Simulation Tools For Machine Backgrounds

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- Overview of the problem.
- Brief overview of existing codes:
- DECAY TURTLE & MUCARLO
- MARS
- Geant3
- `BDSIM`: a Geant4 Beam Delivery System Simulation Program
- Conclusions +Final Remarks

Overview of the Problem

Obvious statements:

- At the end of the accelerator sits a detector.
- That detector needs to be able to turn on.
- One of the (many!) convincing arguments for an e^+e^- linear collider is the cleanliness of the events. This assumes low machine-related backgrounds.
- The detector needs to see signal clearly.
- It needs to last at least about a decade.

There are of course machine/physics-related backgrounds – beam-beam interactions etc.; these are not the subject of this talk.

I will concentrate on issues relating to the Beam Delivery System (BDS).

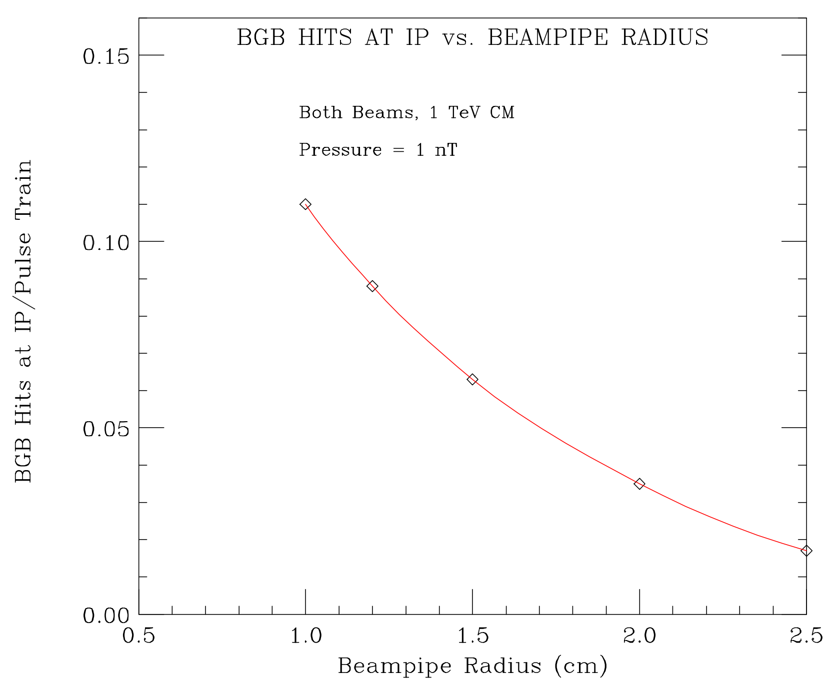
- Particle loss in the BDS.
- Synchrotron radiation in the BDS and Final Focus sections.
- Muon production in spoilers and collimators.
- Neutron production in the BDS and beam dumps.
- Bremsstrahlung off beam-gas in BDS.
- ...

DECAY TURTLE + MUCARLO

(from L. Keller, SLAC)

