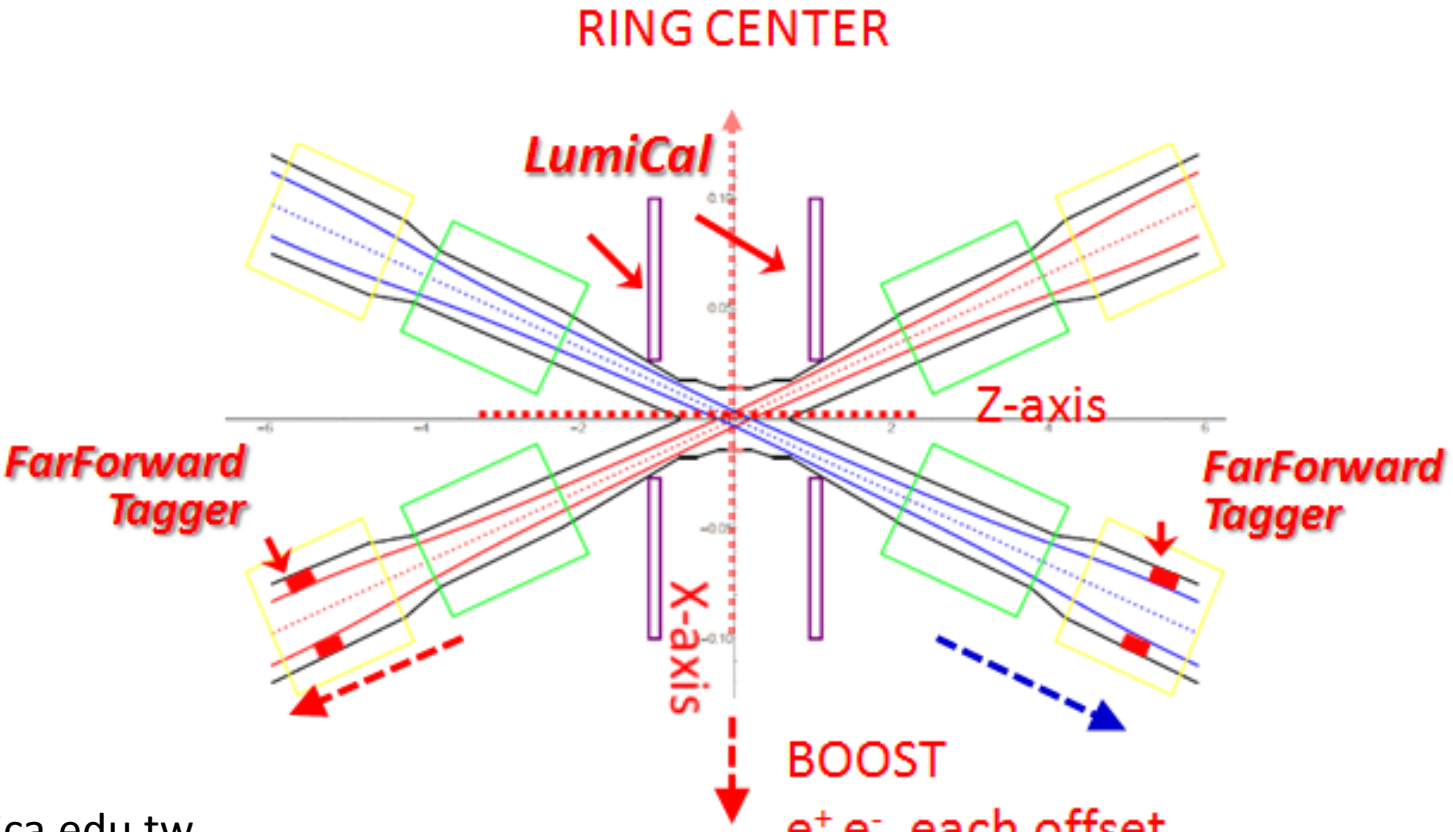
LumiCal Design with 20mm racetreack pipe



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2022.04.20
https://indico.ihep.ac.cn/event/16646/

Outline

- **BHLUMI : Bhabha cross section**

  boost by beam crossing, small beam pipe

  θ_{min} = 30 mRad ➔ σ(Bhabha) > 50 nb

  ϑ_{min} = 15 mRad ➔ σ(Bhabha) > 250 nb

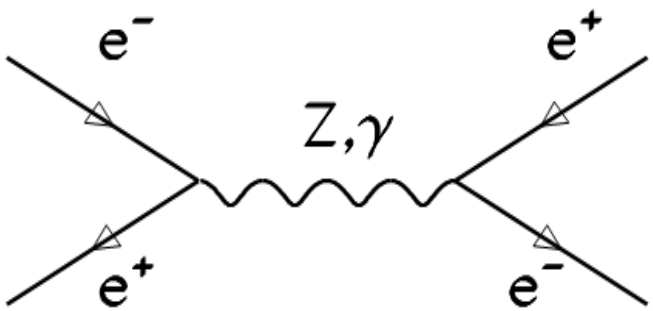
update from 2020.04.15

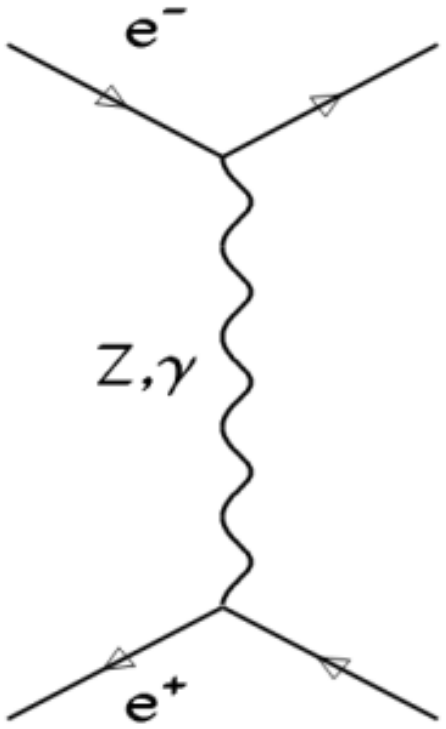
- **LumiCal : beampipe r, flange z →** θ < 16 mRad

  Si layers attached beam-pipe : least multi.scattering effect

  Si layers behind Flange : theta coverage

  Q-pole front : Si layer before calo of LYSO 3x3x50 mm^3 bars





Bhabha elastic e^+e^- scattering as Luminosity reference

Luminosity measurement

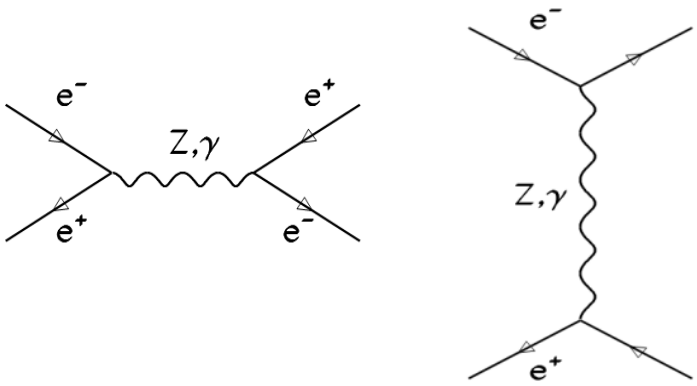
- ***Reference to Z-lineshape, $e^+e^- \to Z \to q\bar{q}$***
- **Luminosity of e^+e^- collisions by measuring Bhabha elastics scattering**

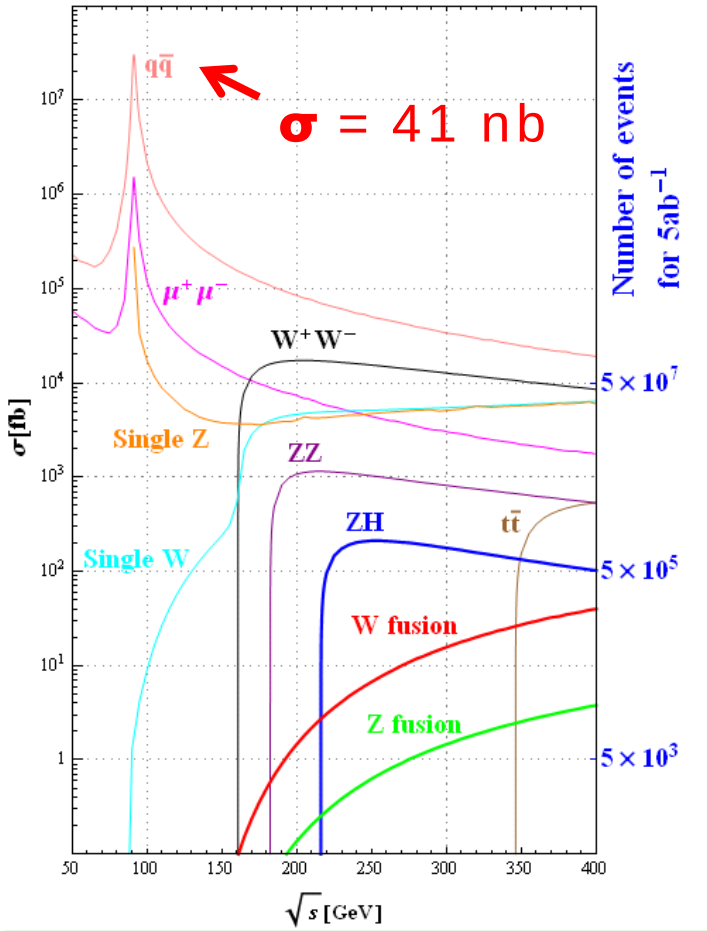
  $$e^+e^- \to e^+e^-$$

  – QED process, theoretical < *0.1%* precision
  – triggering on a pair of scattered e^+e^-

$$\mathcal{L} = \frac{1}{\varepsilon}\frac{N_{\mathrm{acc}}}{\sigma^{\mathrm{vis}}} \qquad \sigma = \frac{16\pi\alpha^2}{s}\cdot\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$

LO diagrams





Luminosity precision

Dominant systematic error

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

Position resolution

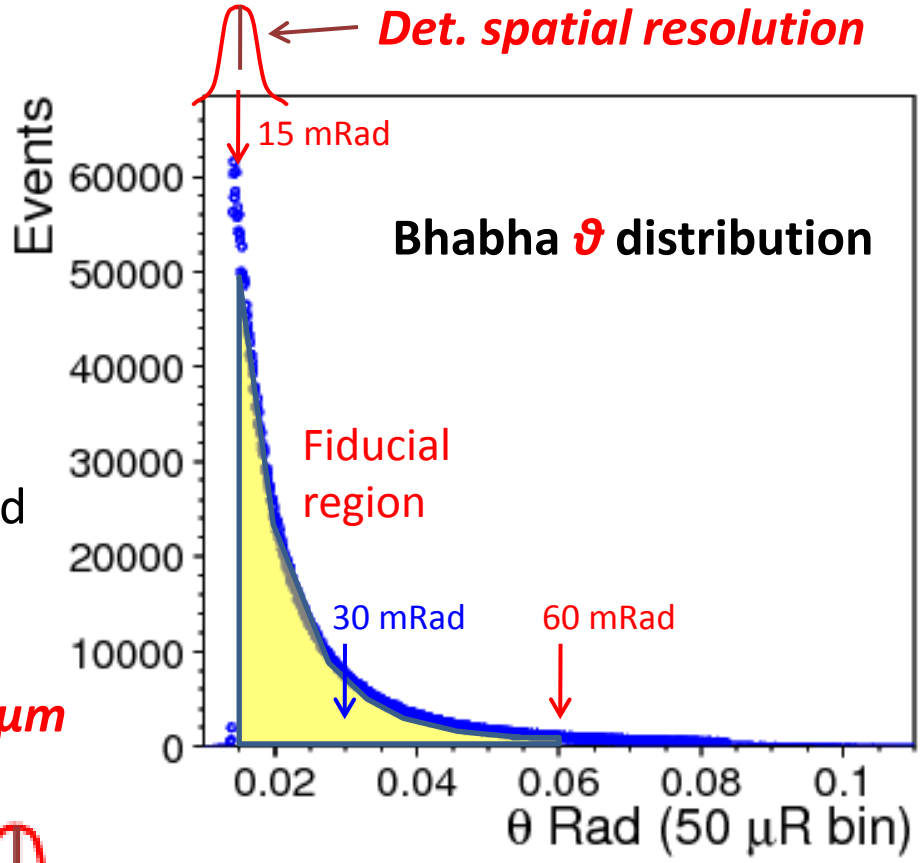
for $\delta L/L < 10^{-3}$

LumiCal at **z = ±1 m,** ➔ θ_{min} = 16 mRad

➔ $\delta\vartheta$ = 8 μRad e.q. ***dr = 8 μm***

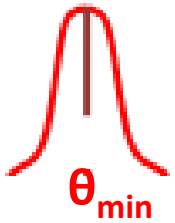
Error due to offset on Z position

➔ *0.1 mm on z* e.q. ***dr = δ R×ϑ = 1.6 μm***



LumiDET design goal:

- *Spatial res. narrow*
- *mean on* θ_{min} < 1 mRad



offset of
the ***mean on*** θ_{min}
➔ ***LUMINOSITY error***

Bhabha detection

- $e^+e^- \rightarrow e^+e^-$ elastics scattering

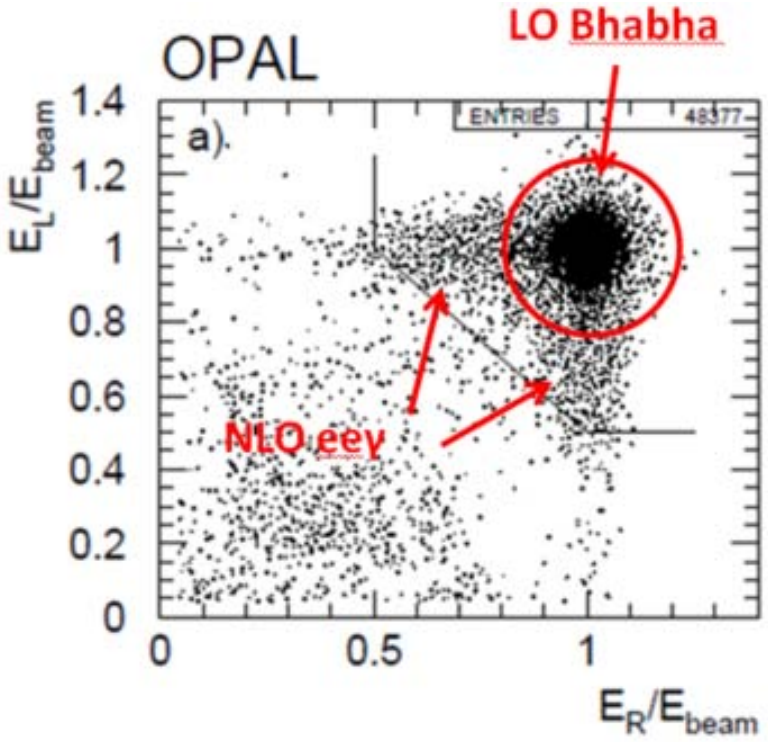
  Event signature

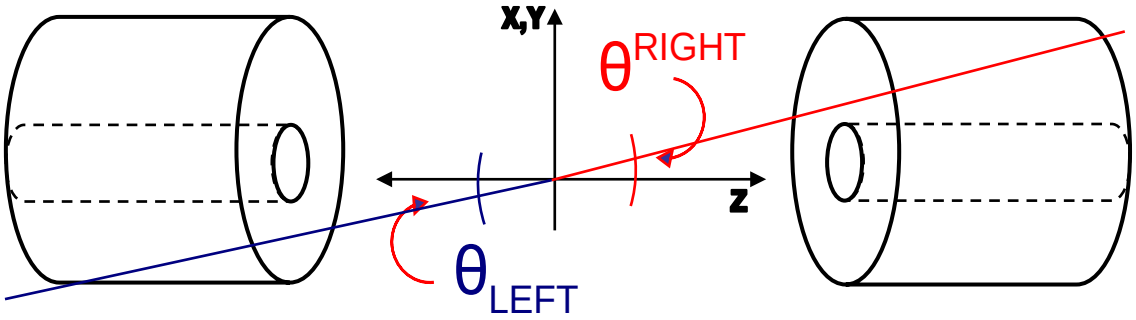
  1. $E(e^{\pm}) = E_{beam}$
  2. e^+, e^- Back-to-Back

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

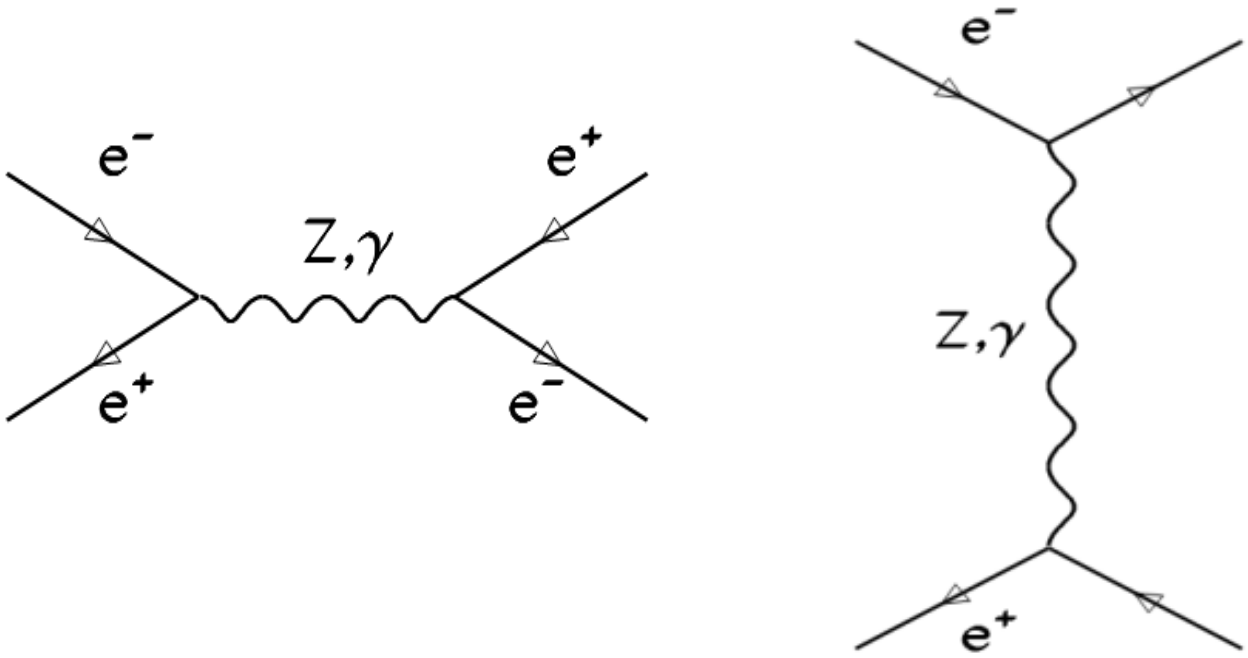
  ~1% events

  1. e^+, e^- approximately Back-to-Back
  2. one electron $E' < E_{beam}$
  3. Detector e/γ ID, spatial resolution





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



BHLUMI
QED calculation, Bhabah cross section

BHLUMI theoretical precision

Bhlumi 4.04 writeup: CERN-TH/96-158

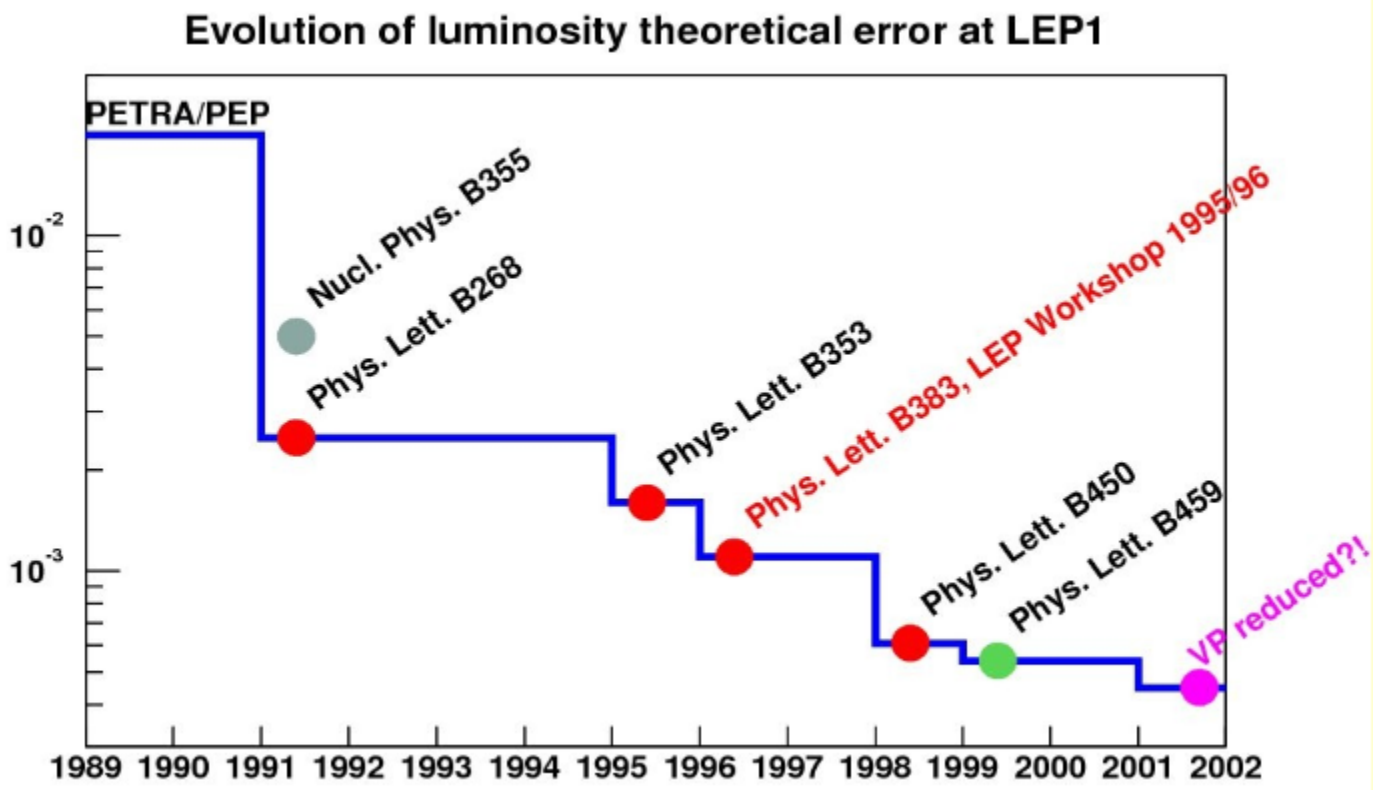
cds.cern.ch/record/310621/files/th-96-158.ps.gz

http://cern.ch/~jadach/public/Bhlumi-linux-4.04-export_2002.11.05.tar.gz

Theory uncertainty: 0.25% was **BHLUMI 2**, reported in CPC package paper

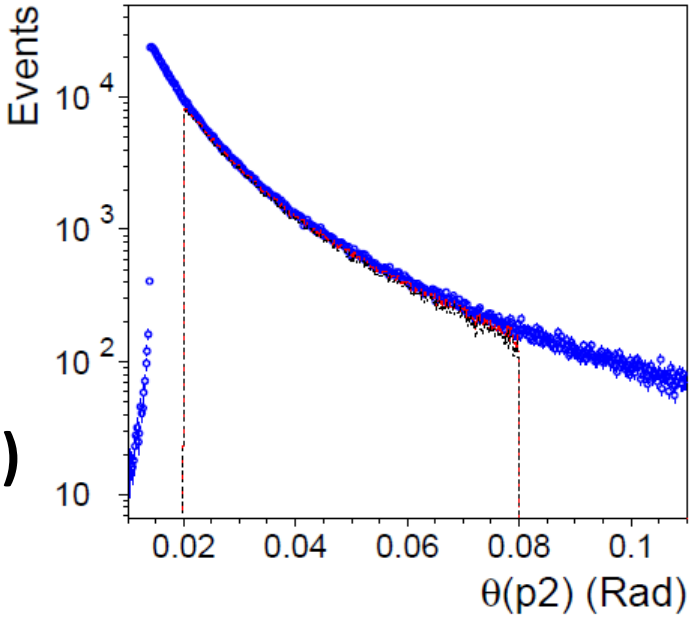
http://inspirehep.net/record/321226?ln=en

The latest BHLUMI 4 report is pushed to < 0.1%



BHLUMI calculations

1. Theta range input : **Th1, Th2**
   Xcru calculated for Thmin=0.7xTh1 to 2xTh2
2. KeyWgt=0 ➔ event wgt=1, for simulation
   count events in chosen condition
   scale to Xcru

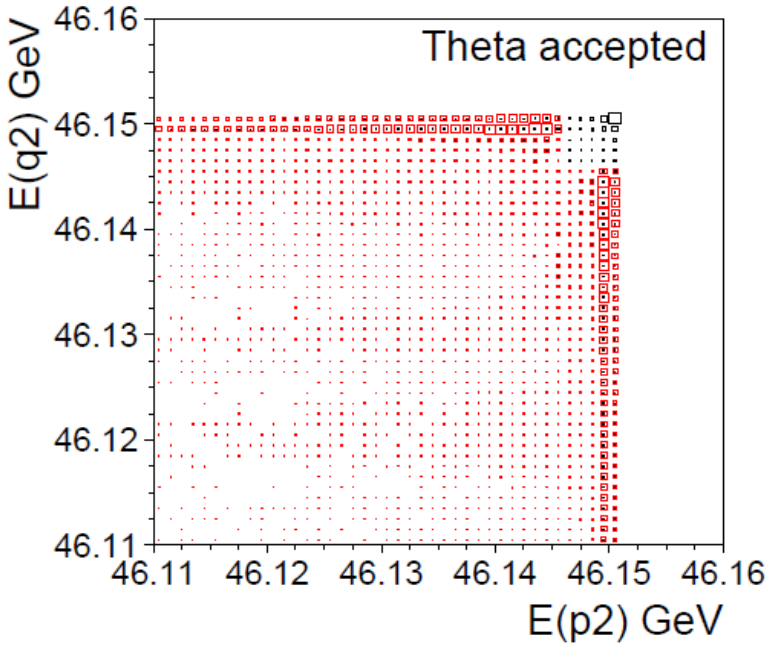


BARE1 X section: (of the bhlumi paper)

Th1 $<\theta_1'$ and $\theta_2' <$ Th2, $s' > 0.5s$

Use BARE1 as reference

Having photon **(red)**
or not at m_Z
➔ 5 MeV precision



Reproduce BHLUMI to 0.1%

Bhlumi-linux-4.04-export_2002.11.05.tar.gz

Compiled by g77 on SL6, **demo.f** produce numbers as in paper **CERN-TH/96-158**

BARE1: .024<θ_1', θ_2' <.058

s'>0.5s

```
Xsec_BARE1 =    169.19520371 Nanob.
error      =      0.67481969 Nanob.
Xsec_CALOZ =    136.21881786 Nanob.
error      =      0.64151939 Nanob.
```

LEP workshop95 on Bhabha established 0.1% precision

Hep-ph/9602393

```
! User should cross-check the folowing two output cross sections
! which are calculated and printed at the very end of the output:
! Workshop95, Table14, BARE1 WW for zmin=0.5:  KeyGen=3, KeyPia=0, KeyZet=0
! Workshop95, Table18, CALOZ WW for zmin=0.5:  KeyGen=3, KeyPia=2, KeyZet=1
```

demo.f

1000000 ev

KeyPia=0, KeyZet=0

CMS = 92.3 GeV

Xsec_BARE1 = **162.5295** Nanob.

