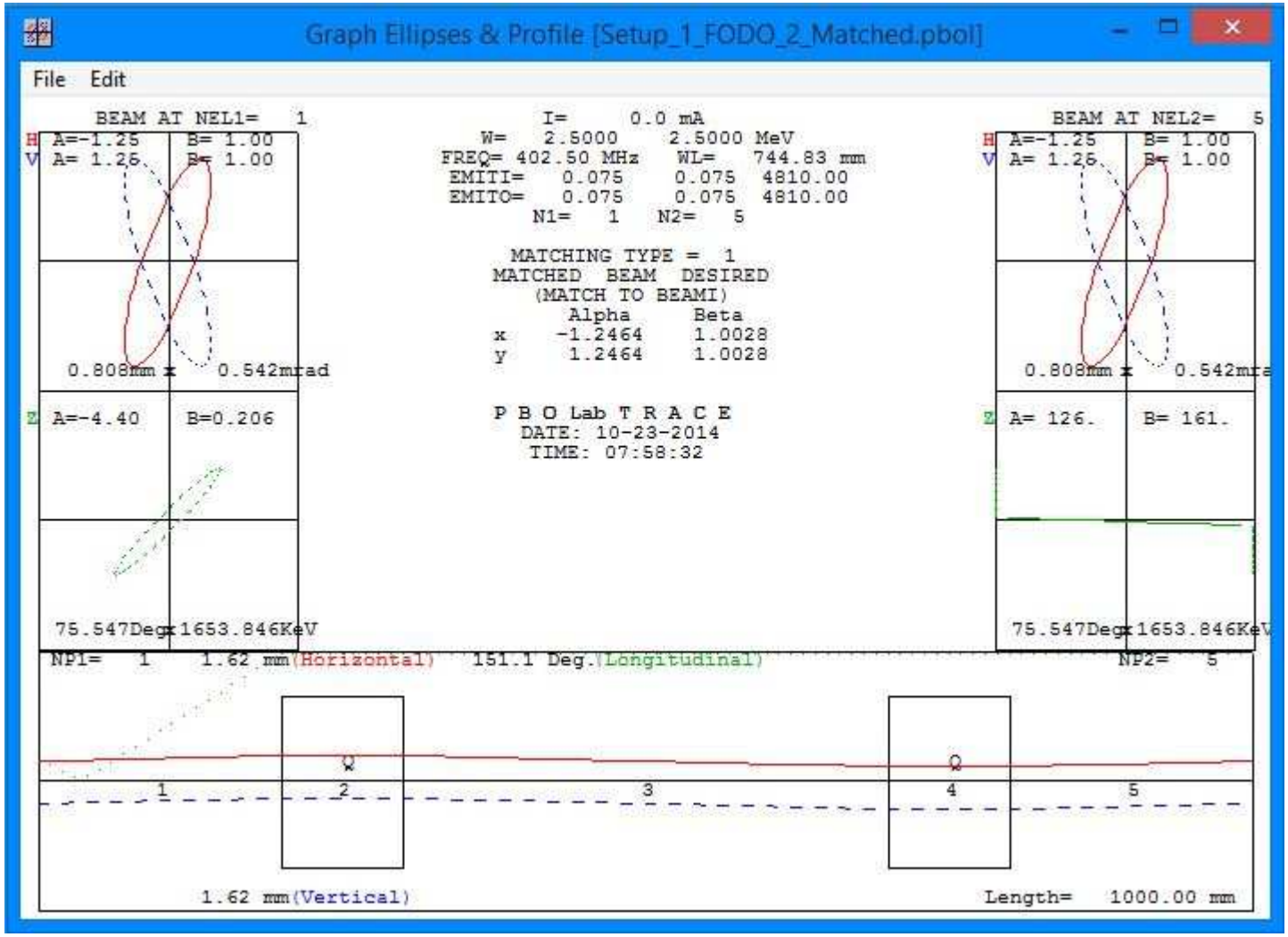
⇒ **Change the Beam Piece Comment to "Beam_1"**

⇒ **Save this example as "Setup_1_FODO_2_Matched"**

Finding Matched Beam for a FODO Lattice

2e. Use the TRACE 3-D Command: Graph Beam Line

You should now get a typical "matched beam" envelope display:



Finding a FODO Lattice for a Matched Beam Requirement

We will Find the Quad Strengths to Transport a Given Beam

⇒ **If you have not already done so, close & reopen PBO Lab**

3. Open the two (2) PBO Lab Files previously saved:

"Setup_1_FODO_1"

"Setup_1_FODO_2_Matched"

In the model "Setup_1_FODO_2_Matched" select (highlight via mouse) "Beam_1" Piece, and then use Edit->Copy

Switch to the model "Setup_1_FODO_1" and use Edit->Paste

⇒ **Beam Piece should appear on the Work Space**

Move Beam Piece to the Model Space of "Setup_1_FODO_1"

Delete the "old" Beam_0" Piece from the Model Space

Close the model "Setup_1_FODO_2_Matched"

