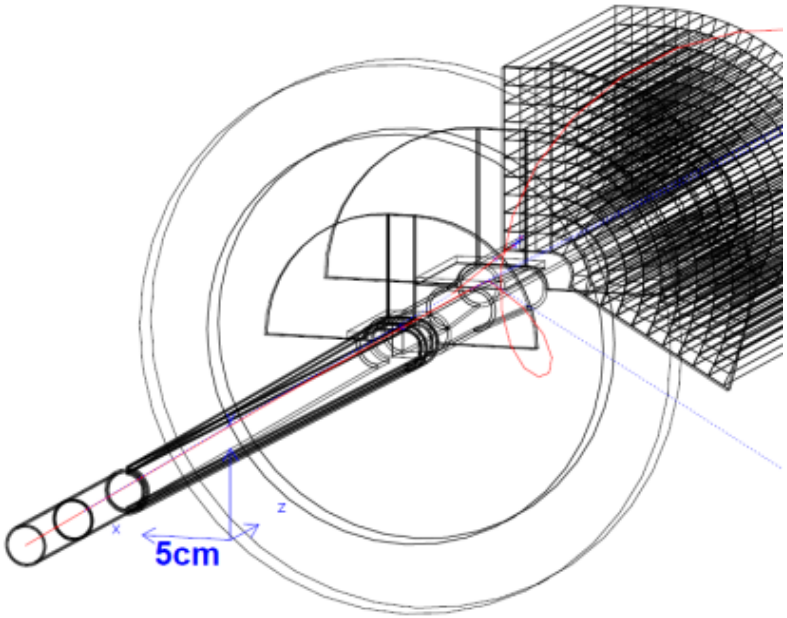
LumiCal

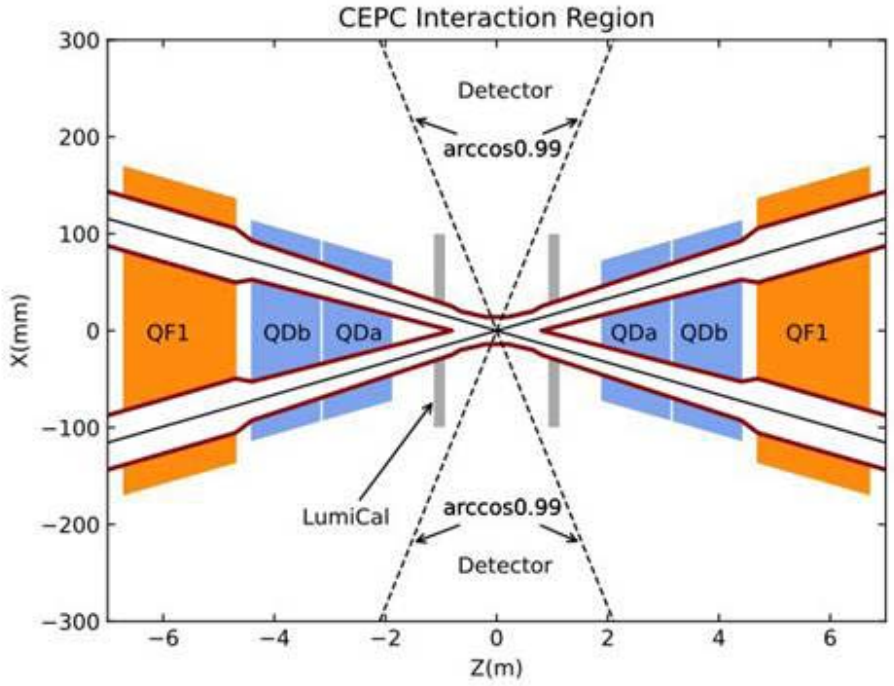
with the race-track beampipe

https://indico.ihep.ac.cn/event/19071/

2023.04.01 09:25

Suen Hou 侯書雲
中央研究院 Acadmia Sinica
suen@sinica.edu.tw



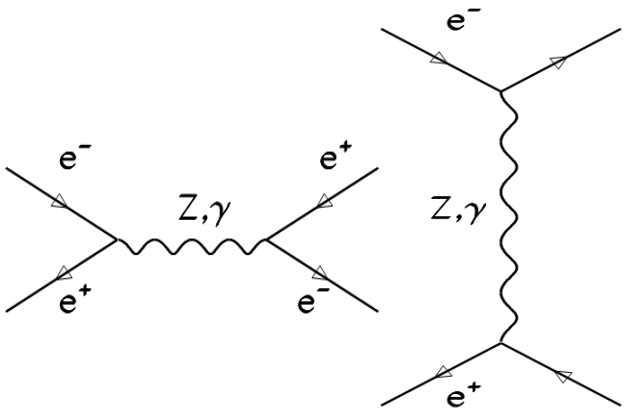


Bhabha e^+e^- Elastic Scattering physics parameters

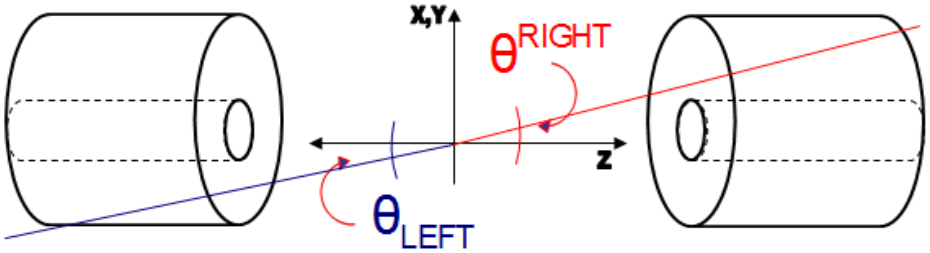
QED Bhabha BHLUMI
Cross section at CEPC

Luminosity by Bhabha elastic scattering

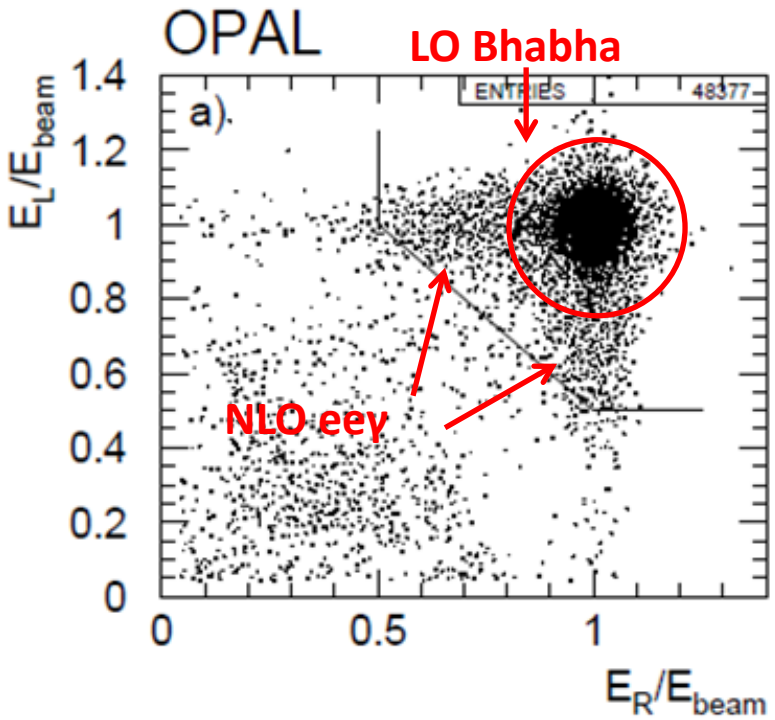
- ***Physics events, e.g. Z pole,***
  $N = \sigma \cdot \int L$ ***L: Luminosity of e^+e^- collisions***
- ***Luminosity* by counting Bhabha events**
  $e^+e^- \rightarrow e^+e^-(\gamma)$ QED *theo. precision < 0.1%*
  1. ***a pair of electrons,*** $E(e^{\pm}) = E_{beam}$ ***back-to-back***
  2. ***precision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



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



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



Bhabha luminosity precision

Luminosity= counting Bhabha events
In a fiducial θ region

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

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

systematic error :

