Halo in CLIC

by Helmut Burkhardt

General definition and concepts

Core : particles < n_σ

Halo = Tail : particles > n_σ

in x,y, z transverse and longitudinal

Luminosity is from the core

for Gaussian beams, 99.2 % of the luminosity from n_σ < 3

see H.B., R.S. Intensity and Luminosity after Beam Scraping, CERN–AB–2004–054

Halo unwanted, to be removed by the collimation system

Halo estimates :

Done for normal conditions. Not dealing with failure scenarios

Halo sources

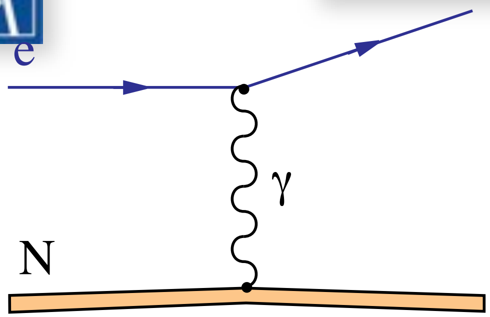
Known sources, 3 categories

- Particle processes : beam gas, (quasi) elastic and inelastic (Bremsstrahlung), thermal photon
- Optics related : mismatch, coupling, dispersion, non-linearities -- requires tracking for the "real" machine, tracking so far was with ideal machine
- Various : noise and vibrations, dark currents, wakefields -- currently not simulated for halo

Caution, by experience :
the actual amount of beam halo is very hard to predict and may vary considerably in a given machine.

HTGEN : halo/tail generation, developed as EuroTeV FP6 activity ; fully integrated in PLACET applied to LINAC, BDS and drive beam; info and references on web page HTGEN.html

Beam gas elastic* scattering



Coulomb (Mott)

* small recoil correction - quasi elastic

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

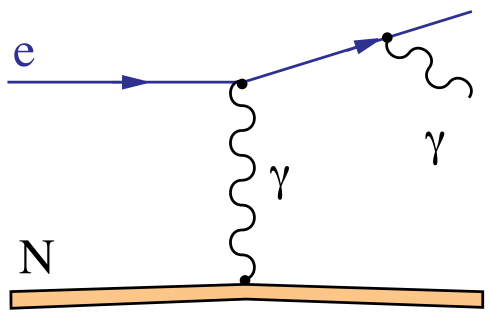
$$\sigma_{\rm el} = \frac{4\pi\, Z^2 r_e^2\, \beta_y}{\epsilon_N\, \gamma}$$

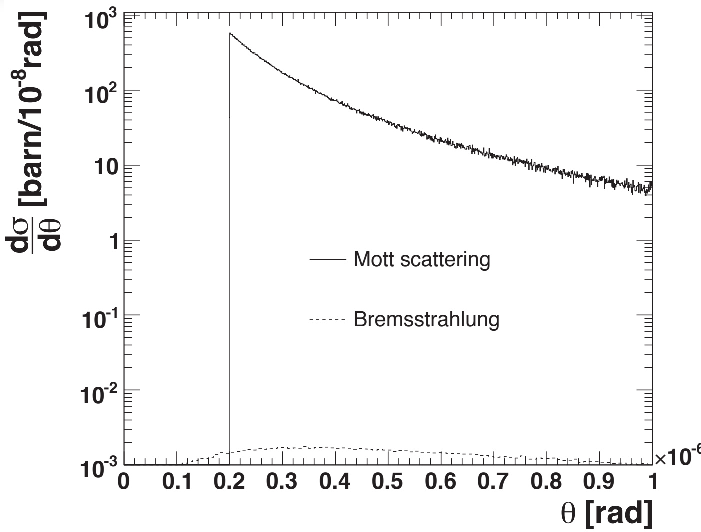
CLIC 2007 estimate. P = probability / m for scattering > 1 σ divergence

Location	E GeV	Gas	ρ m^{-3}	$\sigma_{\rm el}$ Barn	P m^{-1}
LINAC	9	CO	3.2×10^{14}	2.7×10^{7}	8.9×10^{-7}
BDS	1500	CO	3.2×10^{14}	1.7×10^{5}	1.1×10^{-8}

