

# Simulation study of linear collider Beam Delivery System

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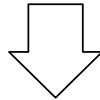
- 1) Introduction
- 2) BDS simulation
  - 2-1) Transportation calculation in Geant4
  - 2-2) Estimation of background with the JLC BDS geometry
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    - From beam halo
  - 2-3) Calculation with the NLC BDS geometry
- 3) Summary

# 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.

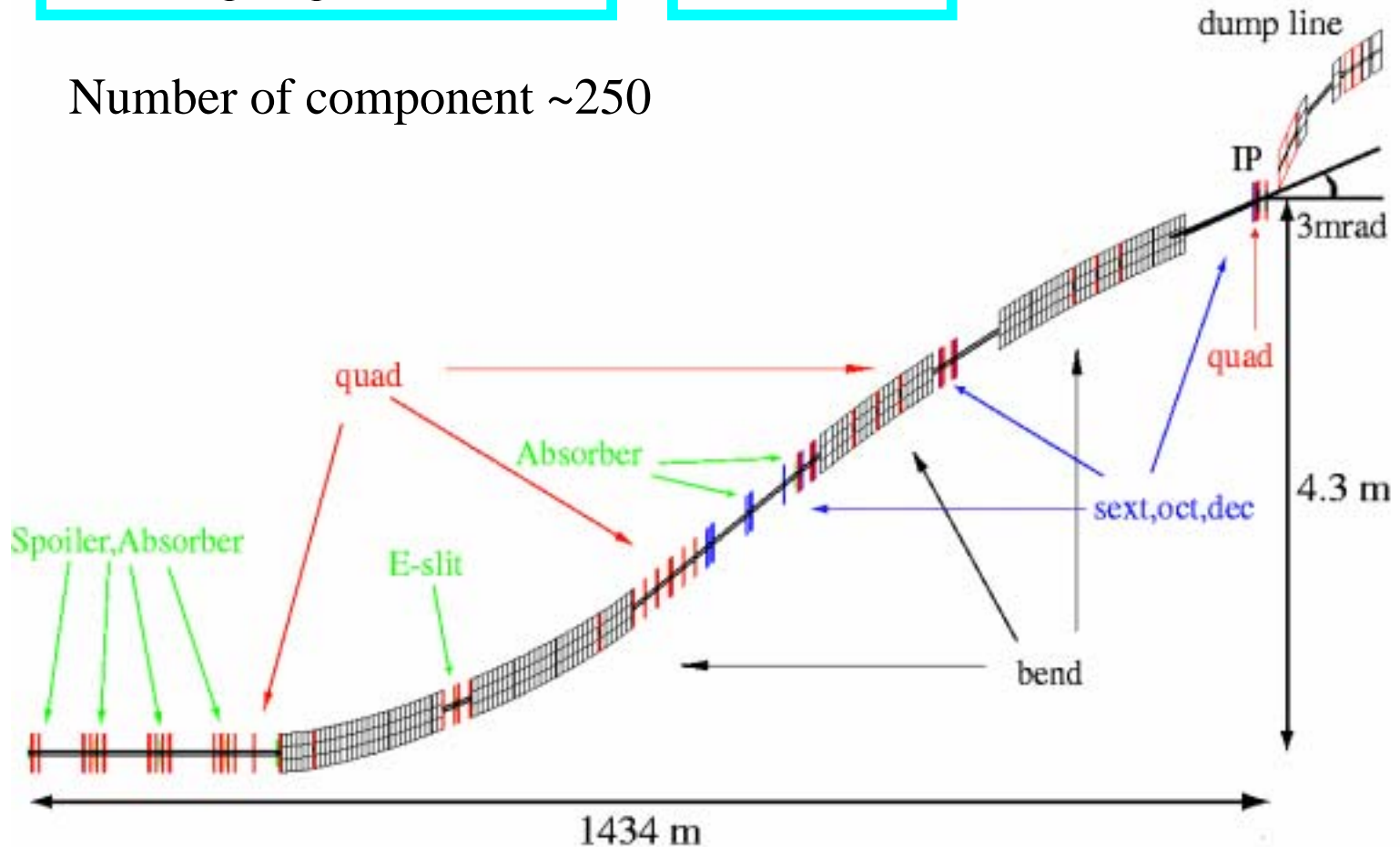
# JLC Beam Delivery System geometry

JLC Beam Delivery System Road Map Report 2002

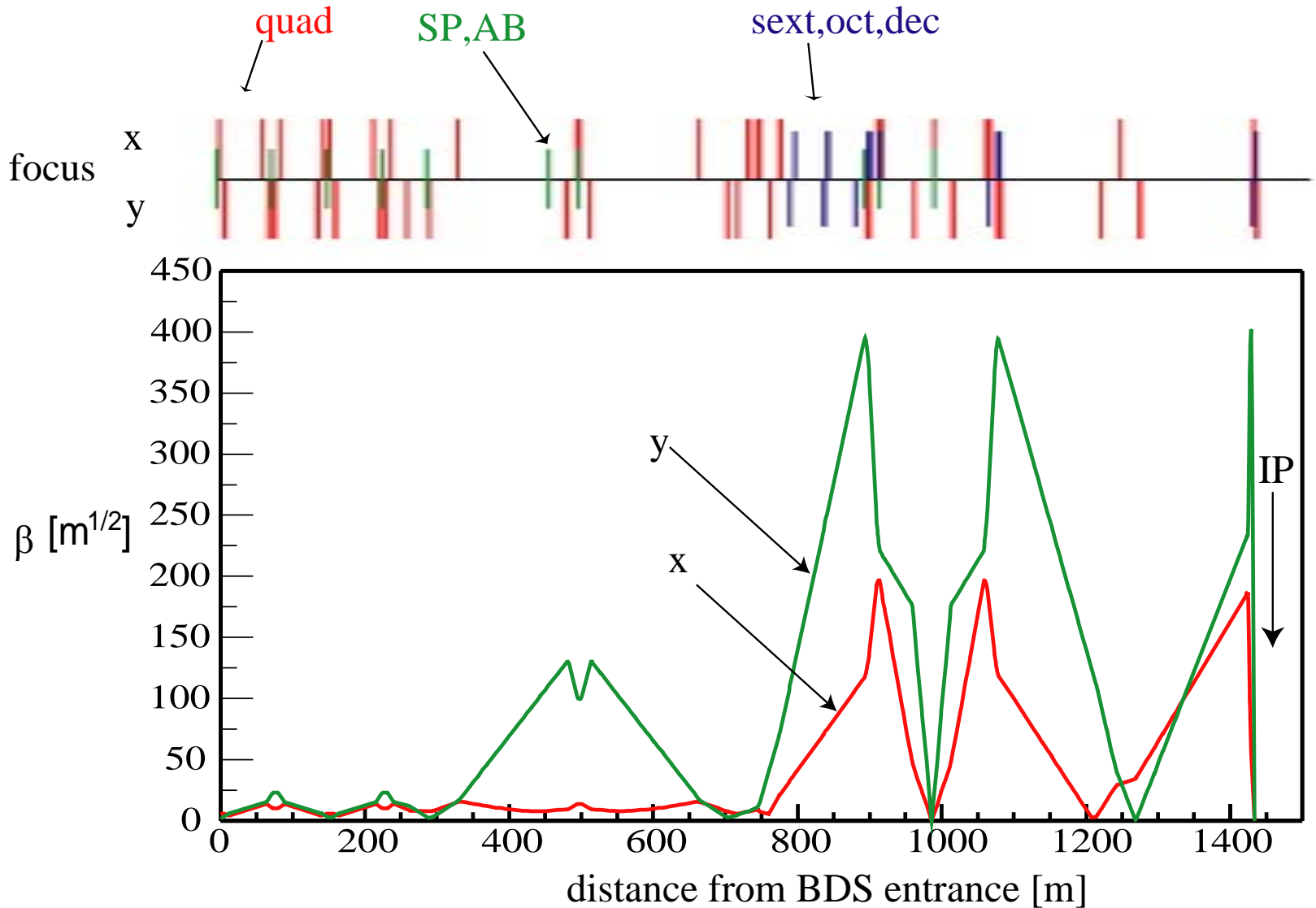
Crossing angle 6mrad

$L^* = 3.5\text{m}$

Number of component ~250

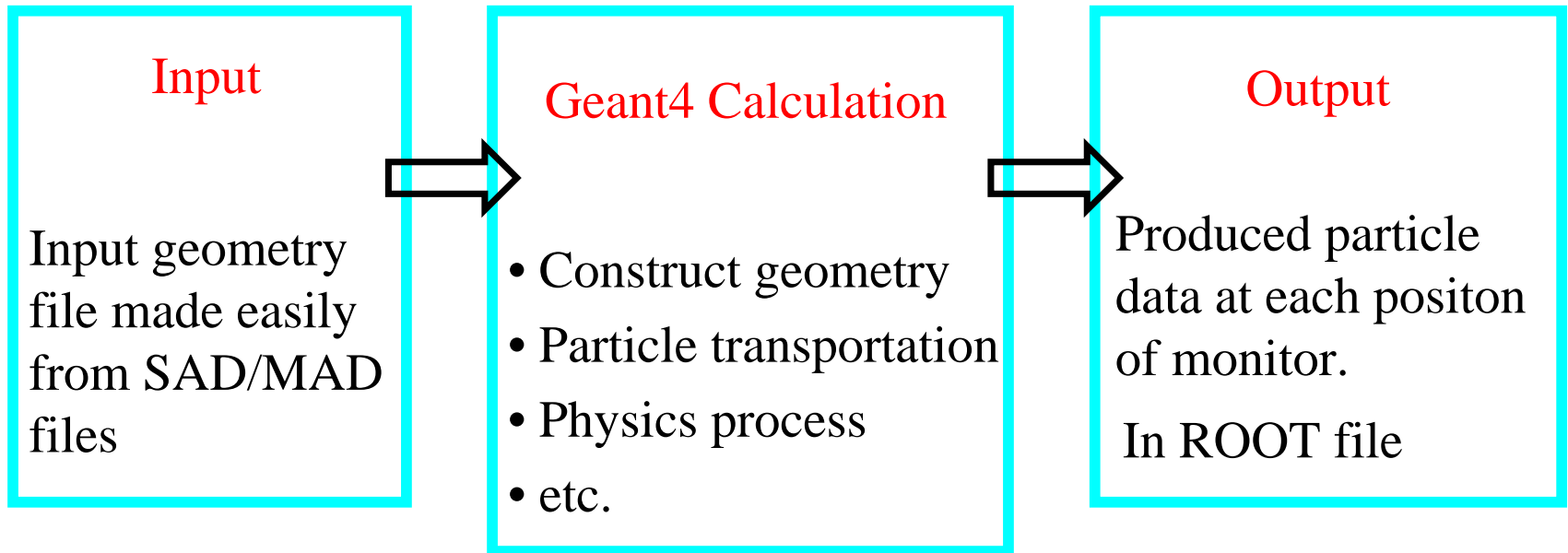


# Beta-function of JLC BDS geometry



# BDS simulation based on Geant4 at U. Tokyo

We construct the BDS simulation using Geant4

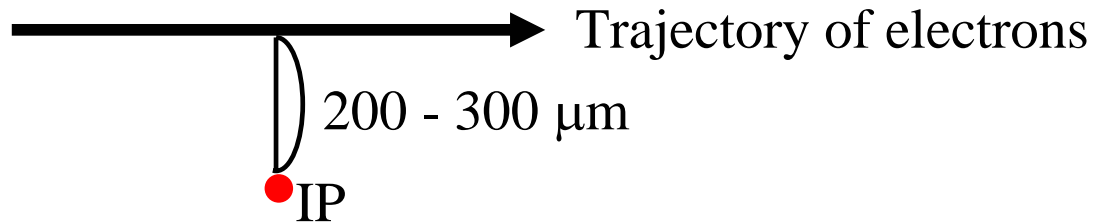


## 2) BDS simulation

### 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  $\mu\text{m}$  shift in x at IP.



Beam size at IP is more than 10 times larger than designed one.

$\text{RMS}_x^* = 3 \mu\text{m}$  (designed size 211nm)

$\text{RMS}_y^* = 370 \text{ nm}$  (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 referred correctly.

Using the analytical stepper instead of the default one

(Geant4 default stepper is 4<sup>th</sup> order Runge-Kutta.)

Bend and Quad  $\implies$  Linear Beam Optics.  
Solve the eq.of mot. using transfer matrix.

Sext,Oct,Dec  $\implies$  Second order linear approximation  
 $r_1 = r_0 + r' * \text{step} + r'' * (\text{step})^2/2$

After these modifications

Transport the electron to IP  $\implies$  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  $\beta$ -function.

