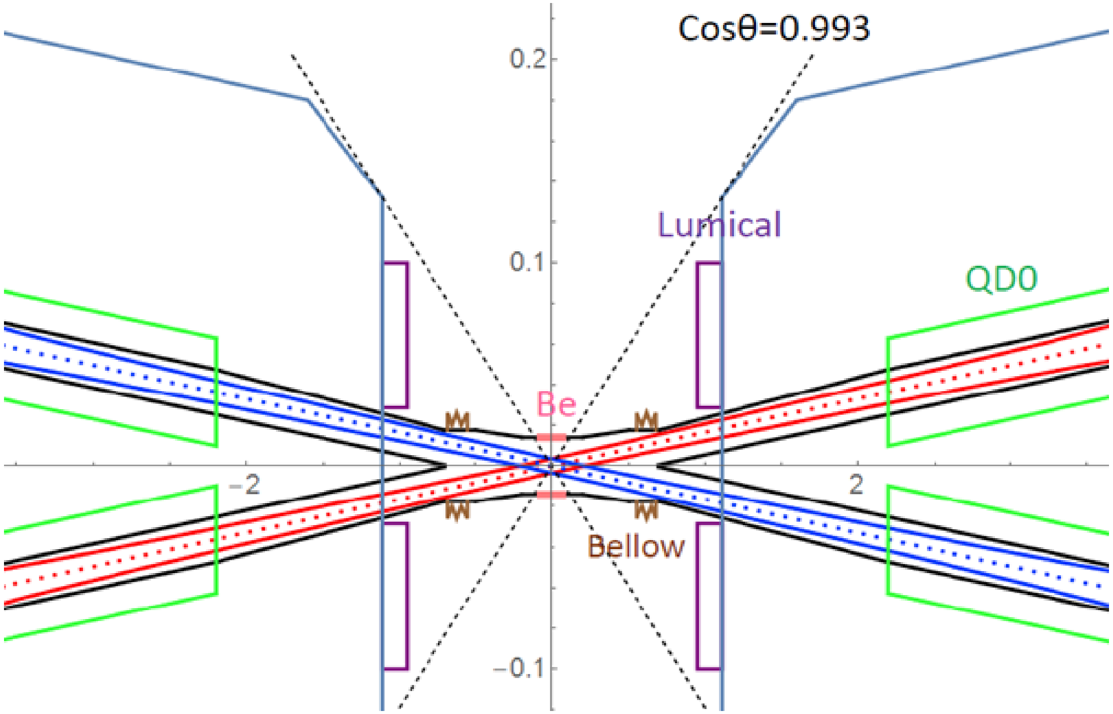
# The LumiCal for luminosity measurement at the CEPC

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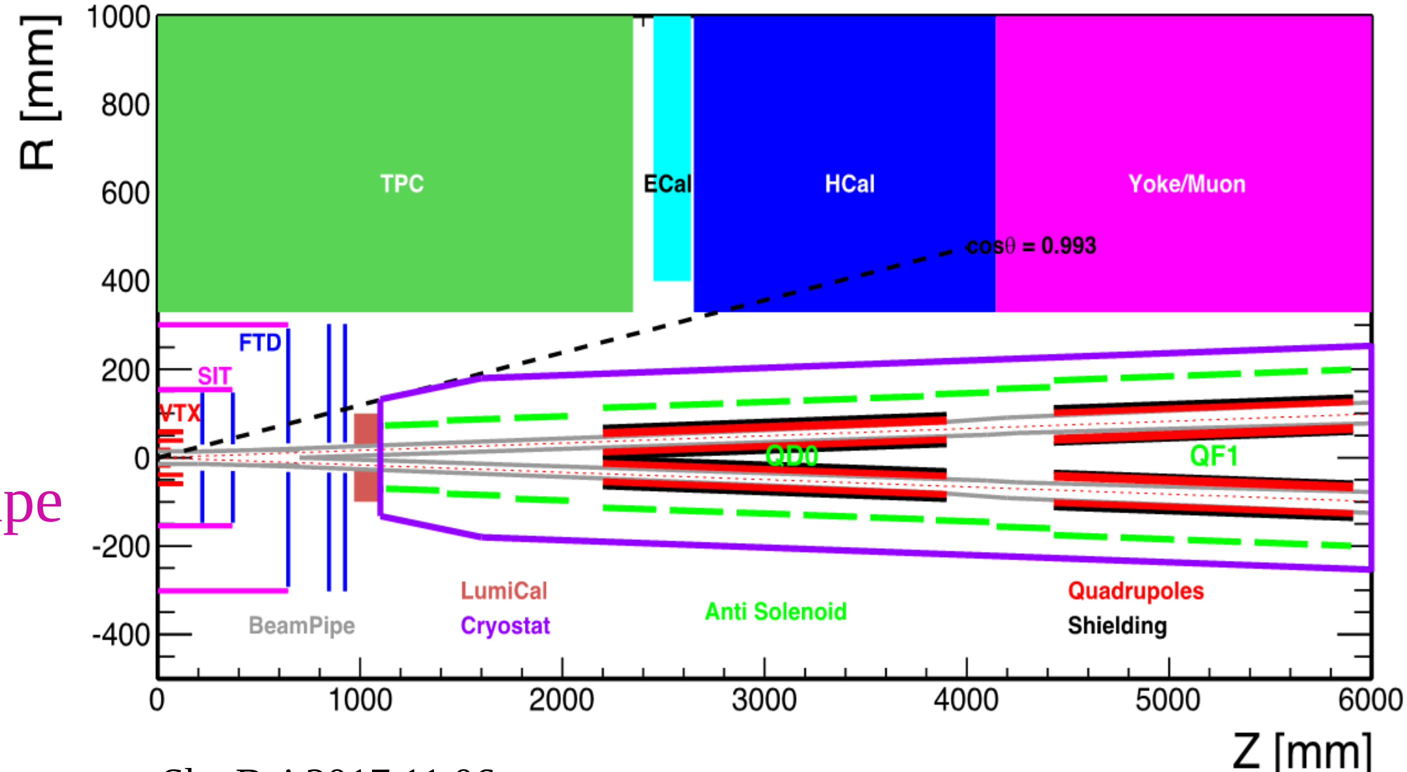
# LumiCal in MDI region at CEPC

***Concept Design:***

***Mounted in front of Quadruple, front  z ~ ±1 m***

**studies are conducted for**

- **Beam crossing  33 mRad**
- **Electron shower leakage** in to TPC volume  ( z to ± 2 m)



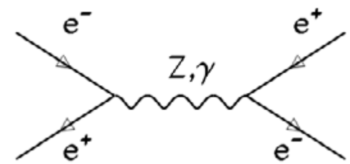

Be beampipe diameter ~ 28 mm

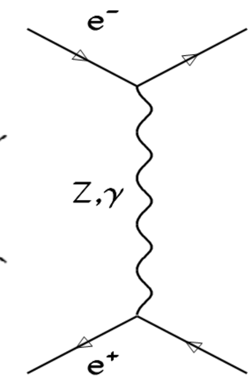
Sha Bei 2017.11.06

# Luminosity measurement

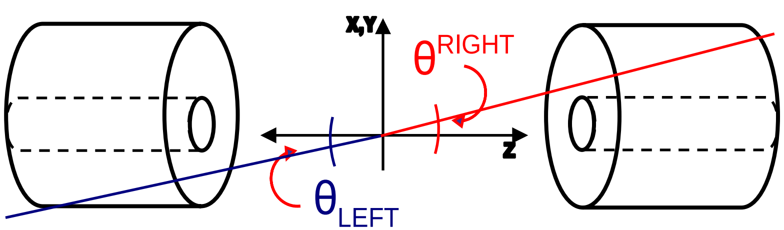
- Z lineshape, $e^+e^- \to Z \to q\bar{q}$ is dominant, ***σ = 41 nb***
- Luminosity is best provided by detecting Bhabha, $e^+e^- \to e^+e^-$, elastics scattering
  - a pure QED process, theoretical MC to <*0.1%* precision
  - triggering on a pair of scattered $e^+e^-$

***$E(e^\pm) \sim E_{beam}$, Back-to-Back***

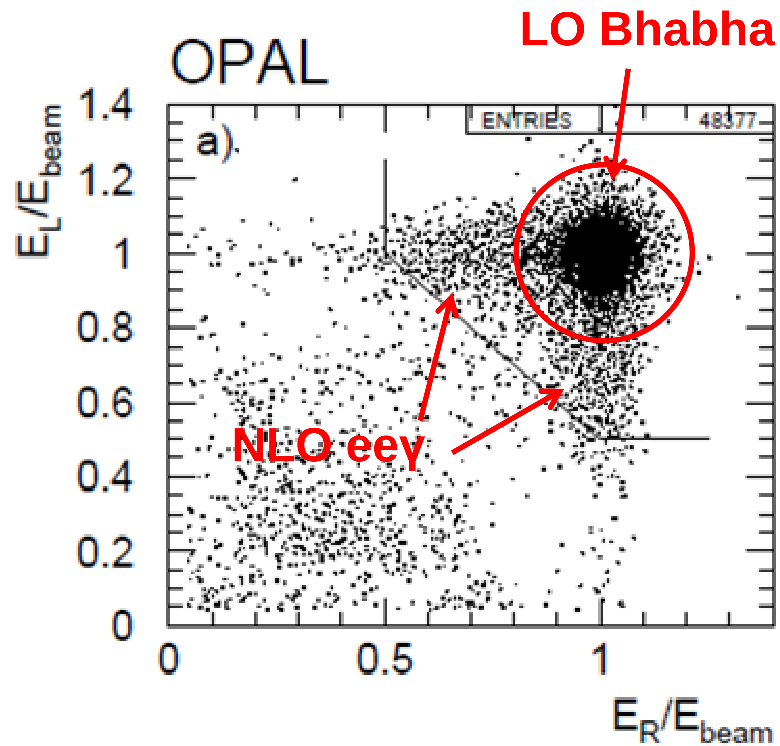



$$\sigma = \frac{16\pi\alpha^2}{s}\left(\frac{1}{\theta^2_{min}} - \frac{1}{\theta^2_{max}}\right)$$



