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Contents

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6. Text Processing

6.1 Drawing Feynman Diagrams with LaTeX and METAFONT. Part 2: Immediate Mode

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Abstract

This is the second article in a series describing the LaTeX package feynMF for easy drawing of professional quality Feynman diagrams with METAFONT (or METAPOST). This time more advanced topics are covered.

6.1.1 Introduction

In [1], I have described the design principles and simple applications of feynMF [2]. Now it is time to discuss the more esoteric features of feynMF that allow efficient creation of rather complicated Feynman diagrams. In this article the emphasis will be on the so called *immediate mode*, while the extension mechanism will be discussed in the third and final article.

6.1.2 Immediate Mode

Most computer graphics systems offer two modes, commonly called *display list mode* and *immediate mode*. The latter performs the drawing operations immediately (whence the name), while the former compiles them into a display list which is executed later.

In addition to the *graph mode* discussed earlier, which corresponds to *display list mode*, feynMF offers an *immediate mode* in which drawing operations are performed immediately. There is another distinction that should be kept in mind: *graph mode* operates on abstract vertices and how they are connected, while *immediate mode* works directly with the coordinates of vertices and the arcs (called *paths* in [3]) connecting them.

With minor exceptions, feynMF's *graph mode* will produce straight lines only. Therefore one of *immediate mode*'s most important applications is the drawing of diagrams with unusually curved arcs. These curved arcs can be drawn in the same line styles as the arcs in *graph mode*. This feature allows us to combine the two modes for maximizing the expressive power and convenience of feynMF.

A comprehensive discussion of METAFONT's facilities for constructing curves is far beyond the scope of this tutorial. Interested readers should consult the first chapters of [3] for the definitive guide.

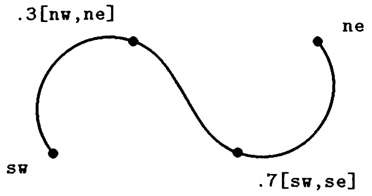
Commands

feynMF's immediate mode commands are easily recognized by their `\fmfi` prefix. They are listed in [2,4]. The most important command is `\fmfi`, which is similar to `\fmf`, except that the second argument is no longer a set of vertices, but a METAFONT expression expanding to a path on which the arc will be drawn in the style specified in the first argument. Similarly, `\fmfiv` behaves like `\fmfv` but takes the coordinates of a vertex as second argument.

`\fmfforce` is used to import immediate mode coordinates to graph mode, while `vpath` and `vloc` are used to import graph mode coordinates to immediate mode. Examples are given below and readers should consult [2,4] for a formal description.

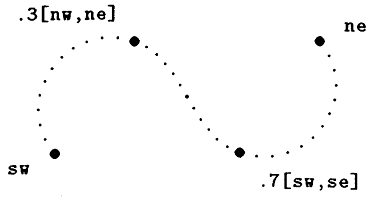
6.1.3 METAFONT Paths

METAFONT constructs paths by connecting vertices with Bezier curves (see [3] for details). The basic operator for connecting vertices smoothly is "`..`". The following example defines a generic macro for the examples below and demonstrates the use of the "`..`" operator"



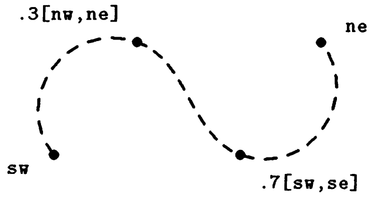
```
\gdef\P#1#2{%
% \begin{fmfgraph*}(40,18)
  \begin{fmfgraph*}(35,15)
    \fmfi{#1}{#2}
    \def\L##1##2{\fmfiv{%
      dec.shape=circle,dec.size=3thin,
      dec.fill=1,lab.dist=5thick,
      lab=\noexpand\texttt{%
        \noexpand\scriptsize ##1}}{##2}}
    \L{sw}{sw}\L{.3[nw,,ne]}{.3[nw,ne]}
    \L{ne}{ne}\L{.7[sw,,se]}{.7[sw,se]}
  \end{fmfgraph*}}
\P{plain}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

The bracket construct `.3[nw,ne]` should be read *"the point 30% of the way from* `nw` *to* `ne`" and is equivalent to 0.7`nw` + 0.3`ne`. Besides predefining the corners as `nw`, `sw`, `se` and `ne`, feynMF's `\fmfi` adds to METAFONT's `draw` the ability to draw the paths in various styles, such as dotted



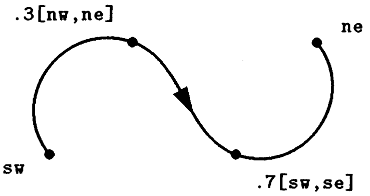
```
\P{dots}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

dashed:



