https://indico.ihep.ac.cn/event/17020/sessions/10729/#20221028

Update on LumiCal for the Ø 20mm Racetrack beampipe

2022.10.28

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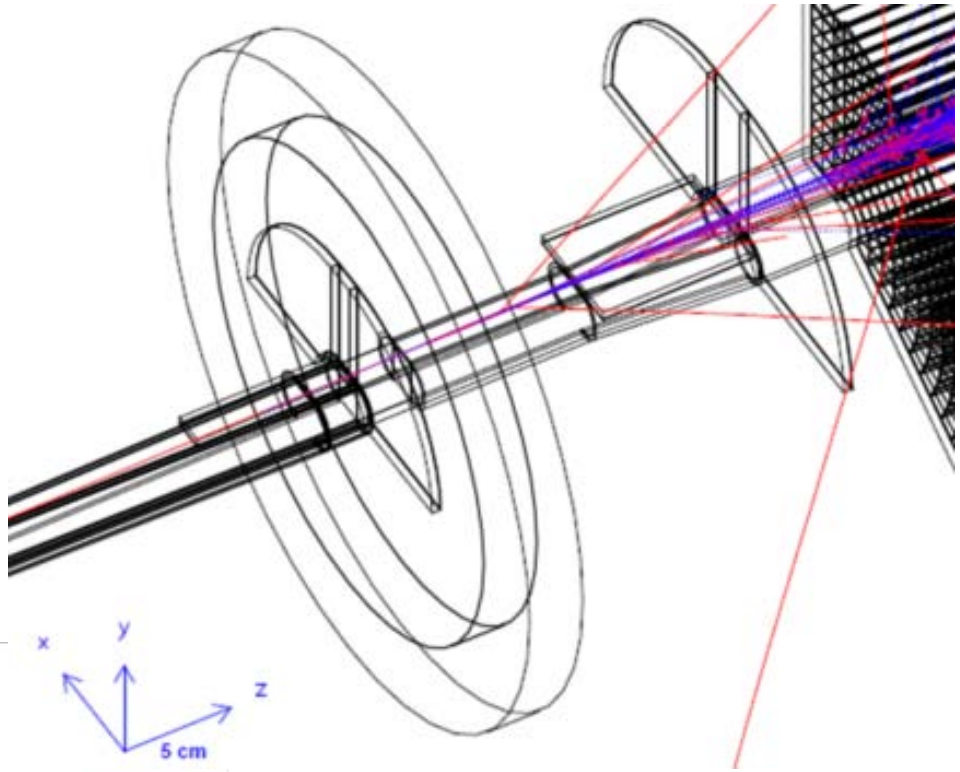
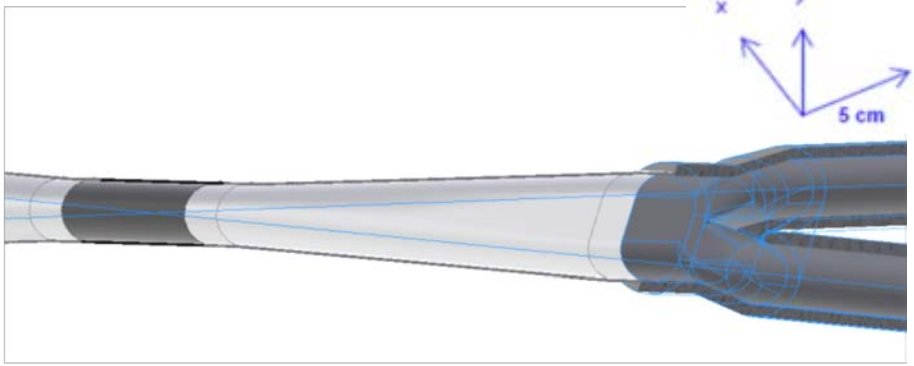
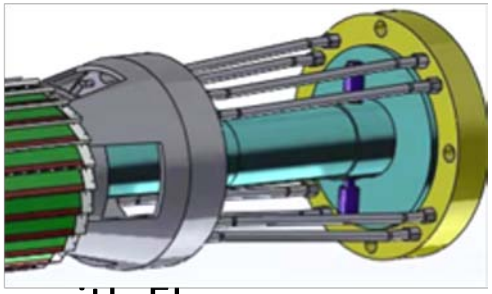
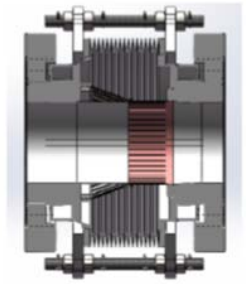




Outline, Systematics → 10^{-4}





- **RaceTrack** beam-pipe

  IP Ø20 mm; *X splitting 20 – 35 – 39 mm*;
  Y Ø20 mm to dual Ø20 mm pipes

- **Bhabha cross section by BHlumi**

  boosted, beam crossing 33 mRad

  ✓ fiducial region: min materials, at z=630mm with Flange
  θ_{min} > 25 mRad. $|y_{z=650mm}|$>15 mm → σ(Bhabha) = 78 nb

  ✓ **estimate event rate, occupancy, pileup systematics**
  bunch crossing 32 ns, High-Lumi Z, L= 10^{36} /cm^{2}s

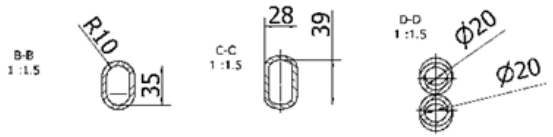
- ***Luminosity → 10^{-4} precision***
  GEANT on smearing factors:
  ✓ Multiple Scattering, beam-pipe
  ✓ Magnet field, helix rotation
  @ preshower, radiative Bbabha, contamination

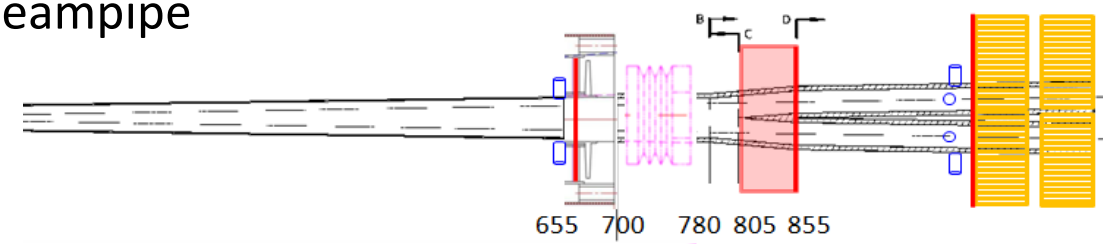
Racetrack beampipe LumiCal

Racetrack beampipe

- beam-pipe r =10 mm, flat y = ± 10 mm
- **33 mRad** beam-crossing,
- boost horizontal, $e^{\pm}$ lost into beampipe

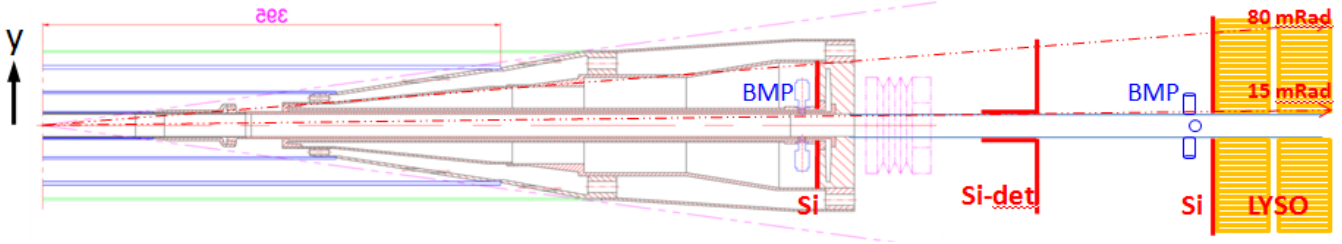
2022.05 report



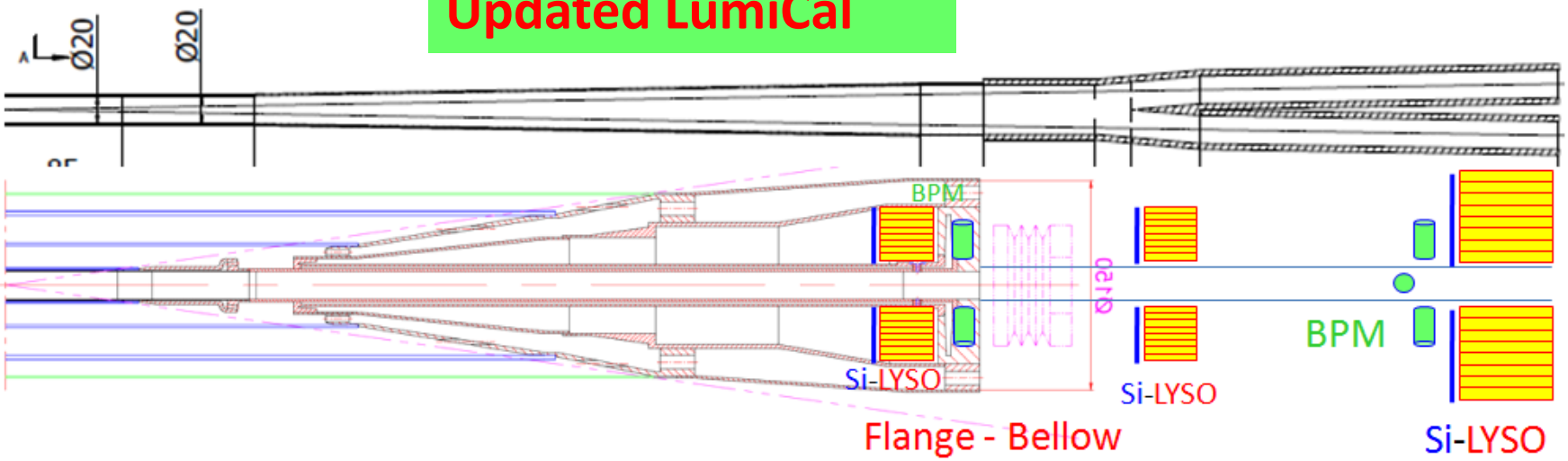


LumiCal sandwiched

- |y|>15 mm
- **Vertical Si-wafers** : $e^{\pm}$ theta tracking
- **LYSO calo** : 3x3x50 mm^3 bars



