Halo and Tail studies for CLIC

H. Burkhardt, L. Neukermans (CERN)

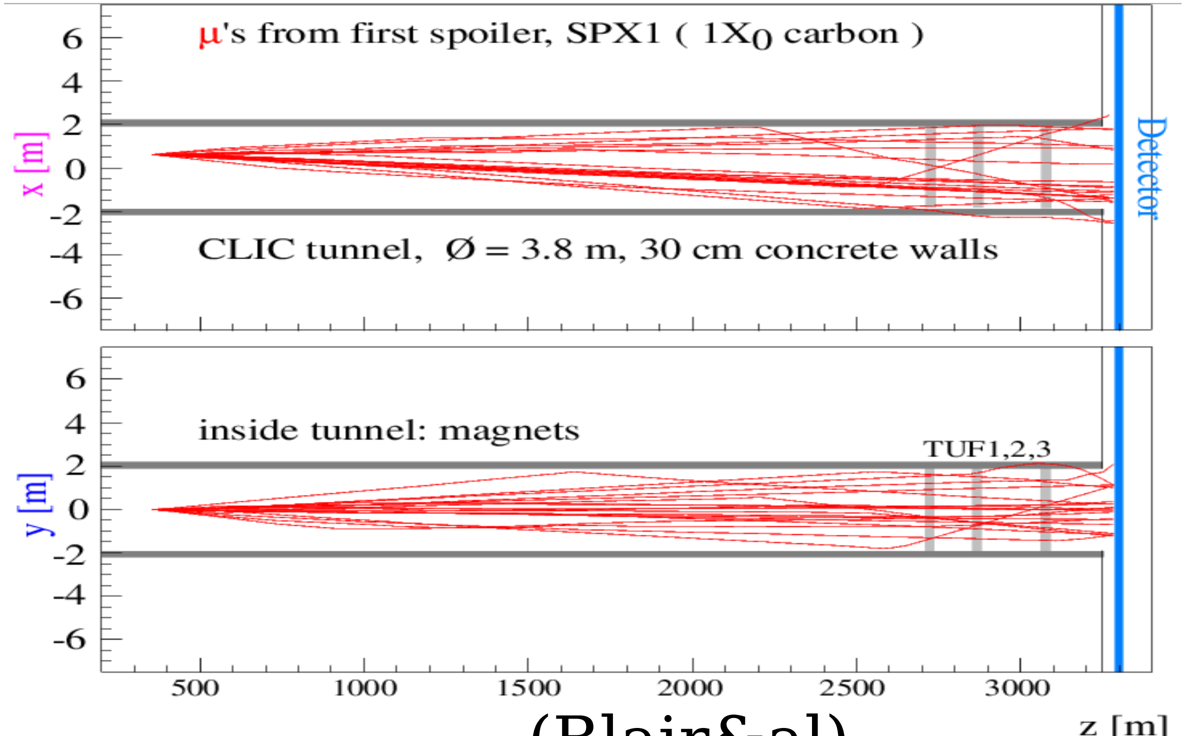
Objectives

- Motivations
  - 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)
- Cover a large area of beam physics
  - All accelerator parts are concerned

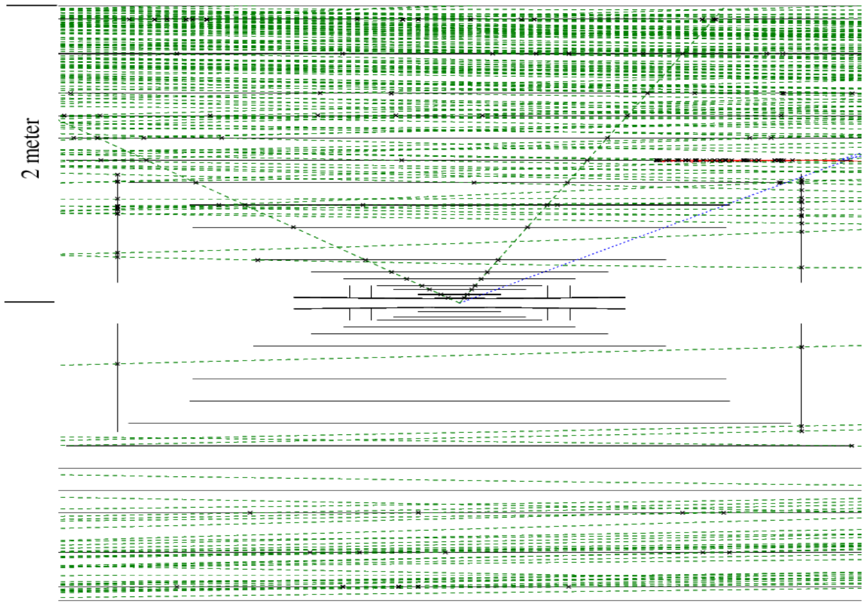
One motivation: Muon background

- Collimation of tails at High energy produces muons in BDS

Muons produced in the first BDS spoiler tracked through the beam line



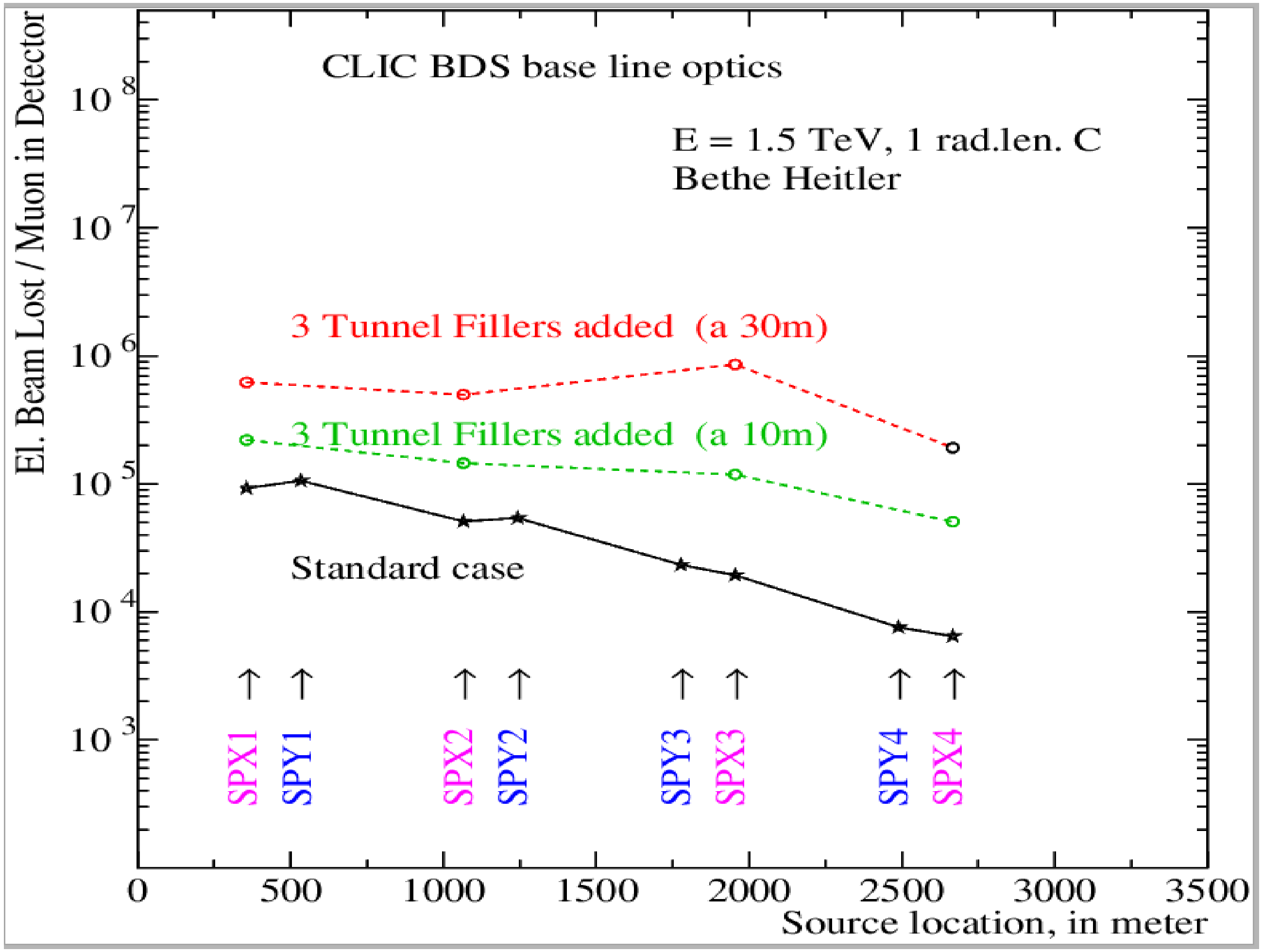
(Blair&al)



