A Beamline Matching Application based on Open Source Software

Jean-François Ostiguy
Beam Physics Department, Fermilab

ACAT 2000, Oct 2000

The Matching Problem

Given a beamline and a set of lattice functions specified at one extremity, determine the strength of beamline elements necessary for the lattice functions to assume prescribed values at one or more distinct locations. A maximum of ten quantities can be prescribed:

- $\beta_{x,y}$ (envelope) $\alpha_{x,y}$ (envelope derivative), $\mu_{x,y}$(phase advance)
- η, η' (dispersion and its derivative)

Global Constraints

Matching problems are notoriously nonlinear; it is sometimes necessary to enforce global constraints based on physical considerations. A typical global constraint would be to limit the beta function amplitude (i.e. the beam size) throughout the beamline.

Applications

- FNAL Recycler Ring phase trombone (provided the motivation)
- Low-beta (interaction point optics) design
- other insertions
- transfer between circular machines

Design Goals

- Allow user to specify all aspects of a matching problem interactively
- Provide graphical feedback and allow dynamic interruption
- Application structured so as to be adaptable for specialized needs
- UNIX and Win32

Building Blocks

- MXYZTPLK (Automatic Differentiation Class Library by Leo Michelotti, FNAL)
- Beamline (Classes for lattice related calculations, built on top of MXYZTPLK. Authored by Leo Michelotti, FNAL)
- FLTK Toolkit (C++-based object-oriented GUI classes, UNIX and Win32)
- Nonlinear optimizer, Davidon-Fletcher-Powell Algorithm. Currently using implementation from Minuit
- Event propagation scheme: generic (C++templates), object-based and type-safe
- Persistent objects
- Multithreading