Updated LumiCal



Luminosity by counting Bhabha events

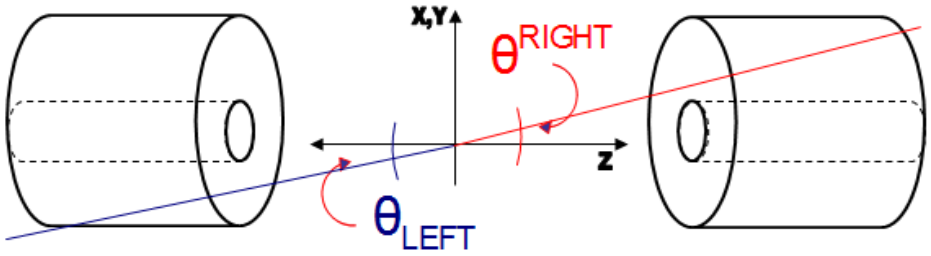
- ***Physics events, e.g. Z pole,***
  N = σ · ∫L ***L: Luminosity of e^+e^- collisions***

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

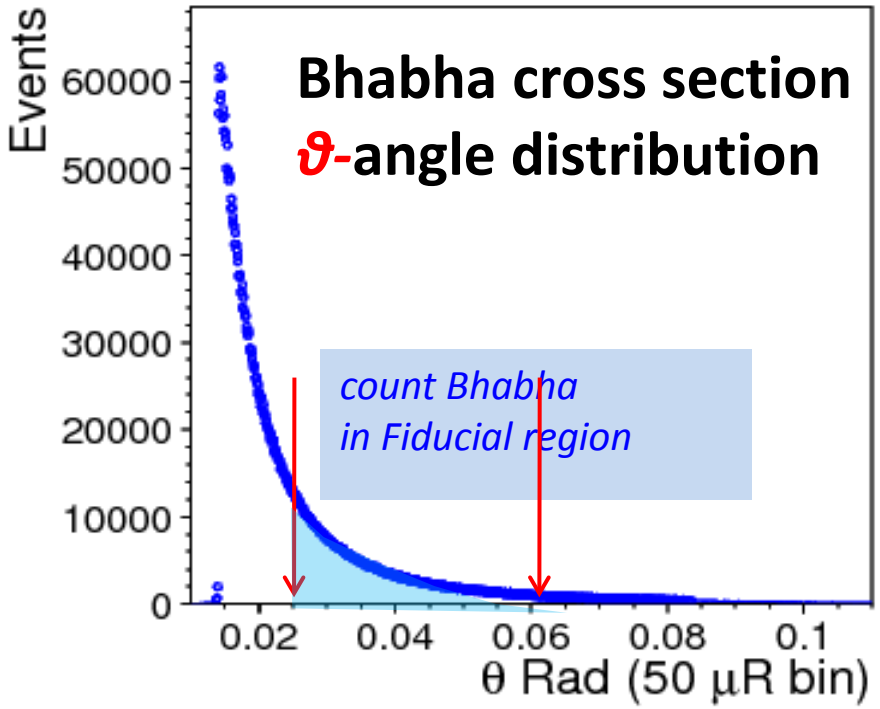
- ***Luminosity* by counting Bhabha events**
  $e^+e^- \rightarrow e^+e^-(\gamma)$ QED *theo. precision < 0.1%*

$$\mathcal{L} = \frac{1}{\varepsilon}\frac{N_{\rm acc}}{\sigma^{\rm vis}}$$

1. ***a pair of electrons,*** $E(e^{\pm}) = E_{beam}$ ***back-to-back***
2. ***precision ϑ of e, e(γ)***
3. ***within fiducial region***



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

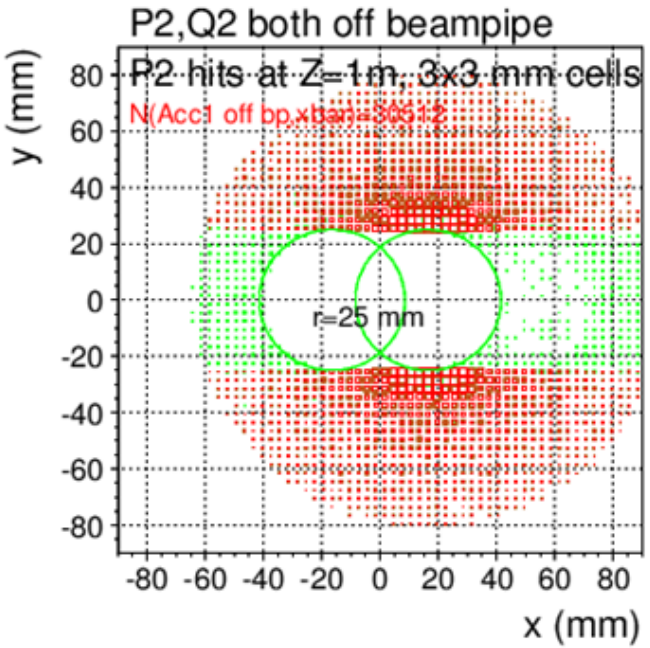


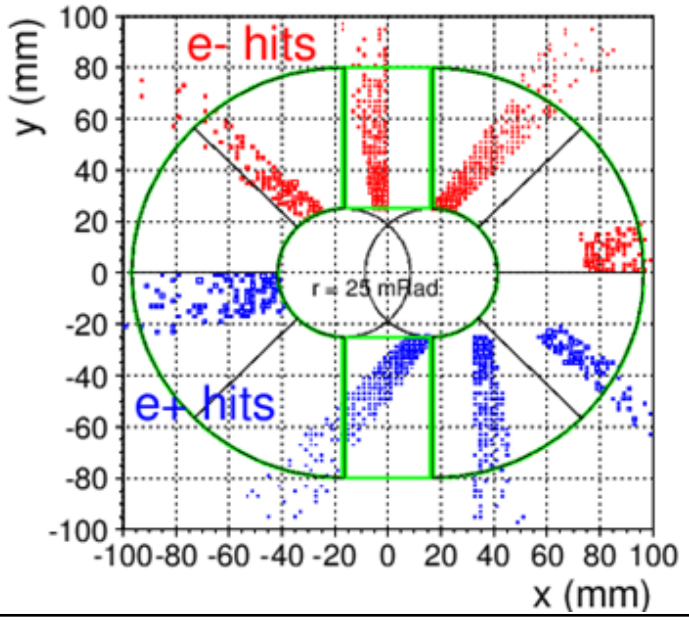
BHLUMI X-section, racetrack @CEPC

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

e+.e- back-to-back
Symmetric to
out-going pipe center

LAB frame
both e+.e-
detected
@ Z=1000 mm





at Z = 1000 mm

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

racetrack

CDR

Systematics against $\delta L/L \sim 10^{-4}$

- $\delta N/N \sim 10^{-4}$ *in fiducial ϑ window*

1. *Det. Position offset*
2. *Multi. Scattering, det. Resolution*
   B-field helix
3. *Rad. Bhabha, preshower offset*

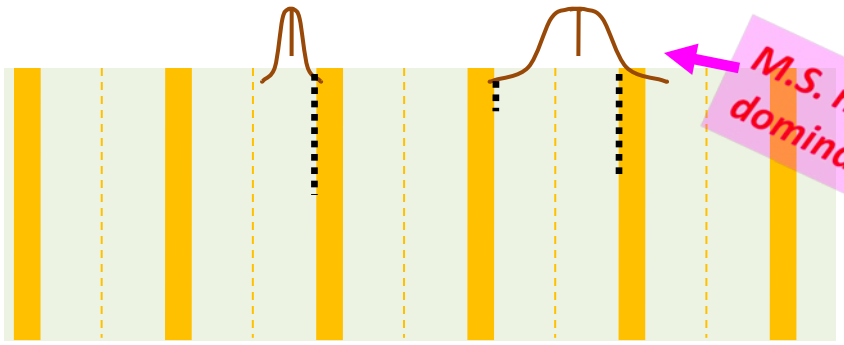
$\delta L/L \sim 2\,\delta\vartheta/\vartheta_{min}$

