



Higgs Boson Transverse Momentum Spectrum at the LHC

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Goal of precision studies of Higgs Boson

- Constrain the Standard Model (SM) and discover physics beyond SM.

Higgs transverse momentum (p_T) measurements at the LHC

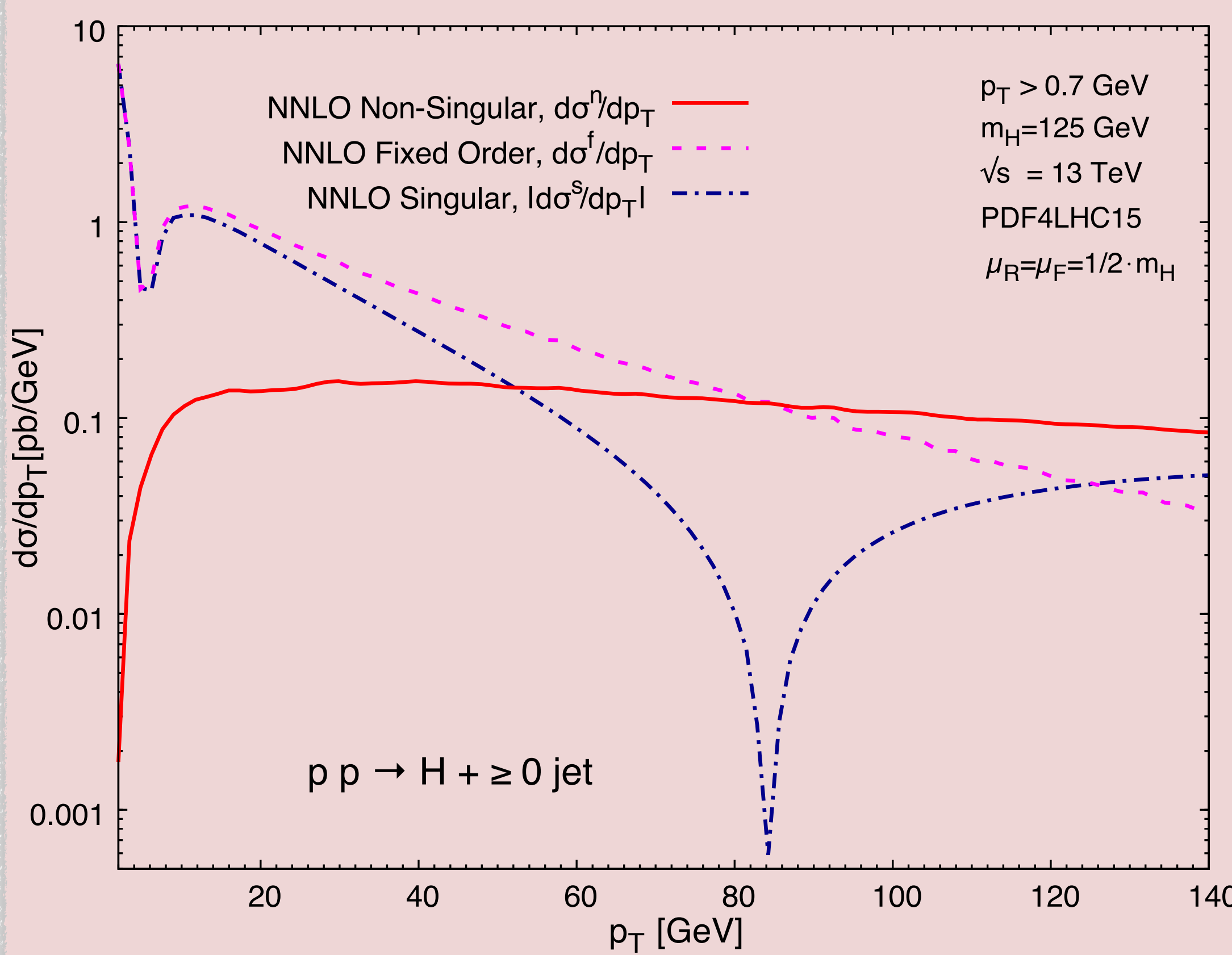
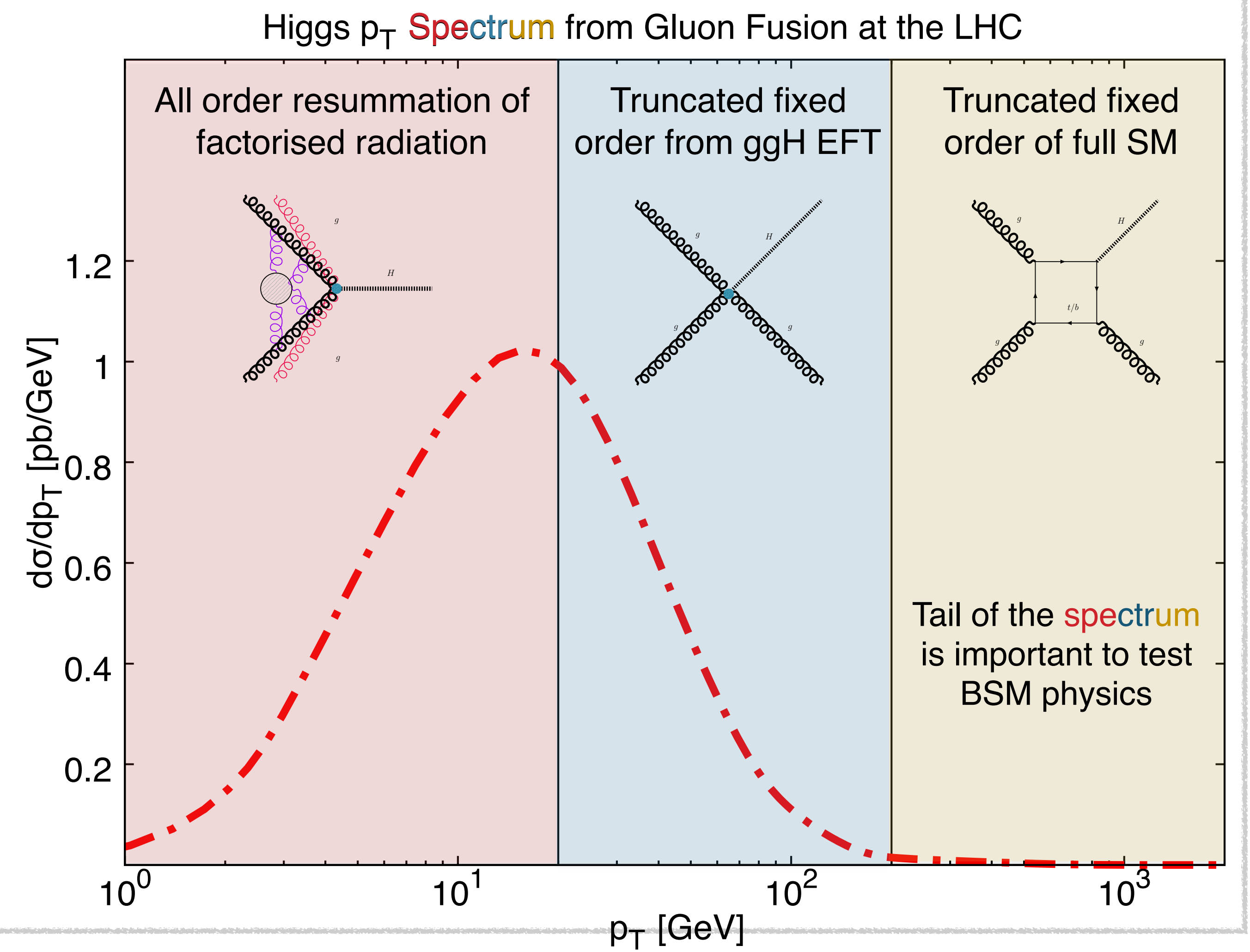
- LHC Run III and HL-LHC expect to achieve $\pm 10\%$ accuracy.
- p_T spectrum covering wide energy range constrains SM in different aspects.

