FCAL Workshop, CERN
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Systematic errors in the luminosity measurement at FCC-ee

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Outline

Focus on $\sqrt{s}$ = 91.2 GeV $\rightarrow \Delta L/L \sim 10^{-4}$

Simulation of FCCee LumiCal

Detector related systematics

- Position / energy reconstruction

Discussion on beam induced bkg

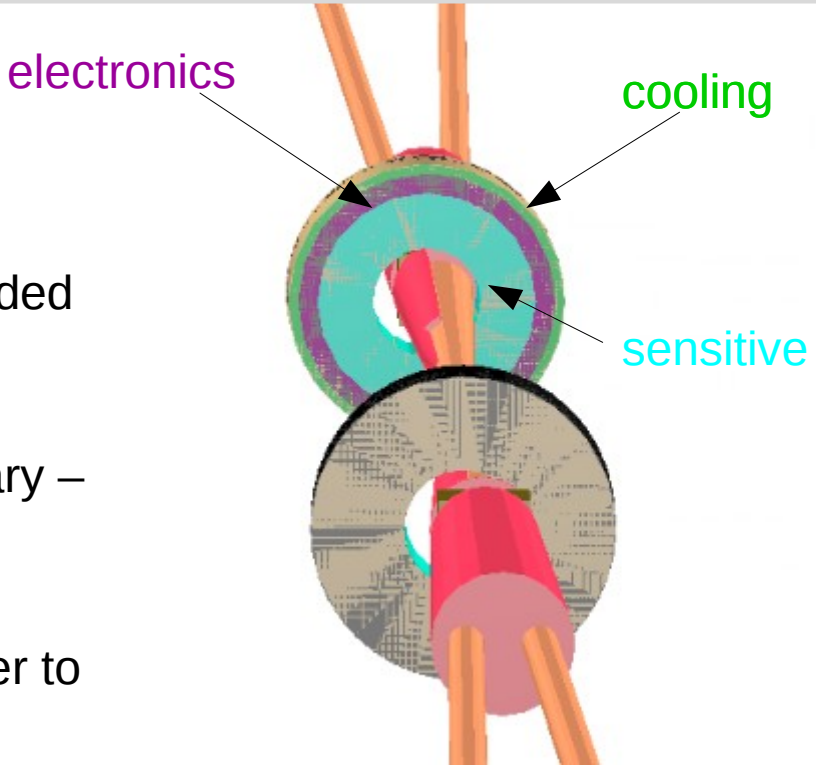
Beam-beam induced systematics

FCCee LumiCal in simulation

The FCCee LumiCal is a parametrisation of an existing DD4hep driver

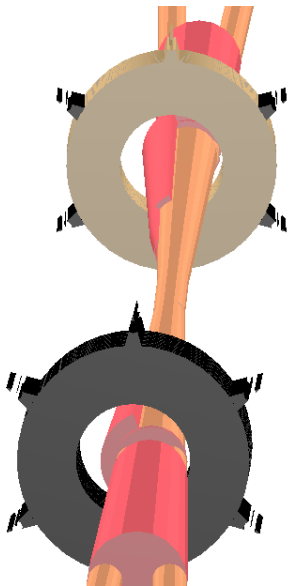
- Space foreseen for electronics & cooling has been added around the sensitive volume
  - Material budget for services & cooling is preliminary – need to be revisited

Shield ($1X_0$ of W) has been added on the back side in order to protect from backscattered particles from pair bkg



More detailed versions (e.g. with the support 'ears') have been created (mostly for reasons of detailed material distribution for bkg studies)

- Based on an ILD driver
- Made no difference in bkg studies – we rather keep it simple



Software tools used

Simulation with DD4Hep (via ILCSoft)

- For clustering used FcalClusterer sw package
- LumiCalClusterer processor (based on I. Sadeh Msc thesis)

Backgrounds were generated with Guinea Pig (GP) for the e^+e^- pairs & SYNC_B for Synchrotron Radiation (SR)