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

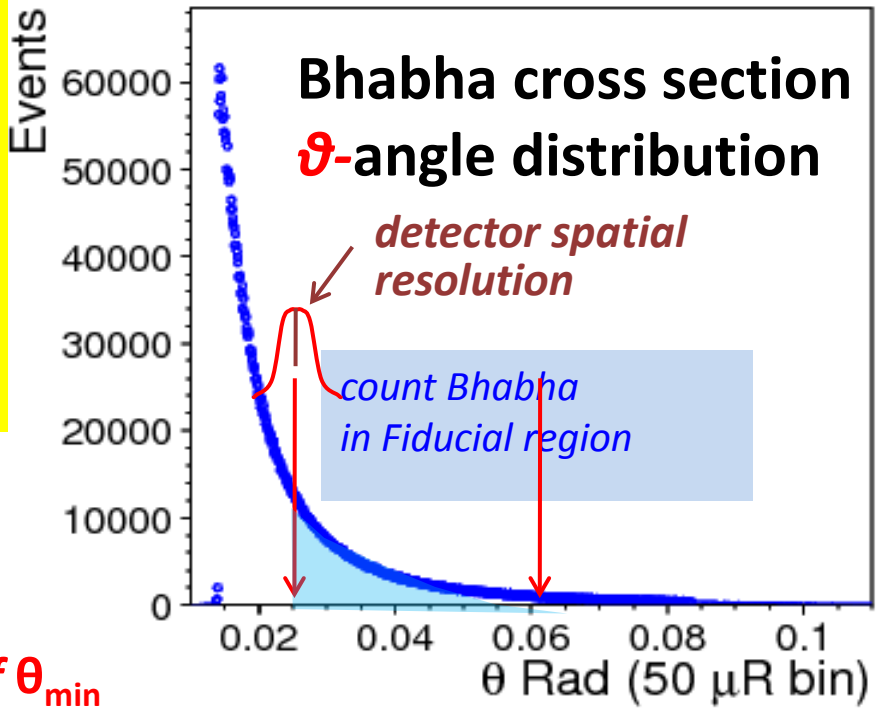
For $\delta L/L = 10^{-3}$

At **z = ±1 m,** θ_{min} = 20 mRad

→ $\delta\vartheta$ = ***10 µRad*** or ***dr = 10 µm***

Error due to offset on Z

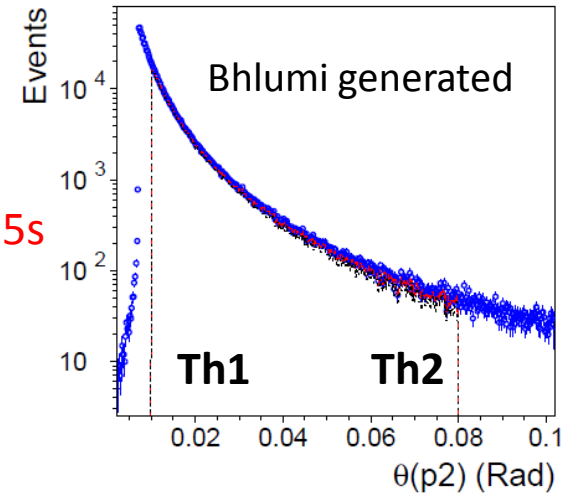
→ ***0.5 mm*** *on Z* or $dr = \delta z \times \vartheta$ = ***10 µm***

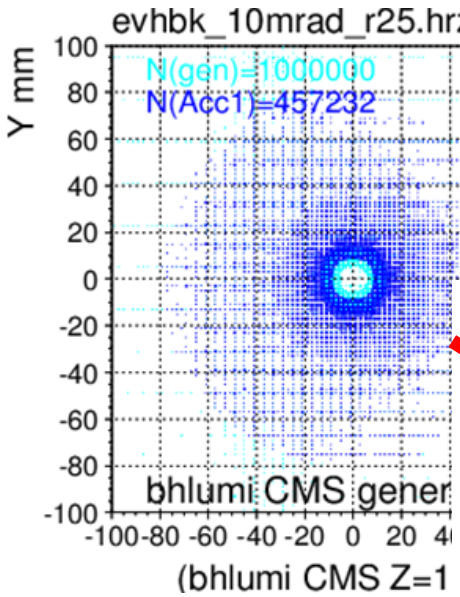


Luminosity Error ***due to***
events counted in/out fiducial region
➔ ***spatial resolution = offset on mean of*** θ_{min}

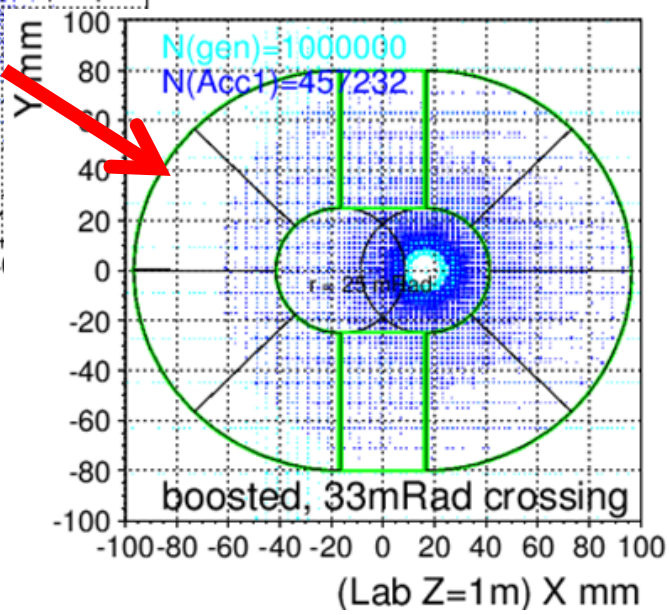
BHLUMI + beam-crossing

1. **BHLUMI** QED 0.06% precision (PLB 450, 262)
   CMS m_Z=92. 3 GeV, **fiducial region:** Th1<θ<Th2, s'> 0.5s
2. **CEPC boost** : e^+e^- beam crossing, **33 mRad**
3. **X-section** : count event fraction in fiducial region

