Discovery
in
Drell-Yan
at the
LHC

Neil Christensen
University of Wisconsin - Madison
in collaboration with
Cheng-Wei Chiang, Gui-Jun Ding and Tao Han

to be published soon!

SM

???

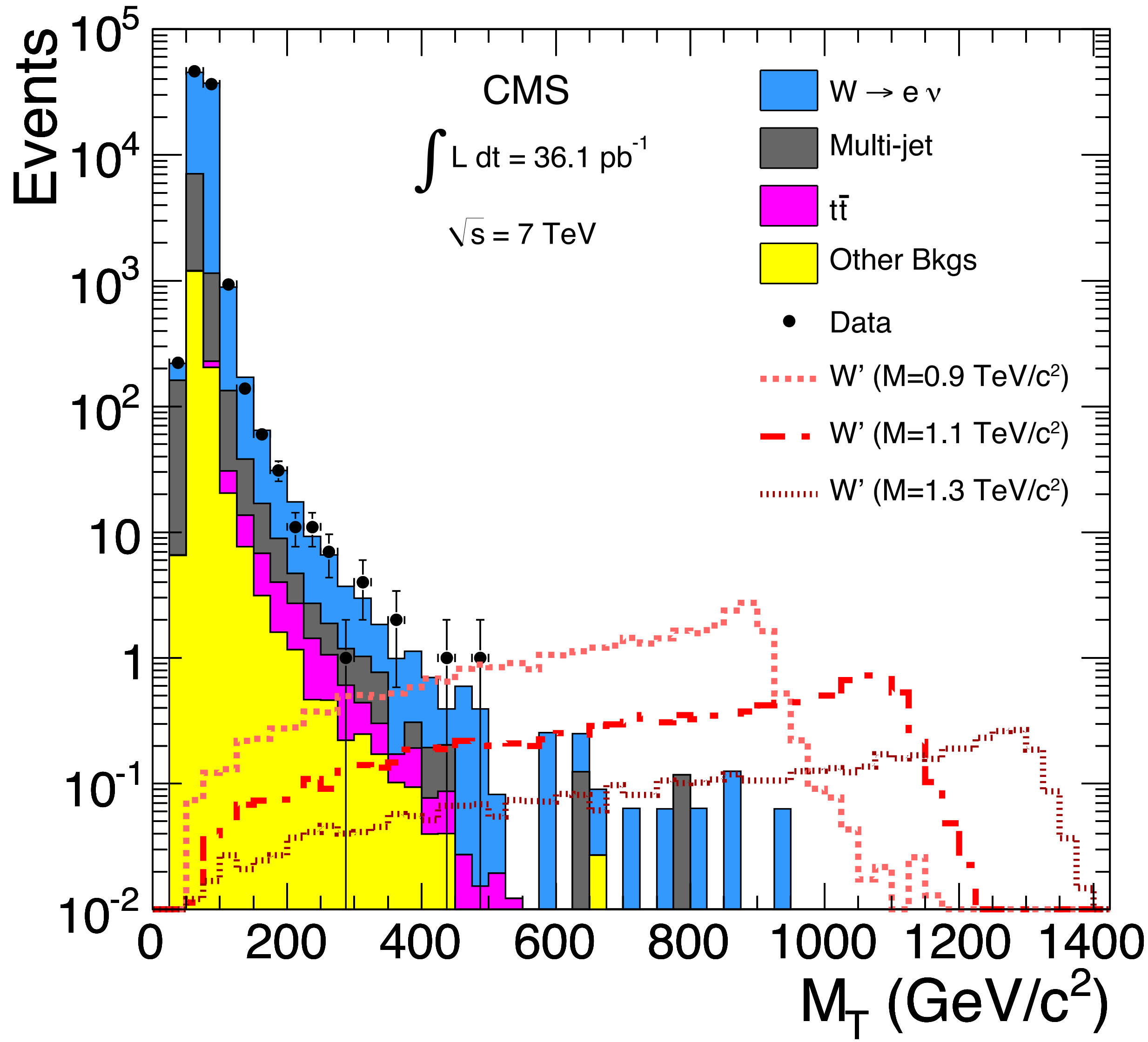
Supersymmetry

Extra
Dimensions

Little Higgs

Higgsless

New Strong
Dynamics



SM

???

