Fixed Order EW Effects at Colliders

Davide Napoletano, Muon Collider Workshop, 03/06/2021

Introduction

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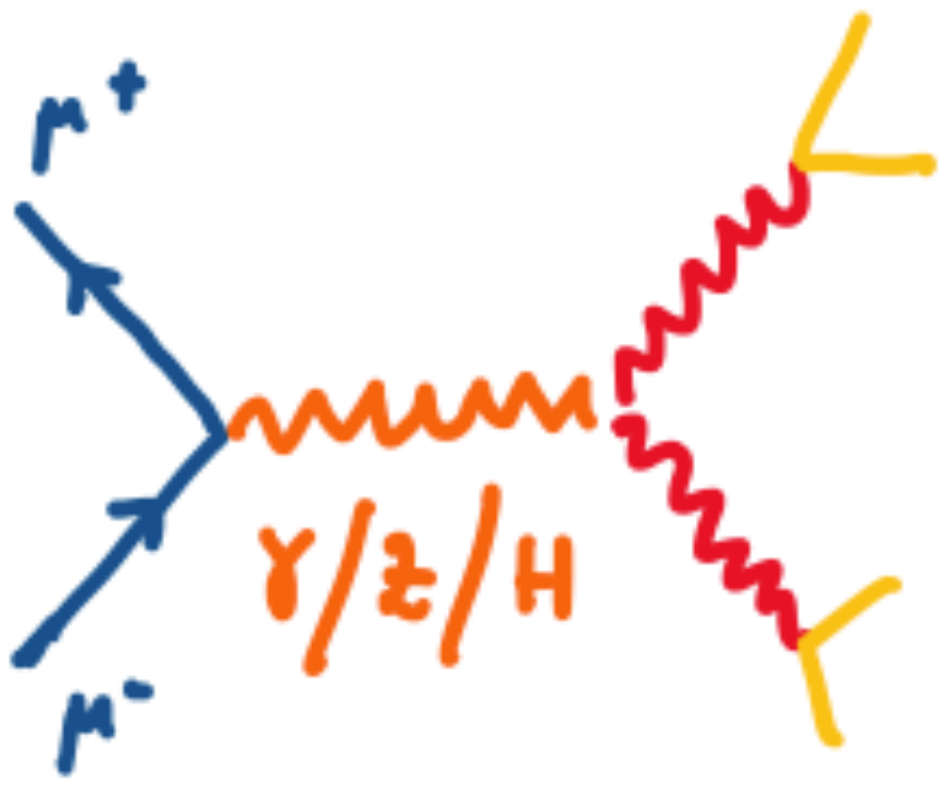

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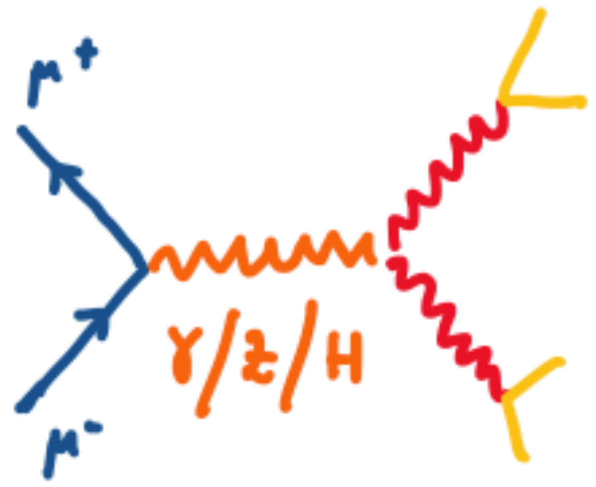

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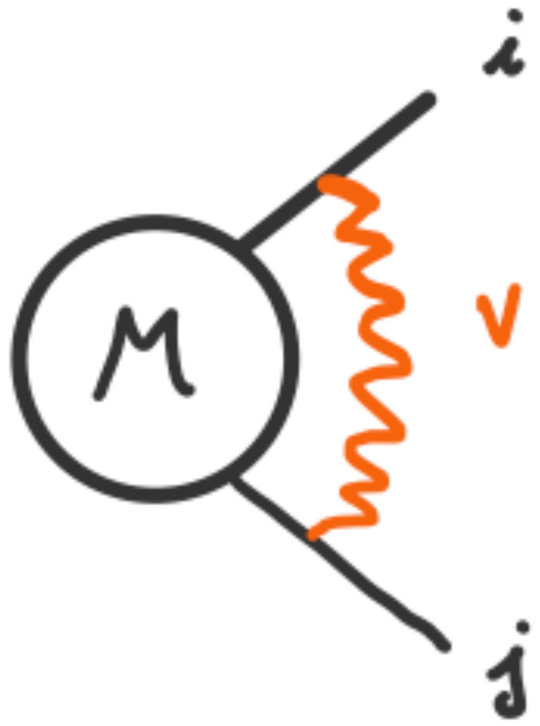

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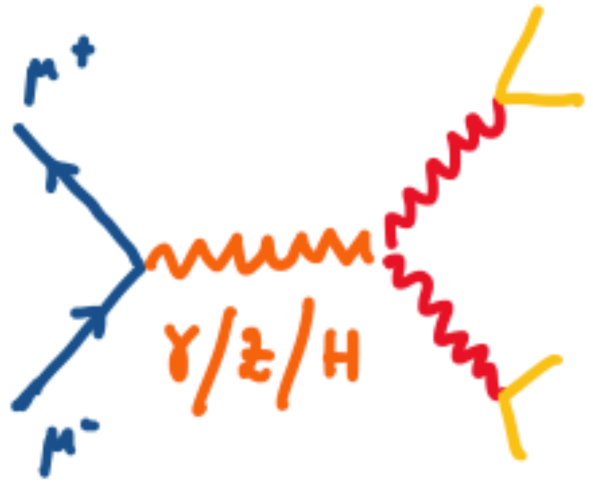

