feynMP / feynMF Examples

Taku Yamanaka
Physics Dept., Osaka Univ.

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Introduction

feynMF is a package made by Thorsten Ohl to draw Feynman diagrams in LaTeXenvironment. You can download bundled feynmf.zip from
`http://www.ctan.org/tex-archive/macros/latex/contrib/feynmf/`.

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 `*.mp` file for each diagram.
2. Run `mpost` for each `.mp` file.
   If you are using cshell (/bin/csh), you can do:
   ```
   % foreach f (*.mp)
   foreach?  mpost $f
   foreach?  end .
   ```

   If you are using bash (/bin/bash), you can do:
   ```
   $ for f in *.mp; do mpost $f; done
   ```
3. Typset again, and you will see the diagrams.
4. If you edit a diagram, make sure that you run `mpost` for the diagram before typesetting.

Note: If you do not have TeXShop, execute:
`% latex fmfsamples.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.

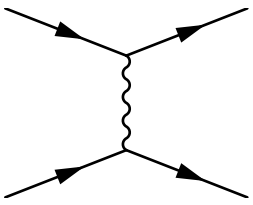
3 Simple examples

To try following examples, they should be surrounded by the lines shown below.

```
\documentclass{article}
\usepackage{feynmp}
\begin{document}
    \unitlength = 1mm
    % determine the unit for the size of diagram.

    ... here comes an example
    \begin{fmffile}{foo}
     ........
    \end{fmffile}

\end{document}
```

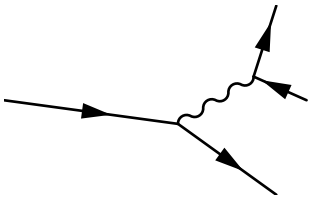
Here are simple examples, without any tuning.

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



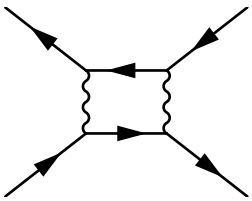
```
\begin{fmffile}{simple}
    \begin{fmfgraph}(40,25)
       % Note that the size is given in normal parentheses
       % instead of curly brackets.

       % 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}
```

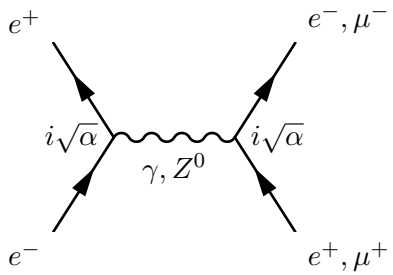
3.3 Simple box diagram



```
\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 and vertecies by using '`fmfgraph*`', instead of '`fmfgraph`'.

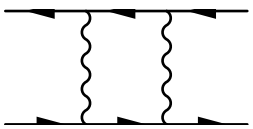



```
\begin{fmffile}{simple_labels}
    \begin{fmfgraph*}(40,25)
        \fmfleft{i1,i2}
        \fmfright{o1,o2}

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

         \fmflabel{$i\sqrt{\alpha}$}{v1}
         \fmflabel{$i\sqrt{\alpha}$}{v2}

        \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.

5 Better looking diagrams

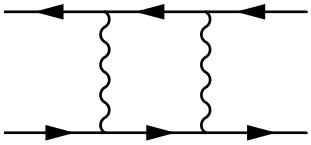
5.1 Box diagram



```
\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}
```

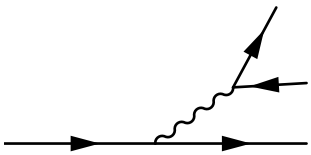
By setting the tension of bosons (type *photon*) to 0, the quark lines are kept straight. However, the arrows are cropped, and the diagram does not look right. This is because vertices i1 and o1 are set at the bottom left and right corners, and anything outside the given box is not shown.

To solve this problem, here is a better way. The trick is to use `\fmftop` and `\fmfbottom`, and add one dummy vertices, `d1` and `d2`. Since vertices are placed along arcs, `i1` and `i2` are a little above `d1` which is at the bottom edge of the drawing box.



