Halo and Tail studies

Helmut Burkardt, Lionel Neukermans (CERN)

- Luminosity performance
- Background in the detectors
- Identify and study critical issues:
  - Halo sources
  - Transfer lines (collimation, final focus ...)
- Provide a generic tool for beam halo studies
  - ILC / CLIC (main beam, drive beam)

Halo sources

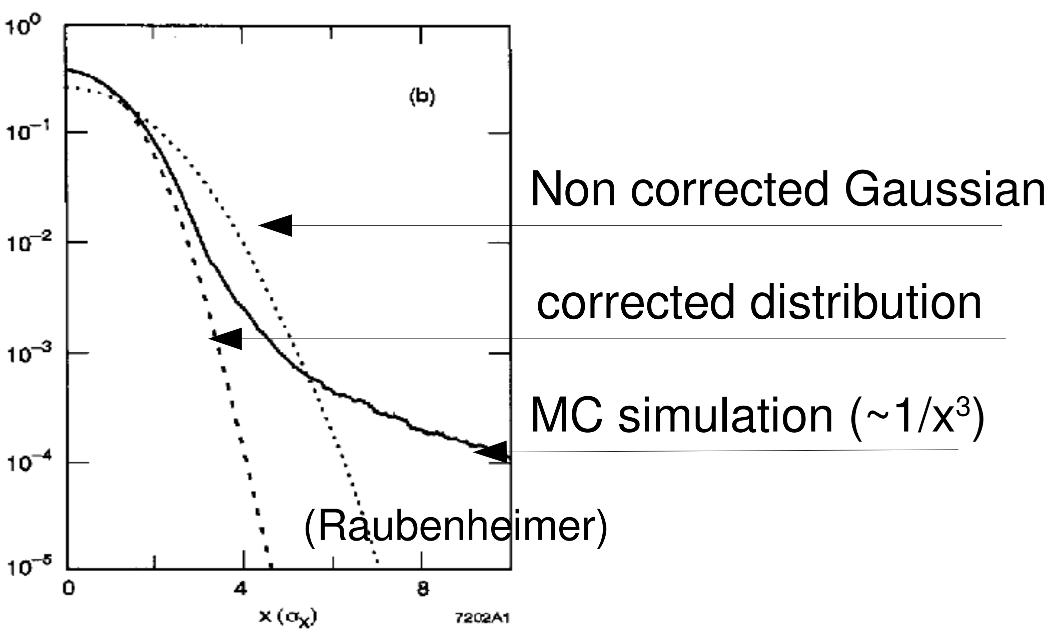
- Particle processes:
  - beam-gas scattering
  - Scattering off thermal photons
  - Intra beam scattering
  - Synchrotron radiation (coherent/incoherent)
- Optics related:
  - Mismatch
  - Coupling
  - Dispersion
  - Non-linearities
- Various:
  - Noise and vibrations
  - Dark currents
  - Wakefield
  - Spoiler scattering