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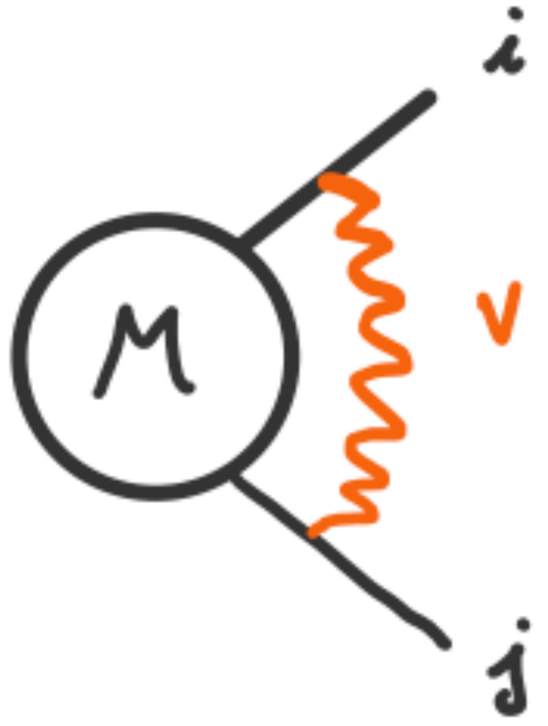

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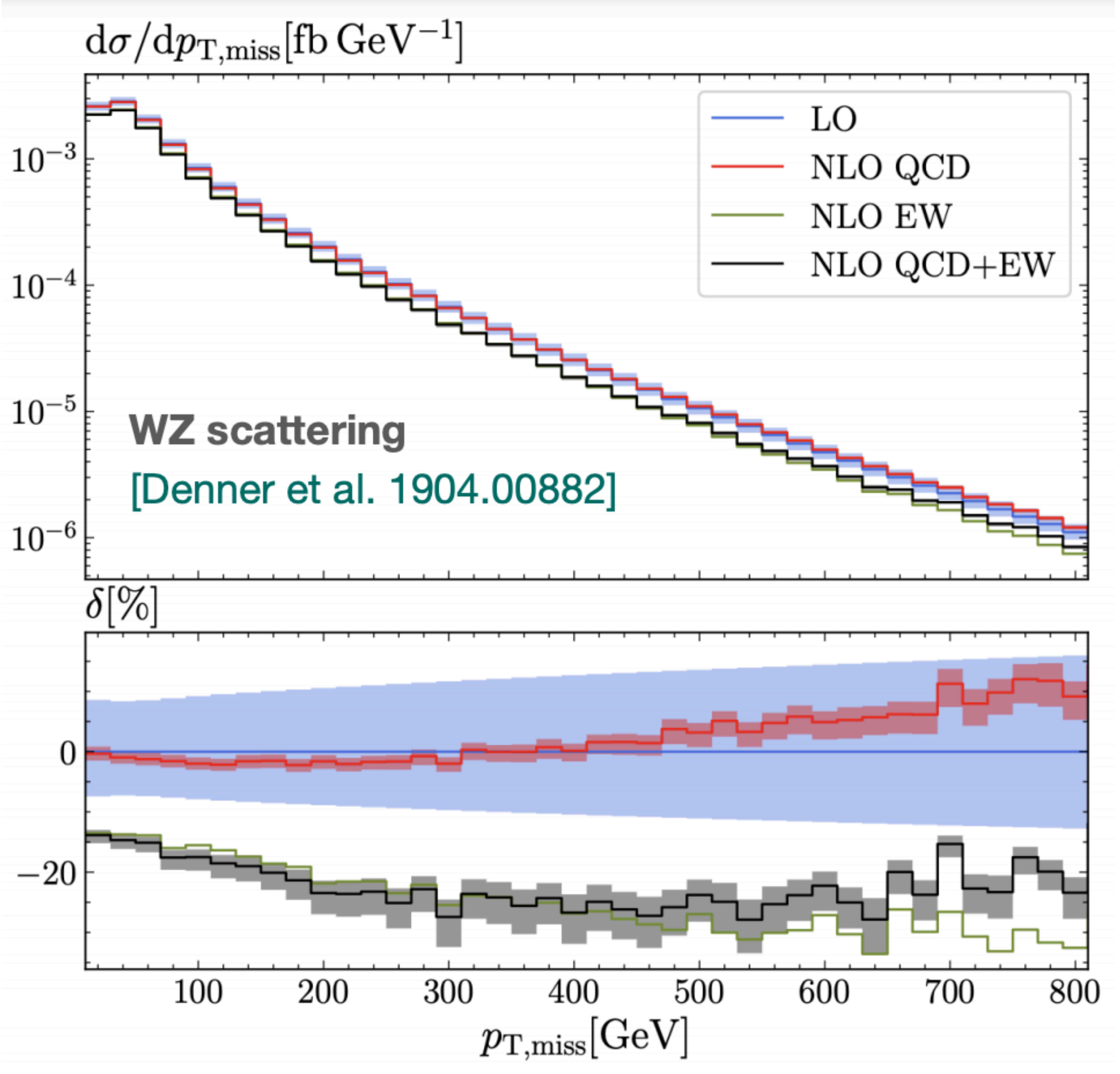
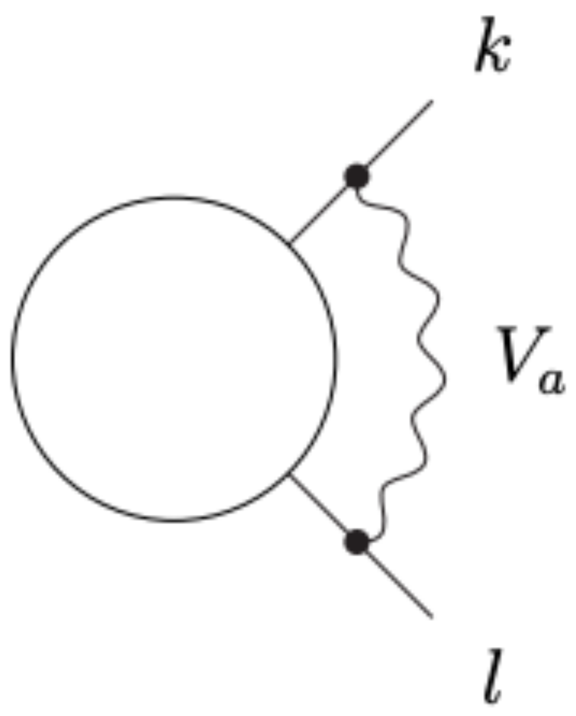


