Model Building in the LHC Era

from model to LHC

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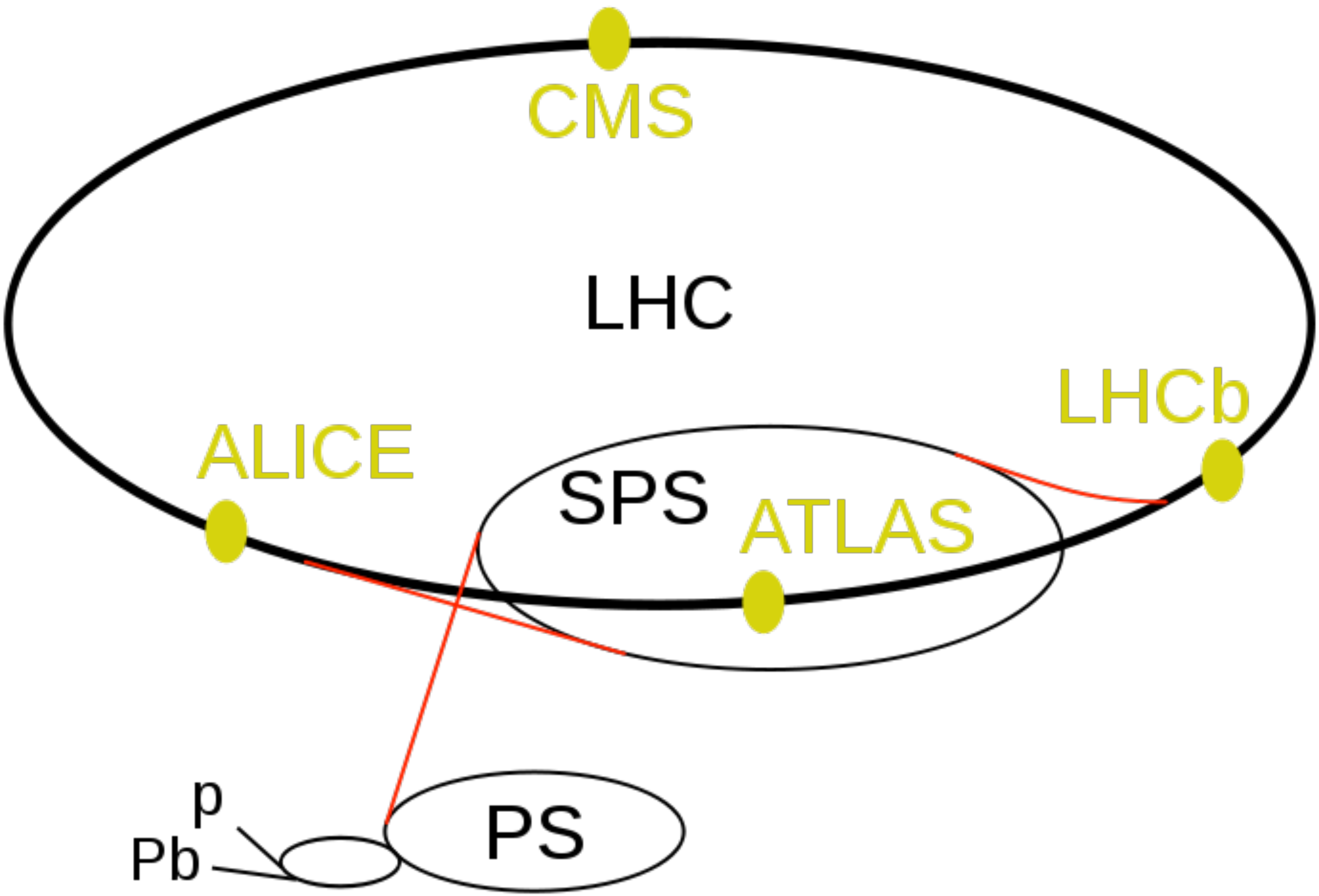
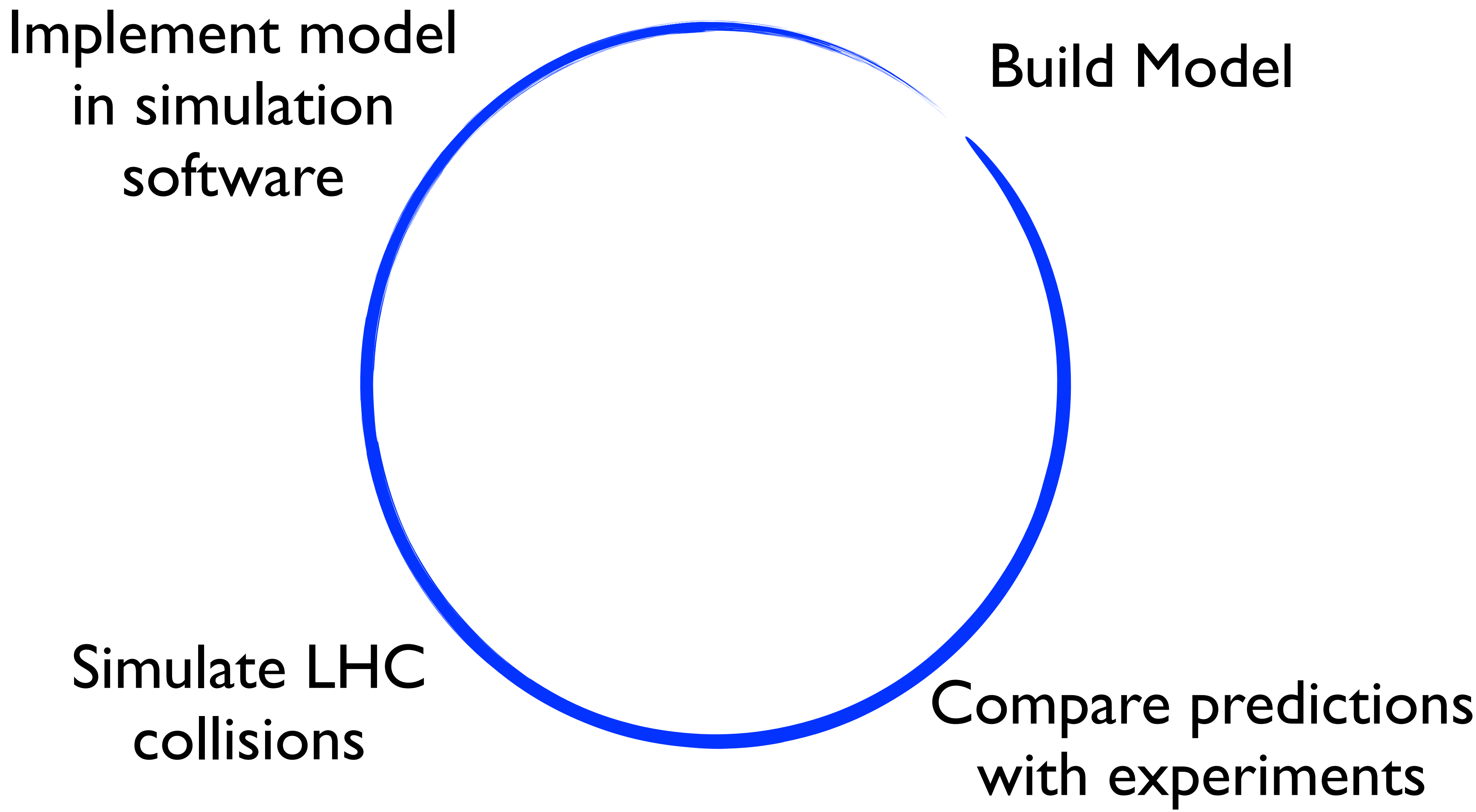
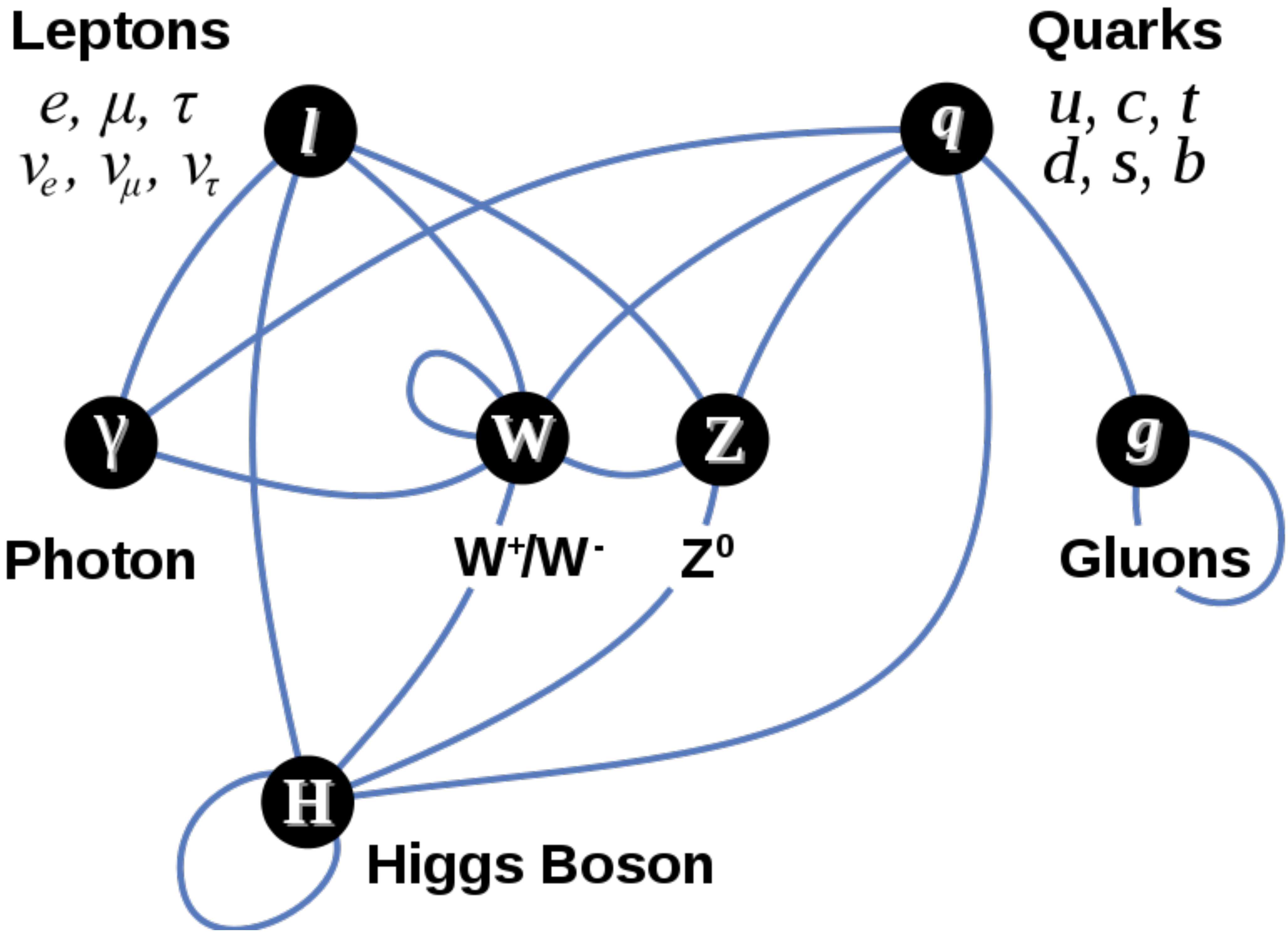
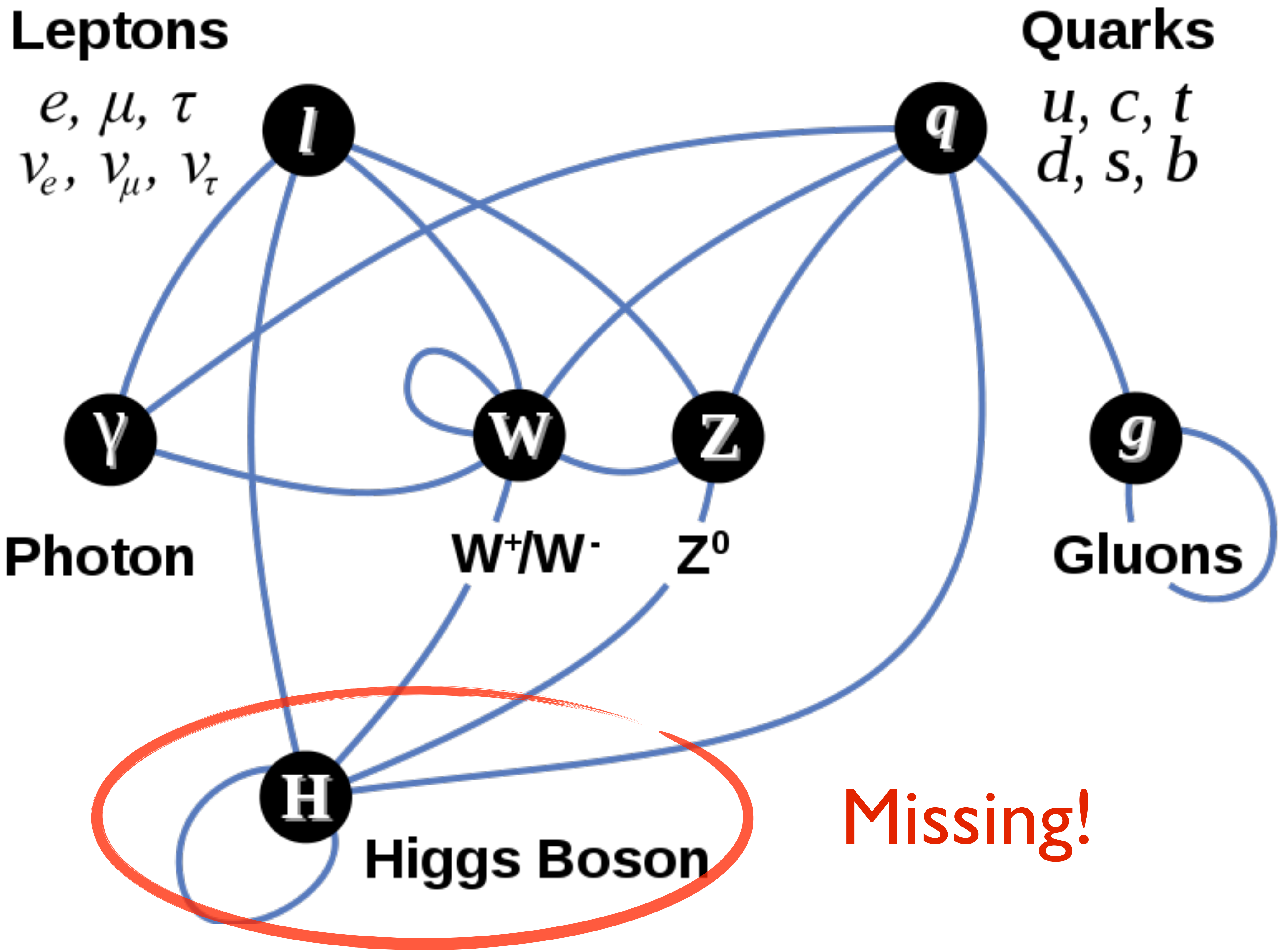

CMS
LHC
LHCb
ALICE
SPS
ATLAS
p
Pb
PS

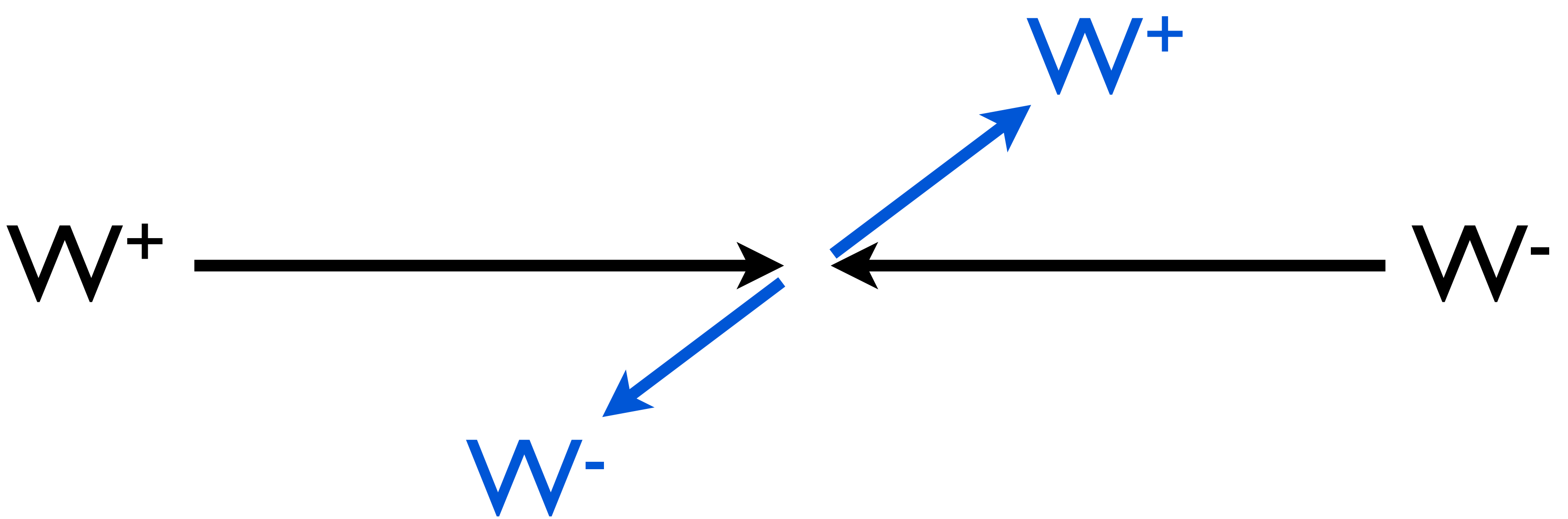

Implement model in simulation software
Build Model
Simulate LHC collisions
Compare predictions with experiments

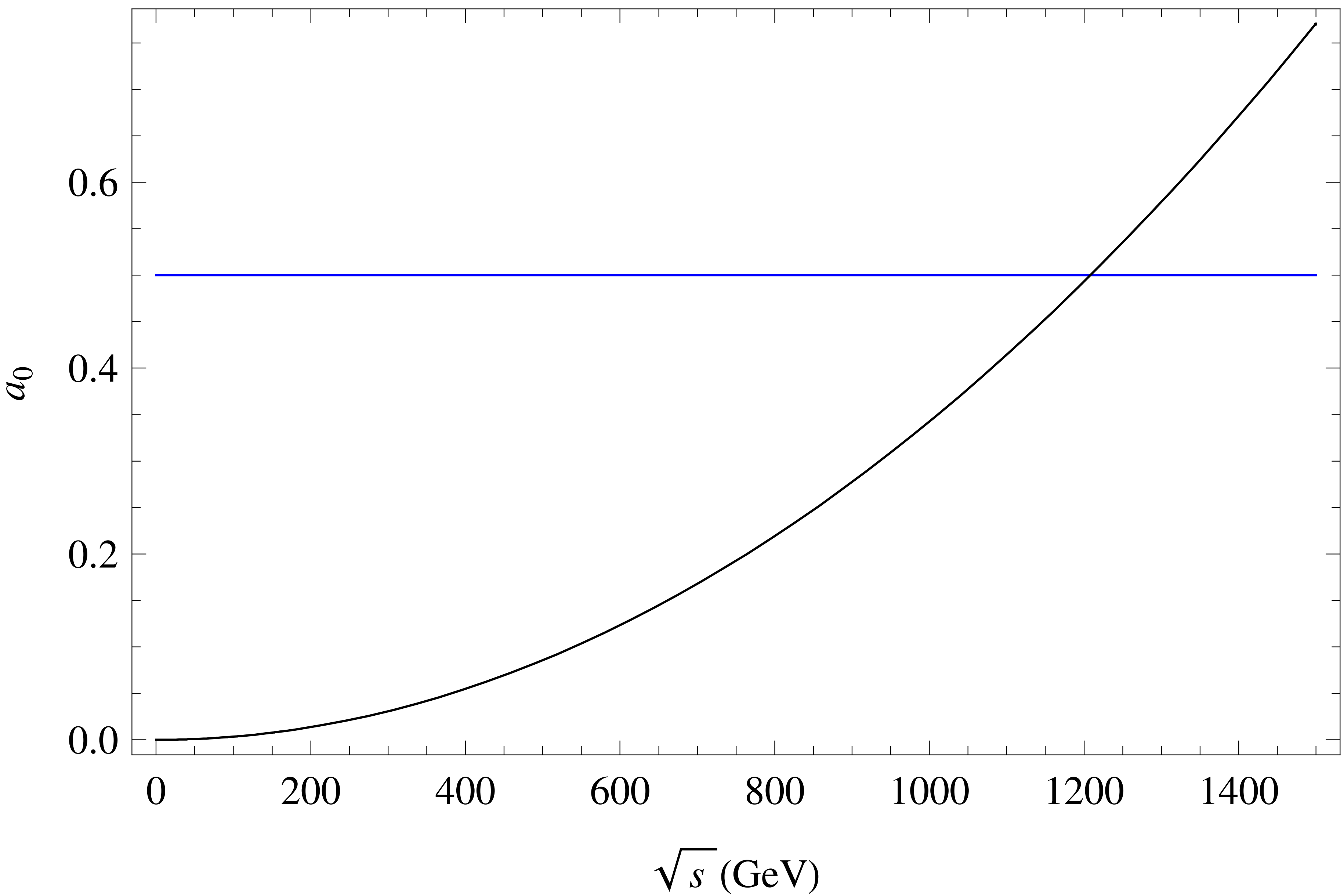


Leptons
e, μ, τ
νe, νμ, ντ
l
Quarks
u, c, t
d, s, b
q
γ
W
Z
g
Photon
W+/W-
Z0
Gluons
H
Higgs Boson



Leptons
e, μ, τ
ν_e, ν_μ, ν_τ
Quarks
u, c, t
d, s, b
l
q
γ
W
Z
g
Photon
W^+/W^-
Z^0
Gluons
H
Higgs Boson
Missing!


W+
W-
W+
W-



a_0
0.0
0.2
0.4
0.6
0
200
400
600
800
1000
1200
1400
$\sqrt{s}$ (GeV)

SM

???

Supersymmetry

Extra
Dimensions

Little Higgs

Higgsless

New Strong
Dynamics

SM

???

