GENEVA

an NNLO / NNLL Event Generator

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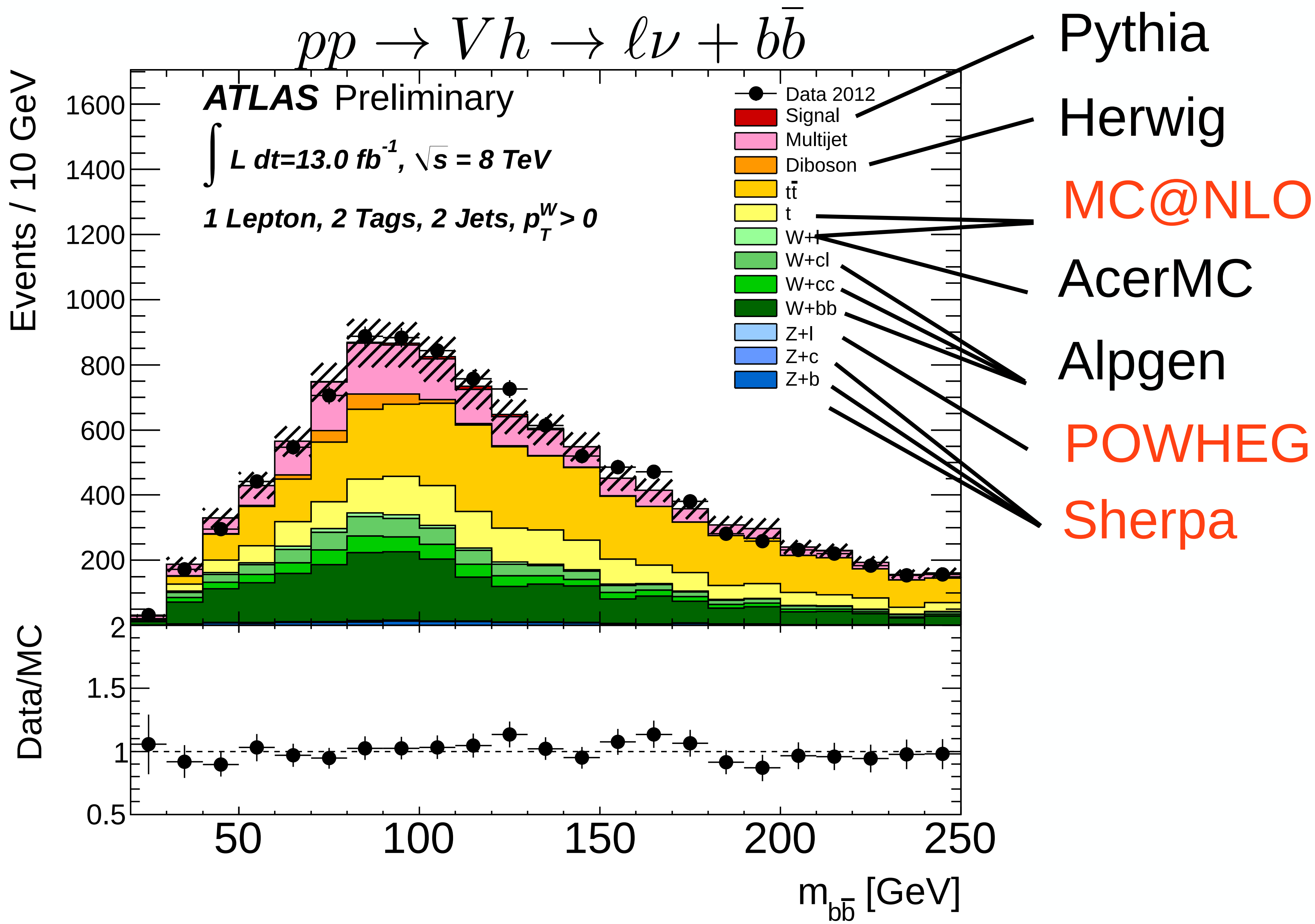
There are two very different ways of making theoretical predictions: perturbative* calculations and event generators

* Can mean either fixed order or resummed

Perturbative calculations	Event generators
Can typically be performed with higher accuracy	Are fully differential, more similar to experimental data
Typically, observables have to be chosen before running code	Can just generate events, define observables later
Intrinsically, has only information on partonic final states	By attaching hadronization model, provides fully hadronized final state

At the LHC, Monte-Carlo is often the only tool to use, even if precision is required



ATLAS-CONF-2012-161

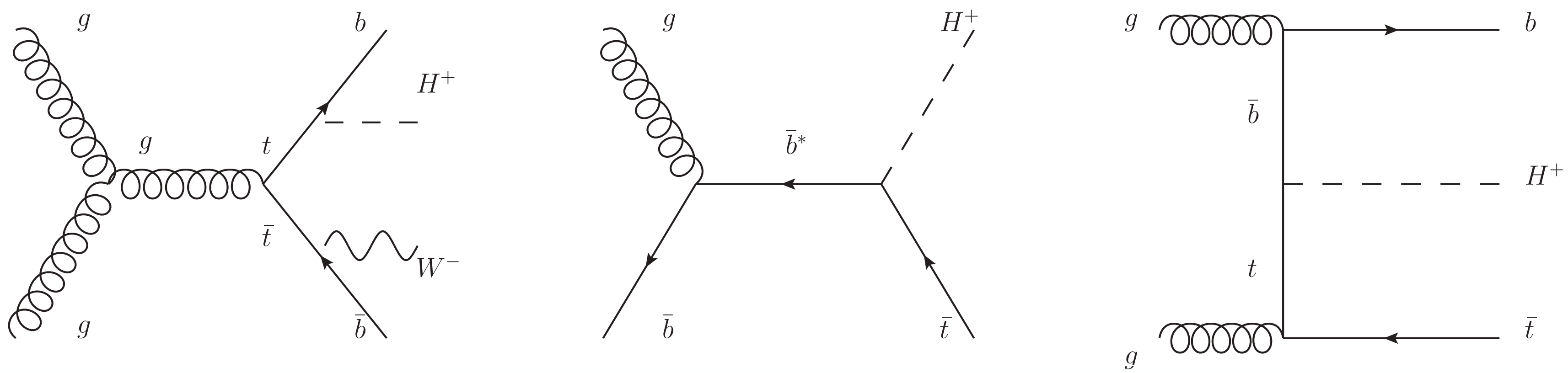
In order to include realistic experimental cuts and detector efficiencies need fully hadronized events

Why do we need fully differential calculations?

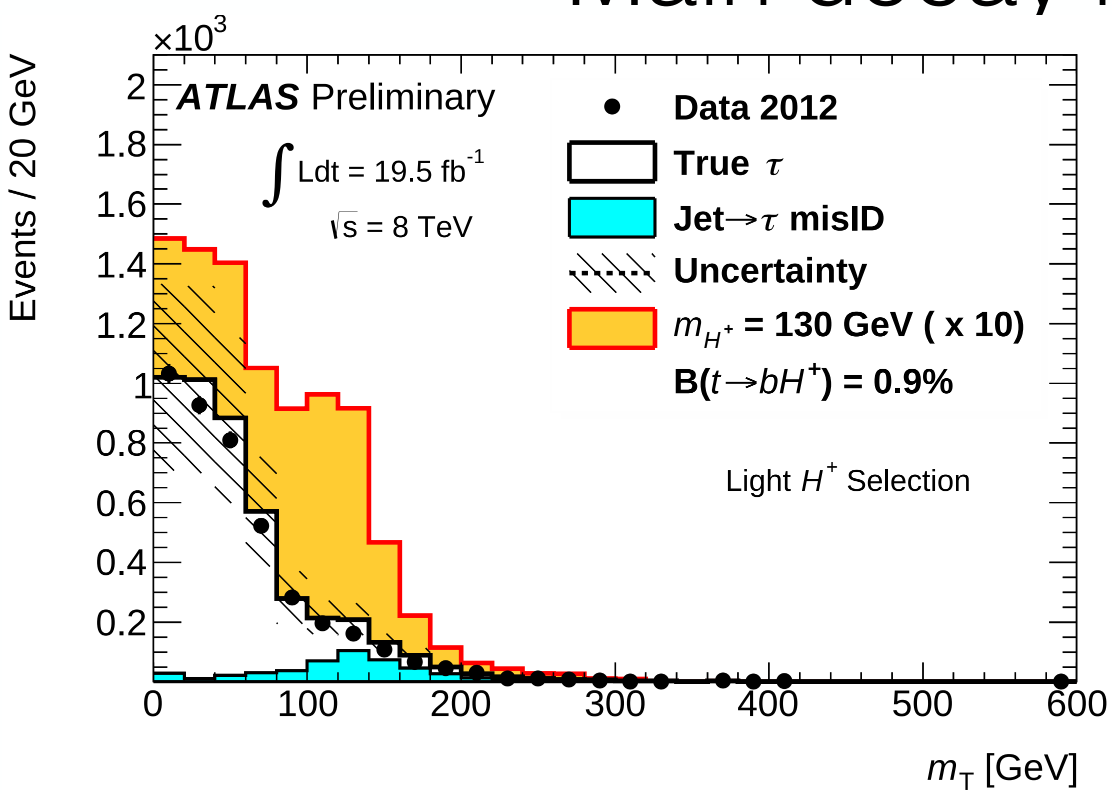
Consider a recent ATLAS search for charged Higgs bosons

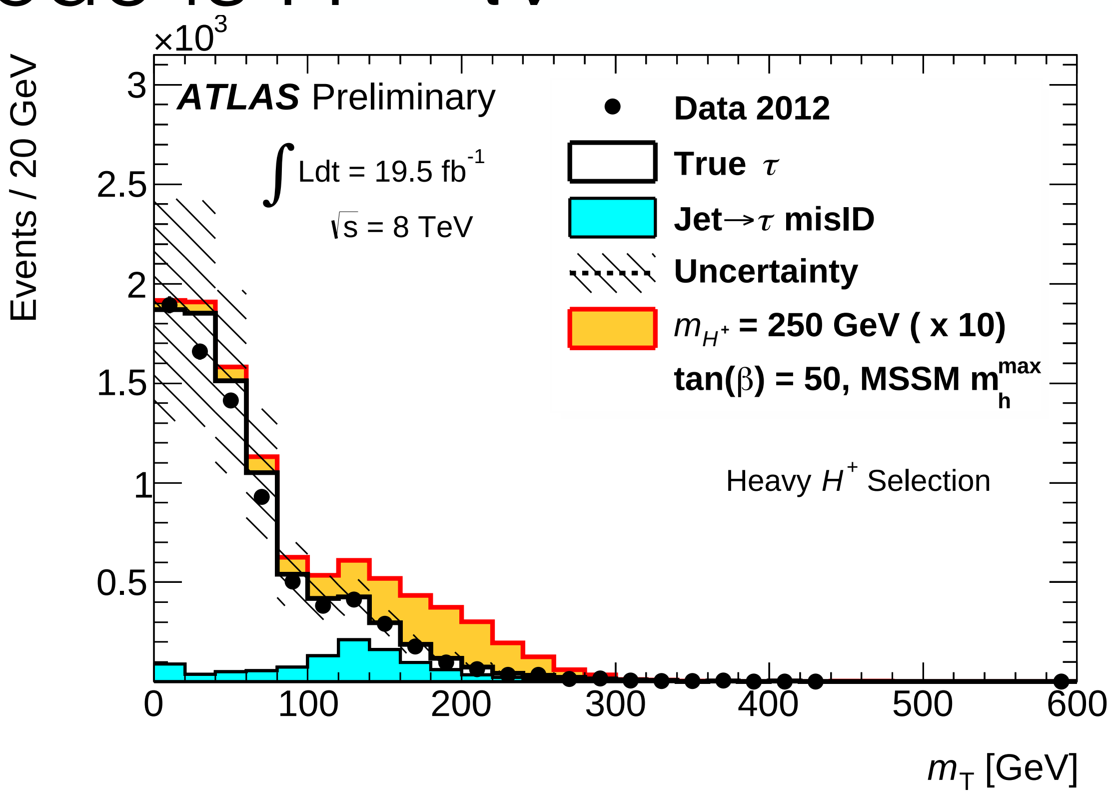
ATLAS-CONF-2013-090

Typical diagrams that contribute



Main decay mode is H →τν





One needs to know a lot more information than the value of a single observable to understand the background

The following requirements are then applied to select events compatible with the signal hypothesis:

- at least 4 (3) jets pass the p_{T}, η and JVF criteria as described in Sec. 3.2 for the light (heavy) signal selection,
- at least one of the selected jets must be b-tagged,
- exactly one hadronically decaying τ has $p_{\mathrm{T}} > 40\,\mathrm{GeV}$ (this $\tau_{\mathrm{had-vis}}$ candidate must match to the τ object used in the trigger decision),
- there must be no additional hadronically decaying τ leptons with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, nor any muon or electron with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$,
- $E_{\mathrm{T}}^{\mathrm{miss}}$ >65 (80) GeV for the light (heavy) charged Higgs boson search,
- a requirement is placed on the quantity $\frac{E_{\mathrm{T}}^{\mathrm{miss}}}{0.5\cdot\sqrt{\sum p_T^{\mathrm{PV\ trk}}}}$ >13 (12) $\mathrm{GeV}^{1/2}$ in the light (heavy) H^+ search. Here $p_T^{\mathrm{PV\ trk}}$ is the transverse momentum of a track originating from the primary vertex and the sum is taken over all tracks from the PV.

The final discriminating variable is the $\tau_{\mathrm{had-vis}} + E_{\mathrm{T}}^{\mathrm{miss}}$ transverse mass, defined as

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\tau} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\Delta\phi_{\tau,\mathrm{miss}})}, \tag{4}$$

To understand the effects of these selection criteria on signal and background simple perturbative calculations not enough

- High multiplicity of particles in final states (at least 4 jets)
- Need information of efficiency of b-tagging
- Several scales make calculations very complicated
- Cuts on complicated kinematical variables are placed

  ($E_T^{miss} / \sqrt{\sum p_T^{PV\ try}}$)

For most efficient experimental use, want fully differential prediction with maximum accuracy possible

- **Fully differential to incorporate complicated experimental cuts**
- **Highest possible accuracy for as many observables as possible**

There are two very different ways of making theoretical predictions: perturbative* calculations and event generators

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Can typically be performed with higher accuracy	Are fully differential, more similar to experimental data
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We all know about fixed order perturbation theory. Why do we need resummation?

Resummation is important when large ratios of scales are present in a perturbative calculation

In general, for every order in perturbation there are 2 power of logarithms that arise for every ratio of scales

If the ratio of scales is large, these logarithms introduce large numerical factors in the perturbative series that can spoil the convergence of perturbation theory

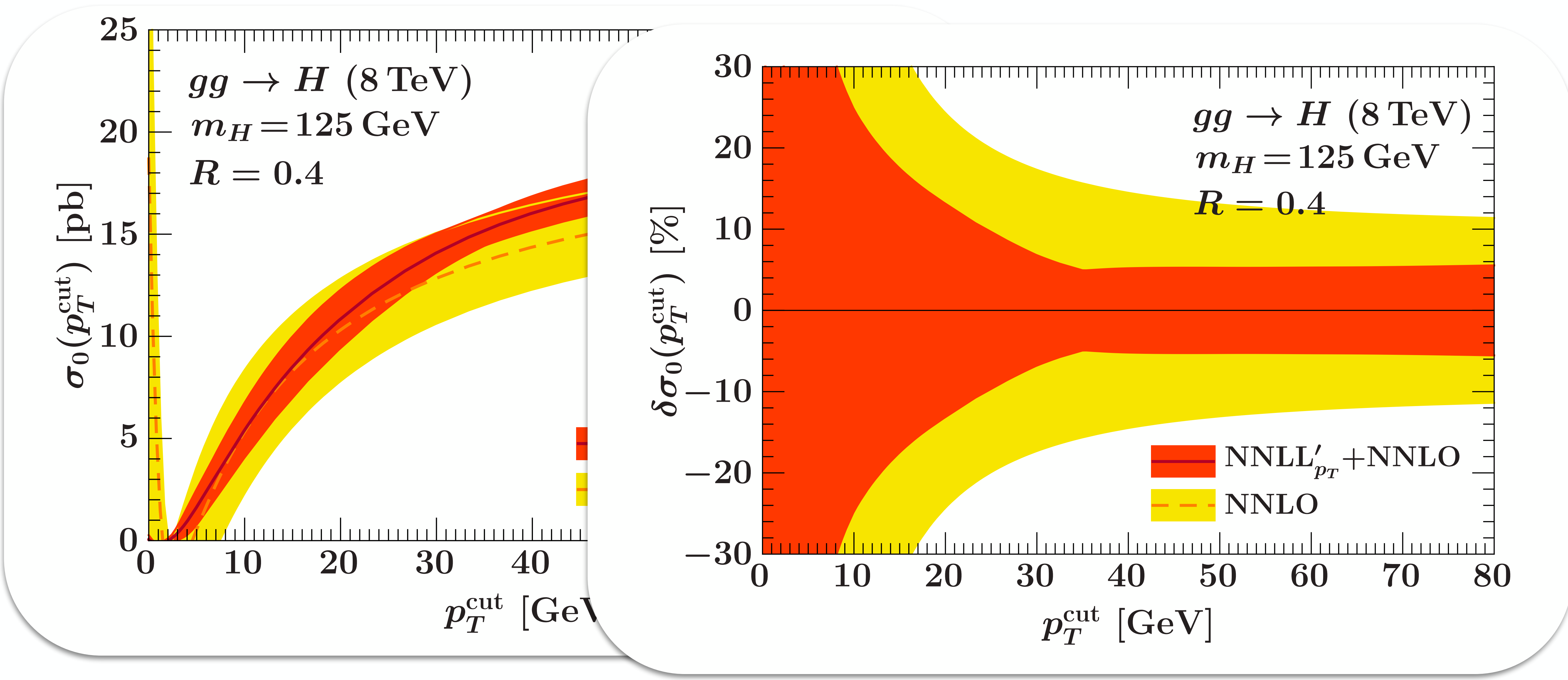
Resummation is a reorganization of the perturbative expansion that sums these logarithms to all orders

Fixed perturbation theory	$\alpha_s \to 0$
Logarithmic resummation	$\alpha_s \to 0$, $\alpha_s L^2$ fixed

For Higgs production, resummation is crucial reduces uncertainties by factor of 2

1205.3806, 1206.4998, 1307.1808

Many experimental analyses split Higgs events into jet bins to deal with different background systematics



Resummation crucial for restricted regions of phase space

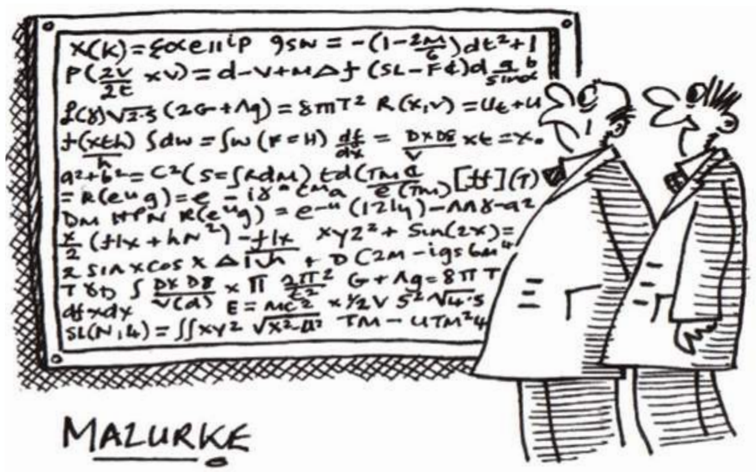
There are two very different ways of making theoretical predictions: perturbative* calculations and event generators

* Can mean either fixed order or resummed

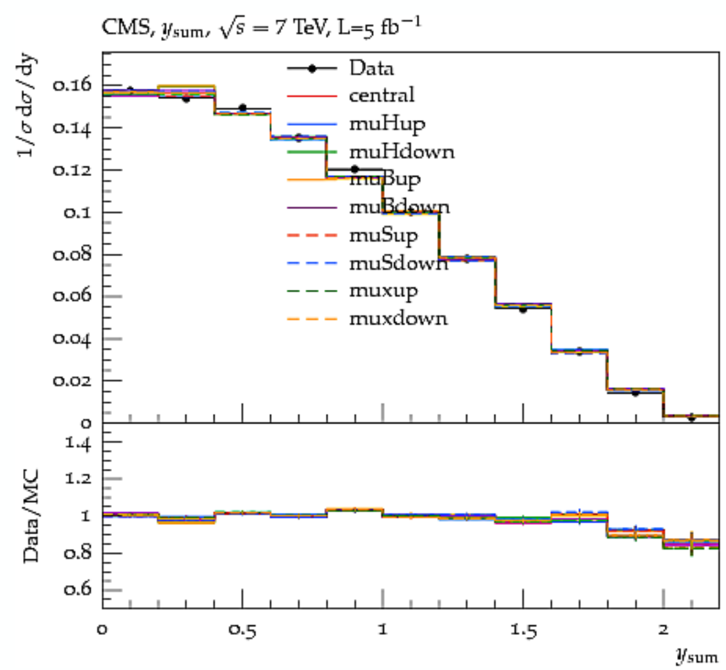
Goal of GENEVA is to generate fully hadronized events that have both higher fixed order and higher resummation accuracy. All results should have realistic event-by-event uncertainties.