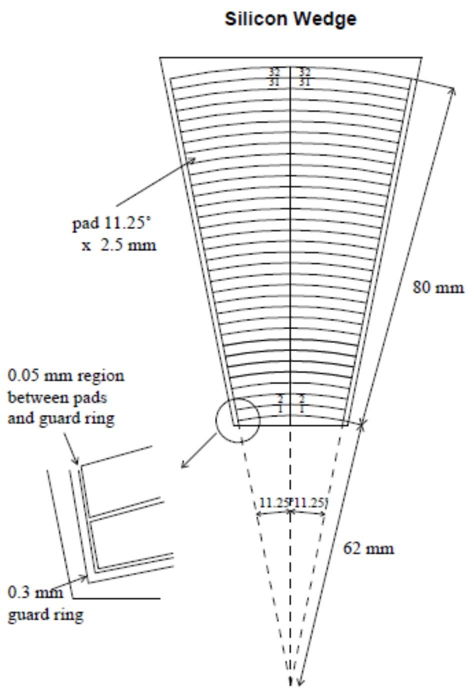

$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$

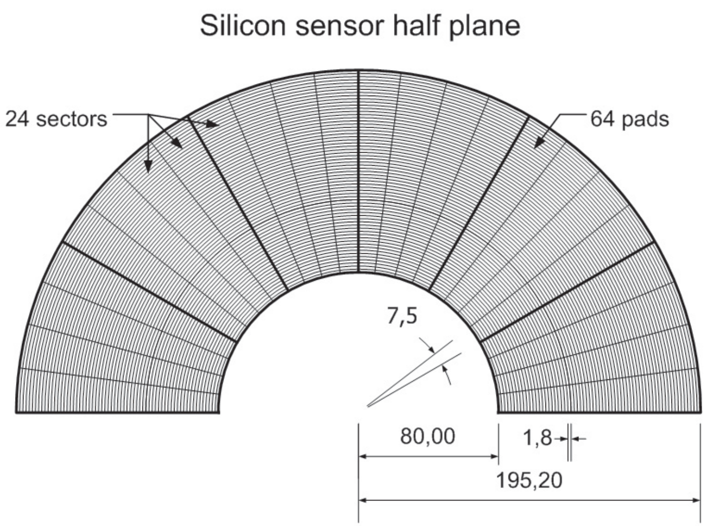


# LumiCal vs LEP/ILD

| | CEPC | OPAL | ILD |
|---|---|---|---|
| z to IP (m) | .95 ~ 1.11 m | 2.5 m | 2.5 m |
| radius (mm) | 28 .5 ~ 100 mm | 62 - 142 mm | 80 – 195 mm |
| θ range | 28.5 ~ 100 mRad | 25 - 57 mRad | 40 – 69 mRad |
| Si r-pitch | *Scale by z coor. to OPAL/ILD* | 2.5 mm | 1.8 mm |
| radius precision | | 4.4 μm | |
| Ref. | | arXiv-0206074v1<br>EPJC 14 373 | Procedia 37 258 |

OPAL SiW




ILD LumiCal

# LumiCal precision

**Luminosity is by counting Bhabha events**

**In a fiducial θ region**

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

Dominant systematic error

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

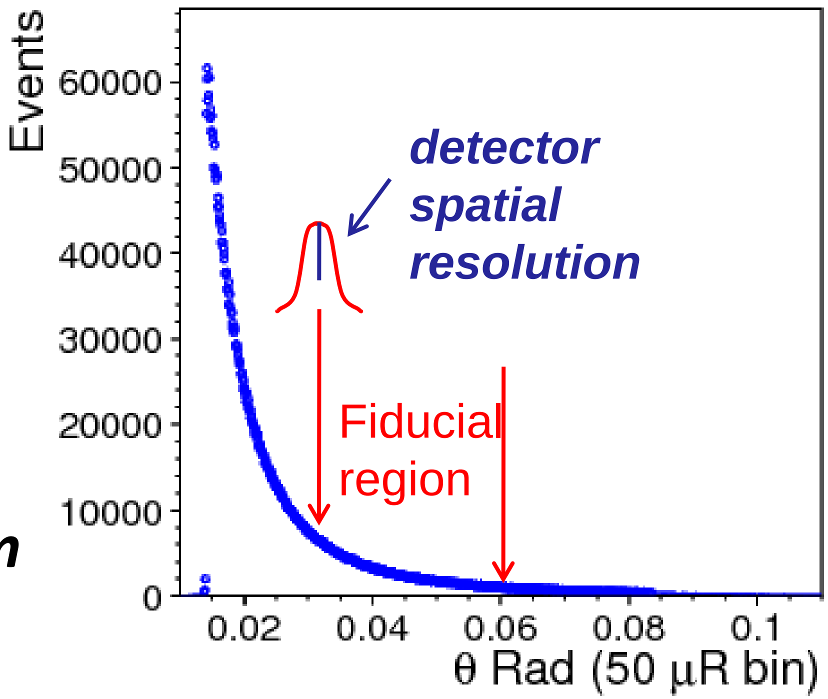
**For a precision of *$\delta L/L < 10^{-3}$***

LumiCal at **z = ±1 m,** $\theta_{min}$ = 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***




*offset on the* ***mean***

***of spatial resolution = offset on $\theta_{min}$***

**→** *dominant* ***LUMINOSITY error***

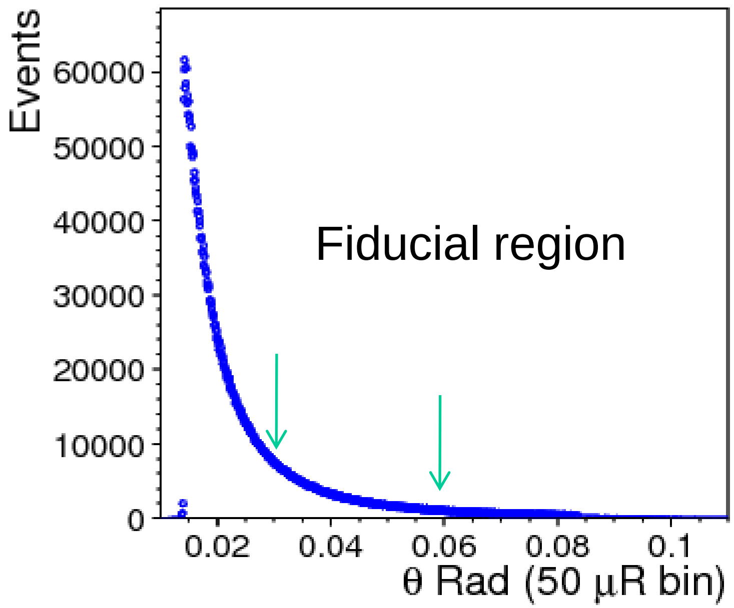
# Event fraction by missing 10 μRad in +x (boosted) side

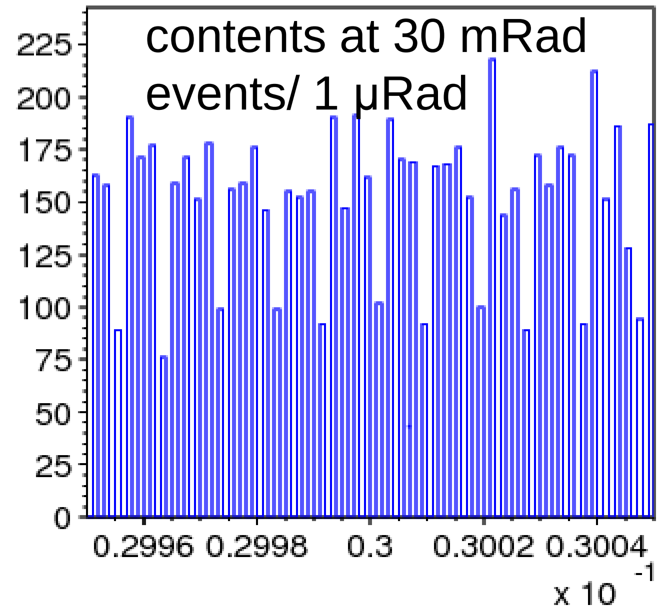
- 0.1 mm offset on Z ➔ ΔRxθ = 3 μm (R=1 m, θ=30 mRad in LumiCal fiducial)
  1 μm in radius at Z = 1m ➔ 1 μRad
- Assume LumiCal fiducial region is 30 – 60 mRad

Count event offset by 10 μm (10 μRad)

**➔ Luminosity uncertainly δL = 0.08%**

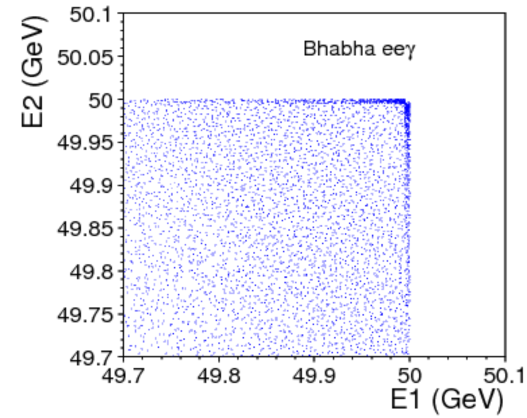
BHlumi generated events in 14~200 mRad
Shifting acceptance 30 mRad to 30.01 mRad ➔ ratio = .08 %



