



# Linear Collider Beam Energy Overview

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SLAC

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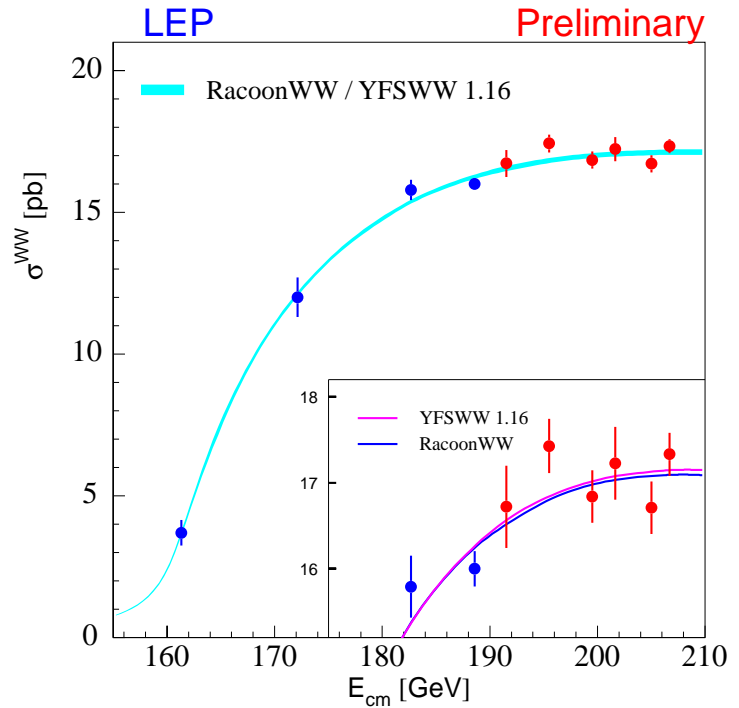
<http://www.slac.stanford.edu/~torrence/ipbi/>



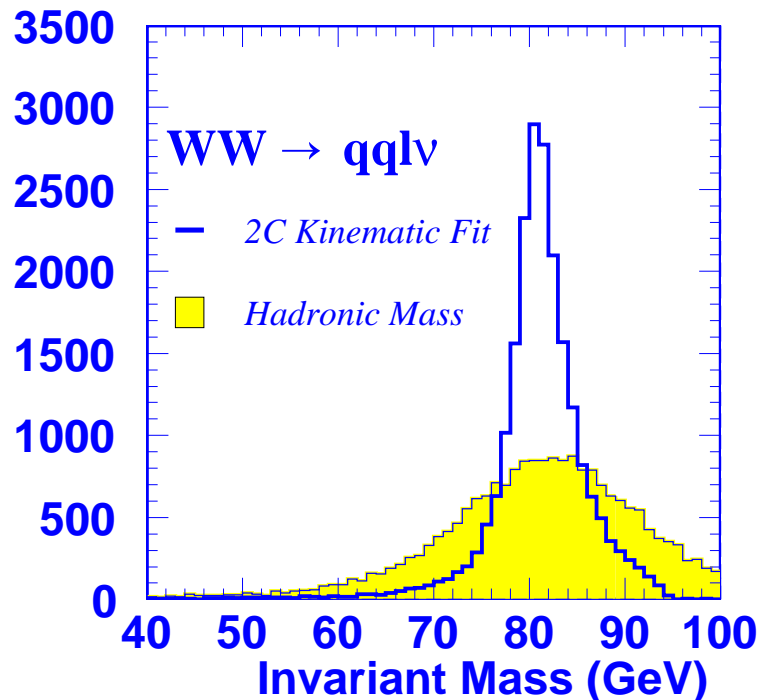
# Beam Energy at LEP II



Production  
Threshold



Kinematic Fits



Common Scale Uncertainty  $\frac{\delta M_W}{M_W} \approx \frac{\delta E_{Beam}}{E_{Beam}}$



