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BNL MAD Program Notes: On Line Charged Particle Tracking the Xtrack Command Group

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1. Xtrack

Xtrack is a menu driven, graphics oriented charged particle tracking procedure. Its features allow particle trajectories to be followed under conditions of influencing fields changing with time, as in various accelerator beam extraction scenarios. It is a separate, considerably enhanced version of the transport style second order tracking of the original MAD program. It is written in the BNL MAD programming environment, with Silicon Graphics, Inc., based menu and graphics features. Supporting features include versatile track pattern generators, a channel element for handling extraction, and utilities for inserting aperture and time dependence information into common groups of lattice elements.

The tracking is performed as a workstation console session using several pop up menus. A Main Menu leads to several other menus which produce initial track coordinate distributions, perform the tracking, handle parameter changes, and provide Track Bank and Beam Line exchanges and other options. A series of lower level menus may also be called for forming numbers, selecting particular stored commands, and doing related tasks.

2. Main Menu

The Main Menu is concerned with generating track distributions, managing Track Bank and Beam Line changes, selecting a particular track to observe, and passing control to a second Tracking Menu for doing particle tracking.

Main Menu
Track = #
Pick Start
Start Branch
Track One
Next Track
Prev Track
Track All
Move All
Clear
Pick Draw
Bank Options
Line Options
Changes
QUIT

The title is *Main Menu*, followed by a passive panel giving the index of the currently observed track, or "All". The routine follows a single selected track, or all tracks together.

Pick Start — Goes to a submenu which presents the names of **Trgen** track generating commands submitted in an **Xmenu** list to the tracking command. Options on the generators include the use of a list of ordinary **START** commands for defining the starting space points. Each generator call produces a Track Bank with a unique name.

Start Branch	Resets flags for tracks in the current Bank which have been captured in Main Ring septum, so they now become the starting tracks in the Branch Line. As the program evolves, related changes, now done separately in other menus, may be combined here. These will likely include switching to the designated Branch Line, and turning off the field updating.
Track One	Causes the program to track one particle, under control of the Tracking Menu.
Next Track	Bumps the track index up by one. Bumping up can be repeated.
Prev Track	Bumps the track index down by one. Bumping down can be repeated.
Track All	Causes the program to track all particles in the current Track Bank, under control of the Tracking Menu.
Move All	Causes the program to track all particles so they catch up with the one farthest ahead in tracking. Listing and plotting are suppressed during this catch up.
Clear	Clears the central part of the screen, and redraws the frame, axes, and labels.
Pick Draw	Presents a menu of the drawing commands in a list attached to the **Xrun** tracking command, such as machine layout survey. Most of the currently developed drawing commands apply more to the usual Twiss tracking than to the phase diagrams here.
Bank Options	Sends the program to the Track Bank submenu (# 4) to change, save, delete, etc the Track Banks attached to the program.
Line Options	Sends the program to the Beam Line submenu (# 5) to change the Beam Line currently attached to the tracking.
Changes	Sends to program to the Changes submenu (# 3) for changing a limited number of graphics and program parameters.

Selections made from this and the other menus are echoed on both the screen, and the MAD ECHO File.

3. Tracking Menu

Given a selection of a particular track, or all tracks, from the Main Menu, the Tracking Menu governs some details of the particle tracking. Counts for the status of tracks in the current Bank are listed on the console after each tracking pass.

Tracking
Track = #
Turn = #
Place = #
Step = #
Coord *
RETURN
Do Places
Do Turns
Clear
Print Tracks
Draw Tracks
Draw Ellipse
Step = 1
Step = 2
Step = 5
Step = 10
Step = 25
Step = All
Draw X, Px
Draw Y, Py
Draw X, Y

The title is *Tracking,* and is followed by four passive panels giving the track number, or "All", the current turn and position number for the track(s), and the number of place or turn steps to be taken during a tracking episode. *Coord* refers to the current plotting variables from among: 1). X, Px; 2). Y, Py; 3). X, Y, and is also passive.

Do Places — Causes the program to track the current particle / all particles for the number of places (positions) given by the current value of "steps". A place is a Beam Line (lattice) location designated on a **PRINT** statement linked to the lattice. If no places are set, the default place is at the end of the Beam Line. Coordinate plotting is geared to places.

