SiD LumiCal Design and Simulation

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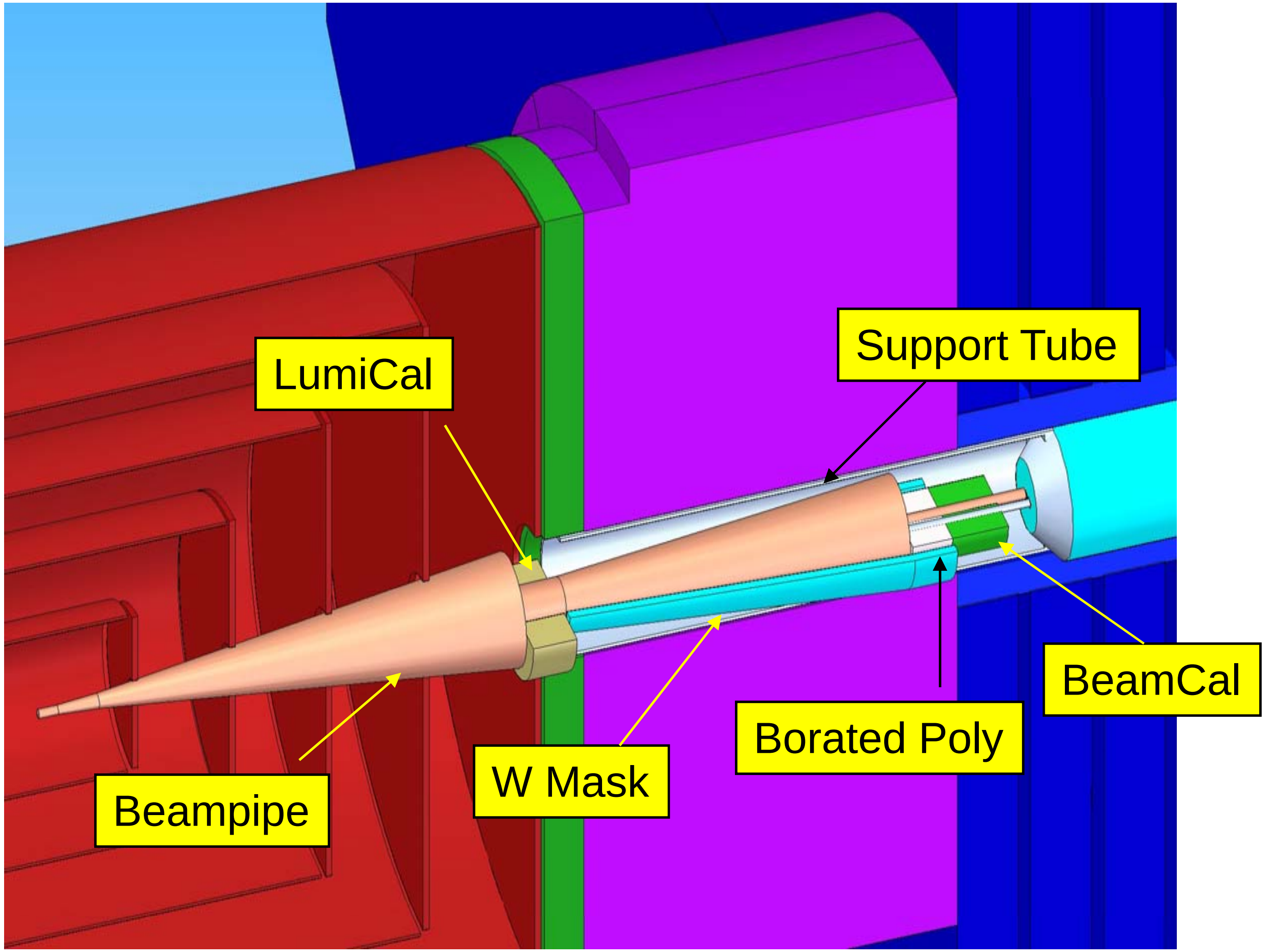
Introduction

- Silicon-Tungsten sampling calorimeter is a mature technology.
- Luminosity calorimeter (LumiCal) based on this technology can achieve high precision.
  - **OPAL $\Delta L/L=3.4\times10^{-4}$**
- Will describe the SiD version of LumiCal
  - **ILC 500 GeV Nominal beam parameters**
  - **14 mrad crossing angle**
  - **5 Tesla solenoid + Anti-DID field**

SiD Forward Region

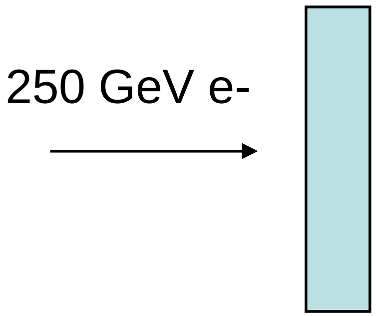


LumiCal related issues

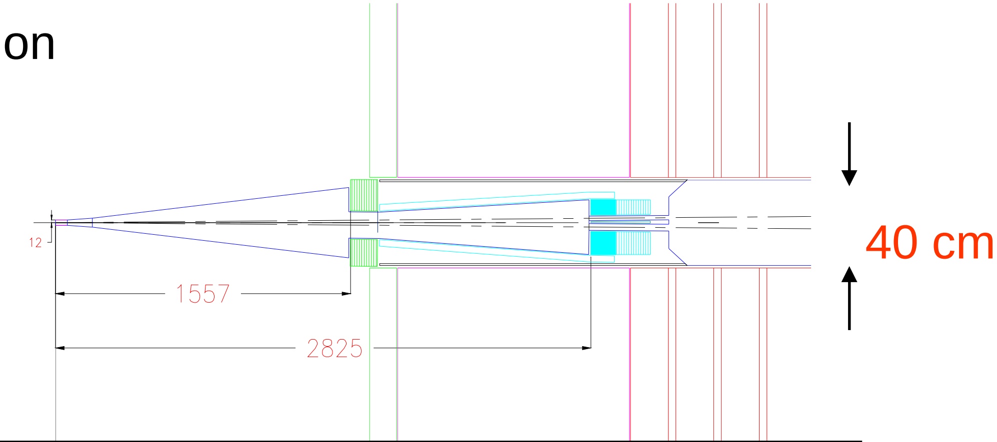
- Geometry
  - **Location and angular acceptance**
  - **Centered on the outgoing beam**
  - **Beampipe**
- Energy resolution
  - **Tungsten thickness and no. of layers**
  - **ECAL 20 layers (2.5mm)+10 layers (5.0mm)**
- Luminosity precision goal and sensor segmentation
- Electronics dynamic range
  - **MIP sensitivity**
- Occupancy
  - **Bhabha event rate**
  - **Pairs, ee+had, eeμμ**