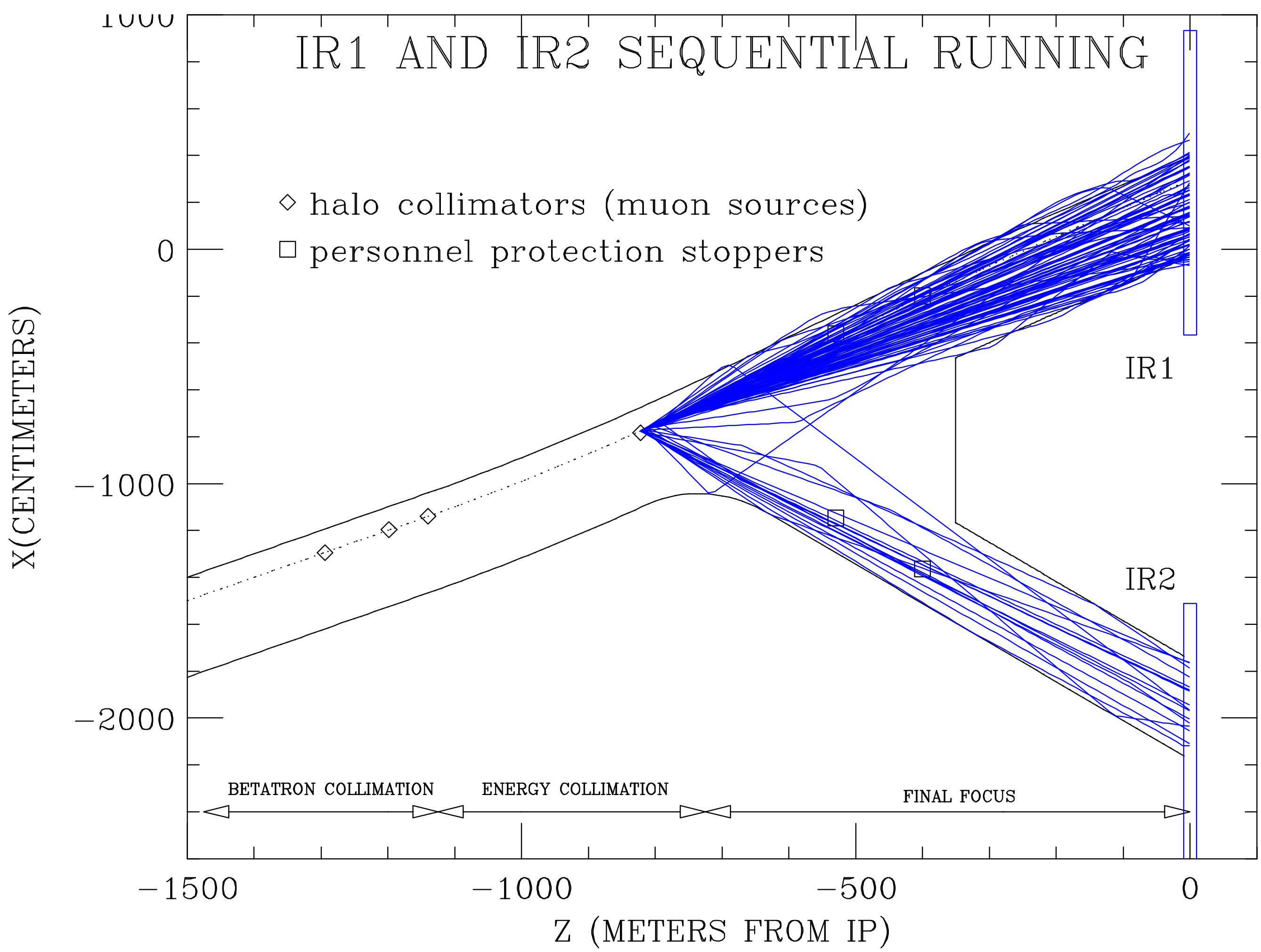
DECAY TURTLE, SLAC-246

- Modified by W. Kozaneki for SLC to include beam-gas bremsstrahlung and by D. Coupal and T. Fieguth for PEP-II.
- The program tracks the photon and degraded electron from bremsstrahlung off residual gas molecules and beam energy electrons from single coulomb scatters.



MUCARLO

- Program MUCARLO was originally written for SLC to estimate muon background in MARK-II and SLD.
- Muons are produced in collimators via the Bethe-Heitler process and direct annihilation of positrons on atomic electrons.
- Muons are stepped through the beamline and tunnel. The model includes tunnel walls, magnet support girders, and all bends and quadrupoles, including return flux in the iron and poletips.
- Various types of magnetized iron spoilers can be added to the tunnel at any location.
- A large variety of one- and two-dimensional histograms of the muon 4-vectors at any point in the tunnel can be generated.
- A particularly useful feature for understanding how muons manage to reach the detector is a printout of individual trajectories $\Longrightarrow$



IR1 AND IR2 SEQUENTIAL RUNNING
◇ halo collimators (muon sources)
□ personnel protection stoppers
IR1
IR2
1000
0
−1000
−2000
X(CENTIMETERS)
BETATRON COLLIMATION
ENERGY COLLIMATION
FINAL FOCUS
−1500
−1000
−500
0
Z (METERS FROM IP)

MARS

(from N. Mokhov, Fermilab)

- Program MARS is a Monte Carlo for inclusive and exclusive simulation of 3-D hadronic and EM showers, muon and low-energy neutron transport in shielding and in accelerator components in the energy range from a fraction of an eV to 100 TeV.
- Hadron and lepton interactions with nuclei and atoms from 0.1 MeV to 100 TeV. Includes a new nuclear cross-section library, a model for soft pion production and many others models.
- Detailed description of negative hadron and muon absorption and a unified treatment of muon and charged hadron EM interactions with matter.
- Particle tracking in magnetic fields, synchrotron radiation by electrons and muons...

