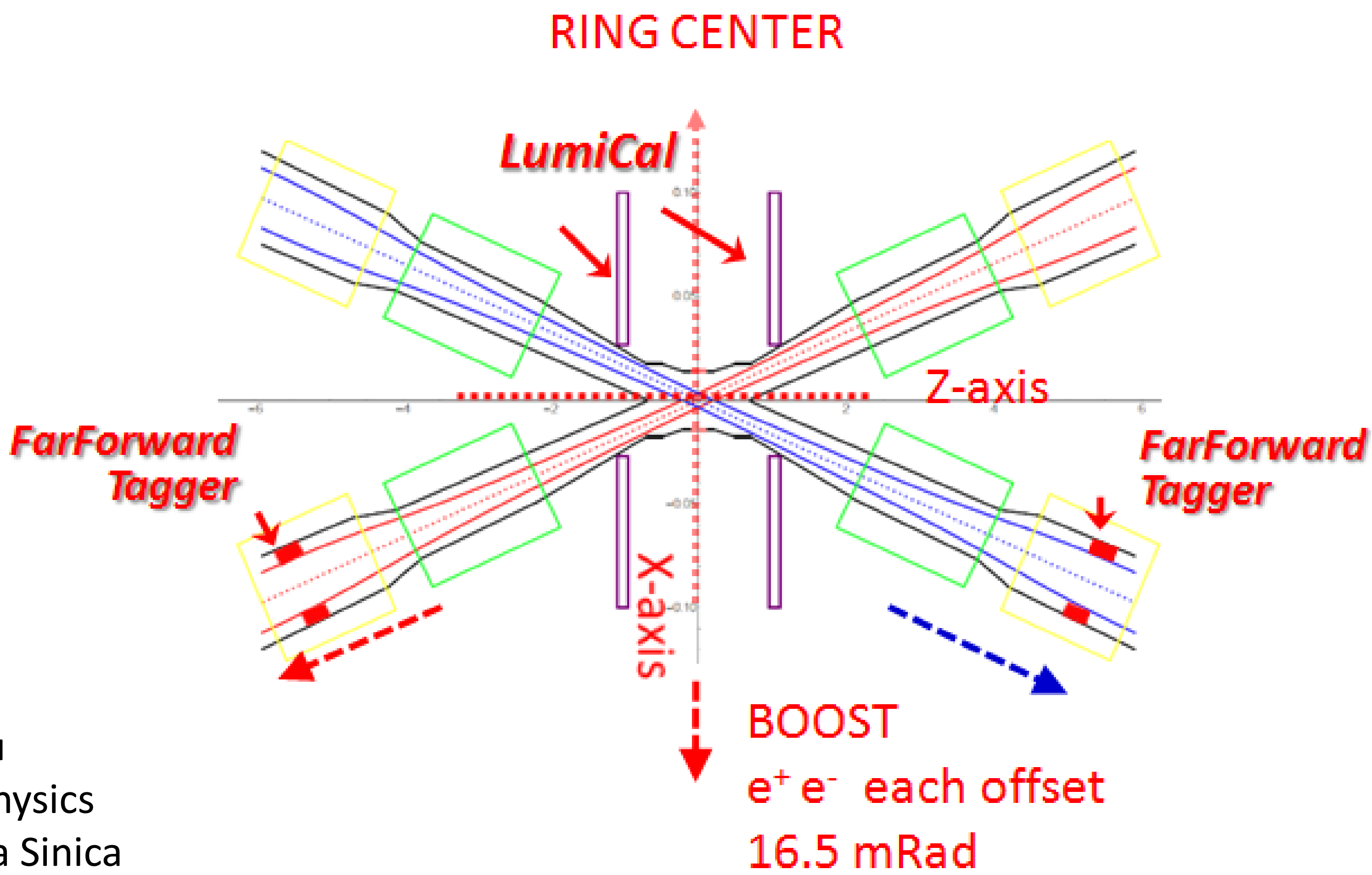
LumiCal Design Status



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2020.05.29
https://indico.ihep.ac.cn/event/11801/

Outline

- **Physics basic, BHLUMI :**

  estimating Bhabha cross section for geom acceptance

  beam crossing boost effect

  → Pushing for θ_{min} < 30 mRad for σ(Bhabha) > 50 nb ✓

- **GEANT study: reality toward δL/L ~ 10^{-4}**

  beampipe material → multiple scattering, EM shower

  beampipe shape, detector position → spatial resolution ✓

- **LumiCal + : Geometry and detector coverage**

  Vertex Si volume : wafer surrounding beampipe

  beampipe Flange : Si disks + LYSO Calorimeter

  Q-pole front : LumiCal calo using LYSO 2x2 mm^2 bars

  outgoing beampipe : Far-Forward Tagger

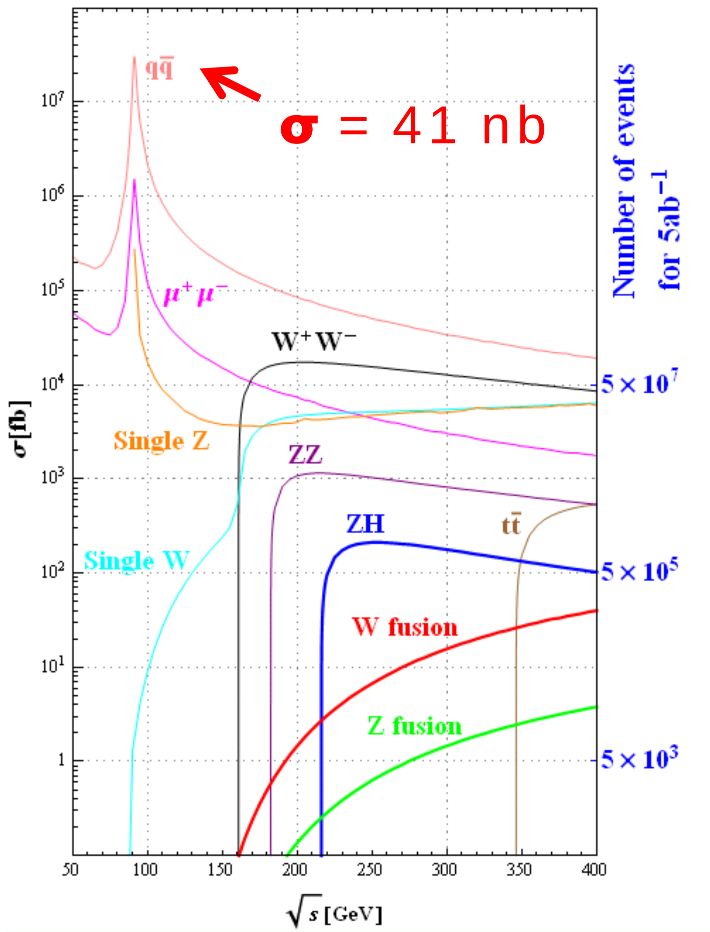
Luminosity measurement

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

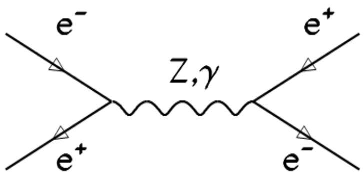
  $$e^+e^- \rightarrow e^+e^-$$

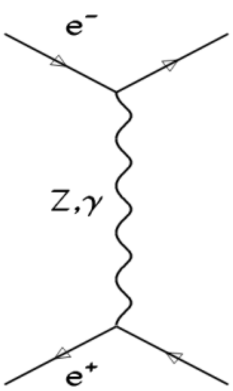
  – QED process, theoretical < *0.1%* precision
  – triggering on a pair of scattered e^+e^-

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



LO diagrams

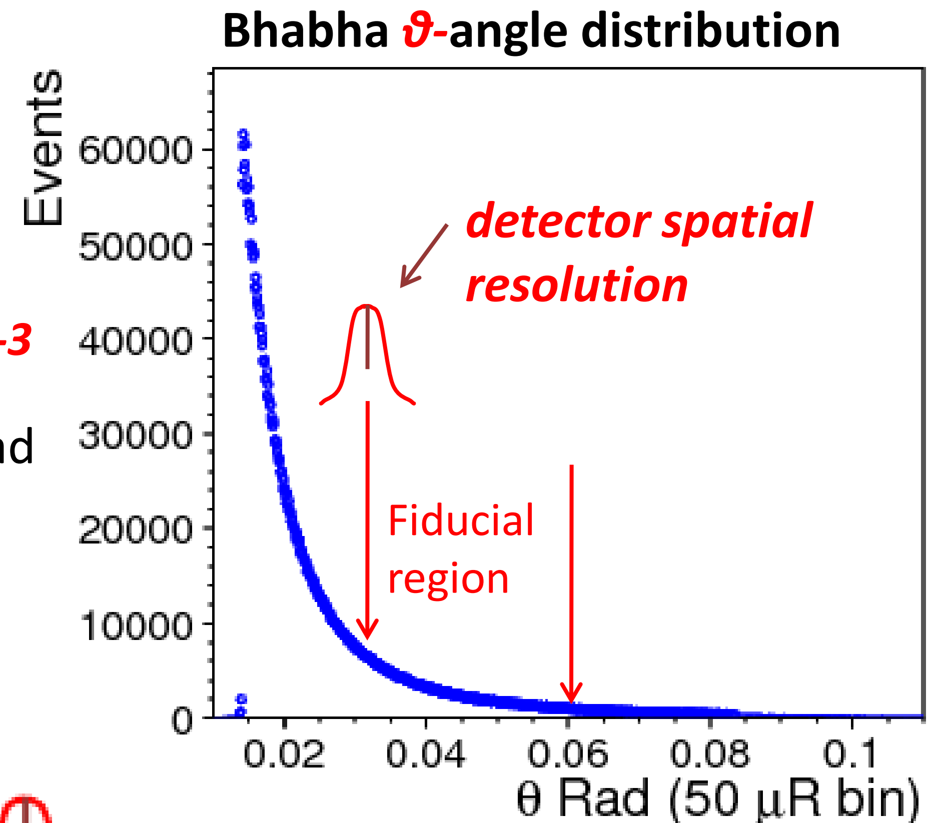




Luminosity precision

Dominant systematic error

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



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

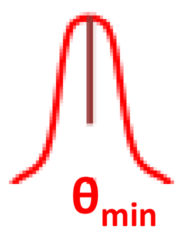
LumiCal at **z = ±1 m, ➔** θ_{min} = 30 mRad

→ *δϑ = 15 μRad* or ***dr = 15 μm***

Error due to offset on Z

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

LumiCal design goal:



- *Spatial res. narrow*
- *"Standard error of the mean"* on θ_{min}: $\sigma/\sqrt{N} < 1$ mRad

offset of fiducial edge to "the ***mean on*** θ_{min}*"*

→ ***LUMINOSITY error***

Bhabha detection

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

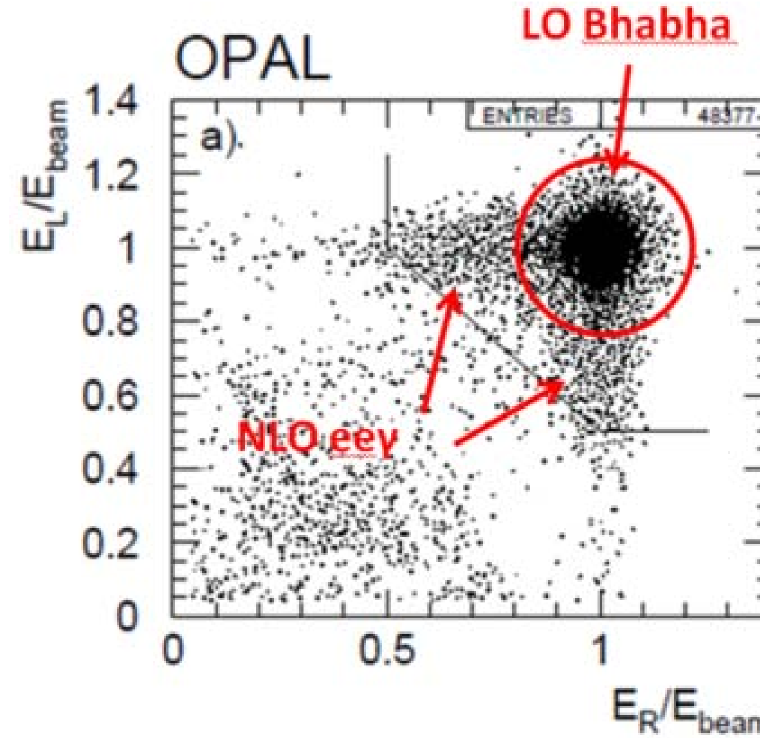
  Event signature

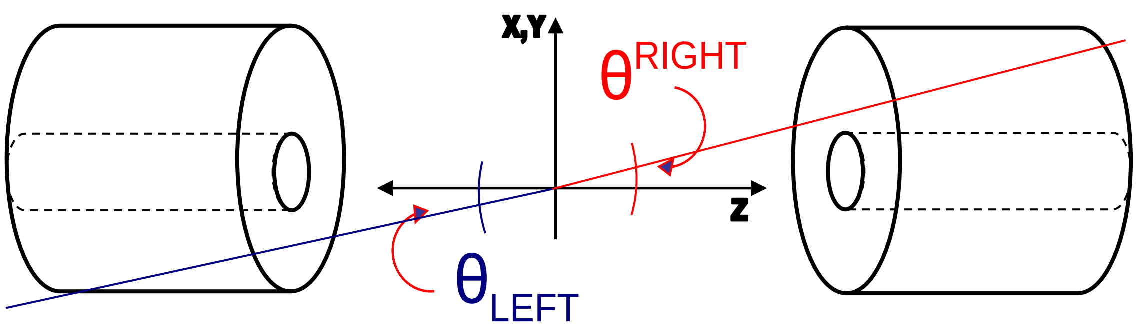
  1. $E(e^{\pm}) = E_{beam}$
  2. e^+, e^- Back-to-Back

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

  ~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

- Bhabha cross section
- 33 mRad beam crossing

  ➔ boosted $ee\gamma$ distribution

BHLUMI theoretical precision

Bhlumi 4.04 writeup: CERN-TH/96-158

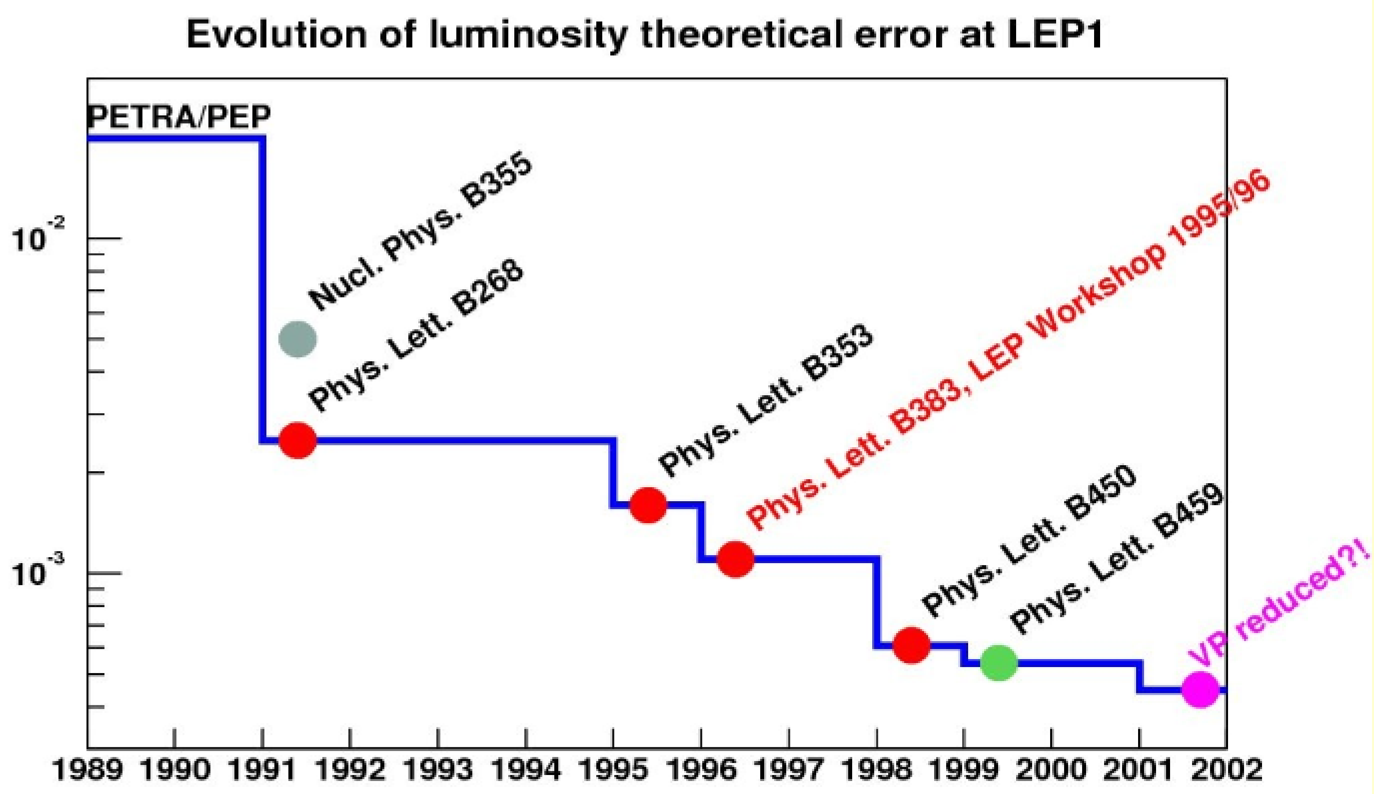
cds.cern.ch/record/310621/files/th-96-158.ps.gz

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%



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 < θ_1', θ_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.

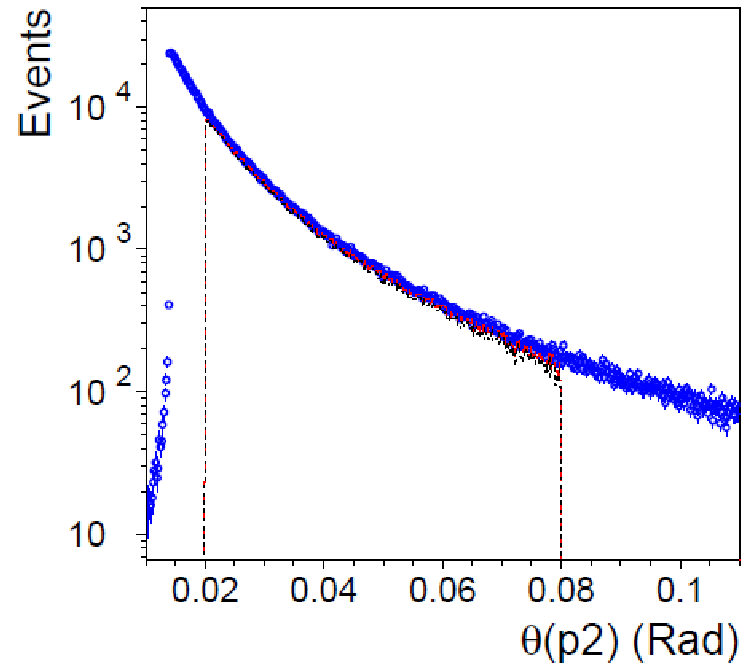
z_{min}	BHLUMI [nb]
.100	166.892 ± .006
.300	165.374 ± .006
.500	162.530 ± .006
.700	155.668 ± .006
.900	137.342 ± .006

Hep-ph/9602393

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

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

Theoretical Error ~ 10^{-3}

is static, dependings on parameters ➔

if there will be more precise calculation

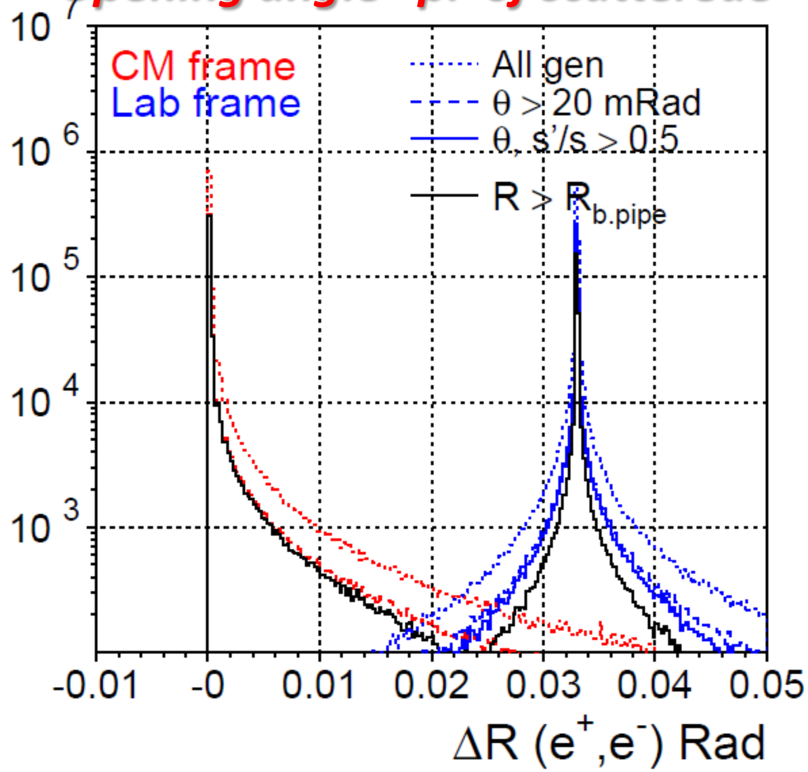
it is constant scaling

➔ it does not limit us from pursuing 10^{-4}

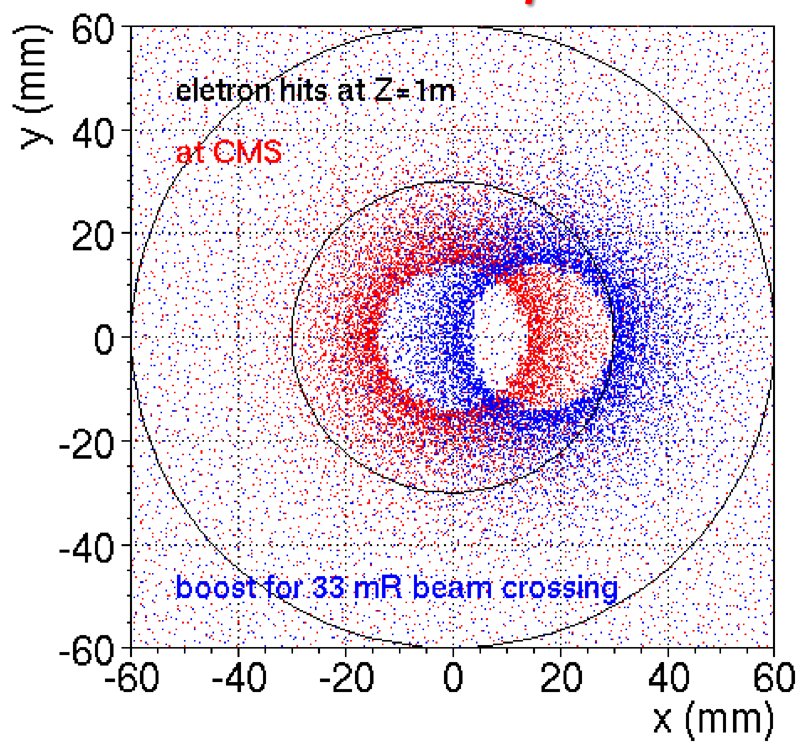
Bhabha back-to-back boosted by 33 mRad beam crossing

