Partial N3LL + NNLO Resummed Predictions for the Drell-Yan Process in Rapidity Dependent Jet Veto Observables

Thomas Clark (University of Manchester)
Based on work done in collaboration with Jonathan Gaunt (University of Manchester) and Shireen Gangal (University of Mumbai)

31st International Workshop on Deep Inelastic Scattering
Grenoble, 10th April 2024

MANCHESTER 1824
The University of Manchester

Aims of Analysis

- Produce partial N3LL + NNLO phenomenological predictions in the Drell-Yan process for two jet veto variables

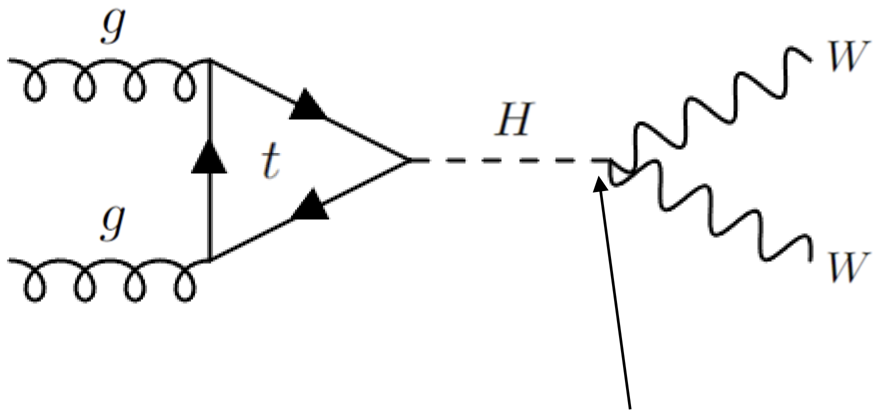
- Demonstrate the benefit of resumming logarithms in these jet veto variables by comparing to fixed-order (FO) predictions

Jet Vetoes

Class of observable used to separate final states by number of final state jets. A common jet veto is the leading jet transverse momentum P_{Tj}.

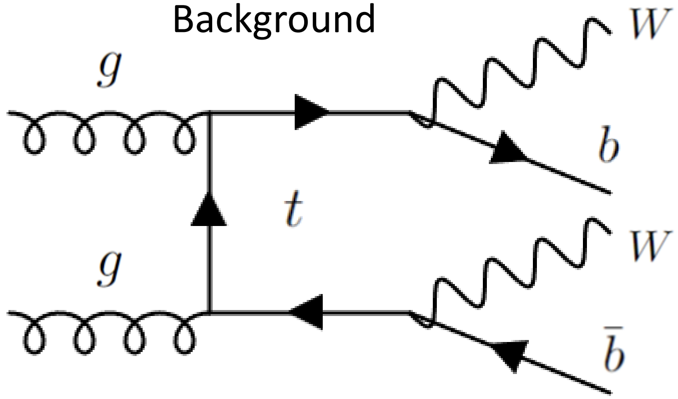
Can separate hard processes, cut out background events and study QCD radiation. For example:

Signal



Same initial states, final states differ by number of jets.

Background



Can be used to study Higgs coupling

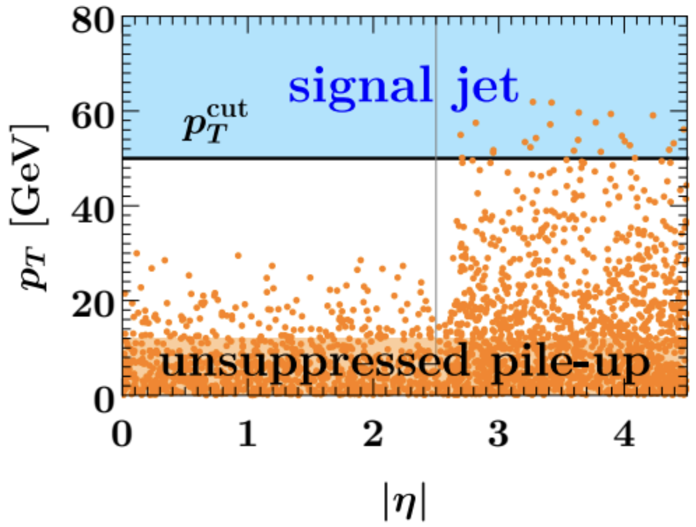
Can be removed with cuts on jet vetoes

Rapidity Dependent Jet Vetoes

Useful to control the tightness of the P_T cut depending on kinematics of jet.

Due to a lack of tracking information, high rapidity, low P_T jets are hard to resolve experimentally.

A rapidity dependent jet veto allows tighter Pt cuts in central rapidites and looser P_T cuts at forward rapidities to cut out these low P_T jets.



Michel, Pietrulewicz, Tackman, arXiv:1810.12911

$$\tau_f^{jet} = \underset{j \in J}{Max} \mid p_{Tj} \mid f\left(Y, y_j\right)$$

Rapidity of hard system

Rapidity of jet

Rapidity Dependent Jet Vetoes

Study two of these based on the different weighing functions.

Tackmann, Walsh, Zuberi, arXiv:1206.4312

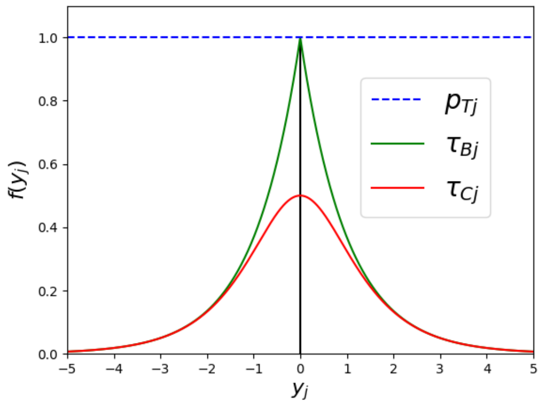
Gangal, Stahlhofen, Tackmann, arXiv:1412.4792

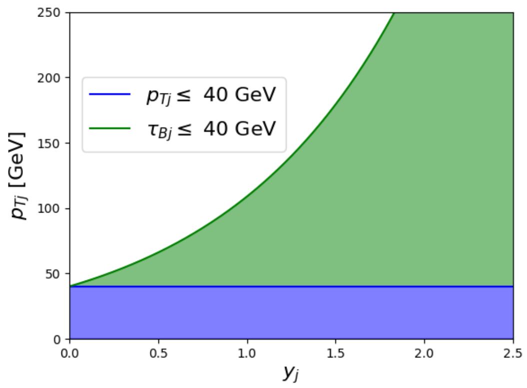
$$\tau_B : f_B(Y, y_j) = e^{-|y_j - Y|}$$

$$\tau_C : f_C(Y, y_j) = \frac{1}{2\cosh(y_j - Y)}$$

τ_B is tighter at central rapidities than τ_C but they are equivalent at forward rapidities.

These jet vetoes are more inclusive of QCD radiation due to tight veto being over smaller range. Allows QCD radiation to be studied from a different point of view.