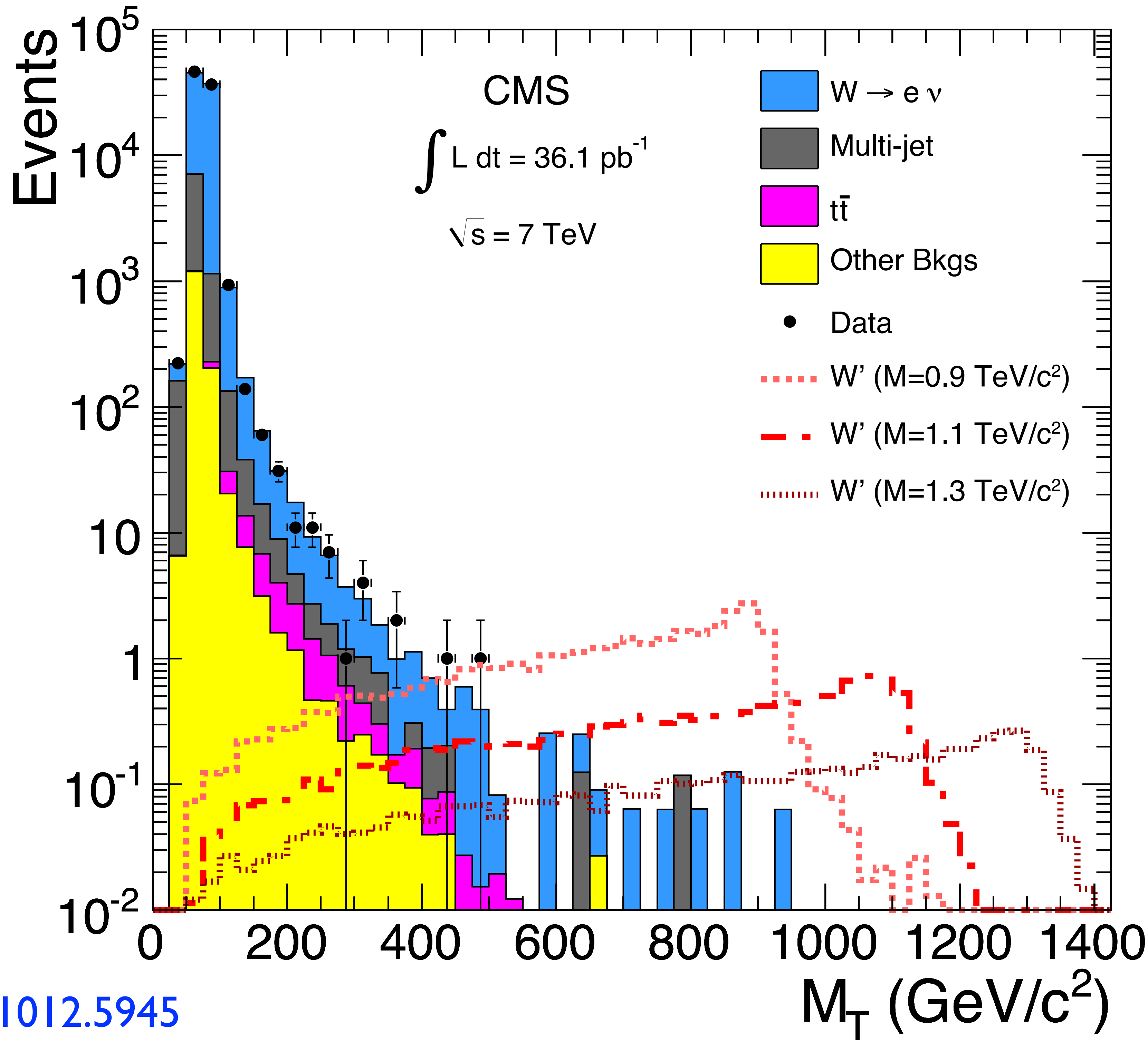
Supersymmetry

Extra Dimensions

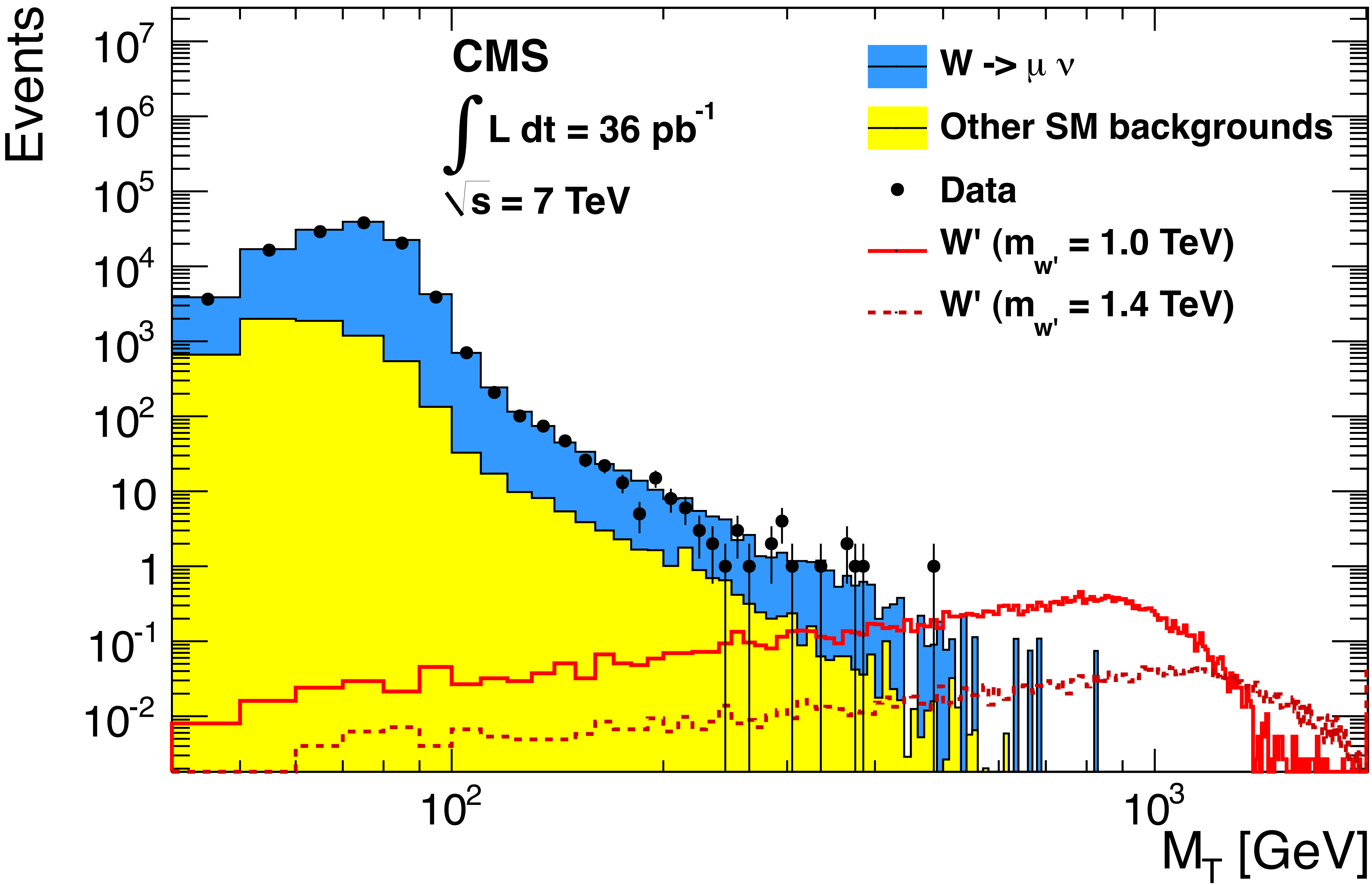
Little Higgs

Higgsless

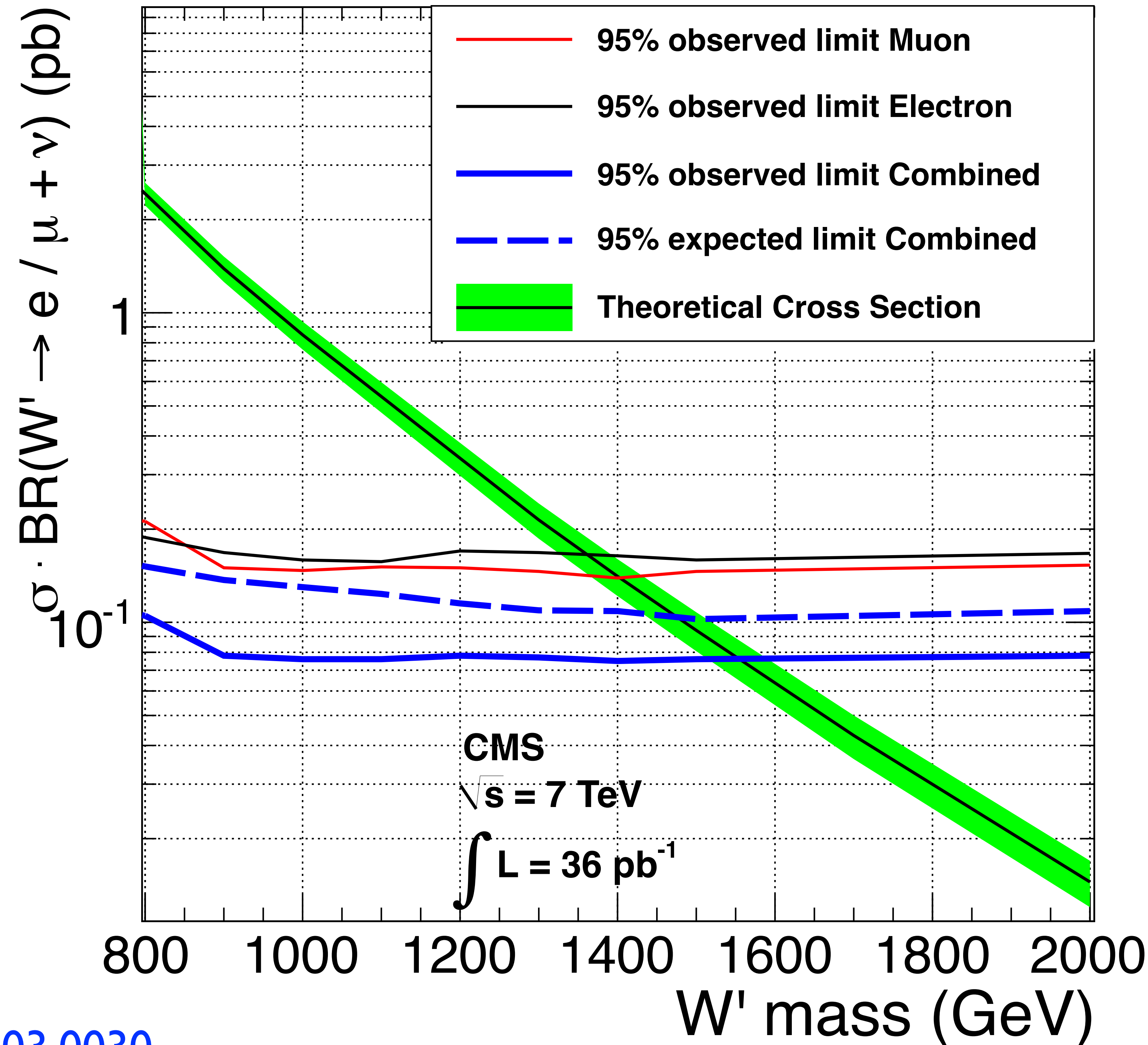
New Strong Dynamics



arXiv:1012.5945



arXiv:1103.0030

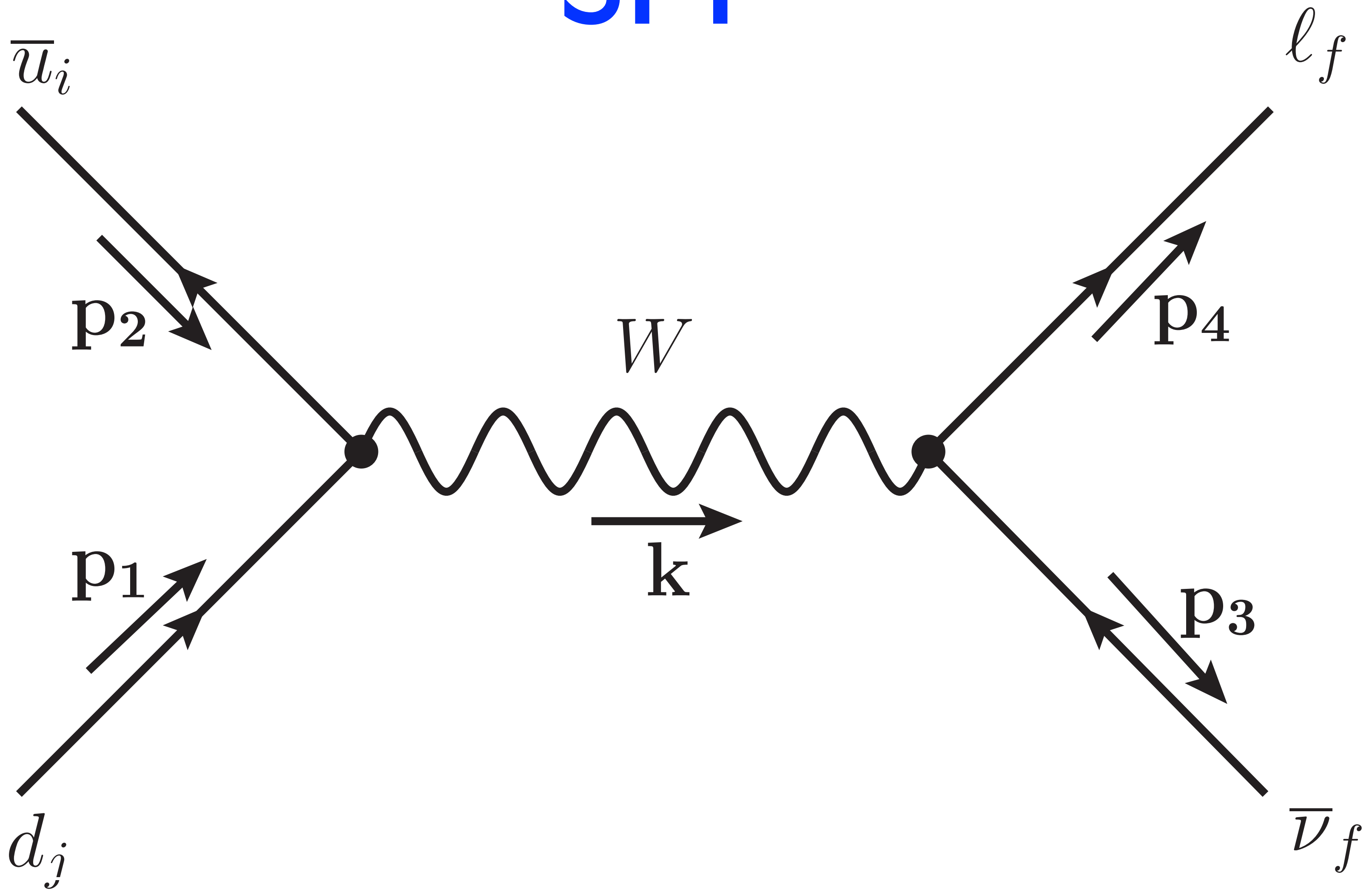


arXiv:1103.0030

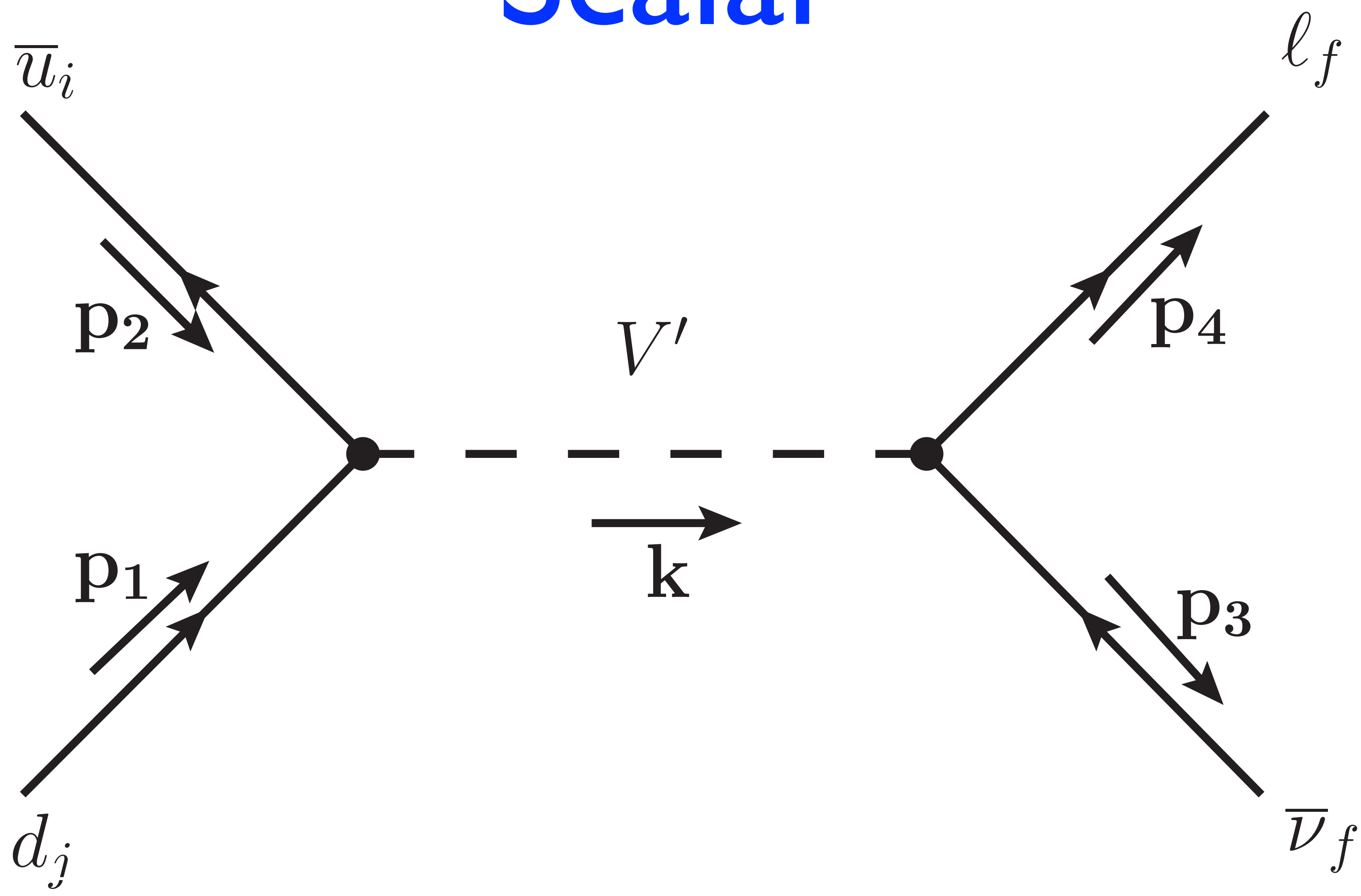
This channel is very simple.

A model independent analysis can be done.

SM

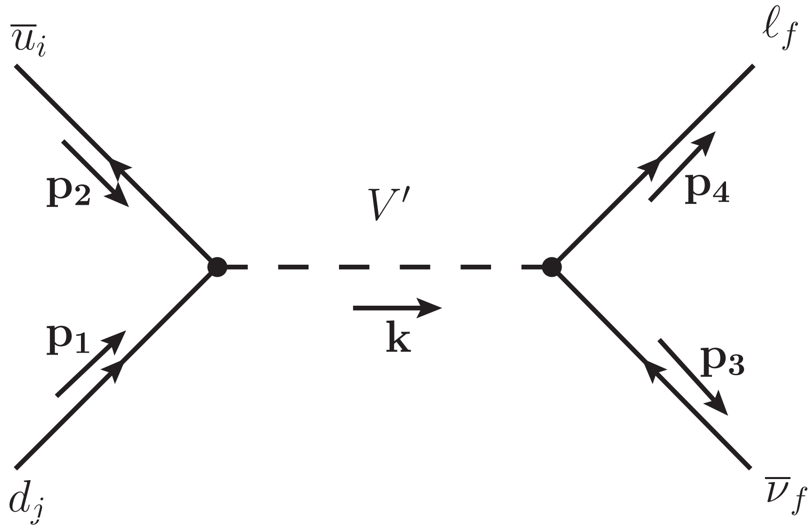

$\overline{u}_i$
ℓ_f
$\mathbf{p_2}$
W
$\mathbf{p_4}$
$\mathbf{p_1}$
$\mathbf{k}$
$\mathbf{p_3}$
d_j
$\overline{\nu}_f$

Scalar



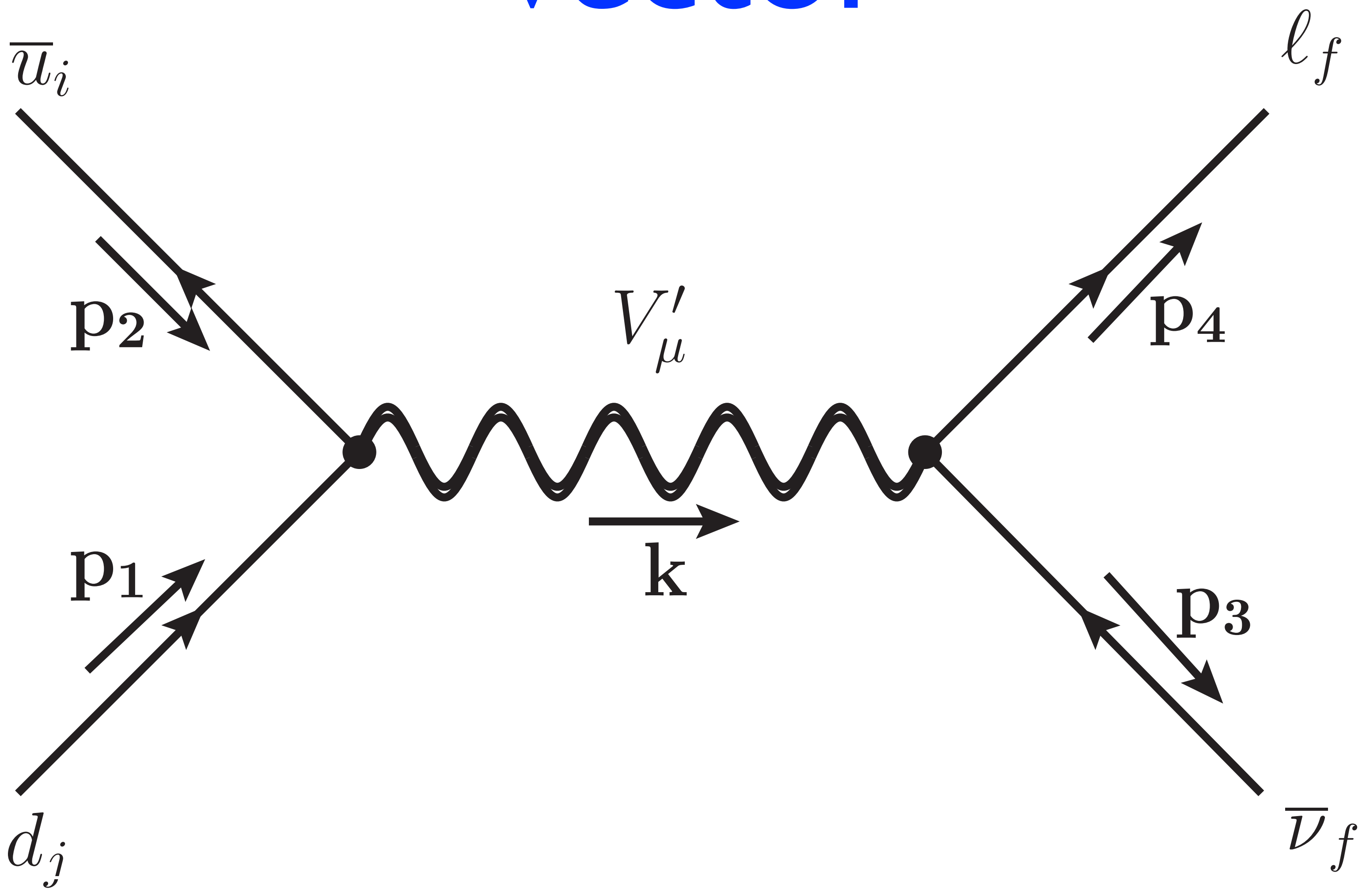
$\overline{u}_i$
ℓ_f
$\mathbf{p_2}$
$\mathbf{p_4}$
V'
$\mathbf{p_1}$
$\mathbf{k}$
$\mathbf{p_3}$
d_j
$\overline{\nu}_f$

Scalar

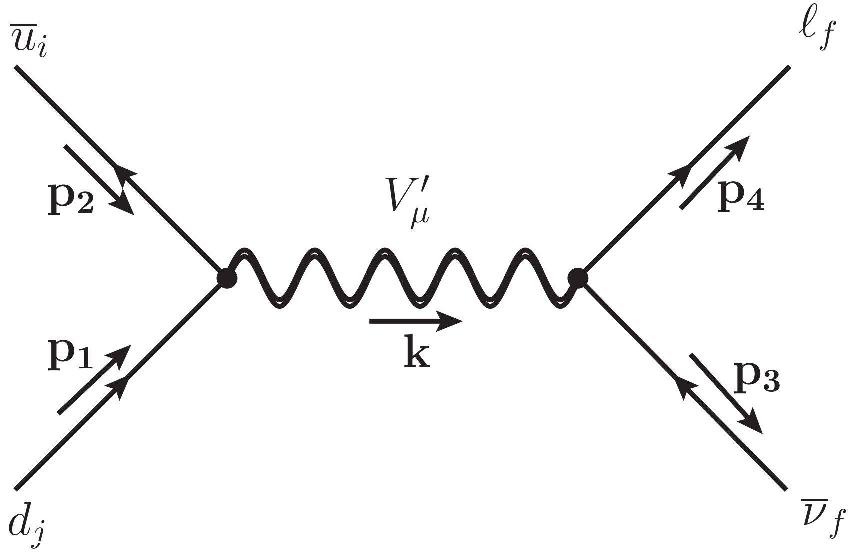


$$
\begin{aligned}
\mathcal{L}^{\text{scalar}}_{V'} &= \overline{u}_i \left(h^q_{Sij} + i h^q_{Pij}\gamma_5 \right) d_j V' + \text{h.c.} \\
&\quad + \overline{\nu}_i \left(h^\ell_{Sij} + i h^\ell_{Pij}\gamma_5 \right) \ell_j V' + \text{h.c.}
\end{aligned}
$$

