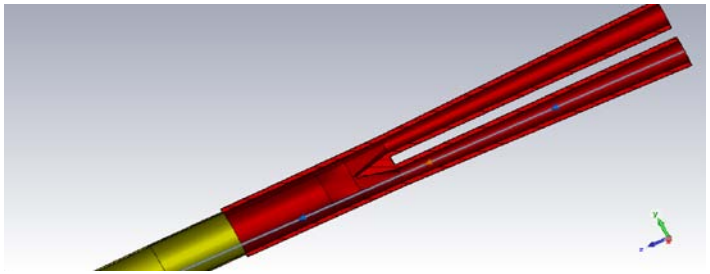
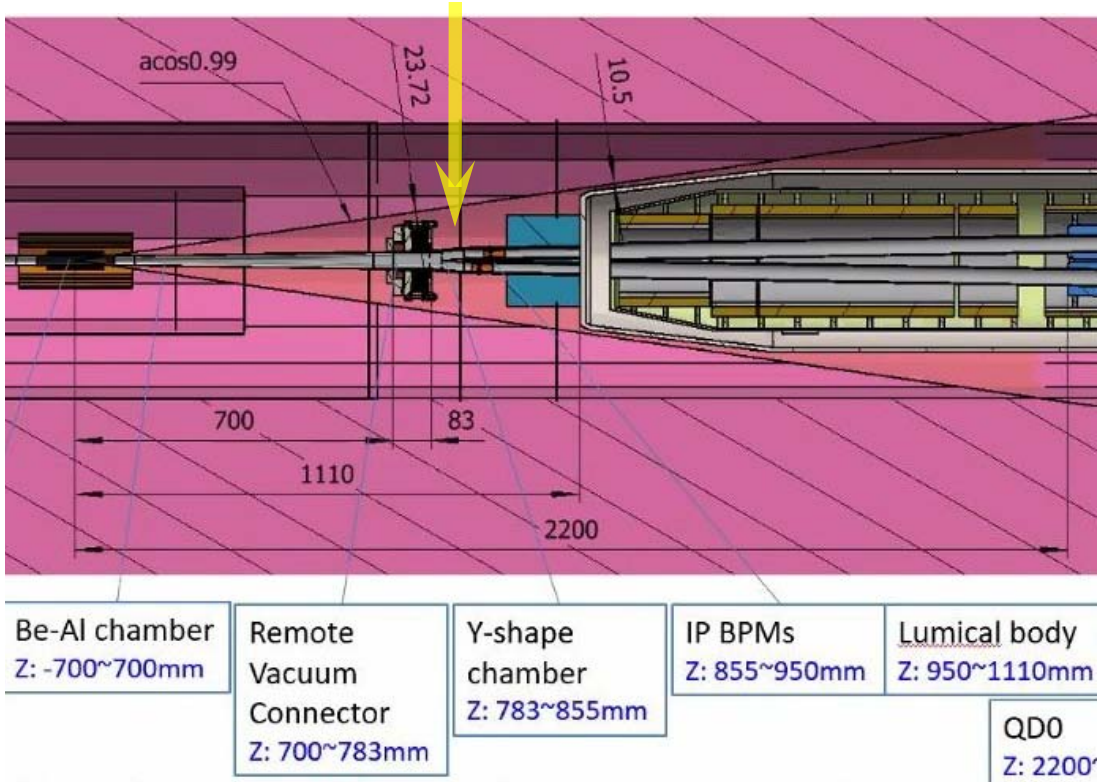
LumiCal:

Spatial resolution for a round 28-40 mm cone with Y-crotch





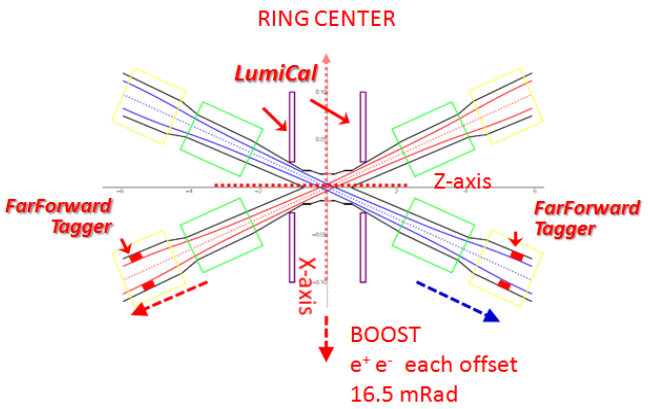
Suen Hou 侯書雲
suen@sinica.edu.tw

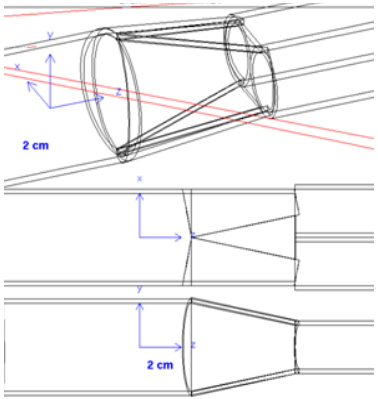
2021.11.11

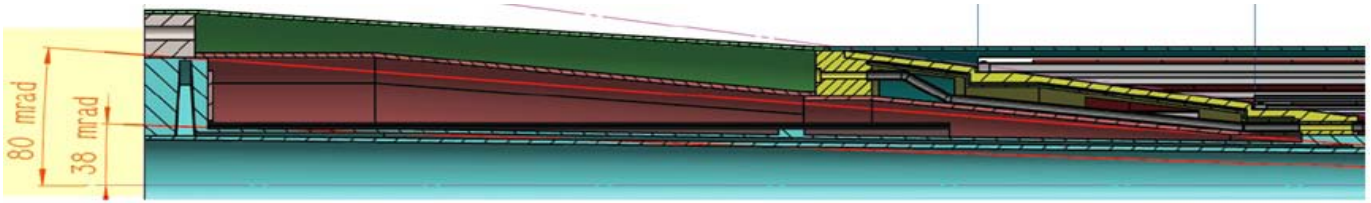
https://indico.ihep.ac.cn/event/14938/

outline

- ***Bhabha Luminosity***
- ***Multiple Scattering***
  before Flange: inner Lumi Si-wafers
  after Flange: Y-crotch, Q-pole front
- ***X-section with a 28-40 round pipe***
  Y-crotch acceptance
- ***LYSO calorimeter option***







Luminosity by Bhabha

- ***For Stanard Model Cross sections***

  Z-lineshape dominant : $e^+e^- \rightarrow Z \rightarrow q\bar{q}$

  SM events: $N = \sigma \cdot \int L$

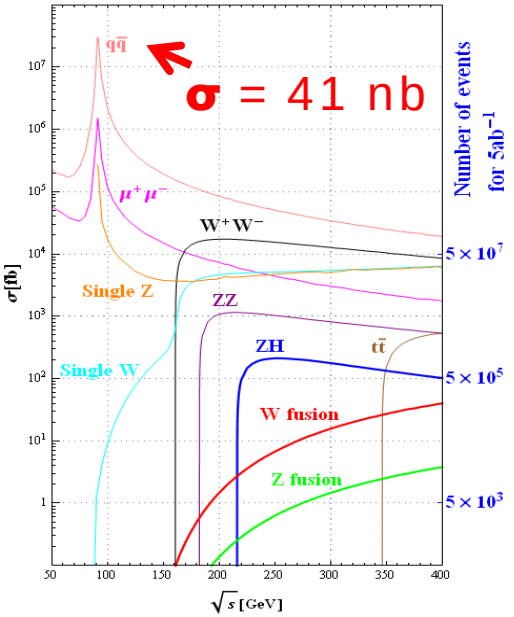
- ***Luminosity*** L

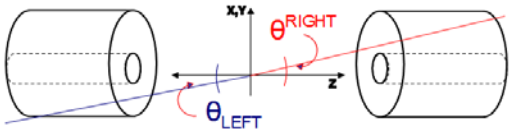
  by counting Bhabha elastics scattering

  $$e^+e^- \longrightarrow e^+e^-$$

  – QED process, ***theoretical < 0.1% precision***

  – detect a pair of ***back-to-back*** e^+e^-



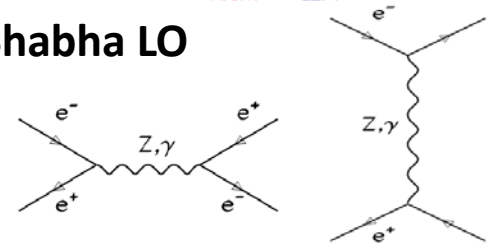


$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$

Bhabha cross section

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

Bhabha LO



Luminosity precision

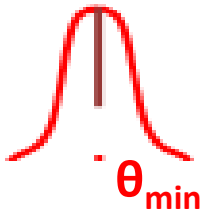
Systematic error, Center-of-Mass frame

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

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

→ $\delta\vartheta = 15\ \mu Rad$ @θ_{min}= 30 mRad

→ ***OFFSET on the***
"mean of fiducial edge"
cause for δN on Bhabha counting
@z = 1000 mm r=30mm,
$\delta\vartheta = 15\ \mu Rad,\ dr = 15\ \mu m$