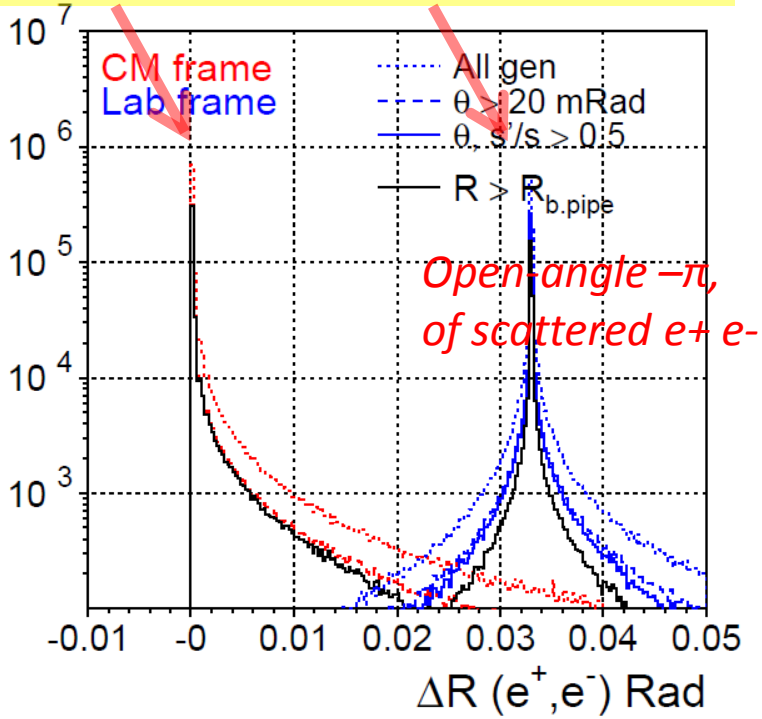




Boost +x,
33 mRad Beam crossing
scattered e+,e-
sym. to outgoing pipe



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



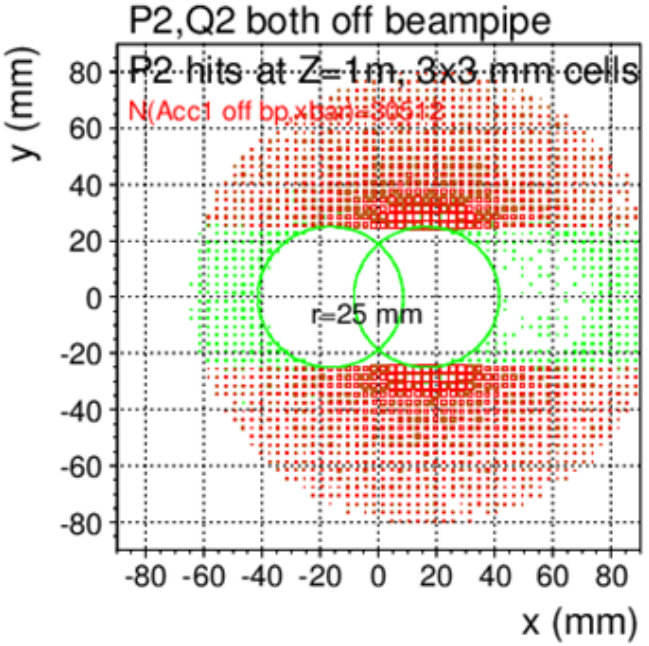
BHLUMI X-section, racetrack @CEPC

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

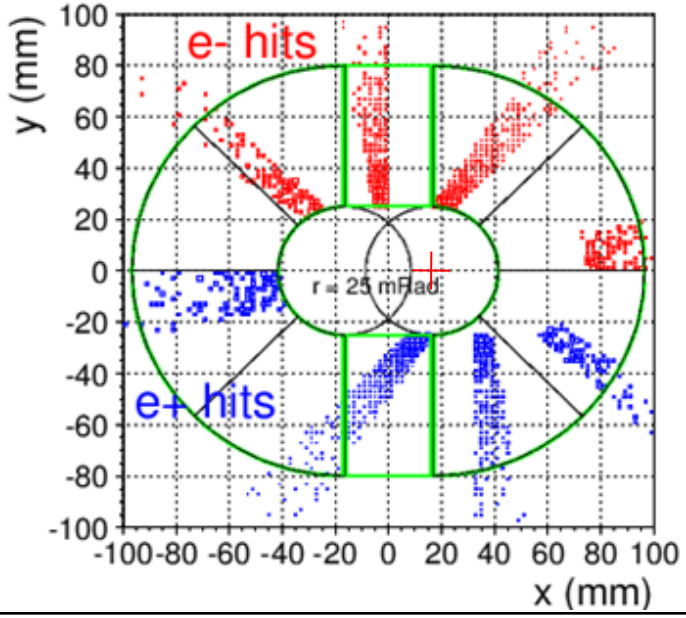
LAB frame

e^+, e^- detected

@ Z=1000 mm



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



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

MDI, beam-pipe materials

GEANT estimation
multiple scattering + preshower
Magnetic field

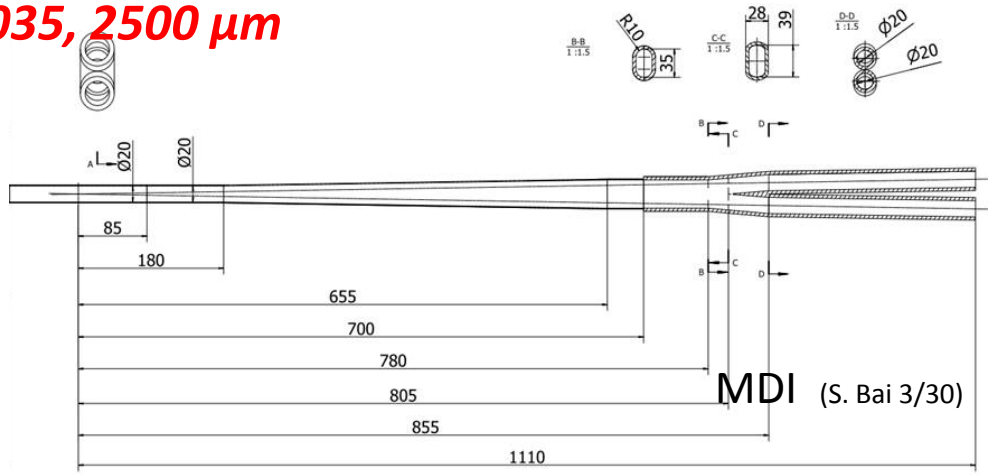
CEPC Accelerator TDR upgrade (J.Gao 3/30)

	Higgs	W	Z	ttbar
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

MDI configurations to LumiCal

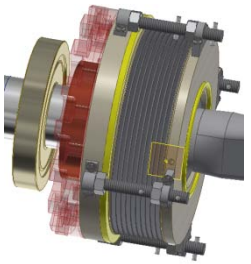
CEPC Accelerator parameters to LumiCal Bhabha detection

- beam-crossing: **33 mRad**
- IP beam spot @Z: $\sigma_x\ \sigma_y\ \sigma_z$ = 6, 0.035, 2500 μm
- Bunch crossing: 23 ns
- per crossing: 3 IP's
- Luminosity: $cm^{-2}s^{-1}$: 2×10^{36}



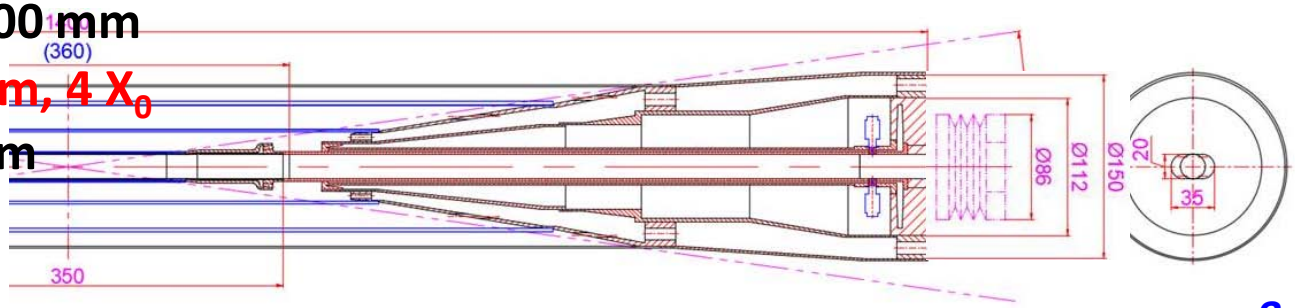
Beam-pipe materials & Space

- **Before Flange: z = 655~700 mm**
  r=10mm, thickness **= 1mm**
  @20 mRad traversing **= 50 mm,**
  = 0.14 X_0 (Be), 0.56 X_0 (Al)
- Install **$2X_0$ LYSO = 23 mm**
- Luminosity: $cm^{-2}s^{-1}$: 2×10^{36}



Behind bellow: 780~1100 mm

- **Flange+Bellow : ~60 mm, 4 X_0**
- Install **$20X_0$ LYSO 233mm**
  for $e^{\pm}$ energy