Simulations

- EGS
  - **Simple geometry**
  - **Study EM shower characteristics**
- FLUKA
  - **Forward region geometry**
  - **LumiCal simulation**
    - OPAL r-ϕ segmentation

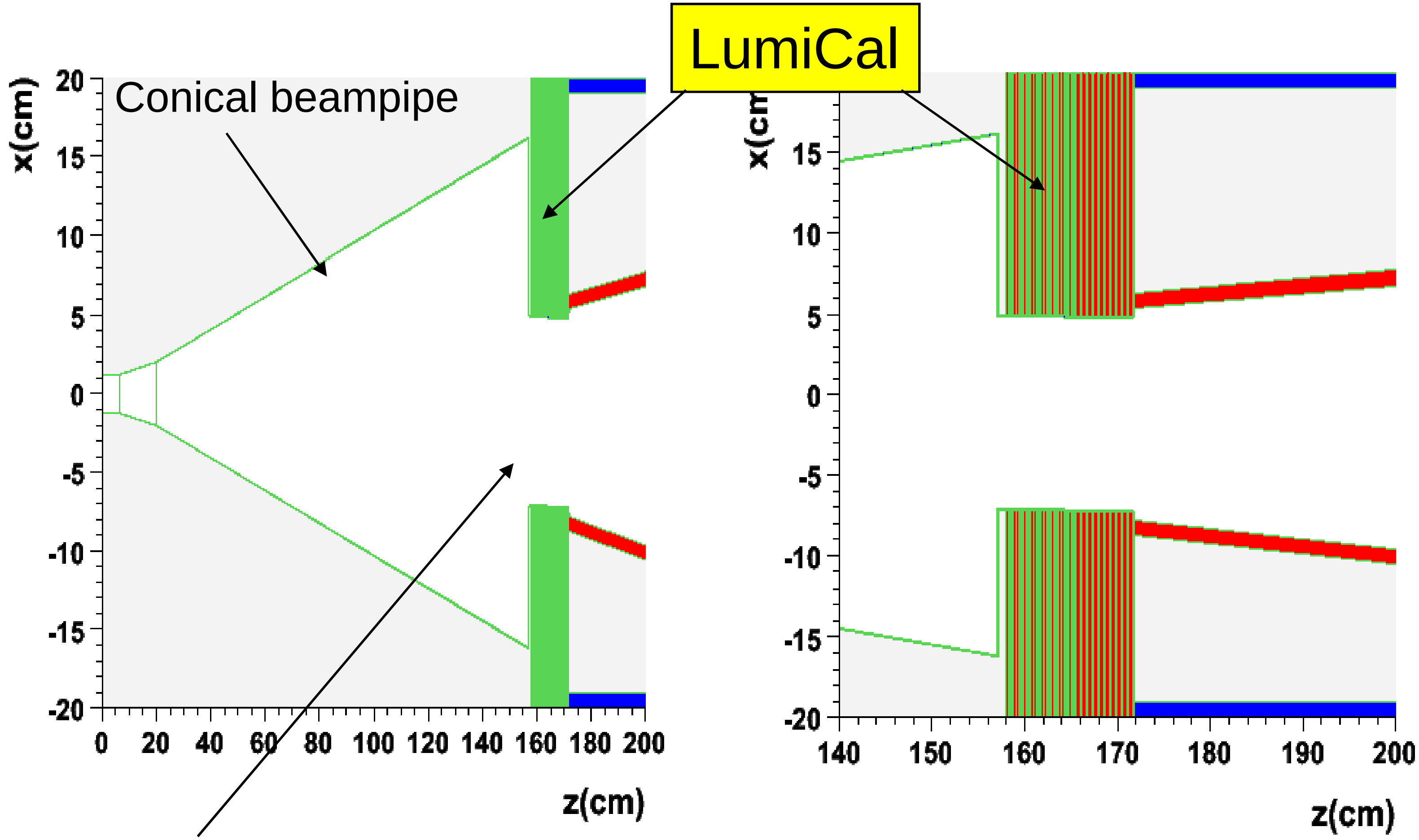


30 ~ 50 layers of
W +
Si (0.032 cm) +
G10 (0.068 cm) +
Air (0.025 cm)



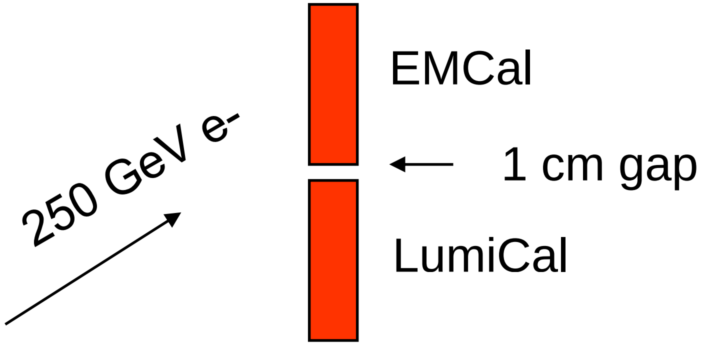
LumiCal / W Mask / BeamCal centered on out beam

