WTO 2.1 - Summary of upgrading

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September 6, 1999

Abstract

Version 2.1 of `WTO` has been restored; it contains:

- WTO 1.0 plus
- + Event generation
- + Interface with JETSET 7.4
- + Fermion loop
- + Basic MSSM
- + TGC
- + CKM-mixing

Note: restoring of single W is not yet active.

1 Structure of the code

`WTO` must be linked with `JETSET` and with `NAGLIB`. The structure of the code is as follows:

1. call `WTOINIT(IPR,OXC,RS,WM,ZM)` for initialization;
2. call `WTOCOPT(OFLAG,IVAL)` to reset the I/O parameters `IOS, IOSF, IPM, IRM`;
3. call `WTOCFLAG(***)` to reset `character*(*)` parameters;
4. call `WTOSOPT(OFLAG,VAL)` to reset MSSM parameters;
5. call `WTOCUTSET(***)` to reset kinematicalcuts;
6. call `wtoacopt(***)` to set A(nomalous)C(ouplings);
7. call `WTO(***)` to run the code;
8. call `wtooutput(ipr)` for printout '

2 I/O parameters of `WTO`

The input parameters of subroutine `WTO` are:

`RS` $\sqrt{s}$, the c.m.s. energy;

`WM` M_W the W mass;

`ZM` M_Z the Z mass;

`ZG` Γ_Z the Z width;

`TQM` m_t the top-quark mass;

`HM` M_H the H mass;

`ALSZ` $\alpha_S(M_Z^2)$;

The input parameters of subroutine `WTOINIT` are `IPR,OXC,RS`; `IPR` and `OXC` are as follows (i.e. available processes are):

- `IPR= 1` $\mu^-, \overline{\nu}_\mu, \nu_\tau, \tau^+$
- `IPR= 2` $\mu^-, \overline{\nu}_\mu, u, \overline{d}$
- `IPR= 3` $d, \overline{u}, c, \overline{s}^{**}$
- `IPR= 4` $e^-, \overline{\nu}_e, \nu_\mu, \mu^+$
- `IPR= 5` $e^-, \overline{\nu}_e, u, \overline{d}$
- `IPR= 6` $\mu^-, \mu^+, \nu_\tau, \overline{\nu}_\tau$
- `IPR= 7` $d, \overline{d}, \nu_\mu, \overline{\nu}_\mu$
- `IPR= 8` $u, \overline{u}, \nu_\mu, \overline{\nu}_\mu$
- `IPR= 9` $\mu^-, \mu^+, \tau^-, \tau^+$
- `IPR= 10` $\mu^-, \mu^+, d, \overline{d}$
- `IPR= 11` $\mu^-, \mu^+, u, \overline{u}$
- `IPR= 12` $\nu_\mu, \overline{\nu}_\mu, \nu_\tau, \overline{\nu}_\tau$
- `IPR= 13` $s, \overline{s}, u, \overline{u}$
- `IPR= 14` $d, \overline{d}, s, \overline{s}$
- `IPR= 15` $u, \overline{u}, c, \overline{c}$
- `IPR= 16` $\nu_\mu, \overline{\nu}_\mu, \nu_e, \overline{\nu}_e$
- `IPR= 17` $\mu^-, \mu^+, \nu_e, \overline{\nu}_e$

- IPR= 18 $u, \overline{u}, \nu_e, \overline{\nu}_e$
- IPR= 19 $d, \overline{d}, \nu_e, \overline{\nu}_e$
- IPR= 20 $\mu^-, \overline{\nu}_\mu, \nu_\mu, \mu^+$
- IPR= 21 $d, \overline{u}, u, \overline{d}^{**}$
- IPR= 22 μ^-, μ^+, e^-, e^+
- IPR= 23 $\nu_\mu, \overline{\nu}_\mu, e^-, e^+$
- IPR= 24 $u, \overline{u}, e^-, e^+$
- IPR= 25 $d, \overline{d}, e^-, e^+$
- IPR= 26 $\mu^-, \mu^+, \mu^-, \mu^+$
- IPR= 27 $\nu_\mu, \overline{\nu}_\mu, \nu_\mu, \overline{\nu}_\mu$
- IPR= 28 $u, \overline{u}, u, \overline{u}$
- IPR= 29 $d, \overline{d}, d, \overline{d}$
- IPR= 30 $b, \overline{b}, \nu_\mu, \overline{\nu}_\mu{}^*$
- IPR= 31 $\mu^-, \mu^+, b, \overline{b}^*$
- IPR= 32 $b, \overline{b}, \nu_e, \overline{\nu}_e{}^*$
- IPR= 33 $b, \overline{b}, e^-, e^{+*}$
- IPR= 34 $u, \overline{u}, b, \overline{b}$
- IPR= 35 $d, \overline{d}, b, \overline{b}$
- IPR= 36 $b, \overline{b}, b, \overline{b}^*$
- IPR= 37 $\tau^-, \tau^+, b, \overline{b}^*$
- IPR= 38 $\tau^-, \overline{\nu}_\tau, c, \overline{s}^*$

