

THEORIST'S TOOLS FOR PRECISION PHYSICS

Jort Sinninghe Damsté, *University of Amsterdam*

Nikhef Jamboree, Amsterdam, December 16-17 2019

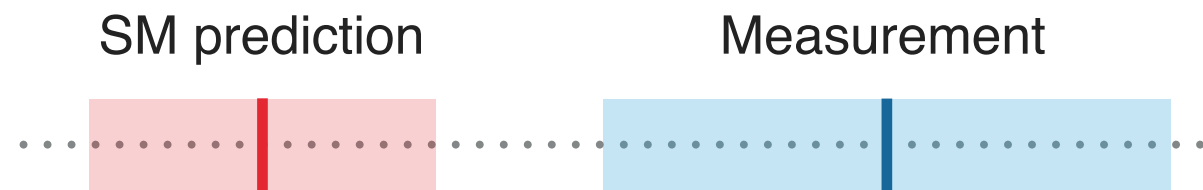


HIGH PRECISION ERA AT THE LHC

- ▶ Discoveries are generally made by comparison: test your hypothesis
- ▶ In particle physics we compare experimental data to theoretical predictions

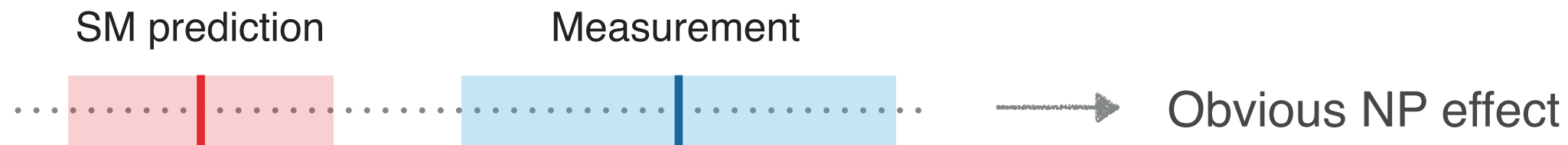
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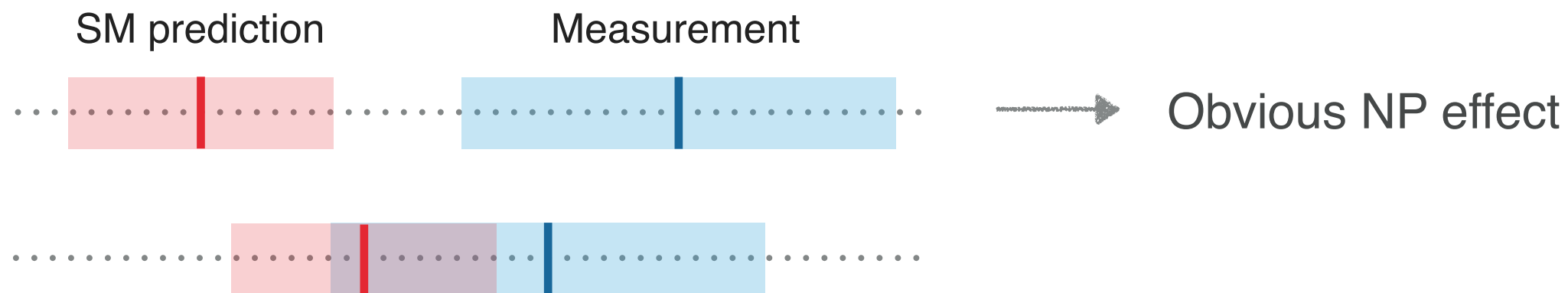
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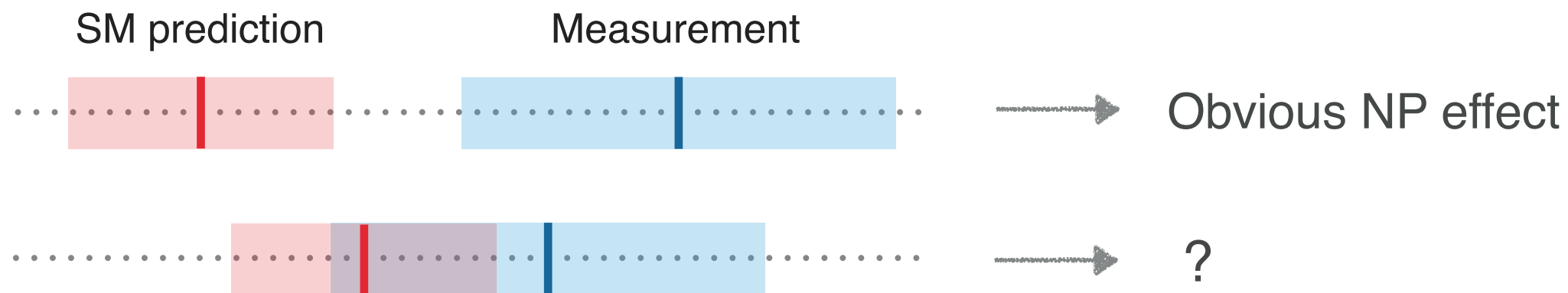
