Physics Related Instrumentation for the ILC

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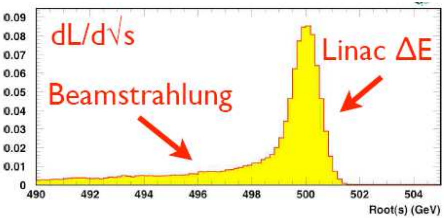
Technical Baseline Review, October 24 2011

Introduction

Goals & Requirements for physics instrumentation

- 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})

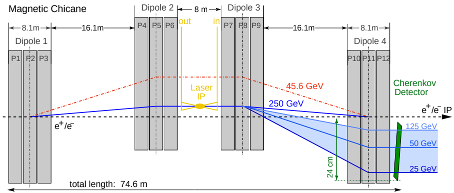
- but: measurement location usually *not* e^+e^- IP $\Rightarrow$ "interpolation"
- and: physics analyses need not only E and $L = \int \mathcal{L} dt$, but $dL/d\sqrt{s}$, and luminosity weighted average polarisation!



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

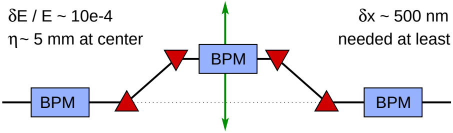
Compton-Polarimeter

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



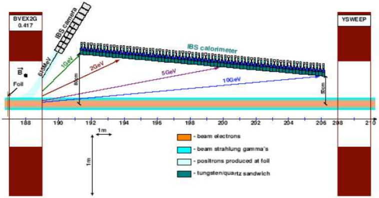
BPM based Energy Spectrometer

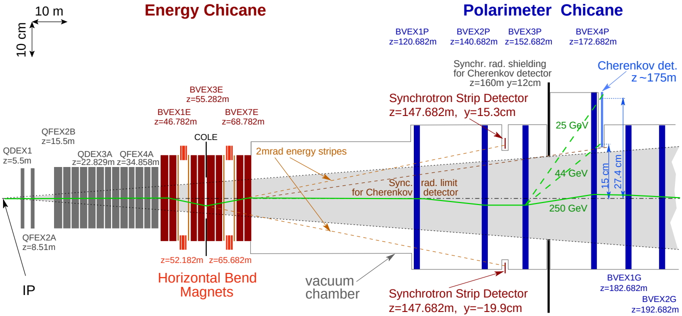
- 700 m upstream of IP
- measure beam position in chicane
- resolutions of $\simeq 1\mu$m achieved



The Key Players - Extraction Line

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





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

⇒ not luxury, but necessary to achieve physics goals!

Energy range

Polarimetry & Beam Energy Measurements

- all devices need to be operational at all beam energies
- scan between $E_b = 100$ GeV ... 250 GeV (500 GeV)
- ... and calibration at the Z pole
- „working point“ should be independent of E_b in order to control systematics!

The BPM-based Energy Spectrometers

- prototype operated sucessfully at Endstation A at SLAC
- resolutions of $\simeq 1\mu$m achieved $\rightarrow$ matches ILC baseline!
- further improvements down to 100 nm resolution could maybe allow to reduce chicane dispersion, i.e. reduce emittance growth

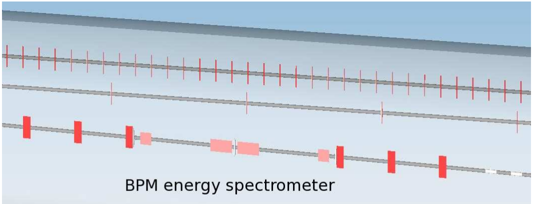
in current SB2009-Nov10 lattice

- e^- beam: 1 directly after end of linac,
  1 ca 700 m before IP, after energy collimation
- e^+ beam: 1 ca 700 m before IP, after energy collimation

e^- BPM spectrometer SB2009-Nov10 lattice

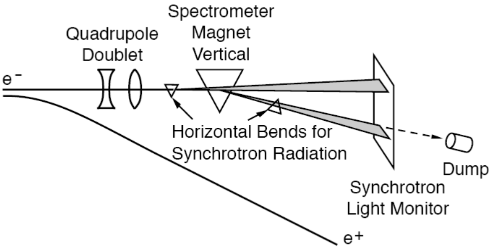
- a BPM type BPMSPE079, „energy spectrometer bpm (20 mm bore)“
- a dipole BEC1 of type H20, length 3 m, bend 0.24272 mrad
- a drift space of 16.1 m
- a dipole BEC2 of type H20, length 6 m, bend 0.24272 mrad
- a BPM type BPMSPE079
- ... and the same backwards
- fixed dispersion of 5 mm

$\Rightarrow$ O.K.!



