Question: Hadron Colliders have now surpassed LEP in m_W Precision. Can ILC be competitive in the LHC era?

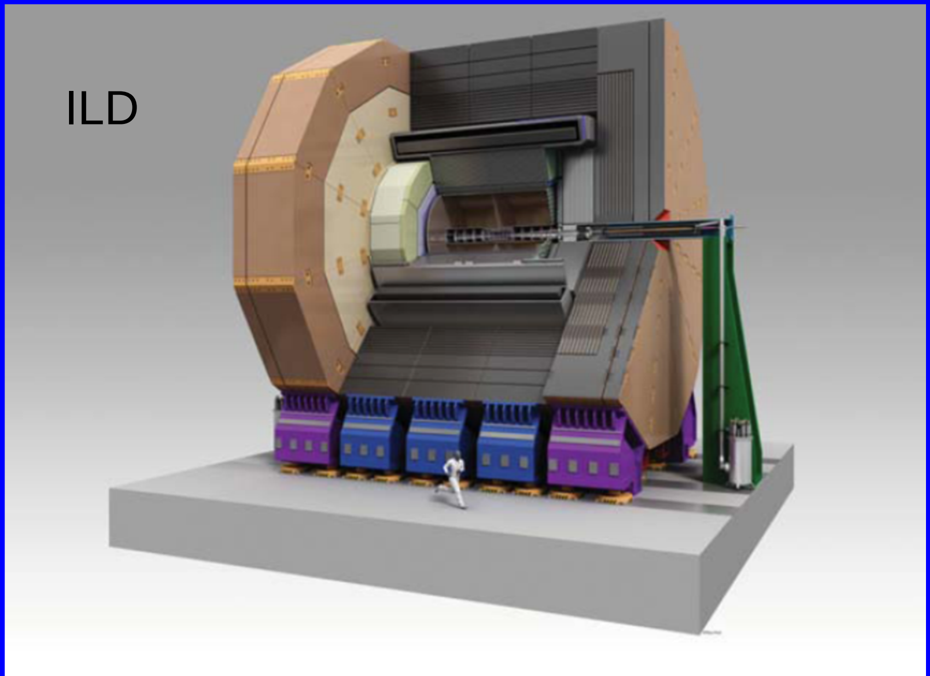
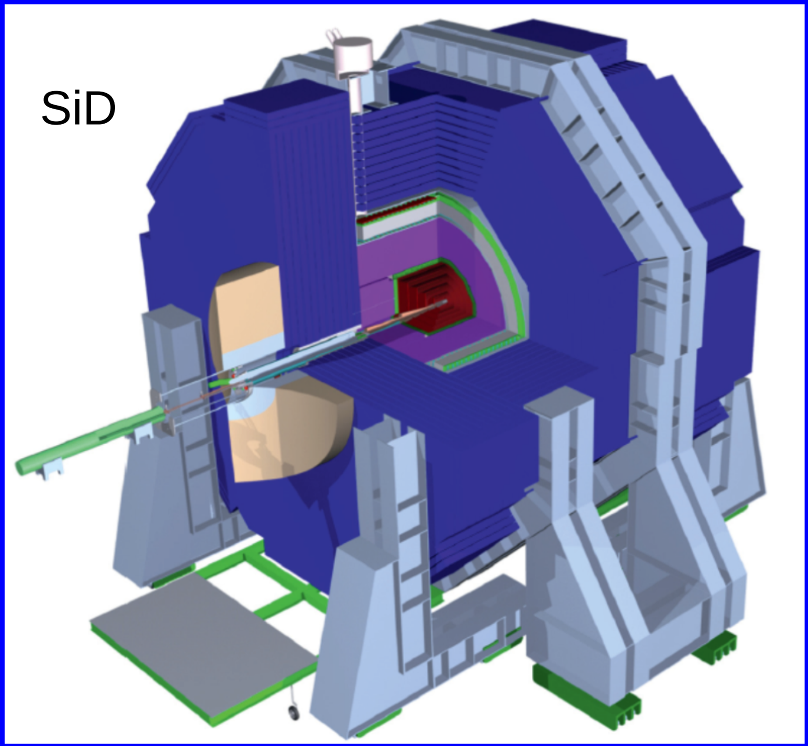


Figure 1.1.1: View of the ILD detector concept.



Graham W. Wilson, University of Kansas,
Snowmass CSS2013, Minneapolis, August 1st 2013

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

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

3 fb^{-1}

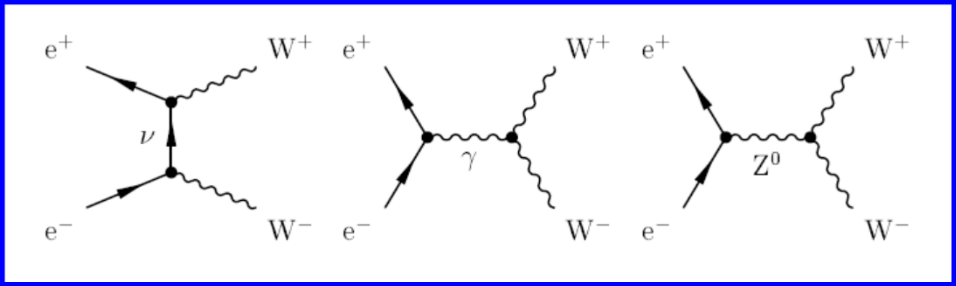
VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
91.1876 ± 0.0021 OUR FIT					
91.1852 ± 0.0030	4.57M	[1] ABBIENDI	01A	OPAL	E^{ee}_{cm} = 88–94 GeV
91.1863 ± 0.0028	4.08M	[2] ABREU	00F	DLPH	E^{ee}_{cm} = 88–94 GeV
91.1898 ± 0.0031	3.96M	[3] ACCIARRI	00C	L3	E^{ee}_{cm} = 88–94 GeV
91.1885 ± 0.0031	4.57M	[4]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

