LumiCal to 10^{-4} systematics

LumiCal collab
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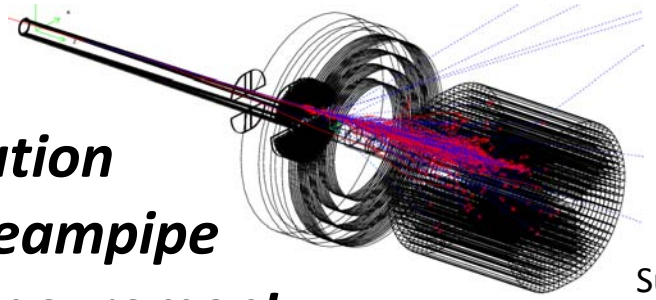
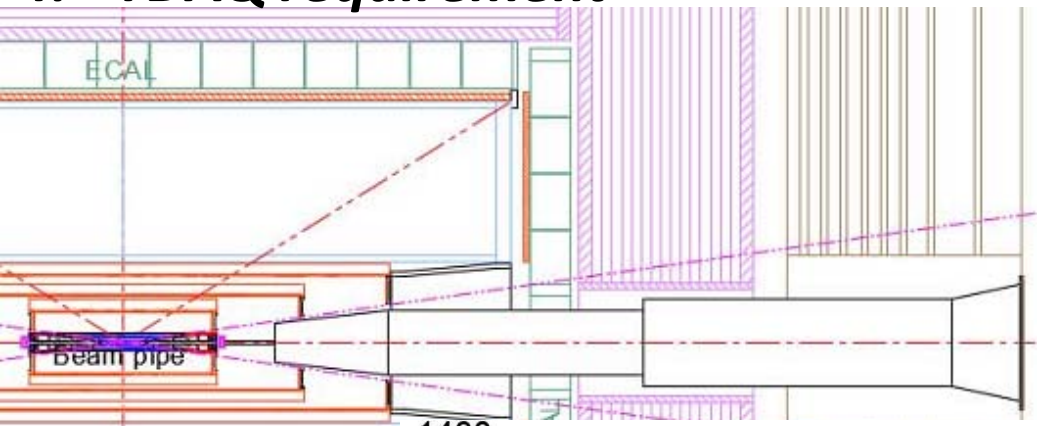
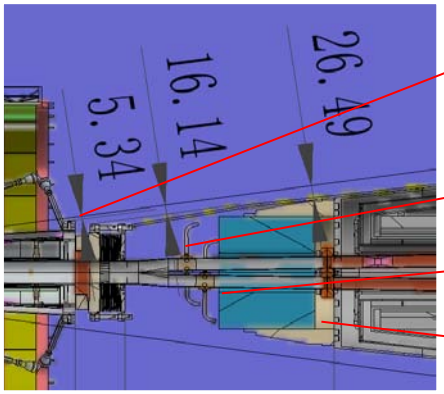
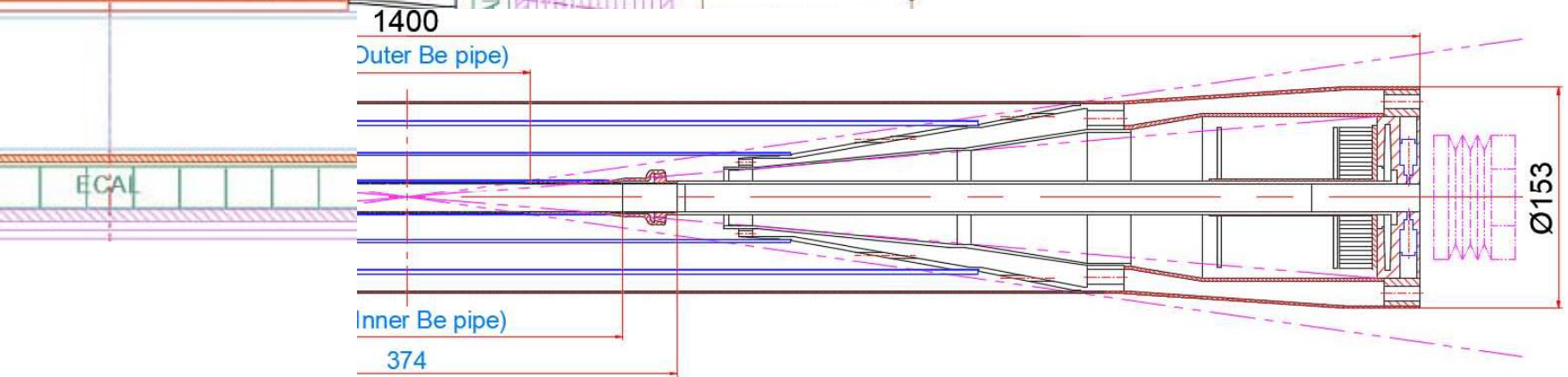


Outline

1. *Bhabha basics and LumiCal evolution*
2. *LumiCal design with Racetrack beampipe*
3. *Systematics and NLO Bhabha measurement*
4. *TDAQ requirement*



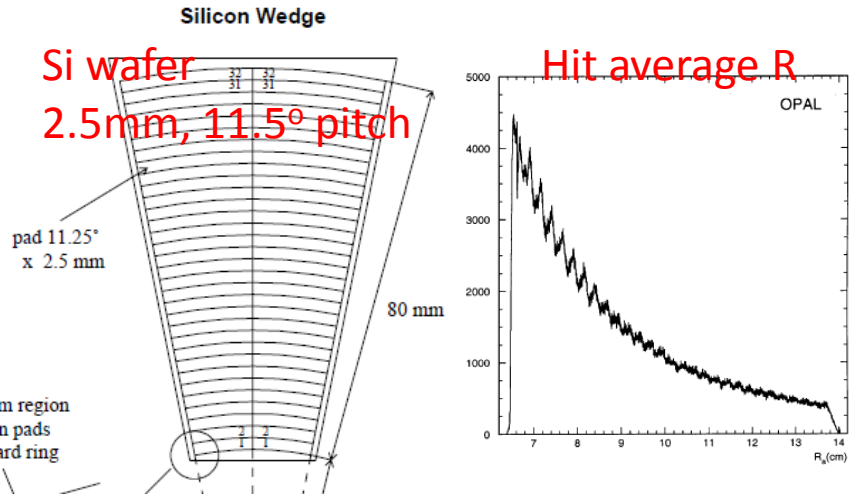


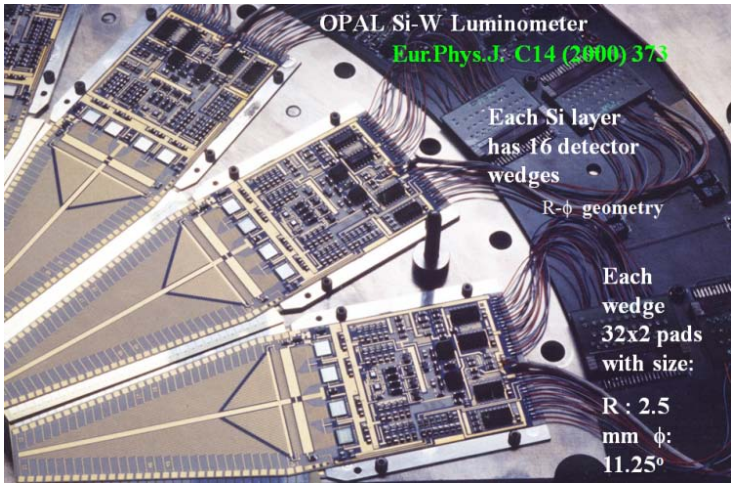


Bhabha @LEP

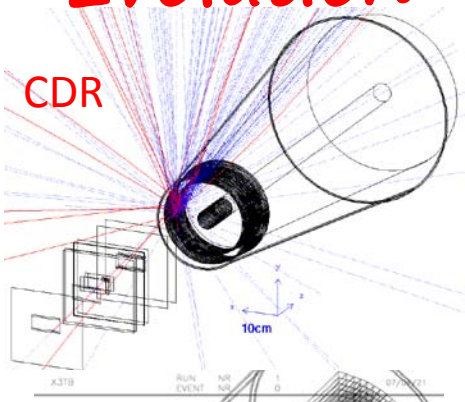
CEPC LumiCal

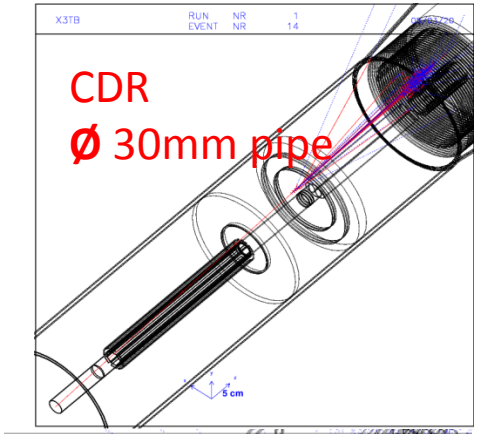
OPAL Si-W	**Bhlumi 0.038%, FCCee → 0.01%**
Fiducial 79 nB	*Jadach arXiv:1812.01004*
Systematics 0.034%	**ReneSANCe FCCee → 0.01%**
EPJC 14 373 (2000)	*CPC 256 107445*

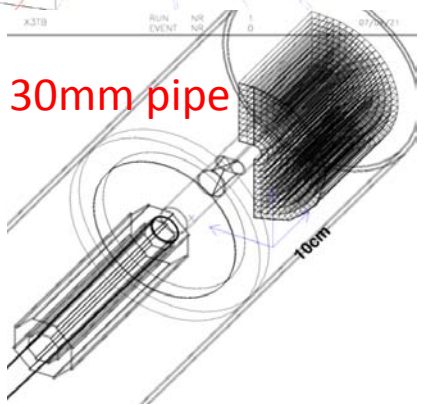


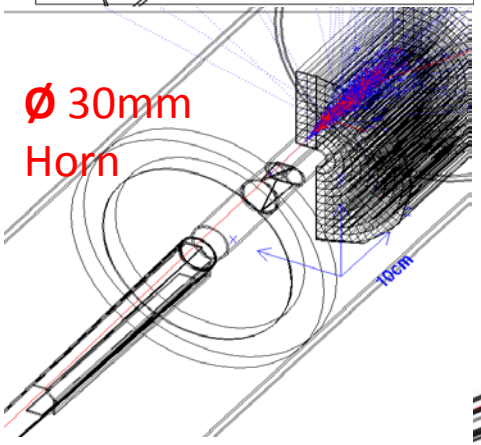


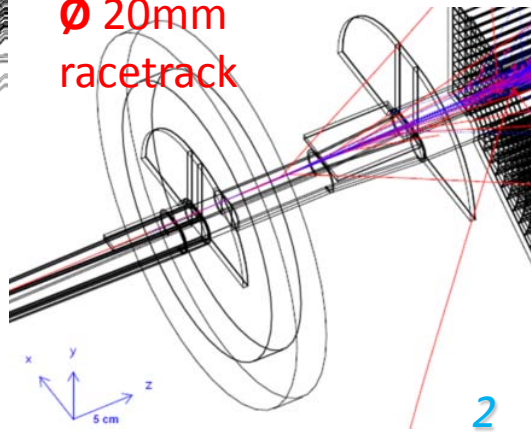
Evolution











CEPCSW LumiCal implementing

- **CEPCSW** GEANT4 implantation by JLU, NJU
- **MDI description**, 33 mRad beam crossing
- **BHlumi Bhabha interface**
- X-check on GEANT tracking steering Multiple-Scattering and Shower **Test-beam** to confirm