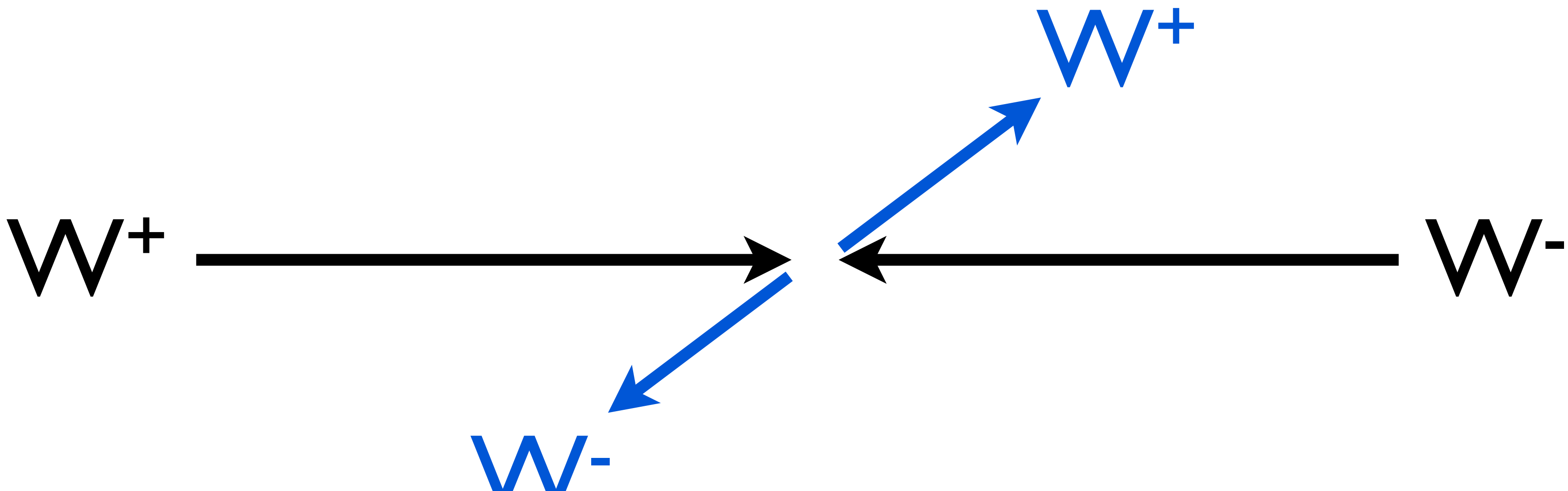
Supersymmetry

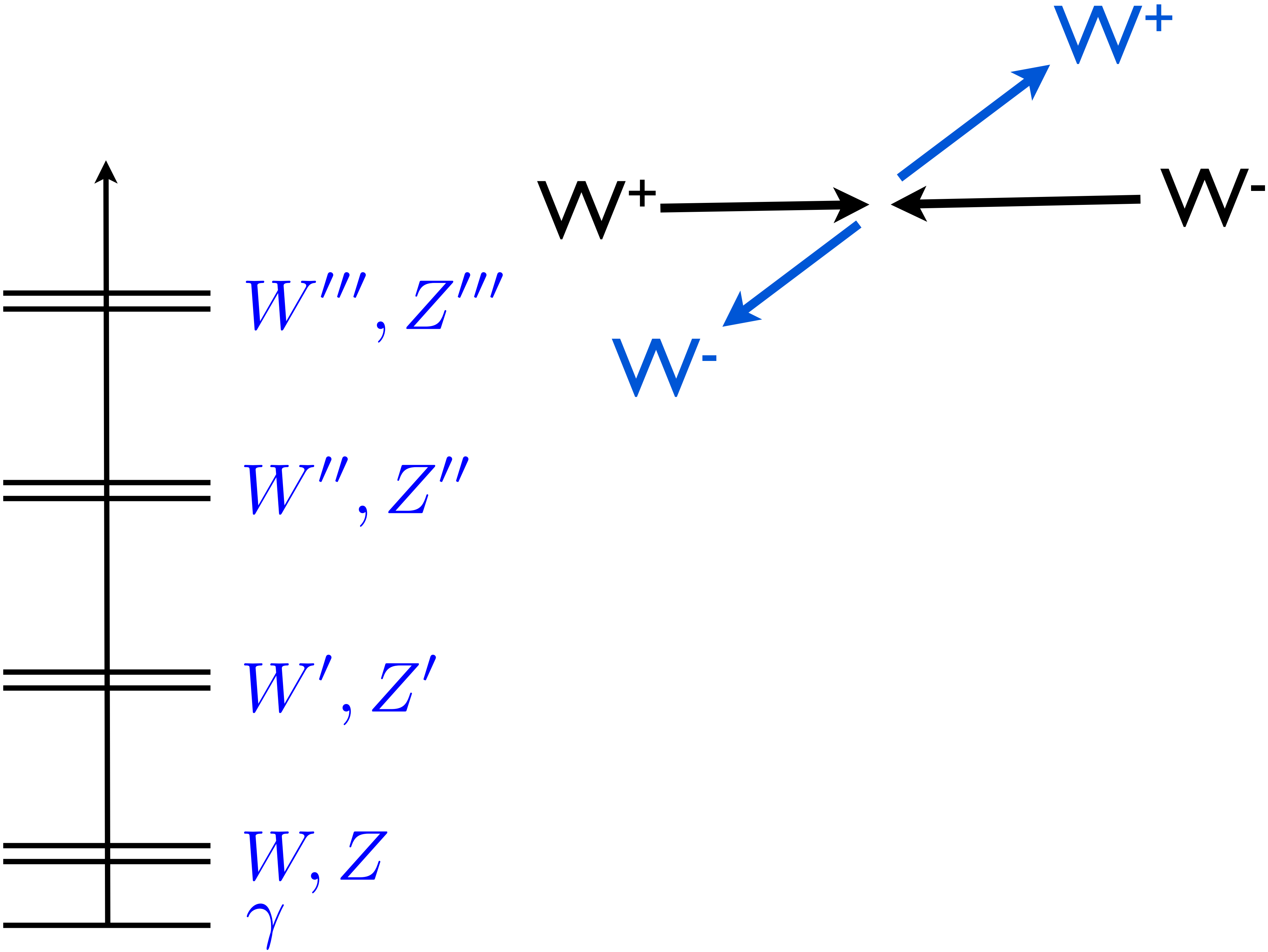
Extra
Dimensions

Little Higgs

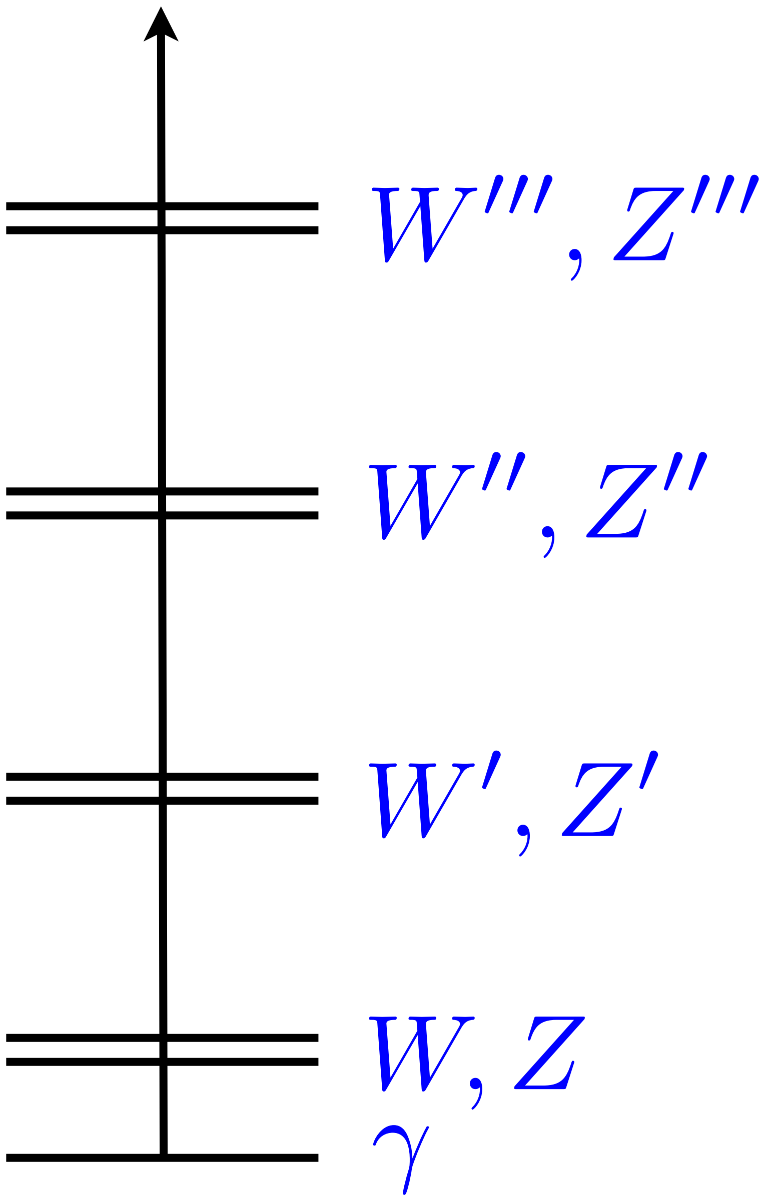
Higgsless

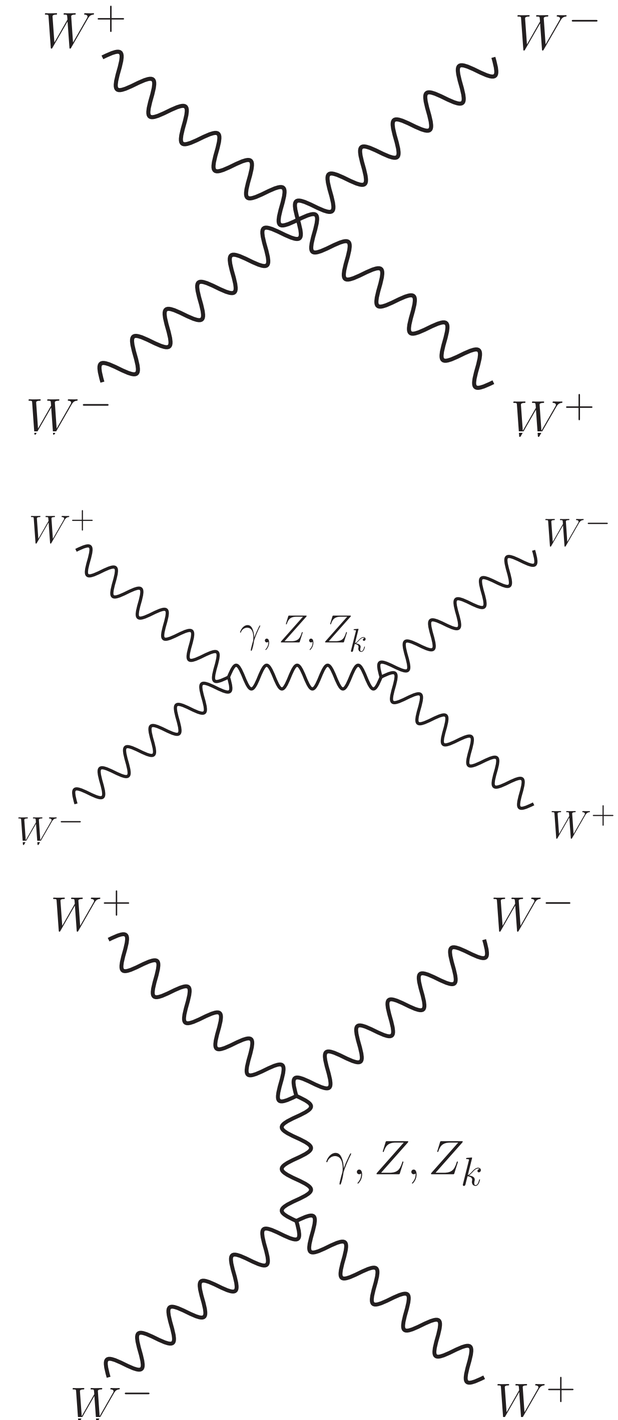
New Strong
Dynamics


W+
W-
W+
W-

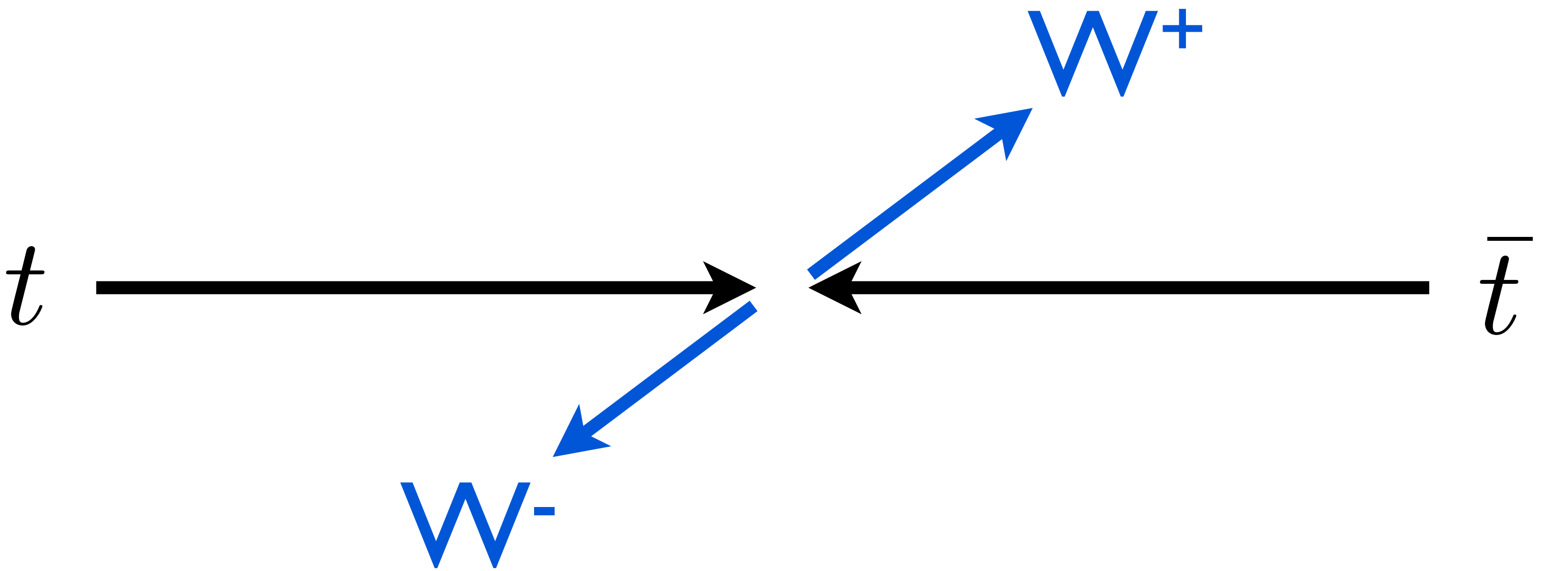


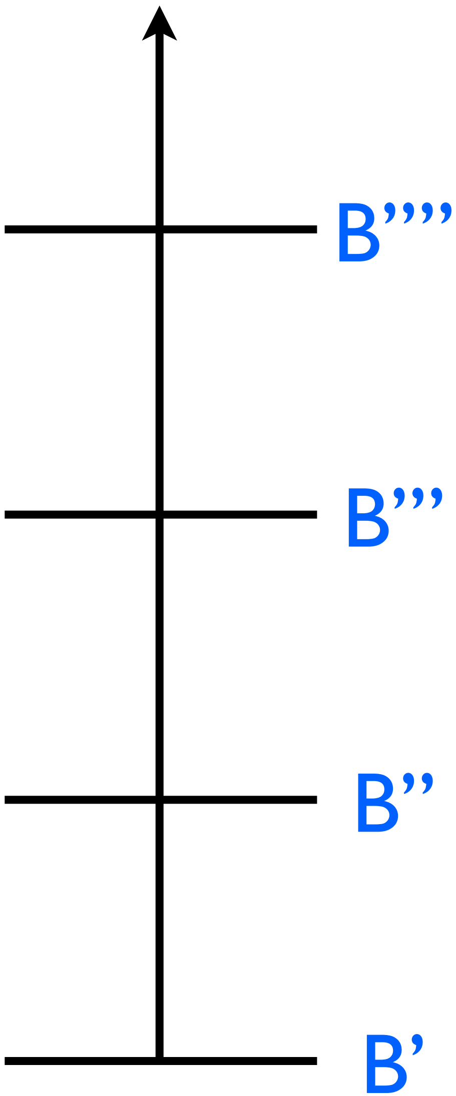
W+
W+
W-
W-
W''', Z'''
W'', Z''
W', Z'
W, Z
γ



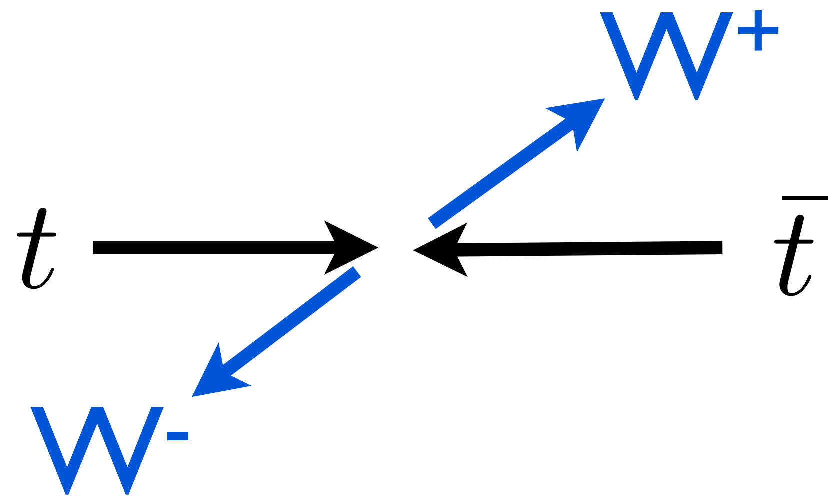


PLB 525, 175 (2002), PLB 532, 121 (2002),
PLB 562, 109 (2003), IJMPA 20, 3362 (2005)

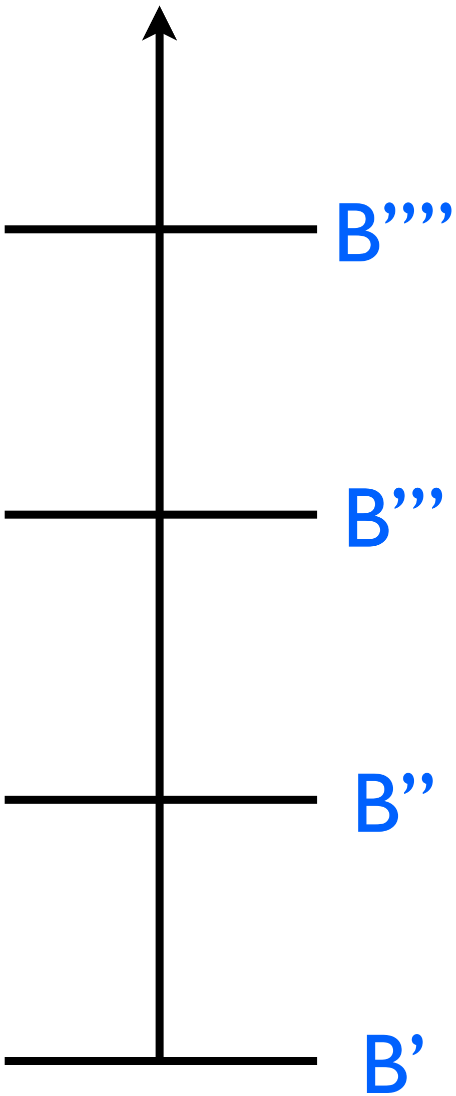

W+
t
$\bar{t}$
W-

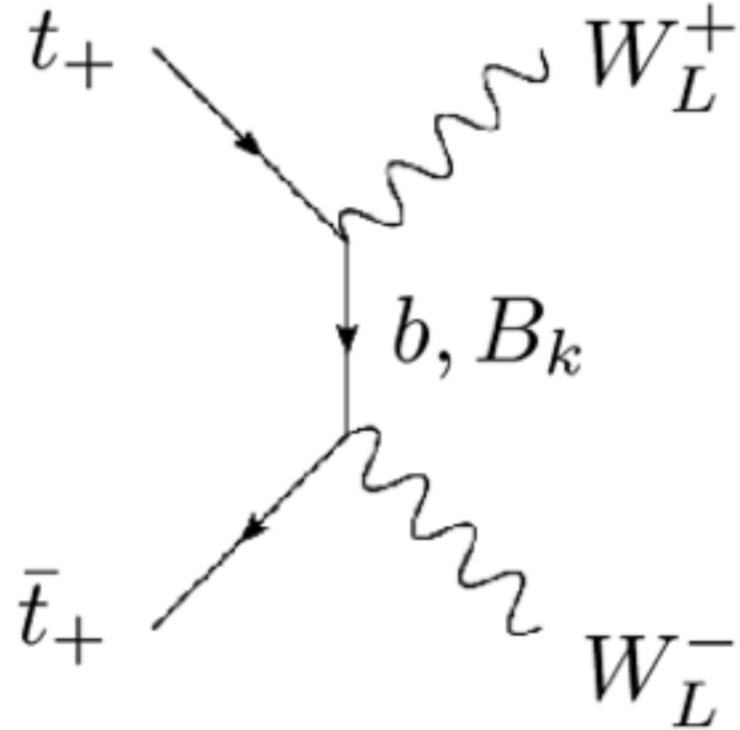


B’’’’
B’’’
B’’
B’

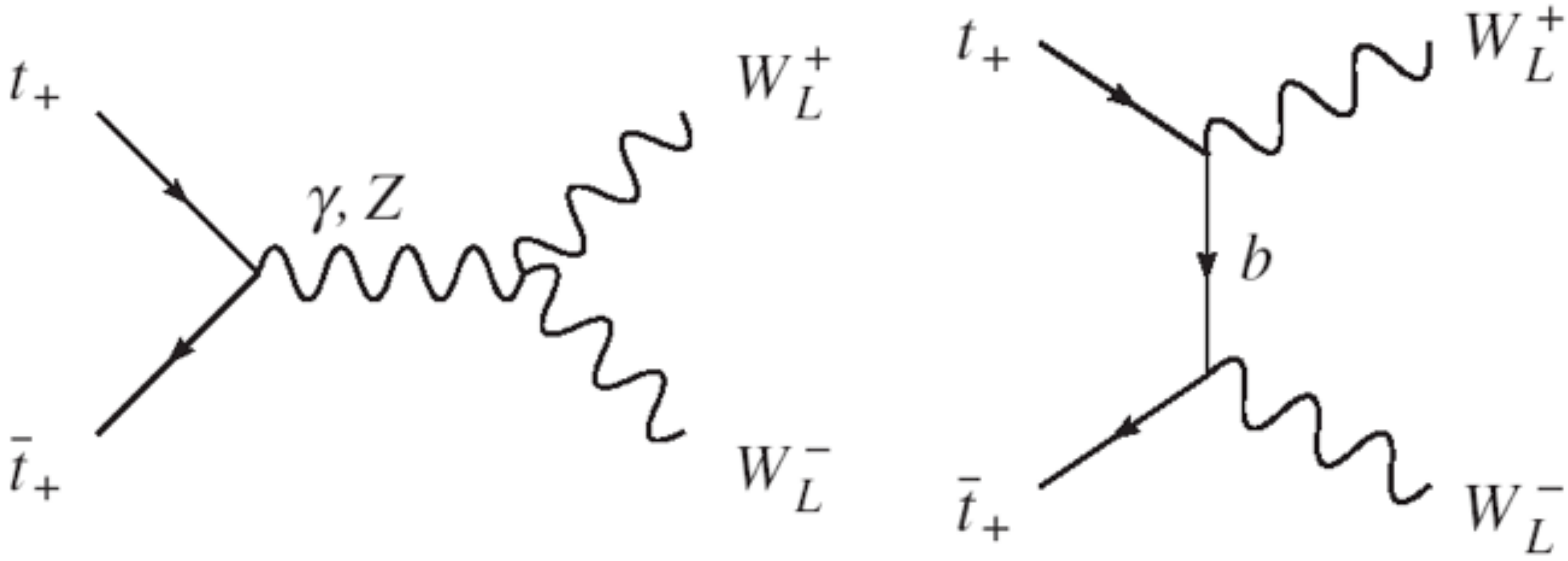


W^+
t
$\bar{t}$
W^-



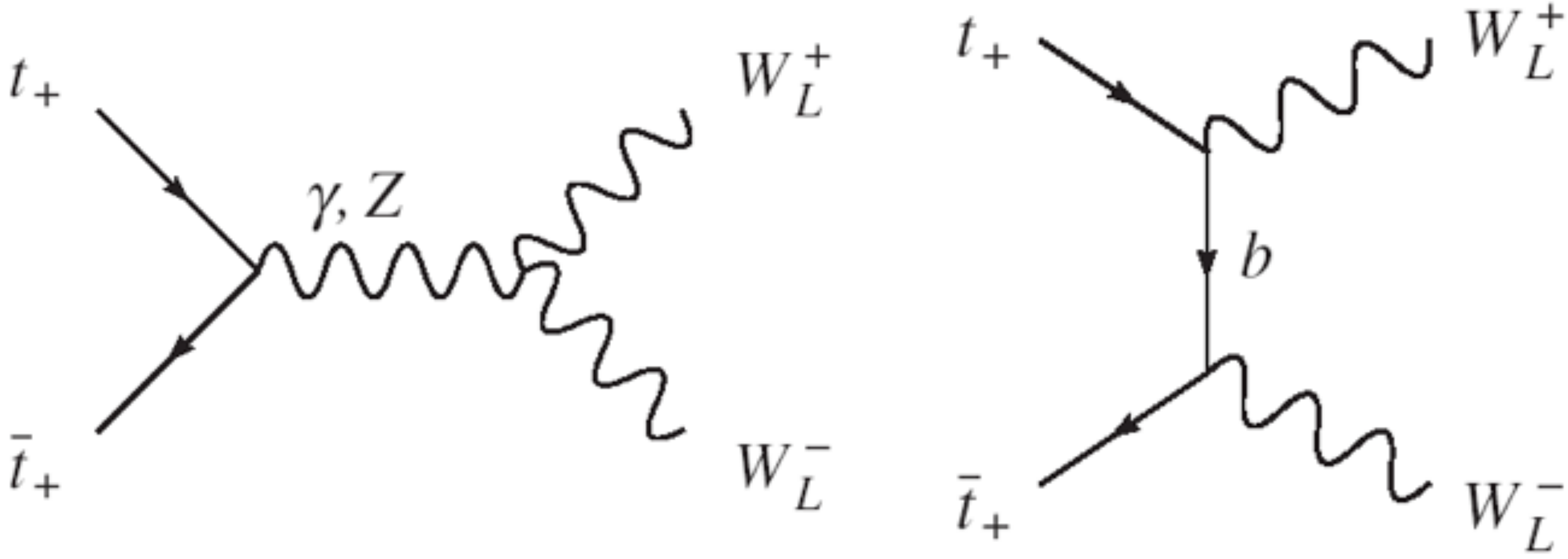


Phys. Rev. D 75, 073018 (2007)



$$\mathcal{M} \simeq \frac{\sqrt{6s}\ m_t \cos\theta}{2M_W^2}\left(2g_{tt\gamma}g_{\gamma WW} + g_{LttZ}g_{ZWW} + g_{RttZ}g_{ZWW} - g_{LtbW}^2\right)$$

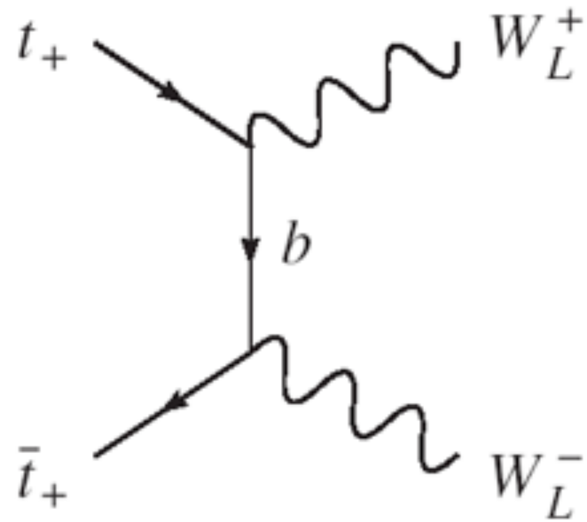
$$+\frac{\sqrt{6s}\ m_t}{2M_W^2}g_{LtbW}^2$$



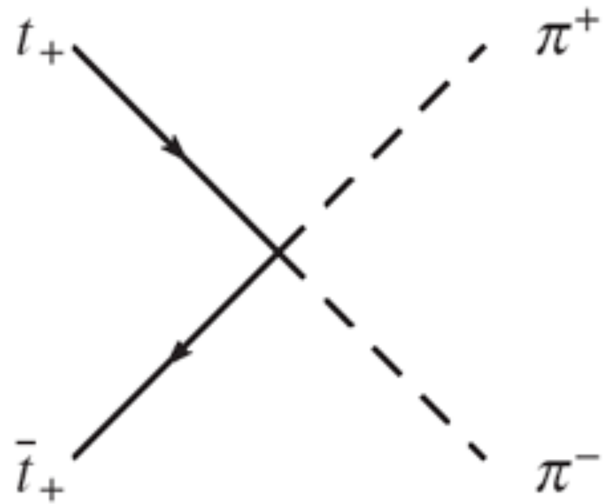
$$\mathcal{M} \simeq \frac{\sqrt{6s}\ m_t \cos\theta}{2M_W^2}\Big(2g_{tt\gamma}g_{\gamma WW} + g_{LttZ}g_{ZWW} + g_{RttZ}g_{ZWW} - g_{LtbW}^2\Big)$$

$$+\frac{\sqrt{6s}\ m_t}{2M_W^2}g_{LtbW}^2$$

$$2g_{tt\gamma}g_{\gamma WW} + g_{LttZ}g_{ZWW} + g_{RttZ}g_{ZWW} - g_{LtbW}^2 = 0$$



$$\mathcal{M} \simeq \frac{\sqrt{6s}\; m_t}{2M_W^2} g_{LtbW}^2 = \frac{\sqrt{6s}\; m_t}{v^2}$$



$$\mathcal{M} \simeq \sqrt{6s}\; g_{tt\pi\pi} = \frac{\sqrt{6s}\; m_t}{v^2}$$

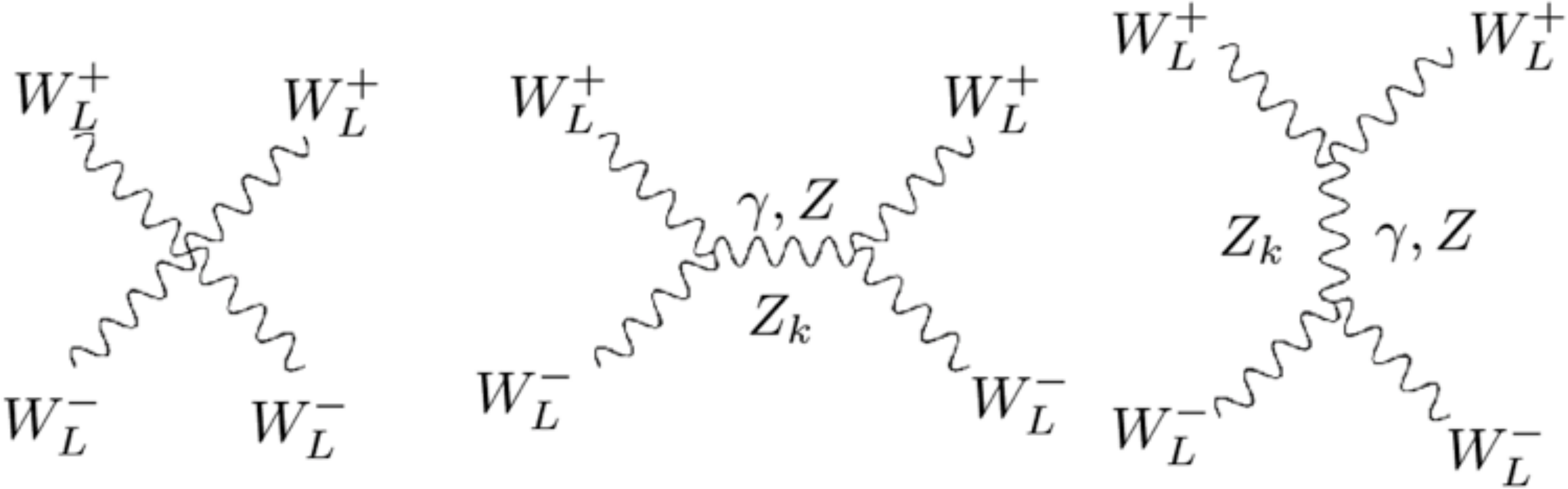
$$a_0 = \frac{1}{32\pi}\int_{-1}^{1} d\cos\theta\ \mathcal{M} < \frac{1}{2}$$

$$a_0 \sim \frac{m_t\sqrt{6s}}{16\pi v^2}$$

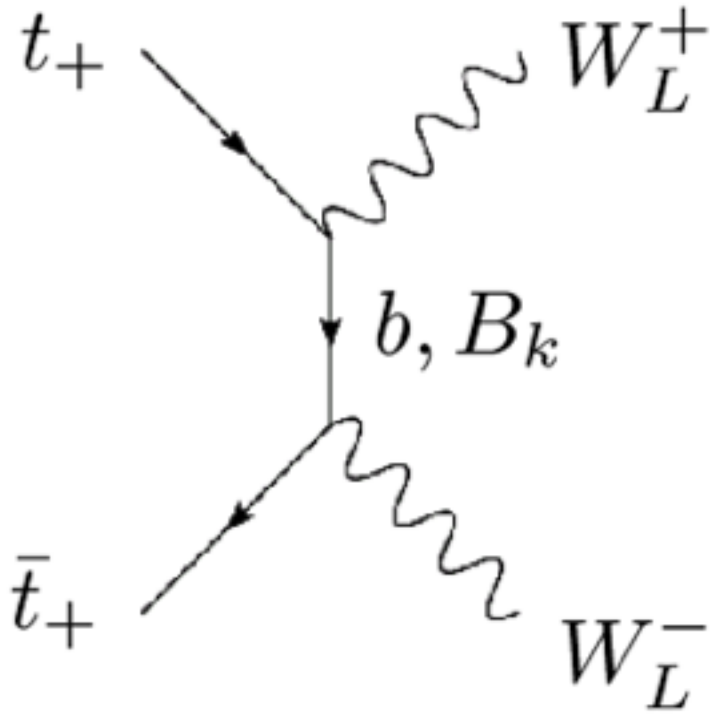
$$\sqrt{s} \lesssim \frac{8\pi v^2}{m_t\sqrt{6}} \sim 3.5\mathrm{TeV}$$

