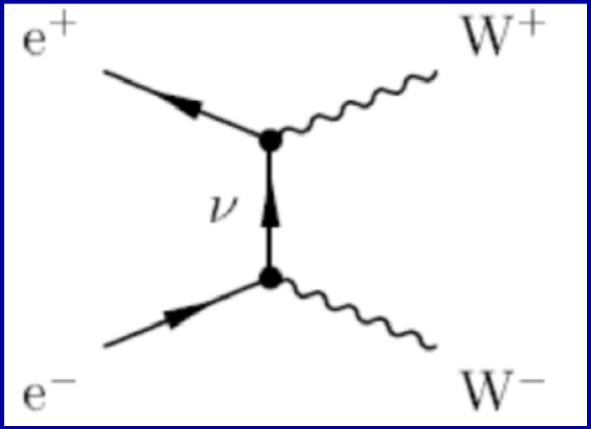
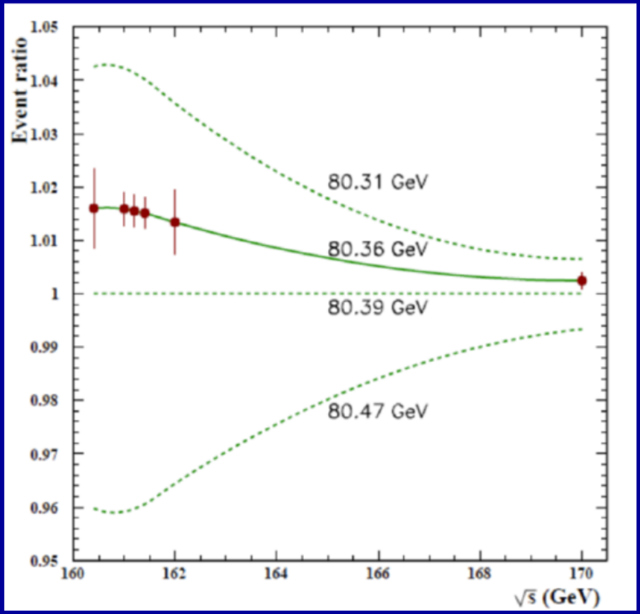
Updated m_W Measurement from Threshold Scan Using Polarized e^- and e^+ at ILC





LCWS2015 Meeting
Whistler, BC, Canada

Graham W. Wilson
University of Kansas

Nov 5th 2015

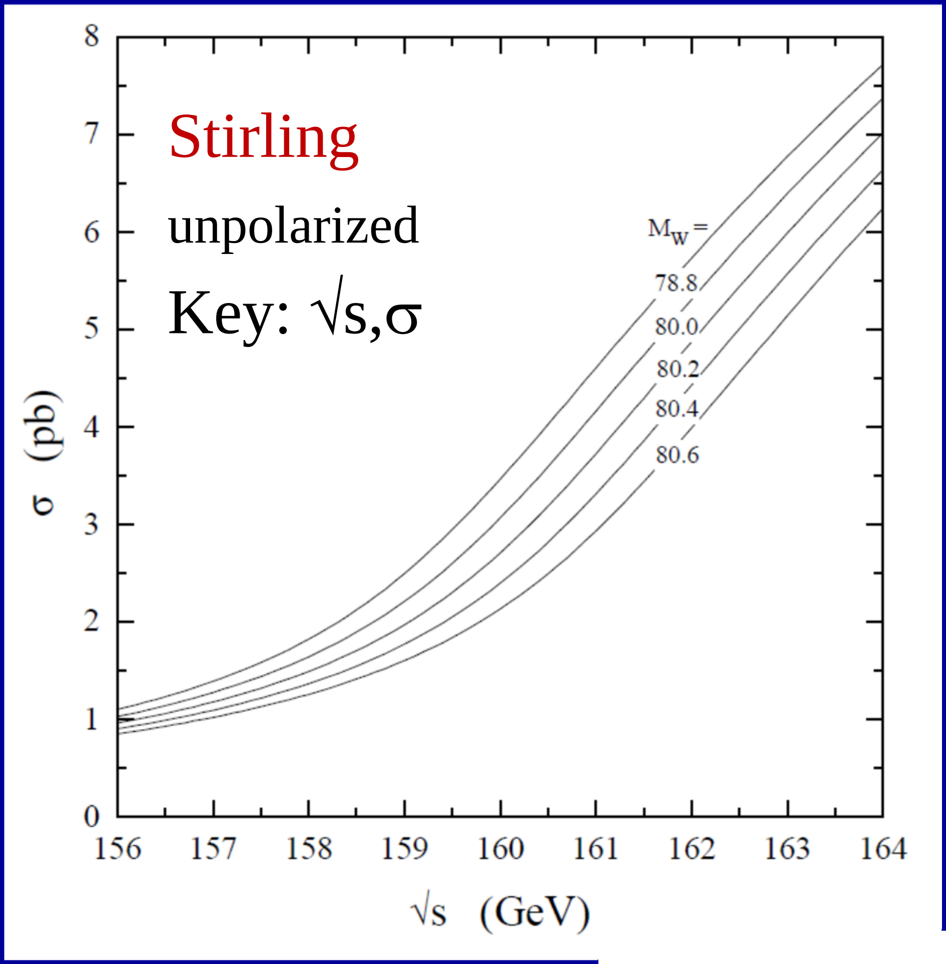
Old TESLA study re-visited.
(LC-PHSM-2001-09)

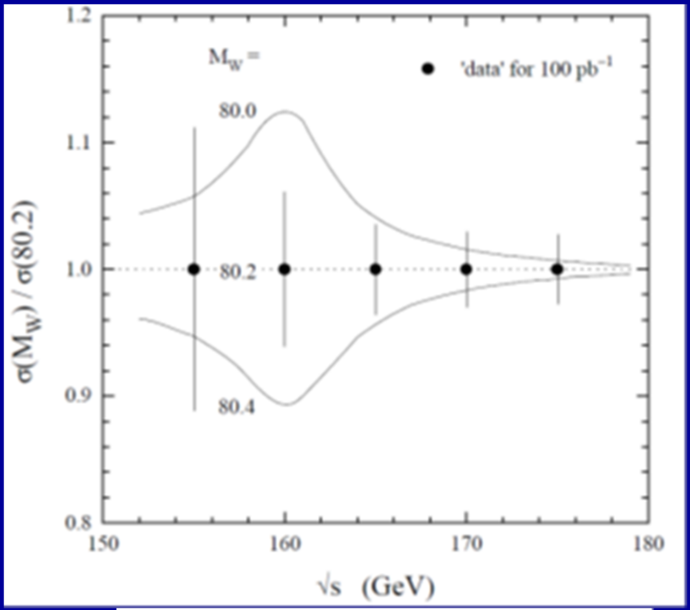
Outline

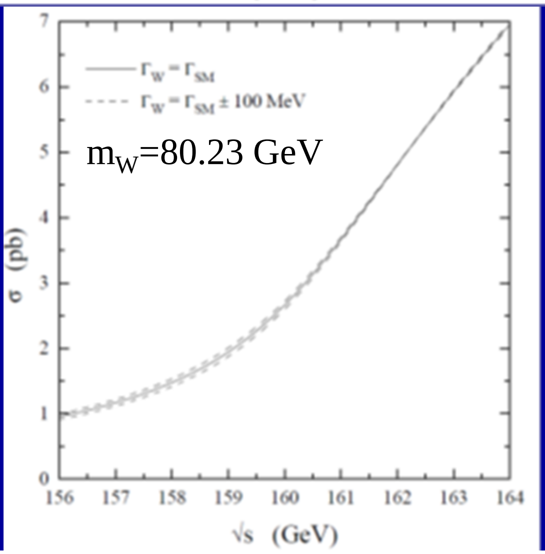
- Give overview of methodology of polarized threshold scan including recent updates.
- Address some of the issues related to the machine.

- (I will focus the talk on the above – and not motivation, other m_W measurements, auxiliary measurements)
- See recent talks on $\sqrt{s_p}$ method (Hamburg-2013), momentum-scale calibration (Fermilab-2014) for absolute $\sqrt{s}$ determination, and m_W generalities at ALCW2015 and backup slides.

m_W from cross-section close to threshold



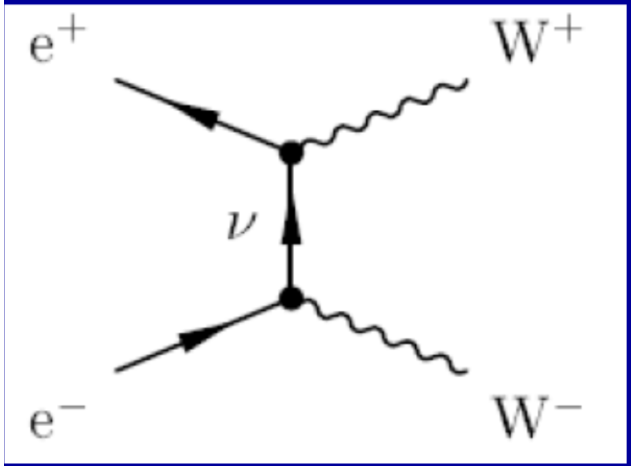




$\sigma_t \sim \beta$ $\sigma_s \sim \beta^3$

$$\Delta M_{\rm sys} = 470\ {\rm MeV} \left[\frac{\Delta\sigma}{1\ {\rm pb}}\right]$$