- 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

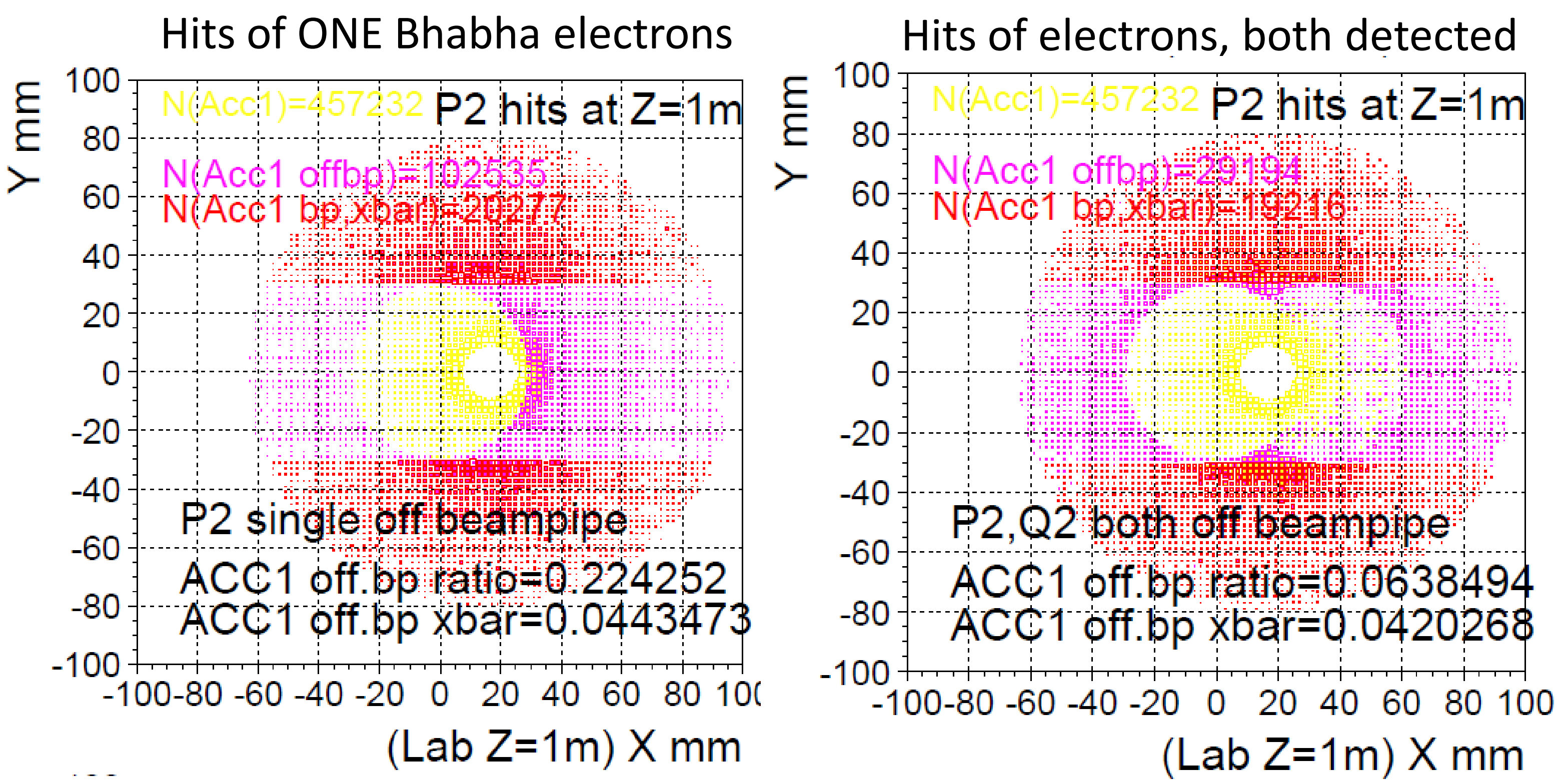


Bhabha X sec. vs Lab z-axis round pipe

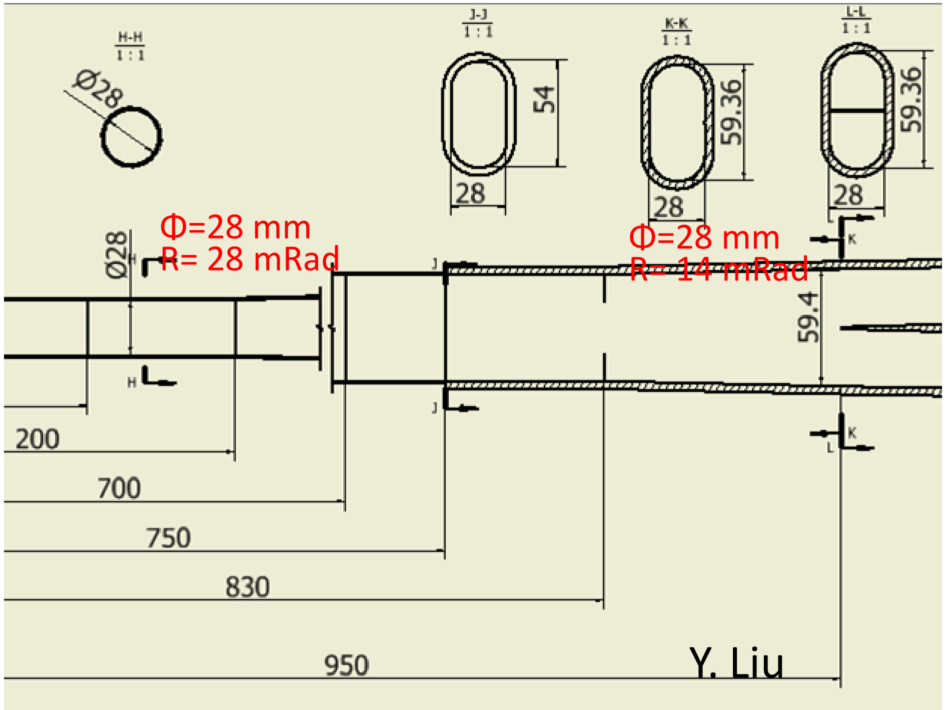
- CMS generated th1=10 mRad ➔ boosted +16.5mRad, +X are low angle Bhabha
- beampipe is LAB z-axis centered, **radius = 30 mRad** (r=30mm **@z=1m**)
  at x=+30 mm, Bhabha electrons are of θ = 13.5 mRad

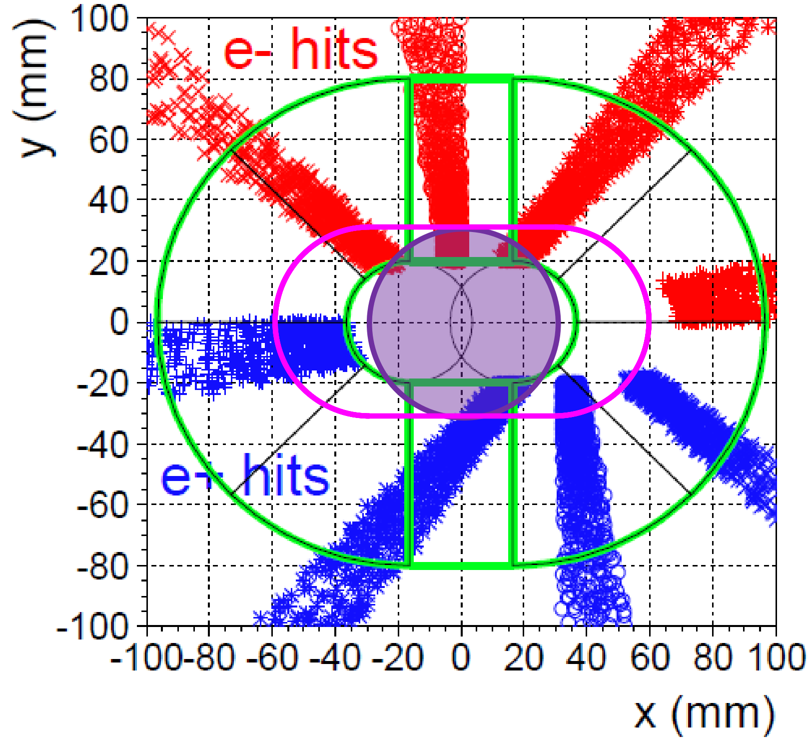
➔ Off beam pipe, detect: **one electron (262 nb) / both electrons (74.6 nb) = 3.51**

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



Bhabha X section





beampipe, r= 30 mRad (vertical) → σ(Bhabha) ≳ 50 nb

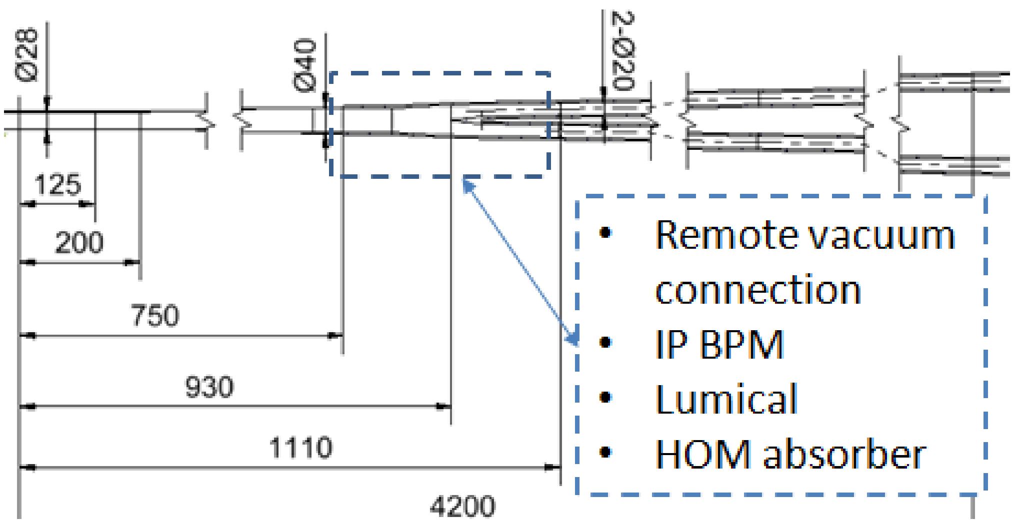
(r=30mm **@z=1m**)

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**

Low θ Bhabha, ONE electron detected

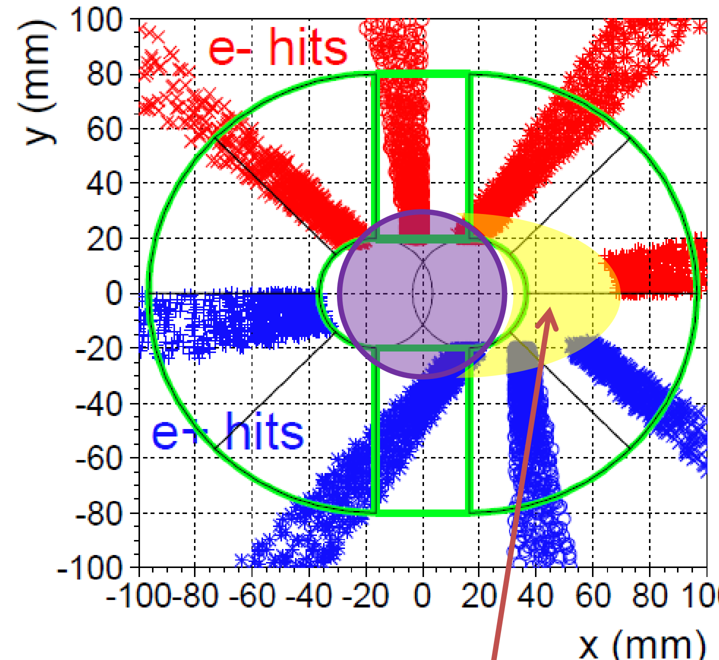
LumiCal beampipe is round
φ = 40 mm?