Vector

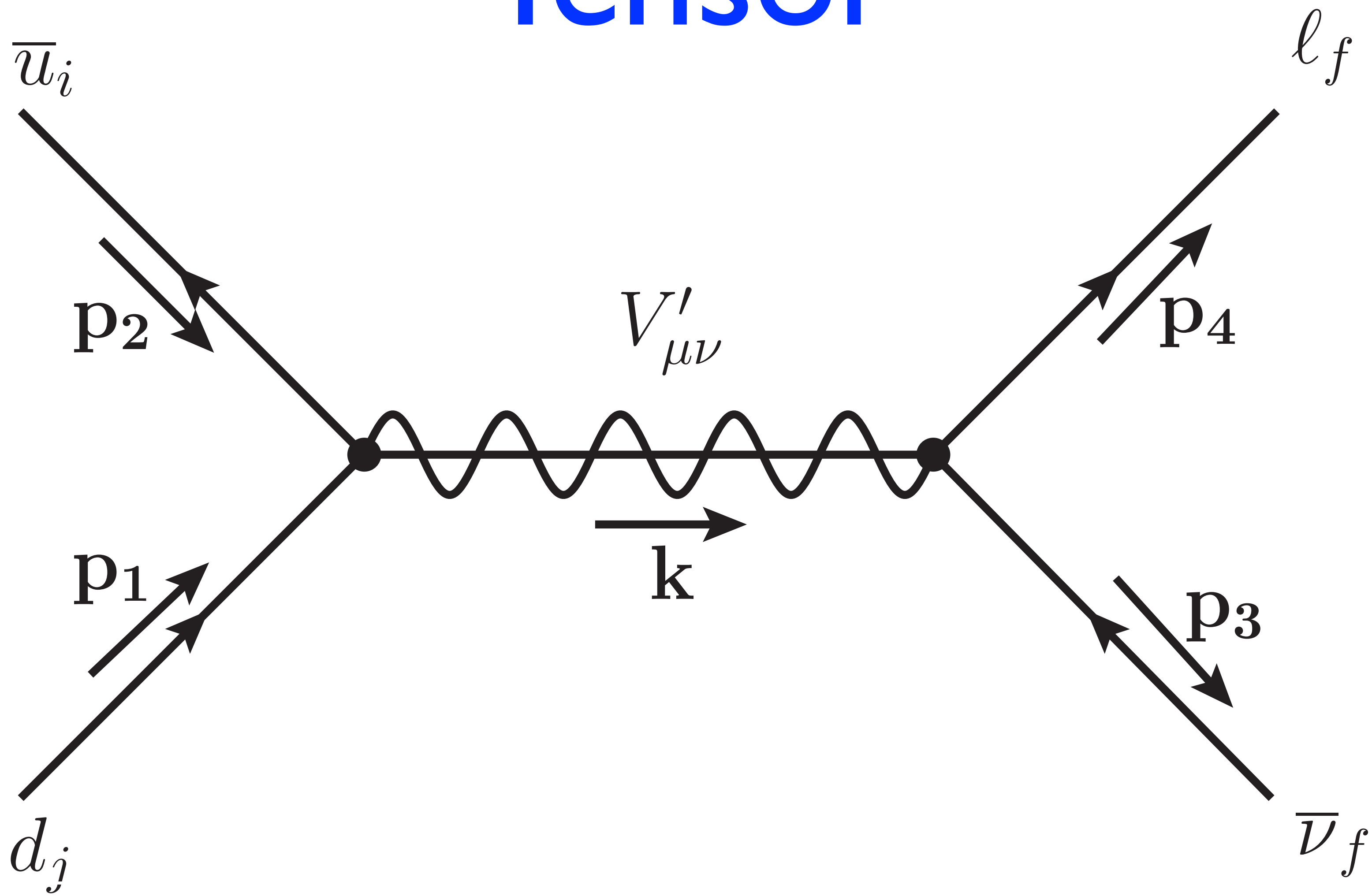

$\overline{u}_i$
ℓ_f
$\mathbf{p_2}$
V'_μ
$\mathbf{p_4}$
$\mathbf{k}$
$\mathbf{p_1}$
$\mathbf{p_3}$
d_j
$\overline{\nu}_f$

Vector



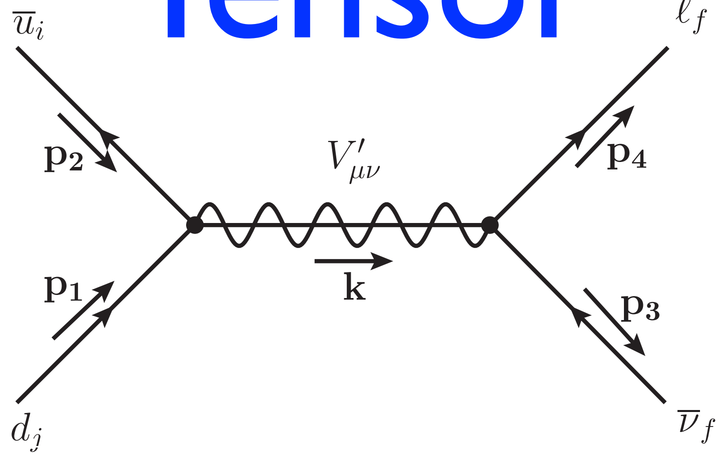
$$\mathcal{L}_{V'}^{\text{vector}} = \overline{u}_i \gamma^\mu \left(h^q_{Vij} + h^q_{Aij}\gamma_5 \right) d_j V'_\mu + \text{h.c.}$$
$$+ \overline{\nu}_i \gamma^\mu \left(h^\ell_{Vij} + h^\ell_{Aij}\gamma_5 \right) \ell_j V'_\mu + \text{h.c.}$$

Tensor

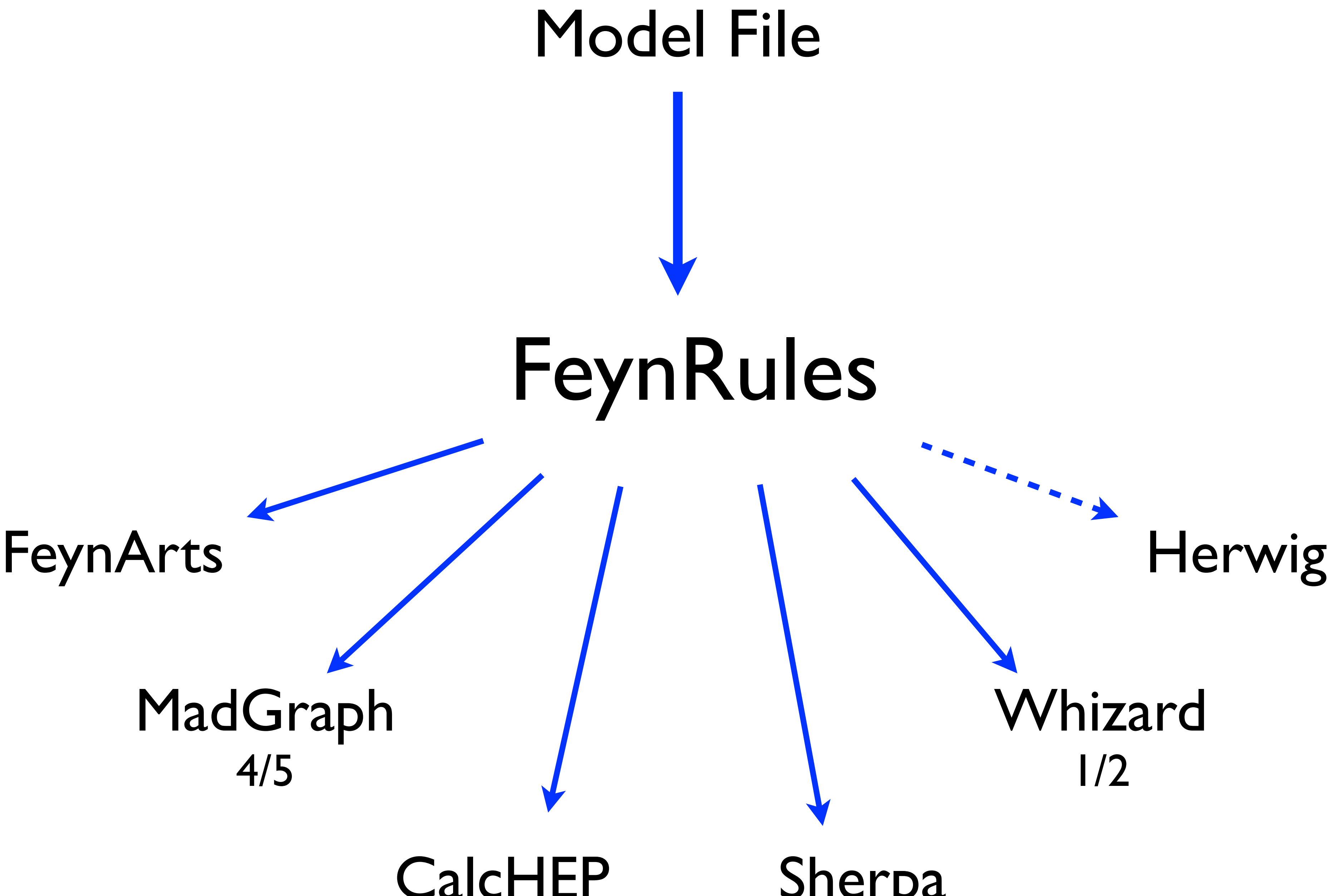


$\overline{u}_i$
ℓ_f
$\mathbf{p_2}$
$V'_{\mu\nu}$
$\mathbf{p_4}$
$\mathbf{p_1}$
$\mathbf{k}$
$\mathbf{p_3}$
d_j
$\overline{\nu}_f$

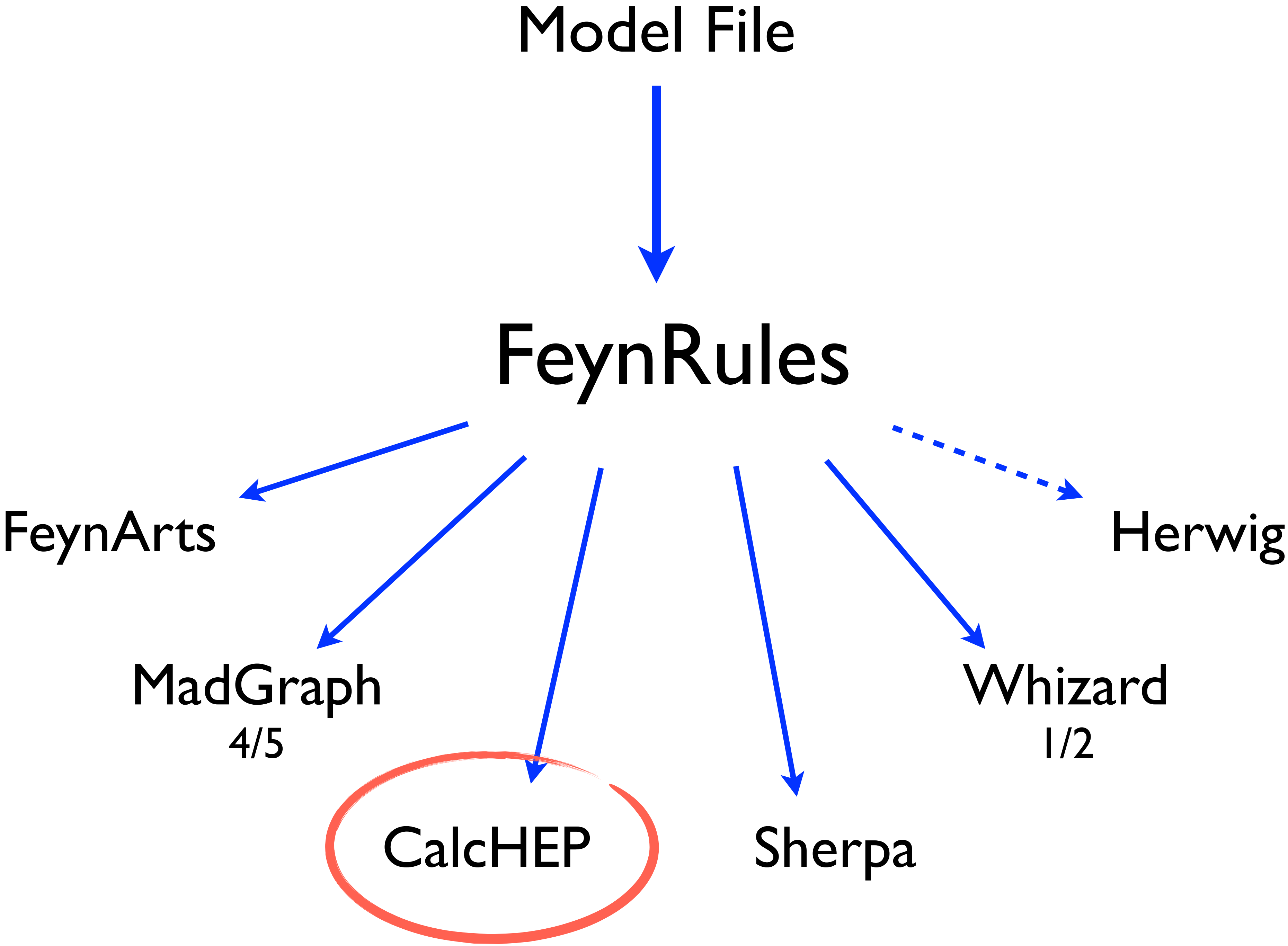
Tensor



$$
\begin{aligned}
\mathcal{L}_{V'}^{\text{tensor}} = \; & \frac{i}{\Lambda}\Big[\overline{u}_i \left(h^q_{Tij} - h^q_{ATij}\gamma_5\right)\left(\gamma^\mu\partial^\nu d_j + \gamma^\nu\partial^\mu d_j\right)V'_{\mu\nu} \\
& -\left(\partial^\mu\overline{u}_i\gamma^\nu + \partial^\nu\overline{u}_i\gamma^\mu\right)\left(\tilde{h}^q_{Tij} + \tilde{h}^q_{ATij}\gamma_5\right)d_j V'_{\mu\nu}\Big] \\
& +\frac{i}{\Lambda}\Big[\overline{\nu}_i\left(h^\ell_{Tij} - h^\ell_{ATij}\gamma_5\right)\left(\gamma^\mu\partial^\nu\ell_j + \gamma^\nu\partial^\mu\ell_j\right)V'_{\mu\nu} \\
& -\left(\partial^\mu\overline{\nu}_i\gamma^\nu + \partial^\nu\overline{\nu}_i\gamma^\mu\right)\left(\tilde{h}^\ell_{Tij} + \tilde{h}^\ell_{ATij}\gamma_5\right)\ell_j V'_{\mu\nu}\Big] \\
& +\text{h.c.}
\end{aligned}
$$



