

Detector Overview

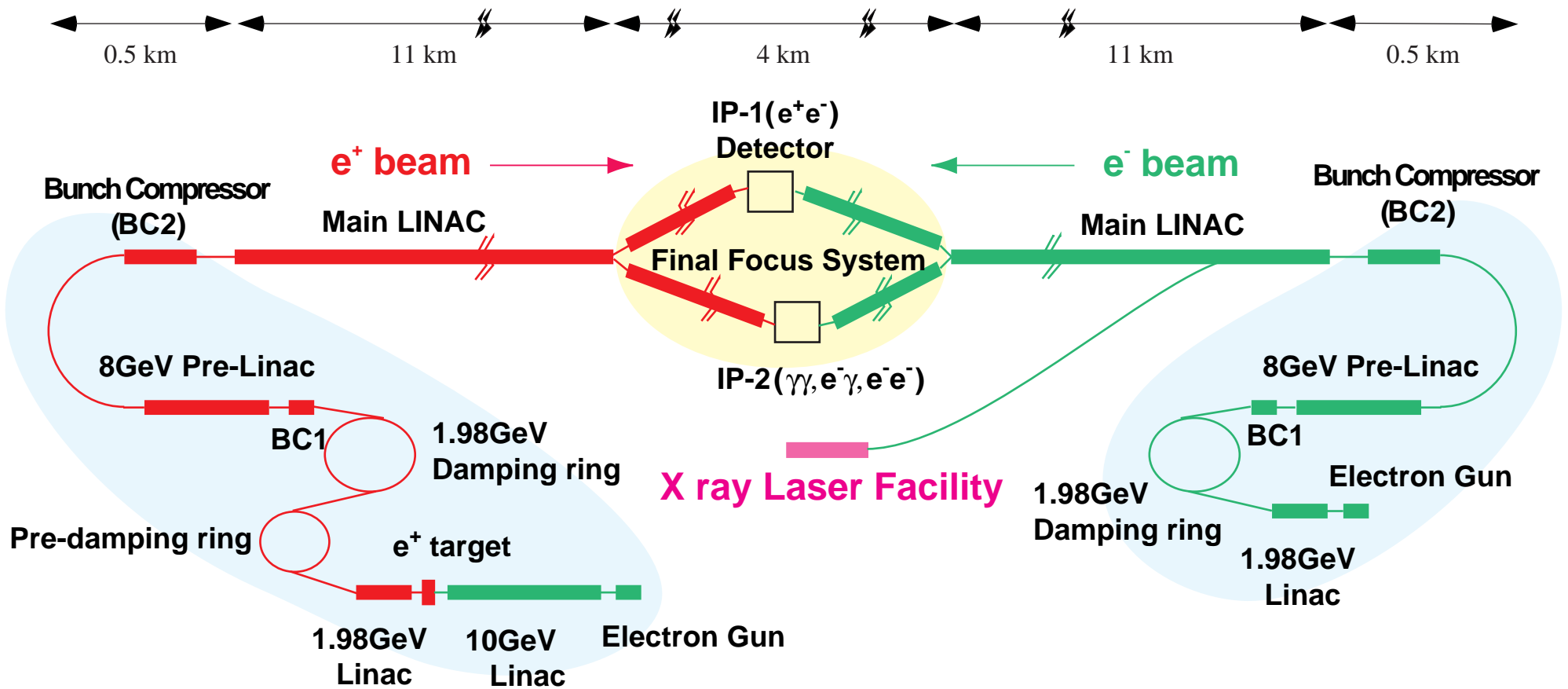
focused on interaction region

The 1st ACFA Workshop on Physics/Detector at the Linear Collider
Tsinghua University, Beijing
T. Tauchi (KEK), November 27, 1998

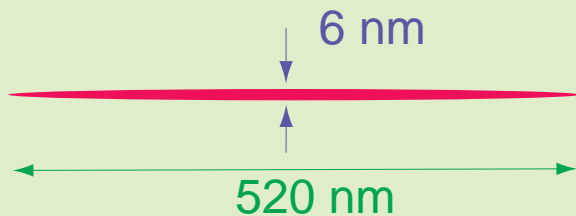
Contents

1. Characteristics of beams
2. Beam delivery system
3. Backgrounds related to beams
4. Interaction region
constraints for experiment
5. Detector
JLC, TESLA, NLC
6. Summary
General issues to be discussed.

Schematics of JLC accelerator complex

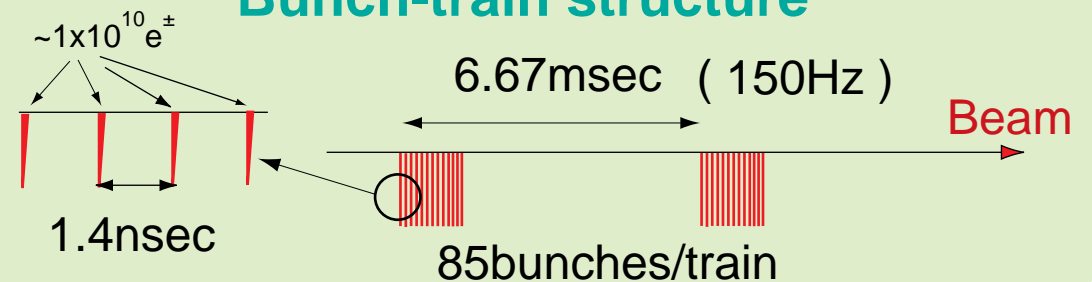


Beam transverse profile



$$\sigma_z = 90 \mu\text{m}$$

Bunch-train structure



JLC Parameters

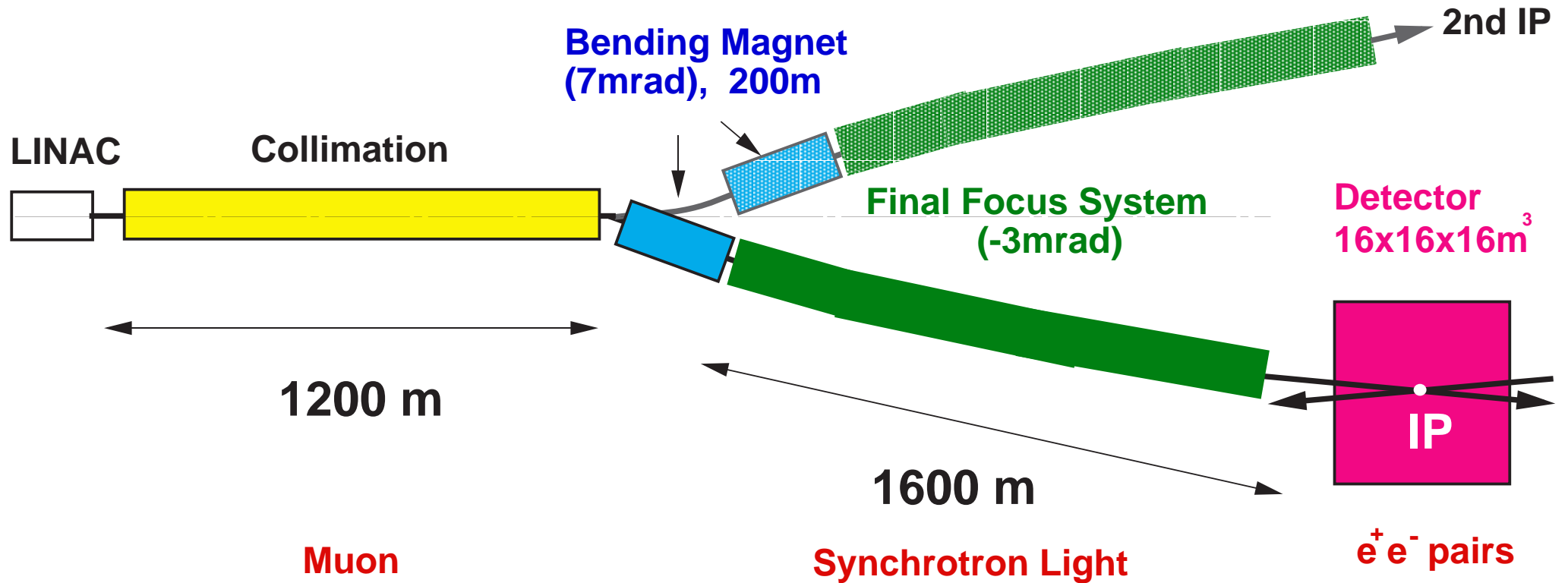
based on the X-band Main Linac (April, 1997)

RF frequency	11.4 GHz ($\lambda=2.6$ cm)
#Electrons/Bunch	7.0×10^9 (6.45×10^9 at IP)
#Banches/Train	85
Bunch separation	1.4 nsec
G(loaded)	55.6 MeV/m
Normalized emittance	3(H) / 0.03(V) 10^{-6} rad m LINAC 3.3(H) / 0.048(V) 10^{-6} rad m IP
Horizontal crossing angle	8 mrad

	Ecm= 250 GeV	500 GeV	1.0 TeV	
#Klystrons/beam	1053	2197	4485	
Length/linac	2.07	4.32	8.81	km
AC-power(wall-plug)	55	115	234	MW
	assuming 28% WP \rightarrow RF efficiency			
Rep.rate	150	150	150	Hz
β_x^* (mm) / β_y^* (μ m)	10 / 100	10 / 100	10 / 100	
σ_x^* (nm) / σ_y^* (nm)	367 / 4.43	260 / 3.14	184/2.28	
$\Delta E/E$ due to BS	1.34	3.40	6.90	%
Pinch enhancement	1.581	1.585	1.599	
Luminosity $\times 10^{33}$	4.13	8.28	16.72	$\text{cm}^{-2} \text{s}^{-1}$

The numbers are those with crab crossing. Luminosities are $3.15, 5.18, 7.66 \times 10^{33}/\text{cm}^2/\text{s}$ for $E_{\text{cm}}=250, 500, 1000\text{GeV}$, respectively, with no crab crossing.