Probability 80x higher beginning of LINAC at 9 GeV compared to end at 1.5 TeV and BDS. Integrated over length using averaged β :
total LINAC Prob. $P = 1.16\times10^{-3}$, BDS $P = 6.0\times10^{-5}$ together 1.2×10^{-3} at 1σ
total LINAC Prob. $P = 1.29\times10^{-6}$, BDS $P = 6.7\times10^{-8}$ together 1.4×10^{-6} at 30 σ (loss)
placet-htgen simulation LINAC+CLIC fraction of 2×10^{-4} lost at spoilers (2007 estimate, 10nTorr)

Inelastic scattering





generated with htgen example TestProcess

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

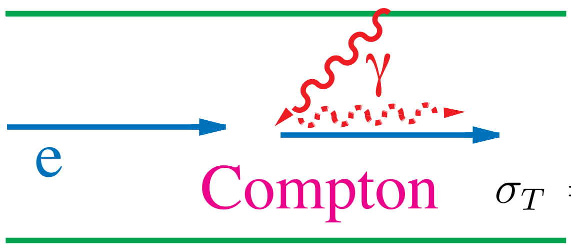
integrated for k > 1% , no E dependence
σ = 6.609 Barn for N_2

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

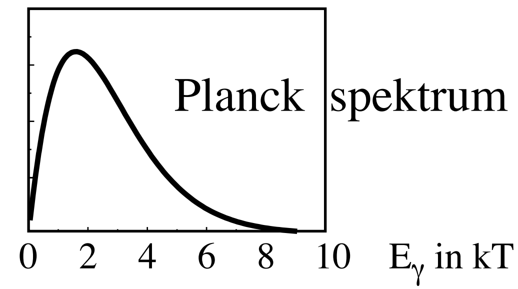
Probability: 2.1×10^{-13}/m
summing up over both LINAC and BDS : P = 5.0×10^{-9}

fully included in current HTGEN, minor contribution for CLIC

Scattering off thermal photons



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



mean energies:

initial : E_γ^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.

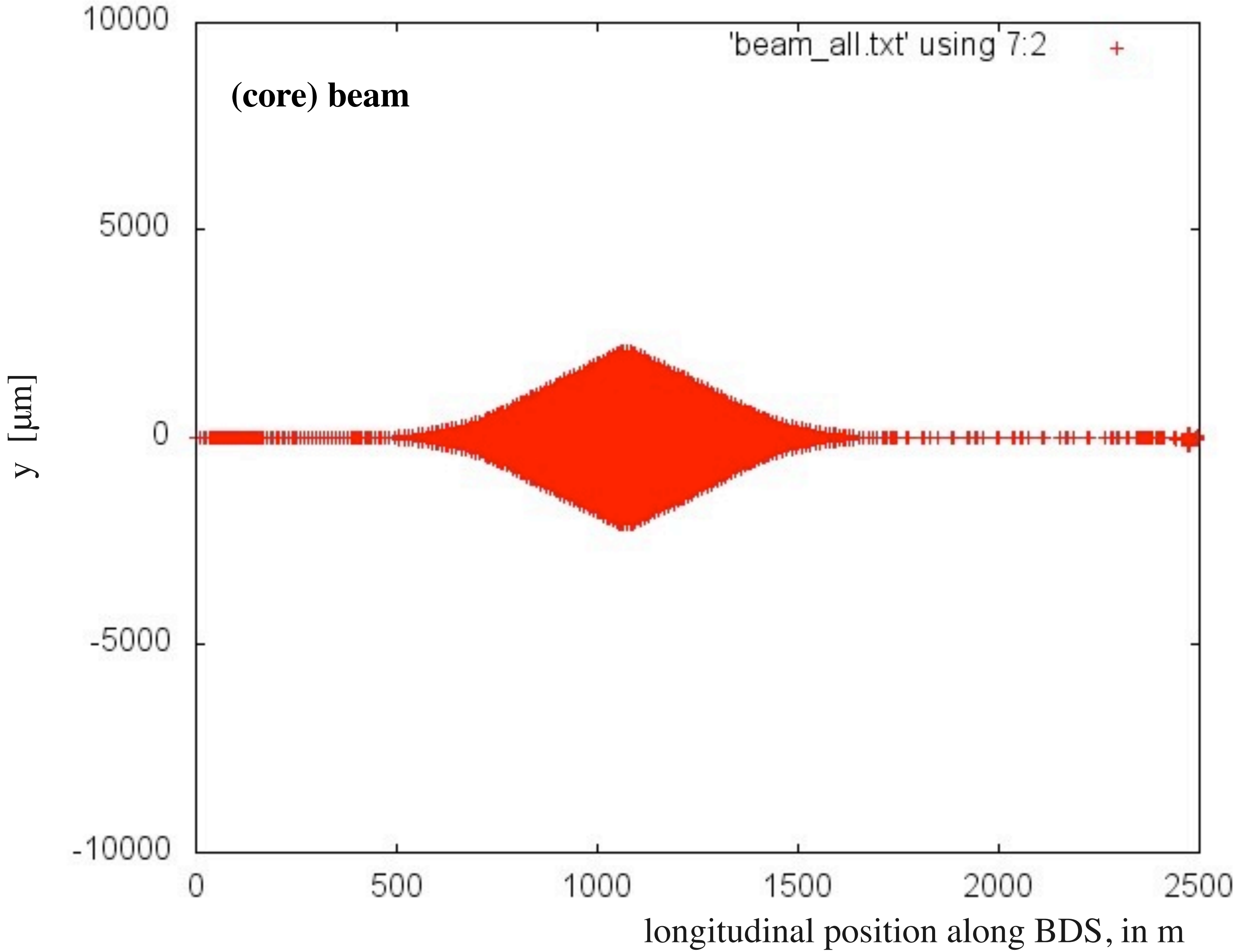
Lab: $E_\gamma' = \gamma E_\gamma^* \cong \gamma^2 E_\gamma^i$ 2.4% at 100 GeV, 5.3% at 250 GeV, 86% at 1.5 TeV