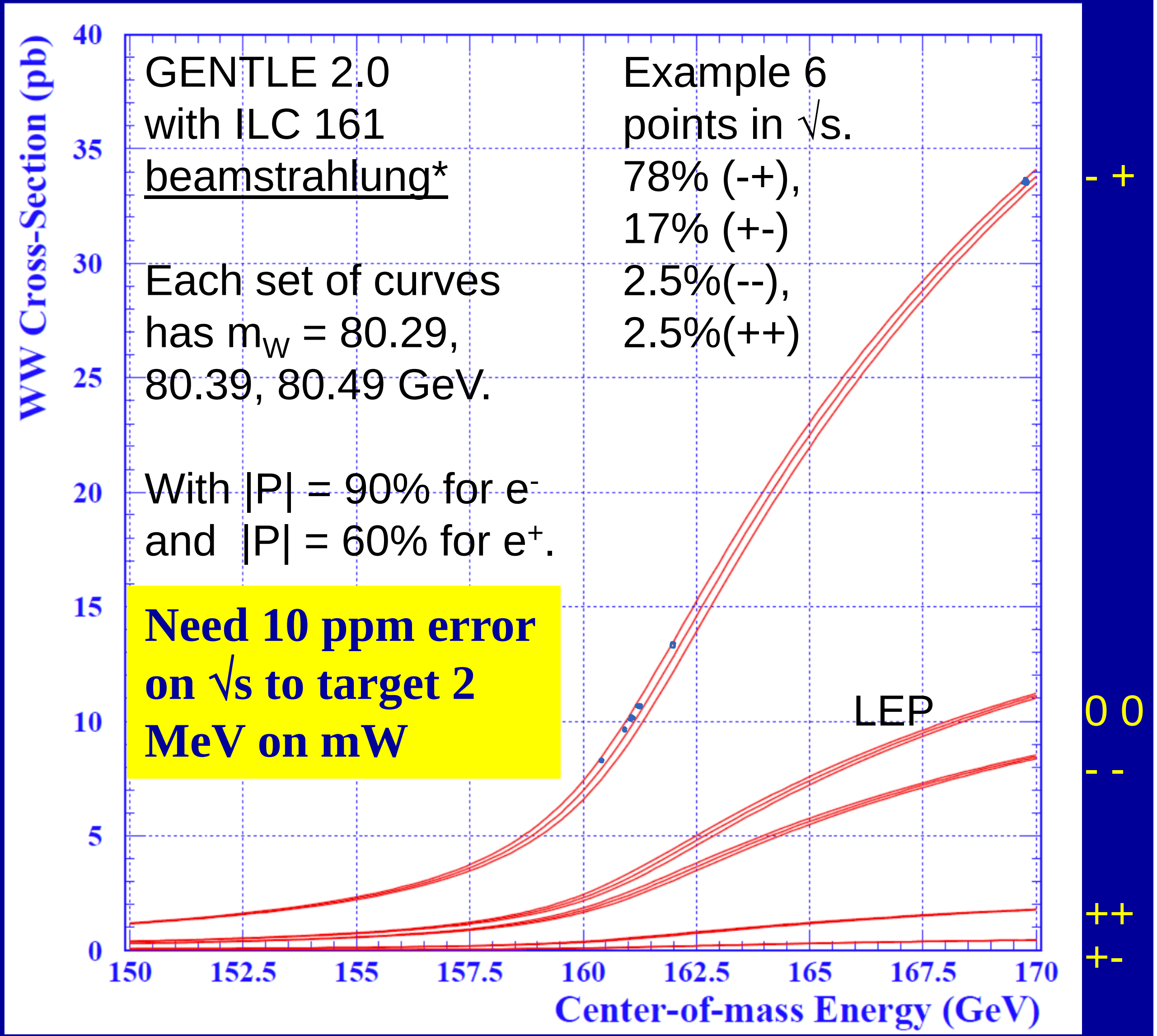
ILC Polarized Threshold Scan



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. Measure pol., bkg. in situ

Counting Experiment

Example: 6 point scan (index i), (90% e-, 60% e+ polarization) with -+, +-, ++ and - - helicity combinations (index k)

Count events in 3 WW candidate categories (lvlv, qqlv, qqqq – index j) with expectation μ_{ijk} and one Z-like category (radiative return and f fbar) with expectation ν_{ik}.

96 event counts

Data could also be taken with other helicity combinations (00, -0,+0,0-,0+) if warranted. (eg. further checks of polarization model)

$\sqrt{s}$ (GeV)	L (fb^{-1})	f	$\lambda_{e^-}\lambda_{e^+}$	N_{ll}	N_{lh}	N_{hh}	N_{RR}
160.6	4.348	0.7789	−+	2752	11279	12321	926968
		0.1704	+−	20	67	158	139932
		0.0254	++	2	19	27	6661
		0.0254	−−	21	100	102	8455
161.2	21.739	0.7789	−+	16096	67610	73538	4635245
		0.1704	+−	98	354	820	697141
		0.0254	++	37	134	130	33202
		0.0254	−−	145	574	622	42832
161.4	21.739	0.7789	−+	17334	72012	77991	4639495
		0.1704	+−	100	376	770	697459
		0.0254	++	28	104	133	33556
		0.0254	−−	135	553	661	42979
161.6	21.739	0.7789	−+	18364	76393	82169	4636591
		0.1704	+−	81	369	803	697851
		0.0254	++	43	135	174	33271
		0.0254	−−	146	618	681	42689
162.2	4.348	0.7789	−+	4159	17814	19145	927793
		0.1704	+−	16	62	173	138837
		0.0254	++	10	28	43	6633
		0.0254	−−	46	135	141	8463
170.0	26.087	0.7789	−+	63621	264869	270577	5560286
		0.1704	+−	244	957	1447	838233
		0.0254	++	106	451	466	40196
		0.0254	−−	508	2215	2282	50979

Table 7: Illustrative example of the numbers of events in each channel for the standard 100 fb^{-1} 6-point ILC scan with 4 helicity combinations.

Fit the Event Counts to Model Expectations

$$x \equiv |P(\mathrm{e}^-)|, \;\; y \equiv |P(\mathrm{e}^+)|$$

Event count expectations:

$$\mu_{ijk} = \left(f_S^k(x,y)\, \sigma_i(m_W, \alpha_S)\, \varepsilon_j B_j + g_B^k(x,y,A_{LR}^B)\, \sigma_B^j \right) f_l L_{ik}$$

$$\nu_{ik} = g_Z^k(x,y,A_{LR}^Z)\, f_l L_{ik}$$

Signal, background, and Z-control sample spin factors:

$$f_S^{-+}(x,y) = (1+x)(1+y)$$
$$f_S^{+-}(x,y) = (1-x)(1-y)$$
$$f_S^{++}(x,y) = (1-x)(1+y)$$
$$f_S^{--}(x,y) = (1+x)(1-y)$$

$$g_{B,Z}^{-+}(x,y,A) = 1 + xy + A(x+y)$$
$$g_{B,Z}^{+-}(x,y,A) = 1 + xy - A(x+y)$$
$$g_{B,Z}^{++}(x,y,A) = 1 - xy - A(x-y)$$
$$g_{B,Z}^{--}(x,y,A) = 1 - xy + A(x-y)$$

Assumes A=1 for WW
(actually about 0.996)

Fit Parameters

No.	Fit Parameter	Comment
1	m_W	
2	α_S	Fixed currently to 0.12
3	σ_B (lvlv)	
4	σ_B (qqlv)	Background cross-section
5	σ_B (qqqq)	
6	f_l	0.1% constrained
7	ε (lvlv)	
8	ε (qqlv)	Signal efficiency
9	ε (qqqq)	(constrained)
10	A^B_{LR} (lvlv)	
11	A^B_{LR} (qqlv)	Background asymmetry
12	A^B_{LR} (qqqq)	(constrained)
13	$\vert P(e^-)\vert$	Assume same for each helicity
14	$\vert P(e^+)\vert$	Assume same for each helicity
15	σ_Z	Z-like 2-fermion ($f\overline{f}(\gamma)$)
16	A^Z_{LR}	

NEW
(previously assumed known perfectly)

Table 10: Fit parameters for 4 helicity combination scans $(-+, +-, ++, --)$

$$\Gamma_W \sim m_W^3 \left(1 + \frac{2\alpha_S(m_W^2)}{3\pi}\right)$$

(Note: within the SM current uncertainty on α_S translates to 0.06 MeV on Γ_W)

Fit Details and Experimental Assumptions

- Use Poisson likelihood (also χ^2 as cross-check)
- Include χ^2 penalty terms to constrain the systematic effects associated with integrated luminosity, signal efficiencies and background asymmetries.
- MEASURE background cross-sections

Channel	Efficiency (%)	σ^U_{bkgd} (fb)	A^B_{LR}	Eff. syst. (%)	Bkgd syst.	A^B_{LR} syst.
ll	87.5	10	0.15	0.1	free	0.025
lh	87.5	40	0.30	0.1	free	0.012
hh	83.5	200	0.48	0.1	free	0.005

Table 4: Experimental assumptions for the WW event selection near threshold using a polarized scan

- NB. Assumed inefficiency and background is halved with respect to TESLA study – based on ILC style detector

4 eqns, 4 unknowns

- Using the large statistics of Z-like events (150 pb).
- Can use the 4 measured Z-like event counts to determine the 4 related parameters (σ, x, y, A).
  - Precise determination of the polarization values, x and y, is key to the m_W measurement

$$g_{B,Z}^{-+}(x,y,A) = 1 + xy + A(x+y)$$

$$g_{B,Z}^{+-}(x,y,A) = 1 + xy - A(x+y)$$

$$g_{B,Z}^{++}(x,y,A) = 1 - xy - A(x-y)$$

$$g_{B,Z}^{--}(x,y,A) = 1 - xy + A(x-y)$$

- Suitable event selection for qq+$\mu\mu$+$\tau\tau$ should be straight-forward
  - Include inclusively full energy events and radiative return
- Can also use data with one or both beams depolarized to check further/constrain beam polarization model.

