Luminosity Energy Polarization Status

Ken Moffeit
3 March 2009

Documentation

Status of Linear Collider Beam Instrumentation Design, D. Cinabro, E. Torrence and M. Woods, LCD-ALCPG-03-0001 (2003). May 2003

Executive Summary of the Workshop on Polarization and Beam Energy Measurements at the ILC, J. List, K. Mönig, K.C. Moffeit, G. Moortgat-Pick, S. Riemann, P. Schüler, E. Torrence, M. Woods, et al,, ILC-NOTE-2008-047, August 2008

Polarimeters and Energy Spectrometers for the ILC Beam Delivery System, S. Boogert, M. Hildreth, D. Käfer, J. List, K. Mönig, K.C. Moffeit, G. Moortgat-Pick, S. Riemann, H.J. Schreiber, P. Schüler, E. Torrence, M. Woods, ILC-NOTE-2009-049, February, 2009

Luminosity Energy Polarization Status

Luminosity and dL/dE

LumiCal -- precision measurement — see also Takashi Maruyama's talk
BeamCal -- beam tuning — see also Takashi Maruyama's talk
GamCal-- beam tuning

Energy

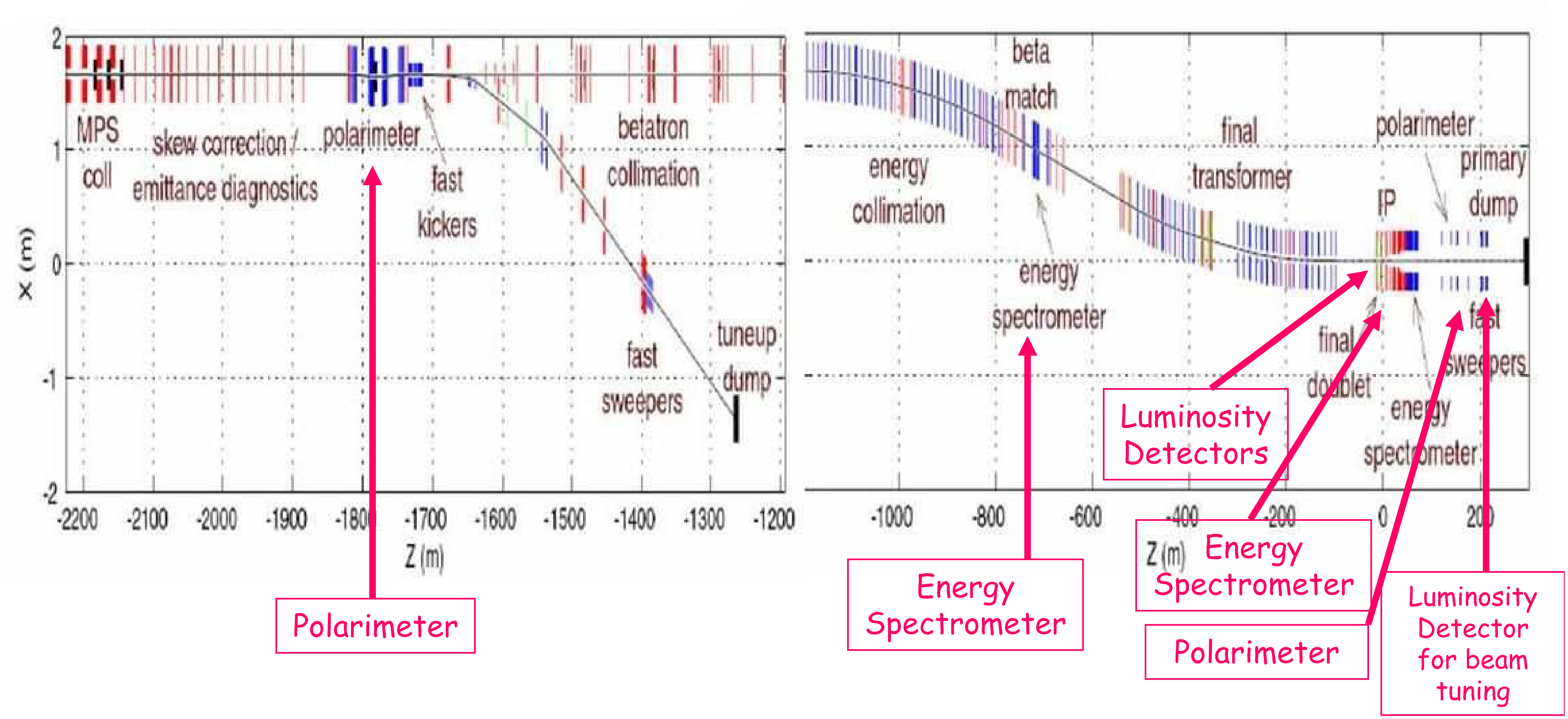
Measure top mass to 100 MeV.
Standard Model Higgs to 50 MeV.
Implies measuring luminosity-weighted mean collision energy to a level of $(1 - 2) \cdot 10^{-4}$

- Upstream BPM-based spectrometer.
- Downstream synchrotron imaging energy spectrometers similar to that used at SLC
  measure disrupted beam energy spectrum
- Luminosity-weighted beam energy from radiative physics data:
  W+W- pairs and $e^+e^- > \gamma Z$ (with Z decay to $\mu^+\mu^-$)
- Precision energy measurement during Z-pole calibration data taking

Polarization

$P_{e-} > 80\%$ $P_{e+} > \sim 30$ to 45%
Spin rotations systems for both electrons and positrons and helicity flip for both e^+ & e^-
Polarization measurements to a precision of dP/P=0.25%
Upstream and downstream polarimeters for both electrons and positrons.
Polarimetry will be complemented by e^+e^- collision data, where processes like W pair production can provide an absolute scale calibration for the luminosity-weighted polarization at the IP, which can differ from the polarimeter measurements due to depolarization in collision.
Precision polarization measurement at the Z-pole during calibration taking: Understand polarimeter and precision EW physics results.

Luminosity, Energy and Polarimetry Measurements at ILC



Beam Delivery System showing the locations of the polarimeter chicane 1800m upstream of the IR and the energy spectrometer 700 m upstream of the IR. The location of the extraction line energy spectrometer and polarimeter are shown on the right side of the figure along with the location of the luminosity detectors.

Luminosity

RDR 4.3.1 Luminosity

Precision extraction of cross sections depends on accurate knowledge of the luminosity. For many measurements, such as those based on threshold scans, one needs to know the luminosity as a function of energy, dL/dE. Low-angle Bhabha scattering detected by dedicated calorimeters can provide the necessary precision for the integrated luminosity.

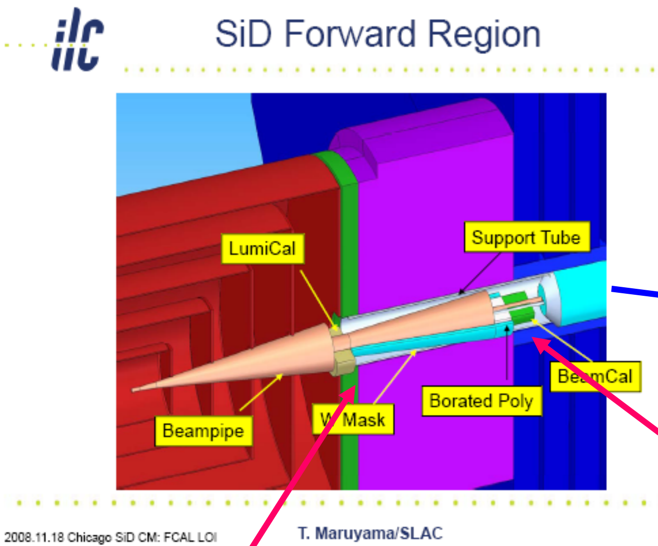
LumiCal - precision measurement of luminosity: **Calorimetry in the polar angle region from 40-120 mrad** Acollinearity and energy measurements of Bhabha, e+e– > e+e– events in the polar angle region from 120-400 mrad can be used to extract dL/dE and are under study. Additional input from measurements of the beam energy spread and beam parameters that control the beamstrahlung spectrum will improve this determination of dL/dE.

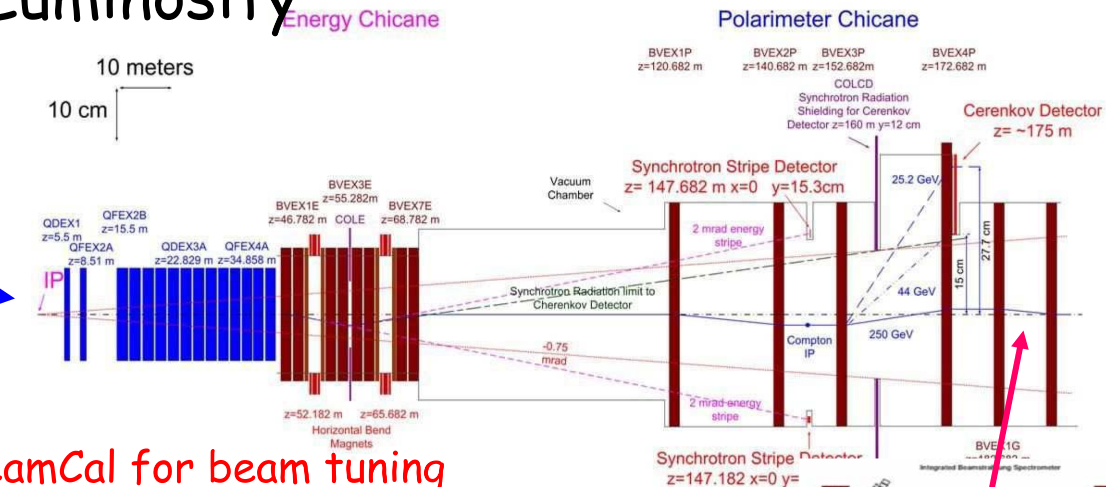
BeamCal – beam tuning: Techniques include measuring the angular distributions of e+e– pairs in the polar angle region from 5-40 mrad

GamCal – beam tuning: detect forward beamstrahlung gammas

All the proposed detectors may also be used for real time luminosity monitoring and tuning.

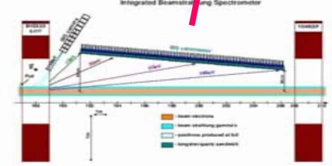
Luminosity





BeamCal for beam tuning
location is in a high radiation environment. This is an integral part of the SiD detector.

GamCal for beam tuning



LumiCal for SiD Detector
(see talk by T. Maruyama)

Bhabha scattering $e^+ e^- > e^+ e^-$ at small angles (~44 to ~86 mrad)

Luminosity precision goal $\Delta L / L < 10^{-3}$

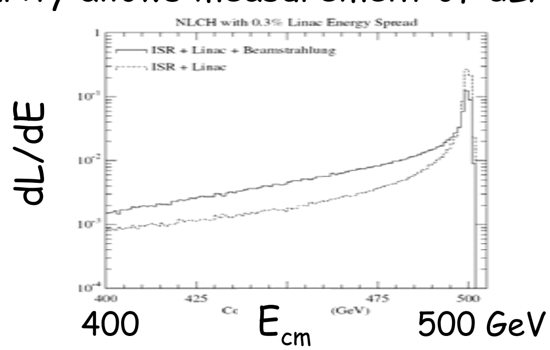
10^6 W+W- events in 5 years (500 fb-1)

$\Delta\theta$ is main systematic error.

