LumiCal Design Options

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15:00 indico.ihep.ac.cn/event/11684/

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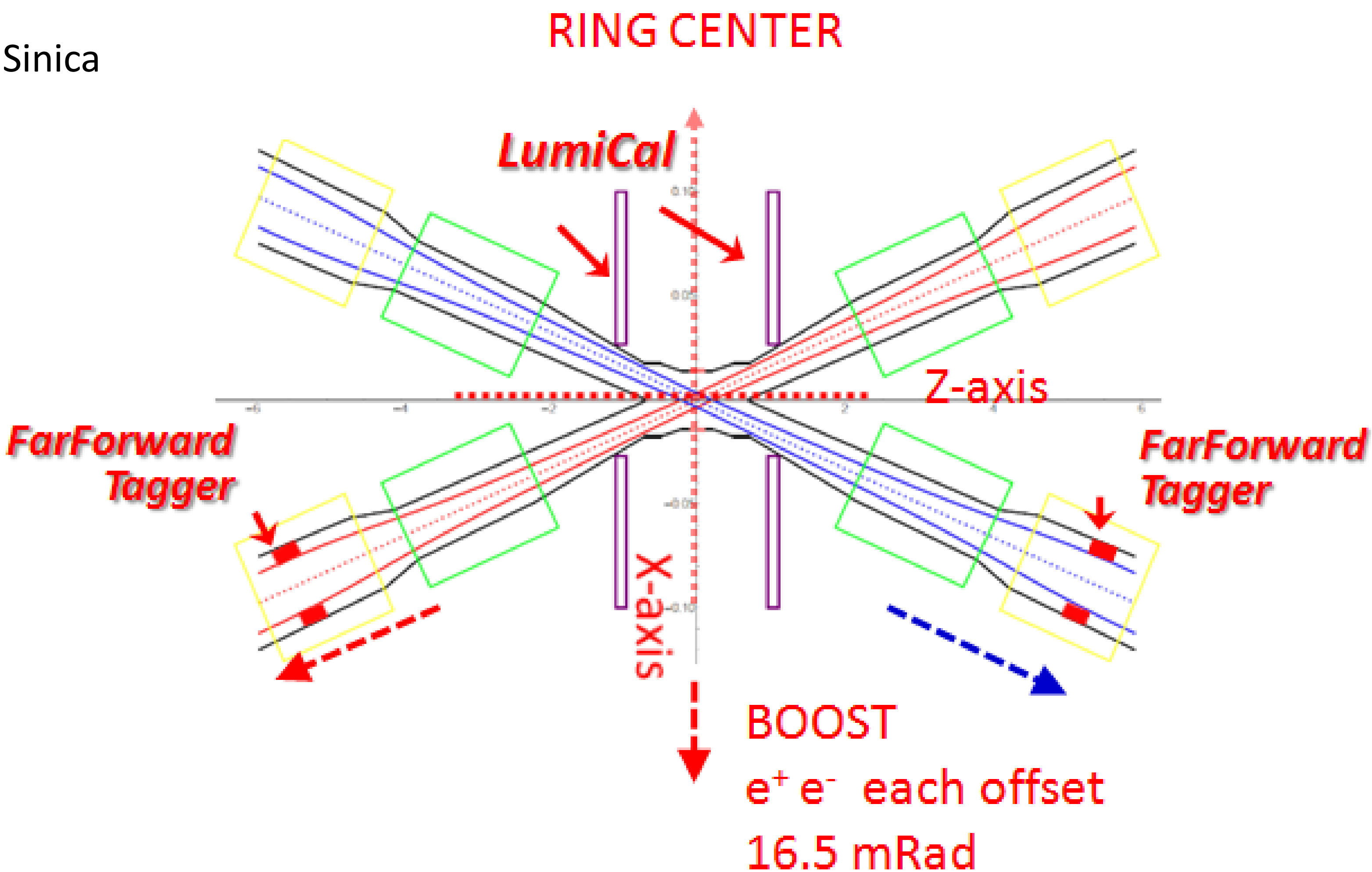


Outline

- **BHLUMI : Bhabha cross section**

  boost by beam crossing, small beam pipe

  $\theta < 30$ mRad ➔ σ(Bhabha) > ~ 50 nb

  OVAL beampipe to opmitize coverage

- **GEANT : intrinsic spatial resolution**

  beampipe cone shape

  beampipe tube shape

- **LumiDET : beampipe r, flange z → $\theta < 30$ mRad**

  Inner-Det Si volume : wafer surrounding beampipe

  beampipe Flange : Si disks

  Q-pole front : calorimeter : LYSO 2x2 mm^2 bars

  outgoing beampipe : Far-Forward Tagger

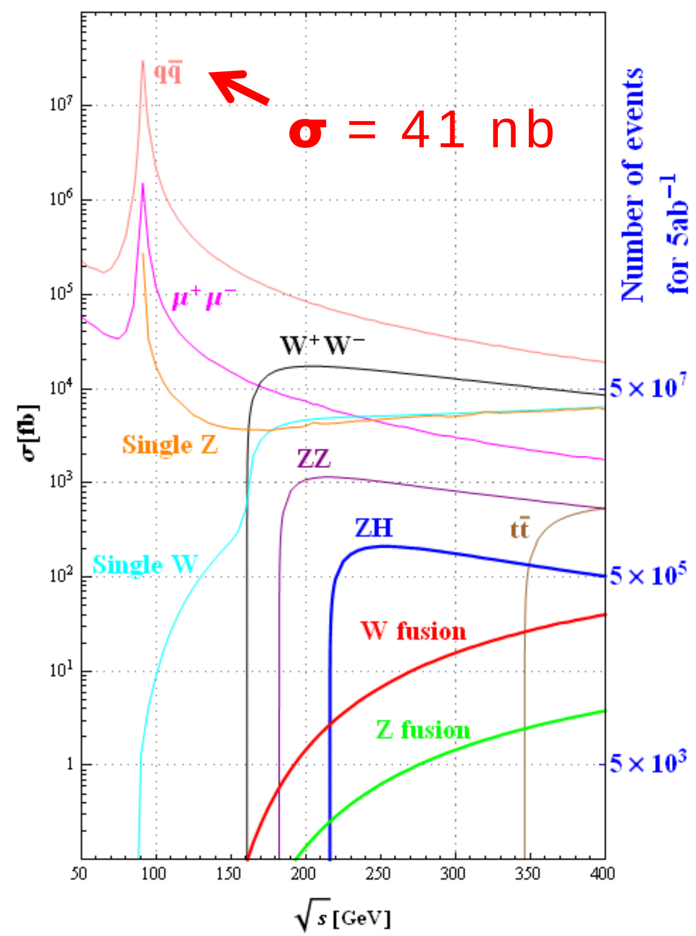
Luminosity measurement

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

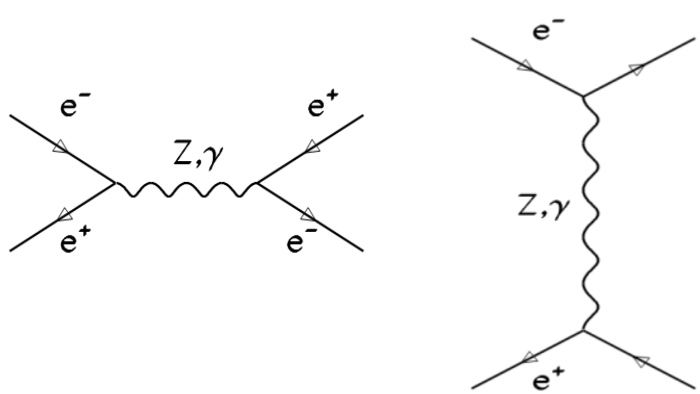
  $$e^+e^- \rightarrow e^+e^-$$

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

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



LO diagrams



Luminosity precision

Dominant systematic error

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

For a precision of $\delta L/L < 10^{-3}$

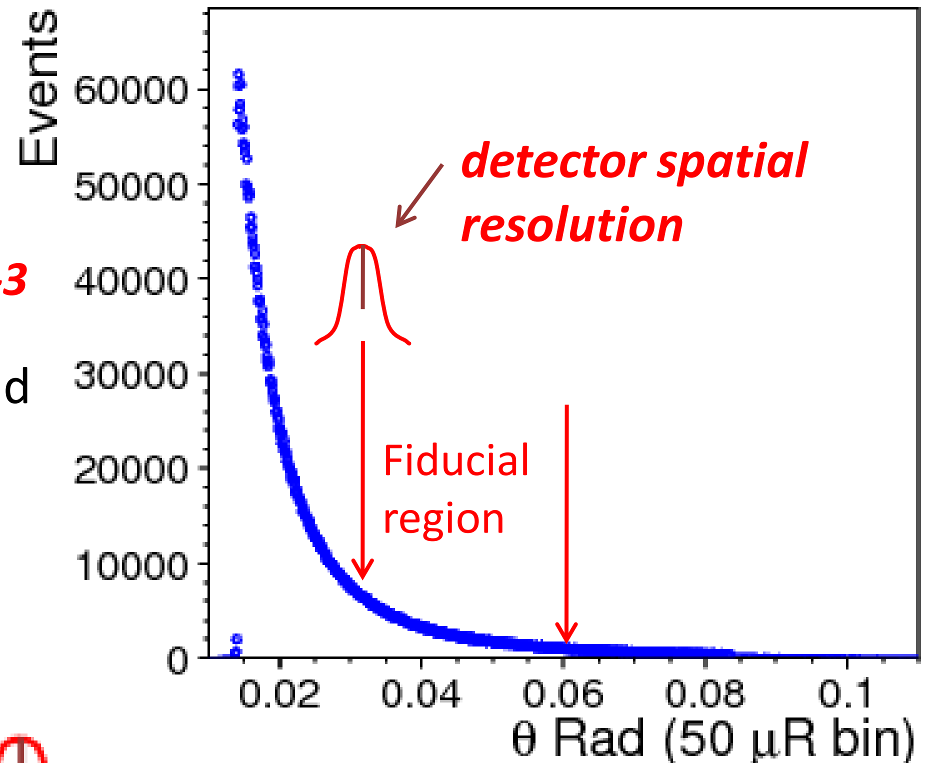
LumiCal at **z = ±1 m, ➔** θ_{min} = 30 mRad

→ $\delta\vartheta$ = 15 μRad or ***dr = 15 μm***

Error due to offset on Z

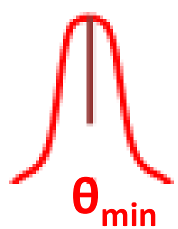
→ *0.1 mm on z* or *dr = δ Rxϑ* ***= 3 μm***

Bhabha ϑ-angle distribution



LumiDET design goal:

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



offset of the mean on $\boldsymbol{\theta_{min}}$

➔***LUMINOSITY error***

Bhabha detection

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

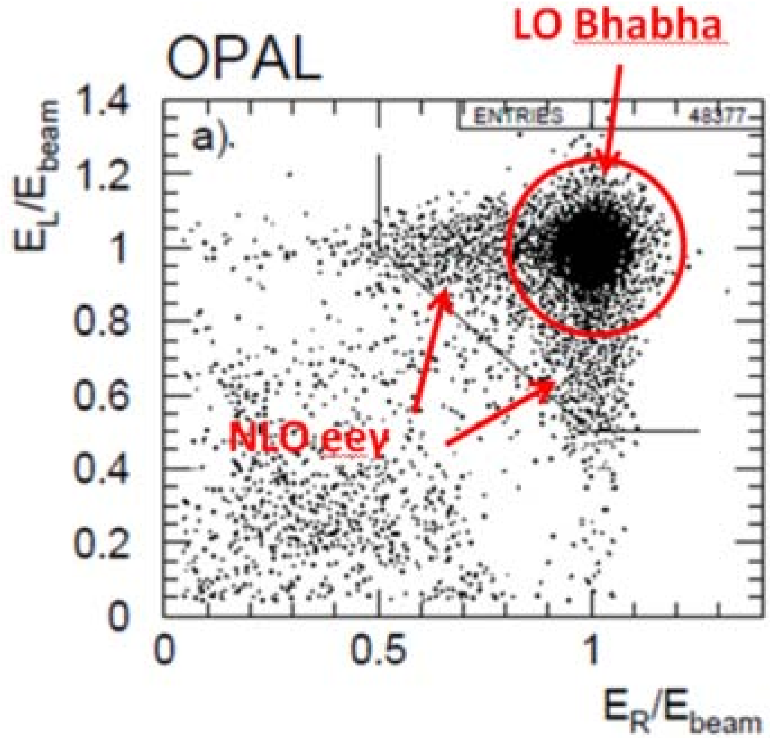
  Event signature

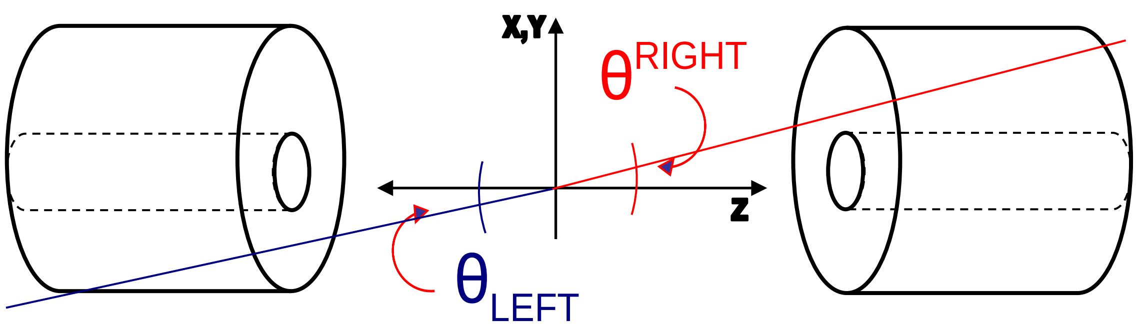
  1. $E(e^\pm) = E_{beam}$
  2. e^+, e^- Back-to-Back

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

  ~1% events

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





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

Study with BHLUMI

- scattered $ee\gamma$ distribution
- cross section
- 33 mRad beam crossing
  ➔ boosted $ee\gamma$ distribution