Systematic on A_{LR}^{B}

- For current studies, I have assumed that this can be controlled to 2.5% (lvlv), 1.2% (qqlv) and 0.5% (qqqq).
  - Previously this systematic was neglected.
- Numbers are based on the expected statistical uncertainty on A_{LR}^{B} for a background side-band with the same statistics of background events as expected for 100 fb^{-1}.
- This needs more study to establish that these errors can be achieved. At this point, I am hesitant to assume that these errors will improve with more integrated luminosity.
- It is also not at all obvious that the background will only couple to LR and RL chiralities (contributions from two-photon, single-W …)

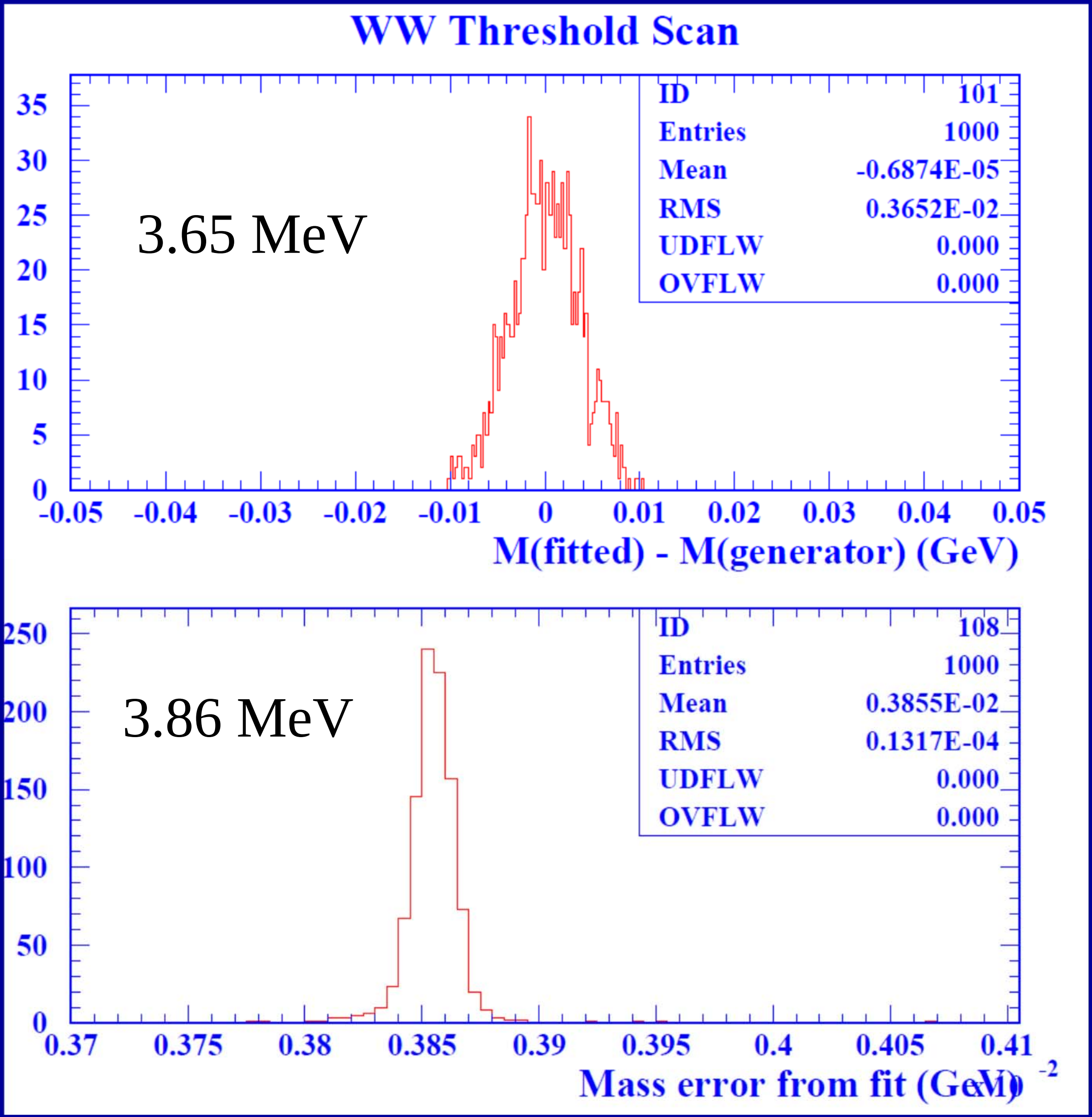
Example Fit

```
MINUIT TASK: FIT W MASS TO NUMBER OF EVENTS in EACH CHANNEL

FCN=    380.8176      FROM MINOS     STATUS=SUCCESSFUL   2234 CALLS      2917 TOTAL
                      EDM=  0.44E-07     STRATEGY= 1       ERROR MATRIX ACCURATE

 EXT PARAMETER                     PARABOLIC          MINOS ERRORS
 NO.    NAME          VALUE          ERROR        NEGATIVE       POSITIVE
  1     WMASS         80.388       0.37711E-02  -0.37702E-02   0.37767E-02
  2     BKGLL       0.10275E-01    0.91639E-03  -0.90194E-03   0.93157E-03
  3     BKGLQ       0.40483E-01    0.22579E-02  -0.22403E-02   0.22807E-02
  4     BKGQQ       0.19637        0.36138E-02  -0.36053E-02   0.36266E-02
  5     FLUMI         1.0002       0.92454E-03  -0.92450E-03   0.92460E-03
  6     REFFLL        1.0004       0.96920E-03  -0.96922E-03   0.96917E-03
  7     REFFLQ      0.99980        0.92946E-03  -0.92942E-03   0.92949E-03
  8     REFFQQ        1.0000       0.94232E-03  -0.94230E-03   0.94235E-03
  9     ALPHAS      0.12000        constant
 10     ALRLL       0.15637        0.24715E-01  -0.24733E-01   0.24697E-01
 11     ALRLQ       0.29841        0.11868E-01  -0.11871E-01   0.11864E-01
 12     ALRQQ       0.48012        0.47202E-02  -0.47227E-02   0.47177E-02
 13     ALRMZ       0.19062        0.28885E-03  -0.28920E-03   0.28924E-03
 14     PELL        0.89925        0.12702E-02  -0.12845E-02   0.12824E-02
 15     PELR        0.90000        constant
 16     PELZ          0.0000       constant
 17     PPOSL       0.60077        0.94144E-03  -0.94833E-03   0.95086E-03
 18     PPOSR       0.60000        constant
 19     PPOSZ         0.0000       constant
 20     XSRR          149.93       0.51934E-01  -0.51984E-01   0.52011E-01
```

Ensemble Tests



1000 experiments.

Use average error from fit in following.

(I just noticed that the empirical error is smaller than the error from the fit … should investigate further)

Results

6-point scan, (90%, 60%)

Fit type	Uncertainty source	ΔM_W [MeV]	ΔM_W (syst.) [MeV]
fixbkg	Background	3.20	2.30
fixpol	Polarization	3.73	1.27
fixeff	Efficiency	3.86	1.18
fixlum	Luminosity	3.76	0.78
fixALRB	A_{LR}^{B}	3.86	0.80
fixall	Statistical	2.43	
	Systematic		3.10
standard	Total Error	3.94	

