Halo estimates and simulations for linear colliders

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Introduction

- **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.**
- **We study halo production by analytic estimates and detailed simulations, to accompany the design studies for future linear colliders such that any performance limitations due to halo and tails can be minimised**

We provide a generic halo&tail generation package with interface to tracking programs and analytic estimates

HTGEN package http://cern.ch/hbu/HTGEN.html

with installation instructions and documentation

Halo sources

- **Particle processes**

  Beam Gas elastic scattering, multiple scattering

  Beam Gas inelastic scattering, Bremsstrahlung

  Scattering off thermal photons

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

  Synchrotron radiation recently upgraded and implemented in GEANT4

  H.B. CLIC-Note-709 EUROTeV-Report-2007-018, 8 June 2007

- **Optics related**

  mismatch

  coupling

  dispersion

  non-linearities

- **Various**

  noise and vibrations

  dark currents

  wakefields

  spoiler scattering

Main particle processes with analytical estimates and simulations for the ILC

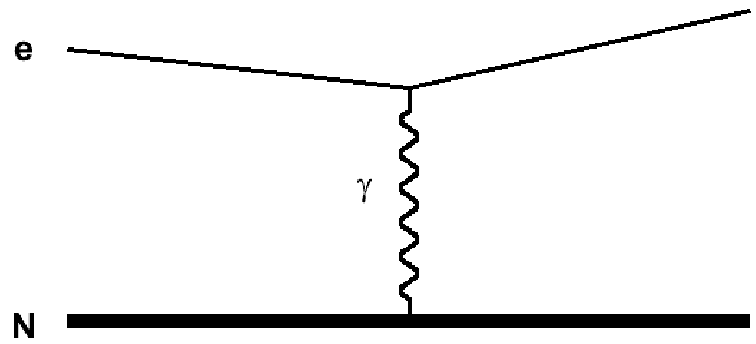
ILC parameters based latest (March 2007) BCD

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

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

Beam gas elastic scattering

total cross section

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

at constant normalized emittance

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

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

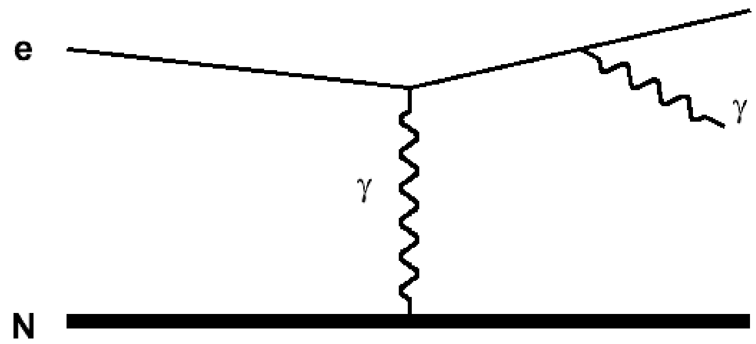
$$\sigma_{\rm el} = \frac{4\pi\, Z^2 r_e^2\, \beta_y}{\epsilon_N\, \gamma}$$

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

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

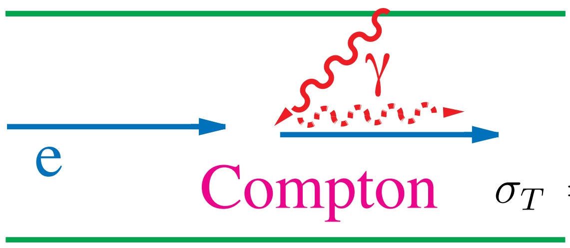
integrated for k > 1%, no E dependence
σ = 0.375 Barn for He, σ = 6.510 Barn for N_2

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

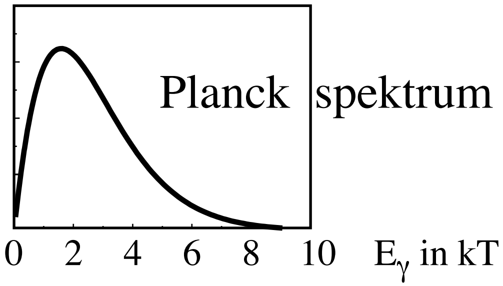
Probability: 1.8×10^{-12}/m in LINAC, 1.8×10^{-12}/m in BDS ; quite similar and small
summing up over both LINAC and BDS : $P = 2.3\times10^{-8}$/m