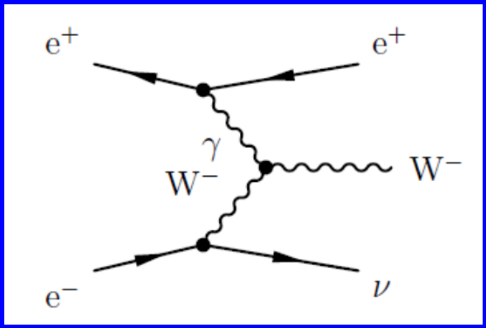
$\Delta M/M = 2.3\times10^{-5}$

0.4 fb^{-1}

m_W is currently a factor of 8 less precise than m_Z

W Production in e+e-

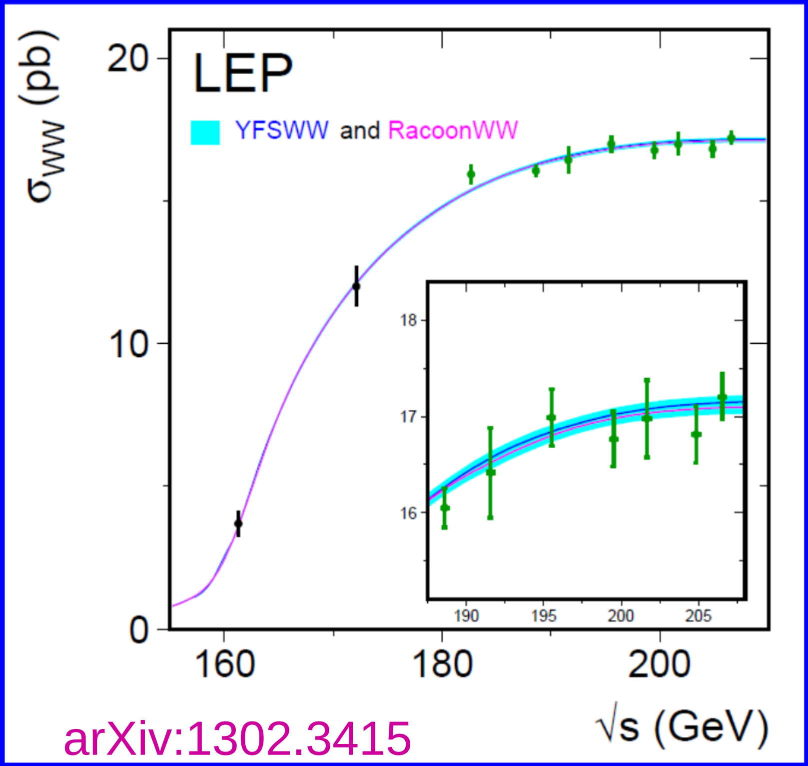


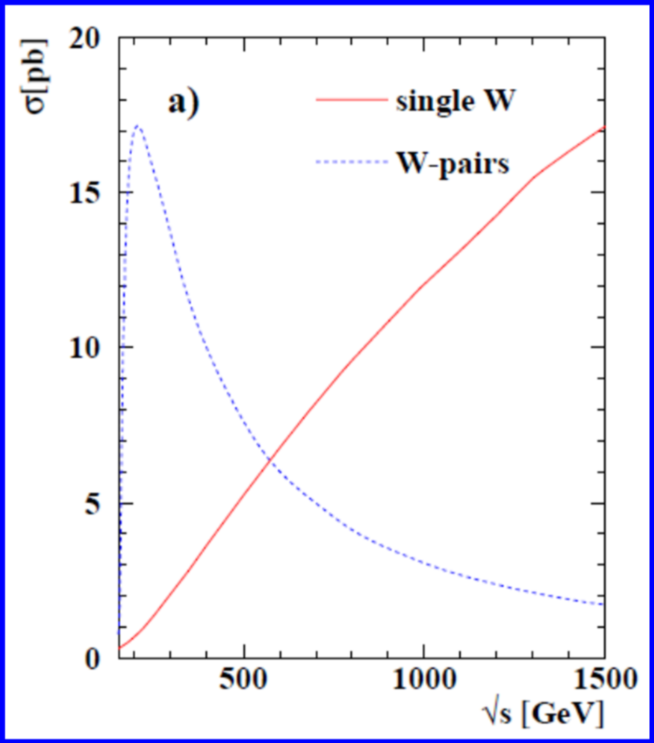


etc ..

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

e+e- $\rightarrow$ W e ν





ILC

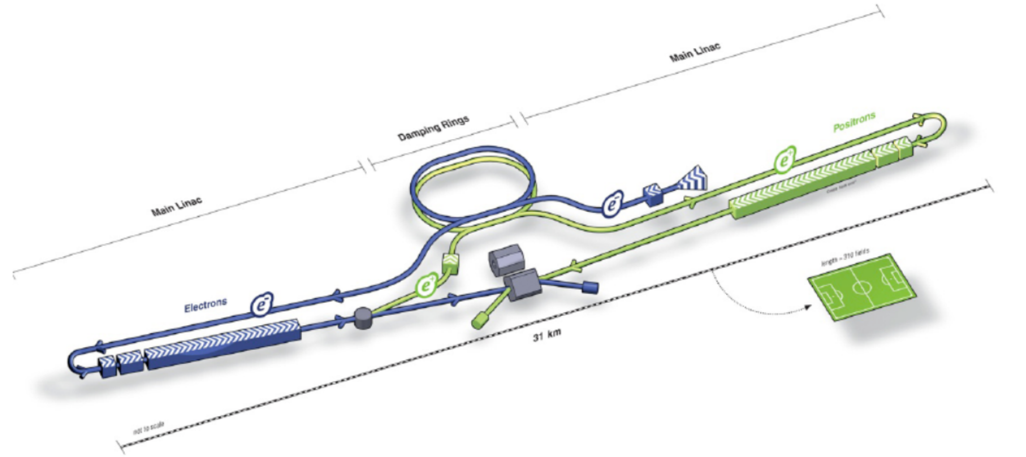


Figure 2: Layout of the ILC accelerator systems.

$\sqrt{s}$ (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

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

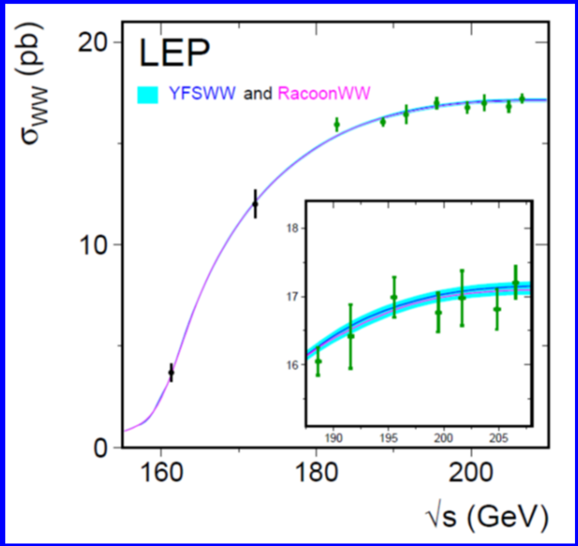
In contrast to circular machines this is not supposed to be in exchange for less luminosity ….

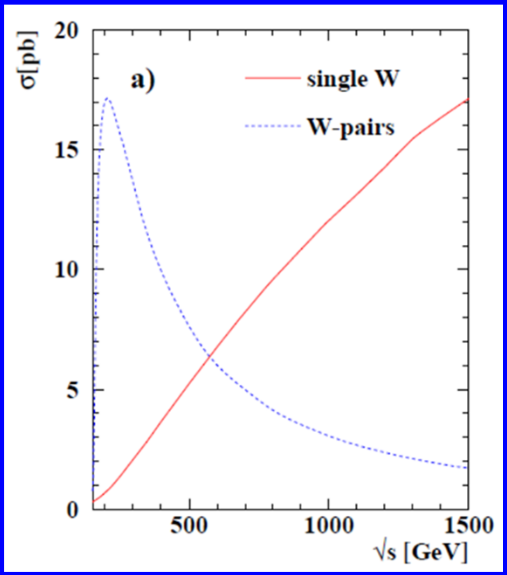
My take on a possible run-plan factoring in L capabilities at each $\sqrt{s}$. Can be further upgraded.

