Luminosity, Beam Energy and Polarisation Measurements at the ILC

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Introduction
Issues to keep in mind:
- Luminosity & Beam Energy
- Complementarity
- Positron Polarisation

Conclusions

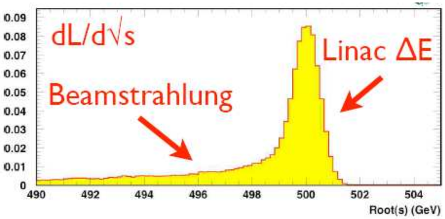
Introduction

- Charge:
  - overview of the design regarding L.E.P.
  - issues which detector groups should keep in mind in post LoI era
  - issues which needs more attention
- $\Rightarrow$ no roller-coaster ride through the on-going fascinating hardware developments!
- For more details: references at the end...
- Special thanks to Wolfgang Lohmann and Eric Torrence!

Goals & Requirements

- luminosity: 10^{-3} (ew precision 10^{-4})
- beam energy: 10^{-4} (ew precision: few 10^{-5})
- polarisation: $\Rightarrow 2.5 \cdot 10^{-3}$ (ew precision 10^{-3})

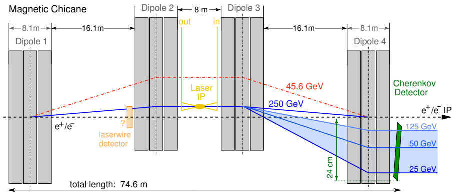
- but: measurement location usually *not* e^+e^- IP $\Rightarrow$ "interpolation"
- and: physics analyses assume not only E and $L = \int \mathcal{L} dt$ known, but full luminosity spectrum, i.e $dL/d\sqrt{s}$



The Key Players - Upstream of the e^+e^- IP

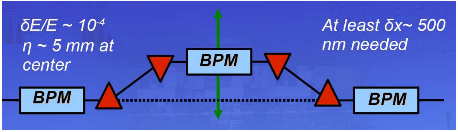
Compton-Polarimeter

- 1.8 km upstream of IP
- backscattering of circular polarised laser
- asymmetry w.r.t. laser helicity $\rightarrow$ polarisation

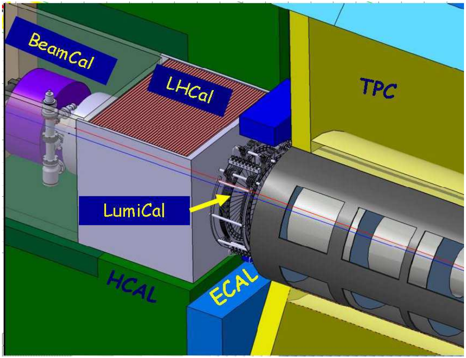


BPM based Energy Spectrometer

- 700 m upstream of IP
- measure beam position in chicane
- resolutions of $\simeq 1\mu$m achieved



The Key Players - e^+e^- Detectors

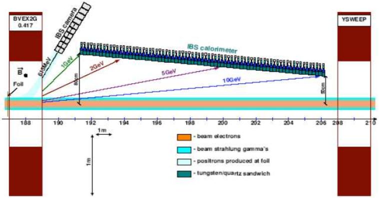


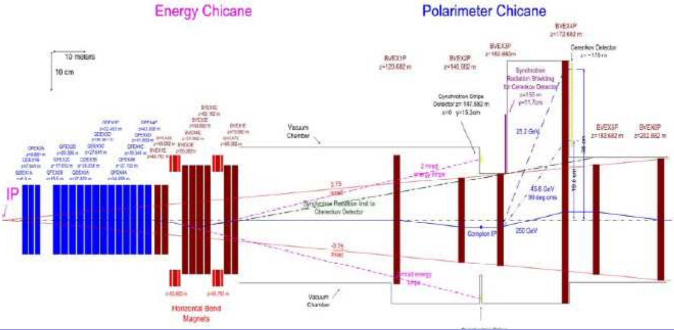
- LumiCal: 20 - 50 mrad, high precision lumi, hermeticity
- BeamCal: 5 - 20 mrad, fast lumi (tuning), collision diagnostics, hermeticity
- PairMonitor: in front of BeamCal, collision diagnostics
- LHCal: more hermeticity

common challenges:
precision & radiation hardness!