BHLUMI theoretical precision

Bhlumi 4.04 writeup: CERN-TH/96-158

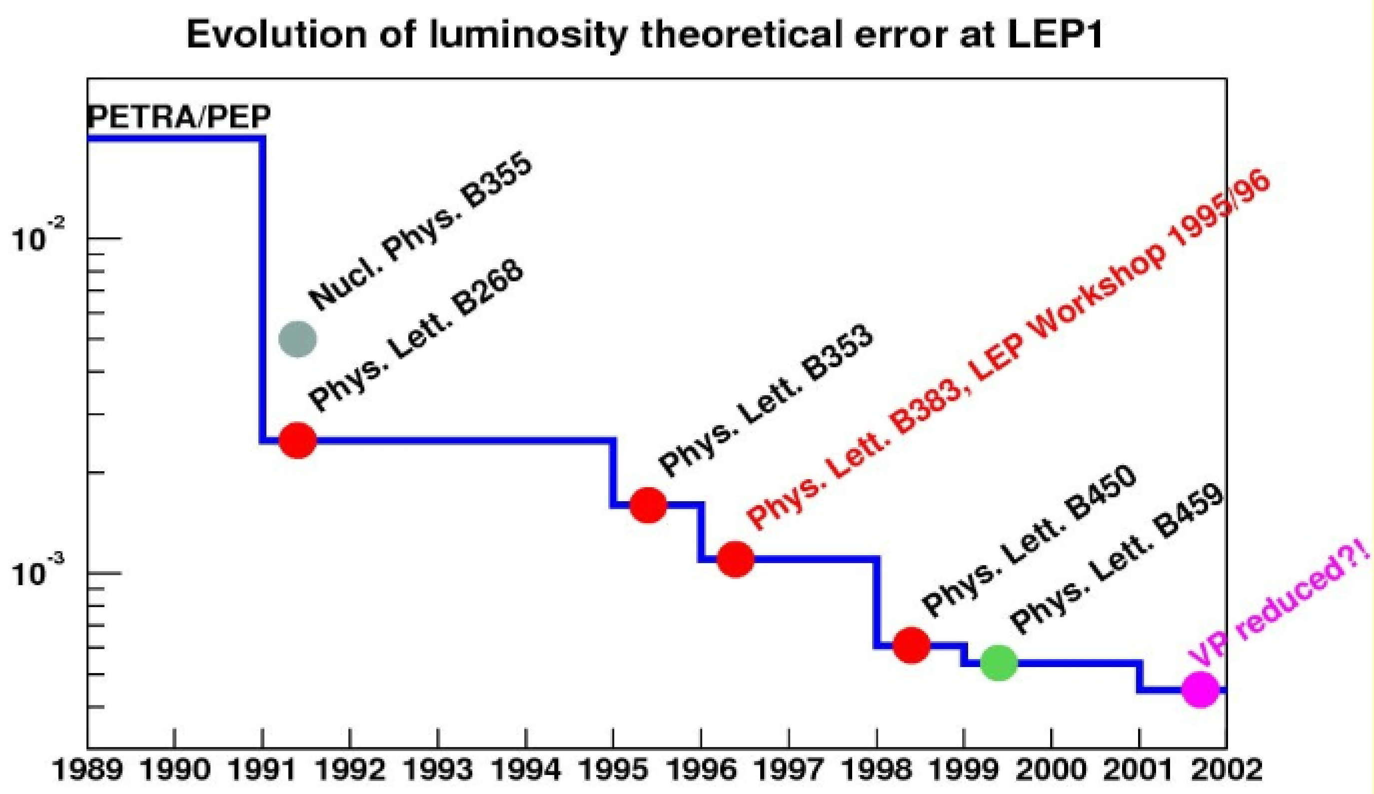
cds.cern.ch/record/310621/files/th-96-158.ps.gz

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

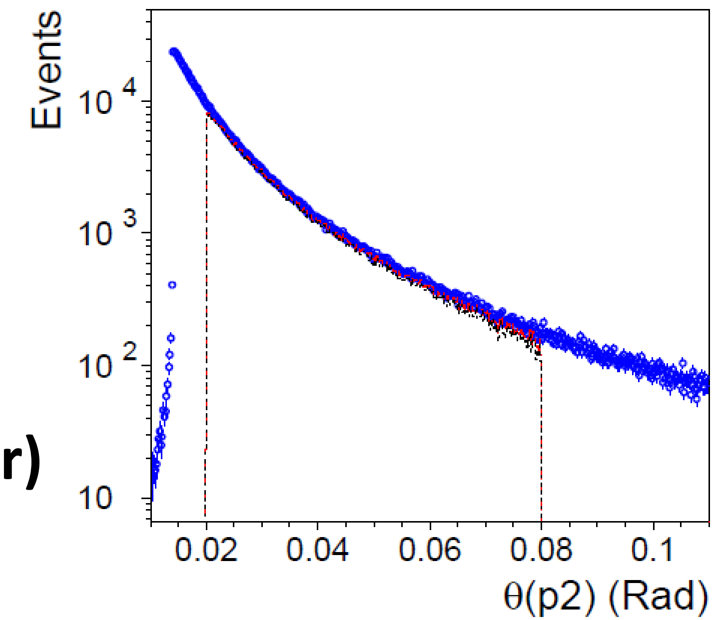
http://inspirehep.net/record/321226?ln=en

The latest BHLUMI 4 report is pushed to < 0.1%



BHLUMI calculations

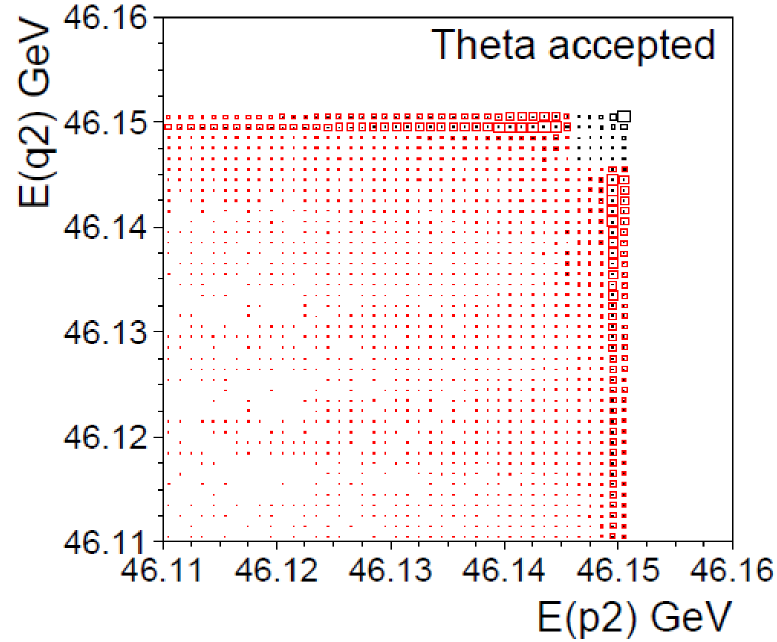
1. Theta range input : **Th1, Th2**
   Xcru calculated for Thmin=0.7xTh1 to 2xTh2
2. KeyWgt=0 ➔ event wgt=1, for simulation
   count events in chosen condition
   scale to Xcru



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: $.024<\theta_1', \theta_2' <.058$