In summary: **A comprehensive and up to date package**

The code is being used extensively for comparative studies of LC BDS and sets a benchmark for development of new code.

For more details see:

http://www-ap.fnal.gov/MARS/

GEANT3

(from T. Maruyama, SLAC)

Much work has been done in simulating BDS with GEANT3.

- Developing a tool based on Geant3 and TRANSPORT lattice.
- Builds geometry automatically.
- Interactions in spoilers and absorbers.
- Synchrotron radiation
- Collimator scattering.

See eg:

`http://www-conf.slac.stanford.edu/lc02/wg3/WG3_maruyama_0207.pdf`

Geant3 is a reliable and long-lived program and is an excellent basis to perform BDS simulations and compare against other codes.

A similar approach is now being adopted in the Geant4 environment $\Longrightarrow$

BDSIM - A GEANT4-Based BDS Simulator

The HEP world is now moving to Geant4.

- A vast library of physics processes from very low to very high energies.
- Object-oriented approach; well adaptable to accelerator objects.
- Code developed in this framework will probably last a very long time.

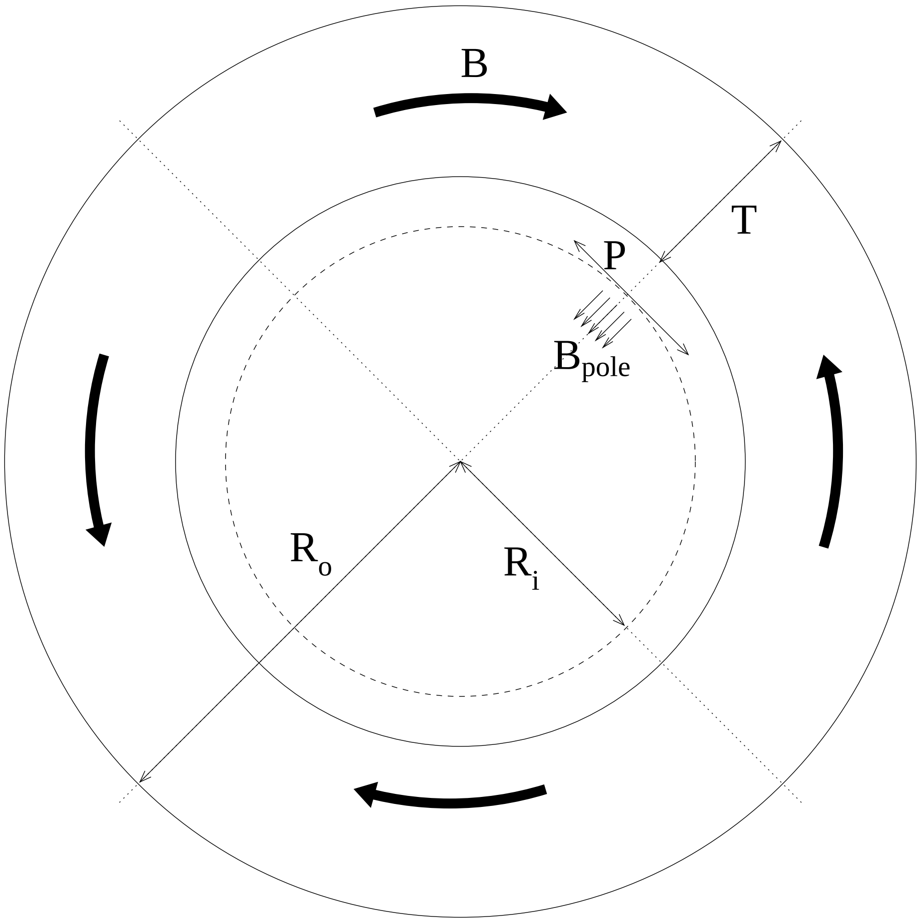
BDSIM has developed in this framework to provide:

- A flexible tool applicable rapidly to any BDS.
- Fast accelerator-style tracking for detailed tracking studies.
- Interface to a MAD-style optics file for easy build of beamlines.
- Full access to the Geant4 physics, geometry packages and visualisation packages.

