# T4 Wobbling
# Solving the Puzzle

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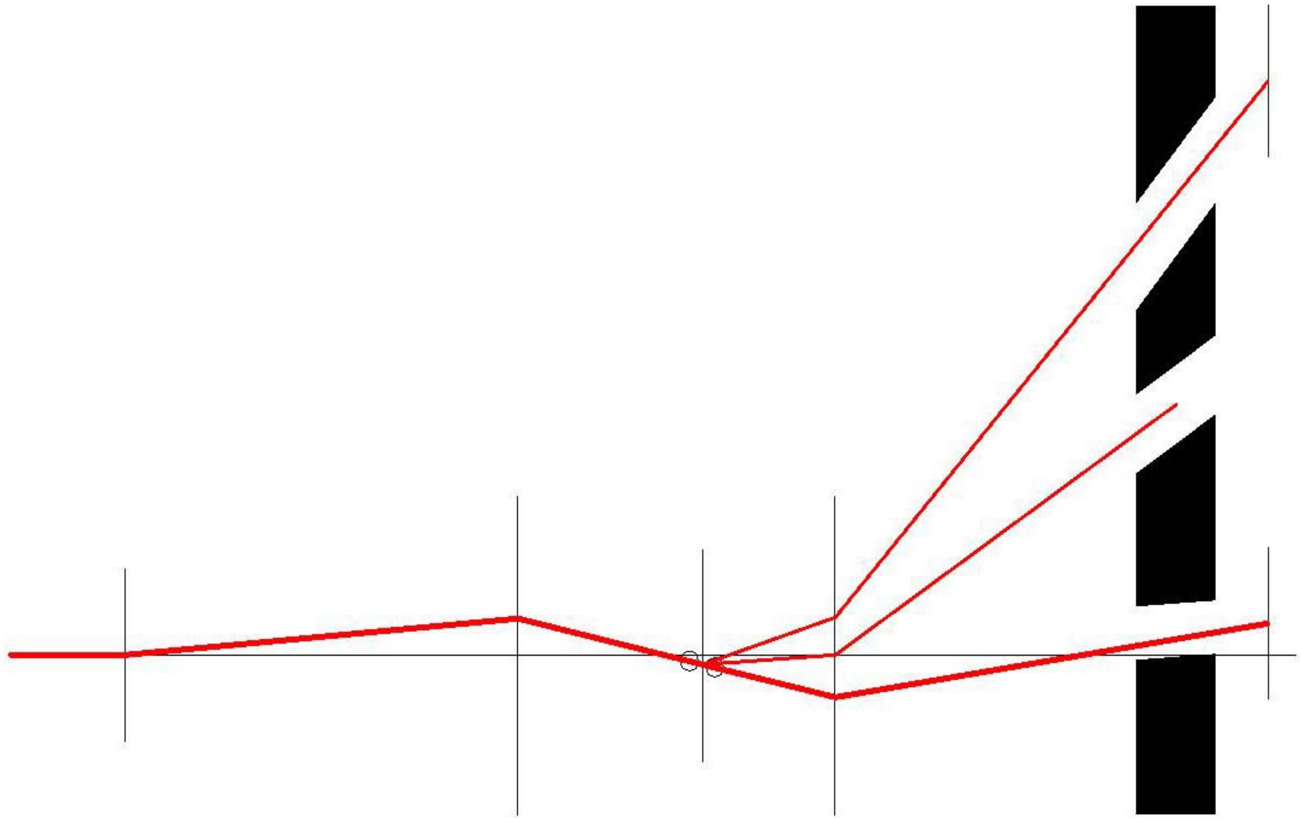

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# Abstract

The project that I was assigned to during my summer placement at the AB-ATB department of CERN involved the solution of the T4 wobbling puzzle. My "wobbling program" implemented in JAVA calculates the different settings of the magnets around the T4 target according to characteristics of the three output beam lines. A brief description of the wobbling problem follows.


# 1. T4 Station geometry

The T4 target in the north area receives the primary protons from SPS and produces the two general-purpose beams H8 (high energy) and H6 (medium energy) for the north experimental area hall EHN1. The attenuated protons from the target typically form the P0 beam, which is transported to the experimental hall EHN3 [**1**]. The T4 target station geometry is shown in **Figure 1**.