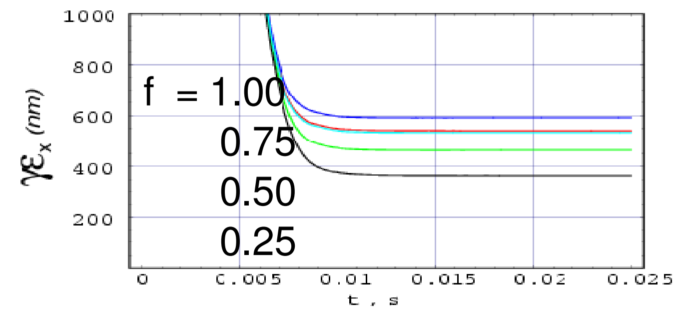
Particle processes : IBS

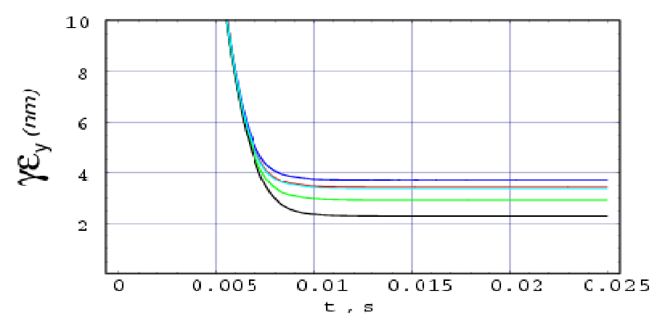
- Emittance growth from multiple scattering inside the bunch
  - Important at low energy and in Damping ring
  - At equilibrium: Transverse and longitudinal distributions with non-Gaussian tails
    - Should be included in emittance growth estimations
    - Tail population estimation (?)
  - Calculations assume a Gaussian beam
- σ_{IBS} phase space integration appears in the so called (log) factor: $(\log) = \ln\left(\frac{\gamma^2 \epsilon_x \sqrt{\beta_y \epsilon_y}}{r_0 \beta_x}\right)$
  - Impact param b_{min} ~ min. distance between 2 particles
  - Impact param. b_{max} ~ beam size

Particle processes: IBS

- “Tail cut” criteria:
  - Exclude rare scatterings: i.e. small impact parameter with rate smaller than damping rate.
  - Consider only particles in the Gaussian core.







Tail cut criteria: $\Delta\varepsilon_{IBS}/\varepsilon_{IBS} \sim 15\%$

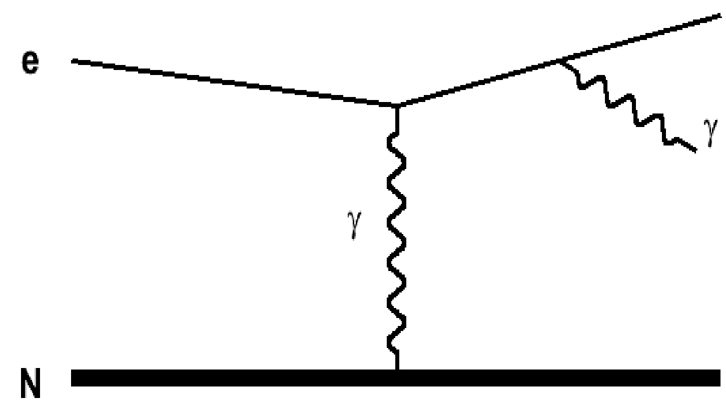
Need a full simulation: under scope of this study

Particle process : scattering off photons

- Important at LEP for single beam
- Compton scattering on Black body radiation
  - Photon density in beam pipe from Planck black body radiation
    - $\rho_\gamma = 8\pi \left(\frac{kT}{hc}\right)^3 \int_0^\infty \frac{x^2}{e^x - 1} dx = 5.3 \times 10^{14} / m^3$
    - $\sigma \sim$ 0.5 barn
    - $N_{scat} \sim$ 1./bunch
  - Minor

Particle process : beam-gas

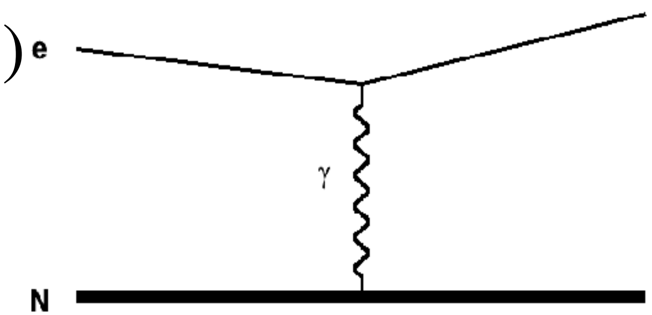
- Inelastic scattering (bremsstrahlung)
  - particle loses energy
  - depends on vacuum
  - For ILC Linac+BDS
    - σ ~ 5.5 barn
    - for 10 nTorr
      - scat. prob. : 2.7x10^{-11}
      - scat./bunch ~ 1300



