Beam Parameters Reconstruction Using Pair Monitor – can we do something more?

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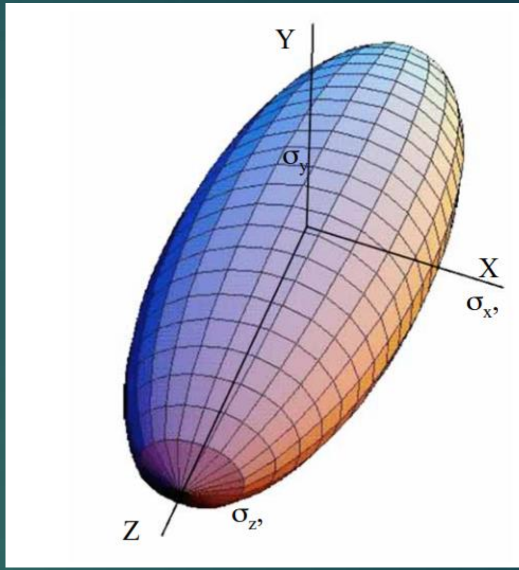
Overview

- ILC beam-parameters
- Instrumentation of the very forward region at ILC
- Pair-monitor
- Beamstrahlung at linear colliders
- (Why) do we need pair-monitor?
- Previous studies
- First results
- Proposal for extended study
- Summary

Beam parameters

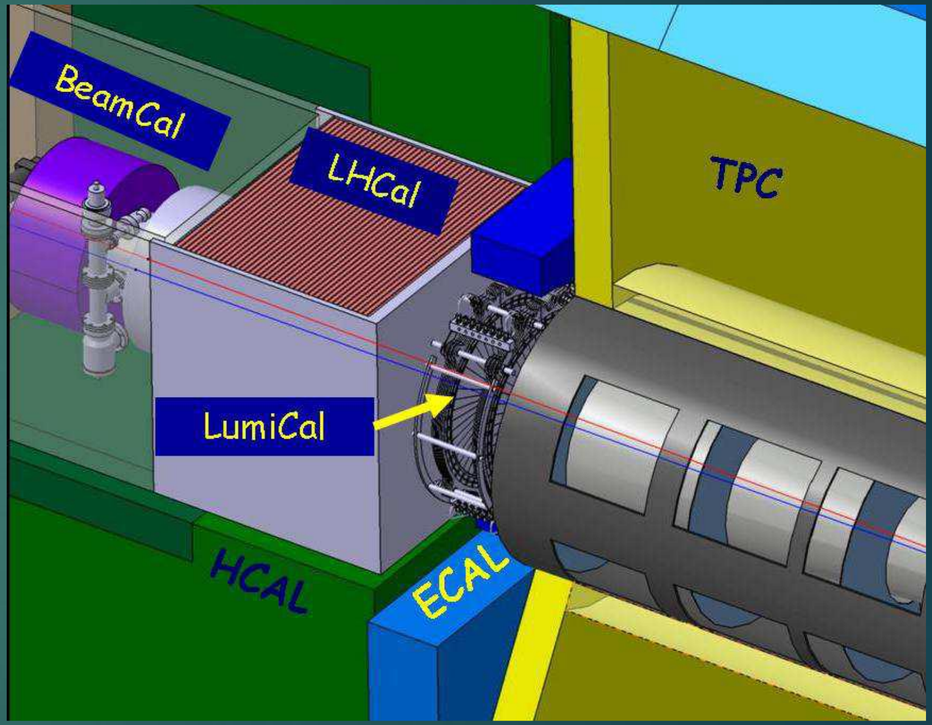
- ILC is projected to have several energy stages: 250 GeV, 500 GeV, 1 TeV
- Crossing angle: 14 mrad
- Luminosity: $L = \frac{N^2 * f_r * n_b^2}{4\pi * \sigma_x * \sigma_y} H_D$
- In order to maintain large luminosity (L $\sim \frac{1}{\sigma_x * \sigma_y}$) and to minimise beamstrahlung ($N_\gamma \sim \frac{1}{\sigma_x + \sigma_y}$) at ILC is chosen ellipsoid beam shape, i.e. $\sigma_x \gg \sigma_y$
- Small changes in beam transverse dimensions give large change in luminosity



