Simulation study of linear collider Beam Delivery System

K. Tanabe

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1) Introduction

There are several background sources in the Linear Collider Accelerator.

- Upstream background

  (Synchrotron Radiation, Muon production)

- Downstream background

  (Neutrons from dump line)

- IP background

  (e^+e^- pairs from beam-beam interaction)

- etc.

Background estimation by Beam Delivery System (BDS) / IR simulation is important for the designing both accelerator and detectors.

⇩

We have developed the BDS full simulation based on Geant4.

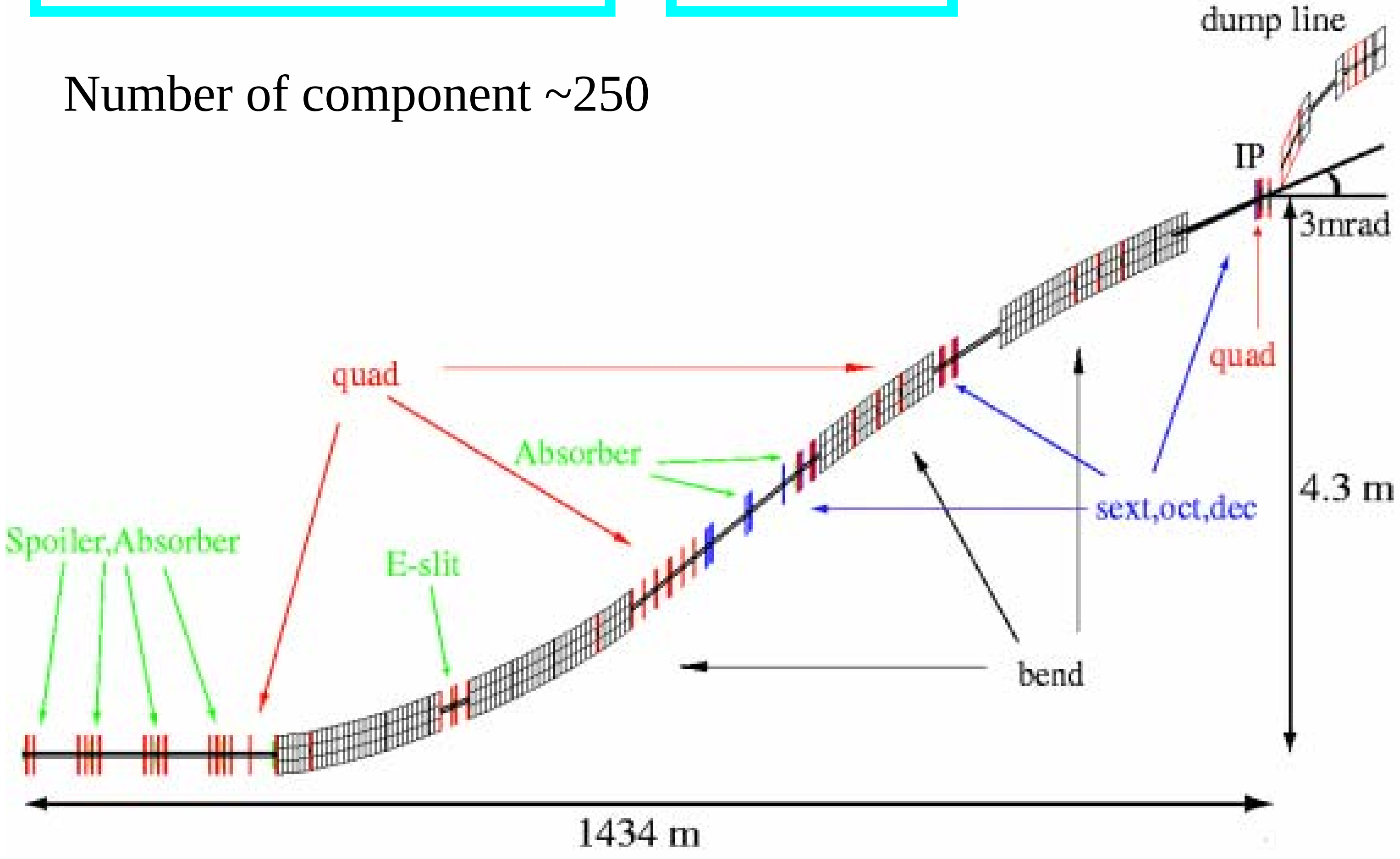
JLC Beam Delivery System geometry

JLC Beam Delivery System Road Map Report 2002

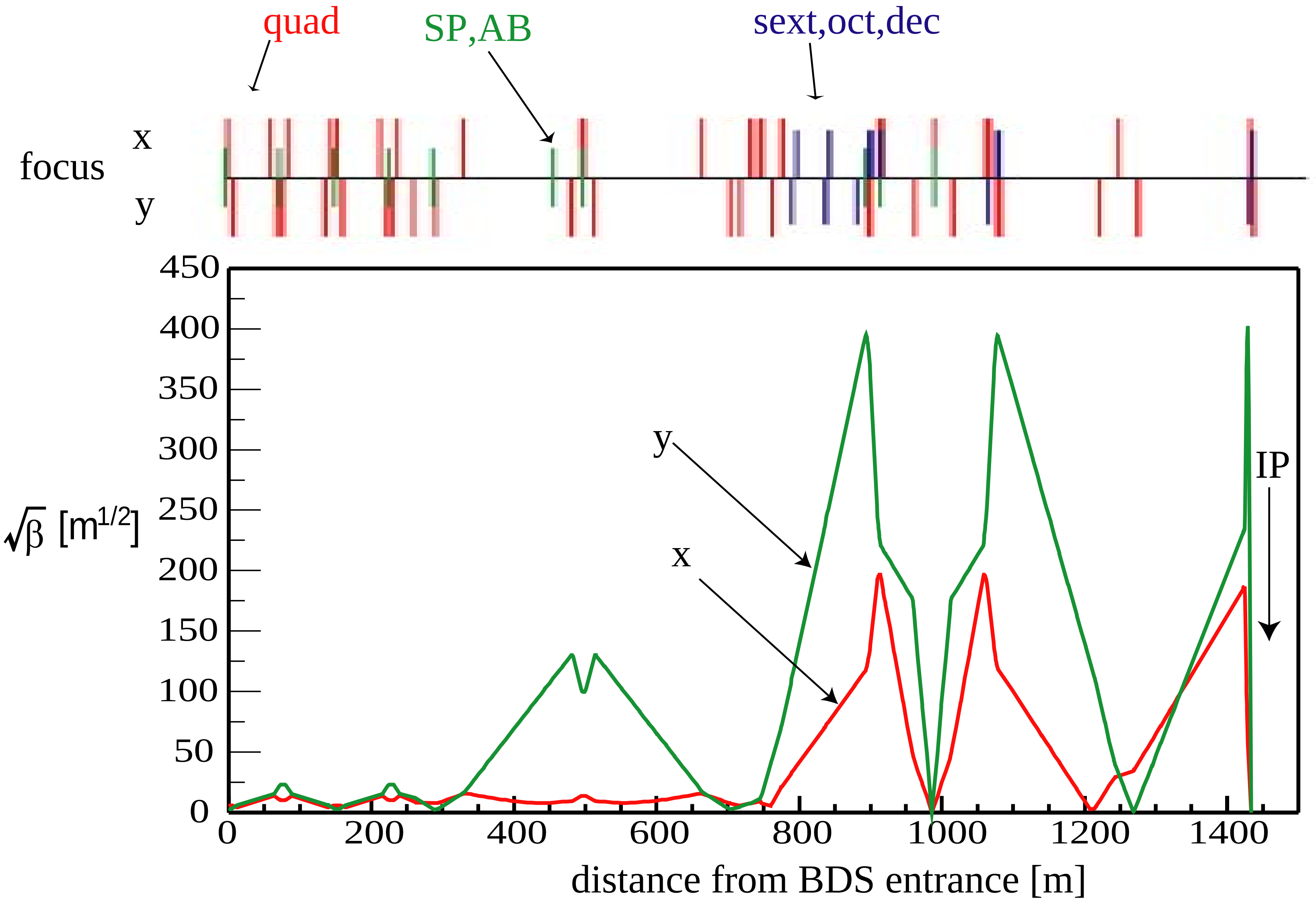
Crossing angle 6mrad

L* = 3.5m

Number of component ~250



Beta-function of JLC BDS geometry



BDS simulation based on Geant4 at U. Tokyo

We construct the BDS simulation using Geant4

Input

Input geometry file made easily from SAD/MAD files

Geant4 Calculation

- Construct geometry
- Particle transportation
- Physics process
- etc.

Output

Produced particle data at each positon of monitor.

