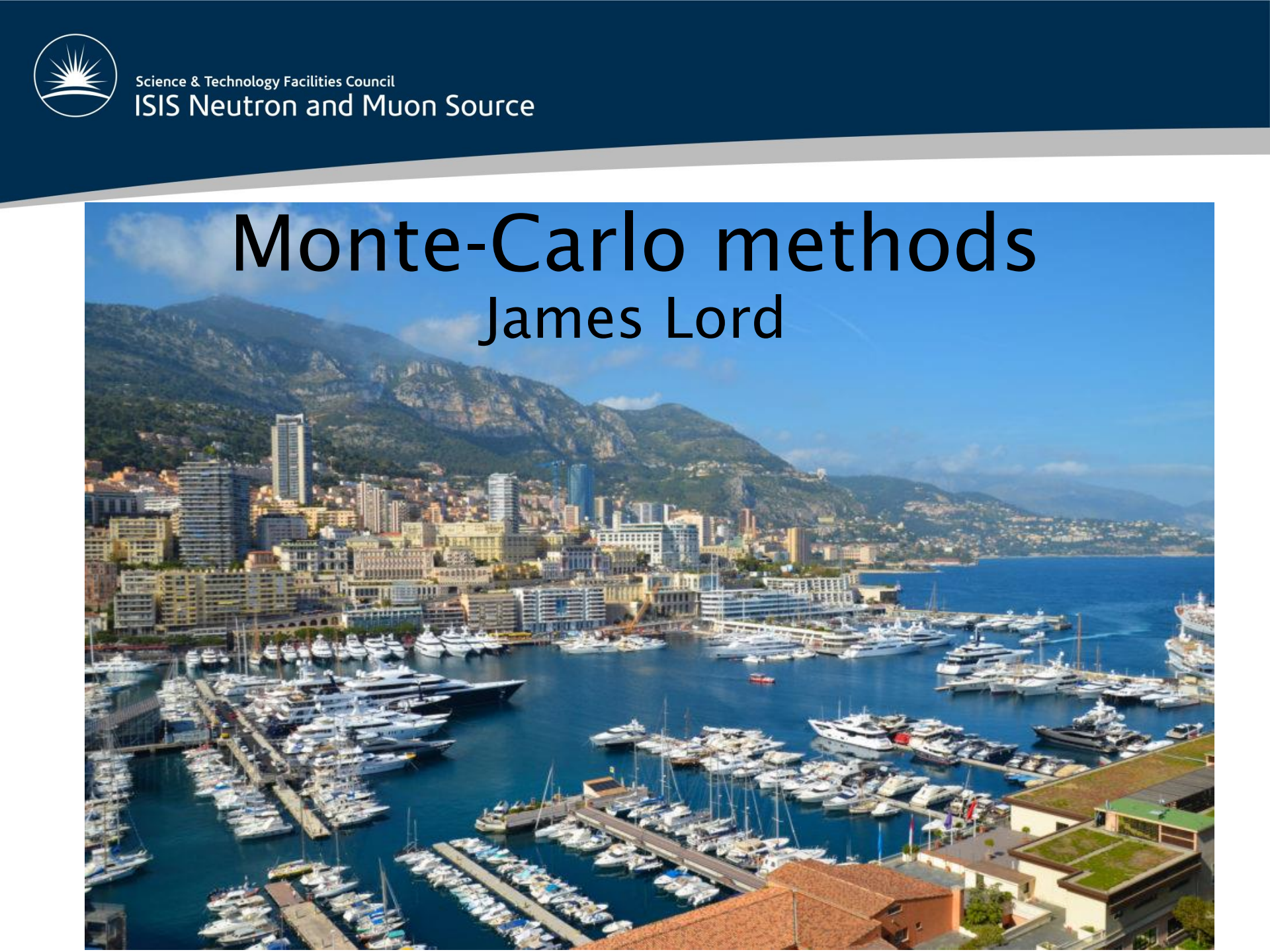

Science & Technology Facilities Council
ISIS Neutron and Muon Source
Monte-Carlo methods
James Lord