The accuracy of GENEVA is at least as good as the competition in most cases.

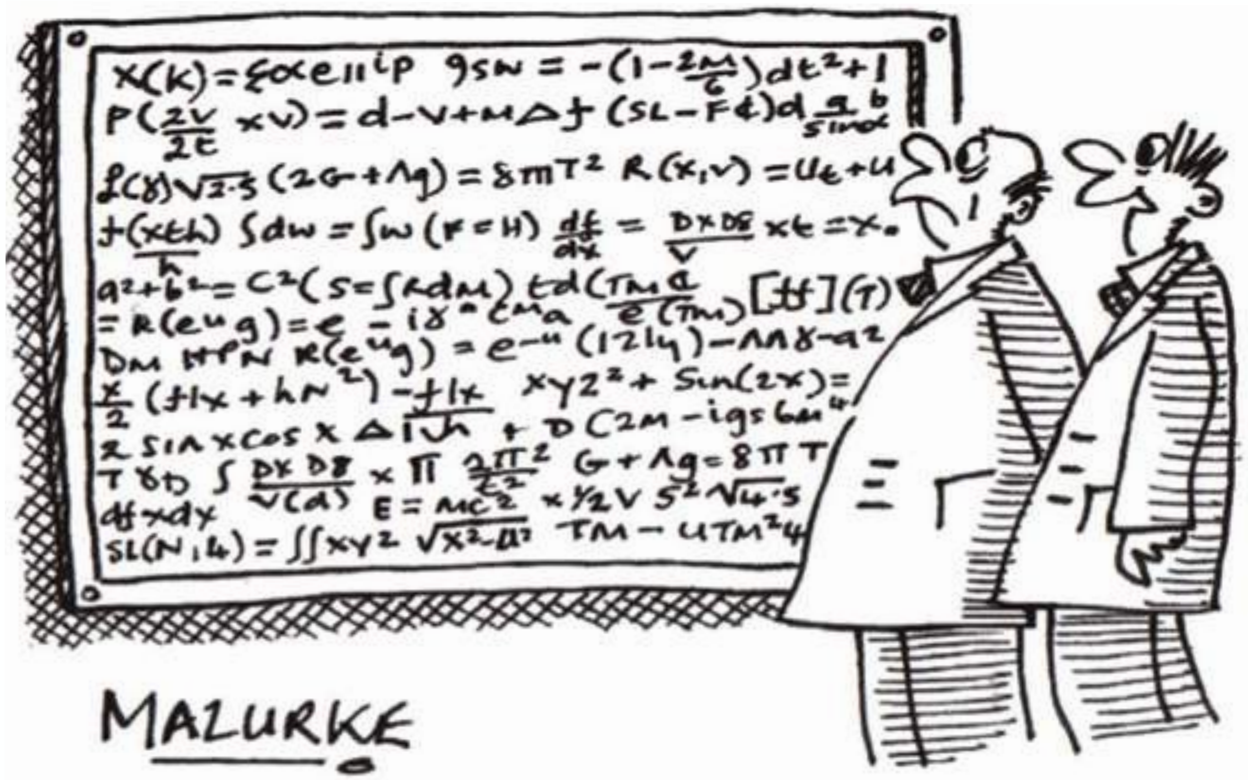
	Powheg / MC@NLO	NNLOPS	Sherpa	UNLOPS	GENEVA
FO Z	NLO	NNLO	NLO	NNLO	NNLO
FO Zj	LO	NLO	NLO	NLO	NLO
FO Zjj	-	LO	NLO	LO	LO
Resummed Z	(N)LL	(N)LL	(N)LL	(N)LL	NNLL’
Uncertainties	only FO	only FO	only FO	only FO	FO and resummed
	0709.2092 1002.2581	1309.0017	1207.5030	1405.3607	



The physics in GENEVA



Results



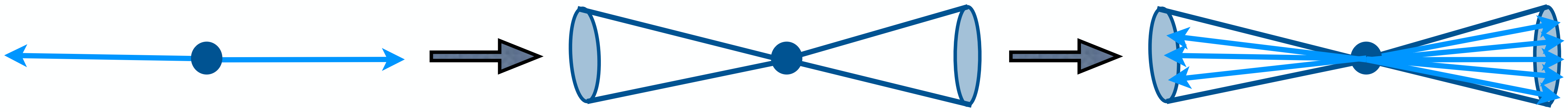
The physics in GENEVA

The main spirit of GENEVA is to calculate physical jet cross-sections

Partonic cross-sections are ill-defined beyond LO in standard perturbation theory

This problem is well known, and always measure and calculate jet cross-sections

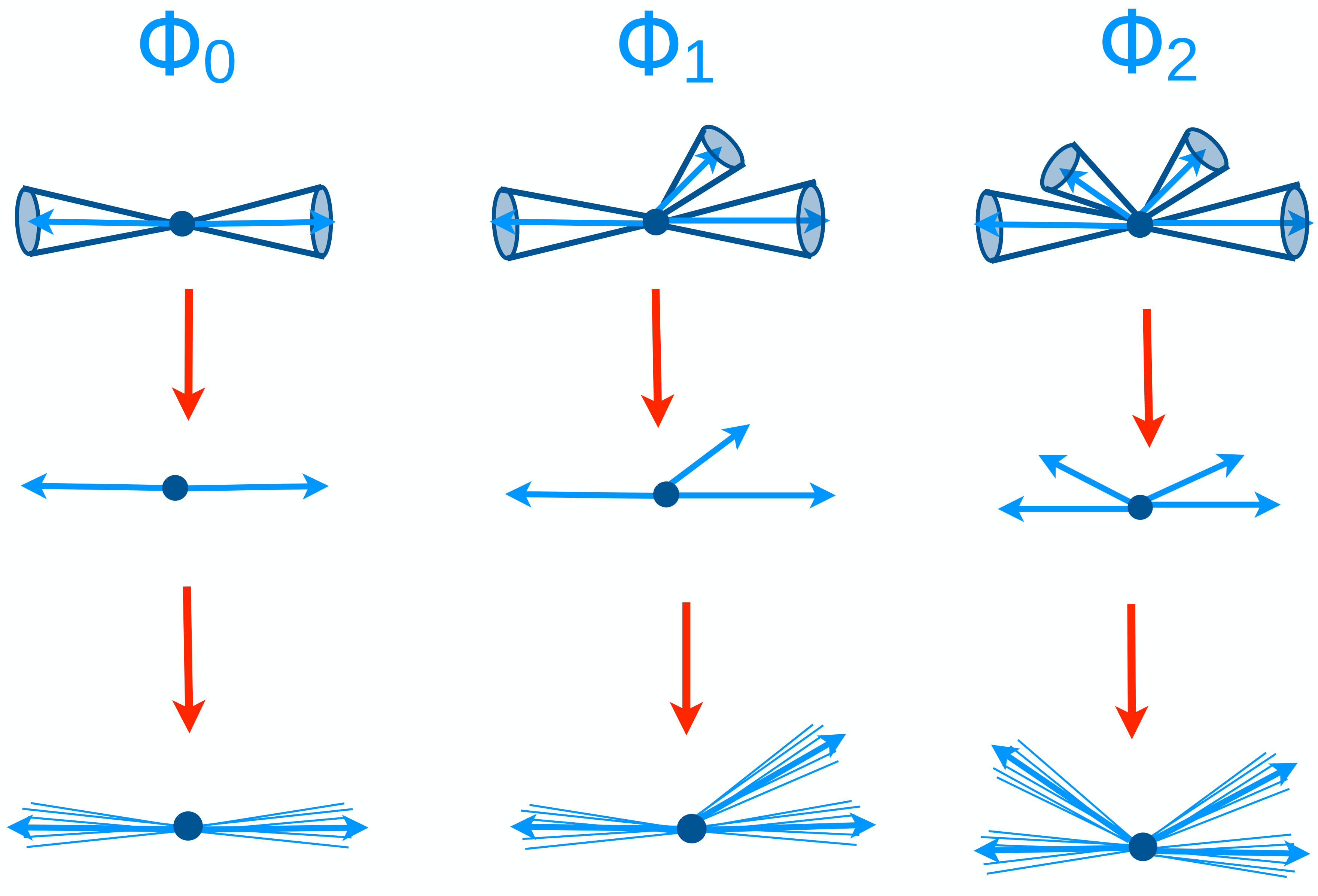
Don’t count number of partons, count number of jets



Do calculations for jet cross-sections, and use shower to fill out jet

In contrast to most other Monte-Carlo generators, Geneva calculates physical jet cross-sections

- Create phase space for jet event
- Calculate cross section and assign to partonic event
- Let parton shower fill jets with radiation



To obtain logarithmic resummation requires a fully factorizable jet definition

A very convenient jet definition is called n-jettiness

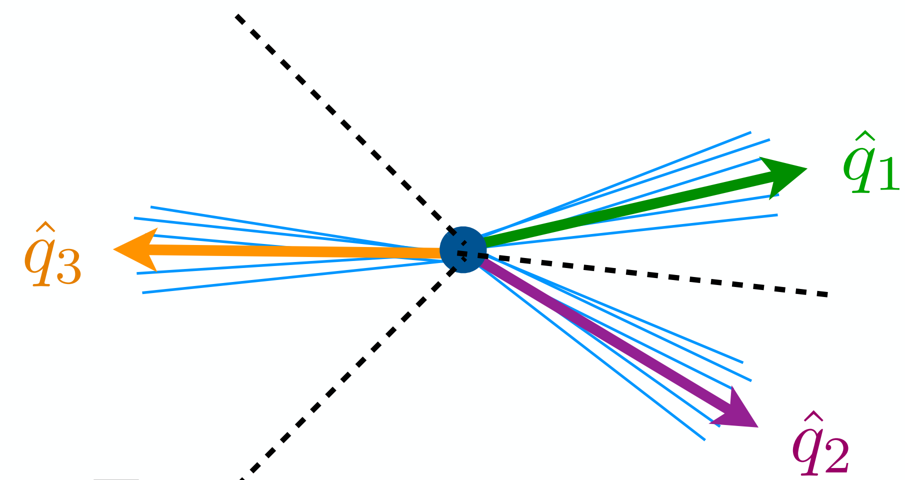
1004.2489

$$\mathcal{T}_N = 2\sum_k \min\{\hat{q}_1 \cdot p_k, \hat{q}_2 \cdot p_k, \cdots, \hat{q}_N \cdot p_k\}$$

$\mathcal{T}_N \to 0$: N pencil-like jets

$\mathcal{T}_N \to Q$: more than N jets

$\mathcal{T}_N < \mathcal{T}_{\mathrm{cut}}$: Veto > N jets

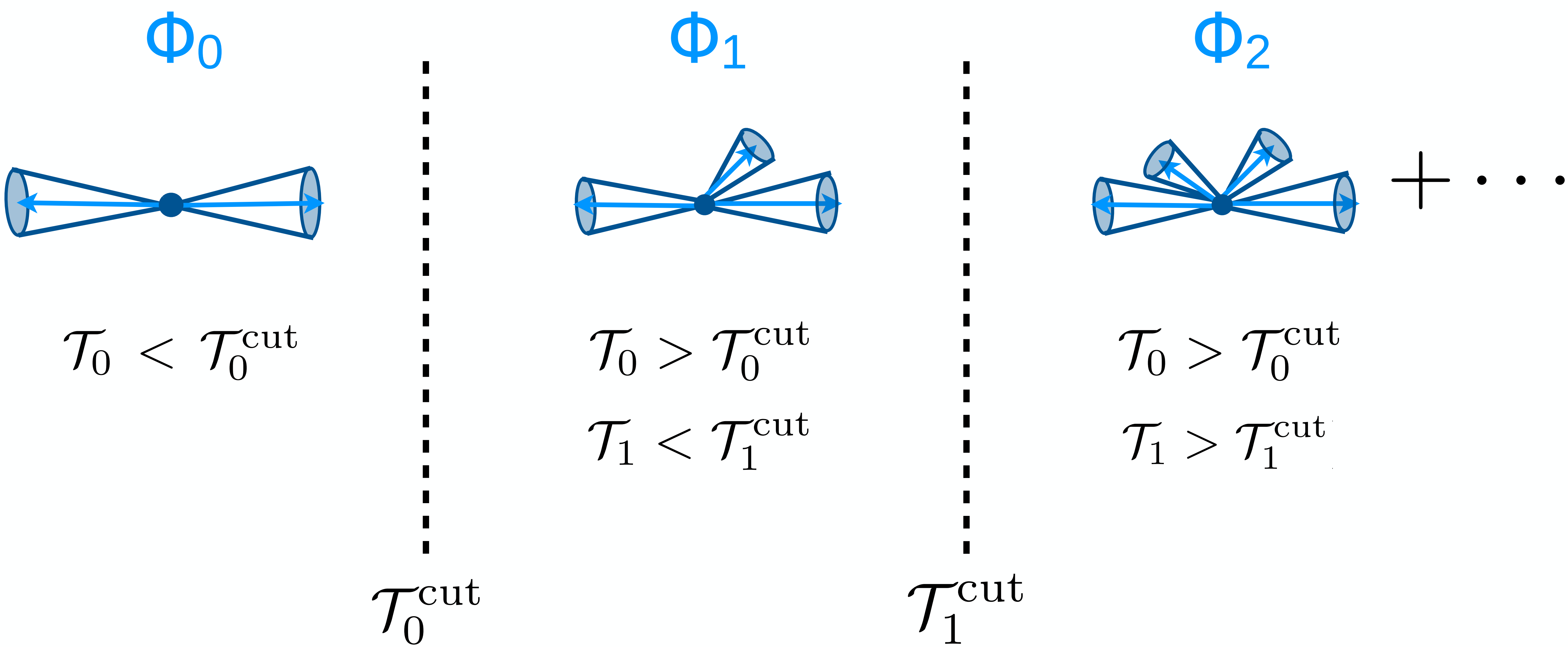


Note that $T_2 = \tau = 1\text{-}T$

Factorization theorem can be proven to all orders

Systematic method to resum logarithms at arbitrary order

This allows us to separate the total hadronic event into different jet multiplicities



Calculate each jet cross section to desired fixed and resummed accuracy, and use shower to fill out jets with radiation

While the equations for the jet cross-sections are a little lengthy, the physics is quite easy to understand

For general NNLO matching, see 1311.0286

The jet cross-sections are written as

$$\text{exclusive 0-jet:} \qquad \frac{d\sigma_0^{\rm MC}}{d\Phi_0}(\mathcal{T}_0^{\rm cut}),$$

$$\text{exclusive 1-jet:} \qquad \frac{d\sigma_1^{\rm MC}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}),$$

$$\text{inclusive 2-jet:} \qquad \frac{d\sigma_{\geq 2}^{\rm MC}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut})$$

Any observable can be calculated from them

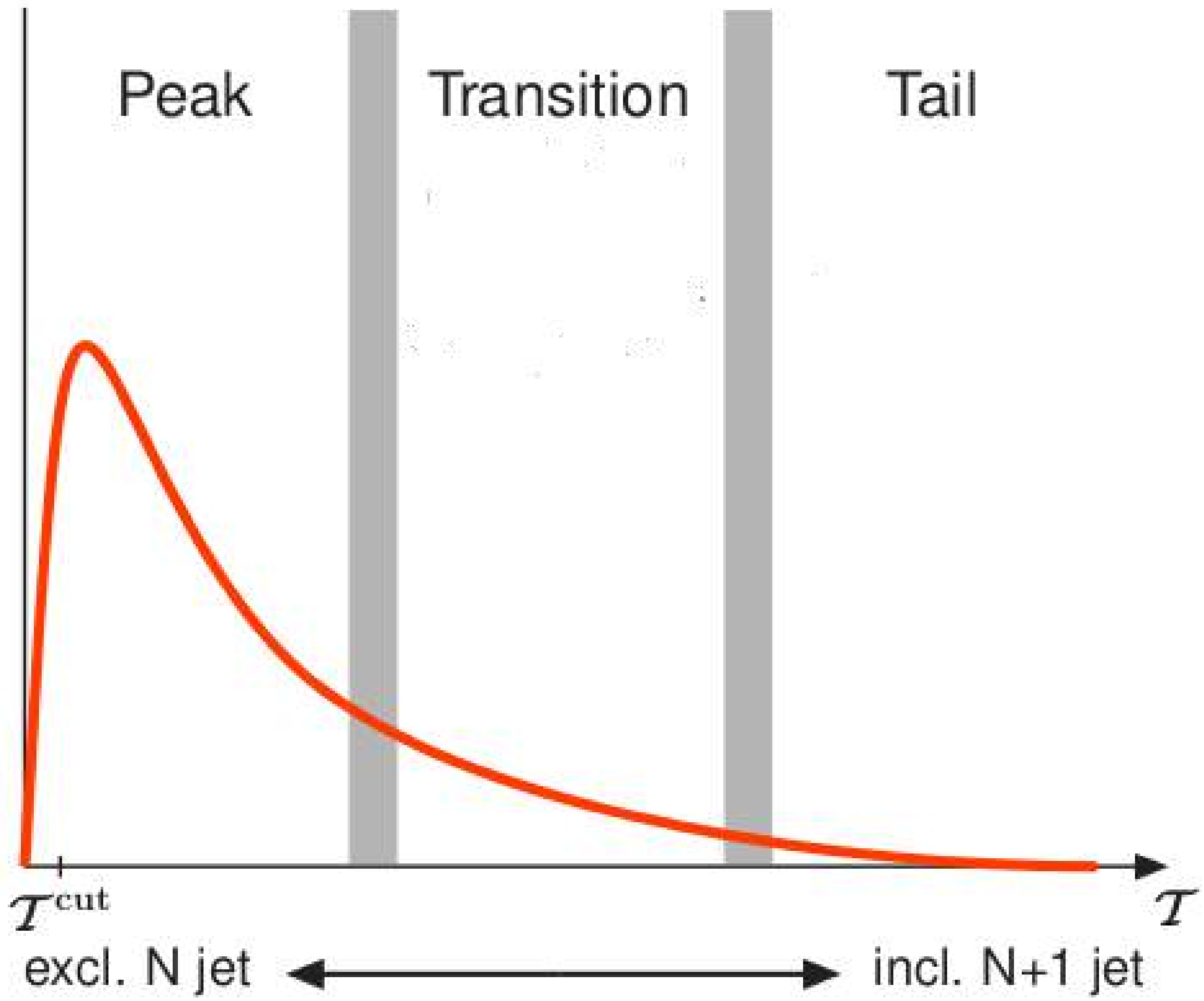
$$\begin{aligned}\sigma(X) = &\int d\Phi_0 \, \frac{d\sigma_0^{\rm MC}}{d\Phi_0}(\mathcal{T}_0^{\rm cut}) \, M_X(\Phi_0) \\ &+ \int d\Phi_1 \, \frac{d\sigma_1^{\rm MC}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}) \, M_X(\Phi_1) \\ &+ \int d\Phi_2 \, \frac{d\sigma_{\geq 2}^{\rm MC}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut}) \, M_X(\Phi_2)\end{aligned}$$