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

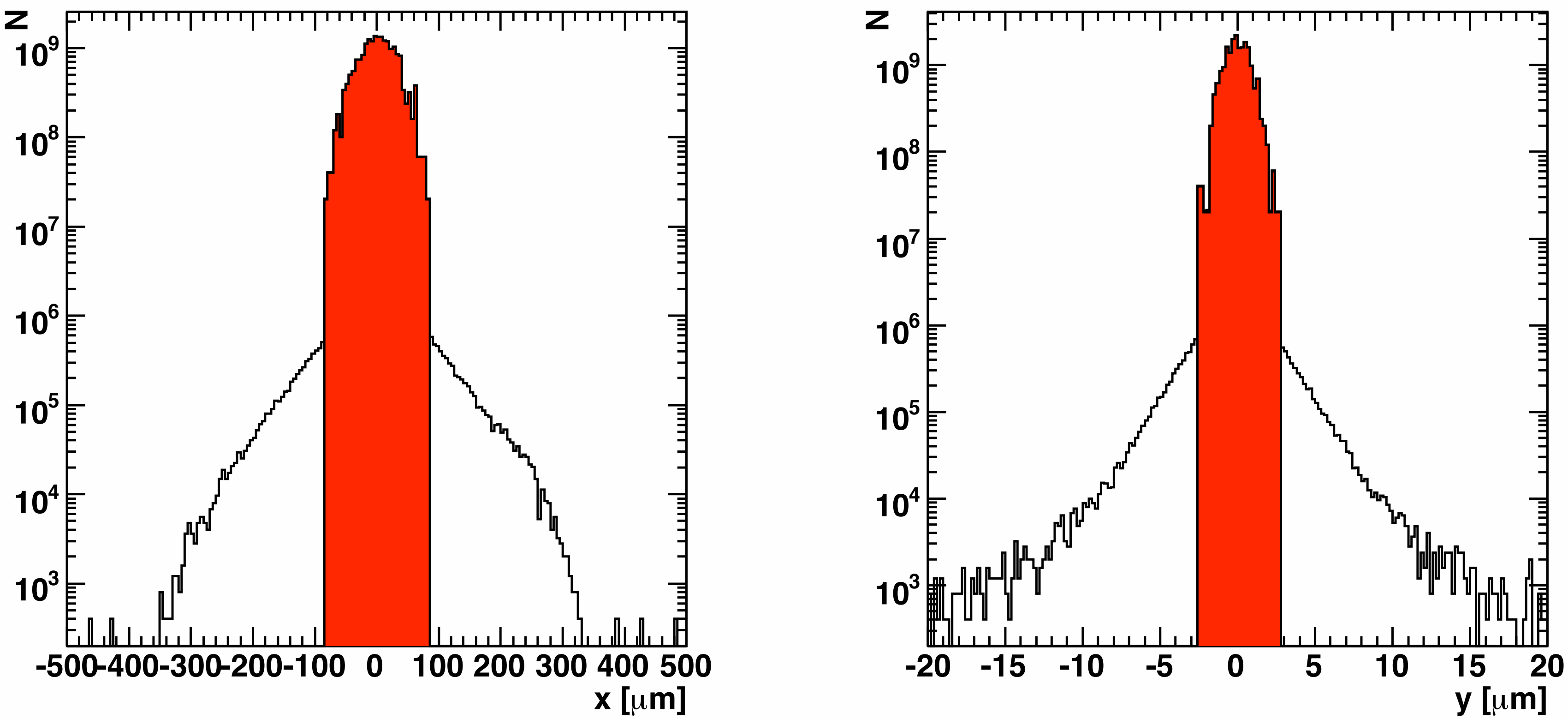
allows to study

- 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

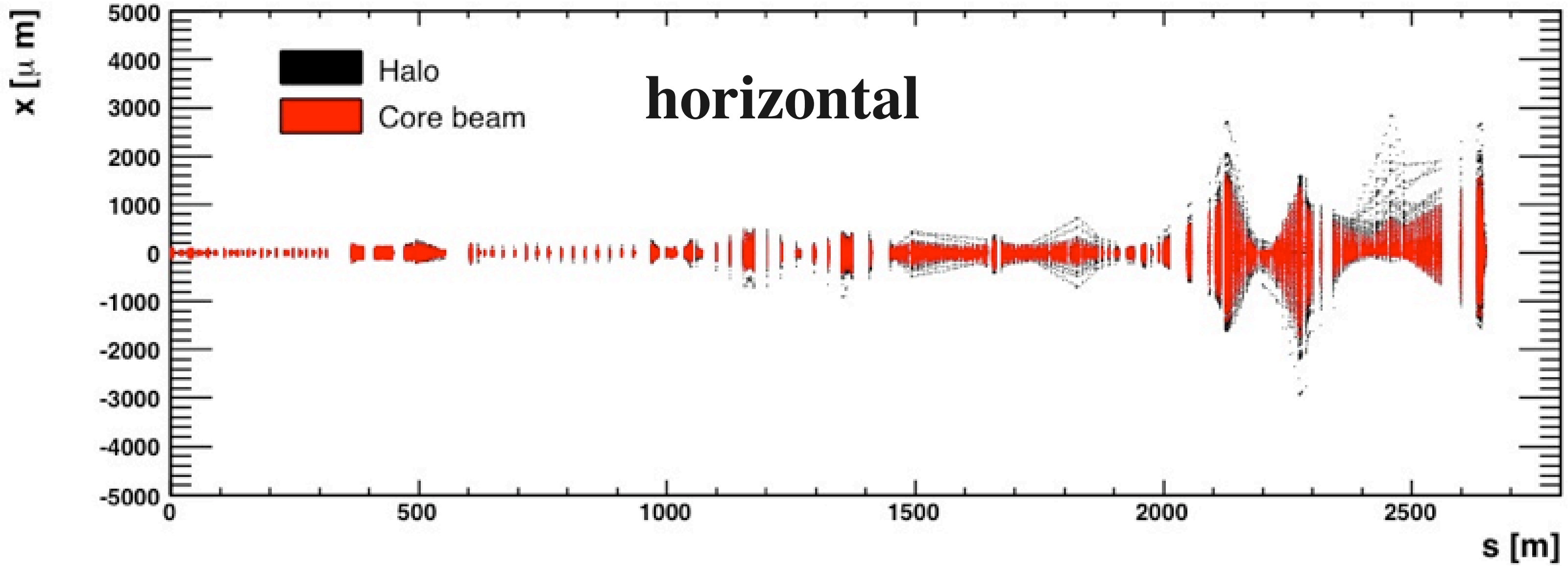
horizontal **vertical**

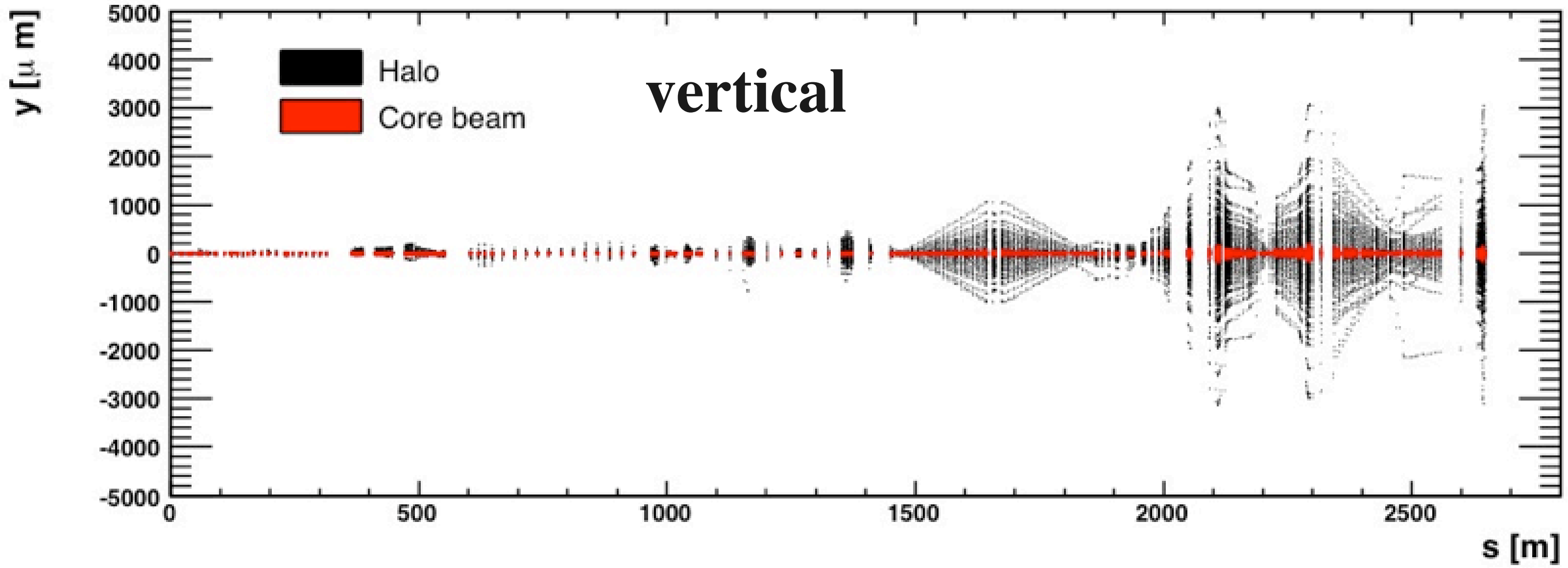


Transverse beam profiles at the BDS entrance

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

Particle flux estimate on spoilers and secondary muons

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

$\sim 2 \times 10^{-5}$ fraction resulting in secondary muons

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

to be verified by combined simulation, HTGEN + BDSIM

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

we plan to combine HTGEN and BDSIM

work started in GEANT4 to implement single scattering in addition to multiple scattering

Installation instructions (web)

- HTGen needs CLHEP
- Optionally, there are histogramming tools which need ROOT

a) if your shell is bash

- Check out HTGen code (from CERN)

export CVS_RSH=ssh
cvs -d :ext:isscvs.cern.ch:/local/reps/htgen co htgen

- OR via anonymous checkout from outside CERN

export CVS_RSH=ssh
cvs -d :pserver:anonymous@isscvs.cern.ch:/local/reps/htgen co htgen

- OR Download the tarball file from cern savannah server (outside CERN)
- Run the setup script

cd htgen;
sh setup.sh;
Answer the questions to describe your environment. Some components are optional (type return if you do not want to use them).
This script will generate two files env.sh and env.csh.
source env.sh

- compile

make libhtgen
make libhthistogrammer (if ROOT is defined)
make libhtplacet (if PLACET is defined)
make libhtmerlin (if MERLIN is defined)

b) if your shell is csh or tcsh . . . .