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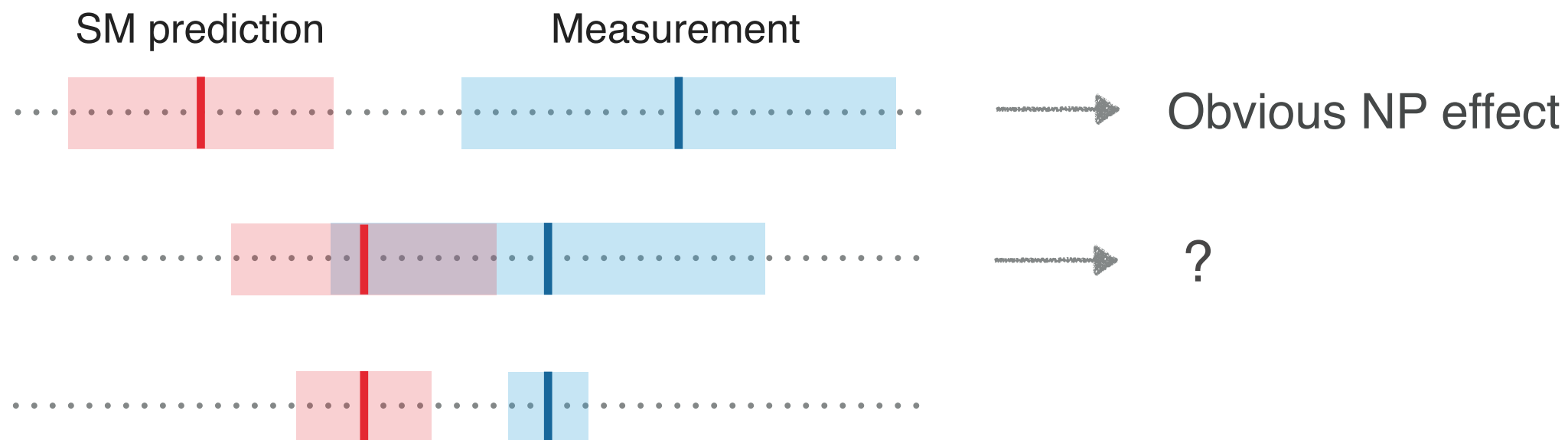
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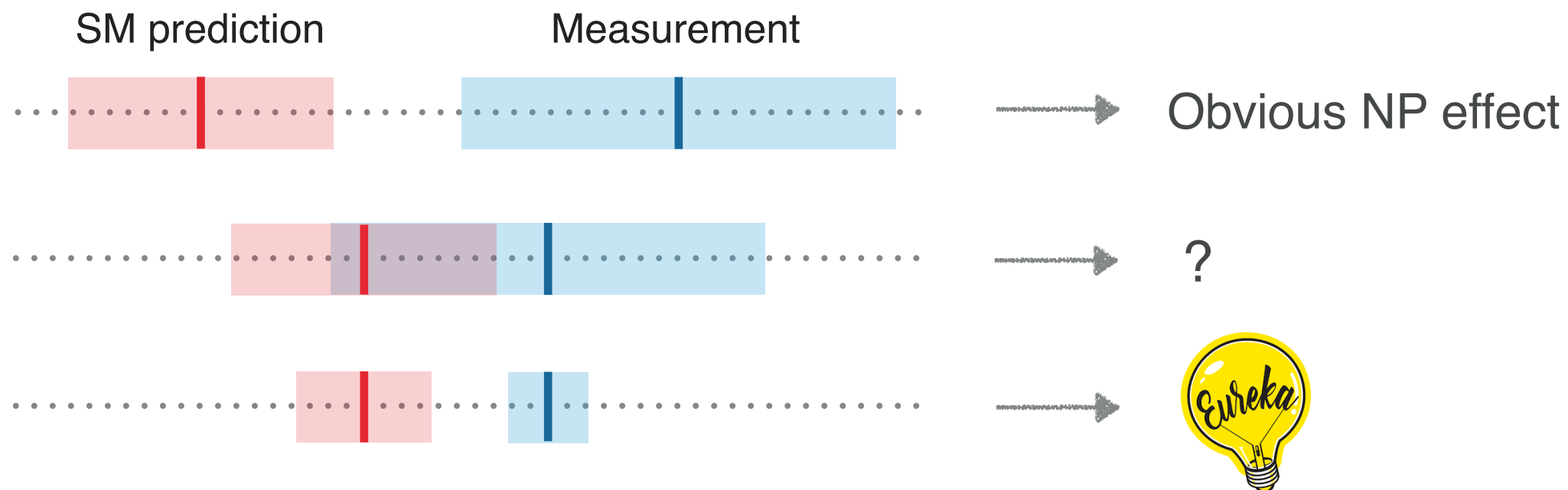
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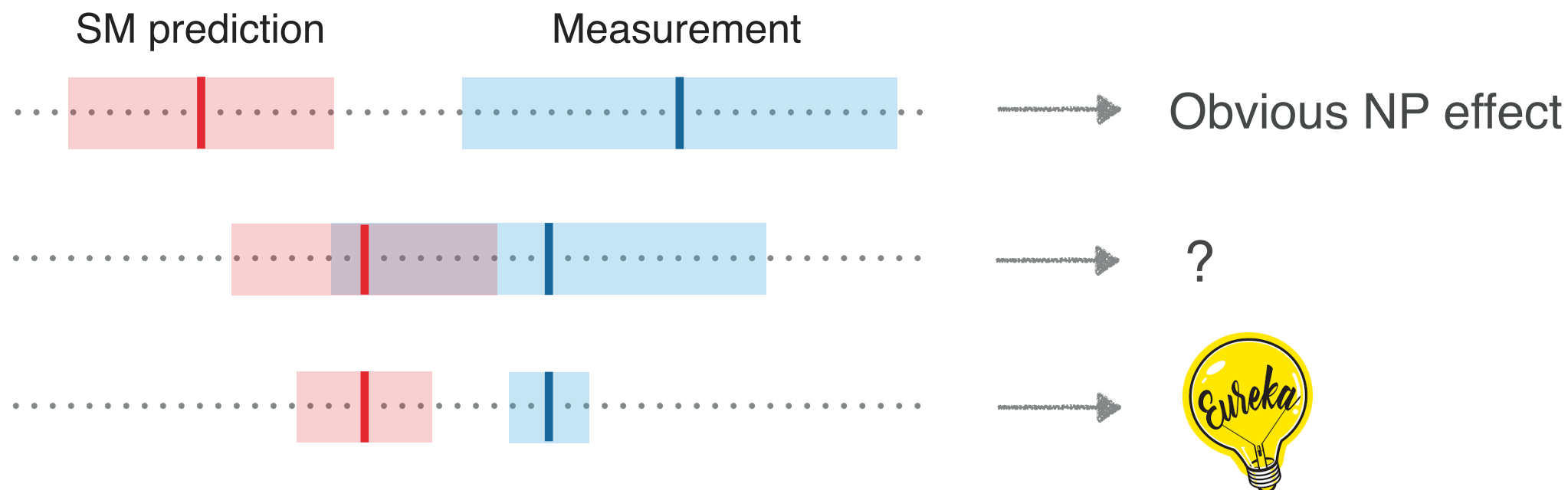
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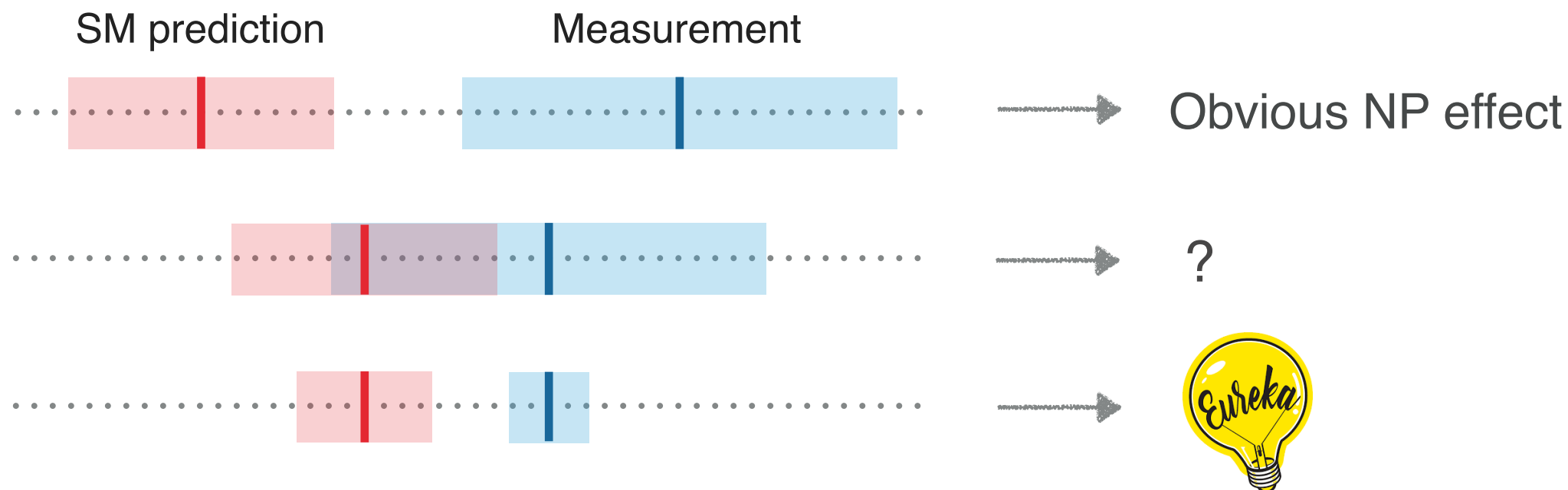
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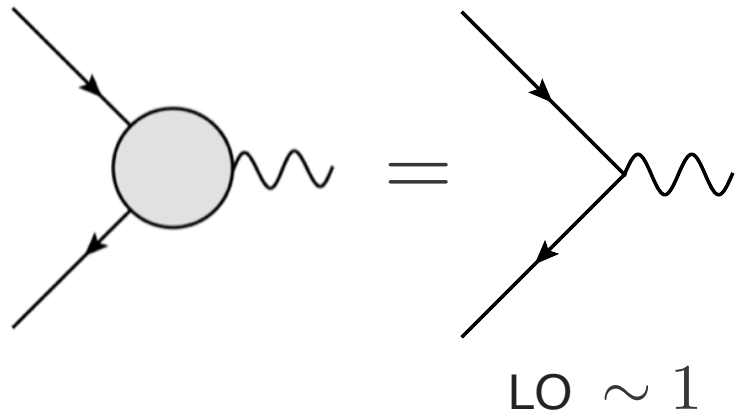
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- ▶ **What are the tools at the theorist's disposal to achieve this?**

