Where Machine and Detector Meet

APS/DPF Joint April Meeting
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Philadelphia

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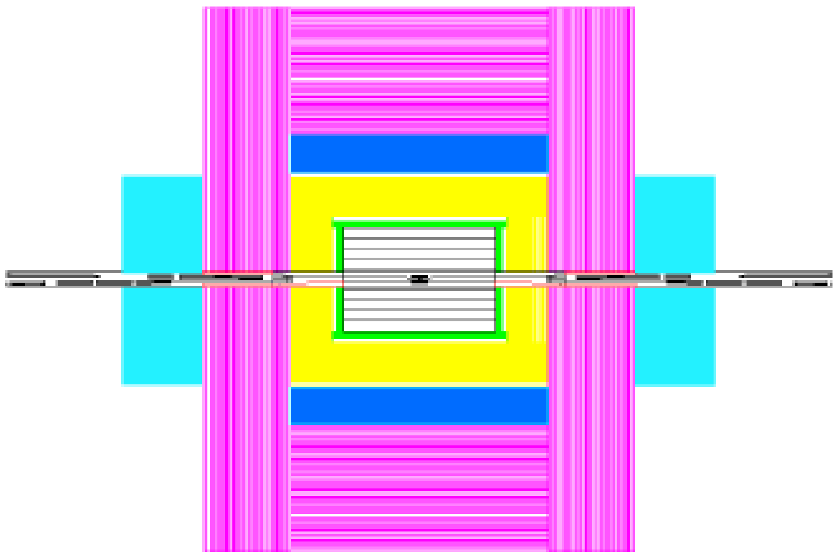
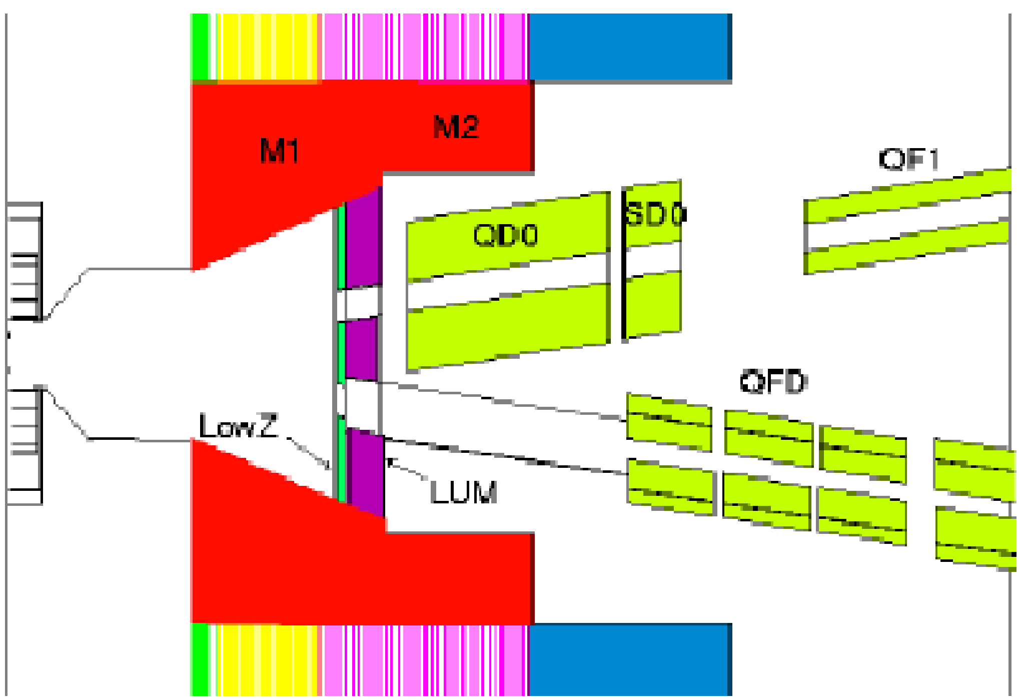
Special thanks to Tom Markiewicz

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

Detector View



Machine View



IP Requirements

High Luminosity

- Stability
- Instrumentation
- Crossing angle (NLC/JLC)

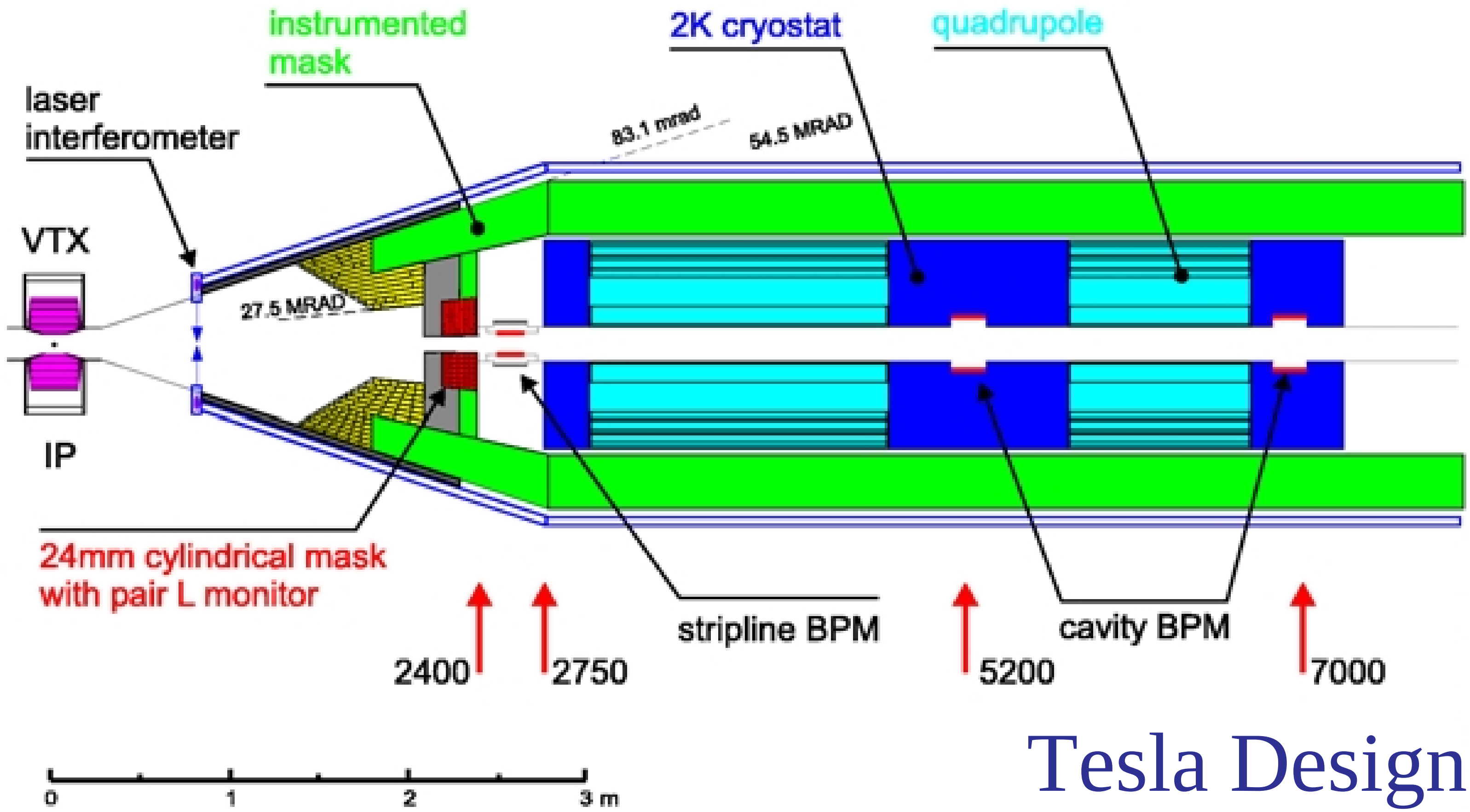
Background Protection

- Collimation
- Shielding from collision products
- Extraction to dump

Collision Properties

- Polarization
- Beam Energy
- Luminosity

Large overlap between traditional detector, accelerator, and analysis camps...



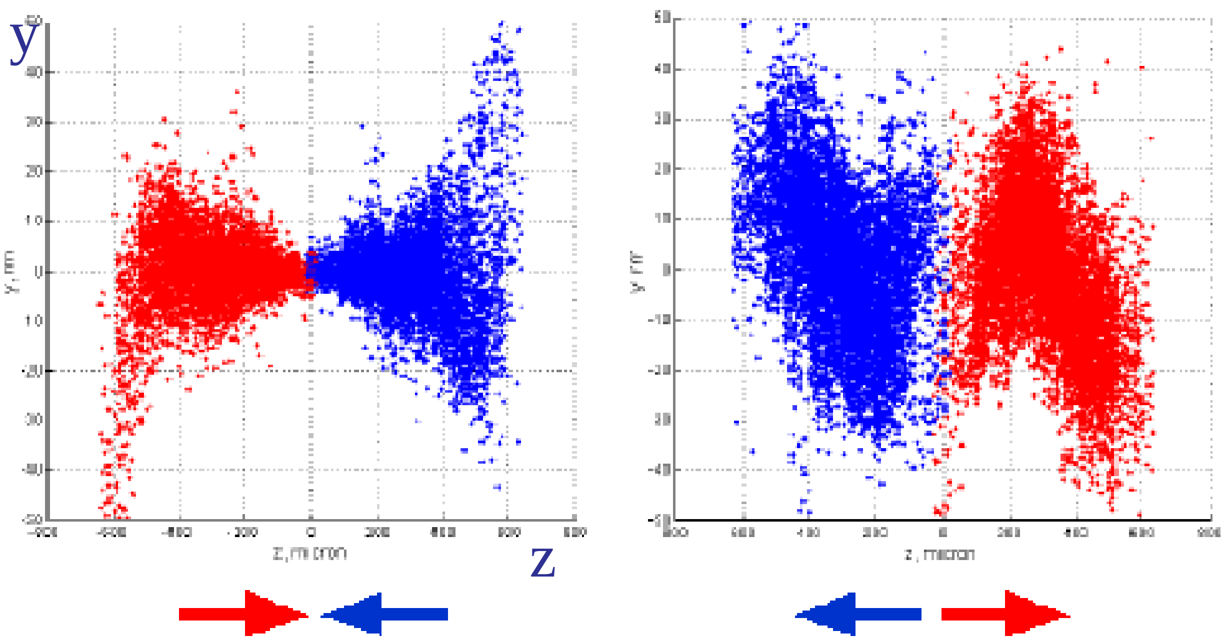
Tesla Design

- Short focal length (L* ~ 3-5 m)
- Large conical mask (~ 50 mRad)
- Integrated instrumentation