The High Energy Logs

Denner, Pozzorini *Eur.Phys.J.C* 18 (2001) 461-480

- **Where do these logs come from?**

$$\sum_{k=1}^{n}\sum_{l<k}\sum_{V_a=\mathrm{A,Z,W}^{\pm}}$$



$$= \sum_{k=1}^{n}\sum_{l<k}\sum_{V_a=A,Z,W^{\pm}}\int \frac{\mathrm{d}^4 q}{(2\pi)^4}\frac{-4ie^2 p_k p_l I^{V_a}_{i'_k i_k}(k) I^{\bar{V}_a}_{i'_l i_l}(l)\mathcal{M}_0^{i_1\ldots i'_k\ldots i'_l\ldots i_n}}{(q^2-M^2_{V_a})[(p_k+q)^2-m^2_{k'}][(p_l-q)^2-m^2_{l'}]}$$

$$= \frac{1}{2}\sum_{k=1}^{n}\sum_{l\neq k}\sum_{V_a=A,Z,W^{\pm}} I^{V_a}_{i'_k i_k}(k) I^{\bar{V}_a}_{i'_l i_l}(l)\mathcal{M}_0^{i_1\ldots i'_k\ldots i'_l\ldots i_n}[L(|r_{kl}|,M^2_{V_a}) - \delta_{V_a A} L(m_k^2,\lambda^2)]$$

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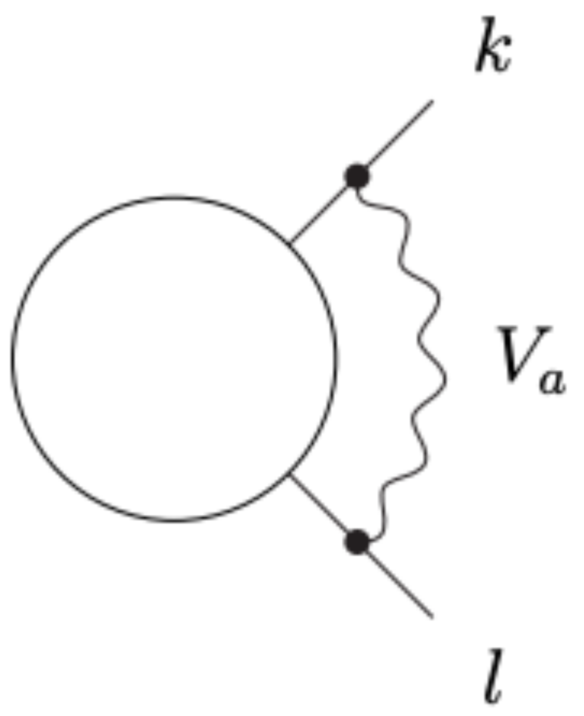

$$= \frac{1}{2}\sum_{k=1}^{n}\sum_{l\neq k}\sum_{V_a=A,Z,W^\pm} I^{V_a}_{i'_k i_k}(k) I^{\bar{V}_a}_{i'_l i_l}(l)\mathcal{M}_0^{i_1\ldots i'_k \ldots i'_l \ldots i_n}\left[L(|r_{kl}|, M^2_{V_a}) - \delta_{V_a A} L(m_k^2, \lambda^2)\right]$$

