WW Boson Production at Dimension 8 in SMEFT

Daniel Gillies

with Andrea Banfi, Adam Martin, Matthew Lim

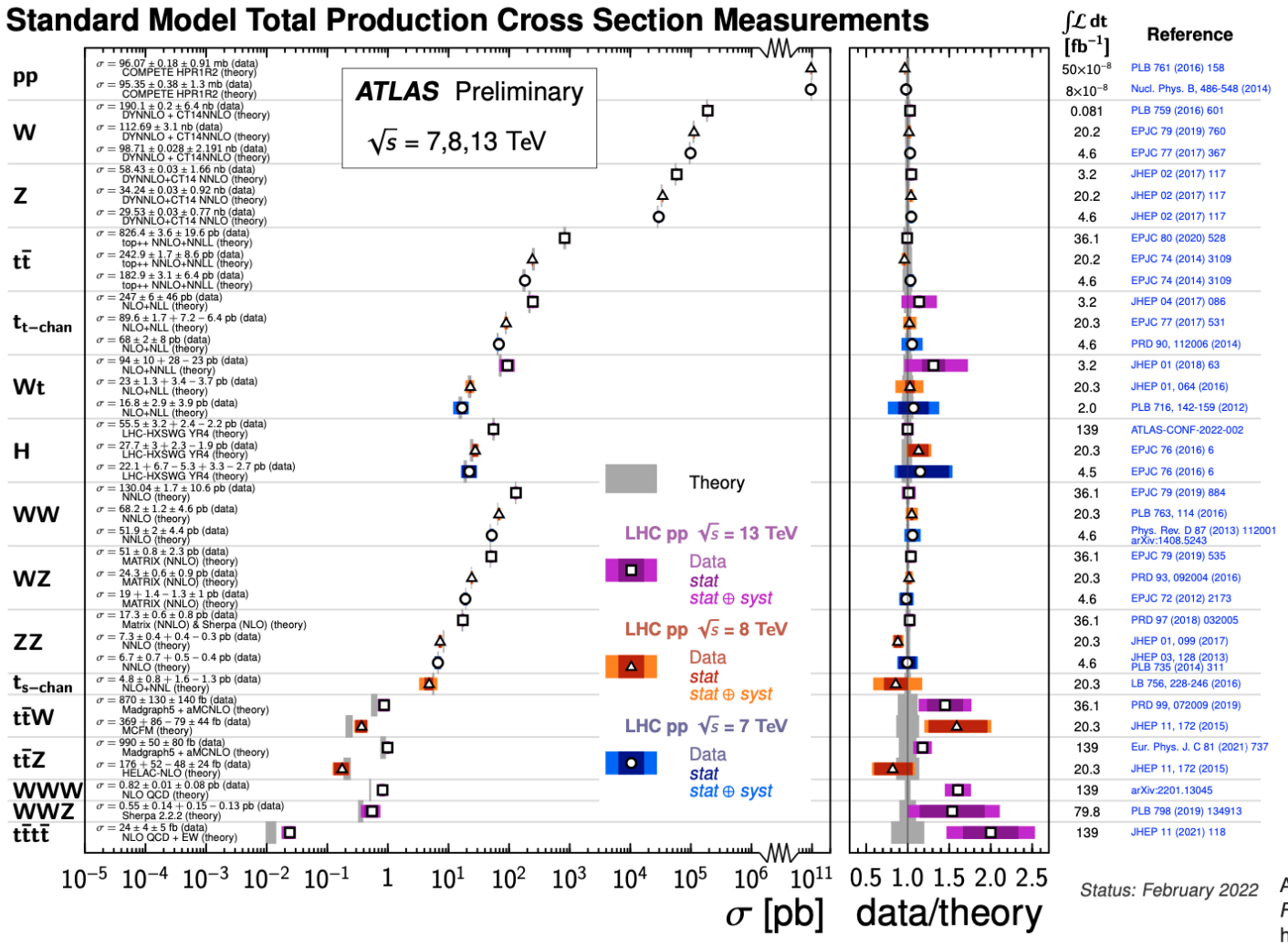
Science & Technology Facilities Council

UNIVERSITY OF SUSSEX

Outline

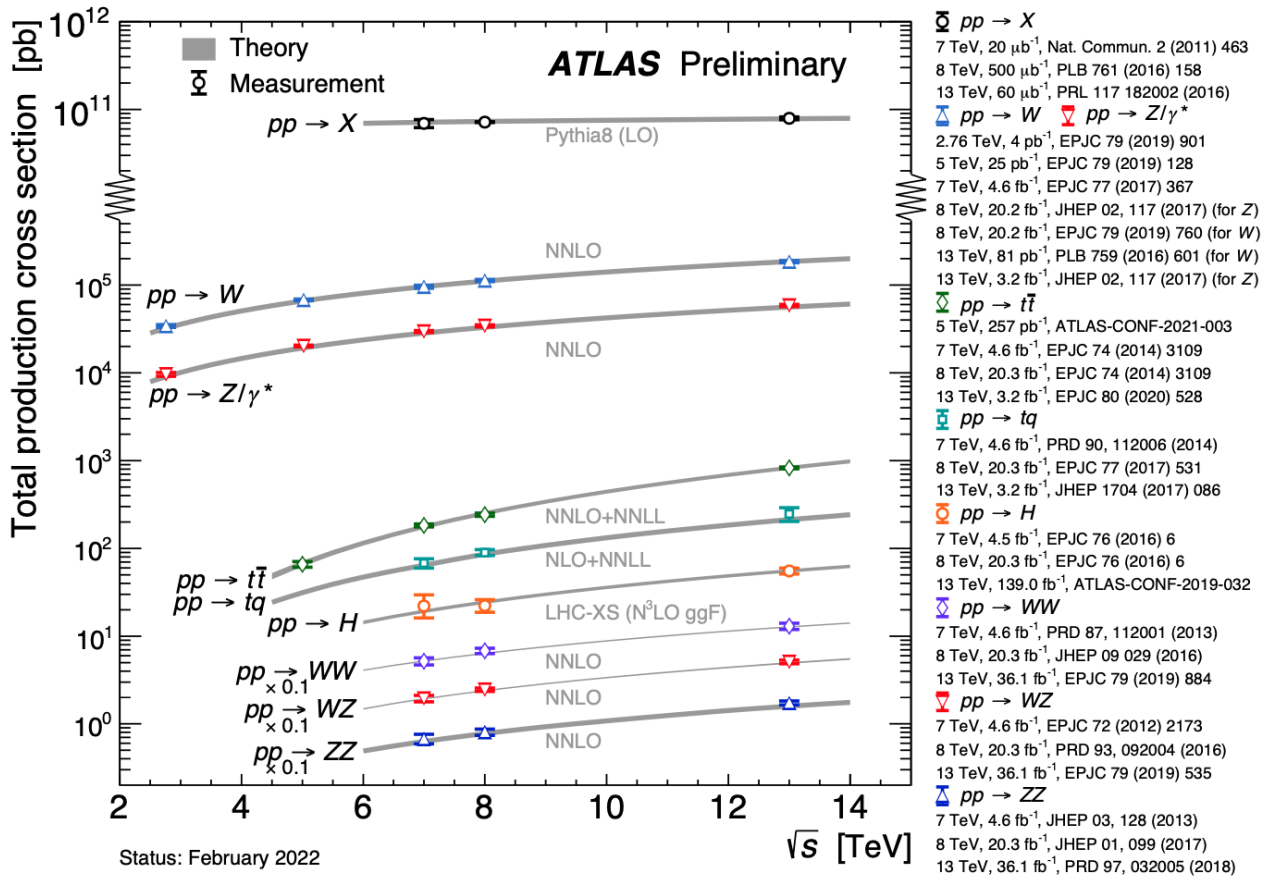
- Motivation
- Background Physics
- Results
- Future Directions

Standard Model Predictions



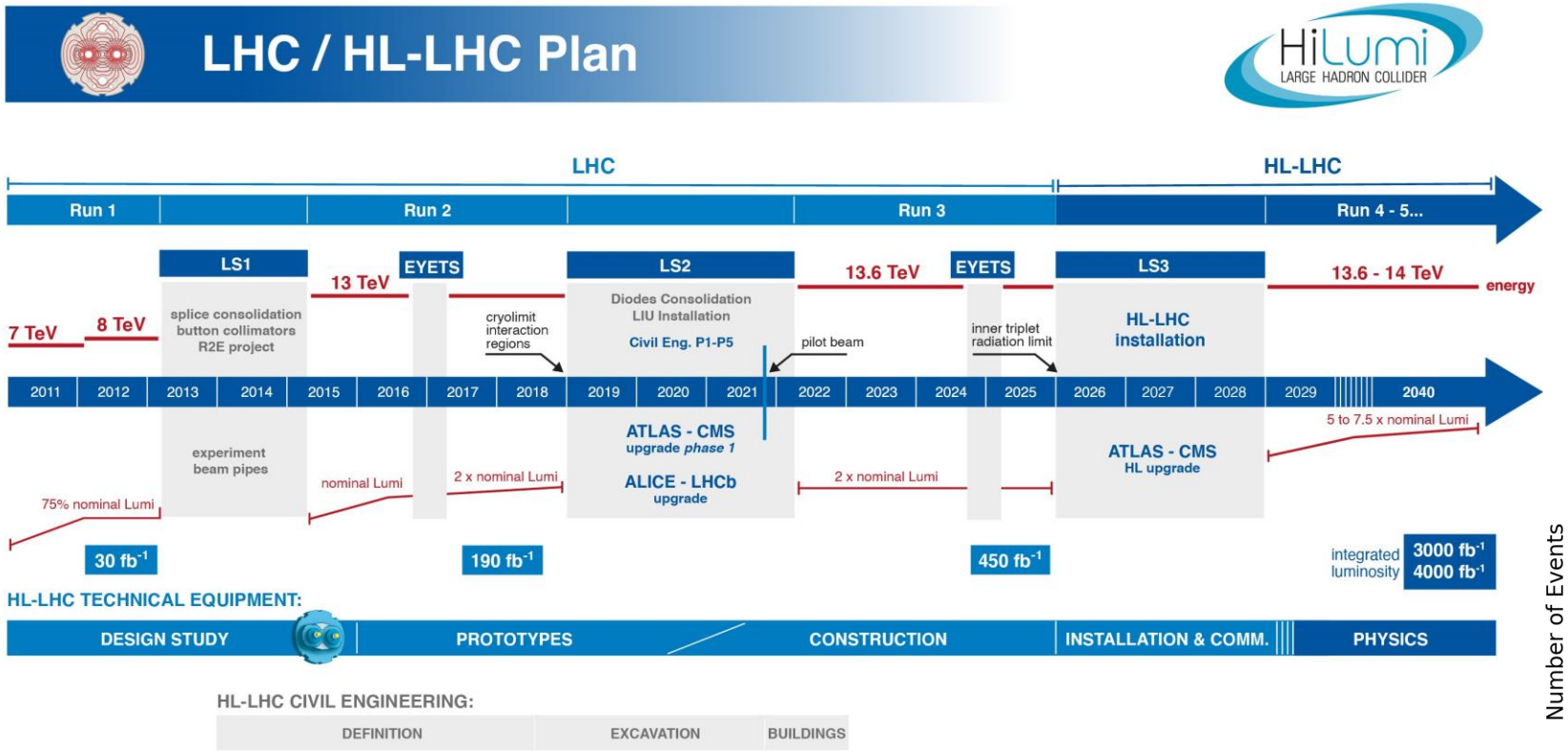
ATLAS Collaboration. *Standard Model Summary Plots February 2022*. ATL-PHYS-PUB-2022-009, 2022, url: https://cds. cern. ch/record/2804061 (cit. on p. 67), 2022.