PRL **59**, 2405

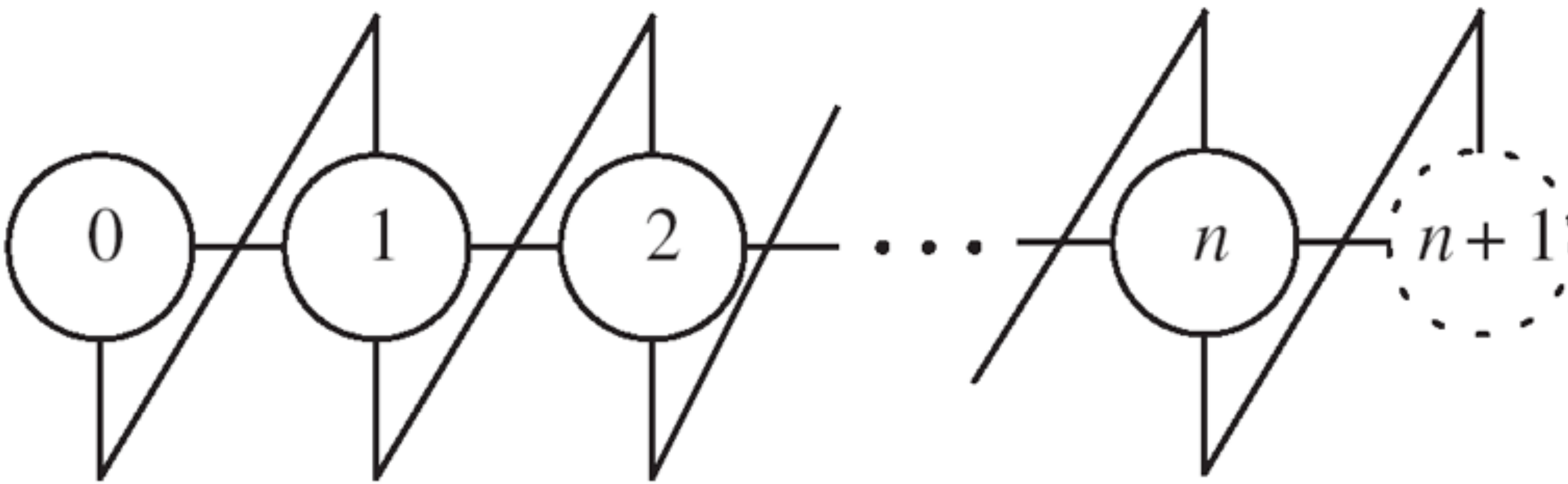
- M. Golden: PLB **338**, 295 (1994)
  - Won't the fields that unitarize $W^+W^- \to W^+W^-$ also unitarize $t\bar{t} \to W^+W^-$?



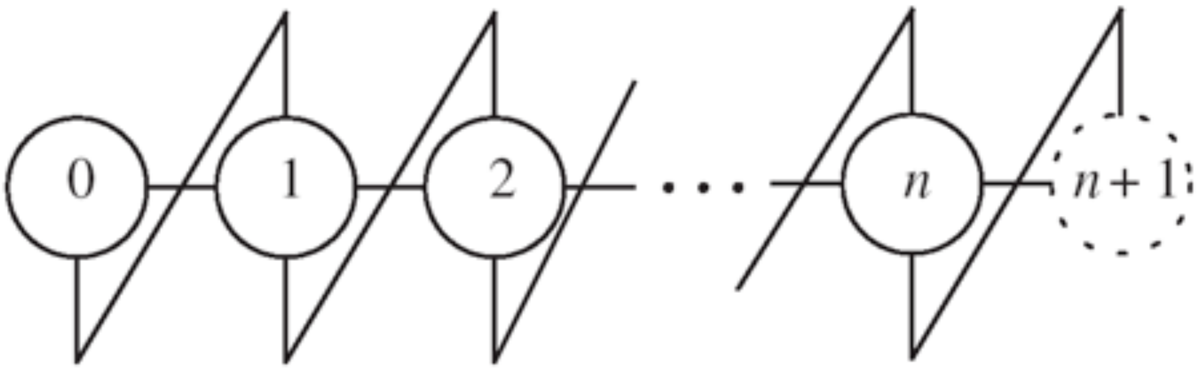
PLB 525, 175 (2002), PLB 532, 121 (2002),
PLB 562, 109 (2003), IJMPA 20, 3362 (2005)



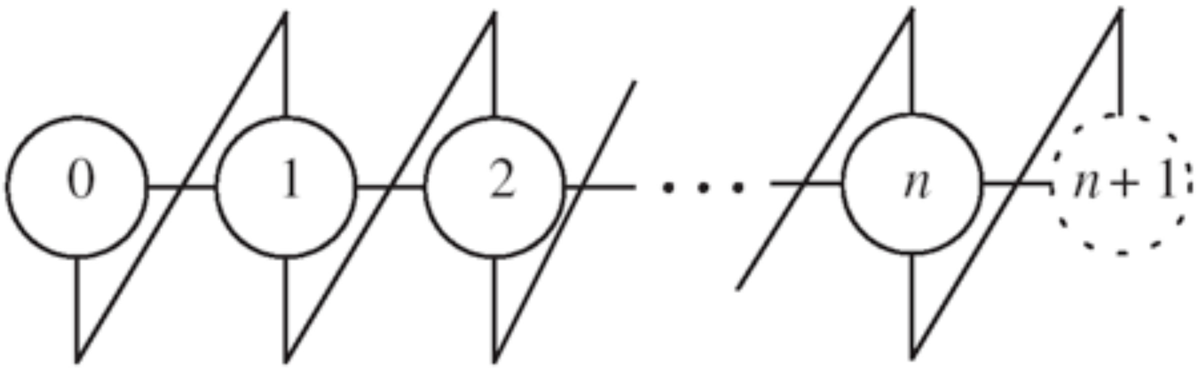
Phys. Rev. D 75, 073018 (2007)



0
1
2
n
n + 1

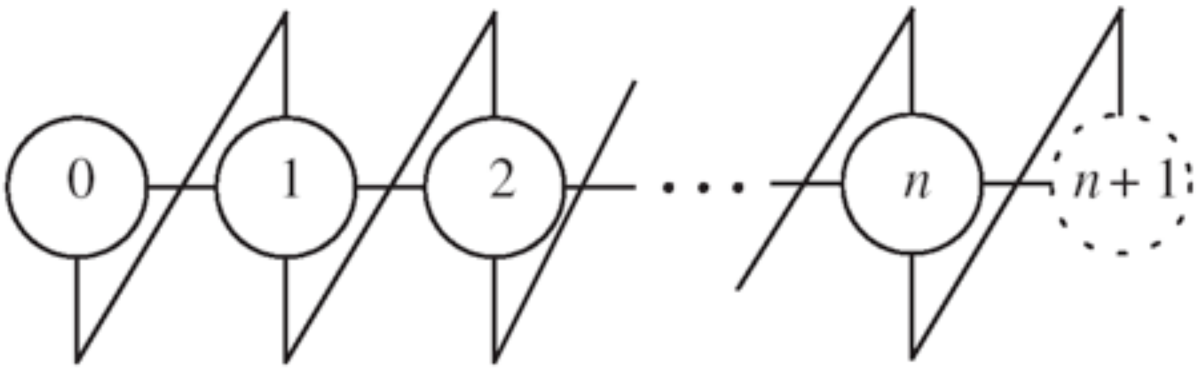


$$\mathcal{L}_{\psi\Sigma} = -M_F\Big[\epsilon_L \bar{\psi}_{L0}\Sigma_0\psi_{R1} - \sum_j \bar{\psi}_{Lj}\psi_{Rj} + \sum_j \bar{\psi}_{Lj}\Sigma_j\psi_{R,j+1} + \bar{\psi}_{Ln}\epsilon_R\Sigma_n\psi_{R,n+1} + \text{H.c.}\Big]$$



$$\mathcal{L}_{\psi\Sigma} = -M_F\Big[\epsilon_L \bar{\psi}_{L0}\Sigma_0\psi_{R1} - \sum_j \bar{\psi}_{Lj}\psi_{Rj} + \sum_j \bar{\psi}_{Lj}\Sigma_j\psi_{R,j+1} + \bar{\psi}_{Ln}\epsilon_R\Sigma_n\psi_{R,n+1} + \text{H.c.}\Big]$$

$$g_{RtF_k\pi} = -i\frac{\sqrt{2}M_F}{f}\Big[\epsilon_L v^0_{LF_k}v^1_{Rt}v^{[0]}_\pi + \sum_i v^i_{LF_k}v^{i+1}_{Rt}v^{[i]}_\pi + \epsilon_{Rt}v^n_{LF_k}v^{n+1}_{Rt}v^{[n]}_\pi\Big] = \frac{i\sqrt{2}M_F\epsilon_R}{\sqrt{2n+1}(n+1)v}\tan\Big[\frac{(n-k+1)\pi}{2n+1}\Big]$$



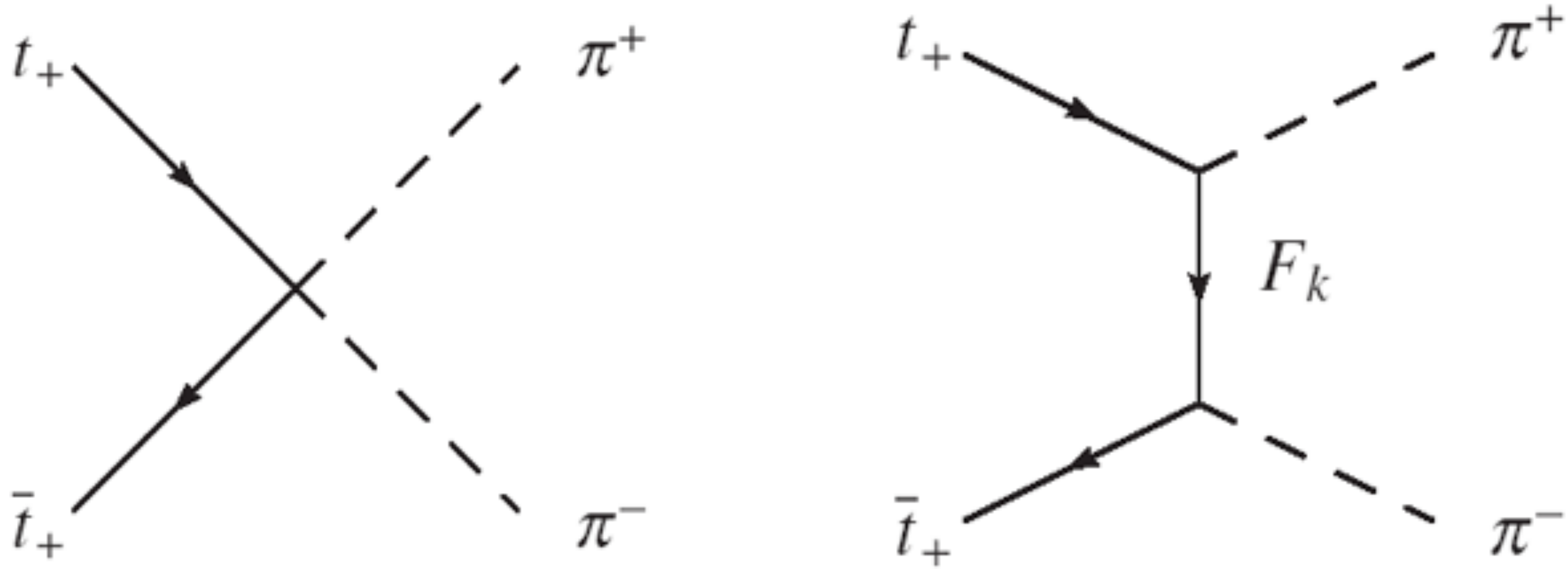
$$\mathcal{L}_{\psi\Sigma} = -M_F\Big[\epsilon_L \bar{\psi}_{L0}\Sigma_0\psi_{R1} - \sum_j \bar{\psi}_{Lj}\psi_{Rj}$$

$$+ \sum_j \bar{\psi}_{Lj}\Sigma_j\psi_{R,j+1} + \bar{\psi}_{Ln}\epsilon_R\Sigma_n\psi_{R,n+1} + \text{H.c.}\Big]$$

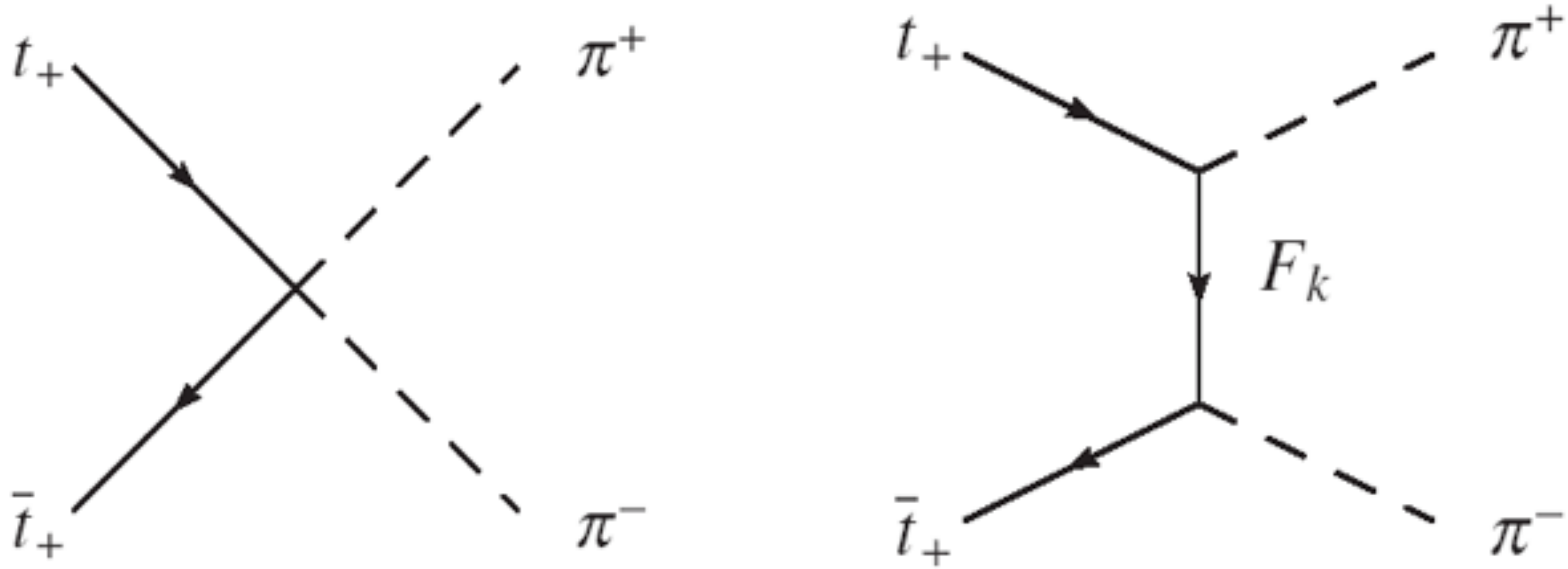
$$g_{tt\pi^+\pi^-} = \frac{M_F}{f^2}\Big[\epsilon_L v_{Lt}^0 v_{Rt}^1 (v_\pi^{[0]})^2 + \sum_i v_{Lt}^i v_{Rt}^{i+1}(v_\pi^{[i]})^2$$

$$+ \epsilon_{Rt} v_{Lt}^n v_{Rt}^{n+1}(v_\pi^{[n]})^2\Big]$$

$$= \frac{m_t}{(n+1)v^2}.$$



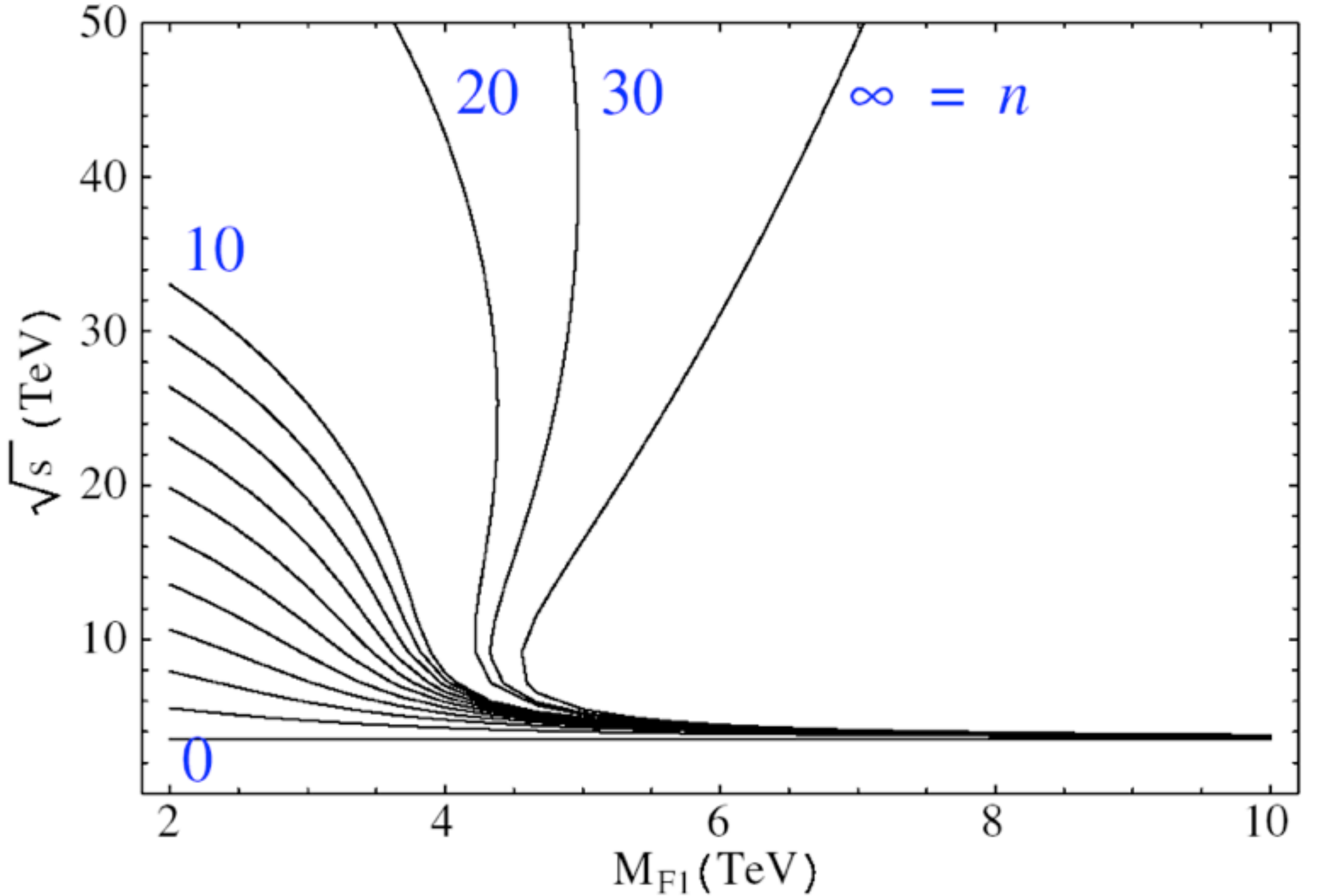
$$\mathcal{M} = \sqrt{6s}\left(g_{tt\pi^+\pi^-} - \sum_k \frac{M_{F_k} g_{LtF_k\pi} g_{RtF_k\pi}}{t - M_{F_k}^2}\right)$$



$$\mathcal{M} = \sqrt{6}s\left(g_{tt\pi^+\pi^-} - \sum_k \frac{M_{F_k} g_{LtF_k\pi} g_{RtF_k\pi}}{t - M_{F_k}^2}\right)$$

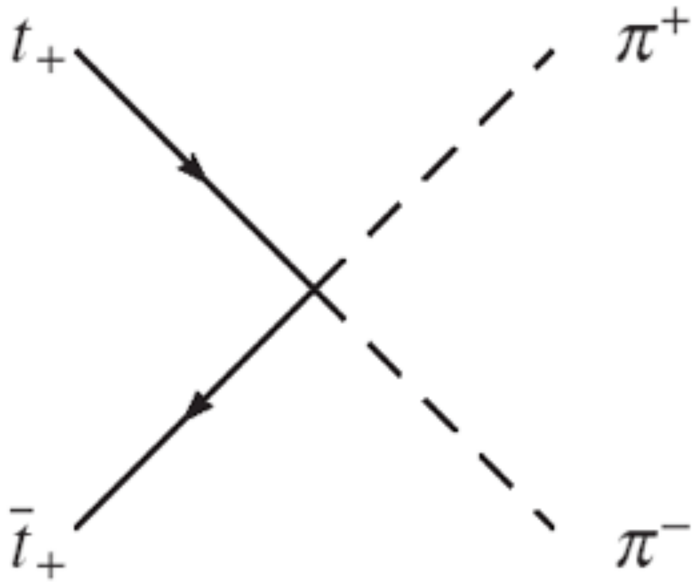
$$\begin{aligned} a_0 &= \frac{1}{32\pi}\int_{-1}^{1} d\cos\theta\,\mathcal{M} \\ &= \frac{\sqrt{6}}{16\pi}\left[g_{tt\pi^+\pi^-}\sqrt{s} + \sum_k g_{LtF_k\pi} g_{RtF_k\pi}\, g\!\left(\frac{\sqrt{s}}{M_{F_k}}\right)\right] \end{aligned}$$