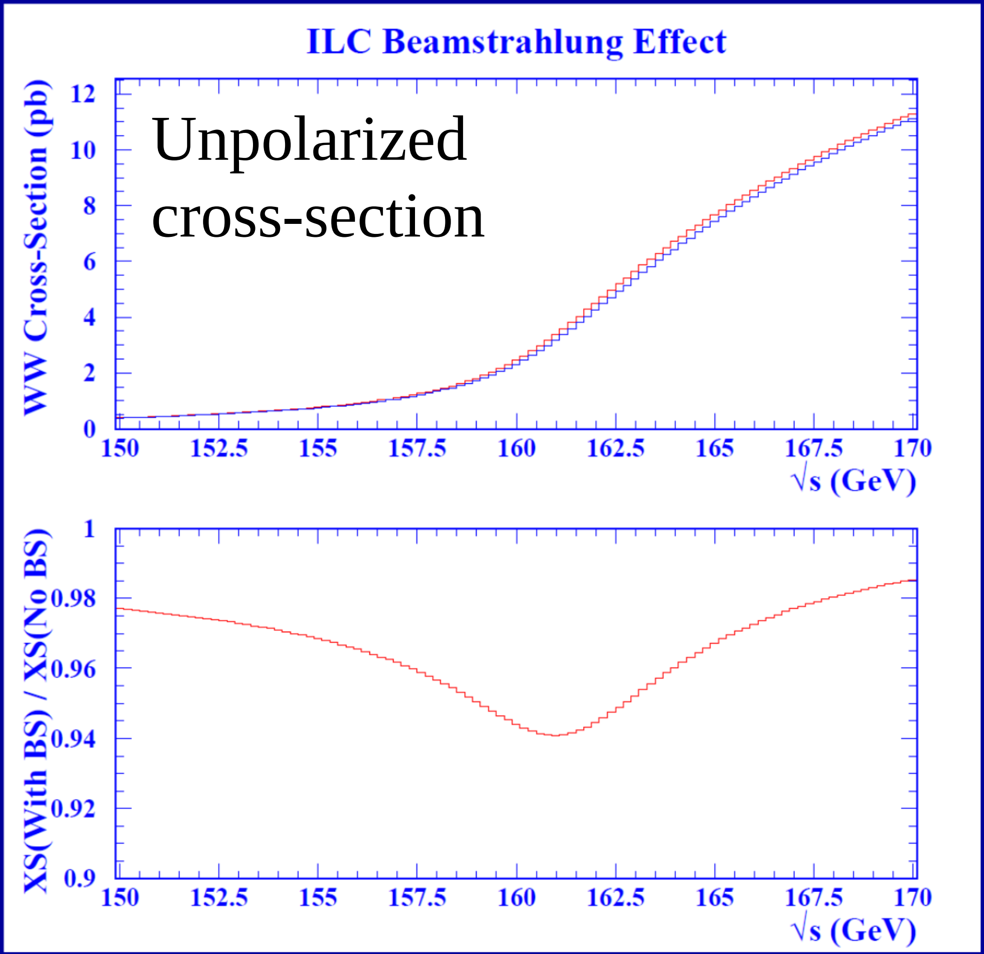
Table 6: Mass errors for various fits for example 100 fb^{-1} scan.

Other systematics	Δ M_W [MeV]
$\sqrt{s}$	0.8
BS shape	small ?
Theory	1 ?

Independent of m_Z

Beamstrahlung Effects

- Used Guinea-Pig to simulate beamstrahlung spectrum using scaled ILC TDR parameters.
- Energy-loss spectrum fitted with CIRCE1 parametrization.
- WW cross-sections from GENTLE2.0/4fan (Bardin, Leike, Riemann) convolved with beam-strahlung.
- Red (NoBS). Blue (With BS)



Modest change to threshold shape. Up to 6% reduction, +- 2% in shape.

(Mea culpa: my original TESLA study erroneously used cross-section with no BS (bug))

Details on Guinea-Pig + Circe Settings

See backup slides 25&26 for more details

```
$ACCELERATOR:: TDR_Apr2013_161GeV
{trav_focus=0;espread.1=0.00206;espread.2=0.00190;
energy=80.5;particles=2;beta_x=16;beta_y=0.34;
emitt_x=10.0;emitt_y=0.035;
sigma_z=300;
offset_y=0.0;offset_x=00.0;waist_x=0000;waist_y=250;f_rep=1.0;n_b=1;
which_espread=3;
charge_sign=-1;scale_step=1.0;angle_y=0.0000;angle_phi=-00.00000;}
```

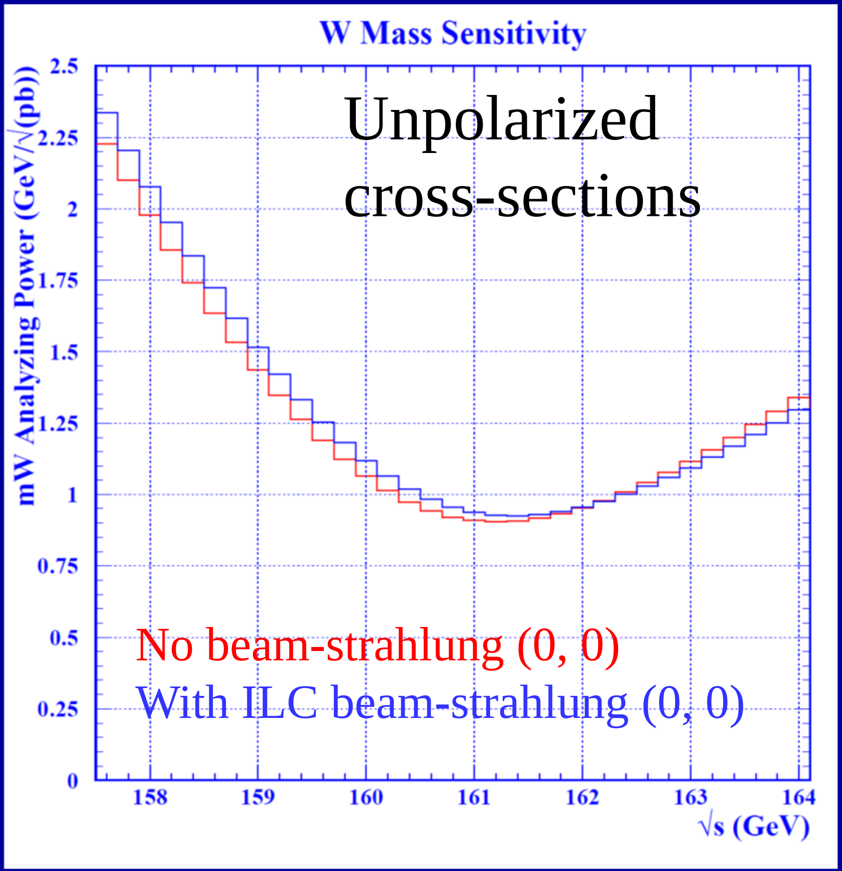
Leading to Circe1 parameters of

0.70648, 0.25305, 50.507 and -0.7305

Note: A machine design with higher luminosity and worse beamstrahlung is likely to be preferred for this physics measurement

Guinea-Pig (D. Schulte)
Circe (T. Ohl)

Sensitivity to m_W

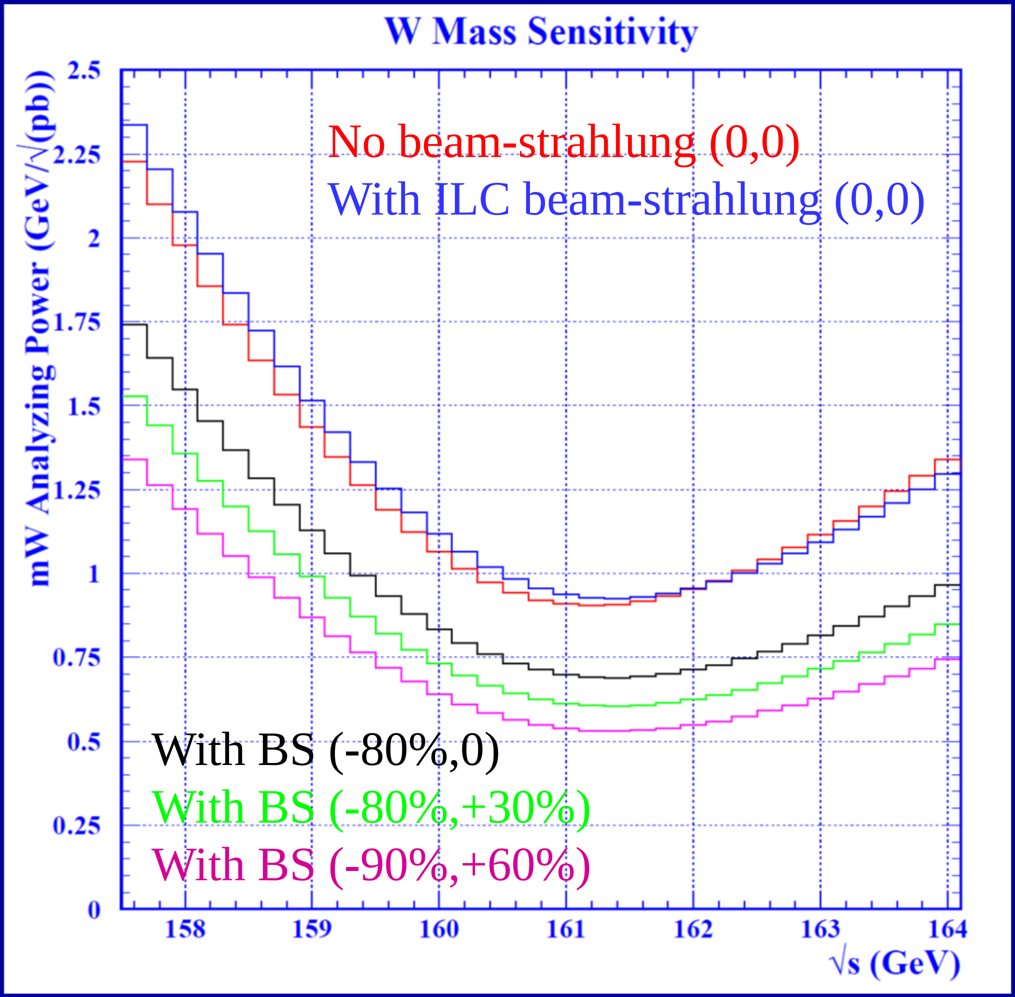


$$\Delta M = K \left[\int L \right]^{-1/2}$$

$$K = \sqrt{\sigma}\, \left| d\sigma/dM \right|^{-1}$$

Fairly negligible effect of beam-strahlung on statistical sensitivity

Sensitivity to m_W



Polarization of electron and positron beams at ILC (necessarily with beamstrahlung) offers MUCH better sensitivity per unit of integrated luminosity than the LEP-like unpolarized case.