Summary and outlook

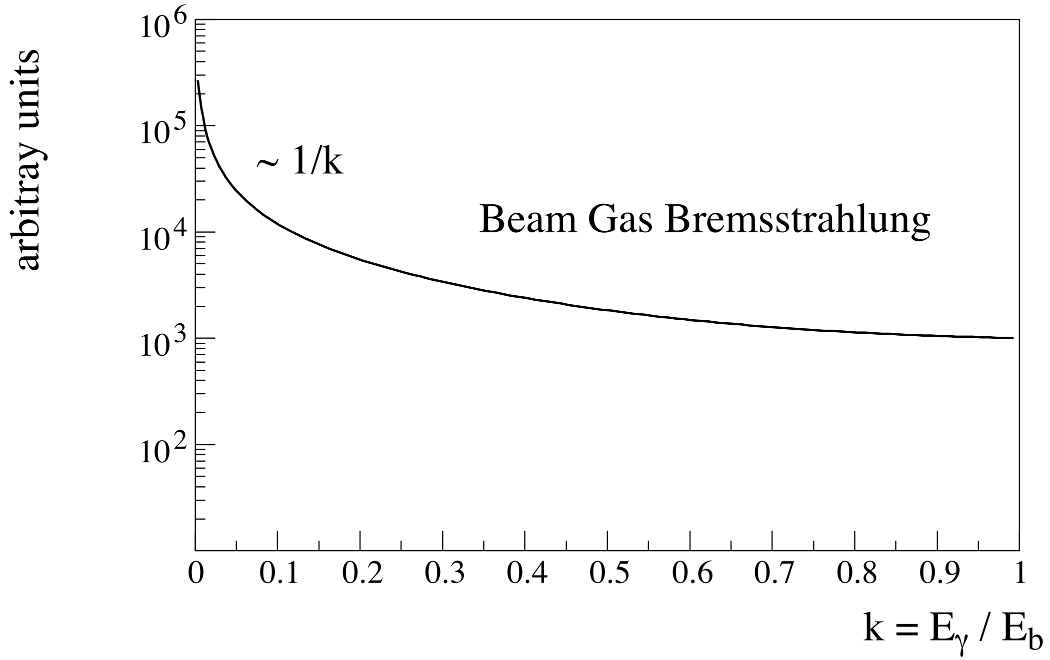
- **we provide a generic package HTGEN with interfaces for PLACET and MERLIN, ready to be used**

- **illustrated here in application to ILC** (for CLIC see EuroTeV-Report-2006-028, CLIC-Note-668)

- **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**

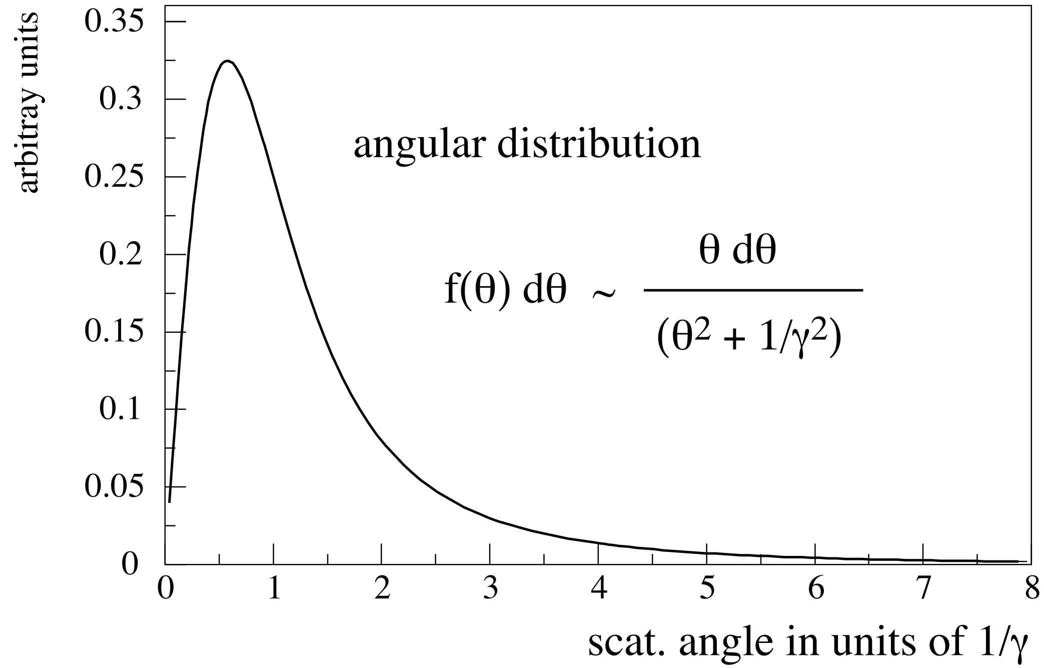
- **We plan to combine HTGEN and BDSIM and to investigate benchmarking with halo measurements in CTF3 and ATF.**

