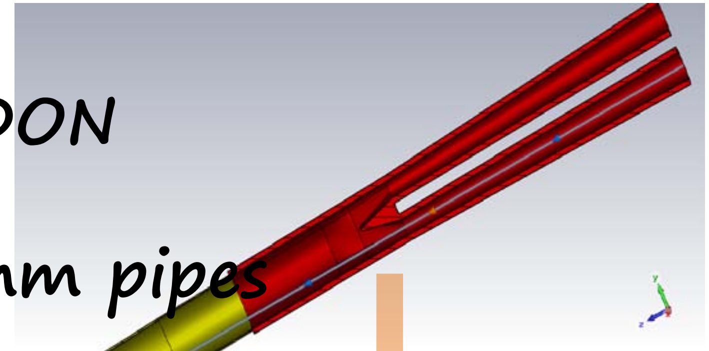
LumiCal Design

Explore the low mass WINDON on duckbill/Y-crotch 40mm flange to dual 20 mm pipes



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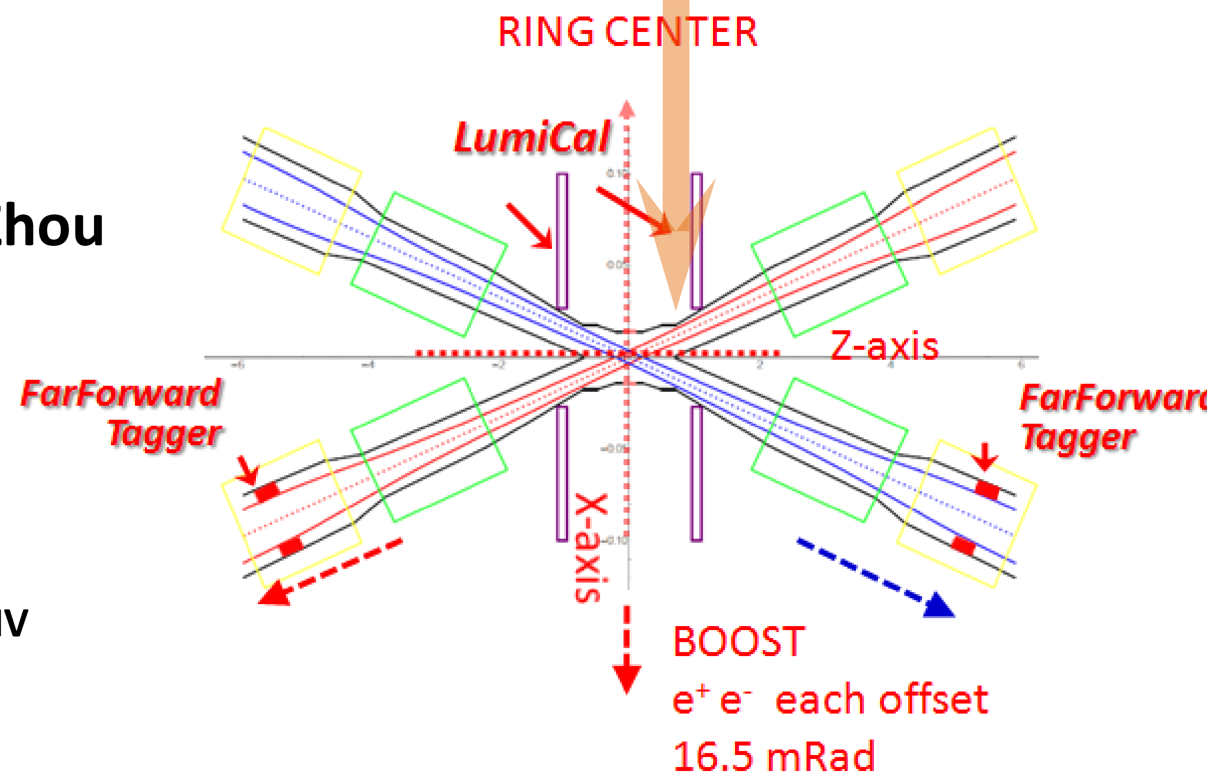
Joint Workshop, YangZhou



2021.04.16 Friday

Detector and Software - Session IV

Topic 主题: CEPC探测器研讨会(Detector)
Meeting ID 会议号: 62375065708
Meeting URL 会议链接::
https://weidijia.zoom.com.cn/j/62375065708?pwd=Zmt1TXVUS2RqQUdRZ0JMVFFvcko5QT09
Password 会议密码: 923421

Outline

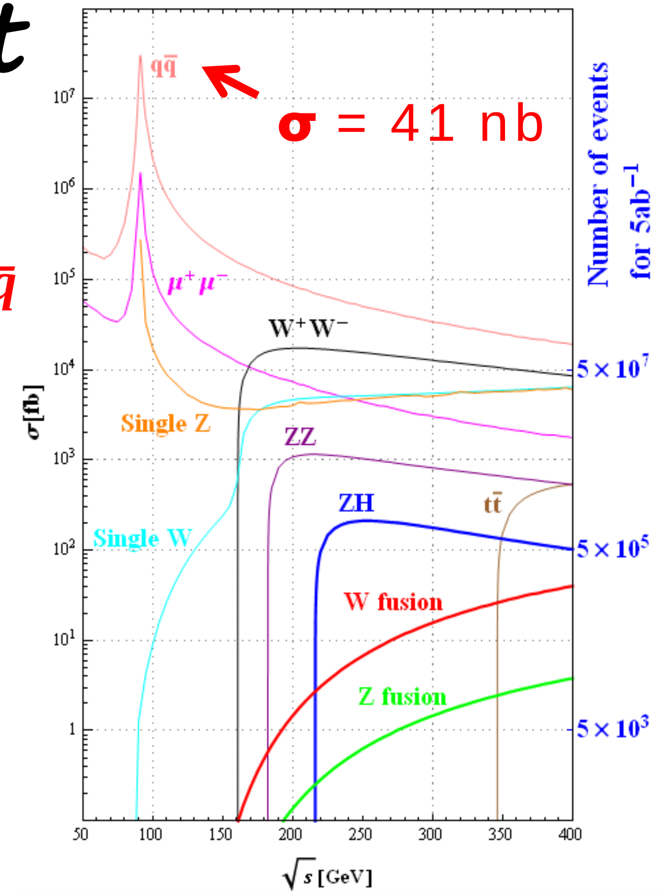
- **Constraints on Bhabha detection**
  CEPC boosted Bhabha cross section, **~ 50 nb for θ > 30 mRad**
  Realistic beampipe (IP 28 mm – 40 mm crutch – dual 20 mm)
  low mass window at Y-crutch, vertically θ : 12 – 25 mRad

- **GEANT on multiple scattering**
  1. **Inner det.** before Flange: **θ > 38 mRad**
     Si layers surrounding beampipe,
     Si layers in front of Flange
  2. **LumiCal** behind Flange on Q-pole magnet
     Si layers on LYSO crystal, Y-axis **θ > 12 mRad**

- **Front-End chip R&D**
  wave-form sampling + flash ADC
  for fast trigger rate, 32 ns bunch crossing

Luminosity measurement

- ***Cross section of a reaction:***
  $N = \sigma \cdot \int L$ Z-lineshape dominant: $e^+e^- \rightarrow Z \rightarrow q\bar{q}$

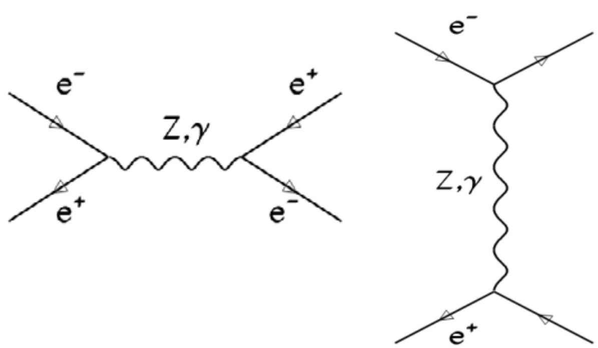


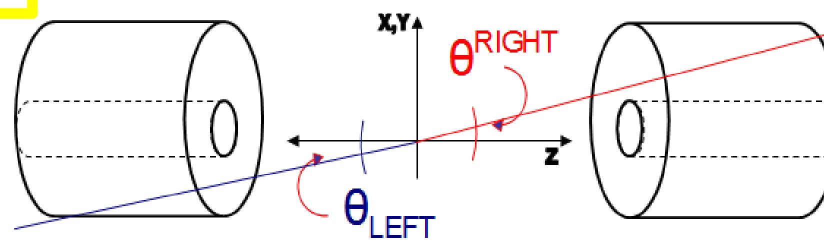
- ***Luminosity L:***
  by measuring **Bhabha elastics scattering**
  $$e^+e^- \rightarrow e^+e^-$$
  - QED process, theoretical < *0.1%* precision
  - triggering on a pair of back-to-back e^+e^-