Predictions of Higgs boson p_T spectrum at the LHC

- The dominant Higgs boson production channel at the LHC is gluon fusion through a quark loop.
- Introduce effective fields (EFT) from SM (integrating out heavy quark loops) to simplify Higgs-gluon couplings:

$$\mathcal{L}_{EFT} = -\frac{\lambda}{4} G^{\mu\nu} G_{\mu\nu} H$$

- Right:** Sketch of the Higgs p_T spectrum from the gluon fusion channel.



All order resummation at small p_T

- Unphysical contributions from singular log terms:

$$\ln^k(m_H^2/p_T^2)/p_T^2$$

- Soft and collinear radiations factorise from hard process.

- Cross check of singular log behaviour (red line in left):

$$[d\sigma^F/dp_T^2 - d\sigma^S/dp_T^2] \xrightarrow{p_T \rightarrow 0} 0$$

- Use renormalisation group to resum the singular terms.

- State-of-the-art precision is N³LL resummation of N³LO [1].

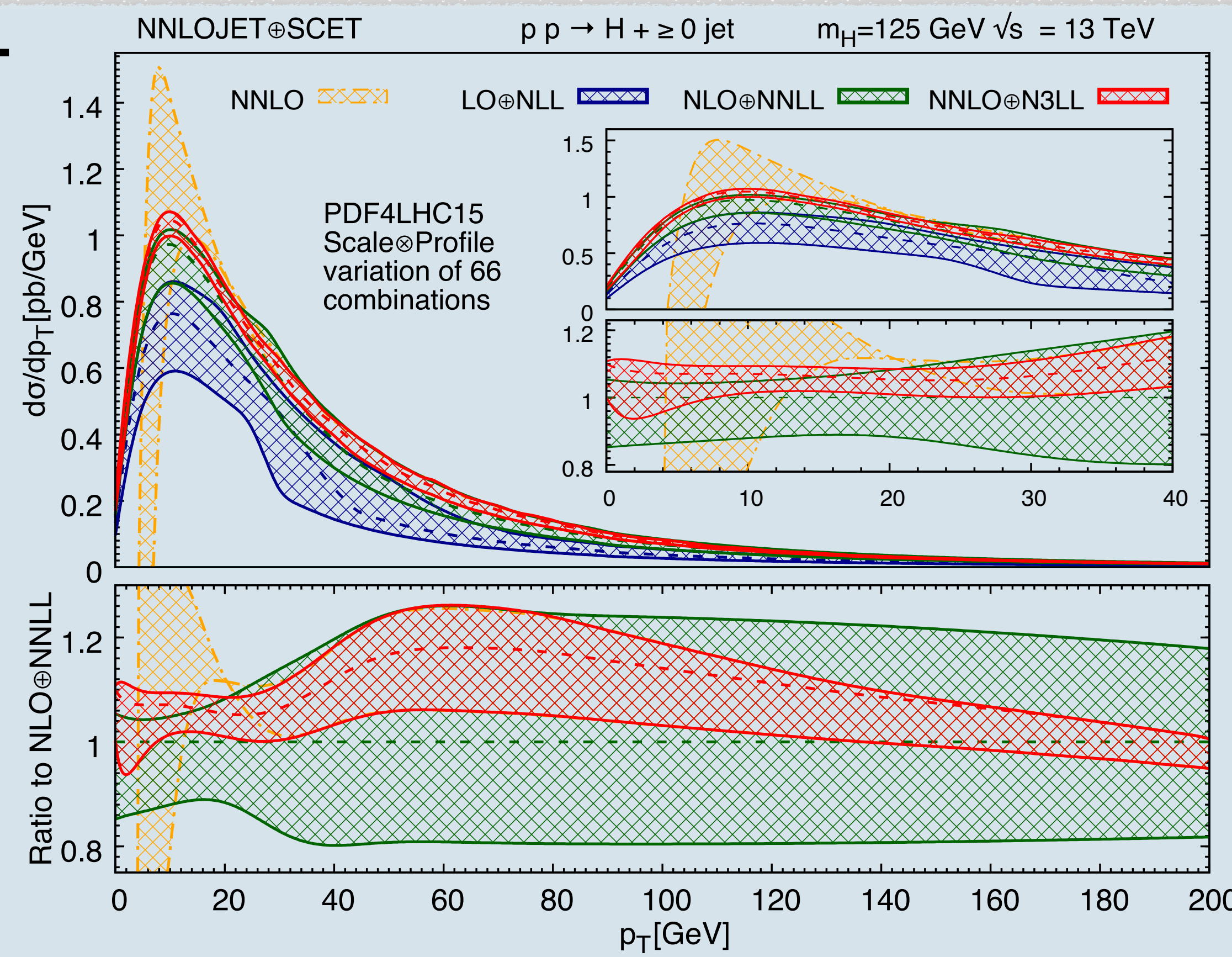
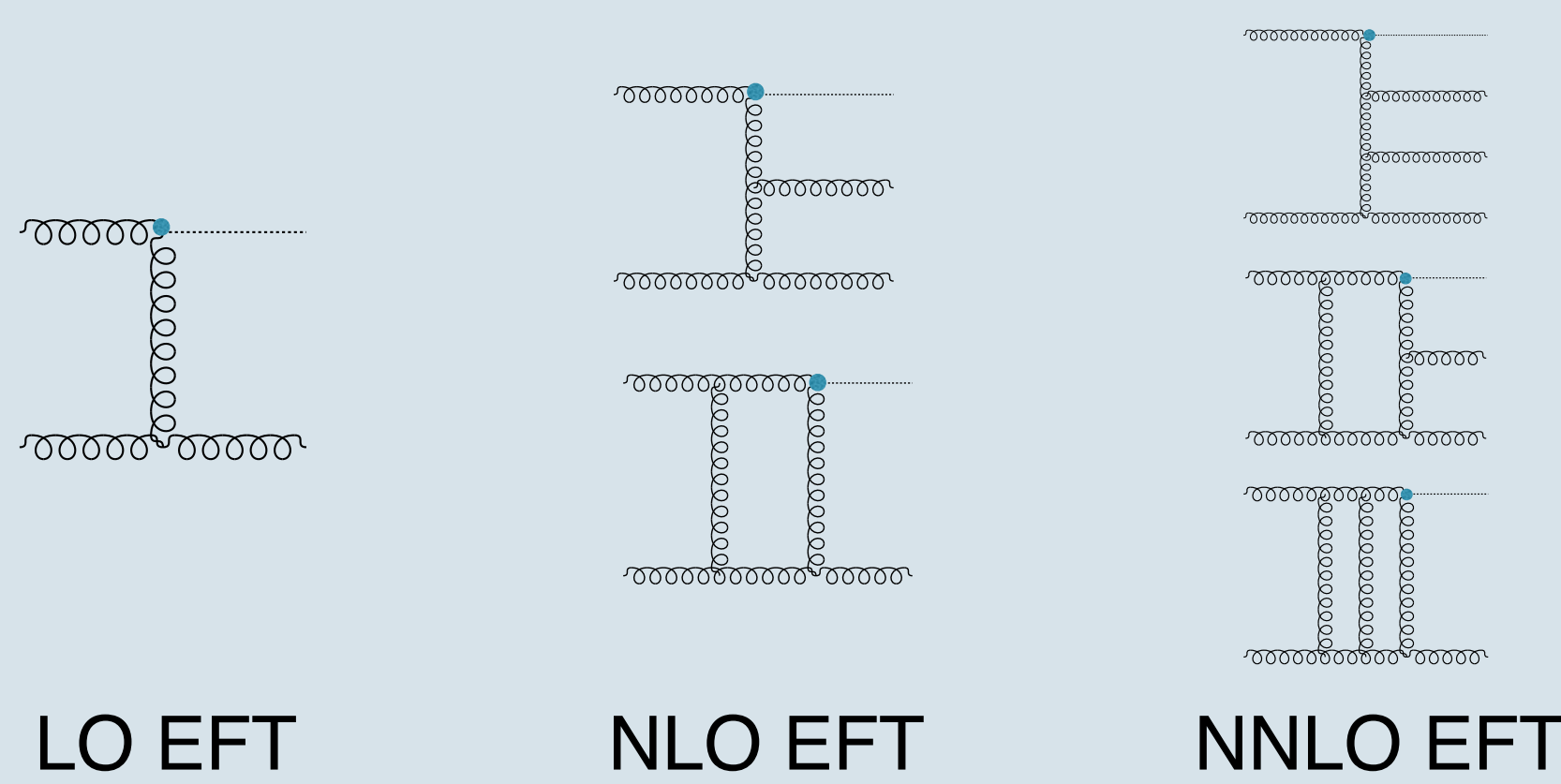
Left: Higgs p_T spectrum from fixed order (F), singular (S) and non-singular (N = FO – S) contributions.