$\delta L/L < 10^{-4}$ *for* $\theta_{min} = 20$ mRad

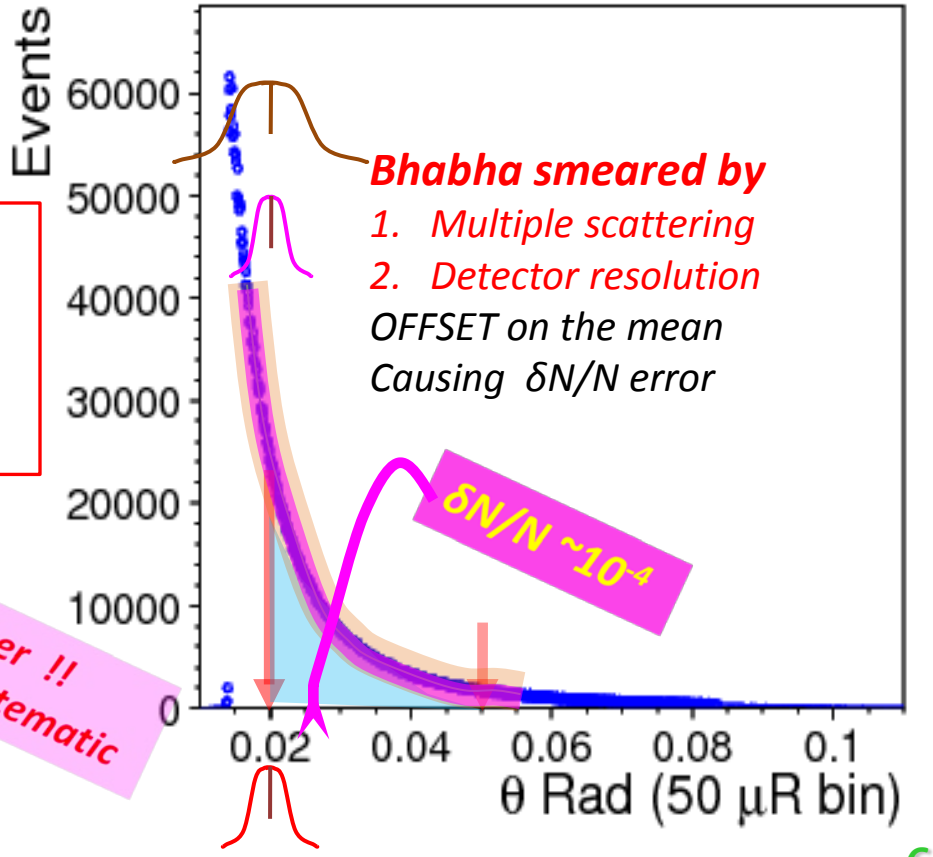
→ $\delta\vartheta = 1\mu$Rad dr=1μm @ z=1m

Si-strip detector

fiducial edge = central line between two strips
Multi.Scattering → events flow in/out Fiducial
+ geo error → event counting error



M.S. non-liner !! dominant systematic

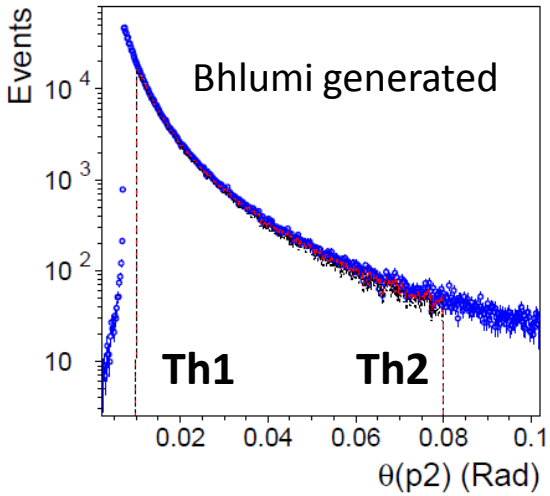


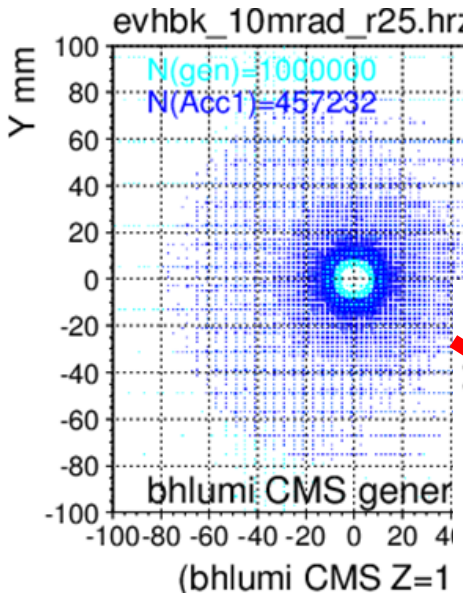
Bhabha smeared by
1. *Multiple scattering*
2. *Detector resolution*

OFFSET on the mean
Causing δN/N error

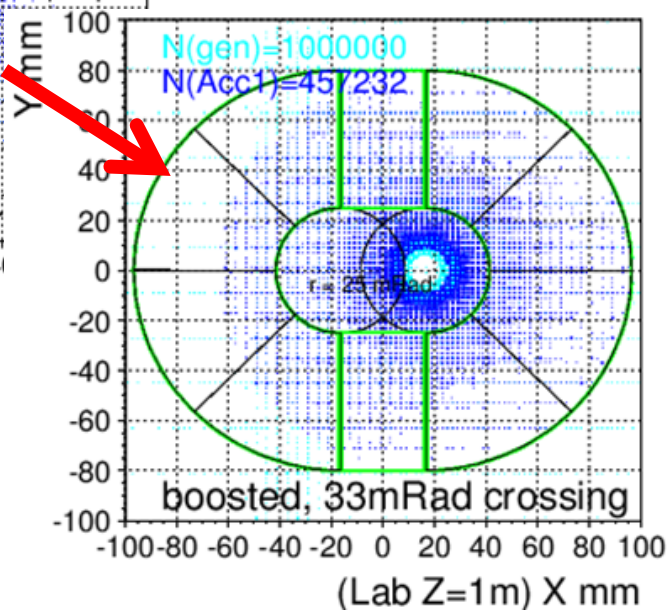
BHLUMI QED calculation

1. **BHLUMI** CMS m_Z=92. 3 GeV
   BARE1 X section: Th1<θ_1' and θ_2'<Th2, s'> 0.5s
2. **Boost +x** : 33 mRad e+,e- beam crossing
3. **X-section** : count event fraction in fiducial region

