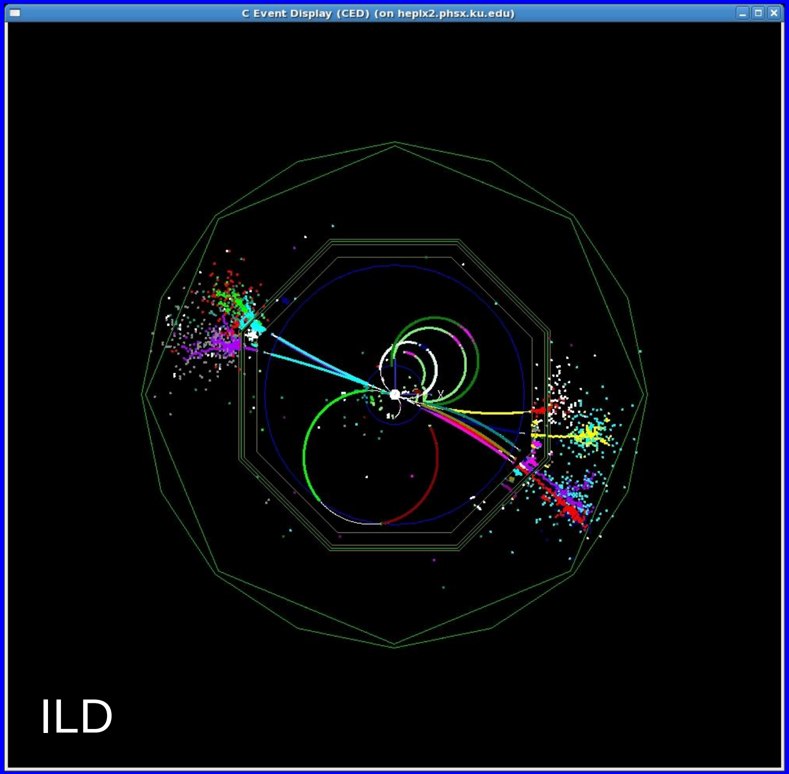
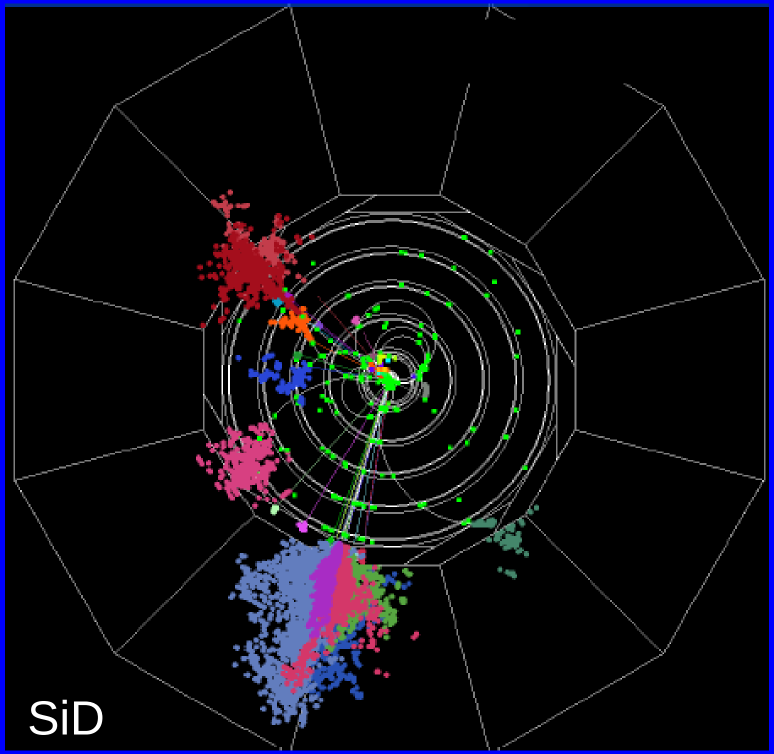
Experimental Aspects of Precision m_W Measurements at High-Luminosity and Highly Polarizable Lepton Colliders



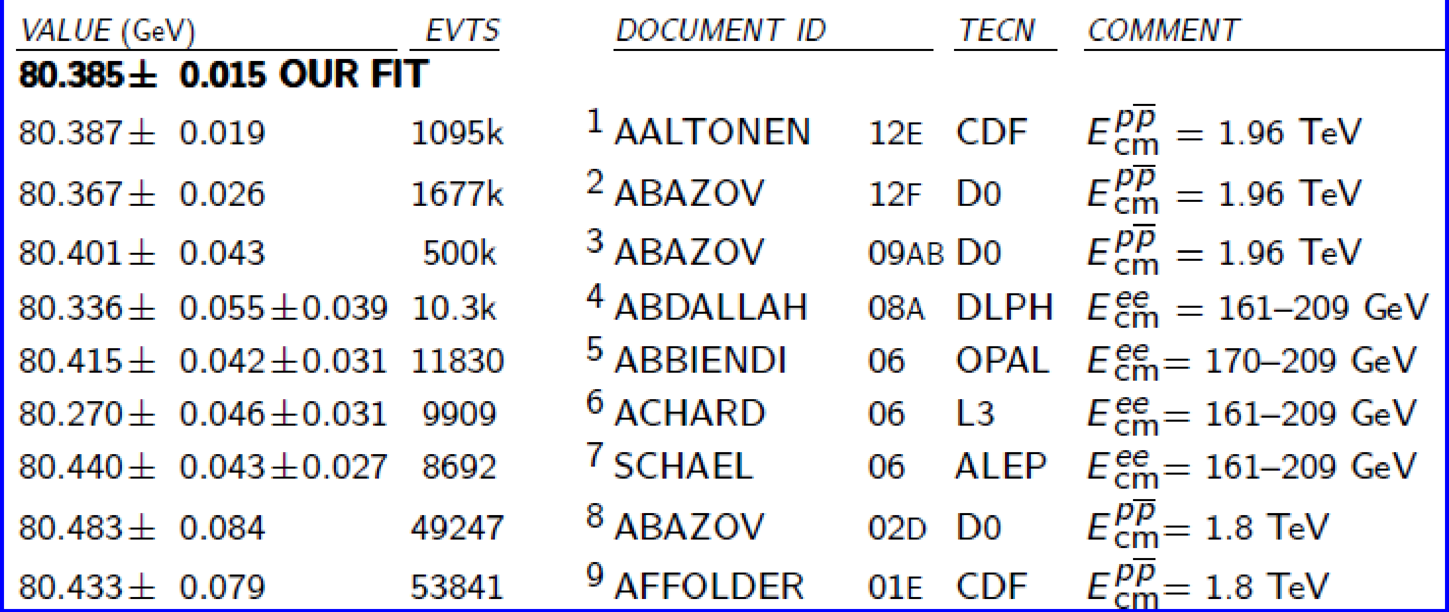


Graham W. Wilson, University of Kansas, Snowmass EF Electroweak Workshop, Duke, February 19th 2013

Plan

- Brief Introduction to m_W Measurement Basics
- Experimentation at Lepton Colliders with Emphasis on ILC.
  - => get appreciation of systematic issues
- Prospects for m_W Measurement
  - Threshold
  - WW in continuum
  - Single-W in continuum
- Conclusion

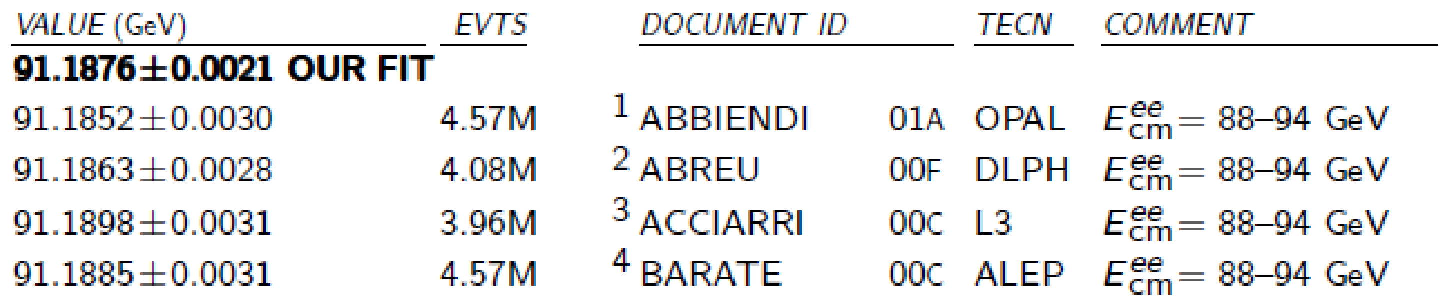
Current Status of m_W and m_Z



VALUE (GeV)	EVTS	DOCUMENT ID	TECN	COMMENT
80.385 ± 0.015 OUR FIT				
80.387 ± 0.019	1095k	[1] AALTONEN 12E	CDF	$E^{p\bar{p}}_{\rm cm}$ = 1.96 TeV
80.367 ± 0.026	1677k	[2] ABAZOV 12F	D0	$E^{p\bar{p}}_{\rm cm}$ = 1.96 TeV
80.401 ± 0.043	500k	[3] ABAZOV 09AB	D0	$E^{p\bar{p}}_{\rm cm}$ = 1.96 TeV
80.336 ± 0.055 ± 0.039	10.3k	[4] ABDALLAH 08A	DLPH	$E^{ee}_{\rm cm}$ = 161–209 GeV
80.415 ± 0.042 ± 0.031	11830	[5] ABBIENDI 06	OPAL	$E^{ee}_{\rm cm}$ = 170–209 GeV
80.270 ± 0.046 ± 0.031	9909	[6] ACHARD 06	L3	$E^{ee}_{\rm cm}$ = 161–209 GeV
80.440 ± 0.043 ± 0.027	8692	[7] SCHAEL 06	ALEP	$E^{ee}_{\rm cm}$ = 161–209 GeV
80.483 ± 0.084	49247	[8] ABAZOV 02D	D0	$E^{p\bar{p}}_{\rm cm}$ = 1.8 TeV
80.433 ± 0.079	53841	[9] AFFOLDER 01E	CDF	$E^{p\bar{p}}_{\rm cm}$ = 1.8 TeV

$\Delta M/M = 1.9\times10^{-4}$

3 fb^{-1}



VALUE (GeV)	EVTS	DOCUMENT ID	TECN	COMMENT
91.1876 ± 0.0021 OUR FIT				
91.1852 ± 0.0030	4.57M	[1] ABBIENDI 01A	OPAL	$E^{ee}_{\rm cm}$ = 88–94 GeV
91.1863 ± 0.0028	4.08M	[2] ABREU 00F	DLPH	$E^{ee}_{\rm cm}$ = 88–94 GeV
91.1898 ± 0.0031	3.96M	[3] ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$ = 88–94 GeV
91.1885 ± 0.0031	4.57M	[4] BARATE 00C	ALEP	$E^{ee}_{\rm cm}$ = 88–94 GeV

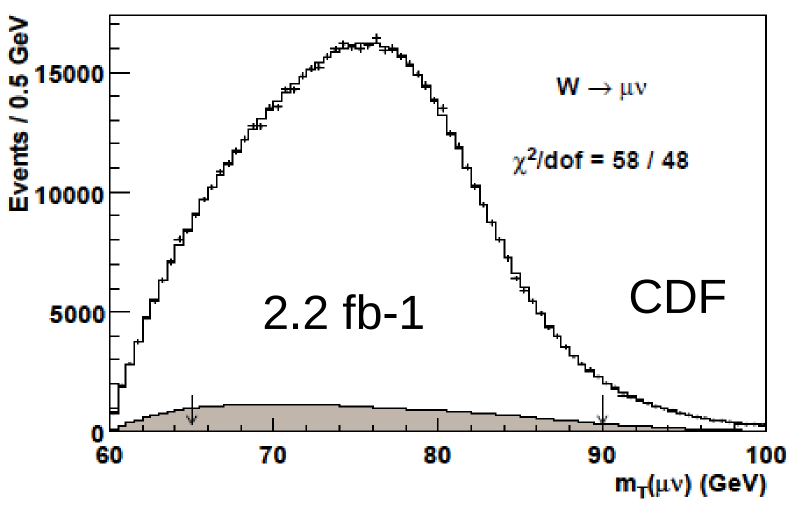
$\Delta M/M = 2.3\times10^{-5}$

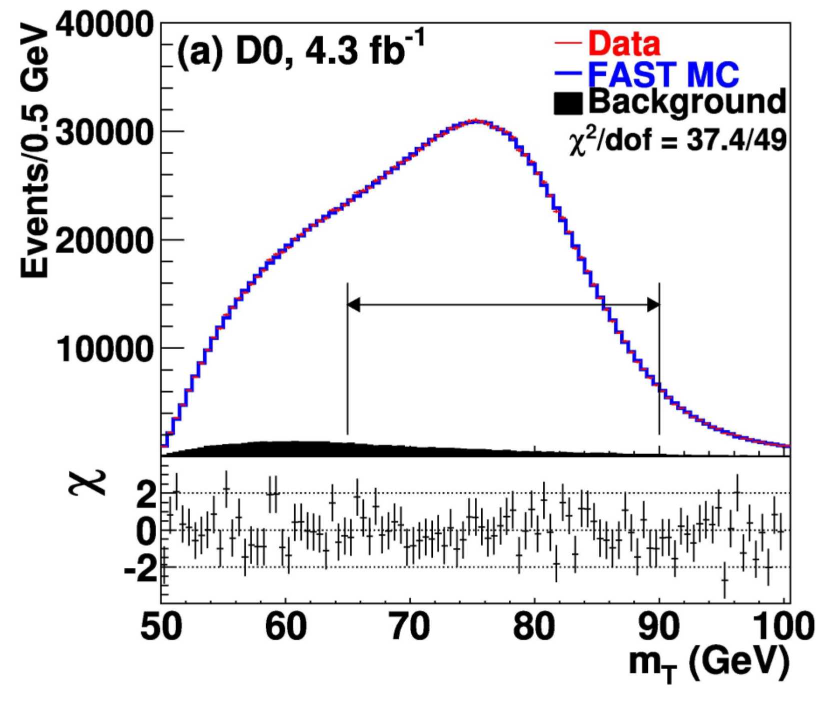
0.4 fb^{-1}

m_W is currently a factor of 8 less precise than m_Z

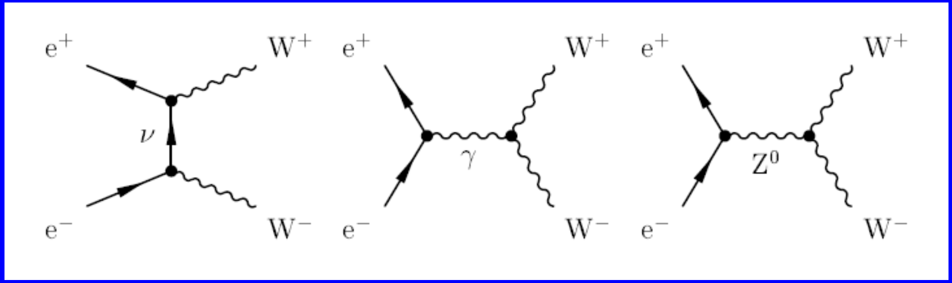
Hadron Collider m_W Measurements

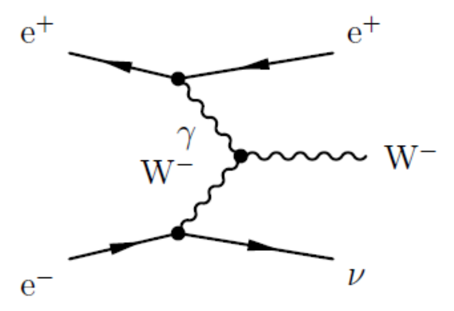
- Tevatron results on partial data-sets
- CDF (e,μ). D0 (e-only)
- Final Tevatron analyses will be challenging
- No results yet from LHC
  - Remember pp (not p-pbar)
  - Low pile-up datasets limited
- It remains to be proven that the LHC in pp mode can supersede the Tevatron.
  - Especially with the focus on HE and HL.





W Production in e+e-

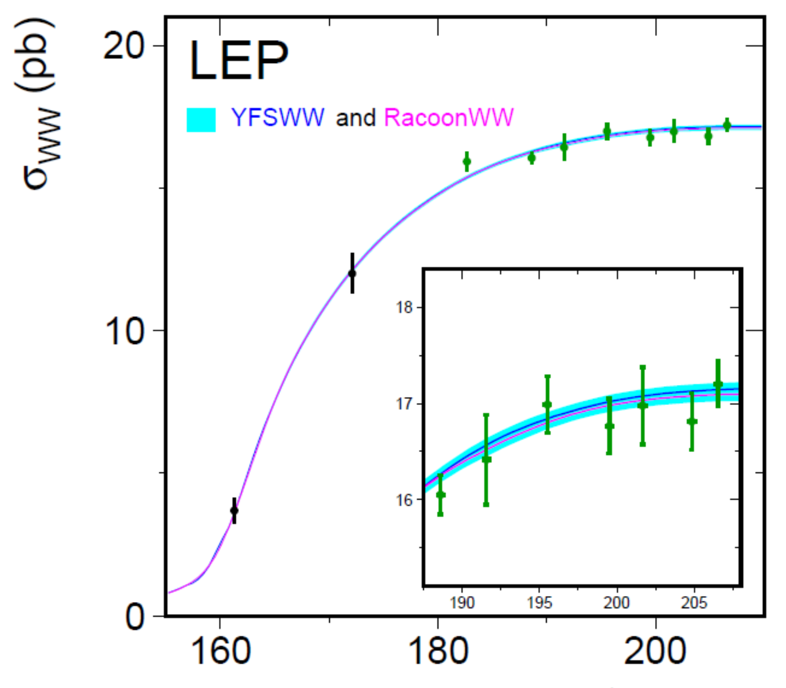




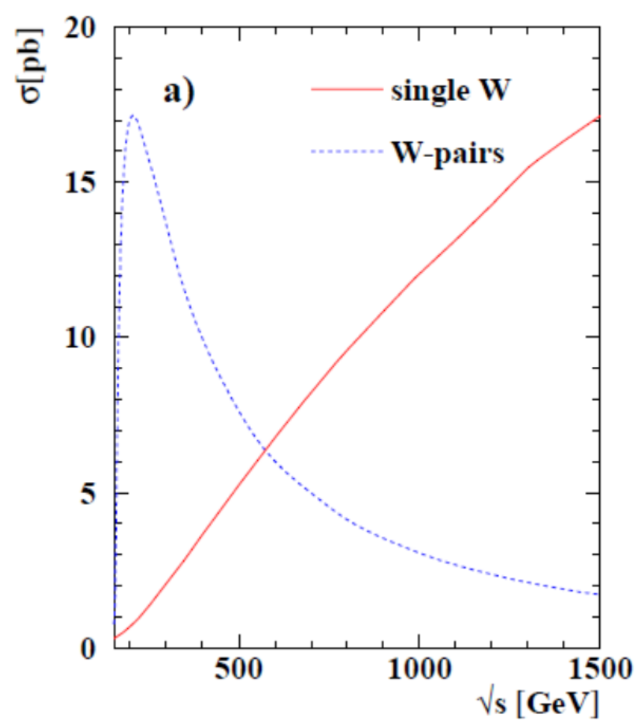
etc ..