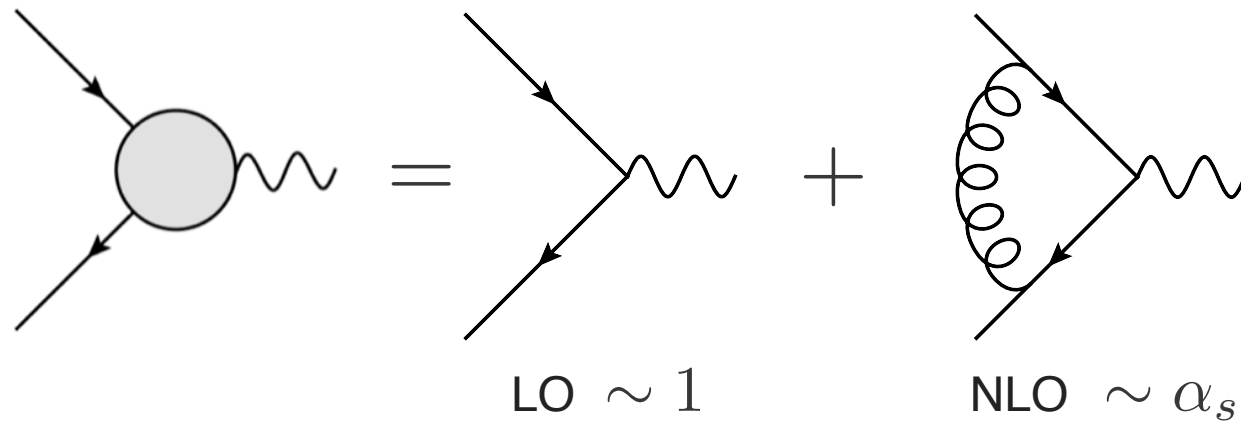
PERTURBATIVE QCD

- ▶ Our first method of choice: *perturbation theory*



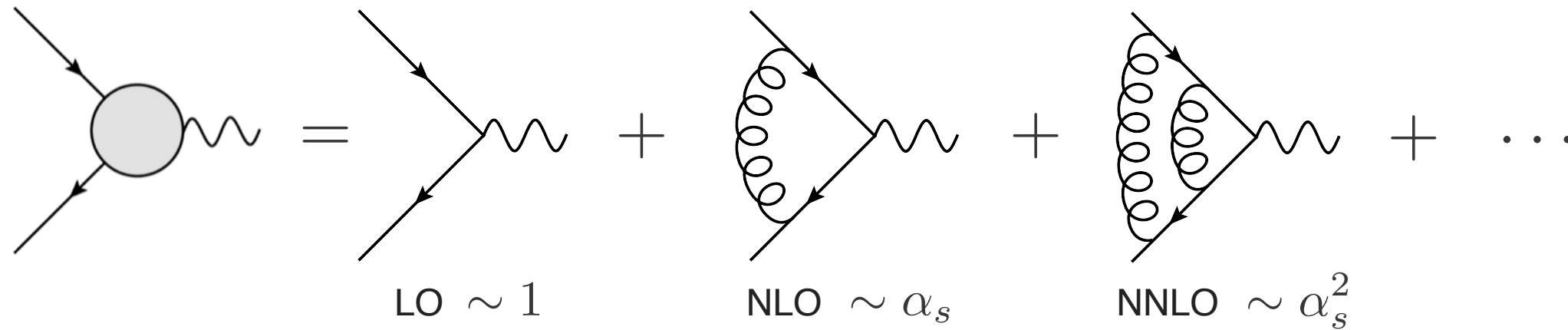
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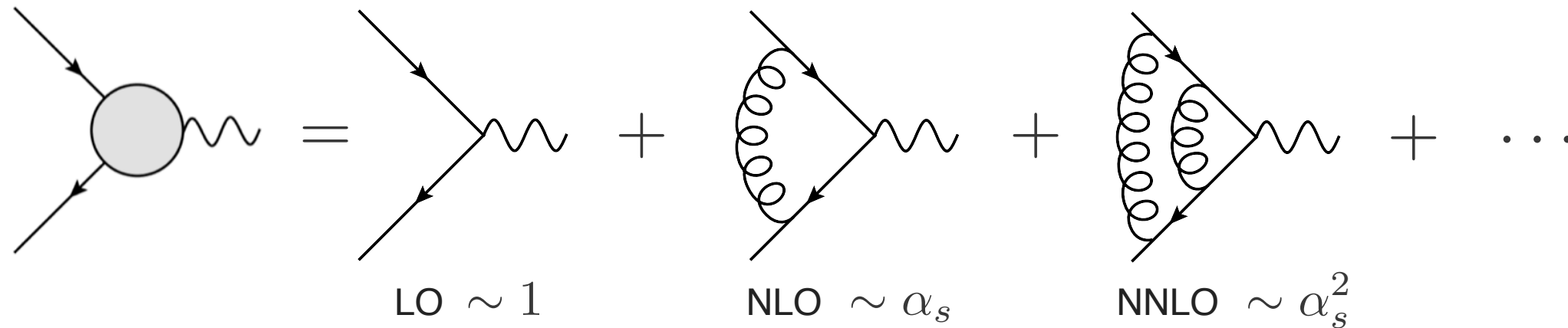
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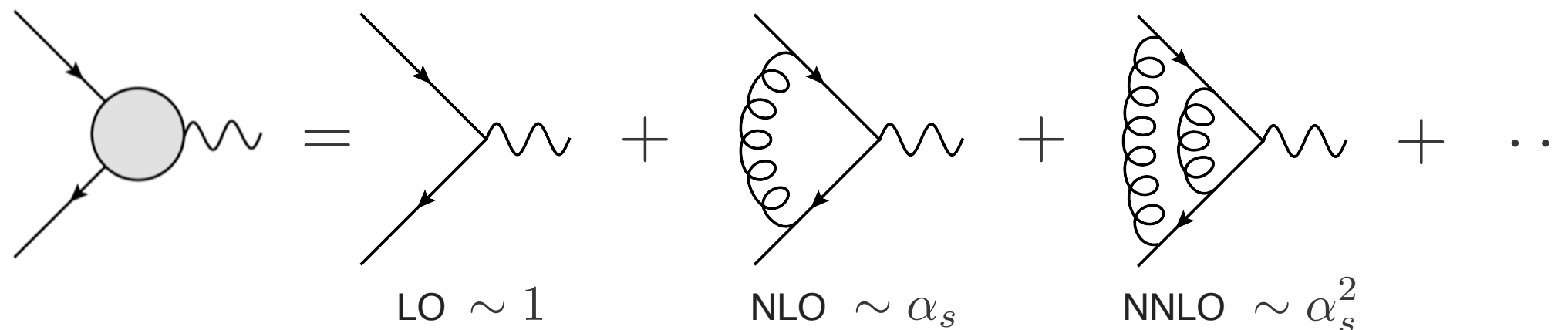
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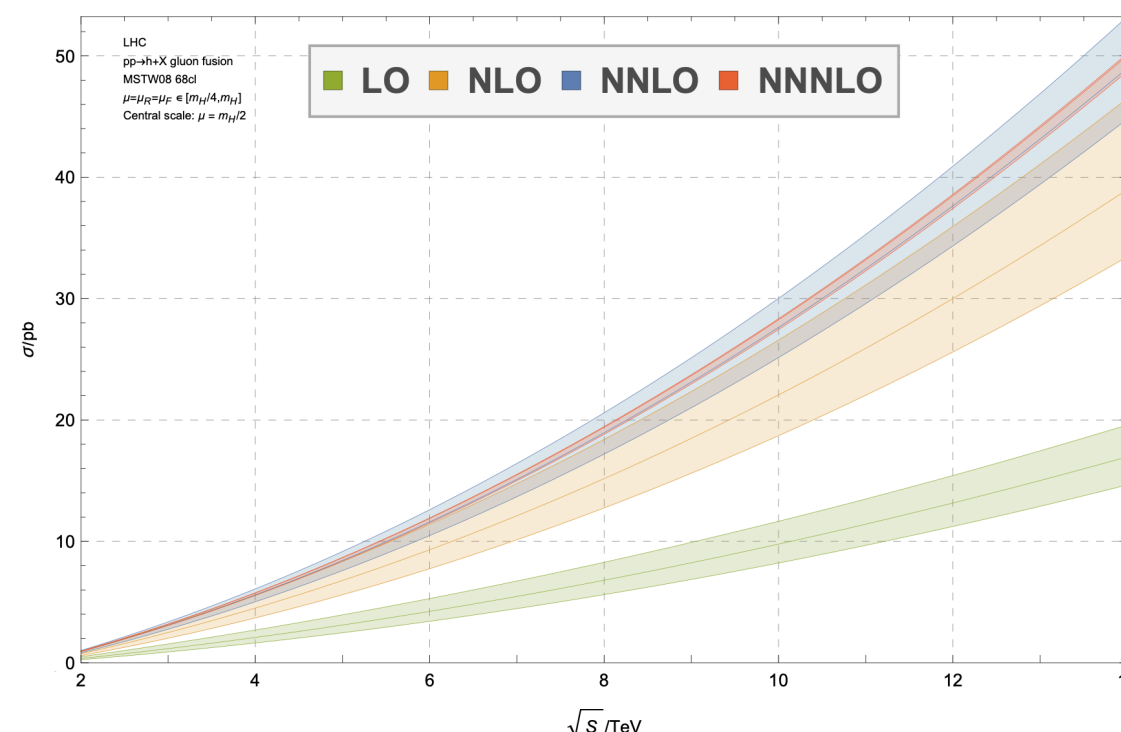
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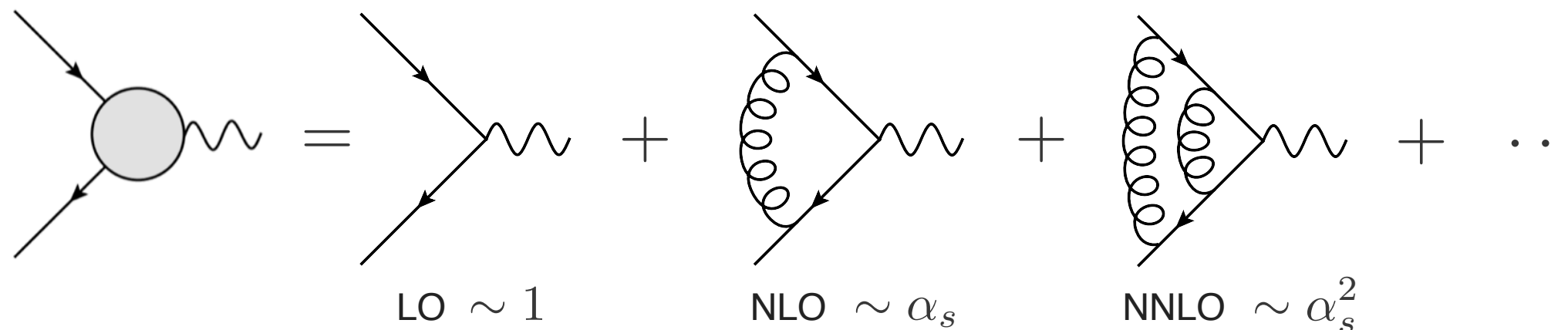
- ▶ **Example:** single Higgs production