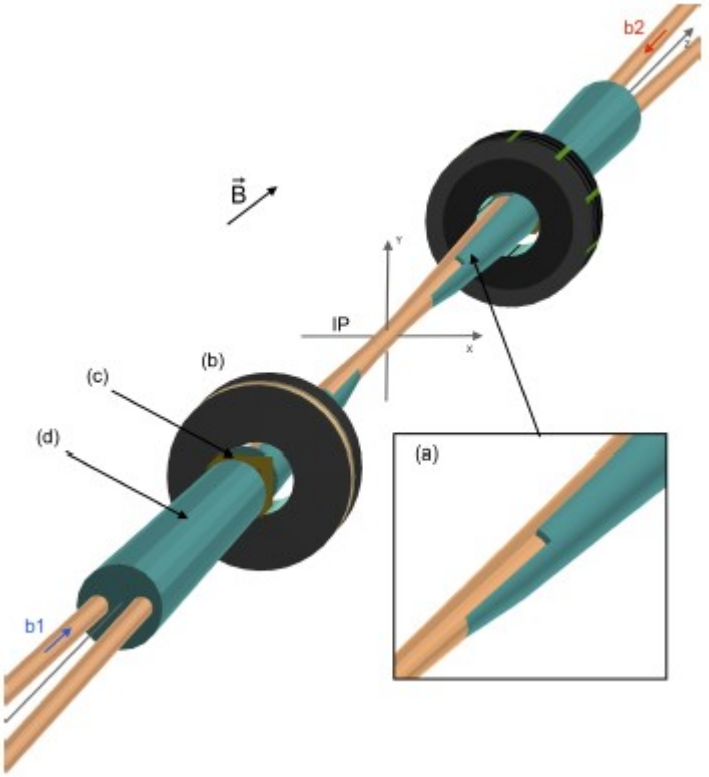
- Fully simulated with ILCSoft

Beam-beam effects were studied using

- BHWIDE for generating the Bhabha samples
- GP to apply the beam-beam effects

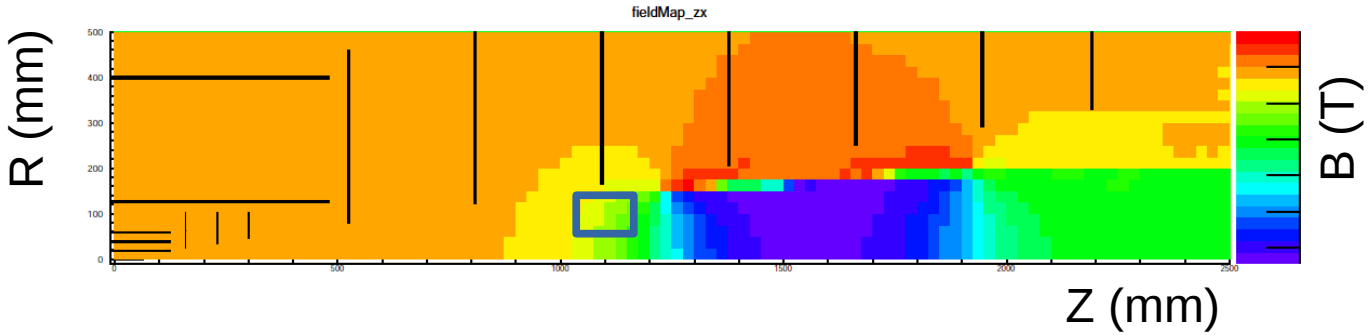
Brief description of FCCee MDI area

The IR elements (beam pipe, W SR shield,LumiCal, HOM absorbers, solenoids) have been implemented in DD4hep



Water cooled Be beam pipe (0.8mm Be, 0.4mm water) + 5μm Au layer →absorbs SR γ and reduces heat on BP

Use of a realistic field map



RZ slices of the field map. The black solid lines correspond to VXD / tracker layers. Box correspond roughly to LCAL position

Polar resolution - bias

Shot single electrons (E=45.6 GeV) inside the FV (θ=66mrad)

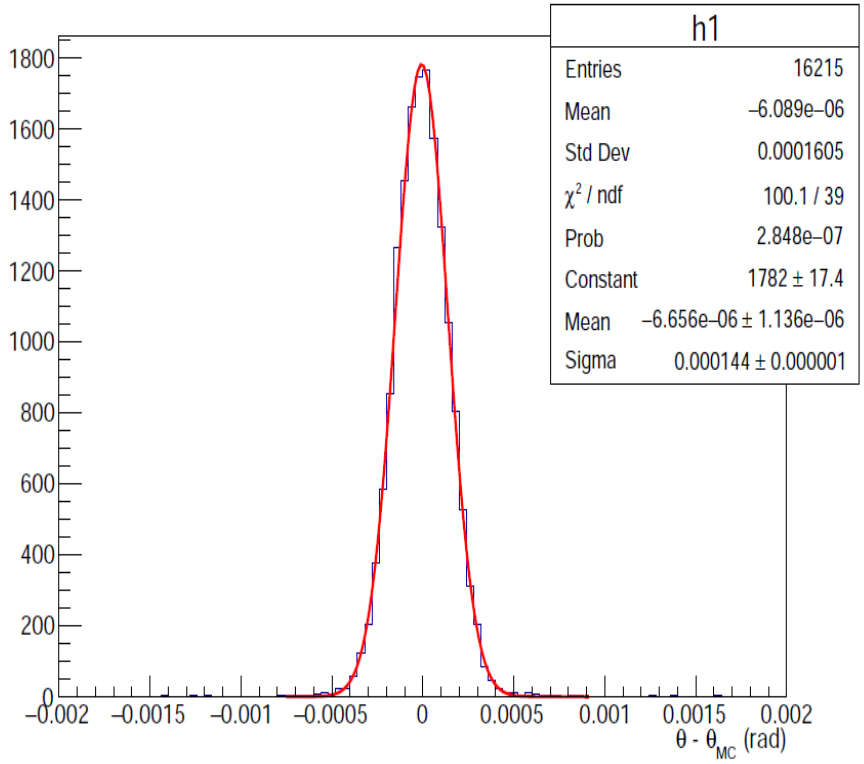
- Full sim with field map
- Fed then to LumiCalClusterer