# Physics Needs



## Weak Mixing Angle

	$\Delta \sin^2 \theta_W^{eff}$	$\Delta P^- / P^-$	$\Delta P_{eff} / P_{eff}$	$\Delta E_{beam}$
SLD	0.00026	0.50%		25 MeV
$e^-$ only	0.00005	0.25%		$\sim 5$ MeV
Blondel	0.00002	0.25%	0.10%	$\sim 2$ MeV

## WW Threshold

$$\Delta m_W \sim 6 \text{ MeV}$$

$$\Rightarrow \Delta E_b < 5 \text{ MeV (60 ppm)}$$

## $t\bar{t}$ Threshold

$$\Delta m_t \sim 50\text{-}100 \text{ MeV}$$

$$\Rightarrow \Delta E_b < 50 \text{ MeV (290 ppm)}$$

## Higgs (direct reconstruction)

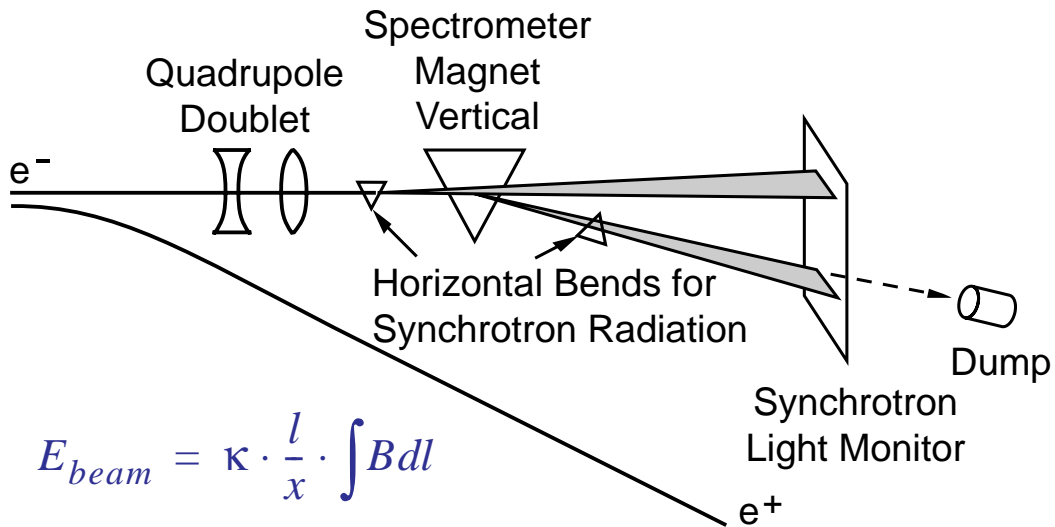
$$\Delta m_H \sim 50 \text{ MeV} \Rightarrow \Delta E_b < 100\text{-}300 \text{ ppm}$$