e+e- $\rightarrow$ W+W-

e+e- $\rightarrow$ W e ν

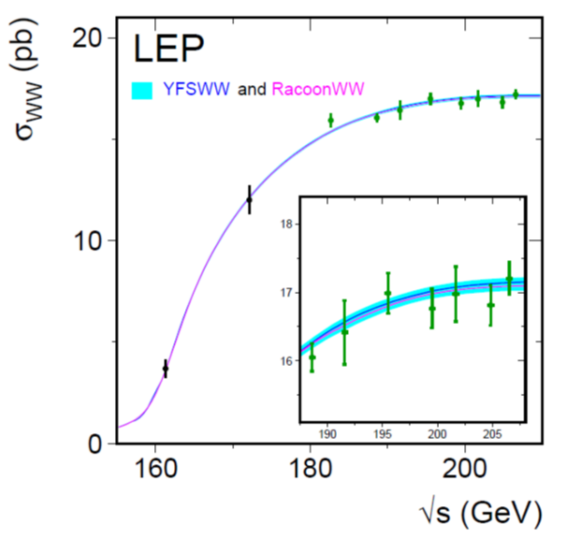


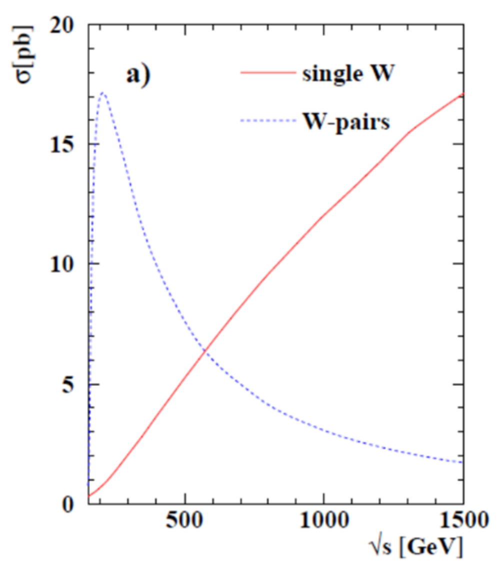
arXiv:1302.3415



W Mass Measurement Strategies

- W+W-
  - 1. Threshold Scan ($\sigma \sim \beta/s$)
    - Can use all WW decay modes
  - 2. Kinematic Reconstruction
    - Apply kinematic constraints
- W e ν
  - 3. Directly measure the hadronic mass in $W \rightarrow q\, q'$ decays.
    - e usually not detectable, so $W \rightarrow l\, \nu$ has 3 undetected particles and is not well suited to W mass measurement





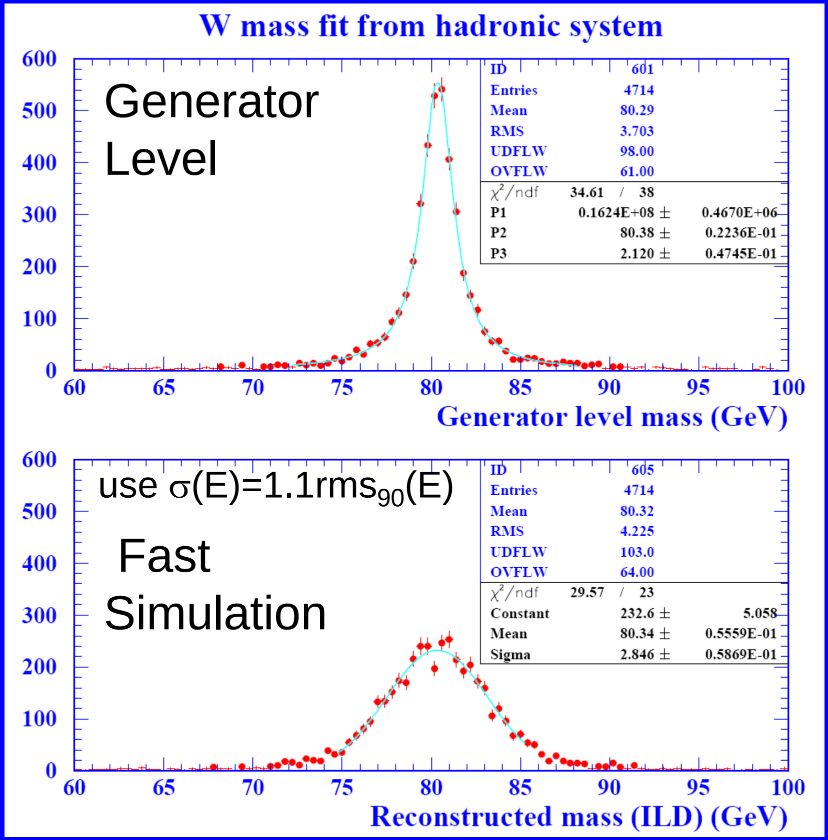
Methods 1 and 2 were used at LEP2. Both require good knowledge of the absolute beam energy.

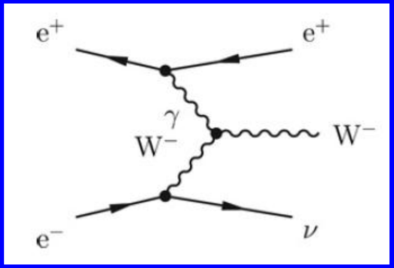
Method 3 is novel (and challenging), very complementary systematics to 1 and 2 if the experimental challenges can be met.

Can one dream of measuring m_W to 1 MeV ?

(and not get locked up ;-))

Single W study at √s = 1TeV (e+e-)

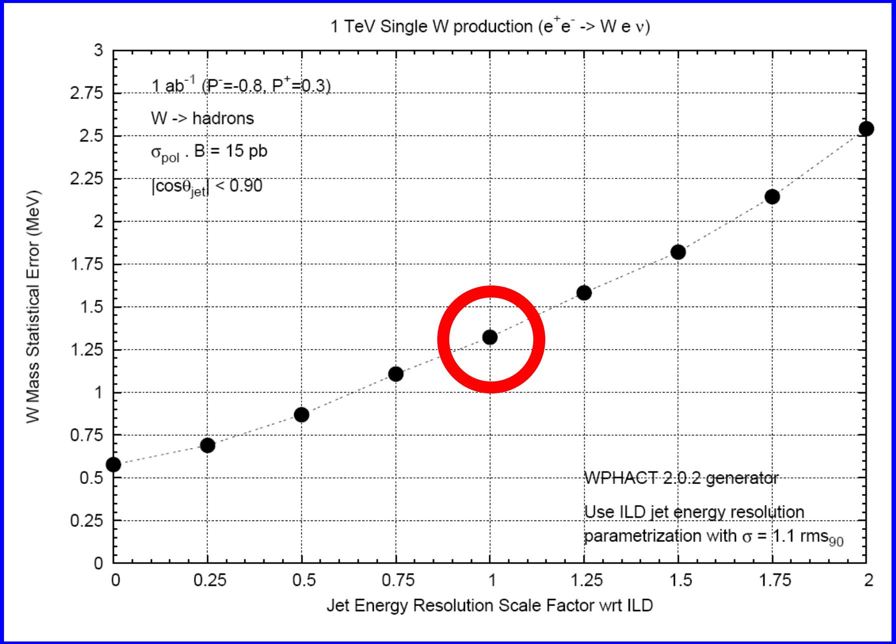




W → q q

(jets are not so energetic)

Is this useful for physics? Example m_W.



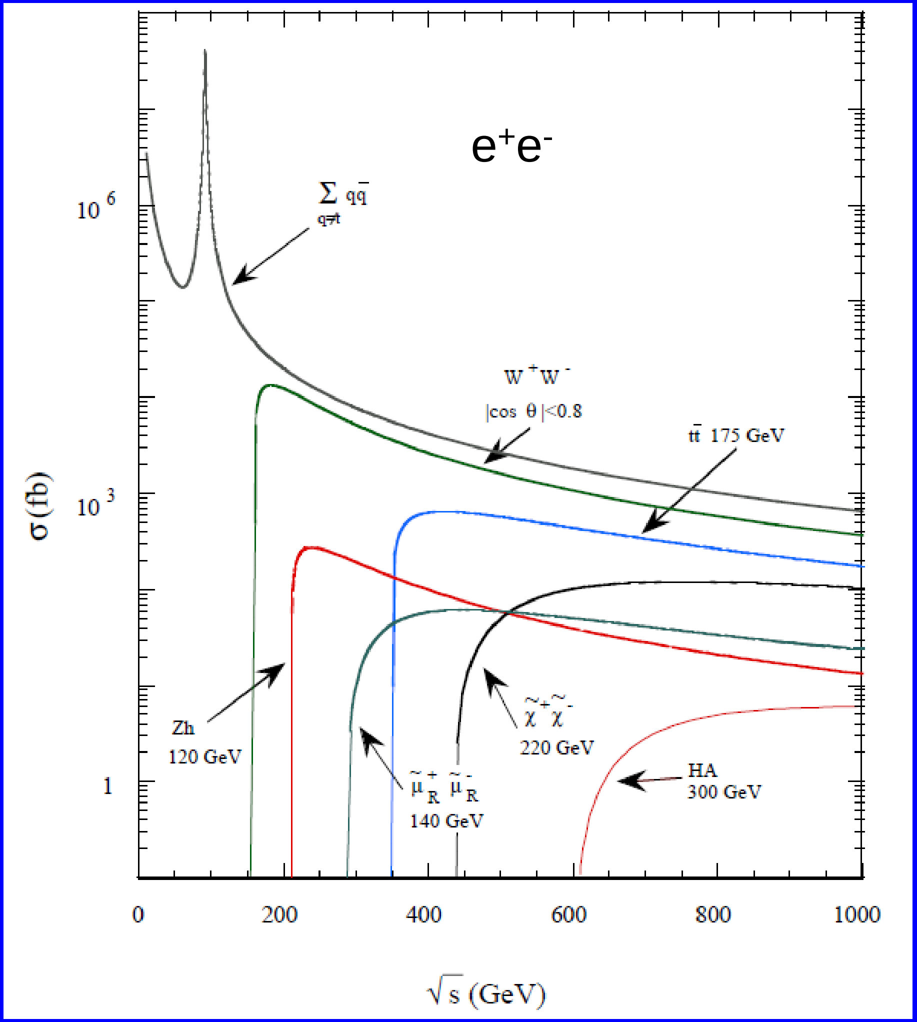
=> Further E_{jet} resolution improvement very desirable

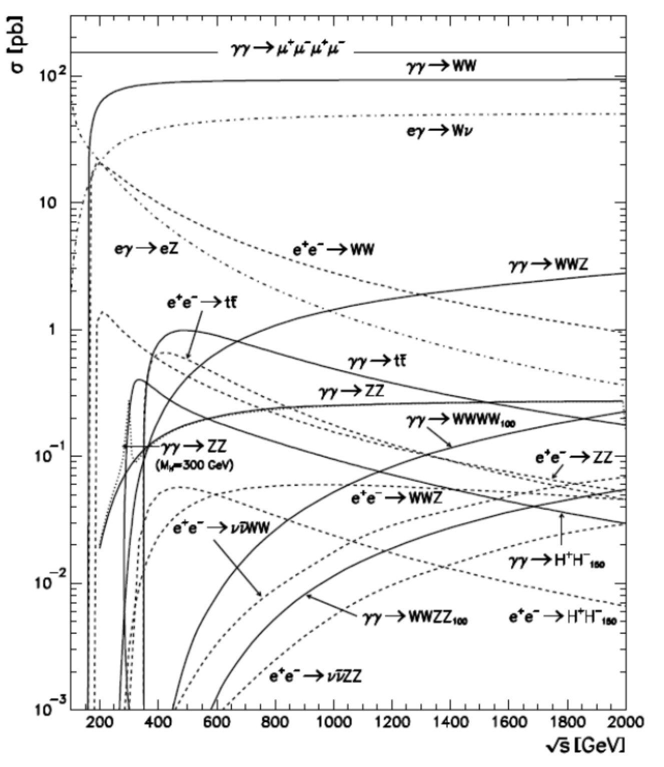
Potentially very useful! (Especially, if the really challenging requirements on jet energy scale and calibration can be met!)

Experimentation at Lepton Colliders

- Facilities under discussion (some more or less seriously)
- ILC e^+e^- : 91 – 1000 GeV
- CLIC e^+e^- : 250 – 3000 GeV
- e^+e^- ring colliders
- muon collider
- e^+e^- (or e^-e^- colliders) operated in either $e\gamma$ or $\gamma\gamma$ modes (or e^-e^-)

e^+e^- Cross-Sections (unpolarized)





ILC

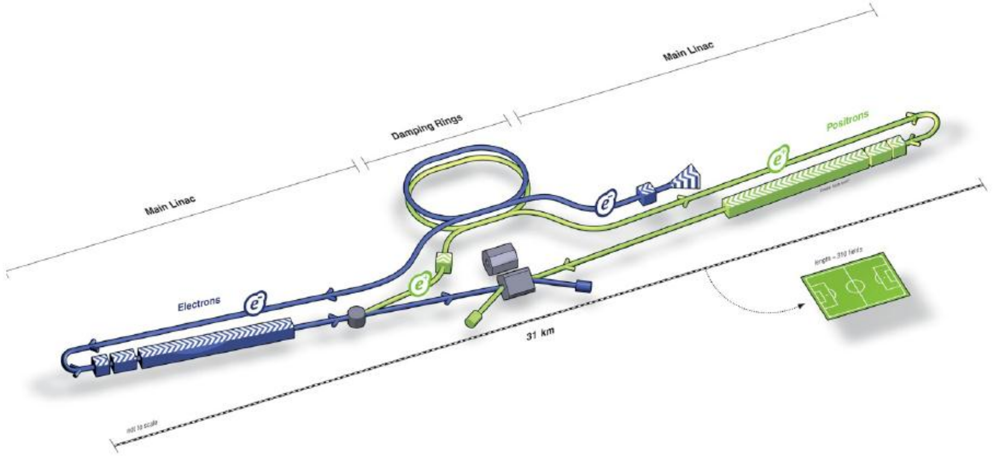


Figure 2: Layout of the ILC accelerator systems.

√s (GeV)	L (fb-1)	Physics
91	100	Z
161	160	WW
250	250	Zh
350	350	t tbar
500	1000	tth, Zhh
1000	2000	vvh, VBS

My take on a possible run-plan factoring in L capabilities at each √s

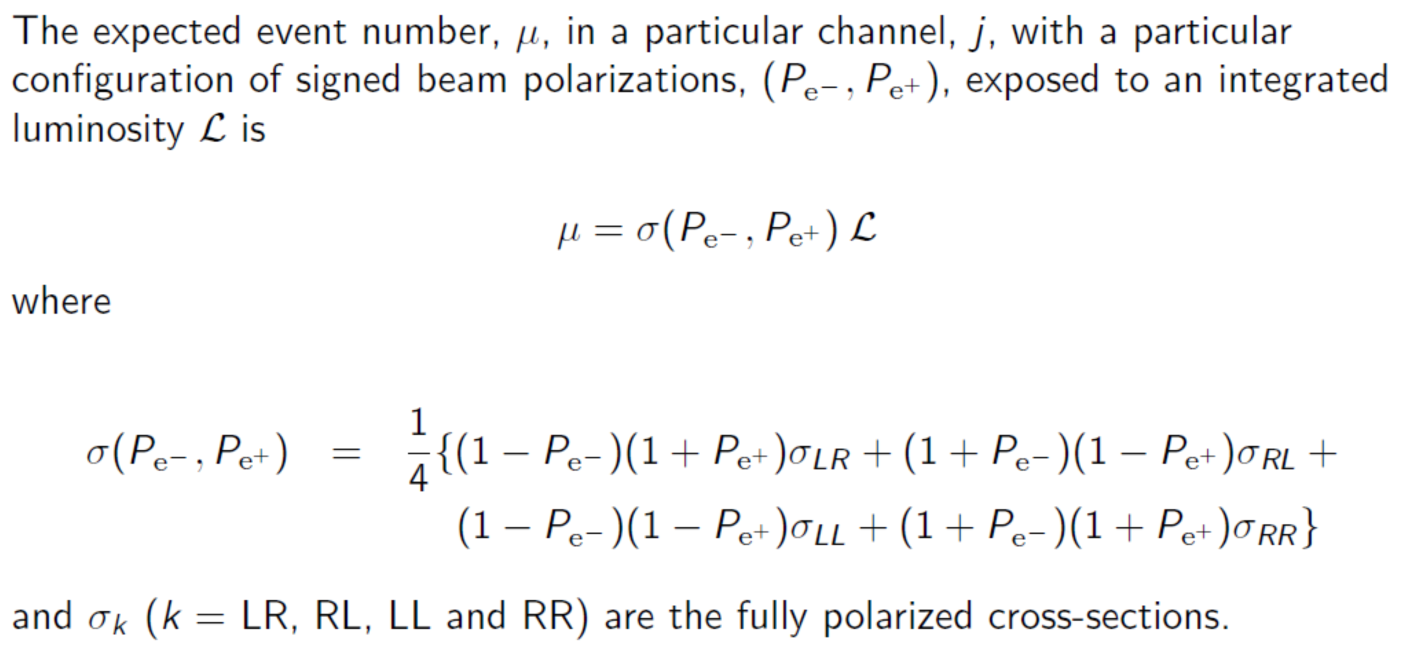
Can polarize both the electron and positron beam.
Electron: 80% …. 90%? Positron 20, 30 … 60%.

In contrast to circular machines this is not supposed to be in exchange for less luminosity ….

Why have longitudinally polarized beams?

Advantages

- Measure polarized cross-sections and asymmetries to better understand new and old physics
- Improve statistical errors by preferentially selecting preferred beam helicities (best with high $|P|$)
- Reduce backgrounds in new physics searches



The expected event number, μ, in a particular channel, j, with a particular configuration of signed beam polarizations, $(P_{\mathrm{e}^-}, P_{\mathrm{e}^+})$, exposed to an integrated luminosity $\mathcal{L}$ is

$$\mu = \sigma(P_{\mathrm{e}^-}, P_{\mathrm{e}^+})\,\mathcal{L}$$

where

$$\begin{aligned}\sigma(P_{\mathrm{e}^-}, P_{\mathrm{e}^+}) \quad = \quad & \frac{1}{4}\{(1-P_{\mathrm{e}^-})(1+P_{\mathrm{e}^+})\sigma_{LR} + (1+P_{\mathrm{e}^-})(1-P_{\mathrm{e}^+})\sigma_{RL} + \\ & (1-P_{\mathrm{e}^-})(1-P_{\mathrm{e}^+})\sigma_{LL} + (1+P_{\mathrm{e}^-})(1+P_{\mathrm{e}^+})\sigma_{RR}\}\end{aligned}$$

and σ_k ($k =$ LR, RL, LL and RR) are the fully polarized cross-sections.

ILC Accelerator Parameters

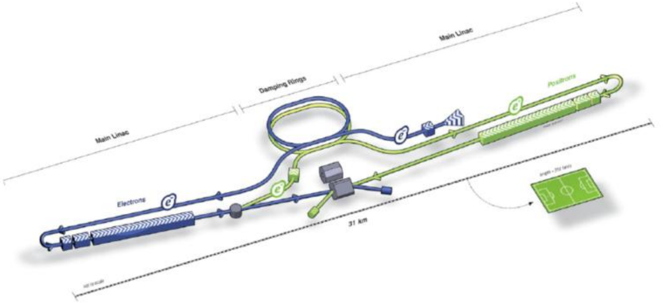
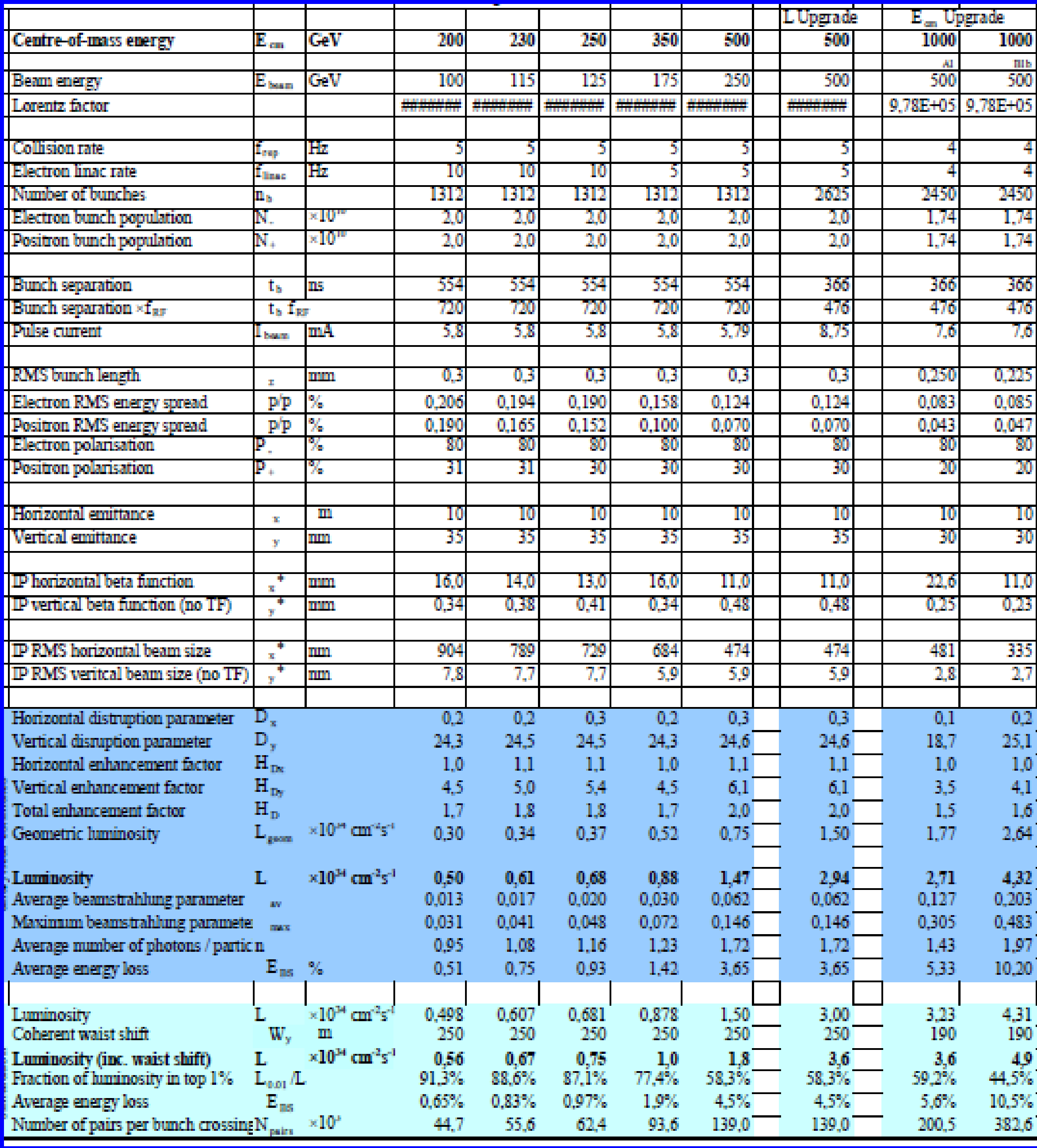


Figure 2: Layout of the ILC accelerator systems.