Do Turns — Causes the program to track the current particle / all particles for the number of turns given by the current value of "steps".

Clear — Clears the central part of the screen, and redraws the frame, axes, and labels.

Print Tracks — Prints the current Track Bank on the listing file (ECHO / PRINT) if any tracks have been moved since the last printing.

Draw Tracks — Draws the current Track Bank on the screen using the current choice of coordinate pairs.

Draw Ellipse — Draws the current Track Bank on the screen using the current choice of coordinate pairs, joining the points or symbols, as in outlining a phase ellipse. Outlining is suppressed if the initial distribution was not formed along the surface of a phase ellipse.

Step = 1, etc — Sets the step count for tracking, for places and turns.

Draw X, Px, etc — Selects the coordinates for drawing. Default is X, Px. All of the three choices can be drawn from any of the available Banks. Clearing between coordinate changes may be

helpful to avoid clutter.

4. Changes Menu

A few other parameter changes can presently be handled by a short menu attached to the tracking operation. The list is easily expanded.

Changes
Plots On
Clock On
RETURN
Change Span
Reset Span
Reset Seed
Plots On Off
Clock On Off

The title is *Changes,* followed by a passive panel that show the status of track coordinate drawing: *Plots On* or *Plots Off,* and a passive panel that shows the status of magnetic field updating: *Clock On* or *Clock Off.*

Change Span Sends the program to the Plotdef changes menu below, for changing the span(s) of the coordinate axes.

Reset Span Resets the spans to the value when the tracking command was started.

Reset Seed Resets the seed in the random number generator used for generating initial track patterns. This allows returning to original conditions within the tracking manager.

Plots On/Off Is a toggle which alternates the plot control switch: On --> Off, or Off --> On. This feature helps manage the screen, which can get rather busy for longer tracking runs.

Clock On/Off Is a toggle which alternates the clock control switch: On --> Off, or Off --> On. This feature turns off magnetic field updating, as for example on fixed field Branch Lines, speeding up tracking.

5. Track Bank Menu

Various features are offered for working among a number of different Track Banks under differing conditions within a given session with the **Xrun** tracking manager.

Bank Options
Bank Name *
Active = #
Starting = #
Eject = #
Lost = #
RETURN
Save
Choose a Bank
Restore
Delete a Clone
Delete All Clones
Begin Bank Merge
Choose for Merge
End Merge
Center Bank

The title panel is *Bank Options*, followed by the name of the current Bank, followed by four passive panels which present a summary of the status of the tracks in the current Track Bank. Unique Bank names are assigned by the track generators, from a given root or a default, and serialized. Assigning root names which help remember the pattern can avoid a lot of confusion if several track generators are attached to the tracking command.

The program attaches a rider to each track, which records the current position, time, and various other details so the program can continue tracking properly at whatever place it may have left off in the past.

RETURN — Goes back to Main Menu.

Save — Causes the program to create a copy (clone) of the current Track Bank. The copy can be recalled at any time.

Choose a Bank — Brings up a submenu with the names of all Track Banks currently resident in the program. If a Bank is selected, it becomes the current Bank for tracking.

Restore — Brings back the Bank, if any, present at entry to the **Xrun** command, and otherwise the first Bank created under the command.

Delete a Clone — Brings up a submenu with the names of all Track Banks currently resident in the program. If a Bank is selected, and it is a clone created during the tracking, it is deleted. This helps reduce clutter.

Delete All Clones — Provides a stronger approach to Bank housecleaning.

Begin Merge — Starts a set of Bank merging steps. This feature allows a certain amount of embellishing distributions, combining beam shapes and the like. Again a submenu with the names of all Track Banks currently resident in the program is brought up, so the first Bank to be merged can be selected. Once in merge mode, merging has to be finished, ala *End Merge*. The merged Bank will take the name of the first Bank in the merge, with a serialized letter suffix added.

Choose for Merge — Continues merging, adding a Bank to the started one. An additional Bank is selected from the Bank submenu.

End Merge	Finishes the merge, and links the new Bank into the program's memory manager.
Center Bank	Adjusts coordinates of all tracks captured in septum relative to average coodinates of ejected tracks. This is a crude way to shift coordinates between the system of the septum relative to the ring lattice, and the system of the branch line.

