

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

George H. Gillespie

**G. H. Gillespie Associates, Inc.
P. O. Box 2961
Del Mar, California 92014, U.S.A.**

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Outline- Part II - Example Set 1

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

- 1. FODO Lattice (Focusing Quad - Drift - Defocusing Quad - Drift)** pp 3-7
- 2. Finding the Matched Beam (Output=Input) for a Given FODO Lattice** pp 8-14
- 3. Finding a FODO Lattice (Quads) for a Given Matched Beam Requirement** pp 15-25

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-Snyder (Twiss) - Beam 2"

Set the horizontal and vertical emittances both to:
0.0015 π -cm-mrad, rms

⇒ 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:

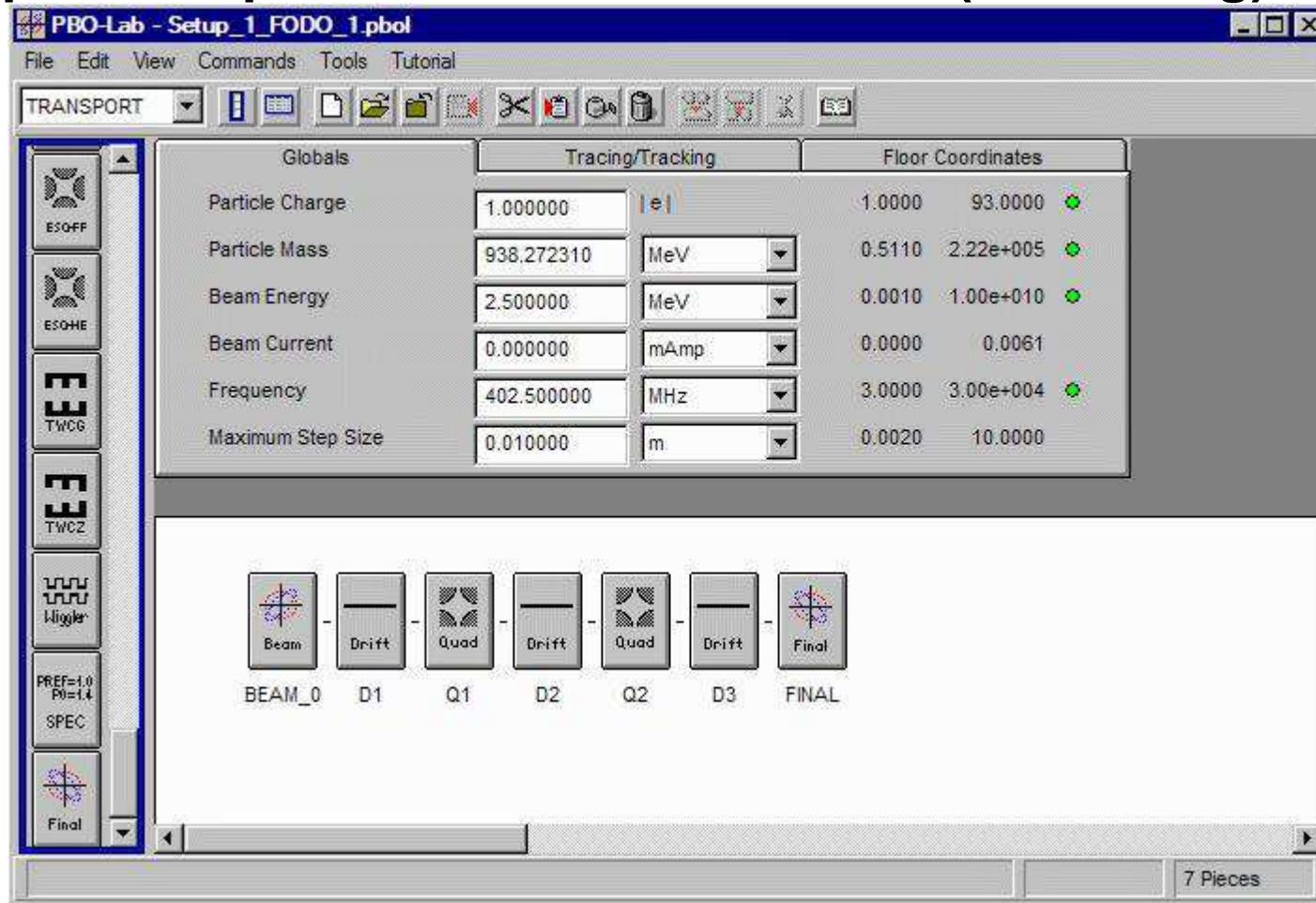
Drift "D1"	20 cm long	
Quad "Q1"	10 cm long	20 T/m field gradient
Drift "D2"	40 cm long	
Quad "Q2"	10 cm long	-20 T/m field gradient
Drift "D3"	20 cm long	

