Particle and Ray Tracing Codes
(PARMILA & TURTLE Introduction)

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Presentation Outline

Particle & Ray Tracing Codes

1. **Beam Dynamics Codes Used in LINAC Design**
2. **Introduction to TURTLE**
3. **Introduction to PARMILA - For Simulation of Transfer Lines**
   $\Rightarrow$ **Other Applications of PARMILA Later in Course**
4. **Space Charge Modeling in PARMILA**
5. **Using PARMILA & TURTLE to Study Some Beamlines**
   $\Rightarrow$ **You will use the Simulation Lab computers in the classroom**

1. Beam Dynamics Codes Used in LINAC Design

- **Very Large Number of Programs Used in Accelerator Community**
  - **More Than 200 Codes Listed in the Los Alamos Accelerator Code Group (LAACG) Compendium of Accelerator Codes (~1990)**
  - **Optics Codes Account for About 1/2**
  - **The LAACG Compendium Represents a Lower Bound!**

- **Restrict Comments to Codes of Interest for LINAC Design & Low β**

"Design Codes" vs "Simulation Codes"
"Envelope Codes" vs "Particle Codes"

- **TRACE 3-D and TRANSPORT are "Design Codes"**
  - **Parameter Variation and Constraint Fitting**
  - **Fast Running by Using Beam Envelopes (No Particles)**

- **To Evaluate a Design One Needs a "Particle" or "Ray Tracing" Code**
  - **Simulates a Group of Macroparticles Transiting the Beamline**
  - **"Simulation Codes" Used for Performance Evaluation of Design**

- **Three "Simulation Codes" on Simulation Lab computers**
  $\Rightarrow$ **PARMILA, PARMTEQ, TURTLE**

- **PARMILA & PARMTEQ are both "Design Codes" & "Simulation Codes"**
  - **Can Produce Structure Layouts & Designs - no envelope calculations**

1. Beam Dynamics Codes Used in LINAC Design (con't)

- **Particle Codes**
  - **Space Charge is a Major Consideration in the Design of a Code**
  - **How Fields Are Modeled is a Major Consideration**
  - **2-D versus 3-D Simulation is Also a Major Consideration**

- **Several Advanced Codes in Varied Use for LINAC Simulation**

- **One Example is WARP (LBNL, LLNL, NRL)**
  - **PIC (Particle-in-Cell) Code**
  - **Detailed Description of External Fields (magnets, cavities,…)**
  - **Parallel (& Serial) Processing Employed**
  - **Applied to Heavy Ion Fusion (HIF) and Intense Electron Beams**

- **Several Other Advanced Codes (PIC and EM) in DOE SciDAC Program**
  - **SciDAC: Scientific Discovery through Advanced Computing**
  - **Capable of Simulating ~10^{+9} Particles / Bunch through Detailed Fields**
  - **Requires Massively Parallel Computer Clusters on the "Petascale"**

- **Use of These Advanced Codes can be Complex**
  - **Assistance of Code Developers Typically Required**
    - $\Rightarrow$ **Not as "User Friendly" as the Codes in the Simulation Lab!**

1. Beam Dynamics Codes Used in LINAC Design (cont'd)

- **For completeness we should mention a few Electron Linac codes**
- **PARMELA**
  - **"Phase And Radial Motion for Electron Linear Accelerators"**
  - **Los Alamos National Laboratory (LANL) code**
  - **Patterned after PARMILA, Includes Space Charge**
  - **Used Primarily for Low Energy Electron Linac Design**
- **LIAR**
  - **LInear Accelerator Research code**
  - **Stanford Linear Accelerator Center (SLAC)**
  - **Used Primarily for High Energy Electron Linacs**
  - **Includes the DIMAD code for Tracking Calculations**
- **DIMAD - a TRANSPORT spin-off with Tracking Capabilities**
  - **SLAC & Thomas Jefferson National Accelerator Facility (TJNAF)**
- **Several Specialized Codes for Electron Guns (Ion Sources)**
- **Some of the Codes in the Simulation Lab are Often Used for Electrons: TRACE 3-D, SUPERFISH, TRANSPORT, TURTLE**

1. Beam Dynamics Codes Used in LINAC Design (cont'd)

Some Electron Linac Codes

Code Name	Version(s)	Website(s)	Ref.
PARMELA*	**LANL**	http://laacg1.lanl.gov	**[E-1]**
LIAR*	**SLAC**	http://www-project.slac.stanford.edu/lc/local/AccelPhysics/Accel_Physics_index.htm	**[E-2]**
DIMAD*	**SLAC**	http://www-project.slac.stanford.edu/lc/local/AccelPhysics/Accel_Physics_index.htm	**[E-3]**
TRACE 3-D	**LANL, PBO Lab Module†**	http://laacg1.lanl.gov http://www.ghga.com/accelsoft	**[2]**
SUPERFISH	**LANL**	http://laacg1.lanl.gov	**[8]**
TRANSPORT	**PBO Lab Module (FNAL)**	http://www.ghga.com/accelsoft http://fermitools.fnal.gov	**[1]**
TURTLE	**PBO Lab Module (FNAL)**	http://www.ghga.com/accelsoft http://fermitools.fnal.gov	**[3]**

***These electron codes are *not* being used in this USPAS course**

† Includes electrostatic elements

References in Preceding Table

[E-1] L. M. Young, "PARMELA," Los Alamos National Laboratory Report No. LA-UR-96-1835 (1996).

[E-2] R. Assmann, C Adolphsen, K. Bane, P. Emma, L. Hendrickson, F. Ostiguy, T. Raubenheimer, A. Seryi, R. Siemann, G. Stupakov, P. Tenenbaum, K. Thompson and F. Zimmerman "LIAR - A Computer Program for the Modeling and Simulation of High Performance Linacs," Stanford Linear Accelerator Center, SLAC/AP-103, 3 February 2003, 131 pages (2003).

[E-3] R. V. Servranckx, K. L. Brown, L. Schachinger, D. Douglas and P. G. Tenenbaum, "User's Guide to the Program DIMAD," Stanford Linear Accelerator Center, 20 April 2001, 57 pp (2001);); R. V. Servranckx, K. L. Brown, L. Schachinger, D. Douglas and P. G. Tenenbaum, "User's Guide to the Program DIMAD," Stanford Linear Accelerator Center, 14 January 2004, 48 pp (2004).

[1] D. C. Carey, K. L. Brown and F. Rothacker, "Third-Order TRANSPORT with MAD Input - A Computer Program for Designing Charged Particle Beam Transport Systems," SLAC-R-530, 316 pp (1998).

[2] K. R. Crandall and D. P. Rusthoi, "TRACE 3-D Documentation," Third Edition, Los Alamos National Laboratory Report No. LA-UR-97-886, 106 pages (1997).

[3] D. C. Carey, "TURTLE with MAD Input (Trace Unlimited Rays Through Lumped Elements), a Computer Program for Simulating Charged Particle Beam Transport Systems, and DECAY-TURTLE Including Decay Calculations," Fermilab-Pub-99/232, 196 pp (1999).

[8] M. T. Menzel and H. K. Stokes, "User's Guide for the POISSON/SUPERFISH Group of Codes," Los Alamos National Laboratory Report No. LA-UR-87-115, ~250 pages (1987); The Los Alamos Accelerator Code Group, "Reference Manual for the POISSON/SUPERFISH Group of Codes," Los Alamos National Laboratory Report No. LA-UR-87-126, ~400 pages (1987).