α_s counting	$\ln W(x_0, x_b, m_H, \vec{b}, \mu = b_0/b) \sim$					
α_s	$\ln^2(b^2 m_H^2)$	$\ln(b^2 m_H^2)$	1			$\frac{d\sigma_{NLO}^H}{dp_T^2}$
α_s^2	$\ln^3(b^2 m_H^2)$	$\ln^2(b^2 m_H^2)$	$\ln(b^2 m_H^2)$	1		$\frac{d\sigma_{NNLO}^H}{dp_T^2}$
α_s^3	$\ln^4(b^2 m_H^2)$	$\ln^3(b^2 m_H^2)$	$\ln^2(b^2 m_H^2)$	$\ln(b^2 m_H^2)$	1	$\frac{d\sigma_{N^3LO}^H}{dp_T^2}$
...
α_s^k	$\ln^{k+1}(b^2 m_H^2)$	$\ln^k(b^2 m_H^2)$	$\ln^{k-1}(b^2 m_H^2)$	$\ln^{k-2}(b^2 m_H^2)$...	$\frac{d\sigma_{N^kLO}^H}{dp_T^2}$
...
Resum order	LL	NLL	NNLL	N3LL	...	N ^{k+1} LL
A expansion	A ₁	A ₂	A ₃	A ₄	...	A _{k+2}
B expansion		B ₁	B ₂	B ₃	...	B _{k+1}

Above: Perturbative expansion of α_s and its corresponding singular log terms in soft-collinear-effective-field theory (SCET) [1].