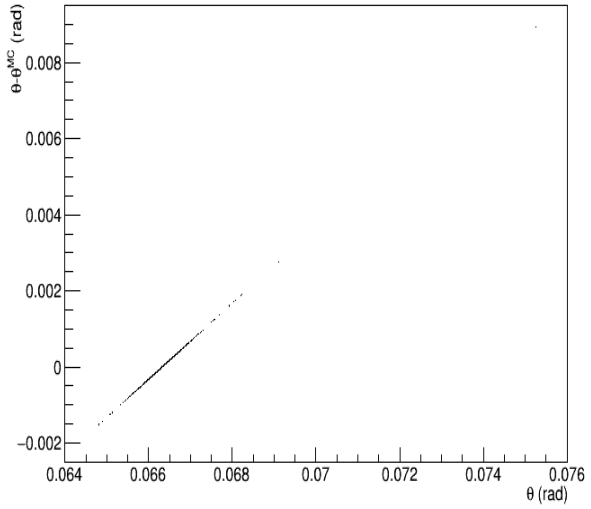
Used Log weight method

Performed scan to find the constant providing the best resolution

Obtained: σ_θ = 1.44 x 10^{-4} rad, Δθ = 6 x 10^{-6} rad

- Induced error due to resolution: $\Delta L/L^{\sigma\theta}$ = 7±3 x 10^{-5}
  - Study Bhabha sample, require std coincidence criteria
  - Smear all polar angles according to the resolution
- Induced error due to bias:
  - Formula $\Delta L/L = 2\Delta\theta/\theta_{min} = 2x10^{-4}$
  - Similar results from event to event analysis
  - Optimal Z position of the hit?
    - Sensitive volume vs middle of the layer





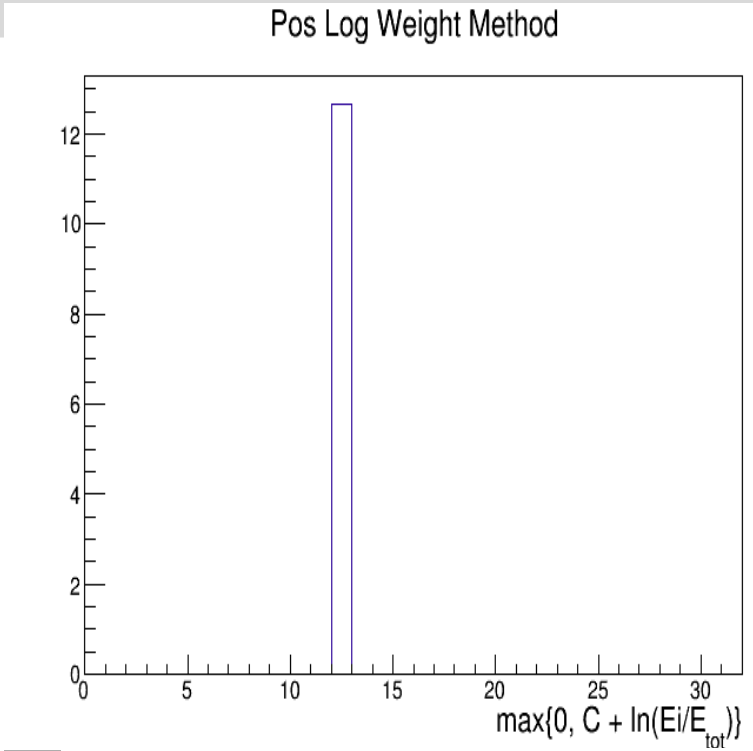
φ angle reconstruction

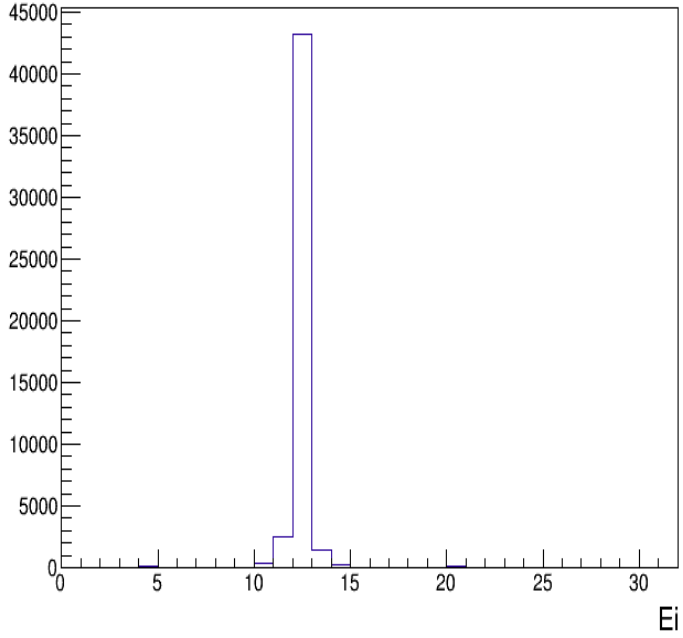
Using std configuration, we get φ resolution ~ 0.053rad, very close to the expected digital one (0.06rad)

- Reasonable, since most of the times only one cell is used
  - Therefore the value close to digital resolution
- Also the plots show us why simple energy weighting method gives best results than log weighting
  - So, σ_φ(log) = 0.053 rad, σ_φ(E) = 0.027 rad
- Checked a LumiCal with 50% more azimuthal divisions (48 cells)
  - σ_φ(log) = 0.034 rad, σ_φ(E) = 0.014 rad

