Analysis Plans Related to Electroweak/Higgs

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Physics Topics of Interest

Precision Electroweak Measurements

1. W Mass at threshold (in OK shape)
2. W Mass from constrained reconstruction (high importance)
3. Revisiting A_{LR} (at $\sqrt{s} = M_{\mathrm{Z}}$). Looking into beam polarization sharing.

Higgs Measurements

1. Higgs Mass ($\nu\nu\mathrm{bb}$). Exploit per event jet energy resolution.
2. Improve Leptonic Recoil? Vertex and beam-spot constraints and electron momentum reconstruction (GSF?)

Z Measurements

1. Physics case for "Giga-Z"
2. Detector case for "Z-running for calibration"
3. Detector performance and systematics minimization

Enabling Techniques and Needed Developments

Exploiting per Event Jet Energy Resolution

1. Work so far has focused on potential of mass-constrained fits
2. Work with Brian van Doren on mass-constrained $\pi^0 \to \gamma\gamma$
3. New work with Justin Anguiano on mass-constrained $\pi^0 \to \mathrm{e}^+\mathrm{e}^-\gamma$ and $\eta \to \pi^+\pi^-\gamma$. Initially started as a precursor to π^0 conversion reconstruction.
4. Can extend to more involved decay chains including vertex constraints.

Absolute Center-of-Mass Energy Determination - Key Issue

1. Need further work on $\mu\mu(\gamma)$ method ($\sqrt{s}_{\mathrm{p}}$)
2. Systematic uncertainty depends directly on absolute momentum scale. Most obvious method is with J/$\psi \to \mu\mu$. Statistics not great. Targeting 10 ppm.
3. Above is realistic? Looking into other methods. Precision measurement of kaon mass using $\mathrm{K}^+ \to \pi^+\pi^-\pi^+$ and use $\mathrm{K}^+ \to \mu^+\nu$??

Ultimate Calorimetry?

1. Precision cell-by-cell time-stamping for particle flow? Ideal for photons.

W Mass

M_{W} is an experimental challenge. Especially so for hadron colliders.

The three most promising approaches to measuring the W mass at an e^+e^- collider are:

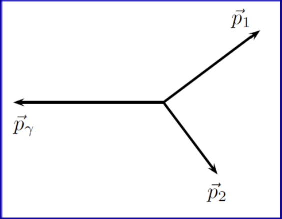
1. Polarized Threshold Scan Measurement of the $\mathrm{W^+W^-}$ cross-section near **threshold** with longitudinally polarized beams.
2. Constrained Reconstruction Kinematically-constrained reconstruction of $\mathrm{W^+W^-}$ using constraints from **four-momentum conservation** and optionally mass-equality as was done at LEP2.
3. Hadronic Mass (discussed by Katsu) Direct measurement of the **hadronic mass**. This can be applied particularly to single-W events decaying hadronically or to the hadronic system in semi-leptonic $\mathrm{W^+W^-}$ events.

Method 1 needs dedicated running near $\sqrt{s} = 161$ GeV. Methods 2 and 3 can exploit the standard $\sqrt{s} \geq 250$ GeV ILC program. Methods 1 and 2 need the absolute $\sqrt{s}$ well measured.

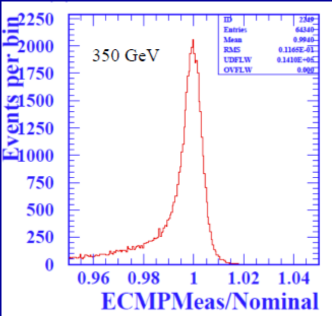
Beam Energy Measurement

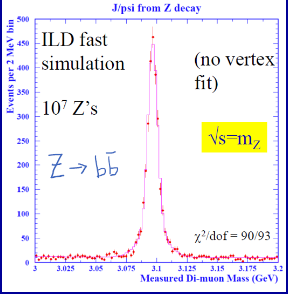
- Critical input to measurements of m_t, m_W, m_H, m_Z, m_X using threshold scans.
- Standard precision $O(10^{-4})$ for m_t straightforward.
- Targeting precision $O(10^{-5})$ for m_W, m_Z
  - Muon momenta based strategy looks feasible

$e^+ e^- \to \mu^+ \mu^- (\gamma)$



Use muon momenta.
Measure $E_1 + E_2 + |\mathbf{p}_{12}|$ as an estimator of $\sqrt{s}$





Momentum Scale Calibration (essential for $\sqrt{s}$)

Most obvious is to use $J/\psi \to \mu^+\mu^-$. But event rate is limited.