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

Particle process : beam-gas

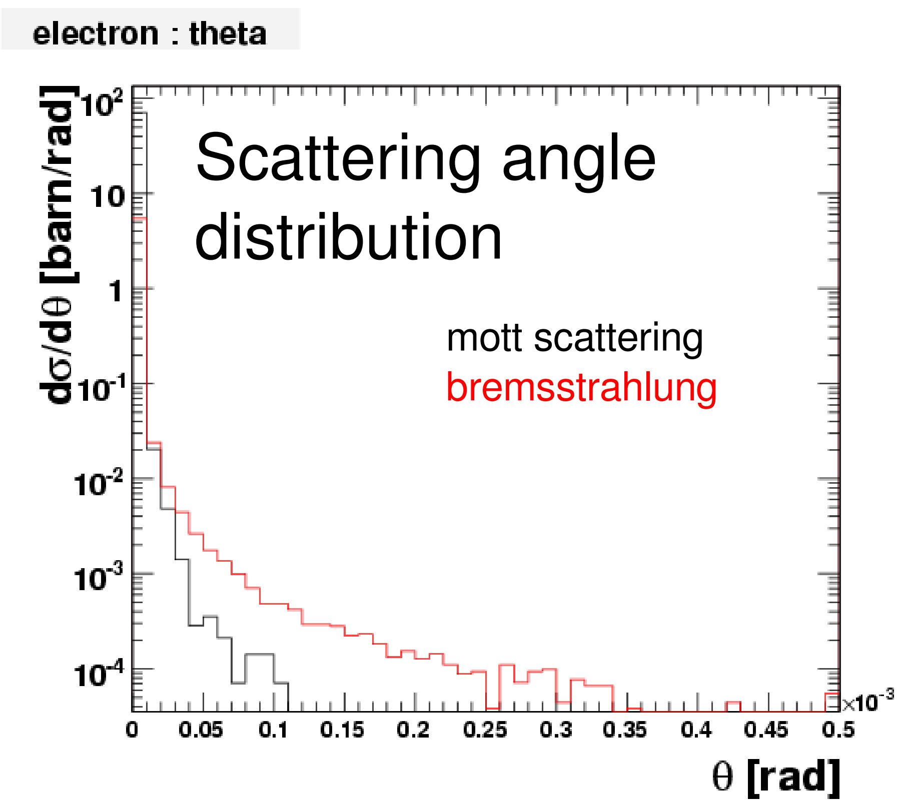
- Elastic scattering (Mott)
  - decreases with energy
  - increases for small beam divergences
  - $\sigma \simeq \left(\frac{Z\alpha\hbar c}{E}\right)^2 \frac{1}{1-\cos\theta_{min}}$
  - ILC Linac+BDS: $\theta_{min} \sim \mathrm{sqrt}(\epsilon/\beta)$
  - for 10 nTorr
    - scat. prob. : $3\mathrm{x}10^{-8}$
    - scat./bunch ~ $2\mathrm{x}10^{7}$

