

# LumiCal integration :

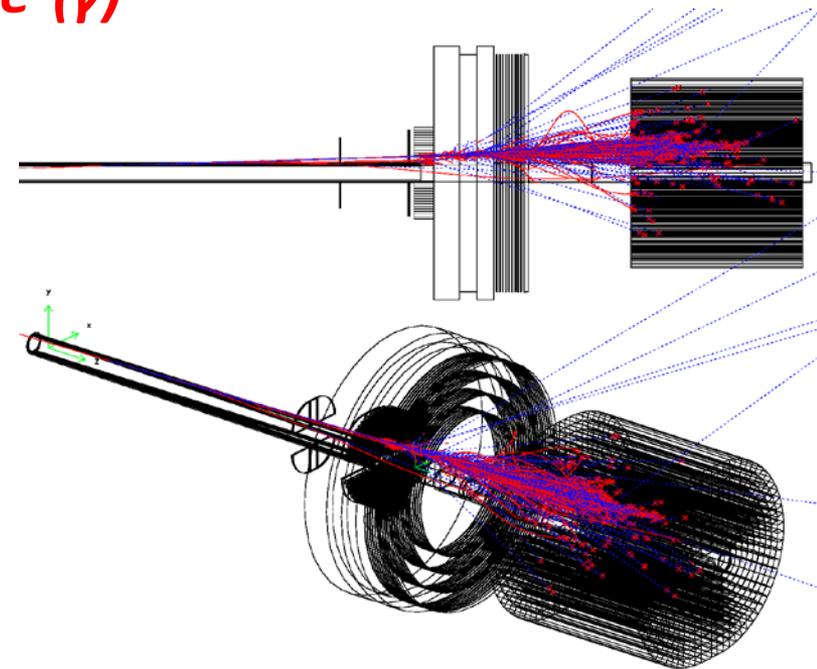
## GEANT simulation on

### BHLUMI Bhabha $e^+e^- (\gamma)$

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- Bhabha parameters for  $10^{-4}$  systematics on  $\int \mathcal{L}$
- **GEANT simulation**  
reading **BHLUMI** generated **Bhabha  $e^+e^- (\gamma)$**
- **IP smearing**  $(\sigma_x, \sigma_z) = (6, 380)$  mm  
propagated to  $\theta_{\min}$  for Bhabha detection
- **Beam-pipe thickness** 1mm Be  
low-mass window to  $\theta_{\min}$  for Bhabha
- **LYSO preshower (2X0)** detecting  
radiative Bhabha,  $e^\pm/\gamma$  separation



# Luminosity to $10^{-4}$ precision

- **Observable cross section**  $N = \sigma \cdot \int L$   $L$ : Luminosity of  $e^+e^-$  collisions
- **Luminosity** measured by counting **Bhabha events**, QED precision  $< 0.1\%$ 
  - a pair of back-back electrons,
  - precision  $\vartheta$  on  $e, e(\gamma)$  in fiducial region

## Bhabha systematic error

$$\delta L/L \sim 2 \delta\vartheta/\vartheta_{\min}$$

requiring  $\delta L/L = 10^{-4}$

at  $z = \pm 1$  m,  $\vartheta_{\min} = 20$  mRad

→  $\delta\vartheta = 1 \mu\text{Rad}$  or  $dr = 1 \mu\text{m}$

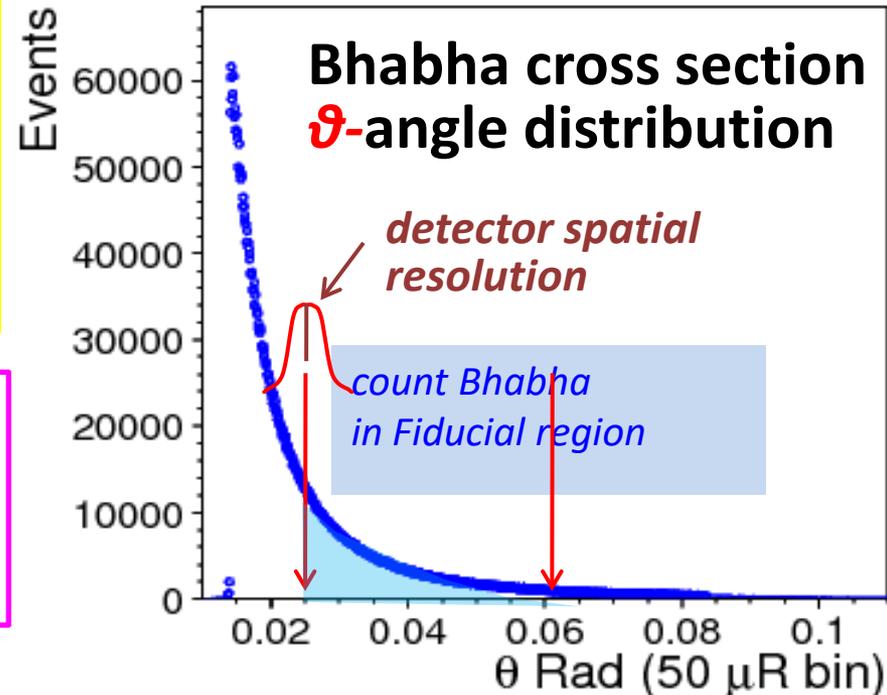
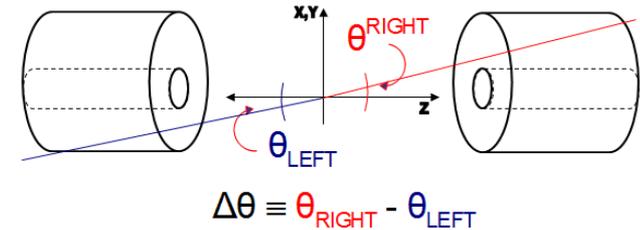
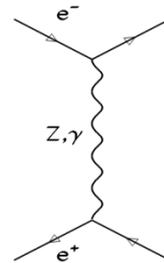
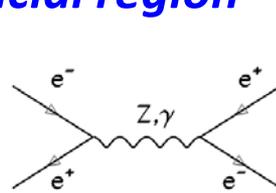
error due to offset on Z

→  $50 \mu\text{m}$  on Z eq.  $dr = \delta z \times \vartheta = 1 \mu\text{m}$

## Luminosity systematics

due to events in/out fiducial edge

→ offset on the mean of  $\vartheta_{\min}$



# LumiCal geometry

➤  $L=2 \times 10^{36} / \text{cm}^2 \text{s}^{-1}$  @Z-pole, goal is  $10^{-4}$  systematics

- $\varnothing 20 \text{ mm}$  racetrack, beam-crossing: **33 mRad**
- IP bunch :  $\sigma_x \sigma_y \sigma_z = 6 \mu\text{m}, 35 \text{ nm}, 9 \text{ mm}$
- Bunch crossing: **23 ns**

➤ **LumiCal before Flange**

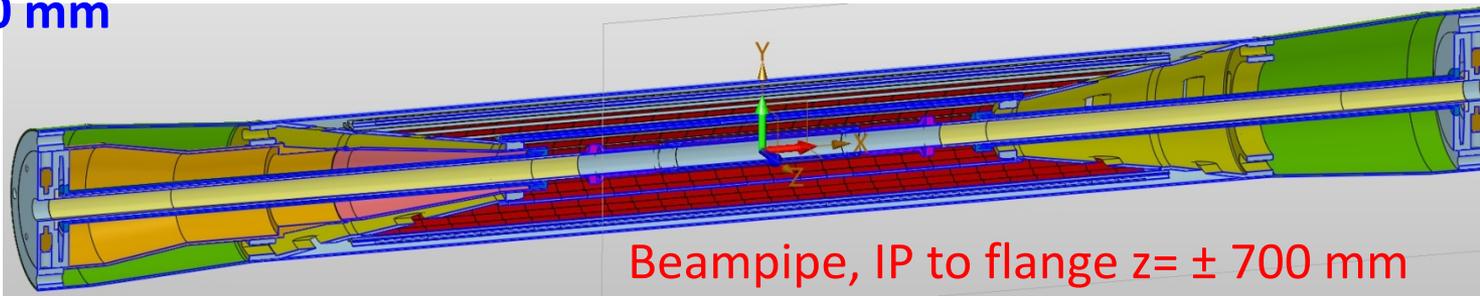
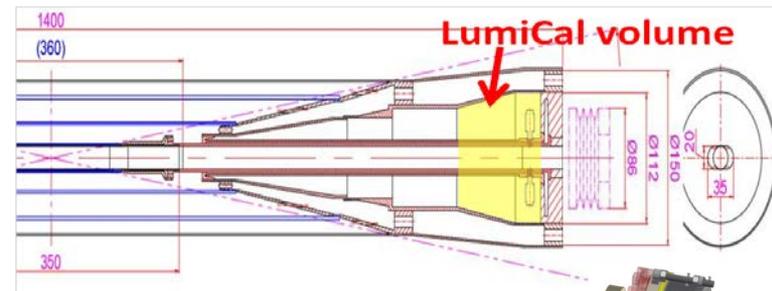
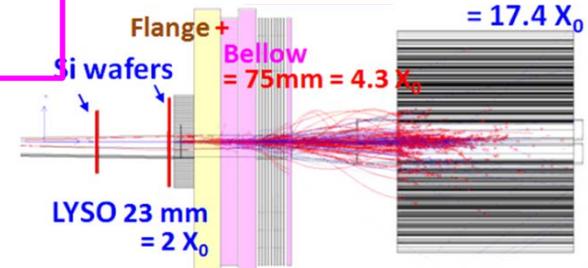
$z = 560 \sim 700 \text{ mm}$

- **Low-mass window: Be 1mm thick** traversing @22 mRad traversing  $L = 45 \text{ mm}$ ,  $= 0.13 X_0 (\text{Be}), 0.50 X_0 (\text{Al})$
- **Two Si-wafers** for  $e^\pm$  impact  $\theta$
- **$2X_0$  LYSO** = 23 mm

