Design of the Forward Region and the Effect of the Shape of the Beampipe on the Luminosity Measurement

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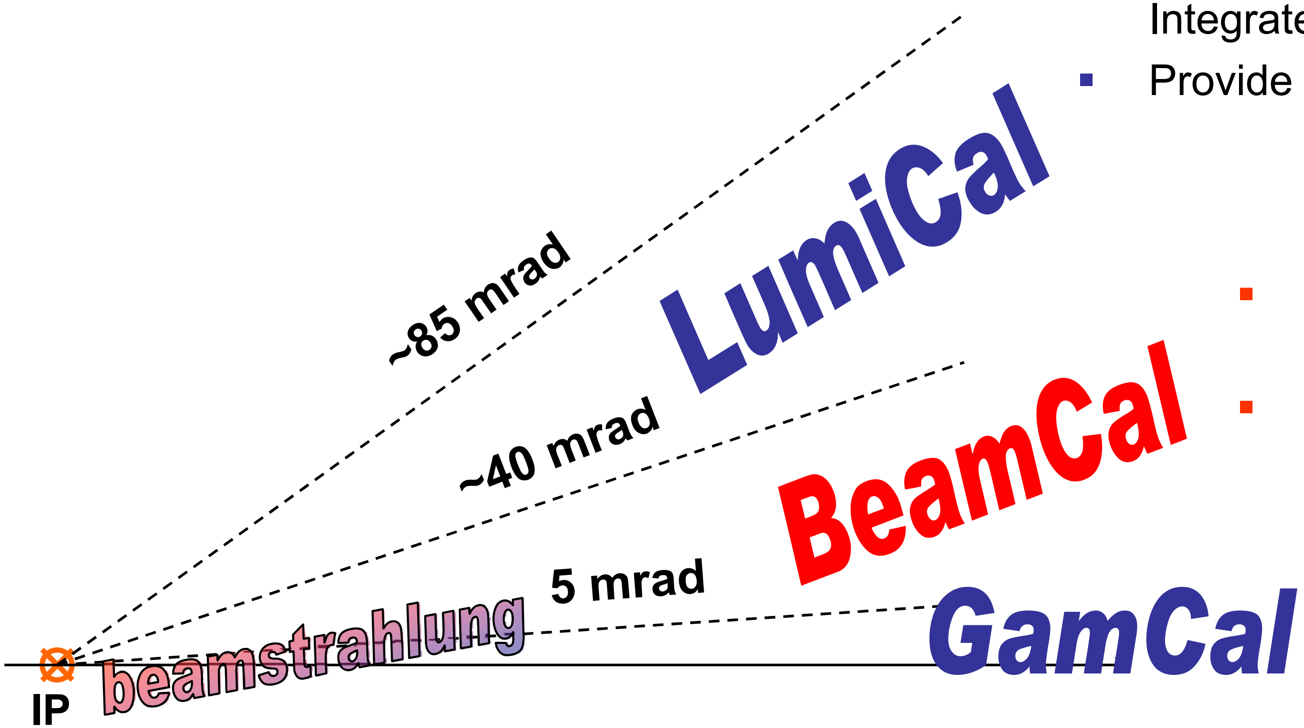
Layout of the Forward Region

ECal and Very Forward Tracker acceptance region.



- Precise measurement of the Integrated Luminosity ($\Delta L/L \sim 10^{-4}$).
- Provide 2 photon veto.

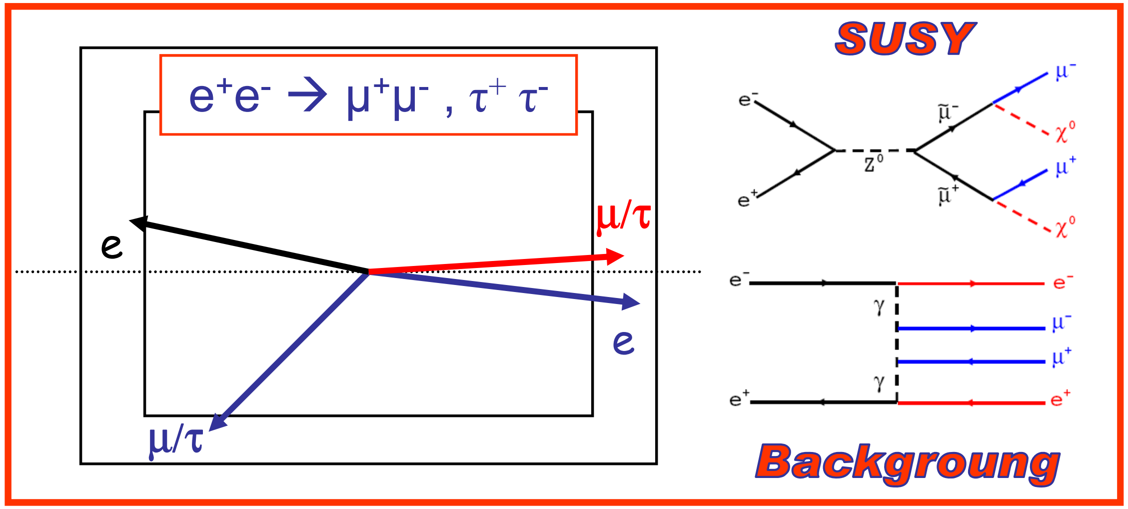
- Beam-Diagnostics using beamstrahlung pairs.
- Provides 2 photon veto.

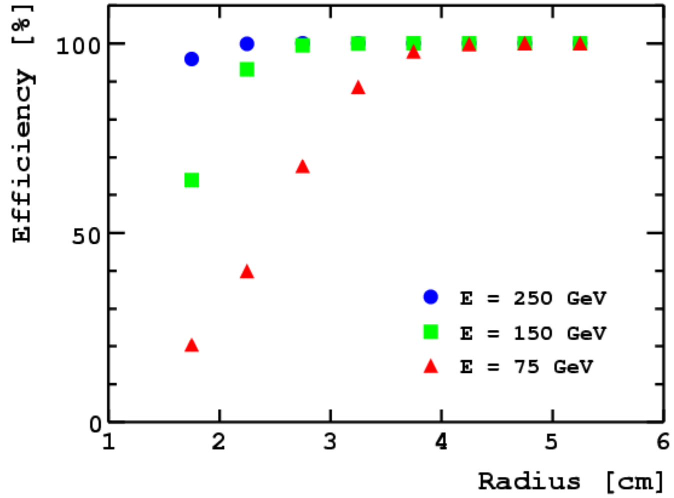
- Beam-Diagnostics using beamstrahlung photons.

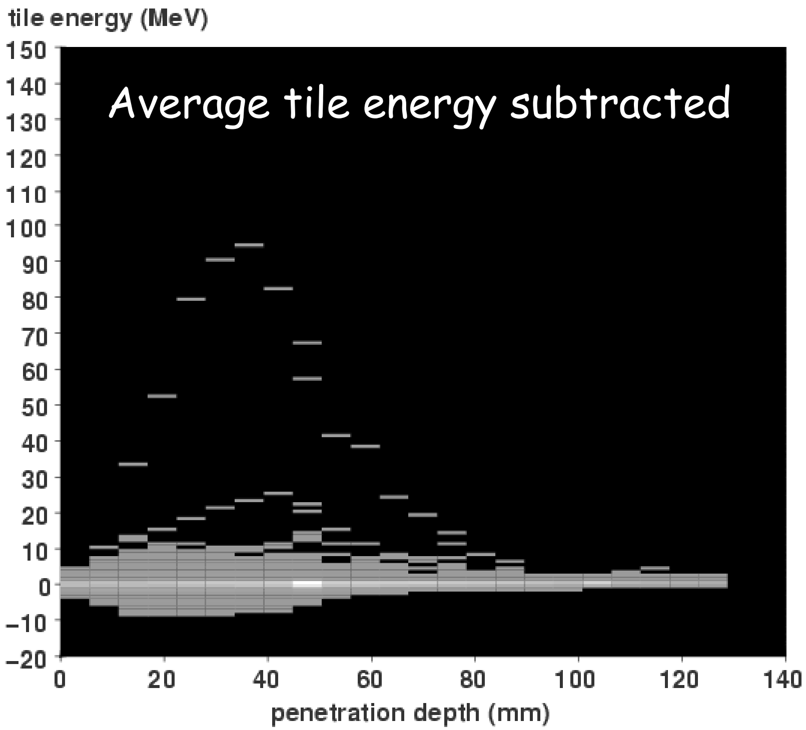
Challenges:

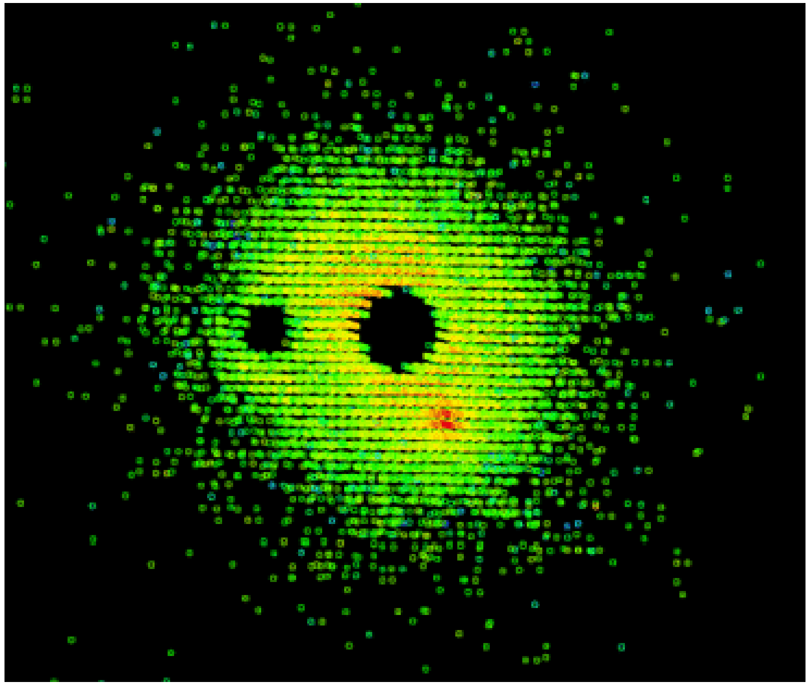
High precision, high occupancy,
high radiation dose, fast read-out!

BeamCal electron veto





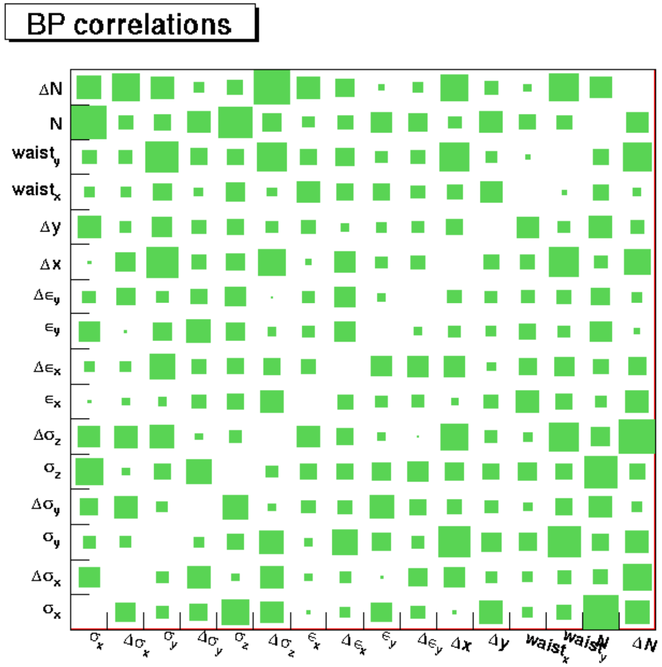




BeamCal beam diagnostics

- **Beam parameters:**

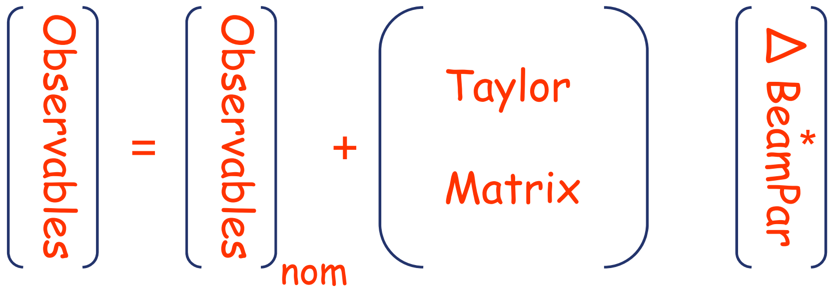
  beam sizes (σx, σy and σz)
  emittances (εx and εy)
  offsets (Δx and Δy)
  waist shifts (wx and wy)
  angles and rotation (αh, αv and φ)
  Particles per bunch (Nb)