Model File
FeynRules
FeynArts
MadGraph
4/5
CalcHEP
Sherpa
Whizard
1/2
Herwig


Model File
FeynRules
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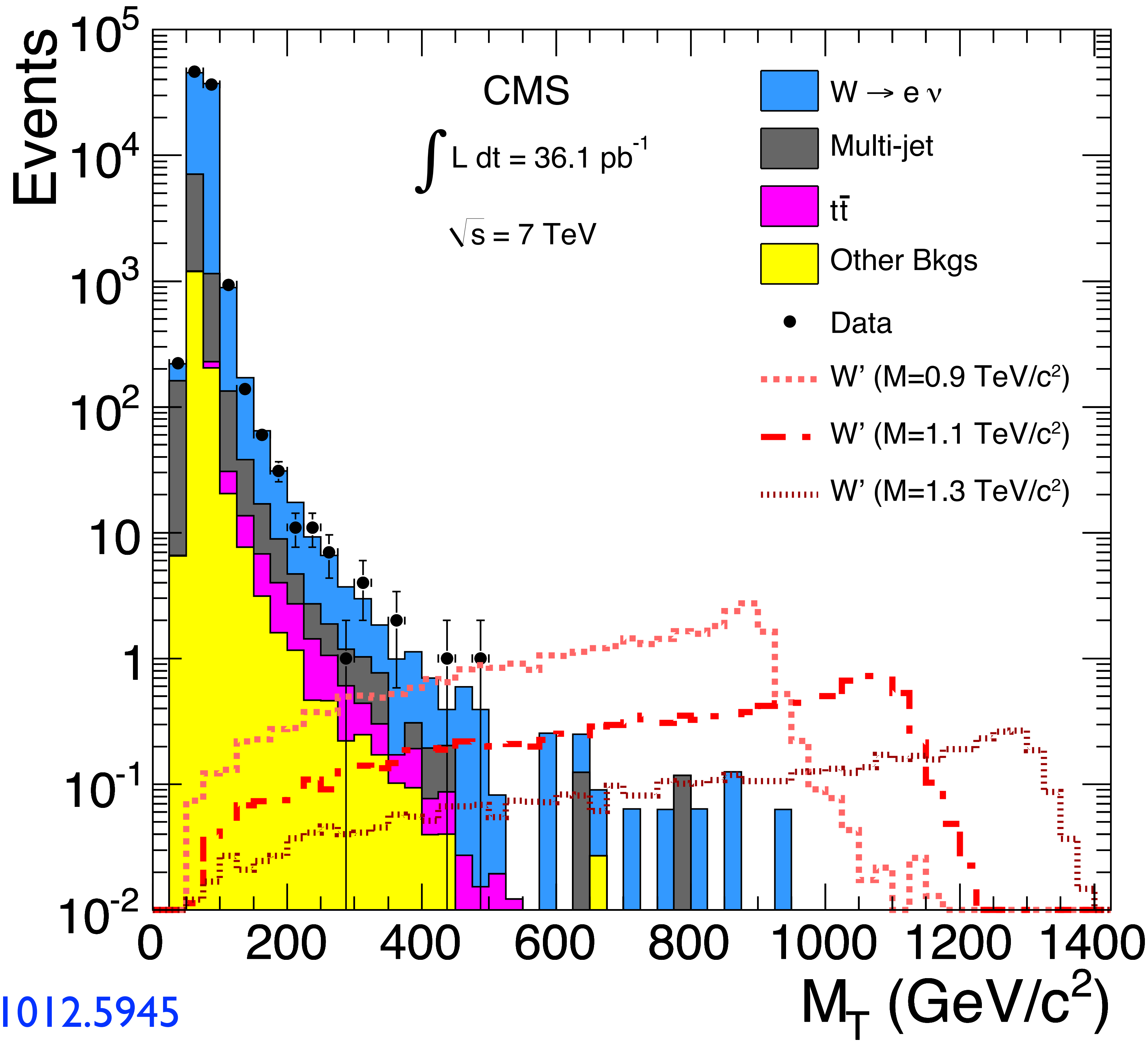
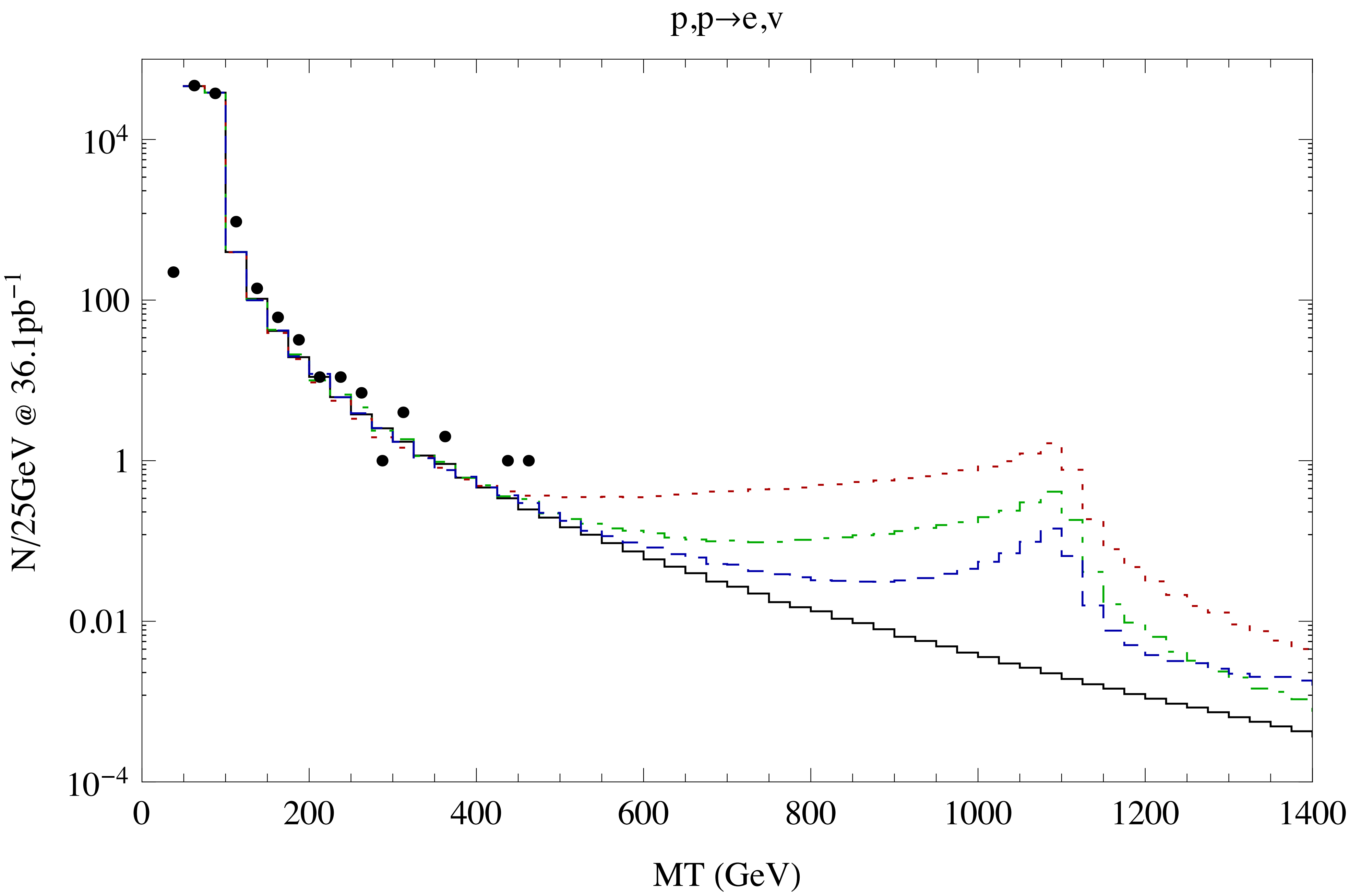
Herwig

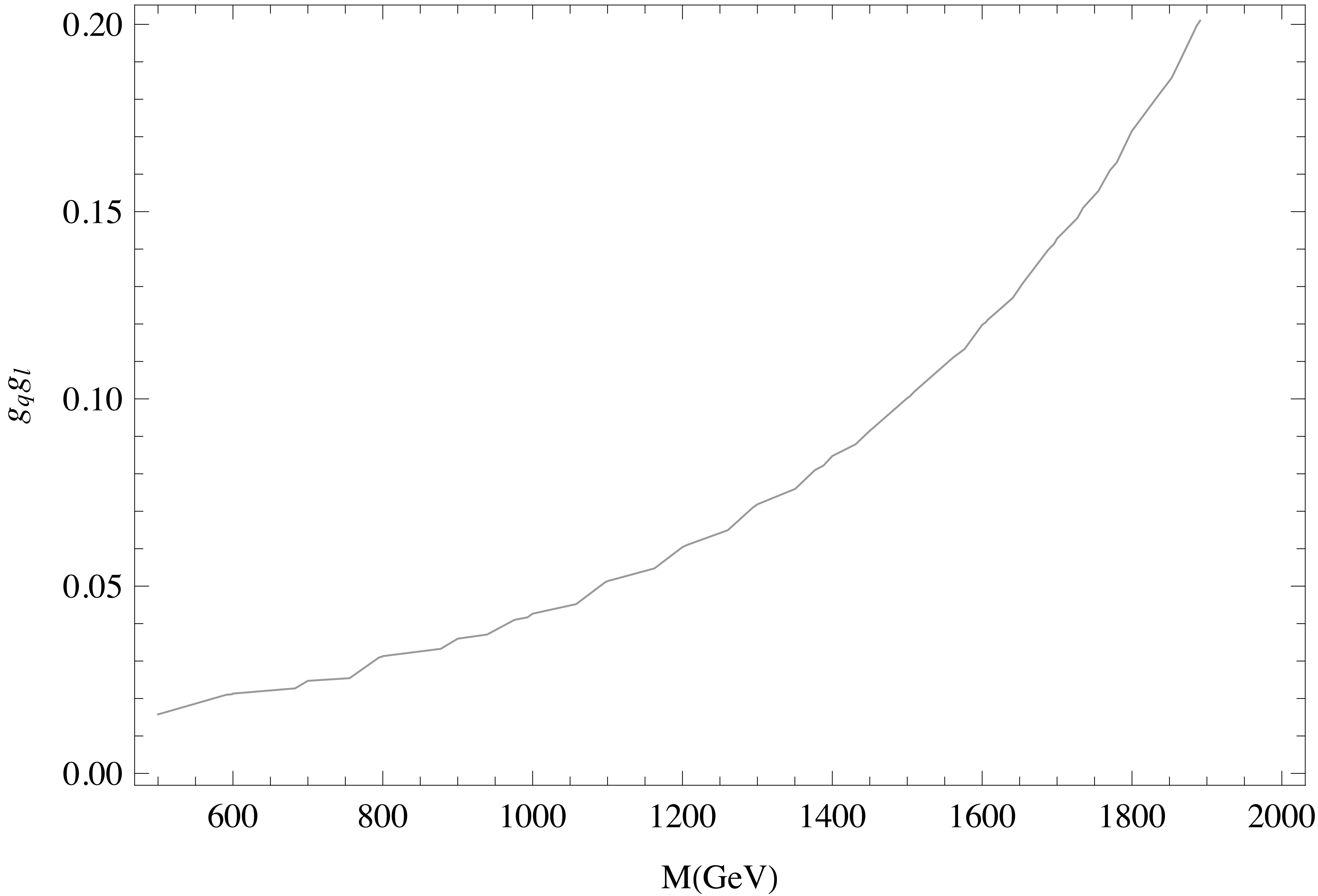


arXiv:1012.5945

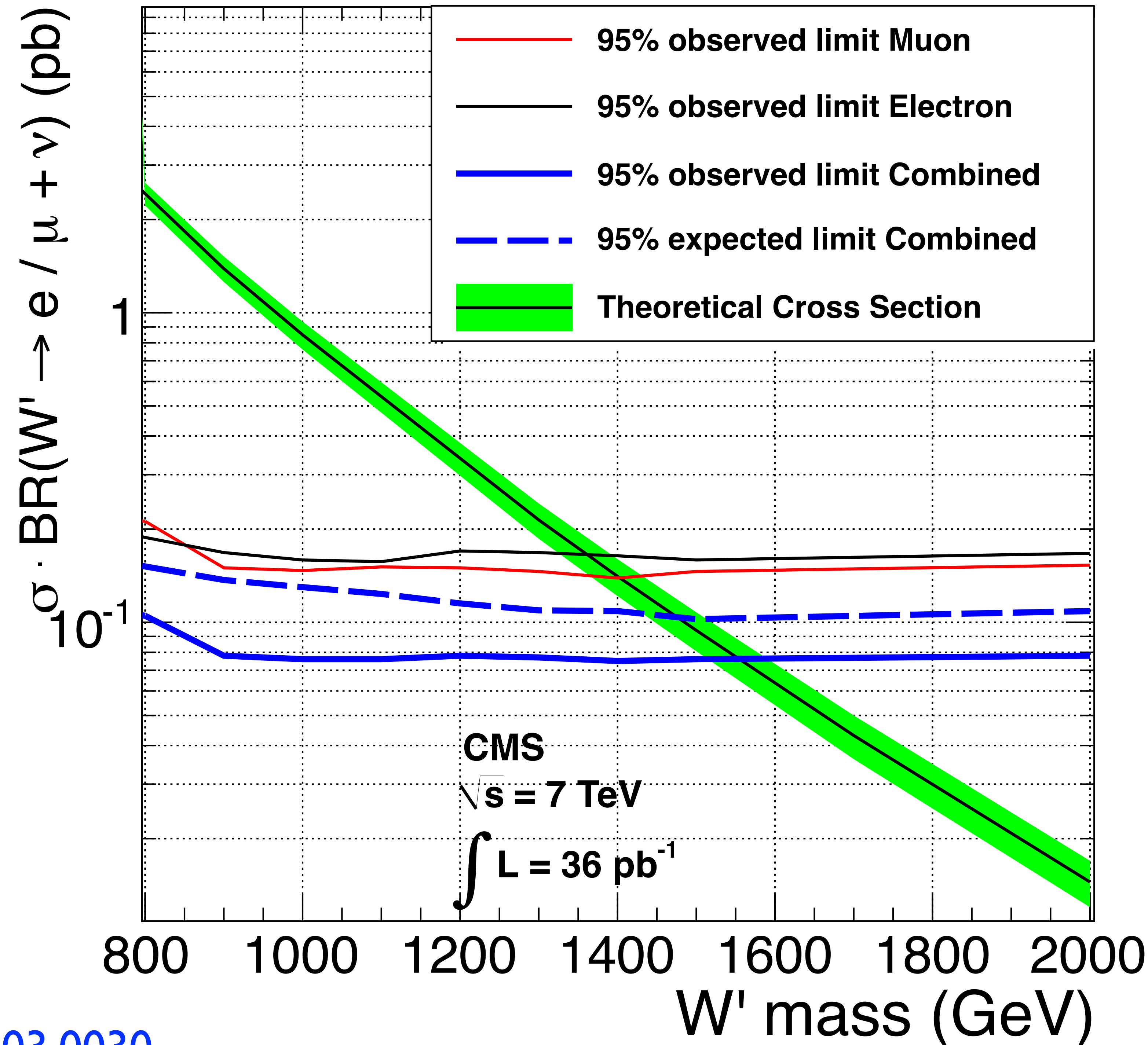


p,p→e,v
N/25GeV @ 36.1pb^{-1}
10^4
100
1
0.01
10^{-4}
0
200
400
600
800
1000
1200
1400
MT (GeV)

Scalar



0.20
0.15
0.10
0.05
0.00
$g_q g_l$
600
800
1000
1200
1400
1600
1800
2000
M(GeV)



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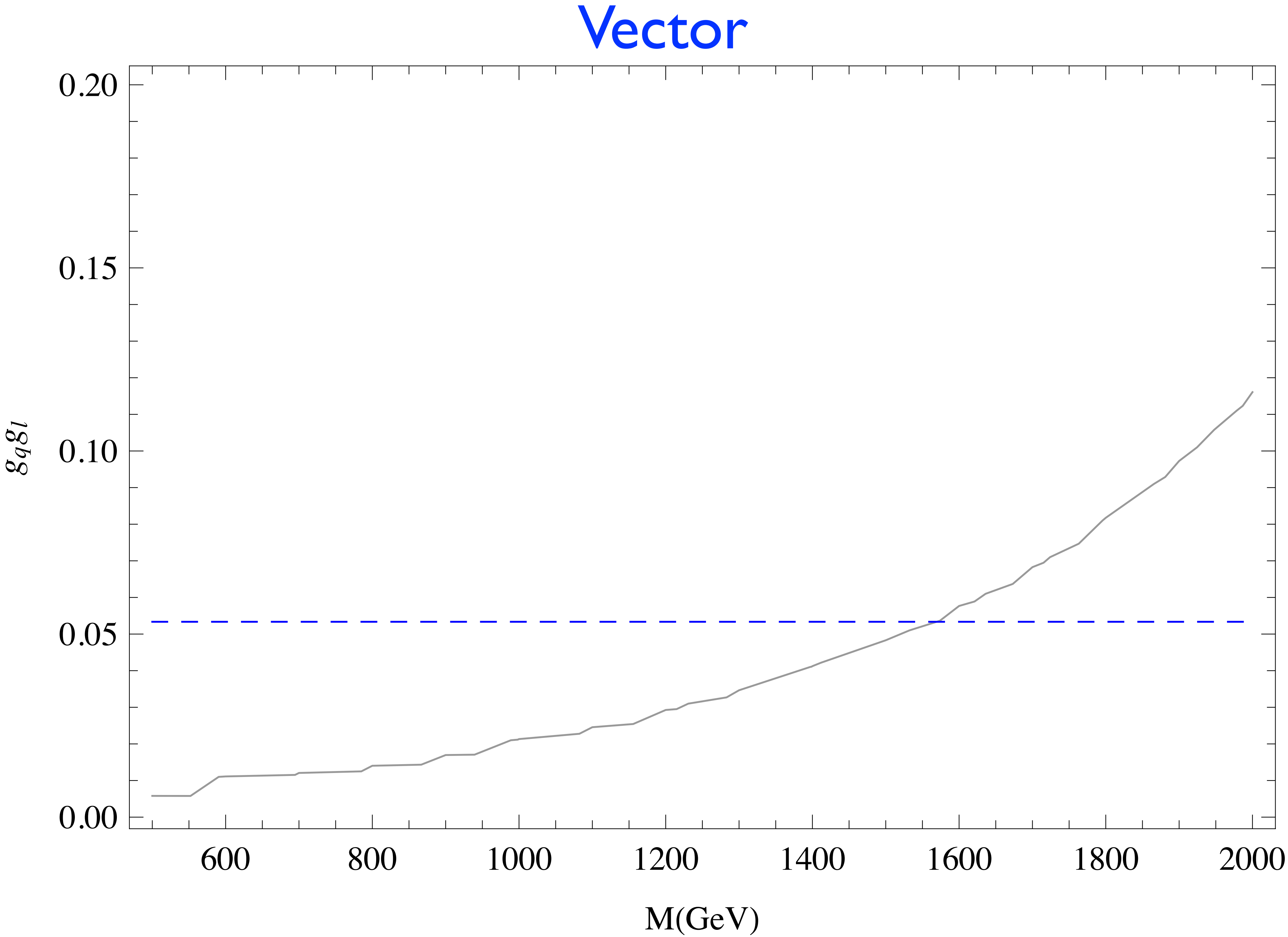
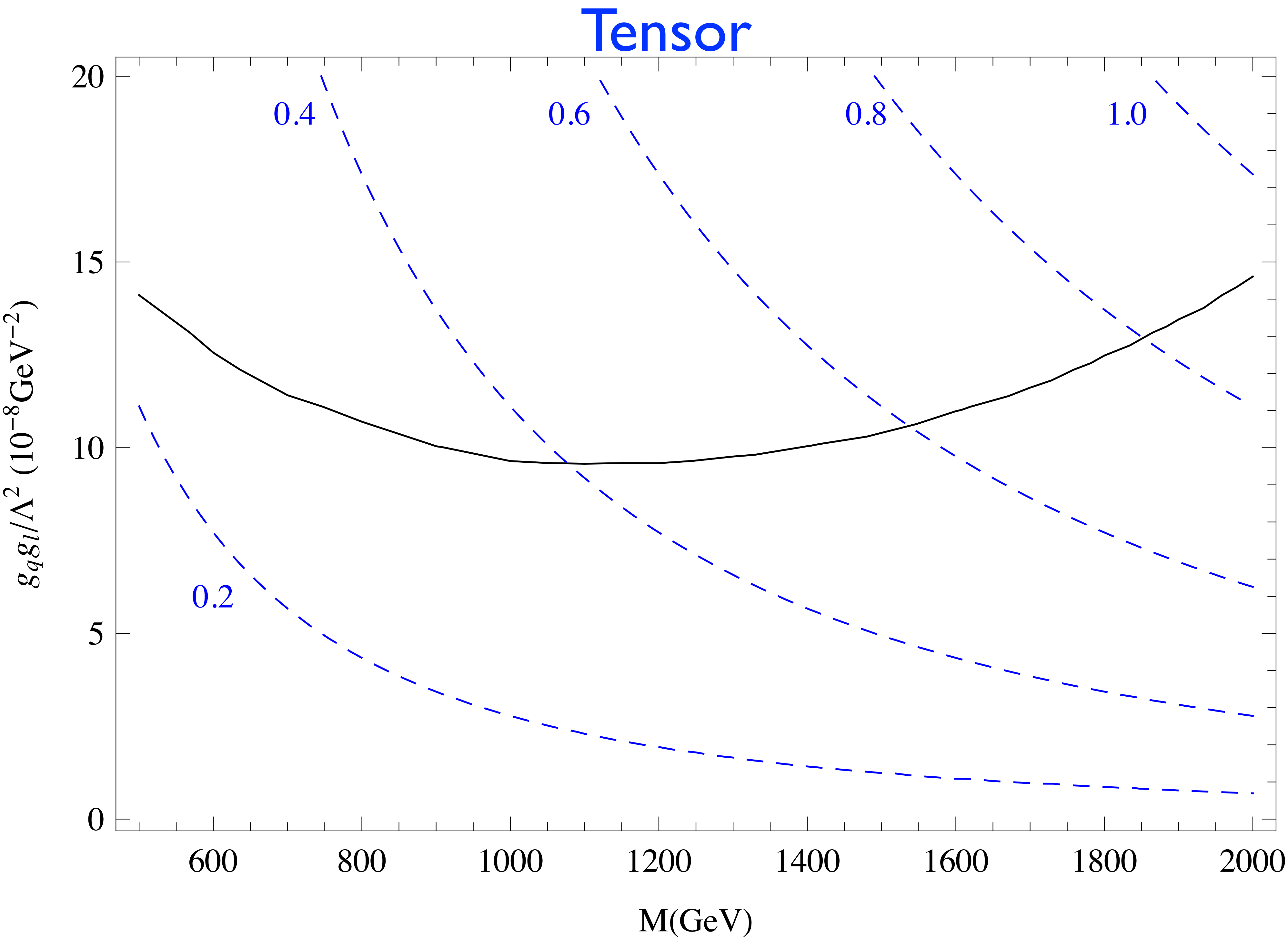