Outline

1. What is the Monte Carlo method?
2. Muon beam and instrument simulation

Muon spin modelling – interactions with the sample (Quantum talk)

Monte Carlo method

- Predicting probability of outcome of sequence of random events

Simple to solve by computer:

- Generate random numbers
- Evaluate functions
- Count outcomes

Easy to run in parallel

Monte Carlo

- How to integrate a “difficult” function?
- $Y = \int f(x,y,z...)\, dx\, dy\, dz...$
- Approximate by:
- $Y=(1/N)\ \Sigma\ f(x_i,y_i,z_i)$
- x_i chosen at random in range (X1,X2)
- Accuracy improves as $1/\sqrt{N}$

Beam modelling

- Muons produced with a spread of energy, direction and location
- Predictable interaction with magnetic or electric fields
- Random interactions with matter (beam windows, samples)
- Muon decays after random time
- Positron emitted randomly within distribution
- Positron might scatter before being detected

Analytical beam model?

- In principle we can define $P(x,y,p,\theta,\varphi)$
  - Probability of particle starting at x,y (implied z=z0) with momentum p and angles θ,φ reaching the sample
- Then just calculate the flux
  - $F = \int e(x,y,p,\theta,\varphi)\, P(x,y,p,\theta,\varphi)\, dx\, dy\, dp\, d\theta\, d\varphi$
- Maximise it with respect to magnet settings
- Possible for a simple pipe
- Very hard for a real beamline!

Monte-Carlo particle modelling

- Generate random initial particles
- Track them
- Make random choices
  - Which direction does it scatter when it hits something?
  - How much energy does it lose?
  - When does it decay?
- Record stopping positions in histogram
  - and other details

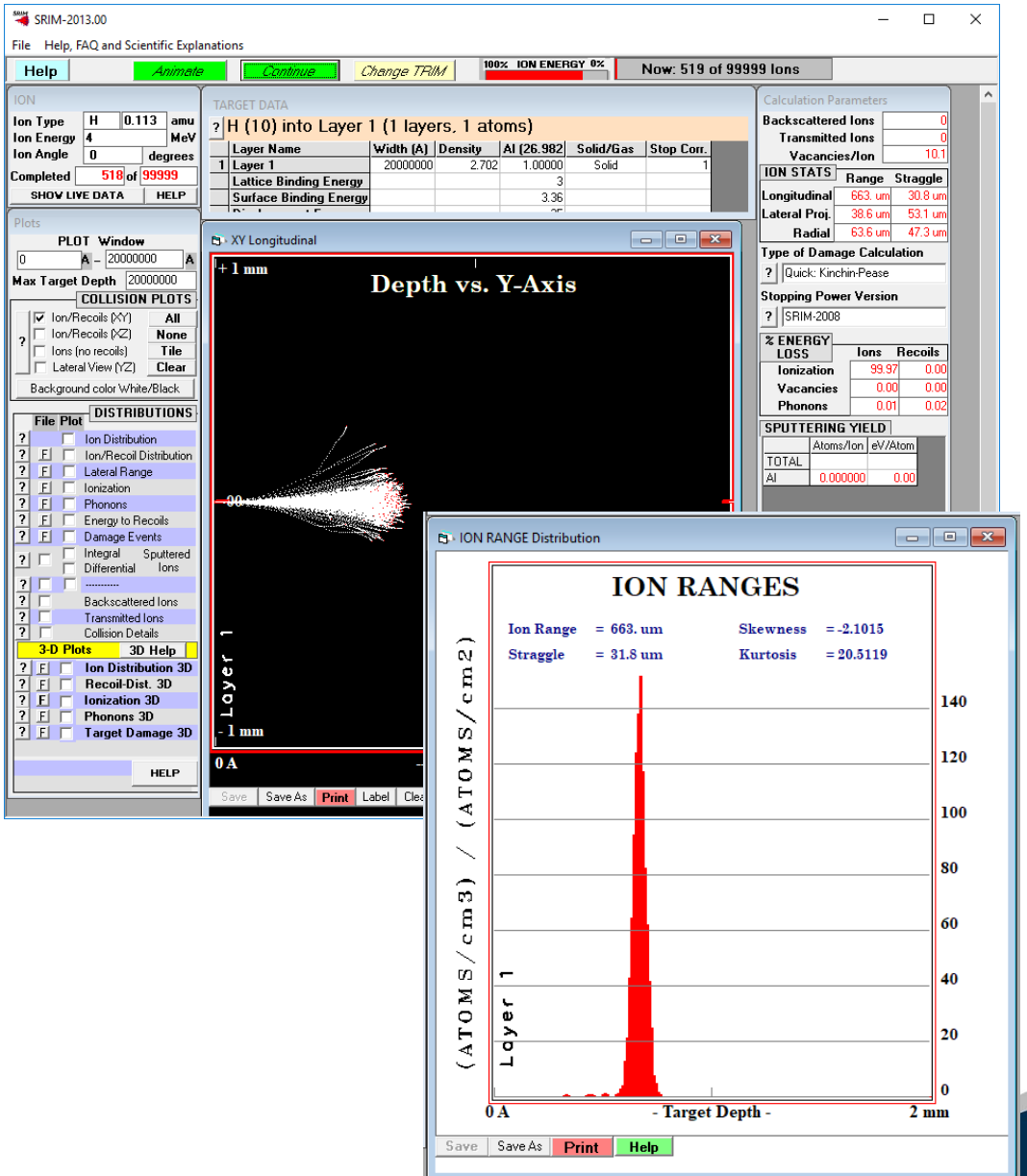
How many dice to throw?