Beam-Beam Interactions

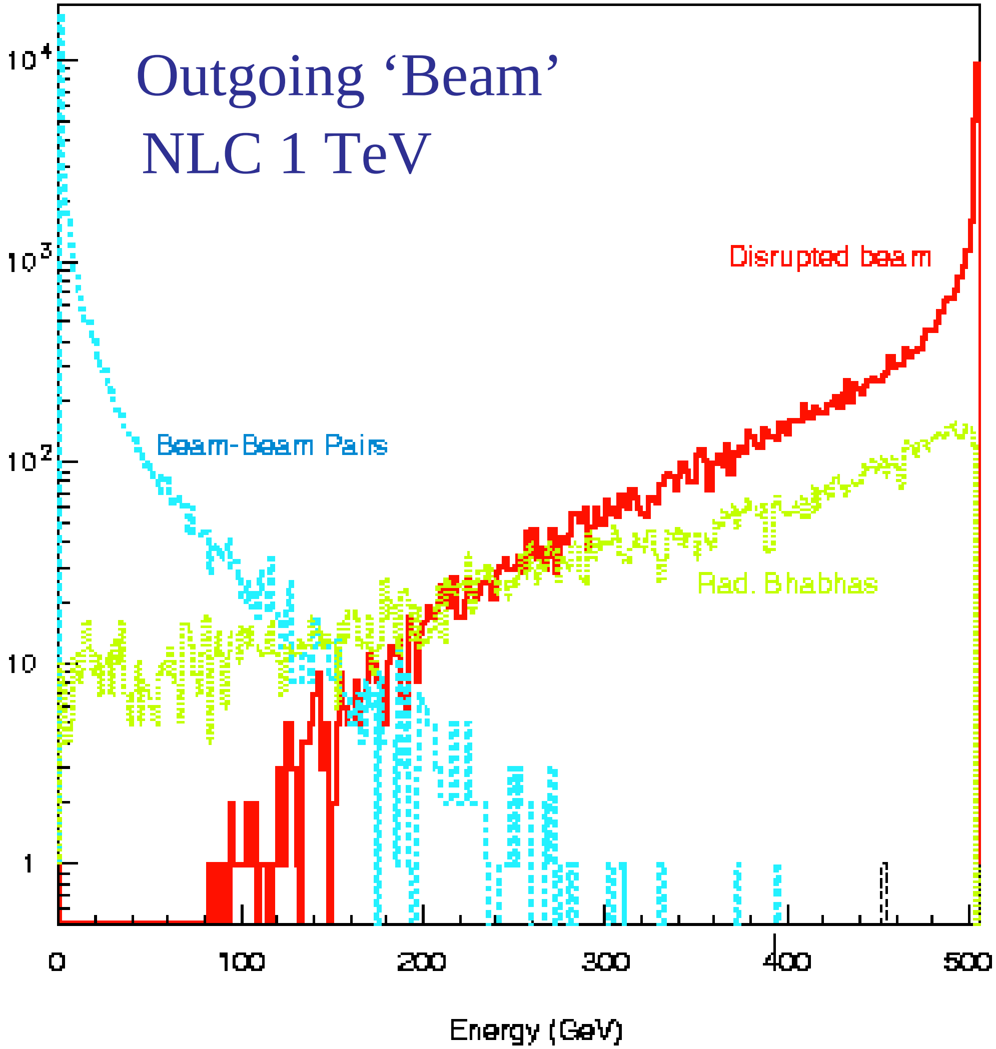
	Tesla 500	NLC/JLC 500
N	2.0×10^{10}	0.75×10^{10}
σ_x	550 nm	250 nm
σ_y	5 nm	3 nm
σ_z	300 μm	110 μm

⇛ Beams strongly attracted to each other!



- Spot size reduced (higher lumi ~ x2)
- Outgoing beam highly disrupted
- Pinch produces ‘beamstrahlung’ photons

Beamstrahlung



Beamstrahlung Photons

- $N_\gamma/N_e \sim 1.5$
- $E_\gamma / E_{beam} \sim$ few percent
- confined to 1 mRad cone
- secondary e^+e^- pairs

Charged Particles

- Long E tail after IP
- Radiative Bhabhas
- Beam-beam pairs

77 kW $E < 50\% \ E_{nom}$

4 kW lost (.25%) to dump

(NLC 1 TeV)

Detector Backgrounds

IP Backgrounds

- Disrupted primary beam
- Beamstrahlung (BSL) photons
- e^+e^- pairs from BSL γs
- Hadrons from BSL or $\gamma\gamma$
- Neutrons from e^+e^- pairs
- Radiative Bhabhas

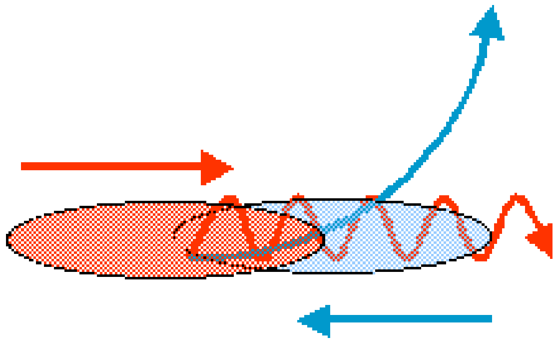
These scale with Luminosity (Good)
Shield from detectors

Machine Backgrounds

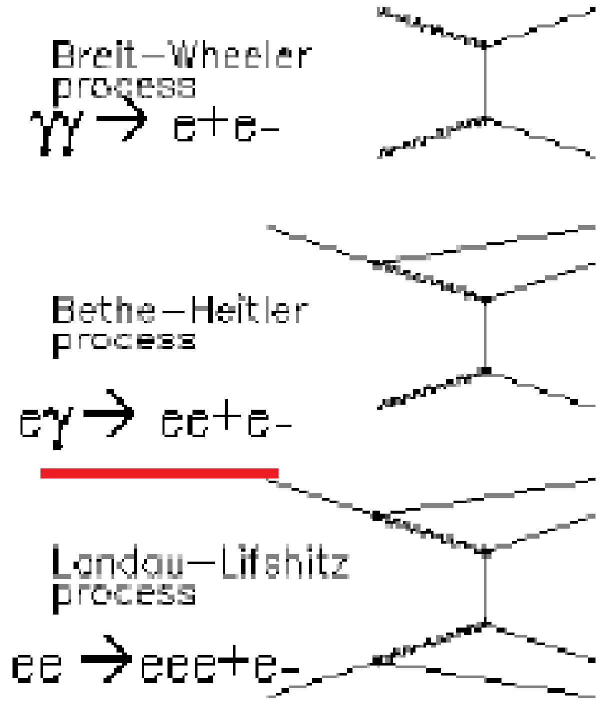
- Neutron back-shine from dump
- Synchrotron radiation
- Muon production
- Collimator scraping

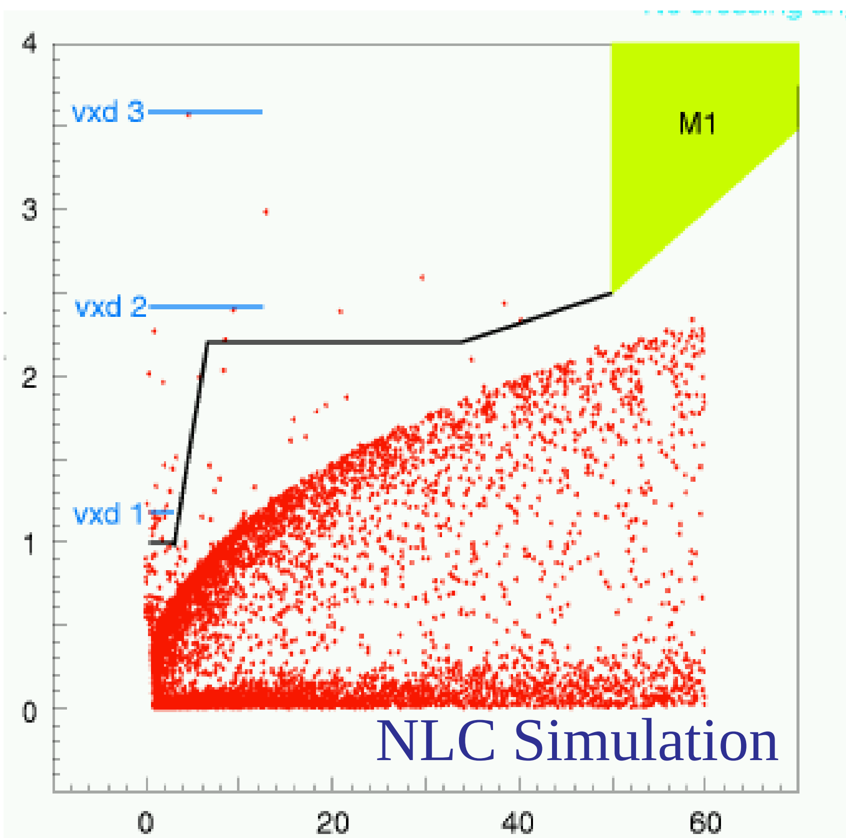
These don't scale with Lumi (Bad)
Avoid near IP