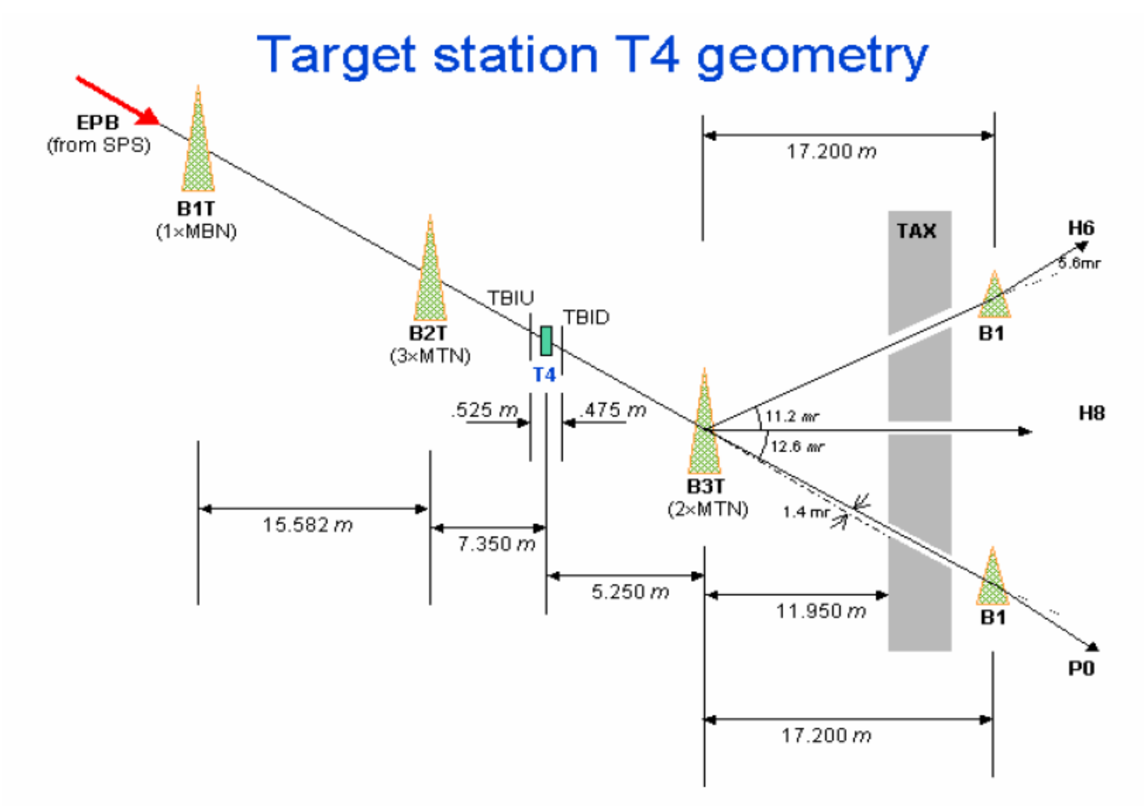


***Figure 1:*** *The T4 target station geometry. B1T, B2T, B3T are the three wobbling magnets. The B1 in P0 and H6 are strong septum magnets. TBIU and TBID are upstream and downstream beam monitors.*

A set of three magnets B1T, B2T, and B3T around the target allows different energies in each beam line to be selected, what is referred to as “T4 wobbling”. P0 and H6 both have a septum magnet following the TAX, which allows accepting particles with a skew or production angle different from zero. H8 does not have this option, therefore can only accept particles which are centered in the B3T magnet.

Downstream the target station magnets and before any of the beam line elements, the TAX blocks are located, whose principal function is to control the beam passage (angle and therefore momentum, as well as intensity), and serve as beam dump whenever access is required in any of the beams or when the beams are not operational.

The solution of the T4 wobbling puzzle comprises the determination of the magnetic fields (currents) of these three magnets so that we can get output beams with the desired characteristics. A brief description of how the real problem was abstracted so that it could be solved using JAVA follows.

# 2. Modeling of the problem

In order to solve the problem for the user defined characteristics of the beams the “wobbling program” first reads the information about the geometry of the target station and its constraints (eg. the maximum magnetic field or aperture of the magnets) from an XML file named “configuration.xml”. The desired characteristics of the beams (eg. momenta, production angles) are also read from an XML file named parametersX where X is the date that the file was created. The T4 target station geometry is shown again in **Figure 2** displaying also the points that are necessary for solving the problem. Some of them are contained in the configuration file but some others are calculated at run time.

At the end of the report you can see the xml file that is used to read the geometry of the problem (when you open it with an editor) as well as the xml file when you double click on it and see it with an explorer (thanks to an XSL document that transforms it into a list of tables).