The main question is what expression to use for the differential jet cross-section

$$\frac{d\sigma^{\mathrm{MC}}}{d\Phi_N}?$$

To have next-to-lowest order accuracy over all phase space needs both higher order fixed and resummed results

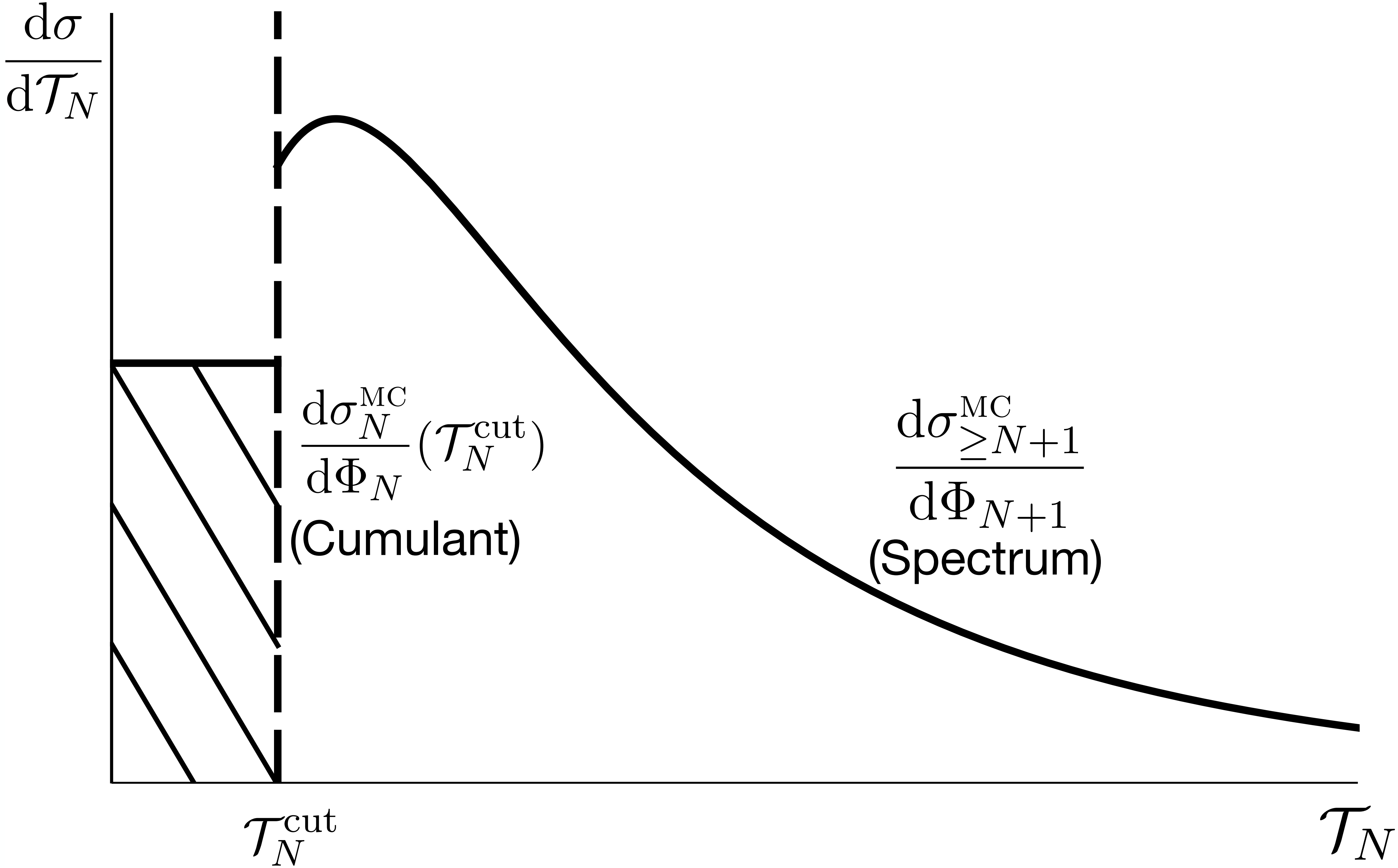
Consider distribution in a jet resolution variable $\mathcal{T}$



In Peak, need resummation

In tail, need fixed order

Before one starts any calculation, a clear idea of the desired accuracy is required



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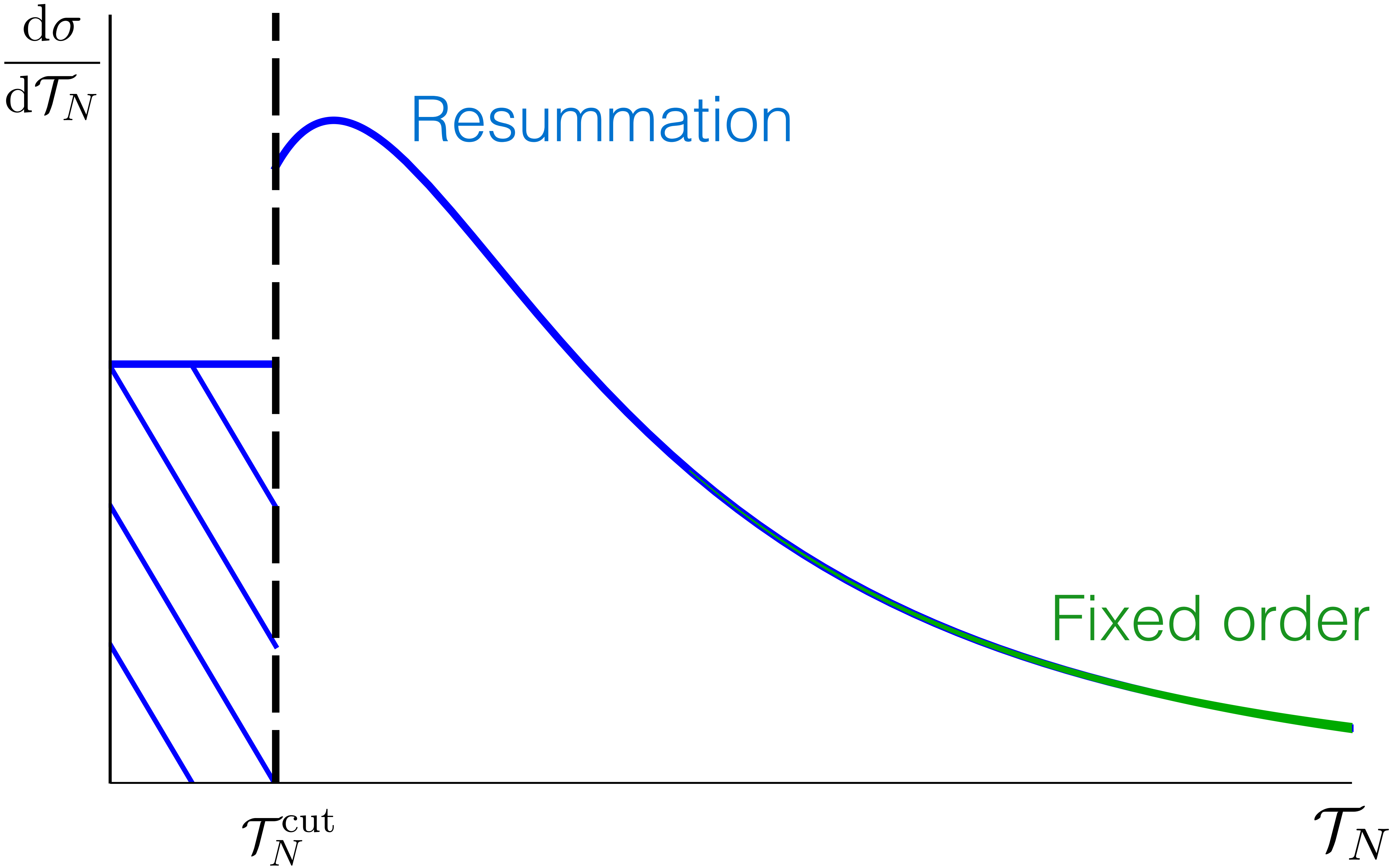

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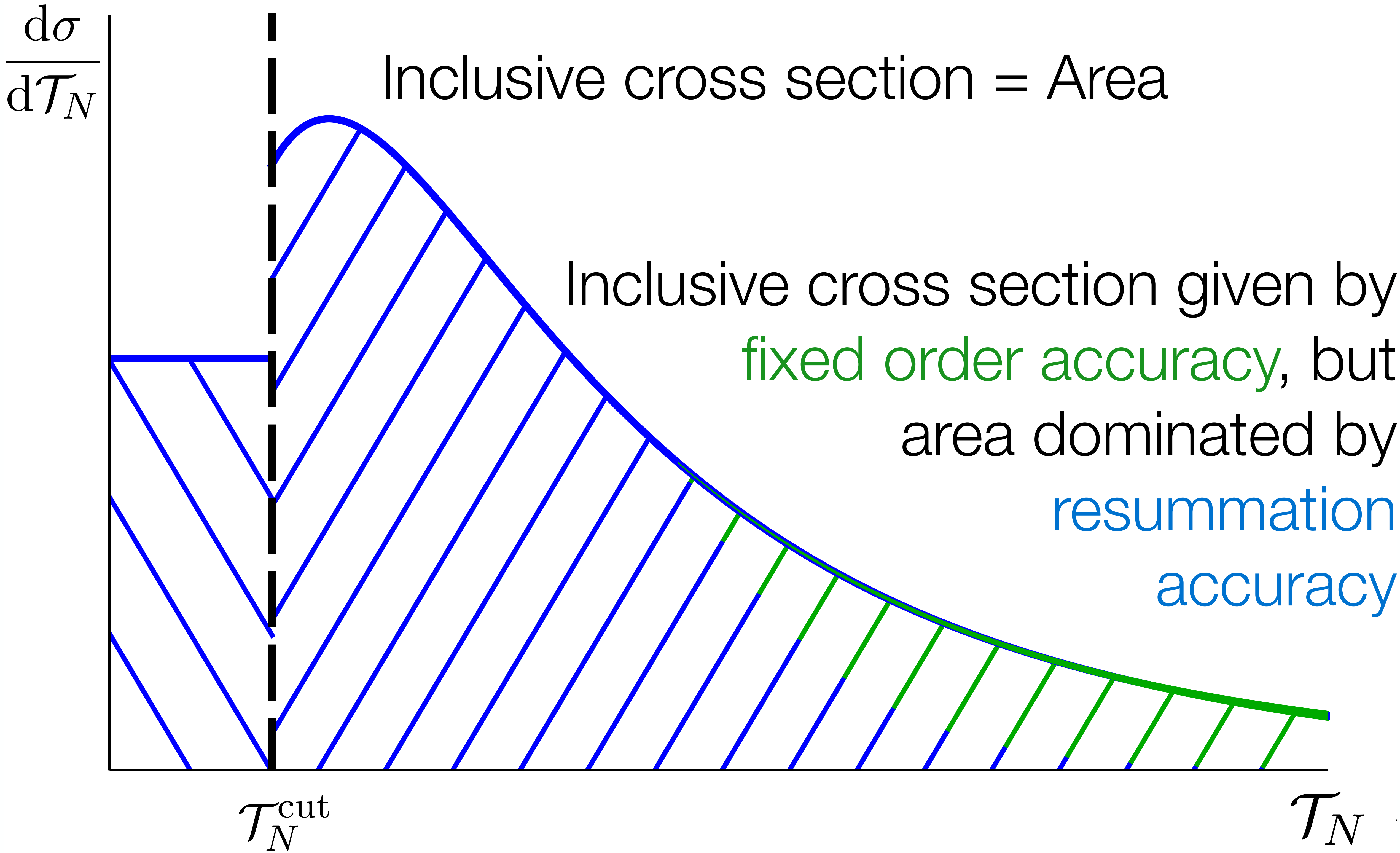

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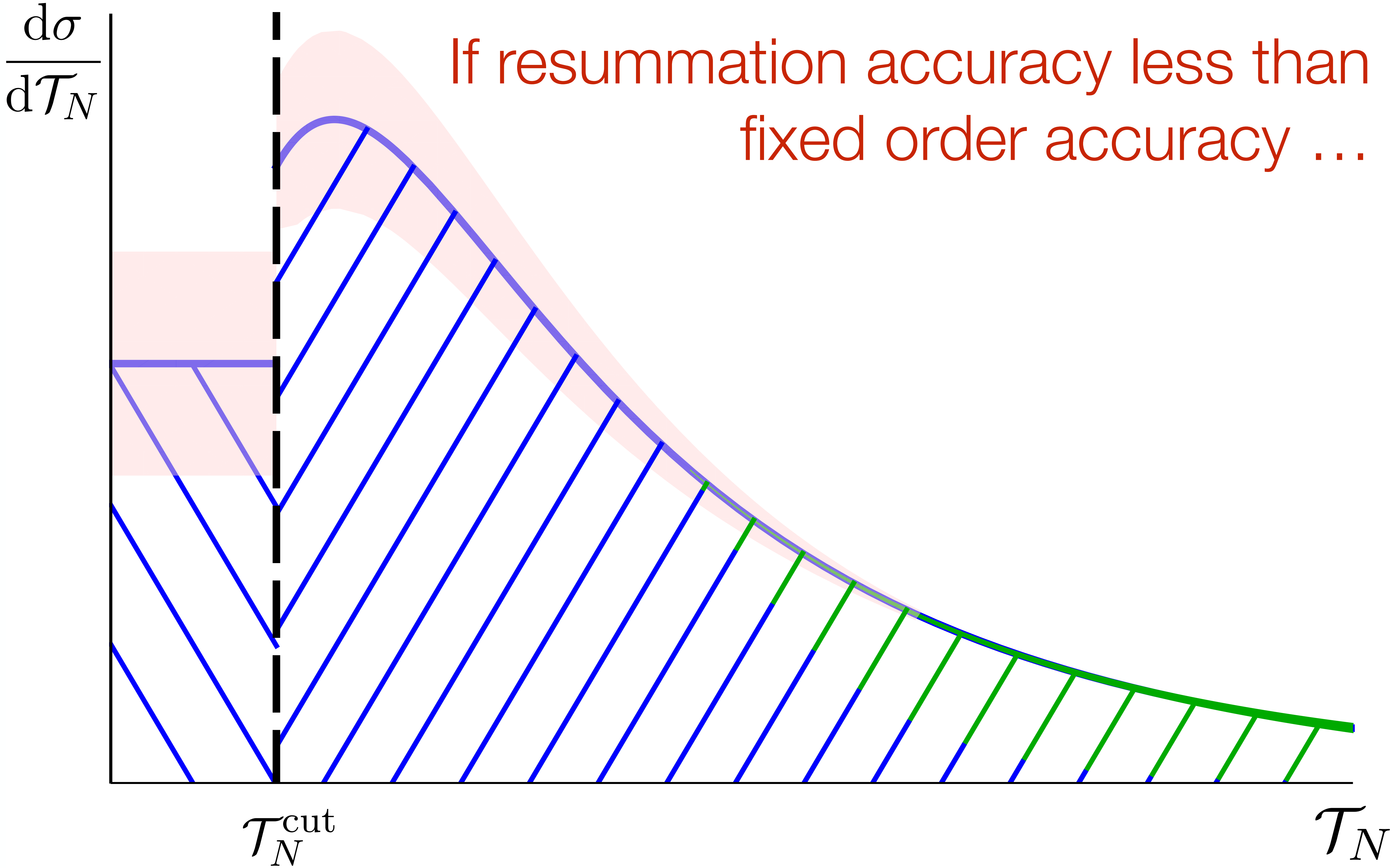

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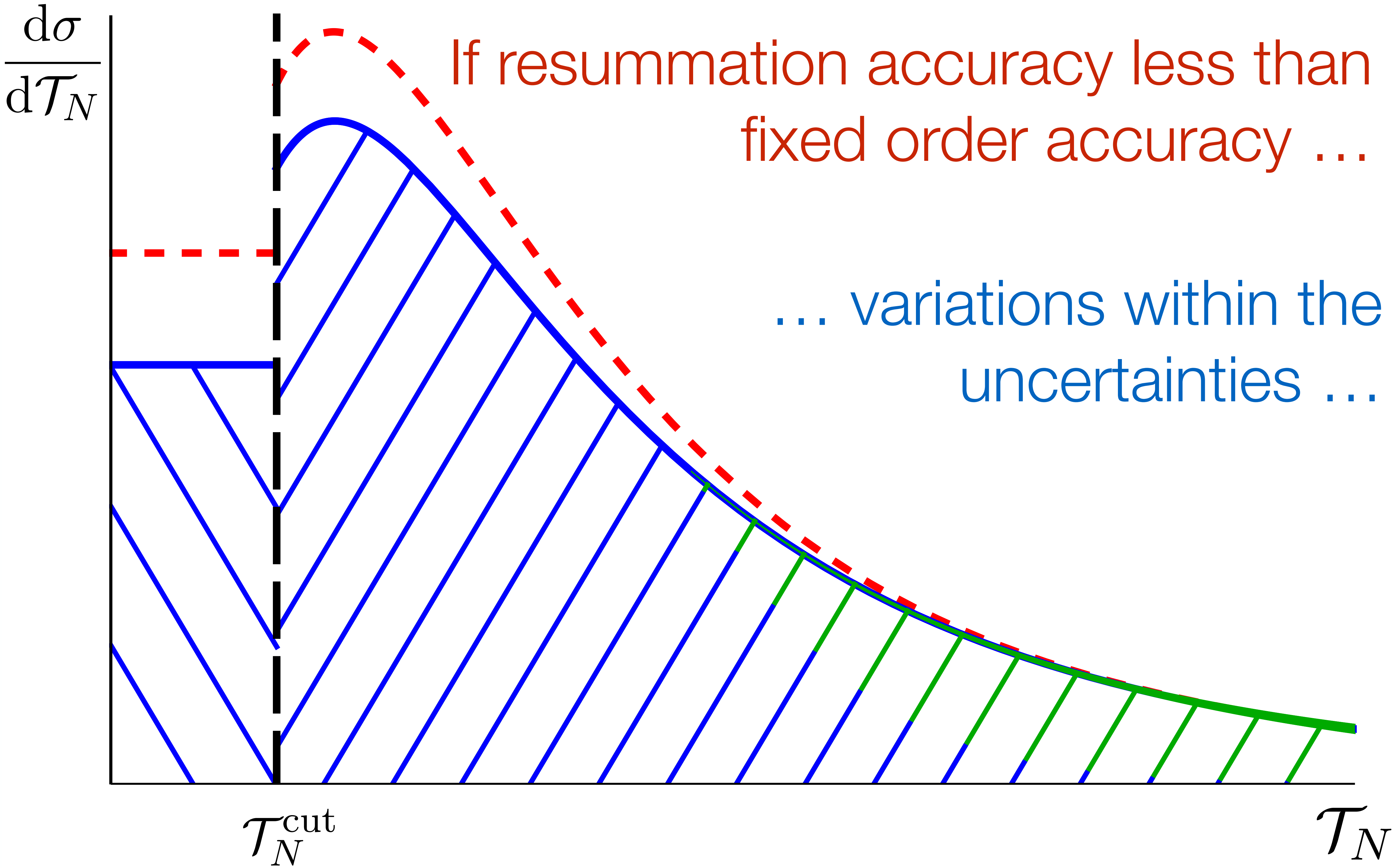