Differential Distributions

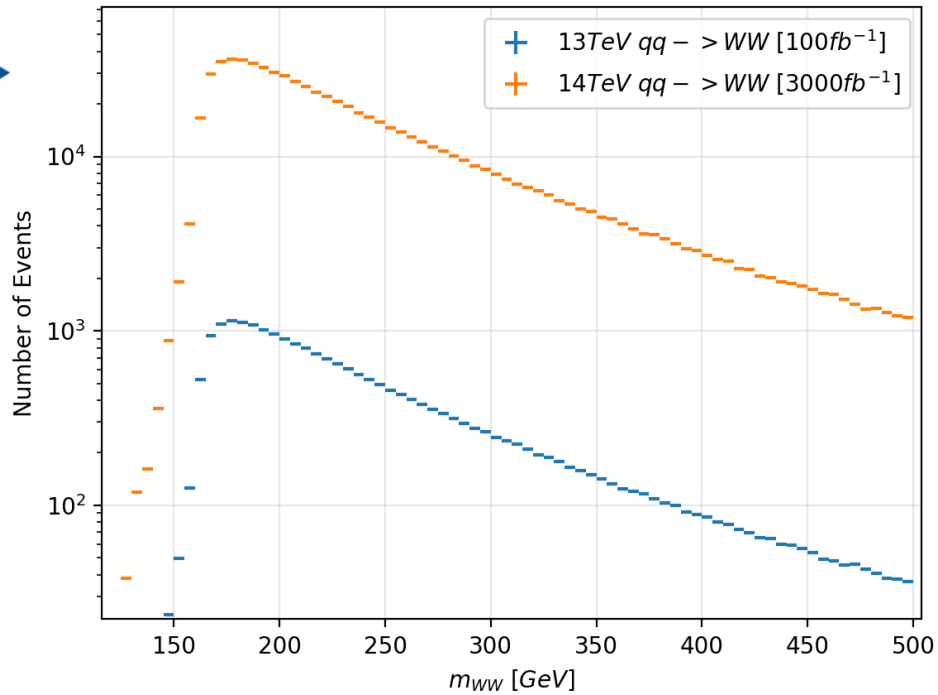


ATLAS Collaboration. *Standard Model Summary Plots February 2022*. ATL-PHYS-PUB-2022-009, 2022, url: https://cds. cern. ch/record/2804061 (cit. on p. 67), 2022.

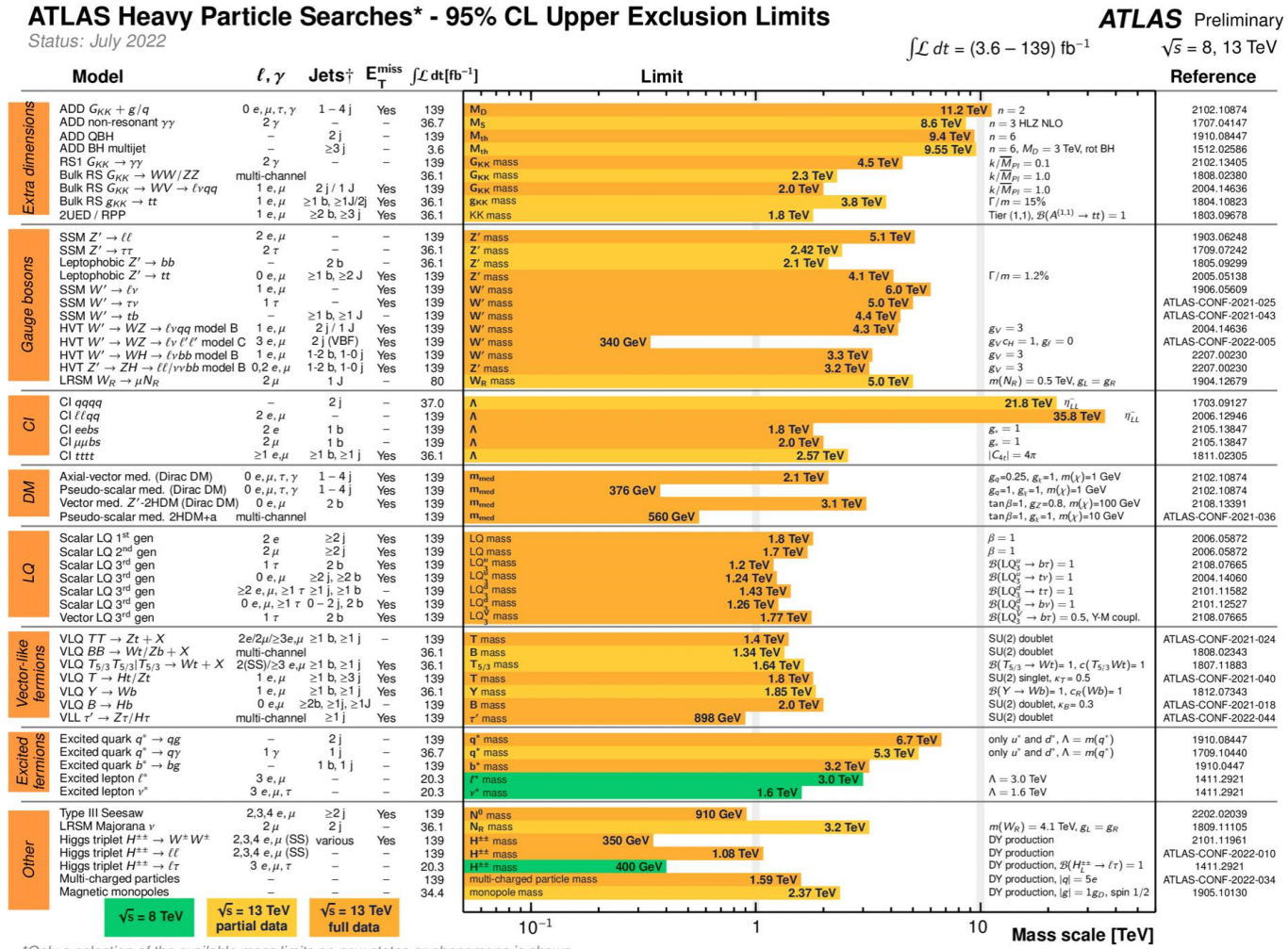
The Future of the LHC



Zerlauth, Markus, et al. "The HL-LHC Project Gets Ready for Its Deployment." *JACoW IPAC* 2022 (2022): 50-53.



Beyond the Standard Model Searches



ATLAS Collaboration. *Summary Plots for Heavy Particle Searches and Long-lived Particle Searches – July 2022*. ATL-PHYS-PUB-2022-034, url: https://cds.cern.ch/record/2815305/files/ATL-PHYS-PUB-2022-034.pdf 2022

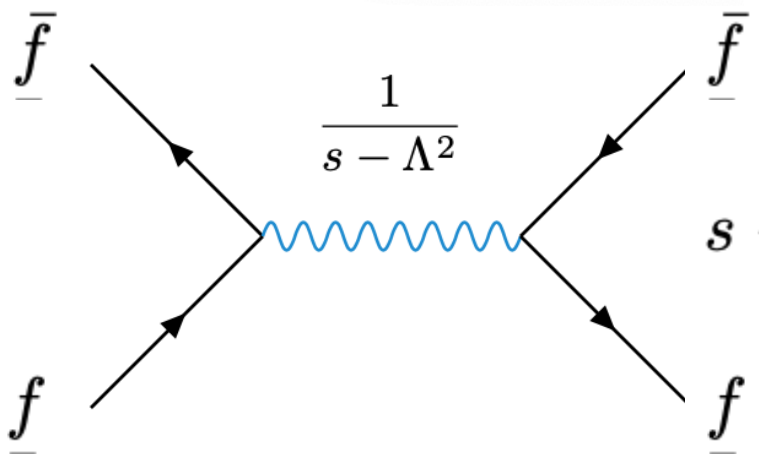
Beyond the Standard Model

- Many different models under consideration
- Would like a model independent method
- Can be achieved using the "Standard Model Effective Field Theory" (SMEFT)

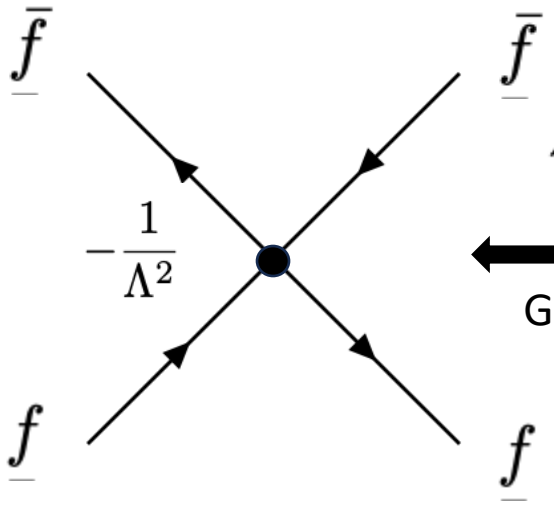
Main SMEFT Assumptions

- Same gauge symmetries and particle content as the standard model.
- New physics lies at a high energy scale and theory reduces to SM at low energies.
- New light and weakly interacting particles not included
- New physics can be reduced to a "tower" of Lagrangian terms with mass dimension greater than four