Bhabha

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

LO diagrams





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

Luminosity, precision on Bhabha

Systematic error

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

$\delta L/L < 10^{-3}$ *for Higgs factory*

→ *$\delta\vartheta$ = 15 μRad* @θ_{min}= 30 mRad

→ ***OFFSET** on the*

"mean of fiducial edge"

cause for δN on Bhabha counting

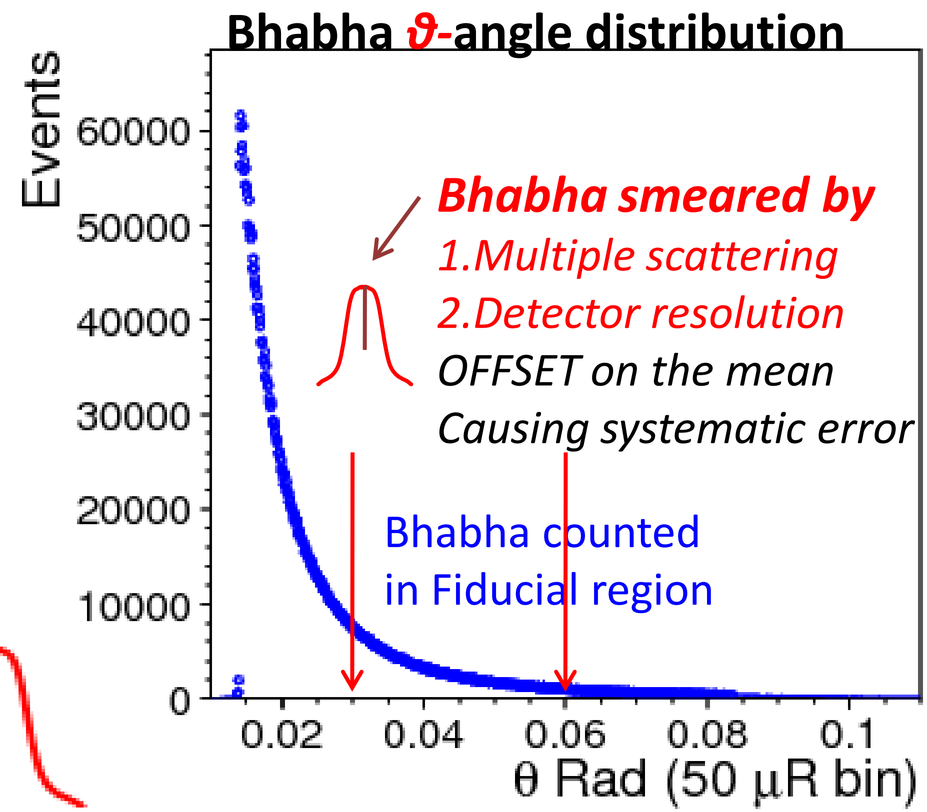
@z = 1000 mm, *$\delta\vartheta$ = 15 μRad*

corresponds to

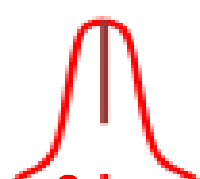
dz = ***0.1 mm*** or *dr = Rxϑ* ***= 3 μm***

*offset on the **mean of** θ_{min}*

→LUMINOSITY error



LumiCal design goal:



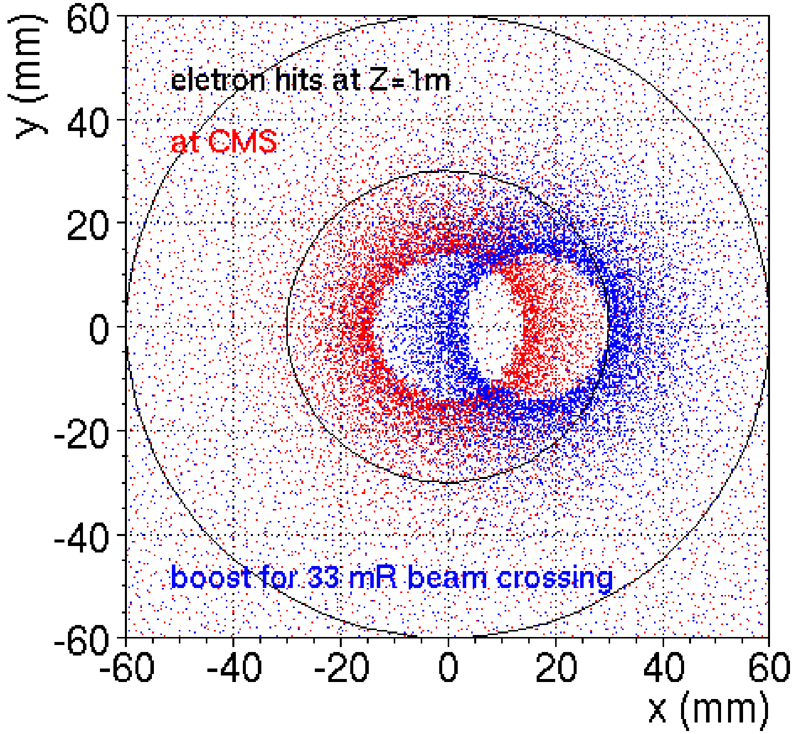
θ_{min}

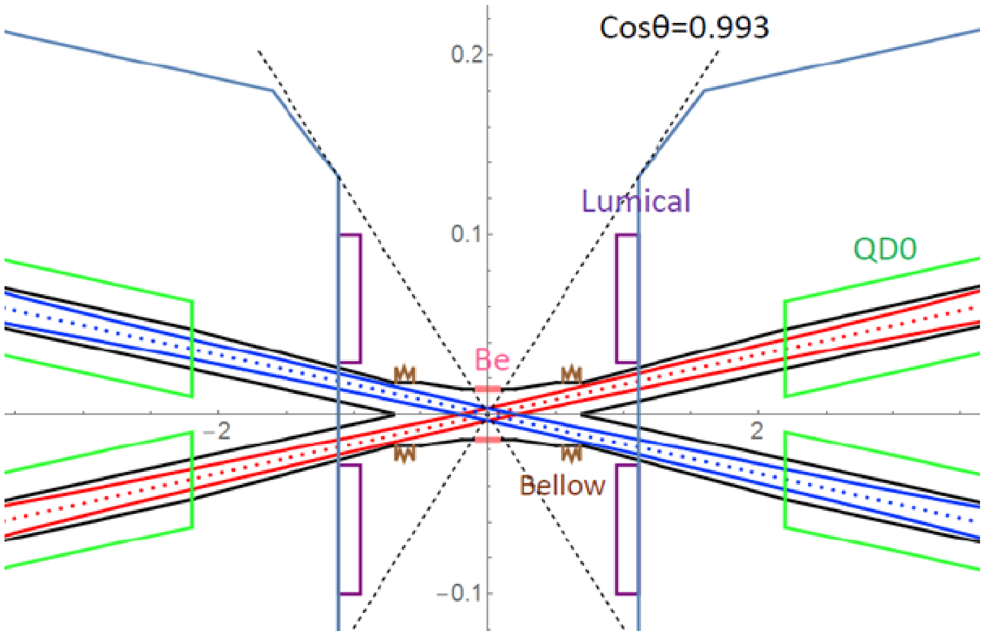
- *Spatial resolution as sharp as possible*
- *Describe the reso./MS shape, $\delta\langle\theta_{min}\rangle$ to 0.3 mRad*

Bhabha at CEPC

1. **Beam crossing, 33 mRad**, $e^+ e^-$ boosted off ring center
   Fiducial cross section ➔ **BHLUMI calculation**
2. **Al beam-pipe ~ 0.3 X_0,** causing multiple scattering (MS)
   Detector location and MS effect ➔ **GEANT simulation**

Bhabha at detector plane Z=1m



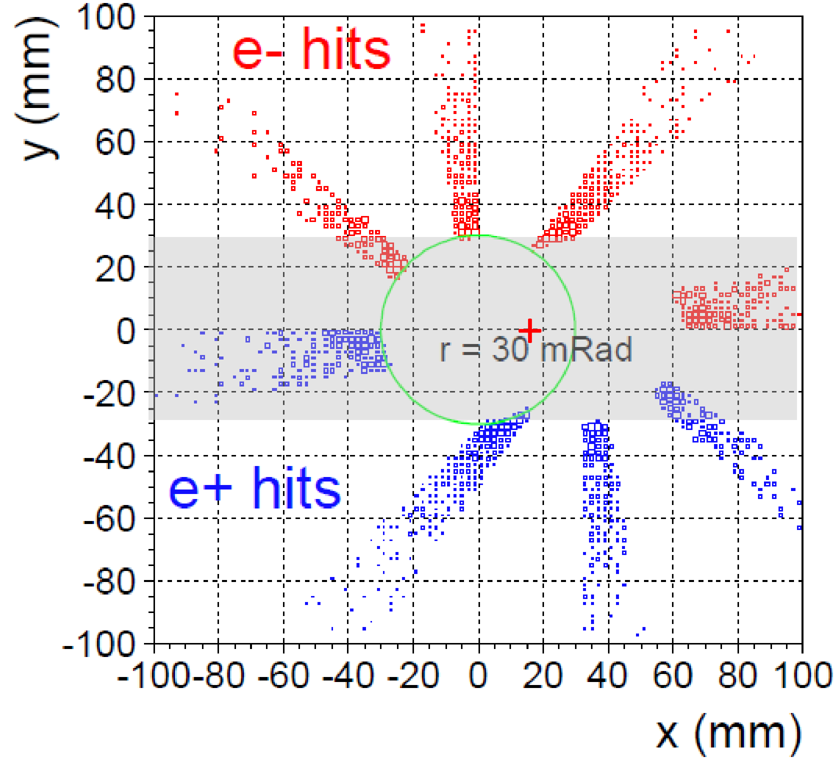


Bhabha cross-section

(2020.04 report)

BHLUMI calculation

- *round beam pipe, r = 30 mRad*
- $e^+ e^-$ boosted for 33mRad crossing back-to-back symmetric to out-going beam center (x,y) = (16.5, 0 mm) *at z = ±1000 mm*



50 GeV beam, both $e^+ e^-$ detected

In fiducial range of

***ϑ range* = 30 – 80 mRad**

Bhabha cross section *> 50 nb*

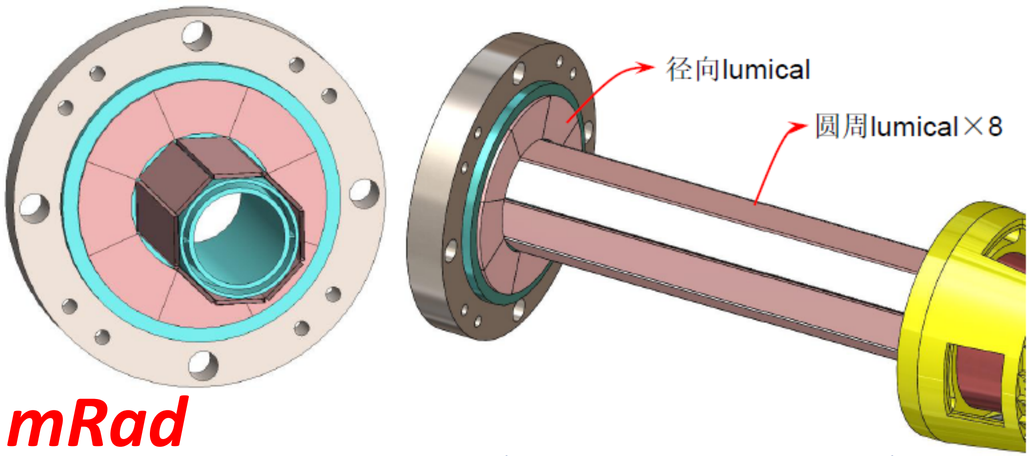
BHLUMI, 50 GeV Bhabha boosted for 33 mRad crossing			
CMS 10 ~ 80 mRad		LAB detect ***both*** **electrons**	
BARE1		**off beampipe full phi coverage**	**off beampipe cut off ±30 mm**
Nevents	457232	29194	19216
Xsec (nb)	1168.3	**74.60 nb**	**49.10 nb**