JLC : Beam Delivery System for $\sqrt{s} = 0.3 - 1.5$ TeV



collimate beam-tail
 $6\sigma_x \times 40\sigma_y$

from collimated beam

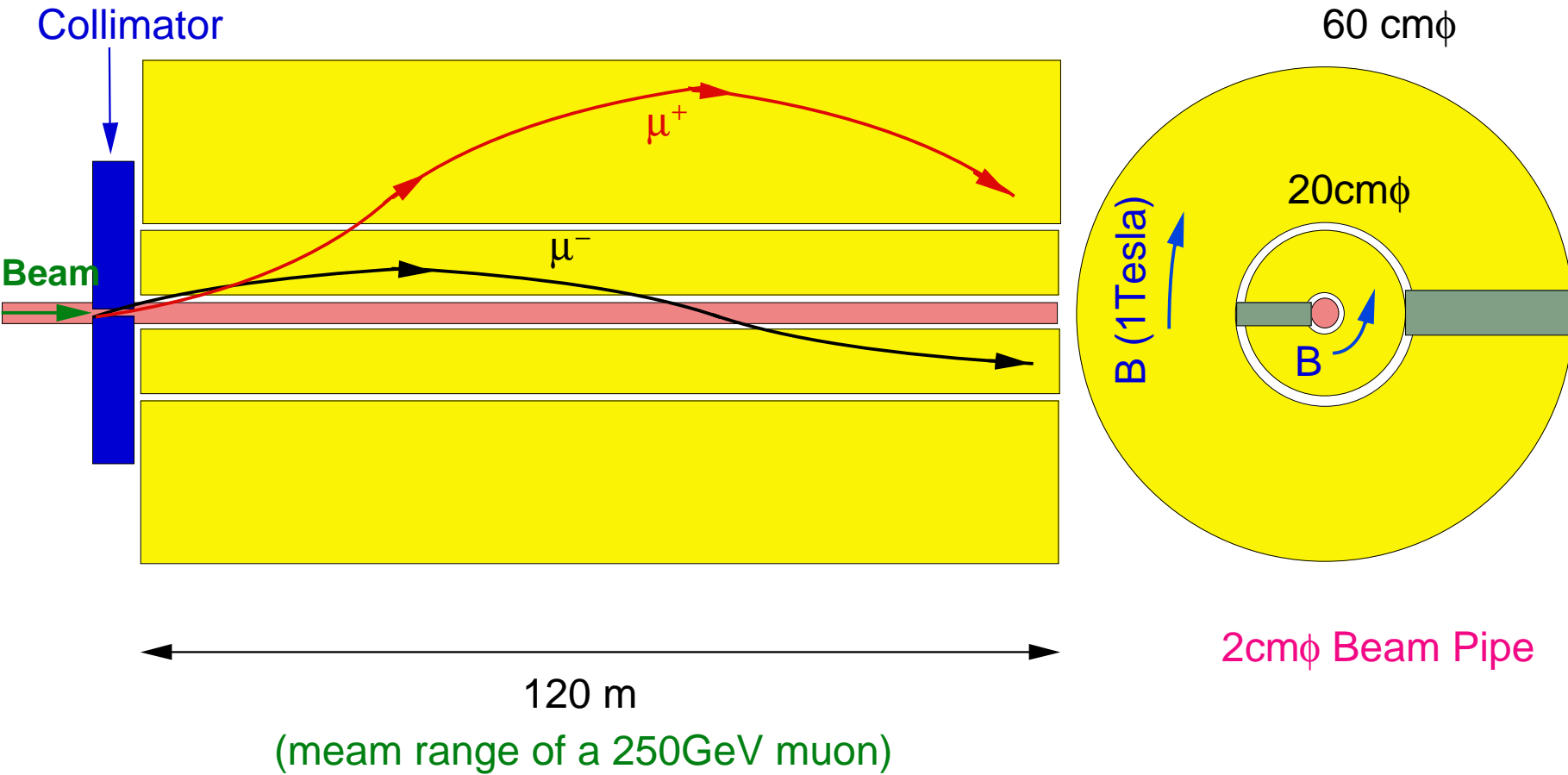
$$\sigma_{\theta_{x(y)}} = \sqrt{\varepsilon_{x(y)} / \beta_{x(y)}}$$