$s'>0.5s$

```
||||||||||||||||||||||||||||||||||||||||||||||||||
Xsec_BARE1 =     169.19520371 Nanob.
error      =       0.67481969 Nanob.
Xsec_CALO2 =     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, CALO2 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

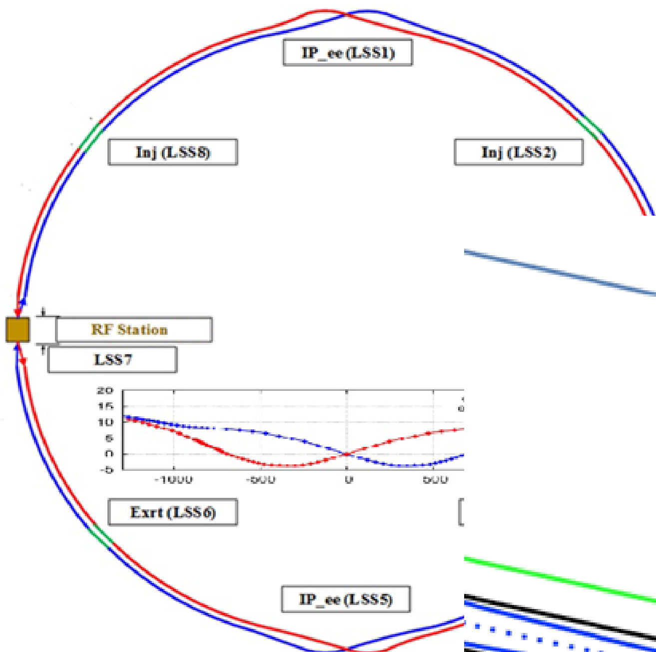
Hep-ph/9602393

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

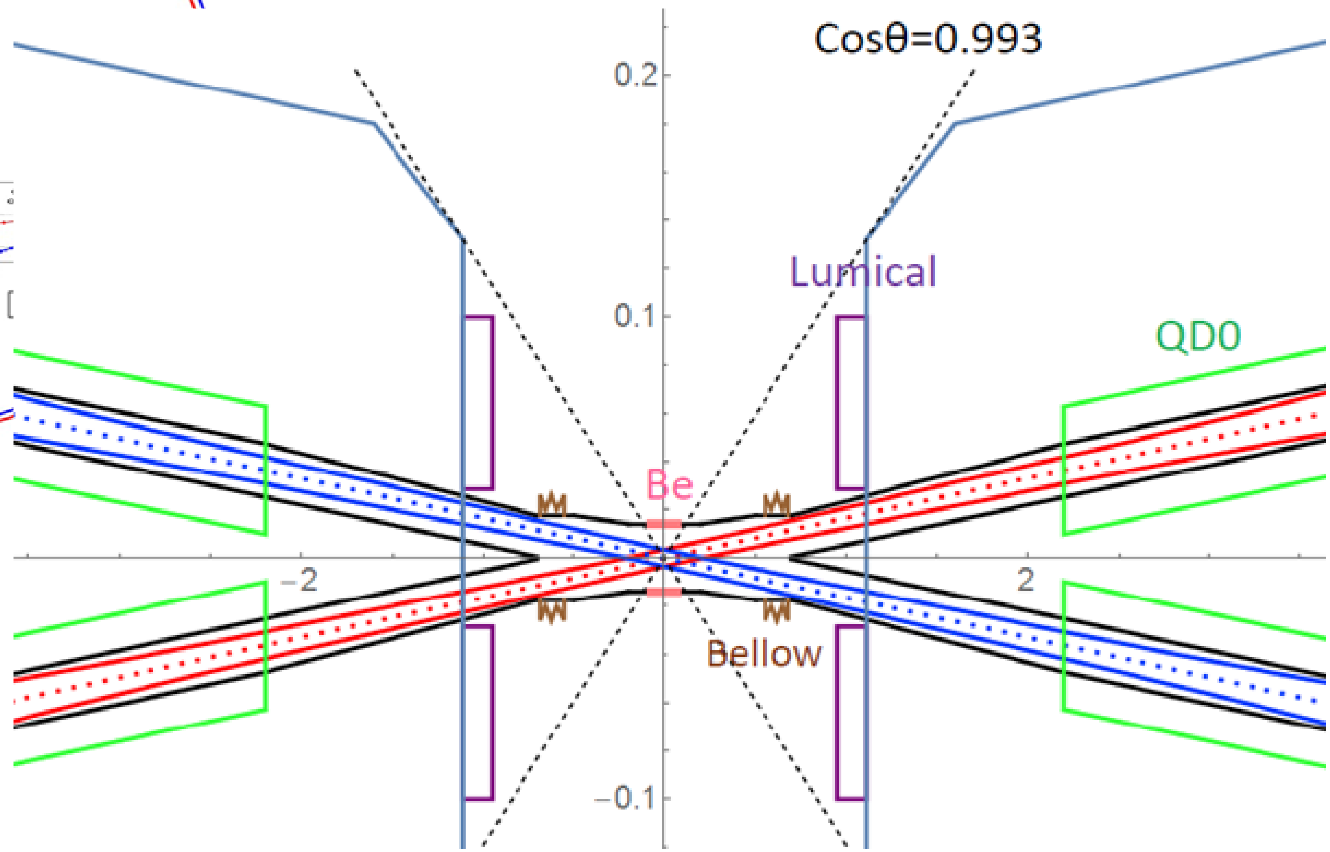
CEPC beam crossing

CEPC double Ring

Beam crossing 33 mRad



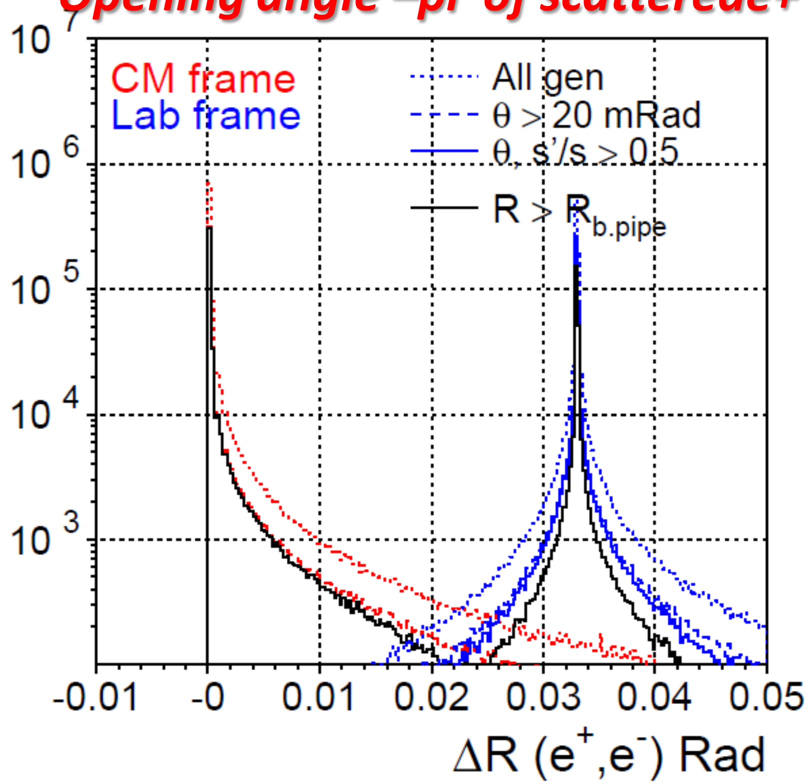
Focal length:
L* 1.5m → 2.2 m



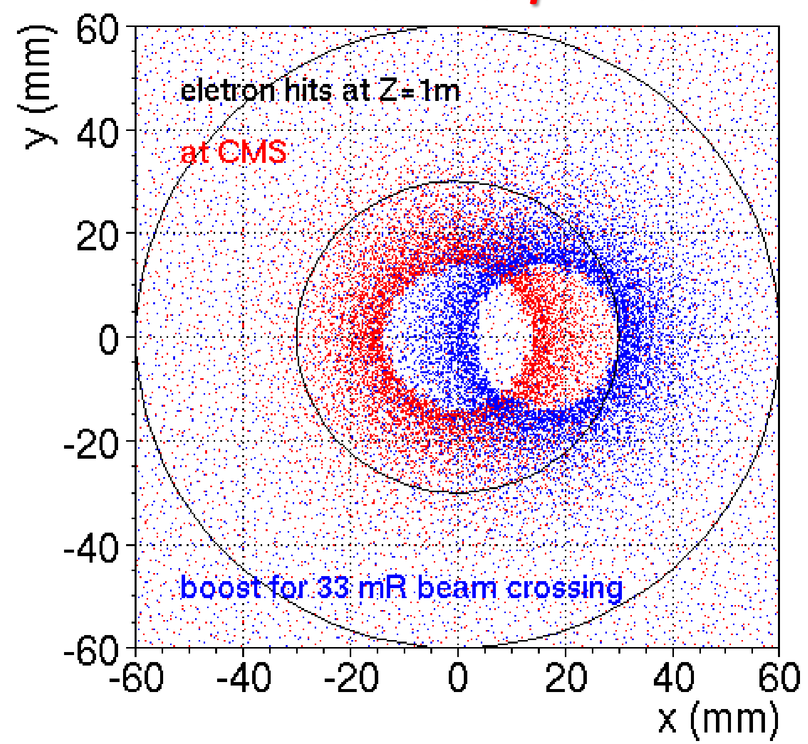
Bhabha back-to-back boosted by 33 mRad beam crossing

- 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



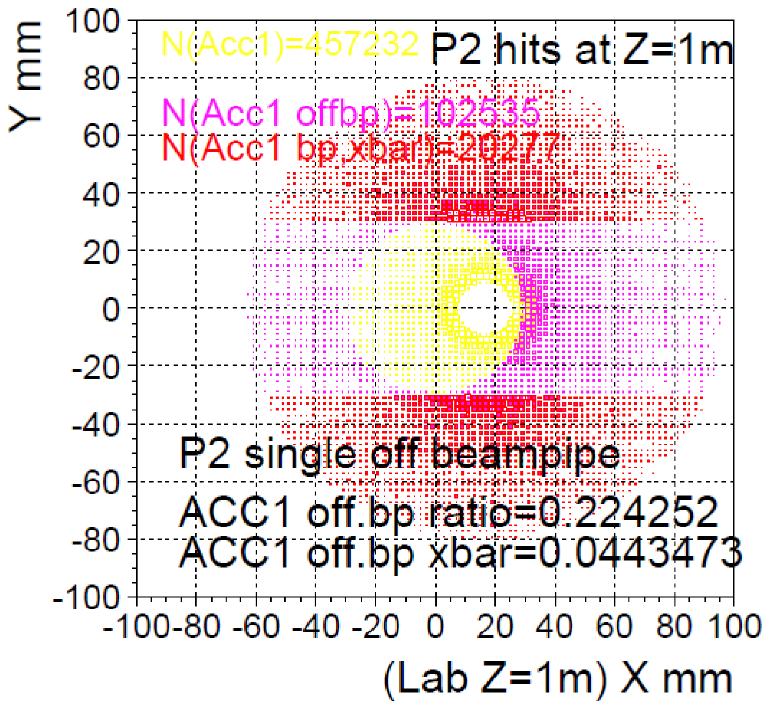
Bhabha X sec. vs Lab z-axis round pipe

- 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

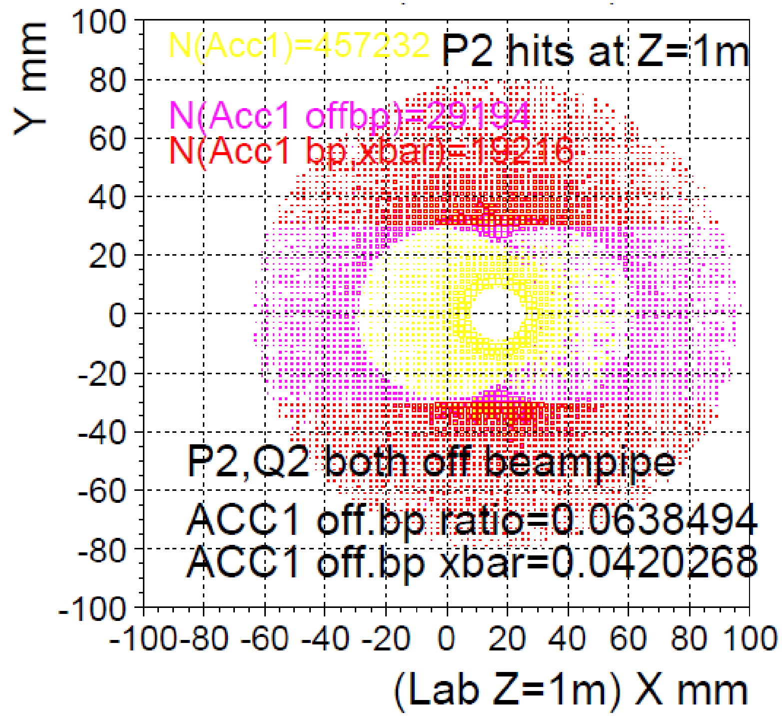
➔Off beam pipe, detect: **one electron (262 nb) / both electrons (74.6 nb) = 3.51**

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

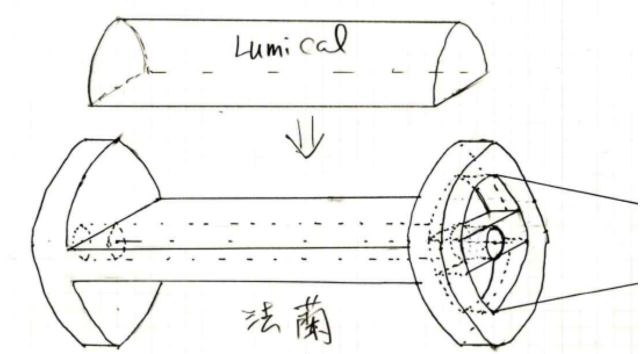
Hits of ONE Bhabha electrons

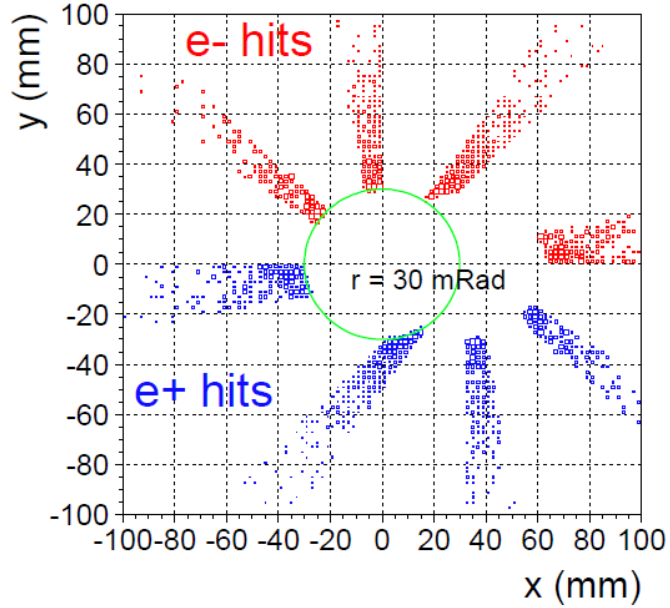


Hits of electrons, both detected



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 ±30mm	off beampipe full phi covearge	off beampipe cut off ±30mm
Nevents	457232	135842	24236	34847	23010
Xsec (nb)	1168.3	**347.1**	**61.93**	**89.04**	**58.80**

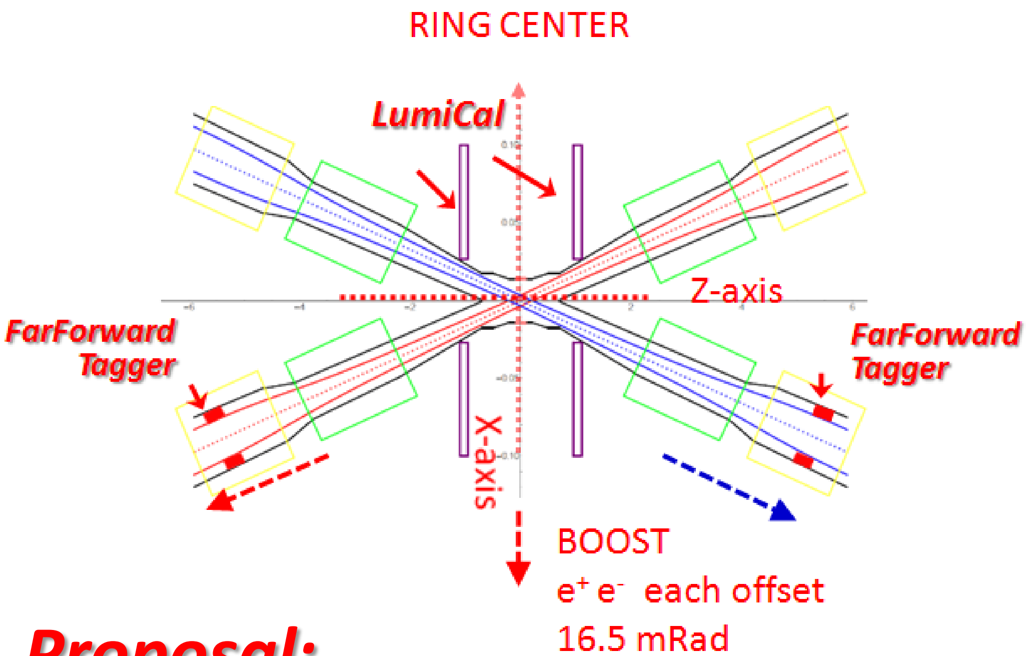
Bhabha ONE electron detection w. Far Forward Tagger

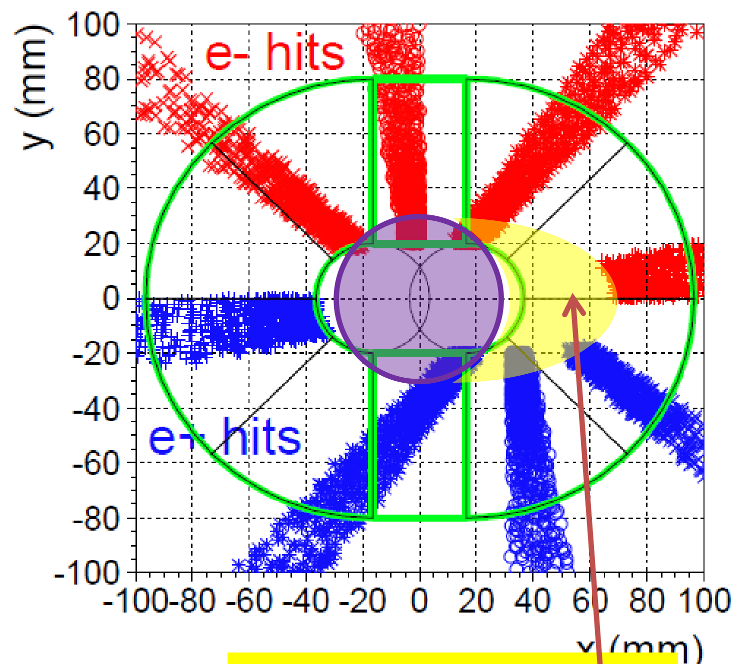
