feynMF Examples

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Introduction

feynMF is a package made by Thorsten Ohl to draw Feynman diagrams in LaTeXenvironment. You can download it from
`http://www.ctan.org/tex-archive/macros/latex/contrib/supported/feynmf/`. Not all the sites have feynMF, but one of the sites which has feynMF is `ftp.dante.de`.

This document shows several examples to help you understand how to draw common diagrams. We will start from very basic diagrams, and then improve them to usable forms. For the description of each command, please refer to manual.ps which comes with the package.

1 How to typeset this document on TeXShop

1. Typeset once by pressing "Typeset" button on TeXShop. This creates `*.mf` file for each diagram.

2. For diagrams with labels on partciles or vertices, you have to execute `mf` command on Terminal. For this document, do:
   ```
   % mf '\mode=localfont;' input simple_labels
   % mf '\mode=localfont;' input cross
   % mf '\mode=localfont;' input penguin_oneside
   % mf '\mode=localfont;' input penguin_full
   ```
   Actually, if you skip running `mf` commands, you will still get the diagrams. The only problem is that the particles and vertices will not be labeled.

3. Typset again, and you will see the diagrams.

4. If you edit a diagram, make sure that you delete the corresponding pk file before typesetting it. The pk files have extensions like '`.600pk`'.

Note: If you do not have TeXShop, execute:
`% latex fmfsample.tex`
to typeset the file.

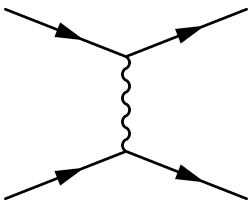
2 Basic idea

The way how feynMF works can be understood easily if you imagine rubber bands. You first place external vertecies (nails?) on the side. Next you string rubber bands between the external vertices. The rubber bands can have internal vertices, and you can string another rubber bands between them. How the internal vertices are pulled together is determined by the tension of the rubber bands.

3 Simple examples

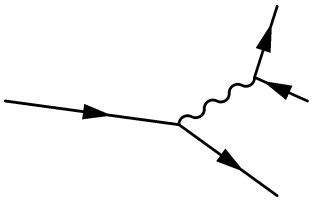
Here are simple examples, without any tuning.

3.1 $\ell\ell \to \ell\ell$



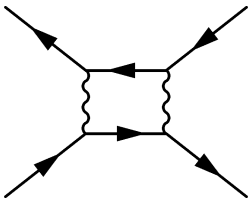
```
\unitlength = 1mm
% determine the unit for the size of diagram.

\begin{fmffile}{simple}
    \begin{fmfgraph}(40,25)
       % Note that the size is given in normal parentheses
       % instead of curly brackets.

       % Define external vertices from bottom to top
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1,o1}
        \fmf{fermion}{i2,v2,o2}
        \fmf{photon}{v1,v2}
   \end{fmfgraph}
\end{fmffile}
```

3.2 Simple tree diagram



```
\begin{fmffile}{simple_tree}
    \begin{fmfgraph}(40,25)
        \fmfleft{i}
        \fmfright{o1,o2,o3}
        \fmf{fermion}{i,v1,o1}
        \fmf{photon}{v1,v2}
        \fmf{fermion}{o2,v2,o3}
    \end{fmfgraph}
\end{fmffile}
```

3.3 Simple box diagram

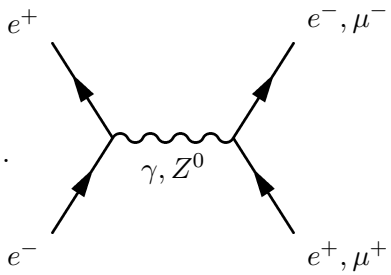


```
\begin{fmffile}{simple_box}
    \begin{fmfgraph}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1,v2,o1}
        \fmf{fermion}{o2,v4,v3,i2}
        \fmf{photon}{v1,v3}
        \fmf{photon}{v2,v4}
    \end{fmfgraph}
\end{fmffile}
```