- LOW angle Bhabha on x-axis
  one electron detected (+x side)
- the other electron (-x side)
  is boosted/lost into beampipe



H. Wang

- ID boosted Bhabha
  by a ***Far-Forward tagger***
  10 mRad < θ < 30 mRad
  for the lost electron
- σ_{Bhabha} is 5x higher



Very hot region, Bhabha got boosted outward

BHLUMI study summary

- Bhabha Θ_{min} ~30 mRad for ~50 nb
  both back-to-back electrons detected

- 33 mRad beam crossing

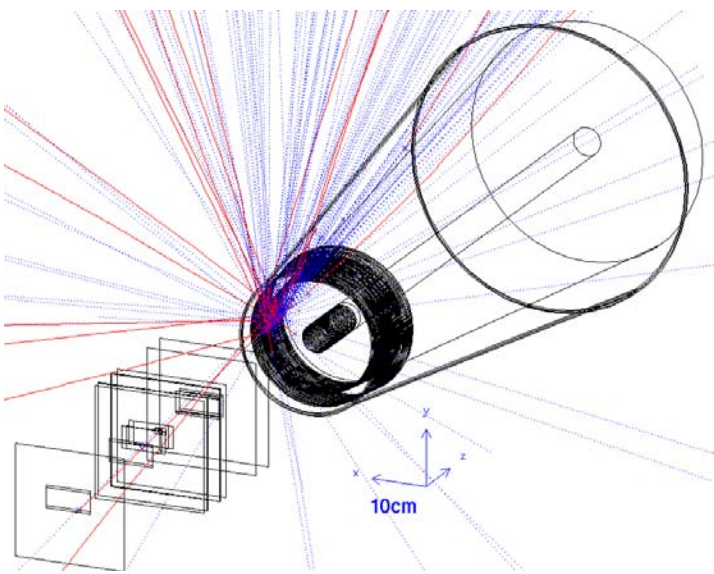
➔ LumiCal +x edge
  having boosted low θ particles (θ~16.5mRad)
  - ✓ x5 Bhabha cross section, ONE electron detected
  - ✓ forward physics, SM NLO, two-photon
  - → add far-forward taggers
    to explore this region

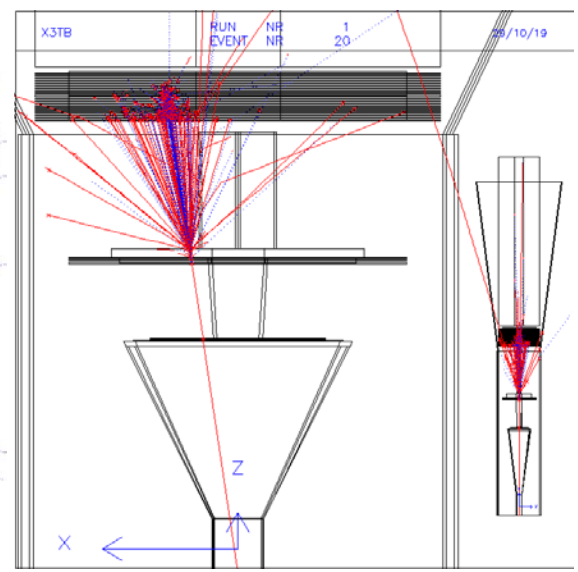
GEANT simulation

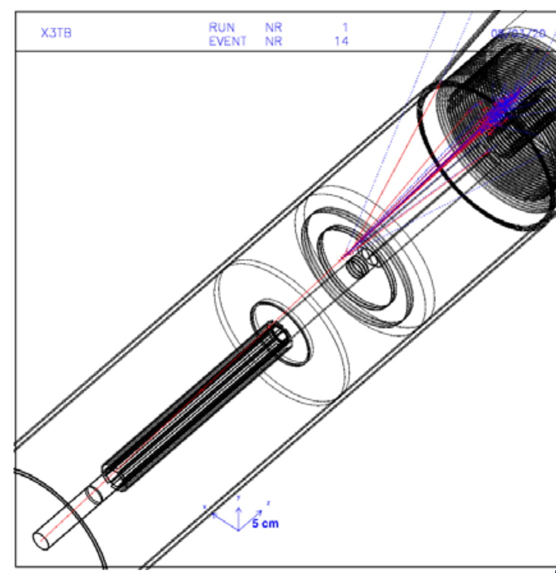
Intrinsic spatial resolution due to multiple scattering, EM shower

LumiCal GEANT versions

- **Code originated from a Si calo test-beam for lateral shower**
- **Version CDR: a SiW sandwich detector**
  no upstream material
- **Version post-CDR:**
  a Cone shape beampipe: optimizing spatial resolution
  a Tube shape close to real pipe, how to get off Mul.Scattering