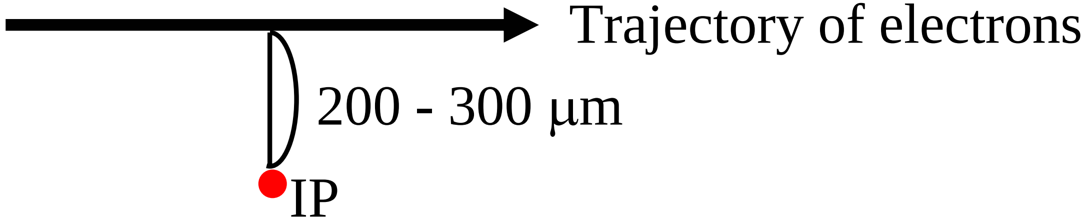
In ROOT file

2) BDS simulation

2-1) Transportation calculation in Geant4

The default Geant4 has a problem on accuracy in the particle transportation.

After transport the 250 GeV electron, there is 200 - 300 μm shift in x at IP.



Beam size at IP is more than 10 times larger than designed one.
RMSx* = 3 μm (designed size 211nm)
RMSy* = 370 nm (designed size 2.7nm)

Many thanks to Dr. Blair (at CLIC) , this problem is fixed.

Improvement of accuracy of transportation calculation in Geant4

Fix the bug of Geant4

In default Geant4, at the boundary, magnetic field cannot be refered correctly.

Using the analytical stepper instead of the default one

(Geant4 default stepper is 4^{th} order Runge-Kutta.)

Bend and Quad ⇨ Linear Beam Optics.
Solve the eq.of mot. using transfer matrix.

Sext,Oct,Dec ⇨ Second order linear approximation
$r1 = r0 + r' * step + r'' * (step)^2/2$

After these modifications

Transport the electron to IP ⇨ **Position shift at IP < 1 nm**

Beam focusing (shape of envelope)

Result of transportation calculation without physics process

Shape of the calculated beam envelope is consistent with the designed β-function.

Initial beam parameter
Gaussian distribution

emittance

$\varepsilon_x = 6.132 \times 10^{-12}$

$\varepsilon_y = 6.132 \times 10^{-14}$

beam size

$\sigma_x = 14.8\ \mu m$

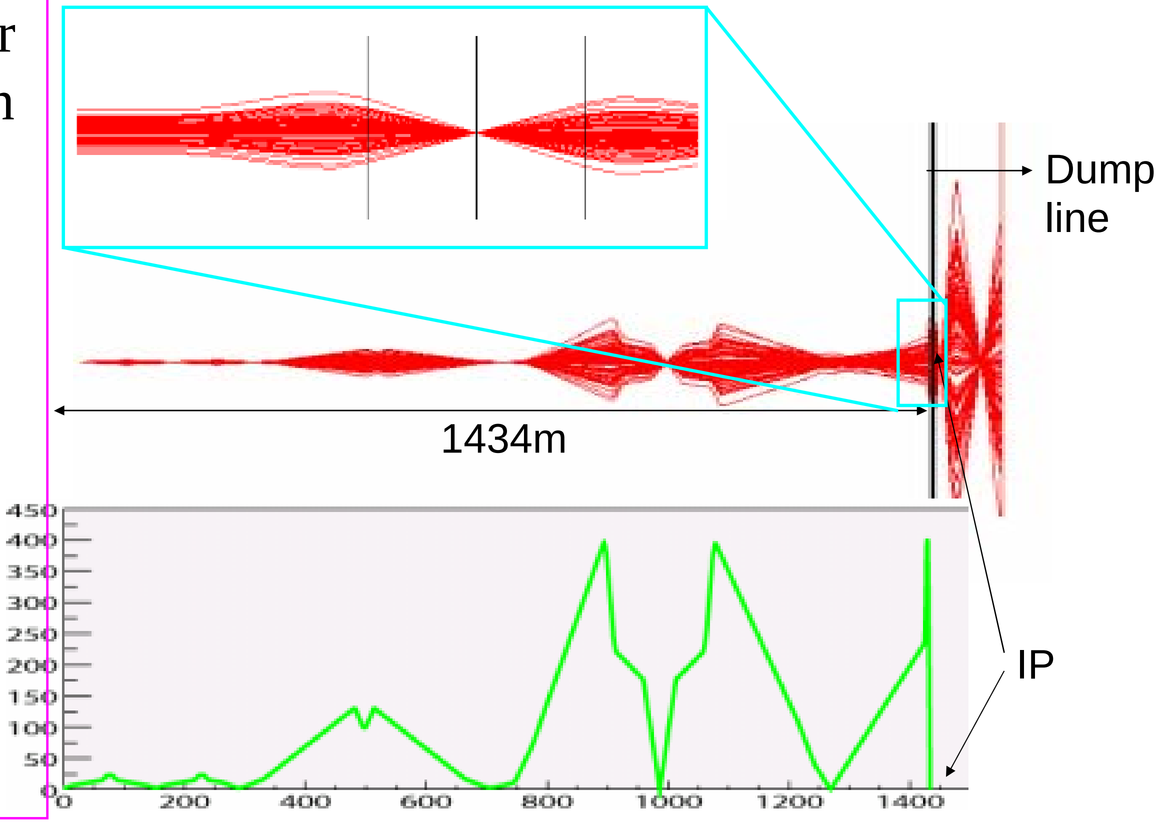
$\sigma_{x'} = 0.413\ \mu rad$

$\sigma_y = 658\ nm$

$\sigma_{y'} = 0.093\ \mu rad$

$E = 250\ GeV$

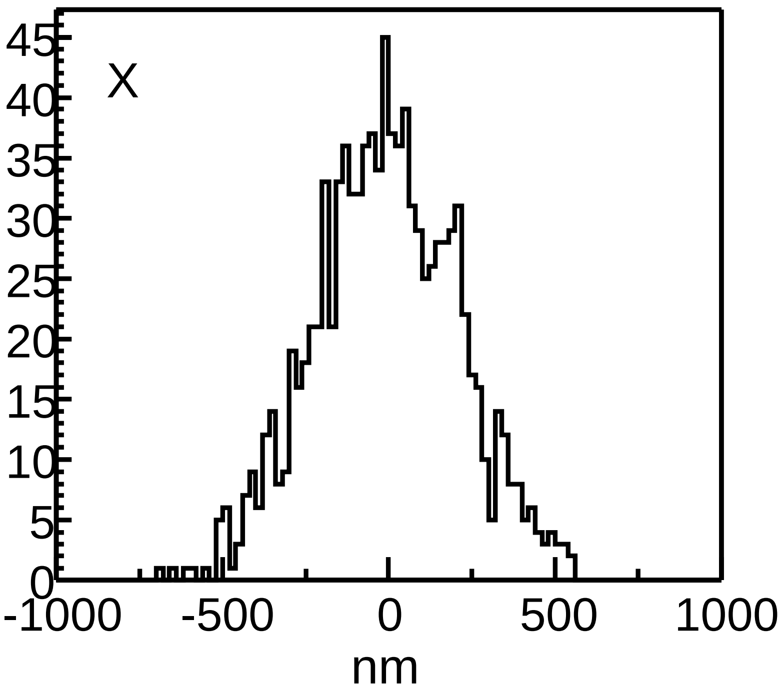
$\Delta E/E = 0.003$

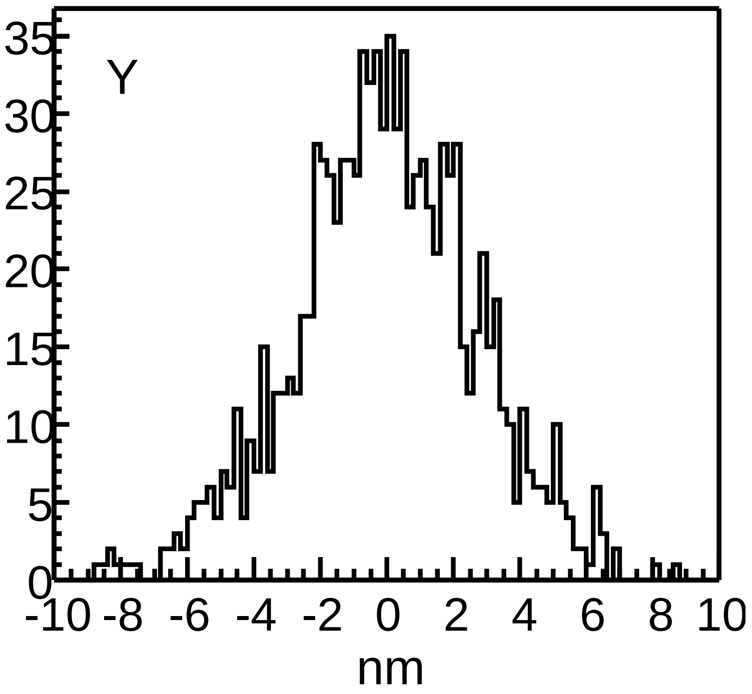


Beam focusing
(beam size at IP)