Fixed order predictions at medium p_T

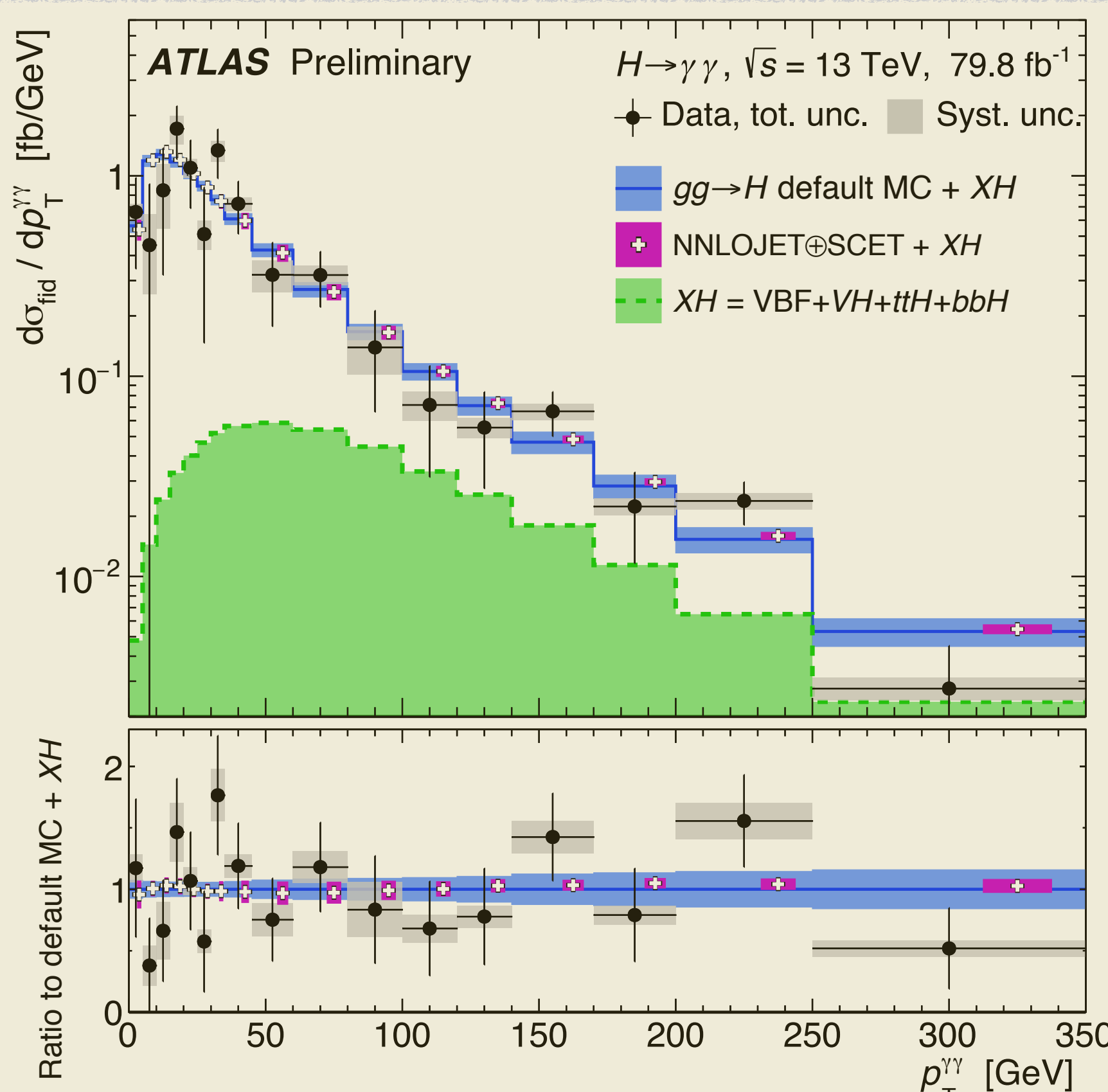
- Use parton level event generator NNLOJET.
- Apply antenna subtraction to regulate NNLO infrared divergences.
- Higgs + jet production in EFT framework at NNLO:



Matching small and medium p_T

- Additive matching NNLOJET ⊕ SCET [1].
- Use profile function for smooth transition.
- Conservative theoretical uncertainty estimation
 - 11 combinations of scale variation
 - 6 profile functions for matching
 - Taking envelope of 66 combinations
- Theoretical uncertainty of Higgs p_T spectrum at N³LL ⊕ NNLO reduces to at most $\pm 10\%$.**

Left: Higgs Boson p_T spectrum below 200 GeV with N³LL resummation matched with NNLO.