Vector
0.20
0.15
0.10
0.05
0.00
$g_q g_l$
600
800
1000
1200
1400
1600
1800
2000
M(GeV)



Tensor
20
15
10
5
0
600
800
1000
1200
1400
1600
1800
2000
M(GeV)
$g_q g_l/\Lambda^2$ (10^{-8}GeV^{-2})
0.2
0.4
0.6
0.8
1.0

What if we actually find a M_T peak?

Can we determine the spin of the resonance?

Can we determine the parity violation?

$$(\lambda, -\lambda) \to (\lambda', -\lambda')$$

$$\mathcal{M}_W^{\lambda\lambda'} = \mathcal{C}_W^{\lambda\lambda'} \delta_{\lambda',-1} d^1_{1,1}$$

$$\mathcal{M}_V^{\lambda\lambda'} = \mathcal{C}_V^{\lambda\lambda'} \, d^1_{1,\lambda\lambda'}$$

$$\mathcal{M}_T^{\lambda\lambda'} = \mathcal{C}_{T2}^{\lambda\lambda'} \, d^2_{1,\lambda\lambda'} + \mathcal{C}_{T1}^{\lambda\lambda'} \, d^1_{1,\lambda\lambda'}$$

$$(\lambda, \lambda) \to (\lambda', \lambda')$$

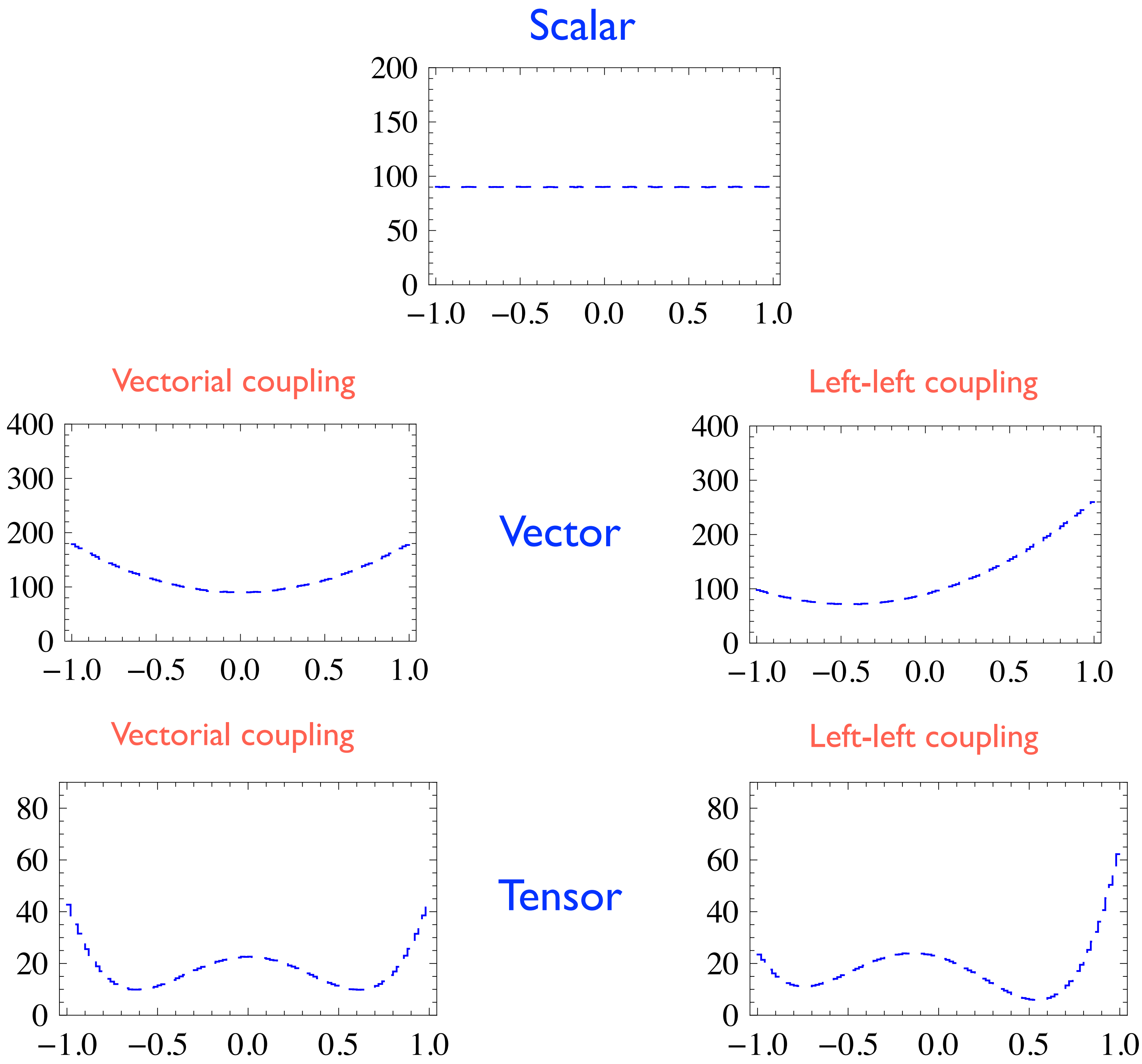
$$\mathcal{M}_S^{\lambda\lambda'} = \mathcal{C}_S^{\lambda\lambda'} \, d^0_{0,0}$$

$$\boxed{\begin{aligned} d^0_{0,0} &= 1 \\ d^1_{1,\pm1} &= \tfrac{1}{2}(1 \pm \cos\theta) \\ d^2_{1,\pm1} &= \tfrac{1}{2}(1 \pm \cos\theta)(2\cos\theta \mp 1) \\ d^2_{2,\pm1} &= -\tfrac{1}{2}(1 \pm \cos\theta)\sin\theta \end{aligned}}$$

What if I knew the full momentum of the neutrino?

Let's concentrate on the signal for now.

But, we will include the pdfs.


Scalar
Vectorial coupling
Left-left coupling
Vector
Vectorial coupling
Left-left coupling
Tensor
200
150
100
50
0
400
300
200
100
80
60
40
20
−1.0
−0.5
0.0
0.5
1.0

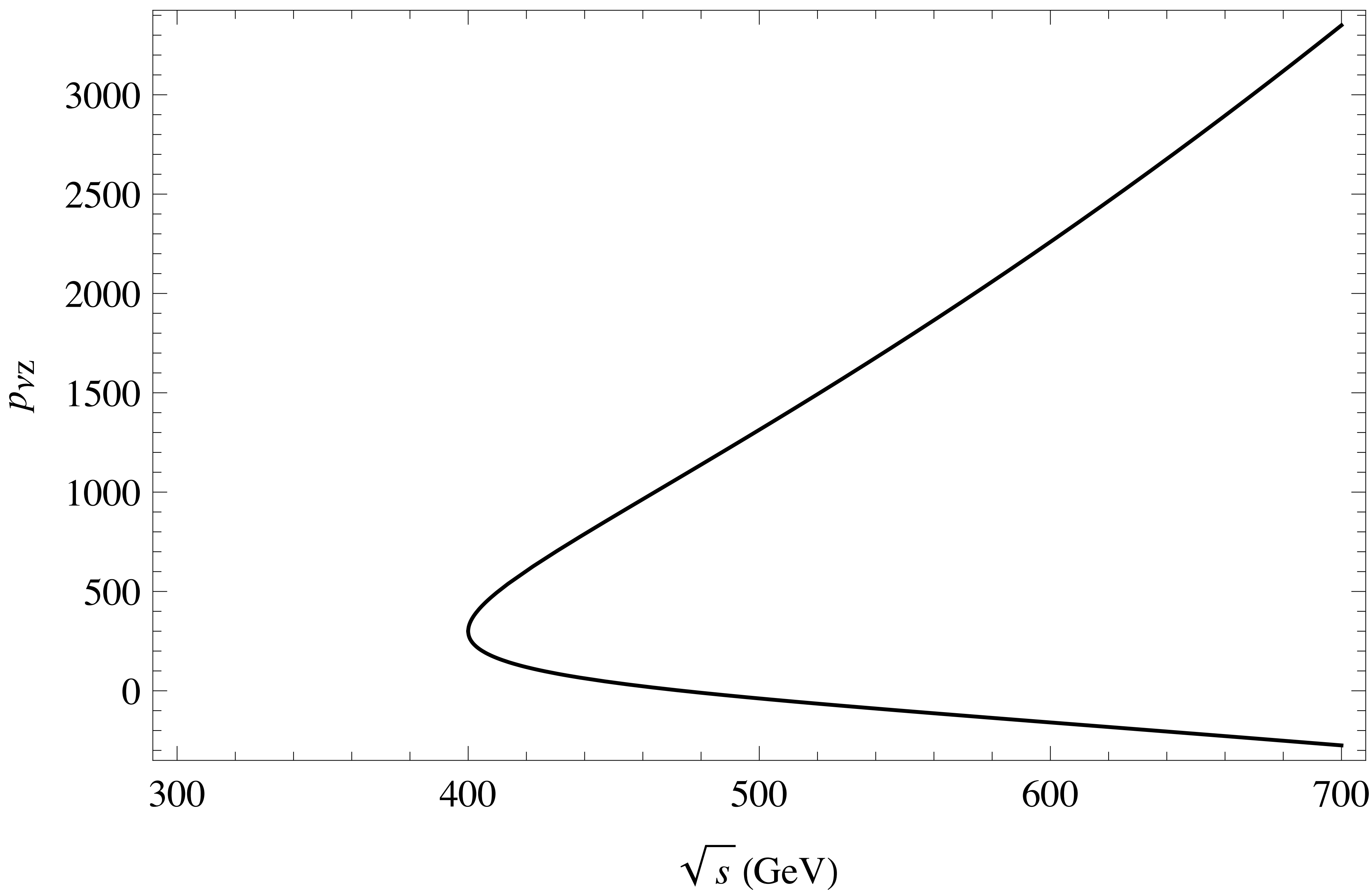
But, we don't know the full momentum of the neutrino!

There is a well-known two-fold ambiguity in the z-component of the neutrino momentum.

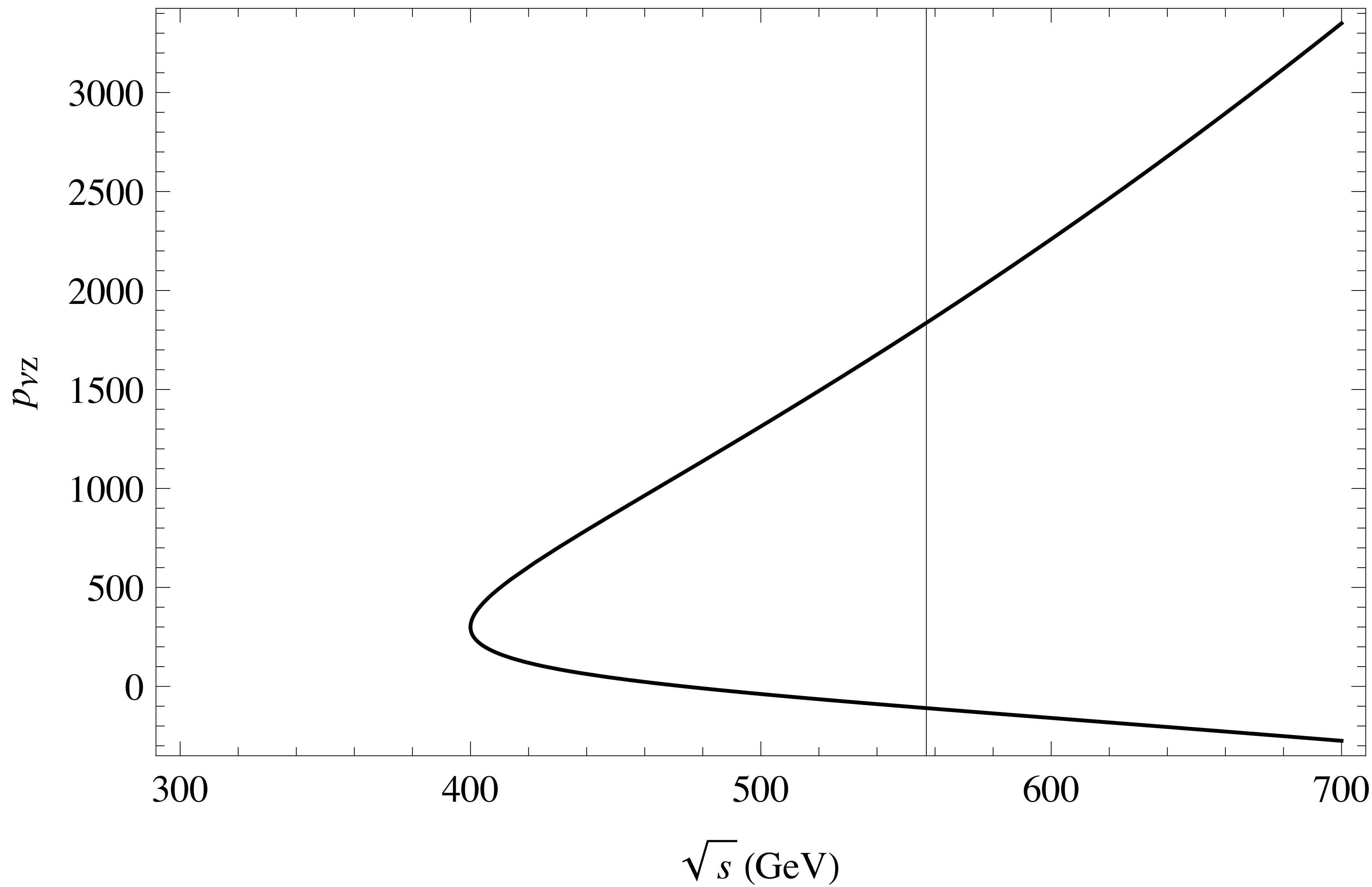
$$s = (E_\ell + E_\nu)^2 - (p_{z\ell} + p_{z\nu})^2$$

$$s = (E_\ell + E_\nu)^2 - (p_{z\ell} + p_{z\nu})^2$$

$$p_{z\nu} = p_{z\ell}\left(\frac{\hat{s}}{2p_{T\ell}^2} - 1\right) \pm \frac{E_\ell\sqrt{\hat{s}}}{p_{T\ell}}\sqrt{\frac{\hat{s}}{4p_{T\ell}^2} - 1}$$



$p_{\nu z}$
3000
2500
2000
1500
1000
500
0
300
400
500
600
700
$\sqrt{s}$ (GeV)



$p_{\nu z}$
3000
2500
2000
1500
1000
500
0
300
400
500
600
700
$\sqrt{s}$ (GeV)

Usually, we try to find a cut that improves our chances of guessing the right solution.