FLUKA Geometry

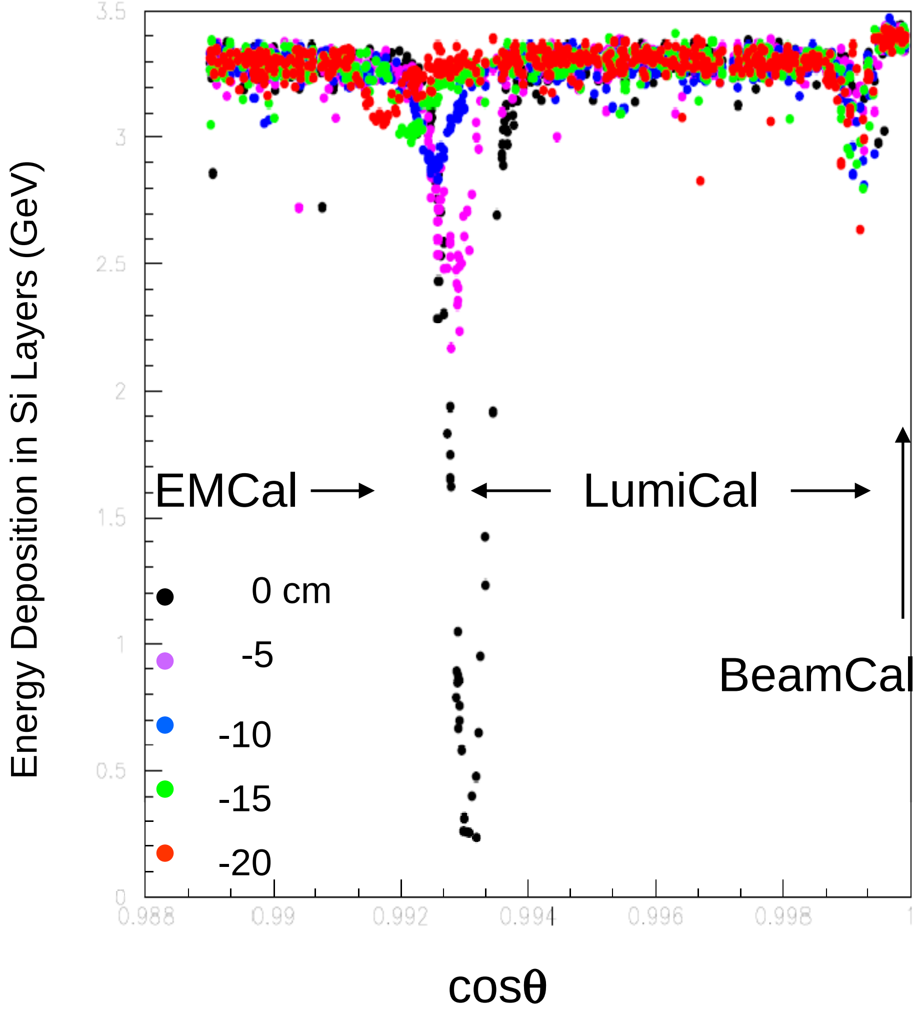


R=6 cm hole displaced by x=-158 cm * 0.007 and centered on out beam

LumiCal Z-location



- Move LumiCal ~10 cm w.r.t. EMCal



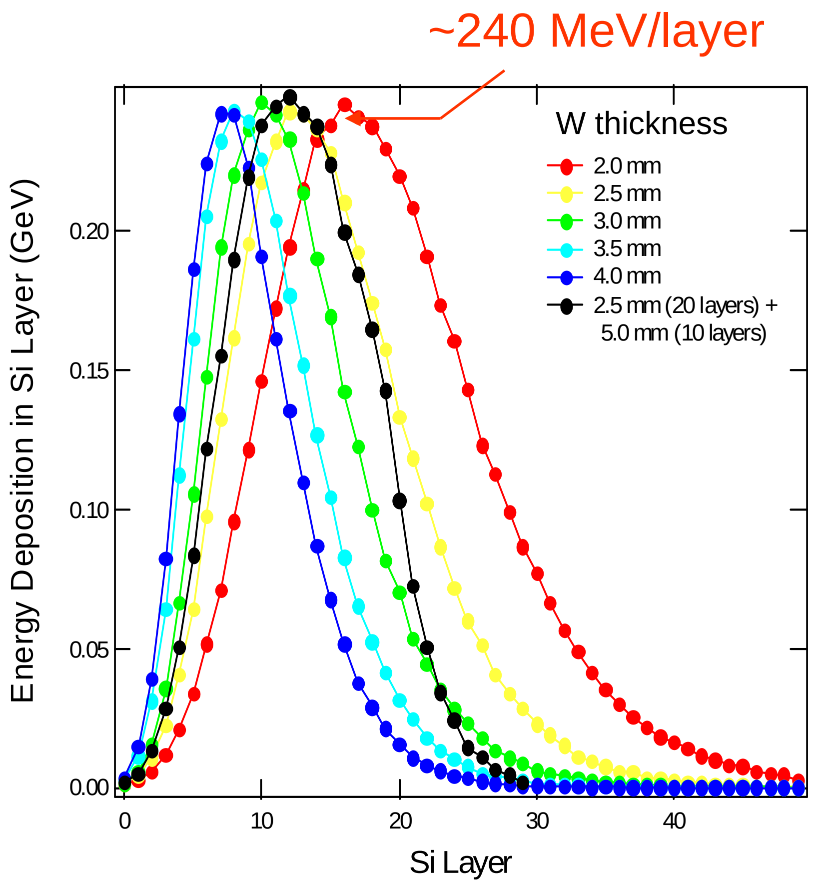
Energy Deposition in Si Layers

250 GeV e- normal incident

- Energy containment

W Thickness (mm)	No Layers
2.0	50
2.5	40
3.0	35
3.5	30
4.0	25

- 20 lyrs of 2.5mm + 10 lyrs of 5.0mm is good.
- Shower max.
  - **Layer #13 is shower max for 2.5 mm W**