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

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

FODO Lattice

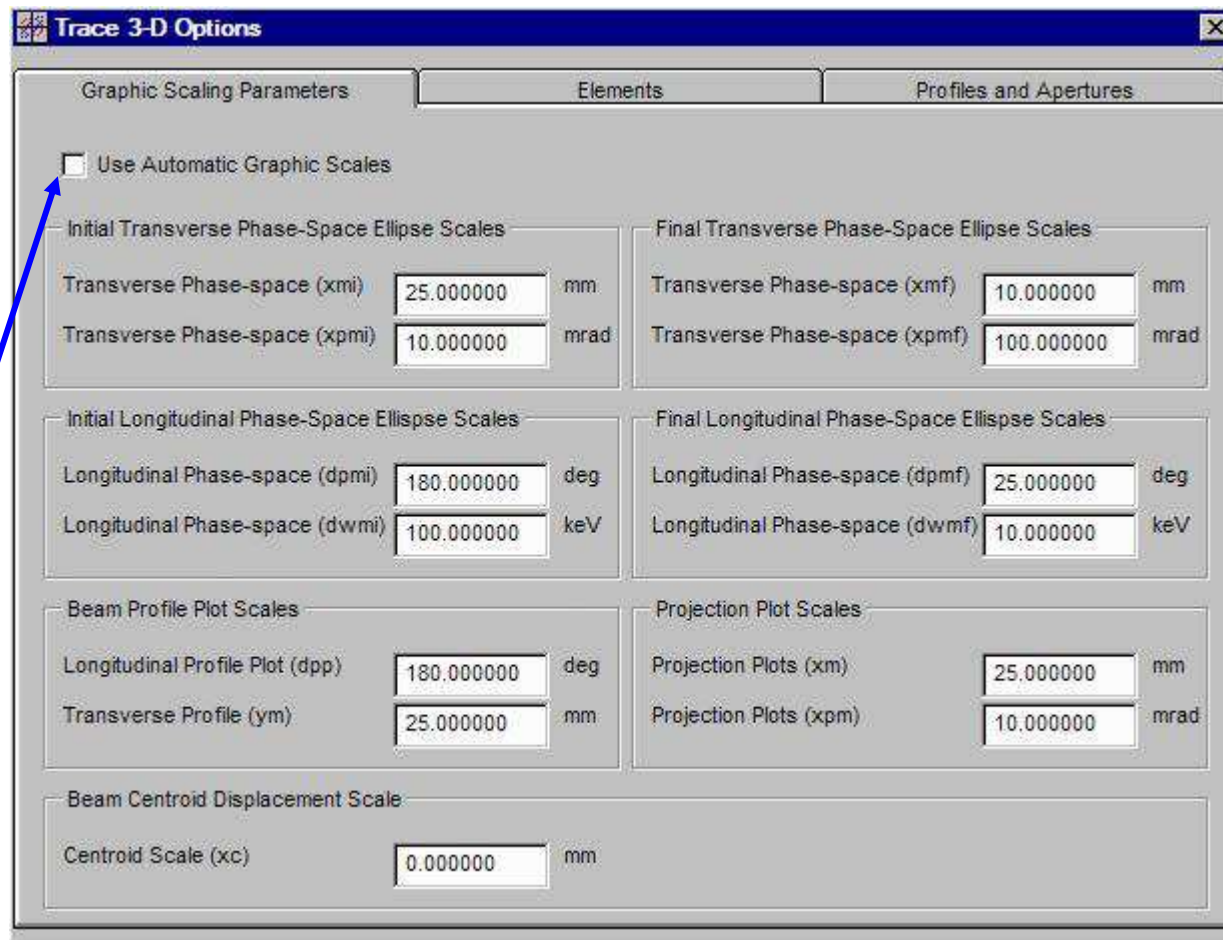
Example "Setup_1_FODO_1" should look (something) like this:



**Use the menu chain: Commands->TRACE 3-D->Graph Beam Line
 => Result Does Not Look So Pretty! Let's Find Some Scales**

FODO Lattice

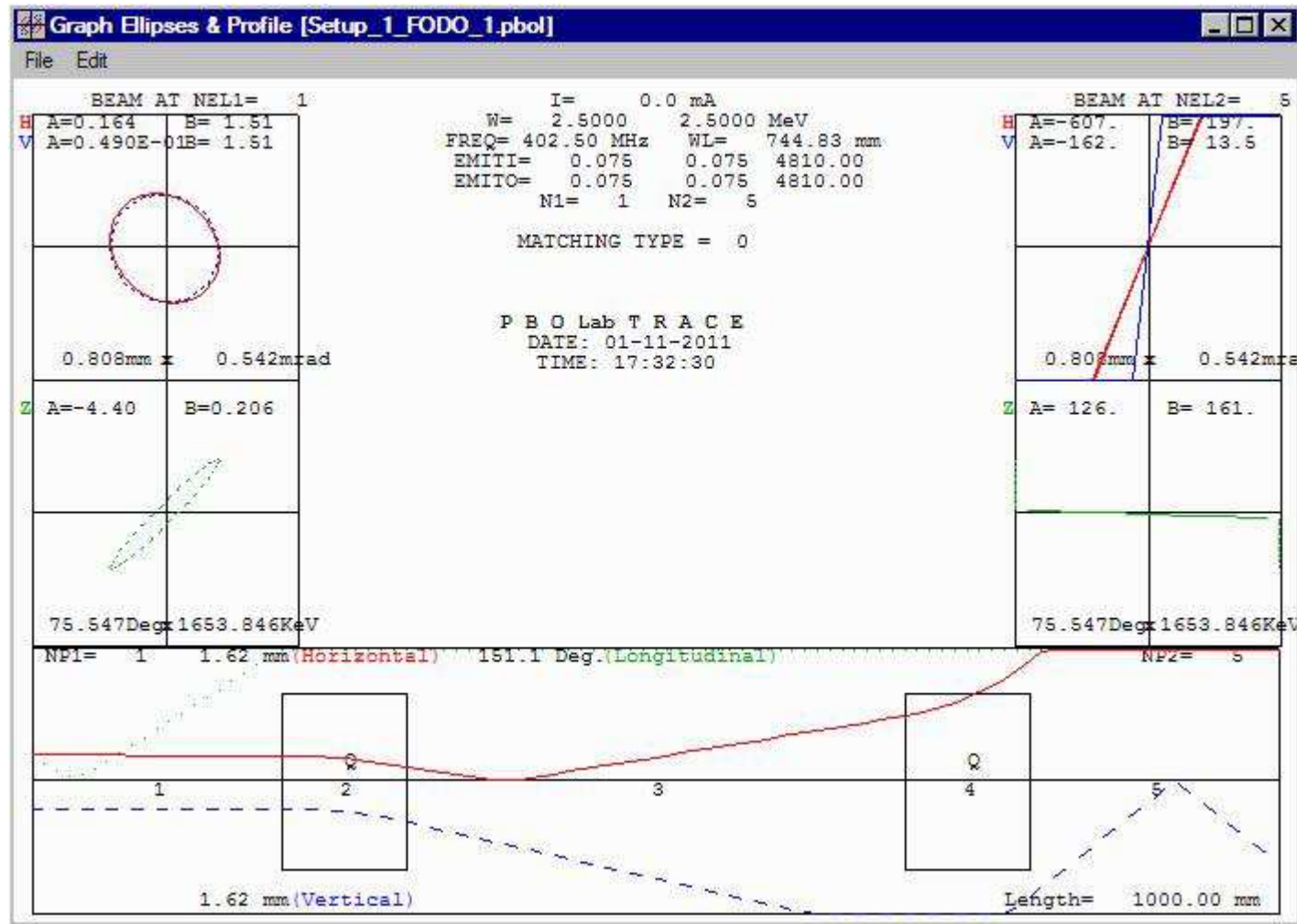
Use the menu chain: **Commands->TRACE 3-D->Options**
A window titled "Trace 3-D Options" should open:



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)

