Proyectors

Comenzamos por correr los paquetes necesarios;

In[556]:=
```
$LoadAddOns={"FeynHelpers","FeynOnium"};
<<FeynCalc`;
```

FeynCalc is already loaded! If you are trying to reload FeynCalc or load FeynArts, TARCER, PHI, FeynHelpers or any other add–on, please restart the kernel.

Out[557]= $Aborted

Cinematica

In[558]:=
```
SP[P,P]=4m_c^2;
SP[P_b,P_b]=m_b^2;
SP[p,p]=0;
SP[P,P_b]= 1/2 (m_b^2+4m_c^2);
SP[P,p]=1/2 (m_b^2-4m_c^2);
SP[P_b,p]=1/2 (m_b^2-4m_c^2);
LPIPS=(1-4m_c^2/m_b^2)/(8Pi);
```

Cinematica en d dimensiones

In[565]:=
```
SP[P,P]=4m_c^2;
SP[p_1,p_1]=m_c^2;
SP[p_2,p_2]=m_c^2;
SPD[p_1,p_1]=m_c^2;
SPD[p_2,p_2]=m_c^2;
SPD[P,P]=4m_c^2;
SP[P_b,P_b]=m_b^2;
SPD[P_b,P_b]=m_b^2;
SP[p,p]=0;
SPD[p,p]=0;
SP[P,P_b]= 1/2 (m_b^2+4m_c^2);
SPD[P,P_b]= 1/2 (m_b^2+4m_c^2);
SP[P,p]=1/2 (m_b^2-4m_c^2);
SPD[P,p]=1/2 (m_b^2-4m_c^2);
SP[P_b,p]=1/2 (m_b^2-4m_c^2);
SPD[P_b,p]=1/2 (m_b^2-4m_c^2);
LPIPS=(1-4m_c^2/m_b^2)/(8Pi);
FCSetDiracGammaScheme["NDR"]
```

Out[582]= NDR

Difinición de los proyectores

Proyectores de color

Singlete

In[583]:=
```
colorsingletproyector=SUNFDelta[SUNFIndex[m],SUNFIndex[n]] 1/(8m_c^3 CA)^(1/2);
```

Octete

In[584]:=
```
coloroctateproyector=SUNTF[c,m,n] 1/(4m_c^3)^(1/2);
```

Proyectores de spin

spin=0

In[585]:=
```
Projector1s0=SpinorVBar[p_2,m_c].GA[5].SpinorU[p_1,m_c];
```

Spin=1

In[586]:=
```
Projector3s1=SpinorVBar[p_2,m_c].GA[α].SpinorU[p_1,m_c];
```

Numero de:

- Colores

Singlete

In[587]:=
```
Numcolor1=2 CA;
```

Octete

In[588]:=
```
Numcolor8=2 CA CF;
```

- Polarizaciones

1S0

In[589]:=
```
Numpol1S0=1;
```

3P0

In[590]:=
```
Numpol3P0=1;
```

3S1

In[591]:=
```
Numpol3S1=3;
```

1P1

In[592]:=
```
Numpol1P1=3;
```

3P1

In[593]:=
```
Numpol3P1=3;
```

3P2

In[594]:=
```
Numpol3P2=5;
```

Amplitudes con la corriente qb amputada

- M_{0_1}

In[595]:=
```
M01=-c1 SUNFDelta[SUNFIndex[i],SUNFIndex[j]]×SpinorUBar[p1,mc].GA[μ].(1-GA[5]).SpinorV[p2,mc];
```

- M_{0_8}

In[596]:=
```
M08=-c8 SUNTF[a,i,j]×SpinorUBar[p1,mc].GA[μ].(1-GA[5]).SpinorV[p2,mc];
```

- M_{0_3}

In[597]:=
```
M03=c3 SUNFDelta[SUNFIndex[i],SUNFIndex[j]]×SpinorUBar[p1,mc].GA[μ].(1-GA[5]).SpinorV[p2,mc];
```

- M_{0_5}

In[598]:=
```
M05=c5 SUNFDelta[SUNFIndex[i],SUNFIndex[j]]×SpinorUBar[p1,mc].GA[μ].(1+GA[5]).SpinorV[p2,mc];
```

- M_{0_4}

In[599]:=
```
M04=c4 SUNFDelta[SUNFIndex[i],SUNFIndex[k]]×SUNFDelta[SUNFIndex[j],SUNFIndex[l]]×SpinorUBar[p
```

- M_{0_6}

In[600]:=
```
M06=c6 SUNFDelta[SUNFIndex[i],SUNFIndex[k]]×SUNFDelta[SUNFIndex[j],SUNFIndex[l]]×SpinorUBar[p
```

Las correspondientes corrientes son

- M_{0_1}

In[601]:=
```
M01qb=SpinorUBar[p,0].GA[μ].(1-GA[5]).SpinorU[Pb,mb]×SUNFDelta[SUNFIndex[k],SUNFIndex[l]];
```

- M_{0_8}

In[602]:=
```
M08qb=SpinorUBar[Momentum[p],0].GA[μ].(1-GA[5]).SpinorU[Pb,mb]×SUNTF[a,l,k];
```

- M_{0_3}

In[603]:=
```
M03qb=SpinorUBar[Momentum[p],0].GA[μ].(1-GA[5]).SpinorU[Pb,mb]×SUNFDelta[SUNFIndex[k],SUNFInde
```

- M_{0_5}

In[604]:=
```
M05qb=SpinorUBar[Momentum[p],0].GA[μ].(1-GA[5]).SpinorU[Pb,mb]×SUNFDelta[SUNFIndex[k],SUNFInde
```

- M_{0_4}

In[605]:=
```
M04qb=SpinorUBar[Momentum[p],0].GA[μ].(1-GA[5]).SpinorU[Pb,mb];
```

- M_{0_6}

In[606]:=
```
M06qb=SpinorUBar[Momentum[p],0].GA[μ].(1-GA[5]).SpinorU[Pb,mb];
```

Completez para los vectores de polarización

Comenzamos por el vector de polarizacion presente en los canales $^3S_1$ y $^1P_1$

In[607]:=
```
sumpolvector=-MT[α',α]+FV[P,α']×FV[P,α]/(4mc^2);
sumpoltensorJ0=1/3 (-MT[α,β]+FV[P,α]×FV[P,β]/(4mc^2)) (-MT[α',β']+FV[P,α']×FV[P,β']/(4mc^2));
sumpoltensorJ1=1/2 ((-MT[α,α']+FV[P,α]×FV[P,α']/(4mc^2)) (-MT[β,β']+FV[P,β]×FV[P,β']/(4mc^2))-(-MT[α,β']+FV[
sumpoltensorJ2=1/2 ((-MT[α,α']+FV[P,α]×FV[P,α']/(4mc^2)) (-MT[β,β']+FV[P,β]×FV[P,β']/(4mc^2))+(-MT[α,β']+FV[
```

Proyecciones de cada canal

M_{0_1}

- Singlete

1S0

In[611]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
M011s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[613]=
$$-\frac{\sqrt{2}\ c_1\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{m_c^2}$$

1P1

In[614]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. p1→ Momentum[P/2+q];
%/. p2→ Momentum[P/2-q];
M011p11=FourDivergence[%,FV[q,α]]
```

Out[617]= 0

3S1

In[618]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M013s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[619]=
$$\frac{2\sqrt{2}\ c_1\ \overline{g}^{\alpha\ \mu}\sqrt{C_A\ m_c^3}}{m_c}-\frac{c_1\ \overline{P}^{\alpha}\ \overline{P}^{\mu}\sqrt{C_A\ m_c^3}}{\sqrt{2}\ m_c^3}$$

3P0

In[620]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p01=%/. Momentum[q]→ 0
```

Out[624]=
$$\frac{i\sqrt{2}\ c_1\sqrt{C_A\ m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{m_c^3}$$

3P1

In[625]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p11=%/. Momentum[q]→ 0
```

Out[629]=
$$\frac{i\sqrt{2}\ c_1\sqrt{C_A\ m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{m_c^3}$$

3P2

In[630]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p21=%/. Momentum[q]→ 0
```

Out[634]=
$$\frac{i\sqrt{2}\ c_1\sqrt{C_A\, m_c^3}\ \bar{\epsilon}^{\alpha\ \beta\ \mu\ \bar{P}}}{m_c^3}$$

Octete

1S0

In[635]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
M011s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[637]= 0

1P1

In[638]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M011p18=FourDivergence[%,FourVector[q,α]]
```

Out[640]= 0

3S1

In[641]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
M013s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[642]= 0

3P0

In[643]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p08=%/. Momentum[q]→ 0
```

Out[647]= 0

3P1

In[648]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p18=%/. Momentum[q]→ 0
```

Out[652]= 0

3P2

In[653]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M013p28=%/. Momentum[q]→ 0
```

Out[657]= 0

M_{0_8}

Singlete

1S0

In[658]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
M081s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[660]= 0

1P1

In[661]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M081p11=FourDivergence[%,FourVector[q,α]]
```

Out[663]= 0

3S1

In[664]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M083s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[665]= 0

3P0

In[666]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p01=%/. Momentum[q]→ 0
```

Out[670]= 0

3P1

In[671]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p11=%/. Momentum[q]→ 0
```

Out[675]= 0

3P2

In[676]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p21=%/. Momentum[q]→ 0
```