Parameters of interest for precision measurements:

Beam energy spread,
Bunch separation,
Bunch length,
e$^-$ Polarization / e$^+$ Polarization,
dL/d$\sqrt{s}$,
Average energy loss,
Pair backgrounds,
Beamstrahlung characteristics,

and of course **luminosity**.



								L Upgrade	E_{cm} Upgrade	
Centre-of-mass energy	**E_{cm}**	**GeV**	**200**	**230**	**250**	**350**	**500**	**500**	**1000**	**1000**
									A1	B1b
Beam energy	E_{beam}	GeV	100	115	125	175	250	500	500	500
Lorentz factor			#######	#######	#######	#######	#######	#######	9,78E+05	9,78E+05
Collision rate	f_{rep}	Hz	5	5	5	5	5	5	4	4
Electron linac rate	f_{linac}	Hz	10	10	10	5	5	5	4	4
Number of bunches	n_b		1312	1312	1312	1312	1312	2625	2450	2450
Electron bunch population	N_-	$\times 10^{10}$	2,0	2,0	2,0	2,0	2,0	2,0	1,74	1,74
Positron bunch population	N_+	$\times 10^{10}$	2,0	2,0	2,0	2,0	2,0	2,0	1,74	1,74
Bunch separation	t_b	ns	554	554	554	554	554	366	366	366
Bunch separation $\times f_{RF}$	t_b f_{RF}		720	720	720	720	720	476	476	476
Pulse current	I_{beam}	mA	5,8	5,8	5,8	5,8	5,79	8,75	7,6	7,6
RMS bunch length	$_z$	mm	0,3	0,3	0,3	0,3	0,3	0,3	0,250	0,225
Electron RMS energy spread	p/p	%	0,206	0,194	0,190	0,158	0,124	0,124	0,083	0,085
Positron RMS energy spread	p/p	%	0,190	0,165	0,152	0,100	0,070	0,070	0,043	0,047
Electron polarisation	P_-	%	80	80	80	80	80	80	80	80
Positron polarisation	P_+	%	31	31	30	30	30	30	20	20
Horizontal emittance	$_x$	m	10	10	10	10	10	10	10	10
Vertical emittance	$_y$	nm	35	35	35	35	35	35	30	30
IP horizontal beta function	$_x^*$	mm	16,0	14,0	13,0	16,0	11,0	11,0	22,6	11,0
IP vertical beta function (no TF)	$_y^*$	mm	0,34	0,38	0,41	0,34	0,48	0,48	0,25	0,23
IP RMS horizontal beam size	$_x^*$	nm	904	789	729	684	474	474	481	335
IP RMS veritcal beam size (no TF)	$_y^*$	nm	7,8	7,7	7,7	5,9	5,9	5,9	2,8	2,7
Horizontal distruption parameter	D_x		0,2	0,2	0,3	0,2	0,3	0,3	0,1	0,2
Vertical disruption parameter	D_y		24,3	24,5	24,5	24,3	24,6	24,6	18,7	25,1
Horizontal enhancement factor	H_{Dx}		1,0	1,1	1,1	1,0	1,1	1,1	1,0	1,0
Vertical enhancement factor	H_{Dy}		4,5	5,0	5,4	4,5	6,1	6,1	3,5	4,1
Total enhancement factor	H_D		1,7	1,8	1,8	1,7	2,0	2,0	1,5	1,6
Geometric luminosity	L_{geom}	$\times 10^{34}$ cm^{-2}s^{-1}	0,30	0,34	0,37	0,52	0,75	1,50	1,77	2,64
Luminosity	**L**	**$\times 10^{34}$ cm^{-2}s^{-1}**	**0,50**	**0,61**	**0,68**	**0,88**	**1,47**	**2,94**	**2,71**	**4,32**
Average beamstrahlung parameter	$_{av}$		0,013	0,017	0,020	0,030	0,062	0,062	0,127	0,203
Maximum beamstrahlung paramete	$_{max}$		0,031	0,041	0,048	0,072	0,146	0,146	0,305	0,483
Average number of photons / partic n			0,95	1,08	1,16	1,23	1,72	1,72	1,43	1,97
Average energy loss	E_{BS}	%	0,51	0,75	0,93	1,42	3,65	3,65	5,33	10,20
Luminosity	L	$\times 10^{34}$ cm^{-2}s^{-1}	0,498	0,607	0,681	0,878	1,50	3,00	3,23	4,31
Coherent waist shift	W_y	m	250	250	250	250	250	250	190	190
Luminosity (inc. waist shift)	**L**	**$\times 10^{34}$ cm^{-2}s^{-1}**	**0,56**	**0,67**	**0,75**	**1,0**	**1,8**	**3,6**	**3,6**	**4,9**
Fraction of luminosity in top 1%	$L_{0.01}$ /L		91,3%	88,6%	87,1%	77,4%	58,3%	58,3%	59,2%	44,5%
Average energy loss	E_{BS}		0,65%	0,83%	0,97%	1,9%	4,5%	4,5%	5,6%	10,5%
Number of pairs per bunch crossing	N_{pairs}	$\times 10^3$	44,7	55,6	62,4	93,6	139,0	139,0	200,5	382,6

Beamstrahlung

- Very strong magnetic field experienced by individual particles of beam during collision.
- Leads to quantum emission of hard photons of order 0.1 E_{beam}.
- See Yokoya and Chen.
- Distorts e^+e^- lumi spectrum
- And in addition to e^+e^- collisions, we also have collisions (with real γ’s).
- $e^-\gamma$, γe^+, $\gamma\gamma$

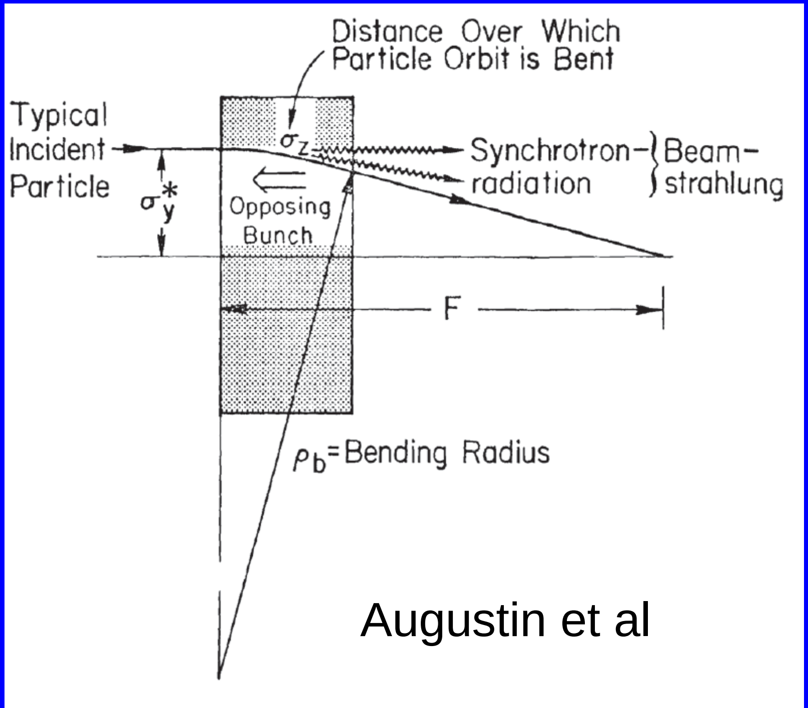


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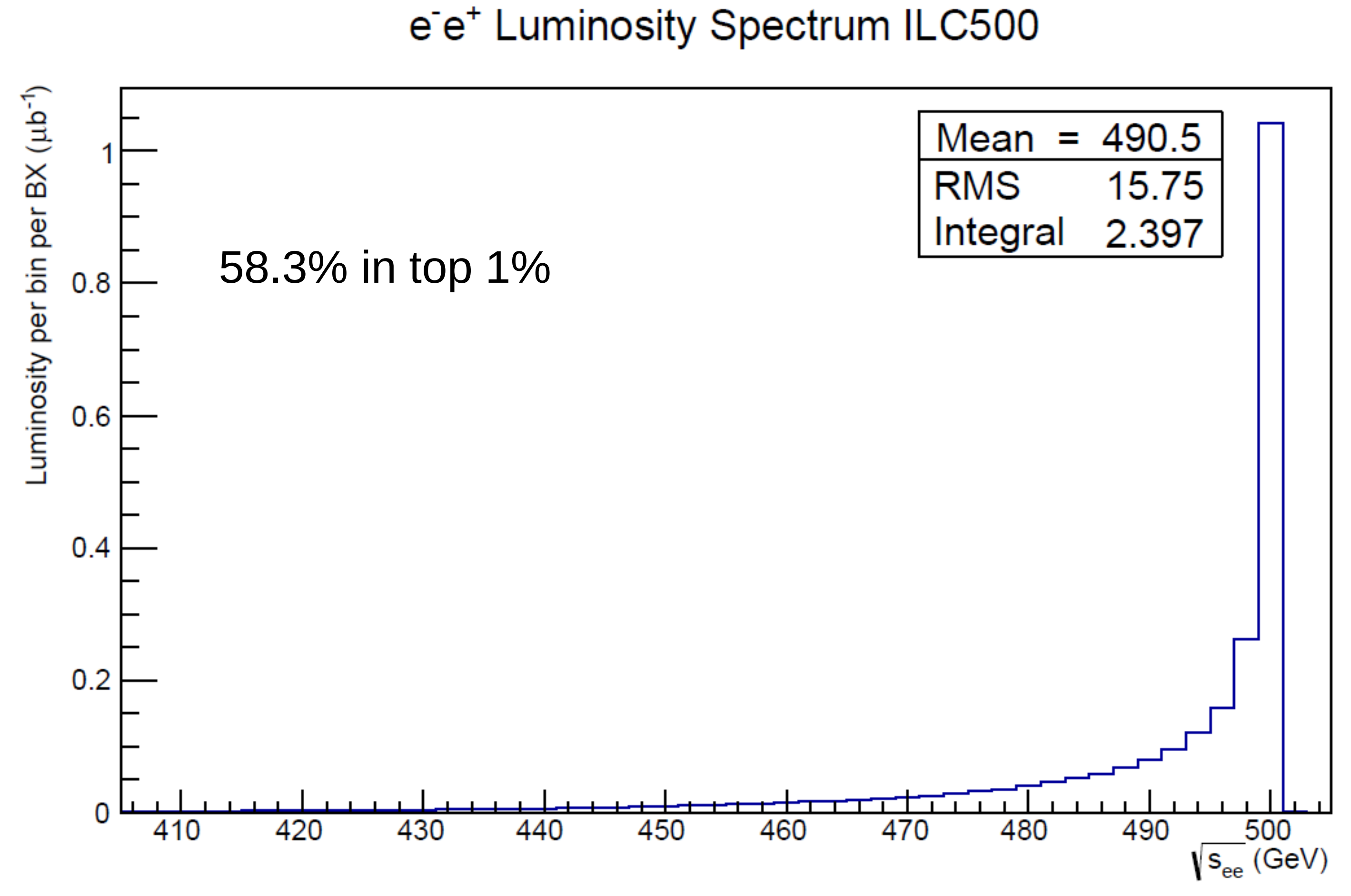
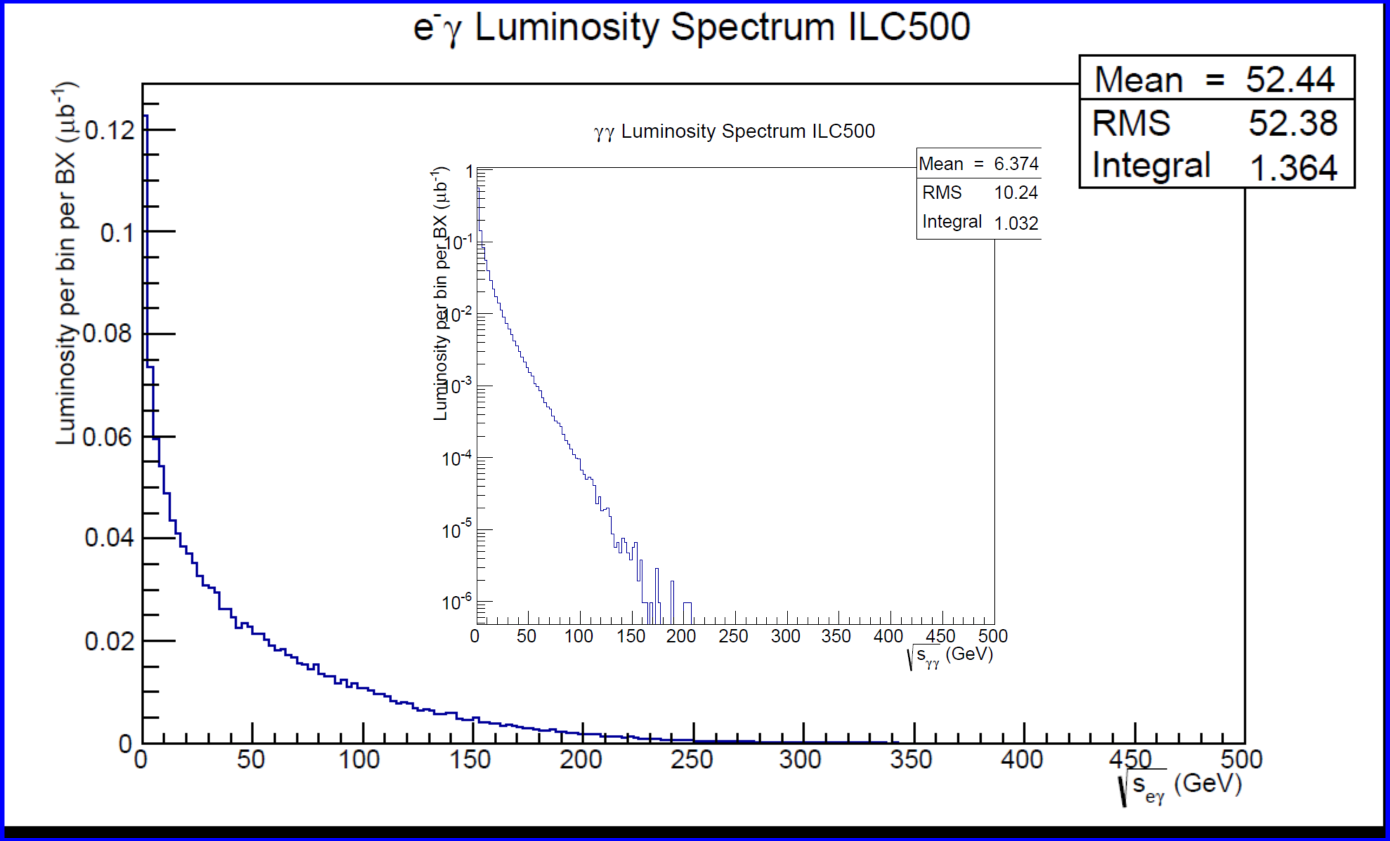
Fig. 1. Typical particle incident on an opposing bunch.

Luminosity Spectrum



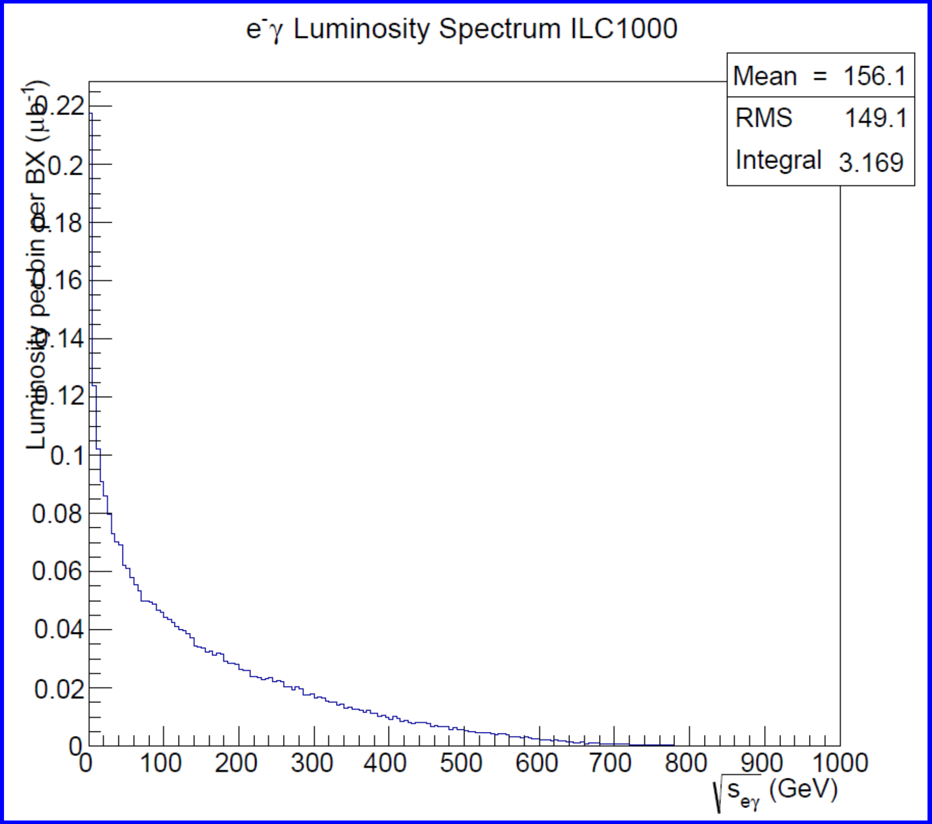
Note plot starts at 405 GeV

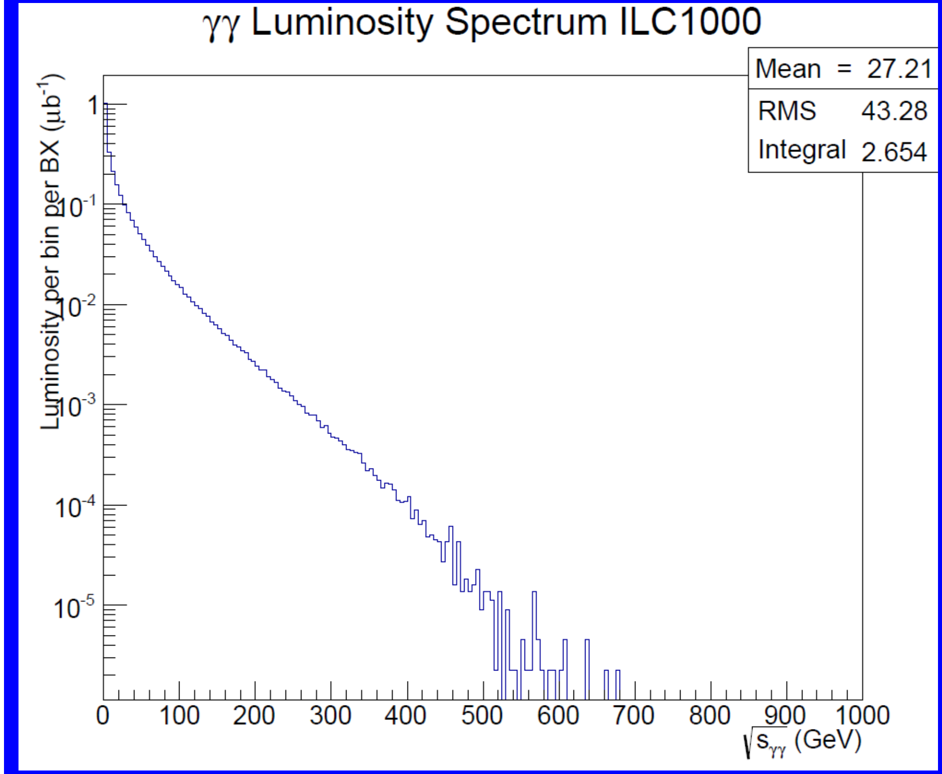
Luminosity Spectrum



<n($\gamma\gamma\rightarrow$ had)> with W > 2 GeV = 0.5

Luminosity Spectrum





$\langle n(\gamma\gamma \rightarrow \text{had})\rangle$ with $W > 2$ GeV = 2.0

ILC Detector Concepts

Large international effort.
See Letters of Intent from 2009. Currently Detailed Baseline Documents in finalization stage (part of ILC TDR)