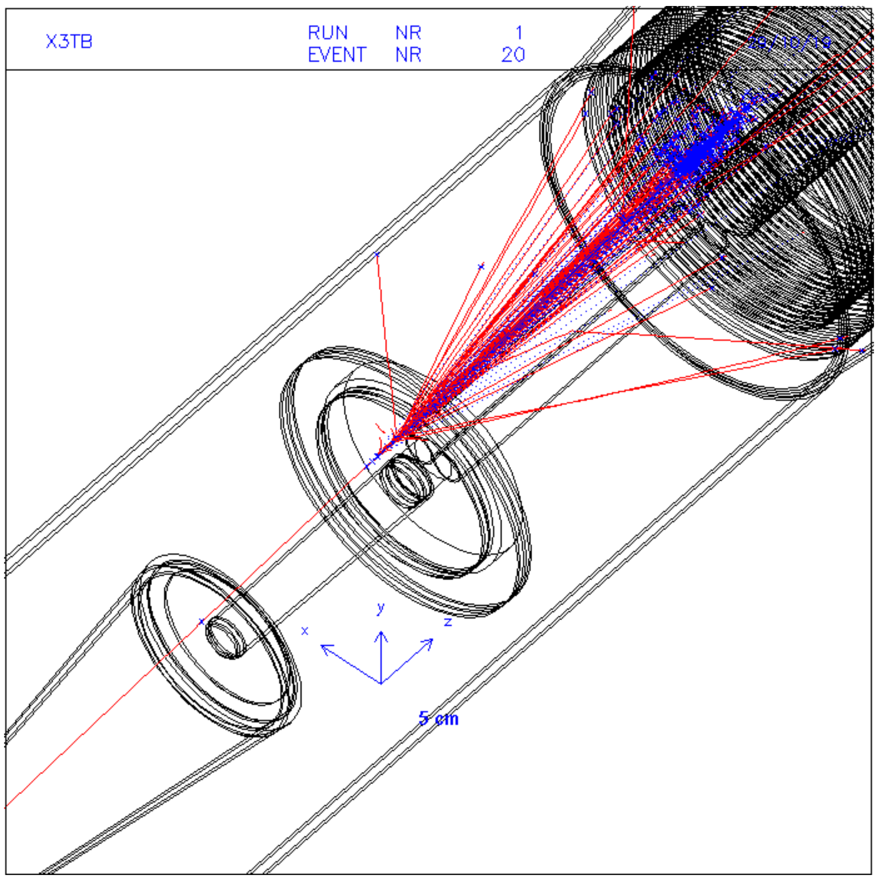
CONE beampipe, electron impact position

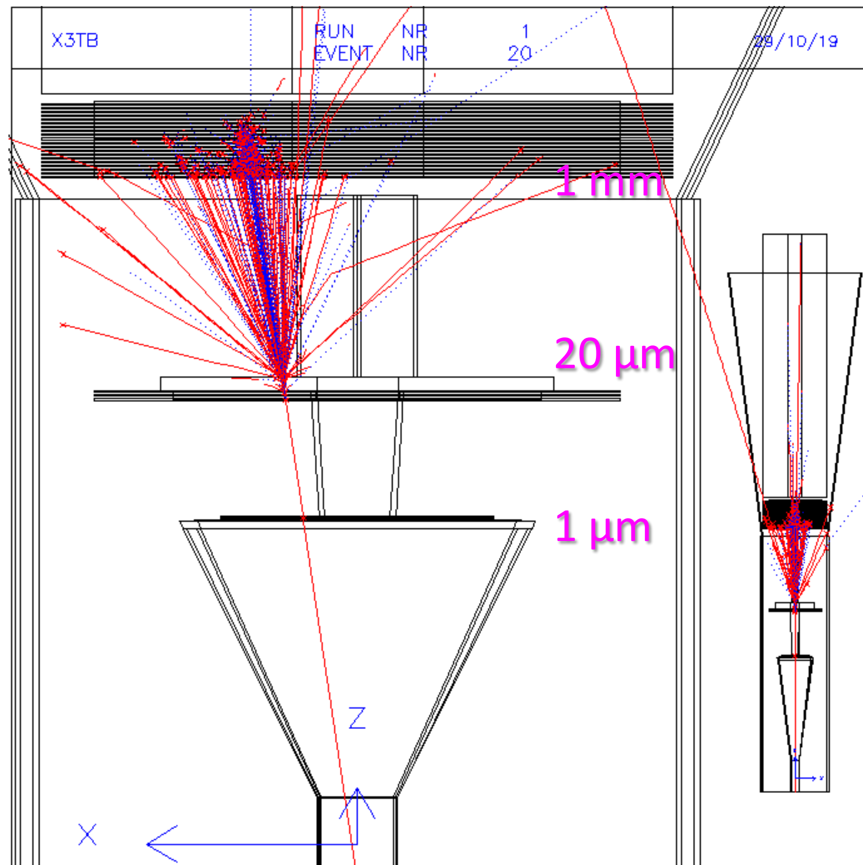
GEANT simulation precision is 0.1 MeV

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



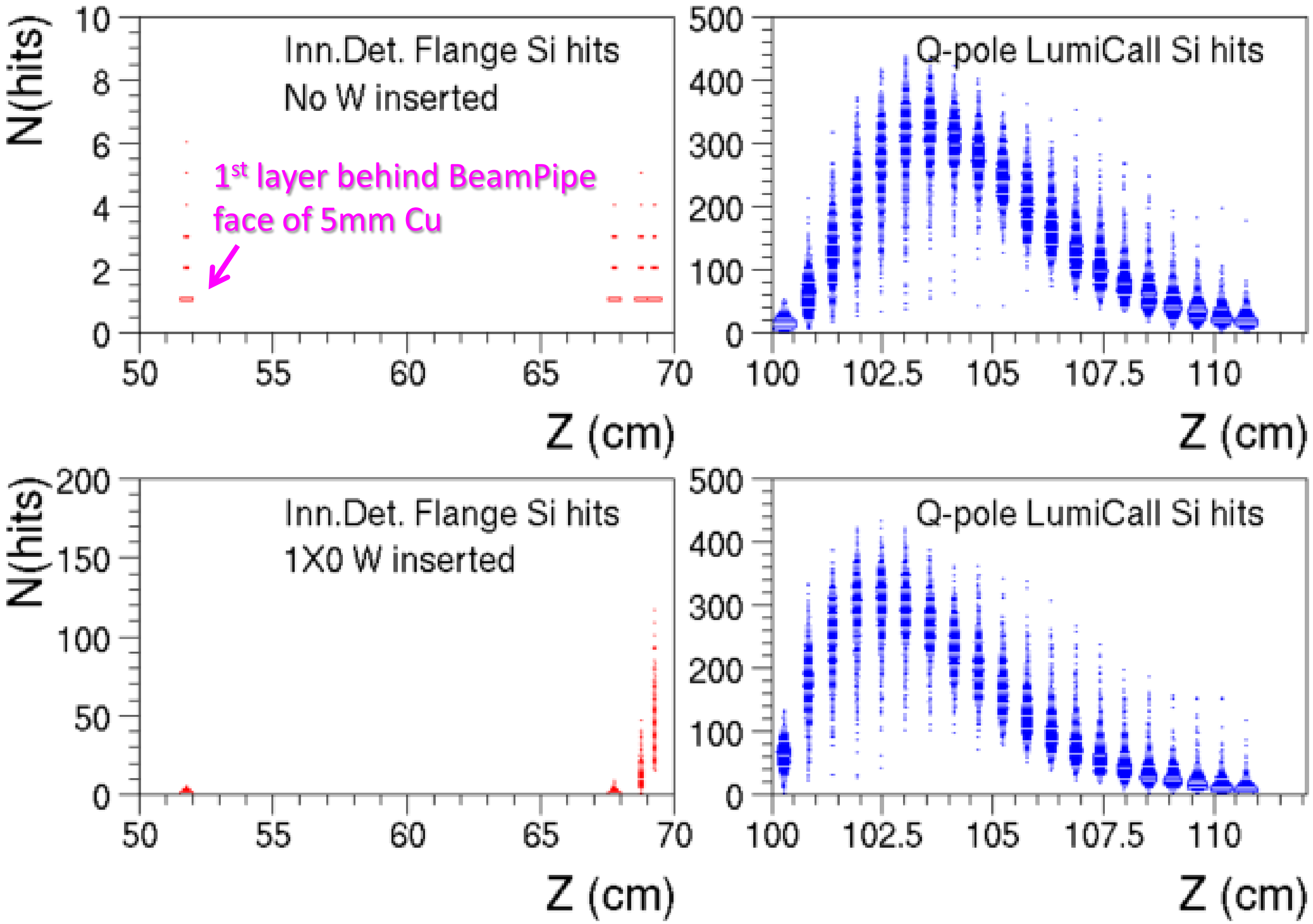


Precision on electron impact position

Compare Flange having two 1X0 Tungsten layers OR NOT

GEANT particles of 0.1MeV

Hits of charged shower secondaries on Si layers

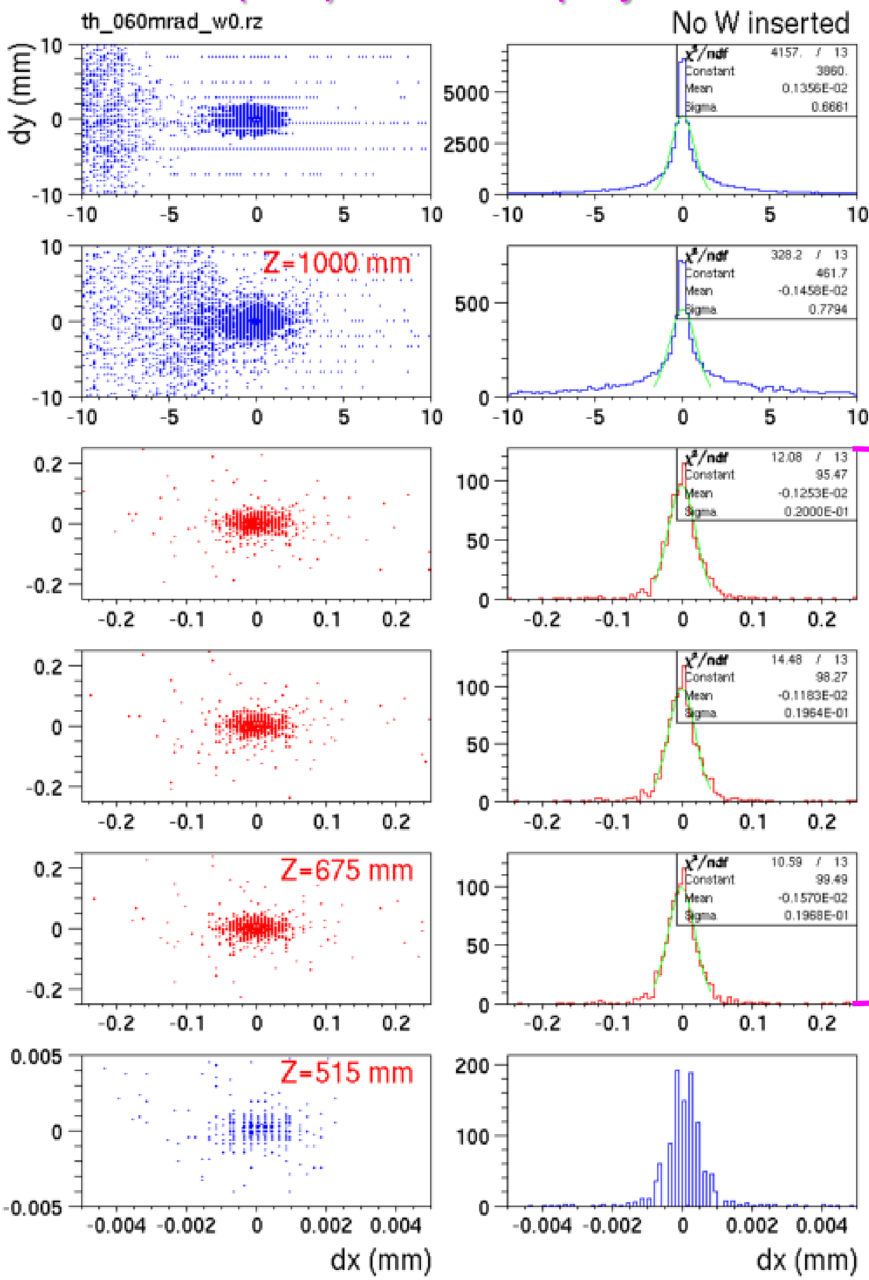


← Flange has
NO Tungsten layers

← 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

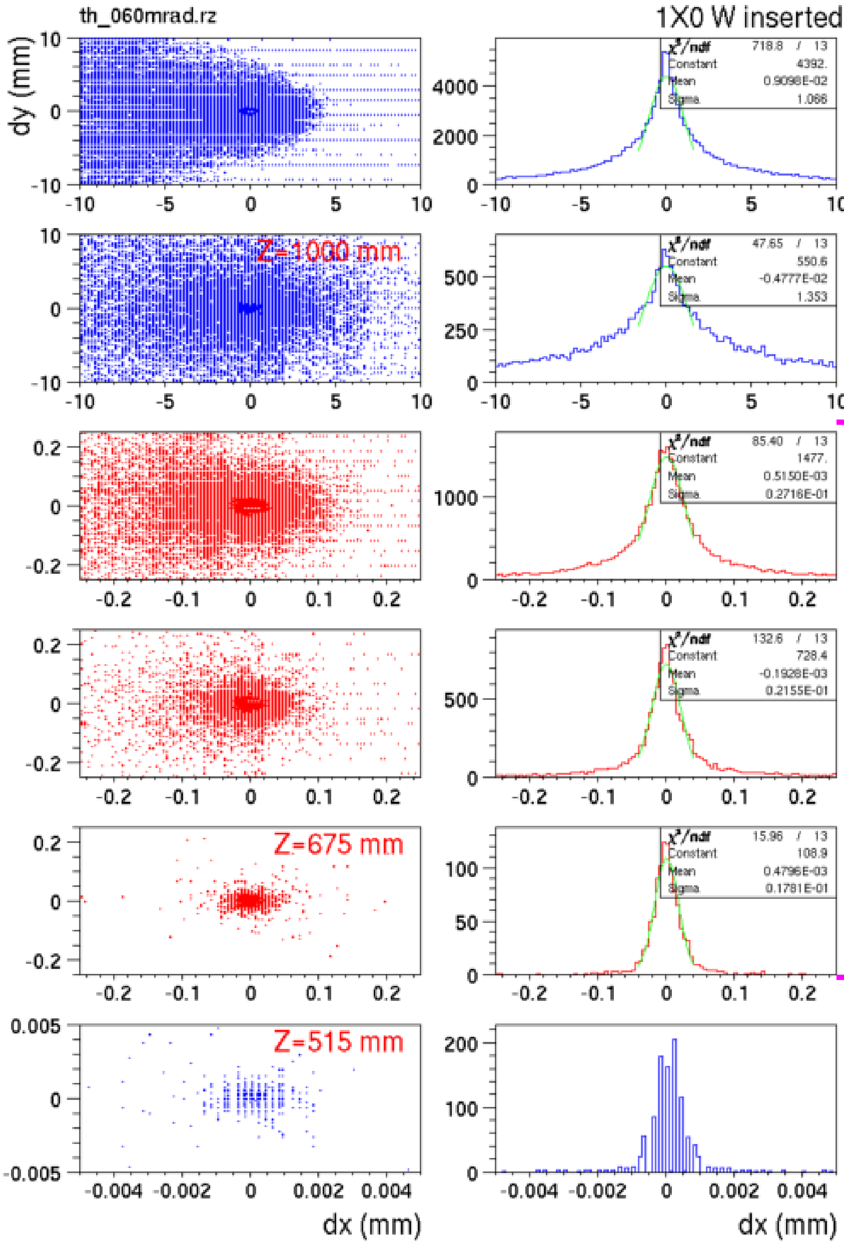
Spatial resolution ~ *20 μm*

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