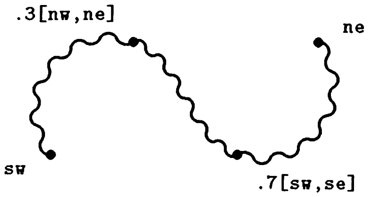
```
\P{dashes}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

or with an arrow:



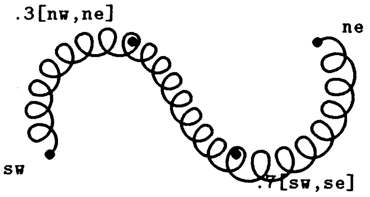
```
\P{fermion}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

It is also possible to draw wiggly:



```
\P{photon}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

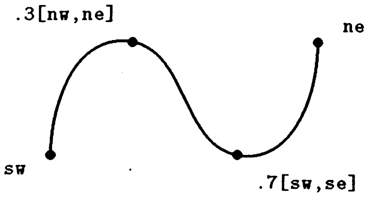
or even curly:



```
\P{gluon}{sw .. .3[nw,ne]
  .. .7[sw,se] .. ne}
```

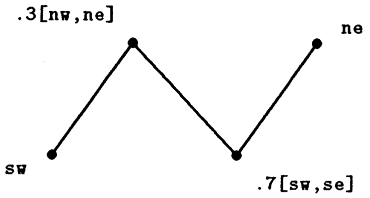
lines along arbitrary paths.

By placing a direction in curly braces next to a vertex, we can fix the direction in which the path will enter or leave this vertex:



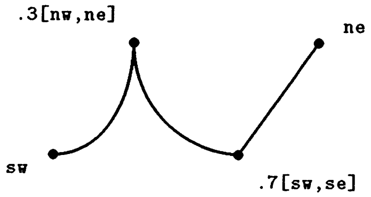
```
\P{plain}{sw{up} .. .3[nw,ne]
  .. .7[sw,se] .. {up}ne}
```

It is also possible to connect vertices with straight lines using the "--" operator:



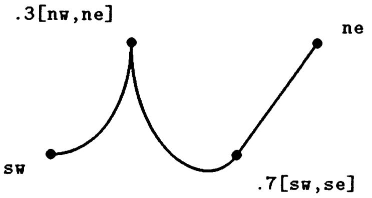
```
\P{plain}{sw -- .3[nw,ne]
  -- .7[sw,se] -- ne}
```

These possibilities can be mixed in the same path:



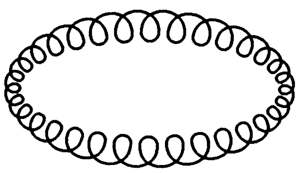
```
\P{plain}{sw{right} .. {up}.3[nw,ne]{down}
  .. .7[sw,se] -- ne}
```

This example shows that a straight line will not be connected smoothly with a neighbouring smooth line. For such a smooth continuation, the "---" operator is provided:



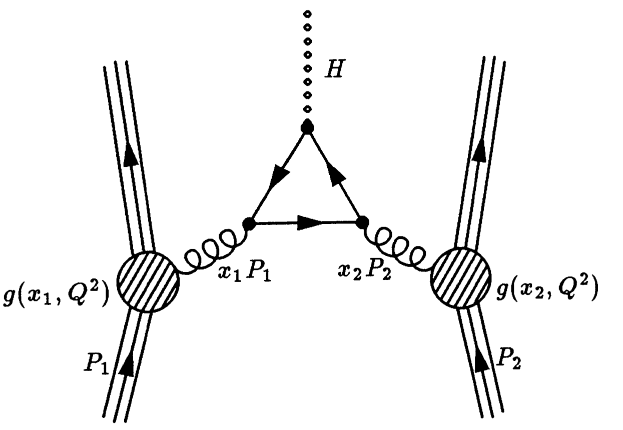
```
\P{plain}{sw{right} .. {up}.3[nw,ne]{down}
  .. .7[sw,se] --- ne}
```

Circles (possibly scaled) are also readily available:



```
\begin{fmfgraph}(35,15)
  \fmfi{gluon}{fullcircle
    xscaled w yscaled h shifted c}
\end{fmfgraph}
```

While this list of examples should be sufficient for all practical purposes, it does not exhaust all the possibilities for constructing paths in METAFONT. A comprehensive account for the curious is given in [3]



```
 1 \begin{fmfgraph*}(50,60)
 2   \fmfbottom{P1,P2} \fmftop{P1',H',P2'}
 3   \fmf{fermion,tension=2,lab=$P_1$}{P1,g1}
 4   \fmf{fermion,tension=2,lab=$P_2$}{P2,g2}
 5   \fmfblob{.16w}{g1,g2}
 6   \fmf{gluon,lab.side=right,
 7     lab=$x_1P_1$}{g1,v1}
 8   \fmf{gluon,lab.side=right,
 9     lab=$x_2P_2$}{v2,g2}
10   \fmf{fermion,tension=.6}{H,v1,v2,H}
11   \fmfdot{H,v1,v2}
12   \fmf{dbl_dots,lab=$H$}{H,H'}
13   \fmf{fermion}{g1,P1'}
14   \fmf{fermion}{g2,P2'}
15   \fmfv{lab=$g(x_1,,Q^2)$,lab.dist=.1w}{g1}
16   \fmfv{lab=$g(x_2,,Q^2)$,lab.dist=.1w}{g2}
17   \fmffreeze
18   \renewcommand{\P}[3]{\fmfi{plain}{%
19     vpath(__#1,__#2) shifted (thick*(#3))}}
20   \P{P1}{g1}{2,0} \P{P1}{g1}{-2,1}
21   \P{P2}{g2}{2,1} \P{P2}{g2}{-2,0}
22   \P{g1}{P1'}{-2,-1} \P{g1}{P1'}{2,0}
23   \P{g2}{P2'}{-2,0} \P{g2}{P2'}{2,-1}
24 \end{fmfgraph*}
```

Figure 6.1: Higgs production through gluon fusion. This example shows that even more complex diagrams can be drawn with very few tuned tension parameters. Since there is no built-in line style for protons, the parallel lines are added ad hoc with the `\fmfi` command.

6.1.4 Examples

Having explained the basic building blocks, I will now continue with realistic applications. I start the examples by describing how to draw two graphs that have been announced in the first part of this tutorial.

Higgs Production

In figure 6.1, I repeat the Higgs production diagram from [1], this time we are in a position to discuss the source code. Lines 1–16 are a straightforward description of the diagram, with some decorations like labels, dots and blobs added. It should need no further comment. Note, however, in lines 15 and 16, that the commas in the TEX labels are doubled, so that feynMF doesn't interpret them as option separators.

The tension of the lower proton lines (lines 3–4) is increased to make a bit more room in the more crowded top half of the diagram. The tension in the fermion loop is decreased (line 10) to make the loop slightly larger. The latter measure is commonly necessary, because an unweighted least-squared layout will generally produce too small loops.

In line 17 the positions of all vertices are calculated by `\fmffreeze`. From then on, we can use the `vloc` and `vpath` function to access the locations of vertices and lines, respectively.

In lines 18 and 19 we use LATEX's macro facility to define a shorthand: `\P{`v_1`}{`v_2`}{`z`}` will draw a line parallel to the line connecting v_1 and v_2 shifted by z (the latter measured in units of `thick`, the width of thick lines). This macro is used in lines 20–23 to decorate the external fermion lines, making them look more like compound states.

Note how the names of vertices are preceded with two underscores ("__") in the arguments of `vpath`. This slight inconvenience in necessary to separate the namespaces of feynMF and METAFONT, thereby avoiding unpleasant surprises if a user accidentally uses a reserved METAFONT word as a vertex name.

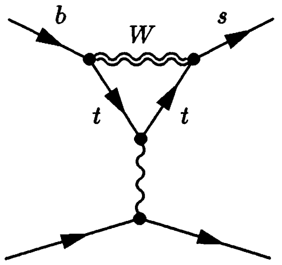
Strictly speaking, lines 18–23 break the concept of structured markup. This seems appropriate here, because it solves the problem straightforwardly without needing more advanced METAFONT programming. Another solution that uses feynMF's extension mechanism to define a `proton` style will be described in the next article.

Penguins

Figures 6.2 and 6.3 display two very different ways of drawing the so-called "penguin" diagrams. The straightforward figure 6.2 uses feynMF graph mode and reproduces the standard way of drawing these diagrams. As usual the `tension` parameter is used to increase the size of the loop compared to the default.

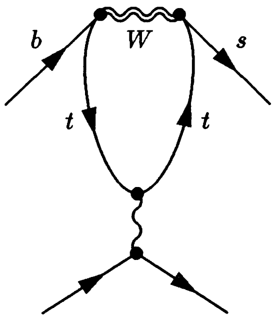
But we can also use feynMF's immediate mode to draw the "penguin' diagram in the way it was drawn by John Ellis and Melissa Franklin, as in figure 6.3. In line 2 the vertices are declared and in lines 3–11 the `\fmfiequ` macro is used to establish linear equations among them (`\fmfiequ{`*expr*$_1$`}{`*expr*$_2$`}` corresponds to *expr*$_1$=*expr*$_2$; in METAFONT).

The variables `ne`, `nw`, `se` and `sw` are predefined to the four cor-