e^+e^- Pairs



P_T from opposing bunch

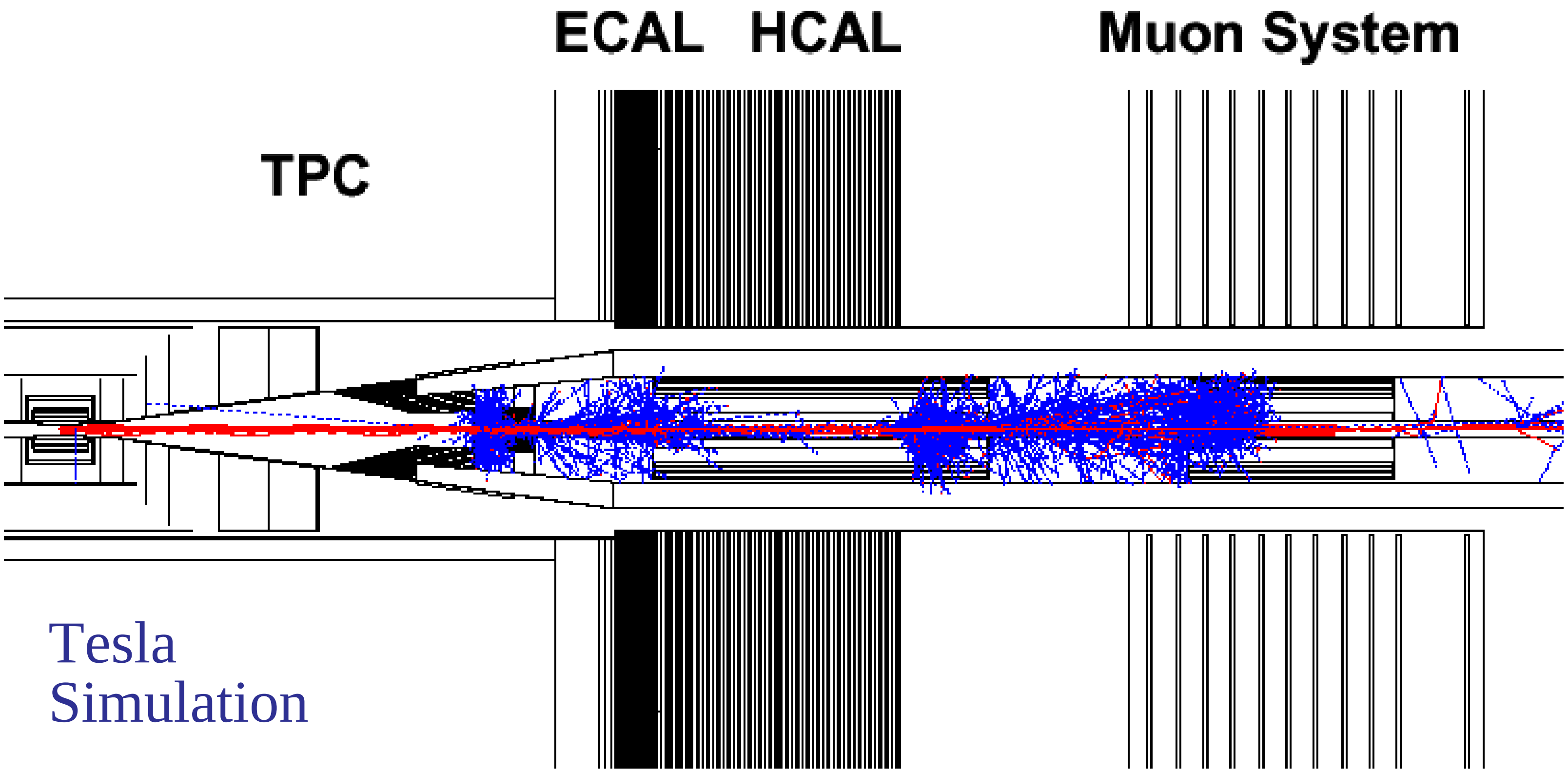




pairs 'curl up' in large solenoid field

must absorb without scattering into detector...

Pair Simulations



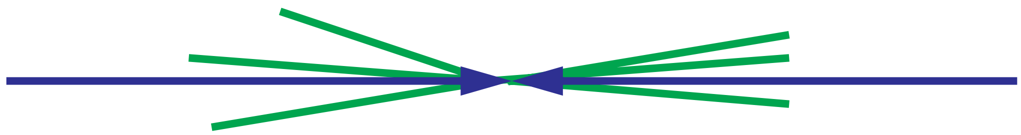
Tesla Simulation

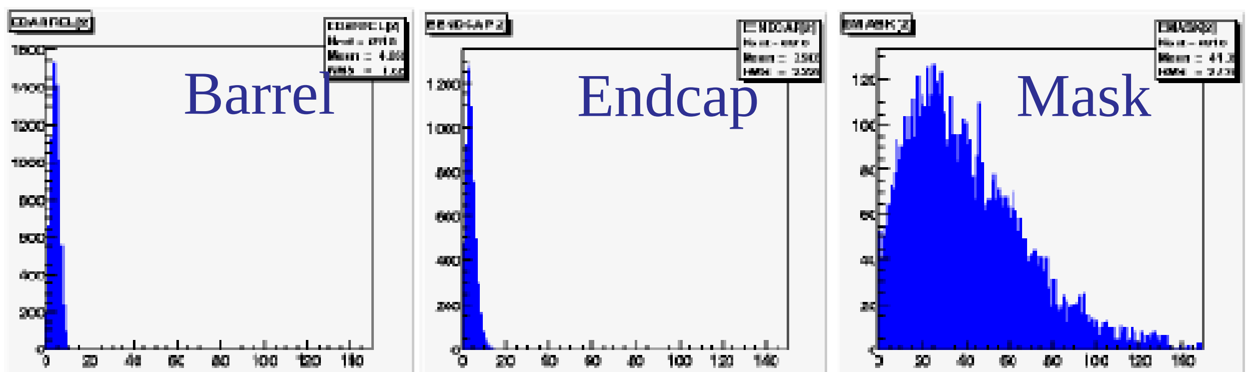
~ 1×10^9 per second (1 Watt)

Pairs also make good monitor of luminosity and collision parameters...