All processes marked with * are also realized in the MSSM. With `IPR.LE.3` and `IPRO = 0`(DEFAULT `1`) the *CC03* processes are selected. Furthermore,

- `IPR= 1-5` $\rightarrow$ `OXC = C`;
- `IPR= 6-19` $\rightarrow$ `OXC = N`;
- `IPR= 20-21` $\rightarrow$ `OXC = M`;
- `IPR= 22-37` $\rightarrow$ `OXC = N`;
- `IPR= 38` $\rightarrow$ `OXC = C`.

3 CKM-mixing

$\boxed{New}$, for including the CKM-mixing one should set `OCKM = Y` through `WTOCFLAG(***)` and call `WTOCKM(VCKM)` to initialize the matrix elements `VCKM(3,3)`. With CKM-mixing processes are specified by `ICKM`: the calling sequence is, therefore:

```
OF= 'OCKM'
OV= 'Y'
CALL WTOCFLAG(RS,OF,OV,ICKM,-1,-1.D0,-1.D0)
```

Allowed processes are:

`IPR = 2 :`

`ICKM = 1`	$\mu^-, \overline{\nu}_\mu, u, \overline{d}$
`ICKM = 2`	$\mu^-, \overline{\nu}_\mu, u, \overline{s}$
`ICKM = 3`	$\mu^-, \overline{\nu}_\mu, u, \overline{b}$
`ICKM = 4`	$\mu^-, \overline{\nu}_\mu, c, \overline{d}$
`ICKM = 5`	$\mu^-, \overline{\nu}_\mu, c, \overline{s}$
`ICKM = 6`	$\mu^-, \overline{\nu}_\mu, c, \overline{b}$

`IPR = 3 :` '

`ICKM = 1`	$d, \overline{u}, c, \overline{s}$
`ICKM = 2`	$d, \overline{u}, c, \overline{d}$
`ICKM = 3`	$d, \overline{u}, c, \overline{b}$
`ICKM = 4`	$s, \overline{u}, c, \overline{s}$
`ICKM = 5`	$s, \overline{u}, c, \overline{d}$
`ICKM = 6`	$s, \overline{u}, c, \overline{b}$
`ICKM = 7`	$b, \overline{u}, c, \overline{s}$
`ICKM = 8`	$b, \overline{u}, c, \overline{d}$
`ICKM = 9`	$b, \overline{u}, c, \overline{b}$
`ICKM = 10`	$d, \overline{u}, u, \overline{s}$
`ICKM = 11`	$d, \overline{u}, u, \overline{b}$
`ICKM = 12`	$s, \overline{u}, u, \overline{b}$
`ICKM = 13`	$d, \overline{c}, c, \overline{s}$
`ICKM = 14`	$d, \overline{c}, c, \overline{b}$
`ICKM = 15`	$s, \overline{c}, c, \overline{b}$

$\mathrm{IPR} = 5$:

`ICKM = 1`	$e^-, \overline{\nu}_e, u, \overline{d}$

ICKM = 2 $e^-, \overline{\nu}_e, u, \overline{s}$

ICKM = 3 $e^-, \overline{\nu}_e, u, \overline{b}$

ICKM = 4 $e^-, \overline{\nu}_e, c, \overline{d}$

ICKM = 5 $e^-, \overline{\nu}_e, c, \overline{s}$

ICKM = 6 $e^-, \overline{\nu}_e, c, \overline{b}$

IPR = 21 :

ICKM = 1 $d, \overline{u}, u, \overline{d}$

ICKM = 2 $s, \overline{u}, u, \overline{s}$

ICKM = 3 $b, \overline{u}, u, \overline{b}$

ICKM = 4 $d, \overline{c}, c, \overline{d}$

ICKM = 5 $s, \overline{c}, c, \overline{s}$

ICKM = 6 $b, \overline{c}, c, \overline{b}$

4 Flags

`IPM,IRM` Number of points and of iterations for the integration. My favorite choices are $(7,6)/(8,6)/(9,6)$ which means increasing precision and increasing CPU time.

