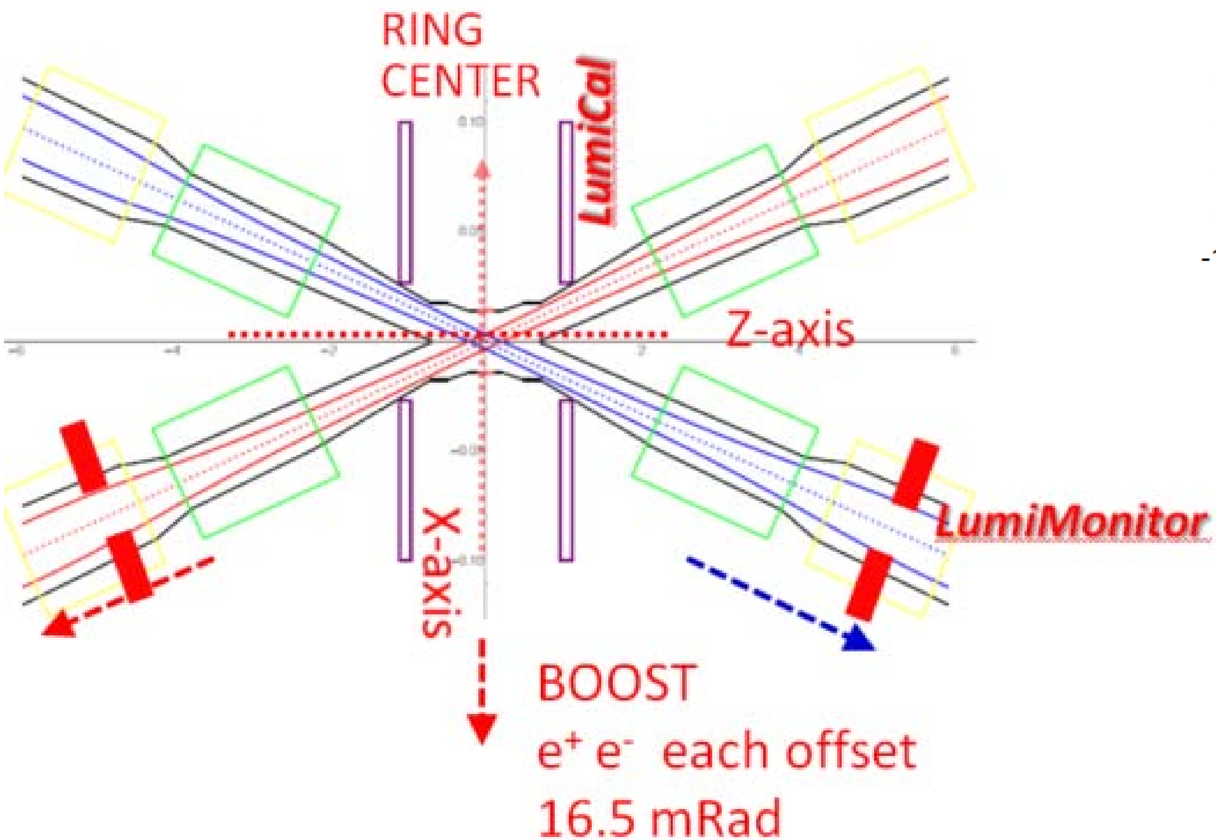
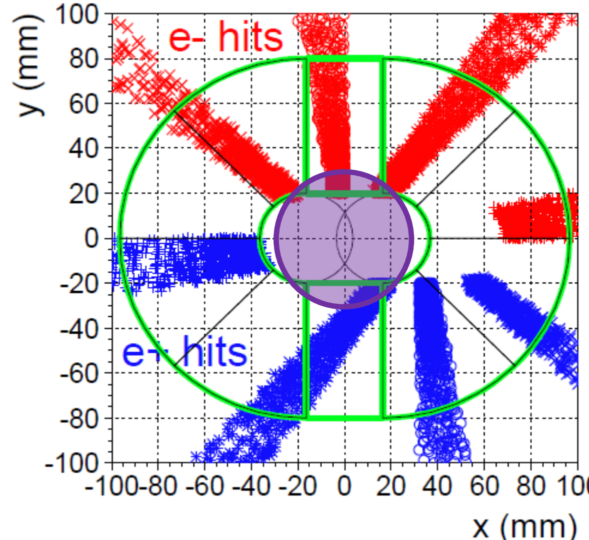
GEANT Status of the CEPC LumiCal Design

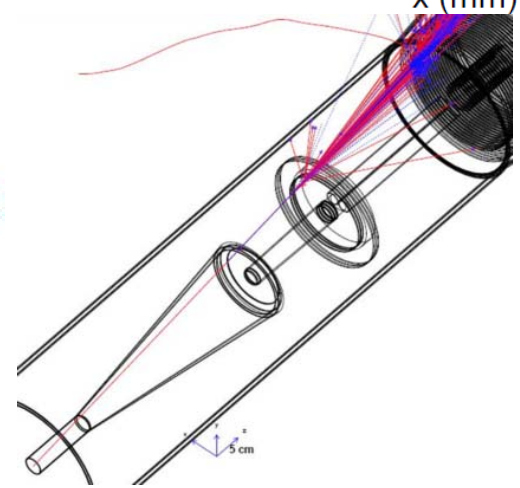
CEPC workshop 2019

2019.11.19
17:00 IHEP A511

Suen Hou
Academia Sinica







Outline

- **Bhabha cross section**

  boost by beam crossing, favoring small beam pipe

  r< 30 mRad ➔   σ(Bhabha) > ~ 50 nb

- **Beampipe material**

  smearing to electron impact position

  shower leakage to Tracker

- GEANT with a cone shape beam pipe

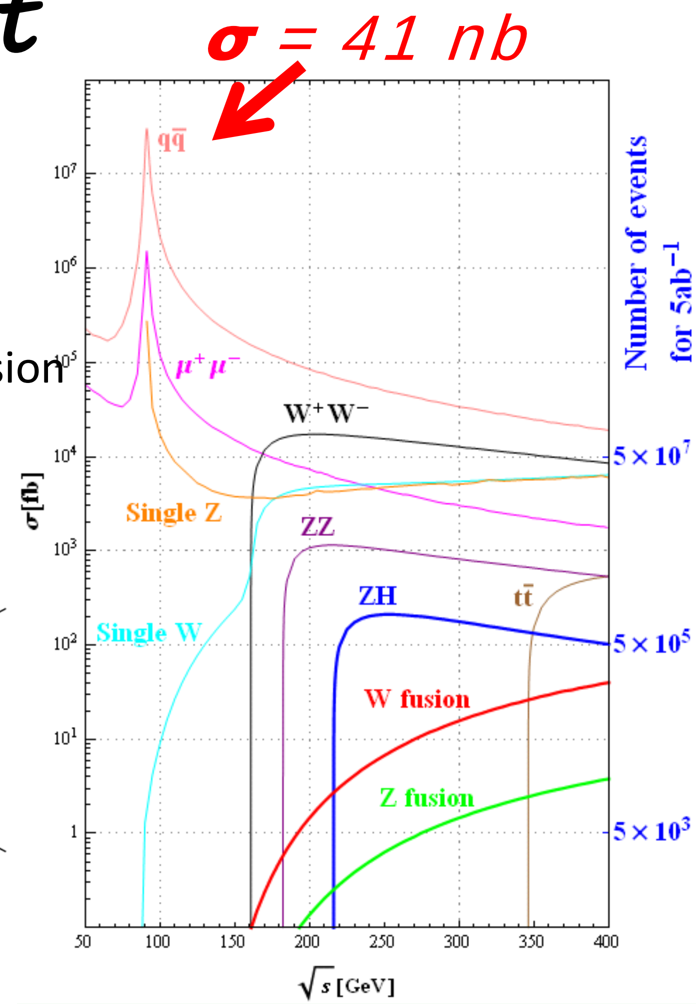
- Perspectives for 10^{-4} luminosity precision

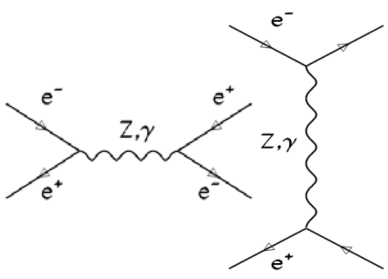
Luminosity measurement

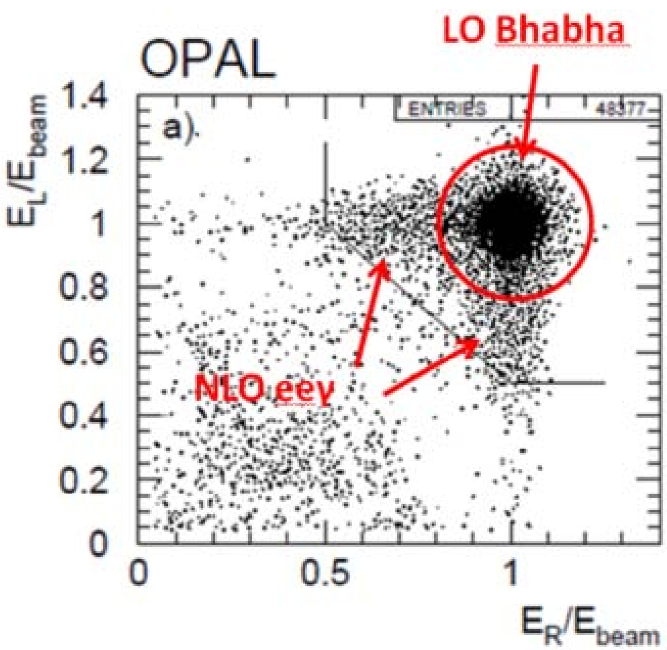
- ***Z*-lineshape,** $e^+e^- \to Z \to q\bar{q}$ is dominant,
- Luminosity is best provided by detecting\
  Bhabha, $e^+e^- \to e^+e^-$, elastics scattering
  - a pure QED process, theoretical MC to *<0.1%* precision
  - triggering on a pair of scattered e^+e^-

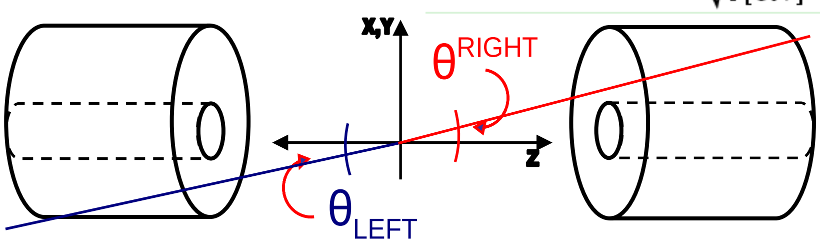
  E(e^±) ~ E_beam , Back-to-Back

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





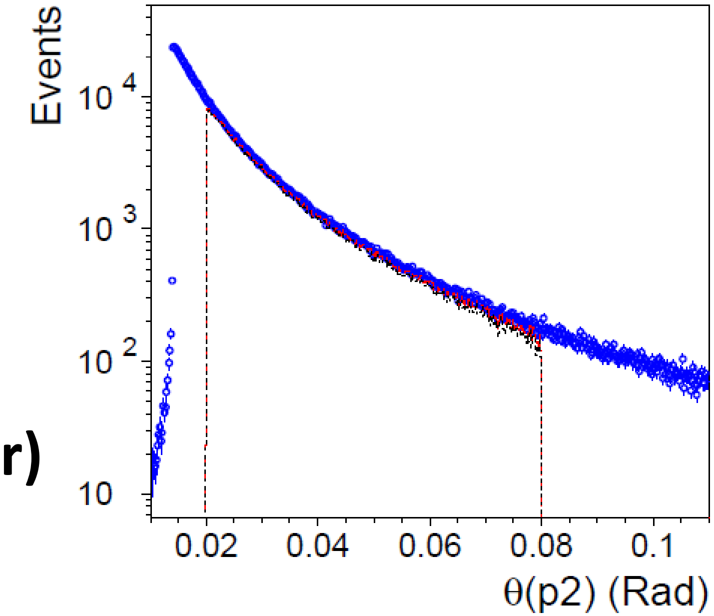




$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$

Bhlumi calculations

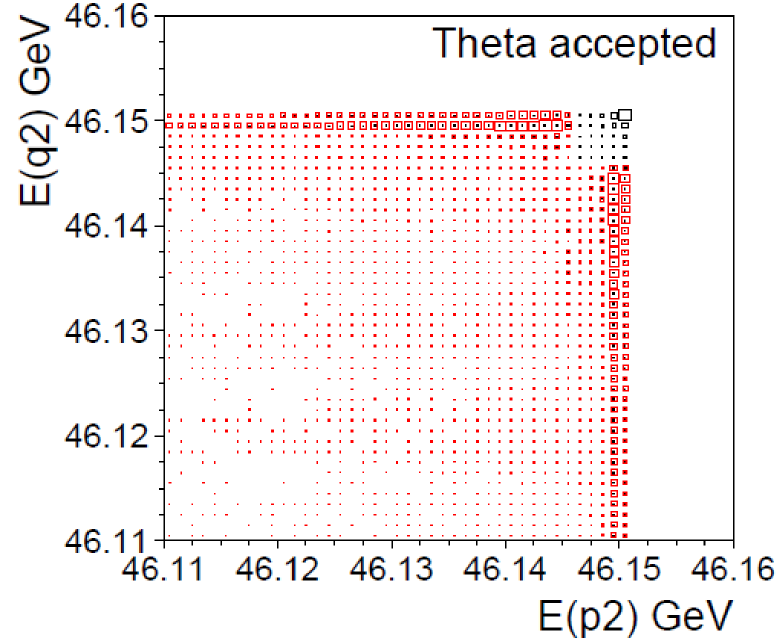
1. Theta range input : **Th1, Th2**
   Xcru calculated for Thmin=0.7xTh1 to 2xTh2
2. KeyWgt=0 ➔ event wgt=1, for simulation
   count events in chosen condition
   scale to Xcru