See ILC TDR (available in Humphrey) for more details

W Mass Measurement Strategies

- W+W-
  - 1. Threshold Scan ($\sigma \sim \beta/s$)
    - Can use all WW decay modes
  - 2. Kinematic Reconstruction (qq e nu and qq mu nu)
    - Apply kinematic constraints
- W e ν (+ WW)
  - 3. Directly measure the hadronic mass in $W \to q\,q'$ decays.
    - Can use WW -> q q tau nu too





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

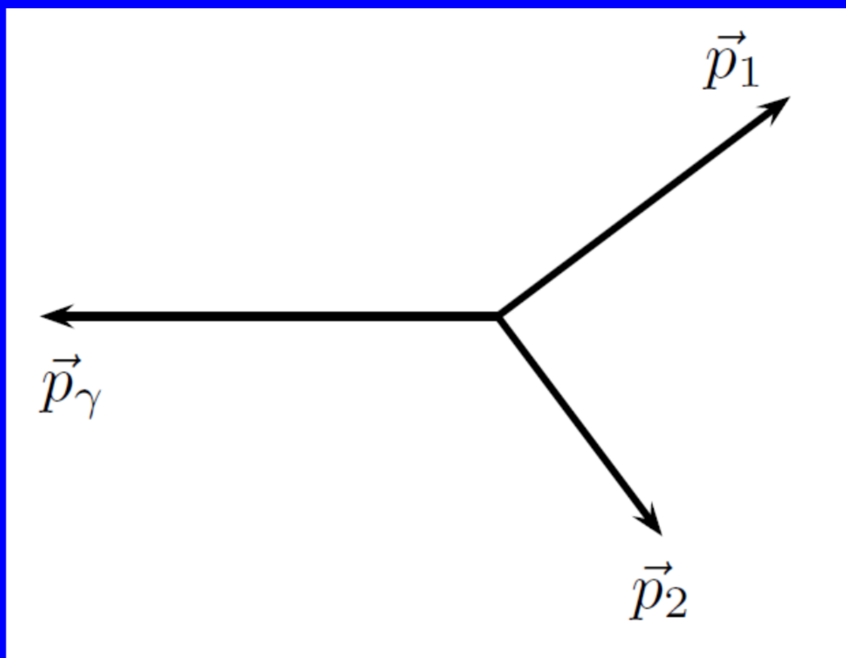
Method 3 is novel (and challenging), very complementary systematics to 1 and 2 if the experimental challenges can be met.

ILC Experimentation Features

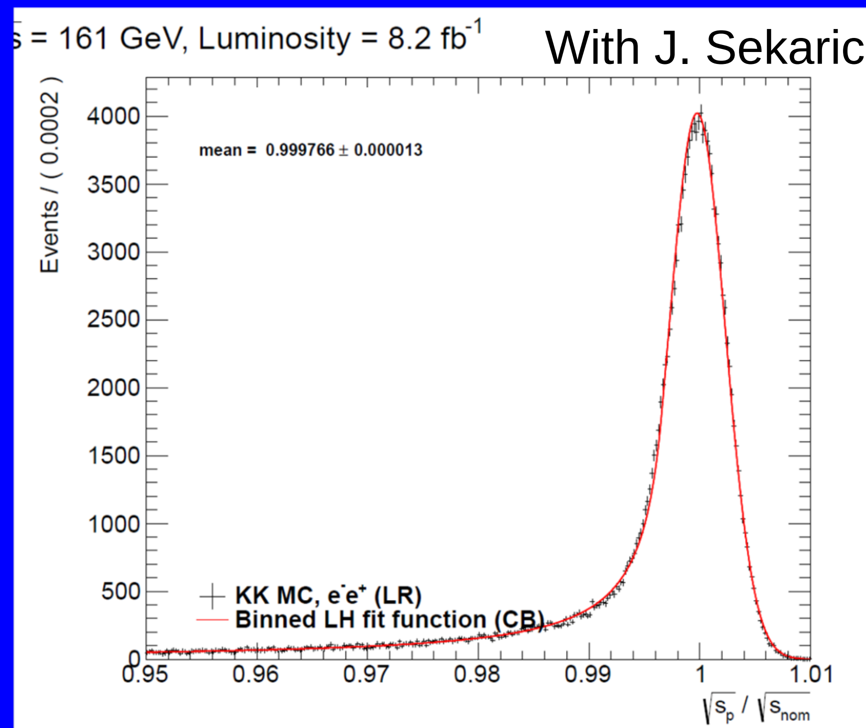
- No trigger necessary.
- Few 100 ns between crossings.
- “Democratic” signal and background.
- Very high efficiency (0.1% errors)
- Absolute luminosity (0.1% errors)
- Initial state beam parameters under good control.
- Initial state radiation – correctable.
- Events reconstructible particle by particle.
- All W’s potentially useful.
- Essentially no pileup.

"New" In-Situ Beam Energy Method

e+e- $\rightarrow \mu\mu(\gamma)$



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



ILC detector momentum resolution (0.15%), gives beam energy to better than 5 ppm statistical. Momentum scale to 10 ppm => 0.8 MeV beam energy error projected on mW. (J/psi)

Beam Energy Uncertainty should be controlled for Methods 1 and 2 for $\sqrt{s}$ <= 500 GeV

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

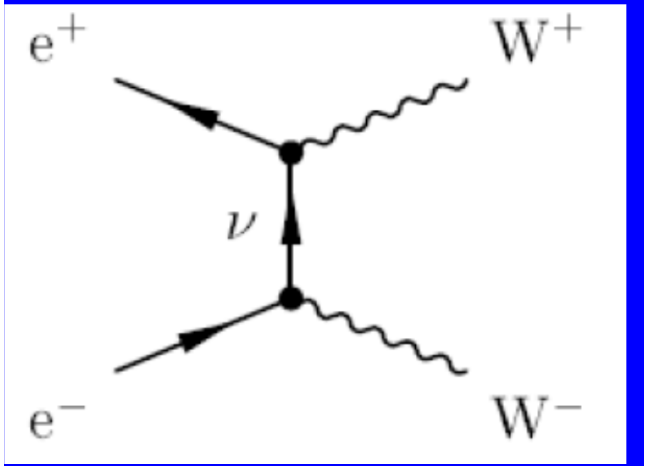
$$\mu = \sigma(P_{\mathrm{e}^-}, P_{\mathrm{e}^+})\,\mathcal{L}$$

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.