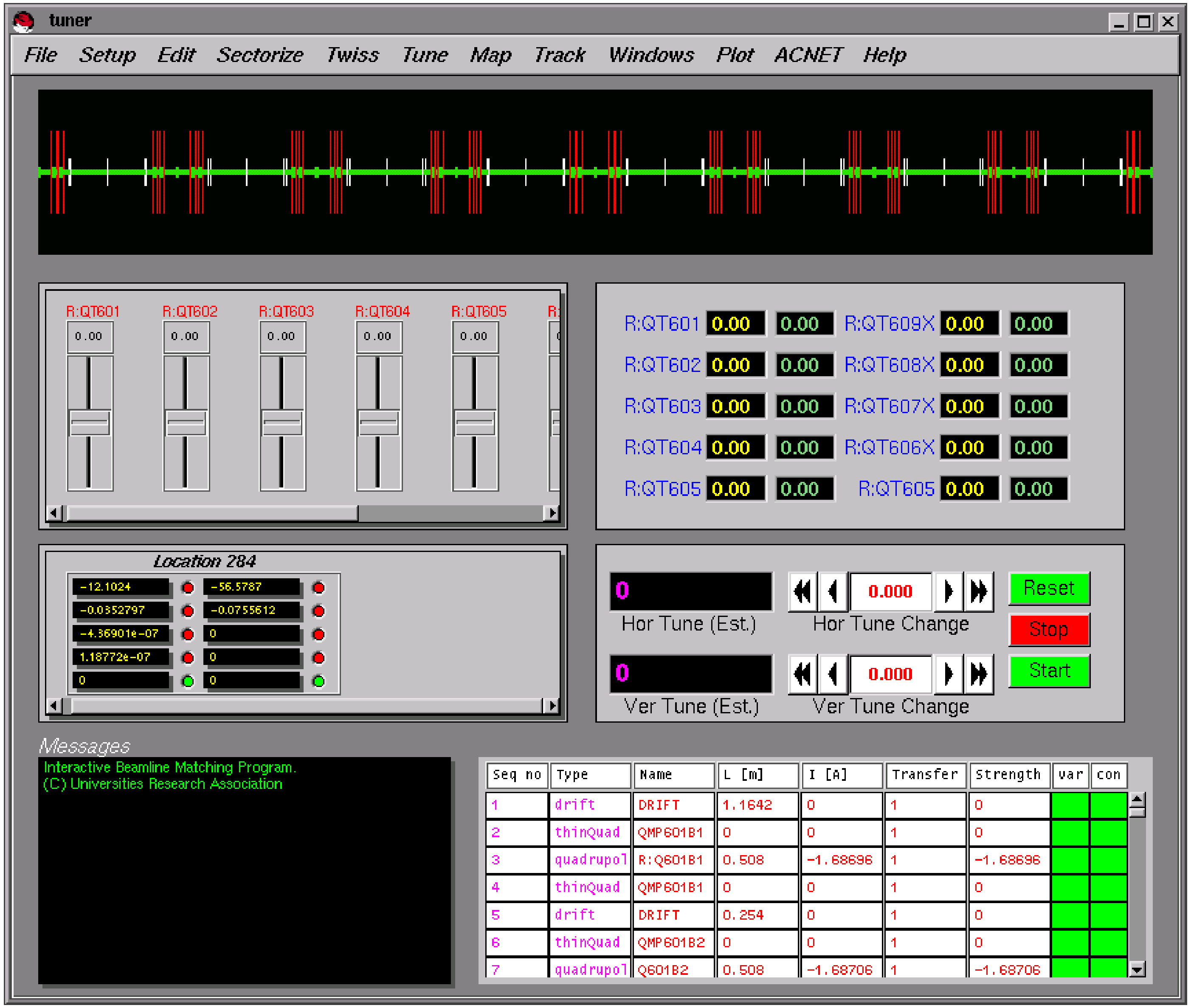
Persistence

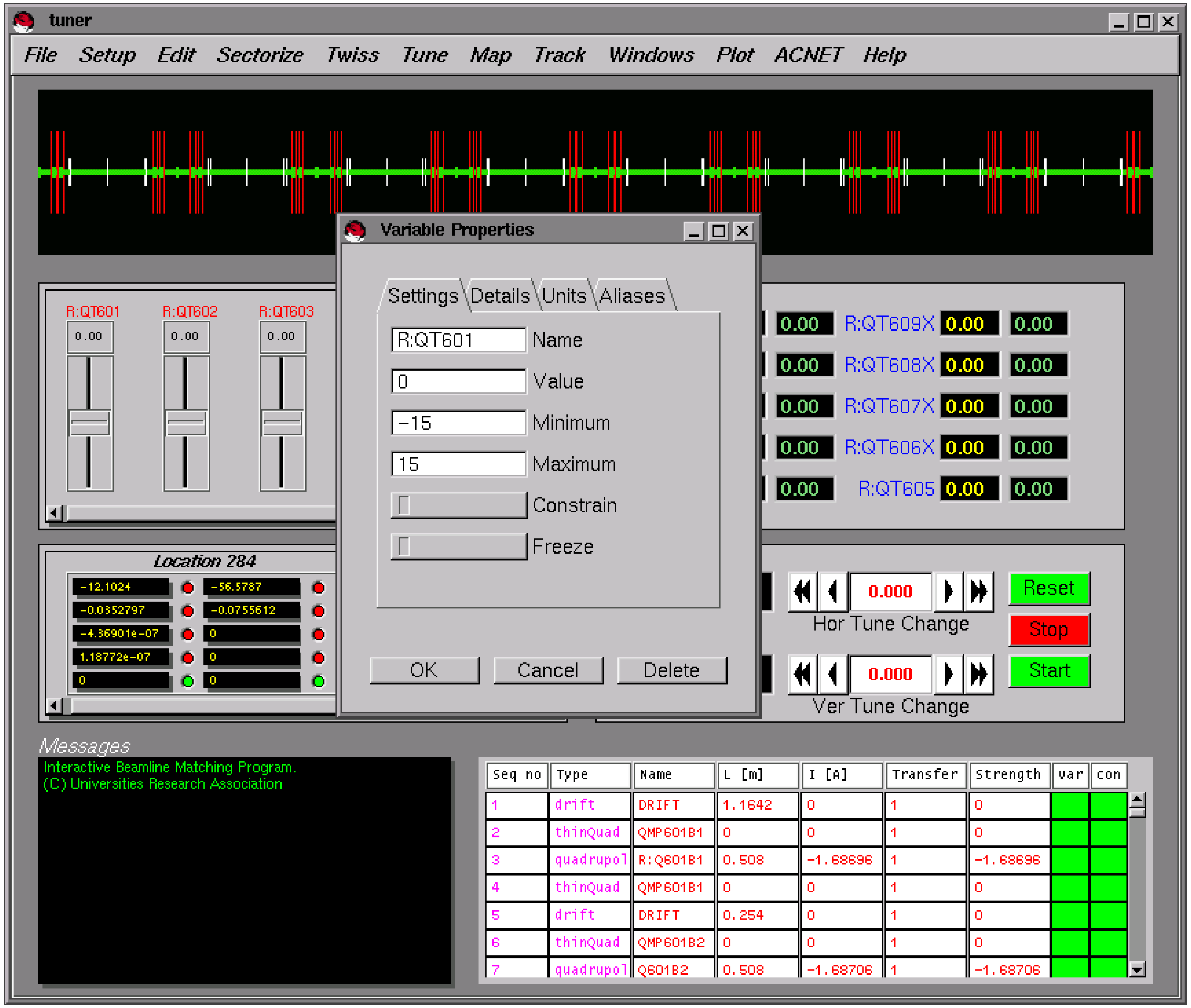
A invaluable feature for an interactive application is ability to save its state. The state is completely defined by a set objects and their relations to each other, as defined by pointers and references and virtual functions. Saving raw objects in memory is not sufficient to save the application state, since pointers are process specific. Memory references can be fixed a posteriori, but virtual function pointers are "hidden". The exact location in memory of a virtual function pointer is compiler dependent. We use the new ANSI C++ placement syntax for the `new` operator to circumvent this difficulty.