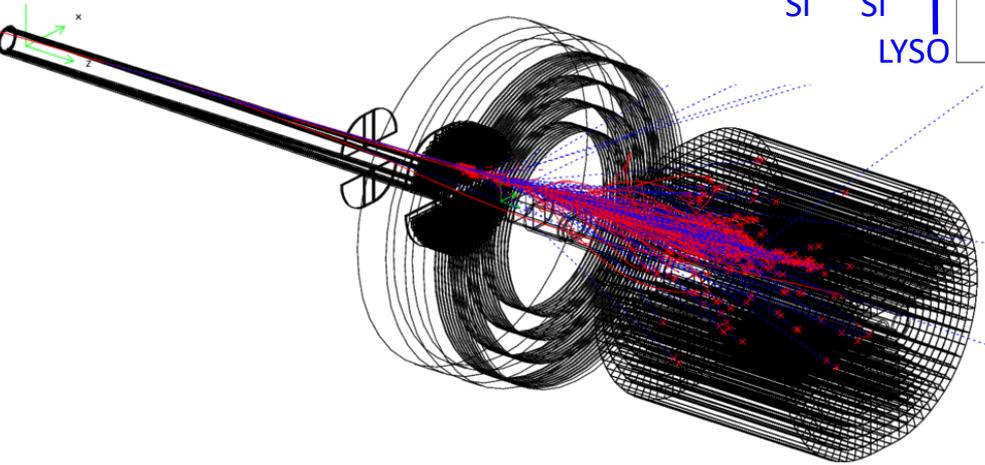
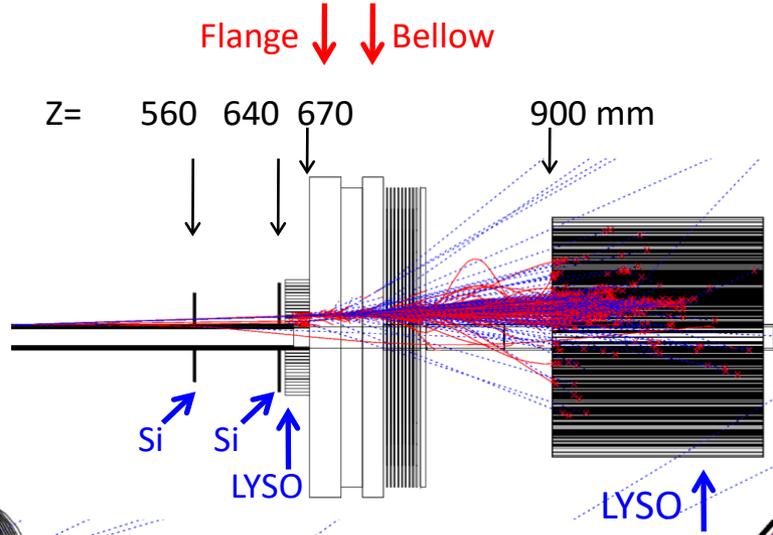
➤ **LumiCal behind Bellow:**

$z = 900 \sim 1100 \text{ mm}$

- **Flange+Bellow** :  $\sim 60 \text{ mm}, 6 X_0$
- **$17 X_0$  LYSO** 200 mm

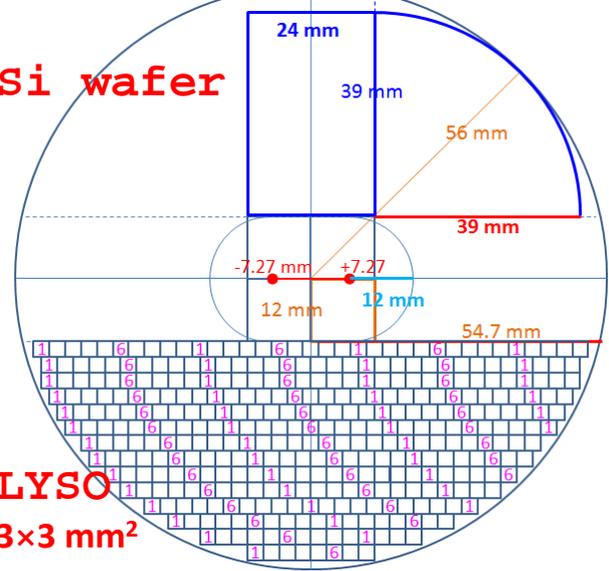


# LumiCal in GEANT



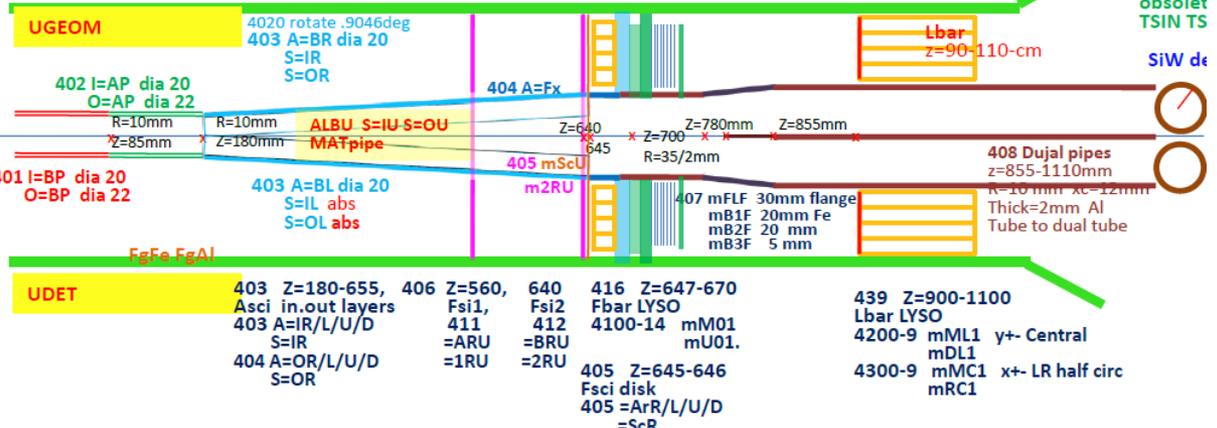
## LumiCal b.f. Flange

### Si wafer



409 TbFe 5mm Fe Tbls TbOs 2mm Scin  
 $r = 15\text{cm} \sim +2, +5, +2$   
 $z = 0 \sim 111\text{cm} \text{ Edge } 15/118 = \tan(.1266) @ \cos Q = .992$

TPC cor  
 TPCC §  
 obsolete  
 TSIN TS



**UGEOm**  
 4020 rotate .9046deg  
 403 A=BR dia 20  
 S=IR  
 S=OR  
 402 I=AP dia 20  
 O=AP dia 22  
 R=10mm  
 Z=85mm  
 R=10mm  
 Z=180mm  
 401 I=BP dia 20  
 O=BP dia 22  
 403 A=BL dia 20  
 S=L abs  
 S=OL abs  
 FeFe FeAl

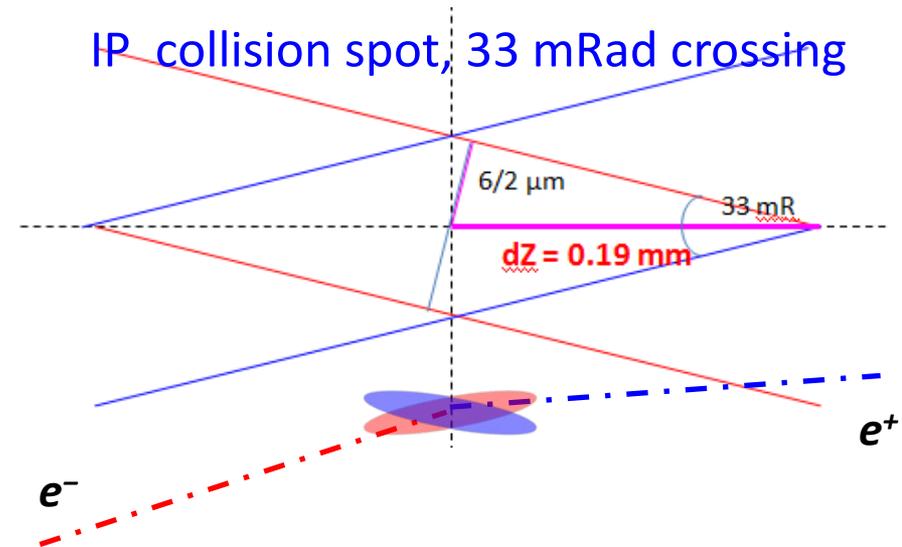
404 A=Fx  
 405 mScU  
 m2RU  
 407 mFLF 30mm flange  
 mB1F 20mm Fe  
 mB2F 20 mm  
 mB3F 5 mm  
 406 Z=560, Fsi1, 411 =ARU =1RU  
 406 Z=560, Fsi2, 412 =BRU =2RU  
 416 Z=647-670 Fbar LYSO 4100-14 mM01 mU01.  
 405 Z=645-646 Fsci disk 405 =ArR/L/U/D =ScR

Lbar z=90 110-cm  
 SIW de  
 408 Dujal pipes z=855-1110mm R=10 mm xc=12mm Thick=2mm Al Tube to dual tube  
 439 Z=900-1100 Lbar LYSO 4200-9 mML1 y+- Central mDL1 4300-9 mMC1 x+- LR half circ mRC1

# IP bunch smearing

- bunch size  $\sigma_x = 6 \mu\text{m}$ ,  $\sigma_z = 9 \text{ mm}$
- ➔ IP spot  $\sigma_x = 6 \mu\text{m}$ ,  $\sigma_z = 380 \mu\text{m}$
- boost by 33 mRad beam crossing
- $Z \rightarrow e^+, e^-$  at  $\vartheta = 30 \text{ mRad}$   
smearing at @z=560mm

smear width  $\sigma(\vartheta) = 24 \mu\text{Rad}$   
back-to-back  $\sigma(\Omega) = 21 \mu\text{Rad}$



CMS ( $\vartheta = 30 \text{ mR}$ ,  $\varphi = \pi/2$ ),  $E = 46 \text{ GeV}$  ➔ *boosted*

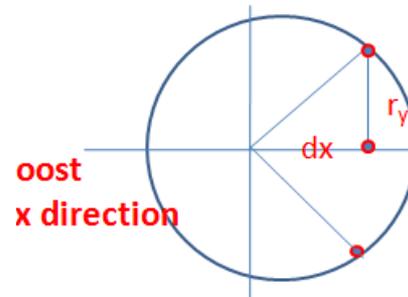
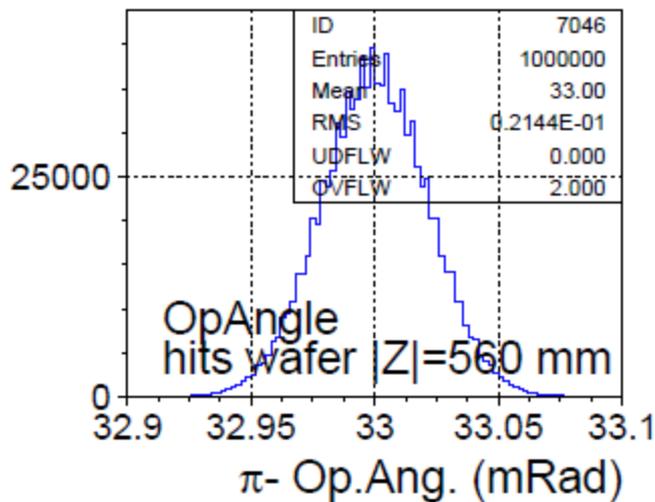
$V1 = (0, +16.8, +560) \text{ mm}$