Initial beam parameter  
Gaussian distribution  
emittance

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

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

beam size

$$\sigma_x = 14.8 \mu\text{m}$$

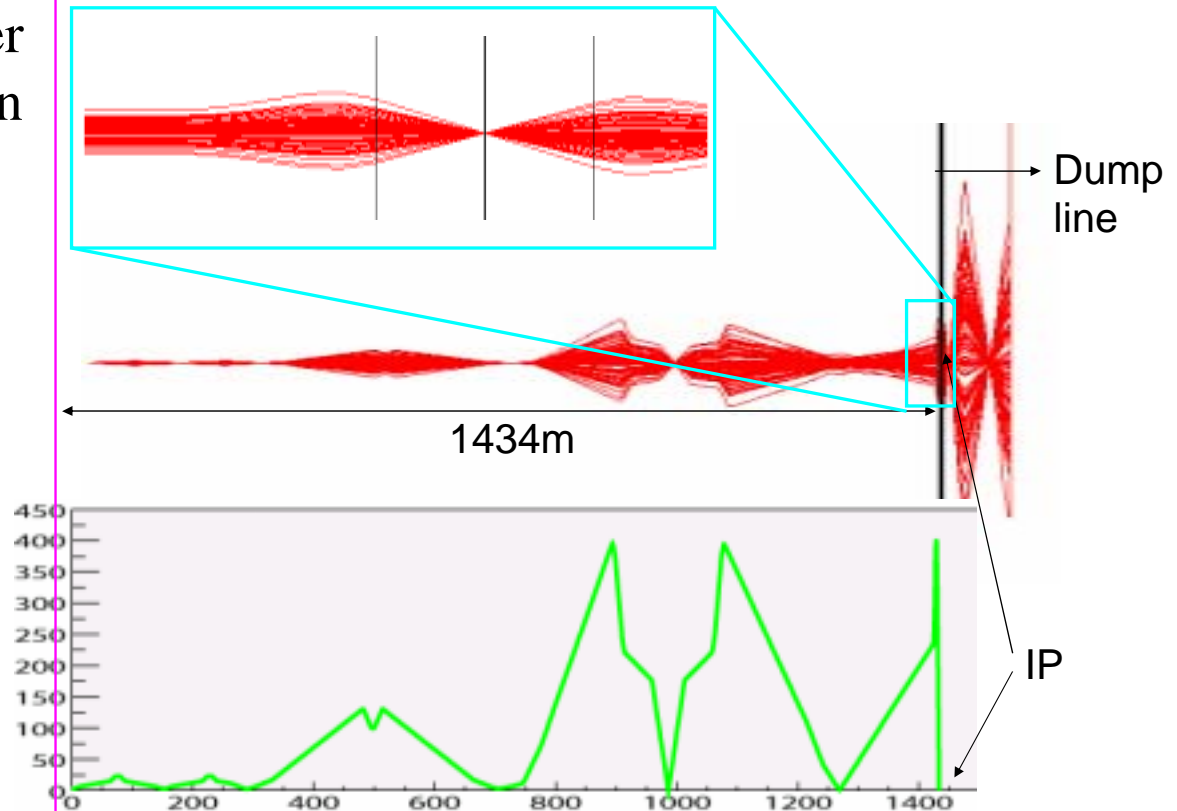
$$\sigma_{x'} = 0.413 \mu\text{rad}$$

$$\sigma_y = 658 \text{ nm}$$

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

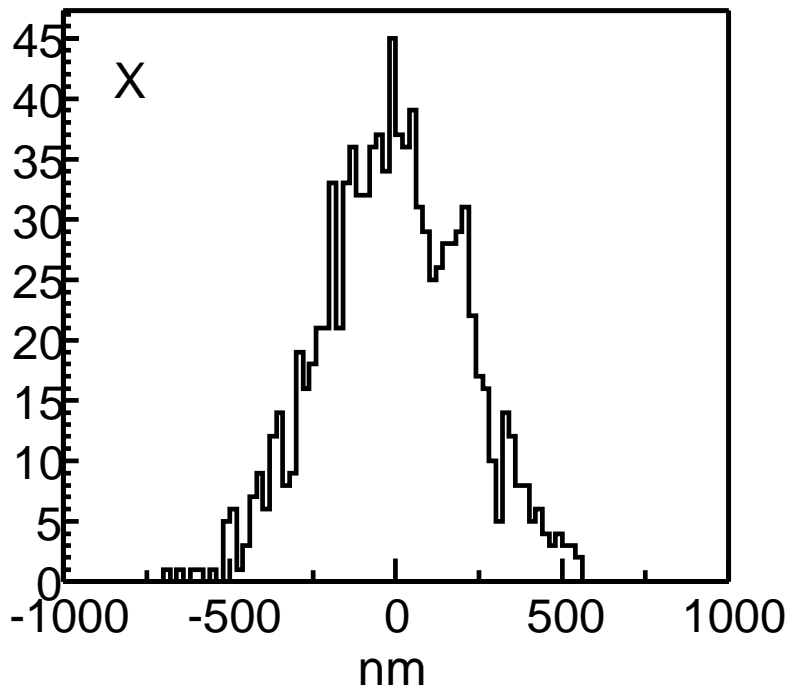
$$E = 250 \text{ GeV}$$

$$\Delta E/E = 0.003$$

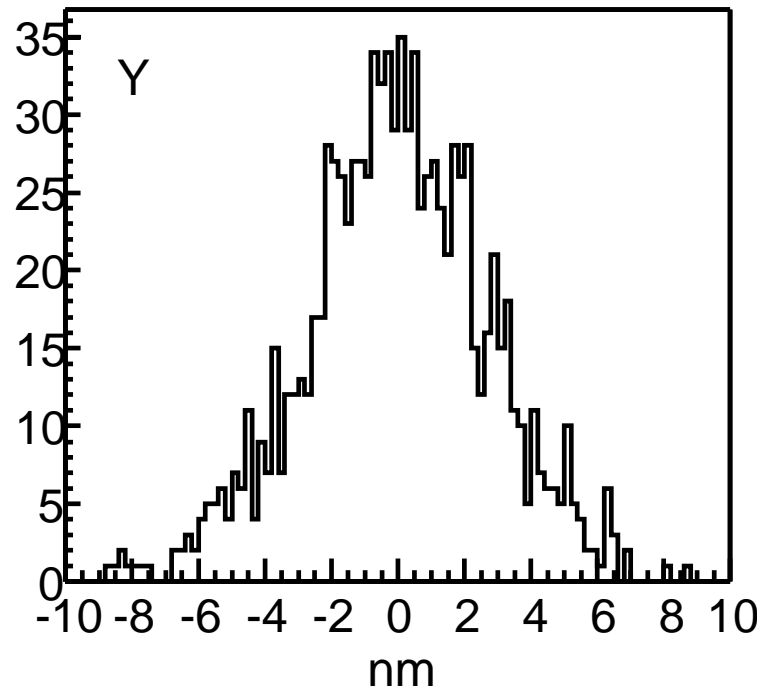


# Beam focusing (beam size at IP)

$\text{RMS}_x^* = 214.5\text{nm}$   