How SMEFT Works

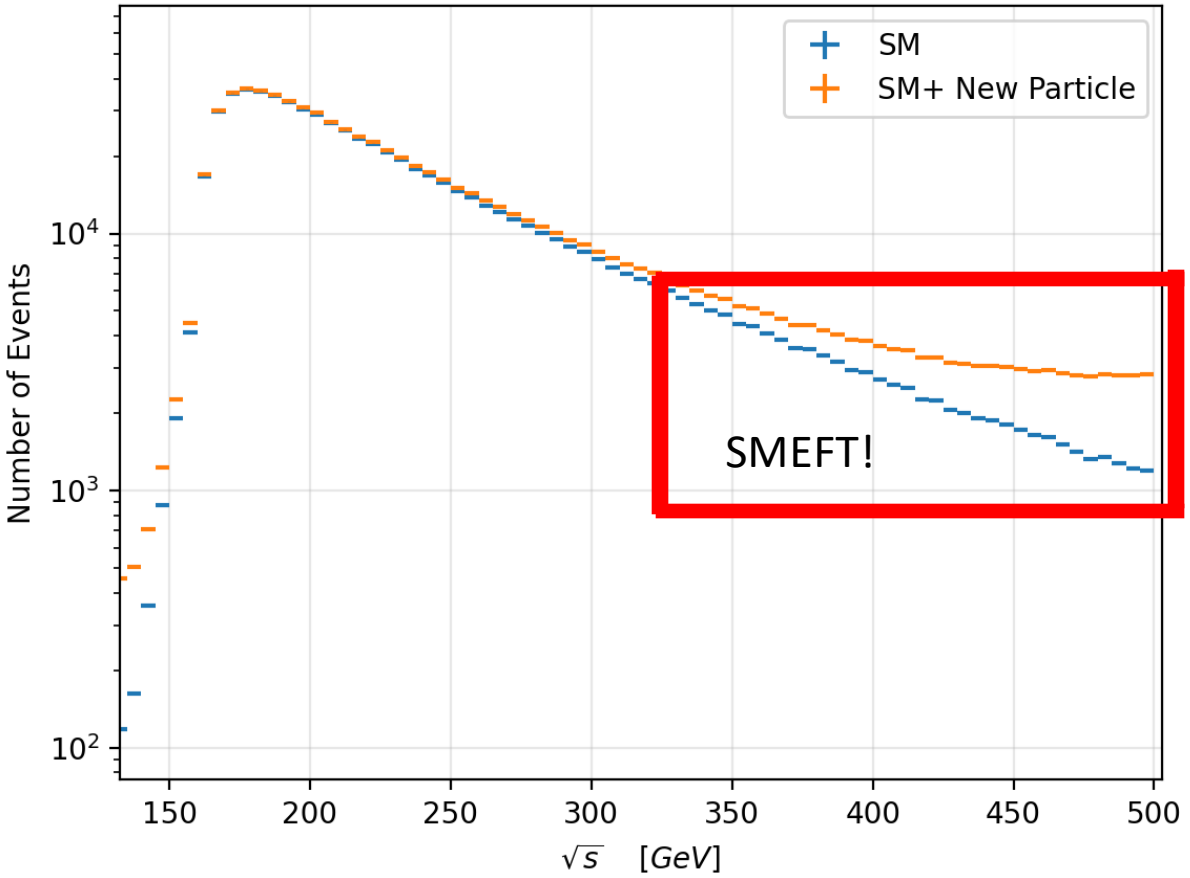


$s \ll \Lambda^2$



$\mathcal{L} \supset g_i \psi\bar{\psi}\psi\bar{\psi}$

Generates



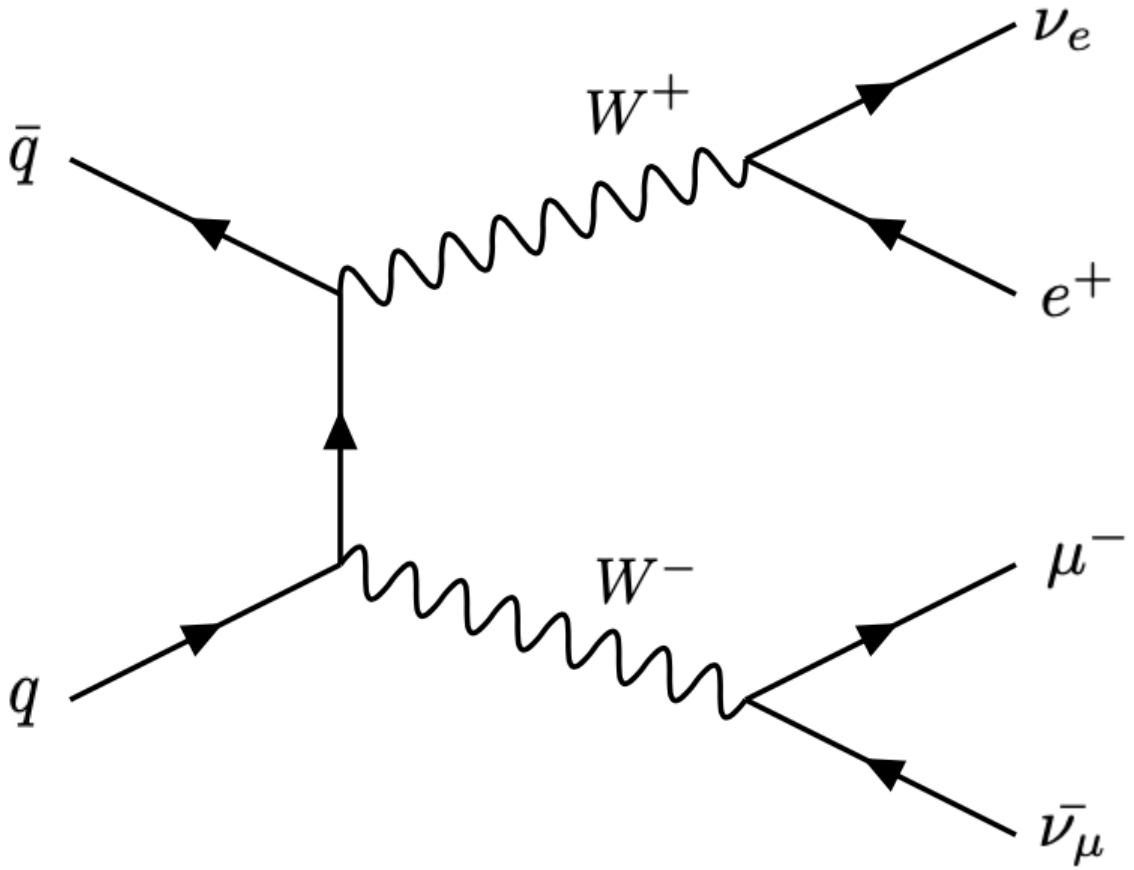
The SMEFT Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{N=4}^{\infty} \sum_{i} \frac{c_N^i}{\Lambda^{N-4}} \mathcal{O}_N^i$$

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{i} \frac{c_6^i}{\Lambda^2} \mathcal{O}_6^i + \sum_{i} \frac{c_8^i}{\Lambda^4} \mathcal{O}_8^i + O(\frac{1}{\Lambda^6})$$

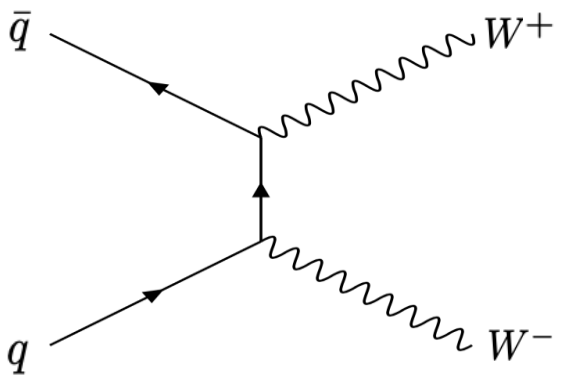
- Each operator gives new Feynman rules.
- Operators are chosen to be independent and must be Lorentz invariant.

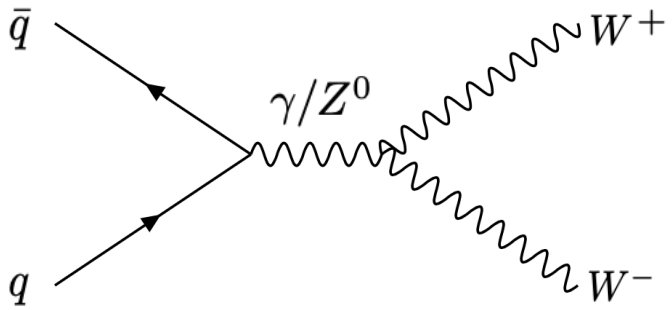
W^+W^- Boson Production



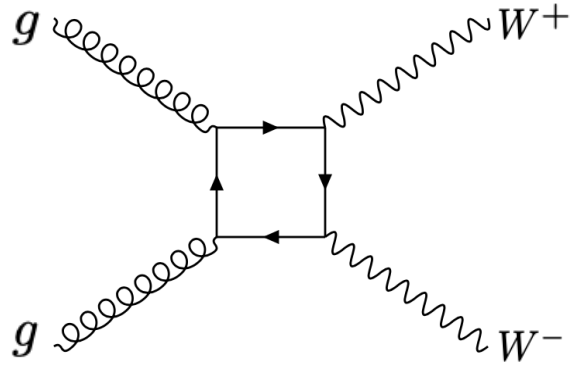
Main Standard Model Channels

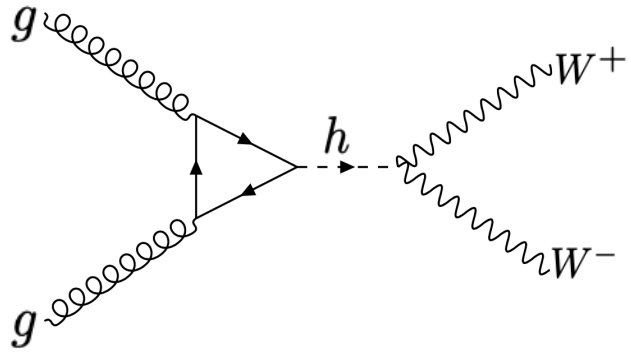
$q\bar{q} \sim 95\%$





$gg \sim 5\%$

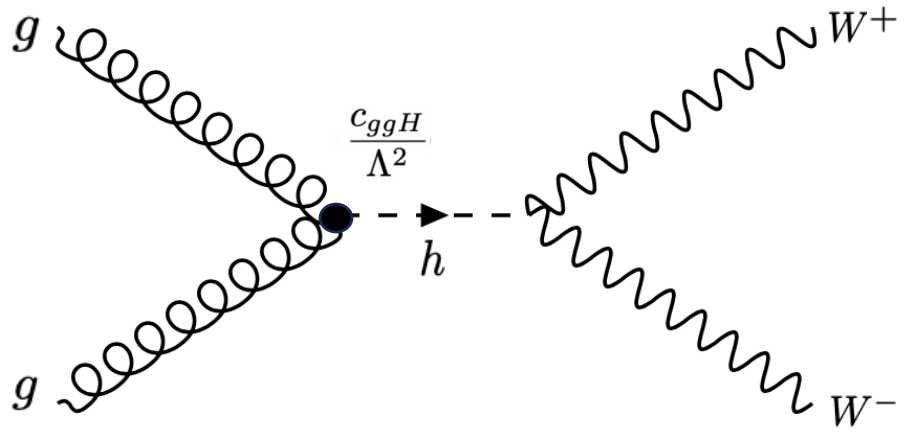




W^+W^- Production at Dimension 6

- One CP-even dimension six operator

$$\mathcal{O}_{ggH} = \frac{c_{ggH}}{\Lambda^2} G^{a,\mu\nu} G^a_{\mu\nu} \phi\phi^\dagger$$