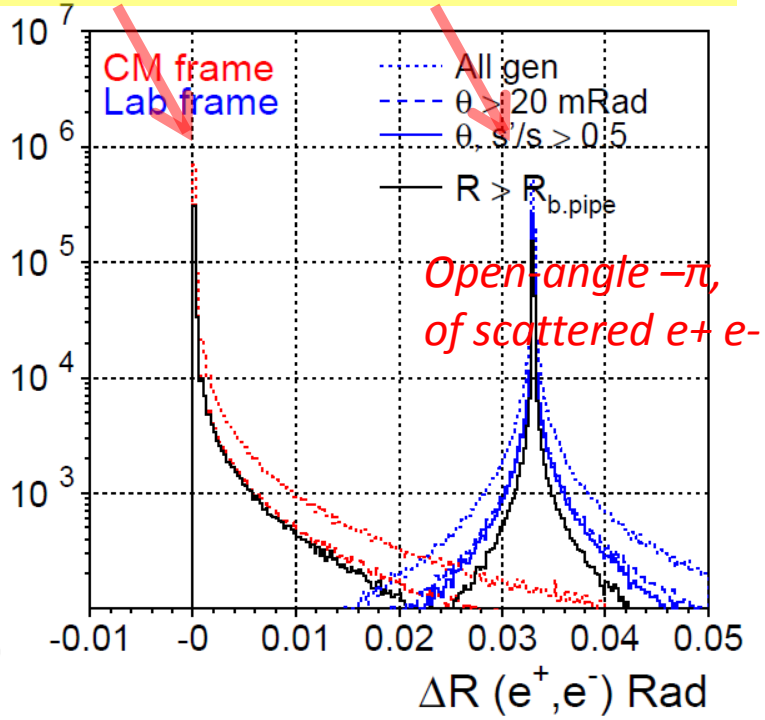




Boost +x,
33 mRad Beam crossing
scattered e+,e-
sym. to outgoing pipe



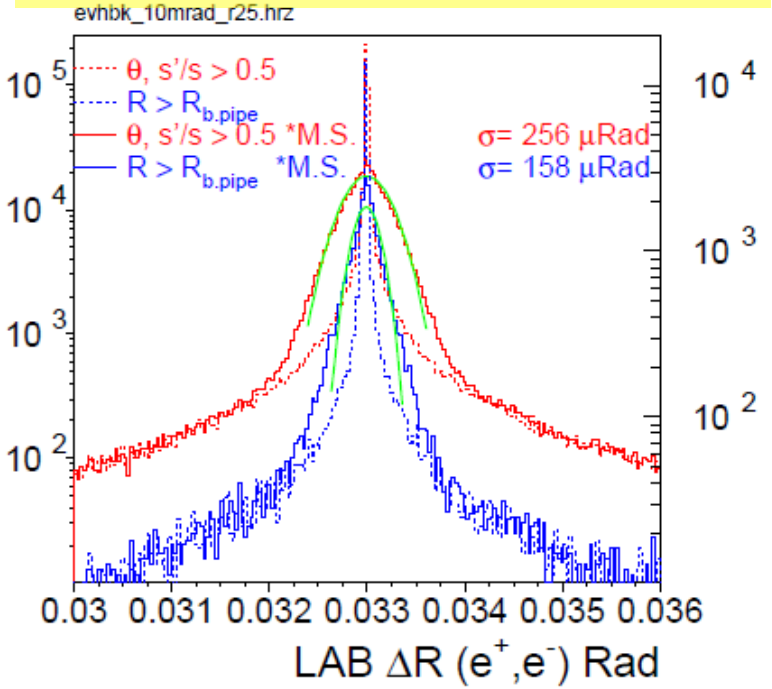
Multi. Scattering, rad. Bhabha, wider back-back distributions

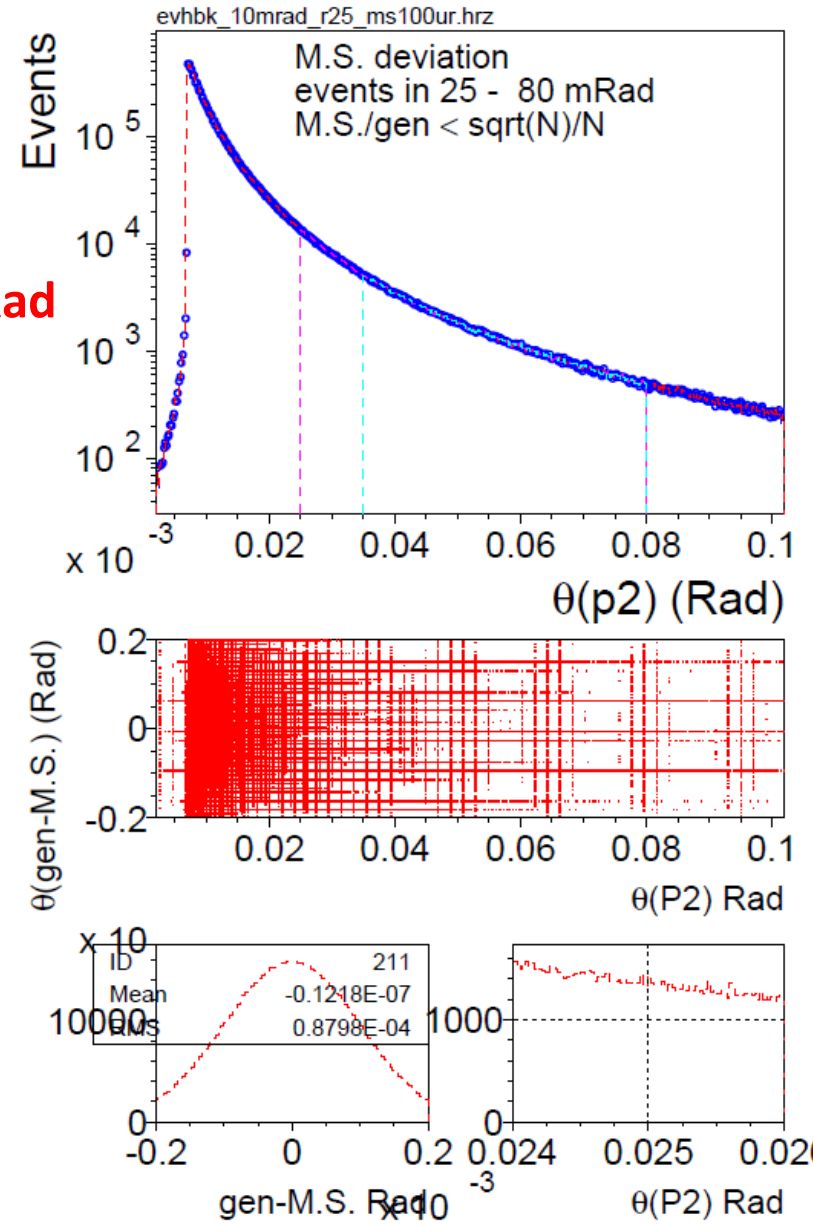


Smeared 100μRad as Multiple scattering

1. **Scattered** e+,e- $\theta' = \theta + \delta^{100\mu R}$, $\phi' = \phi + \delta^{100\mu R}$
   δ = Gaussian smearing as
   Multiple Scattering in theta, phi
2. **δN/N systematics**:
   δN = symmetric Gaussian ➔ **@ θ_{min} = 25 mRad**
   Bhabha shift 100 μRad **δN/N ~ 0**

Multiple scattering 100 μR ➔ wider back-back distributions





Bhabha event 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 = **245.9 nb**
   Event rate = (246x10^{-33}) x (115 x 10^{34}) /sec = ***280 kHz***
3. Event rate / 32ns bunch crossing = **0.009 events /b.c.**
4. **Pile-up: next b.c., @adjacent cell in peak region**

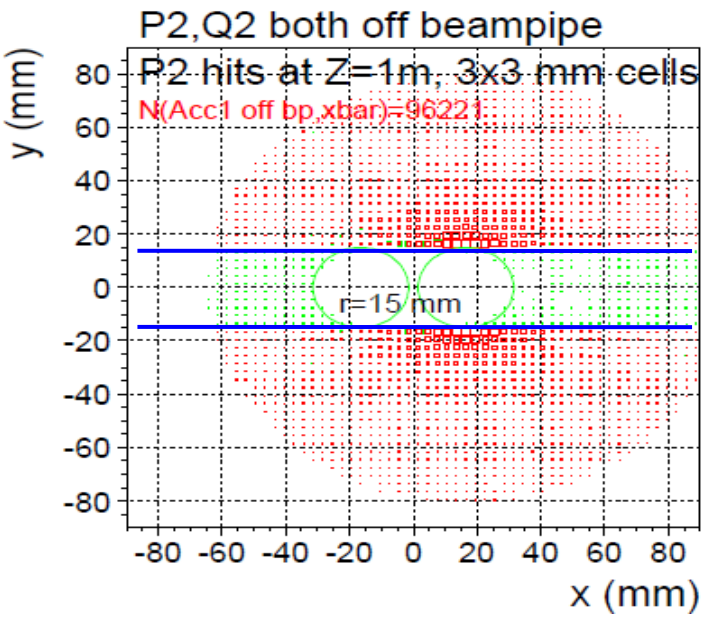
   Pile-up Fraction = 0.018*6cells/2sides = 0.054

Pile-up event rate = 0.009*0.054 = **5x10^{-4}**

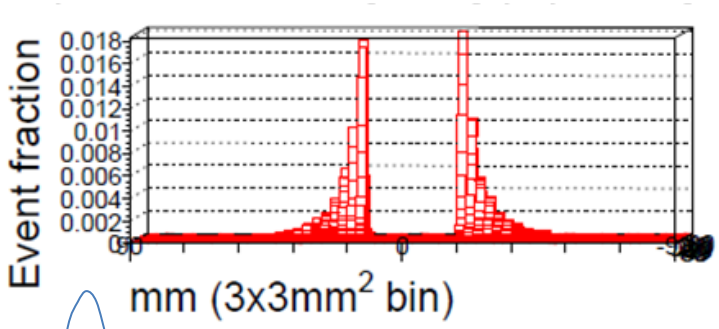
c.f. LEP
L= 1x10^{32}
X-sec= 100nb
Rate= ***10 Hz***