But the question is what σ_φ is required

- Φ resolution -> resolving between clusters (physics & beam bkg, γs)
  - Haven't perform such studies yet
  - Effect on EMD correction (presented in next slides)
  - $\Delta L/L^{EMD}_{\sigma\varphi}$ ~10^{-5} for σ_φ = 0.03rad



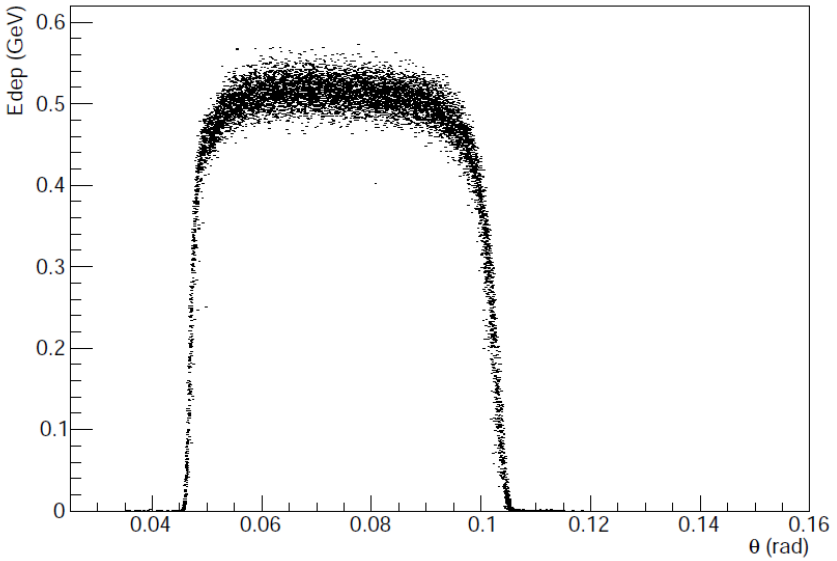


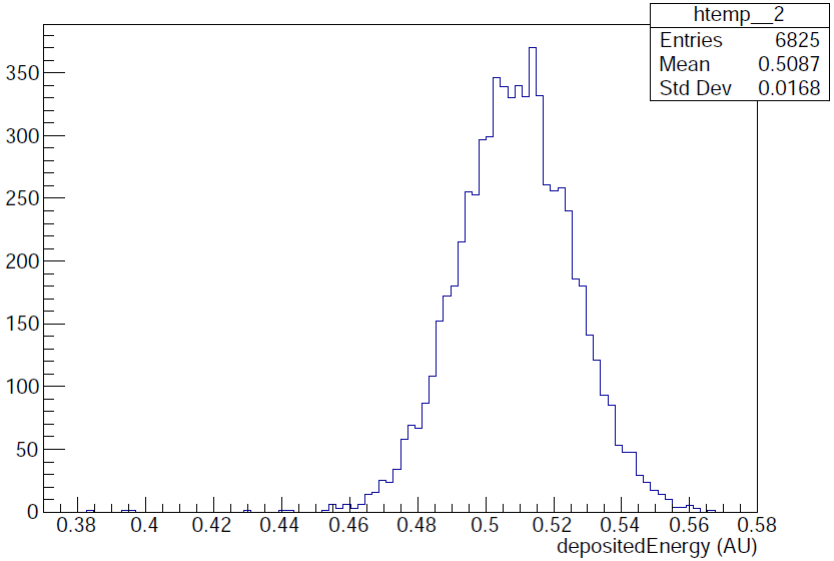
Energy resolution

$$\frac{\sigma_E}{E} = \frac{a_{res}}{\sqrt{E_{beam}}}$$

Shooting electrons of fixed E (45.6 GeV) to the LumiCal

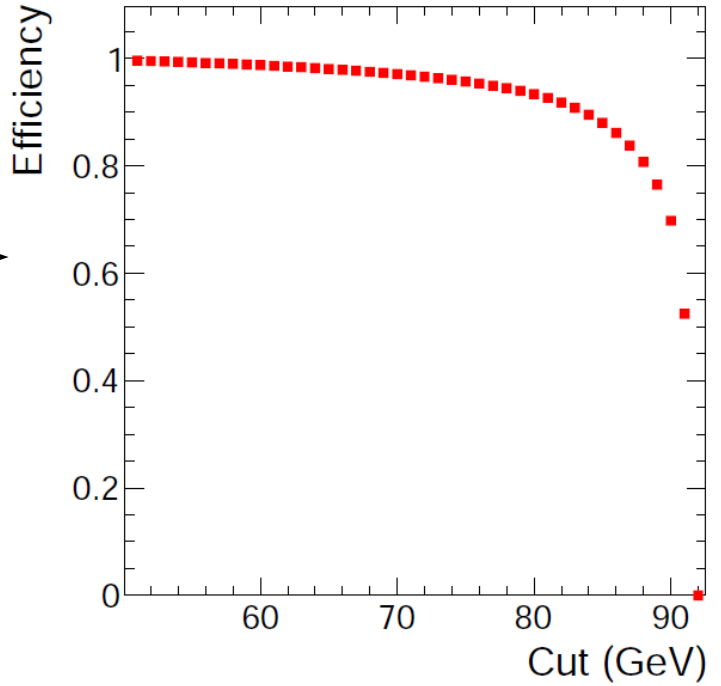
- Taking σ_E from RMS in FV range
- Then $\alpha_{res} = 0.22$
- Similar to ILC/CLIC as expected