Beam crossing: 33 mRad

→ Boost off ring center (+x axis)

→ offset 16.5 mRad maximum
(electrons on x-z plane)

LOW angle Bhabha on x-axis
one electron detected (+x side)
the other electron (-x side)
is boosted into beampipe
NOT counted for Lumi meassurment





Proposal:

***Far Forward Tagger* on outgoing pipe**

→ trigger/back-to-back of low angle electrons

***→ < 50 mRad on x-axis* lost into beam pipe**

Very hot region,
Low angle Bhabha
boosted outward

BHLUMI study summary

- 33 mRad boost to +x direction
  Lab frame asymmetrical coverage
- Bhabha Θ_{min} ~30 mRad for ~50 nb
  having both back-to-back electrons detected
- An OVAL shape Beampipe
  space to LumiDET in y ➔ gain to Bhabha
- F.F tagger to trigger Bhabha
  w. one electron in LumiCal fiducial region

LumiCal in MDI region

Lumi Si wafers before/behind Flange

1st impact Si-wafer <5 um

Tracker/preshower layers in flange

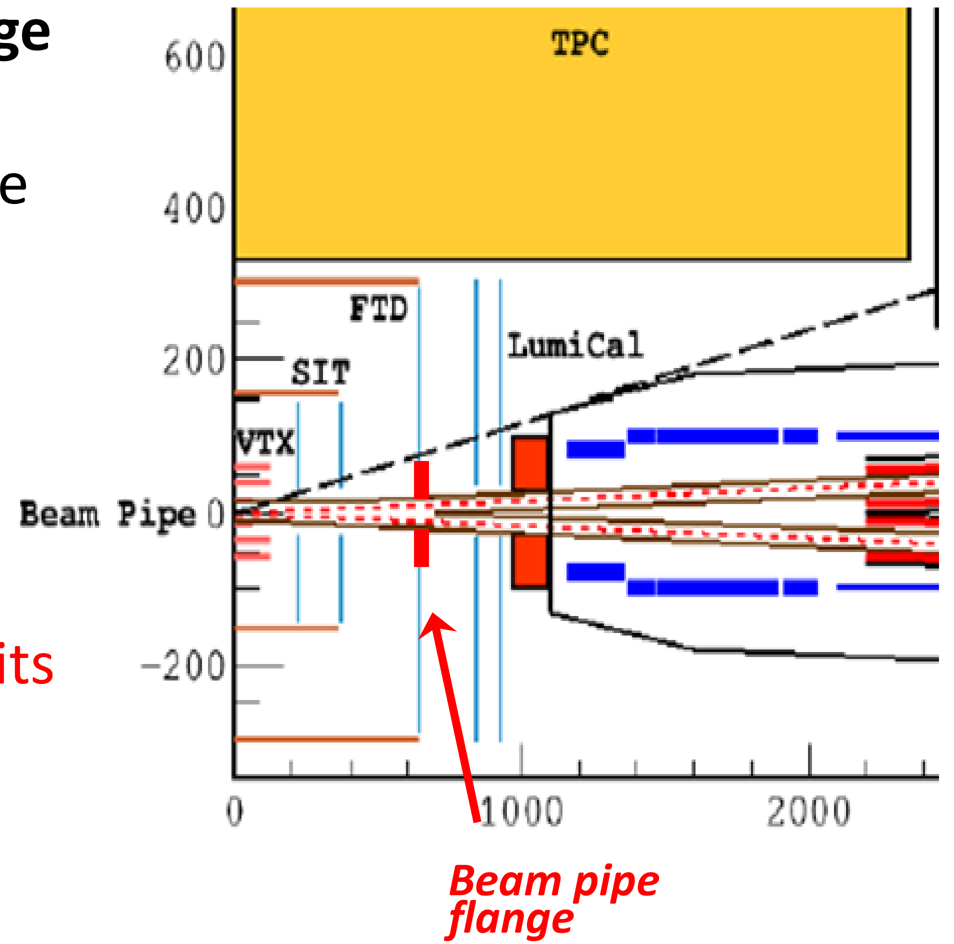
for Bhabha ID, e/γ separation

LumiCal on Quadruple @z ~ ±1 m

Bhabha electron shower energy

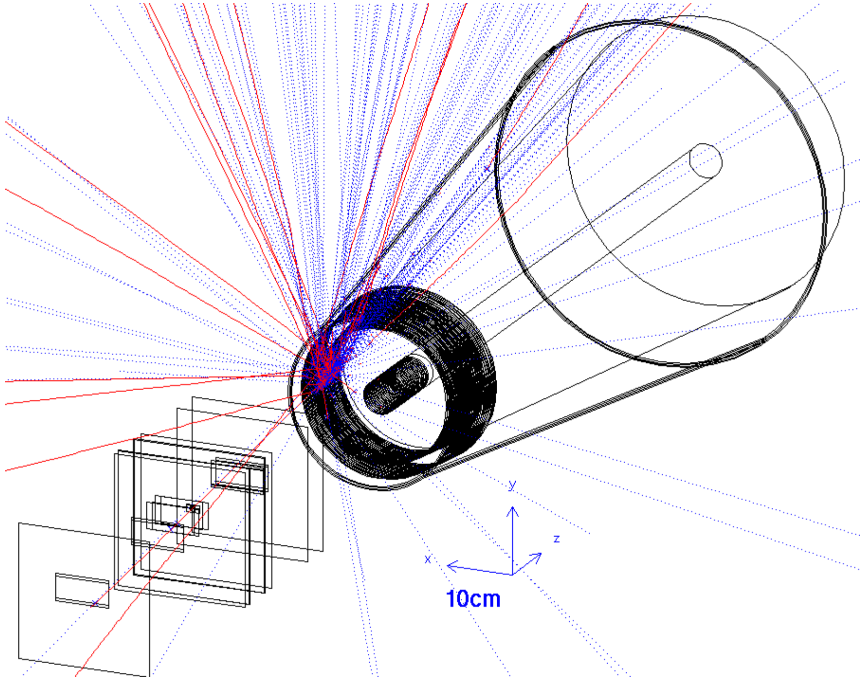
GEANT studies

- Spatial resolution of electron hits
- Shower leakage to TPC tracking volume (z to ± 2 m)



GEANT simulation for spatial resolution

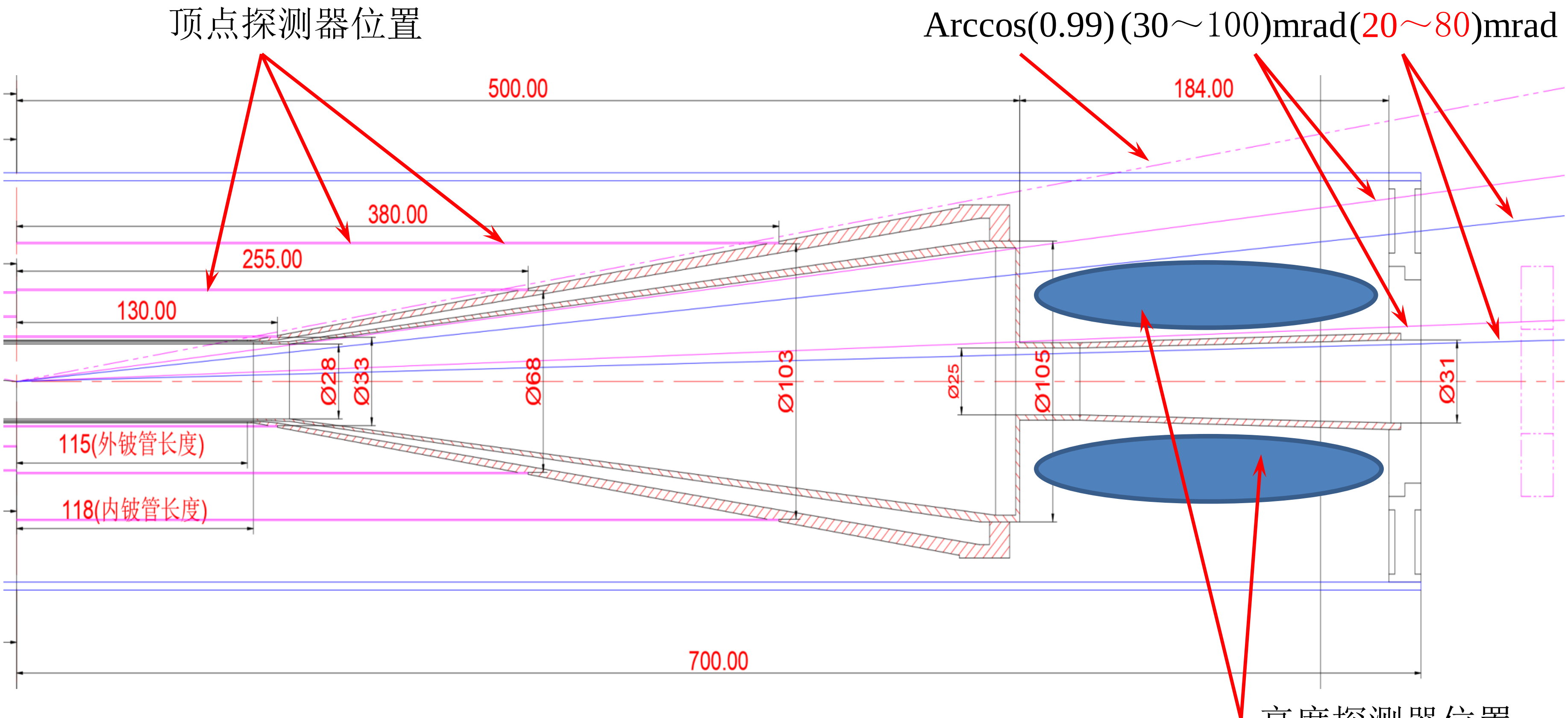
- **A package used for test-beam Si calorimetry study**
  lateral shower spectrum agree with data
- **LumiCal in CDR: a SiW sandwich detector**
  no upstream material
- **post-CDR: a Cone shape beam pipe**
  best spatial resolution
- **tube shape beam-pipe**
  ➔ spatial resolution