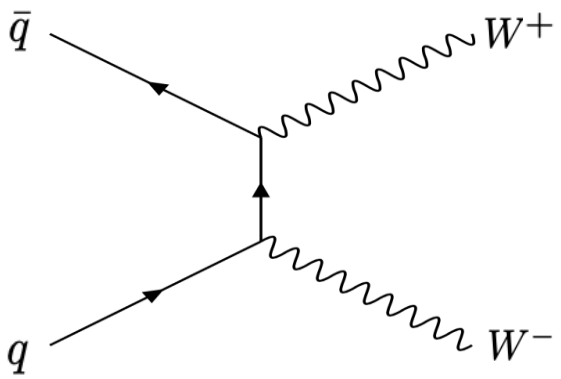
- This augments the (gg) matrix element

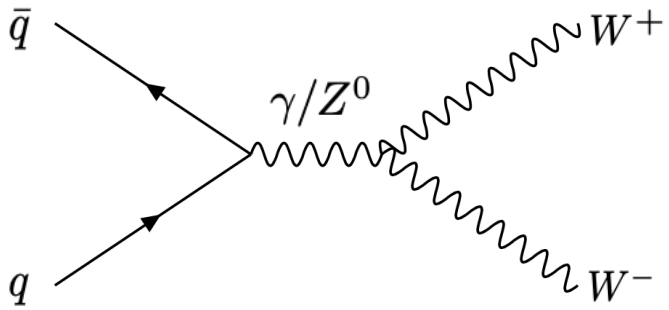
$$\sigma \sim |\mathcal{M}^{gg}|^2 = |\mathcal{M}^{gg}_{SM} + \frac{c}{\Lambda^2}\mathcal{M}_6 + O(\frac{1}{\Lambda^4})|^2$$

$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + O(\frac{1}{\Lambda^4})$$

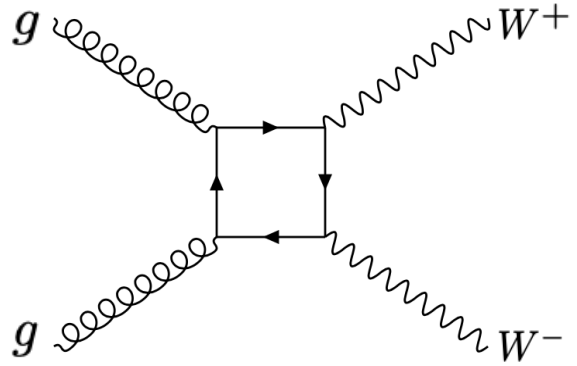
Main Standard Model Channels

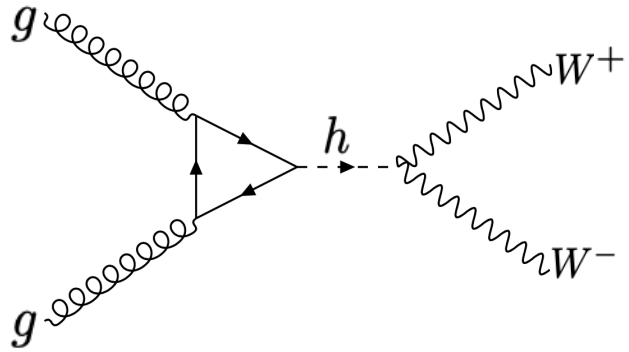
$q\bar{q} \sim 95\%$





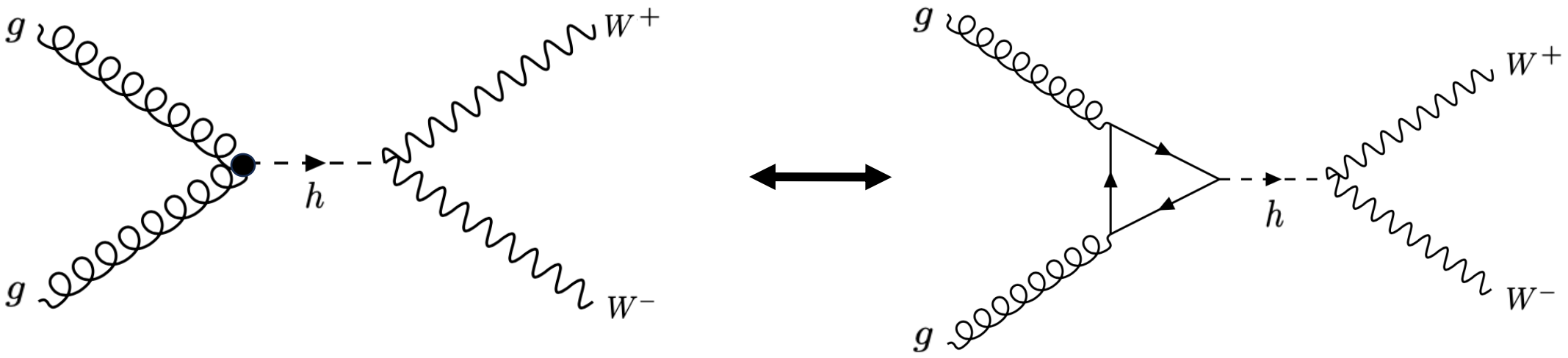
$gg \sim 5\%$





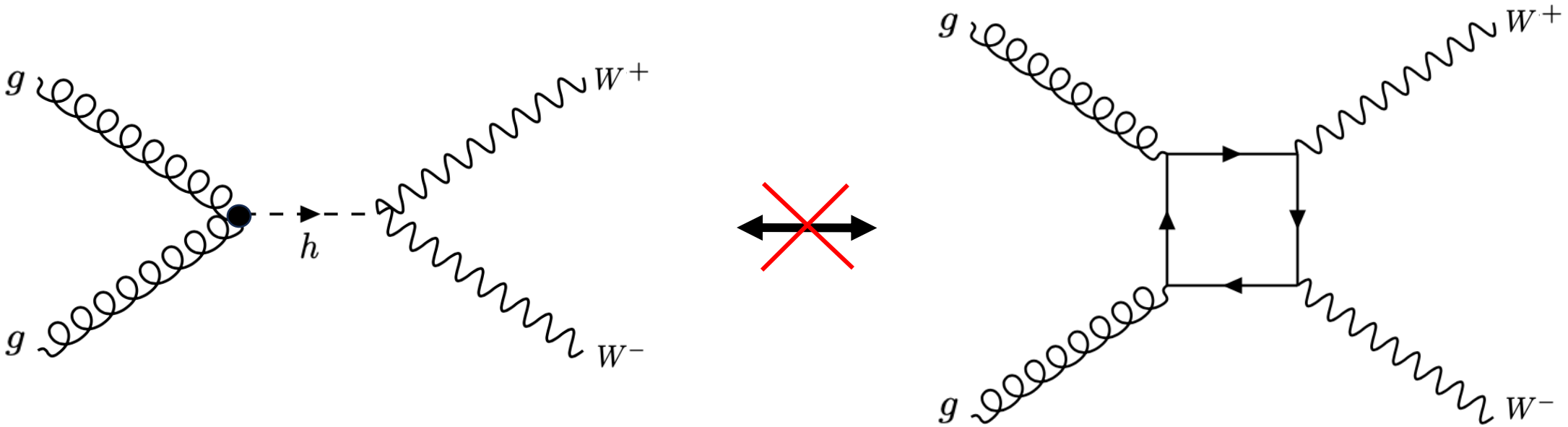
W^+W^- Production at Dimension 6

- Dimension Six Operator interferes well with Higgs channel



W^+W^- Production at Dimension 6

- Dimension Six Operator interferes less well with leading contributions

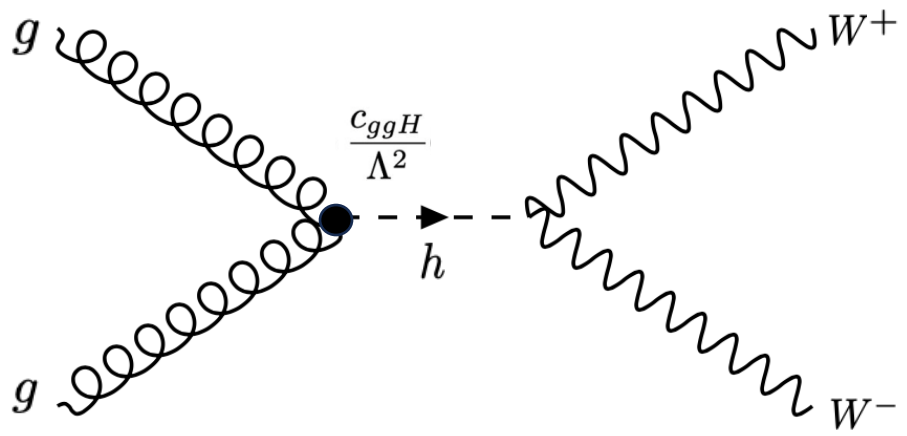


W^+W^- Production at Dimension 6

- One CP-even dimension 6 operator

$$\mathcal{O}_{ggH} = \frac{c_{ggH}}{\Lambda^2} G^{a,\mu\nu} G^a_{\mu\nu} \phi\phi^\dagger$$