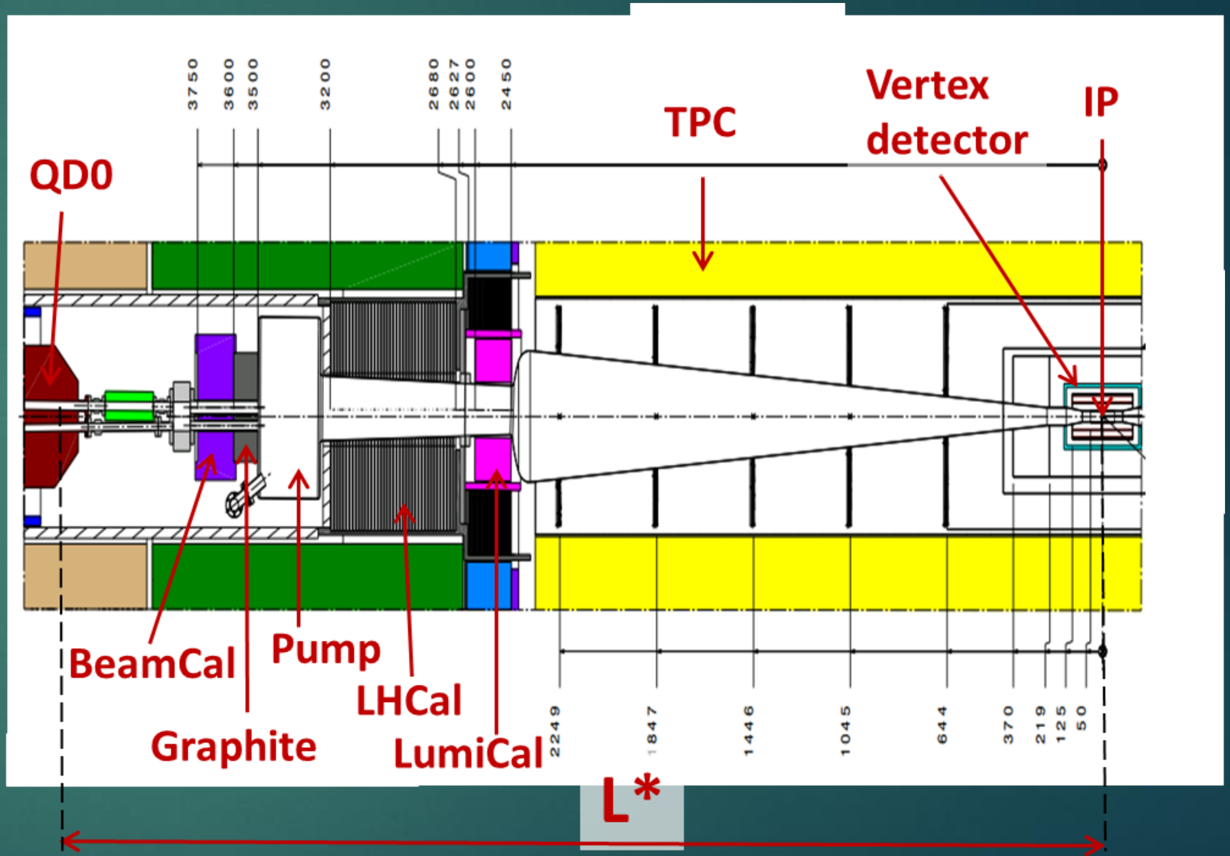
Energy (GeV)	Luminosity (fb^{-1})	Collision rate (Hz)	No of bunches	Bunches separation (ns)	Population (10^{10})	σ_x (nm)	σ_y (nm)	σ_z (mm)
250	250	5	1312	554	2	729	7.7	0.3
500	500	5	1312	554	2	474	5.9	0.3
1000	1000	4	2450	366	1.74	481	2.8	0.25