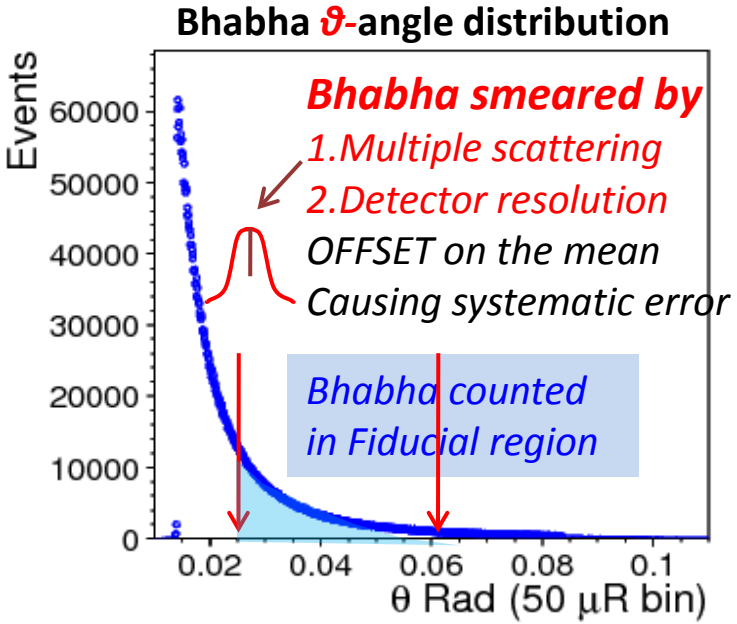


LumiCal design goal:

- *Spatial resolution as sharp as possible*
- *Describe the* ***reso./MS shape of δ<θmin>***

offset on the ***mean of*** θ_{min}

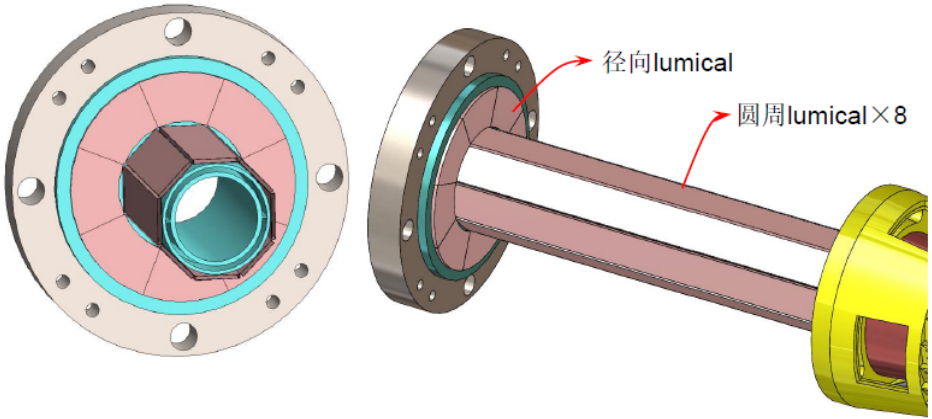
→ ***LUMINOSITY error***

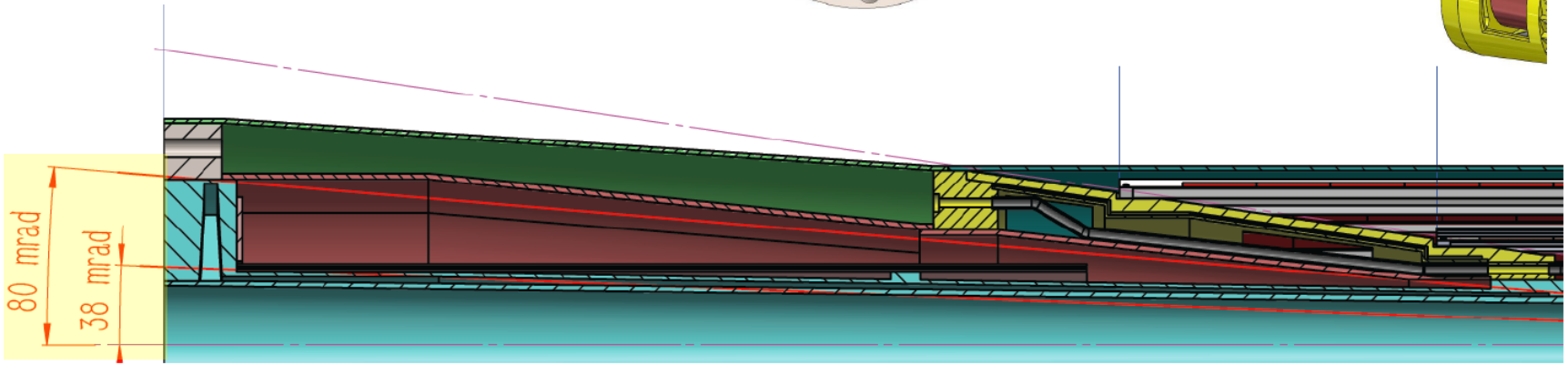


Beam-pipe, 28-40 mm Round

5.5 Preliminary design of lumical

- Detection Angle range: 38~80mrad
- On the detection path, as little mass as possible
- The structure of lumical is not yet determined, so the support and cooling structure should be further optimized and improved.





LumiCal access, ϑ_{min} = 38 mRad is too high

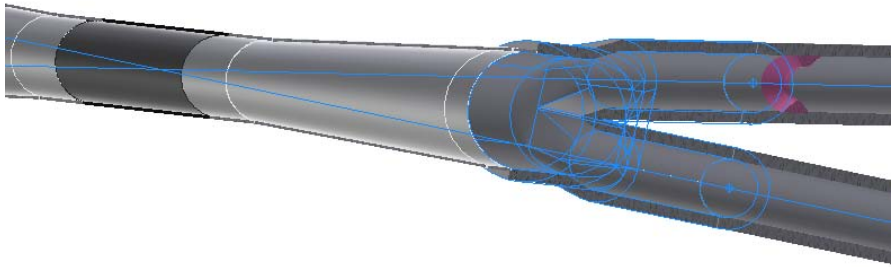
➔ **Bhabha < 40 nb**

Multiple scattering

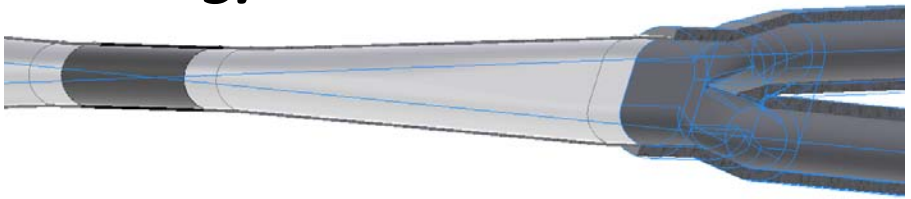
- ***Spatial resolution*** on Bhabha electron impact position
  - ➔ θ of electrons, determine ***δL/L***

- ***GEANT simulation on multiple scattering***
  with silicon wafers surrounding beampipe
  1. **Round, straight beam pipe r=28 mm (CDR design)**
     Si-wafer // beam, air-gap
  2. **Round cone pipe r = 28 - 40 - dual 20 mm**
  3. ***splitting pipes*** **x = 20 - 35 - dual 20 mm, y = 20 mm**

2.



3.