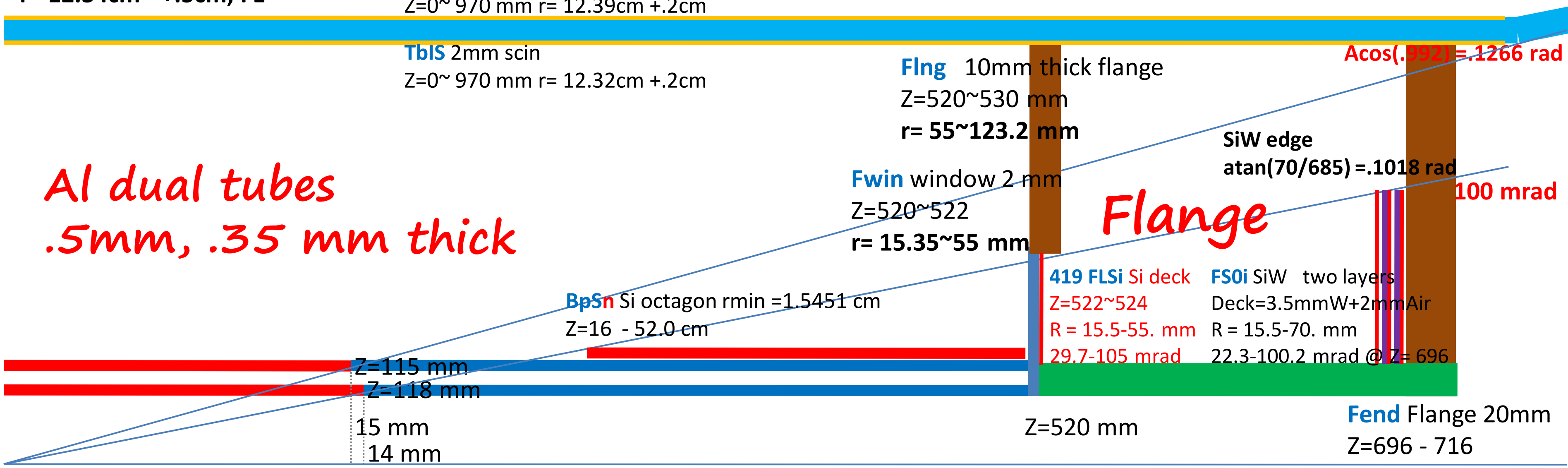
TUBE beam-pipe, preshower in beampipe

acos(.99) = 141.54 mRad @Z=118 → r= 16.81 (=tanQ*118)
acos(.992)= 126.58 mRad @Z=118 → r= 15.02 mm
Q= 100mRad @Z=118 → r= 11.84 mm @Z=153 → r=15.35 mm

Acos(.99) = .14154 rad
Acos(.992) = .1266 rad
atan(123.6/970) = .12678 rad

409 TbFe 5mm Fe
Z=0~ 970 mm connecting to
r= 12.34cm ~+.5cm, FE

TbOS 2mm scin
Z=0~ 970 mm r= 12.39cm +.2cm



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

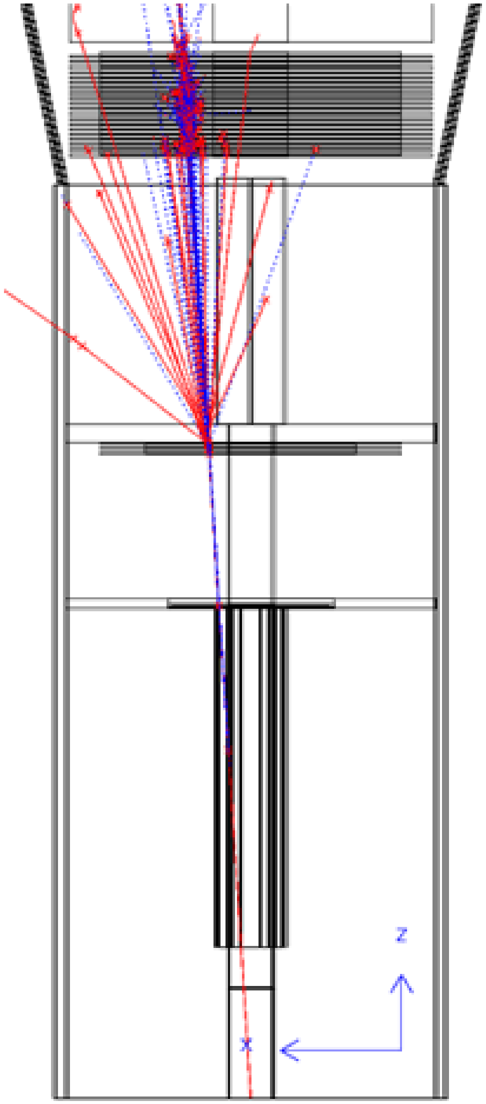
OuAl outer Al pipe
Z=0~115 mm
inner r=28/2+1 mm, 0.35 mm thick

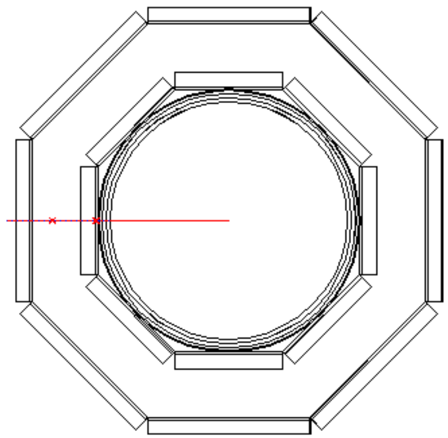
Fpip flange pipe 1.5 mm thick
Z= 522-716 mm
at Z=512 r= 14 – 15.5 mm