2. Introduction to TURTLE

- **Acronym: "Trace Unlimited Rays Through Lumped Elements"**
- **Companion Code to TRANSPORT**
- **" Simulation Code" Rather Than a "Design Code"**
  - **Calculates the 6-D coordinates of macroparticles through beamline**
  - **Same 6-D coordinates as TRANSPORT:** $(q_i)=(x,x',y,y', l,\delta)$
  - **Can routinely run 1,000 - 100,000+ particles on a PC**
  - **No parameter variation, fitting, matching, …**
- **Can examine effects not modeled in TRANSPORT**
  - **Three distributions in standard TURTLE:**
    Gaussian, Rectangular, Uniform
  - **Alternatively can import initial particle distribution from a file**
  - **Beam loss on apertures and slits**
  - **Non elliptical beams - either as input, or created in a beamline**
  - **Can add phase space "cuts" to distributions along beamline**
- **Output Used by Some Radiation Transport Codes - Shielding**
- **No Space Charge**

2. Introduction to TURTLE (continued)

- **TURTLE is complimentary program to TRANSPORT**

  - **Both use same description of beamline and elements**
  - **1st, 2nd, 3rd order calculated in both**
  - **Use the same 6-D phase space coordinates**

  $\Rightarrow$ **Use TRANSPORT to get a design; use TURTLE to evaluate it**

- **A special version, called DECAY-TURTLE, for radioactive beams**

  - **Tracks particles that have a finite lifetime**
  - **Primary particles (parents) decay randomly during beamline passage according to their lifetime**
  - **Tracks the decay product particles (daughters) thru beamline**
  - **User specifies parent lifetime, masses and charges of daughters**
  - **Transparency of apertures and slits can be particle dependent**

- **PBO-Lab provides TURTLE support for the same "non-TRANSPORT" optics elements that PBO-Lab makes available for TRANSPORT**

  - **TRACE 3-D elements: Doublet, Triplet, RF Gap, Thin Lens**
  - **Extended fringe-field elements: Magnetic Quad, ElectroStatic Quad**

2. Introduction to TURTLE (continued)

- **Generates Data for 2 Types of Plots**
  - **Scatter Plots of Phase Space Data (2-D Plot) e.g.** x' **versus** x
  - **Histograms of Data (1-D Plot) e.g. # particle is at bin location** x

  ⇒ **Plot Specifications for TURTLE set in PBO Lab Marker Piece**

- **Any of the 6-D Phase Space Variables Can be Used** x, x', y, y', l, δ
  - **36 Possible Scatter Plots**
  - **6 Possible Histograms**
- **Native Plots are Text Based - "Line Printer" (without a post processor)**
- **Multiple Locations in Beam Line - User Specified Plots at Each**
- **Apertures (on magnets) Can Be Ignored or Included (Particle Loss)**
- **DECAY-TURTLE Version Has Above Capabilities for Decay Particles**
  - **But DECAY-TURTLE does not support all 3rd order modeling**

⇒ **Next week (time permitting) will use TURTLE to simulate the use of *octupoles* in a high energy beam transport (HEBT) line to create a nearly uniform spot density from a Gaussian beam**

Before discussing PARMILA, will look at some typical TURTLE output plots

2. Introduction to TURTLE (continued)

Typical Scatter Plot (TURTLE native output)

```
                    -0.100    -0.060    -0.020     0.020     0.060     0.100
+                                                                           TOTALS
                     I**---**---**---**---**---**---**---**---**---**---**I--------
   -0.003 TO  -0.003 I   1    1 1131  12              B                   I     22
   -0.003 TO  -0.003 I        11 2241  1              711                 I     21
   -0.003 TO  -0.002 I         1 1 33 2                6                  I     16
   -0.002 TO  -0.002 I           113 2321              6                  I     19
   -0.002 TO  -0.002 I          1  255433              E1                 I     38
   -0.002 TO  -0.002 I           1327589443            1B                 I     58
   -0.002 TO  -0.002 I          2 2 4562711             I                 I     48
   -0.002 TO  -0.001 I             4247945521           E2                I     59
   -0.001 TO  -0.001 I    1      1 295BDE8751           I31               I     99
   -0.001 TO  -0.001 I             416P$$UD711          9B 1              I    260
   -0.001 TO  -0.001 I              8B$$$$$XI1           R3   1           I   1182
   -0.001 TO  -0.001 I             12D$$F$$$$8           V2               I    950
   -0.001 TO   0.000 I             14Q$   1X$$5          X121             I    727
    0.000 TO   0.000 I             22R$     3$$E         $7               I    665
    0.000 TO   0.000 I              3V$       $$$        $91              I    638
    0.000 TO   0.000 I              1B$        $$$       $R211            I    616
    0.000 TO   0.000 I              13L         N$$5     $W  1            I    636
    0.000 TO   0.001 I              1 T          9$$$    $Q721            I    753
    0.001 TO   0.001 I              13P           B$$$UA$$U2            1 I    929
    0.001 TO   0.001 I                T           15W$$$$$62 11           I   1194
    0.001 TO   0.001 I            1   E6           47EP$$J854             I    262
    0.001 TO   0.001 I                2J            1ACAI9651 212         I     98
    0.001 TO   0.002 I                 J            322647823             I     56
    0.002 TO   0.002 I                 K             27587623    1        I     61
    0.002 TO   0.002 I                 D3           1124731132 2  1       I     44
    0.002 TO   0.002 I                 5B            1 351331222          I     39
    0.002 TO   0.002 I                 1A                43312            I     24
    0.002 TO   0.003 I                  9              22 4112 1    1     I     23
    0.003 TO   0.003 I                  54               1 11 5 111       I     20
    0.003 TO   0.003 I                  14              1  11 3     1     I     12
                     I**---**---**---**---**---**---**---**---**---**---**I--------
                     I                                                    I
                     I                                                    I
                     I               17543434434444443334471              I
                     I            12555118093180211299858384211           I
             TOTALS  I 00110002247295757521144381220762055313246322020001 I   9569
0          TOTAL NUMBER OF ENTRIES =      10000 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS
0                           LEFT                         RIGHT
           ABOVE             38            173             3
                              1           9569             0
           BELOW              8            174            34

   SUM OF SQUARES =       1777943.
           CENTER =     0.000   RMS HALF WIDTH =     0.032
           CENTER =     0.000   RMS HALF WIDTH =     0.002
           CORRELATION =    0.2913
0NO   4 TWO DIMENSIONAL PLOT OF
 HORIZONTAL AXIS    Y IN M       14.608 M    FROM THE START
 VERTICAL AXIS     Y' IN R       14.608 M    FROM THE START
```

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2. Introduction to TURTLE (continued)

Typical Histogram (TURTLE native output)