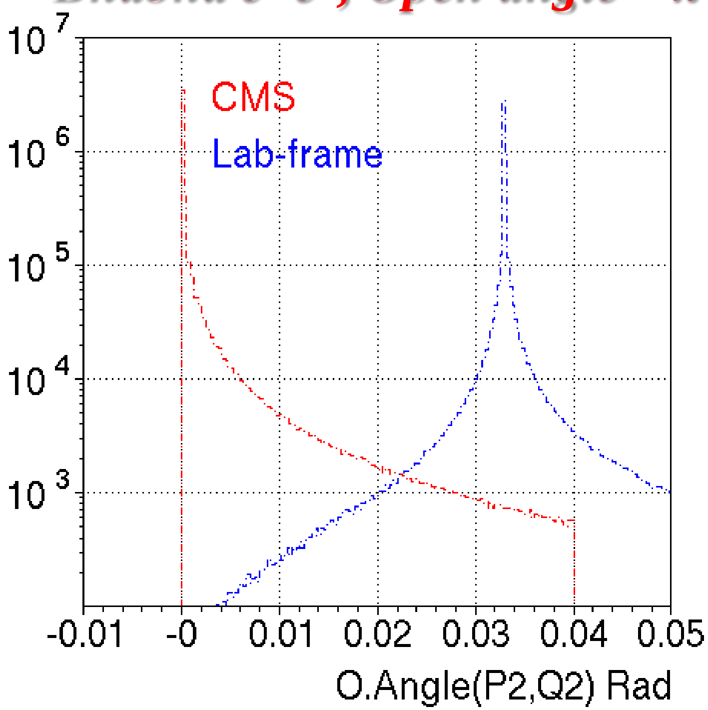



# Boost by CEPC beam crossing angle

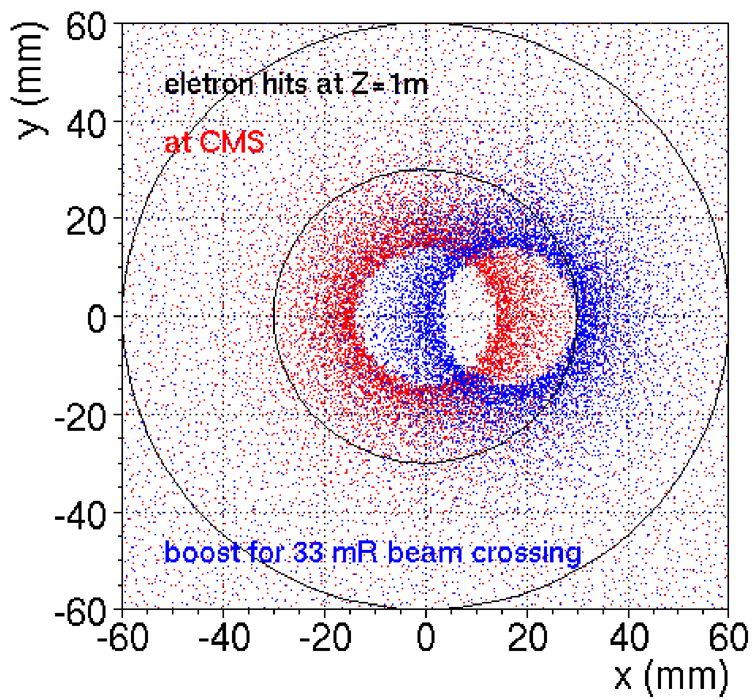
- ***BHlumi*** simulation, most are LO,
  *$E(e^+)=E(e^-) = E_{beam,}$ , OpenAng = $\pi$*
- CMS($e^+e^-$) boosted by beam crossing
- $e^{\pm}$ boosted *~16.5 mRad* off ring-center lost into beam-pipe




**Bhabha $e^+ e^-$, Open angle $-\pi$**




**Bhabha $e^-$ @detector r-φ, z=1m**



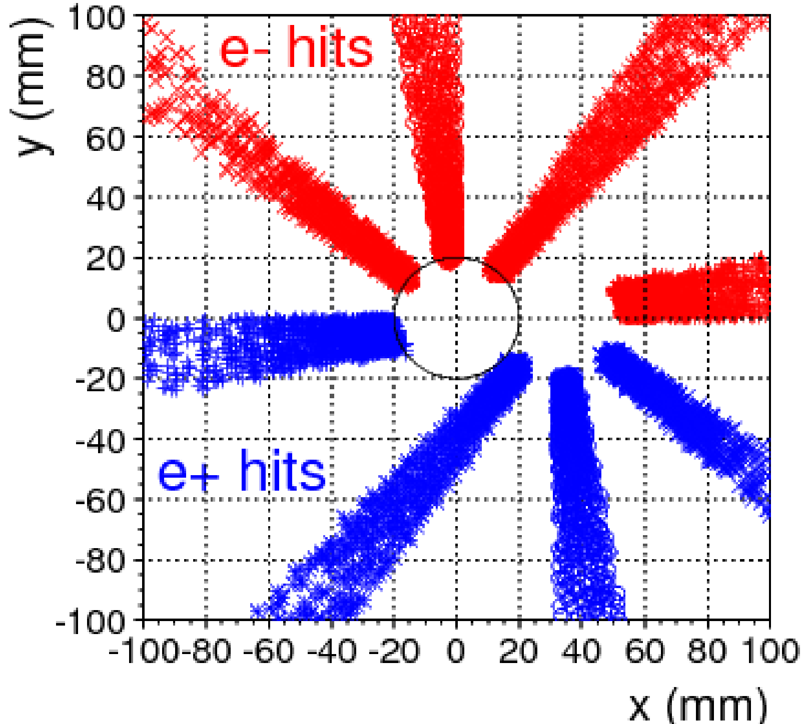
# Boosted Bhabha

BHLUMI colliding e+ e- are back to back
Boost CEPC crossing angle of 33 mRad
Boost Bhlumi e+, e- to CEPC → ***E is larger by ~.01%***
***Ebeam = 50 GeV → boosted E = 50.0068 GeV***

- Boosted LO Bhabha, ($e^+e^-$, no $\gamma$)
- $e^+$, $e^-$ detected in ***fiducial acceptance of r > 20 mm***
- r-$\phi$ plotted in bands (every 45 deg in $\phi$)
- event loss ***163 nb → 98 nb***

→ **loss is SIGNIFICANT**

→ ***LumiCal wants a small inner r, in OVAL shape if feasible***



***Hits on detector x-y planes @z=1m***

# LumiCal detector options

**Luminosity precision = $e^{\pm}$** detection in ***r***, at inner radius of fiducial

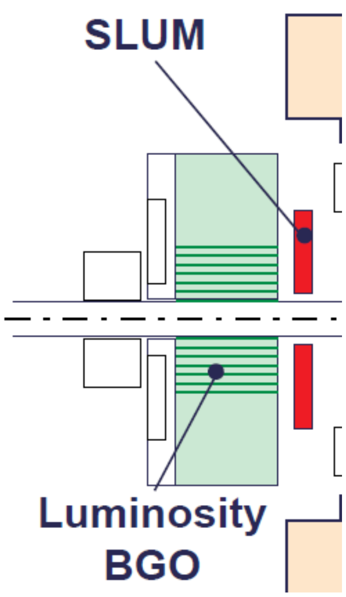
➔ **Silicon strip** is the choice!

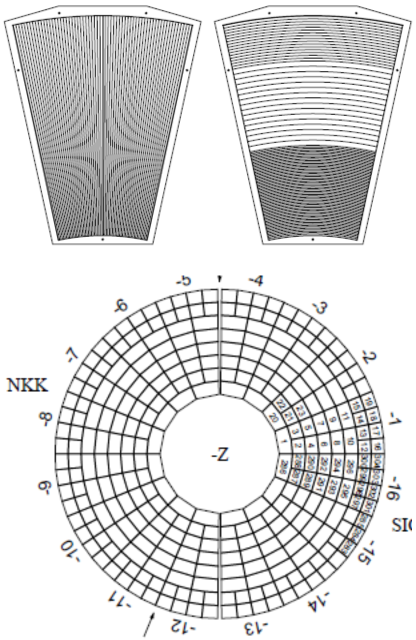
➔ ***Alignment** CAN NOT reach 1 μm*

➔ ***wide strip** (~2mm) CAN NOT reach 10 μm resolution*

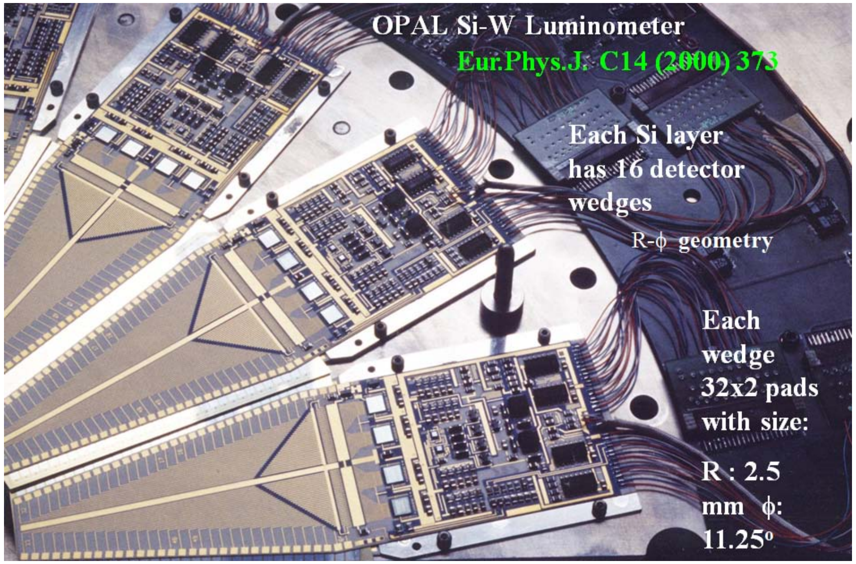
➔ *A **stand-alone LumiCal** CAN NOT calibrate its offsets to IP*