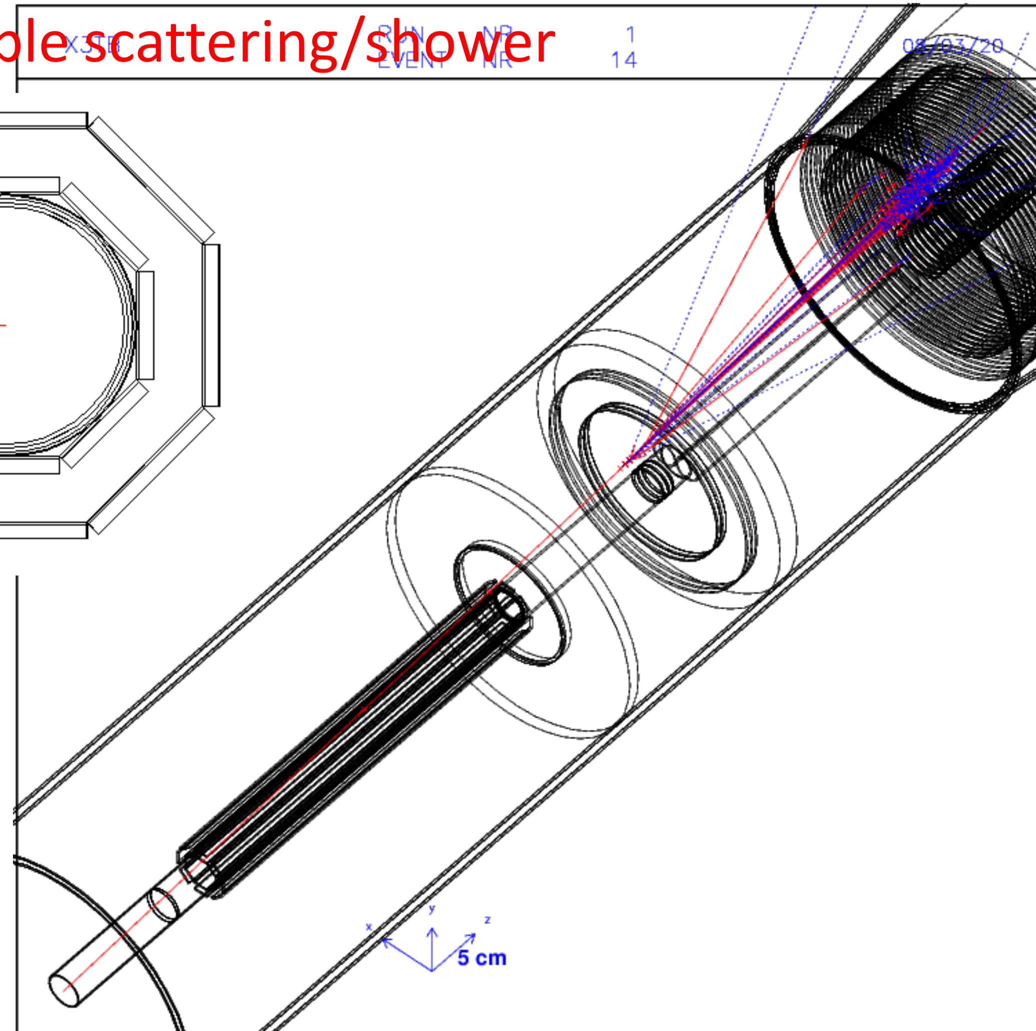
Si octagon wafers surrounding beampipe

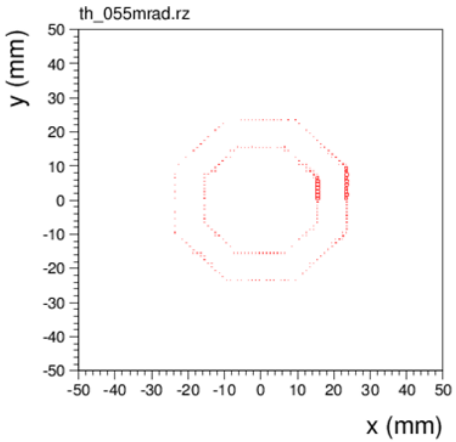
Si wafer attach to beampipe

➔ Impact position w. minimum effect multiple scattering/shower



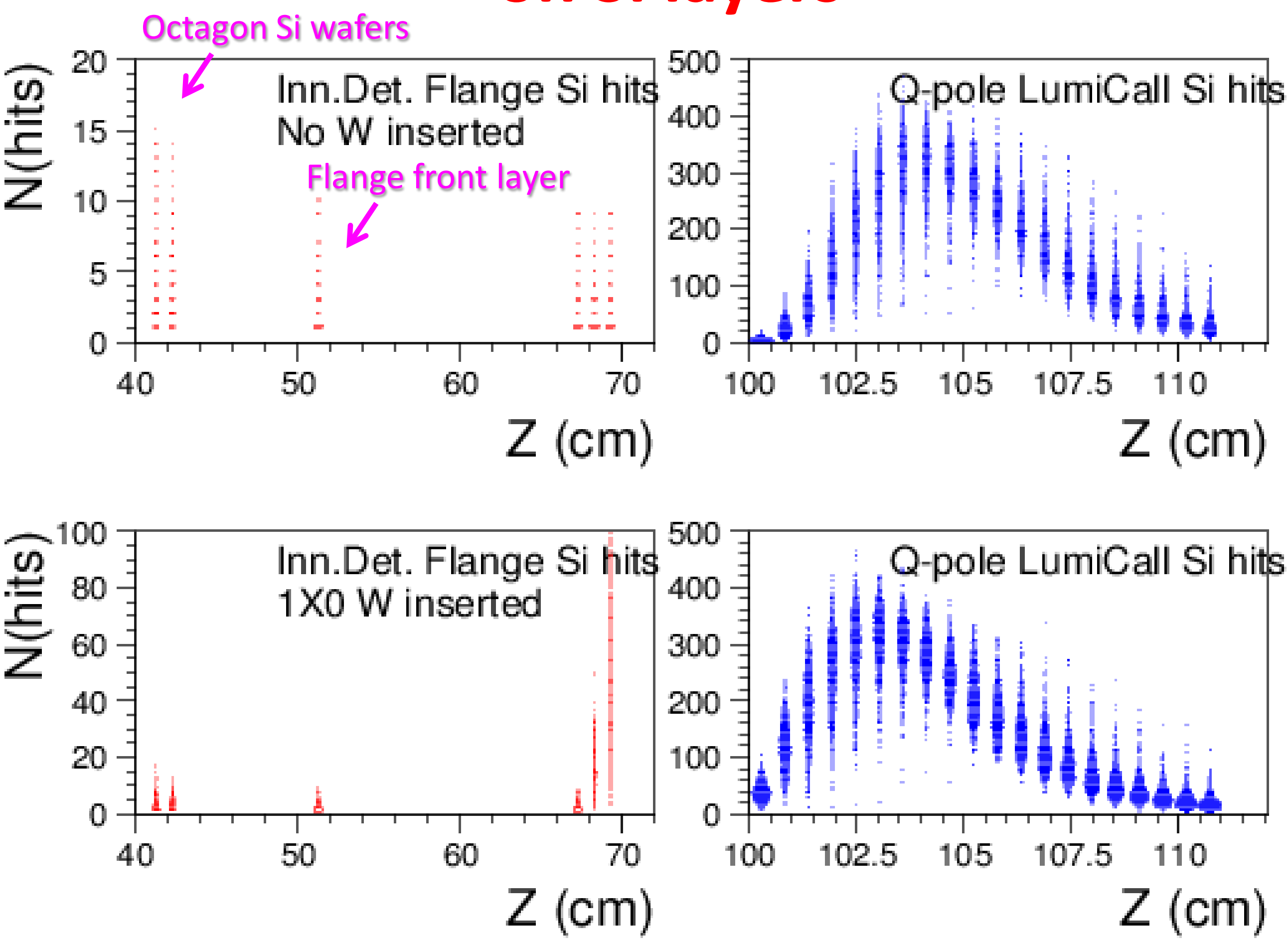






Precision on electron impact position

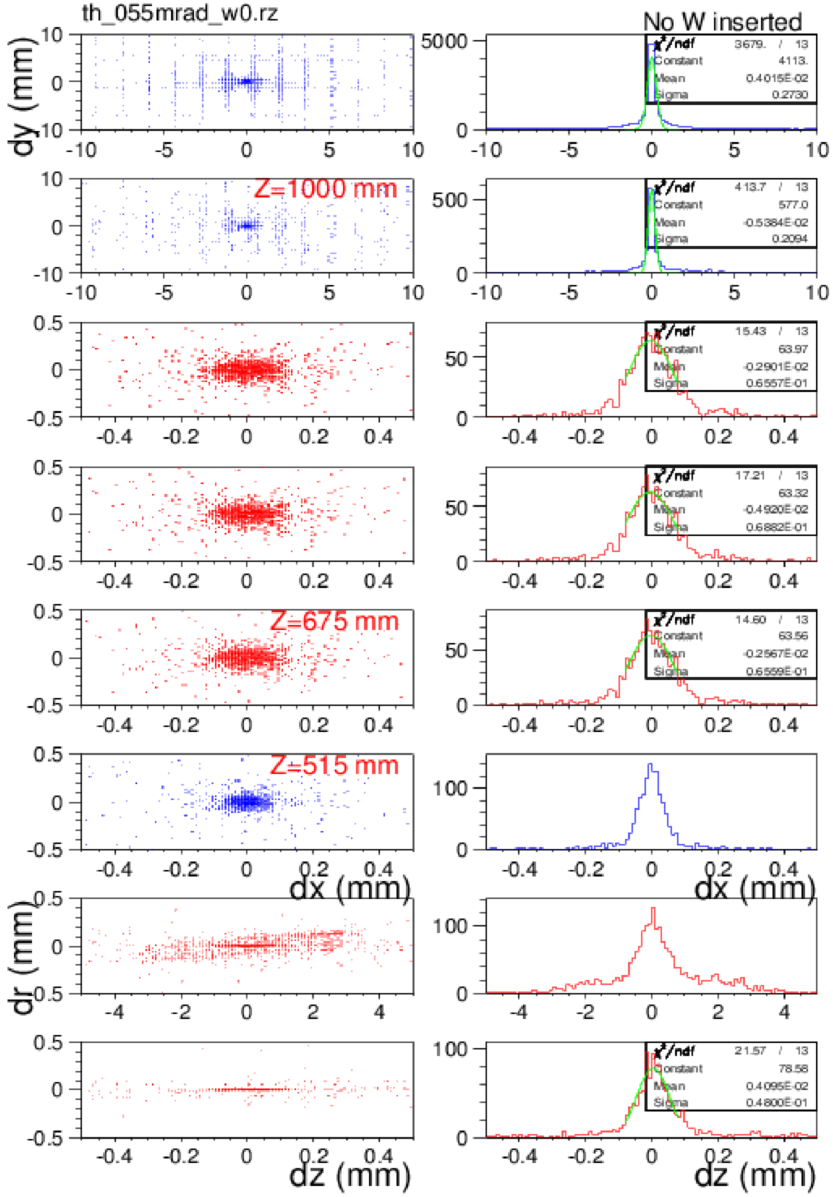
Hits of charged shower secondaries on Si layers



← 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 σ= 65 um

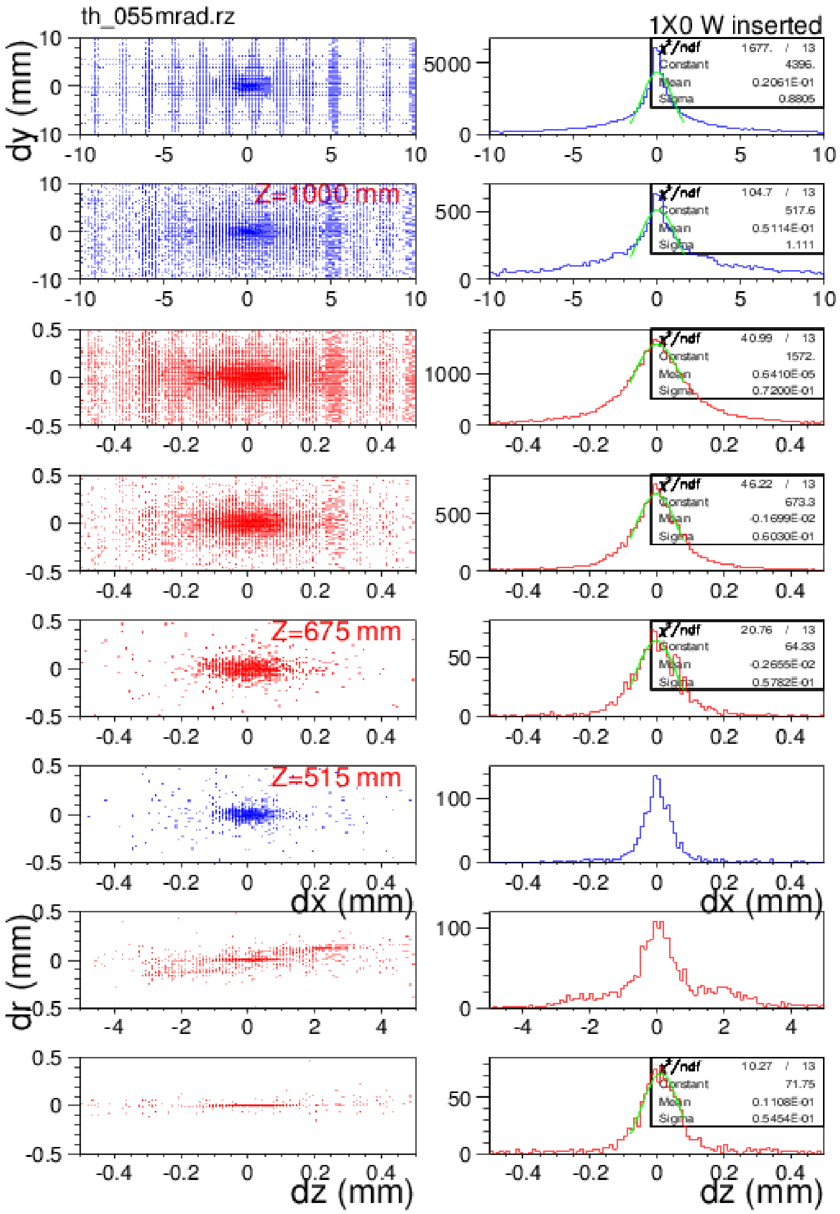
1st Si layer behind flange at Z=515 mm

Octagon Si layers surrounding beampipe

1st layer σ= 50 um

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

Two 1X0 Tungsten layers

between Si wafers σ= 60 um

1st Si layer behind flange at Z=515 mm

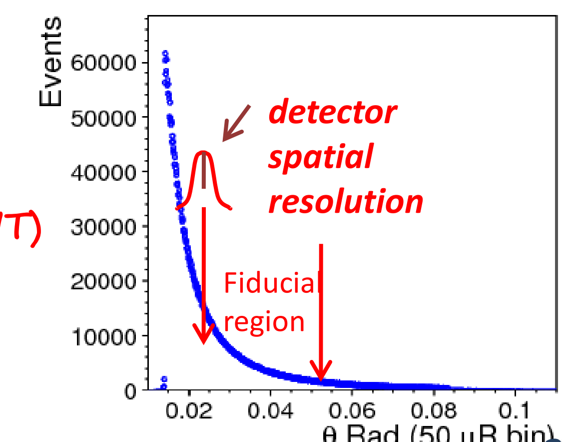
Octagon Si layers surrounding beampipe

1st layer σ= 55 um

Due to Mult. Scattering

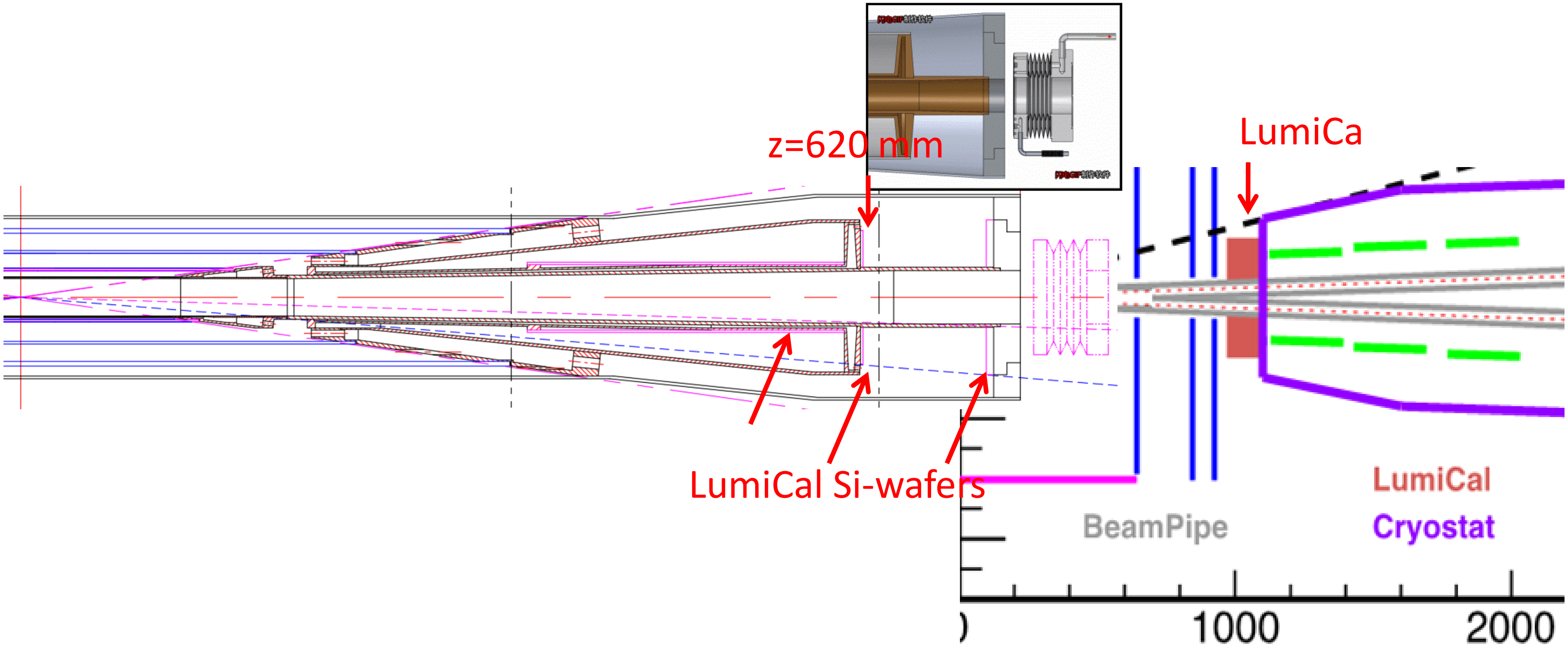
GEANT simulation summary

- Intrinsic spatial resolution
  scattered by multiple scattering, bremsstrahlung
- Luminosity $\delta L/L=10^{-4}$, θ_{min}=30 mRad
  $\delta L/L \sim 2\ \delta\theta/\theta_{min}$ for : $\delta\theta$ = 1.5 μRad
  @ z= 0.5m, dr= 0.75μm; dz=dr/tan(.03)= 25μm
- Electron traversing 1mm thick Al beampipe
  @30 mRad, z=0.5m, dz in beampipe = 33 mm
  GEANT multiple scattering RMS = 50 μm
- $\delta L/L$ is the "error on the mean"
  off the fiducial edge
  1. analytic on Multi. Scattering (GEANT)
  2. detector resolution spectrum
     on fiducial edge

