Geant3 as a tool for Muon Cooling and Acceleration simulations

Rajendran Raja
Fermilab

NUFACT03, Columbia University
Format of talk

• Geant3- Brief description- Best description to date of dE/dx + particle interactions in a simulation code
• Our contribution- Added data driven geometry
• Added electric fields. Both E+B fields are described in general field maps.
• Coupled it to Minuit- MITER
• Result is a tool which can be used for muon cooling + acceleration simulation.
• Modeling- Algebraic, Cosy, Icool, Geant- Each has its niche.
• Before we build a system it needs the best simulation done
• Injection/Extraction studies
• Data Driven geometry using RCP structures developed for D0 Run I.
• No geometry constants in the code.
• Code is Generic. Geometry information contained in structured RCP files. All different simulations have same structure. Understand one understand all.

\ARRAY DETECTOR_SYSTEMS
  'MOTHERS'
  !media 0-99. rot matrices 0-999
'MUCOOL'
  !media 0-99. rot matrices 0-999
'TARGET'
  !target for internal target measurement
'MAPS'
  !Will DO MAPS between any two points in the ring if this RCP file is specified.
\END
**Geant geometry**

- Geant geometry description is like a “Matryushka doll” Mother volume contains daughter volumes in several layers. Complex shapes can be simulated.
Geant Geometry

ECAL TUBE specifications 18/11/93

Tube ah
RMIN = cm 100
RMAX = cm 200
DZ = cm 400

ECAL TUBS specifications 18/11/93

Tubs ah
RMIN = cm 100
RMAX = cm 200
DZ = cm 400
PHI1 = deg 200
PHI2 = deg 340

ECAL CONE specifications 18/11/93

Cone ah
DZ = cm 400
RMN1 = cm 50
RMX1 = cm 100
RMN2 = cm 150
RMX2 = cm 200

ECAL CONS specifications 18/11/93

Cons ah
DZ = cm 400
RMN1 = cm 50
RMX1 = cm 100
RMN2 = cm 150
RMX2 = cm 200
PHI1 = deg 200
PHI2 = deg 340
**Geant Geometry**

### SPHE specifications 18/11/93

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMIN</td>
<td>0 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>400 cm</td>
</tr>
<tr>
<td>THE1</td>
<td>0 deg</td>
</tr>
<tr>
<td>THE2</td>
<td>0 deg</td>
</tr>
<tr>
<td>PHI1</td>
<td>0 deg</td>
</tr>
<tr>
<td>PHI2</td>
<td>0 deg</td>
</tr>
</tbody>
</table>

### PARA specifications 18/11/93

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DX</td>
<td>100 cm</td>
</tr>
<tr>
<td>DY</td>
<td>200 cm</td>
</tr>
<tr>
<td>DZ</td>
<td>400 cm</td>
</tr>
<tr>
<td>ALPH</td>
<td>15 deg</td>
</tr>
<tr>
<td>THET</td>
<td>30 deg</td>
</tr>
<tr>
<td>PHI</td>
<td>30 deg</td>
</tr>
</tbody>
</table>

### PGON specifications 18/11/93

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHI1</td>
<td>180 deg</td>
</tr>
<tr>
<td>DPHI</td>
<td>270 deg</td>
</tr>
<tr>
<td>NZ</td>
<td>6</td>
</tr>
<tr>
<td>NZ</td>
<td>4</td>
</tr>
<tr>
<td>Z</td>
<td>-400 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>250 cm</td>
</tr>
<tr>
<td>Z</td>
<td>-300 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>100 cm</td>
</tr>
<tr>
<td>Z</td>
<td>300 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>100 cm</td>
</tr>
<tr>
<td>Z</td>
<td>400 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>250 cm</td>
</tr>
</tbody>
</table>

### PCON specifications 18/11/93

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHI1</td>
<td>180 deg</td>
</tr>
<tr>
<td>DPHI</td>
<td>270 deg</td>
</tr>
<tr>
<td>NZ</td>
<td>4</td>
</tr>
<tr>
<td>Z</td>
<td>-400 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>250 cm</td>
</tr>
<tr>
<td>Z</td>
<td>-300 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>100 cm</td>
</tr>
<tr>
<td>Z</td>
<td>300 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>100 cm</td>
</tr>
<tr>
<td>Z</td>
<td>400 cm</td>
</tr>
<tr>
<td>RMIN</td>
<td>50 cm</td>
</tr>
<tr>
<td>RMAX</td>
<td>250 cm</td>
</tr>
</tbody>
</table>
**Geant Geometry - Complex example - CMS detector**

charged particles with $p_T > 1 \text{ GeV}$ and $|\eta| \leq 2.5$ are shown
Geant geometry

• Can simulate complex absorber shapes easily. Can calculate deposition of energy due to dE/dx of muons + decay electrons accurately. Can make the simulation very realistic. Needed before building.