- Simulate more particles:
- Better answer $\pm O(1/\sqrt{N})$
- Takes longer $O(N)$

Artefacts or noise can have different appearance:

- Random directions, independently chosen every time (no bias)
- Random directions, same seed each time (better for optimisation)
- Uniformly spaced directions

Muon ranges



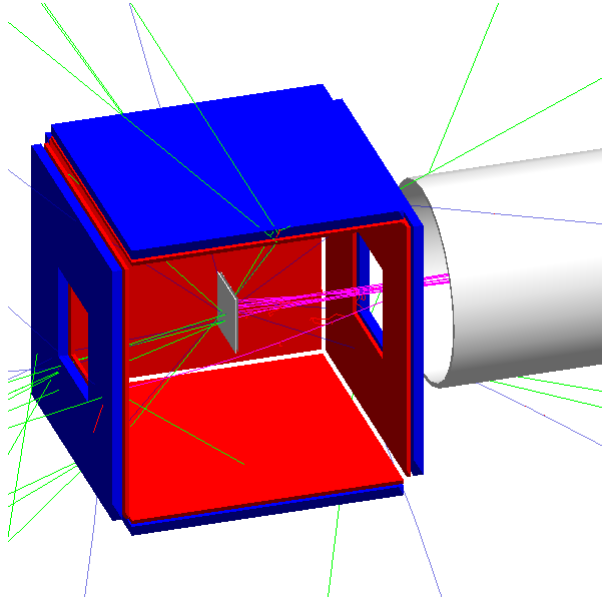
SRIM and TRIM – basic, but fast

- Mono-energetic muon beam
- Sample in uniform layers
- Record stopping histograms (z,xy)
- TRIM-SP optimised for low energy muons

Beamline and instrument modelling

musrSim

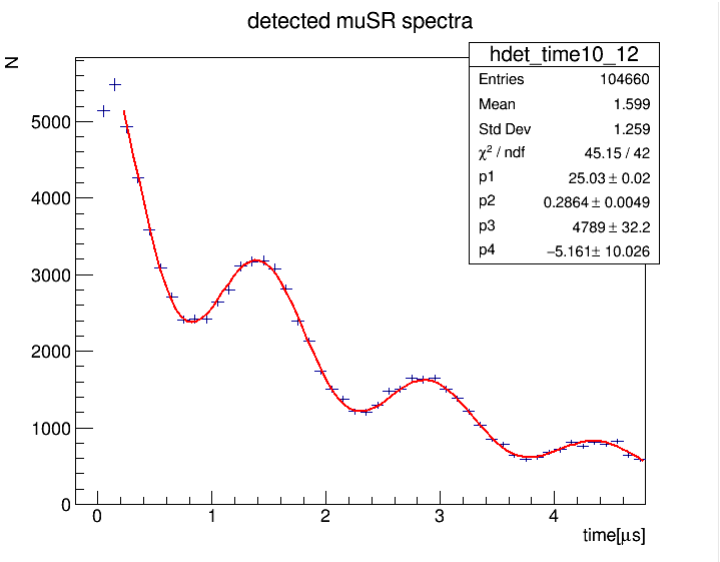
- Based on Geant4 (particle physics)
  - Full details of all possible interactions
- Detailed 3D model, slower
- Tracks pions, muons, positrons, etc
- Record detector hits (with energy)
- Record muon stopping/decay locations