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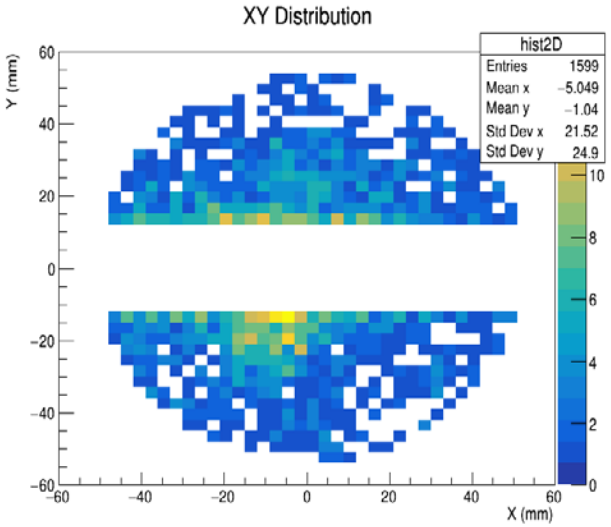
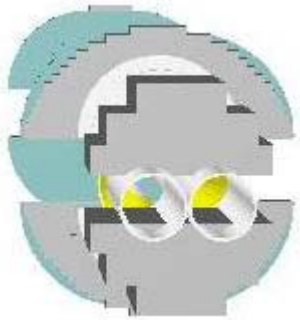
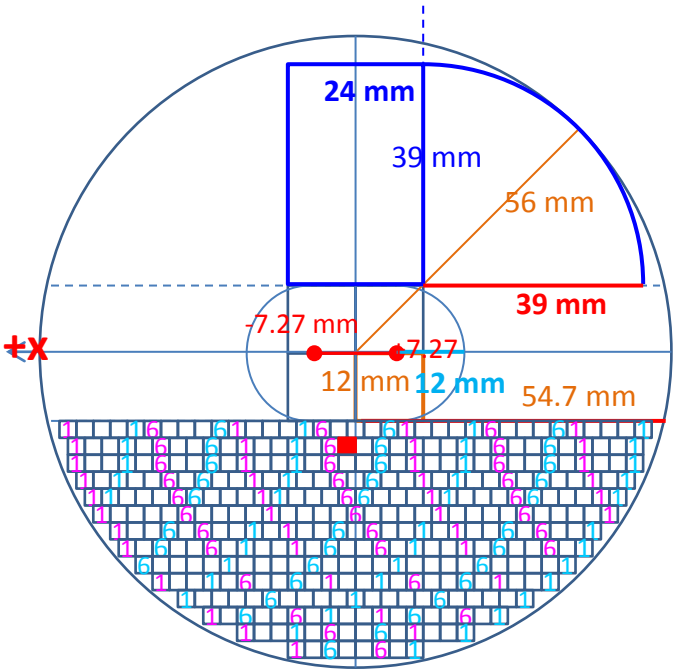
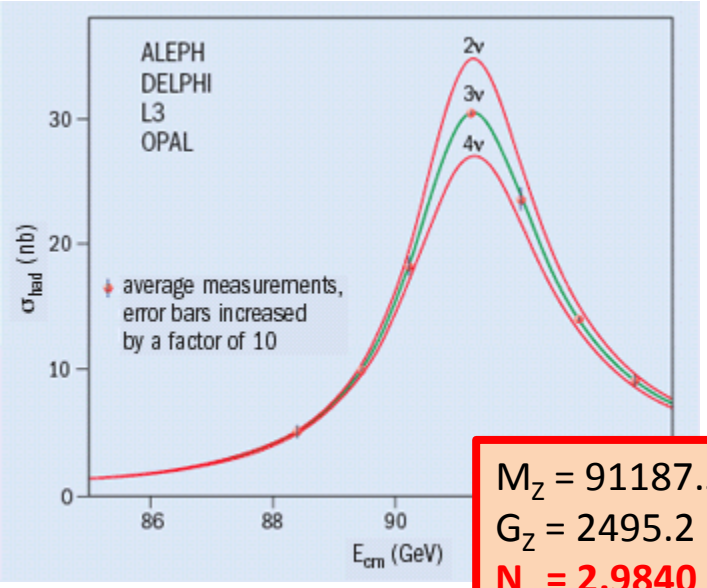






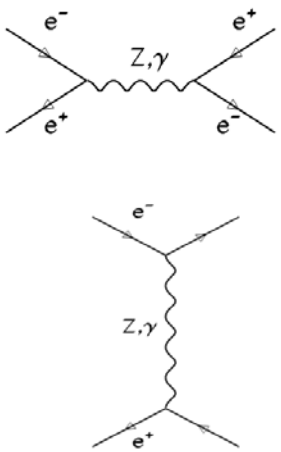
High-Lumi Z-pole Physics goal



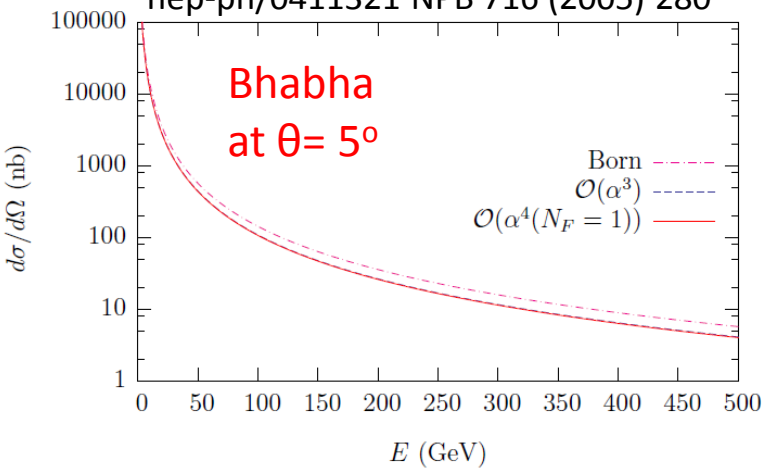
- **Z-lineshape** $e^+e^- \rightarrow Z \rightarrow q\bar{q}$
- **Luminosity by Bhabha** $e^+e^- \rightarrow e^+e^-$

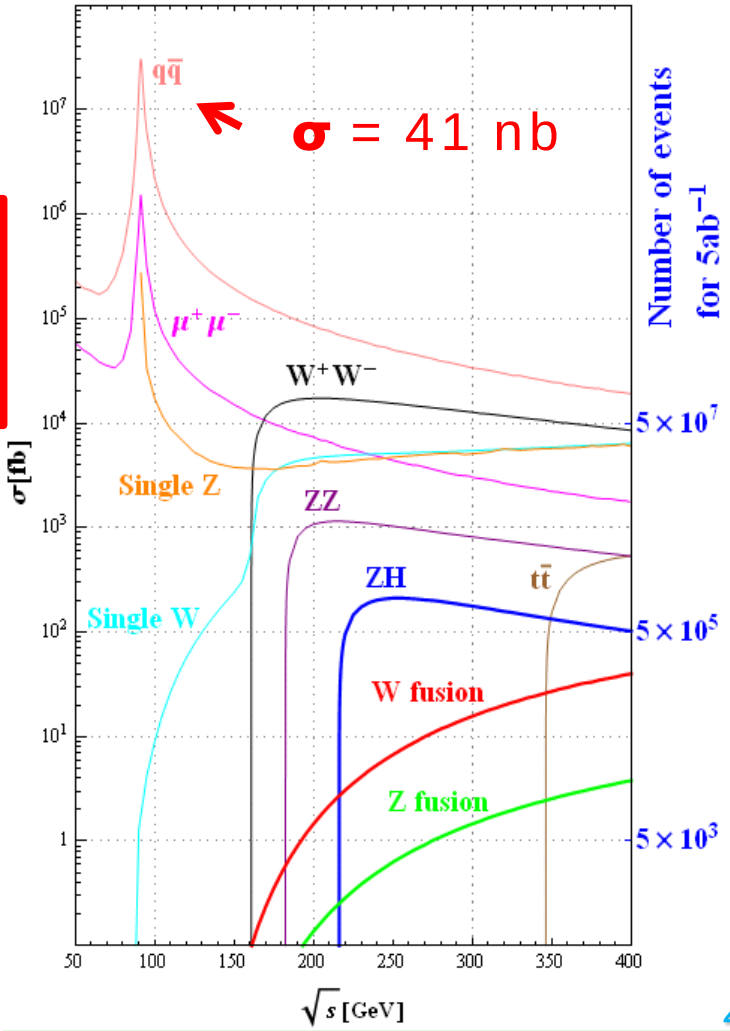
M_Z = 91187.5 ± 2.1 MeV 2.3×10^{-5}
G_Z = 2495.2 ± 2.3 MeV 1‰
N_ν = 2.9840 ± 0.0082
Precision luminosity 3‰