Instrumentation of the very forward region at ILC

- The very forward region at ILC consists of several detectors:
  - Luminometer (LumiCal) to provide precision measurement of integral luminosity
  - BeamCal for a fast luminosity monitoring, beam-tuning and high-energy electron identification
  - Low–angle hadron calorimeter (LHCal) hadron identification at low angles, separation between leptonic and hadronic showers
  - Pair monitor to assist beam-parameter determination, in particular σ_y
- Instrumentation in the very forward region improves detector hermeticity and extend coverage to small polar angles – down to 5 mrad.

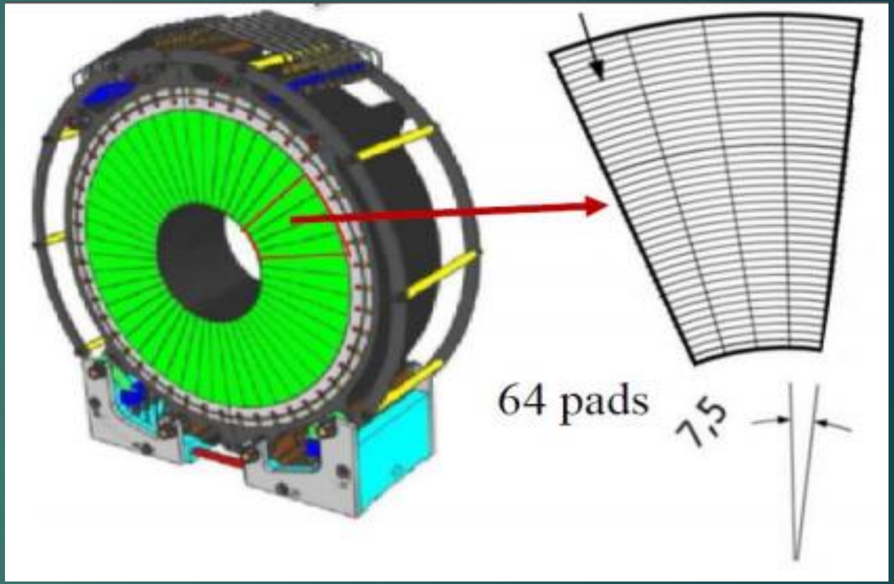


- Focal length L* = 4.1 m is the distance between IP and QD0 magnet.
- L* effectively determines size of a detector as a whole
- Anti-DiD field (0.02 T) is included, intended to lead pair backgrounds into the outgoing beam pipe.
- Very forward regions begins with LumiCal, which is positioned ~ 2.5 m from IP