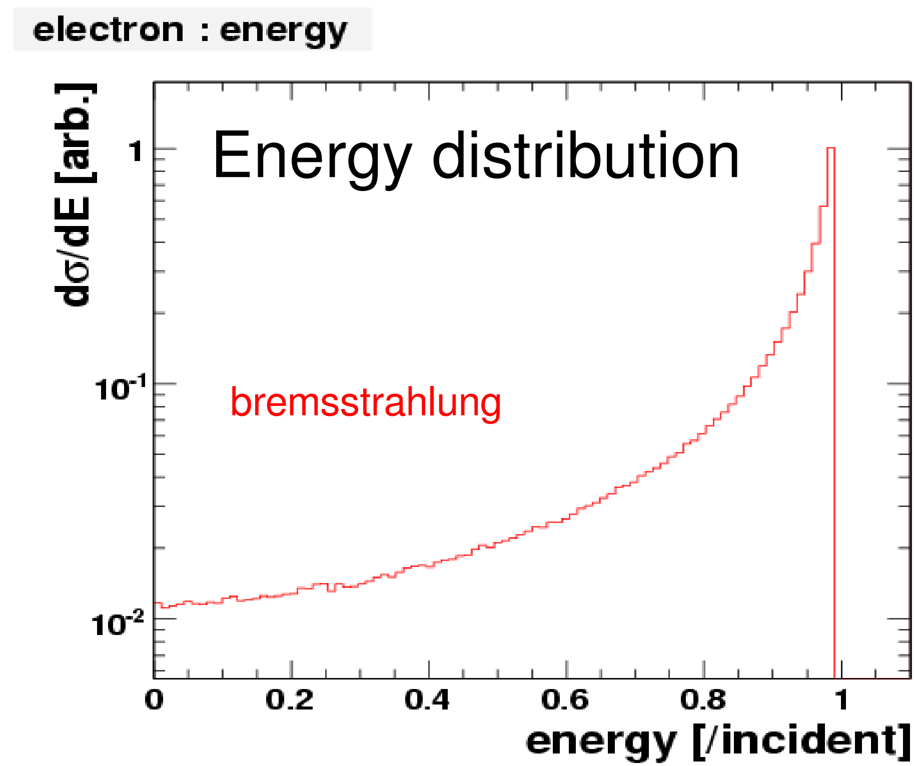


$$\frac{d\sigma}{d\Omega} \simeq \left(\frac{Z\alpha\hbar c}{2pv}\right)^2 \frac{1-\beta^2\sin^2\theta/2}{\sin^4\theta/2}$$

