Halo and Tail Generation HTGEN

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Main deliverable :

The generic Halo and Tail GENeration package was written and made generally available as htgen software package on the web http://cern.ch/hbu/HTGEN.html

HTGEN code repository, with interfaces to tracking codes, installation instructions, examples, and short description
it provides simulation and estimates of main halo production processes ; examples applied to ILC & CLIC

Other deliverables :
analytic estimates and strategies for tests and benchmarking

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Motivation

- **Halo particles contribute very little to the luminosity but may instead be a major source of background and radiation.**
- **Even if most of the halo will be stopped by collimators, the secondary muon background may still be significant.**
- **Studied by analytic estimates and detailed simulations, to accompany the design studies for future linear colliders such that any performance**

Halo sources

- **Particle processes**

  Beam Gas elastic scattering, multiple scattering ✔

  Beam Gas inelastic scattering, Bremsstrahlung ✔

  Scattering off thermal photons - small. analytic estimates + separate MC

  Intrabeam scattering important at low energies and in particular in the damping ring. currently outside the scope of this study

  Synchrotron mismatch upgraded and implemented in GEANT4 ✔ H.B. CLIC-Note-709 EUROTeV-Report-2007-018, 8 June 2007

- **Optics related**

  mismatch

  coupling

  dispersion

  non-linearities

✔ **with tracking**

- **Various**

  noise and vibrations

  dark currents

  wakefields

  spoiler scattering

Main particle processes with analytical estimates example : ILC

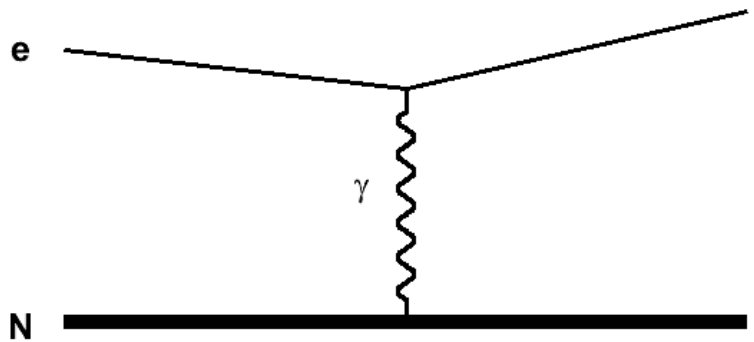
ILC parameters based latest (March 2007) BCD

Beam Gas estimates for

LINAC section 10 nTorr He at 2K

BDS section 50 nTorr N_2 at room temperature (300 K)

Beam gas elastic scattering



angular distribution divergent for $\vartheta \rightarrow 0$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left[\frac{Zr_e}{2\gamma\beta^2}\right]^2 \frac{1-\beta^2\sin^2\frac{\vartheta}{2}}{\sin^4\frac{\vartheta}{2}} \approx 16/\theta^4$$

only relevant for halo if larger than beam-divergence

$$\theta_{\min} = \sqrt{\epsilon/\beta_y} = \sqrt{\epsilon_N/\gamma\beta_y}$$

Beam gas elastic scattering

total cross section

$$\sigma_{\rm el} = \frac{4\pi\, Z^2\, r_e^2}{\gamma^2\, \theta^2_{\rm min}}$$

at constant normalized emittance

$$\epsilon_N = \gamma\, \epsilon$$

scaling as 1/γ or 1/energy
beginning of LINAC important

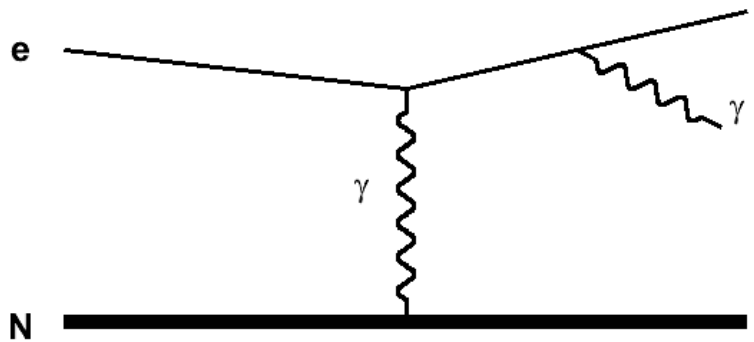
$$\sigma_{\rm el} = \frac{4\pi\, Z^2 r_e^2\, \beta_y}{\epsilon_N\, \gamma}$$