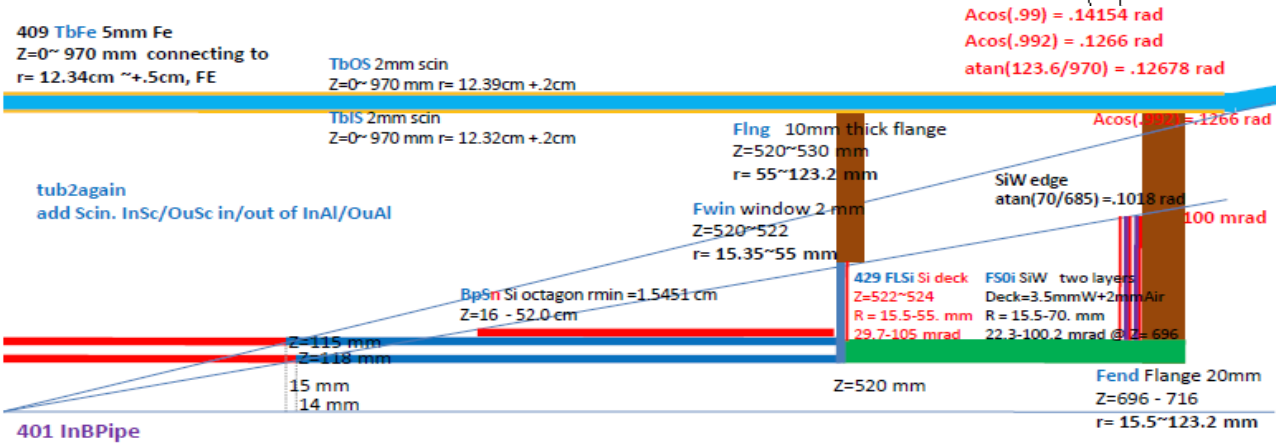
1) Multiple scattering, 28mm straight tube

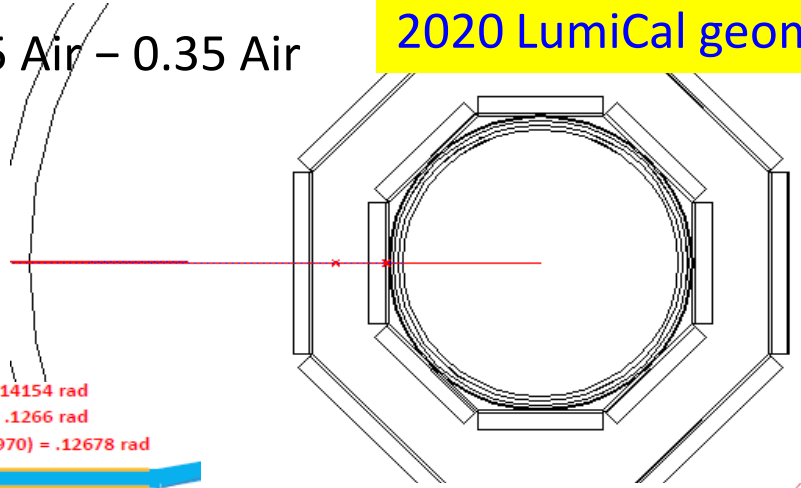
2020 LumiCal geom

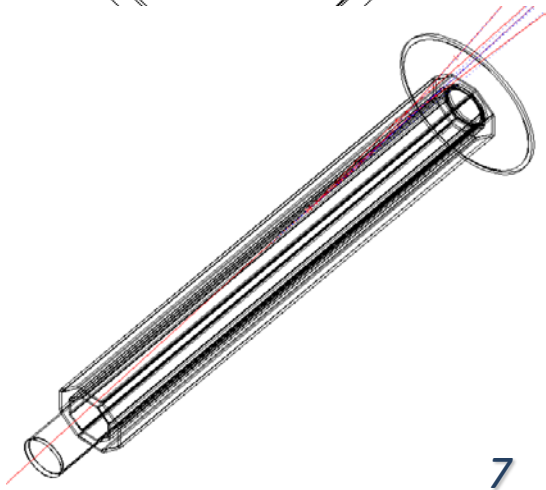
- Tube, ϕ=28 mm, thickness (mm): 0.5 Al – 0.5 Air – 0.35 Air
- Si wafer attacked
- Scintillator layer surrounding Al pipe

➔ observe Multiple-Scattering within Al pipe,

Δz in Al-pipe: 20 to 40 mm



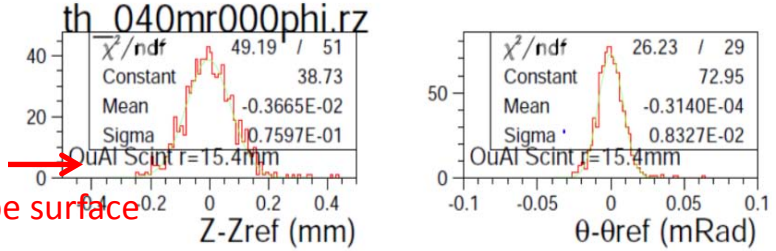




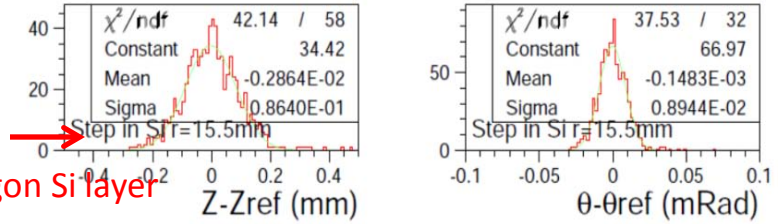
1) Multiple scattering, 28mm straight tube

- ***50 GeV electron*** traversing Al-pipe :
  (0.5 mm Al – 0.5 mm Air – 0.35 mm Air)
- ***Multiple scattering deviation***
  simulated for ϕ=28 mm
  1. exiting Al-pipe
  2. Si-layer attached, ***no air-gap*** (nearest)

dz, dθ
on Al-pipe surface

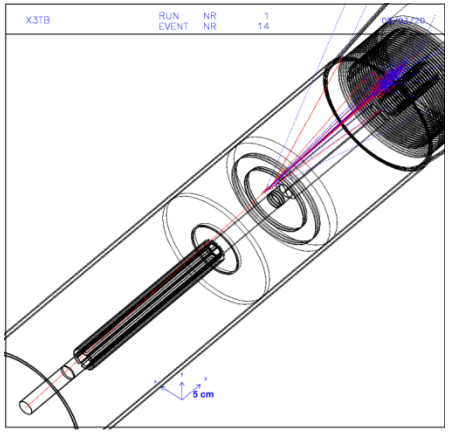


dz, dθ
on Octagon Si layer



θ to z: r/z =tan θ

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

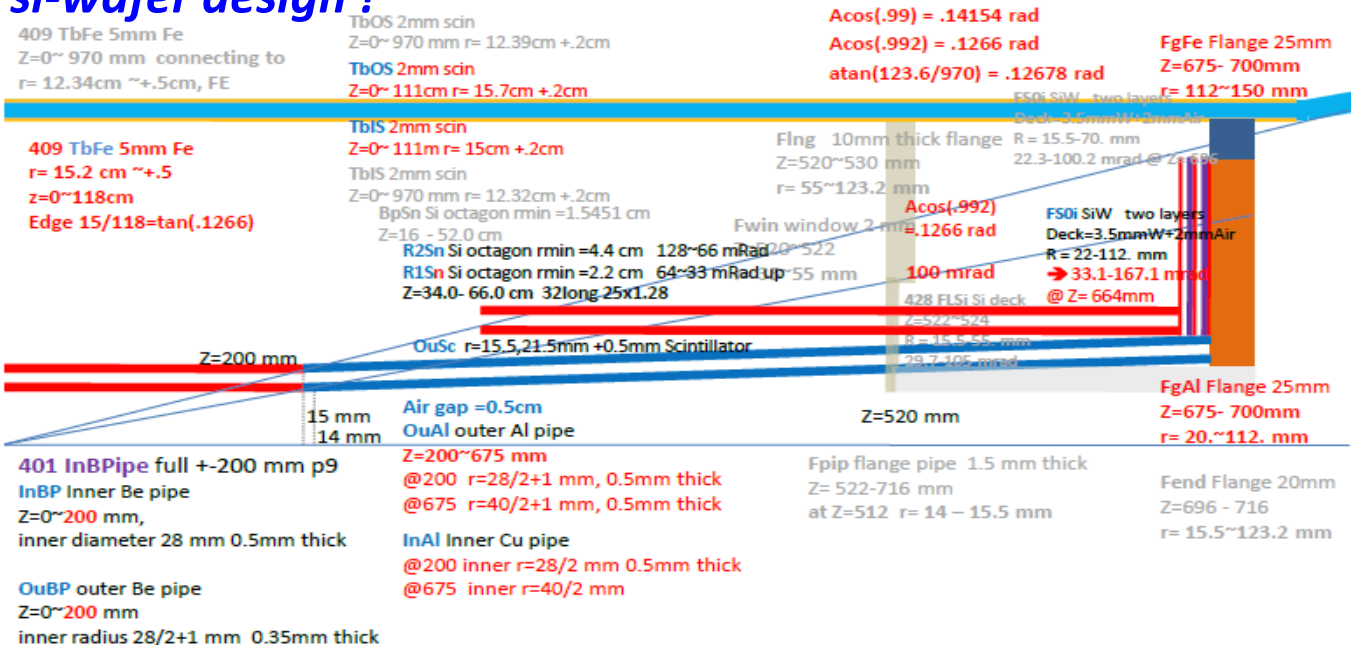


2) 28-40mm cone pipe (2021)