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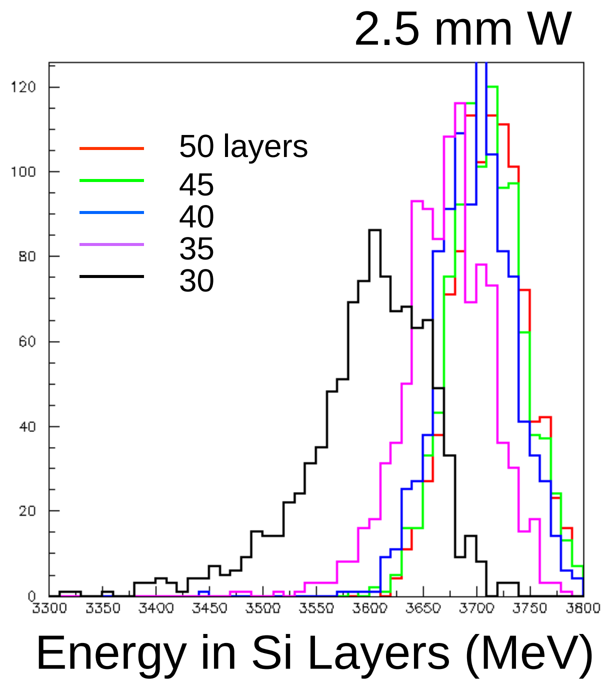
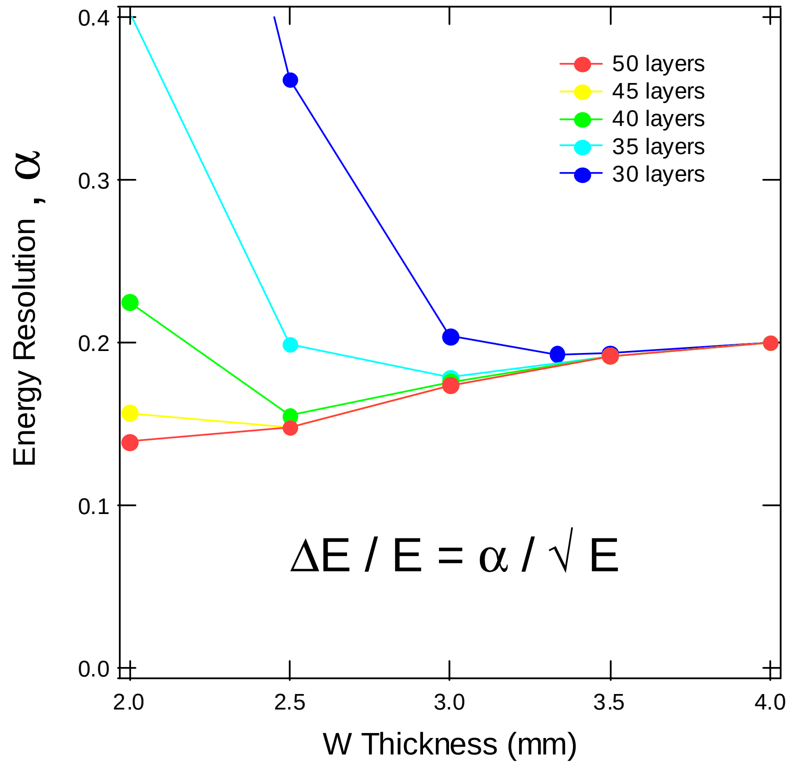
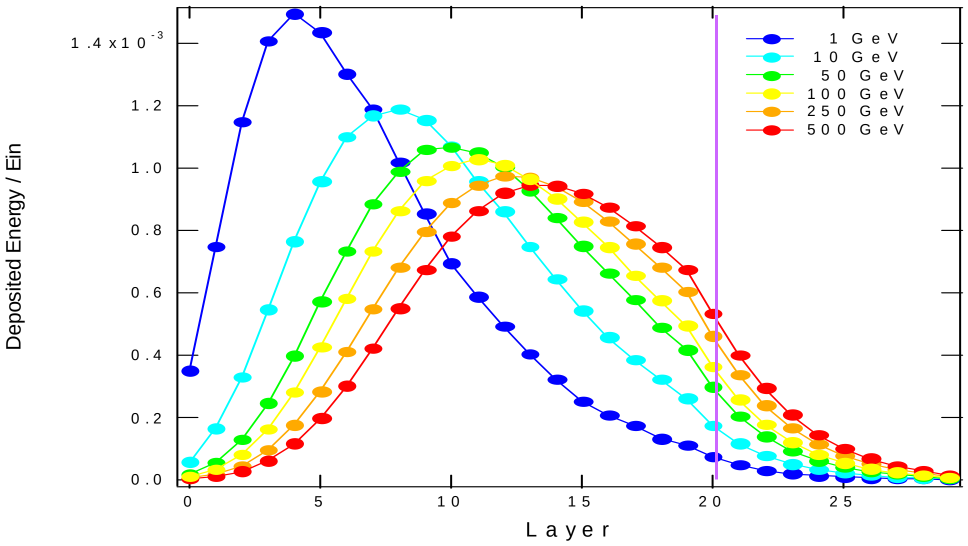


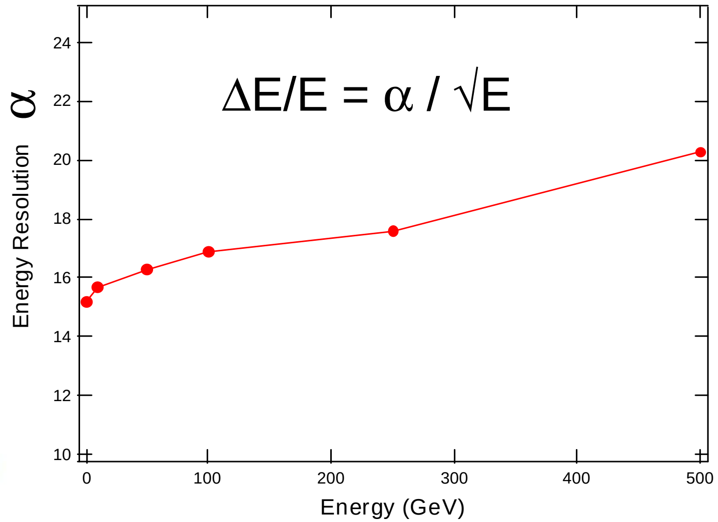


- **Energy resolution improves as W gets thinner.**
- **As long as the energy containment is satisfied.**
- **20 lyrs of 2.5mm + 10 lyrs of 5.0mm yields an optimum resolution for 30 layers.**

More on 20 lyrs (2.5mm)+10 lyrs (5.0mm)

- Energy resolution parameter is dependent on energy
  - **15%/√E at low energy**
  - **20%/ √E at high energy**
- Energy leakage is small even at 500 GeV.





Good configuration for the LumiCal

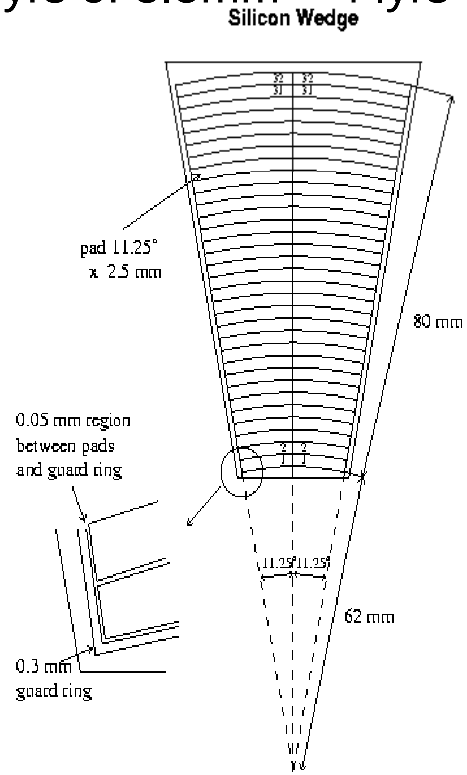
Luminosity measurement

- Luminosity precision goal $\Delta L / L < 10^{-3}$
  - **10^6 W^+W^- events in 5 years (500 fb^{-1})**
- $\Delta L/L = (N_{rec} - N_{gen})/N_{gen}$
  - **Bhabha $d\sigma/d\theta \sim 1/\theta^3$**
  - **$\Delta L/L \sim 2\, \Delta\theta/\theta_{min}$, $\Delta\theta$ is a systematic error.**
- $\Delta\theta$ must be less than ~20μrad to reach $\Delta L/L = 10^{-3}$.
  - **Detector radial location must be know within 30μm.**

LumiCal simulation

- Segment Si layer equally into Δr and $N\phi$, perfect alignment and no dead space.
- Non-projective geometry
  - **Same detector in depth-wise**
- Collect dE/dX in each channels.
- Output lyr, ir, iphi, edep.
- Reconstruct θ_{rec} and compare with θ_{gen}