6. Beam Line Menu

Beam Lines can be exchanged for tracking purposes. These features are designed to combine tracking through transfer (Branch) Lines with tracking within previous Beam Lines, such as accelerators. Acceleration and ejection operations are examples.

Various console diagnostics try to sort out missing Lines, and other needed information.

Line Options
Line Name *
RETURN
Set to Main Line
Set to Branch Line
Get Main
Get Branch
Restore Main
Reset

The menu title is *Line Options*, and the name of the current Beam Line is written in the next panel.

RETURN — Goes back to the Main Menu.

Set to Main Line — Sets the current Beam Line to that tagged as the Main Line in the Beam Line stack. This is normally the Line present at entry to the tracking command, but may be changed during the run.

Set to Branch Line — Sets the current beam line to that tagged as the Branch Line in the Beam Line stack. The program has to be told about this Branch Line, via directives from this menu.

Get Main — Produces a submenu of previously expanded and stored Beam Lines, from which one to be tagged "Main" is to be selected. The selection is put on the Beam Line stack, but not enabled, for safety. The additional step of "Set to Main Line" is needed to make this the current Beam Line.

Get Branch — Like "Get Main", but for a Branch Line.

Restore Main — Moves the Beam Line tagged as the original Main at the start of this run from the stack into the current Line position.

Reset — Moves the Beam Line in effect when the menu was entered from the stack into the current position. This feature is intended to help recover from console mistakes.

7. Pick a Module Submenu

This menu offers a set of names of modules related by class (Keyword) or by being in some list of interest to some part of the program.

Title
Name 1
Name 2
Name ...
Name j

8. Plotdef Changes Menu

This menu and its submenus now deal mainly with span (scale) changes in the current graphics frame. The current picture is cleared, and axes and labels redrawn.

Plotdef Changes
RETURN
Spans

8.1. Plotdef Spans Submenu

H, V Spans
RETURN
Upper
Lower
Left
Right
H Zoom
V Zoom
H Shift
V Shift

The *Upper, Lower, Left,* and *Right* panels select an end of an axis for which a value is to be changed. Various simple minded submenus ask for sign, exponent / multiplier, and one or more base digits in constructing a decimal number for the value.
H Zoom, V Zoom go to a submenu below for stretching or contracting an axis.
H Shift, V Shift go to a submenu below for shifting the scale along an axis.

8.2. Plotdef Zoom Factor Submenu

H Zoom
Sx1 = #
Sx2 = #
RETURN
* 1.1
* 1.2
* 1.5
* 2
* 5
* 10
* .9
* .8
* .5
* .2
* .1

The title is *H Zoom* or *V Zoom.* The next two panels give the current values of the scales, that is the values at the ends of the H or V (X or Y) axes, and are passive. For V, these read: "Sy1 = #", "Sy2 = #". The remaining panels give numerical factors for doing the zoom along the axis previously selected on

the "H, V, Spans" calling menu above.

8.3. Plotdef Shift Value Submenu

H Shift
Sx1 = #
Sx2 = #
RETURN
+
-
1.
.8
.5
.33
.25
.2
.1

The title is *H Shift* or *V Shift*. The next two panels give the current values of the H or V scale ends, and are passive. For V, these read: "Sy1 = #", "Sy2 = #". The sign panels denote the direction of the intended shift. The numerical entries are choices for the fractional shift, along the axis selected on the "H, V Spans" calling menu above. An H shift of + 1. moves the current picture exactly offscale to the right, by one span interval.

9. The Xtrack Command File

A typical tracking setup consists of the usual **Track** initialization command, one or more **Trgen** track generating commands, the new **Xrun** command, and the usual **Endtrack** command for cleanup. **Xrun** is an enhanced RUN command that provides for linking graphics and initial track distribution services to the tracking operation. It is described in detail below.