- Tilt the Al pipe from ϕ=28 mm to ϕ=40 mm
  thickness (mm): 0.5 Al – 0.5 Air – 0.35 Air
- ***Si wafer parallel to z-axis,*** r_{min}=22mm

➔ ***LONG (70~100 mm)*** air gap to Al-pipe, large Multiple Scattering

poor lumi si-wafer design !

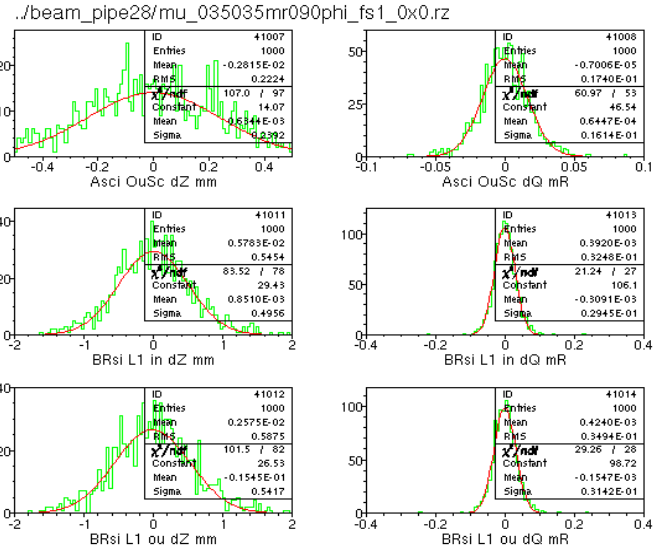


2) Multiple Scattering on Si ring (parallel)

- Al-pipe tilt 12.6 mRad (ϕ28 to 40 mm)
- ***Si-layer (r=22mm) parallel to beam (z-axis)***

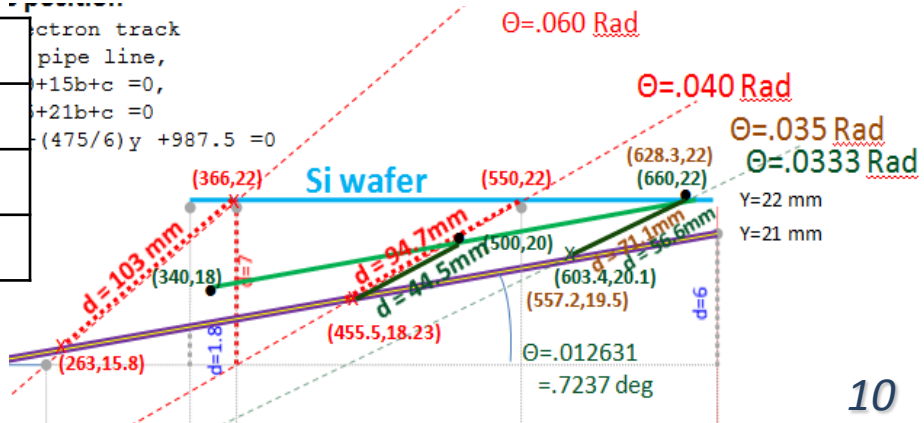
➔ air-gap extracted from IP ***70 ~ 100 mm***

➔ multiple scattering effect is magnified !!



Compare MS on Octagon Si layer,
primary track

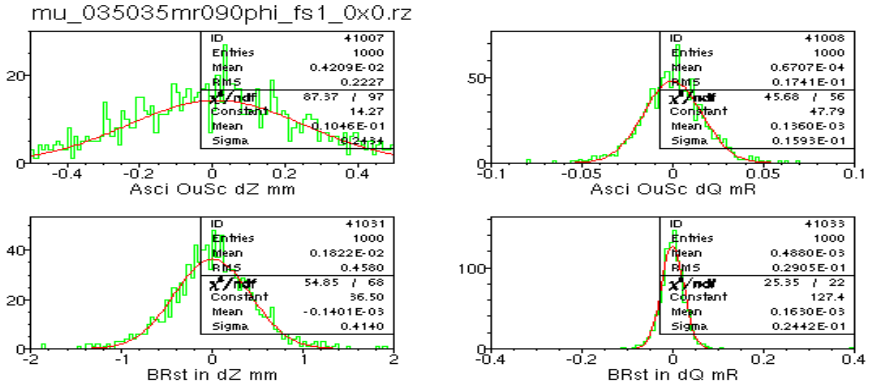
mu (θ,ϕ)	σ(Z) Si^{1st}	σ(θ) Si^{1st}	1/tan(θ)
(35 mR, 90^o)	542 μm	31 μRad	28.6
(40 mR, 90^o)	489 μm	37 μRad	25.0
(55 mR, 90^o)	291 μm	41 μRad	18.2



2) Multiple Scattering on Si ring (stick-on)

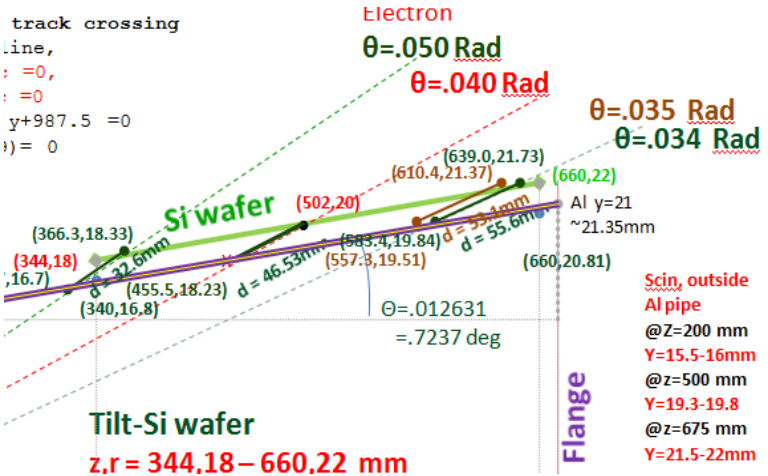
- Al-pipe tilt 12.6 mRad (ϕ 28 to 40 mm)
- ***Si-layer parallel to Al-pipe***, gap = 1mm

➔ air-gap from IP ***~ 50 mm***



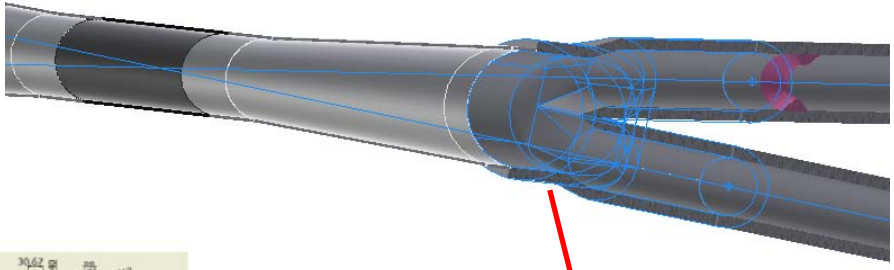
Compare MS on Octagon Si layer,
primary track