⇒ **This is just to avoid any confusion!**

⇒ **Save the new example as "Setup_2_FODO_1"**

Finding a FODO Lattice for a Matched Beam Requirement

"Setup_2_FODO_1"

3a. Open the "Q1" Quad Window

Make Sure the Quadrupole Strength selection is set to Field Gradient

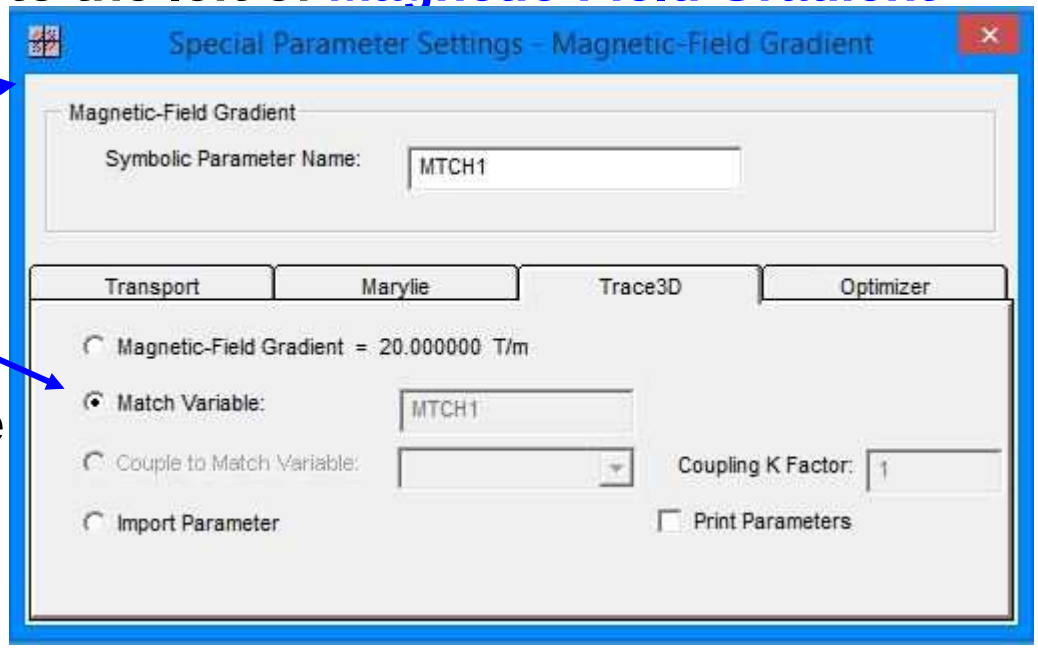
Select the "S" button that is to the left of Magnetic-Field Gradient

You should see a window like this

On the TRACE 3-D panel select Match Variable

"MTCH1" will appear as a Symbolic Parameter Name

Close this "S" window & the "Q1" Quad Window



⇒ **Save this updated example (same name "Setup_2_FODO_1")**

Finding a FODO Lattice for a Matched Beam Requirement

"Setup_2_FODO_1"

3b. Open the "Q2" Quad Window

Select Magnetic-Field Gradient "S" button

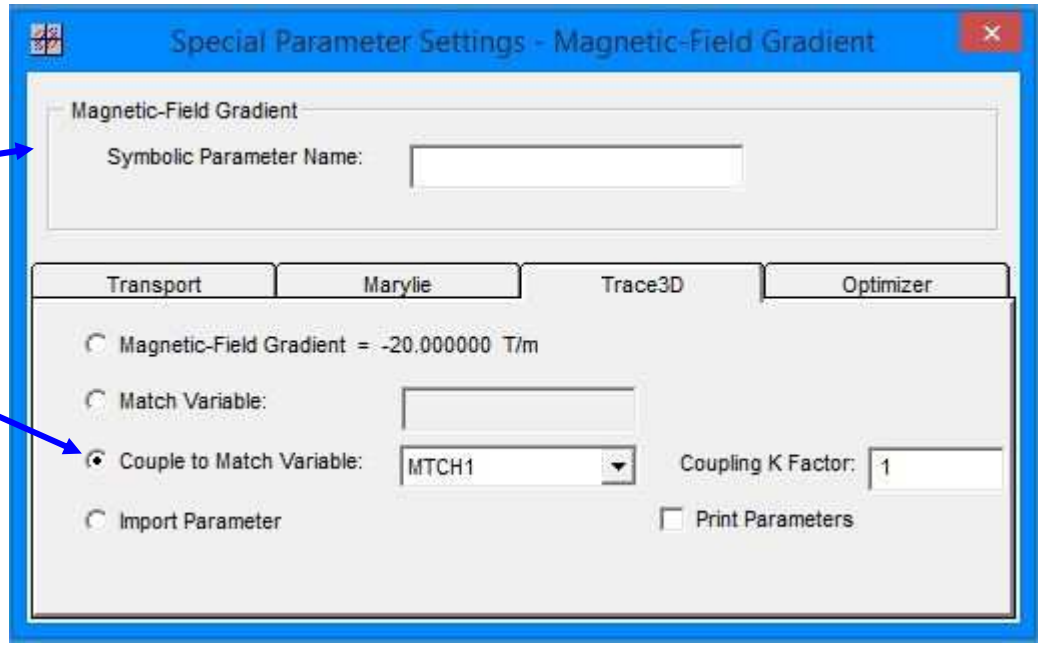
Then select Couple to Match Variable and select the "MTCH1" choice (only one available)

The window should look like this

The Couple to Match Variable set to "MTCH1

What to set for Coupling K Factor?