CERNCOURIER
2 November 2005



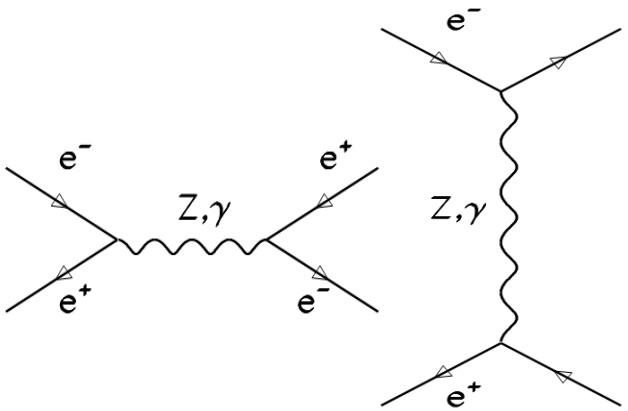
hep-ph/0411321 NPB 716 (2005) 280



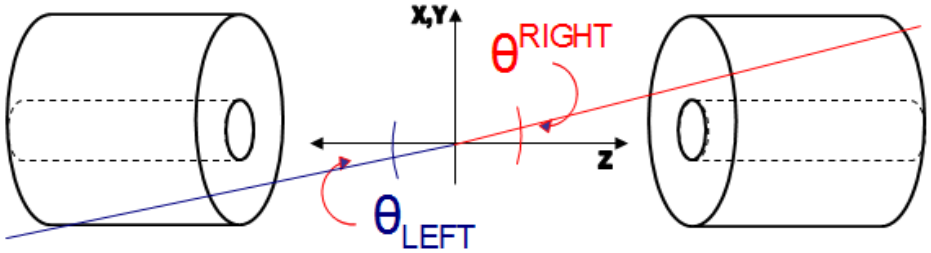


Luminosity by Bhabha elastic scattering

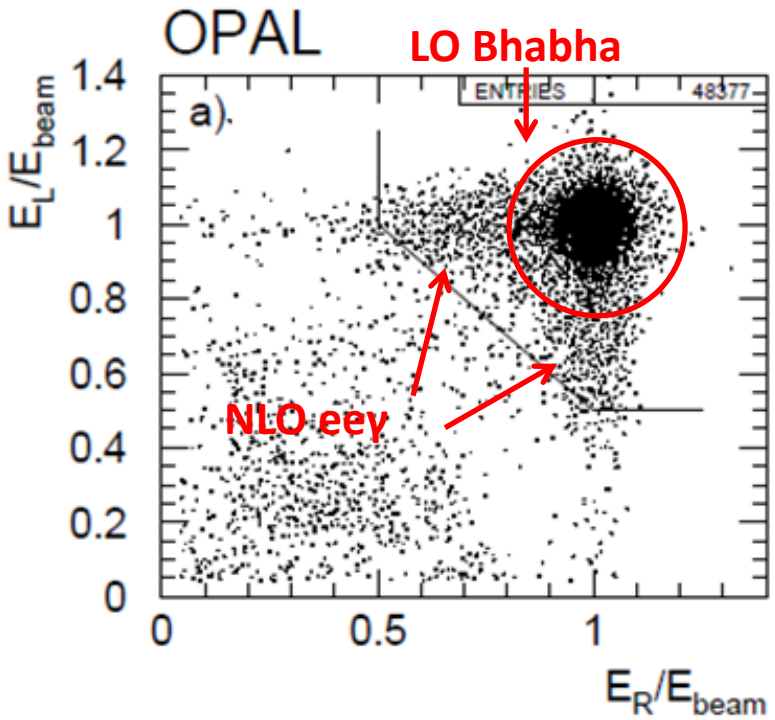
- ***Physics events, e.g. Z-pole,***
  $N = \sigma \cdot \int L$ ***L: Luminosity of e^+e^- collisions***
- ***Luminosity* by counting Bhabha events**
  $e^+e^- \rightarrow e^+e^-(\gamma)$ QED *theo. precision < 0.1%*
  1. ***a pair of electrons,*** $E(e^{\pm}) = E_{beam}$ ***back-to-back***
  2. ***precision ϑ of e, e(γ)***
  3. ***within fiducial region***



$$\sigma = \frac{16\pi\alpha^2}{s}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$



$$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$$



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 ϑ on e,e(γ) in fiducial region***

Bhabha systematic error

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

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

at **z = ±1 m,** θ_{min} **= 20 mRad**

→ $\delta\vartheta$ = ***1 μRad*** or ***dr = 1 μm***

error due to offset on Z

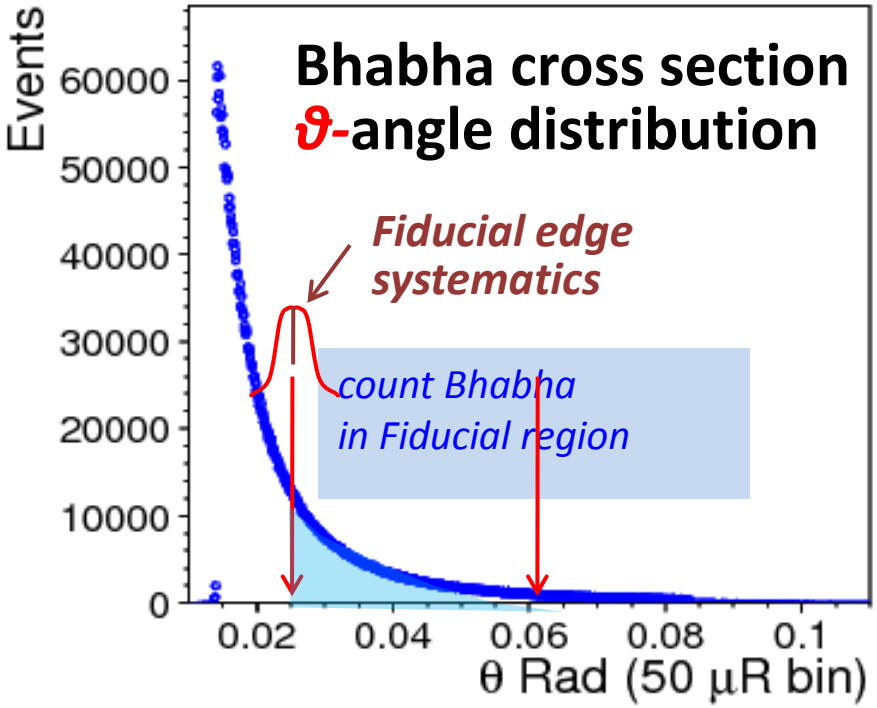
→ *Z eq.* $dr = \delta z \times \vartheta$ ***= 1 μm*** ***dz = 50 μm***

Luminosity systematics

due to events in/out fiducial edge

➔ ***offset on the mean of*** θ_{min}

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

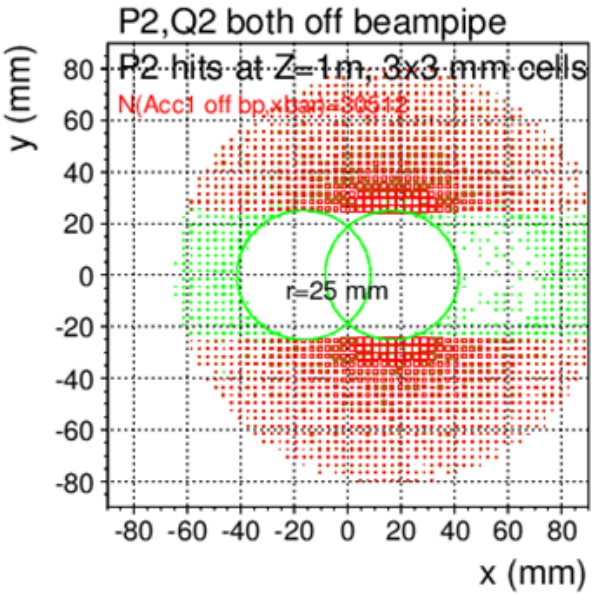


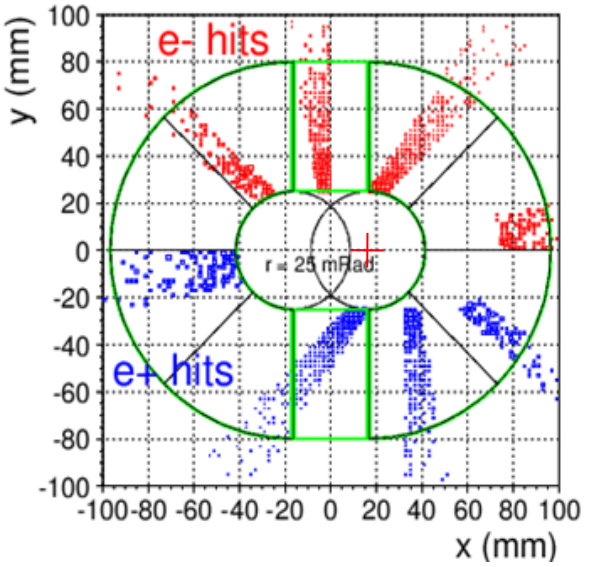
QED BHLUMI X-section

e^+, e^- back-to-back Symmetric to out-going pipe center

Acceptance @z=1m
r>25 mm, |y|>25 mm

LAB frame
e^+, e^- detected
@ Z=1000 mm





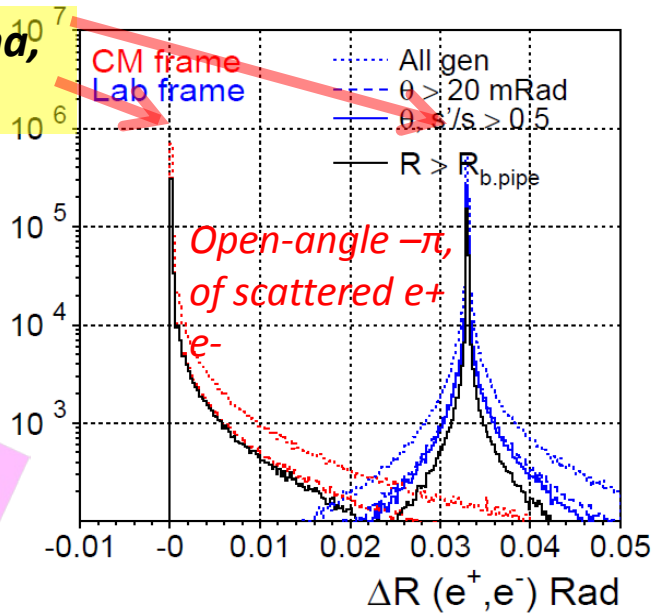
Multi. Scatt., rad. Bhabha,
→ wider back-back

at Z = 1000 mm

LAB ONE e^+ or e^- detected		LAB both e^+, e^- detected	
θ>15 mRad	θ>15mR & |y|>15mm	θ>15 mRad	θ>15mR & |y|>15mm
395.3	255.9	257.8	245.9
θ>25 mRad	θ>25mR & |y|>25mm	θ>25 mRad	θ>15mR & |y|>25mm
133.5 nb	81.8 nb	85.4 nb	78.0 nb
θ>30 mRad	θ>30mR & |y|>30mm	θ>30 mRad	θ>30mR & |y|>30mm
87.2	51.8	54.9	49.1

racetrack

CDR



LumiCal geometry

- ***LumiCal before Flange***

  z = 560~700 mm

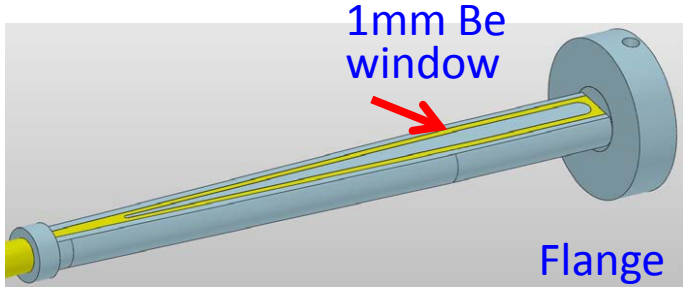
  - **Beam-pipe low-mass window**:

    Be 1mm thick

    traversing @22 mRad traversing L= 45 mm,

    = 0.13 X_0 (Be), 0.50 X_0 (Al)

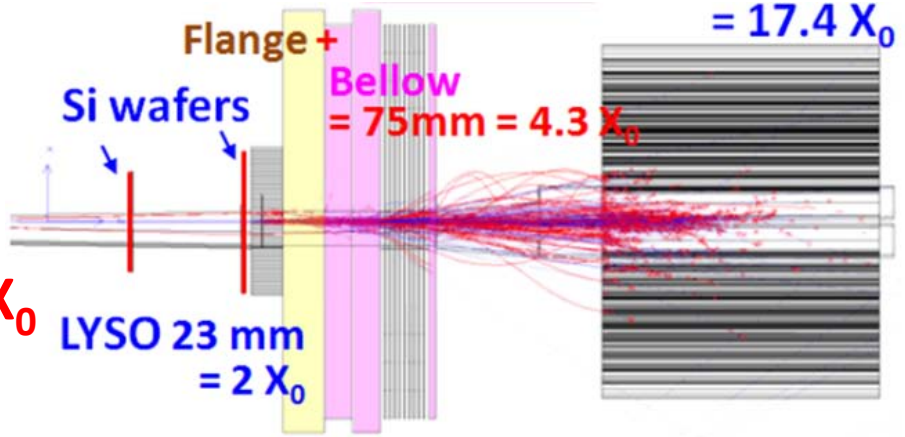
  - **Two Si-wafers** for $e^{\pm}$ θ position
  - **$2X_0$ LYSO** = 23 mm

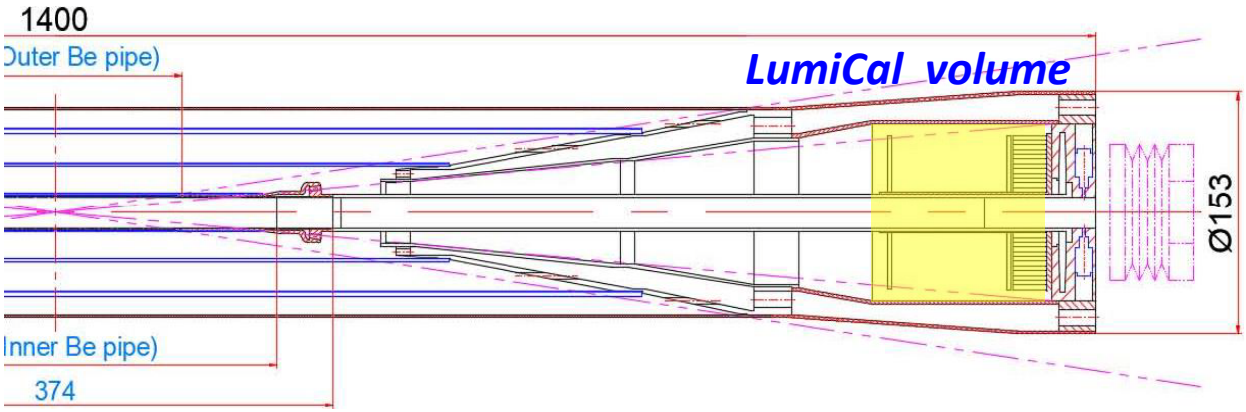


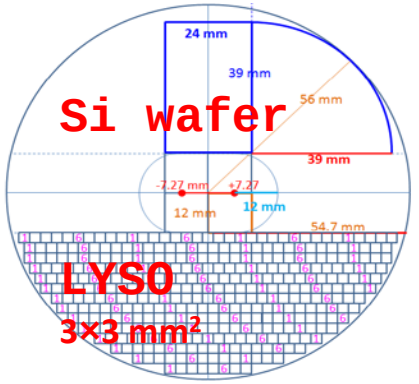
- ***LumiCal* behind Bellow:**

  z= 900~1100 mm

  - **Flange+Bellow : Fe ~75 mm = 4.3 X_0**
  - **17 X_0 LYSO 200 mm**







Electron hits on 1st Si-wafer

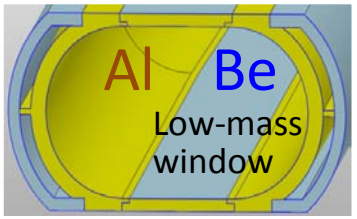
IP (σ_x,σ_z) = (6,380 μm)

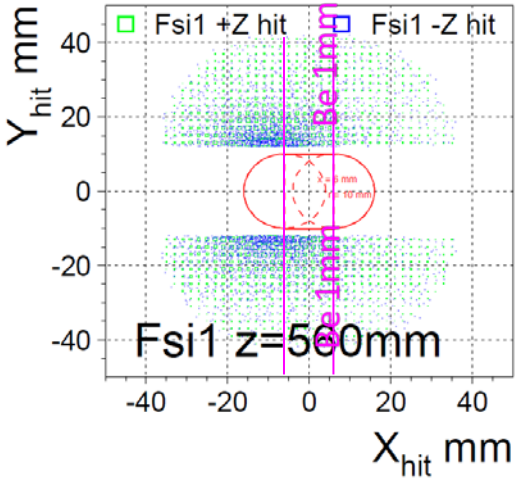
50 GeV e^+, e^-

@ ($\vartheta = \pm 30$ mRad, φ = 1.0, 1.0+π Rad)

Si wafer @z=560mm

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



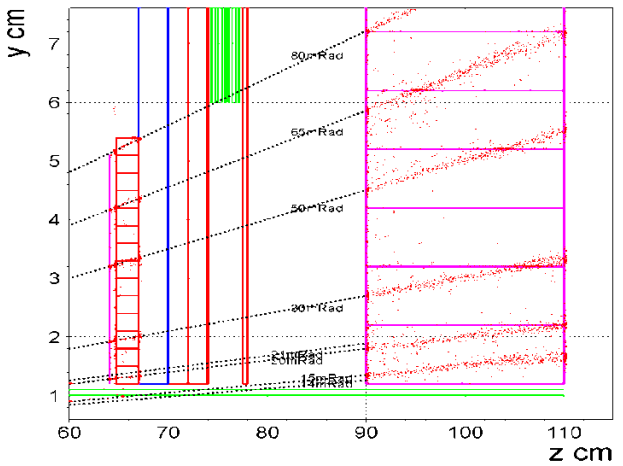


NJU GEANT4 validation, test-beam preparation

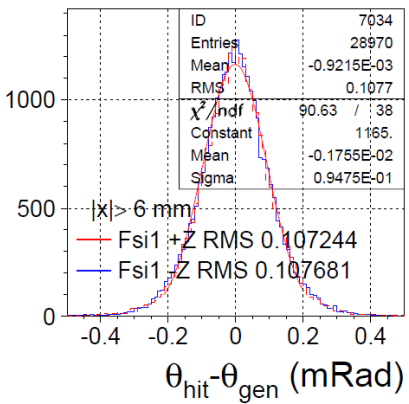
Be(1mm): $\sigma(\vartheta)$ = 30 μR

Be(2mm): $\sigma(\vartheta)$ = 50 μR

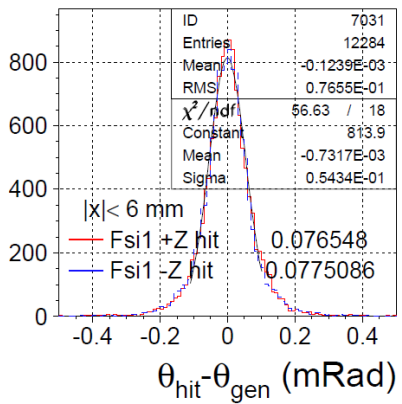
➔ GEANT tracking steering, testbeam confirmation