The Key Players - Extraction Line

- GamCal: 0 - 5 mrad, ca 100 m from IP, total radiation loss
- Compton-Polarimeter
- Energy Meas. (Synchr. Imaging)



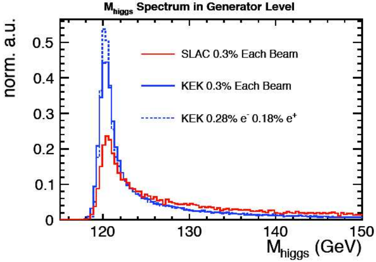


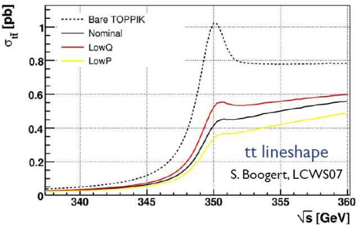
Luminosity, Beam Energy and all that

recall LoI studies:

- $dL/d\sqrt{s}$ assumed to be know perfectly - not only $< dL/d\sqrt{s} >$
- analyses are sensitive to beam energy spread & beamstrahlung (Higgs recoil!)
- not studied in LoI: threshold scans!

⇒ How do we get $dL/d\sqrt{s}$?

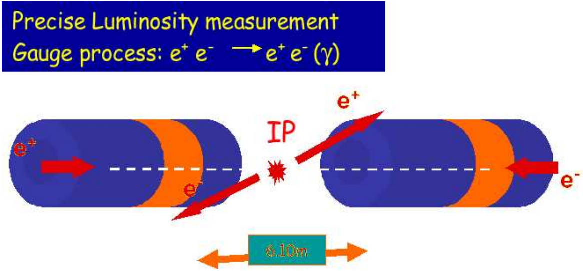




Available Tools

LumiCal

- count Bhabha events, typ. $E_{e^+} + E_{e^-} > 0.8 \cdot \sqrt{s}$
- $\int \mathcal{L} dt = N/\sigma$
- σ: theoretical cross-section $\rightarrow$ needs energy spectrum...
- outgoing Bhabhas might be deflected by bunch charge!



Available Tools

Beam Parameter Determination

- BeamCal & PairMonitor : $N(e^{\pm})$, emittances, bunch sizes, waists, offsets,.. (limited by correlations amoung parameters)
- fit from up-down, left-right asymmetries, energy ratios...
- double read-out: fast coarse read-out for lumi tuning detailed read-out for full analysis
- GamCal: total energy loss into photons $\longrightarrow$ improves resolution

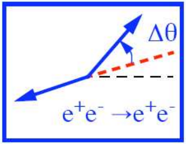
Energy Spectrometers

- upstream: measure energy after linac (no beamstrahlung!)
- downstream: minimize beamstrahlung, measure peak energy and energy spread

Direct measurement of $dL/d\sqrt{s}$ from physics

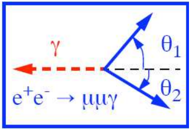
Acolinear Bhabhas

- $\frac{\sqrt{s'}}{\sqrt{s}} = 1 - \frac{\Delta\Theta}{2\sin\Theta_0}$
- $\Rightarrow$ need excellent forward tracking
- what about machine background?



Radiative Returns

- $e^+e^- \rightarrow \mu^+\mu^-\gamma$
- $\frac{s'}{s} = \frac{\sin\Theta_1 + \sin\Theta_2 - |sin(\Theta_1+\Theta_2)|}{\sin\Theta_1 + \sin\Theta_2 + |sin(\Theta_1+\Theta_2)|}$
- absolute $\sqrt{s'}$ calibration via Z resonance
- needs $\delta\Theta = 10^{-4}$



How can all these tools be combined to give the best $dL/d\sqrt{s}$?