$$\sigma_{x(y)} = \sqrt{\varepsilon_{x(y)} \cdot \beta_{x(y)}}$$

$\theta_c = 8$ mrad

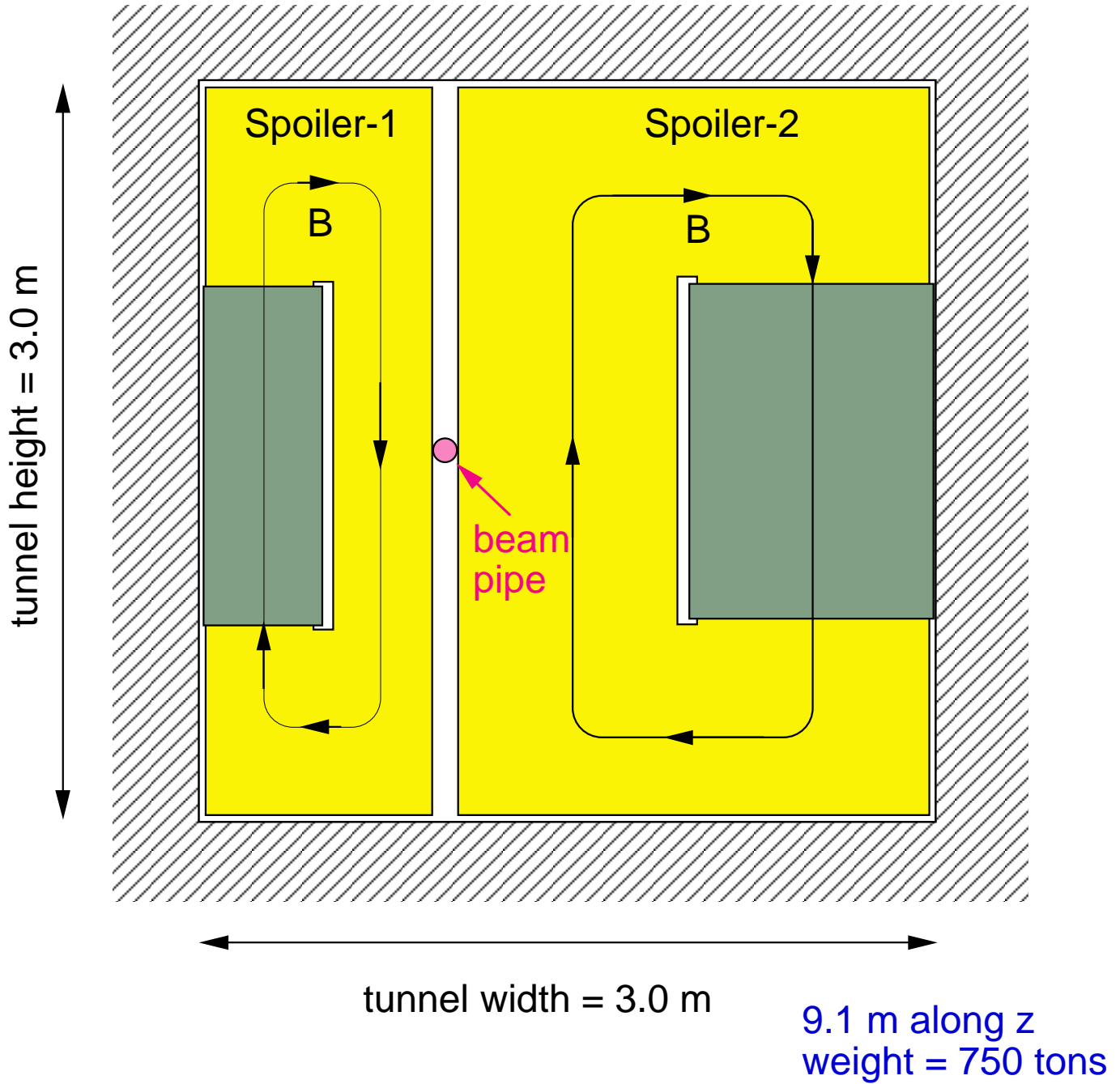
Muon Attenuator

E.A.Kushnirenko, LC92



Muon Spoiler

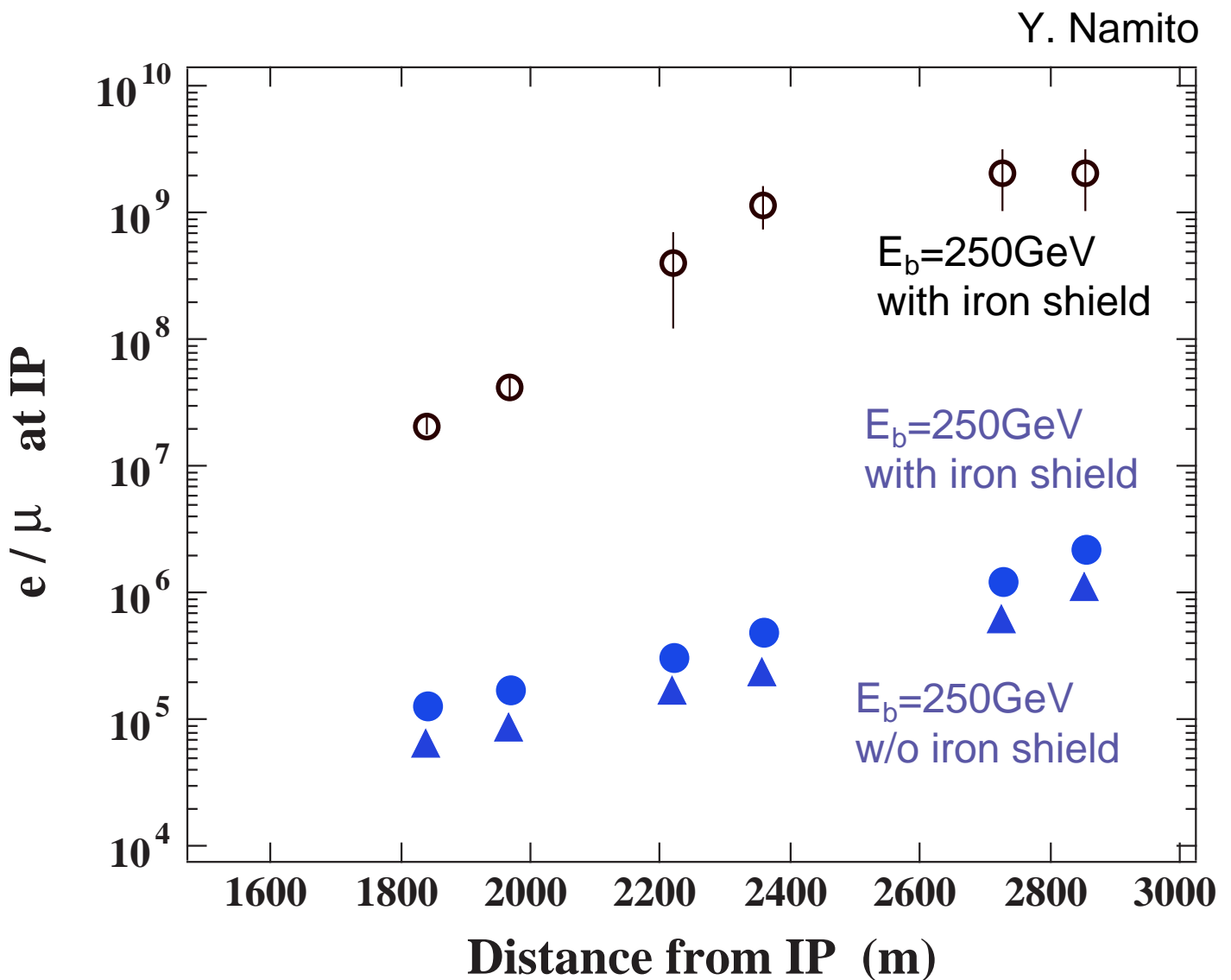
L.Keller,LC93

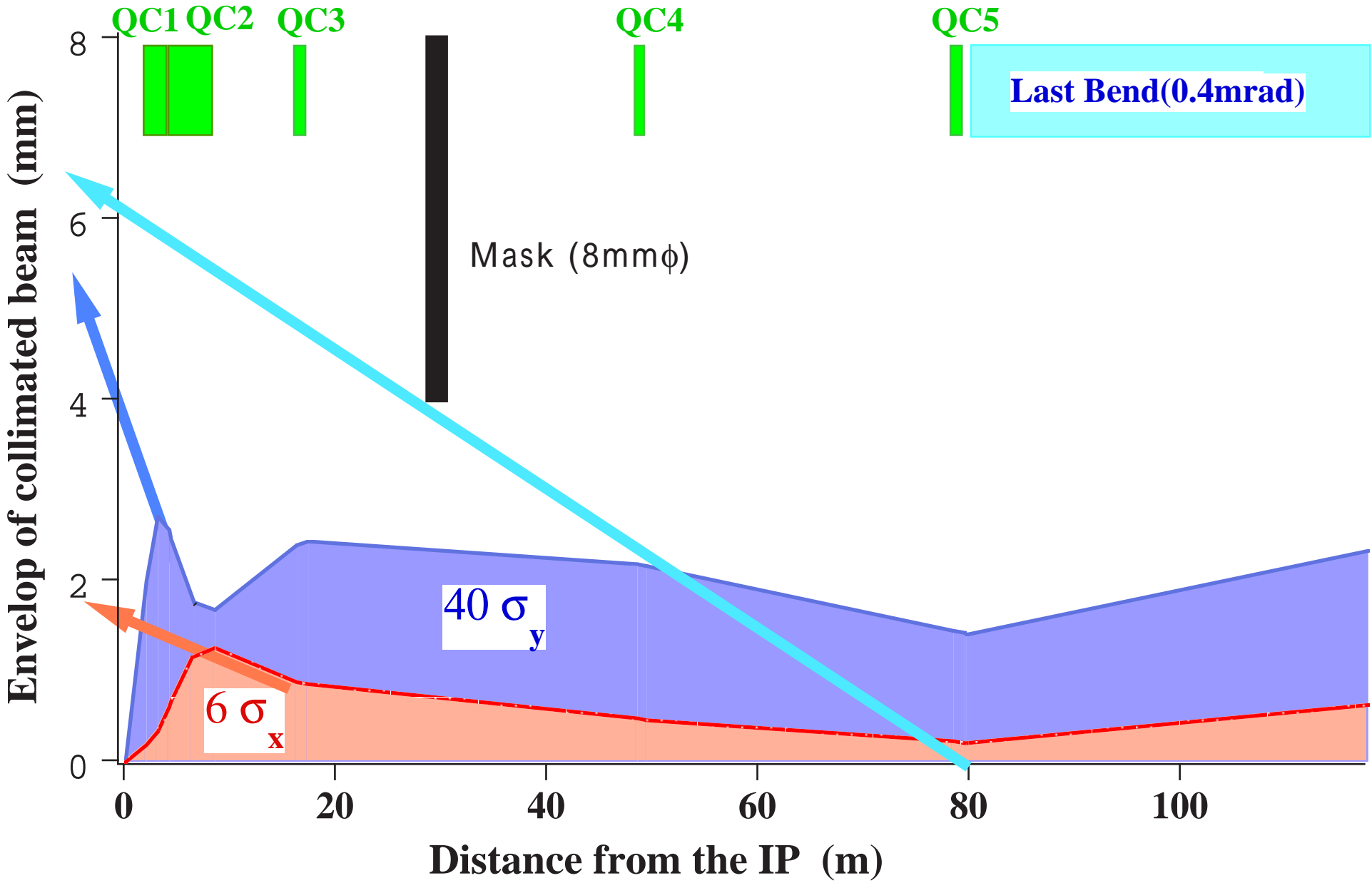


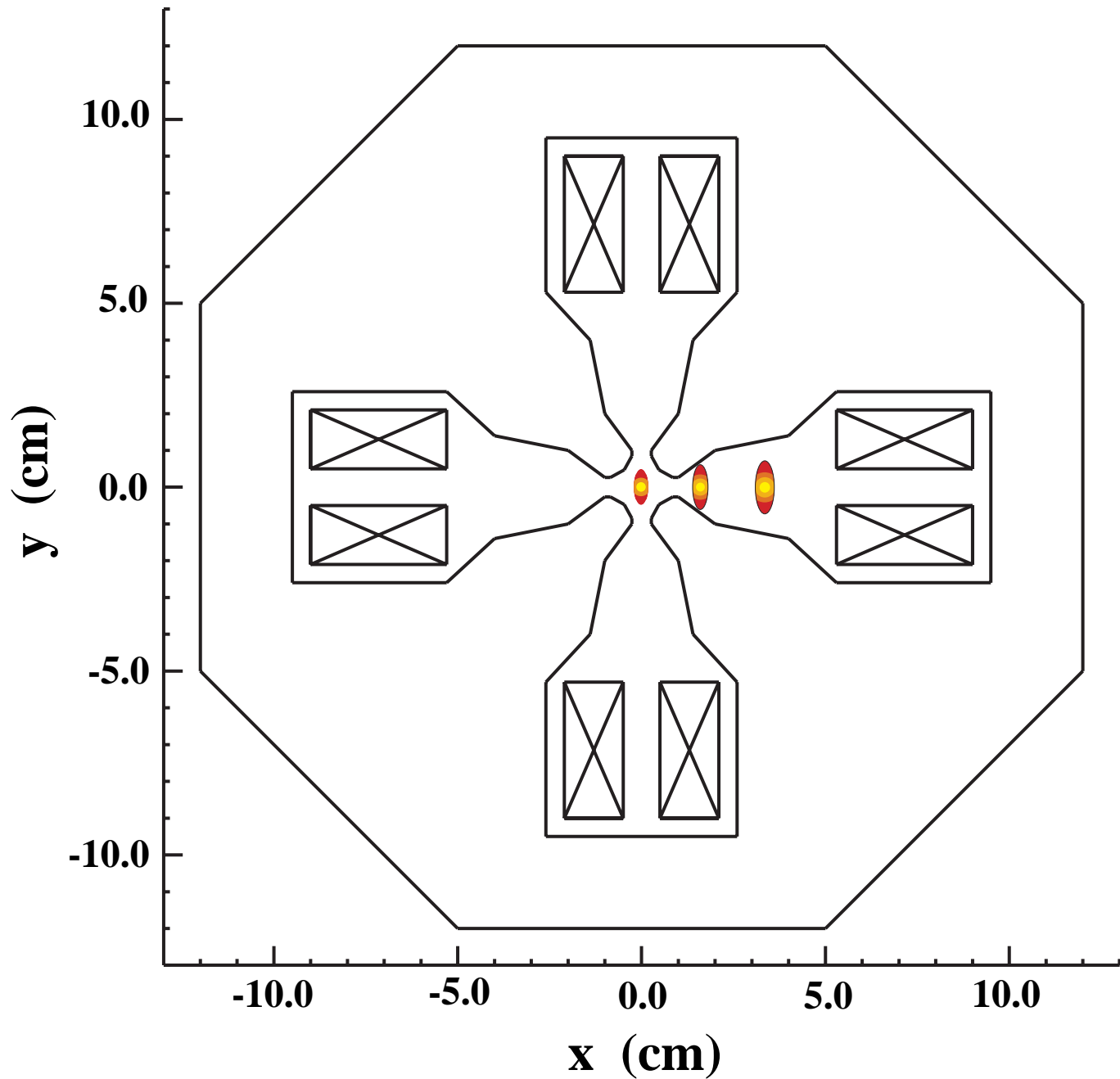
Muon Background

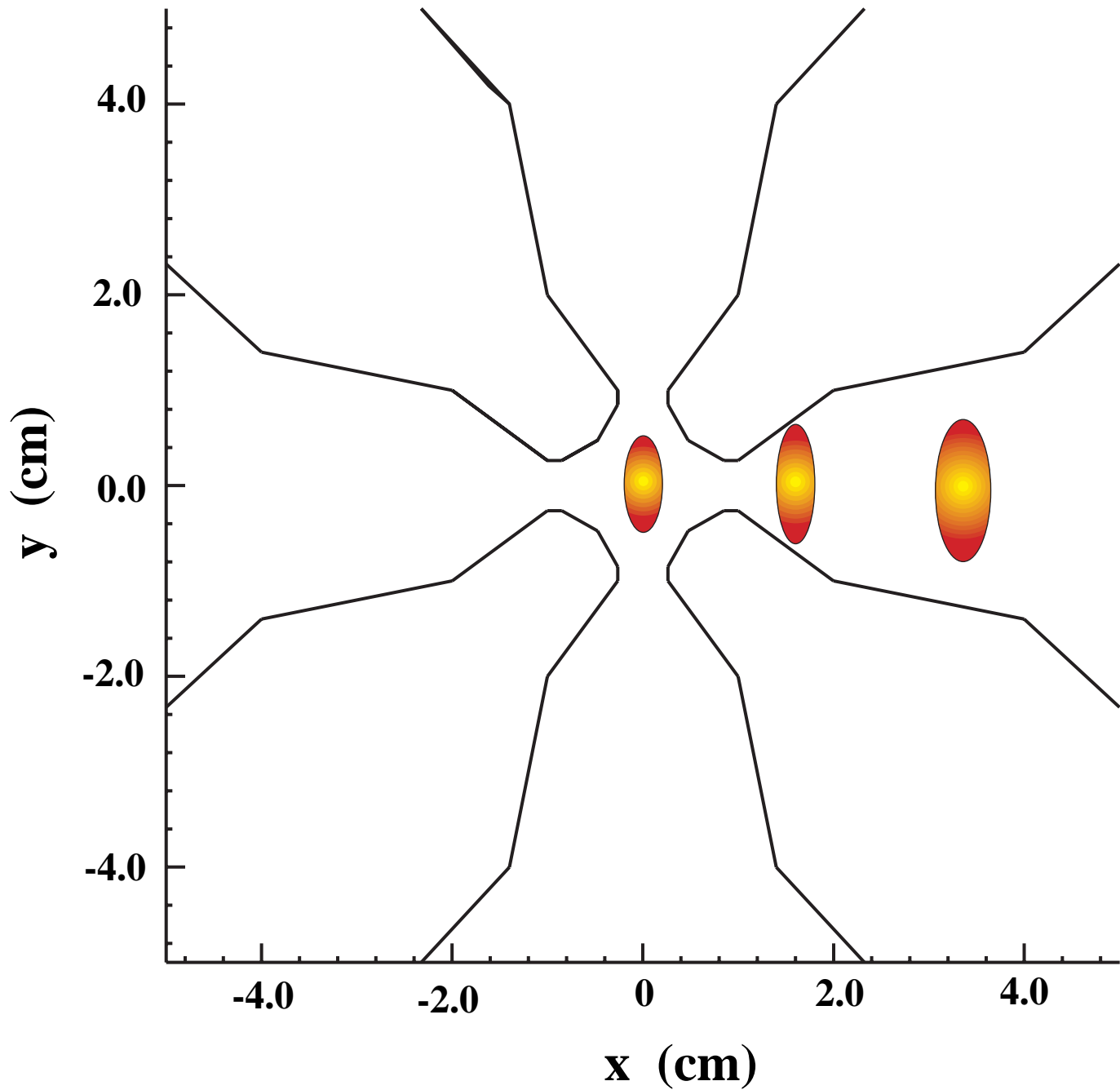
10^8 (1% tail) x 10^2 (bunches) electrons
may hit collimators at 150 Hz

10 muons may be observed in the detector of
 $16 \times 16 \times 16 \text{ m}^3$.









Incoherent e^\pm pairs

Pair creation by virtual and real (beamstrahlung) photons;

$$\begin{aligned}
 e^+e^- &\rightarrow e^+e^-e^+e^- && : \text{LL} \quad \sigma(\text{cm}^{-2}) \sim O(10^{-26}) \\