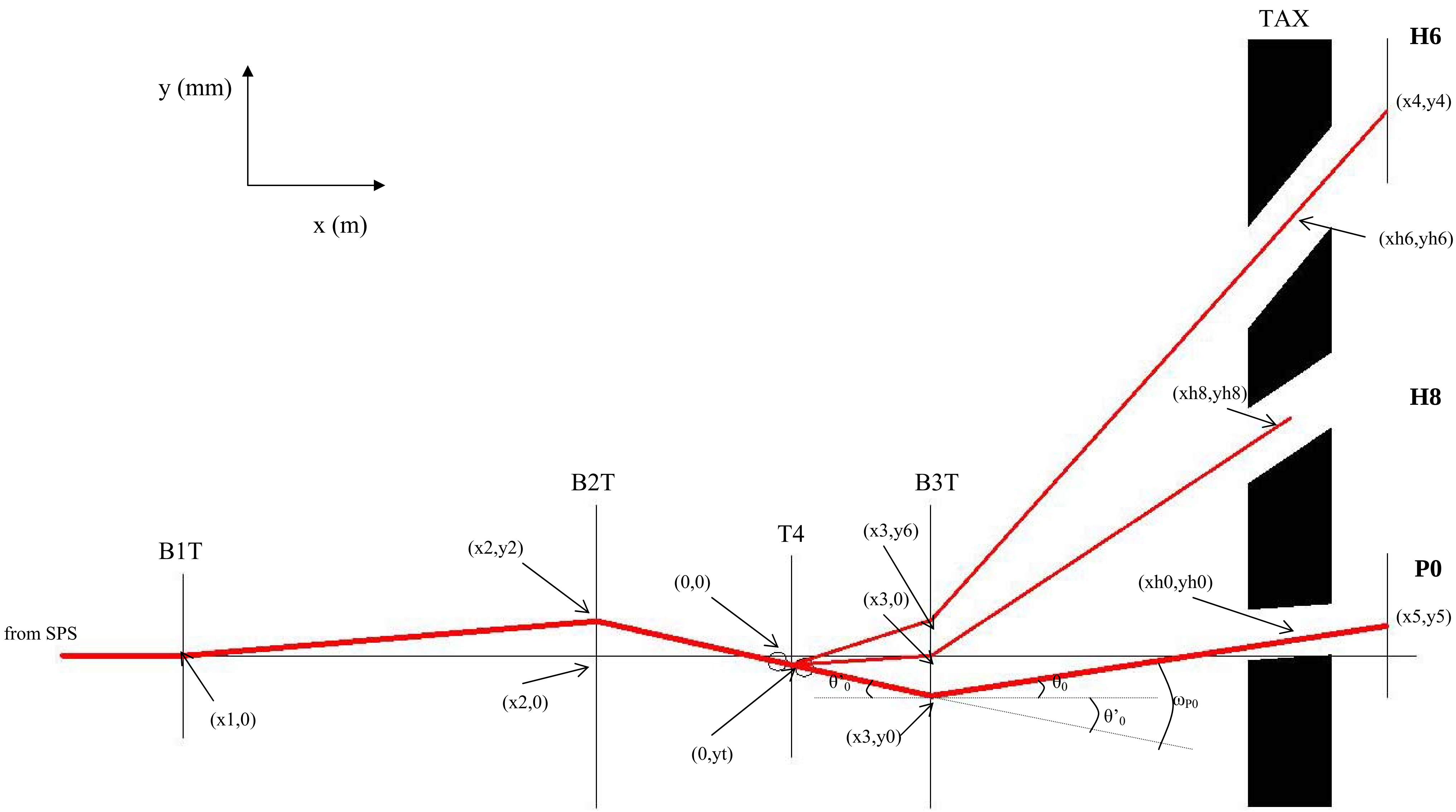


***Figure 2:*** *The T4 target station geometry*

# 3. Solving the T4 wobbling puzzle

Generally there are three options for T4 wobbling (one beam option, two beams option, three beams option) and each option has many sub-options. Details for these options can be found in [1]. In order to solve all these different configurations of the problem geometry equations have been combined with the following formula which determines the beam deflection (for very small angles, some milliradians) as a function of its momentum and the product of the magnetic field and the length of the bending magnet.

$$\theta\,(\mathrm{mrad}) = \frac{299.79}{p\,(\mathrm{GeV}/c)} * Bl\,(T * m)$$

Although all these cases may have different parameters (or have the same but lay different importance (priority) on their satisfaction) we could say as a general rule that the system of linear (thanks to small angle approximations) equations that we get gives as the downstream parameters of the solution (yt,y0,y6,BL3[1]) and then we propagate these values to get the values for the upstream parameters(y2,BL2,BL3).