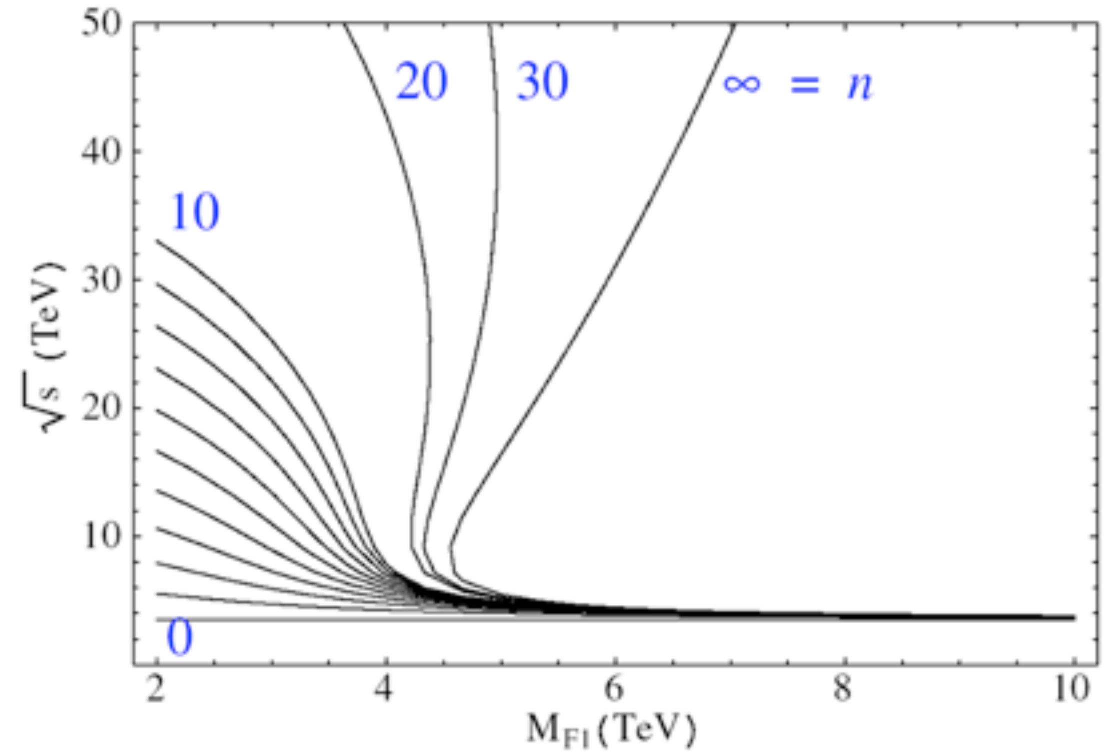
$$g(x) = \tfrac{1}{x}\ln(1 + x^2)$$



50
40
30
20
10
√s (TeV)
2
4
6
8
10
M_F1 (TeV)
10
20
30
∞ = n
0

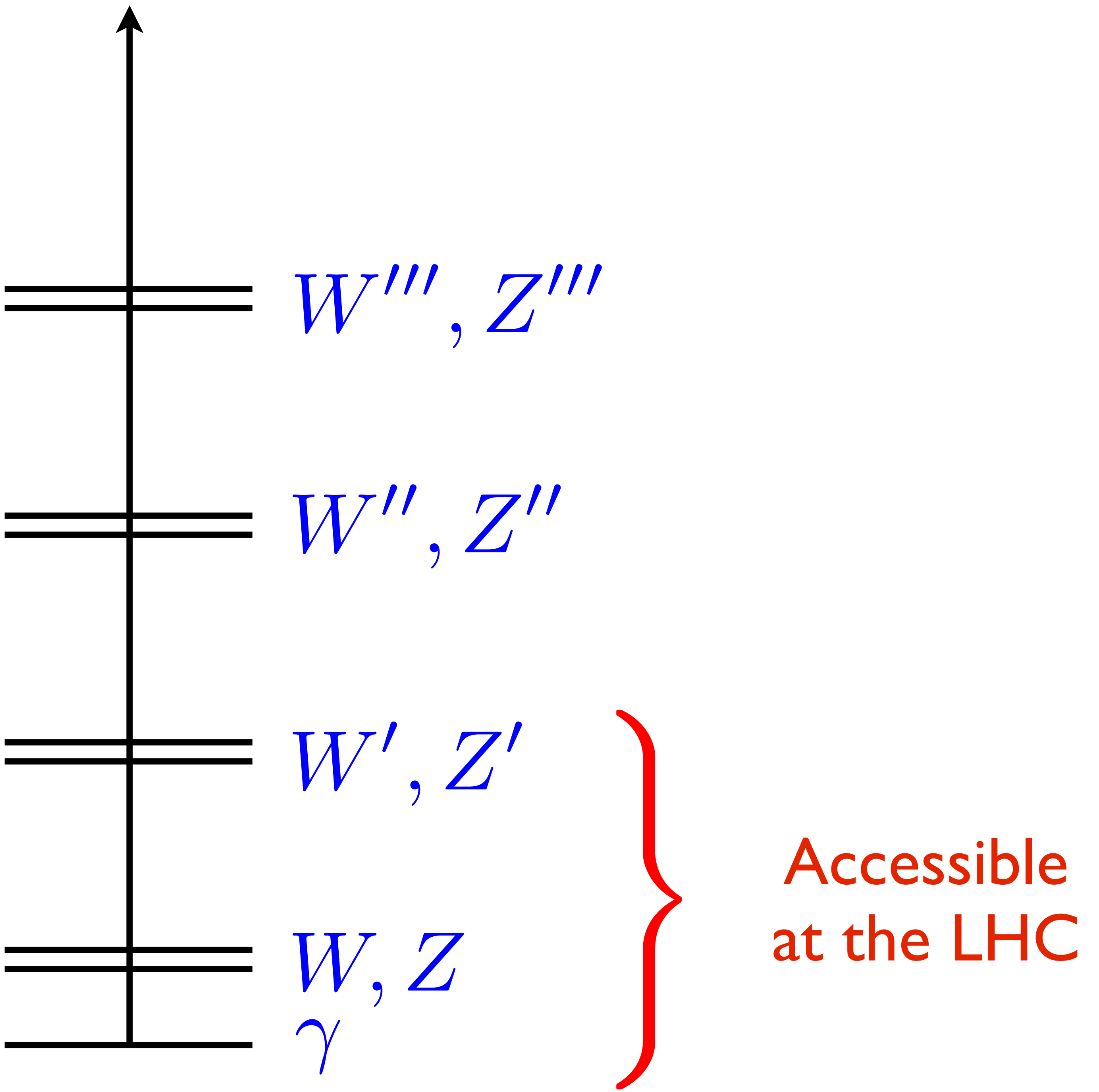
$M_{F1} \ll 4.5\text{TeV}$



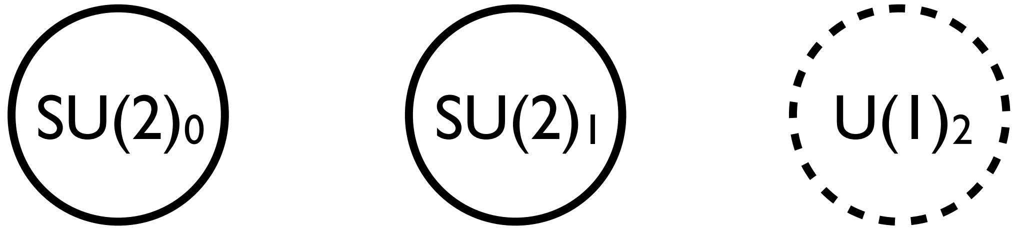


$$a_0 \simeq \frac{\sqrt{6}s m_t}{16\pi v^2 (n+1)} \lesssim \frac{1}{2}$$

$$\sqrt{s} \lesssim (n+1) 3.5 \text{ TeV}$$

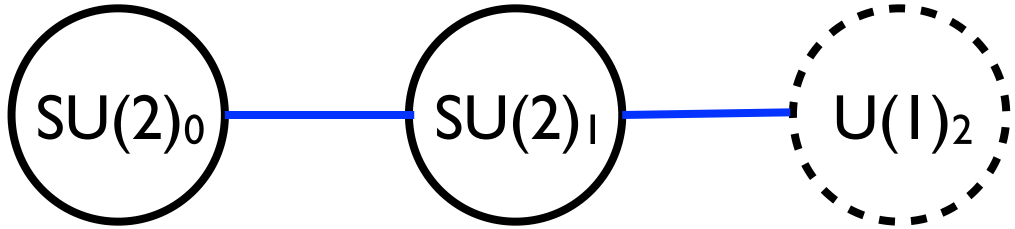


W''', Z'''
W'', Z''
W', Z'
W, Z
γ
Accessible
at the LHC



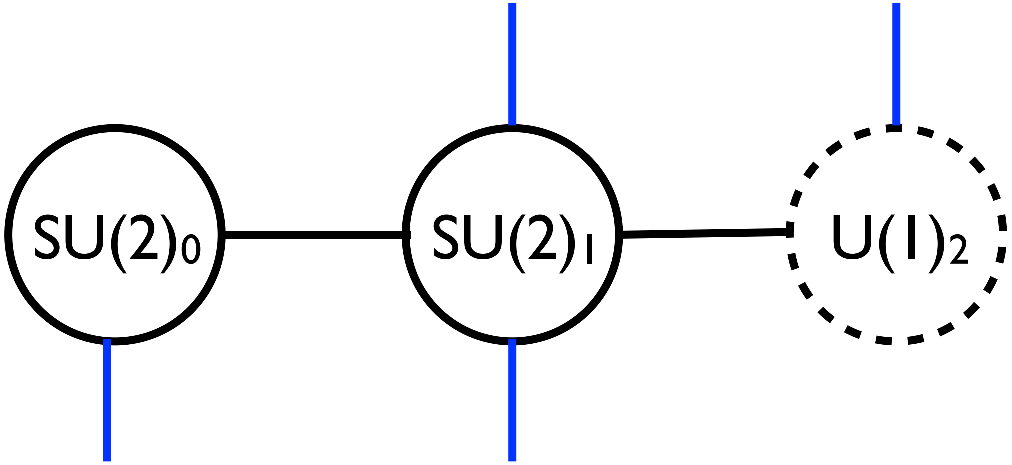
$$
\begin{aligned}
W_0 &\quad : \quad (3,1)_0 \\
W_1 &\quad : \quad (1,3)_0 \\
W_2 &\quad : \quad (1,1)_0
\end{aligned}
$$

$$\mathcal{L} = -\frac{1}{4}F_{0\mu\nu}F_0^{\mu\nu} - \frac{1}{4}F_{1\mu\nu}F_1^{\mu\nu} - \frac{1}{4}F_{2\mu\nu}F_2^{\mu\nu}$$



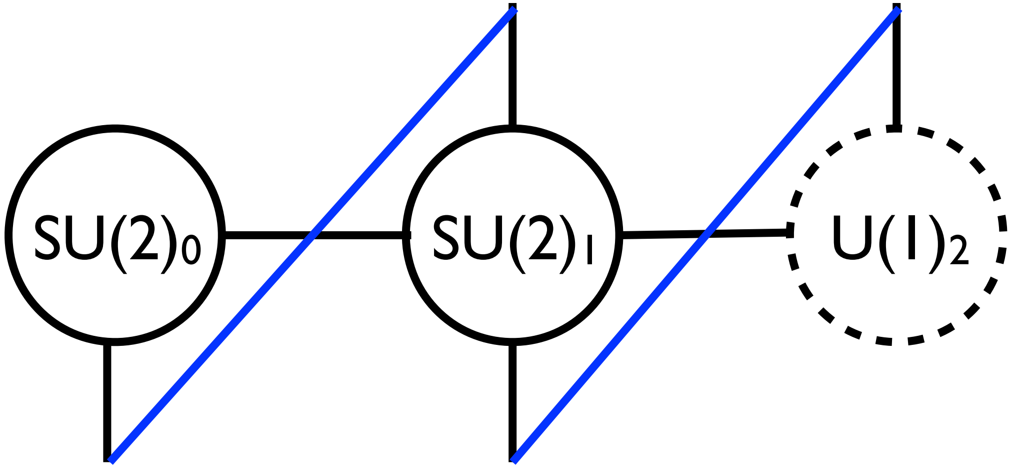
$$\Sigma_{01} \quad : \quad (2, \bar{2})_0$$
$$\Sigma_{12} \quad : \quad (1, 2)_{\pm\frac{1}{2}}$$

$$\mathcal{L} = \frac{f^2}{4} \mathrm{Tr} \left[\left(D_\mu \Sigma_{01} \right)^\dagger D^\mu \Sigma_{01} + \left(D_\mu \Sigma_{12} \right)^\dagger D^\mu \Sigma_{12} \right]$$
$$+ \frac{F^2}{4} \mathrm{Tr} \left[\left(D_\mu \left(\Sigma_{01} \Sigma_{12} \right) \right)^\dagger D^\mu \left(\Sigma_{01} \Sigma_{12} \right) \right]$$



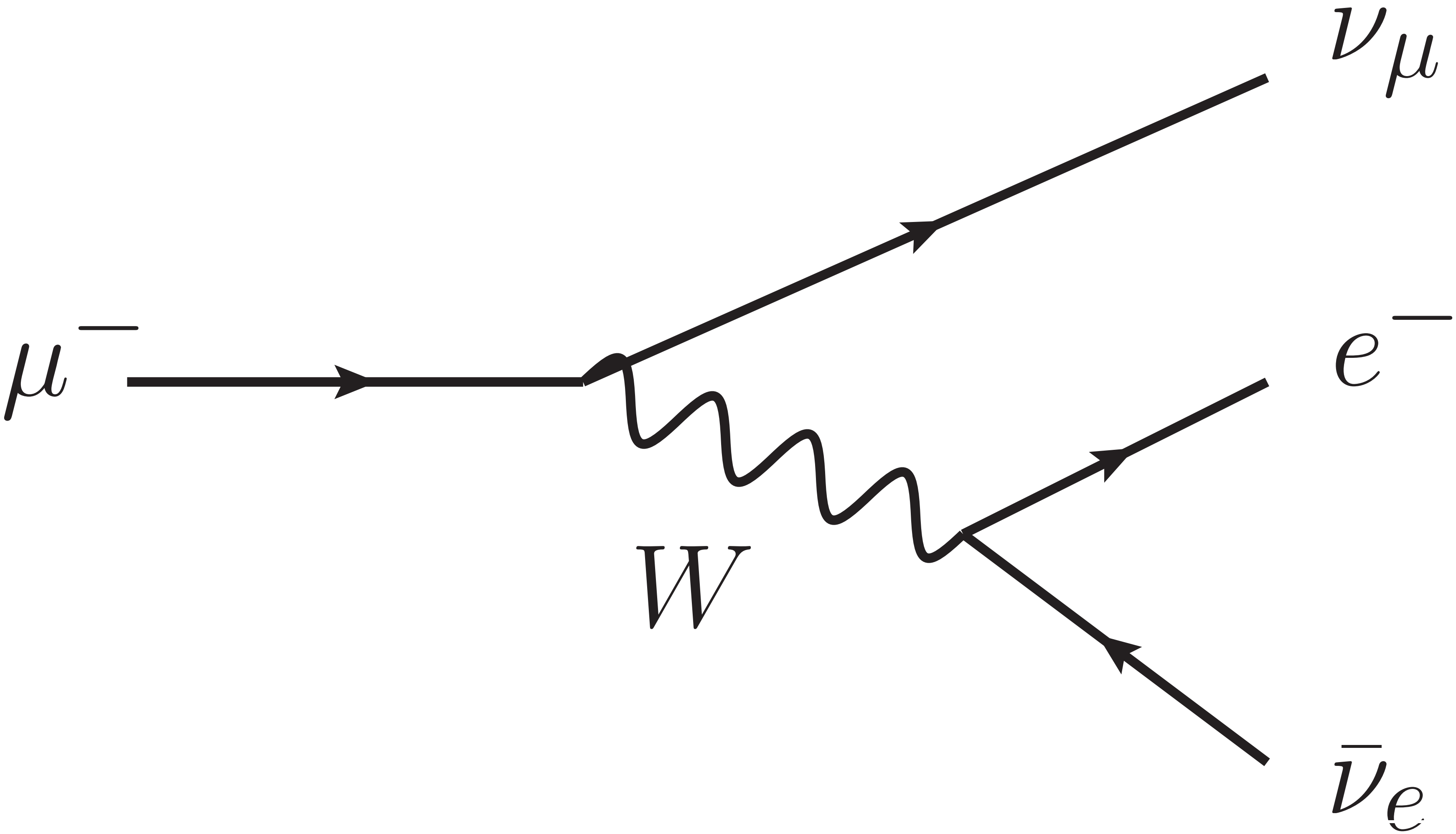
$$
\begin{array}{lcl lcl}
Q_{L0} & : & (2,1)_{\frac{1}{6}} & L_{L0} & : & (2,1)_{-\frac{1}{2}} \\
Q_1 & : & (1,2)_{\frac{1}{6}} & L_1 & : & (1,2)_{-\frac{1}{2}} \\
u_{R2} & : & (1,1)_{\frac{2}{3}} & & & \\
d_{R2} & : & (1,1)_{-\frac{1}{3}} & e_{R2} & : & (1,1)_{-1}
\end{array}
$$

$$\mathcal{L} = i\bar{\psi}_{L0} \not{D} \psi_{L0} + i\bar{\psi}_{L1} \not{D} \psi_{L1} + i\bar{\psi}_{R1} \not{D} \psi_{R1} + i\bar{\psi}_{R2} \not{D} \psi_{R2}$$

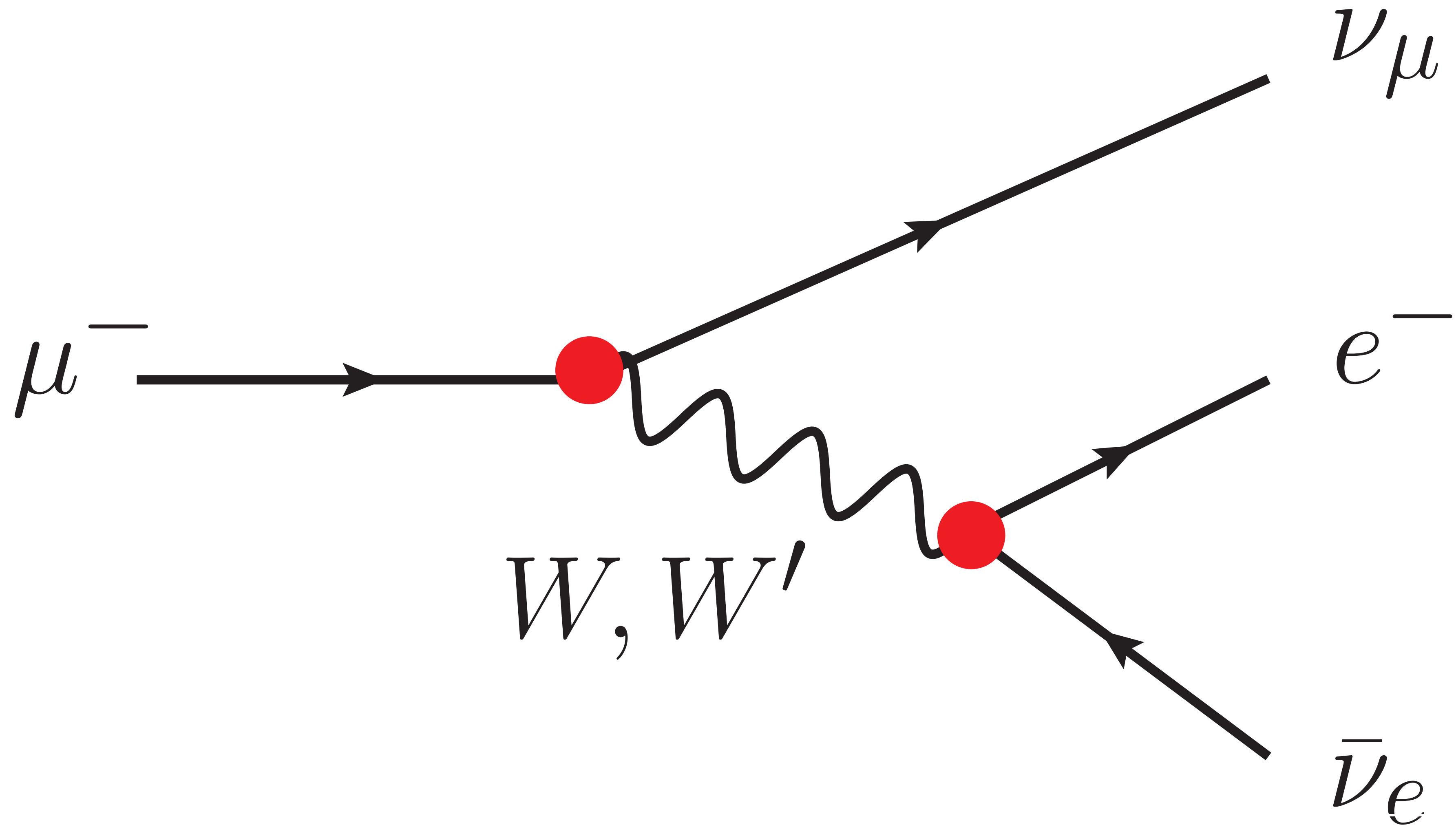


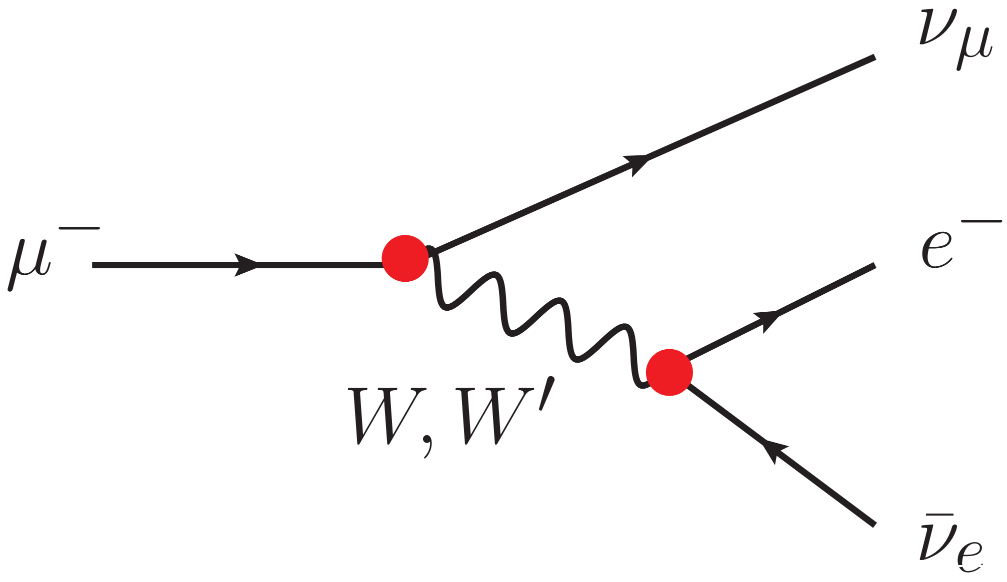
$$Q_{L0} \quad : \quad (2,1)_{\frac{1}{6}} \qquad\qquad L_{L0} \quad : \quad (2,1)_{-\frac{1}{2}}$$
$$Q_{1} \quad : \quad (1,2)_{\frac{1}{6}} \qquad\qquad L_{1} \quad : \quad (1,2)_{-\frac{1}{2}}$$
$$u_{R2} \quad : \quad (1,1)_{\frac{2}{3}}$$
$$d_{R2} \quad : \quad (1,1)_{-\frac{1}{3}} \qquad\qquad e_{R2} \quad : \quad (1,1)_{-1}$$

$$\mathcal{L} = -M_F \left(\epsilon_L \bar{\psi}_{L0} \Sigma_{01} \psi_{R1} + \bar{\psi}_{L1} \psi_{R1} + \bar{\psi}_{L1} \epsilon_R \Sigma_{12} \psi_{R2} \right)$$



μ^-
ν_μ
e^-
W
$\bar{\nu}_e$


μ^-
ν_μ
e^-
$\bar{\nu}_e$
W, W'



$$g_{W e\nu} = g_0 v_W^0 \left(v_L^0\right)^2 + g_1 v_W^1 \left(v_L^1\right)^2$$

Ideal Fermion Delocalization

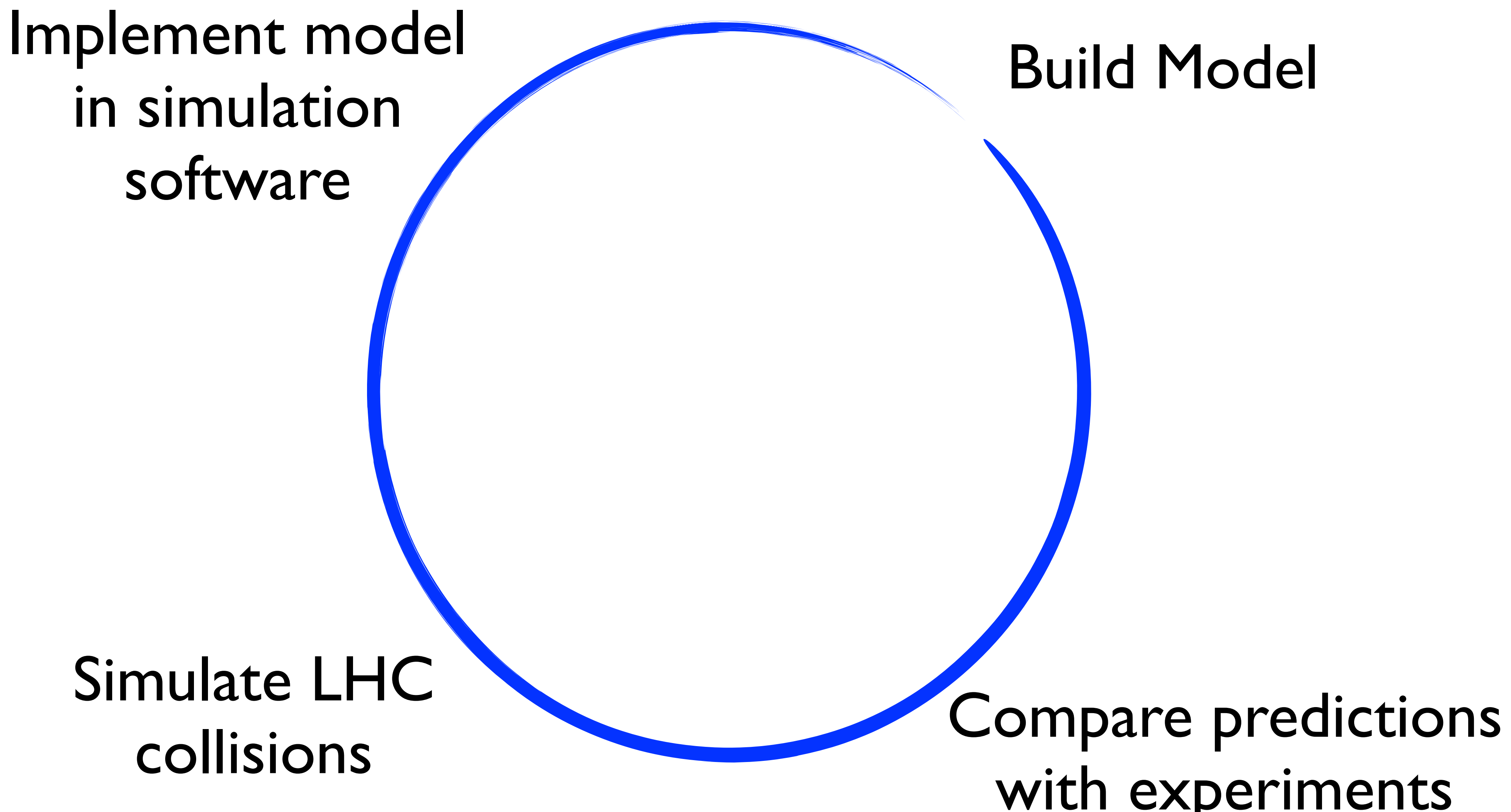
$$g_i \left(v_L^i\right)^2 \propto v_W^i$$

Ideal Fermion Delocalization

$$g_i \left(v_L^i\right)^2 \propto v_W^i$$

$$\begin{aligned} g_{f_L f_L W'} &= \sum_i g_i \left(v_L^i\right)^2 v_{W'}^i \\ &= \sum_i v_W^i v_{W'}^i \\ &= 0 \end{aligned}$$

W' and Z' are "fermiophobic"!
W and Z are SM like.


Implement model in simulation software
Build Model
Compare predictions with experiments
Simulate LHC collisions

CalcHEP

MadGraph

Herwig

Sherpa

Whizard

FeynArts

Problem 1:

Implementing a model was often tedious and error prone.