Particle process : beam-gas

- Kinematics

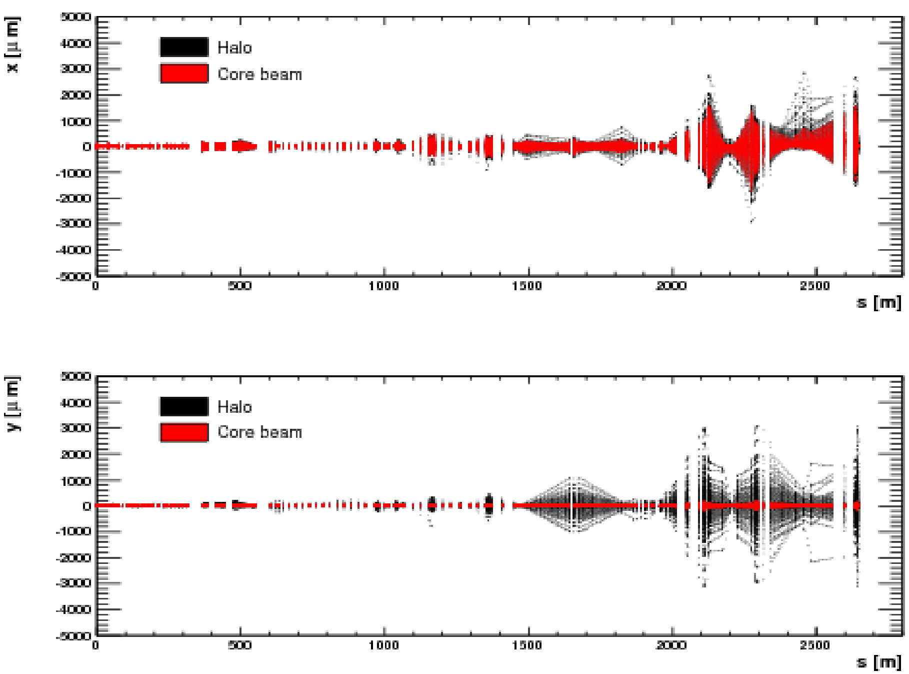




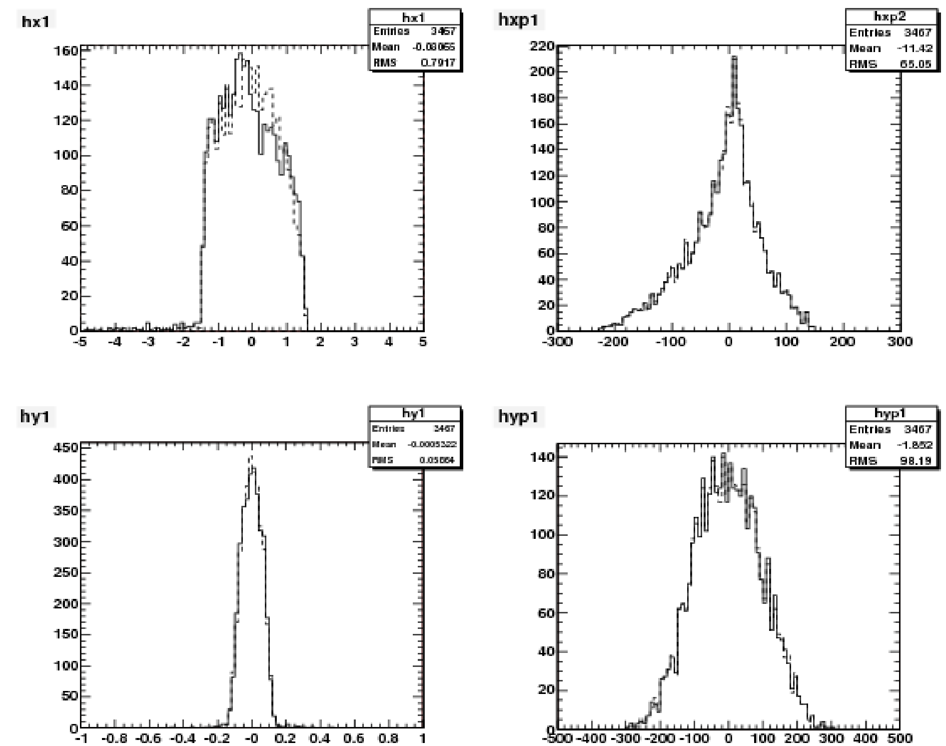
rq: 50% looses more than 10% of their energy

Particle process : Tools

- Standalone fast generators interfaced to Placet, Merlin
  - Beamgas
  - Tracking secondaries and losses