$V1 = (9.2, +16.8, +560) \text{ mm}$

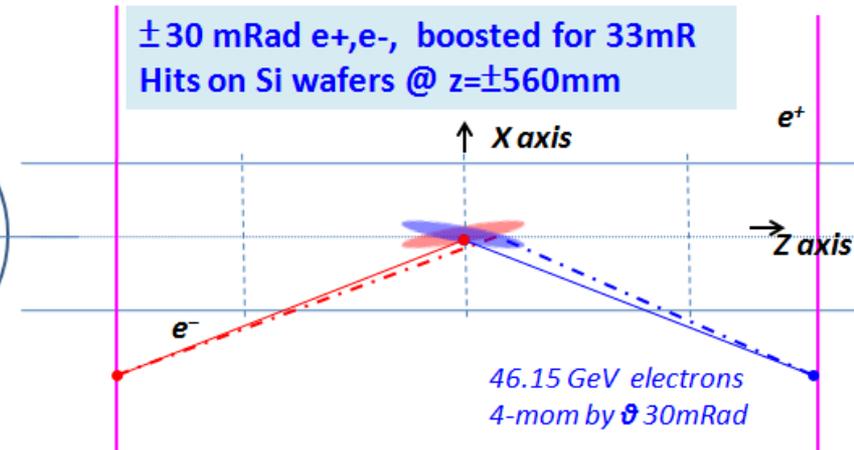
$V2 = (0, -16.8, -560) \text{ mm}$

$V2 = (9.2, -16.8, -560) \text{ mm}$

back-to-back



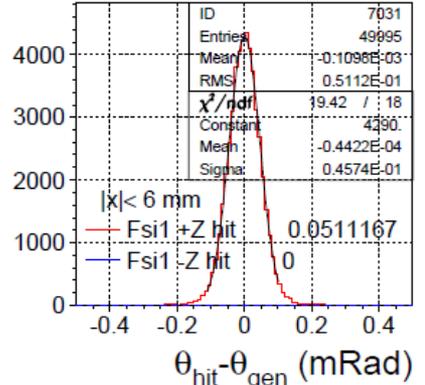
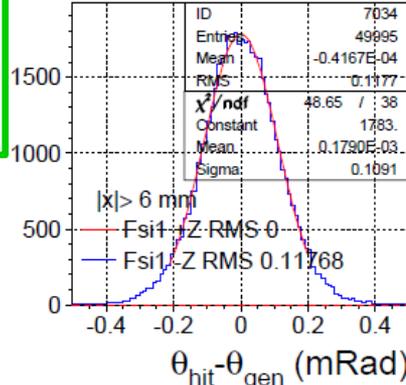
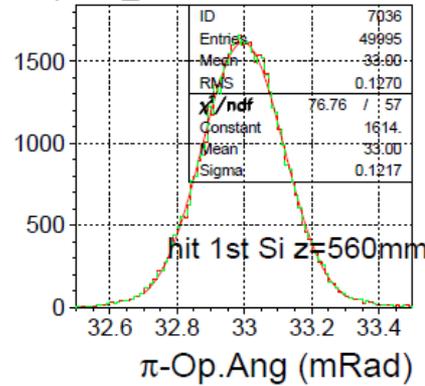
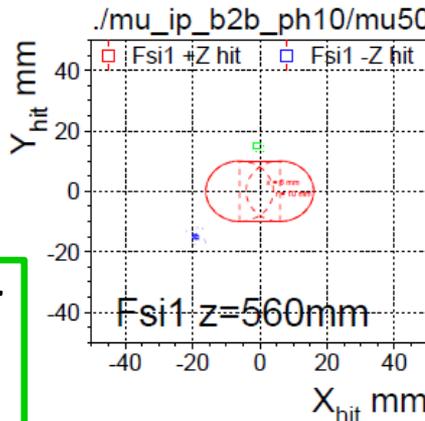
$\pm 30 \text{ mRad } e^+, e^-$ , boosted for 33mR  
Hits on Si wafers @  $z = \pm 560 \text{ mm}$



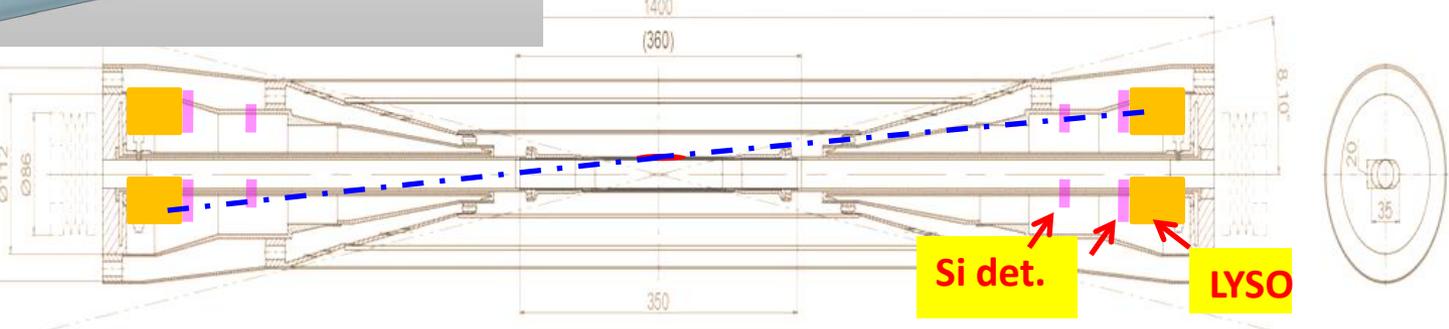
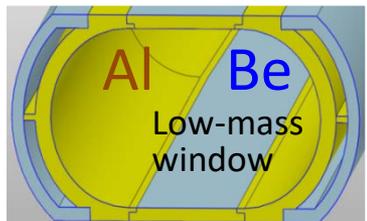
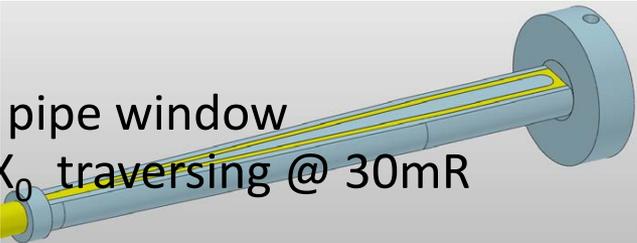
# GEANT beampipe multiple scattering

- IP spot  $(\sigma_x, \sigma_z) = (0, 0), (6, 380 \mu\text{m})$  ← compatible
- boost by 33 mRad beam crossing
- **50 GeV  $\mu^+, \mu^-$**   
@ ( $\vartheta = \pm 30 \text{ mRad}, \varphi = 1.0, 1.0 + \pi \text{ Ra}$ )

smearing at @z=560mm, 1<sup>st</sup> Si wafer  
 $|x| < 6.0 \text{ mm}$ , 1mm Be  
 low mass window  $\sigma(\vartheta) = 46 \mu\text{Rad}$   
 $|x| > 6.0 \text{ mm}$  1mm Al pipe,  $\sigma(\vartheta) = 109 \mu\text{Rad}$   
 back-to-back  $\sigma(\Omega) = 122 \mu\text{Rad}$



**1 mm Be** thin pipe window  
 33mm = 0.09X<sub>0</sub> traversing @ 30mR



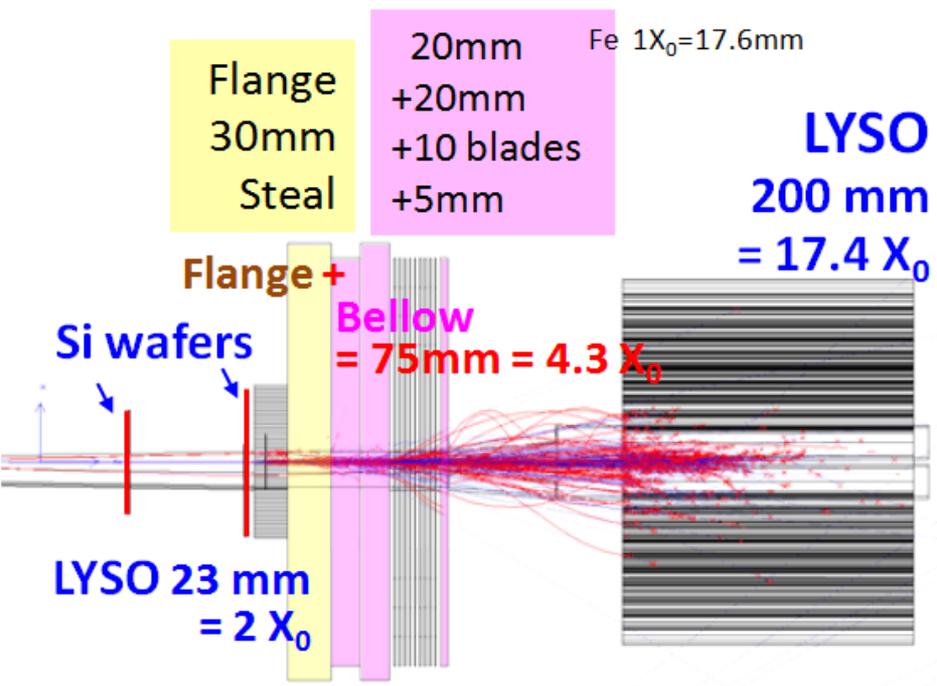
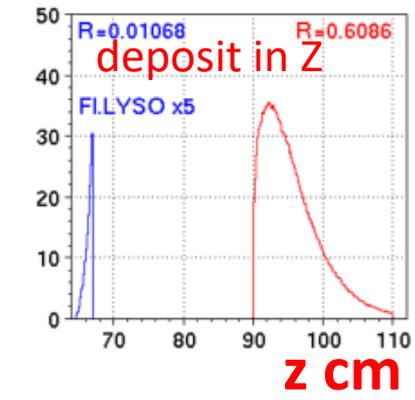
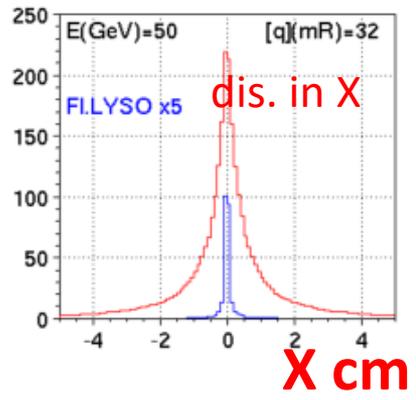
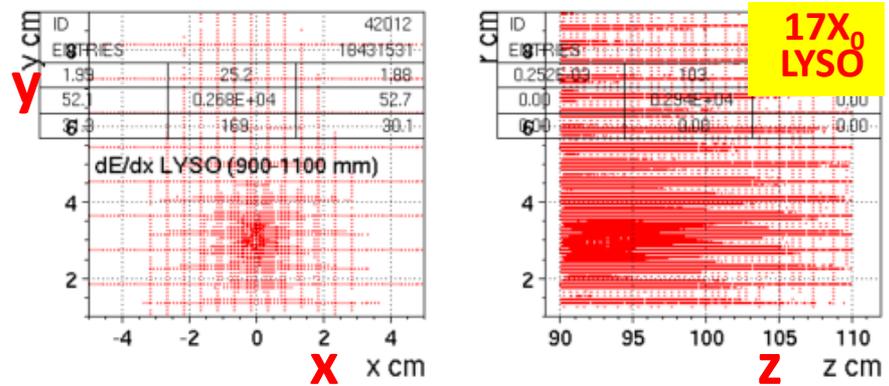
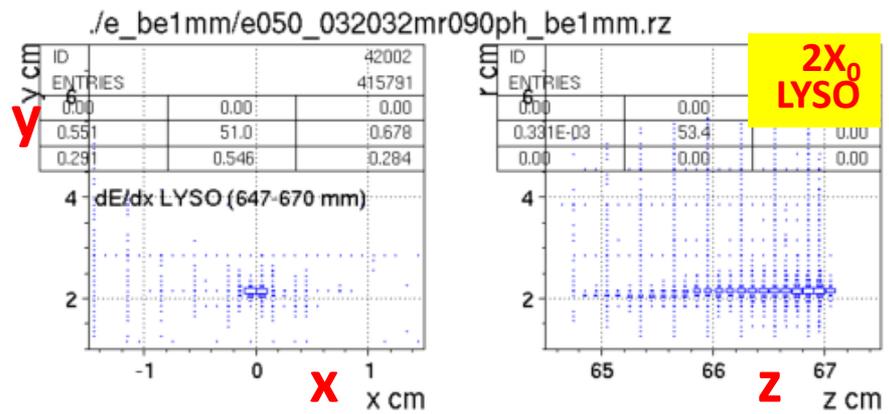
# GEANT LumiCal electron shower