Other Backgrounds

Two Photon



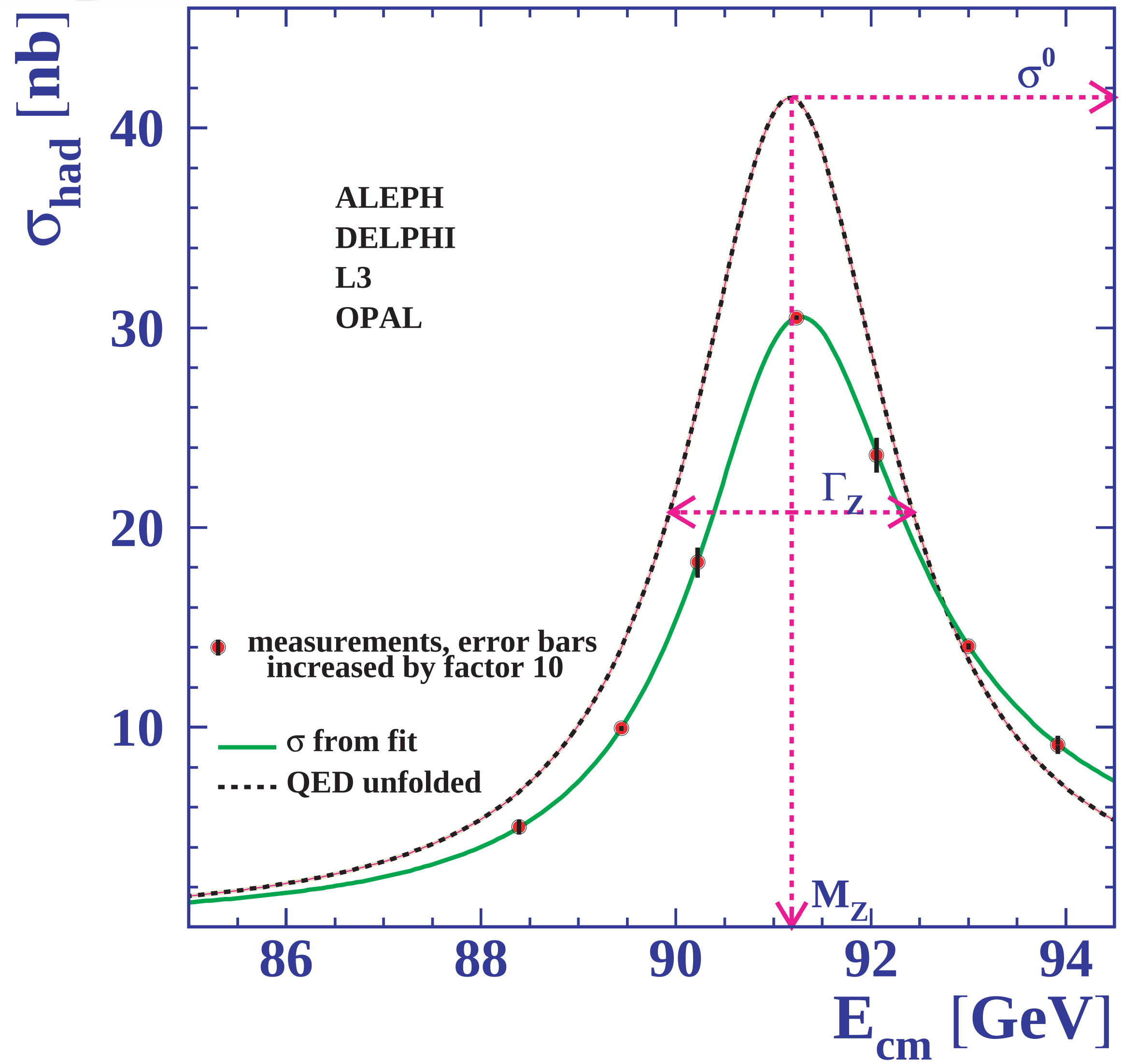


~ 0.5 $\gamma\gamma$ hadron events/NLC train
average 6 GeV in barrel + endcap, 10 tracks
~ 30 GeV in forward mask...

Neutrons

- Expect 0.5×10^9 n/cm^2/yr at VXD (NLC SD)
- Dominated by beam-beam pairs
- Small backshine from dump

Tolerate 3×10^9 n/cm^2/yr for pixel detector



- m_Z, Γ_Z (LEP I) Energy Lumi
- m_W (LEP II) Energy
- $\sin^2\theta_w$ (SLC) Polarization

Dependent upon Beam Instrumentation

Beam Energy

- Absolute energy scale
- Beam energy width

Polarization

- Electron polarization scale
- Positron polarization (if available)

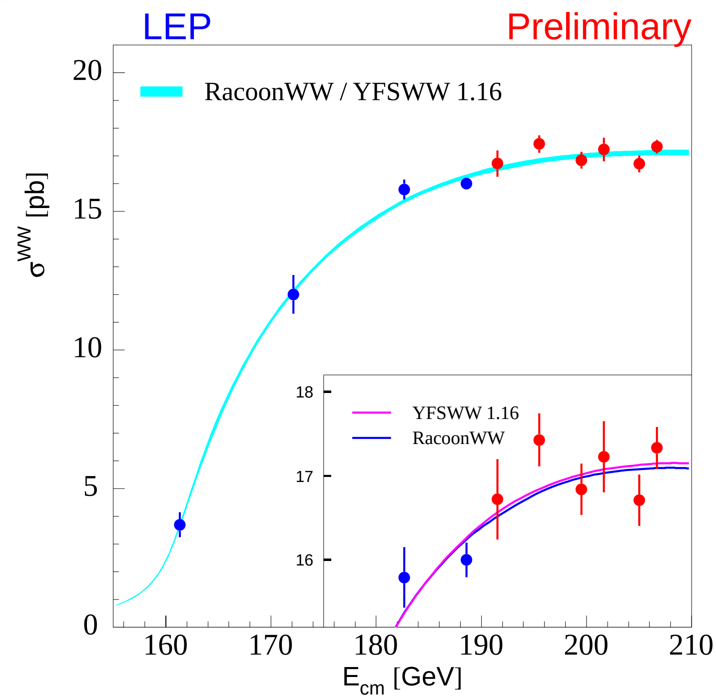
Luminosity

- dL/dE (luminosity spectrum)
- $\int L\,dt$ (total integrated luminosity)

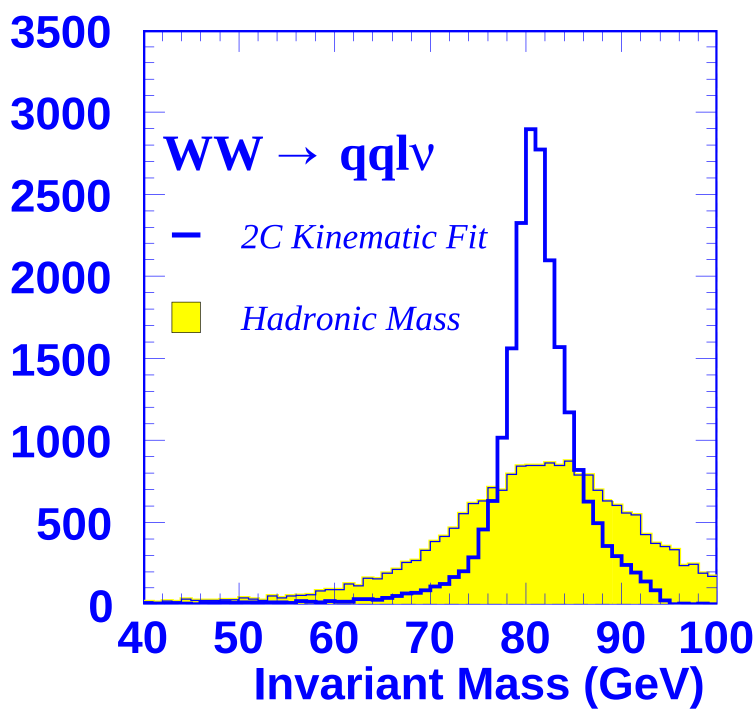
$\Rrightarrow$ Ensure instrumentation for physics needs!

Combination of beam-based and physics-based measurements!

Production
Threshold



Kinematic Fits



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

Energy Needs

- Target 200 ppm from $2m_t < \sqrt{s} < 1TeV$

$$\Delta m_t, \Delta m_H \sim 50 \text{ MeV}$$

- Recognize desire for < 50 ppm at $2m_W$

⇛ Improved precision always welcome...

Energy Proposal

- BPM-style at upstream 1mRad bend

  RT monitor, possible absolute scale

- WISRD-style at post-IP chicane

  RT monitor, possible absolute scale

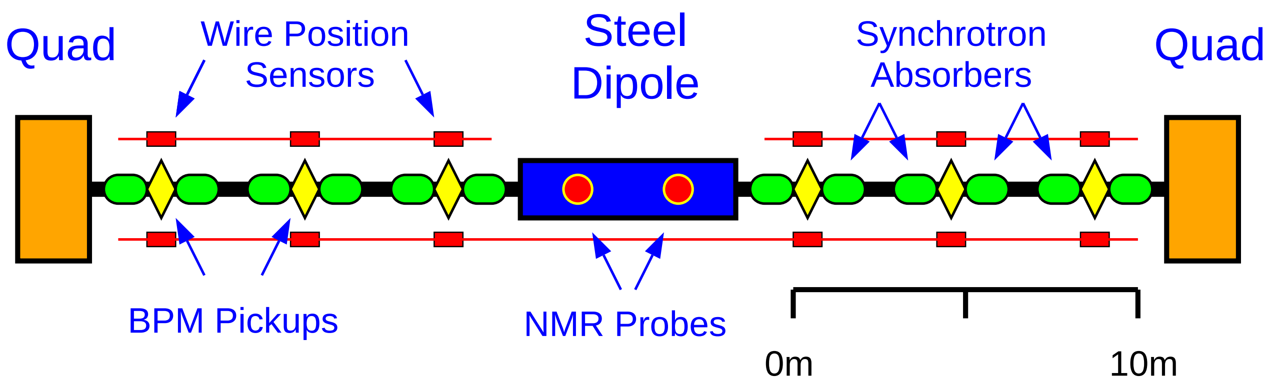
  Energy width?

- Forward tracking 200-500 mRad

  Lumi-weighted absolute scale ($\mu^+\mu^-\gamma$)

BPM Spectrometer

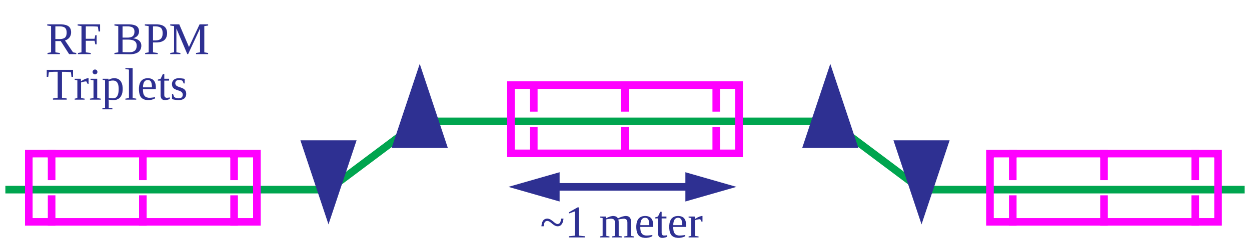
LEP II Spectrometer



- 4.8 mRad Bend ⇛ 1 μm BPM resolution
- Stability maintained for less than 8 hours