These cuts tend to reduce the signal rate
and they tend to modify the angular distribution.

Can we do better?

Can we do better?

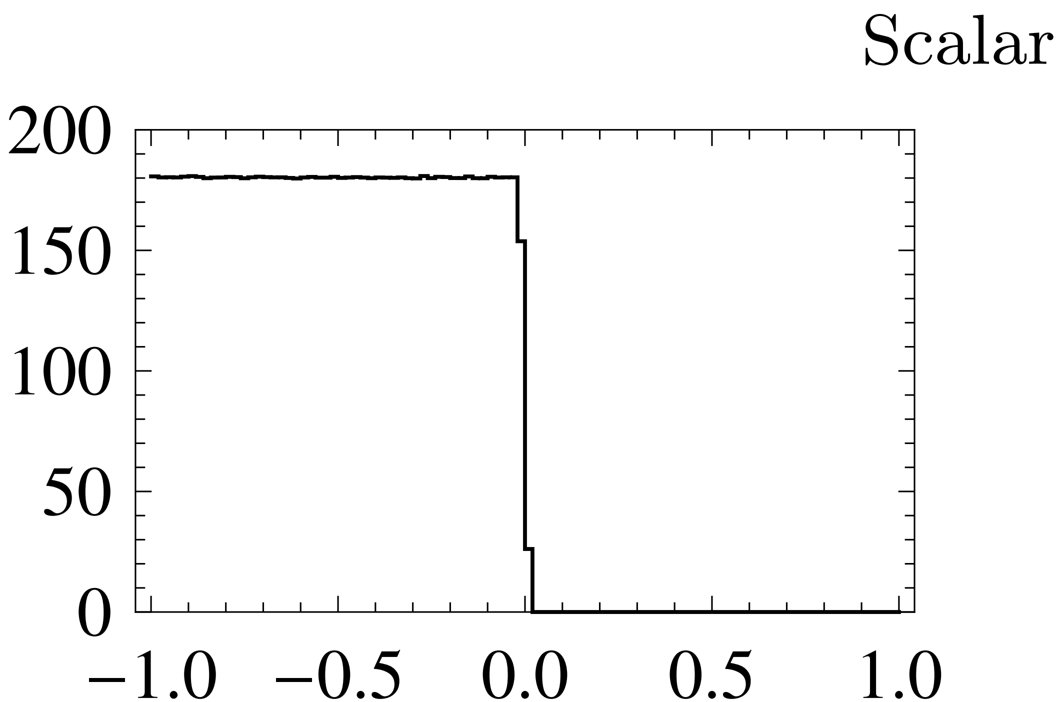
Yes!

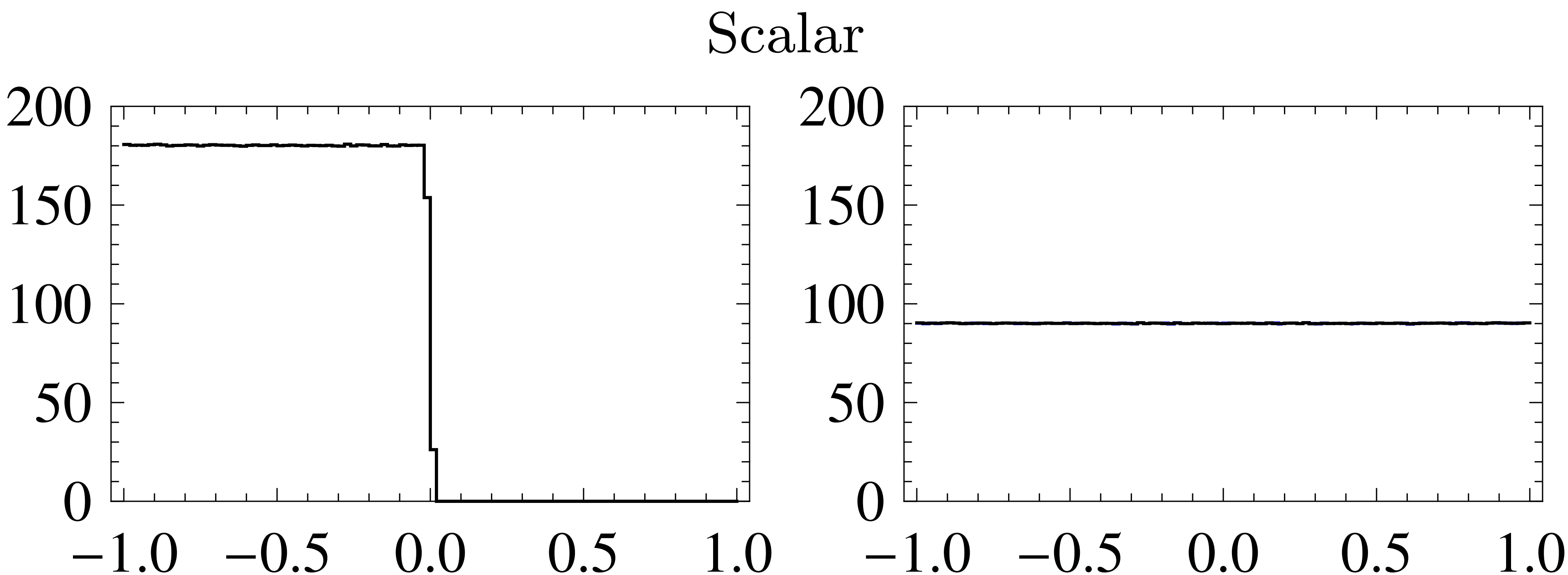
$$\cos\theta_S = -\sqrt{1 - \frac{4p_{Tl}^2}{M^2}}\ \mathrm{sign}\left(\frac{M}{2} - E_l\right)$$

$$\cos\theta_L = -\sqrt{1 - \frac{4p_{Tl}^2}{M^2}}$$

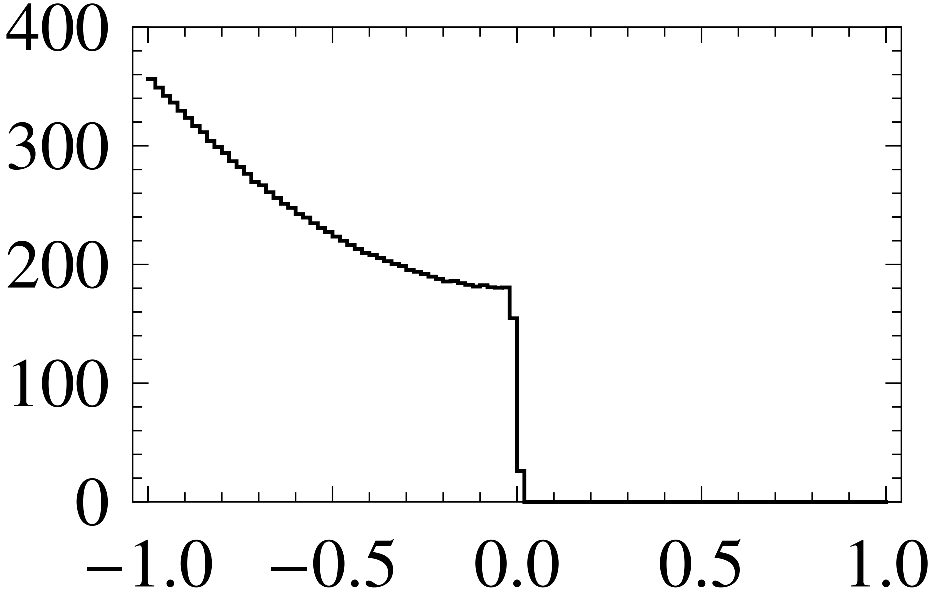
Let’s look at the Large solution first:

We can reconstruct the spin.

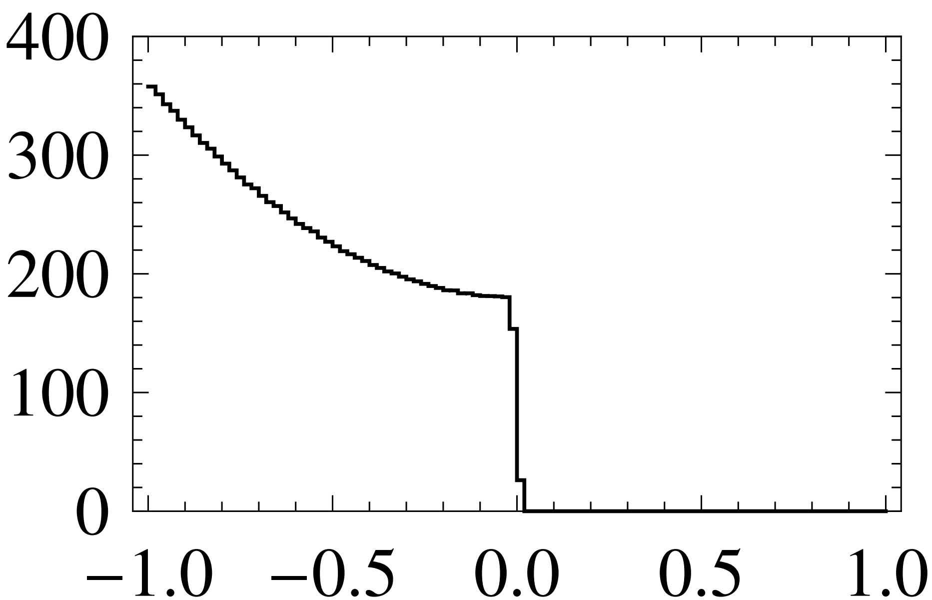

Scalar
200
150
100
50
0
−1.0
−0.5
0.0
0.5
1.0

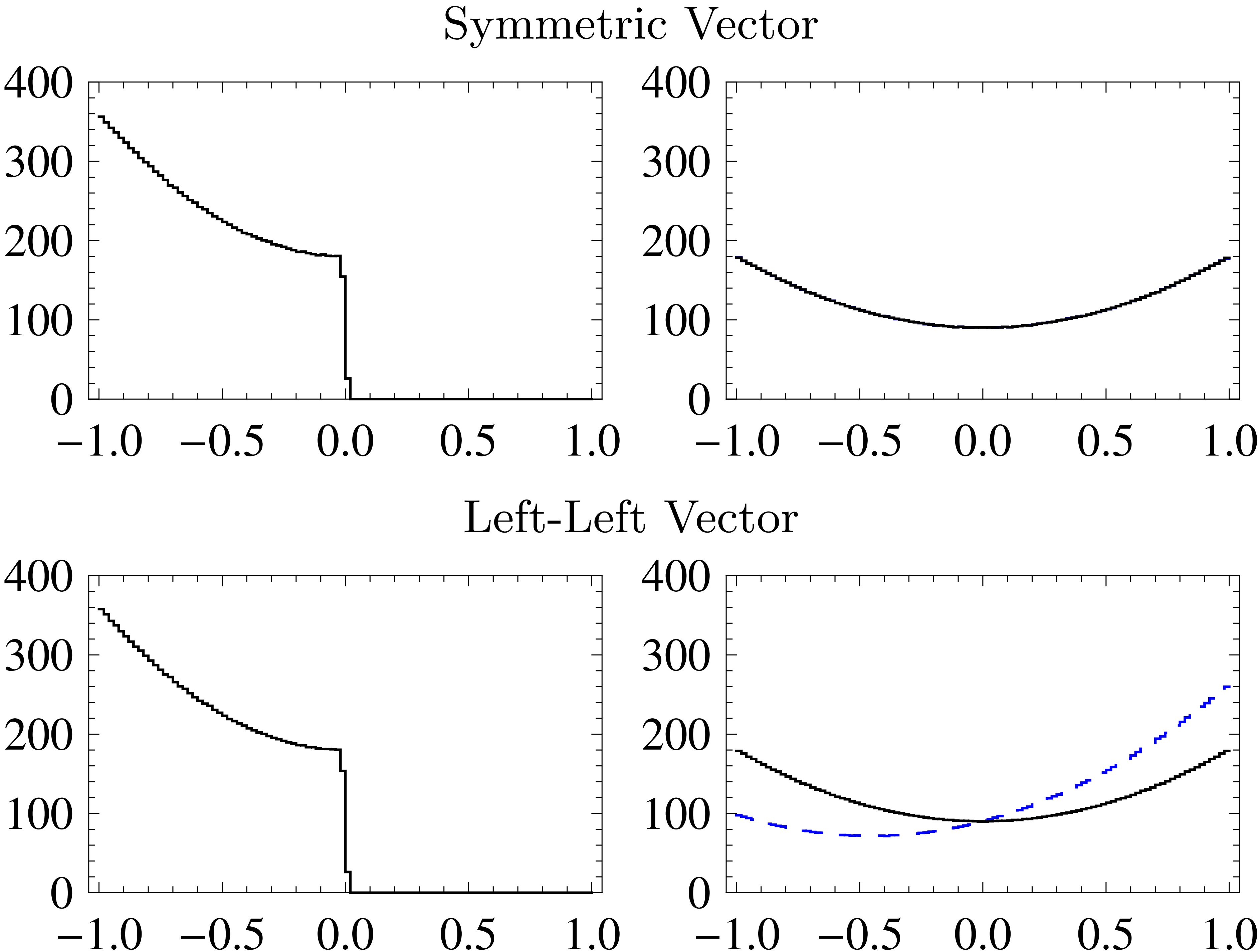

Scalar
200
150
100
50
0
−1.0
−0.5
0.0
0.5
1.0
200
150
100
50
0
−1.0
−0.5
0.0
0.5
1.0