BARE1 X section: (of the bhlumi paper)

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

Use BARE1 as reference



Having photon (red histogram) or not
➔ 5 MeV precision

BHLUMI theoretical precision

Bhlumi 4.04 writeup: CERN-TH/96-158

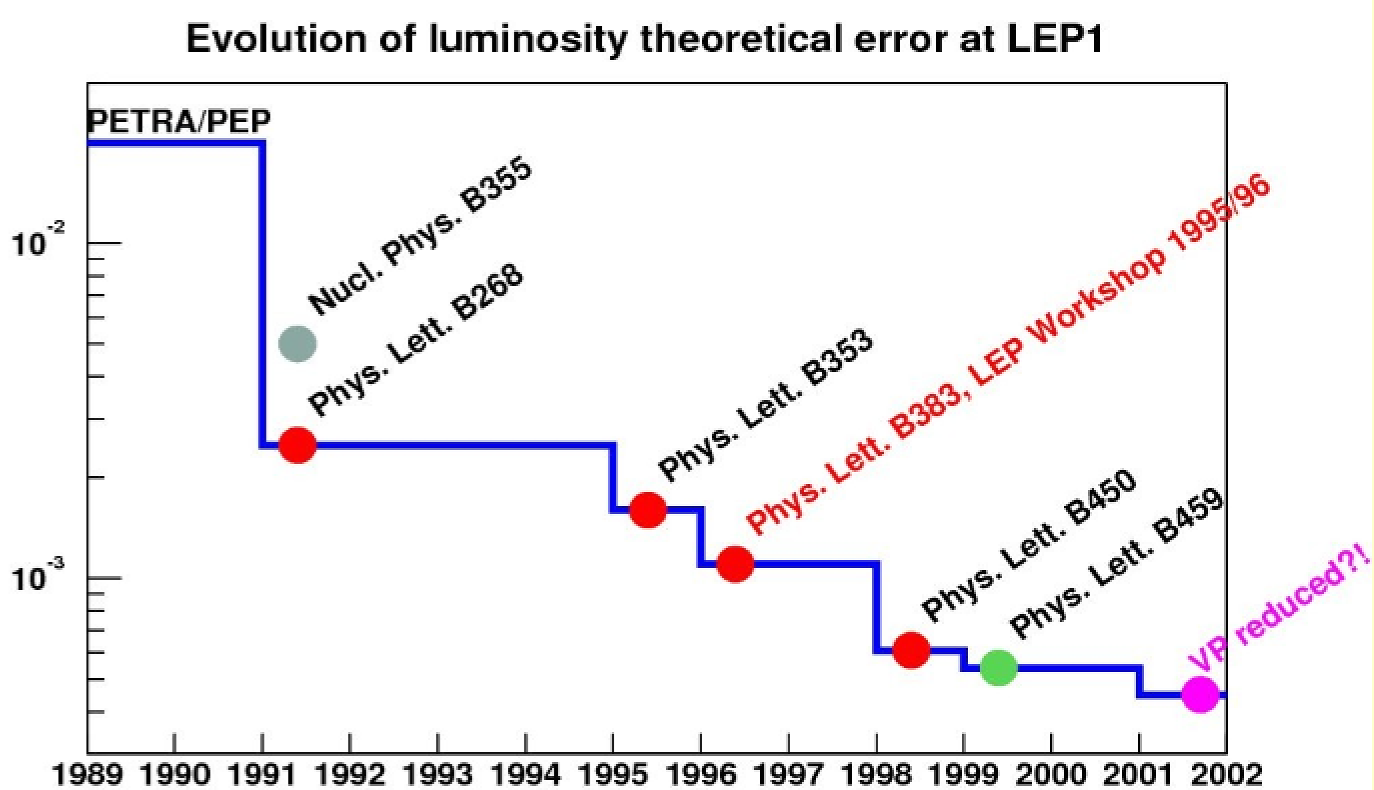
cds.cern.ch/record/310621/files/th-96-158.ps.gz

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%



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.

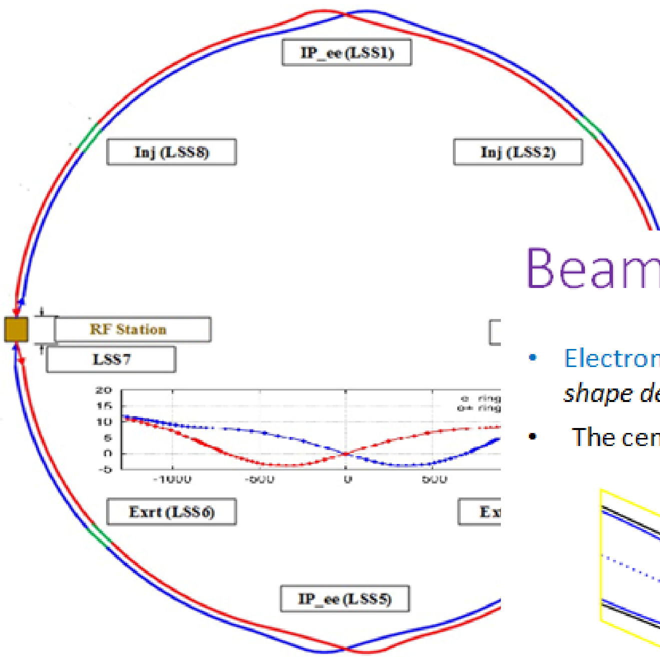
Table 14: Monte Carlo results for the symmetric Wide-Wide ES's BARE1, for matrix elements beyond first order. Z exchange, up-down interference switched off. The center of mass energy is $\sqrt{s} = 92.3$ GeV. Not available x

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



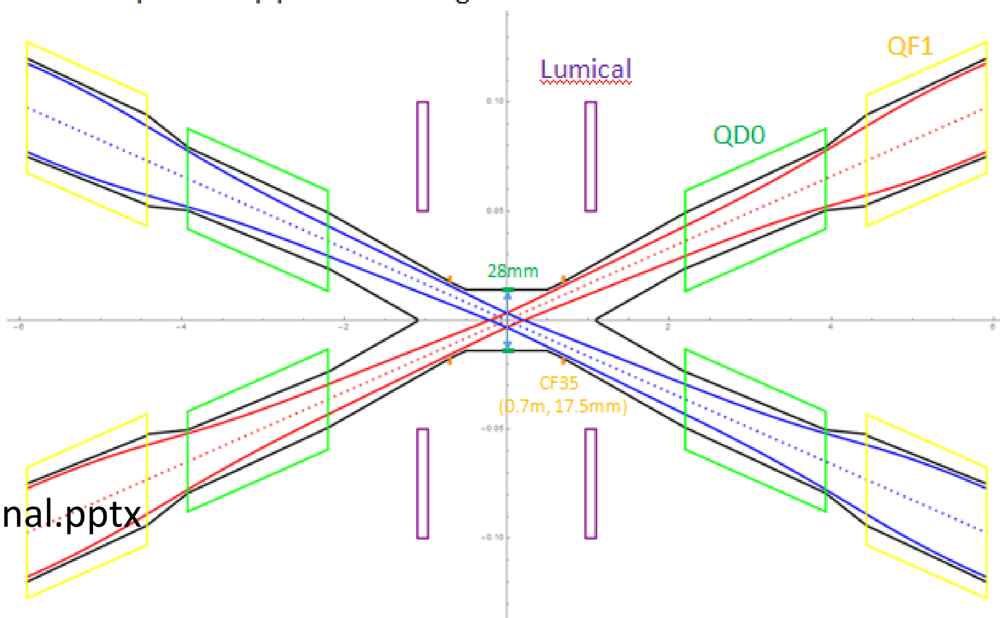
- **Beam crossing 33 mRad**

Focal length:

L* 1.5m → 2.2 m

Beam pipes

- Electron and positron beam stay clear (magnet, vacuum chamber) → *important input into the beam pipe shape design , connection from single pipe to double pipe is realized by flange CF35.*
- The central part is Be pipe with the length of 14cm and inner diameter of 28mm.

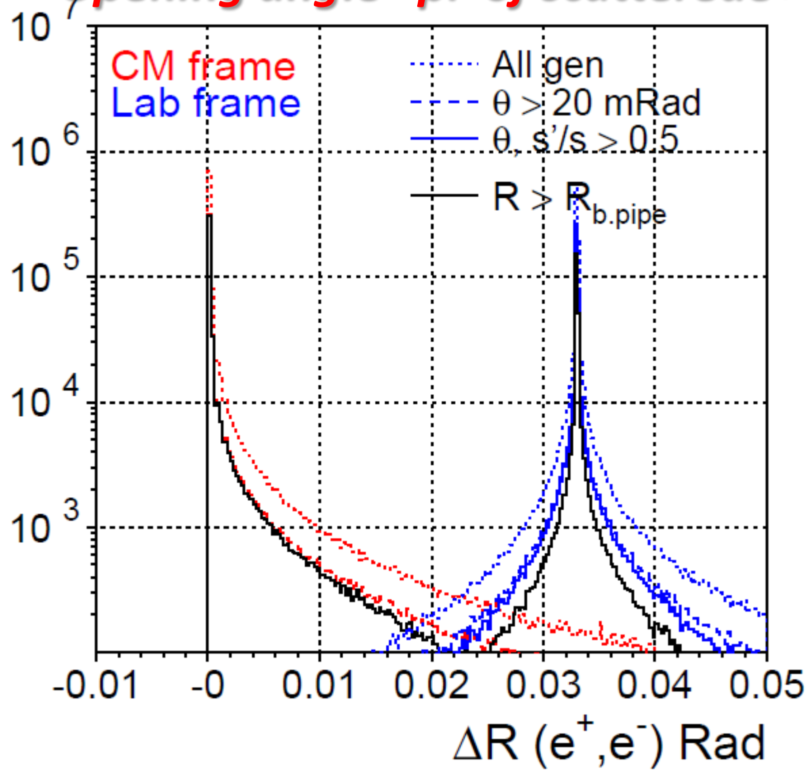


Wuhan 2017.04.19 workshop
Introduction_to_CEPC_MDI_final.pptx

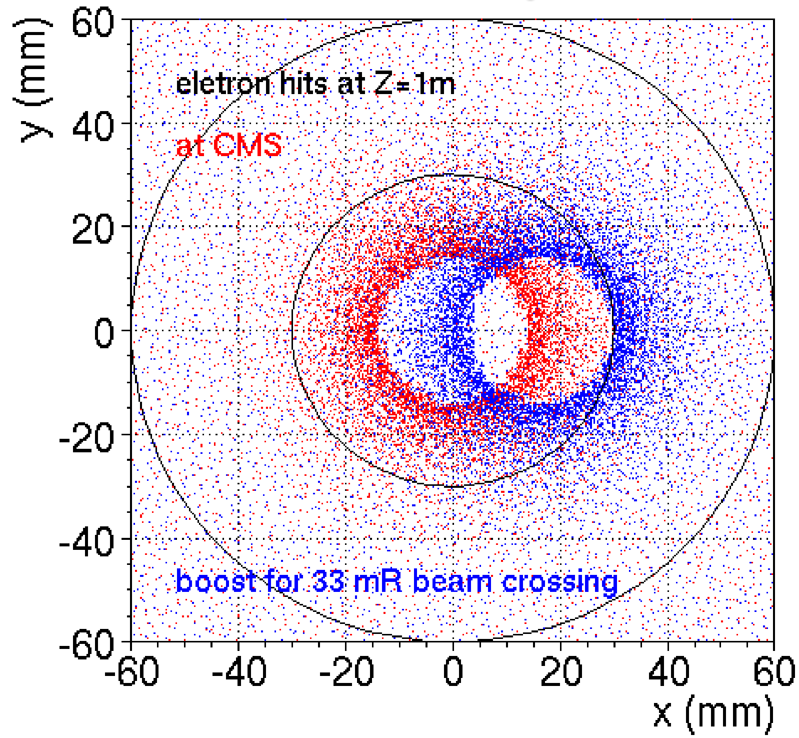
Bhabha back-to-back boosted by CEPC beam crossing