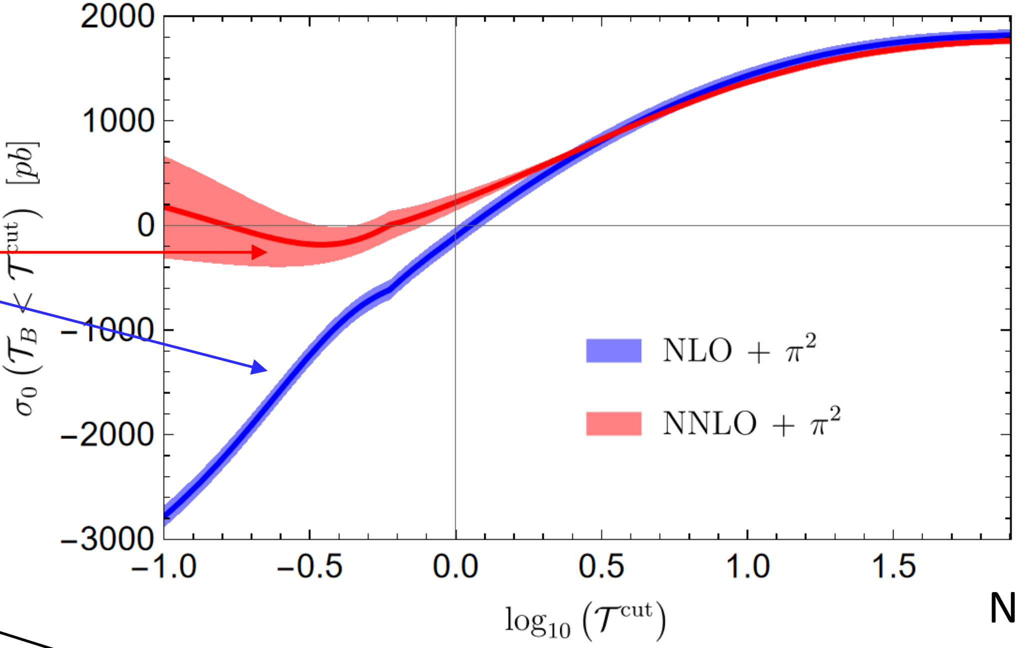




Large Logarithms in Jet Vetoes

Often tight cuts on jet veto variables required. Leads to large logarithms in the FO predictions in τ_{Cut} / Q :

Unphysical prediction due to large logarithms



Leading Log (LL)

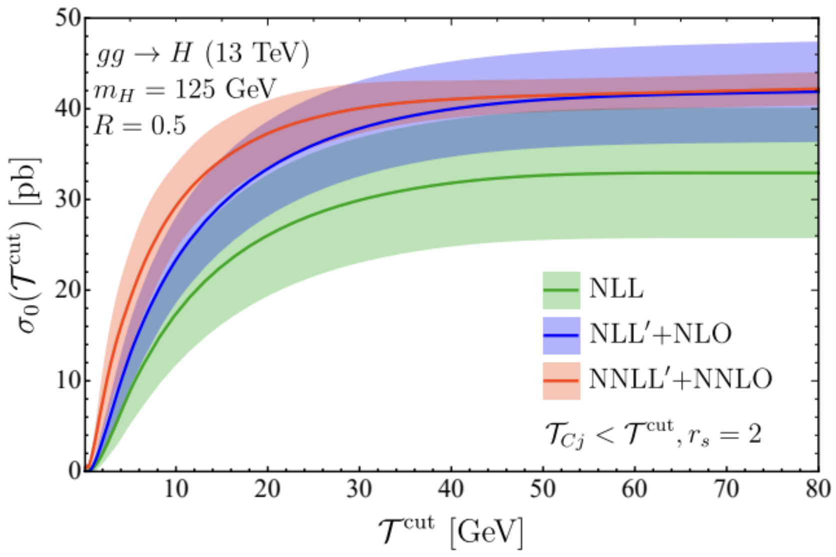
Next to Next to Leading Log (NNLL)

$$\mathcal{O}\left(\alpha_s^n\right) : c_1 \alpha_s^n \ln^m \left(\frac{\mathcal{T}_{\rm cut}}{Q}\right) + c_2 \alpha_s^n \ln^{m-1} \left(\frac{\mathcal{T}_{\rm cut}}{Q}\right) + c_3 \alpha_s^n \ln^{m-2} \left(\frac{\mathcal{T}_{\rm cut}}{Q}\right) + \ldots + c_{m+1} \alpha_s^n$$

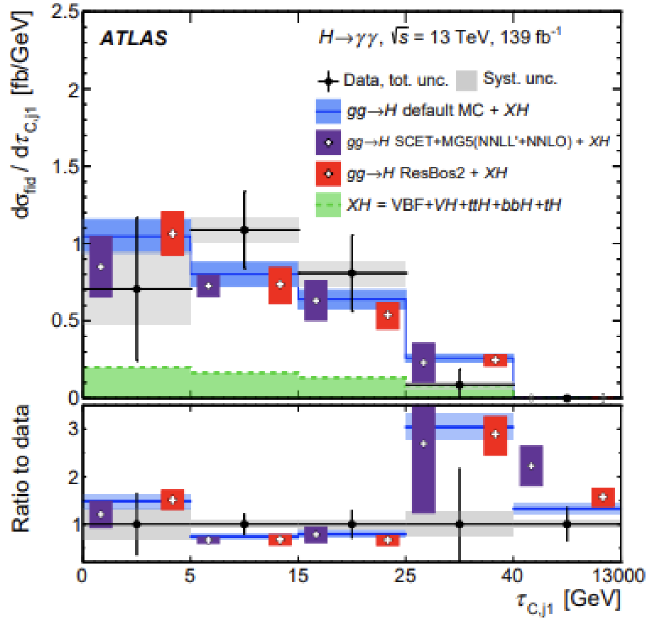
Next to Leading Log (NLL)

Jet Veto Resummation Example: Higgs

Resummation of large logarithms in rapidity dependent jet vetoes for Higgs production has been produced and compared with experimental data.



Gangal, Gaunt, Tackmann, Vryonidou, arXiv:2003.04323



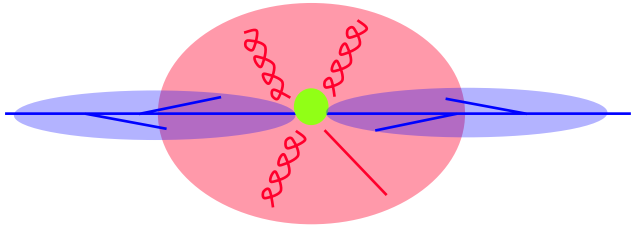
ATLAS collaboration, arXiv:2202.00487

N.B. see talk WG3 talk by Alessandra Cappati for CMS $H \to ZZ$ results in τ_B / τ_c

Factorisation in Jet Vetoes

The below τ_{Cut} cross section can be factorised as follows for $\tau_{Cut} << Q$:

$$H_{q\bar{q}}(Q,\mu)\, B_q(Q\mathcal{T}^{\rm cut}, R, \mu)\, B_{\bar{q}}(Q\mathcal{T}^{\rm cut}, R, \mu)\, S(\mathcal{T}^{\rm cut}, R, \mu)$$



Tackmann, Walsh, Zuberi, arXiv:1206.4312
Gangal, Stahlhofen, Tackmann, arXiv:1412.4792
Gangal, Gaunt, Tackmann, Vryonidou, arXiv:2003.04323

Logarithms can be thought to come from each function in factorised cross section:

$$\ln^2\left(\frac{\mathcal{T}^{\rm cut}}{Q}\right) = 2\ln^2\left(\frac{Q}{\mu}\right) - \ln^2\left(\frac{Q\mathcal{T}^{\rm cut}}{\mu^2}\right) + 2\ln^2\left(\frac{\mathcal{T}^{\rm cut}}{\mu}\right)$$

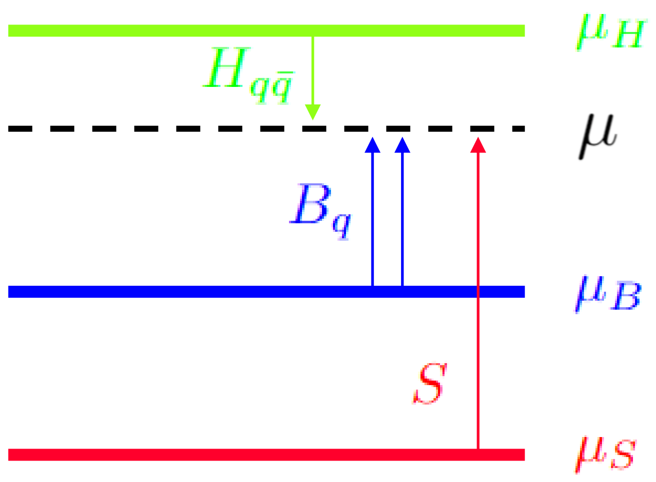
Resummation in Jet Vetoes

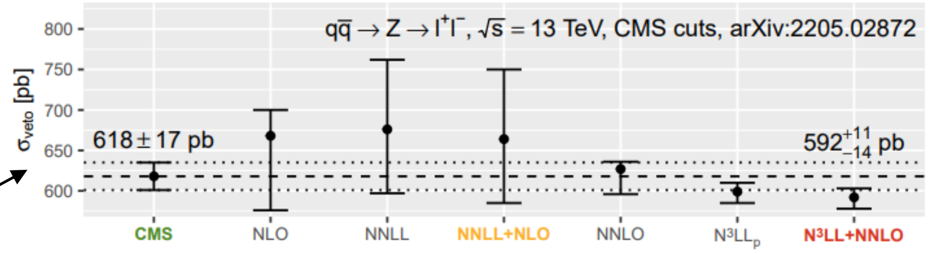
Can sum the logarithms by solving the RGE's of the functions in the factorisation formula.