***L3 Silicon layer + BGO***

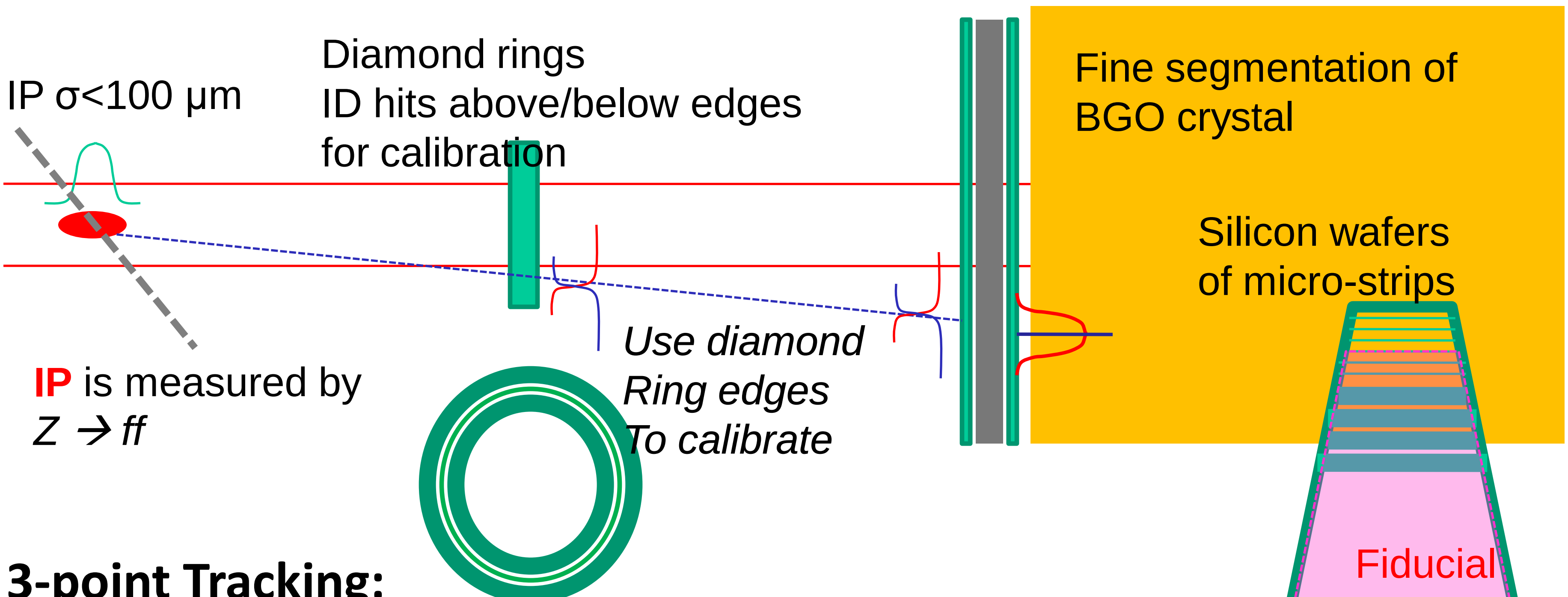



***OPAL Si-W sandwich***



# LumiCal with a simple tracking ring




**3-point Tracking:**

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

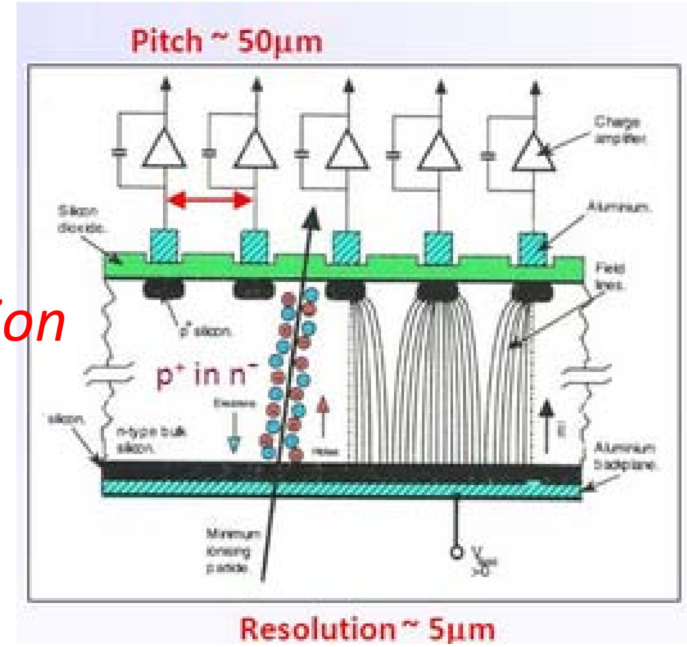
**Calibrate *offset* of the *mean of error* at inner radius**

*Silicon strip resolution **~ 5 um,***

*error on mean is much smaller, **CAN reach 1 μm, δL/L ~ 0.01 %***

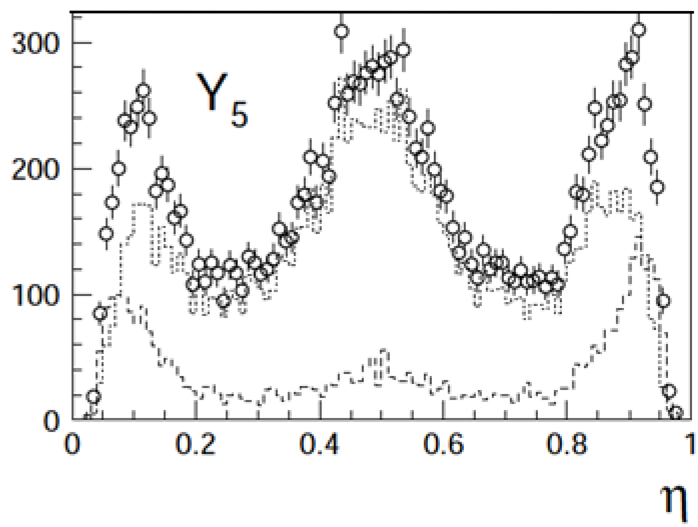
# Si strips resolution

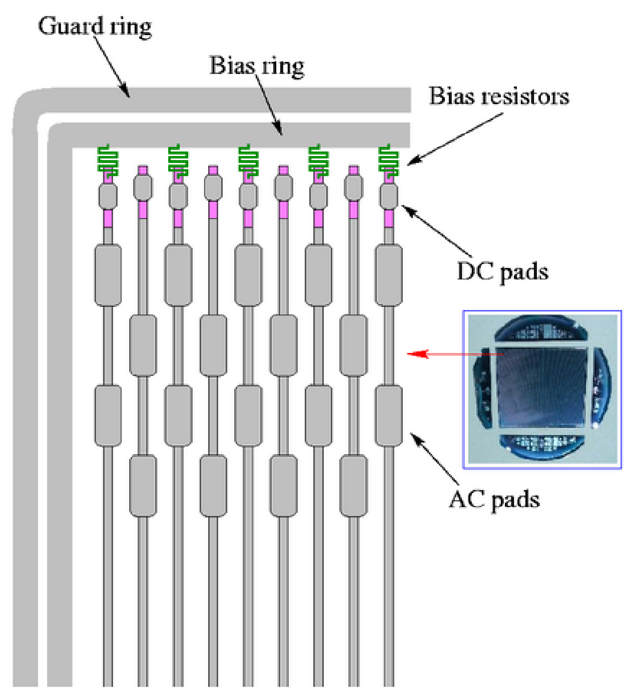
- Silicon strip of p-n on ~300 μm wafer
  ionization e-h ~ 25k pairs in ~20 μm cone
- Readout pitch 50 μm → *~5 μm resolution*
  strip ~10 um, a floating p-implant
- Charge sharing of a MIP
  to neighboring strips




$$\eta = \frac{Q_r}{Q_r + Q_l},$$

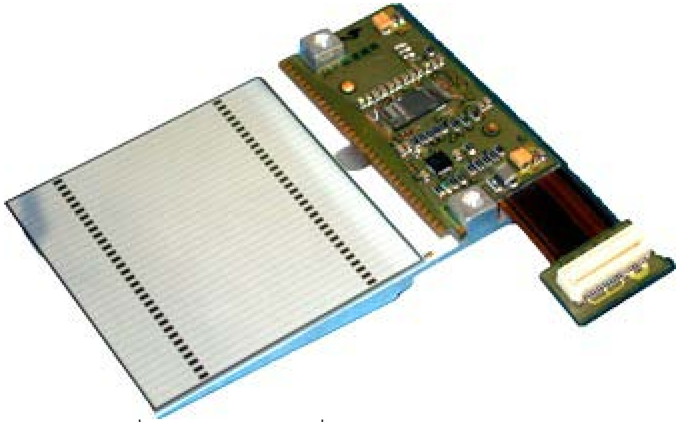
***→A flat η gives better resolution***



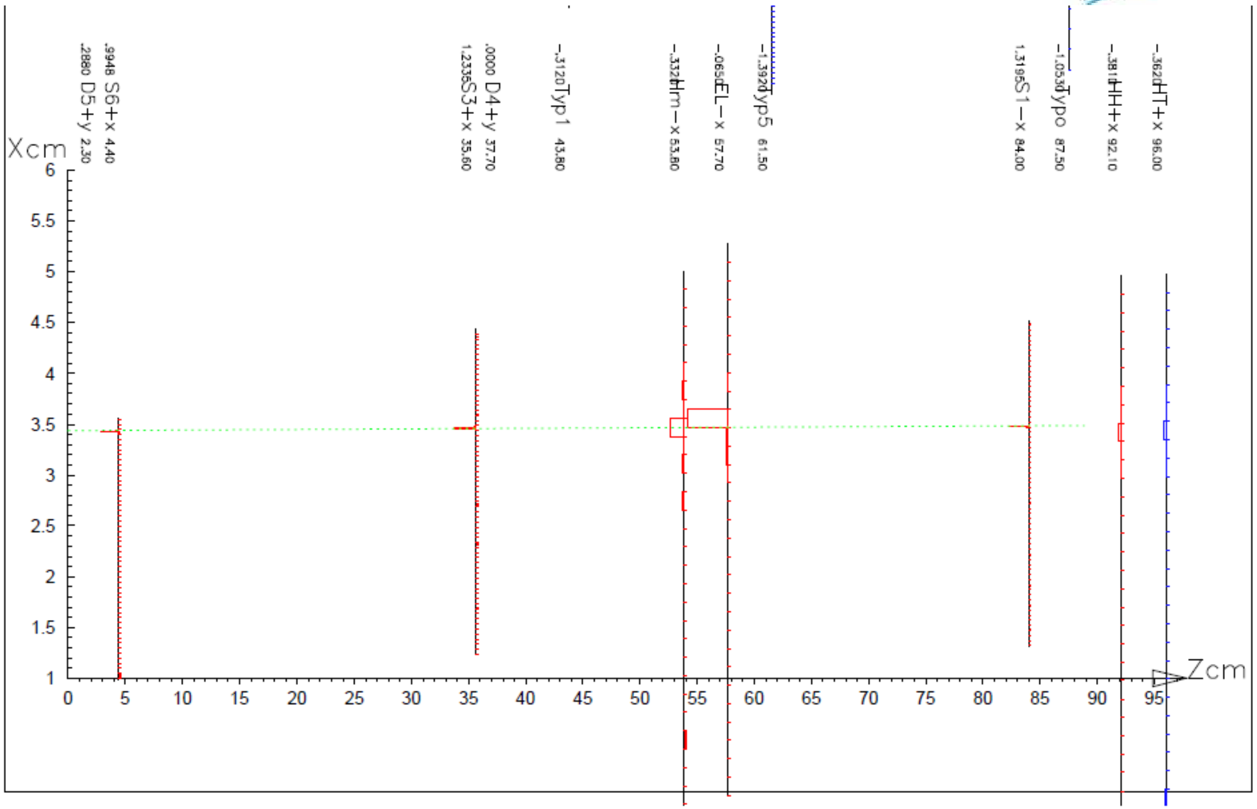



# Spatial resolution of wide Si pads

- Study using CMS preshower prototype
  ***380 μm thick, 1810 μm pitch, 160μm gap***