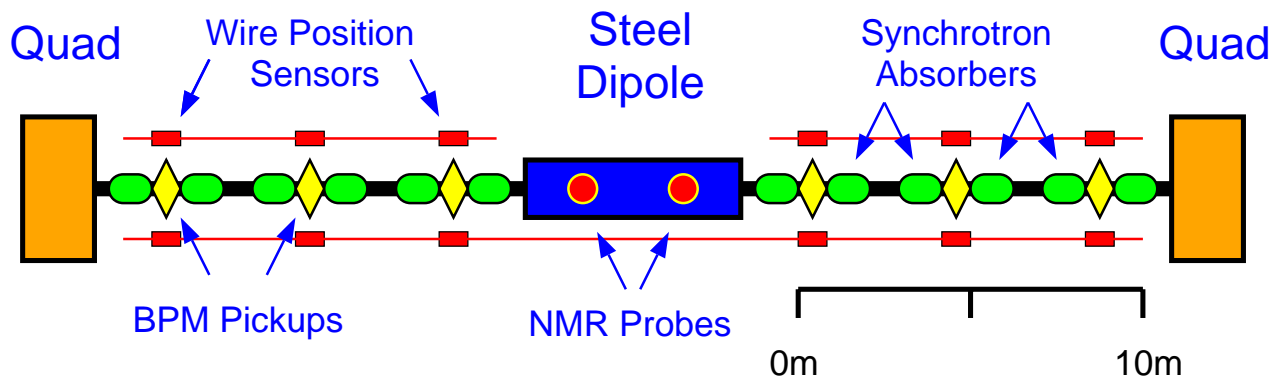
# Spectrometer Methods



WISRD-style



BPM-style



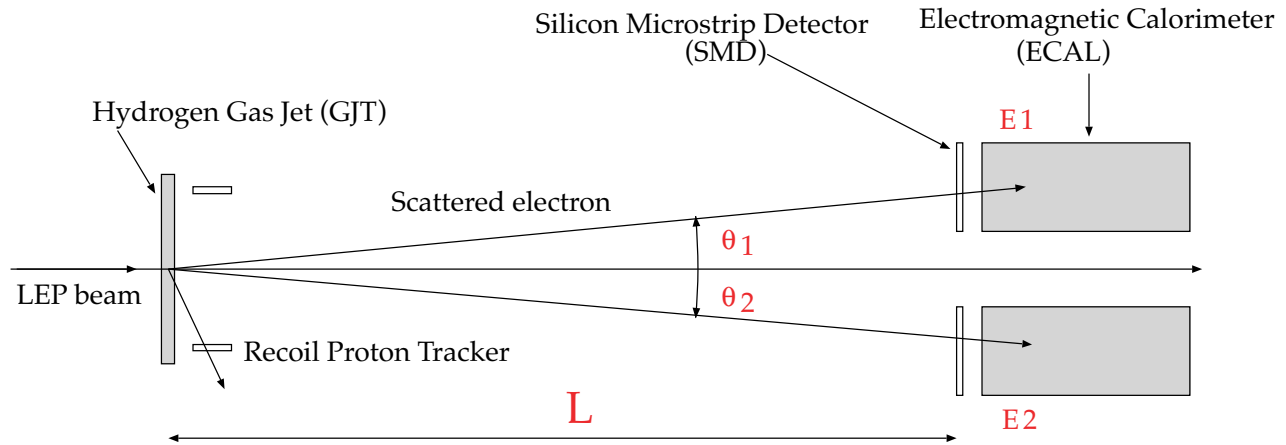
‘Wire’ Scanner

Common Issues

- Need large bend (downstream?)
- Can calibrate at Z-pole ~ yearly?



# Møller Scattering



$$E_{beam} = \frac{8m_e}{(\tan\theta_1 + \tan\theta_2)^2} \frac{1}{1 - \kappa^2} - m_e$$

$$\kappa = \frac{\tan\theta_1 - \tan\theta_2}{\tan\theta_1 + \tan\theta_2} \text{ or } \kappa = \frac{E_1 - E_2}{E_1 + E_2}$$

- Use angles only (need IP position)
- Use energy and angles (independent of IP position)

## LEP II Study [LEP II Yellow Report]

$l = 30$  meters

$\theta = 2 - 6$  mRad angular acceptance

$\sigma_E/E = 3.37/E(\text{GeV})^{1/4}\%$  resolution

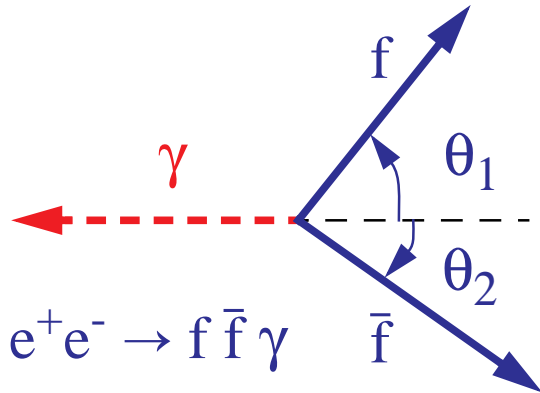
$\Delta E_{stat} = 2\text{MeV}$  in 30 minutes ( $\sim 600$  Hz)

$\Delta E_{syst} \sim 2\text{MeV}$  (dominated by Fermi motion)

$\Rightarrow$  Complete study for LC needed...