Evolve all the scales to a common scale.

The goal precision is NNLL' + π^2 (partial N^{3}LL).

The results is matched to the FO + π^2 cross section. The final precision is NNLL' + NNLO + π^2 (n.b. State of the art for P_T veto is also partial N3LL).





Drell-Yan Ptj resummation at partial N3LL + NNLO compared with experimental data.

Campbell, Ellis, Neumann, Seth, arXiv:2301.11768

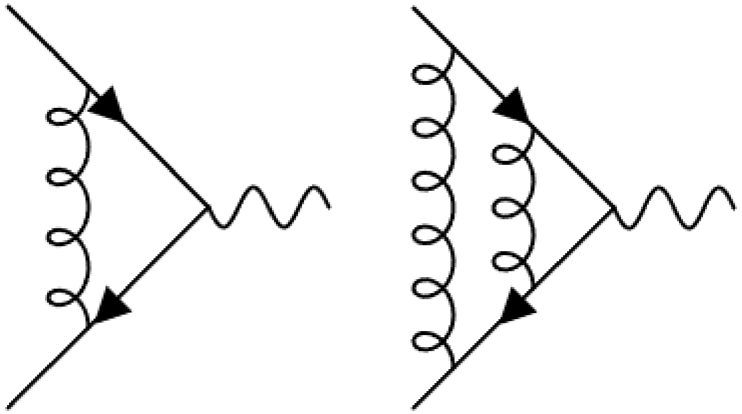
Choice of Scales

For a particular value of τ_{Cut}, need to choose the beam, soft and hard scales.

Hard scale chosen to sum time-like logarithms (π^2 resummation):

$$\mu_H = -i\mu_{\mathrm{FO}}$$

Form of processes resummed by π^2 resummation →



See e.g. Ahrens, Becher, Neubert, Yang, arXiv:0808.3008,0809.4283

The factorisation scale is generally taken to be equal to the beam scale.

Choice of Scales

Non-perturbative region

$\mathcal{T}_{\rm cut} \sim \Lambda_{\rm QCD}$

'Freezing scale' → $\mu_0 > \Lambda_{\rm QCD}$

$\mu_S \sim \mu_0$

$\mu_B \sim \sqrt{\mu_S \mu_0}$

→

Resummation region (Canonical scaling)

$\mathcal{T}_{\rm cut} << Q$

$\mu_S \sim \mathcal{T}_{\rm cut}$

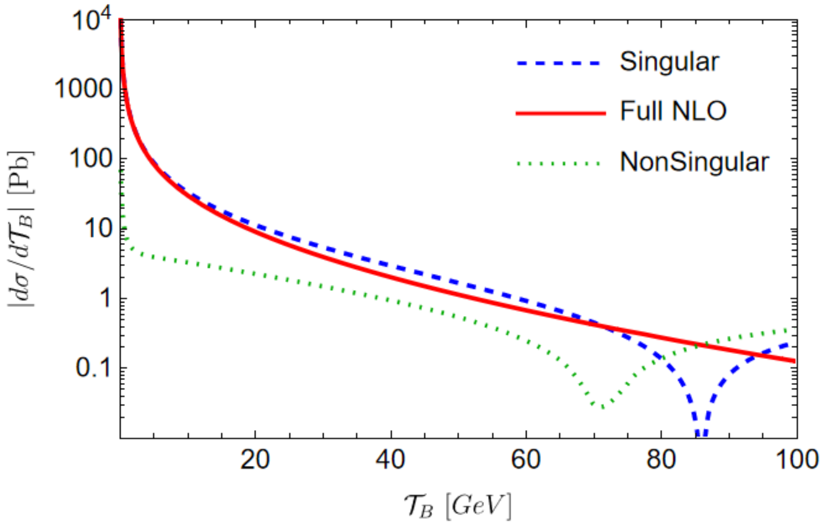
$\mu_B \sim \sqrt{Q\mathcal{T}_{\rm cut}}$

→

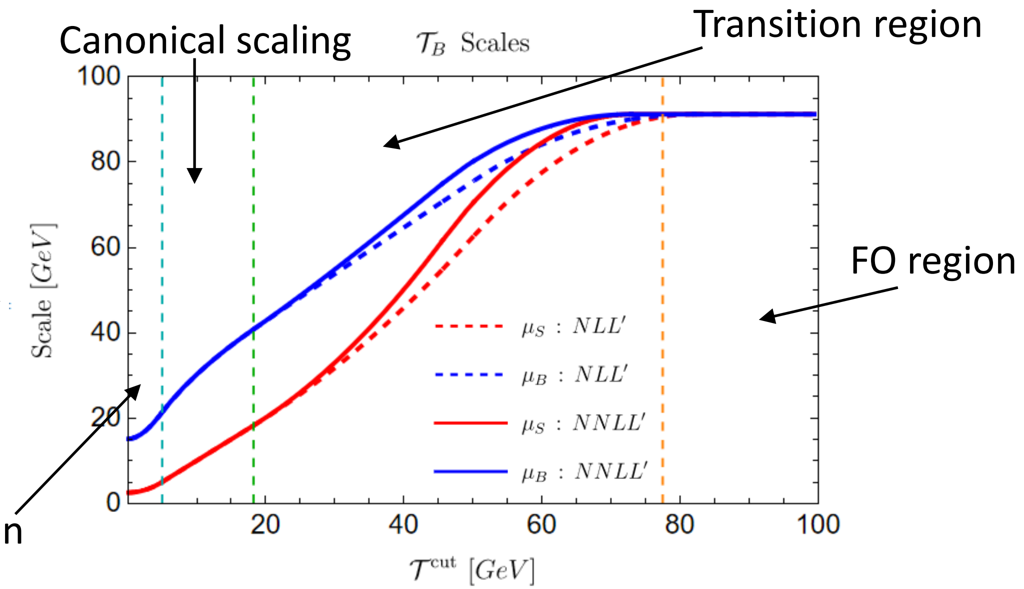
Fixed-order region

$\mathcal{T}_{\rm cut} \sim Q \sim \mu_{\rm FO}$

$\mu_S, \mu_B \sim Q \sim \mu_{\rm FO}$



Used to determine →



Non-perturbative region

Scale Variations

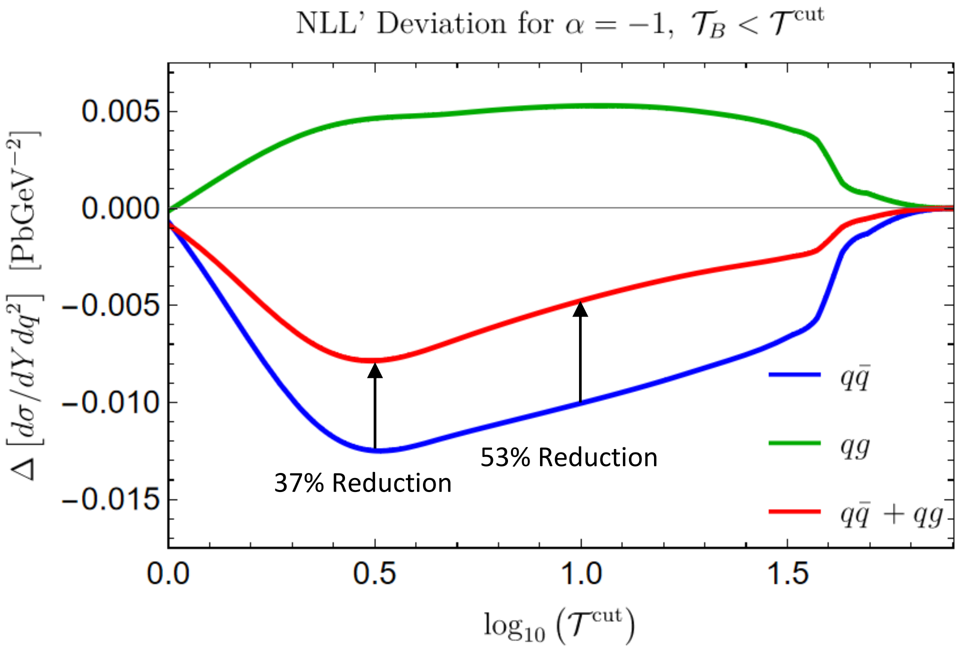
Standard FO variations are used:

$$\mu_{\rm FO} = \{\tfrac{1}{2}M_Z, M_Z, 2M_Z\}$$

Profile scales are varied using two parameters (α,β) that lead to ~2 variation in the beam and soft scales and variation in the canonical beam scaling.