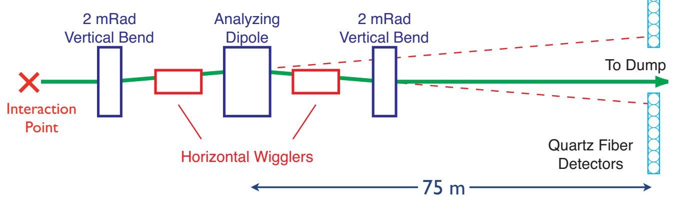
The Downstream Energy Measurement: Synchrotron Radiation Imaging

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



The Downstream Energy Measurement: RDR

Wisrd-Style Spectrometer



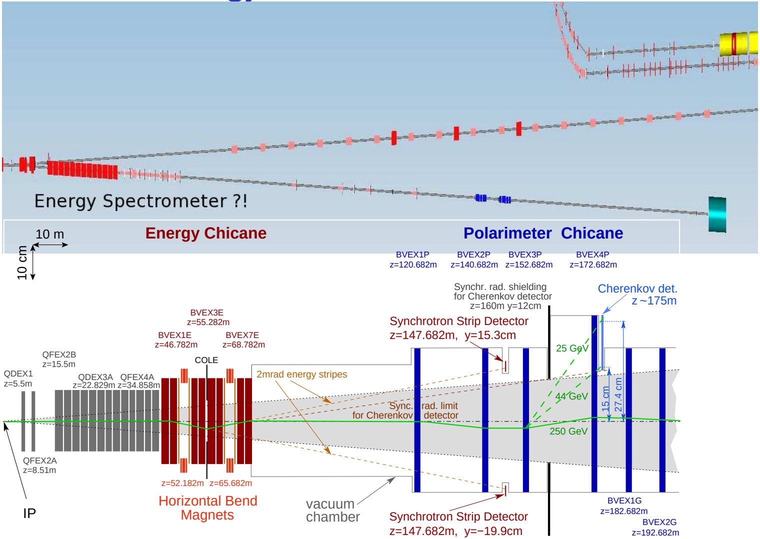
- Detect SR photons on quartz fiber array (~150 μm pitch)
- ±2 mRad bend over 75 m → 125 MeV/100 μm
- Need transverse accuracy of 30 μm at detector plane
- Measure mean beam energy and disrupted tail spectrum

Eric Torrence 51 July 2007

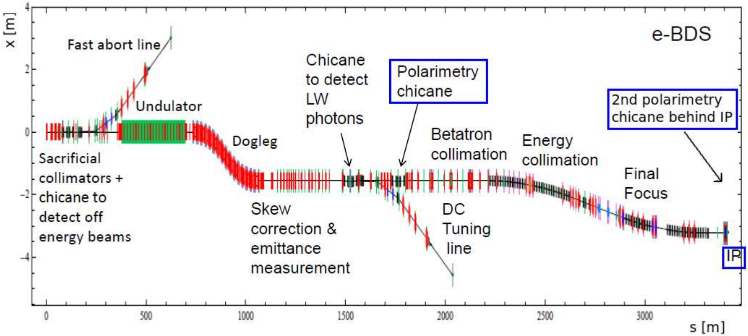
Downstream Energy Measurement - status and requirements

- was fine in RDR, but modifications since haven't been looked at
- main requirement is a secondary focus (same as downstream polarimeter!)
- initial chicane needs enough strength to get the photons out of the downstream stayclear
- might need to adjust some magnet apertures (low P needs larger stayclear!)
- Eric Torrence has a student who could do GEANT4 study (as was done for RDR)
- BUT he'd need help to get the relevant input for this

Downstream Energy Measurement in SB2009-Nov10 lattice

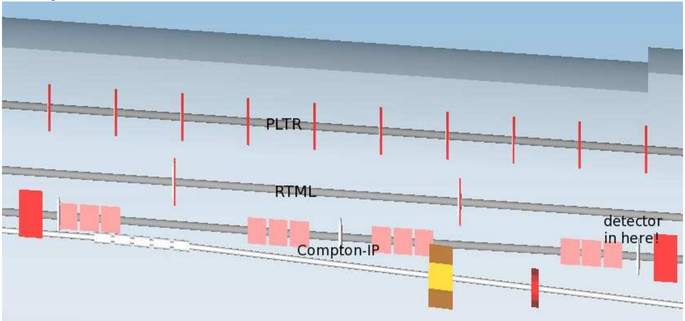


The Upstream Polarimeter: new location after tune-up dump



- enough space towards tune-up dump line?
- enough space for extraction of Compton fan?