# Radiative Returns at LEP



$$\frac{s'}{s} = \frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1 + \theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1 + \theta_2)|}$$

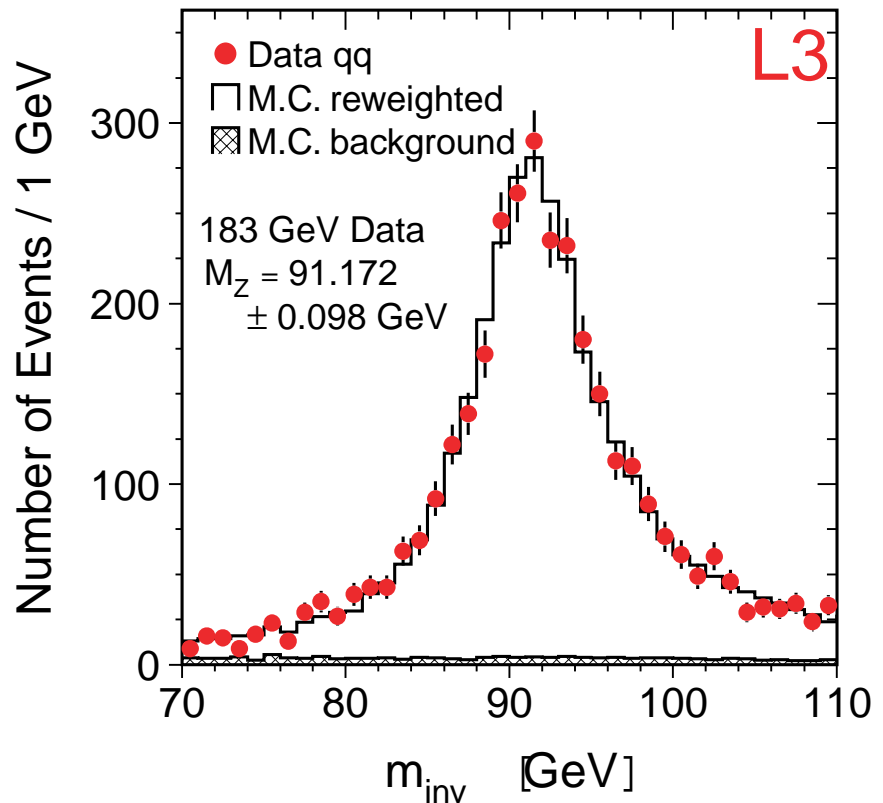
## Statistics

Channel	$\Delta E_{\text{beam}}$
$q\bar{q}\gamma$	$\sim 18 \text{ MeV}$
$\mu\mu\gamma$	$\sim 40 \text{ MeV}$
$ee\gamma$	$\sim 70 \text{ MeV}$