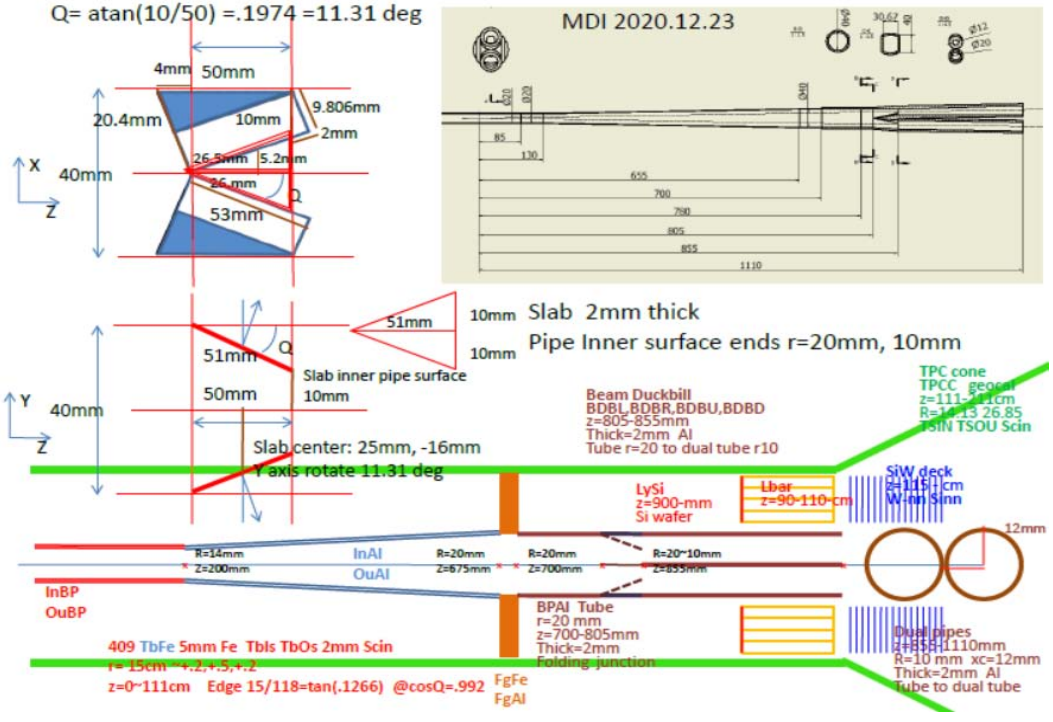
mu (θ,ϕ)	σ(Z) Si^{1st}	σ(θ) Si^{1st}	1/tan(θ)
(35 mR, 90°)	475 µm	28 µRad	28.6
(40 mR, 90°)	301 µm	24 µRad	25.0
(50 mR, 90°)	161 µm	22 µRad	20.0