- This augments the matrix element



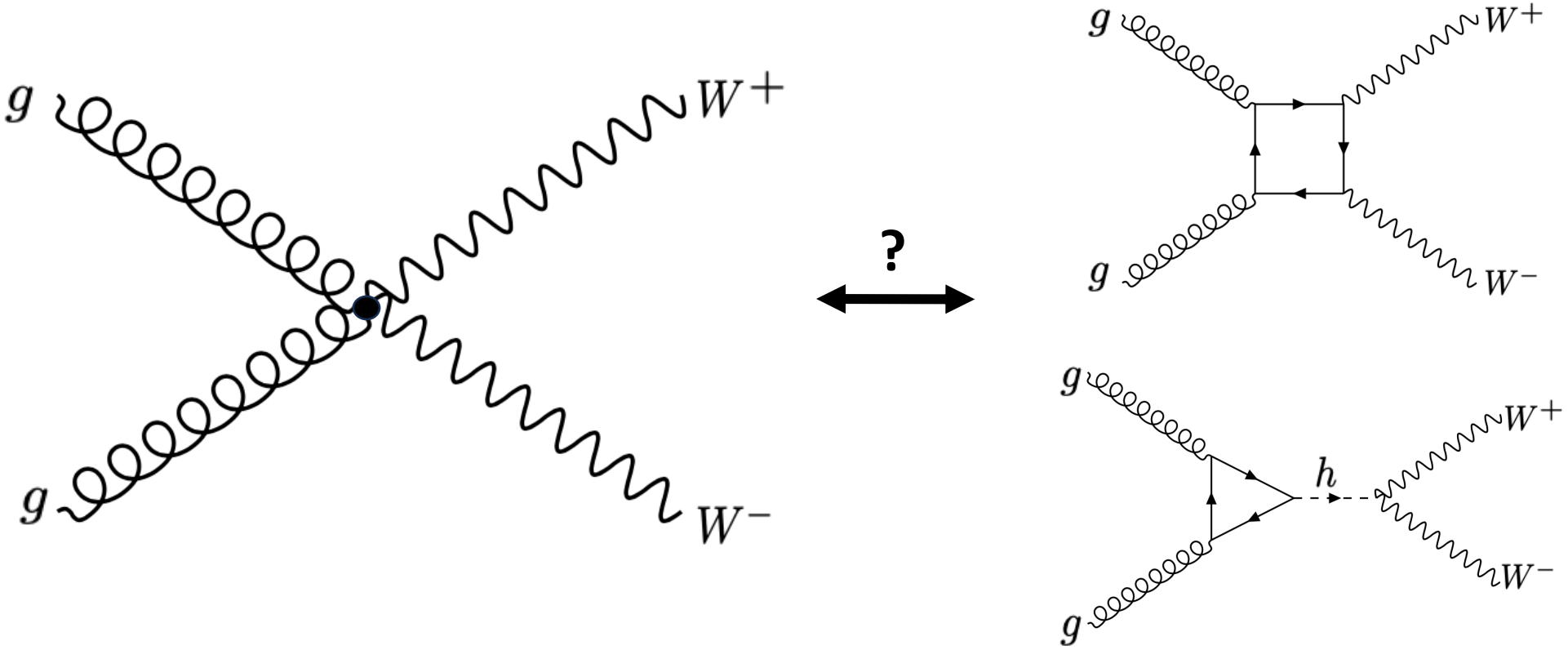
$$|\mathcal{M}^{gg}|^2 = |\mathcal{M}^{gg}_{SM} + \frac{c}{\Lambda^2}\mathcal{M}_6 + O(\frac{1}{\Lambda^4})|^2$$

$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + O(\frac{1}{\Lambda^4})$$

$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + \frac{c^2}{\Lambda^4}|\mathcal{M}_6|^2 + O(\frac{1}{\Lambda^4})$$

W^+W^- Production at Dimension 8

- Dimension 8 operators could have Lorentz structures that interfere much better than at dimension 6



W^+W^- Production at Dimension 6/8

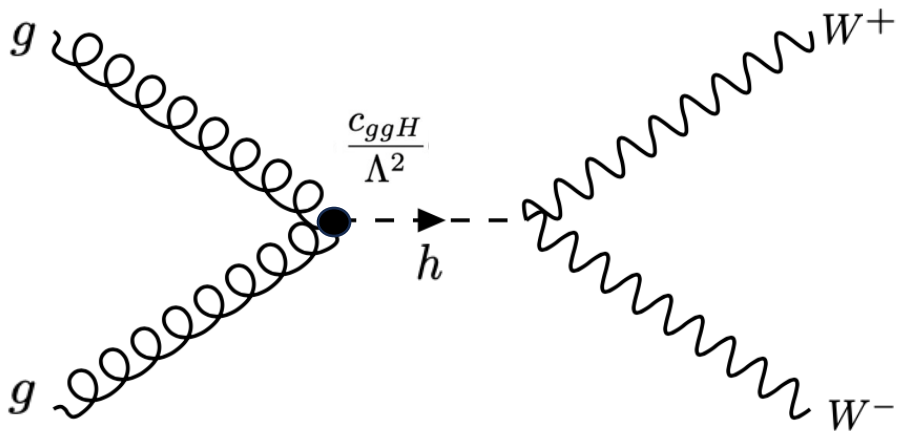
- Back to the matrix element

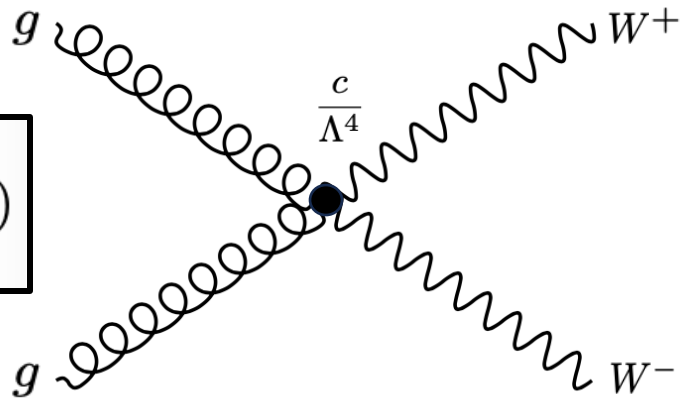
$$|\mathcal{M}^{gg}|^2 = |\mathcal{M}^{gg}_{SM} + \frac{c}{\Lambda^2}\mathcal{M}_6 + O(\frac{1}{\Lambda^4})|^2$$

$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + O(\frac{1}{\Lambda^4})$$

$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + \frac{c^2}{\Lambda^4}|\mathcal{M}_6|^2 + O(\frac{1}{\Lambda^4})$$

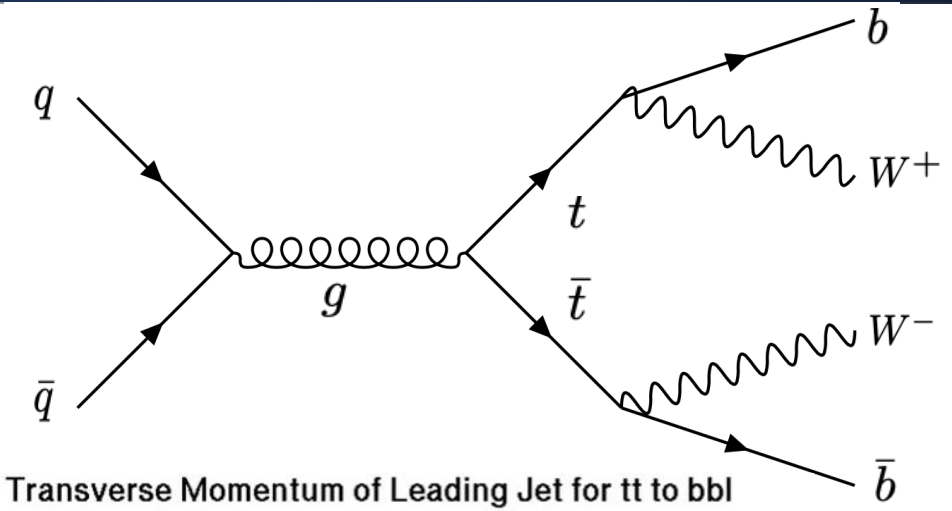
$$= |\mathcal{M}^{gg}_{SM}|^2 + 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^2}\mathcal{M}_6)^*] + \frac{c^2}{\Lambda^4}|\mathcal{M}_6|^2 + \sum_i 2\mathrm{Re}[\mathcal{M}^{gg}_{SM}(\frac{c}{\Lambda^4}\mathcal{M}^i_8)^*] + O(\frac{1}{\Lambda^6})$$

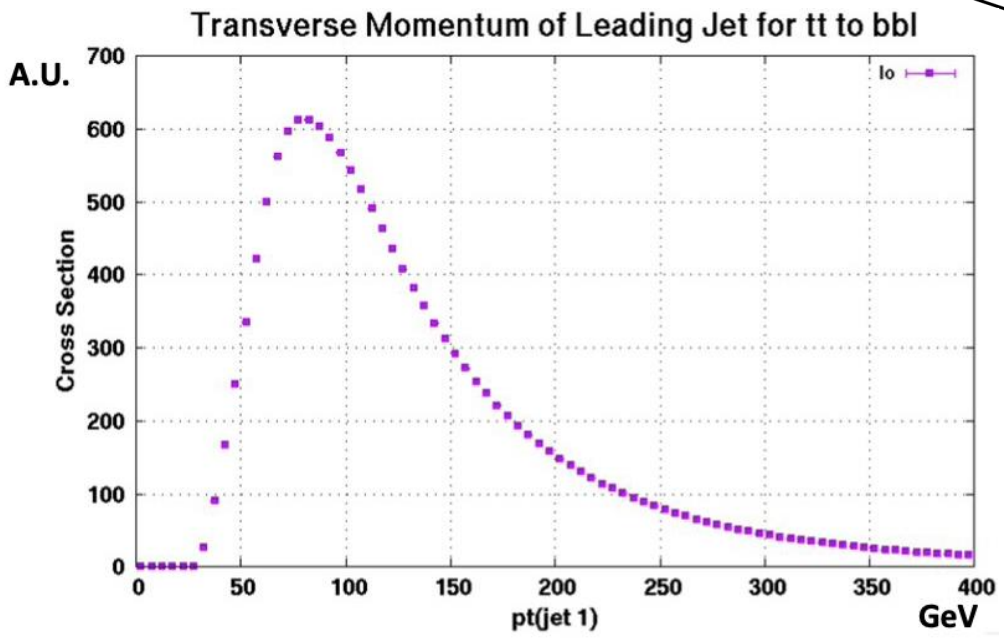




Background Processes

- The process is heavily contaminated with background tt production.
- High level of jet production.
- Can be removed with a jet veto on the leading jet at around 30GeV