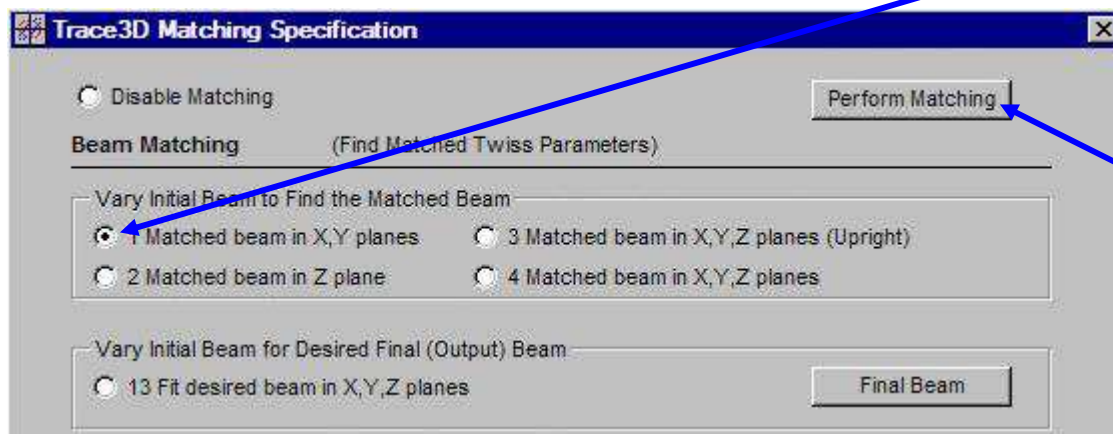
2a. If Necessary Set the **Context Switch** to TRACE 3-D

Open the Final Piece

Use the "Open" button under the Constraints panel

For "Beam Matching" - "Vary Initial Beam to Find Matched Beam"

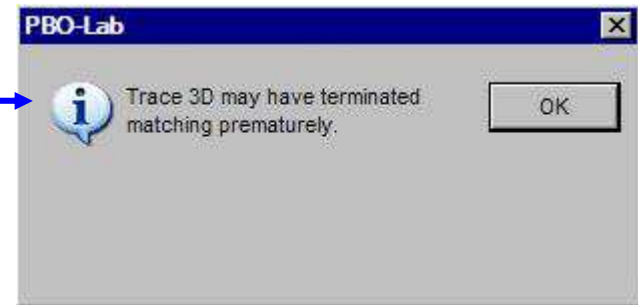
Select the Option: "1 Matched beam in X, Y planes"



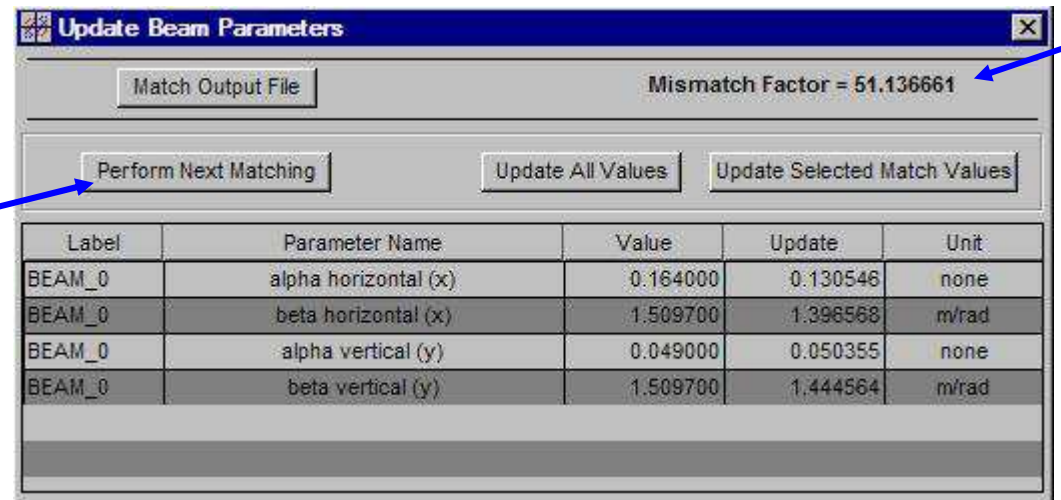
Then use the button
"Perform Matching"

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?

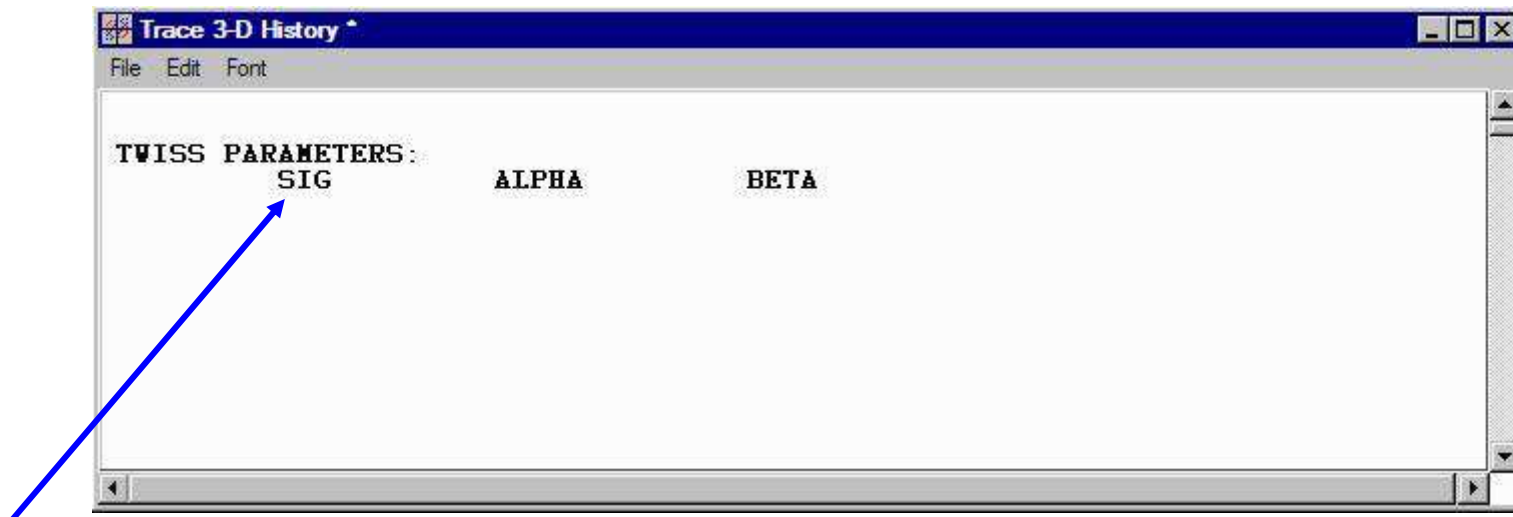
This FODO lattice does *not* have a matched beam solution.