Out[680]= 0

Octete

1S0

In[681]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
M081s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[683]= $-\frac{c_8 \sqrt{m_c^3}\ \overline{P}^{\mu}\ \delta^{a\,c}}{m_c^2}$

1P1

In[684]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M081p18=FourDivergence[%,FourVector[q,α]]
```

Out[686]= 0

3S1

In[687]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
M083s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[688]=
$$\frac{c_8\, m_c^2\, \delta^{a\,c}\, \overline{g}^{\alpha\ \mu}}{\sqrt{m_c^3}} + \frac{c_8\, \sqrt{m_c^3}\, \delta^{a\,c}\, \overline{g}^{\alpha\ \mu}}{m_c} - \frac{c_8\, \overline{P}^{\alpha}\, \overline{P}^{\mu}\, \delta^{a\,c}}{2\sqrt{m_c^3}}$$

3P0

In[689]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p08=%/. Momentum[q]→ 0
```

Out[693]=
$$\frac{i\, c_8\, \delta^{a\,c}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

3P1

In[694]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p18=%/. Momentum[q]→ 0
```

Out[698]=
$$\frac{i\, c_8\, \delta^{a\,c}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

3P2

In[699]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M083p28=%/. Momentum[q]→ 0
```

Out[703]=
$$\frac{i\, c_8\, \delta^{a\,c}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

M_{0_3}

■ Singlete

1S0

In[704]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
M031s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[706]=
$$\frac{\sqrt{2}\ c_3\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{m_c^2}$$

1P1

In[707]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M031p11=FourDivergence[%,FourVector[q,α]]
```

Out[709]= 0

3S1

In[710]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M033s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[711]=
$$\frac{c_3\,\overline{P}^{\alpha}\,\overline{P}^{\mu}\,\sqrt{C_A\,m_c^3}}{\sqrt{2}\;m_c^3}-\frac{2\sqrt{2}\;c_3\,\overline{g}^{\alpha\,\mu}\,\sqrt{C_A\,m_c^3}}{m_c}$$

3P0

In[712]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p01=%/. Momentum[q]→ 0
```

Out[716]=
$$-\frac{i\sqrt{2}\;c_3\,\sqrt{C_A\,m_c^3}\;\overline{\epsilon}^{\alpha\,\beta\,\mu\,\overline{P}}}{m_c^3}$$

3P1

In[717]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p11=%/. Momentum[q]→ 0
```

Out[721]=
$$-\frac{i\sqrt{2}\;c_3\,\sqrt{C_A\,m_c^3}\;\overline{\epsilon}^{\alpha\,\beta\,\mu\,\overline{P}}}{m_c^3}$$

3P2

In[722]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p21=%/. Momentum[q]→ 0
```

Out[726]=
$$-\frac{i\sqrt{2}\ c_3\sqrt{C_A\, m_c^3}\ \bar{\epsilon}^{\alpha\ \beta\ \mu\ \bar{P}}}{m_c^3}$$

Octete

1S0

In[727]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
M031s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[729]= 0

1P1

In[730]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M031p18=FourDivergence[%,FourVector[q,α]]
```

Out[732]= 0

3S1

In[733]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
M033s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[734]= 0

3P0

In[735]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p08=%/. Momentum[q]→ 0
```

Out[739]= 0

3P1

In[740]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p18=%/. Momentum[q]→ 0
```

Out[744]= 0

3P2

In[745]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M033p28=%/. Momentum[q]→ 0
```

Out[749]= 0

M_{0_5}

Singlete

1S0

In[750]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
M051s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[752]= $-\frac{\sqrt{2}\ c_5\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{m_c^2}$

In[753]:=
```
M051s01
```

Out[753]= $-\frac{\sqrt{2}\ c_5\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{m_c^2}$

1P1

In[754]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M051p11=FourDivergence[%,FourVector[q,α]]
```

Out[756]= 0

3S1

In[757]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M053s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[758]= $\frac{c_5\ \overline{P}^{\alpha}\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{\sqrt{2}\ m_c^3} - \frac{2\sqrt{2}\ c_5\ \overline{g}^{\alpha\ \mu}\ \sqrt{C_A\, m_c^3}}{m_c}$

In[759]:=
```
M053s11
```

Out[759]=
$$\frac{c_5\,\overline{P}^{\alpha}\,\overline{P}^{\mu}\,\sqrt{C_A\,m_c^3}}{\sqrt{2}\;m_c^3}-\frac{2\,\sqrt{2}\;c_5\,\overline{g}^{\alpha\,\mu}\,\sqrt{C_A\,m_c^3}}{m_c}$$

3P0

In[760]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p01=%/. Momentum[q]→ 0
```

Out[764]=
$$\frac{i\,\sqrt{2}\;c_5\,\sqrt{C_A\,m_c^3}\;\overline{\epsilon}^{\alpha\;\beta\;\mu\;\overline{P}}}{m_c^3}$$

3P1

In[765]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p11=%/. Momentum[q]→ 0
```

Out[769]=
$$\frac{i\,\sqrt{2}\;c_5\,\sqrt{C_A\,m_c^3}\;\overline{\epsilon}^{\alpha\;\beta\;\mu\;\overline{P}}}{m_c^3}$$

3P2

In[770]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p21=%/. Momentum[q]→ 0
```

Out[774]=
$$\frac{i\,\sqrt{2}\;c_5\,\sqrt{C_A\,m_c^3}\;\overline{\epsilon}^{\alpha\;\beta\;\mu\;\overline{P}}}{m_c^3}$$

Octete

1S0

In[775]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2];
M051s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[777]= 0

1P1

In[778]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M051p18=FourDivergence[%,FourVector[q,α]]
```

Out[780]= 0

3S1

In[781]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
M053s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[782]= 0

3P0

In[783]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p08=%/. Momentum[q]→ 0
```

Out[787]= 0

3P1

In[788]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p18=%/. Momentum[q]→ 0
```

Out[792]= 0

3P2

In[793]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M053p28=%/. Momentum[q]→ 0
```

Out[797]= 0

M_{0_4}

Singlete

1S0

In[798]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
M041s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[800]= $\frac{\sqrt{2}\ c_4\ \overline{P}^{\mu}\ \delta_{k\,l}\ \sqrt{C_A\ m_c^3}}{C_A\ m_c^2}$

1P1

In[801]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2−q]};
M041p11=FourDivergence[%,FourVector[q,α]]
```

Out[803]= 0

3S1

In[804]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M043s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[805]= $\frac{c_4\, \overline{P}^{\alpha}\, \overline{P}^{\mu}\, \delta_{k\,l} \sqrt{C_A\, m_c^3}}{\sqrt{2}\; C_A\, m_c^3} - \frac{2\sqrt{2}\; c_4\, \delta_{k\,l}\, \overline{g}^{\alpha\ \mu} \sqrt{C_A\, m_c^3}}{C_A\, m_c}$

3P0

In[806]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2−q];
FourDivergence[%,FourVector[q,β]];
M043p01=%/. Momentum[q]→ 0
```

Out[810]= $-\frac{i\sqrt{2}\; c_4\, \delta_{k\,l} \sqrt{C_A\, m_c^3}\; \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{C_A\, m_c^3}$

3P1

In[811]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2−q];
FourDivergence[%,FourVector[q,β]];
M043p11=%/. Momentum[q]→ 0
```

Out[815]= $-\frac{i\sqrt{2}\; c_4\, \delta_{k\,l} \sqrt{C_A\, m_c^3}\; \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{C_A\, m_c^3}$

3P2

In[816]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M043p21=%/. Momentum[q]→ 0
```

Out[820]=
$$-\frac{i\sqrt{2}\ c_4\ \delta_{k\,l}\sqrt{C_A\ m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{C_A\ m_c^3}$$

Octete

1S0

In[821]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
M041s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[823]=
$$\frac{2\ c_4\ \sqrt{m_c^3}\ \overline{P}^{\mu}\ T^c_{l\,k}}{m_c^2}$$

1P1

In[824]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M041p18=FourDivergence[%,FourVector[q,α]]
```

Out[826]=
$$0$$

3S1

In[827]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
M043s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[828]=
$$-\frac{2\ c_4\ m_c^2\ \overline{g}^{\alpha\ \mu}\ T^c_{l\,k}}{\sqrt{m_c^3}}-\frac{2\ c_4\ \sqrt{m_c^3}\ \overline{g}^{\alpha\ \mu}\ T^c_{l\,k}}{m_c}+\frac{c_4\ \overline{P}^{\alpha}\ \overline{P}^{\mu}\ T^c_{l\,k}}{\sqrt{m_c^3}}$$

3P0

In[829]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M043p08=%/. Momentum[q]→ 0
```

Out[833]=
$$-\frac{2\,i\,c_4\,T^c_{lk}\,\bar{\epsilon}^{\alpha\,\beta\,\mu\,\bar{P}}}{\sqrt{m_c^3}}$$

3P1

In[834]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M043p18=%/. Momentum[q]→ 0
```

Out[838]=
$$-\frac{2\,i\,c_4\,T^c_{lk}\,\bar{\epsilon}^{\alpha\,\beta\,\mu\,\bar{P}}}{\sqrt{m_c^3}}$$

3P2

In[839]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M043p28=%/. Momentum[q]→ 0
```