Complementarity

Polarimetry & Beam Energy Measurements

- aiming for extreme precisions
- need to interpolate to IP
- different beam conditions
- different technologies
- two devices mean: complementary, redundancy, cross-check
- in addition: absolute calibration from e^+e^- data!

$\Rightarrow$ not luxury, but necessary to achieve physics goals!

Complementarity of Up- and Downstream Polarimetry

Upstream Polarimeter

- 1.8 km upstream of IP
- clean environment
- stat. error 1% after 6 μs
- machine tuning (upstream of tune-up dump)

Downstream Polarimeter

- 140 m downstream of IP
- high backgrounds
- stat. error 1% after $\simeq$ 1 min
- access to depolarisation at IP

Combination

- without collisions: spin transport in Beam Delivery System
- with collisions: depolarisation at IP
- cross check each other![1]

[1] c.f. „Spin Dance“ Exp., Phys. Rev. ST Accel. Beams **7** 042802 (2004)

Positron Polarisation

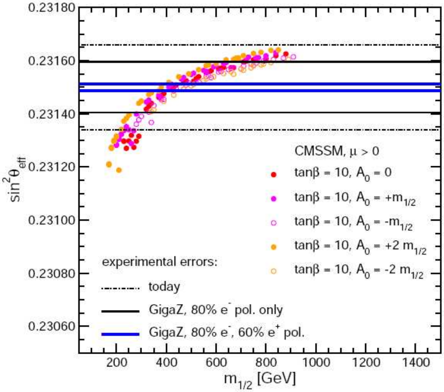
- baseline source delivers 30-45%
- but positron polarisation for experiments is NOT baseline
  $\rightarrow$ could be destroyed
- consequences:
  - damping rings are not enough, need to actively destroy it
  - need to measure extremely precisely if it is really destroyed
  - polarimeter calibration from e^+e^- data much more luminosity demanding,
  - no cancelations of systematics
  - some physics cannot be done at all
    Ex.: disentangling helicity states of new physics

Positron Polarisation: better keep it!

- positron polarimeters forseen
- but no fast helicity flip!
  - e^-: can quickly flip source laser helicity
  - e^+: undulator polarity cannot be reversed, need spin rotators $\Rightarrow$ slow!
- $\Rightarrow$ no cancellation of systematics
- $\Rightarrow$ reduced gain through $P_{\text{eff}} = \frac{P_L + P_R}{1 + P_L \cdot P_R}$
- spending a lot of time on "uninteresting" states LL, RR

Polarimetry at Z pole?

- $\delta \sin^2\theta_{\mathrm{eff}}$ today: $18 \cdot 10^{-5}$
- with $P(e^+, e^-) = (40\%, 90\%)$: $6 \cdot 10^{-5}$ with $\int \mathcal{L}dt = 0.5$ fb^{-1}
- needs
  - positron polarisation at the Z pole (source location?!)
  - fast positron helicity flip
  - best possible polarimetry (systematics limited at $\simeq$ 1 fb^{-1} with $\delta P/P = 0.25\%$)



- $\Rightarrow$ interesting physics with lumi not far from accumulated calibration runs over $\simeq$ 10 years
  - might even investigate a few weeks dedicated running?

Recommendations to GDE and Research Director

1. Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate setup for these two.
2. Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.
3. Include precise polarisation and beam energy measurements for **Z**-pole calibration runs into the baseline configuration.
4. Keep the initial positron polarisation of 30-45% for physics (baseline).
5. Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.
6. Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.
7. Move the pre-DR electron spin rotator system to the source area. This eliminates expensive superconducting magnets and reduces costs.

Conclusions

- need not just E and L, but $dL/d\sqrt{s}$ $\Rightarrow$ need to combine:
    - lumi from LumiCal
    - beam parameters from BeamCal, GamCal
    - information on disrupted beam from downstream beam energy measurement
    - simulations
    - e^+e^- data
- up- *and* downstream instrumentations essential for precision
- with base line source, we could have $P(e^+) = 30\text{-}45\%$,
  BUT: need fast helicity flipping to make it useful for physics!
- $P(e^+)$ and E & P measurements at 91.2 GeV currently not considered to be necessary
  $\Rightarrow$ missing a physics opportunity here?