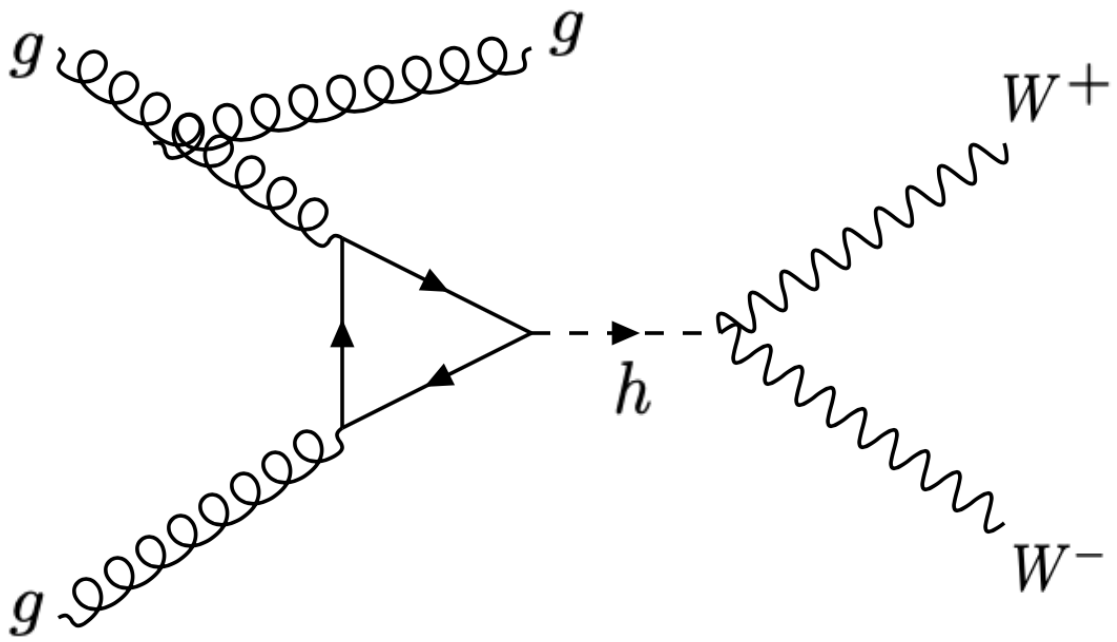
Resummation

- Incoming partons also tend to radiate jets

- Each radiated gluon comes with factors

$$\alpha_s \mathrm{Ln}\left(\frac{M}{p_{t,\mathrm{veto}}}\right) \sim 1$$

- New scale --> requires an all orders resummation



Results

- Resummation already implemented in MCFM "Resummation Edition" - NLL for gluon channel and NNLL quark channels.

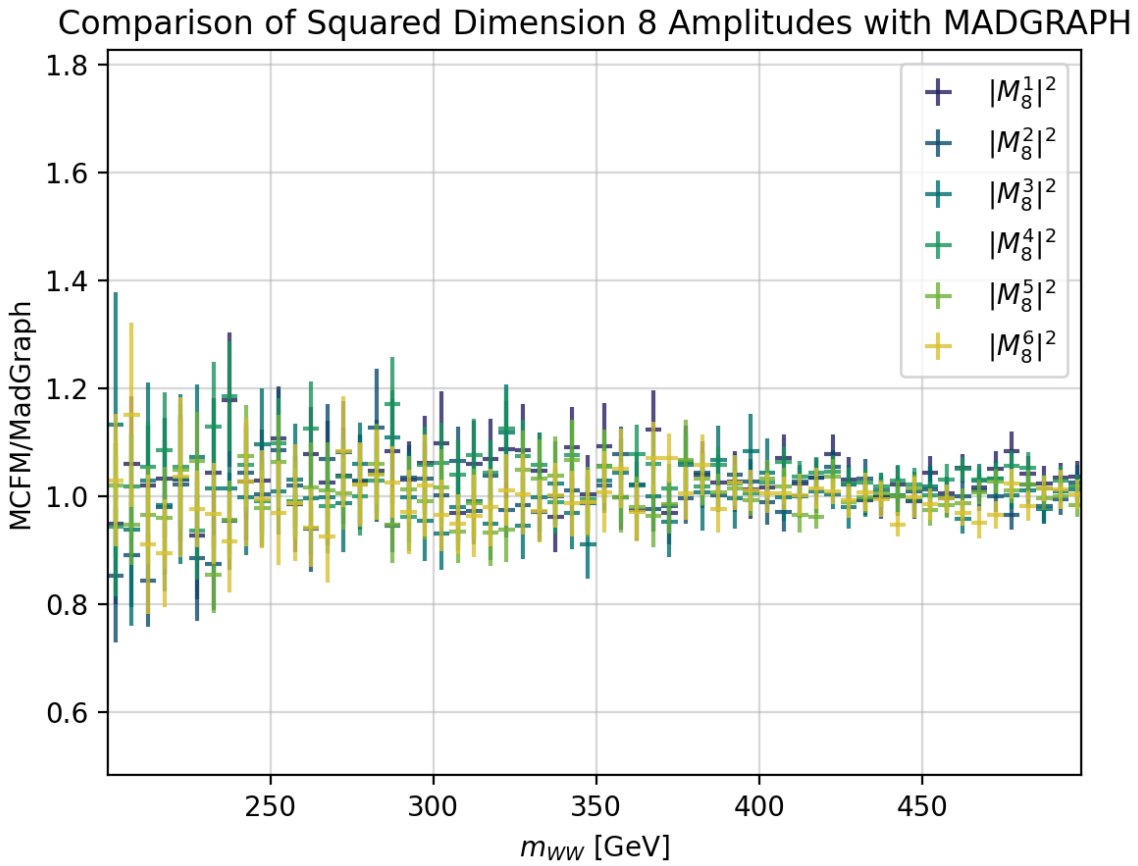
- Resummation only depends on the incoming parton type (quarks or gluons).

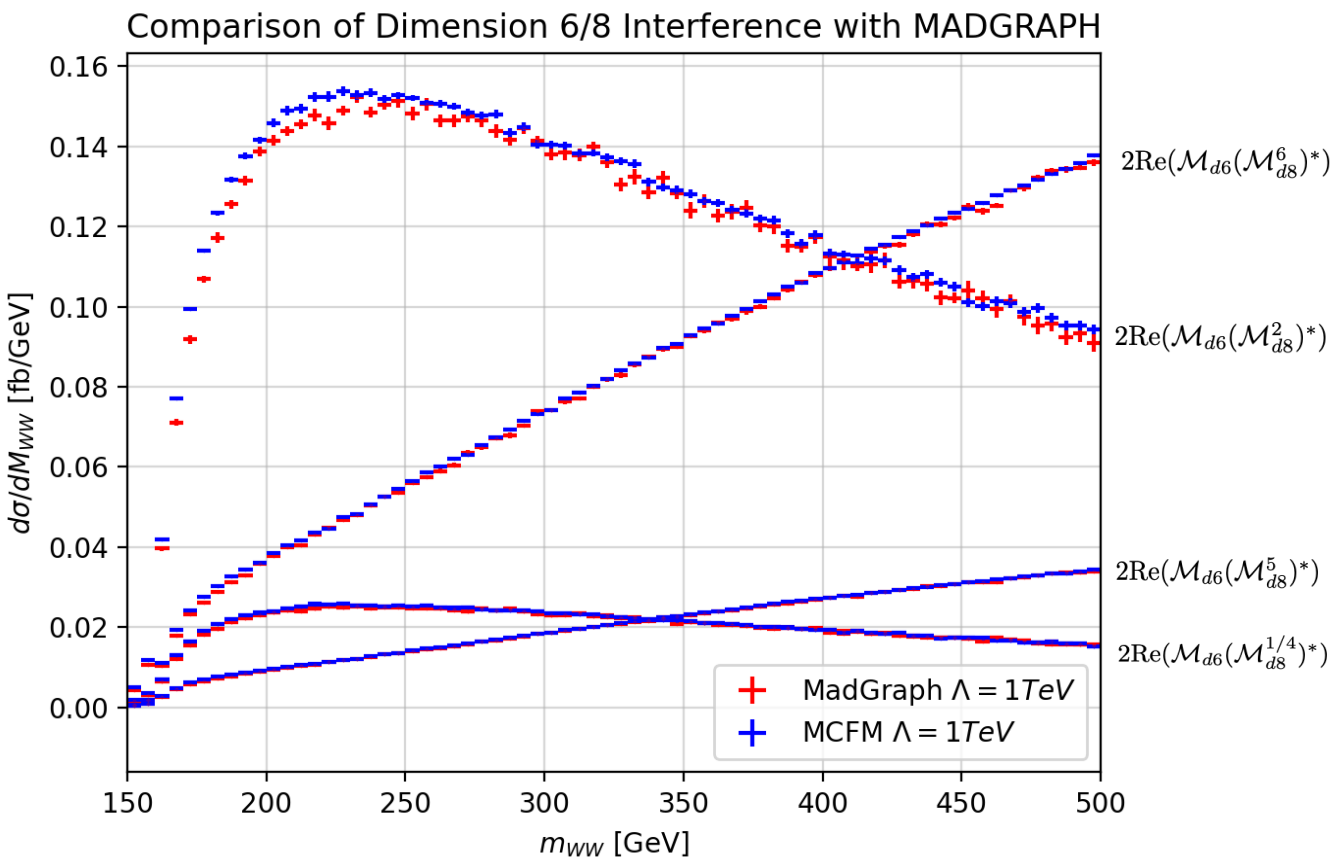
- Can simply change the matrix elements which are corrected by resummation factor.