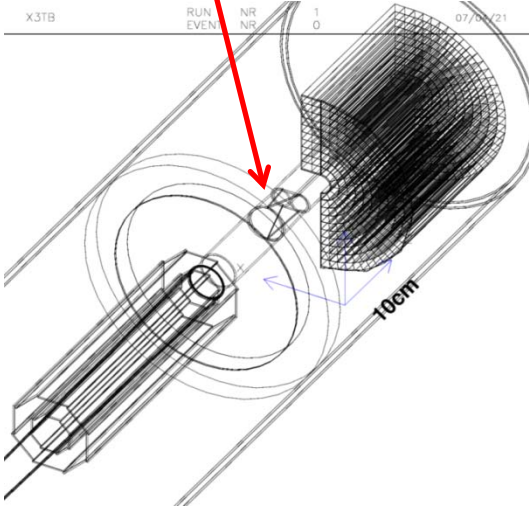


Multiple Scattering behind the Flange

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

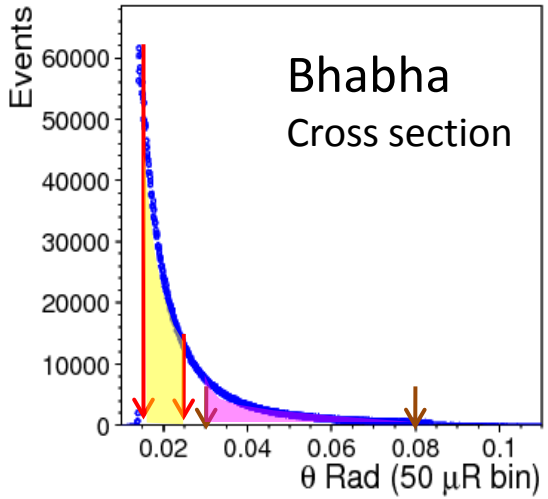


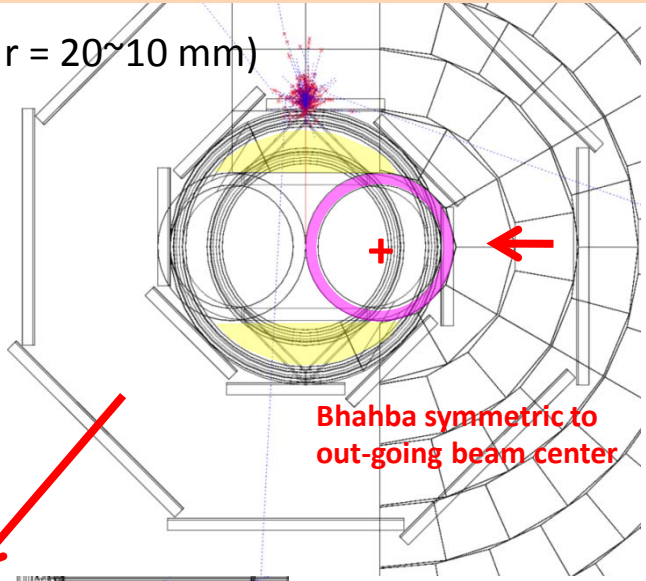


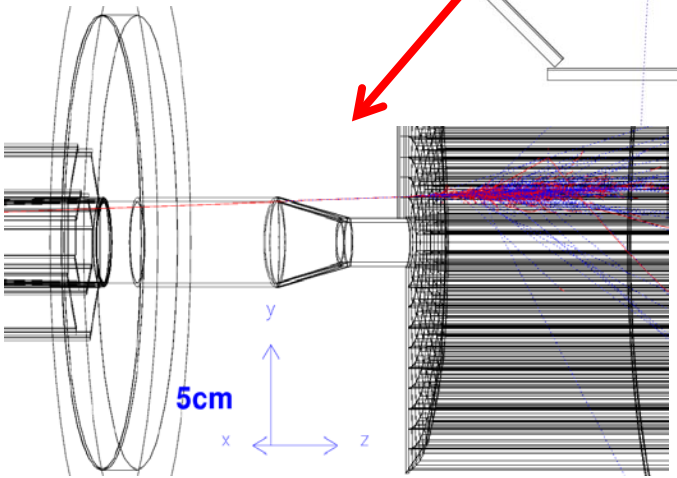


3) Y-crotch window

- 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





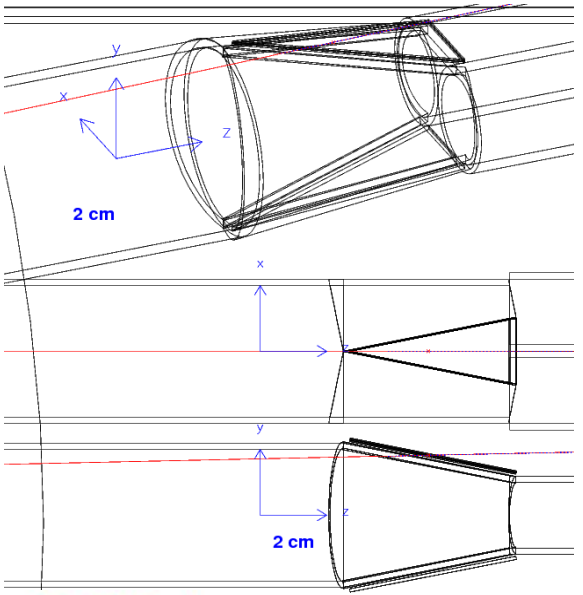


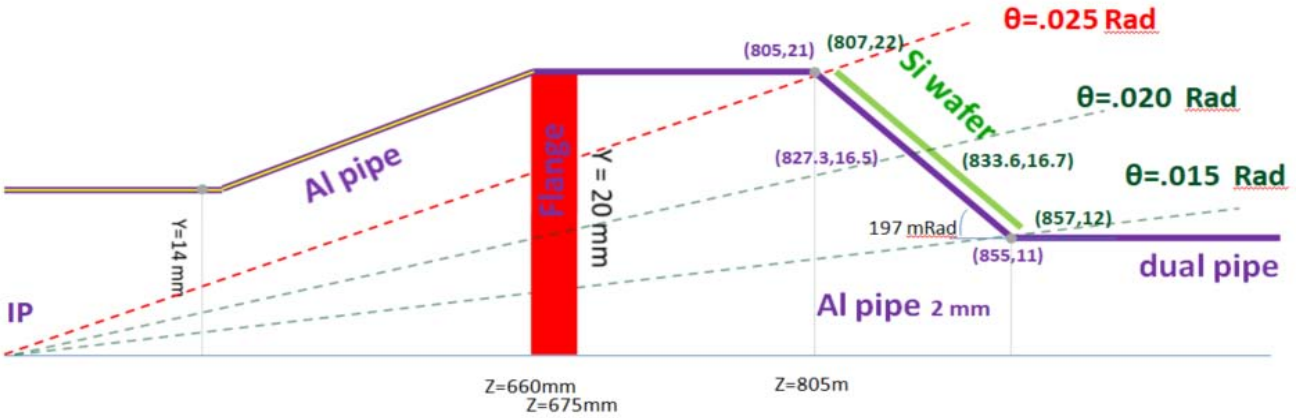
3) Si-wafers on Y-crotch

- 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

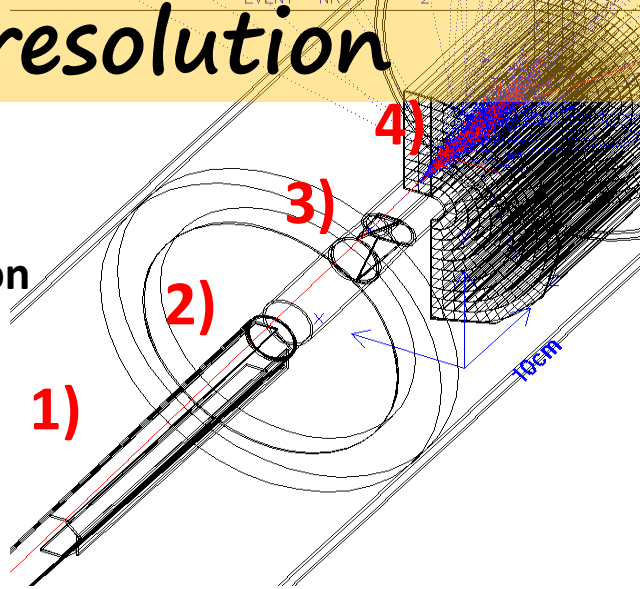




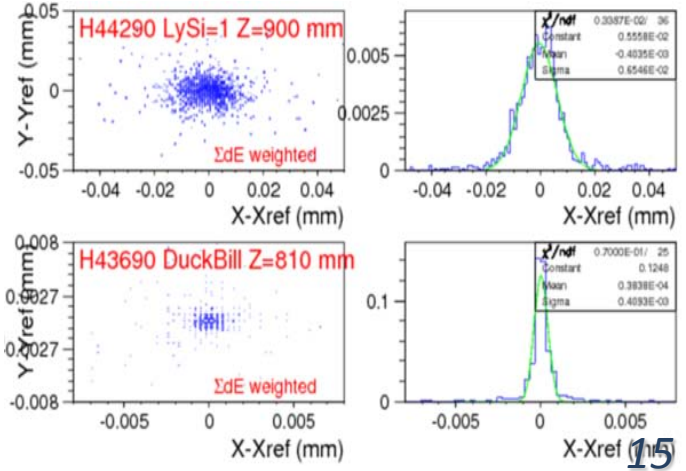
3) LumiCal Si-wafer spatial resolution

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

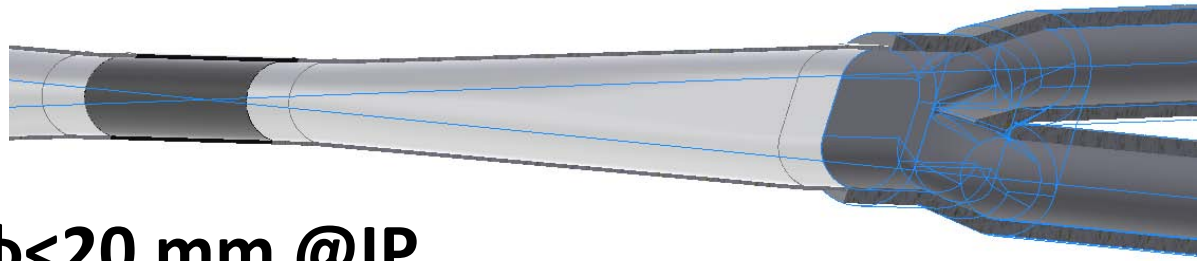
Multiple scattering estimated on
1) Octagon surrounding Al-pipe
2) Flange Si-disk
3) Y-crotch up/down slabs
4) LYSO front Si-disk



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



4) dual-20mm pipes, Lumical option



- **round pipe ϕ<20 mm @IP**
  split slowly to dual pipes, ϕ=20 mm, at Y-crotch

1) LumiCal Si wafers, vertical y-axis **r_{min} = 10 mm**
   ➔ **gain very much Bhabha X.section**

2) Si wafers parallel to beam center
   ➔ **multiple scattering** acceptable **σ(θ) ~10 μRad**

Boosted Bhabha distribution

- Bhabha symmetric to out-going beam center boosted by the 33 mRad beam crossing
  (x,y) = (16.5, 0) @ z = 1000 mm
- High cross-section, low mass region:
  phi ~ 60^{o} to 120^{o} *to beam center*
- Bhabha acceptance: both e^+ e^- detected

Lab frame @ z = 1000 mm

dual beampipe: r = 10 mm

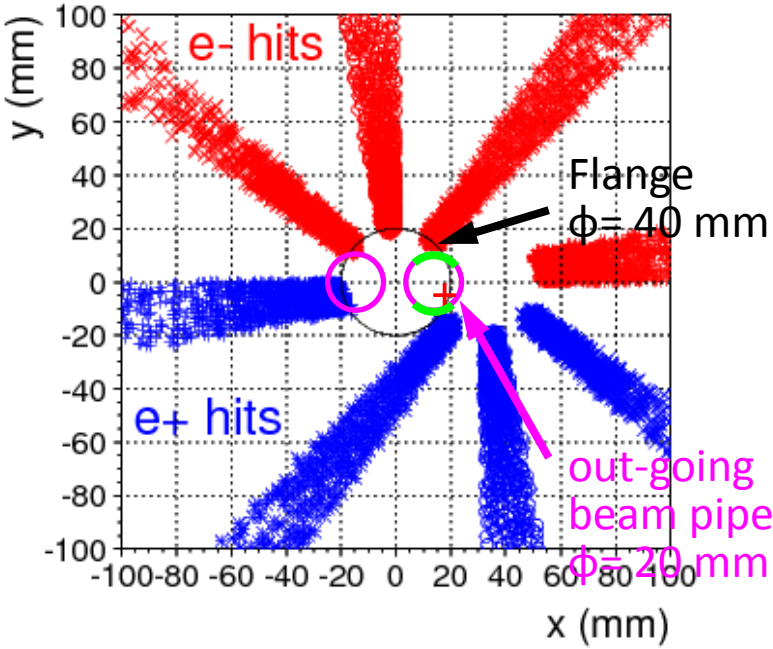
y-axis: |y|>10 mm,

x-axis: (± 43 mRad to out-going beam center)