(design : 211nm)



$\text{RMS}_y^* = 2.73\text{nm}$   
(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

$$\sigma_x = 14.8 \mu\text{m}$$

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

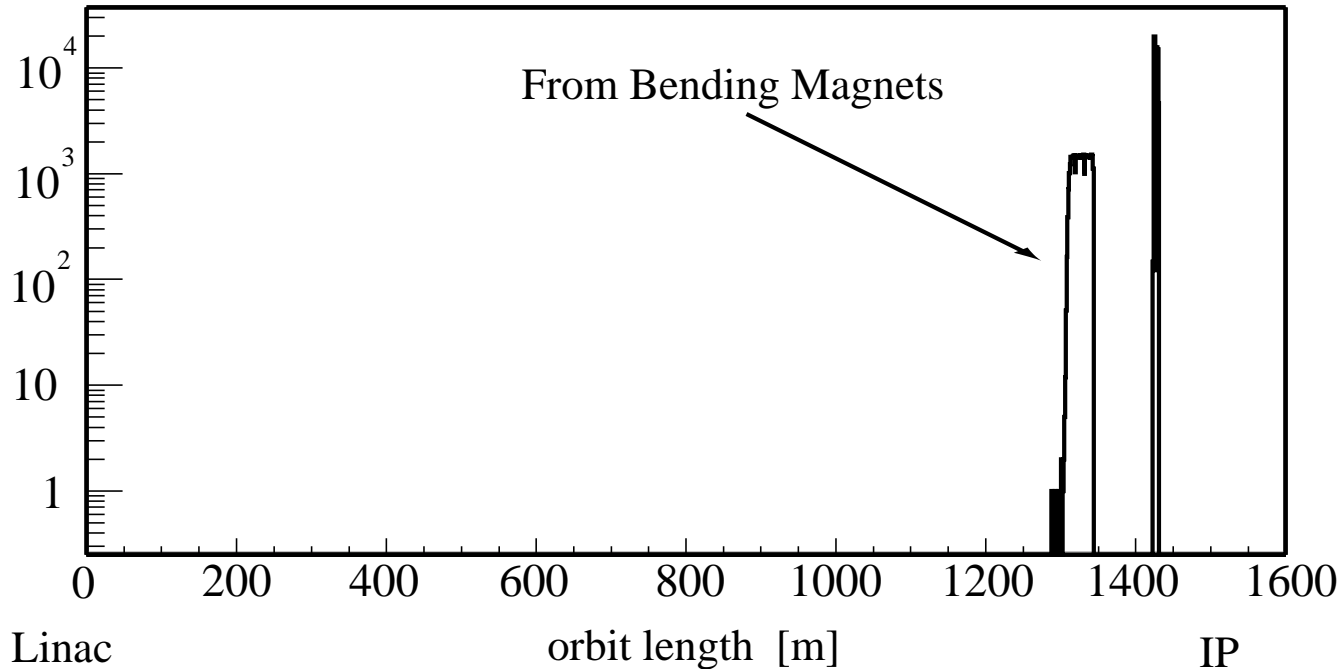
$$\sigma_y = 658 \text{ nm}$$

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

$$E = 250 \text{ GeV}$$

$$\Delta E/E = 0.003$$

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



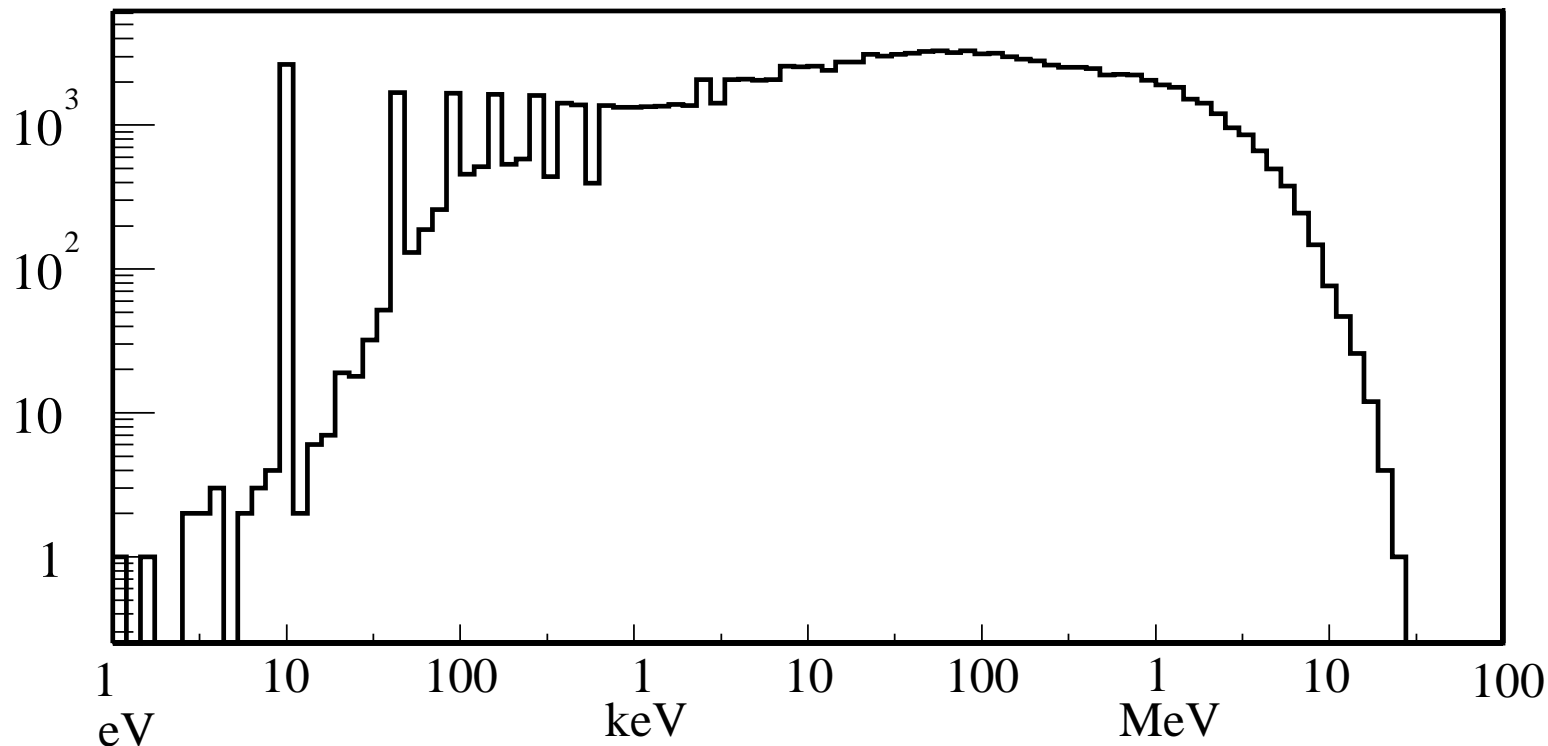
Photons reached to IP are  
mainly produced at FF-  
quadrupole and the last bend