  w. Octagon Si wafers
  surrounding beampipe



New Beam pipe is LAB centered

Ji Quan

束流管内方案



内铍管厚度: 0.50
外皮管厚度: 0.35
内外铍管间隙: 0.5
冷却介质:1号电火花油

说明:
1.Ø25和Ø31是根据白莎的计算，最小束流管孔径
2.亮度探测器对应管道为单层管(无冷却),
需根据计算确定184mm 是否满足温度要求

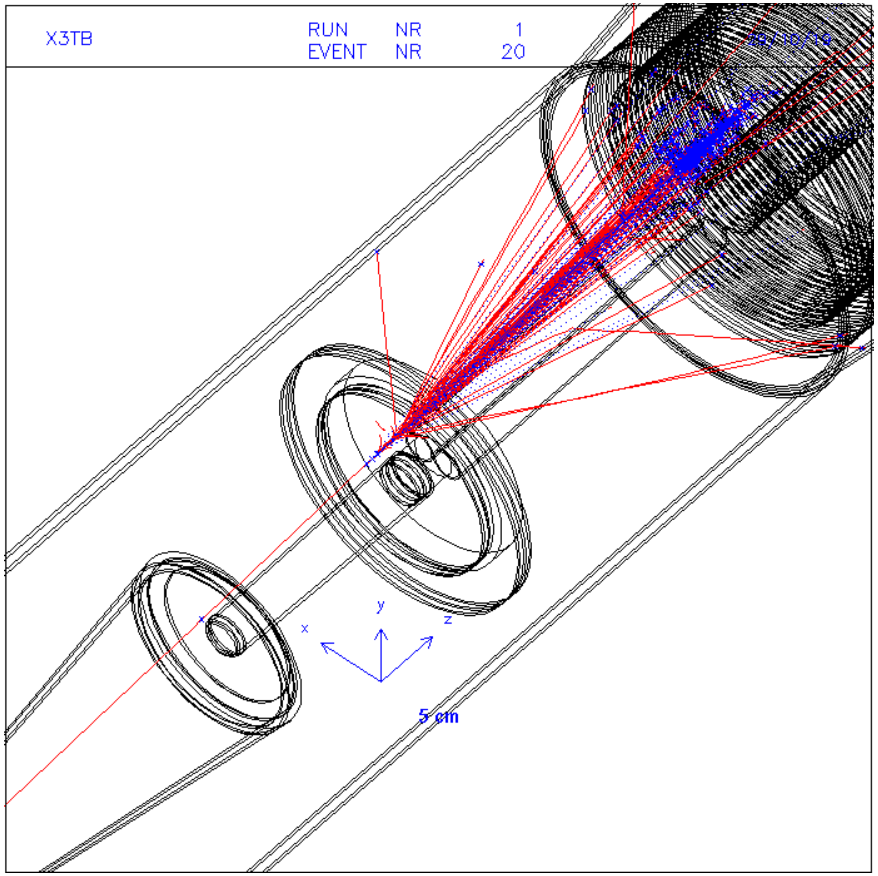
Precision on electron impact position

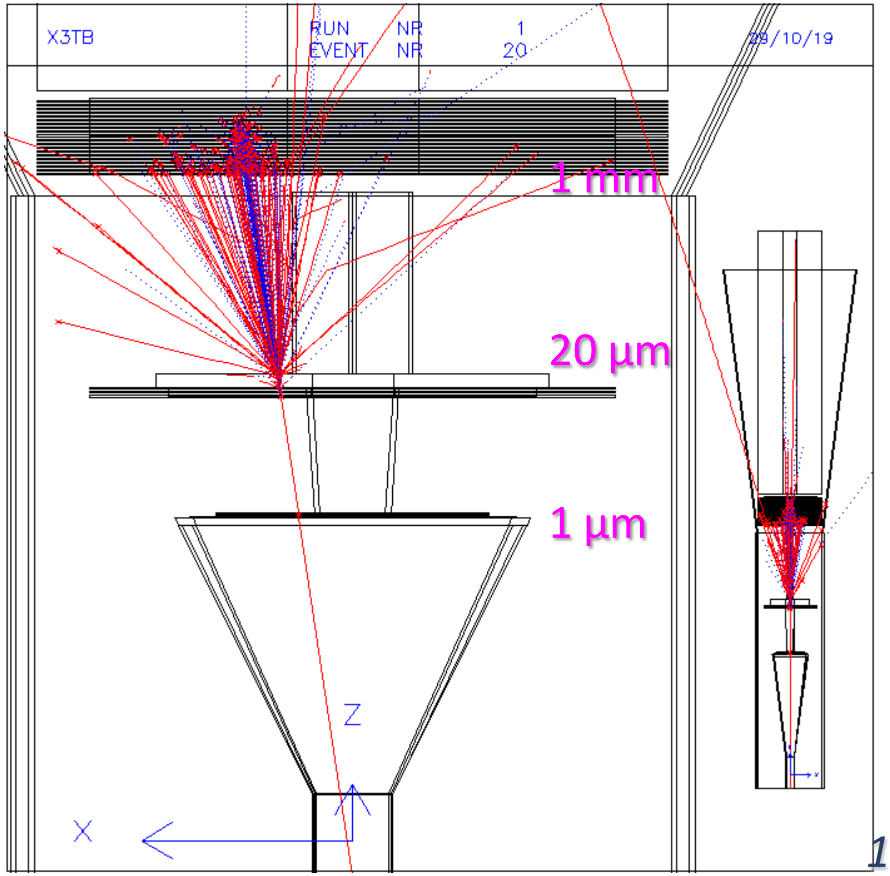
GEANT simulation precision is 0.1 MeV

Si wafer behind beam-pipe cone face, whatever material thickness,
Impact position is not effected by multiple scattering/fragmentation

➔ Better than 1 μm

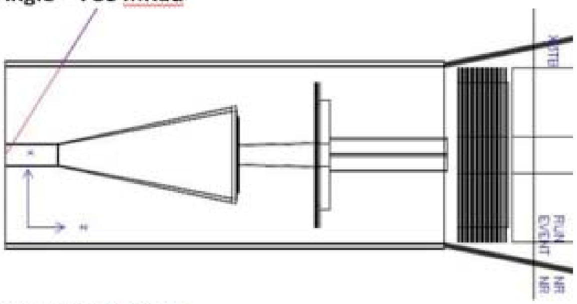
50 GeV electron, shoot LumCal center theta = 40 mRad



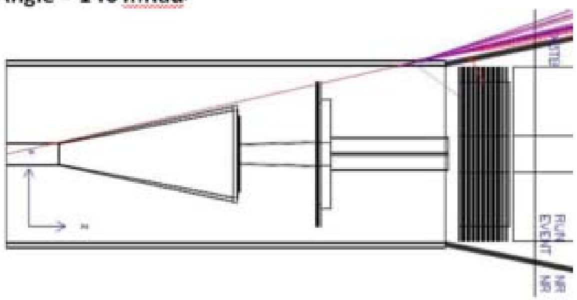


50 GeV electron shower vs. angle

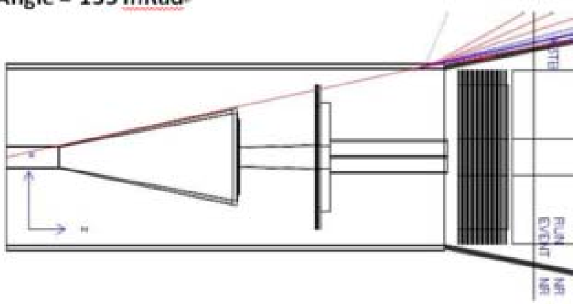
Angle = 785 mRad



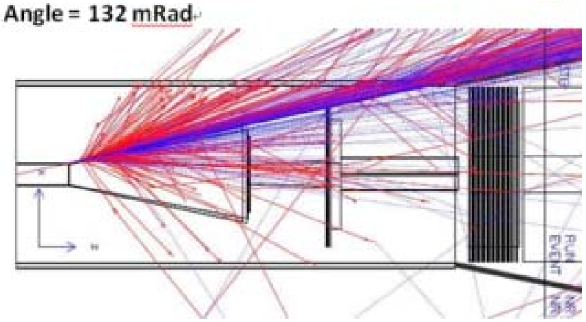
Angle = 140 mRad



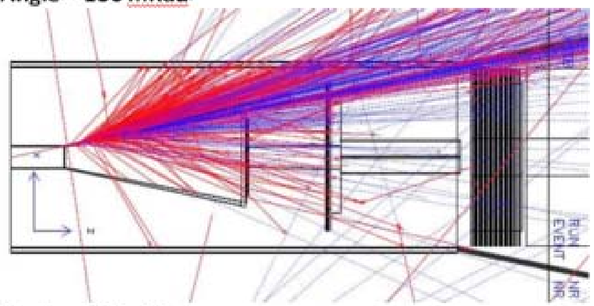
Angle = 135 mRad



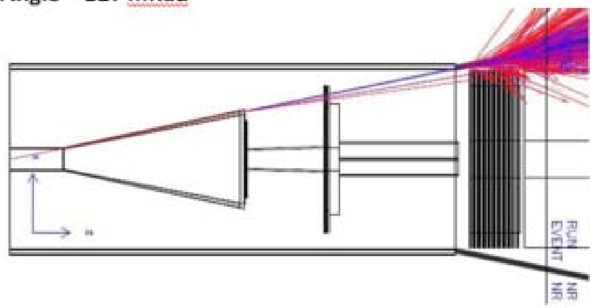
Angle = 132 mRad



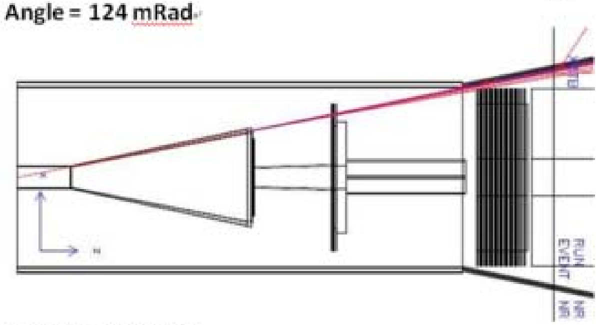
Angle = 130 mRad



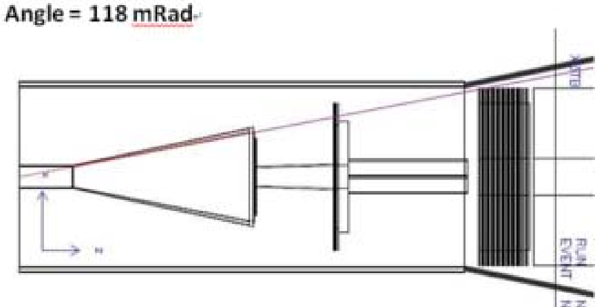
Angle = 127 mRad



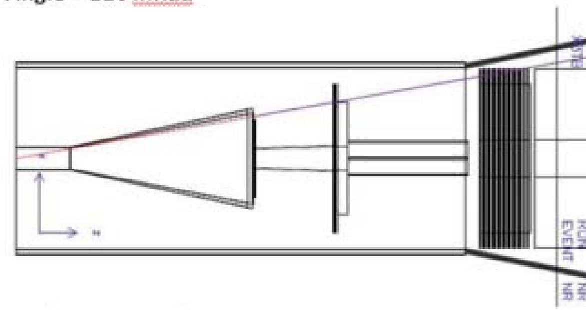
Angle = 124 mRad



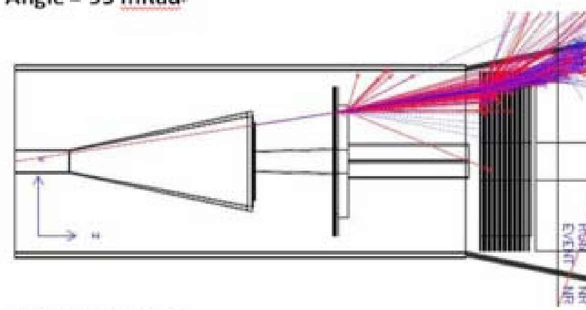
Angle = 118 mRad



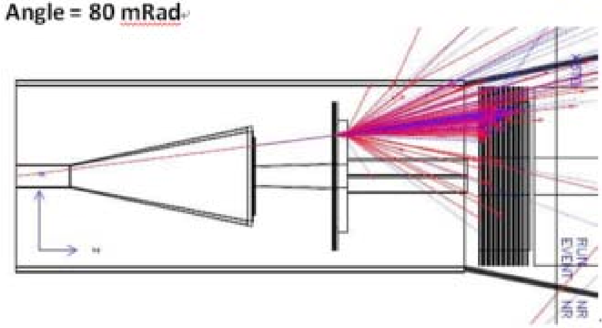
Angle = 110 mRad



Angle = 95 mRad



Angle = 80 mRad

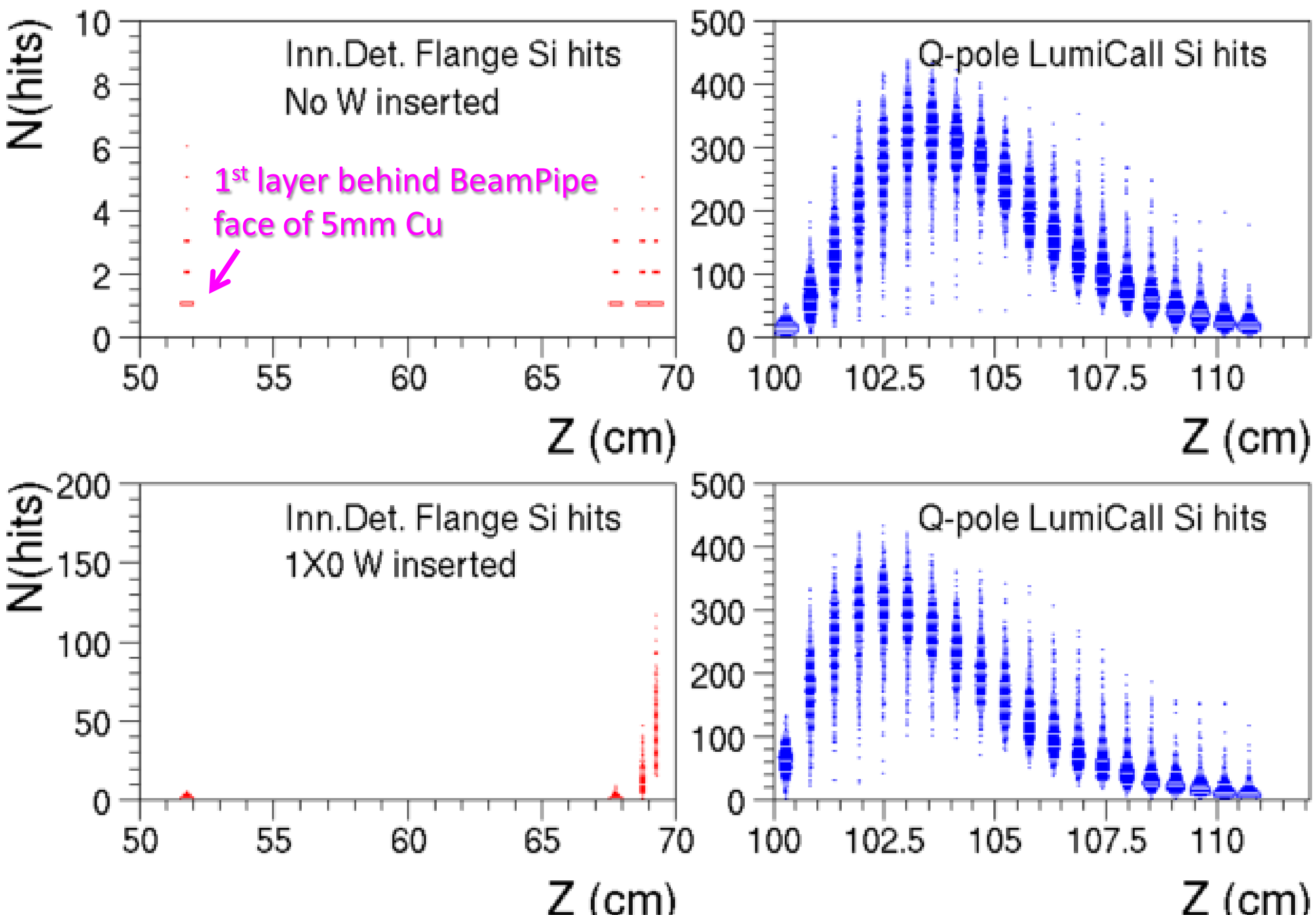


Precision on electron impact position

Compare Flange having two 1X0 Tungsten layers OR NOT

GEANT particles of 0.1MeV

Hits of shower secondaries on Si layers

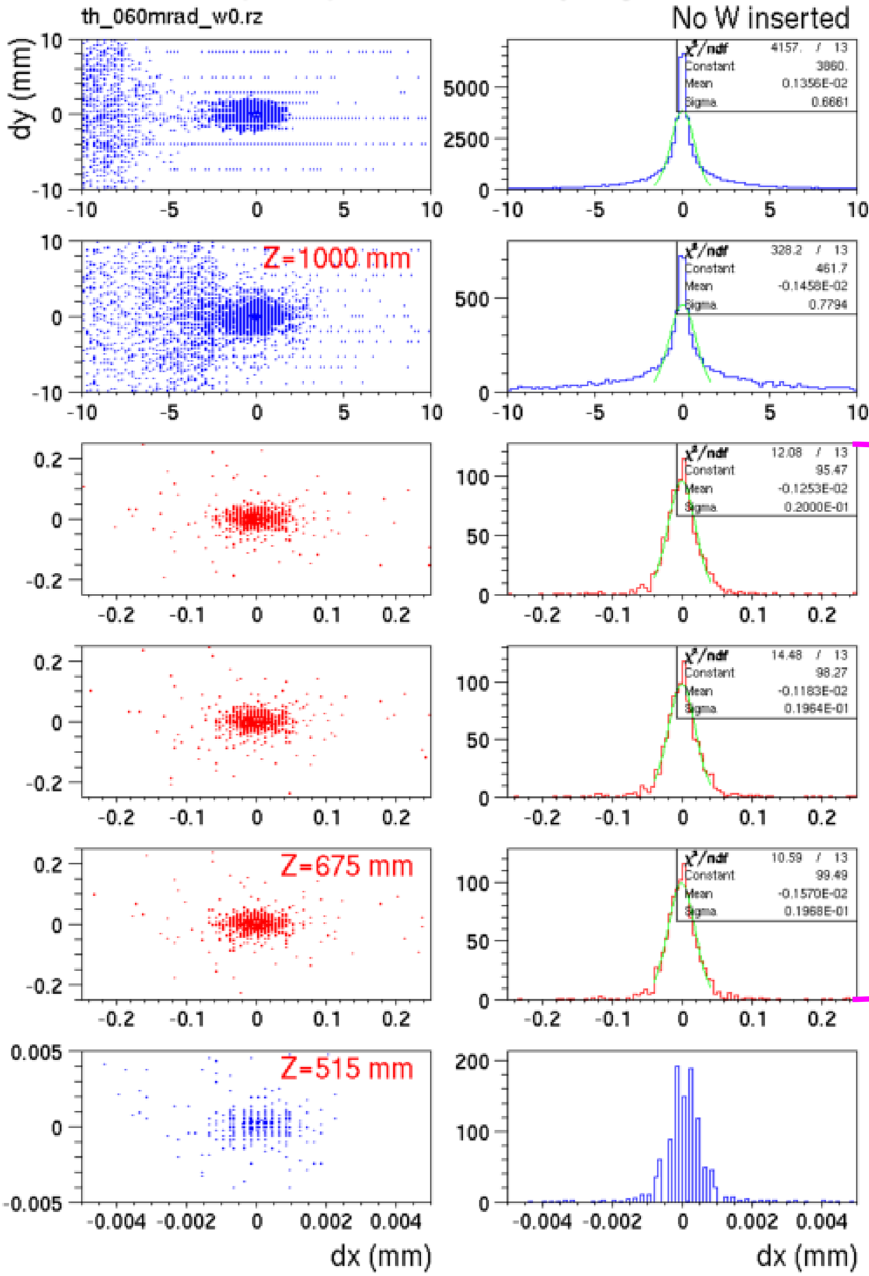