Results

- Feynman rules and helicity amplitudes have been calculated and benchmarked against the automatic generation in MadGraph

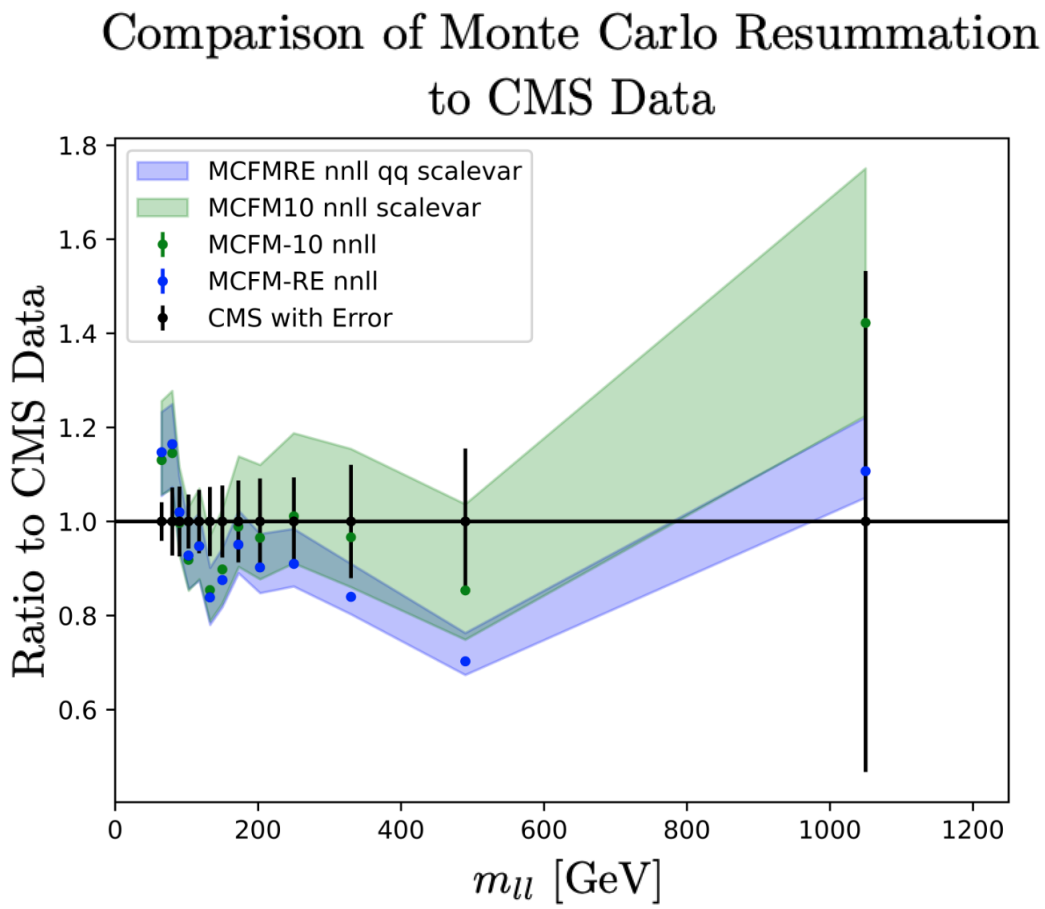
$2\mathrm{Re}(\mathcal{M}_{d6}(\mathcal{M}_{d8}^{3})^{*})=0$





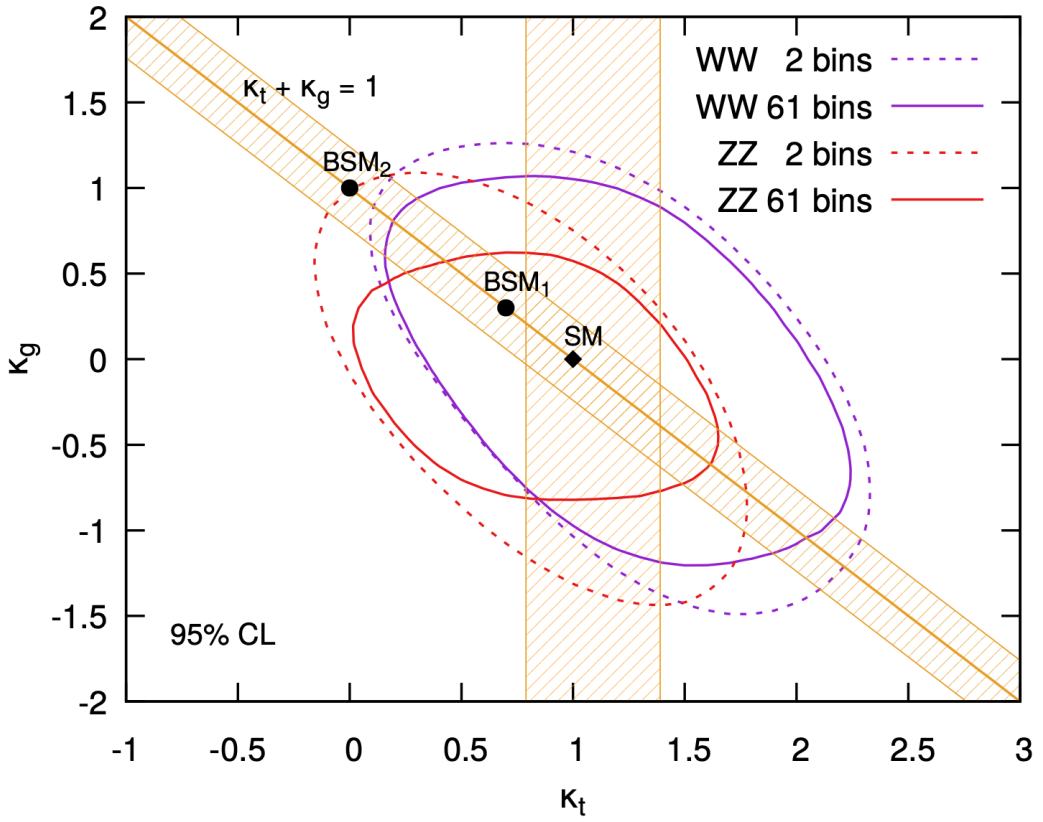
Results

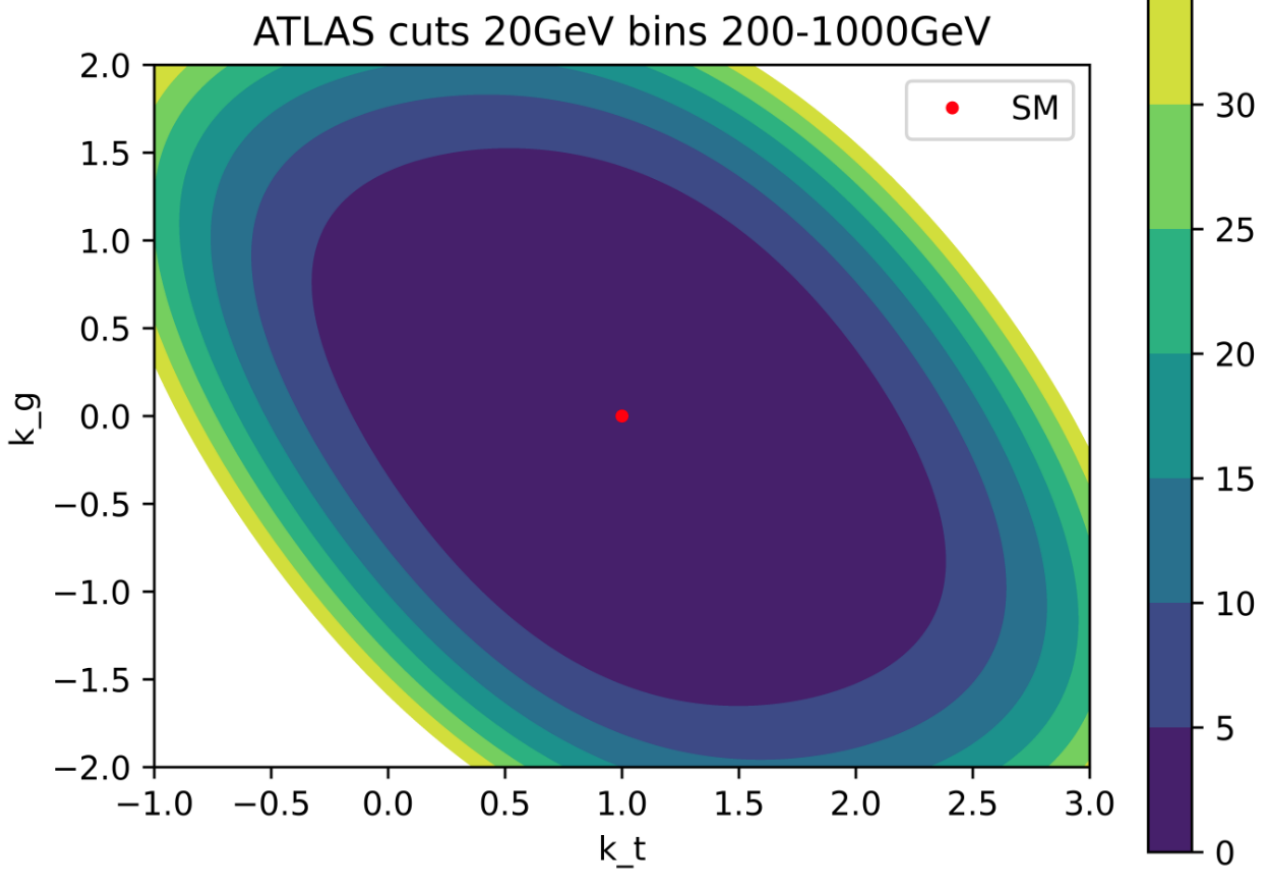
- Resummation was tested against that from MCFM-10 and MATRIX
- Theoretical uncertainty was also extracted from scale variation
- Also compared to CMS data
- Can generate pseudo data for sensitivity studies