4 Labeling particles

You can put labels on particles, but to do this, you have to run `mf` command once from Terminal for each diagam with labels, as;

```
% mf '\mode=localfont;' input simple_labels
```

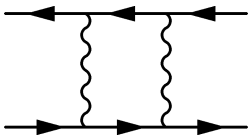



```
\begin{fmffile}{simple_labels}
    \begin{fmfgraph*}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}

        \fmflabel{$e^-$}{i1}
        \fmflabel{$e^+$}{i2}
        \fmflabel{$e^+,\mu^+$}{o1}
        \fmflabel{$e^-,\mu^-$}{o2}

        \fmf{fermion}{i1,v1,i2}
        \fmf{fermion}{o1,v2,o2}

        \fmf{photon,label=$\gamma,,Z^0$}{v1,v2}
    \end{fmfgraph*}
\end{fmffile}
```

Note that you need two commas inside \fmf command to make single comma. Also, you have to use 'fmfgraph*', instead of 'fmfgraph'.

5 Better looking diagrams

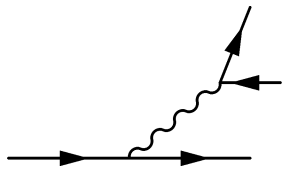
5.1 Box diagram



```
\begin{fmffile}{box}
    \begin{fmfgraph*}(40,15)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1,v2,o1}
        \fmf{fermion}{o2,v4,v3,i2}
        \fmf{photon,tension=0}{v1,v3}
        \fmf{photon,tension=0}{v2,v4}
    \end{fmfgraph*}
\end{fmffile}
```

By setting the tension of bosons (type *photon*) to 0, the quark lines are kept straight.

5.2 Tree diagram

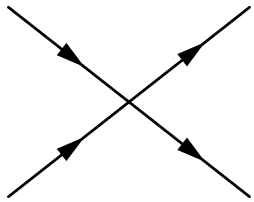


```
\begin{fmffile}{tree}
    \begin{fmfgraph*}(40,20)
        \fmfleft{i1,g2,g3} % g2 and g3 are dummies
        \fmfright{o1,o2,o3}
        \fmf{fermion}{i1,v1,o1}
        \fmffreeze
        \fmf{fermion}{o2,v2,o3}
        \fmf{photon}{v1,v2}
    \end{fmfgraph*}
\end{fmffile}
```

Two ghost vertecies, `g2` and `g3` are declared to place i1 at the bottom left. Also, `\fmffreeze` is used after stringing a line from `i1` to `o1` so that the line will be frozen as is (straight).

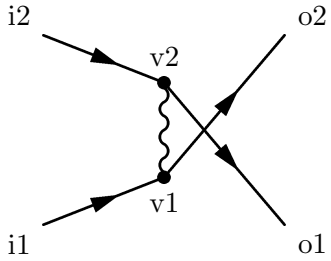
5.3 Cross diagram

You would think that a cross diagram of the first simple diagram in Section 3.1 can be made by just switching two fermions. However, this will collapse the boson line to a point. (Back to Fermi coupling)



```
\begin{fmffile}{simple_cross} % This is a bad sample.
    \begin{fmfgraph*}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1,o2}
        \fmf{fermion}{i2,v2,o1}
        \fmf{photon}{v1,v2}
    \end{fmfgraph*}
\end{fmffile}
```

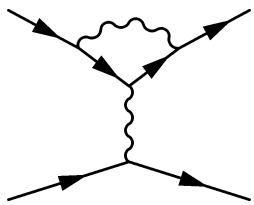
One way to avoid the collapsing boson is to replace the outgoing leptons by invisible `phantom` lines to keep the boson line in the same place. You can then draw crossing outgoing leptons with `tension=0`.




```
\begin{fmffile}{cross}
    \begin{fmfgraph*}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1}
        \fmf{phantom}{v1,o1} % Invisible rubber band
        \fmf{fermion}{i2,v2}
        \fmf{phantom}{v2,o2} % also invisible rubber band
        \fmf{photon}{v1,v2}

        % These are visible, but have no tension.
        \fmf{fermion,tension=0}{v1,o2}
        \fmf{fermion,tension=0}{v2,o1}

        \fmfdot{v1,v2}

        \fmflabel{i1}{i1}
        \fmflabel{i2}{i2}
        \fmflabel{o1}{o1}
        \fmflabel{o2}{o2}
        \fmflabel{v1}{v1}
        \fmflabel{v2}{v2}

    \end{fmfgraph*}
\end{fmffile}
```