RMSx* = 214.5nm
(design : 211nm)

RMSy* = 2.73nm
(design : 2.7nm)





2-2) Estimation of background

By including physics process, estimate the following background

- multiple scattering
- electromagnetic shower
- synchrotron radiation
- photon conversion to electrons / muons

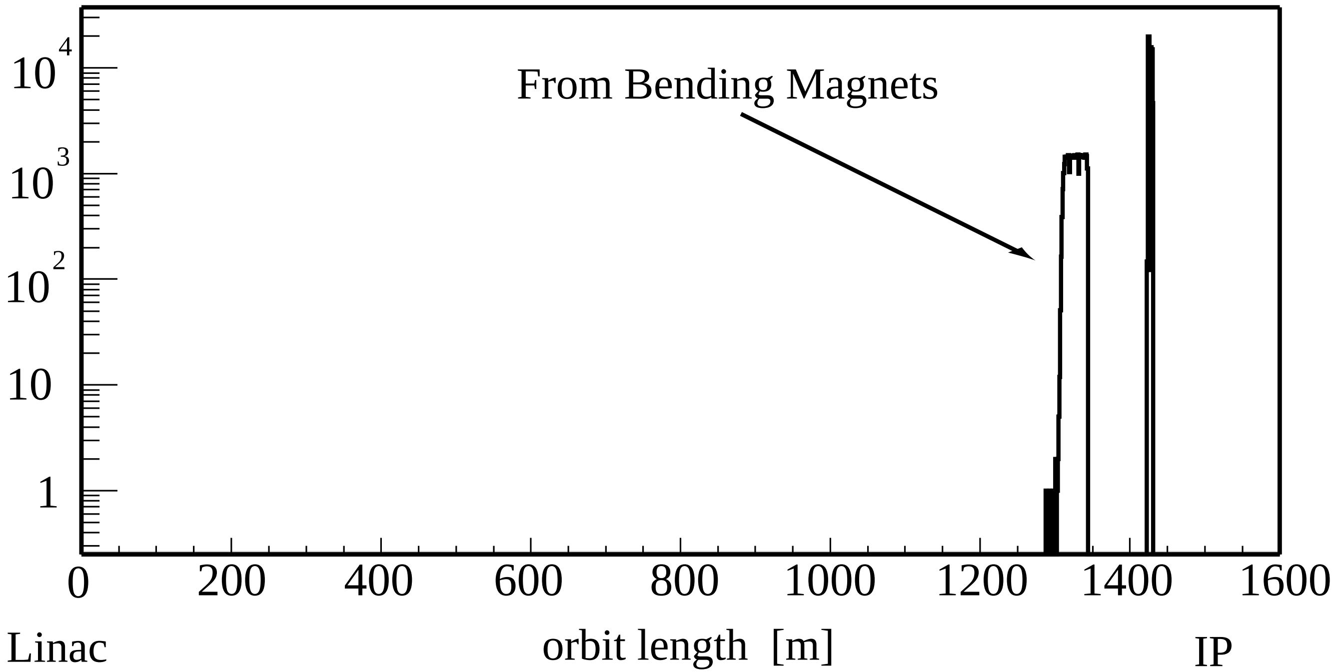
We estimate these background in beam core (nominal)
and beam halo, separately.

Estimation of background (Beam Core)

Assume beam core as Gaussian distribution

Initial beam parameters
Gaussian distribution
beam size
$\sigma_x = 14.8\ \mu m$
$\sigma_{x'} = 0.413\ \mu rad$
$\sigma_y = 658\ nm$
$\sigma_{y'} = 0.093\ \mu rad$
$E = 250\ GeV$
$\Delta E/E = 0.003$

Synchrotron radiation from beam core (production position for photons reached to IP)



Photons reached to IP are mainly produced at FF-quadrupole and the last bend

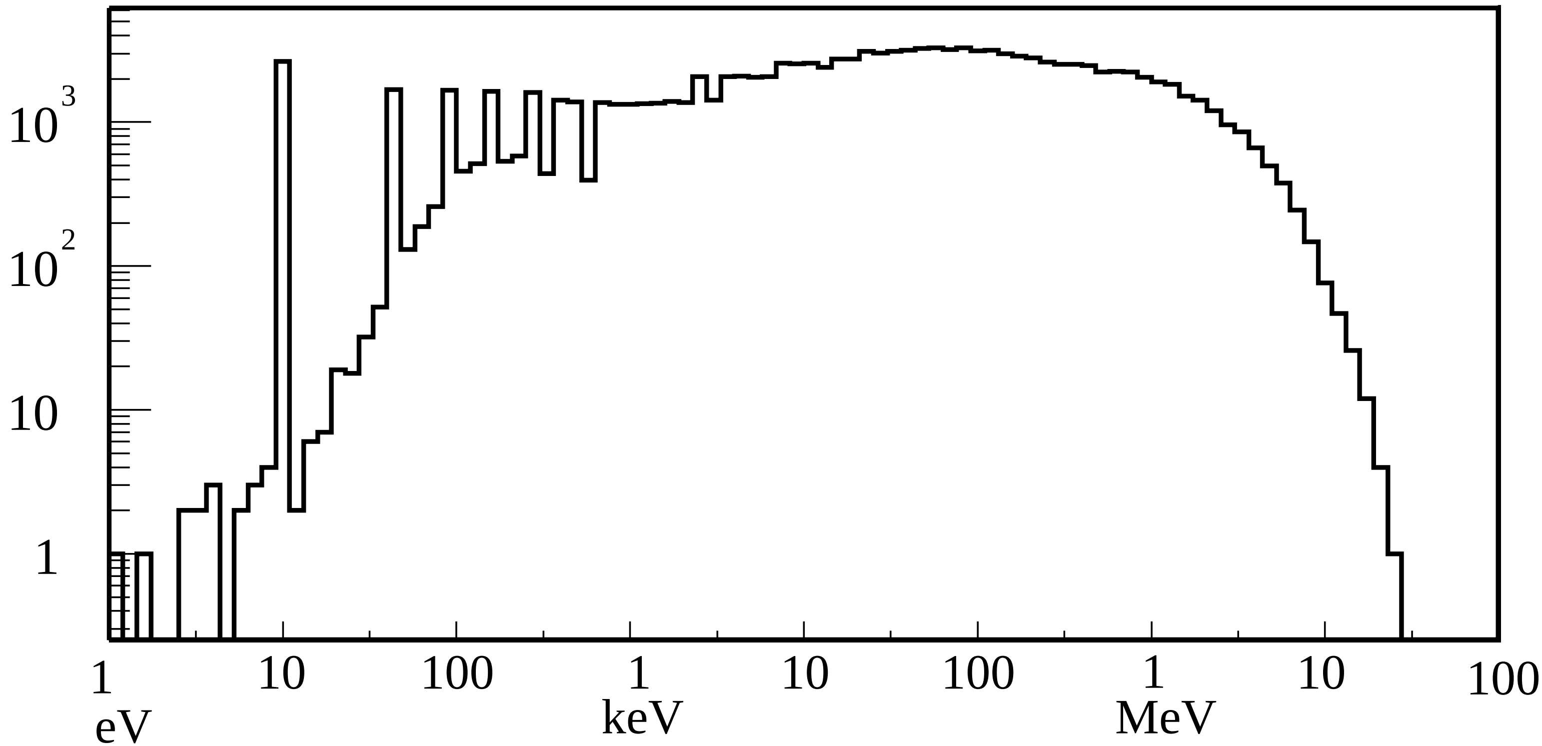
Synchrotron radiation from beam core (energy distribution of photons at IP)