- ⇒ **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.

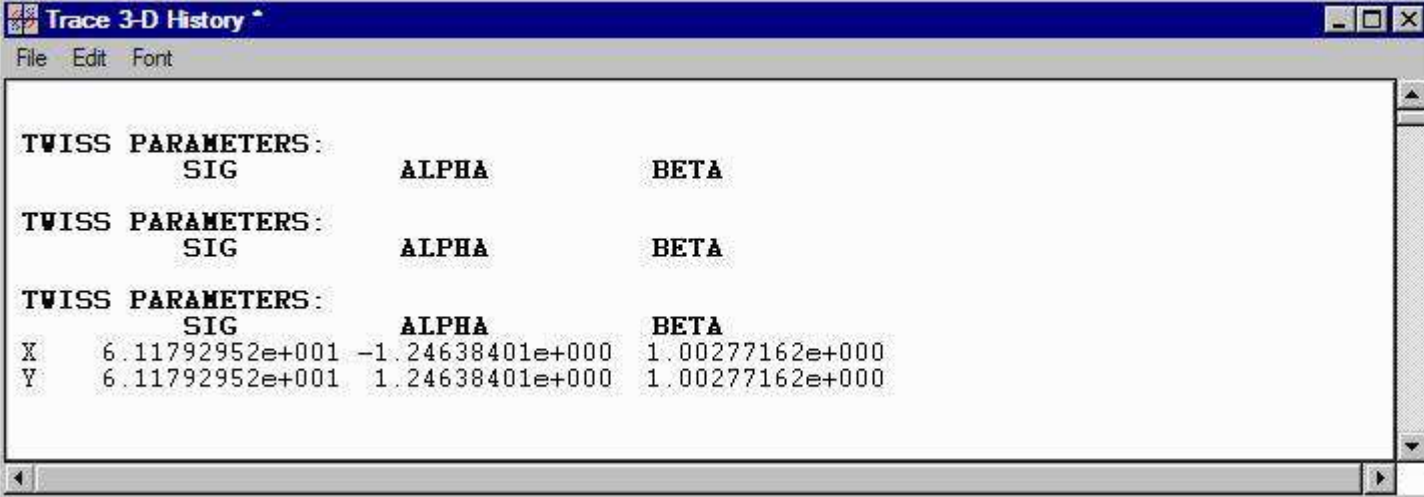
Do you think you can find a matched beam now?

⇒ **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:



```
Trace 3-D History *
File Edit Font

TWISS PARAMETERS:
      SIG      ALPHA      BETA
TWISS PARAMETERS:
      SIG      ALPHA      BETA
TWISS PARAMETERS:
      SIG      ALPHA      BETA
X   6.11792952e+001 -1.24638401e+000 1.00277162e+000
Y   6.11792952e+001  1.24638401e+000 1.00277162e+000
```

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:

Label	Parameter Name	Value	Update	Unit
BEAM_0	alpha horizontal (x)	0.164000	-1.246384	none
BEAM_0	beta horizontal (x)	1.509700	1.002772	m/rad
BEAM_0	alpha vertical (y)	0.049000	1.246384	none
BEAM_0	beta vertical (y)	1.509700	1.002772	m/rad

**Update
All Values**

Note MMF

Start Values

Solutions

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

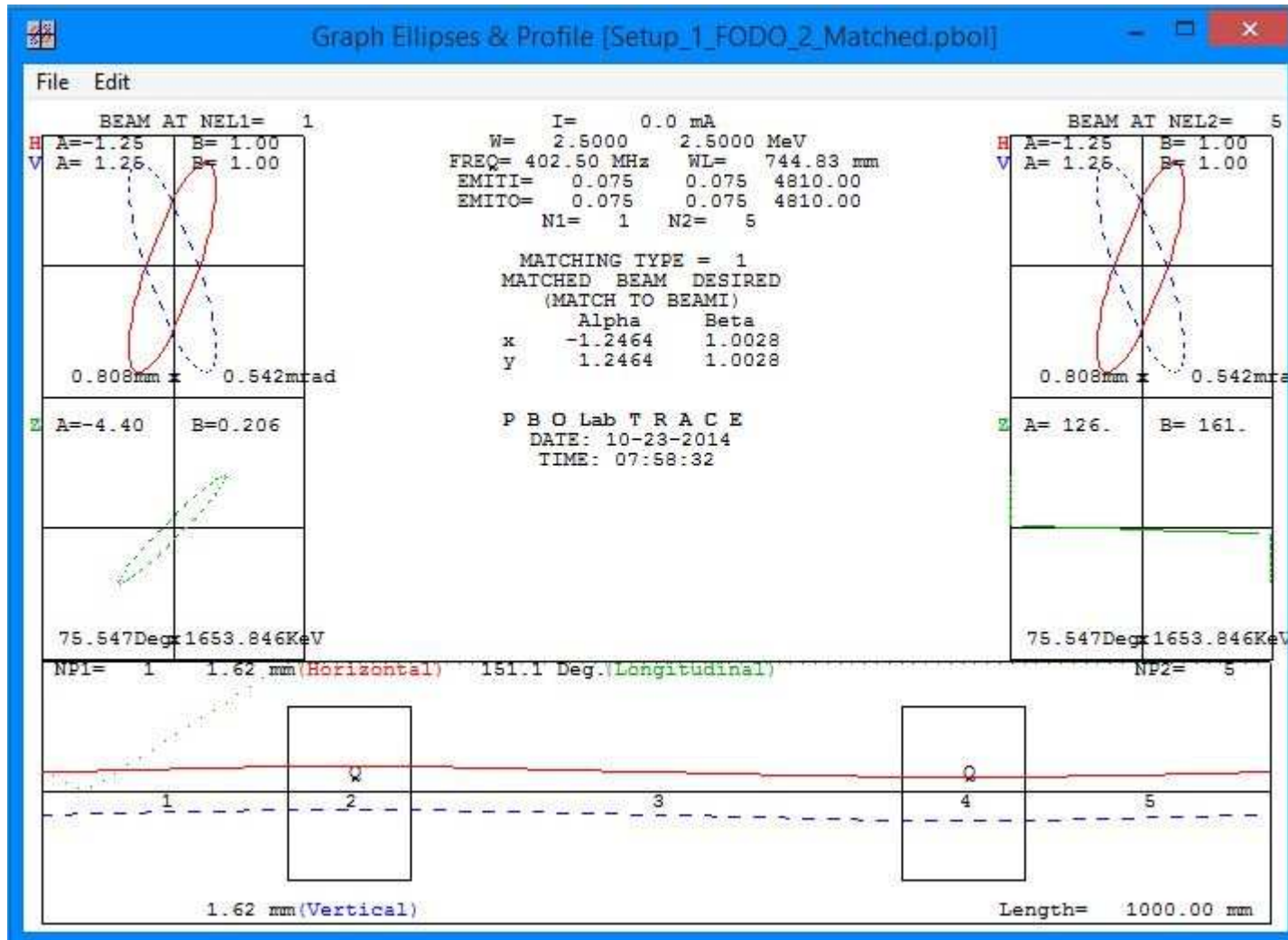
⇒ **Change the Beam Piece Comment to "Beam_1"**