$\Delta\theta$ must be less than ~20μrad to reach $\Delta L/L = 10^{-3}$

Detector radial location must be know within 30μm.

Acolinearity allows measurement of dL/dE



GamCal measures Beamstrahlung Photons

Power(γ) ≈ 2% Power(e) ≈ 0.3MW Nγ ≈ 1.5Ne ≈ 3×10^{10} /BX

Small radiation length convertor (e.g. gas target) gives e+e- pairs from beamstrahlung photons.
Dipole magnet gives P_t kick of 0.25 GeV/c
Calorimeter measures 1-10 GeV positrons.

BeamCal measures Beamstrahlung Pairs

Bethe-Heitler: $\gamma e \rightarrow e\ e{+}e{-}$

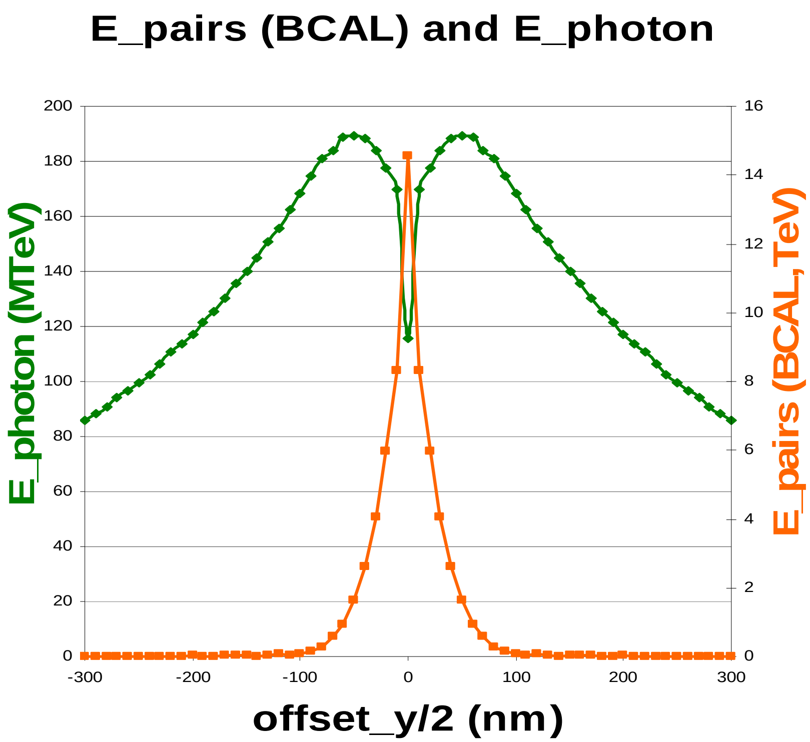
$\sigma_{BH} \approx 38$ mb ‹E› ≈ 1GeV

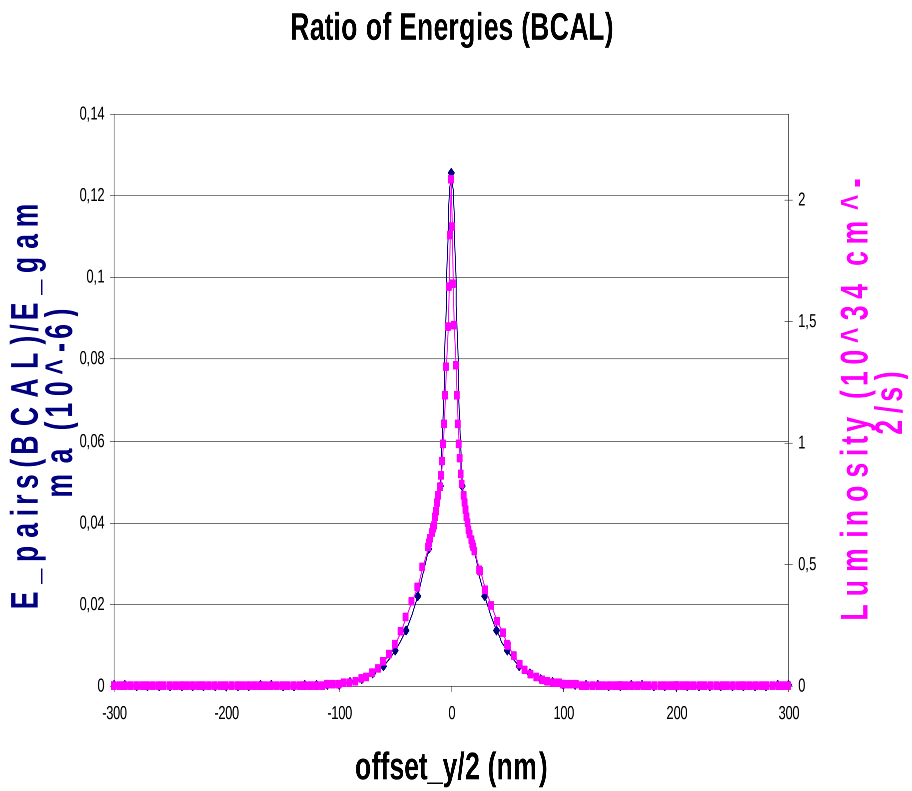
Landau-Lifshitz: $ee \rightarrow ee\ e{+}e{-}$

$\sigma_{LL} \approx 19$ mb ‹E› ≈ 0.15GeV

Ratio of BeamCal pairs to GamCal gammas is largely proportional to the instantaneous luminosity

GamCal and BeamCal signals for Vertical Offsets





complementary information from

1. total photon energy vs offset_y
2. BeamCal pair energy vs offset_y

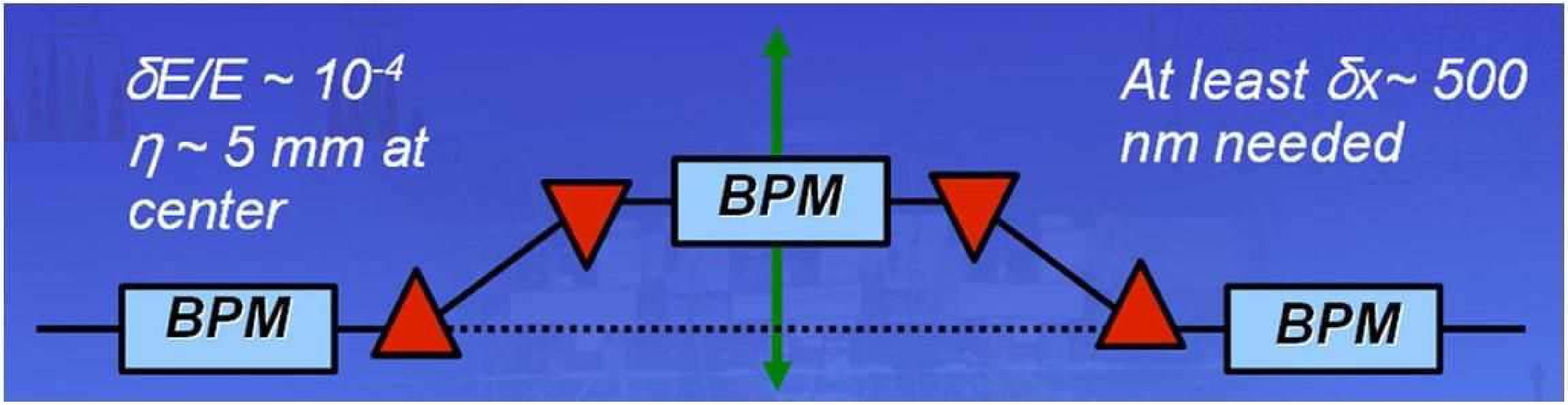
ratio of E_pairs/E_gam vs offset_y
is proportional to the luminosity

similar behaviour for angle_y, waist_y ...

see: William M. Morse, GamCal - A Beam-strahlung Gamma Detector for Beam Diagnostics

Statistical precision of 1% per beam crossing

Upstream Energy Spectrometer



Schematic for the upstream energy spectrometer using precision BPMs.

Located ~700 meter upstream of the IR

Precision measurements between 45.6 and 500 GeV

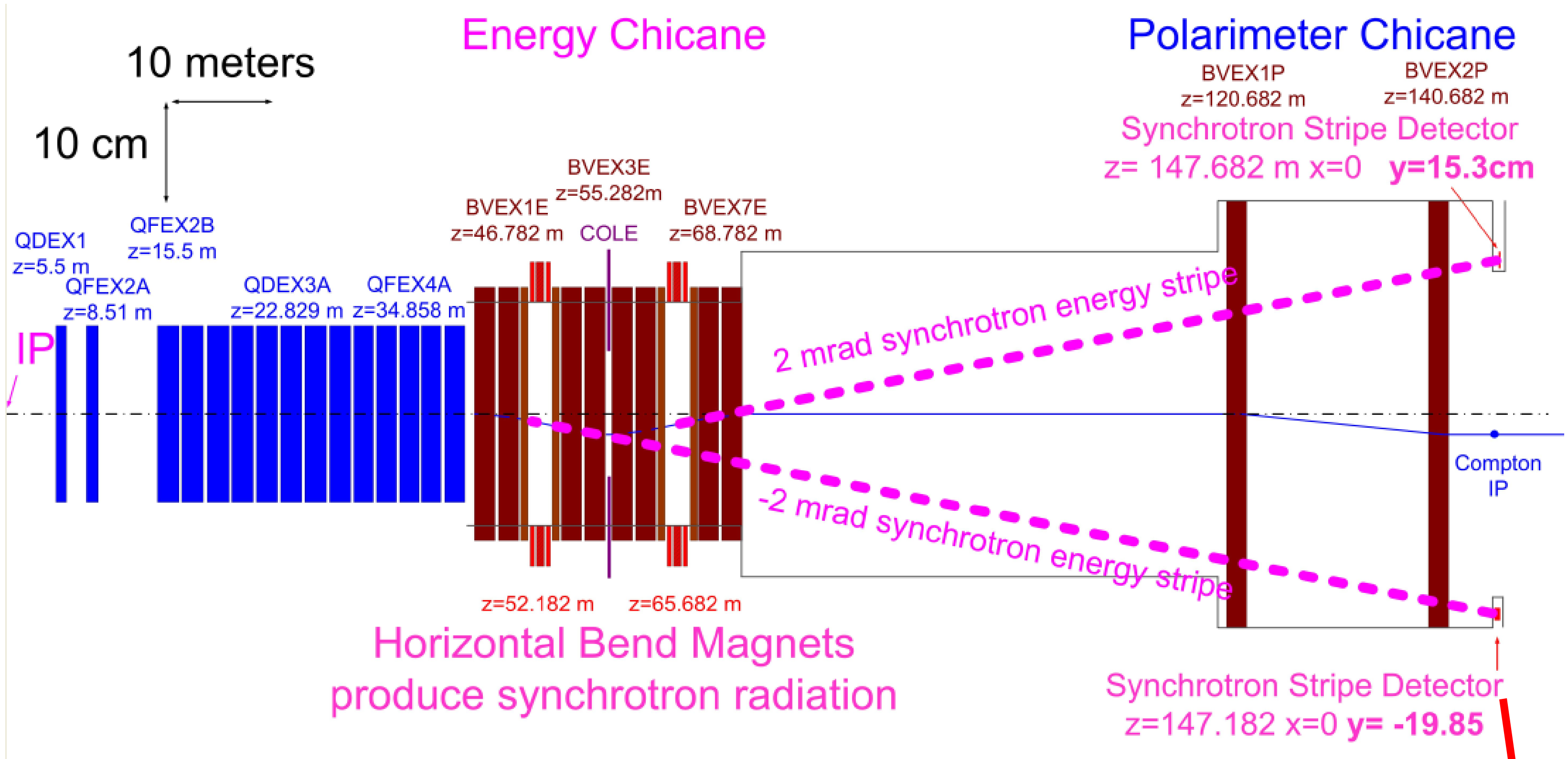
Note due to fixed dispersion magnets operate at low field at 45.6 GeV where field measurement may not be accurate enough.