- **Observables:**

  total energy
  first radial moment
  thrust value
  angular spread
  E(ring ≥ 4) / Etot
  r-φ observables T1, T2
  E / N
  l/r, u/d, f/b asymmetries

Moore Penrose Method

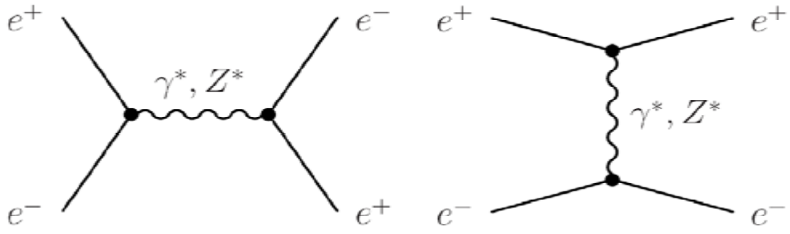


"Diagnostics of Colliding Bunches from Pair Production and Beam Strahlung at the IP"
– Achim Stahl (LC-DET-2005-003)

LumiCal performance requirements

1. Required precision is:
$$\frac{\Delta L}{L} \sim 10^{-4} \quad , \quad \text{GigaZ (hadronic Z decays)} \quad 10^{9}\ /\ \text{year}$$
$$\frac{\Delta L}{L} \sim 10^{-3} \quad , \quad e^{+}e^{-} \rightarrow W^{+}W^{-} \quad 10^{6}\ /\ \text{year}$$
$$\frac{\Delta L}{L} \sim 10^{-3} \quad , \quad e^{+}e^{-} \rightarrow q^{+}q^{-} \quad 10^{6}\ /\ \text{year}$$

2. Measure luminosity by counting the number of Bhabha events (N_B):

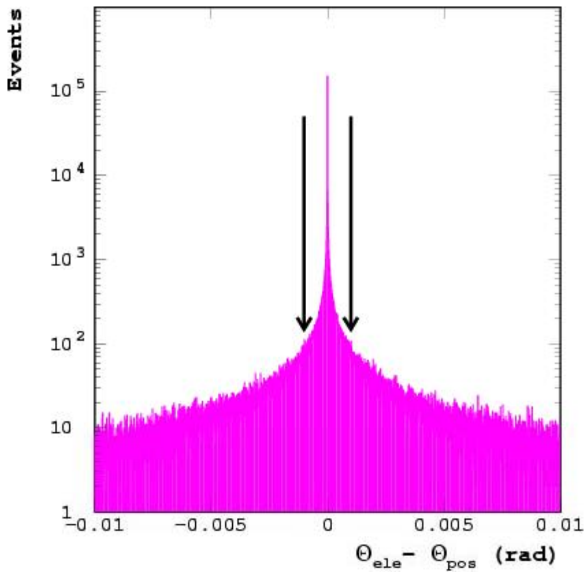


(a) s channel (b) t channel

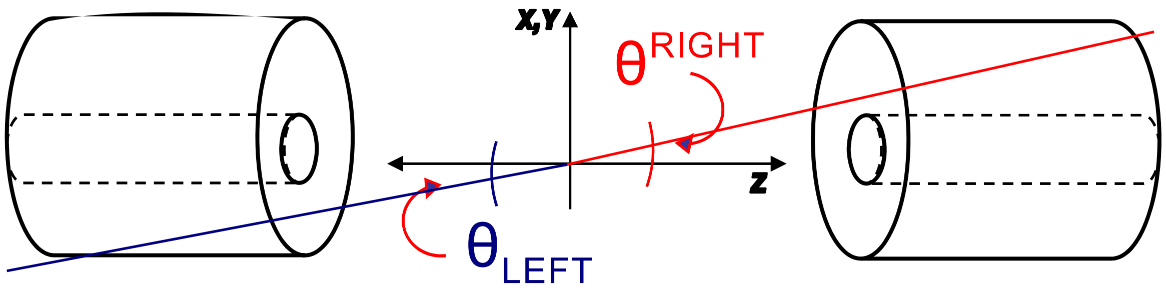
$$\frac{d\sigma_B}{d\theta} \propto \frac{1}{\theta^3}$$

$$L = \frac{N_B}{\sigma_B} \quad , \quad \frac{\Delta L}{L} = \frac{\Delta N_B}{N_B} = \left. \frac{N_{rec} - N_{gen}}{N_{gen}} \right|_{\theta_{min}}^{\theta_{max}}$$

Selection cuts for Bhabha events



Compare Angles & Energy



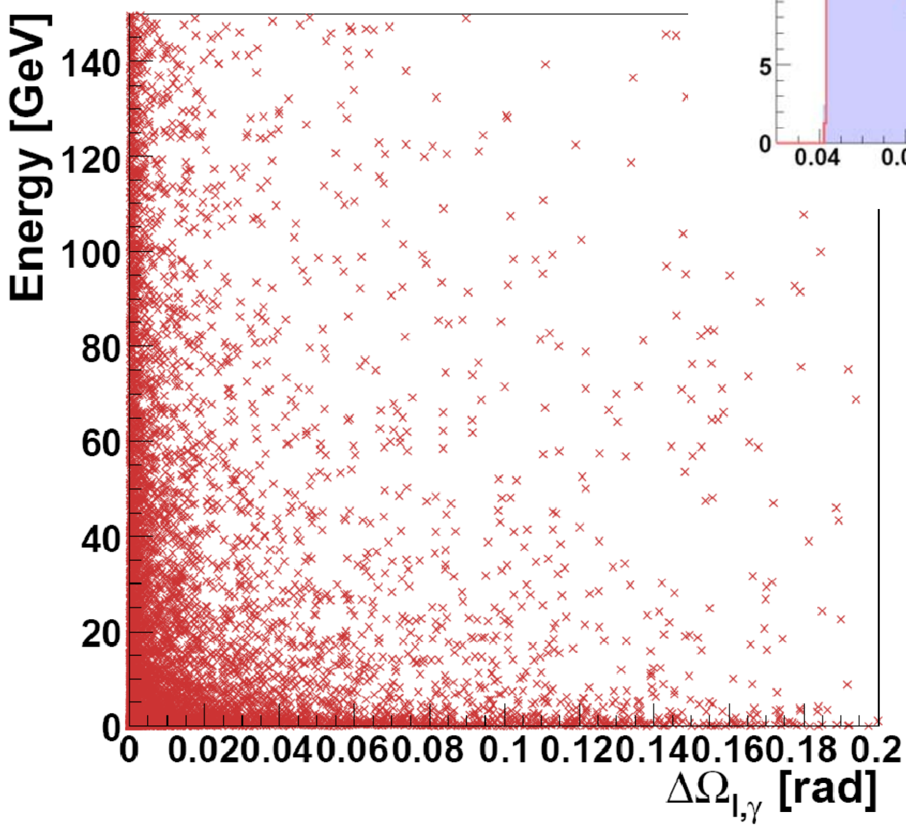
$$\Delta\theta_{R\text{-}L} \equiv \theta_{RIGHT} - \theta_{LEFT}$$

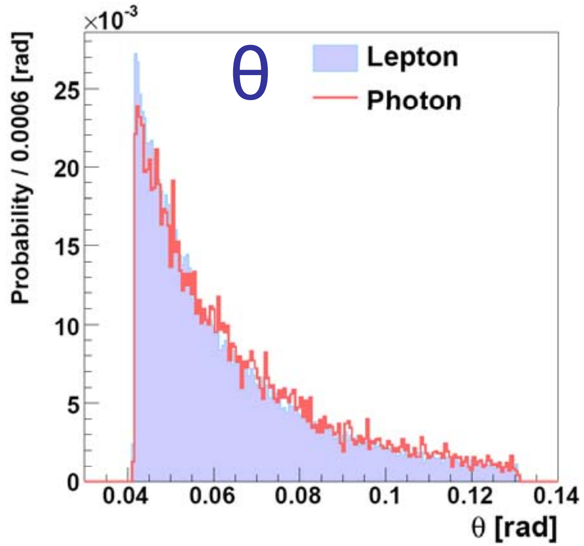
- Collinearity: $|\Delta\theta_{R\text{-}L}| < 1$ mrad
- Energy balance: $|E_R - E_L| < 0.1 \cdot \min(E_R, E_L)$
- Energy minimum: $E_R, E_L \geq 0.8 \cdot E_{beam}$ (200 GeV)

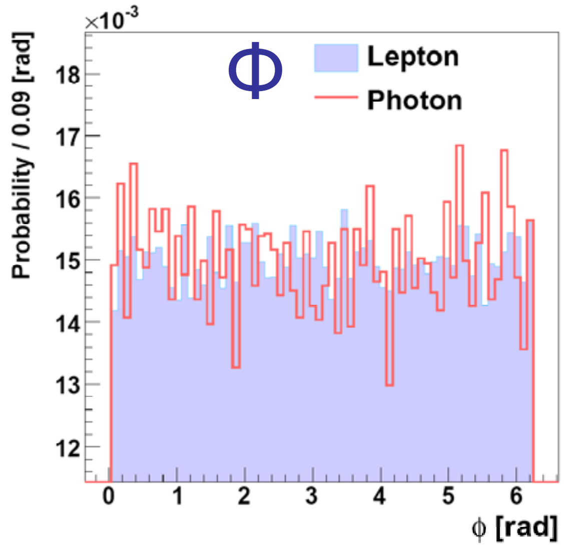
Topology of Bhabha scattering

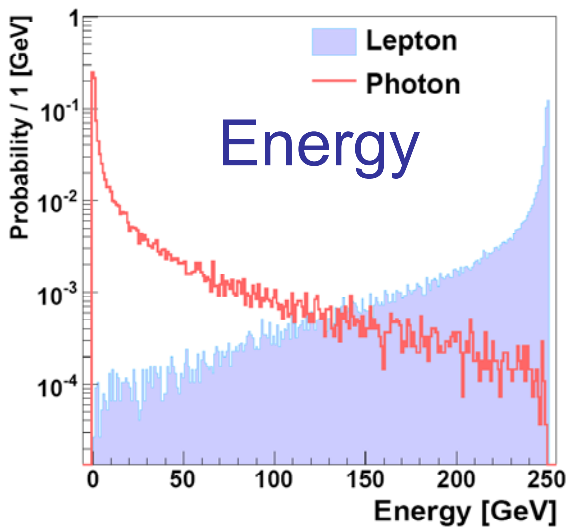
- Bhabha scattering with √s = 500 GeV

- Separation between photons and leptons, as a function of the energy of the low-energy-particle.



