Linear Collider
Beam Instrumentation Overview

Linear Collider R&D Opportunities Workshop

May 31st, 2002

SLAC

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*with M.Woods and D.Cinabro

- BI Overview
- Beam Energy
- Polarization
- Luminosity

http://physics.uoregon.edu/~torrence/talks/

BI Overview

Beam Instrumentation Topics

- Beam Energy Scale and Width
- Beam Polarization
- Integrated Luminosity and Spectrum

Instrumentation needed for physics...

State of Affairs

- Many conceptual ideas
- Few concrete designs or detailed studies
- First meeting of new study June 26th

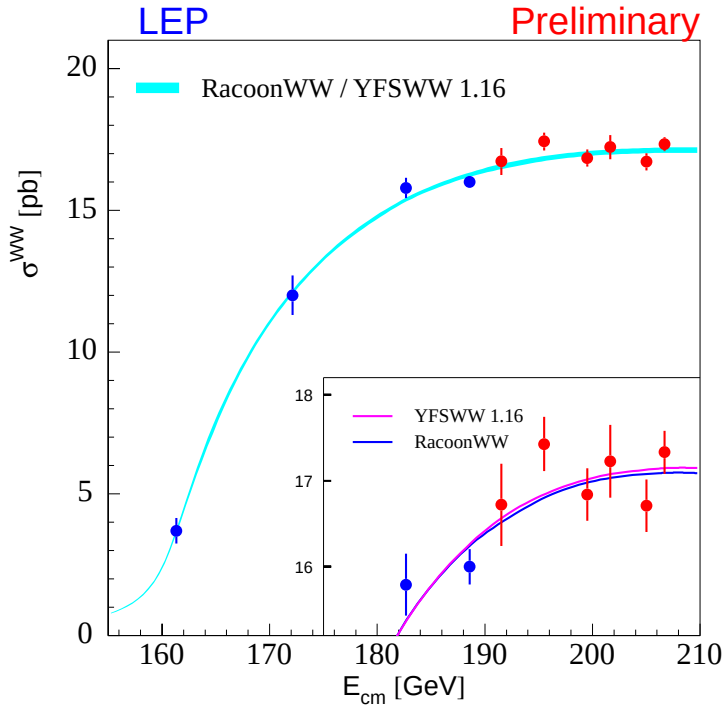
`http://www.slac.stanford.edu/~torrence/ipbi/`

Significant Overlap

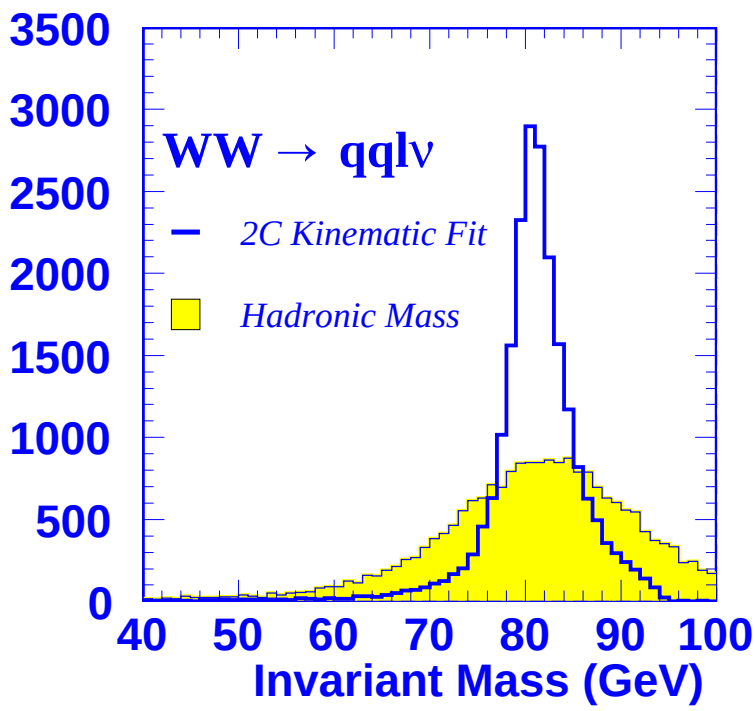
- Detector/Physics groups
- Beam delivery/Final focus activities
- Accelerator instrumentation

Beam Energy at LEP II

Production Threshold



Kinematic Fits



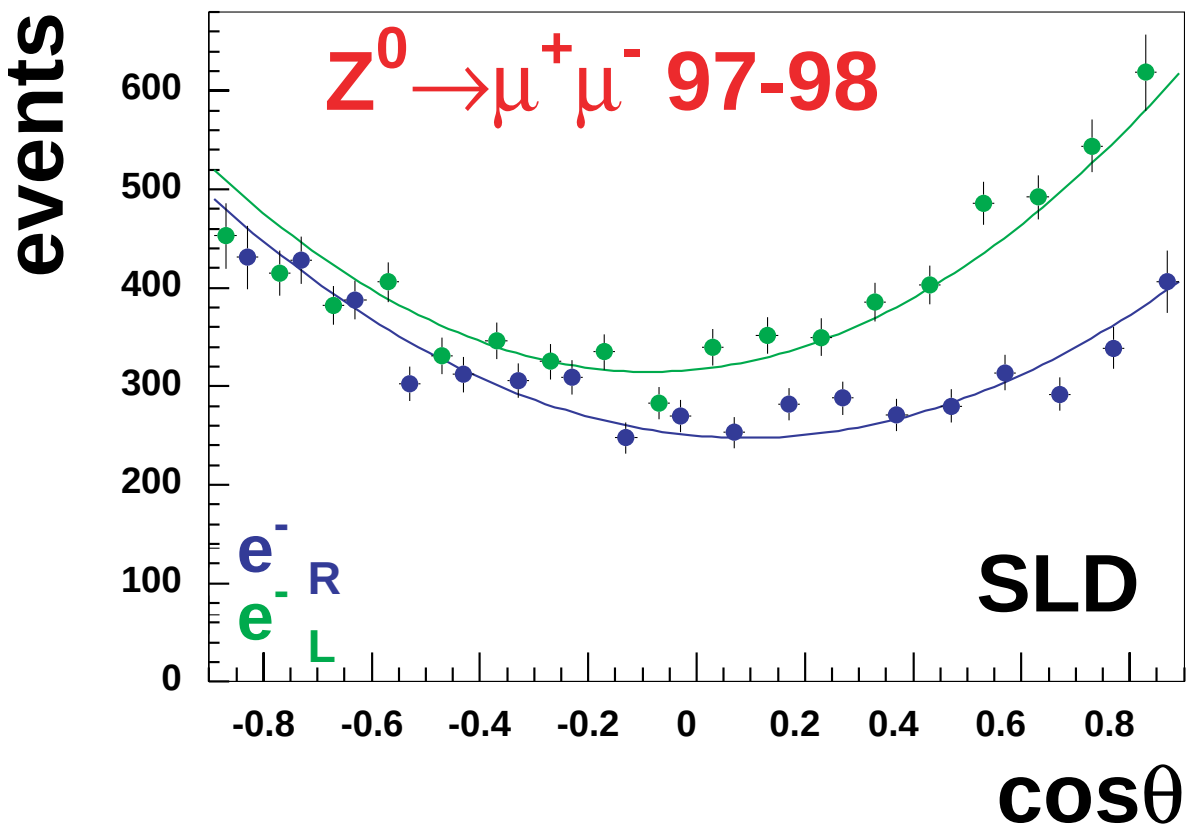
Common Scale Uncertainty $\frac{\delta M_W}{M_W} \approx \frac{\delta E_{Beam}}{E_{Beam}}$