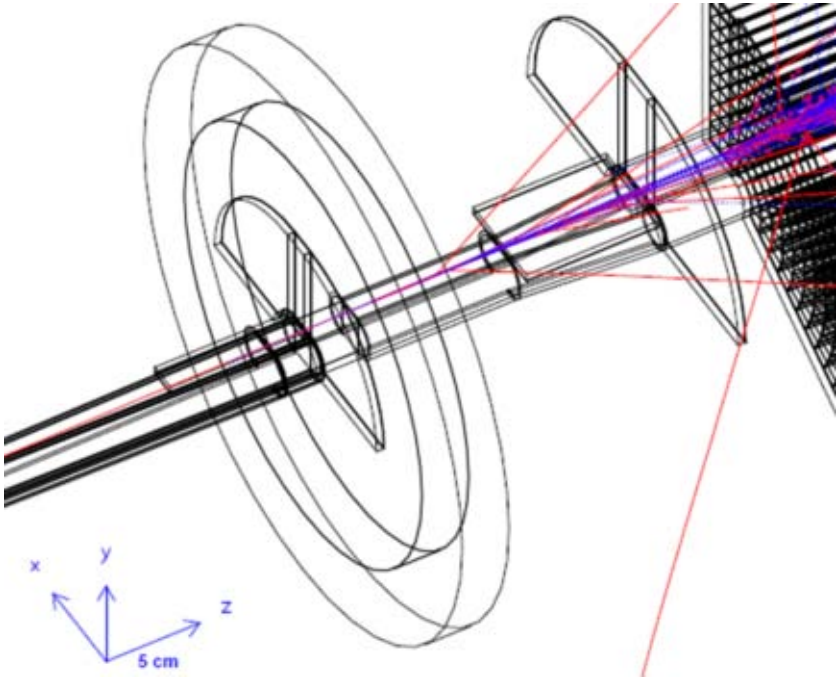
LumiCal on Racetrack beampipe

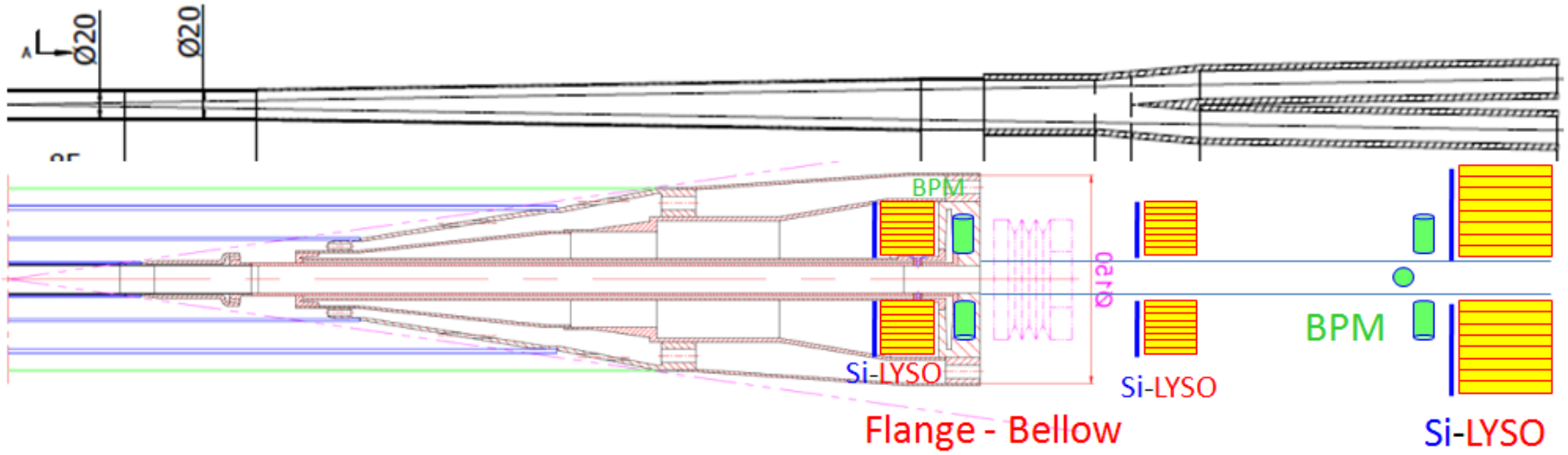
Racetrack beampipe

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

LumiCal sandwiched

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





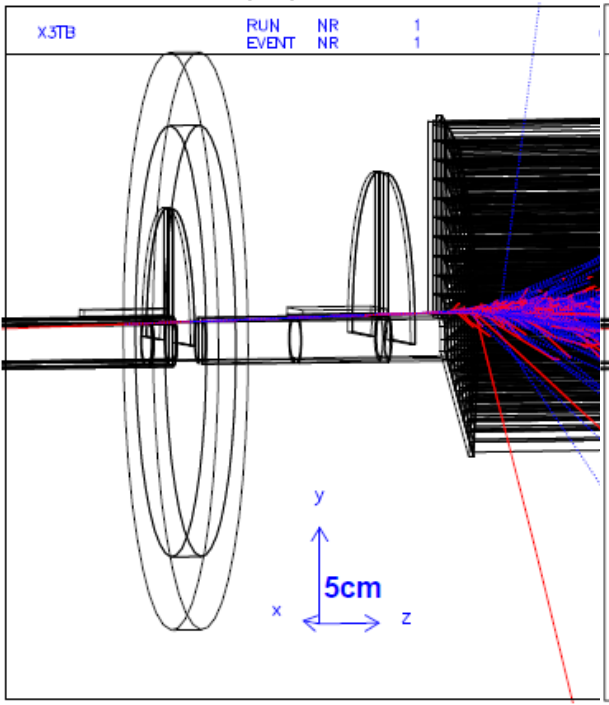
M.S. & preshower caused by beampipe

- ***Beam Pipe possible 1mm Be ??***
  ➔ ***<0.2 X_0***
- ***Preshower @ z < 1m Background to tracker***

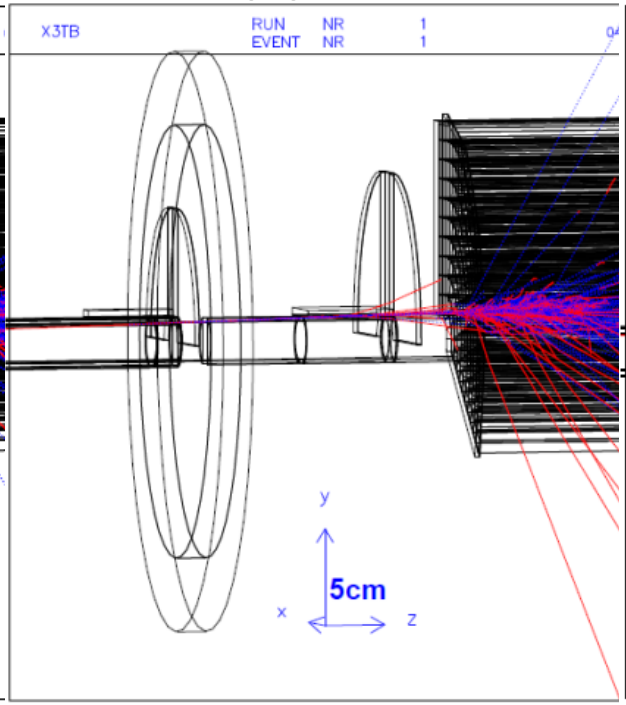
2mm beam-pipe, material budget

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

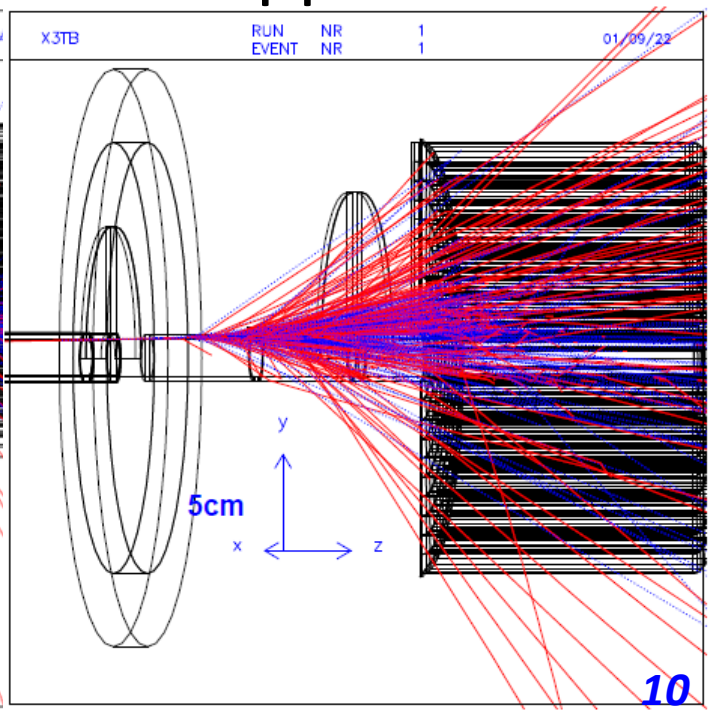
Be 2mm pipe



Al 2mm pipe



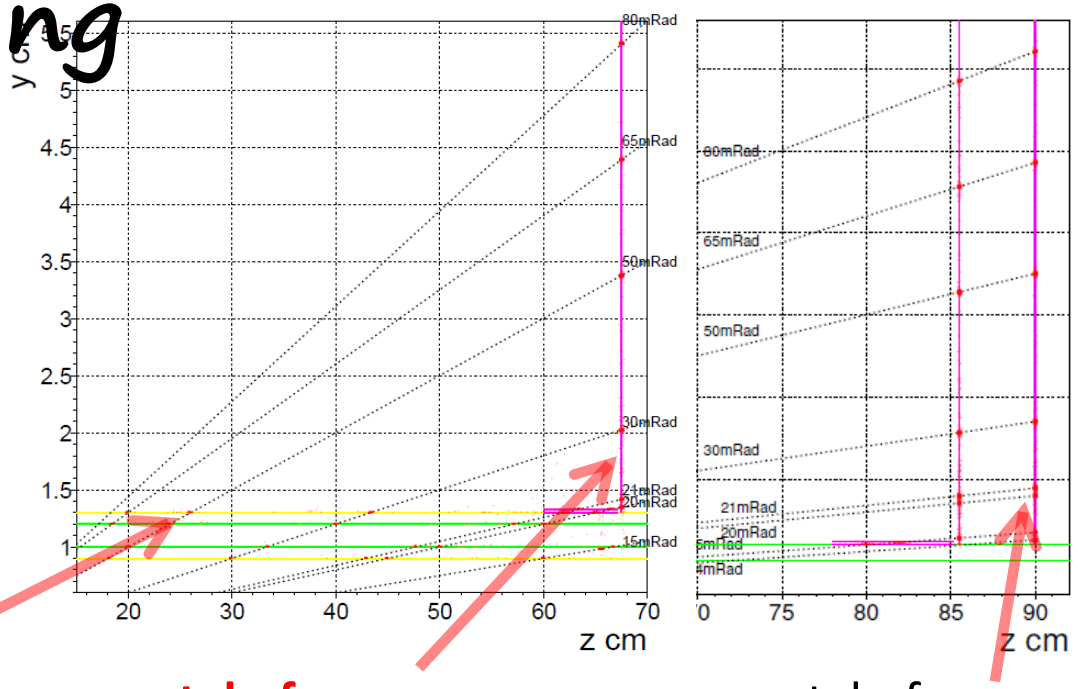
Cu 2mm pipe



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 Qpole z=900mm

Muon θ	1/tanθ	Exit pipe dz dθ	Slab / pip dz dθ	B.F flange dr dθ	B.H flange dz dθ	B.H flange dr dθ	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