Terminal — less — 82×38

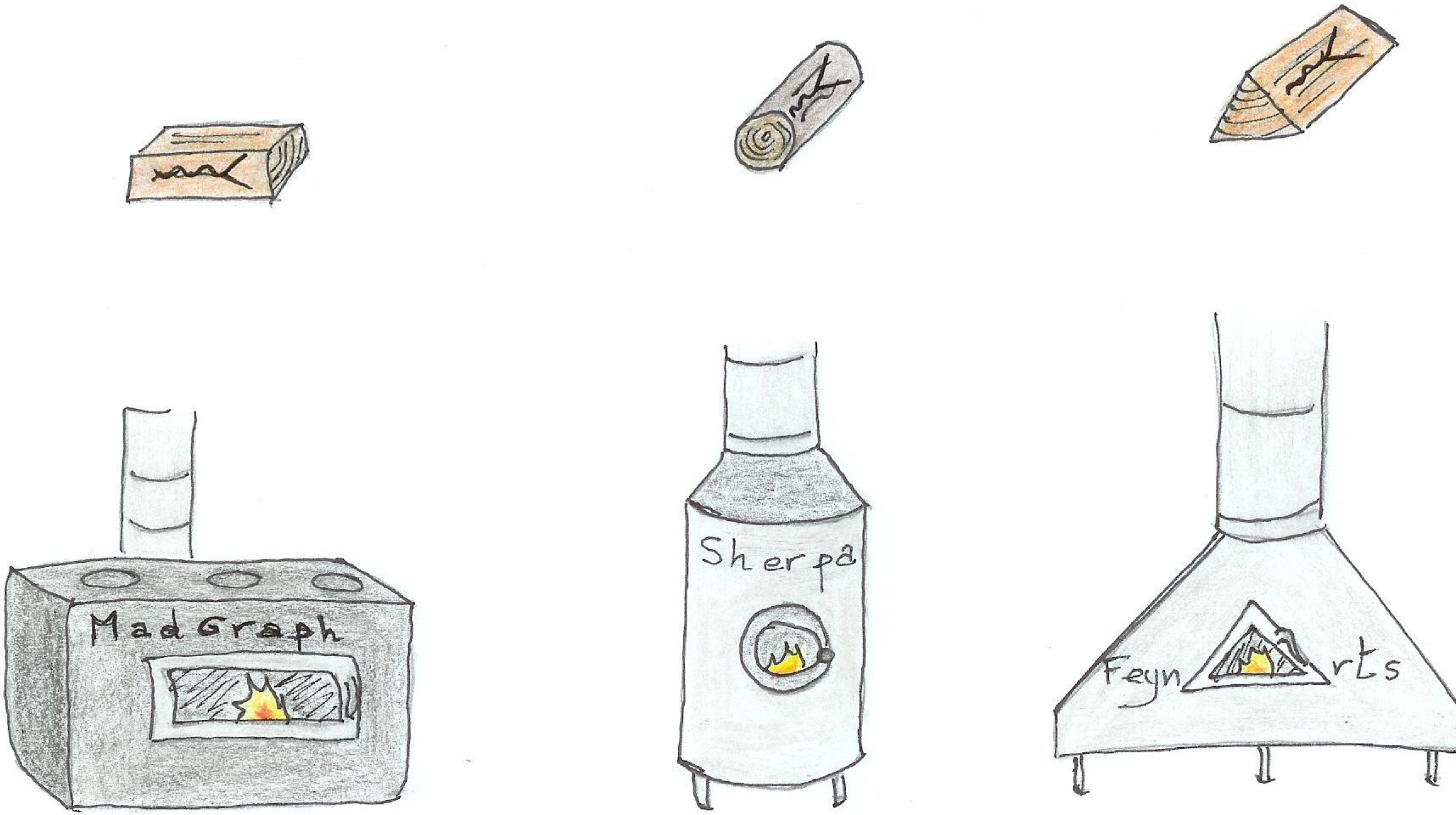
```
#################################
# QFD Interactions
# 2 heavy fermions - 1 light weak gauge boson
#################################

# FFV (qqZ)
dp dp z GZDp QED-HF
up up z GZUp QED-HF
sp sp z GZDp QED-HF
cp cp z GZUp QED-HF
bp bp z GZDp QED-HF
tp tp z GZTp QED-HF

# FFV (llZ)
ep-  ep-  z GZLp QED-HF
mup- mup- z GZLp QED-HF
tap- tap- z GZLp QED-HF
vep  vep  z GZNp QED-HF
vmp  vmp  z GZNp QED-HF
vtp  vtp  z GZNp QED-HF

# FFV (qq'W) - diagonal CKM
dp up w- GWFp QED-HF
sp cp w- GWFp QED-HF
bp tp w- GWTp QED-HF
up dp w+ GWFp QED-HF
cp sp w+ GWFp QED-HF
tp bp w+ GWTp QED-HF

# FFV (ll'W)
vep  ep-  w+ GWFp QED-HF
vmp  mup- w+ GWFp QED-HF
vtp  tap- w+ GWFp QED-HF
ep-  vep  w- GWFp QED-HF
mup- vmp  w- GWFp QED-HF
tap- vtp  w- GWFp QED-HF
:
```

Terminal — bash — 82×38

```
c-------------------------------------------
c     V-light    F-heavy     F-heavy
c-------------------------------------------
      GZDpL =
     - -1d0/2d0*gf(-ee,WMASS,ZMASS,MWP)
     -  *vZ0f(WMASS,ZMASS,MWP)*vLP0f(WMASS,MWP)**2
     - -1d0/2d0*gtf(-ee,WMASS,ZMASS,MWP)
     -  *VZ1f(WMASS,ZMASS,MWP)*vLP1f(WMASS,MWP)**2
     - +1d0/6d0*gpf(-ee,WMASS,ZMASS,MWP)
     -  *vZ2f(WMASS,ZMASS,MWP)
       GZDpR =
     - -1d0/2d0*gtf(-ee,WMASS,ZMASS,MWP)
     -  *VZ1f(WMASS,ZMASS,MWP)
     - +1d0/6d0*gpf(-ee,WMASS,ZMASS,MWP)
     -  *vZ2f(WMASS,ZMASS,MWP)
      GZDp(1)=dcmplx(GZDpL,Zero)
      GZDp(2)=dcmplx(GZDpR,Zero)
      write(*,10) 'GZDpL = ',GZDpL
      write(*,10) 'GZDpR = ',GZDpR

      GZUpL =
     - 1d0/2d0*gf(-ee,WMASS,ZMASS,MWP)
     -  *vZ0f(WMASS,ZMASS,MWP)*vLP0f(WMASS,MWP)**2
     - +1d0/2d0*gtf(-ee,WMASS,ZMASS,MWP)
     -  *VZ1f(WMASS,ZMASS,MWP)*vLP1f(WMASS,MWP)**2
     - +1d0/6d0*gpf(-ee,WMASS,ZMASS,MWP)
     -  *vZ2f(WMASS,ZMASS,MWP)
       GZUpR =
     - 1d0/2d0*gtf(-ee,WMASS,ZMASS,MWP)
     -  *VZ1f(WMASS,ZMASS,MWP)
     - +1d0/6d0*gpf(-ee,WMASS,ZMASS,MWP)
     -  *vZ2f(WMASS,ZMASS,MWP)
      GZUp(1)=dcmplx(GZUpL,Zero)
      GZUp(2)=dcmplx(GZUpR,Zero)
      write(*,10) 'GZUpL = ',GZUpL
      write(*,10) 'GZUpR = ',GZUpR

:
```

Problem 2:

Each matrix element generator has its strengths. What if you need more than one? In the past you had to start over.


MadGraph
Sherpa
Feyn
rts

Problem 3:

Implementations often did not transfer well to experimentalists.

Problem 3:

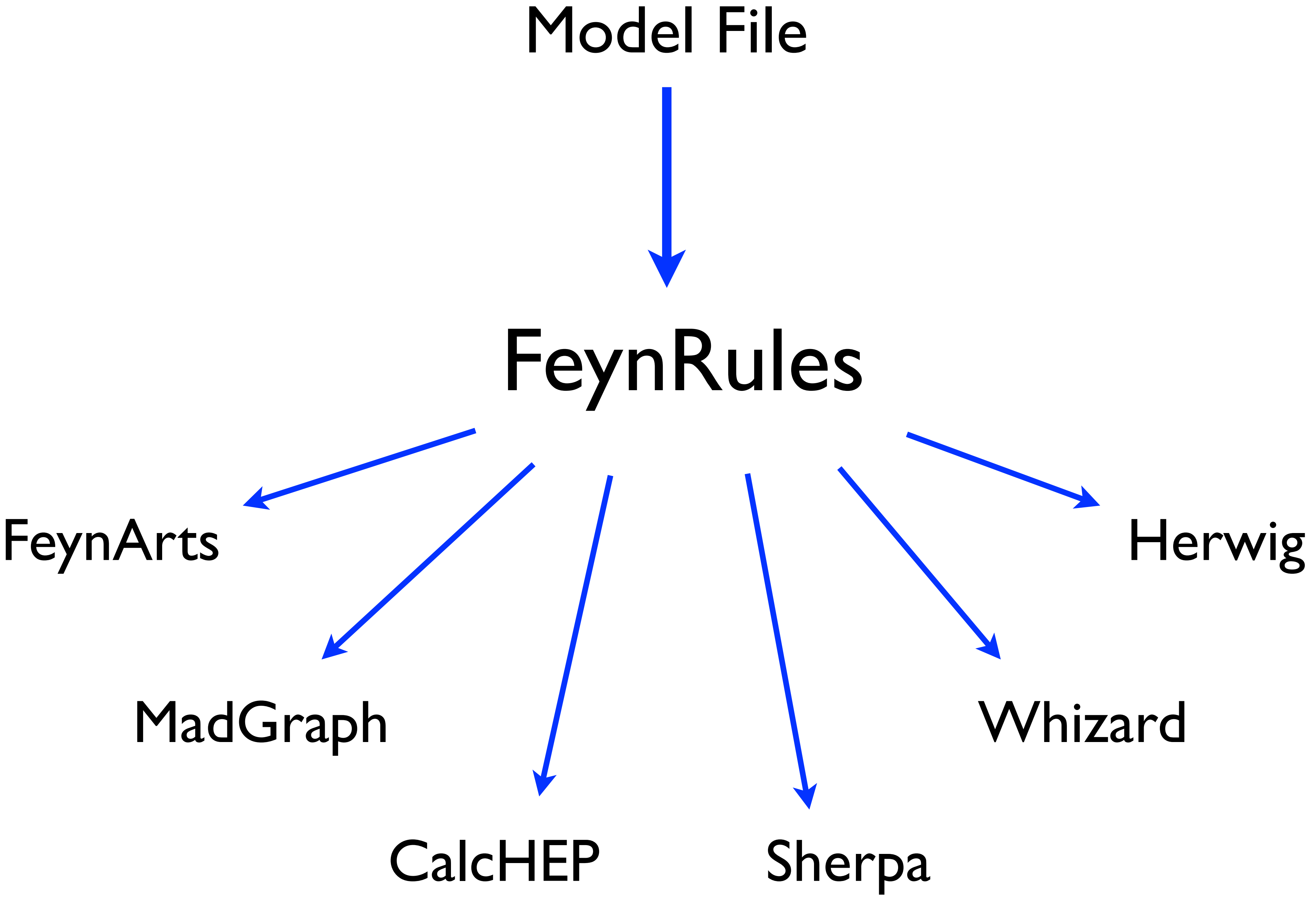
Implementations often did not transfer well to experimentalists.

It often required modifying the code of the matrix element generator.

FeynRules

In collaboration with:

Claude Duhr, Benjamin Fuks,
P. de Aquino, C. Degrande, D. Grellscheid, W. Link,
F. Maltoni, O. Mattelaer, T. Reiter, C. Speckner,
S. Schumann, M. Wiebusch


Model File
FeynRules
FeynArts
MadGraph
CalcHEP
Sherpa
Whizard
Herwig

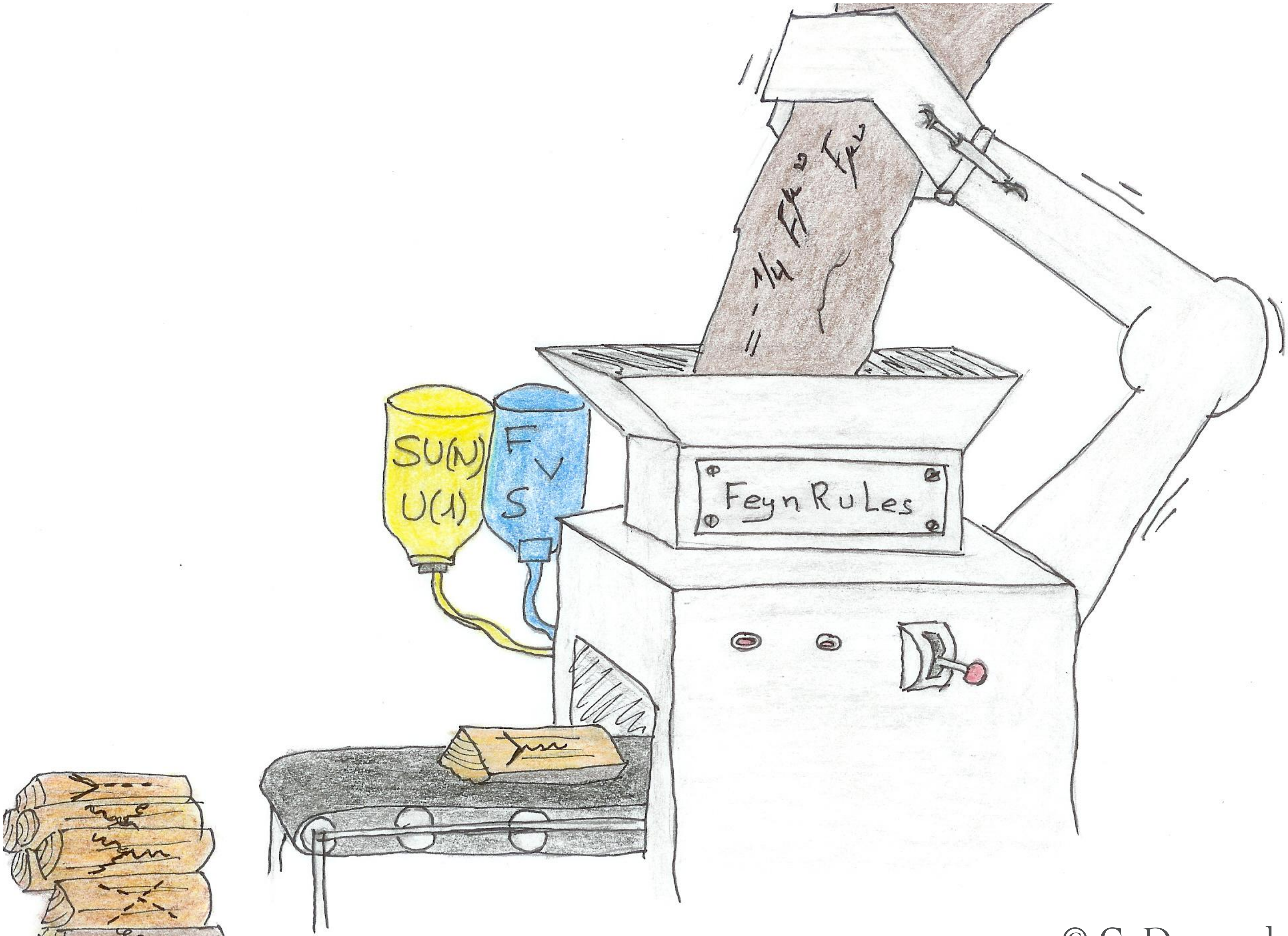
```
F[1]  ==
   {ClassName       ->   q,
    SelfConjugate ->  False,
    Indices             ->  {Index[Colour]},
    Mass                ->  {MQ,  200},
    Width               ->  {WQ, 5}   }
```

```
L =
-1/4 FS[G,mu,nu,a] FS[G,mu,nu,a]
+ I qbar.Ga[mu].del[q,mu]
+ gs qbar.Ga[mu].T[a].q G[mu,a]
- MQ qbar.q
```

3-Site-lagrangian.fr

```
(*******************************************************************************)
(*********************** Gauge Bosons kinetic terms ******************************)
(*******************************************************************************)
LGauge := Module[{FGlue,F0,F1,F2,LGlue,L0,L1,L2},

        (*********** Glue*)
        FGlue[mu_,nu_,a_] := Module[{b,c},
                del[G[nu, a], mu] - del[G[mu, a], nu] - gs f[a,b,c] G[mu, b] G[nu, c]
                ];
        LGlue := -1/4 FGlue[mu,nu,a]FGlue[mu,nu,a];

        (*********** Site 0*)
        F0[mu_,nu_,a_] := Module[{b,c},
                del[W0[nu,a],mu]-del[W0[mu,a],nu] - g*ep0[a,b,c]*W0[mu,b]*W0[nu,c]
                ];
        L0 := -1/4 F0[mu,nu,a]F0[mu,nu,a];

        (*********** Site 1*)
        F1[mu_,nu_,a_] := Module[{b,c},
                del[W1[nu,a],mu]-del[W1[mu,a],nu] - gt*ep1[a,b,c]*W1[mu,b]*W1[nu,c]
                ];
        L1 := -1/4 F1[mu,nu,a]F1[mu,nu,a];

        (*********** Site 2*)
        F2[mu_,nu_] := Module[{tmp},
                del[W23[nu],mu]-del[W23[mu],nu]
                ];
        L2 := -1/4 F2[mu,nu]F2[mu,nu];


        LGlue+L0+L1+L2
];
```

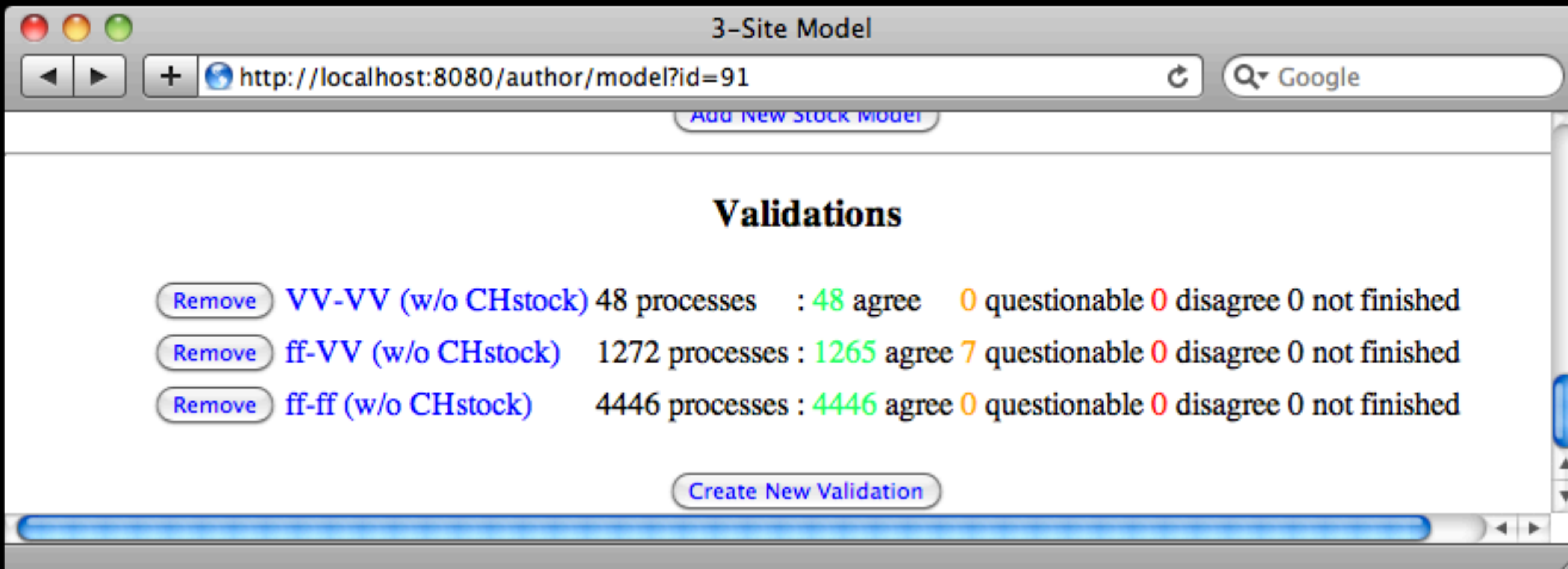
-:-- 3-Site-lagrangian.fr   9% (22,51)   (Fundamental)


SU(N)
U(1)
F
V
S
FeynRules


Celine Sasha Priscila Martin Benj Christian Claude Will Olivier David Neil Thomas

Development

- Superfield Formalism (B. Fuks)
- New FeynArts Interface (C. Degrande, C. Duhr)
- Automatic Mass Matrix Diagonalization (M. Wiebusch, NDC)
- New MadGraph5/Herwig Interface (P. de Aquino, C. Duhr, D. Grellscheid, W. Link, O. Mattelaer, T. Reiter)
- New Whizard Interface (arXiv:1010.325) (NDC, C. Duhr, B. Fuks, J. Rueter, C. Speckner)
- Model Database (all)
- New automatized Web Validation (NDC)


3-Site Model
http://localhost:8080/author/model?id=91
Google
Add New Stock Model
Validations
Remove VV-VV (w/o CHstock) 48 processes : 48 agree 0 questionable 0 disagree 0 not finished
Remove ff-VV (w/o CHstock) 1272 processes : 1265 agree 7 questionable 0 disagree 0 not finished
Remove ff-ff (w/o CHstock) 4446 processes : 4446 agree 0 questionable 0 disagree 0 not finished
Create New Validation

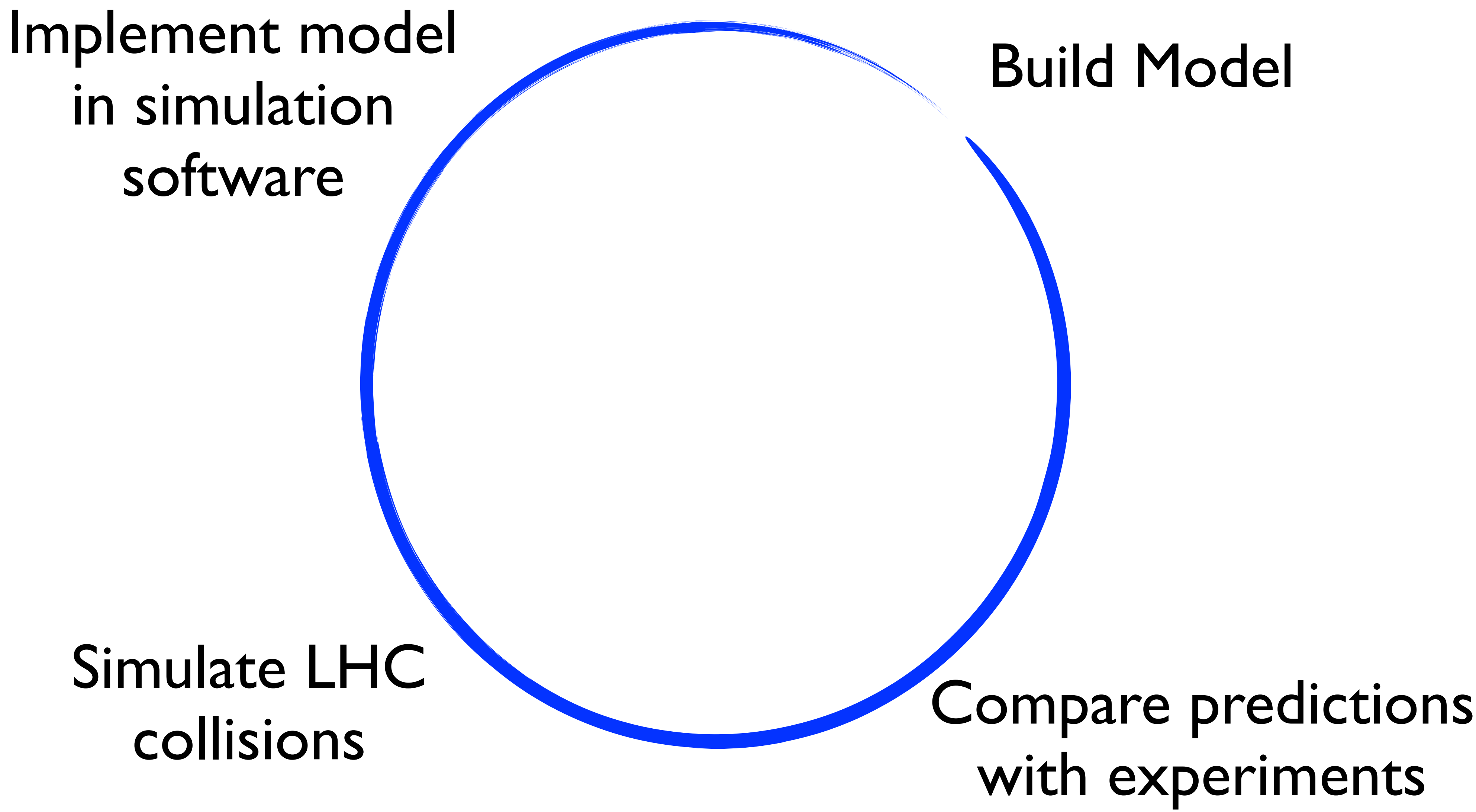
3-Site Model : VV-VV (w/o CHstock)

http://localhost:8080/author/validation?vdtnId=118

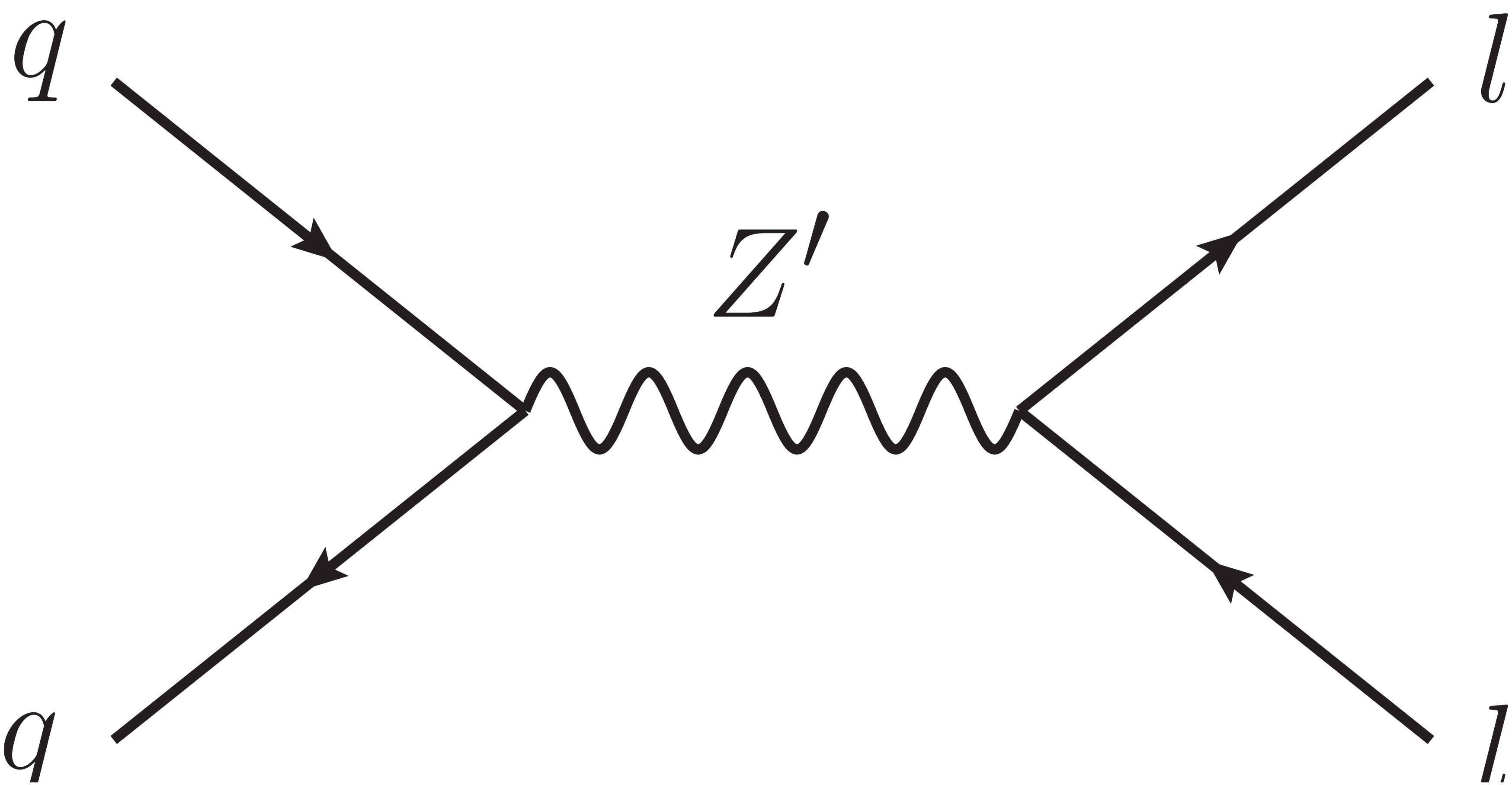
Start Fresh Validations | Finish Validations

