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Fermion Loops, conserved currents and single-W

- Introduction
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- Single W
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- FL and Non Conserved Currents
- Conclusions

Loops and Legs 2000
Bastei/Königstein
April 2000

Introduction

Unstable particles and gauge invariance:

Use of width ($i\Gamma M$) in s-channel propagators necessary to prevent divergences.

Destroys gauge invariance.

Various examples of numerical relevance at tree level with four fermion final states:

- WW production at high energies (gauge cancellations among CC03 diagrams) ∘
- t channel contributions at low e^- angle ∘
  gauge invariance determines t behaviour
  Relevant for final states like $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$
  with e^- undetected : single-W.

In such cases broken gauge invariance may easily give results totally wrong (not %).
Various Gauge restoring methods:

Fixed width(FW): In all massive-boson propagators

$$M^2 \;\to\; M^2 - i\Gamma M$$

This gives an unphysical width in t channel, but retains U(1) gauge invariance.

Complex Mass(CM): $M^2 \rightarrow M^2 - i\Gamma M$ not only in propagators but also in coupling relations. As before, but preserves both U(1) and SU(2) Ward identities .

Overall scheme(OA): When resonant propagators are present, multiply all diagrams (not only resonant ones) by $(q^2 - M^2)/(q^2 - M^2 + iM\Gamma)$.

Retains gauge invariance but mistreats non resonant terms.

...

Fermion LOOP Use at least Im of all (propagators and vertices) fermion loop corrections together with resummed boson propagators.

Only scheme fully consistent and justified in FT.

The real part of FL can be added as it consitutes a gi subset of radiative corrections.

Review FL and application to Single W processes.
Latest results which take into account current non conservation (massive external fermions)

Fermion Loop

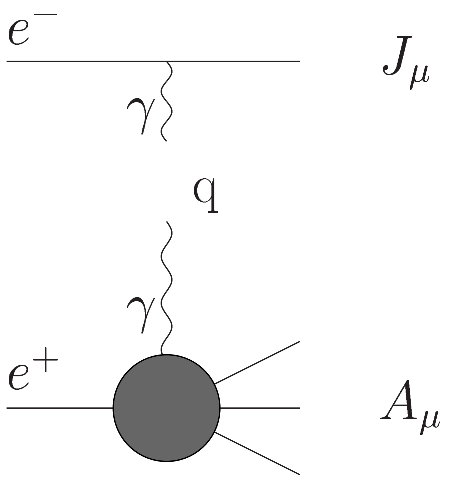
Application of FL to 4f processes

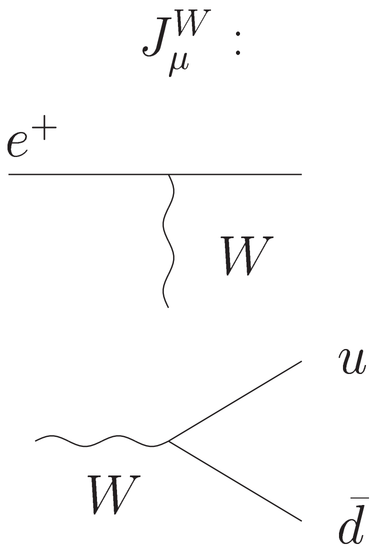
(Argyres et al, Beenakker et al,...BHF)

IFL

Case study CC20: $e^- e^+ \to e^- \bar{\nu}_e u \bar{d}$

Massless external fermions $\to$ Conserved currents (J^W_μ).



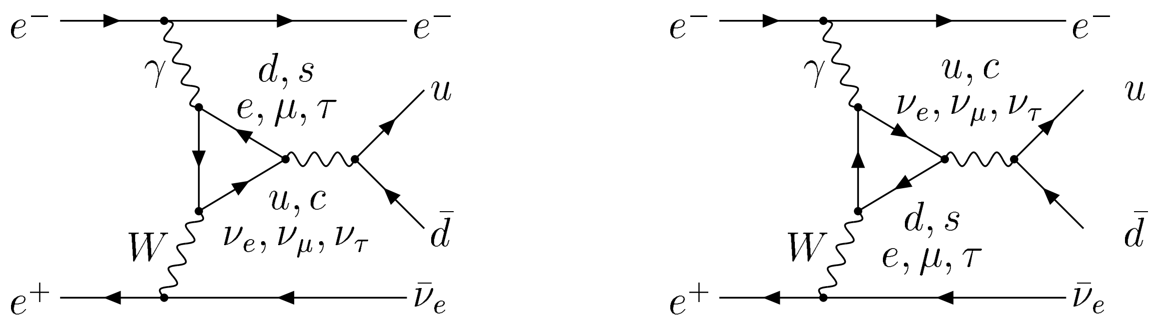


In this approximation WI $q \cdot A = 0 \to$ satisfied with

Fixed width $i\Gamma M$

No physical justification

Im FL: Resum Im part of fermionic loop corrections in propagators and add Im part of



Minimum for restoring gauge invariance.

With massles internal fermions in diagrams above and for decay width, $i\frac{\Gamma p^2}{M}$ in propagators satisfies gauge invariance.