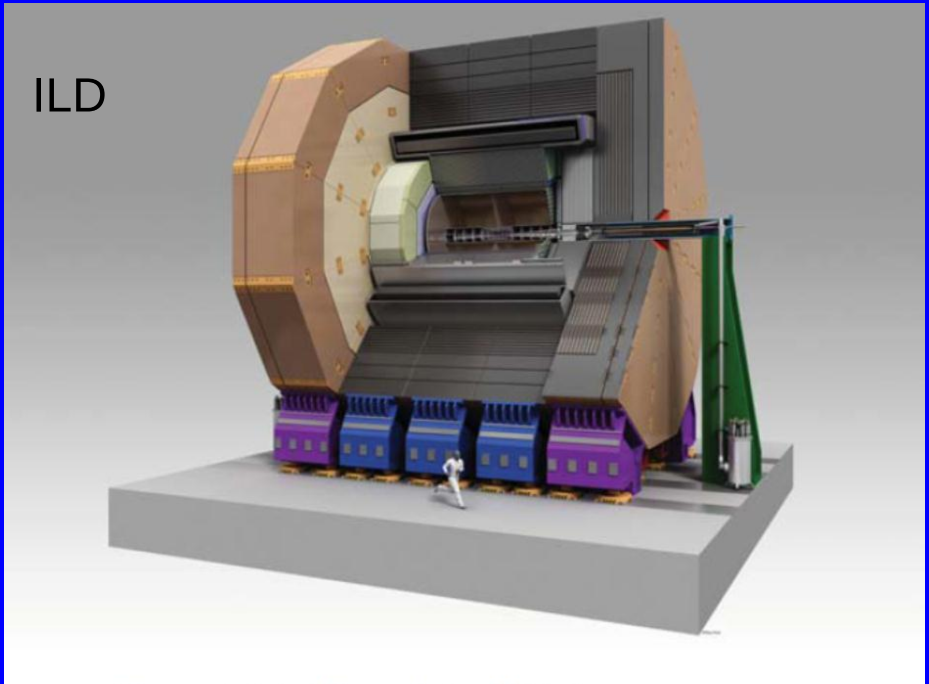
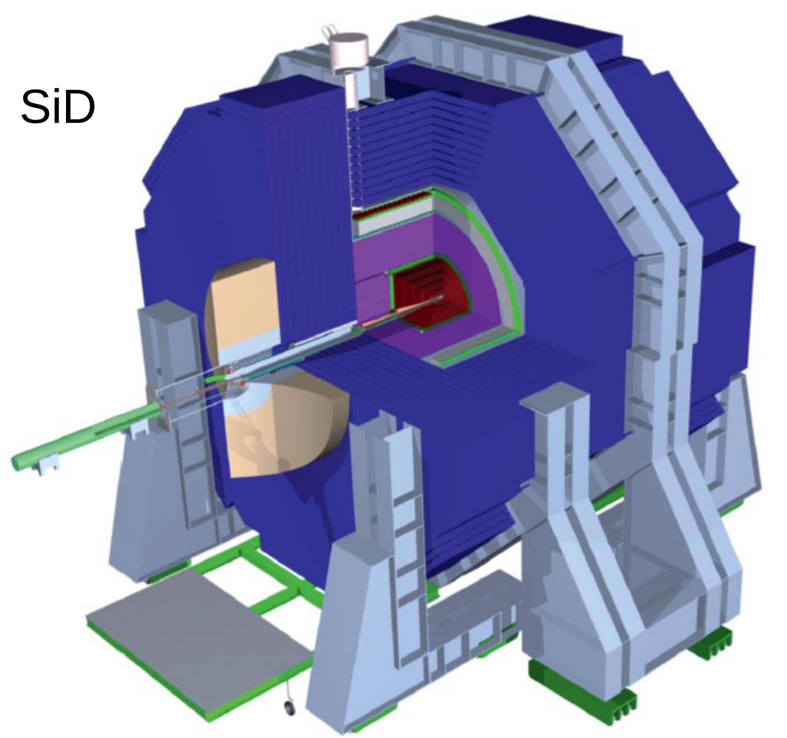


Figure 1.1.1: View of the ILD detector concept.



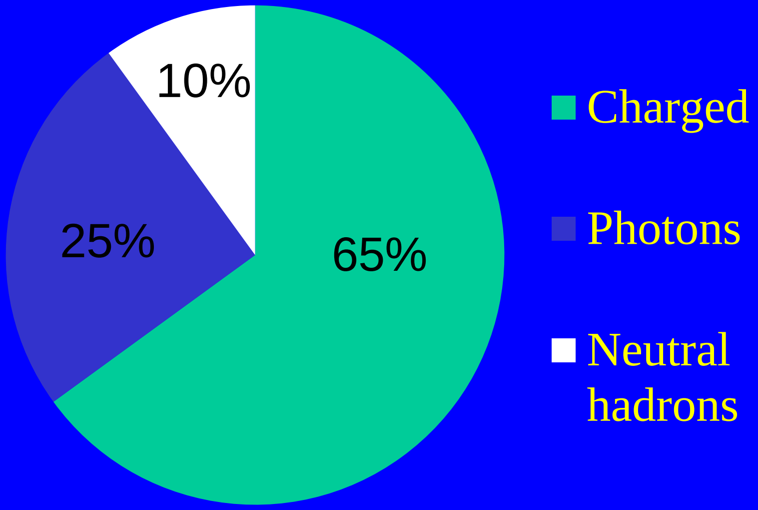
Detailed designs with engineering realism. Full simulations with backgrounds. Advanced reconstruction algorithms. Performance in many respects (not all) much better than the LHC experiments. Central theme: particle-flow based jet reconstruction. New people welcome !

Particle-Flow in a Nut-Shell

E(jet) = E(charged) + E(photons) + E(neutral hadrons)

- Basics
  - Outsource **65%** of the event-energy measurement responsibility from the calorimeter to the tracker
    - Emphasize particle separability and tracking
    - Leading to better jet energy precision
  - Reduce importance of hadronic leakage
    - Now only 10% instead of 75% of the average jet energy is susceptible
    - Detector designs suited to wide energy range
  - Maximize event information
    - Aim for full reconstruction of each particle including V0s, kinks, π^0 etc.
    - Facilitates software compensation and application of multi-variate techniques

Particle AVERAGEs

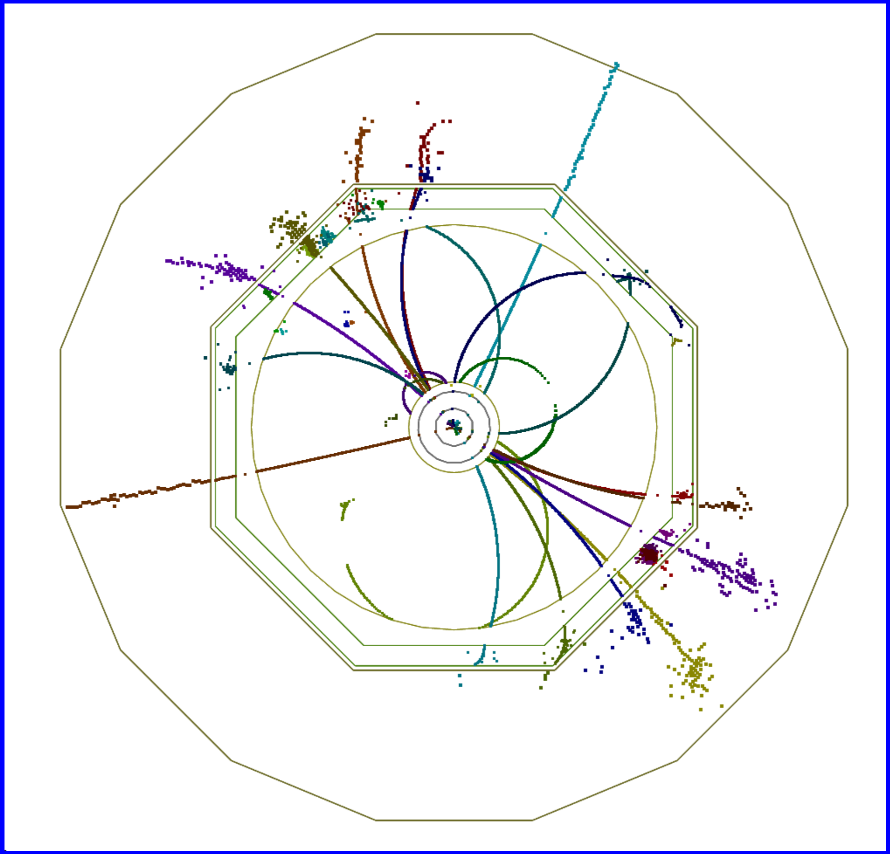


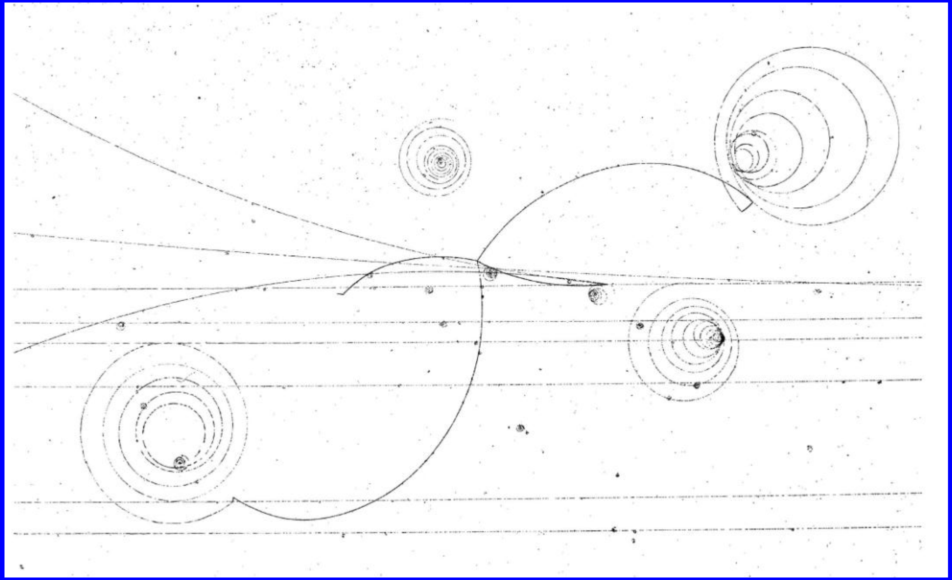
This used to be controversial – but already was well established at LEP. Now is widely applied at LHC in particular in CMS.

Bubble Chamber

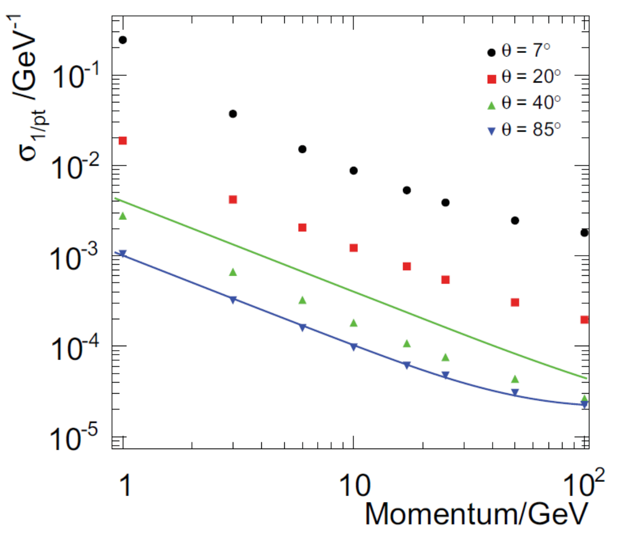
The vision is to do the best possible physics at the linear collider, by reconstructing as far as possible every single piece of each event.

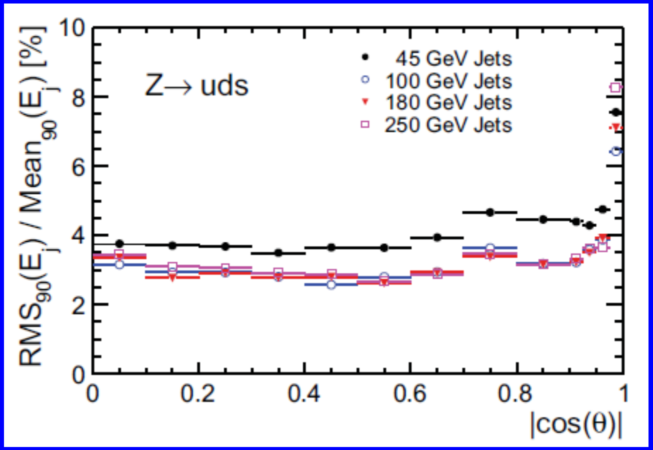
Very much in the spirit of bubble chamber reconstruction – but with full efficiency for photons and neutral hadrons, and in a high multiplicity environment at high luminosity.