- A test beam at CERN
  mixed $e^-$, $\pi^-$, 1-12 GeV



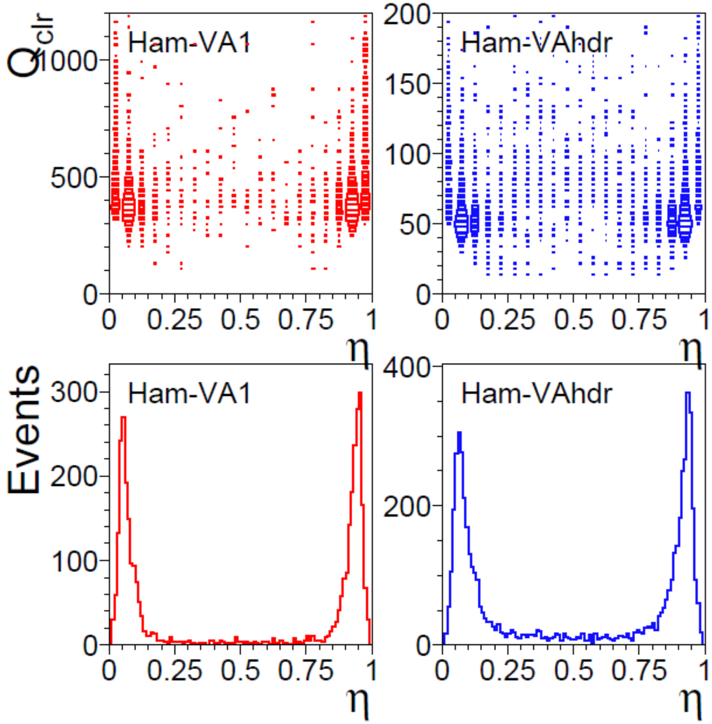
# Ionization charge of hits on wide Si pads

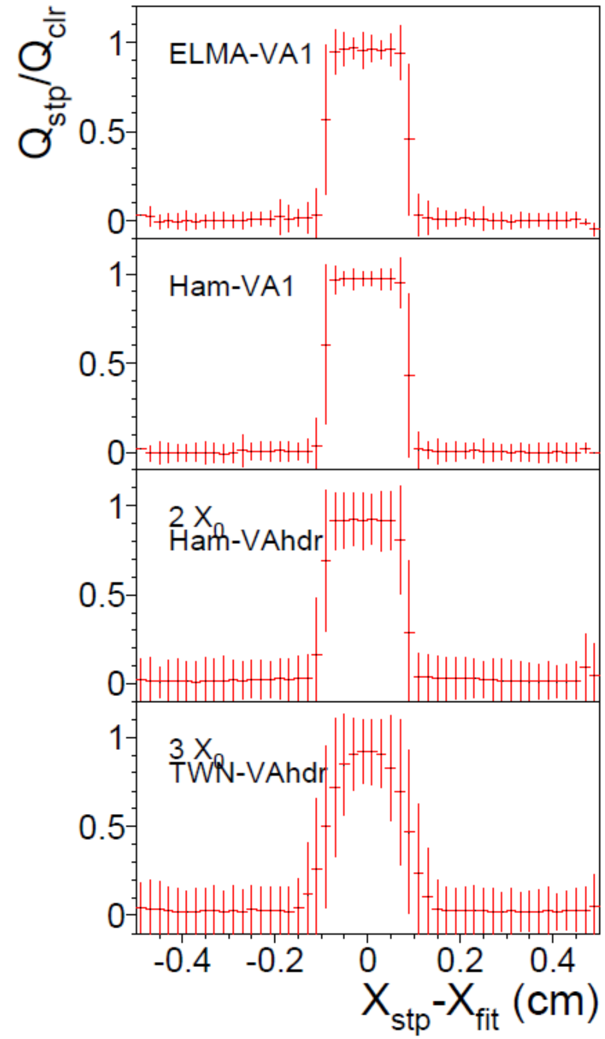
- Linear fit to Telescope track to predict hit position on pads
- ***MIP charge is collected mostly in one trip***

Ionization charge of MIP hits on Si strip versus ref. position

A hit in gap between two Si strips
Ionization charge in a narrow (~20μm cone)
Drift mostly to the nearest strip