[Anastasiou *et. al.*, 2015]



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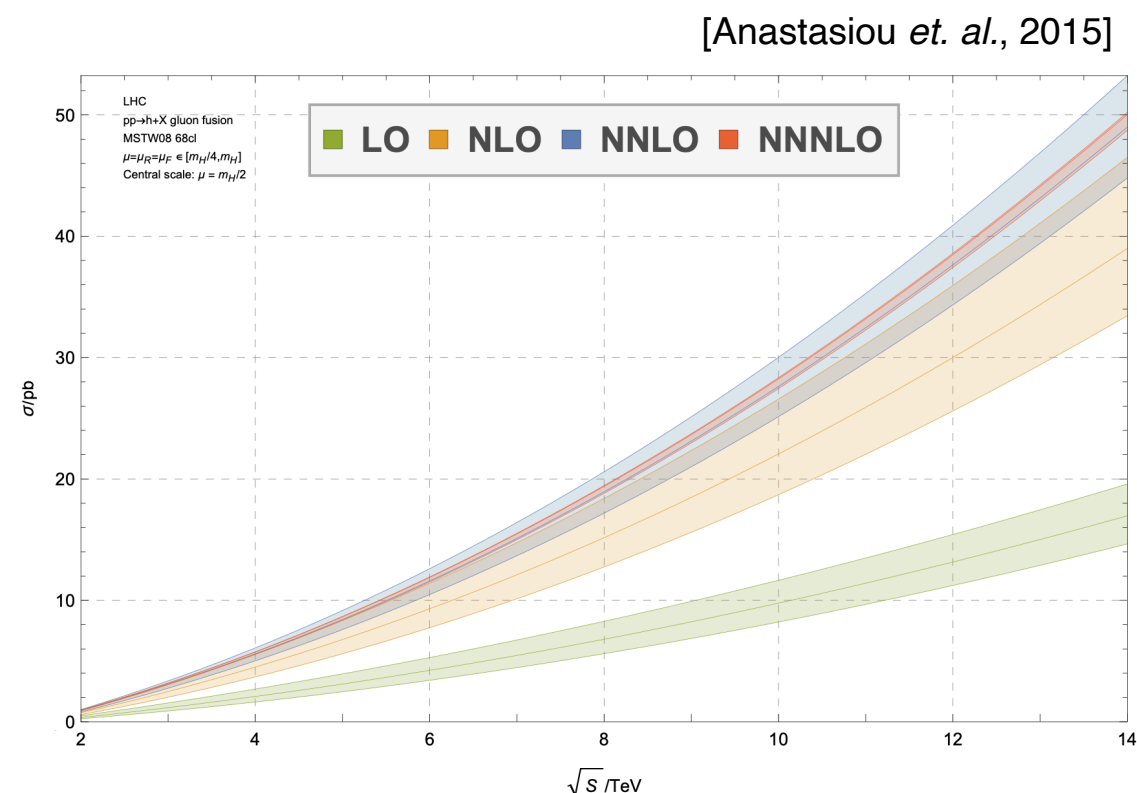
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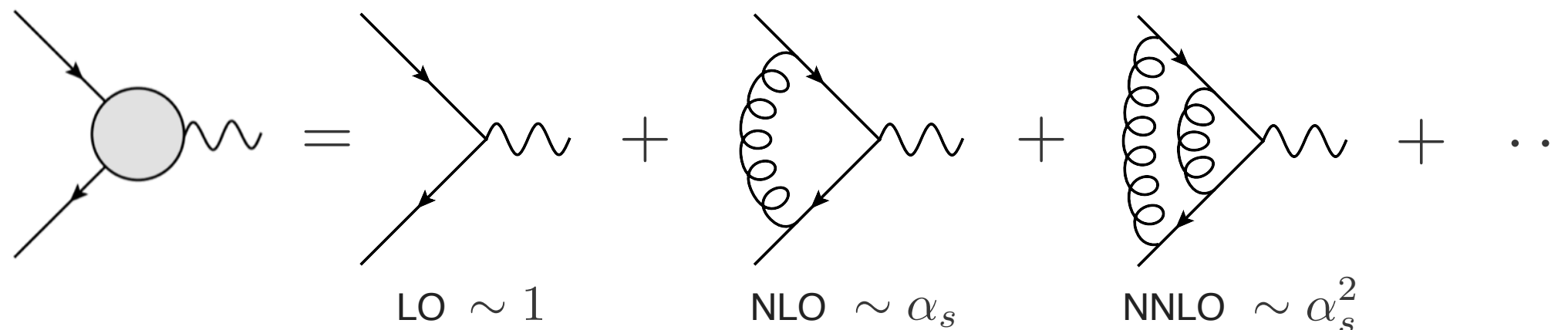
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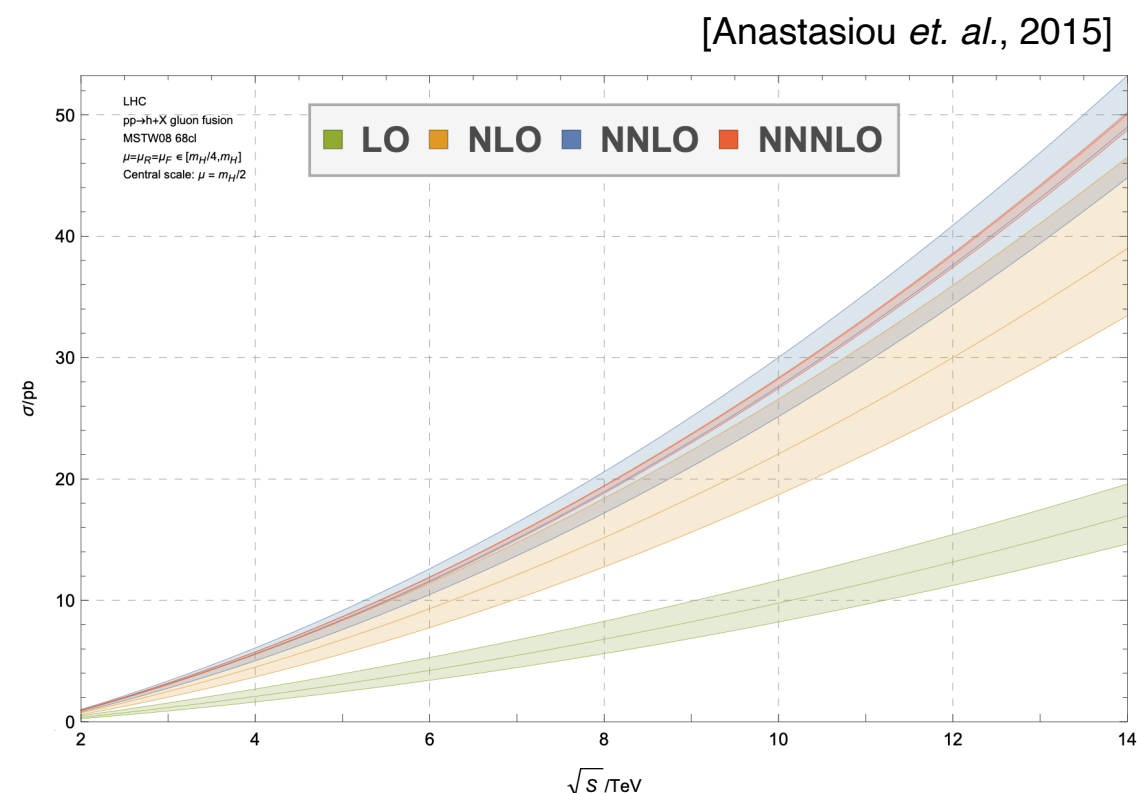
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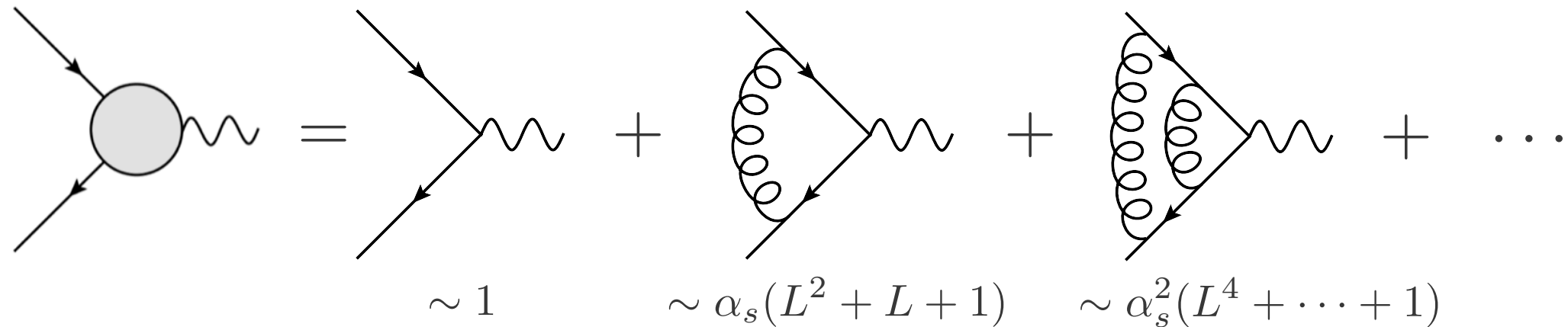
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1. Great convergence of series
2. Very precise prediction at N3LO