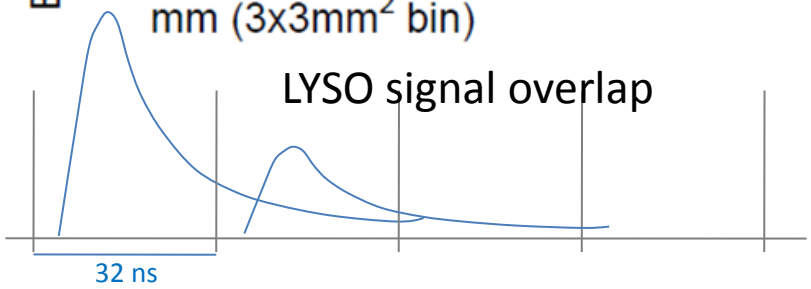
> systematic criteria

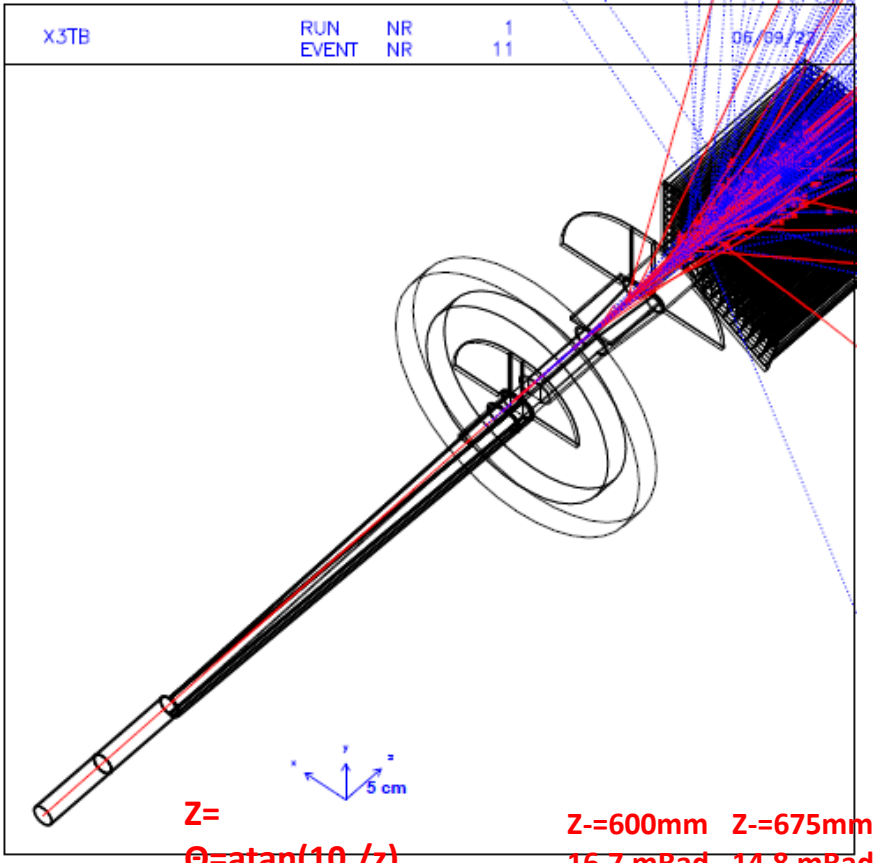
50 GeV e- shower in 3x3 mm^2 cells



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







GEANT racetrack beampipe

LySi angles

Vertical Y, 12 mm BOX lower edge
atan(12/900) = 13.33 mRad

Horizontal X, dual pipe edge 12+13.5
atan(25.5/900)= 28.33 mrad

Z=
Θ=atan(10./z)
Sinθ=2/s

Z-=600mm	Z-=675mm	Z-=700 mm	Z=780 855	Z=900
16.7 mRad	14.8 mRad	14.3 mRad	11.7-12.8mRad	1.1mRad
S= 120 mm	S= 135 mm	S= 140 mm	S=156 ~171 mm	S= 180 mm

TPC cone
TPCC geocal
z=111-211cm
R=14.13 26.85
TSIN TSOU Scin

UGEOM

SiW deck
z=115 - cm
W-nn Sinn

Flange 25mm thick
405 FgFe
404 ALFx FgAl

402 InAP dia 20
OuAP dia 22
R=10mm
Z=85mm

4020 rotate .9046deg
403 ALBx dia 20
R=10mm
Z=180mm

ALBU
MATpipe

401 InBP dia 20
OuBP dia 22

SiBR SiBR
SoBR SoBU

404
SiFR SiFR
SoFR SoFU
SwFU

CuBU
MATfold
Z=655
Z=700
R=35/2mm

YCBU
MATYCrot
Z=780mm

407 Y crotch
YCBx
Z=855mm

Lbar
z=90-110-cm

439
YpSi XmSi
z=900-mm
Si wafer

R=10mm

408 Dual pipes
z=855-1110mm
R=10 mm xc=12mm
Thick=2mm Al
Tube to dual tube

405
FSiR
FSiU
FSiL

YSiU
VSiR
VSiU
VSiL

406 CuBx
Folding pipe

409 TbFe 5mm Fe TbIs TbOs 2mm Scin
r= 15cm ~+.2,+.5,+.2
z=0~111cm Edge 15/118=tan(.1266) @cosQ=.992

FgFe
FgAl

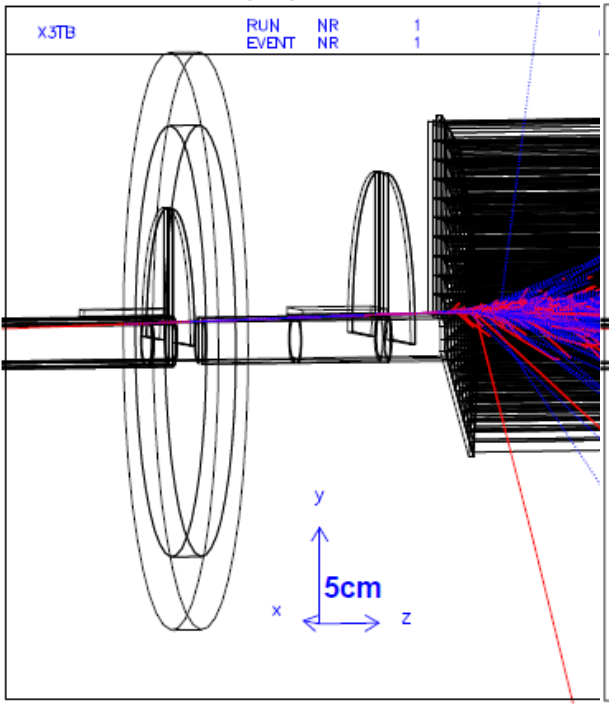
M.S. & preshower caused by beampipe

- ***Beam Pipe possible 1mm Be ??***
  ➔ <0.2 X0
- ***Preshower @ z < 1m Background to tracker***

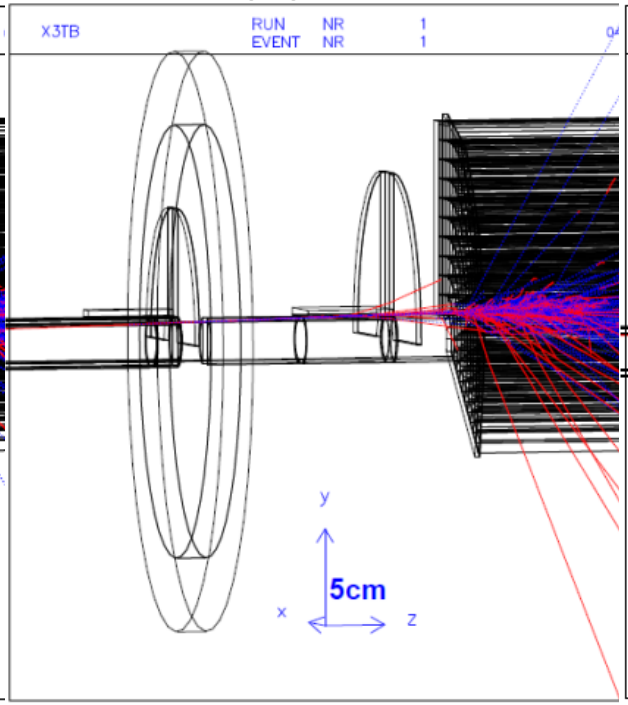
2mm beam-pipe, material budget

tanθ= 2mm/L	1/ tanθ	**Be** X0=353mm	**Al** X0=89mm	**Cu** X0=14.4mm	CosQ
15mRad L= 133 mm	66.66	0.378 X0	1.498 X0	9.259 X0	.9999
20mRad L= 100 mm	**49.99**	**0.283 X0**	**1.123 X0**	**6.944 X0**	.9998
25mRad L= 80 mm	39.99	0.227 X0	0.899 X0	5.554 X0	.9997
30mRad L= 67 mm	33.32	0.189 X0	0.749 X0	4.628 X0	.9996
35mRad L= 57 mm	28.56	**0.162 X0 (LEP)**	0.642 X0	3.967 X0	.9994
50mRad L= 40 mm	19.98	0.113 X0	0.449 X0	2.775 X0	.9996
65mRad L= 31 mm	15.36	0.087 X0	0.345 X0	2.134 X0	.9996
80mRad L= 25 mm	12.46	0.071 X0	0.280 X0	1.732 X0	.9996

