



# A technical subtlety in Pythia8.3

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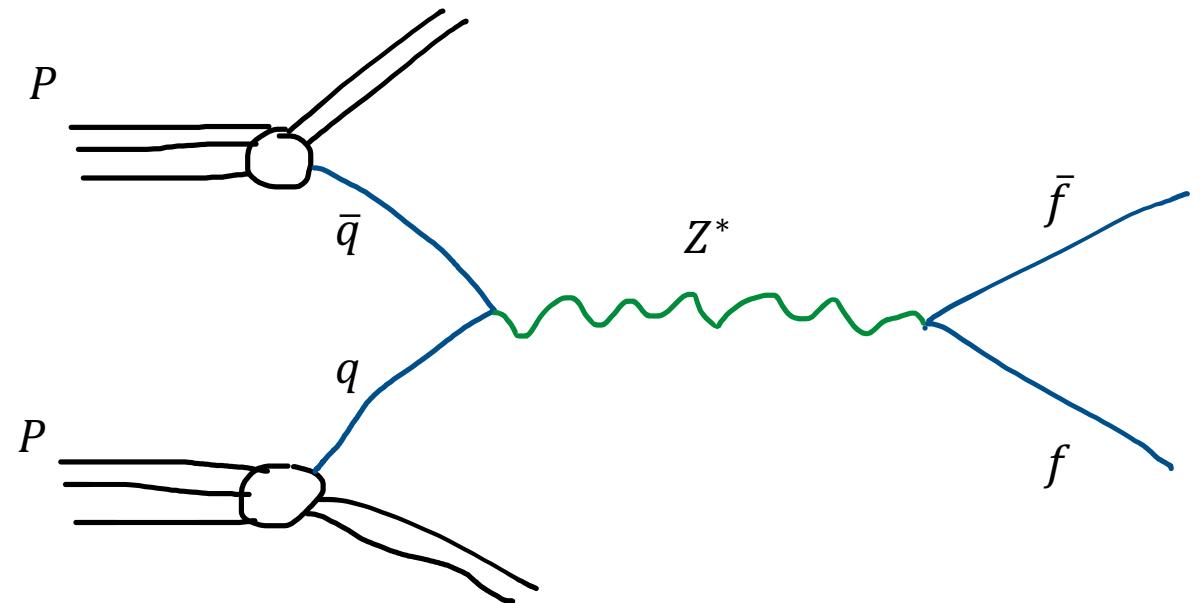
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By definition, no transverse momentum for partons from longitudinal PDFs<sup>[1]</sup>,

$$0 = P_T(q) = P_T(\bar{q})$$

Using LO matrix element to calculate the hard part,

$$\Rightarrow 0 = P_T(Z^*) = P_T(f\bar{f})$$



[1] In this study, CT14 LO is used for PDFs input.

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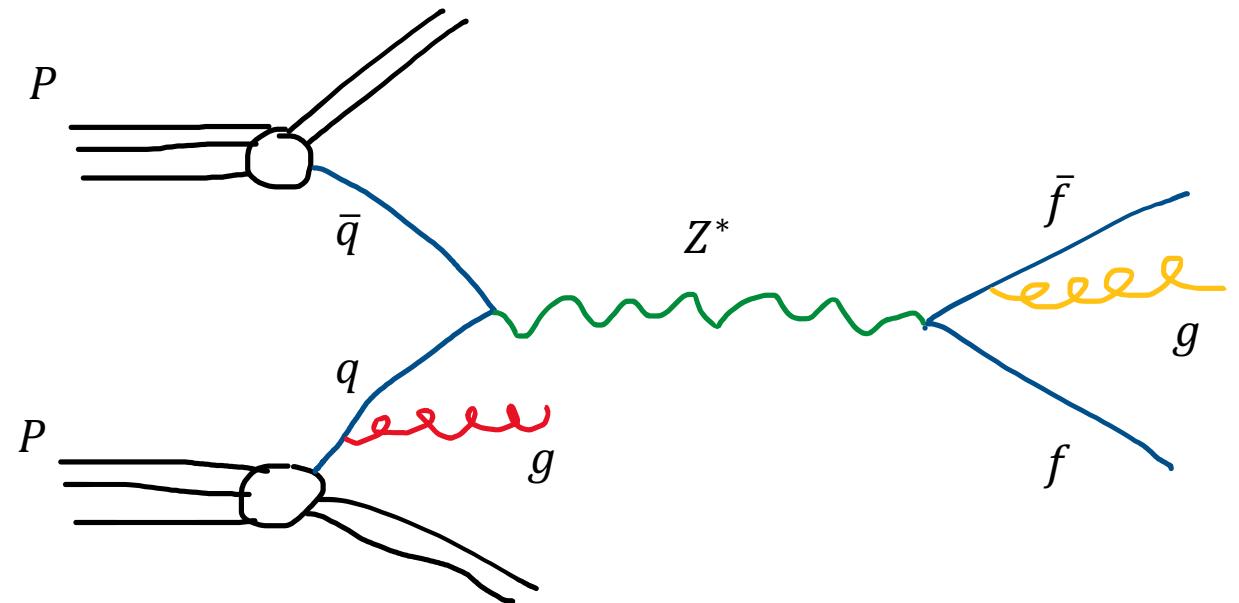
Using LO matrix element to calculate the hard part,