 \gamma e^\pm &\rightarrow e^+e^-e^\pm && : \text{BH} \quad \sigma(\text{cm}^{-2}) \sim O(10^{-25}) \\
 \gamma\gamma &\rightarrow e^+e^- && : \text{BW} \quad \sigma(\text{cm}^{-2}) \sim O(10^{-27})
 \end{aligned}$$

Typical scattering angles $\sim m_e/E_e = 1/\gamma_e$ (small), however, the pairs are kicked by the strong magnetic field produced by comming beam.

\Rightarrow Background !

$$\theta_{x(y)}^{\text{kick}} \sim \frac{2Nr_e}{\gamma_e} \frac{x(y)}{\sigma_{x(y)}(\sigma_x + \sigma_y)} \sim O(10^{-1}) \gg \frac{1}{\gamma_e}$$

$$\gamma_e \sim \gamma_{\text{beam}} \cdot 10^{-3}$$

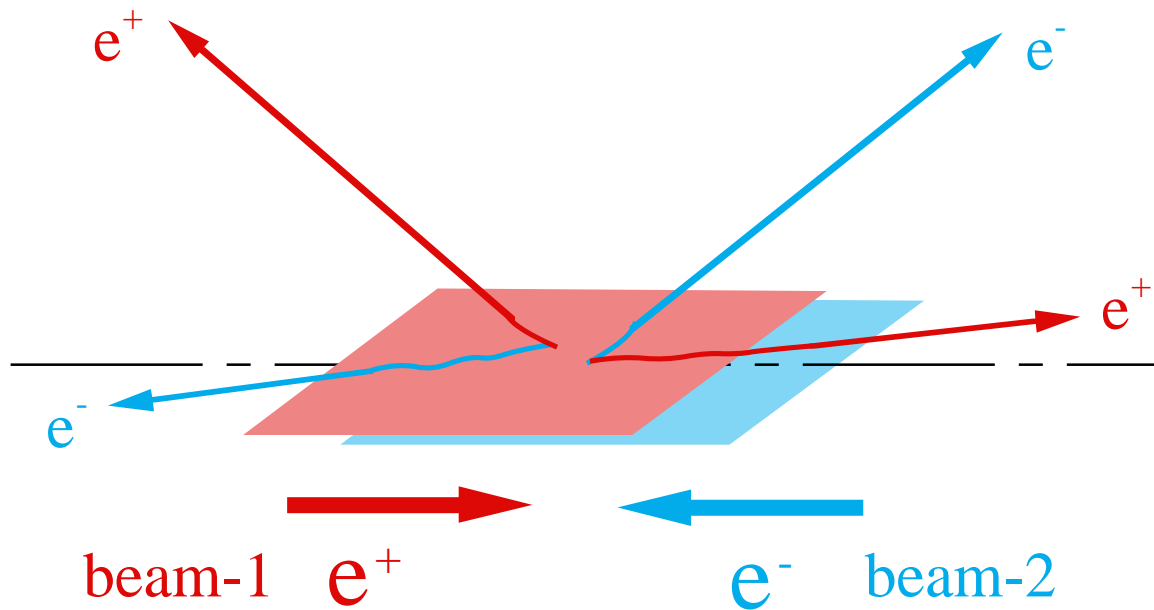
N : number of particles/bunch $\sim 10^{10}$