Used in numerical applications for CC20

FL

BHF has computed also full FL corrections.

Again in massless external fermion approximaton, but with massive internal fermions in loops.

Renormalization of gauge boson masses at their (gi) complex poles (Veltman, Stuart).

All corrections can be reabsorbed in running couplings and renormalized propagator functions and triple vertices, so that an effective Born prescription can be used in which tree level type diagrams only appear.

Numerical applications to $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$ at low e^- angle and $e^-e^+ \to \mu^-\bar{\nu}_\mu u\bar{d}$ at high energies show differences from other schemes

At high energies differences also with IFL.

Single W

Processes like

CC20 $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$

CC18 $e^-e^+ \to e^-\bar{\nu}_e \mu^+ \bar{\nu}_m u$

MIX56 $e^-e^+ \to e^-e^+\bar{\nu}_e \nu_e$

relevant not only to WW or ZZ physics, but also when e^- lost in the pipe.

- as a background to searches
- for anomalous coupling studies.
- cross sections measured at LEP2.

  Experimental error still $\sim 10\%$.

Divergent in massless approximation.

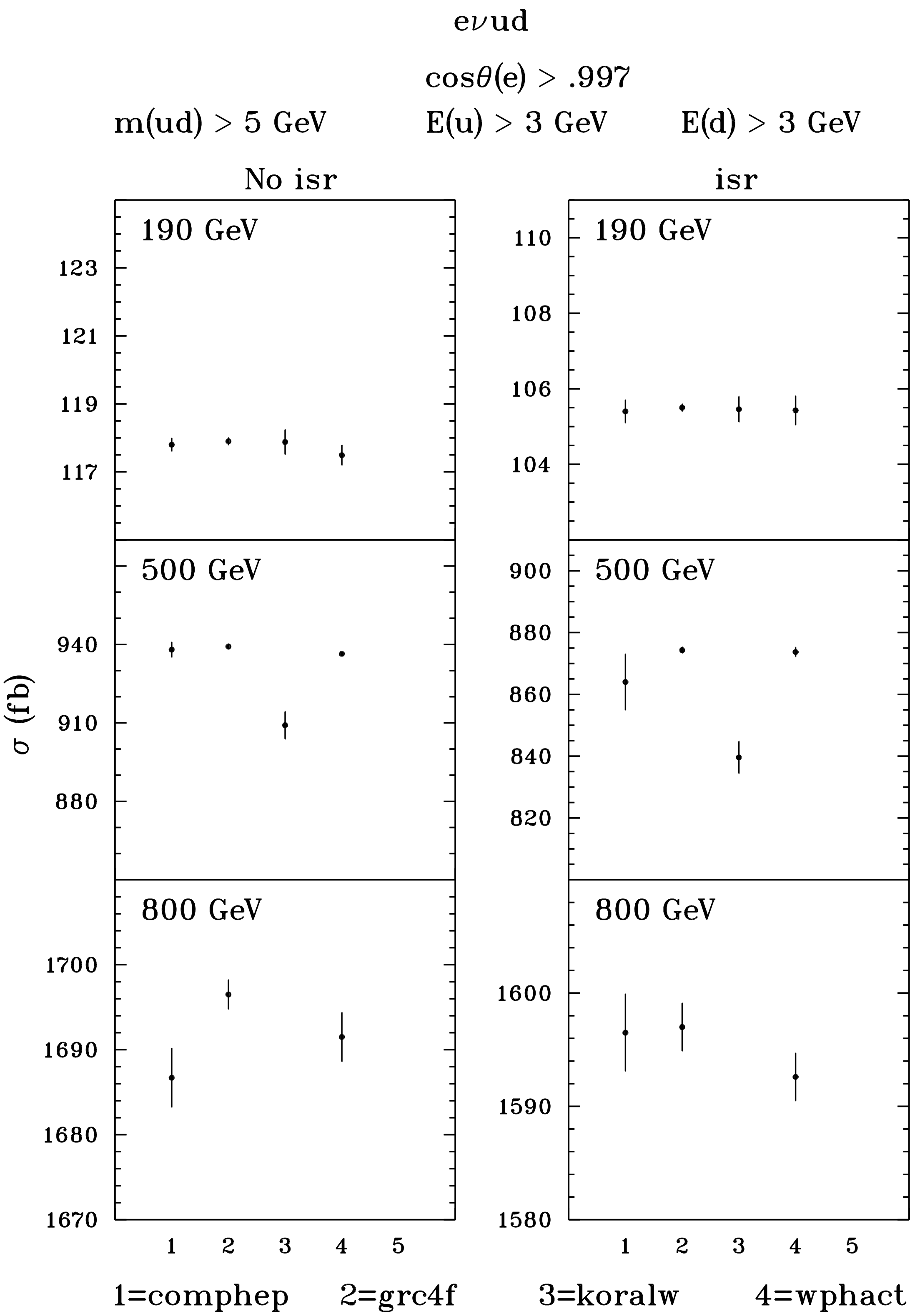
Not only for e but also for u, d, μ

Several fully massive 4f MC now available:

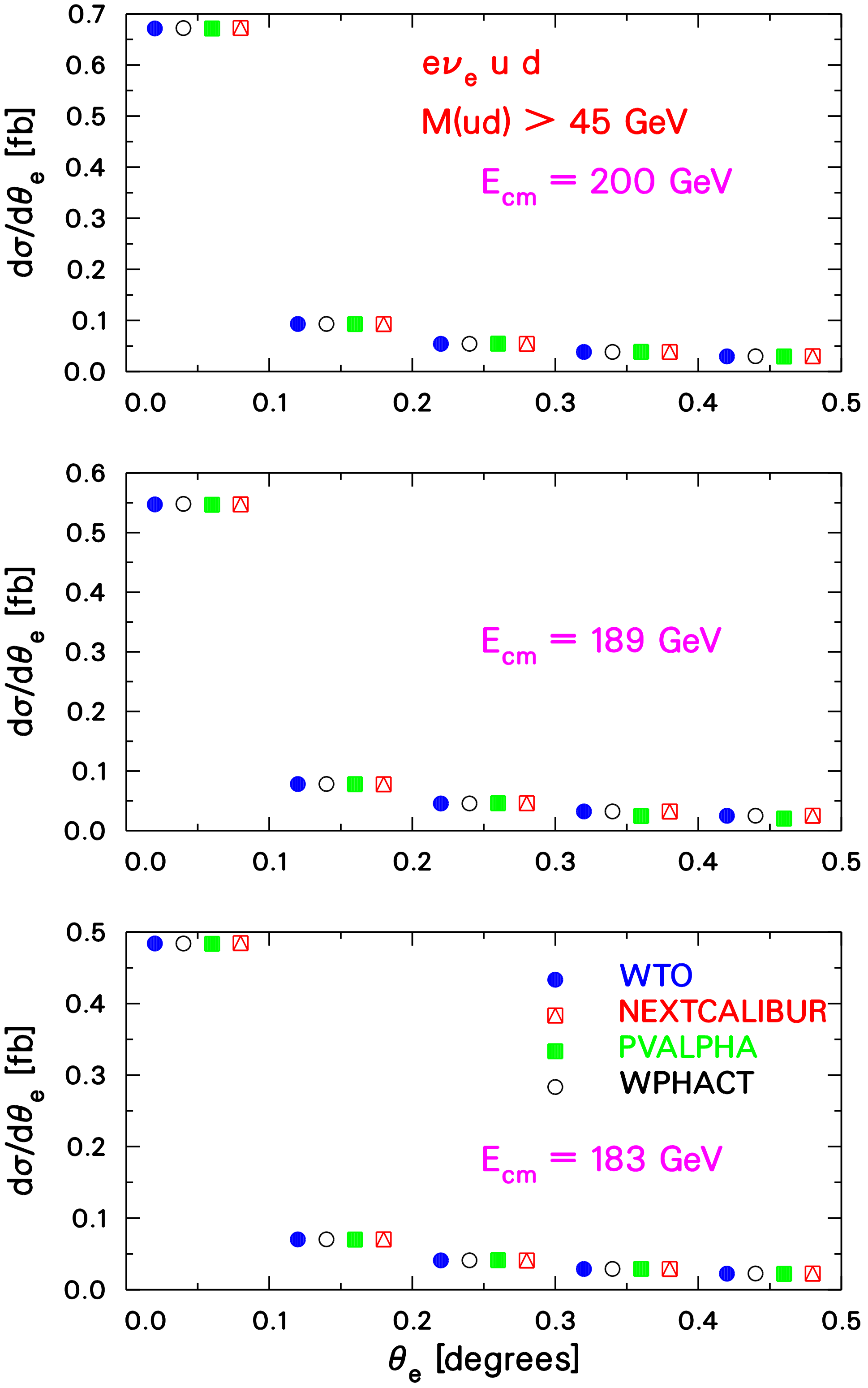
`COMPHEP, GRC4F, KORALW, WPHACT, NEXTCALIBUR, SWAP + WTO` (masses where needed)

Good agreement among them with different gauge restoring schemes

(overall, fixed width, $L_{\mu\nu}$ transform method)



eνud
cosθ(e) > .997
m(ud) > 5 GeV
E(u) > 3 GeV
E(d) > 3 GeV
No isr
isr
190 GeV
500 GeV
800 GeV
σ (fb)
123
121
119
117
110
108
106
104
940
910
880
900
880
860
840
820
1700
1690
1680
1670
1600
1590
1580
1 2 3 4 5
1=comphep
2=grc4f
3=koralw
4=wphact



eνe u d
M(ud) > 45 GeV
Ecm = 200 GeV
Ecm = 189 GeV
Ecm = 183 GeV
WTO
NEXTCALIBUR
PVALPHA
WPHACT
dσ/dθe [fb]
θe [degrees]

IFL and Non Conserved Currents

FL calculations by BHF cannot be used for single W (assumption of conserved currents → massless external fermions).

Numerical studies of massive (Madgraph) ME with Conserved Current FL approximation performed

(Hoogland Van Oldenborgh).