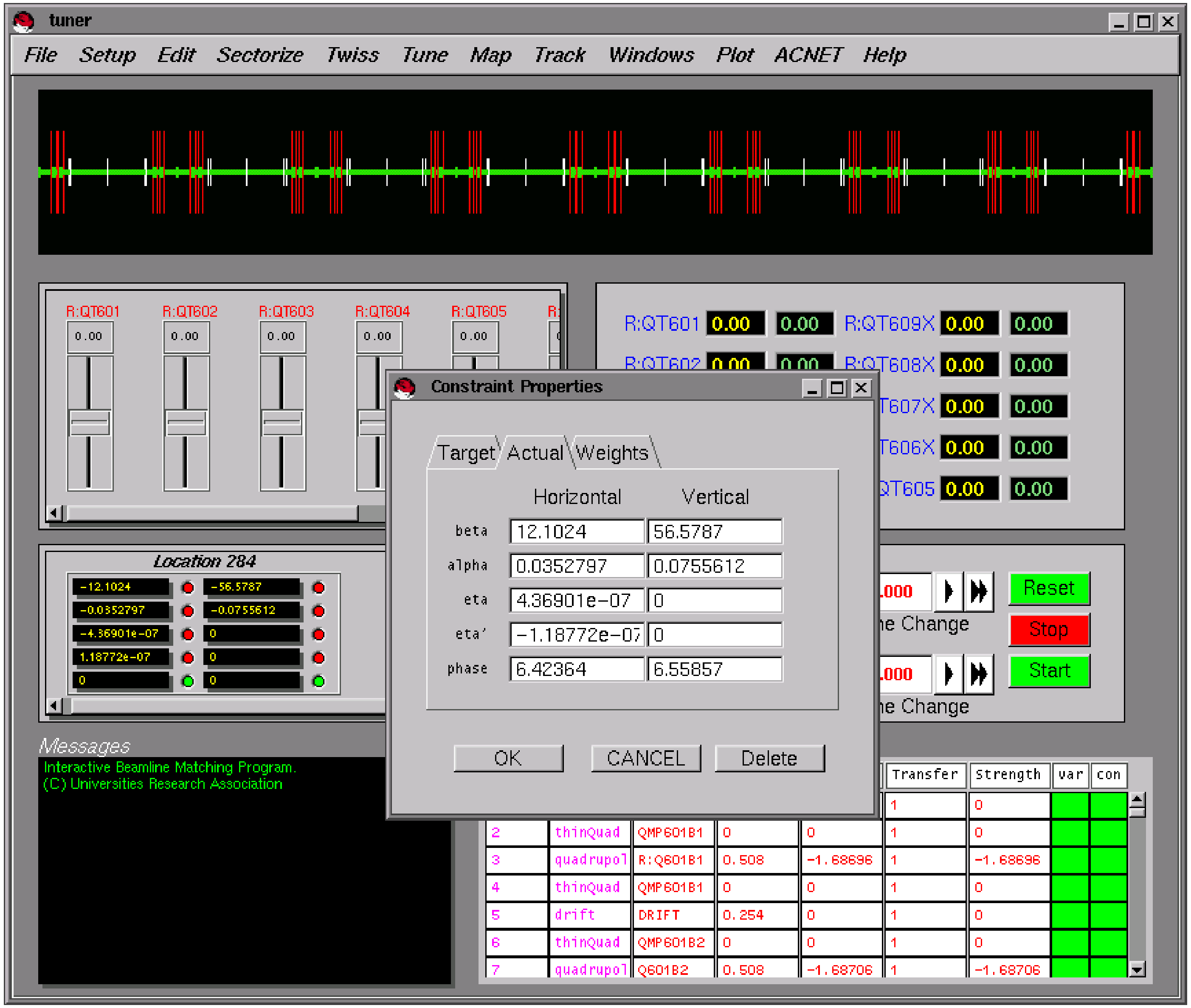
Persistent versions of both `MXYZTPLK` and `Beamline` have been implemented.