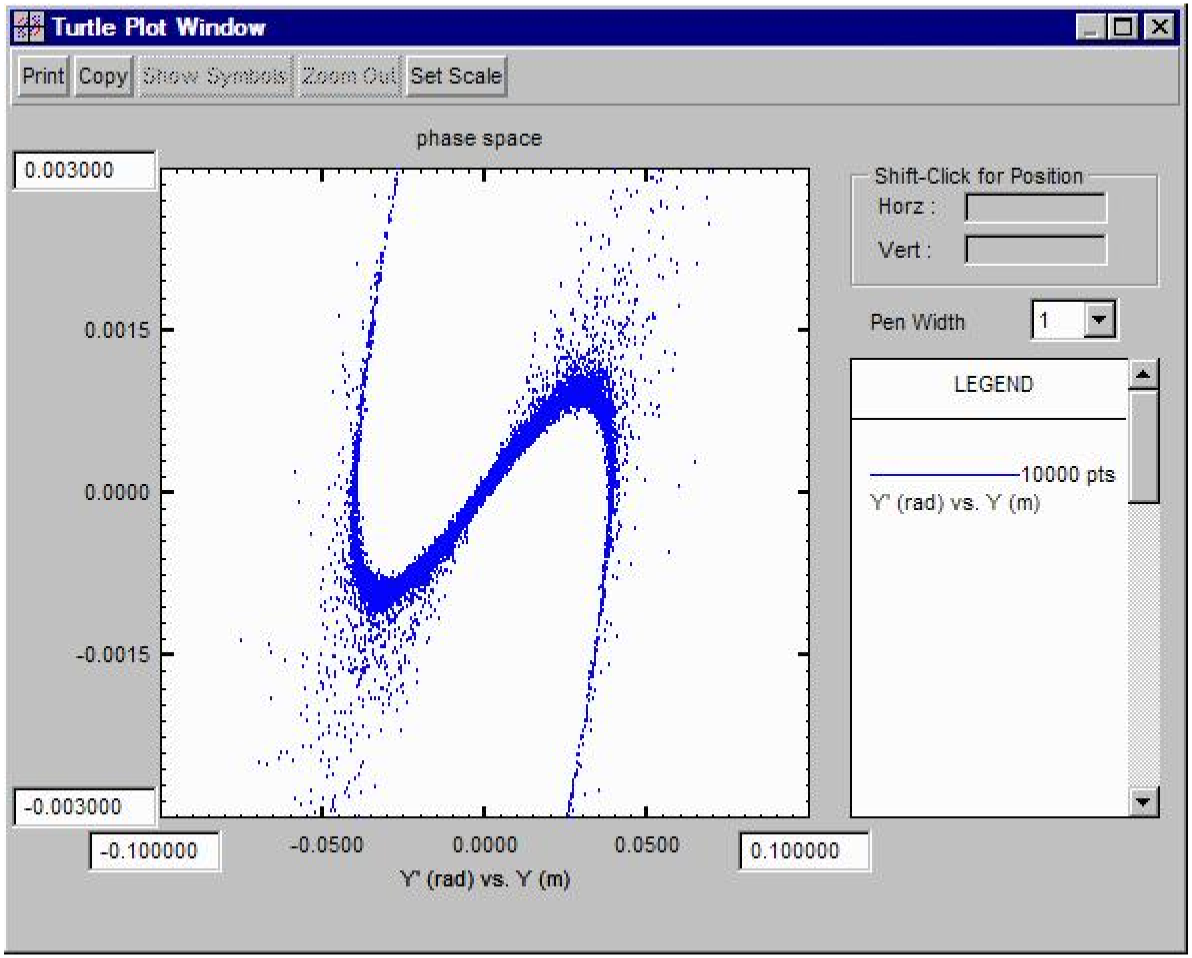
```
DISTRIBUTION OF    Y IN M       14.608 M    FROM THE START
0
           INTERVAL                             SCALE FACTOR:  100 X'S EQUAL   908 RAYS
0LESS THAN     -0.100       47   XXXXX

   -0.100 TO   -0.095        3
   -0.095 TO   -0.090        8
   -0.090 TO   -0.085        7
   -0.085 TO   -0.080        3
   -0.080 TO   -0.075       11   X
   -0.075 TO   -0.070        8
   -0.070 TO   -0.065       10   X
   -0.065 TO   -0.060       15   X
   -0.060 TO   -0.055       13   X
   -0.055 TO   -0.050       29   XXX
   -0.050 TO   -0.045       55   XXXXXX
   -0.045 TO   -0.040      184   XXXXXXXXXXXXXXXXXXXX
   -0.040 TO   -0.035      908   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.035 TO   -0.030      591   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.030 TO   -0.025      491   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.025 TO   -0.020      510   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.020 TO   -0.015      529   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.015 TO   -0.010      527   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.010 TO   -0.005      514   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -0.005 TO    0.000      520   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.000 TO    0.005      548   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.005 TO    0.010      508   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.010 TO    0.015      535   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.015 TO    0.020      515   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.020 TO    0.025      524   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.025 TO    0.030      507   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.030 TO    0.035      607   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.035 TO    0.040      859   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.040 TO    0.045      205   XXXXXXXXXXXXXXXXXXXXXX
    0.045 TO    0.050       47   XXXXX
    0.050 TO    0.055       28   XXX
    0.055 TO    0.060       24   XX
    0.060 TO    0.065       17   X
    0.065 TO    0.070        9
    0.070 TO    0.075       19   XX
    0.075 TO    0.080        6
    0.080 TO    0.085        9
    0.085 TO    0.090        4
    0.090 TO    0.095        4
    0.095 TO    0.100        5
0GREATER THAN   0.100       37   XXXX
0          TOTAL NUMBER OF ENTRIES =     10000     INCLUDING UNDERFLOW AND OVERFLOW
0          CENTER =     0.000   RMS HALF WIDTH =     0.032
0
```

[MS Word font: Courier New 7 pt., normal spacing]

2. Introduction to TURTLE (continued)

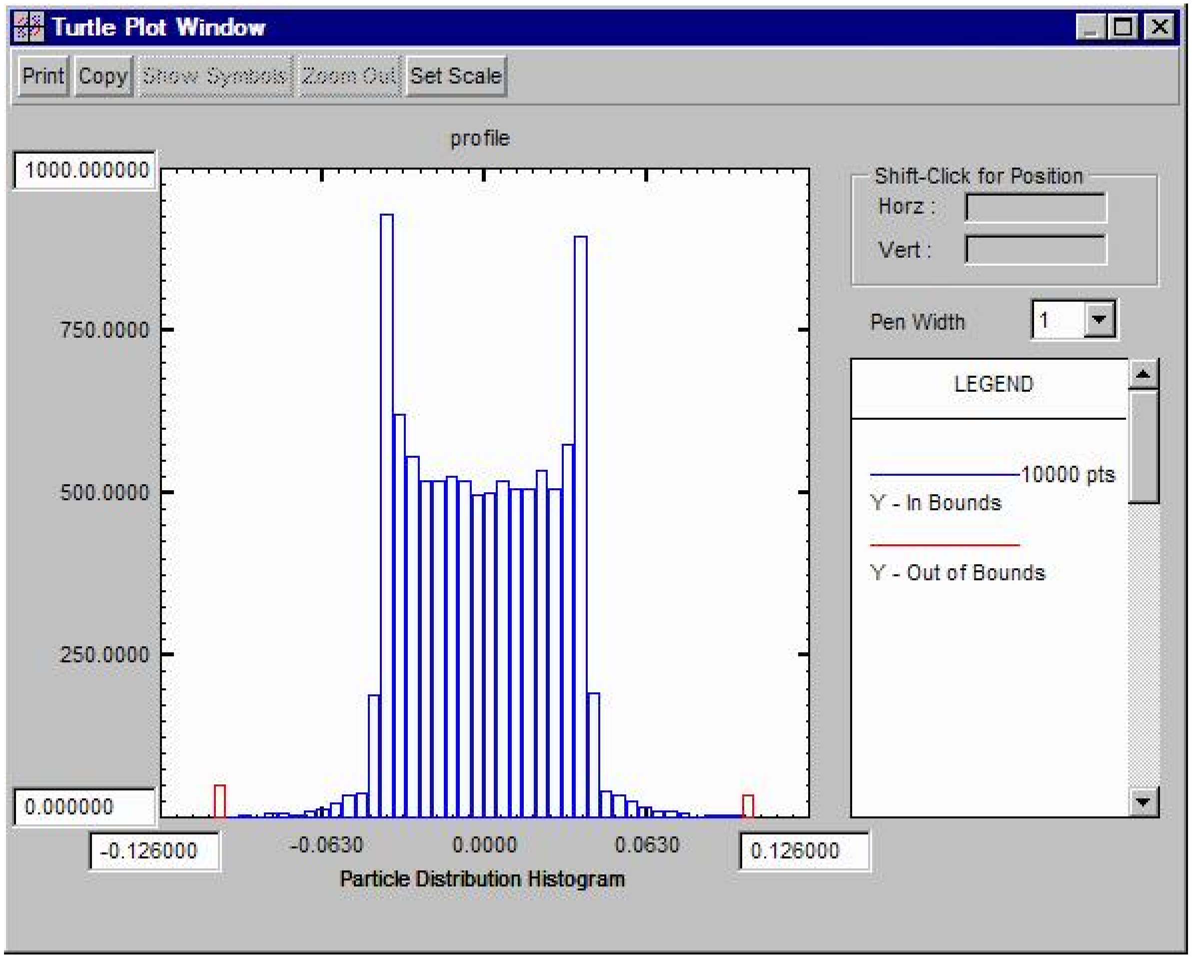
Typical Scatter Plot (PBO Lab postprocessor plot)