Polarization at SLC

Hadronic Final States

$$A_{LR} = \frac{1}{P_e} \frac{N_L - N_R}{N_L + N_R}$$

Leptonic Final States



Combined

$$\sin^2\theta_W^{eff} = 0.23098 \pm 0.00026$$

Still statistics limited...

Linear Collider Requirements

Beam Energy Scale

- m_t from $t\bar{t}$ threshold
- m_H from direct reconstruction
- m_{new} from either

$$\delta E_b / E_b \sim 100\text{-}200 \text{ ppm}$$

Polarization

- SM asymmetries (l^+l^-, $q\bar{q}$, WW, ...)
- Background suppression of WW
- SUSY quantum numbers

$$\delta P / P \sim 0.25 - 0.5\%$$

Luminosity Spectrum

- m_t from $t\bar{t}$ threshold
- most every physics result! (at some level)

Know $dL/dE \sim 1\%$

⇛ Very challenging in LC environment!

GigaZ Requirements

Weak Mixing Angle

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

$$A_{LR} = \frac{1}{P_{eff}} \frac{N_L - N_R}{N_L + N_R} \text{ where } P_{eff} = \frac{P^- + P^+}{1 + P^- P^+}$$

WW Threshold

$$\Delta m_W \sim 6 \text{ MeV} \Rightarrow \Delta E_b < 5 \text{ MeV}$$

Also Needed

- Low beamstrahlung (separate IP)
- Positron polarization
- Theory improvements

$\Rightarrow$ Very challenging for BI!

General Issues

Measurement time scales

- Luminosity averaged - months
- Operator tuning - minutes
- Train-to-train - 10 ms
- Bunch-to-bunch - 1 ns

Correlations between L, E, P need to be understood

Measurement Location

- At IP (luminosity weighted)
- Near IP in final focus (upstream/downstream)
- Elsewhere in machine

Measurement Frequency

- Every pulse - in collision
- Sampled (dropouts?)
- Dedicated runs

⇛ How much time needed for calibration?

Must compare physics needs to operational needs...

Linear Collider Beam Energy Measurements

(E. Torrence)

Energy Overview

Energy needs

- 100-200 ppm absolute energy scale
- pulse-by-pulse relative measurement?
- Detailed width measurement also

Can calibrate at Z-pole ~ yearly?

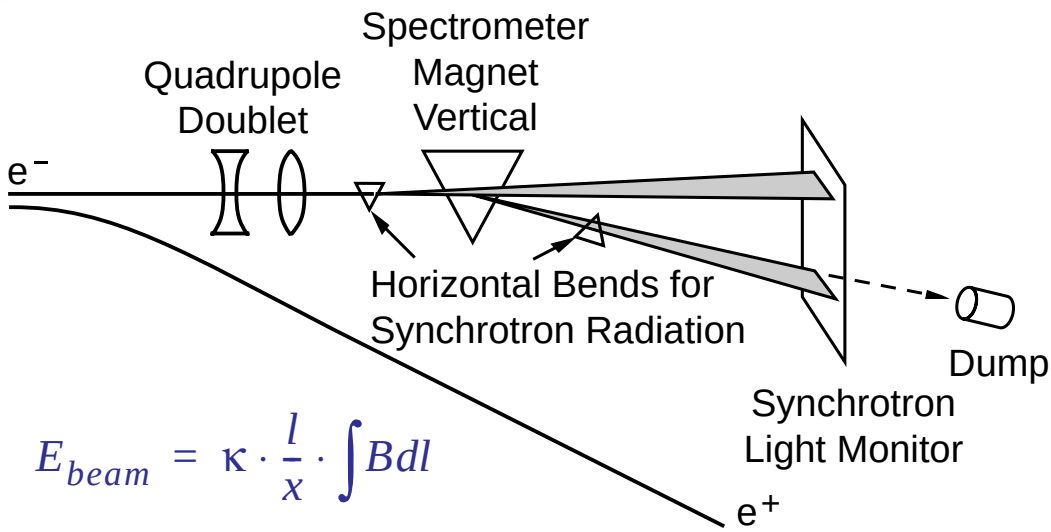
Potential beam methods

- WISRD-style spectrometer
- LEP-style BPM spectrometer
- Møller/Bhabha scattering target
- 'Wire' scanner at high dispersion
- Your good idea???

Potential detector methods

- Radiative return ($\mu^+\mu^-\gamma$) kinematics
- Mu-pair momenta?

Meet the WISRD



$$E_{beam} = \kappa \cdot \frac{l}{x} \cdot \int Bdl$$

$\int Bdl = 3.05$ T m $\quad l = 15$ m $\quad x = 27$ cm at 50 GeV

Systematic Errors per Beam

$\Delta \int Bdl$:	100 ppm
Alignment:	190 ppm
Detector - IP:	135 ppm
Total:	250 ppm ⇛ 12.5 MeV at 50 GeV

⇛ 1998 SLC m_Z scan implies a ~ 40 ± 20 MeV offset in E_{CM}

NLC Questions

- Stronger bend (and where)?
- Better detector technology
- Possible downstream (in collision)?
- Also measure energy shape?