$$L(|r_{kl}|, M^2) := \frac{\alpha}{4\pi}\log^2\frac{r_{kl}}{M^2}$$

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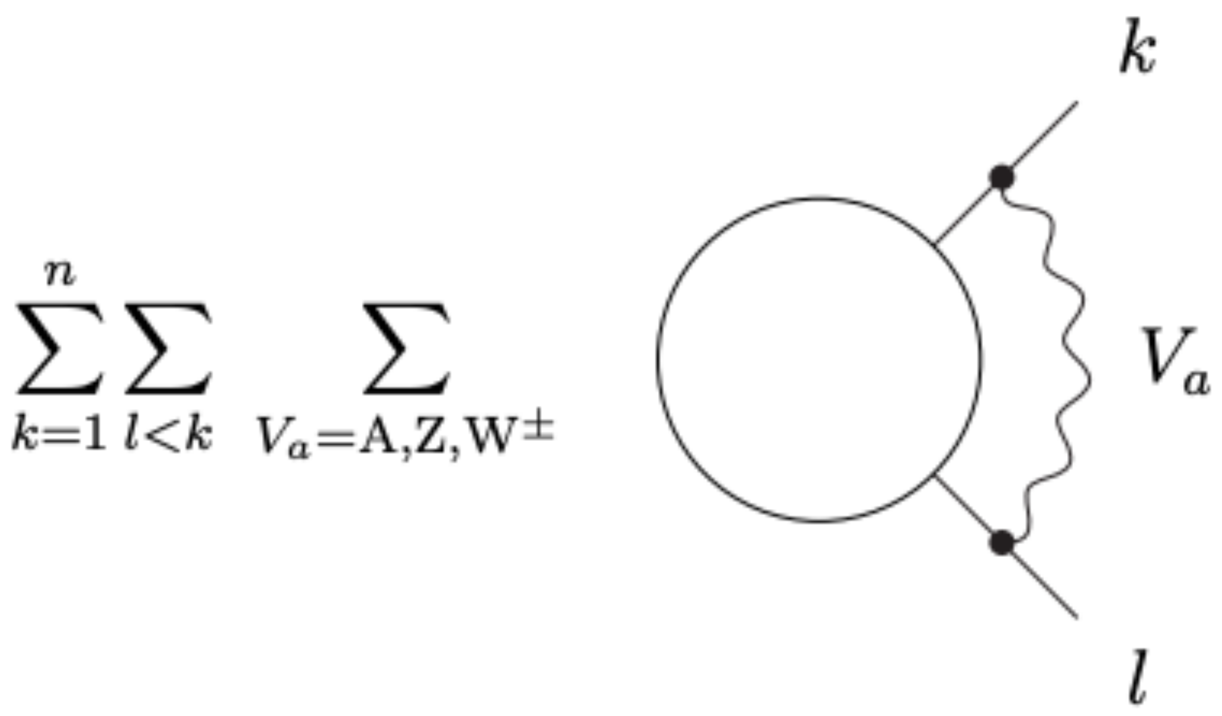
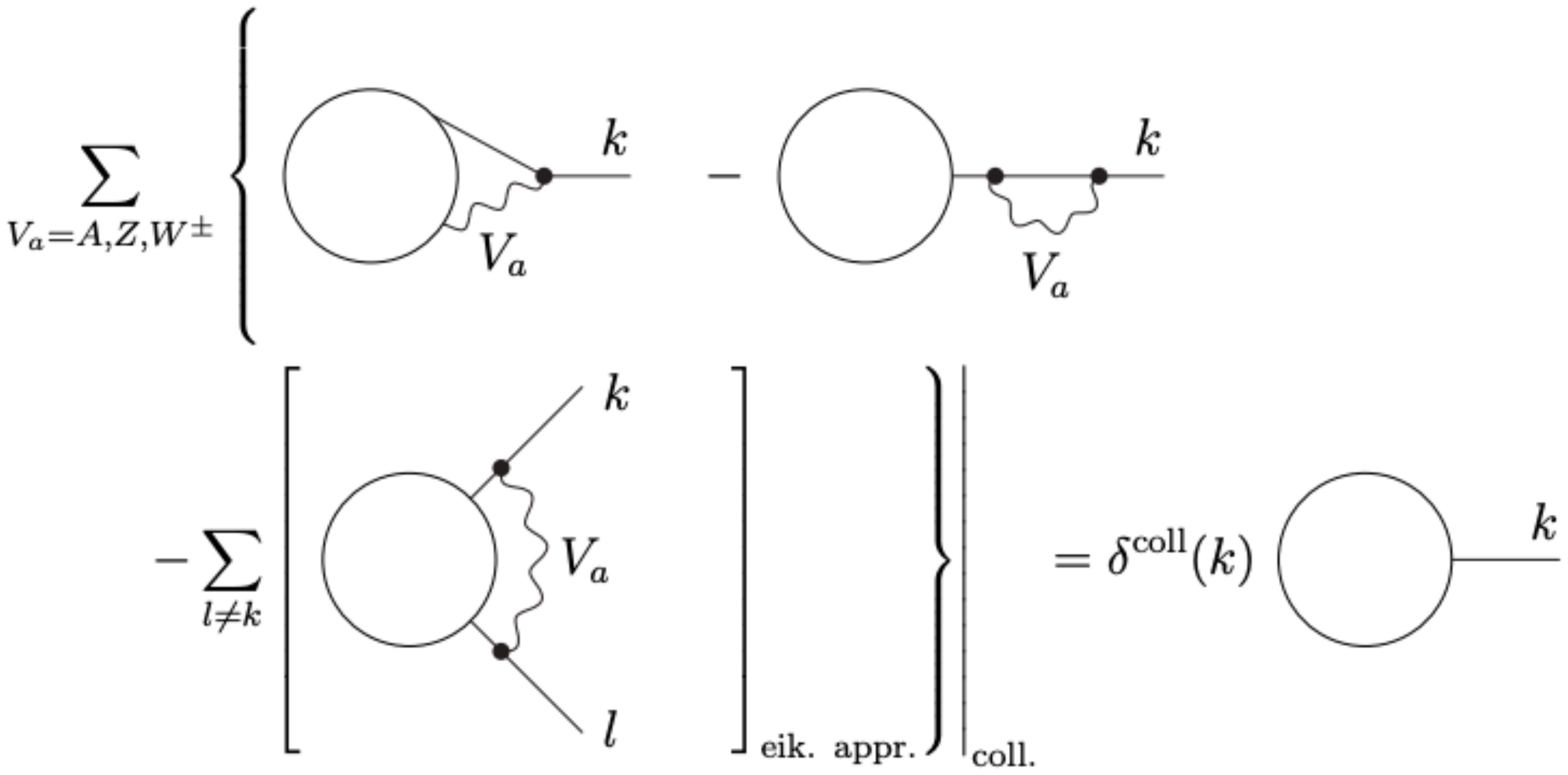
Denner, Pozzorini *Eur.Phys.J.C* 18 (2001) 461-480

- **Where do these logs come from?**



Double Logs



Single Logs

The High Energy Logs

Bothmann, DN, *Eur.Phys.J.C* 80 (2020) 11, 1024

- EW Sudakov approximation

Keep only high energy limit logs!

$$K_{\mathrm{NLL}}(\Phi) = 1 + \sum_c \Delta^c = 1 + \Delta^{\overline{\mathrm{LSC}}} + \Delta^{\mathrm{Z}} + \Delta^{\mathrm{SSC}} + \Delta^{\overline{\mathrm{C}}} + \Delta^{\mathrm{Yuk}} + \Delta^{\mathrm{PR}}$$

Double Logs ($\Delta^{\overline{\mathrm{LSC}}} + \Delta^{\mathrm{Z}}$)

Single Logs ($\Delta^{\mathrm{SSC}} + \Delta^{\overline{\mathrm{C}}} + \Delta^{\mathrm{Yuk}} + \Delta^{\mathrm{PR}}$)

The High Energy Logs

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- **EW Sudakov approximation**

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$$\mathrm{d}\sigma^{\mathrm{LO\,+\,NLL}}(\Phi) = \mathrm{d}\Phi\,\mathcal{B}(\Phi)\;K_{\mathrm{NLL}}(\Phi)$$

EWSud @ FixedOrder

$$\mathrm{d}\sigma^{\mathrm{LO\,+\,NLL\,(resum)}}(\Phi) = \mathrm{d}\Phi\,\mathcal{B}(\Phi)\;K^{\mathrm{resum}}_{\mathrm{NLL}}(\Phi) = \mathrm{d}\Phi\,\mathcal{B}(\Phi)\;e^{(1-K_{\mathrm{NLL}}(\Phi))}$$