$$\eta = \frac{Q_r}{Q_r + Q_l}$$



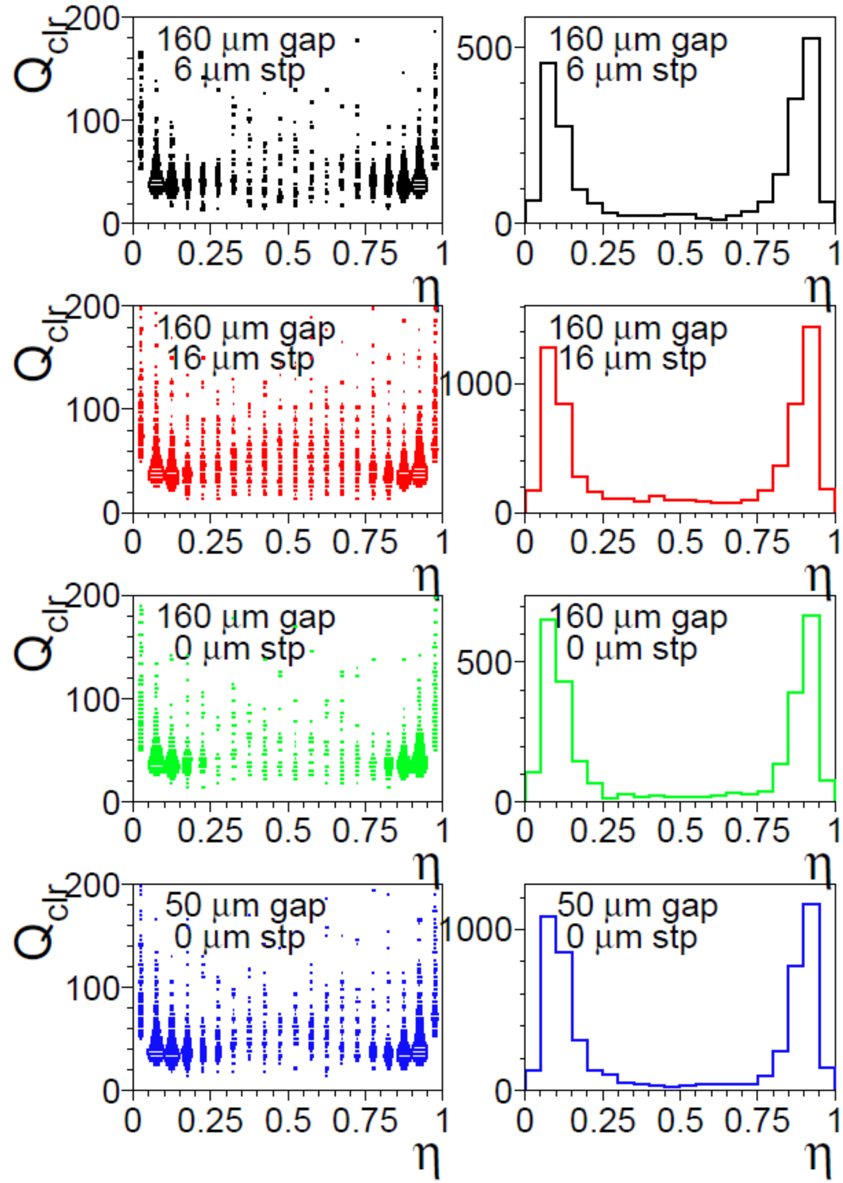



# Spatial resolution of wide Si pads

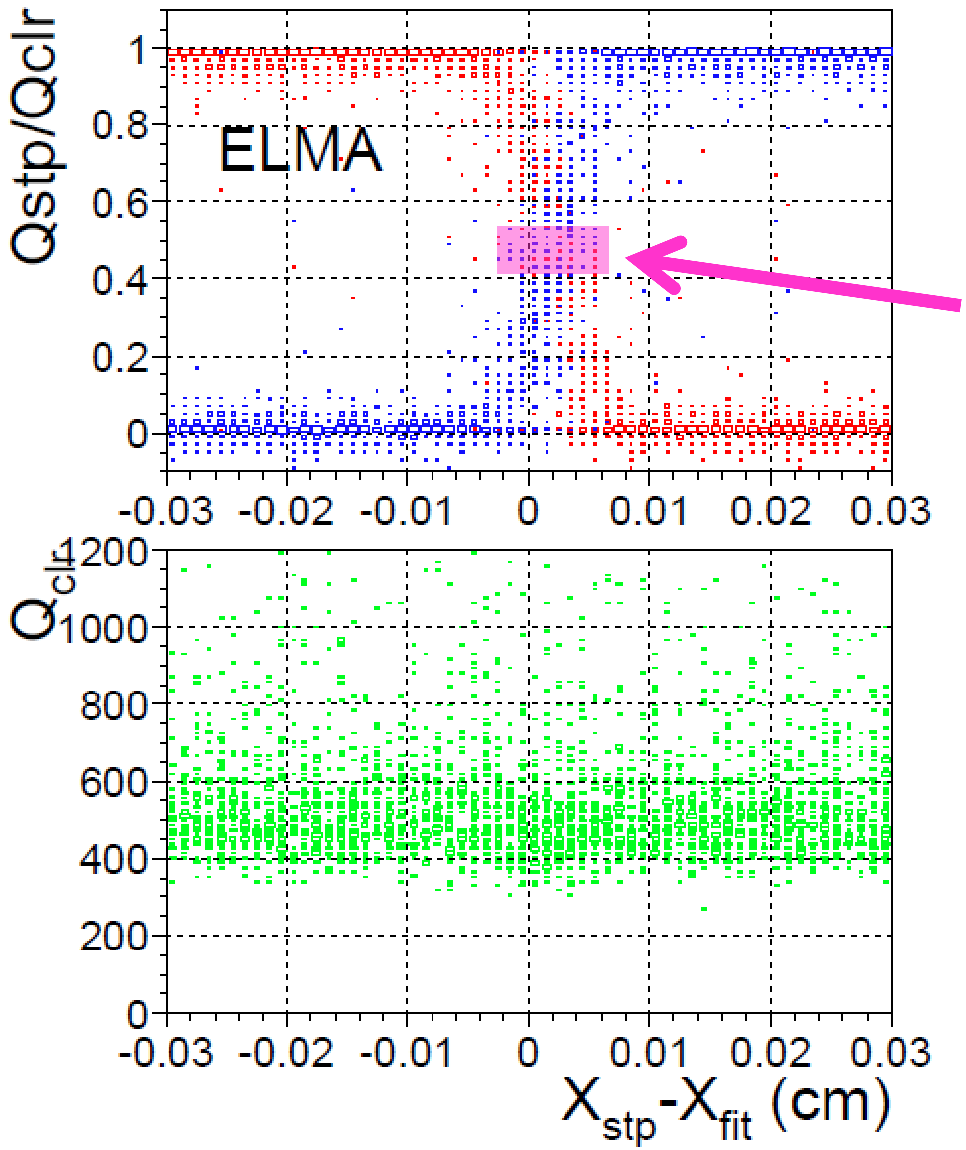
- Gap structure compared gaps of 50, 160 µm, with an intermediate strip of 0, 6, 16 µm

➔ η distributions of diff. widths, inter-strip structure are compatible

$$\eta = \frac{Q_r}{Q_r + Q_l}$$



# Spatial resolution using wide Si pads




- Select hits in a fiducial at the gap of two strips n-1, n
- ***Width here is the resolution***

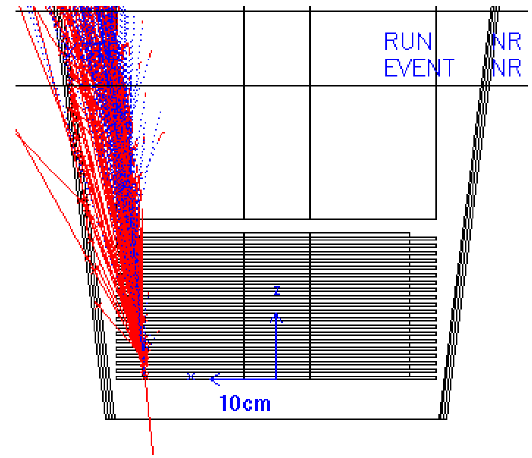
**Gap width is 160 *μm***

**➔ *Resolution ~ 30 μm***

**Events in gap**
**Charge sum are compatible**

**➔ *100% detection efficiency***

# LumiCal as a Si-W




## Detector assembly:

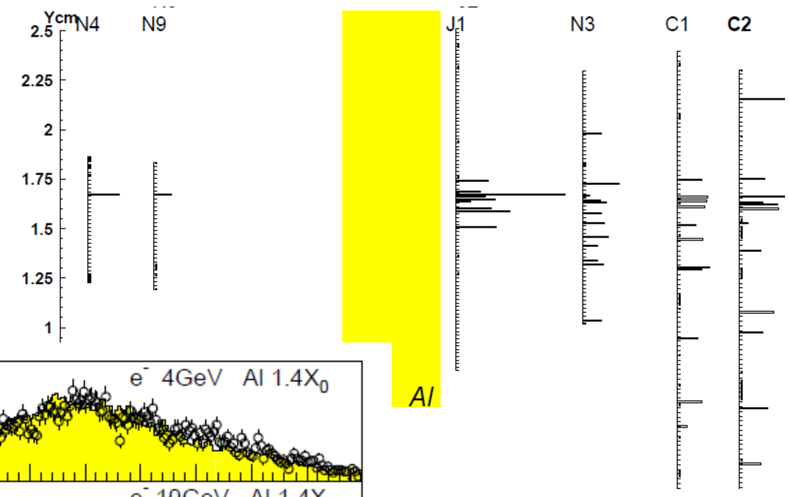
*first layer:* high resolution tracking for electron hit r, φ position

*energy resolution:* Si-wafer detector charged particles only
each is a MIP of Landau ionization charge
EM shower = # of charged particles.

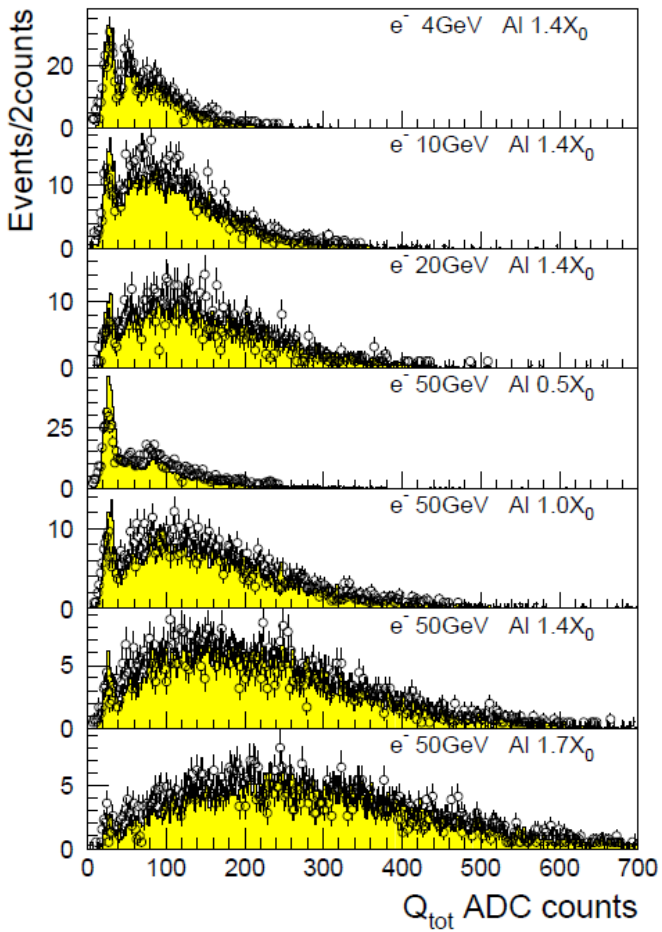
## $e^{\pm}$, γ Identification:

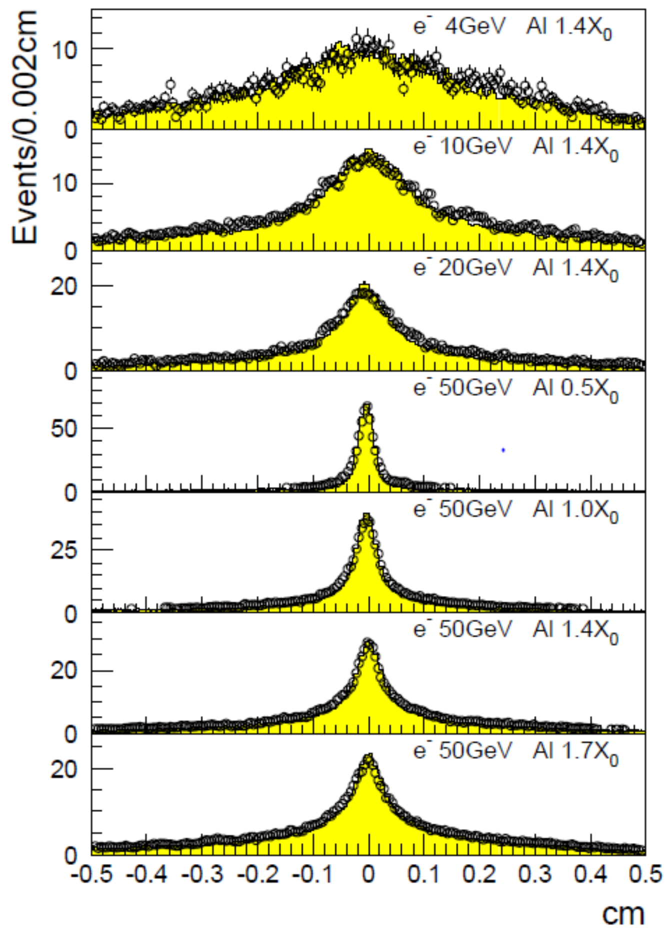
photon has no signal on Si-wafer
photon fragmentation after ~1 $X_0$
photon ID: EM shower with no $1^{st}$ layer hits
photon spatial resolution: Calo segmentation

# LumiCal lateral shower distribution




Lateral shower distribution behind a *1.4 $X_0$ Al* absorber
Data vs MC (histogram)