ILC estimate. P = probability / m for scattering > 1 σ divergence

Location	E GeV	Gas	ρ m^{-3}	$\sigma_{\rm el}$ Barn	P m^{-1}
LINAC	5	He	4.8×10^{16}	2.0×10^{6}	9.9×10^{-6}
LINAC	250	He	4.8×10^{16}	3.8×10^{4}	1.8×10^{-7}
BDS	250	N_2	1.6×10^{15}	4.6×10^{5}	1.5×10^{-7}

Probability 50x higher beginning of LINAC at 5 GeV compared to end at 250 GeV
Probability end of LINAC and BDS similar
Integrated over LINAC + BDS : Prob. = 9×10^{-3} to scatter > beam divergence
Probability for > 30σ (loss) ; integrated over LINAC = 10^{-5} over BDS = 5×10^{-7}

Inelastic scattering



scattering angle (of γ with respect to incident e)

$$f(\theta)d\theta \propto \frac{\theta\, d\theta}{(\theta^2+\gamma^{-2})^2}\,.$$

energy fraction k going to photon

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

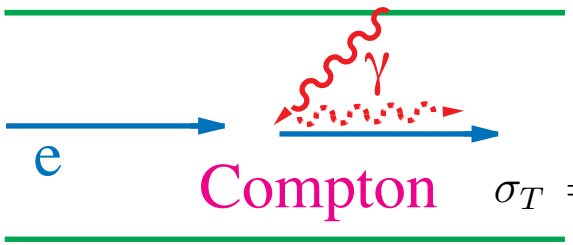
integrated for k > 1%, no E dependence
σ = 0.375 Barn for He, σ = 6.510 Barn for N_2

$$\sigma_{\rm in} = \frac{A}{N_A X_0}\left(-\frac{4}{3}\log k_{\rm min} - \frac{5}{6} + \frac{4}{3}k_{\rm min} - \frac{k_{\rm min}^2}{2}\right)$$

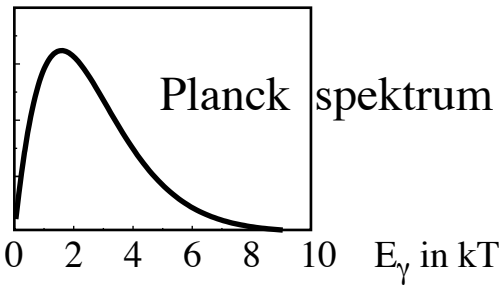
Probability: 1.8×10^{-12}/m in LINAC, 1.8×10^{-12}/m in BDS ; quite similar and small summing up over both LINAC and BDS : $P = 2.3\times10^{-8}$/m

fully included in current HTGEN, minor contribution for ILC

Scattering off thermal photons



$\sigma_T = \frac{8\pi}{3} r_e^2 = 0.6652$ barn



mean energies:

initial : $E_\gamma^i =$ 2.7 kT = 0.07 eV

e-rest: $E_\gamma = \gamma E_\gamma^i = 6.2$ keV << m_e

$$\rho_\gamma = 8\pi \left(\frac{kT}{hc}\right)^3 \cdot \underbrace{\int_0^\infty \frac{x^2}{e^x - 1} dx}_{2.404114}$$

$5.32\times10^{14}/m^3$ at room temp.

Lab: $E_\gamma' = \gamma E_\gamma^* \cong \gamma^2 E_\gamma^i$ 2.4% at 100 GeV, 5.3% at 250 GeV

P = 2.3×10^{-14}/m at 300K, 9×10^{-11} for full BDS

Was important for beam halo in LEP and the dominant single beam lifetime. Practically negligible for the ILC.