EWSud @ Resummed

The High Energy Logs

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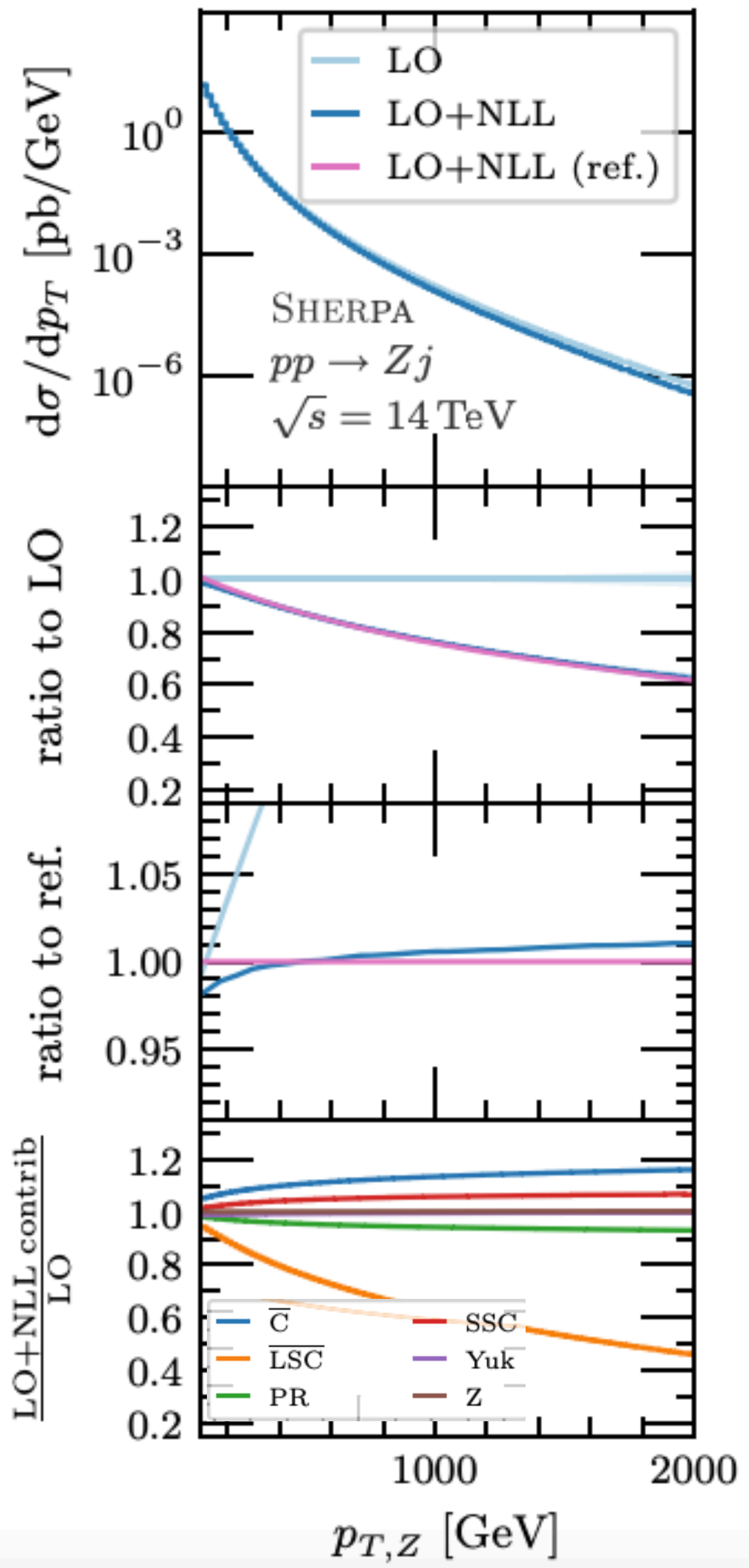

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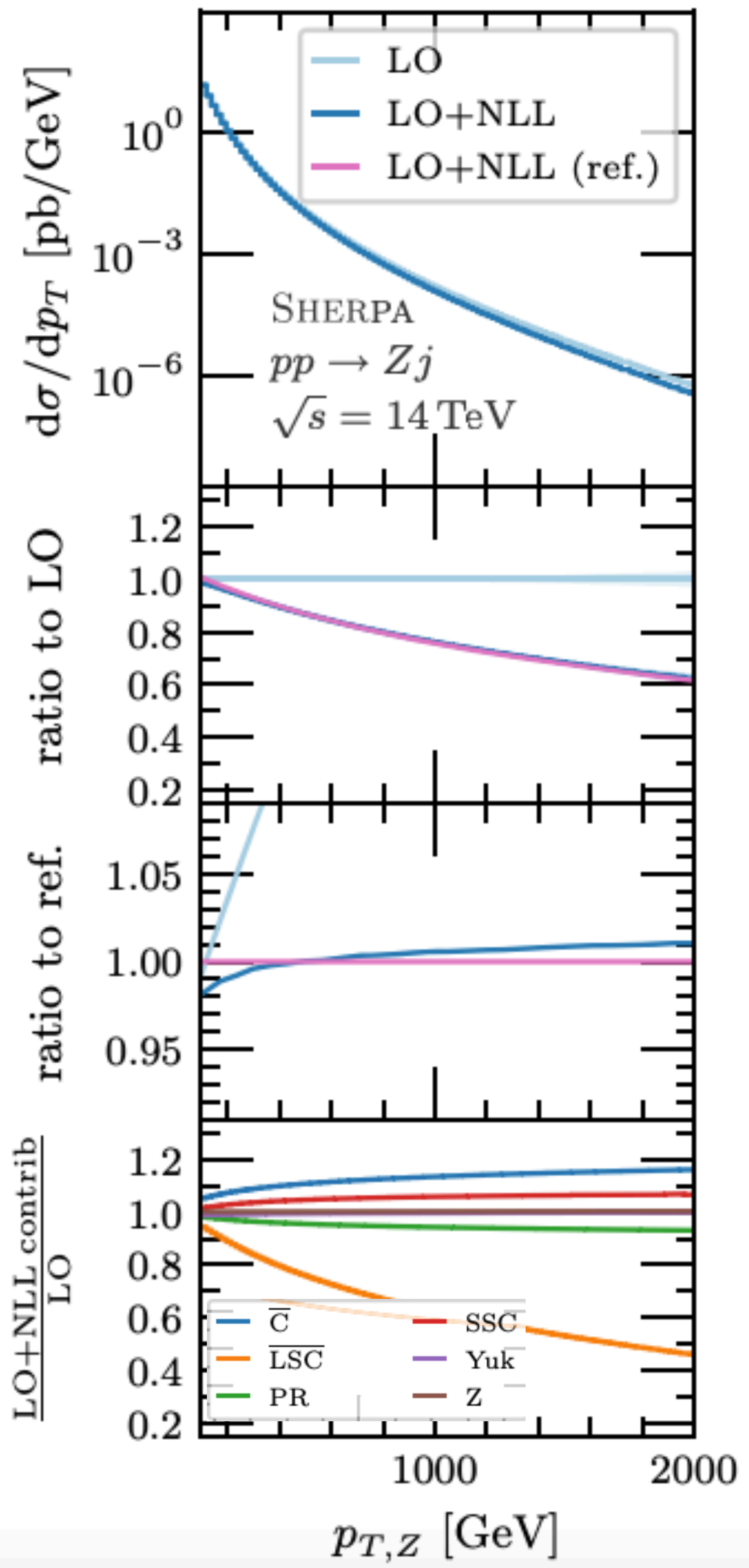
These logs can become quite large in the tail!