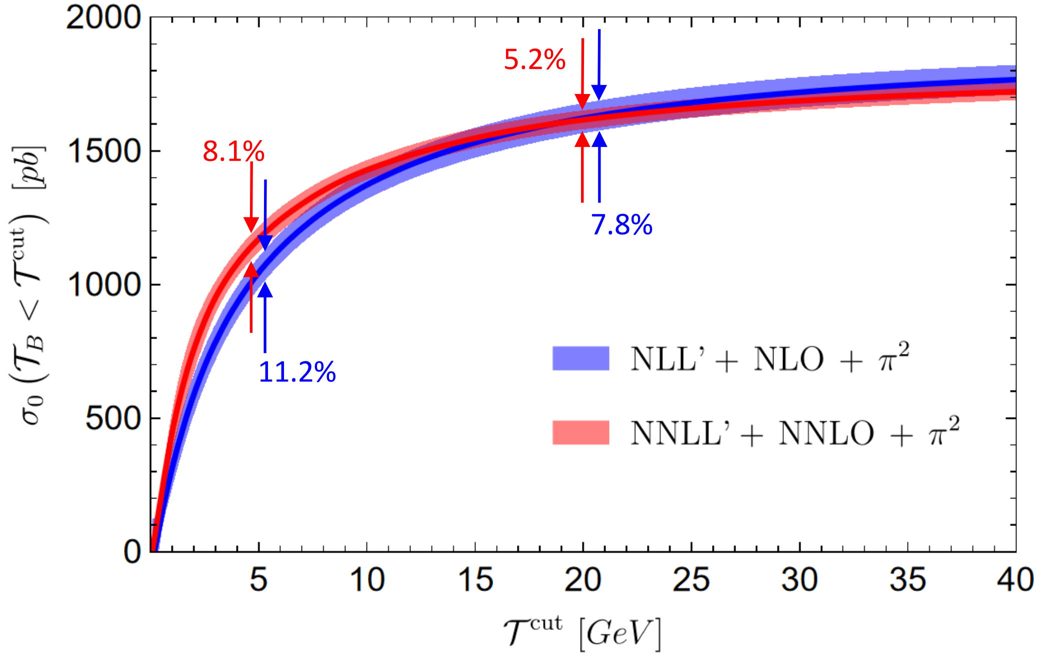
Cancellation between the $q\bar{q}$ and qg channel variations led to only the $q\bar{q}$ channel's beam scale being varied.

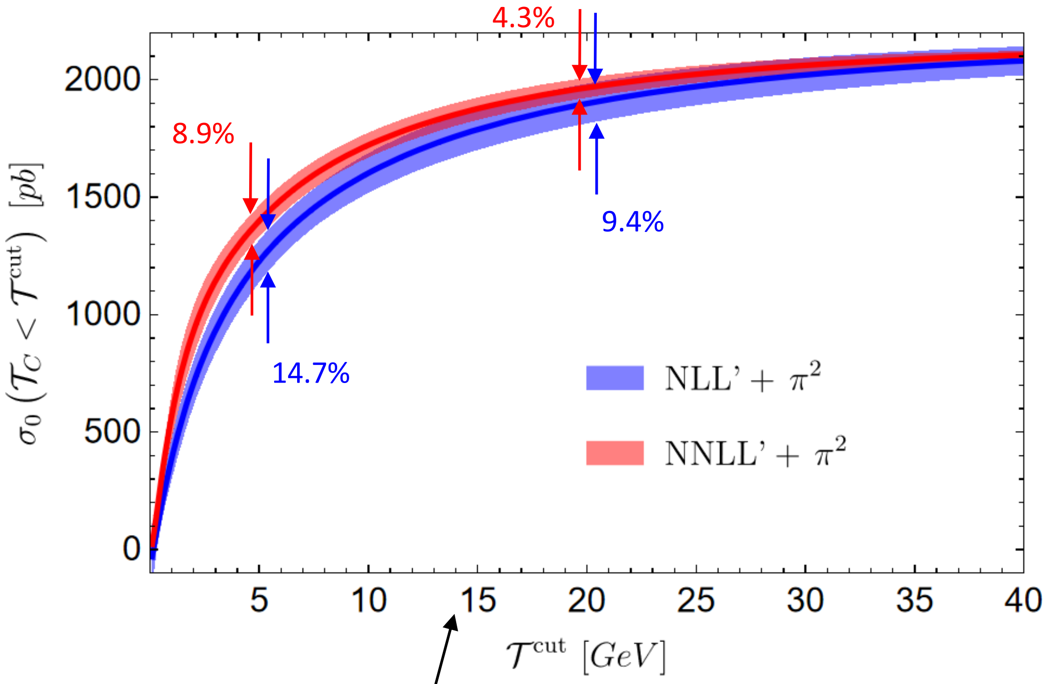
This cancellation was larger for NLL' than NNLL'.



Jet Veto Predictions for Drell-Yan

$R = 0.5 \qquad 80\text{GeV} \leq Q \leq 100\text{GeV}$





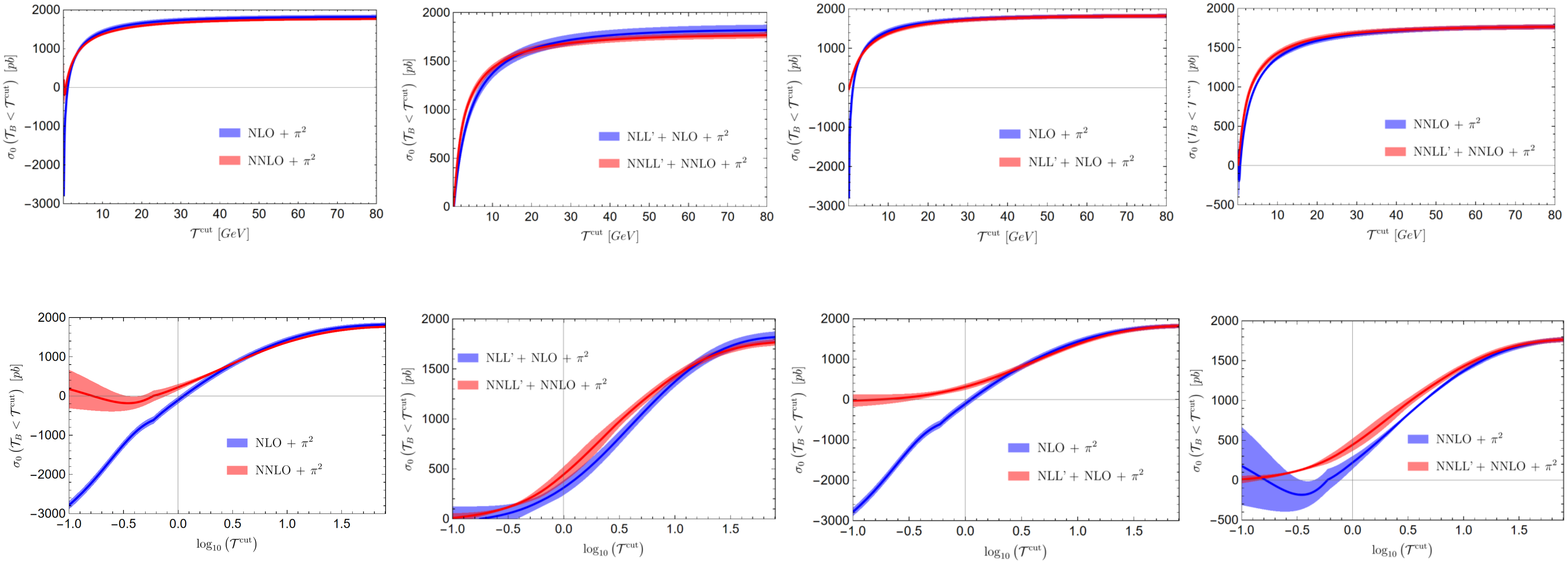
PRELIMINARY

Needs to be matched to FO, to come very soon!