Out[843]=
$$-\frac{2\,i\,c_4\,T^c_{lk}\,\bar{\epsilon}^{\alpha\,\beta\,\mu\,\bar{P}}}{\sqrt{m_c^3}}$$

M_{0_6}

Singlete

1S0

In[844]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
M061s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[846]= $$-\frac{\sqrt{2}\ c_6\ \overline{P}^{\mu}\ \delta_{k\,l}\ \sqrt{C_A\ m_c^3}}{C_A\ m_c^2}$$

1P1

In[847]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M061p11=FourDivergence[%,FourVector[q,α]]
```

Out[849]= 0

3S1

In[850]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
M063s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[851]= $$\frac{c_6\ \overline{P}^{\alpha}\ \overline{P}^{\mu}\ \delta_{k\,l}\ \sqrt{C_A\ m_c^3}}{\sqrt{2}\ C_A\ m_c^3} - \frac{2\ \sqrt{2}\ c_6\ \delta_{k\,l}\ \overline{g}^{\alpha\ \mu}\ \sqrt{C_A\ m_c^3}}{C_A\ m_c}$$

3P0

In[852]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p01=%/. Momentum[q]→ 0
```

Out[856]=
$$\frac{i\sqrt{2}\ c_6\ \delta_{k\,l}\sqrt{C_A\,m_c^3}\ \bar{\epsilon}^{\alpha\ \beta\ \mu\ \bar{P}}}{C_A\,m_c^3}$$

3P1

In[857]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p11=%/. Momentum[q]→ 0
```

Out[861]=
$$\frac{i\sqrt{2}\ c_6\ \delta_{k\,l}\sqrt{C_A\,m_c^3}\ \bar{\epsilon}^{\alpha\ \beta\ \mu\ \bar{P}}}{C_A\,m_c^3}$$

3P2

In[862]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p21=%/. Momentum[q]→ 0
```

Out[866]=
$$\frac{i\sqrt{2}\ c_6\ \delta_{k\,l}\sqrt{C_A\,m_c^3}\ \bar{\epsilon}^{\alpha\ \beta\ \mu\ \bar{P}}}{C_A\,m_c^3}$$

Octete

1S0

In[867]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2];
M061s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[869]=
$$-\frac{2\, c_6 \sqrt{m_c^3}\ \overline{P}^{\mu}\ T_{lk}^{c}}{m_c^2}$$

1P1

In[870]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M061p18=FourDivergence[%,FourVector[q,α]]
```

Out[872]=
$$0$$

3S1

In[873]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
M063s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[874]=
$$-\frac{2\, c_6\, m_c^2\, \overline{g}^{\nu\ \mu}\ T_{lk}^{c}}{\sqrt{m_c^3}} - \frac{2\, c_6 \sqrt{m_c^3}\ \overline{g}^{\nu\ \mu}\ T_{lk}^{c}}{m_c} + \frac{c_6\, \overline{P}^{\alpha}\ \overline{P}^{\mu}\ T_{lk}^{c}}{\sqrt{m_c^3}}$$

3P0

In[875]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p08=%/. Momentum[q]→ 0
```

Out[879]=
$$\frac{2\, i\, c_6\, T_{lk}^{c}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

3P1

In[880]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p18=%/. Momentum[q]→ 0
```

Out[884]=
$$\frac{2\, i\, c_6\, T^c_{lk}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

3P2

In[885]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFIndex
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M063p28=%/. Momentum[q]→ 0
```

Out[889]=
$$\frac{2\, i\, c_6\, T^c_{lk}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$$

Contribuciones totales

Singlete

- $|M_{01}|^2$

${}^1S_0$

In[890]:=
```
CM01s01=ComplexConjugate[M01s01 M01qb]/.{k →g, l→h};
Simplify[ 1/(2mb Numcolor1 Numpol1S0) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUNFIndex[k],SUNFIndex[g]]×
```

Out[891]=
$$\frac{c_1^2\, C_A \left(m_b^2 - 4\, m_c^2\right)^2}{8\,\pi\, m_b\, m_c}$$

${}^1P_1$

In[892]:=
```
CM01p11=ComplexConjugate[M01p11 M01qb]/.{k →g, l→h, α→ α'};
Contract[sumpolvector Simplify[ 1/(2mb Numcolor1 Numpol1P1) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUN
```

Out[893]= 0

${}^3S_1$

In[894]:=
```
CM03s11=ComplexConjugate[M03s11 M01qb]/.{k →g, l→h, α→ α'};
Simplify[Contract[sumpolvector 1/(2mb Numcolor1 Numpol3S1) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUNF
```

Out[895]=
$$\frac{c_1^2\, C_A \left(-48\, m_b^2\, m_c^4 + m_b^6 + 128\, m_c^6\right)}{24\,\pi\, m_b^3\, m_c}$$

${}^3P_0$

In[896]:=
```
CM013p01=ComplexConjugate[M013p01 M01qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ0 1/(2mb Numcolor1 Numpol3P0) LPIPS^1_2 SUNFSimplify[ SUNFDelta[SU
```

Out[897]= 0

${}^3P_1$

In[898]:=
```
CM013p11=ComplexConjugate[M013p11 M01qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ1 1/(2mb Numcolor1 Numpol3P1) LPIPS^1_2 SUNFSimplify[ SUNFDelta[SU
```

Out[899]= $\frac{c_1^2\, C_A\left(-48\, m_b^2\, m_c^4 + m_b^6 + 128\, m_c^6\right)}{12\,\pi\, m_b^3\, m_c^3}$

${}^3P_2$

In[900]:=
```
CM013p21=ComplexConjugate[M013p21 M01qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ2 1/(2mb Numcolor1 Numpol3P2) LPIPS^1_2 SUNFSimplify[ SUNFDelta[SU
```

Out[901]= 0

2Re($M_{01}M_{0i}^{*}$) penguins

$^{1}S_{0}$

In[902]:=
```
CM031s01=ComplexConjugate[M031s01 M03qb]/.{k →g, l→h};
CM051s01=ComplexConjugate[M051s01 M05qb]/.{k →g, l→h};
CM041s01=ComplexConjugate[M041s01 M04qb]/.{k →g, l→h};
CM061s01=ComplexConjugate[M061s01 M06qb]/.{k →g, l→h};
2Re[Simplify[1/(2m_b Numcolor1 Numpol1S0) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUNFIndex[k],SUNFIndex
```

Out[906]=
$$-\frac{\mathrm{Re}\left(\frac{c_1\,(c_3\,C_A-c_5\,C_A+c_4-c_6)\,(m_b^2-4\,m_c^2)^2}{m_b\,m_c}\right)}{4\,\pi}$$

$^{1}P_{1}$

In[907]:=
```
CM031p11=ComplexConjugate[M031p11 M03qb]/.{k →g, l→h, α→ α'};
CM051p11=ComplexConjugate[M051p11 M05qb]/.{k →g, l→h, α→ α'};
CM041p11=ComplexConjugate[M041p11 M04qb]/.{k →g, l→h, α→ α'};
CM061p11=ComplexConjugate[M061p11 M06qb]/.{k →g, l→h, α→ α'};
Contract[sumpolvector Simplify[1/(2m_b Numcolor1 Numpol1P1) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUN
```

Out[911]= 0

$^{3}S_{1}$

In[912]:=
```
CM033s11=ComplexConjugate[M033s11 M03qb]/.{k →g, l→h, α→ α'};
CM053s11=ComplexConjugate[M053s11 M05qb]/.{k →g, l→h, α→ α'};
CM043s11=ComplexConjugate[M043s11 M04qb]/.{k →g, l→h, α→ α'};
CM063s11=ComplexConjugate[M063s11 M06qb]/.{k →g, l→h, α→ α'};
Simplify[Contract[sumpolvector 1/(2m_b Numcolor1 Numpol3S1) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUNF
```

Out[916]=
$$-\frac{c_1\,(c_3\,C_A+c_5\,C_A+c_4+c_6)\,(m_b^2-4\,m_c^2)^2\,(m_b^2+8\,m_c^2)}{24\,\pi\,m_b^3\,m_c}$$

${}^3P_0$

In[917]:=
```
CM033p01=ComplexConjugate[M033p01 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p01=ComplexConjugate[M053p01 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p01=ComplexConjugate[M043p01 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p01=ComplexConjugate[M063p01 M06qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ0 1/(2mb Numcolor1 Numpol3P0) LPIPS SUNFSimplify[ SUNFDelta[SU
```

Out[921]= 0

${}^3P_1$

In[922]:=
```
CM033p11=ComplexConjugate[M033p11 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p11=ComplexConjugate[M053p11 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p11=ComplexConjugate[M043p11 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p11=ComplexConjugate[M063p11 M06qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ1 1/(2mb Numcolor1 Numpol3P1) LPIPS SUNFSimplify[ SUNFDelta[SU
```

Out[926]= $$-\frac{c_1\,(c_3\,C_A - c_5\,C_A + c_4 - c_6)\left(m_b^2 - 4\,m_c^2\right)^2\left(m_b^2 + 8\,m_c^2\right)}{12\,\pi\,m_b^3\,m_c^3}$$