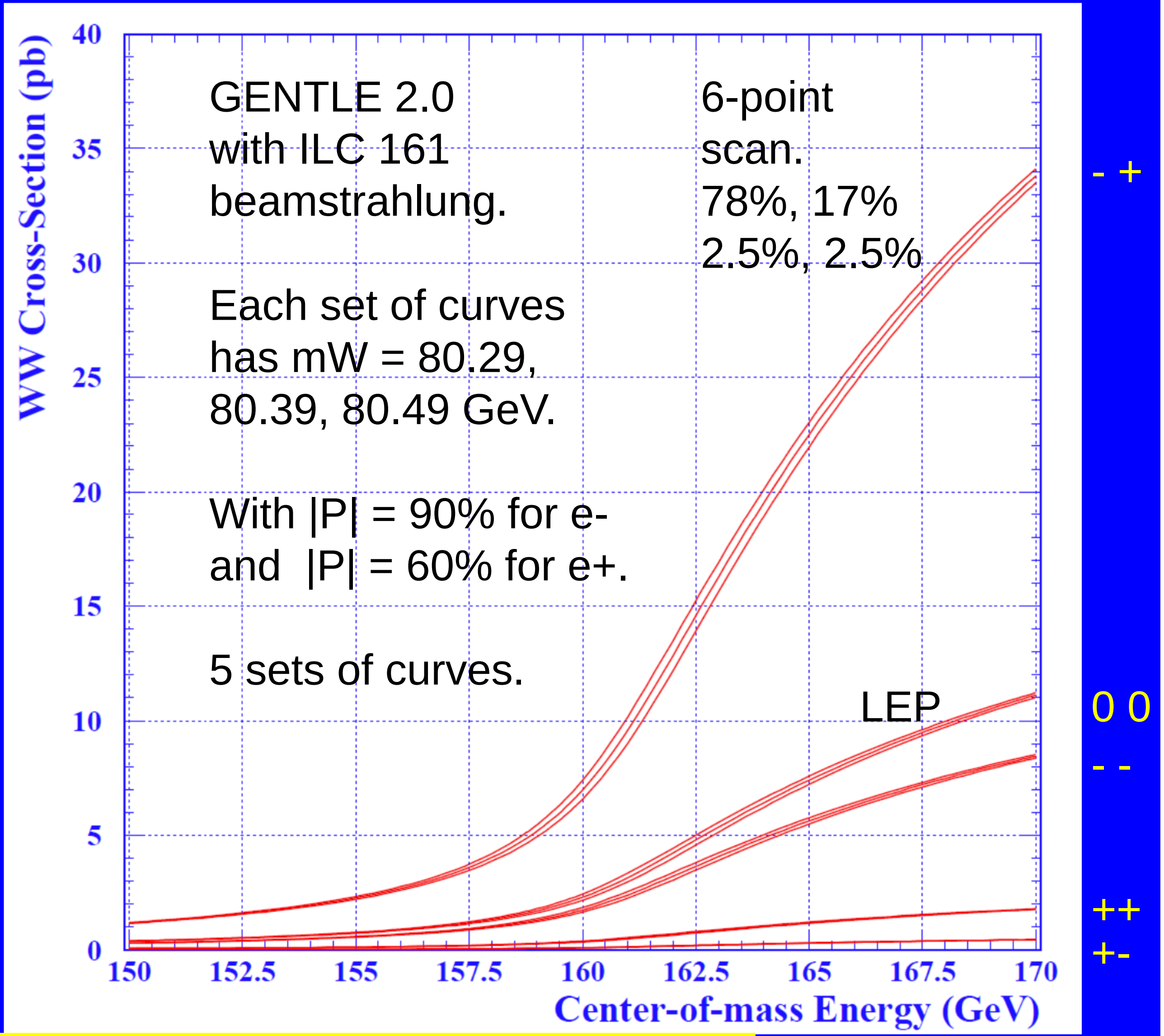
Polarized Threshold Scan



Use (-+) helicity combination of e- and e+ to enhance WW.

Use (+-) helicity to suppress WW and measure background.

Use (--) and (++) to control polarization (also use 150 pb qq events)



Experimentally very robust. Fit for eff, pol, bkg, lumi

1. Polarized Threshold Scan
2. Kinematic Reconstruction
3. Hadronic Mass

Method 1: Statistics limited.

Method 2: With up to 1000 the LEP statistics and much better detectors. Can target factor of 10 reduction in systematics.

Method 3: Depends on di-jet mass scale. Plenty Z's for 3 MeV.

1

ΔM_W [MeV]	LEP2	ILC	ILC
$\sqrt{s}$ [GeV]	161	161	161
$\mathcal{L}$ [fb^{-1}]	0.040	100	480
$P(e^-)$ [%]	0	90	90
$P(e^+)$ [%]	0	60	60
statistics	200	2.4	1.1
background		2.0	0.9
efficiency		1.2	0.9
luminosity		1.8	1.2
polarization		0.9	0.4
systematics	70	3.0	1.6
experimental total	210	3.9	1.9
beam energy	13	0.8	0.8
theory	-	(1.0)	(1.0)
total	210	4.1	2.3

(2)

ΔM_W [MeV]	LEP2	ILC	ILC	ILC
$\sqrt{s}$ [GeV]	172-209	250	350	500
$\mathcal{L}$ [fb^{-1}]	3.0	500	350	1000
$P(e^-)$ [%]	0	80	80	80
$P(e^+)$ [%]	0	30	30	30
beam energy	9	0.8	1.1	1.6
luminosity spectrum	N/A	1.0	1.4	2.0
hadronization	13	1.3	1.3	1.3
radiative corrections	8	1.2	1.5	1.8
detector effects	10	1.0	1.0	1.0
other systematics	3	0.3	0.3	0.3
total systematics	21	2.4	2.9	3.5
statistical	30	1.5	2.1	1.8
total	36	2.8	3.6	3.9

(3)

ΔM_W [MeV]	ILC	ILC	ILC	ILC
$\sqrt{s}$ [GeV]	250	350	500	1000
$\mathcal{L}$ [fb^{-1}]	500	350	1000	2000
$P(e^-)$ [%]	80	80	80	80
$P(e^+)$ [%]	30	30	30	30
jet energy scale	3.0	3.0	3.0	3.0
hadronization	1.5	1.5	1.5	1.5
pileup	0.5	0.7	1.0	2.0
total systematics	3.4	3.4	3.5	3.9
statistical	1.5	1.5	1.0	0.5
total	3.7	3.7	3.6	3.9

Summary

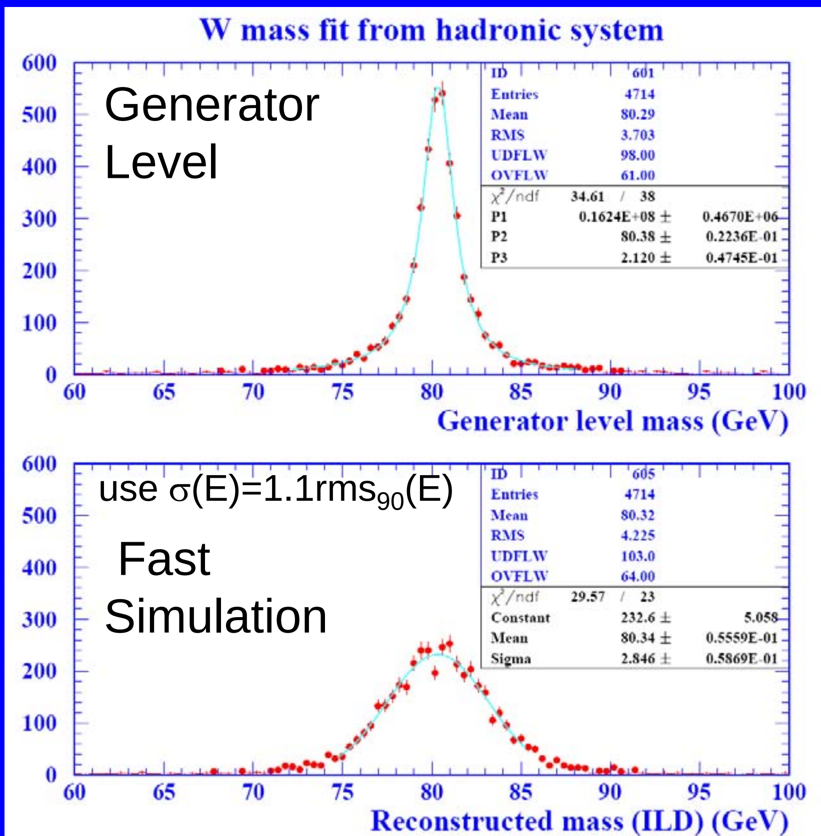
- Current Tevatron combined uncertainty: 16 MeV
- Final Tevatron and first LHC measurements still to come.
- The ILC program (of order 3000 fb^{-1}) can make efficient use of W's.
- Three complementary methods
  - Each currently targets 2-4 MeV
  - Much better precision possible if systematics can be controlled better especially for methods 2 and 3.

Backup Slides

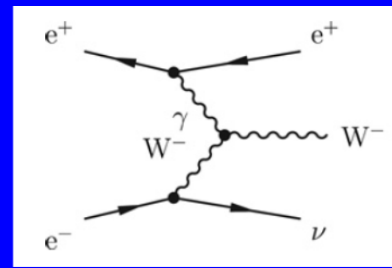
Can one dream of measuring m_W to 1 MeV ?