Symmetric Vector

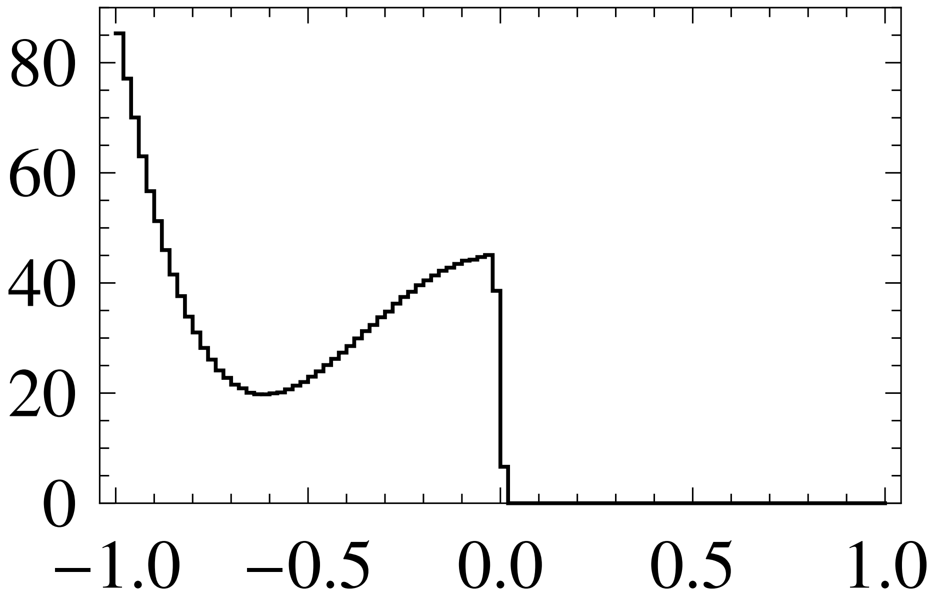


Left-Left Vector

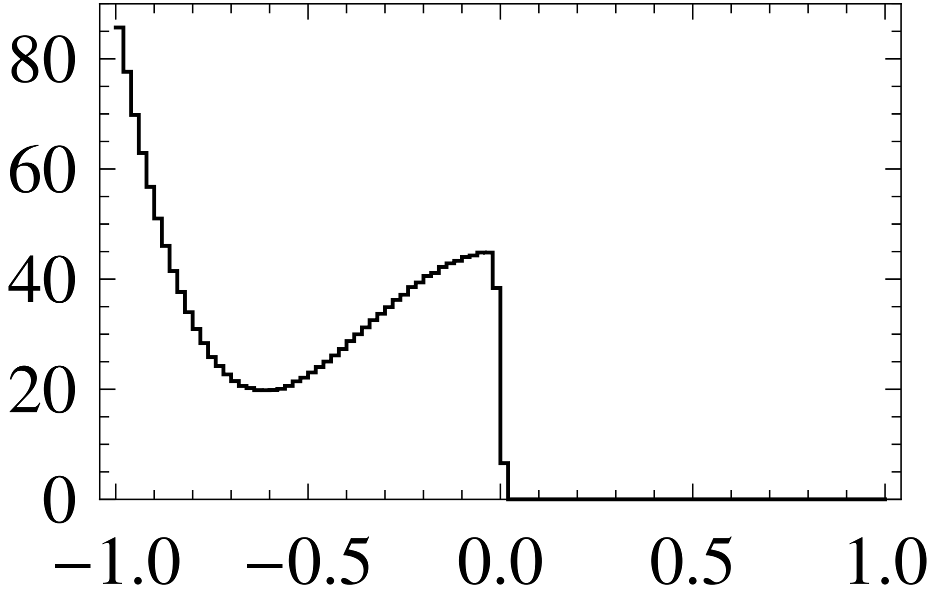


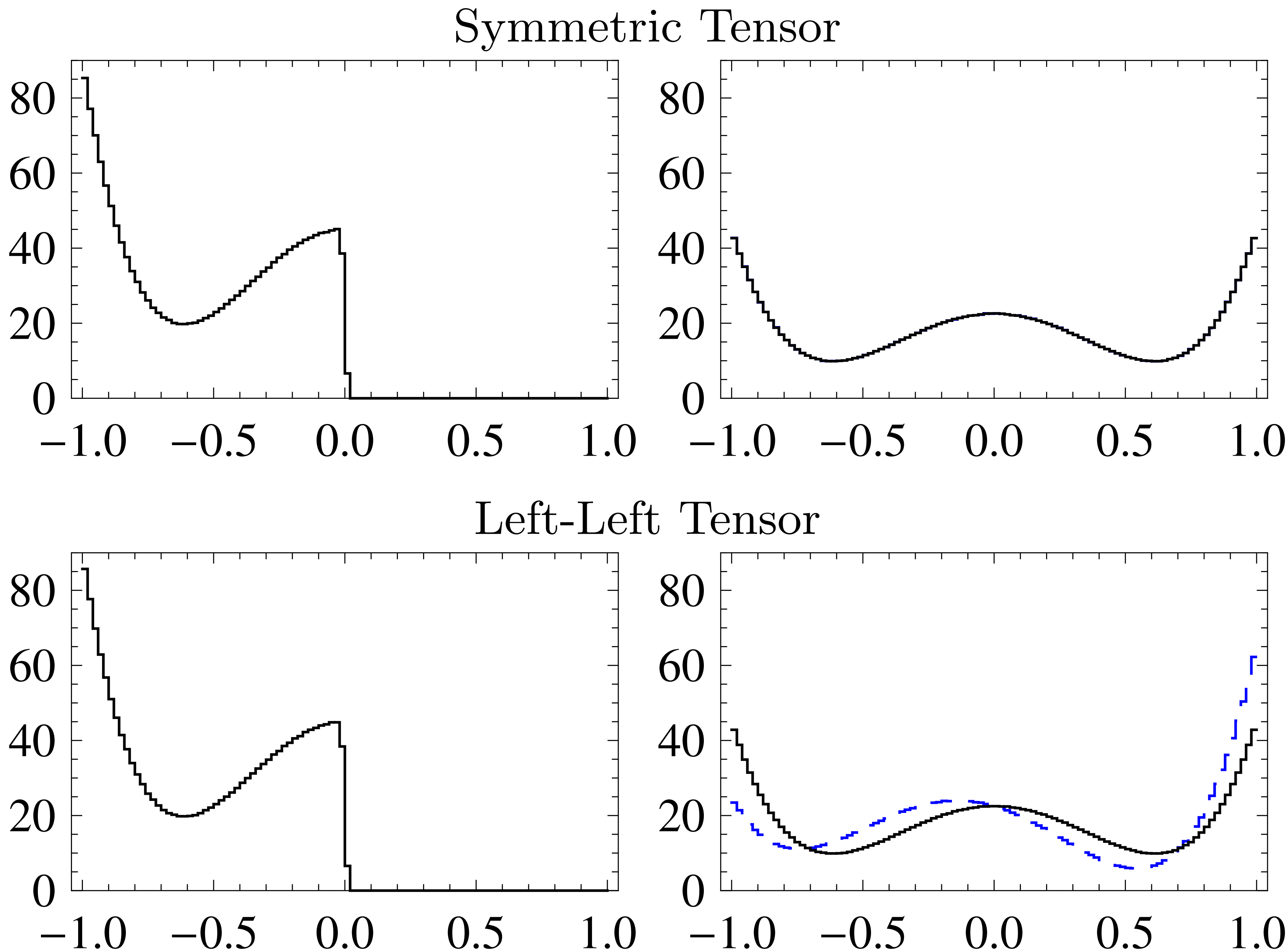

Symmetric Vector
Left-Left Vector
400
300
200
100
0
−1.0
−0.5
0.0
0.5
1.0

Symmetric Tensor



Left-Left Tensor

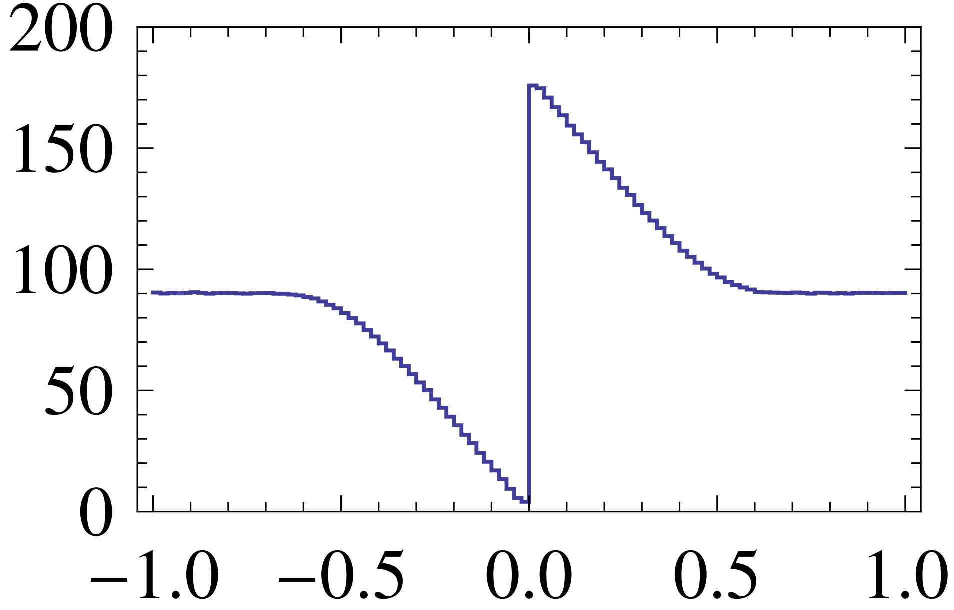


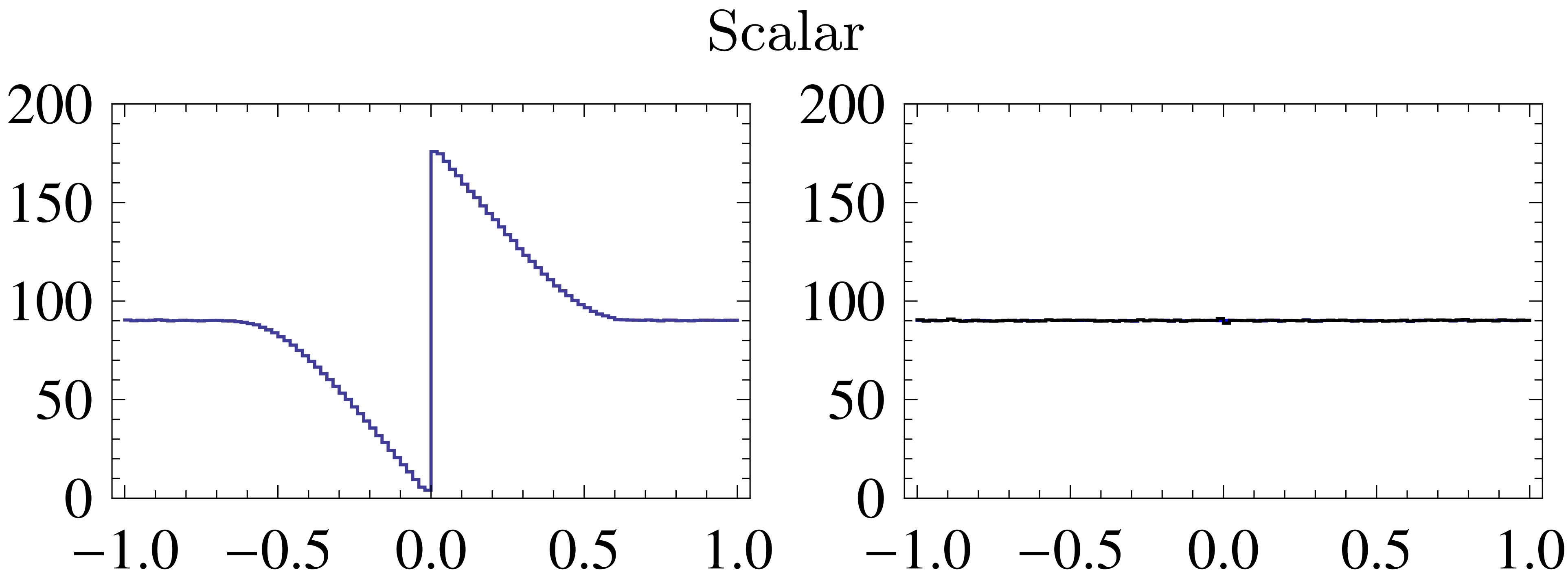

Symmetric Tensor
Left-Left Tensor
0
20
40
60
80
−1.0
−0.5
0.0
0.5
1.0

Let's look at the small solution next:

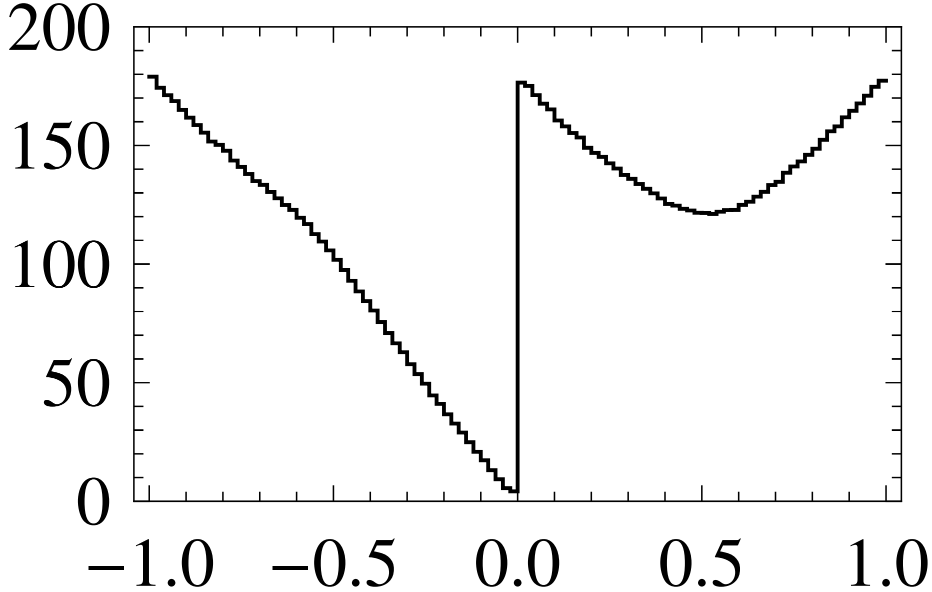
We can also reconstruct the parity violation.
(Look in our paper for the details.)

Scalar

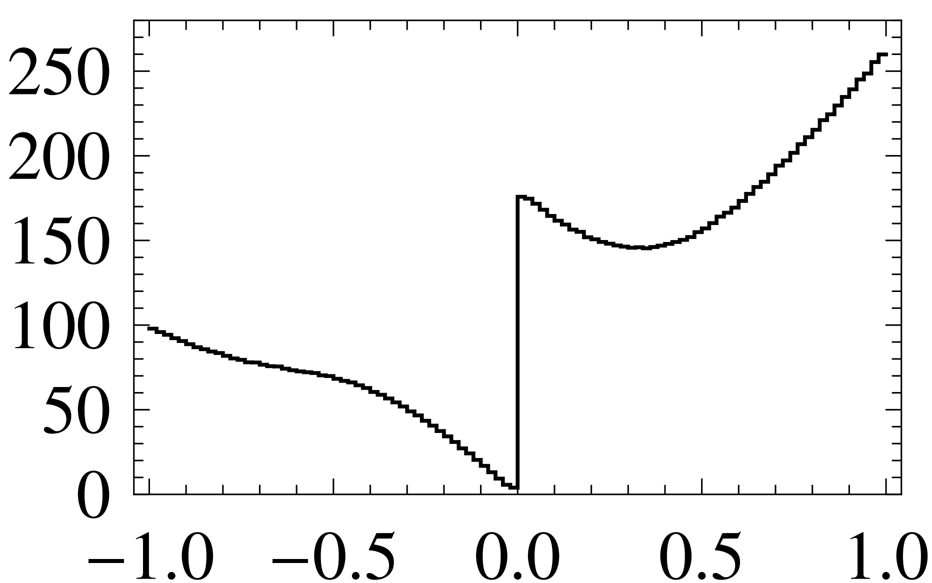


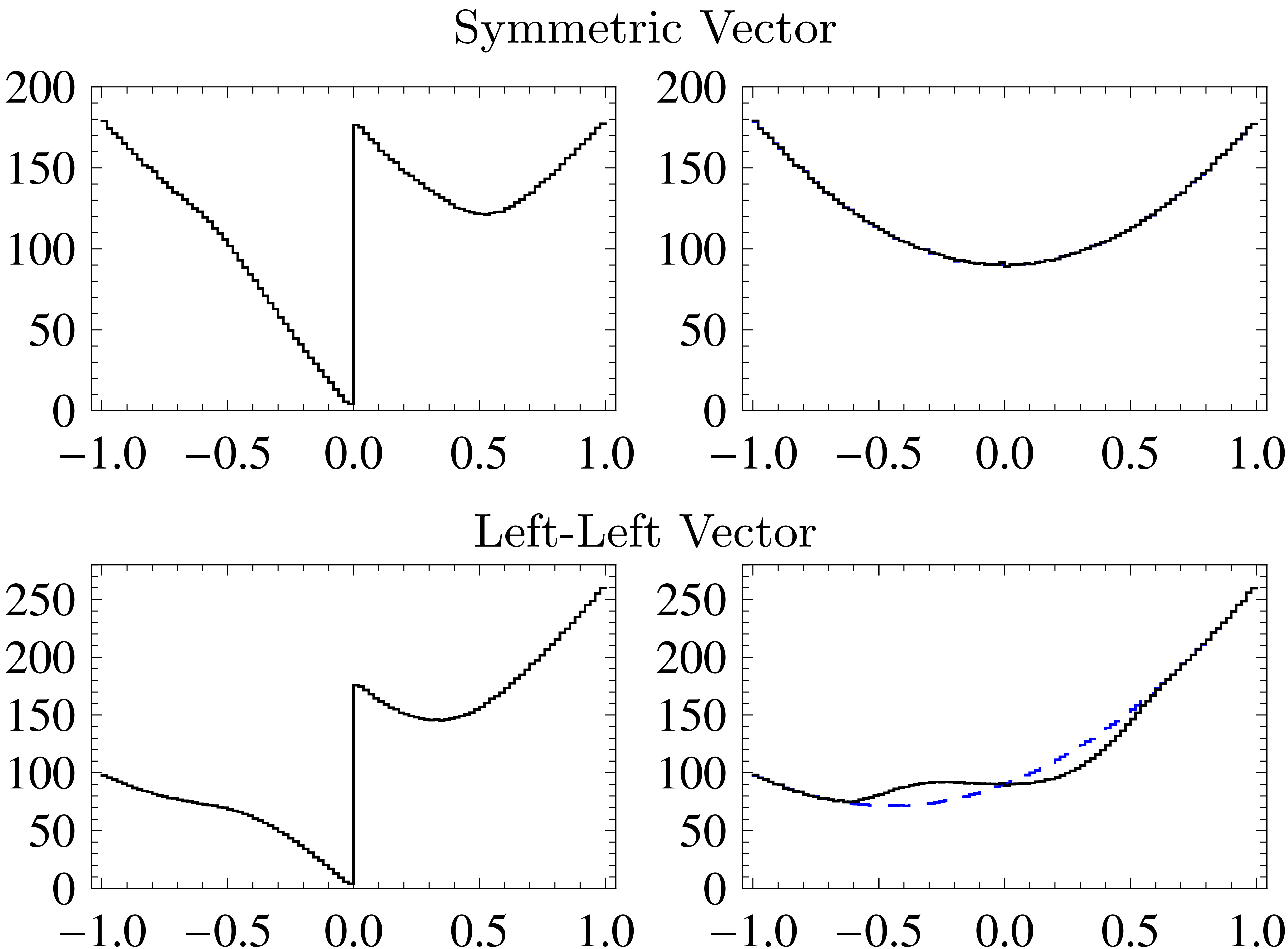

Scalar
200
150
100
50
0
−1.0
−0.5
0.0
0.5
1.0
200
150
100
50
0
−1.0
−0.5
0.0
0.5
1.0