${}^3P_2$

In[927]:=
```
CM033p21=ComplexConjugate[M033p21 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p21=ComplexConjugate[M053p21 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p21=ComplexConjugate[M043p21 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p21=ComplexConjugate[M063p21 M06qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ2 1/(2mb Numcolor1 Numpol3P2) LPIPS SUNFSimplify[ SUNFDelta[SU
```

Out[931]= 0

Octete

$|M_{08}|^2$

${}^1S_0$

In[932]:=
```
CM08s08=ComplexConjugate[M08s08 M08qb]/.{k →g, l→h};
SUNSimplify[Simplify[1/(2mb Numcolor8 Numpol1S0) LPIPS[1/2] SUNFSimplify[ SUNFDelta[SUNFIndex[k],S
```

Out[933]=
$$\frac{c_8^2 \left(m_b^2 - 4\, m_c^2\right)^2}{16\, \pi\, m_b\, m_c}$$

${}^1P_1$

In[934]:=
```
CM08p18=ComplexConjugate[M08p18 M08qb]/.{k →g, l→h, α→ α'};
SUNSimplify[Contract[sumpolvector Simplify[1/(2mb Numcolor8 Numpol1P1) LPIPS[1/2] SUNFSimplify[ S
```

Out[935]=
$$0$$

${}^3S_1$

In[936]:=
```
CM083s18=ComplexConjugate[M083s18 M08qb]/.{k →g, l→h, α→ α'};
SUNSimplify[Simplify[Contract[sumpolvector 1/(2mb Numcolor8 Numpol3S1) LPIPS[1/2] SUNFSimplify[ SU
```

Out[937]=
$$\frac{c_8^2 \left(-48\, m_b^2\, m_c^4 + m_b^6 + 128\, m_c^6\right)}{48\, \pi\, m_b^3\, m_c}$$

$^3P_0$

In[938]:=
```
CM083p08=ComplexConjugate[M083p08 M08qb]/.{k →g, l→h, α→ α', β→ β'};
SUNSimplify[Simplify[Contract[sumpoltensorJ0 1/(2mb Numcolor8 Numpol3P0) LPIPS 1/2 SUNFSimplify[
```

Out[939]= 0

$^3P_1$

In[940]:=
```
CM083p18=ComplexConjugate[M083p18 M08qb]/.{k →g, l→h, α→ α', β→ β'};
SUNSimplify[Simplify[Contract[sumpoltensorJ1 1/(2mb Numcolor8 Numpol3P1) LPIPS 1/2 SUNFSimplify[
```

Out[941]= $\frac{c_8^2\left(-48\, m_b^2\, m_c^4 + m_b^6 + 128\, m_c^6\right)}{24\,\pi\, m_b^3\, m_c^3}$

$^3P_2$

In[942]:=
```
CM083p28=ComplexConjugate[M083p28 M08qb]/.{k →g, l→h, α→ α', β→ β'};
SUNSimplify[Simplify[Contract[sumpoltensorJ2 1/(2mb Numcolor8 Numpol3P2) LPIPS 1/2 SUNFSimplify[
```

Out[943]= 0

2Re($M_{08}M_{0i}^*$) penguins

$^1S_0$

In[944]:=
```
CM031s08=ComplexConjugate[M031s08M03qb]/.{k →g, l→h};
CM051s08=ComplexConjugate[M051s08M05qb]/.{k →g, l→h};
CM041s08=ComplexConjugate[M041s08M04qb]/.{k →g, l→h};
CM061s08=ComplexConjugate[M061s08M06qb]/.{k →g, l→h};
SUNSimplify[2Re[Simplify[1/(2m_b Numcolor8 Numpol1S0) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SUNFIndex[
```

Out[948]= $-\frac{\mathrm{Re}\left(\frac{(c_4-c_6)\, c_8\, (m_b^2-4\, m_c^2)^2}{m_b\, m_c}\right)}{4\,\pi}$

$^1P_1$

In[949]:=
```
CM031p18=ComplexConjugate[M031p18M03qb]/.{k →g, l→h, α→ α'};
CM051p18=ComplexConjugate[M051p18M05qb]/.{k →g, l→h, α→ α'};
CM041p18=ComplexConjugate[M041p18M04qb]/.{k →g, l→h, α→ α'};
CM061p18=ComplexConjugate[M061p18M06qb]/.{k →g, l→h, α→ α'};
SUNSimplify[Contract[sumpolvector Simplify[1/(2m_b Numcolor8 Numpol1P1) LPIPS 1/2 SUNFSimplify[ S
```

Out[953]= 0

$^3S_1$

In[954]:=
```
CM033s18=ComplexConjugate[M033s18M03qb]/.{k →g, l→h, α→ α'};
CM053s18=ComplexConjugate[M053s18M05qb]/.{k →g, l→h, α→ α'};
CM043s18=ComplexConjugate[M043s18M04qb]/.{k →g, l→h, α→ α'};
CM063s18=ComplexConjugate[M063s18M06qb]/.{k →g, l→h, α→ α'};
SUNSimplify[Simplify[Contract[sumpolvector 1/(2m_b Numcolor8 Numpol3S1) LPIPS 1/2 SUNFSimplify[ SU
```

Out[958]= $-\frac{(c_4+c_6)\, c_8\, (m_b^2-4\, m_c^2)^2\, (m_b^2+8\, m_c^2)}{24\,\pi\, m_b^3\, m_c}$

${}^3P_0$

In[959]:=
```
CM033p01=ComplexConjugate[M033p01 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p01=ComplexConjugate[M053p01 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p01=ComplexConjugate[M043p01 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p01=ComplexConjugate[M063p01 M06qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ0 1/(2mb Numcolor1 Numpol3P0) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SU
```

Out[963]= 0

${}^3P_1$

In[964]:=
```
CM033p18=ComplexConjugate[M033p18 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p18=ComplexConjugate[M053p18 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p18=ComplexConjugate[M043p18 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p18=ComplexConjugate[M063p18 M06qb]/.{k →g, l→h, α→ α', β→ β'};
SUNSimplify[Simplify[Contract[sumpoltensorJ1 1/(2mb Numcolor8 Numpol3P1) LPIPS 1/2 SUNFSimplify[
```

Out[968]= $$-\frac{(c_4-c_6)\,c_8\left(m_b^2-4\,m_c^2\right)^2\left(m_b^2+8\,m_c^2\right)}{12\,\pi\,m_b^3\,m_c^3}$$

${}^3P_2$

In[969]:=
```
CM033p21=ComplexConjugate[M033p21 M03qb]/.{k →g, l→h, α→ α', β→ β'};
CM053p21=ComplexConjugate[M053p21 M05qb]/.{k →g, l→h, α→ α', β→ β'};
CM043p21=ComplexConjugate[M043p21 M04qb]/.{k →g, l→h, α→ α', β→ β'};
CM063p21=ComplexConjugate[M063p21 M06qb]/.{k →g, l→h, α→ α', β→ β'};
Simplify[Contract[sumpoltensorJ2 1/(2mb Numcolor1 Numpol3P2) LPIPS 1/2 SUNFSimplify[ SUNFDelta[SU
```

Out[973]= 0

NLO corrections

Vertex

bq vertex

M_{01} Singlete

In[974]:=
```
Mqb01NLO = (-c1*g^2*CF/Sqrt[-1])SUNFDelta[SUNFIndex[i],SUNFIndex[j]]×SUNFDelta[SUNFIndex[k],SU
```

1 S0

In[975]:=
```
M011s01
```

Out[975]=
$$-\frac{\sqrt{2}\ c_1\ \overline{P}^{\mu}\ \sqrt{C_A\, m_c^3}}{m_c^2}$$

In[976]:=
```
M011s01 M01qb
```

Out[976]=
$$-\frac{\sqrt{2}\ c_1\ \overline{P}^{\mu}\ \delta_{k\,l}\ \sqrt{C_A\, m_c^3}\ \ \overline{u}(p).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).u(P_b,\ m_b)}{m_c^2}$$

In[977]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M011s01M01qb/.{k → g,l → h}]%SU
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[%];
2Re[1/(2mbNumcolor1 Numpol1S0) LPIPS 1/2 ×%]
```

Out[982]=
$$-\frac{1}{768\,\pi^3}\,\mathrm{Re}\left(\frac{1}{m_c^3}\,c_1^2\,g^2\,C_A\,m_b\,C_F\left(m_b^2-4\,m_c^2\right)\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.$$
$$\left(m_c^2\left(-12\left(-2\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+\gamma-\log(4\,\pi)\right)\log\left(\frac{\mu^2}{m_b^2}\right)-24\,\mathrm{Li}_2\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+12\log^2\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+\right.\right.$$
$$24\log(4\,\pi)\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+6\log^2\left(\frac{\mu^2}{m_b^2}\right)+12\log\left(\frac{4\,\pi\,\mu^2}{m_b^2}\right)+$$
$$\left.\left.\left.\pi^2+6\,\gamma^2-12\,\gamma+24+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)\right)+6\,m_b^2\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)\right)\right)$$

1 P1

In[983]:=
```
M011p11
```

Out[983]= 0

In[984]:=
```
0
```

Out[984]= 0

3 S1

In[985]:=
```
M013s11
```

Out[985]=
$$\frac{2\sqrt{2}\ c_1\ \overline{g}^{\alpha\ \mu}\ \sqrt{C_A\ m_c^3}}{m_c} - \frac{c_1\ \overline{P}^{\alpha}\ \overline{P}^{\mu}\ \sqrt{C_A\ m_c^3}}{\sqrt{2}\ m_c^3}$$

In[986]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M013s11M01qb/.{k → g,l → h,α →
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[Contract[sumpolvector %]];
2Re[1/(2mbNumcolor1 Numpol3S1) LPIPS 1/2 ×%]
```