Error should be proportional to m_e.

IFL with fully massive ME and exact non corserved current contributions studied recently

(Accomando, A. B., Maina)

and implemented in `WPHACT`.

Unitary gauge.

For massless internal fermions WI satisfied for fixed width:

$$\frac{-i}{p^2 - M^2 + i\Gamma M_W}\left\{g^{\mu\nu} - \frac{p^\mu p^\nu}{M^2 - i\Gamma M_W}\right\}$$

Resummed propagator is instead

$$\frac{-i}{p^2 - M^2 + i\Pi}\left\{g^{\mu\nu} - \frac{p^\mu p^\nu}{M^2}\left(1 + \frac{i\Pi}{p^2}\right)\right\}$$

with "running width" $\Pi = p^2 \frac{\Gamma_W}{M_W}$.

It properly satisfies WI only if exact IFL triple vertex corrections are computed.

No significant numerical differences with "ad hoc" schemes for cross sections.

Non conserved currents + massive ME lead to inconsistent results at high energies.

	190 GeV	800 GeV	1500 GeV
IFL	0.11815 (13)	1.6978 (15)	3.0414 (35)
FW	0.11798 (11)	1.6948 (12)	3.0453 (41)
CM	0.11791 (12)	1.6953 (16)	3.0529 (60)
OA	0.11760 (10)	1.6953 (13)	3.0401 (23)
IFLCC	0.11813 (12)	1.7987 (16)	5.0706 (44)

Cross sections for $e^+e^- \rightarrow e^-\bar{\nu}_e u\bar{d}$ and various gauge restoring schemes. No ISR.

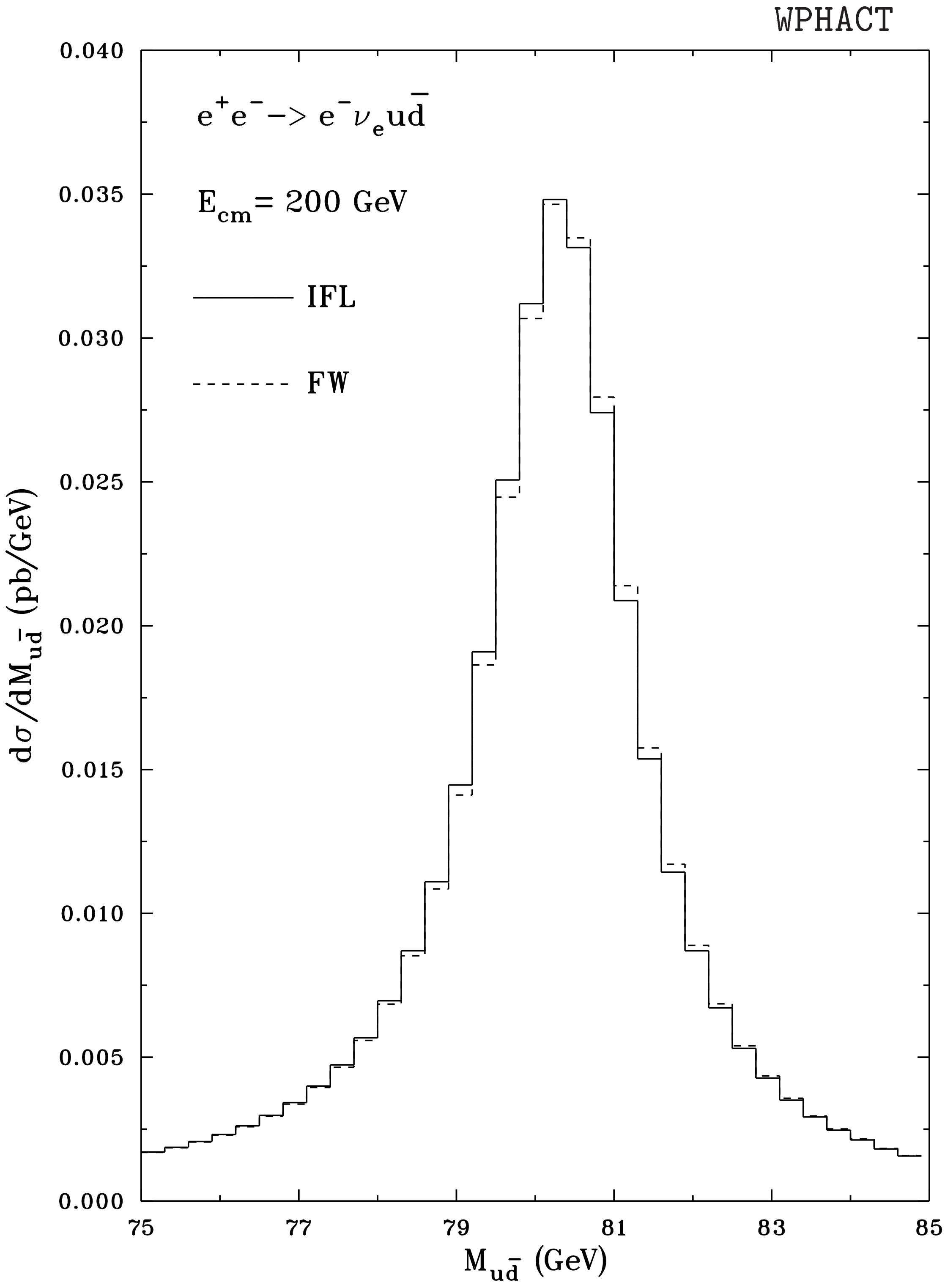
$M(u\bar{d}) > 5$ GeV , $E_u > 3$ GeV, $E_{\bar{d}} > 3$ GeV, $\cos(\theta_e) > .997$