If the solution of the problem is not possible, i.e not all characteristics of the beams can be satisfied the program tries to find the best solution (closest to the user defined values) by solving the problem iteratively by changing the least significant parameter by a user defined (at run time) step. Sometimes if the change of only one parameter is not enough it tries to solve the problem by changing a second parameter. The user has also the possibility of having the various solutions of the problem displayed in the form of a chart. This is done by keeping some "important" parameters fixed and finding the possible values for the two least significant parameters (e.g. the momentum and production angle of H6 by considering the properties of the P0 and H8 beams as important and keeping them fixed).

An example of the solution of a very frequent case in which P0 is set for protons and H8 and H6 set for secondary hadrons at different production angles follows.

## Example

Here the method for solving the 3A case in [1] will be explained. Actually this case because of its importance has been split into 2 different cases.

[1] BL3: is the product of the magnetic field and the length of the B3T magnet. Similarly we have BL1 and BL2 for B1T and B2T magnets.

1. The importance is laid on the satisfaction of the H8 beam characteristics
2. The importance is laid on the satisfaction of the H6 beam characteristics

We will explain here the first one which is easier when it comes to solving the linear system[2]. In this case the momentum of P0 is of course fixed as it is the attenuated primary proton beam and we also keep the momentum of H8 fixed. That is to say that the solution calculated by the program should have these particular values for the momentum of P0 and H8. The program also tries to satisfy the user defined values of the production angle of H8 and the momentum of H6. However if there is no solution (because of the constraints of the problem (like for example the finiteness of the magnetic fields and aperture of the magnets or the maximum value that the beams' skew angle can have) the program first tries to change the value of H6 momentum by a user defined step and if the change of only this parameter is not enough for getting a solution, it tries to find one by changing also the production angle of H8 again by a user defined step.

The equations that we get from the deflection of the P0 beam are:

$$\omega_{P0} = \frac{299.79}{P_{P0}} Bl_3 \quad (1)$$

$$\omega_{P0} = \theta_0 - \theta_0' = \frac{y5 - y0}{x5 - x3} - \frac{y0 - yt}{x3} \quad (2)$$

In order to get the above linear equation we have used the small angle approximation:

$$\theta = \tan(\theta) \quad (3)$$

Similarly for H8 and H6 beams we have:

$$\omega_{H8} = \frac{299.79}{P_{H8}} Bl_3 \quad (4)$$

$$\omega_{H8} = \theta_8 - \theta_8' = \frac{yh8}{xh8 - x3} + \frac{yt}{x3} \quad (5)$$

[2] If you want to check the validity of the solutions of the system you are advised not to use maths softaware (like Mathematica for example) as the solution that you may get especially for the second case is much more complicated than the one produced by hand .

$$\omega_{H6} = \frac{299.79}{P_{H6}} Bl_3 \qquad (6)$$

$$\omega_{H6} = \theta_6 - \theta_6' = \frac{y4 - y6}{x4 - x3} - \frac{y6 - yt}{x3} \qquad (7)$$

From figure 2 we can also derive the following equation for the production angles of H8 and H6:

$$\theta_{P_{H8}} = -\frac{y0}{x3} \qquad (8)$$

$$\theta_{P_{H6}} = \frac{y6 - y0}{x3} \qquad (9)$$

As it was stated, before in this case we want to have the values of $P_{P0}$ , $P_{H8}$ and $\Theta_{PH8}$ (if possible) fixed. Of course the skew angle of H8 is strictly zero. So first we solve the system of the equations (1),(2),(3),(4) and (8) and …

1) we get the following expression for the value of yt:

$$yt = \frac{x3 \, \frac{P_8}{P_0} \, \frac{yh8}{xh8 - x3} - x3 \, \frac{y5 - y0}{x5 - x3} + y0}{1 - \frac{P_8}{P_0}}$$

2) we calculate the value of $BL_3$ :

$$BL_3 = \frac{P_8}{c} \left( \frac{yh8}{(xh8 - x3)} + \frac{yt}{x3} \right)$$

3) the value of y2:

$$y2 = (y0 - yt) \frac{x2}{x3} + yt$$

4)the value of $BL_2$:

$$BL_2 = \frac{\omega_2 \, P_{P0}}{c}$$

where $$\omega_2 = \frac{y0 - yt}{x3} - \frac{y2}{x2 - x1}$$

5)the value of $BL_1$:

$$BL_1 = \frac{\omega_1 \; P_{P0}}{c}$$

where $$\omega_1 = \frac{y2}{x2 - x1}$$

6) the value of y6:

$$y6 = -\frac{(x4 - x3)\left(x3 \; \frac{c \; BL_3}{P_6} - yt\right) - y4 \; x3}{x4}$$

The equations for solving all the other cases can be found in the various java files that solve each case.