**50 GeV electron** @  $\theta = 32$  mRad,  $\phi=90^\circ$

- 2X0 LYSO + 4.3X0 Flange,Bellow + 17X0 LYSO

**Shower deposition, by Sum(dE/dx)**

- in front LYSO:  $\sim 1.0\%$
- in back LYSO:  $\sim 61\%$



Flange  
30mm  
Steel

20mm  
+20mm  
+10 blades  
+5mm

# BHLUMI QED generator $e^+e^- \rightarrow e^+e^-(\gamma)$

$E_{\text{CMS}} = 92.3 \text{ GeV}$   $\theta_{\gamma} = 10 \sim 80 \text{ mRad}$

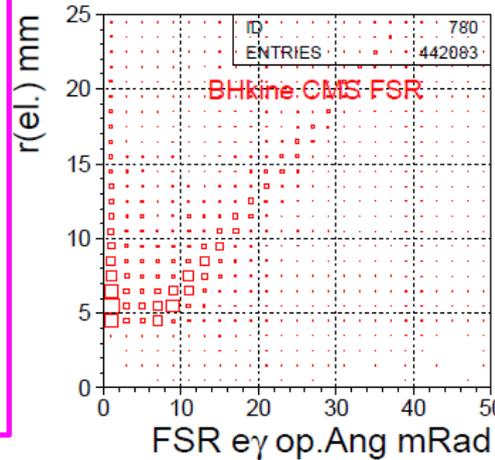
- **Bhabha**

$e^+e^- \rightarrow e^+e^- + N\gamma \rightarrow E_{\gamma} > 50 \text{ MeV}$

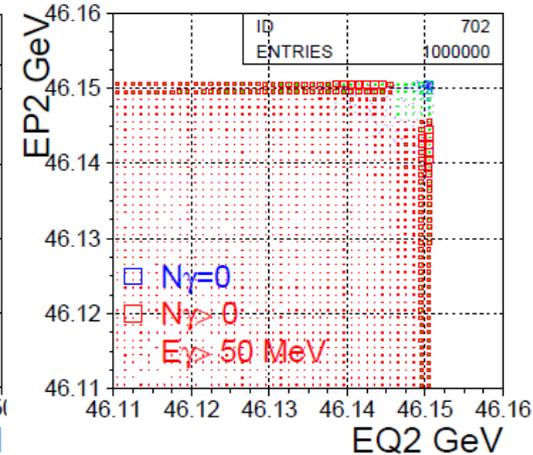
- **Opening angle**  $\Omega(e, \gamma)$  vs.  $r(e)$   
increase w. electron  $\vartheta$

- **radiative Bhabha** examined for  
max. photon vs paired electron

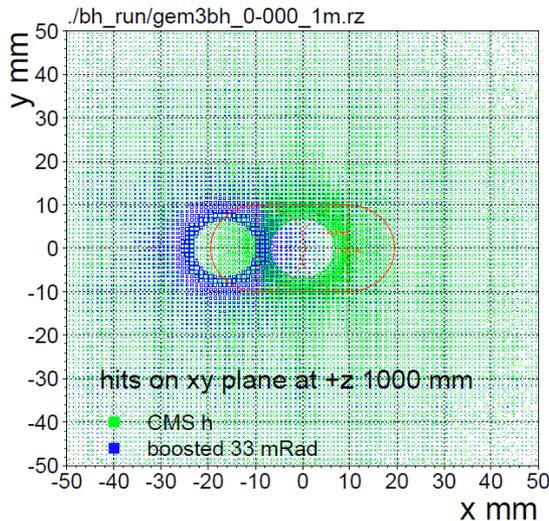
**CMS radius( $e^{\pm}$ ) vs.  $\Omega$**



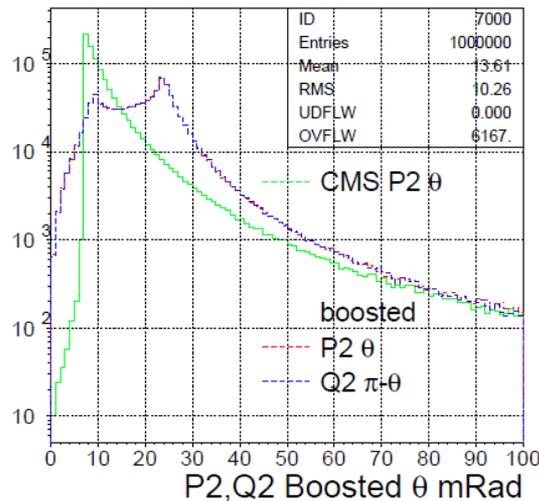
**$E(e^+) \text{ vs } E(e^-)$**



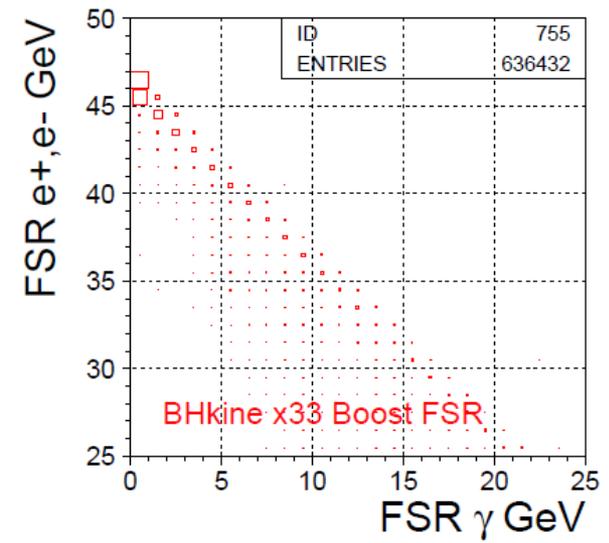
hit (x,y) distributions  
generated @z=1m  
boosted @z=1m



Scattered electron  $\theta$   
CMS generated ( $\theta > 10 \text{ mR}$ )  
x33mR boosted



Radiative Bhabha  
 $E(e^{\pm}) \text{ vs } E(\gamma)$



# Electron hits on 1<sup>st</sup> Si-wafer, LYSO @z=647mm

IP ( $\sigma_x, \sigma_z$ ) = (6,380  $\mu\text{m}$ ) ← compatible w. (0,0)

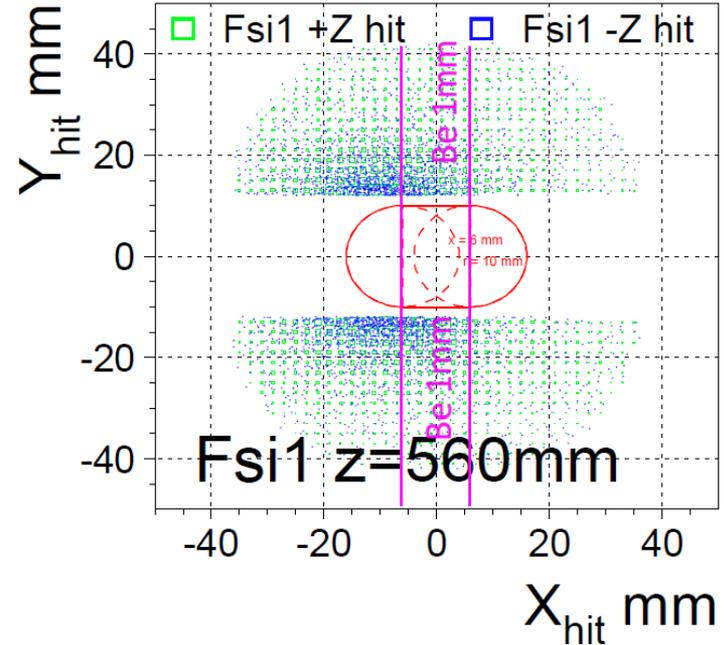
## Electrons hits

### Si wafer @z=560mm

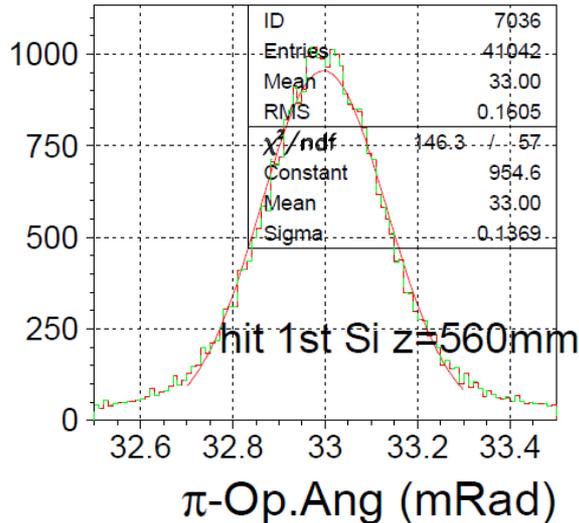
- $|x| < 6.0$  mm  $\sigma(\vartheta) = 54$  uR (1mm Be)
- $|x| > 6.0$  mm  $\sigma(\vartheta) = 95$  uR (1m Al pipe)
- back-back Op.Ang  $\sigma(\Omega) = 137$  uR

### LYSO (2X<sub>0</sub>) @z=647mm

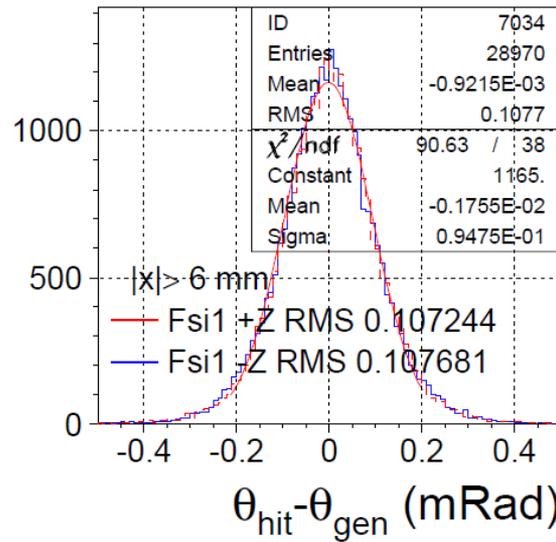
- $|x| < 7.3$  mm  $\sigma(\vartheta) = 54$  uR
- $|x| > 7.3$  mm  $\sigma(\vartheta) = 100$  uR
- back-back Op.Ang  $\sigma(\Omega) = 144$  uR