Was important for beam halo in LEP and the dominant single beam lifetime

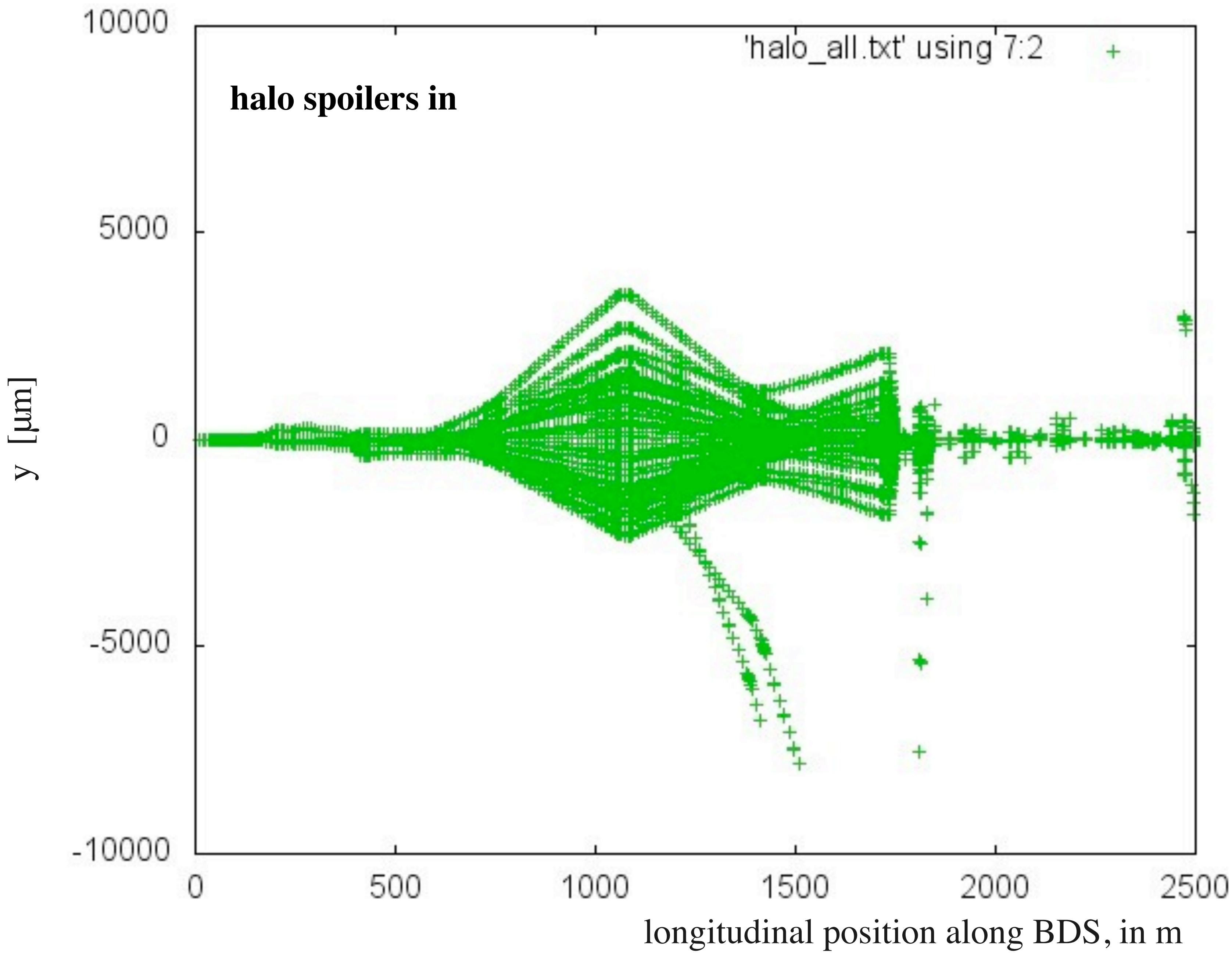
CLIC 1.5 TeV P = 1.9×10^{-14}/m for 2% energy loss.
integrated over LINAC + BDS still below 10^{-9}
not an issue