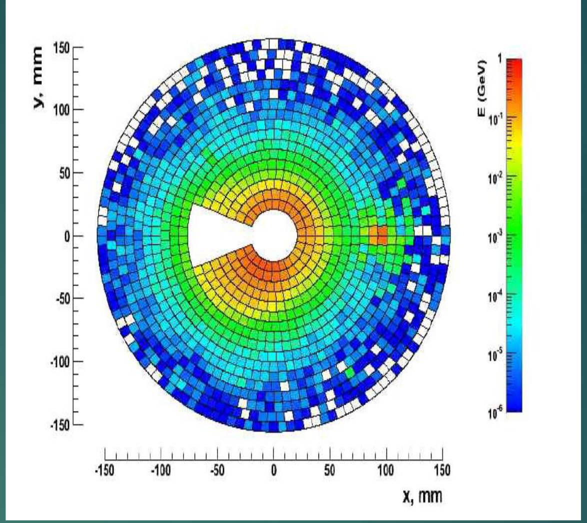
LumiCal

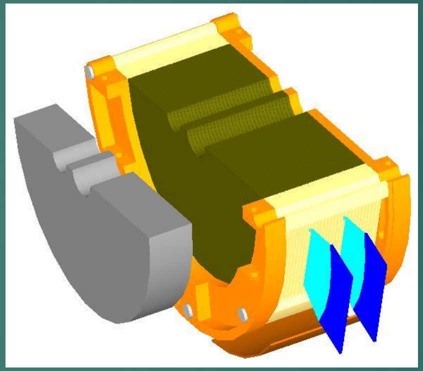
- Silicon-Tungsten sandwich calorimeter consisting of 30 layers
- 12 tiles divided into 4 azimuthal sectors (7.5 deg) and 64 rings with 1.8 mm pitch
- Each layer is 1 X_0 long, correcponding to 3.5 mm thick tungsten plates interleaved with 320 μm silicon sensors
- Coverage down to low polar angles (31 – 77 mrad)
- Compact calorimeter to identify EM showers from Bhabha events (small Moliere radius ≤1 cm)
- (Integral) luminosity uncertainty from the detector performance (E and θ resolution) ≤ $2 \cdot 10^{-4}$ [1]



BeamCal

- Si-W sandwich calorimeter consisting of 30 layers, sensors must be very radiation hard (1 Mgy/year)
- Several purposes:
  - Improving hermeticity down do low angles (5 – 40 mrad)
  - High-energy electron identification
  - Assisting beam diagnostics. Shape of the energy deposition from pairs helps reconstruction of the bam-parameters on bunch-by-bunch basis
  - In the single (beam) parameter determination uncertainties are below 10% (4.3%, 8.3%, 1.2% for σ_x, σ_y, σ_z) [2]
  - In simultaneous beam-parameters measurement correlations appear, boosting uncertainties several times
  - Bhaba scattering (1/10 BX) seems not to degrade severely beam-parameter measurement [2]



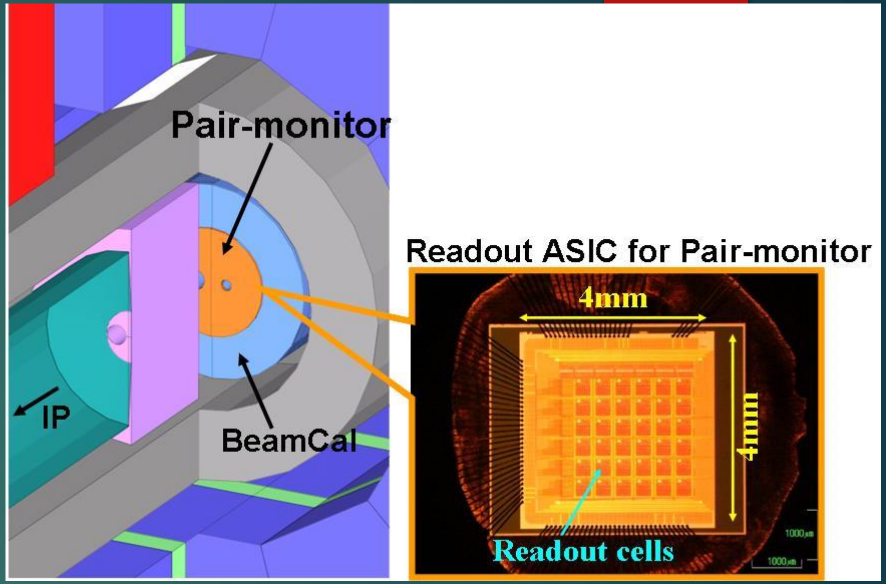


		Unit	14 mrad
0.8 R_M cell size	Rings	int	16
	ΔR	mm	8.125
	Sectors	int	8 of 45 degree
	Cells per sector	int	160
	Cells/layer	int	1280
	Blind area	degree	±22.5 around incoming beam, rings with R>63.4 are complete (n > 6)

parameter	unit	nom.	14 mrad, no E_γ	14 mrad, with E_γ
σ_x	nm	655.0	654.7 ± 2.8	653.7 ± 1.3
σ_y	nm	5.7	5.63 ± 0.47	5.61 ± 0.39
σ_z	μm	300	305.7 ± 3.6	300.8 ± 1.7