$N\gamma^* = 1.3Ne$

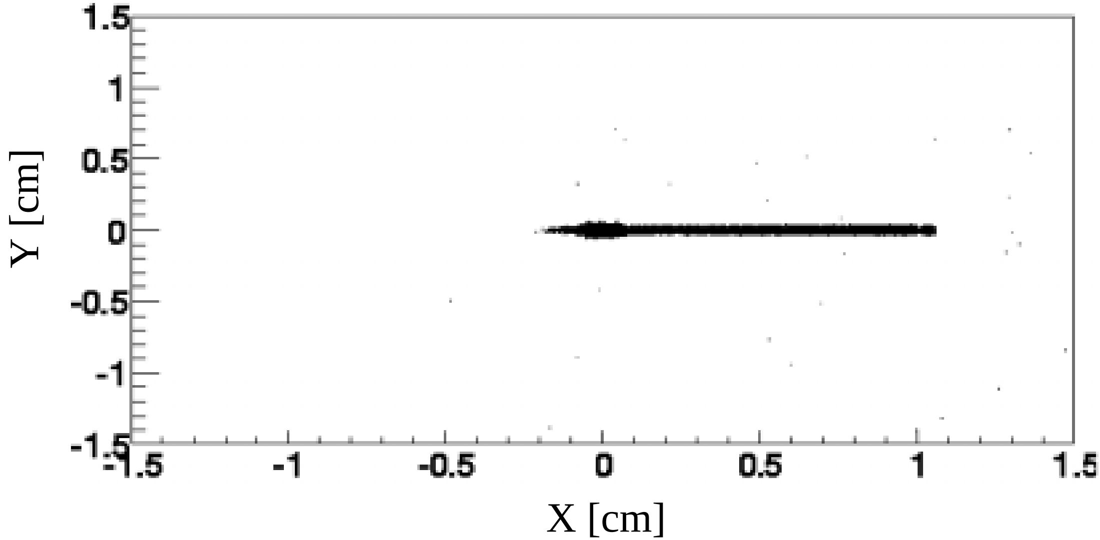
$= 0.81Ne\ (E\gamma^* > 10keV)$

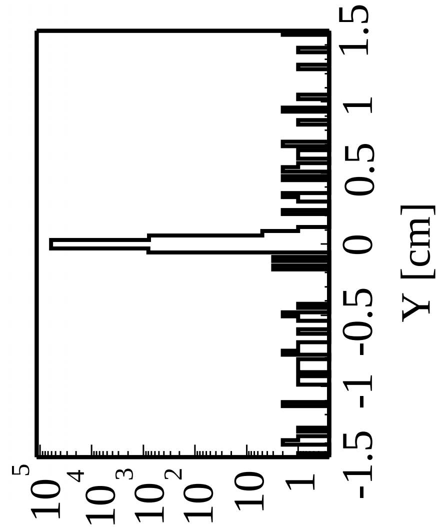
$\langle E\gamma^* \rangle = 0.35MeV$

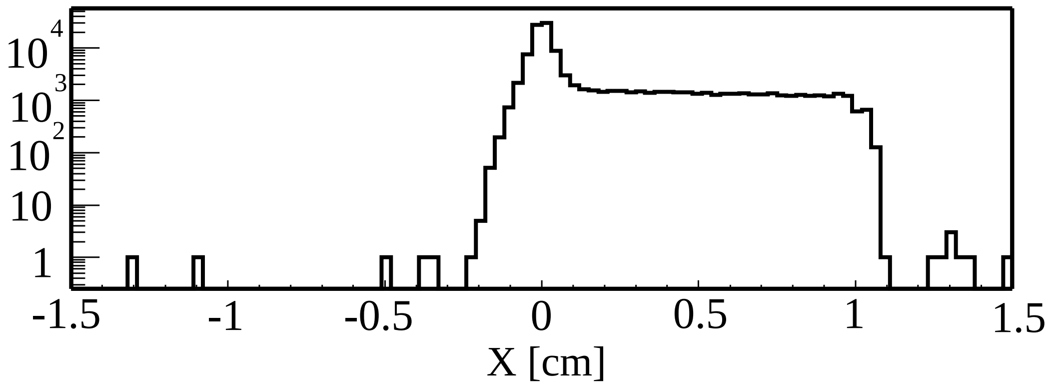
$(Ne = 94760)$



Synchrotron radiation from beam core (spatial distribution of photons at IP)







Photons from beam-bending distributes in the horizontal direction

photons are predominantly contained within beam pipe (normally 1cm radius)

Estimation of background (Beam Halo)

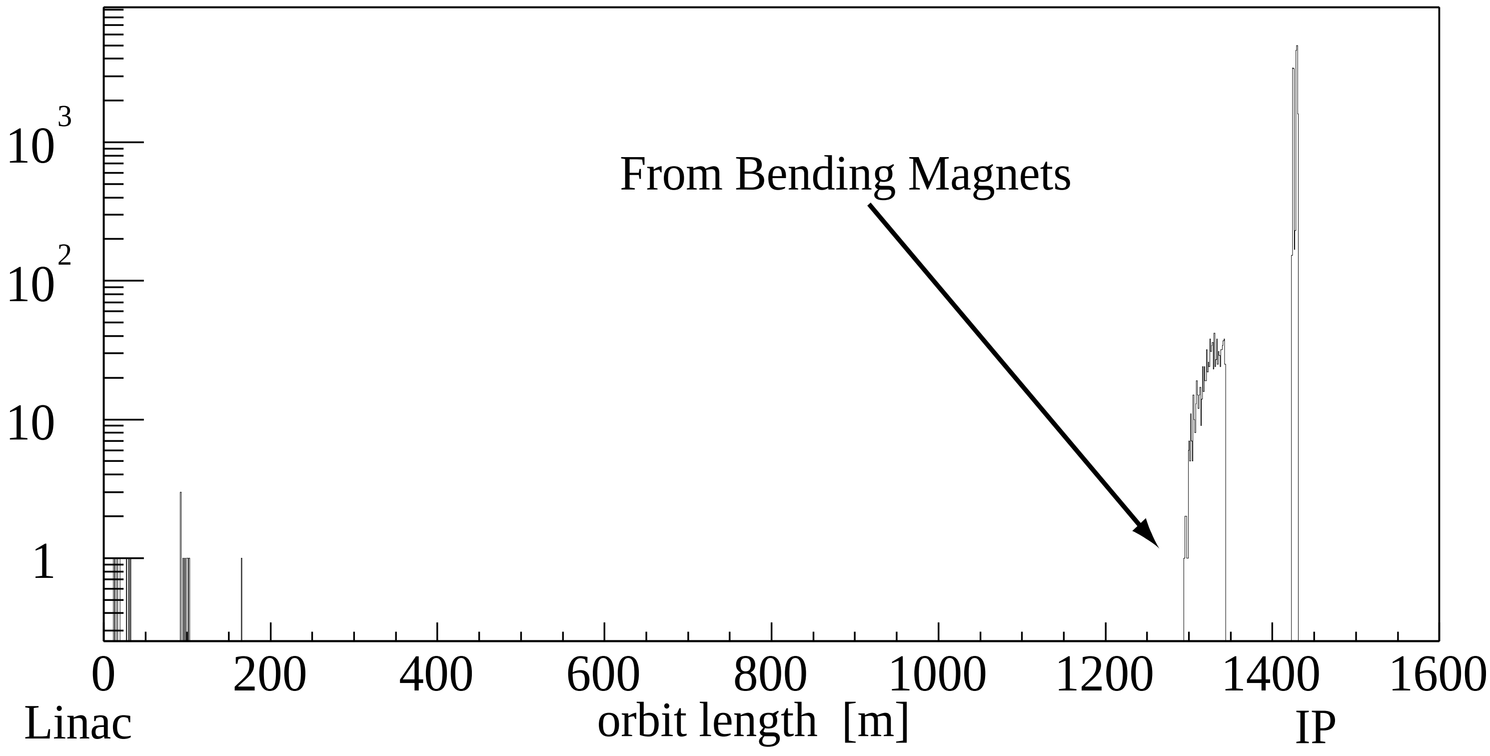
Assume beam halo as flat distribution

beam size
50 x σ_x = 0.75 mm
50 x $\sigma_{x'}$ = 21 μrad
200 x σ_y = 0.13 mm
200 x $\sigma_{y'}$ = 19 μrad
E = 250 GeV
$\Delta E/E$ = 0.003

Collimator section is designed to remove the halo particles.

Minimum gap size in collimator section
~12 σ_x , ~50 σ_y

Synchrotron radiation from beam halo (production position for photons at IP)



Photons reached to IP are mainly produced at FF-quadrupole and last bend

Synchrotron radiation from beam halo (energy distribution of photons at IP)