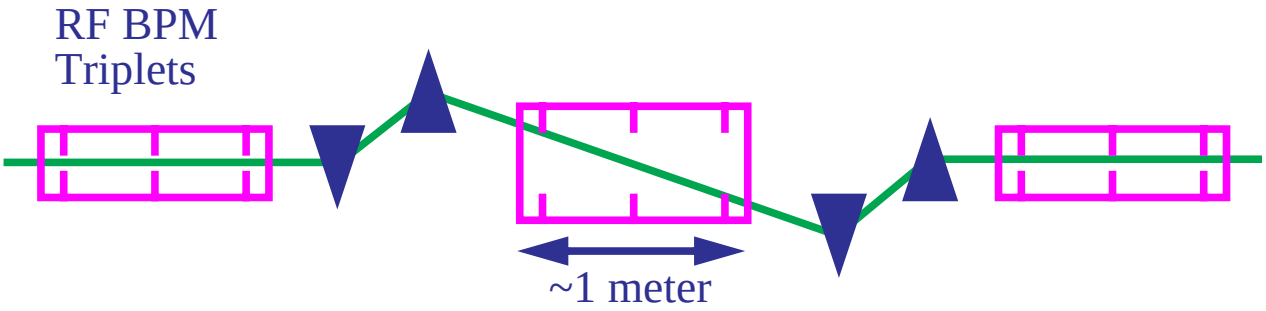
BPM Spectrometer

LEPII Spectrometer

- Relies heavily on frequent calibrations
- 1 micron stability for less than 8 hours
- Operated within tight dynamic range
- Beam position and bend held constant

⇛ Very low duty factor for LC operations

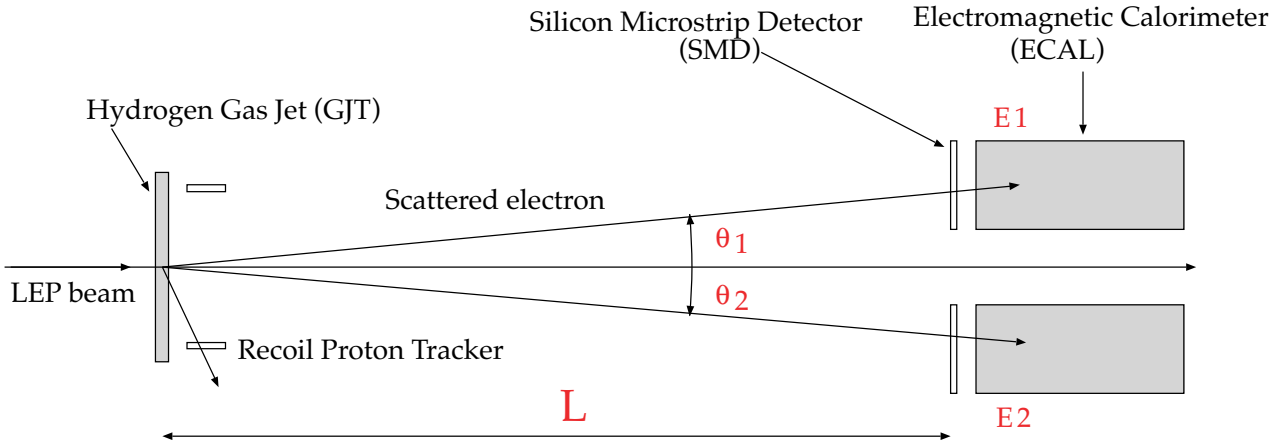
RF Spectrometer



- Compact 1m RF BPM triplet blocks
- Chicane layout for better alignment control
- Magnet system more complicated

⇛ 100 nm precision required...
(assuming 1 mRad bending)

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

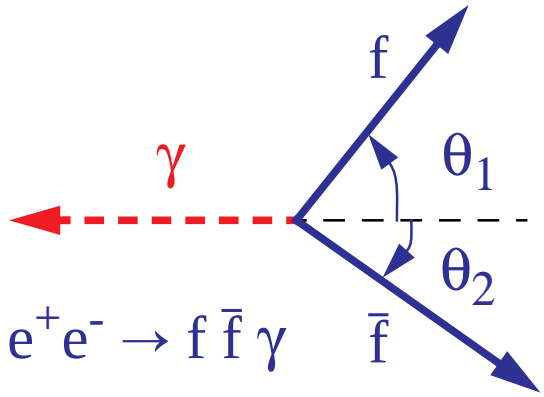
$\sigma_E/E = 3.37/E(GeV)^{1/4}\%$ resolution

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

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

⇛ Complete study for LC needed...

Radiative Returns at LEP



$e^+e^- \rightarrow f\,\bar{f}\,\gamma$

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

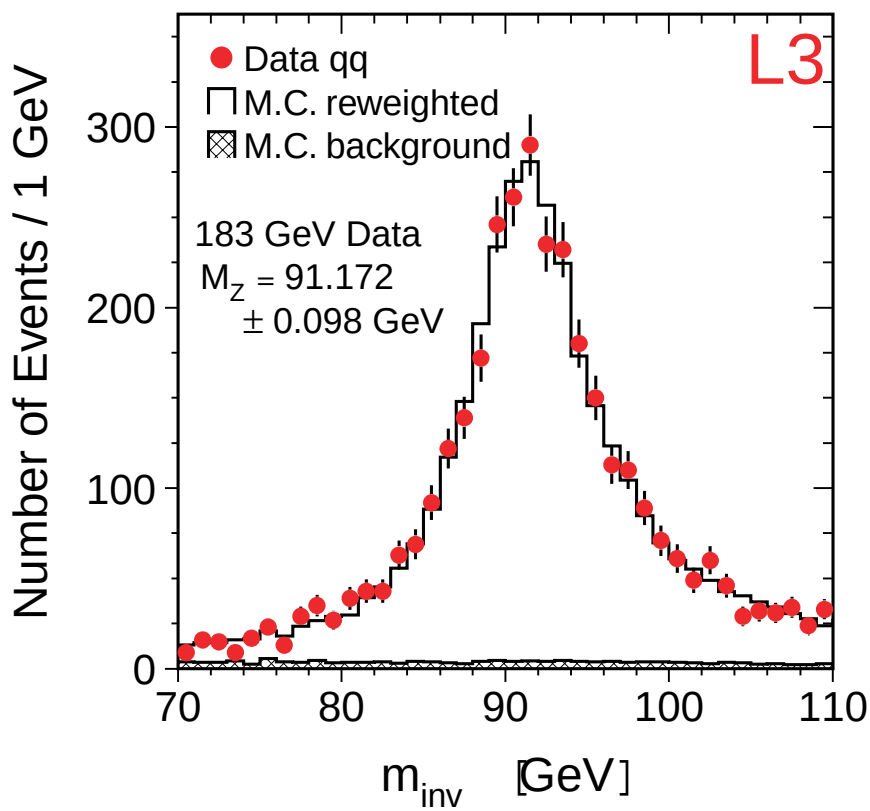
Statistics

Channel	ΔE_{beam}
$q\bar{q}\gamma$	~ 18 MeV
$\mu\mu\gamma$	~ 40 MeV
$ee\gamma$	~ 70 MeV