`OWW,OZZ` Allow you to have fixed W, Z widths; choices are: `R`(unning) (DEFAULT), `F`(ixed) and `I`(mproved). The last two are theorist madness, do not use them unless you want a safe estimate at small scattering angles in *CC20* or at high energy in *CC11/CC20*.

`OPEAKA` Allows you for a special treatment of some diagrams at very small scattering angles, is a theorist madness, do not use it.

`OPGLU= N` (`Y` = DEFAULT) allows to switch off all diagrams with internal gluons.

`OM` = `E` is evaluation, = `G` is generation of events.

`OSM` If you generate events then you first set `OSM = N`, and call `WTO` which computes the cross-sections and the maxima. A file `DUMMY.DAT` is created where they are stored. Next you really generate, calling again `WTO` with `OSM = G`.

`OSTOP` = `S`(DEFAULT) or `I`. If = `I` then an improved calculation of the maxima is performed.

`ITMX` You generate a number of events equal to `ITMX`.

`OSEED` = `Y`(DEFAULT), you do not get the same `ITMX` events for every run.

The calling procedure is therefore:

```
CALL WTOINIT(***)
OFLAG= 'OM'
OVAL= 'Y'
CALL WTOCFLAG(***)
CALL WTO(***)
OFLAG= 'OSM'
OVAL= 'G'
CALL WTOCFLAG(***)
CALL WTO(***)
```

`OSTORE` = `I`(DEFAULT). STORAGING: Mandelstam invariants are stored in the file `INV.DAT`. $\boxed{\textit{New}}$, `OSTORE = M`. Momenta are stored in the file `MOM.DAT` with the squared amplitude for the event. For *Mix43* (`IPR = 21`) and for *NC64* (`IPR = 28-29`) and `OINT = Y`(DEFAULT = `N`) stored are: `AMPS, AMPS1, AMPS2` corresponding to `ATOTSQ, A1SQ, A2SQ` of subroutine `LU4FRM`. In this case gluons should be switched off. ' For all processes but the previous ones one must set `ISTRAT = 0`. So far this represents a problem for $4b$ due to diagrams with Higgses; THUS: do NOT generate $4b$ + interface with `LU4FRM`. If `OSTORE = M` and `OSMASS = Y` then FS masses must be supplied (in `WTO` ordering) and momenta are scaled. `OSTORE = D`. Built-in configurations are stored in `XXX.DAT`. $\boxed{\textit{New}}$, when `OSTORE = M` is set then a call to `WTOCALLJS` is performed. It reads all relevant variables from `MOM.DAT` and a call is performed to `LU4FRM`. In version 2.2 there is a subroutine (in `WTO21IO`) `WTJETSETINI`. The user may set his own switches to `JETSET`.

`OPEAK` Mapping of the resonating peaks, to be used when the resonating diagrams dominate.

`OQCD` Final state naive QCD corrections.

`IQCD` For most of the processes you are allowed to have 3 choices:

`IQCD = 0` , α_s is fixed and corrections applied only to double resonant diagrams,

`IQCD = 1` (DEFAULT) α_s fixed and all diagrams are corrected,

`IQCD = 2` α_s is running at the scale fixed ' by the invariant mass of that $\overline{q}q$ pair.

`OFL` Gauge restoring (Fermion Loop) corrections in *CC11/CC20* at small scattering angles and/or high energies (very CPU time consuming). DEFAULT (no corrections) is `N`. Otherwise there are many different implementations. The user is strongly invited to avoid intermediate steps and to run (eventually) the complete corrections `OFL = C` with only two options:

`RIO = A` all corrections;

RIO = I imaginary parts only.

Additionally one has to specify:'

OTOP = F , fixed top mass to be entered;

OTOP = D , top mass derived from a consistency relation by the code.

Any chain but OFL = N requires OWW,OZZ= R. To summarize:

OFL = N is the DEFAULT, no corrections;

OFL = E an effective and quick gauge restoring for *CC20* at small scattering angle;

OFL = C , and RIO = A,I are the full(imaginary) corrections.

IOS Controls the renormalization scheme, i.e. the choice of input parameters. Options are:

IOS = 1 , α-scheme – coupling constant in terms of α(scale), you may choose α with ORAL = F and ALWI = $1/\alpha_{\rm QED}$ or let it run at a scale = $E_{\rm cm}$ with ORAL = R;

IOS = 2 . It is the G_F scheme (DEFAULT).

IOS = 3 . LEP 1 scheme – almost as α-scheme but for internal photons α willbe evaluated at the corresponding scale (useful if photons dominate). General usage should be avoided.'

IOSF several options:

IOSF = 0 Born, while IOSF > 0 includes IS QED radiation in different schemes;

IOSF = 1 is the β-scheme (DEFAULT);

IOSF = 2 is the η-scheme;

IOSF = 3 is the mixed-scheme.