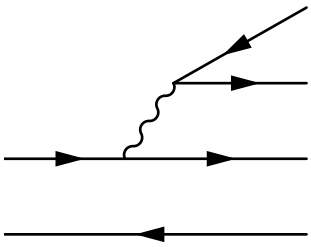
```
\begin{fmffile}{box}
    \begin{fmfgraph}(40,20)
        \fmfbottom{i1,d1,o1}
        \fmftop{i2,d2,o2}
        \fmf{fermion}{i1,v1,v2,o1}
        \fmf{fermion}{o2,v4,v3,i2}
        \fmf{photon,tension=0}{v1,v3}
        \fmf{photon,tension=0}{v2,v4}
    \end{fmfgraph}
\end{fmffile}
```

5.2 Tree diagrams

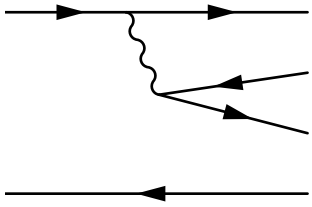


```
\begin{fmffile}{tree}
    \begin{fmfgraph}(40,30)
        \fmfbottom{i1,d1,o1}
        \fmfright{o0,o2,o3}
        \fmf{fermion}{i1,v1,o1}
        \fmffreeze
        \fmf{fermion}{o2,v2,o3}
        \fmf{photon,tension=1.5}{v1,v2}
    \end{fmfgraph}
\end{fmffile}
```

\fmffreeze is used after stringing a line from i1 to o1 so that the line will be frozen as is (straight).



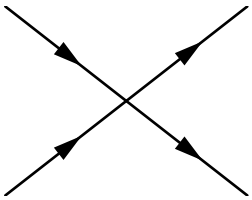
```
\begin{fmffile}{tree2}
    \begin{fmfgraph}(40,40)
        \fmfstraight
        \fmfleft{i0,i1,i2,i3,i4}
        \fmfright{o0,o1,o2,o3,o4}
        \fmf{fermion}{o1,i1}
        \fmf{fermion,tension=1.5}{i2,v2}
        \fmf{fermion}{v2,o2}
        \fmffreeze
        \fmf{fermion}{o4,v3,o3}
        \fmf{photon,tension=2}{v2,v3}
        \fmf{phantom}{i4,v3}
    \end{fmfgraph}
\end{fmffile}
```



```
\begin{fmffile}{tree3}
    \begin{fmfgraph}(40,40)
        \fmfstraight
        \fmfleft{i0,i1,i2,i3,i4,i5}
        \fmfright{o0,o1,o2,o3,o4,o5}
        \fmf{fermion}{o1,i1}
        \fmf{fermion,tension=1.5}{i4,v2}
        \fmf{fermion}{v2,o4}
        \fmffreeze
        \fmf{fermion}{o3,v3,o2}
        \fmf{photon,tension=2}{v2,v3}
        \fmf{phantom,tension=1.5}{i1,v3}
    \end{fmfgraph}
\end{fmffile}
```

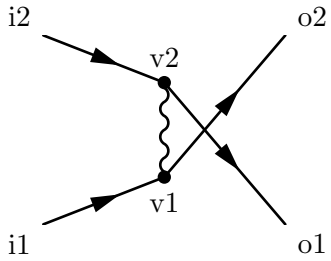
5.3 Cross diagram

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}
```

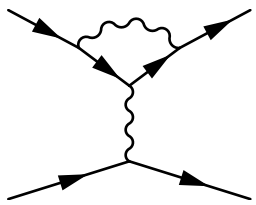
One way to avoid the collapsing boson is to replace the outgoing leptons by invisible `phantom` lines to keep the boson line in the same place. You can then draw crossing outgoing leptons with `tension=0`.




```
\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

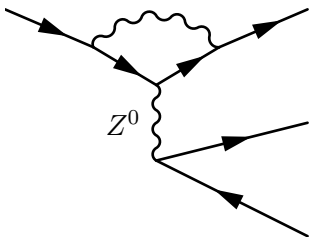
5.4.1 Legs on both sides



```
\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*}(40,30)
        \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.

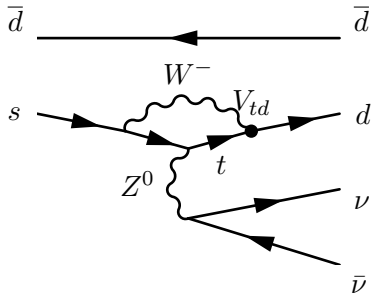


Figure 1: The penguin diagram for $K_L \to \pi^0 \nu \bar{\nu}$ decay.

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

        \fmfstraight

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

        \fmfright{n1,n2,d,dsright,gr}
        \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=$Z^0$,right=0.5,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}
```