(and not get locked up ;-))

Single W study at $\sqrt{s}$ = 1TeV (e+e-)



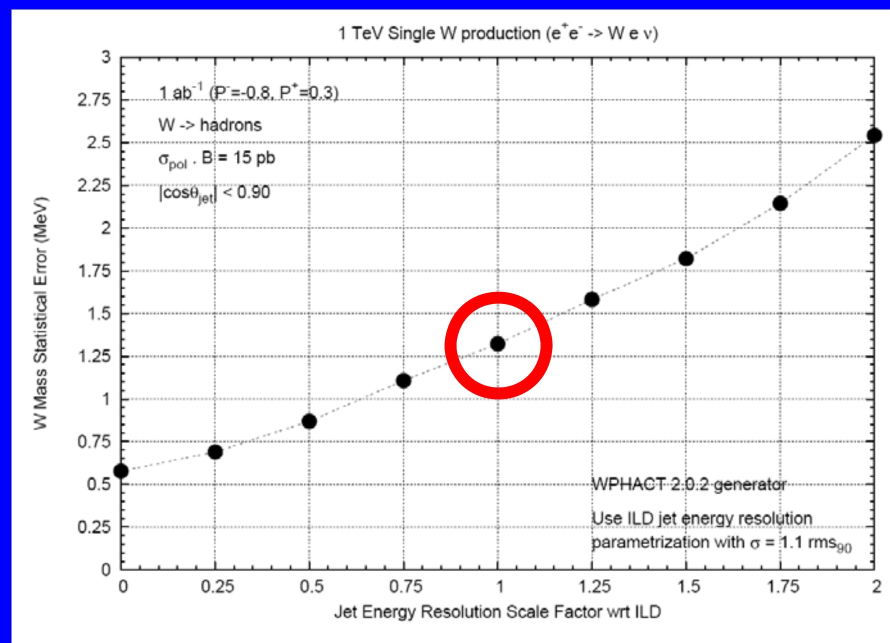
=> Further E_{jet} resolution improvement very desirable



$W \rightarrow q\ q$

(jets are not so energetic)

Is this useful for physics? Example m_W.

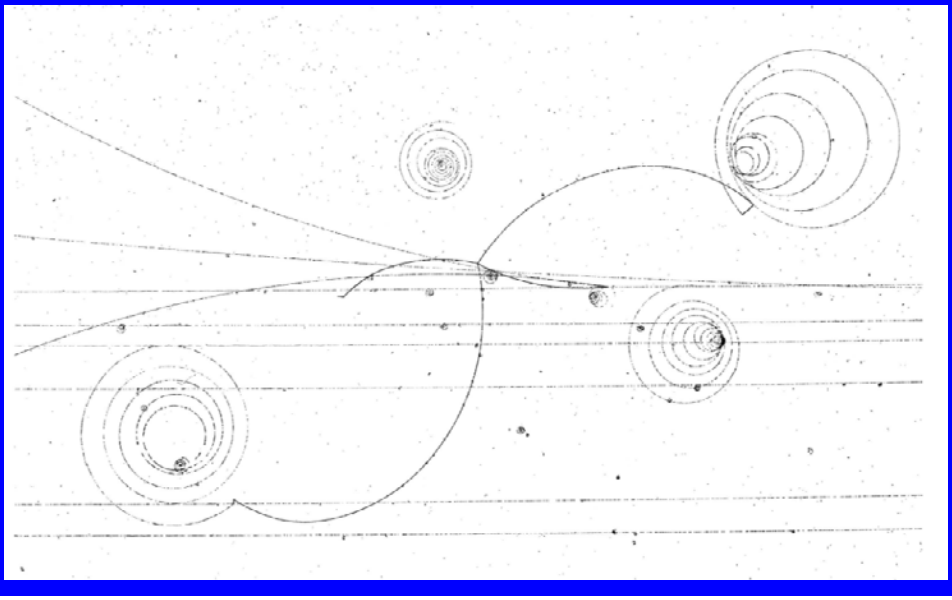


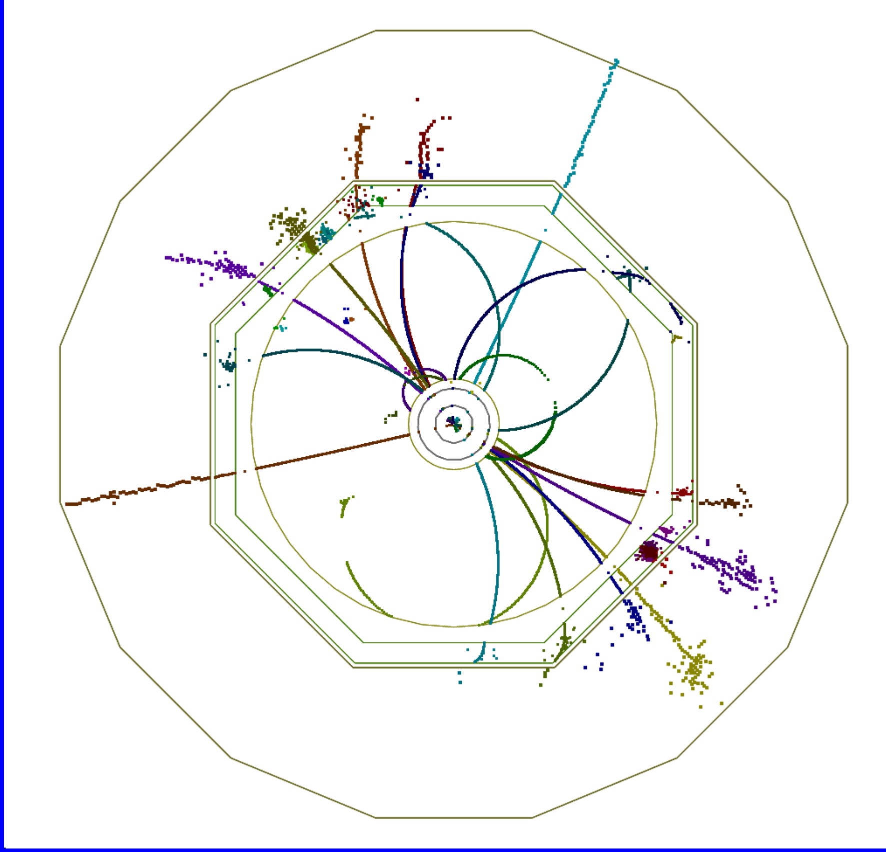
Potentially very useful! (Especially, if the really challenging requirements on jet energy scale and calibration can be met!)

Bubble Chamber

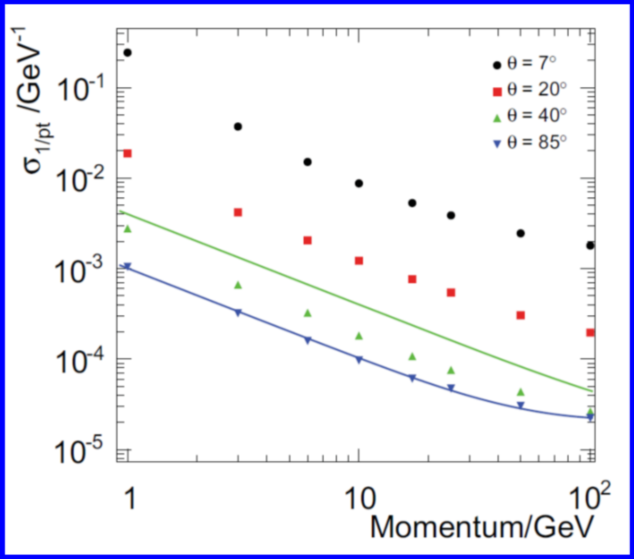
The vision is to do the best possible physics at the linear collider, by reconstructing as far as possible every single piece of each event.