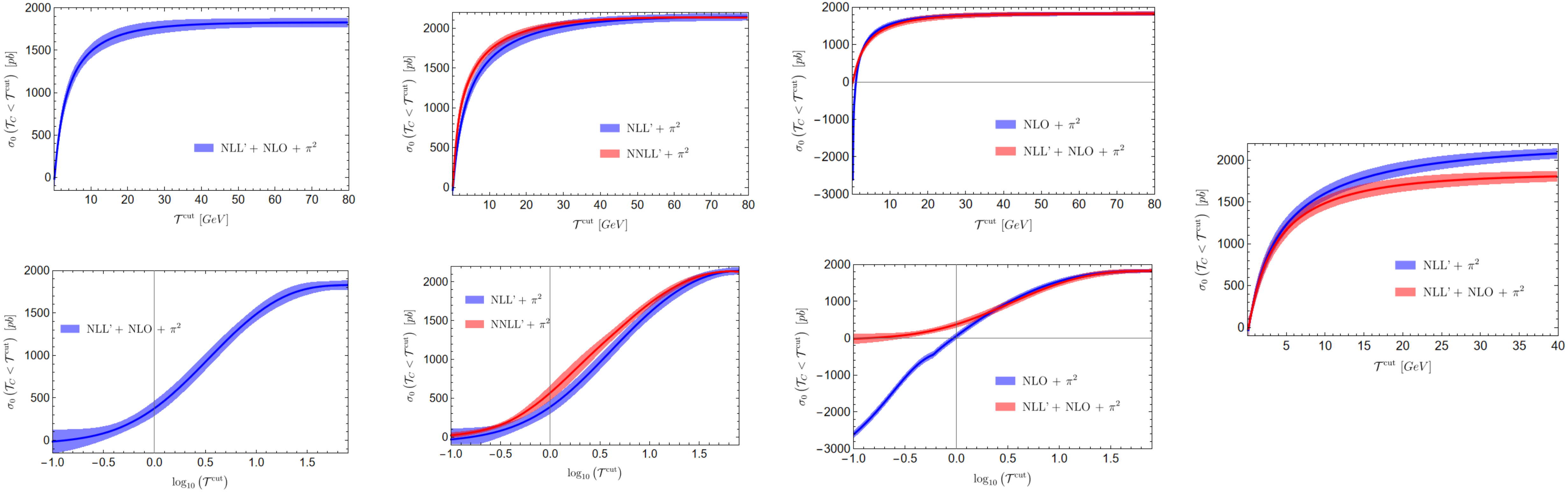
Summary

- Produced cutting edge NLL’ + NLO + π^2 and NNLL’ + NNLO + π^2 predictions for τ_B
- Produced cutting edge NLL’ + π^2 and NNLL’ + π^2 predictions for τ_c, in the process of matching to FO
- Demonstrated the need to perform resummation when tight cuts on τ_B produce unphysical FO predictions
- The next key step is to compare these high precision results against experimental data

Additional: All final plots τ_B



Additional: All final plots τ_C



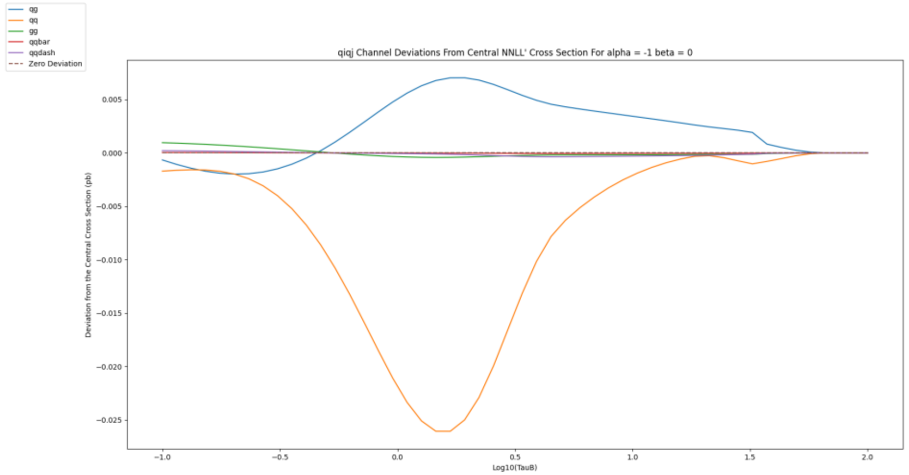
Additional: Parameter Values

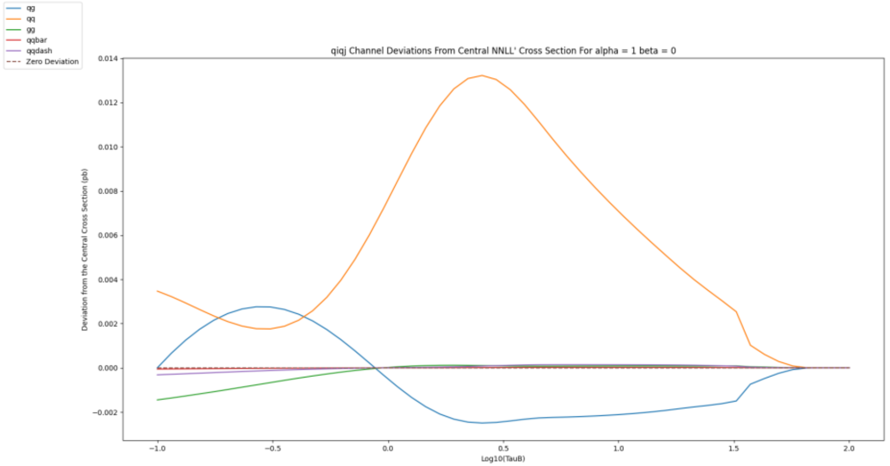
Description	Parameter	Value	Unit
Z boson mass	M_Z	91.1876	GeV
Z boson width	Γ_Z	2.4952	GeV
Centre of mass energy	E_{COM}	13	TeV
Jet Radius	R	0.5	N/A
Sin squared of weak mixing angle	$\sin^2(\theta_W)$	0.22301383694753507	N/A
Fine structure constant	α_{EM}	0.0075652121285480845	N/A
NLO strong coupling at M_Z	$\alpha_s^{\text{NLO}}(M_Z)$	0.120	N/A
NNLO strong coupling at M_Z	$\alpha_s^{\text{NNLO}}(M_Z)$	0.118	N/A