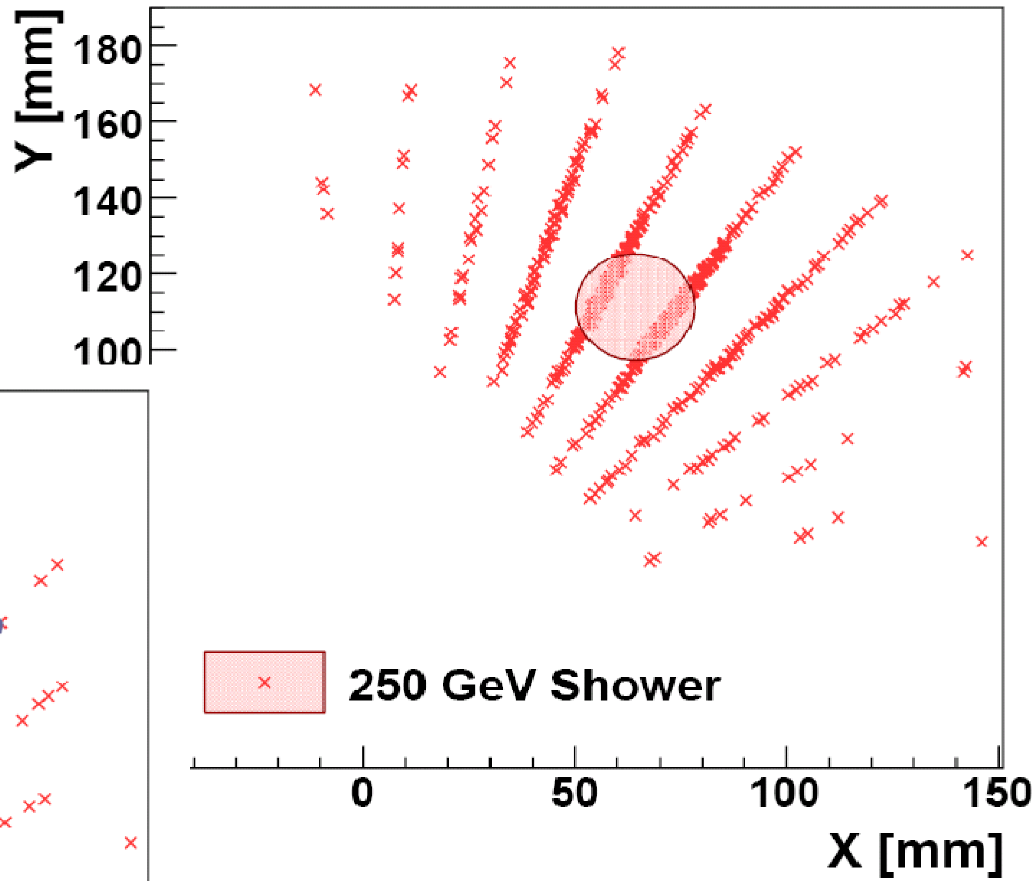


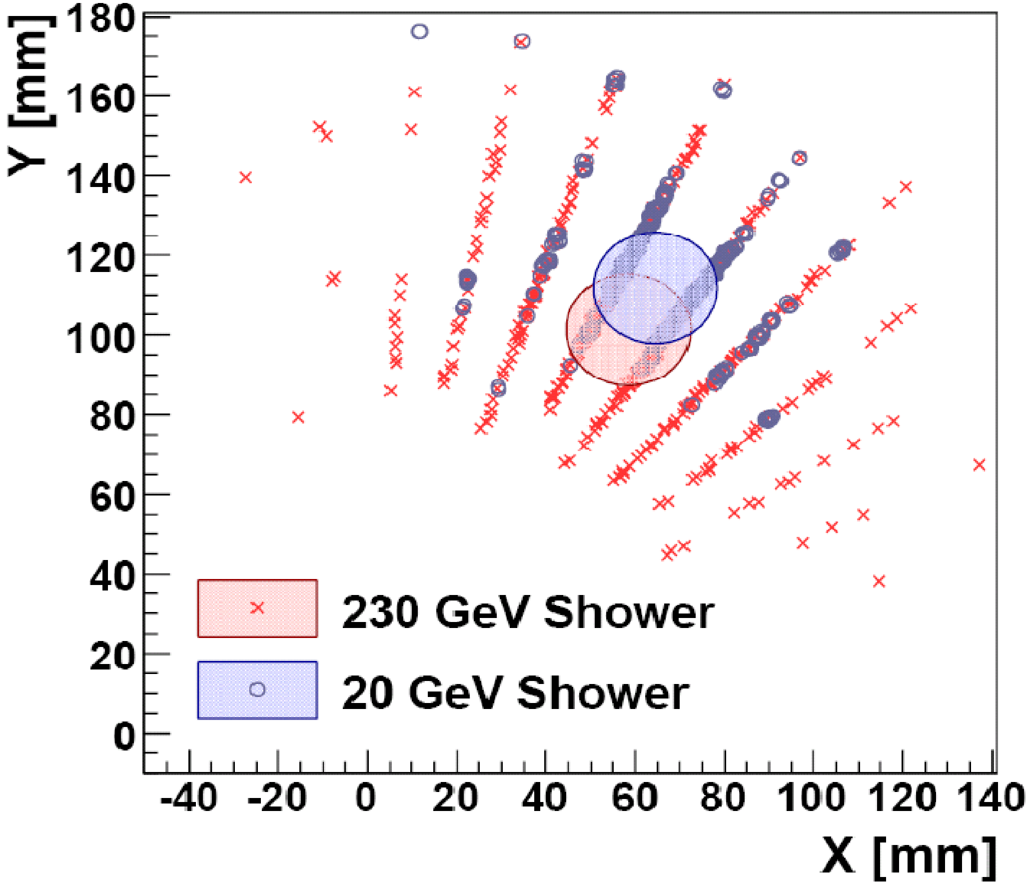




Overlap of multiple showers

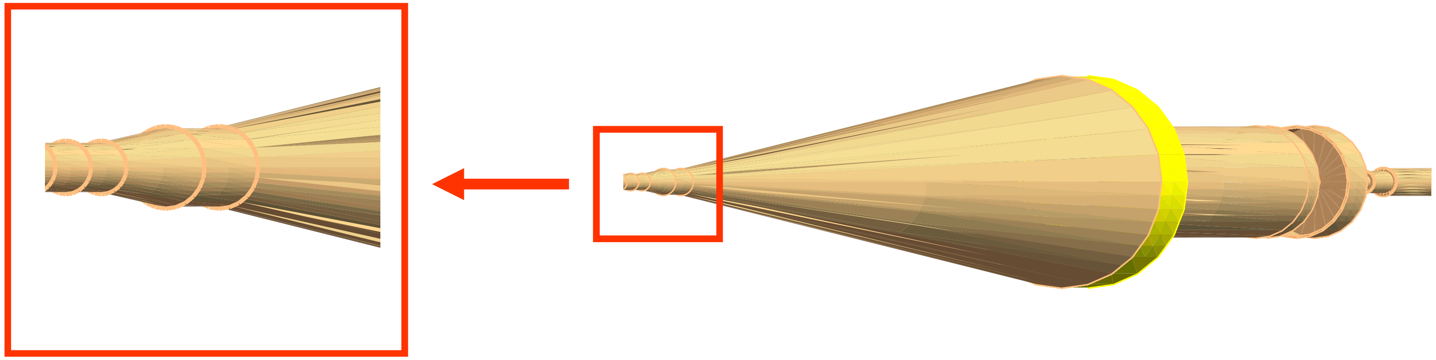
- Profile of the energy of a single 250 GeV shower.





- Profile of the energy of two showers (230 and 20 GeV) separated by one Moliere radius (indicated by the circles).

The shape of the beampipe

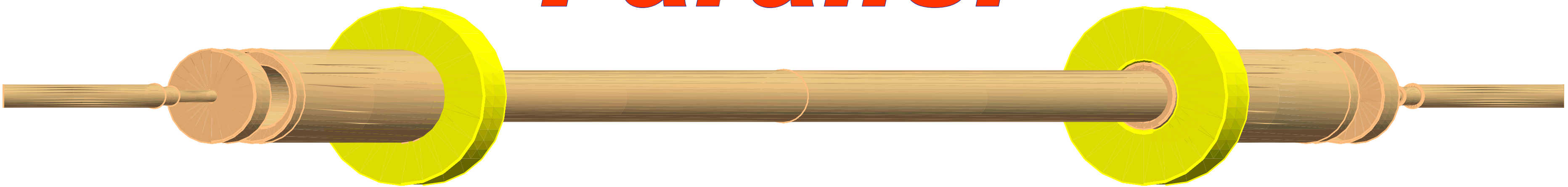


1. LumiCal is represented by the yellow disk, and the beampipe by the brownish cone.
2. Currently the beam-pipe has a “conical” shape, made up of Beryllium, with a small-radius section at the IP (for the vertex detector), and a conical extension which goes up to the outer radius of LumiCal.
3. Particles traveling to LumiCal from the IP don’t pass through any material.
4. Problems with this design:
   - It is hard to achieve the required vacuum at the edges of the beampipe near the LumiCal (no place to put a pump in the forward section).
   - There is some high-order-mode (HOM) beam energy loss (~20W) (see: http://ilcagenda.linearcollider.org/getFile.py/access?contribId=84&sessionId=10&resId=3&materialId=slides&confId=2169).
   - There are disturbances to the magnetic field due to the boundary conditions.

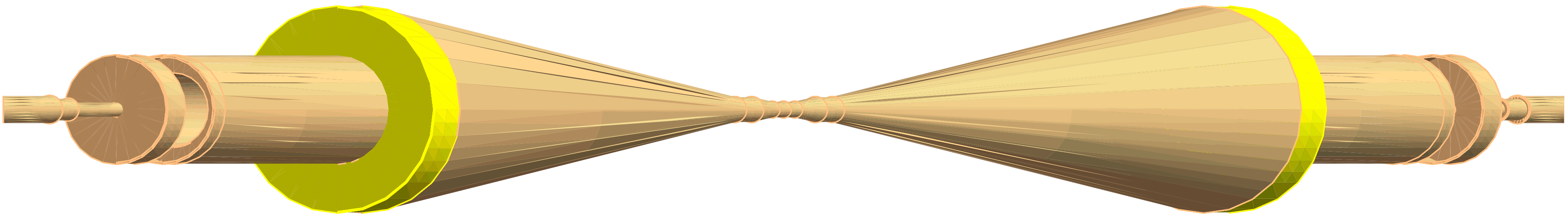
The shape of the beampipe

A new, simpler, shape of the beampipe will be investigated:

Parallel



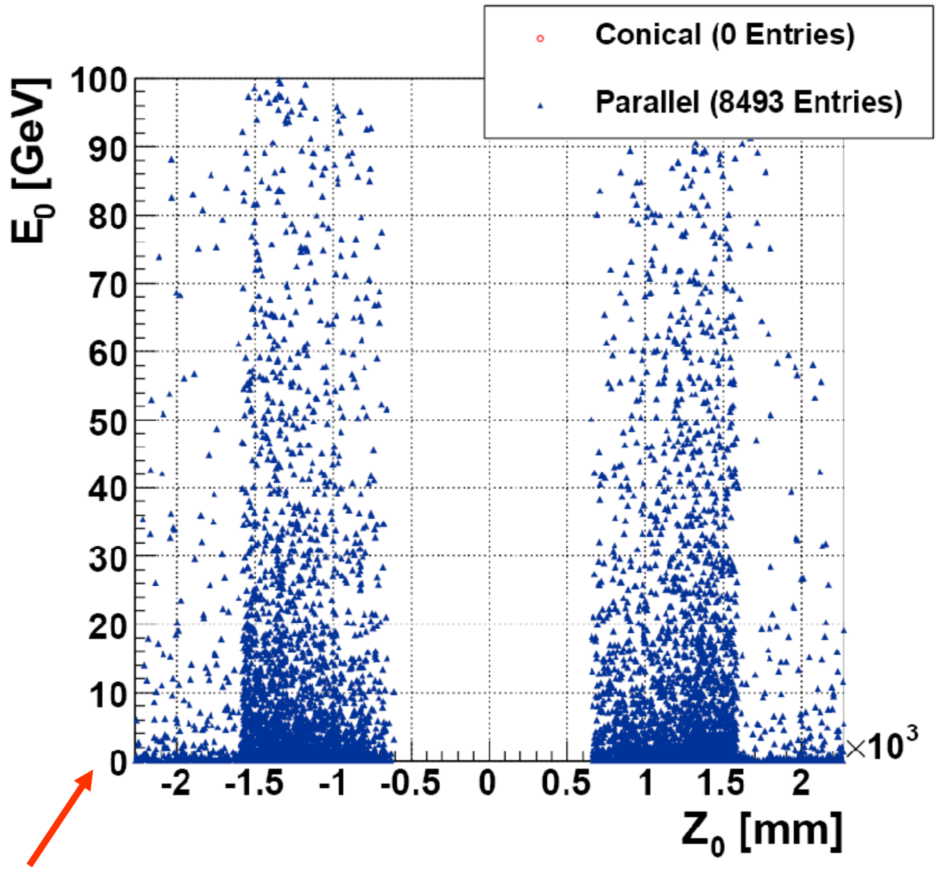
- Beryllium beampipe, with inner radius of 5.5cm, and outer radius of 6cm (the minimal radii for a 14 mrad crossing angle).