OPAL Luminometer:
14 lyrs of 3.5mm + 4 lyrs of 7.0mm

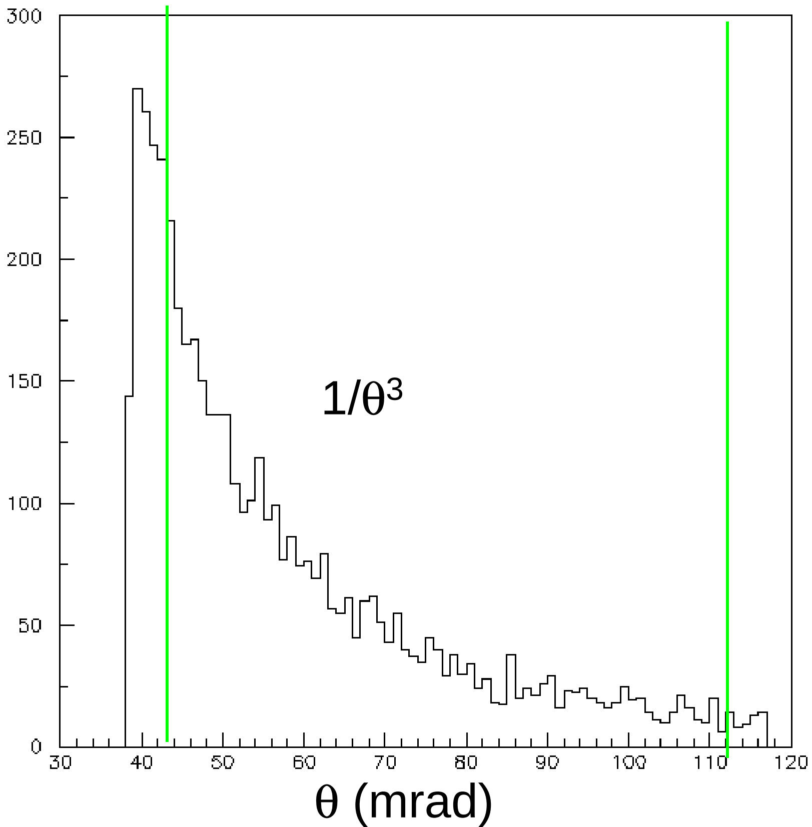


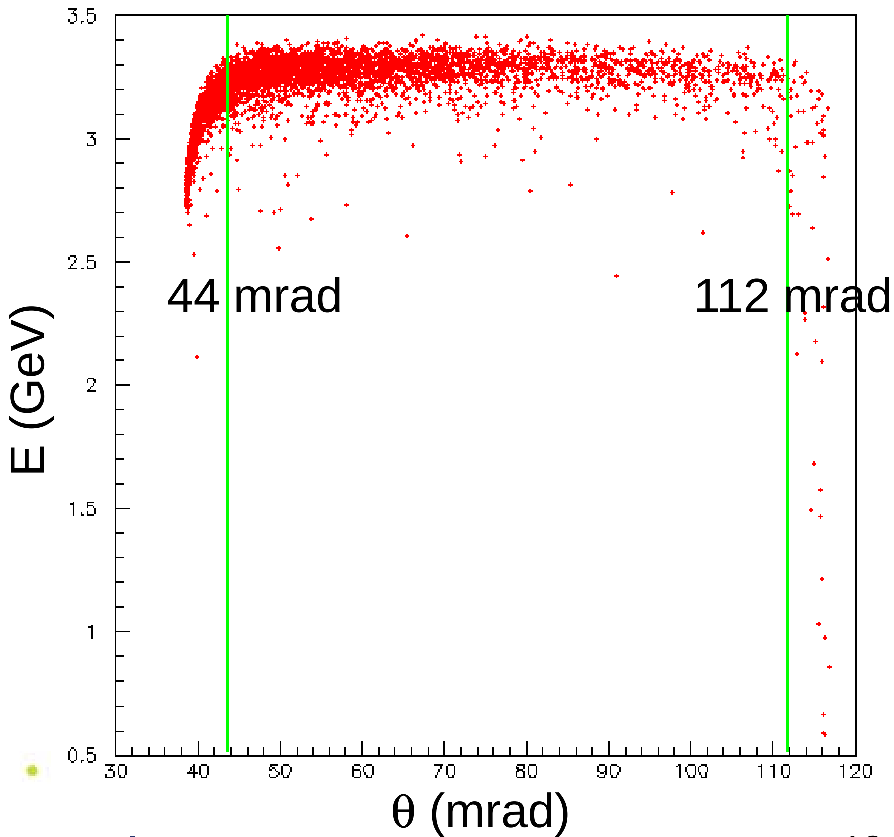
R-ϕ segmentation
Δr = 2.5 mm
$\Delta\phi$ = 11.25° (=360°/32)

OPAL achieved $\Delta L/L = 3.4 \times 10^{-4}$

250 GeV Pseudo-Bhabha events

- Although good Bhabha generator is available, real Bhabha events obscure the angular resolution issue.
  - **Bhabhas need to be separated from radiative Bhabhas.**
  - **Shower finder needs to be optimized for different segmentation.**
- Genetate 250 GeV e- with $1/\theta^3$ distribution