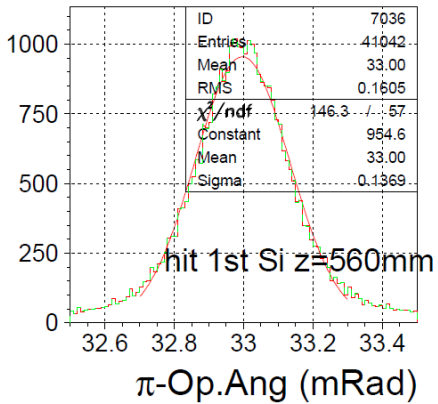
e± GEANT hit – gen. |x|>6



hit – gen. |x|<6



e+,e- back-back angle



Smearing @ IP position

- bunch size $\sigma_x = 6\ \mu m$, $\sigma_z = 9\ mm$

➔ *IP spot, 33mRad Xing* $\sigma_x = 6\ \mu m$, $\sigma_z = 380\ \mu m$

- $Z \rightarrow e^+, e^-$ at $\vartheta = 30\ mRad$

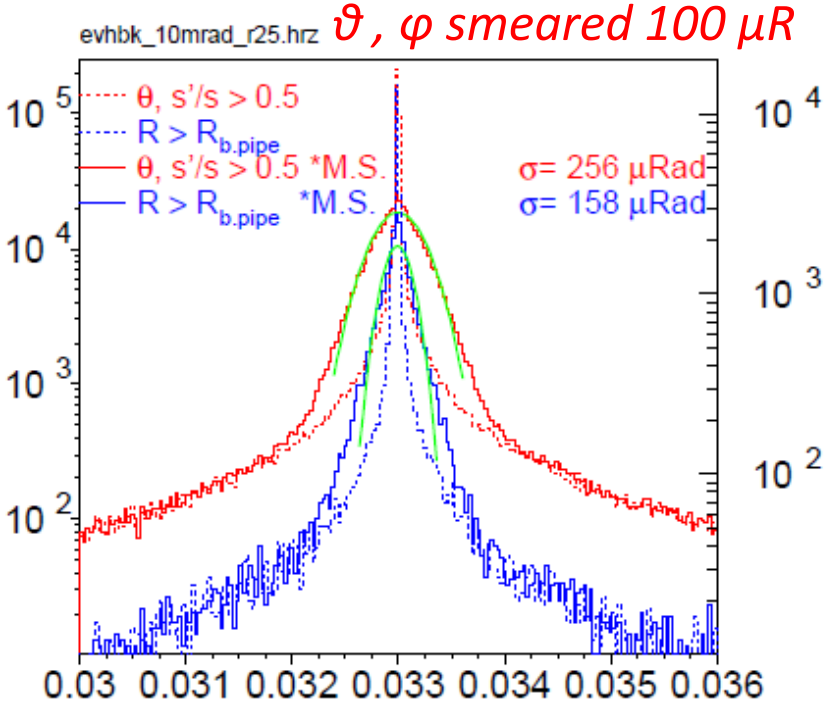
  smearing at @z=560mm

  smeared width $\sigma(\vartheta) = 24\ \mu Rad$

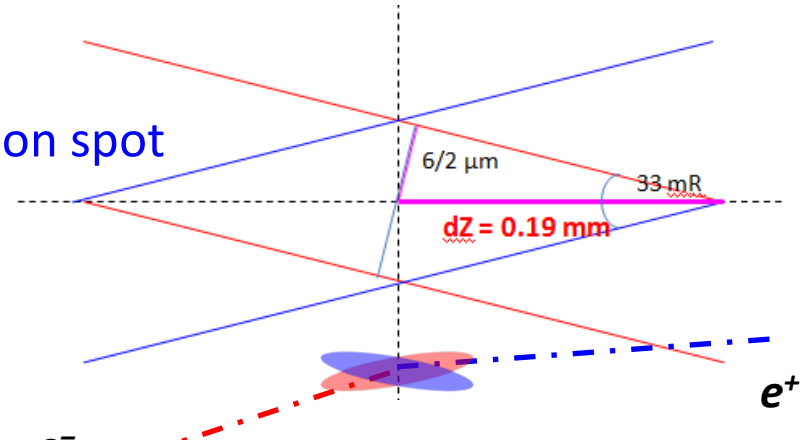
  back-to-back $\sigma(\Omega) = 21\ \mu Rad$

e^+, e^- back-back angle

compare scattered e^+, e^- ϑ, φ *smeared 100 µR*



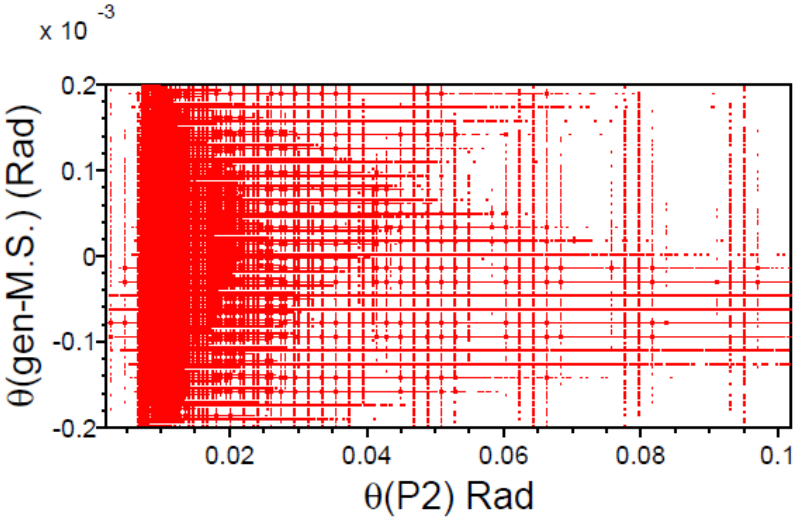
IP collision spot

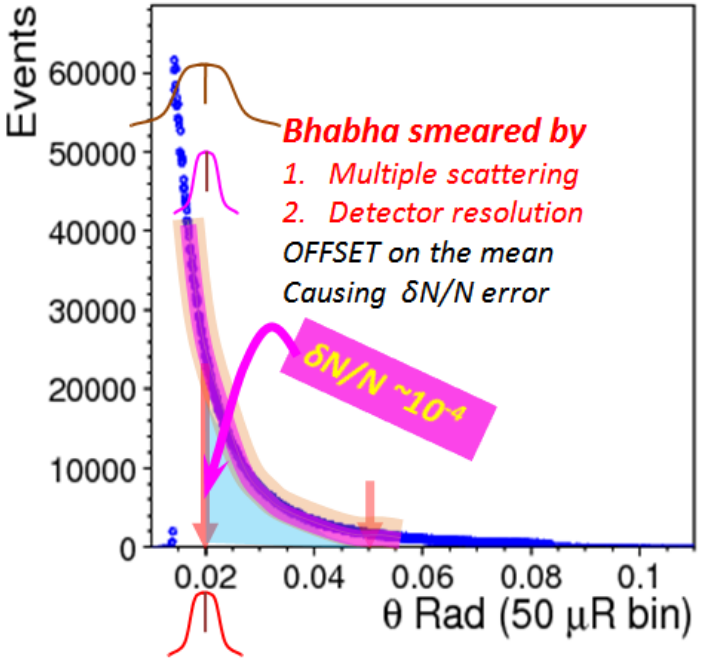


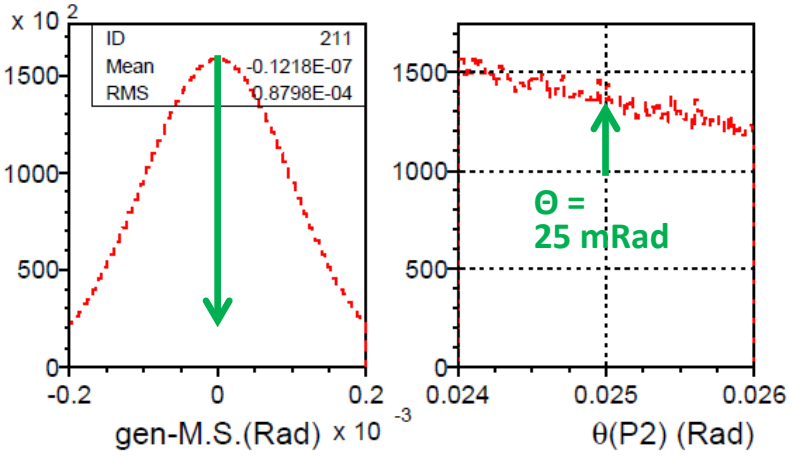
10^{-4} systematics, multiple scattering

1. **BHLUMI** smear θ', ϕ' of scattered e^+, e^-
   Multi. Scatt. 100 µRad θ'= θ · Gauss(100µR), ϕ'= ϕ · Gauss(100µR)

2. **δN/N systematics**:
   δN = #event deviation due to M.S.
   M.S is Gaussian, Symmetric
   at **θ_{min}= 25 mRad, slope of Bbhabha**
   in neiboring 100 µRad bins to 25mR
   δN(@25mR)/N(25-80 mR) <10^{-4}