	IFL	FW
$e^-e^+ \rightarrow e^-\bar{\nu}_e u\bar{d} \quad M_{u\bar{d}} > 45$ GeV	0.12043 (10)	0.12041 (11)
$e^-e^+ \rightarrow e^-\bar{\nu}_e u\bar{d} \quad M_{u\bar{d}} < 45$ GeV	0.028585 (14)	0.028564 (14)
$e^-e^+ \rightarrow e^-\bar{\nu}_e \mu^+\nu_\mu$	0.035926 (34)	0.035886 (32)
$e^-e^+ \rightarrow e^-\bar{\nu}_e e^+\nu_e$	0.050209 (38)	0.050145 (32)

Comparison of FW and IFL schemes for different single W cross sections at $\sqrt{s} = 200$ GeV. No ISR.

$|\cos\theta_e| > 0.997$, $E_\mu > 15\,\mathrm{GeV}$, and $|\cos\theta_\mu| < 0.95$.

Mass distributions different:



No ISR. $|\cos\theta_e^-| > 0.997$

FL and Non Conserved Currents

Big theoretical uncertainties for Single W processes, in absence of complete $O(\alpha)$, are connected to the scales of the couplings and to the scale for ISR with dominating t-channel contributions.

Complete FL calculations with massive external fermions (Passarino)

Necessary to answer the first of these problems.

Again complex mass renormalization leads to effective Born calculation.

Besides running couplings and renormalized propagators now also running boson masses needed, defined by

$$\frac{1}{M^2(p^2)} = \frac{1}{M^2} \frac{p^2 - S_W^0 + \frac{M^2}{p^2} S_\phi}{p^2 - S_\phi}$$

which for a massless internal world reduces to

$$M^2(p^2) = \frac{g^2(p^2)}{g^2(p_W)} p_W, \qquad M^2(p_W) = p_W.$$

$$\frac{1}{g^2(s)} = \frac{1}{g^2} - \frac{1}{16\,\pi^2} \Pi_{3Q}(s)$$

Starting with Feynman gauge, complete one loop resummation equivalent to some effective "unitary gauge" W-propagator:

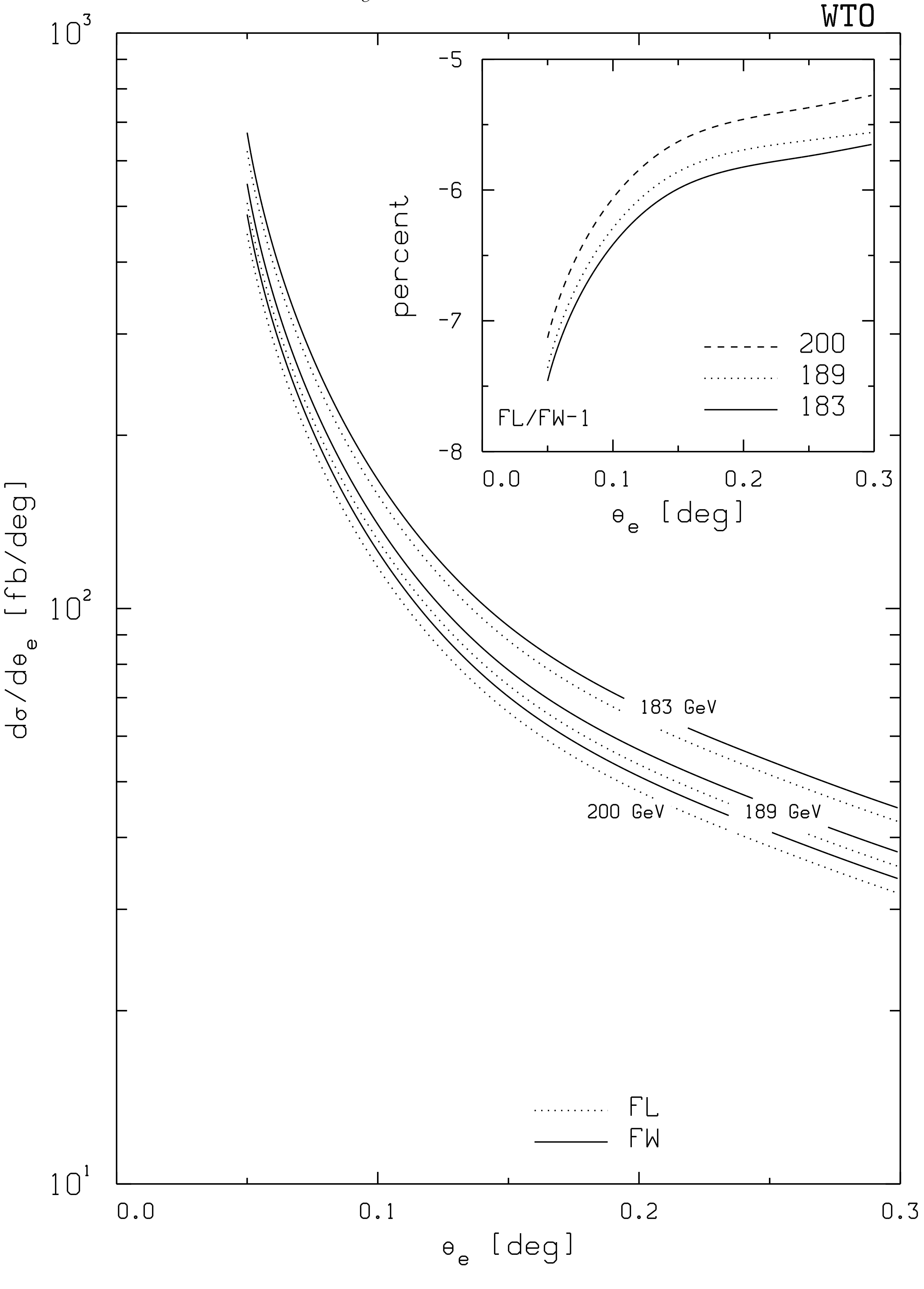
$$\Delta^{\mu\nu}_{\text{eff}} = \frac{1}{p^2 - M^2 + S^0_W}\,[\delta^{\mu\nu} + \frac{p^\mu p^\nu}{M^2(p^2)}].$$