- **PBO-Lab uses same (default) color assignments for all codes**
- **Provide for "Auto-Scaling" of Plots - Useful for Initial Setup**
- **Can Adjust Scales <u>After</u> a Run- Unlimited "Zoom" Capability**

2. Introduction to TURTLE (continued)

Typical Histogram (PBO Lab postprocessor plot)



- **PBO-Lab plots provide data visualization & document preparation tools**
- **Print, Copy, scale adjustment, …**
- **Need to look at TURTLE (text) output for selected quantitative data**

3. Introduction to PARMILA - For Simulation of Transfer Lines

- **PARMILA is Both a Simulation Code and a Design Code ("Dual" Modes)**
  - **Much More than Just a Companion to TRACE 3-D**
  - **First Version Written by Don Swenson (~1963) for DTL Modeling**
  - **"PARMILA 1" (~1990) Transport Lines, Matching Sections, DTLs**
  - **"PARMILA 2" (~1998) Several New RF Structures / Capabilities**
    Coupled Cavity Linac (CCL)
    Coupled Cavity DTL (CCDTL)
    Superconducting Cavity (SC) Linac (2 types)
    Funnels, Choppers, Improved Space Charge, …

- **Simulation Mode - Can be used for Transfer Lines, Matching Sections**
  - **Solves (Numerically "Integrates") the Particle Equations of Motion**
  - **Conceptually Similar to Differential Matrix Model of Components**
  - **Advances Individual Macroparticles in Steps**
  - **Space Charge Calculated & Applied at Certain Steps - "Scheff"**
  - **Particles Removed (& Logged) Once Outside an**
  - **Inherently a Nonlinear Code (especially space charge)**

  $\Rightarrow$ **Use TRACE 3-D to get a design; use PARMILA to evaluate it**

- **Design Mode - Used for DTLs, CCLs, Superconducting Structures**
  - **Will Discuss This in Detail Later in Course**
  - **For Now, Just a Brief Overview**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

- **Design Mode**
  - **PARMILA's Most Important Capabilities - Few Other Codes Have This**

- **How Does the Design Mode Work for a DTL?**
  - **User Specifies Certain "Goals" for the DTL Design**
    e.g. Final Output Energy (but also other options for DTL goals)
  - **User Sets Some Initial Values for Various Parameters**
    e.g. Initial Quadrupole Strength at DTL Entrance
  - **Options to Specify "Ramping" or Changes with Distance**
    e.g. Ramp Accelerating Gradient
  - **… Other DTL Criteria/Options that will be Discussed Later**

- **When PARMILA is Run in Design Mode:**
  - **A DTL LINAC Design is Generated (Subroutines GENLINx)**
  - **The Design is Output to Several Text Files**

- **With PARMILA 2 Several Other Capabilities**
  - **Design of CCL, CCDTL, and Superconducting Structures**
  - **A TRACE 3-D Equivalent Lattice (of DTL, CCL, …) is Output to a File**
  - **Other Files Generated for use in Graphics Displays**
  - **Can Run an "End-to-End" Simulation of Complete LINAC (after RFQ)**

$\Rightarrow$ **Design Mode is Similar to an "Expert System"**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Optical Elements in PARMILA-2

- **Standard Beamline Optical Elements (~12)**
  - **Eight are Essentially Same as TRACE 3-D / TRANSPORT Elements:**
    Drift, Quad, Bend (with Edges), Solenoid*,
    RF Gap, Thin Lens, Rotate (Displace & Tilt elements)
  - **Steering Magnet ("Kicker") - Similar to TRANSPORT, TURTLE**
  - **Element Displacement - Similar to TRACE 3-D, TRANSPORT, TURTLE**
  - **Apertures (Circular, Rectangular) - Similar to TURTLE**

  ***Solenoid in PARMILA version 2.36 does not work correctly**

  $\Rightarrow$ **Use PBO Lab PARMILA-2 Module - it has a fix**

- **Magnetic Quadrupole with Higher-Order Multipoles ("Mpoles")**

- **A Few Additional "Element" Type Items (i.e. Location Specific)**
  - **Funnel: Doubles RF Frequency and Beam Current (power only)**
  - **Chopper: Reduces Average Beam Current (power only)**
  - **Chopper: Reduces Average Beam Current (power only)**

- **Documentation (LA-UR-98-4478) Says Electrostatic (ES) Elements:**
  - **ES Quadrupole, ES Deflector, DC Column**
  - **However, these are not in PARMILA version 2.36**

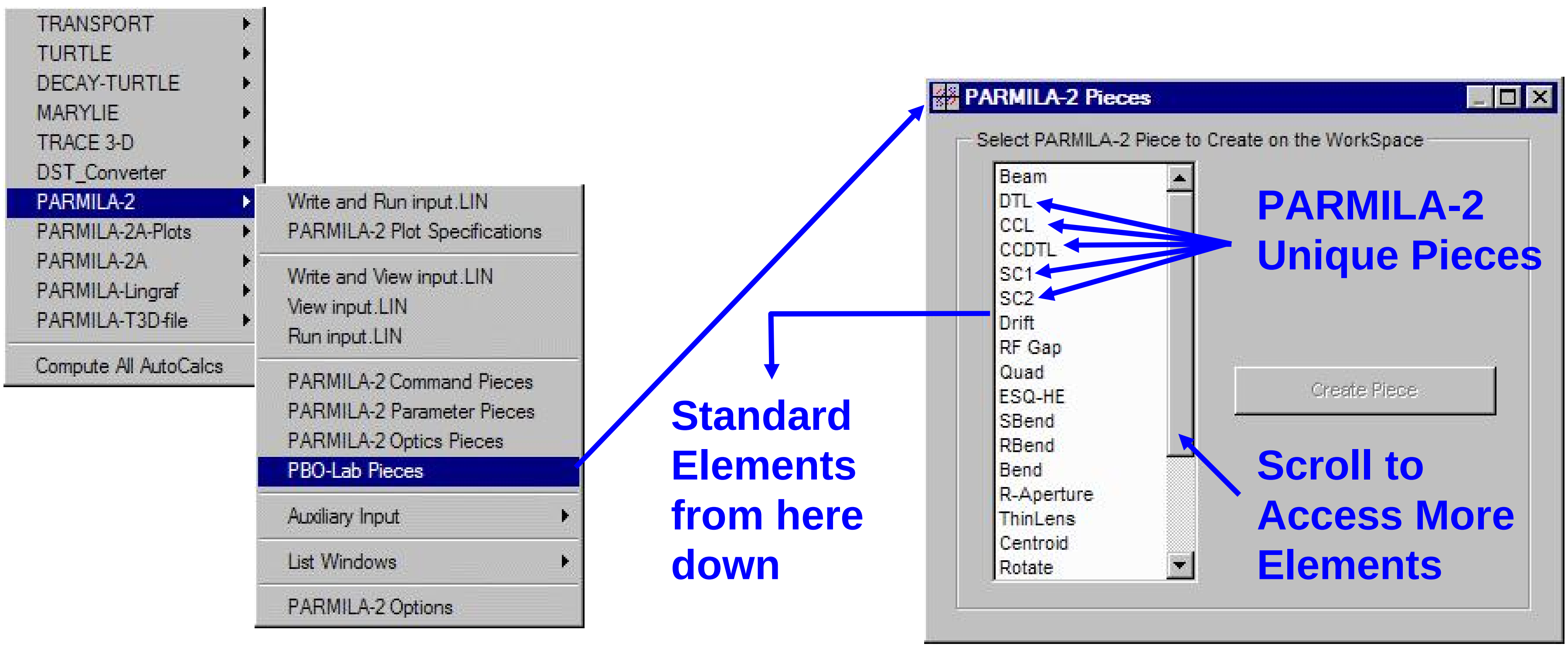
3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