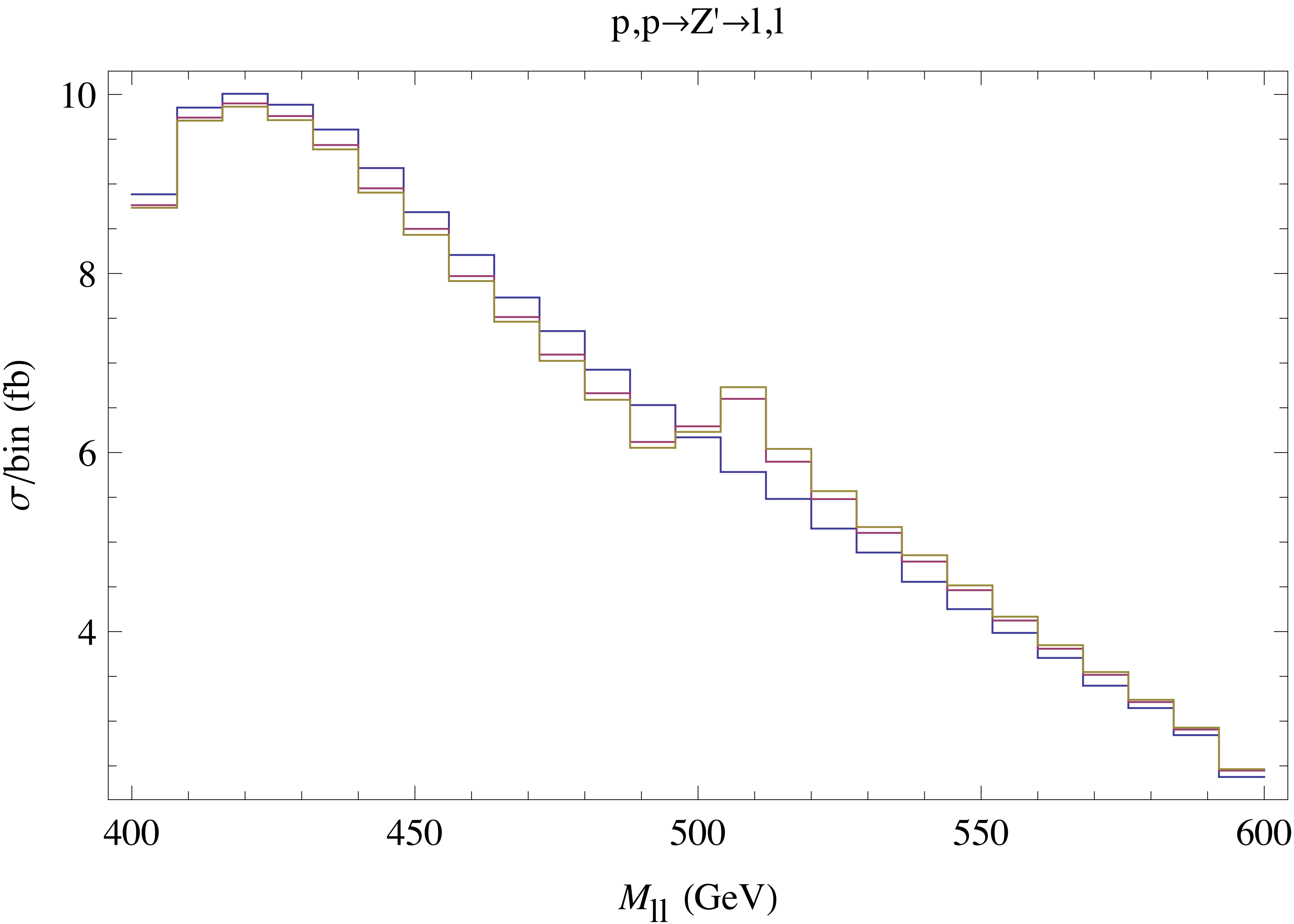
48 processes : 48 agree, 0 questionable, 0 disagree, 0 not finished

	√s	p_{Tcut}	CH(F)	CH(u)	MG4	WO1(F)	WO1(u)	WO2(F)	WO2(u)	WO-ST	Δ
Z , W+ → ~Z , ~W+	4693.0	1173.25	102.67	102.67	102.4	102.672	102.679	102.691	102.682	102.676	✔ 0.24%
W+ , W+ → W+ , ~W+	2965.0	741.25	2.4203	2.4203	2.4141	2.42005	2.41998	2.42014	2.41914	2.42078	✔ 0.22%
W+ , ~W+ → ~W+ , ~W+	6322.0	1580.5	3.3141	3.3141	3.3217	3.31304	3.31371	3.31373	3.31409	3.31557	✔ 0.2%
W+ , W+ → W+ , W+	1286.0	321.5	76.03	76.03	76.188	76.0095	76.0285	76.0867	75.9919	76.0325	✔ 0.18%
~W+ , ~W+ → ~W+ , ~W+	8000.0	2000.0	567.33	567.33	566.24	567.314	567.18	567.244	567.249	567.35	✔ 0.16%
~Z , ~Z → ~W+ , ~W-	8013.0	2003.25	1133.9	1133.9	1131.7	1133.48	1133.53	1133.76	1133.73	1133.59	✔ 0.15%
A , A → W+ , W-	643.0	160.75	16.11	16.11	16.108	16.111	16.1075	16.1075	16.0846	16.1064	✔ 0.13%
Z , Z → W+ , W-	1373.0	343.25	130.02	130.02	130.21	129.98	130.079	130.023	130.035	129.965	✔ 0.13%
Z , Z → ~W+ , ~W-	4730.0	1182.5	313.8	313.8	313.42	313.828	313.791	313.759	313.955	313.862	✔ 0.11%
G , G → G , G	200.0	50.0	18835.0	18835.0	18816.0	18831.7	18831.2	18842.3	18845.4	18841.9	✔ 0.1%
A , A → ~W+ , ~W-	8000.0	2000.0	0.12636	0.12636	0.1265	0.126312	0.12635	0.126452	0.126347	0.12637	✔ 0.09%
Z , Z → W+ , ~W-	3051.0	762.75	1.1376	1.1376	1.138	1.13758	1.13784	1.13857	1.13718	1.13735	✔ 0.08%
A , Z → ~W+ , ~W-	8730.0	2182.5	0.041172	0.041172	0.041175	0.0411638	0.0411898	0.0411888	0.0411406	0.0411586	✔ 0.07%
A , ~Z → ~W+ , ~W-	6007.0	1501.75	6.3818	6.3818	6.3866	6.38627	6.38614	6.38229	6.38421	6.37878	✔ 0.07%
A , Z → W+ , W-	1008.0	252.0	20.969	20.969	20.961	20.9732	20.9758	20.9558	20.9718	20.9649	✔ 0.06%
W+ , W+ → ~W+ , ~W+	4643.0	1160.75	150.92	150.92	150.79	150.942	150.919	150.815	150.875	150.921	✔ 0.06%
A , W+ → W+ , ~Z	2650.0	662.5	0.16856	0.16856	0.16866	0.168592	0.168542	0.168497	0.168558	0.168573	✔ 0.05%
A , W+ → ~Z , ~W+	8656.0	2164.0	0.034886	0.034886	0.034866	0.034879	0.034886	0.0348662	0.034893	0.034872	✔ 0.04%
Z , W+ → W+ , ~Z	3015.0	753.75	0.7552	0.7552	0.75509	0.755298	0.755141	0.755171	0.755301	0.755573	✔ 0.04%

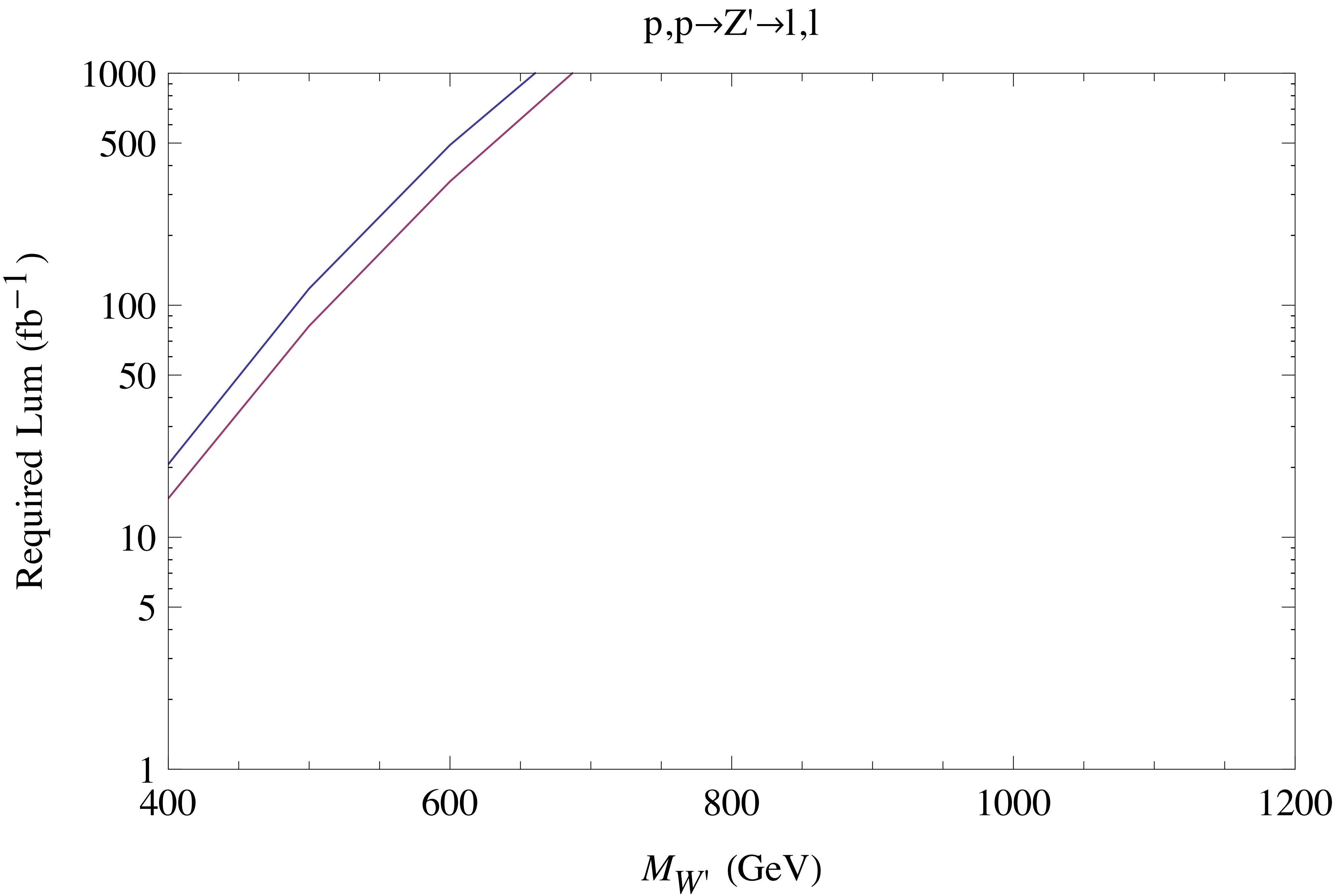


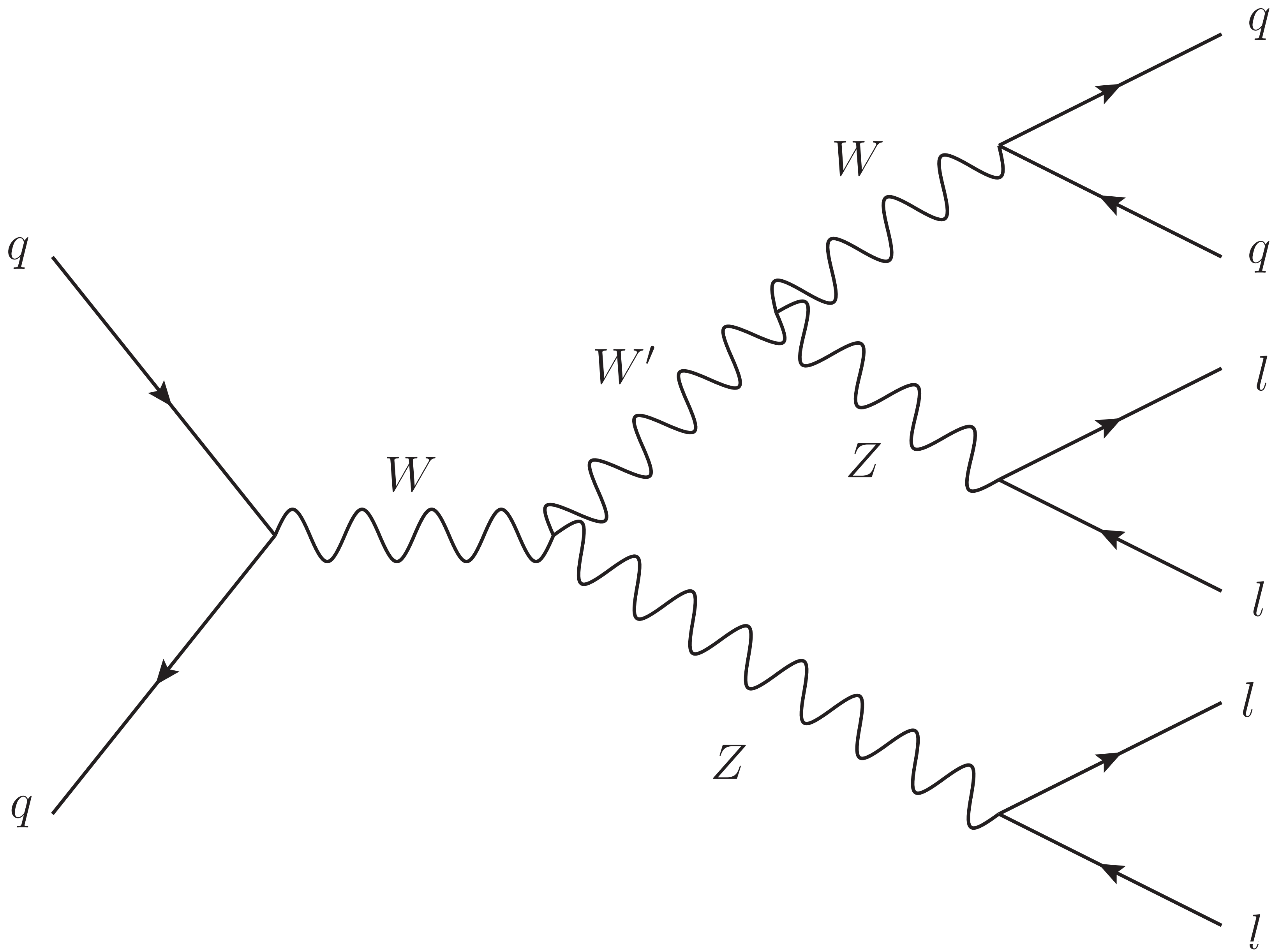
Build Model
Compare predictions with experiments
Simulate LHC collisions
Implement model in simulation software

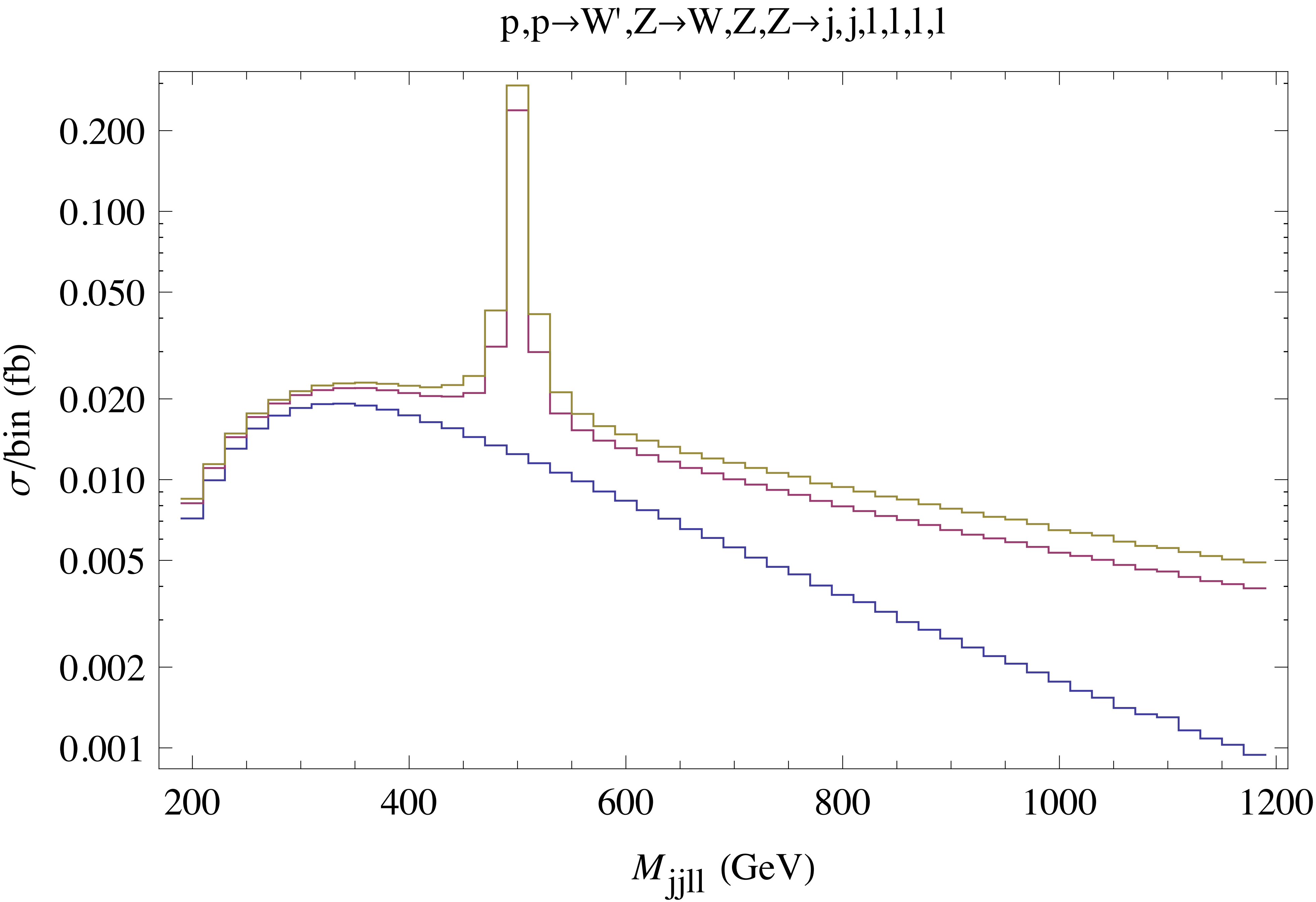

q
q
Z′
l
l

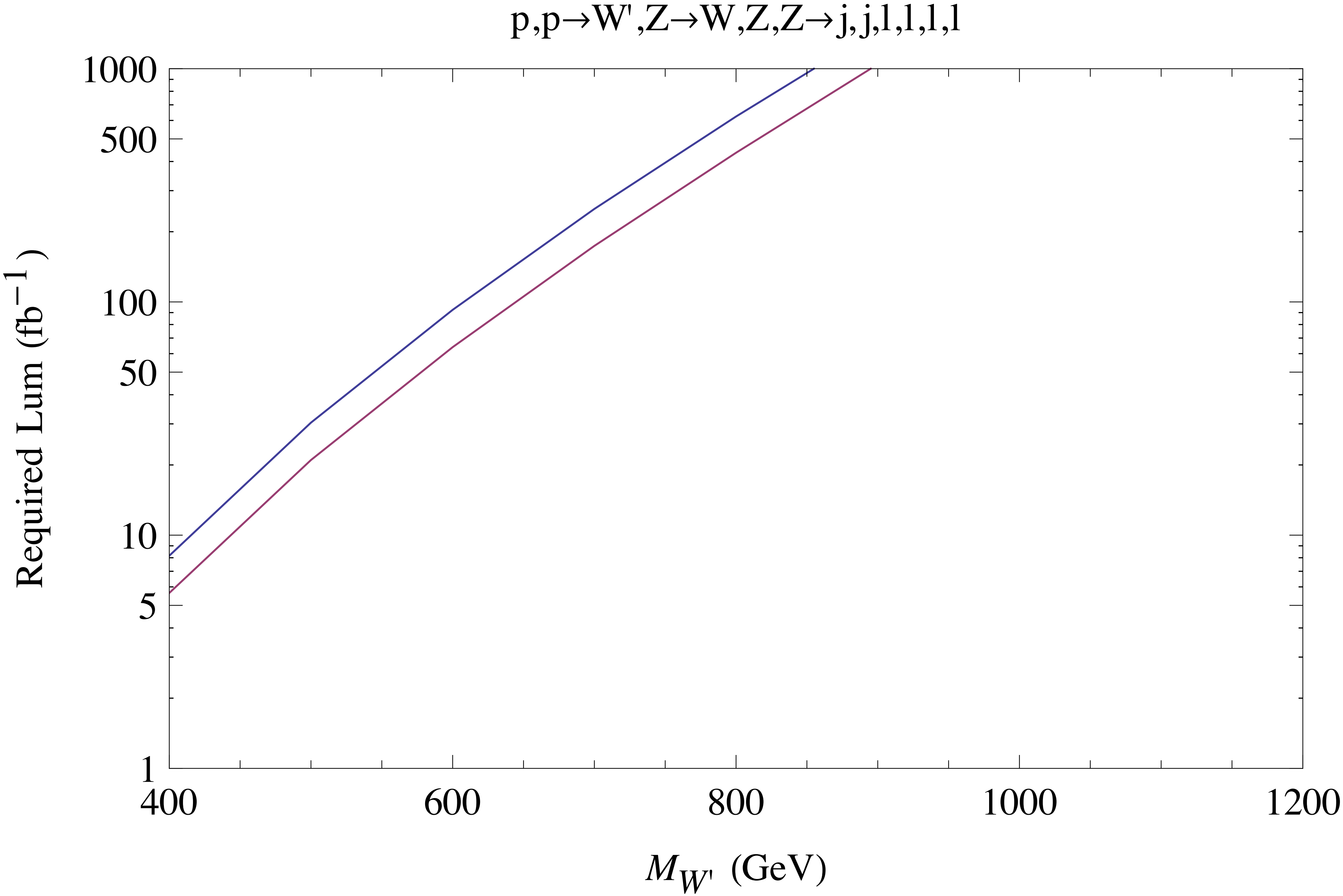


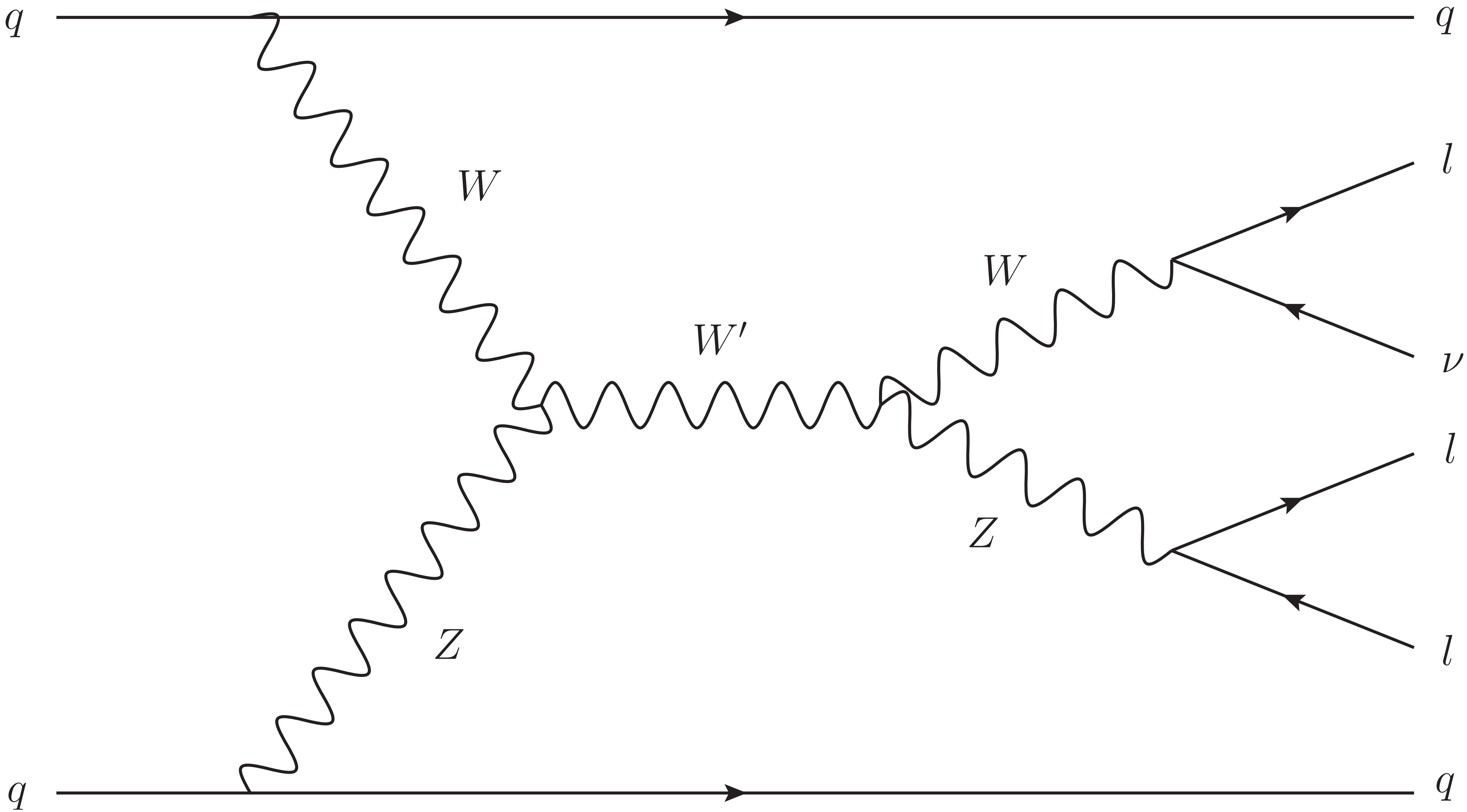
p,p→Z'→l,l
10
8
6
4
σ/bin (fb)
400
450
500
550
600
M_{ll} (GeV)