Error = 0.2061 Nanob.

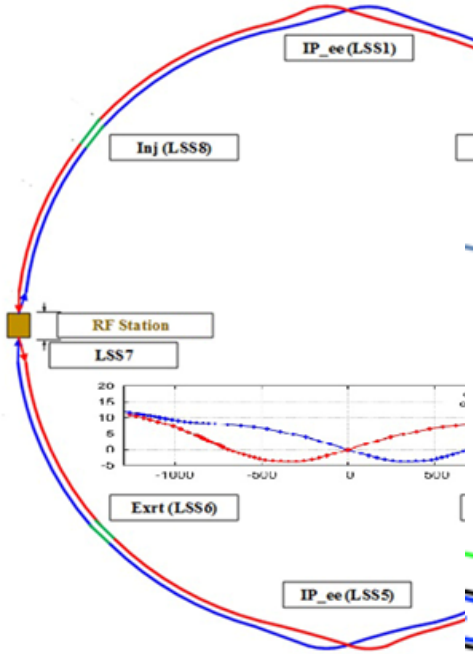
Table 14: Monte Carlo results for the symmetric Wide-Wide ES's BARE1, for matrix elements beyond first order. Z exchange, up-down interference switched off. The center of mass energy is $\sqrt{s} = 92.3$ GeV. Not available x

Hep-ph/9602393

z_{min}	BHLUMI [nb]
.100	166.892 ± .006
.300	165.374 ± .006
.500	162.530 ± .006
.700	155.668 ± .006
.900	137.342 ± .006

CEPC beam crossing

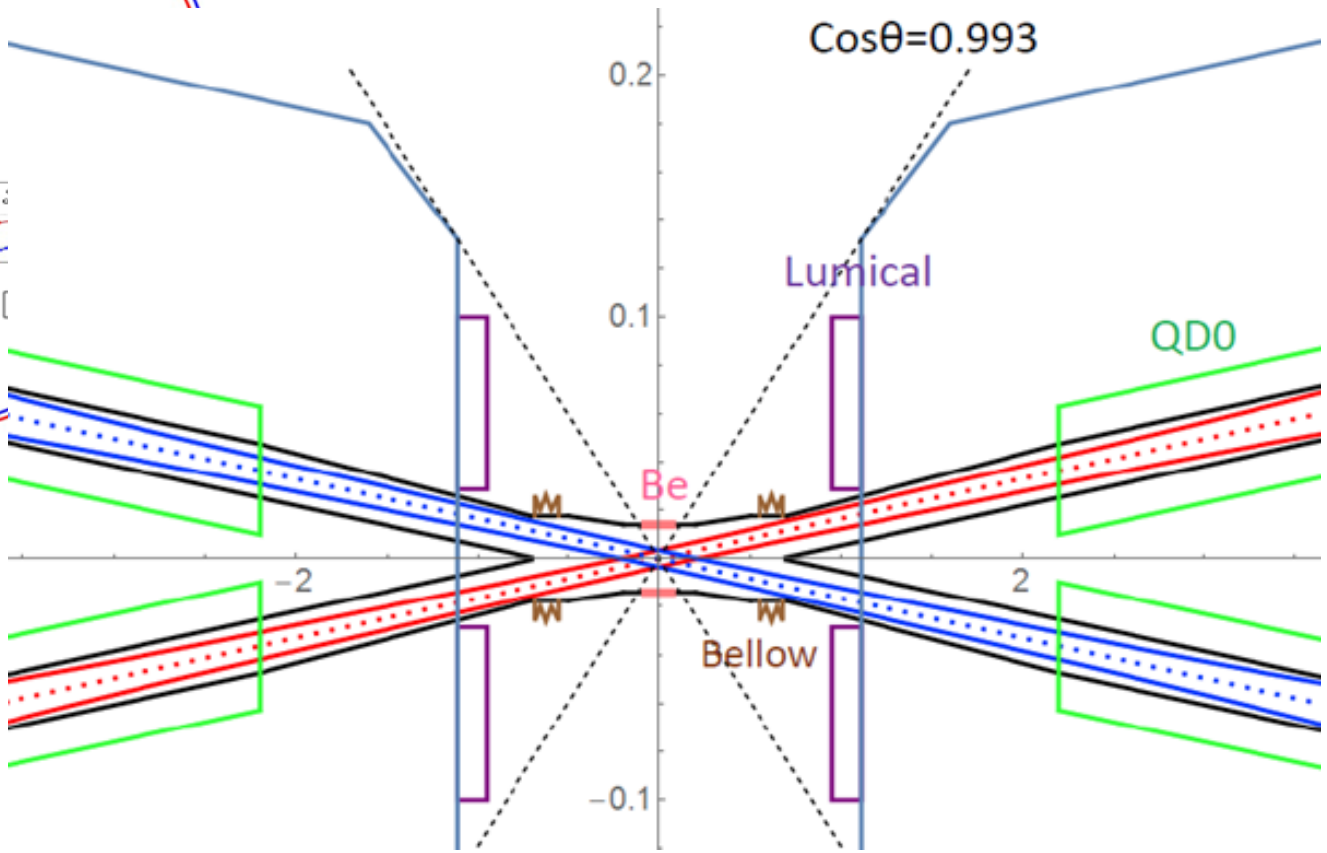
CEPC double Ring



Beam crossing 33 mRad

Focal length:

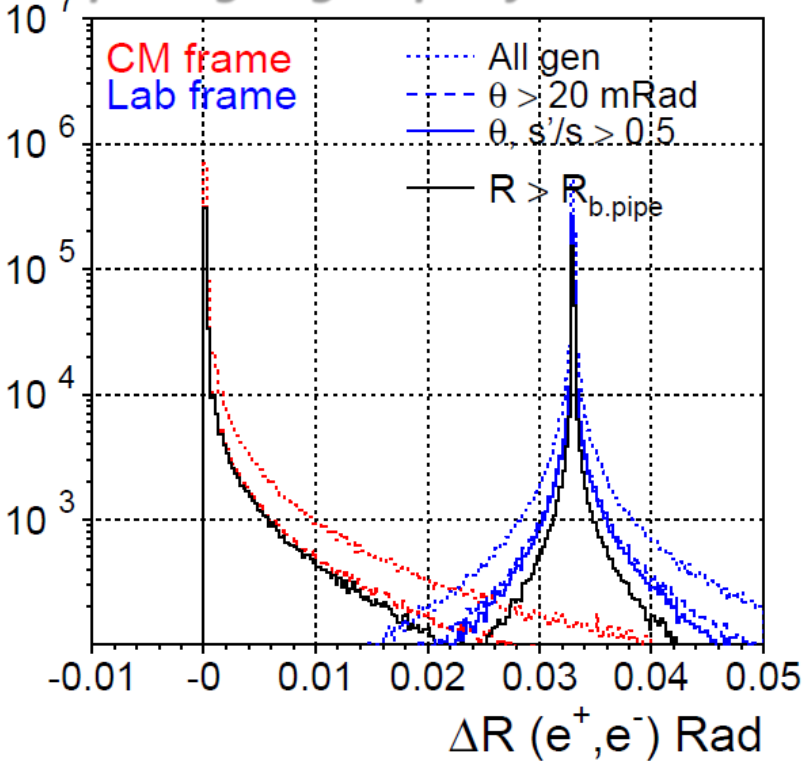
L* 1.5m →2.2 m



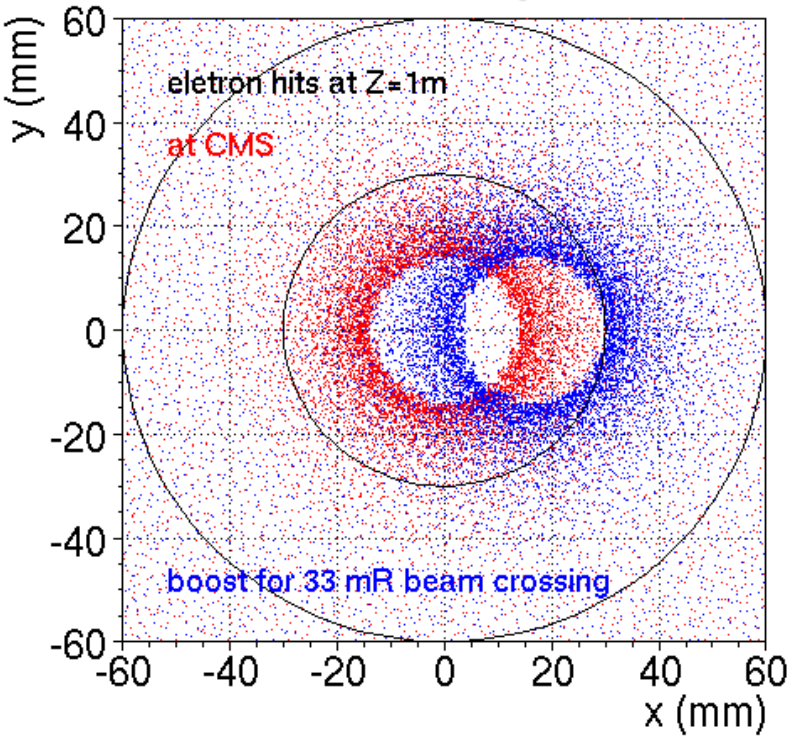
Bhabha back-to-back boosted by 33 mRad beam crossing

- Bhlumi electrons boosted for the 33 beam crossing by ~16.5 mRad to +x direction
- Compared for Bhabha selection conditions

Opening angle –pi of scatterede+ e-



Bhabha at detector plane Z=1m



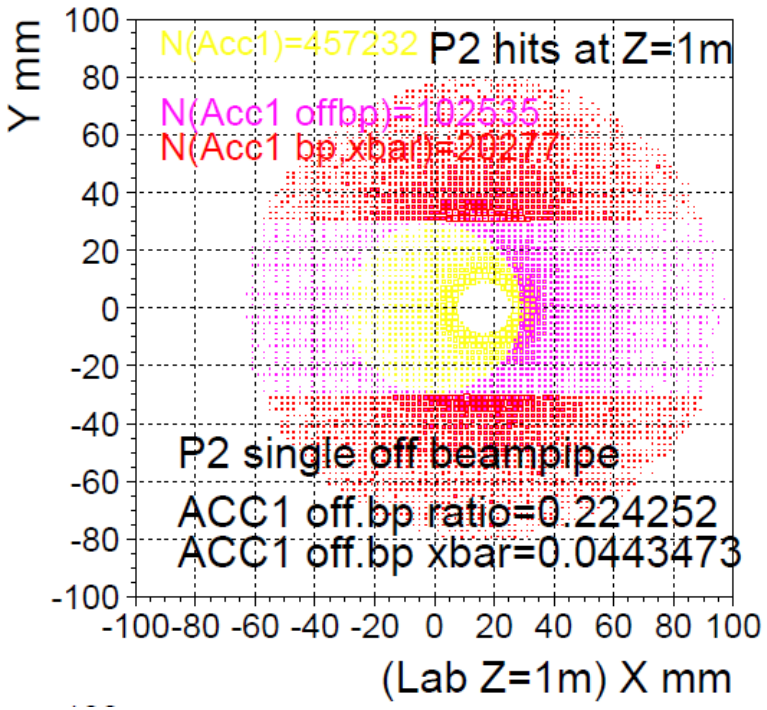
Bhabha X sec. vs Lab z-axis round pipe

- CMS generated th1=10 mRad ➔ boosted +16.5mRad, +X are low angle Bhabha
- Assuming beam pipe is LAB z-axis centered, **radius = 30 mRad** (r=30mm @z=1m)
  at x=+30 mm, Bhabha electrons are of θ=13.5 mRad