LEP Potential

Statistics Only

2.7 fb^{-1}



Systematics

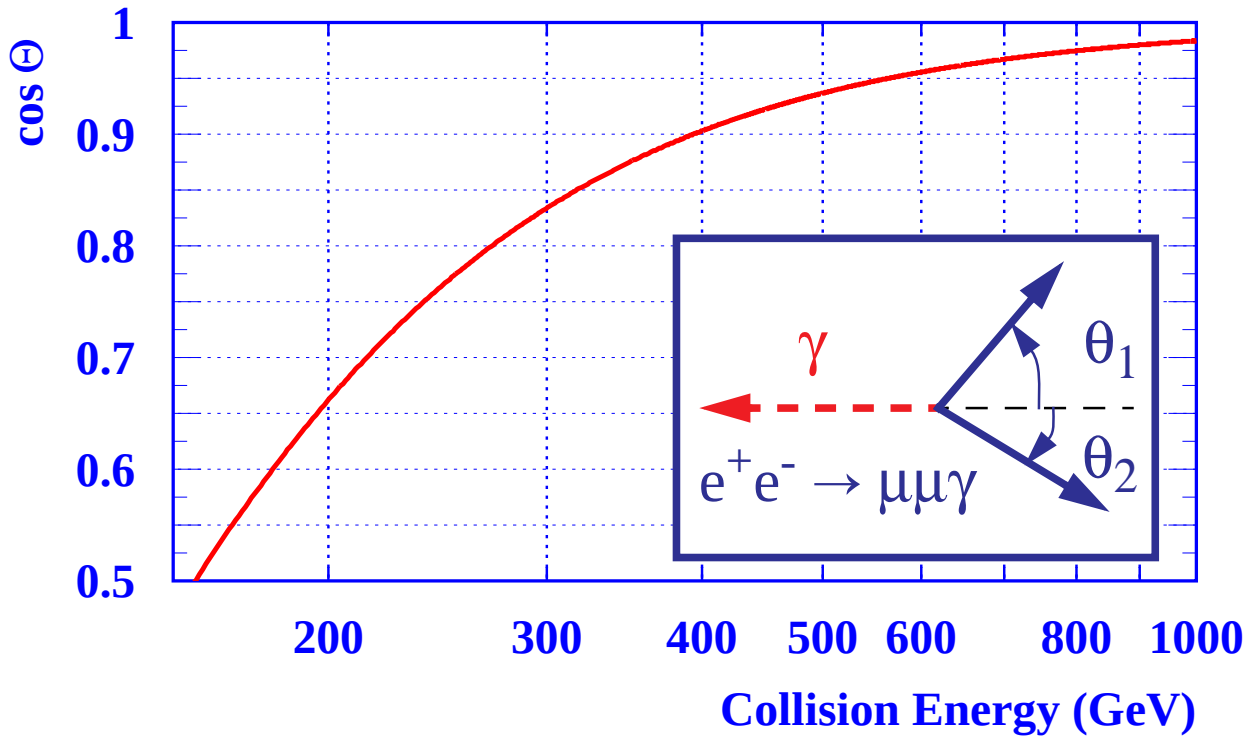
- Theoretical Description
- Hadronization Uncertainties
- Detector Understanding

Need absolute θ measurement!

Opal Estimates

$q\bar{q}\gamma$	ΔE_{beam} ~ 70 MeV
$\mu\mu\gamma$	ΔE_{beam} ~ 20 MeV
$ee\gamma$	ΔE_{beam} ~ 80 MeV

Radiative Returns at NLC



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

Collision Energy	$\cos\Theta$	Θ (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 Θ

$\delta\Theta \approx 0.1\%$ per event (Γ_Z limit)

Linear Collider Polarimetry (M. Woods)

Polarimetry Overview

Polarization Needs

- $\delta P/P \sim 0.25 - 0.5\%$
- Each helicity state separately
- In vs. out of collision difference?

$\Rightarrow e^+$ polarization a big help!