ee->$\mu\mu$ in a CLIC detector

One motivation: Muon background

- Geant simulation of muon production in CLIC BDS
  - $f_{tail} = 10^{-3}$ hitting first spoiler leads to ~3.10^4 muons/ bunch train in detector
  - e/μ ratio: $10^4 \rightarrow 10^6$



Halo sources

- Particle processes:
  - beam-gas scattering (elastic, inelastic)
  - Synchrotron radiation (coherent/incoherent)
  - Scattering off thermal photons
  - Ion/electron cloud effects
  - Intrabeam scattering
  - Touschek scattering

Halo sources

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

Halo sources

- Various (equipment related, collective)
  - Noise and vibration
  - Dark currents
  - Space charge effects close to source
  - Wake fields
  - Beam loading
  - Spoiler scattering
  - Bunch compressor

Particle Process: Intra Beam Scattering

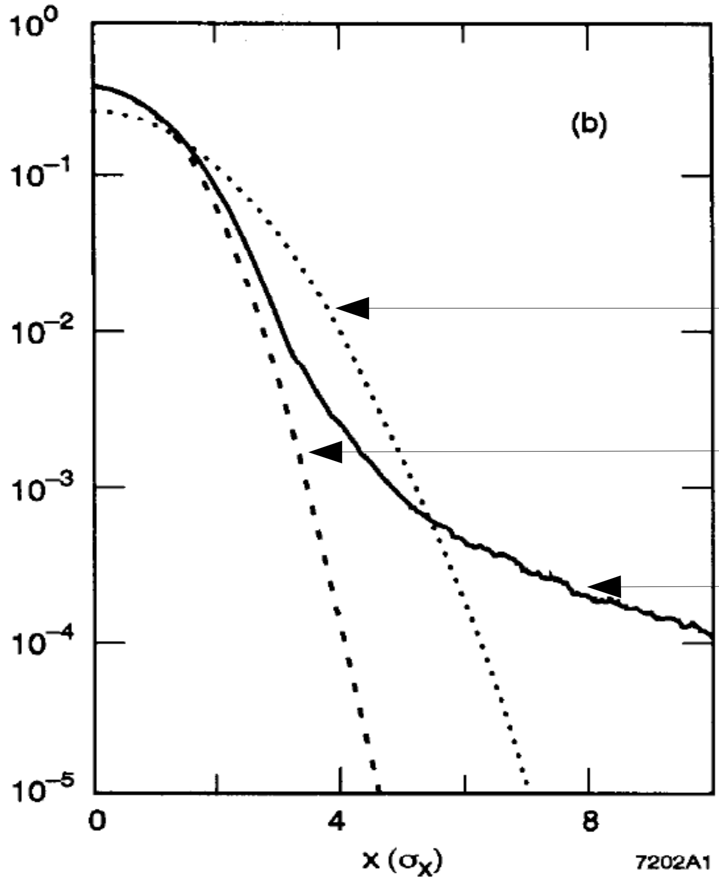
- Emittance growth from multiple scattering inside the bunch
  - Important at low energy and in Damping ring
  - Equilibrium transverse and longitudinal distributions with non-Gaussian tails
    - Should be included in emittance growth estimations
    - Tail population estimation (?)

Particle Process: Intra Beam Scattering

- Emittance growth with IBS
  - $\dot{\epsilon}_\mu = \frac{-2}{\tau_\mu}(\epsilon_\mu - \epsilon_{\mu 0}) + \frac{2\epsilon_\mu}{T_\mu(\epsilon_x, \epsilon_y, \epsilon_t)} \quad \mu \in \{x, y, t\}$
  - $\frac{1}{T_t} \propto A \times (\log) \langle \sigma_H g_{bane} (\beta_x \beta_y)^{-1/4} \rangle$
  - $\frac{1}{T_{x,y}} \approx \frac{\sigma_p \langle H_{x,y} \rangle}{\epsilon_{x,y}} \frac{1}{T_t}$
- 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} ~ minimal distance between 2 particles
  - Impact param. b_{max}~ beam size

Particle Process: Intra Beam Scattering

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



Non corrected gaussian

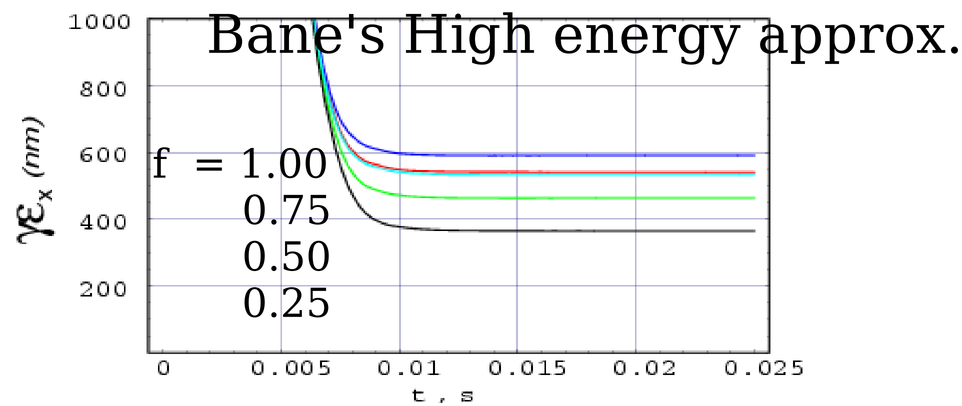
corrected distribution

MC simulation (~1/x^3)

(Raubenheimer)

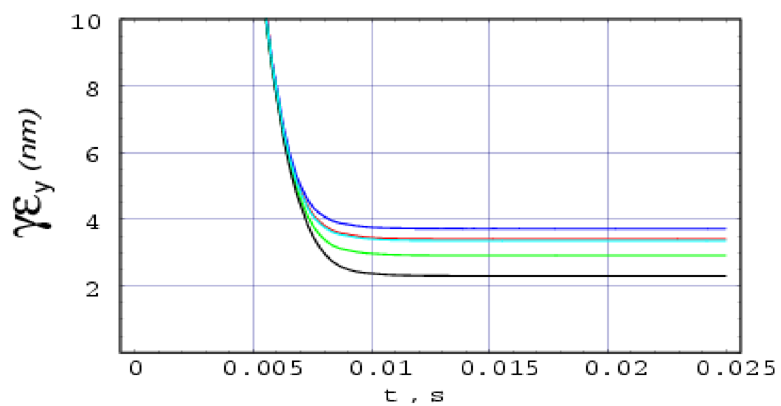
Particle Process: Intra Beam Scattering

- For CLIC Damping-ring
  - (log) ~ 13.6
  - with “tail cut” approximation
    - $b_{min} \approx \sqrt{\dfrac{1}{\pi < \rho > \nu \tau_{SR}}}$
    - -> (log) ~10