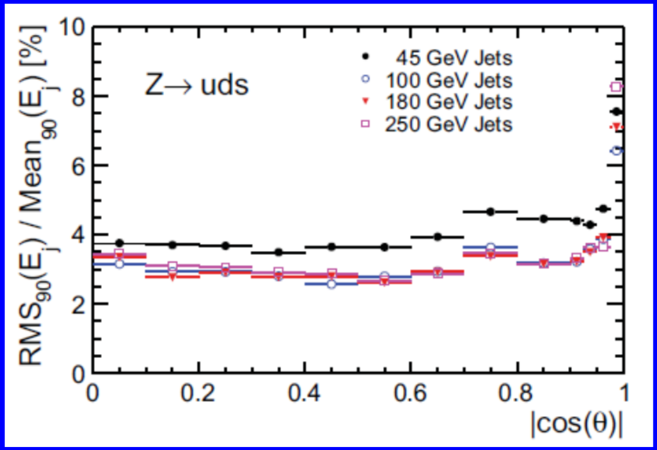
Very much in the spirit of bubble chamber reconstruction – but with full efficiency for photons and neutral hadrons, and in a high multiplicity environment at high luminosity.

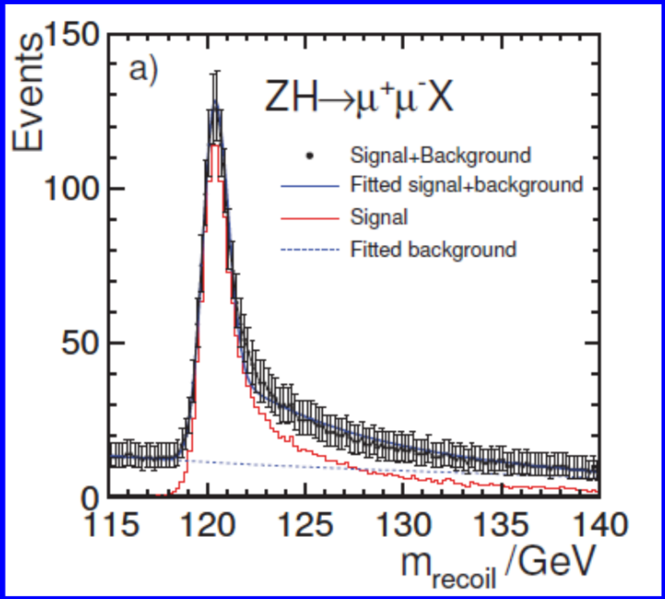




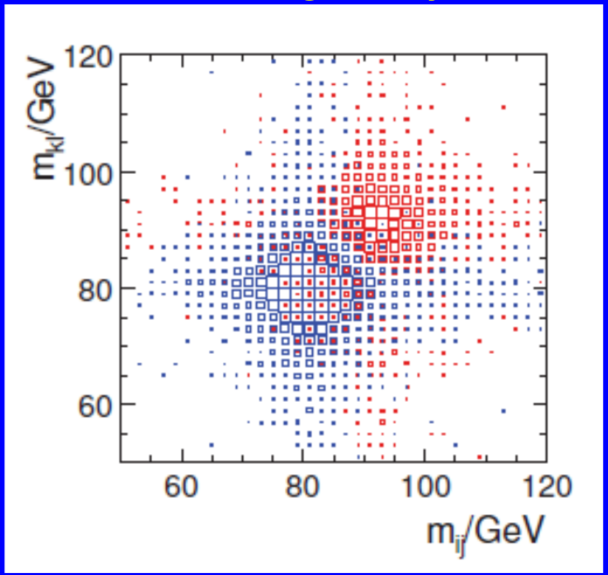
Detector Performance







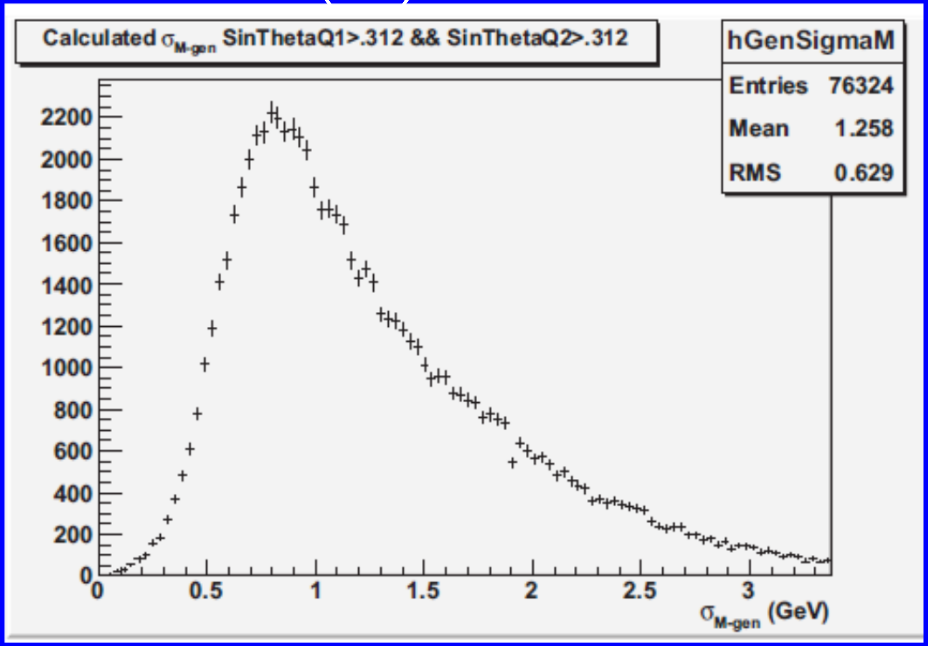
WW scattering to 4 jets