10^{-4} is determined by survey of the mean position

GEANT LumiCal electron shower

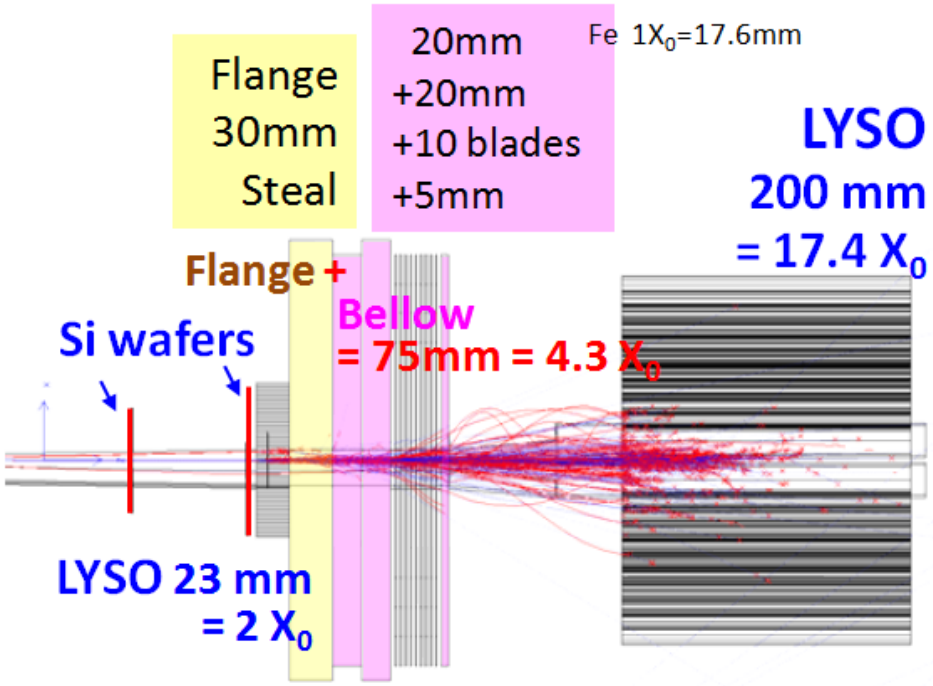
50 GeV electron @ θ = 32 mRad, ϕ=90°

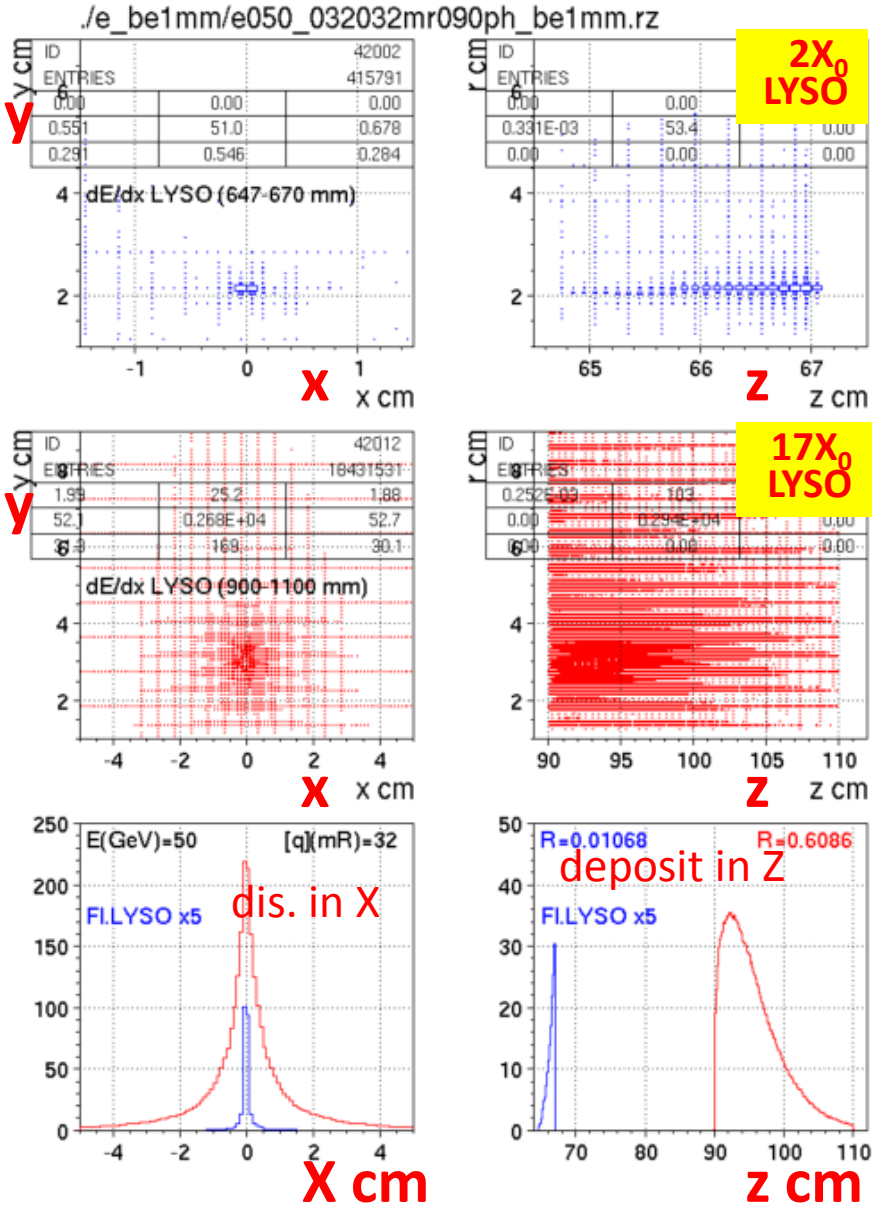
2X0 LYSO + 4.3X0 Flange,Bellow

+ 17X0 LYSO

Shower deposition, by Sum(dE/dx)

- in front LYSO: ~1.0 %
- in back LYSO: ~ 61 %

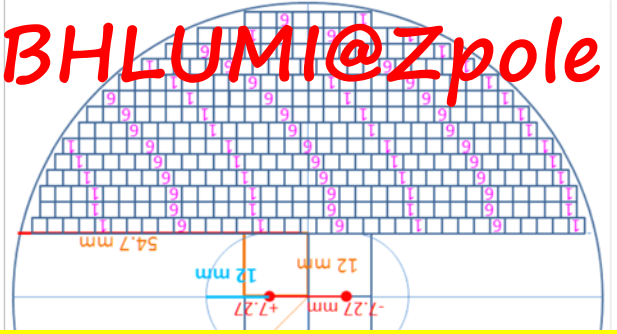




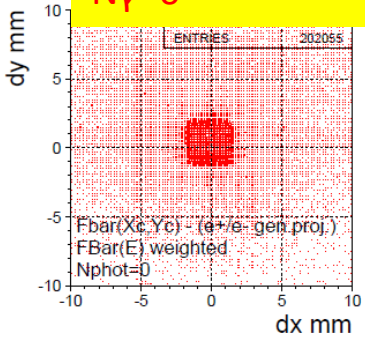
$2X_0$ LYSO bars observables, w. BHLUMI@Zpole

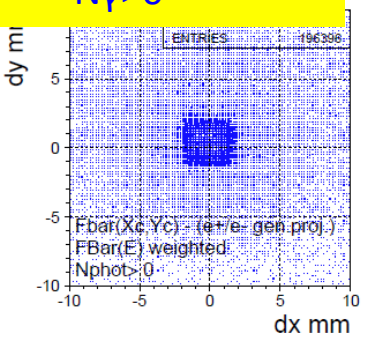
incident particles are $e^{\pm}$,(γ) and secondaries

- **GEANT sum dE/dx in each LYSO bars**
  $3x3mm^2$, 23 mm long, $2X_0$
- **Deviation to $e^{\pm}$ truth** (impact hit >Eb/2)
  mostly < 0.2mm
- **Hit distributions in a Bar**
  distributed due to Bhabha θ, w./w.o. photon

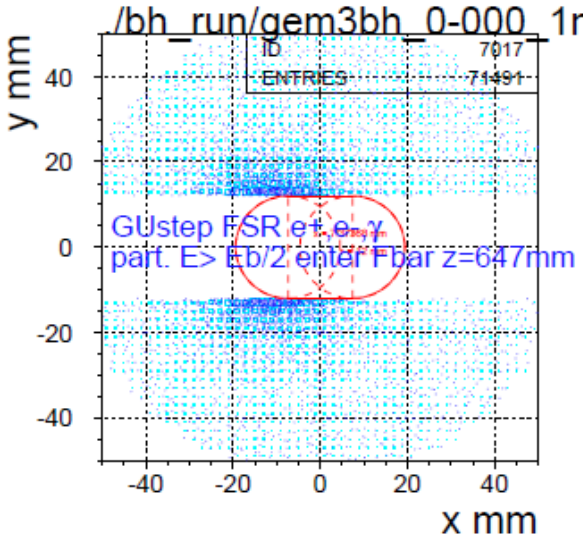


Loop Bars
Nγ=0 Nγ>0

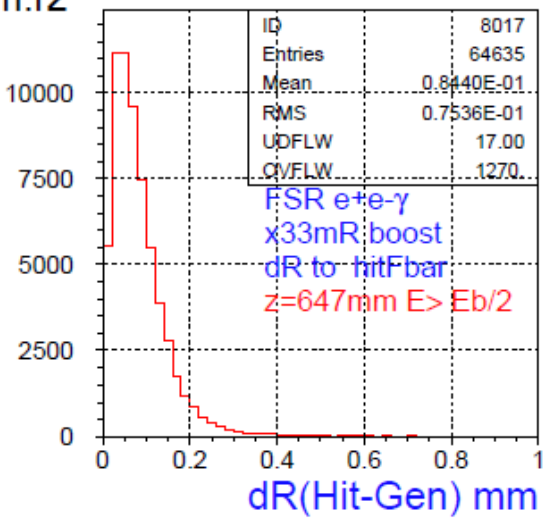


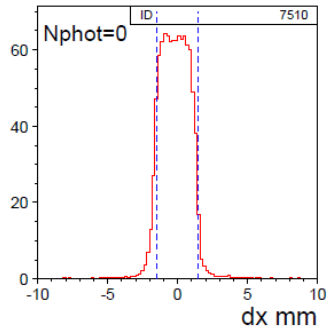


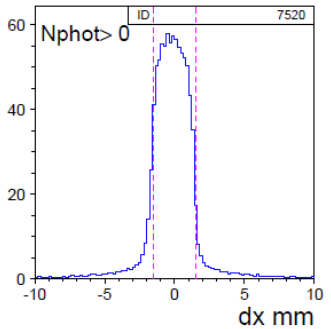
GEANT hits E>Eb/2
On LYSO @647mm

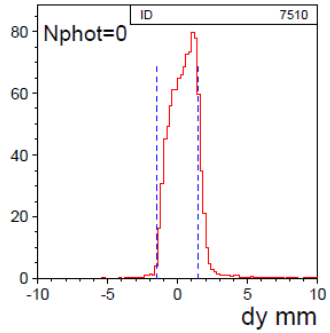


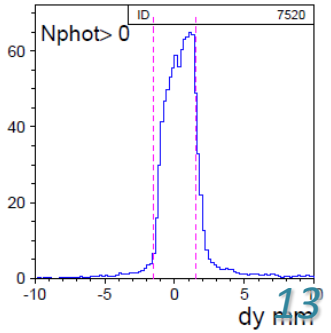
dR to Truth Nγ > 0
(boosted BHLUMI $e^{\pm}$)









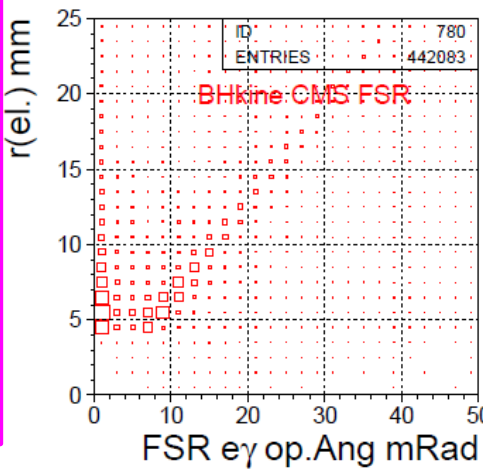


BHLUMI QED generator $e^+e^- \rightarrow e^+e^-(\gamma)$

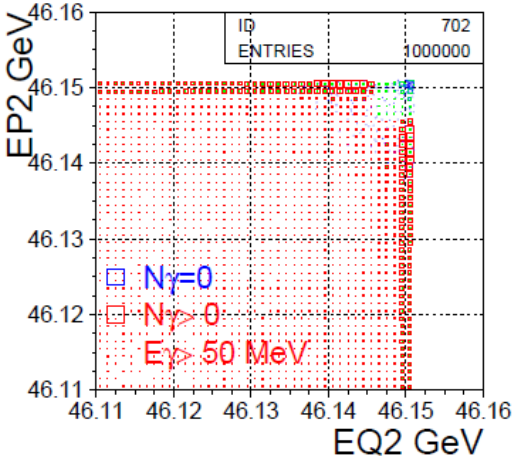
E_{CMS} = 92.3 GeV θ_l= 10~80 mRad

- ***Bhabha***
  $e^+e^- \rightarrow e^+e^- + N\gamma$ *$\rightarrow E\gamma > 50MeV$*
- ***Opening angle*** *$\Omega(e,\gamma)$ vs. r(e) increase w. electron ϑ*
- ***radiative Bhabha*** *examined for max. photon vs paired electron*