For now leave a "+1" choice



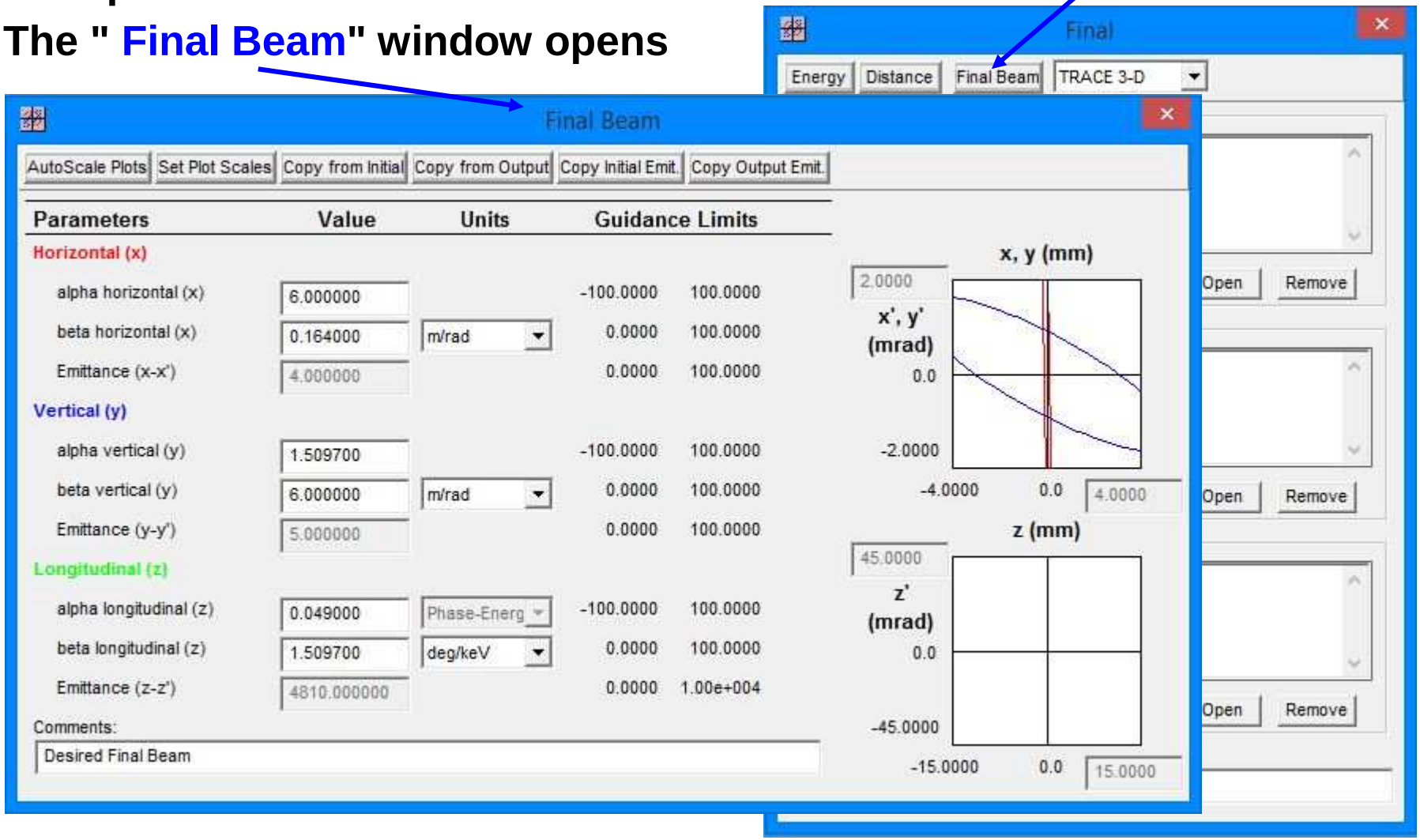
Close this "S" window & the "Q2" Quad Window

⇒ **Save this updated example (same name "Setup_2_FODO_1")**

Finding a FODO Lattice for a Matched Beam Requirement

3c. Open the Final Piece window and select Final Beam button

The " Final Beam" window opens



At This Point, One Could Enter the Desired Matched Beam Parameters: i.e. Open the Initial Beam, Copy α and β Values into Final Beam window