Conical

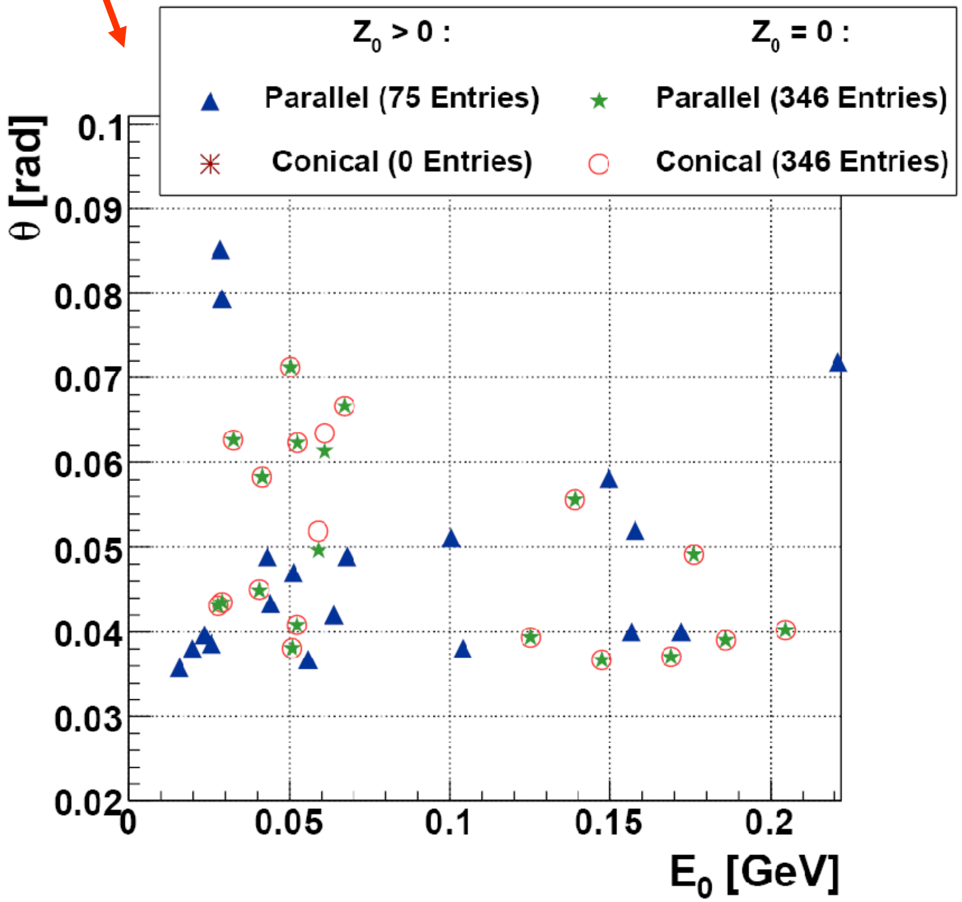
Generated (MC) particle information

- Due to passage of particles through the beampipe, pre-showering occurs, and new particles are created in front of LumiCal.

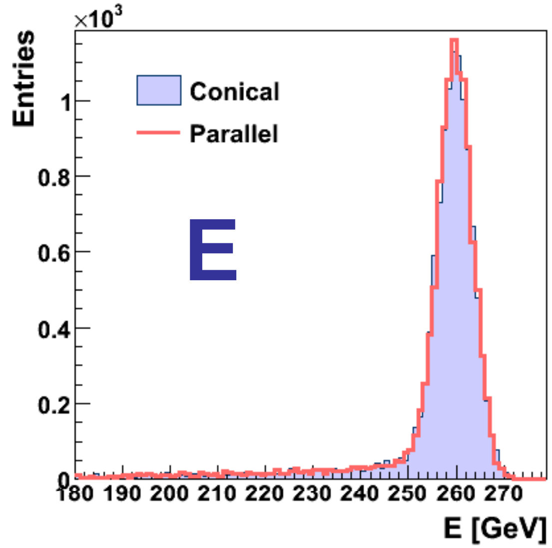


- Particles which are created between LumiCal and the IP for ~10^4 events (Z_0 is the point of creation).

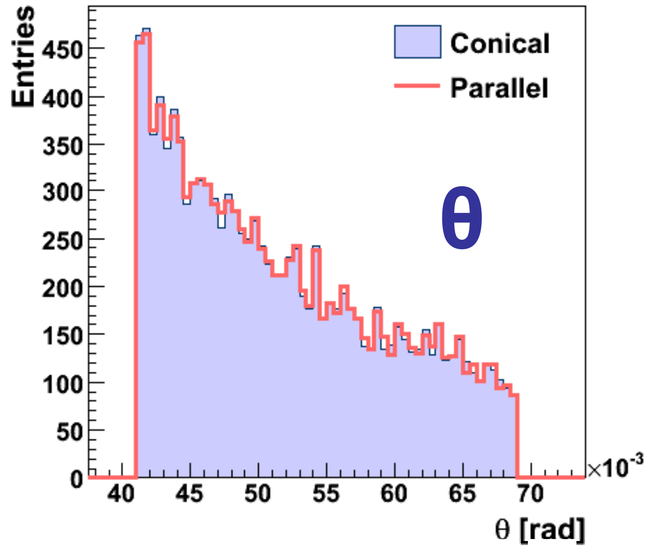
- Particles that reach the face of LumiCal, z = 2.27m (~100 events).

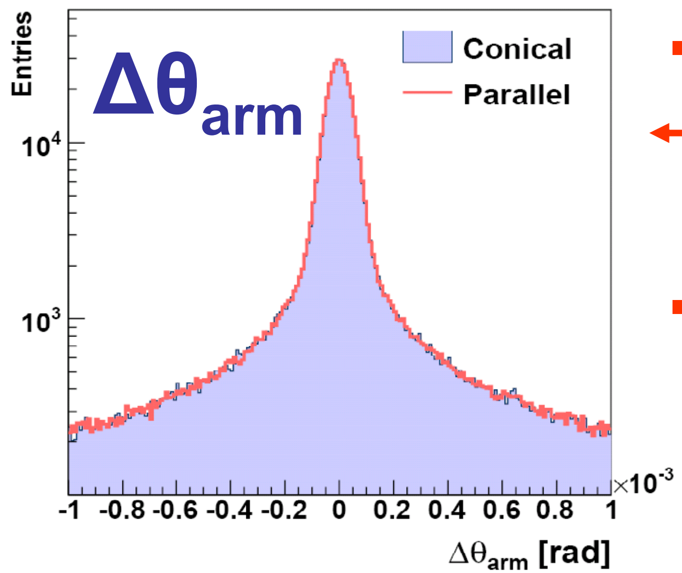


Reconstructed (cluster) information

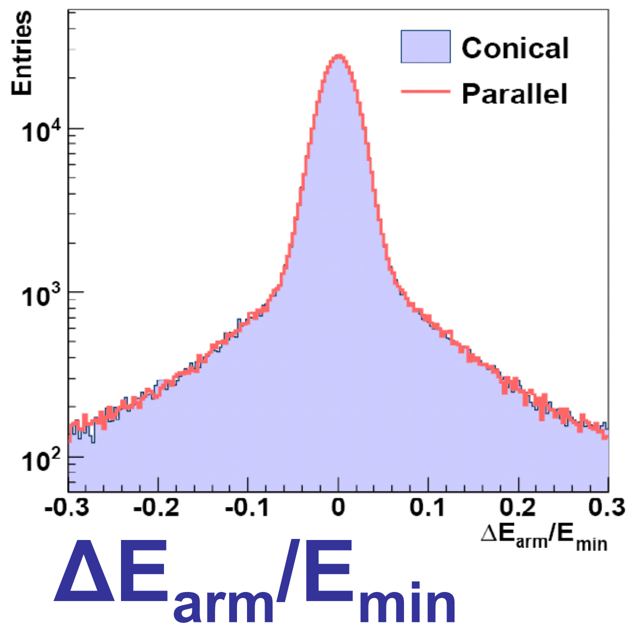


- Energy of highest-energy cluster in LumiCal.
- Polar angle of highest-energy cluster in LumiCal.





- Collinearity (difference in polar angle) between the arms: $\Delta\theta_{R\text{-}L}$.
- Energy balance between the arms: $|E_R - E_L| / \min(E_R , E_L)$



Comparison strategy of the acceptance

1. The luminosity measurement is done by counting the number of accepted Bhabha events after applying well defined cuts.
2. We compare the number of Bhabha events, which pass the cuts, between the parallel and conical cases:

- **Event-by-event comparison – possible outcomes**:
  1. In both the conical and the parallel configurations a Bhabha event is accepted.
  2. In both cases a Bhabha event is rejected.
  3. Only in one case (parallel or conical) a Bhabha event is accepted.
- **Sum of accepted Bhabha events for a large data sample**:
  - Cases where only the parallel configuration accepted a Bhabha event, and where only the conical configuration accepted a Bhabha event, will **cancel each other out**.
  - The final difference in the counting rate between the two cases will, therefore, be smaller than the event-by-event difference.

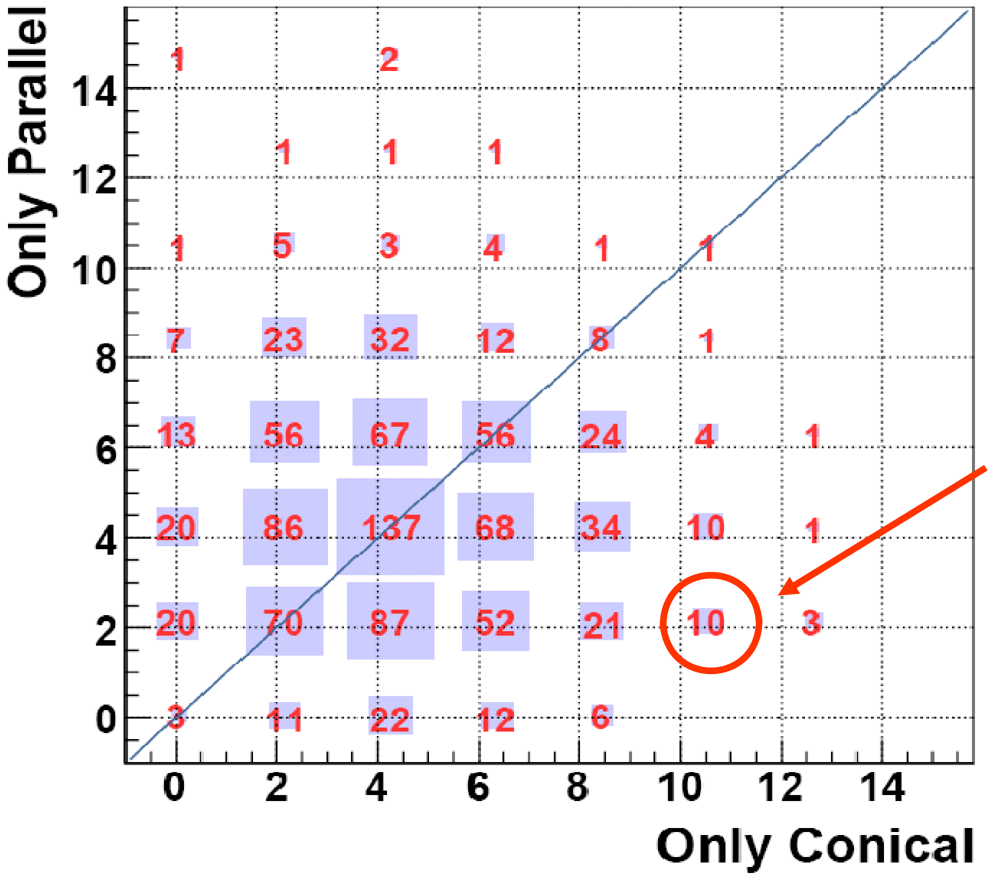
Simplified example of differences in acceptance

Event index	The event passes (+) or fails (-) the acceptance cuts	
	Conical	Parallel
1	+	+
2	-	-
3	+	-
4	-	+
5	+	-
Independent acceptance:	2 out of 5	1 out of 5
Total acceptance:	3 / 5 = 60%	2 / 5 = 40 %
Difference in acceptance:	1 out of 5 → (2 - 3) / 3 = relative error of 33%	

Relative error: $\Delta N / N \equiv (N_{parallel} - N_{conical}) / N_{conical}$

Event-by-event comparison of acceptance

- 1000 groups of 1000 events were considered (1M events in total).
- In each group of events the number of accepted Bhabha events was counted for each configuration.



- **Y-Axis:** Number of cases where a Bhabha event was accepted in the parallel configuration, but not in the conical configuration.
- **X-Axis:** a Bhabha event was accepted only in the conical configuration, but not in the parallel.
- **Example**:
  There were 10 groups of 1000 Bhabha events, out of which there were 11 events where a Bhabha was accepted only in the conical configuration, and 2 events where a Bhabha was accepted only in the parallel configuration.