← Flange has
NO Tungsten layers

← Flange has 1X0
2 Tungsten layers

Spatial Resolution of piled up hits
(50 GeV electrons)

Position(Hits) – Electron projected



Front 2 Si-layers of Q-pole LumiCal

Pileup of shower ~1 mm resolution

Three Si layers at Z>670 mm

NO Tungsten layers

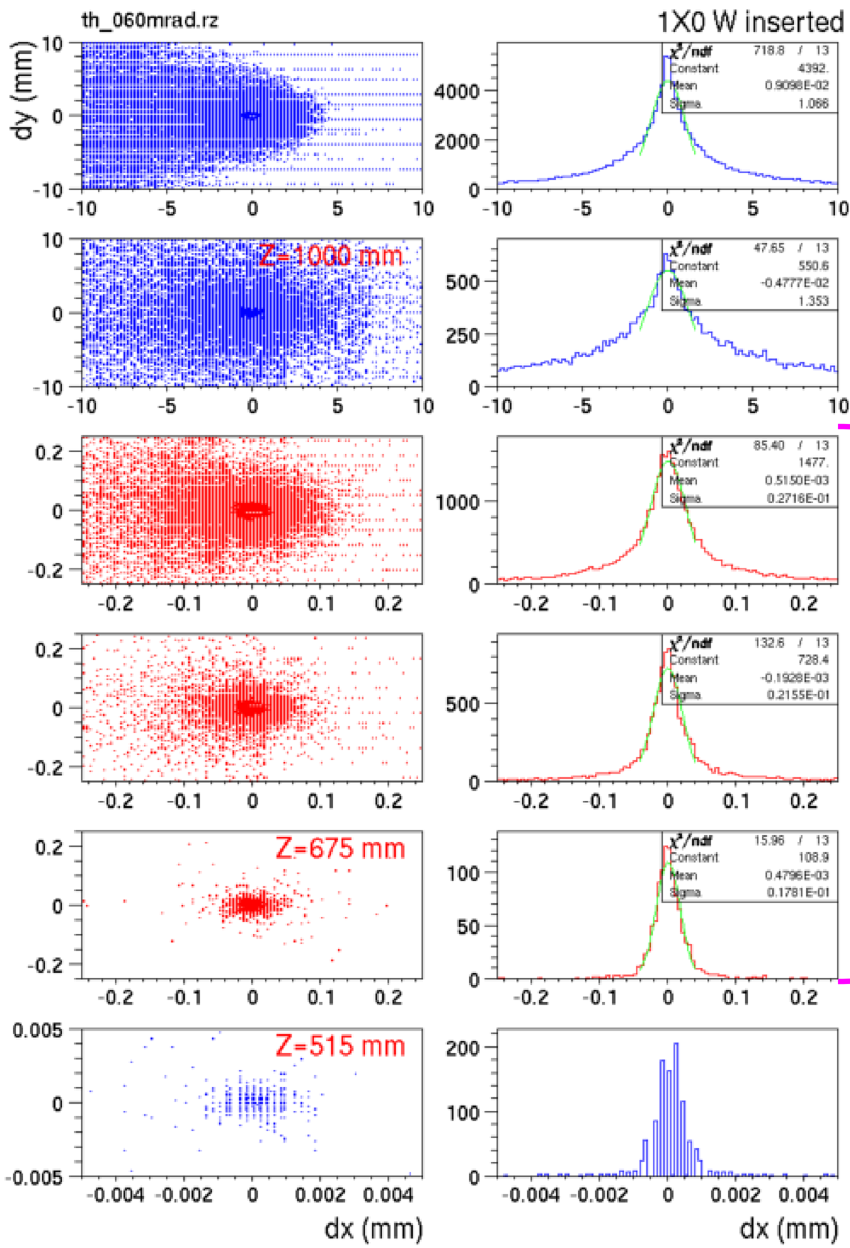
Spatial resolution ~ *20 μm*

1st Si layer behind Beampipe cone at Z=515 mm

Hit deviation better than *1 μm*

Spatial Resolution of piled up hits
(50 GeV electrons)

Position(Hits) – Electron projected



Front 2 Si-layers of Q-pole LumiCal
Pileup of shower ~1 mm resolution

Three Si layers at Z>670 mm
Two 1X0 Tungsten layers behind Si wafers
Spatial resolution ~ 20 μm

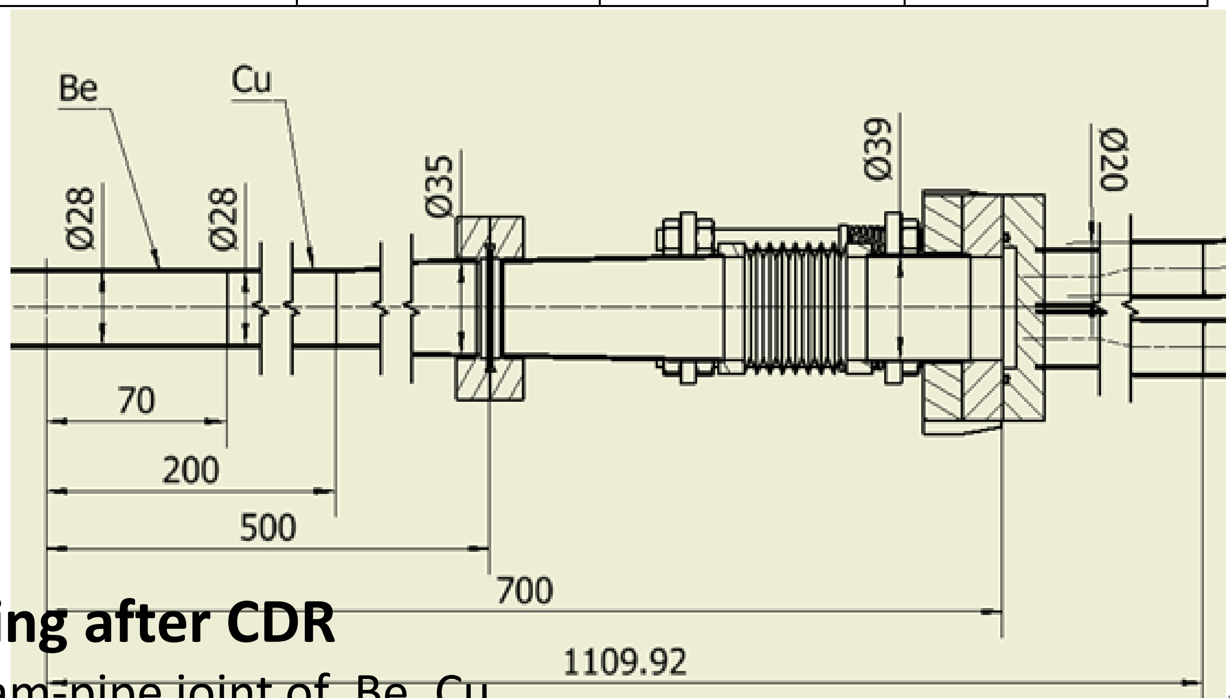
1st Si layer behind Beampipe cone at Z=515 mm
Hit deviation better than 1 μm

Beampipe post-CDR

1. Be 的長度為 140mm，Z 範圍-70~70mm。

2. 以 IP 單側為例，Be 管及銅管的尺寸見下表及附圖，真空管相對於 IP 對稱。

材料	Z 範圍（mm）	內直徑（mm）	備註
Be	0~70	28	直管
Copper	70~200	28	直管
	200~500	28~35	錐管
	500~700	35~39	錐管，包含波紋管

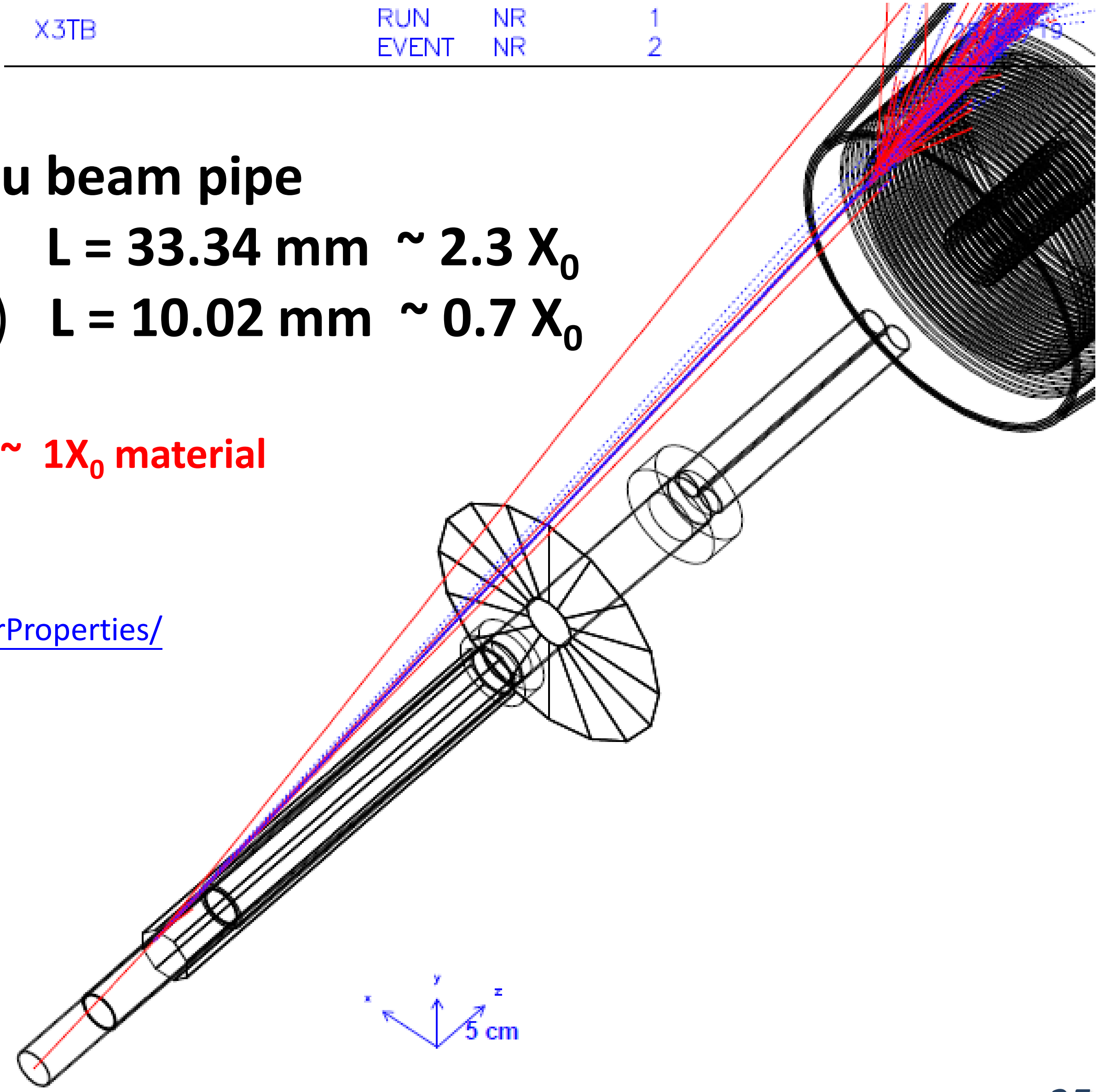


Beam pipe drawing after CDR

Assuming a tube beam-pipe joint of Be, Cu

Electron Traversing 2mm Cu pipe ➔ very “THICK” in forward direction

GEANT with post-CDR beam-pipe



Material thickness

traversing 2mm thick Cu beam pipe

2mm/L = tan(30 mRad) **L = 33.34 mm ~ 2.3 X_0**

2mm/L = tan(100 mRad) **L = 10.02 mm ~ 0.7 X_0**

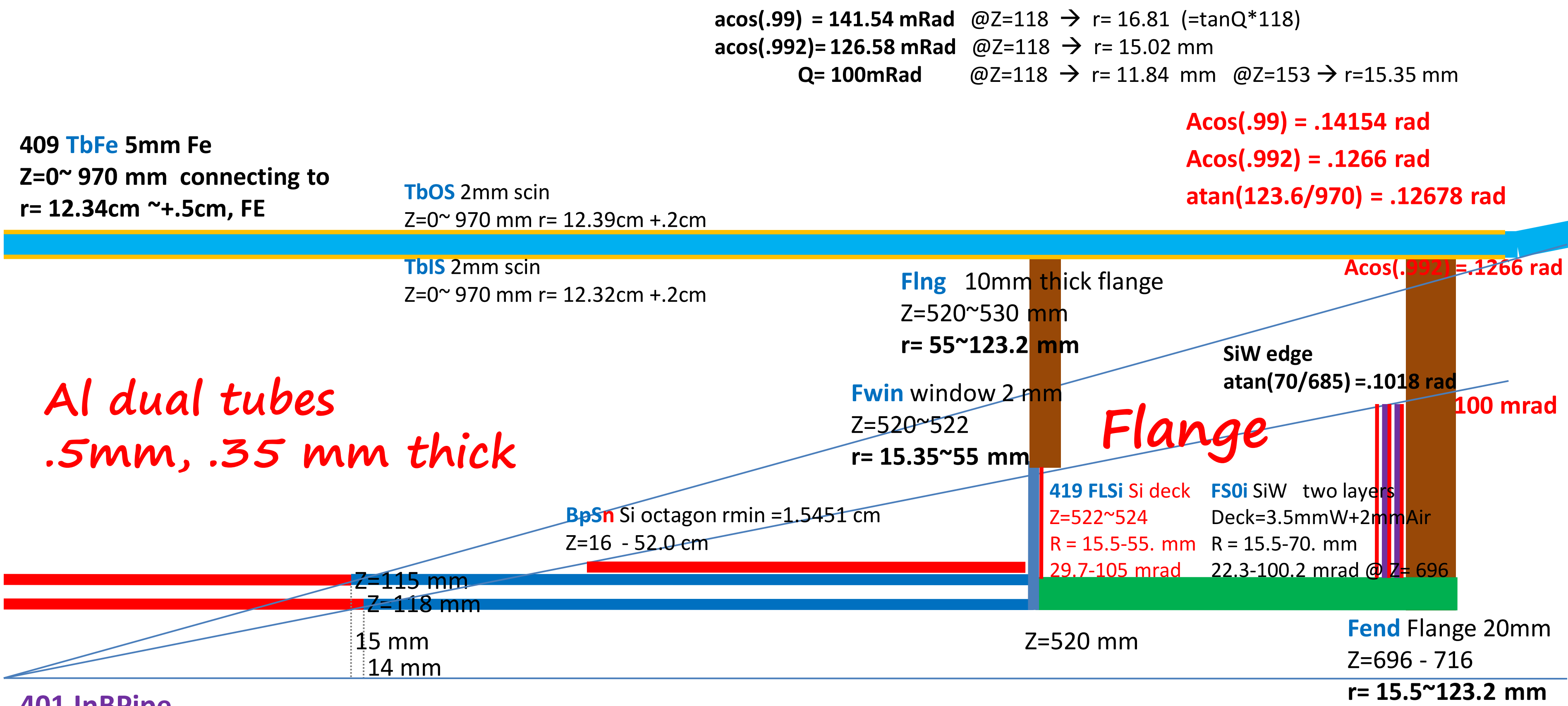
At Z=50cm passing 1mm Cu ~ 1X_0 material

Radiation length

http://pdg.lbl.gov/2014/AtomicNuclearProperties/