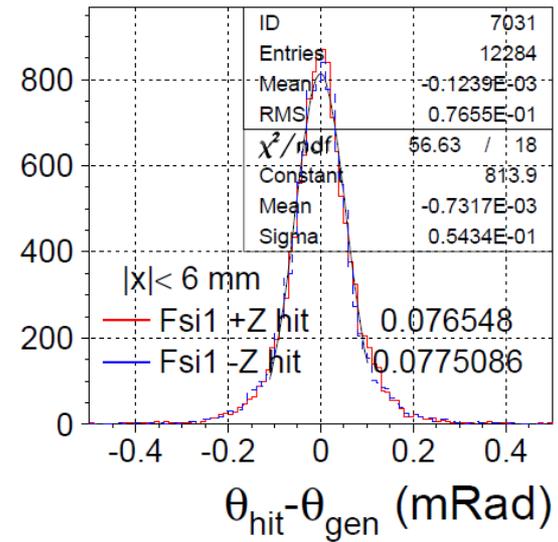
### e+,e- back-back angle



### e± GEANT hit – gen. $|x| > 6$



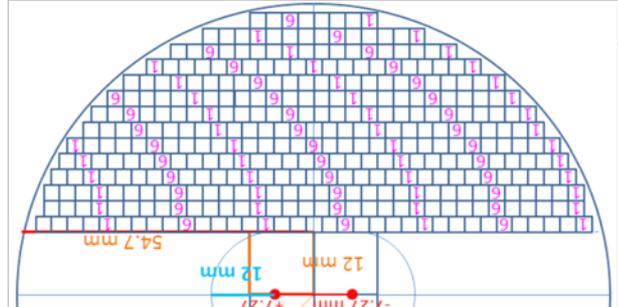
### hit – gen. $|x| < 6$



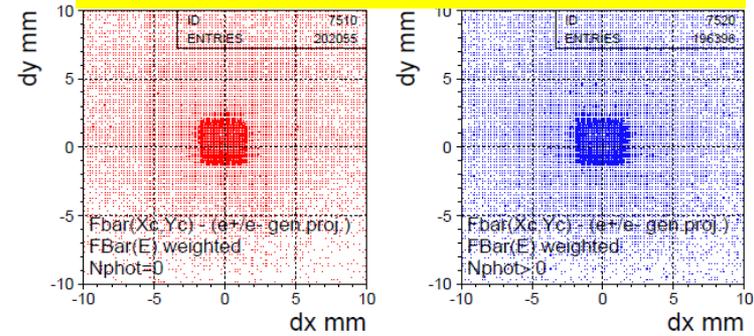
# 2X<sub>0</sub> LYSO bars observables

incident particles are e<sup>±</sup>,(γ) and secondaries

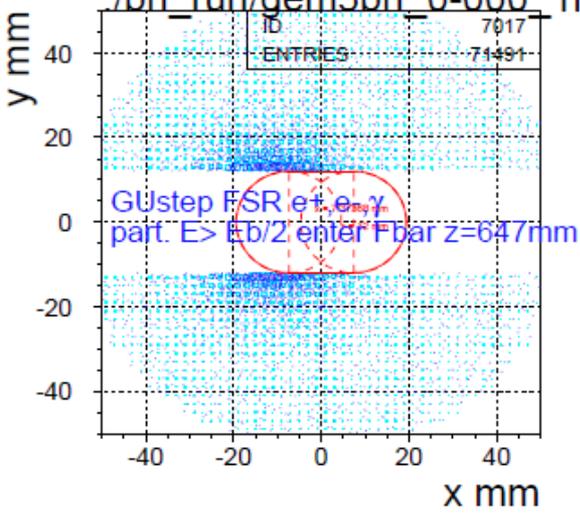
- GEANT sum dE/dx in each LYSO bars  
3x3mm<sup>2</sup>, 23 mm long, 2X<sub>0</sub>
- Deviation to e<sup>±</sup> truth (impact hit >Eb/2)  
mostly < 0.2mm
- Hit distributions in a Bar  
distributed due to Bhabha θ, w./w.o. photon



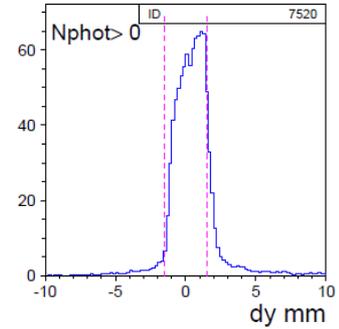
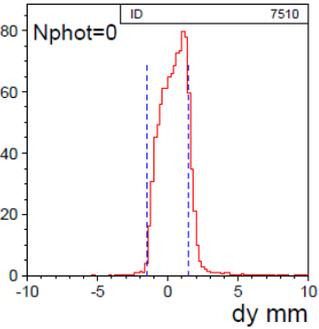
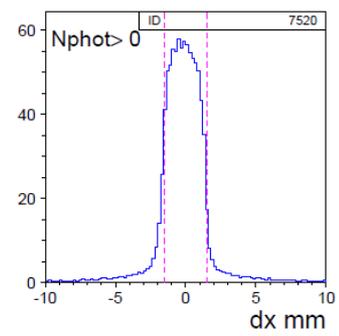
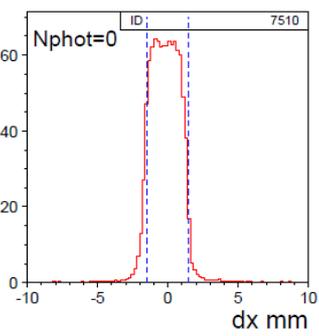
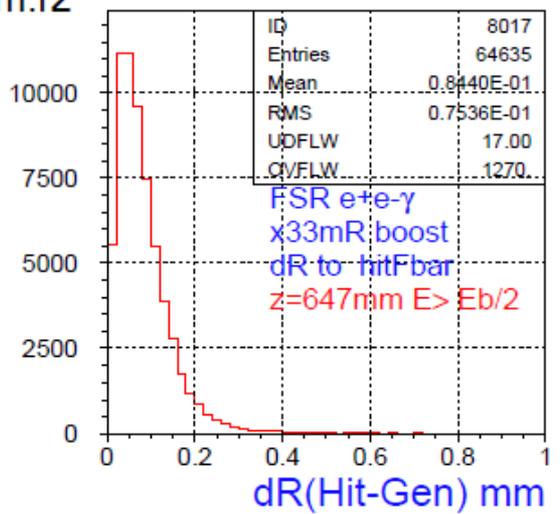
Loop Bars  
N<sub>γ</sub>=0                      N<sub>γ</sub>>0



GEANT hits E>Eb/2  
On LYSO @647mm  
/bh\_run/gem3bh\_0-000\_1m.rz

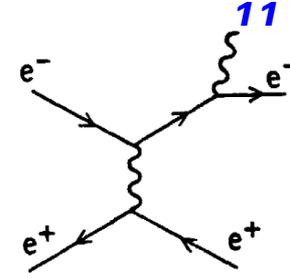


dR to Truth N<sub>γ</sub> > 0  
(boosted BHLUMI e<sup>±</sup>)



# 2X<sub>0</sub> LYSO observables for rad. Bhabha

$e^+e^- \rightarrow e^+e^-(\gamma)$

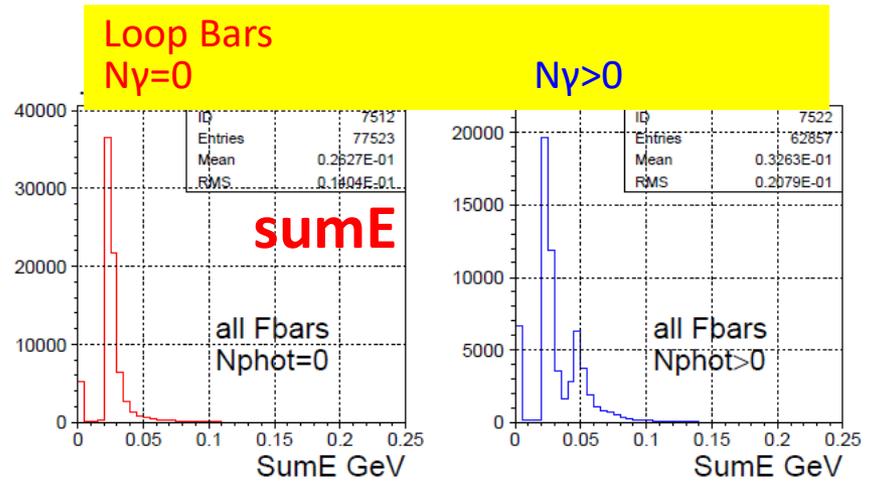
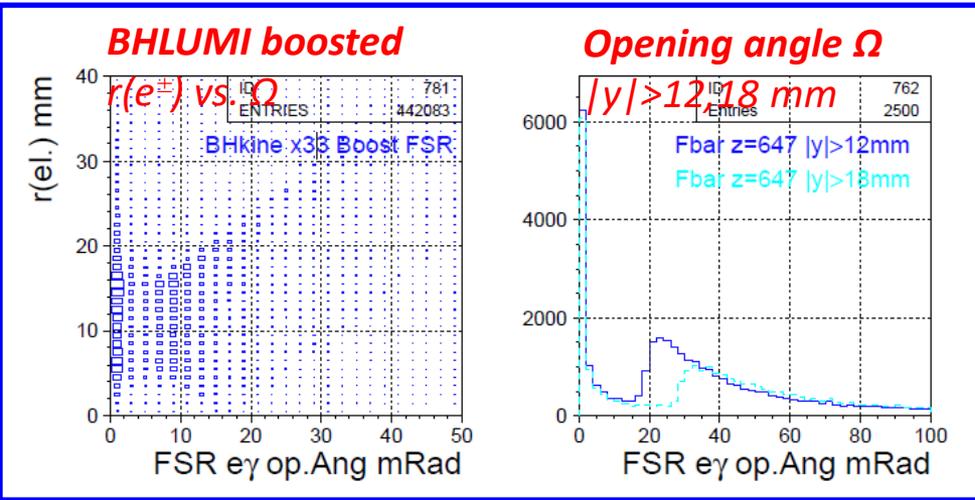


$\Omega(e^\pm, \gamma)$  Opening Angle

- Increase w. electron  $\theta$
- $r > 12\text{mm}$ ,  $\Omega(e, \gamma) = 20 \text{ mRad}$  (13mm@647)

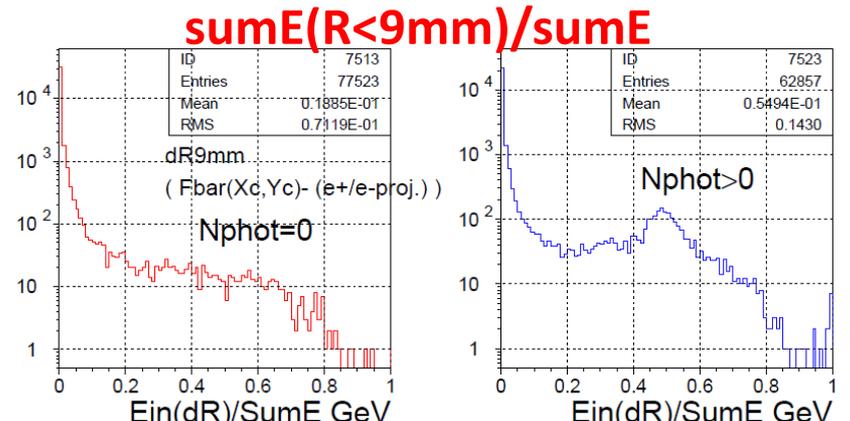
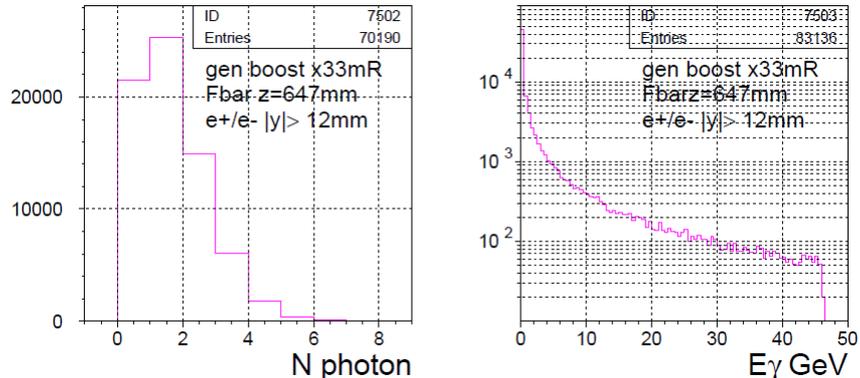
sum dE/dx all LYSO bars (a plane)