$$\Rightarrow 0 = P_T(Z^*) = P_T(f\bar{f})$$

With **initial-state radiation (ISR)**,

$$P_T(Z^*) = P_T(f\bar{f}) \neq 0$$

Final-state radiation (FSR) won't affect  $P_T(Z^*)$



[1] In this study, CT14 LO is used for PDFs input.







$P_T$  for Z boson

ISR turned off

$$P_T = 0$$

PYTHIA Event Listing (complete event)														
no	id	name	status	mothers	daughters	colours	p_x	p_y	p_z	e	m			
0	90	(system)	-11	0	0	0	0.000	0.000	0.000	14000.000	14000.000			
1	2212	(p+)	-12	0	0	6	0	0.000	0.000	7000.000	7000.000	0.938		
2	2212	(p+)	-12	0	0	7	0	0.000	0.000	-7000.000	7000.000	0.938		
3	2	(u)	-21	6	6	5	0	0.000	0.000	207.679	207.679	0.000		
4	-2	(ubar)	-21	7	7	5	0	0.000	0.000	-10.133	10.133	0.000		
5	23	(Z0)	-22	3	4	8	8	0.000	0.000	197.545	217.812	91.748		
6	2	(u)	-61	1	0	3	3	1.828	-0.785	207.616	207.625	0.000		
7	-2	(ubar)	-61	2	0	4	4	-1.676	-0.189	-10.059	10.199	0.000		
8	23	(Z0)	-62	5	5	15	16	0.152	-0.975	197.557	217.824	91.748		
9	2103	(ud_-1)	-63	1	0	33	33	-0.597	-0.006	3099.744	3099.745	0.771		
10	2	(u)	-63	1	0	21	23	104	-0.058	0.525	3487.544	3487.544	0.330	
11	-2	(ubar)	-63	1	0	21	23	0	1.172	0.265	205.019	205.023	0.330	
12	2	(u)	-63	2	0	32	32	101	0	1.051	0.301	-2705.618	2705.618	0.330
13	2101	(ud_0)	-63	2	0	18	18	0	107	0.673	-0.195	-4203.252	4203.252	0.579
14	2	(u)	-63	2	0	17	17	107	0	-0.047	0.084	-80.994	80.995	0.330
15	4	(c)	-23	8	0	24	31	102	0	41.654	13.235	130.917	138.028	1.500
16	-4	(cbar)	-23	8	0	24	31	0	102	-41.502	-14.209	66.640	79.797	1.500

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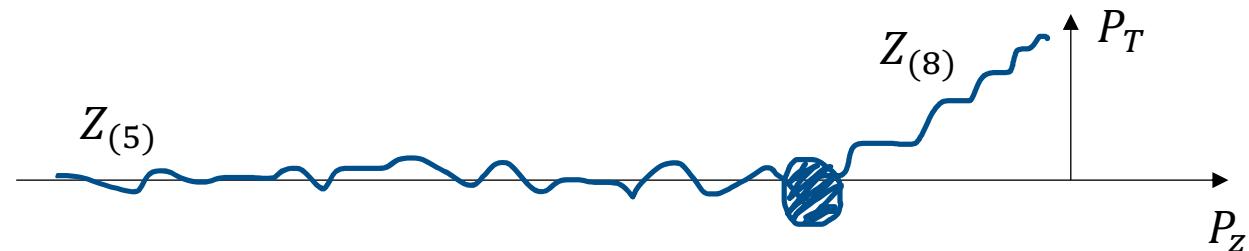
$$P_T \neq 0$$