Systematic due to energy resolution – on going

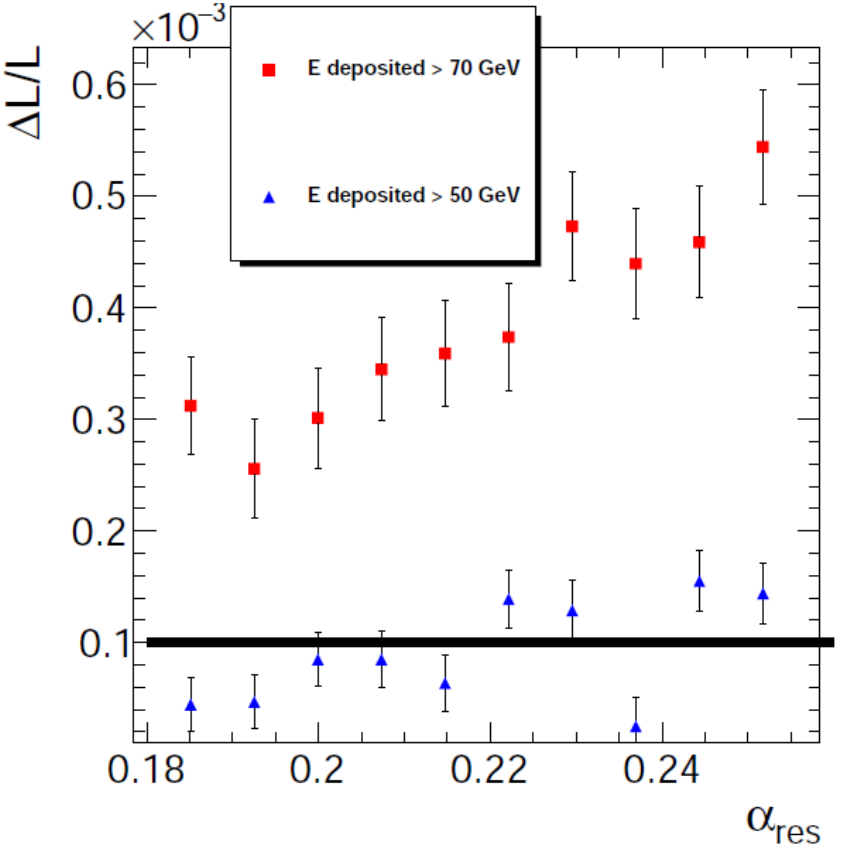
#coincidences (no Edep cut) / #coincidences (no Edep cut)



- Requirements on knowledge of E depend on how strict cut is applied on deposited E
- Value of cut depends on phys/machine bkgs
  - No such study performed yet
  - Value of cut not precisely known

Assumed 2 scenarios (Edep >50GeV & Edep > 70GeV)

- STD acceptance criteria, smear MC energies wrt to resolution
- Plot systematic due to energy resolution on Lumi measurement
- For stricter Edep cut →seems that a correction is needed



Beam bkg on LumiCal

Full sim studies of IR bkgs

- Main focus on √s = 91.2 GeV

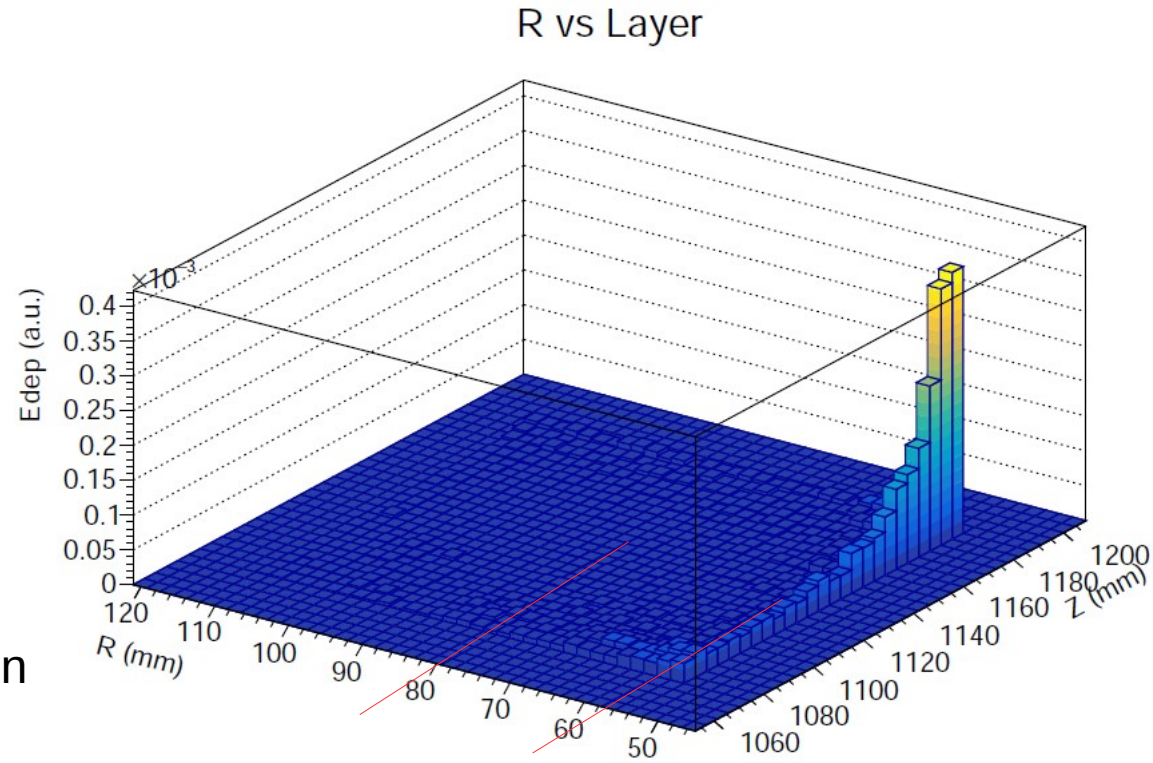
SR is effectively stopped by masking / beam pipe shielding to neglgible levels