For more Details:

- E&P workshop Zeuthen 2008
  `http://indico.desy.de/conferenceDisplay.py?confId=585`
- its Executive Summary
  arXiv:0903.2959 [physics.acc-ph]
- E&P LoI support document
  arXiv:0904.0122 [physics.ins-det]
- Z pole physics: talk by G.Moortgat-Pick at LCWS08
  `http://ilcagenda.linearcollider.org/materialDisplay.py?contribId=403&sessionId=16&materialId=slides&confId=2628`
- Lecture by Eric Torrence
  `http://physics.uoregon.edu/~torrence/talks/FNAL07/torrence_mdi.pdf`

BACKUP

Polarimetry with Annihilation Data

if no positron polarisation

- $\sigma = \sigma_0[1 - P(e^-)A_{LR}]$
- $\Rightarrow \frac{\delta A_{LR}}{A_{LR}} = \frac{\delta P}{P}$
- scale uncertainty enters directly
- polarimeter calibration: at Z pole w.r.t. to SLD measurement of A_{LR}[2]

[2] remember $\sin\theta_{\mathrm{eff}}$ from A_{LR} and $A_{\mathrm{FB}^{\mathrm{had}}}$ inconsistent!

Polarimetry with Annihilation Data

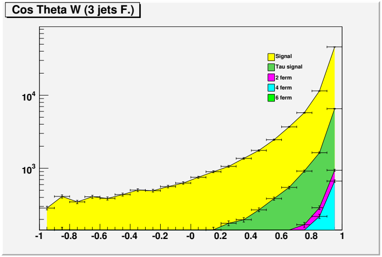
if positron polarisation

- $\sigma = \sigma_0[1 - P(e^+) \cdot P(e^-) + (P(e^+) - P(e^-))A_{LR}]$
- $\Rightarrow$ correlations matter!
- can calibrate polarimeters with modified Blondel Scheme: $|P(e^\pm)| = \sqrt{\frac{(\sigma_{LR}+\sigma_{RL}-\sigma_{LL}-\sigma_{RR})\cdot(\pm\sigma_{LR}\mp\sigma_{RL}+\sigma_{LL}-\sigma_{RR})}{(\sigma_{LR}+\sigma_{RL}+\sigma_{LL}+\sigma_{RR})\cdot(\pm\sigma_{LR}\mp\sigma_{RL}-\sigma_{LL}+\sigma_{RR})}}$
- **if $P_L = P_R$** (for each beam)
- if not: corrections $\simeq$ uncorrelated polarimeter error on $P_L - P_R$
- advantage: model independent!
- need to spend substancial amount of running time on LL and RR $\longrightarrow$ expensive!

$e^+e^- \rightarrow W^+W^-$

preliminary results from full simulation (ILD)

- Blondel scheme for 100 fb^{-1} for each helicity state: $\delta P(e^-)/P(e^-) = 0.1\%$, $\delta P(e^+)/P(e^+) = 0.2\%$
- from $\frac{d\sigma}{d\cos\theta}$: large $\cos\theta$ t-channel domianted, P changes relative contribution of t-channel
- contribution of new physics? $\Rightarrow$ common determination with triple gauge couplings

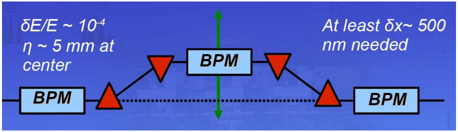


fit yields for 20 fb^{-1}:
$P(e^-) = 80.17 \pm 0.15$,
$P(e^+) = 60.10 \pm 0.20$
(no backgrounds yet)

The Baseline Energy Spectrometers

Upstream:
Chicane + BPMs

- prototype at Endstation A at SLAC
- resolutions of $\simeq 1\mu$m achieved
- to watch: drifts....



Downstream:
Synchrotron Radiation Imaging

- detector test at Endstation A
- chicane provides 2mrad vertical bend + wigglers
- array 100 μm quartz fibers detects Cherekov light