# LumiCal shower leakage

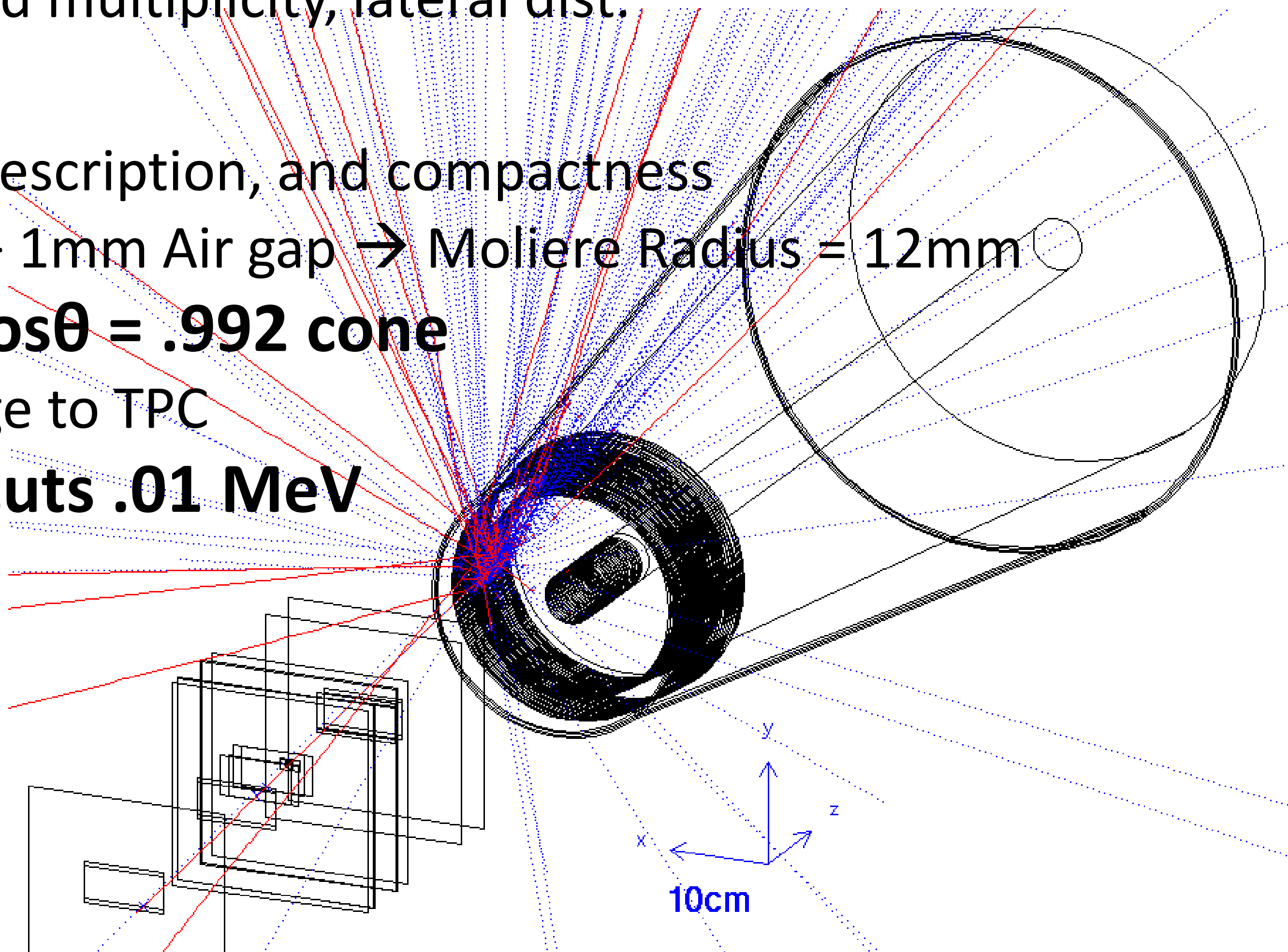
- **GEANT3 of a lateral shower testbeam***

  agree on charged multiplicity, lateral dist.
- **Si-W sandwich**

  better shower description, and compactness

  W $1X_0$(3.5mm) + 1mm Air gap → Moliere Radius = 12mm
- **Mockup of a cosθ = .992 cone**

  detecting leakage to TPC
- **Mininum e/γ cuts .01 MeV**




```
C============
c    ( CUTGAM,CUTELE,CUTNEU,CUTHAD,CUTMUO, BCUTE,BCUTM, DCUTE)
CUTS   .00001  .00001   .01     .01     .01    .0001  .0001   .0002
c
```

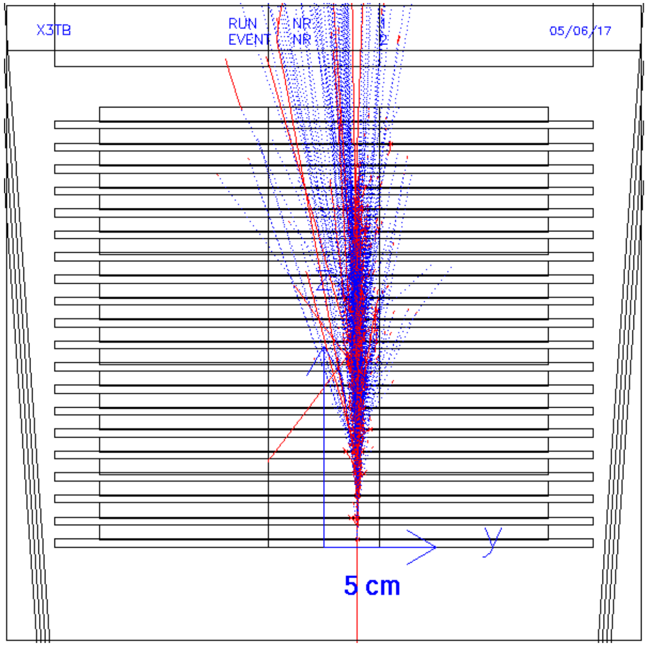
* NIM A 388 (1997) 135.

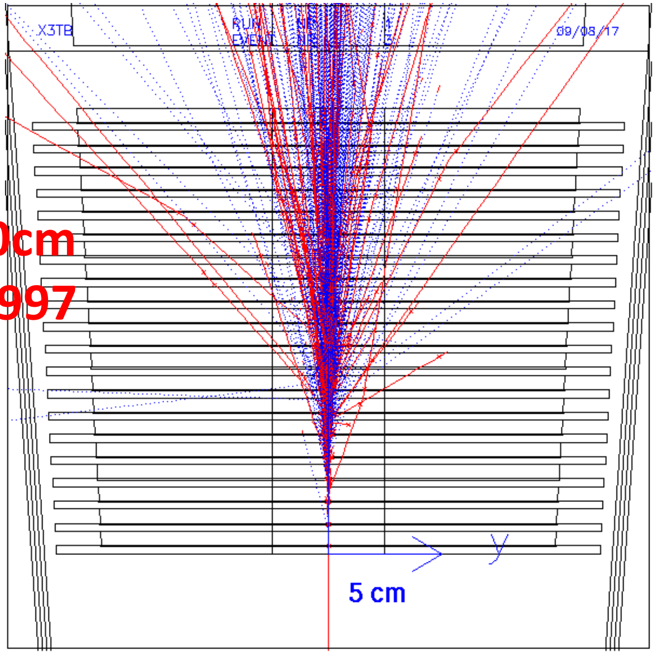
# LumiCal simulation

- **TPC cone**: θ=126.6 mRad (cosθ=.992)
  **Fe 0.5 cm**
  scintillators on surfaces detecting charged hits
- **DQ0 support**: Fe=100 cm tube, behind LumiCal

- **TUBE SiW**: 20 decks of tubes
  **W: 0.35 cm** ($1X_0$), **r = 2.5 - 10 cm**
  **Airgap: 0.2 cm**
  **Si: 0.03 cm thick**, r = 2.5 - 10 cm

- **CONE SiW**: 20 decks of **cones**
  **W: 0.35 cm** ($1X_0$), front **r = 2.5 - 10 cm @z=100cm**
  **Airgap: 0.2 cm** **outer edge radially to IP, θ=.997**
  **Si: 0.03 cm thick**, front r = 2.5 - 10 cm