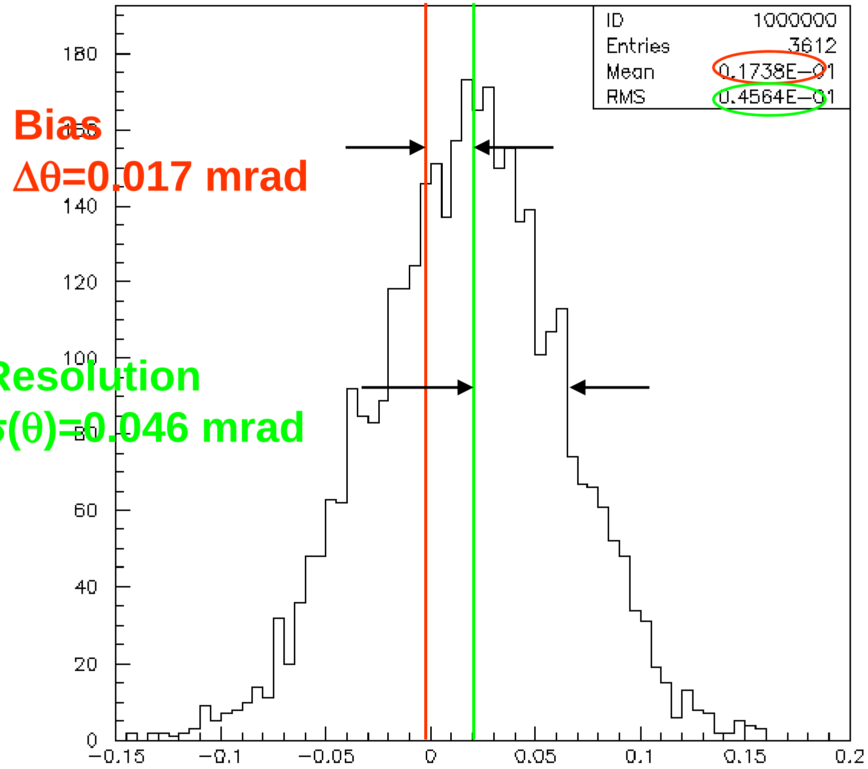
Angular resolution and bias

$$\theta = \frac{\sum w_i \theta_i}{\sum w_i}$$

W_i = Log energy weight*

Max{0, const.+ln(E_i/E_{tot})}

Δr=2.5mm, Nφ=32



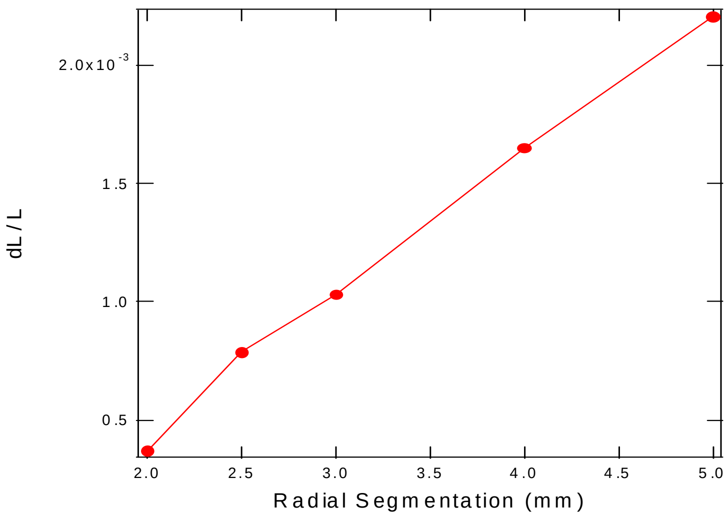
θ(rec) – θ(gen) (mrad)

* Linear energy weight is much worse.
Awes et al, NIM A311, 130 (1992)

ΔL/L vs. segmentation

Radial segmentation $N\phi = 32$

Δr (mm)	Δθ (mrad)	σ(θ) (mrad)	ΔL/L
2.0	0.008	0.042	3.3×10^{-4}
2.5	0.017	0.046	7.9×10^{-4}
3.0	0.023	0.050	1.0×10^{-3}
4.0	0.036	0.058	1.7×10^{-3}
5.0	0.049	0.069	2.2×10^{-3}



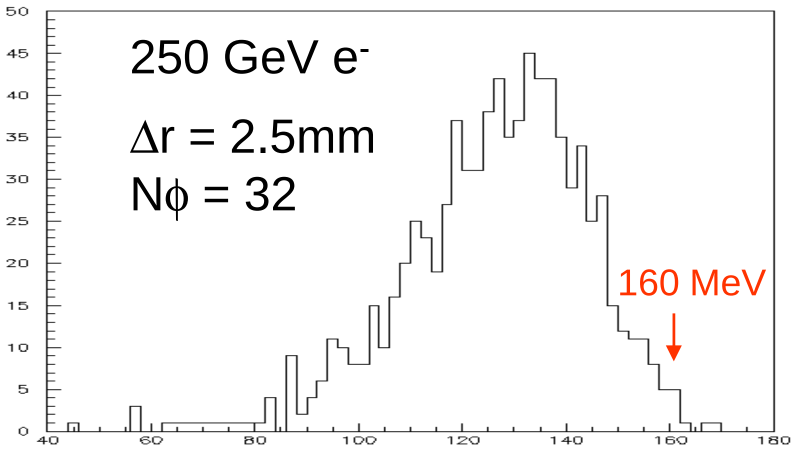
ϕ segmentation   Δr = 2.5 mm

Nϕ	Δθ (mrad)	σ(θ) (mrad)	ΔL/L
16	0.017	0.046	7.7×10^{-4}
32	0.017	0.046	7.9×10^{-4}
48	0.017	0.045	7.6×10^{-4}
64	0.014	0.045	6.6×10^{-4}

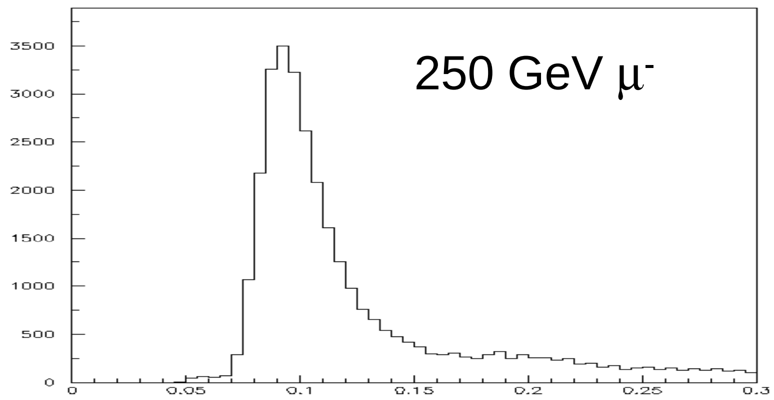
- $\Delta L / L < 10^{-3}$ can be reached by $\Delta r <$ 3mm.
- Finer ϕ segmentation helps, but not much.
  - **Finer ϕ segmentation will help shower separation.**

Max Energy Deposition in Si channel

- Max energy deposition
  - **160 MeV (7010 fC*)**
- MIP
  - **MPV~0.0925 MeV (4.1 fC)**
- Bhabha ~ 1710 MIP
- If we want S/N ~ 10 for MIP, we need 17,000 dynamic range.
  - **2 gains + 10 bit ADC**



Max Energy Deposition (MeV)



Energy Deposition (MeV)