Pair Monitor

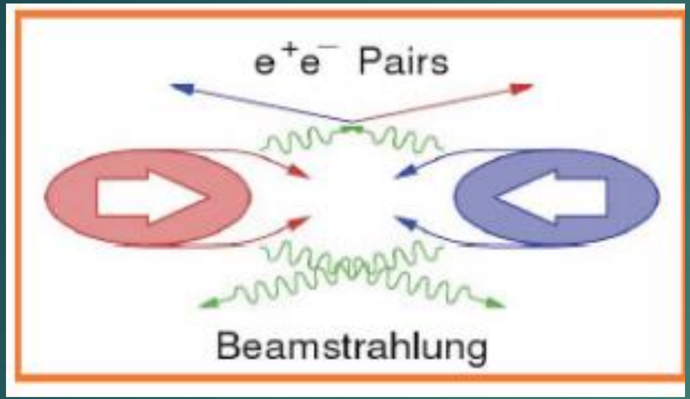
- Pair Monitor is a highly segmented silicon detector located in front of the BeamCal
- It is followed by a graphite shilled, preventing contamination of the tracking volume (but also Pair monitor) from particles backscattered from the BeamCal
- Pair Monitor can measure beam profile at the IP by measuring distribution of Beamstrahlung pairs

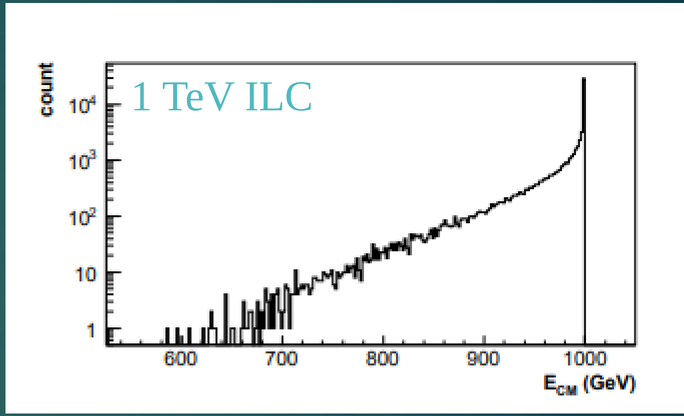


Pair Monitor parameters	
Sensitive area	10 cm
Thickness of sensor layer	0.3 mm
Tilt angle	7 mrad
Pixel size	0.4 mm × 0.4 mm
Total number of readout pixel	190 000
Hole radius (Upstream)	1 cm
Hole radius (Downstream)	1.8 cm

- Pair monitor can provide separate measurement to the one with the BeamCal
- Possibly can improve beam-parameter determination (in particular σ_{y},)
- An updated study is needed