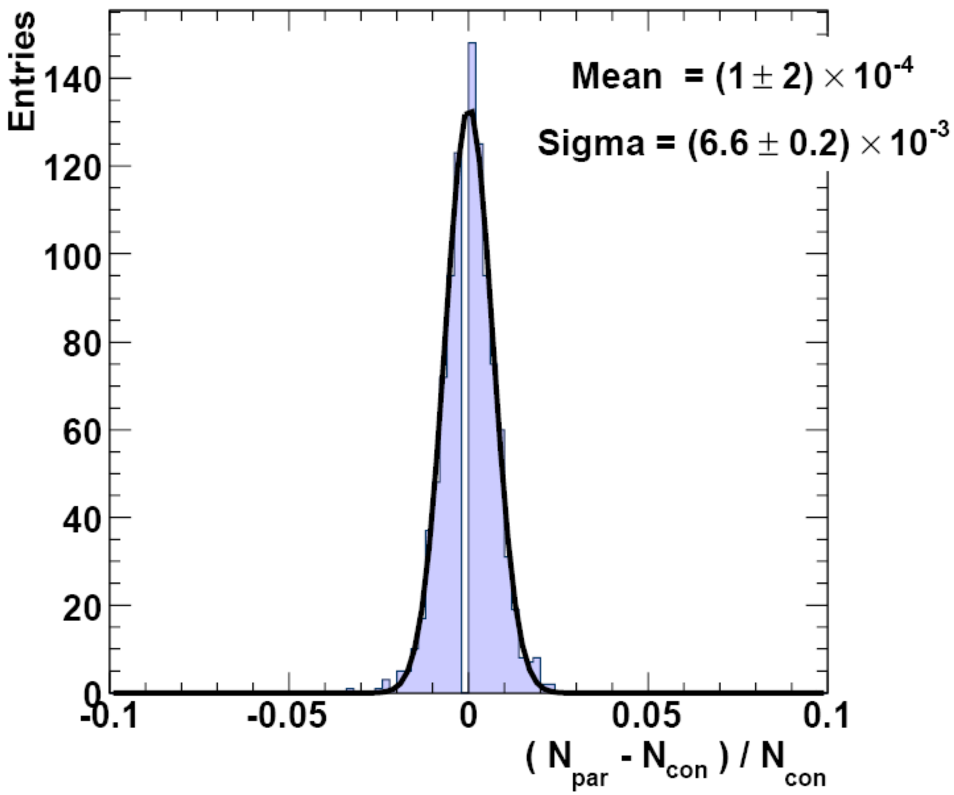
Counting rate of Bhabha events

- Distribution of the normalized difference in the number of accepted Bhabha events between the parallel and conical cases, ΔN / N.
- Each entry represents the difference in the number of accepted Bhabha events for a sample of 1000 events.
- 1M events (1000 entries) were considered in total.

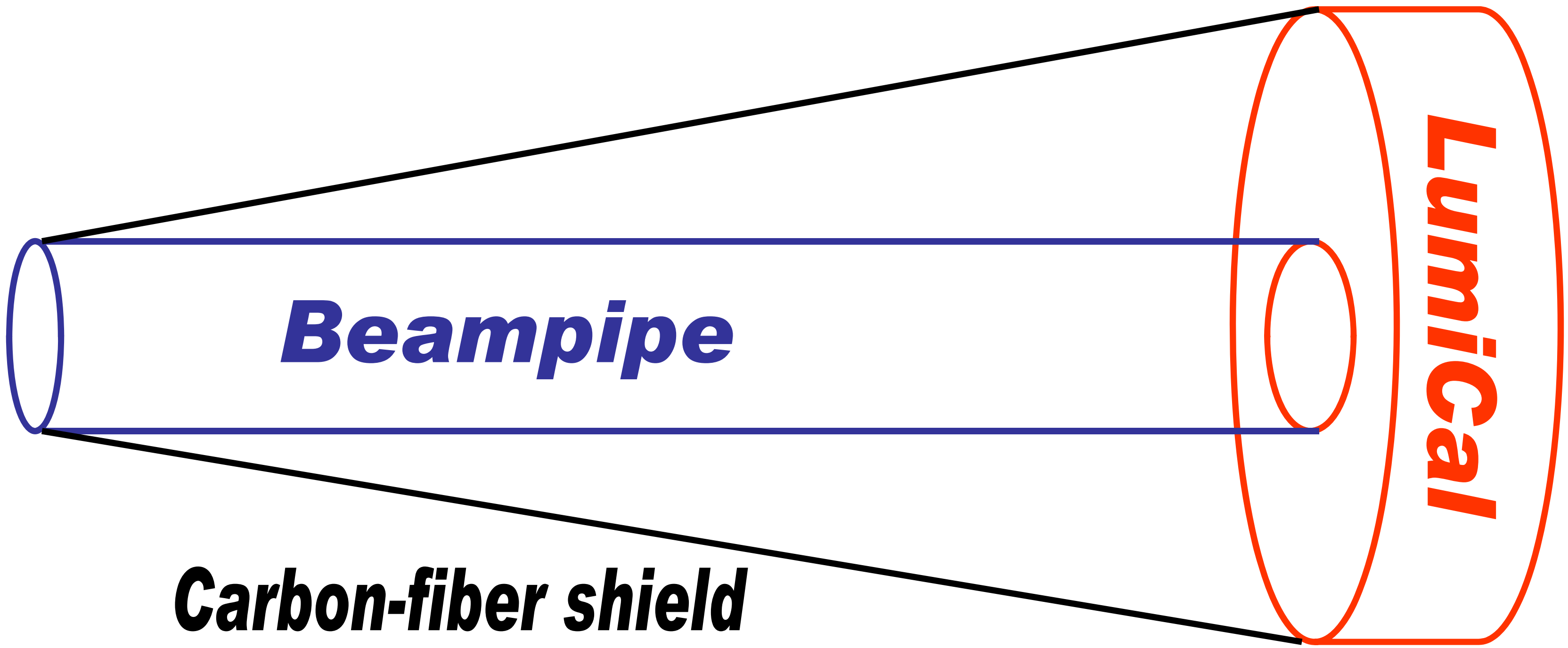
$$\Delta N / N \equiv (N_{parallel} - N_{conical}) / N_{conical}$$

Mean = $(1 \pm 2) \cdot 10^{-4}$

Sigma = $(6.6 \pm 0.2) \cdot 10^{-3}$



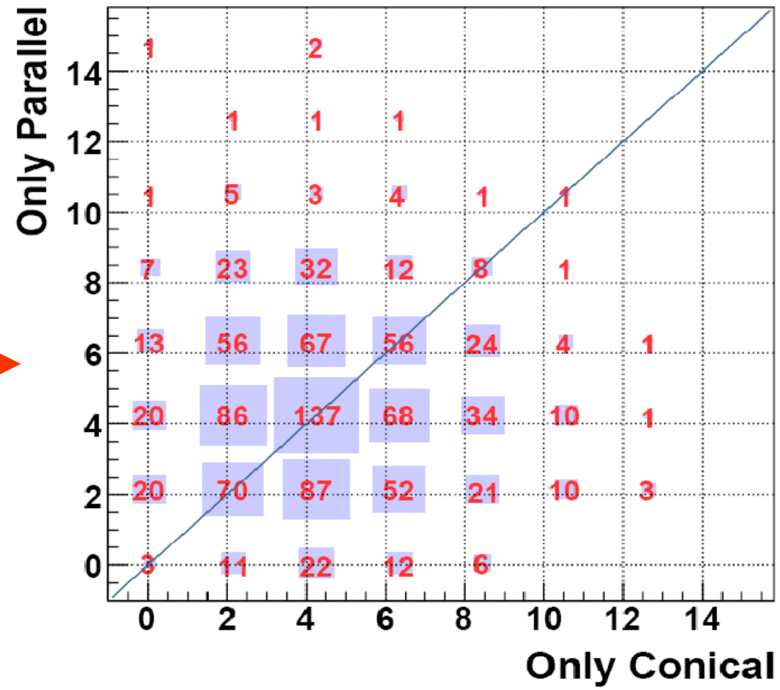
Safety measure



- A carbon-fiber envelope should be added if the parallel configuration is chosen, in order to block off the area in front of LumiCal.
- This would prevent stray cabling or some other additional material from being placed in front of LumiCal.

Summary

1. For the parallel case, particles are created in front of LumiCal, due to passage of the primary particles through the beampipe.
2. The new particles sometimes increase the count rate of Bhabha events, and sometimes decrease it, compared to the conical case.
3. The differences in the count rate tend to cancel out, up to a relative bias, $\Delta N/N \sim 10^{-4}$.
4. A carbon-fiber envelope is needed for the parallel configuration (as a safety measure) in order to insure clearance of the area in front of LumiCal.



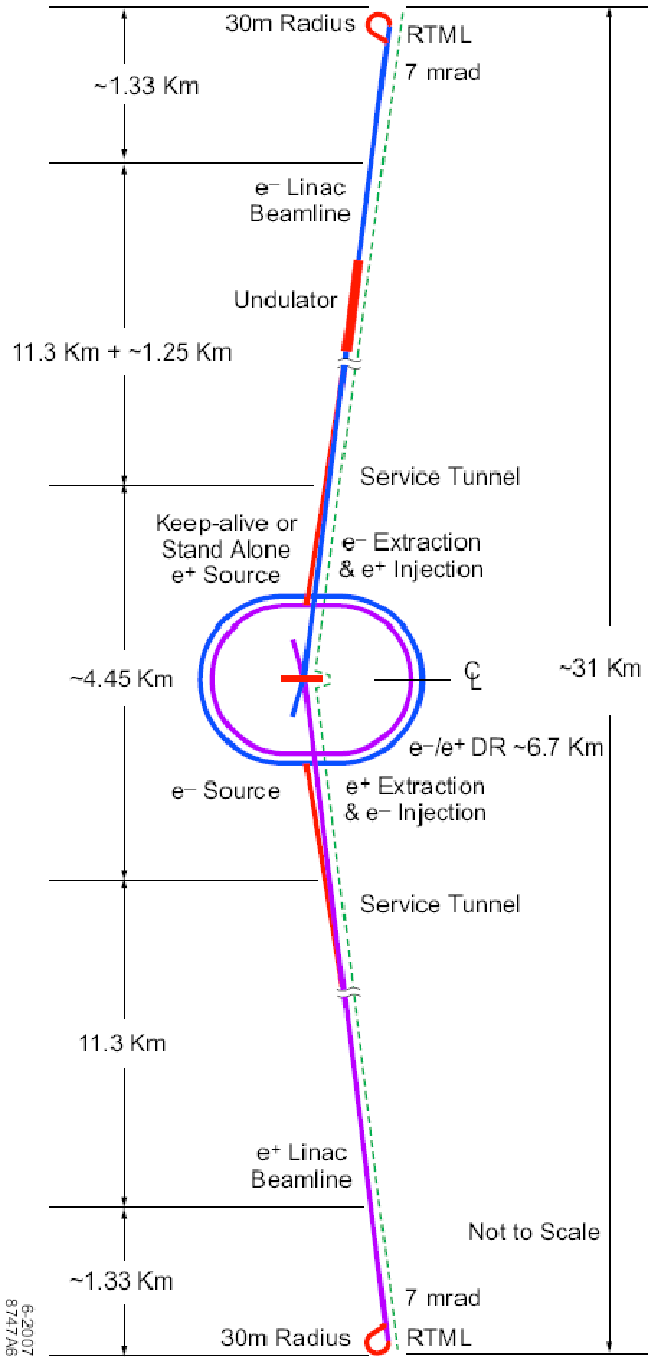
ΔN / N :