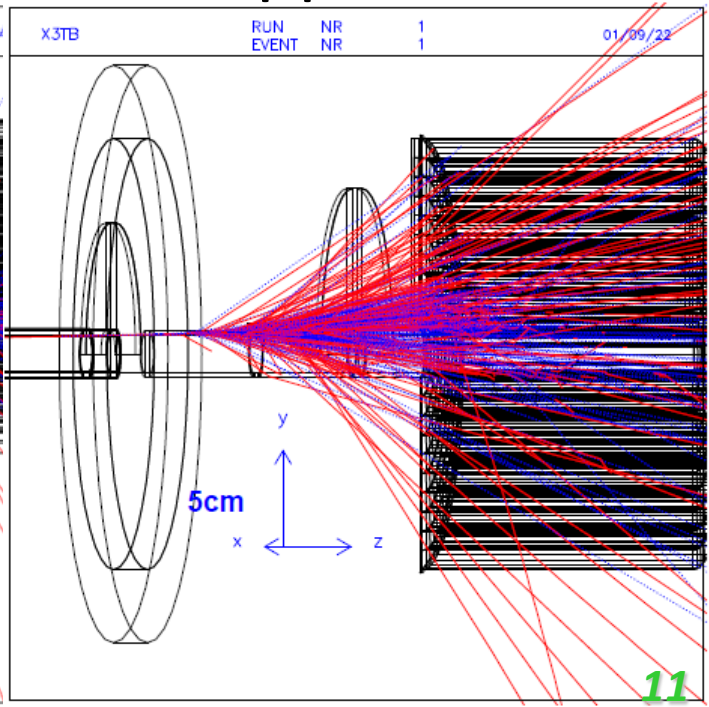
Be 2mm pipe



Al 2mm pipe



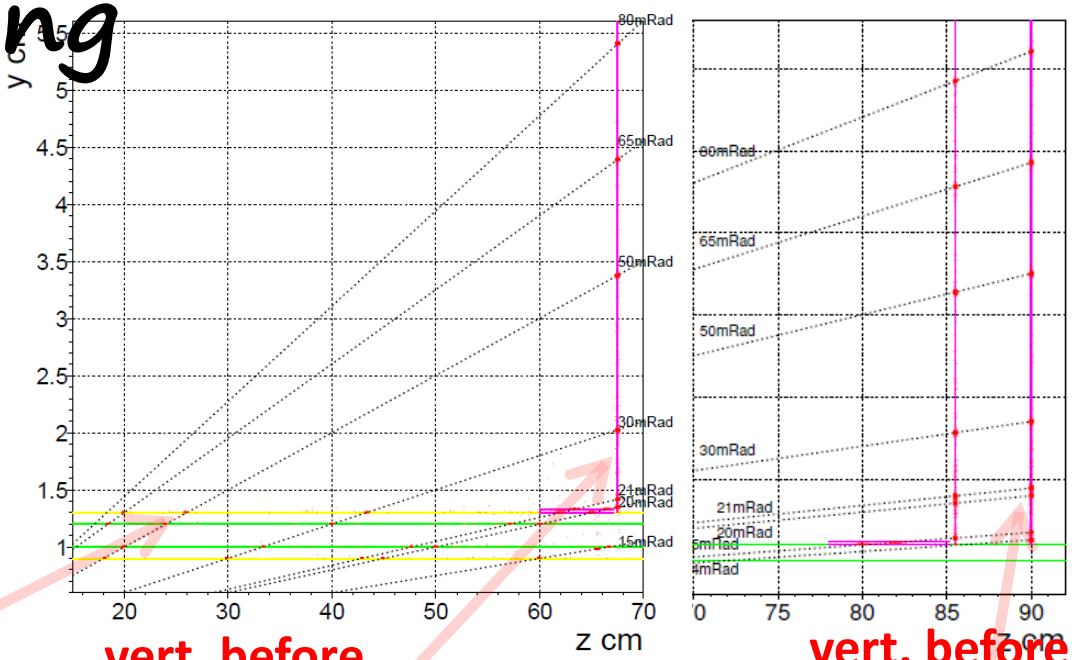
Cu 2mm pipe



Multi. Scattering

1mm Be pipe,
10 mm Al Flange

50 GeV muon
Mutiple scattering only



θ to z:
r/z =tan θ

Exit pipe

vert. before flange z=655mm

vert. before flange z=900mm

Muon θ RMS	1/tanθ	41005/41006 Exit pipe dz dθ	41007/41008 Slab / pip dz dθ	41009/41010 B.F flange dr dθ	41013/41014 B.H flange dz dθ	41015/41016 B.H flange dr dθ	41017/41018 B.H flange dr dθ
80	12.5			53 um 76 uR		74 um 87 uR	80 um 88 uR
65	15.4	32 um 11 uR		58 um 85 uR		84 um 98 uR	90 um 100 uR
50	20.0	43 um 9 uR		53 um 77 uR		79 um 92 uR	82 um 94 uR
30	33.3	160 um 12 uR		48 um 70 uR		76 um 88 uR	83 um 92 uR
21	47.6	396 um 18 uR	1.05 mm 36 uR	32 um 47 uR		72 um 84 uR	82 um 91 uR
20	**50.0**	449 um 16 uR	1.25 mm 40 uR	**31 um 46 uR**		74 um 87 uR	**85 um 95 uR**
15	66.7				1.63 mm 32 uR	36 um 43 uR	46 um 52 uR
14.5	69.0				1.78 mm 32 uR	33 um 37 uR	42 um 46 uR

smeared by Multi. Scat, Preshower

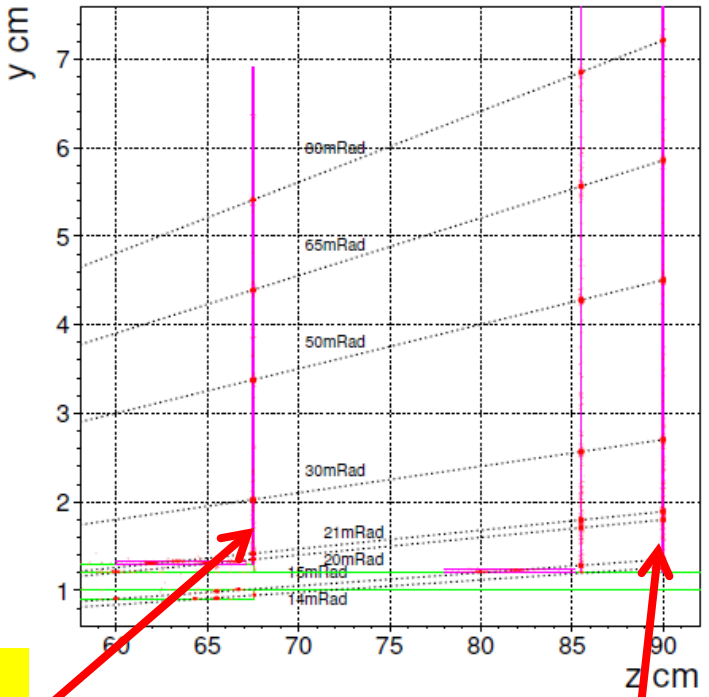
50 GeV muon, electrons

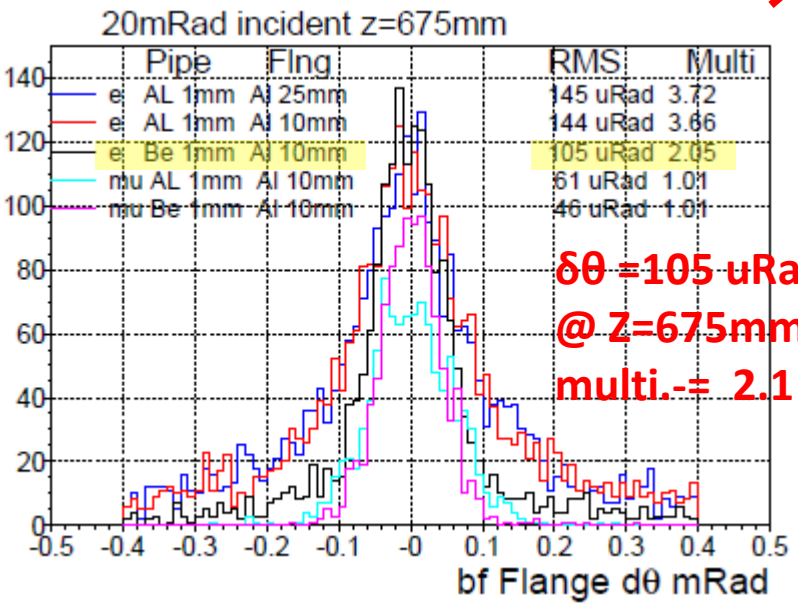
Muon: mutiple scattering only

Electron: M.S. + EM bramsstrahlung

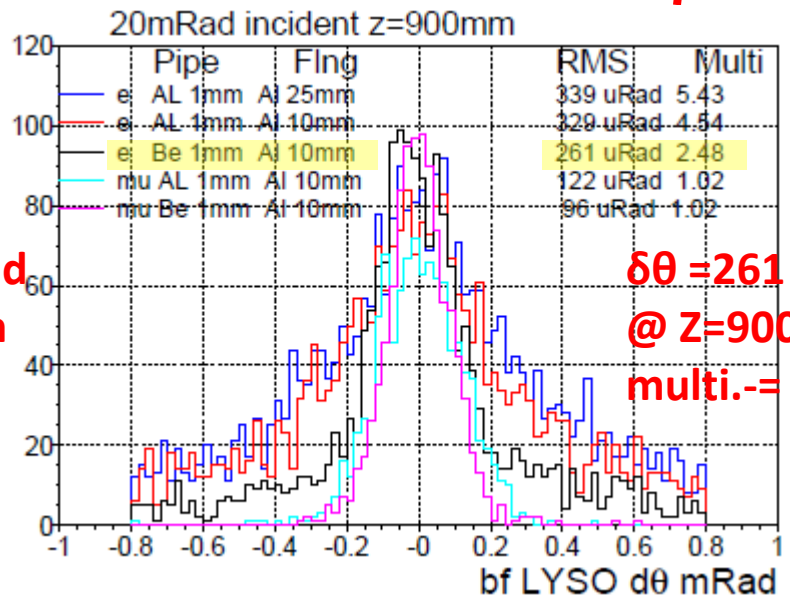
E.M. shower → shower mulitplicity & widen position resolution