$N\gamma^* = 0.2Ne$

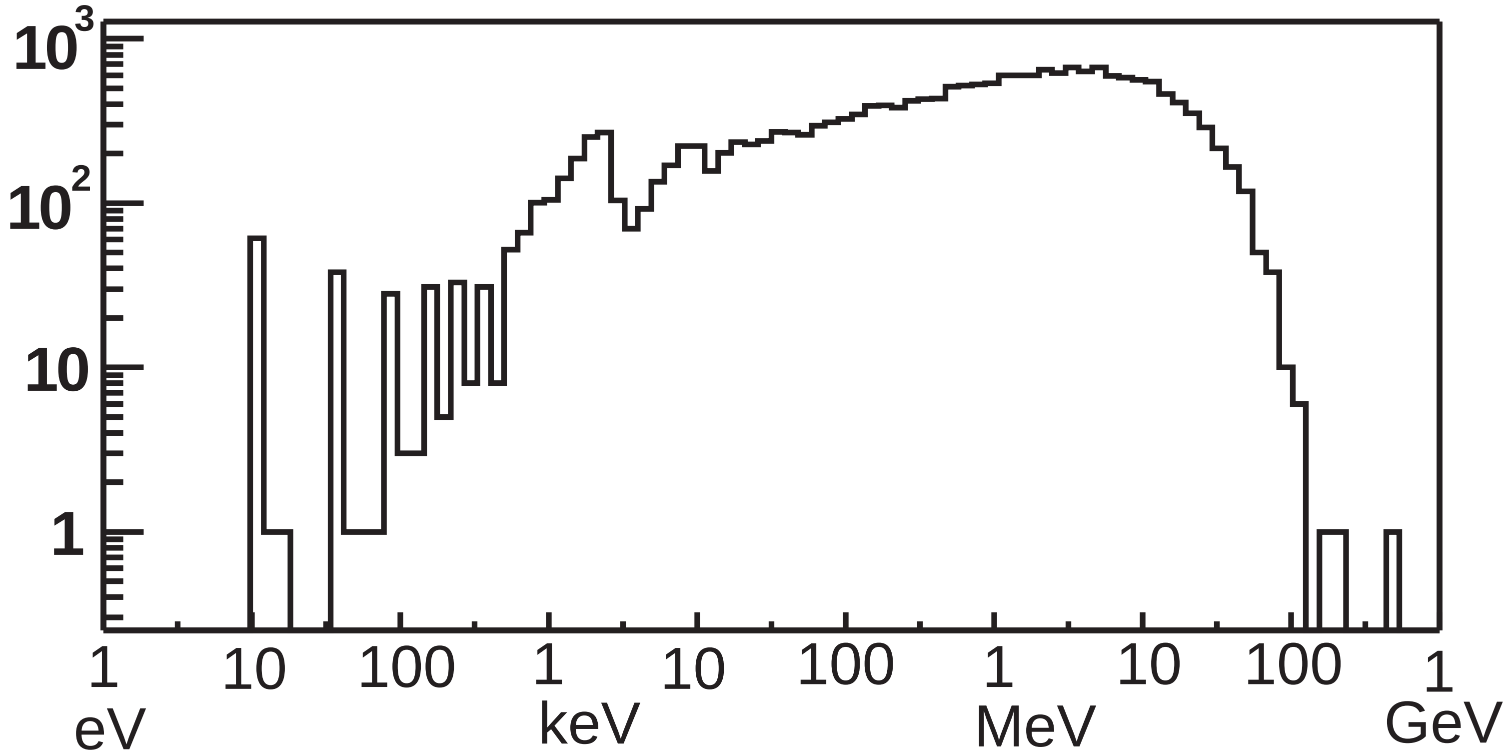
$= 0.18Ne \ (E\gamma^* > 10keV)$

$\langle E\gamma^* \rangle = 4.76MeV$

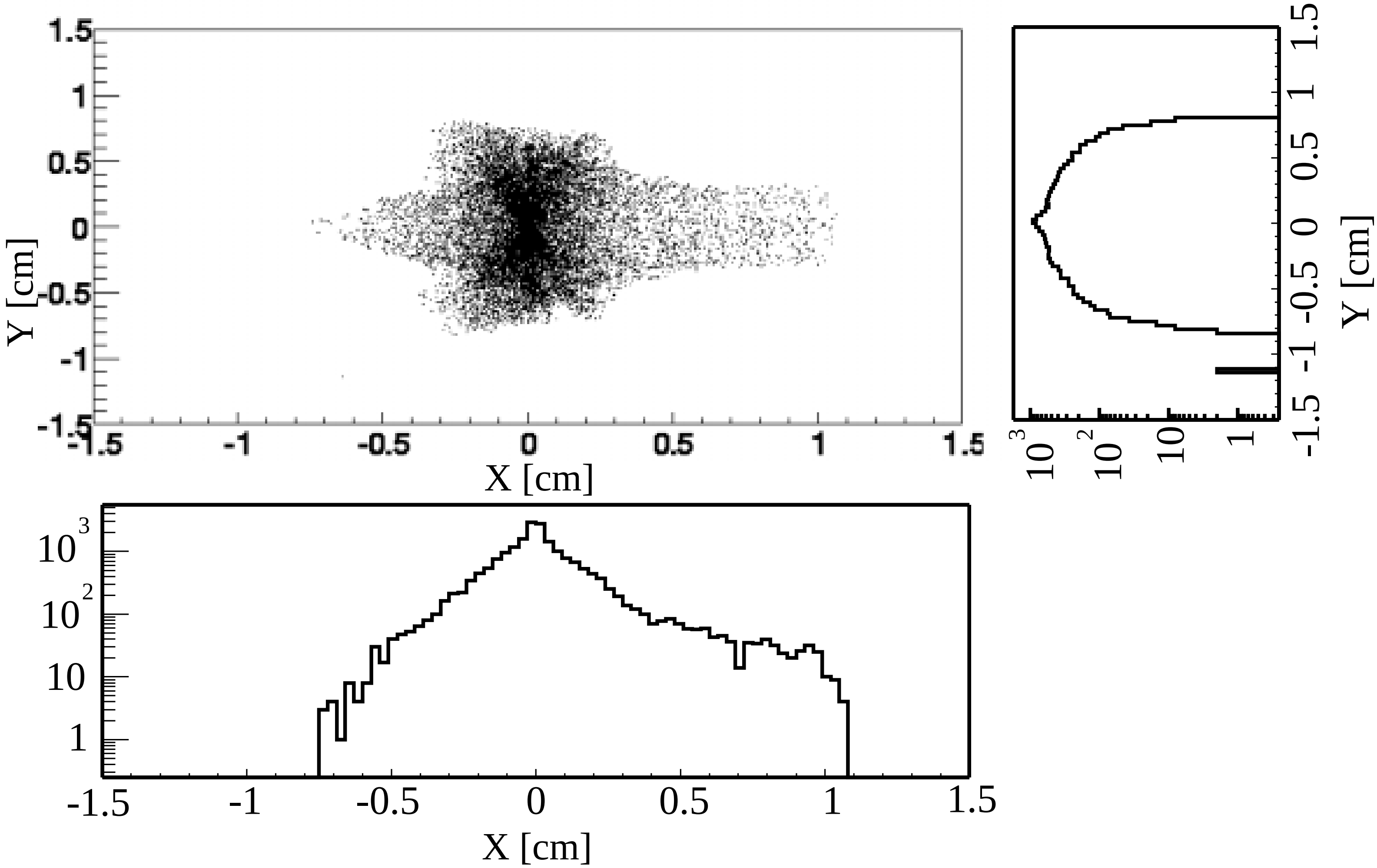
Ne = 94808

(at the entrance of BDS)

=2141 (at IP)

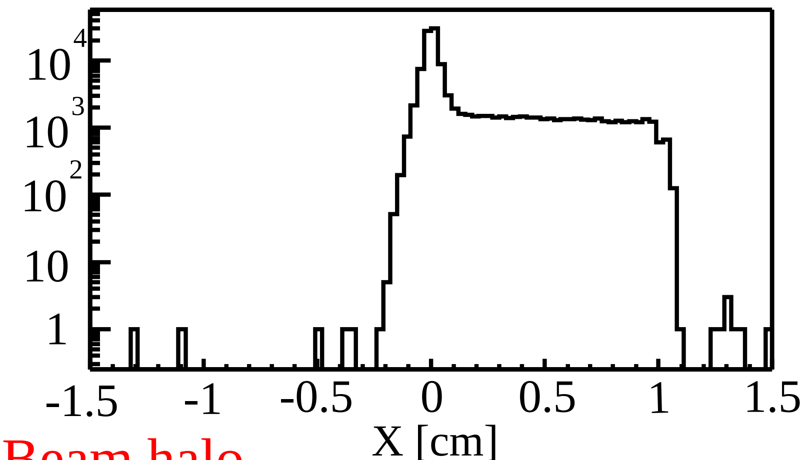


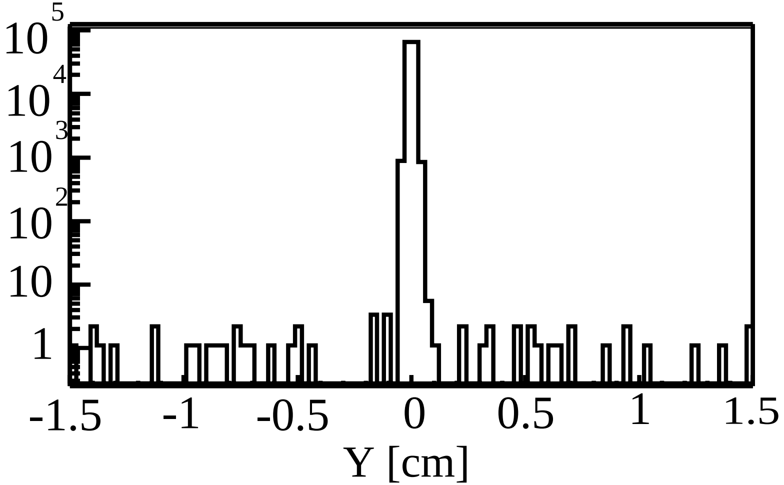
Synchrotron radiation from beam halo (spatial distribution of photons at IP)