5.4 Penguin diagrams

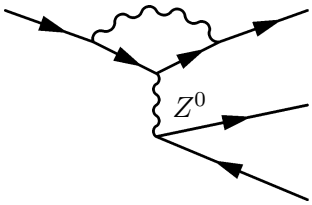
5.4.1 Legs on both sides



```
\begin{fmffile}{penguin_both}
    \begin{fmfgraph*}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}
        \fmf{fermion}{i1,v1,o1}
        \fmf{fermion}{i2,v2,v3,v4,o2}
        \fmf{photon}{v1,v3}
        \fmf{photon,left=0.5,tension=0.2}{v2,v4} % W line
    \end{fmfgraph*}
\end{fmffile}
```

The `\fmf{photon,left=0.5,tension=0.2}{v2,v4}` tells the boson in the loop to arc left and loosen the tension to expand the loop.

5.4.2 Legs on one side




```
\begin{fmffile}{penguin_oneside}
    \begin{fmfgraph*}(40,25)
        \fmfstraight
        \fmfleft{g1,g2,i3}  % g1 and g2 will be used later
        \fmfright{o1,o2,o3}
        \fmf{fermion}{i3,v2,v3,v4,o3}
        \fmf{fermion}{o1,v1,o2}
        \fmf{photon,label=$Z^0$}{v1,v3}
        \fmf{photon,left=0.5,tension=0.2}{v2,v4}

        \fmf{phantom}{g1,v1,g2} % pull Z0 from the left
    \end{fmfgraph*}
\end{fmffile}
```

Invisible `phantom` line is strung from the left to pull the bottom of Z^0 with equal tensions from both sides. This keeps the body of the penguin straight up.

Figure 1 shows the full-blown penguin diagrams with labels. To make the labels appear, run
`% mf 'mode=localfont;' input penguin_full`
from Terminal.

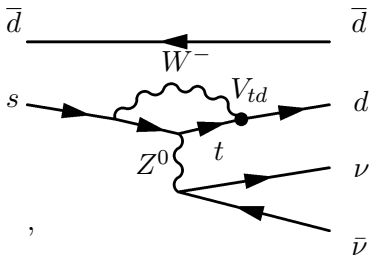


Figure 1: The penguin diagram for $K_L \to \pi^0 \nu \overline{\nu}$ decay.

```
\begin{fmffile}{penguin_full}
    \begin{fmfgraph*}(40,25)

        \fmfstraight

        \fmfleft{g1,g2,s,dsleft}
        \fmflabel{$s$}{s}
        \fmflabel{$\overline{d}$}{dsleft}

        \fmfright{n1,n2,d,dsright}
        \fmflabel{$\bar \nu$}{n1}
        \fmflabel{$\nu$}{n2},
        \fmflabel{$d$}{d}
        \fmflabel{$\overline{d}$}{dsright}

        \fmf{fermion}{dsright,dsleft}

        \fmf{fermion,tension=1}{s,v1}
        \fmf{fermion,tension=1}{v3,d}

        \fmf{fermion}{v1,v2}
        \fmf{fermion,label=$t$}{v2,v3}

        \fmf{photon,label=$W^-$, left=0.5, tension=0.2}{v1,v3}
        \fmf{photon,label=$Z^0$, tension=0.5}{v2,v4}
        \fmf{fermion}{n1,v4,n2}
        \fmf{phantom}{g1,v4,g2}

        \fmfv{label=$V_{td}$,label.angle=90,
                  decor.shape=circle,
                  decor.filled=full,decor.size=2thick}{v3}

    \end{fmfgraph*}
\end{fmffile}
```