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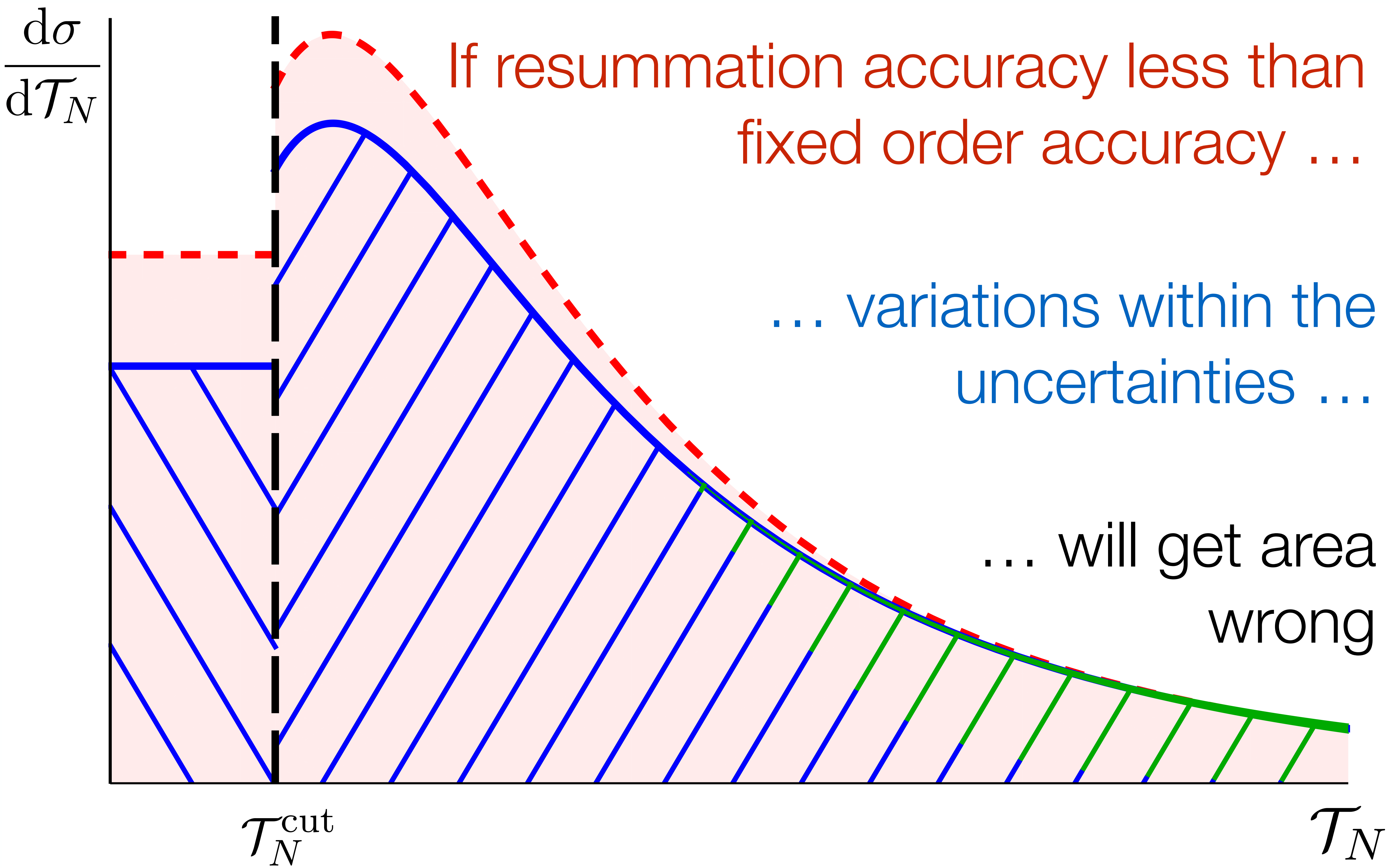

Before one starts any calculation, a clear idea of the desired accuracy is required

need correlation between exclusive N-jet and inclusive (N+1)-jet rates

or

need resummation accuracy match fixed order accuracy

What do I mean by fixed order accuracy matching resummed accuracy?

Relative accuracy if $\alpha_s \mathrm{Log}^2 \sim 1$ α_s^k	FO Accuracy	Resummation Accuracy
k = 0	LO	LL
k = 1	NLO	NLL'
k = 2	NNLO	NNLL'

Use SCET to determine the expressions for the differential jet cross-sections with resummed and fixed accuracy

Use the full power of SCET to obtain exclusive jet distributions that are correct to given fixed order and resummation accuracy

Fixed Order Z+0	Fixed order Z+1	Fixed order Z+2	0-jet resolution	1-jet resolution
NNLO	NLO	LO	NNLL'	LL

No other generator on the market with this level of accuracy

In the following slides, I will show you some of the details of our formalism

If you just care about the results you can

I will wake you up again!

While the equations for the jet cross-sections are a little lengthy, the physics is quite easy to understand

We will first focus on the 0-jet cross-section and the inclusive 1-jet cross-section

$$\frac{d\sigma_0^{\mathrm{MC}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) \quad , \qquad\qquad \frac{d\sigma_{\geq 1}^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

with the inclusive 1-jet rate defined as

$$\begin{aligned}\frac{d\sigma_{\geq 1}^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) =& \frac{d\sigma_1^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}}) \\ &+ \int \frac{d\Phi_2}{d\Phi_1} \frac{d\sigma_{\geq 2}^{\mathrm{MC}}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}, \mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}})\end{aligned}$$

While the equations for the jet cross-sections are a little lengthy, the physics is quite easy to understand

We take the resummed result at NNLL' and match it to a fixed order result

$$\frac{d\sigma_0^{\mathrm{MC}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}),$$

$$\frac{d\sigma_{\geq 1}^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_{\geq 1}^{\mathrm{NNLL}'}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_{\geq 1}^{\mathrm{nons}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

The matching is given by a standard result

$$\frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{NNLO}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) - \left[\frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})\right]_{\mathrm{NNLO}}$$

$$\frac{d\sigma_{\geq 1}^{\mathrm{nons}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \left\{\frac{d\sigma_{\geq 1}^{\mathrm{NLO}}}{d\Phi_1} - \left[\frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_1}\right]_{\mathrm{NLO}} \mathcal{P}(\Phi_1)\right\} \theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

While the equations for the jet cross-sections are a little lengthy, the physics is quite easy to understand

$$\frac{d\sigma_0^{\mathrm{MC}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_0^{\mathrm{nons}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}),$$

$$\frac{d\sigma_{\geq 1}^{\mathrm{MC}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{d\sigma_{\geq 1}^{\mathrm{NNLL}'}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \frac{d\sigma_{\geq 1}^{\mathrm{nons}}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})$$

Since the NNLL' resummation includes 2-loop singular terms, actual NNLO terms power suppressed

$$\frac{d\sigma_0^{\mathrm{NNLO}}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}}) - \left[\frac{d\sigma_0^{\mathrm{NNLL}'}}{d\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})\right]_{\mathrm{NNLO}} \to \left[\alpha_s f_1(\mathcal{T}_0^{\mathrm{cut}}, \Phi_0) + \alpha_s^2 f_2(\mathcal{T}_0^{\mathrm{cut}}, \Phi_0)\right] \mathcal{T}_0^{\mathrm{cut}}$$

This is same idea that is now being used in the N-jettiness subtraction

See next talk

While the equations for the jet cross-sections are a little lengthy, the physics is quite easy to understand

$$\frac{d\sigma_0^{\rm MC}}{d\Phi_0}(\mathcal{T}_0^{\rm cut}) = \frac{d\sigma_0^{\rm NNLL'}}{d\Phi_0}(\mathcal{T}_0^{\rm cut}) + \frac{d\sigma_0^{\rm nons}}{d\Phi_0}(\mathcal{T}_0^{\rm cut})\,,$$

$$\frac{d\sigma_{\geq 1}^{\rm MC}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}) = \frac{d\sigma_{\geq 1}^{\rm NNLL'}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}) + \frac{d\sigma_{\geq 1}^{\rm nons}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut})$$

Now we have exclusive 0-jet and inclusive 1-jet, and we split up the inclusive 1-jet into an exclusive 1-jet and inclusive 2-jet result

$$\frac{d\sigma_1^{\rm MC}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}) = \frac{d\sigma_1^{\rm resum}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut}) + \frac{d\sigma_1^{\rm nons}}{d\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}; \mathcal{T}_1^{\rm cut})\,,$$

$$\frac{d\sigma_{\geq 2}^{\rm MC}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut}) = \frac{d\sigma_{\geq 2}^{\rm resum}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut})\,\theta(\mathcal{T}_1 > \mathcal{T}_1^{\rm cut}) + \frac{d\sigma_{\geq 2}^{\rm nons}}{d\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\rm cut}, \mathcal{T}_1 > \mathcal{T}_1^{\rm cut})$$

Use SCET to determine the expressions for the differential jet cross-sections with resummed and fixed accuracy

Resummed

$$\frac{\mathrm{d}\sigma_1^{\mathrm{resum}}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}}) = \frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\, U_1(\Phi_1, \mathcal{T}_1^{\mathrm{cut}})\,,$$

$$\frac{\mathrm{d}\sigma_{\geq 2}^{\mathrm{resum}}}{\mathrm{d}\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\, U_1'(\Phi_1, \mathcal{T}_1)\Big|_{\Phi_1 = \Phi_1^{\mathcal{T}}(\Phi_2)} \mathcal{P}(\Phi_2)\, \theta(\mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}})$$

with

$$\frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) = \frac{\mathrm{d}\sigma_{\geq 1}^{\mathrm{resum}}}{\mathrm{d}\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}) + \left[\frac{\mathrm{d}\sigma_{\geq 1}^{C}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\right]_{\mathrm{NLO}_1} - \left[\frac{\mathrm{d}\sigma_{\geq 1}^{\mathrm{resum}}}{\mathrm{d}\Phi_1}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\right]_{\mathrm{NLO}_1}$$

Non-singular

$$\frac{\mathrm{d}\sigma_1^{\mathrm{nons}}}{\mathrm{d}\Phi_1}(\mathcal{T}_1^{\mathrm{cut}}) = \int \mathrm{d}\Phi_2 \left[\frac{B_2(\Phi_2)}{\mathrm{d}\Phi_1^{\mathcal{T}}}\,\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\theta(\mathcal{T}_1 < \mathcal{T}_1^{\mathrm{cut}}) - \frac{C_2(\Phi_2)}{\mathrm{d}\tilde{\Phi}_1}\theta(\tilde{\mathcal{T}}_0 > \mathcal{T}_0^{\mathrm{cut}})\right]$$
$$- B_1(\Phi_1)\, U_1^{(1)}(\Phi_1, \mathcal{T}_1^{\mathrm{cut}})\,,$$

$$\frac{\mathrm{d}\sigma_{\geq 2}^{\mathrm{nons}}}{\mathrm{d}\Phi_2}(\mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}}) = \big\{B_2(\Phi_2)\,[1 - \Theta^{\mathcal{T}}(\Phi_2)\,\theta(\mathcal{T}_1 < \mathcal{T}_1^{\mathrm{cut}})]$$
$$- B_1(\Phi_1^{\mathcal{T}})\, U_1^{(1)\prime}(\Phi_1^{\mathcal{T}}, \mathcal{T}_1)\, \mathcal{P}(\Phi_2)\, \theta(\mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}})\big\}\theta(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}})\,,$$

When showering these events, we need to make sure that we don't violate the accuracy we have obtained

The parton shower should fill the jets with radiation, but that means it needs to know about our definition of jets

Here is a table with all info that went into our jet definition

	Φ_0	Φ_1	Φ_2	Φ_N
$\frac{d\sigma_0^{\mathrm{MC}}}{d\Phi_0}$	All	$\theta_{\mathcal{T}_0}(\Phi_1)$ and $\theta_{\mathrm{map}}(\Phi_0;\Phi_1)$	$\theta_{\mathcal{T}_0}(\Phi_2)$	$\theta_{\mathcal{T}_0}(\Phi_N)$
$\frac{d\sigma_1^{\mathrm{MC}}}{d\Phi_1}$	–	$\overline{\theta}_{\mathcal{T}_0}(\Phi_1)$ or $\overline{\theta}_{\mathrm{map}}(\Phi_1)$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_2)$ and $\theta_{\mathcal{T}_1}(\Phi_2)$ and $\theta_{\mathrm{map}}(\Phi_1;\Phi_2)$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_N)$ and $\theta_{\mathcal{T}_1}(\Phi_N)$
$\frac{d\sigma_{\geq 2}^{\mathrm{MC}}}{d\Phi_2}$	–	–	$\overline{\theta}_{\mathcal{T}_0}(\Phi_2)$ and $\left[\overline{\theta}_{\mathcal{T}_1}(\Phi_2)\right.$ or $\left.\overline{\theta}_{\mathrm{map}}(\Phi_2)\right]$	$\overline{\theta}_{\mathcal{T}_0}(\Phi_N)$ and $\overline{\theta}_{\mathcal{T}_1}(\Phi_N)$

Important point is that up to Φ_2, fixed order calculation demands carefully defined jets. Beyond that accuracy, only knows about values of jet resolution variable

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Important point is that up to Φ_2, fixed order calculation demands carefully defined jets. Beyond that accuracy, only knows about values of jet resolution variable

This is not an issue for showering 0-jet events, where Pythia is respecting our definition well.

But for 1-jet events we perform the first emission analytically, and only then hand the event to Pythia

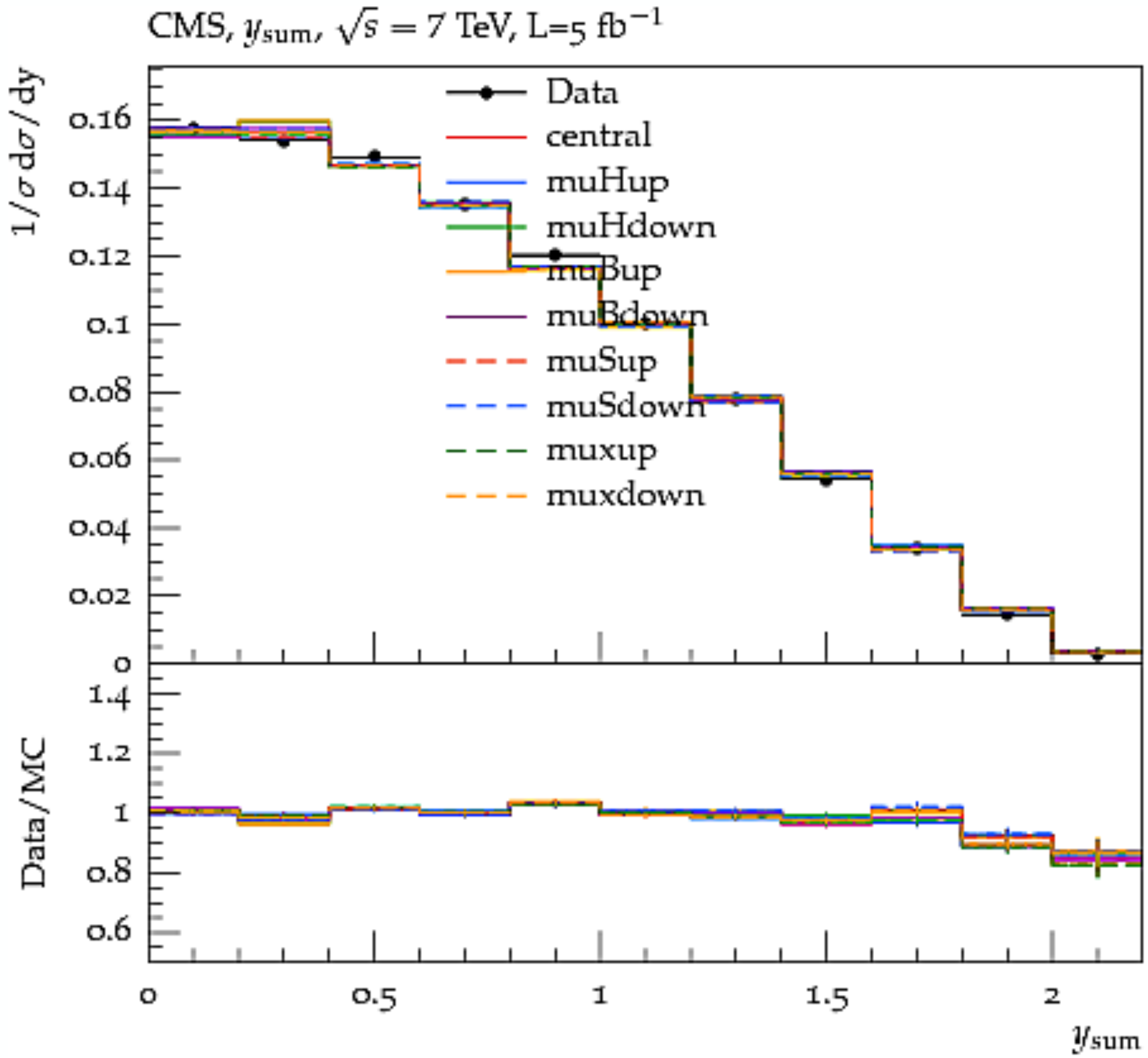
Only constraint we put on Pythia is that $\tau_N < \tau_N^{cut}$
(since we don’t have shower with evolution variable τ_N)

In summary, Geneva implements the following results for the fully differential jet cross-sections

exclusive 0-jet: $\frac{\mathrm{d}\sigma_0^{\mathrm{MC}}}{\mathrm{d}\Phi_0}(\mathcal{T}_0^{\mathrm{cut}})$ @ NNLO / NNLL'

exclusive 1-jet: $\frac{\mathrm{d}\sigma_1^{\mathrm{MC}}}{\mathrm{d}\Phi_1}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}; \mathcal{T}_1^{\mathrm{cut}})$ @ NLO / NNLL' / LL