T-474 End Station A test: 4 dipole magnets and high precision RF cavity BPM's with test beam similar to ILC expectation. System measured a resolution of 0.8 μm in x and 1.2 μm in y and was stable at micron level, which would translate to an energy precision of 200 ppm.

M. Slater et al., Cavity BPM system tests for the ILC energy spectrometer Nucl. Instrum. Meth. A592, 201-217 (2008)
A. Lyapin, B. Maiheu, F. Gournaris, M. Wing, D. Miller, University College London (UCL) M. Slater, D. Ward, M. Thomson, University of Cambrige S. Boogert, G. Boorman Royal Holloway, University of London (RHUL) M. Woods, R. Arnold, Z. Szalata, C. Hast, D. McCormick, J. Ng, C. Adolphson Stanford Linear Accelerator Center (SLAC) S. Kostromin, N. Morozov, V. Duginov Joint Insitute for Nuclear Research (JINR) Y. Kolomensky, M. Chistiakova, E. Petigura University of California, Berkeley and LBNL H.-J. Schreiber, M. Viti Deutsches Elektronen Synchrothron (DESY) M. Hildreth University of Notre-Dame

Extraction Line Energy Spectrometer

E. Torrence, Downstream Synchrotron Radiation Stripe Spectrometer Status, 2008 Workshop on Polarization and Energy Measurements at the ILC.



Vertical separation of synchrotron stripes is ~351 mm

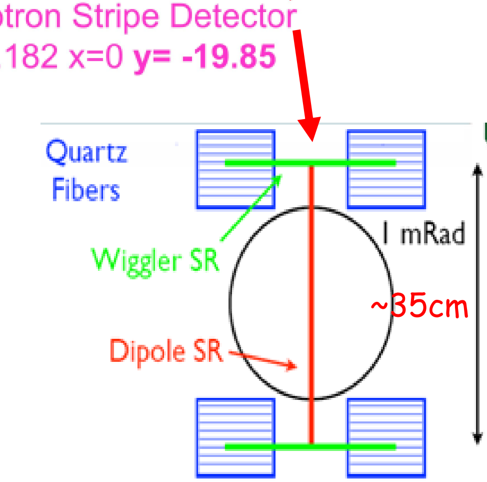
Goal for detector: Precision measurement of synchrotron stripes to ~40µm using radiation-hard 100 µm quartz fibers.

$\delta E_b/E_b \sim 1$ to $2 * 10^{-4}$

Systematic errors: Relative component alignment and magnetic field mapping.

Energy measurement between 45.6 GeV and the highest ILC energy of 500 GeV

Some information about the beam energy width can be extracted using information from the undisrupted energy spread and the disrupted beam energy distribution



Alternative Methods for Energy Measurement

Compton backscattering (Muchnoi, Schreiber and Viti)

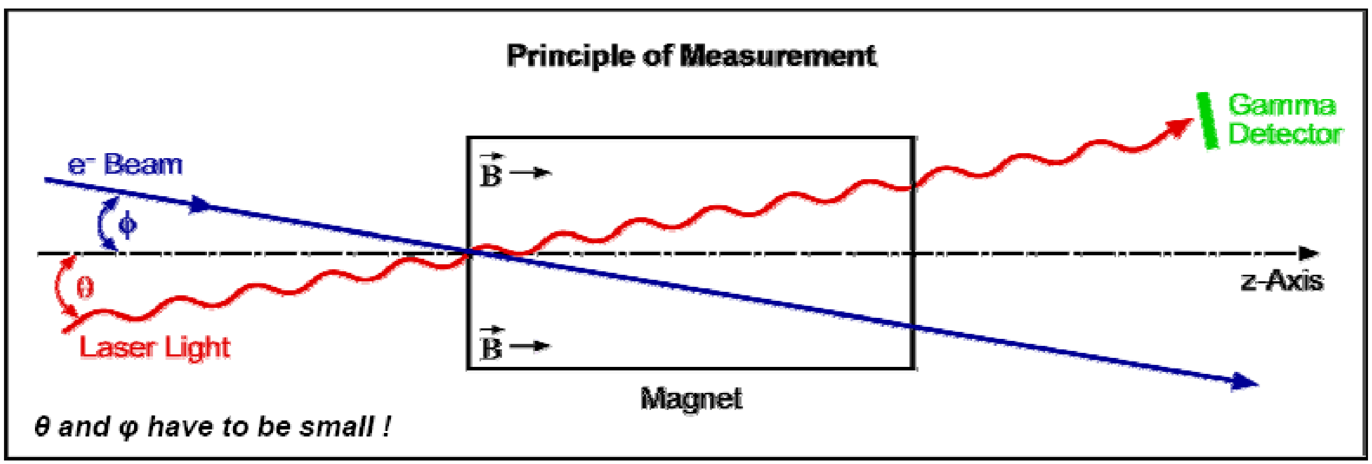
- A magnetic spectrometer (~25 m long)
- precise position of the electron beam 0.5 μm
- The centroid of the Compton Photons to 1 μm
- Kinematic edge of the Compton-scattered electrons of 10 μm

Synchrotron radiation (Hiller, Makarov, Schreiber, Syresin, Zalikhanov)

- In the dipole magnets of the upstream BPM-based spectrometer
- Measure edges of the synchrotron radiation fan.

MEASUREMENT OF THE BEAM ENERGY USING RESONANT ABSORPTION OF LASER LIGHT (R. Melikian, A. Ghalumyan)

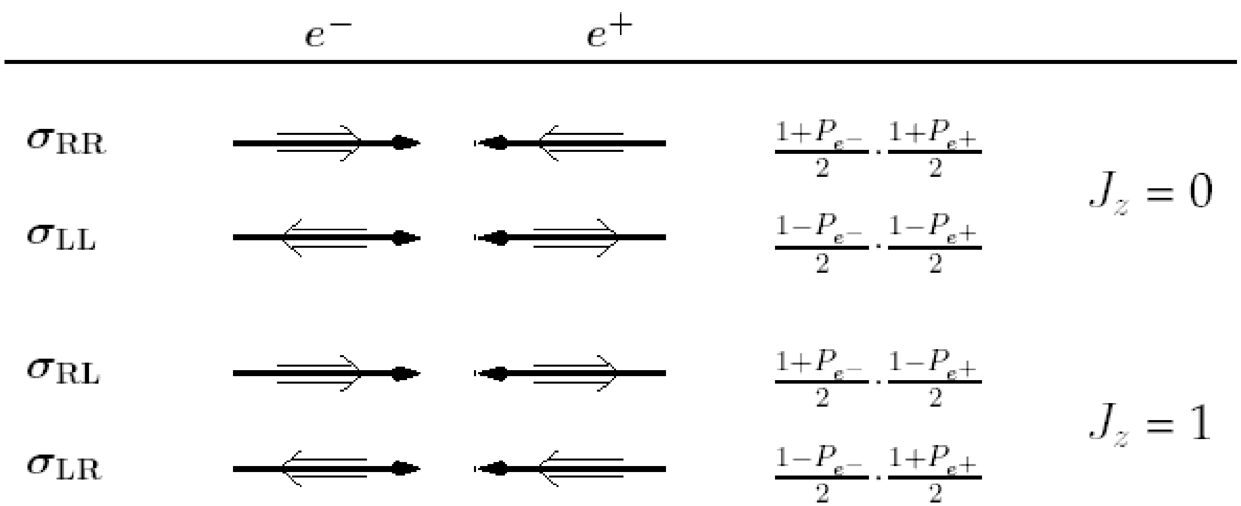
Absorption of circular polarized laser light by the beam particles in a static magnetic field permits to measure the beam energy with high precision, $\Delta E_b/E_b = 10^{-4}...10^{-5}$



Physics with polarized beams: motivation and requirements

$$\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4}\{(1+P_{e^-})(1+P_{e^+})\sigma_{\mathrm{RR}} + (1-P_{e^-})(1-P_{e^+})\sigma_{\mathrm{LL}} + (1+P_{e^-})(1-P_{e^+})\sigma_{\mathrm{RL}} + (1-P_{e^-})(1+P_{e^+})\sigma_{\mathrm{LR}}\}$$

σ_{RL} cross section e- beam is completely right-handed polarized ($P_{e-} = +1$)
e+ beam is completely left-handed polarized ($P_{e+} = -1$)

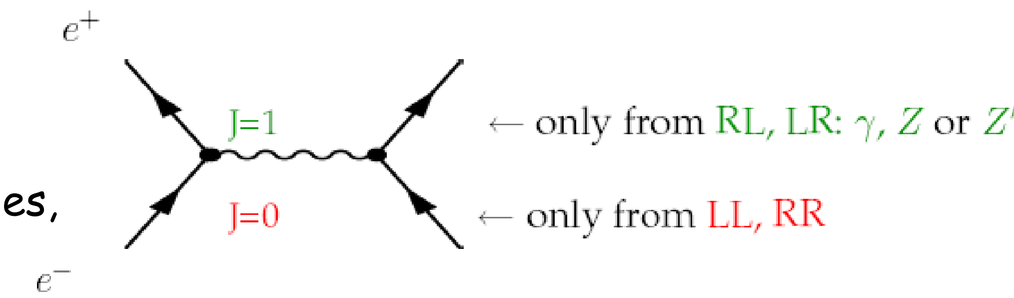


Physics with polarized beams: motivation and requirements

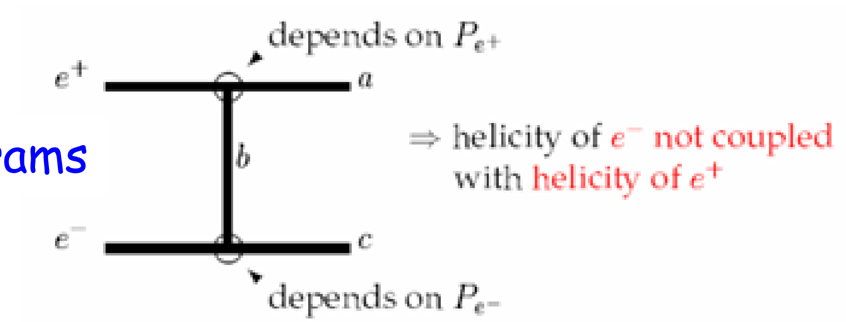
Annihilation diagrams

Standard Model only J = 1 is possible.

New Physics models:
- may contribute to J = 1
- may allow the production of scalar particles, J = 0 would be allowed

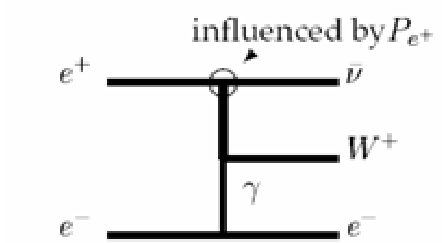


Exchange diagrams



T- and u- channel diagrams

The helicity of the incoming beam is directly coupled to the helicity of the final particle and is completely independent of the helicity of the second incoming particle.