FL implemented in `WTO` for $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$ and $e^-e^+ \to e^-\bar{\nu}_e \mu^+\bar{\nu}_m u$.

Masses are accounted for "when needed": in t channel γ exchange diagrams for $log(m^2/s)$ and constant contributions.

Results. Expected differences with G_f tree level scheme are up to $\sim 7\%$

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



$M(u\bar{d}) > 45\,\mathrm{GeV}$

One may expect that the bulk of the differences comes from α running effects.

$\alpha(t)$ with IFL (IFLα) implemented in `WPHACT` for t-channel contribution only.

For cuts used at LEP2 energies, this seems to be the case for $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$.

$\sqrt{s}$	FW	IFL	IFLα	FL	FL/FW-1 (percent)
183 GeV	88.17(44)	88.50(4)	83.26(5)	83.28(6)	-5.5(5)
189 GeV	98.45(25)	99.26(4)	93.60(9)	93.79(7)	-4.7(3)
200 GeV	119.77(67)	120.43(10)	113.24(8)	113.67(8)	-5.1(5)

Total single-W cross-section in fb for $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$, for $M(u\bar{d}) >$ 45 GeV and $|\cos\theta_e| > 0.997$.No ISR.

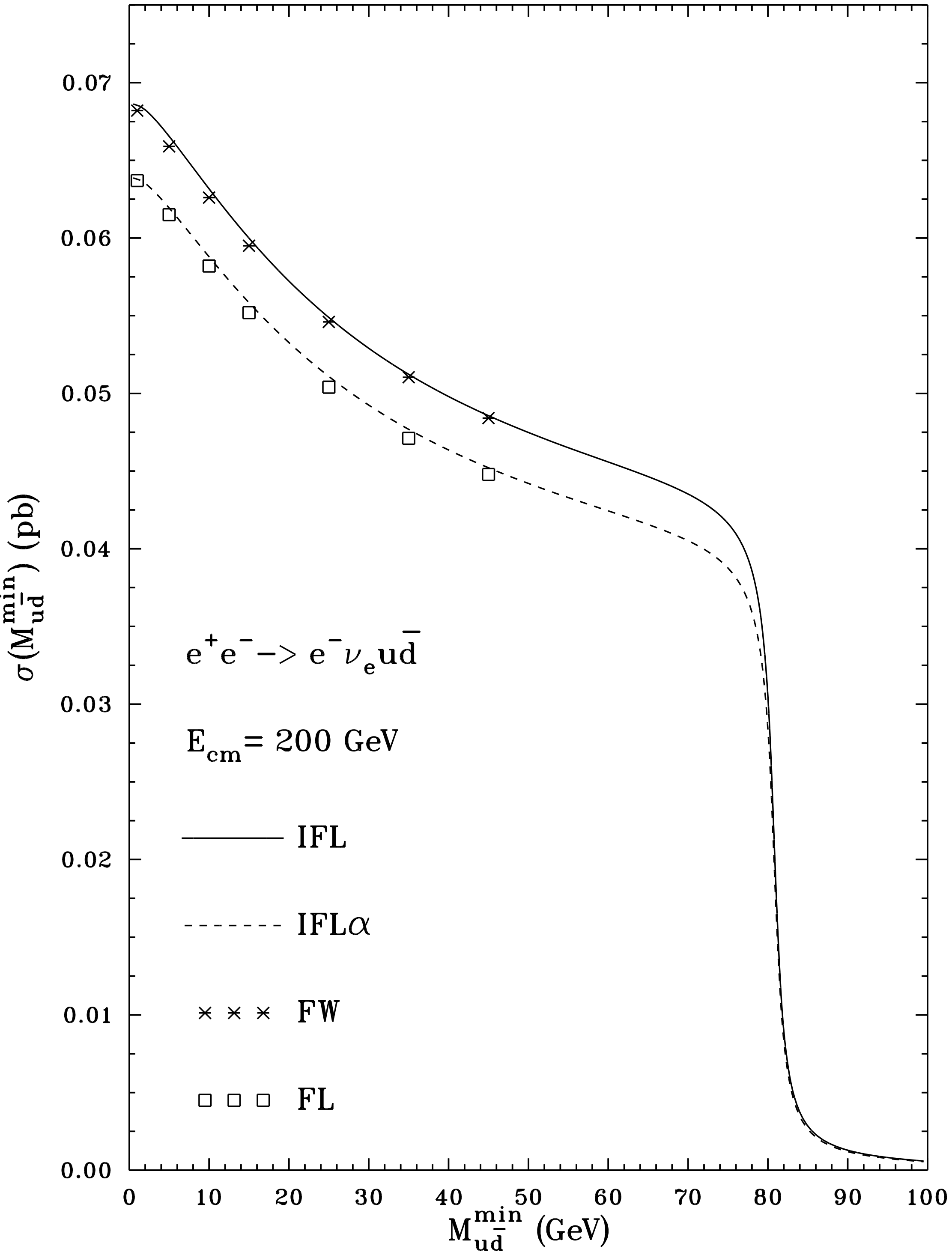
FW and FL are computed by `WTO`, IFL and IFLα by `WPHACT`.