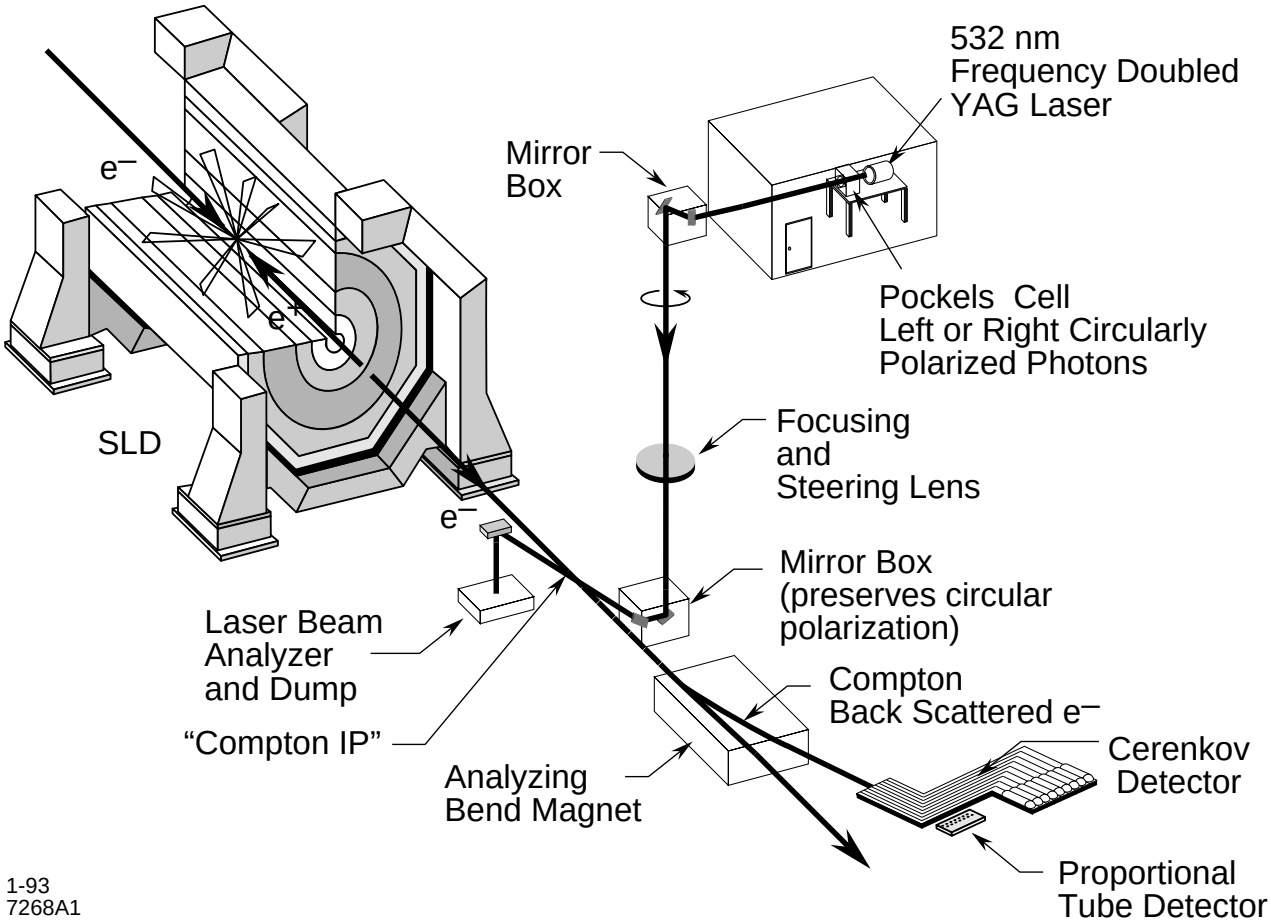
Location and Technology

- Source - Mott scattering
- Damping ring - Synchrotron?
- DR - IP - Laser Wire?
- Interaction point - WW pairs or Blondel (e^+)
- Post IP - Compton scattering

Other issues

- Significant depolarization during collisions
- In-collision measurements desired
- Post-IP environment very difficult

Compton Polarimetry

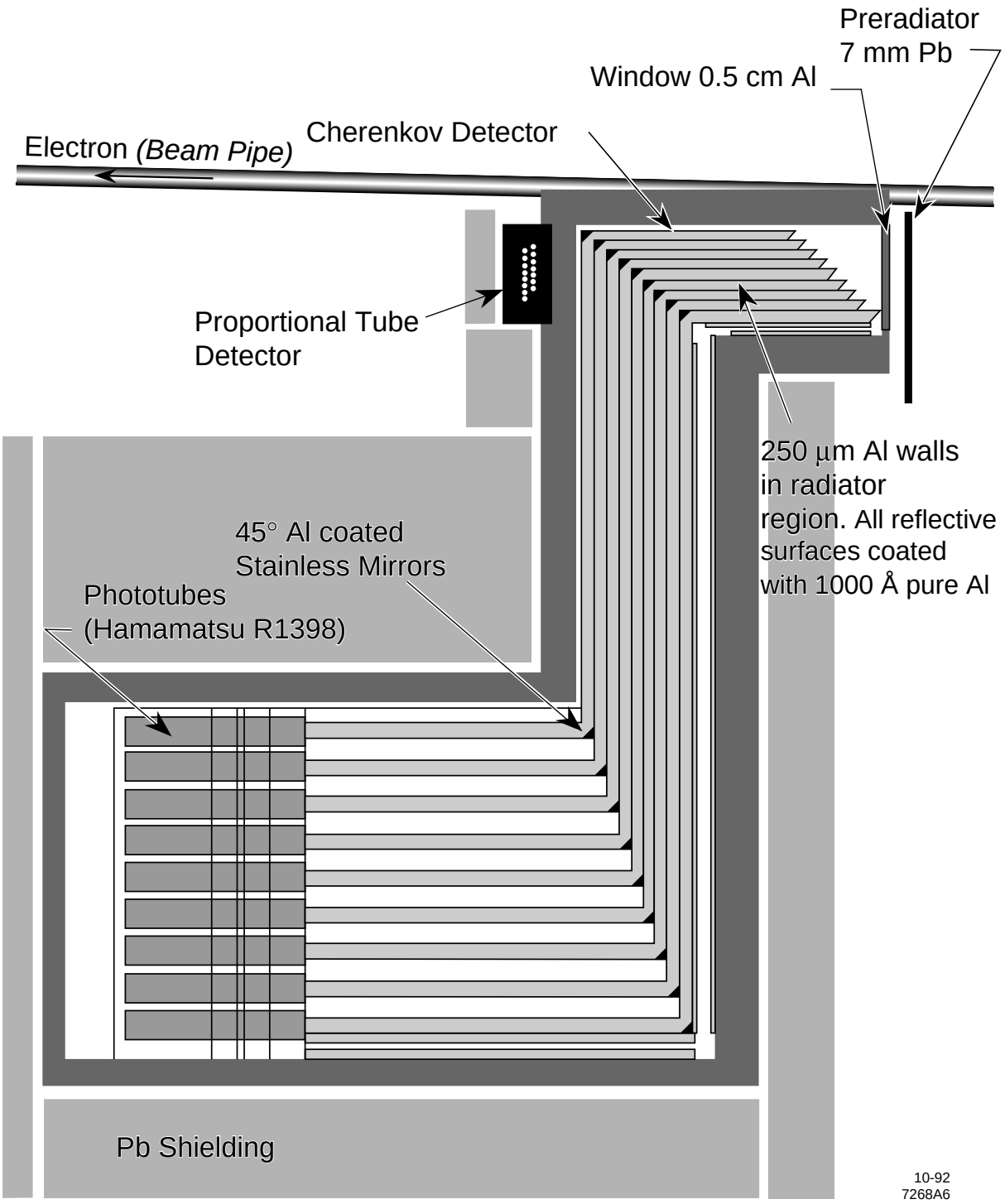


Multiple Detectors

- Çerenkov counter - scattered e^- asymmetry
- Photon counter - integral γ E asymmetry
- Quartz fiber calorimeter - transverse γ asym.