Out[991]=
$$-\frac{1}{2304\,\pi^3}\,\mathrm{Re}\left(\frac{1}{m_b\,m_c}\,c_1^2\,g^2\,C_A\,C_F\left(m_b^2-4\,m_c^2\right)\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.$$
$$\left(m_b^2\left(-12\left(-2\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+\gamma-\log(4\,\pi)\right)\log\left(\frac{\mu^2}{m_b^2}\right)-24\,\mathrm{Li}_2\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+\right.\right.$$
$$12\log^2\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+24\log(4\,\pi)\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+$$
$$6\log^2\left(\frac{\mu^2}{m_b^2}\right)+12\log\left(\frac{4\,\pi\,\mu^2}{m_b^2}\right)+\pi^2+6\,\gamma^2-12\,\gamma+48+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)\Big)+$$
$$8\,m_c^2\left(-12\left(-2\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+\gamma-\log(4\,\pi)\right)\log\left(\frac{\mu^2}{m_b^2}\right)-24\,\mathrm{Li}_2\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+12\log^2\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+\right.$$
$$24\log(4\,\pi)\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+36\log\left(\frac{m_b^2}{m_b^2-4\,m_c^2}\right)+$$
$$\left.\left.\left.6\log^2\left(\frac{\mu^2}{m_b^2}\right)+12\log\left(\frac{4\,\pi\,\mu^2}{m_b^2}\right)+\pi^2+6\,\gamma^2-12\,\gamma+48+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)\right)\right)\right)$$

3P0

In[992]:= `M013p01`

Out[992]= $$\frac{i\sqrt{2}\ c_1\sqrt{C_A\, m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{m_c^3}$$

3P1

In[993]:= `M013p11`

Out[993]= $$\frac{i\sqrt{2}\ c_1\sqrt{C_A\, m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{m_c^3}$$

3P2

In[994]:= `M013p21`

Out[994]= $$\frac{i\sqrt{2}\ c_1\sqrt{C_A\, m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{m_c^3}$$

M_{08} Singlete

In[995]:=
```
0
```

Out[995]= 0

In[996]:= **bc vertex**

Out[996]= bc vertex

M_{01} Octete

In[997]:=
```
0
```

Out[997]= 0

M_{08} Octete

In[998]:=
```
Mbc08NLO = (-c8*g^2/Sqrt[-1])SUNTF[e,i,r]×SUNTF[a,r,j]×SUNTF[a,l,s]×SUNTF[e,s,k]×ChangeDimensi
```

1 s0

In[999]:=
```
M081s08
```

Out[999]=
$$-\frac{c_8 \sqrt{m_c^3}\ \overline{P}^{\mu}\ \delta^{a\,c}}{m_c^2}$$

In[1000]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M081s08M08qb/.{k →
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[%];
2Re[1/(2mbNumcolor8 Numpol1S0) LPIPS 1/2 ×%]
```

Out[1005]=
$$-\frac{1}{512\,\pi^3}\,\mathrm{Re}\left(\left(\left(C_A^2-2\right) g^2\, c_8^2\, m_b \left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.\right.$$
$$\left(-\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\right.$$
$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$
$$\left.\left.\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+\right.\right.$$

$$4 \log\left(\frac{2\, m_b\, m_c}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{4\, m_b\, m_c}{m_b^2 + 4\, m_c^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$2 \log\left(\frac{3\, m_b^2 - 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(-\frac{2\left(m_b^2 - 2\, m_c^2\right)}{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$4 \log\left(\frac{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2} - m_b^2}\right) +$$

$$4 \log\left(\frac{\mu^2}{m_b^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 2 \log\left(\frac{m_b^2}{m_c^2}\right)$$

$$\log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 4 \log(4\,\pi) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$4\, \gamma \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 2 \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$4\, \mathrm{Li}_2\left(\frac{1}{2} - \frac{m_b^2}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) + 4\, \mathrm{Li}_2\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right)\Bigg) m_b^8 +$$

$$\left(4\left(\log^2\left(\frac{2\left(m_b^2 - 2\, m_c^2\right)}{m_b^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) + 2 \log\left(\frac{m_b^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(\frac{2\left(m_b^2 - 2\, m_c^2\right)}{m_b^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -\right.\right.$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+6\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^2+$$

$$\left(4\log\left(\frac{\mu^2}{m_b^2}\right)-6\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-2\log(\pi)-\log(16)+2\,\gamma-4\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\Bigg)$$

$$m_b^6-4\Bigg(\Bigg(\Bigg(-3\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-6\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+3\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-3\log^2\Bigg($$

$$\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\Bigg)+3\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$12\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$6\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$12 \log\left(\frac{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2} - m_b^2}\right) -$$

$$12 \log\left(\frac{\mu^2}{m_b^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$6 \log\left(\frac{m_b^2}{m_c^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$12 \log(4\,\pi) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$12\, \gamma \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 28 \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$12\, \mathrm{Li}_2\left(\frac{1}{2} - \frac{m_b^2}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) - 12\, \mathrm{Li}_2\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right)\Bigg) m_c^4 +$$

$$\left(6 \log\left(\frac{\mu^2}{m_b^2}\right) - 10 \log\left(\frac{\mu^2}{m_c^2}\right) + 4 \log\left(\frac{m_b^2}{m_c^2}\right) - 4 \log(\pi) - \log(256) + 4\, \gamma - 9\right)$$

$$\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}\; m_c^2\Bigg) m_b^4 +$$

$$8\left(\left(8\log\left(\frac{\mu^2}{m_b^2}\right)-12\log\left(\frac{\mu^2}{m_c^2}\right)-\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+5\log\left(\frac{m_b^2}{m_c^2}\right)-4\log(4\,\pi)+5\,\gamma-13\right)m_c^4\right.$$

$$\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-8\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-4\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^6\Bigg)m_b^2+$$

$$64\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-4\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)\,m_c^8-$$

$$32\left(2\log\left(\frac{\mu^2}{m_b^2}\right)-3\log\left(\frac{\mu^2}{m_c^2}\right)+\log\left(\frac{m_b^2}{4\,\pi\,m_c^2}\right)+\gamma-3\right)m_c^6$$

$$\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}\Bigg)\Bigg)\Bigg/$$

$$\left(C_A\, m_c \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}\ \left(m_b^2 - 2\, m_c^2\right)^2\right)$$

1P1

In[1006]:=
```
0
```

Out[1006]= 0

3S1

In[1007]:=
```
M083s18
```

Out[1007]=
$$\frac{c_8\, m_c^2\, \delta^{a\,c}\, \overline{g}^{\alpha\ \mu}}{\sqrt{m_c^3}} + \frac{c_8\, \sqrt{m_c^3}\ \delta^{a\,c}\, \overline{g}^{\alpha\ \mu}}{m_c} - \frac{c_8\, \overline{P}^{\alpha}\ \overline{P}^{\mu}\, \delta^{a\,c}}{2\, \sqrt{m_c^3}}$$

In[1008]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M083s18M08qb/.{k →

%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];

Simplify[Contract[sumpolvector %]];

2Re[1/(2mbNumcolor8 Numpol3S1) LPIPS 1/2 ×%]
```

Out[1013]=
$$-\frac{1}{1536\,\pi^3}\,\mathrm{Re}\left(\left(\left(C_A^2 - 2\right) g^2\, c_8^2 \left(1 - \frac{4\, m_c^2}{m_b^2}\right)\right.\right.$$

$$\left(-\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\right.$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+2\log\left(\frac{m_b^2}{m_c^2}\right)$$

$$\left.\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-\right.$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+2\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_b^{10}+$$

$$\Bigg(\left(4\log\left(\frac{\mu^2}{m_b^2}\right)-6\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-2\log(\pi)-\log(16)+2\,\gamma-4\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-$$

$$4\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+8\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^2\Bigg)m_b^8+$$

$$4\Bigg(\Bigg(11\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+22\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-11\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$11 \log^2\left(\frac{3\, m_b^2 - 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) -$$

$$11 \log^2\left(-\frac{2\left(m_b^2 - 2\, m_c^2\right)}{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) +$$

$$44 \log\left(\frac{2\, m_b\, m_c}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{4\, m_b\, m_c}{m_b^2 + 4\, m_c^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$22 \log\left(\frac{3\, m_b^2 - 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(-\frac{2\left(m_b^2 - 2\, m_c^2\right)}{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$44 \log\left(\frac{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2} - m_b^2}\right) +$$

$$44 \log\left(\frac{\mu^2}{m_b^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$22 \log\left(\frac{m_b^2}{m_c^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$44 \log(4\,\pi) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$44\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+116\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$44\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+44\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^4+$$

$$\left(14\log\left(\frac{\mu^2}{m_b^2}\right)-14\log\left(\frac{\mu^2}{m_c^2}\right)+17\log\left(\frac{m_b^2}{m_c^2}\right)-5\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;\;m_c^2\Bigg)m_b^6-$$