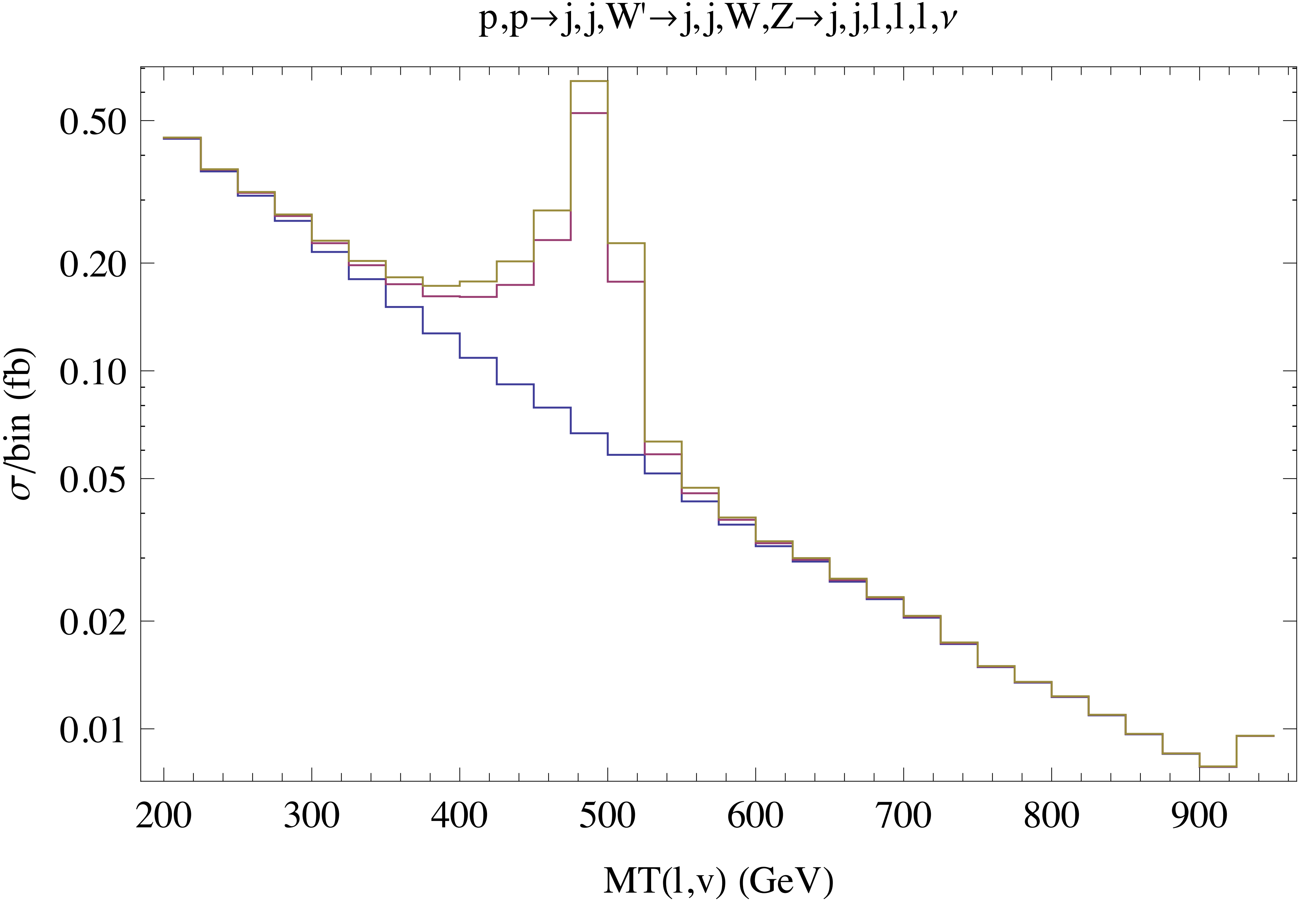

p,p→Z'→l,l
Required Lum (fb^{-1})
1000
500
100
50
10
5
1
400
600
800
1000
1200
$M_{W'}$ (GeV)


q
q
W
W′
W
Z
Z
q
q
l
l
l
l

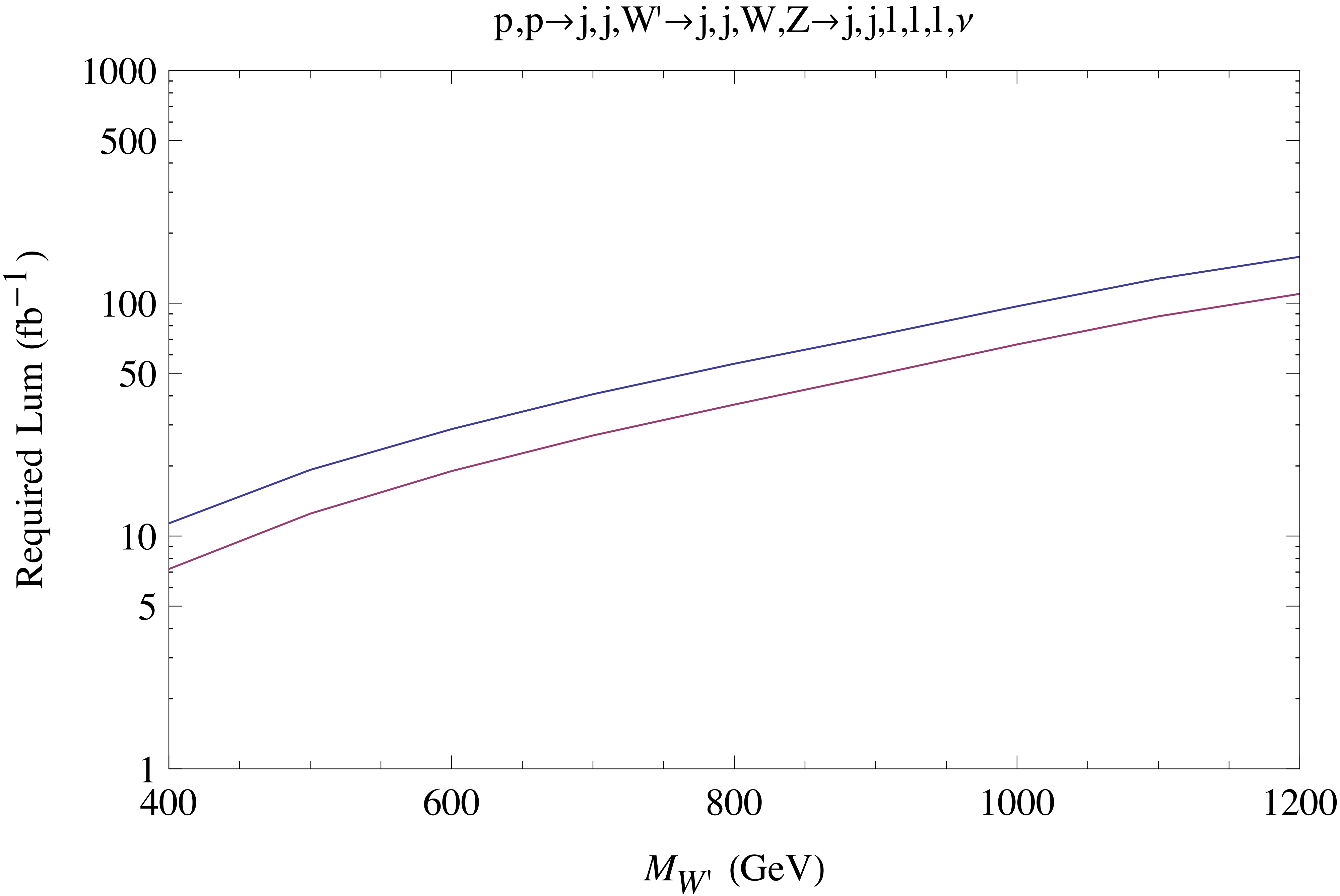

p,p→W',Z→W,Z,Z→j,j,l,l,l,l
σ/bin (fb)
0.200
0.100
0.050
0.020
0.010
0.005
0.002
0.001
200
400
600
800
1000
1200
M_{jjll} (GeV)


p,p→W',Z→W,Z,Z→j,j,l,l,l,l
Required Lum (fb^{-1})
1000
500
100
50
10
5
1
400
600
800
1000
1200
$M_{W'}$ (GeV)

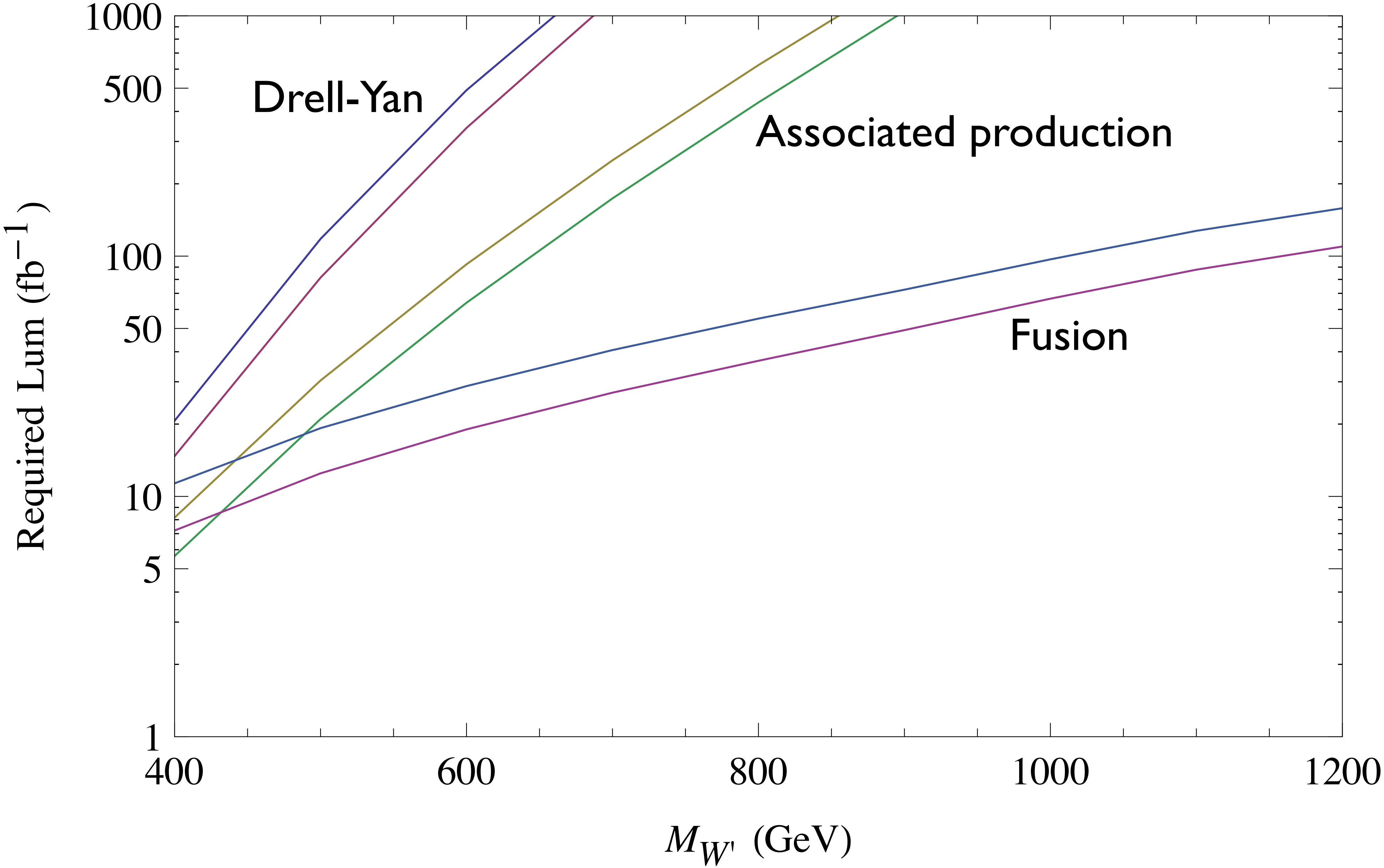

q
q
W
l
W
W′
ν
l
Z
Z
q
q
l



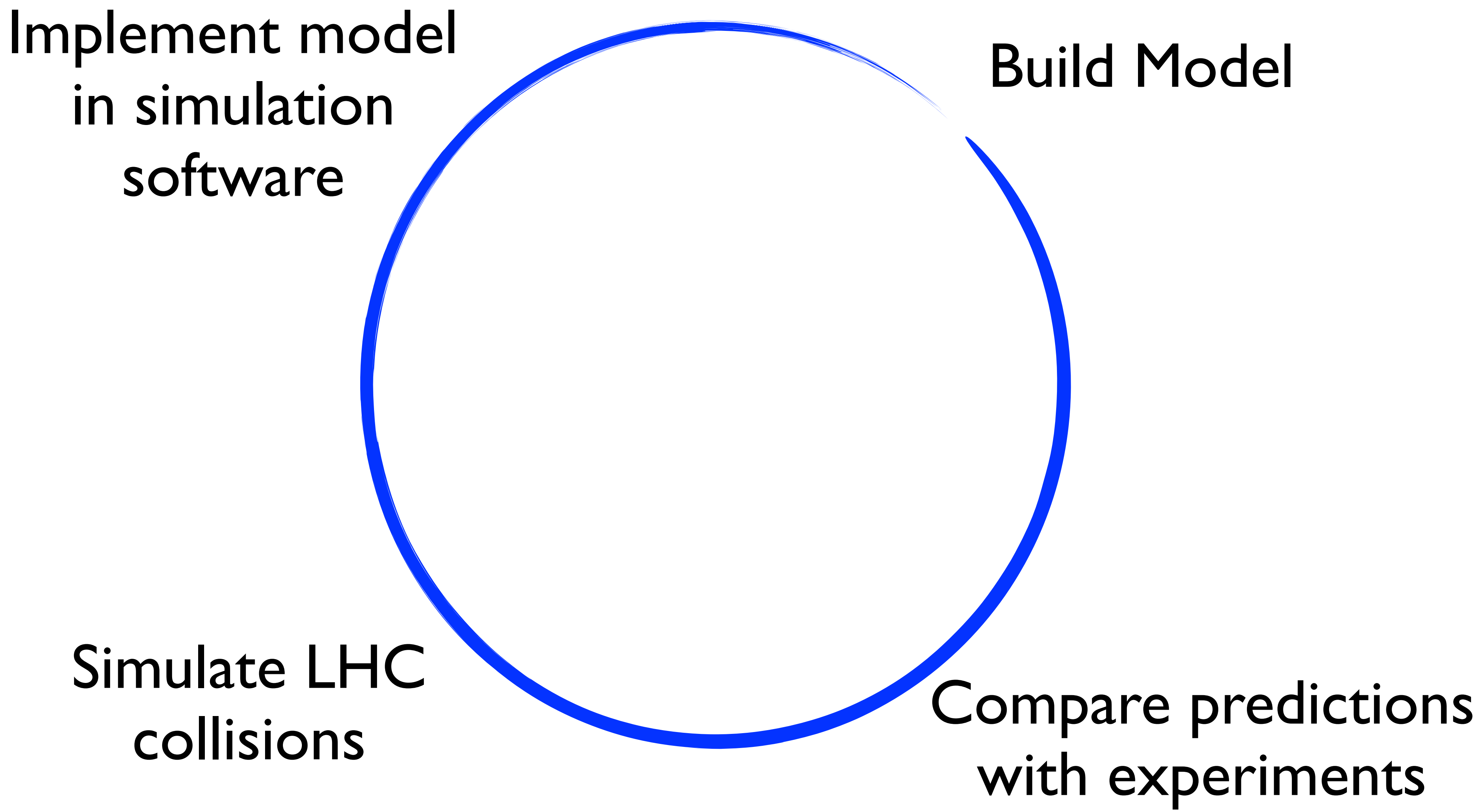
p,p→j,j,W'→j,j,W,Z→j,j,l,l,l,ν
σ/bin (fb)
0.50
0.20
0.10
0.05
0.02
0.01
200
300
400
500
600
700
800
900
MT(l,v) (GeV)

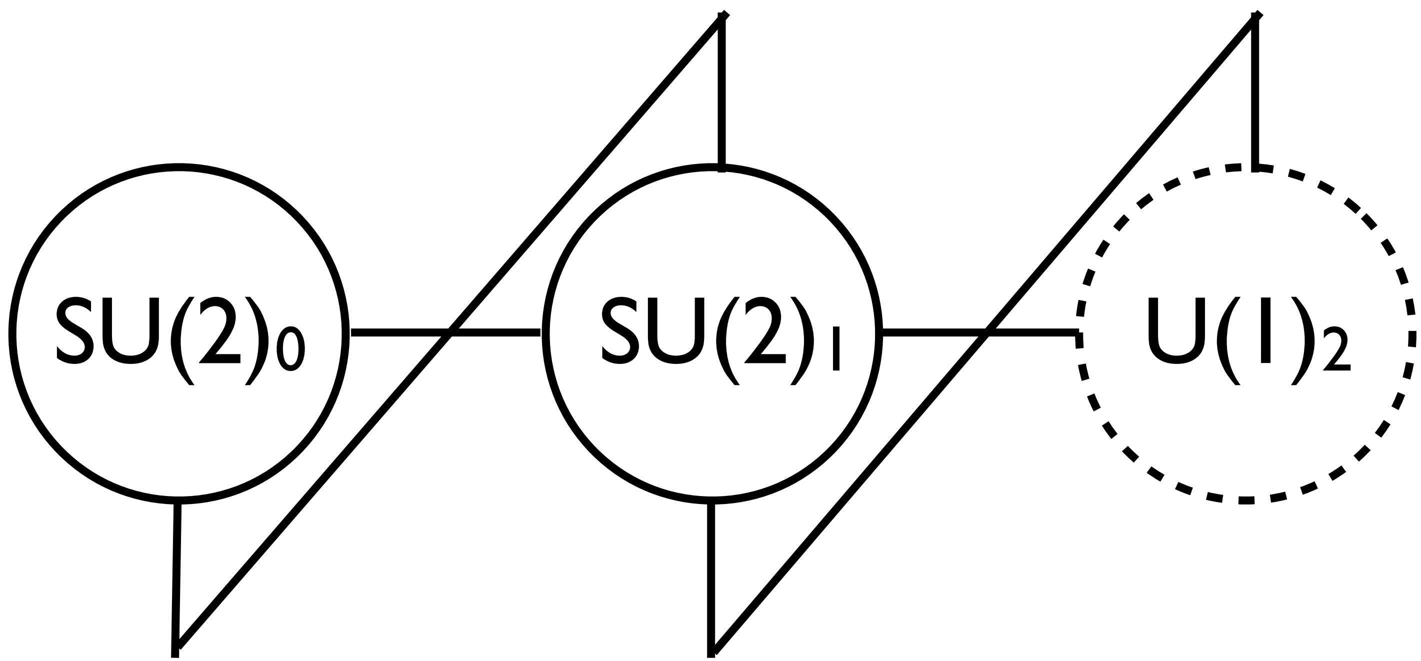


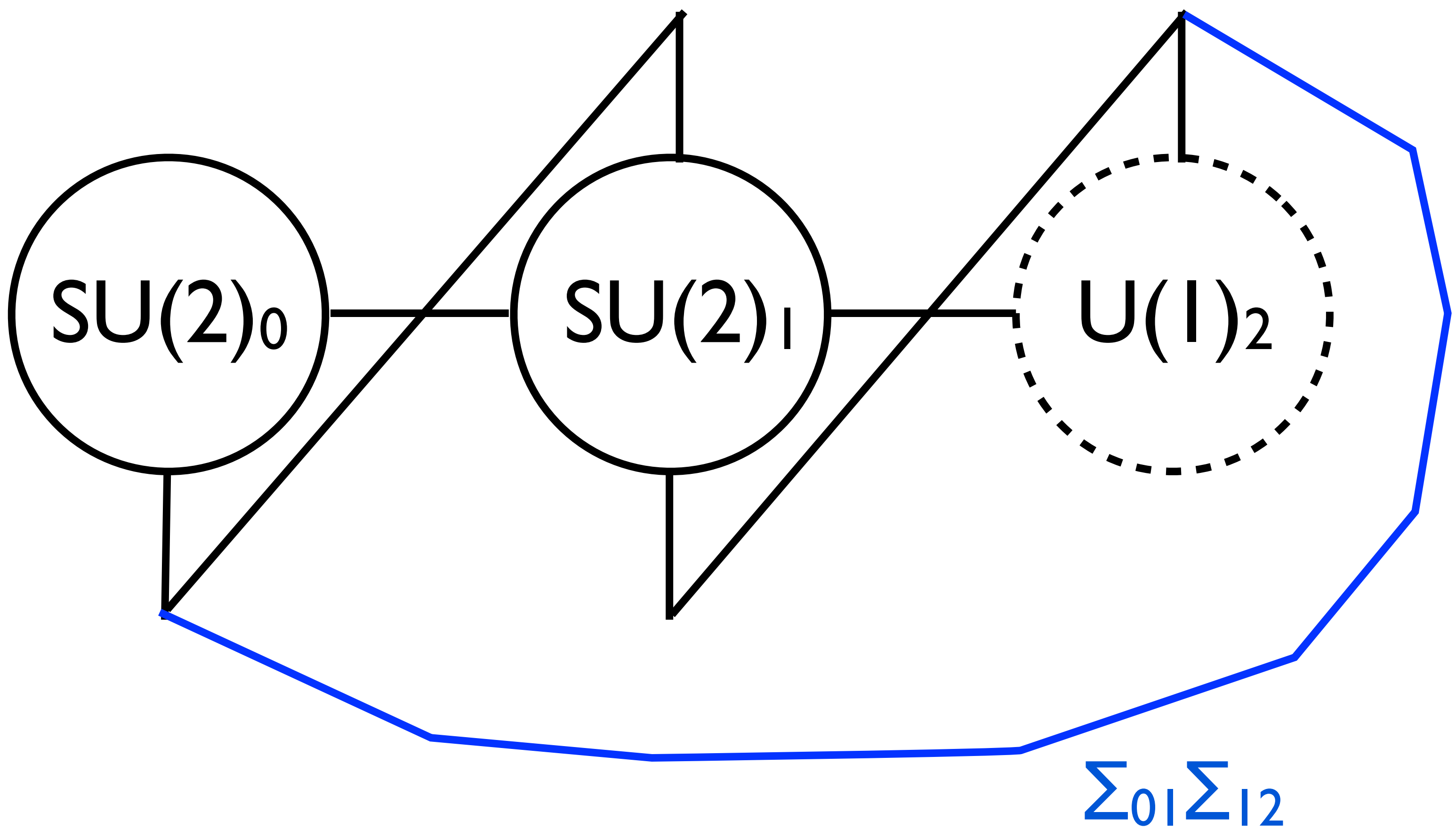
p,p→j,j,W'→j,j,W,Z→j,j,l,l,l,ν
Required Lum (fb^{-1})
1000
500
100
50
10
5
1
400
600
800
1000
1200
$M_{W'}$ (GeV)



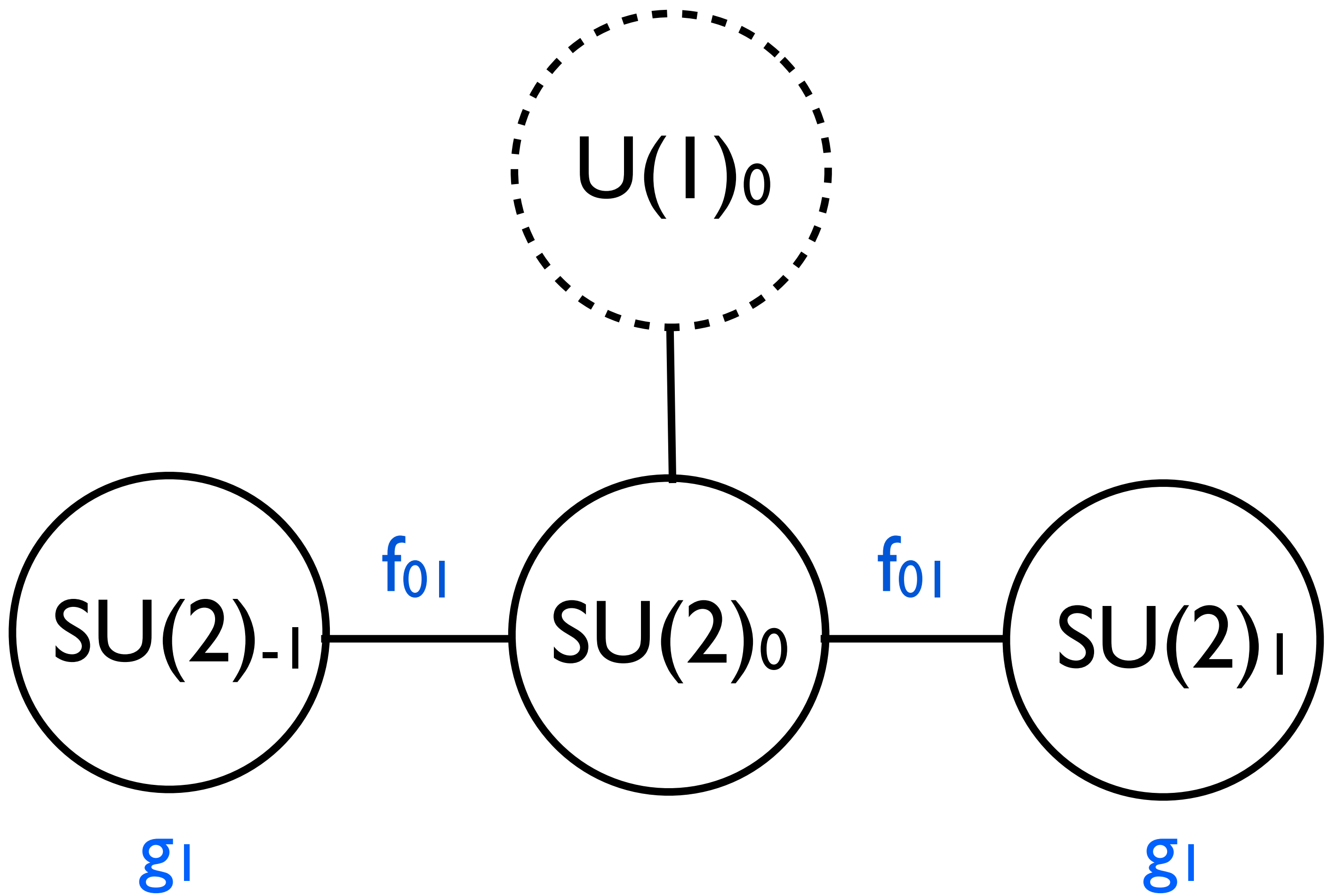
Drell-Yan
Associated production
Fusion
Required Lum (fb^{-1})
1000
500
100
50
10
5
1
400
600
800
1000
1200
$M_{W'}$ (GeV)


Build Model
Compare predictions with experiments
Simulate LHC collisions
Implement model in simulation software