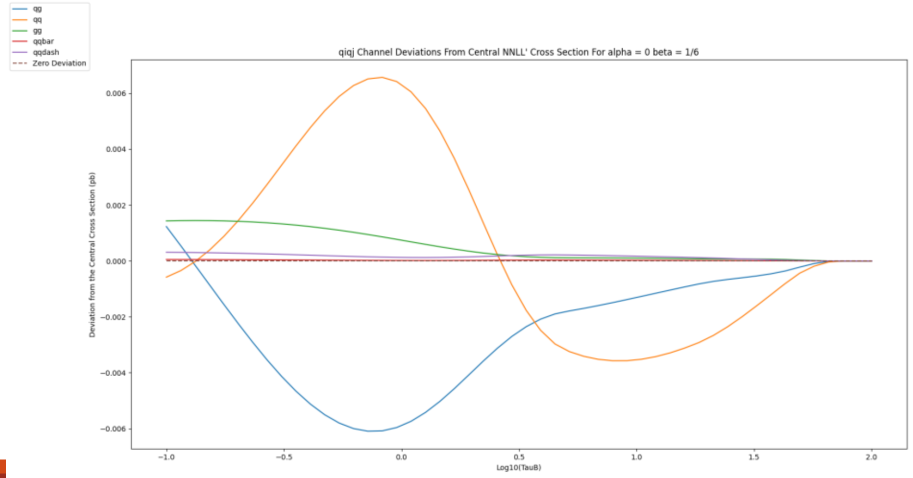
PDF Set for NLL’ + NLO: MSHT20nlo_as120

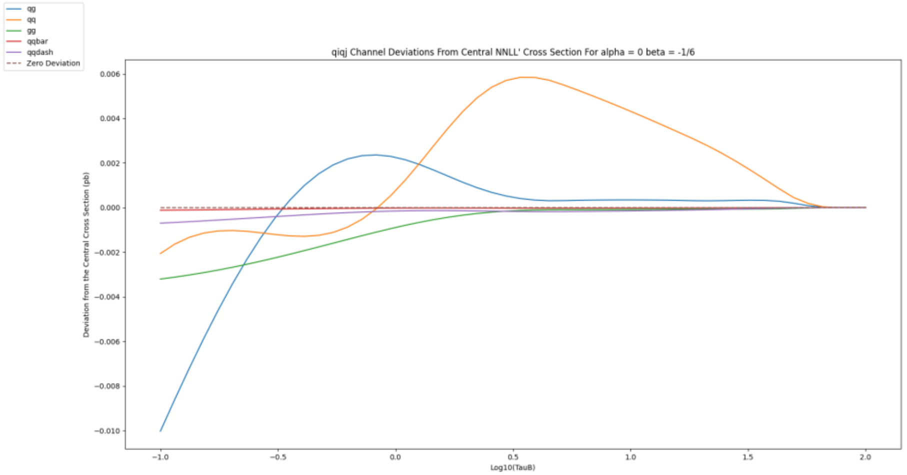
PDF Set for NNLL’ + NNLO: MSHT20nnlo_as118