(Maxim)

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



Particle Process: Intra Beam Scattering

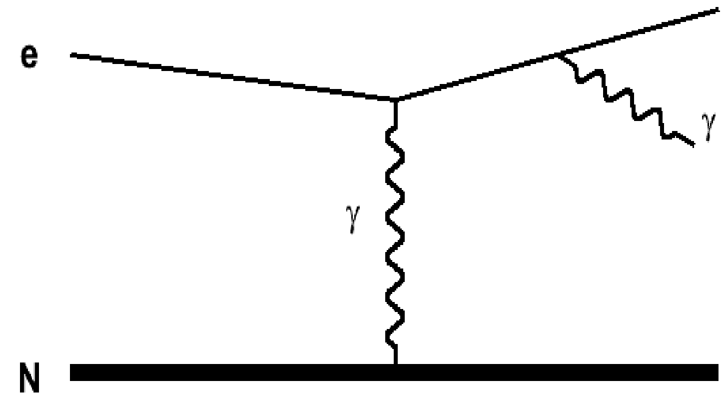
- IBS tails could lead to large effect in emittance calculations:
  - Need for detailed IBS simulation
    - Better estimation of tails
    - Better lattice tuning
  - Halo population in DR + transport lines
    - Strong candidate for prime halo source at CLIC
    - Collimation issue in bunch compressor line (?)

Particle Process: scattering off photon

- 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 scattering

- Inelastic scattering (bremsstrahlung)
  - particle loses energy
  - depends on vacuum
  - For CLIC LINAC + BDS
    - σ ~ 5.5 barn
    - for 10 nTorr
      - scat. prob. : 1.8×10^{-13}
      - scat./bunch ~ 10
    - Minor

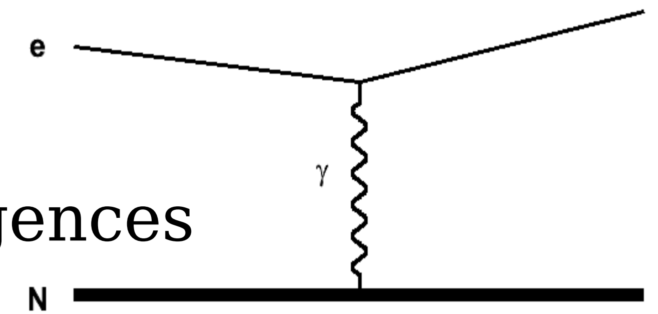


$$\frac{d\sigma}{d\Omega} \simeq \frac{A}{N_A X_0} \frac{1}{k} \left(\frac{4}{3} - \frac{4}{3} k + k^2 \right)$$

(fast and accurate (3%))

Particle Process: Beam-Gas scattering

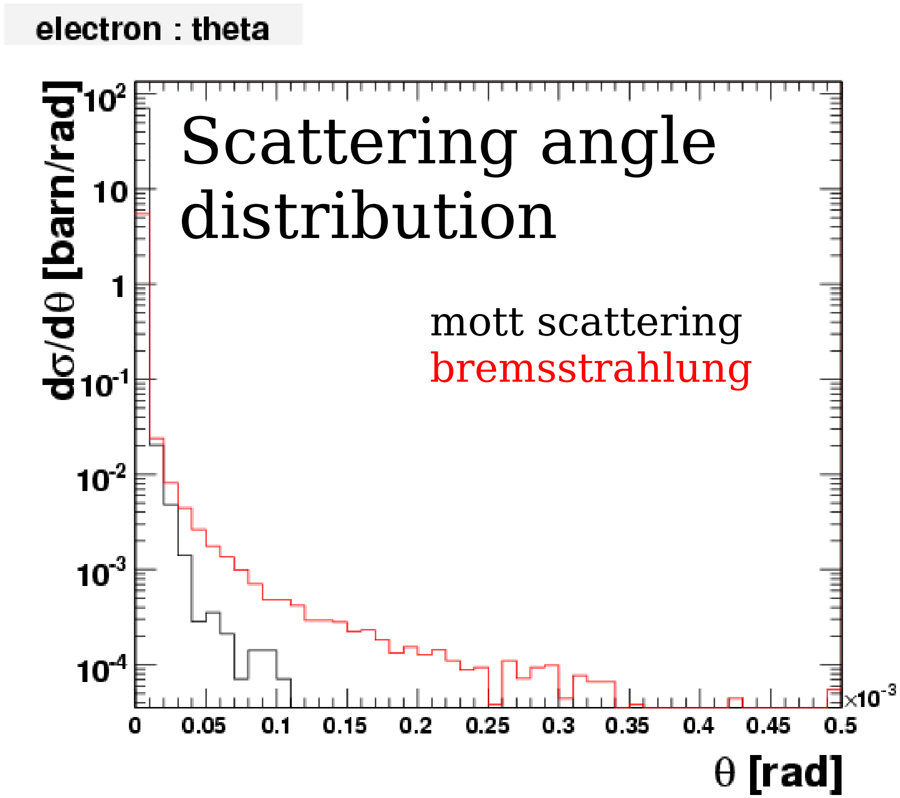
- Elastic scattering (Mott)
    - decreases with energy
    - increases for small beam divergences
  - $\sigma \simeq \left(\frac{Z\alpha\hbar c}{E}\right)^2 \frac{1}{1-\cos\theta_{min}}$
  - CLIC BDS: $\theta_{min} \sim 1.$ nrad
  - for 10 nTorr
    - scat. prob. : $1.9\text{x}10^{-7}$
    - scat./bunch ~ 2.10^6

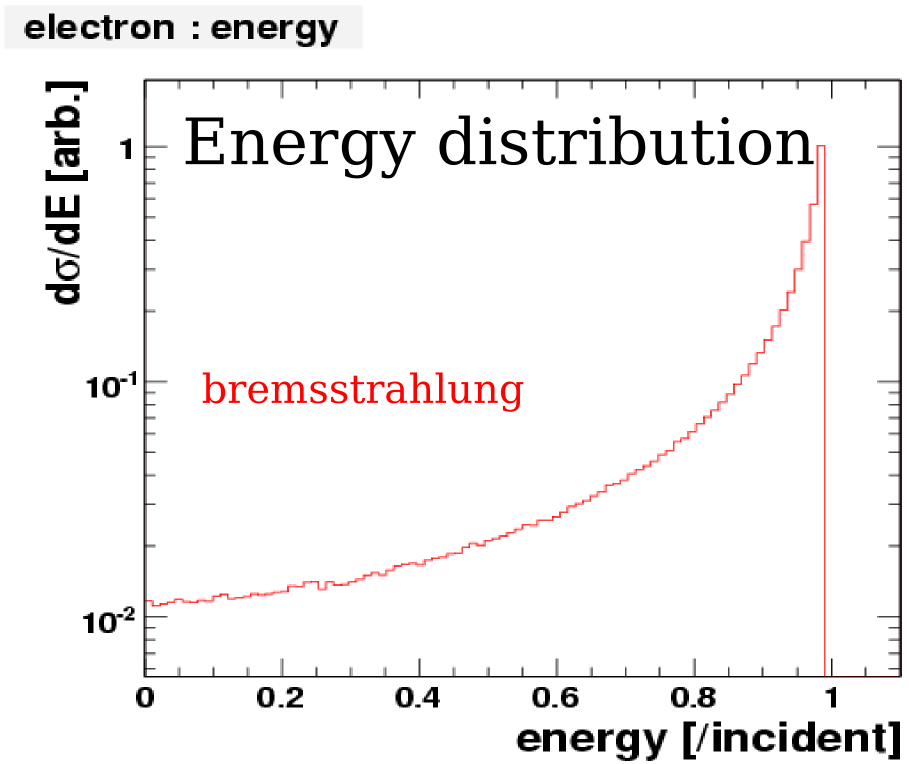


$$\frac{d\sigma}{d\Omega} \simeq \left(\frac{Z\alpha\hbar c}{2\ p v}\right)^2 \frac{1-\beta^2\sin^2\theta/2}{\sin^4\theta/2}$$