```
 1 \begin{fmfgraph*}(35,40)
 2   \fmftop{b,s} \fmfbottom{ep,em}
 3   \fmf{fermion,lab=$b$,lab.sid=left}{b,Vtb}
 4   \fmf{fermion,lab=$s$,lab.sid=left}{Vts,s}
 5   \fmf{fermion,tension=.5,
 6     lab=$t$,lab.sid=right}{Vtb,g,Vts}
 7   \fmf{dbl_wiggly,tension=.5,
 8     lab=$W$,lab.sid=left}{Vtb,Vts}
 9   \fmf{photon}{g,g'}
10   \fmf{fermion}{ep,g',em}
11   \fmfdot{Vtb,Vts,g,g'}
12 \end{fmfgraph*}
```

Figure 6.2: Penguin diagram in the standard layout



```
 1 \begin{fmfgraph*}(35,40)
 2   \fmfipair{Vtb,Vts,b,s,ep,em,p,p'}
 3   \fmfiequ{.5[Vtb,Vts]}{.5[nw,ne]}
 4   \fmfiequ{Vts}{Vtb+(.3w,0)}
 5   \fmfiequ{b}{.7[sw,nw]}
 6   \fmfiequ{s}{.7[se,ne]}
 7   \fmfiequ{xpart(p')}{xpart(.5[ep,em])}
 8   \fmfiequ{ypart(p')}{.2h}
 9   \fmfiequ{p}{p'+(0,.2h)}
10   \fmfiequ{.5[ep,em]}{.5[sw,se]}
11   \fmfiequ{em}{ep+(.7w,0)}
12   \fmfi{dbl_wiggly,lab=$W$,
13     lab.sid=right}{Vtb--Vts}
14   \fmfi{fermion,lab=$b$,
15     lab.sid=left}{b--Vtb}
16   \fmfi{fermion,lab=$s$,
17     lab.sid=left}{Vts--s}
18   \fmfi{fermion,lab=$t$}{Vtb{b-Vtb}
19     .. tension 2 .. {right}p}
20   \fmfi{fermion,lab=$t$}{p{right}
21     .. tension 2 .. {Vts-s}Vts}
22   \fmfi{photon}{p--p'}
23   \fmfi{fermion}{ep--p'}
24   \fmfi{fermion}{p'--em}
25   \fmfiv{d.sh=circle,d.siz=2thick}{Vtb}
26   \fmfiv{d.sh=circle,d.siz=2thick}{Vts}
27   \fmfiv{d.sh=circle,d.siz=2thick}{p}
28   \fmfiv{d.sh=circle,d.siz=2thick}{p'}
29 \end{fmfgraph*}
```

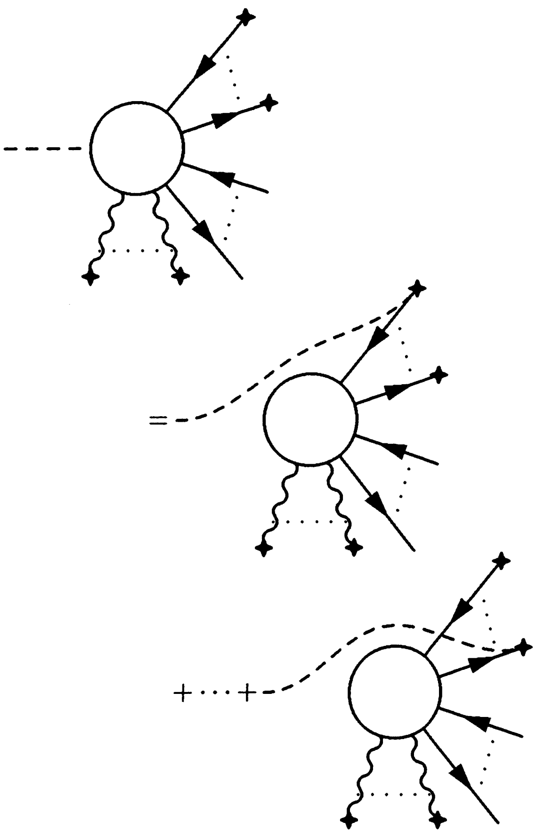
Figure 6.3: Penguin diagram in fancy layout.

ners of the diagram ("north-east" etc.). In line 3 the midpoint `.5[Vtb,Vts]` between the V_{tb} and V_{ts} vertices is set to the centre of the top side of the diagram. In line 4 the V_{ts} is defined to lie 30% of the width of the diagram to the right of V_{tb}. The external b and s quarks are set at 70% of the full height of the left and right sides of the diagram in lines 5 and 6. The vertices `p` and `p'` connected by the photon are defined similarly in lines 7–9. Finally, in lines 10 and 11, the external $e^{\pm}$ vertices are defined in the same fashion as V_{tb} and V_{ts} above.

In lines 12–17 and 22–24 the straight connections are drawn, using METAFONT's `--` operator. Particularly interesting are lines 18–21 in which METAFONT's flexible path construction primitives [3] are used to draw the body of the penguin. The expression `Vtb{b-Vtb} .. tension 2 .. {right}p` denotes a path starting at V_{tb} in the direction of the straight line connecting this vertex with the external b quark and ending at the upper photon vertex in the horizontal direction.

It should be noted that METAFONT's `tension` parameter appearing here is unrelated to `feynMF`'s `tension` parameter. Here it is used to "pull in" the arc slightly compared to the default Bezier curve which would result in a much fatter penguin.

The diagram is completed in lines 25–28 by placing dots at all internal vertices.



(6.1)