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  Z/H/W tagging? What happens at high energies?

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- How well the log approximation captures the full behaviour?

  How large high energies need to be?

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- How well the log approximation captures the full behaviour?

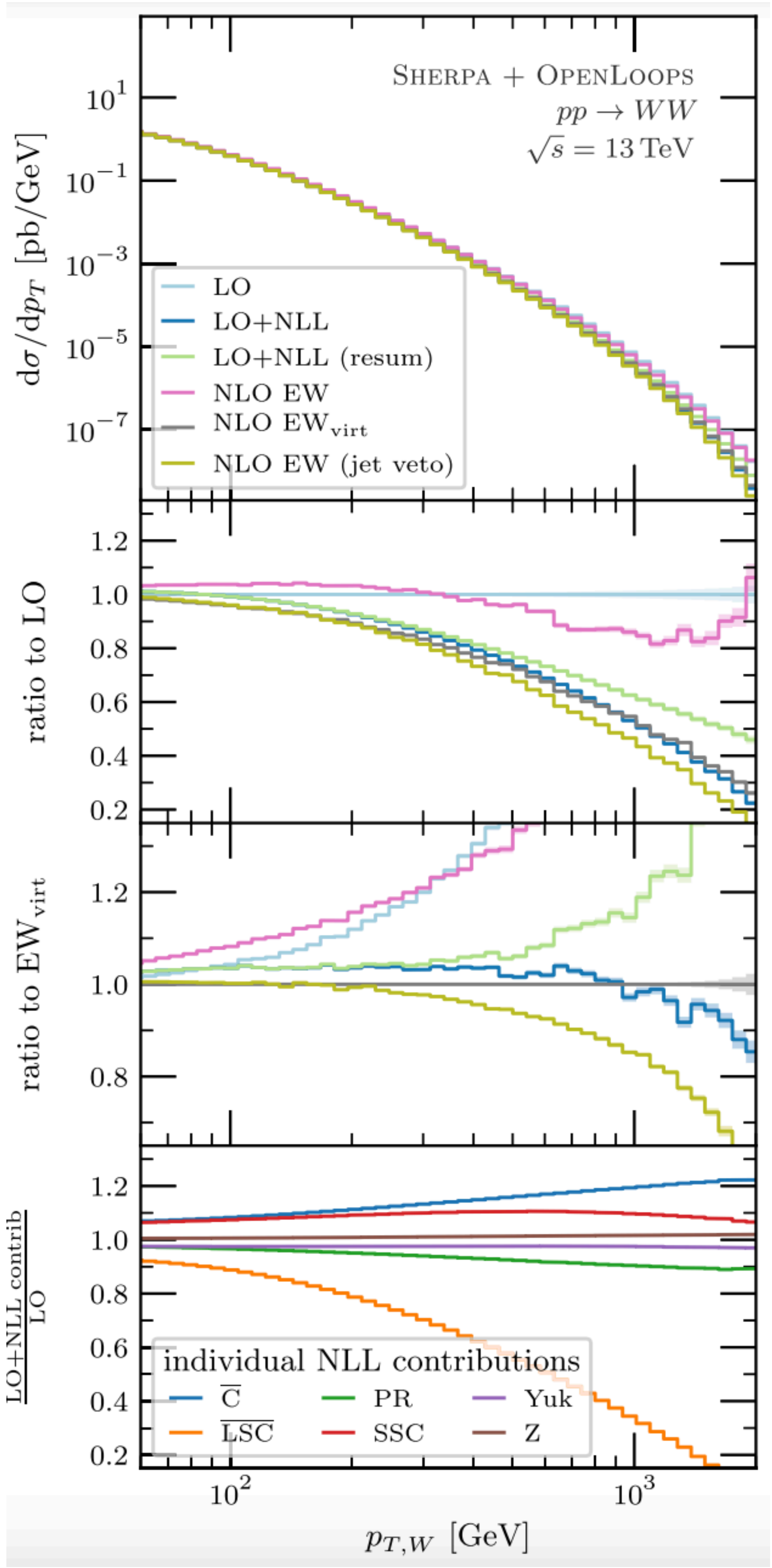
  How large high energies need to be?

- Are there other valid approximations?