LOGS LOOMING LARGE

- ▶ Higher order corrections contain *logarithmic* terms

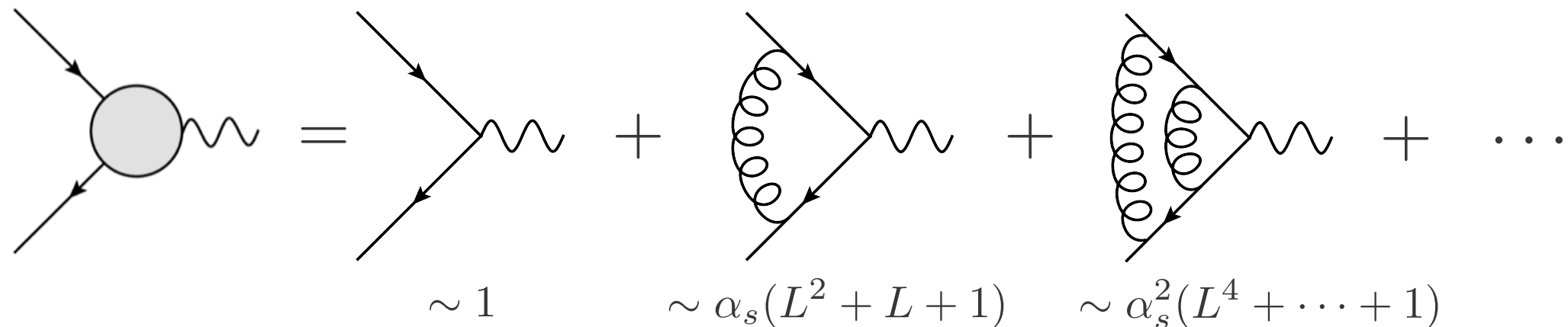


The diagram shows the expansion of a vertex correction. On the left, a grey circle represents the full vertex. It is equal to a sum of terms: a tree-level vertex (two incoming lines, one outgoing wavy line), a one-loop correction (triangle with one gluon loop), and a two-loop correction (triangle with two gluon loops), followed by an ellipsis. Below each term is its asymptotic behavior in terms of the number of loops L and the strong coupling α_s .

$$\sim 1 \quad \sim \alpha_s (L^2 + L + 1) \quad \sim \alpha_s^2 (L^4 + \dots + 1)$$

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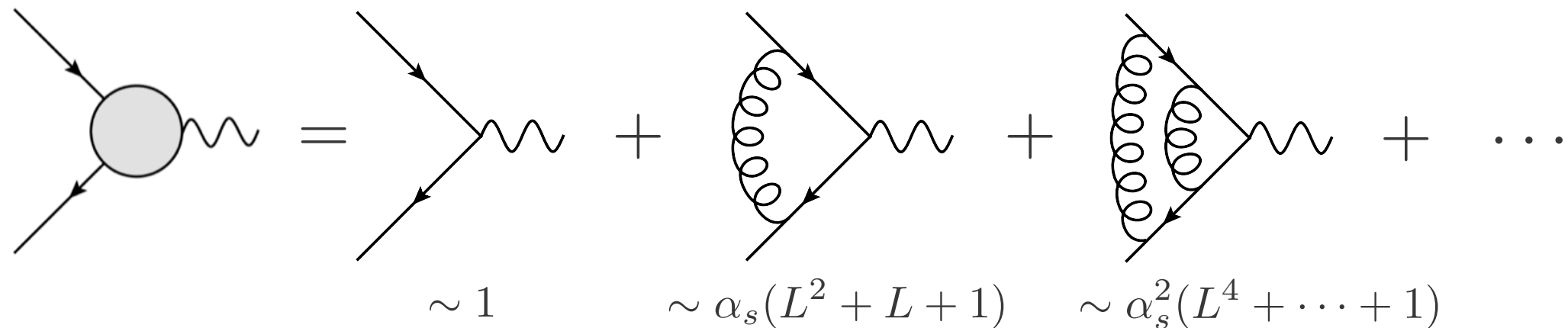
The diagram shows the expansion of a vertex correction. On the left, a grey circle represents the full vertex, with two incoming fermion lines and one outgoing gluon line. This is equal to a series of diagrams: 1) A tree-level vertex (a point) with two incoming fermion lines and one outgoing gluon line, labeled ~ 1 . 2) A one-loop correction (a triangle with two gluon lines) with two incoming fermion lines and one outgoing gluon line, labeled $\sim \alpha_s(L^2 + L + 1)$. 3) A two-loop correction (a triangle with two gluon lines and a gluon self-energy loop) with two incoming fermion lines and one outgoing gluon line, labeled $\sim \alpha_s^2(L^4 + \dots + 1)$. The series continues with an ellipsis.

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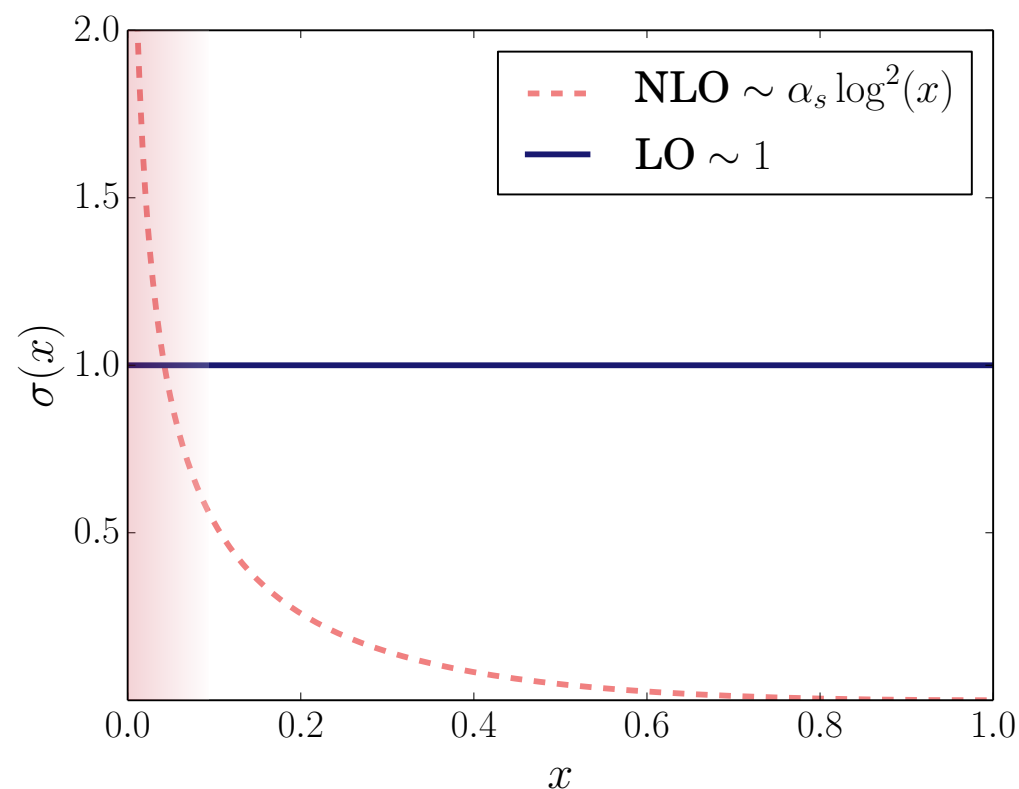
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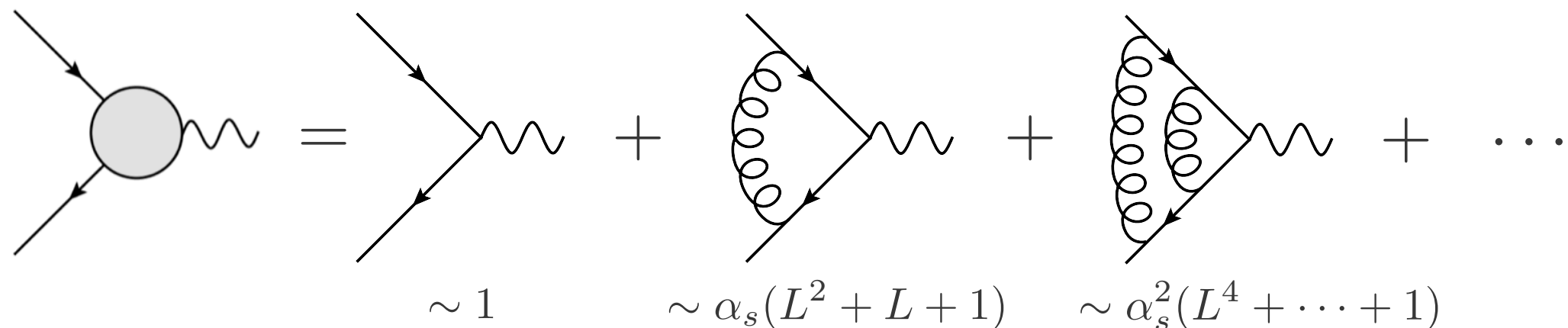