- No hits recorded for √s = 91.2 GeV

First studied of bkg due to off-momentum particles coming from beam-gas interaction shown a negligible effect

IPC main source of bkg

- ~300MeV E dep on LumiCal
- Mostly concentrated at small radius close to the back of the calorimeter
  - Mostly outside the FV



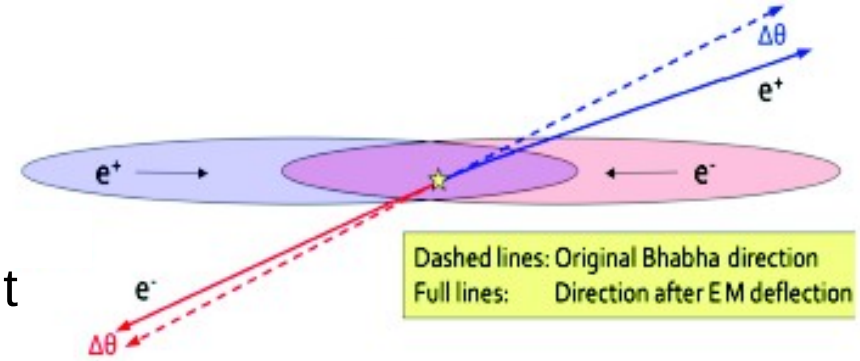
R-Z distribution of energy deposits in LumiCal from IPC particles (arbitrary units). Each bin corresponds to a calorimeter cell. (E_{cm} = 91.2 GeV). The 2 red lines are roughly indicating the fiducial volume.