Also for angular distributions

θ_e [Deg]	FW	IFL	IFLα	FL	FL/FW-1 (percent)
$0.0^\circ \div 0.1^\circ$	0.67147	0.67077	0.62404	0.62357	-7.13
$0.1^\circ \div 0.2^\circ$	0.09323	0.09321	0.08753	0.08798	-5.63
$0.2^\circ \div 0.3^\circ$	0.05433	0.05455	0.05141	0.05141	-5.37
$0.3^\circ \div 0.4^\circ$	0.03845	0.03867	0.03624	0.03646	-5.18

$d\sigma/d\theta_e$ [pb/degrees] for $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$. $M(u\bar{d}) > 45\,\text{GeV}$, $\sqrt{s}$=200 GeV. No ISR.
FW and FL computed by `WTO`, IFL and IFLα by `WPHACT`.

and down to the lowest $M(u\bar{d})$ invariant mass.



Total cross section for $\theta_e < 0.1^\circ$ as a function of the lower cut on $\mathrm{M}_{u\bar{d}}$ in IFL and IFLα schemes. Curves computed with `WPHACT`. Markers give the results of FW and FL by `WTO`.

For $e^-e^+ \to e^-\bar{\nu}_e\mu^+\bar{\nu}_\mu$ 2-3% difference between FL and IFLα remains both in cross sections

$\sqrt{s}$	FW	IFL	IFLα	FL	FL/FW-1 (percent)
183 GeV	26.77(14)	26.45(1)	24.90(1)	25.53(4)	-4.6(5)
189 GeV	29.73(14)	29.70(2)	27.98(2)	28.78(4)	-3.2(5)
200 GeV	36.45(23)	35.93(4)	33.85(4)	34.97(6)	-4.1(6)