Beam-pipe reality

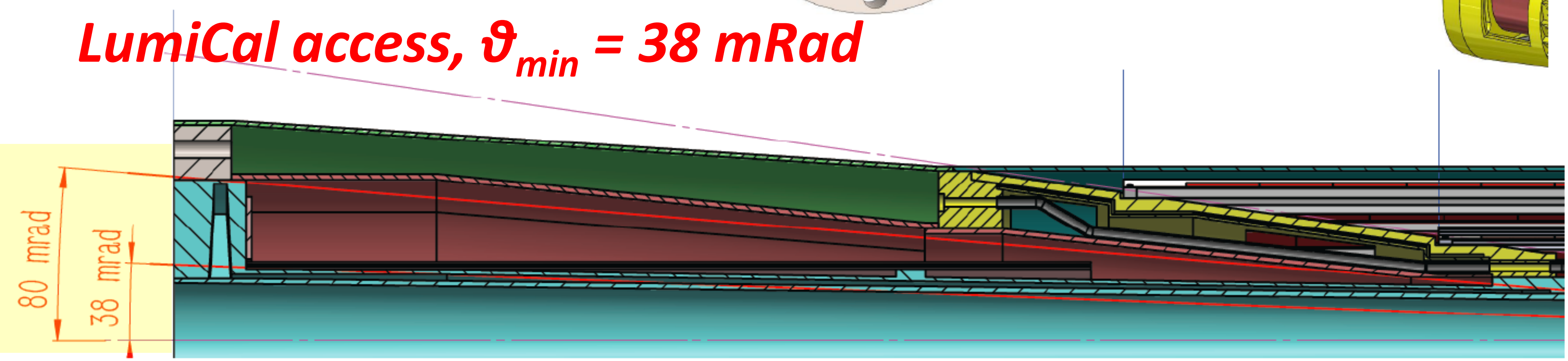
Workshop_20200828_Dongguan东莞

5.5 Preliminary design of lumical

- Detection Angle range: 38~80mrad
- On the detection path, as little mass as possible
- The structure of lumical is not yet determined, so the support and cooling structure should be further optimized and improved.



LumiCal access, ϑ_{min} = 38 mRad



Al pipe x = 200 - 700 mm, inner 0.5mm, outer 0.35 mm thick

Inner diameter @Z=200 φ = 28 mm

Inner diameter @Z=675 ***φ = 40 mm*** *➔ atan =* ***29.6 mRad***

Flange z=675~700, dia.=40 mm flat

Corner of ***38 mRad*** *@ Z=(700-25) mm*

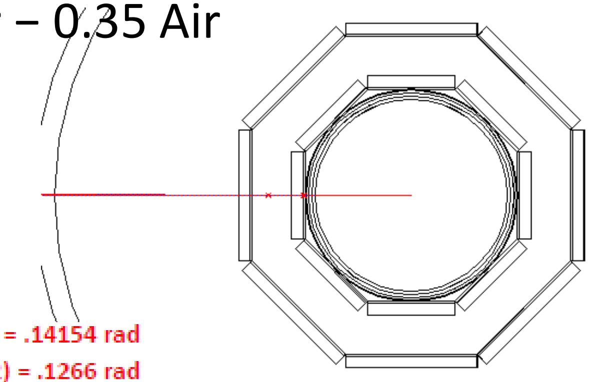
*Radius = (700-25)*tan(.038)* ***r= 25.66 mm***

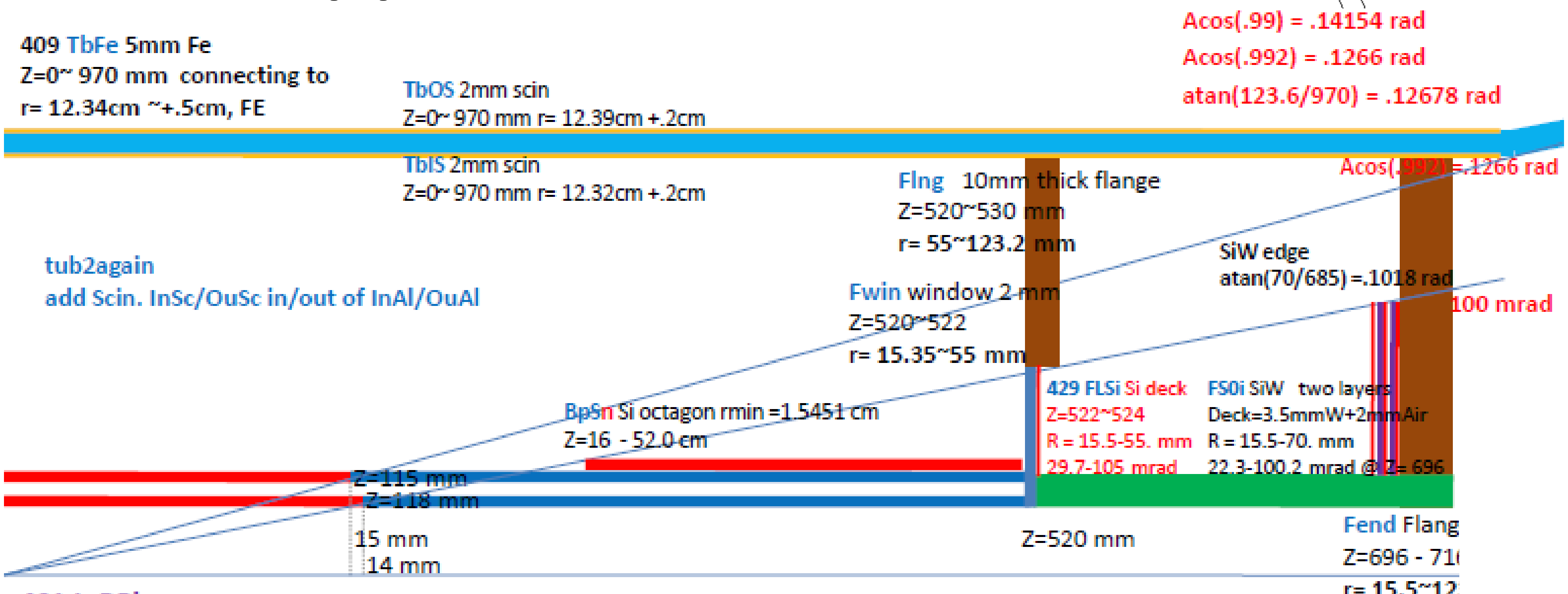
GEANT: Multiple scattering in Al pipe

- Tube design, ϕ=28 mm, thickness (mm): 0.5 Al – 0.5 Air – 0.35 Air
- Si wafer attacked tightly
- Scintillator layer surrounding Al pipe

➔ observe Multiple-Scattering within Al pipe,

Δz in Al-pipe: 20 – 40 mm





401 InBPipe

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

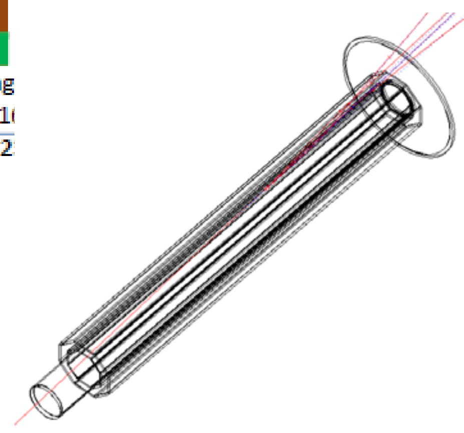
InAl Inner Cu pipe
Z=118~500 mm,
inner diameter 28 mm 0.5mm thick

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

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

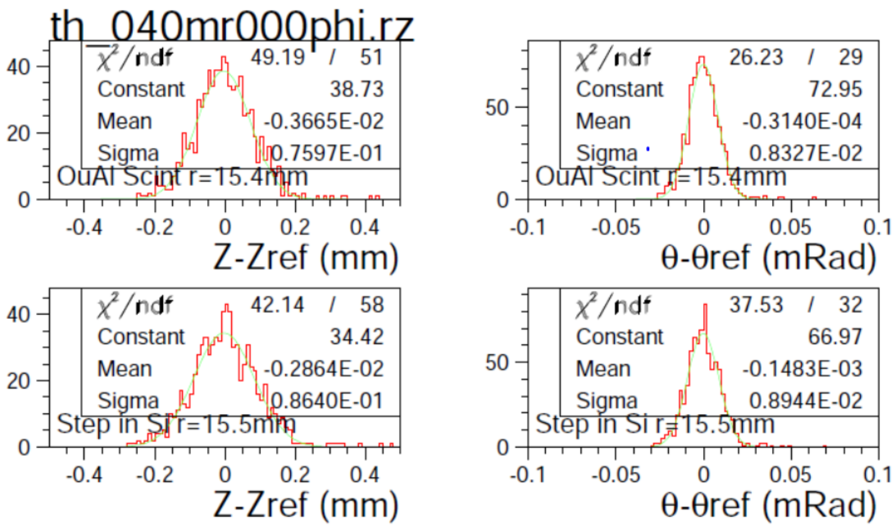
OuAl outer Al pipe
Z=0~115 mm
inner r=28/2+1 mm, 0.35 mm thick