Beamstrahlung at linear colliders

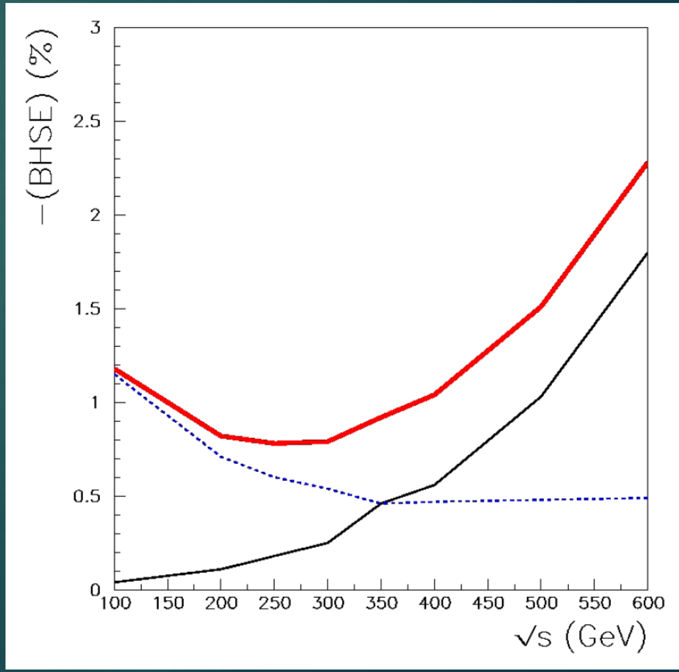




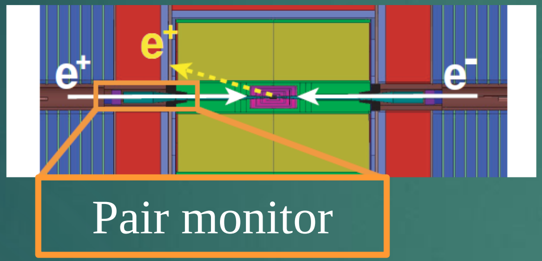
- Strong EM field of the opposite bunch force initial state (electrons and positrons) to radiate photons (Beamstrahlung)

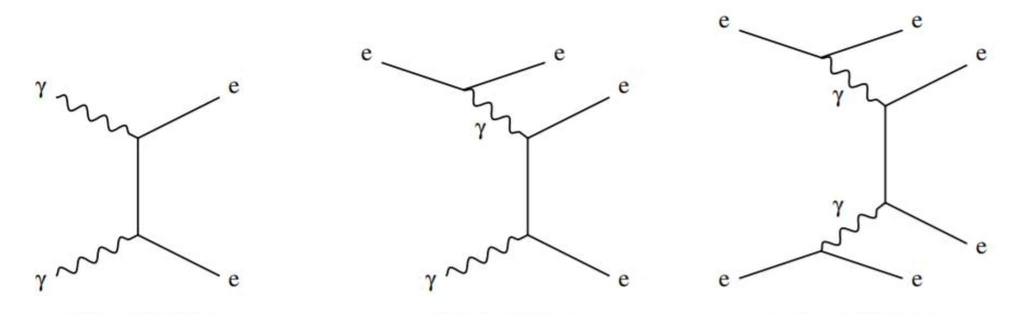
$$\Delta E \propto \Upsilon^2 \sigma_z \propto \frac{N}{(\sigma_x + \sigma_y)} \frac{N}{(\sigma_x + \sigma_y)\sigma_z}$$

- Emission of Beamstrahlung changes the four-momenta of both initial and final state particles (Bhabha scattering) causing a tail in the luminosity spectrum (than can be corrected [3])
- The effect is more pronounced at high center-of-mass energies [4]



- Beamstrahlung photons are emitted at angles < 1 mrad w.r.t. the primary beam
- Small fraction of BS photons convert to e^+ e^- pairs via incoherent processes.





(a) Breit-Wheeler (b) Bethe-Heitler (c) Landau-Lifshitz

- Particles with opposite charge w.r.t. the oncoming beam will oscillate in the EM field of the oncoming beam and will be scattered at very small angles
- Same-charge particles will be deflected at larger angles ~mrad (i.e. hitting the Pair monitor) carrying the information about the EM field of the (oncoming) beam
- EM field properties are strongly correlated to the beam parameters