- 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

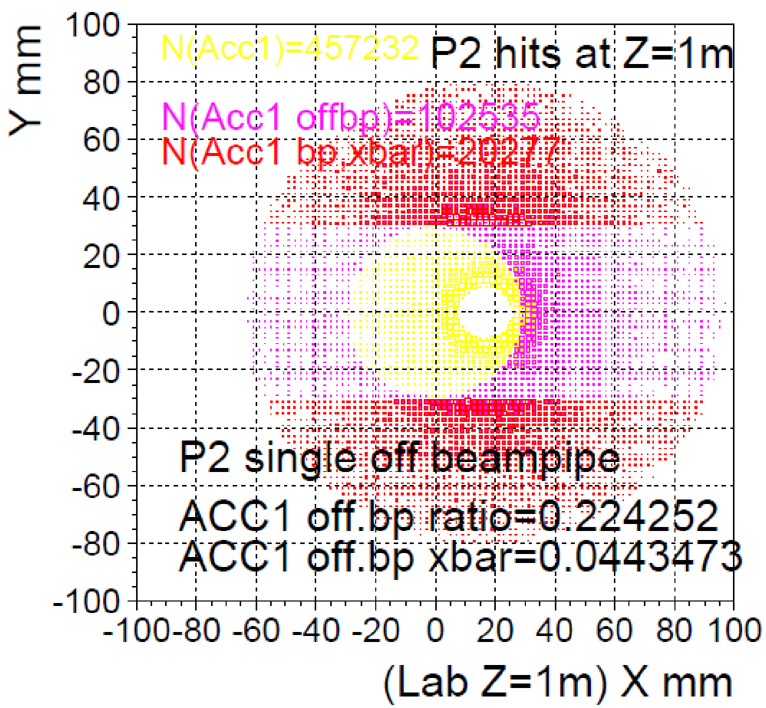


Bhabha X sec. vs Lab z-axis round pipe

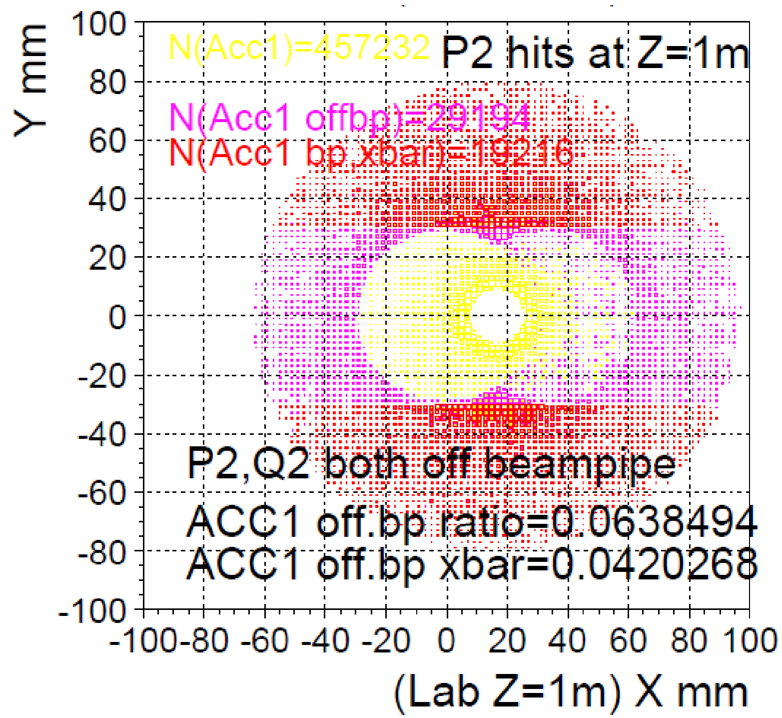
- CMS generated th1=10 mRad ➔ boosted +16.5mRad, +X are low angle Bhabha
- Assuming beam pipe is LAB z-axis centered, **radius = 30 mRad** (r=30mm @z=1m)
  at x=+30 mm, Bhabha electrons are of θ=13.5 mRad

➔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**

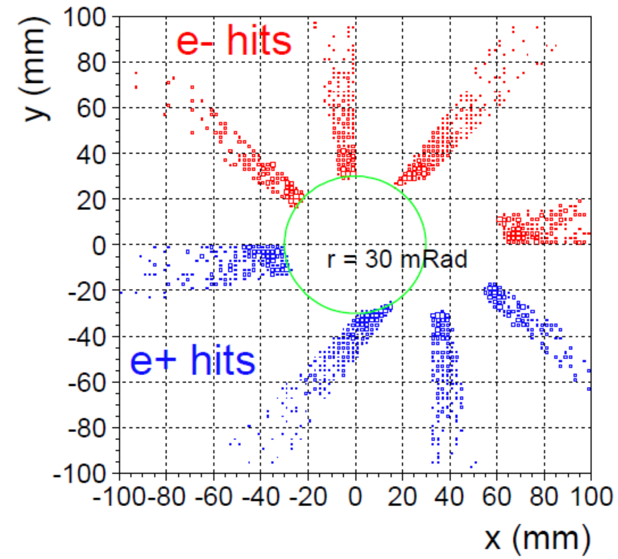
Hits of ONE Bhabha electrons



Hits of electrons, both detected



Bhabha X sec. vs Lab beampipe options



Round beam pipe, 30 mRad

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 coverage	off beampipe cut off ±30mm
Nevents	457232	102535	20277	29194	19216
Xsec (nb)	1168.3	**262.0**	**51.81**	**74.60**	**49.10**

-2 mRad radius → 20% increase in X section

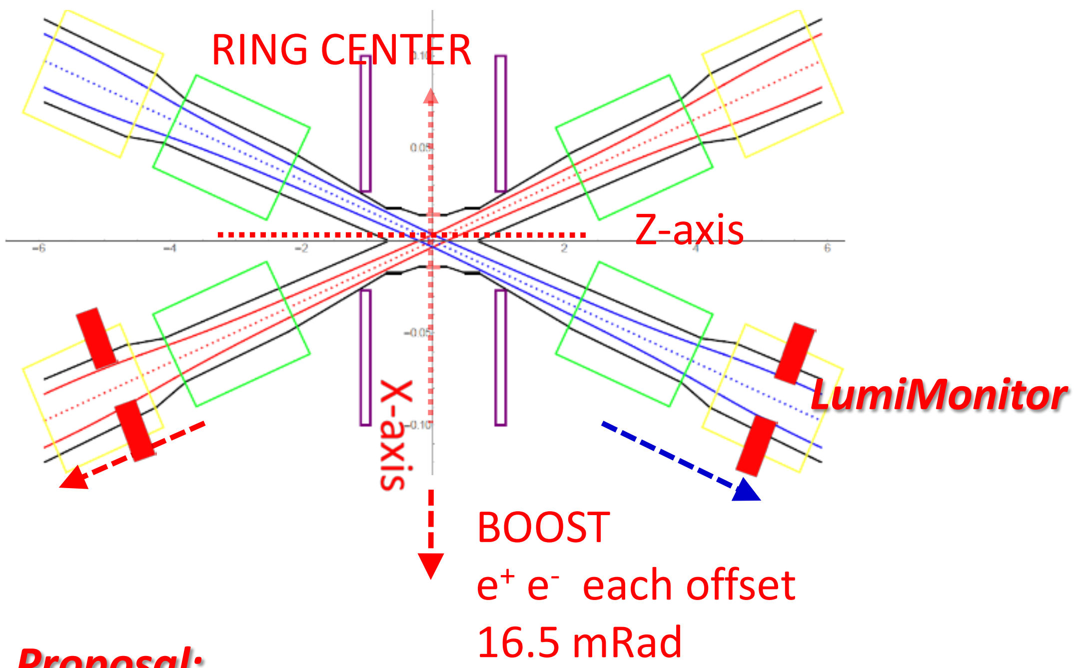
Round beam pipe, 28 mRad

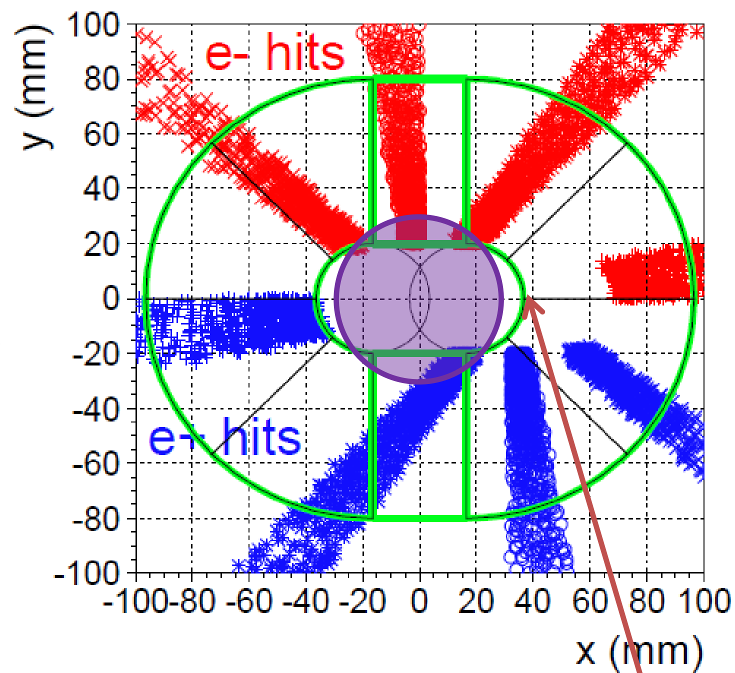
CMS 10 ~ 80 mRad		LAB ONE electron		LAB both electrons	
BARE1		off beampipe full phi coverage	off beampipe cut off ±30mm	off beampipe full phi covearge	off beampipe cut off ±30mm
Nevents	457232	135842	24236	34847	23010
Xsec (nb)	1168.3	**347.1**	**61.93**	**89.04**	**58.80**

Bhabha measurement

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





Very hot region,
Low angle Bhabha
boosted outward

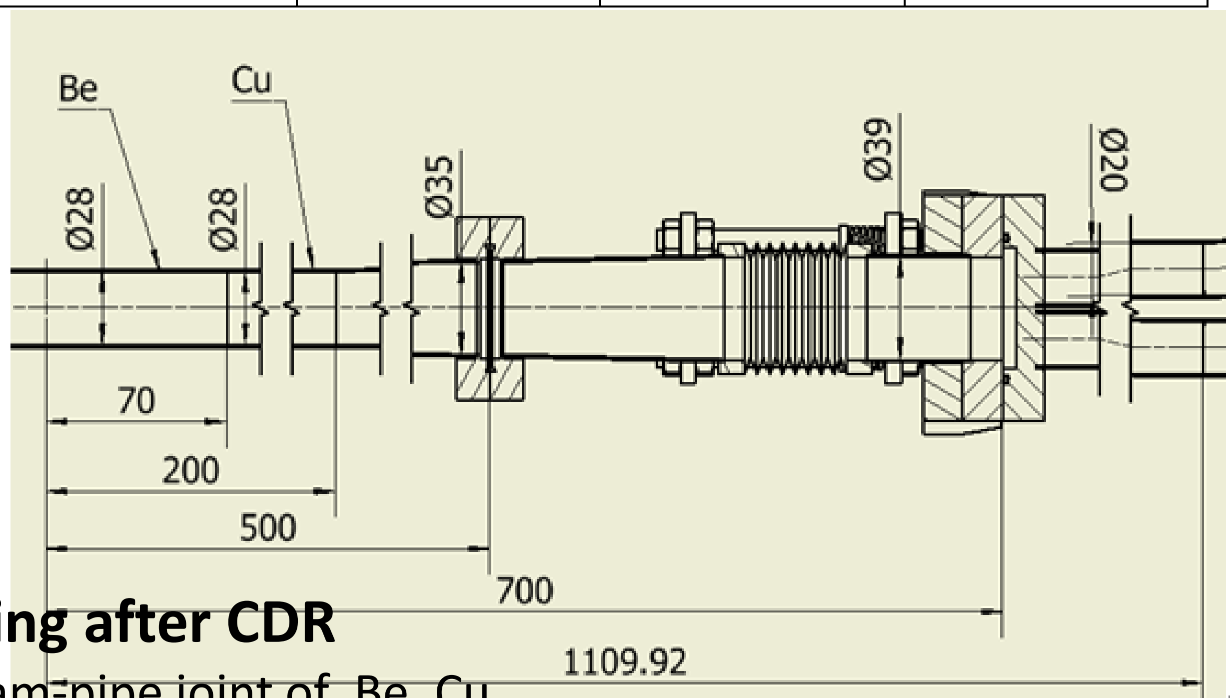
Proposal:
Insert Crystal Scint. LumiMon on outgoing pipe
to trigger/back-to-back for Bhabha <50mRad on x-axis
with one electron lost into beam pipe