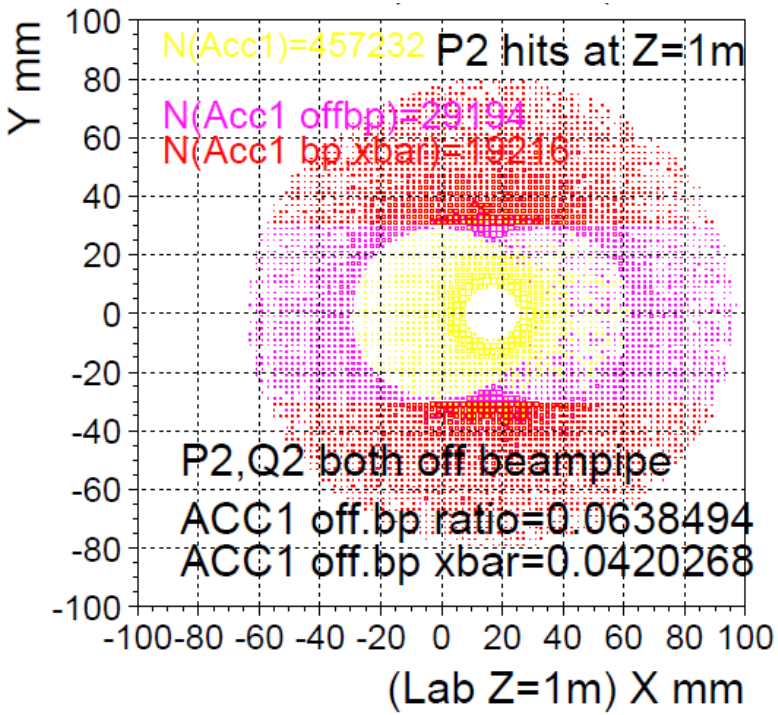
➔Off beam pipe, detect: **one electron (262 nb) / both electrons (74.6 nb) = 3.51**

➔Hori. cut +/- 30mm : **one electron (51.8 nb) / both electrons (49.1 nb) = 1.05**

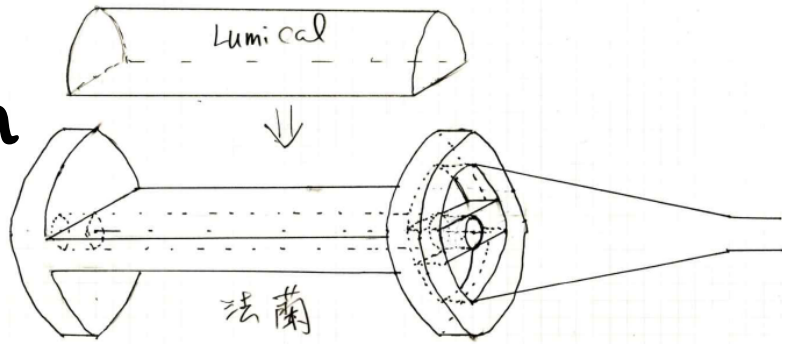
Hits of ONE Bhabha electrons

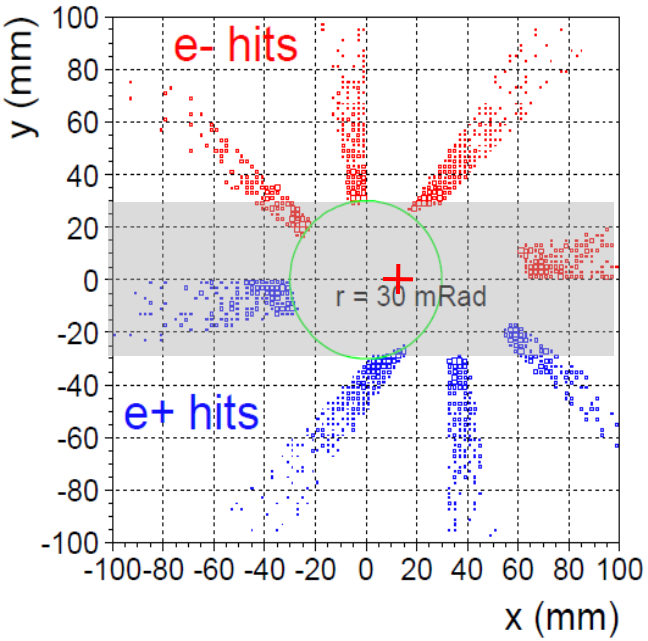


Hits of electrons, both detected



Bhabha X section





Round beam pipe, r= 30 mRad

CMS 10 ~ 80 mRad		LAB detect *ONE* electron		LAB detect *both* electrons	
BARE1		off beampipe full phi coverage	off beampipe cut off ±30mm	off beampipe full phi coverage	off beampipe cut off ±30 mm
Nevents	457232	102535	20277	29194	19216
Xsec (nb)	1168.3	262.0	51.81	74.60	49.10

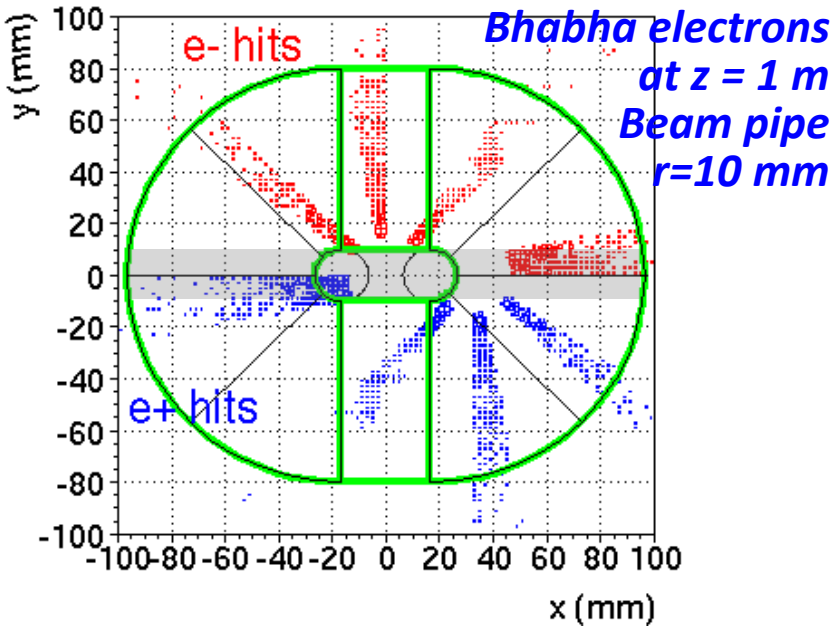
-2 mRad in radius (r=28 mRad) ➔ 20% increase in X section

CMS 10 ~ 80 mRad		LAB ONE electron		LAB both electrons	
BARE1		off beampipe full phi coverage	off beampipe cut off ±28mm	off beampipe full phi coverage	off beampipe cut off ±28mm
Nevents	457232	135842	24236	34847	23010
Xsec (nb)	1168.3	347.1	61.93	89.04	58.80

BHlumi X-section

flat beam pipe, y= ±10 mm

Bhlumi counting electrons in fiducial region at z = 1m



Lab round r>20 mRad, |y|>20 mm

CMS 10 ~ 80 mRad		LAB detect ***ONE*** electron		LAB detect ***both*** electrons	
BARE1		R>20 mRad full phi coverage	R>20 mRad cut off ±20mm	R>20 mRad full phi coverage	R>20 mRad cut off ±20 mm
Nevents	457232	274420	53724	93311	51360
Xsec (nb)	1168.3	701.2	137.3	238.4	131.2

Lab round r>15 mRad, |y|>15 mm

CMS 10 ~ 80 mRad		LAB ONE electron		LAB both electrons	
BARE1		R>15 mRad full phi coverage	R>15 mRad cut off ±15mm	R>15 mRad full phi covearge	R>15 mRad cut off ±15mm
Nevents	457232	330952	100152	204263	96221
Xsec (nb)	1168.3	845.6	255.9	521.9	245.9

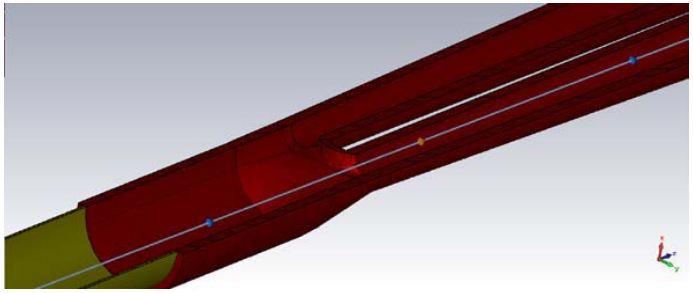
BHLUMI
QED calculation, Bhabah cross section

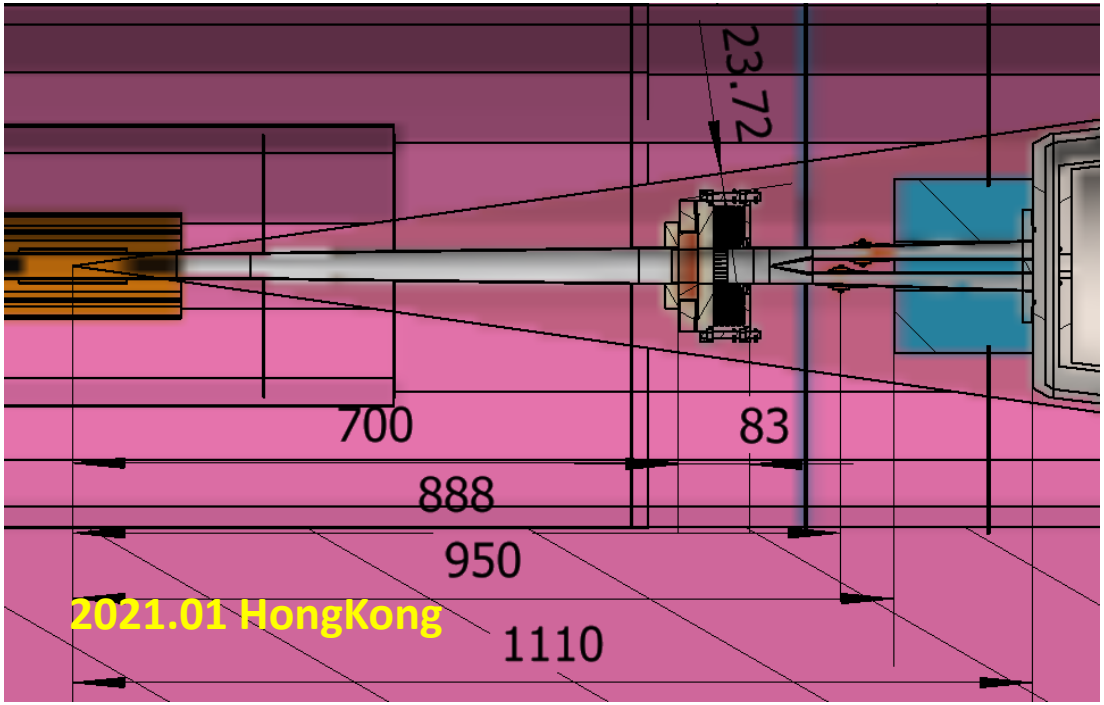
To Do:

CEPC segmentation and

Event pileup estimation for 32ns bunch crossing

LumiCal for CEPC





GEANT TUBE pipe, multiple scattering

2020.10.28

Ver. TUBE pipe

acos(.99) = 141.54 mRad @Z=118 → r= 16.81 (=tanQ*118)
acos(.992)= 126.58 mRad @Z=118 → r= 15.02 mm
Q= 100mRad @Z=118 → r= 11.84 mm @Z=153 → r=15.35 mm

409 TbFe 5mm Fe
Z=0~ 970 mm connecting to
r= 12.34cm ~+.5cm, FE

Acos(.99) = .14154 rad
Acos(.992) = .1266 rad
atan(123.6/970) = .12678 rad

TbOS 2mm scin
Z=0~ 970 mm r= 12.39cm +.2cm

TbIS 2mm scin
Z=0~ 970 mm r= 12.32cm +.2cm

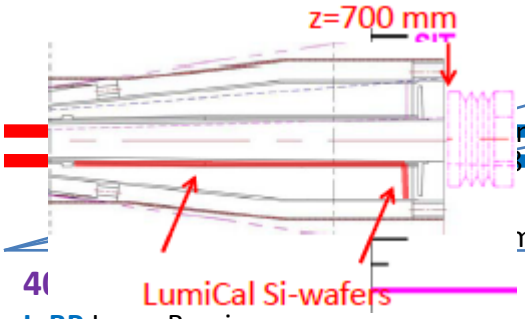
Flange

Acos(.992) =.1266 rad

SiW edge
atan(70/685) =.1018 rad

100 mrad

Al dual tubes
.5mm. .35 mm thick



Fwin window 2 mm
Z=520~522
r= 15.35~55 mm

BpSn Si octagon rmin =1.5451 cm
Z=16 - 52.0 cm

419 FLSi Si deck
Z=522~524
R = 15.5-55. mm
29.7-105 mrad

FS0i SiW two layers
Deck=3.5mmW+2mmAir
R = 15.5-70. mm
22.3-100.2 mrad @ Z= 696

Z=520 mm

Fend Flange 20mm
Z=696 - 716
r= 15.5~123.2 mm

InBP Inner Be pipe
Z=0~118 mm,
inner diameter 28 mm 0.5mm thick

InAl Inner Al pipe
Z=118~500 mm,
inner diameter 28 mm 0.5mm thick

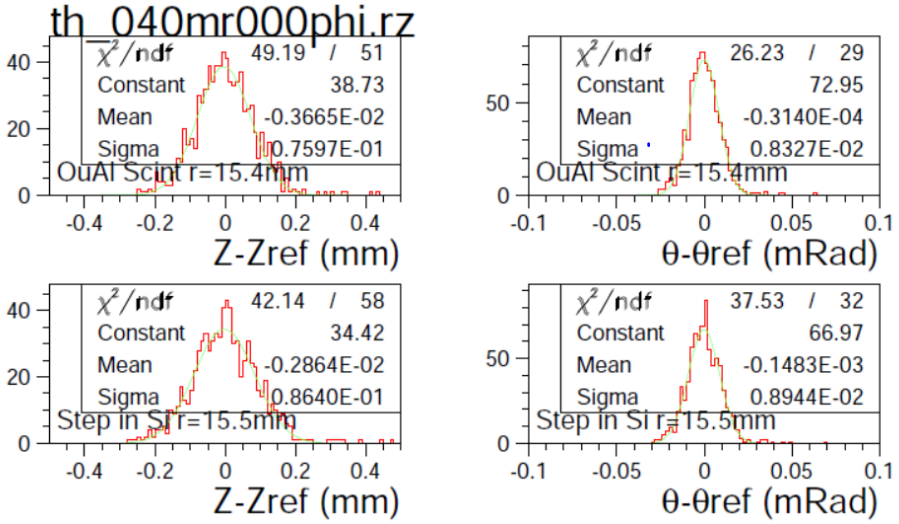
Fpip flange pipe 1.5 mm thick
Z= 522-716 mm
at Z=512 r= 14 – 15.5 mm