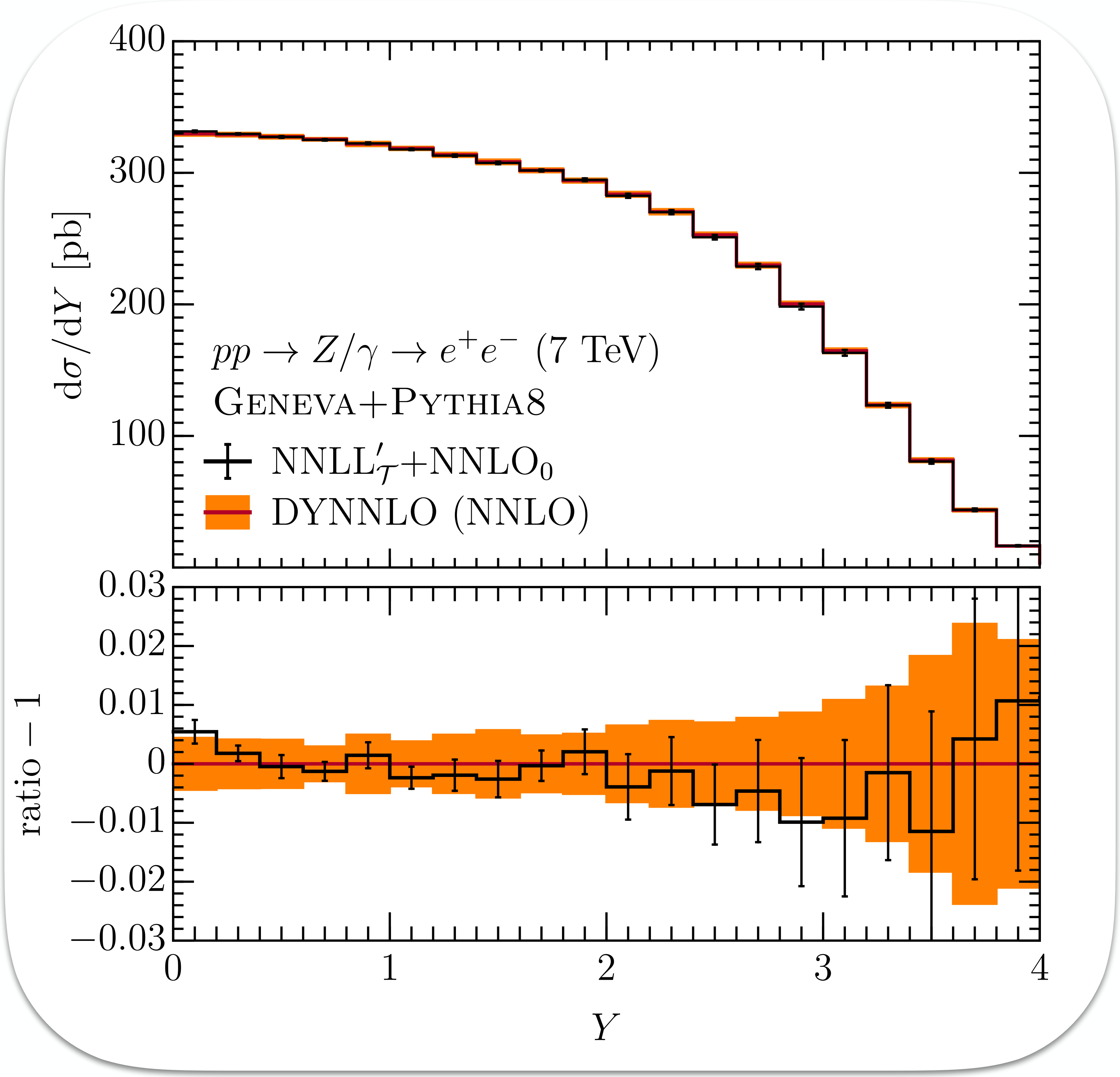
inclusive 2-jet: $\frac{\mathrm{d}\sigma_{\geq 2}^{\mathrm{MC}}}{\mathrm{d}\Phi_2}(\mathcal{T}_0 > \mathcal{T}_0^{\mathrm{cut}}, \mathcal{T}_1 > \mathcal{T}_1^{\mathrm{cut}})$ @ LO / NNLL' / LL


CMS, y_{sum}, $\sqrt{s}$ = 7 TeV, L=5 fb^{-1}
1/σ dσ/dy
Data
central
muHup
muHdown
muBup
muBdown
muSup
muSdown
muxup
muxdown
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1.4
1.2
1
0.8
0.6
Data/MC
0
0.5
1
1.5
2
y_{sum}

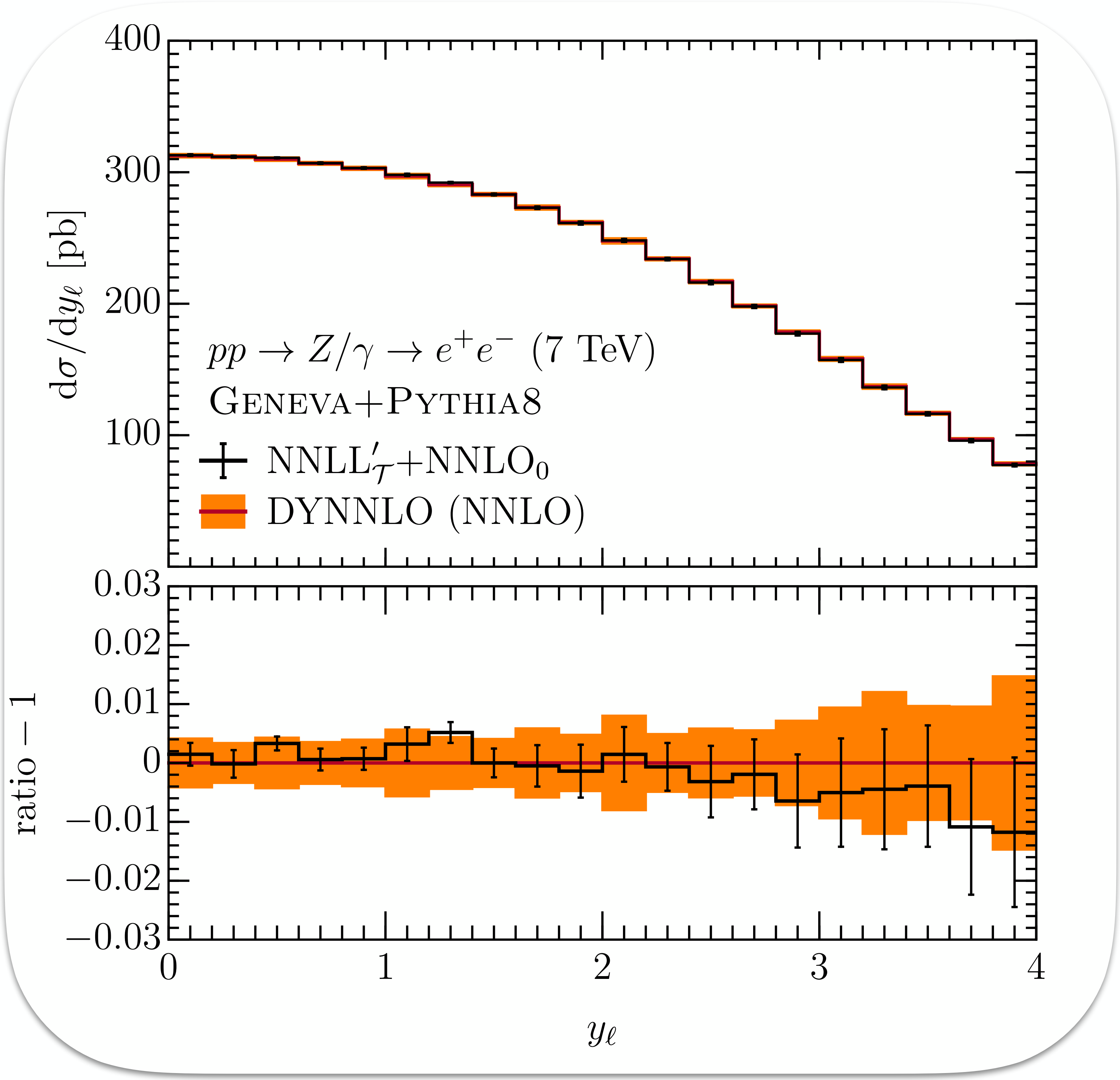
Results

Let me begin by showing comparisons to perturbative calculations

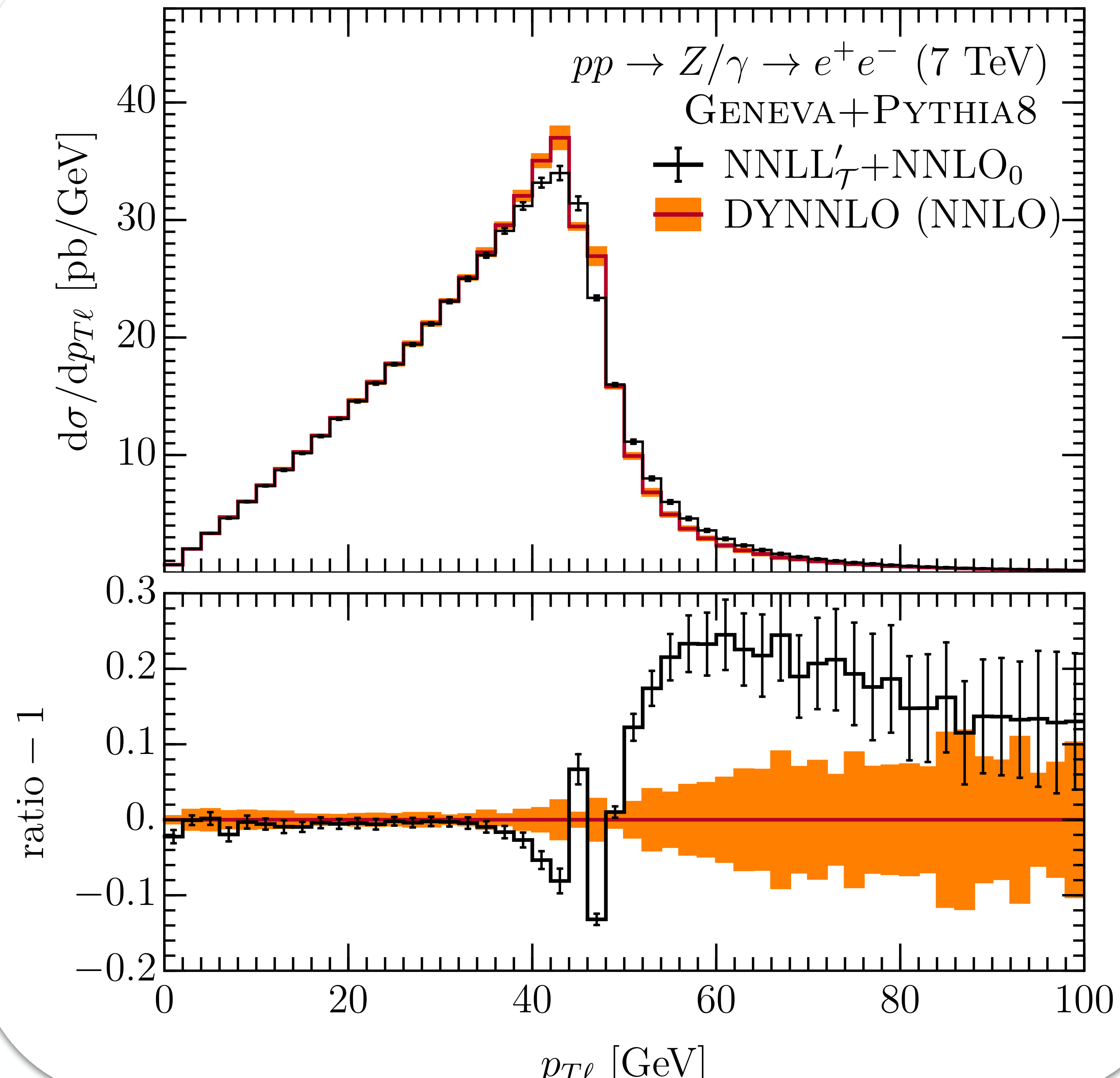
Fully inclusive Z boson spectra agree with NNLO fixed order calculation



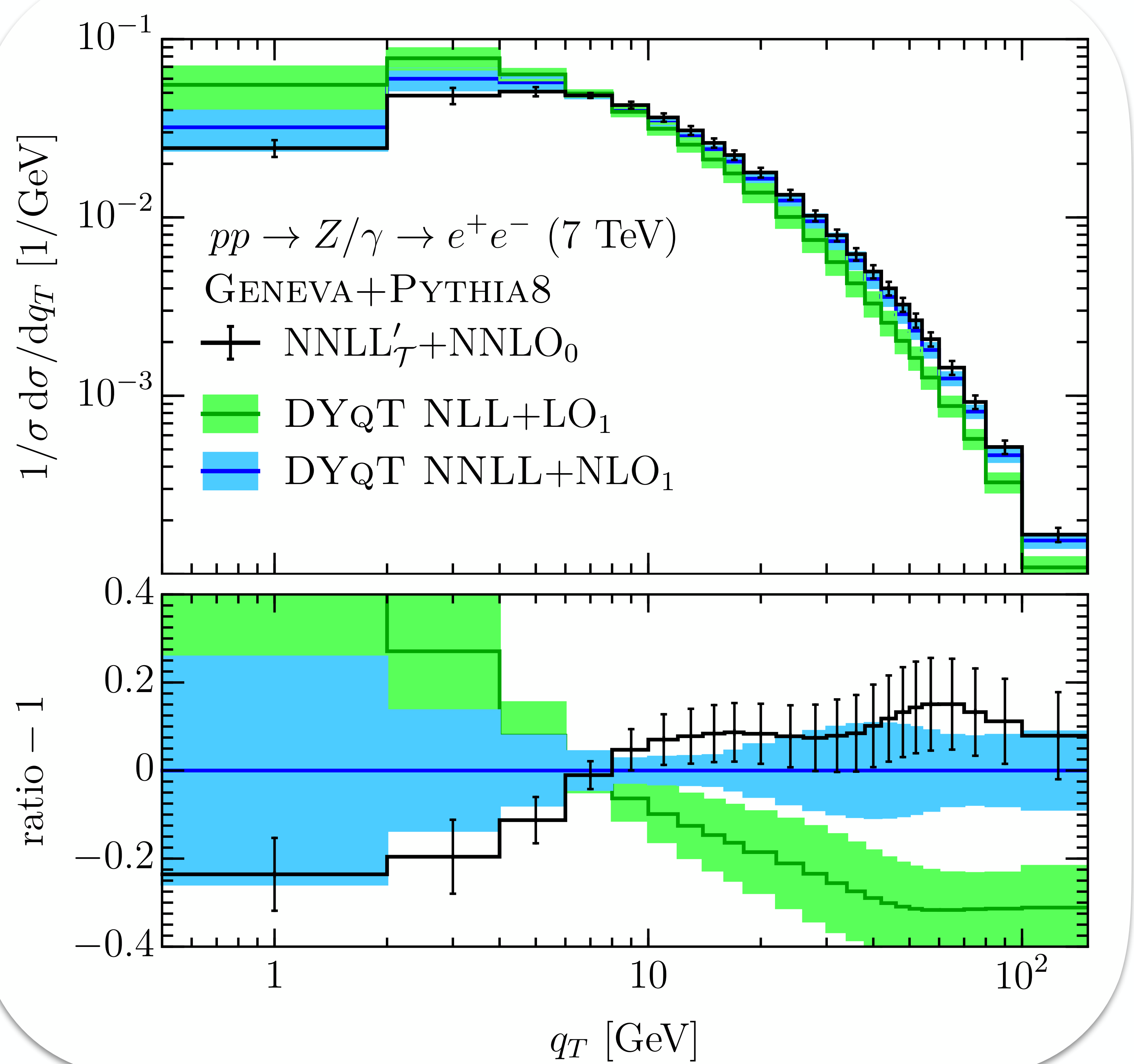
Fully inclusive Z boson spectra agree with NNLO fixed order calculation



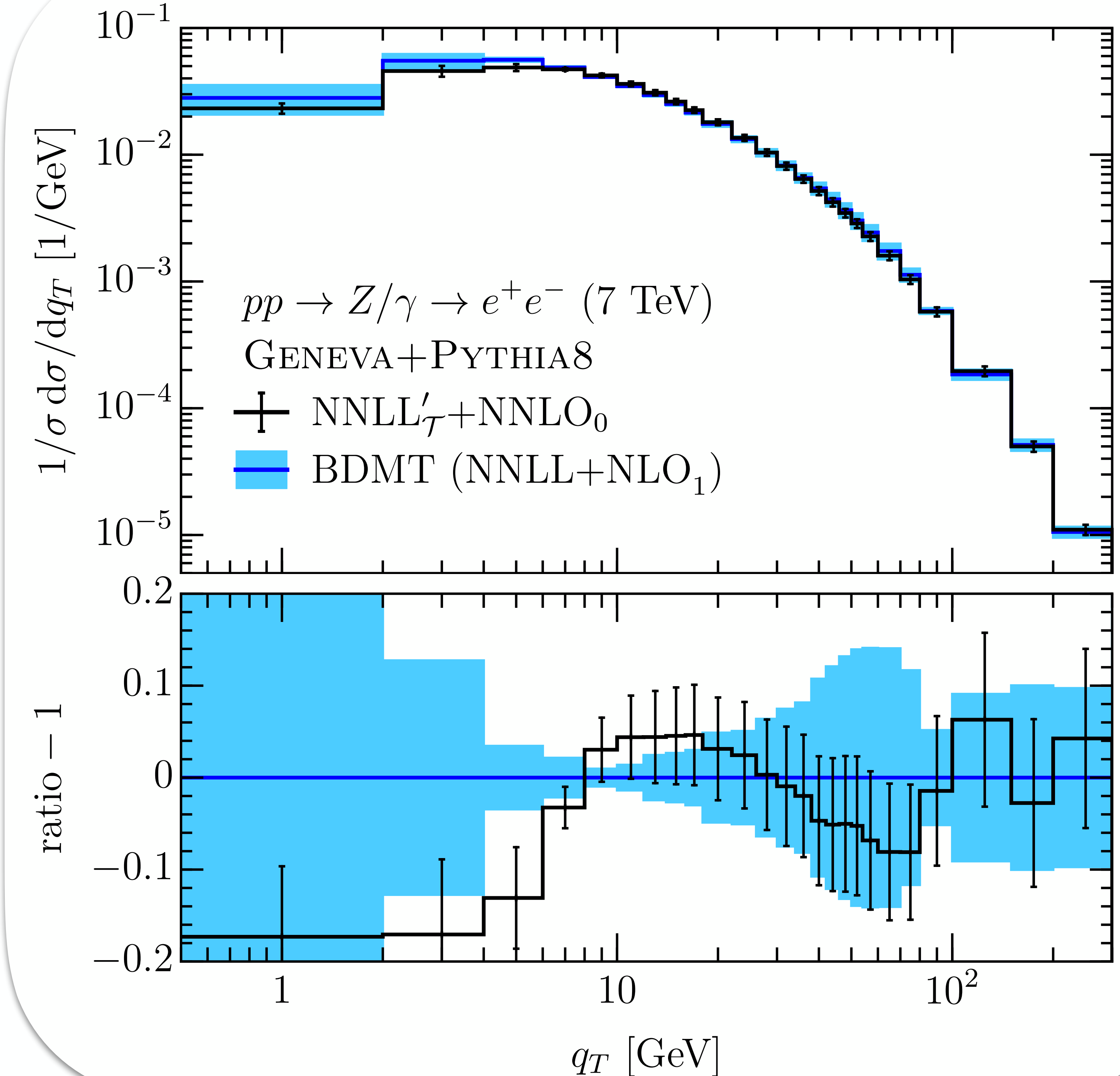
Fully inclusive Z boson spectra agree with NNLO fixed order calculation