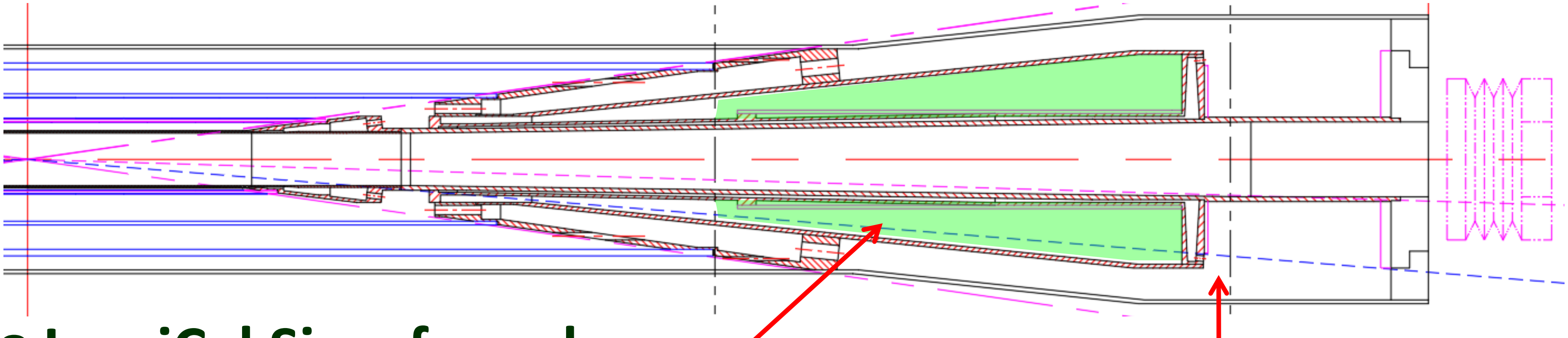


Detector options

- Silicon wafer on beampipe
- Calo for beam eletron/gamma ID



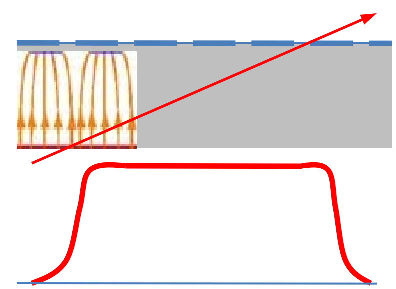
LumiCal Si-wafer option



z=620 mm

- **LumiCal Si wafer volume**
  round beampipe ϕ = 28 mm
  θ=30 mRad @ z=500 mm

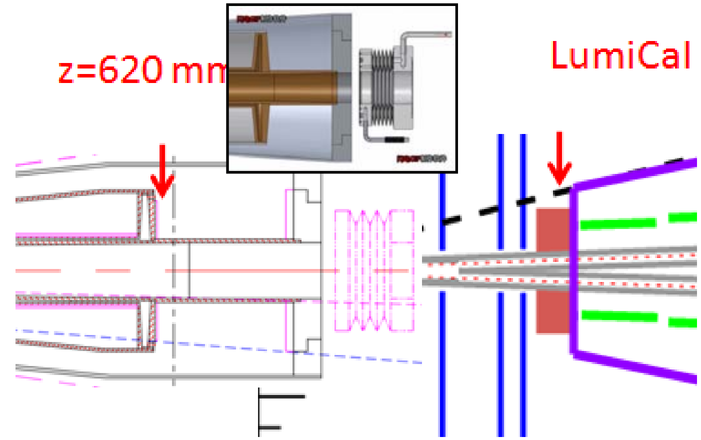
- **Si wafer option:**
  binary strip, pitch in z,
  resolution for 25 µm = pitch/√12 ➔ **pitch = 86 µm**
  Multi.scattering (50 µm) is narrower, can be differentiated



Assuming Si strip 300 µm thick, ADC readout, pitch = 100 µm,
resolution by the fraction of entrance strip (low z)

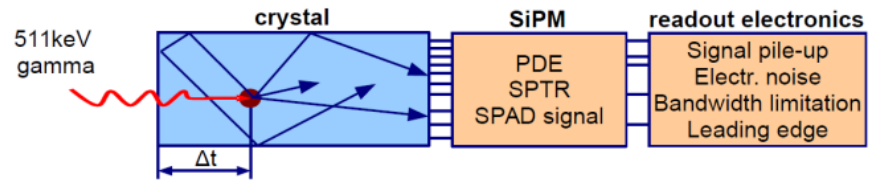
➔ *fire 100 strips @ 30 mRad* 🡐 *rather extreme for Si strip*
resolution by charge sharing on the edge strip

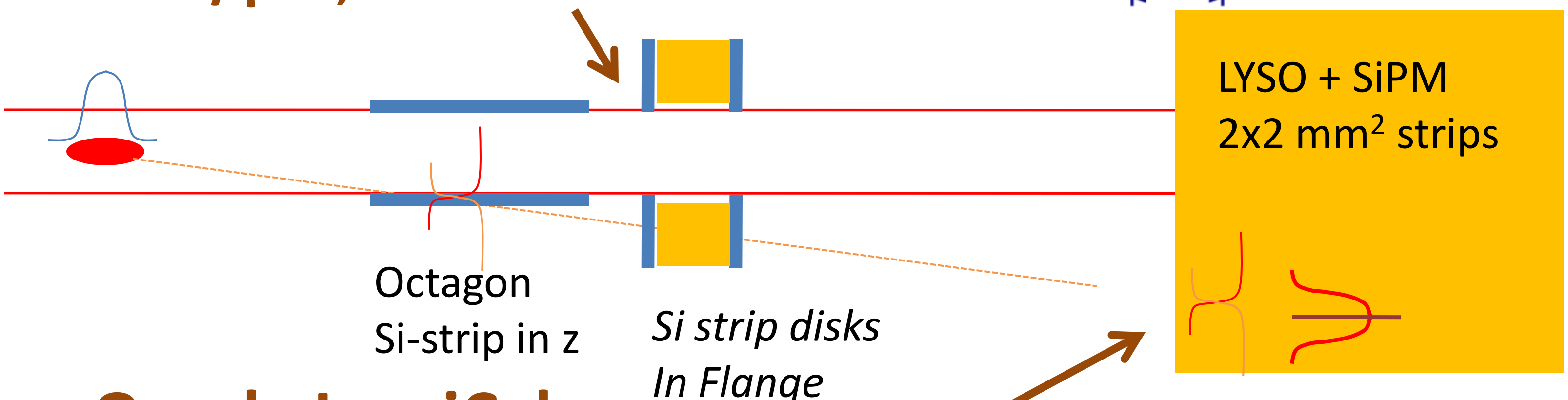
LumiCal Calo option



- **Calo options**
  spatial resolution is not good
  LYSO + SiPM is compact
  minimize space for electronics

- **In the flange, as preshower**
  front wafer disk (20µm) + 50 mm LYSO
  for e/γ ID, NLO Bhabha etc





- **Q-pole LumiCal**
  front wafer disk (1 mm) + 100 mm LYSO
  for Bhabha beam electron EM shower

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*

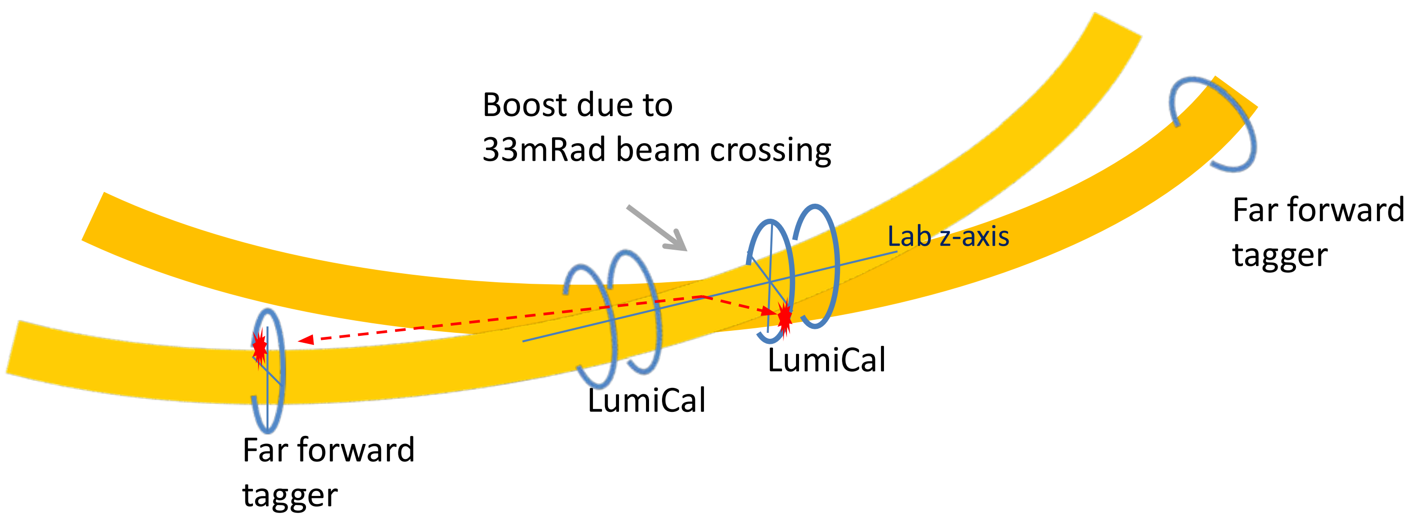
➔ *LumiCal @ Lab +x region is **VERY HOT** by low ϑ beam electrons*

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



Conclusion

- Bhabha feasibility studied for luminosity of 10^{-4}
- X-section matches to Z(qq) pole
- Spatial resolution with Si-wafer in z, ~ 25 μm
- LYSO + SiPM for Calo, compact in space for electronics

➔ Continue on prototyping of Detectors and Electronics