Detailed tracking

- **HTGEN runs standalone or interfaced to detailed tracking programs**
- **interfaces to PLACET and MERLIN are available from our website**

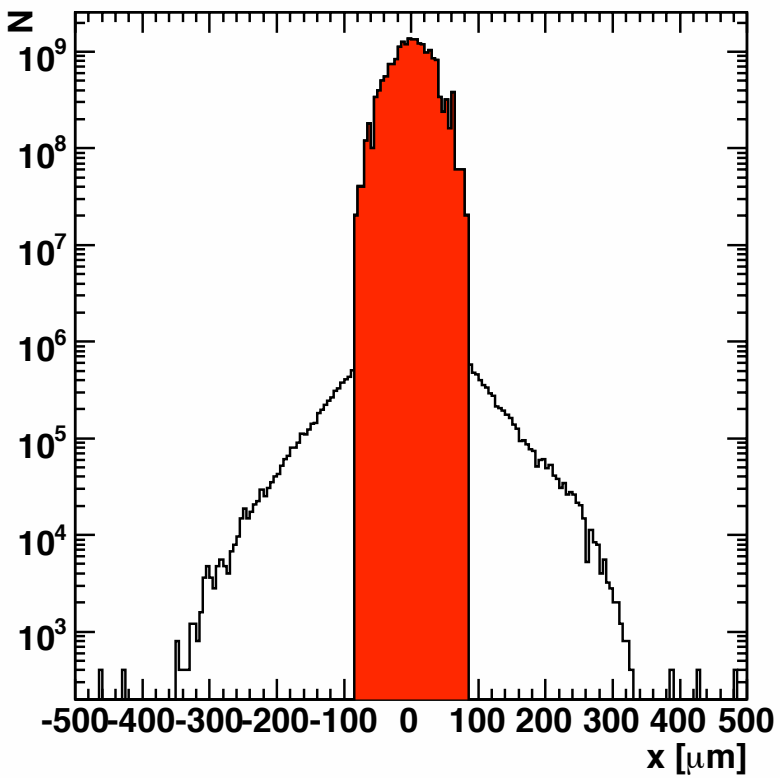
allows to study

- **tails enhancement / production / folding related to optics**

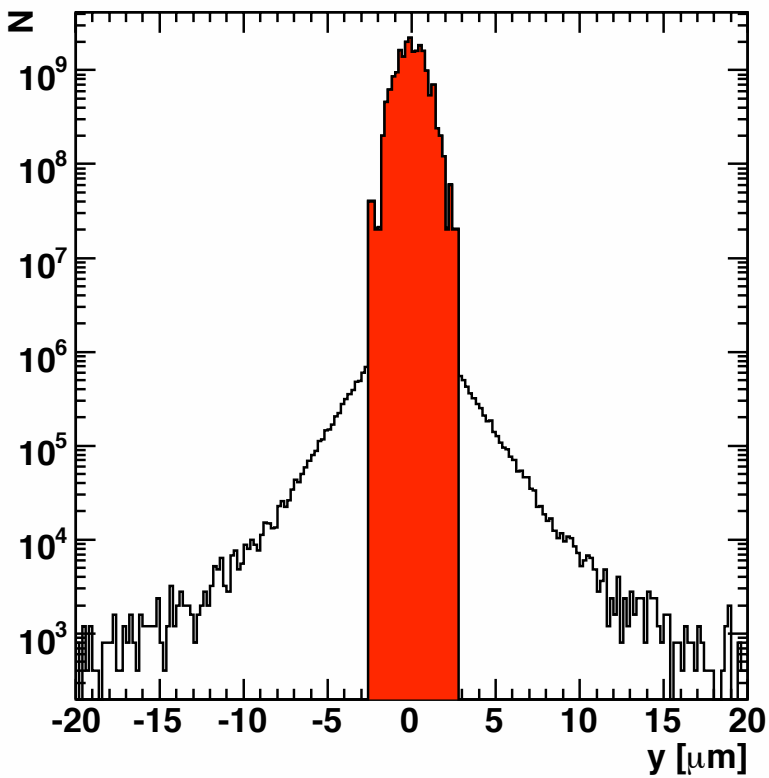
  mismatch, coupling, dispersion, non-linearities
- **synchrotron radiation, included in tracking programs**
- **detailed loss maps and distributions**
- **follow up of secondary particles**