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

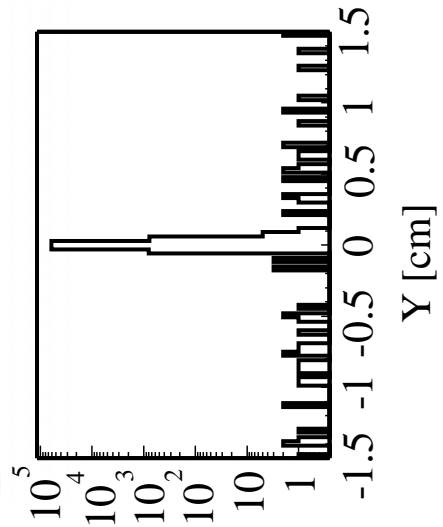
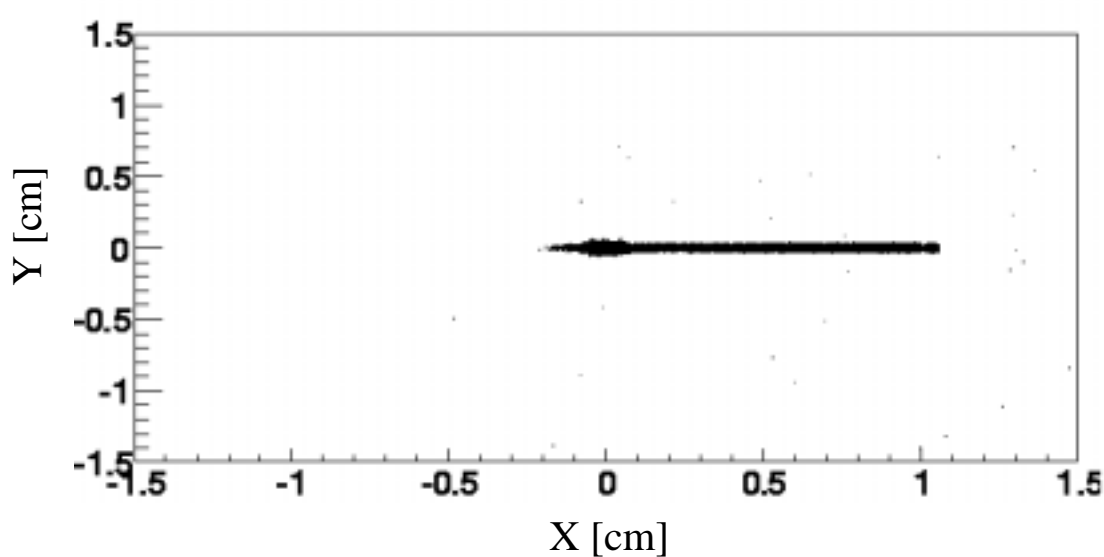
$$N_{\gamma}^* = 1.3N_e$$

$$= 0.81N_e (E_{\gamma}^* > 10\text{keV}) \quad (N_e = 94760)$$

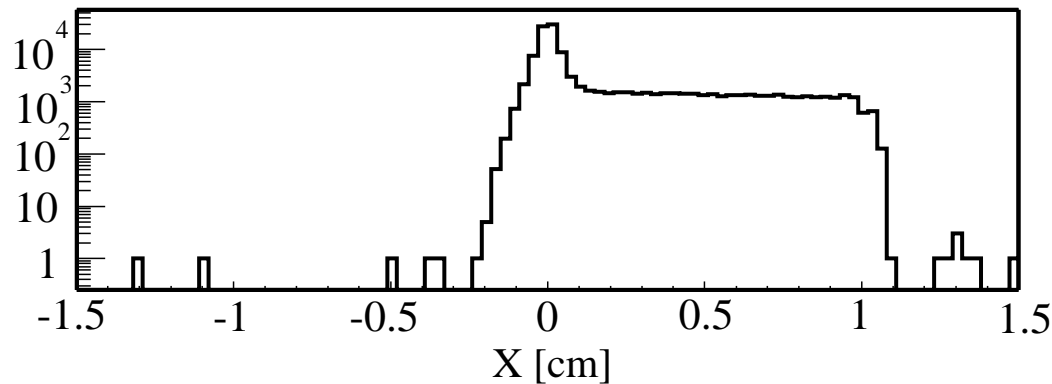
$$\langle E_{\gamma}^* \rangle = 0.35\text{MeV}$$



# 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

$$50 \times \sigma_x = 0.75 \text{ mm}$$

$$50 \times \sigma_x' = 21 \text{ } \mu\text{rad}$$

$$200 \times \sigma_y = 0.13 \text{ mm}$$

$$200 \times \sigma_y' = 19 \text{ } \mu\text{rad}$$

$$E = 250 \text{ GeV}$$

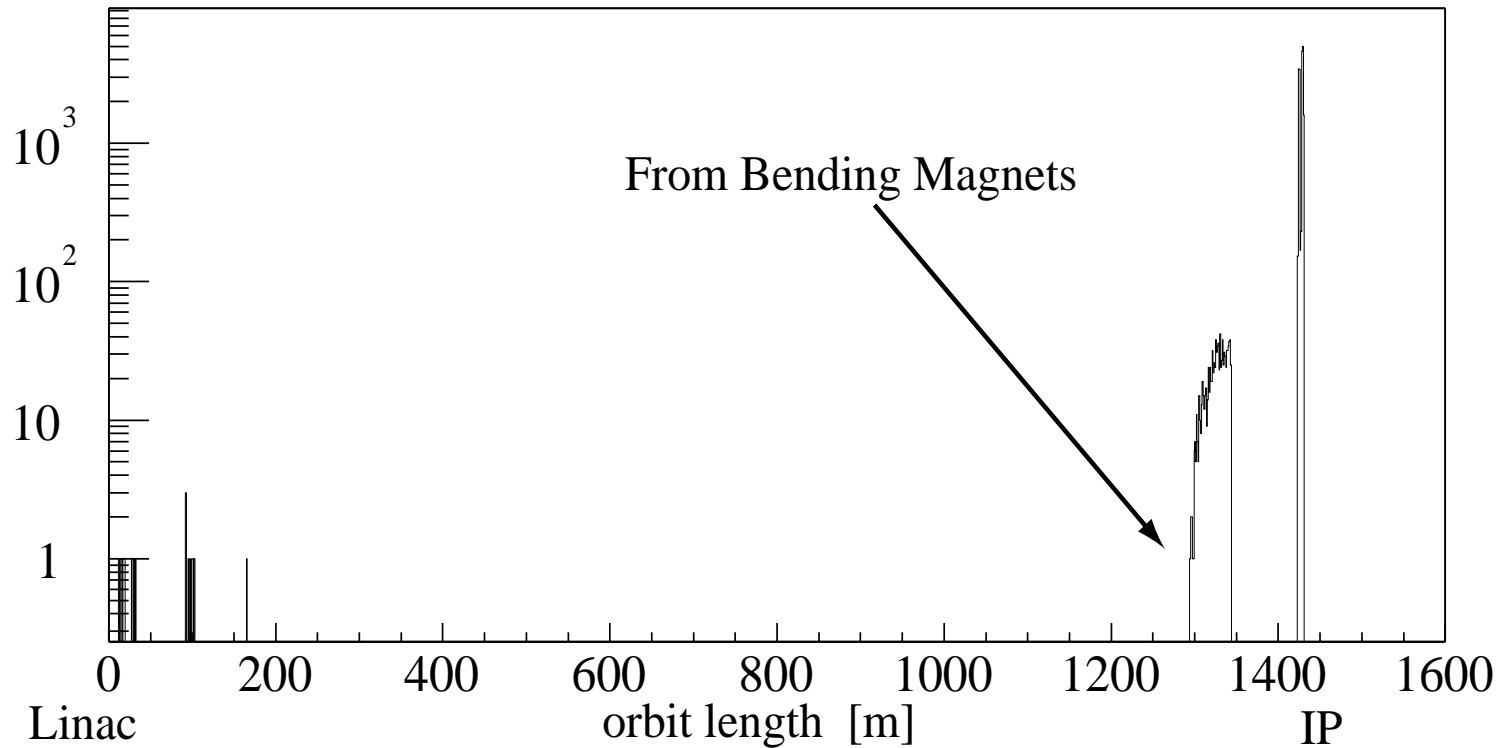
$$\Delta E/E = 0.003$$

Collimator section is designed to  
remove the halo particles.