<u>Simulating Transfer Lines in PARMILA-2 with PBO Lab</u>

- **For a PBO Lab Model of Standard Beamline Optical Elements**

  ⇒ **The Beamline on the Model Space is Already "PARMILA-2 Complete"**

- **What "Standard Beamline Optical Elements" are supported?**
- **Get List from PARMILA-2 Menu "PBO Lab Pieces":**



3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Simulating Transfer Lines in PARMILA-2 with PBO Lab

- **PBO Lab will write PARMILA-2 formatted element parameters (input.LIN file)**

- **PBO Lab also writes automatically other input lines required by PARMILA-2**
  - **Will look at these "other" required input lines shortly**
  - **Just note that PBO Lab provides *default* data for required input lines**

- **Use PARMILA-2 Command "Write and View 'input.LIN' " to see the results**

- **Use PARMILA-2 Command "Write and Run 'input.LIN' " to execute**
  $\Rightarrow$ **PBO Lab will produce a default "Simulation" for the transfer line**

- **Error messages may be generated by PARMILA-2 if defaults not adequate**

- **Note: PARMILA-2 input file format significantly different from PARMILA-1**
  $\Rightarrow$ **PARMILA-2 cannot read PARMILA-1 input files**

- **Let's look at a transfer line (Example B with RF gaps) input file for PARMILA-2**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Transfer Line Input File ("input.LIN") for PARMILA-2

```
run   1 1
title
Example B.pbol run on 01/15/11 07:04:56
; *** PARMILA OASIS Module Version 2.2.1.4 for PBO Lab 3.0 ***
; linac:  W0,     Fbunch,     Ibeam,     Mc^2,      Nq
linac  2.00000000  80.00000000  100.00000000  1875.00000000  1.00000000
```

- run 1 1 — Generally Starts File
- title — Title indicates next line is not to be executed
- Example B.pbol run on ... — PBO Lab automatically writes a Title with date & time
- ; means a comment follows (until next line)
- PBO Lab has a *liberal* use of comments
- linac = Global Parameters: Initial Beam Energy MeV), Radio-Frequency (MHz), Current (mA), Particle Mass (MeV), Particle Charge (|e|)

```
; *******   End of the input.lin HEADER SECTION  *******
; ***  User Auxillary HEADER INPUT will appear here  ***
; ******* Start of the input.lin LATTICE SECTION *******
;  Initial beam parameters data format:
;   type, number of macorparticles, alpha-x, beta-x (cm/rad), emittance-x (pi-cm-rad, boundary)
;   line 2:   alpha-y, beta-y (cm/rad), emittance-y (pi-cm-rad, boundary)
;   line 3:   alpha-z, beta-z (cm/rad), emittance-z (pi-cm-rad, boundary)
;   line 4:   centroids: x (cm), xp (rad), y(cm), yp (rad), del-phi (degrees), del-E (MeV)
;;  input  0  1000  3.11400000  75.36000000  0.00600000
;  input  -0  1000  3.11400000  75.36000000  0.00600000
```

PBO Lab extensive use of comments!

```
  input  -8  1000  3.11400000  75.36000000  0.00600000
            -2.62020000  57.89000000  0.00600000
            -0.12100000  109.22502084  0.01201661
    0.00000000  0.00000000  0.00000000  0.00000000  0.000  0.00000000  0.500000

; ReadDist  0.000000  part_rfq.dst
```

- 1000 — number of macroparticles (PBO Lab Global)
- input: (4 lines) Initial Twiss Parameters for X, Y, Z
- -8 = Uniform in 3-D Spatial Coords. (-) Fit to Twiss: Alpha, Beta, Emittance (Attention to UNITS, "0.0"!)
- Beam Centroids (see comments)
- 0.500000 — Random number seed
- ; ReadDist — Reads Input Beam Data from "part_rfq.dst" File (IF Uncommented)

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Transfer Line Input File ("input.LIN") for PARMILA-2 (con't)

- **Setting up the "input" (initial beam) line can be challenging**
- **PARMILA-2 has numerous distribution possibilities (not quite limitless!)**
  - **Nine basic "types" (0-8) with *numerous* variants**
  - **Basic type & variants set using a signed 3-digit *Type* code (*lmn*)**
  - **The last digit (*n*) defines the Basic "type" described in Documentation**
  - **The first two digits (*lm*) are *not* commonly used (no entry, only *n*)**
  - **Minus (-*lmn*) adjusts random distributions to achieve exact (Twiss) values**
  - **Units for longitudinal Twiss & emittance differ for different "type"**
  - **Documentation (LA-UR-98-4478) not always "clear"**
- **PBO Lab Beam Piece is useful for some commonly used distributions**
  - **PBO Lab:** 6-D Equivalent Uniform
    "-8" PARMILA-2 Type Code
    Uniform in Spatial Coordinates
    ***and* Uniform in Divergences**
    Emittances are Boundary Values

  - **PBO Lab:** 4-D Equivalent Uniform (KV) **"-6" PARMILA-2 Type Code**
  - **PBO Lab:** Gaussian (5-Sigma) **"-52" PARMILA-2 Type Code**
- **PBO Lab "input" line "type" can be overridden with PARMILA-2 Options**
- **PBO Lab PARMILA-2 Options used to read distribution from file, set file name**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Transfer Line Input File ("input.LIN") for PARMILA-2 (con't)

PBO Lab Beam Piece writes several additional lines *required* for *simulations*:

STRUCTURE 0 0 80.00000000 ← **STRUCTURE defines a new PARMILA-2 *Linac Section* (DTL, …)**
TRANSPORT ← **TRANSPORT specifies the type of PARMILA-2 Structure**
Drift 0.00000000 20000.00000000 0 1 ← **Drift is a zero length drift (not required, but useful for output)**
Bore 20000.00000000 ← **Bore sets an radial aperture (in cm) for removing particles**
Scheff 0.05000000 0.05000000 9 9 0 1 1 ← **Scheff necessary for simulation (more about this later)**
PrtBeam 99.00000000 ← **PrtBeam writes out 99% rms beam data ("Beam.out" file)**
OUTPUT 2 1 1 1000 1 ← **OUTPUT specifies how often to output data ("part_dtl.dst" file)**
; End of PBO Lab Beam Piece data, including STRUCTURE 0 for writing input beam to Parmila.out

PBO Lab also has a PARMILA-2 Command Piece named
"Start a TRANSPORT STRUCTURE"
Needed for matching sections between *complex* Structures (DTL, CCL, SCL)
Not necessary for a simple transfer line simulation, but this is an example
This Command Piece writes 4 data lines (& 1 comment line):