2020 LumiCal geom



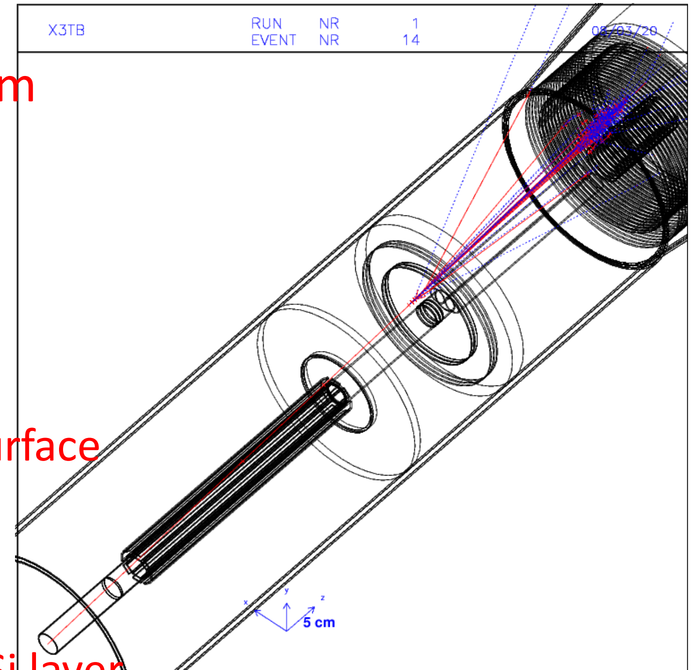
Multiple scattering off Al beampipe

- ***50 GeV electron*** traversing Al-pipe (mm): 0.5 Al – 0.5 Air – 0.35 Air @ fixed theta, phi=0°
- ***Multiple scattering deviation*** simulated for ϕ=28 mm
  1. exiting Al-pipe (a Scintillator layer on surface)
  2. no air-gap, Si-layer attached



← dz, dθ on Al-pipe surface

← dz, dθ on Octagon Si layer

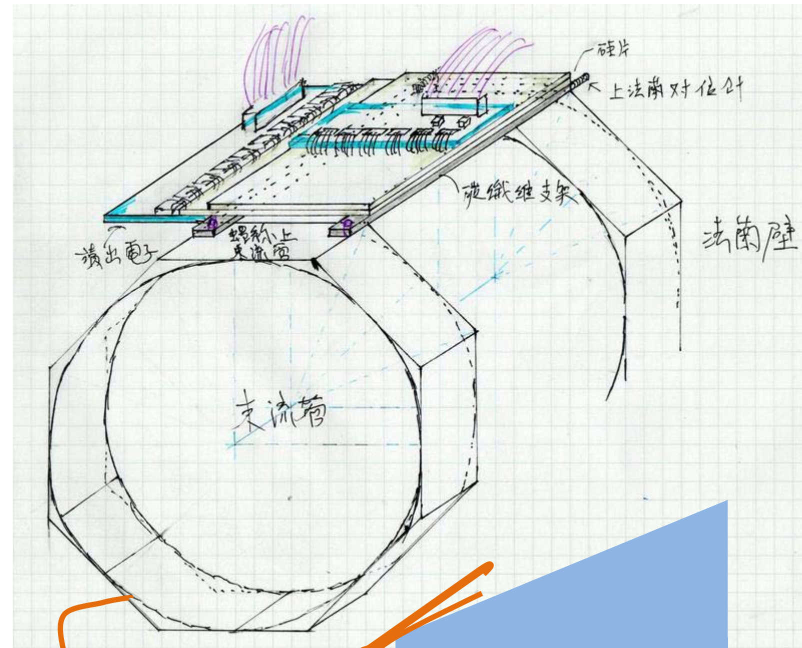


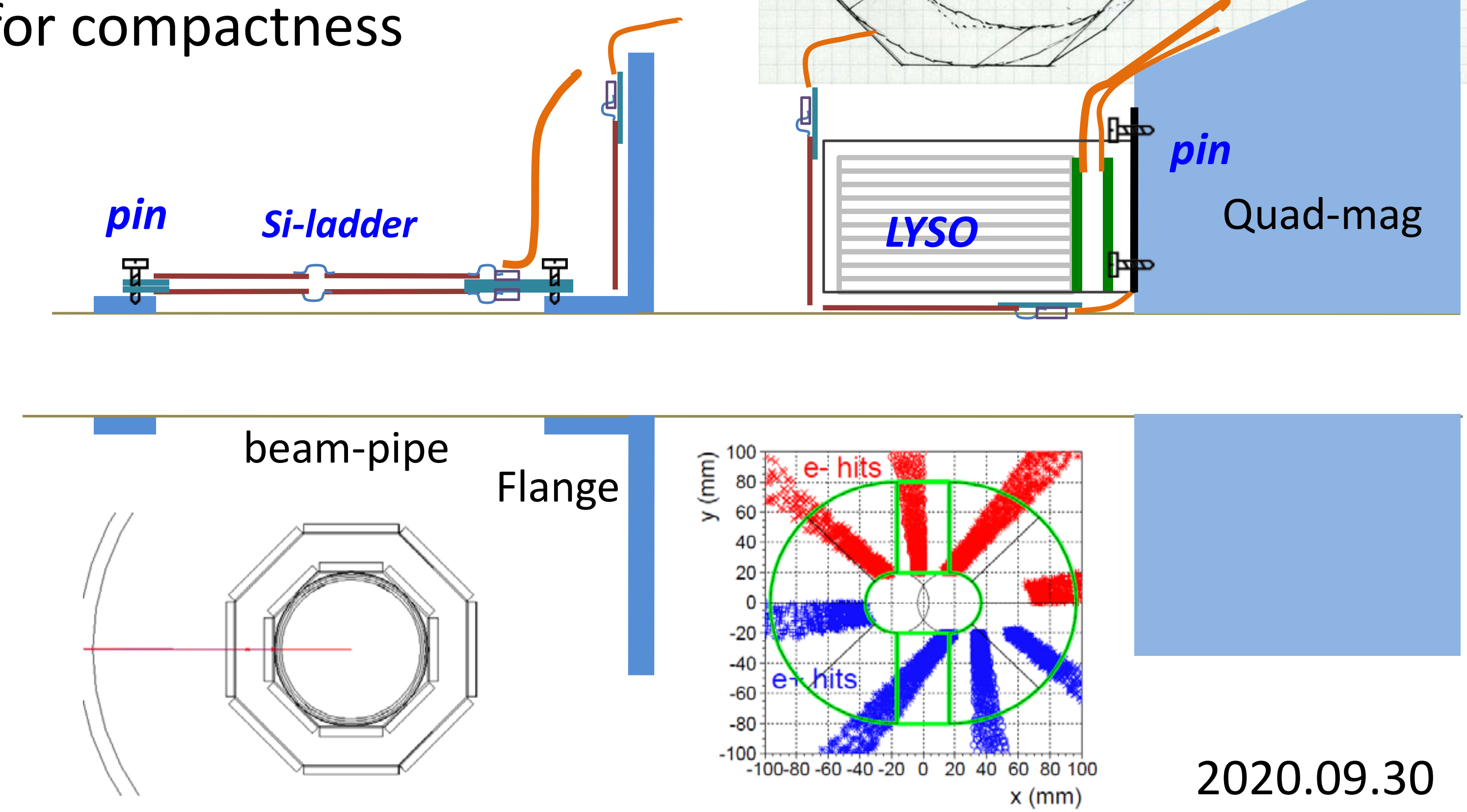
50 GeV (θ,ϕ)	σ (Z)	σ(θ)	1/tan(θ)
e (40 mR, 0°)	86 μm	8.9 μRad	25.0
e (55 mR, 0°)	37 μm	7.3 μRad	18.2
e (60 mR, 0°)	28 μm	6.5 μRad	16.6
e (70 mR, 0°)	19 μm	5.8 μRad	14.3

θ to z: r/z = tan θ

LumiCal components

- **Inner Detector volume before Flange**
  1. Si-layer surrounding beampipe
  2. r-ϕ Si-disk on Flange
- **Calorimeter before Q-pole magnet**
  1. r-ϕ Si-disk on Calo surface
  2. LYSO for compactness



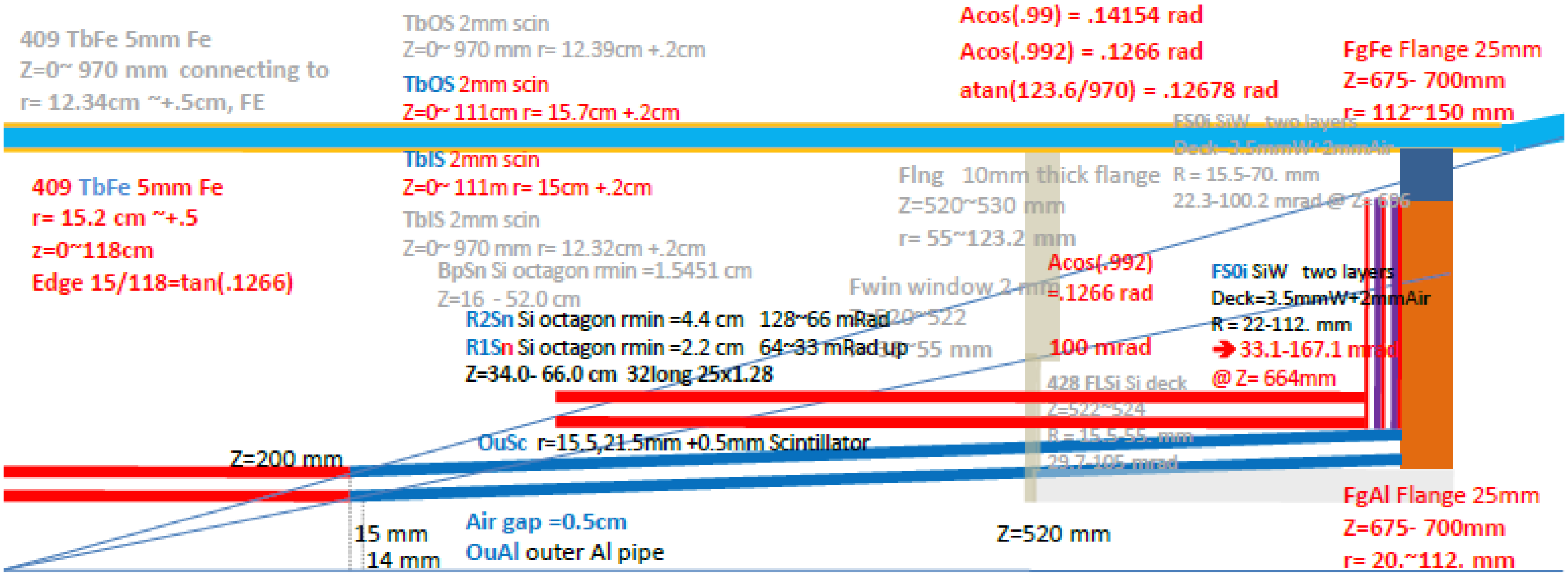


Realistic beampipe, GEANT (2021)