$$8\Bigg(\left(20\log\left(\frac{\mu^2}{m_b^2}\right)-31\log\left(\frac{\mu^2}{m_c^2}\right)+33\log\left(\frac{m_b^2}{m_c^2}\right)-11\log(\pi)-\log(4\,194\,304)+11\,\gamma-41\right)$$

$$m_c^4\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-4\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-52\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^6\Bigg)m_b^4+$$

$$32\left(\left(-6\log\left(\frac{\mu^2}{m_b^2}\right)-3\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+7\log\left(\frac{m_b^2}{m_c^2}\right)-6\log(4\,\pi)+9\,\gamma-29\right)m_c^6\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-\right.$$

$$
\begin{aligned}
&14\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.\\
&\left.\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\right.\\
&\left.\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+\right.\\
&\left.4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\\
&\left.2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\\
&\left.4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+\right.\\
&\left.4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+\right.\\
&\left.2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+\right.
\end{aligned}
$$

$$4\log(4\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-4\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^8\Bigg)m_b^2-$$

$$256\,m_c^8\Bigg(\left(-2\log\left(\frac{\mu^2}{m_b^2}\right)+\log\left(\frac{\mu^2}{4\,\pi\,m_c^2}\right)+\gamma-3\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-$$

$$2\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+4\log(4\,\pi)$$

$$\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)\Bigg)\Bigg)\Bigg/\left(C_A\,m_b\,m_c\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;\left(m_b^2-2\,m_c^2\right)^2\right)$$

In[1014]:=

bcbar vertex

Out[1014]= bcbar vertex

M_{01} Octete

In[1015]:=
```
0
```

Out[1015]= 0

M_{08} Octete

In[1016]:=
```
Mbcbar08NLO = (-c8*g^2/Sqrt[-1])SUNTF[e,r,j]×SUNTF[a,i,r]×SUNTF[a,l,s]×SUNTF[e,s,k]×ChangeDime
```

1S0

In[1017]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M081s08M08qb/.{k →
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[%];
2Re[1/(2mbNumcolor8 Numpol1S0) LPIPS1/2×%]
```

Out[1022]=
$$-\frac{1}{256\,\pi^3}\,\mathrm{Re}\left(\left(g^2\,c_8^2\,m_b\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.\right.$$
$$\left(-\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\right.$$
$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$
$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4 \log\left(\frac{2\, m_b\, m_c}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{4\, m_b\, m_c}{m_b^2 + 4\, m_c^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$2 \log\left(\frac{3\, m_b^2 - 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(-\frac{2\left(m_b^2 - 2\, m_c^2\right)}{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$4 \log\left(\frac{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2} - m_b^2}\right) +$$

$$4 \log\left(\frac{\mu^2}{m_b^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 2 \log\left(\frac{m_b^2}{m_c^2}\right)$$

$$\log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 4 \log(4\,\pi) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$4\, \gamma \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 8 \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$4\, \mathrm{Li}_2\left(\frac{1}{2} - \frac{m_b^2}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) + 4\, \mathrm{Li}_2\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right)\Bigg) m_b^6 +$$

$$2\Bigg(\Bigg(\log^2\left(\frac{2\left(m_b^2 - 2\, m_c^2\right)}{m_b^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) + 2 \log\left(\frac{m_b^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(\frac{2\left(m_b^2 - 2\, m_c^2\right)}{m_b^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) -$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+44\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^2+$$

$$2\left(\log\left(\frac{\mu^2}{16\,m_b^2}\right)-3\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-2\log(\pi)+2\,\gamma-5\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\Bigg)m_b^4-$$

$$4\Bigg(\left(2\log\left(\frac{\mu^2}{m_b^2}\right)-2\log\left(\frac{\mu^2}{m_c^2}\right)-12\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+13\log\left(\frac{m_b^2}{m_c^2}\right)+12\,\gamma-30\right)m_c^2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-$$

$$4\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-20\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^4\Bigg)m_b^2+$$

$$16\left(\left(-4\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-4\log(\pi)-\log(256)+4\,\gamma-10\right)m_c^4\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-\right.$$

$$2\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$\left.2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+\right.$$

$$4\log(4\pi)\log\left(\frac{m_b^2+4m_c^2+\sqrt{(m_b^2-4m_c^2)^2}}{4m_bm_c}\right)-$$

$$4\gamma\log\left(\frac{m_b^2+4m_c^2+\sqrt{(m_b^2-4m_c^2)^2}}{4m_bm_c}\right)-12\log\left(\frac{m_b^2+4m_c^2+\sqrt{(m_b^2-4m_c^2)^2}}{4m_bm_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{(m_b^2-4m_c^2)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3m_b^2+4m_c^2+\sqrt{(m_b^2-4m_c^2)^2}}{2\sqrt{(m_b^2-4m_c^2)^2}}\right)\Bigg)\Bigg)\Bigg)\Bigg/\left(C_A\,m_c\sqrt{(m_b^2-4m_c^2)^2}\;(m_b^2-2m_c^2)\right)$$

1P1

In[1023]:=
```
0
```

Out[1023]= 0

3S1

In[1024]:=
```
M083s18
```

Out[1024]= $\frac{c_8\,m_c^2\,\delta^{a\,c}\,\overline{g}^{\alpha\;\mu}}{\sqrt{m_c^3}}+\frac{c_8\sqrt{m_c^3}\;\delta^{a\,c}\,\overline{g}^{\alpha\;\mu}}{m_c}-\frac{c_8\,\overline{P}^{\alpha}\,\overline{P}^{\mu}\,\delta^{a\,c}}{2\sqrt{m_c^3}}$

In[1025]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M083s18M08qb/.{k →

%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];

Simplify[Contract[sumpolvector %]];

2Re[1/(2mbNumcolor8 Numpol3S1) LPIPS 1/2 ×%]
```

Out[1030]=

$$\frac{1}{768\,\pi^3}\,\mathrm{Re}\left(\left(g^2\,c_8^2\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.\right.$$

$$\left(-\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\right.$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2\ -m_b^2}}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+2\log\left(\frac{m_b^2}{m_c^2}\right)$$

$$\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+8\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_b^8+$$

$$2\Bigg(\Bigg(-3\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-6\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+3\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-3\log^2\Bigg(\Bigg($$

$$\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\Bigg)+3\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$12 \log\left(\frac{2\, m_b\, m_c}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{4\, m_b\, m_c}{m_b^2 + 4\, m_c^2 - \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) +$$

$$6 \log\left(\frac{3\, m_b^2 - 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\, m_b^2 - 4\, m_c^2}\right) \log\left(-\frac{2\left(m_b^2 - 2\, m_c^2\right)}{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) +$$

$$12 \log\left(\frac{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{m_b^2 - 2\, m_c^2}\right) \log\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2 \;} - m_b^2}\right) -$$

$$12 \log\left(\frac{\mu^2}{m_b^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$6 \log\left(\frac{m_b^2}{m_c^2}\right) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) -$$

$$12 \log(4\,\pi) \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$12\, \gamma \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) + 44 \log\left(\frac{m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{4\, m_b\, m_c}\right) +$$

$$12\, \mathrm{Li}_2\left(\frac{1}{2} - \frac{m_b^2}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right) - 12\, \mathrm{Li}_2\left(\frac{-3\, m_b^2 + 4\, m_c^2 + \sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}{2\sqrt{\left(m_b^2 - 4\, m_c^2\right)^2}}\right)\Bigg) m_c^2 +$$

$$2\left(\log\left(\frac{\mu^2}{16\,m_b^2}\right)-3\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-2\log(\pi)+2\,\gamma-5\right)\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\Bigg)\,m_b^6+$$

$$4\left(8\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\right.\right.$$

$$\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-8\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^4-$$

$$\left(18\log\left(\frac{\mu^2}{m_b^2}\right)-14\log\left(\frac{\mu^2}{m_c^2}\right)+13\log\left(\frac{m_b^2}{m_c^2}\right)+4\log(\pi)+\log(256)-4\,\gamma+10\right)$$

$$m_c^2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\Bigg)m_b^4-$$

$$16\left(\left(-16\log\left(\frac{\mu^2}{m_b^2}\right)-4\log\left(\frac{\mu^2}{m_c^2}\right)+3\log\left(\frac{m_b^2}{m_c^2}\right)-20\log(\pi)-\log(1\,099\,511\,627\,776)+20\,\gamma-50\right)\right.$$

$$m_c^4\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\Bigg)-2\left(3\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+\right.$$

$$6\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$3\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+3\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-$$

$$3\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$12\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$6\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$12\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$12\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$6\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+12\log(4\,\pi)$$

$$\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-12\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-12\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$12\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)m_c^6\Bigg)m_b^2+$$

$$128\Bigg(\left(-2\log\left(\frac{\mu^2}{m_b^2}\right)-2\log\left(\frac{\mu^2}{m_c^2}\right)+\log\left(\frac{m_b^2}{256\,m_c^2}\right)-4\log(\pi)+4\,\gamma-10\right)m_c^6\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-$$

$$2\left(\log^2\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+2\log\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\right.$$

$$\log\left(\frac{2\left(m_b^2-2\,m_c^2\right)}{m_b^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-\log^2\left(\frac{m_b^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)+$$

$$\log^2\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)-\log^2\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+$$

$$4\log\left(\frac{2\,m_b\,m_c}{m_b^2-2\,m_c^2}\right)\log\left(\frac{4\,m_b\,m_c}{m_b^2+4\,m_c^2-\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$2\log\left(\frac{3\,m_b^2-4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\,m_b^2-4\,m_c^2}\right)\log\left(-\frac{2\left(m_b^2-2\,m_c^2\right)}{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)-$$

$$4\log\left(\frac{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{m_b^2-2\,m_c^2}\right)\log\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;-m_b^2}\right)+$$

$$4\log\left(\frac{\mu^2}{m_b^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$2\log\left(\frac{m_b^2}{m_c^2}\right)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)+$$

$$4\log(4\,\pi)\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\gamma\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-4\log\left(\frac{m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{4\,m_b\,m_c}\right)-$$

$$4\,\mathrm{Li}_2\left(\frac{1}{2}-\frac{m_b^2}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)+4\,\mathrm{Li}_2\left(\frac{-3\,m_b^2+4\,m_c^2+\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}{2\sqrt{\left(m_b^2-4\,m_c^2\right)^2}}\right)\Bigg)\Bigg)\Bigg)\Bigg)\Bigg)\Bigg/\left(C_A\,m_b\sqrt{\left(m_b^2-4\,m_c^2\right)^2}\;\left(2\,m_c^3-m_b^2\,m_c\right)\right)$$