Backup Slides



inelastic beam Gas

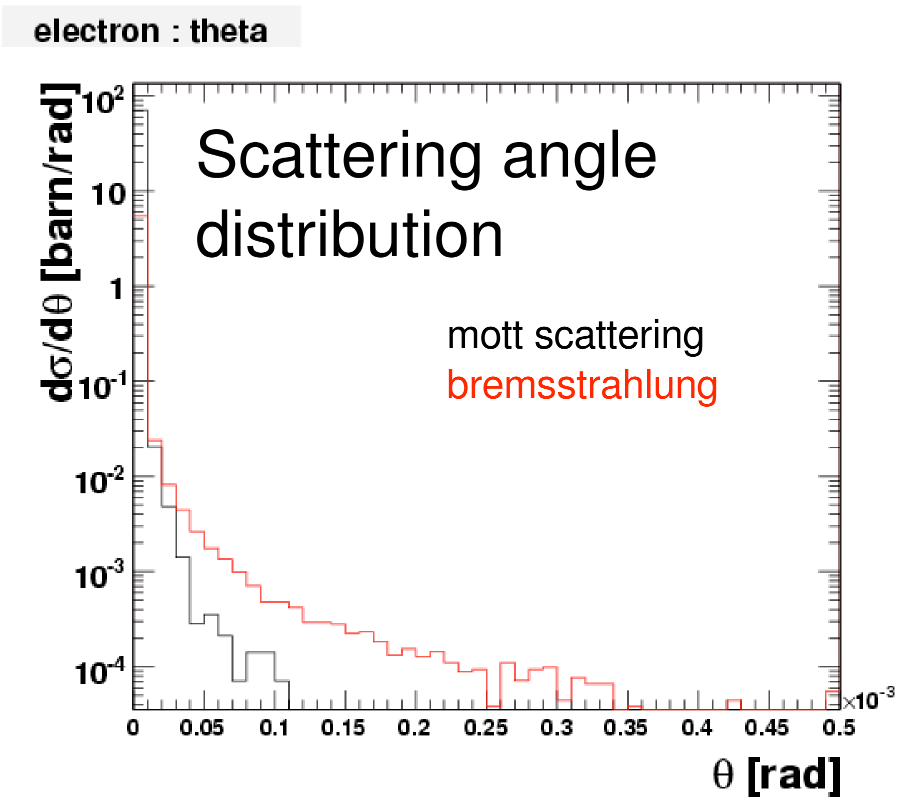
energy and angular distributions

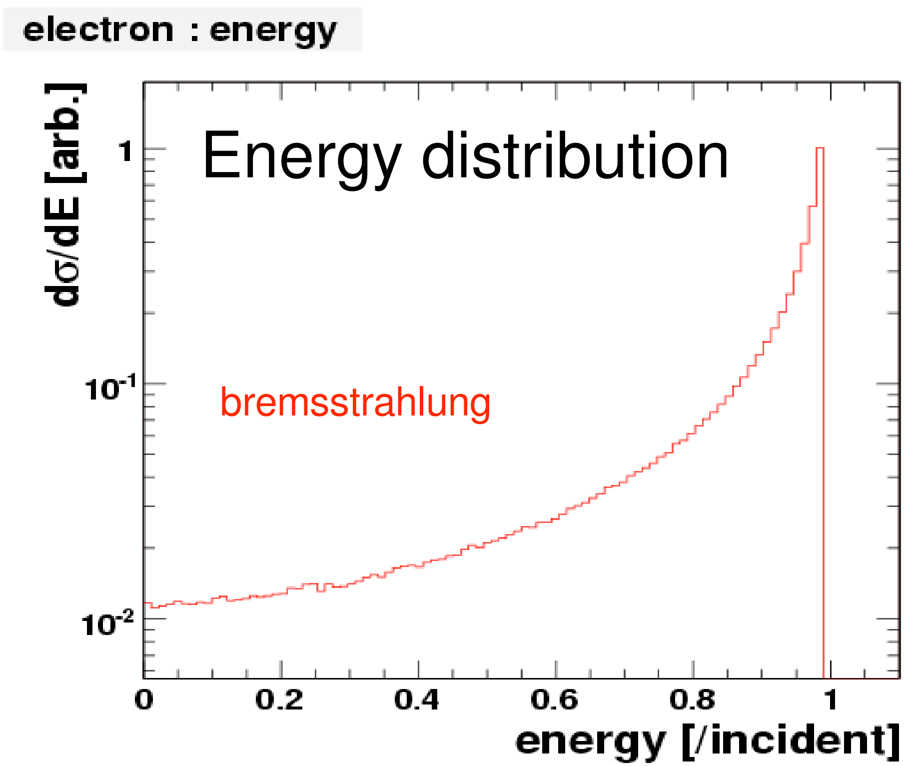


peaked at $1/\gamma$ or 2 μrad at 250 GeV, ~ negligible

Particle process : beam-gas

- Kinematics

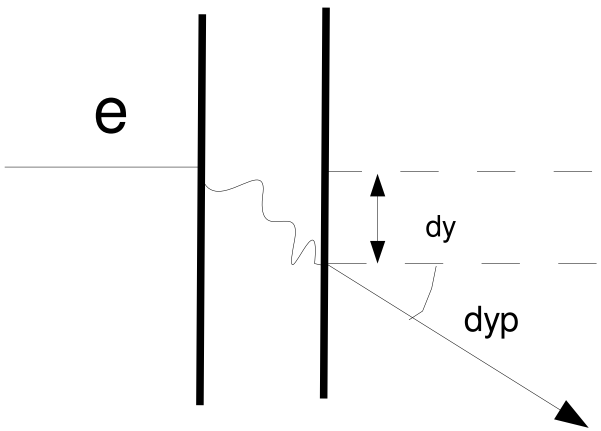