OuBP outer Be pipe
Z=0~115 mm
inner radius 28/2+1 mm 0.35mm thick

OuAl outer Al pipe
Z=0~115 mm
inner r=28/2+1 mm, 0.35 mm thick

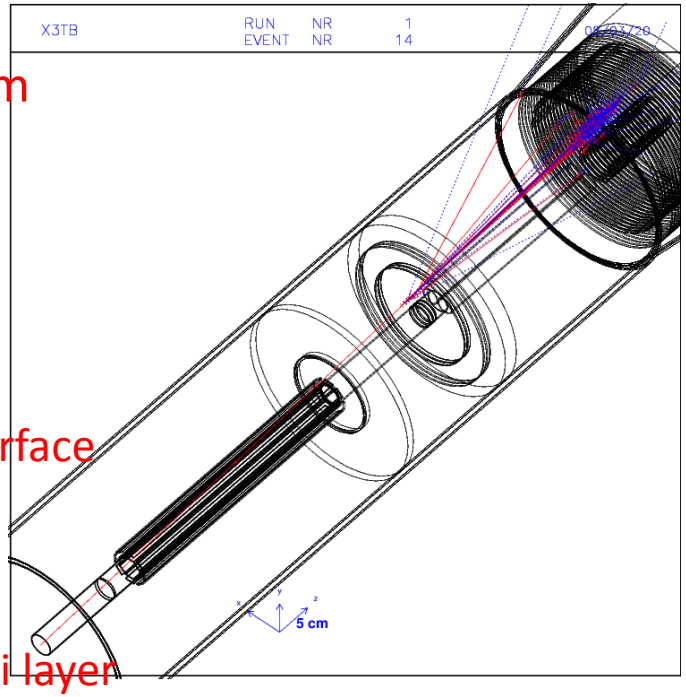
Multiple scattering off Al beampipe

- ***50 GeV electron*** traversing Al-pipe (mm): 0.5 Al – 0.5 Air – 0.35 Air @ fixed theta, phi=0°
- ***Multiple scattering deviation*** simulated for ϕ=28 mm
  1. exiting Al-pipe (a Scintillator layer on surface)
  2. no air-gap, Si-layer attached



dz, dθ on Al-pipe surface

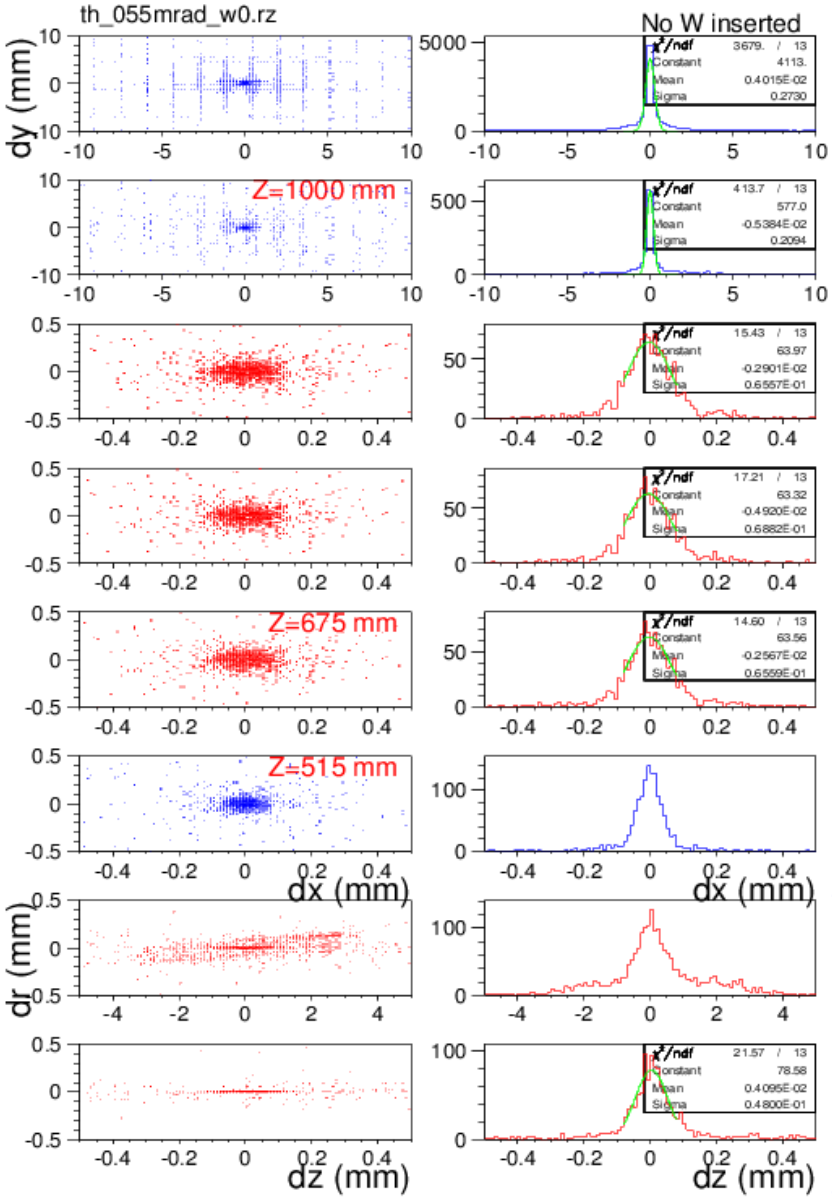
dz, dθ on Octagon Si-layer



50 GeV (θ,ϕ)	σ (Z)	σ(θ)	1/tan(θ)
e (40 mR, 0°)	86 μm	8.9 μRad	25.0
e (55 mR, 0°)	37 μm	7.3 μRad	18.2
e (60 mR, 0°)	28 μm	6.5 μRad	16.6
e (70 mR, 0°)	19 μm	5.8 μRad	14.3

θ to z: r/z =tan θ

Position(Hits) – Electron shower



electron @ 55 mRad

Front 2 Si-layers of Q-pole LumiCal

Pileup of shower ~1 mm resolution

Three Si layers at Z>670 mm
Vertical to beam-pipe

NO Tungsten layers σ= 65 μm

1st Si layer behind flange at Z=515 mm

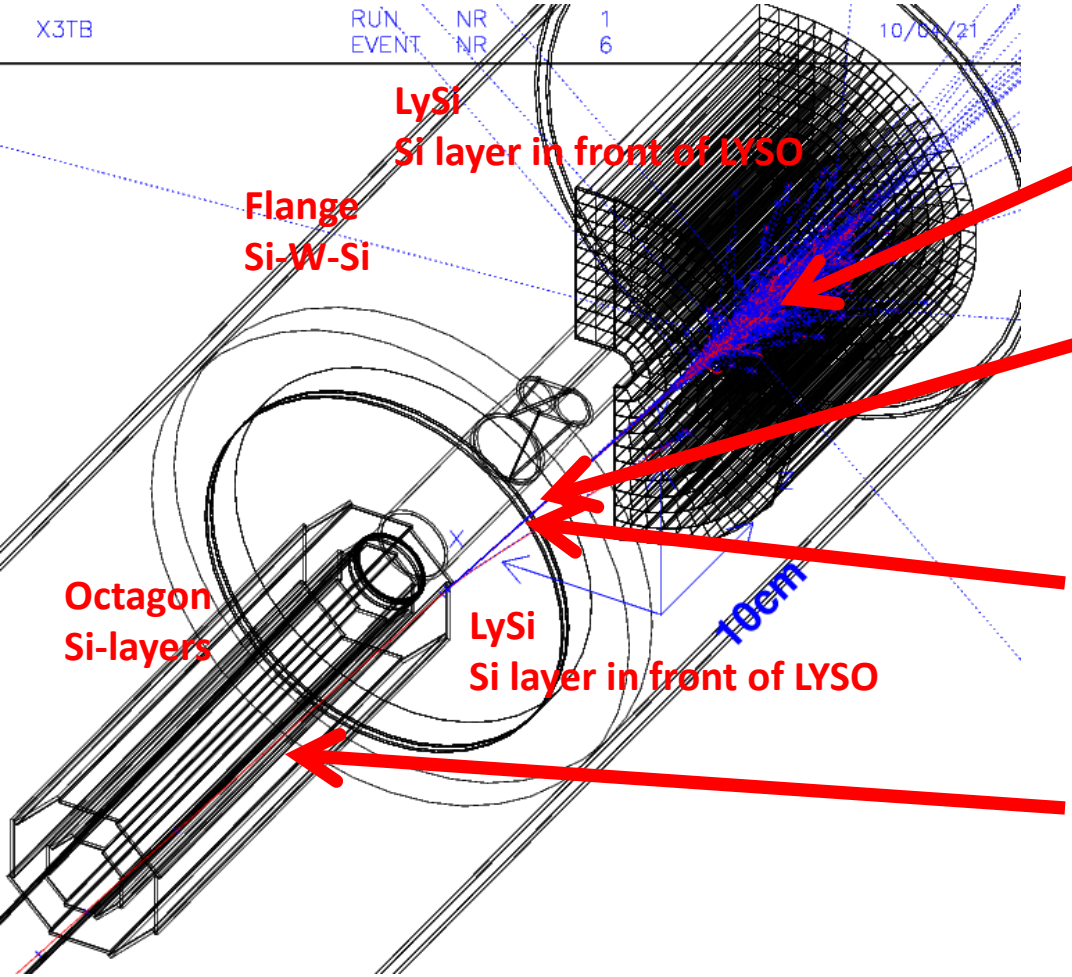
Octagon Si-ladders
surrounding beampipe

1st layer σ(z) = 50 μm

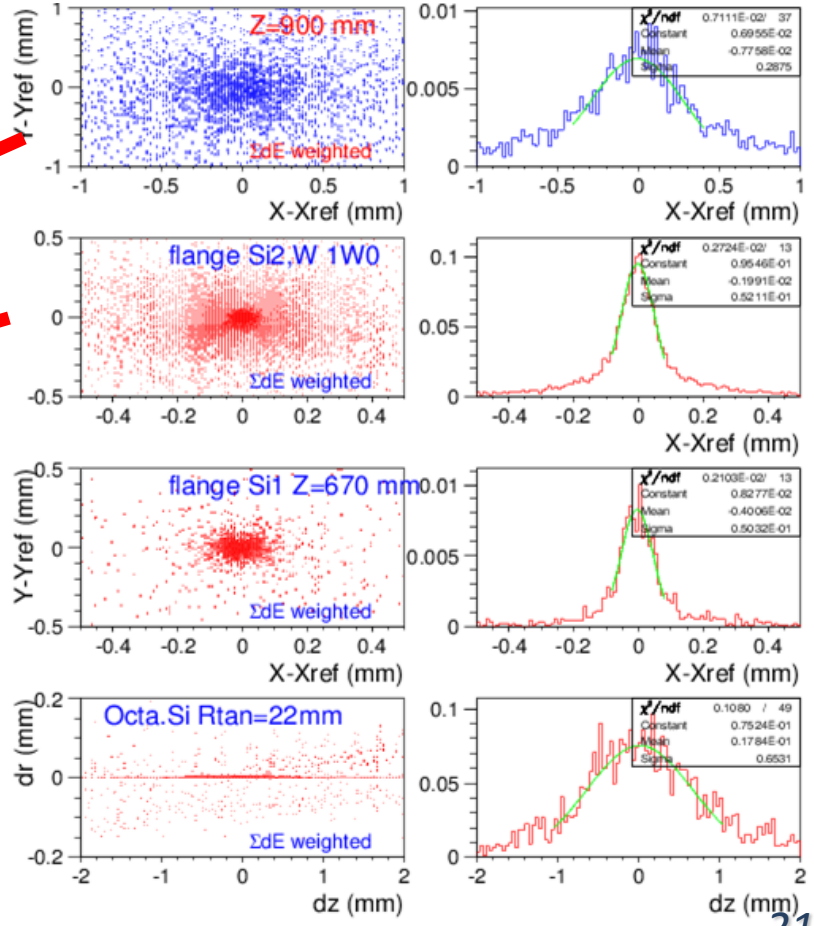
LumiCal spatial resolution

- Octagon Si-layer surrounding beampipe
- Flange Si-disk (1X0 + Si disk)
- Calo Si-disk, front of LYSO