EMD of Bhabhas

The particles will be focussed by the field of the opposite bunch

Change in their θ angle →bias in L measurement

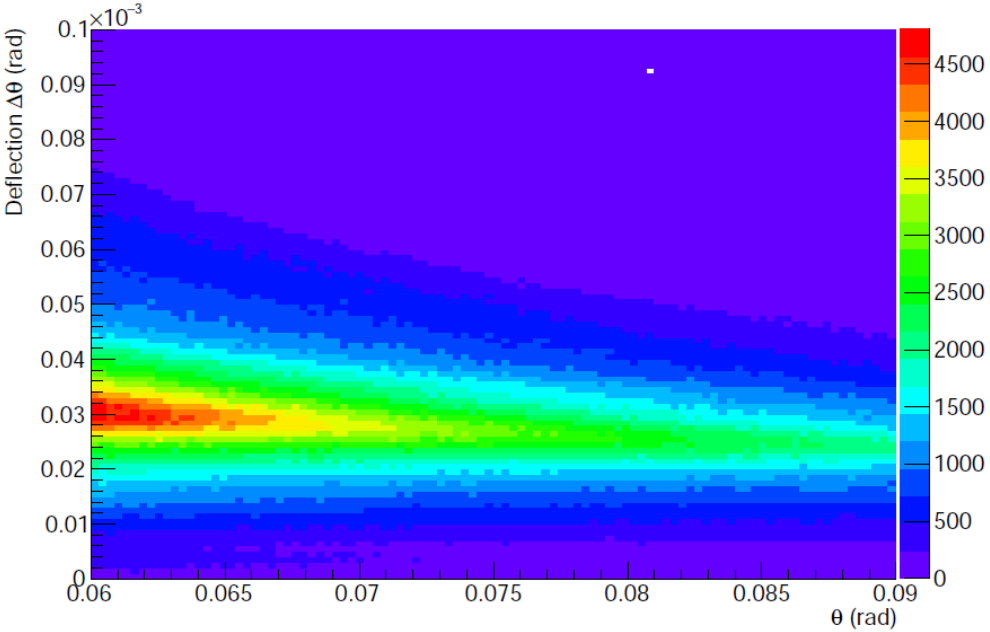
First studied for the ILC*



Simplified sketch for head-on collisions

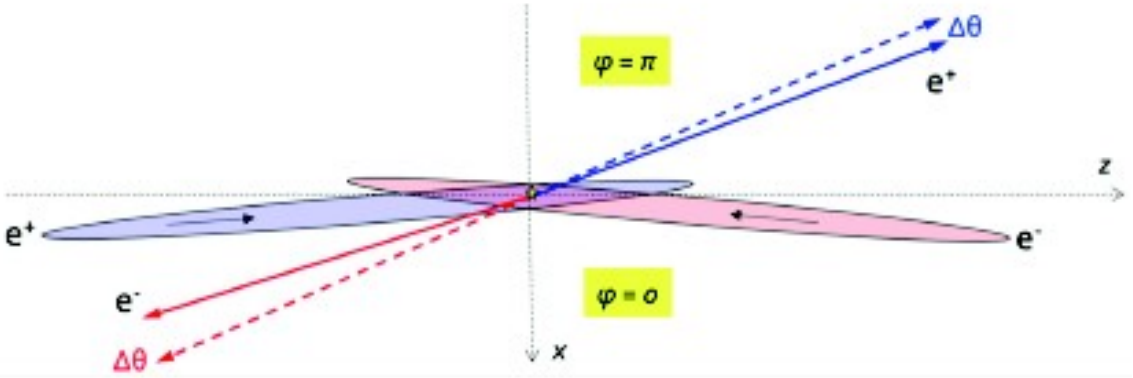
Mean deflection angle ~ 30μrad

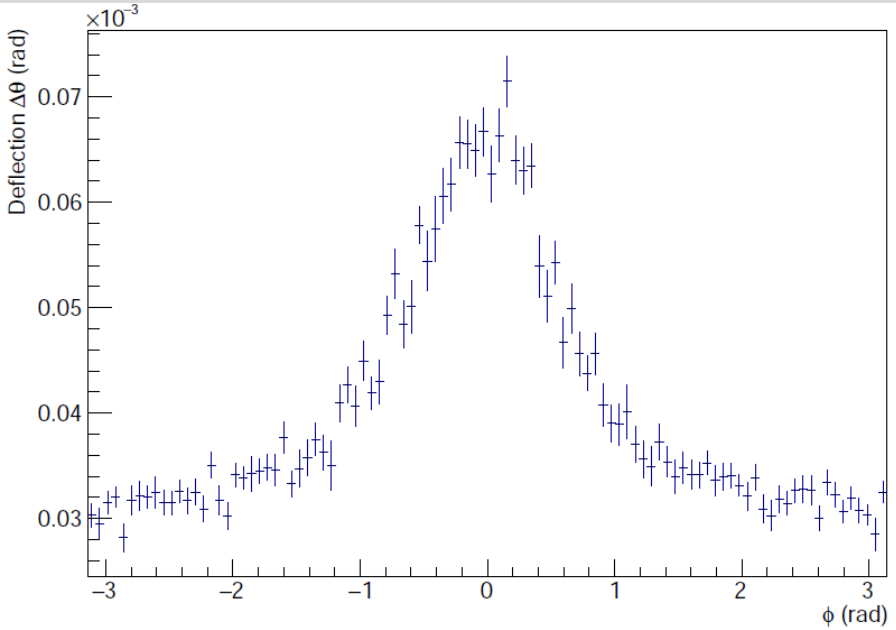
- Bias: ~15 larger than the precision
- Need to be corrected
  - 7% precision in the correction is required



* C. Rimbault et al, 'Impact of beam-beam effects on precision luminosity measurements at the ILC' JINST 2 P09001, September 2007

EMD & crossing angle





60 mrad < θ < 90 mrad
Typical LumiCal FV acceptance

The focussing is more pronounced for tracks going along positive X axis

- Electrons (positrons) emitted along positive x-axis are closer to the opposite positron (electron) bunch →the focussing is stronger

The expected φ asymmetry in LumiCal's counting rate can be exploited to provide a correction

Proposed correction (on going work)

The deflection angle cannot be measured

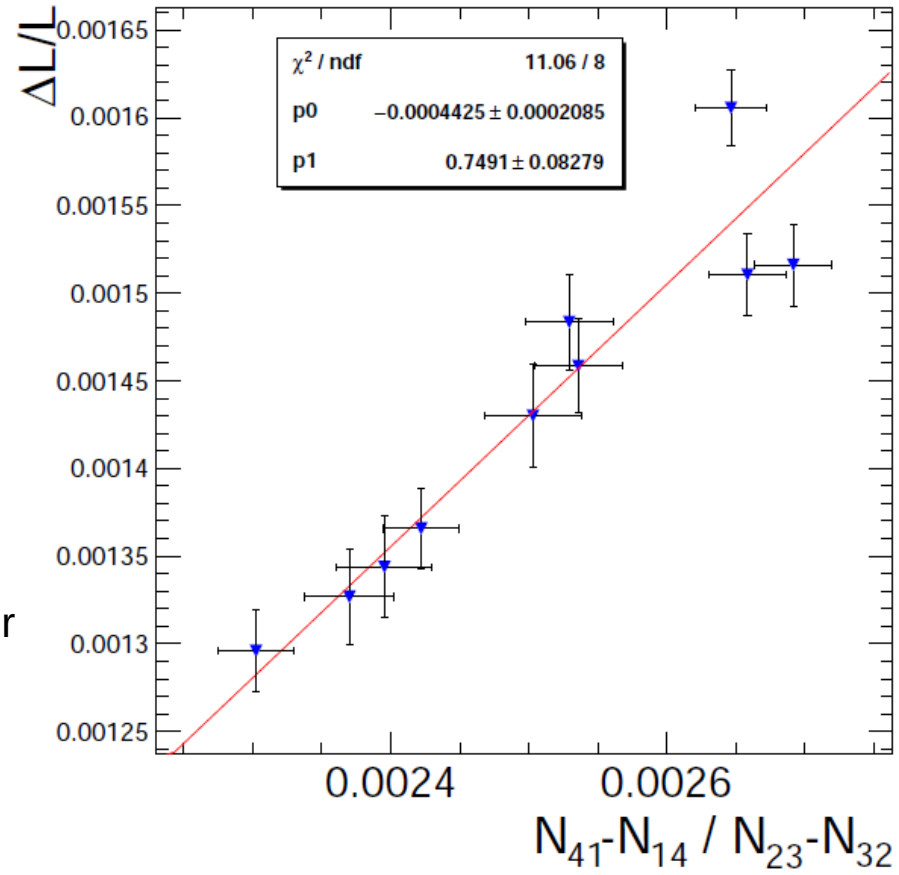
- The idea is: use GP simulations to calculate the asymmetry expected for various values of the bias $\Delta L/L^{EMD}$
- Measure the asymmetry in LumiCal from the data and then map it to the corresponding $\Delta L/L^{EMD}$