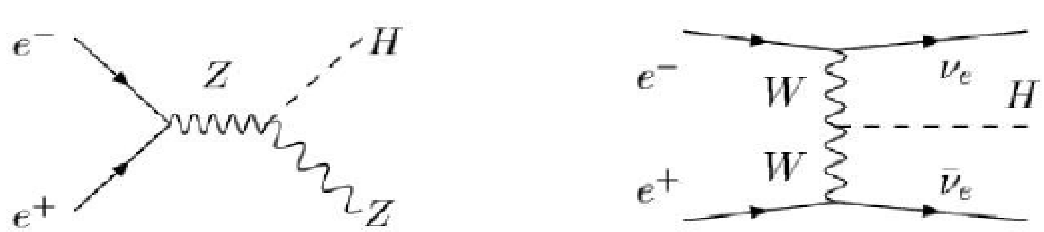
Single W^+ production: the vertex $e^+W^+\bar{\nu}$ depends only on P_{e^+}.

Physics with polarized beams: motivation and requirements

Comparison with (80%,0): estimated gain factor when

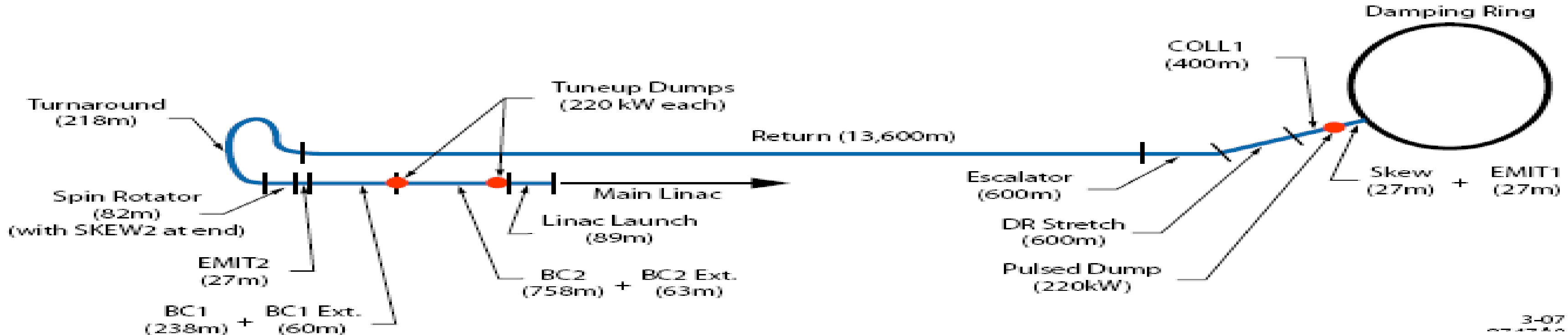
Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	most (80%, 60%) Gain& Requirement	(80%, 30%)
Standard Model:			
top threshold	Electroweak coupling measurement	factor 3	gain factor 2
$t\bar{q}$	Limits for FCN top couplings improved	factor 1.8	gain factor 1.4
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P^T_{e^-}P^T_{e^+}$ required	$P^T_{e^-}P^T_{e^+}$ required factor 1.3 worse than with P_{e+}=60%
W^+W^-	Enhancement of $\frac{S}{B}, \frac{S}{\sqrt{B}}$	up to a factor 2	
	TGC: error reduction of $\Delta\kappa_\gamma, \Delta\lambda_\gamma, \Delta\kappa_Z, \Delta\lambda_Z$	factor 1.8	
	Specific TGC $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P^T_{e^-}P^T_{e^+}$ required	$P^T_{e^-}P^T_{e^+}$ required
CPV in γZ	Anomalous TGC $\gamma\gamma Z, \gamma ZZ$	$P^T_{e^-}P^T_{e^+}$ required	
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4	gain factor 2
	Suppression of $B = W^+\ell^-\nu$	factor 1.7	
$t\bar{t}H$	Top Yukawa coupling measurement at $\sqrt{s} = 500$ GeV	factor 2.5	gain factor 1.6

Light Higgs, e.g. mH=130 GeV: HZ and H νν similar rates at 500 GeV



Spin Rotation

RDR Baseline: Spin rotations systems for both electrons and positrons



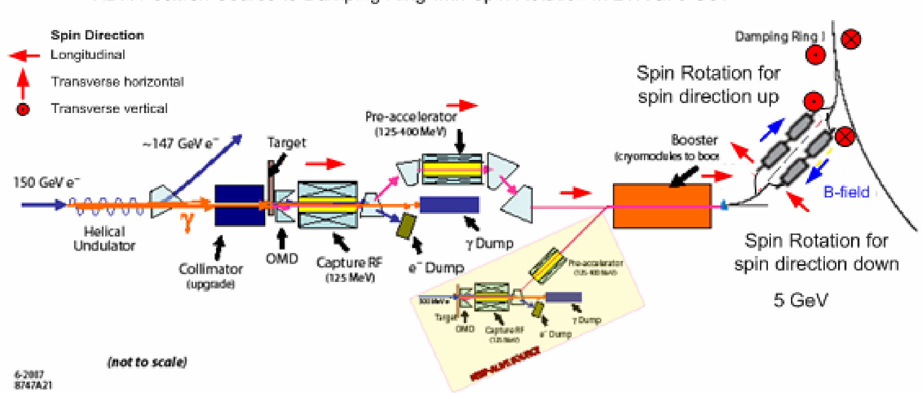
$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend}$$

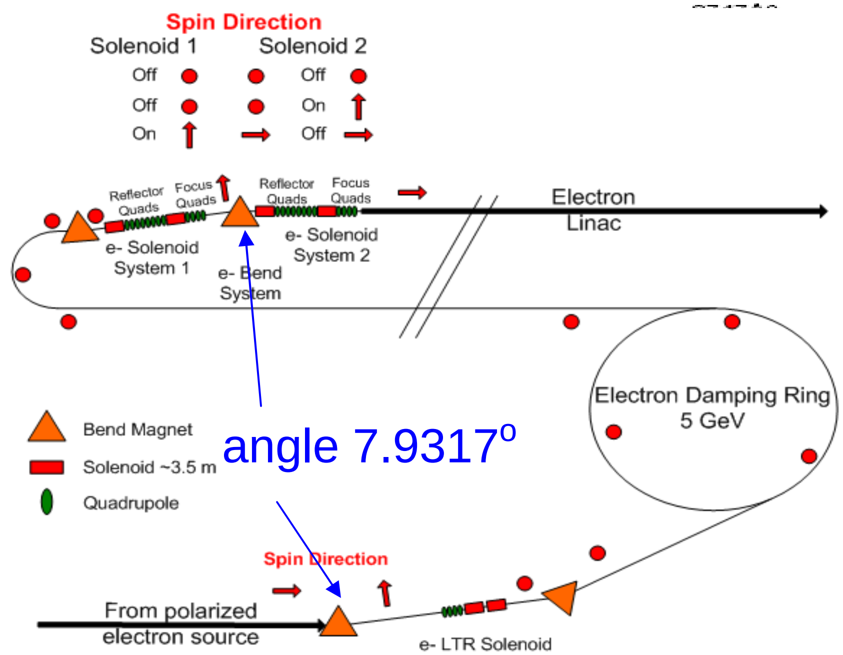
At 5 GeV rotate spin transverse with a bend of 7.9317^o

Superconducting solenoid of 26.2 Tesla-meters rotates to the vertical

Positron helicity flip not in baseline. Scheme for fast positron helicity flipping has been proposed.

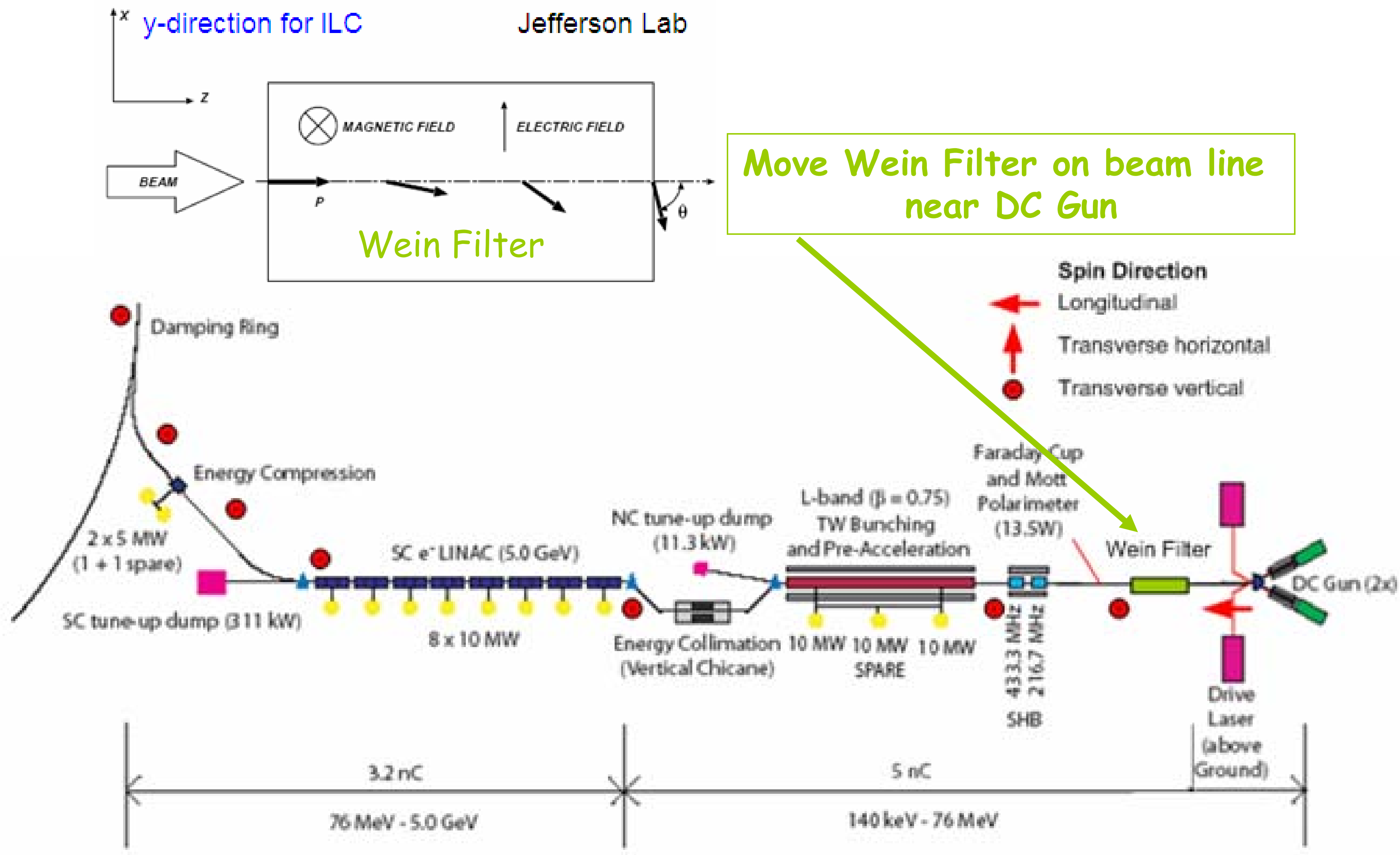
RDR Positron Source to Damping Ring with Spin Rotation in LTR at 5 GeV