Track
[Track Generators and their Xmenu]

Xrun, ...
Endtrack

9.1. Beam Lines

If more than one Beam Line is to be followed, each must be established with its own **USE, Fsetmats,** and **PRINT** command groups. **USE** expands a Beam Line, preparing a table (lattice map) of the actual sequence of elements from various statements which describe parts of the Line. **Fsetmats** prepares a table of matrices, terms, and factors for tracking based on the material of the lattice map. **PRINT** notes positions in the lattice at which tracking information is to be listed and graphed. Both **Fsetmats** and **PRINT** commands apply to the current Beam Line. Any number of Beam Lines can be expanded, have tables appended, have positions marked, and reside in the program's data base. The attribute distribution commands, **Aperture** and **Timedeps,** which are also keyed to the lattice map and matrix table currently in effect, may also be included with these groups. These distribution commands are noted here described further in their own manual pages.

```
!      Branch Line
USE  Bix
Fsetmats, Second
PRINT  FlagA, FlagB

.....

!      Booster Ring
USE  BoosterA
Fsetmats, Second
PRINT  SHA2, QHF6
```

9.2. Track Distributions.

One or more issues of the track generation command **Trgen** are to be attached to the Xtrack session. The command generates phase ellipses in X, Px and Y, Py coordinates from one or more space points along a cross sectional shape in X, Y, and dP coordinates, based on information derived from the current closed orbit, or otherwise given. If the closed orbit data is to be used, the generator needs to be matched to the appropriate Beam Line and orbit. A library of typical generators can be assembled, and particular ones selected by including them in a list which is input to the **Xrun** command. Those generators in the list can be operated from a menu of the tracking section. The **Trgen** command is described in its own manual pages. A related command, **Mtrgen** can also be called. It generates parallel tracks in the X or Y plane, or fans of tracks distributed along a plane (Px, or Py).

```
Store
"Tr_xaxis"  Trgen                          &
        Track = "Xaxis",  Ngtr  = 11,      &
        Npoint =  3,      Xaxis,           &
        Dw    = .005,     Dh    = .005,    &
        X0    = 0.,       Px0   = 0.,      &
        Y0    = 0.,       Py0   = 0.,      &
        DeltaP = 0.,  Sameabe
"Tr_cross"  Trgen                          &
        Track = "Cross",  Ngtr  = 11,      &
        Npoint =  5,      Cross,           &
        Dw    = .005,     Dh    = .005,    &
        X0    = 0.,       Px0   = 0.,      &
        Y0    = 0.,       Py0   = 0.,      &
        DeltaP = 0.,  Sameabe
Endstore
"S_list"   Xmenu   "Tr.xaxis", "Tr.cross"
```

10. The Xrun Command

Xrun is an enhanced MAD RUN command, with additional information linking the tracking to graphics services, additional drawing commands, track generation commands, and drawing symbols. This BNL version also has gross rectangular aperture cut data.

All displays of tracking patterns are on line. Unlike with the **RUN** command, the calculation does not produce a direct access History Bank, a turn by turn record of the Track Bank. *Save* and other Bank features allow snapshots of the Track Bank at any time. Saved Banks can be recalled for graphics and further tracking.

Tracking with time dependent magnetic fields is considerably slower than ordinary tracking. In ordinary tracking, all of the particles experience the same set of fields, which do not have to be updated in time.

Under conditions such as extraction, particles may spread out over time, so each tends to experience a different field history. The program therefore recomputes the field for every magnetic element as each particle enters it. Workstation computing speeds are adequate for observing a handful of particles through typically a few hundred turns of an extraction cycle. For larger numbers of particles and turns, tracking times run rather slow, and some more efficient field updating may be called for. Fields in the Branch Line are usually steady, and for these field updating can be turned off. (Clock On / Off parameter)

Xrun attributes are:

Mode	A name, normally Synchrotron, the default, indicating the style of tracking.
Method	A name, ignored. "Xtransport" is performed.
Turns	An integer, ignored. Obtained from the Tracking Menu within the session.
Fprint	An integer, indicates printing frequency in turns for Track Bank.
Sample	An integer, ignored. Sampling frequency for recording tracks in a History Bank, which is not done here.
Buffer	Name of Buffer for direct access History Bank, not used here.
Track	Name of Track Bank. Ignored here. Bank names are provided by track generating commands.
Xmax	Decimal number in meters for maximum aperture X in out of pipe testing. This is a default, used in the absence of aperture data for individual elements.
Ymax	Same for Y.
Short	A Logical Flag: If True, abbreviated printing of one line per track will be done.
Plotdef	Name of a **Plotdef,** a graphics coordinating command. Normally this links an ensemble of information about axes, pen colors, labels, and the like, on its own CALL File.
Drawlist	Name of an **Xmenu** form of list with the names of drawing commands to be linked to the session. Optional. Examples might be lattice schematics, or survey schematics.
Startlist	Name of an **Xmenu** form of list of names of **Trgen** and **Mtrgen** commands to be attached to the session. Each such command can be operated from the *Starts* menu. Individual **Start** commands can also be gathered in a list and attached to a **Trgen** command.
Plsymbol	The name of a **Plsymbol** command that gives details about how plotting symbols are to be drawn. This kind of command is usually in the graphics demo file provided.
Symbols(10)	A list of names of kind of symbol, usually keyed to the places at which the Track Bank coordinates are graphed. Examples are CRoss, TRiangle, SQuare, etc.
Abuffer	Internal name group and pointers for Buffer. Not used in this version.
Atrack(3)	Internal name group and pointers for Track Bank modules, treated as a stack of 1). current, 2). original or first created, and 3). most recently created.
Abank	Internal name group and pointers for Track History Bank. Not used in this version.
Apdef	Internal name group and pointers for actual Plotdef, given or default.
Amap(5)	Internal name group and pointers for Beam Lines. Treated as a stack of 1). current Line, 2). original Main Line, 3). original Branch Line, 4). most recently called Main Line, and 5). most recently called Branch Line. Lines are called from the Line Options submenu of the program.
Adlist	Internal name group and pointers for Drawing command list, if any.
Aslist	Internal name group and pointers for Track Generator command list.
Asymbol	Internal name group and pointers for the attached **Plsymbol** command, if any.
/pindex(2)	Internal integers noting drawing frame index and pointer.
Status, Stamp	Internal integers noting status of **Xrun** command.

11. Additional Element Data

11.1. Time Dependent Fields

The main magnetic field elements have been given additional attributes to express simple forms of time variation, and the starting time at which the changes are to begin. These data items can be supplied individually for each magnet, or perhaps more conveniently by attribute commands that fill values common to a number of identical magnets. All of these data items default to 0.

Start — The time in seconds for which the field changes are to begin, relative to the start of tracking. This is generally not the same as the accelerator master clock.

Five kinds of field data of five items each have been treated.

Dadt(5) — Variation in the main bend field, decimal in radians per second for **Rbend** and **Sbend** classes.

Dk1Dt(5) — Variation in the quadrupole component, for **Rbend, Sbend,** and **Quad** classes.

Dk2Dt(5) — Variation in the sextupole component, for **Rbend, Sbend,** and **Sextupole** classes.

DhkickDt(5) — Variation in the horizontal kick angle in radians per second for **Hkicker** and **Kicker** classes.

DvkickDt(5) — Variation in the vertical kick angle in radians per second for **Vkicker** and **Kicker** classes.

The five decimal data items are applied as follows:

$$A = (A_0 + V(1)\,)\,(\,1. + V(2)\,t + V(3)\,t^2)$$

$$V(4) < A < V(5)$$

V(1). A fixed increment value to be added to the given value, in the units of the given field value.

V(2). A coefficient for the changes linear with time. Fractional, units of per second.

V(3). A coefficient for the changes quadratic with time. Fractional, units of per second squared.

V(4). A lower bound for the value of the field strength involved, in units of the given field. No bound is applied if the bound is not given.

V(5). An upper bound for the value of the field strength involved, in units of the given field. No bound is applied if the bound is not given.

t — The difference between the clock time measured from the time of the start of tracking, and the value given on the *Start* attribute.

Example

```
QVA1    Quad L    = .5040,  K1    = - .5713,          &
                Start = .00,                          &
                Dk1Dt = .00,  .100,  .200,  -.59,  -.55
```

11.2. Apertures

In this more detailed kind of tracking, particle tracking losses usually have to be considered more seriously. One consequence is a need for relatively accurate information about the apertures of magnets and connecting structures seen by the beam, and program services to handle this information. In BNL MAD, all Beam Line elements have been given aperture description attributes. Tracking can now test for losses with realistic aperture limits on each element. These data can also be used for plotting apertures along with orbit functions.

Aperx(4) — A group of four decimal numbers:

1). Minimum X at entrance

2). Maximum X at entrance.