• Also, magnetic fields are described as field maps (not expansions about the closed orbit). This enables easier investigation of perturbations to optics of say ring coolers by the introduction of injection/extraction systems.

• Geant does not have electric fields. We have changed the Runge-Kutta routine in Geant to use electric fields correctly. Integration of tof done correctly.
Geant3 modified

- Electric fields added
- dE/dx, multiple scattering done well in Geant3
- Electromagnetic showers and hadronic interactions done well
- Arbitrarily complex geometry shapes available by nesting Geant3 shapes
- One can feed in 3D magnetic fields that are realistic.
- We hope to study the problem of injection/extraction into ring coolers using these tools.
Equations of motion in presence of electric and magnetic fields

\( \vec{p}, E \) is the particle 4 vector, \( \vec{u} \) is the tangent to the trajectory, \( y \), \( s \) the arc length, \( v \) the velocity, \( \eta \) is the Lorentz factor, \( c \) the velocity of light, \( m_0 \) the particle mass, \( q \) the charge, \( \vec{E} \) is the electric field, \( \vec{B} \) is the magnetic field.

\[
\frac{d\vec{p}}{dt} = q \left( \vec{E} + \vec{v} \times \vec{B} \right)
\]

\[
\frac{d\vec{p}}{dt} = \frac{d\vec{p}}{ds} \times \frac{ds}{dt} = v \frac{d\vec{p}}{ds}
\]

\[
\vec{p} = \vec{u} m_0 c \eta
\]

\[
p \frac{dp}{ds} = \vec{p} \cdot \frac{d\vec{p}}{ds} \Rightarrow \frac{dE}{ds} = q \left( \vec{E} \cdot \vec{u} \right) \quad (1)
\]

\[
\frac{d\vec{u}}{ds} = \frac{d^2\vec{x}}{ds^2} = \frac{q}{p} \left( \vec{u} \times \vec{B} + \frac{\vec{E}}{v} - \frac{\vec{E} \cdot \vec{u}}{v} \vec{u} \right) \quad (2)
\]

\[
\frac{dt}{ds} = \frac{1}{v} \quad (3)
\]
Runge-Kutta Equations

Runge-Kutta is performed on 3 equations simultaneously. Nystrom algorithm

\[ y'' = f (y', y, x) \]
solves to

\[ y(x + h) = y(x) + hy'(x) + (h^2 / 6)(K_1 + K_2 + K_3) + O(h^5) \]
\[ y'(x + h) = y'(x) + (h/6)(K_1 + 2K_2 + 2K_3 + K_4) + O(h^5) \]
\[ K_j = f (y_j', y_j, x_j) \text{ for } j = 1, 2, 3, 4 \]
\[ x_1 = x, x_2 = x_3 = x + h / 2, x_4 = x + h \]
\[ y_1 = y(x), y_2 = y_3 = y(x) + (h/2)y'(x) + (h^2/8)K_1 \]
\[ y_4 = y(x) + hy'(x) + (h^2/2)K_3 \]
\[ y_1' = y'(x), y_2' = y'(x) + (h/2)K_1, y_3' = y'(x) + (h/2)K_2, \]
\[ y_4' = y'(x) + hK_3 \]
Geant Simulation of ring cooler
Geant Simulation of ring cooler
MITER

- Separate program that calls Geant.
- Has interface to MINUIT
- Present algorithm
- Remove all absorbers.
- Acquire times at which on momentum particle crosses all rf volumes (16x4)
- Start particle at beginning of quadrant and track one turn
- Work out rf frequency for a harmonic number =28
- Replace main absorbers. No wedges.
- Iterate One Turn with no straggling or multiple scattering or decay.
- Re-work out the times.
- Re calculate RF gradient such that loss per absorber = gain / quadrant.
- Re work out the rf frequency. Iterate 30 times till convergence.
- RF entry at –15 degrees and exit at ~ 75 degrees. Sin Wave.
RF Frequency evolution

HZ $\times 10^5$

Iteration number