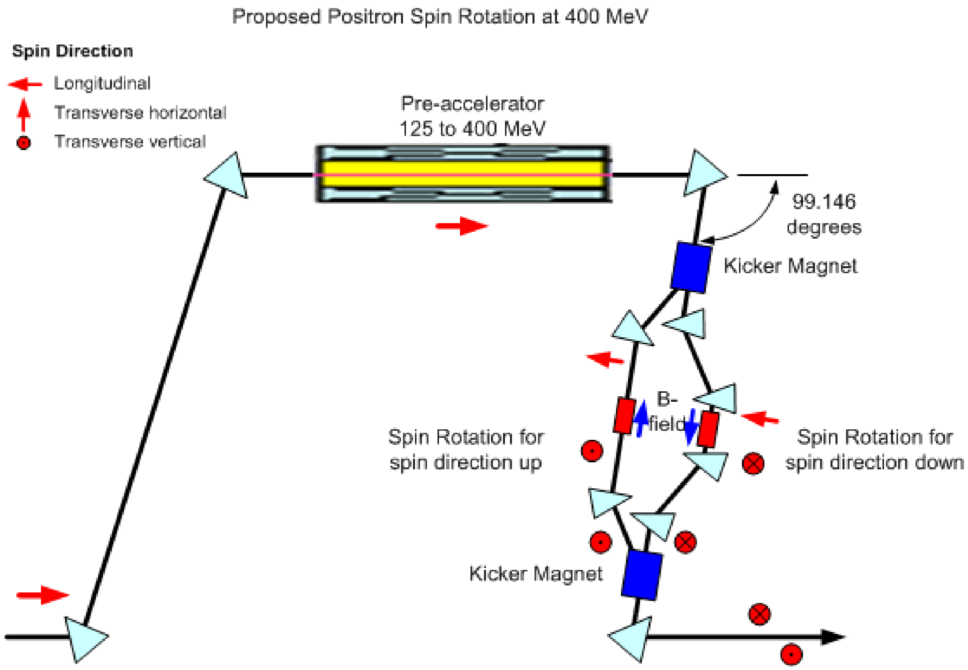
SiD endorses implementing capability for fast positron helicity flipping, which is needed to minimize systematic errors for some of the precision measurements planned.

Proposed electron spin rotation to the vertical near polarized electron source



Space charge affecting beam as it traverses the Wein Filter needs study. At Jefferson Lab this was done at 5 MeV. May need to go after the SHB.

Spin Rotation for positrons at 400 MeV directly following Pre-accelerator when beam energy is 400 MeV

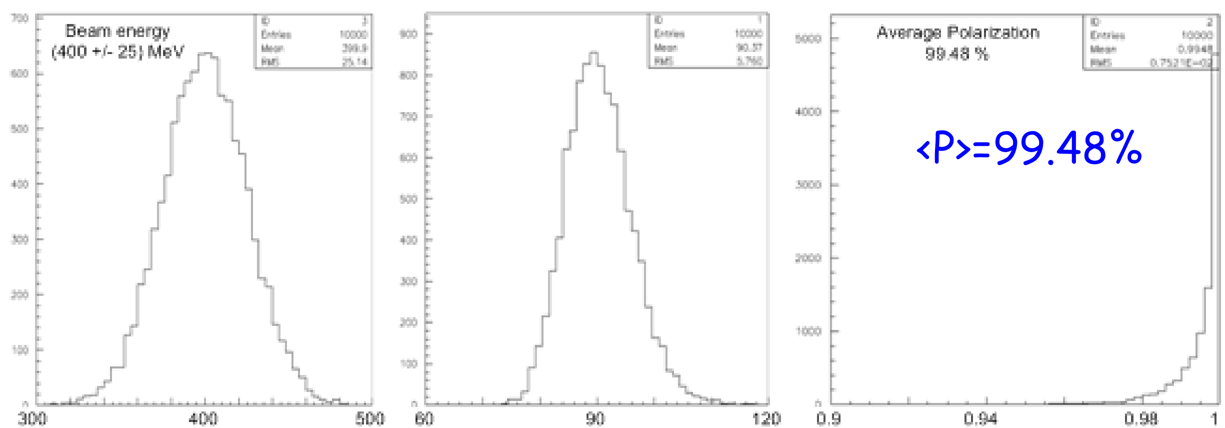


After a bend of 99.146 degrees a copper wound solenoid of 2.096 Tesla meters 2.2 meters long with an axial field of 9.53 Kilogauss will rotate the spin from the transverse horizontal direction to the vertical.

Criteria for the kicker magnets for spin flip and tunnel space is much less demanding at 400 MeV than at 5 GeV.

Energy Spread at 400MeV may be as large as +/- 25MeV

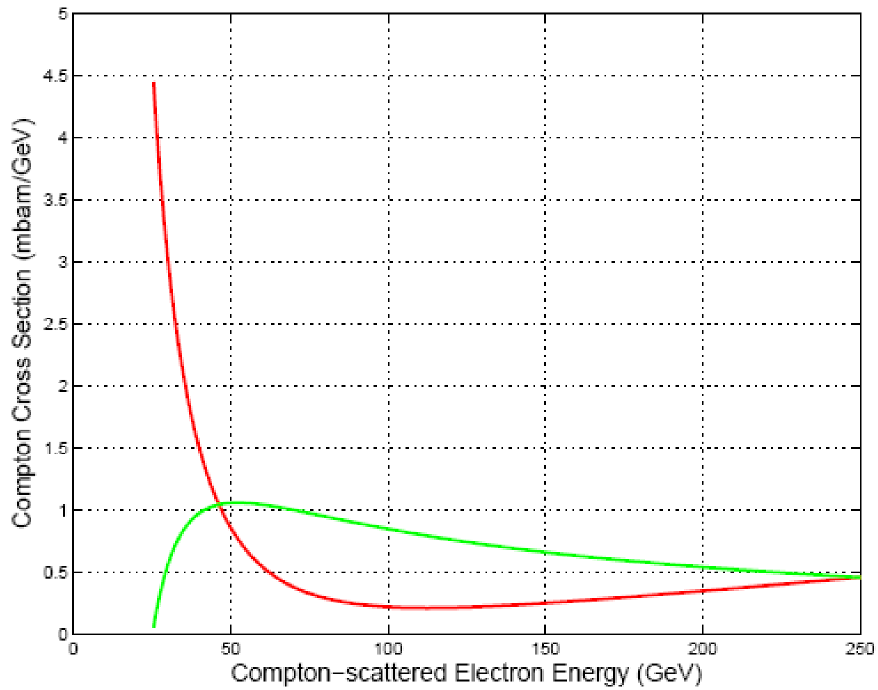
- Depolarization: only 0.52%
- Positron beam loss in 99.146° bends and parallel spin rotation lines is a concern.



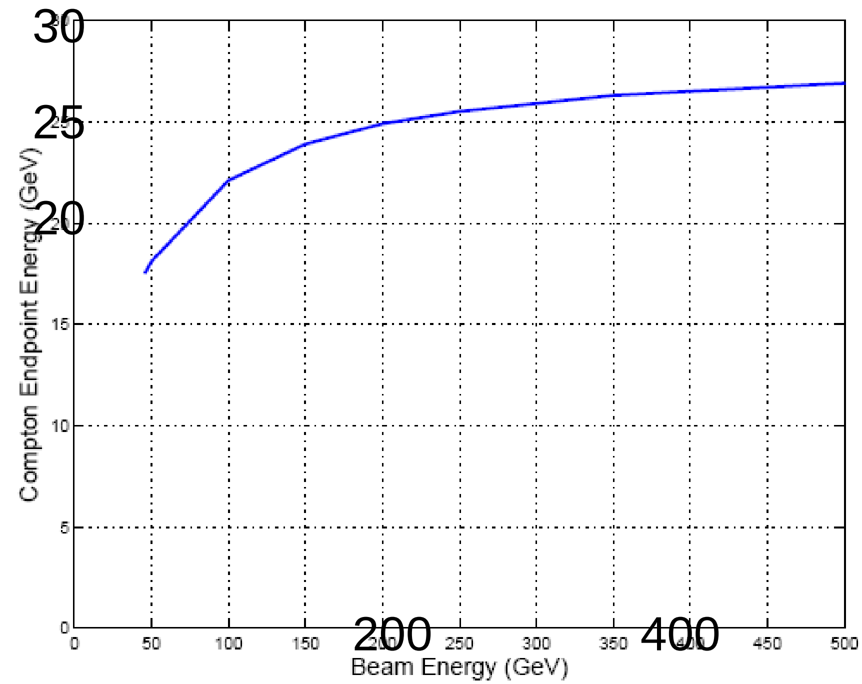
Energy Spin Rotation Angle Polarization

IPBI_TN-2008-1. ***Spin Rotation at lower energy than the damping ring,*** K. Moffeit, D. Walz and M. Woods, ILC-NOTE-2008-040 February 2008.

Compton Scattering Polarimetry



Compton differential cross section versus scattered electron energy for J=3/2 (red curve) and J=1/2 (green curve). Beam energy is 250 GeV and laser photon energy is 2.3 eV.

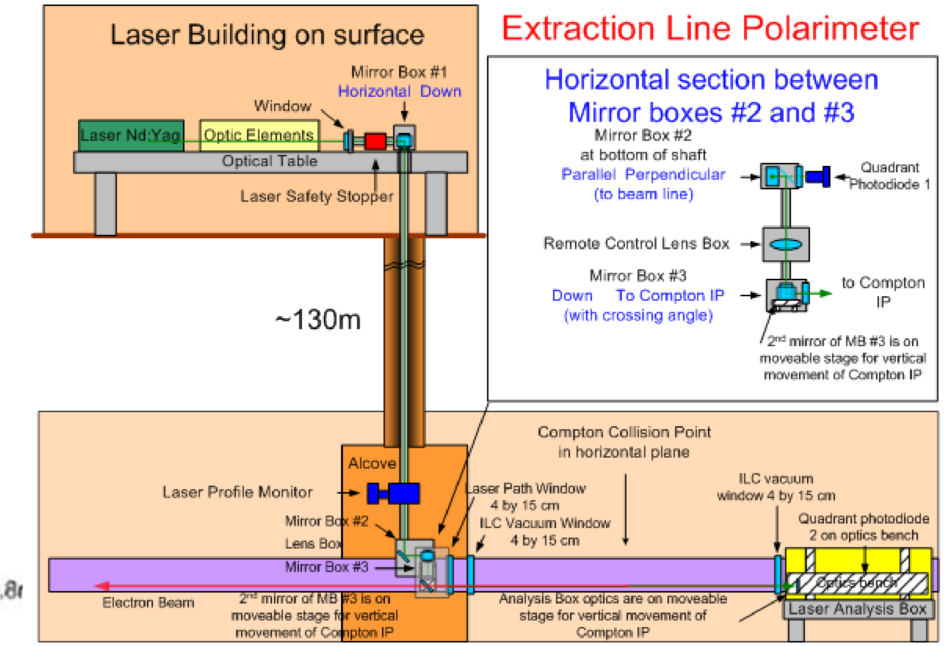


Compton edge energy dependence on beam energy.