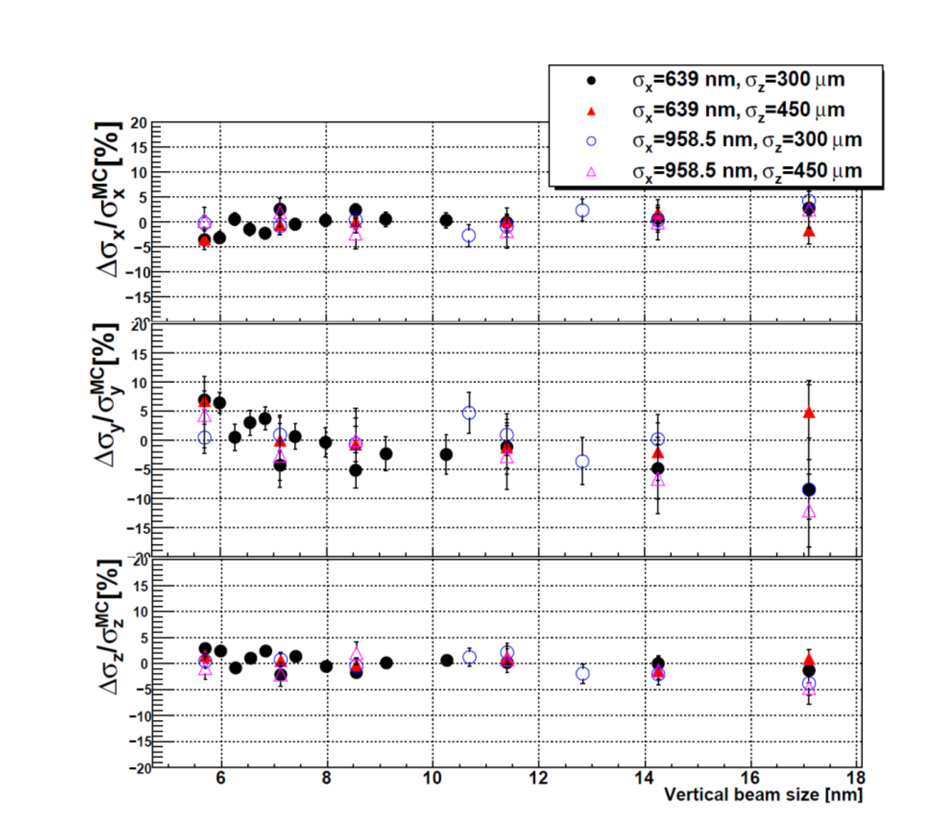
(Why) do we need Pair Monitor ?

- Changes in horizontal and vertical beam dimensions leads to large luminosity changes and have to be checked on bunch by bunch basis
- Relative uncertainties of σ_x and σ_y translates into luminosity uncertainty
- In addition, other measurements depends on the uncertainty of beam-parameters (i.e. correction of EMD in integral luminosity measurement [5])
- Sufficient number of incoherent pairs (~10^5) is produced per BX to enable such measurement

- Is it possible to improve BeamCal measurements of σ_x , σ_y , σ_z with a Pair monitor?

Status of the previous studies

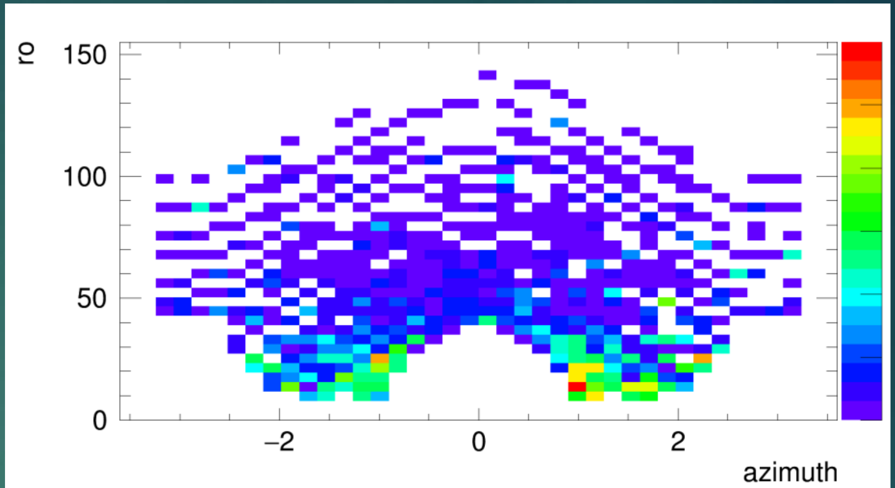
- The latest study of the has been done at 2009 In GLD setup where pair monitor was located 400 cm from IP, needs to be tested with new ILD geometry where pair monitor is closer to the IP– 311 cm.
- The study is done at 500 GeV and ILC will be operated (at first) at 250 GeV.
- Measurement accuracies 5.1%, 10.0% and 4.0% for σ_x, σ_y, σ_z are found, integrated over 50 BX crossings
- Total number of particles, shoulder radius and r-ϕ distribution gave sensitive observables
- The method used second order Taylor expansion of sensitive observables over beam paramters
- Moore Penrose inverse matrix is used to recover beam parameters from the measured observables