Ver. CONE y-crotch

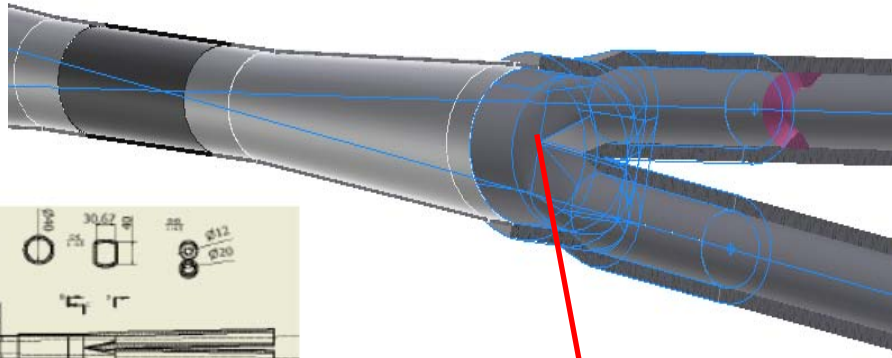


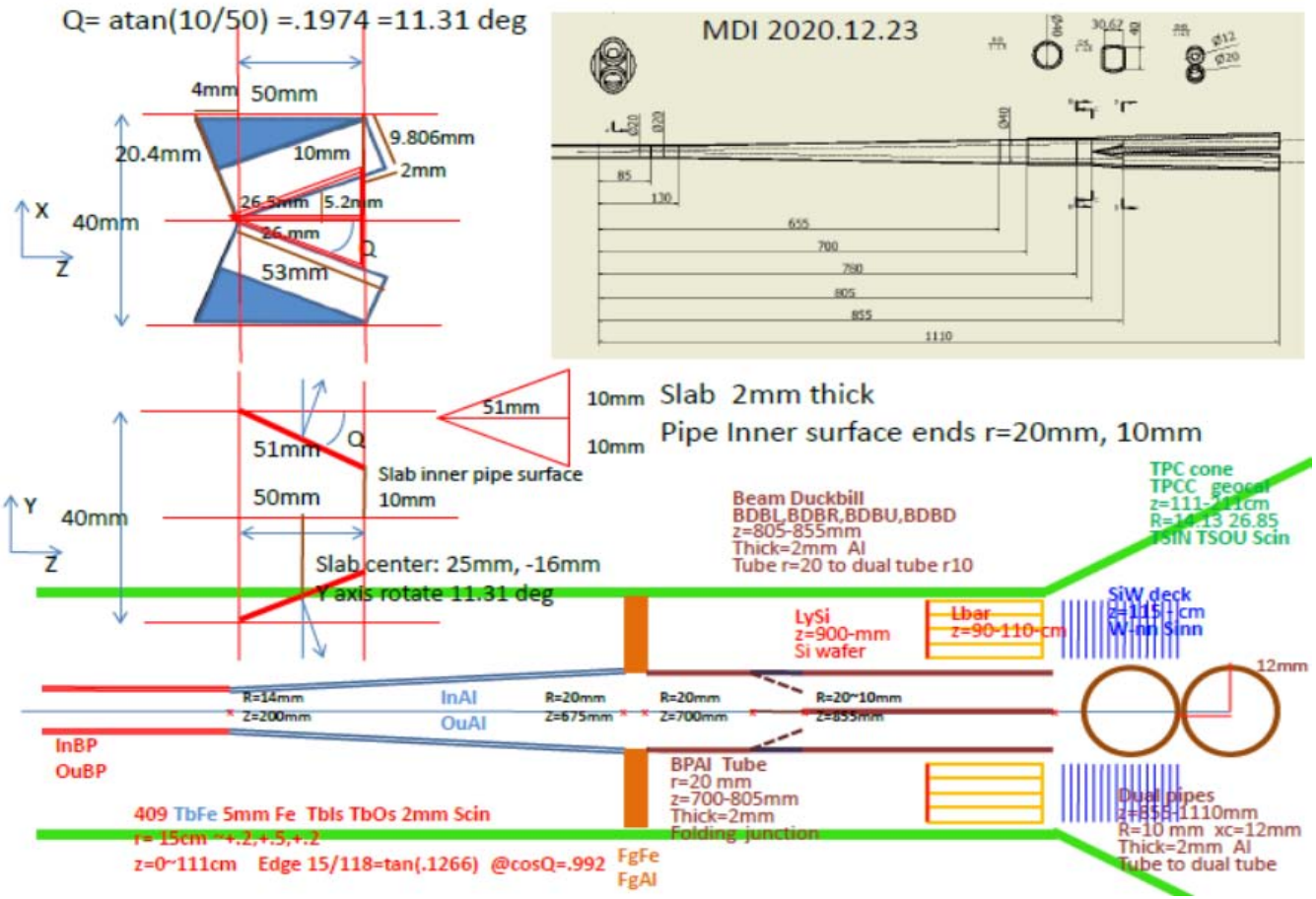
e 50G_40mRad_phi180

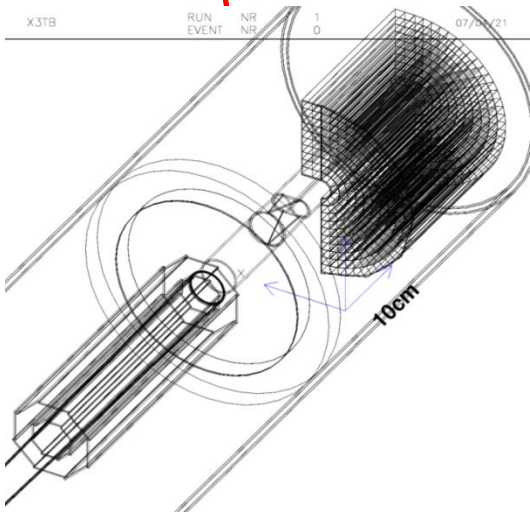


Multiple Scattering behind the Flange

the ***y-crotch*** ϕ=40 to dual 20 mm pipes
is ***a low-mass, high cross section*** window
for Bhabha

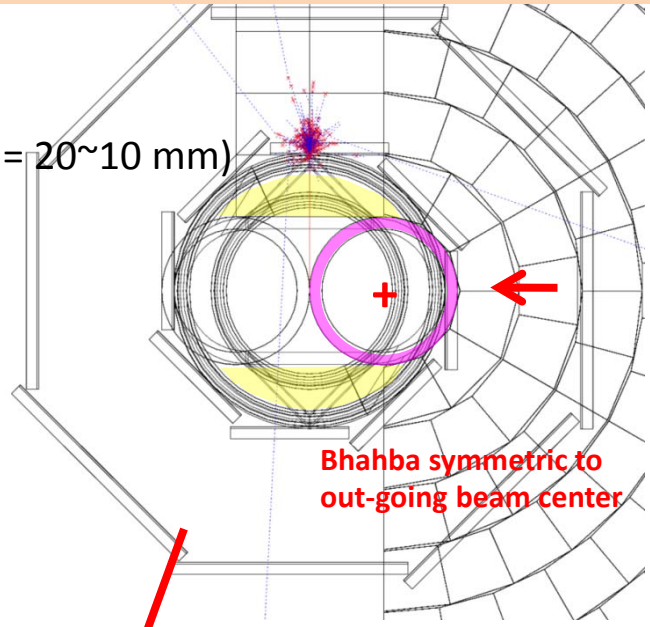


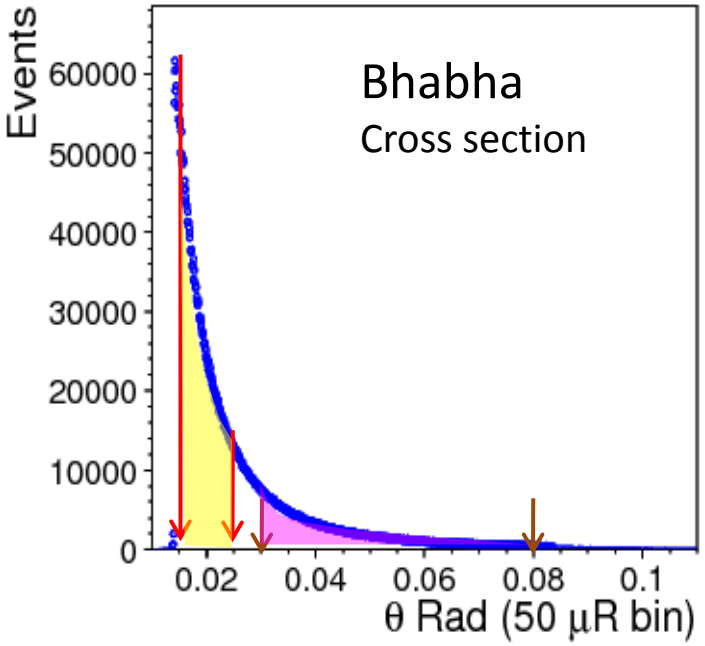


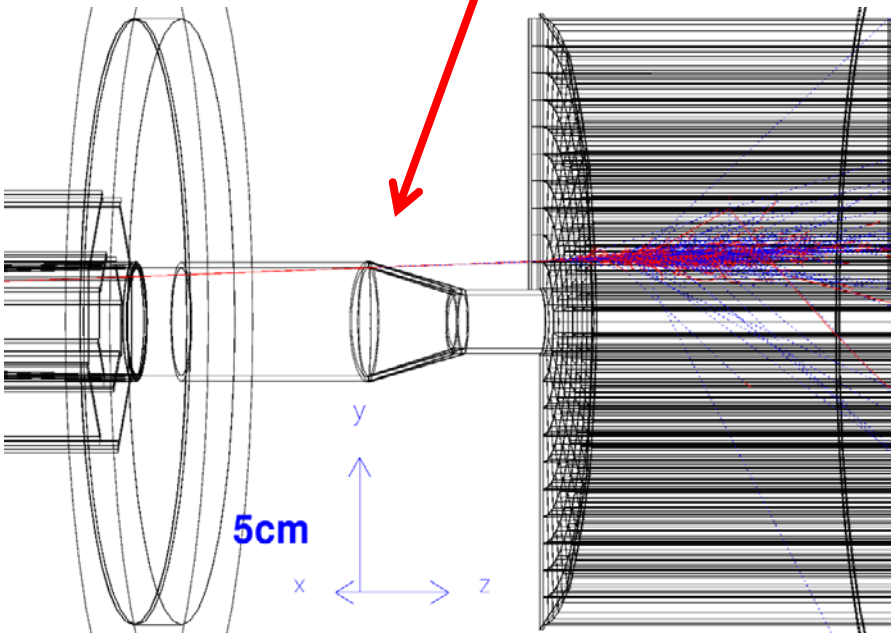


Y-crotch window

- Duckbill slope on y-axis is **200 mRad**, (z = 805−855mm, r = 20~10 mm) electron traversing distance **< 10 mm**
- Window on lab y-axis: **θ = 15 – 25 mRad** Bhabha cross section in clean phi region **~ 100 nb**
- Electron θ measured by Si r-ϕ disk before LYSO