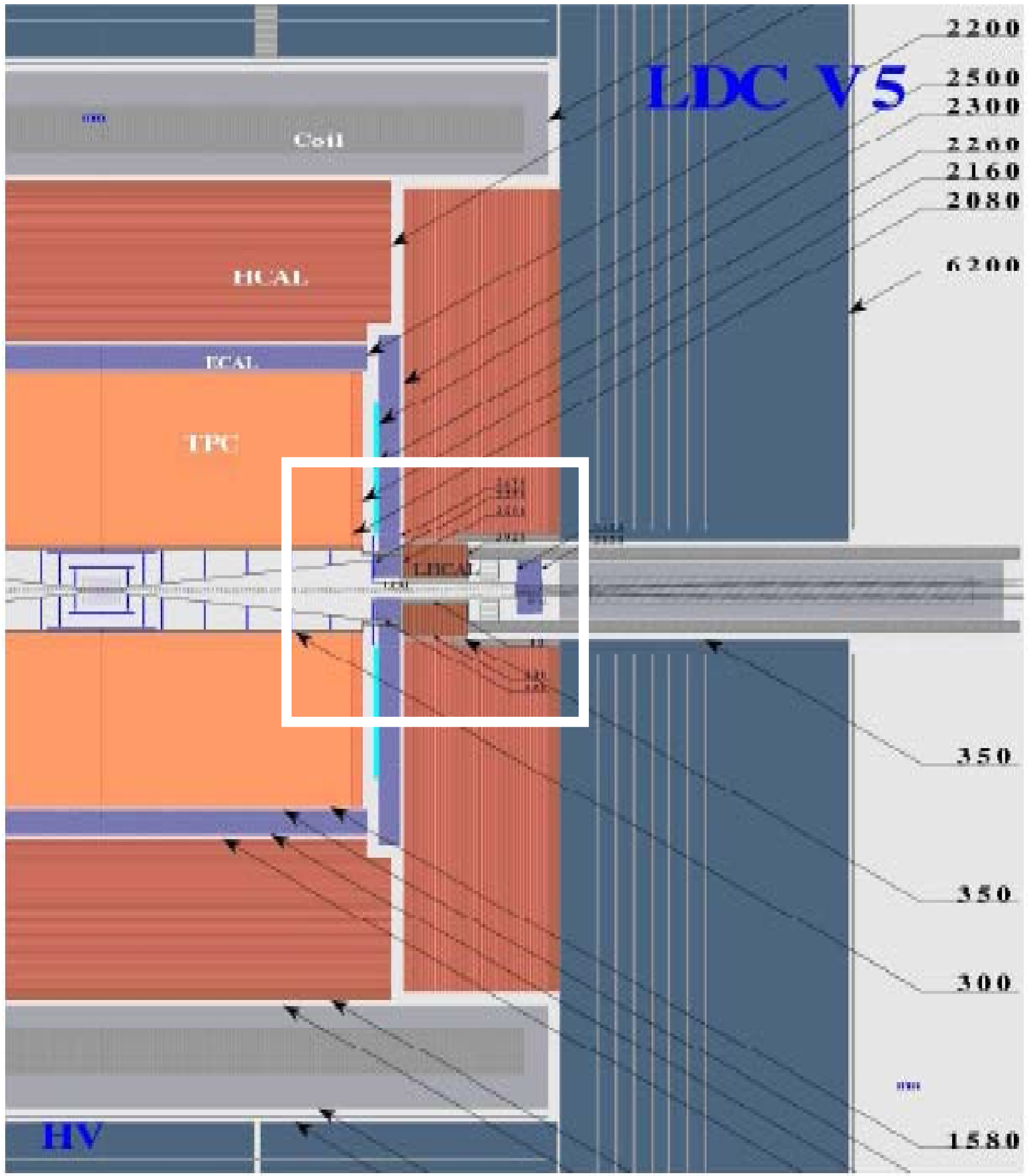
Mean = $(1 \pm 2) \cdot 10^{-4}$

Sigma = $(6.6 \pm 0.2) \cdot 10^{-3}$

Auxiliary Slides

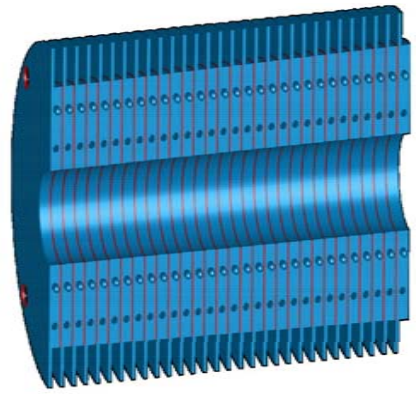
The ILC & The LDC detector



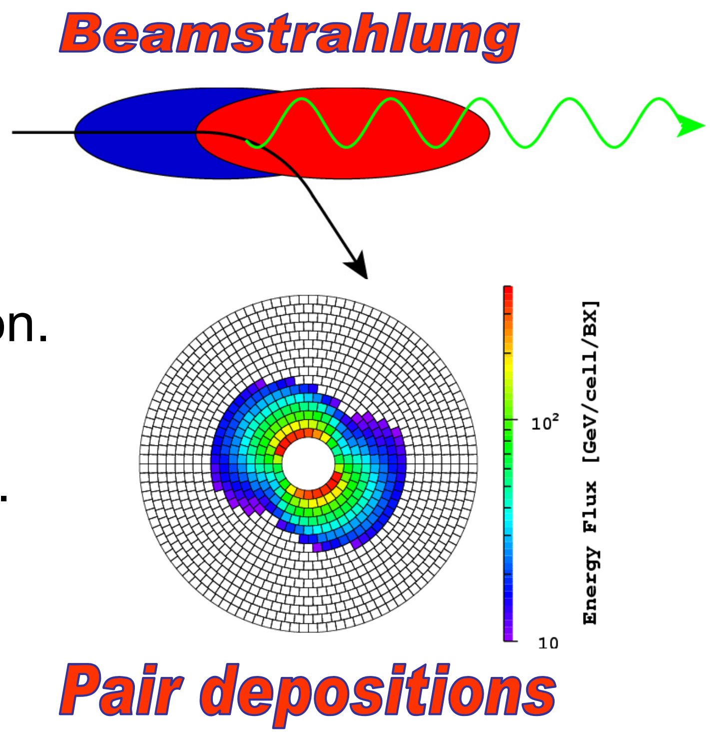


BeamCal Overview

- **Compact EM calorimeter with sandwich structure**:
  1. 30 layers of 1 X_0 : 3.5 mm W and 0.3 mm sensor.
  2. Angular coverage from ~ [5,40] mrad
  3. Moliére radius (R_M) ~ 1 cm
  4. Segmentation between 0.5 and 0.8 x R_M.



- **Functionality**:
  1. Provide electron veto.
  2. Perform beam diagnostics for a feedback loop on luminosity optimization.
  3. Shield the inner part of the detector from upstream backscattered particles..



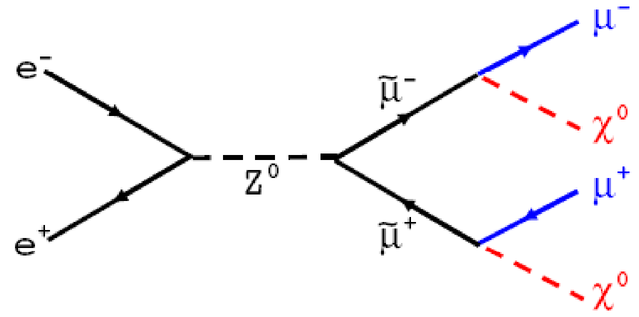
BeamCal electron veto

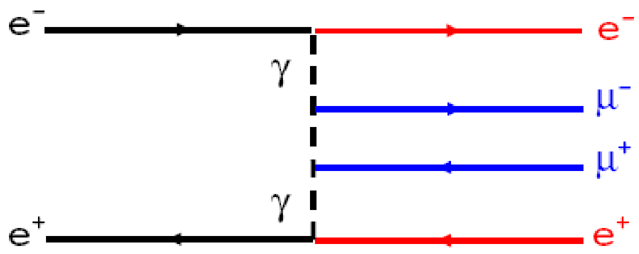
- Two photon events constitute the most serious background for many search channels which are characterized by missing energy and missing momentum.
- **Example**: stau/smuon production:
  1. Large SM background:

     $\gamma^*\gamma^* \rightarrow \tau^+\tau^-$ ($E_t > 4.5$GeV) $\sigma \sim 4.3 \cdot 10^5$ fb
     $\rightarrow \mu^+\mu^-$ ($E_t > 2$GeV) $\sigma \sim 5.2 \cdot 10^6$ fb
     $\rightarrow$ WW

     $e^+e^- \rightarrow \mu^+\mu^-$, $\tau^+\tau^-$ $\sigma \sim 1.0 \cdot 10^3$ fb
     $\rightarrow$ WW
  2. Some cuts based on event topology & kinematics help, but are not enough due to the high background cross-section.
  3. Missing energy (the neutralino (LSP?)).
  4. The difference between SUSY and the SM background is the final state electron.

SUSY



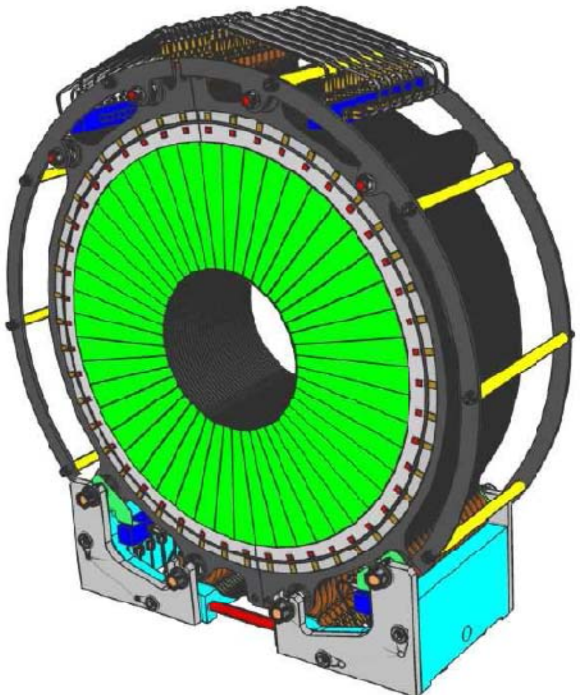


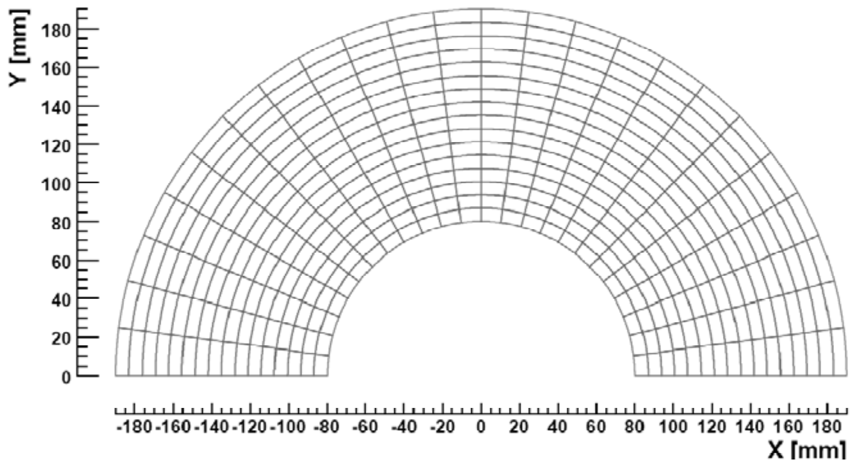
Backgroung

(Talk by Z. Zhang , FCAL Collaboration Meeting , October 2007, http://events.lal.in2p3.fr/conferences/FCAL07/)

LumiCal design parameters

1. **Placement:**
   - 2270 mm from the IP
   - Inner Radius - 80 mm
   - Outer Radius - 190 mm
2. **Segmentation:**
   - 48 azimuthal & 64 radial divisions:
   - Azimuthal Cell Size - 131 mrad
   - Radial Cell Size - 0.8 mrad

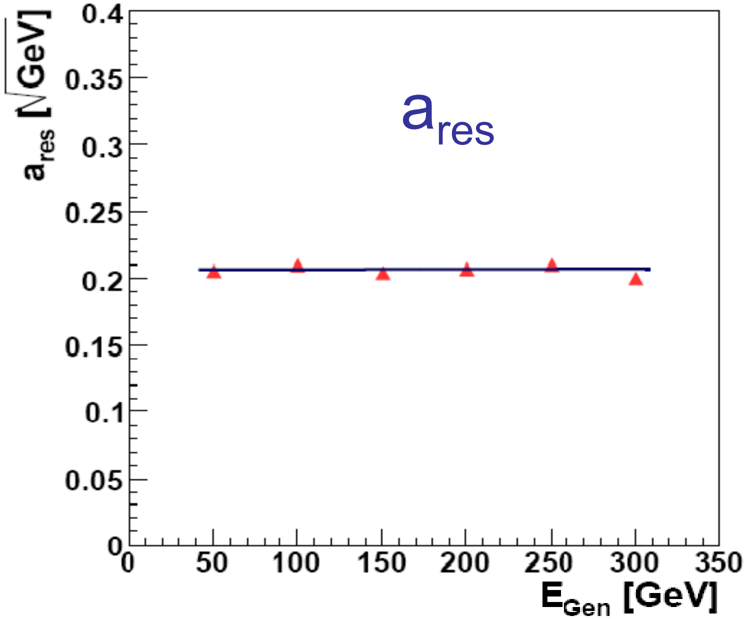




(every fourth radial segment is drawn)