Updated Results

- Use re-optimized 2-point "scan". Working on optimizing this analytically.

$\sqrt{s}$ (GeV)	L (fb^{-1})	f	$\lambda_{e^-}\lambda_{e^+}$	N_{ll}	N_{lh}	N_{hh}	N_{RR}
161.4	86.957	0.7111	$-+$	63443	262469	283058	16927120
161.4	86.957	0.2000	$+-$	463	1736	3740	3270457
161.4	86.957	0.0444	$++$	219	922	1023	233371
161.4	86.957	0.0444	$--$	997	4043	4463	299399
170.0	13.043	0.7111	$-+$	29299	121140	123460	2542743
170.0	13.043	0.2000	$+-$	126	567	900	490497
170.0	13.043	0.0444	$++$	92	454	404	35300
170.0	13.043	0.0444	$--$	445	1905	1927	44740

Table 8: Illustrative example of the numbers of events in each channel for a re-optimized 100 fb^{-1} 2-point ILC scan with 4 helicity combinations.

$\|P(e^-)\|$ (%)	$\|P(e^+)\|$ (%)	100 fb^{-1}	500 fb^{-1}
80	30	6.02	2.88
90	30	5.24	2.60
80	60	4.05	2.21
90	60	3.77	2.12

Errors on m_W (MeV)

Summary I

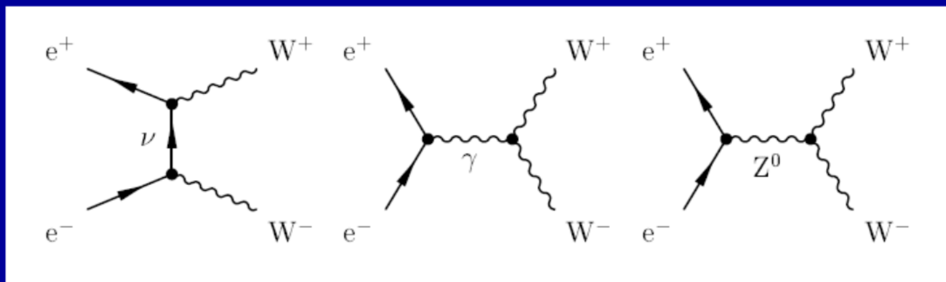
- Threshold scan can yield a precision measurement of m_W at a linear collider with polarized electron AND positron beams.
  - Errors at the few MeV level can be envisaged.
  - With $100 fb^{-1}$, find 2.4 (stat.) $\oplus$ 3.1 (syst.) $\oplus$ 0.8 ($\sqrt{s}$) $\oplus$ theory (MeV)
- ILC design can and should evolve to make this feasible (proof of concept is in the TESLA TDR).
  - Supported machine parameters would be helpful.
  - Better awareness of these issues by LCC management …
- Regressing to no positron polarization should be avoided!
  - Controlling the background is very challenging without it.
    - I am not confident that a useful m_W measurement can be made at threshold with no positron polarization. Limited by absolute polarization measurement – 0.5% systematic.
    - I am certain that a competitive m_W measurement at threshold is very challenging with no beam polarization at all

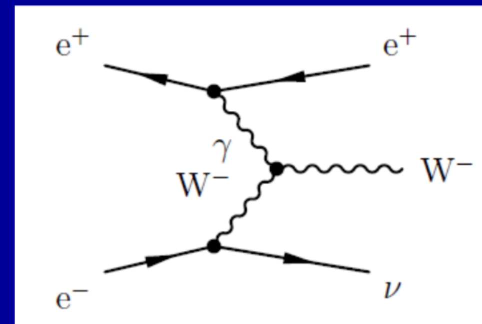
Take-Home Messages

- ILC has very good prospects for measuring m_W with very high precision
  - Not much work yet on measurements at standard ILC √s values (√s ≥ 250 GeV). Needs more effort.
  - Measurement at threshold expected to be very robust with polarized electrons and polarized positrons (experimentally and theoretically).
- Precision m_W needs precision √s.
  - $\sqrt{s_P}$ method very promising
  - Need precise momentum scale.
    - J/psi method using Z's needs 40M Z's…..
  - Error on m_W from √s knowledge of 0.8 MeV can be targeted.
- ILC accelerator
  - Need to preserve the option to run with high L and highly polarized electrons **AND POSITRONS** at WW threshold. No experimental show-stoppers.
    - This is a great advantage of ILC over other accelerator concepts.
  - We should DEMAND capability for high luminosity for calibration at the Z.
  - We should DEMAND capability for reasonable luminosity at the Z with polarized beams for physics.

Backup Slides

W Production in e^+e^-

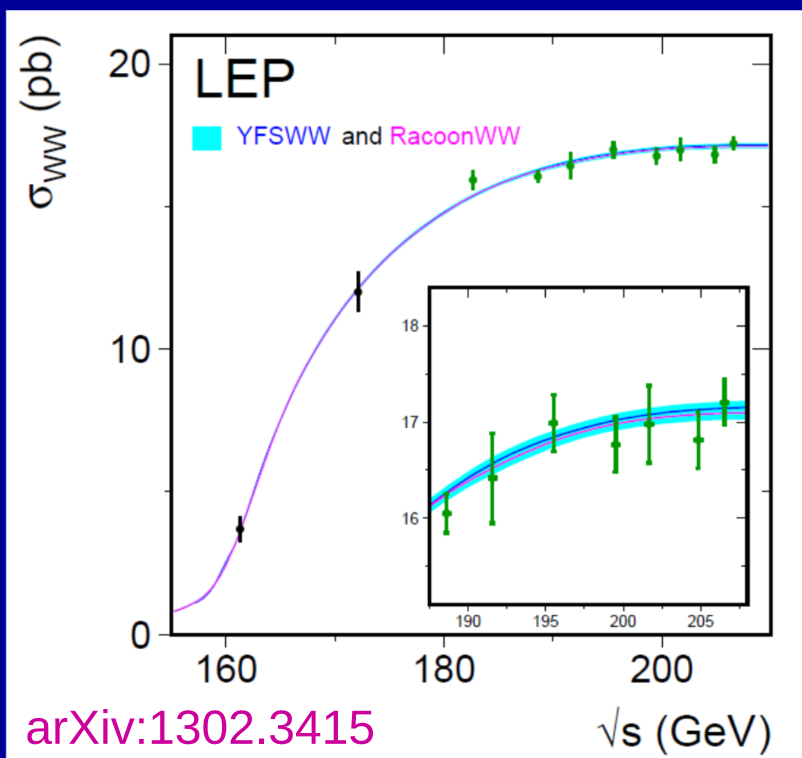


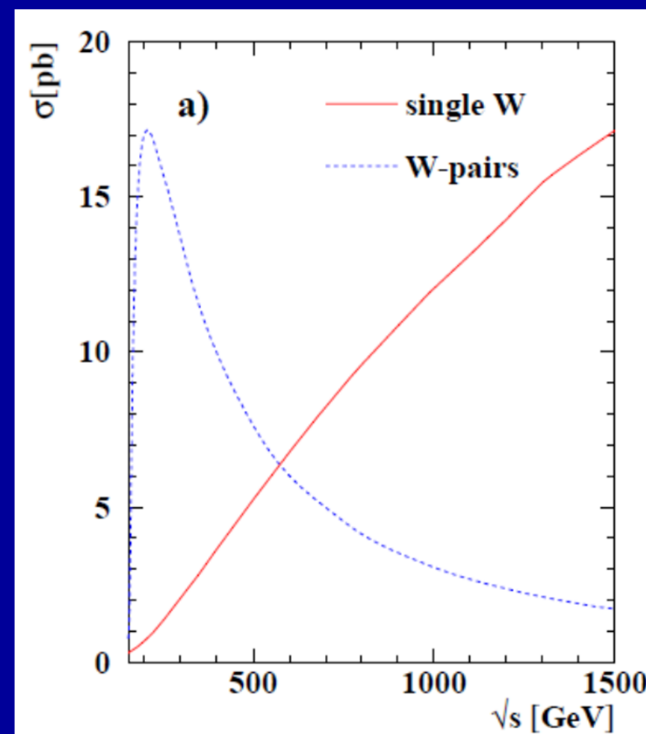


etc ..