OCOUL = Y (N DEFAULT) sets the Coulomb term.

ITC = 0 Is the DEFAULT for computing the cross-section. Other values select particular distributions. Not for general use.

OBIN DEFAULT is N. It could be used for producing differential distributions. Not for general use.

OMDIST = Y (N = DEFAULT) allows the following procedure: FS four-momenta must be supplied and the code returns the multi-distribution for the configuration integrated over ISR. Calling procedure will be: ' The matrix ARRMOM(4,4) has to be supplied, where the first index is Lorentz while the second labels the final state. BEWARE of the metric: $q^2 = q_i * q_i - q_4^2$. Then:

```
OFLAG = OMDIST
OVAL = 'Y'
CALL WTOMULTID(RS,OFLAG,OVAL,ARRMOM)
```

5 anomalous couplings

Anomalous couplings are obtainable with `OFL = A` with the further specification of `OANOM = F`(ull),`R(estricted)`. The full set of AC is:

`ACG1G` g_1^γ

`ACLG` λ_γ

`ACKG` κ_γ

`ACG4G` g_4^γ

`ACKTG` $\tilde{\kappa}_\gamma$

`ACLTG` $\tilde{\lambda}_\gamma$

`ACG5G` g_5^γ

`ACG1Z` g_1^Z

`ACLZ` λ_Z

`ACKZ` κ_Z

`ACG4Z` g_4^Z

`ACKTZ` $\tilde{\kappa}_Z$

`ACLTZ` $\tilde{\lambda}_Z$

`ACG5Z` g_5^Z

The restricted set of AC is:

`DG1Z` $\Delta(g_1^Z)$

`DKG` $\Delta(\kappa_\gamma)$

`RLG` λ_γ

N.B. The anomlaous couplings are only implemented for the *CC*-family and for the *Mix*-family

6 Higgs and MSSM

For processes which include the Higgs boson exchange all fermions are taken to be massless (a part from couplings). However since here the narrow width approximation would be not too far from reality fermion masses can be included in some effective way.

`OGLU = Y` (DEFAULT) or `N`), Γ_H will include the mode $H \to gg$.

`OMSSM = N` (DEFAULT) or `Y` includes the MSSM. `AM,TBETA,RMU,SCALM,BAT,BAB` can be changed if `OMSSM = Y`, they are:

`AM` M_A, DEFAULT = 90 GeV;

`TBETA` $\tan\beta$ DEFAULT = 20;

`RMU` μ DEFAULT = - M_s;

`SCALM` M_s DEFAULT = 1000 GeV;

`BAT` A_t DEFAULT = M_s;

`BAB` A_b DEFAULT = M_s

7 How to use `WTOCUTSET`

Arguments of subroutine `WTOCUTSET` are `integer1, arrayl1, arrayu1, integer2, array2, integer3, arrayl3, arrayu3, integer4, arrayl4, arrayu4`. Setting is as follows:

- `arrayl1` < inv mass(`integer1`) < `arrayu1`;
- `arrayl1` < energy(`integer2`);
- `arrayl3` < scatt. ang.(`integer3`) < `arrayu3`;
- `arrayl4` < FS ang.(`integer4`) < `arrayu4`.

Invariant masses/FS angles corresponding to pair (i, j) are stored as a vector(k), with k = 1-2/1-3/1-4/2-3/2-4/3-4.

8 Default values

The defaults are set by subroutine `WTOINIT` and are:

`OMSMM = 'N'`

`OWW = 'R'`

`OZZ = 'R'`

`OPEAKA = 'N'`

```
          OCKM = 'N'
           ICKM= = 0
         OPGLU = 'Y'
        OMDIST = 'N'
          OINT = 'N'
            OM = 'E'
           OSM = 'N'
    ITMX = '100000'
         OSTOP = 'S'
        OSTORE = 'I'
         OSEED = 'Y'
VCKM(1,1)= 0.9753D0
VCKM(1,3)= 0.0035D0
VCKM(2,2)= 0.9745D0
 VCKM(2,3)= 0.040D0
 VCKM(3,3)= 0.99915
VCKM(3,1)= 0.0095D0
          OTOP = 'D'
           OMH = 'N'
         OPEAK = 'Y'
        OPEAKN = 'N'
          OQCD = 'N'
            IQCD = 1
           OFL = 'N'
           RIO = 'A'
         OANOM = 'R'
          OGLU = 'Y'
          ORAL = 'F'
```

```
ALWI = 128.07D0
    OCOUL = 'N'
        IOS = 2
       IOSF = 1
```