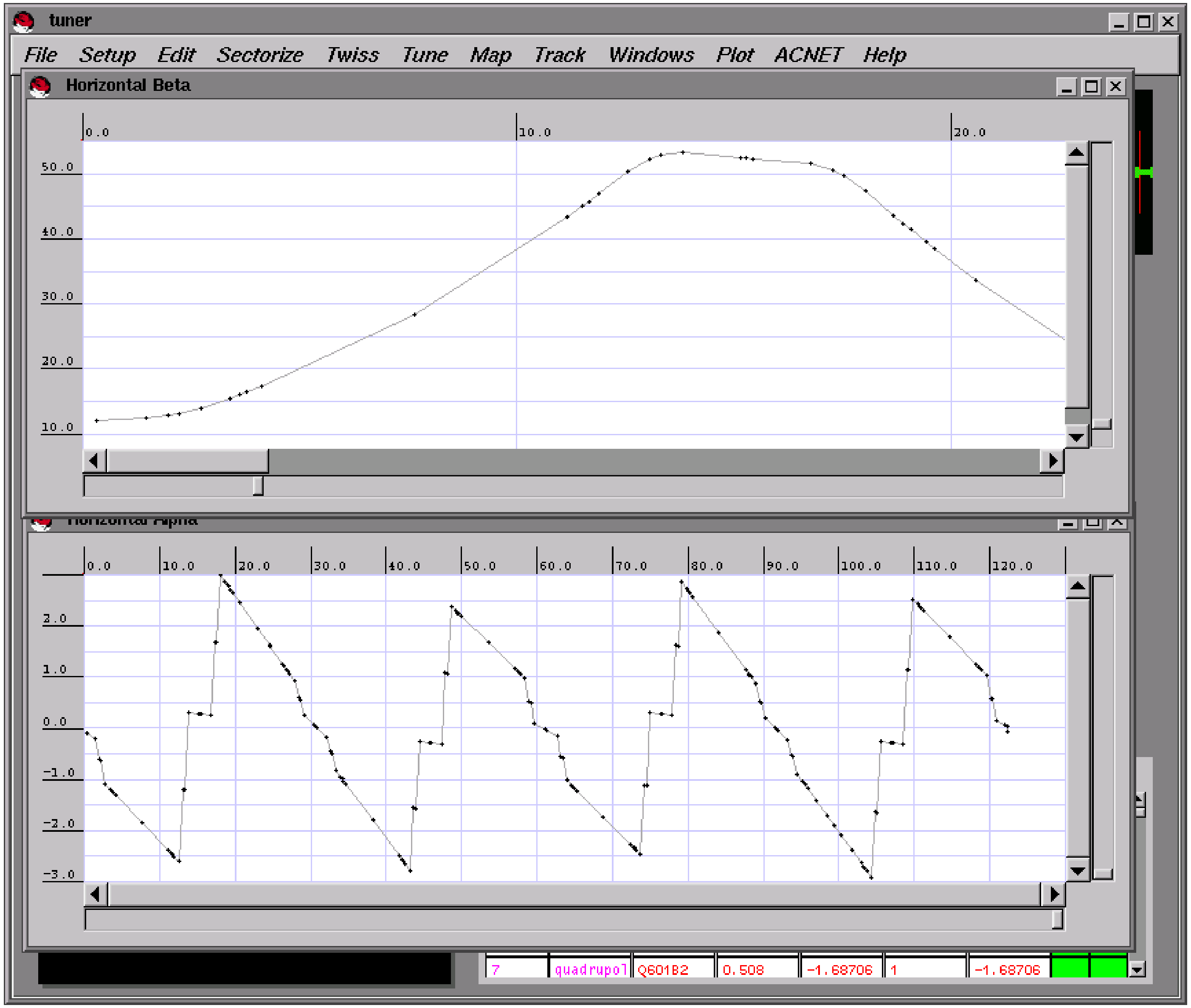
Some Bonus Features

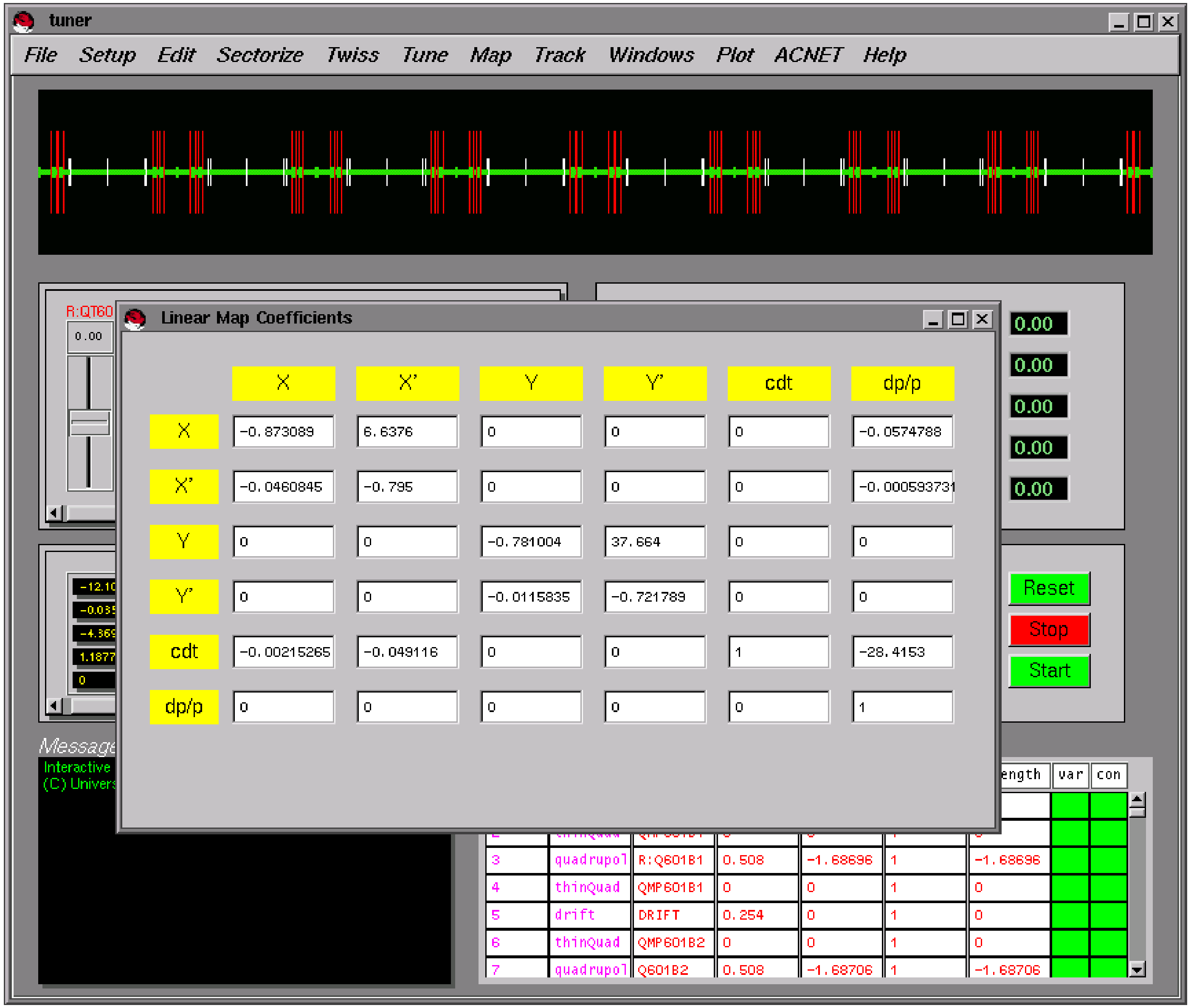
- The fact that BLIMP is based on `MXYZTPLK` and `Beamline` automatically allows the computation of nonlinear Taylor maps of arbitrary order.
- Beamlines can be edited using all the facilities of the beamline library.
- For the application to the FNAL Recycler Ring Phase Trombone, access to the Fermilab Accelerator Control system has been implemented. One can get and set device settings through a simple TCP/IP based protocol.