Minimum gap size in collimator section

$$\sim 12 \sigma_x , \sim 50 \sigma_y$$

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

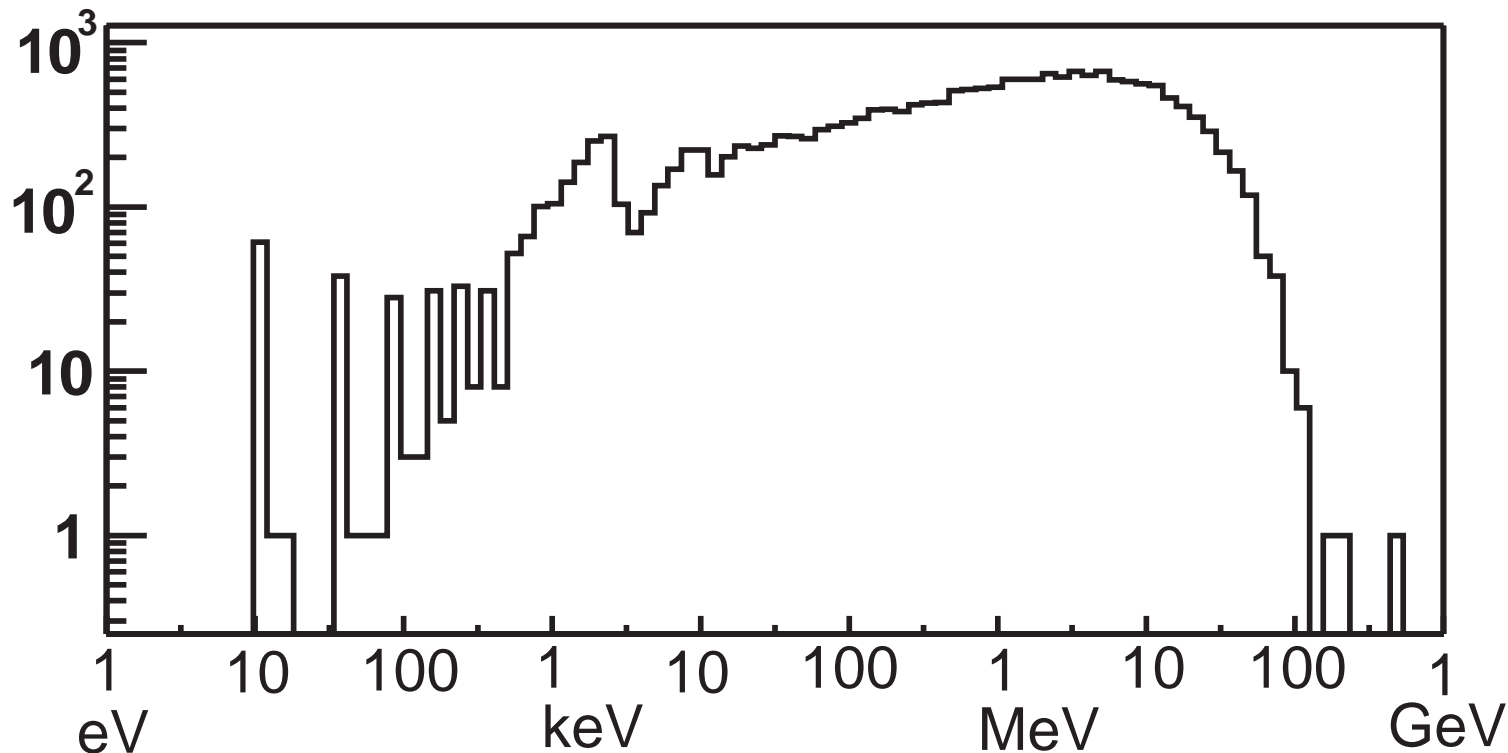


Photons reached to IP are  
mainly produced at FF-  
quadrupole and last bend

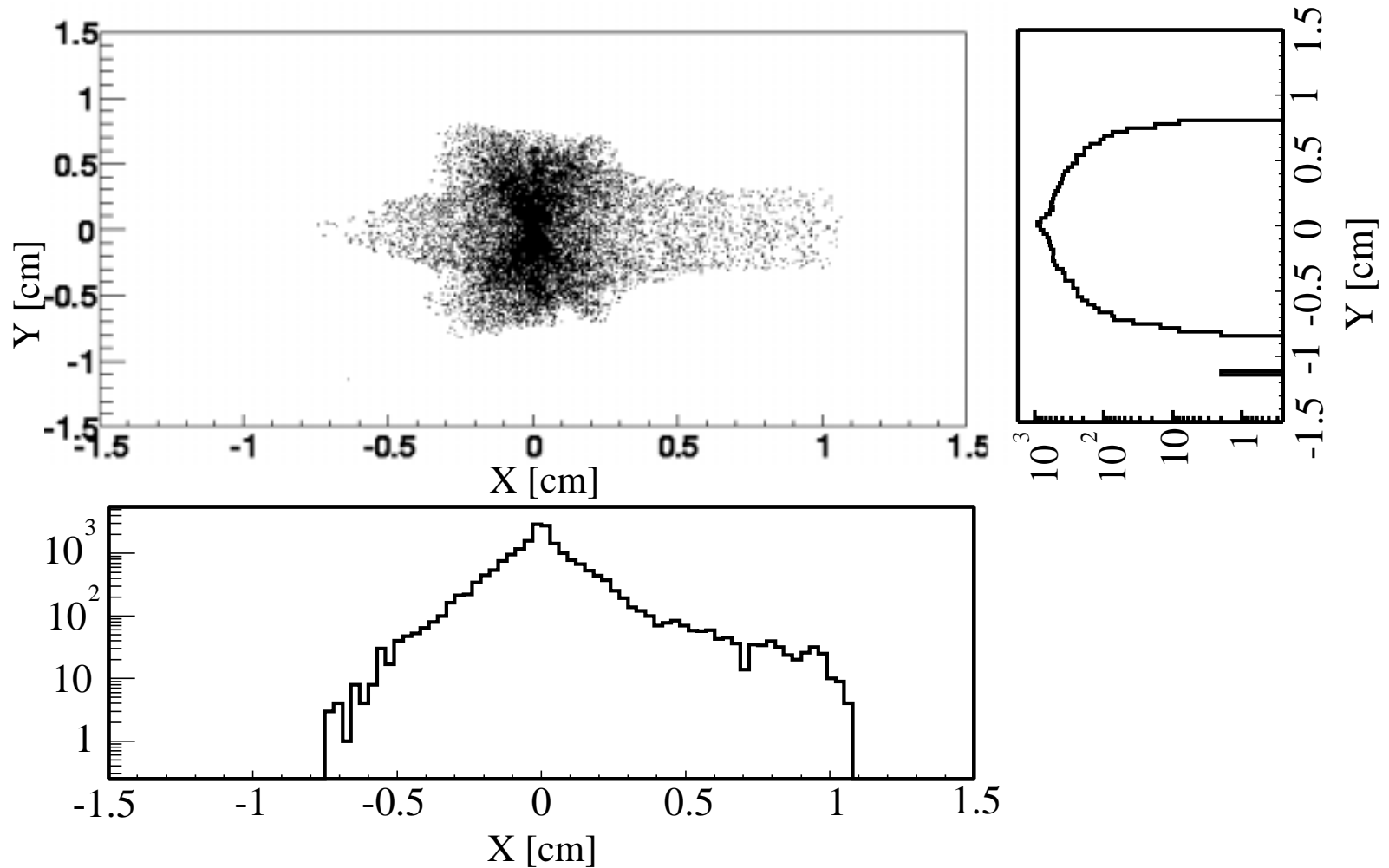
# Synchrotron radiation from beam halo (energy distribution of photons at IP)

$$\begin{aligned} N_{\gamma^*} &= 0.2N_e \\ &= 0.18N_e (E_{\gamma^*} > 10\text{keV}) \\ \langle E_{\gamma^*} \rangle &= 4.76\text{MeV} \end{aligned}$$

$$\begin{aligned} N_e &= 94808 \\ &\text{(at the entrance of BDS)} \\ &= 2141 \text{ (at IP)} \end{aligned}$$

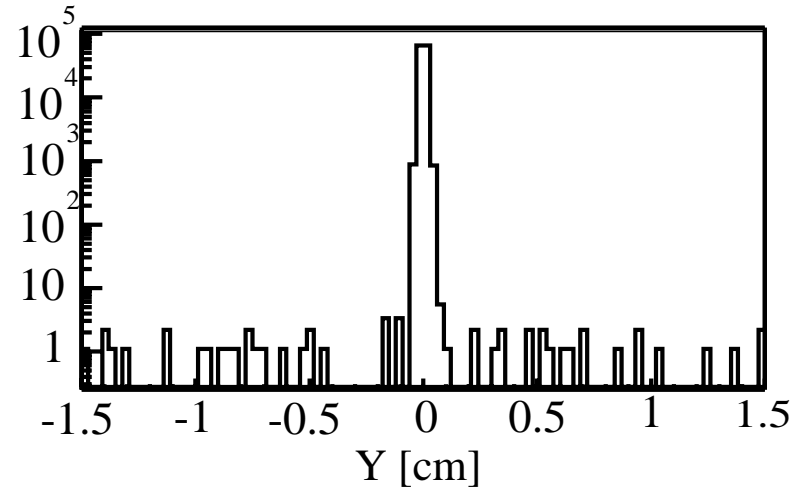
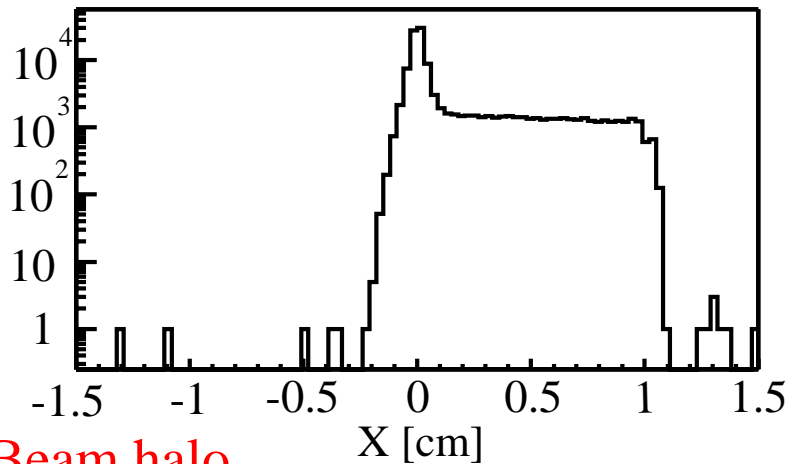