MC generator, see [SL/Note 93-73 (OP)]

PLACET-HTGEN tracking



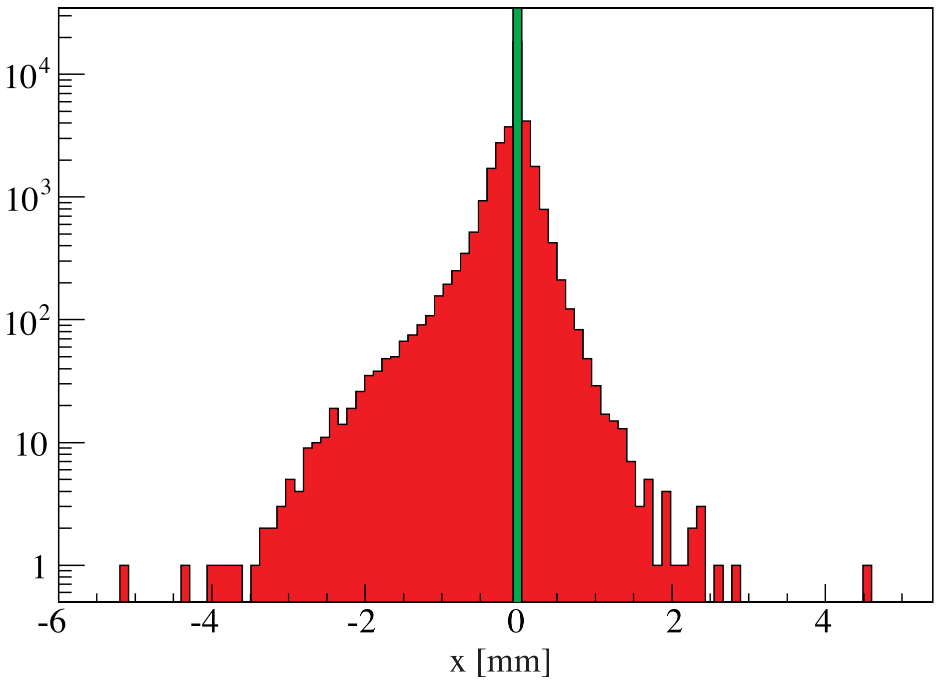
PLACET-HTGEN tracking

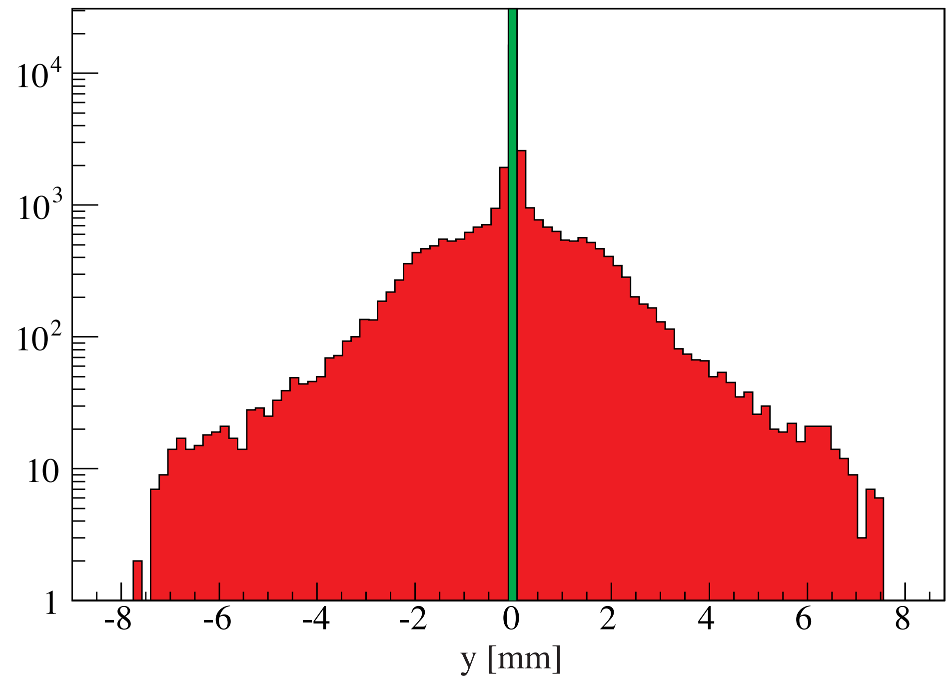


using apertures from v_09_04_01/bds.name.aperture.FixedSR.collaper

Projection at the 1st spoiler

HTGEN + PLACET, at XSP1, YSP1





Halo estimate, main beam, CLIC 1.5 TeV

2007 estimate, 10 nTorr

total LINAC Prob. $P = 1.16\times10^{-3}$, BDS $P = 6.0\times10^{-5}$ together **1.2×10^{-3} at 1σ**

HTGEN simulation : losses **~ 2×10^{-4}** , mostly hitting the first spoiler

2011

several very significant changes compared to 2007

- significantly modified BDS optics / layout
- very good vacuum specified for the CDR (required for fast ion instability)

unbaked vacuum ~1nTorr, 40% H_2, 40% H_2O, 10% CO, 10% CO_2

PLACET+HTGEN updated and kept working, used as input to BDSIM for muon background estimates ;

Caution : no recent complete tracking campaign

Estimates relying on extrapolations and analytical estimates

requirement from muon background **halo losses on the level of 10^{-6}**

purely analytic, spoiler at 55 σ_y **halo losses on the level of 10^{-7}**

with a significant contribution from the very high beta collimation region in the BDS

Halo estimate, CLIC drive beam

HTGEN extension to the drive beam

non-trivial ; only meaningful for full intensity

- **drive beam using macroparticles / slices**
- **halo simulation, scattering processes done on single particle level**