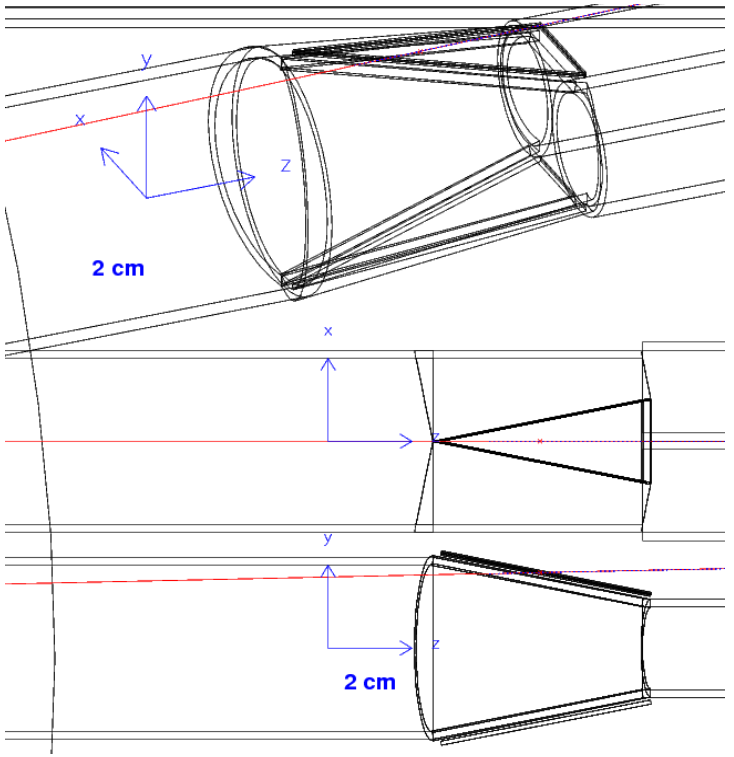


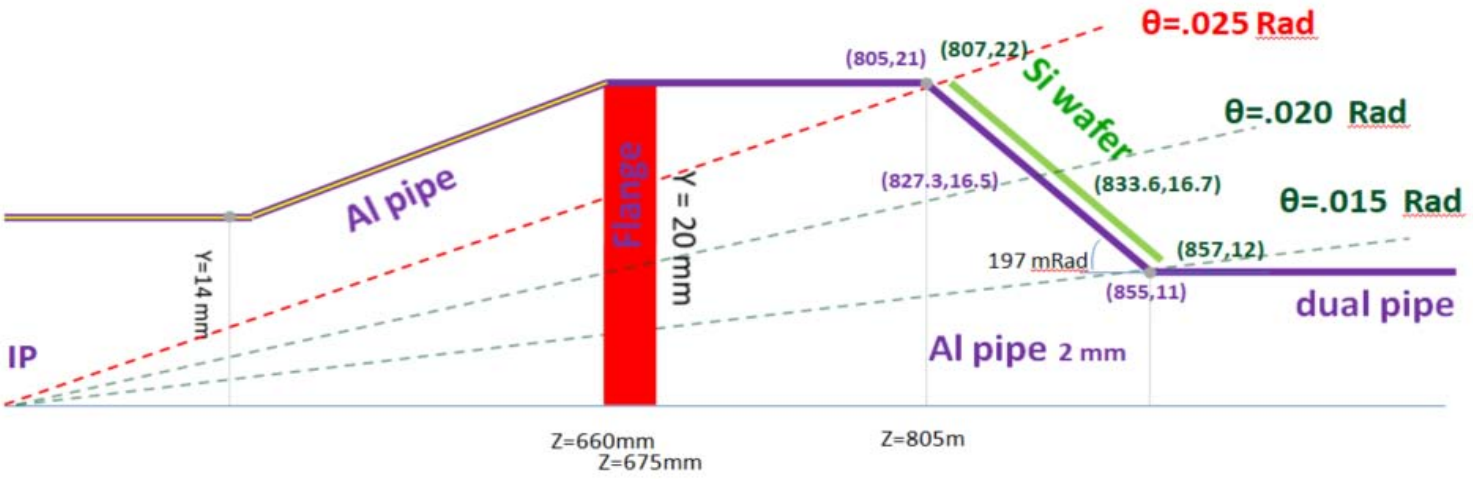




Si-wafers on Y-crotch

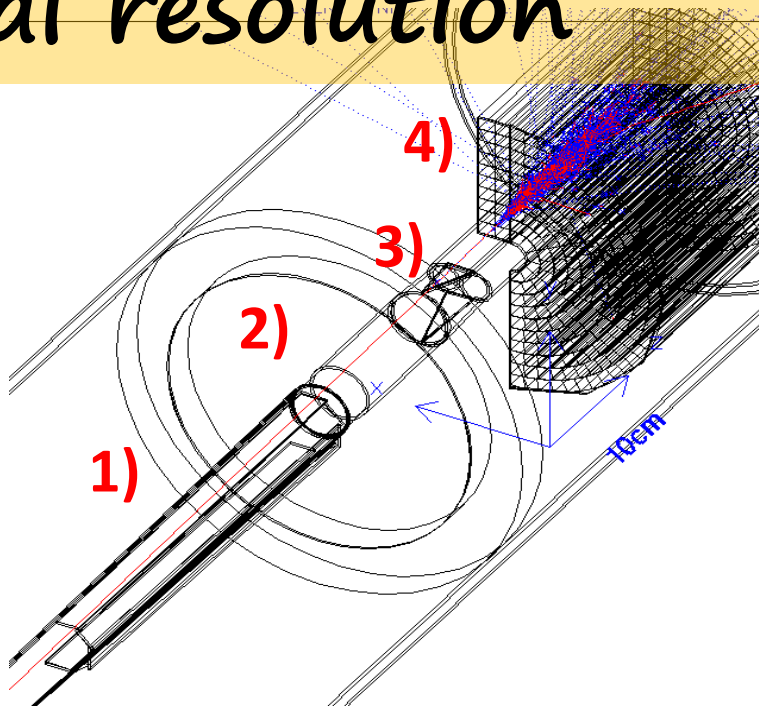
- Round pipe ϕ=40 mm to dual pipes ϕ=20 mm
  Slabs on top/down of the Y-crotch
  z= 805 to 855 mm
  slope = 197 mRad (11.3 deg)
- Si wafer 1mm above
  ➔ air gap from IP: ***6~6.5 mm***
  Multiple Scattering effect suppressed very much





LumiCal Si-wafer spatial resolution

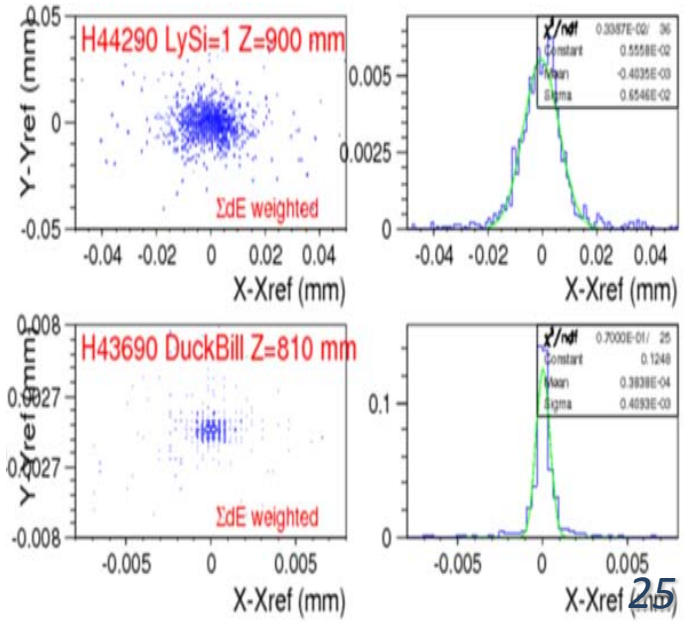
50 GeV electron, *all hits* on Si wafers
(primary e^- and secondaries)
Scan vertically phi = 90°
through Y-crotch window



Multiple scattering estimated on

1) Octagon surrounding Al-pipe
2) Flange Si-disk
3) Y-crotch up/down slabs
4) LYSO front Si-disk

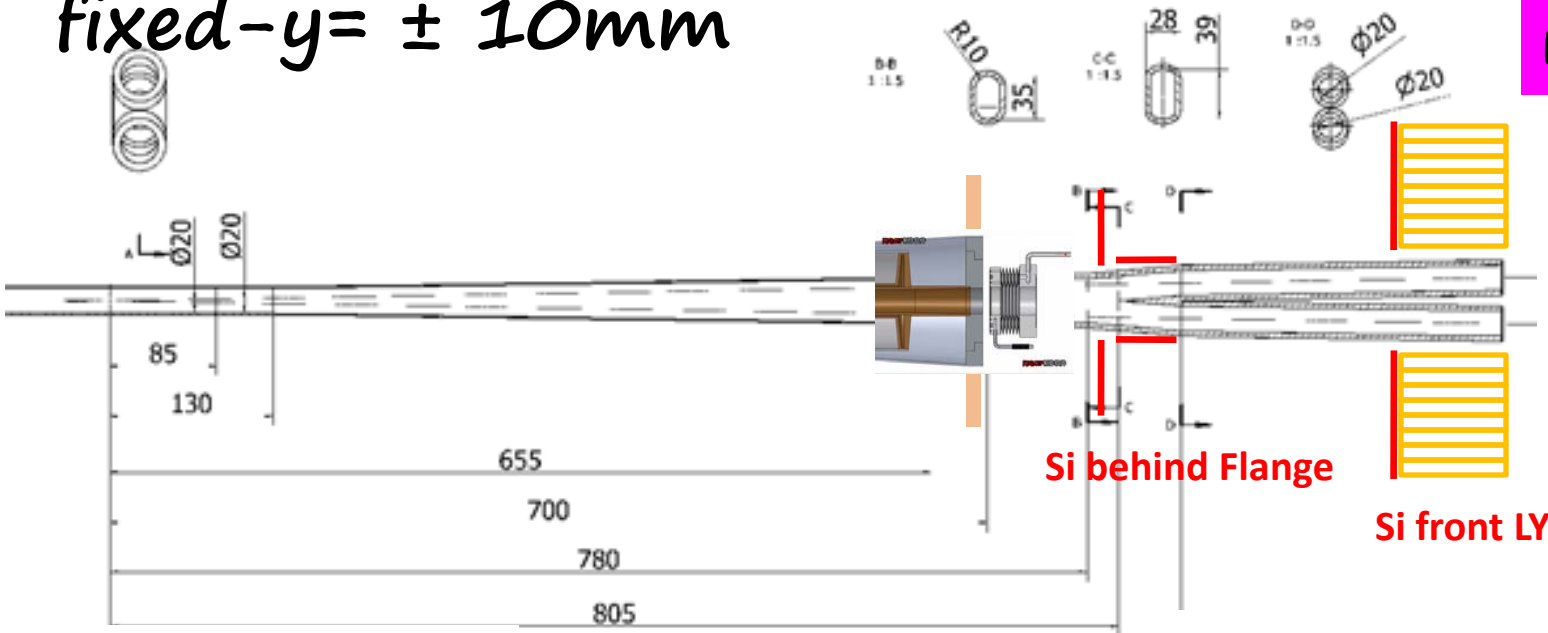
Lab (θ,ϕ)	1) σ(z) Oct Si	2) σ(x) Flg Si	3) σ(x) Y-cr. Si	4) σ (x) Ly-Si
e (15 mR, 90°)	–	–	**0.55 µm**	**5.3 µm**
e (20 mR, 90°)	–	–	**0.41 µm**	**6.5 µm**
e (25 mR, 90°)	–	–	**0.88 µm**	**9.8 µm**
e (30 mR, 90°)	–	–		95 µm
e (40 mR, 90°)	620 µm	52 µm		129 µm
e (55 mR, 90°)	373 µm	58 µm		114 µm
e (60 mR, 90°)	308 µm	65 µm		111 µm

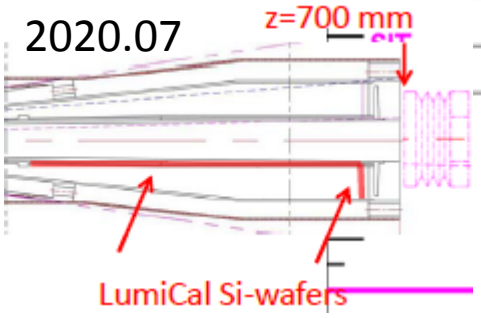


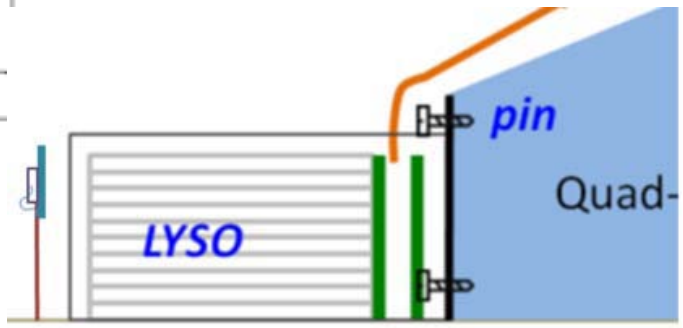
2022.03 racetrack beampipe

fixed-y= ± 10mm

2022 racetrack







asin(10./340) = 29.4 mRad
asin(10./780) = 12.8 mRad
asin(10./805) = 12.4 mRad
asin(10./855) = 11.7 mRad

asin(12./340) = 35.3 mRad
asin(12./780) = 15.4 mRad
asin(12./805) = 14.9 mRad
asin(12./855) = 14.0 mRad

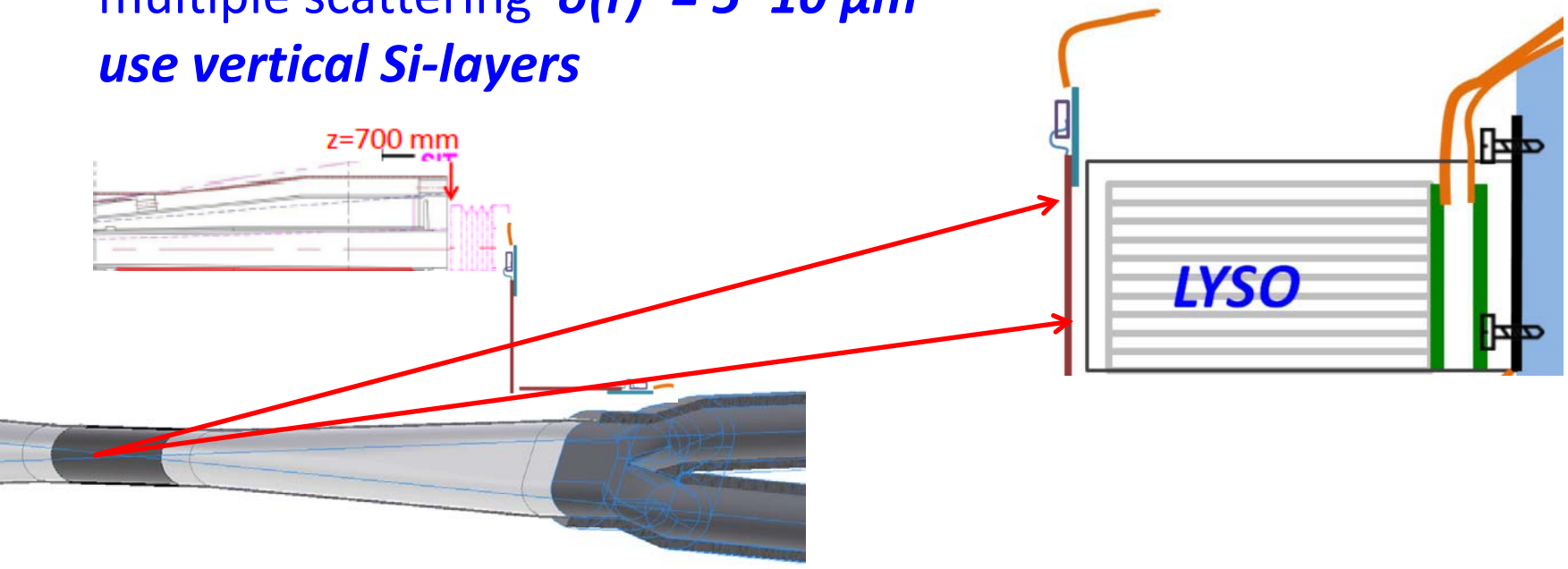
asin(15./340) = 44.1 mRad
asin(15./780) = 19.2 mRad
asin(15./805) = 18.6 mRad
asin(15./855) = 17.5 mRad