The Upstream Polarimeter in SB2009-Nov10 lattice

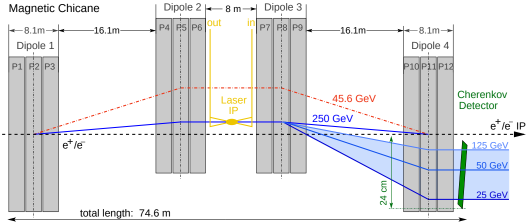


- distance Compton-IP to dump line ca 30 cm at 250 GeV
- fixed field → down to ca 20 cm at lowest energies - enough?
- what is the yellow thing in dump line? current size meaningful?!
- how big are the chicane magnets really, esp. first dipol group?

The Upstream Polarimeter:

need special beam pipe through out whole chicane

- to allow for varying bending angle
- to guide laser in and out
- to let fan of Compton scattered electrons pass
- to extract Compton fan to detector

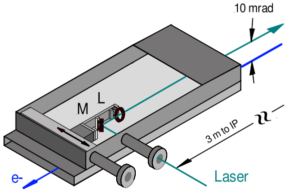


Attention: deflection of chicane the otherway round as on previous page!

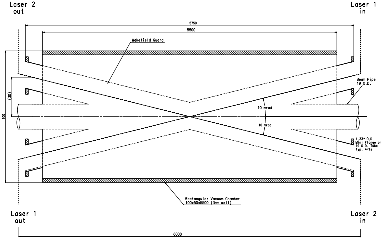
lengths of dipoles / drifts agree with SB2009-Nov10 lattice

The Upstream Polarimeter: Laser in / out

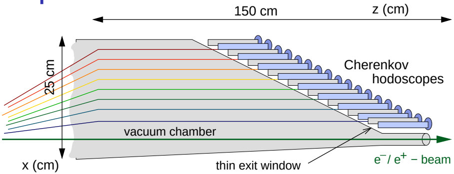
- Laser enters chicane *horizontally* (far side from tune-up dump line!)
- final mirror / lens movable to adjust to e^- beam
- had been designed to some extent for TESLA (!) by N. Meyners, P. Schüler



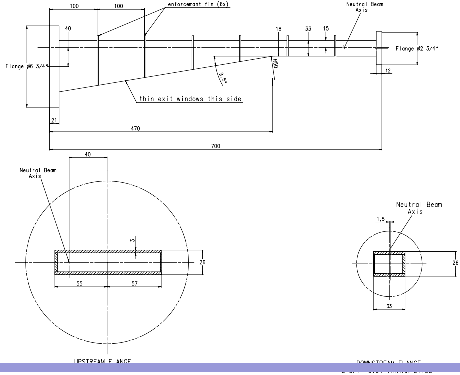
Movable Laser Beam



The Upstream Polarimeter: Compton fan out



- need tapered exit window to avoid wake fields
- again estimate from TESLA: $\simeq 10^\circ$ is fine (opinions?)
- need $\simeq 1.5$ m for detector array, make it 2 m for shielding, accessability,...
- fine with current lattice



The Upstream Polarimeter: Alignment Compton IP vs e^+e^- IP

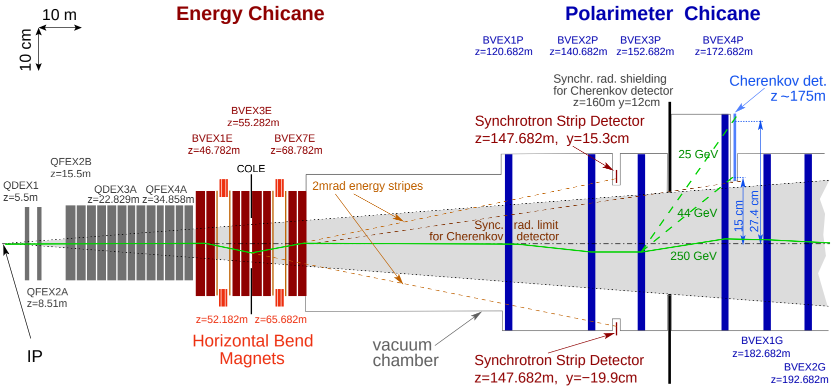
- requirement: control P_z at e^+e^- IP to 0.1%
- $\theta_{\mathrm{spin}} = (a\gamma + 1) \cdot \theta_{\mathrm{orbit}}$
- $\Rightarrow$ need to know orbit angle between Compton IP and e^+e^- IP to 20 μrad (10 μrad) at 500 GeV (1 TeV)
- level arm at Compton IP $\simeq$ 5 m
  $\Rightarrow$ require BPM resolution of 100 (50) μm (i.e. 2 orders of magnitude worse than for energy spectrometer)
- more precise study of effects of (mis)alignments in BDS and feed-back system on polarisation under way in time for TDR (M.Beckmann).