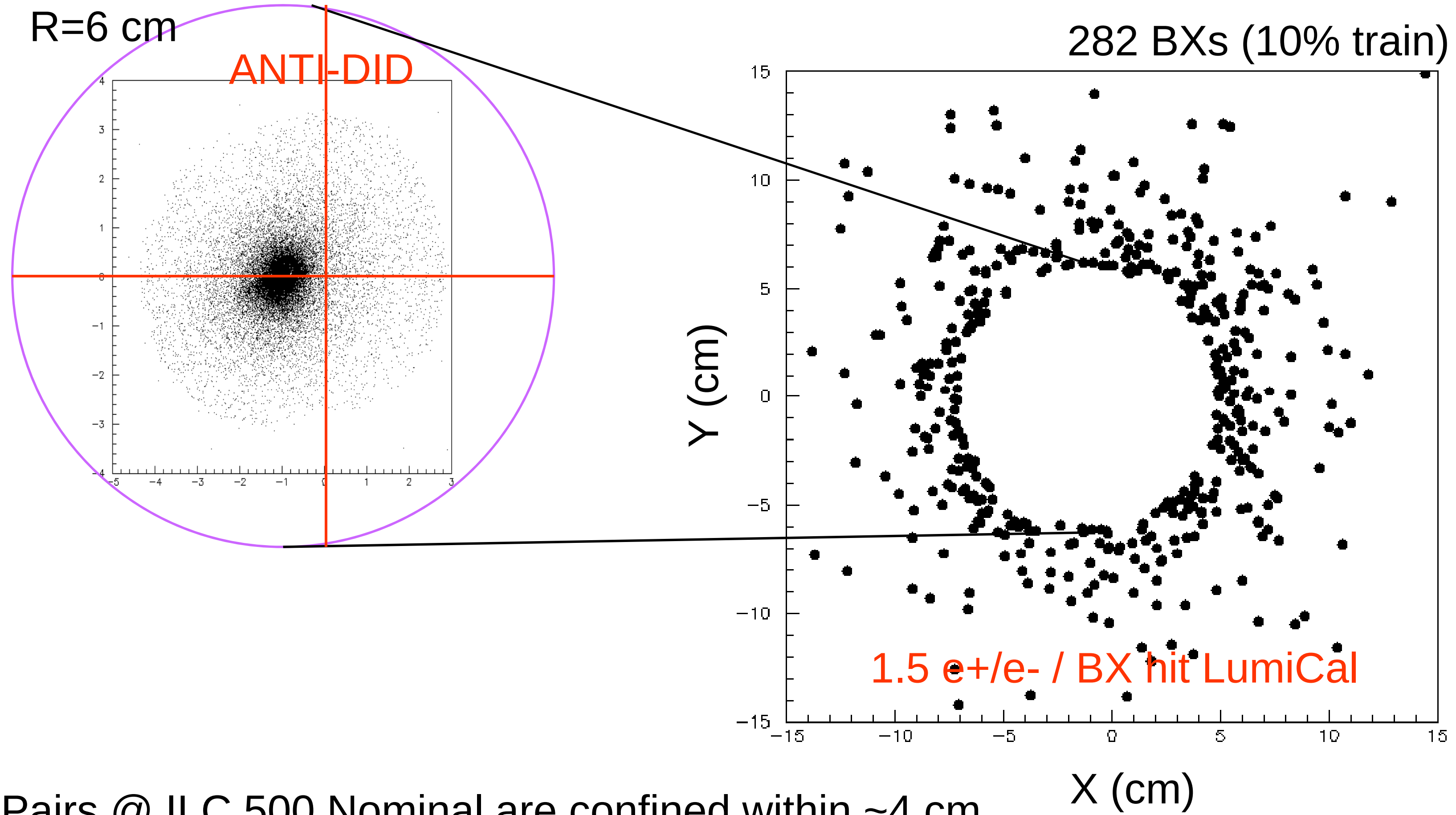
KPiX (2 gains + 13 bits) can handle it.

* 3.65 eV to generate e-h pair

Occupancy

- Bhabha event rate
  - **N_{ev} per BX @ILC 500 Nominal=**
    $5.9\ [1/\theta^2_{min} - 1/\theta^2_{max}]$ (θ in mrads)
  - **7 ev/train for θ_{min}=44 mrad, θ_{max}=112 mrad**
- Backgrounds
  - **Pairs**
  - **$\gamma\gamma\rightarrow$hadrons**
  - **$\gamma\gamma\rightarrow\mu\mu$**

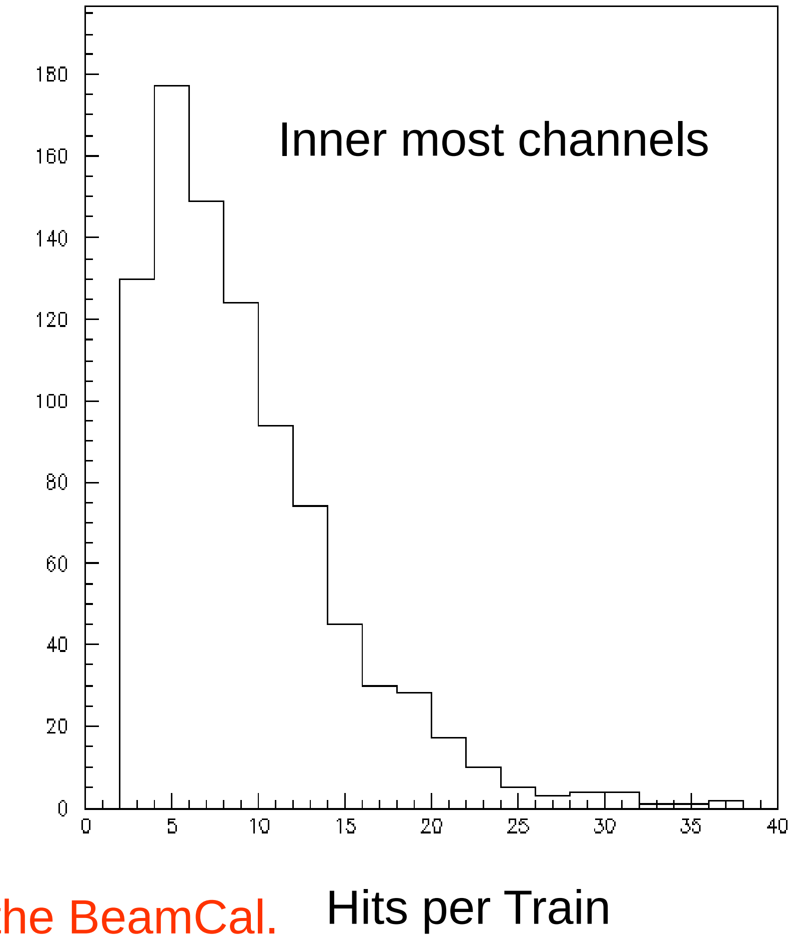
Pairs in LumiCal



Pairs @ ILC 500 Nominal are confined within ~4 cm.
However, there are pairs outside the ring of death,
and >4000 e+/e-/train hit the LumiCal.