3). Minimum X at Exit.

4). Maximum X at Exit.

Apery(4) Corresponding decimal values for Y.

Aptype A name, such as Rect, Ellipse, Square, Circle, or Limits noting the type or shape of aperture. All shapes are presumed centered on the reference axis. For most cases, a single X and Y value is adequate. In the case of Limits, the tests expect a particle to fall between X1 and X2, and Y1 and Y2.

11.3. Common Attribute Commands

In Beam Lines in which magnets are individually named, supplying aperture and additional magnet data can become a major editing problem. The **Aperture** and **Timedeps** commands can usually simplify this data entry by inserting values common to all magnets of the same kind. These commands are described futher in their own manual pages.

Example

```
"Td.q1"  Timedeps,  Eltype = "Qv1", Start = 00.,                    &
         Dk1Dt = .00,  .100,  .200,  -.59,  -.55
"Ap.q1"  Aperture,  Eltype = "Qv1",                                 &
         Aptype = Circle, X = .076, y = .076
```

12. Extraction Modeling

One of the intended ways to use the **Xtrack** services is to circulate particle distributions in a Main Ring, and apply a **Channel** (Septum) kind of element to select particles that meet ejection criteria. Particles in the septum entrance are in a sense frozen, while the remainder continue to circulate or be lost in the walls. Particles passing through septum material can be given an appropriate energy loss. When all of the circulating particles are ejected or lost, the set of particles in the septum entrance can then be tracked further along some Branch Line.

12.1. Channel Element

This element is based upon the MAD **Kicker** class of element. **Channel** and **Septum** are equivalent class names. Attributes are:

L Length, decimal in meters.

Tilt Usual tilt angle, around beam axis, decimal in radians.

Aperx(4) X Dimensions of full aperture, inside and outside borders, entrance and exit.

Apery(4) Y Dimensions of full aperture, down and up borders, entrance and exit.

Aptype A name consisting of Square, Rectangle, Circle, Ellipse, Limits, or Diamond. Default is centered rectangle.

Optics Logical Flag: If true, orbit data is recorded during Twiss tracking.

Chdef(6) These are names of what are basically position cuts, which define the spatial region of the channel aperture. The names of the kinds of cuts, enclosed in quotes, are chosen from among:

1.) "> X2" Applied for all Xi > X2.

2.) "> X1" Applied for all X1 < X < X2

3.) "< X1" Applied for all Xi < X1.

4.) "> Y2"

5.) "> Y1"

6.) "< Y1"

Those cuts specified from the above three kinds are applied in an OR sense for both X and for Y options. At least one X and one Y condition must be satisfied to enter the channel. The MAD interpreter needs quotes to deal with the ">" and "<" characters. Blanks within these Quotes are ignored.

Xch(2)	X position cuts, decimal in meters, used to define the ejection region of the channel cross section. X(1) should be less than X(2).
Ych(2)	Same for Y.
Absdef(6)	The same choice of cuts to define the part of the channel which may be traversed by particles of the beam.
Xabs(2)	X position cuts, decimal in meters, used to define the absorbing region of the channel cross section.
Yabs(2)	Same for Y.
DeDs	Rate of energy loss per unit length of channel material, decimal, in units of gev/meter.

12.2. Shift Command

Moving between the Main Ring and a Branch Line may involve different coordinate systems. The **Shift** element provides for a change in coordinates for the particles of a Track Bank at the entrance to a Branch Line.

Shift attributes are:

L	Length, decimal in meters. If not zero, functions like a drift over the length.
Dx	Shift in track displacement X, at end of element, decimal in meters.
Dy	Shift in track displacement Y, at end of element, decimal in meters.
Dpx	Shift in track angle Px, at end of element, decimal in radians.
Dpy	Shift in track angle Py, at end of element, decimal in radians.

Manual Files.

Manual sources are in Unix troff (psroff) format.

Host:	**rapt.ags.bnl.gov**
This Report:	/usr/disc2/Docum+/Xtrack.man
Trgen:	/usr/disc2/Docum+/Trgen.man
Aperture:	/usr/disc2/Docum+/Atts.man
Timedeps:	/usr/disc2/Docum+/Atts.man
Plsymbol:	/usr/disc2/Docum+/Plsymbols.man