In[1031]:= # qc vertex

Out[1031]= qc vertex

In[1032]:=
```
M_qc08NLO = (-c_8*g^2/Sqrt[-1])SUNTF[e,i,r]×SUNTF[a,r,j]×SUNTF[a,s,k]×SUNTF[e,l,s]×ChangeDimens
```

M_{01}Octete

In[1033]:=
```
0
```

Out[1033]= 0

M_{08} Octete

1S0

In[1034]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M08ls08M08qb/.{k →
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[%];
2Re[1/(2mbNumcolor8 Numpol1S0) LPIPS 1/2 ×%]
```

Out[1039]=
$$\frac{1}{1536\,\pi^3}\,\mathrm{Re}\left(\frac{1}{C_A\left(2\,m_c^3-m_b^2\,m_c\right)}\,c_8^2\,g^2\,m_b\left(m_b^2-4\,m_c^2\right)\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.$$
$$\left(m_b^2\left(-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+\gamma-2-\log(\pi)\right)\log\left(\frac{\mu^2}{m_c^2}\right)-24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+\right.\right.$$
$$12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+6\log^2\left(\frac{\mu^2}{m_c^2}\right)-$$
$$\left.48\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+\pi^2+6\,\gamma^2+24\,\gamma-72+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)\right)-$$
$$2\,m_c^2\left(-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+\gamma-2-\log(\pi)\right)\log\left(\frac{\mu^2}{m_c^2}\right)-24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+\right.$$
$$12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$
$$24\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+6\log^2\left(\frac{\mu^2}{m_c^2}\right)-48\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+\pi^2+$$
$$\left.\left.\left.6\,\gamma^2+24\,\gamma-72+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)\right)\right)\right)$$

1P1

In[1040]:=
```
0
```

Out[1040]= 0

3S1

In[1041]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M083s18M08qb/.{k →

%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];

Simplify[Contract[sumpolvector %]];

2Re[ 1 / (2mb Numcolor8 Numpol3S1) LPIPS 1/2 ×%]
```

Out[1046]=
$$\frac{1}{4608\,\pi^3}\,\mathrm{Re}\left(\frac{1}{C_A\,m_b\left(2\,m_c^3-m_b^2\,m_c\right)}\,c_8^2\,g^2\left(1-\frac{4\,m_c^2}{m_b^2}\right)\left(4\,m_b^2\,m_c^2+m_b^4-32\,m_c^4\right)\right.$$
$$\left(m_b^2\left(-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+\gamma-2-\log(\pi)\right)\log\left(\frac{\mu^2}{m_c^2}\right)-24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+\right.\right.$$
$$12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+6\log^2\left(\frac{\mu^2}{m_c^2}\right)-$$
$$\left.48\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+\pi^2+6\,\gamma^2+24\,\gamma-72+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)\right)-$$
$$2\,m_c^2\left(-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)+\gamma-2-\log(\pi)\right)\log\left(\frac{\mu^2}{m_c^2}\right)-24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+\right.$$
$$12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$
$$24\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+6\log^2\left(\frac{\mu^2}{m_c^2}\right)-48\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+\pi^2+$$
$$\left.\left.\left.6\,\gamma^2+24\,\gamma-72+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)\right)\right)\right)$$

In[1047]:=

qcbar vertex

Out[1047]= qcbar vertex

In[1048]:=
```
M_qcbar08NLO = (-c8*g^2/Sqrt[-1])SUNTF[e,r,j]×SUNTF[a,i,r]×SUNTF[a,s,k]×SUNTF[e,l,s]×ChangeDime
```

1S0

In[1049]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M08ls08M08qb/.{k →
%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];
Simplify[%];
2Re[1/(2mb Numcolor8 Numpol1S0) LPIPS[1/2]×%]
```

Out[1054]=
$$-\frac{1}{3072\,\pi^3}\,\mathrm{Re}\left(\frac{1}{C_A\,m_c\left(m_b^2-2\,m_c^2\right)^2}\left(C_A^2-2\right)g^2\,c_8^2\,m_b\left(m_b^2-4\,m_c^2\right)\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.$$
$$\left(\left(\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-12\right.\right.\right.$$
$$\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+36\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$
$$\left.24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma+24\right)m_b^4-$$
$$4\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+\right.$$
$$12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-12\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$
$$24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+36\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+$$
$$\left.6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma+18\right)m_c^2\,m_b^2+$$
$$4\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-12\right.$$
$$\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+24\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$
$$\left.\left.\left.24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma+12\right)m_c^4\right)\right)$$

1P1

In[1055]:=
```
0
```

Out[1055]= 0

3S1

In[1056]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
SUNSimplify[SUNFSimplify[DiracSimplify[FermionSpinSum[ComplexConjugate[M083s18 M08qb /.{k →

%/. Momentum[p1]→ Momentum[P/2];
%/. Momentum[p2]→ Momentum[P/2];

Simplify[Contract[sumpolvector %]];

2Re[1/(2mb Numcolor8 Numpol3S1) LPIPS 1/2 × %]
```

Out[1061]=

$$-\frac{1}{9216\,\pi^3}\,\mathrm{Re}\left(\frac{1}{C_A\,m_b\,m_c\left(m_b^2-2\,m_c^2\right)^2}\left(C_A^2-2\right)g^2\,c_8^2\left(m_b^2-4\,m_c^2\right)\left(1-\frac{4\,m_c^2}{m_b^2}\right)\right.$$

$$\left(\left(\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-12\right.\right.\right.$$

$$\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)+36\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$

$$\left.24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma+24\right)m_b^6+$$

$$4\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-12\right.$$

$$\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$

$$\left.24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma-6\right)m_c^2\,m_b^4-$$

$$4\left(42\log^2\left(\frac{\mu^2}{m_c^2}\right)-84\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+\right.$$

$$84\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-84\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+168\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$

$$168\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-168\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+$$

$$\left.42\log^2(4\,\pi)-84\,\gamma\log(4\,\pi)+168\log(4\,\pi)+7\,\pi^2+42\,\gamma^2-84\,\gamma+60\right)m_c^4\,m_b^2+$$

$$32\left(6\log^2\left(\frac{\mu^2}{m_c^2}\right)-12\left(-2\log\left(-\frac{4\,m_c^2}{m_b^2-4\,m_c^2}\right)-\log(\pi)+\gamma-2\right)\log\left(\frac{\mu^2}{m_c^2}\right)+12\log^2\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-\right.$$

$$12\log\left(\frac{4\,\pi\,\mu^2}{m_c^2}\right)+24\log(4\,\pi)\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-24\,\gamma\log\left(-\frac{2\,m_c^2}{m_b^2-4\,m_c^2}\right)-$$

$$\left.\left.\left.24\,\mathrm{Li}_2\left(\frac{2\,m_c^2}{m_b^2-4\,m_c^2}+1\right)+6\log^2(4\,\pi)-12\,\gamma\log(4\,\pi)+24\log(4\,\pi)+\pi^2+6\,\gamma^2-12\,\gamma+12\right)m_c^6\right)\right)$$

Correcciones Reales

Amplitud c con la corriente qb amputada

In[1062]:=
```
Mc1 = -c1 Sqrt[-1] (Sqrt[-1] g) SUNTF[b, i, j] ×
  SpinorUBar[p1, mc].GA[μ].(1 - GA[5]).SpinorV[p2, mc]
```

Out[1062]= $c_1\, g\, T^b_{i\,j}\, \overline{u}(p_1,\, m_c).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).v(p_2,\, m_c)$

In[1063]:=
```
Mc8 = -c8 Sqrt[-1] (Sqrt[-1] g) SUNTF[b, i, r] ×
  SUNTF[a, r, j] × SpinorUBar[p1, mc].GA[μ].(1 - GA[5]).SpinorV[p2, mc]
```

Out[1063]= $c_8\, g\, T^a_{r\,j}\, T^b_{i\,r}\, \overline{u}(p_1,\, m_c).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).v(p_2,\, m_c)$