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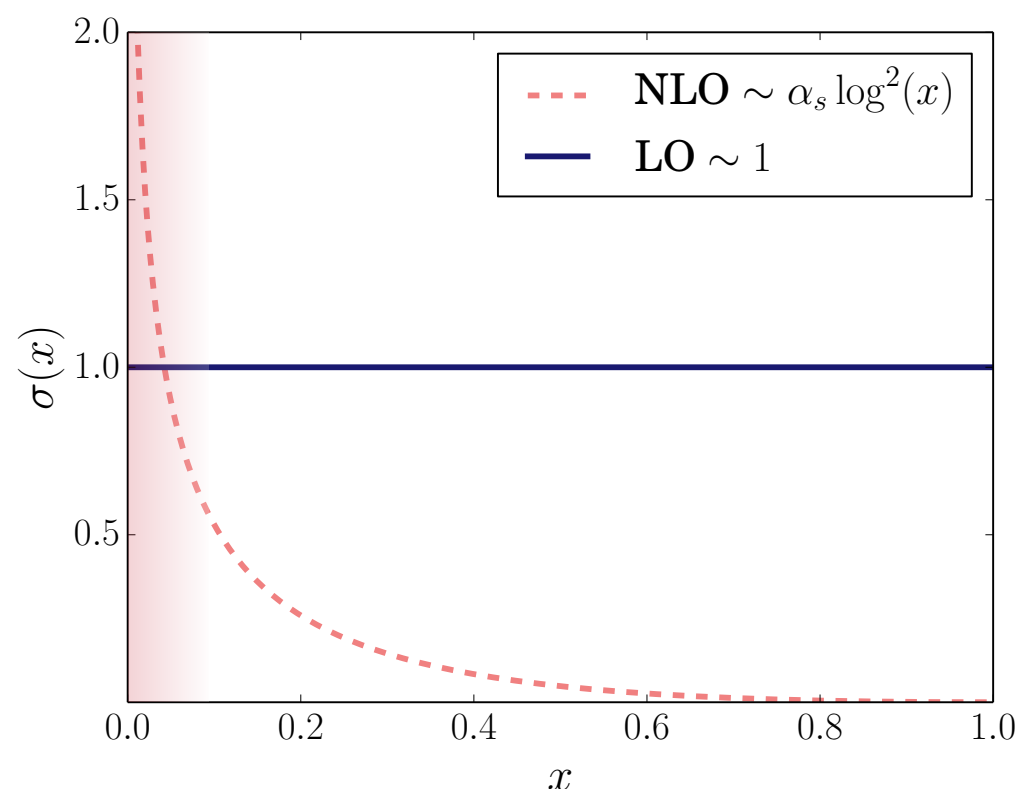


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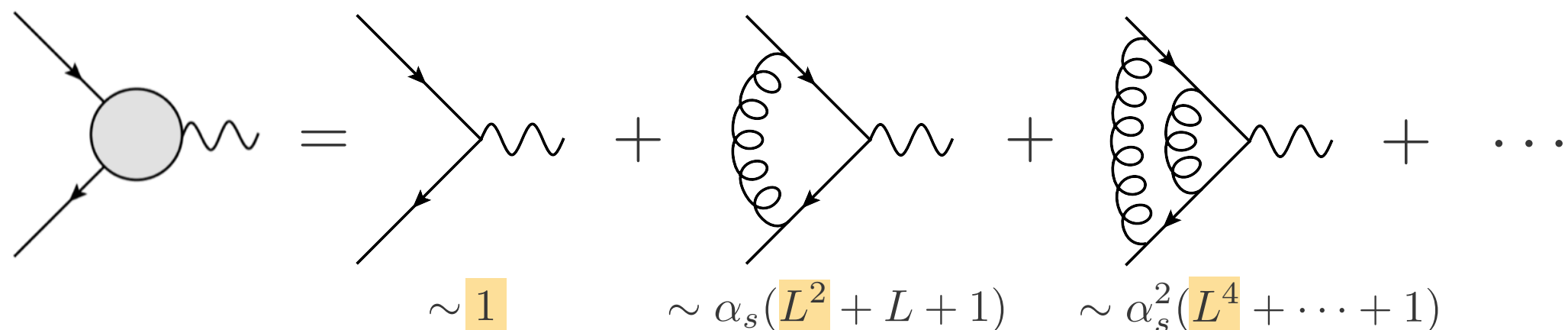


- Solution:** the (re)summation of these logarithms to all orders

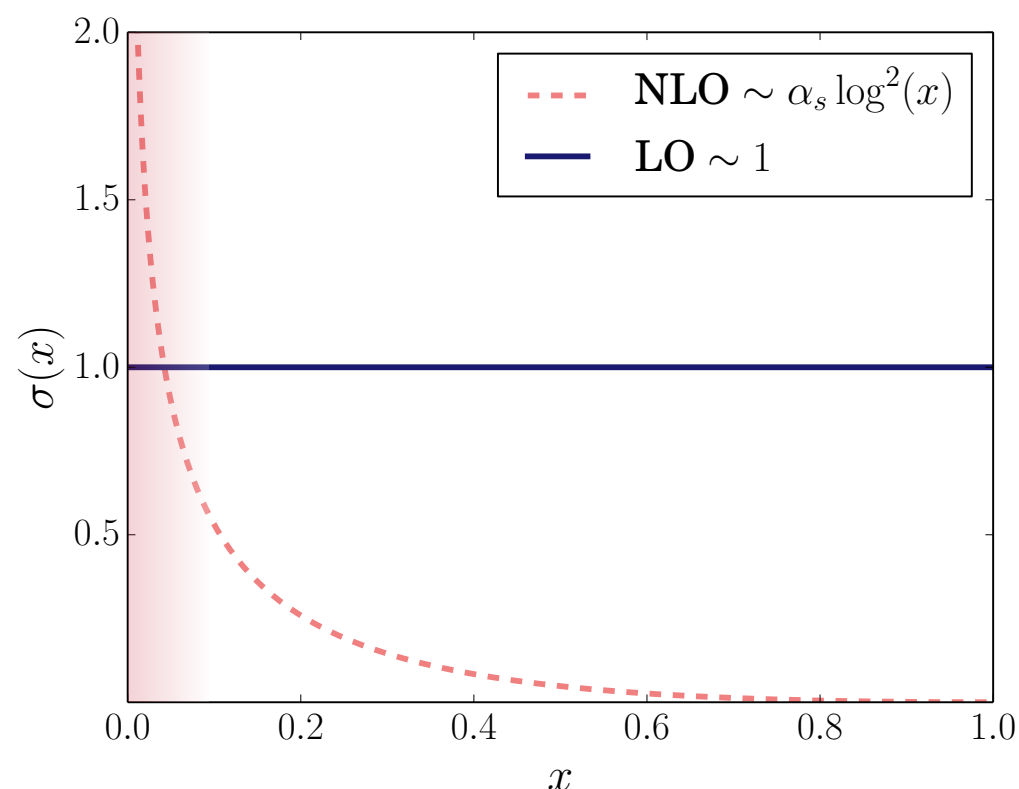
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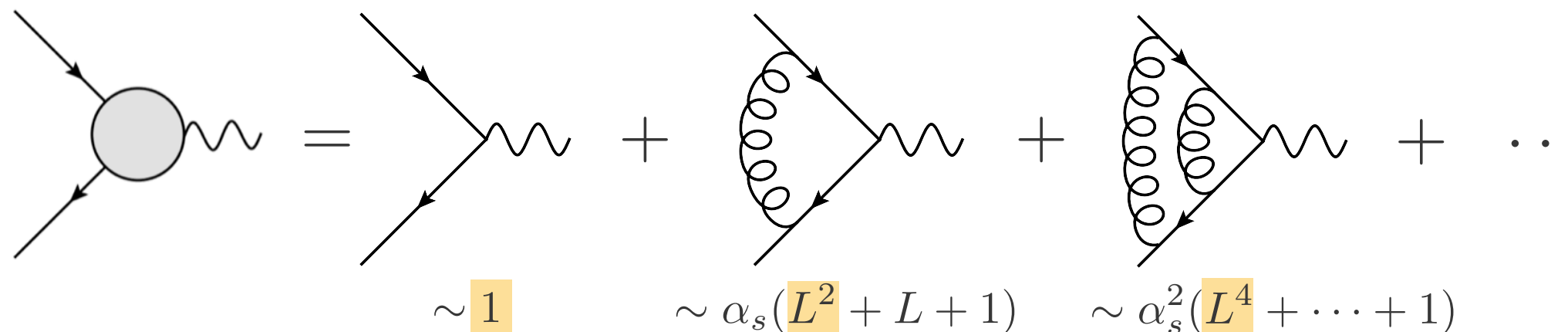