Detailed tracking example, ILC Linac

horizontal



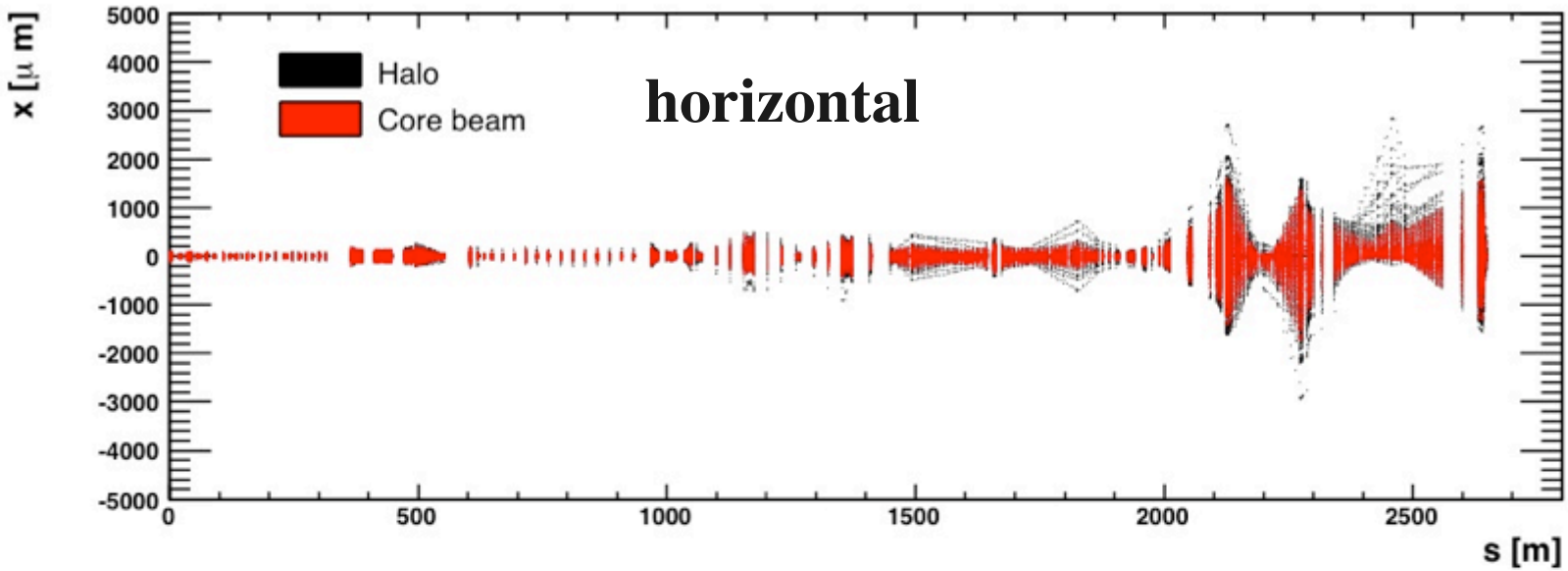
vertical

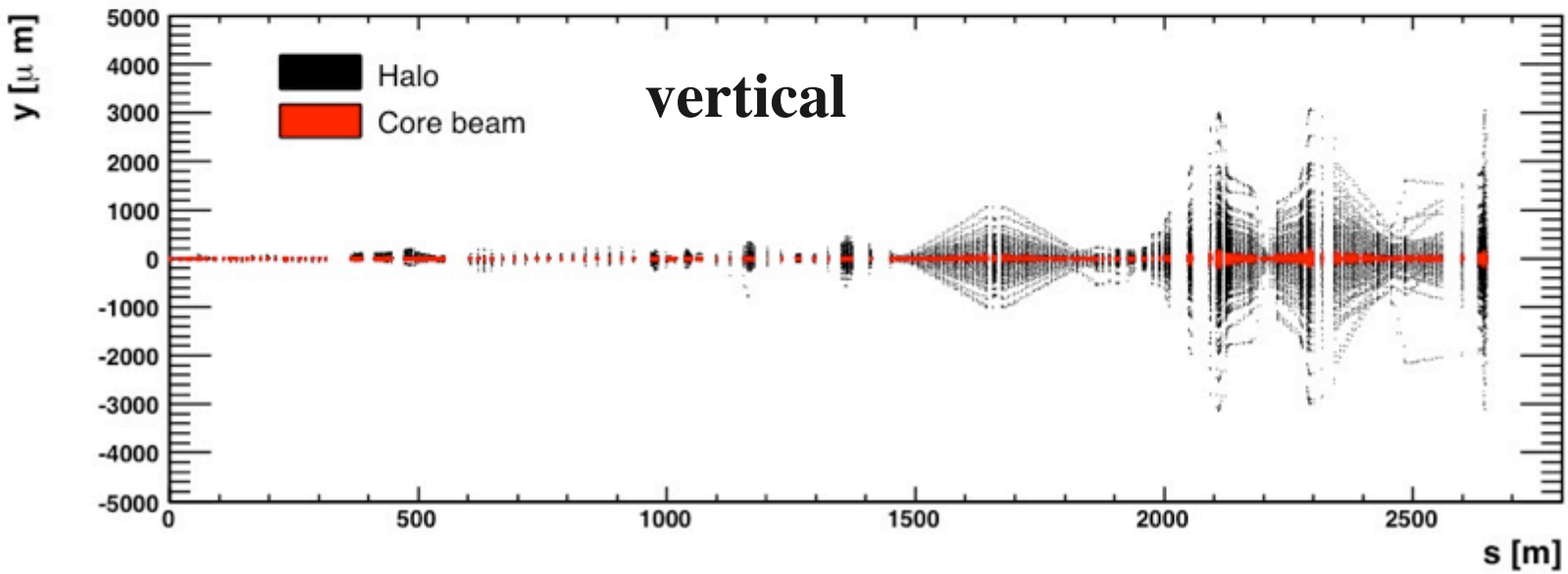


Transverse beam profiles at the BDS entrance

3×10^{-5} above 10σ

Detailed tracking example, ILC BDS





LINAC + BDS : fraction of 10^{-4} of beam particles hit spoilers in ideal machine - no misalignment / errors

ILC Particle flux estimate on spoilers and secondary

2×10^{10} e/bunch
2820 bunches

5.64×10^{13} e/train

$\times\ 10^{-4}$ fraction hitting spoilers, HTGEN + tracking, LINAC + BDS

5.6×10^{9} e/train on spoilers

$\sim\ 2\times10^{-5}$ fraction resulting in secondary muons

$\sim\ 10^{5}$ muons / train end of BDS

to be verified by detailed tracking of lattice + collimation (with errors) and combined simulation, HTGEN + BDSIM

Reports and Presentations

reference to all material, software package for download, installation instructions, answers to frequently asked questions:
HTGEN page http://hbu.home.cern.ch/hbu/HTGEN.html

Reports

Monte Carlo generation of the energy spectrum of synchrotron radiation, by. H. Burkhardt, 8 June 2007, CERN-OPEN-2007-018; CLIC-Note-709; EUROTEV-Report-2007-018

Halo Estimates and Simulations for Linear Colliders, PAC'07 Proc. WEOCC03 ; CLIC-Note-714, CERN-AB-2007-045, EUROTeV-Report-2007-064

Presentations

LC workshop Daresbury : 8-11 Jan 2007, Halo and Tail Generation Studies, by L Neukermans

PAC June 2007 : Halo Estimates and Simulations for Linear Colliders, by H.Burkhardt

CLIC'07 workshop : Halo and Tail Generation, by H.Burkhardt on 17 Oct. 2007