BEGIN ; starts beam dynamics calculation for prior STRUCTURE
;********************* Start of New STRUCTURE - PBO Lab PARMILA-2 Module *************************
STRUCTURE 1 0 80.00000000 80.00000000 ← **1 = Structure ID (unique, increasing)**
0 = Specifies the space charge routine
80.0 = Radiofrequency (MHz) for Section
80.0 = SF Data Radiofrequency (not used here)
TRANSPORT 0.00000000 ; TRANS ← **0.0 = Starting RF Phase (degrees) for initial beam distribution**
QuadCalc 1 1 1 ← **QuadCalc = Activates *quadrupole* simulation options:**
Fringe Fields
Third Order
Conserve Energy

- **PBO Lab writes certain default "input.LIN" lines so PARMILA-2 will execute**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Transfer Line Input File ("input.LIN") for PARMILA-2 (con't)

PBO Lab writes optics elements in format and units needed by PARMILA -2:

```
Drift   17.30000000  20000.00000000  1  1   ; Comment: D4
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Quad   9.60000000  1.00000000  1  -2650.00000000  0  ; Comment: Q5
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Drift   3.97500000  20000.00000000  1  1   ; Comment: D6
Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G7
Drift   3.97500000  20000.00000000  1  1   ; Comment: D8
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Quad   9.60000000  1.00000000  1  2650.00000000  0  ; Comment: Q9
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Drift   4.27400000  20000.00000000  1  1   ; Comment: D10 ;
Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G11
Drift   4.27400000  20000.00000000  1  1   ; Comment: D12
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Quad   9.60000000  1.00000000  1  -2650.00000000  0  ; Comment: Q13
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Drift   4.57400000  20000.00000000  1  1   ; Comment: D14
Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G15
Drift   4.57400000  20000.00000000  1  1   ; Comment: D16
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Quad   9.60000000  1.00000000  1  2650.00000000  0  ; Comment: Q17
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Drift   4.87300000  20000.00000000  1  1   ; Comment: D18
Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G19
Drift   4.87300000  20000.00000000  1  1   ; Comment: D20
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
Quad   4.80000000  1.00000000  1  -2650.00000000  0  ; Comment: Q21
;Displace  0.0  0.0  1  0.0  0.0  0.00000000
```

This example has optics elements for:
- **Drift**
- **Quad**
- **Cavity (RF Gap)**

Commented (;) lines are Piece Parameters that user has elected to not use. This example has quadrupole *rolls* and *displacements* (;Displace) turned off.

Suggestion: Use PBO Lab Piece Comment field to help identify elements in "input.LIN"

Third entry (0 or 1) controls output to "Parmila.plt" binary file used by Lingraf.
Suggestion: Use PBO Lab PARMILA-2 Option "OutputFlag" to turn ALL on (or off).

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Transfer Line Input File ("input.LIN") for PARMILA-2 (con't)

PBO Lab has custom PARMILA -2 Command Pieces and Parameter Pieces to specify space charge details, cutoff parameters, output details, etc.

```
Bore  2000.00000000
; SC:   delta-R  dellta-L  N-rad N-long N-adj N-beta-lambda   Remesh
Scheff  0.05000000  0.05000000  9    9    0    1    1
PrtBeam  99.00000000
 ; OUTPUT  1  1    1    2    3    4    5    6    7    8
OUTPUT  2  1    1    1000  1
 ; OUTPUT  3  1    1    2    3    4
 ; OUTPUT  4  1    1    2    3    4
```

This group is similar to the "default" lines PBO Lab writes for "STRUCTURE 0" however user sets the parameter values

PBO Lab automatically writes needed simulation "begin" and "end" lines

```
begin
end
```

- **SCHEFF ("Space Charge EFFects") line needed for PARMILA-2 simulations**
- **SCHEFF, together with optional lines, control space charge calculations**
- **Will look at the space charge models and options available, but first look at some typical PARMILA-2 outputs for the above transfer line**

3. Introduction to PARMILA - For Simulation of Transfer Lines

PARMILA-2 Outputs - Example B with RF Gaps

Main Output File: "Parmila.out"

```
Los Alamos National Laboratory Parmila - Ion Linac Design Code
Program Parmila written by Harunori Takeda

This program is provided as a service to the accelerator community by the Los Alamos Accelerator Code Group (LAACG).
(c) Copyright 1985-2004, by the Regents of the University of California.

This software is produced under U. S. Government contract W-7405-ENG-36 by Los Alamos National Laboratory, which is
operated by the University of California for the U. S. Department of Energy.  Neither the Government nor the University
makes any warranty, express or implied, or assumes any liability or responsibility for its use, or represents that use
of this software would not infringe privately owned rights.
Unpublished - rights reserved under Copyright Laws of the United States.
```

Copyright, disclaimers, etc.

```
Program Parmila 2.35  released 7-25-2005

Parmila starting at 01-16-2011  14:28:25
Parmila input file: input.lin
LANL.INI file: C:\OASIS\LANL.INI  8-11-2010  16:59:46
First random number (using system clock) for linac error studies = 0.251825749465751880

Lines that start with "LIN:" are from file input.lin:
LIN: run   1 1
```

Reiteration of parts of input file

```
********************************************************************************
Example B.pbol run on 01/16/11 14:28:23
********************************************************************************

LIN: linac  2.00000000  80.00000000  100.00000000  1875.00000000  1.00000000
Maximum numbers of Particles:  90000
                   Cells:      10000
                   Tanks:      25
                   Structures: 50
       Space-charge mesh size: 80 (radial), 200 (longitudinal)
LIN:   input  -8  1000  3.11400000  75.36000000  0.00600000
LIN:                -2.62020000  57.89000000  0.00600000
LIN:                -0.12100000  109.22502084  0.01201661
LIN:      0.00000000  0.00000000  0.00000000  0.00000000  0.000  0.00000000  0.500000
● ● ●
LIN: PrtBeam  99.00000000
LIN: OUTPUT  2  1    1     1000   1
LIN: BEGIN  ; starts beam dynamics calculation for prior STRUCTURE
Starting beam dynamics...  Current = 100.0 mA
Space charge calculations use the Scheff algorithm.
```

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

PARMILA-2 Outputs - Example B with RF Gaps (con't)

Main Output File: "Parmila.out" (con't)

PBO Lab Structure "Zero"

Provides initial beam calculation summary

```
--------------------------------------------------------------------------------
Starting Transport section

Wsync =     2.0000 MeV, 1000 good particles
Beam centroid: x (cm)  xp (mr)    y (cm)  yp (mr)   phi (deg)    W (MeV)
              0.00000  0.00000   0.00000  0.00000       0.000      2.000
Phis =     0.0000 deg
Transport finished element 1:   1. Drift

Longitudinal normalized emittance is in deg MeV, beta(n) is in deg/MeV.
Emittance, Twiss parameters, beam sizes, energy and phases are at the end of the element.
element ngood    plane   emittance (cm-mrad),(deg-MeV)   alpha      beta(u)    rms(u)   max     Design   Average    Reference   Average
                              100%        90%      rms(n)               (cm/mrad),  x or y  x or y   Phase    Phase       Energy     Energy
                                                                        (deg/MeV)   (cm)    (cm)     (deg)    (deg)       (MeV)      (MeV)

   1    1000     x-xp     0.30472    0.22549    0.05531  3.05259    0.07252    0.2947  0.6763    0.0000    0.0000     2.0000     2.0000
                 y-yp     0.30766    0.22182    0.05542 -2.64926    0.05899    0.2660  0.6100
                 phi-w    1.13070    0.81924    0.20009 -0.13512    570.366   10.6828  0.0000

Transport length differs from n*beta*lambda by    0.0000 deg, equivalent to  0.0000 cm.

End of structure 1  Run 1
=============================================================================================================================
```