```
1 \def\F#1#2{%
2  \fmfi{dots}{.8[vloc(__v),vloc(__#1)]
3     -- .8[vloc(__v),vloc(__#2)]}}
4 \def\D#1{\parbox{35mm}{%
5  \begin{fmfgraph}(35,35)
6   \fmfleft{s}\fmfrightn{f}{4}
7   \fmfbottomn{b}{4}\fmfforce{c}{v}
8   \fmfv{dec.shape=circle,dec.fill=0,
9    dec.size=.35w}{v}
10  \fmfv{dec.shape=tetragram,dec.fill=1,
11   dec.size=3thick}{f3,f4,b2,b3}
12  \fmf{fermion}{f4,v,f3}
13  \fmf{fermion}{f2,v,f1}
14  \fmf{photon}{b2,v,b3}
15  \fmffreeze #1
16  \F{f1}{f2}\F{f3}{f4}\F{b2}{b3}
17 \end{fmfgraph}}}
18 \begin{multline}
19  \D{\fmf{dashes}{s,v}}\\
20  =\D{\fmfi{dashes}{%
21   vloc(__s){vloc(__v)-vloc(__s)}
22     .. .5[vloc(__s),vloc(__f4)] ..
23    {vloc(__f4)-vloc(__v)} vloc(__f4)}}\\
24  +\cdots+\D{\fmfi{dashes}{%
25   vloc(__s){vloc(__v)-vloc(__s)}
26     .. .5[vloc(__s),vloc(__f4)] ..
27    {vloc(__f3)-vloc(__v)} vloc(__f3)}}
28 \end{multline}
```

Figure 6.4: Ward identities

In figure 6.4 the figure from the bottom of p. 211 of [5] is reproduced. Careful inspection will reveal that the reproduction is not faithful in one point: on the left-hand side, the doubled head of the dashed line is left out. This is easy to fix, but the most elegant solution uses feynMF's extension mechanism and will be discussed next time.

This example shows that feynMF is very convenient for creating several structurally similar diagrams and how unusually curved lines are inserted in immediate mode. Lines 1–3 define a little macro that is used for drawing the dotted lines denoting omitted propagators. In lines 4-17 a straightforward macro is defined that sets up the common parts of the three diagrams. Note that the argument inserted *after* this diagram is frozen by an explicit \fmffreeze. In line 18 this macro is used with another simple line. In lines 20–23 and 24–27 this simple line is replaced by two curved lines that avoid the big blob and connect external vertices.

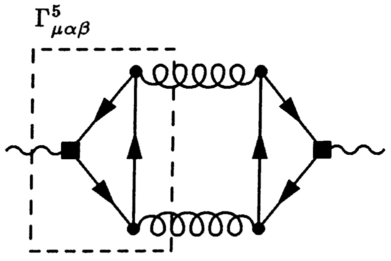
Subgraphs

Finally, figure 6.5 is a slightly more advanced example: a three-loop QCD correction to the axial vector part of the Z^0-self-energy. The beginning (lines 1–8) is straightforward: we connect the vertices. It is beneficial to give a higher tension to the bosons and a lower tension to the gluons to balance the diagram. In lines 9–11 we add dots to the vector vertices and big squares to the axial vector vertices. As it stands, the diagram will have all vertices on a straight line. To remedy this situations, we use \fmffixed to open the triangles in lines 12–13. We could also have used phantom arcs to achieve similar results, but here the linear constraints are more concise and intuitive.

For illustration, we mark the left triangle subgraph by a dashed box. As of version 1.0, feynMF does not have a built-in function for calculating the enclosing box of a list of vertices. However, this is easily done in a few lines of METAFONT. Before we start, we have to force the layout calculation in line 14. For convenience, we store the coordinates of the vertices in temporary variables in lines 16–18. It is trivial to get the coordinates of the enclosing box in lines 19–22. The remaining lines use immediate mode to draw this box, thinly dashed and labelled.

6.1.5 Conclusions and Outlook

This concludes our tour of feynMF's *immediate mode.* In the final part of this tutorial, I will describe how to define customized line styles. Knowing how to define a bag full of new line styles should come handy if the LEP2 experiments really discover supersymmetry!