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

$e^+e^- \rightarrow W e \nu$

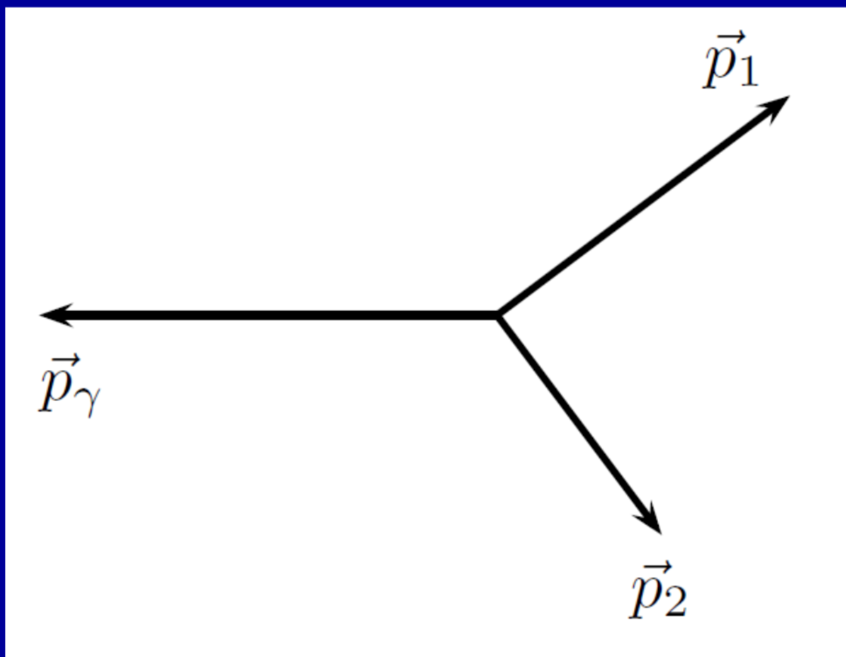




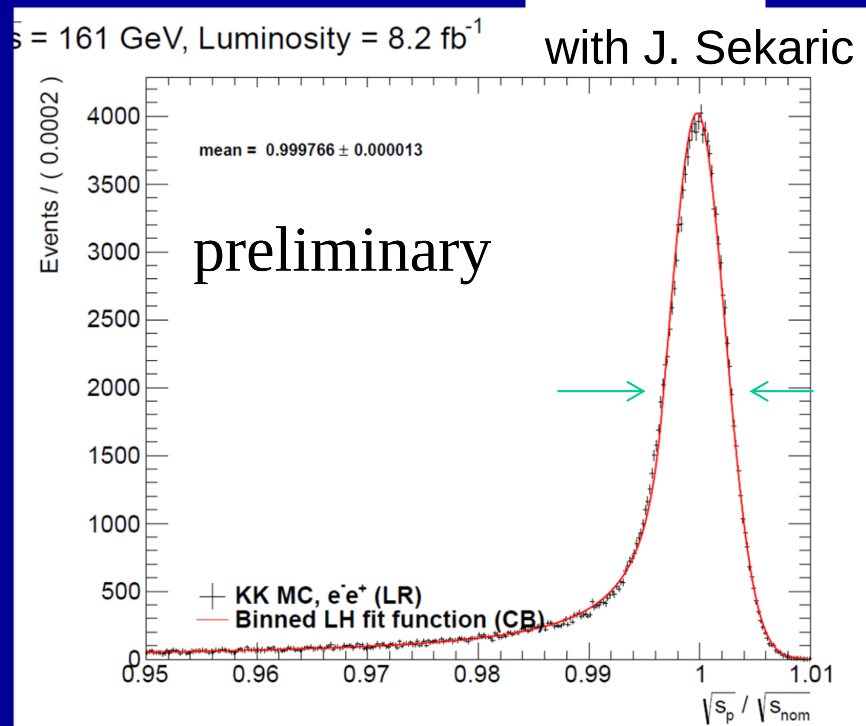
unpolarized cross-sections

"New" $\sqrt{s_P}$ In-Situ Beam Energy Method

$e^+ e^- \to \mu^+ \mu^- (\gamma)$



GWW
with J. Sekaric



Use muon momenta.
Measure $E_1 + E_2 + |\mathbf{p}_{12}|$ as an estimator of $\sqrt{s}$
(no assumption that $m_{12} \approx m_Z$)

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

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

m_W Prospects

1. Polarized Threshold Scan (GWW)
2. Kinematic Reconstruction
3. Hadronic Mass (GWW, BvD, KT)

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	4.0	2.1

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

See Snowmass document for more details

Bottom-line: 3 different methods with prospects to measure mW with error < 5 MeV

ILC Accelerator Features

$L \sim (P/E_{CM}) \sqrt{(\delta_E / \varepsilon_{y,N})}\, H_D$

$P \sim f_c N$ $\qquad \delta_E \sim (N^2 \gamma^2)/(\varepsilon_{x,N}\, \beta_x\, \sigma_z)\, U_1 (\Psi_{av})$

Machine design has focused on 500 GeV baseline

$\sqrt{s}$	$\mathcal{L}[10^{34}]$	dE [%]	(dp/p)(+) [%]	(dp/p)(-) [%]
200	0.56	0.65	0.190	0.206
250	0.75	0.97	0.152	0.190
350	1.0	1.9	0.100	0.158
500	1.8/3.6	4.5	0.070	0.124
1000	4.9	10.5	0.047	0.085

dp/p same as LEP2 at 200 GeV

dp/p typically better than an e^+e^- ring which worsens linearly with $\sqrt{s}$

Scope for improving luminosity performance.

1. Increase number of bunches (f_c)
2. Decrease vertical emittance (ε_y)
3. Increase bunch charge (N)
4. Decrease σ_z
5. Decrease β_x

3,4,5 => L, BS trade-off
Can trade more BS for more L or lower L for lower BS.

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 tiny compared to beam energy spread.

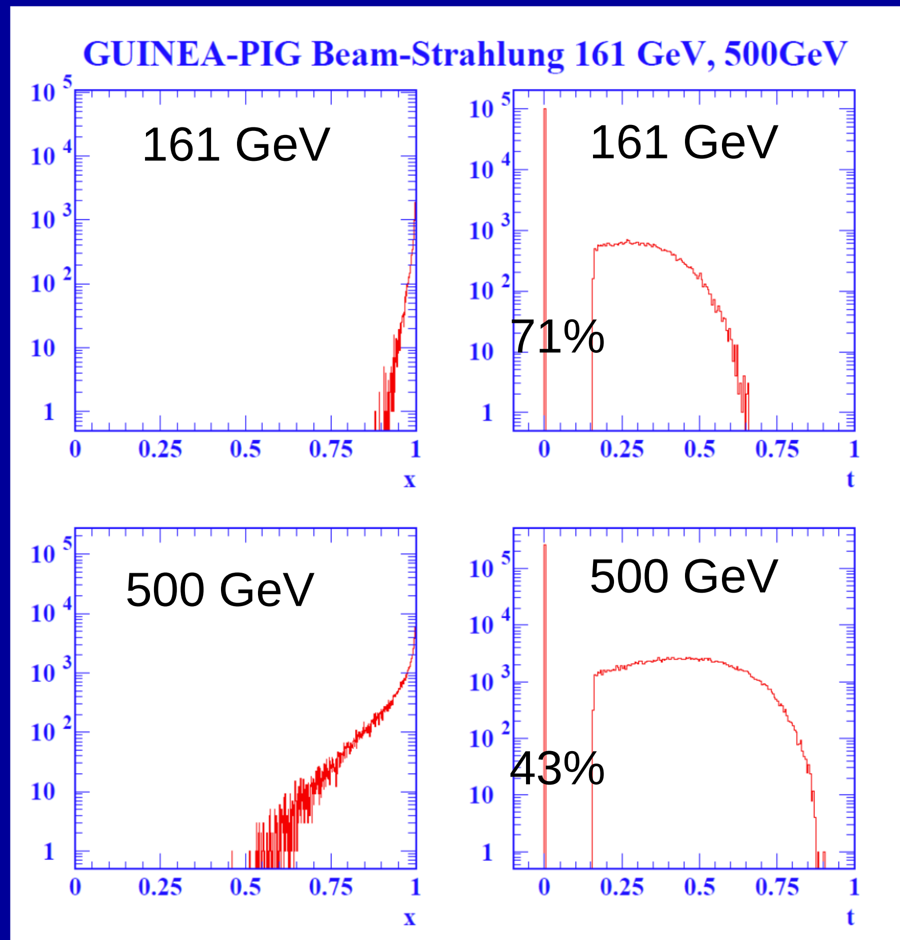
Parametrized with CIRCE functions.

f $\delta(1\text{-}x) + (1\text{-}f)\,\mathrm{Beta}(a_2,a_3)$

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

In general beamstrahlung is a less important issue than ISR. Worse BS could be tolerated in the WW threshold scan

Scaled energy of colliding beams



t=0.25 => x = 0.999

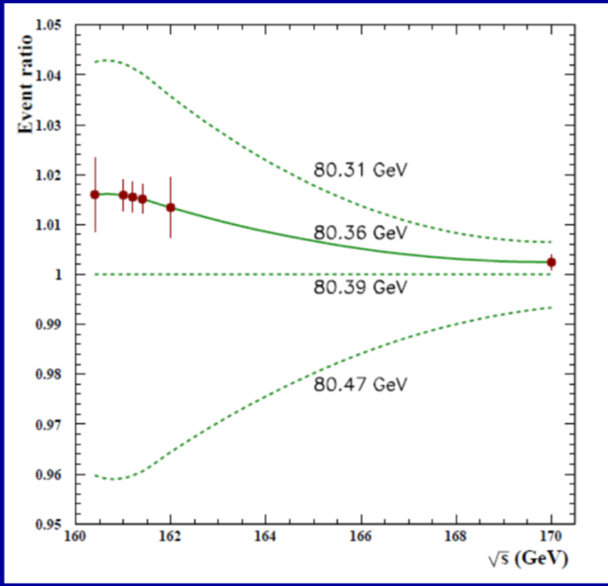
x >0.9999 in first bin

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.