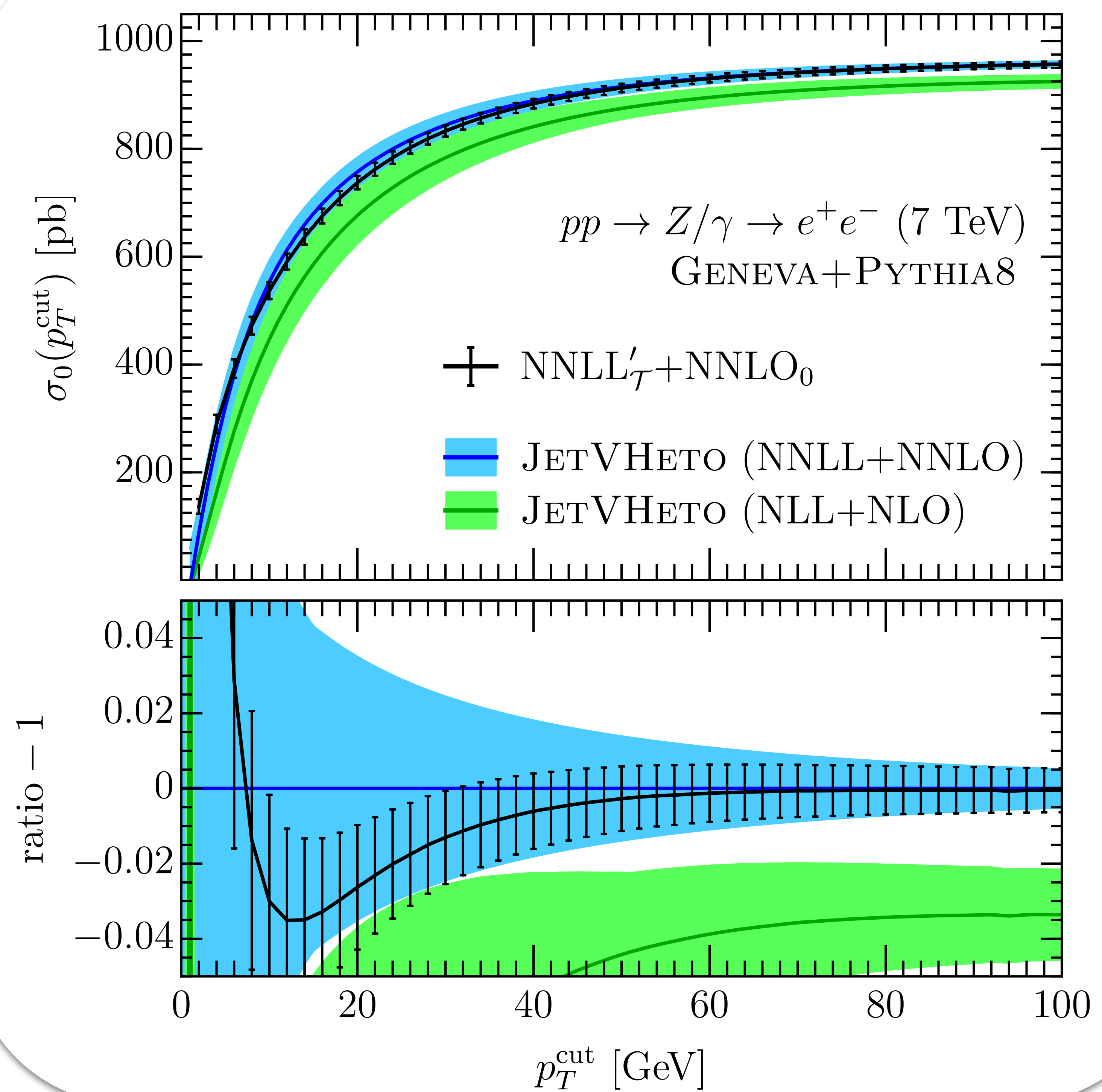
Resummed observables are predicted with accuracies which compare well with dedicated NNLL calculations



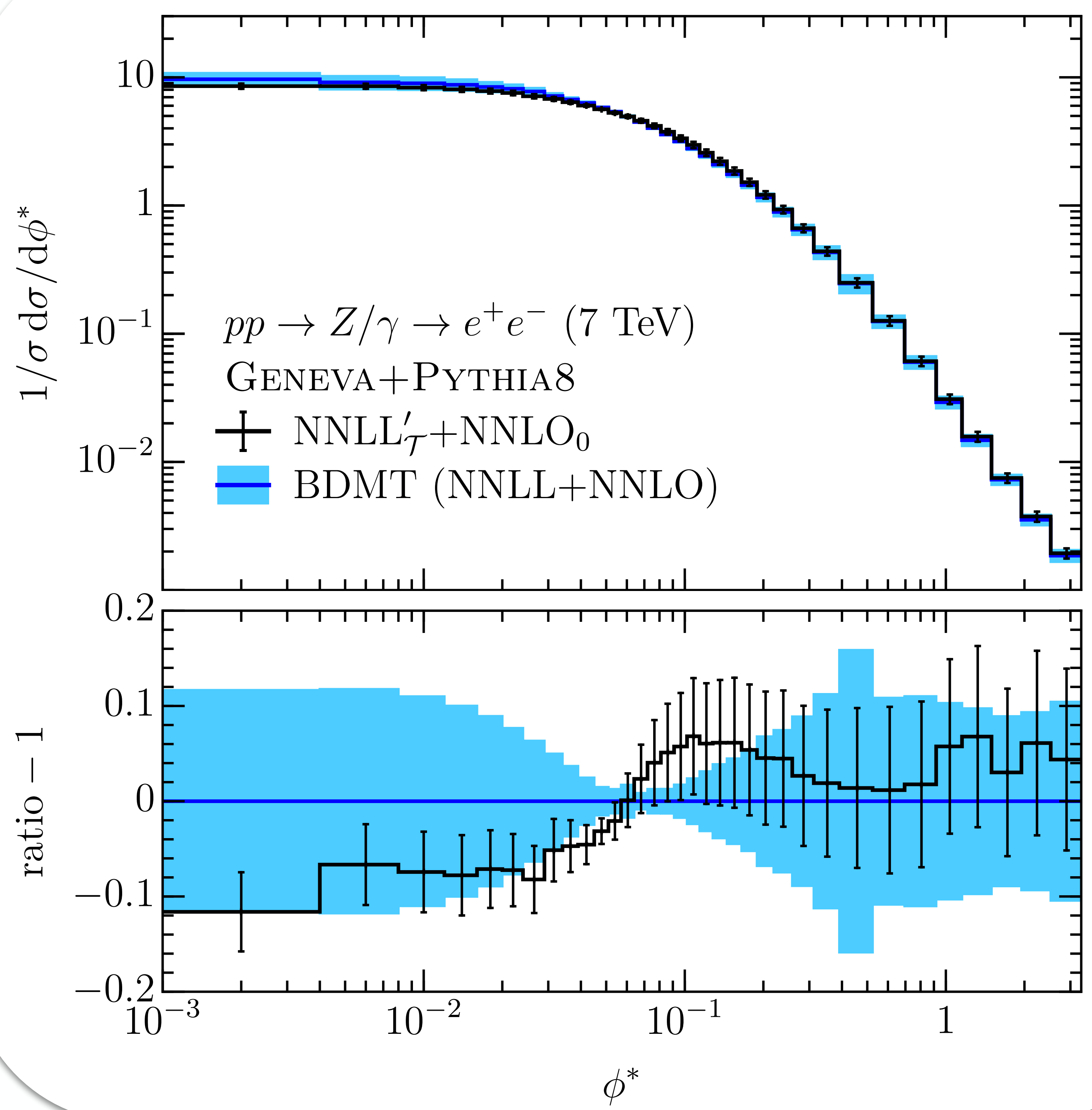
Resummed observables are predicted with accuracies which compare well with dedicated NNLL calculations



Resummed observables are predicted with accuracies which compare well with dedicated NNLL calculations



Resummed observables are predicted with accuracies which compare well with dedicated NNLL calculations



Now let me compare to data from ATLAS and CMS

Comparisons to ATLAS and CMS data looks very encouraging

CMS arXiv:1110.4973

PHYSICAL REVIEW D **85,** 032002 (2012)

Measurement of the rapidity and transverse momentum distributions of Z bosons in pp collisions at $\sqrt(s)$=7 TeV

S. Chatrchyan *et al.**
(CMS Collaboration)

(Received 23 October 2011; published 7 February 2012)

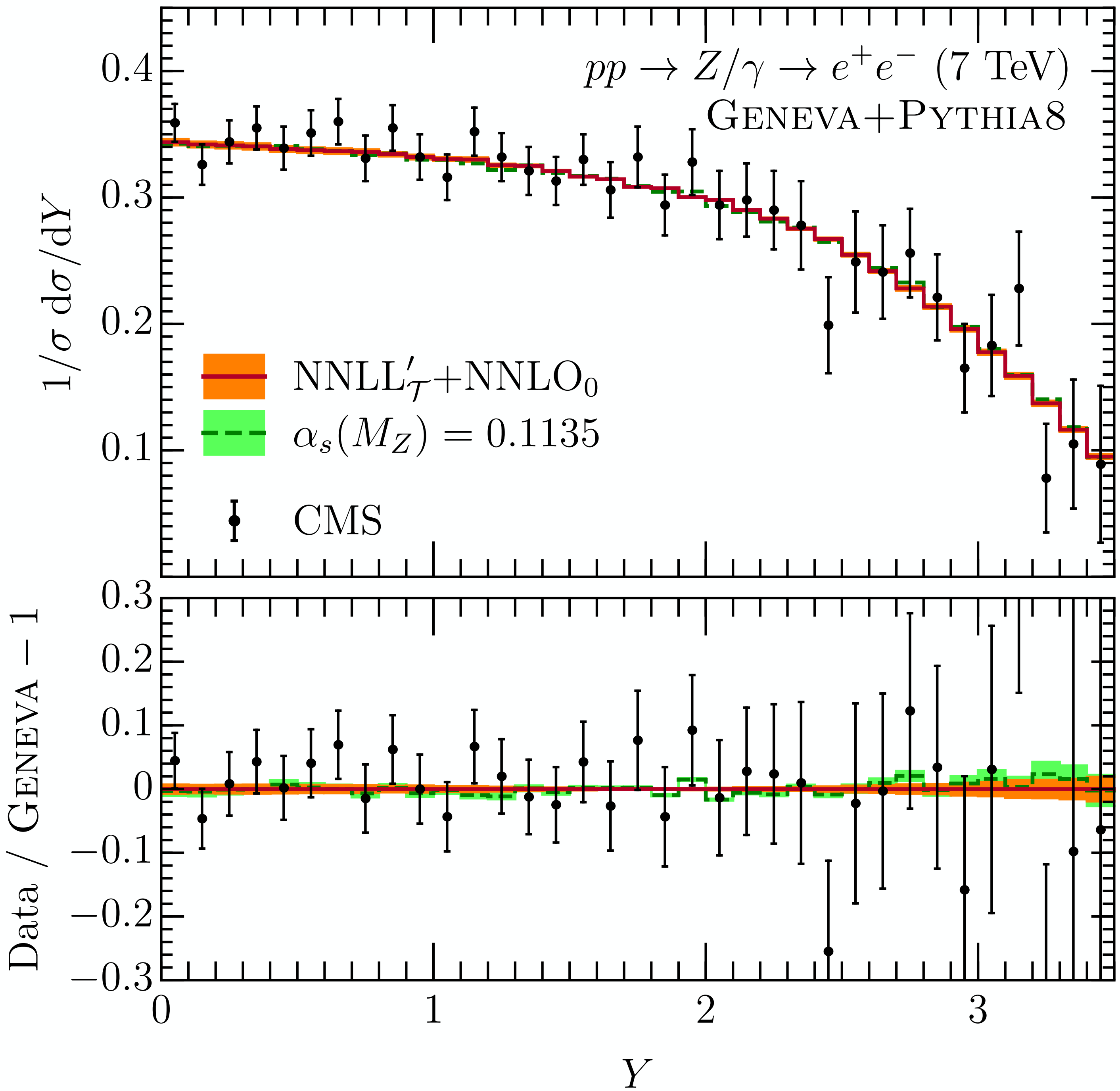
Measurements of the normalized rapidity (y) and transverse-momentum (q_T) distributions of Drell–Yan muon and electron pairs in the Z-boson mass region ($60 < M_{\ell\ell} < 120$ GeV) are reported. The results are obtained using a data sample of proton-proton collisions at a center-of-mass energy of 7 TeV, collected by the CMS experiment at the Large Hadron Collider (LHC), corresponding to an integrated luminosity of 36 pb^{-1}. The distributions are measured over the ranges $|y| < 3.5$ and $q_T < 600$ GeV and compared with quantum chromodynamics (QCD) calculations using recent parton distribution functions to model the momenta of the quarks and gluons in the protons. Overall agreement is observed between the models and data for the rapidity distribution, while no single model describes the Z transverse-momentum distribution over the full range.

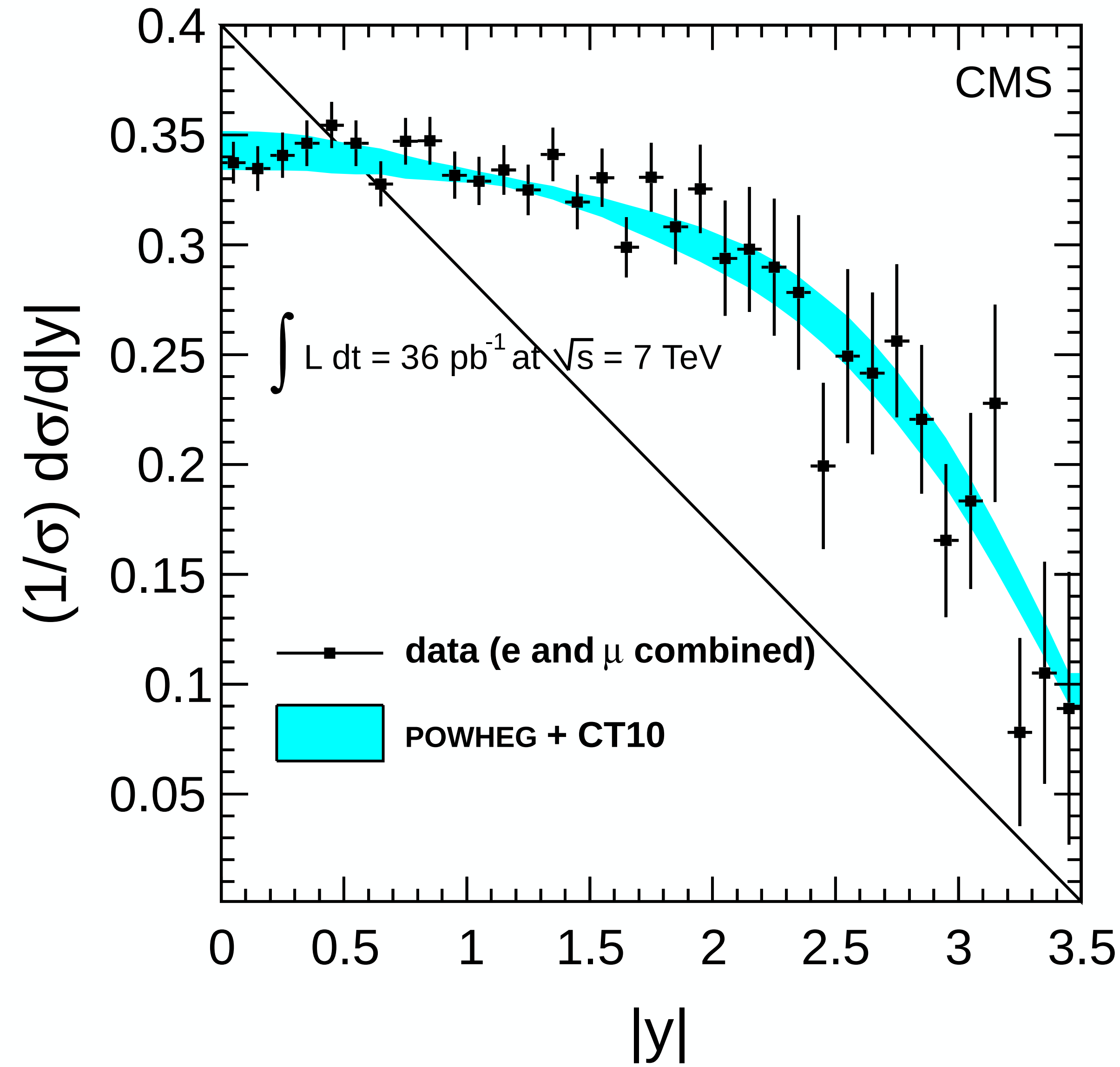
DOI: 10.1103/PhysRevD.85.032002 PACS numbers: 13.60.Hb, 13.38.Dg, 13.85.Qk

Comparisons to ATLAS and CMS data looks very encouraging

CMS arXiv:1110.4973

Rapidity of the vector boson





Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1304.7098

Measurement of the production cross section of jets in association with a Z boson in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ with the ATLAS detector

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

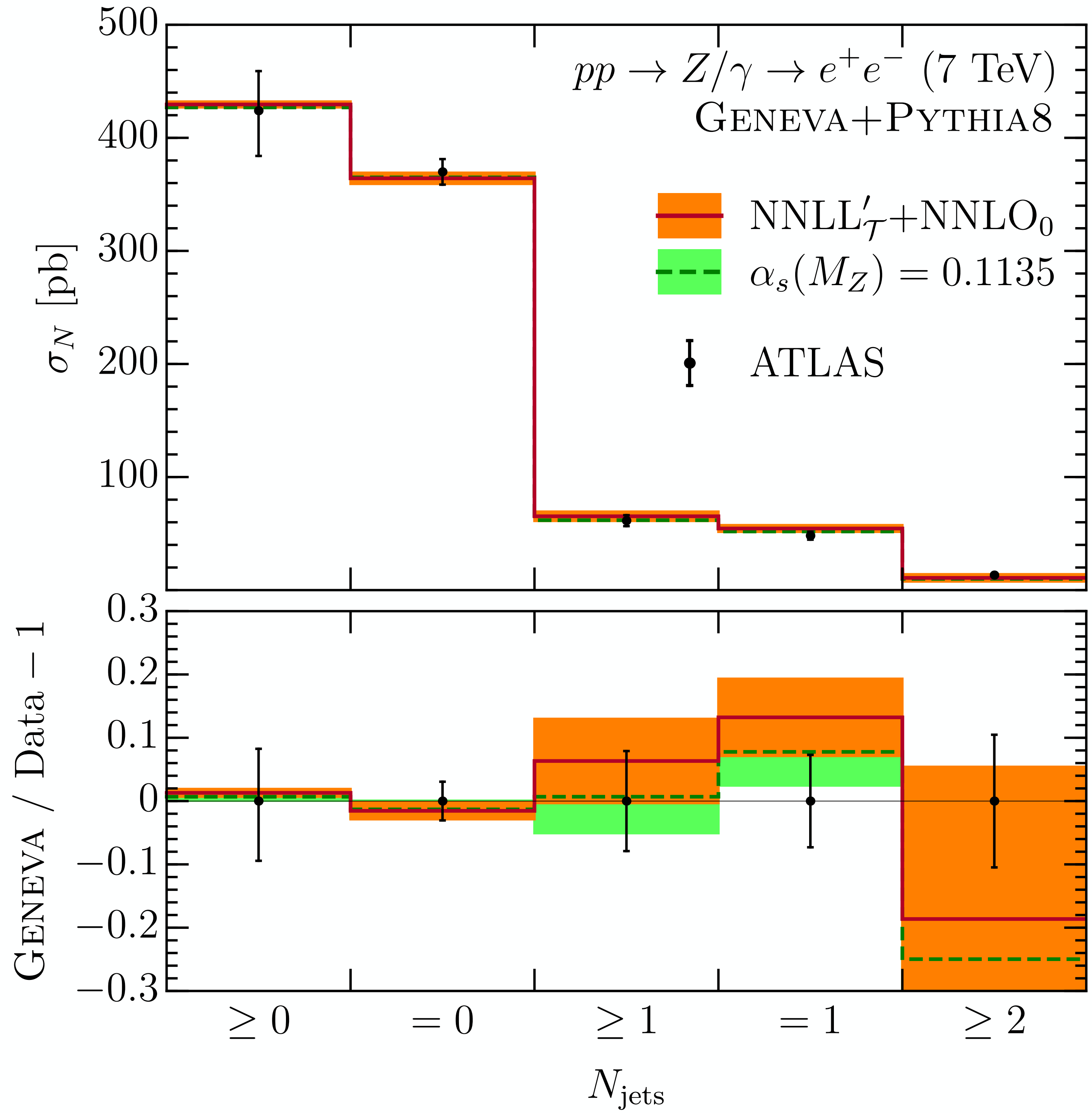
ABSTRACT: Measurements of the production of jets of particles in association with a Z boson in pp collisions at $\sqrt{s} = 7$ TeV are presented, using data corresponding to an integrated luminosity of $4.6\,\mathrm{fb}^{-1}$ collected by the ATLAS experiment at the Large Hadron Collider. Inclusive and differential jet cross sections in Z events, with Z decaying into electron or muon pairs, are measured for jets with transverse momentum $p_{\mathrm{T}} > 30$ GeV and rapidity $|y| < 4.4$. The results are compared to next-to-leading-order perturbative QCD calculations, and to predictions from different Monte Carlo generators based on leading-order and next-to-leading-order matrix elements supplemented by parton showers.