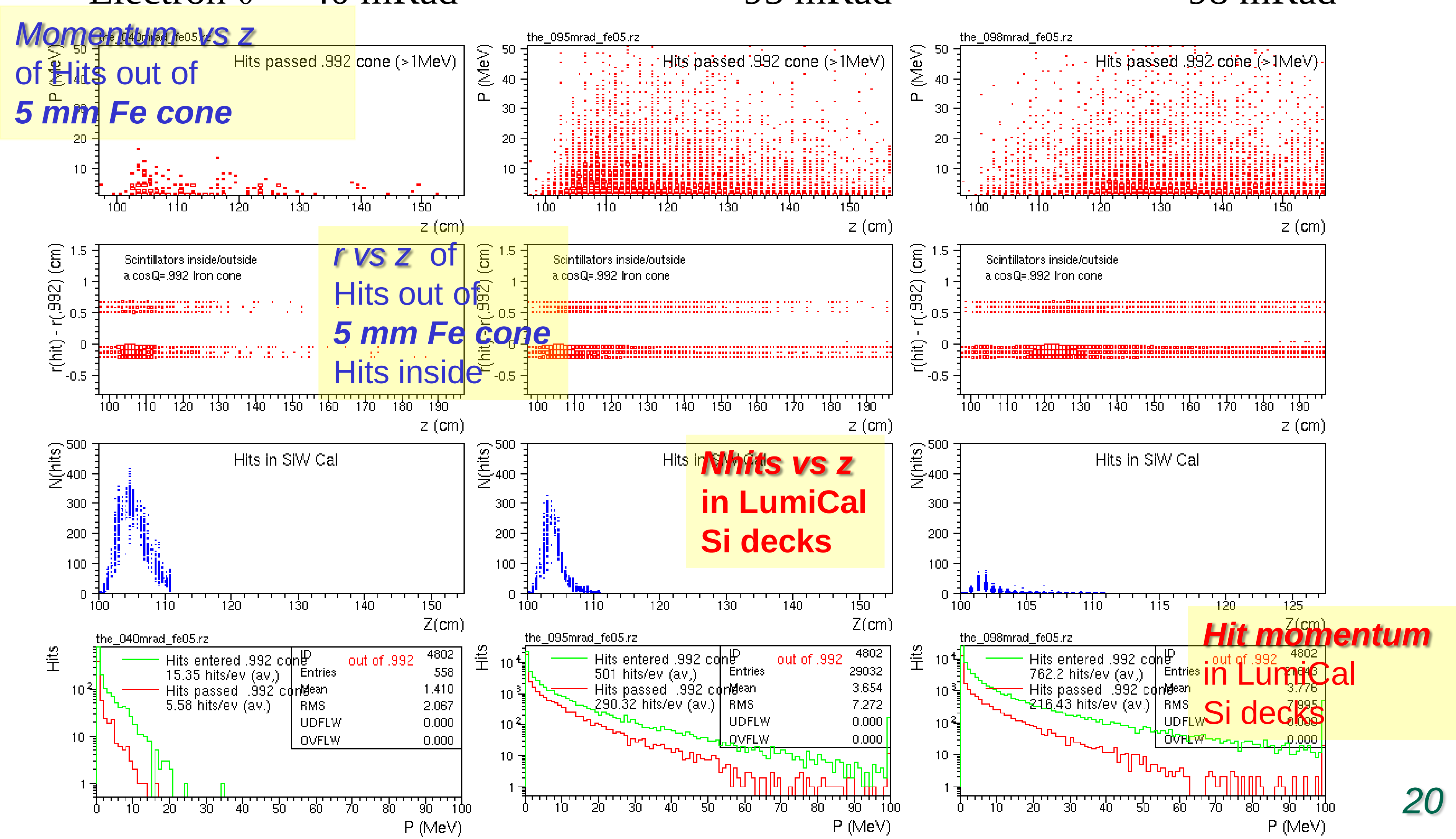


# "TUBE" LumiCal shower leak distribution

50 GeV electron shower, reaching the outer Fe cone (5mm) at θ=.992

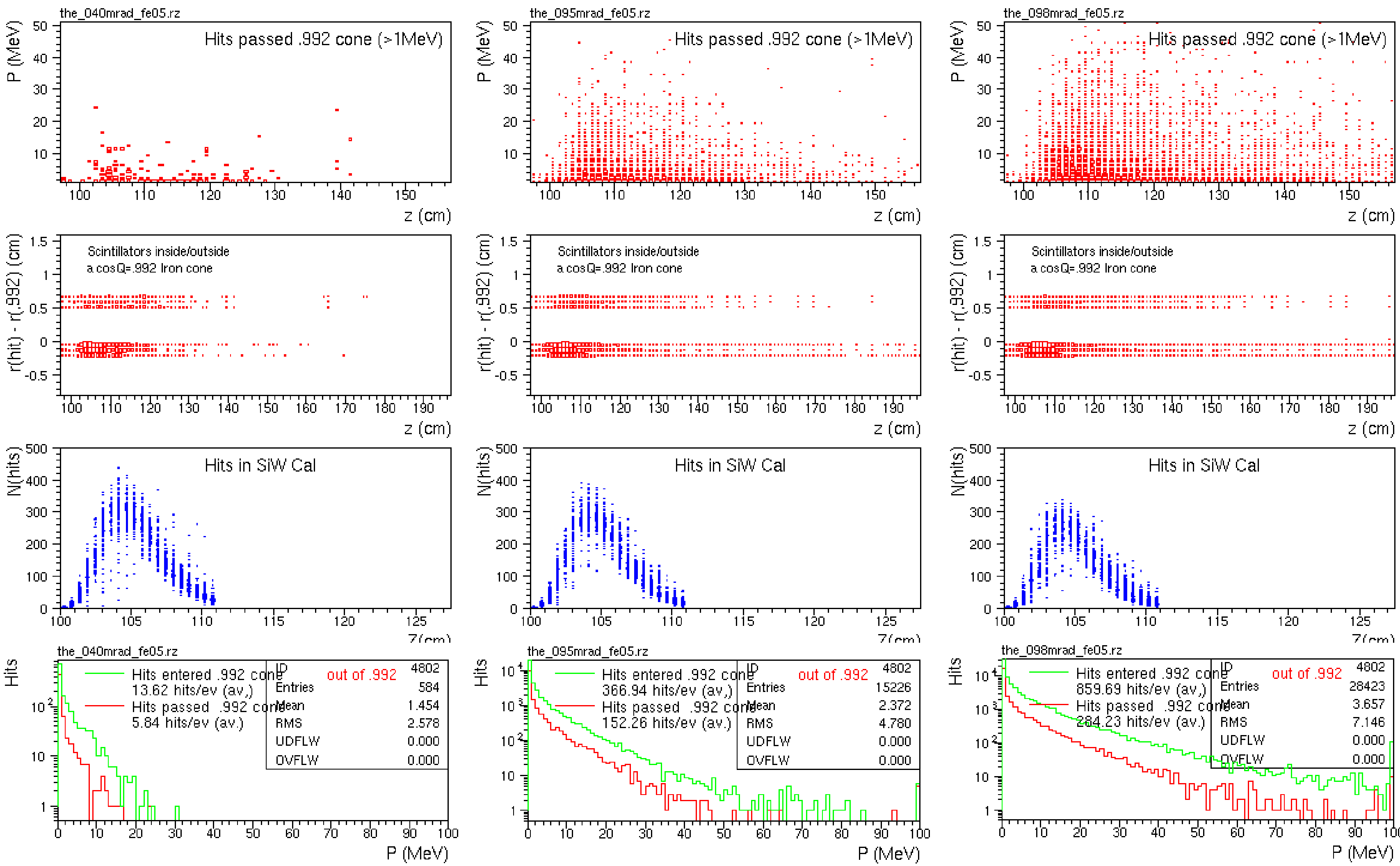
Electron θ= 40 mRad 95 mRad 98 mRad



# "CONE" LumiCal shower leak distribution

50 GeV electron shower, particles off Calo to outer cone at θ=.992

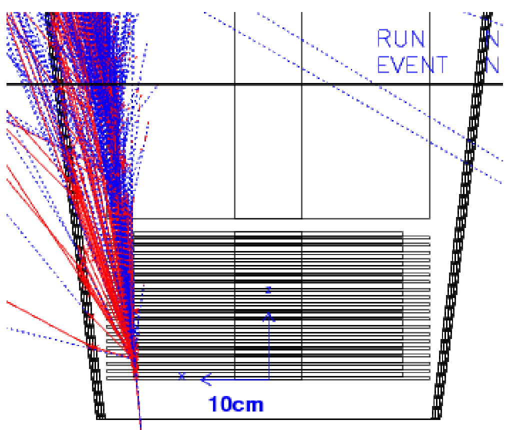
Electron θ= 40 mRad 95 mRad 98 mRad

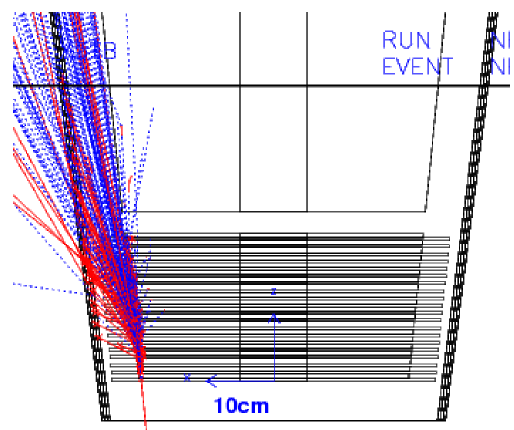


# 50GeV electron shower leak vs theta

Simulate 50 GeV electron from IP at fixed theta
Shower leakage are mostly low energy < 100 MeV particles

| 50 GeV electron | average events enter/pass 5 mm Fe cone at 0.992 Rad | |
|---|---|---|
| electron θ (mRad) | TUBE LumiCal N(enter) /N(pass) | CONE LumiCal N(enter) /N(pass) |
| 40 | 15.4 / 5.6 | 13.6 / 5.8 |
| 90 | 392 / 155 | 173 / 76 |
| 95 | 501 / 290 | 367 / 152 |
| 98 | 762 / 216 | 860 / 284 |
| 99 | 553 / 140 | 1331 / 367 |

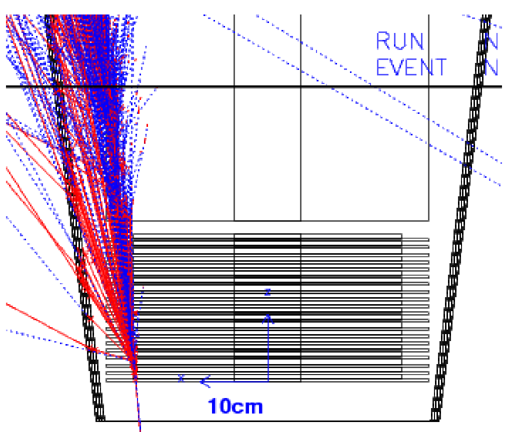


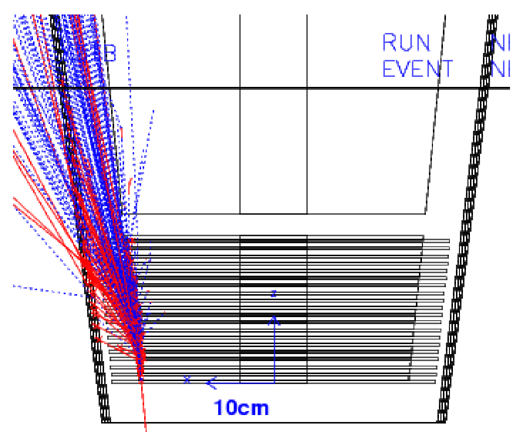



# 125GeV electron shower leak vs theta

Simulate 125 GeV electron from IP at fixed theta
Shower leakage are mostly low energy < 100 MeV particles

| 125 GeV electron | average events enter/pass 5 mm Fe cone at 0.992 Rad | |
|---|---|---|
| electron θ (mRad) | TUBE LumiCal N(enter) /N(pass) | CONE LumiCal N(enter) /N(pass) |
| 40 | 38.0 / 16.0 | 35.8 / 14.7 |
| 90 | 1028 / 399 | 434 / 19 7 |
| 95 | 2389 / 720 | 937 / 382 |
| 98 | 1718 / 473 | 2176 / 725 |
| 99 | 1102 / 273 | 3306 / 915 |



# Summary

1. Luminosity of Bhabha counting is demanded to $\delta L/L$ **~ *0.1%***
   wtih Si Strip to reach $\boldsymbol{r_{inner}}$ to resolution ***<10 μm***

   A "floating LumiCal" has unknown systematics on $\boldsymbol{r_{inner}}$

   By adding electron tracking to calibrate
   "mean of $\boldsymbol{r_{inner}}$" to ***1 μm*** → ***to reach*** $\delta L/L$ **~ *0.01%***

2. Beam crossing boosts electrons and
   → loss of event requiring both $e^+$, $e^-$ detected by LumiCal
   → smaller $\boldsymbol{r_{inner}}$ ***of LumiCal*** is demanded for ***σ> 50 nb***

3. Shower leakage is **~ *1k*** secondaries, mostly *<100 MeV*
   to TPC