r_e (electron classical radius) = $2.8 \cdot 10^{-15}$ m

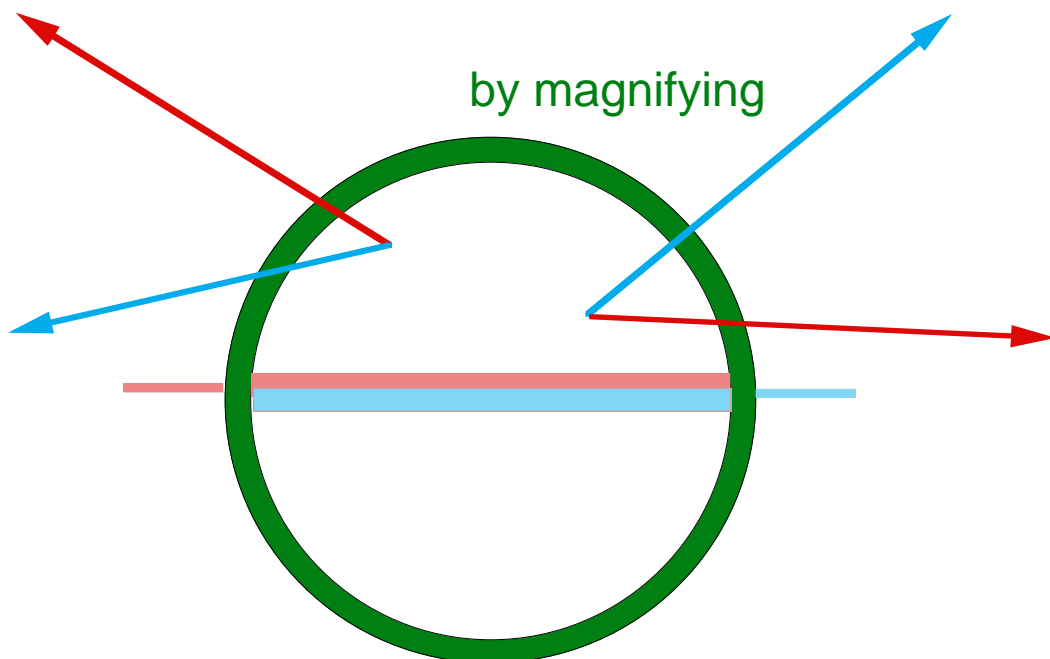
$x \sim \sigma_x \sim 10^{-7}$ m

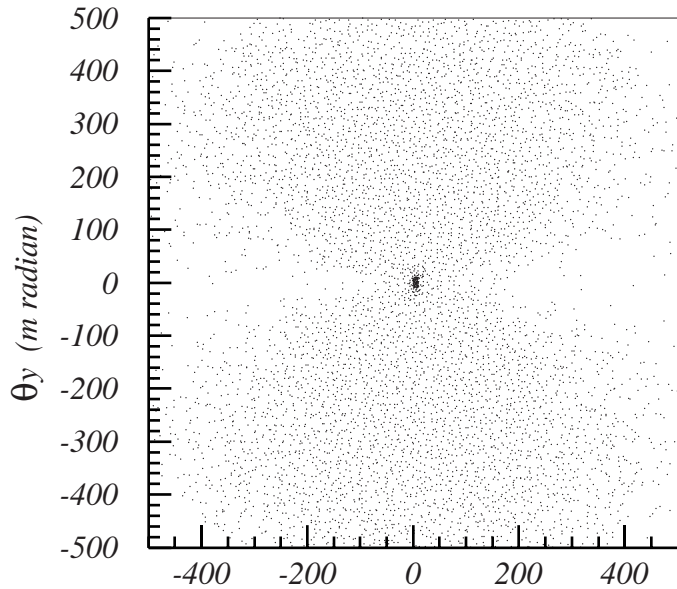
$y \sim \sigma_y \sim 10^{-9}$ m

e^\pm pair creation and deflection during a collision

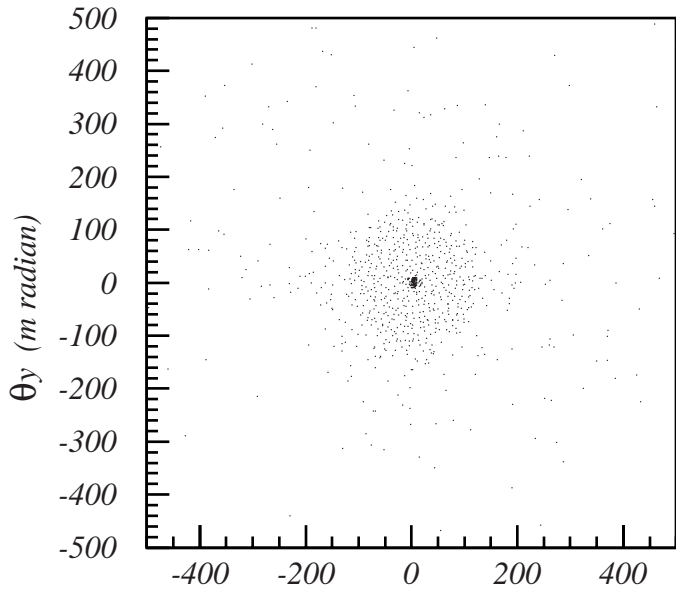


side view

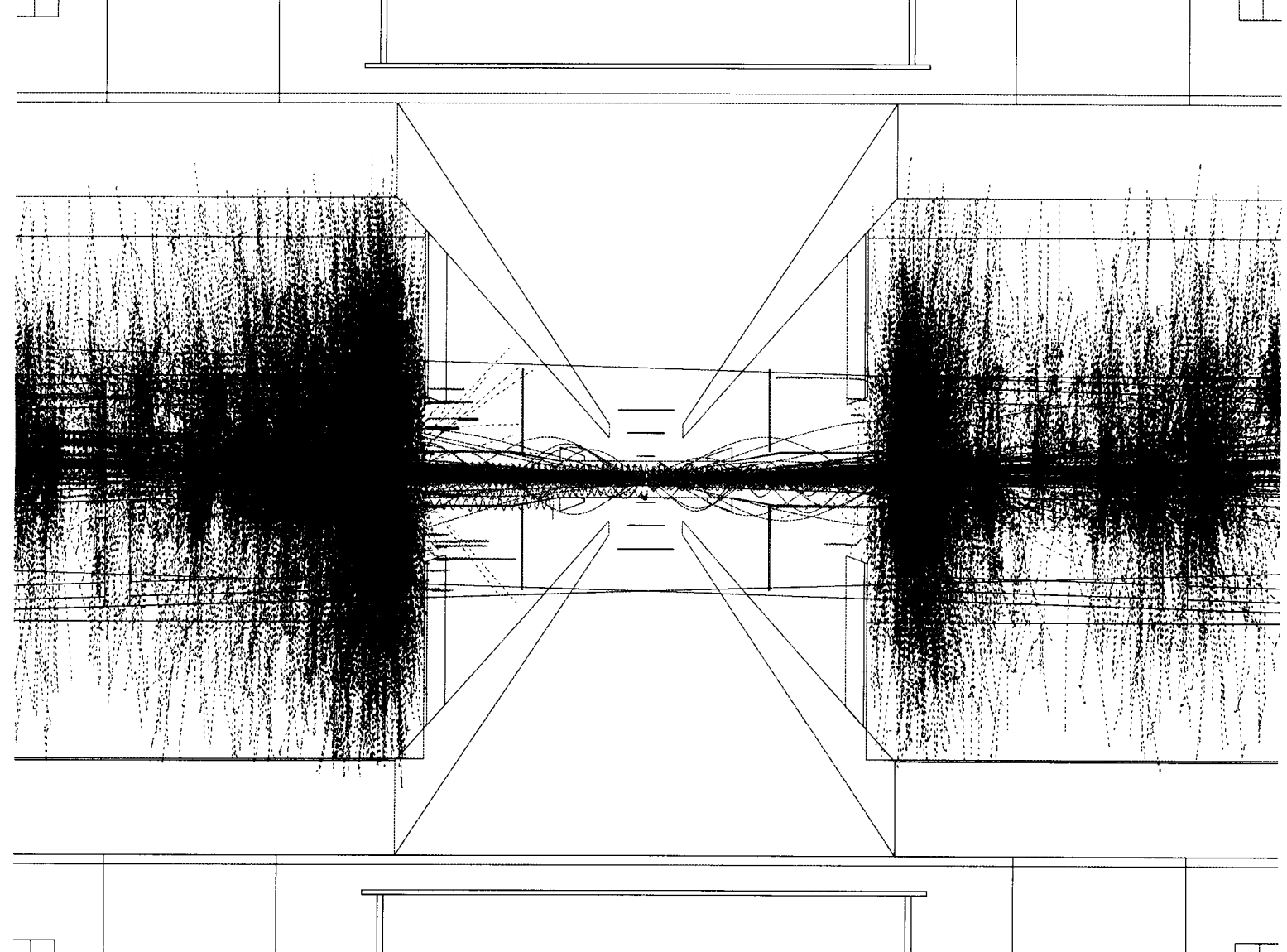




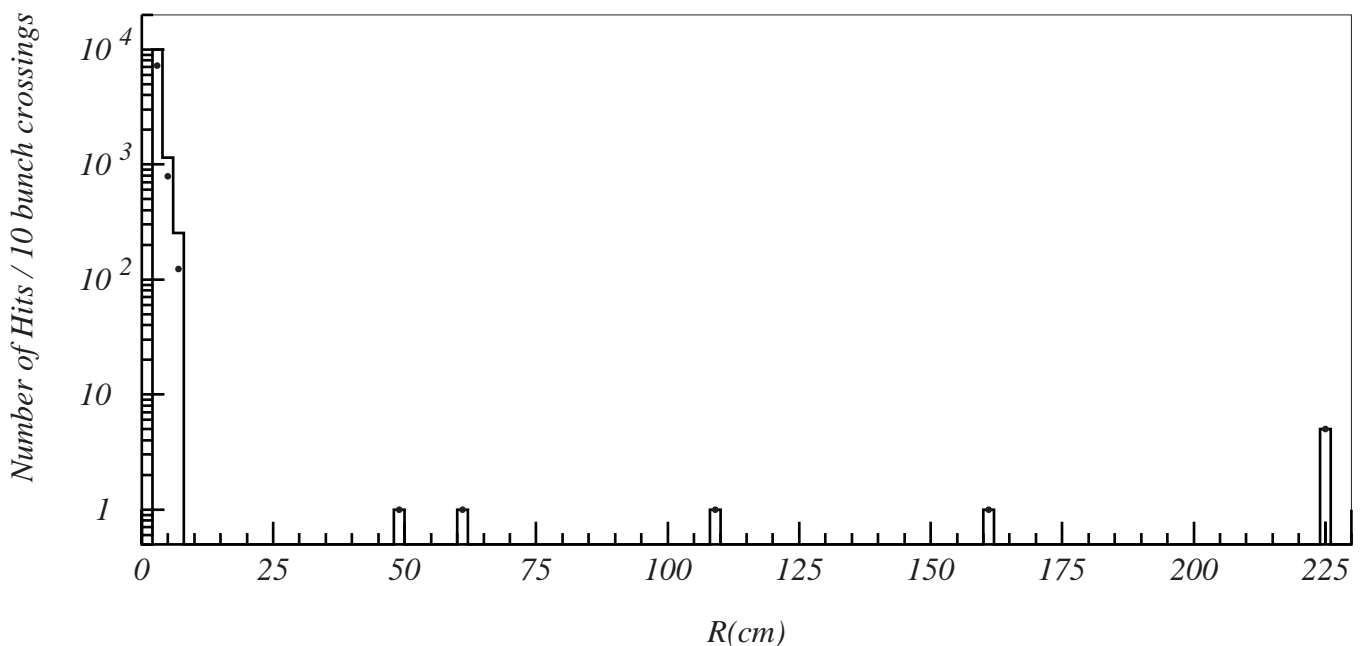
$e^+ : \theta_x$ (m radian)



$e^- : \theta_x$ (m radian)



Background hits per 10 bunch crossings due to e^+e^- pairs



Hits rates for a train of 85 bunches at 150Hz

VTX-layer	r (cm)	z (cm)	hits/mm ²
1	2.5	±7.5	3.6
2	5.0	±15.0	0.1
3	7.5	±22.5	0.01

tolerable hit rate = 1.0/mm²

note: A track produces 20 hits at the VTX.

Neutron Background

$$N_n \sim 0.13 \Sigma E_e \text{ (GeV)}$$

then

$$10^6 \text{ n/pulse at } 150\text{Hz}$$

in total

$$10^6 \cdot 10^2 \cdot 10^7 = 10^{15} \text{ n/year}$$

n/pulse Hz s/year

at the 1st layer of the VTX,

$$10^{15} \cdot 5 \cdot 10^{-3} \cdot 10^{-3} \sim 5 \cdot 10^9 \text{ n/year/cm}^2$$

n/year /cm² $\Delta\Omega_{\text{VTX}}$

Is this acceptable?