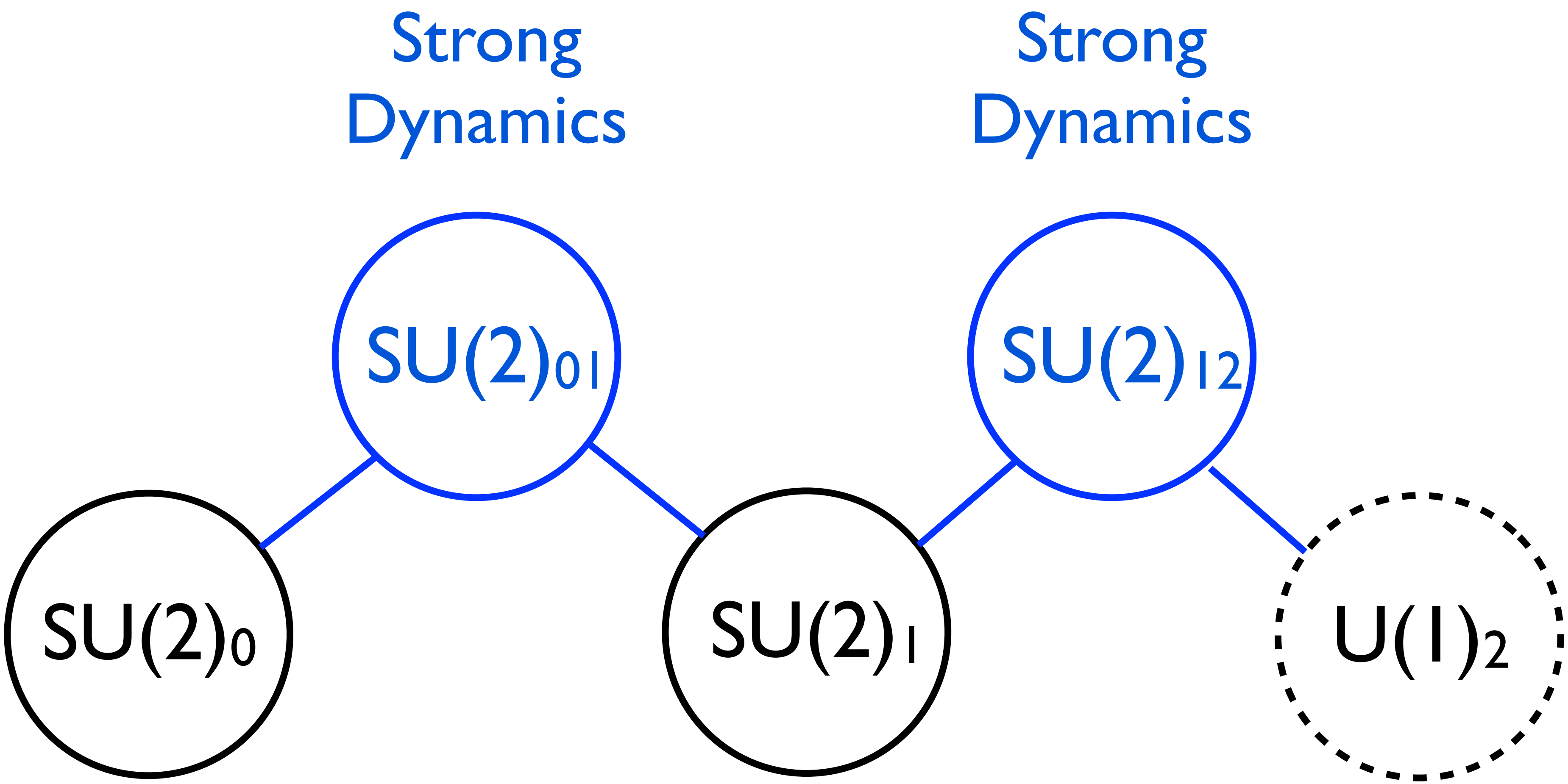

SU(2)0
SU(2)1
U(1)2

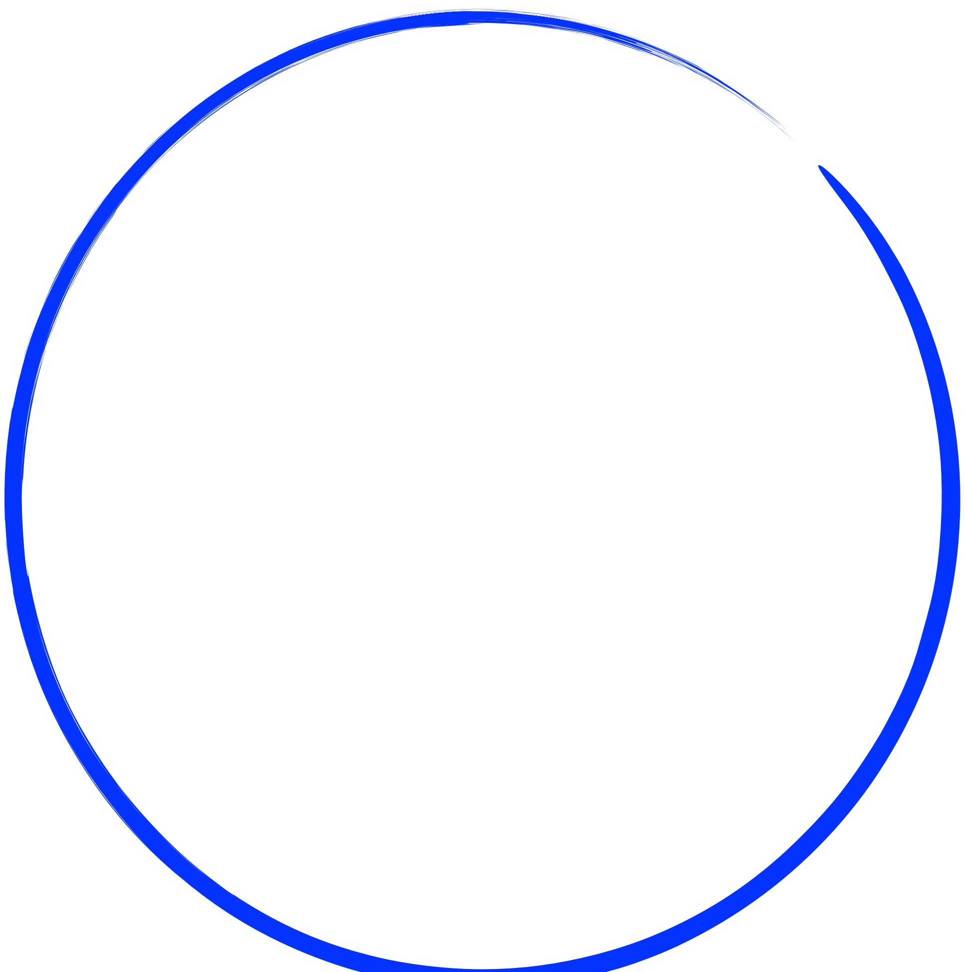


SU(2)0
SU(2)1
U(1)2
Σ01Σ12



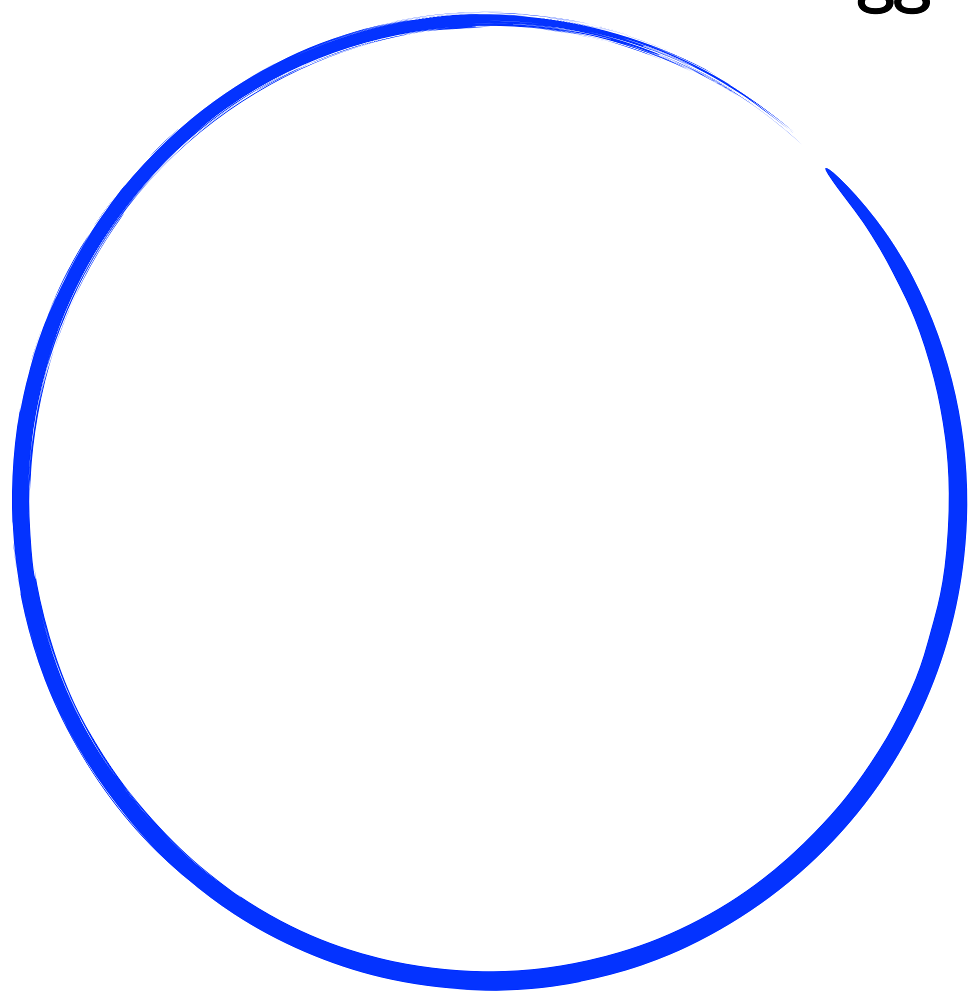
U(1)0
SU(2)-1
f01
SU(2)0
f01
SU(2)1
g1
g1

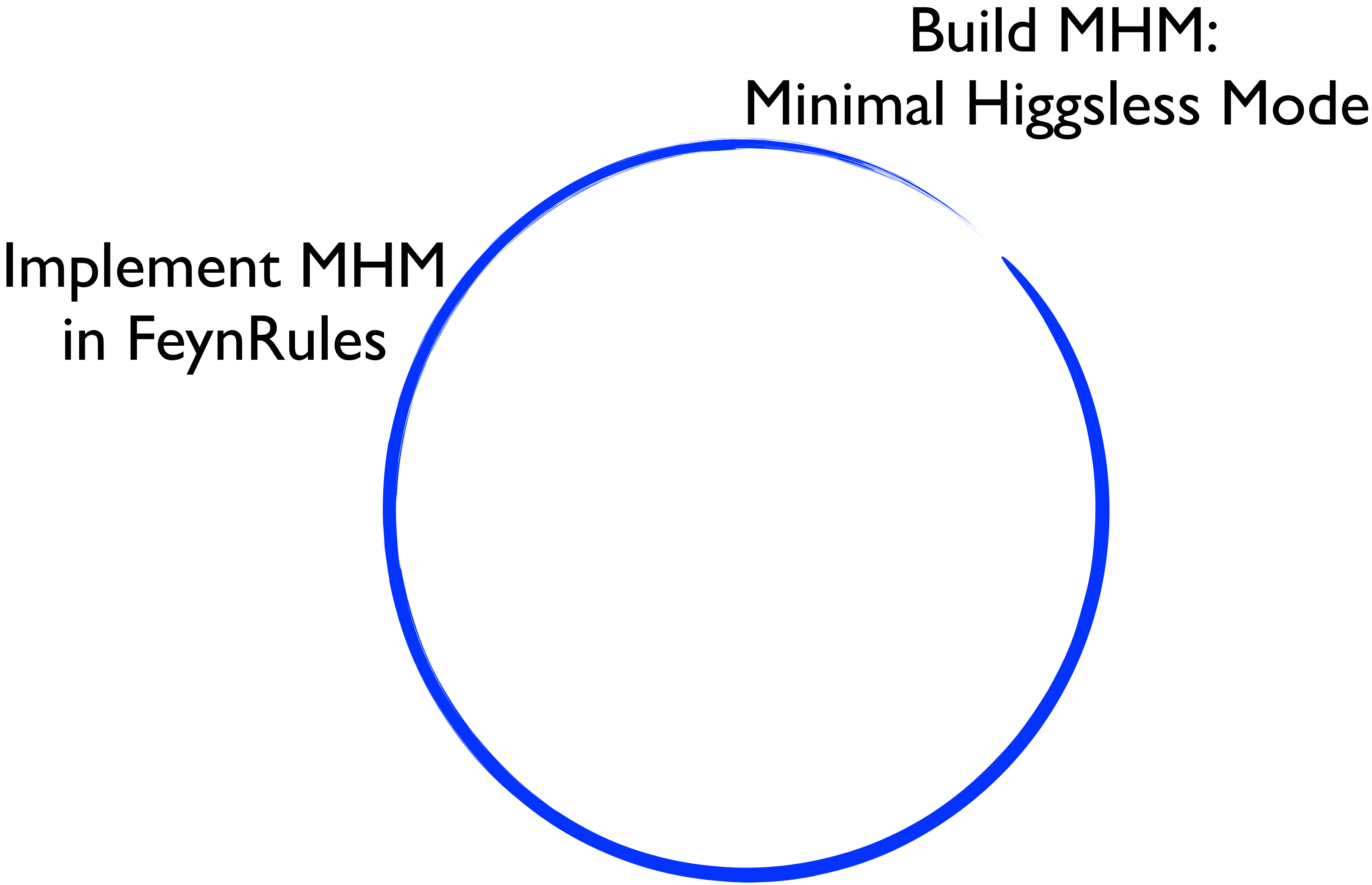

Strong Dynamics
Strong Dynamics
SU(2)01
SU(2)12
SU(2)0
SU(2)1
U(1)2

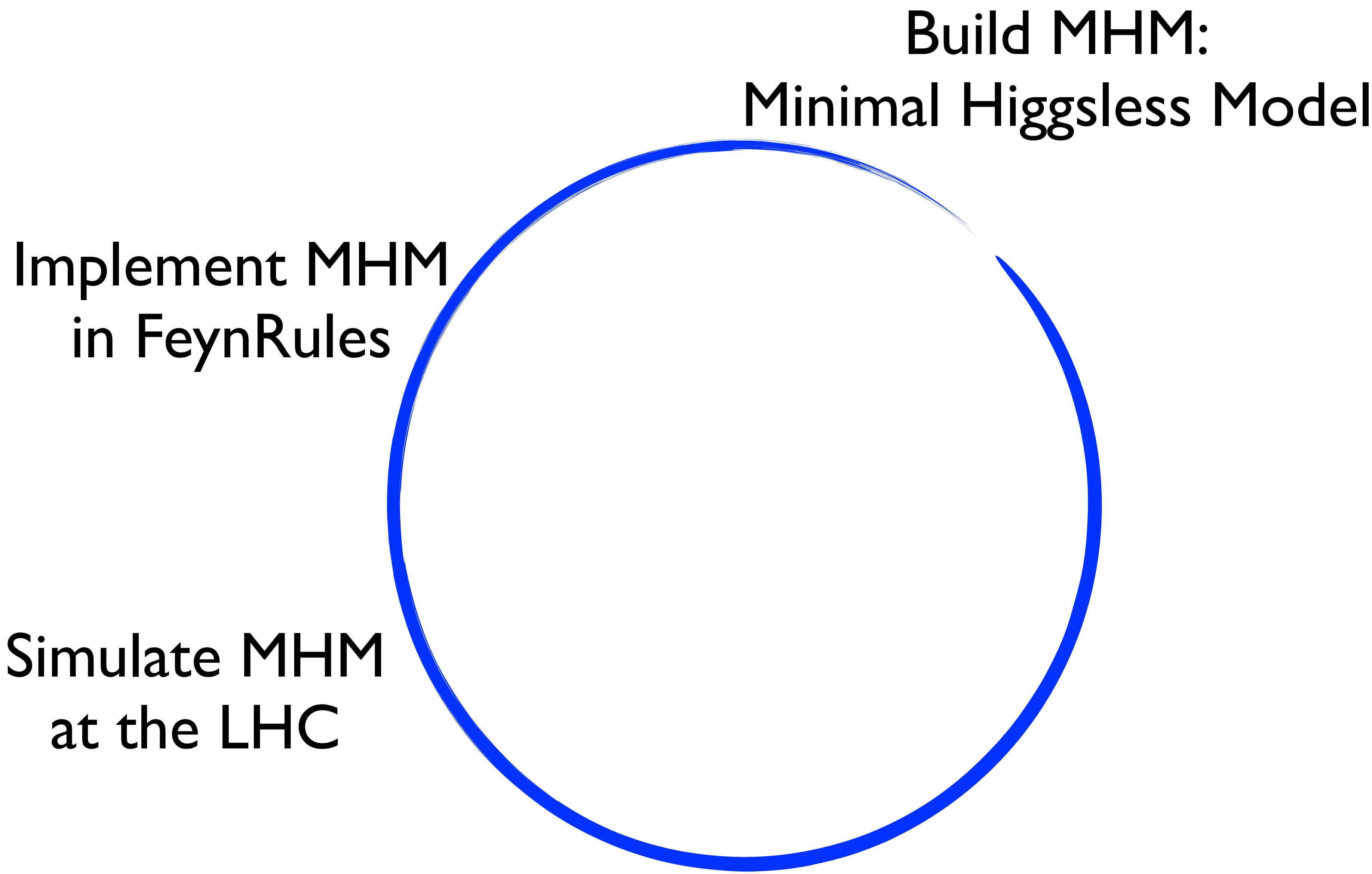


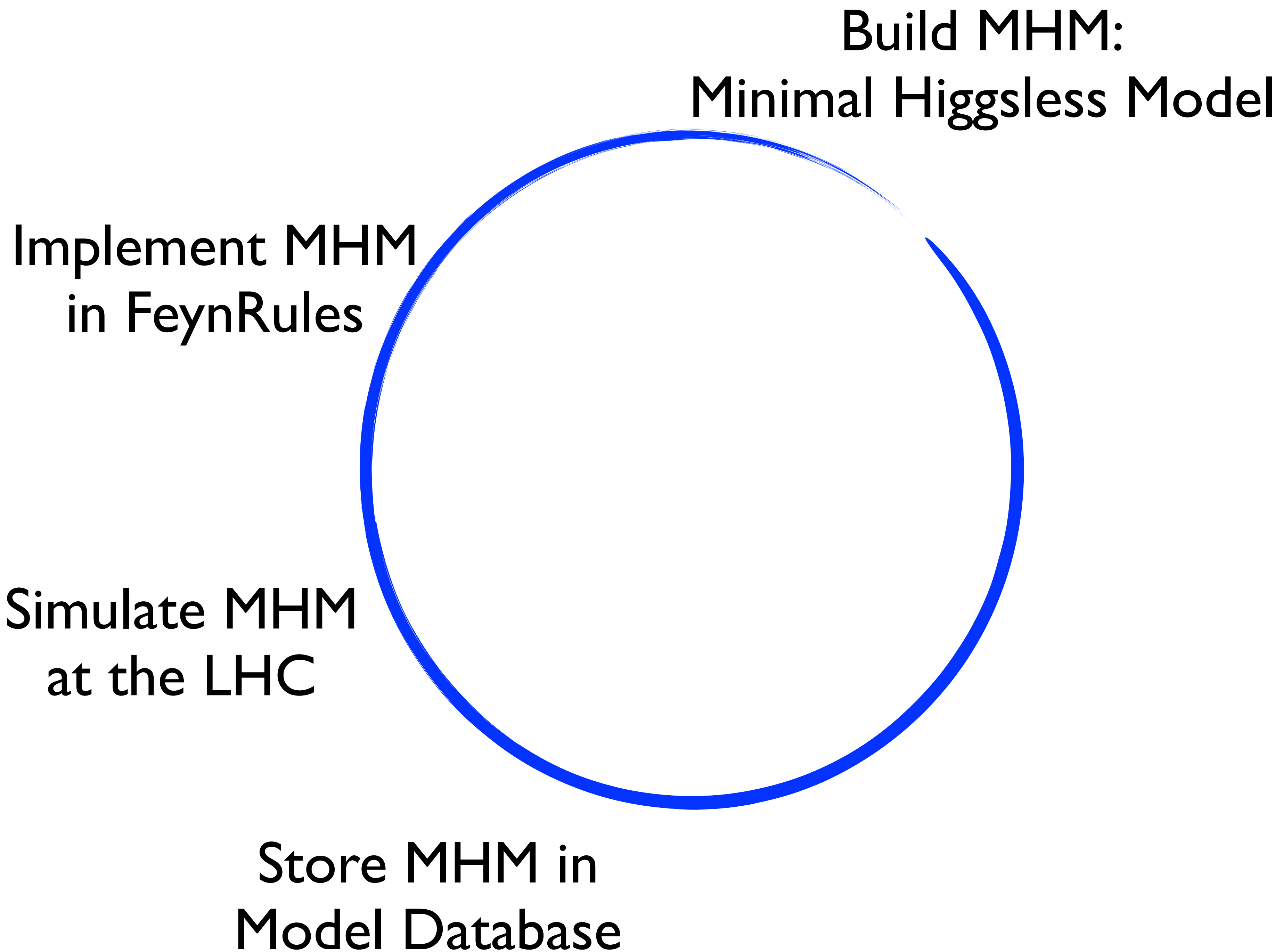
Build MHM:

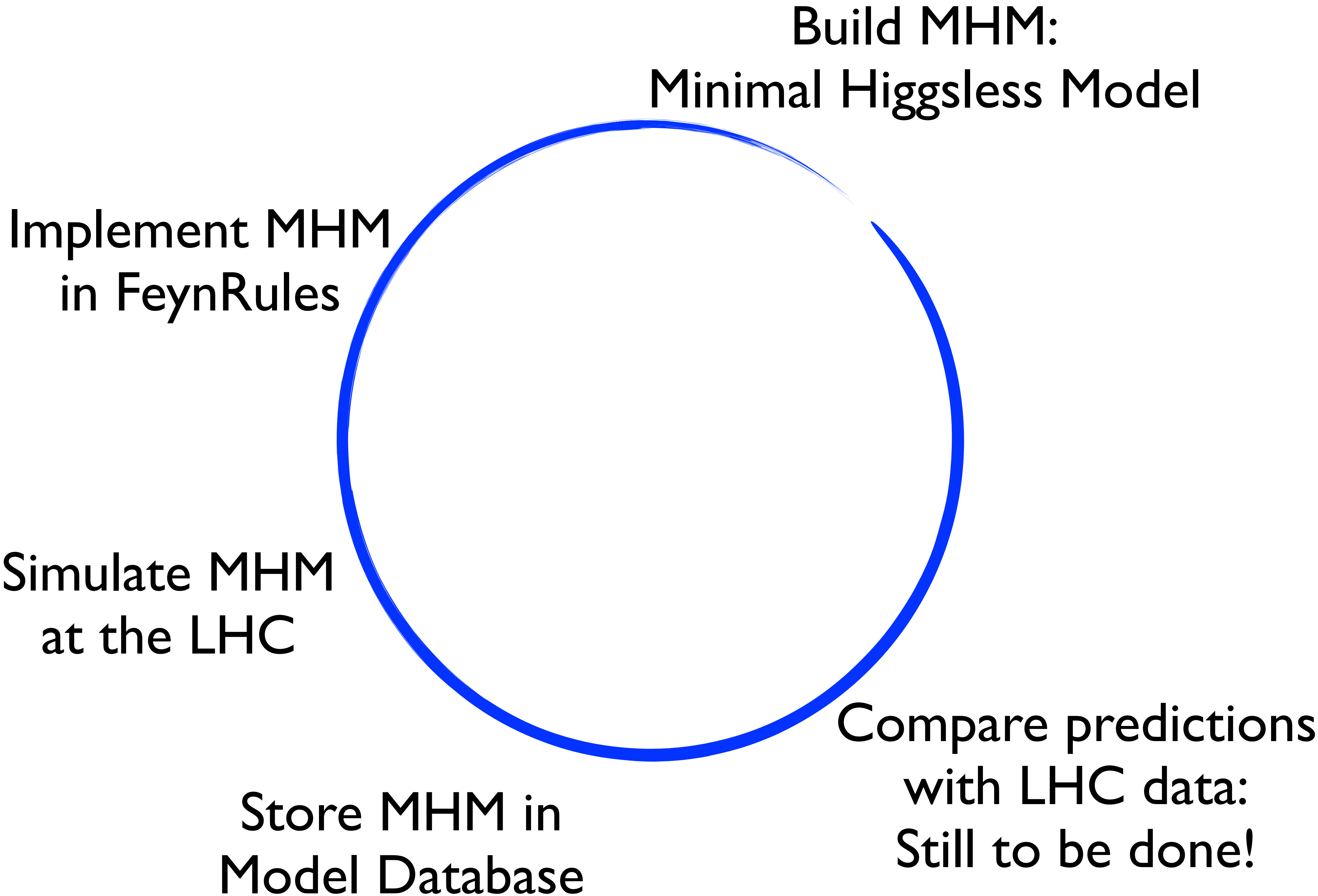
Minimal Higgsless Model

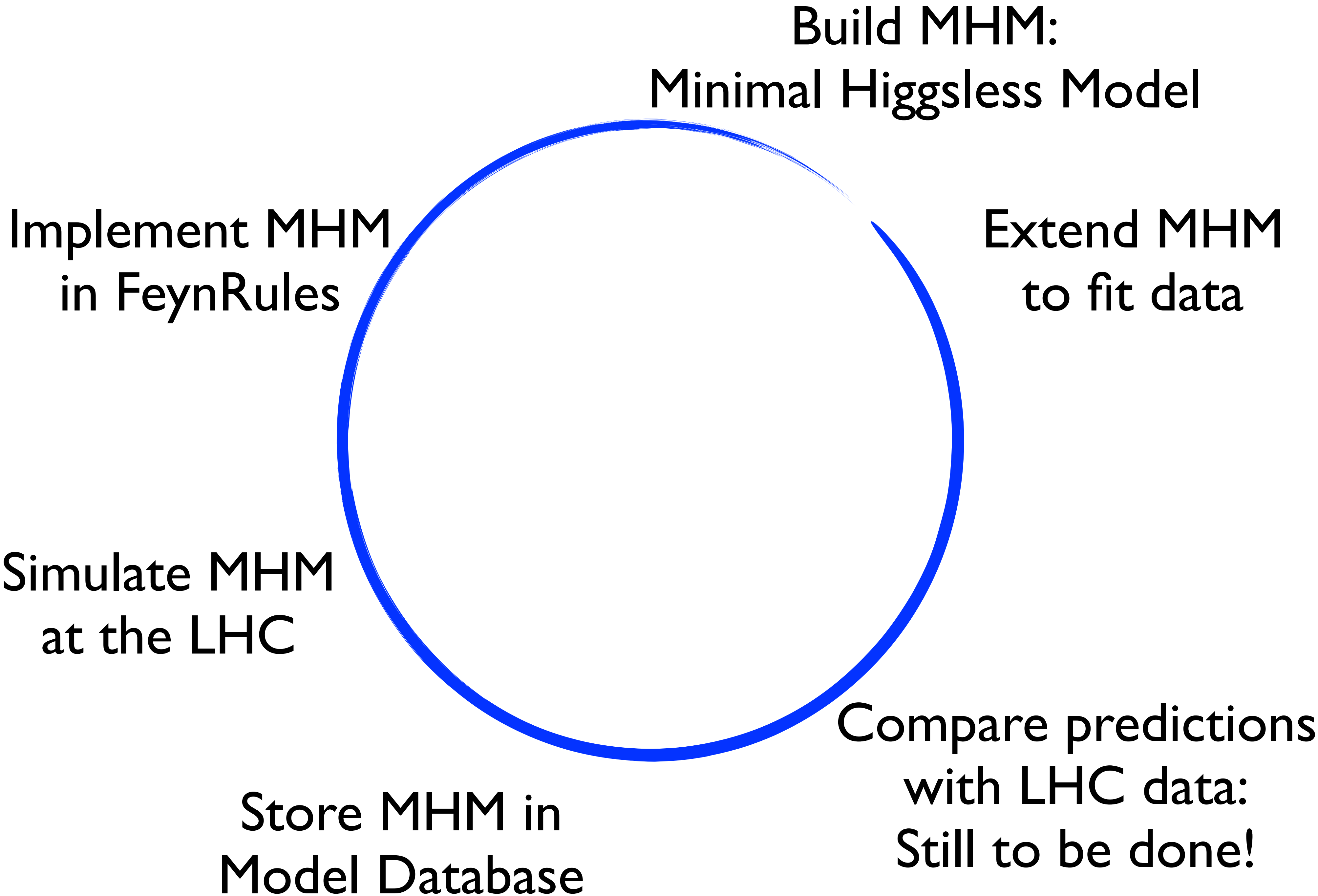



Build MHM:
Minimal Higgsless Model
Implement MHM
in FeynRules


Build MHM:
Minimal Higgsless Model
Implement MHM
in FeynRules
Simulate MHM
at the LHC


Build MHM:
Minimal Higgsless Model
Implement MHM
in FeynRules
Simulate MHM
at the LHC
Store MHM in
Model Database


Build MHM:
Minimal Higgsless Model
Compare predictions
with LHC data:
Still to be done!
Store MHM in
Model Database
Simulate MHM
at the LHC
Implement MHM
in FeynRules


Build MHM:
Minimal Higgsless Model
Extend MHM
to fit data
Compare predictions
with LHC data:
Still to be done!
Store MHM in
Model Database
Simulate MHM
at the LHC
Implement MHM
in FeynRules