Additional: qiqj Channel Breakdown

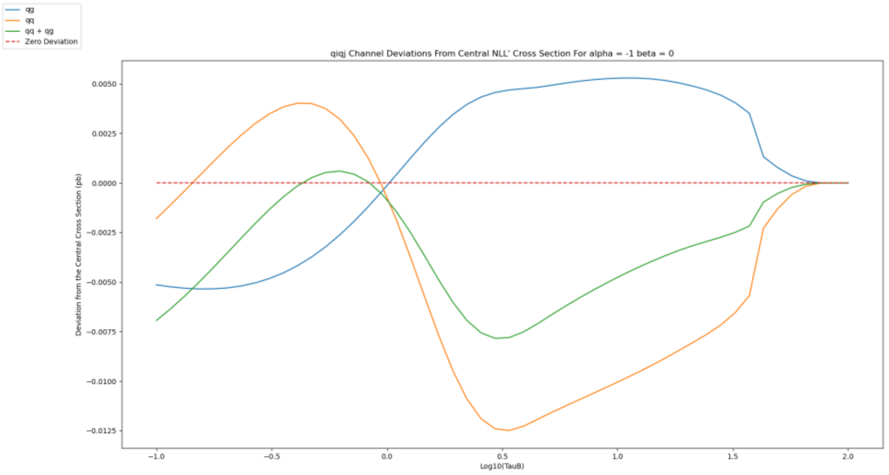


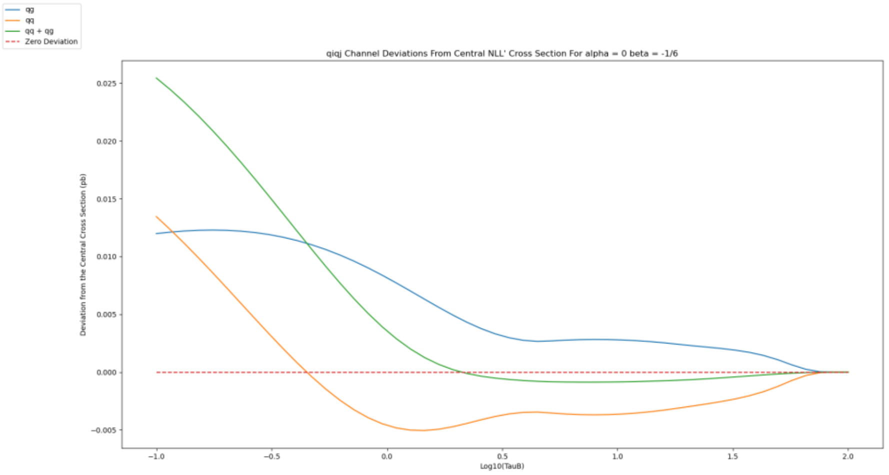


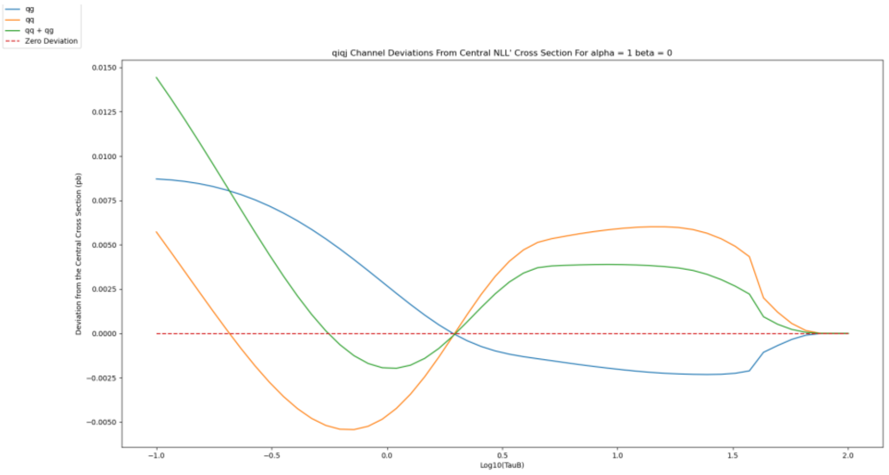


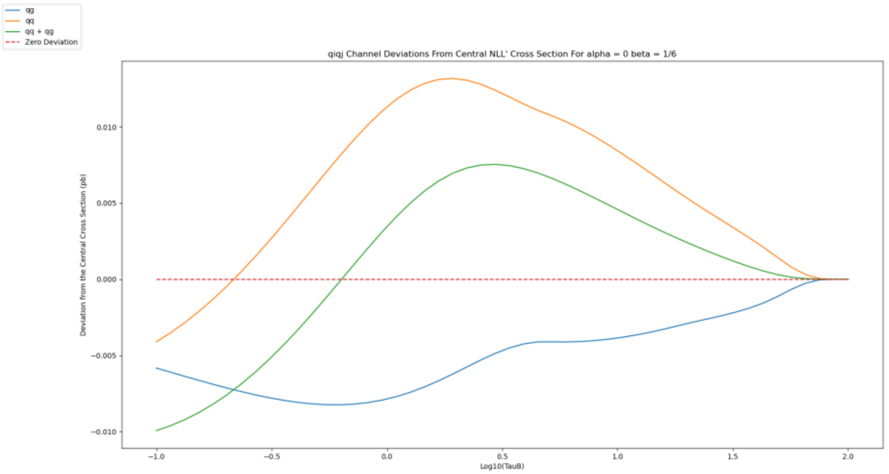


Additional: qiqj Channel Breakdown

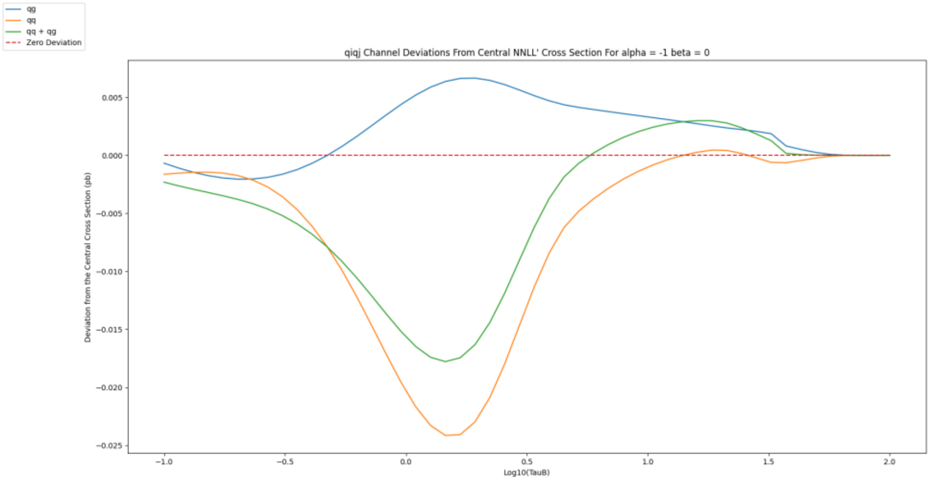


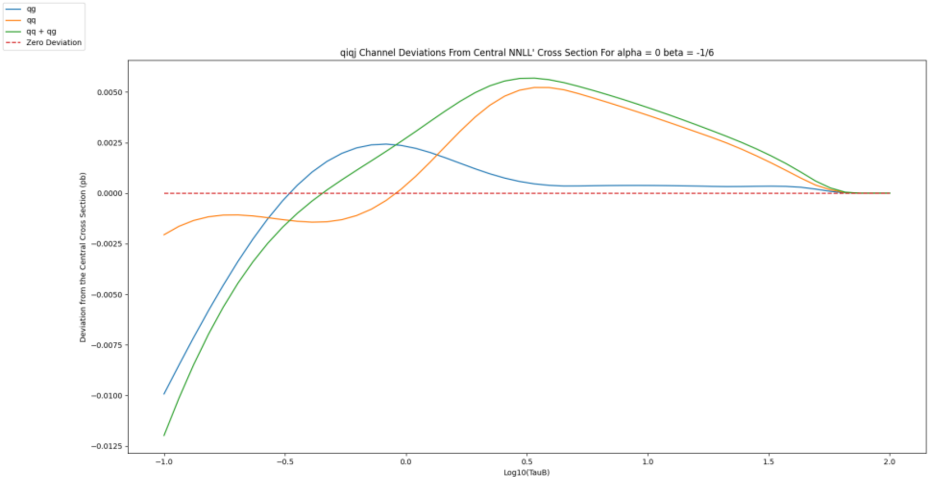


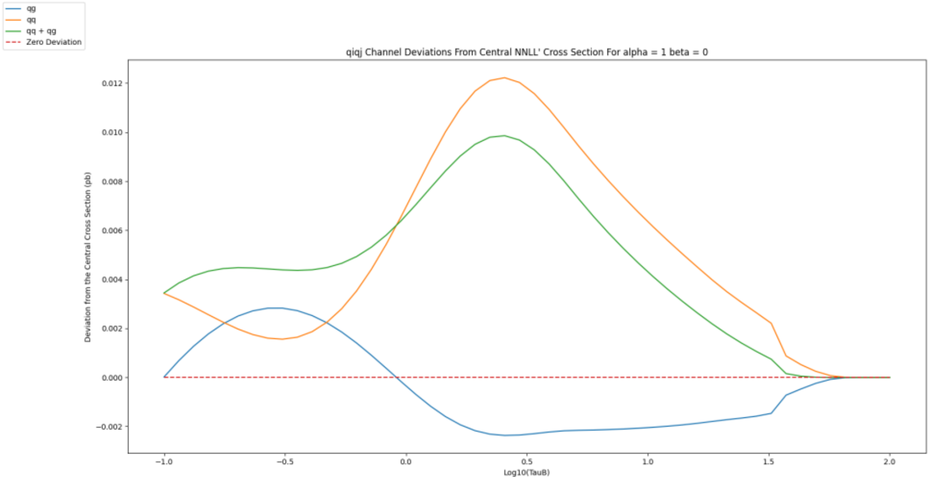


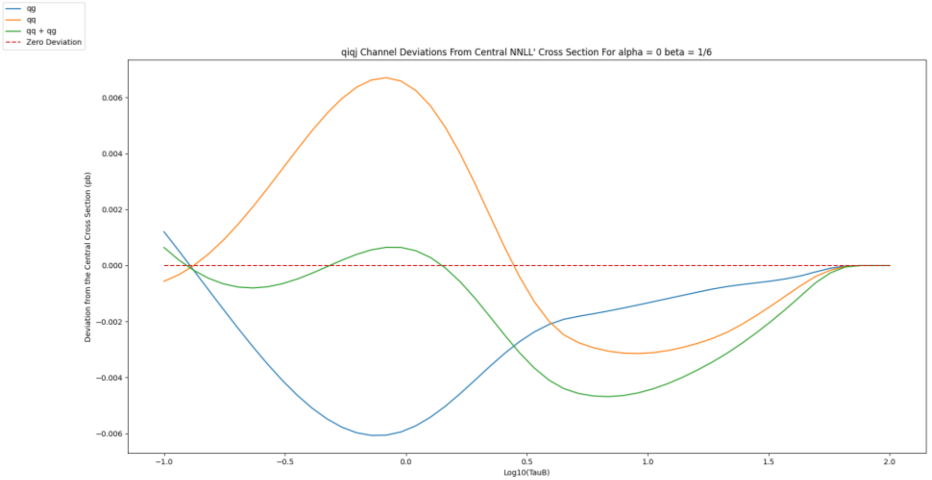


Additional: qiqj Channel Breakdown

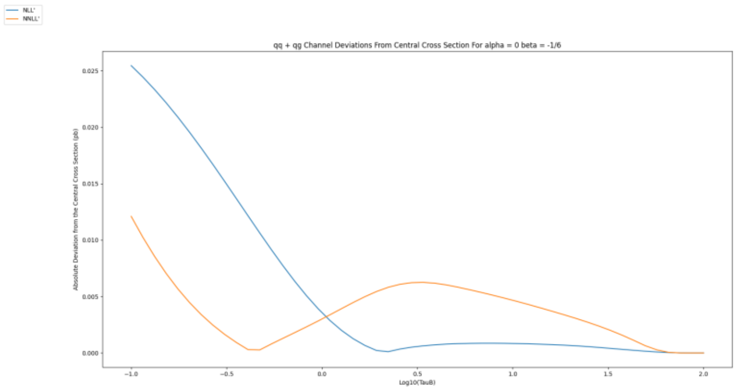


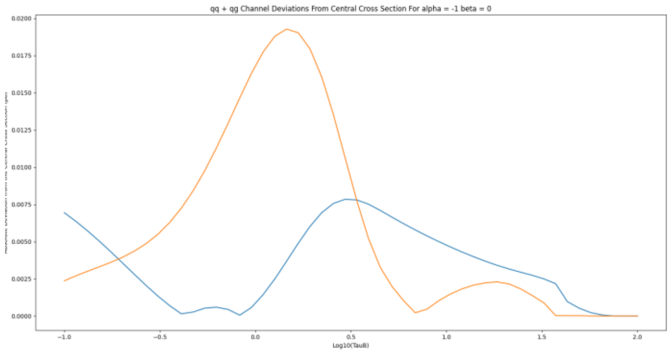