# 4.Wobbling program

## Options

When you execute the wobbling program the dialog shown in **Figure 3** appears displaying the options that the user has for solving the various cases.

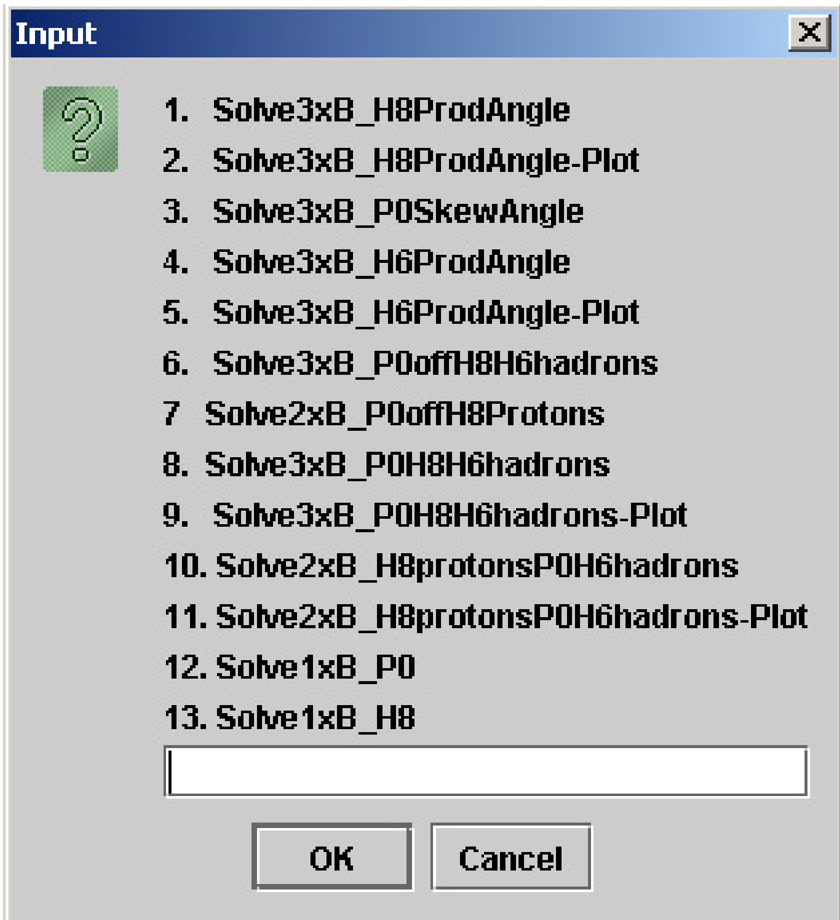


***Figure 3:*** *Main menu of the wobbling program*

In the table of the next page one can find a short description about these methods