⇒ **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**

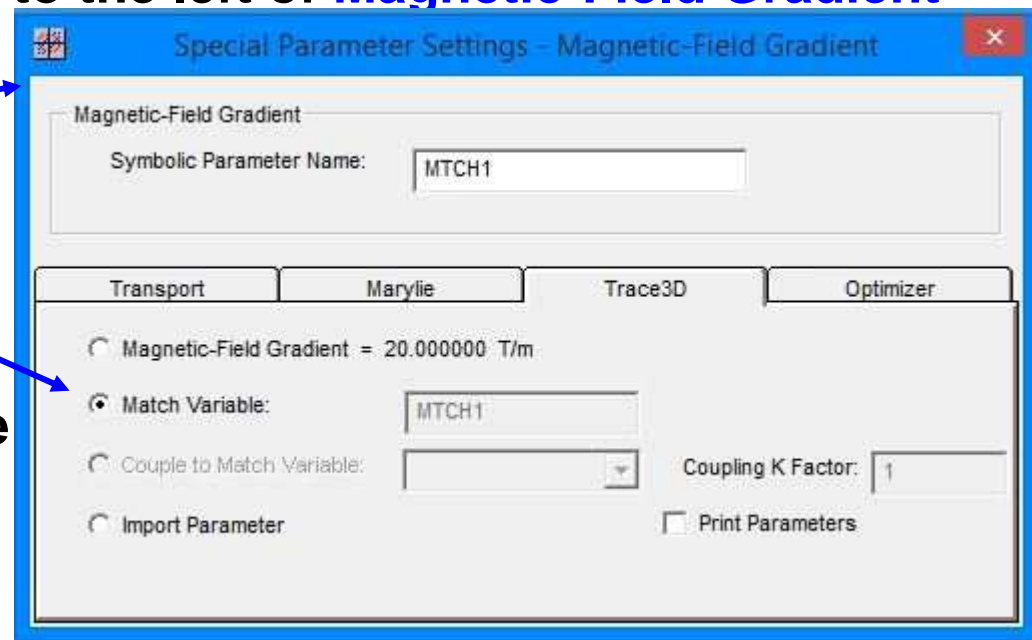
Select the "S" button that is to the left of **Magnetic-Field Gradient**

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

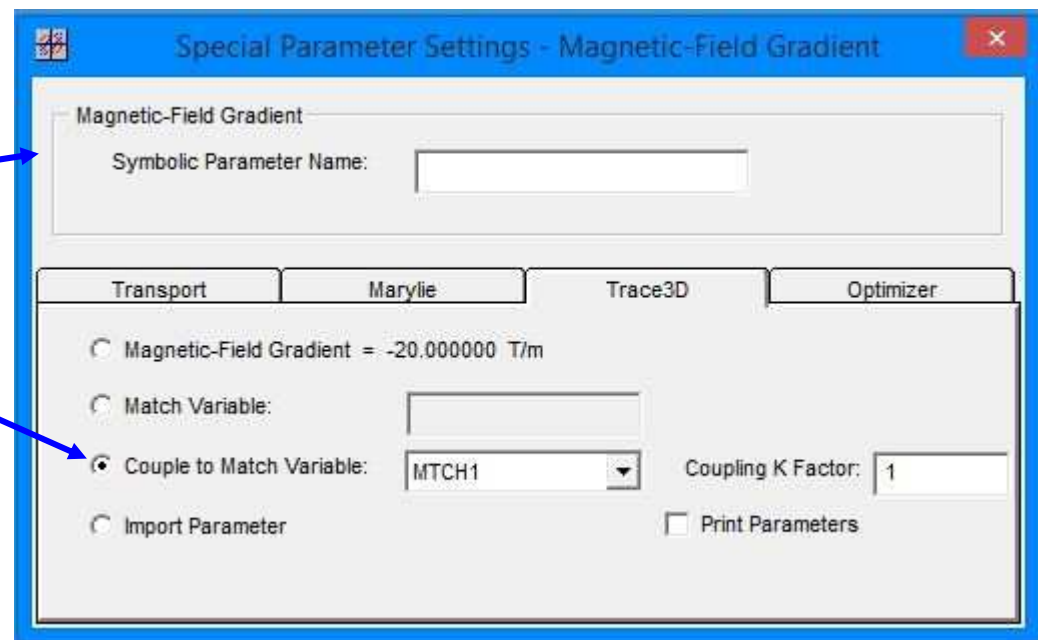
Then select **Couple to Match Variable** and select the **"MTCH1"** choice (only one available)

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

The screenshot shows the 'Final Beam' window in TRACE 3-D. The window title is 'Final Beam'. At the top, there are buttons for 'Energy', 'Distance', 'Final Beam', and 'TRACE 3-D'. Below these are several utility buttons: 'AutoScale Plots', 'Set Plot Scales', 'Copy from Initial', 'Copy from Output', 'Copy Initial Emit.', and 'Copy Output Emit.'. The main area is a table of parameters:

Parameters	Value	Units	Guidance Limits
Horizontal (x)			
alpha horizontal (x)	6.000000		-100.0000 100.0000
beta horizontal (x)	0.164000	mrad	0.0000 100.0000
Emittance (x-x')	4.000000		0.0000 100.0000
Vertical (y)			
alpha vertical (y)	1.509700		-100.0000 100.0000
beta vertical (y)	6.000000	mrad	0.0000 100.0000
Emittance (y-y')	5.000000		0.0000 100.0000
Longitudinal (z)			
alpha longitudinal (z)	0.049000	Phase-Energ	-100.0000 100.0000
beta longitudinal (z)	1.509700	deg/keV	0.0000 100.0000
Emittance (z-z')	4810.000000		0.0000 1.00e+004

Below the table is a 'Comments:' field with the text 'Desired Final Beam'. To the right of the table are two plots. The top plot is titled 'x, y (mm)' and shows trajectories for x' and y' (mrad) versus z (mm). The bottom plot is titled 'z (mm)' and shows z' (mrad) versus z (mm). Both plots have axes ranging from -4.0000 to 4.0000 for x, y and -15.0000 to 15.0000 for z. There are 'Open' and 'Remove' buttons next to each plot.