More reiteration of input file data

```
LIN: STRUCTURE  1  0  80.00000000  80.00000000
LIN: TRANSPORT  0.00000000   ; TRANS
LIN: QuadCalc  1     1     1
LIN: Drift    17.30000000  20000.00000000  1  1    ; Comment: D4
LIN: Quad   9.60000000  1.00000000  1  -2650.00000000  0  ; Comment: Q5
LIN: Drift    3.97500000  20000.00000000  1  1    ; Comment: D6
LIN: Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G7
LIN: Drift    3.97500000  20000.00000000  1  1    ; Comment: D8
● ● ●
LIN: Drift    4.87300000  20000.00000000  1  1    ; Comment: D18
LIN: Cavity  0.0  20000.  1   0.18150000   80.00000000   -40.00000000  ; Comment: G19
LIN: Drift    4.87300000  20000.00000000  1  1    ; Comment: D20
LIN: Quad   4.80000000  1.00000000  1  -2650.00000000  0  ; Comment: Q21
LIN: Bore  2000.00000000
LIN: Scheff  0.05000000  0.05000000  9     9     0     1     1
```

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

PARMILA-2 Outputs - Example B with RF Gaps (con't)

Main Output File: "Parmila.out" (con't)

Standard PARMILA-2 initial beam summary

```
Beam distribution parameters:
        rms(n)  100% ellipse  alfa    beta(u)
        (cm-mr)    (cm-mr)   (cm/rad),(deg/MeV)
    1    0.0553    0.3047    3.0526   72.5210
    2    0.0554    0.3077   -2.6493   58.9937
    3    0.2001    1.1307   -0.1351  570.3655
LIN: PrtBeam  99.00000000
LIN: OUTPUT  2  1    1     1000  1
LIN: begin
Starting beam dynamics...  Current = 100.0 mA
Space charge calculations use the Scheff algorithm.

--------------------------------------------------------------------------------
Starting Transport section
```

Beam simulation summary

```
Wsync =     2.0000 MeV, 1000 good particles
Beam centroid: x (cm)  xp (mr)    y (cm)  yp (mr)   phi (deg)    W (MeV)
              0.00000  0.00000   0.00000  0.00000       0.000      2.000
Phis =     0.0000 deg
Transport finished element 1:   1. Drift
Emittance, Twiss parameters, beam sizes, energy and phases are at the end of the element.
element ngood    plane   emittance (cm-mrad),(deg-MeV)   alpha      beta(u)     rms(u)   max     Design    Average    Reference   Average
                           100%        90%      rms(n)              (cm/mrad),  x or y  x or y   Phase     Phase       Energy     Energy
                                                                     (deg/MeV)    (cm)    (cm)    (deg)     (deg)       (MeV)      (MeV)

   1    1000     x-xp     0.34947    0.23100    0.05630  0.50220    0.01481    0.1343  0.3010    0.0000   -0.0023     2.0000     2.0001
                 y-yp     0.42452    0.24132    0.05799 -6.56283    0.20755    0.5104  1.1460
                 phi-w    1.49577    0.83265    0.20511  0.75988    611.154   11.1962  0.0000
Transport finished element 2:   3. Quadrupole magnet

   2     960     x-xp     0.35399    0.23080    0.05677 -2.19065    0.02729    0.1831  0.4352    0.0000    0.1122     2.0000     1.9989
                 y-yp     0.53637    0.23958    0.05750  8.72791    0.14375    0.4230  0.8385
                 phi-w    1.71989    0.87469    0.21239  1.26147    691.166   12.1160  0.0000
Transport finished element 3:   1. Drift

   3     960     x-xp     0.35532    0.23025    0.05667 -3.18785    0.04867    0.2443  0.5923    0.0000    0.1121     2.0000     1.9989
                 y-yp     0.55389    0.24556    0.05837  6.35442    0.08226    0.3224  0.6423
                 phi-w    1.77224    0.87824    0.21334  1.47655    744.456   12.6025  0.0000
RF gap   Wsync =     2.1390 MeV
Beam centroid: x (cm)  xp (mr)    y (cm)  yp (mr)   phi (deg)    W (MeV)
          -0.00154 -0.13805  -0.00071 -0.02453       0.112      2.136
Transport finished element 4:   2. RF Cavity
```

• • •

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

PARMILA-2 Outputs - Example B with RF Gaps (con't)

Main Output File: "Parmila.out" (con't)

• • •

```
Transport finished element 17:   1. Drift

  17     910     x-xp     0.60290    0.22709    0.05735  4.48549    0.07977    0.2960  0.5930    0.0000    0.3259     2.5561     2.5458
                 y-yp     0.81246    0.26269    0.06238-10.02267    0.21431    0.5059  1.3492
                 phi-w    2.46901    1.01229    0.23985 -1.47309    504.815   11.0036  0.0000
Transport finished element 18:   3. Quadrupole magnet

  18     829     x-xp     0.63402    0.22914    0.05804  1.22366    0.05471    0.2466  0.5064    0.0000    0.0951     2.5561     2.5466
                 y-yp     0.35664    0.20040    0.05098 -1.17775    0.22395    0.4675  0.9924
                 phi-w    2.26173    0.98204    0.22782 -1.31140    494.279   10.6115  0.0000

Transport length differs from n*beta*lambda by  -34.0009 deg, equivalent to -1.8462 cm.

End of structure 2  Run 1
==============================================================================================================
LIN: end
Beam centroid: x (cm)  xp (mr)    y (cm)  yp (mr)   phi (deg)    W (MeV)
             0.00562 -0.36958   0.00727  0.05663       0.157      2.546

Parmila finished at 01-16-2011  14:28:26
**************************************************
To eliminate SFdata output, insert NoSFTableOut before any SFdata table.
**************************************************
Total  time     0 min       1.69 sec
Scheff time     0 min       0.05 sec, S/T=   2.96 %
```

Number of particles surviving (arrow to 829)

Beam dynamics RF phase shift (arrow to -34.0009)

PARMILA-2 run summary

- **"Parmila.out" for PARMILA-2 transport simulations provides RMS beam data**
- **Other *text* file outputs: "Quad.out" "Design.out" "Beam.out" "Tr3din.t3d"**
  - ⇒ **Use PBO Lab menu: View -> PARMILA-2 -> Auxiliary Files**
- **Special (Lingraf) plot data written in *binary* format to "Parmila.plt"**
  - ⇒ **Use PBO Lab PARMILA-Lingraf Module**
- **Final particle distribution data written in *binary* format to "part_dtl.dst"**

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

PARMILA-2 Outputs - Example B with RF Gaps (con't)