HTGEN, recent and current activities

- improve HTGEN interface, eliminate external libary (CLHEP dependence) ✔
- HTGEN+PLACET application to low energy CLIC drive beam, started ✔
  potential for benchmarking - CTF3
- collaboration with Forschungszentrum Karlsruhe - student starting 9/2008 using HTGEN + analytic estimates
- Summarize combined results in a Comprehensive Report
- Provide an online manual for the HTGEN software package (with help of I.Ahmed)

HTGEN - good basis exists, was and is used

Still a lot of potential for further work with application to detailed designs and benchmarking

Summary

- **we provide a generic package HTGEN with interfaces for PLACET** and MERLIN, **ready to be used**
- **sample jobs and estimates are provided both for CLIC and the ILC and documented** (EUROTeV-Report-2006-028, EUROTeV-Report-2007-064)
- **used as basis for the CLIC vacuum specification** (CLIC Technical Committee - Meeting on 17/06/2008)
- **the most important particle scattering process in the LINAC+BDS is the elastic beam gas scattering; good vacuum important, particularly at beginning of the LINAC ; from tracking with errors : fraction of about 10^{-4} of beam particles hit spoilers for ILC**

Reserve

HTGEN, BDSIM and GEANT4

HTGEN and BDSIM / GEANT4 are at present mostly complementory

BDSIM/GEANT4 allow for simulations of many processes ; they are well adapted to simulate cascades and multiple scattering in dense materials

HTGEN is well adapted to simulate relatively rare single scattering processes

combine HTGEN and BDSIM ?