Geant implementing new GEOM

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

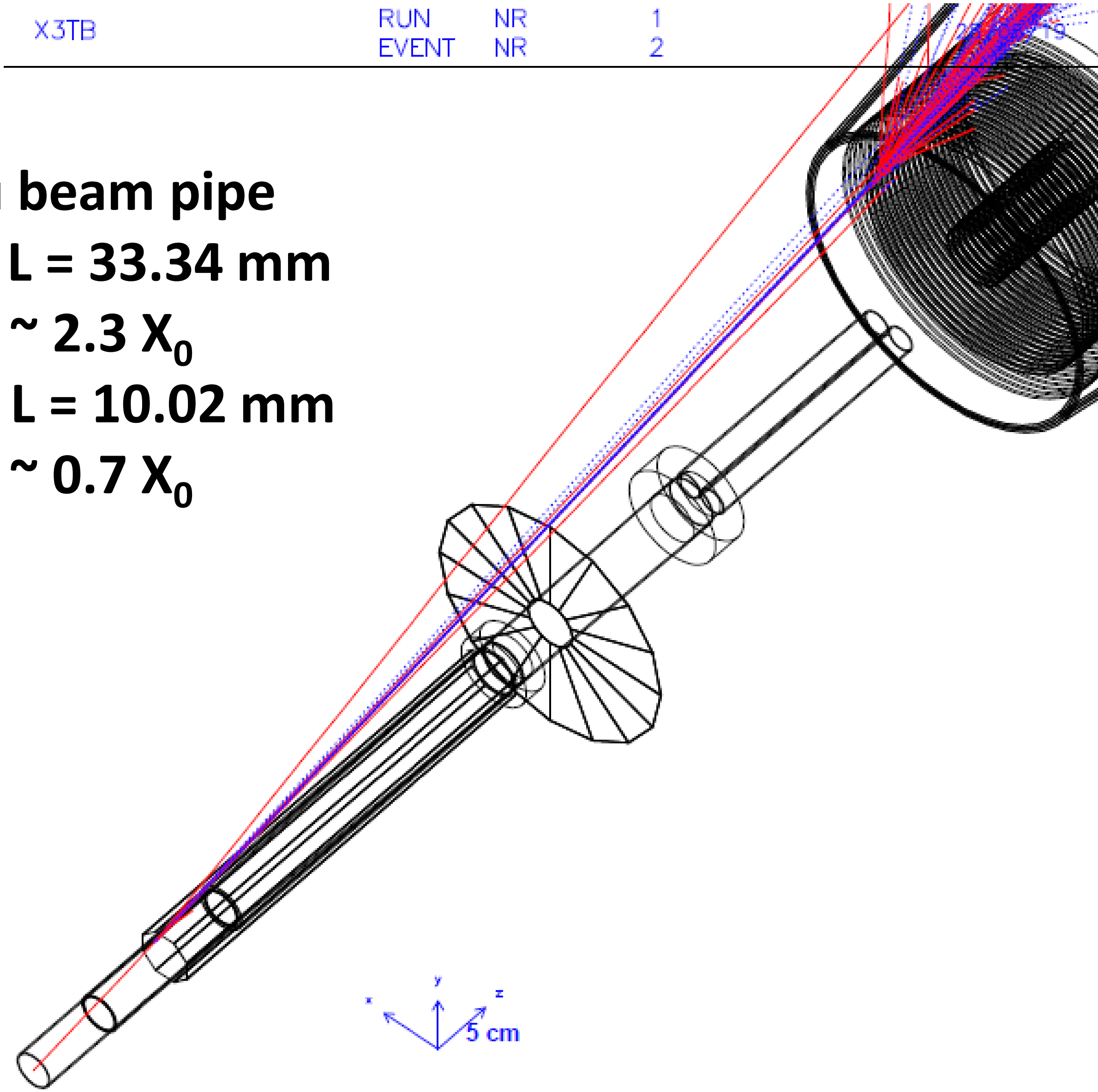


Beam pipe drawing after CDR

Assuming a tube beam-pipe joint of Be, Cu

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

Geant implementing new GEOM



Material thickness

traversing 2mm thick Cu beam pipe

2mm/L = sin (30mRad) **L = 33.34 mm**

~ 2.3 X_0

2mm/L = sin (100mRad) **L = 10.02 mm**

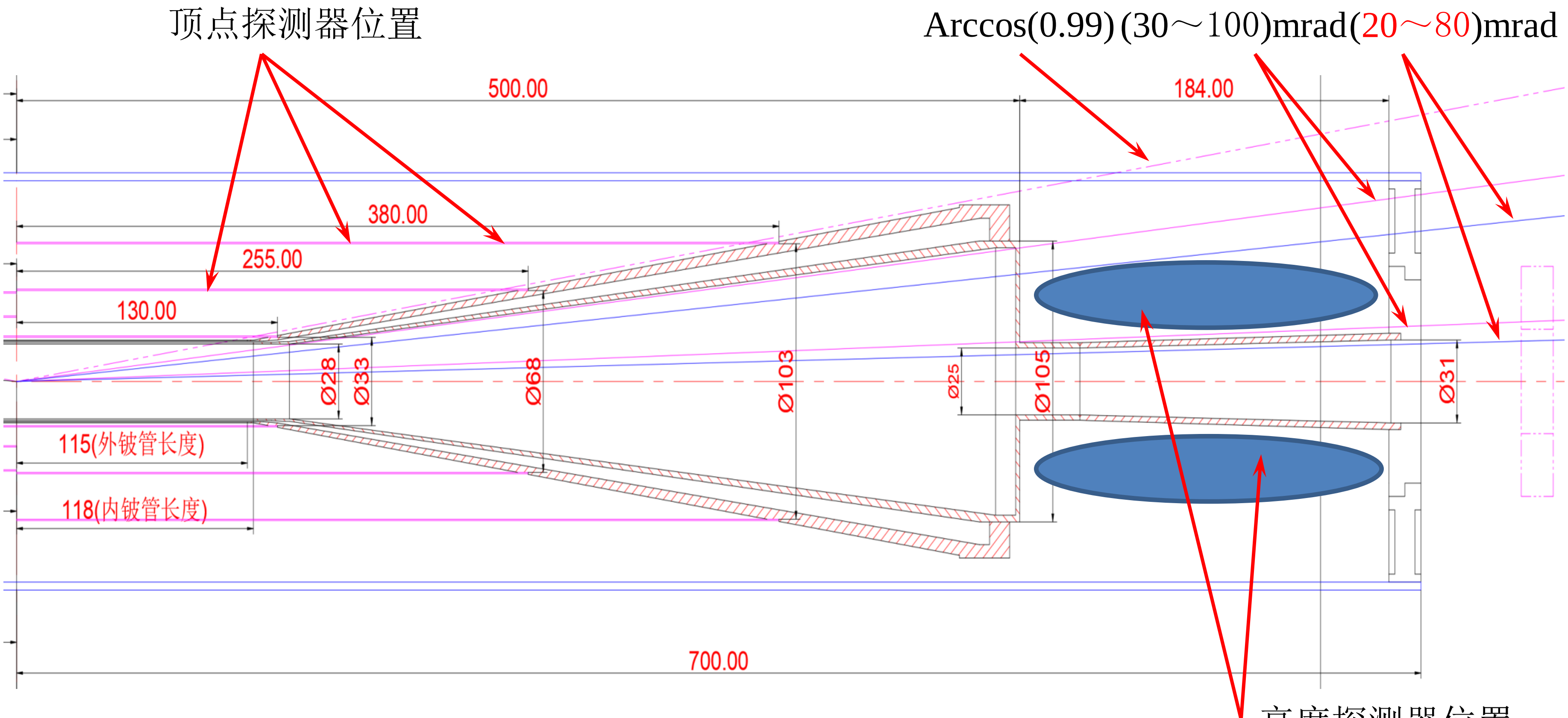
~ 0.7 X_0

X_0(Cu) = 1.44 cm

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

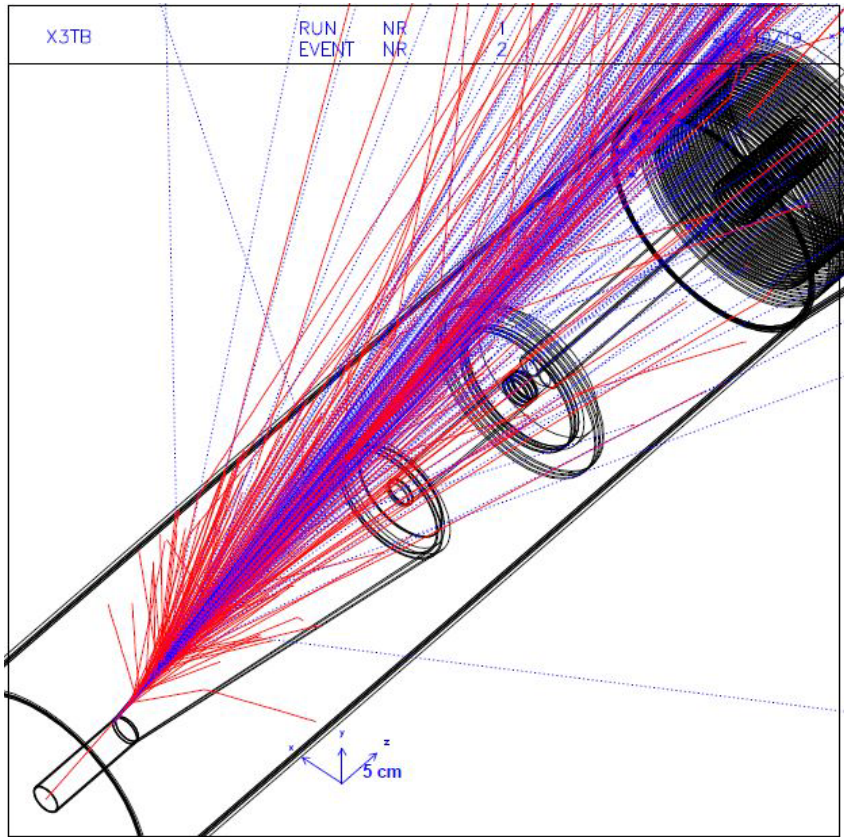
说明:
1.Ø25和Ø31是根据白莎的计算，最小束流管孔径
2.亮度探测器对应管道为单层管(无冷却)，
需根据计算确定184mm 是否满足温度要求