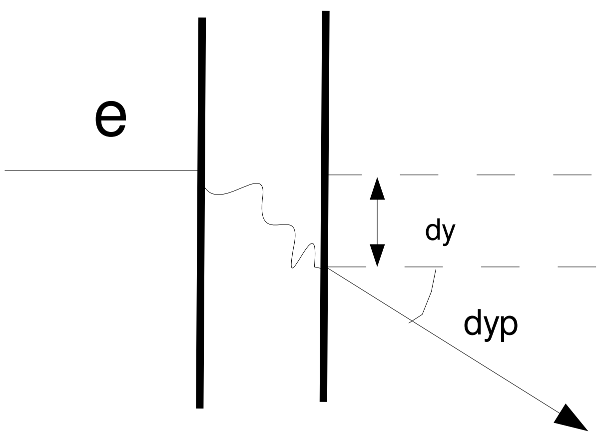
Beam-gas background tracking in ILC BDS

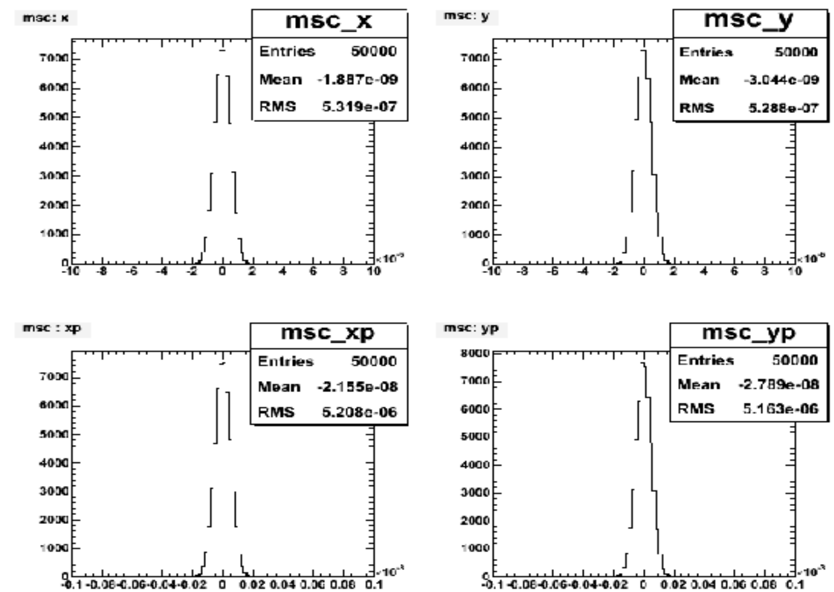


Flat halo distributions at IP after tracking placet vs BDSIM

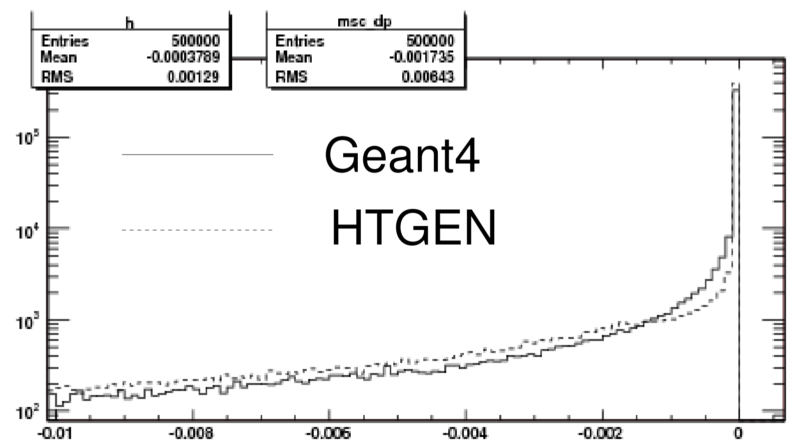
Particle process : Tools

- Multiple scattering in spoilers





Beam axis electrons hitting a $0.5X_0$ Be material

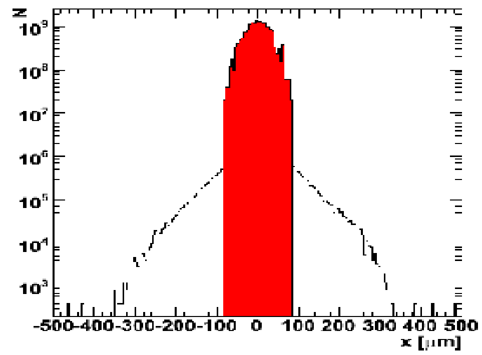


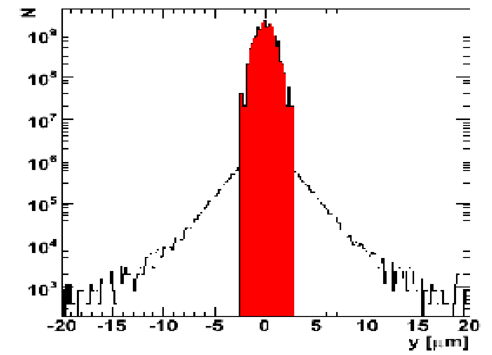
Energy loss
Comparison vs Geant4

Multiple scattering generator interfaced to PLACET

Particle process : Tools : application to beamgas

- Production in Linac:
  - 10 nTorr @ 2K
  - $\theta_{Scattering} > \mathrm{sqrt}(\epsilon/\beta)$
  - particles above $10\sigma_{CORE}$ represents 3.10^{-5} of total
    - $2x10^6$ /bunch (10^{-4}) of these particles are lost in SP2,SP4.





- Nominal vacuum in BDS leads to 10^3 losses/bunch
  - 50 nTorr @ 300 K in the first section
  - 10 nTorr @ 2K in the last final doublet
- This represents ~ $5x10^5$ muons / bunch train produced