BDSIM - Geometry

Each component has its own geometry

- Outer Volume with magnetic field.
- Beampipe
- Inner beamipipe with fast “Stepper” for machine-style tracking.



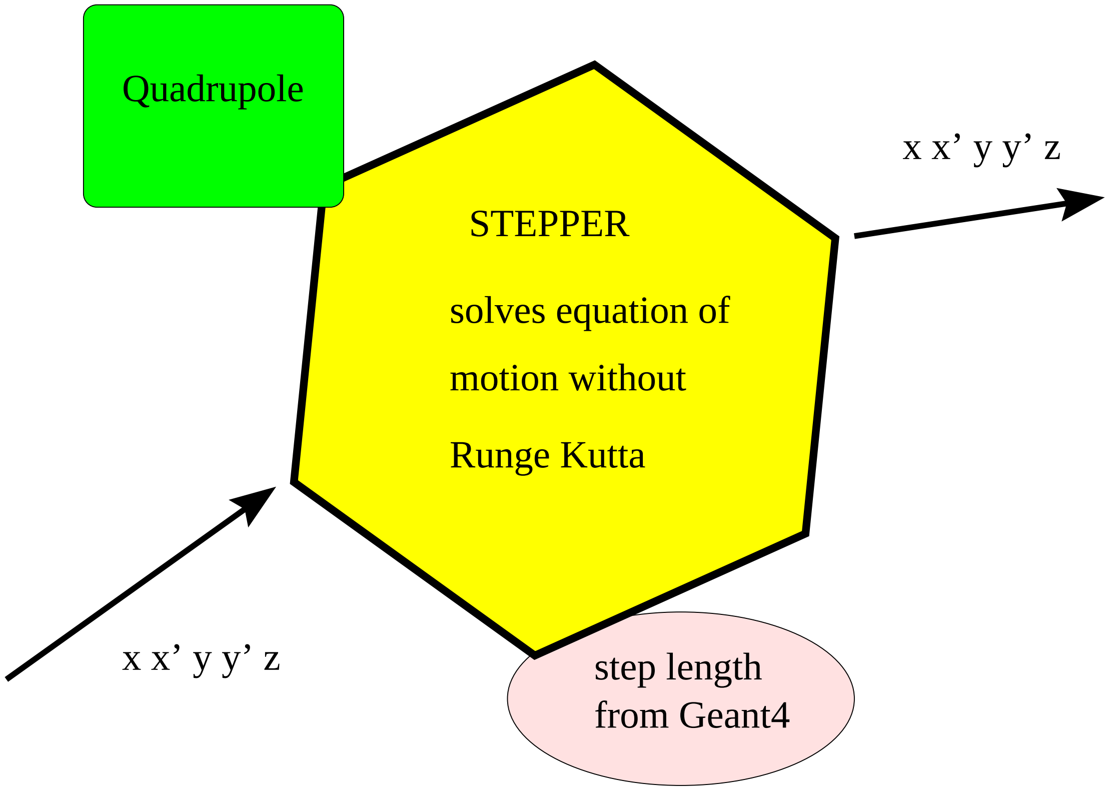
These objects can be repeated many times and placed along beamline by dedicated MAD-style interface.

Multipoles up to and including decapoles are included.

The detail of the G4 geometry can be easily increased, subject to memory capacity of the computer.