LEP Potential

Statistics Only

$2.7 \text{ fb}^{-1}$



## Systematics

- Theoretical Description
- Hadronization Uncertainties
- Detector Understanding

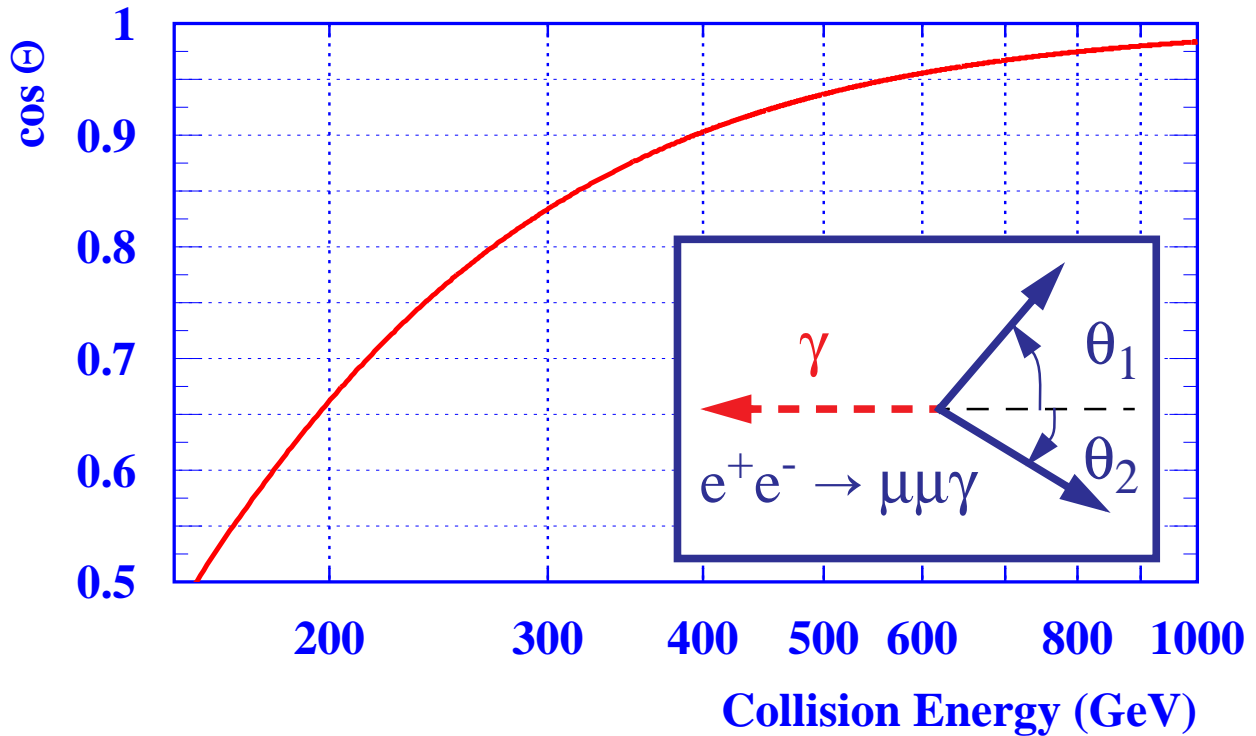
### Opal Estimates

$q\bar{q}\gamma$	$\Delta E_{\text{beam}} \sim 70 \text{ MeV}$
$\mu\mu\gamma$	$\Delta E_{\text{beam}} \sim 20 \text{ MeV}$
$ee\gamma$	$\Delta E_{\text{beam}} \sim 80 \text{ MeV}$

Need absolute  $\theta$  measurement!



# Radiative Returns at LC



Symmetric production:  $s' = m_Z^2, \Theta_1 = \Theta_2$

Collision Energy	$\cos \Theta$	$\Theta$ (mRad)
$2 m_W$	0.522	1000
$2 m_t$	0.875	500
500 GeV	0.937	360
1 TeV	0.984	180

Need **precision** and **accuracy** at small  $\Theta$

$$\delta\Theta \approx 0.1\% \text{ per event } (\Gamma_Z \text{ limit})$$

# Summary



## Required Precision

~ 200 ppm at HE, ~50 ppm at WW

Other needs at HE? (slepton production?)

Needed to  $\sqrt{s} = 1 \text{ TeV}$ ?

Beam-based methods (others?)

- Spectrometer
- Kinematic
- Dispersion

Different benefits for **absolute/relative** precision  
and measurement **timescales**

Energy width measurements?

Detector/physics methods

- Radiative returns ( $\mu^+\mu^-\gamma$ )
- $\mu^+\mu^-$  momenta
- Direct reconstruction  $m_W, m_Z$  (statistics?)

⇒ absolute energy Luminosity weighted