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

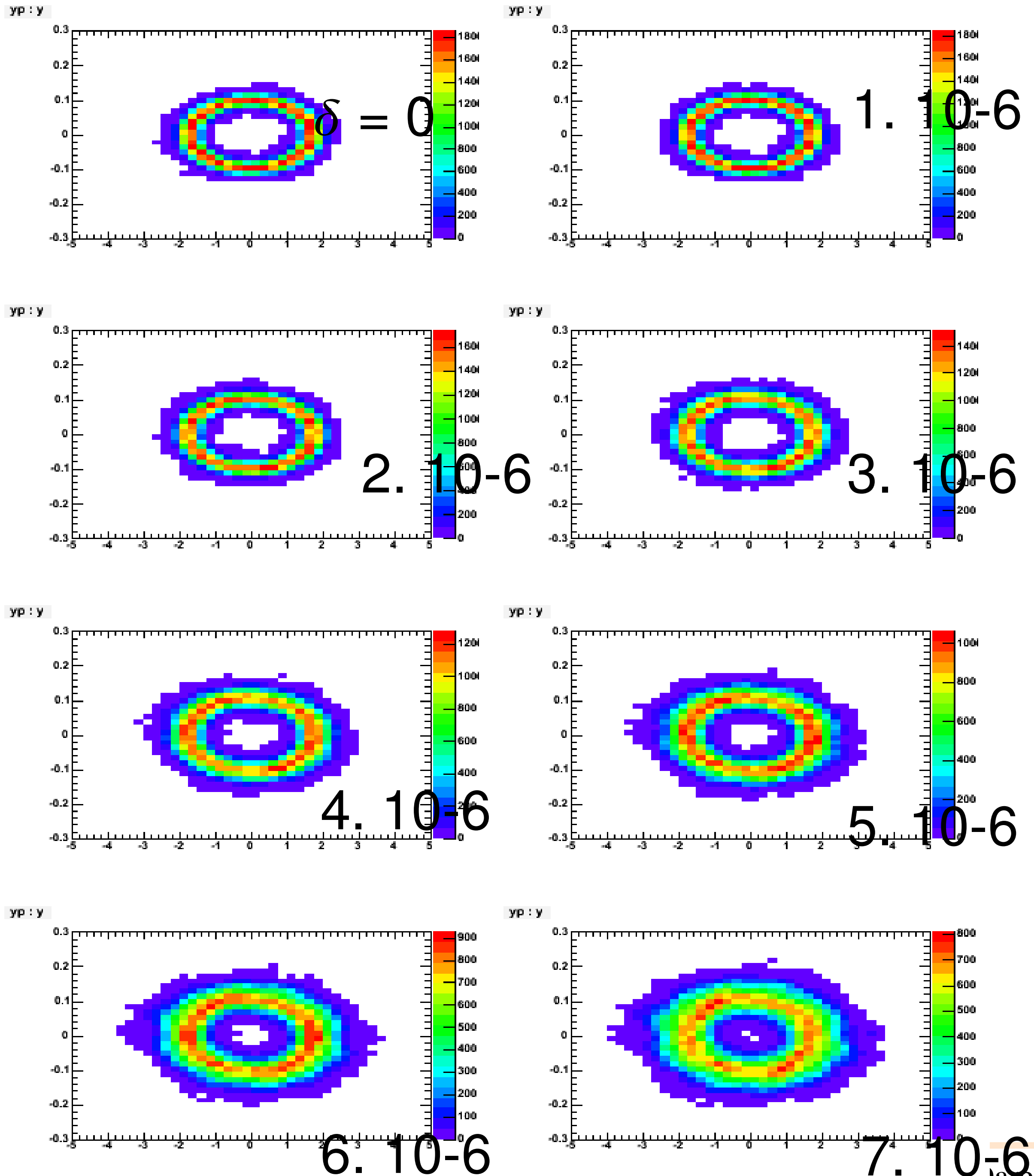
- Alignment
  - Orbital kick
  - Dispersive effect
- Nonlinear fields
  - Fringe fields, geometry, remanence, saturation
  - Nonlinear elements
  - Beam core small w.r.t magnet aperture
  - Intermediate halo from pre-linac
- Realistic machine description needed

Optical distortions: Multipole errors

- Multipole error in LINAC
  - Define errors with two thin multipole before and after each quad.
  - Multipole strength : $K_i = \delta \times K2$
  - 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