Lab $\theta(e^+)$ > 26.5 mRad

Lab $\theta(e^-)$ > 59.5 mRad

Lab frame ***@z=1000***
Bhabha distribution

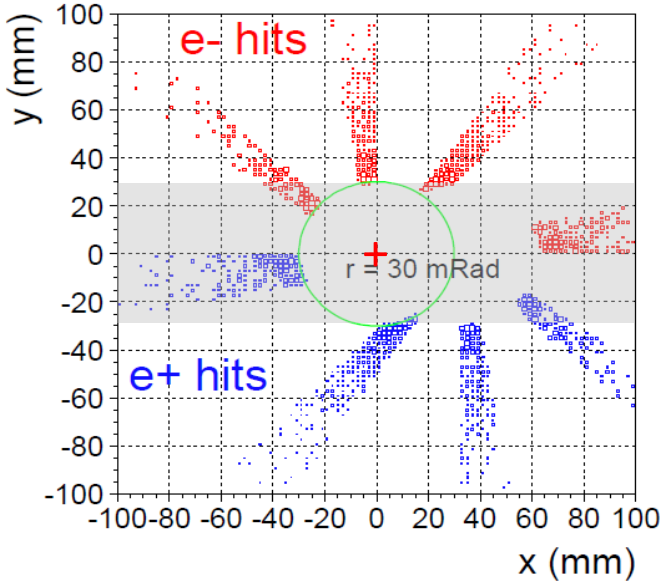


Bhabha cross-section, BHLUMI calculation

Beam crossing 33 mRad,

- $e^+ e^-$ boosted to +x, off ring center
- back-to-back symmetric to
  out-going beam center
  (x,y) = (16.5, 0 mm) *at z = ±1000 mm*

@z = 1000 mm 2020.04 report



50 GeV beam, both $e^+ e^-$ detected
In fiducial range of *r > 30 mRad*

***ϑ range* = 30 – 80 mRad**

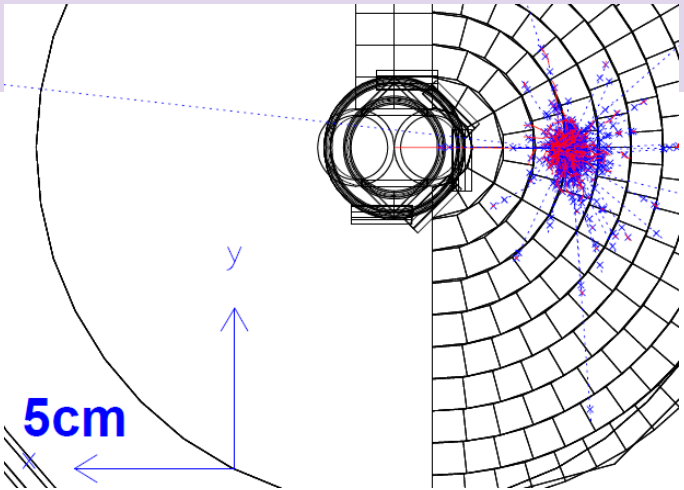
Bhabha cross section *> 50 nb*

BHLUMI, 50 GeV Bhabha boosted for 33 mRad crossing			
CMS 10 ~ 80 mRad		LAB detect ***both*** electrons	
BARE1		off beampipe full phi coverage	off beampipe cut off ±30 mm
Nevents	457232	29194	19216
Xsec (nb)	1168.3	**74.60 nb**	**49.10 nb**

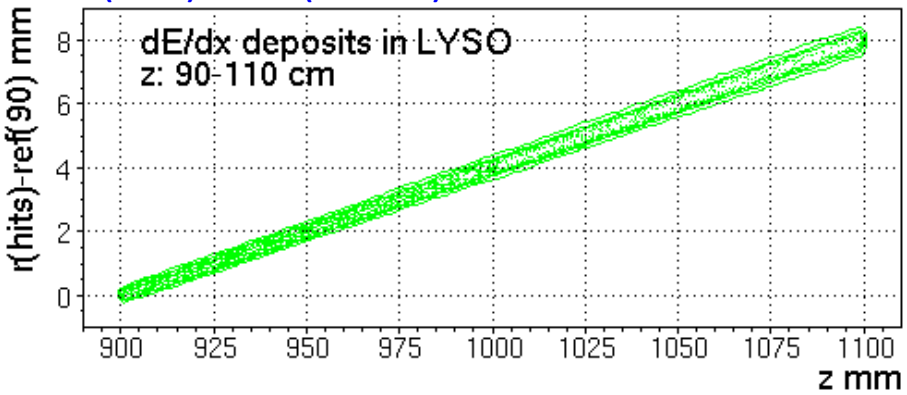
LYSO shower distribution

- **Muon in 20 cm long LYSO**
- **GEANT at 40 mRad, dE/dx distributions**

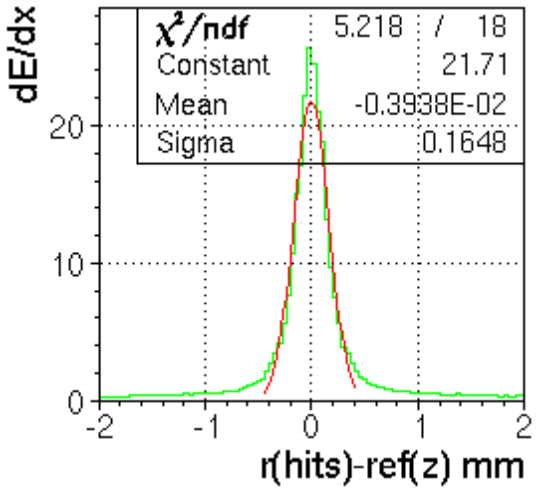
- Muon 50 GeV @40 mRad
- Multiple Scattering ***~ 160 µm*** from upstream



r(hits) – ref(z=900)



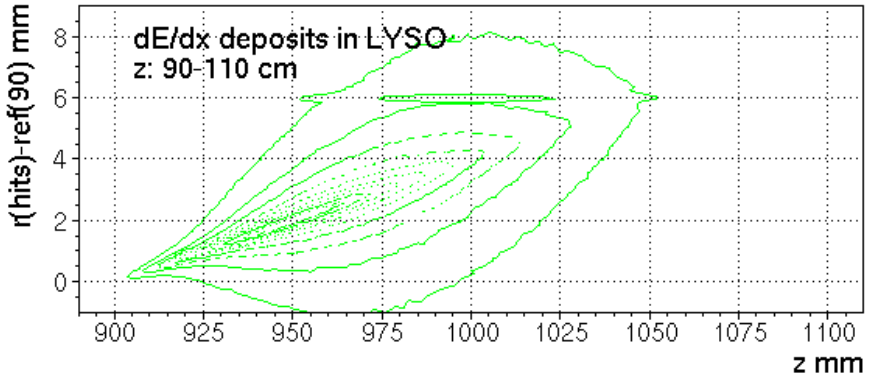
r(hits) – ref(z of hits)



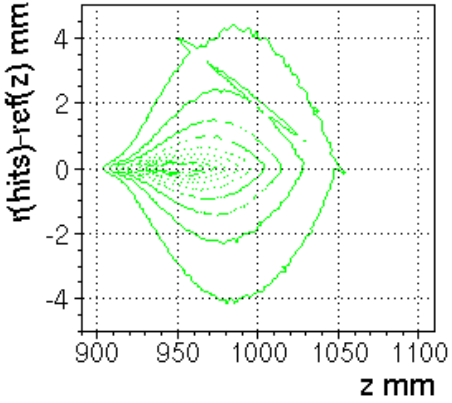
LYSO shower distribution

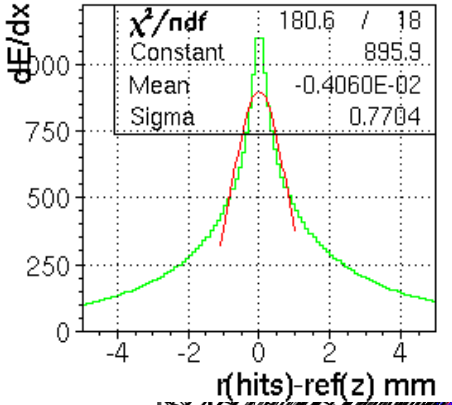
- **Electron shower in 20 cm long LYSO**
- GEANT electron **50 GeV at 40 mRad**
- Shower spread ~1 mm width
- Shower max ~7cm long

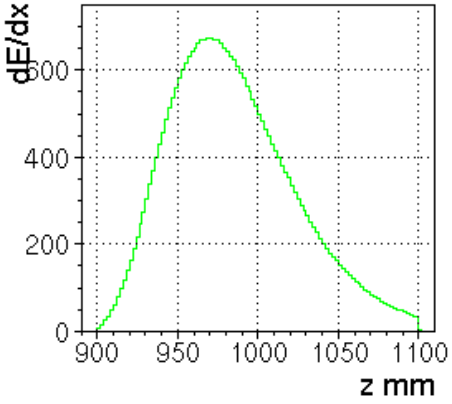
r(hits) – ref(z=900)