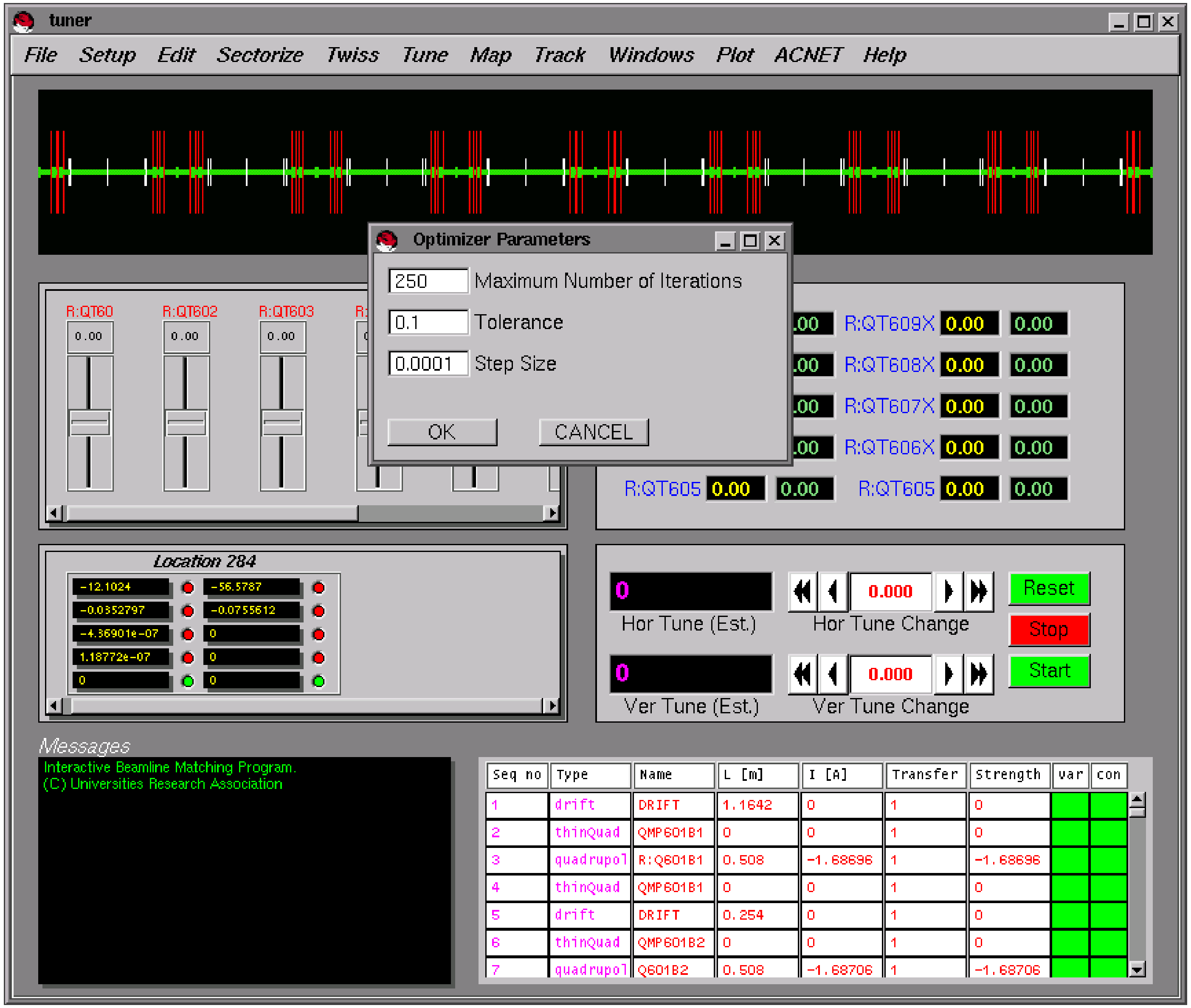

tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
R:QT601 R:QT602 R:QT603 R:QT604 R:QT605
0.00 0.00 0.00 0.00 0.00
R:QT601 0.00 0.00 R:QT609X 0.00 0.00
R:QT602 0.00 0.00 R:QT608X 0.00 0.00
R:QT603 0.00 0.00 R:QT607X 0.00 0.00
R:QT604 0.00 0.00 R:QT606X 0.00 0.00
R:QT605 0.00 0.00 R:QT605 0.00 0.00
Location 284
-12.1024 -56.5787
-0.0352797 -0.0755612
-4.36901e-07 0
1.18772e-07 0
0 0
0
Hor Tune (Est.)
0.000
Hor Tune Change
0
Ver Tune (Est.)
0.000
Ver Tune Change
Reset
Stop
Start
Messages
Interactive Beamline Matching Program.
(C) Universities Research Association
Seq no Type Name L [m] I [A] Transfer Strength var con
1 drift DRIFT 1.1642 0 1 0
2 thinQuad QMP601B1 0 0 1 0
3 quadrupol R:Q601B1 0.508 -1.68696 1 -1.68696
4 thinQuad QMP601B1 0 0 1 0
5 drift DRIFT 0.254 0 1 0
6 thinQuad QMP601B2 0 0 1 0
7 quadrupol Q601B2 0.508 -1.68706 1 -1.68706