Unique systematics help reduce errors

Çerenkov Detector



NLC Polarimetry Goals

Uncertainty Source	$\delta P/P$ SLD	$\delta P/P$ LC
Analyzing Power	0.40%	0.20%
Detector Linearity	0.20%	0.10%
Laser Polarization	0.10%	0.10%
Electronic Noise	0.20%	0.05%
Total Uncertainty	0.50%	0.25%
IP Corrections	0.15%	< 0.05%

Improvements

- Better segmentation in Cherenkov counter
- Better design to define active volume
- Additional e^- detectors?

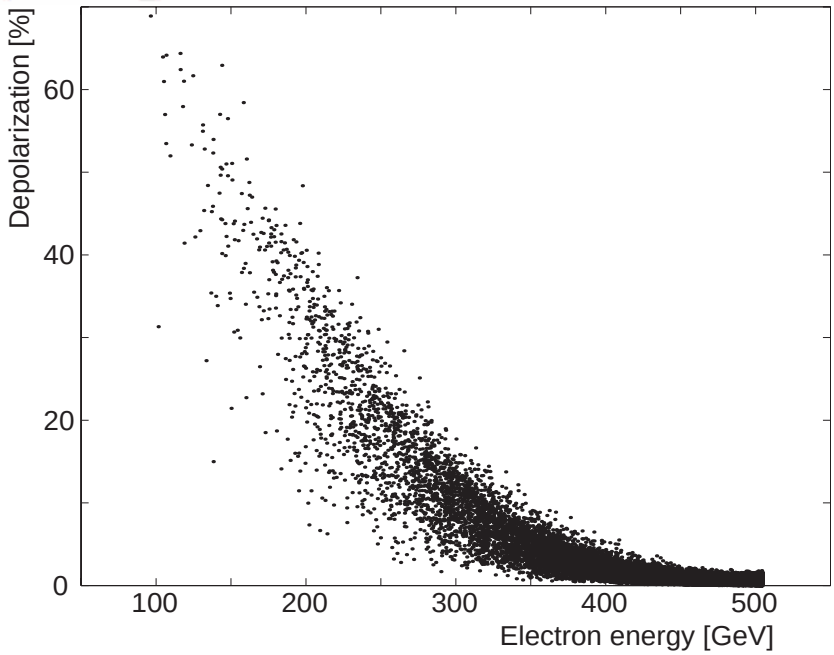
Kinematics at high energy are favorable!

Outstanding Issues

- Extraction line design
- Background tolerance
- NLC bunch structure/timing

⇛ 1-2% depolarization in collision process!