- $e^\pm$  one track : sumE min. 20 MeV
- $(e^\pm + \gamma)$  : two tracks, sumE x2



## Bhabha hits on LYSO |y| > 12mm

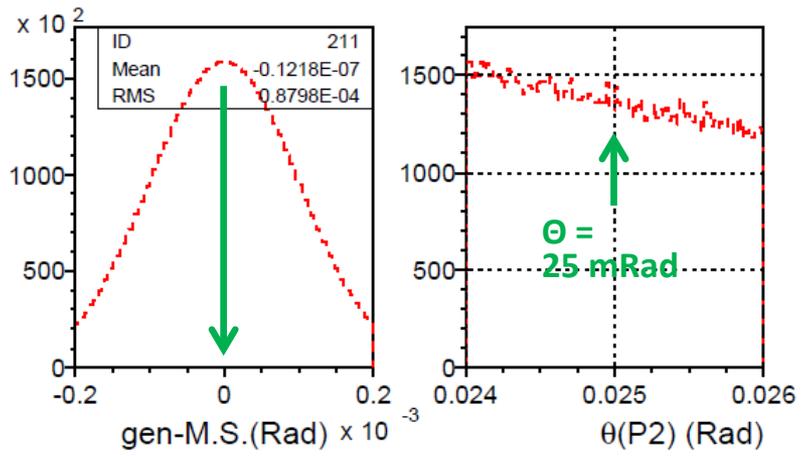
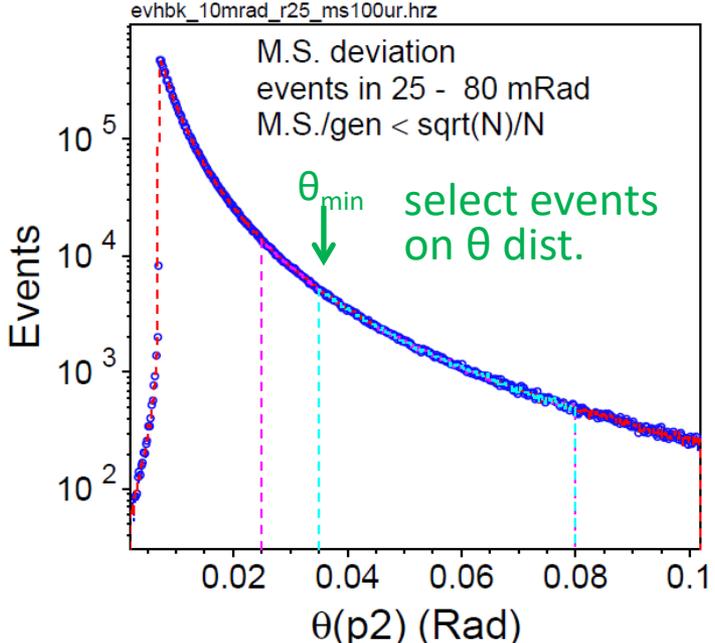
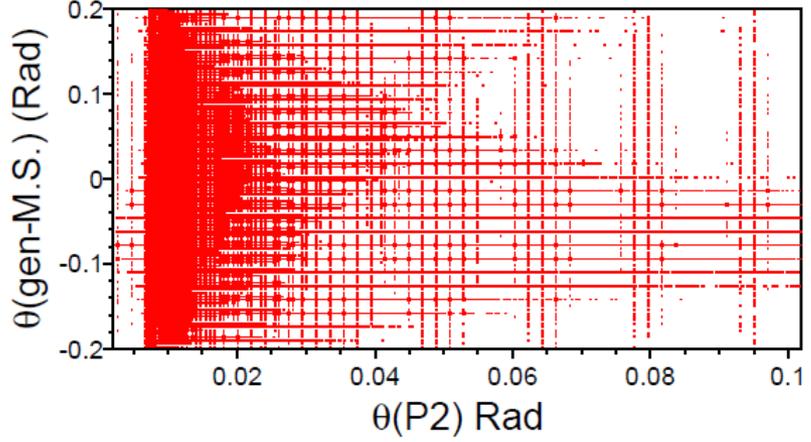
- BHLUMI ~80% having photons



# 10<sup>-4</sup> systematics, multiple scattering

1. BHLUMI smear  $\theta'$ ,  $\phi'$  of scattered e<sup>+</sup>, e<sup>-</sup>  
**Multi. Scatt. 100  $\mu$ Rad**  $\theta' = \theta \times \text{Gauss}(100 \mu\text{R})$ ,  $\phi' = \phi \times \text{Gauss}(100 \mu\text{R})$

2.  $\delta N/N$  systematics:  
 **$\delta N$**  = count event deviation due to M.S.  
 M.S is Gaussian, Symmetric  
 at  $\theta_{\min} = 25 \text{ mRad}$ , slope of Bhabha  
 in neighboring 100  $\mu$ Rad bins to 25mR  
 **$\delta N(@25\text{mR})/N(25-80 \text{ mR}) < 10^{-4}$**



**10<sup>-4</sup> is determined by survey of the mean position**

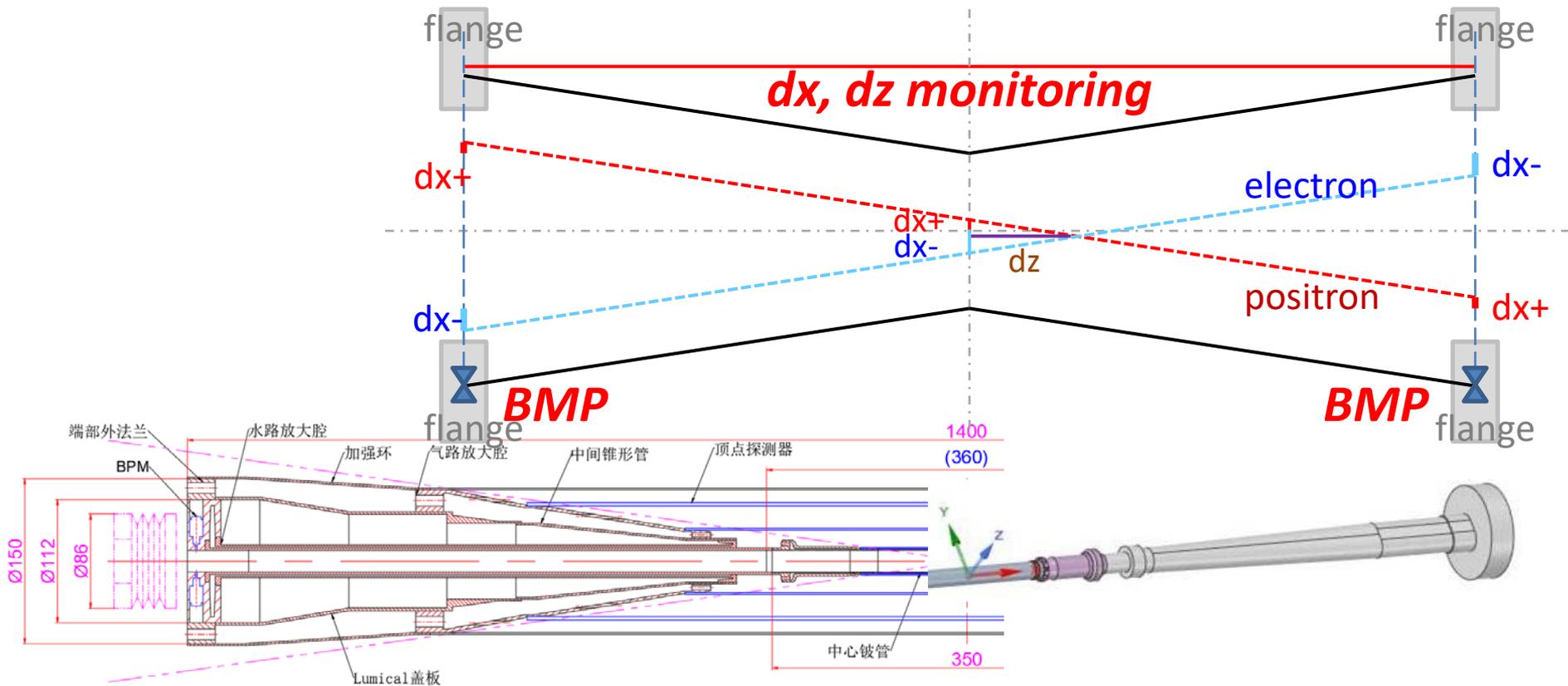
# Survey precision for $10^{-4}$ on Luminosity