Ref: Be 1 mm pipe, 1/tan θ =50
50 GeV 20mRad electrons



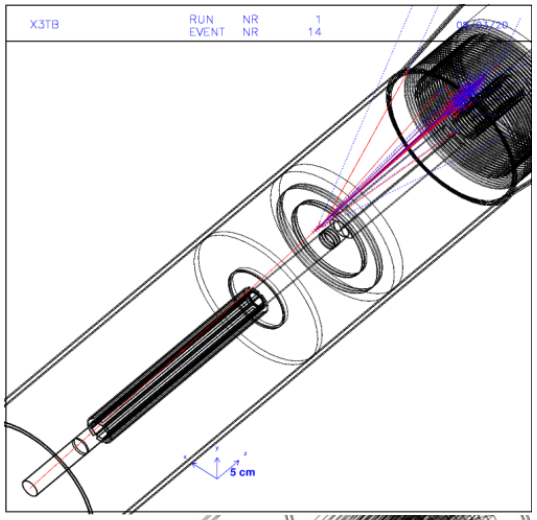


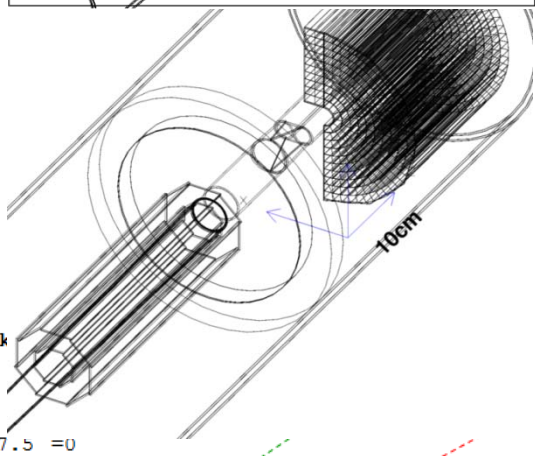
δθ =105 uRad
@ Z=675mm
multi.-= 2.1



δθ =261 uRad
@ Z=900mm
multi.-= 2.5

vs. CDR 28mm tube, 28-40mm cone pipe





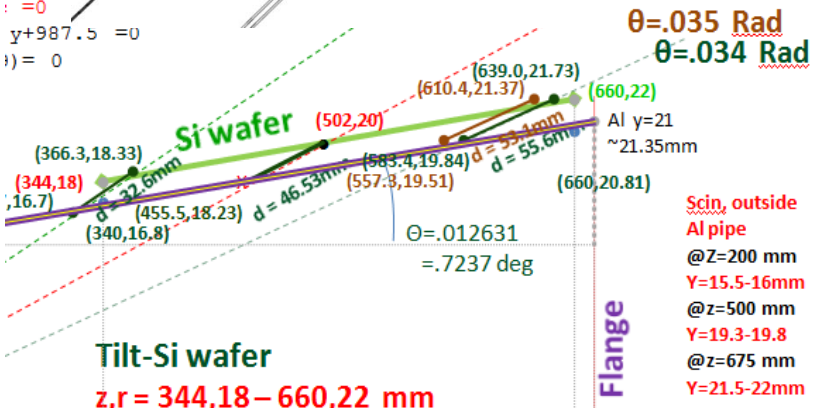
- ***50 GeV electron*** traversing Al-pipe :
  (0.5 mm Al – 0.5 mm Air – 0.35 mm Air)
- ***Multiple scattering deviation***
  simulated for ϕ=28 mm
  exiting Al-pipe Si-layer attached, ***no air-gap*** (nearest)

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

- 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***



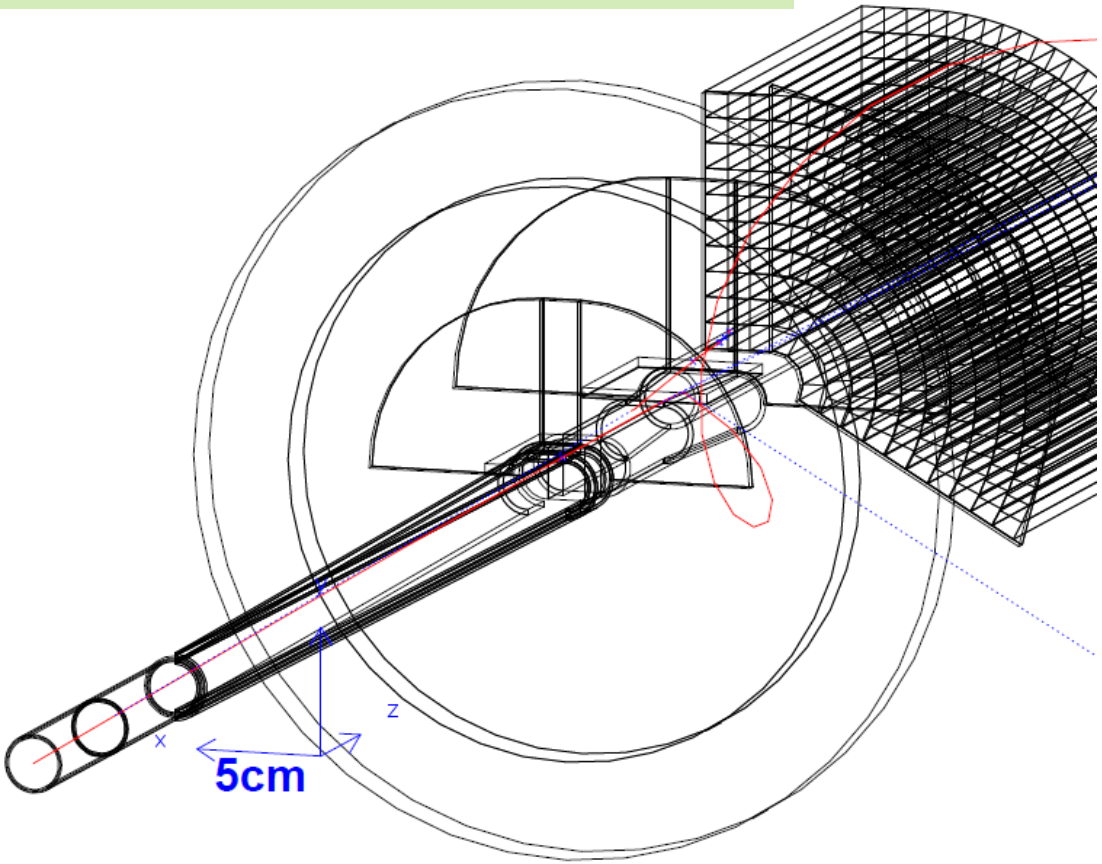
mu (θ,ϕ)	σ(Z) Si^{1st}	σ(θ) Si^{1st}	1/tan(θ)
(35 mR, 90°)	475 μm	28 μRad	28.6
(40 mR, 90°)	301 μm	24 μRad	25.0
(50 mR, 90°)	161 μm	22 μRad	20.0