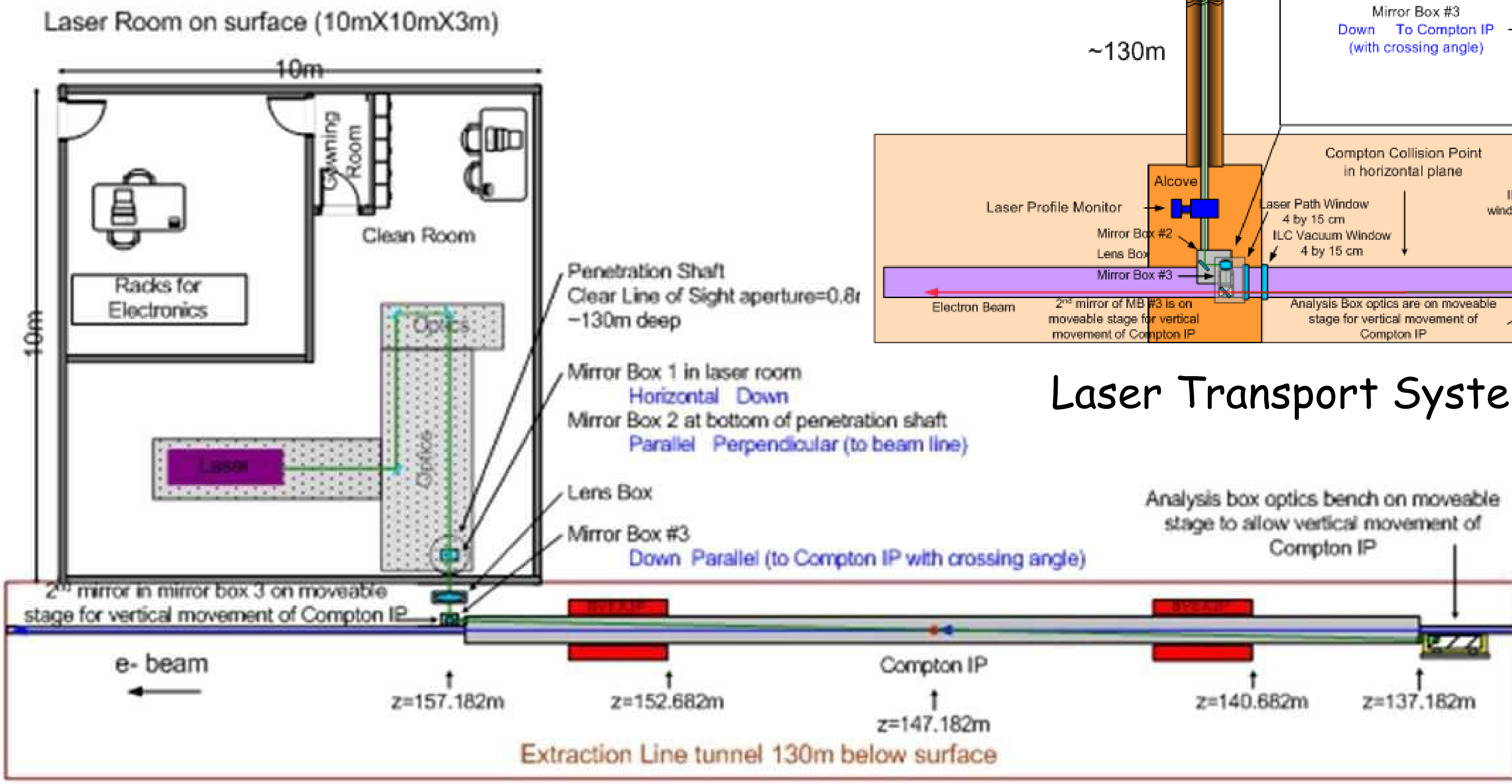
- Compton scattering understood with radiative corrections less than 0.1%.
- Detector backgrounds measured with laser off pulses.
- Compton electrons (E~25 GeV) can be identified, measured and isolated from backgrounds
- Polarimetry data taken parasitic to physics data
- Compton rate high with sub-1% precision in one minute
- Laser helicity selected pulse-by-pulse
- Laser circular polarization determined with 0.1% accuracy

Laser room and laser transport to Compton IP

Laser Transport



Laser Transport System

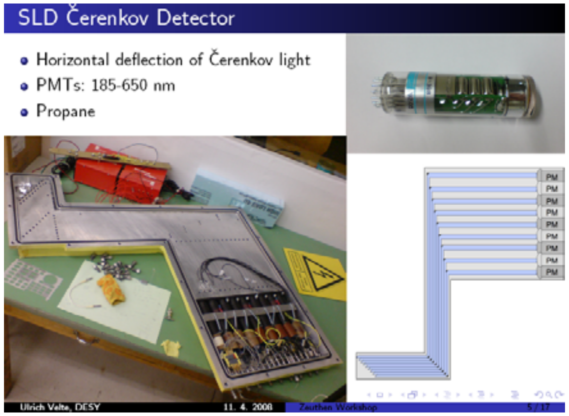


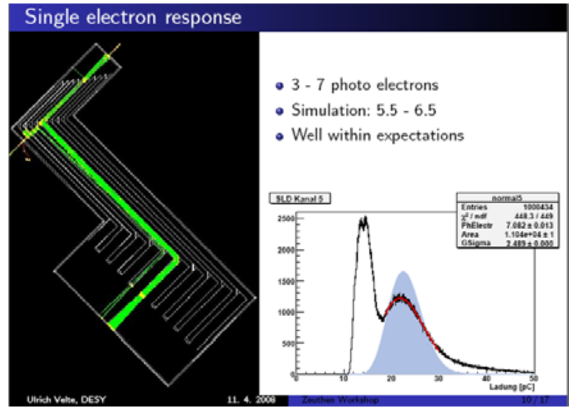
Laser Room on surface above Compton IP ~130m underground

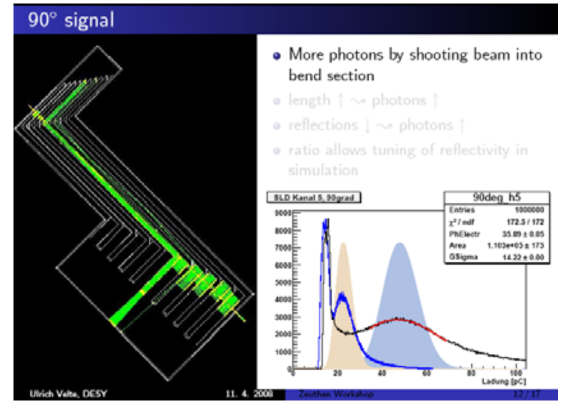
Magnetic chicane parameters for the BDS Compton polarimeters.

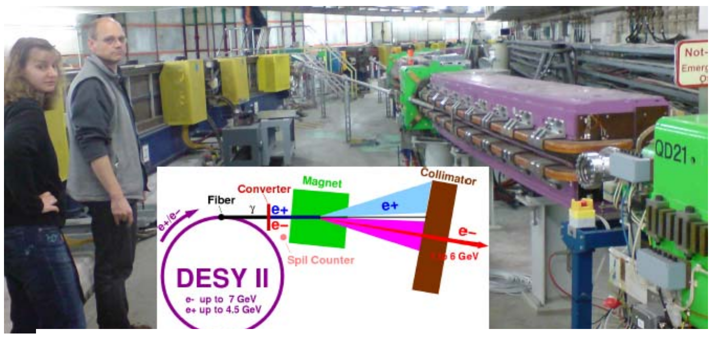
Chicane Parameters	Upstream Polarimeter	Downstream Polarimeter
Chicane Length (m)	75.6	72.0
No. magnets	12	6
Magnetic Field (T)	0.0982	0.4170 (1, 2) 0.6254 (3, 4) 0.4170 (5,6)
Magnet Length (m)	2.4	2.0
Magnet 1/2-gap (cm)	1.25	11.7 (1-3) 13.2 (4) 14.7 (5,6)
Magnet pole-face width (cm)	10.0 (1-3) 20.0 (4-9) 30.0 (10-12)	40.0 (1-3) 54.0 (4) 40.0 (5-6)
Dispersion at mid-chicane at 250 GeV (mm)	20	20