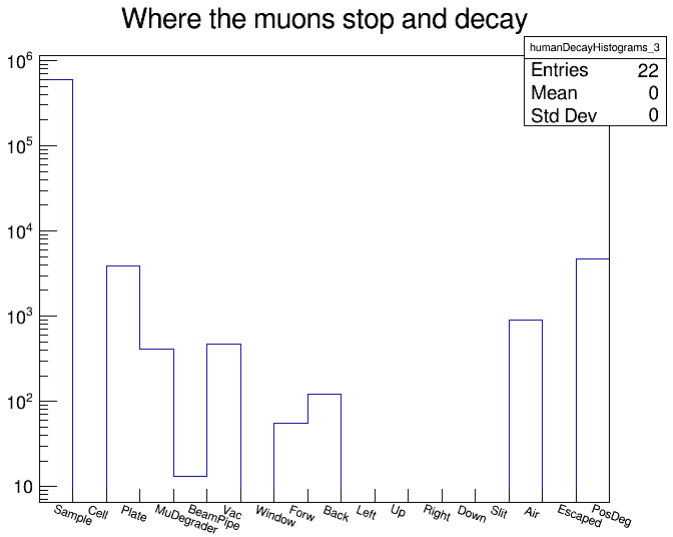


Simulated data analysis

musrSimAna

- Examine output from musrSim
- Compare detector hits against threshold
- Identify events where the muon was in the sample
- Identify sources of background signals
- Model “pile up” and “dead time”
- Generate realistic histograms