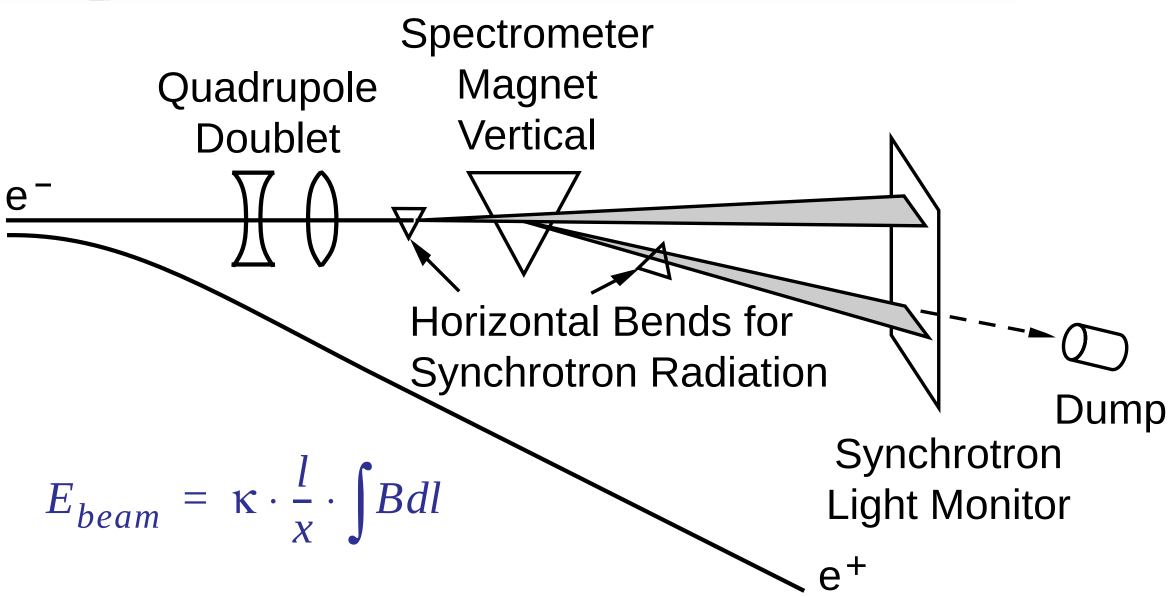
~200 ppm achieved (relative)

RF Spectrometer



- 200 μRad Bend ⇛ < 100 nm BPM resolution
- Move the BPMs to the beam
- *In situ* alignment

⇛ Upstream of IP only!



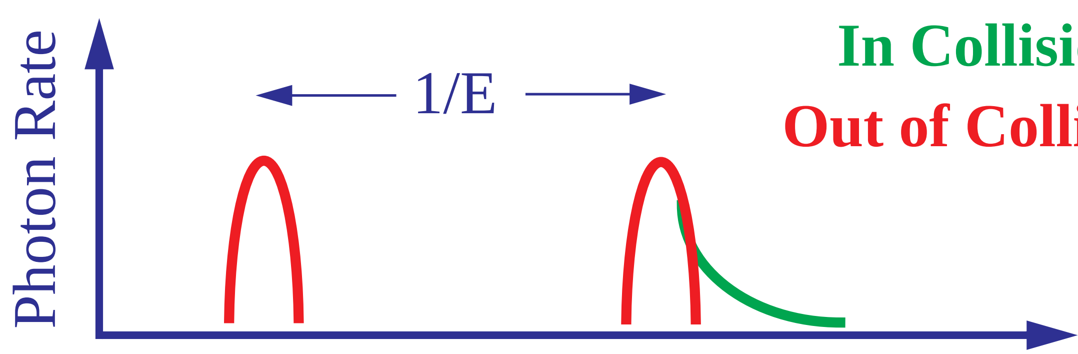
$$E_{beam} = \kappa \cdot \frac{l}{x} \cdot \int B dl$$

$$\int B dl = 3.05 \text{ T m} \quad l = 15 \text{ m} \quad x = 27 \text{ cm at 50 GeV}$$

Operated for 8 years ⇛ ~250 ppm achieved

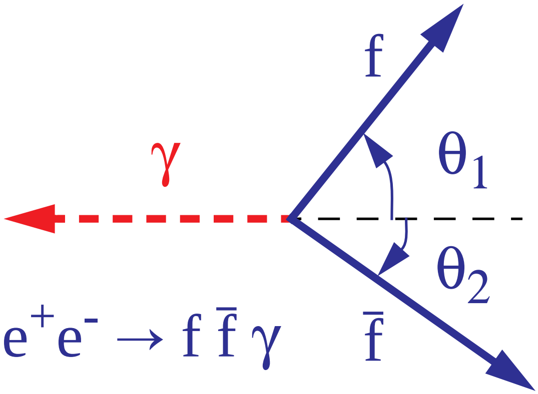
NLC Questions

- Improved detector?
- Downstream operation?
- Energy distribution?