- Tilt the Al pipe from ϕ=28 mm to ϕ=40 mm
  thickness (mm): 0.5 Al – 0.5 Air – 0.35 Air
- Si wafer parallel to z-axis r_{min}=22mm

➔air gap to Al-pipe, large Multiple Scattering

poor design !



401 InBPipe full +-200 mm p9

InBP Inner Be pipe
Z=0~200 mm,
inner diameter 28 mm 0.5mm thick

OuBP outer Be pipe
Z=0~200 mm
inner radius 28/2+1 mm 0.35mm thick

Z=200~675 mm
@200 r=28/2+1 mm, 0.5mm thick
@675 r=40/2+1 mm, 0.5mm thick

InAl Inner Cu pipe
@200 inner r=28/2 mm 0.5mm thick
@675 inner r=40/2 mm

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

Fend Flange 20mm
Z=696 - 716
r= 15.5~123.2 mm

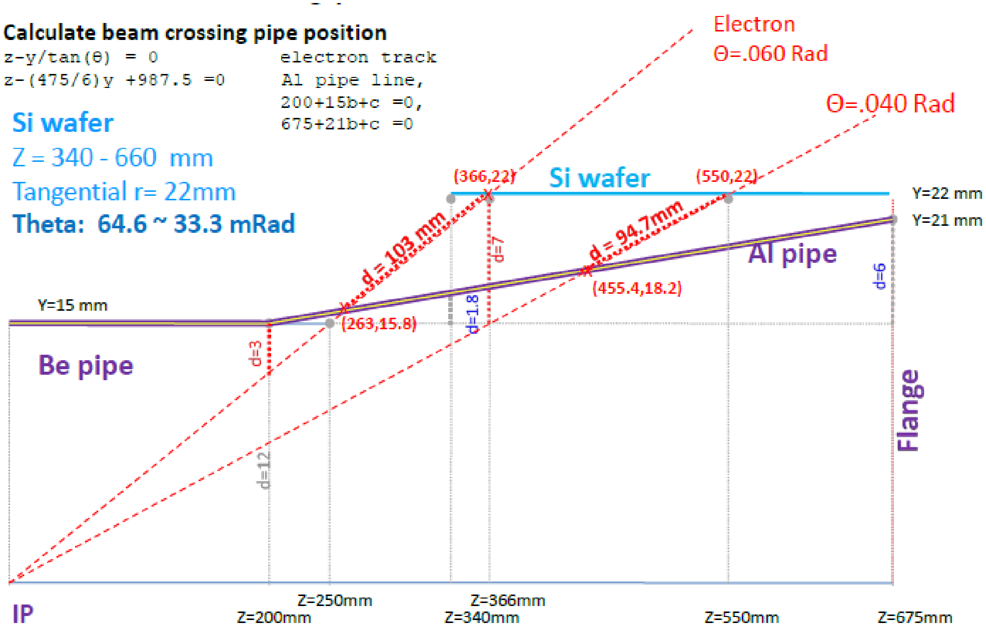
Multiple Scattering on Si ring

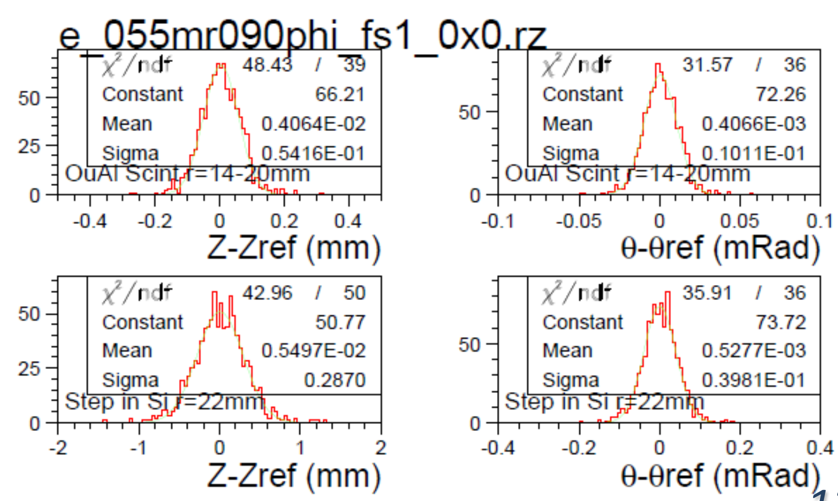
- Al-pipe tilt 12.6 mRad (ϕ28 to 40 mm)
- Si-layer (r=22mm) parallel to z-axis ➔ air-gap from IP ~ 100 mm

➔ multiple scattering effect is magnified !!

Compare MS on Al-pipe surface (Scin layer) and on Octagon Si layer, ***primary track***

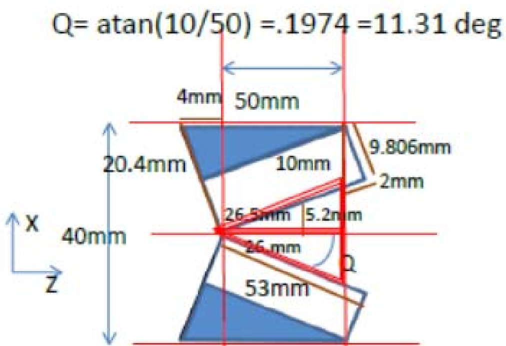
(θ,ϕ)	σ (Z) Scin	σ(θ) Scin	σ(Z) Si[1st]	σ(θ) Si[1st]	1/tan(θ-Δ)
e (40 mR, 0°)	153 μm	13.6 μRad	458 μm	35 μRad	36.5
e (55 mR, 0°)	54 μm	10.1 μRad	287 μm	40 μRad	23.6
e (60 mR, 0°)	44 μm	9.7 μRad	251 μm	40 μRad	21.1
e (70 mR, 0°)	22μm	7.0 μRad	-	-	17.4