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

The screenshot shows the 'Final Beam' window with the following parameters table:

Parameters	Value	Units	Guidance Limits
Horizontal (x)			
alpha horizontal (x)	-1.246384		-100.0000 100.0000
beta horizontal (x)	1.002772	mrad	0.0000 100.0000
Emittance (x-x')	0.075000		0.0000 100.0000
Vertical (y)			
alpha vertical (y)	1.246384		-100.0000 100.0000
beta vertical (y)	1.002772	mrad	0.0000 100.0000
Emittance (y-y')	0.075000		0.0000 100.0000
Longitudinal (z)			
alpha longitudinal (z)	-4.397400	Phase-Energ	-100.0000 100.0000
beta longitudinal (z)	0.206000	deg/keV	0.0000 100.0000
Emittance (z-z')	4810.000000		0.0000 1.00e+004

The 'Comments' field contains: Desired Final Beam

The 'x, y (mm)' plot shows a four-lobed beam distribution with axes ranging from -0.524417 to 0.5244.

The 'z (mm)' plot shows a beam distribution with axes ranging from -826.92281 to 826.9228.

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 ->

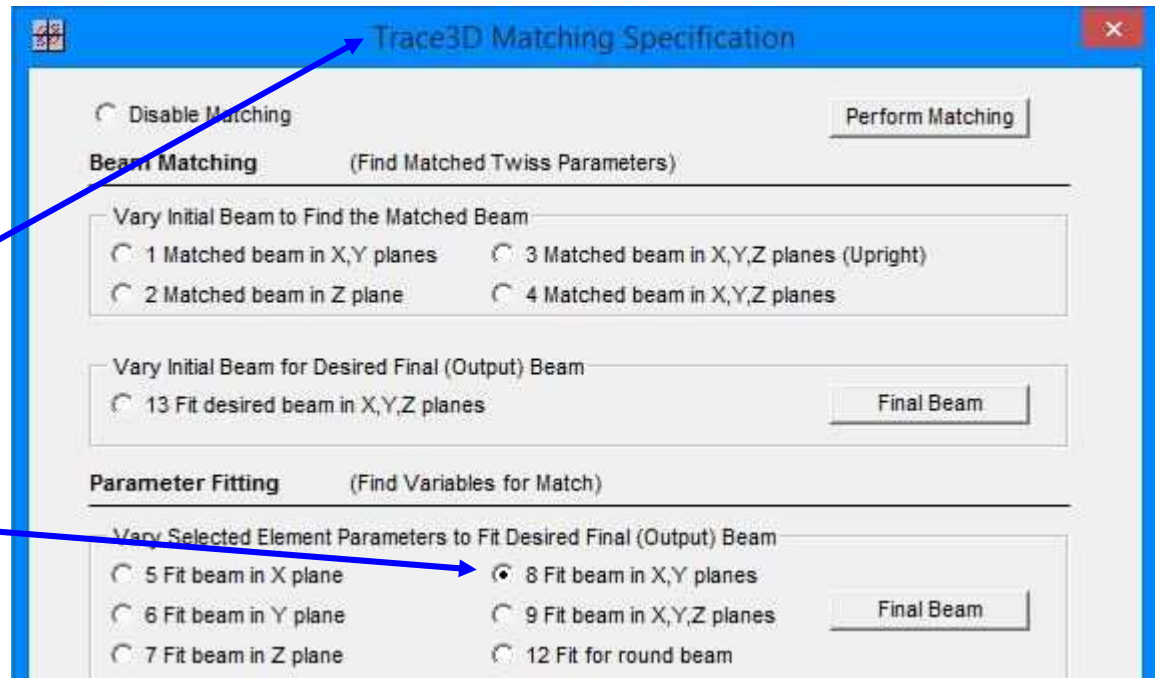
TRACE 3-D ->

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

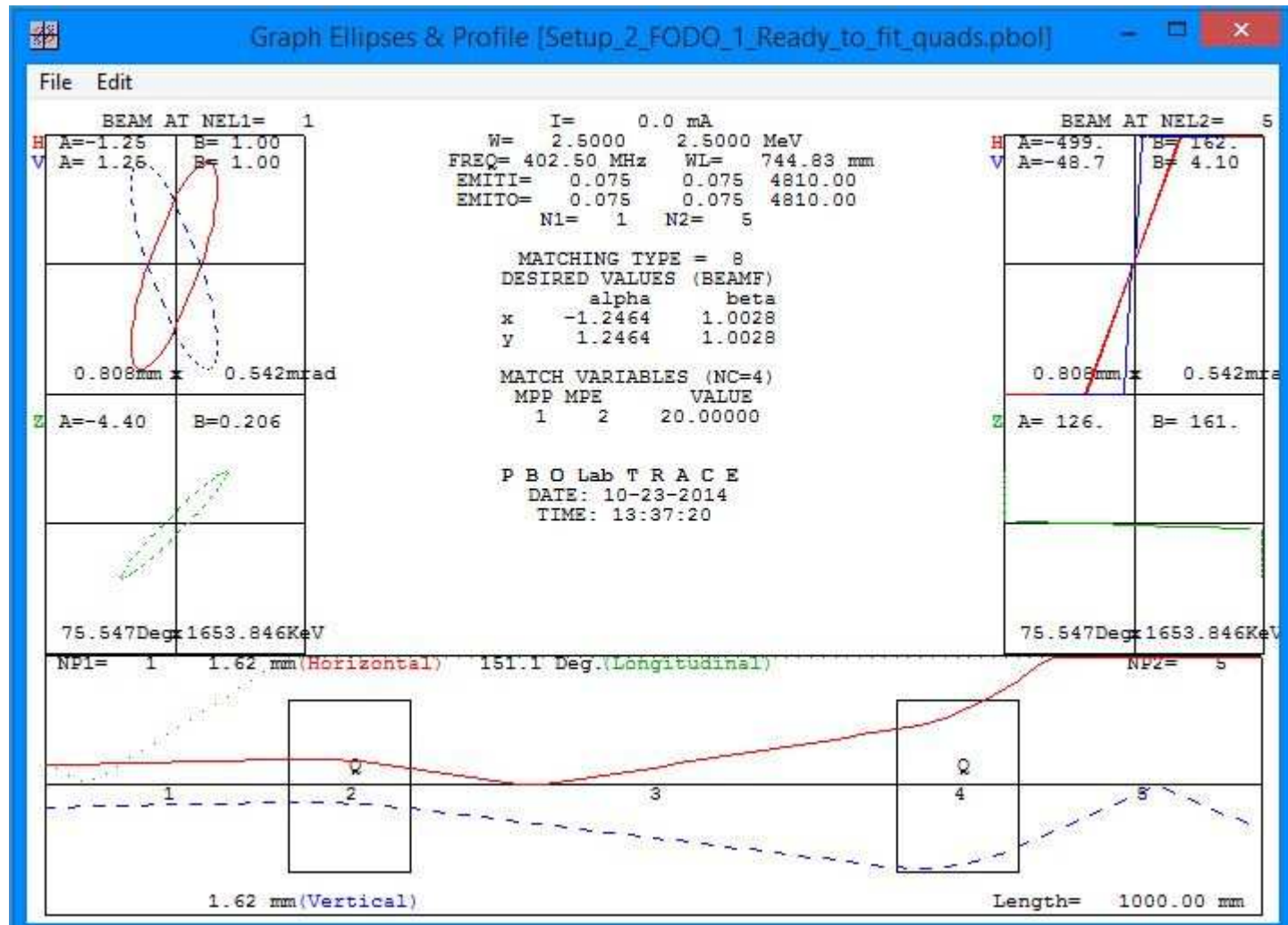
Look at the "Setup_2_FODO_1" beam envelopes

