Density in longitudinal phase space, from a 25 million particle simulation of a mismatched beam.
OUTLINE

- Scope
- Feasibility / Practicality of the project
- Available tools
- Status
- Goals and work plan
# PROTONS v MUONS

<table>
<thead>
<tr>
<th>Protons</th>
<th>Muons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainly linear optics, with 3rd order corrections</td>
<td>Non-linear optics, with high order terms necessary</td>
</tr>
<tr>
<td>Ray tracing not possible</td>
<td>Ray-tracing techniques</td>
</tr>
<tr>
<td>Transverse emittances</td>
<td>Transverse acceptances</td>
</tr>
<tr>
<td>$\epsilon_T = 50 \pi \text{ mm.mrad}$</td>
<td>$\epsilon_T = 30,000 \pi \text{ mm.mrad}$</td>
</tr>
<tr>
<td>Space charge, instabilities, coherent resonances etc</td>
<td>No space charge, incoherent resonances</td>
</tr>
</tbody>
</table>
SCOPE

- From target through capture channel, phase rotation, bunching, cooling
- transmission/losses, decay, emittance growth
- Muon acceleration
- Muon storage and decay
- neutrino distribution
FEASIBILITY

- True end-to-end simulation probably unrealistic
- Decay and losses (poor transmission)
  - $10^6$ simulation particles at input become <2000 at end of front-end
- Simulation carried out in segments with re-generation of distribution at each stage
  - codes must have input-output compatibility
SIMULATION TOOLS

- ICOOL (R. Fernow)
- G4Mice (C. Rogers)
- G4Beamline (T. Roberts)
- Muon1 (S. Brooks)
- Optim (V. Lebedev)
- S-Code (S. Machida)
- Zgoubi (F. Méot)
- others?

- Need more than one code for each section
- Ensure same quantities are being calculated, same definitions used
- Codes need to be benchmarked
- Codes should be portable and user friendly
- Need clear understanding of capabilities of each code.
MUON1

Pion decay channel
Field maps and grid for modelling an ionisation cooling ring
G4MICE Functionality

- Combined accelerator and detector simulation
  - Most (all?) Neutrino Factory accelerator components
    - Solenoids
    - Arbitrary order multipoles with enge fringe fields
    - Arbitrary 3d field maps
    - Pillboxes
    - Superfish RF cavities
    - FFAGs
      - by displaced quads
      - by superposed multipoles
      - by 3d field map
  - Full suite of **GEANT4 tracking and physics processes**
    - Particle-matter interactions
    - Decays
G4MICE Functionality

- **Linear beam optics** for arbitrary orbits through arbitrary field maps
- Second order **Lie algebra** algorithms partially implemented
  - Aim for 3rd order in coming months
- **Accelerator analysis tools** for 2d, 4d, 6d emittances, amplitudes and beta functions (plus all the other standard stuff) + GUI
  - Read/write in G4MICE, G4Beamline, ICOOL formats
- Visualisation and **animation** of accelerator simulations
- Easily readable text-file based **user interface**
- Track fitting, **detector** electronics simulation and reconstruction
- Paper in preparation
G4BEAMLINE

- Intended to perform accurate and realistic simulations of beamlines and related systems.
- Based on the Geant4 toolkit.
  - Like a real experiment, one must pay attention to proper shielding, unwanted particles (e.g. delta rays and neutrons from vacuum windows), etc.
- Includes all beamline elements used in current muon collider and neutrino factory designs:
  - bends, quads, solenoids, pillbox RF cavities, absorbers with shaped windows, helical solenoids, beam pipes, targets, etc.
  - new components implemented on demand.
- User-friendly interfaces - "even a professor can use it".
MICE BEAMLINE

A view of the MICE Beamline generated by G4Beamline
A view of the Mu2e experiment being proposed at Fermilab. The proton target is at the left, the bent solenoid transport channel is in the middle, and the stopping-muon target and spectrometer are on the right.
Close-up of the Mu2e proton target (which produces pions that decay into the muons used by the experiment). It is inside a solenoid that tapers from 5T to 2.5 T (L to R). The target is hidden behind all the particles at the centre. The proton beam is not shown, and goes right-to-left (the muon beam comes off backwards to keep backgrounds down).
OPTIM (LEBEDEV)