Results

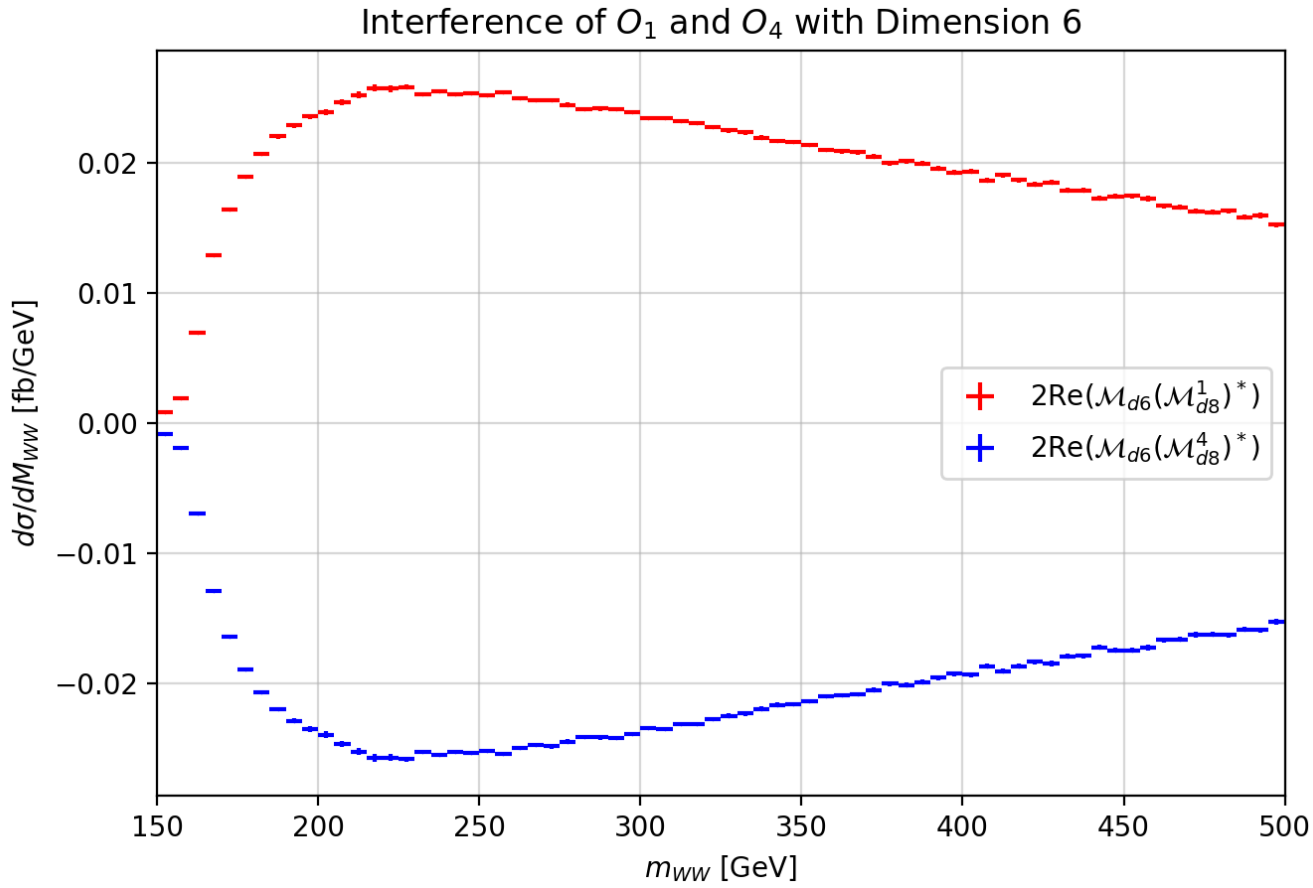
- Extracted a similar shape at dimension six to that of previous studies.





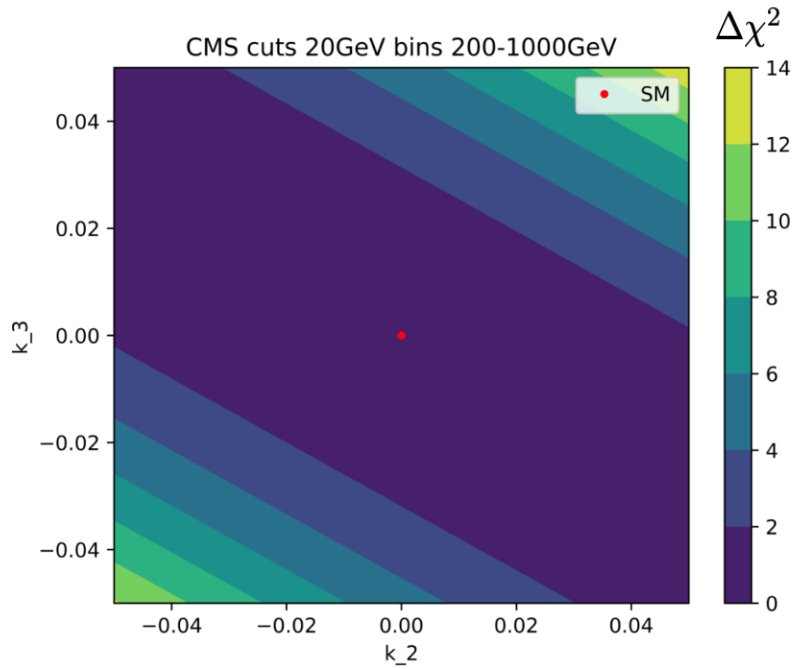
Results

- Some distributions cancel



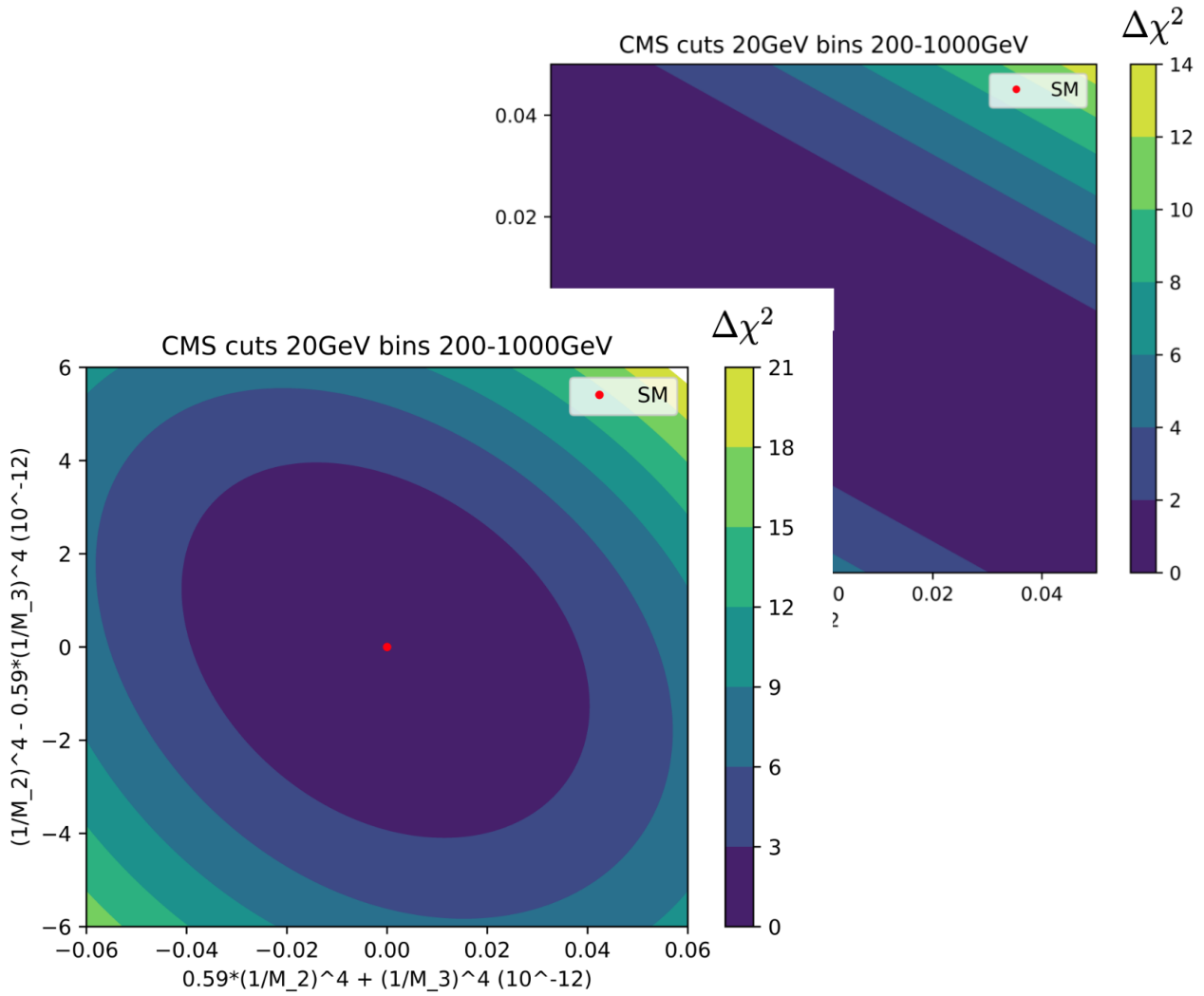
Results

- Cancelation can be seen as a straight line on contour plot
- It reduces the ability to constrain in a multivariate analysis.
- Could be possible to fix the sign of some of the coefficients on theoretical grounds.



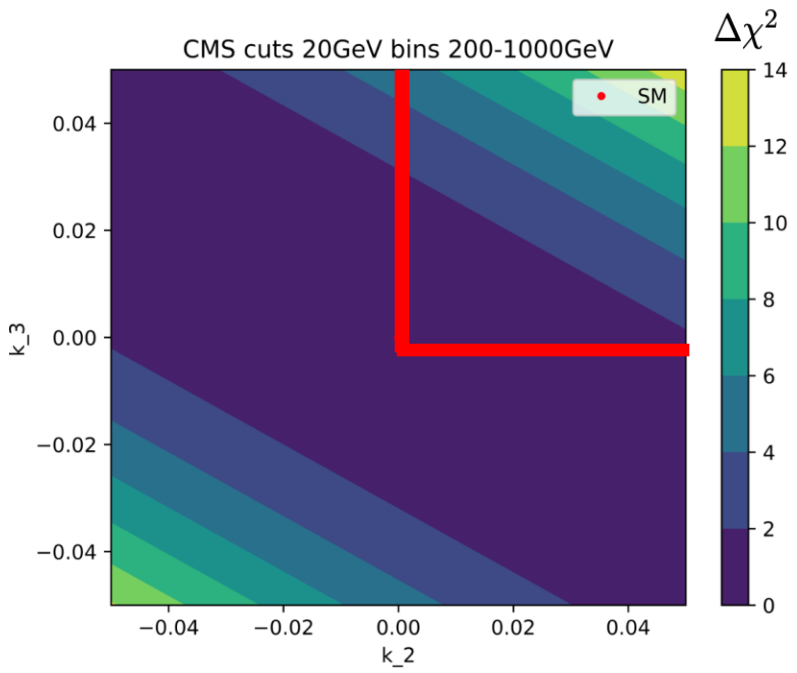
Results

- Cancelation can be seen as a straight line on contour plot
- It reduces the ability to constrain in a multivariate analysis.
- Could be possible to fix the sign of some of the coefficients on theoretical grounds.



Results

- Cancelation can be seen as a straight line on contour plot
- It reduces the ability to constrain in a multivariate analysis.
- Could be possible to fix the sign of some of the coefficients on theoretical grounds.



Future Directions

- Produce the final sensitivity plots with pseudo data using 14TeV and 3000 fb^{-1}
- Could also add CP-odd squared and study quark operators.
- May also add this to other resummation codes such as Geneva (Uses a different resummation scheme).
- This would be easy to do for the gluon operators but harder for the quark operators because of "Soft" function.