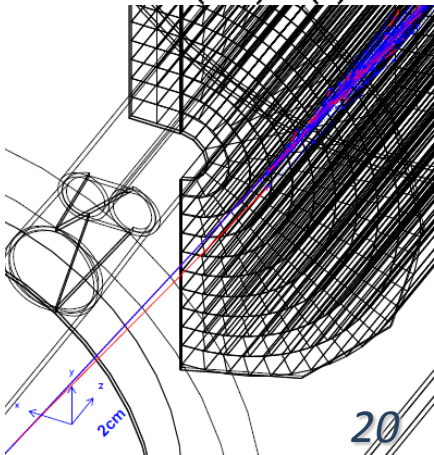


r(hits) – ref(z of hits)





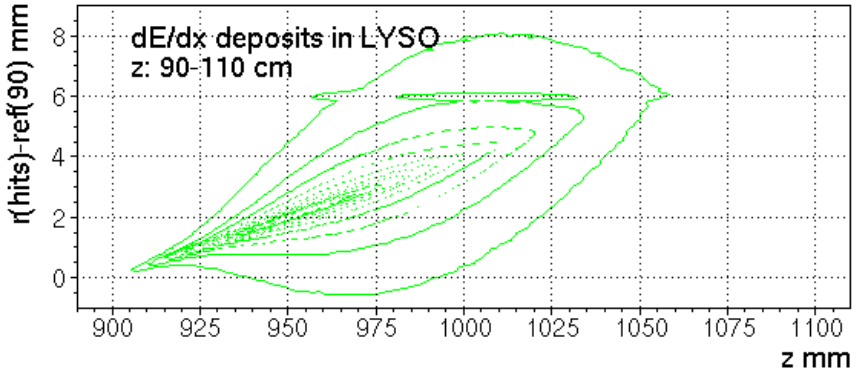




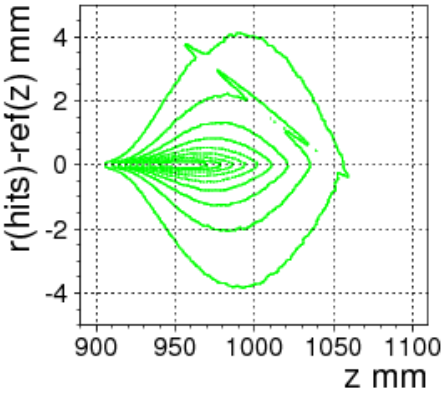
LYSO shower distribution

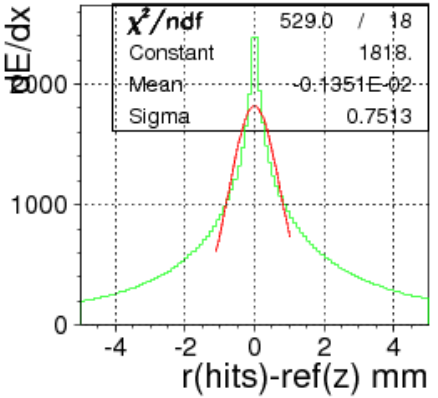
- **Electron shower in 20 cm long LYSO**
- GEANT electron **100 GeV at 40 mRad**
- Shower spread ~1 mm, max ~7cm long
- Distributions 100 GeV grow in z compatible to 50 GeV

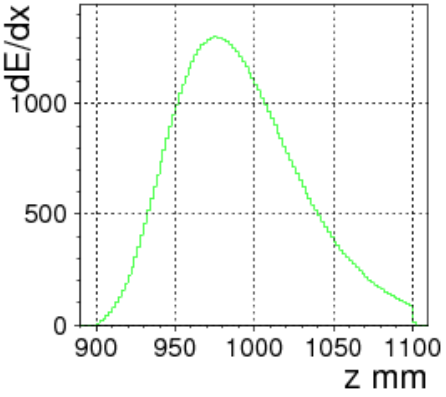
r(hits) – ref(z=900)



r(hits) – ref(z of hits)

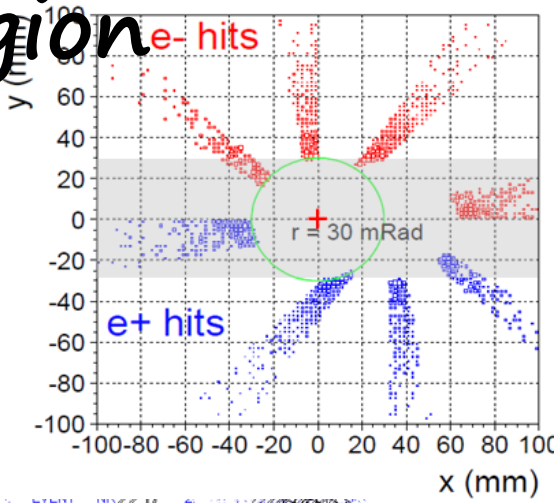


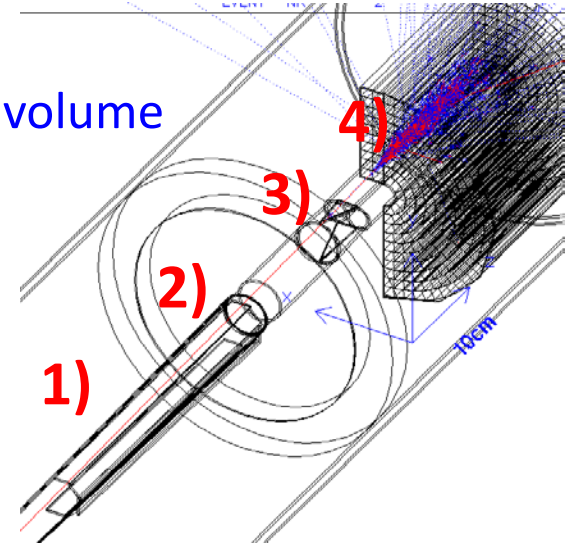




Discussion: Bhabha fiducial region

- **For Bhabha X.section > 50 nB**
  require θ_{min} < 30 mRad coverage, favor vert. direction
- **Precision luminosity, $\Delta \int L \sim 10^{-4}$**
  requires minimal multiple scattering effect
  favor Y-crotch negative slope
- **LumiCal Si wafer systems**
  before Flange: surrounding beampipe inner det volume
  behind Flange: ***on Y-crotch***, ***front of LYSO***





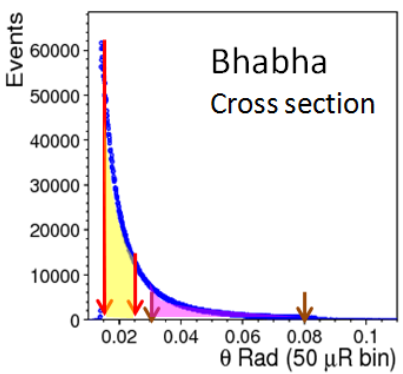
Discussion: Bhabha event ID

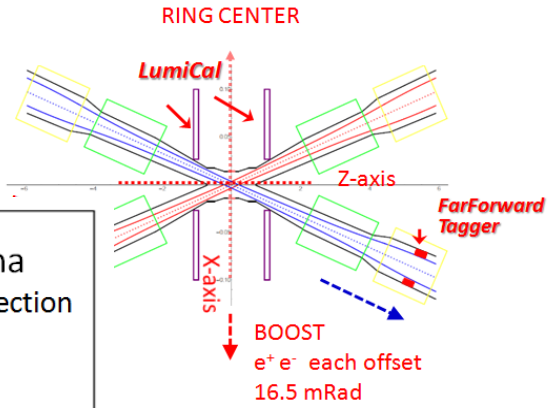
- **Colliding electrons bunch crossing *32 ns***

  Bhabha detected with

  1. both +z, -z Calo's E(cluster) > 0.5 E(beam)
  2. back-to-back in phi

  event dominate in low theta edge





- **CALO system**
  1. **shower coverage**
     favor >15cm crystal bar for shower coverage
     trade hori.-axis area to e.g. BPMs
  2. **segmentation (fine LYSO bars of 2x2mm)**
     fast DAQ → 32 ns/event
     to eliminate event overlap
     DAQ deadtime