LEP2 numbers

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 9 different helicity combinations.

Estimate error of 6 MeV (includes Eb error of 2.5 MeV from Z γ) per 100 fb^{-1} polarized scan (assumed 60% e+ polarization)

Use RR (100 pb) cross-section to control polarization

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MINUIT TASK: FIT W MASS TO NUMBER OF EVENTS in EACH CHANNEL

FCN= 211.4589 FROM MINOS STATUS=SUCCESSFUL 1984 CALLS 3004 TOTAL
EDM= .70E-06 STRATEGY= 1 ERROR MATRIX ACCURATE

	EXT NO.	PARAMETER NAME	VALUE	PARABOLIC ERROR	MINOS ERRORS NEGATIVE	MINOS ERRORS POSITIVE
	1	WMASS	80.383	.52990E-02	-.53041E-02	.52938E-02
	2	BKGLL	.19168E-01	.10968E-02	-.10973E-02	.10963E-02
	3	BKGLQ	.80181E-01	.30944E-02	-.30967E-02	.30919E-02
	4	BKGQQ	.39732	.47314E-02	-.47324E-02	.47302E-02
	5	FLUMI	1.0000	.23151E-02	-.23138E-02	.23161E-02
	6	REFFLL	1.0023	.21894E-02	-.21892E-02	.21897E-02
	7	REFFLQ	.99853	.19873E-02	-.19867E-02	.19878E-02
	8	REFFQQ	.99922	.20900E-02	-.20896E-02	.20903E-02
	9	ALPHAS	.12000	constant		
	10	ALRLL	.15000	constant		
	11	ALRLQ	.33000	constant		
	12	ALRQQ	.49000	constant		
	13	ALRMZ	.15940	.20791E-02	-.20803E-02	.20776E-02
0.78	14	PELL	.78225	.50929E-02	-.50870E-02	.50950E-02
0.82	15	PELR	.82069	.28556E-02	-.28522E-02	.28577E-02
0.01	16	PELZ	.60436E-02	.33653E-02	-.33673E-02	.33629E-02
0.62	17	PPOSL	.61810	.29707E-02	-.29685E-02	.29717E-02
0.58	18	PPOSR	.58001	.37921E-02	-.37892E-02	.37927E-02
-0.01	19	PPOSZ	-.11807E-01	.28543E-02	-.28538E-02	.28547E-02
	20	XSRR	99.948	.85487E-01	-.85206E-01	.85759E-01

$\Rightarrow \Delta M_W = 5.3$ MeV for $\int \mathcal{L}dt = 100\ fb^{-1}$
assuming $\Gamma_W = f_{SM}(M_W)$, A_{LR}^{bkgd} known.

Systematics are treated as nuisance parameters that can be fitted. Errors should scale statistically.

Polarized Threshold Scan Errors

- conservative – viewed from + 15 years ....
- Non-Ebeam experimental error (stat + syst)
  - 5.2 MeV

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
L (fb^{-1})	100	160*3	100	100
Pol. (e^-/e^+)	80/60	90/60	90/60	90/60
Inefficiency	LEP2	0.5*LEP2	0.5*LEP2	0.5*LEP2
Background	LEP2	0.5*LEP2	0.5*LEP2	0.5*LEP2
Effy/L syst	0.25%	0.25%	0.25%	0.1%
Δm_W(MeV)	5.2	2.0	4.3	3.9

In-situ Physics Based Beam Energy Measurements

- Potential Mass-Scale References for Energy Calibration

Particle	ΔM/M (PDG) (ppm)
J/psi	3.6
Upsilon	27
Z	23
W	190
H	2400

Conventional wisdom has been to use Z's, but with ILC detector designs J/psi's look attractive.

Prefer not to use something that one plans to measure better or something that will limit the precision.

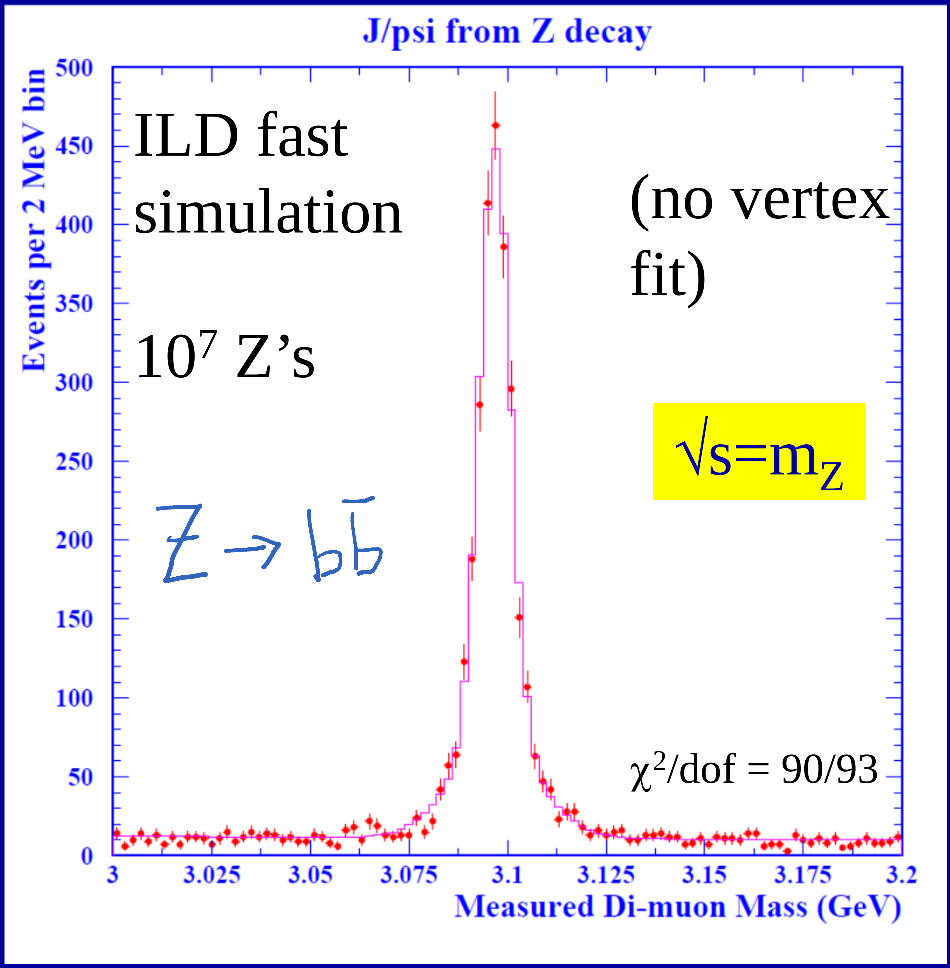
Use J/psi from Z for momentum scale.

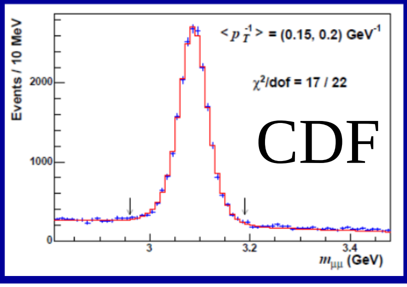
Momentum Scale with J/psi

With 10^9 Z's expect statistical error on mass scale of 1.7 ppm given ILD momentum resolution and vertexing based on fast simulation.

Most of the J/psi's are from B decays. J/psi mass is known to 3.6 ppm. < p > = 20 GeV.

Can envisage also improving on the measurement of the Z mass (23 ppm error)