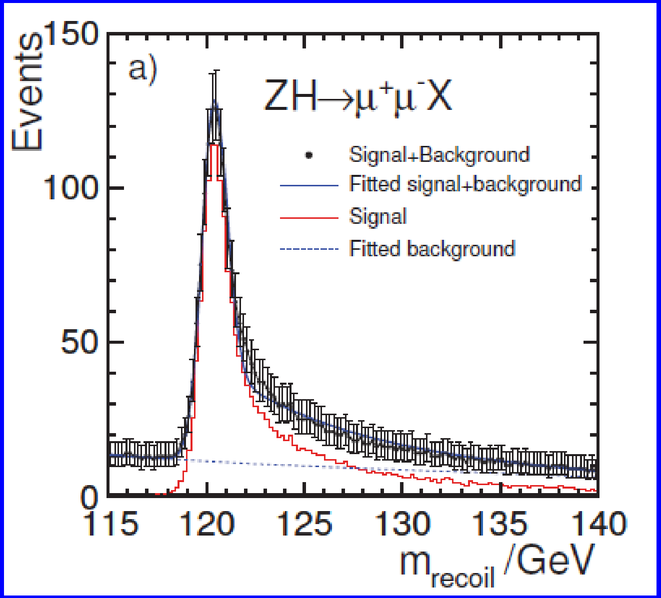


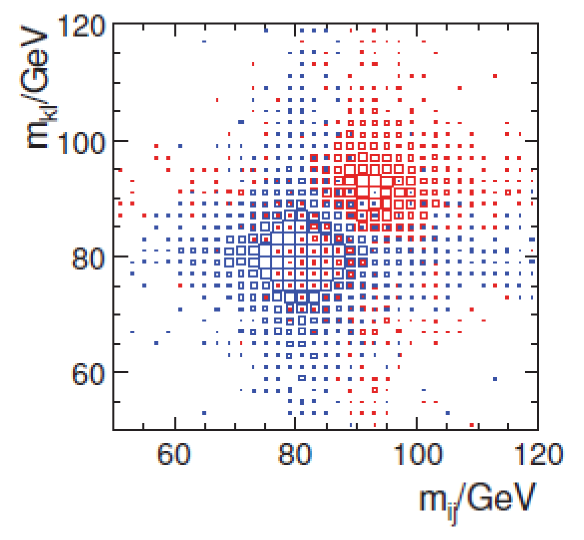
Detector Performance





WW scattering to 4 jets

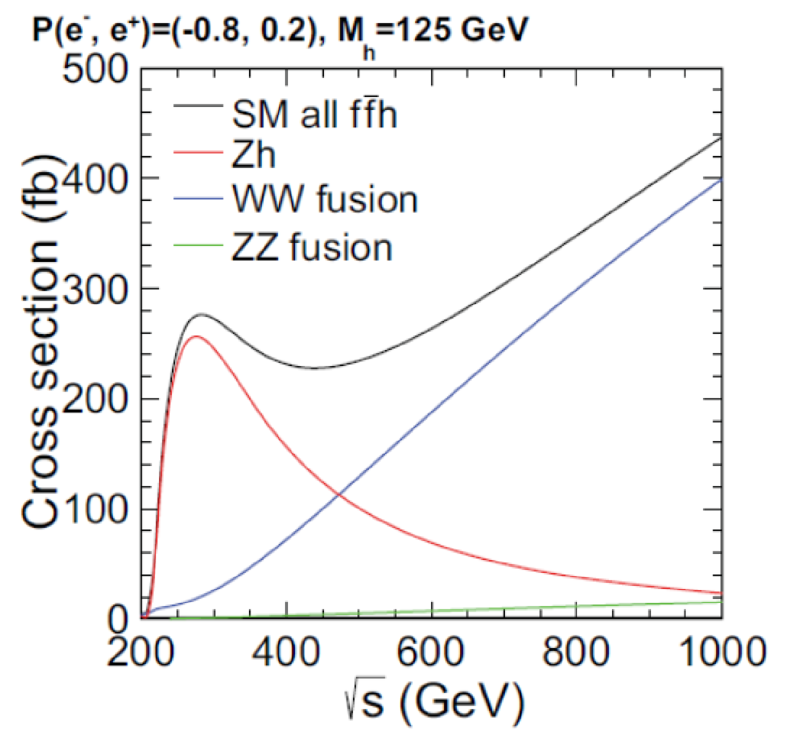


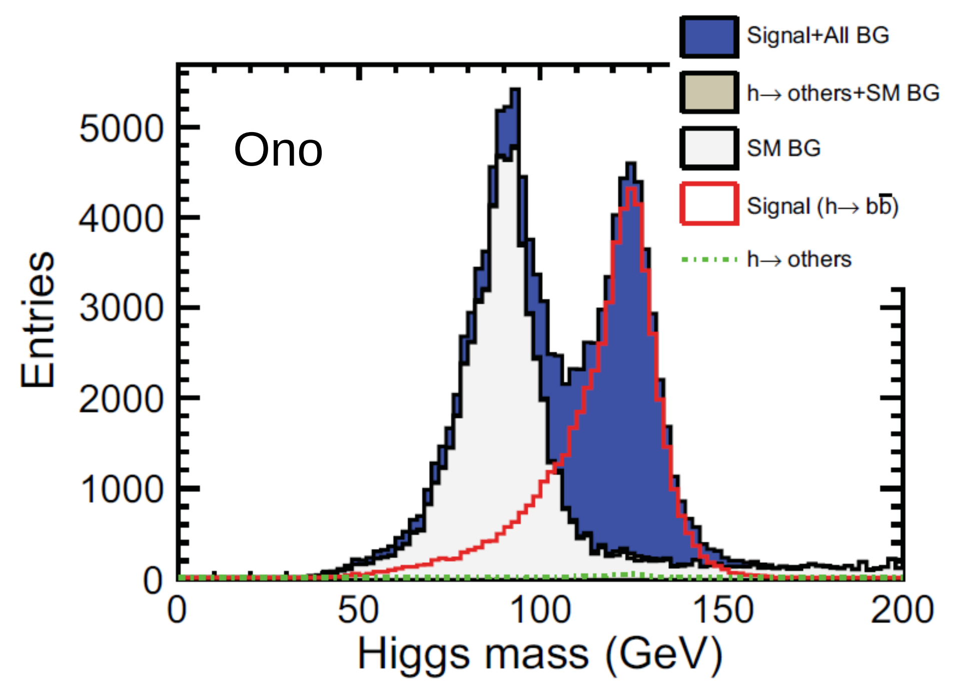


ννWW / ννZZ

ILD Full Simulation with Background

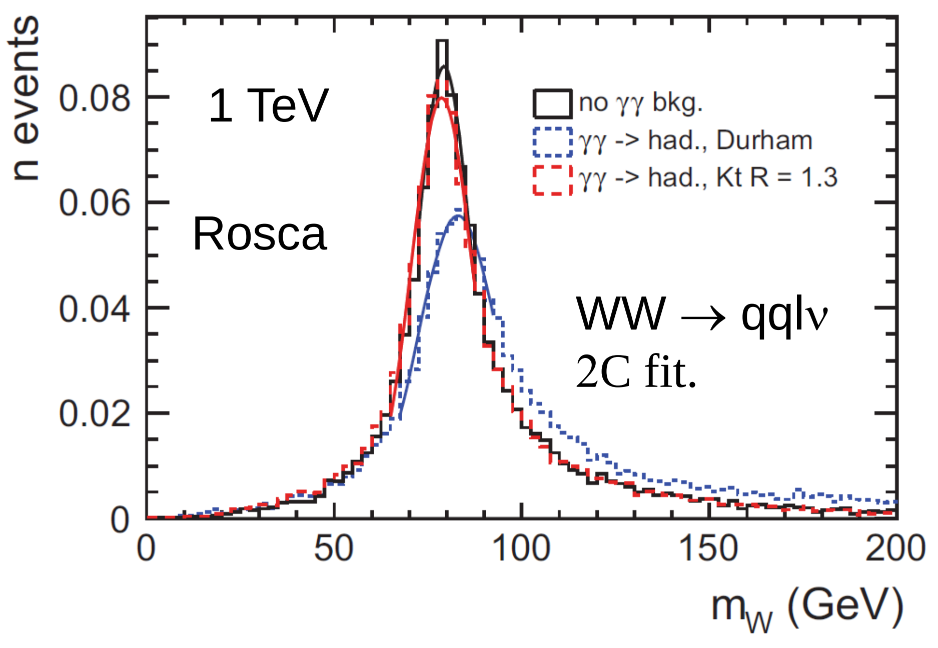
1 TeV. $e^+e^- \to \nu\,\nu\, h\,(125) \to \nu\,\nu\, b\, b$

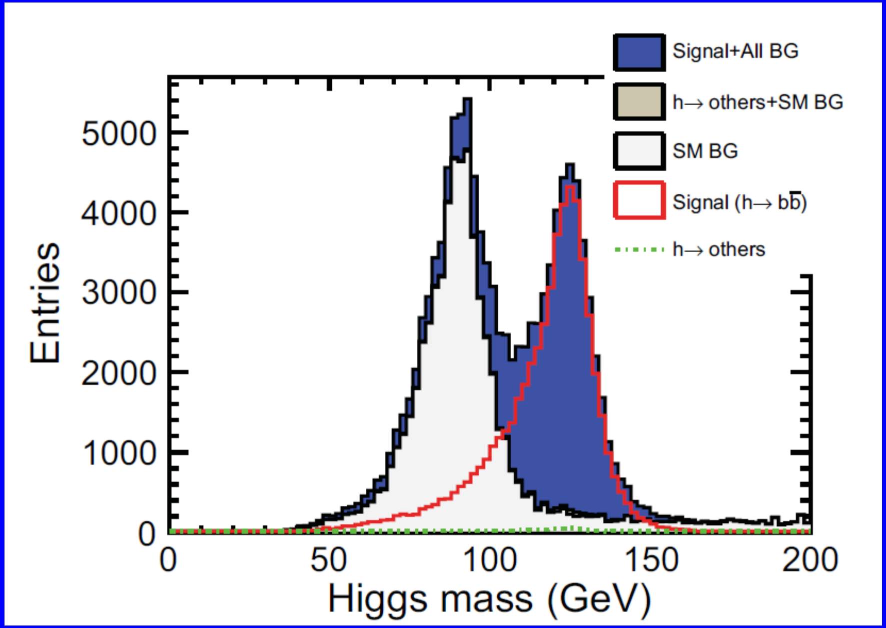




ILD Full Simulation with Background

Inclusion of backgrounds associated with γγ interactions – although typically with low γγ mass – have necessitated changes to more HC-like jet finders – particularly for higher √s





You basically see in these two plots: W, Z, h reconstructed hadronically.

m_W Measurement Prospects

- A crucial systematic common to the threshold measurement and kinematic reconstruction is the absolute beam energy knowledge.
- This is expected to worsen with √s. (statistics & BS).
- Direct E_{beam} measurements target 10^{-4} precision.
- One way to control it - discussed by me in 1996 …is to use radiative return to the Z events: f f (γ) events.
  - Study by Kinze & Moenig, 2005
    - Confirms that the uncertainty worsens significantly with √s
  - Measured by OPAL, L3, DELPHI
  - This looks solid – but statistics limited.
    - Needs control of detector aspect ratio (in polar angle measurement).

In-situ Beam-Energy Calibration

Hinze & Moenig

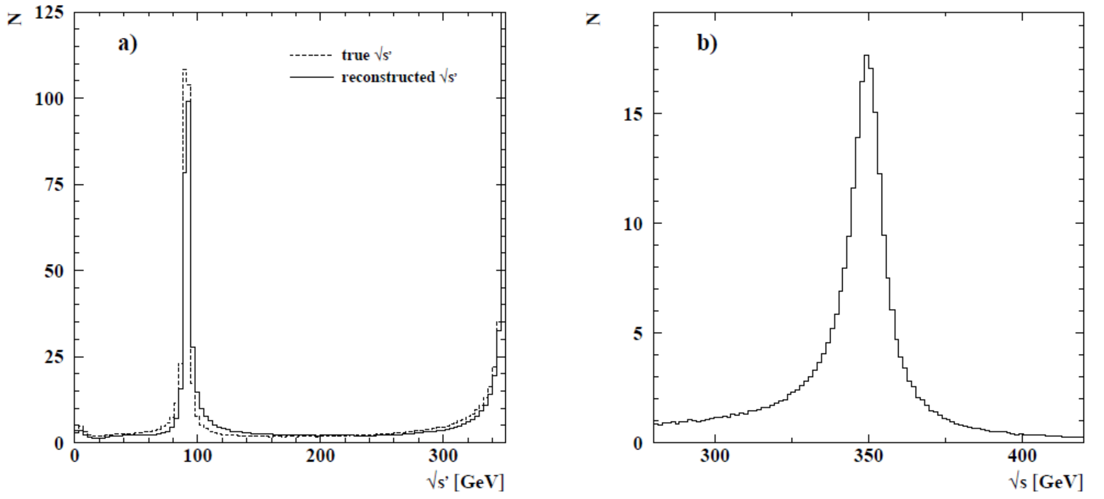


Figure 2: True and reconstructed $\sqrt{s'}$ (a) and reconstructed $\sqrt{s}$ for $e^+e^- \to Z\gamma \to \mu^+\mu^-\gamma$ at $\sqrt{s} = 350\,\mathrm{GeV}$

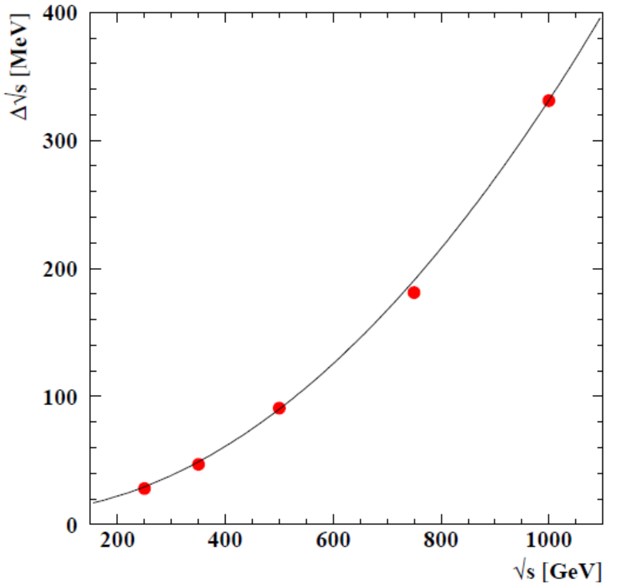


Figure 3: Energy dependence of $\Delta\sqrt{s}$ for $\mathcal{L} = 100\ \mathrm{fb}^{-1}$.

$$\sqrt{s} = m_Z \sqrt{\frac{\sin\theta_1 + \sin\theta_2 - \sin(\theta_1+\theta_2)}{\sin\theta_1 + \sin\theta_2 + \sin(\theta_1+\theta_2)}}$$

Studies (by T. Barklow) including p measurement indicate factors of 2-4 better precision

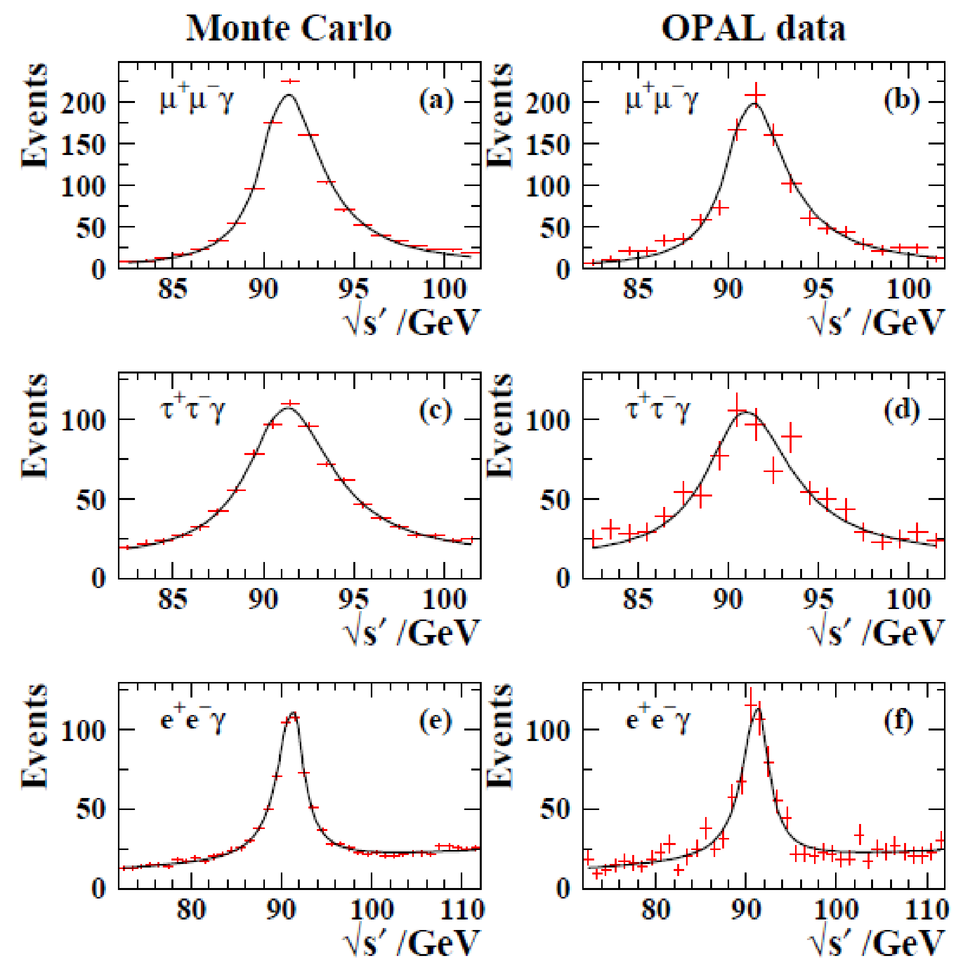
$$\Delta\sqrt{s} = \left(8.8 + 0.0026\sqrt{s}/\,\mathrm{GeV} + 0.0032 s/\,\mathrm{GeV}^2\right)\ \mathrm{MeV}.$$

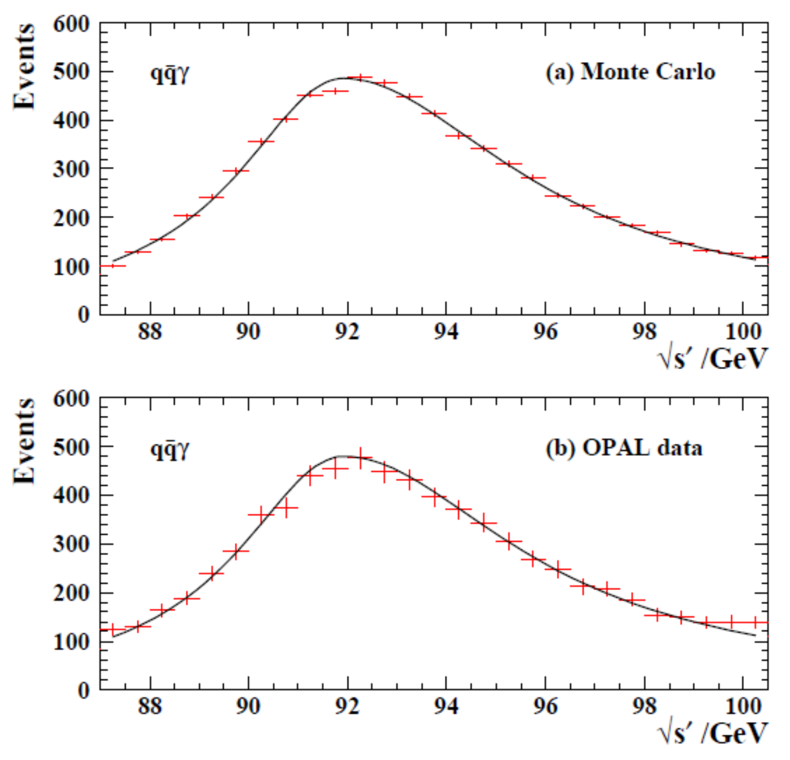
Suspect +ve linear term is in fact –ve.

(Note. At 161 GeV my error estimate (ee,μμ) on √s is 5 MeV)

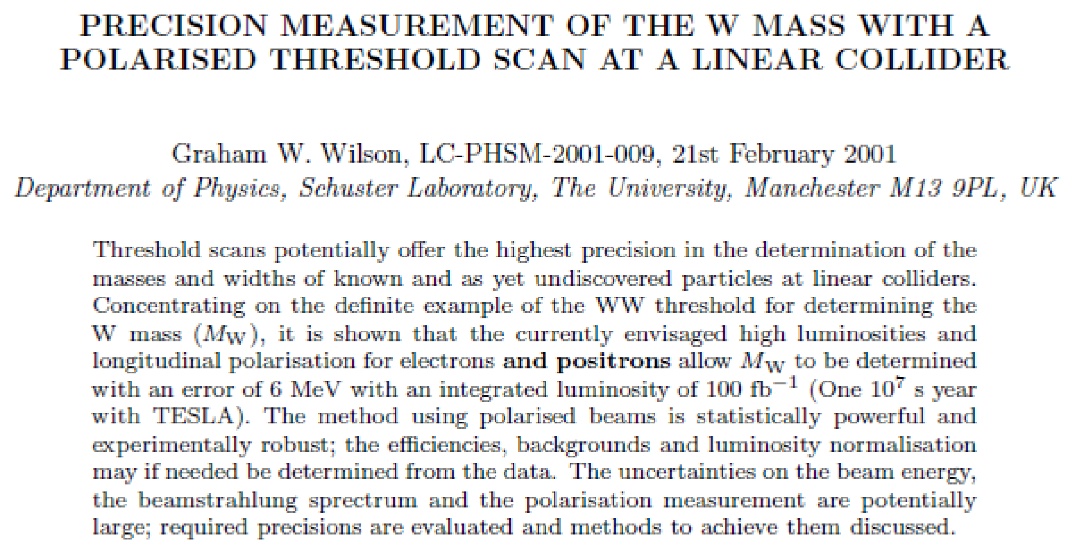
Z γ Beam Energy Measurement (OPAL)

PLB 604 (2004) 31-47





m_W Measurement Prospects Near Threshold

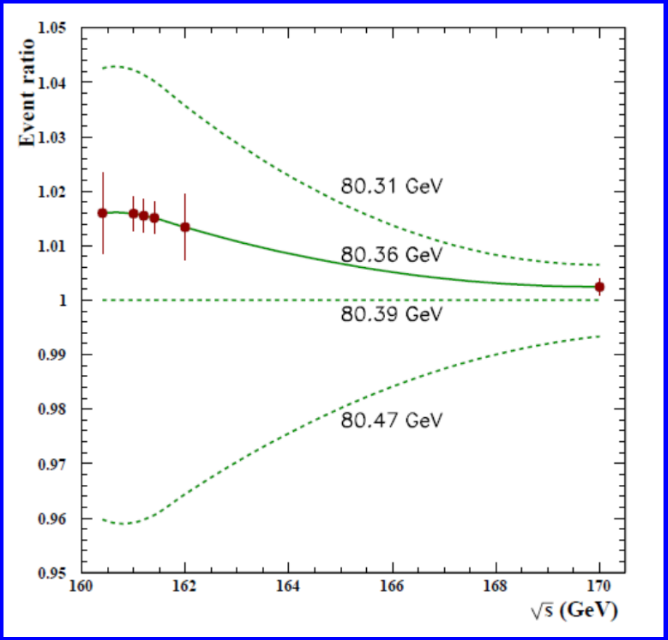


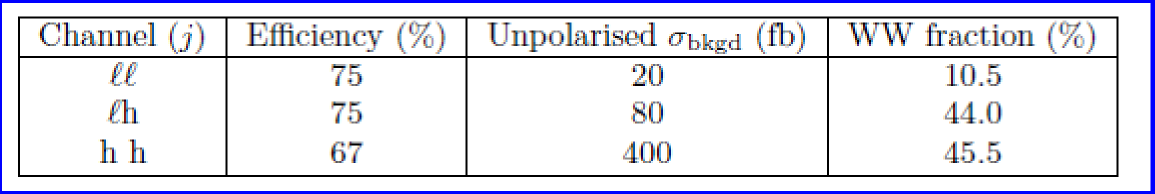
PRECISION MEASUREMENT OF THE W MASS WITH A POLARISED THRESHOLD SCAN AT A LINEAR COLLIDER

Graham W. Wilson, LC-PHSM-2001-009, 21st February 2001

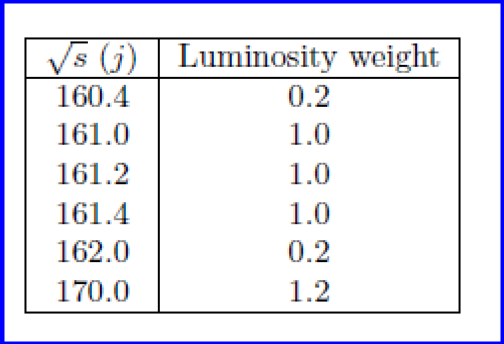
Department of Physics, Schuster Laboratory, The University, Manchester M13 9PL, UK

Threshold scans potentially offer the highest precision in the determination of the masses and widths of known and as yet undiscovered particles at linear colliders. Concentrating on the definite example of the WW threshold for determining the W mass (M_W), it is shown that the currently envisaged high luminosities and longitudinal polarisation for electrons **and positrons** allow M_W to be determined with an error of 6 MeV with an integrated luminosity of 100 fb^{-1} (One 10^7 s year with TESLA). The method using polarised beams is statistically powerful and experimentally robust; the efficiencies, backgrounds and luminosity normalisation may if needed be determined from the data. The uncertainties on the beam energy, the beamstrahlung sprectrum and the polarisation measurement are potentially large; required precisions are evaluated and methods to achieve them discussed.