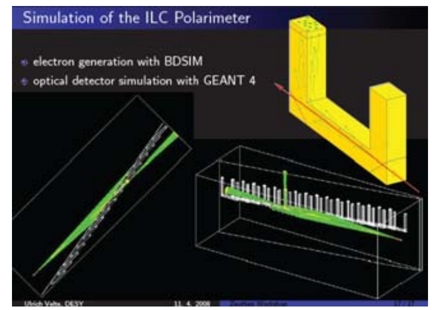
Polarimeter Cherenkov Detector

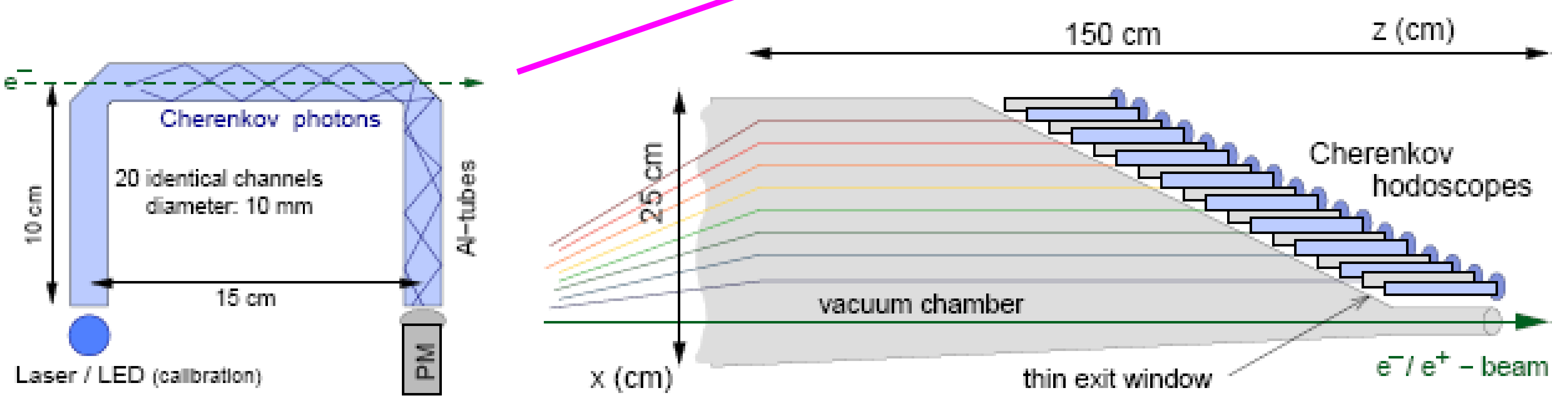






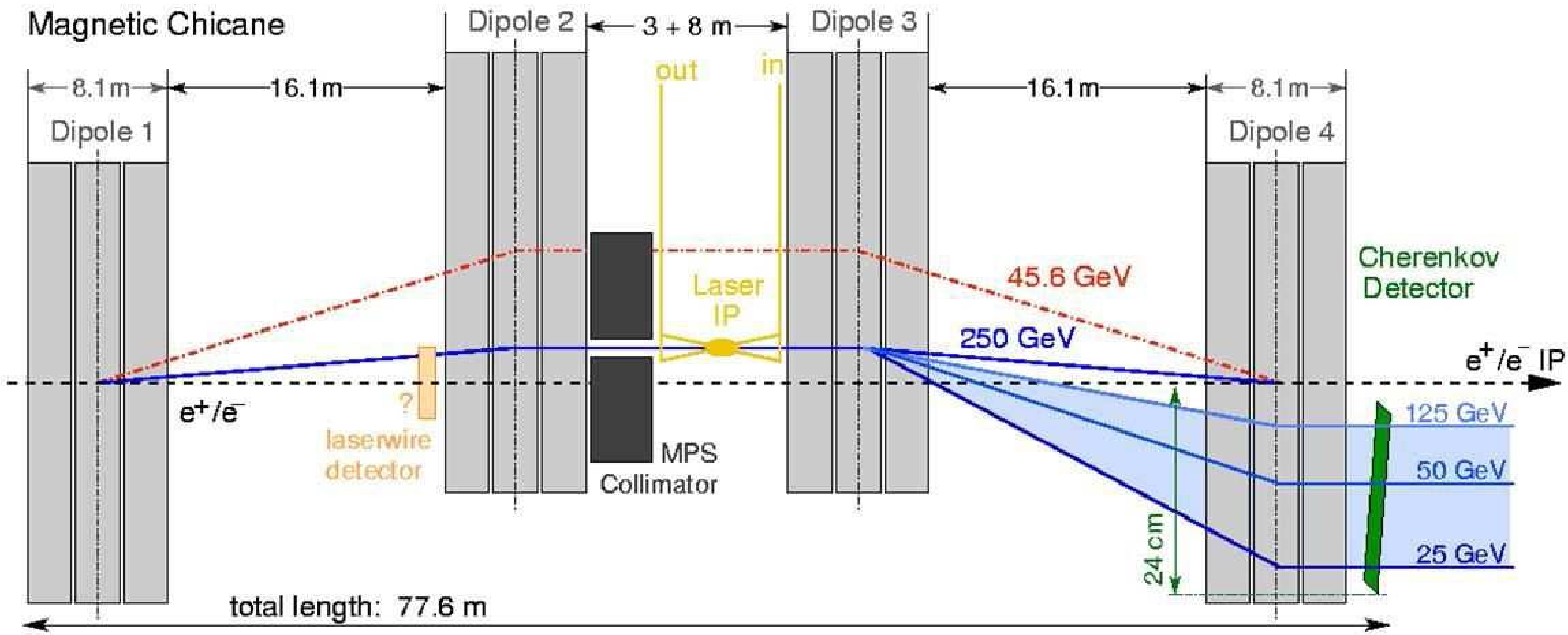






Schematic of a single gas tube (left) and the complete array of 18 tubes(right) as foreseen for the Cherenkov detector for the polarimeters.

Upstream Polarimeter



Schematic of the upstream polarimeter chicane described in the Reference Design Report. This system combines functions for the laserwire detector, machine protection collimator and the Compton polarimeter.

Polarization group recommends to ILC management to relocate the laser-wire emittance diagnostic and MPS energy collimator away from the upstream polarimeter chicane.

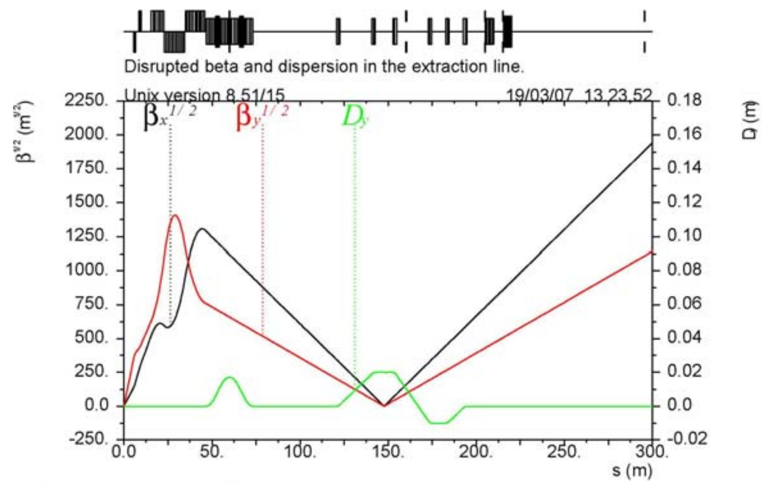
Laser similar to source laser permitting measurement of every bunch with percision of 1% in 4 sec

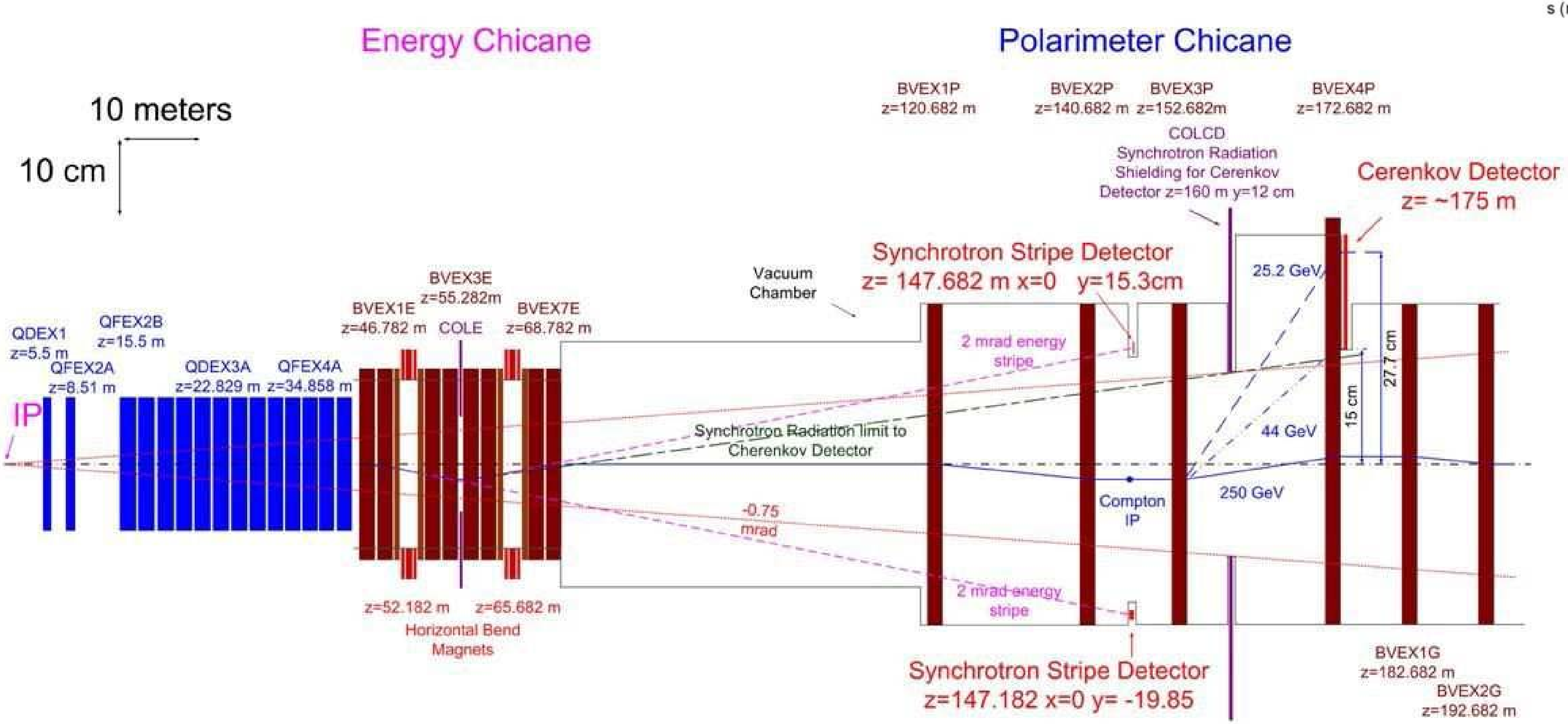
dP/P = 0.25% or better with the largest uncertainties coming from the analyzing power calibration (0.2%) and the detector linearity (0.1%)

Extraction Line Polarimeter and Energy Spectrometer

High power low rate lasers give **1000 Compton scattered electrons** on 3 bunches. 1% statistical uncertainty in less than 1 minute. Cycle through bunches in train.

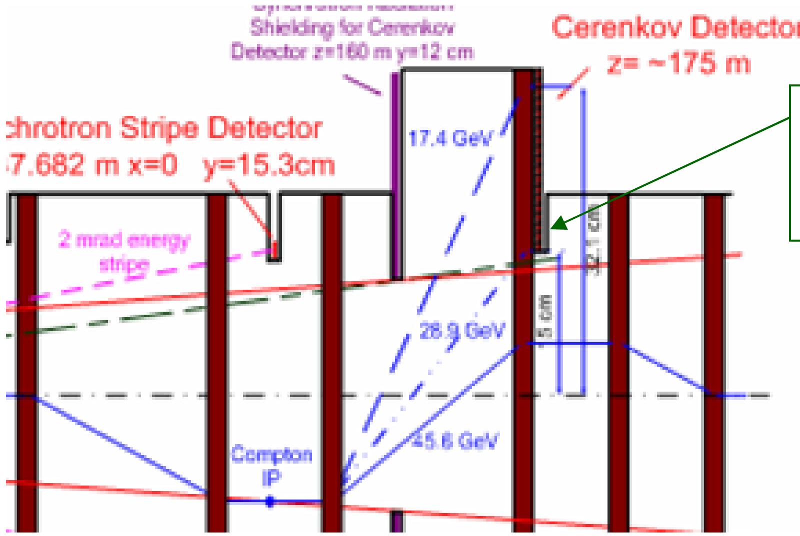
Systematic errors at dP/P = 0.25% with contributions from detector Analyzing power of 0.2%, linearity 0.1%, laser polarization 0.1% and electronic noise and background subtraction 0.05%.