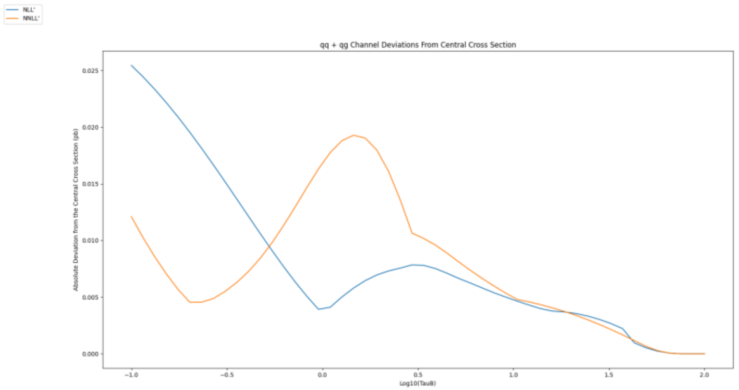


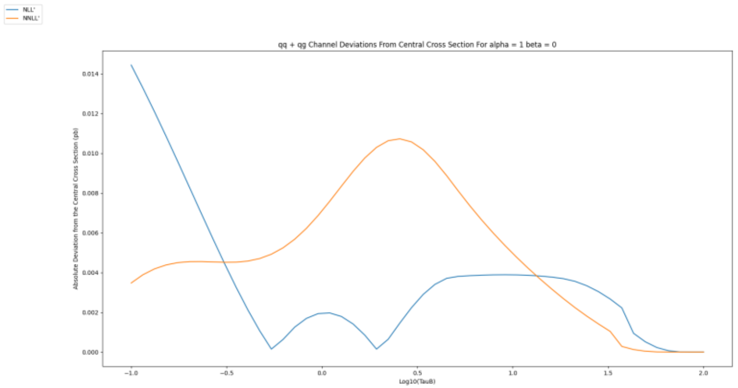


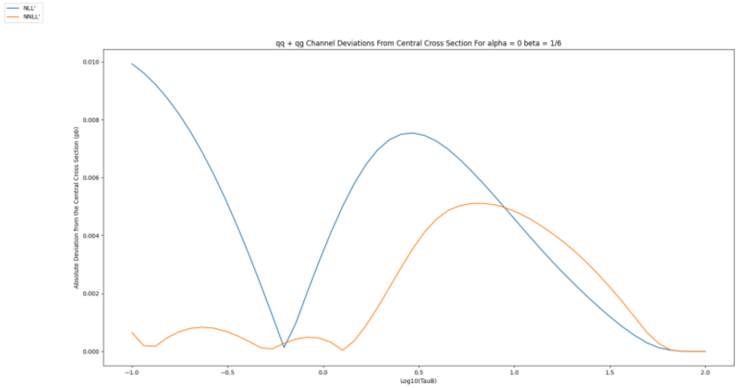
Additional: qiqj Channel Breakdown



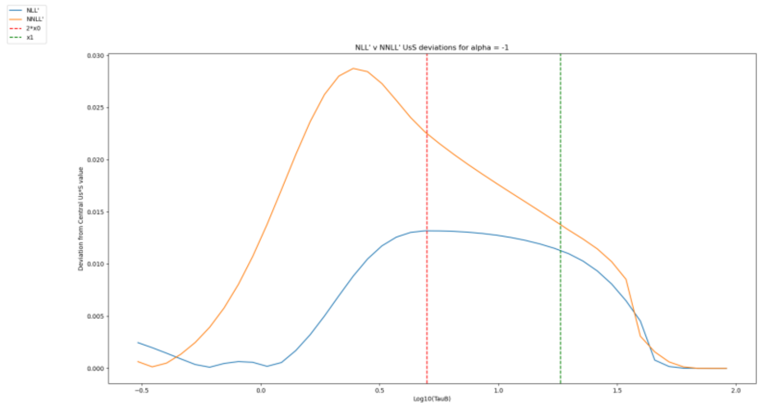


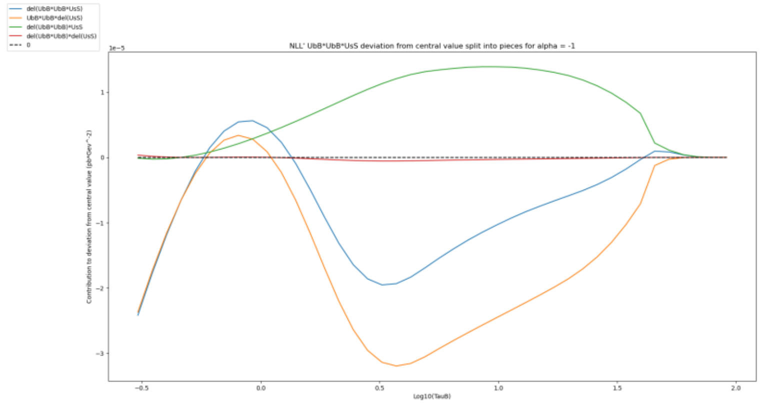


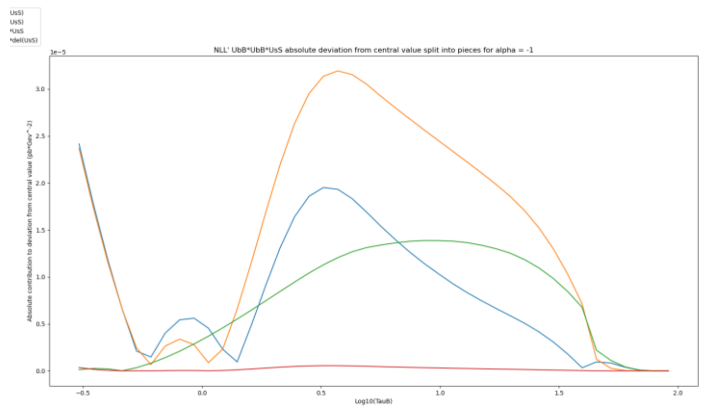


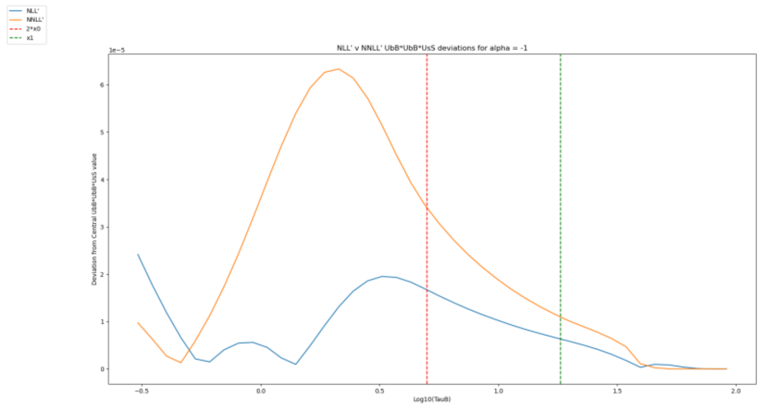


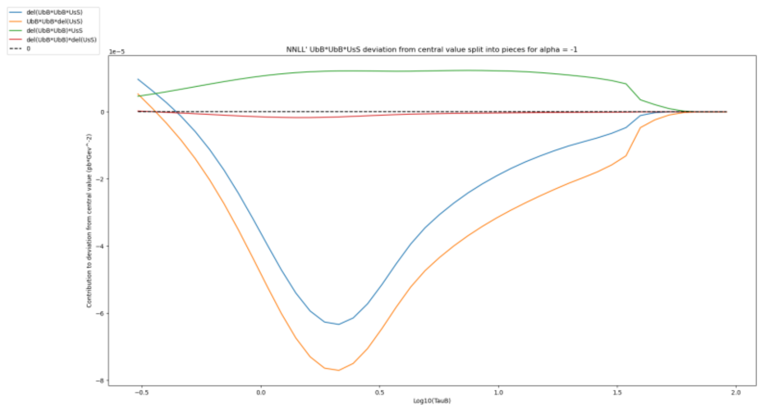
Additional: Factorisation Formula Error Breakdown alpha = -1

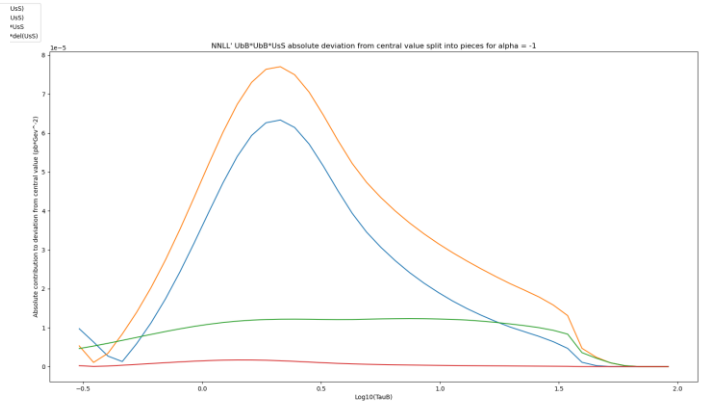












Additional: Factorisation Formula Error Breakdown alpha = 1