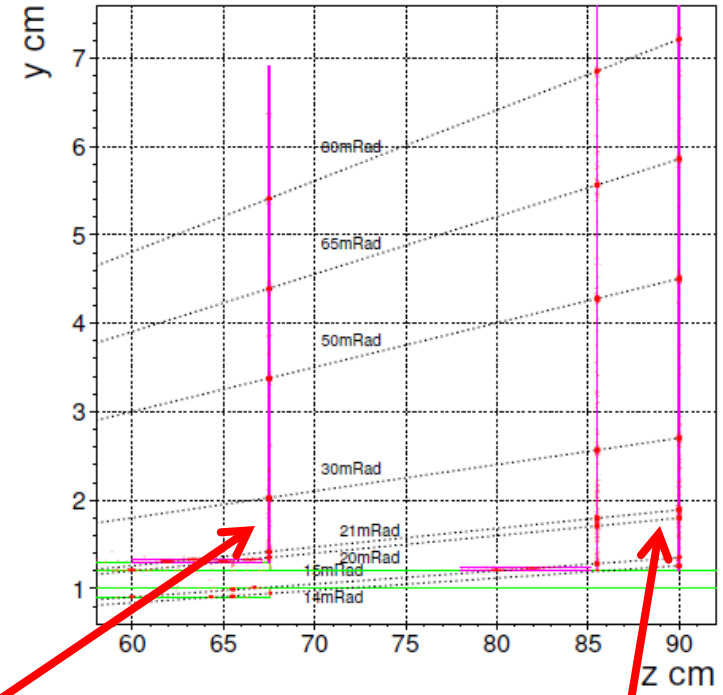
50 GeV muon, electrons @ θ=20 mRad

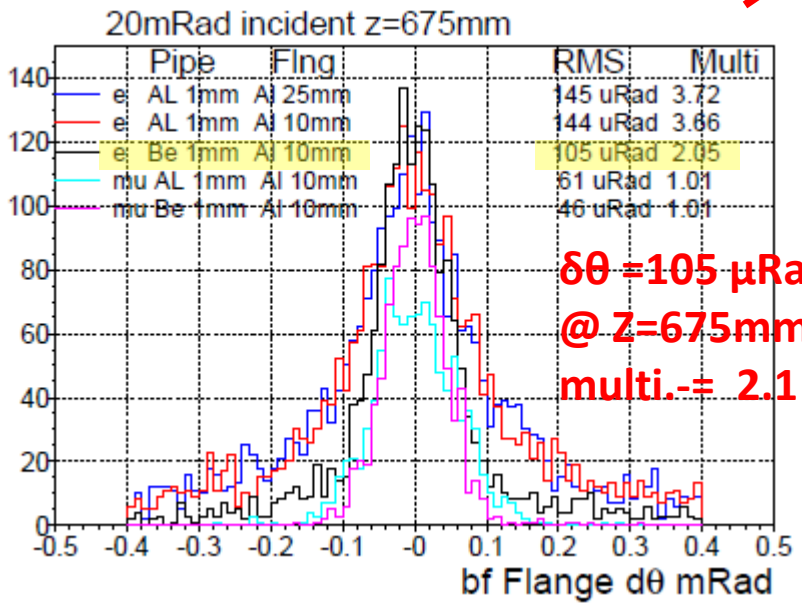
Muon: mutiple scattering only

Electron: M.S. + EM bremsstrahlung

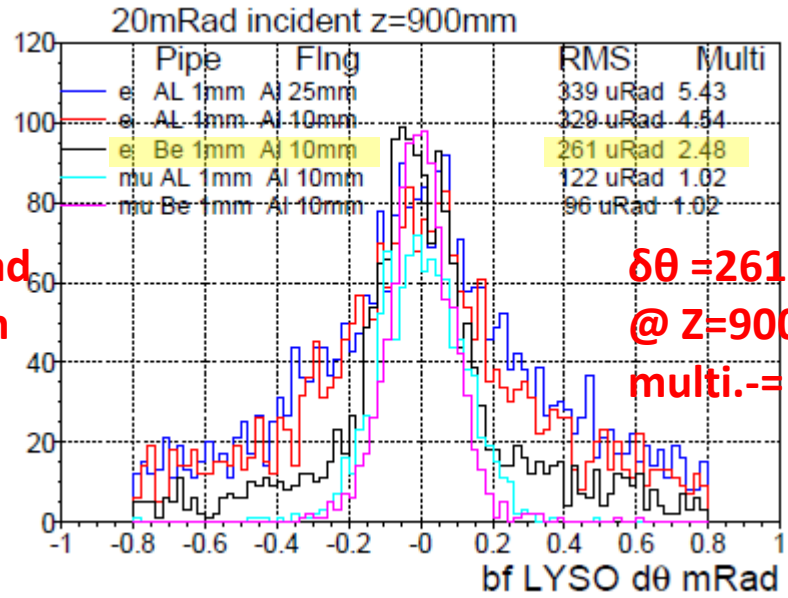
E.M. shower → shower multiplicity widen position resolution