Double-Gaussian + Linear Fit

Full Simulation + Kalman Filter

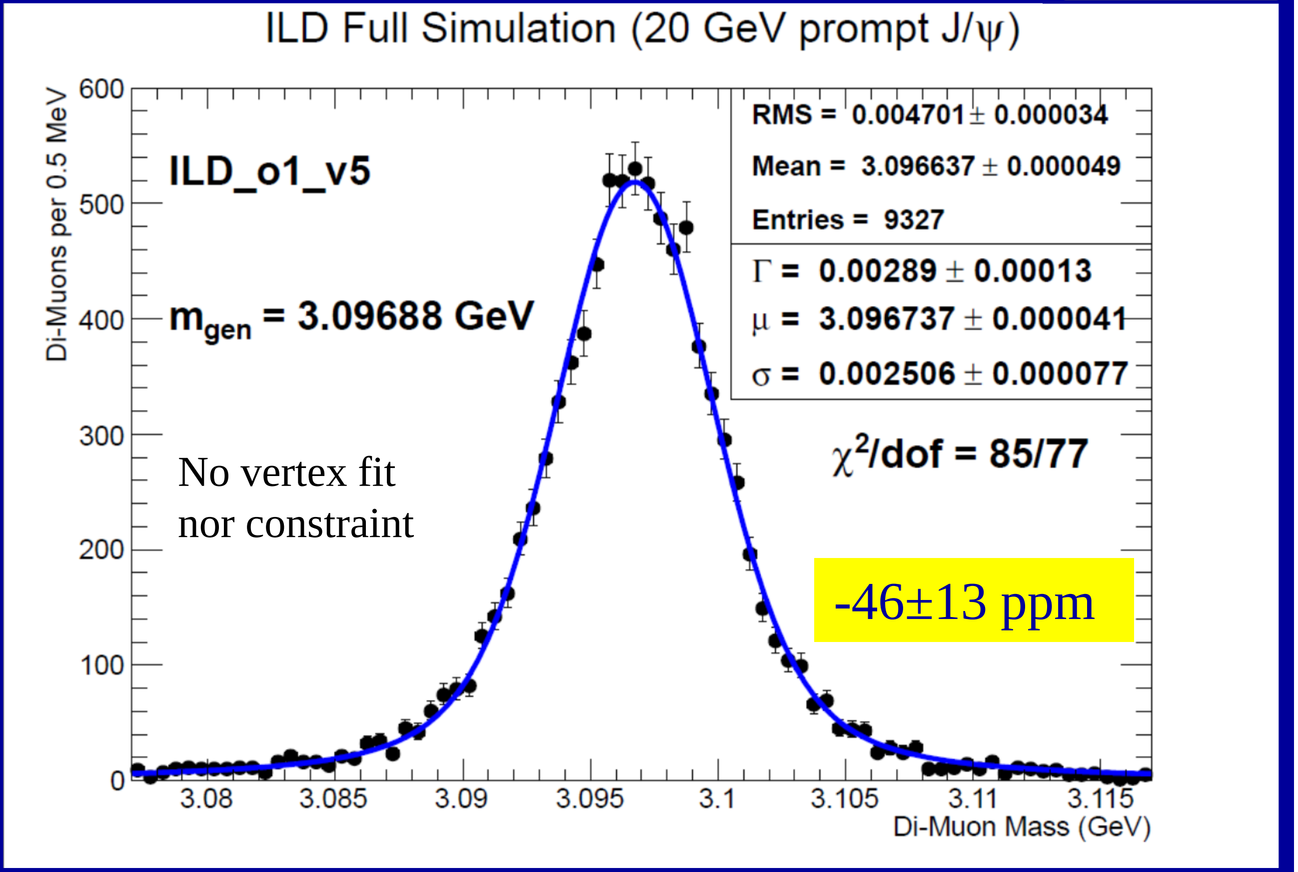
10k “single particle events”

$\sqrt{s}=m_Z$

Work in progress – likely need to pay attention to issues like energy loss model and FSR.

Preliminary statistical precision similar.

More realistic material, energy loss and multiple scattering.

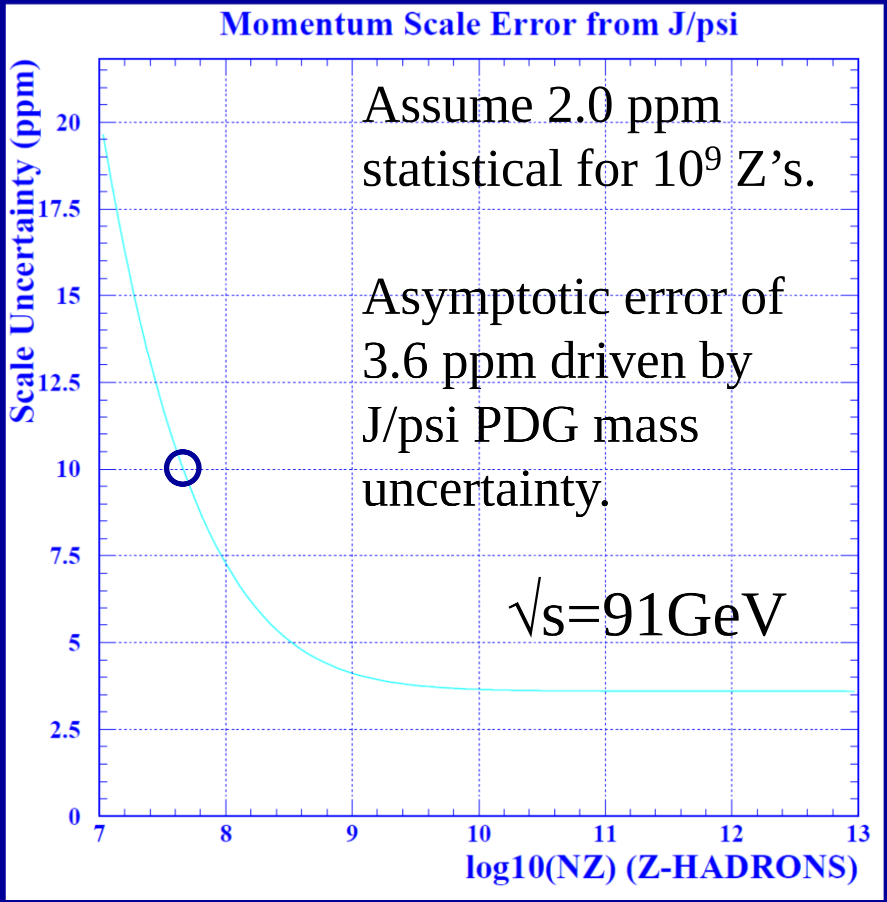


Empirical Voigtian fit.

Need consistent material model in simulation AND reconstruction

“Calibration” Run at $\sqrt{s}=m_Z$ for detector p-scale calibration

If detector is stable and not pushed, pulled and shaken, one could hope that such a calibration could be maintained long term at high energy.

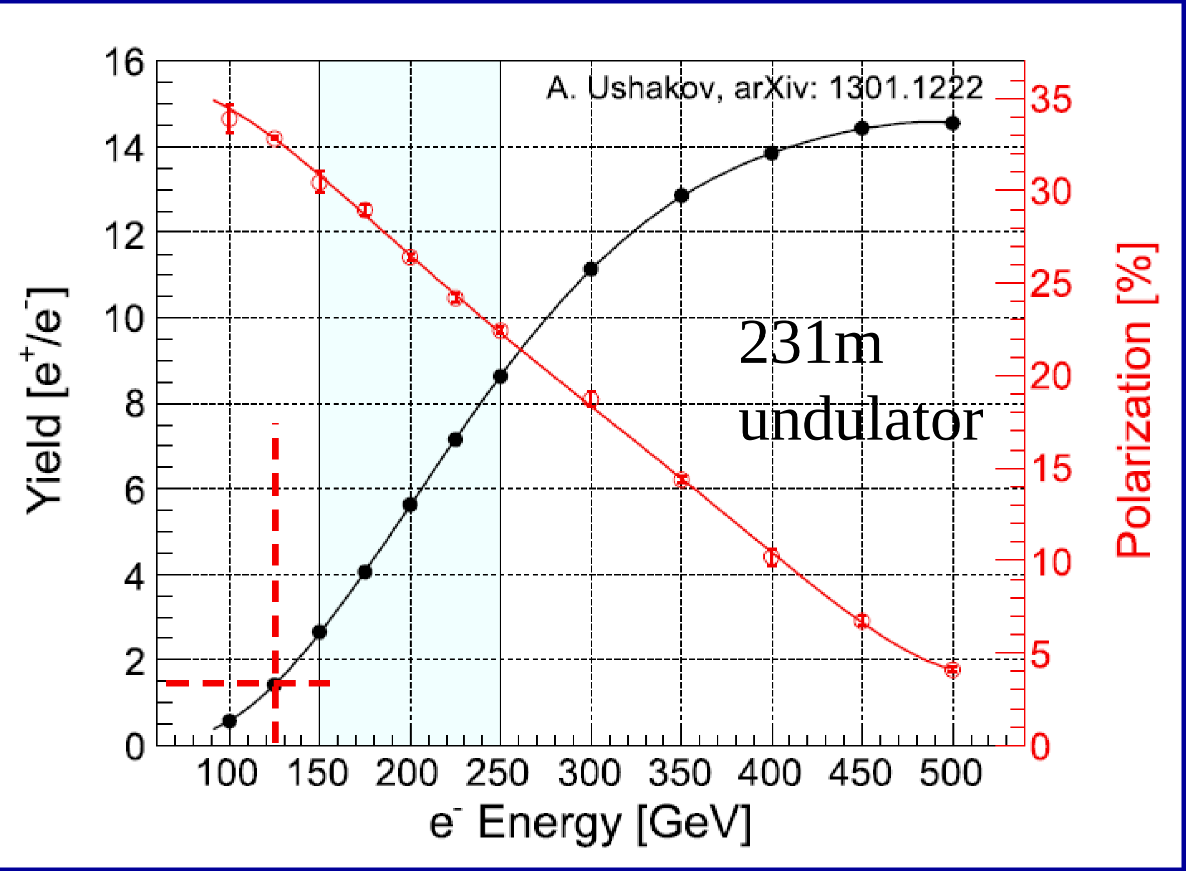


Plot assumes negligible systematics from tracking modeling …

$\Rightarrow$ Need at least 40 M hadronic Z’s for 10 ppm

$\Rightarrow$ Corresponds to $\geq 1.3\ fb^{-1}$ ($L \geq 1.3 \times 10^{33}$ for 10^6s) assuming unpolarized beams

Positron Source



For √s ≪ 250 GeV, still need a high energy e^- beam for adequate e^+ production.