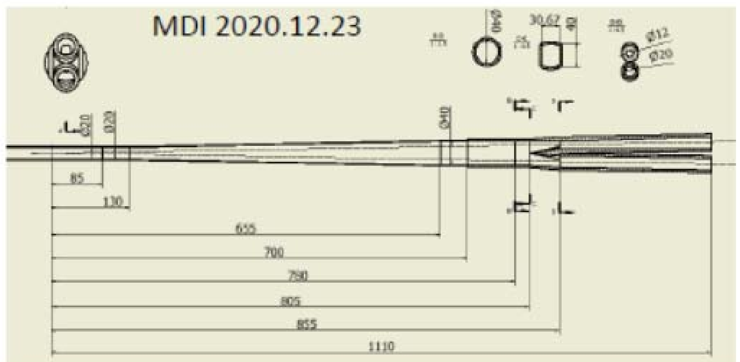


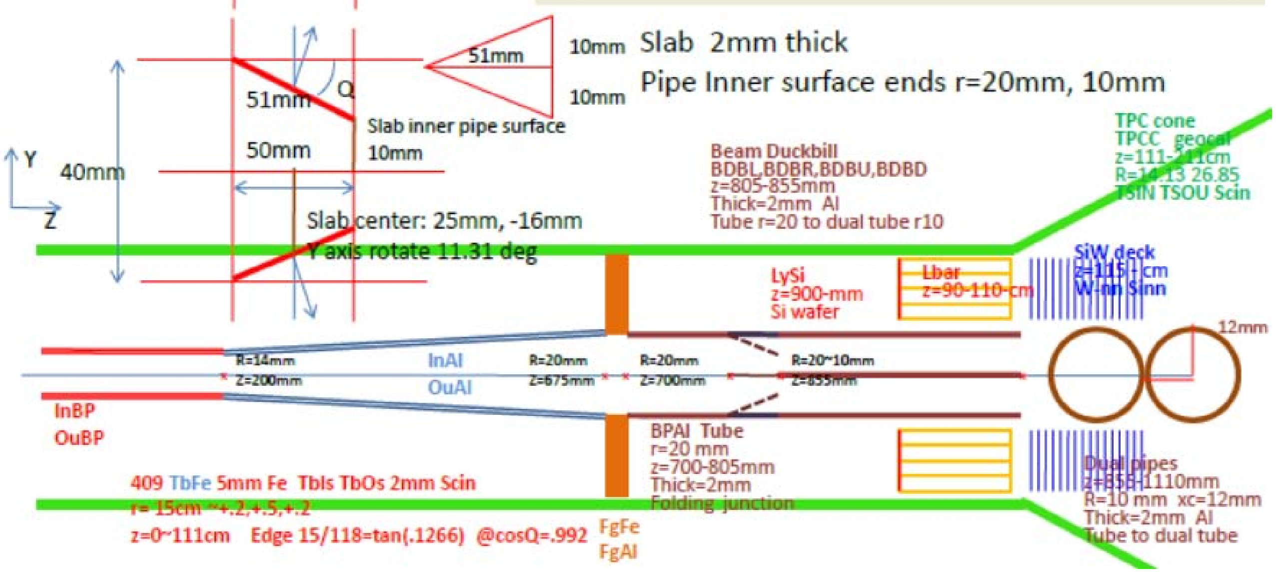


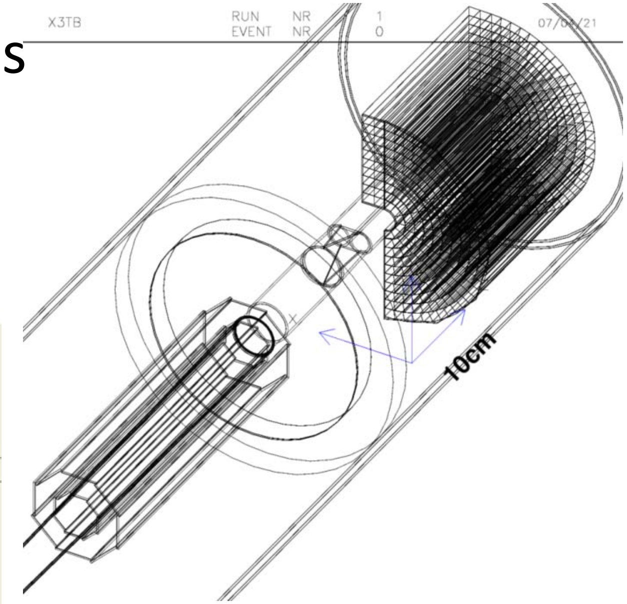
GEANT behind the Flange

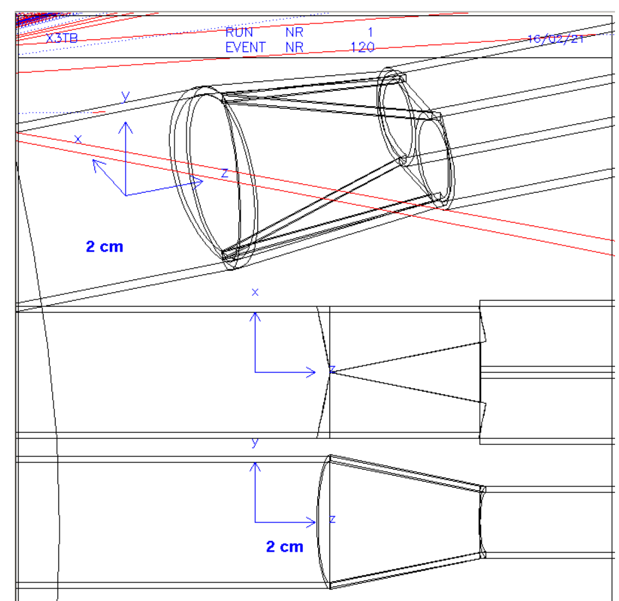
the ***duckbill/y-crotch*** ϕ=40 to dual 20 mm pipes is ***a low-mass, high cross section*** window for Bhabha





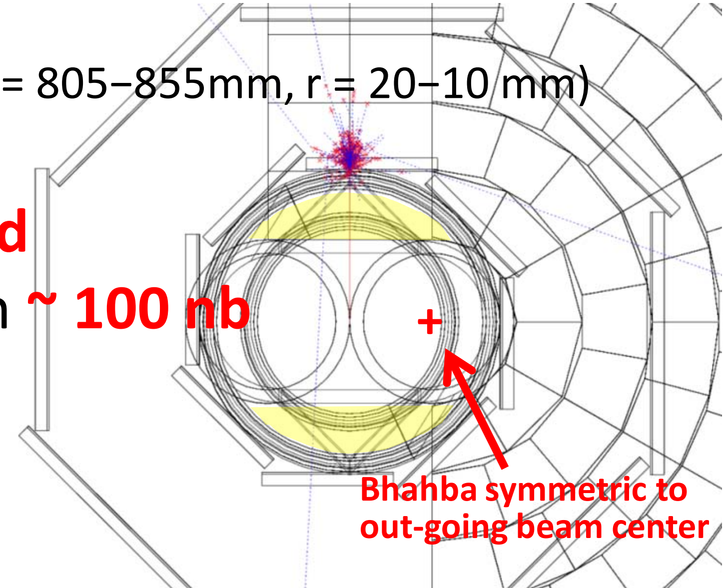


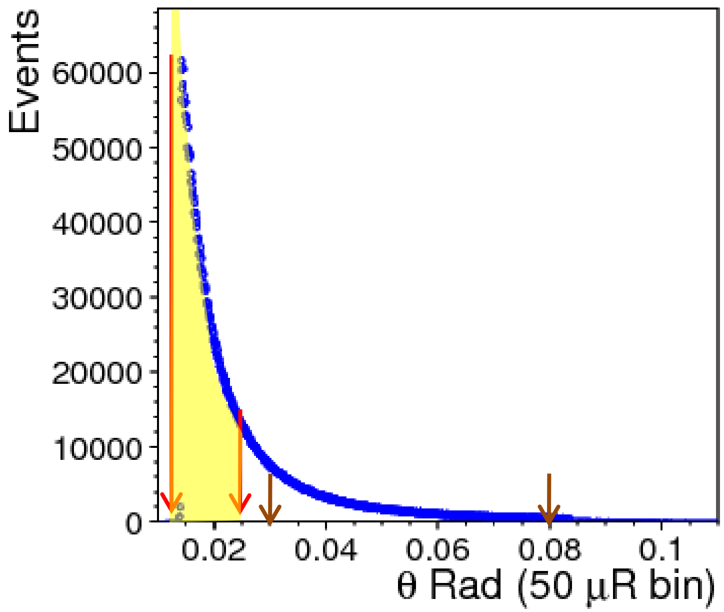


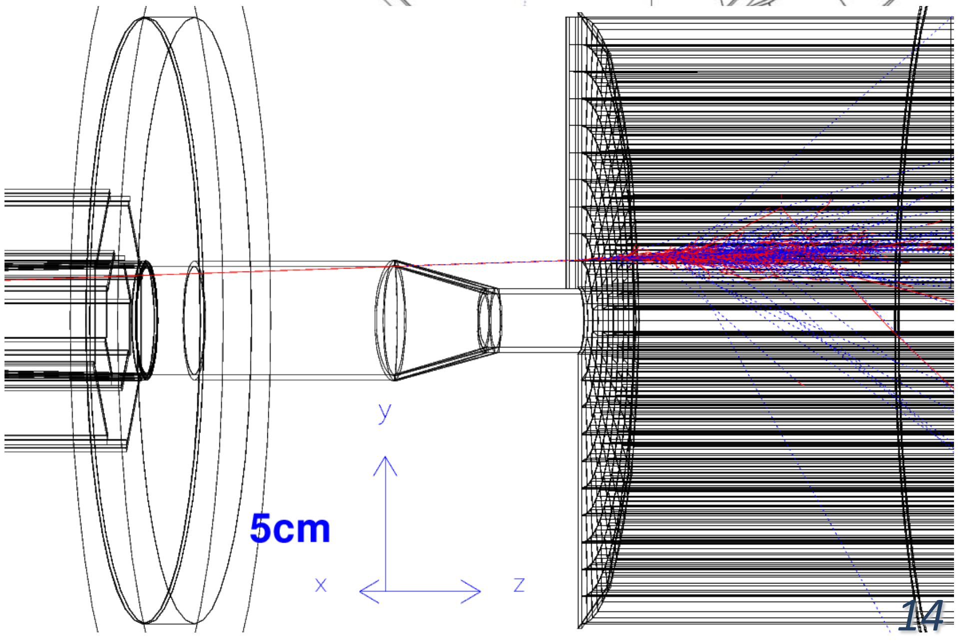


Duckbill/y-crotch window for Bhabha

- Duckbill slope on y-axis is **200 mRad**, (z = 805–855mm, r = 20–10 mm) electron traversing distance **~ 10 mm**
- Window on lab y-axis: **θ = 12 – 25 mRad** Bhabha cross section in clean phi region **~ 100 nb**
- Electron θ measured by Si r-ϕ disk before LYSO







Bhabha in duckbill window

- Bhabha symmetric to out-going beam center
  (x,y) = (16.5, 0) @ z = 1000 mm
- High cross-section, low mass region:
  phi ~ 60º to 120º *to beam center*
- Bhabha acceptance: both $e^+ e^-$ detected

Lab frame @ z = 1000 mm

dual beampipe: r = 10 mm

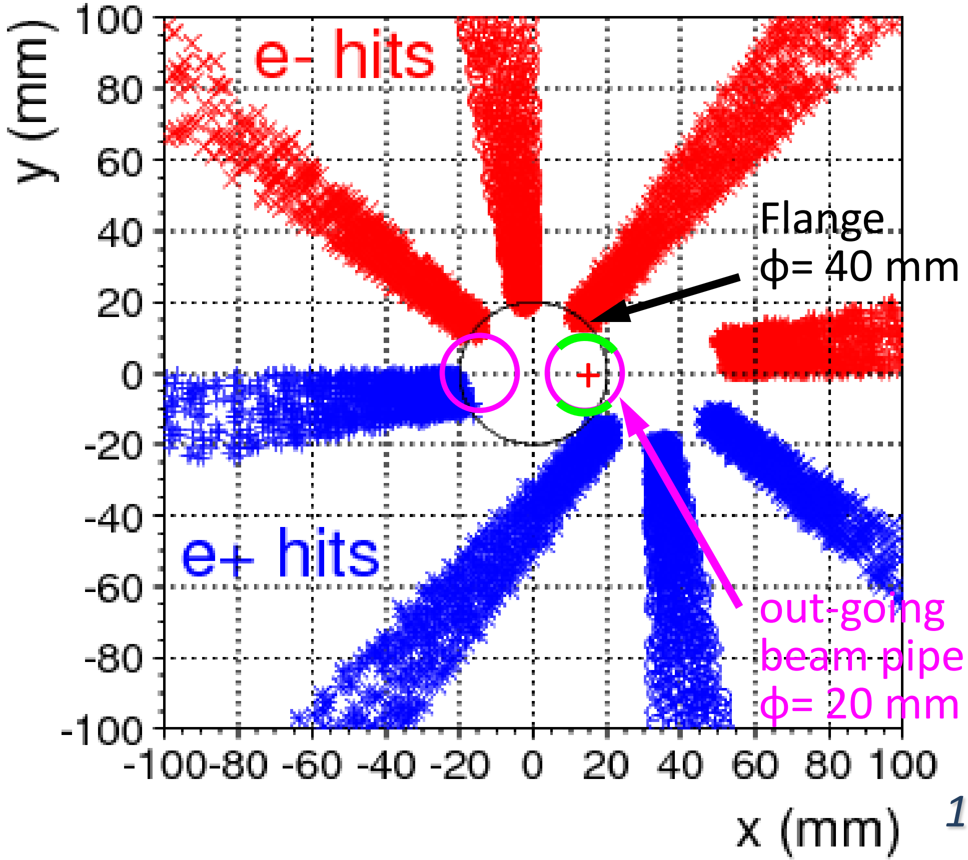
y-axis: |y|>10 mm,

x-axis: (± 43 mRad to out-going beam center)