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





δθ =105 μRad
@ Z=675mm
multi.-= 2.1

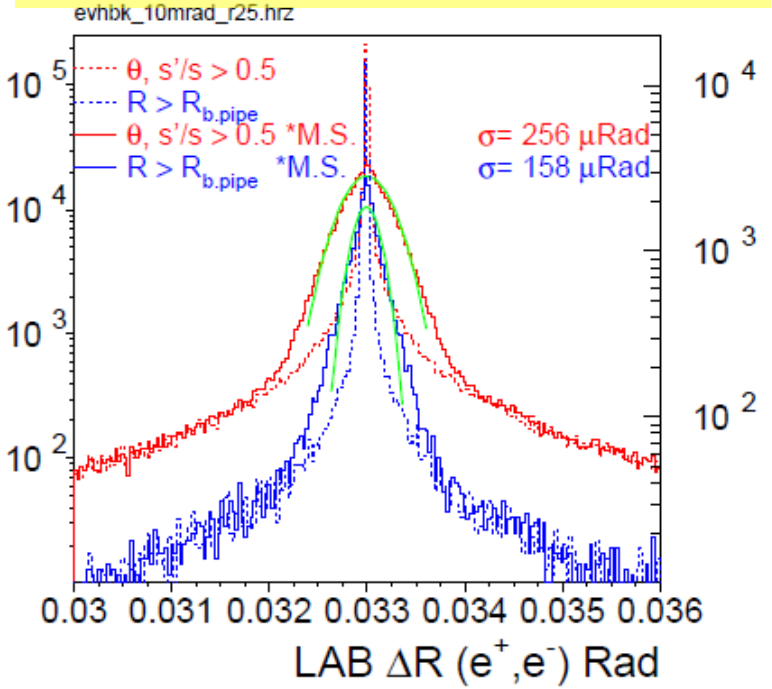


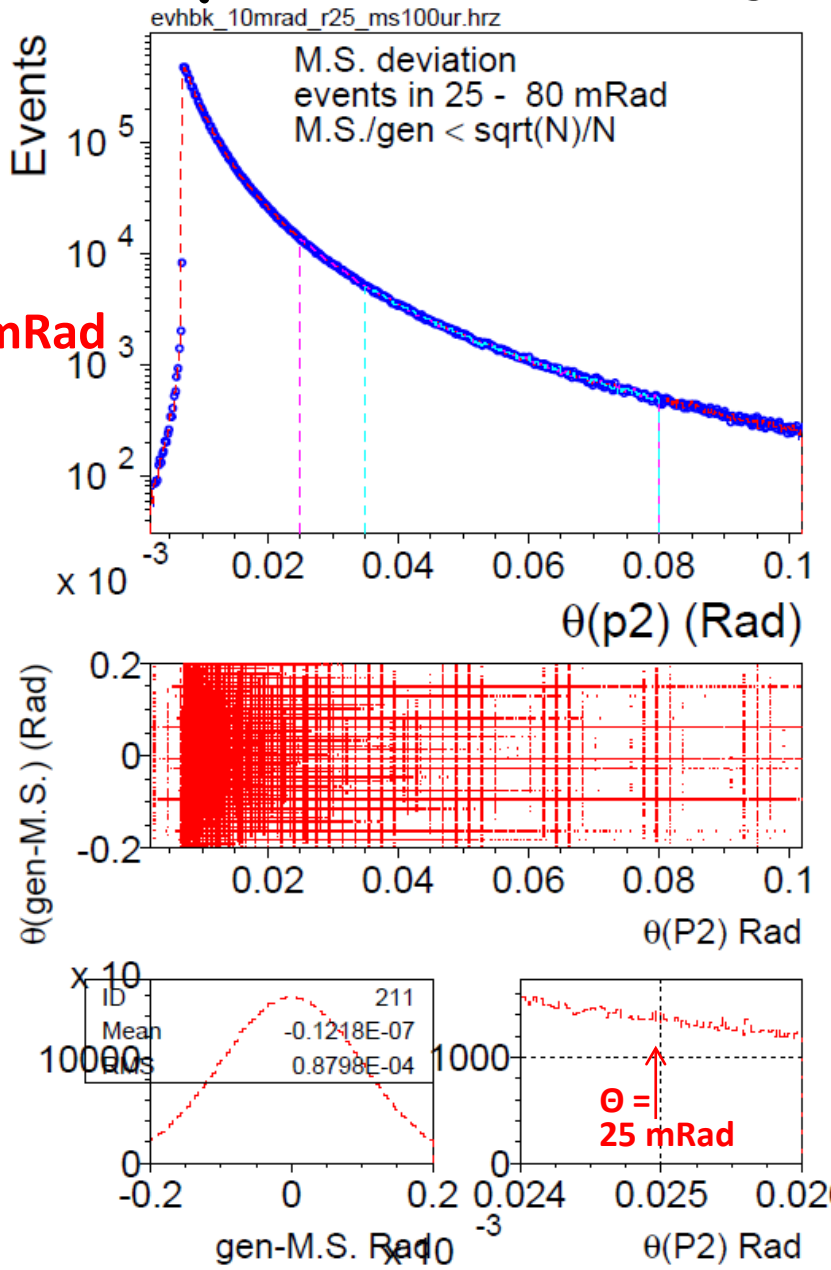
δθ =261 μRad
@ Z=900mm
multi.-= 2.5

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



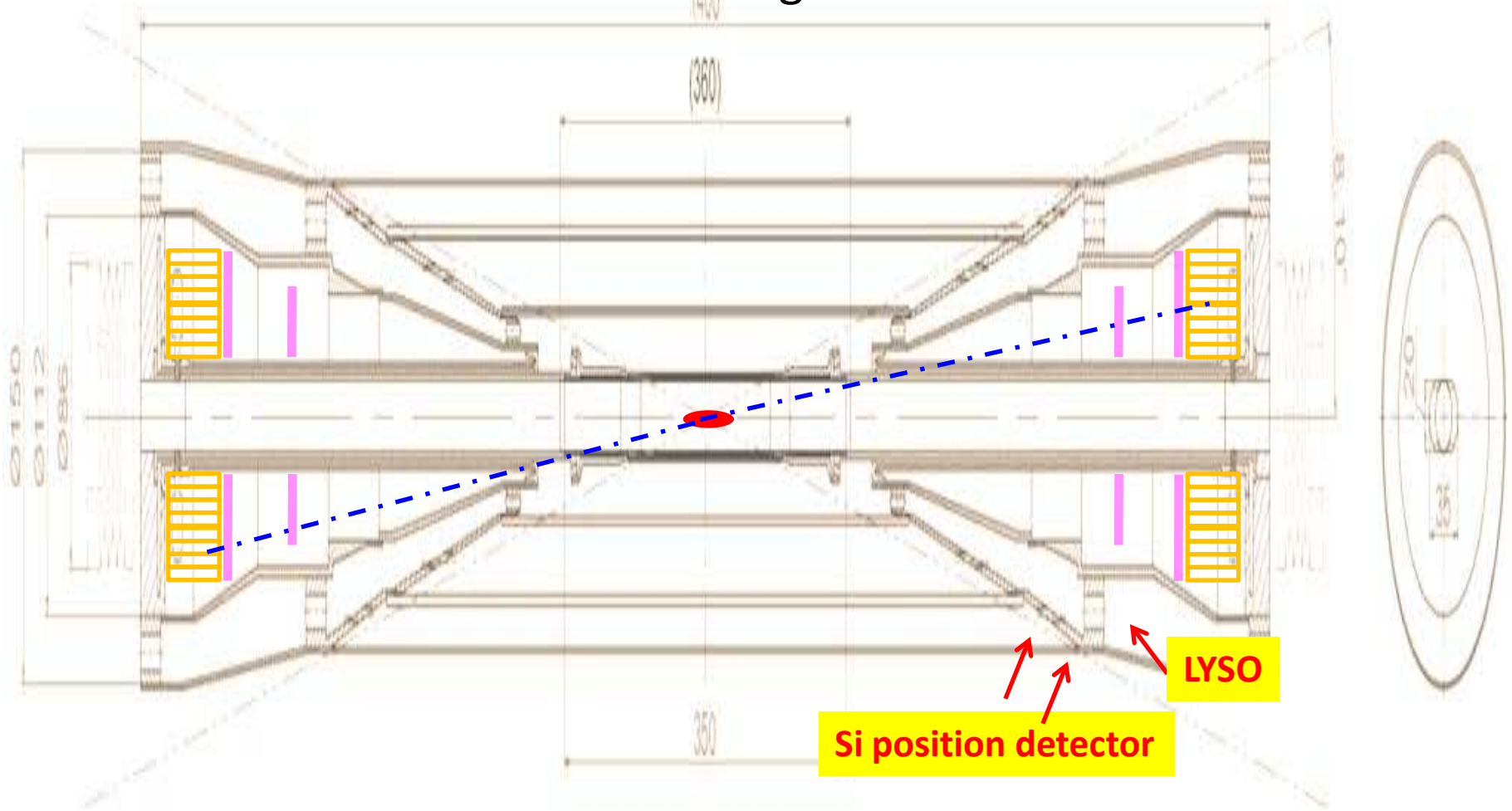


LumiCal to 1 μRad precision

1. IP beam spot 2.5mm spread
2. beampipe multiple scattering

1. tracking on IP position

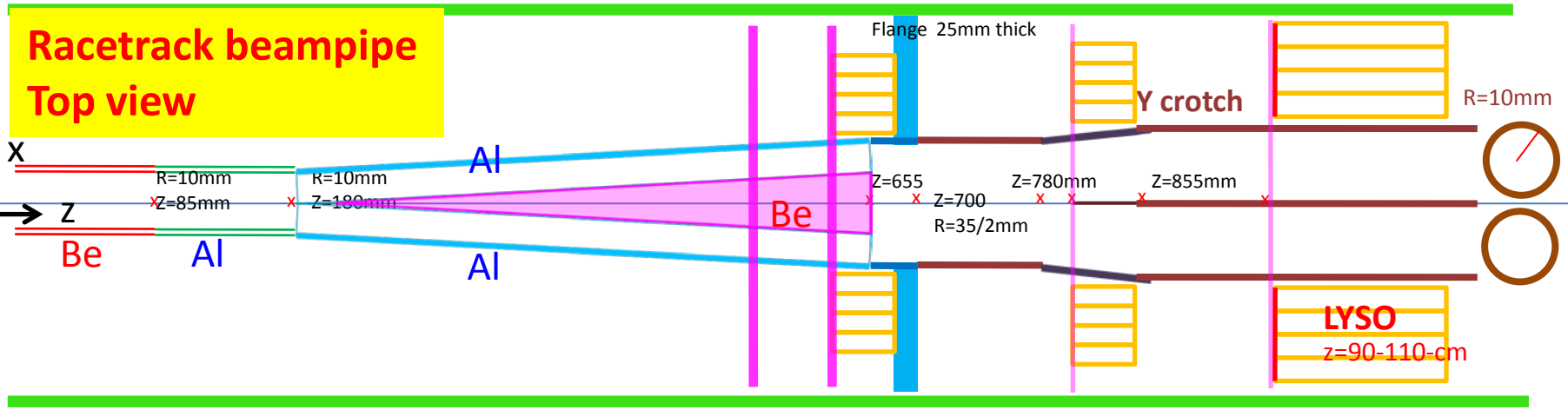
- **Beam spot σ_z = 2.5 mm :**
  need Bhabha electron tracking



2. Reduce Beampipe material

- **Low-mass beam-pipe window :**
  less multiple scattering

Low-mass window **<0.07 X_0 (20mR) window:**
single layer Be slab **0.5mm**

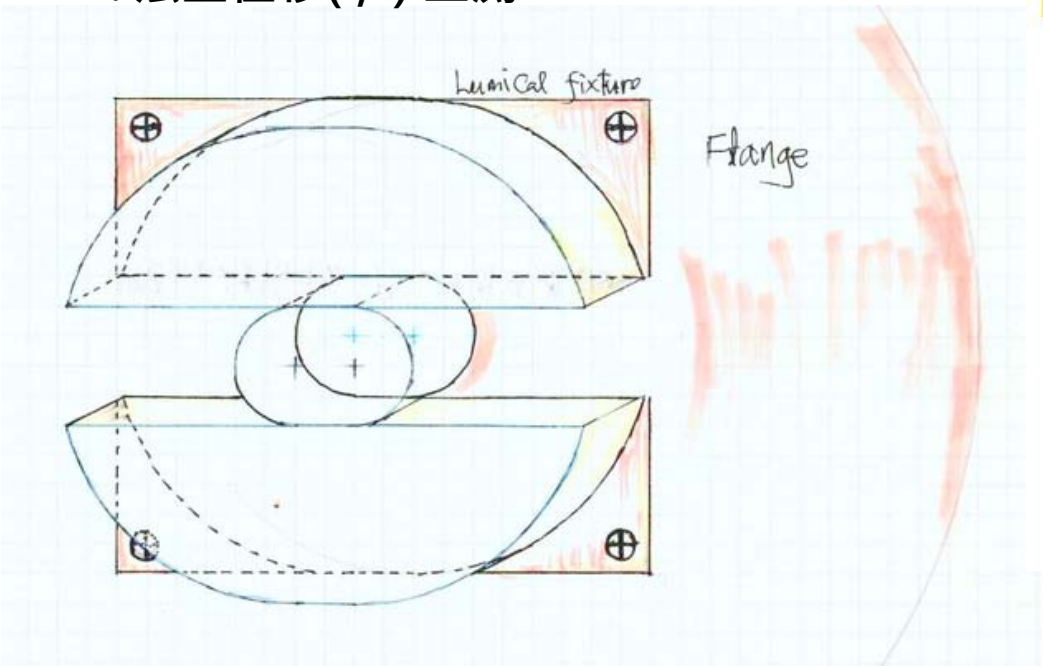


Mounting LumiCal on Flange/SC-magnet

LumiCal precision, 1 μRad to the IP ➔ survey/monitor:
Survey of detector edges w.r.t IP, beampipe center to <1m