Depolarization Effects

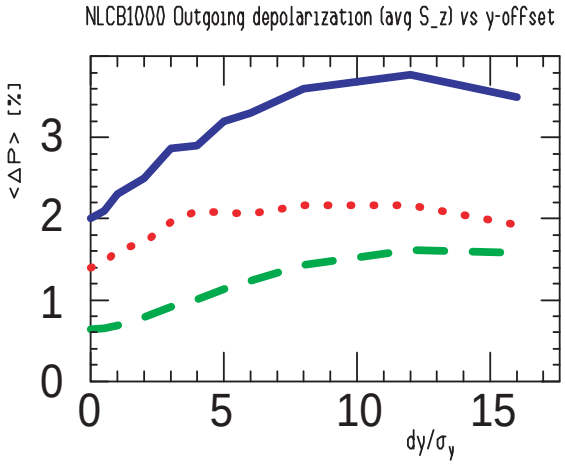


ΔP vs. E_{final}

K. Thompson
January 2001
SLAC PUB 8716

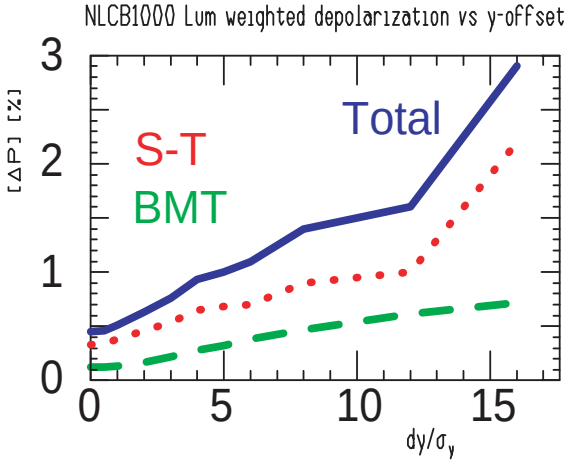
ΔP vs. $\Delta y/\sigma_y$

Total Outgoing Bunch ⇛



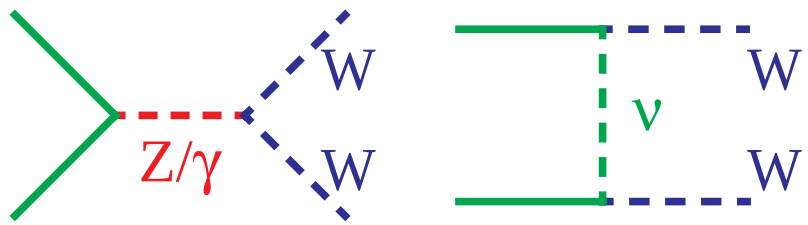
Lumi weighted ~ 25% of bunch average ΔP

Lumi Weighted ⇛

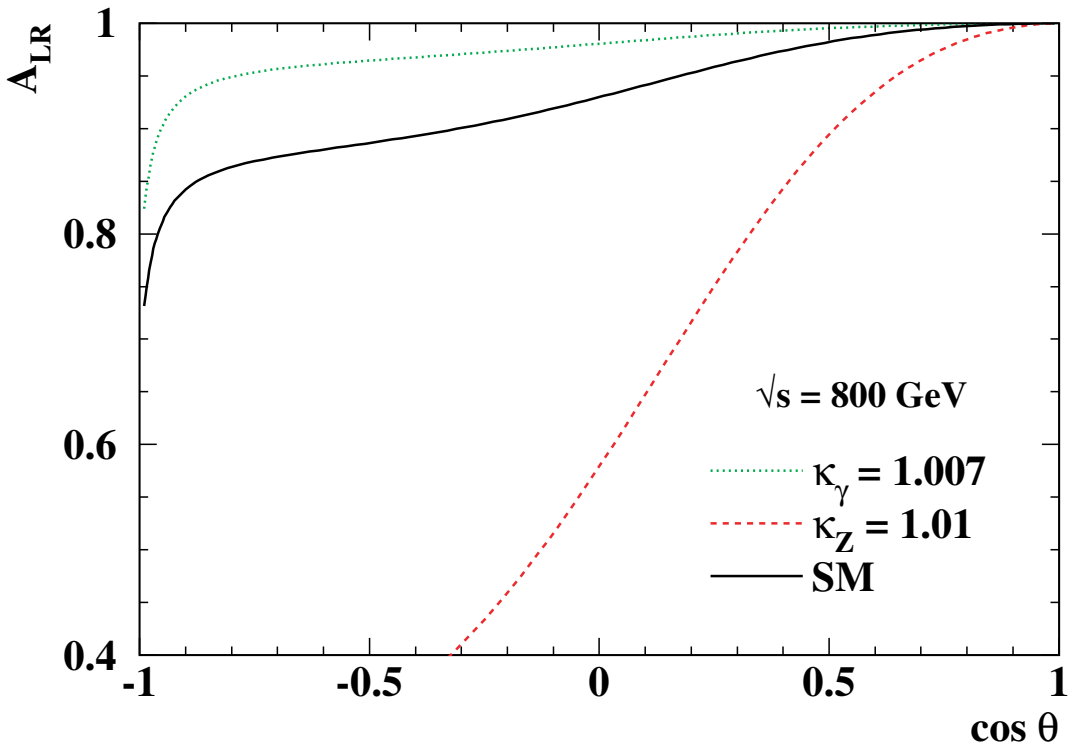


How well can this be determined???

Direct Polarization



$\sigma = 12 - 7$ pb at $\sqrt{s} = 350 - 500$ GeV



[K. Mönig, Snowmass 2001]

$\delta P/P < 0.1\%$ for 500 fb^{-1} at 350 GeV (9/1 L ratio)

⇛ Similar with e$^-$ only

Linear Collider Luminosity Issues

(D. Cinabro)

Luminosity Overview

Luminosity Needs

- Precise knowledge of dL/dE (~ 1%)
- Need to know incoming energy distribution
- Want relative lumi monitor pulse-to-pulse?

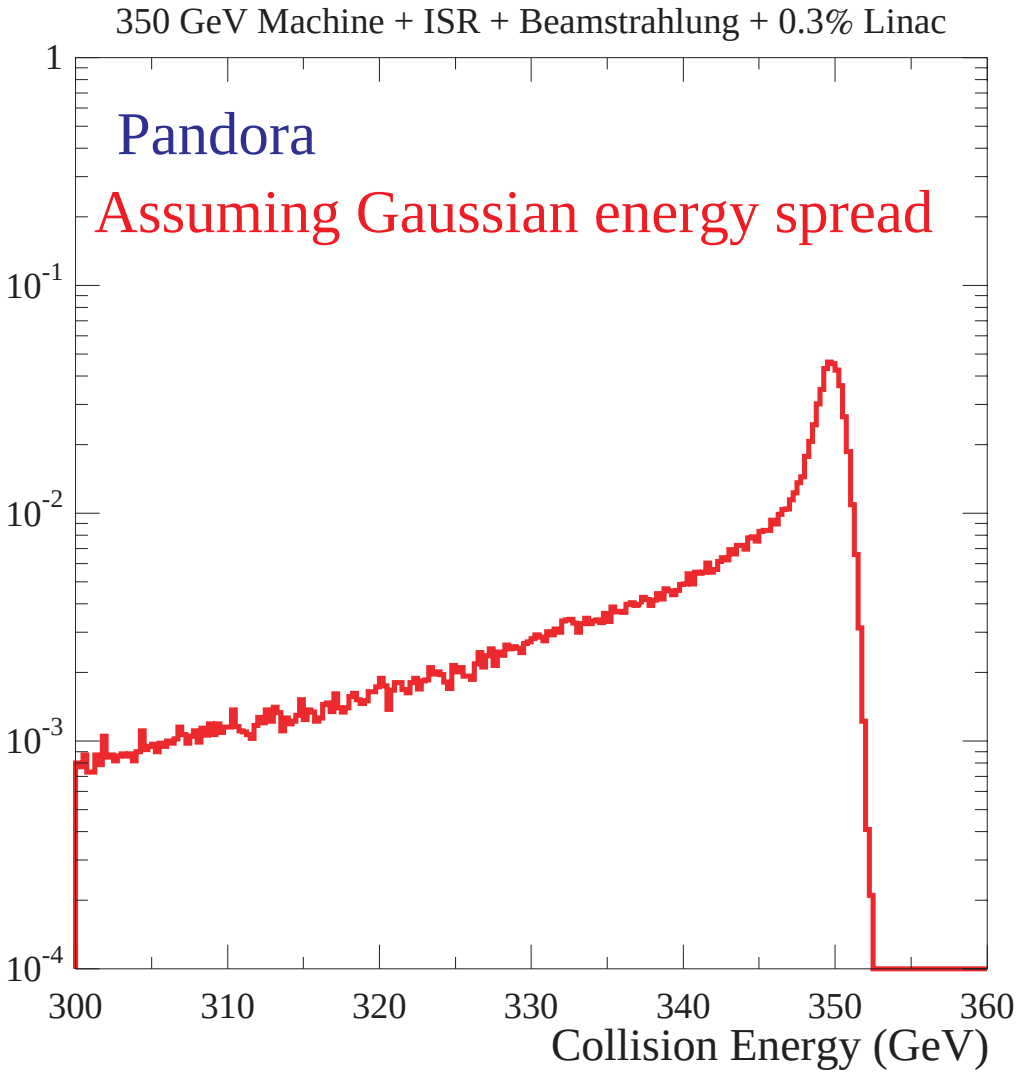
Beam Instrumentation

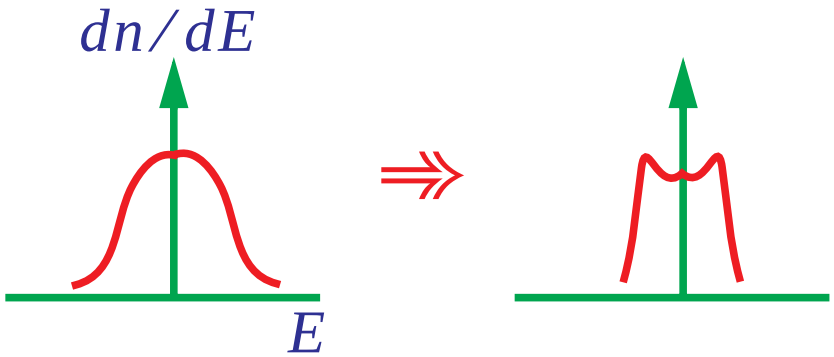
- Beamstrahlung monitors
- Spot size/bunch length/deflection scans
- Pair monitor
- Radiative Bhabha
- Two photon monitor
- ?????