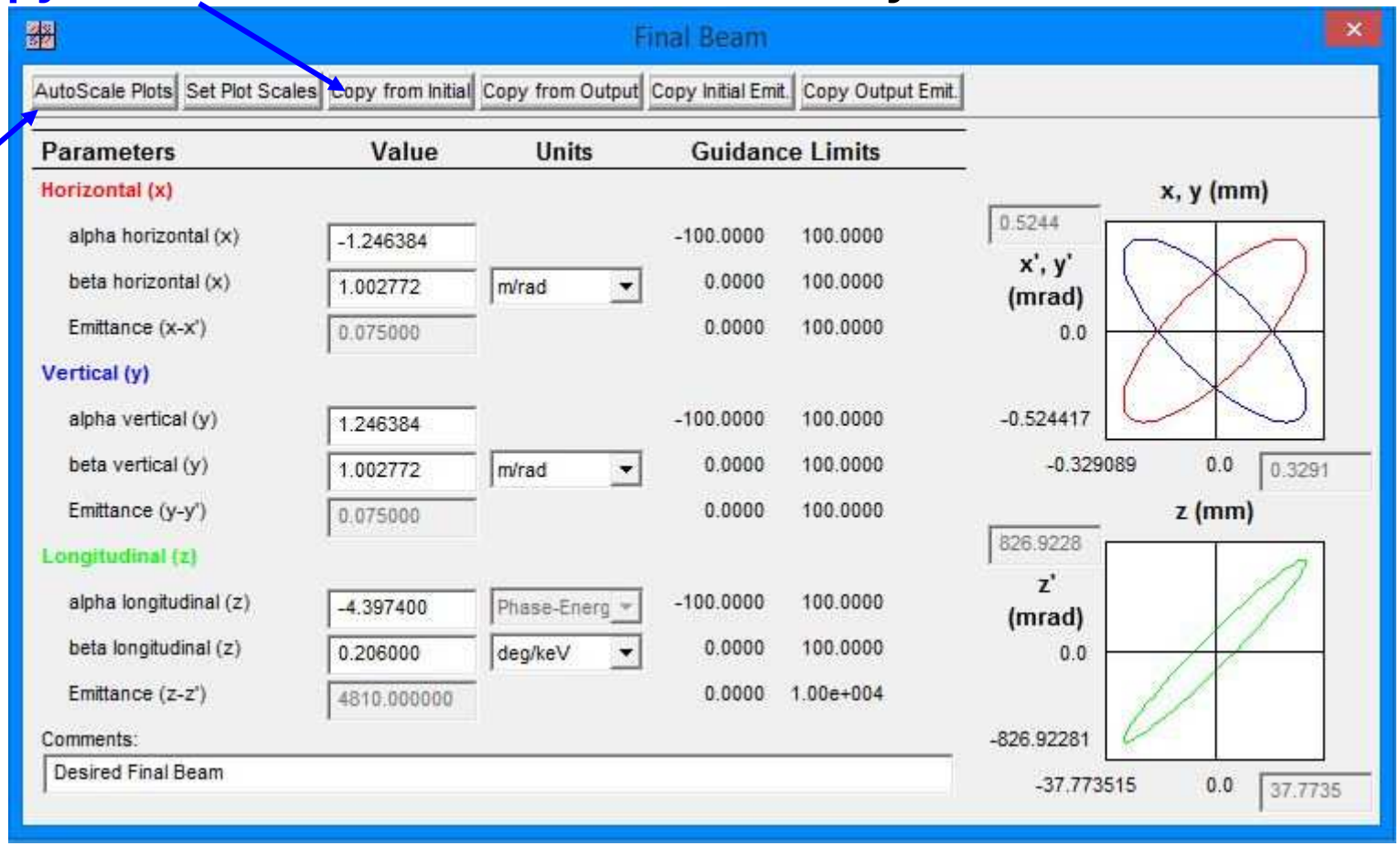
Finding a FODO Lattice for a Matched Beam Requirement

But There is an Easier Way Using a PBO Lab Feature

The Desired Matched Beam Parameters are Already in the Initial Beam

Use the "Copy from Initial" Button to Automatically Fill in the Data

Also Select "AutoScale Plots" Button



Open Initial Beam Piece to Confirm that Initial and Final Beams Same

Finding a FODO Lattice for a Matched Beam Requirement

⇒ **Save this updated example (same name "Setup_2_FODO_1")**

To This Point Have Set Up:

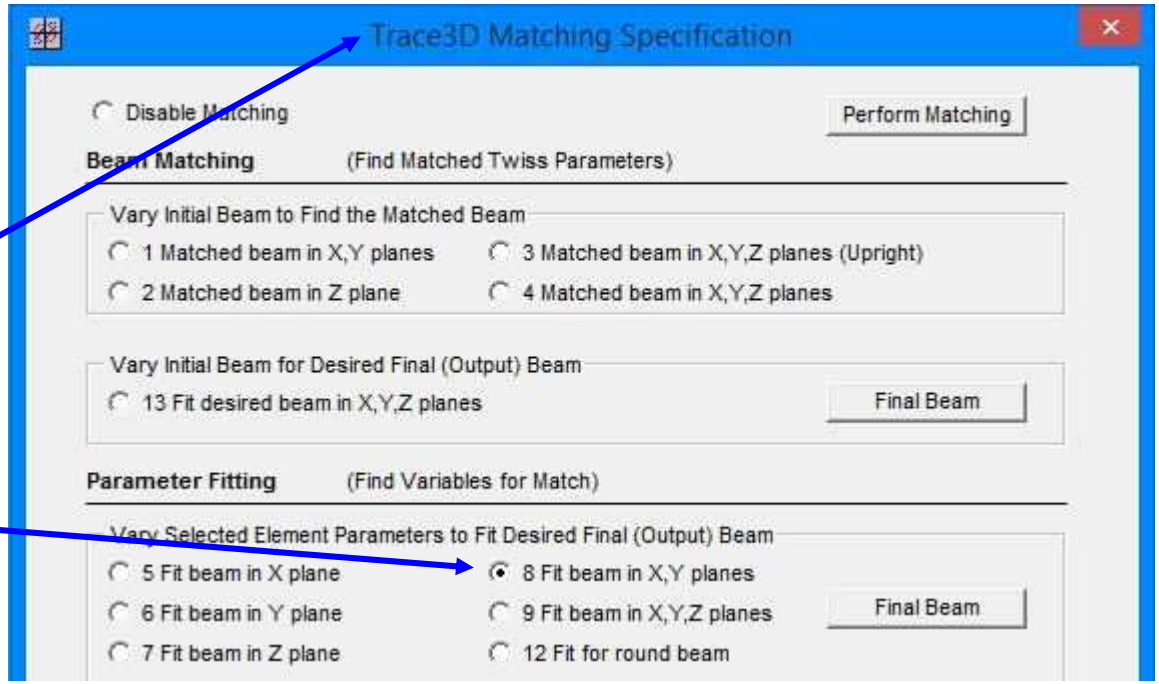
- **Match ("Vary") Parameters (Quad Strengths to Vary & Couple)**
- **Desired Matched Beam (Final α's and β's = Initial α's and β's)**

Last Step in Set Up is to Specify the TRACE 3-D "Match" Type:

⇒ **PBO Lab menu chain:**
Commands ->
TRACE 3-D ->
Match Specification:

Opens Window for Match Specification

Select the Option:
"8 Fit beam in X, Y planes"



⇒ **Save this updated example (same name "Setup_2_FODO_1")**

⇒ **Do Not Execute "Perform Matching" Yet**

Finding a FODO Lattice for a Matched Beam Requirement

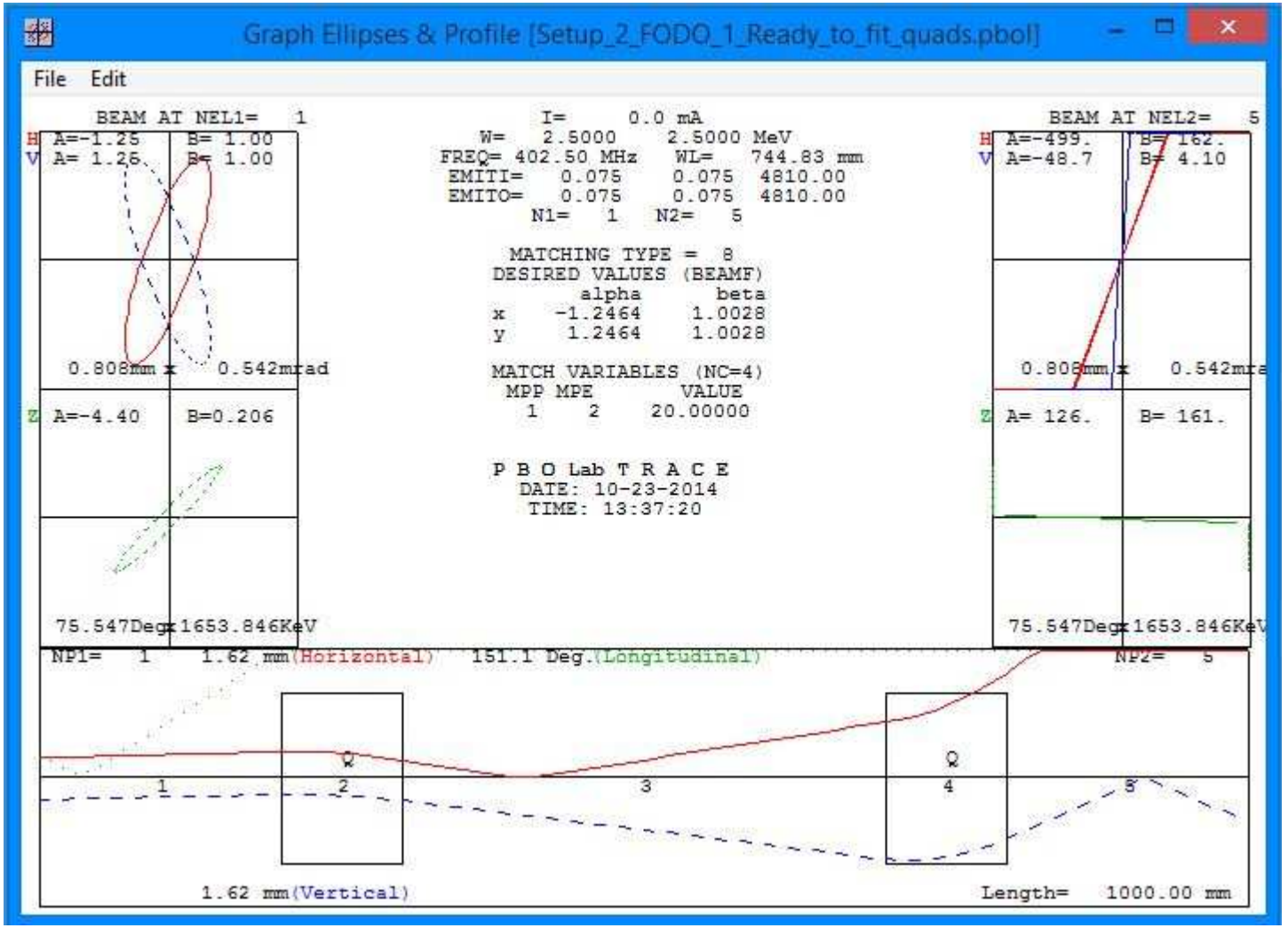
Look at the "Setup_2_FODO_1" beam envelopes