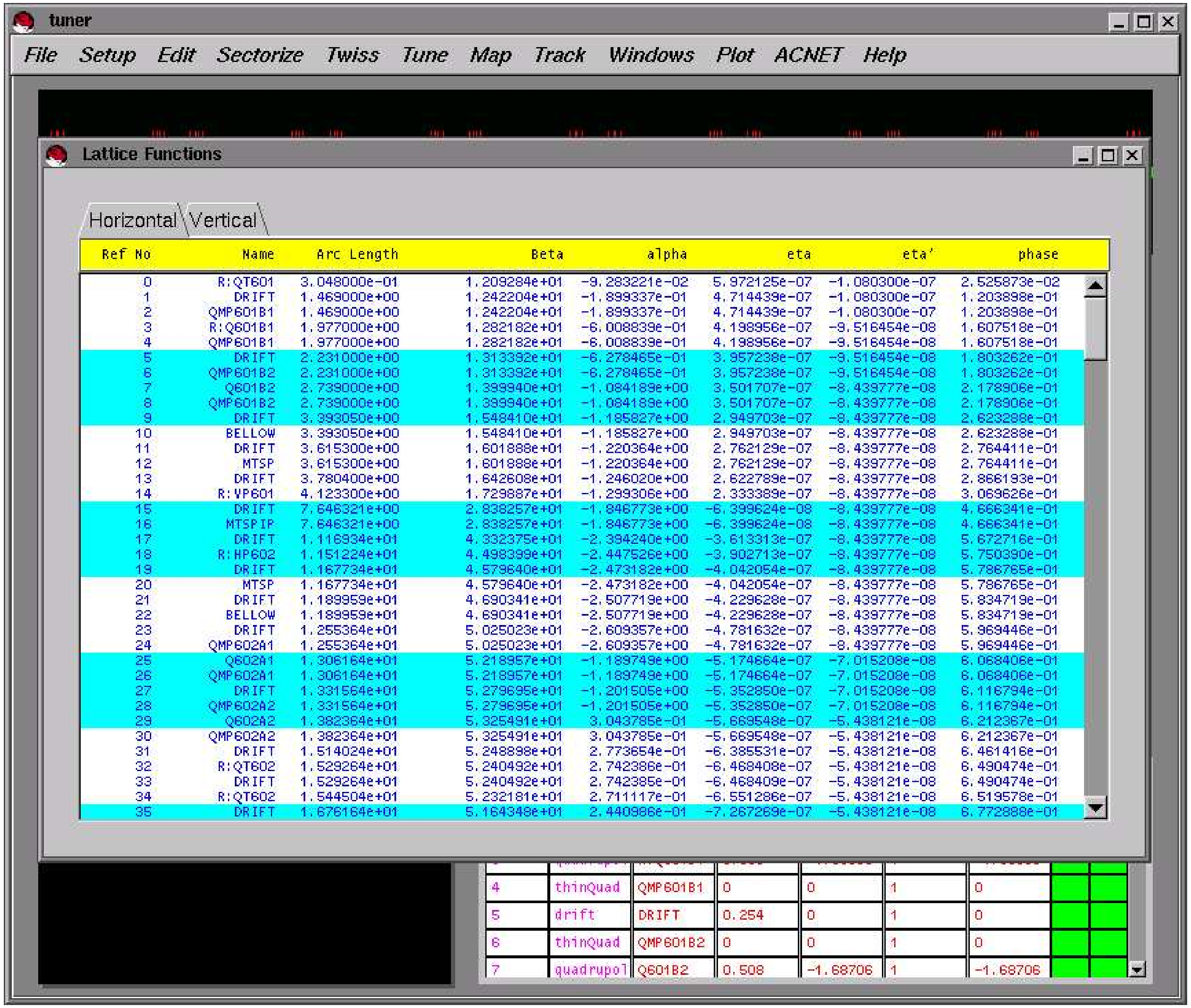

tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
Variable Properties
Settings Details Units Aliases
R:QT601 Name
0 Value
-15 Minimum
15 Maximum
Constrain
Freeze
OK Cancel Delete
R:QT601 R:QT602 R:QT603
Location 284
R:QT609X
R:QT608X
R:QT607X
R:QT606X
R:QT605
Hor Tune Change
Ver Tune Change
Reset
Stop
Start
Messages
Interactive Beamline Matching Program.
(C) Universities Research Association
Seq no Type Name L [m] I [A] Transfer Strength var con


tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
R:QT601 R:QT602 R:QT603 R:QT604 R:QT605
0.00 0.00 0.00 0.00 0.00
R:QT601 0.00 0.00 R:QT609X 0.00 0.00
R:QT602 0.00 0.00 R:QT608X 0.00 0.00
T607X 0.00 0.00
T606X 0.00 0.00
QT605 0.00 0.00
Location 284
-12.1024 -56.5787
-0.0352797 -0.0755612
-4.36901e-07 0
1.18772e-07 0
0 0
Constraint Properties
Target Actual Weights
Horizontal Vertical
beta 12.1024 56.5787
alpha 0.0352797 0.0755612
eta 4.36901e-07 0
eta' -1.18772e-07 0
phase 6.42364 6.55857
OK CANCEL Delete
Reset
Stop
Start
Messages
Interactive Beamline Matching Program.
(C) Universities Research Association
Transfer Strength var con
2 thinQuad QMP601B1 0 0 1 0
3 quadrupol R:Q601B1 0.508 -1.68696 1 -1.68696
4 thinQuad QMP601B1 0 0 1 0
5 drift DRIFT 0.254 0 1 0
6 thinQuad QMP601B2 0 0 1 0
7 quadrupol Q601B2 0.508 -1.68706 1 -1.68706


tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
Horizontal Beta
0.0
10.0
20.0
50.0
40.0
30.0
20.0
10.0
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0 110.0 120.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
7
quadrupol
Q60182
0.508
-1.68706
1
-1.68706


tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
Linear Map Coefficients
X X' Y Y' cdt dp/p
X -0.873089 6.6376 0 0 0 -0.0574788
X' -0.0460845 -0.795 0 0 0 -0.000593731
Y 0 0 -0.781004 37.664 0 0
Y' 0 0 -0.0115835 -0.721789 0 0
cdt -0.00215265 -0.049116 0 0 1 -28.4153
dp/p 0 0 0 0 0 1
Reset
Stop
Start
var
con
3 quadrupol R:Q601B1 0.508 -1.68696 1 -1.68696
4 thinQuad QMP601B1 0 0 1 0
5 drift DRIFT 0.254 0 1 0
6 thinQuad QMP601B2 0 0 1 0
7 quadrupol Q601B2 0.508 -1.68706 1 -1.68706


tuner
File Setup Edit Sectorize Twiss Tune Map Track Windows Plot ACNET Help
Optimizer Parameters
250 Maximum Number of Iterations
0.1 Tolerance
0.0001 Step Size
OK
CANCEL
R:QT60
R:QT602
R:QT603
R:QT609X 0.00 0.00
R:QT608X 0.00 0.00
R:QT607X 0.00 0.00
R:QT606X 0.00 0.00
R:QT605 0.00 0.00
R:QT605 0.00 0.00
Location 284
-12.1024
-56.5787
-0.0352797
-0.0755612
-4.36901e-07
1.18772e-07
Hor Tune (Est.)
Hor Tune Change
0.000
Ver Tune (Est.)
Ver Tune Change
Reset
Stop
Start
Messages
Interactive Beamline Matching Program.
(C) Universities Research Association
Seq no Type Name L [m] I [A] Transfer Strength var con
1 drift DRIFT 1.1642 0 1 0
2 thinQuad QMP601B1 0 0 1 0
3 quadrupol R:Q601B1 0.508 -1.68696 1 -1.68696
4 thinQuad QMP601B1 0 0 1 0
5 drift DRIFT 0.254 0 1 0
6 thinQuad QMP601B2 0 0 1 0
7 quadrupol Q601B2 0.508 -1.68706 1 -1.68706