- Originated as a linear optics code
- Integrated system for optics design, support and measurement analysis
- Similar to MAD but has integrated GUI
- Design intention
  - User friendly
  - On-line help
- Complete machine description
  - Magnet strength is computed from magnet currents using results of magnet measurements, additional fudge factors (up to a few percent) are applied to match computations with optics measurements
  - Aperture limitations, control system names
  - Standard instrumentation (BPMs, Profile monitors, current monitors, scrapers)
- 6D computations
  - Large set of optics elements
  - X-Y coupling, Acceleration (focusing in cavities is taken into account)
Linac1-to-Arc2 - Chromatic Corrections

initial

uncorrected

two families of sextupoles

\[ G_{\text{sext}} \ [\text{kGauss/cm}] = S \times \frac{\Delta p}{p} \times \bar{D} \approx 0.2 \times 0.01 \times 150 = 0.3 \ [\text{kGauss/cm}] \]

\[ G_{\text{quad}} \approx 10 \ [\text{kGauss/cm}] \]
Summary

- IDS Goals – laying engineering design foundation
  - Define beamlines/lattices for all components
  - Design lattices for transfer lines between the components
  - Resolve physical interferences, beamline crossings etc ⇒ Floor Coordinates

- Carry out end-to-end tracking study ⇒ Machine Acceptance

- Chromatic corrections with sextupoles implemented

- Engineer individual active elements (magnets and RF cryo modules)

- Element count and costing

- Presently completed Optics design
  - Pre-accelerator (244 MeV-0.9) + injection double chicane
  - RLA I (0.9-3.6 GeV)
    - 4.5 pass linac
    - Droplet Arcs1-4
S-CODE (MACHIDA)

- New code developed initially for non-scaling FFAGs
- Now very general:
  - handles lattice geometry and particle optics separately
  - includes field maps, (linear) space charge, non-linear elements etc.
- Now being used for RLA switchyard study

*Details in ICFA Beam Dynamics Newsletter 43, August 2007*

First Attempt at End to End Simulation
Muon Acceleration - longitudinal phase space

\[ \epsilon_T = 0.001 \pi \text{ mm.rad} \]

Linac 0.13-2.48 GeV

RLA 2.48-11 GeV
Racetrack, USII, 2 turns

FFAG 11-20 GeV

\[ \epsilon_T = 30 \pi \text{ mm.rad} \]

Linac 0.13-2.48 GeV

RLA 2.48-11 GeV

FFAG 11-20 GeV

S. Machida - NUFACT’06
End to End Simulation - NUFAC'T’06
Evolution of emittance and beam loss

- Initial parameters
  - 0.07%, 0.20/β*2π
  - 30 π mm
  - Waterbag distribution
ZGOUBI (F. MÉOT)

ICFA Beam Dynamics Newsletter 43, August 2007

- Ray-tracing code
  - stepwise resolution of Lorentz equations with Taylor series expansion of fields
- Many recent developments
  - models all types of FFAG magnets
  - accurately simulated beam dynamics in all types of FFAGs

Muon Acceleration 5-10 GeV: Horizontal stability limits around closed orbits at various energies; vertical stability limits at various energies; muon beam path in the tune diagram; muon beam motion in the longitudinal phase space
SUMMARY

- MARS output from target
- Track through Front-End with ICOOL, G4Beamline, G4Mice, Muon1
- Track through RLAs with S-Code, OptiM
- FFAGs with S-Code, Zgoubi
- Storage Rings with S-Code, Zgoubi
- Assume matching between sections possible, but need to design transfer lines (final task)
The SciDAC Accelerator Modeling Project team: A multidisciplinary, multi-institutional team producing comprehensive terascale accelerator design tools

- **LBNL (AFRD)**: Beam-Beam; Space Charge in linacs & rings; parallel Poisson solvers
- **UC Davis**: Particle & Mesh Visualization
- **SLAC**: Large-Scale Electromagnetic Modeling
- **Stanford, LBNL (CRD)**: Parallel Linear Solvers, Eigensolvers, PDE Solvers, AMR
- **UCLA, USC, Tech-X, U. Colorado**: Plasma-Based Accelerator Modeling; Parallel PIC frameworks (UPIC)
- **FNAL**: Space-charge in rings; software integration; Booster expts
- **UC Davis**: Space-charge in rings; software integration; Booster expts
- **BNL**: Space-charge in rings; wakefield effects; Booster expts
- **U. Maryland**: Lie Methods in Accelerator Physics
- **SLAC**: Large-Scale Electromagnetic Modeling
- **LANL**: High Intensity Linacs, Computer Model Evaluation

Mathematical equation:

\[ M = e^{\frac{f_2}{2}} e^{\frac{f_3}{3}} e^{\frac{f_4}{4}} \ldots \]

\[ N = A^{-1} M A \]
Dr. "Nick" Bostrom of Oxford University has come to the conclusion that "it is almost a mathematical certainty" that we are merely the constructs of some elaborate computer simulation—or even a simulation inside a simulation inside a simulation and on and on like a set of Russian cyberdolls.