# Options Table

| | Class | Method | P0 | H8 | H6 | Fixed values | Variable / Plot B=f(A) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | A | B |
| 1 | Solve3xB_H8ProdAngle | public Solution solve(Parameters p)[3] | P | H | H | $P_{P0}, P_{H8}$ | $\theta_{pH8}$ | $P_{H6}$ |
| 2 | Solve3xB_H8ProdAngle-Plot | public boolean plotP6_pa6(Parameters p) | P | H | H | $P_{P0}, P_{H8}, \theta_{pH8}$ | $P_{H6}$ | $\theta_{pH6}$ |
| 3 | Solve3xB_P0SkewAngle | public Solution solve(Parameters p) | P | H | H | $P_{P0}, P_{H8}$ | $\theta_{skewP0}$ | $P_{H6}$ |
| 4 | Solve3xB_H6ProdAngle | public Solution solve(Parameters p) | P | H | H | $P_{P0}, P_{H6}$ | $\theta_{pH6}$ | $P_{H8}$ |
| 5 | Solve3xB_H6ProdAngle-Plot | public boolean plotP8_pa8(Parameters p) | P | H | H | $P_{P0}, P_{H6}, \theta_{pH6}$ | $P_{H8}$ | $\theta_{pH8}$ |
| 6 | Solve3xB_P0offH8H6hadrons | public Solution solve(Parameters p) | OFF | H | H | $P_{P0}, P_{H8}, P_{H6}$ | $\theta_{pH8}$ | $\theta_{pH6}$ |
| 7 | Solve2xB_P0offH8Protons | public Solution solve(Parameters p) | OFF | P | H | $P_{H8} = P_{SPS}, \theta_{pH8}=0$ | $P_{H6}$ | $\theta_{pH6}$ |
| 8 | Solve3xB_P0H8H6hadrons | public Solution solve(Parameters p) | H | H | H | $P_{P0}, \theta_{pH8}=0$ | $P_{H8}$ | $P_{H6}$ |
| 9 | Solve3xB_P0H8H6hadrons-Plot | public boolean plotP6_pa6(Parameters p) | H | H | H | $P_{P0}, P_{H8}, \theta_{pH8}=0$ | $P_{H6}$ | $\theta_{pH6}$ |
| 10 | Solve2xB_H8protonsP0H6hadrons | public Solution solve(Parameters p) | H | P | H | $P_{P0}, P_{H8} = P_{SPS}, (\theta_{pH8}=0)$ | $P_{H6}$ | |
| 11 | Solve2xB_H8protonsP0H6hadrons-Plot | public Solution solve(Parameters p) | H | P | H | $P_{P0}, P_{H8} = P_{SPS}, (\theta_{pH8}=0)$ | $P_{H6}$ | $\theta_{pH6}$ |
| 12 | Solve1xB_P0 | public Solution solve(Parameters p) | P | - | - | $P_{P0}$ | | |
| 13 | Solve1xB_H8 | public Solution solve(Parameters p) | - | P | - | $P_{H8}$ | | |

[3] Method **solve** tries to solve each time one of the different kind of problems according to the class it belongs to. It tries to find a solution with the user defined values for the parameters in the "Fixed values" and "Variable / Plot B=f(A)" columns and if such a solution does not exist then it tries to find one as close to the user defined values as possible by keeping the parameters in the "Fixed values" fixed and changing the value of the parameter in column B and if it is necessary also the value of the parameter in column A.

# Execution Examples

If we choose “1” at the options dialog (main menu) shown at Figure 3 then we get the drawing of the beams (**Figure 4**) and an XML file is generated with the results. You can find the configuration file and the parameters file for this example as well as the results xml file generated at the end of this report. Generally for about a dozen of different parameters the results from this wobbling program were with very good precision close to the ones from NODAL.

If you choose “2” then you get for the specified (in the parameters xml file) momenta of P0 and H8 and production angle of H8 the different possible pairs of momenta and production angles for H6 (**Figure 5,6**)