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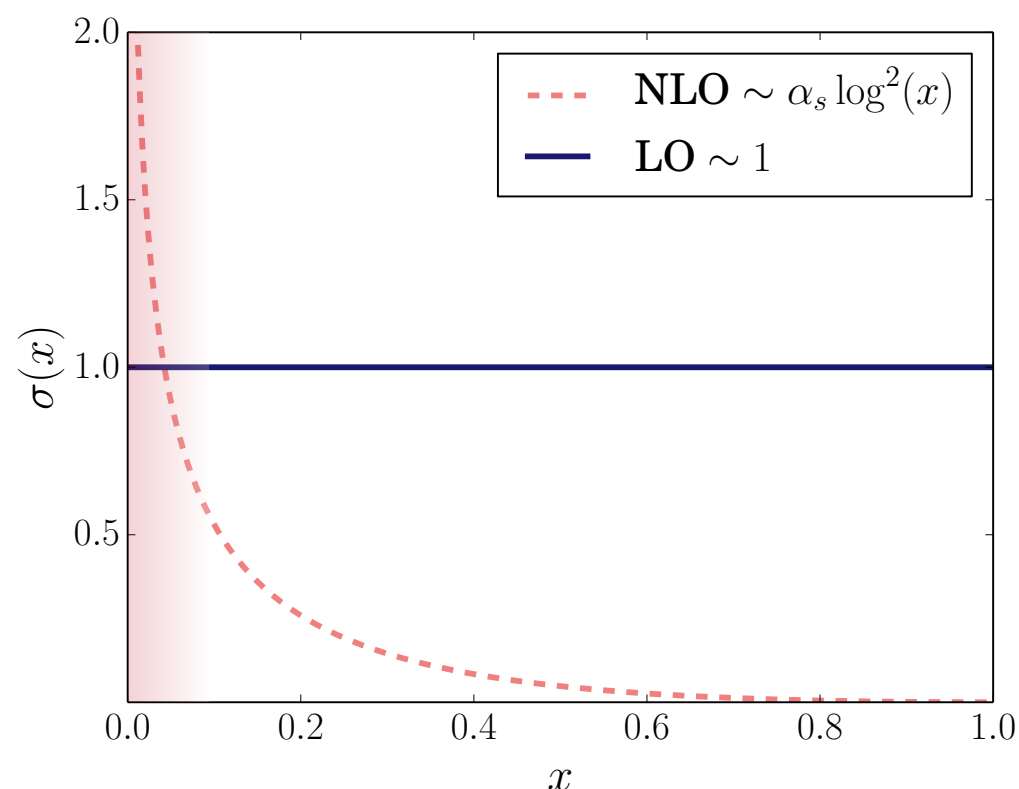
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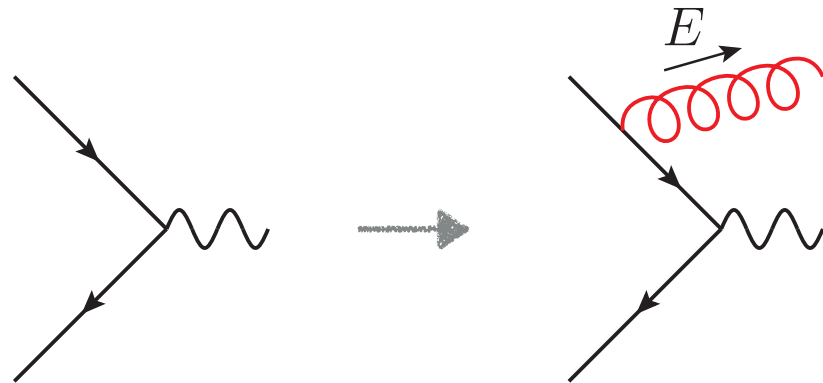
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- How do these logarithms appear?

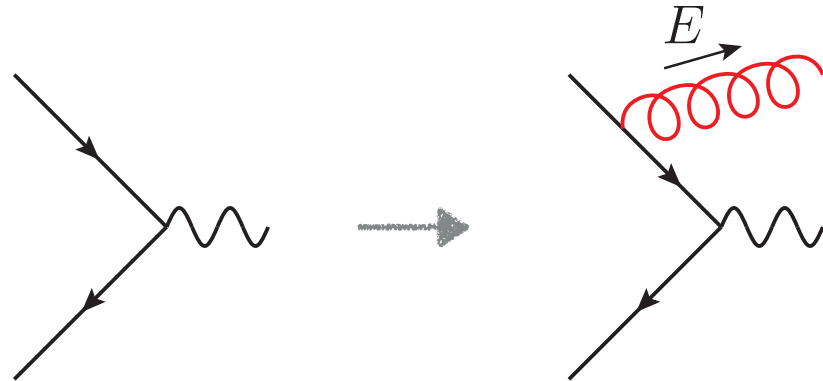
ORIGIN OF LARGE LOGARITHMS

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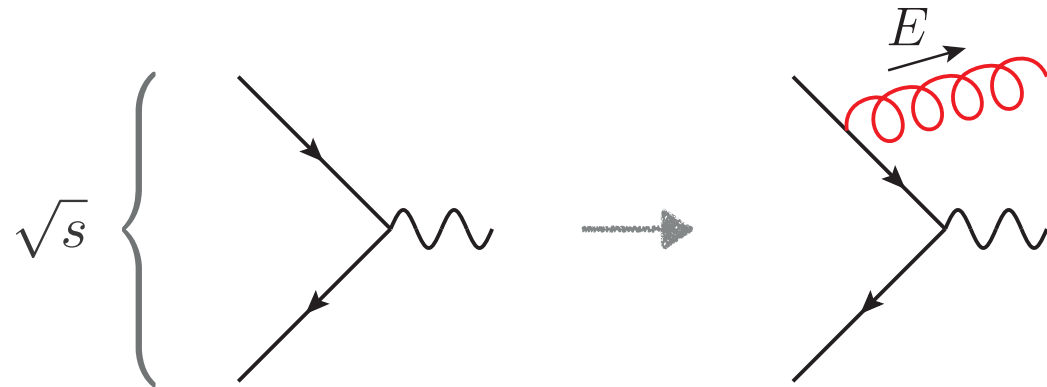
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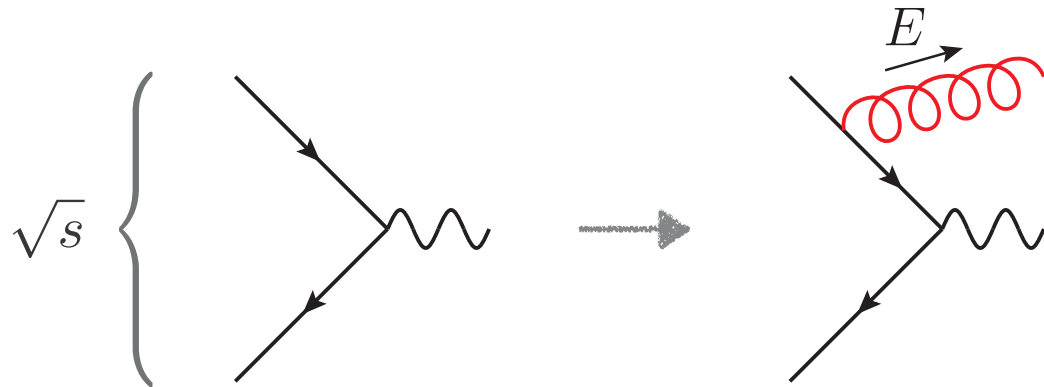
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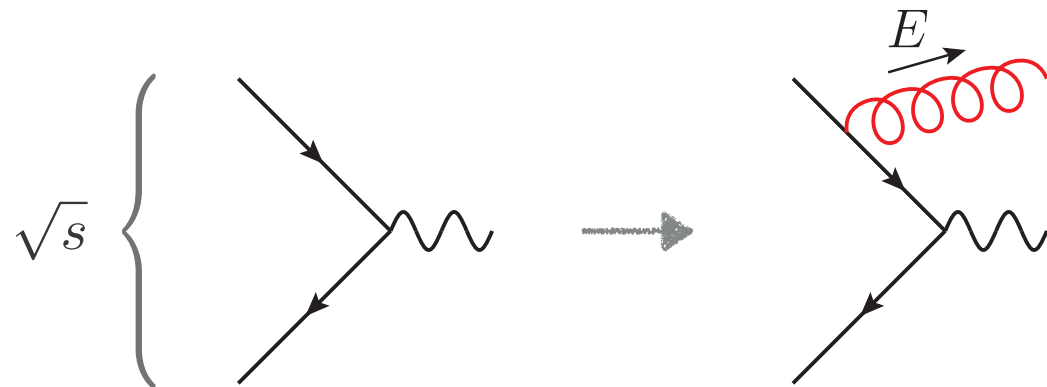
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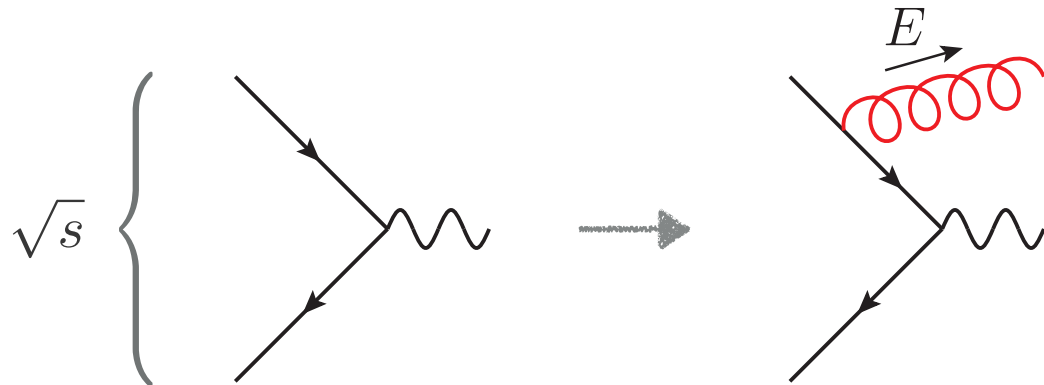
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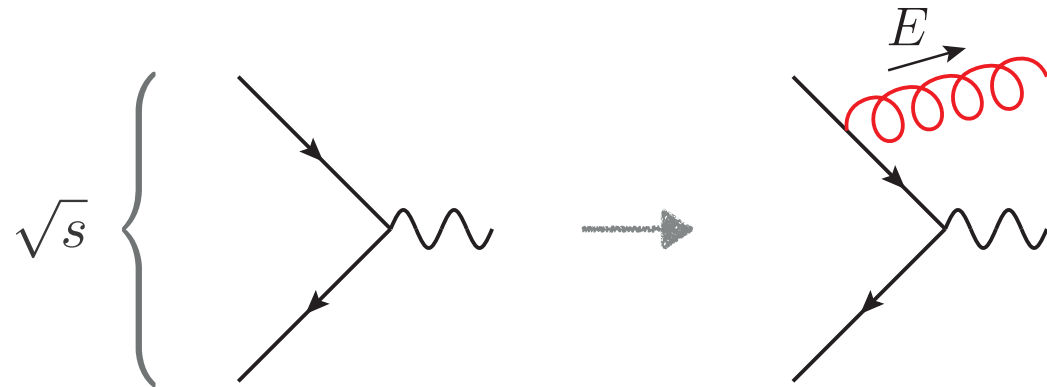
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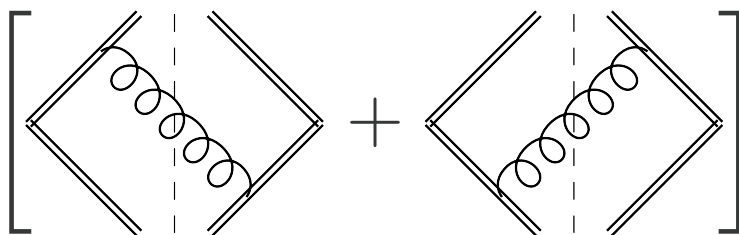
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A SIMPLE RESUMMATION FORMULA