$P_T$  for Z boson

ISR turned off

PYTHIA Event Listing (complete event)												
no	id	name	status	mothers	daughters	colours	p_x	p_y	p_z	e	m	
0	90	(system)	-11	0 0	0 0	0 0	0.000	0.000	0.000	14000.000	14000.000	
1	2212	(p+)	-12	0 0	6 0	0 0	0.000	0.000	7000.000	7000.000	0.938	
2	2212	(p+)	-12	0 0	7 0	0 0	0.000	0.000	-7000.000	7000.000	0.938	
3	2	(u)	-21	6 6	5 0	101 0	0.000	0.000	207.679	207.679	0.000	
4	-2	(ubar)	-21	7 7	5 0	0 101	0.000	0.000	-10.133	10.133	0.000	
5	23	(Z0)	-22	3 4	8 8	0 0	0.000	0.000	197.545	217.812	91.748	
6	2	(u)	-61	1 0	3 3	101 0	1.828	-0.785	207.616	207.625	0.000	
7	-2	(ubar)	-61	2 0	4 4	0 101	-1.676	-0.189	-10.059	10.199	0.000	
8	23	(Z0)	-62	5 5	15 16	0 0	0.152	-0.975	197.557	217.824	91.748	
9	2103	(ud_-1)	-63	1 0	33 33	0 101	-0.597	-0.006	3099.744	3099.745	0.771	
10	2	(u)	-63	1 0	21 23	104 0	-0.058	0.525	3487.544	3487.544	0.330	
11	-2	(ubar)	-63	1 0	21 23	0 104	-1.172	0.265	205.019	205.023	0.330	
12	2	(u)	-63	2 0	32 32	101 0	1.051	0.301	-2705.618	2705.618	0.330	
13	2101	(ud_0)	-63	2 0	18 18	0 107	0.673	-0.195	-4203.252	4203.252	0.579	
14	2	(u)	-63	2 0	17 17	107 0	-0.047	0.084	-80.994	80.995	0.330	
15	4	(c)	-23	8 0	24 31	102 0	41.654	13.235	130.917	138.028	1.500	
16	-4	(cbar)	-23	8 0	24 31	0 102	-41.502	-14.209	66.640	79.797	1.500	

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## **$P_T$ for Z boson**

## ISR turned off

- $\text{status} = \pm (10 * i + j)$
  - $+$  : still remaining particles
  - $-$  : decayed/branched/fragmented/... and not remaining

- 61 - 69 : particles produced by beam-remnant treatment
    - 61 : incoming subprocess particle with primordial  $kT$  included
    - 62 : outgoing subprocess particle with primordial  $kT$  included
    - 63 : outgoing beam remnant
    - 64 : copied particle with new colour according to the colour coi

PYTHIA Event Listing (complete event)														
no	id	name	status	mothers	daughters	colours	p_x	p_y	p_z	e	m			
0	90	(system)	-11	0	0	0	0	0	0.000	0.000	0.000	14000.000	14000.000	
1	2212	(p+)	-12	0	0	6	0	0	0.000	0.000	7000.000	7000.000	0.938	
2	2212	(p+)	-12	0	0	7	0	0	0.000	0.000	-7000.000	7000.000	0.938	
3	2	(u)	-21	6	6	5	0	101	0	0.000	0.000	207.679	207.679	0.000
4	-2	(ubar)	-21	7	7	5	0	0	101	0.000	0.000	-10.133	10.133	0.000
5	23	(Z0)	-22	3	4	8	8	0	0	0.000	0.000	197.545	217.812	91.748
6	2	(u)	-61	1	0	3	3	101	0	1.828	-0.785	207.616	207.625	0.000
7	-2	(ubar)	-61	2	0	4	4	0	101	-1.676	-0.189	-10.059	10.199	0.000
8	23	(Z0)	-62	5	5	15	16	0	0	0.152	-0.975	197.557	217.824	91.748
9	2103	(ud_1)	-63	1	0	33	33	0	101	-0.597	-0.006	3099.744	3099.745	0.771
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11	-2	(ubar)	-63	1	0	21	23	0	104	-1.172	0.265	205.019	205.023	0.330
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13	2101	(ud_0)	-63	2	0	18	18	0	107	0.673	-0.195	-4203.252	4203.252	0.579
14	2	(u)	-63	2	0	17	17	107	0	-0.047	0.084	-80.994	80.995	0.330
15	4	(c)	-23	8	0	24	31	102	0	41.654	13.235	130.917	138.028	1.500
16	-4	(cbar)	-23	8	0	24	31	0	102	-41.502	-14.209	66.640	79.797	1.500