```
\begin{fmfgraph*}(50,30)
  \fmfleft{i} \fmfright{o}
  \fmf{boson,tension=2}{i,iv3}
  \fmf{boson,tension=2}{o,ov3}
  \fmf{quark}{iv1,iv2,iv3,iv1}
  \fmf{quark}{ov1,ov2,ov3,ov1}
  \fmf{gluon,tension=.5}{ov1,iv1}
  \fmf{gluon,tension=.5}{iv2,ov2}
  \fmfv{decor.shape=square,
    decor.size=3thick}{iv3,ov3}
  \fmfdot{iv1,iv2,ov1,ov2}
  \fmffixed{(0,.7h)}{iv1,iv2}
  \fmffixed{(0,.7h)}{ov1,ov2}
  \fmffreeze
  \fmfcmd{save loc, bmin, bmax;
    forsuffixes $ = 1, 2, 3:
      (loc.$.x, loc.$.y) = vloc __iv.$;
    endfor
    bmax.x = max(loc1x,loc2x,loc3x) + .1w;
    bmax.y = max(loc1y,loc2y,loc3y) + .1h;
    bmin.x = min(loc1x,loc2x,loc3x) - .1w;
    bmin.y = min(loc1y,loc2y,loc3y) - .1h;}
  \fmfi{dashes,width=thin}{(bmin.x,bmin.y)
    -- (bmax.x,bmin.y) -- (bmax.x,bmax.y)
    -- (bmin.x,bmax.y) -- cycle}
  \fmfiv{label=$\Gamma^5_{\mu\alpha\beta}$}
    {(.5[bmin.x,bmax.x],bmax.y)}
\end{fmfgraph*}
```

Figure 6.5: Three loop QCD correction to the axial vector part of the Z^0-self-energy. The Feynman diagram can be drawn easily with feynMF and the box enclosing one of the fermionic loops can be added with a few simple METAFONT commands.

Bibliography

[1] T. Ohl, CERN Computer Newsletter **220**, 22-27 (1995).

[2] T. Ohl, Comp. Phys. Comm. (1995), in print.

[3] D. E. Knuth, *The METAFONTbook* (Addison-Wesley, Reading, MA, 1986).

[4] T. Ohl, *feynMF user's manual*, 1995, TEX file accompanying the distribution.

[5] M. Veltman, *Diagrammatica*, Vol. 4 of *Cambridge Lecture Notes in Physics* (Cambridge University Press, Cambridge, 1994).