## LumiCal within beampipe flange

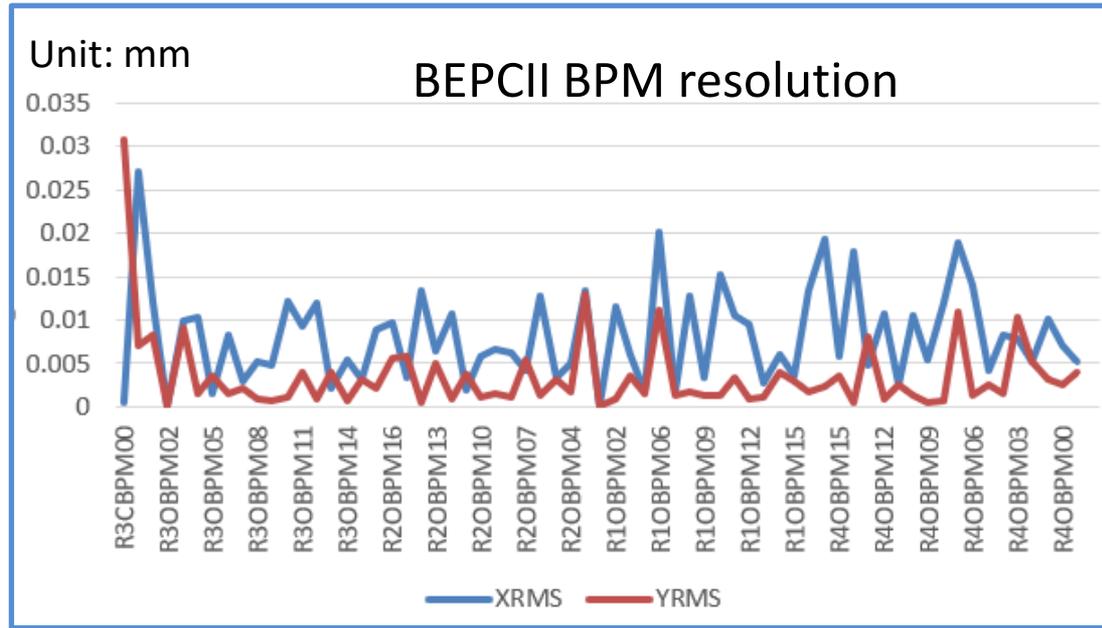
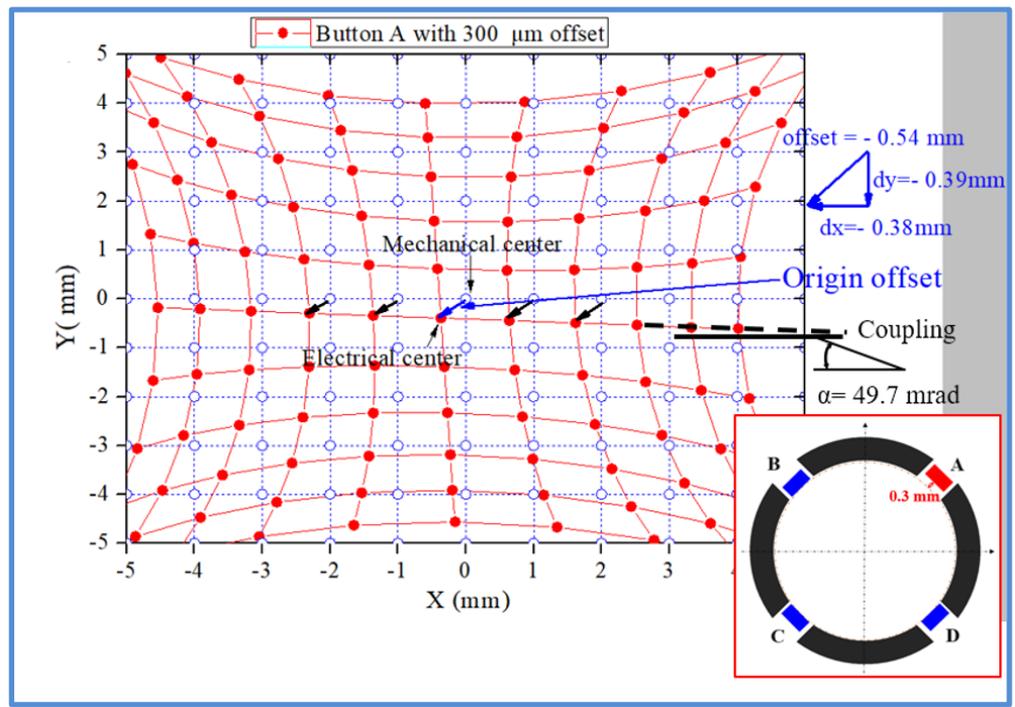
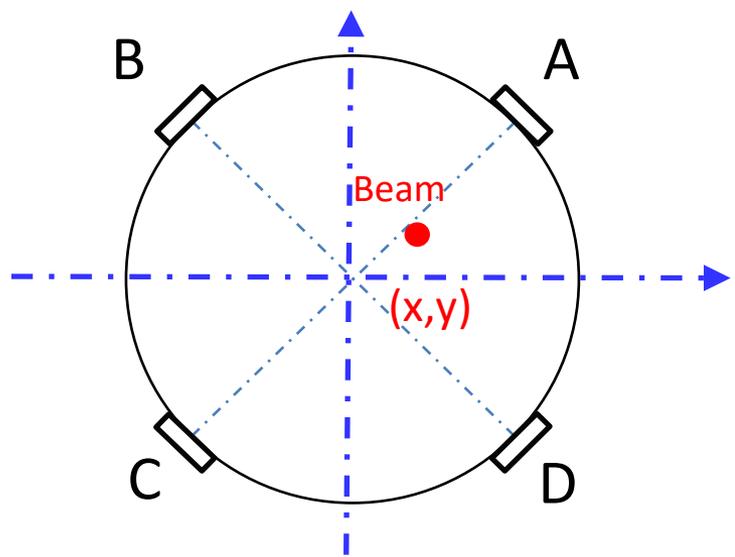
- Multiple scattering :  $\sim 50 \mu\text{m}$
  - $e, \gamma$  cluster-size in LYSO:  $\sim 100 \mu\text{m}$
  - Error on mean of (Bhabha  $> \theta_{\text{min}}$ )  $< 10^{-4}$
- $10^{-4}$  by survey precision on *Si wafer position* requiring  $\sigma_y = 1 \mu\text{m}, \sigma_z = 50 \mu\text{m}$

## Survey monitoring

- Beam Monitoring Probe *BPM* on beam line crossing IP
- Survey (Flange+ to Flange-) (1.4m) to  $50 \mu\text{m}$



# CEPC WS2023, J. He



# summary

the GOAL is for luminosity to  $10^{-4}$ ,  
Bhabha counting in a fiducial  $>\theta_{\min}$

- IP smearing, Multiple Scattering  $\rightarrow \sim 50 \mu\text{m}$
- Preshower LYSO  $< 2X_0$ 
  - hit cluster size  $< 200 \mu\text{m}$
  - $e/\gamma$  hit-cluster  $\text{sum}(dE/dx) \sim 20 \text{ MeV}$
- Planning for testbeam  $e/\gamma$  1 to 100 GeV
  - hit cluster size  $< 200 \mu\text{m}$
  - Preshower in BGO/LYSO for shower size,  $\text{sum}(dE/dx)$

*backup*

# Beam-pipe multiple scattering

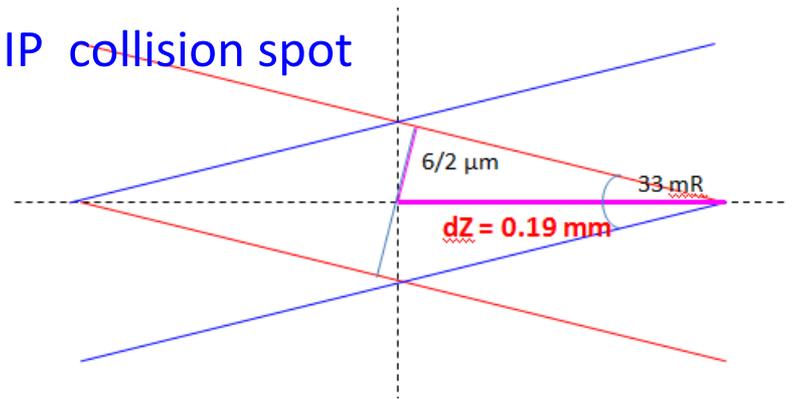
- Deviation to electron  $\theta$  by IP spread

beam bunch  $\sigma_x = 6 \mu\text{m}$   $\sigma_z = 9 \text{mm}$

crossing @ 33 mRad

- Beam crossing spot:  $\sigma_z = 0.38 \text{mm}$

IP collision spot

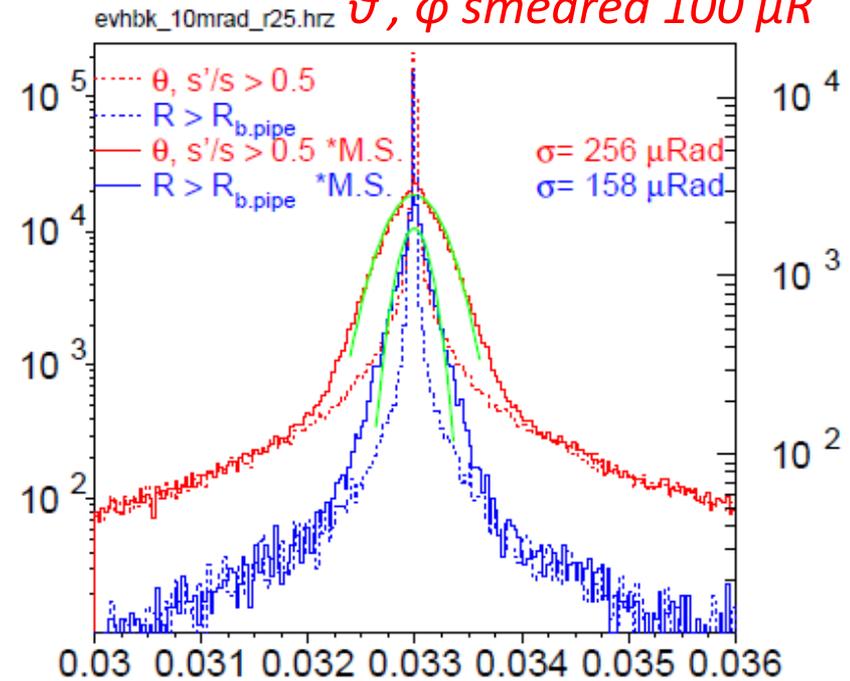


$e^-$   $e^+$



$e^+, e^-$  back-back angle

compare scattered  $e^+, e^-$   
 $\vartheta, \varphi$  smeared  $100 \mu\text{R}$

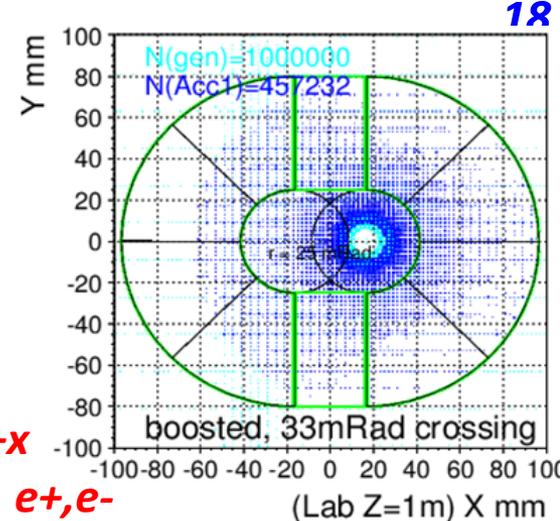


# BHLUMI + beam-crossing

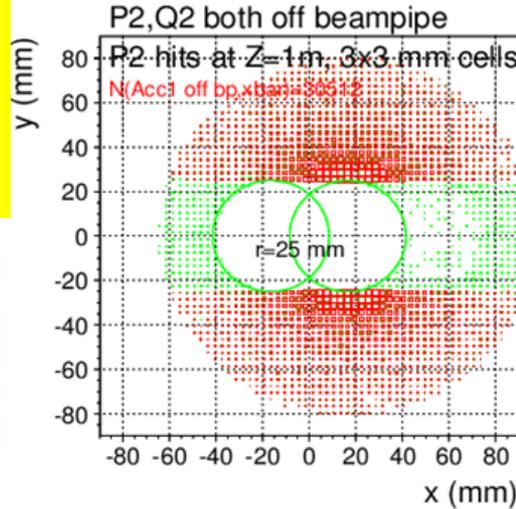
- BHLUMI** QED 0.06% precision (PLB 450, 262)  
CMS  $m_z = 92.3$  GeV, fiducial region:  $\text{Th1} < \theta < \text{Th2}, s' > 0.5s$
- CEPC boost** :  $e^+e^-$  beam crossing, **33 mRad**
- X-section** : count events in fiducial region, w.r.t. QED calculation