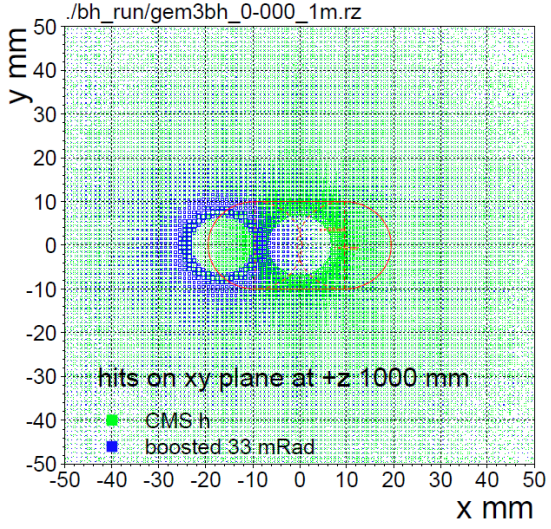
CMS radius($e^{\pm}$) vs. Ω



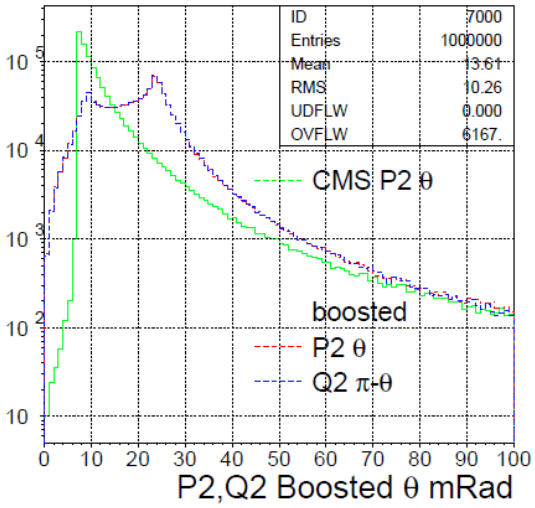
E(e+) vs E(e-)



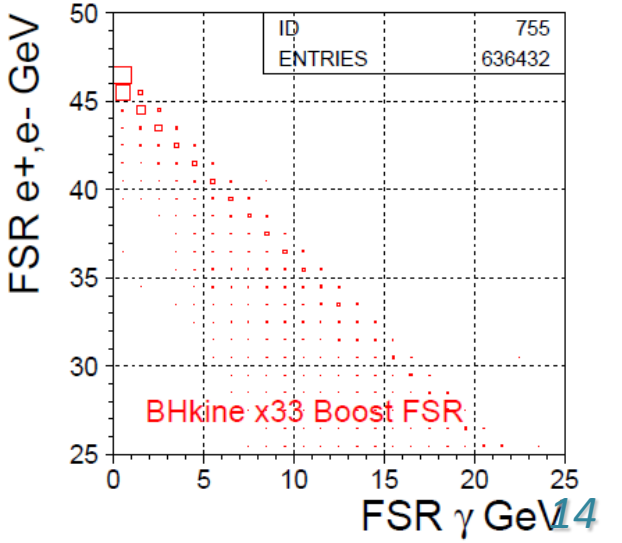
hit (x,y) distributions
generated @z=1m
boosted @z=1m



Scattered electron θ
CMS generated (θ>10mR)
x33mR boosted

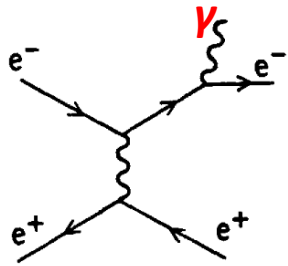


Radiative Bhabha
E(e±) vs E(γ)



$2X_o$ LYSO observables for rad. Bhabha

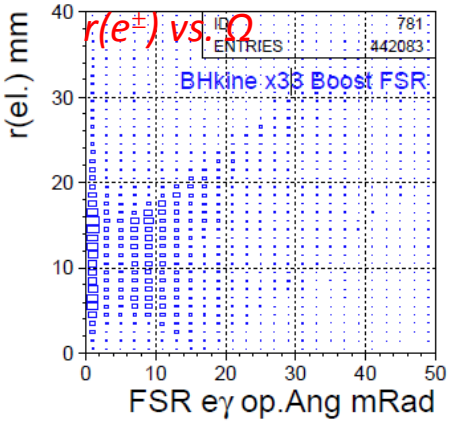
$e^+e^- \rightarrow e^+e^-\gamma$



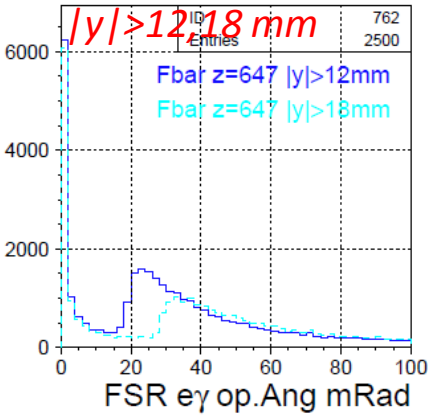
Ω(e±,γ) Opening Angle

- Increase w. electron θ
- r > 12mm, Ω(e,γ) = 20 mRad (13mm@647)

BHLUMI boosted *r(e±) vs.Ω*



Opening angle Ω *|y|>12,18 mm*

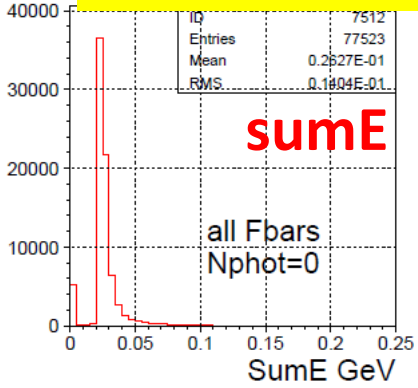


sum dE/dx all LYSO bars (a plane)

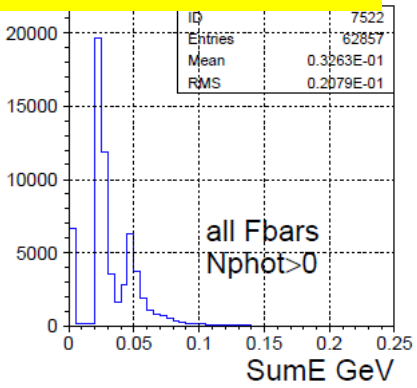
- $e^{\pm}$ one track : sumE min. 20 MeV
- $(e^{\pm}+\gamma)$: two tracks, sumE x2