Particle Process: Beam-Gas scattering

- Kinematics





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

Particle Process: Beam-gas in LINAC

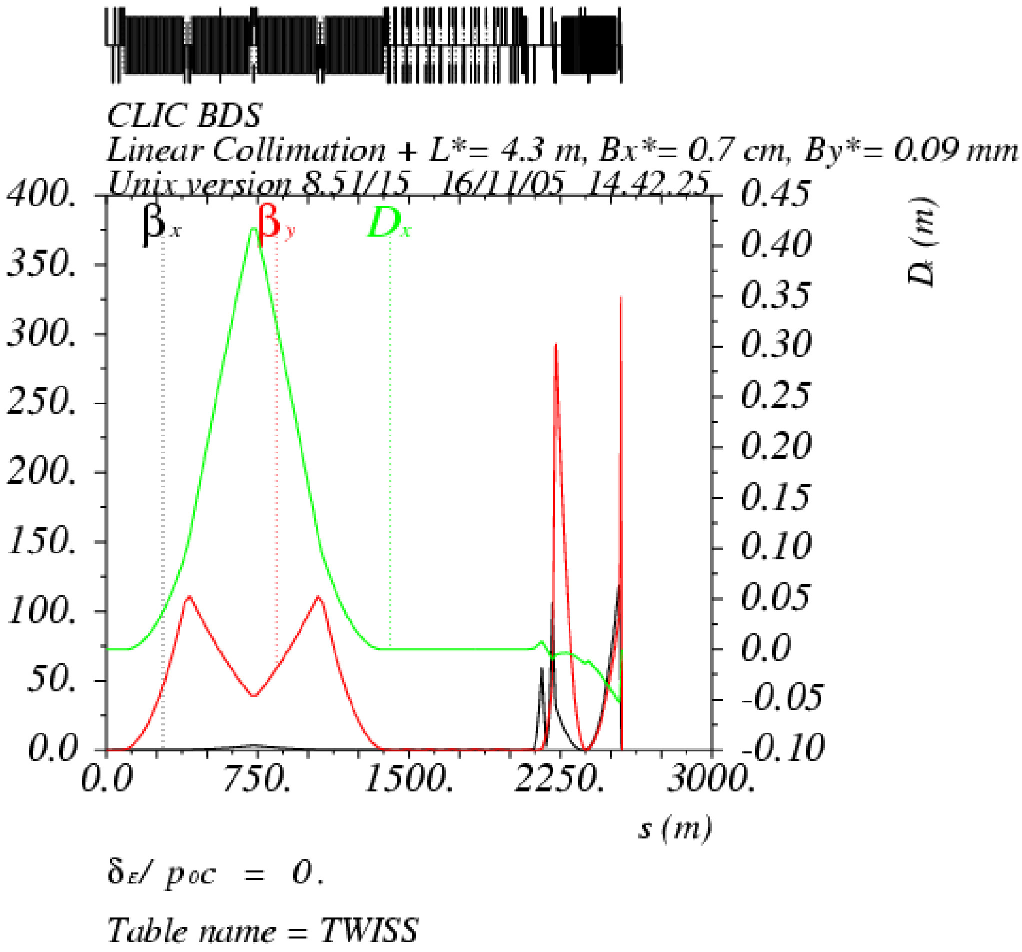
- Global estimation for Mott scattering:
  - $\sigma \simeq \left(\frac{Z \alpha \hbar c}{E}\right)^2 \frac{1}{1-\cos\theta_{min}}$ $\theta_{min} \simeq N_\theta \sqrt{\varepsilon / \gamma \beta}$
  - $N_{scat} \simeq \frac{2PN_{part}}{kT} \int_{Linac} \sigma_{el} \, ds$

- with N_θ=10 and P=10 nTorr
  - Nscat ~ 2.10^4 / bunch ($\sim 10^{-5}$)

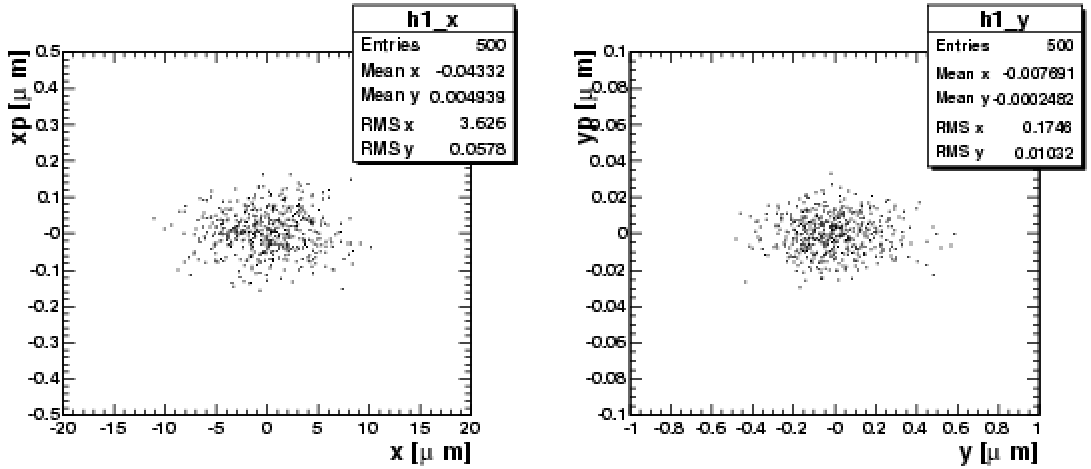
Particle Process: Elastic scattering in BDS

- Mott scattering in Beam Delivery System

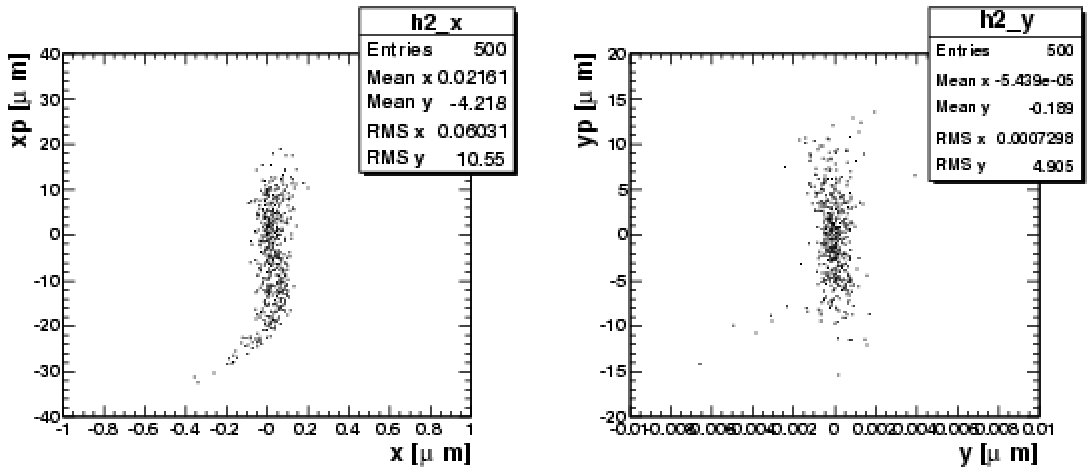
BDS entrance		
Beam Energy	E	15000 GeV
Particles/ bunch	N_{part}	4.10^9
Bunches per train	N_{bunch}	154
Energy spread	$\Delta E/E$	1%
Hor. beta functions	β_x α_x	66.868 m -1.721 m
Vert. beta functions	β_y α_y	27.269 m 0.785 m
Norm. emittances	ϵ_x ϵ_y	680 nm 5 nm
Bunch length	σ_z	35 μm
Interaction point		
beta functions	β^*_x β^*_y	7 mm 90 μm