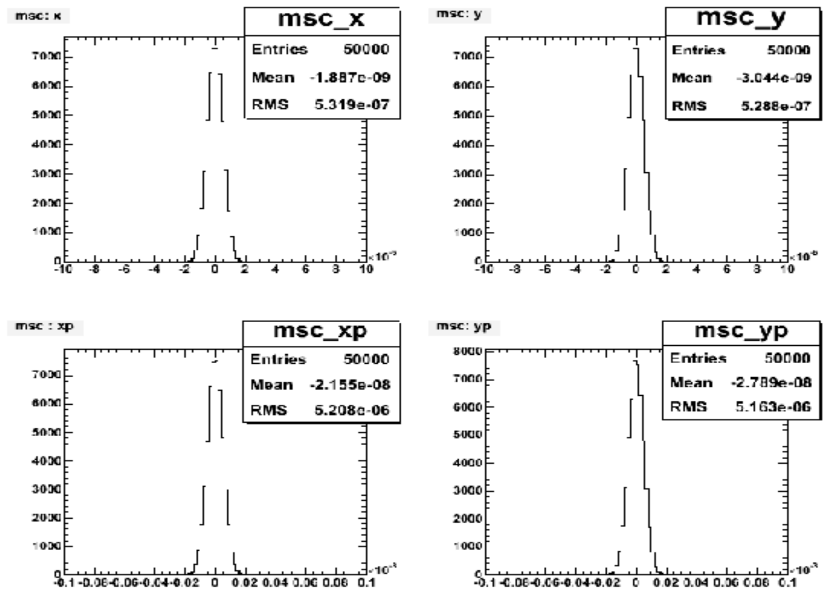


rq: 50% looses more than 10% of their energy

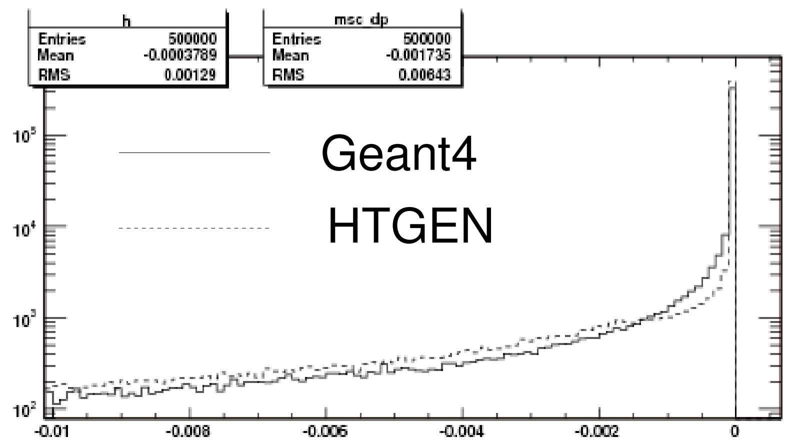
Particle process : Tools

- Multiple scattering in spoilers





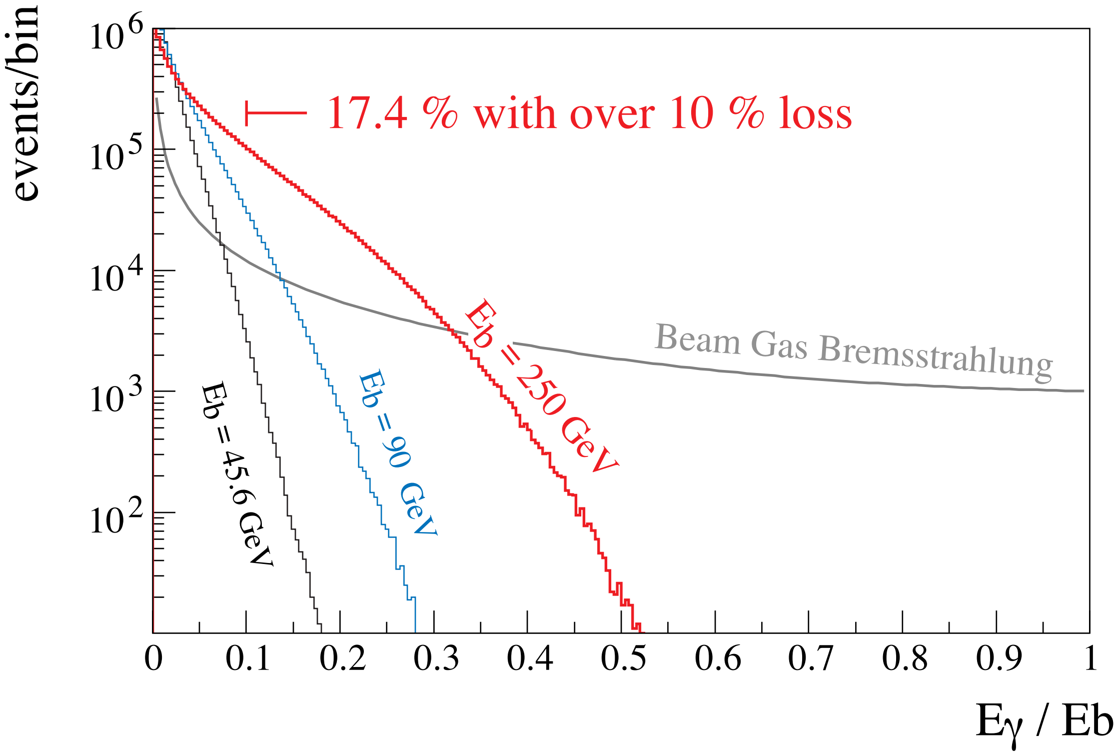
Beam axis electrons hitting a $0.5X_0$ Be material