Symmetric Vector



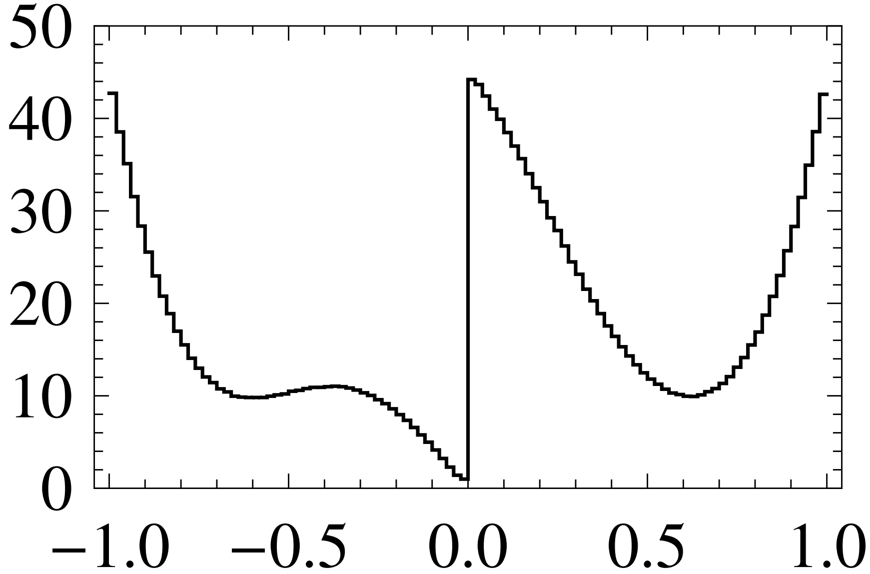
Left-Left Vector



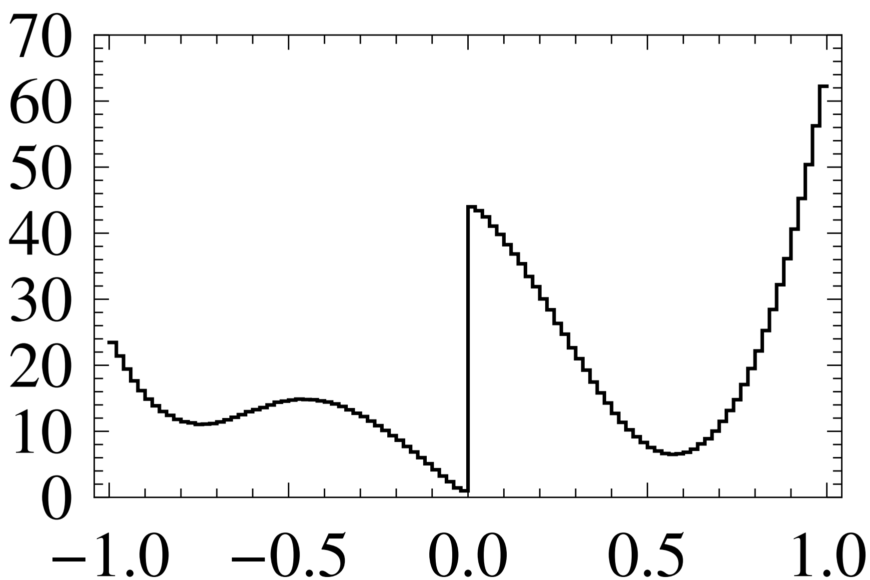


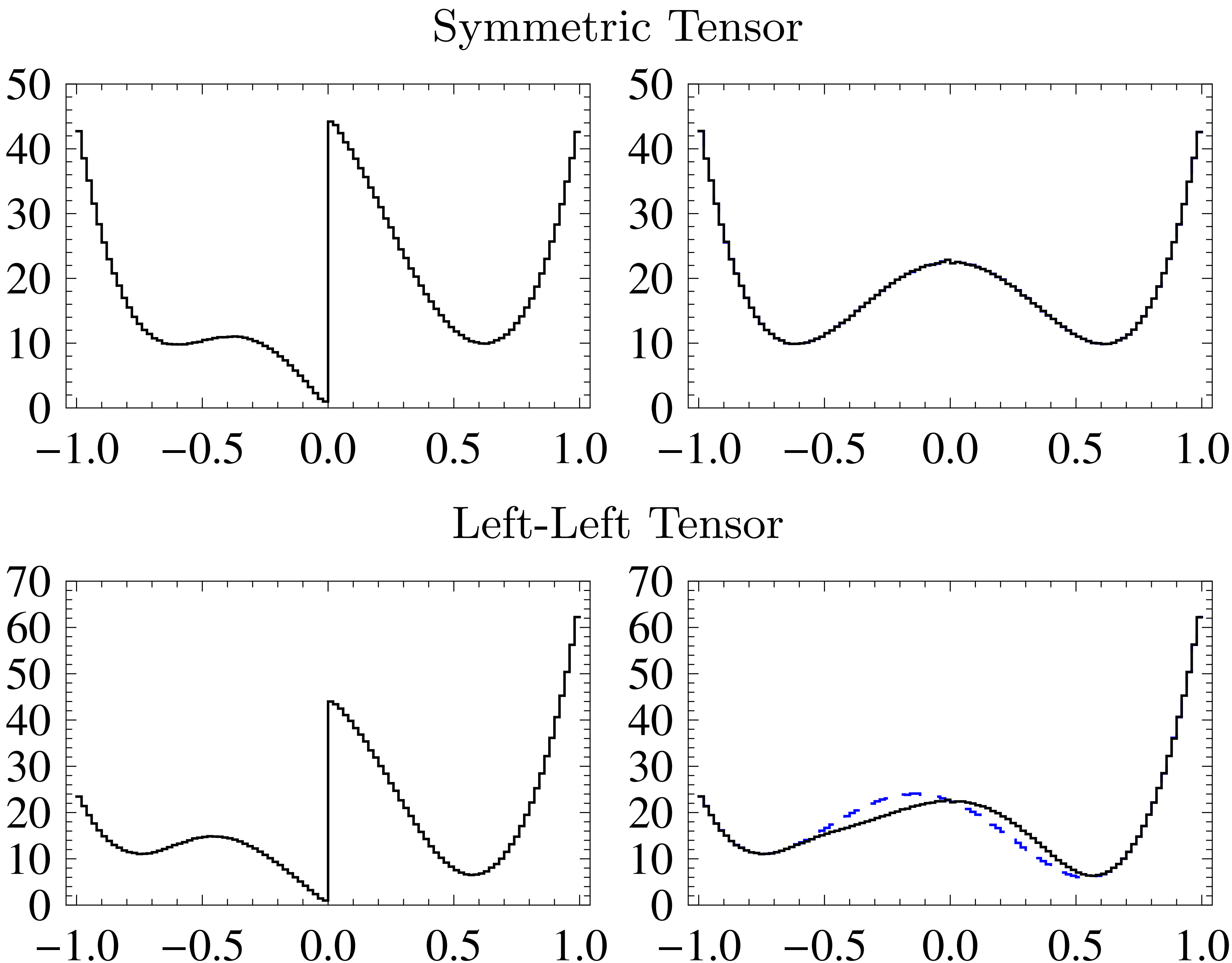
Symmetric Vector
Left-Left Vector
200
150
100
50
0
250
−1.0
−0.5
0.0
0.5
1.0

Symmetric Tensor



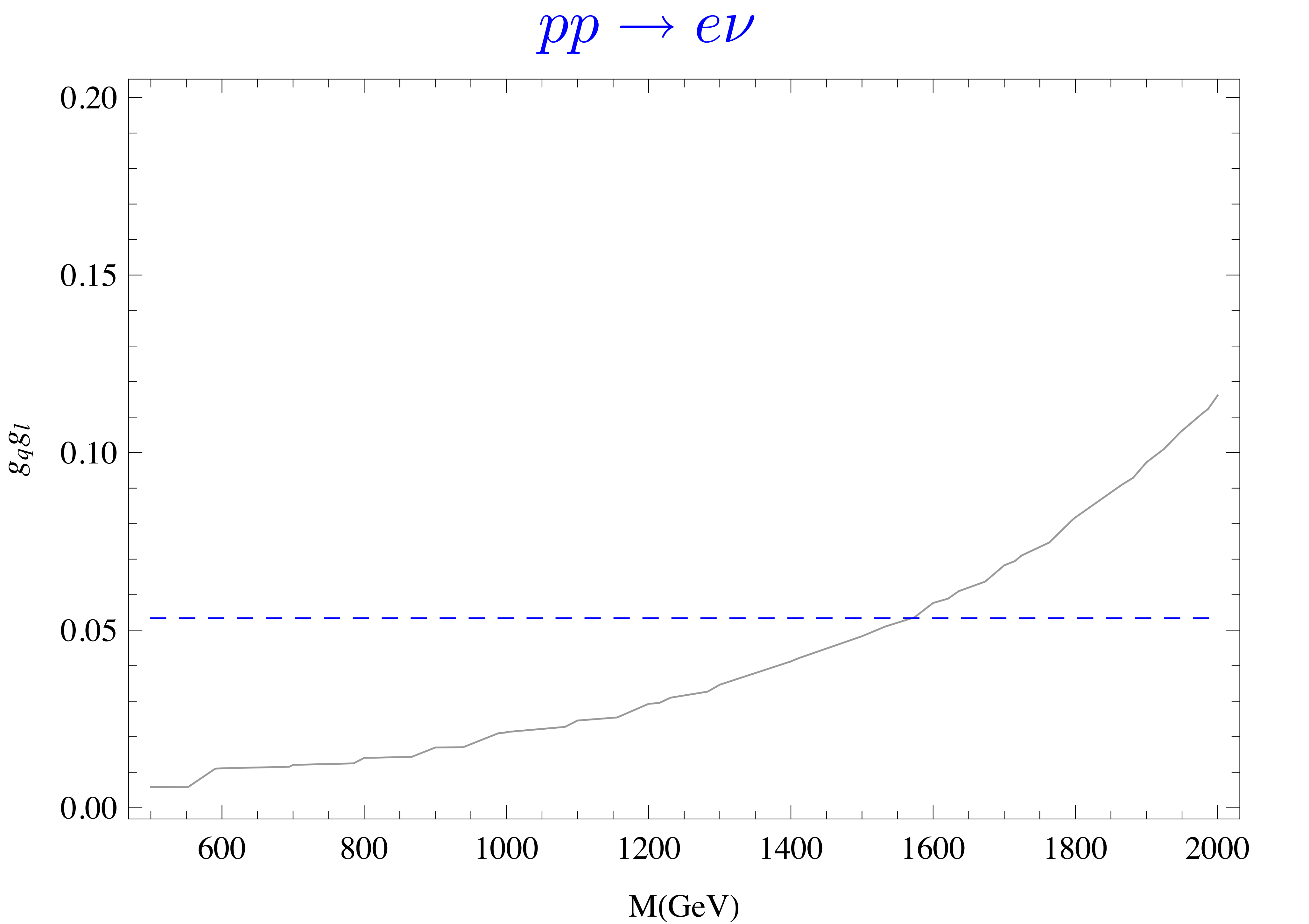
Left-Left Tensor





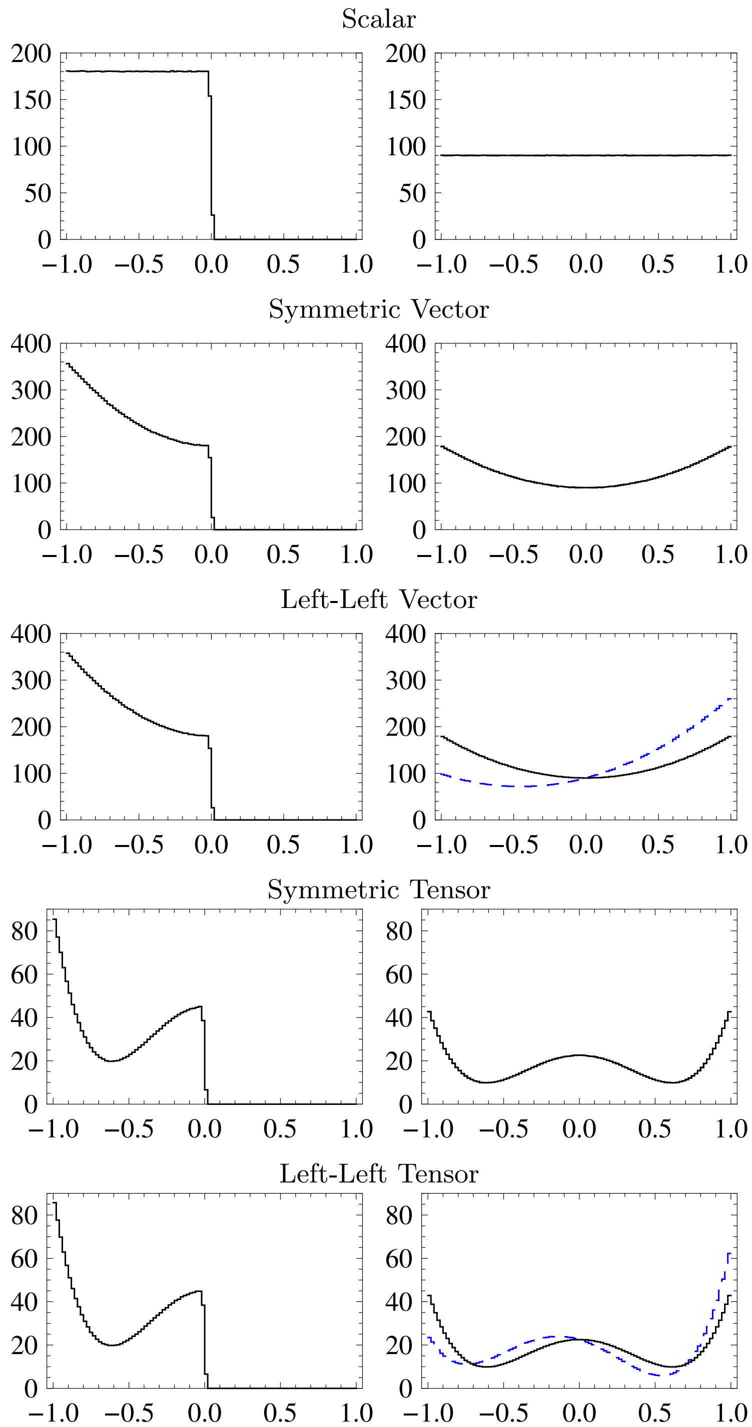
Symmetric Tensor
Left-Left Tensor
0
10
20
30
40
50
60
70
−1.0
−0.5
0.0
0.5
1.0

To summarize:



$pp \to e\nu$
0.20
0.15
0.10
0.05
0.00
$g_q g_l$
600
800
1000
1200
1400
1600
1800
2000
M(GeV)

Large solution



Small solution