Detector Instrumentation

- Low angle e^+e^- tagger
- Forward tracker (e^+e^- acolinearity)

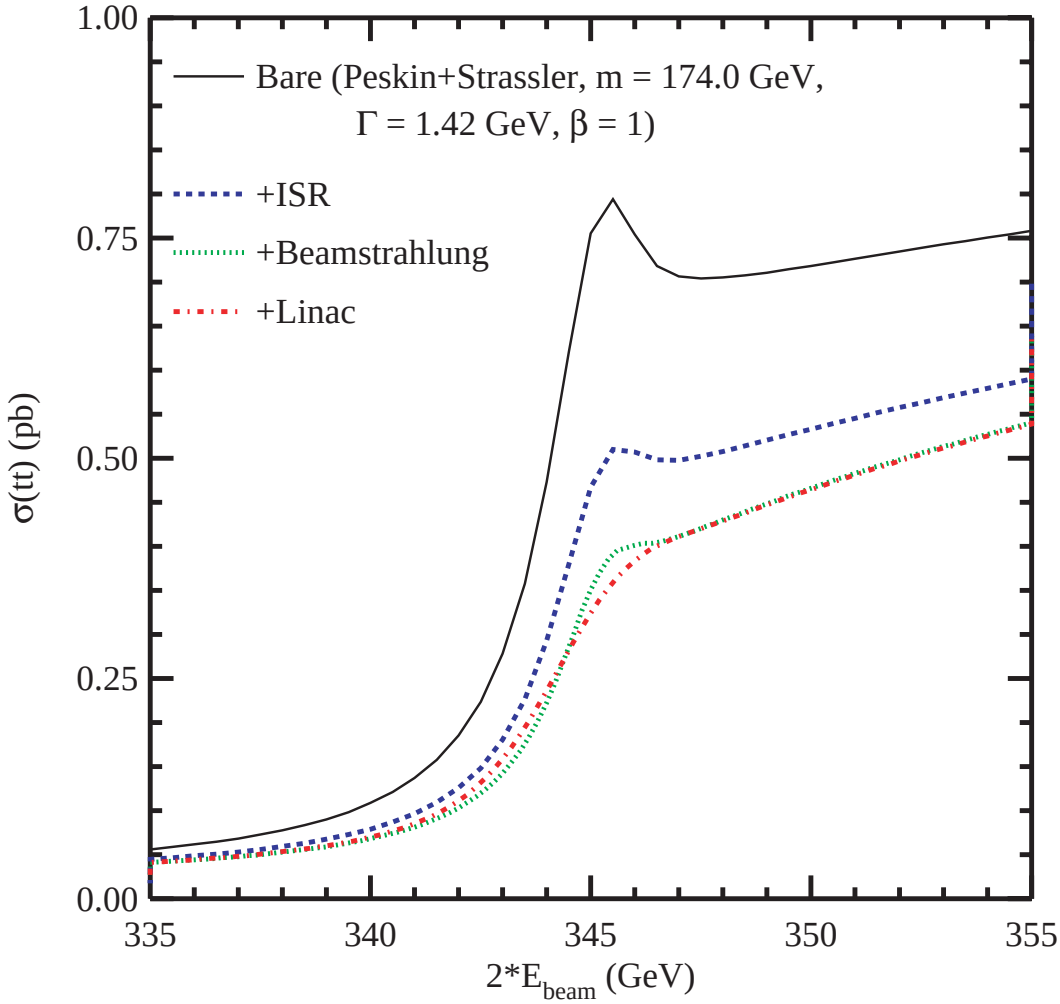
Beyond ISR





Luminosity spectrum highly dynamic!

Physics Example $t\bar{t}$



Simple Model (D. Cinabro June 26th)

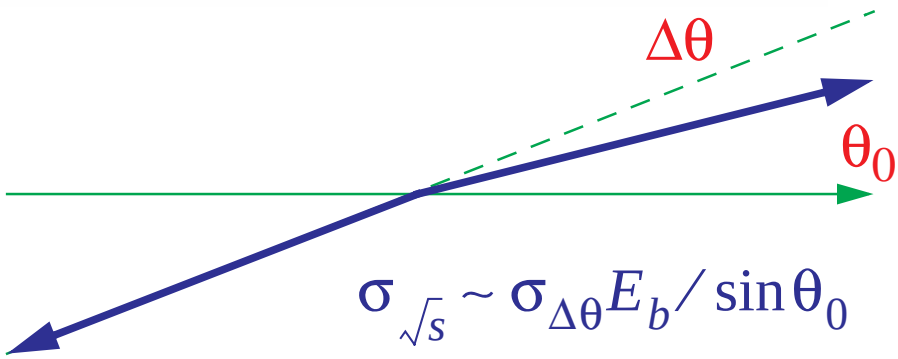
Flat tail + Gaussian core $R = A_{tail}/A_{core}$

dm_t/dR = 40 MeV / 1%

$d\Gamma_t/dR$ = 100 MeV / 1%

Comparable to other systematics

Bhabha Acolinearity



Bhabha rates

- Forward (180-300 mRad) ~ 200 R
- Intermediate (300-800 mRad) ~ 100 R
- Barrel (> 800 mRad) ~ 8 R

Need rates from forward events, but not too far ...

Tracking Based (silicon)

- Excellent angular resolution $\sigma_{\sqrt{s}} \sim 0.1\%$?
- Backgrounds and radiation?

Calorimeter Based (energy balance)

- $\sigma_E / E < 1\%$ at 100 GeV
- Need well understood acceptance/uniformity
- Need segmentation (backgrounds)

⇛ Detailed studies with backgrounds needed

BI Wrap-up

General Thoughts

- Many conceptual ideas
- Need more concrete planning
- IPBI meeting June 26th to kick this off

Beam Energy

- Where to put spectrometer device?
- Detector requirements for radiative returns
- Other clever ideas???

Polarization

- Possible during collisions?
- Detailed polarimeter design
- Depolarization model

Luminosity

- Very challenging problem
- Large overlap with machine side
- Impacts detector design
- Detailed studies needed now!