SB2009-Nov10 lattice: **no BPMs at all** in polarimeter chicane! Could we pleeeeease get some....?

Downstream Polarimeter

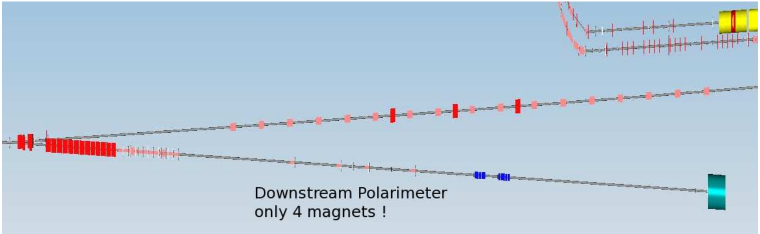
6-magnet chicane suggested in 2007 by Ken Moffeit et al:

- kick Compton e^- further out of the synchrotron radiation fan



Downstream Polarimeter in SB2009-Nov10 lattice

- still 4-magnet chicane - please upgrade to 6-magnet design as propsed in SLAC-PUB-12425
- necessary due to push-pull related changes to the extraction SC quadrupoles
- at the same time gives better shielding of magnets due to additional collimators
- even more impact due to worse spent beam in low power configuration....



Special Positron issues

- fully exploiting $P(e^+)$: cancellation of systematics
- works only with fast helicity reversal also for positrons!
- new baseline initially reduced $P(e^+)$ from 30-45% to 22%
  - corresponds to a 20-30% loss of effective luminosity
  - systematic error on polarisation itself will increase c.f. thesis of I.Marchesini on $e^+e^- \to W^+W^-$: systematic limit at $\delta P/P = 0.14\%$ (0.34%) for $P(e^+) = 60\%$ (30%)
- can be avoided by reoptimisation of e^+ source
- important to keep $P(e^+)$ high for an *irresistable* physics case!

for details see also talk by S.Riemann on Wednesday!

2008: 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 an initial positron polarisation of 30-45% for physics, don't reduce to 22% .
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.

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]
- publication on beam energy and polarisation measurements
  JINST **4** (2009) P10015, arXiv:0904.0122 [physics.ins-det]
- recent publication on upstream beam energy measurement:
  JINST **6** (2011) P02002, arXiv:1011.0337 [physics.acc-ph]
- downstream polarimeter 6-magnet chicane
  `http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-12425.pdf`

BACKUP

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)

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

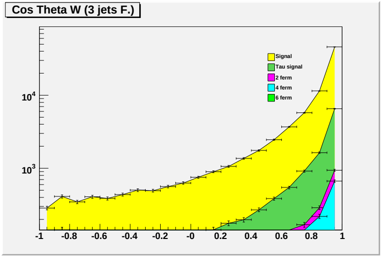
if positron polarisation

- $\sigma = \sigma_0[1 - P(e^+) \cdot P(e^-) + (P(e^+) - P(e^-))A_{LR}]$
- $\Rightarrow$ 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 $\rightarrow$ 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

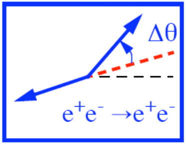


fit yields for 20 fb^{-1}:
$P(e^-) = 80.17 \pm 0.15$,
$P(e^+) = 60.10 \pm 0.20$
(no backgrounds yet)

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

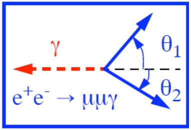
Acolinear Bhabhas

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



Radiative Returns

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

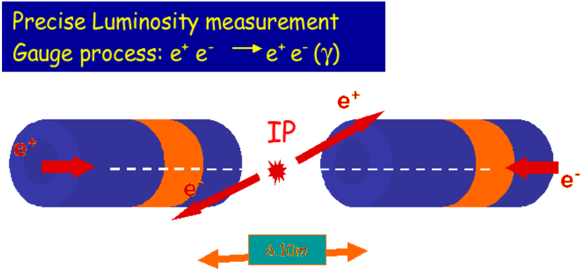


How can all these tools be combined to give the best $dL/d\sqrt{s}$?

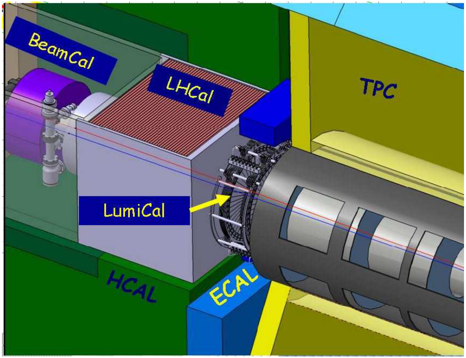
Available Tools

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!



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!

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