# Synchrotron radiation from beam halo (spatial distribution of photons at IP)

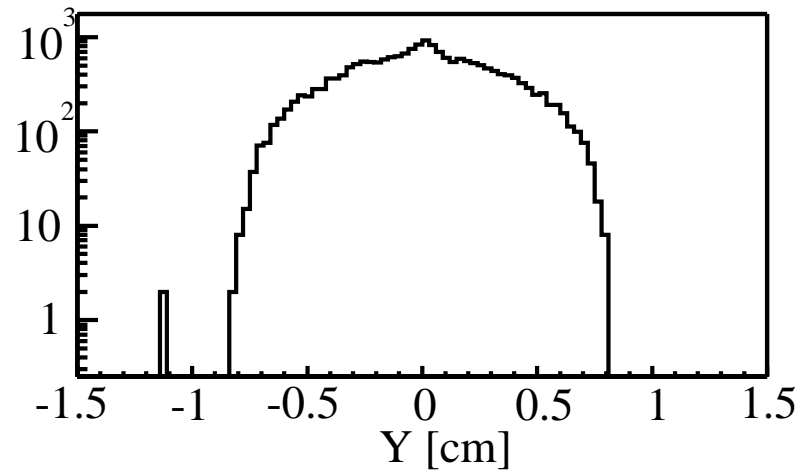
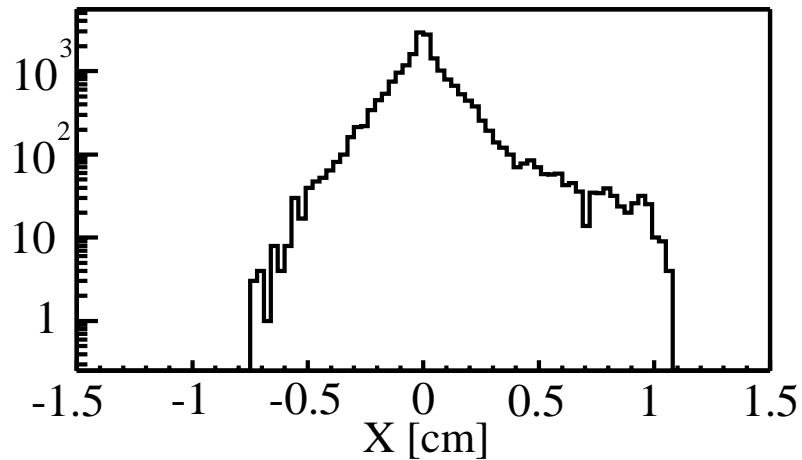


# Synchrotron radiation (Beam core vs Beam halo)

Beam core



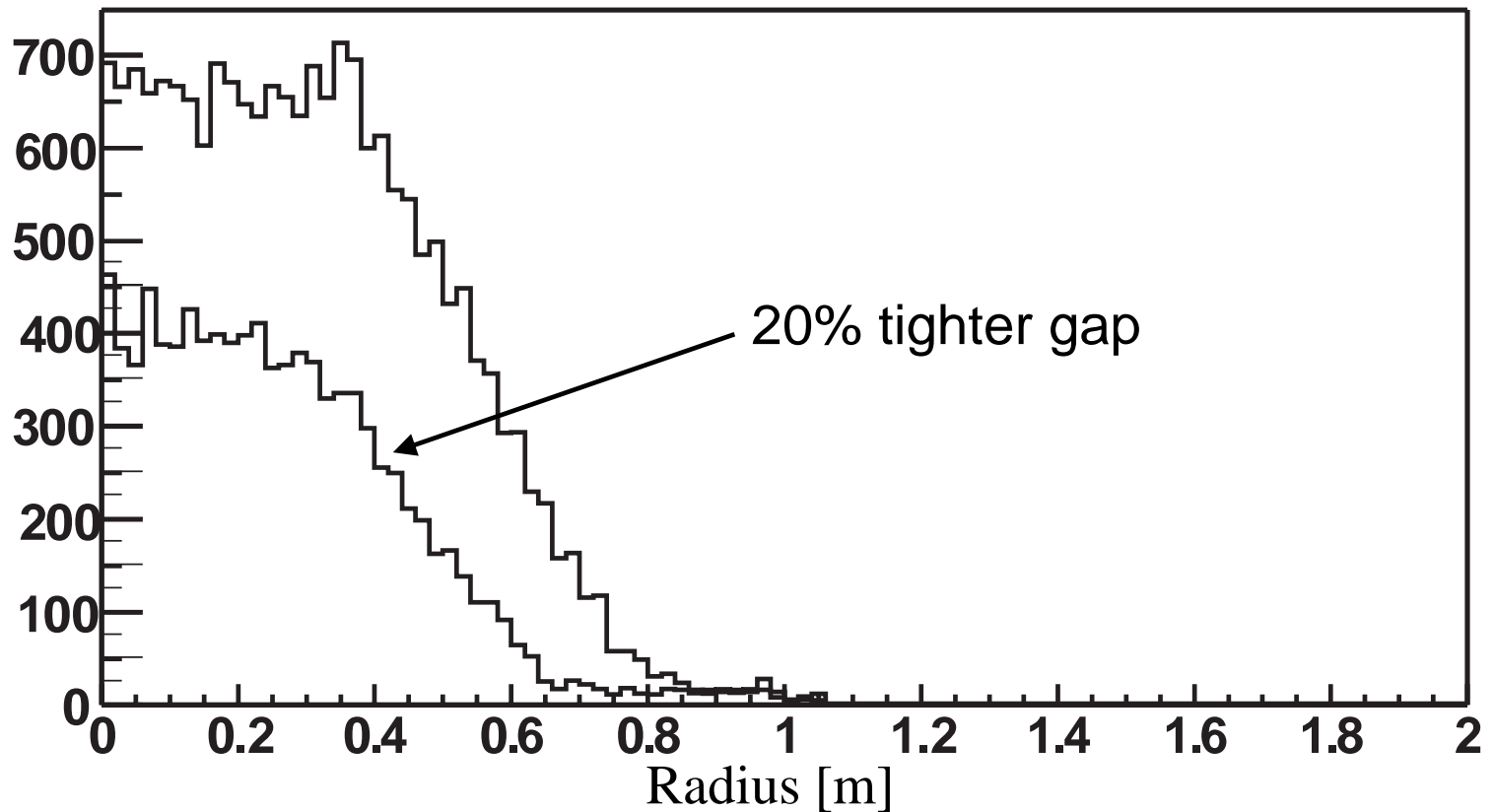
Beam halo



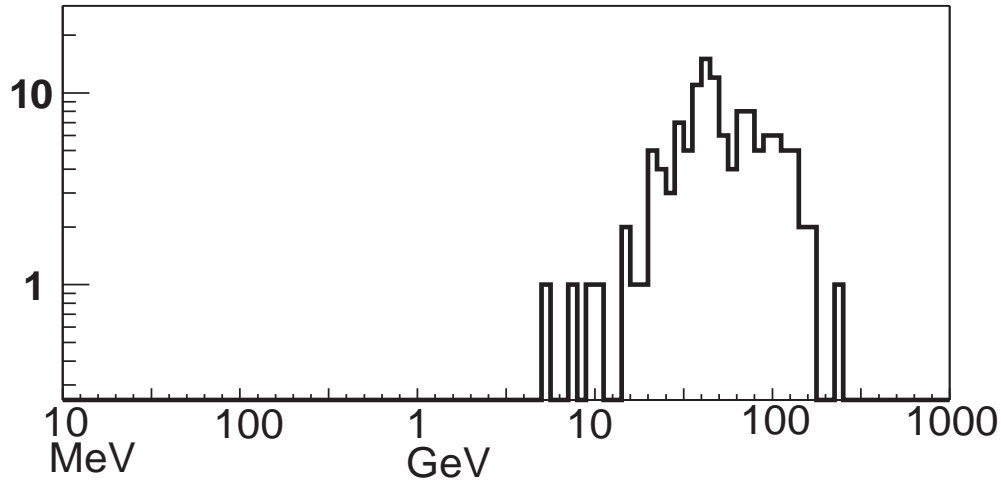
# Synchrotron radiation from beam halo (effect of modification on collimator gap size)