JLC detector

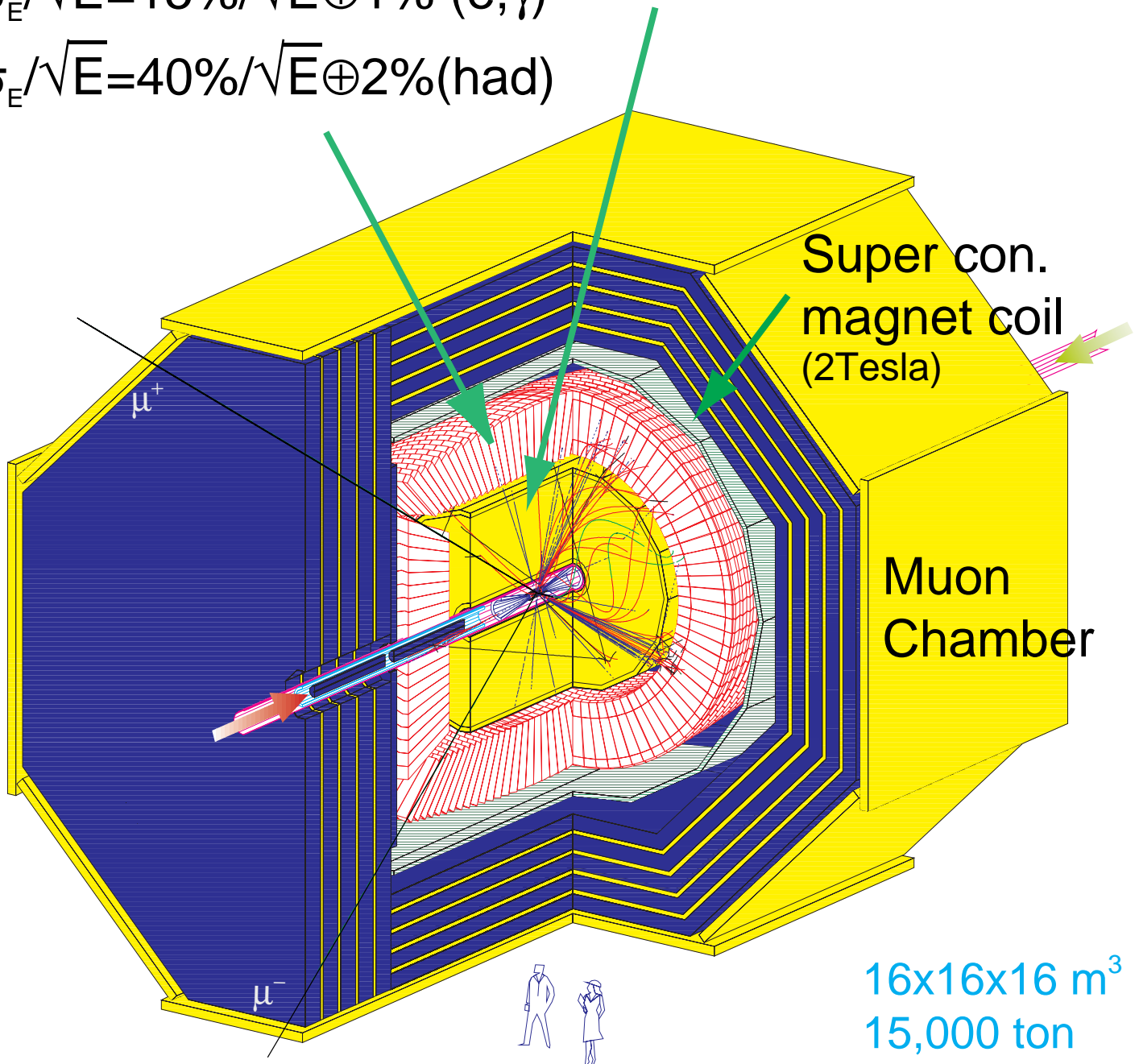
Calorimeter

$$\sigma_E/\sqrt{E}=15\%/\sqrt{E}\oplus 1\% (e,\gamma)$$

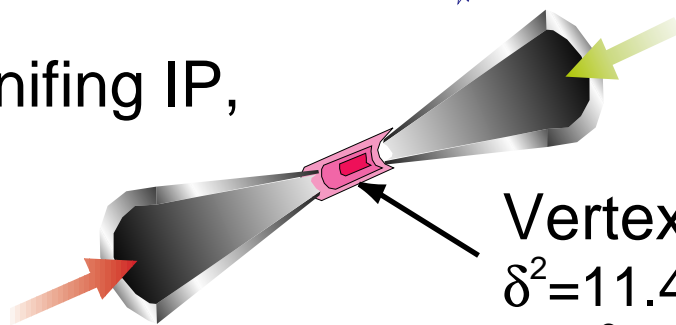
$$\sigma_E/\sqrt{E}=40\%/\sqrt{E}\oplus 2\%(\text{had})$$

Central Drift Chamber

$$\sigma_{P_t}/P_t=1.1\times 10^{-4}P_t\oplus 0.1\%$$



magnifying IP,



Vertex Detector

$$\delta^2=11.4^2+(28.8/P)^2/\sin^3\theta$$

(μm^2)

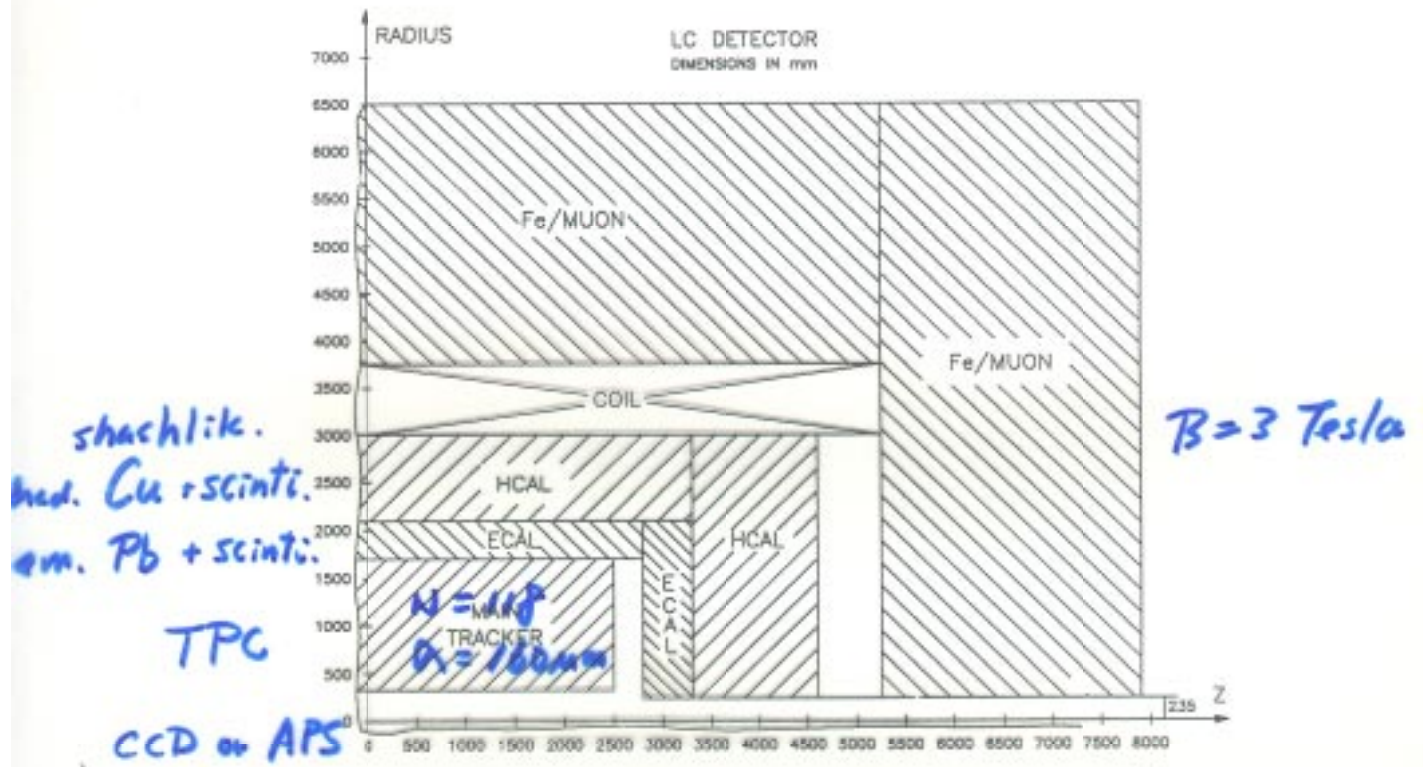


Figure 2.1.1: Schematic layout of one quadrant of the LC Detector.

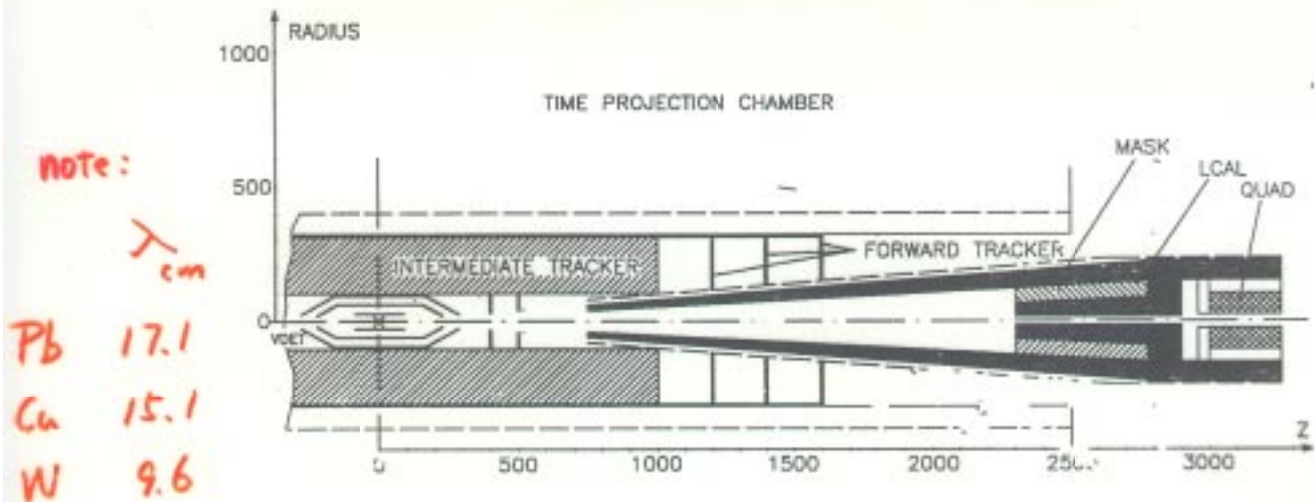


Figure 2.1.2: Schematic layout of the inner region of the detector.