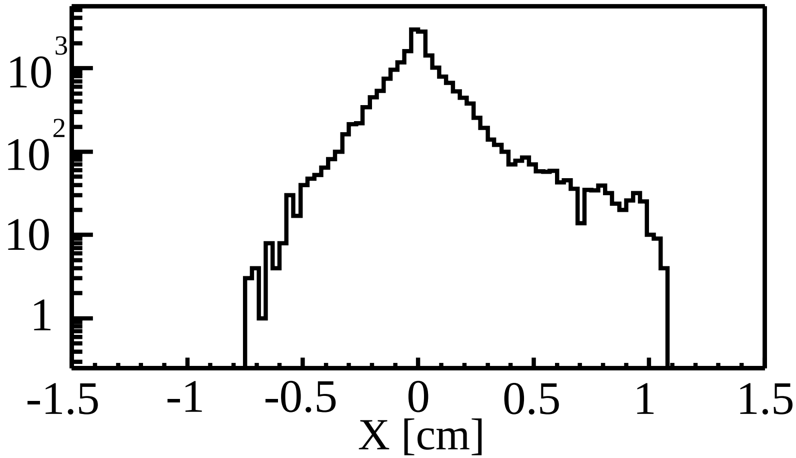
Synchrotron radiation
(Beam core vs Beam halo)

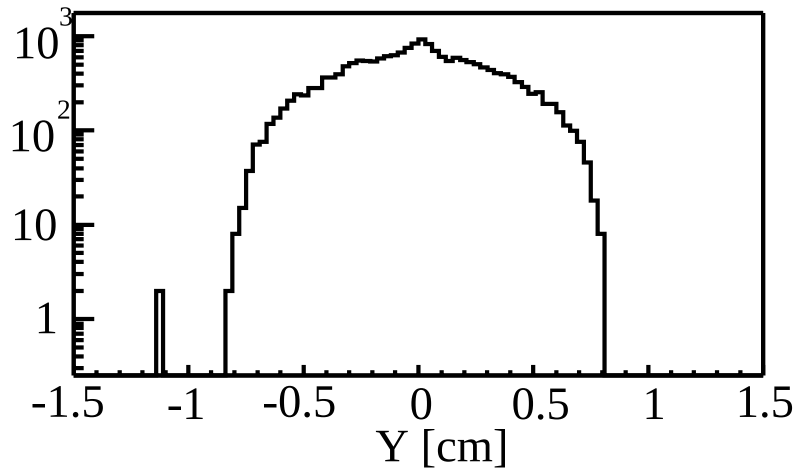
Beam core





Beam halo

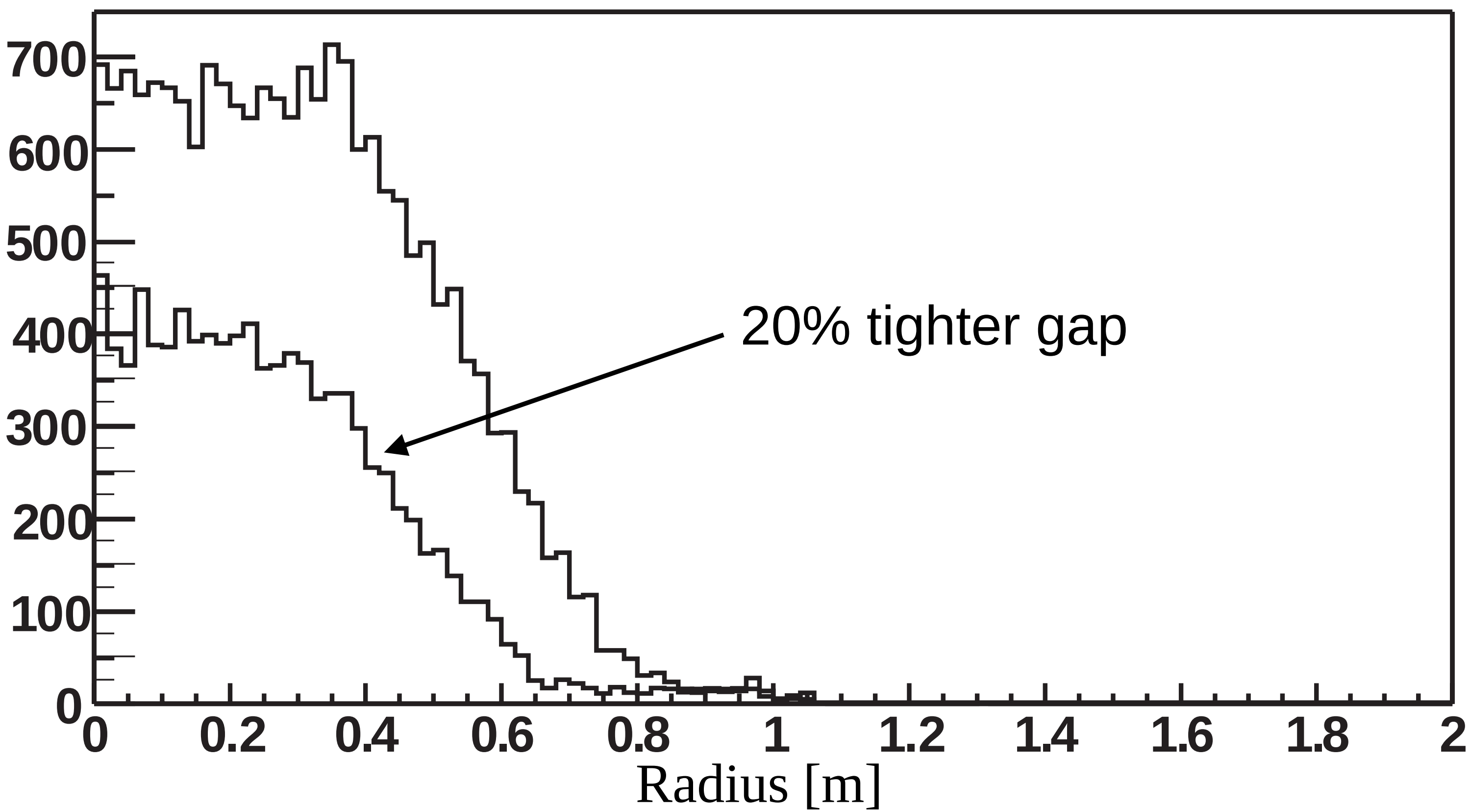




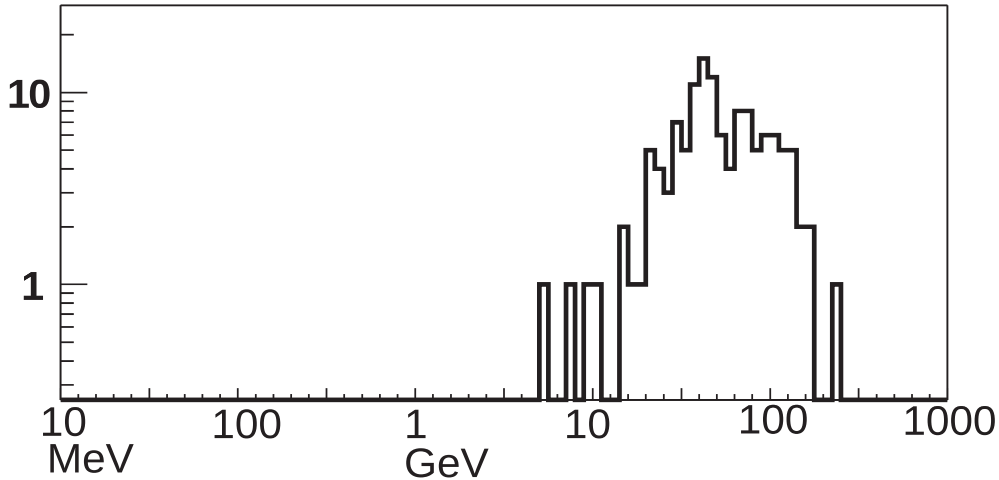
Synchrotron radiation from beam halo (effect of modification on collimator gap size)

SR photons from Beam halo

Radial distribution of photons at IP



Muon background from beam halo
(energy and spatial distribution of muons at IP)