Energy loss Comparison vs Geant4

Multiple scattering generator interfaced to PLACET

thermal photon and beam gas inelastic energy spectra



Dark currents

- Surface physics process
  - Thermal emission
  - Secondary emission
  - Field emission (Fowler-Nordheim approximation)
  - typical emission energy ~ 30 MeV
    - Low energy band of LINAC starts at 15 GeV
    - Strong focusing lattice
    - Placet simulation shows that particles are loss within 1 FODO
    - beam/dark currents interactions?
- Dark currents should not be a problem

Optical distortions

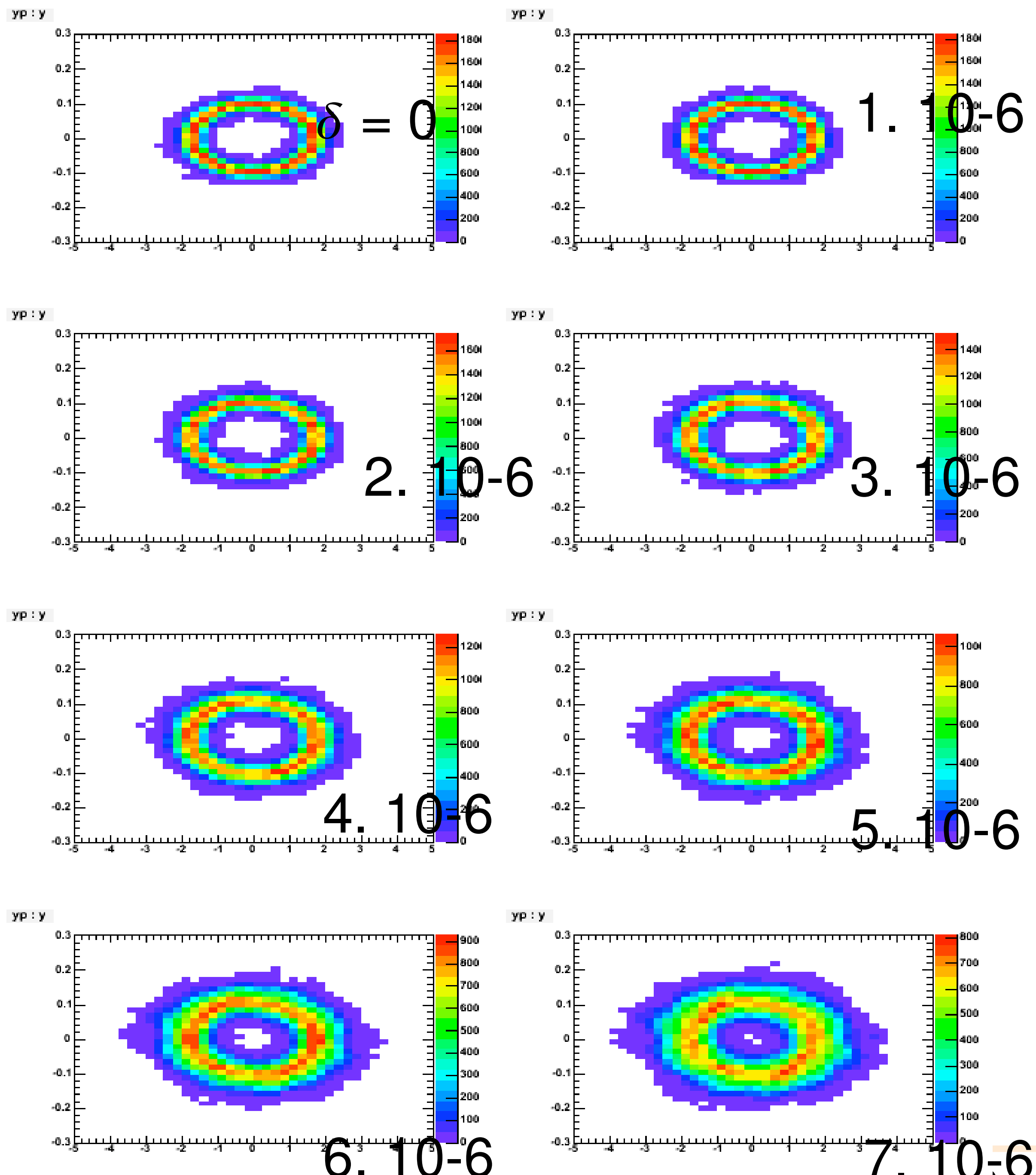
- Alignment
  - Orbital kick
  - Dispersive effect
- Nonlinear fields
  - Fringe fields, geometry, remanence, saturation
  - Nonlinear elements
  - Beam core small w.r.t magnet aperture
  - Intermediate halo from pre-linac
- Realistic machine description needed