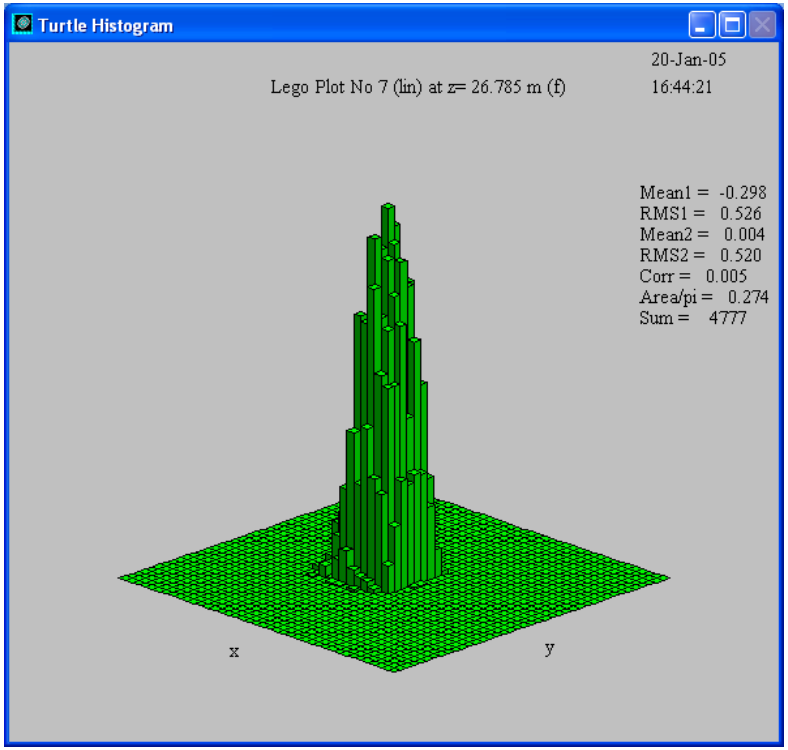




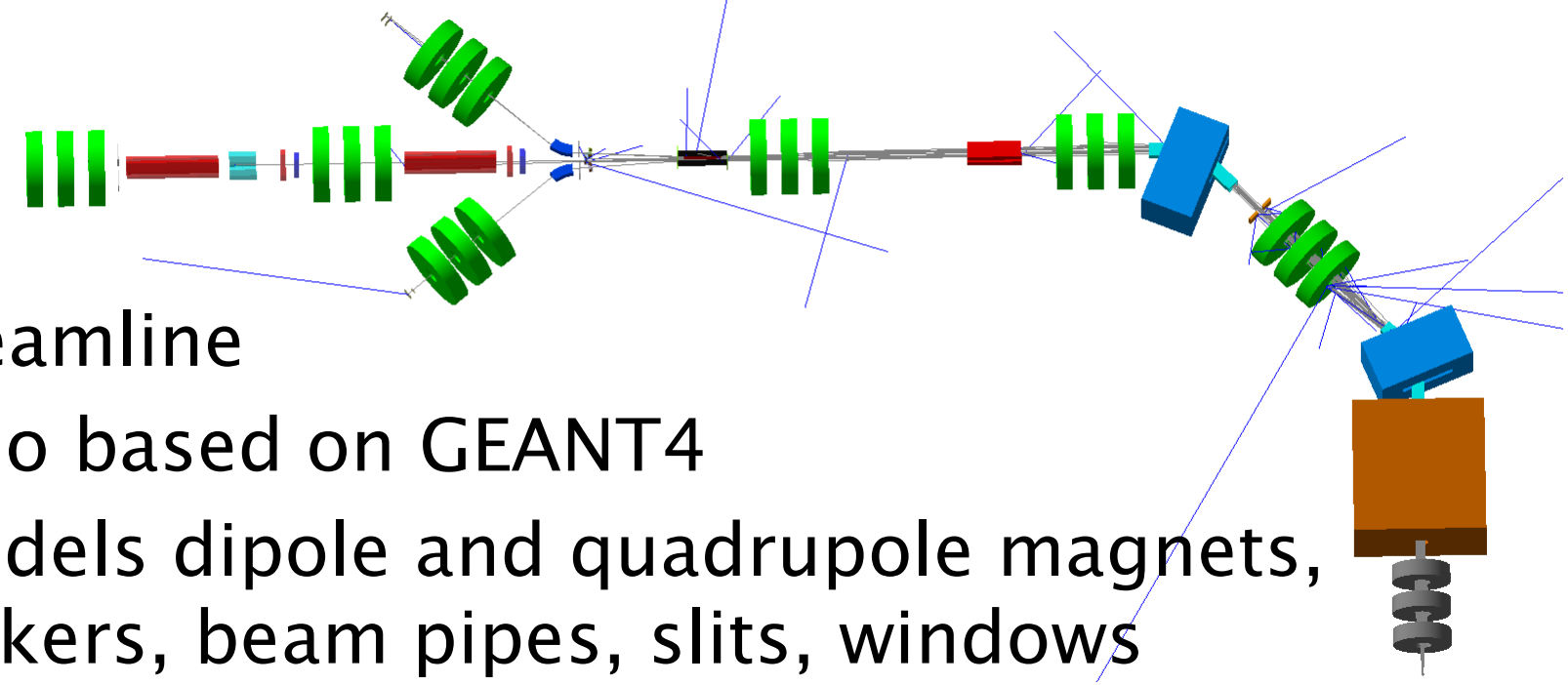
Beamline modelling

TURTLE

- Random initial particles within the beam
- Linear sequence of magnets, slits, etc
- Particles stopped if they hit the magnet apertures
- Calculate beam spot profiles and flux
- Relatively fast



Beamline modelling



G4Beamline

- Also based on GEANT4
- Models dipole and quadrupole magnets, kickers, beam pipes, slits, windows
  - Full 3d model
  - Particles can be scattered, or stop and decay in components
- Examine beam flux, spot sizes, pulse length, particle types