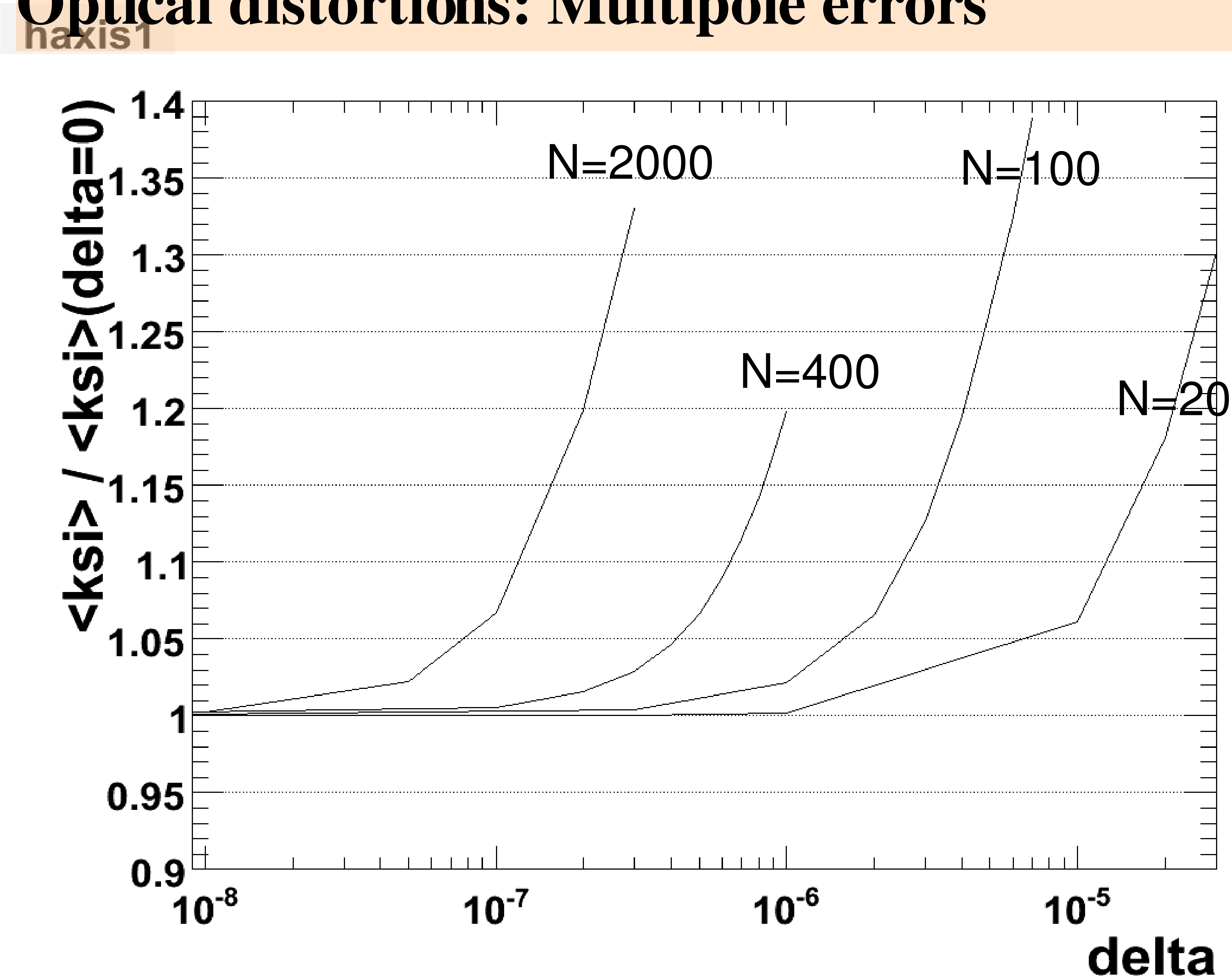
Optical distortions: Multipole errors

N = 100



Extract phase and deformation factor

Optical distortions: Multipole errors



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

List of tools

- Standalone code (HTGen, C++)
  - Beam Gas studies
  - Multiple scattering
- Tools developed in placet (HTGen module)
  - Produce, track and record secondaries through all elements
  - Locate scattering event for each secondary (mother id)
  - Generate halo distribution (flat, Gaussian, on ellipse, from file)
  - Track and record SR photons through all elements
  - Define a vacuum structure for each element (Temp.,Press.,Z)
  - Define spoilers (L, X0)
- Documentation
  - web page : http://cern.ch/neukerma/htgen
  - code available: https://savannah.cern.ch/projects/htgen