In Collision
Out of Collision

Radiative Returns at LEP



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

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

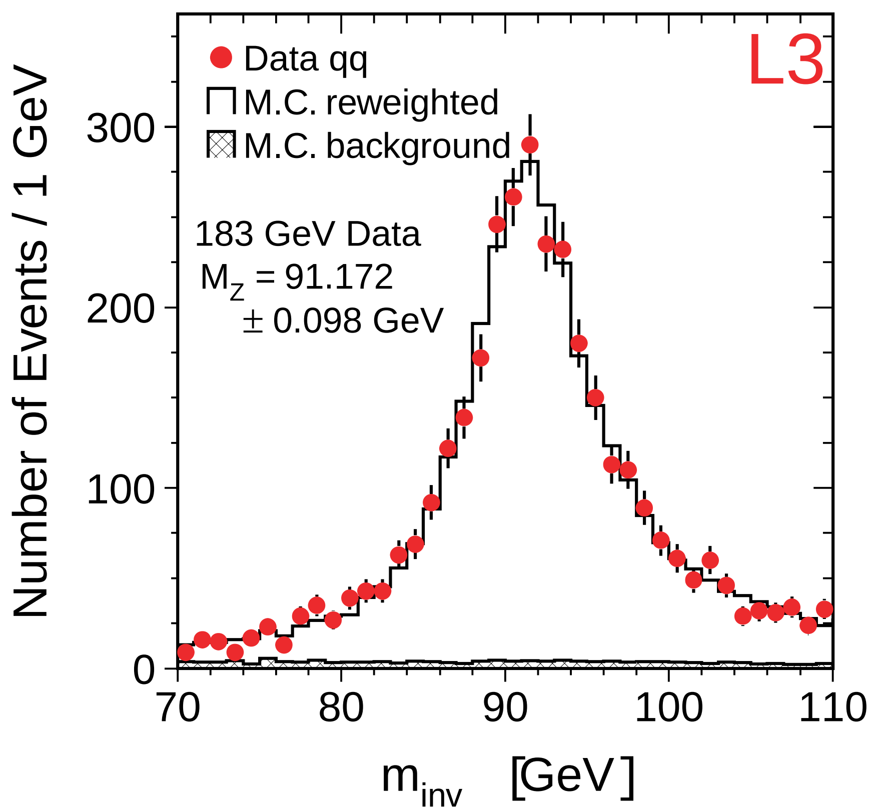
Statistics

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}



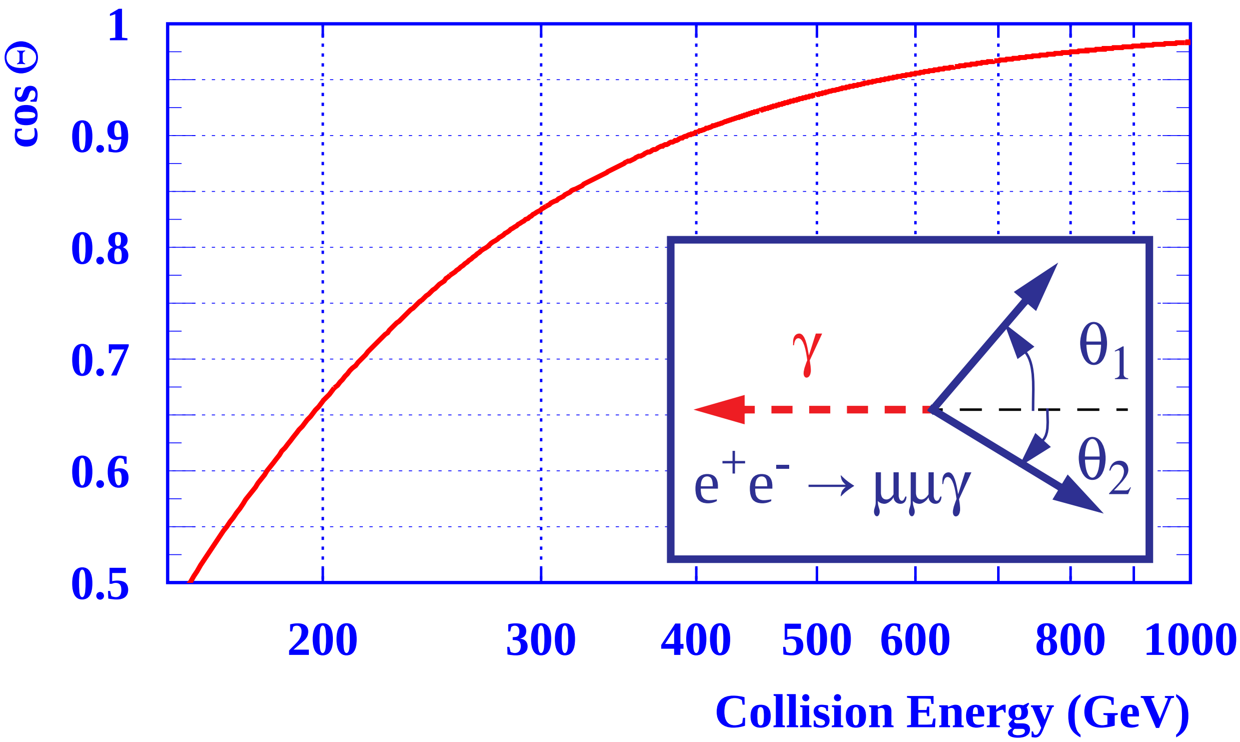
Systematics

- 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



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

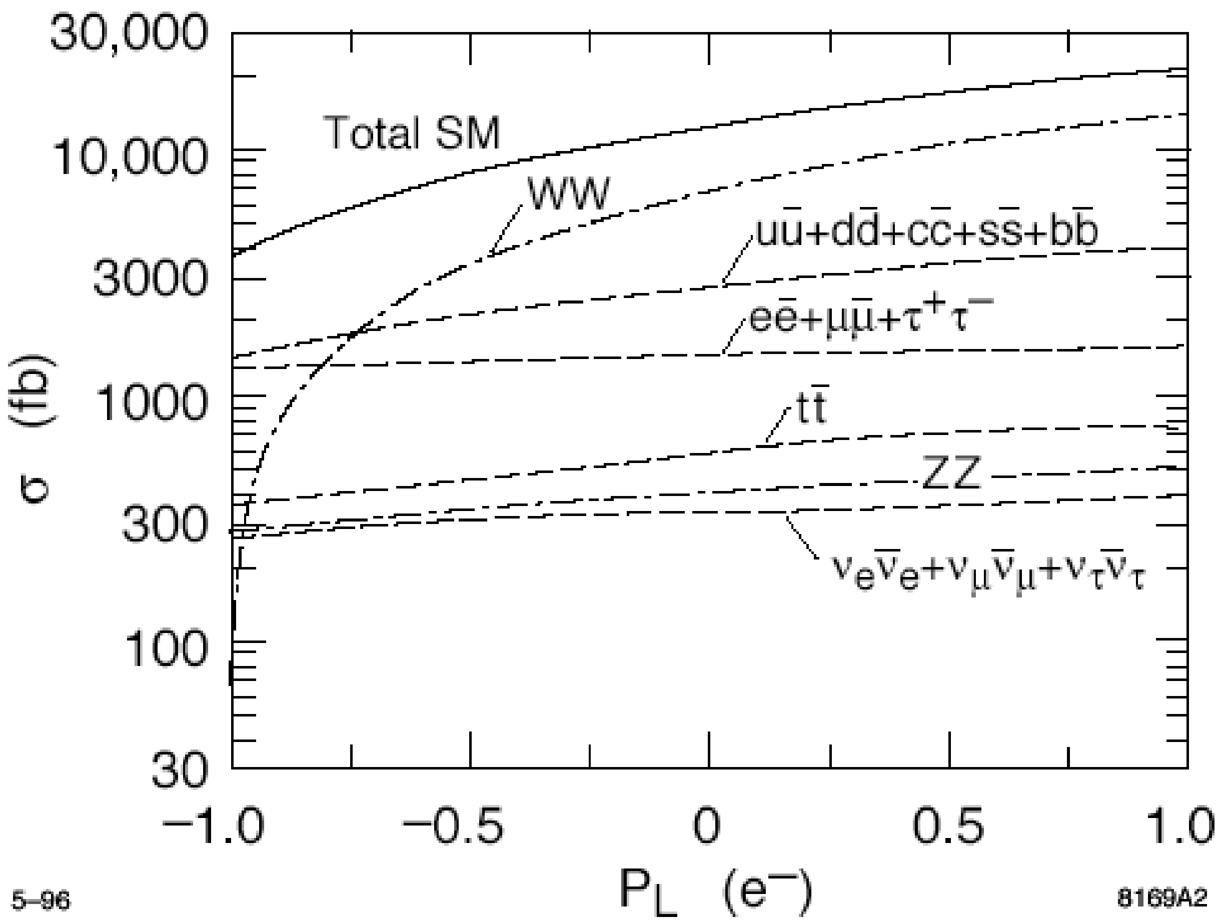
Collision Energy	cos Θ	Θ (mRad)
2 m_W	0.522	1000
2 m_t	0.875	500
500 GeV	0.937	360
1 TeV	0.984	180

Need precision and accuracy at small Θ

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

100ppm accuracy (20 μm @ 2 meters)

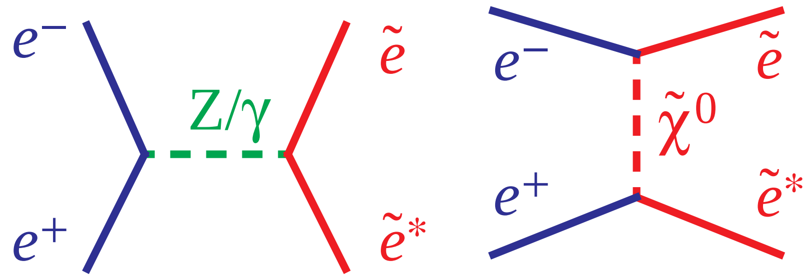
Polarization Physics



Process	Events per 80 fb^{-1}	A_{LR}	dA/A (stat) in %
WW	560 k	99%	0.07
qq	250 k	45%	0.5
ll	120 k	10%	3.2

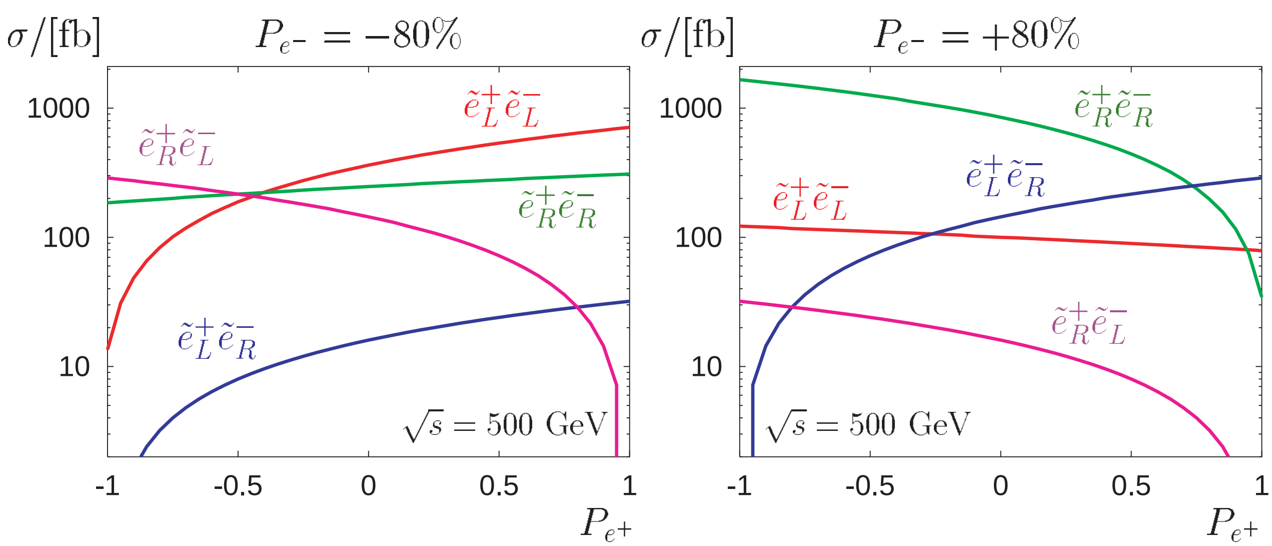
⇛ Also WW background suppression, SUSY, new physics, etc.