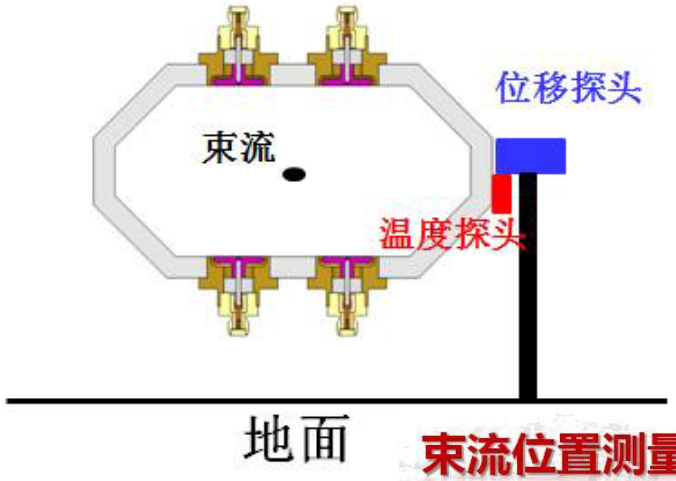
1. x,y w.r.t BPM position
2. add Z position monitor

1. 架上法蓝后定位测量
2. 法蓝位移(r,z) 监测



微米级精度

- 温度引起的形变，改变电中心、机械中心

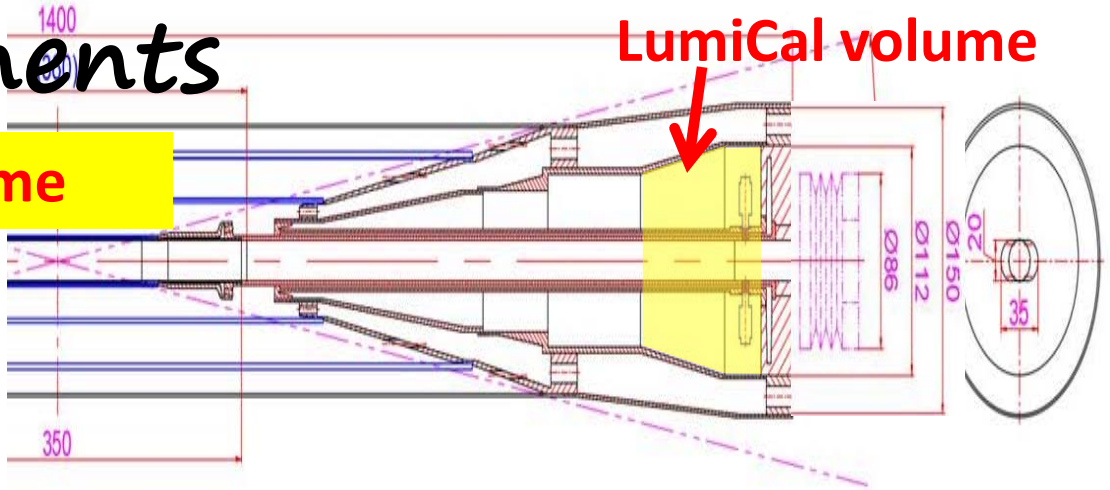


束流位置测量

随艳峰、何 俊
高能所加速器中心束测组
2022-05-06

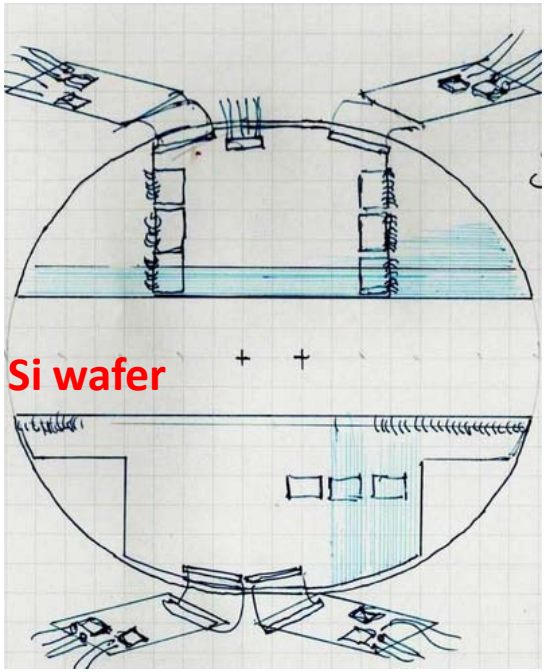
LumiCal conponents

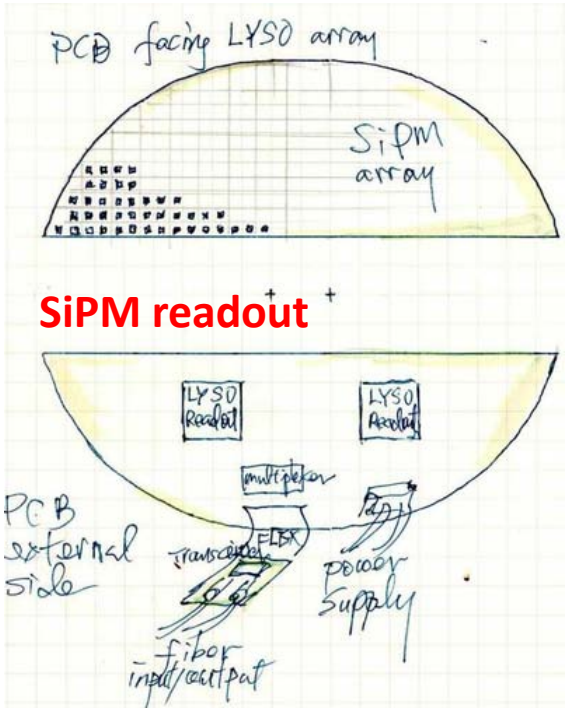
Before flange, VTXdet volume

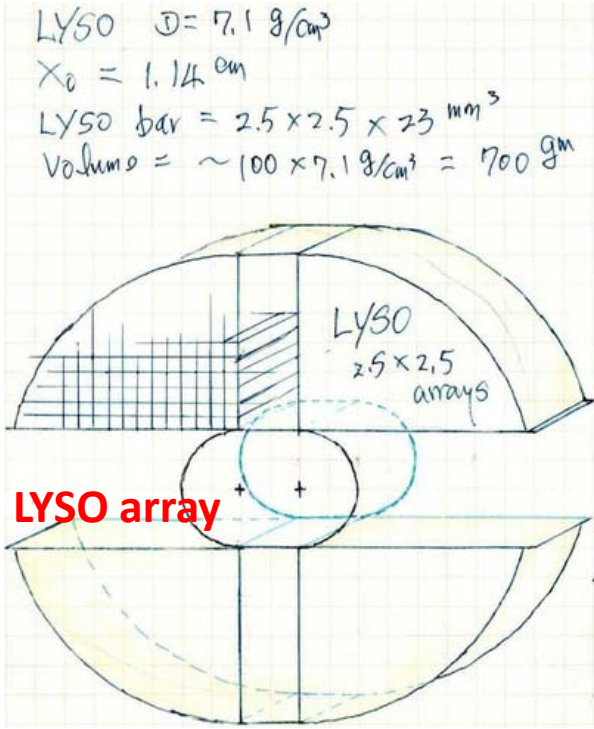


Precision electron θ
e/ γ identification

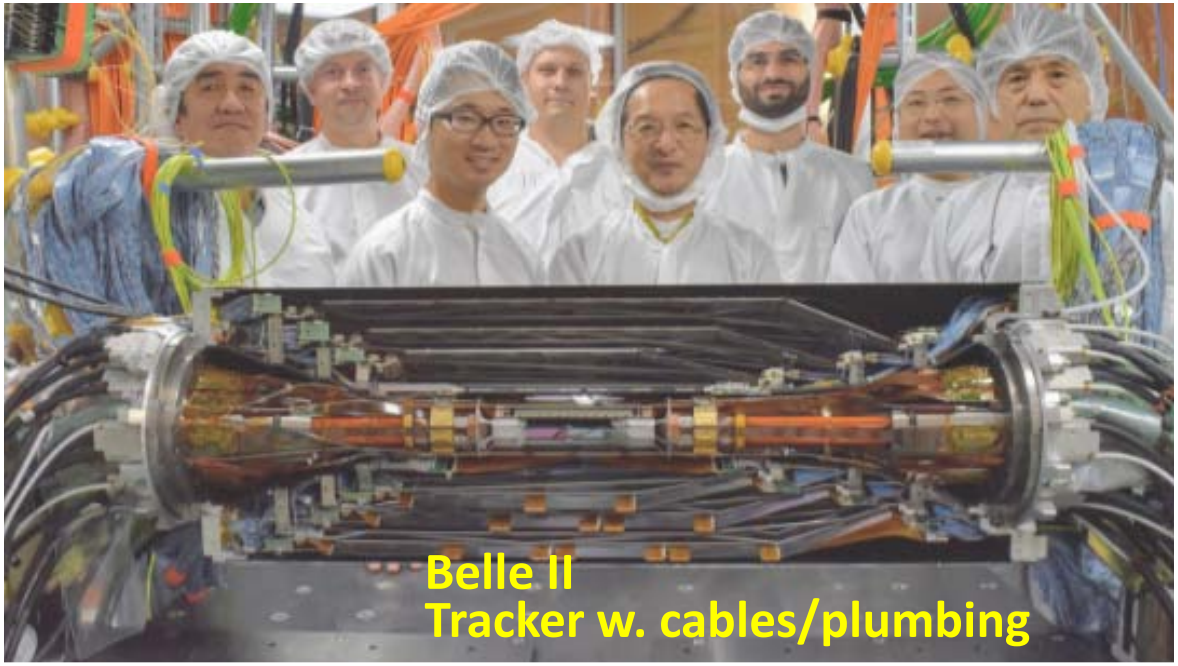
- **Si tracking layers :** $\sigma_r < 5\ \mu m$
- **LYSO array, $2X_0$:** $2.5 \times 2.5 \times 23\ mm^3$



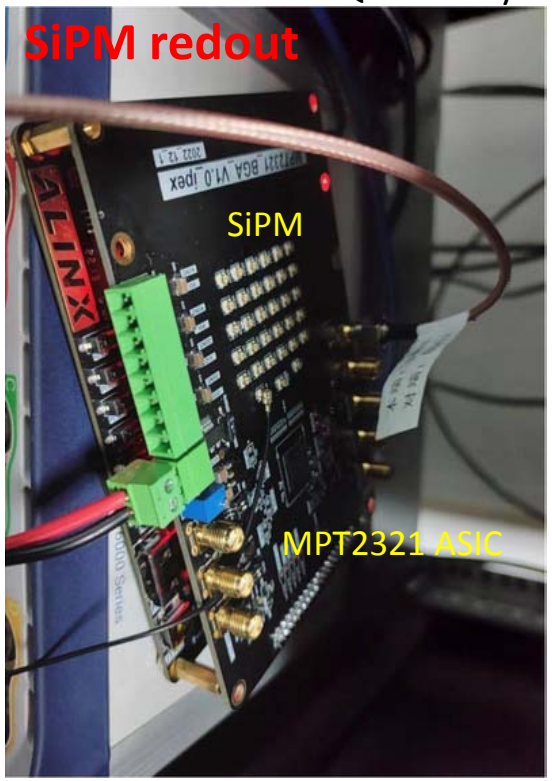


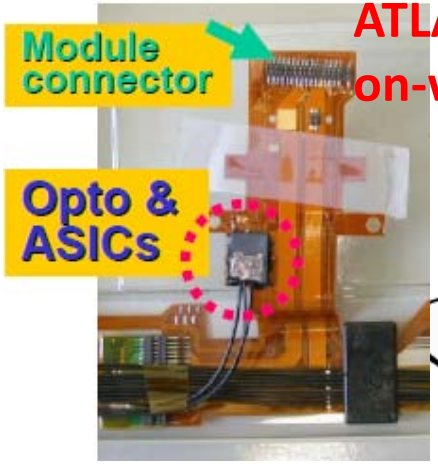


Example technology

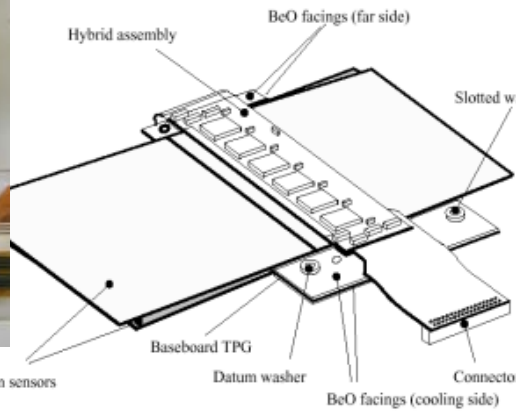


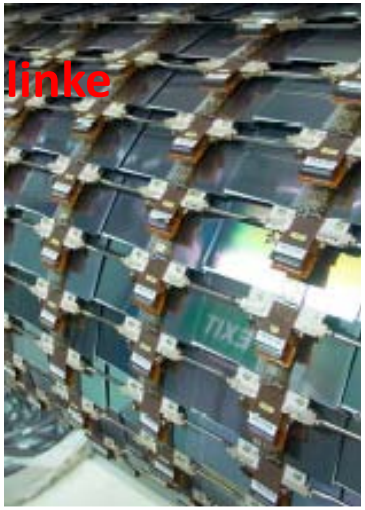
MPT2321 B. Qi Ecal 03/22





ATLAS SCT module
on-wafer Frontend/optical linke