Extension to high p_T region and compare the full spectrum with LHC data

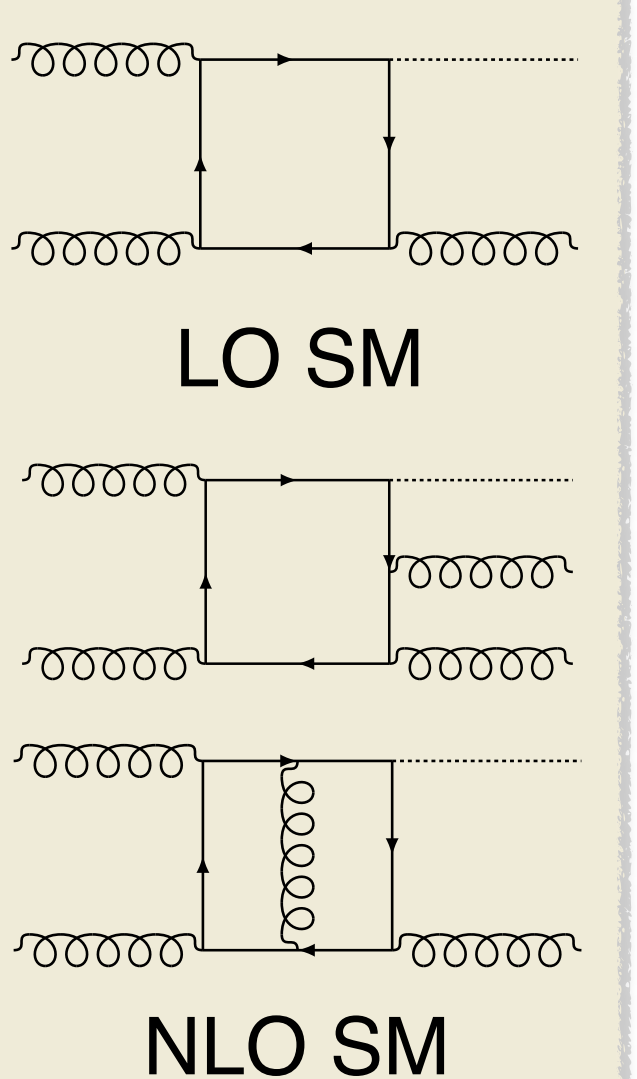
- EFT approach breaks down at large p_T region (> 200 GeV) due to high energy flow in the quark loop.
- Need to consider the full SM gluon fusion to Higgs boson where only the second order contribution (NLO) in the perturbative expansion is known recently [2].
- To achieve reliable predictions, we extrapolate LO mass effects to NNLO EFT by re-weighting:

$$\frac{d\sigma_{reweight}}{dp_T} = \frac{d\sigma_{NNLO}^{EFT}}{dp_T} \times \frac{d\sigma_{LO}^{SM}}{d\sigma_{LO}^{EFT}}$$

- The re-weighted p_T spectrum is used by ATLAS collaboration for detailed comparison with data.

Left: Higgs p_T spectrum fb^{-1} measured by ATLAS detector at the LHC up to 350 GeV with integrated luminosity about 80 [3].

NNLOJET ⊕ SCET. Current experiment precision is about in good



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References

- [1] X. Chen, T. Gehrmann et al., Precise QCD Description of the Higgs Boson Transverse Momentum Spectrum, arXiv:1805.00736 [hep-ph].
- [2] S. P. Jones, M. Kerner et al., Next-to-Leading-Order QCD Corrections to Higgs Boson Plus Jet Production with Full Top-Quark Mass Dependence Phys. Rev. Lett. 120 (2018) no.16, 162001
- [3] The ATLAS collaboration, Measurements of Higgs Boson Properties in the Diphoton Decay Channel Using 80 fb⁻¹ of pp Collision Data at $\sqrt{s} = 13$ TeV with the ATLAS Detector, ATLAS-CONF=2018-028.