Thanks

# Pythia Event Listing

# ISR turned on

- 21 - 29 : particles of the hardest subprocess
    - 21 : incoming
    - 22 : intermediate (intended to have preserved mass)
    - 23 : outgoing
    - 24 : outgoing, nonperturbatively kicked out in diffraction

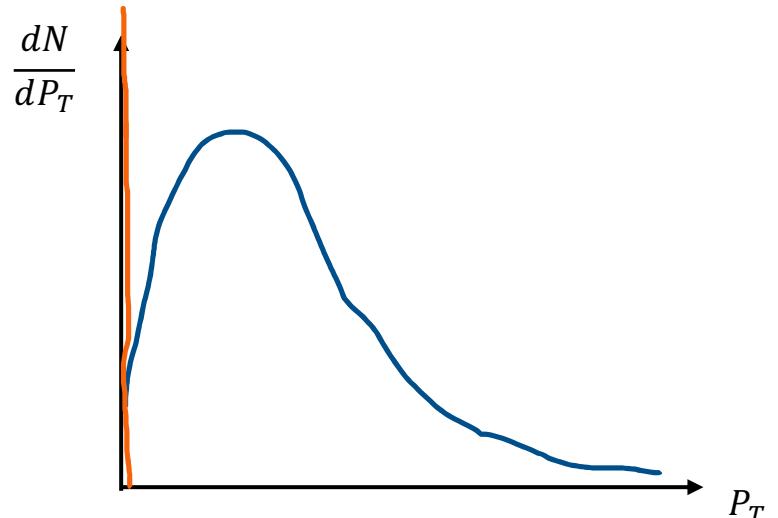
- 41 - 49 : particles produced by initial-state-showers
    - 41 : incoming on spacelike main branch
    - 42 : incoming copy of recoiler
    - 43 : outgoing produced by a branching
    - 44 : outgoing shifted by a branching

PYTHIA Event Listing (complete event)												
no	id	name	status	mothers	daughters	colours	p_x	p_y	p_z	e	m	
0	90	(system)	-11	0	0	0	0	0	0.000	0.000	0.000	14000.000
1	2212	(p+)	-12	0	0	72	0	0	0.000	0.000	7000.000	7000.000
2	2212	(p+)	-12	0	0	73	0	0	0.000	0.000	-7000.000	7000.000
3	2	(u)	-21	6	0	5	0	101	0	0.000	0.000	207.679
4	-2	(ubar)	21	7	7	5	0	0	101	0.000	0.000	-10.133
5	23	(Z0)	-22	3	4	8	8	0	0	0.000	0.000	197.545
6	21	(g)	-41	10	10	9	3	101	103	0.000	0.000	330.593
7	-2	(ubar)	-42	11	0	4	4	0	101	-0.000	0.000	-10.133
8	23	(Z0)	-44	5	5	12	12	0	0	-3.288	8.970	204.135
9	-2	(ubar)	-43	6	0	13	13	0	103	3.288	-8.970	116.325
10	21	(g)	-42	15	0	6	6	101	103	0.000	0.000	330.593
11	21	(g)	-41	16	16	14	7	104	101	0.000	0.000	-16.528
12	23	(Z0)	-44	8	8	17	17	0	0	-6.681	14.006	206.201
13	-2	(ubar)	-44	9	9	18	18	0	103	3.221	-8.871	112.662
14	2	(u)	-43	11	0	19	19	104	0	3.461	-5.135	-4.797
15	21	(g)	-41	21	21	20	10	105	103	0.000	-0.000	572.962
16	21	(g)	-42	22	0	11	11	104	101	0.000	0.000	-16.528
17	23	(Z0)	-44	12	12	23	23	0	0	-8.601	11.684	206.757
18	-2	(ubar)	-44	13	13	24	24	0	103	2.219	-10.082	112.883
19	2	(u)	-44	14	14	25	25	104	0	3.447	-5.151	-4.792
20	21	(q)	-43	15	0	26	26	105	101	2.935	3.549	241.585

## Pythia Event Listing

ISR turned on

- Picked up by `pTZ.fill( pythia.info.pTHat() );`
- Picked up by `pTZ.fill( pythia.event[iZ].pT() );`