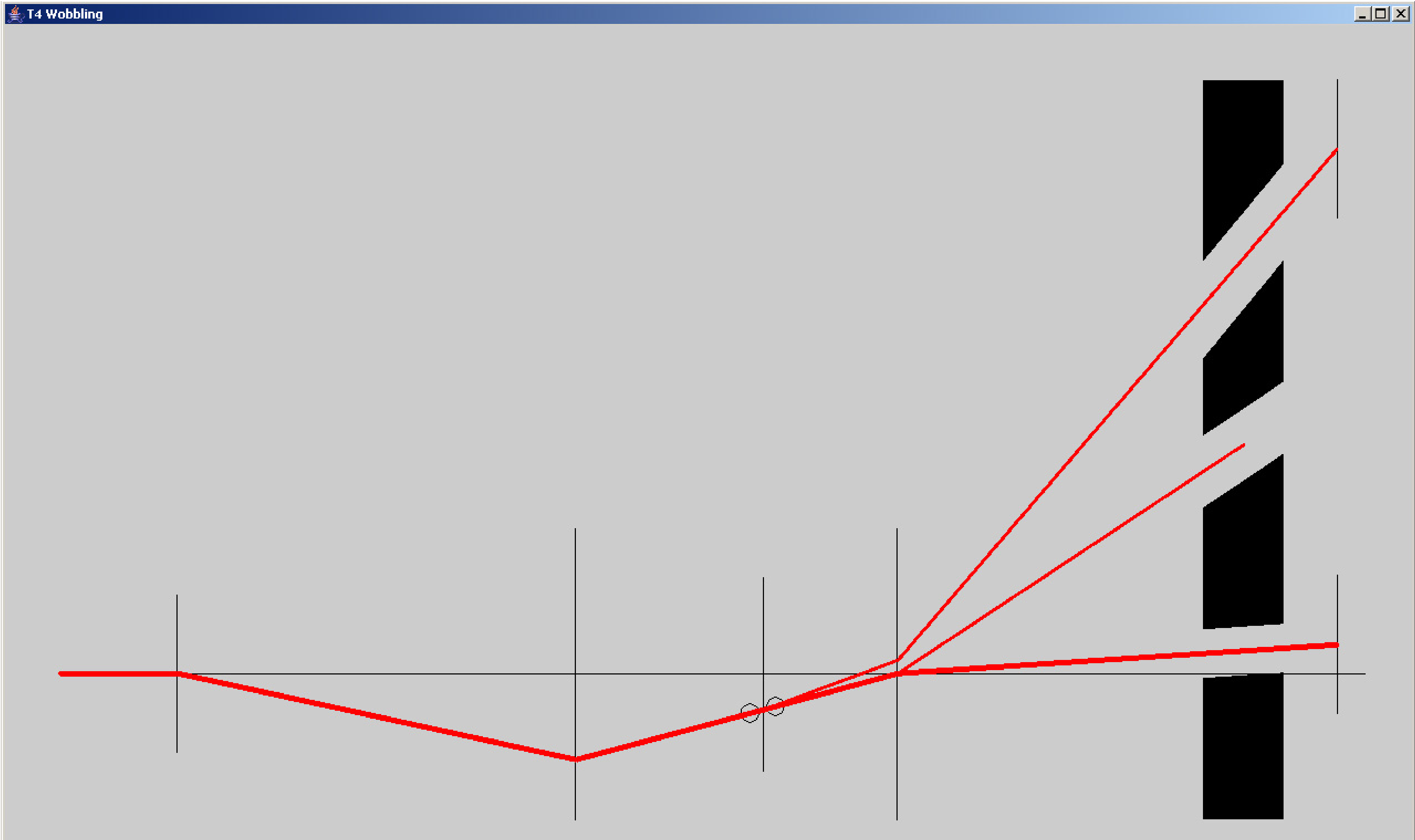


***Figure 4:*** *Execution example – Beams Drawing*

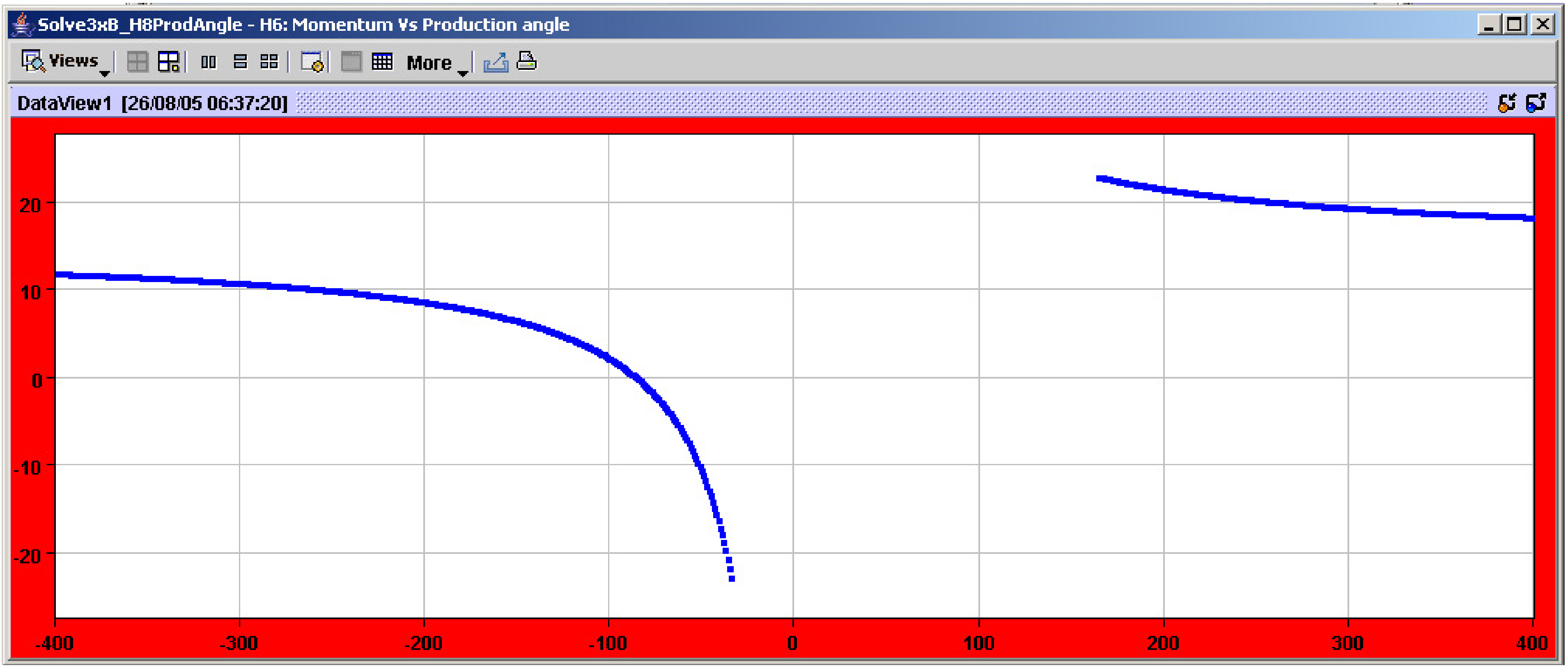


***Figure 5:*** *Execution example – H6: Momentum Vs Production angle*