Slepton Production



s-channel: $\tilde{e}_L\tilde{e}_L{}^*$ or $\tilde{e}_R\tilde{e}_R{}^*$ only

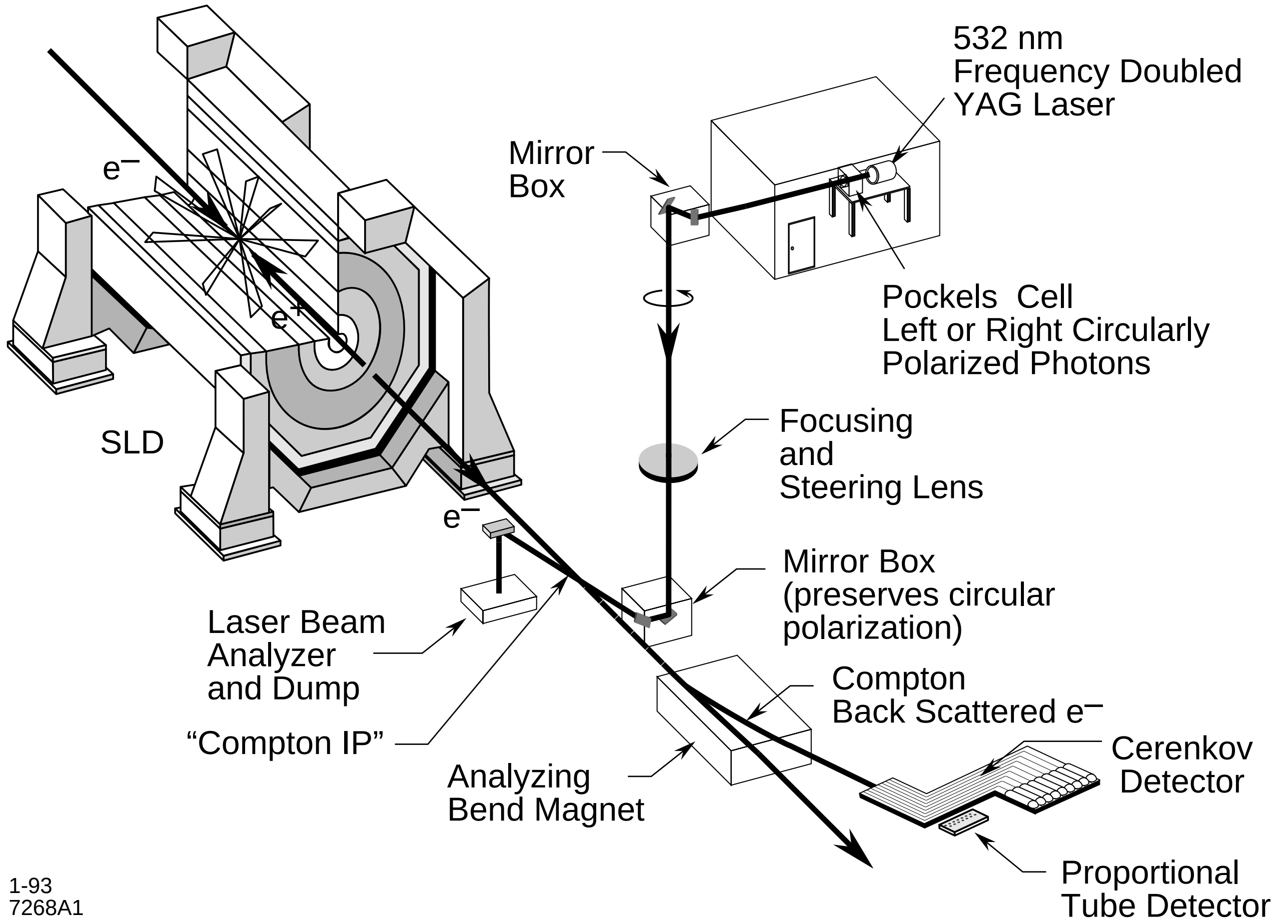
t-channel: $\tilde{e}_L\tilde{e}_R{}^*$ and $\tilde{e}_R\tilde{e}_L{}^*$ also



[G. Moortgat-Pick, H. Steiner, 2000]

$\Rrightarrow$ Unique manipulation of helicity states

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

$\delta P / P = 0.5\%$ achieved at SLD

Polarization Precision

Electron polarization only

- absolute scale limiting factor
- IP depolarization significant

Lum Weighted != Polarimeter

0.25% per beam possible (not proven)

Positron polarization also

$$P_{eff} = (P^+ + P^-)/(1 + P^+P^-)$$

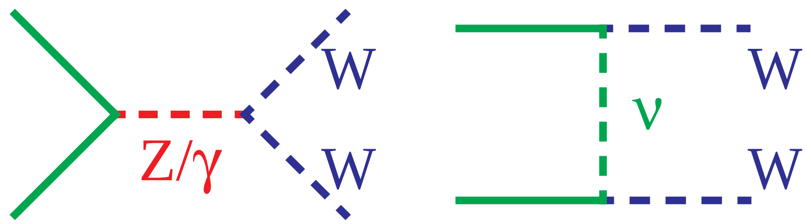
$\Rightarrow$ 0.1% precision achievable

Blondel scheme gives lumi-weighted P^+, P^-

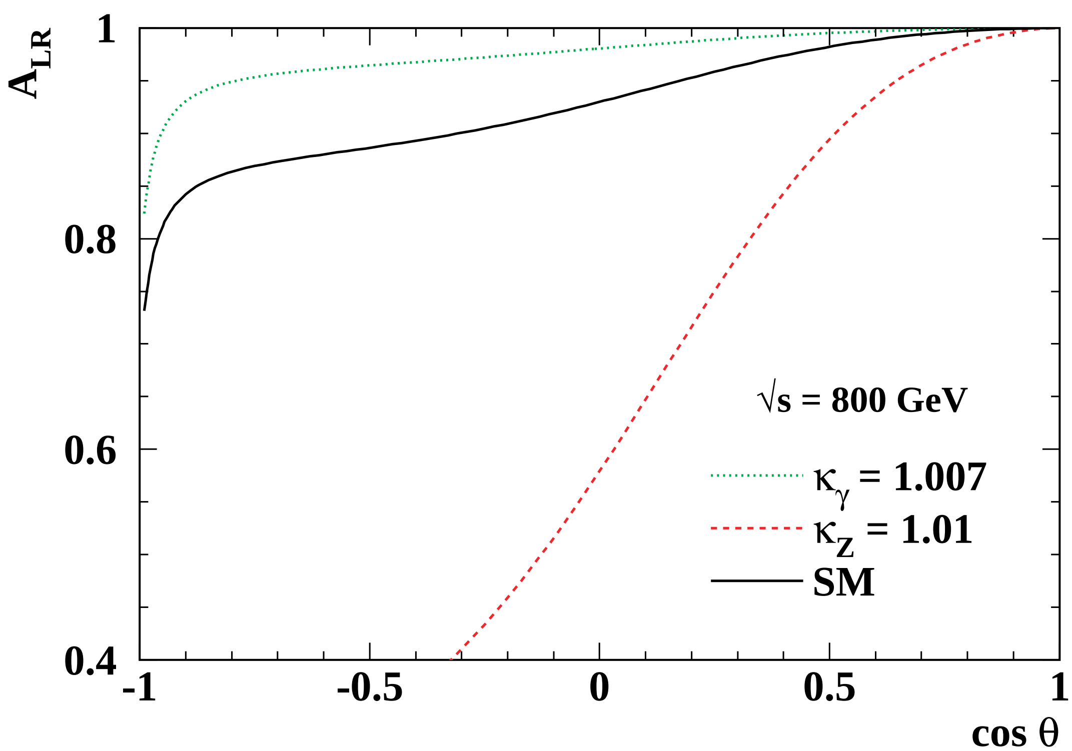
90% 'correct' **10% 'wrong'**

- Lose some luminosity (or don't gain as much)
- Still need $\Delta = |P_L| - |P_R|$, relative Lumi
- Precision depends upon P^+ reversal freq.

Direct Polarization



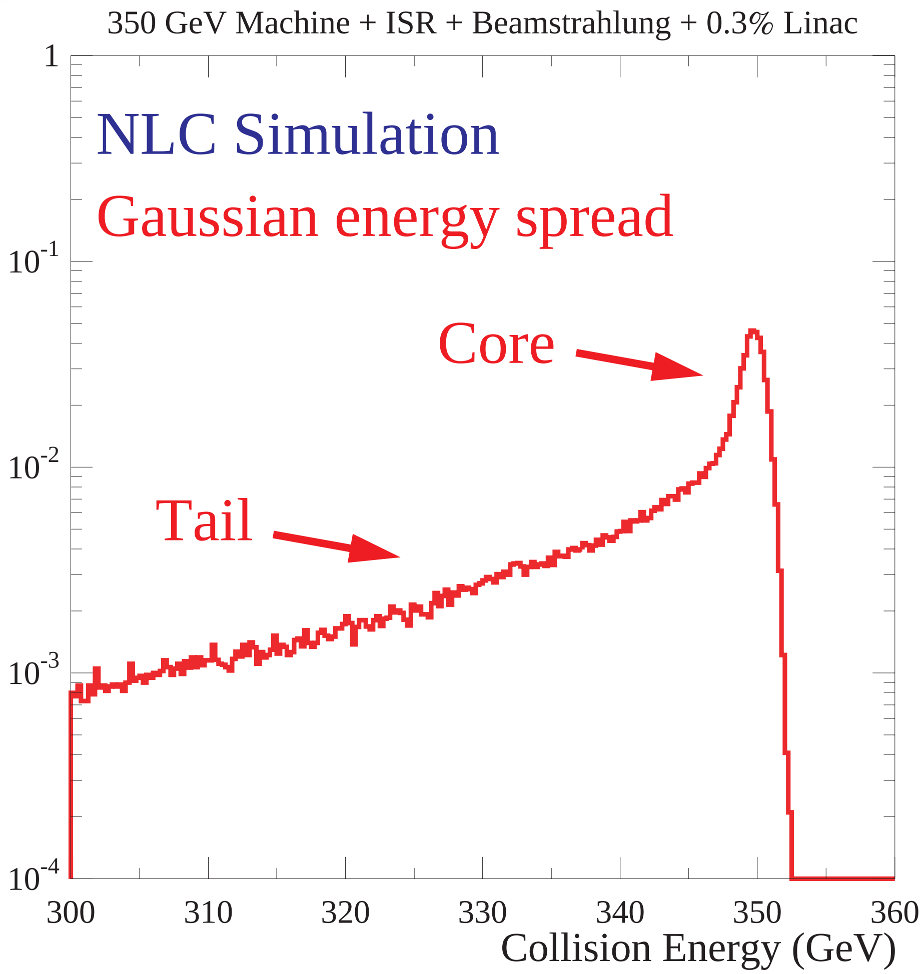
$$\sigma = 7 \text{ pb at } \sqrt{s} = 500 \text{ GeV}$$



[K. Mönig, Snowmass 2001]