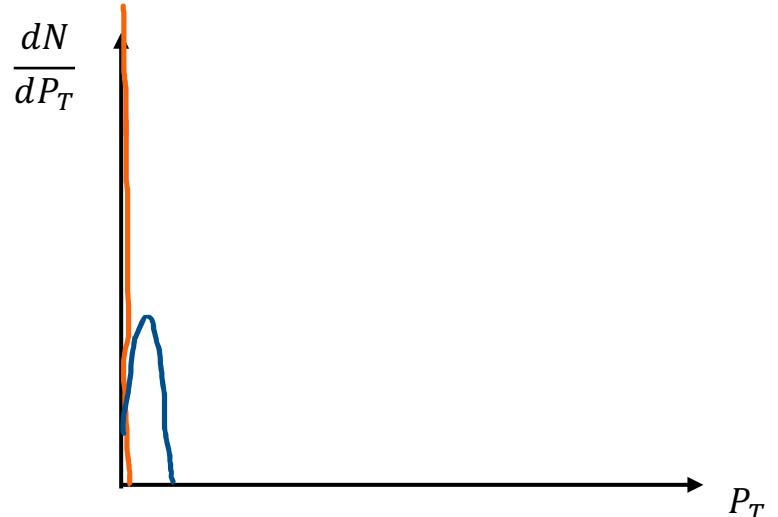


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2	2212	(p+)	-12	0	0	73	0	0	0.000	-7000.000	7000.000	
3	2	(u)	-21	6	0	5	0	101	0	0.000	207.679	
4	-2	(ubar)	-21	7	7	5	0	0	101	0.000	-10.133	
5	23	(Z0)	-22	3	4	8	8	0	0	0.000	197.545	
6	21	(g)	-41	10	10	9	3	101	103	0.000	330.593	
7	-2	(ubar)	-42	11	0	4	4	0	101	-0.000	-10.133	
8	23	(Z0)	-44	5	5	12	12	0	0	-3.288	8.970	
9	-2	(ubar)	-43	6	0	13	13	0	103	3.288	-8.970	
10	21	(g)	-42	15	0	6	6	101	103	0.000	330.593	
11	21	(g)	-41	16	16	14	7	104	101	0.000	-16.528	
12	23	(Z0)	-44	8	8	17	17	0	0	-6.681	14.006	
13	-2	(ubar)	-44	9	9	18	18	0	103	3.221	-8.871	
14	2	(u)	-43	11	0	19	19	104	0	3.461	-5.135	
15	21	(g)	-41	21	21	20	10	105	103	0.000	-0.000	
16	21	(g)	-42	22	0	11	11	104	101	0.000	-16.528	
17	23	(Z0)	-44	12	12	23	23	0	0	-8.601	11.684	
18	-2	(ubar)	-44	13	13	24	24	0	103	2.219	-10.082	
19	2	(u)	-44	14	14	25	25	104	0	3.447	-5.151	
20	21	(g)	-43	15	0	26	26	105	101	2.935	3.549	

## Pythia Event Listing

ISR turned off

- Picked up by `pTZ.fill( pythia.info.pTHat() );`
- Picked up by `pTZ.fill( pythia.event[iZ].pT() );`



PYTHIA Event Listing (complete event)												
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1	2212	(p+)	-12	0	0	6	0	0	0.000	7000.000	7000.000	
2	2212	(p+)	-12	0	0	7	0	0	0.000	-7000.000	7000.000	
3	2	(u)	-21	6	6	5	0	101	0	0.000	207.679	
4	-2	(ubar)	-21	7	7	5	0	0	101	0.000	-10.133	
5	23	(Z0)	-22	3	4	8	8	0	0	0.000	197.545	
6	2	(u)	-61	1	0	3	3	101	0	1.828	-0.785	
7	-2	(ubar)	-61	2	0	4	4	0	101	-1.676	-0.189	
8	23	(Z0)	-62	5	5	15	16	0	0	0.152	-0.975	
9	2103	(ud_1)	-63	1	0	33	33	0	101	-0.597	-0.006	
10	2	(u)	-63	1	0	21	23	104	0	-0.058	0.525	
11	-2	(ubar)	-63	1	0	21	23	0	104	-1.172	0.265	
12	2	(u)	-63	2	0	32	32	101	0	1.051	0.301	
13	2101	(ud_0)	-63	2	0	18	18	0	107	0.673	-0.195	
14	2	(u)	-63	2	0	17	17	107	0	-0.047	0.084	
15	4	(c)	-23	8	0	24	31	102	0	41.654	13.235	
16	-4	(cbar)	-23	8	0	24	31	0	102	-41.502	-14.209	

## Some Pythia commands

`pythia.info.pTHat()`

### Hard process kinematics

The methods in this section provide info on the kinematics of the hard processes, with special emphasis on  $2 \rightarrow 2$  (diffraction excluded; see below).