θ(e^+) > 26.5 mRad

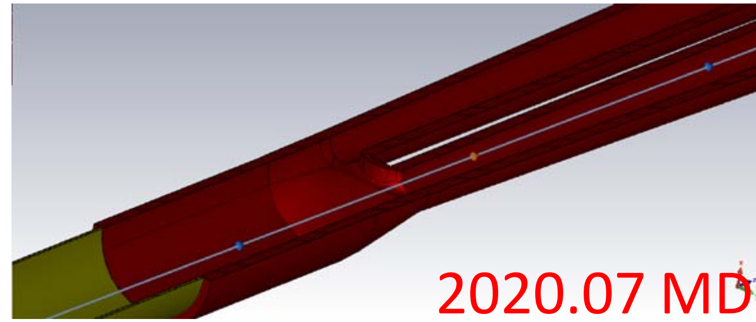
θ(e^-) > 59.5 mRad

Lab frame
Bhabha distribution

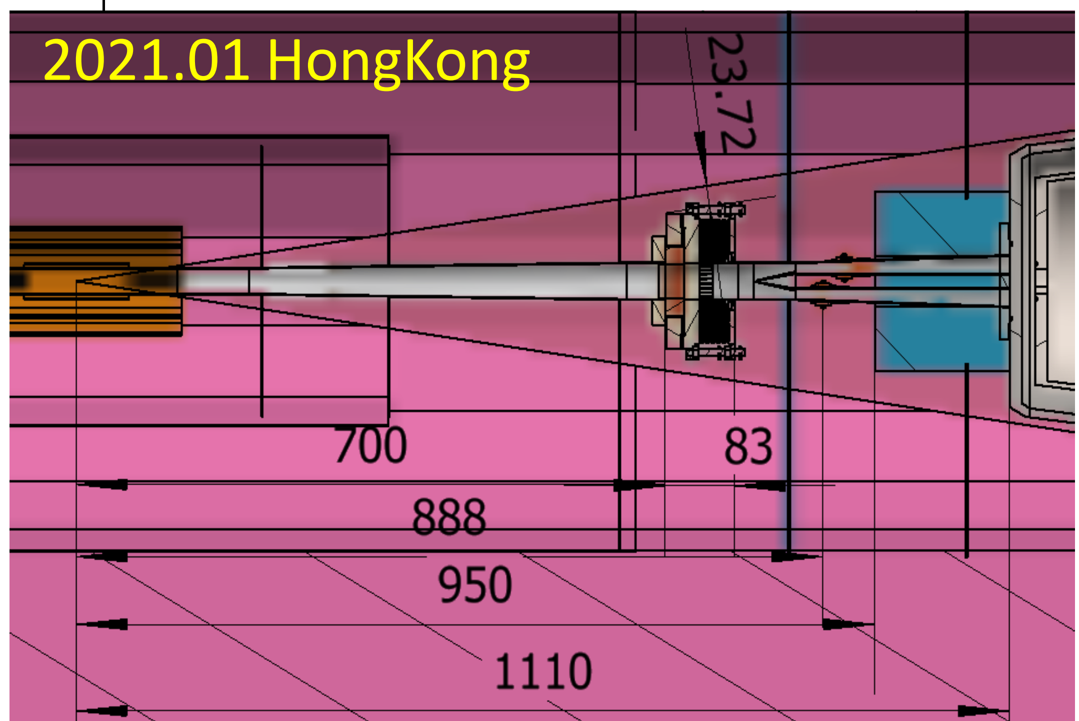


Duckbill/y-crotch window, low mass

- Duckbill can be ***Aluminum***, instead of Copper ?
- ***No*** other object below ϕ = 40 mm ?

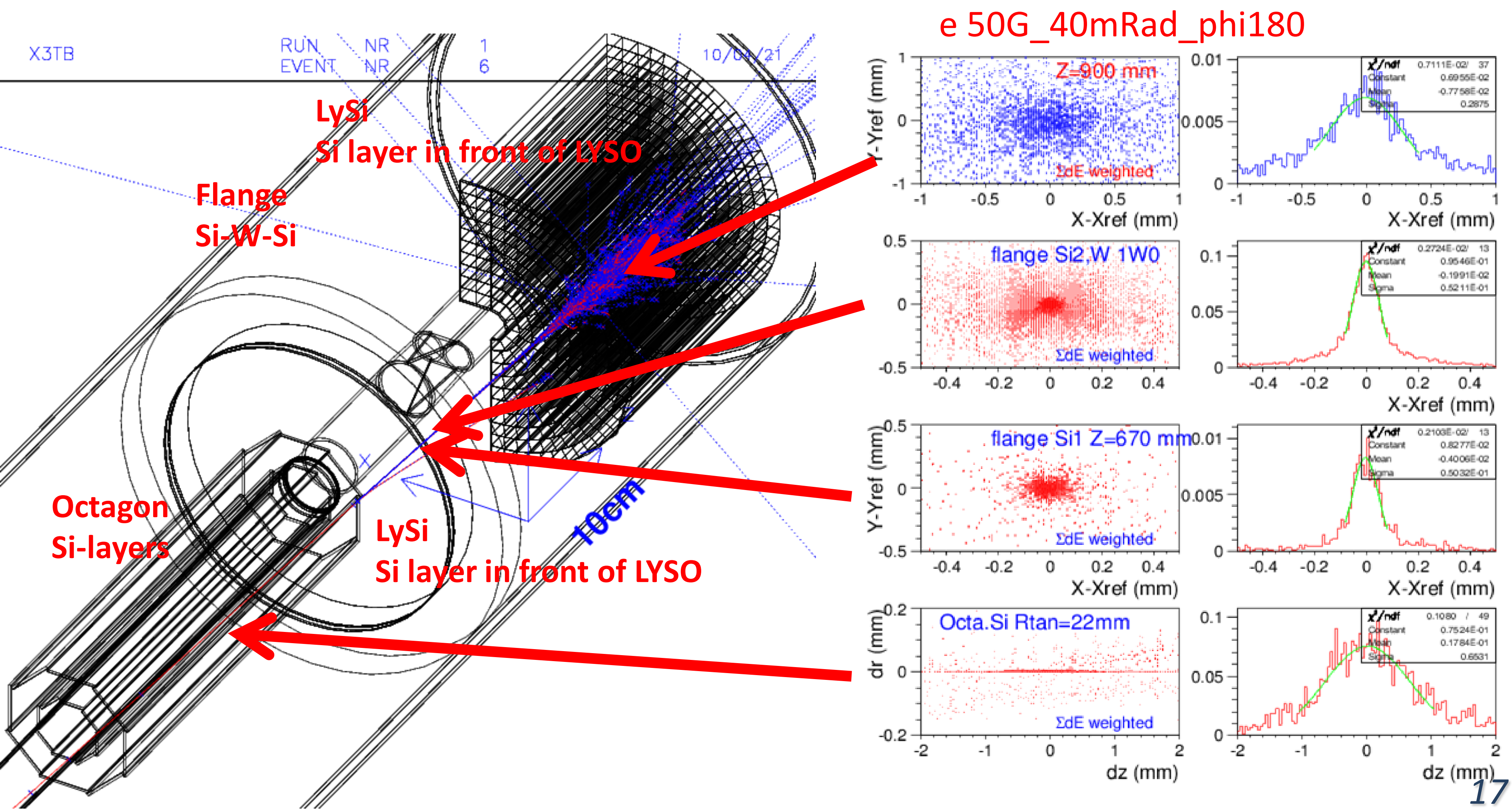


ver20200628 d28-d40-d20叉管前移真空说明					
距IP距离	内壁尺寸（mm）	材料	备注		
1-120	直径28	Be		探测器部分	
120-205	直径28	Al			
205-655	直径28过渡到直径40	Al	taper1:75		
655-670	直径40	Al			
670-750	直径40	Cu	远程连接装置预留	加速器部分	
750-820	直径40过渡到20-47.1跑道型。水平方向40-47.1，垂直方向40-20	Cu	水平方向taper1:19.7 垂直方向taper1:7		
820-855	分叉，分别从半跑道型过渡到直径20	Cu	水平方向taper1:11.7		
855-1110	直径20	Cu	BPM 预留空间		