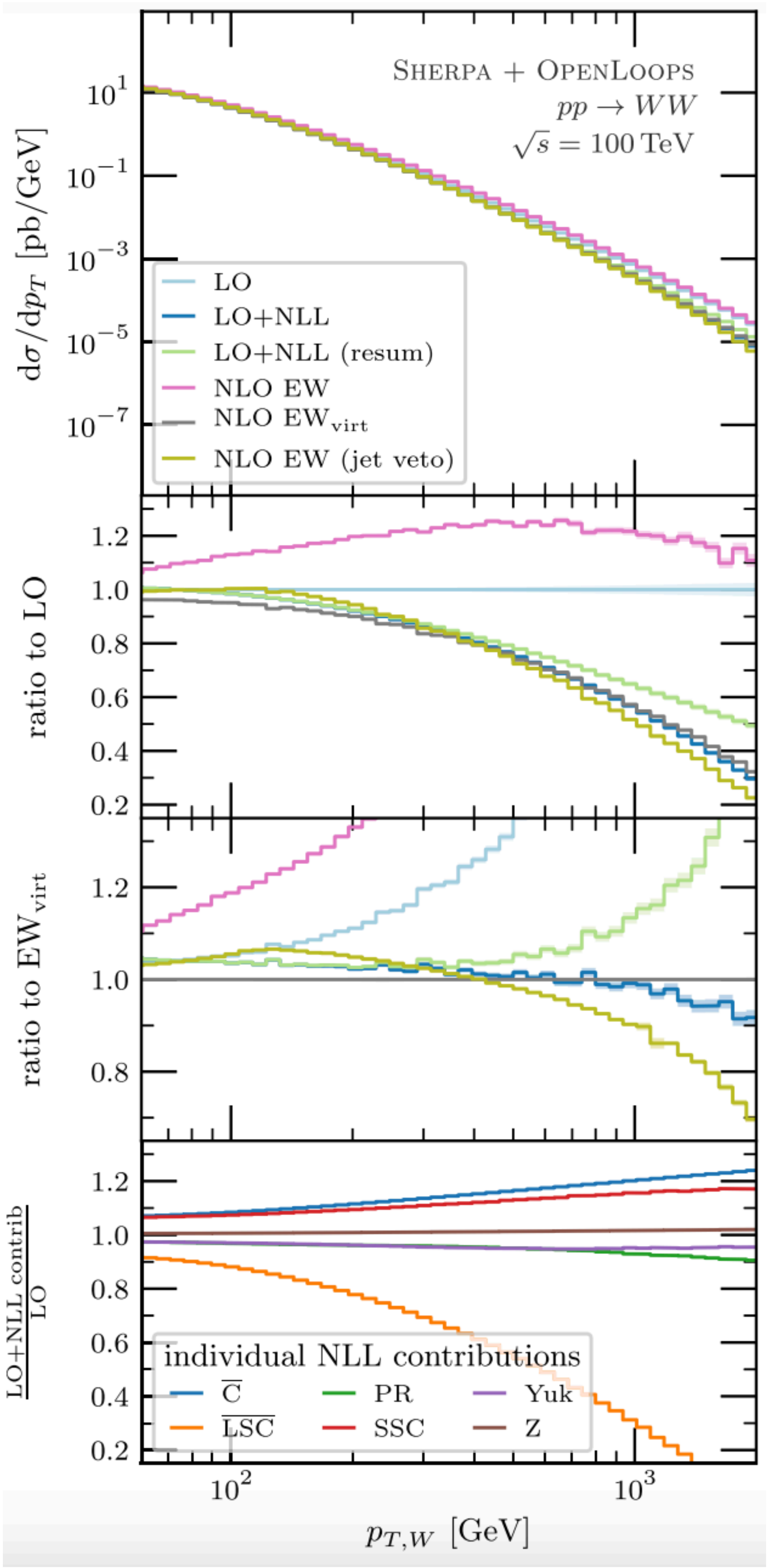
  Including only Virtuals and integrated dipoles? (EWVirt)