BDSIM - Tracking

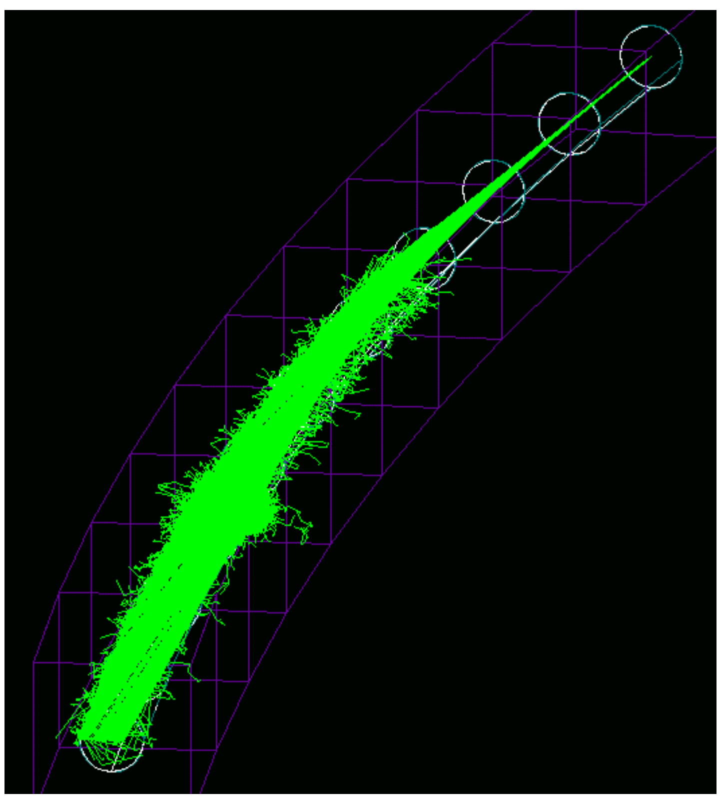
Fast Accelerator-style tracing has been developed:



- Known solution to equation of motion applied for Sector Bends and Quadrupoles
- Simple "kick" dynamics for higher multipoles.
- Avoids the use of Runge-Kutte techniques (time-consuming) for particles inside beampipe.
- Outside beampipe, default Geant4 tracking is used - slower, but allows more complicated outer fields etc. to be incorporated.
- Tracking is accurate - the nm spotsizes and distributions are obtained over many km (eg 6km CLIC BDS).
- Particle trajectories are in principle available, but not yet implemented directly.
- Step-length provided by Geant4; depends on processes present ⟹

BDSIM Processes

- Multiple Scattering - there “for free” in Geant4. Input via a “pressure” variable in BDS code for beam-gas studies.
- Muon production in spoilers etc. is included (H.Burkhardt et al. $\Longrightarrow$ next talk)
- Synchrotron radiation is included.
- Compton Scattering “Engine” included for scattering off thermal photons and also Laserwire ($\Longrightarrow$ Laser-Wire Mini-Workshop on Wednesday).
- Entire G4 Physics Library easily accessible. Includes photo-nuclear and lepton-nucleon processes $\Longrightarrow$ neutron production etc.

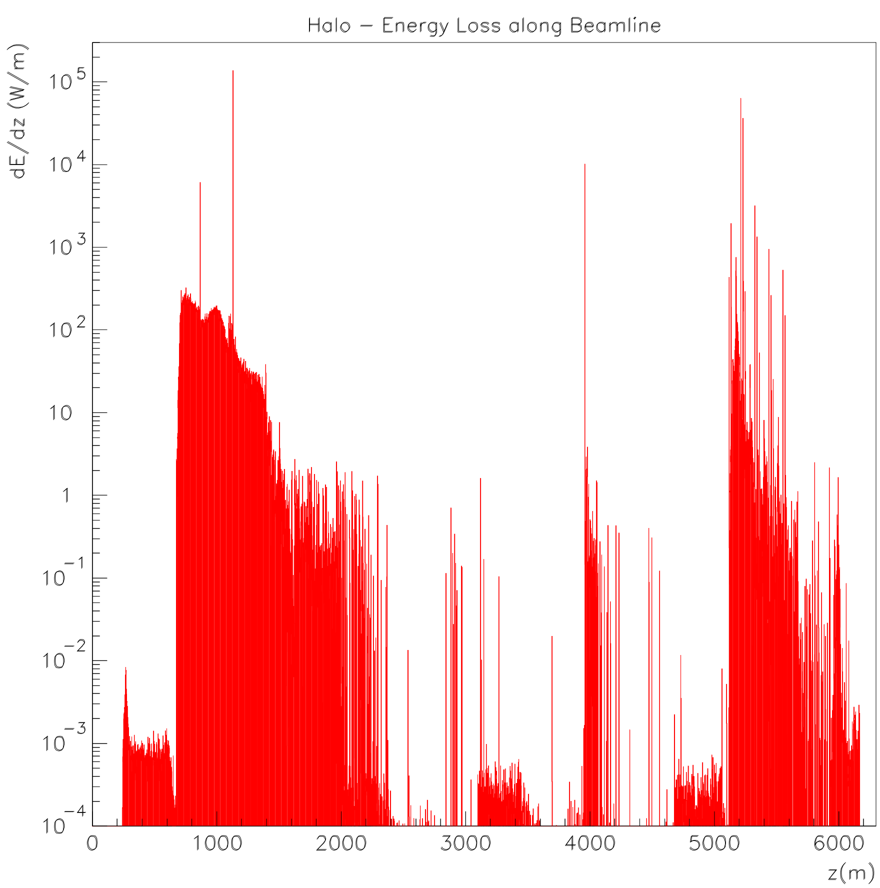


CLIC Halo

Assuming a halo with uniform distribution of electrons leaving the linac with widths:

Bunch parameter	Range
x	10.× 1.25 $\times \sigma_x$
y	70.× 1.25 $\times \sigma_y$
x′	10.× 1.25 $\times \sigma_x$
y′	70.× 1.25 $\times \sigma_y$
E	(0.98 - 1.02)$\times E_0$

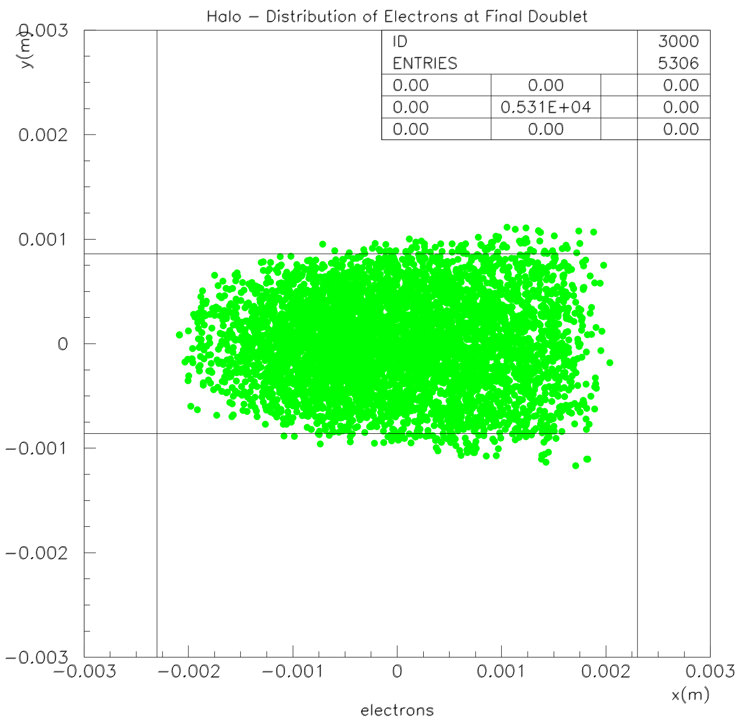
The energy loss along the entire beam delivery system, including spoilers and absorbers gives, for 50k electrons:

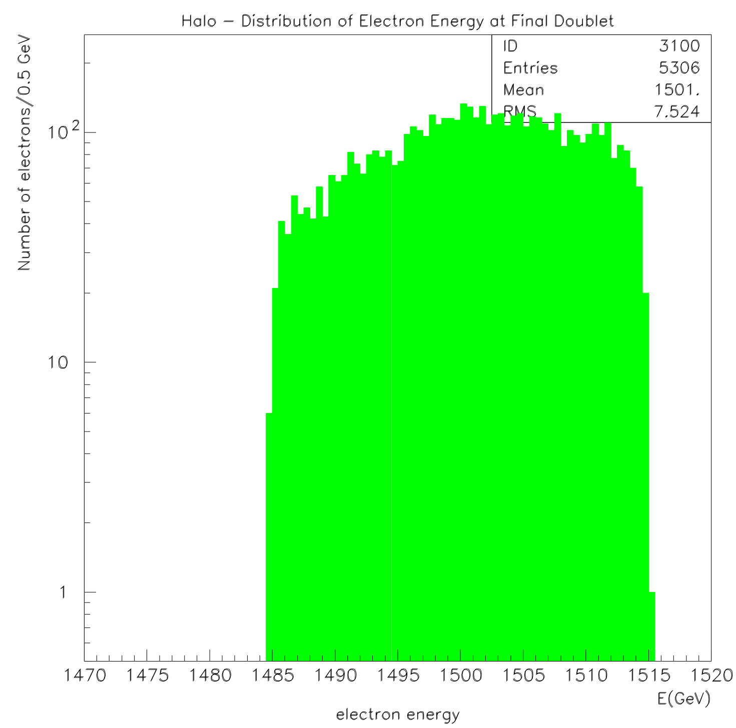


Electrons

50k CLIC halo electrons generated

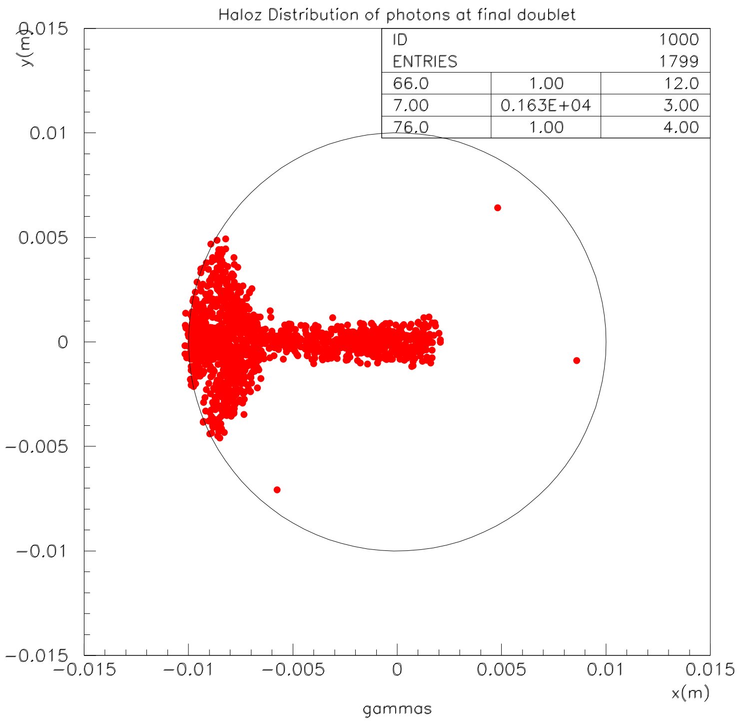
Particle halo distributions (top) and energies (bottom) at the CLIC IP:

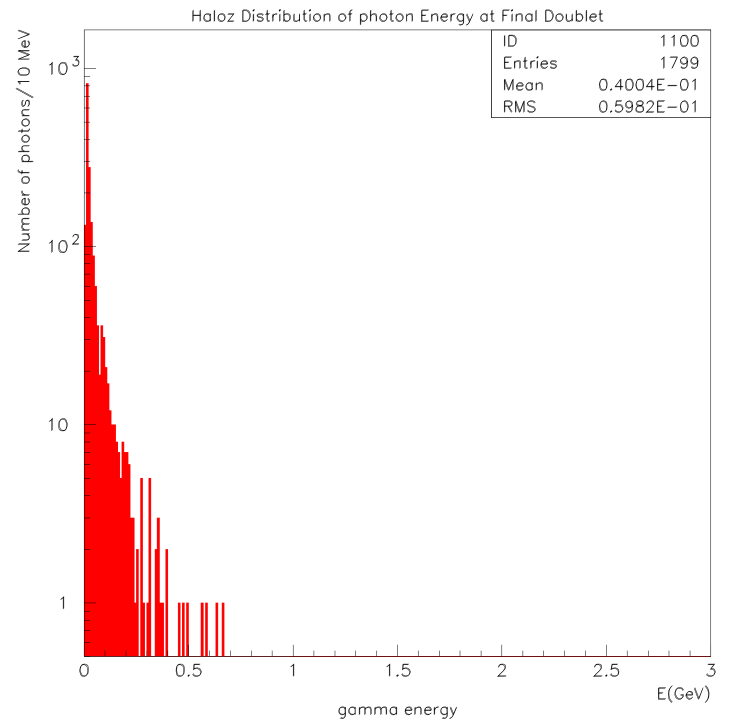




Photons

50k CLIC halo electrons generated

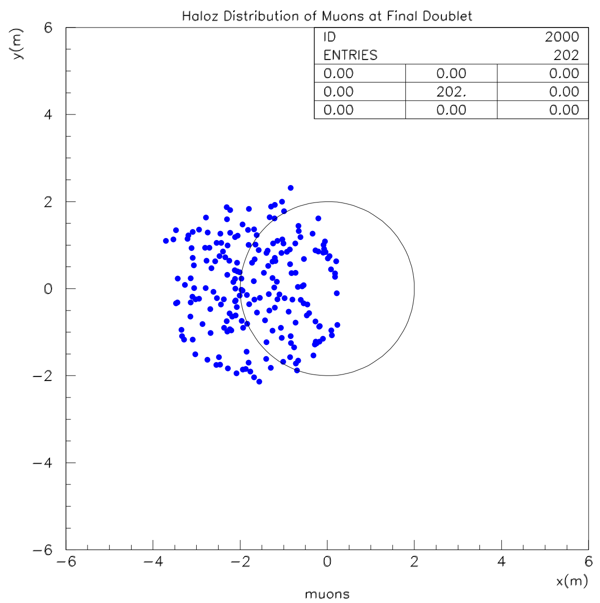


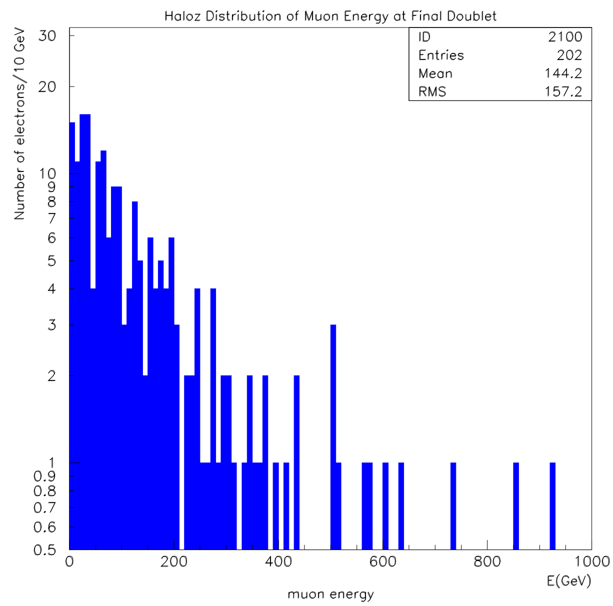


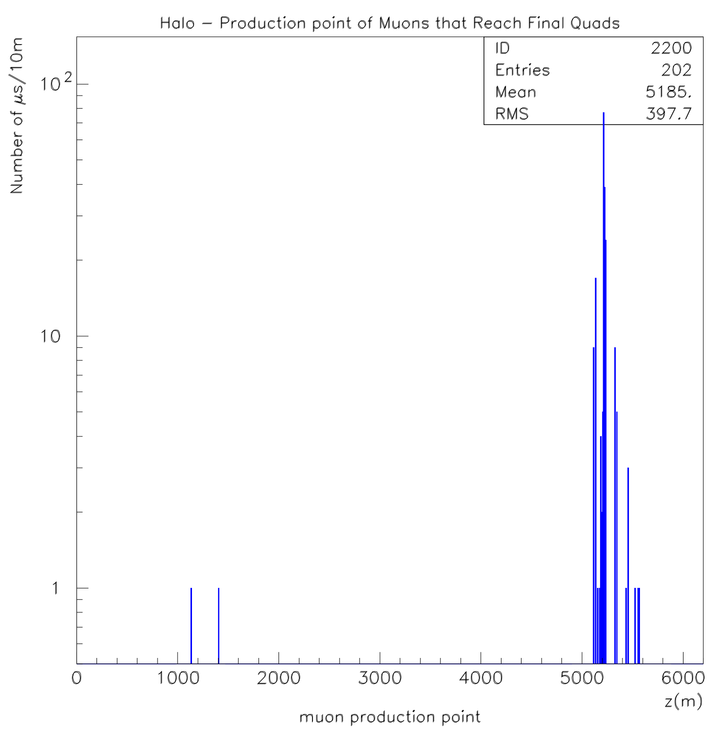
Muons

50k CLIC halo electrons generated

Distributions at final doublet:







Conclusions and Final Remarks

- Much progress has now been made through full simulation.
- A variety of tools is now emerging which will lead to independent cross-checks and development.
- I have not covered the usual accelerator tracking codes - but they are also very useful in determining backgrounds and collimator efficiencies etc.
- As the codes develop, it is increasingly important to apply consistent cross-checks.
- CPU is limited, but we need to address this to really pin down tails of distributions.

This is a field that needs lots of effort - feel encouraged to join in!