```
X0(Be) = 35.28cm
X0(Al) = 8.90 cm
X0(Si) = 9.37 cm
X0(Fe) = 1.76 cm
X0(Cu) = 1.44 cm
X0(W)  = 0.35 cm
```

Flat tube beam-pipe (2020 practice)



401 InBPipe

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

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

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

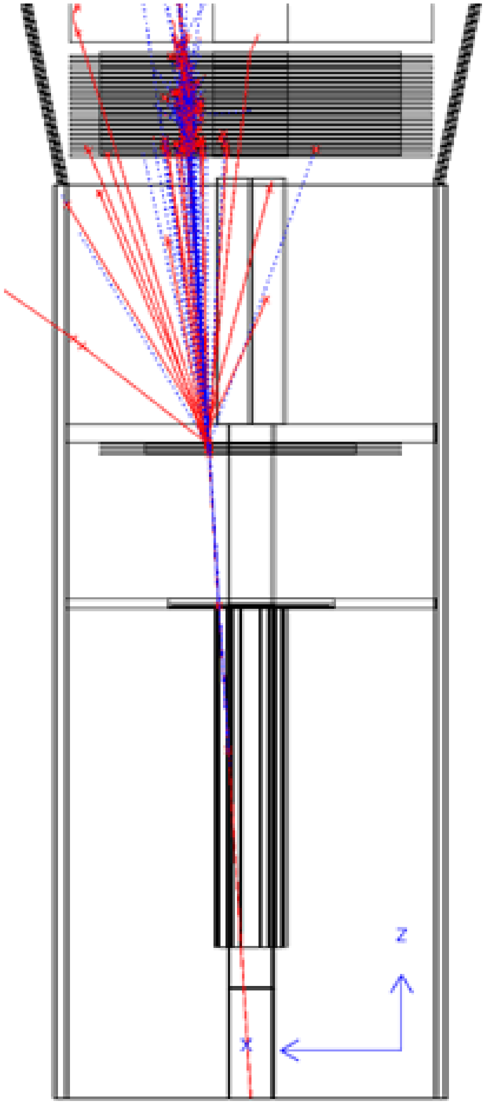
OuAl outer Al pipe
Z=0~115 mm
inner r=28/2+1 mm, 0.35 mm thick

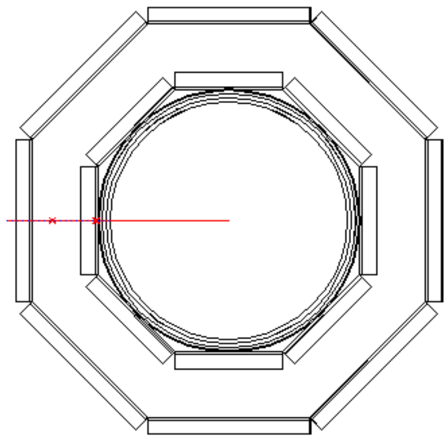
Fpip flange pipe 1.5 mm thick
Z= 522-716 mm
at Z=512 r= 14 – 15.5 mm

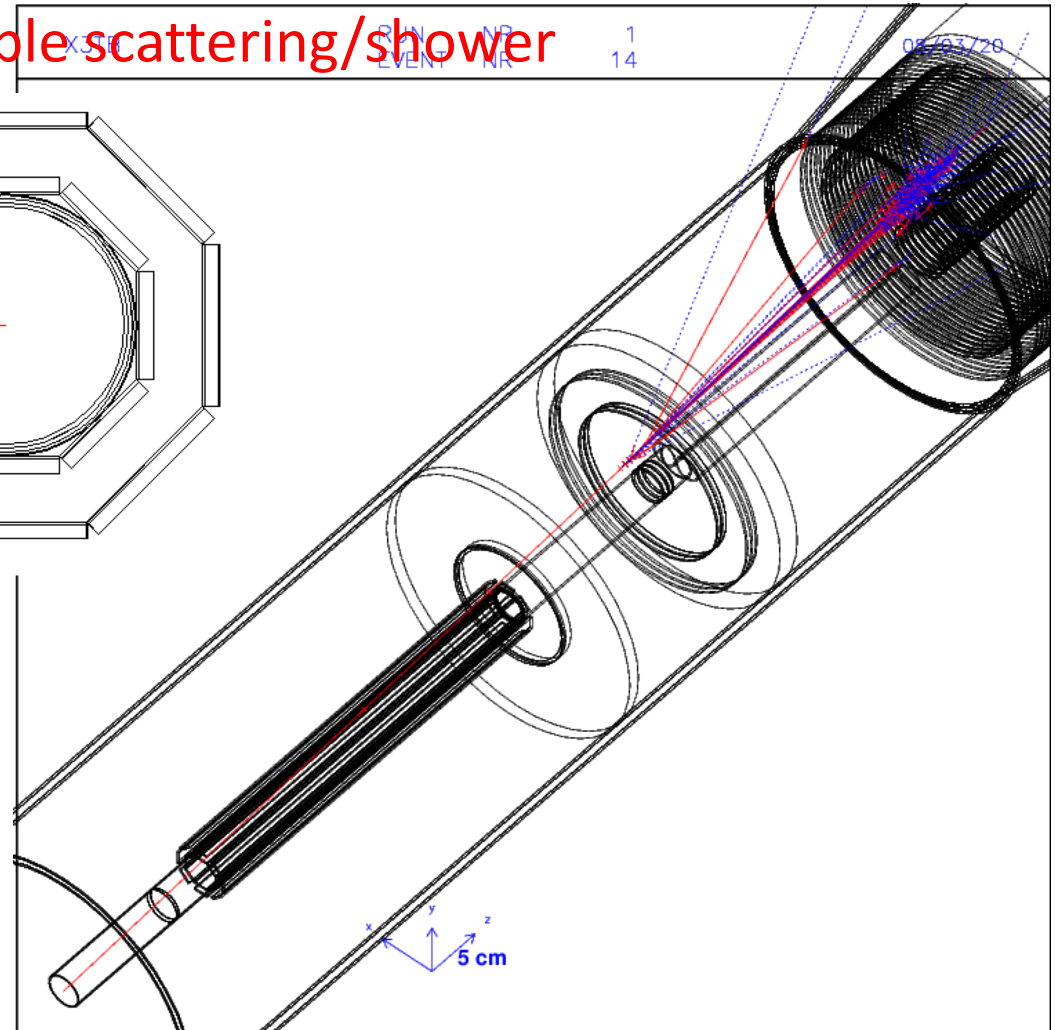
Si octagon wafers surrounding beampipe

Si wafer attach to beampipe

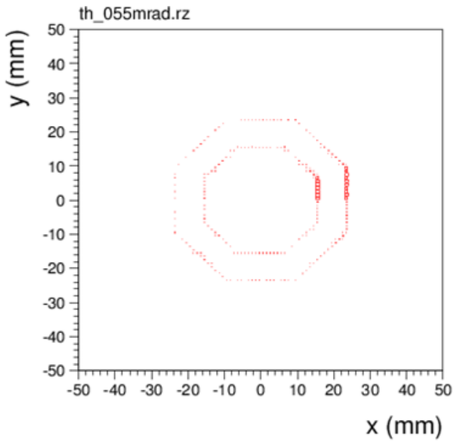
➔ Impact position w. minimum effect multiple scattering/shower



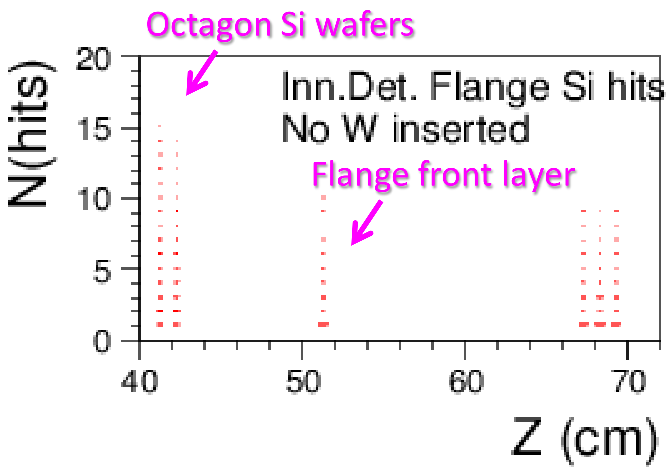


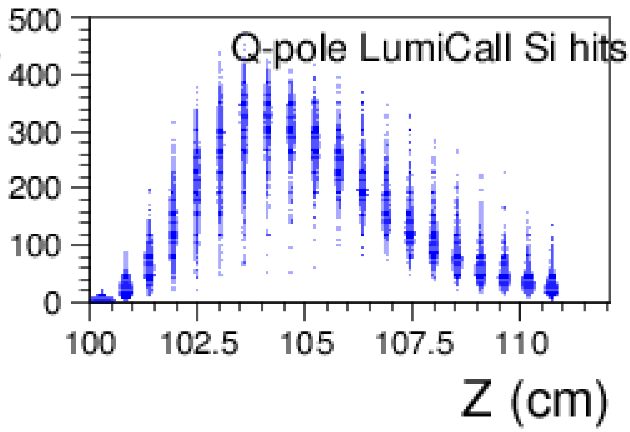


Precision on electron impact position

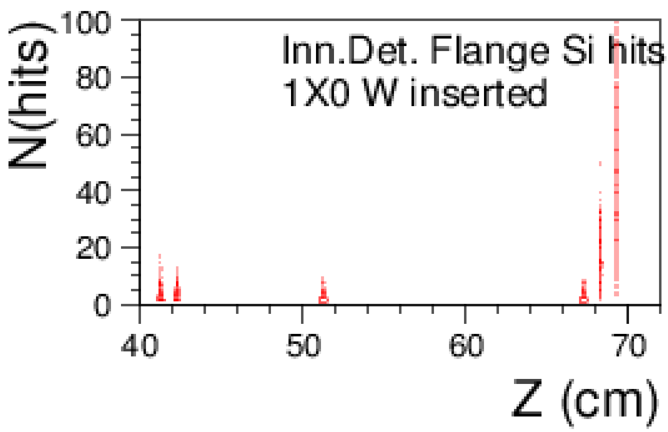


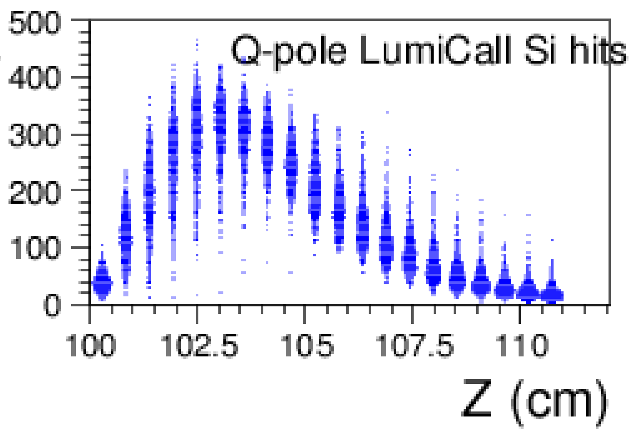
Hits of shower secondaries on Si layers





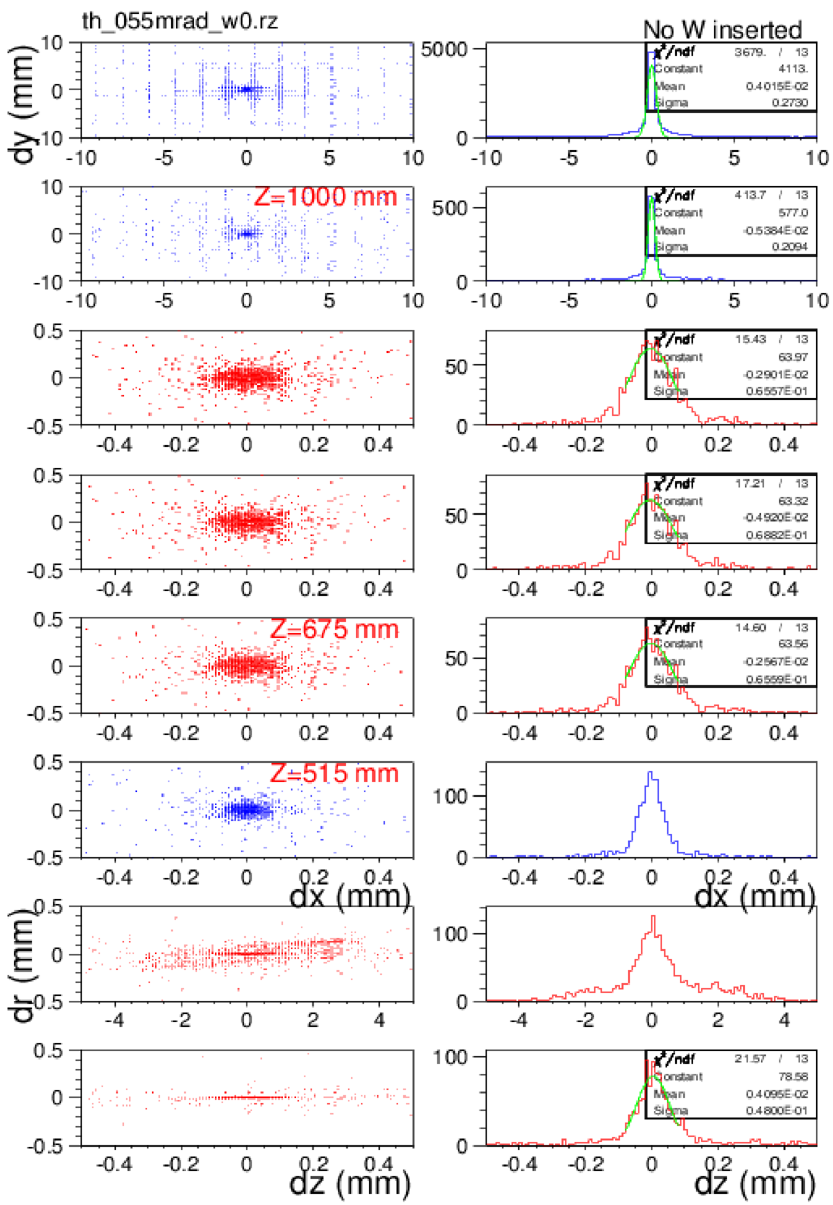
← Flange has NO Tungsten layers





← Flange has two 1X0 Tungsten layers

Position(Hits) – Electron shower



Piled up of shower hits
(50 GeV electrons)

Front 2 Si-layers of Q-pole LumiCal
Pileup of shower ~1 mm resolution

Three Si layers at Z>670 mm
NO Tungsten layers

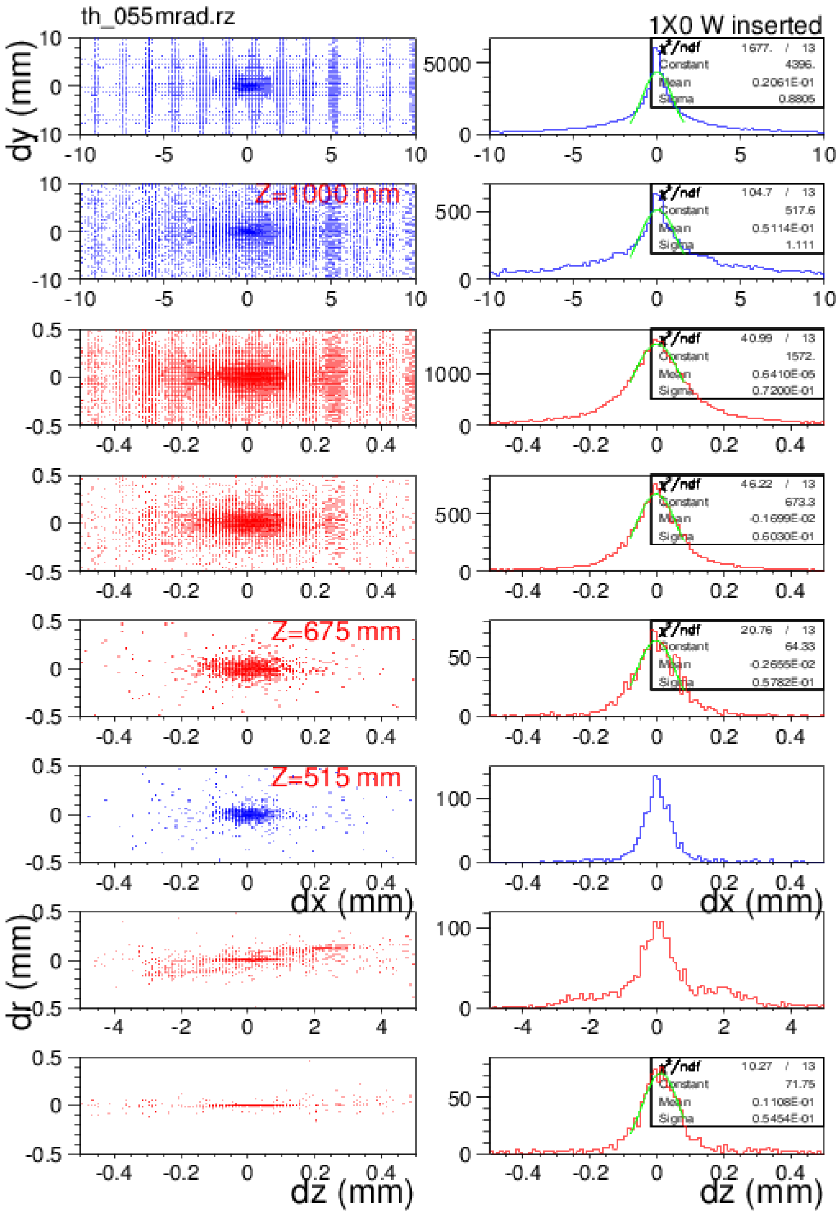
1st Si layer behind flange at Z=515 mm

Octagon Si layers surrounding beampipe

1st layer σ= 50 um

Piled up of shower hits
(50 GeV electrons)

Position(Hits) – Electron shower



Front 2 Si-layers of Q-pole LumiCal
Pileup of shower ~1 mm resolution

Three Si layers at Z>670 mm
Two 1X0 Tungsten layers between Si wafers

1st Si layer behind flange at Z=515 mm

Octagon Si layers surrounding beampipe

1st layer σ= 55 um

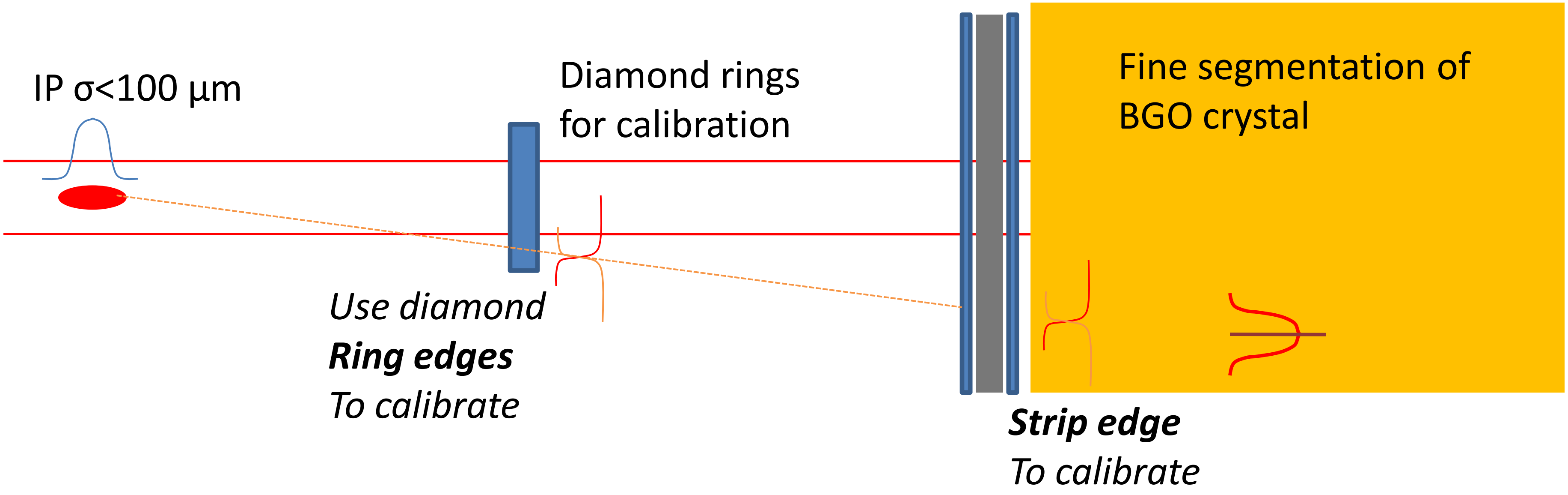
LumiCal tracking (CDR proposal)

- IP + Diamond ➔ calibrate Lumi strip position
- Diamond + LumiCal ➔ measure IP size

Calibrate *offset* of the *mean of error* at inner radius

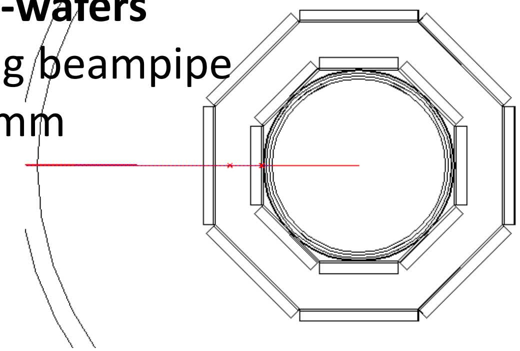
*Silicon strip resolution **~ 5 um,** error on mean **CAN reach 1 μm,***

➔ δL/L ~ 0.01 %



LumiCal tracking