Kallweit et al. *JHEP* 04 (2016) 021

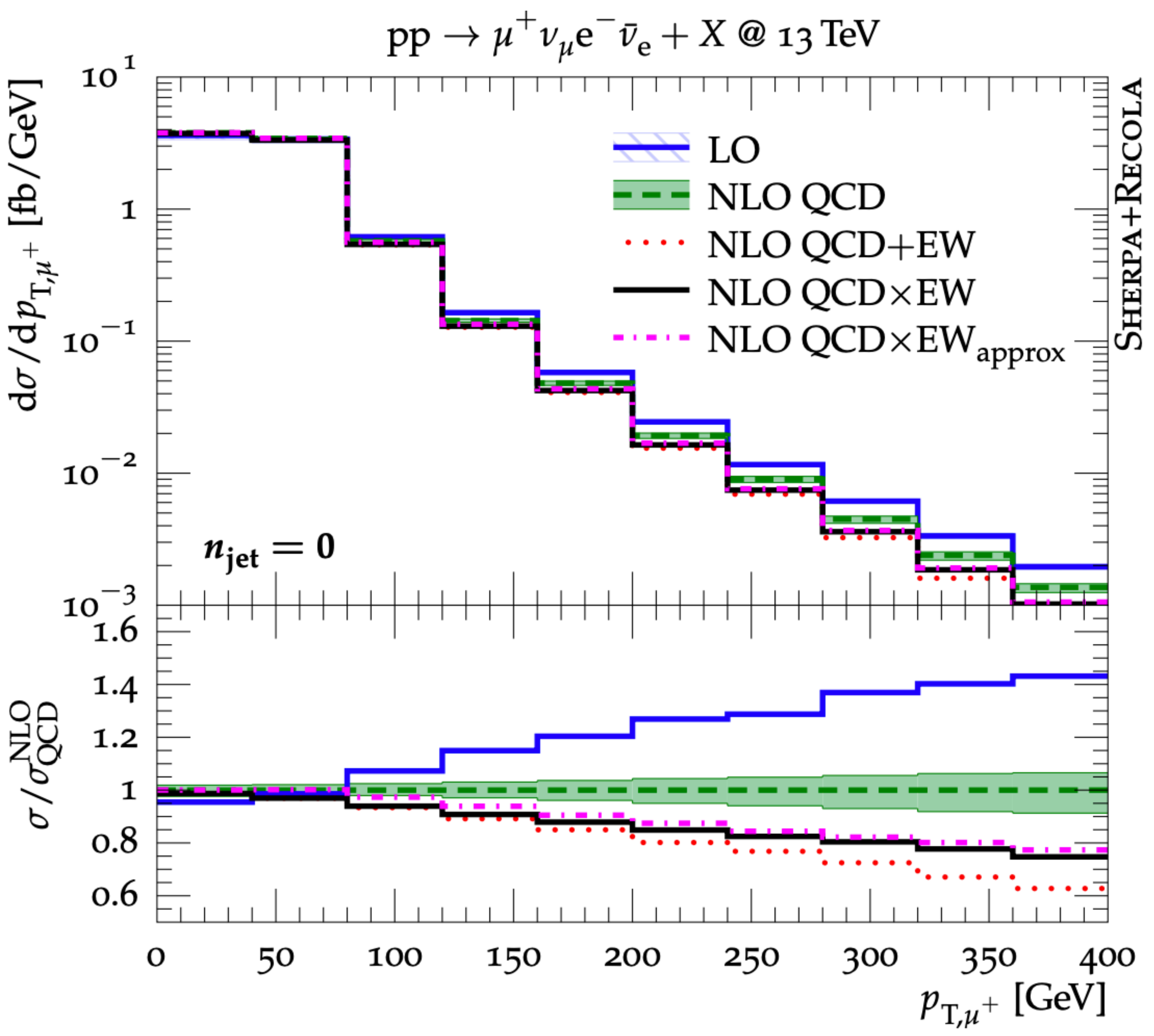
Comparing the approximations



- **Consistent picture across CoM energies**
- **Approximations capture the direction**
- **Real EW corrections are ~ - Virtual!**
- **Constant offset**



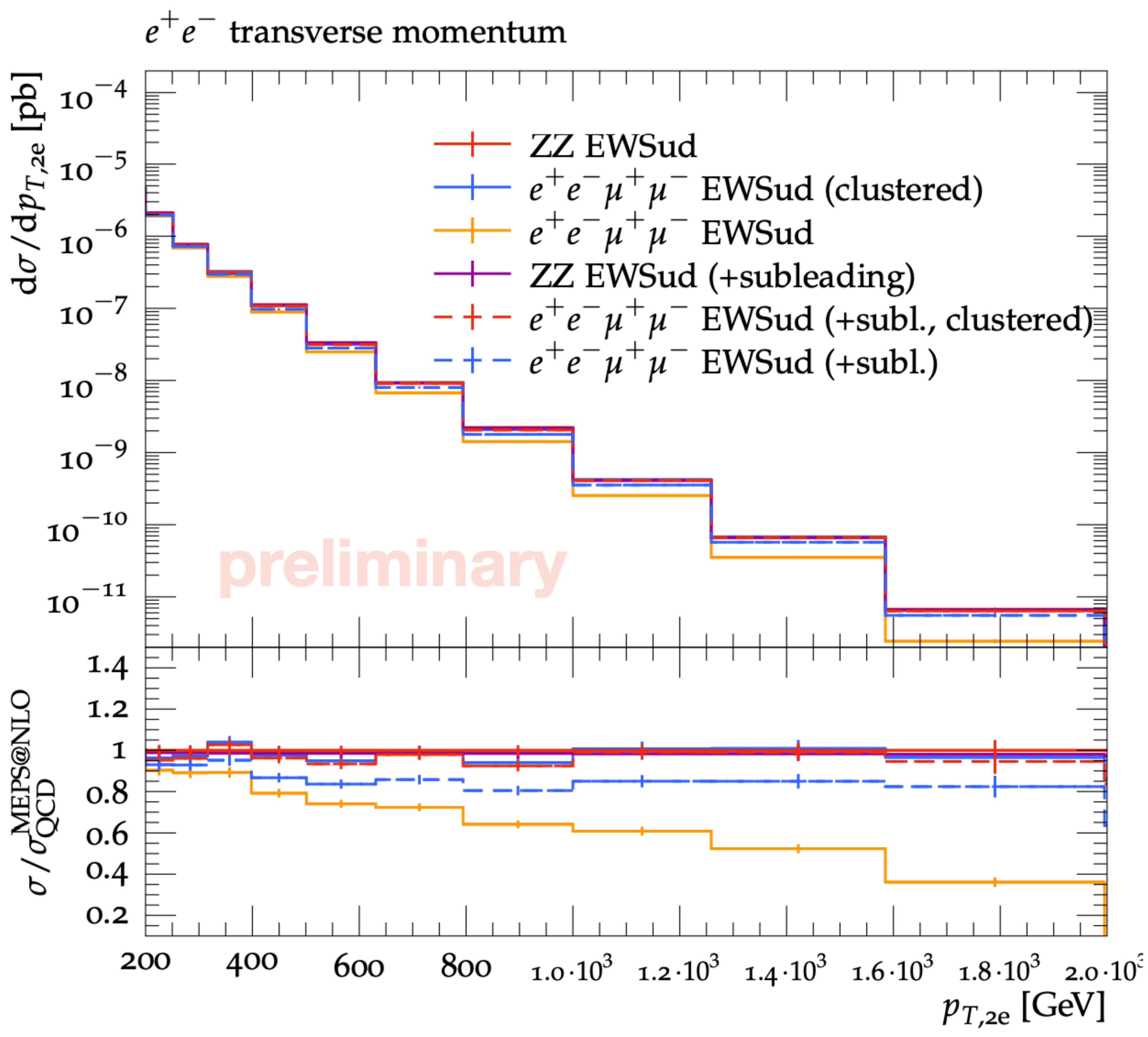
Matching of EW and QCD (more logs)



- **Beware of subtleties in combination**
- **Having a jet-veto can cause log diffs**
- **B (1+Kew) + NLO vs (B+NLO) (1+Kew)**

Bräuer et al. *JHEP* 10 (2020) 159

Resonances (more large logs)



$$L\left(\left|r_{kl}\right|, M^2\right) = L\left(s, M^2\right) + 2l\left(s, M^2\right)\log\frac{\left|r_{kl}\right|}{s} + L\left(\left|r_{kl}\right|, s\right)$$

$$L\left(\left|r_{kl}\right|, M^2\right) := \frac{\alpha}{4\pi}\log^2\frac{r_{kl}}{M^2}$$

- **But decay particles can form small rkl**
- **Clustering helps solving this issue**
- **Need to be careful though, small pT jets can suffer from the same issue**

Conclusions

- **EW corrections can lead to large logarithmic effects in tails of distributions**
- **These become relatively more important the (QCD) cleaner the environment is**
- **Knowing at least the fixed order logs can help in providing approximations**
- **Given the particles being massive everything leads to a log!**