Loop Bars

Nγ=0

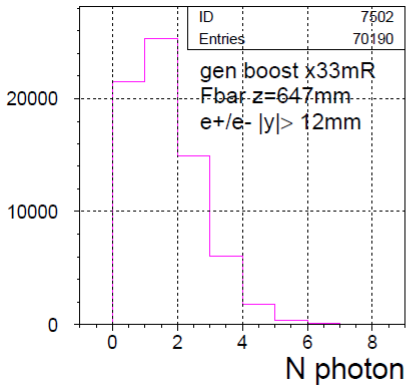


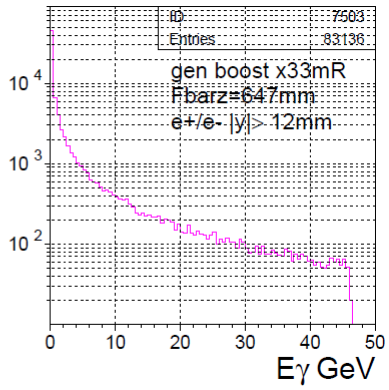
Nγ>0



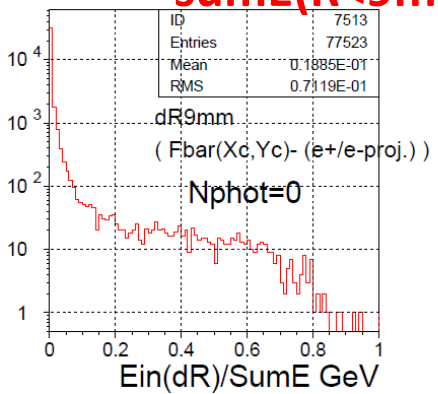
Bhabha hits on LYSO |y|>12mm

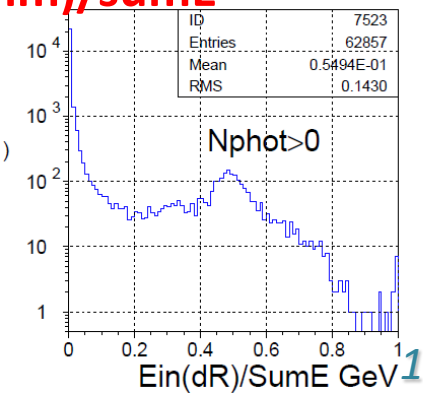
- BHLUMI ~80% having photons





sumE(R<9mm)/sumE

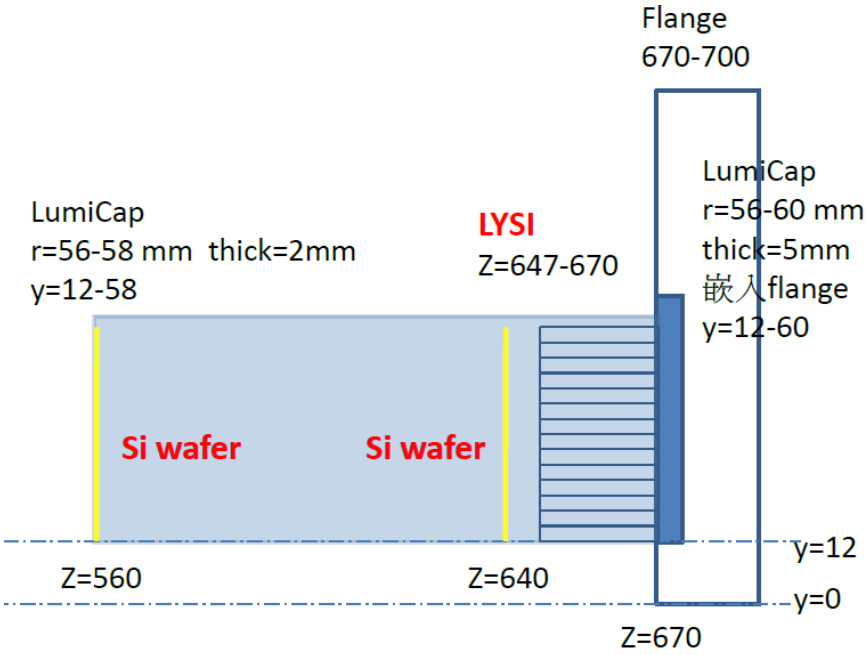




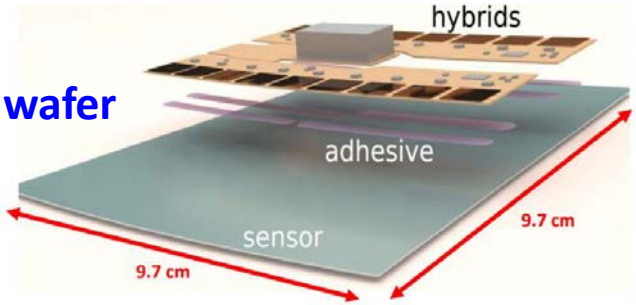
LumiCal components, electronics

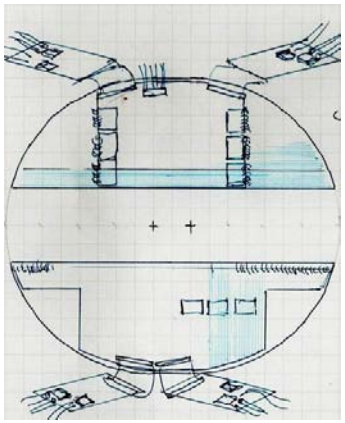
Electronics preparation @NJU

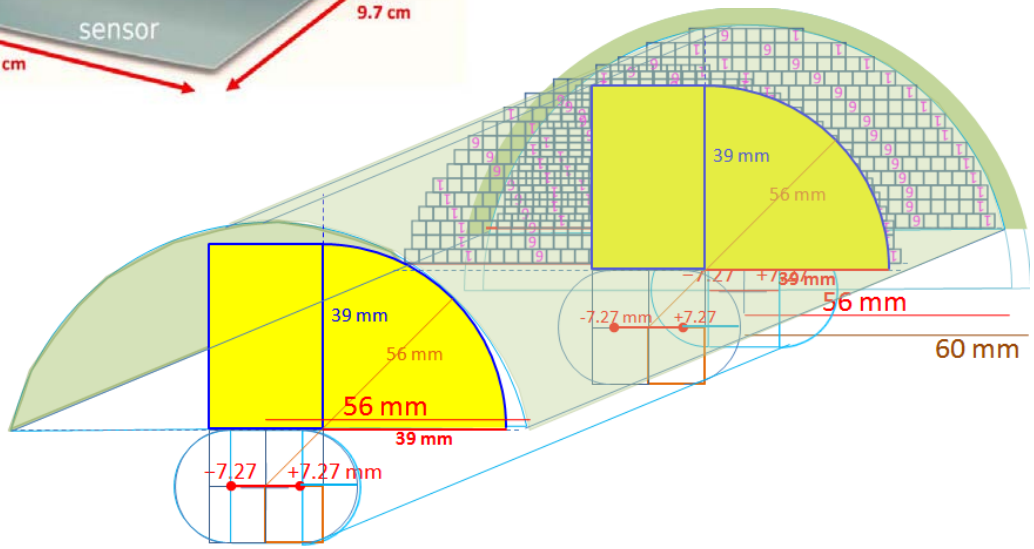
- **Si tracking :** $\sigma_r \sim 5$ µm, test-beam Mult.Scatt. Validation
- **Crystal SiPM:** readout setup, mechanics

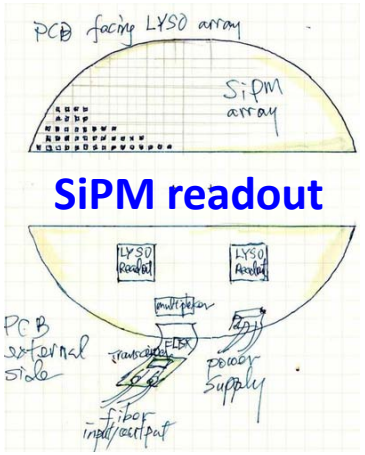


ATLAS ITk P2 wafer









Bhabha pile-up rate @High-Lumi Z

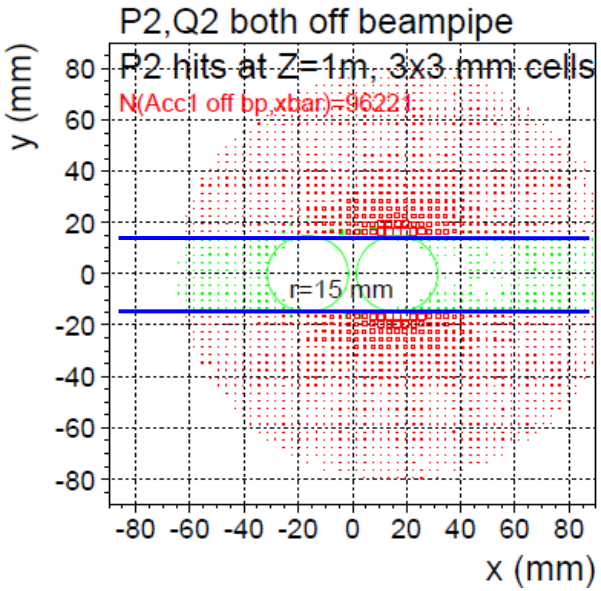
1. High-Lumi Z (2021 design) L_{max}/IP = **115 x 10^{34}/cm^{2}s**
2. Bhabha both e^+, e^- detected, X-sec = **100 nb**
   Event rate = (100x10^{-33}) x (115 x 10^{34}) /sec = ***115 kHz***
3. Event rate / **25 ns** bunch crossing = **0.003 events /b.c.**
4. **Pile-up: next b.c., @adjacent cell in peak region**

c.f. LEP
L= 1x10^{32}
X-sec= 100nb
Rate= ***10 Hz***

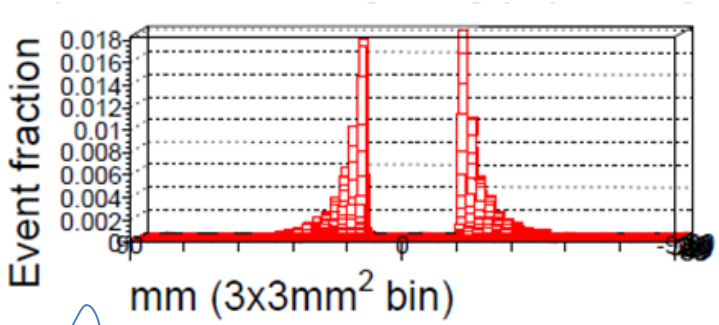
Pile-up Fraction = 0.018*6cells/2sides = **0.054**

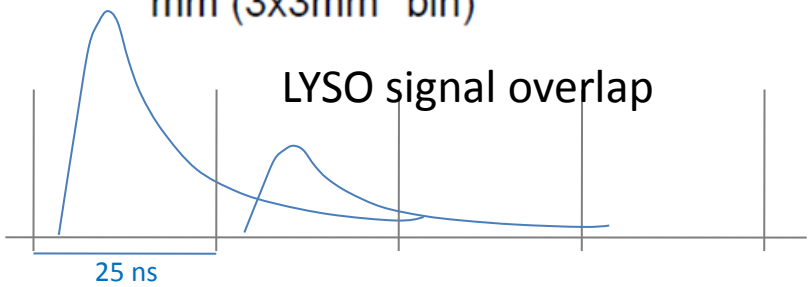
Pile-up event rate = 0.003*0.054 = **1.6 x 10^{-4}** **in 3x3 mm^2 cells**

50 GeV e- shower in 3x3 mm^2 cells



event fraction /(cell of 3x3mm^2)
maximum at beampipe edge = 0.018





$Z \rightarrow q\bar{q}$ pile-up rate @High-Lumi Z

1. High-Lumi Z (2021 design) L_{max}/IP = **115 x $10^{34}/cm^2s$**
2. **$Z \rightarrow q\bar{q}$** , X-sec = **41 nb**

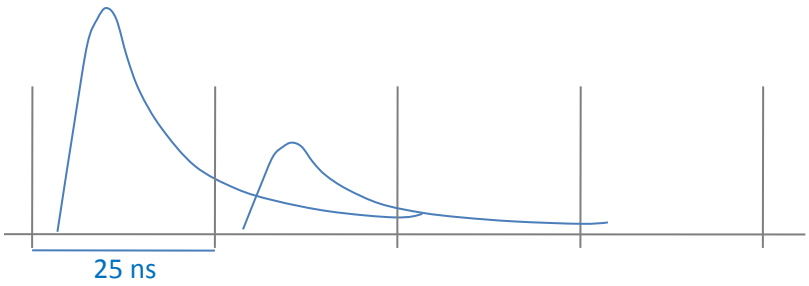
   Event rate = ($41x10^{-33}$) x (115×10^{34}) /sec = ***47 kHz***

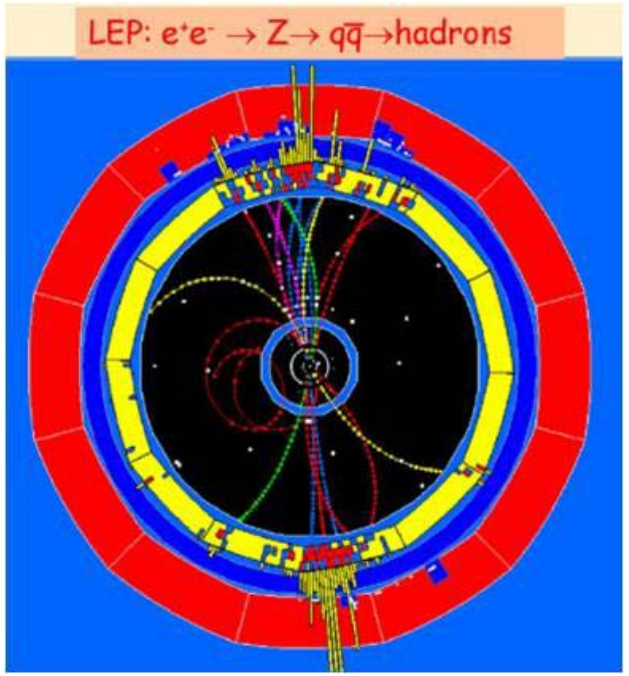
   bunch cross = 40 MHz
3. Event rate / 25 ns bunch crossing = **0.001 events /b.c.**
4. **next b.c. having a $Z \rightarrow q\bar{q}$**

Pile-up rate 4π coverage ~ $1x\ 10^{-3}$

if BCID not identified

- **pileup of two 2-jets ➔ 4-jet**
- **rare decay precision ~$1x\ 10^{-3}$**





LumiCal Summary

- **Detector Si-strip + LYSO**

  AC-Lgad strip — 5 µm resolution, measuring 50 µm Mult.Scat.

  Survey monitoring — mean-on-error to better than 1 µm

  Bhabha Fiducial — precise to better than 10^{-4}

- **DAQ SiPM MIP and Shower modes**

  MIP mode — on front LYSO for e/γ layers,

  Shower mode — on long LYSO bars for electron Ebeam

  pile-up veto — high-lumi Z-pole 25 ns bunch crossing, wave-form sampling bettering 40 MHz

- **Bhabha QED**

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

  against *BHLUMI to* 10^{-4}