50 GeV electron shower on beam pipe

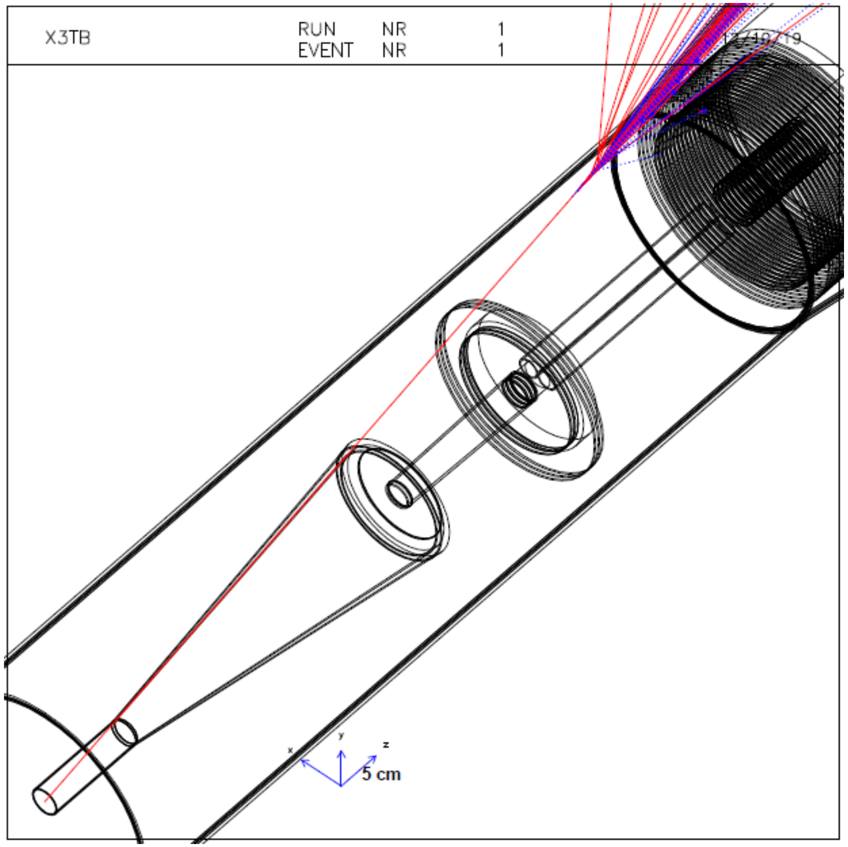
GEANT simulation precision is 0.1 MeV

Beam pipe cone is at Theta= 130 mRad
Material is a Delta function at 130 mRad

shoot at 130 mrad, hit the cone pipe

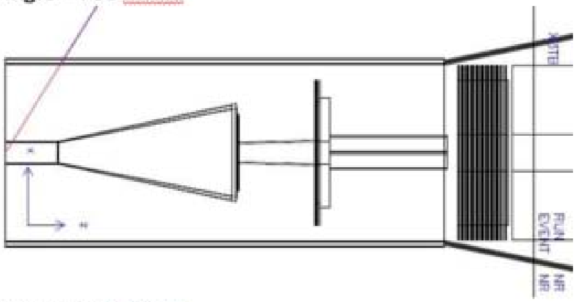


shoot at 134 mrad

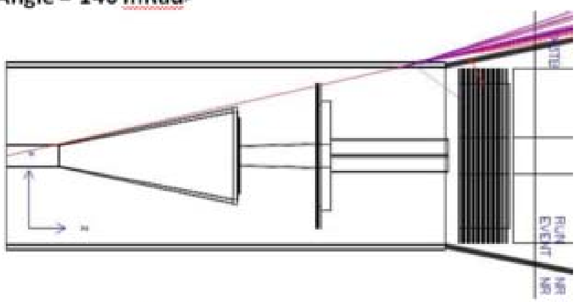


50 GeV electron shower vs. angle

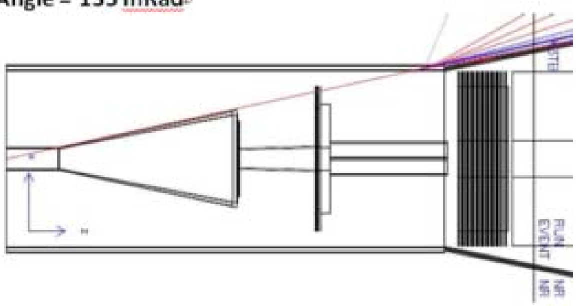
Angle = 785 mRad



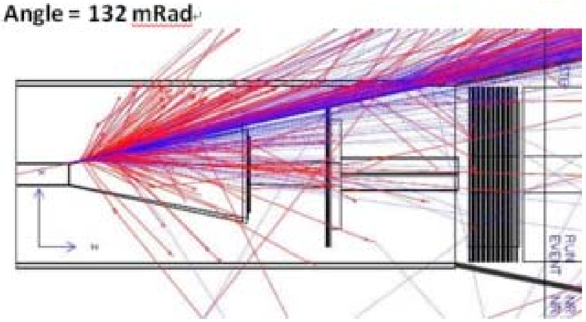
Angle = 140 mRad



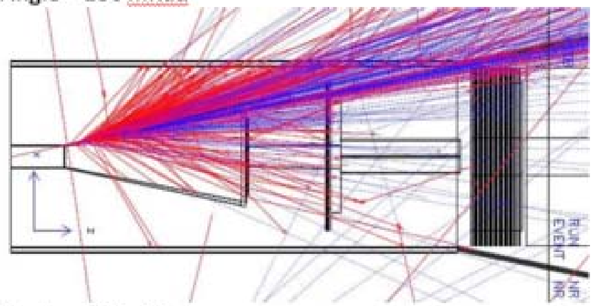
Angle = 135 mRad



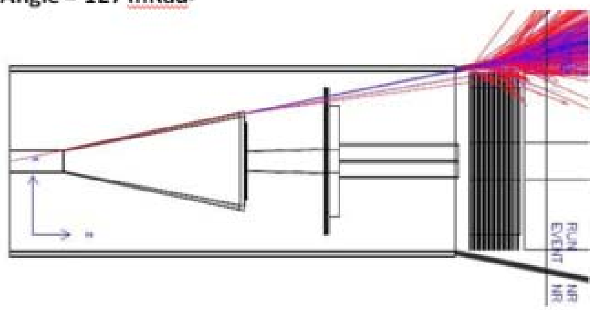
Angle = 132 mRad



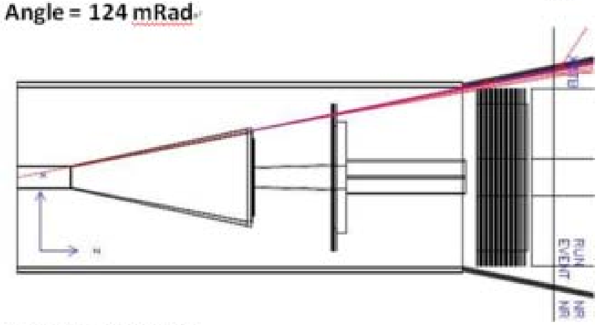
Angle = 130 mRad



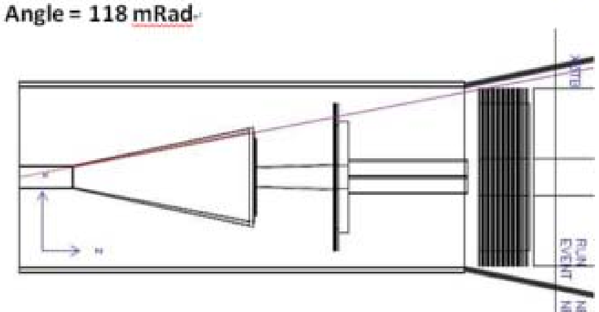
Angle = 127 mRad



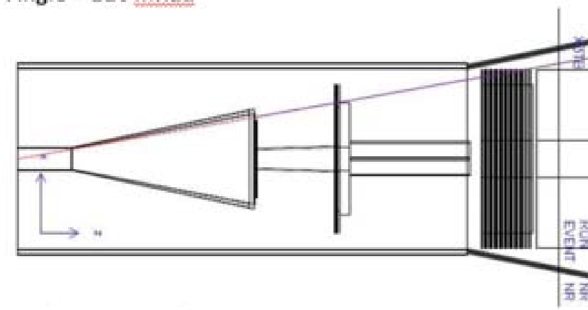
Angle = 124 mRad



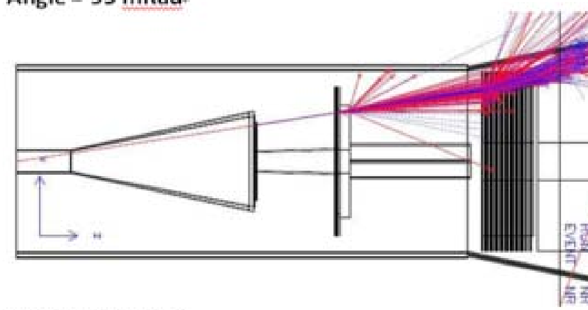
Angle = 118 mRad



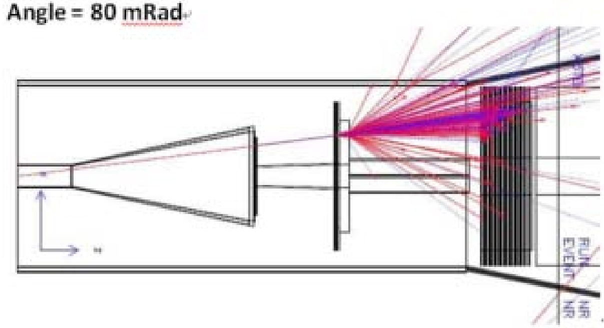
Angle = 110 mRad



Angle = 95 mRad



Angle = 80 mRad

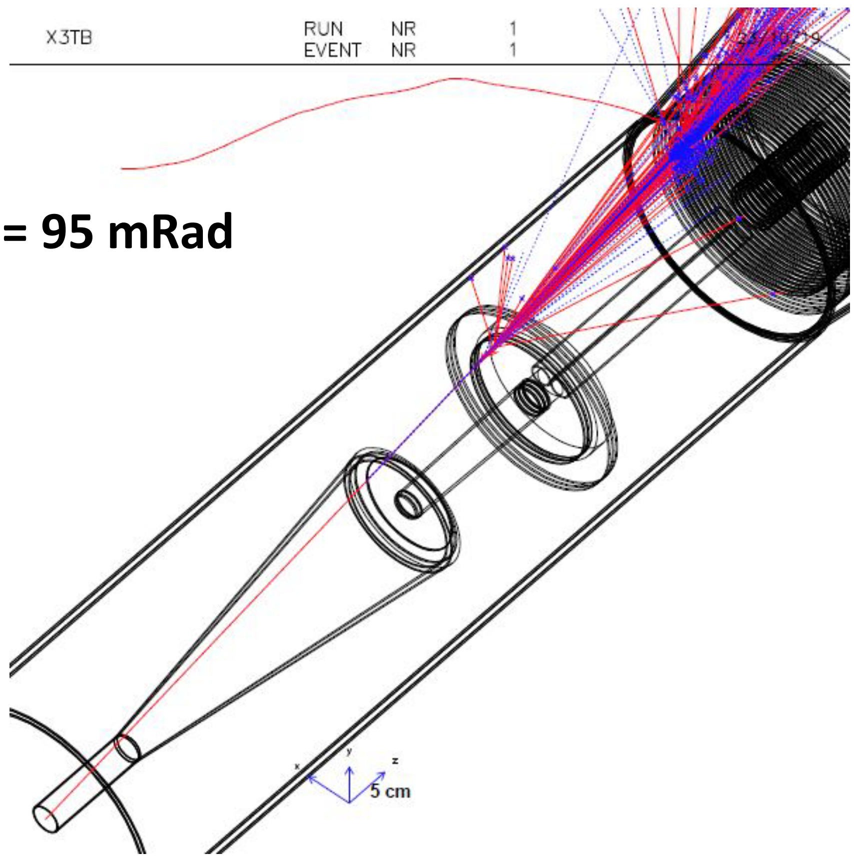


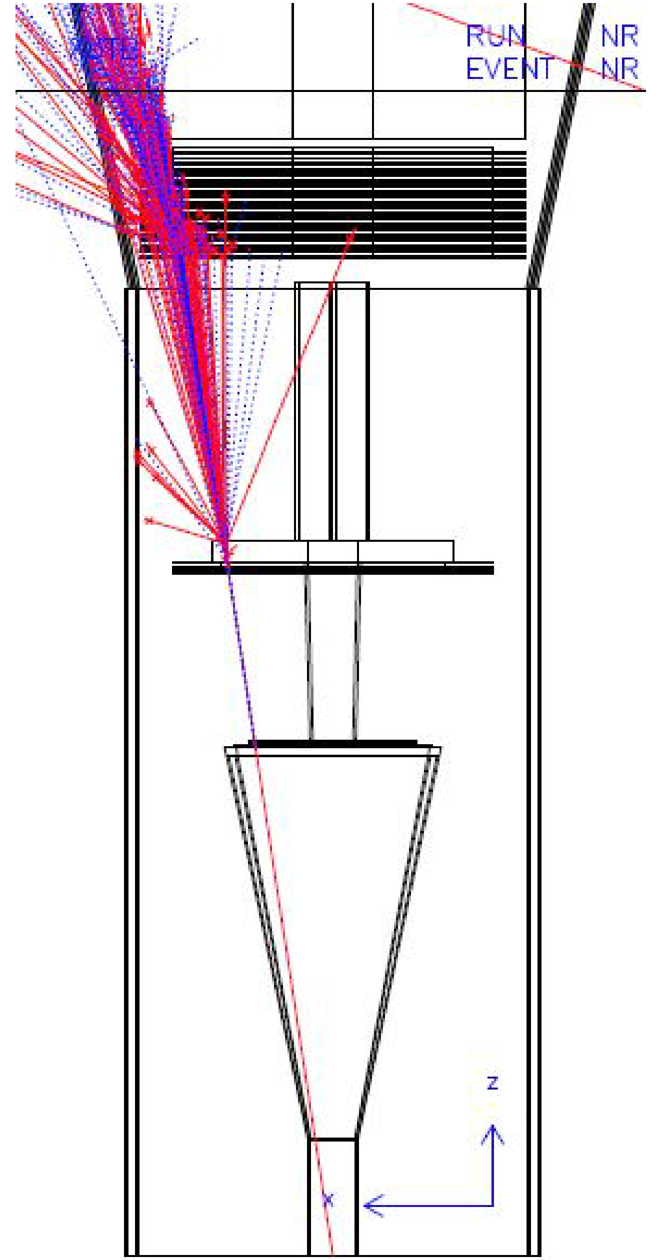
Shower leakage, electron <130 mRad

Negligible to Tracking volume

- Material ~ 2X0 (<3X0), energetic secondaries go forward toward Q-pole
- Large angle secodaries are very low energy (<100 MeV), mostly stopped by the 5 mm Fe TUBE