Electron @ 15 mRad

Beampipe= $0.5^{Al}+0.5^{Air}+0.35^{Al}$
Distance dz in beampipe=
1.35/tan(0.015 mRad) = 90 mm

- Electrons at ϑ_{min} = 15 mRad
  needs a Si-layer attached on beam-pipe
  to minimize multiple scattering expansion
  σ(Z) ~ 200 μm, σ(ϑ) ~ 20 μRad,
- Inner tracker region z = 400~700 mm
  (ϑ range 15 ~35 mRad)
  multiple scattering ***σ(r) = 5~10 μm***
  use vertical Si-layers

2022 racetrack

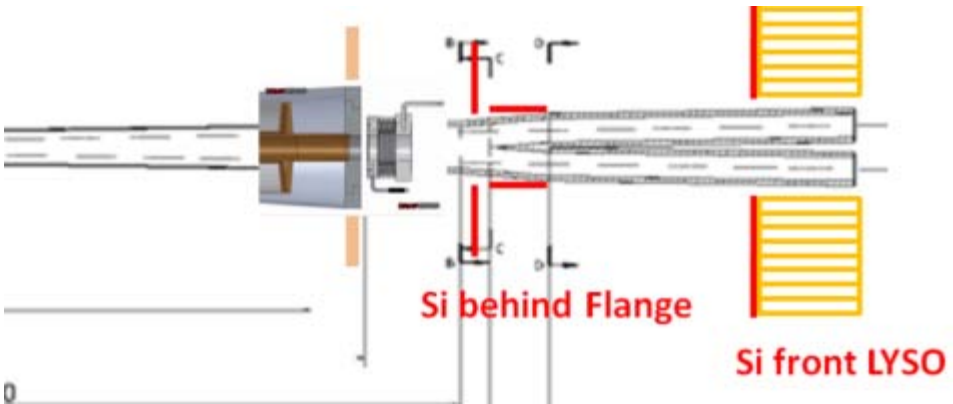


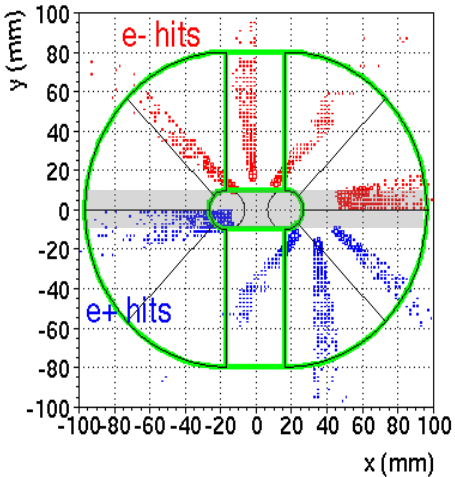
Racetrack-pipe
Fixed r_y= ±10mm, split-x to dual-pipes

- **Bhabha cross-section** with both electrons detected in Lab frame of Θ_{min} >15 mRad, |y|>15mm
  ➔ X-section ~250 nb

2022 racetrack

- **LumiCal simplified** (need detailed GEANT study)
  - fiducial range cut off x-axis for mechanical and probes
  - Si-layers outside Flange
    two horizontal flat layers upon/below beam-pipe ➔ θ_{min} edge
    vertical layers to beampipe for θ coverage





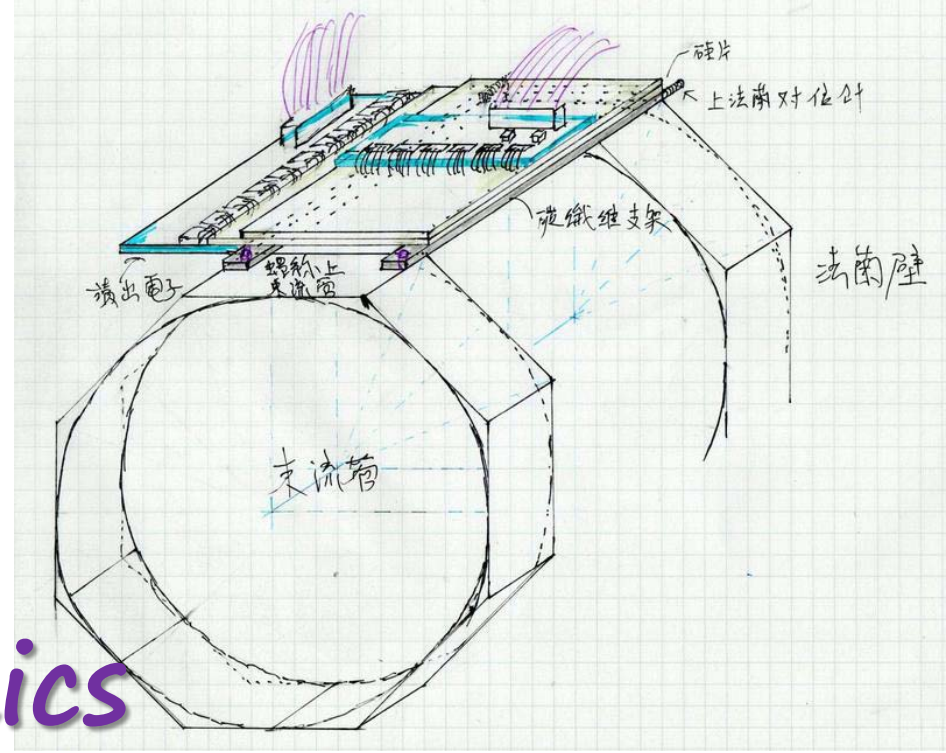
LumiCal for CEPC

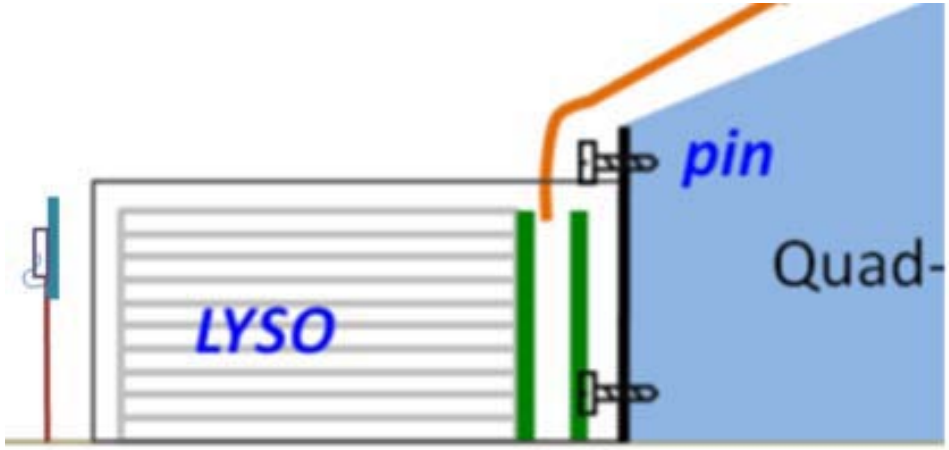
To Do:

GEANT racetrack geom

1. **Multiple scattering**
2. **LYSO shower and pileup**

LumiCal electronics





Front-end for LumiCal

N= 10^{34} /cm^{2}s x 100 nb (Bhabha)
= 10^{38}/m^{2}s x100 x10^{-9} x10^{-28} m^2
= 10^3/sec

- **CEPC bunch crossing：32 ns**

  Low θ Bhabha event rate @ instant L = 10^{34}/cm^{2}s **~ 1k Hz**
  Readout for LumiCal aims for : 30 ns/event

- **Viking type FE**, outstanding S/N

  Long shaping time, VA ~2 μm (IHEP has a version), APV25 ~100 ns
  Analog output, long readout chain, requires repeater near by

- **Telescope with IHEP Viking** (new chips in this summer)

  plan to build a testbeam system to study Si-wafer charge

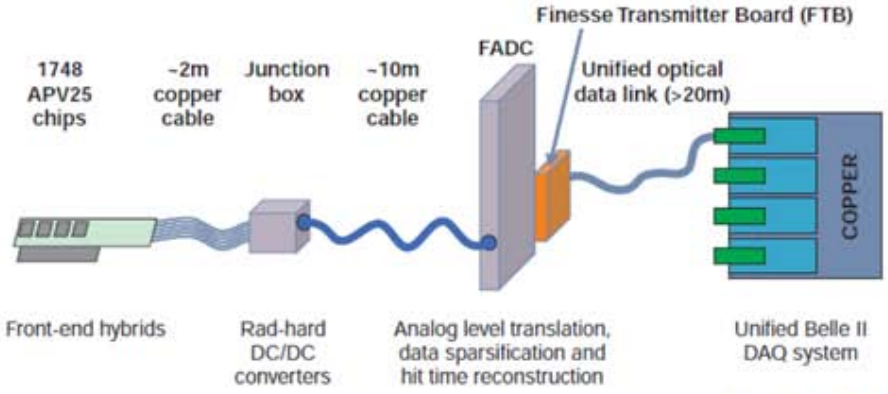


Figure 2. Overview of the SVD readout chain.

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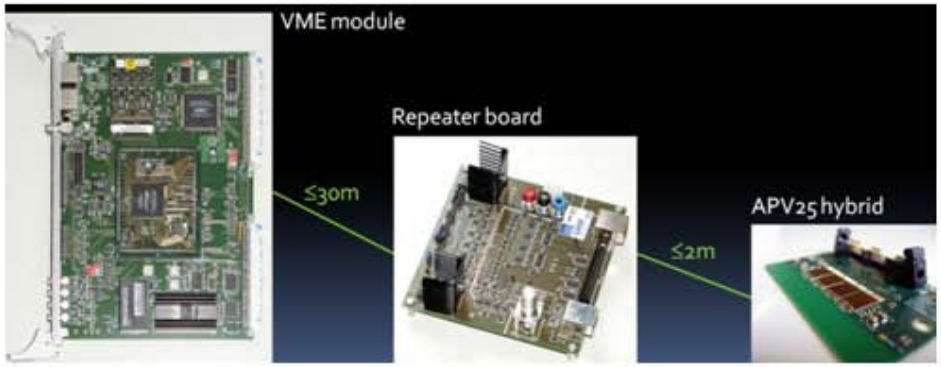
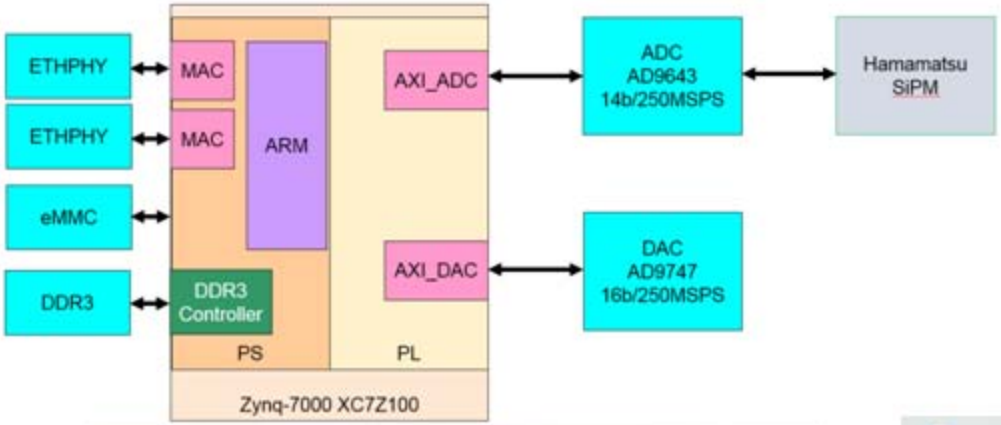
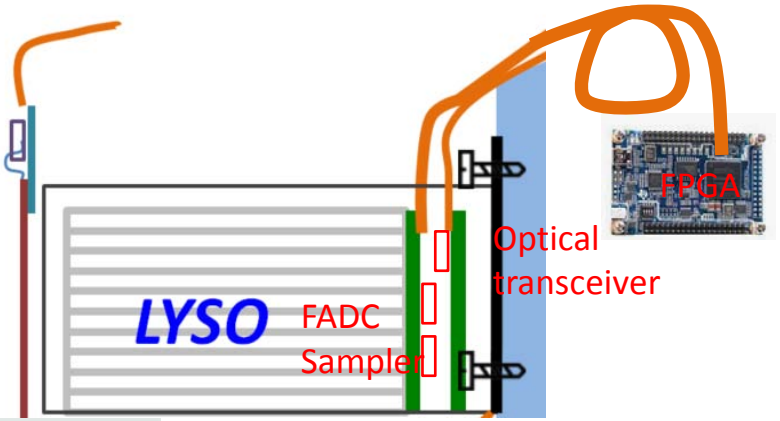


Readout chip for LumiCal

- **Proposal for a fast sampling chip for Si-wafer and SiPM**
  Compact FE for LumiCal
  proposal with SMU on ASIC design: a signal **sampler**, and a **FADC**
  signal simpling @ 500 MHz → FADC output (Optical link) → FPGA event selection
- **Lab study with commercial boards**
  experience with SiPM signal with LYSO crystal, Sc137 source, testbeam, etc
  commercial FADC and feedback to ASIC design





LumiCal electronics

To Do:

All electronics are missing