Particle Process: Elastic scattering in BDS



Beam profile at BDS entrance



Beam profile at IP

Particle Process: Elastic scattering in BDS

s[m]	Name	ax[mm]	ay[mm]
14541	ENGYSP	1,3	25
14716	ENGYAB	2	25
15464	YSP1	10	0,17
15480	XSP1	0,34	10
15577	YSP1	10	0,17
15592	XSP2	0,34	10
15690	YSP3	10	0,17
15706	XSP3	0,34	10
15802	YSP4	10	0,17
15818	XSP4	0,34	10

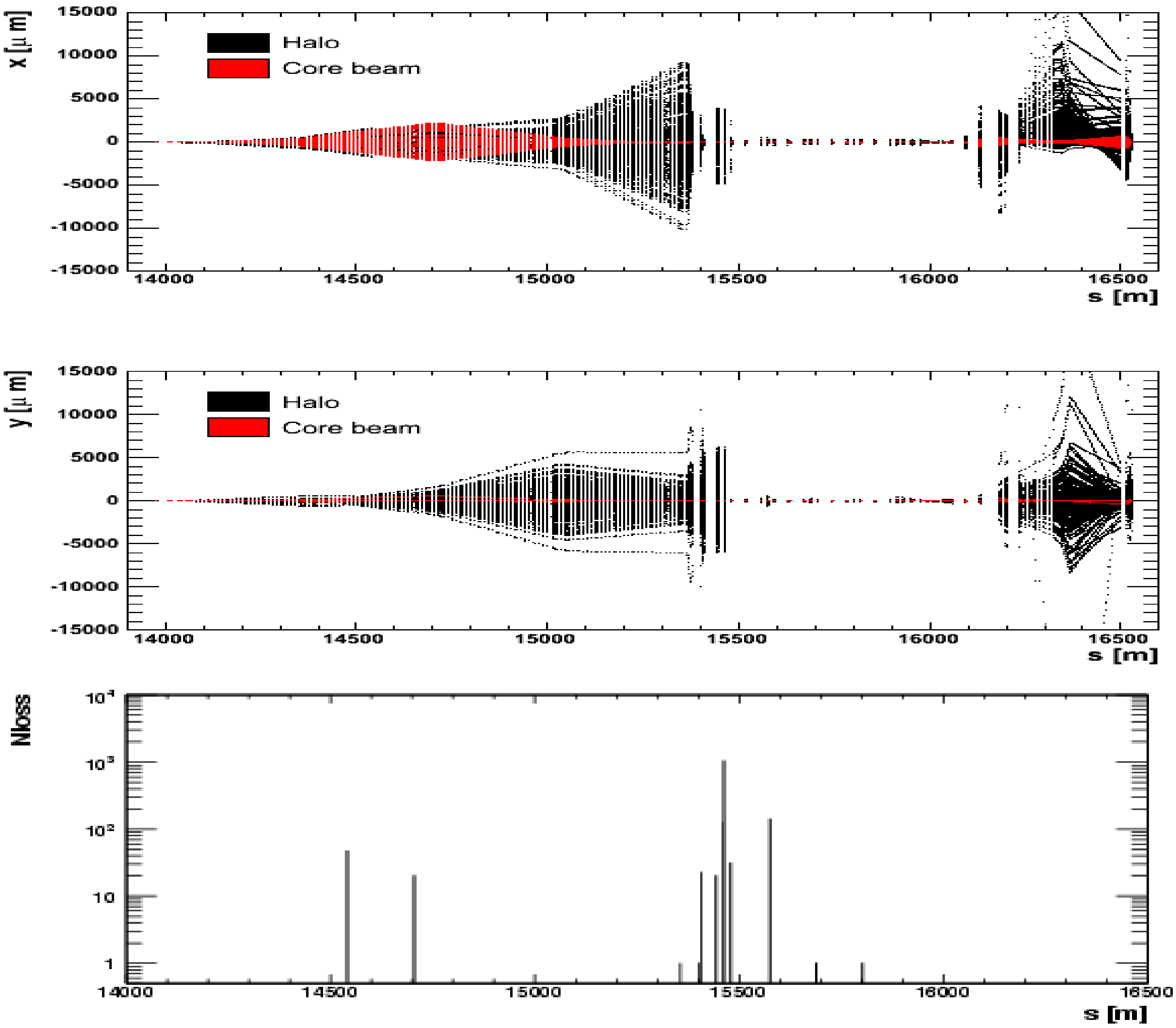
- Collimation system:
  - Energy collimation at 1%
  - Betatron collimation
    - 10 σ_x
    - 80 σ_y

- Beam divergence ~ 10^{-9} rad [Energy collimation section] -> $N_{scat.} \sim 10^6$
  - Only few are lost ~ 2.10^3/bunch
  - Contribute to tails