Angle = 95 mRad





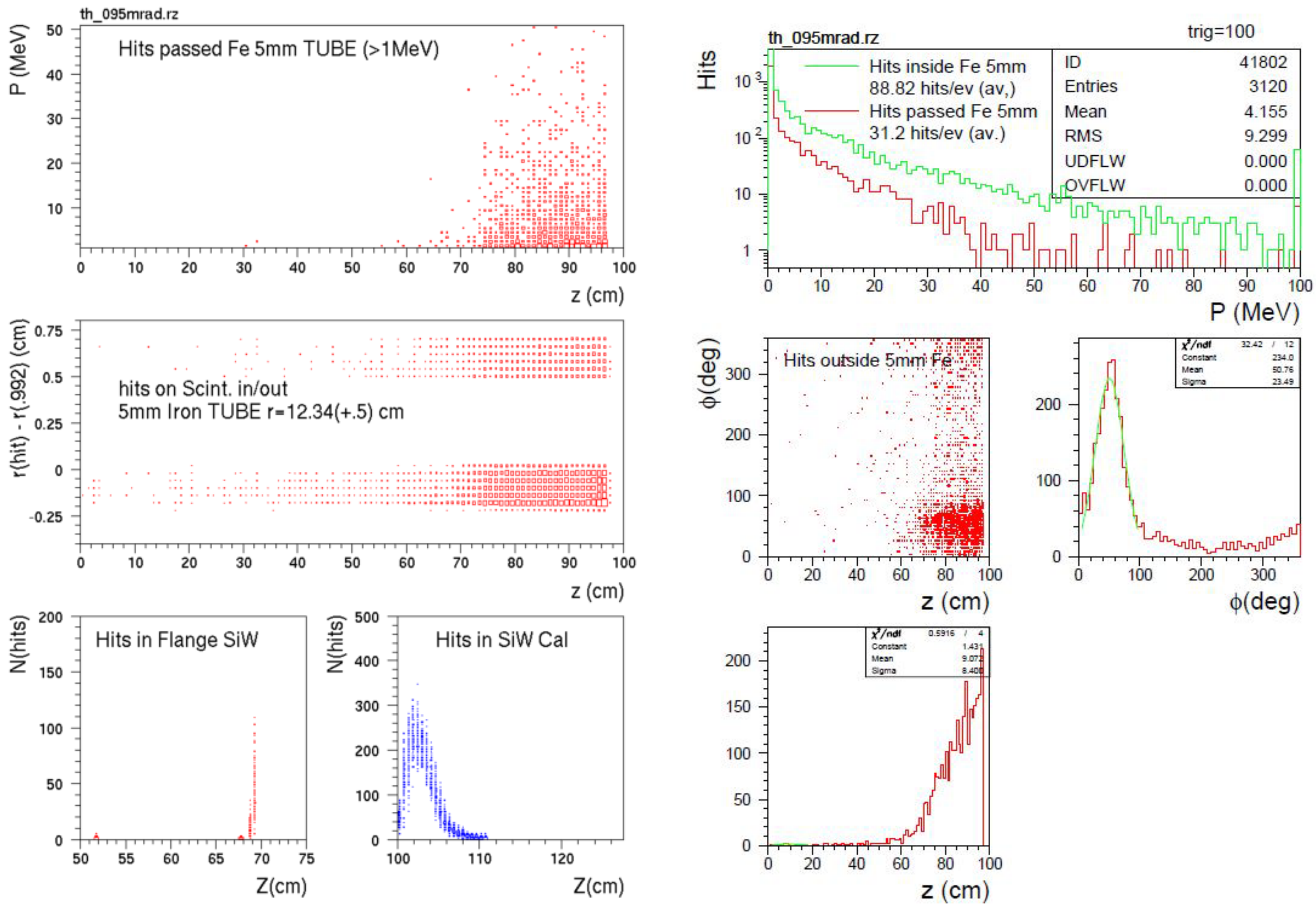
Shower on Z<970 5mm Fe TUBE

Monitor particle hits before/after 5mm Fe support TUBE (r = 123.4 mm)

50 GeV electrons at theta = 95 mRad **edge of LumiCal**

Shower by Flange and 2 layers of W (1X0)

Secondaries are behind Z>700mm



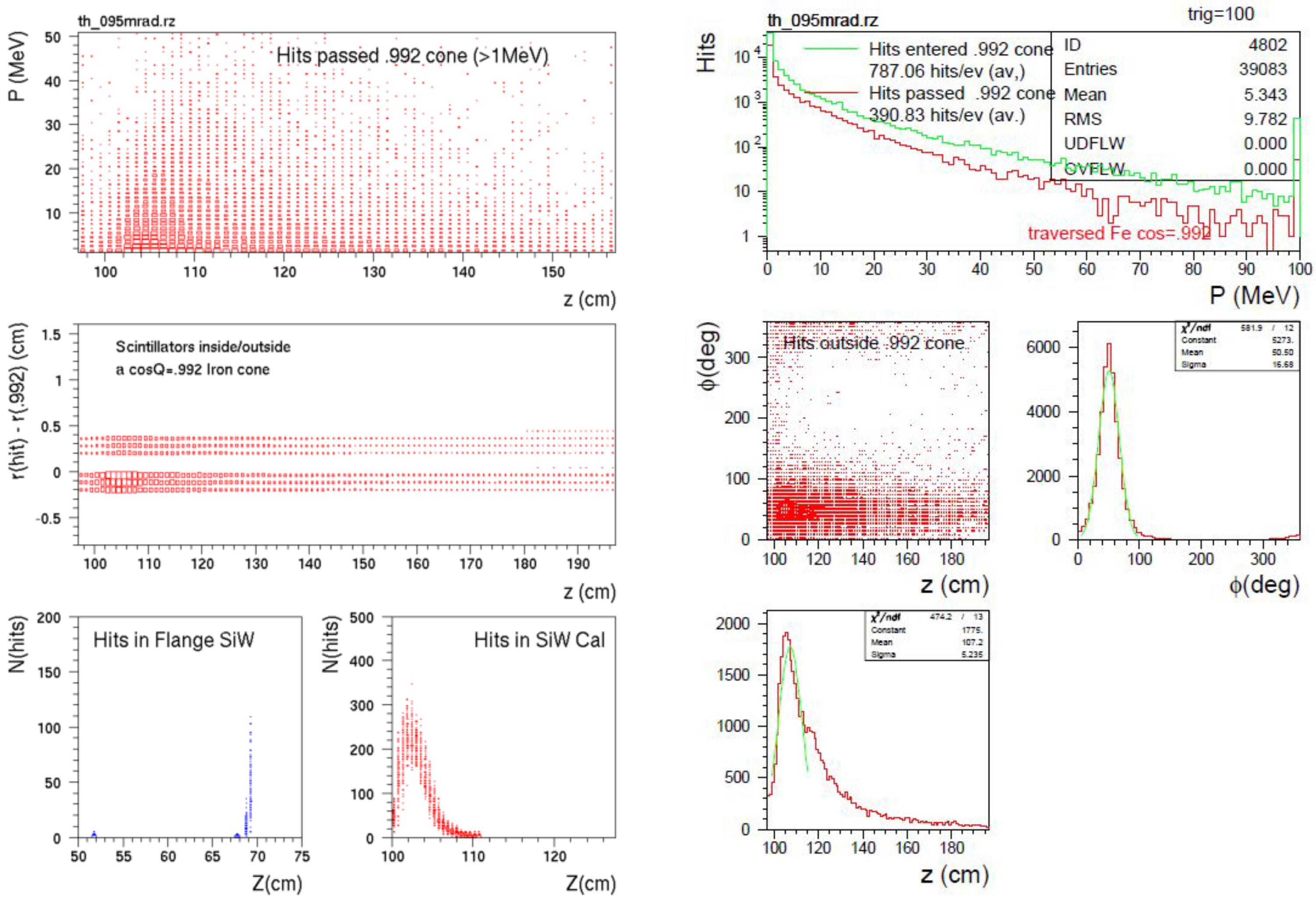
Shower on Z>970 5mm Fe CONE

Particle hits before/after 5mm Fe CONE around LumiCal **(r = 123.4 mm @Z=970mm)**

50 GeV electrons at theta = 95 mRad

Shower by Flange and 2 layers of W (1X0)

Secondaries are behind Z>700mm, **continue on at LummiCal**



5 mm Fe blocking shower to Tracker

GEANT particle momentum unit/precision is 0.1 MeV

5mm Fe surrounding beampipe, 2X0 Tunsteng in Flange, 20X0 in LumiCal

- **> 130 mRad** → shower caused by 5mm Fe layer
- **@130 mRad** → max shower by beampipe, Q-pole edge
- **~100 mRad** → LumiCal leakage

→ ***< 100 mRad Tungsten, 2X0 in Flange has little leakage effect***

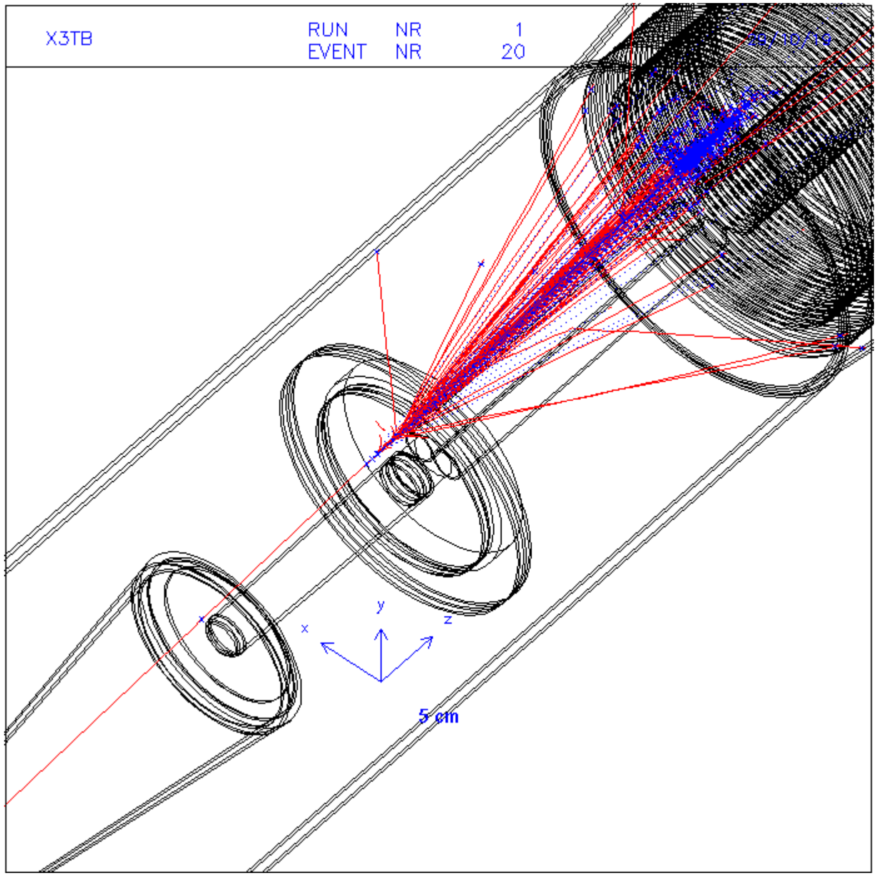
Electron theta Angle mRad	Hits/event z<970mm outside/inside TUBE	Hits/event z>970mm outside/inside CONE	
785 mRad	28.3 / 12.0	.029 / .003	← Support Tube shower
140 mRad	75.8 / 10.8	32.7 / 16.4	
135 mRad	80.7 / 9.92	61.0 / 27.9	
132 mRad	539 / 1162	123 / 122	← Beampipe shower
130 mRad	444 / 1138	129 / 227	
127 mRad	6.40 / 27.5	836 / 1605	← Q-pole edge shower
124 mRad	1.88 / 4.84	9.46 / 28.4	
118 mRad	.023 / .183	.036 / .153	
110 mRad	.022 / .172	.031 / .139	
95 mRad	31.2 / 88.8	391 / 787	← LumiCal edge shower
80 mRad	25.1 / 72.4	81.6 / 159	