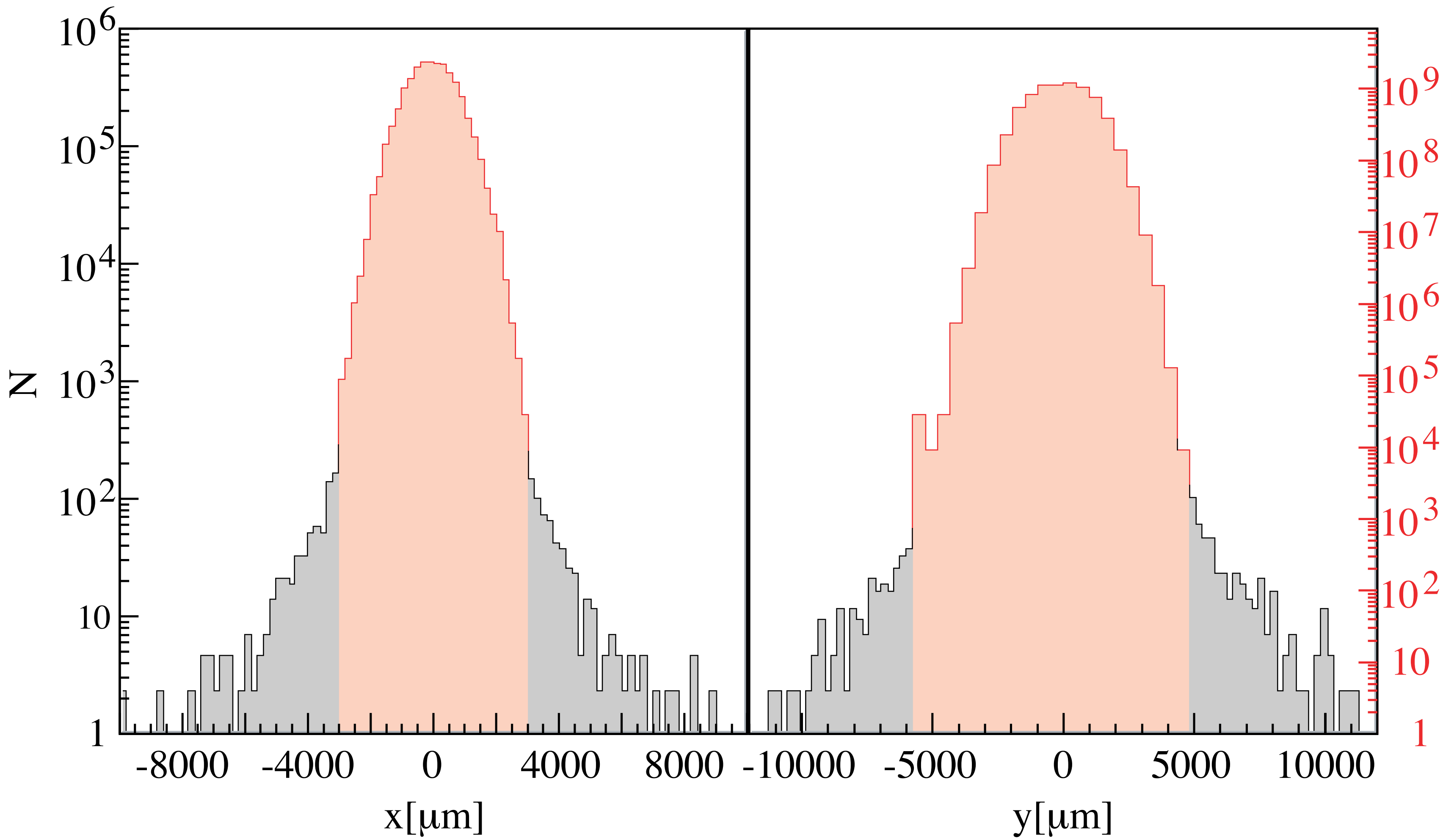
possible by considering only collective effects from the core, acting on both core and tail