Particle Process: Elastic scattering in BDS

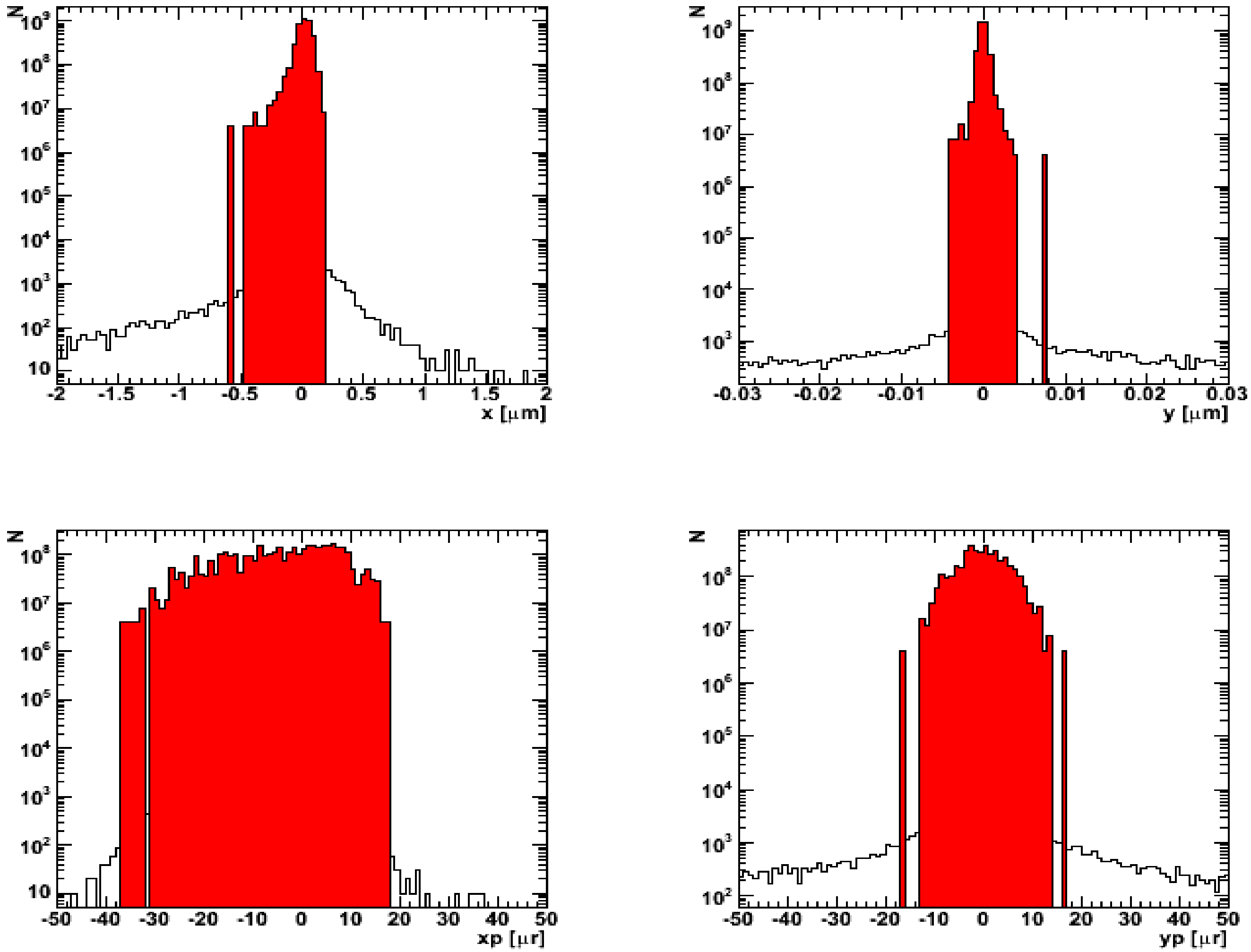
- Tool for simulation:
  - PLACET interfaced to Beam-Gas scattering Monte-Carlo Generator
  - Constant Temperature T=300K and pressure P=10nTorr
  - Tracking and hard collimation of secondaries through BDS

Particle Process: Elastic scattering in BDS



Particle Process: Elastic scattering in BDS

- Transverse distributions at IP



Fraction in tails

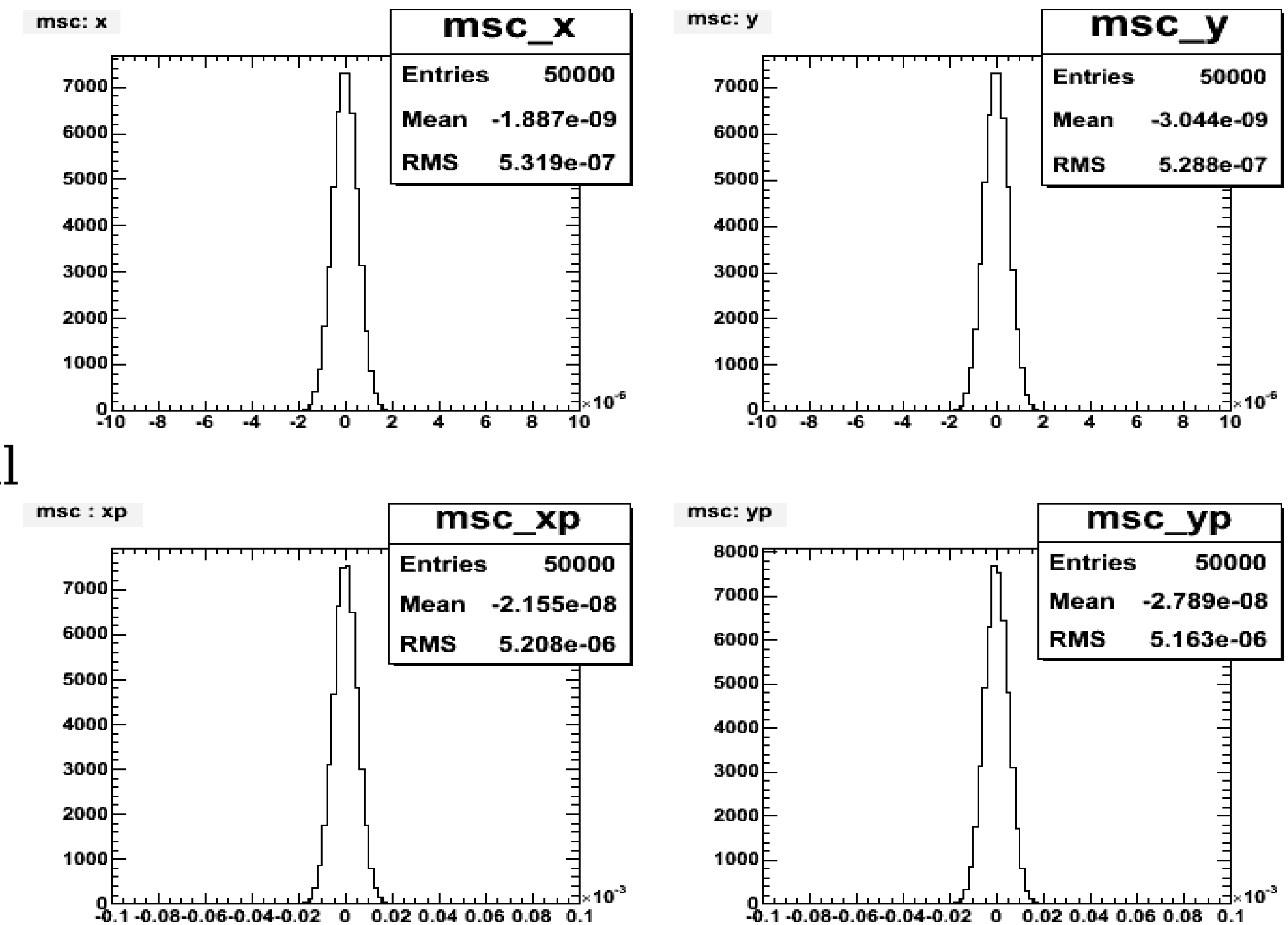
10^{-3} at $10.\sigma_{CORE}$

10^{-6} at $20.\sigma_{CORE}$

Particle Process: Elastic scattering in BDS

- Multiple scattering in spoilers
  - Potential detector background to be studied

Beam axis electrons hitting a $0.5X_0$ Be material



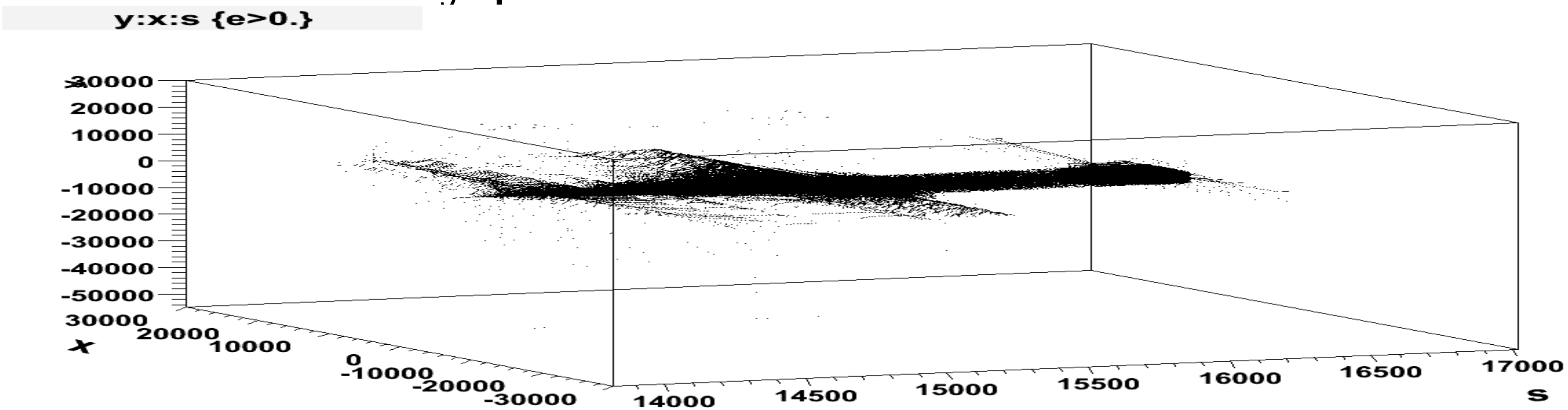
Multiple scattering generator interfaced to PLACET