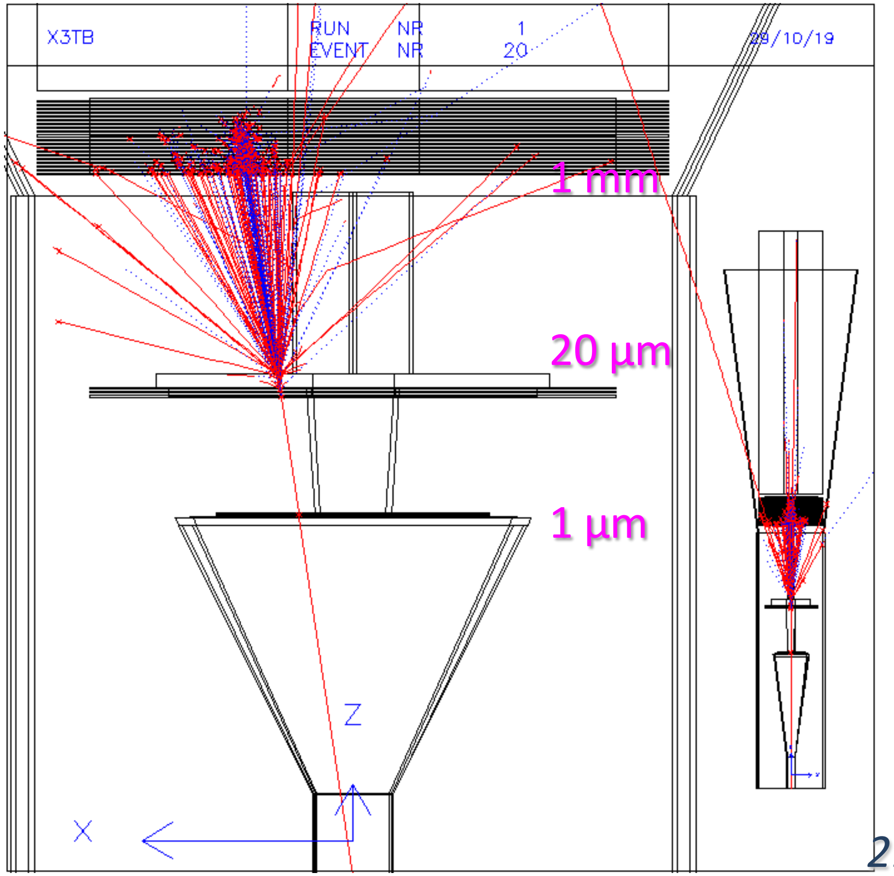
Precision on electron impact position

Attach 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



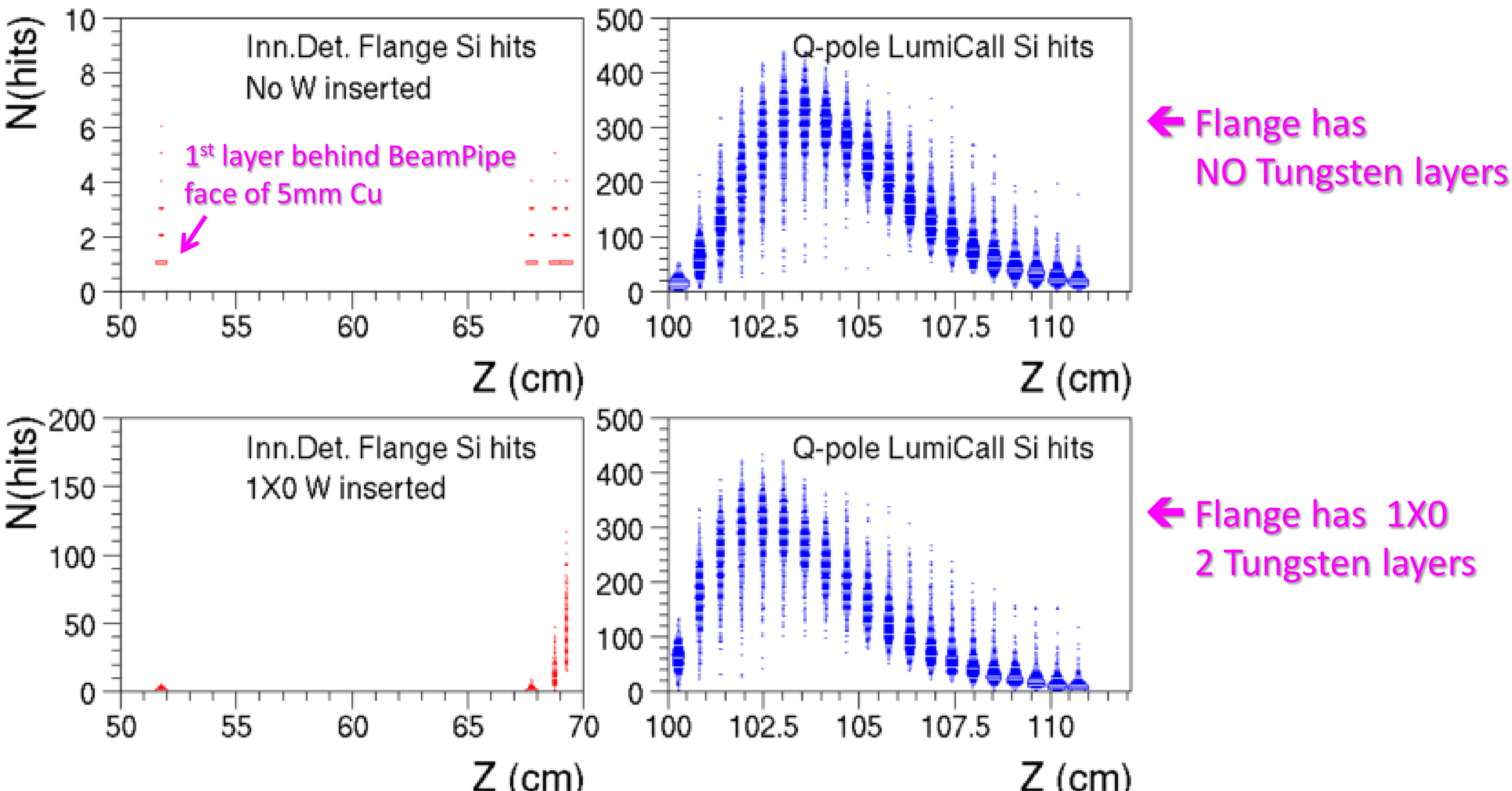


Precision on electron impact position

Compare Flange having 2X0 Tungsten layers OR NOT

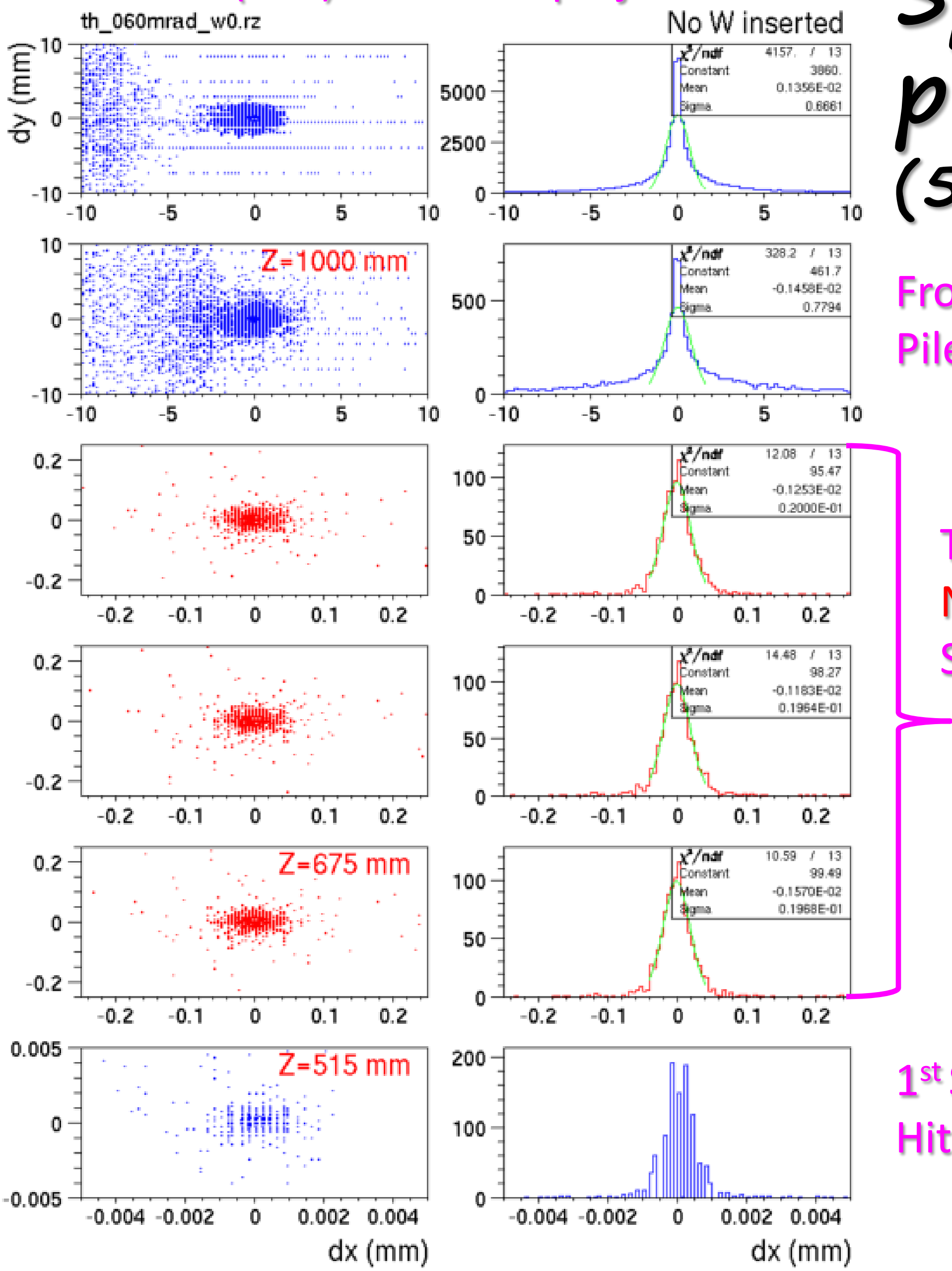
GEANT particles of 0.1MeV

Hits of shower secondaries on Si 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