VTX : $10\mu m \oplus \frac{30\mu m}{P \sin^2 \theta}$

TPC : $\frac{\sigma_P}{P} < 1 \cdot 10^{-4}$

CAL : $10\% \sqrt{E} \oplus 1\% [e.m.]$, $50\% \sqrt{E} \oplus 4\% [had]$

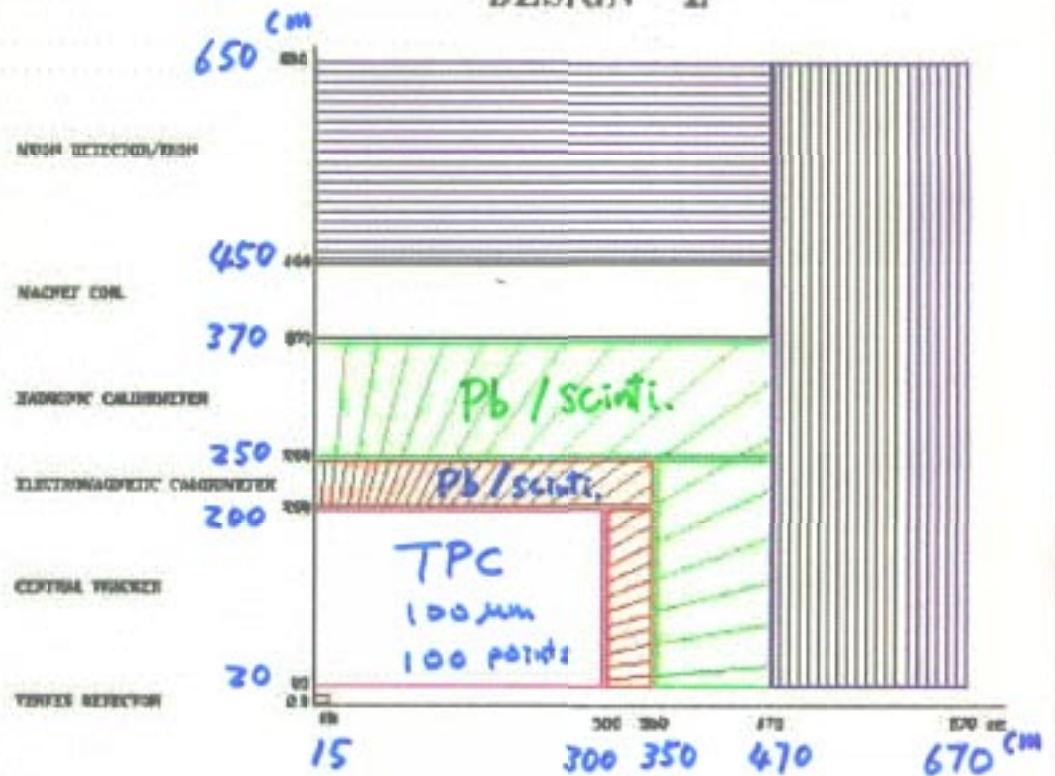
NLC

DESIGN "S"
QUADRANT VIEW
AS OF 20 OCT 1985



6 Tesla

DESIGN "L"



2 Tesla

Quadrant Views of Designs S and L on same scale

$$\text{VTX} : 4.5 \mu\text{m} \oplus \frac{5.5 \mu\text{m}}{P \sin^{3/2} \theta}$$

$$\text{Si-strip} : \sigma_P / p^2 \sim 1.6 \times 10^{-4}$$

$$\text{CAL} : 12\% / \sqrt{E} \oplus 1\% \text{ (p.m.)}, 50\% / \sqrt{E} \oplus 2\% \text{ (had)}$$

$$10 \mu\text{m} \oplus \frac{30 \mu\text{m}}{P \sin^{3/2} \theta}$$

$$\sigma_P / p^2 \sim 5 \times 10^{-5}$$

$$15\% / \sqrt{E} \oplus 1\% \text{ (p.m.)}, 40\% / \sqrt{E} \oplus 2\% \text{ (had)}$$

Summary: General issues to be discussed

1. Detector size

Large

CDC: 4.6m ϕ x 4.6m (z)
jet-type or TPC
long wire wire-less
good matching between
tracks and CAL-clusters
note: $R_{95\%} \sim \lambda$ for hadrons

Small (compact)

CDC: 1.1m ϕ x 2.4m (z)
micro-strips
robust against background
FF-Q can be outside of
detector

2. Electromagnetic calorimeter

Better energy resolution ($< 5\%/\sqrt{E}$) is needed ?
such as PbWO_4 crystals.... for measurement of $H \rightarrow \gamma\gamma$.

3. Hadron calorimeter

The same response ($e/\pi=1$) is necessary ?
Offline (software) compensation may work.

4. Vertex detector: CCD or pixel

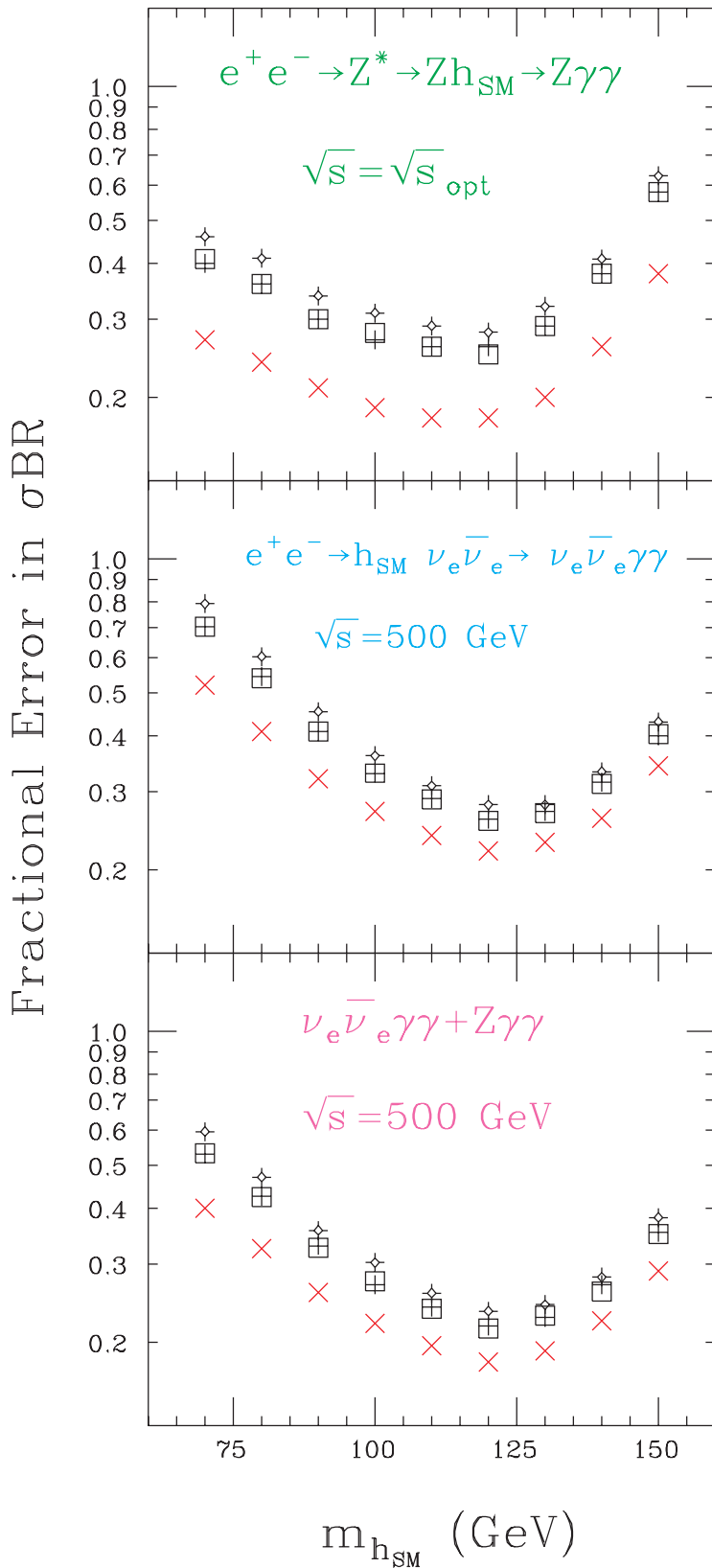
CCD : radiation hardness ($> 10^9$ n/cm²)
fast readout of 10^8 channels (100MHz)

Pixel : spatial resolution is enough ?

Minimal radius should be 1cm with $B = 4$ Tesla ?

optimum r_{VTX} and B ?

Resolutions: \times (I); $+$ (II); \square (III); \diamond (IV)
 $L = 200 \text{ fb}^{-1}$



Electromagnetic Cal.

(I) $\Delta E/E = 2\%/\sqrt{E} \oplus 0.5\%$
 $\oplus 20\%/E$
 (CMS, PbWO_4)

(II) $\Delta E/E = 10\%/\sqrt{E} \oplus 1\%$

(III) $\Delta E/E = 12\%/\sqrt{E} \oplus 0.5\%$

(IV) $\Delta E/E = 15\%/\sqrt{E} \oplus 1\%$
 (JLC)

CCD/VTX

C. Damerell

Present(SLD)

LC

$$\sigma_{xy} \approx 11\mu\text{m} \oplus \frac{29\mu\text{m}}{p \cdot \sin^{3/2} \theta}$$

$$\sigma_{xy} (\sigma_{RZ}) \approx 3\mu\text{m} \oplus \frac{5.5\mu\text{m}}{p \cdot \sin^{3/2} \theta}$$

$$\sigma_{RZ} \approx 18\mu\text{m} \oplus \frac{29\mu\text{m}}{p \cdot \sin^{3/2} \theta}$$

$$\sigma \approx (\text{pixel size, } R_{\min}) \oplus (\text{multiple scattering})$$

$$R_{\min} : \quad 3 \text{ cm}$$

$$\sim 1 \text{ cm}$$

(B=4 Tesla)

$$X_0 : \quad 0.35\% \text{ rl/layer}$$

$$0.12\% \text{ rl/layer}$$

$$(\text{Si} : 200 \mu\text{m}^t)$$

$$20 \mu\text{m}^t)$$

$$(\beta\text{e} : 0.38 \text{ mm}^t)$$

$$0.38 \text{ mm}^t)$$



Significantly improves 3D topological vertex reconstruction



**Primary, Secondary, Tertiary Vertices
Charm and bottom quark ID**

5. Minimum veto angle

$$\theta_{\text{veto}} = 200 \text{ mrad ?}$$

= 50 mrad ? even smaller ?

in order to veto two-photon process for SUSY studies such as stau pair production.

The mask shall be active, and calorimeter inside of the mask must work.

6. Intermediate tracker

in order to link charged tracks between CDC and VTX, where there is space from $r=7.5\text{cm}$ to $r=40\text{cm}$.

How is it important?

What kind of device is appropriate?

7. Endcap tracker

in order to measure forward(backward) scattering angles precisely, especially for Bhabha scattering to measure the acollinearity angles which determine the luminosity as a function of E_{cm} .

Is it necessary ? If so, what is detector-type ?