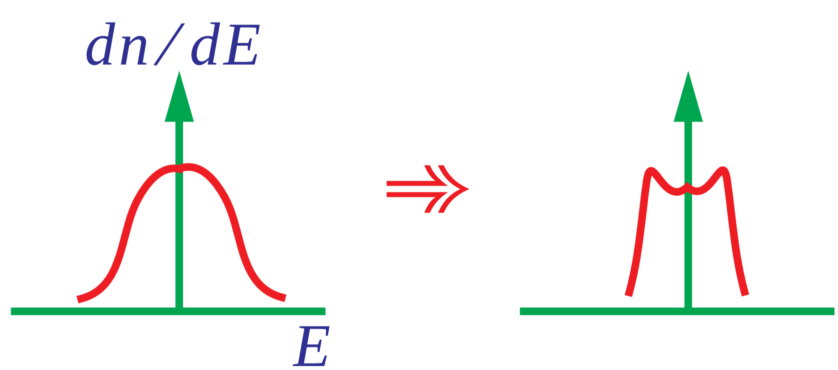
$\delta P/P < 0.15\%$ for 500 fb^{-1} at 500 GeV (9/1 L ratio)

⇛ Similar with e$^-$ pol only

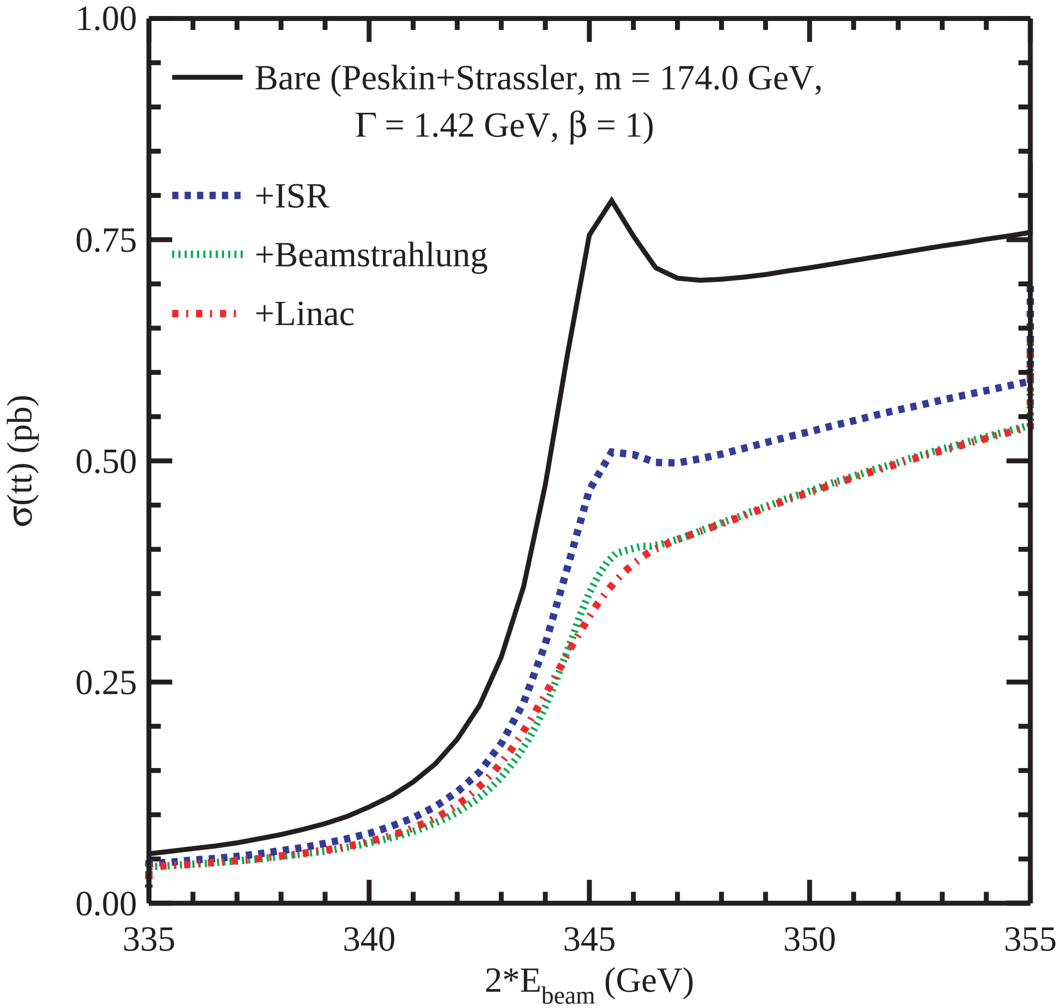


Highly dynamic distribution...

Linac energy spread



Physics Example $t\bar{t}$



[D. Cinabro]

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

The Uncertainty of it all

Key Reactions

- Threshold scans (top mass)
- Mass reconstruction (Higgs mass)

⇛ Plus many, many more...

Highly dynamic distribution

- Variance: increased statistical errors
- Uncertainty: increased systematic errors

Both need consideration

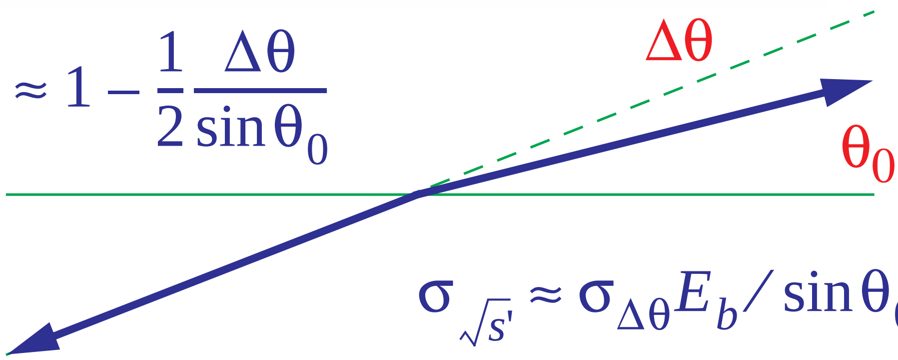
Rough physics needs

- Scans mostly need shape (tails to 1%)
- Mass analyses need mean $\sqrt{s}'$ (200 ppm)

⇛ New instrumentation problem for e^+e^-

Bhabha Acolinearity

$$\sqrt{s'/s} \approx 1 - \frac{1}{2}\frac{\Delta\theta}{\sin\theta_0}$$



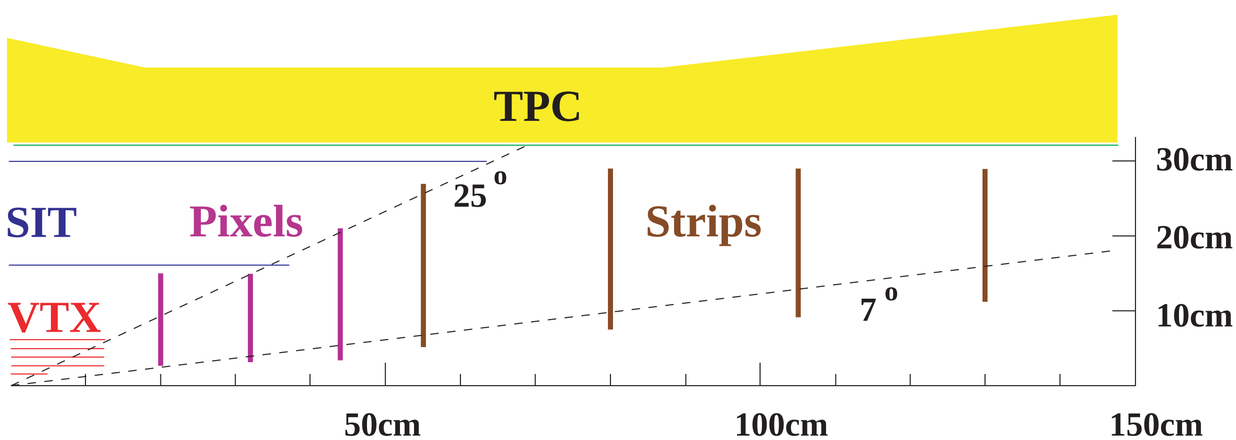
$$\sigma_{\sqrt{s'}} \approx \sigma_{\Delta\theta} E_b / \sin\theta_0$$

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 forward...

Forward Tracker (Tesla design)



Silicon planes 100 - 400 mRad

dL/dE concerns

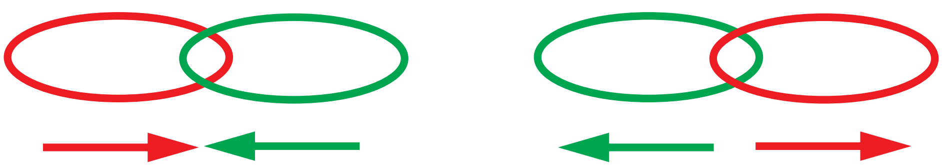
Acolinearity Limitations

- Bhabha analysis measures boost not $\sqrt{s'}$
- Other inputs (e.g. energy width, asymmetry)
- Detector alignment systematics

$\Rrightarrow$ Area of active study...

Beamstrahlung Correlations

- Dispersion effects
- Early-late correlations
- Banana tail effects



Higher L, less tail   Lower L, more tail

$\Rrightarrow$ Can't trust simulation alone...

Need data-tuned models
integrated into generators

The Linear Collider Interaction Region
must be carefully planned between
accelerator, detector, and analysis-minded people.

New challenges exist for the LC environment

- Nanometer-sized beams, IP stability
- Large beam disruption
- Large e^+e^- pair background
- Uncertain luminosity spectrum

Old challenges for e^+e^- also exist

- Beam energy/width
- Beam polarization
- Absolute luminosity scale

Lots of interesting work going on NOW!
Plenty of work still to be done...