- ▶ LL resummation in Drell-Yan and single Higgs production:

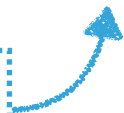
$$\sigma_{\text{NLP}; \text{LL}} = \exp \left[\text{diagram 1} + \text{diagram 2} \right] \times (1 - x) \sigma_{LO}$$


[N. Bahjat-Abbas, D. Bonocore, JSD, E. Laenen, L. Magnea, L. Vernazza, C.D. White; [JHEP 11 \(2019\) 002](#)]

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“Webs” 

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$$\sigma_{\text{NLP}; \text{LL}} = \exp \left[\text{Diagrams} \right] \times (1 - x) \sigma_{LO}$$

The "Diagrams" term in the exponent consists of two diagrams representing webs, separated by a plus sign and enclosed in large square brackets. Each diagram shows a fermion loop with a gluon exchange between two vertices. A blue dashed box labeled "Webs" with an arrow points to the first diagram.

The term $(1 - x)$ is associated with the NLP term through a "kinematic shift", as indicated by a blue dashed box with an arrow pointing to it.

[N. Bahjat-Abbas, D. Bonocore, JSD, E. Laenen, L. Magnea, L. Vernazza, C.D. White; [JHEP 11 \(2019\) 002](#)]

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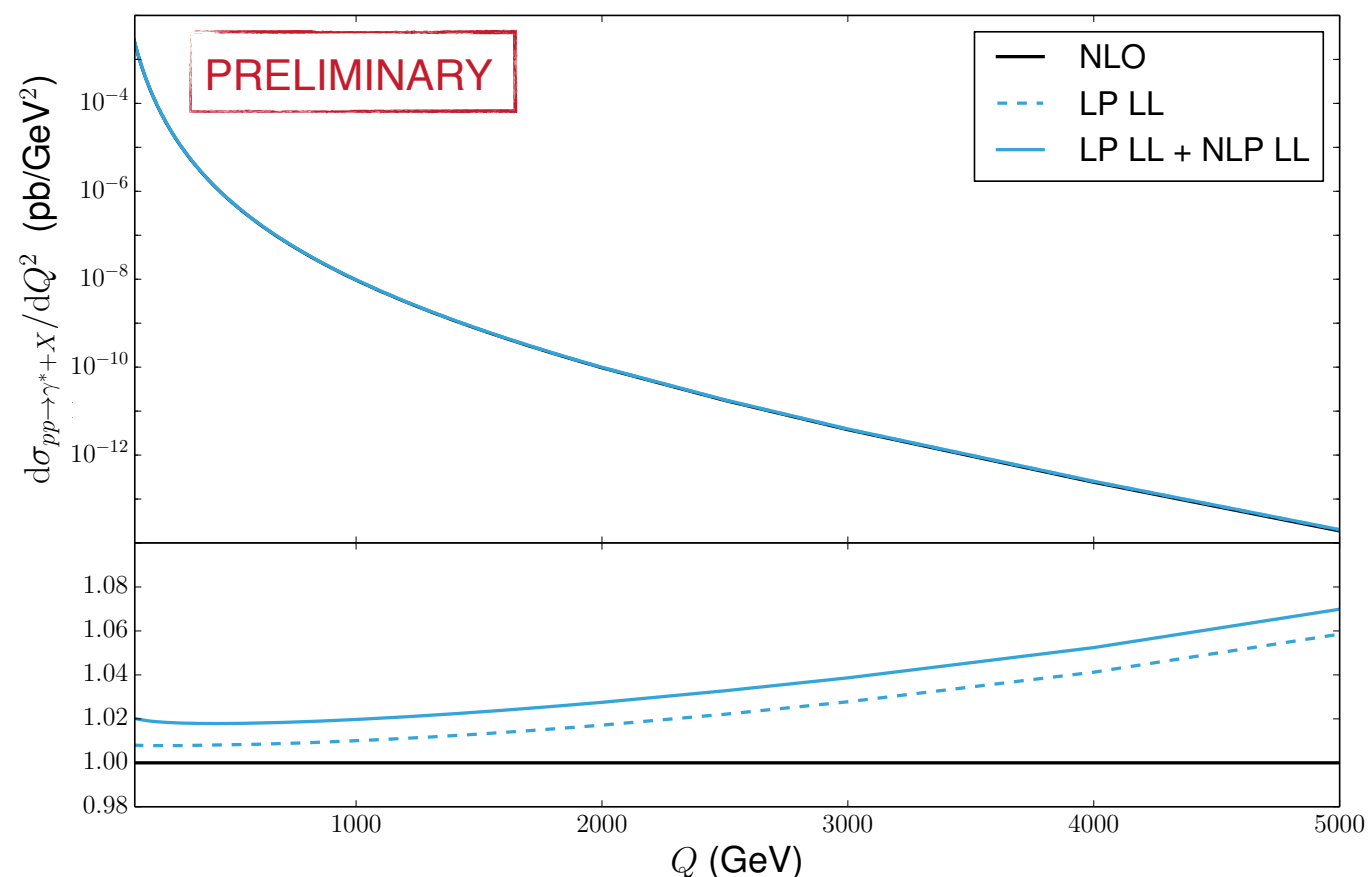
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NLP term through “kinematic shift”

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- Numerical effects are sizeable for invariant mass distribution in DY:



[M. van Beekveld, E. Laenen, L. Vernazza, JSD; in preparation]

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The quest for precision continues...