Octagon Si-wafers
surrounding beampipe
Radius 15 mm

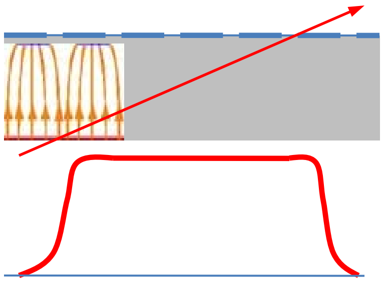


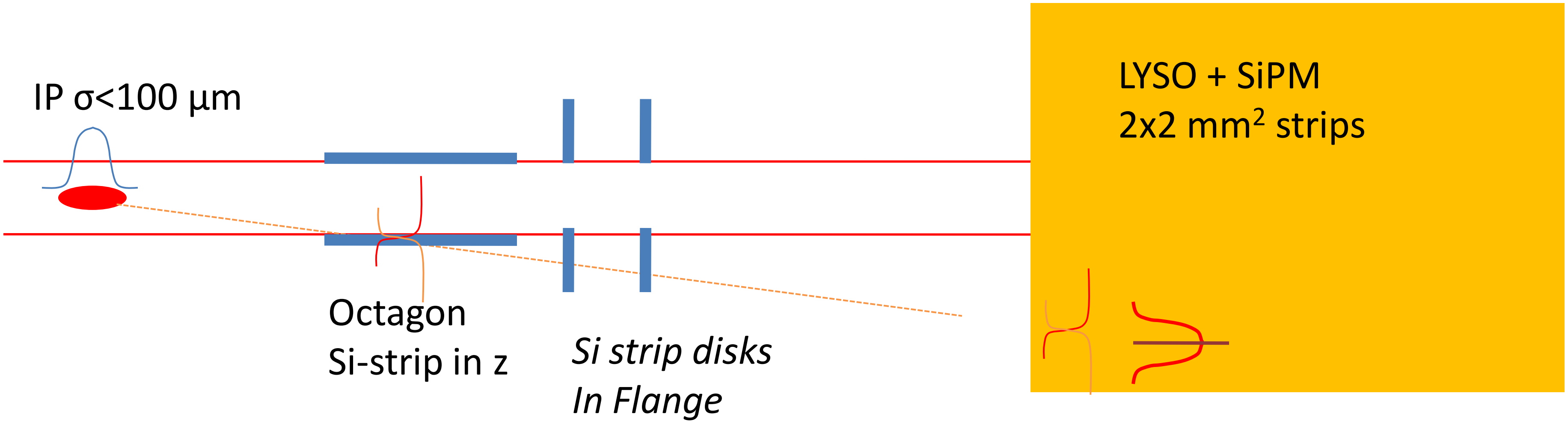
for luminosity ***δL/L = 10⁻⁴***

at z=50 cm, θ= 30 mRad → *δϑ = .75 μRad* or ***dr = .75 μm***
scaling to dz by 1/tan(.030)= 33 → **dz = 25 μm**

Si strip, pitch in Z, 300 μm thick → traversing distance in z = 10 mm
Si wafer coverage (30-100 mRad) → z range 150 – 500 mm

Assuming Si strip pitch = 100 μm *(fire 100 strips @ 30mRad)*
resolution is determined by the fraction of entrance strip (low z)
→ *Optimized the pitch vs the 25 um resolution requirement and resolution distraction for the error on mean*





Far-forward tagger

Bhabha scattered electrons

Symmetric to out-going beam-pipe, NOT the LAB frame

➔ *hit @ +x Lab frame : ϑ_{cms} is 16.5 mRad lower*

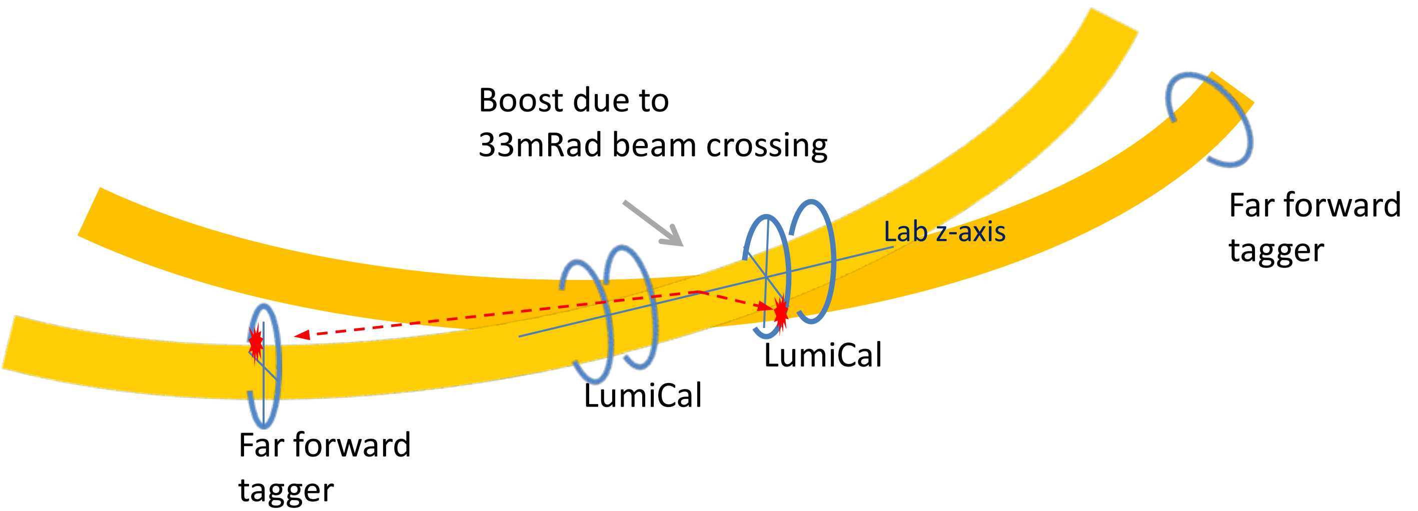
➔ *LumiCal @ Lab +x region is **VERY HOT** by low ϑ beam electrons*

tag Bhabha electrons by far-forward tagger

back-to-back in ϑ/φ to LumiCal hit

Detector option:

LYSO+SiPM in a ring, slide to position



Far-forward tagger

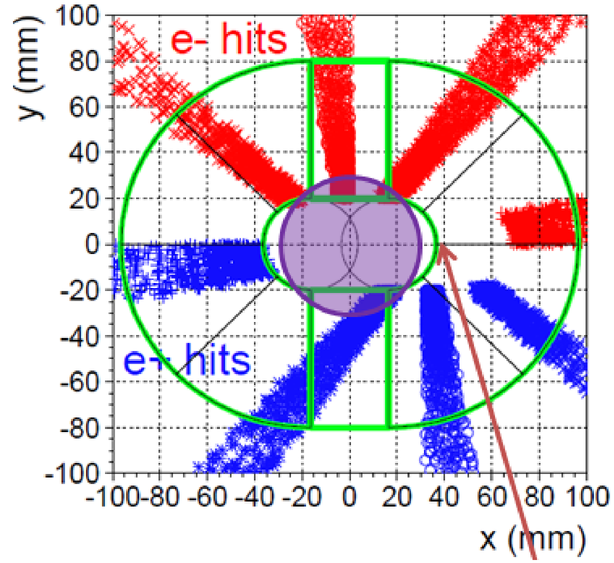
Luminosity, Bhabha 測量條件：

1. back-to-back colliding electrons
2. Electron(+ISR photon) = Ebeam
3. 截面 > Z(qq) at Z-pole, 41 nb

LumiCal challenge：

1. Beampipe 限制 θmin = 30 mRad
2. Beam crossing, x-axis θmin = θmin +33/2 mrad
   → -x 方向 electron 被推進 beampipe, 截面 減少 1/3

➔ Bhabha 截面 > 41 nb 有困難

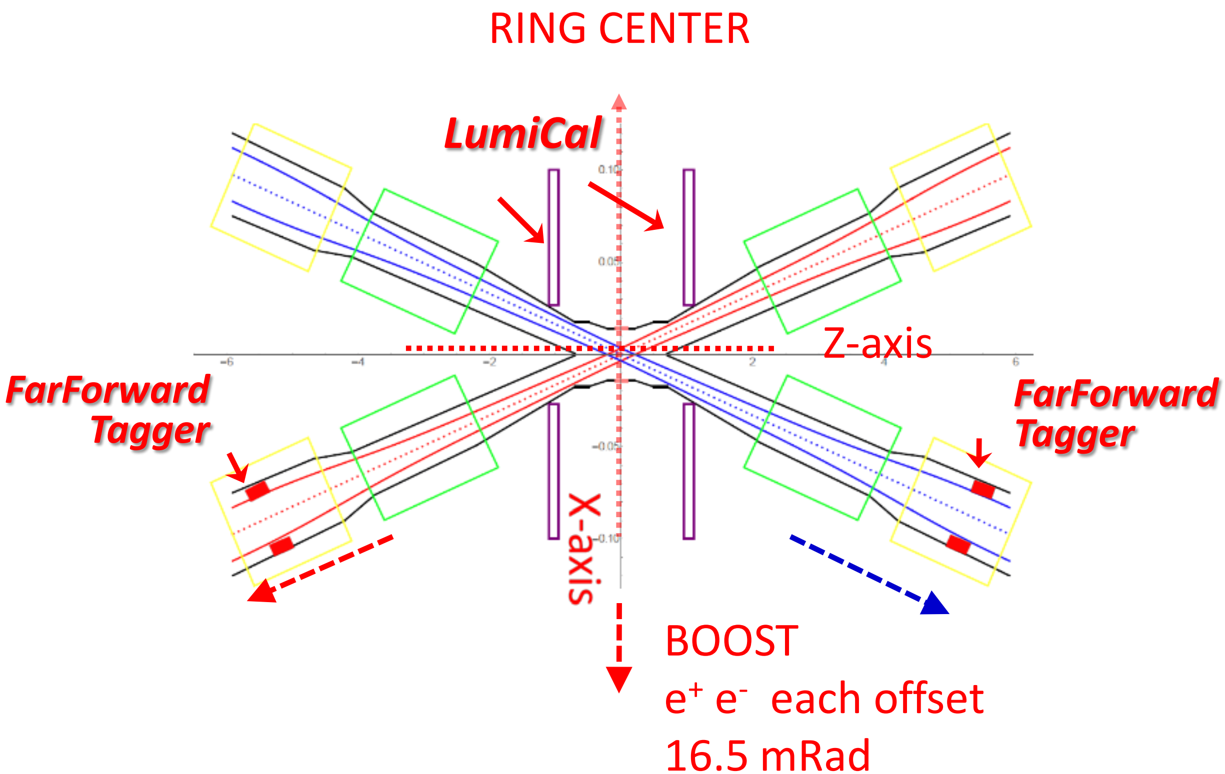


Recover "Single Electron Bhabha" with Far-forward LumiMonitor

LumiCal 設計限制

1. **Inner Tube, @z= 500 mm**, Cone beampipe 法藍之間，沒有材料阻檔，最乾淨的 Bhabha
   → 不能放Calo, 會導致 shower background to tracker
2. **Q-pole front, @z=1000 mm**, 前端有beampipe 材料，
   → full Calo, 量 electron Ebeam, Bhabha Theta 模糊
3. **Q-pole outgoing beampipe, @ Z>2000 mm**
   beam monitoring, 測量小角度 Bhabha,
   閃鑠體，包覆約2cm厚 2~5cm長，phi 細分割，標定 beam electron
   ➔ 在前端單管時, -x 方向被boost 進 beampipe Bhabha，分管後能被 trigger
   以 back-to-back coincident，**另一端 "single electron Bhabha" 是精密測量到的**
   這些 Bbabha ，是 33mRad 丟失掉的 1/3事例截面

Backup



RING CENTER
LumiCal
Z-axis
FarForward Tagger
FarForward Tagger
X-axis
BOOST
e+ e- each offset
16.5 mRad