Channel (j)	Efficiency (%)	Unpolarised σ_{bkgd} (fb)	WW fraction (%)
$\ell\ell$	75	20	10.5
ℓh	75	80	44.0
h h	67	400	45.5



$\sqrt{s}$ (j)	Luminosity weight
160.4	0.2
161.0	1.0
161.2	1.0
161.4	1.0
162.0	0.2
170.0	1.2

Measure at 6 values of √s, in 3 channels, and with up to 7 different helicity combinations.

Estimate error of 6 MeV (includes Ebeam error from Z γ) per 100 fb^{-1} polarized scan (assumed 60% e+ polarization)

m_W Measurement Near Threshold

- Requires dedicated running at an energy which is mostly only good for m_W measurement.
- The envisaged Higgs and top producing next lepton collider may not spend much time if any near W threshold – especially if there are other ways to access the m_W with competitive precision.
- Could still be a very useful thing to do for a less ambitious regional machine (say a Z and WW factory).
- (Note that resonant depolarization measurement of beam energy (used for m_Z) was not possible above 60 GeV)

m_W Prospects from Kinematic Reconstruction

- WW statistics are plentiful in envisaged run plan.
- Especially so wrt LEP2 using polarized beams.
- Detector performance much better than LEP detectors (helps also threshold cross-section).
- Can envisage samples with 1000 times more events than the 4 LEP experiments combined.
  - Statistical reasons to countenance error on the 1 MeV scale
  - But straightforward application of LEP2 techniques is unlikely to be the way to achieve this goal.

m_W from Kinematic Reconstruction

- qqlv Channel
- Apply (E, **p**) conservation constraint.
- 3 unknowns for v momentum.
- 1C fit.

Bottom-line.

Need beam energy and beamstrahlung under control.

Latter is thought doable.

- qqqq
- Apply (E, **p**) conservation constraint
- 4C fit.
- Final LEP2 results suffered from “color reconnection” systematic.

- Also lvlv channel.
- Use lepton endpoints and pseudo-mass.

Beam Energy Calibration

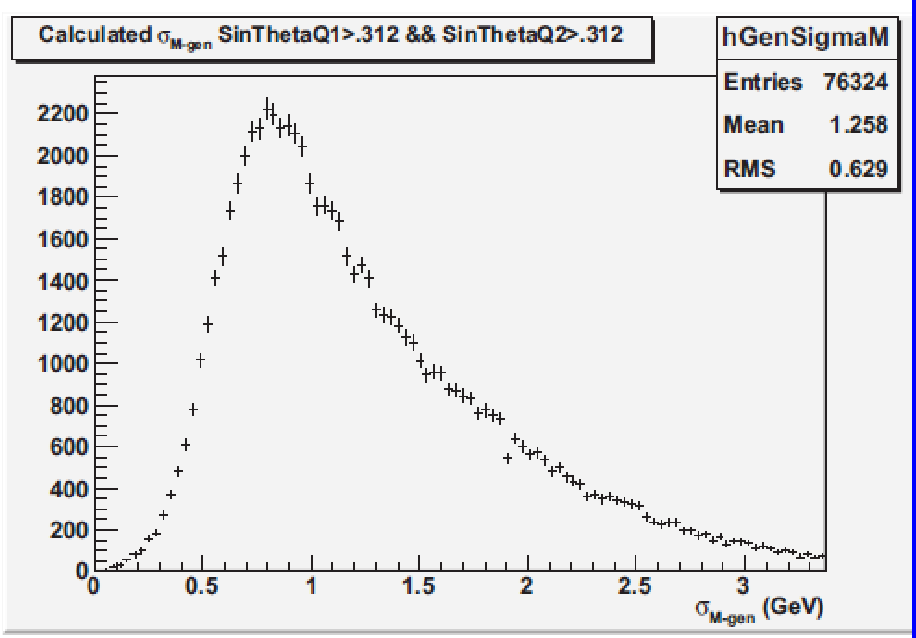
- Ideas of using a mini-scan at the Z to calibrate say a spectrometer – which can be extrapolated to higher energy.
- Even the calorimeter – potentially calibrated at the Z using Bhabhas can be used in a similar fashion ?? (although calorimeter non-linearities can be unfavorable…)

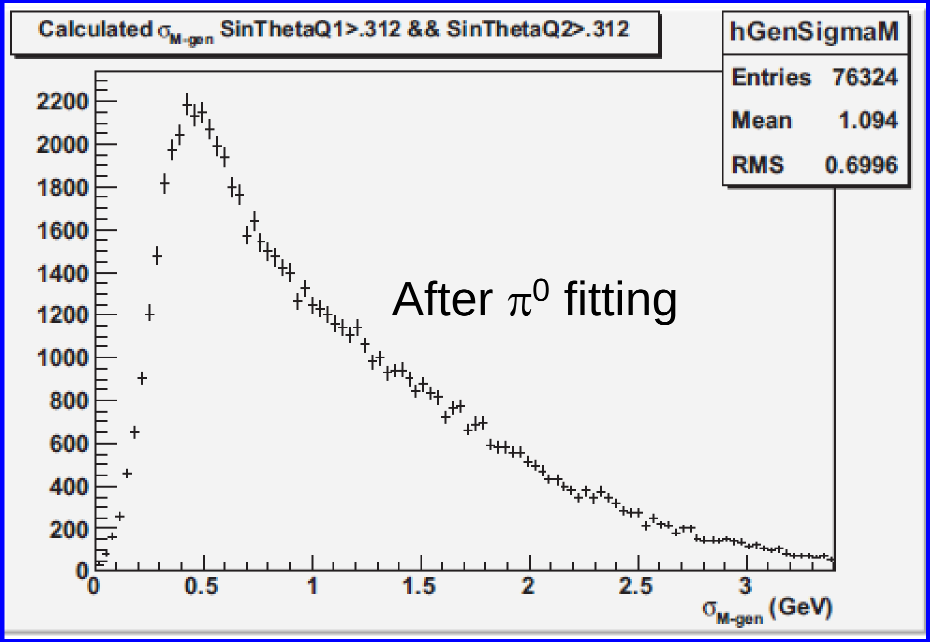
m_W from Hadronic Mass in Single W

- Cross-section including eγ induced reactions with -80% (e-), +20% (e+) is 40 pb at 1 TeV.
- Per event mass resolution is the convolution of the intrinsic width, (2.08 GeV), and detector resolution.
- The latter varies significantly from event-to-event.
  - Depends a lot on the amount of neutral hadron energy.

Event-Specific Hadronic Mass Resolution

B. van Doren (KU)



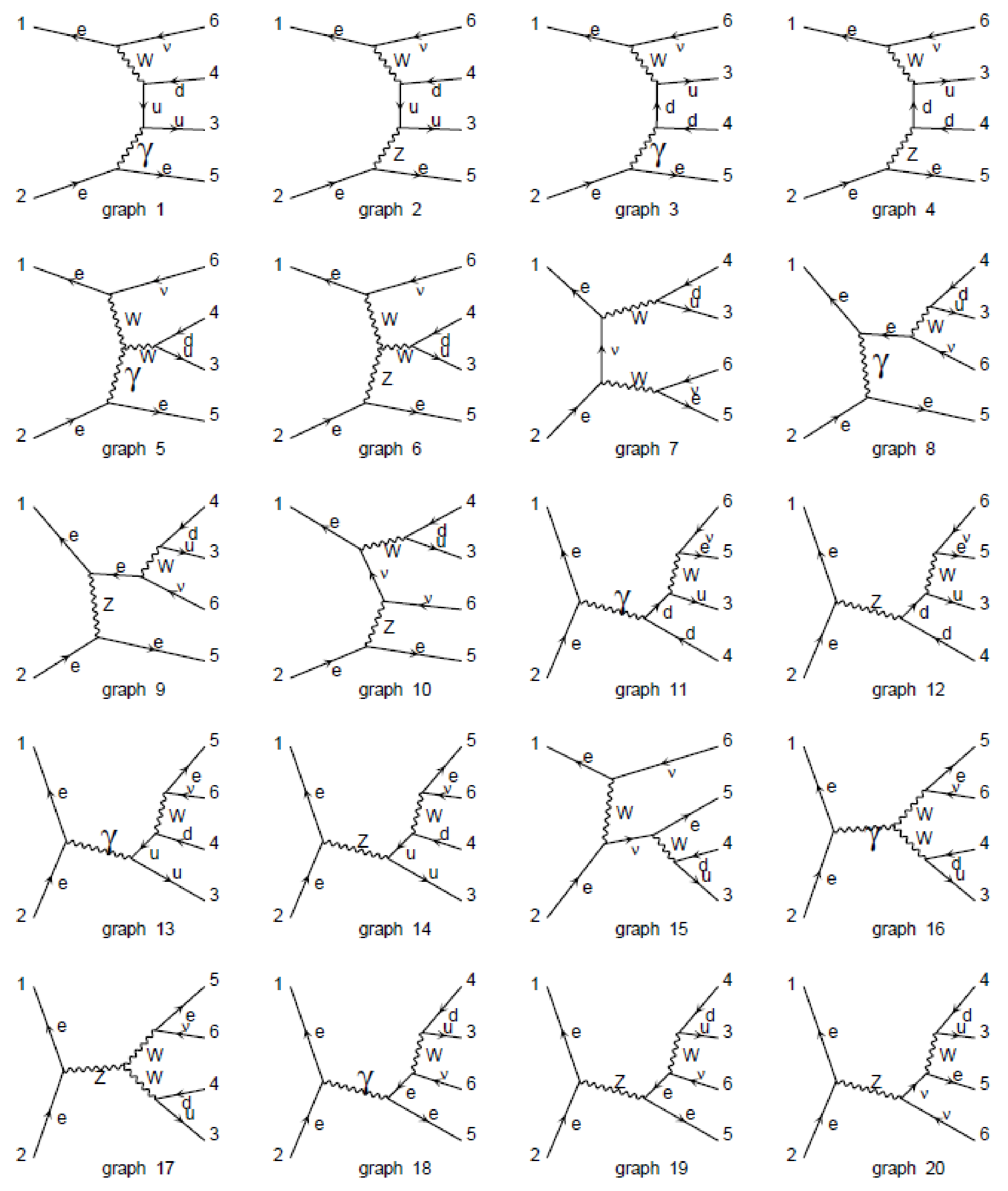


Assumes individual particles are reconstructed, resolved and measured with perfect efficiency, intrinsic detector resolutions and perfect mass assignments.
(Also no confusion: valid for low jet-energy and jet multiplicity environment)

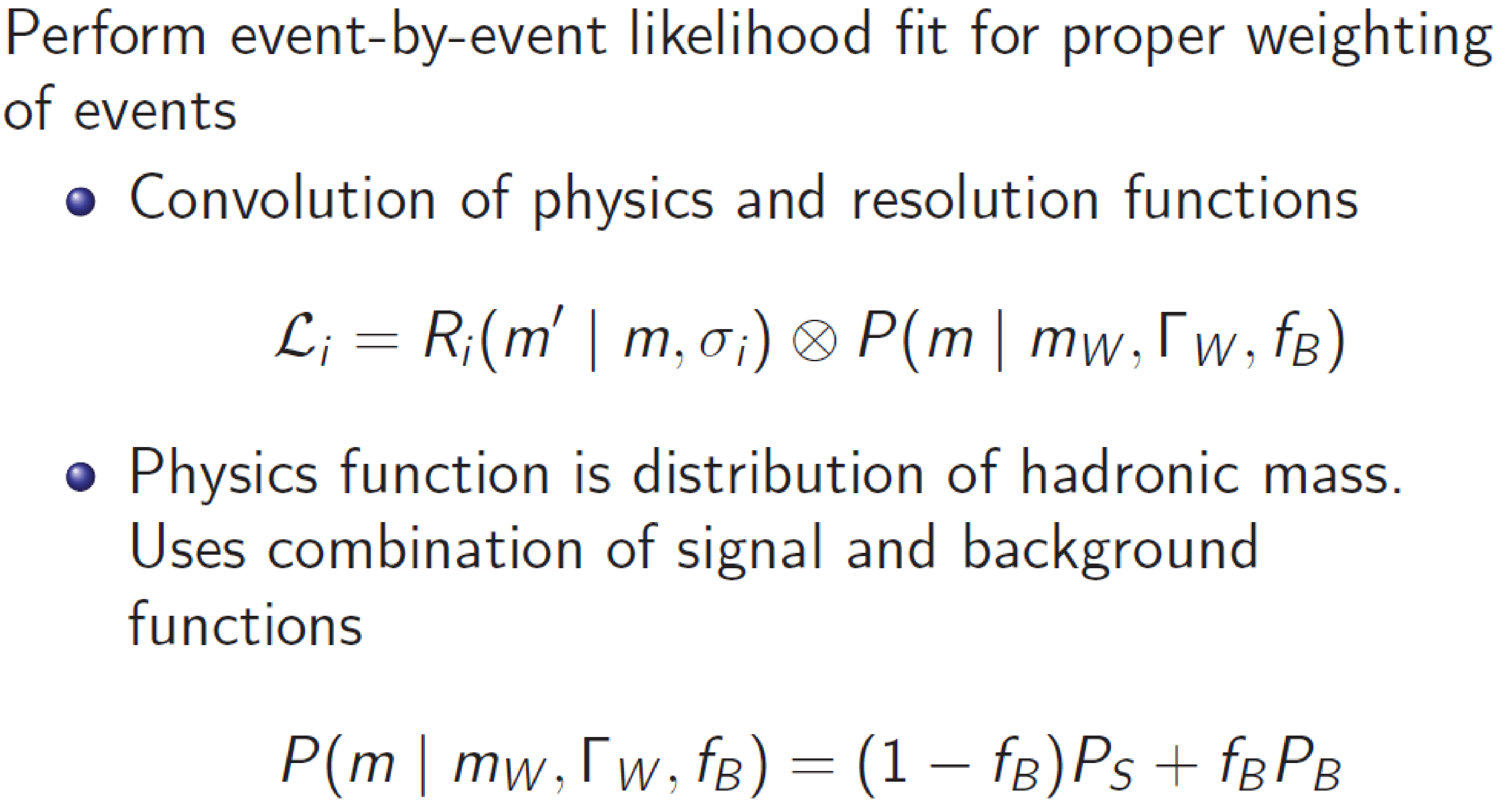
Many experimental systematics need to be included: including effects like multiple interactions ($\gamma\gamma \rightarrow$ hadrons)

$e^+e^- \to u\bar{d}e^-\bar{\nu}_e$

- CC20
- 4 non-resonant
- 3 are doubly-resonant (WW)
- Graphs 5, 8, 15 particularly important.
- Graphs 11-14 have non-resonant $u\bar{d}$



Convolution Fit



Perform event-by-event likelihood fit for proper weighting of events

- Convolution of physics and resolution functions

$$\mathcal{L}_i = R_i(m' \mid m, \sigma_i) \otimes P(m \mid m_W, \Gamma_W, f_B)$$

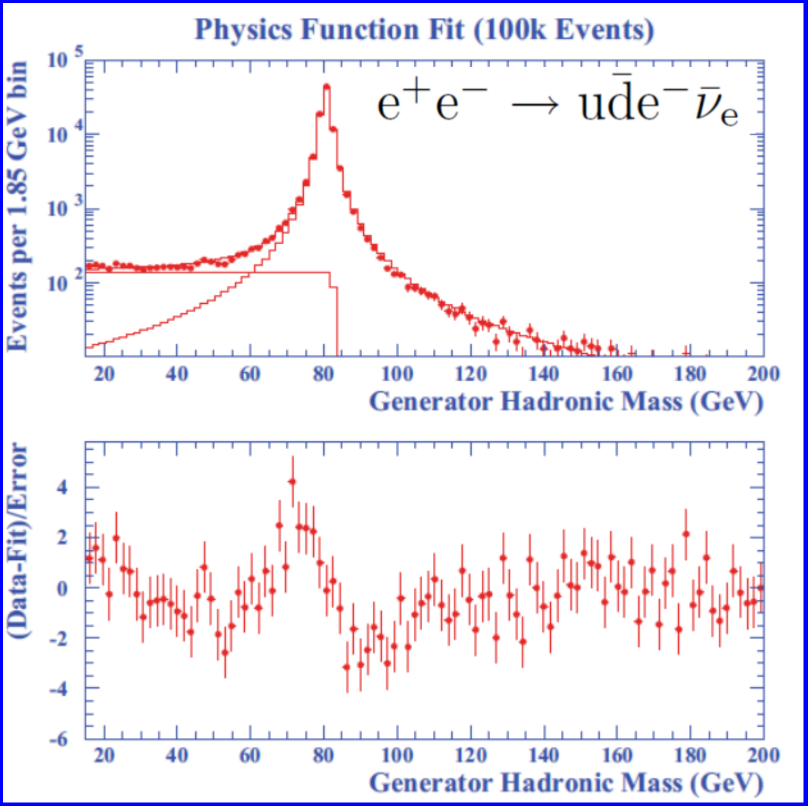
- Physics function is distribution of hadronic mass. Uses combination of signal and background functions

$$P(m \mid m_W, \Gamma_W, f_B) = (1 - f_B) P_S + f_B P_B$$

Can use the estimated hadronic mass resolution for each event (can be vastly different)

Physics Function

- Ideally, parametrize the physics function (dσ/dm_had) analytically (M_W, Γ_W as parameters).
- Example: ECM = 500 GeV
- Plot for non doubly-resonant helicity configuration (LL) for illustration.
- Physics function needs the resonance, phase-space, non-resonant background, interference.
- With this in hand it would be fairly trivial to include detector resolution in a convolution fit.