neglecting collective effects of the halo

Subject of a diploma thesis by M. Fitterer

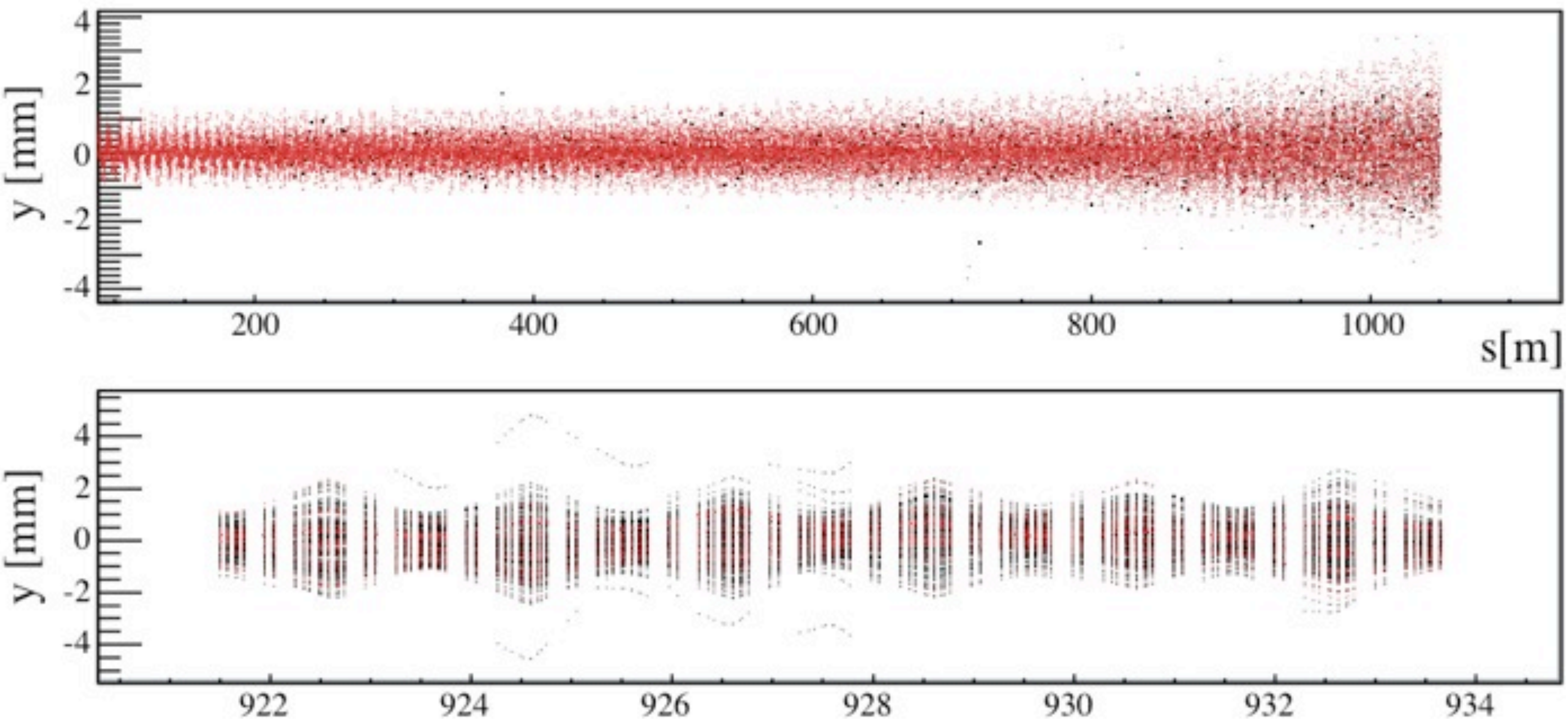
Short summary published as PAC 2009 paper WE6PFP085

Tracking results, CLIC drive beam



Transverse Beam profiles at the exit of the CLIC decelerator
PLACET + HTGEN simulation

Tracking with halo, CLIC drive beam



Vertical beam position along a complete CLIC decelerator
+ zoom towards end
Halo particles are shown in **black**, **beam (core) particles in red**

Main conclusion : fraction of halo particles lost at (the very large) aperture is small, of order 10^{-7} ; residual gas pressure 10 nTorr

Summary

CLIC as currently specified :

Very good vacuum ; assuming an ideal machine, no failures

Expected halo losses from the known, unavoidable sources

(mostly quasi-elastic beam-gas scattering)

are low, typically on the $\sim 10^{-6}$ level

mostly localized to the collimation section

Reserve

Tail Population

Daniel Schulte, review of the CLIC detector / physics CDR, 18 October 2011, on indico

$$p \approx \sum \rho_i Z_i^2 \frac{4\pi r_e^2 mc^2}{n^2\epsilon} \int_0^L \frac{\beta}{E} ds$$

Unbaked vacuum (1nTorr)

40% H_2, 40% H_2O, 10% CO, 10%CO_2

average Z^2=53.6

density=3.2 10^{22}molecules/Torr

Hence:

$$p \approx 8.64 \times 10^{-17}\,\mathrm{m}^{-1} \frac{1}{n^2\epsilon} \int_0^L \frac{\beta}{E} ds$$

Tightest constraint is 55 σ_y:

Main linac $\int_0^L \frac{\beta}{E} ds \approx 1000\,\frac{\mathrm{m}^2}{\mathrm{GeV}}$ p=1.43 10^{-9}

BDS horizontal $\int_0^L \frac{\beta_x}{E} ds \approx 832\,\frac{\mathrm{m}^2}{\mathrm{GeV}}$ p=1.19 10^{-9}

BDS vertical $\int_0^L \frac{\beta_y}{E} ds \approx 48667\,\frac{\mathrm{m}^2}{\mathrm{GeV}}$ p=6.95 10^{-8}

For both sides together:
~530 particle/bunch