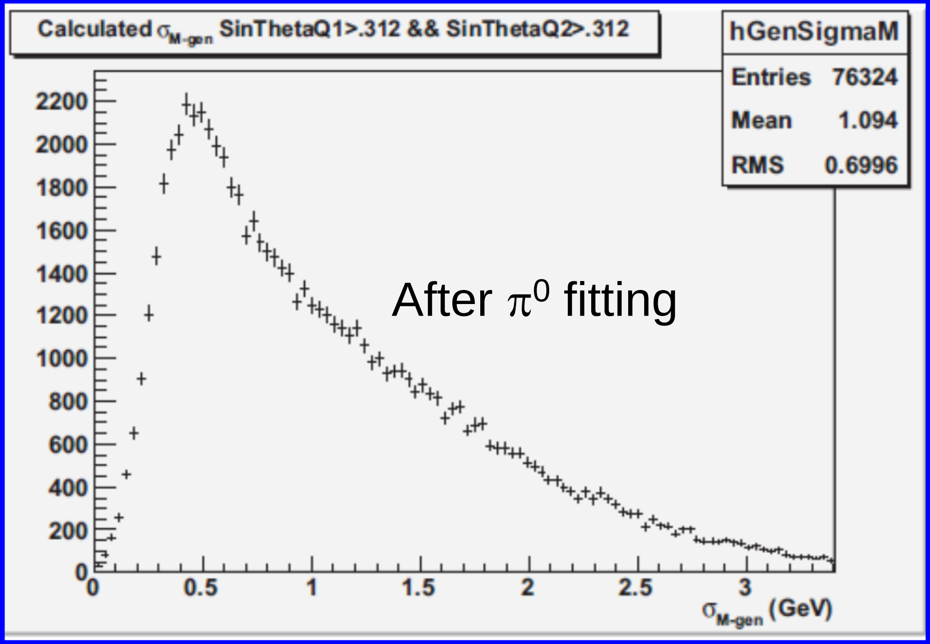


ννWW / ννZZ

Event-Specific Hadronic Mass Resolution

B. van Doren (KU)



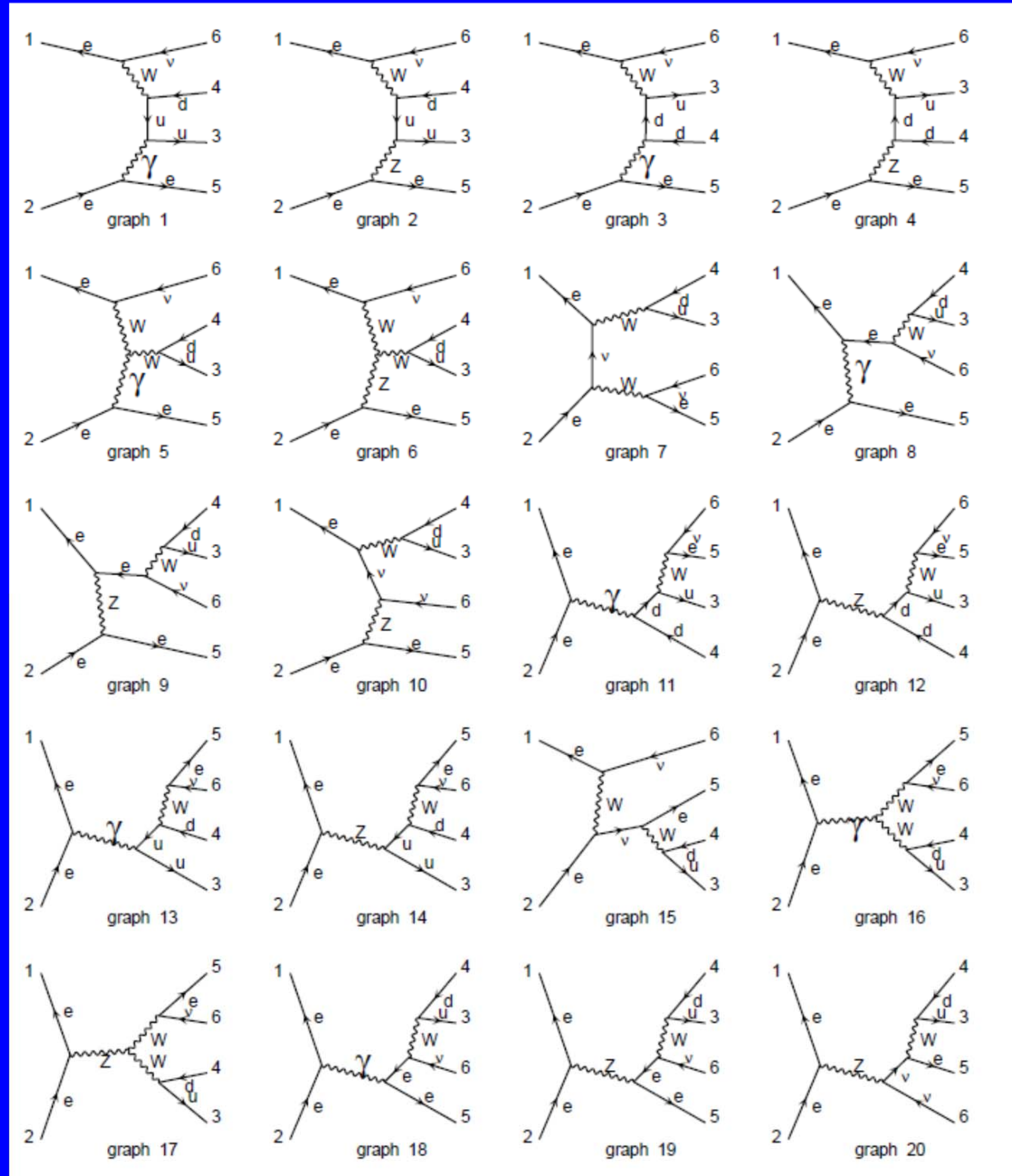


Assumes individual particles are reconstructed, resolved and measured with perfect efficiency, intrinsic detector resolutions and perfect mass assignments.
(Also no confusion: valid for low jet-energy and jet multiplicity environment)