KEYWORDS: Hadron-Hadron Scattering

Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1304.7098

Exclusive jet cross-sections

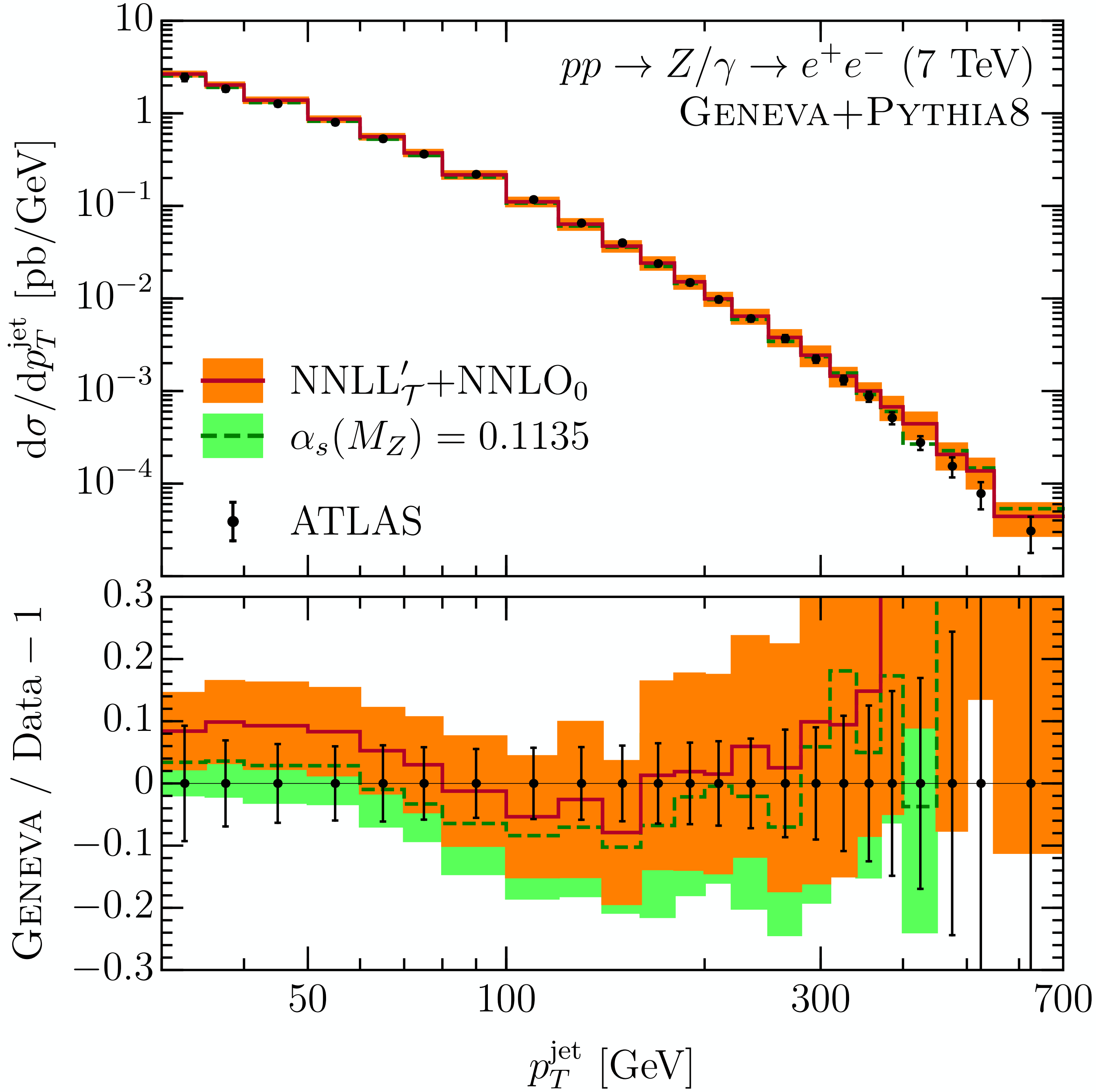


Not shown in paper

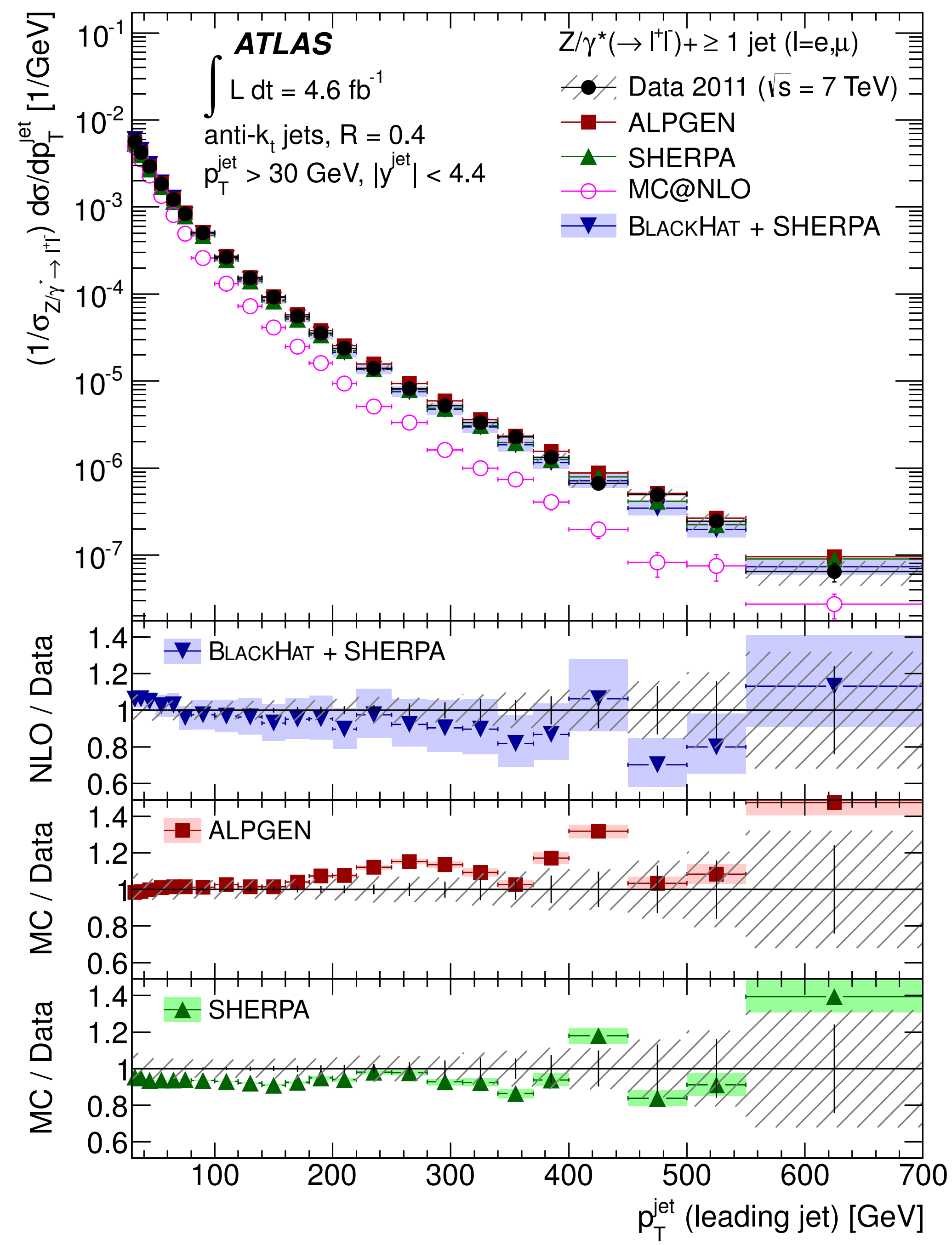
Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1304.7098

pT of first jet



Note that paper shows normalized distribution



Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1406.3660

Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

Abstract: This paper describes a measurement of the Z/γ^* boson transverse momentum spectrum using ATLAS proton-proton collision data at a centre-of-mass energy of $\sqrt{s} = 7\,\mathrm{TeV}$ at the LHC. The measurement is performed in the $Z/\gamma^* \to e^+e^-$ and $Z/\gamma^* \to \mu^+\mu^-$ channels, using data corresponding to an integrated luminosity of $4.7\,\mathrm{fb}^{-1}$. Normalized differential cross sections as a function of the Z/γ^* boson transverse momentum are measured for transverse momenta up to 800 GeV. The measurement is performed inclusively for Z/γ^* rapidities up to 2.4, as well as in three rapidity bins. The channel results are combined, compared to perturbative and resummed QCD calculations and used to constrain the parton shower parameters of Monte Carlo generators.

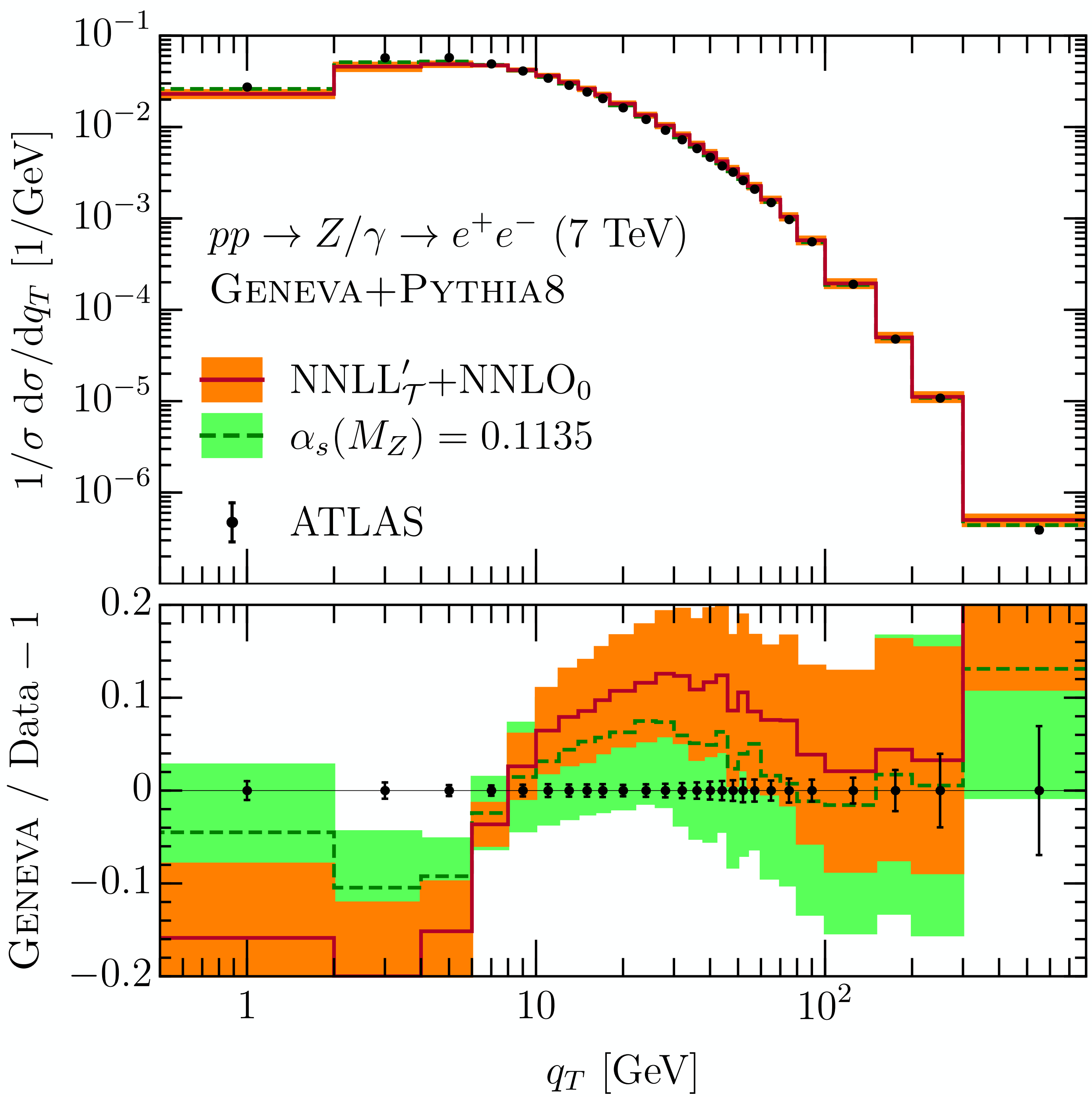
Keywords: Hadron-Hadron Scattering

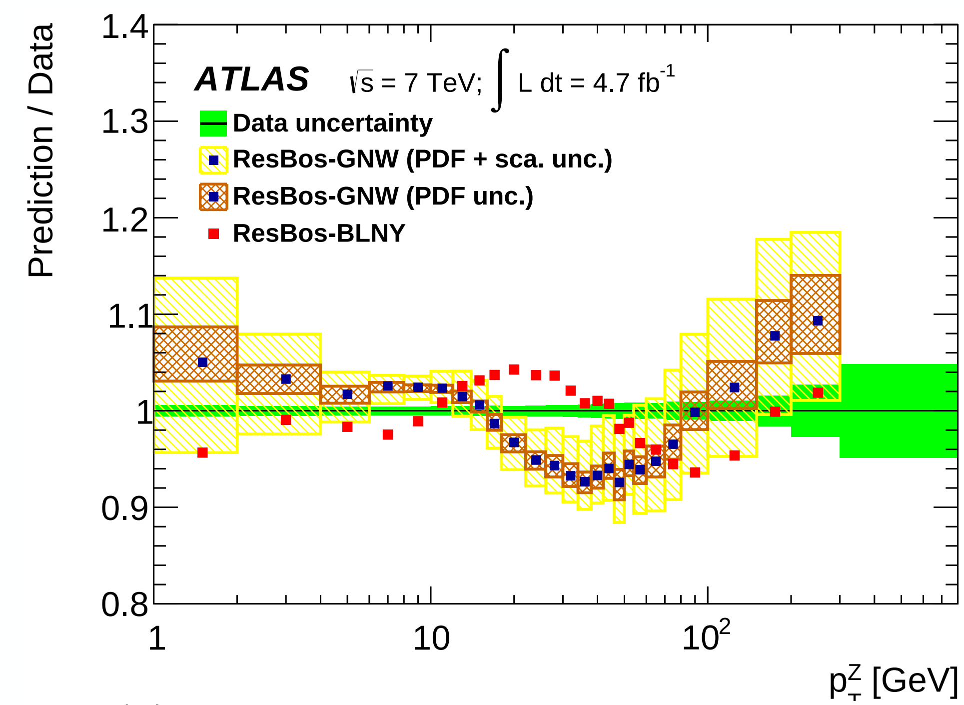
ArXiv ePrint: 1406.3660

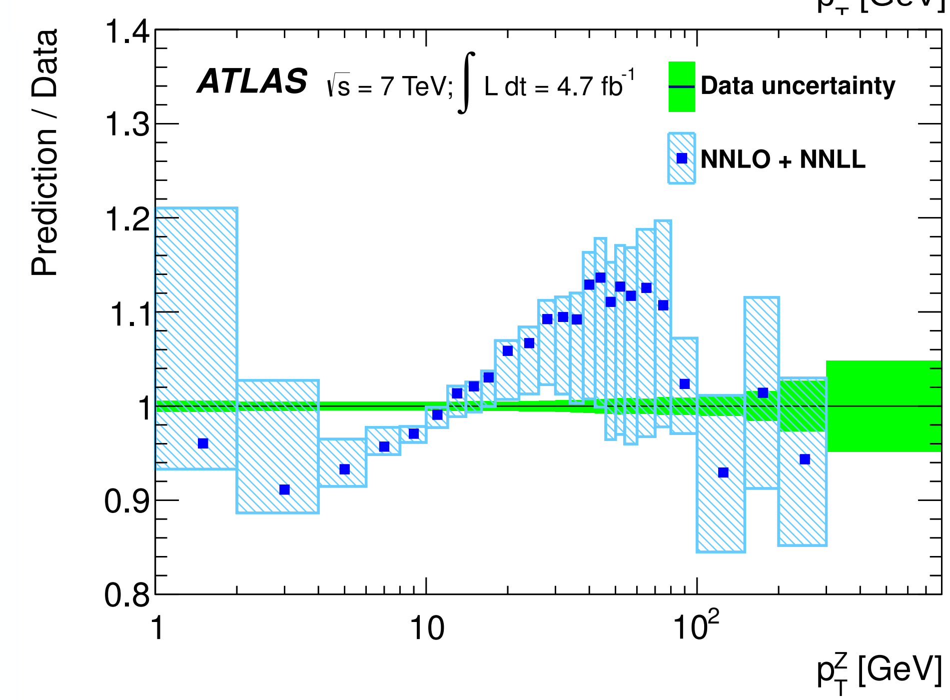
Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1406.3660