Amplitud cbar con la corriente qb amputada

In[1064]:=
```
Mcbar1 =
 -c1 Sqrt[-1] (Sqrt[-1] g) SUNTF[b, i, j] × SpinorUBar[p1, mc].GA[μ].(1 - GA[5]).SpinorV[p2, mc]
```

Out[1064]= $c_1\, g\, T^b_{i\,j}\, \overline{u}(p_1,\, m_c).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).v(p_2,\, m_c)$

In[1065]:=
```
Mcbar8 = -c8 Sqrt[-1] (Sqrt[-1] g) SUNTF[a, i, r] ×
  SUNTF[b, r, j] × SpinorUBar[p1, mc].GA[μ].(1 - GA[5]).SpinorV[p2, mc]
```

Out[1065]= $c_8\, g\, T^a_{i\,r}\, T^b_{r\,j}\, \overline{u}(p_1,\, m_c).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).v(p_2,\, m_c)$

Amplitud qb

In[1066]:=
```
Mc1qb =
 SUNFDelta[SUNFIndex[l], SUNFIndex[k]] × SpinorUBar[p, 0].GA[μ].(1 - GA[5]).SpinorU[Pb, mb]
```

Out[1066]= $\delta_{k\,l}\, \overline{u}(p).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).u(P_b,\, m_b)$

In[1067]:=
```
Mc8qb = SpinorUBar[Momentum[p], 0].GA[μ].(1 - GA[5]).SpinorU[Pb, mb] × SUNTF[a, l, k]
```

Out[1067]= $T^a_{l\,k}\, \overline{u}(\overline{p}).\overline{\gamma}^{\mu}.\left(1-\overline{\gamma}^5\right).u(P_b,\, m_b)$

M_{c8} c gluon emission

Singlet channel

1S0

In[1068]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2];
Mc81s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[1070]=
$$\frac{c_8\, g\, \overline{P}^{\mu}\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}}{\sqrt{2}\ C_A\, m_c^2}$$

1P1

In[1071]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
Mc81p11=FourDivergence[%,FourVector[q,α]]
```

Out[1073]= 0

3 S1

In[1074]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
Mc83s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[1075]=
$$\frac{c_8\, g\, \overline{P}^{\alpha}\ \overline{P}^{\mu}\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}}{2\,\sqrt{2}\ C_A\, m_c^3} - \frac{\sqrt{2}\ c_8\, g\, \delta^{a\,b}\, \overline{g}^{\alpha\ \mu}\, \sqrt{C_A\, m_c^3}}{C_A\, m_c}$$

3PJ

In[1076]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
Mc83pj1=%/. Momentum[q]→ 0
```

Out[1080]=
$$-\frac{i\, c_8\, g\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}\ \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{2}\ C_A\, m_c^3}$$

Octet channel

1S0

In[1081]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
Mc81s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[1083]=
$$\frac{2\, c_8\, g\, \sqrt{m_c^3}\ \overline{P}^{\mu}\, \left(\mathrm{tr}\left(\, T^c.T^b.T^a\,\right)\right)}{m_c^2}$$

1P1

In[1084]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
Mc81p18=FourDivergence[%,FourVector[q,α]]
```

Out[1086]= 0

3S1

In[1087]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
Mc83s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[1088]= $\frac{c_8\, g\, \overline{P}^{\alpha}\, \overline{P}^{\mu}\, (\mathrm{tr}\,(\,T^c.T^b.T^a\,))}{\sqrt{m_c^3}} - \frac{2\, c_8\, g\, m_c^2\, \overline{g}^{\alpha\,\mu}\, (\mathrm{tr}\,(\,T^c.T^b.T^a\,))}{\sqrt{m_c^3}} - \frac{2\, c_8\, g\, \sqrt{m_c^3}\, \overline{g}^{\alpha\,\mu}\, (\mathrm{tr}\,(\,T^c.T^b.T^a\,))}{m_c}$

3PJ

In[1089]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
Mc83pj8=%/. Momentum[q]→ 0
```

Out[1093]= $-\frac{2\, i\, c_8\, g\, \overline{\epsilon}^{\alpha\,\beta\,\mu\,\overline{P}}\, (\mathrm{tr}\,(\,T^c.T^b.T^a\,))}{\sqrt{m_c^3}}$

M_{01} cbar gluon emission

Octet channel

1S0

In[1094]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
Mcbar11s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[1096]= $\frac{c_1\, g\, \sqrt{m_c^3}\, \overline{P}^{\mu}\, \delta^{b\,c}}{m_c^2}$

1P1

In[1097]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
M$c11p18=FourDivergence[%,FourVector[q,α]]
```

Out[1099]= 0

3S1

In[1100]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
M$c13s18=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[1101]= $-\frac{c_1\, g\, m_c^2\, \delta^{b\,c}\, \overline{g}^{\alpha\ \mu}}{\sqrt{m_c^3}} - \frac{c_1\, g\, \sqrt{m_c^3}\ \delta^{b\,c}\, \overline{g}^{\alpha\ \mu}}{m_c} + \frac{c_1\, g\, \overline{P}^{\alpha}\ \overline{P}^{\mu}\, \delta^{b\,c}}{2\, \sqrt{m_c^3}}$

3PJ

In[1102]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M$c13p08=%/. Momentum[q]→ 0
```

Out[1106]= $-\frac{i\, c_1\, g\, \delta^{b\,c}\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}}{\sqrt{m_c^3}}$

M_{cbar8} cbar gluon emission

Singlet channel

1S0

In[1107]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInc
%/. Momentum[p1]→ Momentum[P/2];
M$cbar81s01=%/. Momentum[p2]→ Momentum[P/2]
```

Out[1109]= $\frac{c_8\, g\, \overline{P}^{\mu}\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}}{\sqrt{2}\ C_A\, m_c^2}$

1P1

In[1110]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
Mcbar81p11=FourDivergence[%,FourVector[q,α]]
```

Out[1112]= 0

3S1

In[1113]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
Mcbar83s11=%/. {Momentum[p1]→ Momentum[P/2], Momentum[p2]→ Momentum[P/2]}
```

Out[1114]= $\frac{c_8\, g\, \overline{P}^{\alpha}\, \overline{P}^{\mu}\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}}{2\,\sqrt{2}\;C_A\, m_c^3} - \frac{\sqrt{2}\;c_8\, g\, \delta^{a\,b}\, \overline{g}^{\alpha\;\mu}\, \sqrt{C_A\, m_c^3}}{C_A\, m_c}$

3PJ

In[1115]:=
```
SUNFSimplify[colorsingletproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInd
%/. Momentum[p1]→ Momentum[P/2+q];
%/. Momentum[p2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
Mcbar83pj1=%/. Momentum[q]→ 0
```

Out[1119]= $-\frac{i\, c_8\, g\, \delta^{a\,b}\, \sqrt{C_A\, m_c^3}\;\overline{\epsilon}^{\alpha\;\beta\;\mu\;\overline{P}}}{\sqrt{2}\;C_A\, m_c^3}$

Octet channel

1S0

In[1120]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. Momentum[p1]→ Momentum[P/2];
Mcbar81s08=%/. Momentum[p2]→ Momentum[P/2]
```

Out[1122]= $\frac{2\, c_8\, g\, \sqrt{m_c^3}\;\overline{P}^{\mu}\, \left(\mathrm{tr}\left(\, T^c.T^a.T^b\,\right)\right)}{m_c^2}$

1P1

In[1123]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]×SUNFDelta[SUNFInde
%/. {Momentum[p1]→ Momentum[P/2+q], Momentum[p2]→ Momentum[P/2-q]};
Mcbar81p18=FourDivergence[%,FourVector[q,α]]
```

Out[1125]= 0

3S1

In[1126]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]*SUNFDelta[SUNFInde
M_cbar83s18=%/. {Momentum[p_1]→ Momentum[P/2], Momentum[p_2]→ Momentum[P/2]}
```

Out[1127]=
$$\frac{c_8\, g\, \overline{P}^{\alpha}\ \overline{P}^{\mu}\left(\mathrm{tr}\left(\ T^c.T^a.T^b\ \right)\right)}{\sqrt{m_c^3}}-\frac{2\, c_8\, g\, m_c^2\, \overline{g}^{\nu\ \mu}\left(\mathrm{tr}\left(\ T^c.T^a.T^b\ \right)\right)}{\sqrt{m_c^3}}-\frac{2\, c_8\, g\, \sqrt{m_c^3}\ \overline{g}^{\nu\ \mu}\left(\mathrm{tr}\left(\ T^c.T^a.T^b\ \right)\right)}{m_c}$$

3PJ

In[1128]:=
```
SUNFSimplify[coloroctateproyector SUNFDelta[SUNFIndex[n],SUNFIndex[i]]*SUNFDelta[SUNFInde
%/. Momentum[p_1]→ Momentum[P/2+q];
%/. Momentum[p_2]→ Momentum[P/2-q];
FourDivergence[%,FourVector[q,β]];
M_cbar83pj8=%/. Momentum[q]→ 0
```

Out[1132]=
$$-\frac{2\, i\, c_8\, g\, \overline{\epsilon}^{\alpha\ \beta\ \mu\ \overline{P}}\left(\mathrm{tr}\left(\ T^c.T^a.T^b\ \right)\right)}{\sqrt{m_c^3}}$$