SR photons from Beam halo

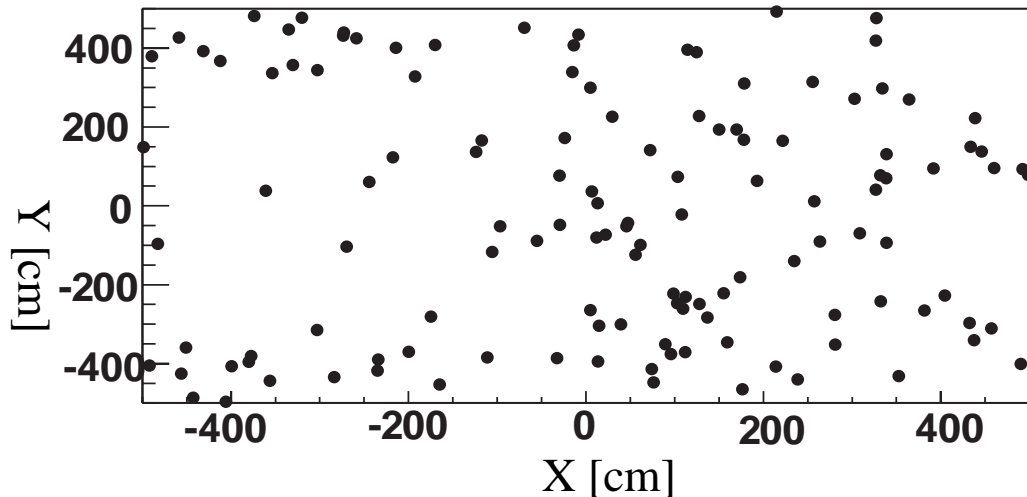
Radial distribution of photons at IP



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



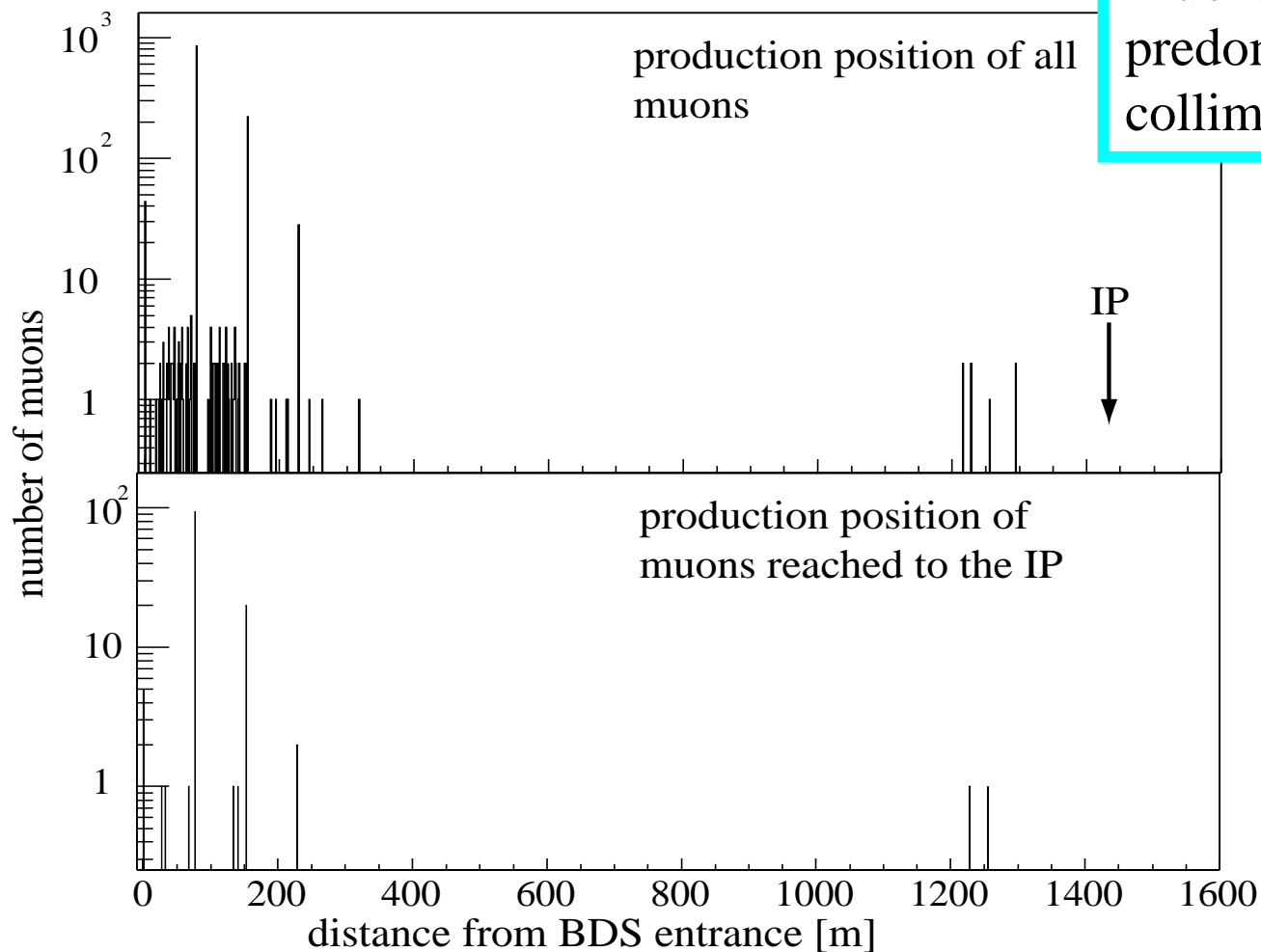
$N_e = 94808$   
(at the entrance of BDS)  
 $= 2141$  (at IP)



Without muon shield

$N_{\text{muon}} = 1.4 \times 10^{-5} N_e$   
 $\langle E_{\text{muon}} \rangle = 61 \text{ GeV}$  (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