pT of the Z-boson



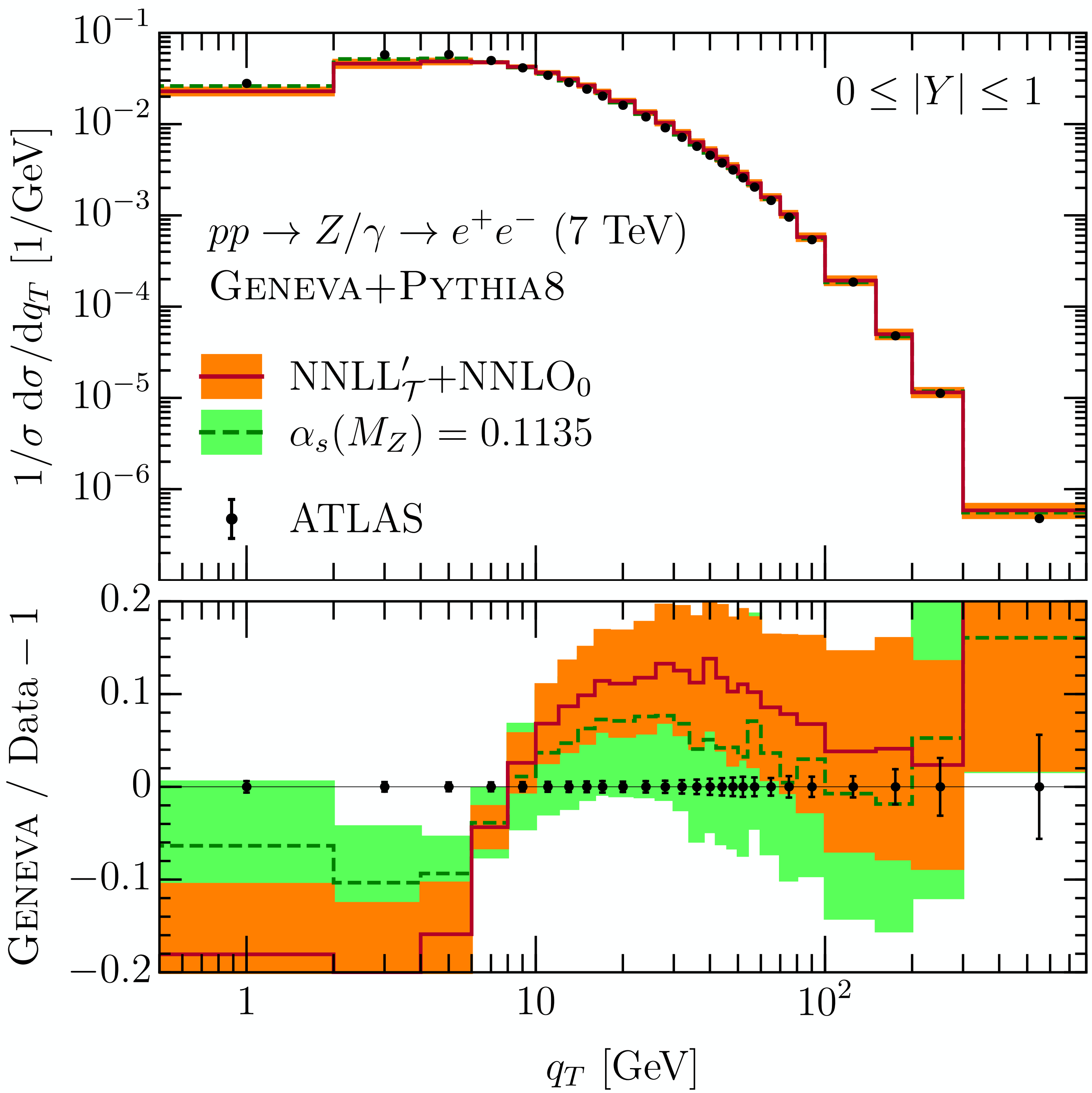


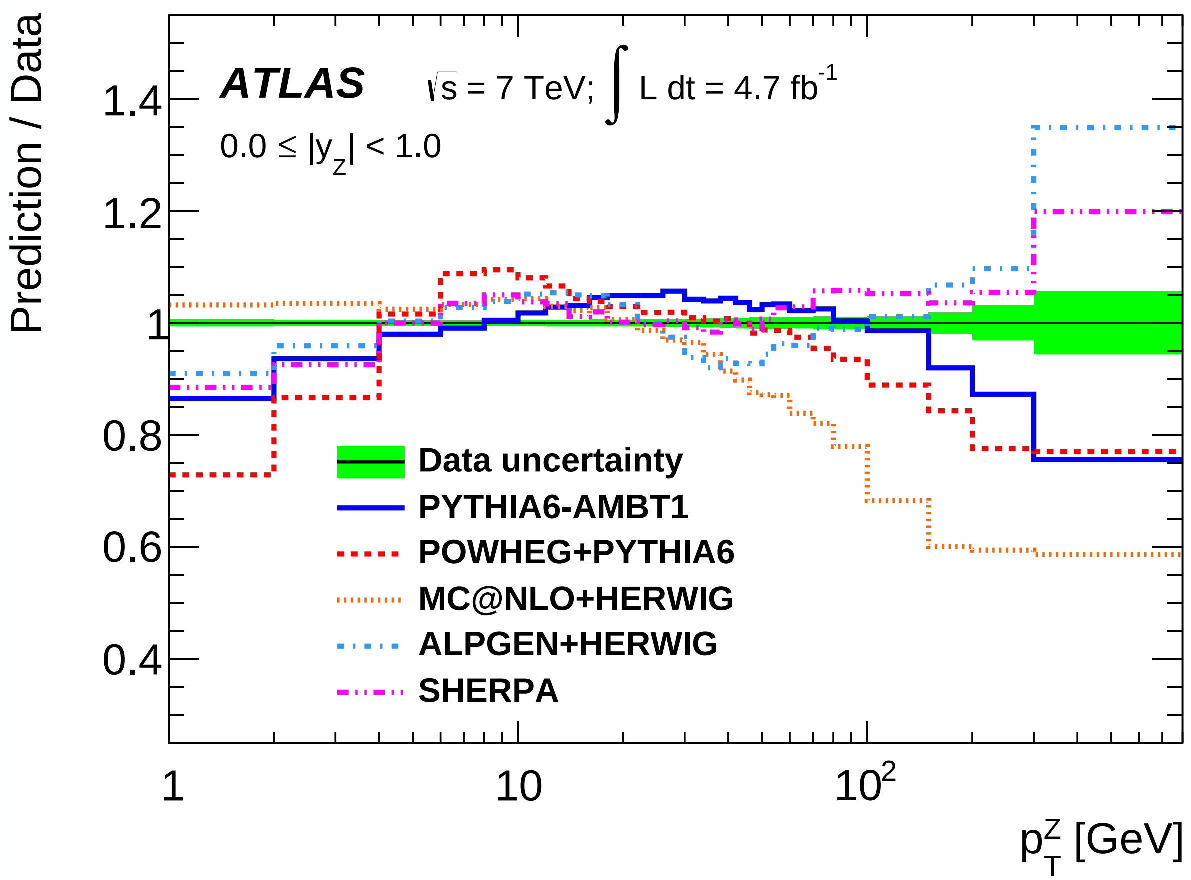


Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1406.3660

pT of the Z-boson for 0 < Y < 1

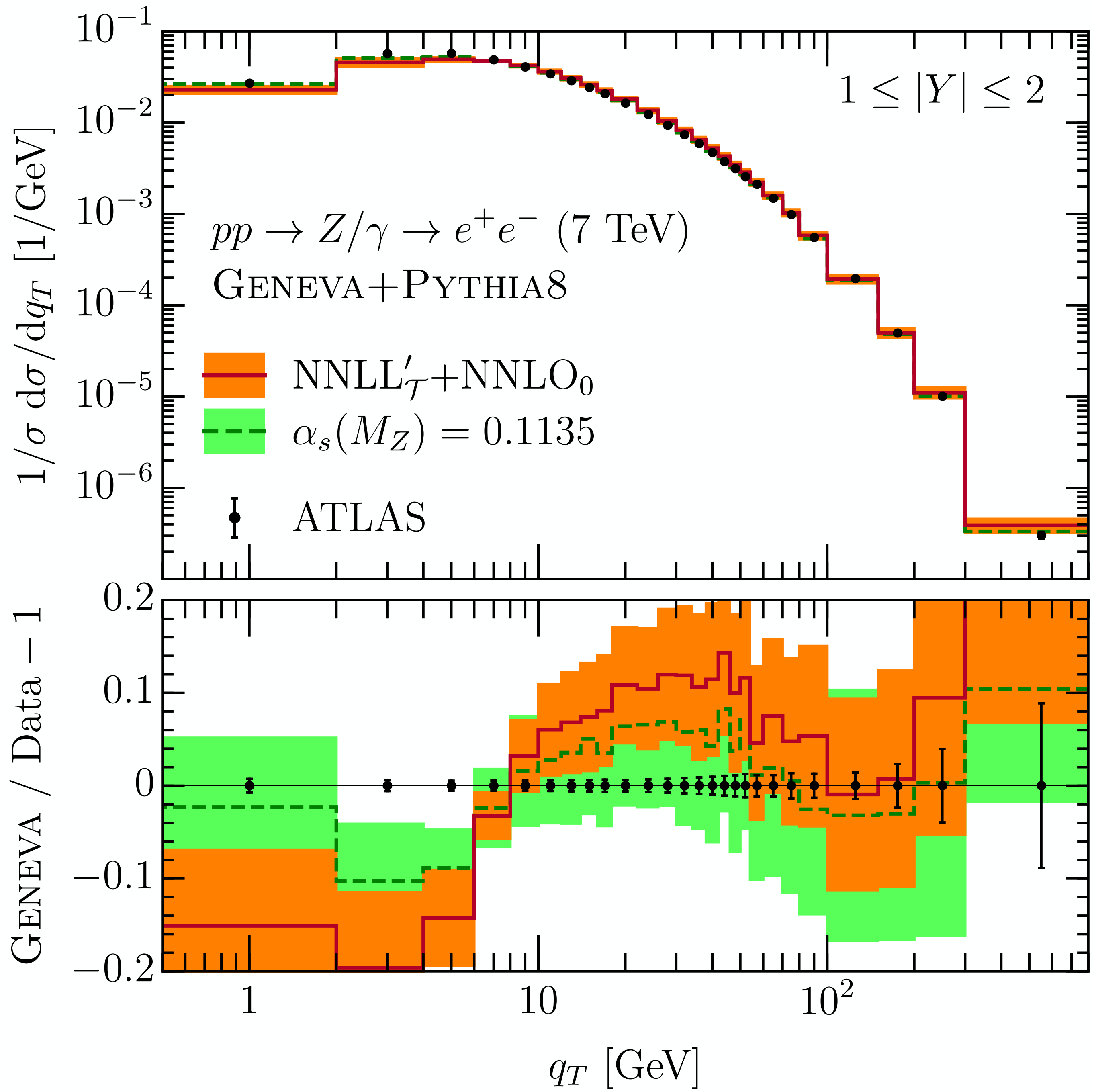


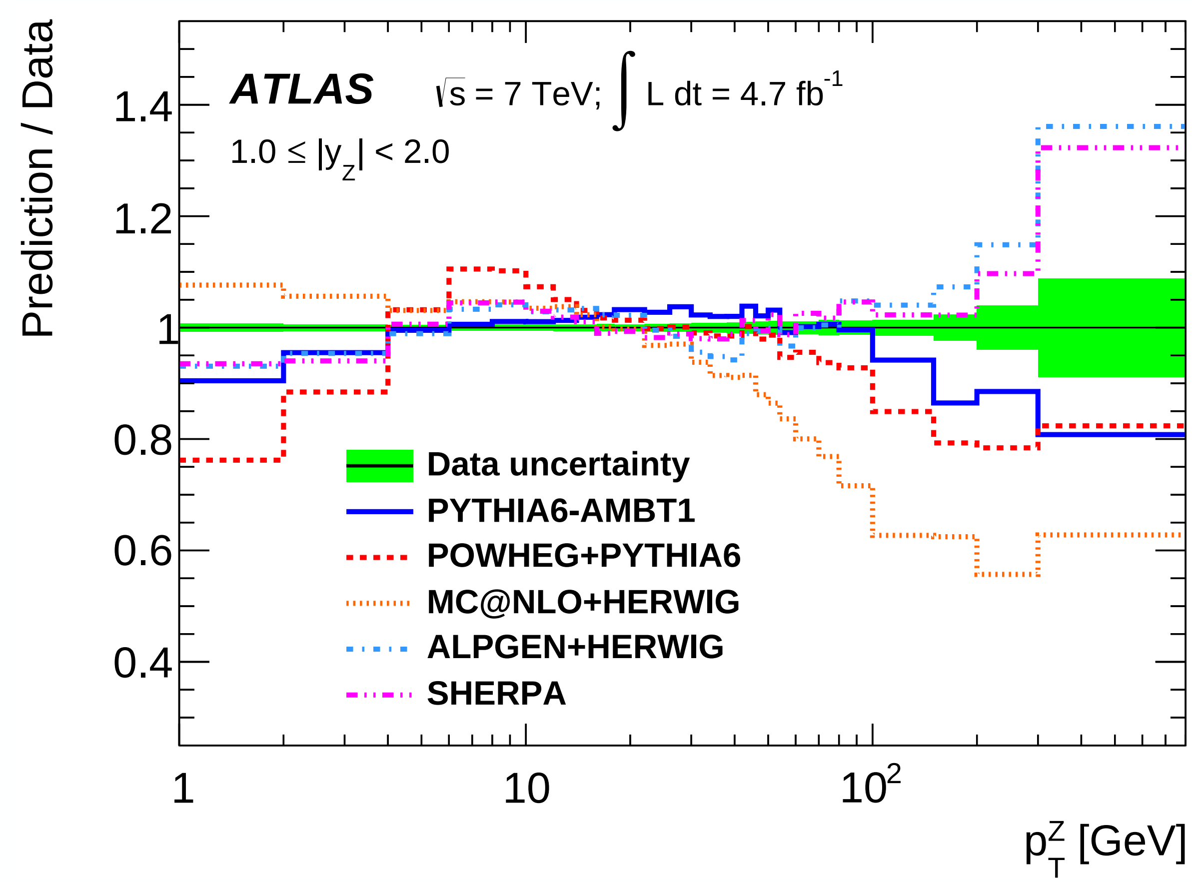


Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1406.3660

pT of the Z-boson for 1 < Y < 2

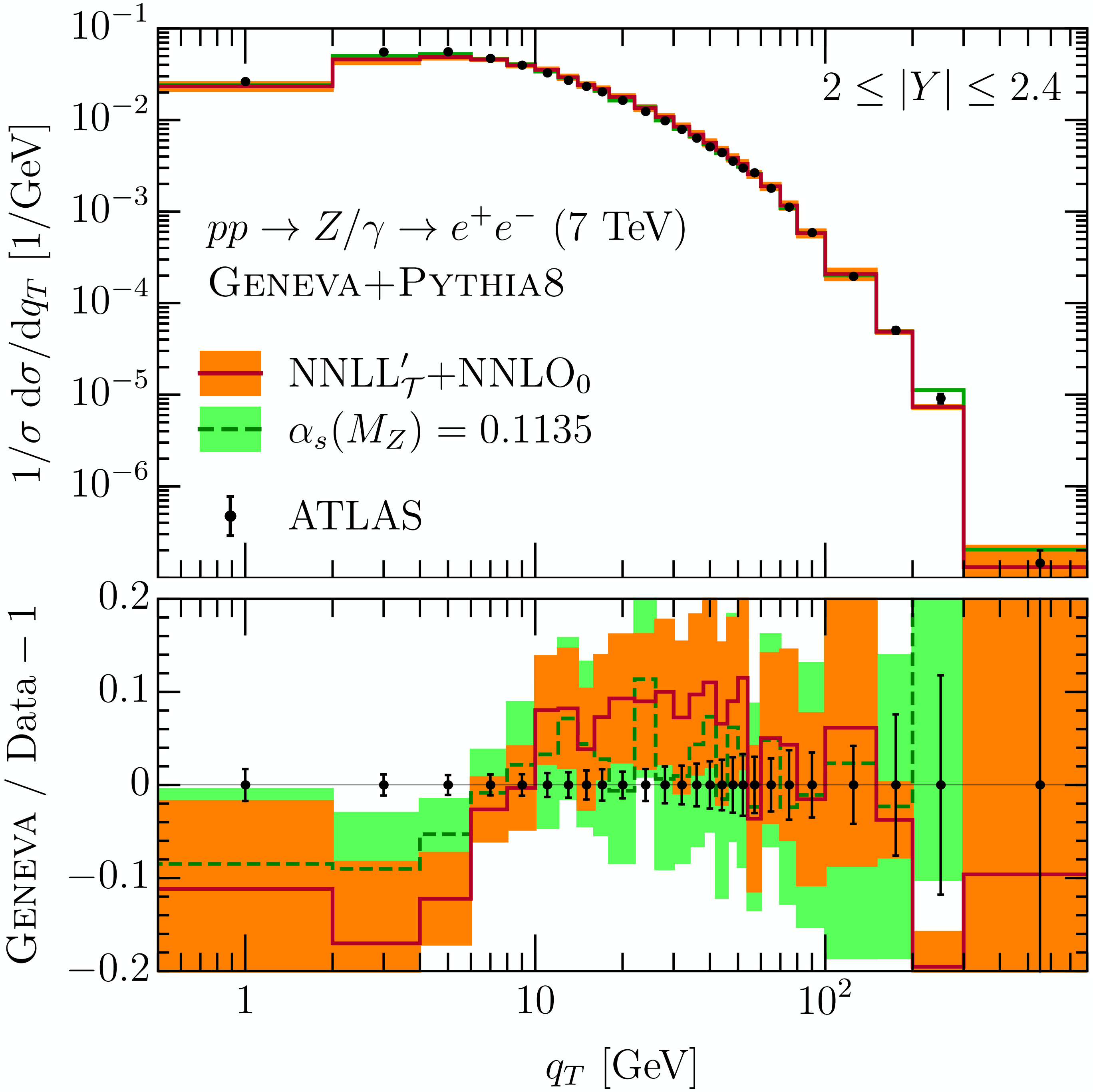


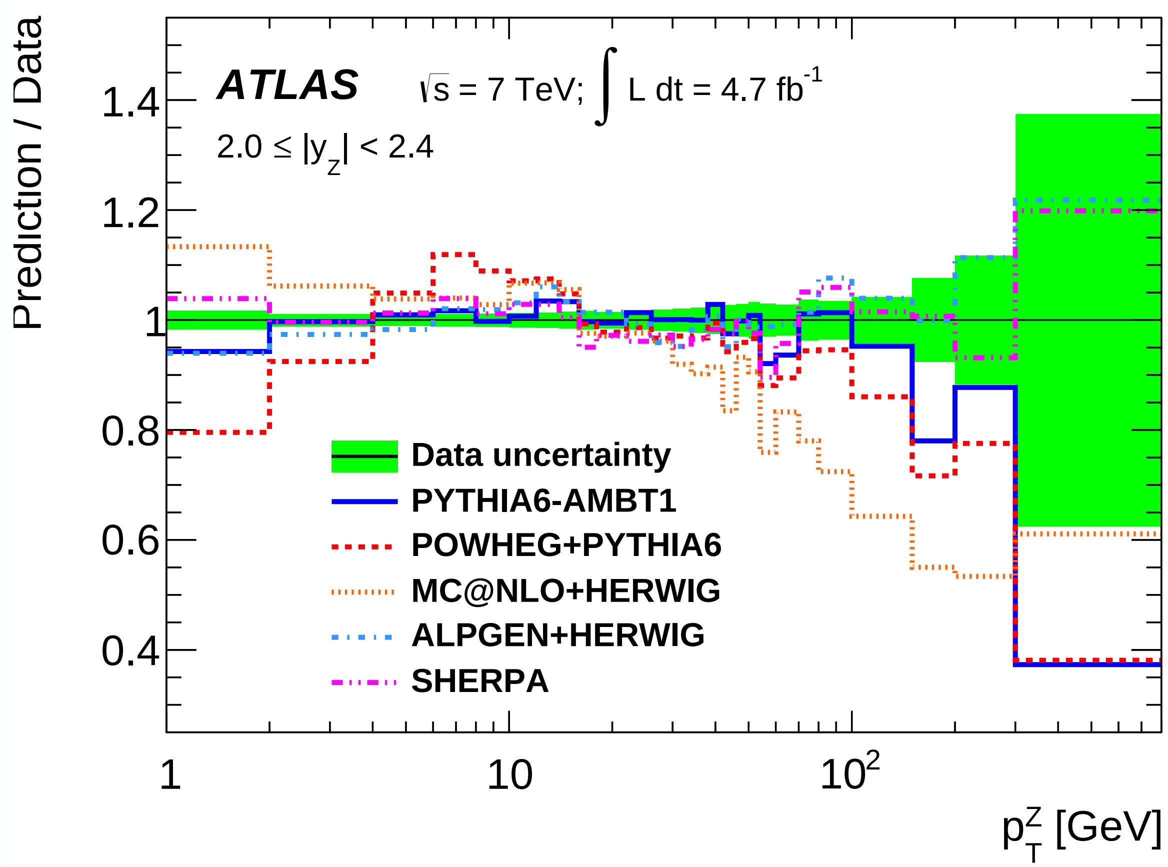


Comparisons to ATLAS and CMS data looks very encouraging

ATLAS arXiv:1406.3660

pT of the Z-boson for 2 < Y < 2.4





In conclusion, GENEVA is a fully exclusive event generator with the best available perturbative accuracy

I hope I was able to give you a glimpse into the exciting field of making event generators more precise by combining them with perturbative calculations.

Presented results for Z + jets, but method is extendable to processes other than Z + jets

QUESTIONS?