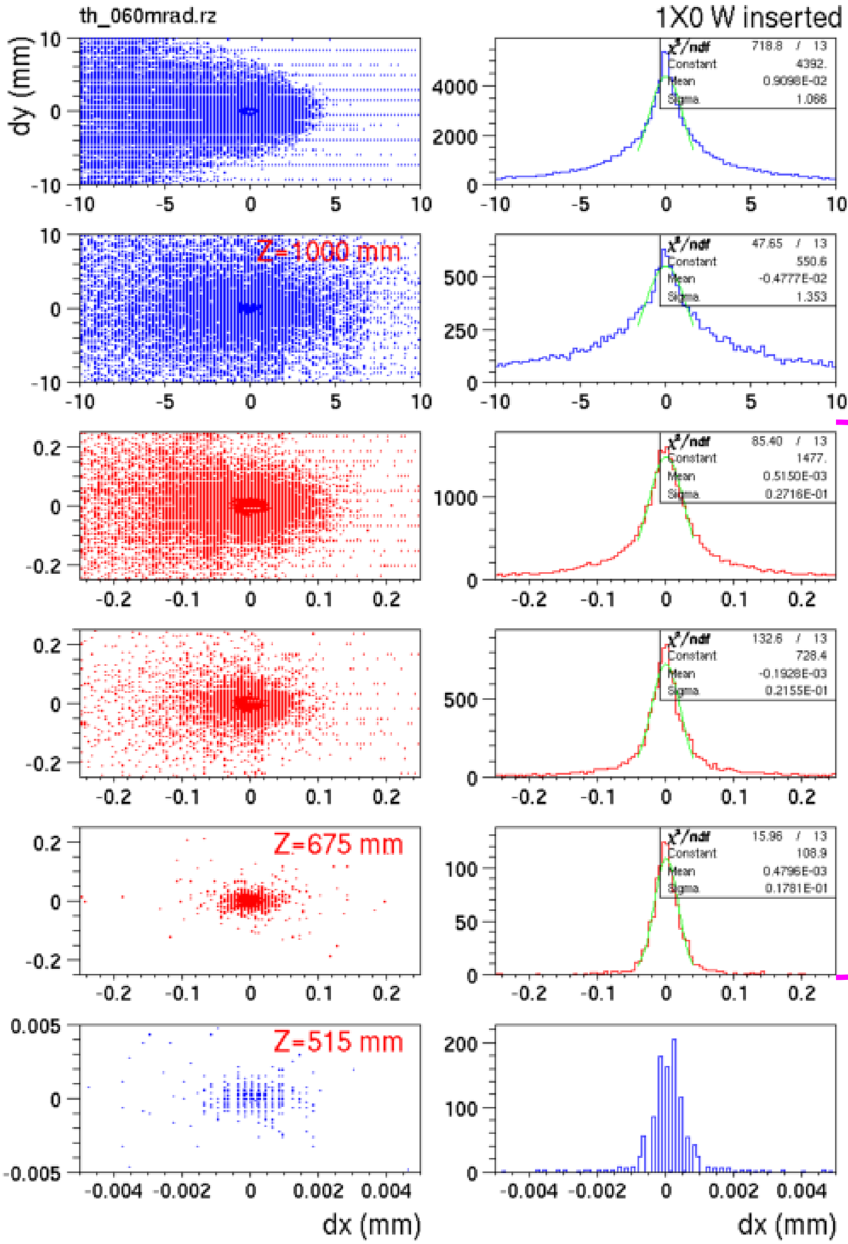
Spatial resolution ~ 20 μm

1st Si layer behinde 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



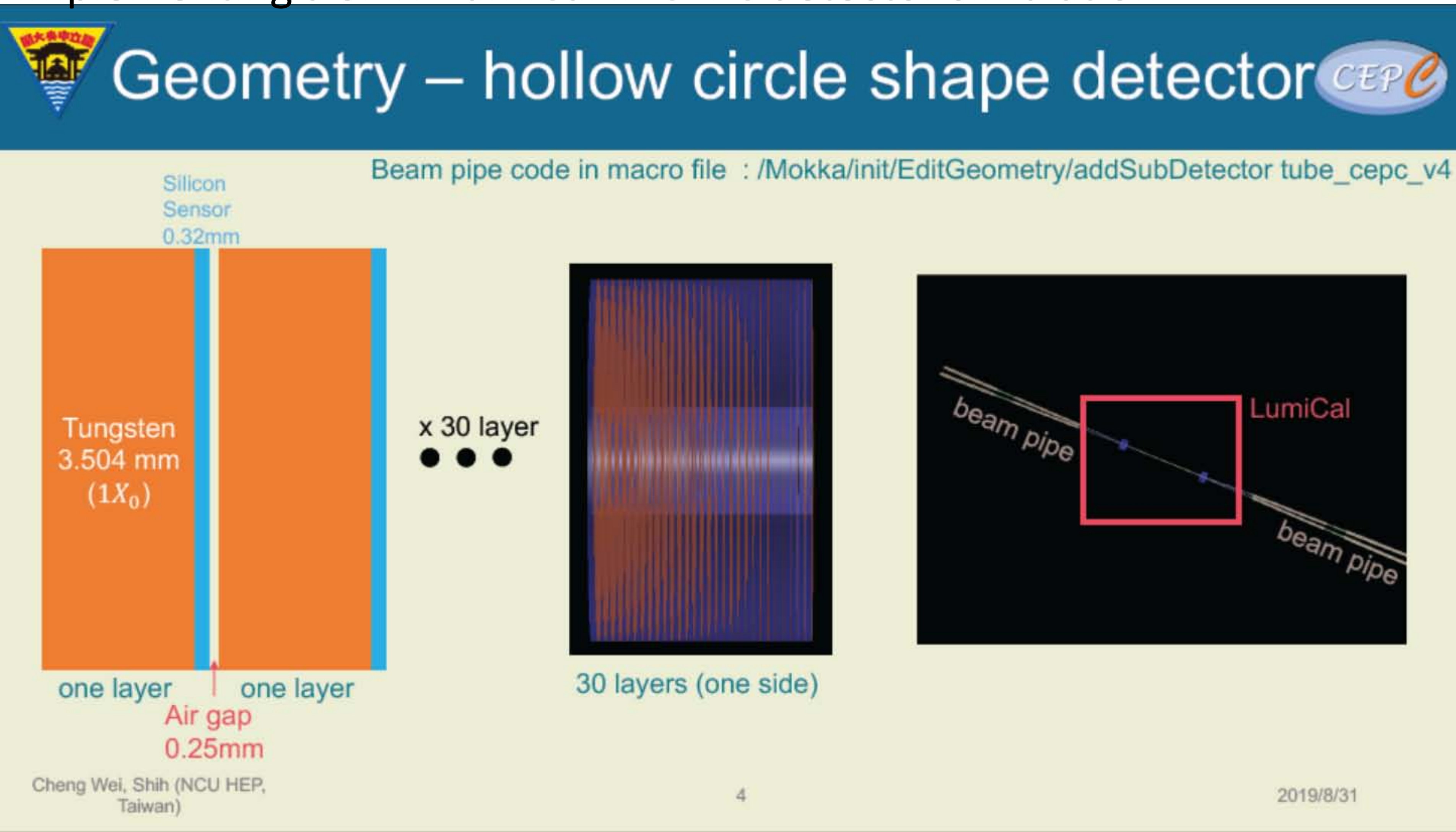
Front 2 Si-layers of Q-pole LumiCal
Pileup of shower ~1 mm resolution

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

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

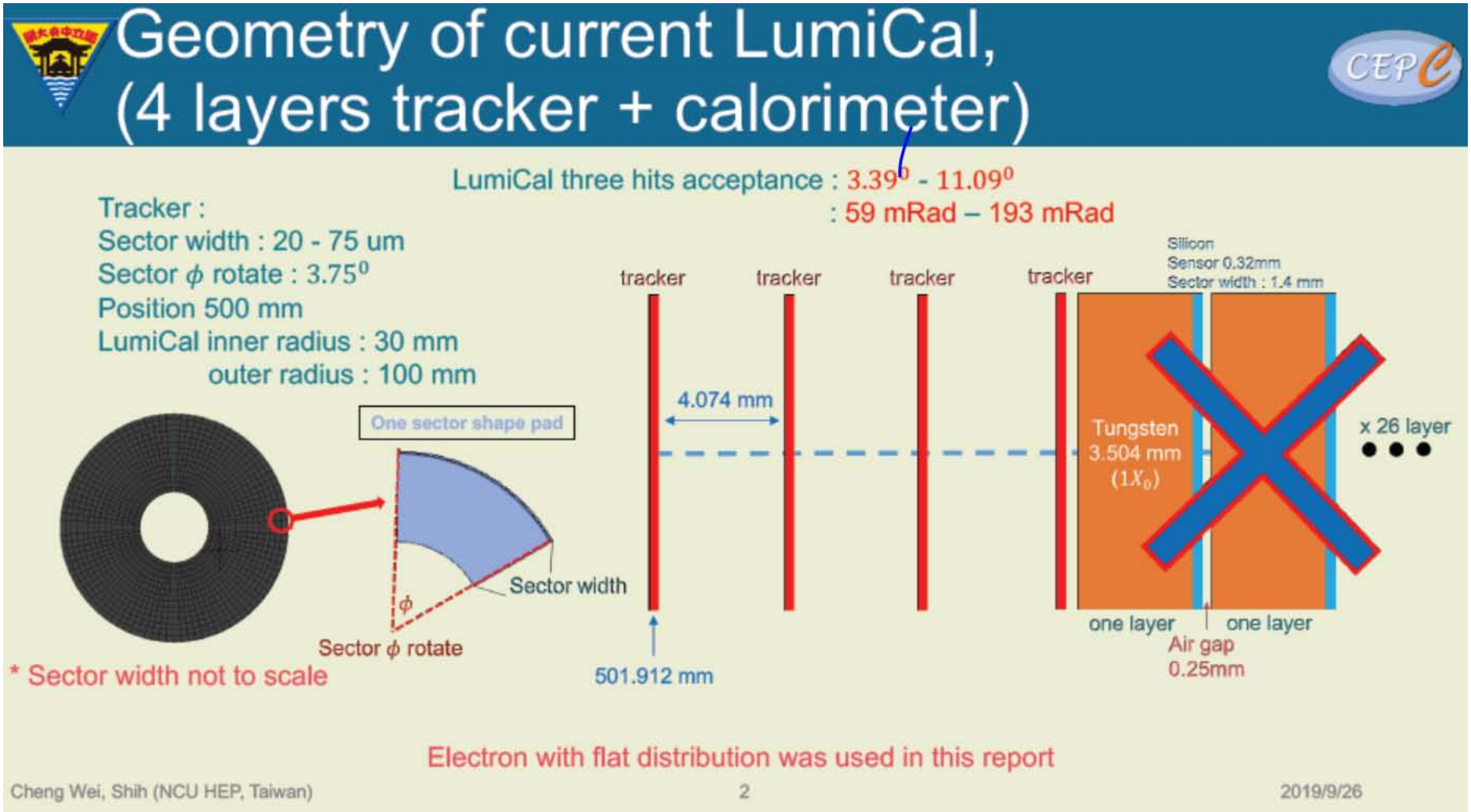
Detector segmentation for LumiCal

Implementing a Si-W LumiCal in CEPC detector simulation



Detector segmentation for LumiCal

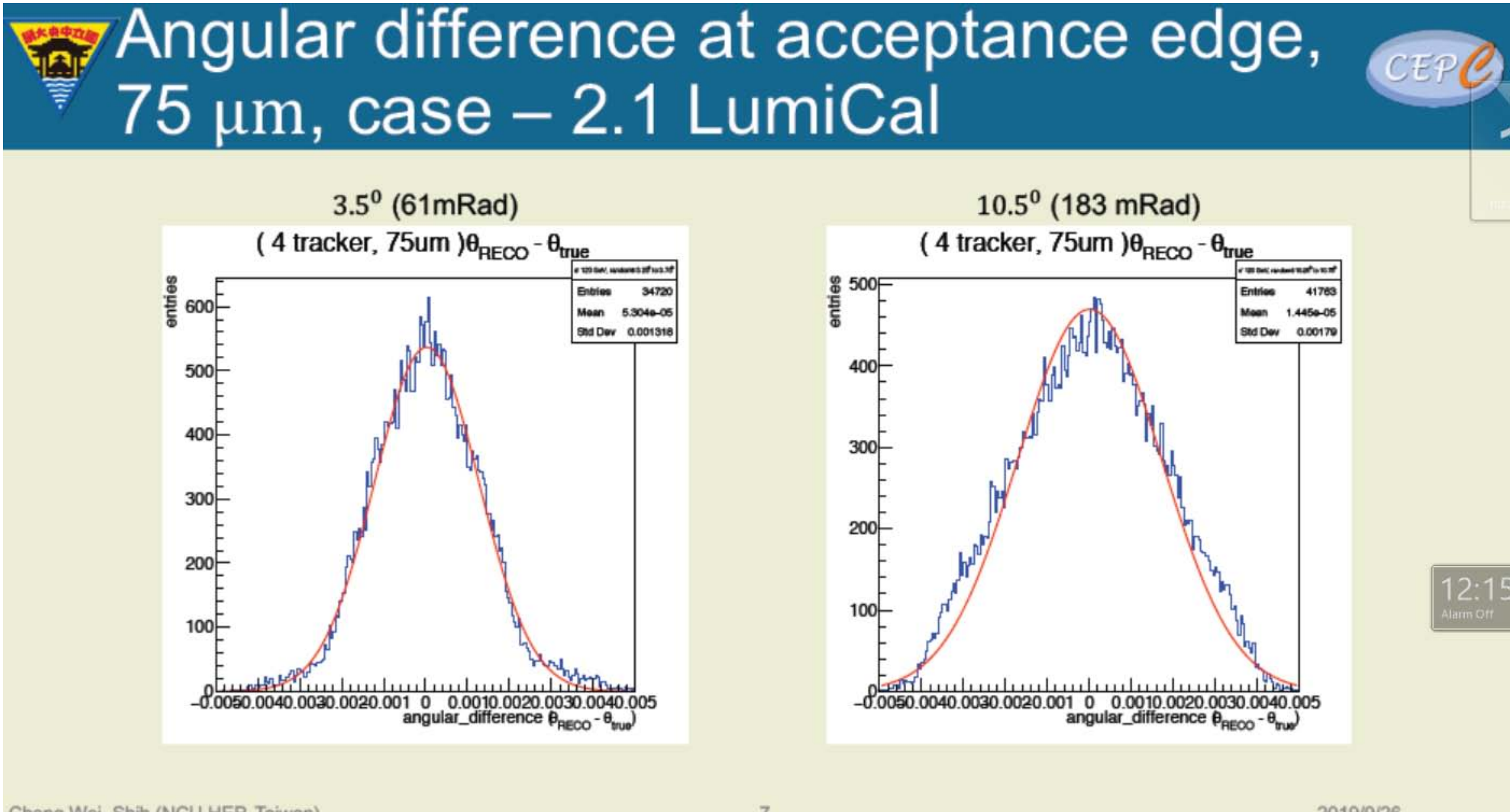
Vary the pixel size in Theta, LumiCal at Z=500 mm



Detector segmentation for LumiCal

Pixel size in Theta, 75µm (=.15mRad) LumiCal at Z=500 mm

LumiCal only, Electron hit position resolution **~ 2 mRad**



Detector options

Electron impact position to 1 μm precision

- fine pitch Si-wafer stick to beampipe
- covering theta range ~30 to 100 mRad

Electron/Photon ID

- Multiple Si-wafers to ID photon tracks
  being originated from IP or beampipe fragmentation

Beam electron ID

- LumiCal segmentation for 1 mm resolution
- Could be Crystal + SiPM

Combined detection of Bhabha,

- Detect Bhabha single-electron Bhabha at low +X region
- Build far-forward tagger on –X electron (behind Q-pole)
  to trigger Back-to-Back Bhabha