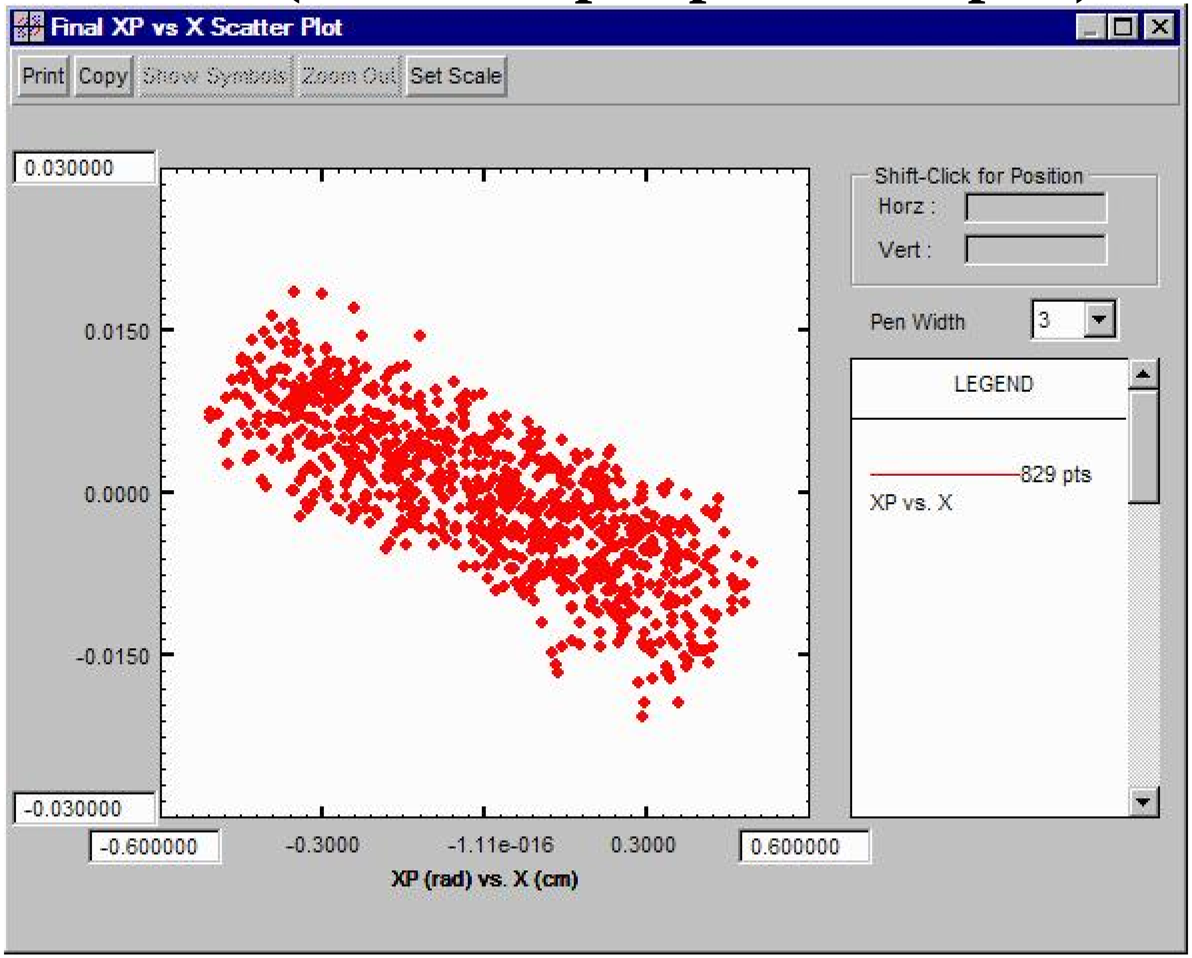
Binary Output File: "part_dtl.dst"

- **Program "readdst.exe"**
  - **- Converts *binary* file "part_dtl.dst" to *formatted text* file "part_dtl.TXT"**
- **From PBO Lab use: Commands->PARMILA Plots->Write and Run 'input.temp'**
  - **- Use the Windows file open dialog to select "part_dtl.dst"**
  - **- Formatted text file "part_dtl.TXT" will be opened at completion**
  - **- Three default phase space plots will be displayed for x-x', y-y', W-phi**
  - **- Other plots of the data can be selected by the user (histogram, scatter)**
- **First few lines from "part_dtl.TXT" illustrated below**

```
Parmila data from "Example B.pbol run on 01/16/11 14:28:23" run at time 01-16-2011  14:28:25
Structure number        =          2
Cell or element number =          0
Design particle energy =   2.000000     MeV
Number of particles     =        829
Beam current            =   82.90000     (frequency scaled equivalent for every rf bucket filled)
RF Frequency            =   80.00000     MHz
Bunch Freq              =   80.00000     MHz
Chopper fraction        =   1.000000
The input file particle coordinates were written in double precision.
   x(cm)              xpr(=dx/ds)      y(cm)              ypr(=dy/ds)       phi(radian)        W(MeV)
 -0.2740483529      8.5920352496E-03  0.5239293919      2.4765092954E-03 -1.9268399094E-02   2.529683666
 -0.1522036535      2.6527460134E-03 -7.0805802018E-02  1.0753200838E-03 -0.2567370817       2.453311165
 -0.1422078128      2.5051232246E-03 -0.3606680071      1.3703372955E-03  0.1262587515       2.577495844
  0.2895415372     -8.4868751524E-03 -0.3359137013     -7.3630744864E-04 -0.2435264125       2.489523835
 -0.3386279447      7.8457234313E-03 -0.3981546281      6.2457500245E-04  7.7077898501E-02   2.581053081
```

3. Introduction to PARMILA - For Simulation of Transfer Lines (continued)

Typical Scatter Plot (PBO Lab postprocessor plot) PARMILA-2



- **PBO-Lab PARMILA Plots has same basic features as plots for TURTLE**
- **Apertures (of quadrupoles) responsible for beam loss in this example**

4. Space Charge Modeling in PARMILA

Space Charge in PARMILA-2

- **PARMILA-2 has two basic space charge calculation algorithms**
  - **- SCHEFF is a 2-D method that is the default**
  - **- PICNIC is a 3-D that is an option**
  - **- To invoke either algorithm the "input.LIN" file must have a SCHEFF line**
- **SCHEFF ("Space Charge EFFects")**
  - **- Particles first transformed to beam rest frame (from lab frame)**
  - **- r-z mesh centered on the beam rest frame (rectangular mesh of r & z)**
  - **- Data on the SCHEFF line is used to define mesh parameter**
  - **- At specific steps for each element (# depends upon element):**
    - **Charge is allocated to points on the mesh to determine effective field**
    - **Space charge impulse force is applied to particles using that field**
  - **- Particles then transformed back to lab frame**
- **PICNIC (written by Nicolas Pichoff) computes the fields differently**
  - **- Computes RMS beam size for all 3 dimensions (x_{rms}, y_{rms}, z_{rms})**
  - **- Uses a 3-D mesh given by 3.5×RMS sizes ($3.5x_{rms}$, $3.5y_{rms}$, $3.5z_{rms}$)**
  - **- For particle outside the core, the force for a Gaussian fit to core used**
- **Both use the number of mesh points parameters defined by Scheff line**

4. Space Charge Modeling in PARMILA

Space Charge in PARMILA-2

- **SCHEFF line has form**

  Scheff ΔR_{SC} ΔZ_{SC} N_R N_Z N_{bunch} $N_{\beta\lambda}$ Remesh

  e.g. Scheff 0.05000 0.05000 9 9 0 1 1

- **The mesh intervals will be dynamically recalculated with SCHEFF method**
  - **According the Remesh value on the Scheff line**
  - **The dynamical mesh intervals of SCHEFF can be overridden using a line**

    MeshFact 2.0 3.0 $\Rightarrow$ mesh intervals changed to: $2.0\times\Delta R_{SC}$ $2.0\times\Delta Z_{SC}$

- **SCHEFF includes space charge from adjacent bunches according to N_{bunch}**
  - **According the Remesh value on the Scheff line**
  - **Adjacent bunches are take to be $N_{\beta\lambda}\times\beta\lambda$ from bunch being computed**

- **PICNIC is invoked with line:**

  Use3DPicnic

- **The number of mesh points for PICNIC are given by**

  $N_x = 2\times N_R$ $N_Y = 2\times N_R$ $N_Z = 2\times N_Z$

- **SCHEFF can be re-invoked using line**

  UseSCHEFF

- **Note that loss particles can impact the dynamic meshing for either method**

5. Using PARMILA & TURTLE to Study Some Beamlines
$\Rightarrow$ Use the Simulation Lab computers in the classroom

- **Compare PARMILA & TRACE 3-D at Low (~0) Current**
- **Explore the use of Lingraf to display data**
- **Compare PARMILA & TURTLE at Low (~0) Current**
- **Use PARMILA to Study High Current Transport**
- **Compare SCHEFF & PICNIC Space Charge Calculations**
- **Compare PARMILA & TRACE 3-D at High Current**