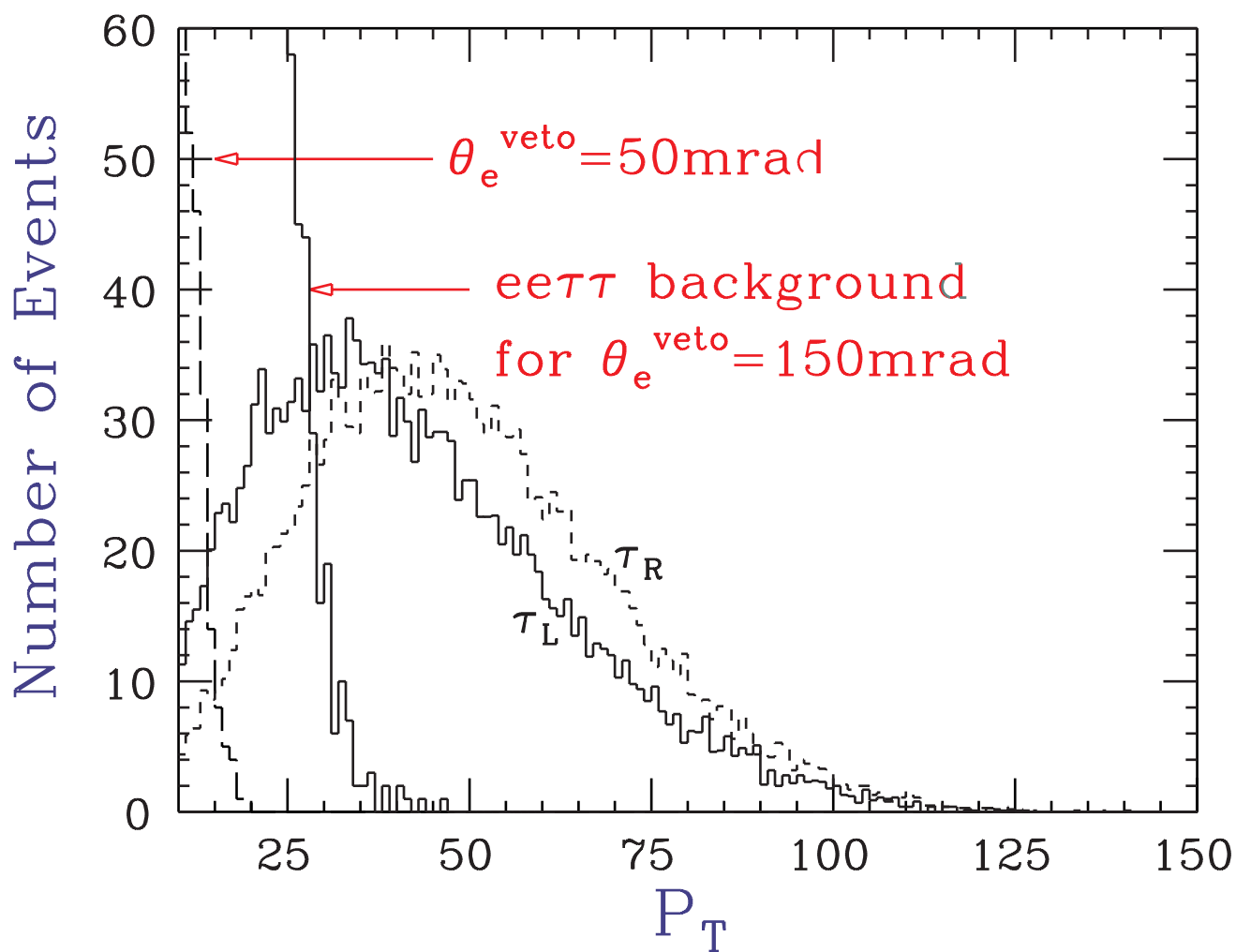
8. Particle identification

dE/dX measurement in CDC is necessary?

Any detector dedicated to particle-ID is necessary?
for NLSP of gauge mediated SUSY

Importance of small veto angle for

$$e^+e^- \rightarrow \tilde{\tau}_{L(R)}^+ \tilde{\tau}_{L(R)}^-$$



9. Good timing information(CDC,CAL,VTX)

The goal is to identify an event in a specific bunch, where the bunch separation is 1.4-2.8 nsec,

in order to discriminate a physics event from minijets etc. .

For an example, if a physics event with a minijet,

$$\sigma_{jj}(2 \text{ jet mass})=3.9\text{GeV} \rightarrow 5.4\text{GeV}$$

$c\bar{c}$ minijet is serious background for $h \rightarrow b\bar{b}$?

10. Trigger

Do we need a hardware trigger?

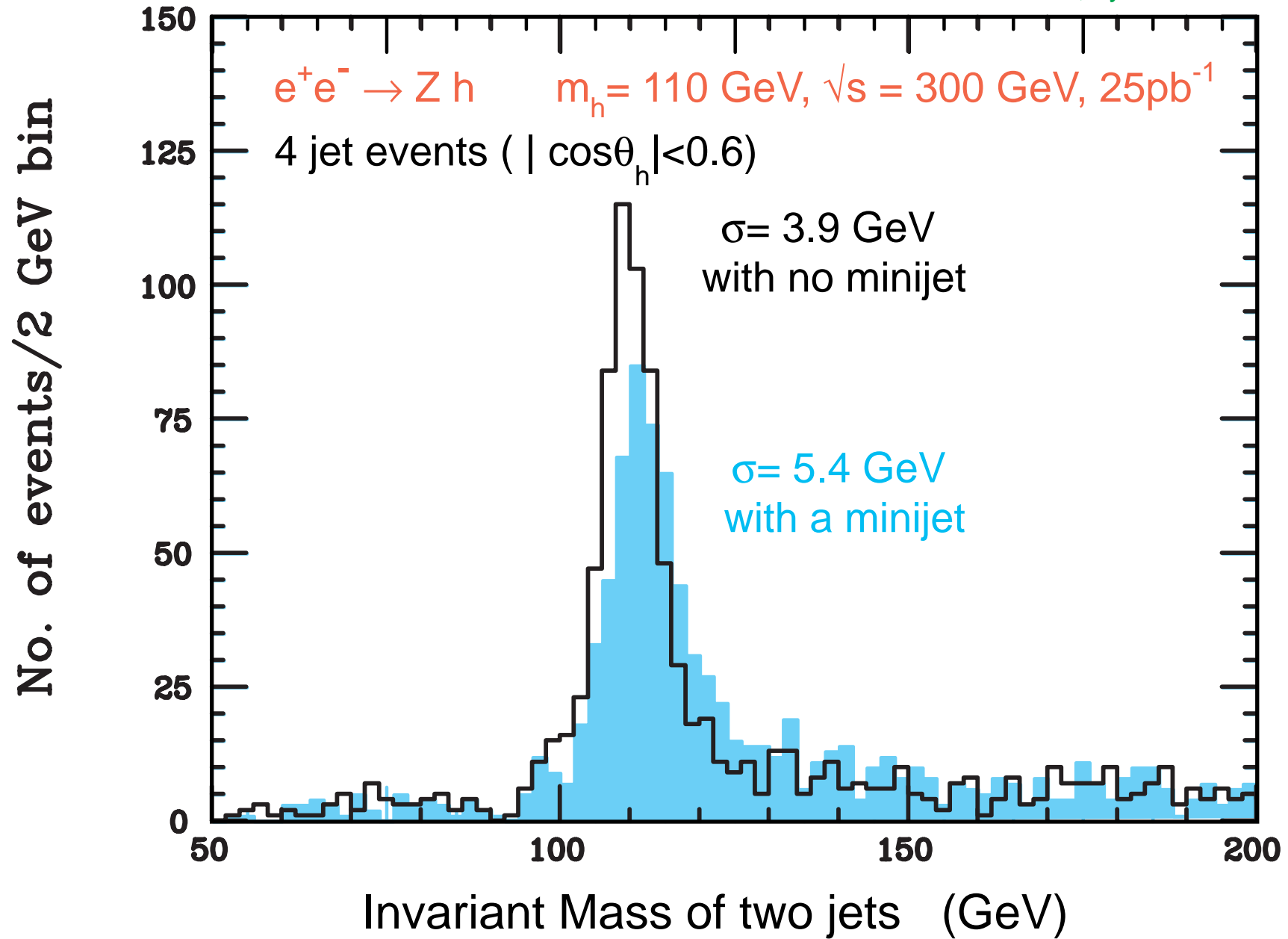
A software trigger is of-course needed, however what is the difference?

11. Data aquisition

For the JLC-1 detector;

Typical data size: 12 Mbyte/hadronic event

Readout speed (no data save on tapes): 150 Hz max.



Sizes and Electronics for the JLC detector

total size: 16 x 16 x 16 m³, 14,783 tons

Detector	Total channels	Typical data size	Method	weight	Power consumption
Vertex	6×10^3	68 kbytes/bunch-crossing	Flash ADC		12kW 0.5kW(preamp)
CDC	1.8×10^4 r=0.3-2.3m, 4.5mlong,	12 Mbytes/hadronic-event 73.5m ³ of CO2-isobutane(90:10)	500MHz,8bit Flash ADC(22W/ch)	3 tons	397kW 1.0kW****(preamp)
CAL	3×10^4 2×10^6 of Si pads	30kbytes/hadronic-event	FASTBUS-ADC	1,500(barrel) +1,280(endcap) tons	12.4kW** 300kW***(preamp)
MDC	1.25×10^4 ~4x10m long(barrel), ~4x15m long (endcap),	40kbytes	Conventional TDC 745m ³ of HRS gas		9.4kW* 0.7kW****(preamp)
Magnet	9m diameter x 10m long			12,000tons with iron	500kW
Liq.Helium	500 liters			(coil:52x3tons; 720tons without iron)	

*FASTBUS-TDC(LecRoy1879) 71.8W/96ch

**FASTBUS-ADC(LecRoy1885) 39.6W/96ch

***preamplifier(TOPAZ-FCL type) 150mW/ch

****preamplifier(TOPAZ-VTX type) 50mW/ch

Utilities for the JLC detector

1) total size: 16 x 16 x 16 m³, 14,783 tons

2) Largest component

(a) Magnet coil 9m diameter x 10m long

It can be divided into 3 coils of 3.2m long; 52 x 3 tons

(b) MDC 7m x 15m

It can be divided into 2.

3) Electric power consumption

(a) Electronics Hut 430.8kW

(b) Detector side 302.2kW

(c) Magnet 500kW

Total 1233kW

4) Cooling water*

(a) Electronics Hut 90 liters/sec

(b) Detector side 75.4 liters/sec

(c) Magnet 125 liters/sec

Total 299.4 liters/sec

5) Liquid He

500 liters

*50 kcal/sec=50 kg/sec=50 liters/sec corresponding to 200 kW
cooling