Ref No	Name	Arc Length	Beta	alpha	eta	eta'	phase
0	R:QT601	3.048000e-01	1.209284e+01	-9.283221e-02	5.972125e-07	-1.080300e-07	2.525873e-02
1	DRIFT	1.469000e+00	1.242204e+01	-1.899337e-01	4.714439e-07	-1.080300e-07	1.203898e-01
2	QMP601B1	1.469000e+00	1.242204e+01	-1.899337e-01	4.714439e-07	-1.080300e-07	1.203898e-01
3	R:Q601B1	1.977000e+00	1.282182e+01	-6.008839e-01	4.198956e-07	-9.516454e-08	1.607518e-01
4	QMP601B1	1.977000e+00	1.282182e+01	-6.008839e-01	4.198956e-07	-9.516454e-08	1.607518e-01
5	DRIFT	2.231000e+00	1.313392e+01	-6.278465e-01	3.957238e-07	-9.516454e-08	1.803262e-01
6	QMP601B2	2.231000e+00	1.313392e+01	-6.278465e-01	3.957238e-07	-9.516454e-08	1.803262e-01
7	Q601B2	2.739000e+00	1.399940e+01	-1.084189e+00	3.501707e-07	-8.439777e-08	2.178906e-01
8	QMP601B2	2.739000e+00	1.399940e+01	-1.084189e+00	3.501707e-07	-8.439777e-08	2.178906e-01
9	DRIFT	3.393050e+00	1.548410e+01	-1.185827e+00	2.949703e-07	-8.439777e-08	2.623288e-01
10	BELLOW	3.393050e+00	1.548410e+01	-1.185827e+00	2.949703e-07	-8.439777e-08	2.623288e-01
11	DRIFT	3.615300e+00	1.601888e+01	-1.220364e+00	2.762129e-07	-8.439777e-08	2.764411e-01
12	MTSP	3.615300e+00	1.601888e+01	-1.220364e+00	2.762129e-07	-8.439777e-08	2.764411e-01
13	DRIFT	3.780400e+00	1.642608e+01	-1.246020e+00	2.622789e-07	-8.439777e-08	2.866193e-01
14	R:VP601	4.123300e+00	1.729887e+01	-1.299306e+00	2.333389e-07	-8.439777e-08	3.069626e-01
15	DRIFT	7.646321e+00	2.838257e+01	-1.846773e+00	-6.399624e-08	-8.439777e-08	4.666341e-01
16	MTSPIP	7.646321e+00	2.838257e+01	-1.846773e+00	-6.399624e-08	-8.439777e-08	4.666341e-01
17	DRIFT	1.116934e+01	4.332375e+01	-2.394240e+00	-3.613313e-07	-8.439777e-08	5.672716e-01
18	R:HP602	1.151224e+01	4.498399e+01	-2.447526e+00	-3.902713e-07	-8.439777e-08	5.750390e-01
19	DRIFT	1.167734e+01	4.579640e+01	-2.473182e+00	-4.042054e-07	-8.439777e-08	5.786765e-01
20	MTSP	1.167734e+01	4.579640e+01	-2.473182e+00	-4.042054e-07	-8.439777e-08	5.786765e-01
21	DRIFT	1.189959e+01	4.690341e+01	-2.507719e+00	-4.229628e-07	-8.439777e-08	5.834719e-01
22	BELLOW	1.189959e+01	4.690341e+01	-2.507719e+00	-4.229628e-07	-8.439777e-08	5.834719e-01
23	DRIFT	1.255364e+01	5.025023e+01	-2.609357e+00	-4.781632e-07	-8.439777e-08	5.969446e-01
24	QMP602A1	1.255364e+01	5.025023e+01	-2.609357e+00	-4.781632e-07	-8.439777e-08	5.969446e-01
25	Q602A1	1.306164e+01	5.218957e+01	-1.189749e+00	-5.174664e-07	-7.015208e-08	6.068406e-01
26	QMP602A1	1.306164e+01	5.218957e+01	-1.189749e+00	-5.174664e-07	-7.015208e-08	6.068406e-01
27	DRIFT	1.331564e+01	5.279695e+01	-1.201505e+00	-5.352850e-07	-7.015208e-08	6.116794e-01
28	QMP602A2	1.331564e+01	5.279695e+01	-1.201505e+00	-5.352850e-07	-7.015208e-08	6.116794e-01
29	Q602A2	1.382364e+01	5.325491e+01	3.043785e-01	-5.669548e-07	-5.438121e-08	6.212367e-01
30	QMP602A2	1.382364e+01	5.325491e+01	3.043785e-01	-5.669548e-07	-5.438121e-08	6.212367e-01
31	DRIFT	1.514024e+01	5.248898e+01	2.773654e-01	-6.385531e-07	-5.438121e-08	6.461416e-01
32	R:QT602	1.529264e+01	5.240492e+01	2.742386e-01	-6.468408e-07	-5.438121e-08	6.490474e-01
33	DRIFT	1.529264e+01	5.240492e+01	2.742385e-01	-6.468409e-07	-5.438121e-08	6.490474e-01
34	R:QT602	1.544504e+01	5.232181e+01	2.711117e-01	-6.551286e-07	-5.438121e-08	6.519578e-01
35	DRIFT	1.676164e+01	5.164348e+01	2.440986e-01	-7.267269e-07	-5.438121e-08	6.772888e-01

4	thinQuad	QMP601B1	0	0	1	0
5	drift	DRIFT	0.254	0	1	0
6	thinQuad	QMP601B2	0	0	1	0
7	quadrupol	Q601B2	0.508	-1.68706	1	-1.68706

Conclusions

- BLIMP is still a work in progress
- Current priority is to make application fully multithreaded
- Port to Qt, a commercially supported GPLed framework more mature than FLTK is being seriously considered.
- Hierarchical browsing and edition of beamlines would be desirable