Particle Process: Beam-gas

- Beam-Gas scattering
  - This process is not dominant in ideal machine
    - ~2.10^{5} losses / bunch train (5.10^{-6})
    - ~few muons / bunch train in detector
  - It can be reducible
    - Exists everywhere
    - It will be important at starting
    - Potential local sources

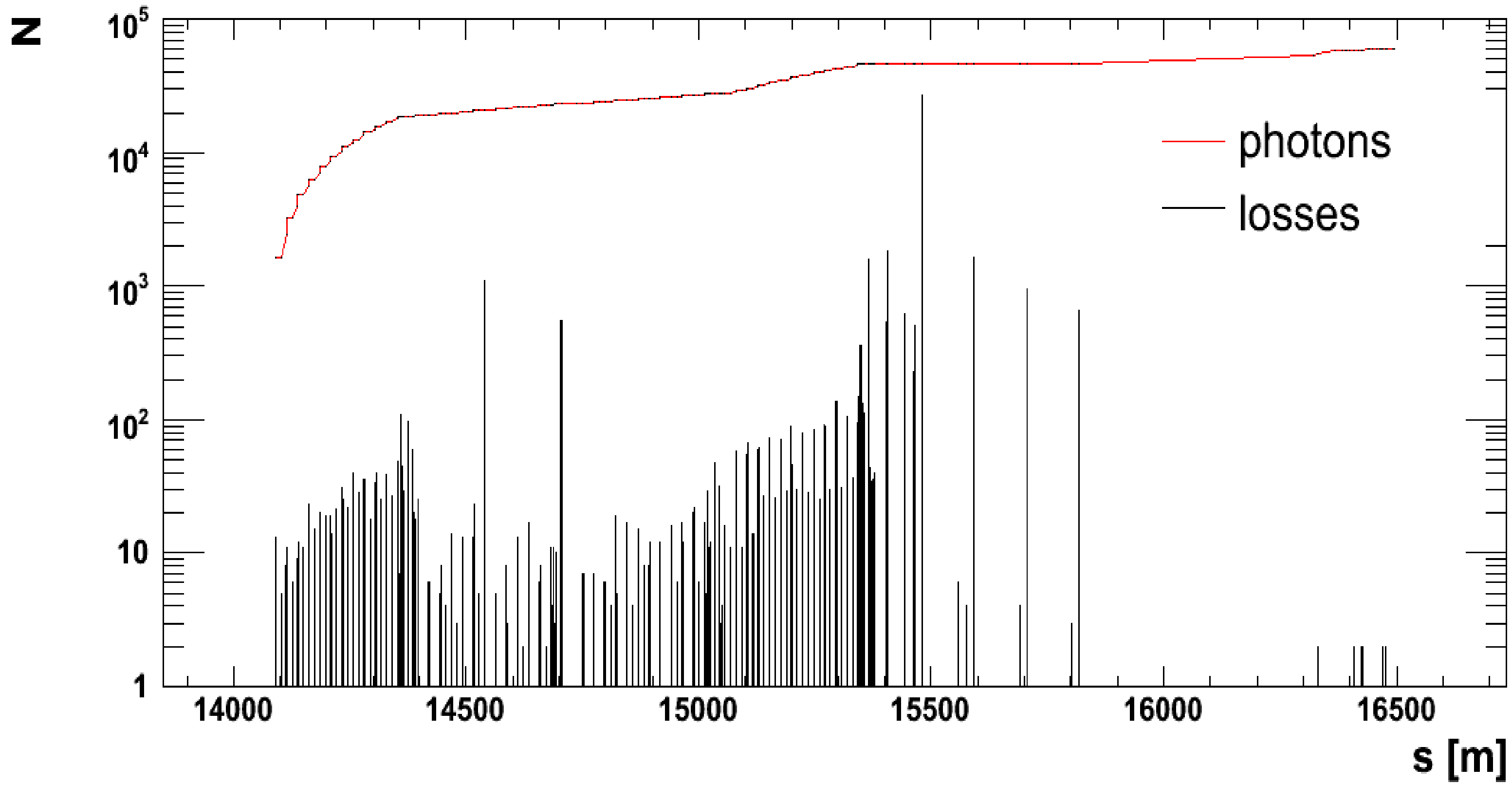
Particle Process: Synchrotron radiation

- Synchrotron radiation distributions affected by tails.
  - Harder energy spectrum
  - Photon distribution at IP
- Tool for study:
  - Photon tracker interfaced to placet
  - Primary photons tracked