Particle	$n_{Z\mathrm{had}}$	Decay	BR (%)	$n_{Z\mathrm{had}} \cdot$ BR	Γ/M	PDG ($\Delta M/M$)
J/ψ	0.0052	$\mu^+\mu^-$	5.93	0.00031	3.0×10^{-5}	3.6×10^{-6}
K^0_S	1.02	$\pi^+\pi^-$	69.2	0.71	1.5×10^{-14}	2.6×10^{-5}
Λ	0.39	π^-p	63.9	0.25	2.2×10^{-15}	5.4×10^{-6}
D^0	0.45	$K^-\pi^+$	3.88	0.0175	8.6×10^{-13}	2.7×10^{-5}
K^+	2.05	various	-	-	1.1×10^{-16}	3.2×10^{-5}
π^+	17.0	$\mu^+\nu_\mu$	100	-	1.8×10^{-16}	2.5×10^{-6}

Candidate particles for momentum scale calibration and abundances in Z decay

Sensitivity of mass-measurement to p-scale (α) depends on daughter masses and decay

$$m_{12}^2 = m_1^2 + m_2^2 + 2p_1 p_2 \left[(\beta_1\beta_2)^{-1} - \cos\psi_{12}\right]$$

Particle	Decay	$<\alpha>$	max α	σ_M/M	$\Delta p/p$ (10 MZ)	$\Delta p/p$ (GZ)	PDG limit
J/ψ	$\mu^+\mu^-$	0.99	0.995	7.4×10^{-4}	13 ppm	1.3 ppm	3.6 ppm
K^0_S	$\pi^+\pi^-$	0.55	0.685	1.7×10^{-3}	1.2 ppm	0.12 ppm	38 ppm
Λ	π^-p	0.044	0.067	2.6×10^{-4}	3.7 ppm	0.37 ppm	80 ppm
D^0	$K^-\pi^+$	0.77	0.885	7.6×10^{-4}	2.4 ppm	0.24 ppm	30 ppm

Estimated momentum scale statistical errors ($p = 20$ GeV)

Use of J/ψ would decouple $\sqrt{s}$ determination from M_Z knowledge.
Opens up possibility of improved M_Z measurements.

Backup Slides

ILC runs below $\sqrt{s} = 250$ GeV ?

- ILC TDR design focused on $\sqrt{s} > 200$ GeV.
- Luminosity naturally scales with γ at a linear collider.
- For nominal $L = 1.8 \times 10^{34}$ at $\sqrt{s} = 500$ GeV corresponding L at $\sqrt{s} = 91$ GeV is 3.3×10^{33}.
- Need modification to the e^+ production scheme.
- Details need detailed design - but no obvious technical show-stoppers.

Precision Electroweak Physics Motivation

- Direct discovery of new physics would be wonderful. Looking forward to new results from LHC Run II.
- In the years before the direct discoveries of the top quark and the Higgs boson, precision measurements of the then observable Standard Model parameters pointed the way.
- If new physics continues to evade direct detection, ultra-precise measurements of the fundamental parameters of the Standard Model will become especially compelling. Can probe, albeit indirectly, potentially much higher energy scales and associated new physics.

A_{LR} at $\sqrt{s} = M_{\mathrm{Z}}$

Studied by K. Mönig 1999
For $\mathrm{Z} \to \mathrm{f}\bar{\mathrm{f}}$, general cross-section formula simplifies to

$$\sigma = \sigma_u[1 - P^+P^- + A_{\mathrm{LR}}(P^+ - P^-)]$$

With four combinations of helicities, 4 equations in 4 unknowns. Can solve for A_{LR} in terms of the four measured cross-sections (assumes helicity reversal for each beam maintains identical absolute polarization).

$$\begin{aligned}
\sigma_{++} &= \sigma_u[1 - P^+P^- + A_{\mathrm{LR}}(P^+ - P^-)] \\
\sigma_{-+} &= \sigma_u[1 + P^+P^- + A_{\mathrm{LR}}(-P^+ - P^-)] \\
\sigma_{+-} &= \sigma_u[1 + P^+P^- + A_{\mathrm{LR}}(P^+ + P^-)] \\
\sigma_{--} &= \sigma_u[1 - P^+P^- + A_{\mathrm{LR}}(-P^+ + P^-)]
\end{aligned}$$

For $P^- = 0.8$, $P^+ = 0.6$, $f_{\mathrm{SS}} = 0.08$, $\sigma_U^{vis} = 33$ nb:

$$\Delta A_{\mathrm{LR}}(\mathrm{stat}) = 1.7 \times 10^{-5}/\sqrt{\mathrm{L}(100\ \mathrm{fb}^{-1})}$$