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

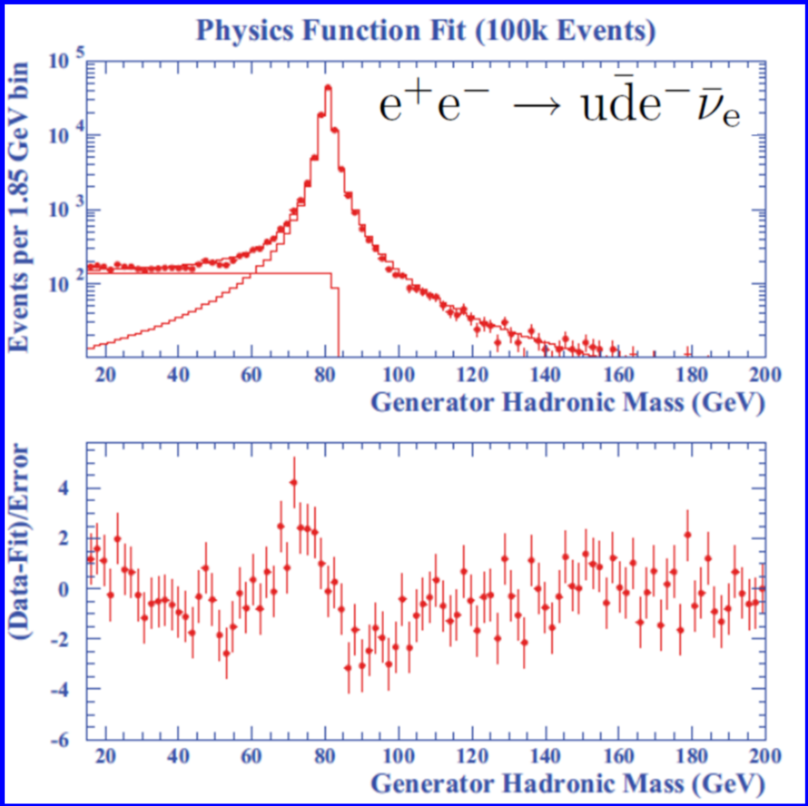
$e^+e^- \to u\bar{d}e^-\bar{\nu}_e$

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



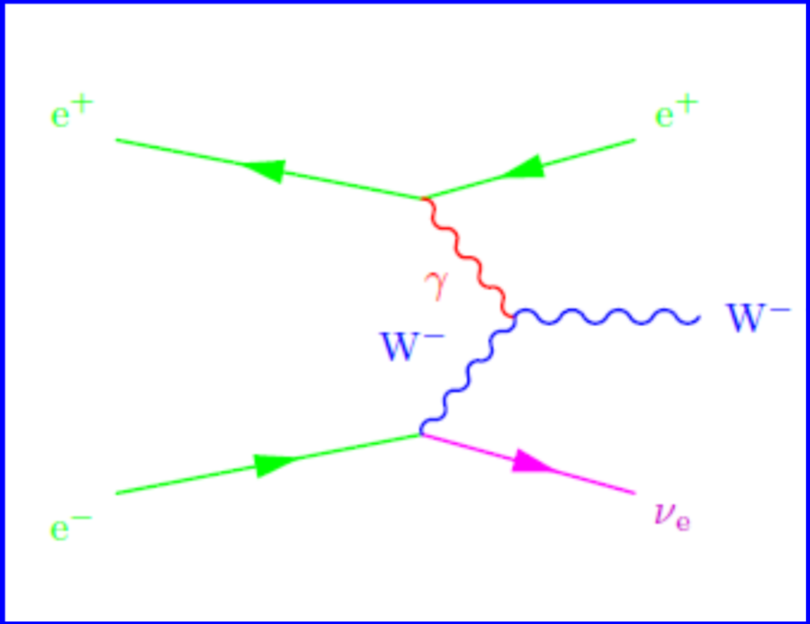
Physics Function

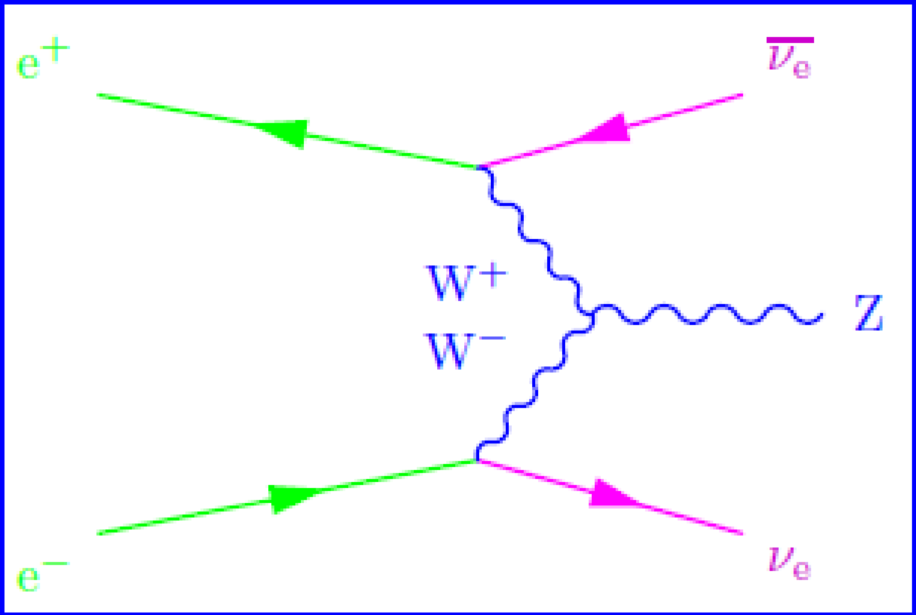
- Ideally, parametrize the physics function (dσ/dm_had) analytically (M_W, Γ_W as parameters).
- Example: ECM = 500 GeV
- Plot for non doubly-resonant helicity configuration (LL) for illustration.
- Physics function needs the resonance, phase-space, non-resonant background, interference.
- With this 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 …

Z Calibration Methods





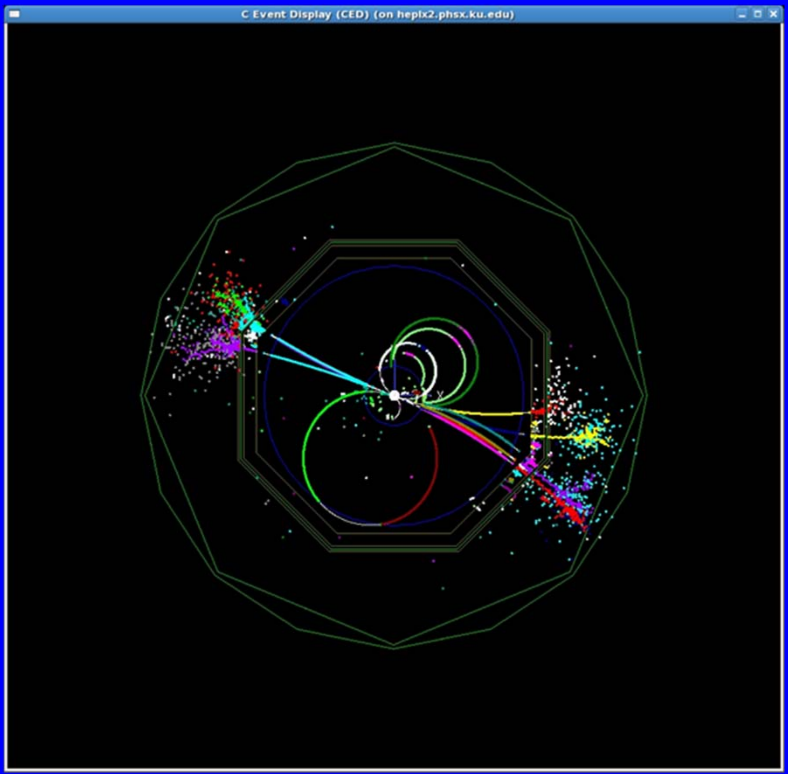
$$(\Delta M/M)_Z = 2.3\times10^{-5}$$

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.

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)



BeamStrahlung

Average energy loss of beams is not what matters for physics.

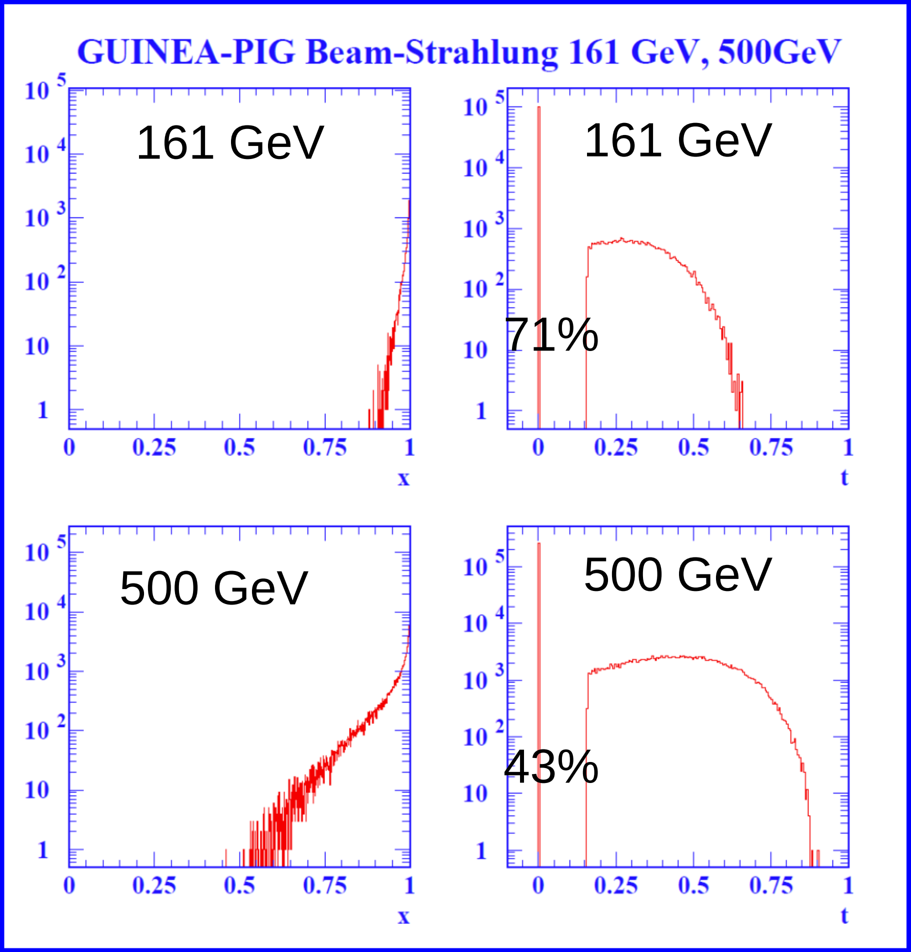
Average energy loss of colliding beams is factor of 2 smaller.

Median energy loss per beam from beamstrahlung typically ZERO.

Parametrized with CIRCE functions.

f δ(1-x) + (1-f) Beta(a2,a3)

Define $t = (1 - x)^{1/5}$



In general beamstrahlung is a less important issue than ISR for kinematic fits

t=0.25 => x = 0.999