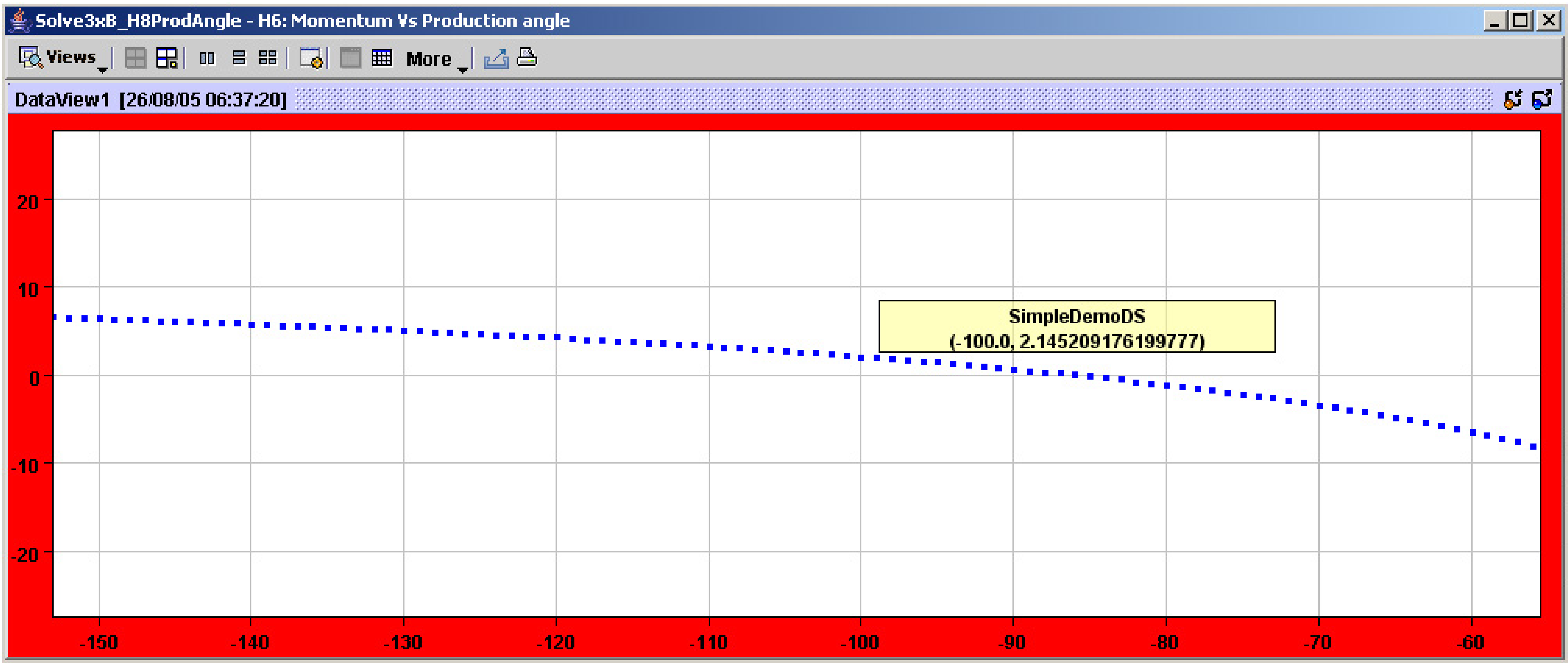


***Figure 6:*** *Execution example – H6: Momentum Vs Production angl – Zoomed at 100GeV*

# 5.References

[1] EFTHYMIOLPOULOS Ilias: Target Station T4 Wobbling - Explained