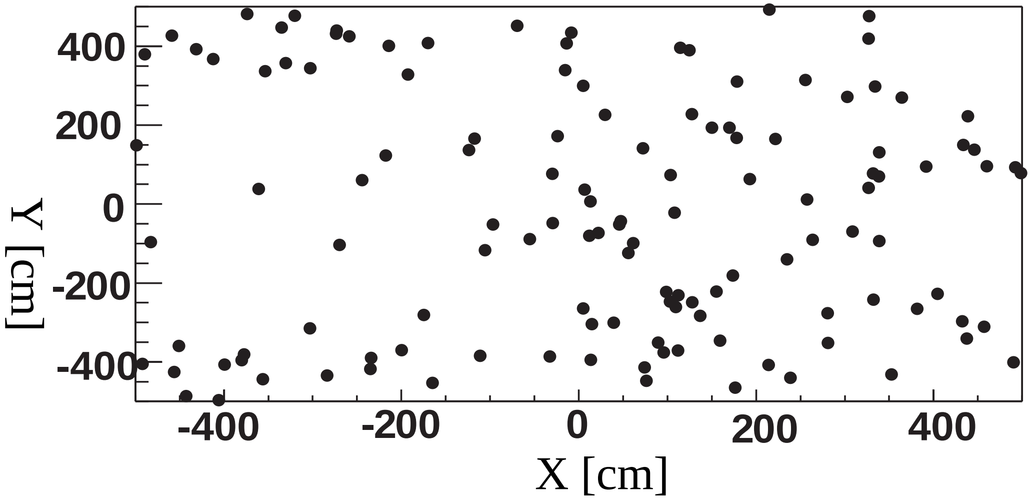


Ne = 94808

(at the entrance of BDS)

=2141 (at IP)

Without muon shield

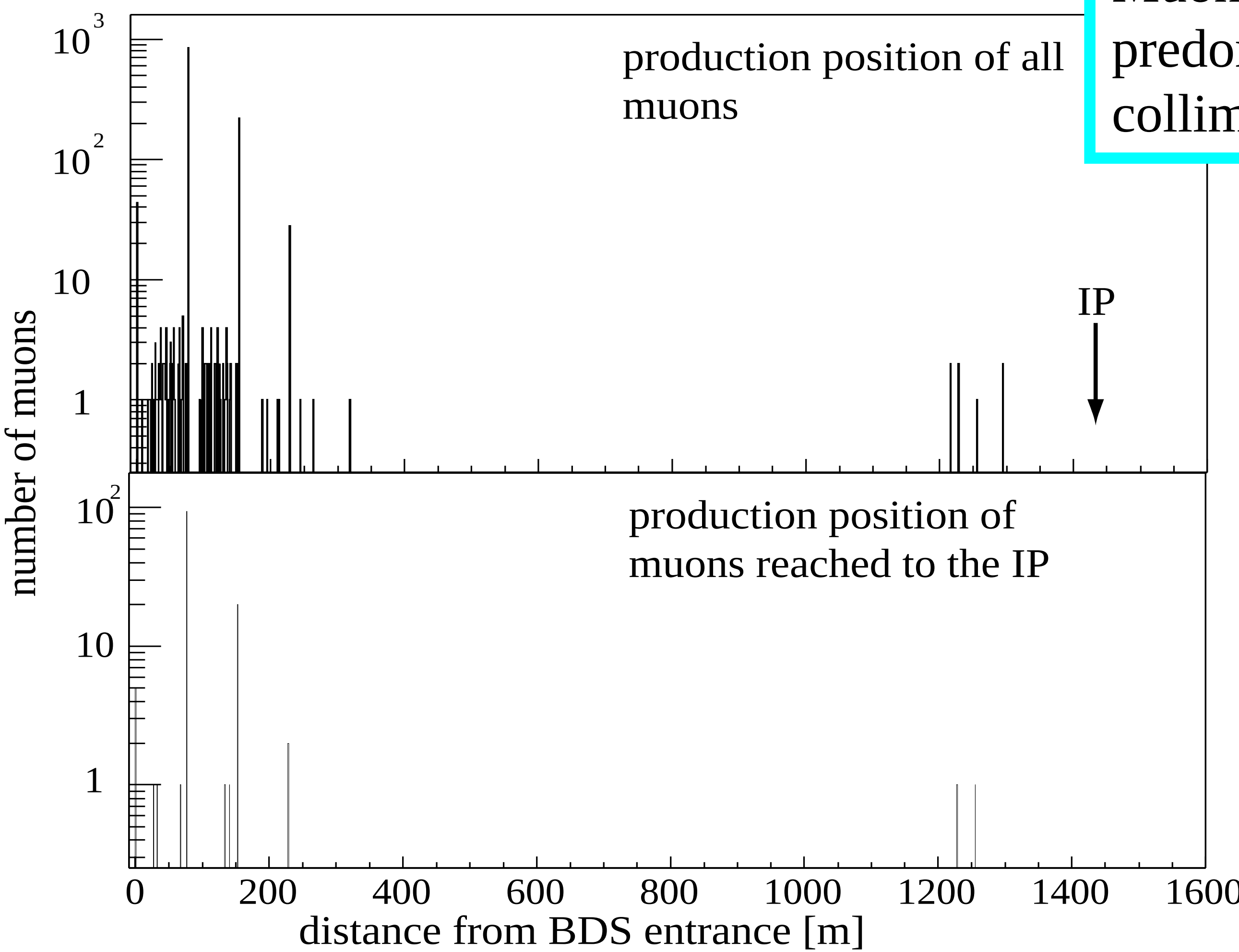


Nmuon = 1.4 x 10^{-5} Ne

<Emuon> = 61GeV (at IP)

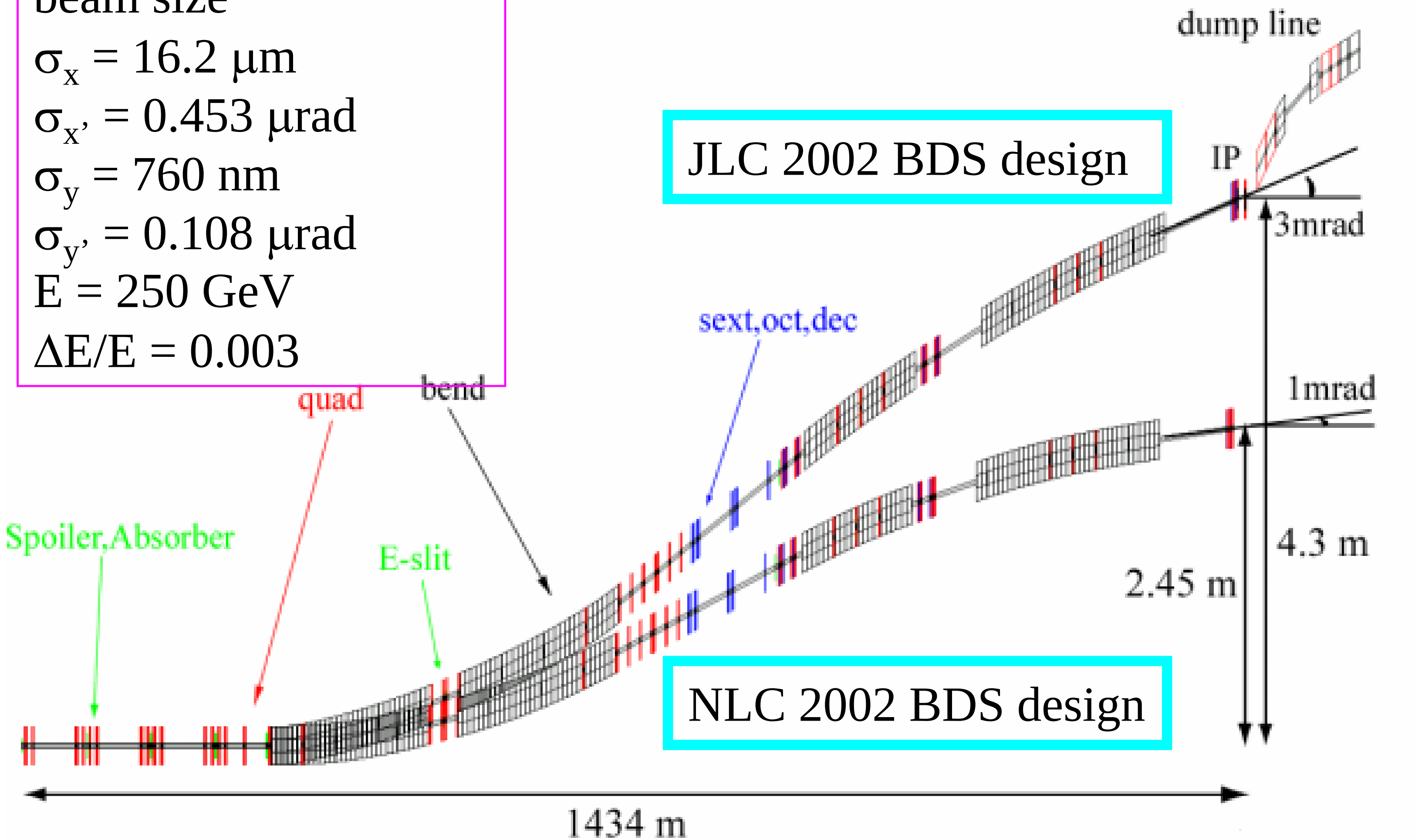
Muon background from beam halo (production position of muons)

Muons are produced predominantly at the collimator section.