**X-sec. Lab frame acceptance @  $z=1m$**   
 $r > 25$  mm,  $|y| > 25$  mm

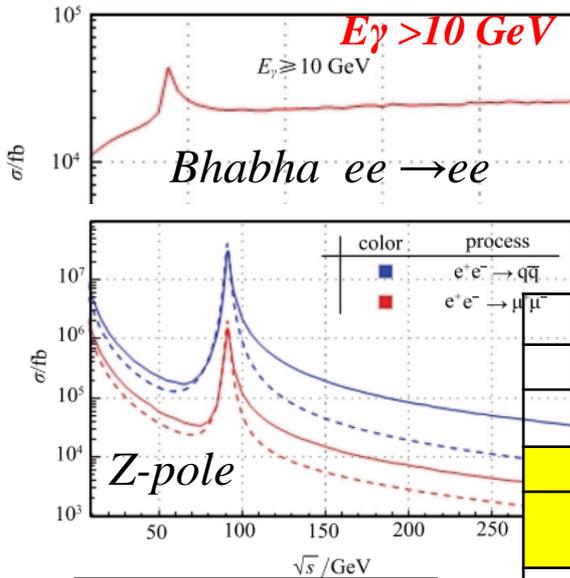
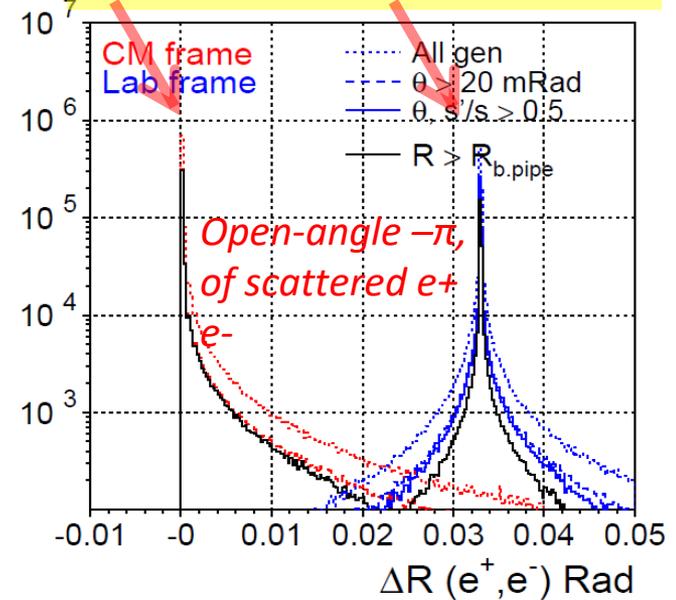
c.f.  $\sigma(Z \rightarrow qq) = 41$  nb



**Boost to +x**  
**scattered  $e^+, e^-$**   
**symm. to outgoing pipe**



**Multi. Scatt., rad. Bhabha,**  
**→ wider back-back**



LAB both $e^+, e^-$ detected	
$\theta > 15$ mRad	$\theta > 15\text{mR} \ \& \  y  > 15\text{mm}$
<b>257.8</b>	<b>245.9</b>
$\theta > 25$ mRad	$\theta > 25\text{mR} \ \& \  y  > 25\text{mm}$
<b>85.4 nb</b>	<b>78.0 nb</b>
$\theta > 30$ mRad	$\theta > 30\text{mR} \ \& \  y  > 30\text{mm}$
<b>54.9</b>	<b>49.1</b>

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# Bhabha event pile-up rate @High-Lumi Z<sup>19</sup>

1. High-Lumi Z (2021 design)  $L_{\max}/IP = 115 \times 10^{34}/\text{cm}^2\text{s}$

2. Bhabha both  $e^+$ ,  $e^-$  detected, X-sec = **100 nb**

Event rate =  $(246 \times 10^{-33}) \times (115 \times 10^{34}) / \text{sec} = 115 \text{ kHz}$

3. Event rate / 25 ns bunch crossing = **0.003 events / b.c.**

**4. Pile-up: next b.c., @adjacent cell in peak region**

Pile-up Fraction =  $0.018 \times 6 \text{ cells} / 2 \text{ sides} = 0.054$

**Pile-up event rate =  $0.003 \times 0.054 = 1.6 \times 10^{-4}$**

*c.f. LEP*

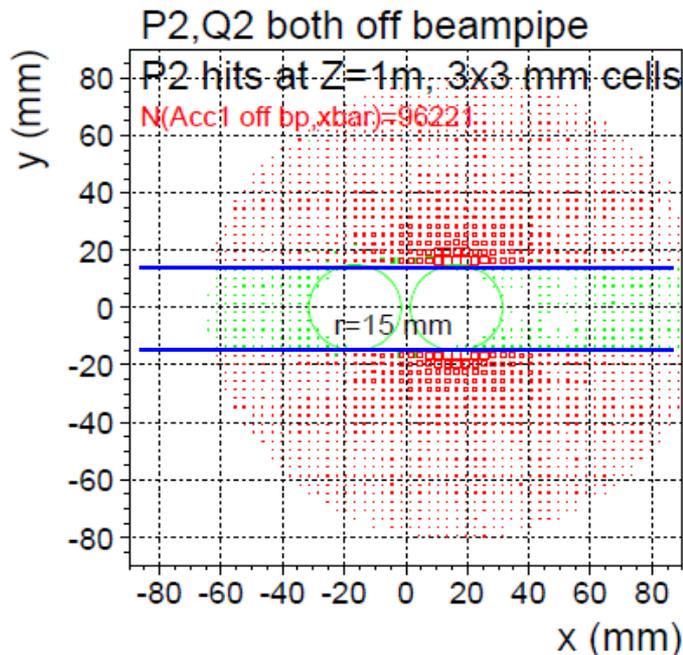
$L = 1 \times 10^{32}$

X-sec = 100 nb

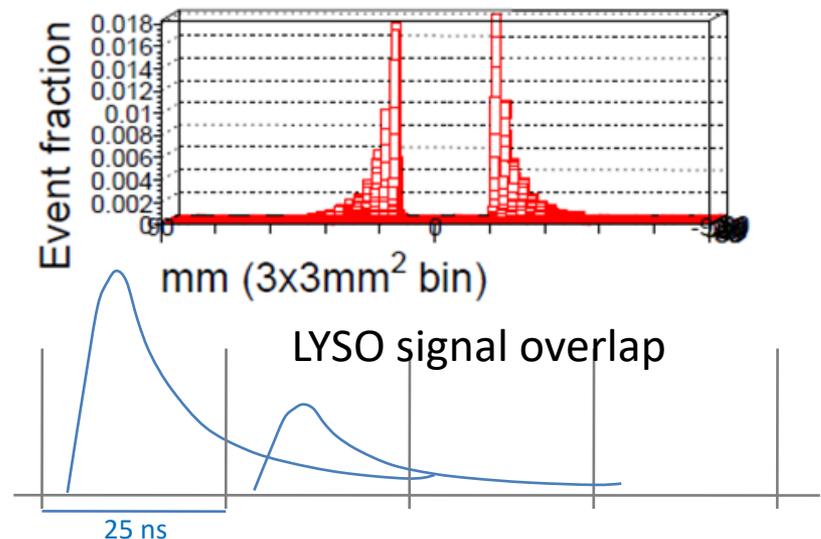
Rate = 10 Hz

> systematic criteria

**50 GeV  $e^-$  shower in  $3 \times 3 \text{ mm}^2$  cells**



event fraction / (cell of  $3 \times 3 \text{ mm}^2$ )  
maximum at beampipe edge = **0.018**



### 1. 探测器名和基本功能 ( 比如TPC , 测带电粒子径迹 ) :

LumiCal, 测量加速器束流 $e^+e^-$  碰撞亮度 Luminosity

架设在束流管  $\pm z = 700$  mm , 法蓝内外 , 探测低角度电子 ,

在 $e^+e^-$  碰撞时区内 , 筛选 Bhabha 弹性碰撞正负电子对事例 ,

Monte Carlo QED 计算探测器事例量 , 反推出 Integrated Luminosity .

精度要求  $10^{-4}$  .

### 2. 需要探测的物理量 ( 比如时间 , 能量 , 原初电离 $dE/dx$ , 原初电离束团数 $dN/dx$ , 闪烁光 , 等等 ) :

探测粒子 : Ebeam 正负电子 , 及跟随的 Final State Radiation 低能光子 (  $> \sim 1\text{GeV}$  )

在 bunch crossing 25 nsec , 分辨束流正负电子弹性反射

硅探测器 : 电子 theta, phi 角度, 极端驱近 1 uRad 精准位置 ,

LYSO 晶调 : 标定  $> E_{\text{beam}}/2$  电子 , 及区隔邻近的 FSR 光子

### 3. 探测器对电子学输出的通道数 ,

电子碰撞点硅条探测器: 每侧两层共4层 , 每层4k ch. 总共16k 通道数

LYSO 晶条 SiPM 读出: 每侧 分前(2X0) 后(17X0) 共4套 LYSO

每套  $170\text{cm}^2$ , 需1.7k ch. 总共 7k通道数

### 4. 单通道预计计数率 ,

Z lumi  $L_{\text{max}} = 115 \times 10^{34}/\text{cm}^2\text{s}$ , LumiCal Bhabha 探测器覆盖截面 100 nb

Event rate =  $(246 \times 10^{-33}) \times (115 \times 10^{34}) / \text{sec} = 115 \text{ kHz}$

Event rate / 25 ns bunch crossing = 0.003 events / b.c.

lowest theta (束流管上/下) hot LYSO  $3 \times 3 \text{ mm}^2$  6-cell cluster

event fraction = 0.12, 最热区每LYSO cell事例量  $\rightarrow 0.00016 \text{ events/b.c.}$

5. 信号特征：电荷？电流？电压？上升、下降时间，宽度？  
硅条: PN 二级 25k 电子电荷, ADC 需要极快, 宽 50 ns 内, 在 25 ns B.C. 前后事例分辨开  
LYSO SiPM: ADC 需要极快, 宽 50 ns 内, 在 25 ns B.C. 前后事例分辨开,  
12bit 100 GeV 线性能量测量
6. 信号传输方式（比如同轴电缆，PCB，接插件），阻抗特性。  
前端PCB 缆线空间紧迫，可能放 ADC，serializer 接 10 Gbps 光纤读出  
不做 trigger, 接 FPGA 做事例筛选
7. 最小、最大信号（也就是动态范围）。  
硅条 测 MIP 单点电离电荷  
LYSO SiPM 比照 ECAL 量测 300 MeV 到 100 GeV 电子
8. 对数字化的要求（LSB, 精度，线性度）。  
LYSO SiPM 比照ECAL,  
需要监测 Pileup, 因此，每25 ns B.C. 做一次 Signal Level comparator 确认临接事例讯号是否被叠高
9. 探测器的工作温度和范围，如果电子学需要散热，可否和探测器温控在一起？有无对电子学的功耗限制和多少。  
LumiCal 硅条及 SiPM 工作温度跟顶点探测器一致，约20 °C  
LumiCal 每层硅条 4k 通道需 40颗读出chip 估计发热 10W 内，  
LYSO 每套 1.7k 通道也在 10W 内。每Z侧 40W，地线接到束流管冷确面。