⇒ Use the TRACE 3-D Command: Graph Beam Line

You should get an envelope display something like:

Current Quad Settings Do Not Preserve Beam

Keep This Window Open for Future Use

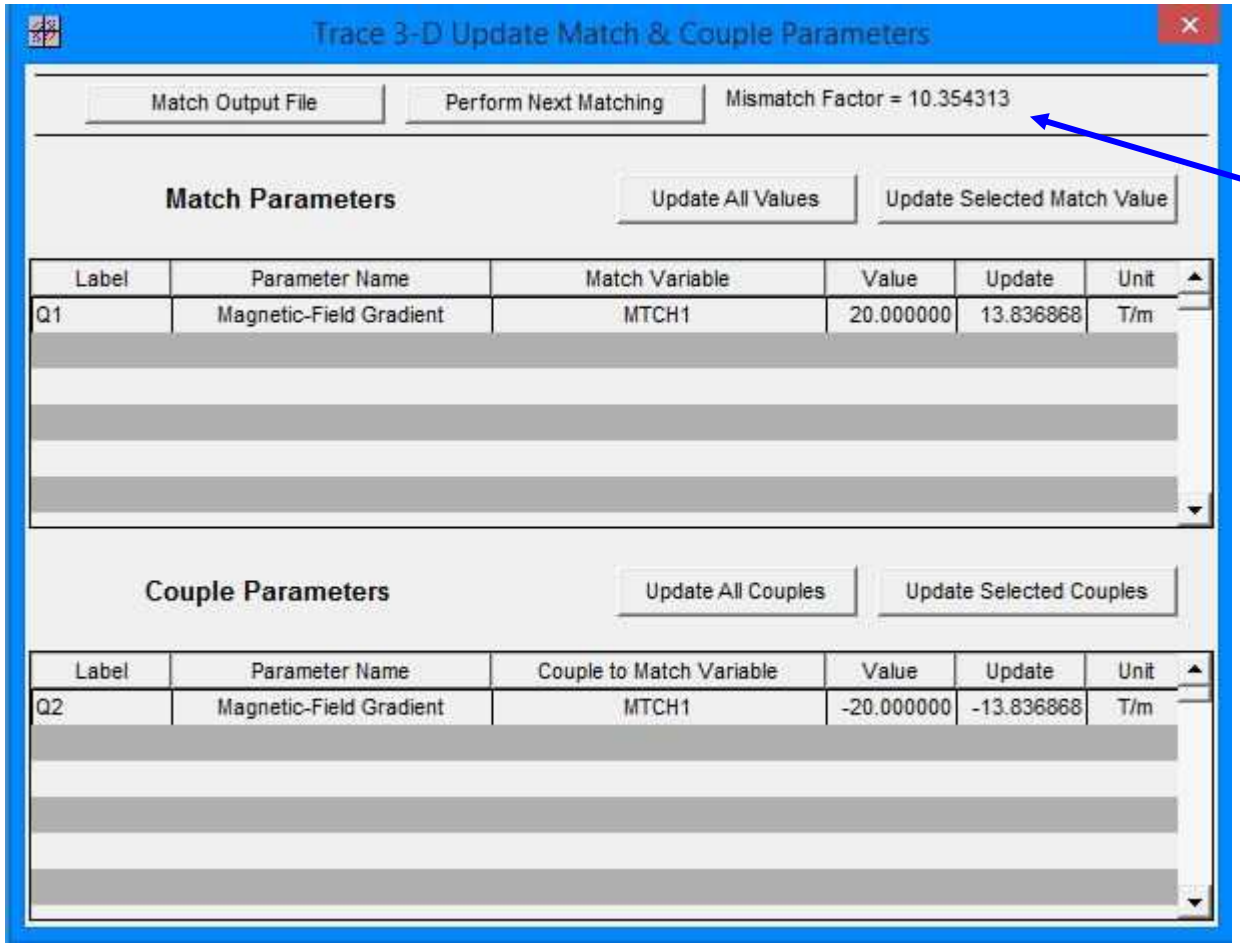


Finding a FODO Lattice for a Matched Beam Requirement

3d. Use the menu chain:

Commands -> TRACE 3-D -> Perform Matching

You should get a window that looks (something like) this:



Solution Not Very Good on First Attempt

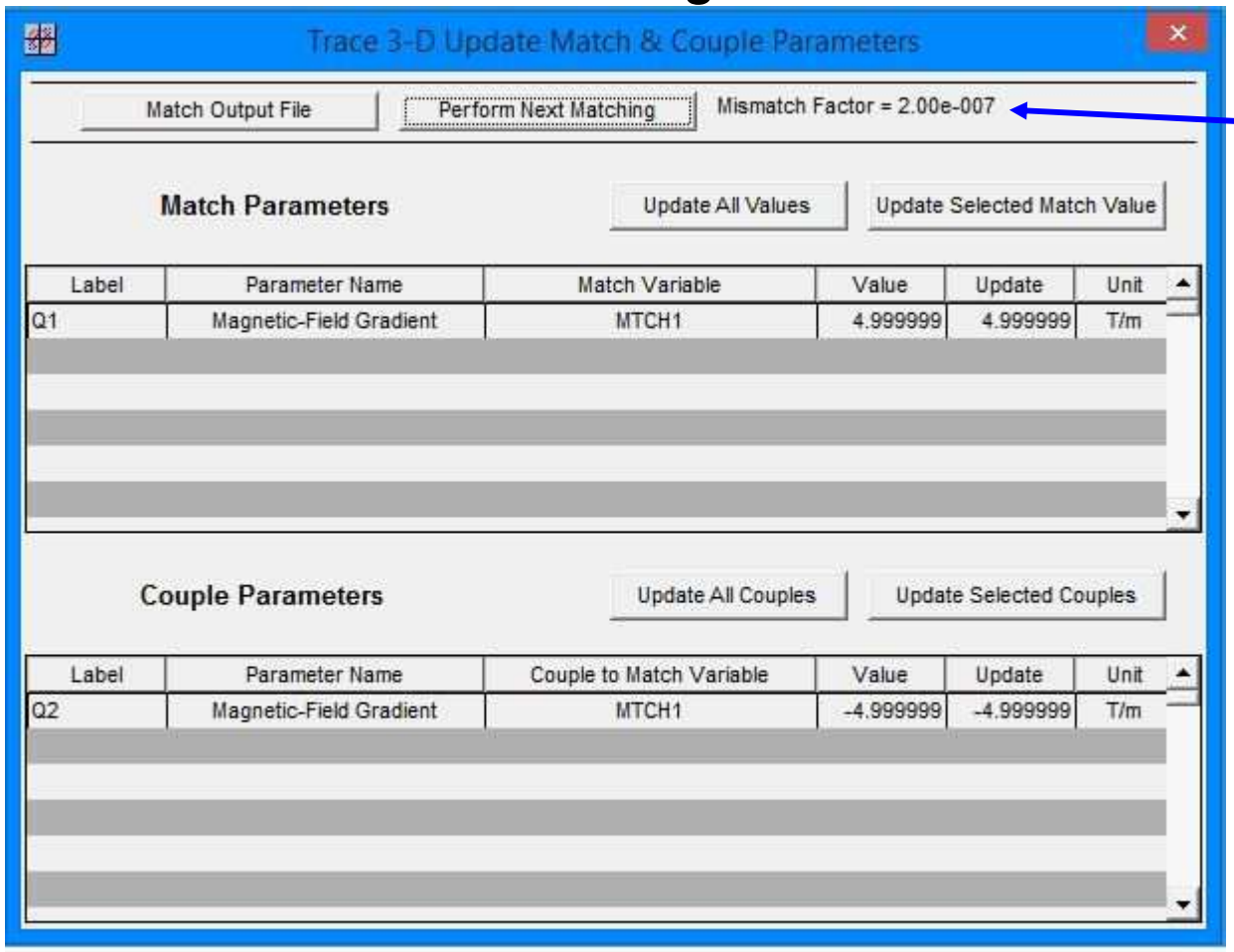
Note MMF >> 0

We Will Iterate on this Solution To See If It Improves

Finding a FODO Lattice for a Matched Beam Requirement

Select Button "Perform Next Matching" ⇒ **Repeat This Several Times**

Watch How the MMF Changes - After 4 or so Iterations You Should Get:



MMF ≈ 0

Very Good Solution!