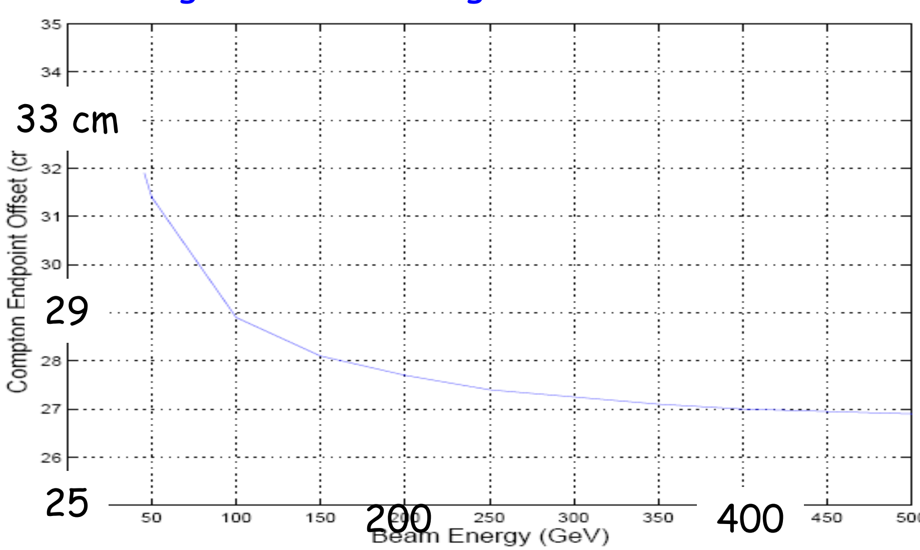
Recommend 6-magnet chicane to move Compton electrons further away from beam line

Beam Energy and Compton Endpoint

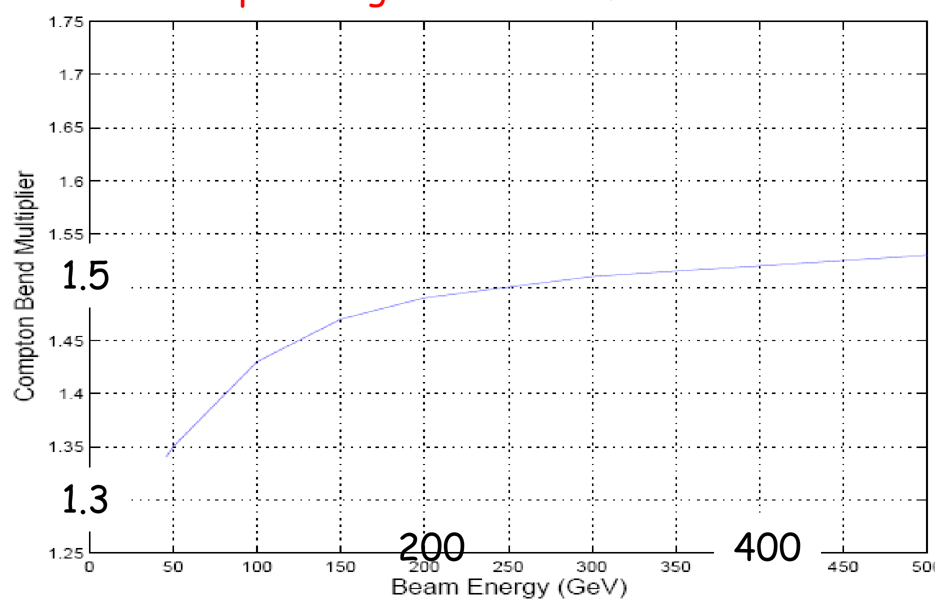


Compton endpoint
E=45.6 GeV y =32.1 cm
E=250 GeV y=27.4 cm

Vertical offset of the Compton endpoint for a fixed-field chicane with 20mm dispersion at 250 GeV and the last 2 polarimeter "chicane" magnets 50% stronger than the first two.



Scaling Multiplier of the last two dipoles to keep the Compton edge at 27.4cm from beamline



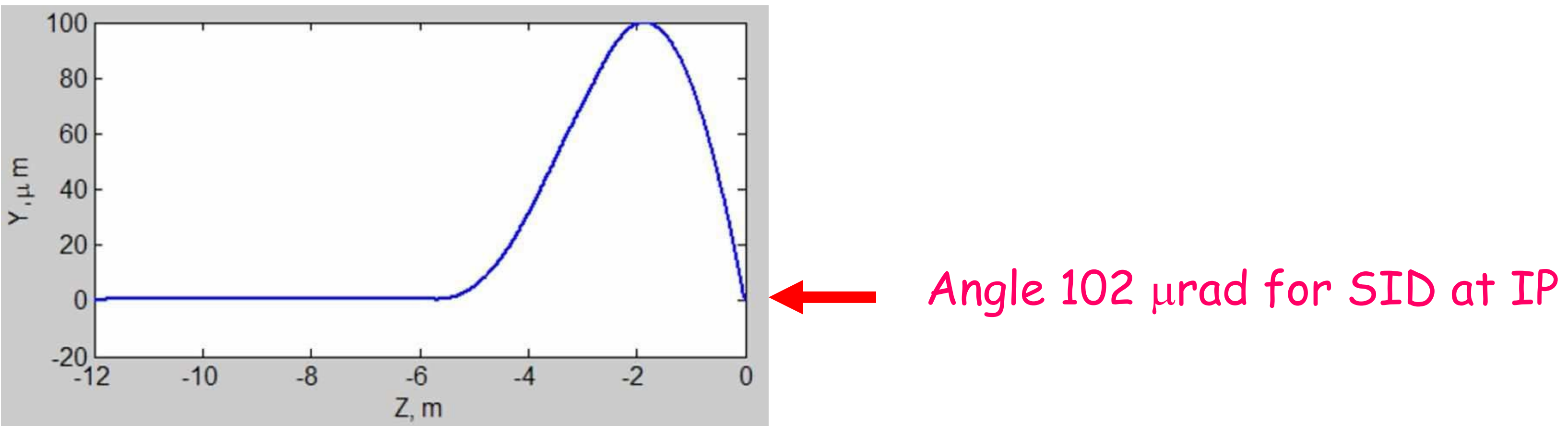
Beam Energy (GeV)

Impact of Crossing Angle and IR Magnets on Polarimetry

Beam trajectory and detector solenoid axis are not aligned due to crossing angle results in vertical deflection of the beam and impacts trajectory of low energy pairs produced in the collisions.

A detector integrated dipole (DID) included in the solenoid compensates for the problems.

To reduce backscattering of the pair background into the tracking detectors it is preferable to align the trajectory of low energy pairs with the extraction beamline (anti-DID solution) resulting in a significant vertical beam angle at the IP.



Beam angle at IR is different than the beam trajectory before and after the detector.
However, the beam trajectory at the upstream and downstream Compton IP s must be within 50μrad of that at e^+e^- Interaction Region.

- Corrector compensation in polarimeter chicane is more easily done for the downstream polarimeter.

- For the upstream polarimeter, it is highly desirable to implement local orbit compensation near the IR to align the incoming vertical beam trajectory with the trajectory at the collider IP. **Correction in the upstream polarimeter chicane may not be feasible due to vertical emittance growth.**

Measurement of beam polarization using $W^+ W^-$ production

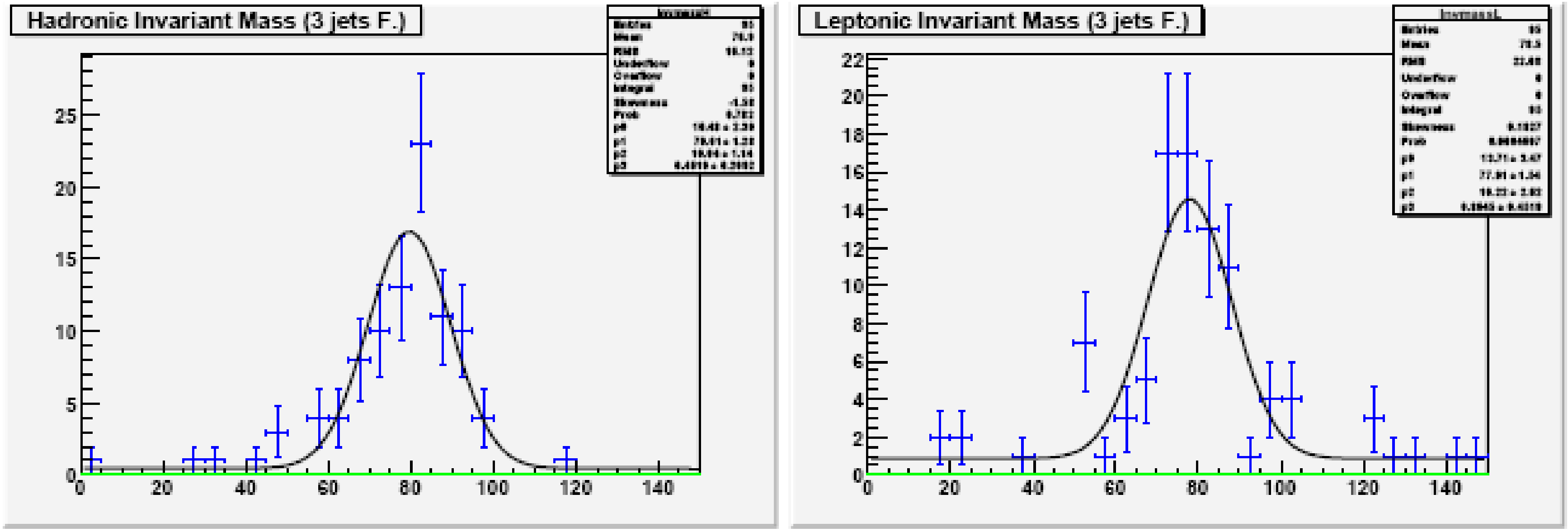


Figure 2: The W invariant mass measured from the hadronic decay (left) and from the leptonic decay (right).

The Blondel scheme

$$| P_{e^\pm} | = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}},$$

With 860 fb-1 of luminosity, the error on P_e- ~ 0.1% and the error on P_e+ ~ 0.2%.

Requires randomly flipping positron polarization.

Comments:

The Blondel scheme can be used for any J=1 process not just W-pairs. The scheme requires that both beam be polarized. W-pairs gives an additional tool since Ws couple only to left-handed particles. One can make use of W-pairs for a beam-based measurement if only the electrons are polarized. Non-standard W couplings can be extracted from the angular dependence of the W asymmetry.

Integration with SiD

LumiCal and BeamCal need to be a subsystem of the SiD Detector collaboration since they are integral to the SiD detector.

GamCal can be a joint effort of the ILC BDS team and the SiD Detector collaboration.

The polarimeter and energy spectrometer systems need to be a joint effort of the ILC BDS team and the SiD Detector collaboration. SiD intends to take significant responsibility for the design, development, operation and performance of these systems.

- SiD participants are already active in making significant contributions to their design and development.
- Data from the polarimeters and spectrometers must be delivered to the SiD DAQ in real time to be logged and permit fast online analysis.

Fast online analysis results must also be provided to the ILC controls system for beam tuning and diagnostics.

Details for integrating the luminosity, polarimeter and energy spectrometer data with the SiD DAQ remain to be worked out. SiD DAQ experts will assume responsibility for integrating the luminosity, polarimeter and spectrometer data streams with the SiD DAQ.

Conclusions

Members of the SiD collaboration have worked for many years on the luminosity, energy and polarization systems for the ILC. This effort has been important in establishing the footprint/baseline parameters for the ILC that allows precision physics measurements depending on luminosity, energy and polarization and is reflected in the baseline of the ILC described in the RDR. Proposals to modify the baseline ILC were made at the 2008 Workshop on Polarization and Beam Energy Measurements at the ILC:

- Relocate the laser-wire emittance diagnostic and MPS energy collimator away from the upstream polarimeter chicane. SiD LOI endorses!
- Modify the extraction line polarimeter chicane from 4 magnets to 6 magnets to allow the Compton electrons to be deflected further from the disrupted beam line. SiD LOI endorses!
- Include precise polarization and beam energy measurements for Z-pole calibration runs into the baseline configuration. SiD LOI endorses!
- Realize the physics potential for the initial positron polarization of 30-45% SiD LOI endorses!
- Implement parallel spin rotator beamlines with a kicker system before the damping ring (DR) to provide rapid helicity flipping of the positron spin. SiD LOI endorses!
- Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV to eliminate expensive superconducting magnets and reduce costs. ILC cost reduction-does not effect physics!
- Move the pre-DR electron spin rotator system to the source area to eliminate expensive superconducting magnets and reduce costs. ILC cost reduction-does not effect physics!

Continued active SiD participation in ILC machine design is important for optimizing physics results depending on polarization, energy and luminosity measurements.

SiD participation in machine design should emphasize those areas that impact capabilities for polarization and energy. These include:

Energy spread
Correlations in beam parameters such as E-z correlations,
Spin diffusion and de-polarization effects,
Polarization and energy measurements.