$$\sigma_x = 16.2 \mu\text{m}$$

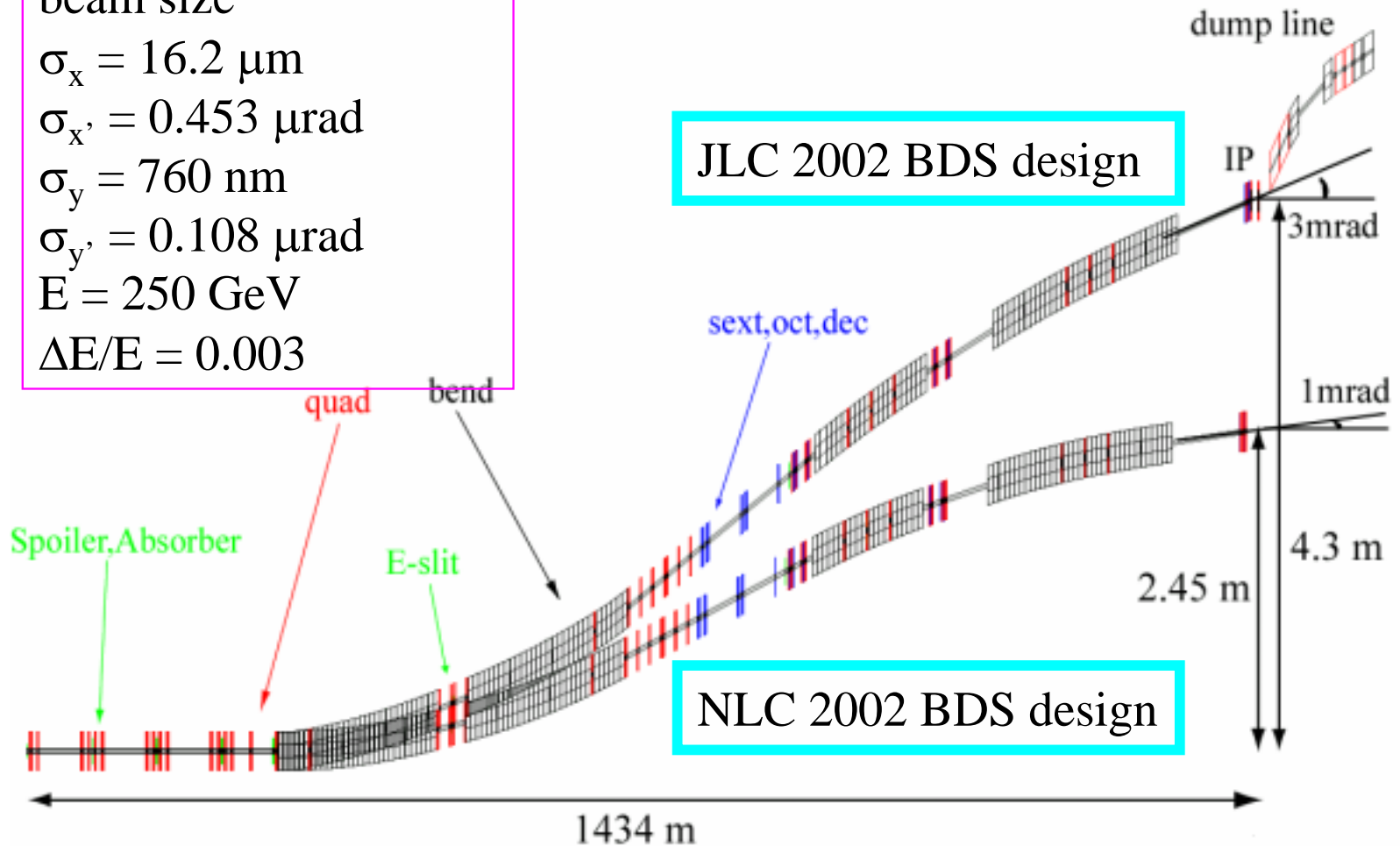
$$\sigma_{x'} = 0.453 \mu\text{rad}$$

$$\sigma_y = 760 \text{ nm}$$

$$\sigma_{y'} = 0.108 \mu\text{rad}$$

$$E = 250 \text{ GeV}$$

$$\Delta E/E = 0.003$$



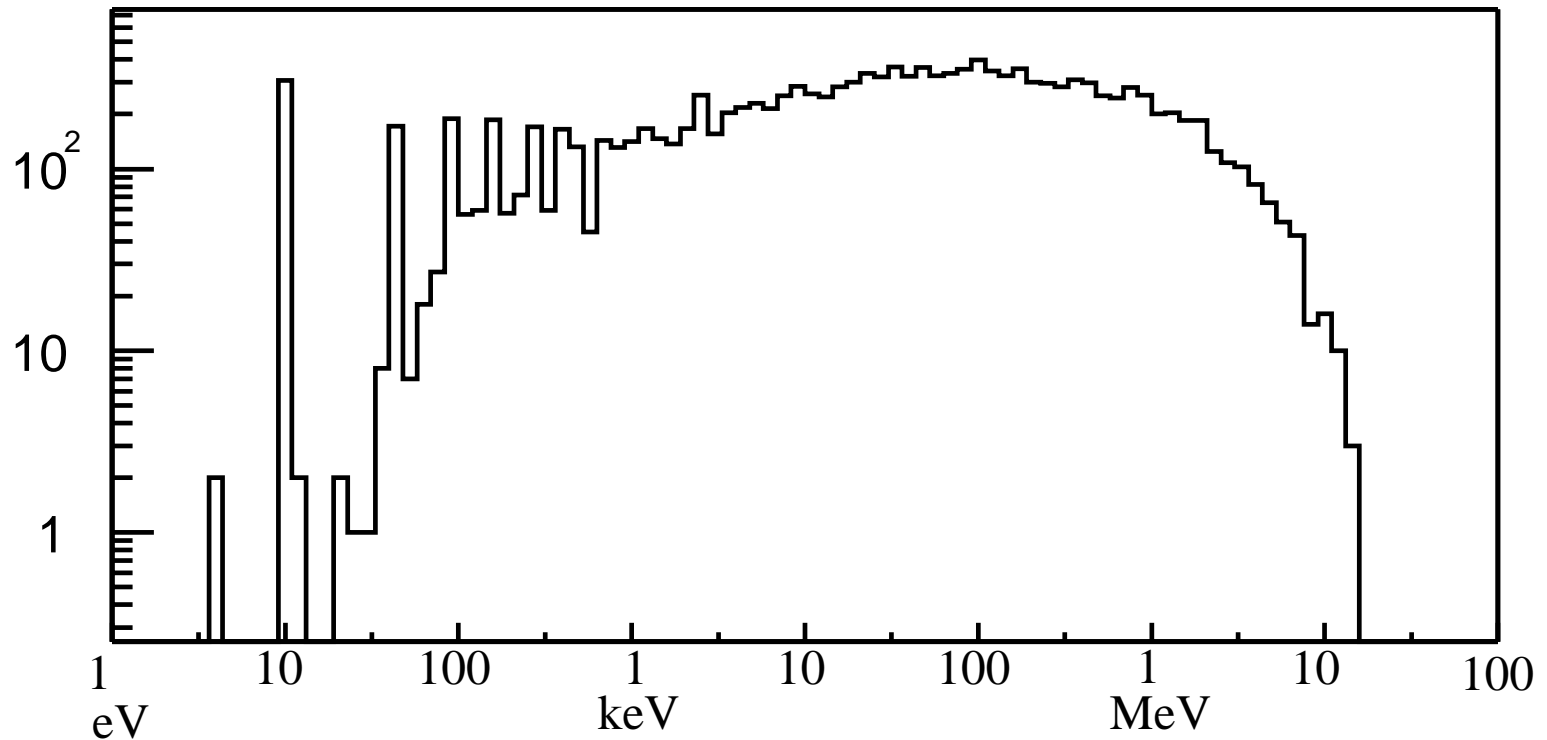
# Synchrotron radiation from beam core (NLC, energy distribution of photons at IP)

$N_e = 10000$

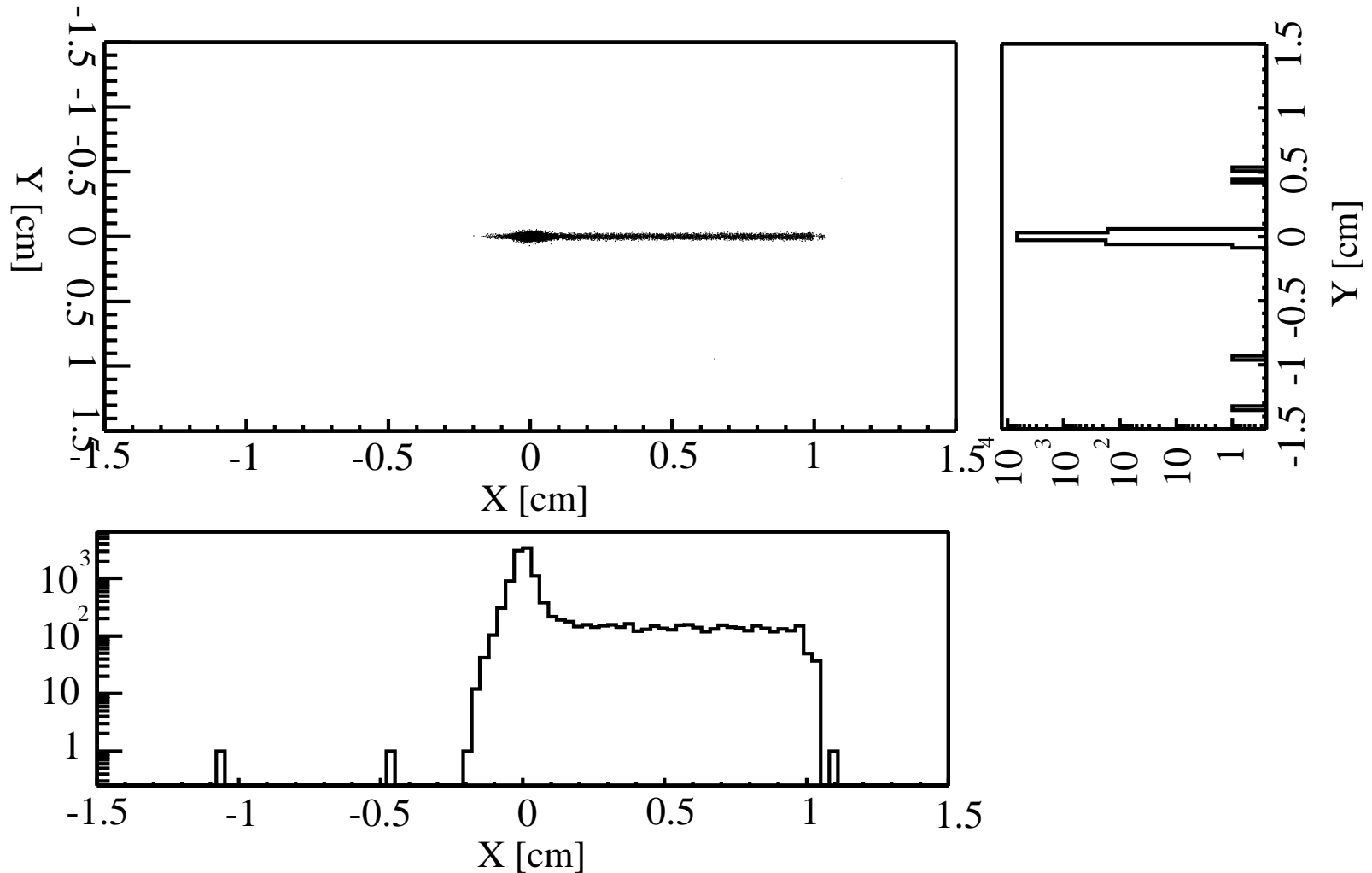
$$N_{\gamma^*} = 1.4N_e \text{ (1.3}N_e \text{ : JLC)}$$

$$= 0.9N_e (>10\text{keV}) \text{ (0.81}N_e \text{ : JLC)}$$

$$\langle E_{\gamma^*} \rangle = 0.38\text{MeV (0.35MeV : JLC)}$$



# 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  $\implies$  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.