⇒ **Save this example as "Setup_2_FODO_2_Fitted"**

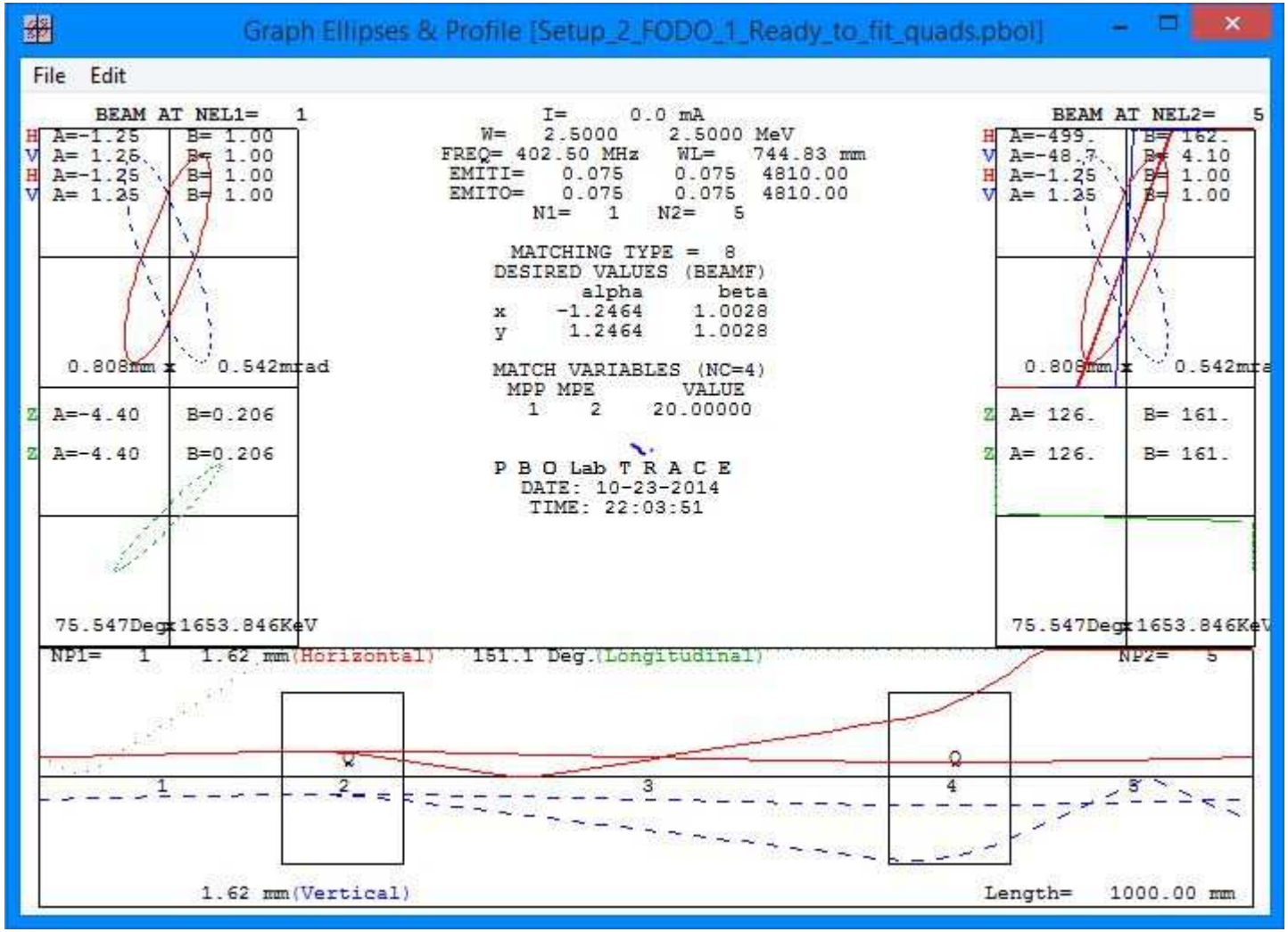
Finding a FODO Lattice for a Matched Beam Requirement

Let's Compare "Setup_2_FODO_1" & "Setup_2_FODO_2_Fitted"

⇒ Use the TRACE 3-D Command: "Trace On Background"

Envelopes for "Setup_2_FODO_2_Fitted" Over Lay Prior Ones:

New Quad Settings Do Preserve Beam



Finding a FODO Lattice for a Matched Beam Requirement

Examples 2 and 3 Solve Two *Different Types* of Problems

Are the results for "Setup_2_FODO_2_Fitted" consistent with the results from 2.d (saved as "Setup_1_FODO_2_Matched")?

3e. For the file " Setup_2_FODO_2_Fitted"

⇒ **Use the menu chain: Commands->TRACE 3-D->Options**

3f. Open the file "Setup_1_FODO_2_Matched" (from 2.d)

⇒ **Use the menu chain: Commands->TRACE 3-D->Options**

You should have virtually identical TRACE 3-D Beamline Plots

- **In example 2 the Quad strengths were reduce until a stable FODO was obtained, then the Matched Beam was found.**
- **In example 3 the Quad strengths were solved for a stable FODO that corresponded to a given Matched Beam.**