Optical distortions: Multipole errors

- Multipole error in LINAC
  - Define errors with two thin multipole before and after each quad.
  - Multipole strength : $K_i = \delta$ x K2
  - Random value $[-K_i, +K_i]$
- Beam :
  - Nominal beam
  - Tail particles on ellipse such as Courant-Snyder amplitude A -> N x A
  - Assume : $N.\epsilon$ (-> LINAC ->) $N . \xi . \epsilon'$
- ξ : deformation factor

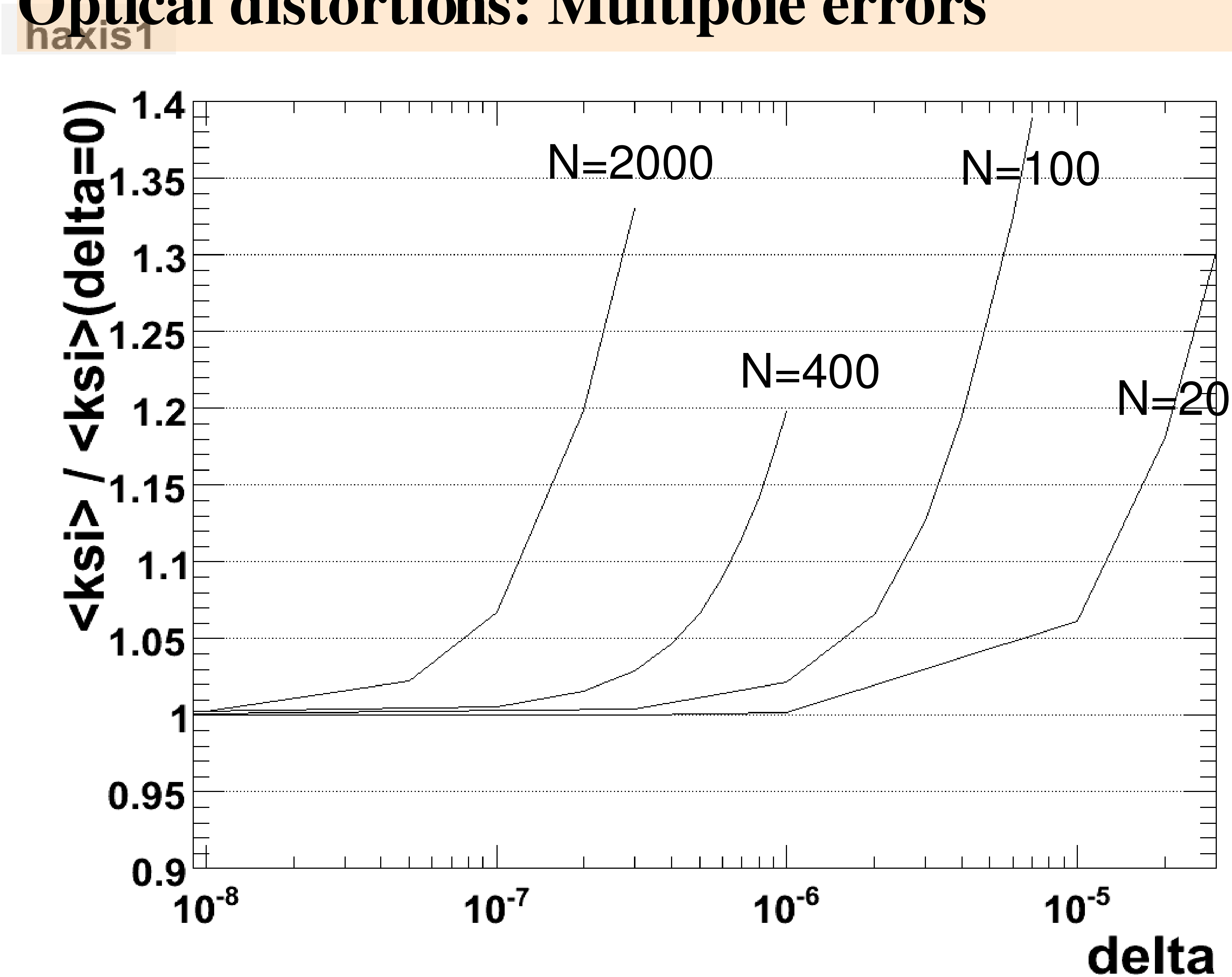
Optical distortions: Multipole errors

N = 100



Extract phase and deformation factor

Optical distortions: Multipole errors



Next: Extract semi-analytical transfert function for tails due to multipole errors