3. **Layers:**
   - Number of layers - 30
   - Tungsten Thickness - 3.5 mm
   - Silicon Thickness - 0.3 mm
   - Elec. Space - 0.1 mm
   - Support Thickness - 0.6 mm

LumiCal intrinsic parameters



- Relative energy resolution:

$$\frac{\sigma_E}{E} = \frac{a_{res}}{\sqrt{E_{beam}\ (\mathrm{GeV})}}$$

$$a_{res} \approx 0.21\ \sqrt{(\mathrm{GeV})}$$

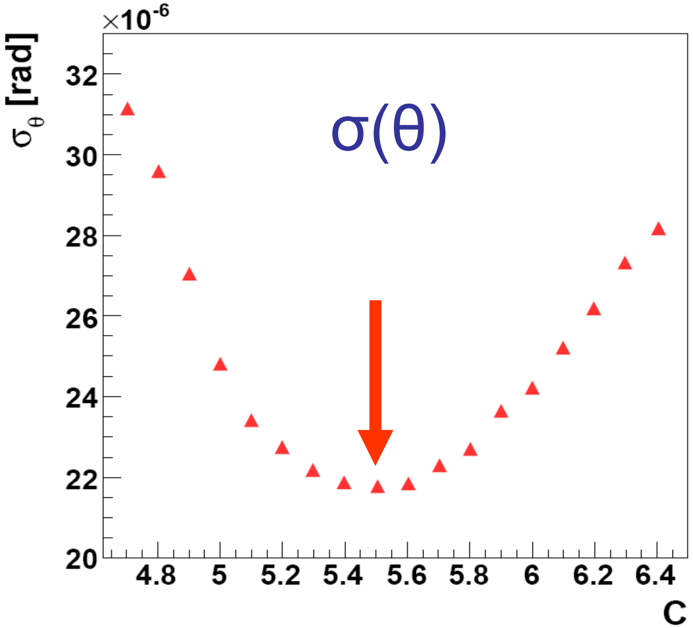
- Position reconstruction (polar angle):

$$<\theta> = \frac{\sum_i \theta_i \cdot \mathcal{W}_i}{\sum_i \mathcal{W}_i}$$

$$\mathcal{W}_i = \max\{\ 0\ ,\ \mathcal{C} + \ln\frac{E_i}{E_{tot}}\}$$

$$\Delta\theta = (3.2\ \pm\ 0.1) \cdot 10^{-3}\ \mathrm{mrad}$$

$$\sigma_\theta = (2.18\ \pm\ 0.01) \cdot 10^{-2}\ \mathrm{mrad}$$

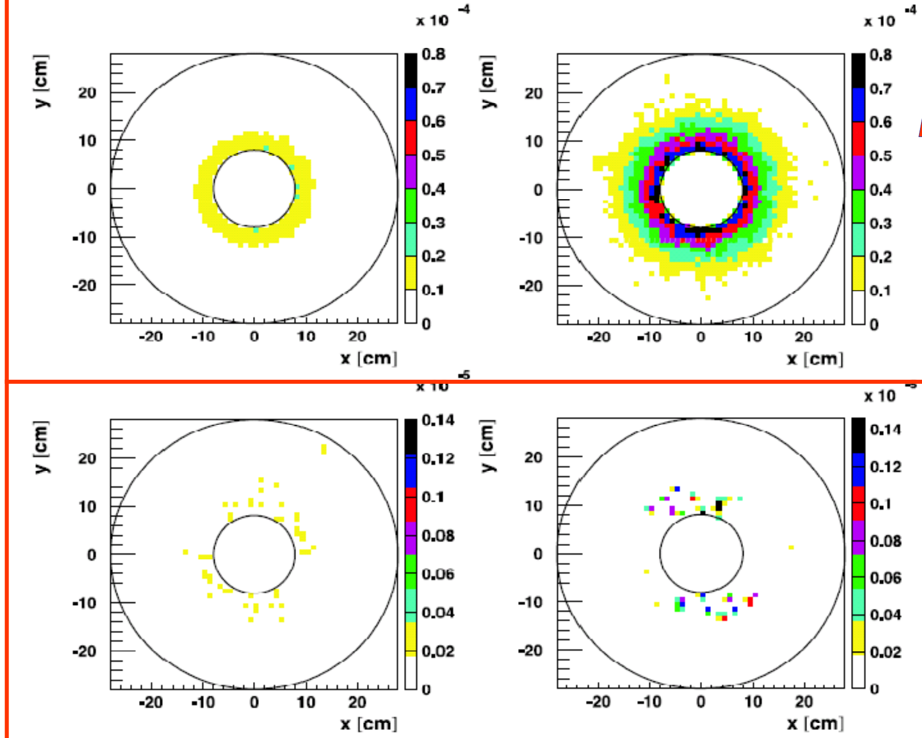


Physics Background

- Four-fermion processes are the main background, dominated by two-photon events (bottom right diagram).

BEFORE → AFTER cut

leptonic

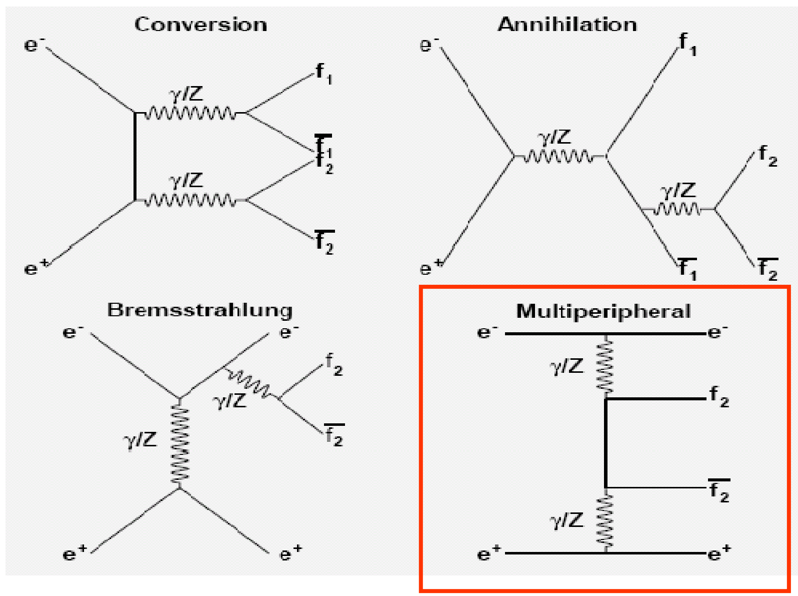


hadronic

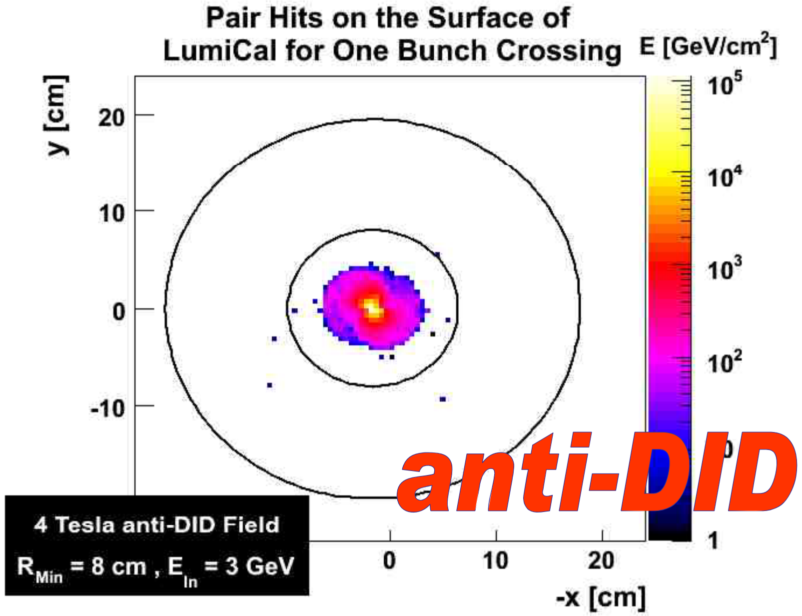
The cuts reduce the background to the level of 10^{-4}