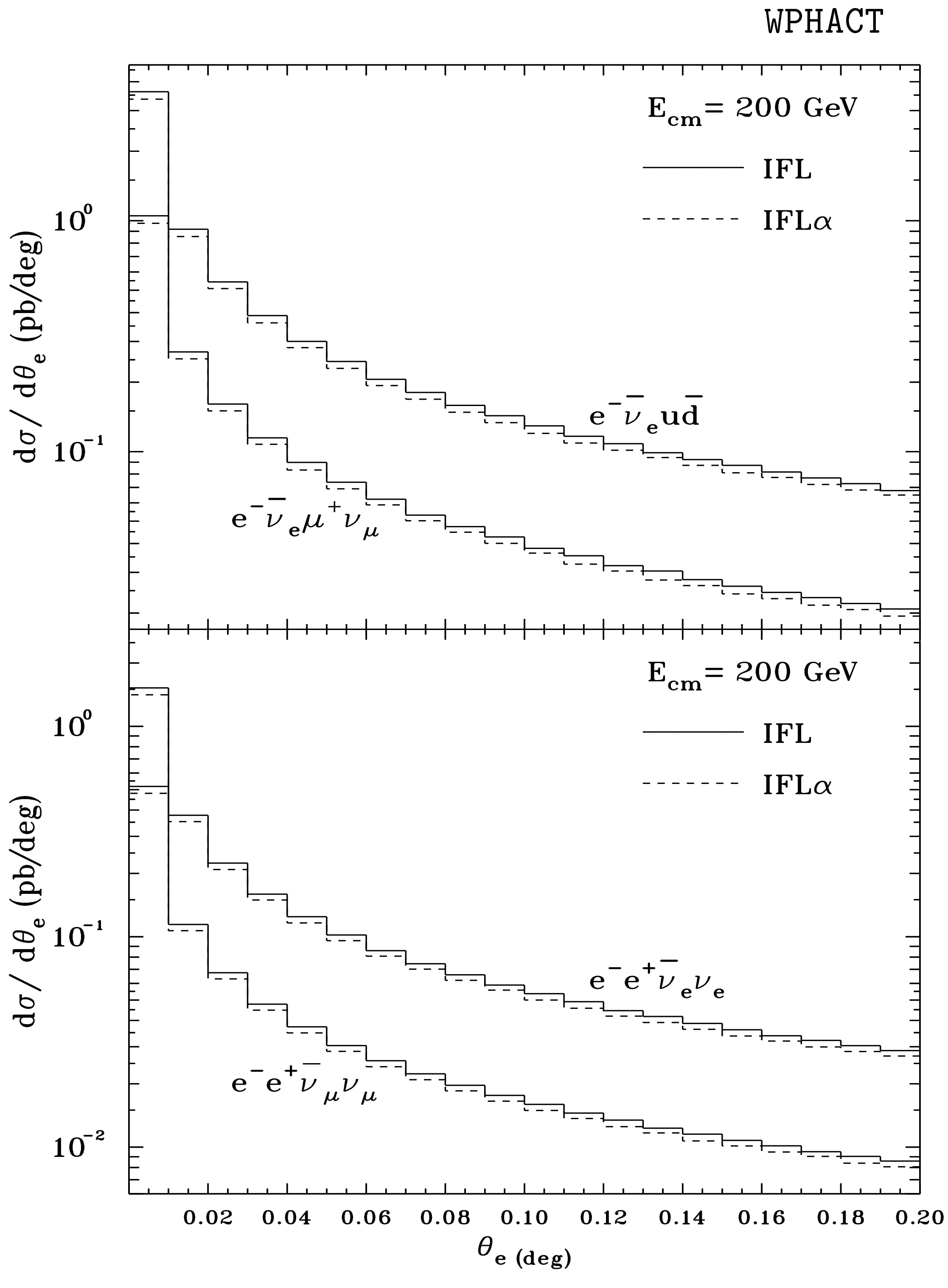
Total single-W cross-section in fb for $e^+e^- \to e^-\bar{\nu}_e\mu^+\nu_\mu$, for $|\cos\theta_e| > 0.997$, $E_\mu > 15\,\mathrm{GeV}$, and $|\cos\theta_\mu| < 0.95$. No ISR.
FW and FL are computed by `WTO`, IFL and IFLα by `WPHACT`.

and in angular distributions.

θ_e [Deg]	FW	IFL	IFLα	FL	FL/FW-1 (percent)
$0.0^\circ \div 0.1^\circ$	0.14154	0.14170	0.1319	0.13448	-4.99
$0.1^\circ \div 0.2^\circ$	0.02113	0.02117	0.01987	0.02031	-3.88
$0.2^\circ \div 0.3^\circ$	0.01238	0.01240	0.01166	0.01194	-3.55
$0.3^\circ \div 0.4^\circ$	0.00880	0.00879	0.00830	0.00851	-3.30

$d\sigma/d\theta_e$ in [pb/degrees] for $e^+e^- \to e^-\bar{\nu}_e\nu_\mu\mu^+$, for $|\cos\theta_e| > 0.997$, $E_\mu > 15\,\mathrm{GeV}$, and $|\cos\theta_\mu| < 0.95$. $\sqrt{s} = 183\,\mathrm{GeV}$. No ISR.
FW and FL are computed by **WTO**, IFL and IFLα by **WPHACT**.

A much better agreement in this case if only α running used only at one vertex in t channel. Purely accidental. Used to extimate theoretical uncertainties of IFLα calculations for $e^+e^- \to e^+e^-\nu\bar{\nu}$ where FL corrections not available yet.



Angular distributions for different single W processes at $\sqrt{s} = 200$ GeV in the IFL and IFLα scheme.

Conclusions

FL extended to massive external fermions in 4f physics.

With it calculations can be performed dow to $\theta_e = 0$.

Single W is one of the main applications.

IFL shows that "ad hoc" gauge restoring schemes are reliable for total cross sections but not for distributions.

Complete FL are a gauge invariant subset of radiative corrections.

Its results differ from G_f scheme by several percent for single W.

IFL + α running for t channel reproduces FL results at less than 1% level for $e^-e^+ \to e^-\bar{\nu}_e u\bar{d}$ and at 2-3% for $e^-e^+ \to e^-\bar{\nu}_e\mu^+\bar{\nu}_\mu$.

Further theoretical uncertainties for single W connected with ISR in t-channel dominated processes (PV, Grace).

Further analyses and improvements needed for LC.