⇒ 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

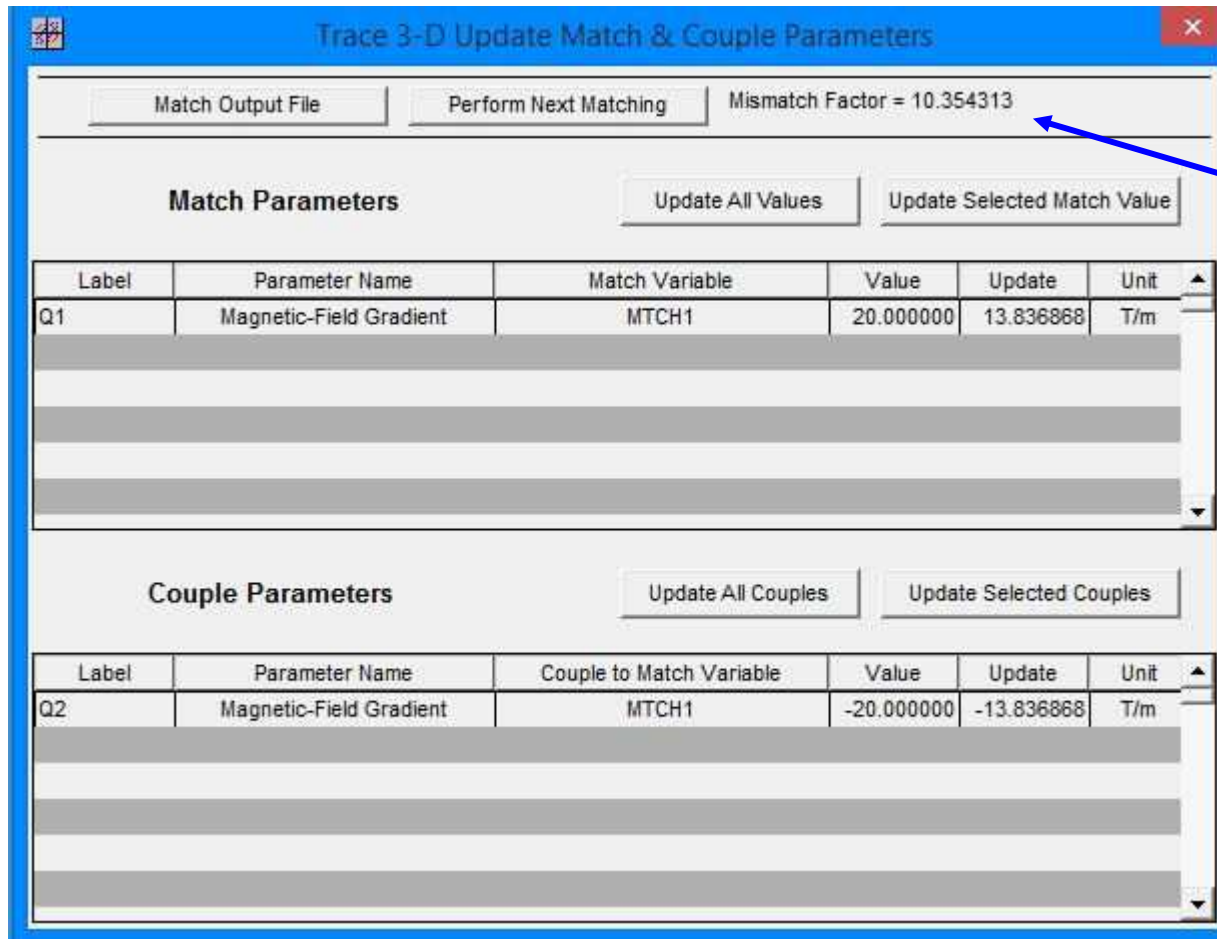


Finding a FODO Lattice for a Matched Beam Requirement

3d. Use the menu chain:

Commands -> TRACE 3-D -> Perform Matching

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



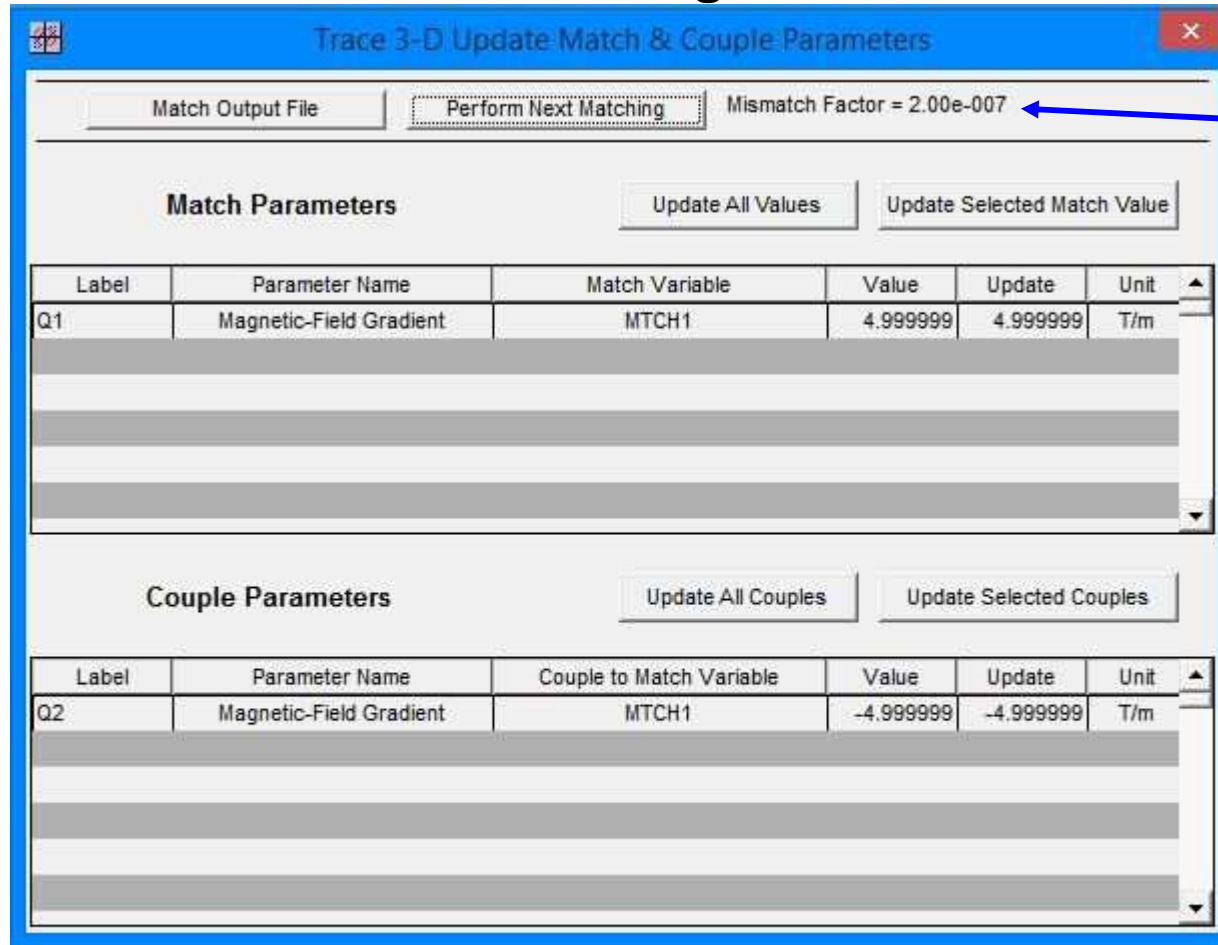
Solution Not Very Good on First Attempt

Note MMF $\gg 0$

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"

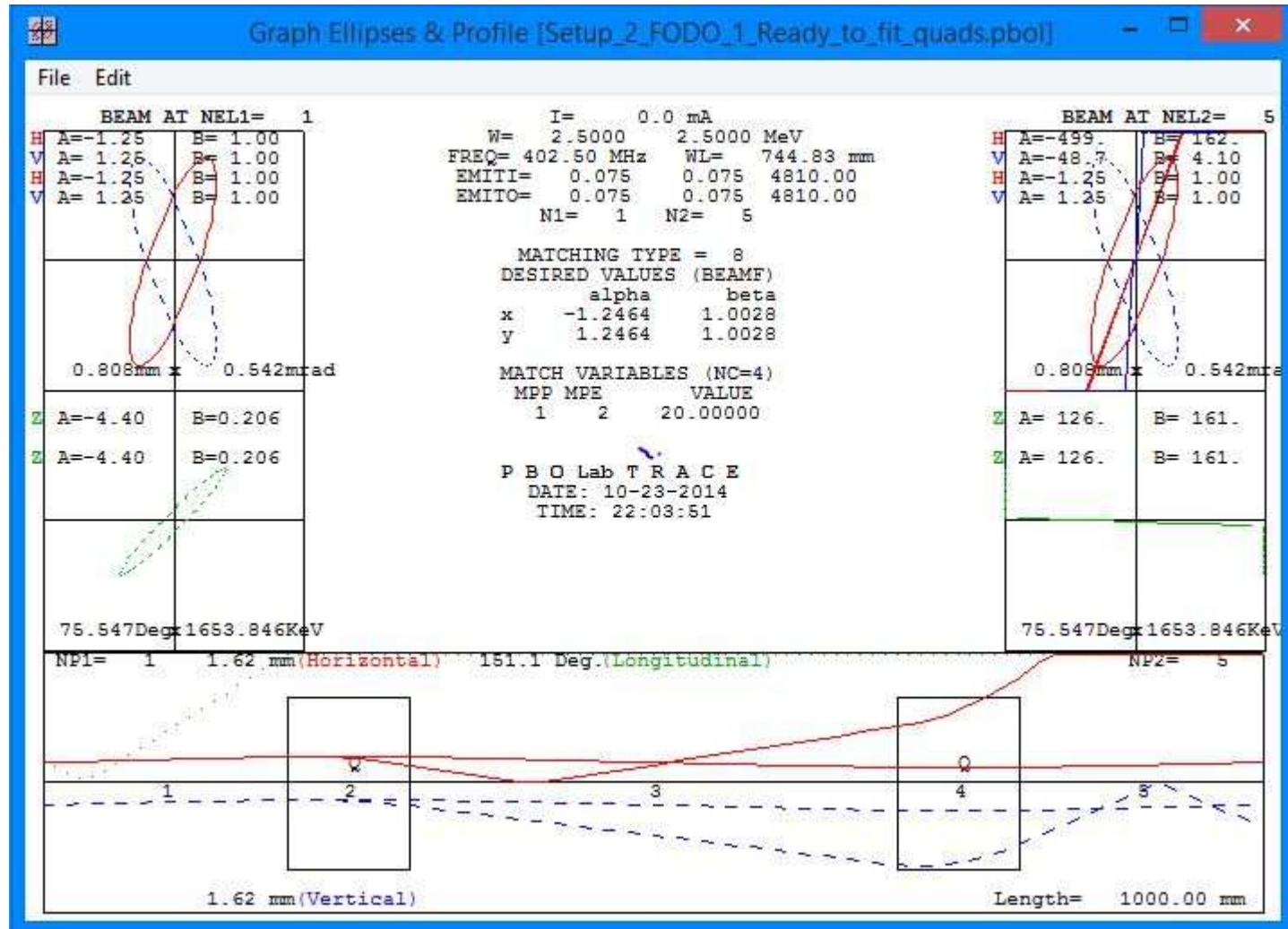
Finding a FODO Lattice for a Matched Beam Requirement

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.