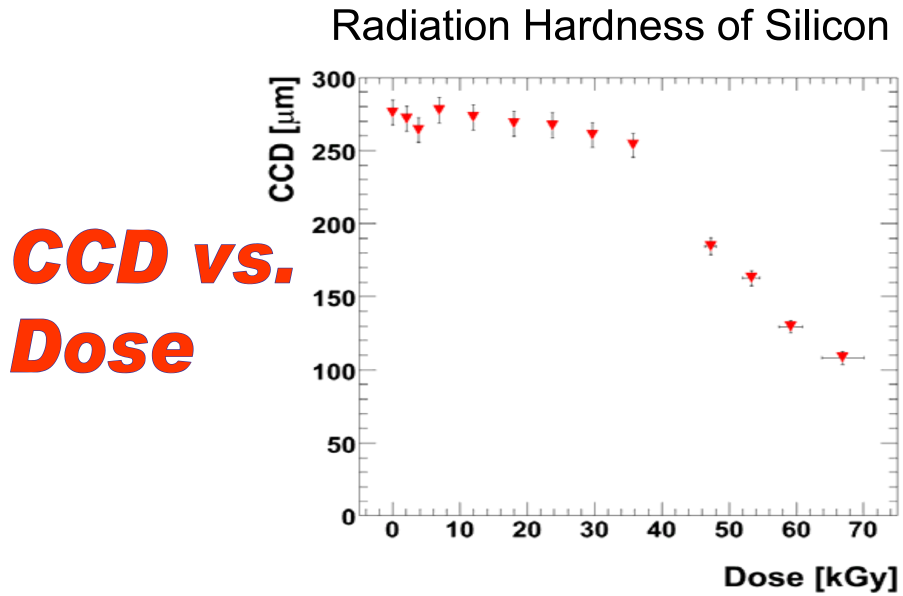
Four-fermion processes

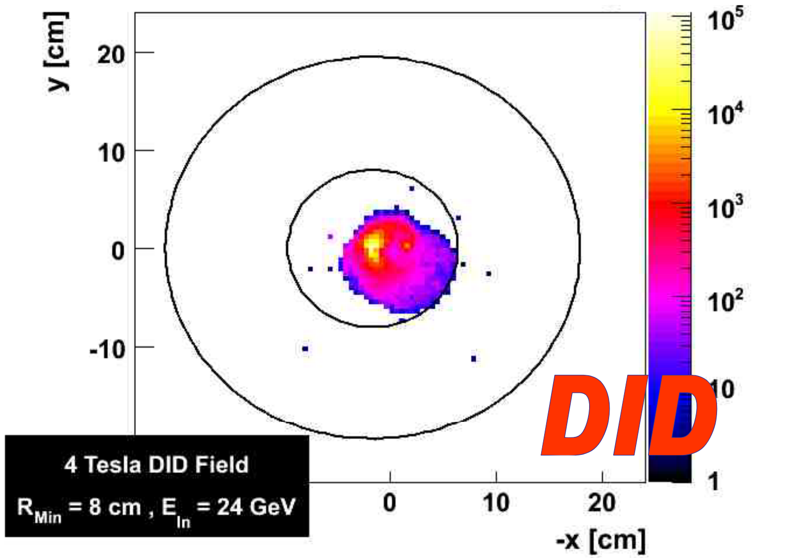
$$e^+ e^- \rightarrow e^+ e^- f^+ f^-$$



Machine background in LumiCal



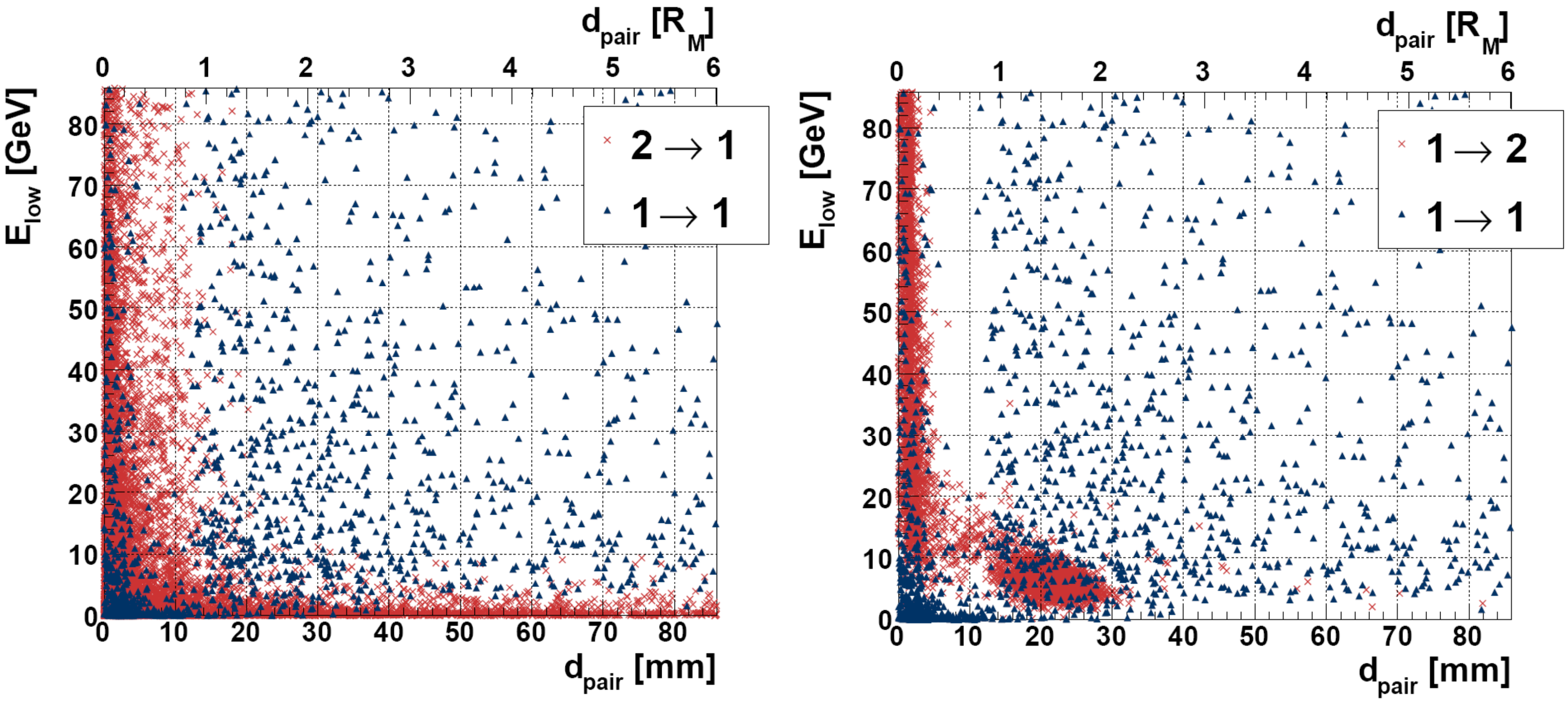




- Negative effect of grazing LumiCal with the pair distribution:
  1. Radiation damage to the silicon sensors ~O(MGy/year).
  2. Detrimental to the Luminosity measurement.
  3. Backscattering to the inner part of the detector.

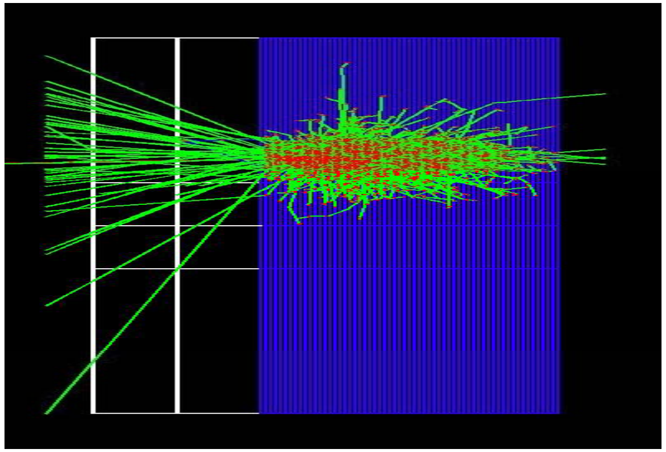
Clustering in LumiCal

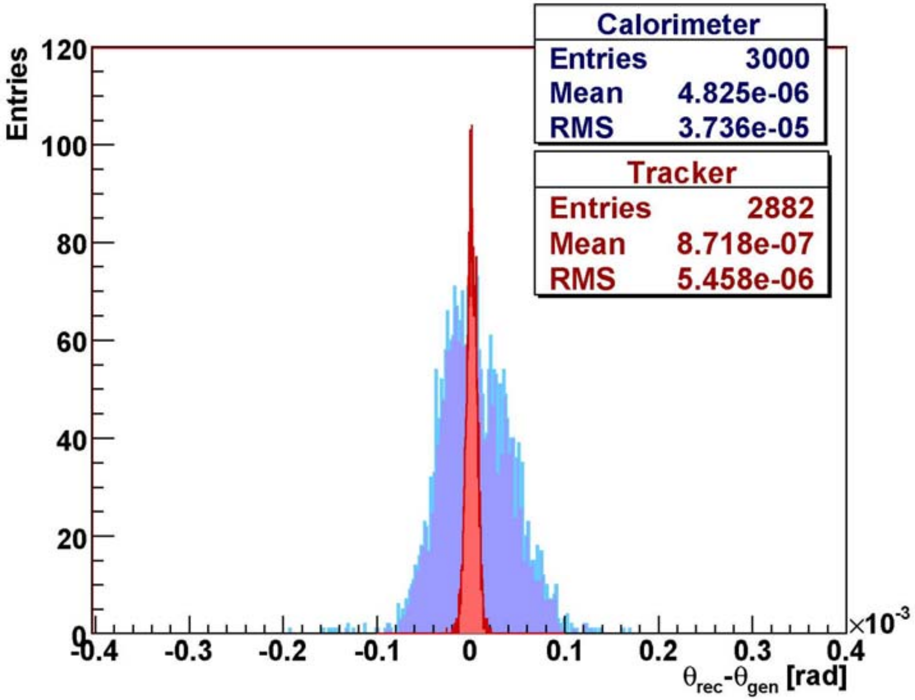
- (2→1): Two showers were merged into one cluster.
- (1→2): One shower was split into two clusters.
- The Moliere radius is R_M = 14mm, d_{pair} is the distance between a pair of showers, and E_{low} is the energy of the low-energy shower.

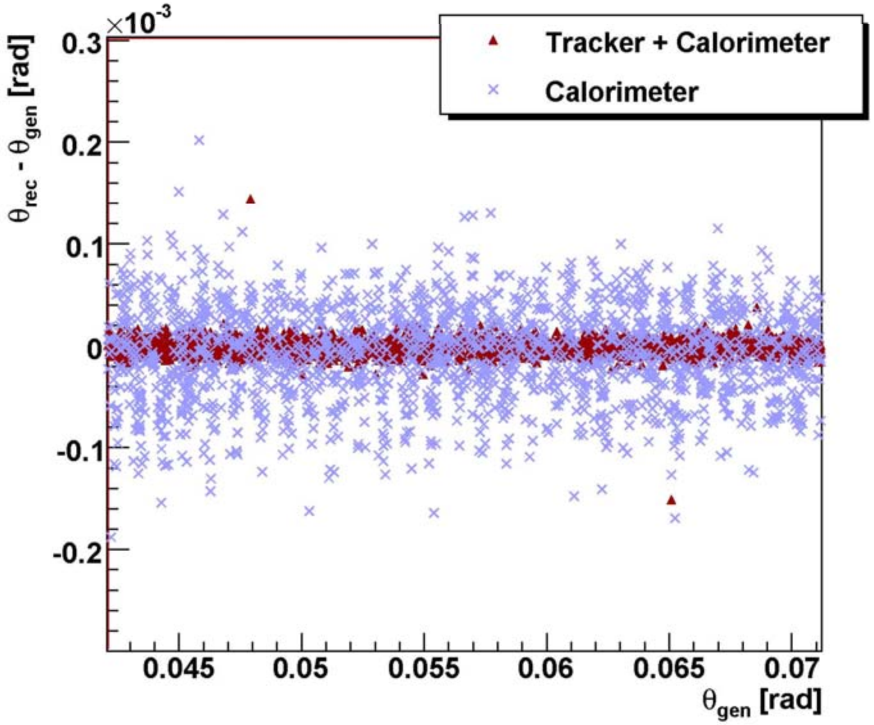


Silicon Tracker in front of LumiCal

- **Tracker parameters** (still being optimized…): 2 silicon layers, 5 cm gap between layers, 0.3 mm silicon thickness, 1000 azimuthal divisions , 1600 radial divisions.
- Use Tracker information to correct the Calorimeter reconstruction of the polar angle, θ.







MIP (muon) Detection in LumiCal

- Many physics studies demand the ability to detect muons (or the lack thereof) in the Forward Region.
- **Example**: Discrimination between super-symmetry (SUSY) and the universal extra dimensions (UED) theories may be done by measuring the smuon-pair production process. The observable in the figure, $\boldsymbol{\theta_\mu}$, denotes the scattering angle of the two final state muons.

UED:

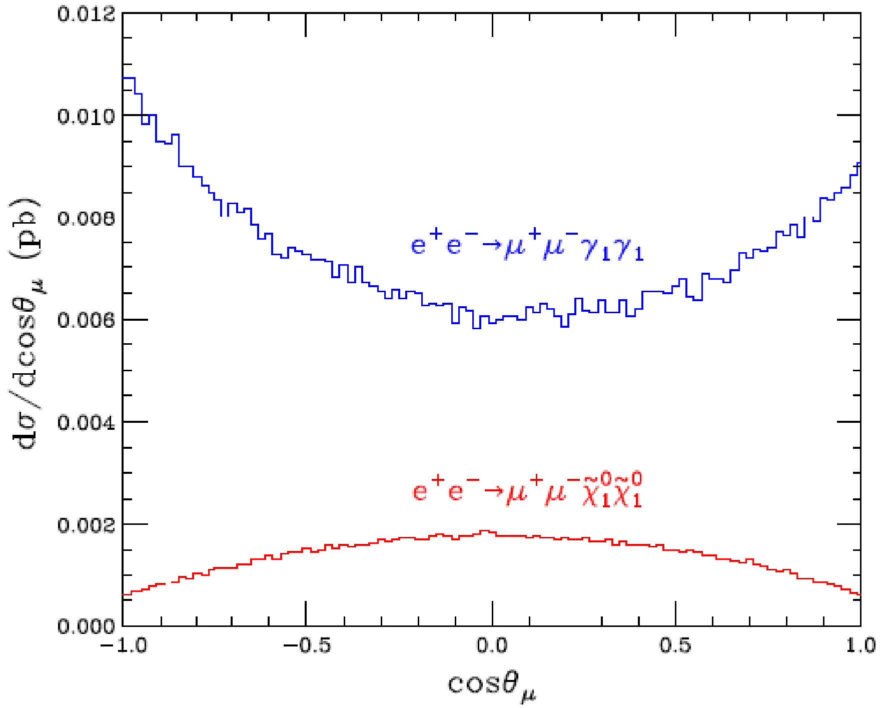
$$e^+e^- \to \mu_1^+\mu_1^- \to \mu^+\mu^-\gamma_1\gamma_1$$

$$\frac{d\sigma}{d\cos\theta} \sim 1+\cos^2\theta$$

SUSY:

$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

$$\frac{d\sigma}{d\cos\theta} \sim 1-\cos^2\theta$$



"Contrasting Supersymmetry and Universal Extra Dimensions at Colliders"
– M. Battaglia et al. (http://arxiv.org/pdf/hep-ph/0507284)

MIP (muon) Detection in LumiCal

- Multiple hits for the same radius (non-zero cell size).
- After averaging and fitting, an extrapolation to the IP (z = 0) can be made.