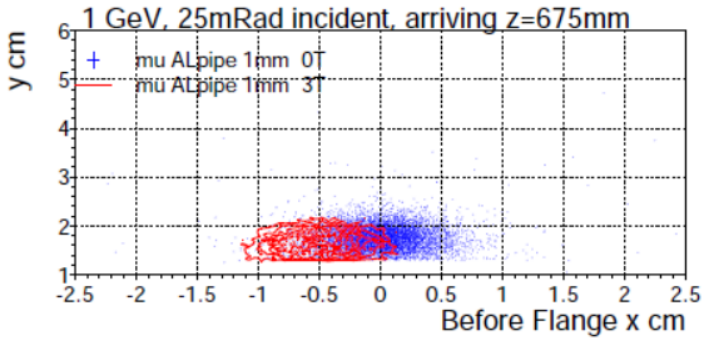
Mag. Field bending Bz = 3T

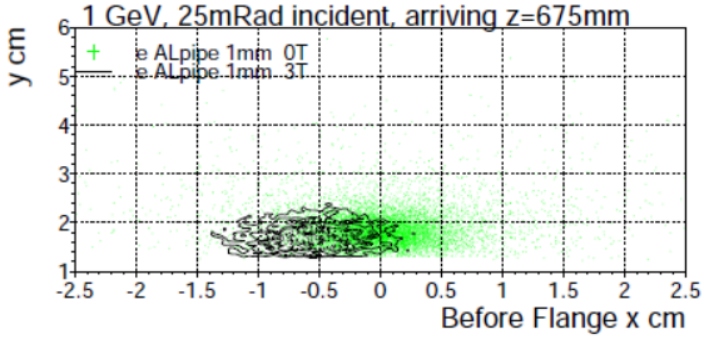
1 GeV electron, 3T Helix

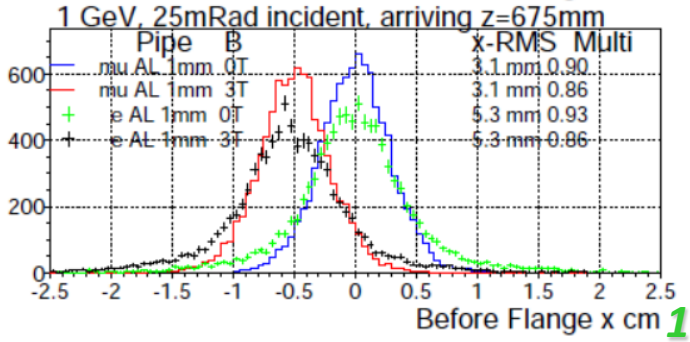
1GeV electron @25mRad
1 mm Al pipe, 25mm Flange
M.S. +3T Helix z=675mm

2 mm Al pipe, 20mm Flange









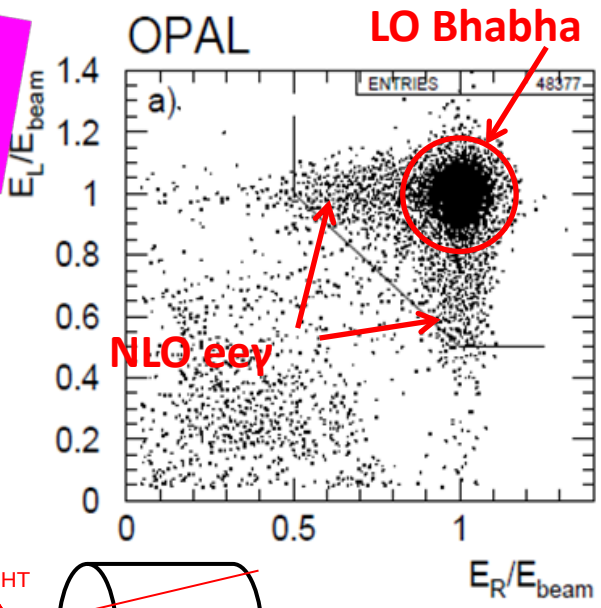
Task: full GEANT on BHLUMI events

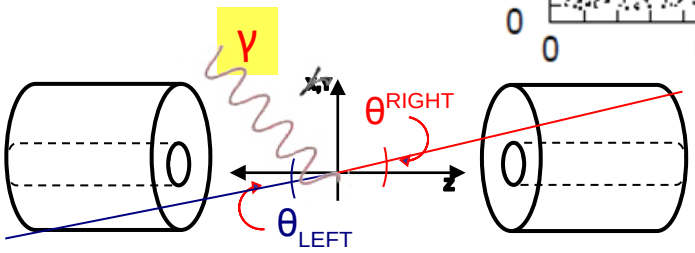
GEANT : Beam-pipe + LumiCal

BHLUMI : e^+ , e^- ,γ

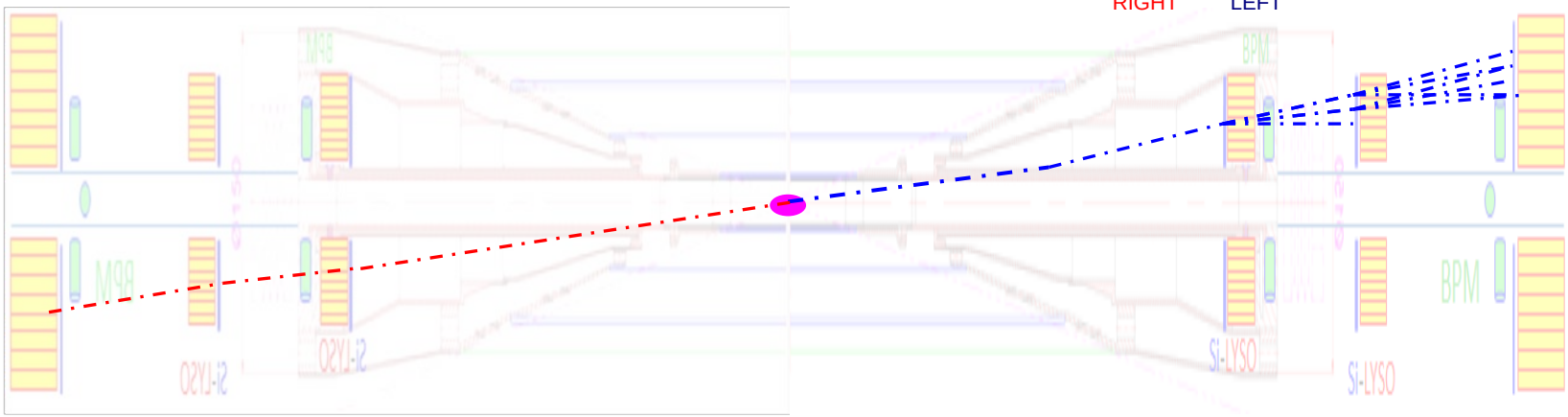
evaluation for 10^{-4}

1. **Linear fit** (e^+ , IP, e^-)
   - ➔ back-to-back vs Mult.Scatt.
   - ➔ IP (x,y) calibration
2. **Radiation Bhabha** (~1% event rate) :
   $e^{\pm}$, $e^{\pm}$ γ selections
3. **LumiCal resolution** :
   before Flange, behind Bellow
   $E(e^{\pm})$ + E_γ resolution,
   preshower effect



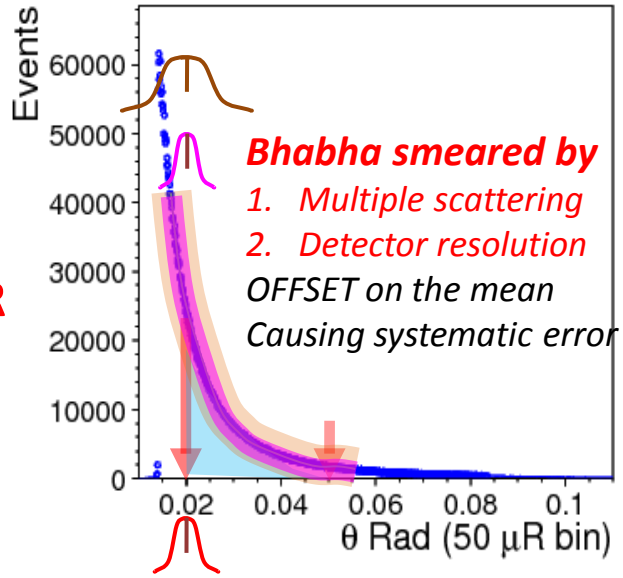


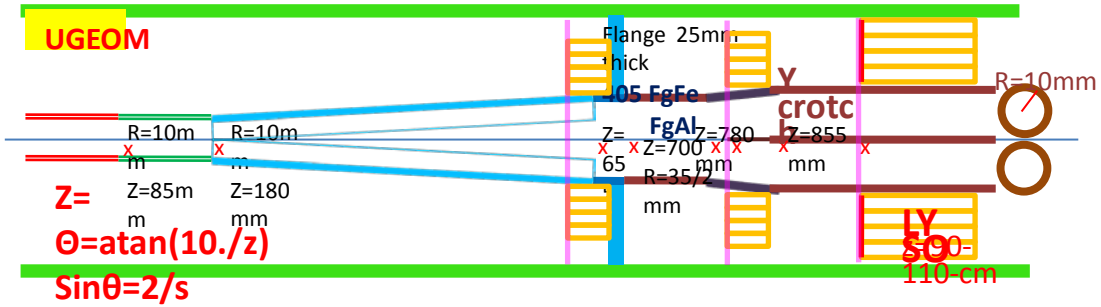
$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$



Discussion, summary

1. **Ø20mm Racetrack beampipe**
   Bhabha X-section fiducial ➔ **lower Θ_{min}**
   longerbeampipe material ➔ **Multi.Scatt. δθ~100 μR**
2. **Lumical optimization: Si+LYSO sectors**
   before Flange: impact position, e,γ ID, preshower
   after Bellow: Y-crotch sector, QP sector





Study Items :

1. ***threatening δL/L ~10^{-4}***
   Mult.Scatt., B-field helix : symmetric dN/N ~0
   detector offset, resolution : **calibrated to 1 μm required!!**
2. ***Full GEANT, BHLUMI e^+, e^-,γ inputs***
   confirm Multi.Scatt, B-field, preshower factors
3. ***Calibrate IP (x,y)***
   by linear track fitting of **e^+, IP, e^- positions**