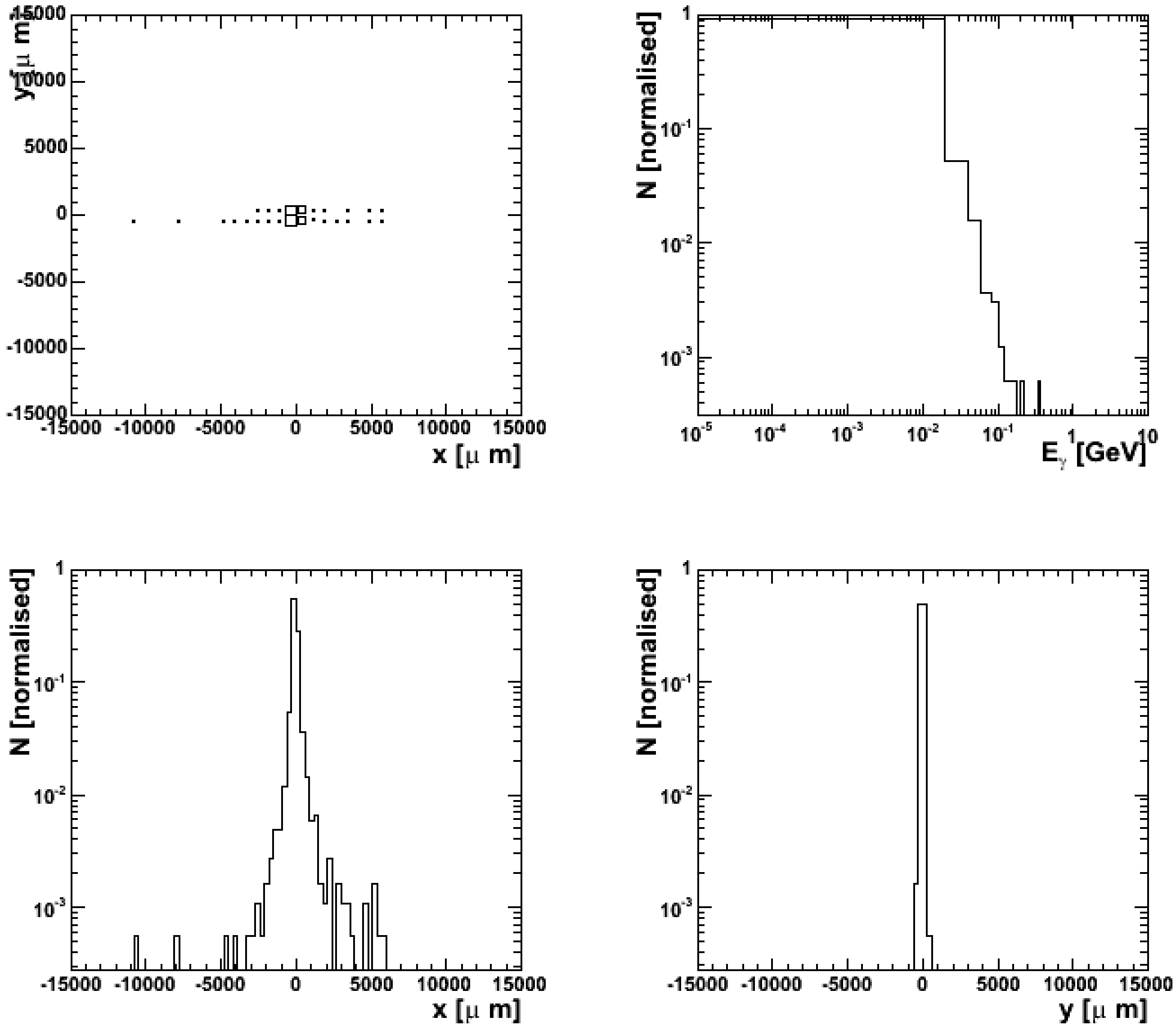
Particle Process: Synchrotron radiation

- Most of the losses are in the first section where betatron amplitude is maximum



Particle Process: Synchrotron radiation

- Beam Core



At IP:

$\sigma_x = 0.6$ mm

$\sigma_y = 0.04$ mm

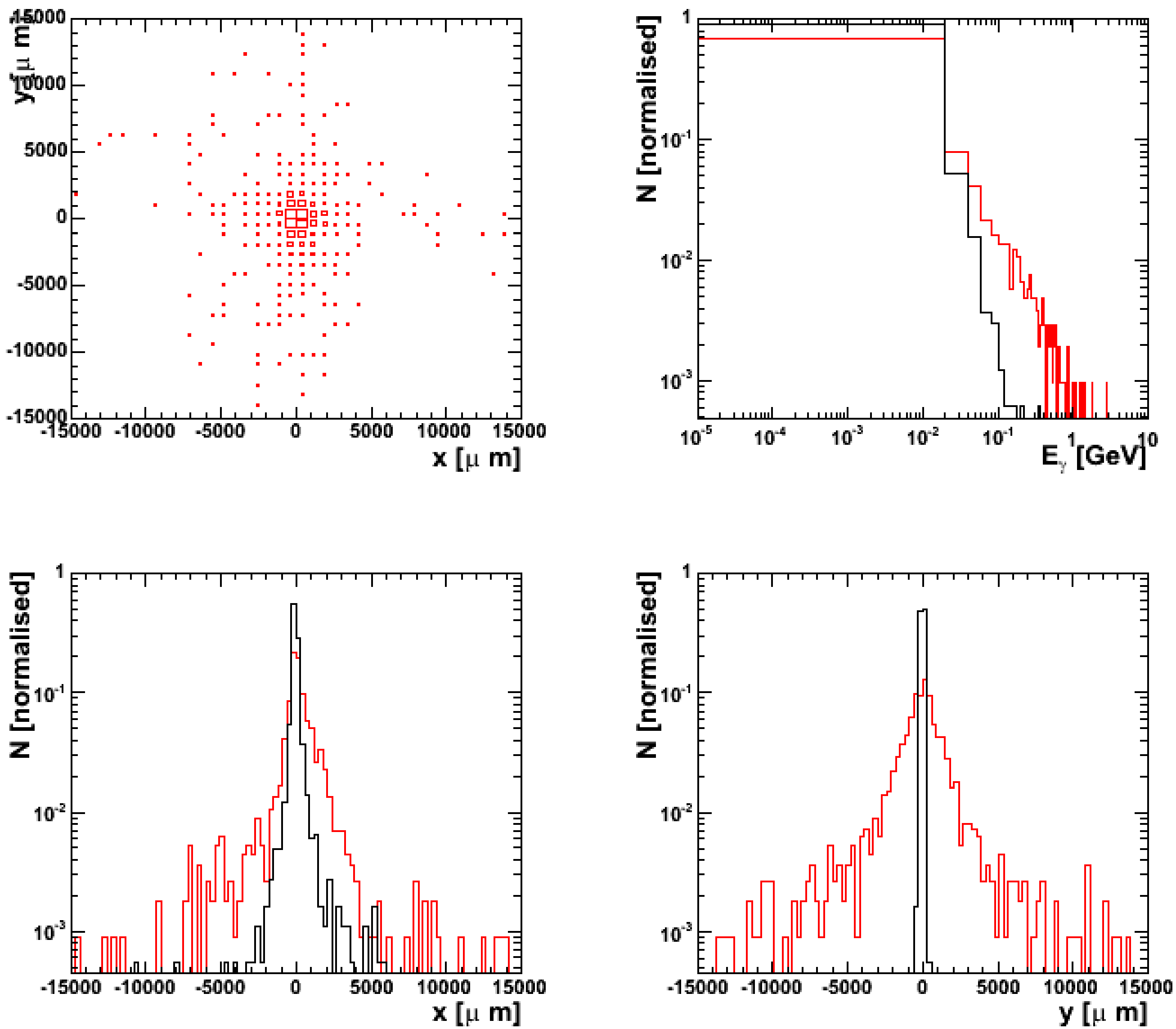
$\langle E_\gamma \rangle = 6$MeV

Particle Process: Synchrotron radiation

- Beam Halo
  - Simulate 2.10^4 halo particles at BDS entrance
    - 1/x distribution
    - 20 σ_x
    - 80 σ_y

Particle Process: Synchrotron radiation

- Beam Halo



At IP:

$\sigma_x = 2.1$ mm

$\sigma_y = 2.7$ mm

$\langle E_\gamma \rangle = 67$ MeV

Dark currents

- Surface physics process
  - Thermal emission
  - Secondary emission
  - Field emission (Fowler-Nordheim approximation)
    - $$I_{FN} \approx k_1 A \frac{(\beta E)^2}{\phi} e^{(\frac{k_2 \phi^{3/2}}{\beta E})}$$
      - A: Active emitter area
      - β : field enhancement factor : β ~ 100
      - I~5-10mA for 100MV/m structures
  - typical emission energy ~ 10 MeV
    - Only electrons emitted in low energy band of LINAC could survive
      - But strong focusing lattice
    - beam/dark currents interactions?

Optical distortions

- Alignment
  - residual dispersion in both planes
  - To be done
- Nonlinear fields
  - Fringe fields
  - Geometry, remanence, saturation

$$\frac{\Delta x'}{\sigma_{x'}} = \frac{-\beta}{\sigma_{x'}} \frac{k_n}{(n-1)!} x^{n-1} \qquad k_n = \frac{\partial^{n} B_y / \partial x^n}{B\rho} l_n$$

  - Nonlinear elements
- Realistic machine description needed

Conclusions and outlook

- Detailed list of candidates
  - Standalone generators available for beam-gas, synchrotron radiation
    - Tools available
- Comments are welcome!
- Informations on:
  `http://hbu.home.cern.ch/hbu/HTGEN.html`