LumiCal spatial resolution

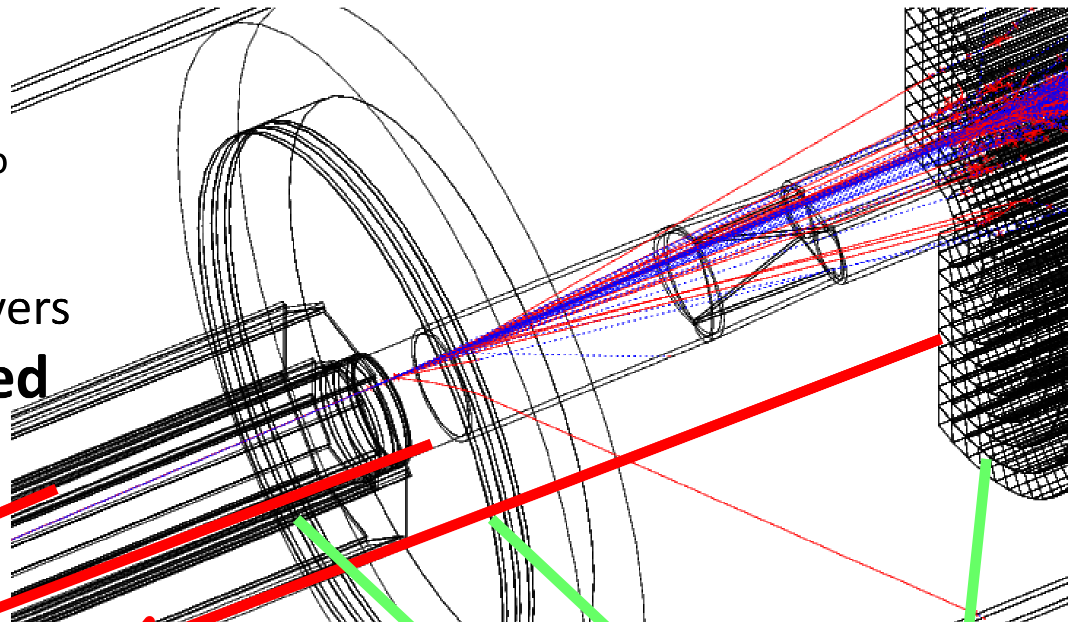
- Octagon Si-layer surrounding beampipe
- Flange Si-disk (1X0 + Si disk)
- Calo Si-disk, front of LYSO



LumiCal spatial resolution

50 GeV electron, *all hits* on Si wafers (primary e^- and secondaries)

1. Scan vertically phi = 90°
   through Duckbill window
2. Scan horizontally phi = 180°
   thick mass
   add 0/1 X0 between Flange Si layers
3. **Multiple scattering observed**
   @ Octagon surrounding Al-pipe
   @ Flange Si-disk
   @ LYSO front Si-disk



Lab (θ,ϕ)	σ(z) Oct Si	σ(x) Flg Si	σ (x) LySi
e (15 mR, 90°)	–	–	**4.8 μm**
e (20 mR, 90°)	–	–	**6.3 μm**
e (25 mR, 90°)	–	–	**9.8 μm**
e (30 mR, 90°)	–	–	95 μm
e (40 mR, 90°)	620 μm	52 μm	129 μm
e (55 mR, 90°)	373 μm	58 μm	114 μm
e (60 mR, 90°)	308 μm	65 μm	111 μm

(θ,ϕ)	σ (z) Oct Si	σ (x) Flg Si X0 Si	σ (x) LySi 0/1 X0
e (30 mR, 180°)	–	–	106/107 μm
e (40 mR, 180°)	653 μm	50, 51 μm	168/288 μm
e (55 mR, 180°)	375 μm	61, 60 μm	146/265 μm
e (60 mR, 180°)	307 μm	56, 57 μm	155/256 μm

Front-end for LumiCal

$N = 10^{34}\ /cm^2s \times 100\ nb$ (Bhabha)
$= 10^{38}/m^2s \times 100 \times 10^{-9} \times 10^{-28}\ m^2$
$= 10^3/sec$

- **CEPC bunch crossing：32 ns**
  Low θ Bhabha event rate @ instant L = $10^{34}/cm^2s$ **~ 1k Hz**
  Readout for LumiCal aims for : 30 ns/event
- **Viking type FE**, outstanding S/N
  Long shaping time, VA ~2 μm (IHEP has a version), APV25 ~100 ns
  Analog output, long readout chain, requires repeater near by
- **Telescope with IHEP Viking** (new chips in this summer)
  plan to build a testbeam system to study Si-wafer charge

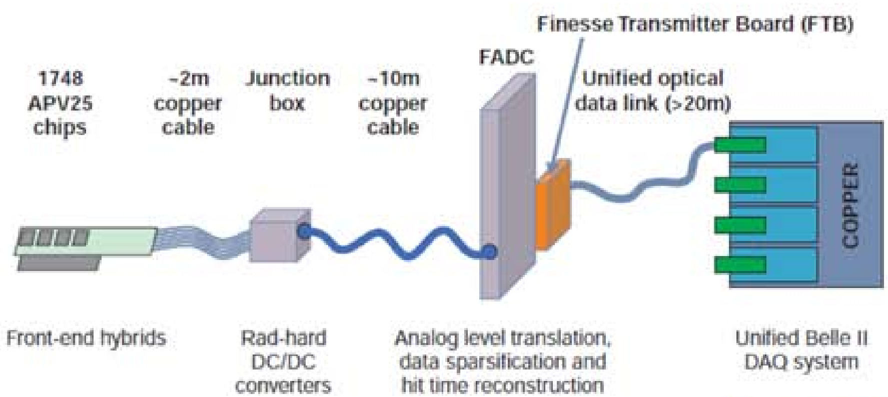
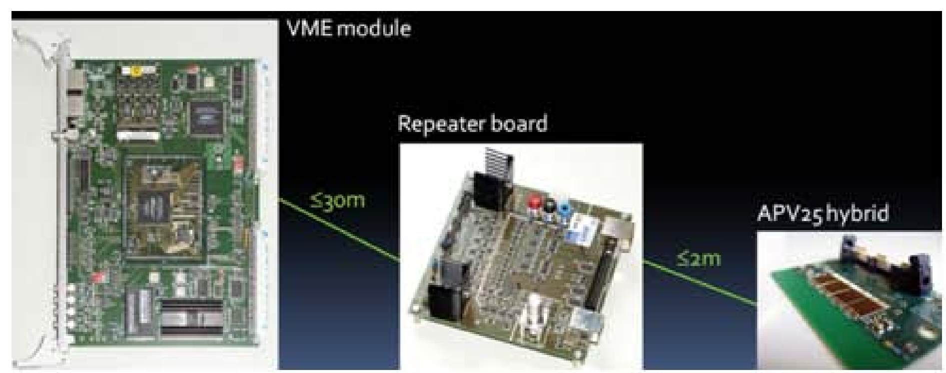


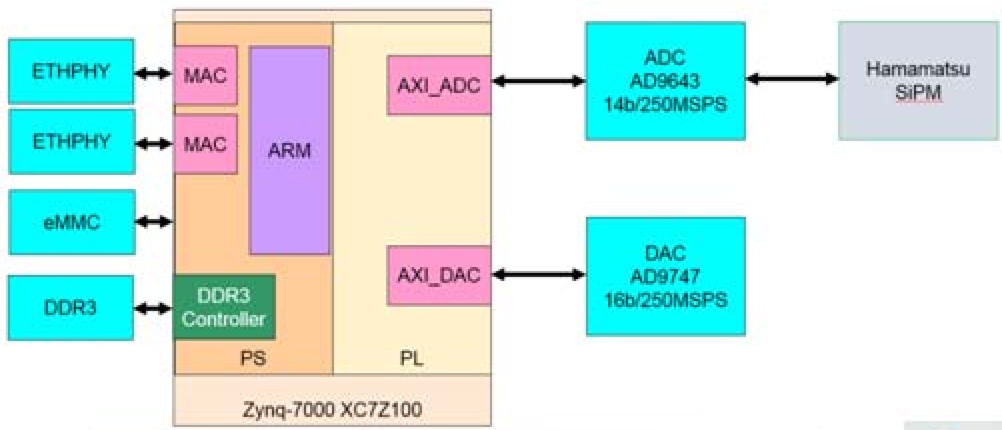
Figure 2. Overview of the SVD readout chain.

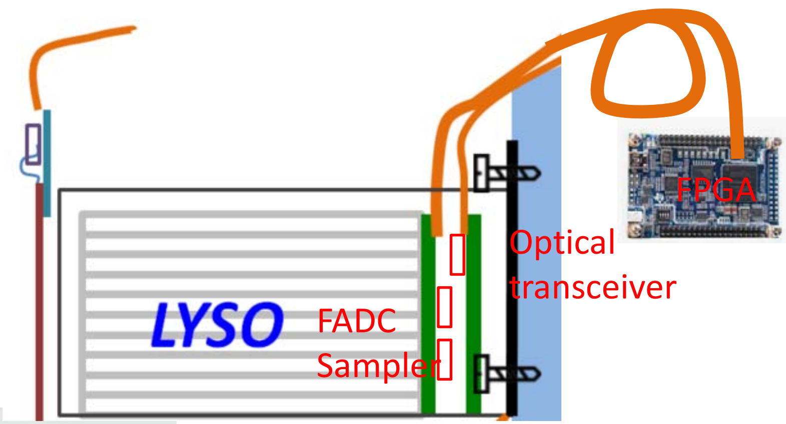


JINST ***8* C02037**

Readout chip for LumiCal

- **Proposal for a fast sampling chip for Si-wafer and SiPM**
  Compact FE for LumiCal
  proposal with SMU on ASIC design: a signal **sampler**, and a **FADC**
  signal simpling @ 500 MHz → FADC output (Optical link) → FPGA event selection
- **Lab study with commercial boards**
  experience with SiPM signal with LYSO crystal, Sc137 source, testbeam, etc
  commercial FADC and feedback to ASIC design





Summary

- **Explore Duckbill/y-crotch window for Bhabha**

  low mass, high cross section
  Q: before ϕ = 20 mm dual-pile, change Cu to Al
  Q: behind flange, keep ϕ < 40 mm vacancy for Bhabha

- **Prototyping**

  - IHEP Viking type FE with Si-wafer for RD (late summer 2021)
  - LYSO crystal with SiPM, commercial FADC/FPGA for RD,
    proposing ASIC with fast sampler/flash-ADC for event rate every 32 ns\

- **To Do**

  - precise GEOM in GEANT
    interface BHLUMI Bhabha events for event selection
    LYSO simulation and segmentation for shower center
  - Build Viking Si-det. as RD samples
    LYSO readout with sources to characterize FE