Pair occupancy in LumiCal

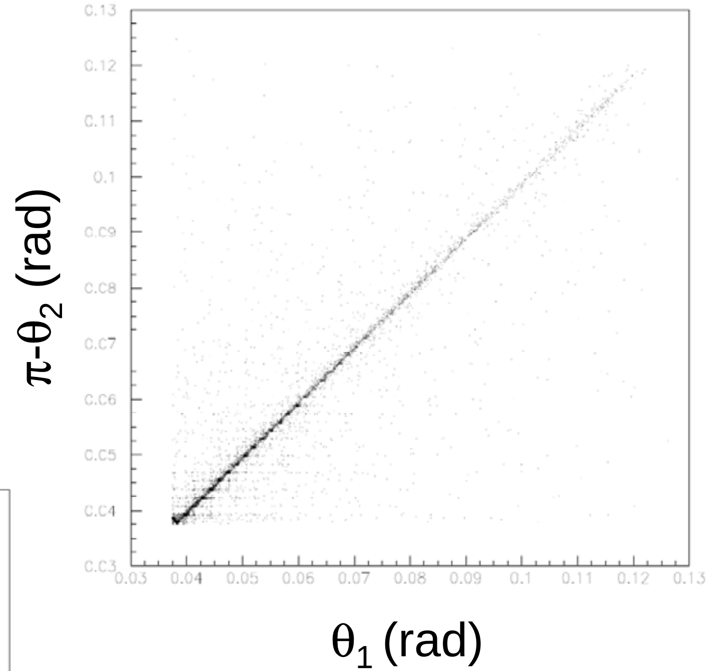
- 1.5 e+/e- / BX reaching LumiCal
- Hits are mostly in the front ~10 layers.
- Inner most channels have more than 4 hits.

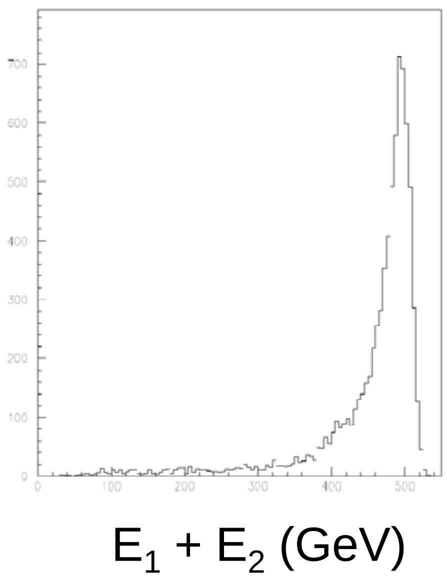


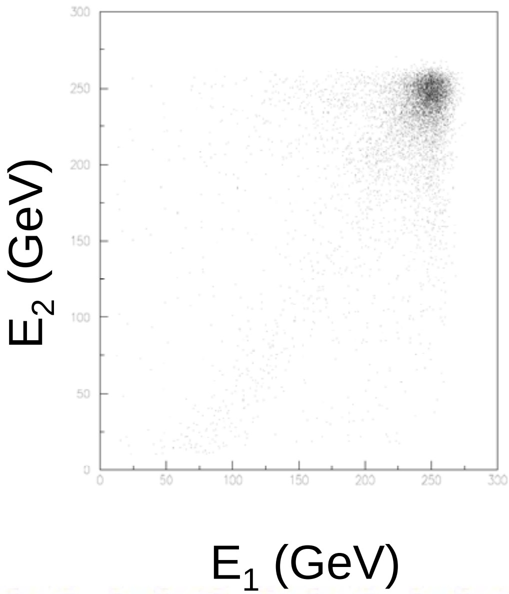
KPiX has only 4 buffers.
Need FCAL chip being developed for the BeamCal.

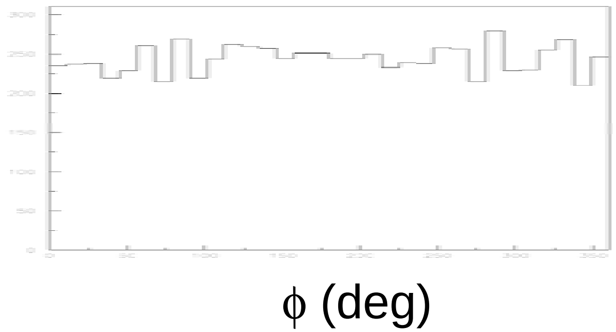
Bhabha events in LumiCal

- BHWIDE to generate Bhabha events
- Move to 14 mrad crossing angle
- Simulate LumiCal response
- Reconstruct showers
- Move to CM system
- Look at the distributions



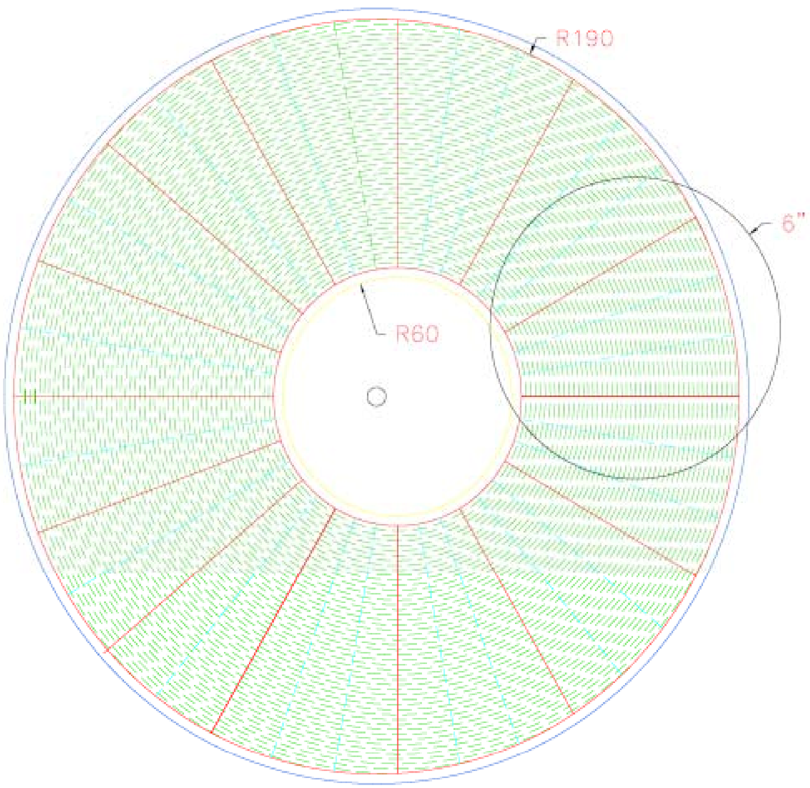






LumiCal sensor design

- Based on 6" wafer.
- The inner radius centered on the out-beam, while the outer radius on the detector.
- 14 petals are all different; need different Masks.
- $\Delta r = 2.5$ mm, $\Delta\phi = 10°$
- Radial division varies from 46 to 54 channels.
- Non-projective geometry; same sensors in depth-wise.



Summary

- LumiCal design has been developed for the SiD detector.
- Luminosity precision less than 10^{-3} can be reached with a radial pitch less than 3 mm.
- Pair occupancy can reach 40 hits / train
- Bhabha events are analyzed under the 14 mrad crossing angle configuration.
- Si sensors can be made from 6” wafer.