**double Info::mHat()**  
**double Info::sHat()**

the invariant mass and its square for the hard process.

**double Info::tHat()**  
**double Info::uHat()**

the remaining two Mandelstam variables; only defined for  $2 \rightarrow 2$  processes.

**double Info::pTHat()**  
**double Info::pT2Hat()**

transverse momentum and its square in the rest frame of a  $2 \rightarrow 2$  processes.

**double Info::m3Hat()**  
**double Info::m4Hat()**

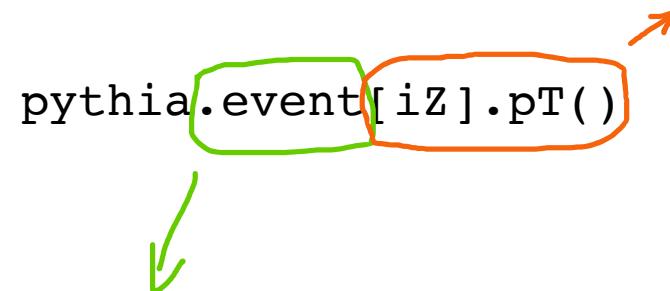
the masses of the two outgoing particles in a  $2 \rightarrow 2$  processes.

**double Info::thetaHat()**  
**double Info::phiHat()**

the polar and azimuthal scattering angles in the rest frame of a  $2 \rightarrow 2$  process.

## Some Pythia commands

**double Particle::pT()**  
**double Particle::pT2()**  
(squared) transverse momentum.



```
pythia.event[iZ].pT()
```

The **Event** class to first approximation is a vector of **Particles**, so that it can expand to fit the current event size. The index operator is overloaded, so that e.g. **event[i]** corresponds to the *i*'th particle of the object **event**. Thus **event[i].id()** returns the identity of the *i*'th particle, and so on. Therefore the methods of the **Particle** class are at least as essential as those of the **Event** class itself.

## Some Pythia commands

`WeakSingleBoson:ffbar2gmZ = on`

Single boson

`flag WeakSingleBoson:all (default = off)`

Common switch for the group of a single  $\gamma^*/Z^0$  or  $W^{+-}$  production.

`flag WeakSingleBoson:ffbar2gmZ (default = off)`

Scattering  $f\bar{f} \rightarrow \gamma^*/Z^0$ , with full interference between the  $\gamma^*$  and  $Z^0$ . Code 221.

`flag WeakSingleBoson:ffbar2W (default = off)`

Scattering  $f\bar{f} \rightarrow W^{+-}$ . Code 222.

`flag WeakSingleBoson:ffbar2ffbar(s:gm) (default = off)`

Scattering  $f\bar{f} \rightarrow \gamma^* \rightarrow f'\bar{f}'$ . Subset of process 221, but written as a  $2 \rightarrow 2$  process, so that  $pT$  can be used as ordering variable, e.g. in multiparton interactions. Hardcoded for the final state being either of the five quark flavours or three lepton ones. Not included in the `WeakSingleBoson:all` set, but included in the multiparton-interactions framework. Code 223.

`flag WeakSingleBoson:ffbar2ffbar(s:gmZ) (default = off)`

Scattering  $f\bar{f} \rightarrow \gamma^*/Z^0 \rightarrow f'\bar{f}'$ . Equivalent to process 221, but written as a  $2 \rightarrow 2$  process, so that  $pT$  could be used as cut or ordering variable. Final-state flavour selection is based on the  $Z^0$  allowed decay modes, and the `WeakZ0:gmZmode` options are implemented. Not included in the `WeakSingleBoson:all` set. Code 224.

`flag WeakSingleBoson:ffbar2ffbar(s:W) (default = off)`

Scattering  $f_1\bar{f}_2 \rightarrow W^{+-} \rightarrow f_3\bar{f}_4$ . Almost equivalent to process 222, but written as a  $2 \rightarrow 2$  process, so that  $pT$  could be used as cut or ordering variable. Final-state flavour selection is based on the  $W$  allowed decay modes. There are two simplifications relative to the implementation in process 222. Firstly, it is not possible to set different decay modes for the  $W^+$  and the  $W^-$ ; instead the allowed  $W^+$  ones will be used throughout, with charge conjugation for the  $W^-$ . Secondly, quark mass corrections are neglected in the decay angular distribution. Not included in the `WeakSingleBoson:all` set. Code 225.