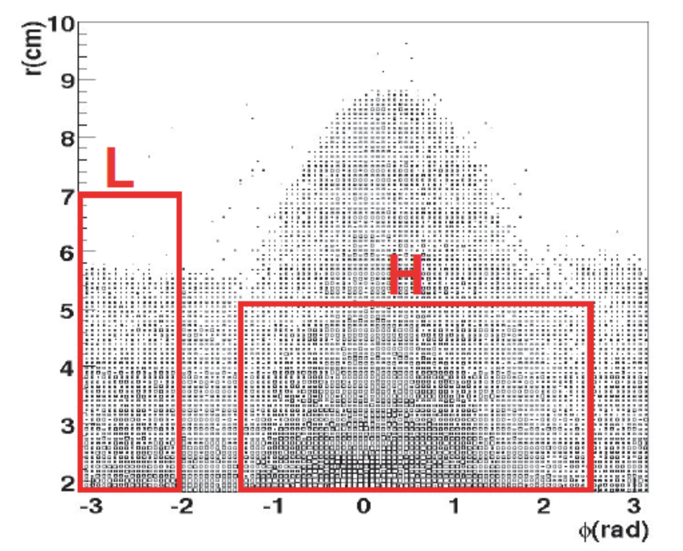


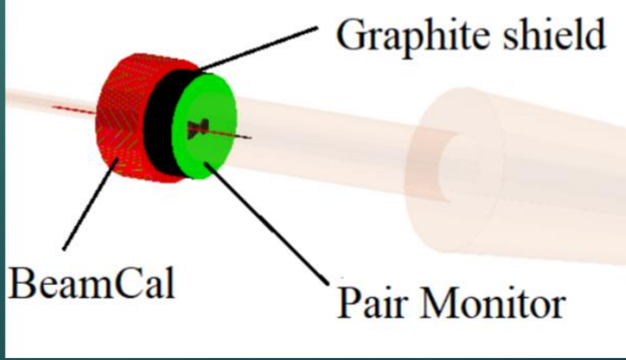
First results

- Simulation:
  - 500 GeV with nominal beam parameters
  - Guinea Pig V 1-4-4
  - 9 BX
  - ~ 185000 electrons in the pair monitor
- Detector:
  - Distance from the IP 311 cm
  - Segmentation: 1344 pixels
  - There are two holes whose radius are 1.0 cm and 1.8 cm for the incoming and outgoing beams, respectively.

Managed to reproduce results from [7]







Proposal for extended study

- Simulate state-of-the art design with the state of the art tools
- …at all ILC energies
- Are more variables giving better results?

In example, [7] using only r-ϕ denisities gives better precision in σ_y than [6] using multiple variables (but with different statistics)

- Similarly to BeamCal, additional variables can be tried:
  - Total number of particles: N_{TOT}
  - Vertical count imbalance: $(U - D)/N_{tot}$
  - Horizontal count imbalance: $(R - L)/ N_{tot}$
  - Diagonal count imbalance: $((N_{UR} + N_{DL}) - (N_{UL} + N_{DR}))/ N_{tot}$
  - Direct forward backward asymmetry: A_{dir} (forw) = $(N_{UF} - N_{UB})/(N_{UF} + N_{UB})$; A_{dir} (back) = $(N_{DF} - N_{DB})/(N_{DF} + N_{DB})$
  - $R_{shoulder}$ and R-Φ distribution
- How to properly take into account correlations (for simultaneous fit)?
- Can tools like MVA be employed?

Summary

- There are studies done for the Pair monitor, but not with the currently proposed energies and design for ILC
- There is a room for an update, but also for an attempt to improve precision, in particular for σ_y
- It is worth investigating if additional sensitive observables can be used
- Measurement of beam parameters could employ novel techniques i.e. MVA

References

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