What M_W? What Γ_W? s-dependent width? Phase-space? Theoretical input welcome !
May be a problem which naturally needs MC though …

Estimated Statistical Uncertainties

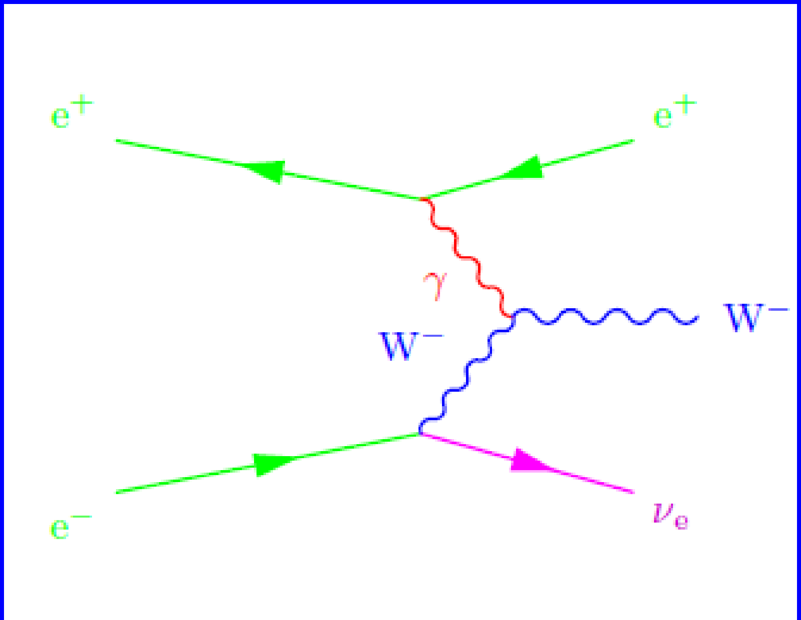
- 38 pb Single W → hadron cross-section
- Assumes 1000 fb^{-1} at 1 TeV (80,20 polarization).
- Estimate 20 M accepted W-like events
    - ILD00 jet resolution model and simple Gaussian fit (see slide 7).
        - ΔM_W (stat) = 1.0 MeV
    - With toyMC assumptions and simple fit
        - ΔM_W (stat) = 0.68 MeV
    - With toyMC assumptions and convolution fit
        - ΔM_W (stat) = 0.52 MeV
    - With toyMC assumptions and convolution fit and $\pi 0$ fitting
        - ΔM_W (stat) = 0.46 MeV
    - With perfect resolution (intrinsic width limit)
        - ΔM_W (stat) = 0.34 MeV

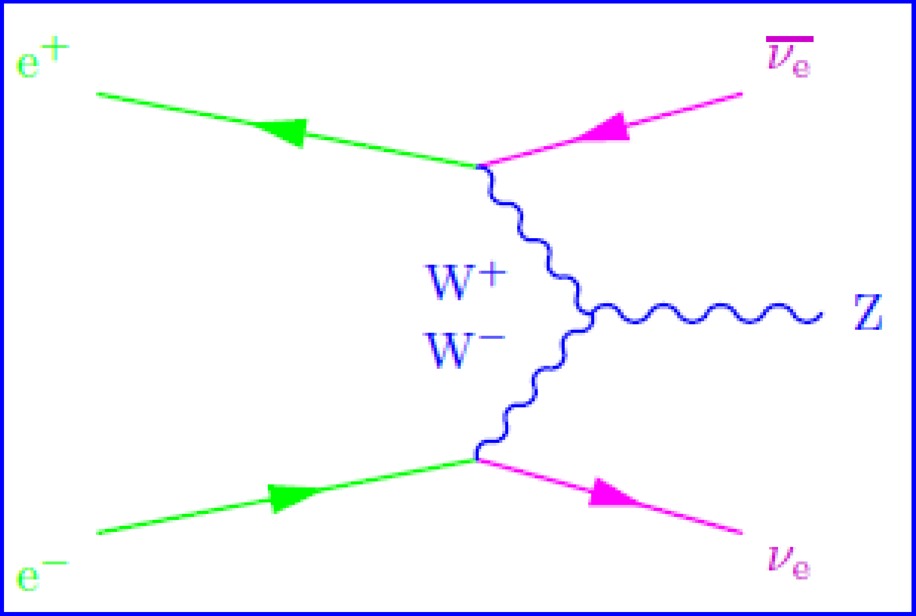
Similar Exercise Done with $\nu\nu h$

with B. van Doren

- Require h decays hadronically.
- Require no secondary neutrinos (from b, c, W, Z).
  - Likely a lepton veto in reality
- h (126 GeV) intrinsic width is very small. (4 MeV).
- For 1 TeV find following errors on m_H from convolution fits ignoring the (tiny) width, background etc.
  - 6.6 MeV : standard
  - 4.8 MeV: with π^0 fitting
  - 8.7 MeV: allow neutral hadron energy scale to float.

Z Calibration Methods



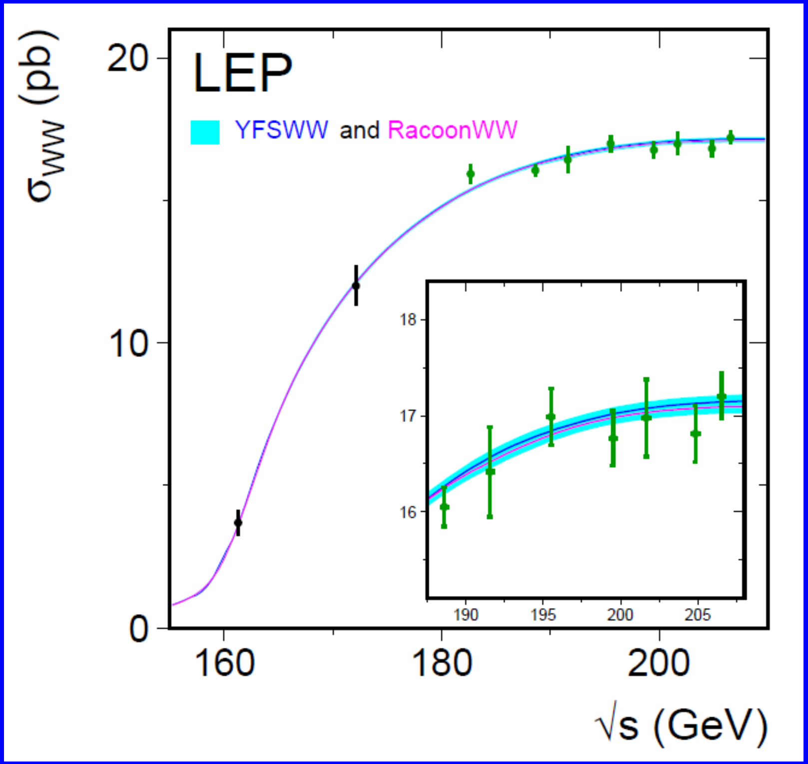


$(\Delta M/M)_Z = 2.3\times 10^{-5}$

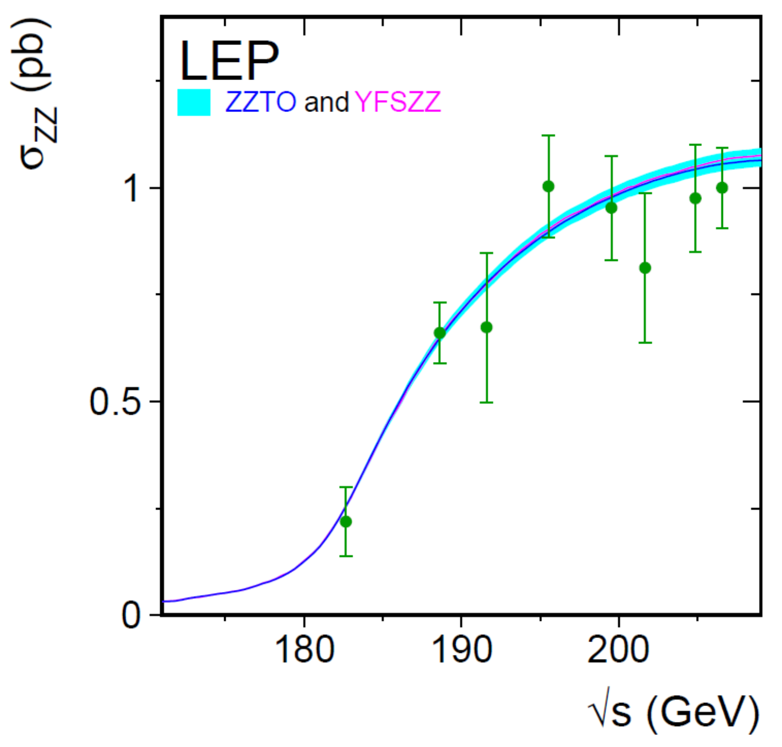
Zνν.
Effective cross-section for final states with Z → hadrons are around 1.3 pb at 1 TeV.

Also Zee. Cross-sections huge (20 pb) when including eγ -> eZ. Need to check acceptance.

WW and ZZ



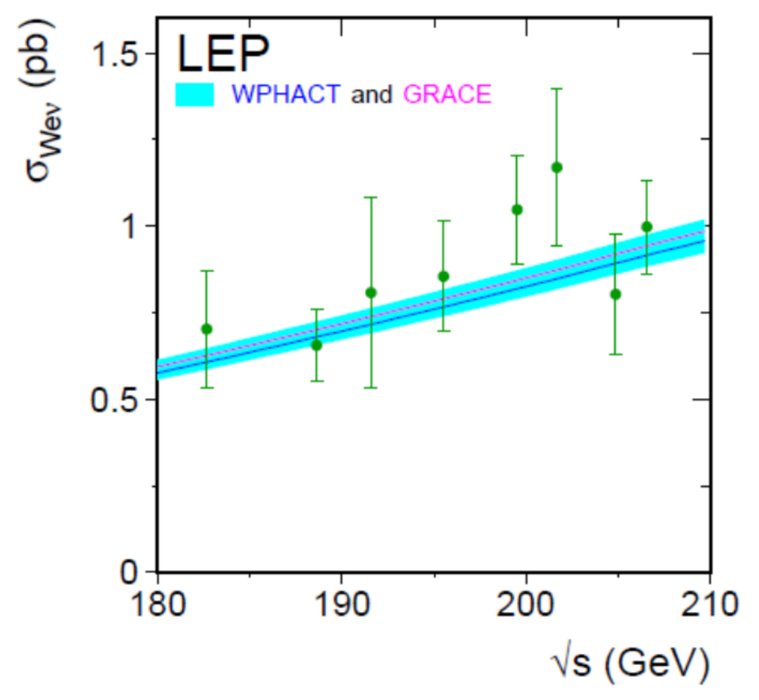
WW

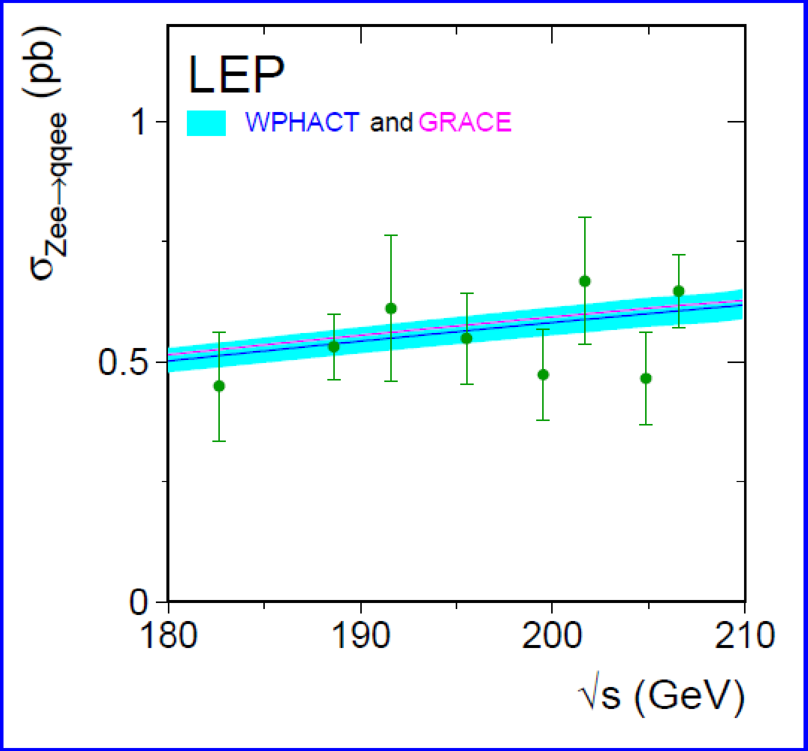


ZZ

At ILC can potentially use ZZ to control beam energy systematics in WW production using PDG Z mass (LEP). ZZ cross-sections lower by factor of 25 (15 and up to 2 for polarization…)

4f processes with resonant W, Z





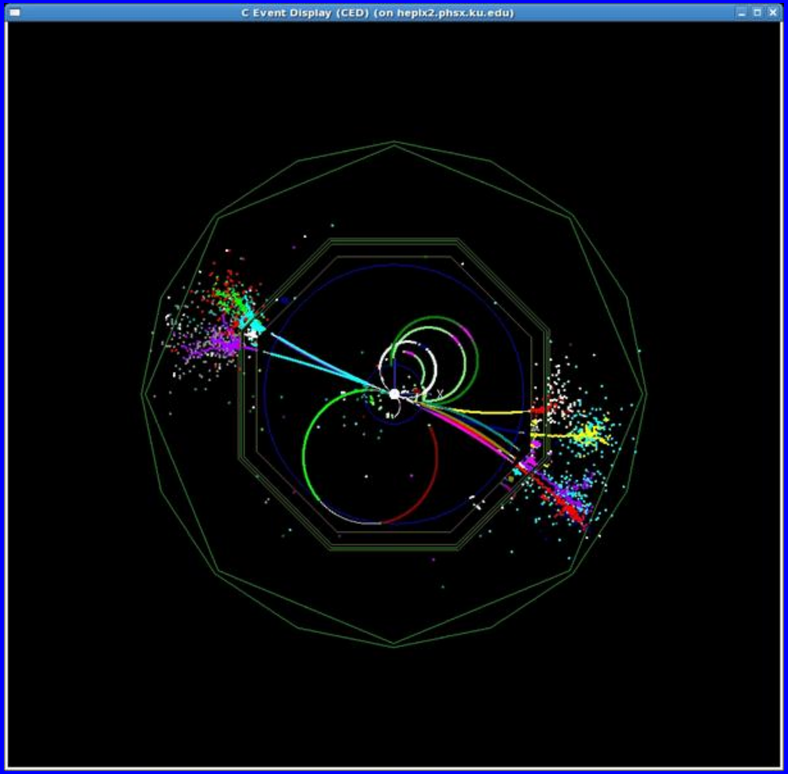
Wev

Zee

Experimentally feasible to get similar in-situ Z statistics to W.

Jet Energy Scale Particle-by-Particle

- One can also consider calibrating absolutely given the m_Z uncertainty.
- Need
  - Tracker p-scale
  - EM Cal E-scale
  - Calorimeter neutral-hadron energy scale
- Can use precisely known particle scales: Λ^0, π^0, ϕ, Σ.
- Also fragmentation errors (K_L, n)



Conclusions

- Many ways to measure m_W at a lepton collider like ILC with modern detectors.
- Statistics is not the issue.
  - Worth doing this well and with different methods.
- Plausible approaches to exploit 1 MeV statistical precision likely rely on the known m_Z
  - Setting an error scale of 2 MeV
- Can also potentially measure the X(125) mass to the 10 MeV level at ILC with similar technique.
- The next question will be can we do better on measuring m_Z ?
- Bottom-line:
- It is reasonable to expect a 5 MeV error on m_W from ILC.
- It is not unreasonable to target a 2.5 MeV error – needs work!

ILC References

- http://www.linearcollider.org/physics-detectors/WWS
- ILC Reference Design Report 2007 has links to
  - i) Physics at the ILC (Vol II)
  - ii) Detectors (Vol IV).
- Detector Letters of Intent 2009. (ILD and SiD).
- Currently, ILC TDR report is being finalized with Documents (DBDs) for the detectors.
- Visit/subscribe to http://newsline.linearcollider.org/ to find out more and stay informed.

Backup

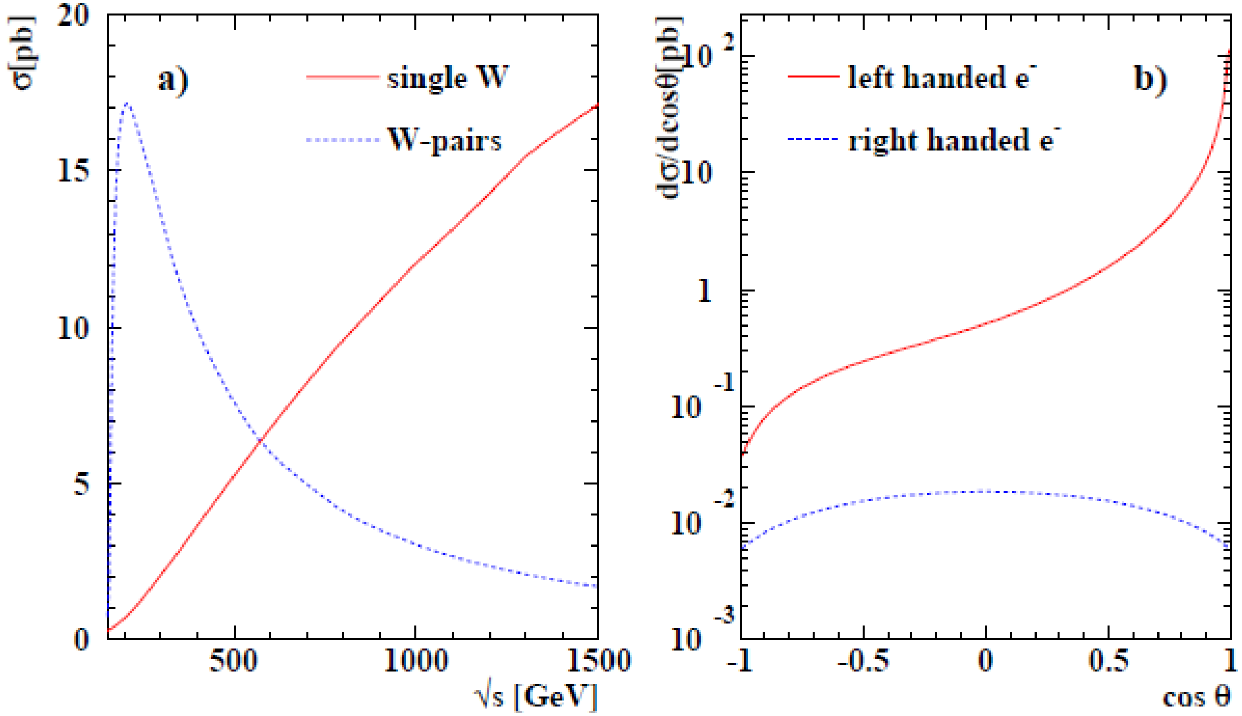


Figure 5.1.3: *a): Total cross section for single W [1] and W pair production [2] as a function of the centre of mass energy. b): Differential cross section for W-pair production for different beam polarisation.*

