Halo and Tail Generation Studies

HTGEN task, part of **W**ork**p**ackage WP6 on **I**ntegrated **L**uminosity **P**erformance **S**tudies

general study of potential sources of halo and tail generation and modelling

by myself + Lionel Neukermans (EuroTeV fellow, started 1st September 2005), both CERN

- **List of candidate processes**
  Is the list complete ?
  Priorities and possibilities of benchmarking

- **Status : work on synchrotron radiation, Bremstrahlung, elastic scattering**
  ideas on interfaces and benchmarking

Halo & Tail. Candidate Processes http://hbu.home.cern.ch/hbu/HTGEN.html

- **Particle processes**
  Beam Gas elastic scattering
  inelastic scattering, bremsstrahlung
  Ion or electron-cloud effects
  Intrabeam scattering
  Touschek scattering
  Synchrotron radiation (coherent and incoherent)
  Scattering off thermal photons

- **Optics related**
  Mismatch
  Coupling
  Dispersion
  Non-linearities

- **Various,** equipment related, collective
  Noise and vibration
  Dark currents
  Space charge effects close to source
  Wake-fields
  Beam Loading
  (thin) Spoiler (Bremsstrahlung, scattering)

(Proposal for) Priorities and Possibilities of Benchmarking

General considerations :

We are a small task (1.5 FTE)

Start simple and fast, few processes, with flexible interface to existing tracking programs

Take advantage of contacts and expertise within CERN

currently in progress :

- **generator for Bremsstrahlung and Mott scattering**
  general interface : htgen class, with Z, A, pressure, mean free path calculation,...
  1st application : PLACET

- **update of synchrotron radiation as part of standard e.m. package of Geant4 and for Mad-X**

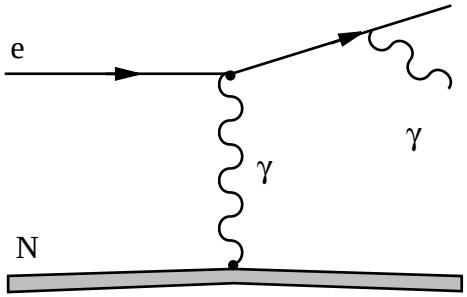
possibilities of benchmarking

- **comparison with older code and data (DIMAD, LEP tail measurements by H.B. et al.)**
- **CTF3 in contact with Thibaut Lefevre + Carsten Welsch / BI, Frank Tecker et al. / OP**
  we expect help on monitors and measurements and offer predictions and input for proposals on further instrumentation
  OTR with telescope to scan beam, consider scrapers + beam loss monitoring

Scattering processes

based on the material independent, complete screening
Tsai (Rev.Mod.Phys. 46) formula, accurate to ~ 2.5 %

$$\frac{d\sigma}{dk} = \frac{A}{N_A X_0}\,\frac{1}{k}\left(\frac{4}{3} - \frac{4}{3}k + k^2\right)$$



(inelastic) Bremsstrahlung

$\frac{A}{N_A X_0}$ = 1.224 barn for N_2 (≈ CO) $k = E\gamma / E_e$

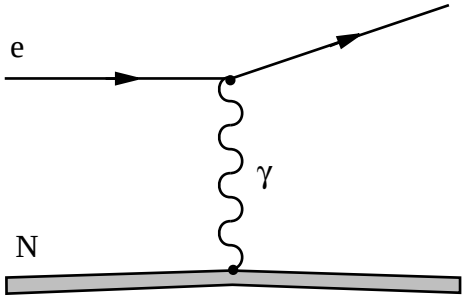
X_0 = rad. length ~ $A / Z(Z+1)$

σ = 6.510 barn ≥ 1% loss

ρ = P_{gas} / kT = 3.26x10^{14} molecules / m^3 (10 nTorr 23ºC)

scat. prob. P = ρ σ = 2.1x10^{-13}/m

$$\frac{d\sigma}{d\Omega} = \left[\frac{Z\,\alpha\hbar c}{2\,p\,v}\right]^2 \frac{1 - \beta^2 \sin^2\frac{\vartheta}{2}}{\sin^4\frac{\vartheta}{2}}$$



quasielastic Mott scattering

θ_{min} = 0.08 μrad

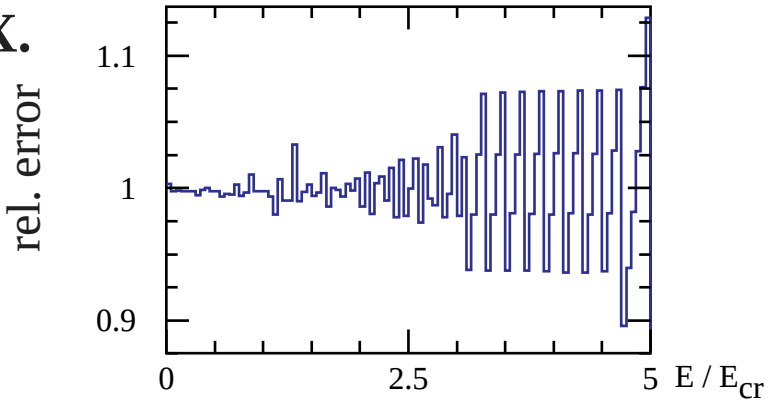
equal to vertical beam divergence
ε_{yN} = .03 mrad, 250 GeV, β = 10 m