But we can map it versus the asymmetry A measured in LumiCal

- $\Delta\theta$ seems to be a linear function of A
- As a first step, to see the dependence on the various beam parameters, we run scans where 1 parameter was changed each time, and plot $\Delta L/L = f(A)$
- The obtained linear fits were consistent

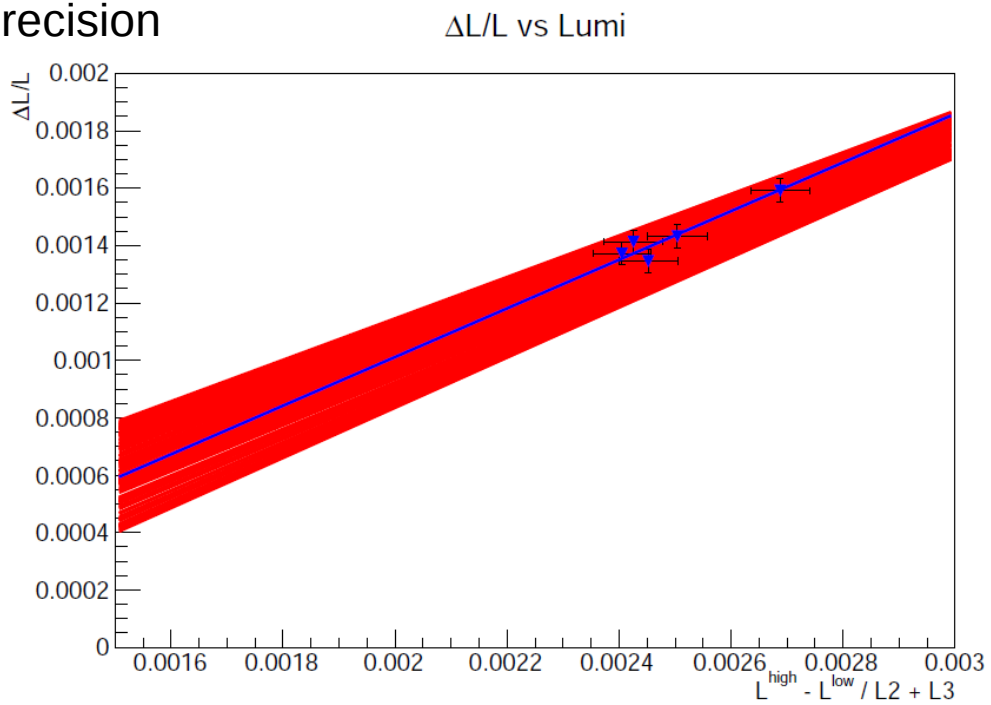
Then created 10 beam par. Sets

- All parameters were varied randomly inside expected limits around their nominal values
- The L bias seems to be indeed proportional to the measured asymmetry
- Data needed in order to correct with the required correction uncertainty can be collected in few min



Beam-beam effects & misalignment

Our first studies indicate that a knowledge of the relative transverse misalignment between the 2 LumiCal arms with a precision better than 10μmis required in order to correct for EMD with the required precision



Blue line: Fit obtained from the original (perfectly aligned) data

Red envelope: fits obtained from 1000 simulations, where in each of them one LumiCal arm has been randomly displaced in X within the range [-10μm, +10μm]

- Roughly: 10μm uncertainty in alignment knowledge will introduce a ~1.5x10^{-4} uncertainty in ΔL/L

Summary

source	Induced ΔL/L (x 10^{-4})	Correction
θ resolution	0.7 ± 0.3	no
Δθ	~2	needed
Φ resolution	N/A	
E resolution	N/A	
EMD	~15	Yes / on going

Not an exhaustive list

- For geometrical precision, see Mogens talk

To do

Study position/energy reconstruction in presence of beam bkgs

- Use of BeamCal clustering algo instead of LumiCal's one?

Understand better requirements on E/φ reconstruction

- Propose corrections in case they are needed

Finalise correction for bias coming from beam-beam effect