W Mass from Di-lepton Events

Eur.Phys.J.C.26 (2003) 321-330

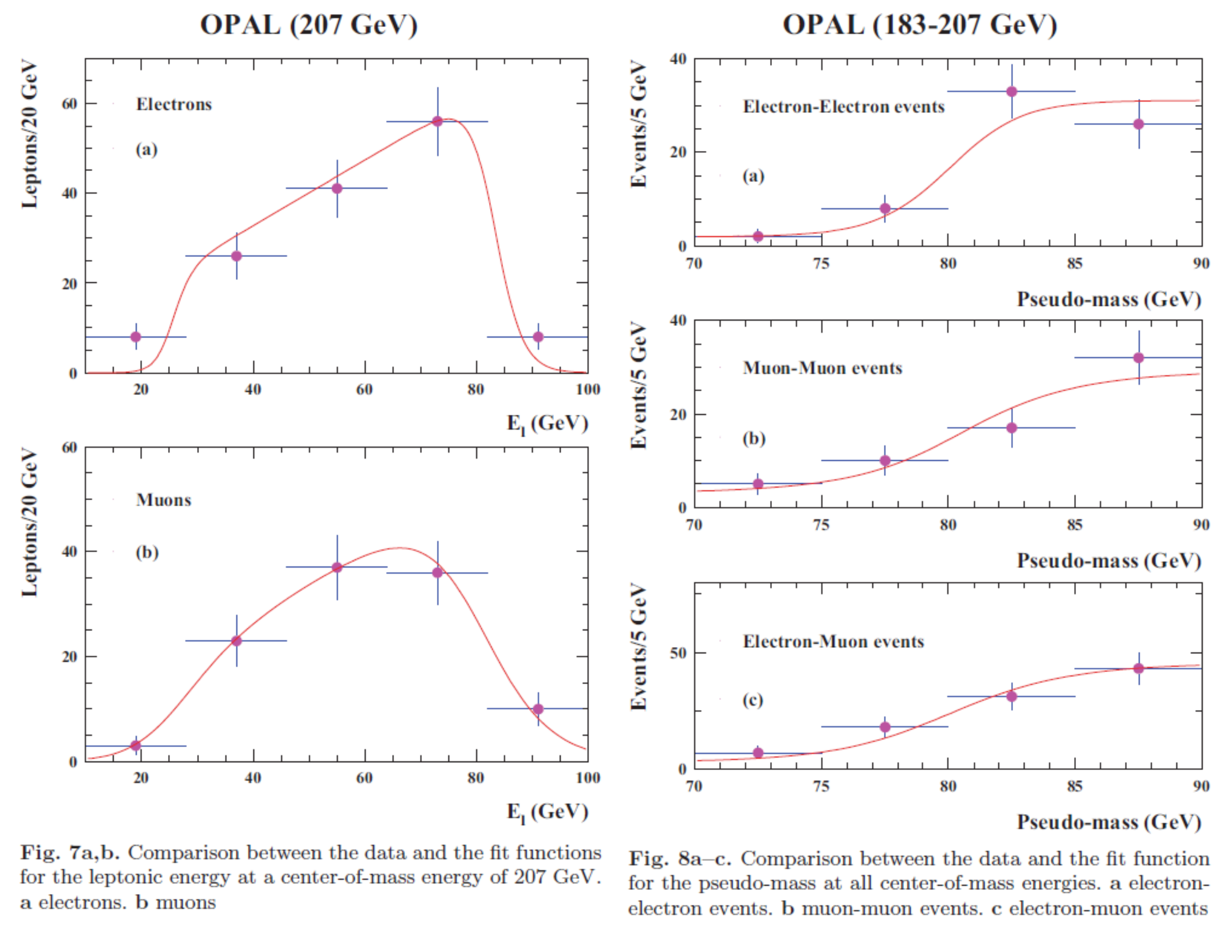
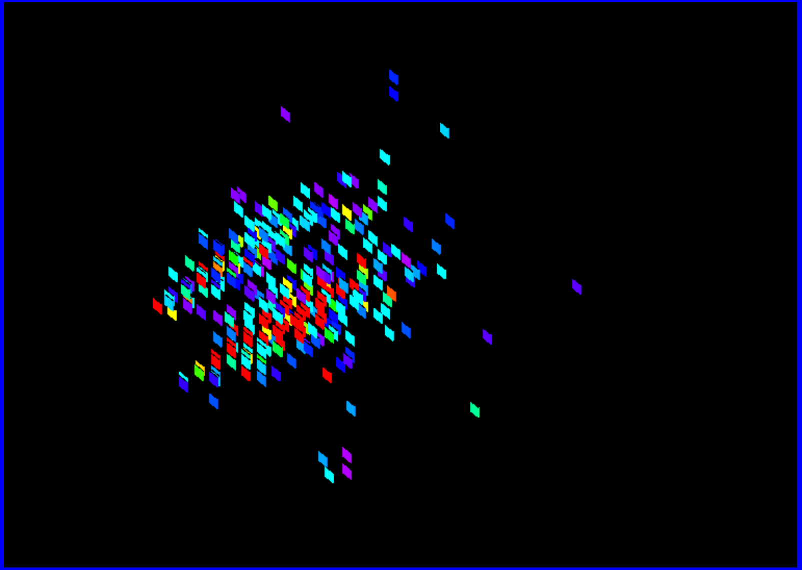
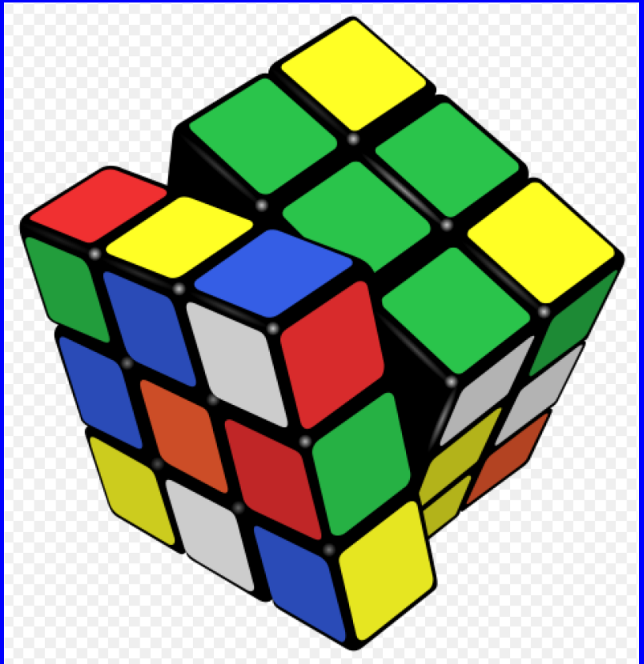


Fig. 7a,b. Comparison between the data and the fit functions for the leptonic energy at a center-of-mass energy of 207 GeV. **a** electrons. **b** muons

Fig. 8a–c. Comparison between the data and the fit function for the pseudo-mass at all center-of-mass energies. **a** electron-electron events. **b** muon-muon events. **c** electron-muon events

Imaging Calorimeters



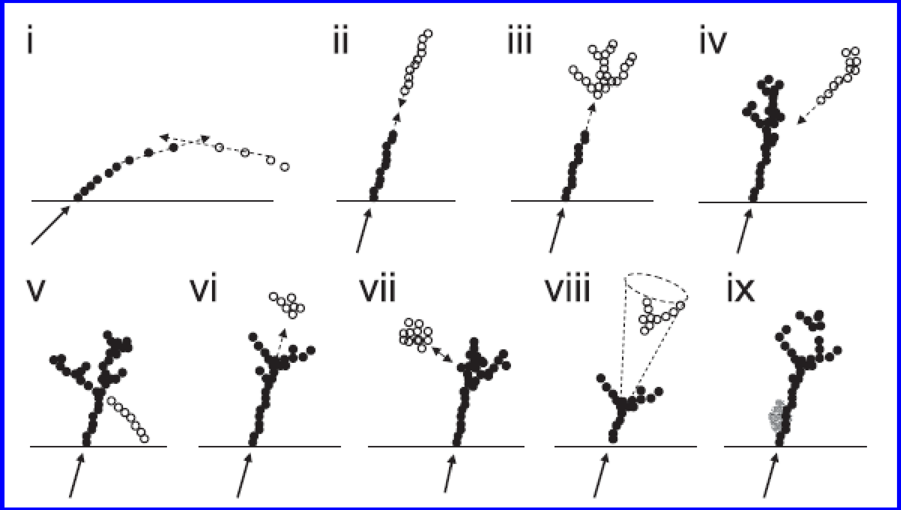


- Standard cell-sizes under discussion
- ECAL : 5mm X 5mm X 30 layers
  - 10,000 more channels than OPAL
- HCAL : 10 mm X 10 mm X 50 layers
- Immense amount of information.
- Potentially (E, time) for each volume pixel.

Particle Flow Algorithms

- Highly non-trivial.
  - Many groups have worked in this area
  - To date, PandoraPFA developed primarily by M. Thomson for ILD and using the Mokka/Marlin framework and now rewritten by J. Marshall has set the performance bar.

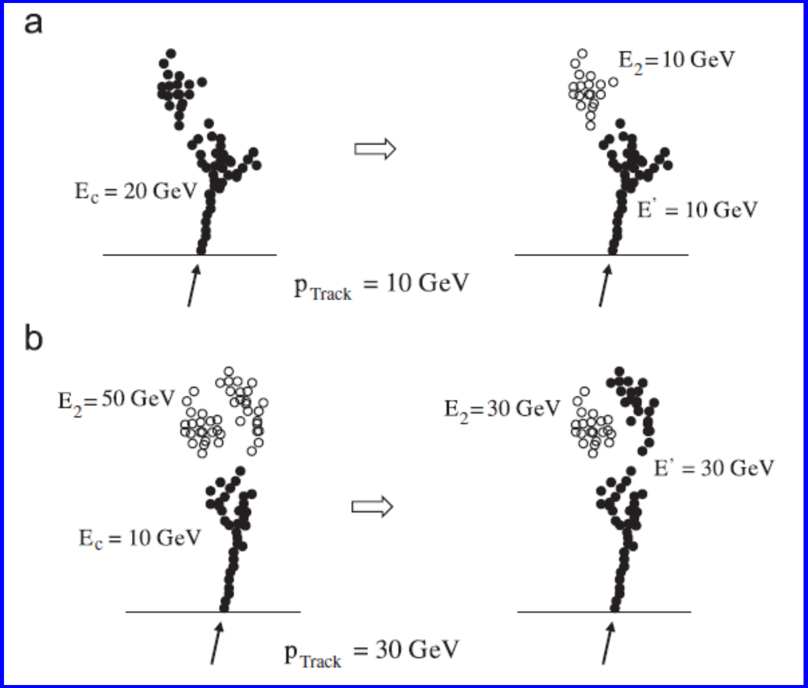
Depends at basic level on calorimeter clustering.



Topological clustering

M. Thomson, NIM A611 (2009) 25.

Reclustering



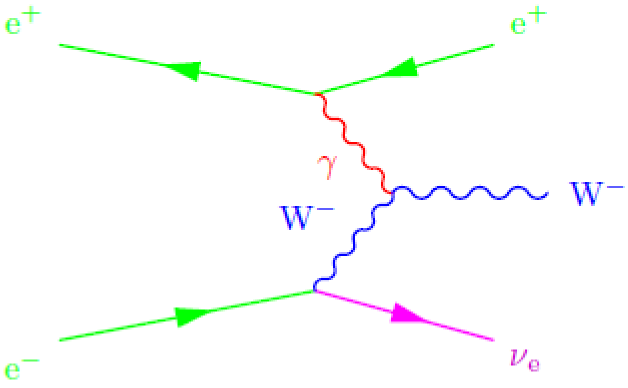
Use track-momentum – cluster-energy consistency to drive re-partitioning of energy.

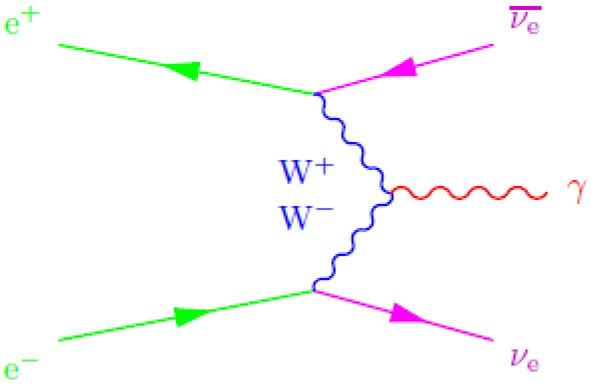
Beam Polarization Measurement Using Single Bosons with Missing Energy

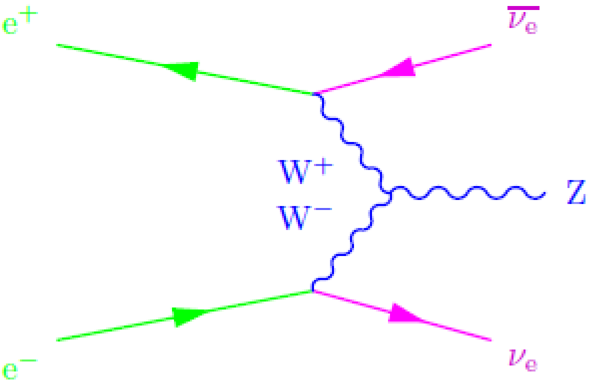
Graham W. Wilson

University of Kansas

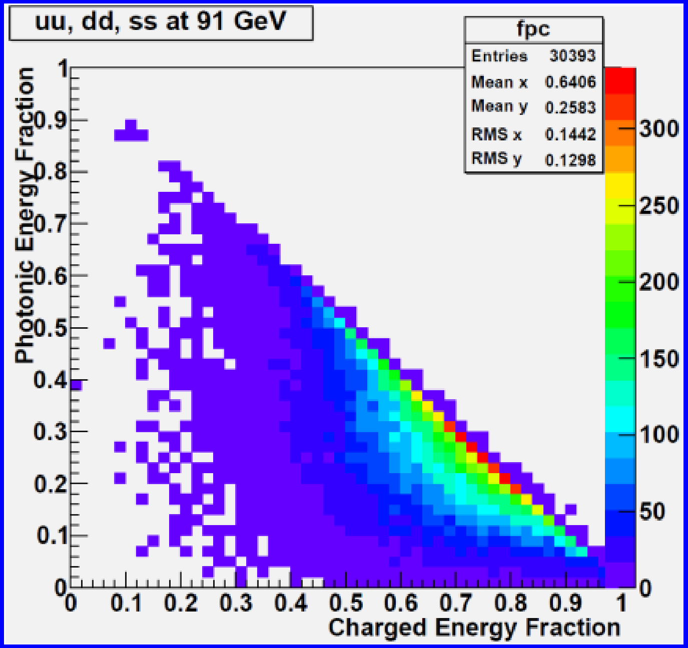
October 23rd 2012

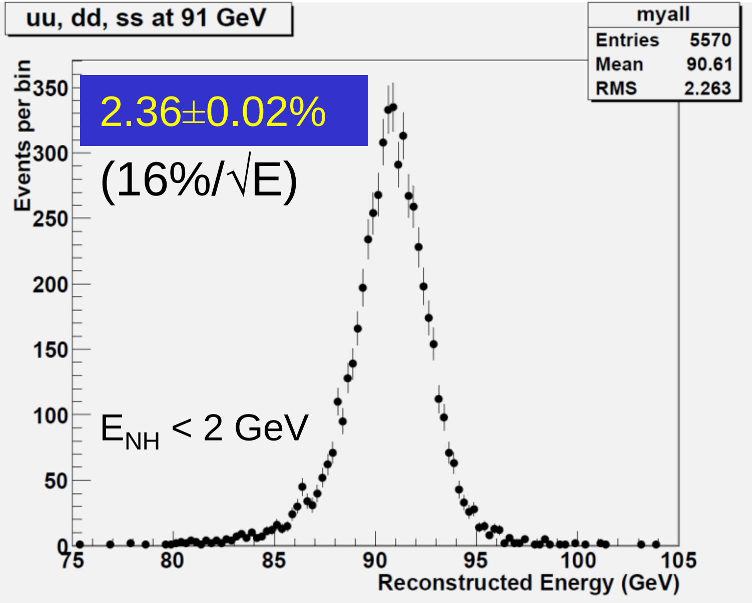






Event-Specific Resolution

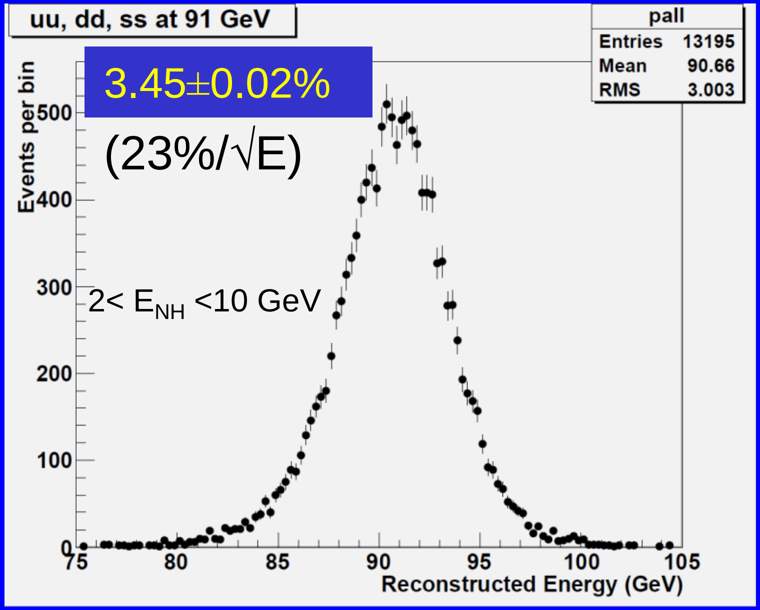




2.36±0.02%

(16%/√E)

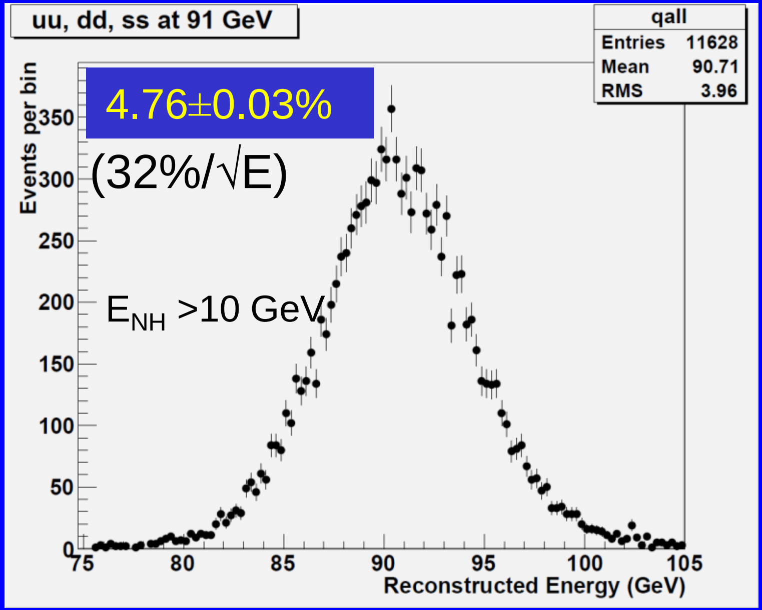
E_{NH} < 2 GeV



3.45±0.02%

(23%/√E)

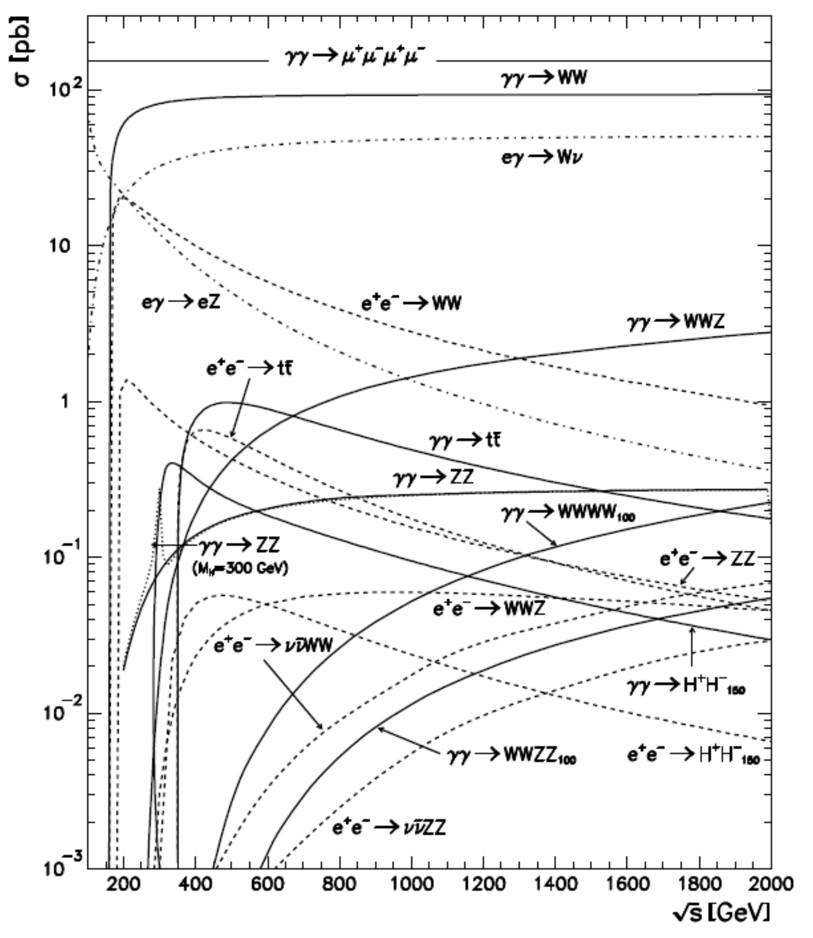
2< E_{NH} <10 GeV



4.76±0.03%

(32%/√E)

E_{NH} >10 GeV


σ [pb]
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
200
400
600
800
1000
1200
1400
1600
1800
2000
$\sqrt{s}$ [GeV]
$\gamma\gamma \rightarrow \mu^+\mu^-\mu^+\mu^-$
$\gamma\gamma \rightarrow WW$
$e\gamma \rightarrow W\nu$
$e\gamma \rightarrow eZ$
$e^+e^- \rightarrow WW$
$\gamma\gamma \rightarrow WWZ$
$e^+e^- \rightarrow t\bar{t}$
$\gamma\gamma \rightarrow t\bar{t}$
$\gamma\gamma \rightarrow ZZ$
$\gamma\gamma \rightarrow WWWW_{100}$
$\gamma\gamma \rightarrow ZZ$
(M_H=300 GeV)
$e^+e^- \rightarrow ZZ$
$e^+e^- \rightarrow WWZ$
$e^+e^- \rightarrow \nu\bar{\nu}WW$
$\gamma\gamma \rightarrow H^+H^-_{150}$
$\gamma\gamma \rightarrow WWZZ_{100}$
$e^+e^- \rightarrow H^+H^-_{150}$
$e^+e^- \rightarrow \nu\bar{\nu}ZZ$