2-4) Calculation with the NLC BDS geometry

Initial beam parameter
Gaussian distribution.
beam size
σ_x = 16.2 μm
$\sigma_{x'}$ = 0.453 μrad
σ_y = 760 nm
$\sigma_{y'}$ = 0.108 μrad
E = 250 GeV
ΔE/E = 0.003



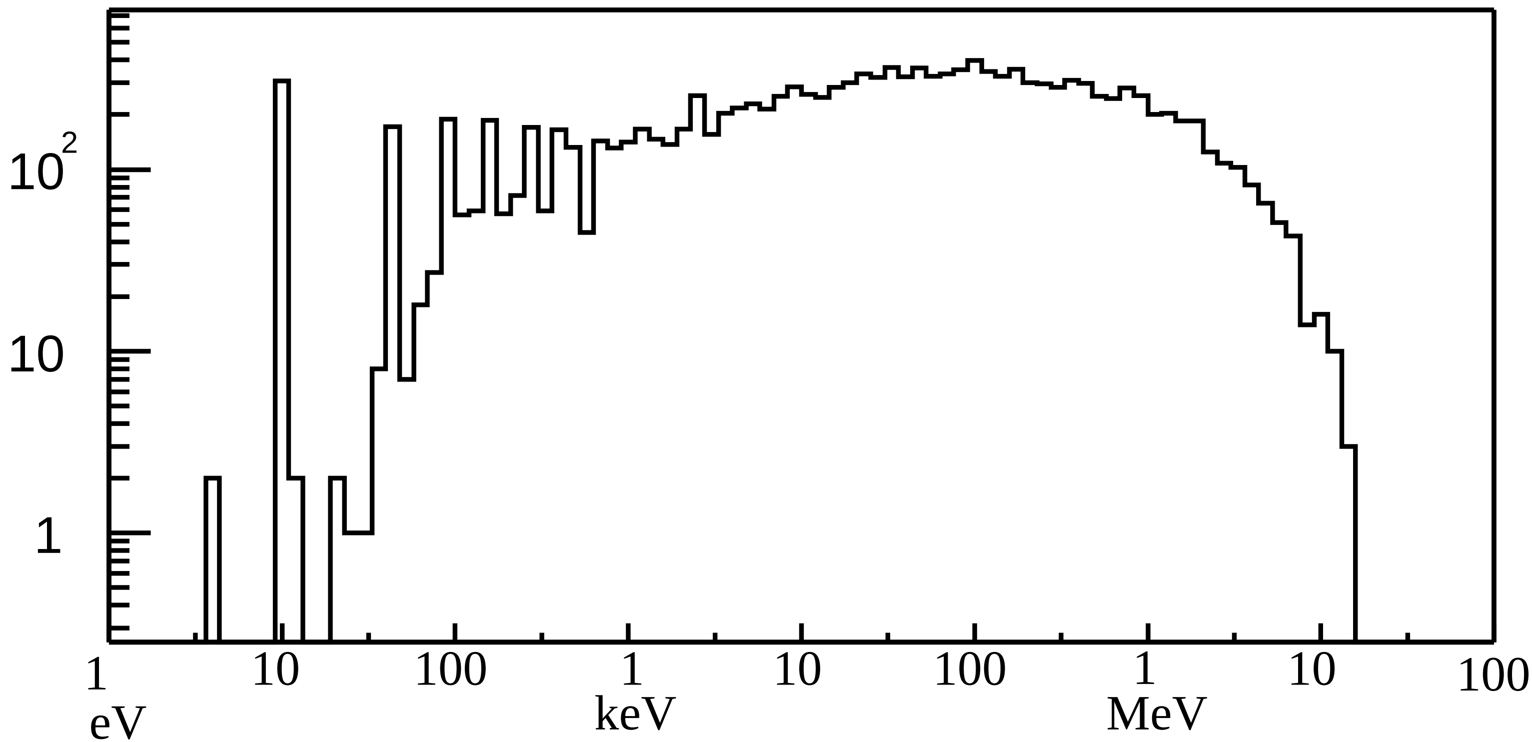
Synchrotron radiation from beam core (NLC, energy distribution of photons at IP)

Ne = 10000

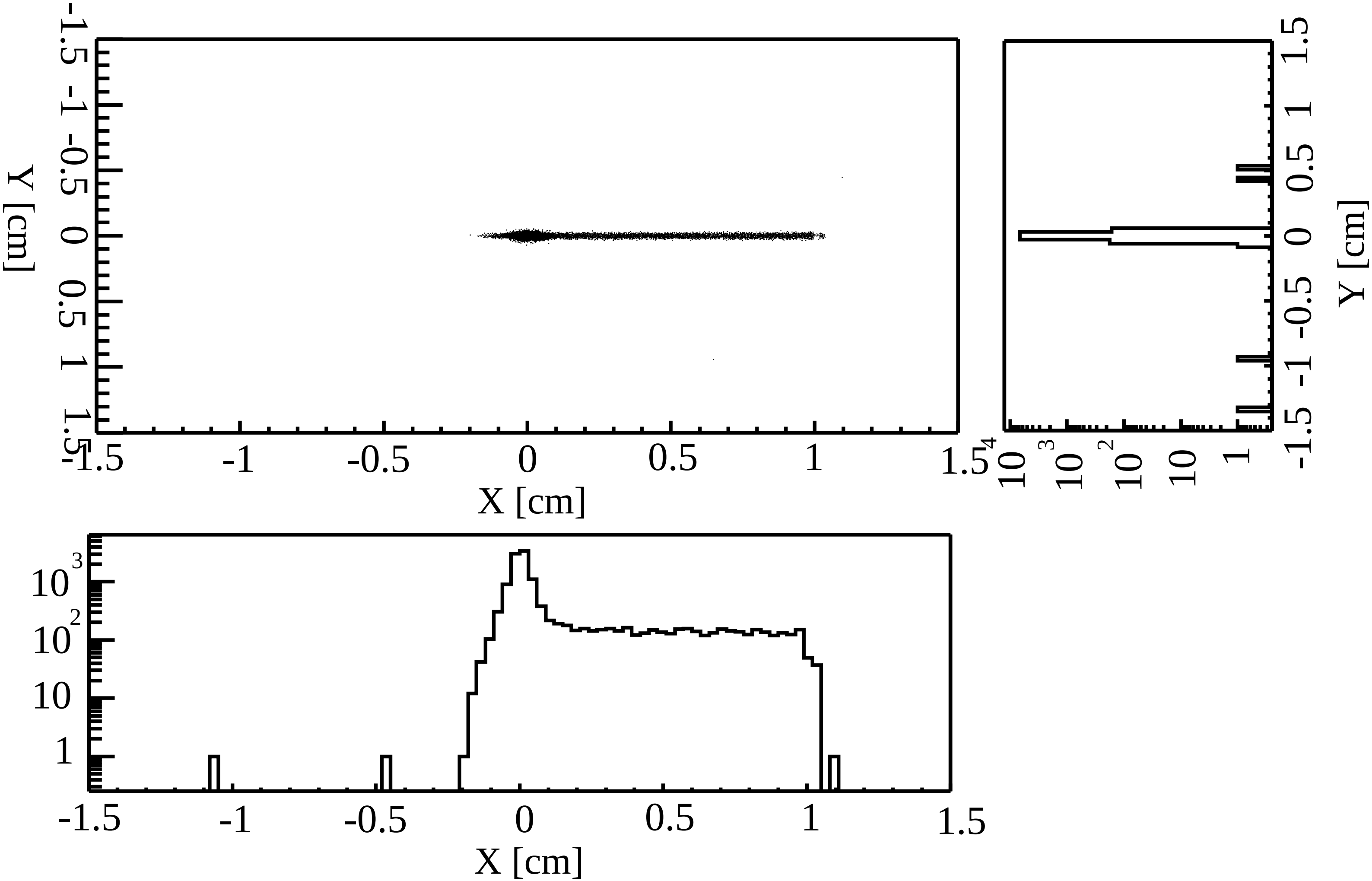
Nγ* = 1.4Ne (1.3Ne : JLC)

= 0.9Ne (>10keV) (0.81Ne : JLC)

<Eγ*> = 0.38MeV (0.35MeV : JLC)



Synchrotron radiation from beam core (NLC, spatial distribution of photons at IP)



3) Summary

- Beam Delivery System simulation based on Geant4 has been developed.
- Geant4 accuracy problem is fixed ⇨ Many thanks to Dr. Blair.
- Background generated from synchrotron radiation and muon production are included.
- Our code can be also applied to NLC.

Future plan

- Estimation of the background from neutrons produced at the extraction line and beam dump.
- Input the geometries of mask and muon shield component.
- Public release of the source programs.