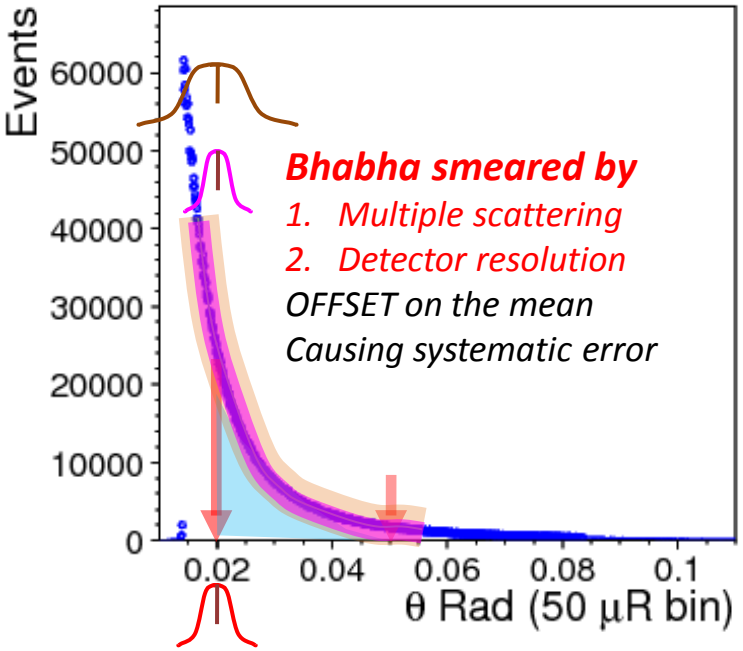




Summary, LumiCal to 10^{-4} Luminosity

Ø20 mm Racetrack

- Bhabha fiducial large X-section w. **lower θ_{min}**
- **IP tracking, 0.5mm** Be beampipe window
- aim for <20 **µRad resolution**
- **error on-mean on θ_{min} → 10^{-4}**



LumiCal optimization:

before Flange is w. Si wafer + $2X_0$ LYSO :
after Bellow (6X0): $20X_0$ LYSO for $e^{\pm}$ energy

Works to do:

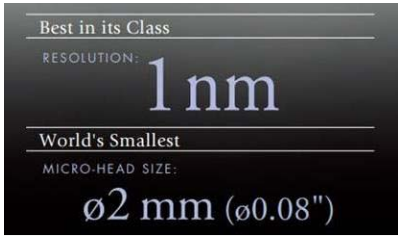
- GEANT for new configuration + BHLUMI events
  identify e/γ and Bhabha selection
- Detector electronics prototyping

Industrial measurement tools, e.g. keyence

Detector assembly precision

- measure lower fiducial edge to < 1 µm
- easy under microscope and survey equipments

AS_85026_SI-F1000_C_611297_US_1126-7



SI Series Measurement Principles (Spectral-Interference type) micro-head ultra high accuracy

AS_86990_MEASUREMENT_GC_611914_US_1018-9