σ = 1.64 x10^4 barn, scat. prob. P = ρσ = 5.35x10^{-10} / m

Status : standalone generators available, working on interface to PLACET

Synchrotron radiation spectrum generator and its implementation

• implement my accurate (14 decimal digits) and rather fast SynGen
Monte Carlo Generator for Synchrotron Radiation, LEP Note 632, Dec. 1990 http://hbu.home.cern.ch/hbu/gesynrad.pdf
in further programs and in particular in **Geant4** and **Mad-X.**
Mad-X (and mad8 and dimad) still use the slower
and much less accurate (10% above 2 E_{cr})
table search based generator by Ghislain Roy



• and further improve the speed of the generator
SynGen uses internally two approximate expressions, involving x^y and exp library functions
and the hit&miss method to arrive at the accurate synchrotron radiation spectrum
which is an integral over the Bessel $K_{5/3}$, function based on Chebyshev polynomials

• idea : attempt to find the *ultimate* generator, also interesting for other 1-dim. smooth functions,
in which the generation is achieved by a single function call which directly transforms the
flat random generator spectrum into the synchrotron radiation spectrum.
Can be as fast as a standard library function like *sin* or *cos*,
or still about five times faster than my previous version.

Literature:
Y. Luke, “The special functions and their approximations” New York, NY: Academic Press
L. Devroye, Non-Uniform Random Variate Generation. Springer, 1986
W. Press, S. Teukolsky, W. Vetterling, and B. Flannery, Numerical Recipes, Cambridge University Press

the cumulative synchrotron radiation photon spectrum in units of the critical energy :

$z = E / E_{cr}$ $\quad$ SynRadInt(0) = 5π/3

$$\mathrm{SynRadInt}(z) = \int_z^\infty \int_x^\infty K_{5/3}(t)dt\,dx$$

the fraction of photons below z

$$\mathrm{SynFracInt}(z) = \frac{3}{5\pi}\int_0^z \int_x^\infty K_{5/3}(t)dt\,dx = 1 - \frac{3}{5\pi}\mathrm{SynRadInt}(z)$$

Direct inversion : fast (Chebyshev polynomial P_{Ch}) **algorithm for (SynFracInt)$^{-1}$**

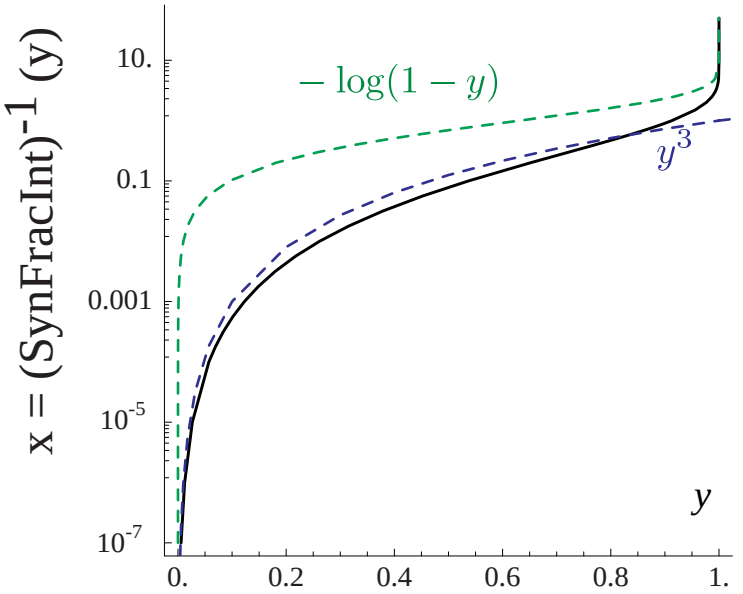
needs several intervals and suitable transformations inspired by the low and high y approximations

y="random" on (0,1)

y < .7 : y^3 P_{Ch} (y)

.7 < y < .9999 : P_{Ch} (y)

y > 0.9999 : -log(1-y) P_{Ch} (-log(1-y))



Geant4 details, synchrotron radiation

implementation comes with three parts

- **Code**
  $G4INSTALL/source/processes/electromagnetic/standard/src/G4SynchrotronRadiation.cc , hh

- **Documentation**
  $G4INSTALL/documents/UserDoc/UsersGuides/PhysicsReferenceManual/latex/electromagnetic/standard/synch.tex

- **Example(s)**
  http://geant4.web.cern.ch/geant4/G4UsersDocuments/UsersGuides/ForApplicationDeveloper/html70/Examples/ExtendedCodes.html

currently tested using a modified existing electromagnetic example (TestEm6)

Any feedback or ideas on dedicated examples and usage of Geant4 synchrotron radiation welcome

status : implementation and testing within geant4-07-01, for general distribution next year

Status, Summary

We have a list of candidate processes
and detailed work on several of them has started

- **elastic and inelastic scattering**
  with general interface, test with PLACET

- **optimized synchrotron radiation spectrum generator**
  with interface to Geant4, Mad-X

We are in an early phase of the project, open for comments and suggestions.