SCET and Monte-Carlo generators

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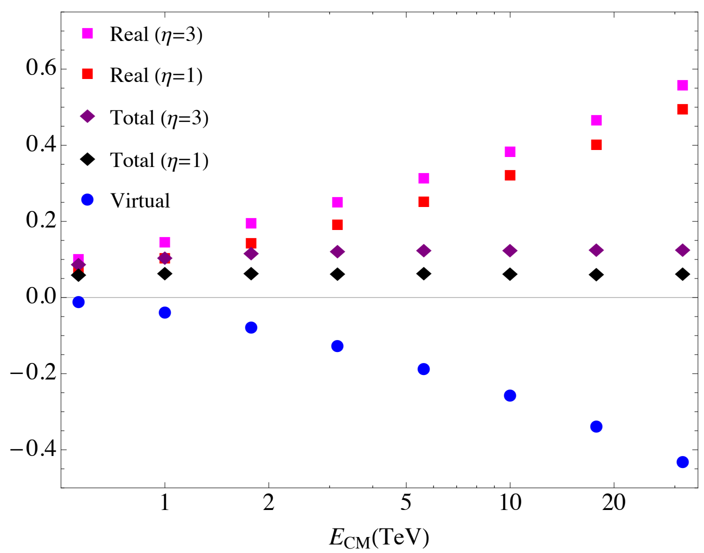
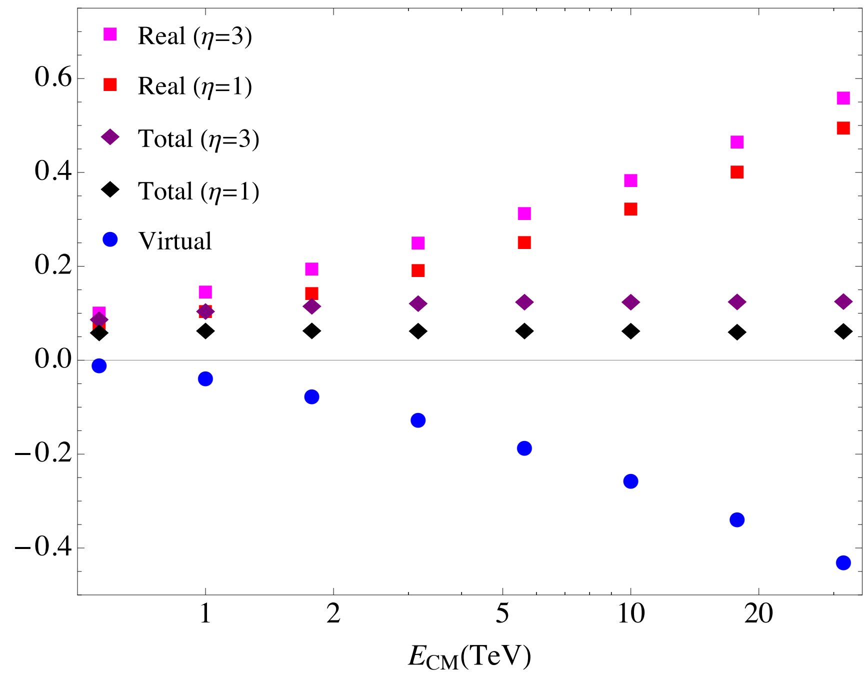
In this talk, will briefly show 2 different topics, for which SCET has allowed for some significant advances



Resummation of EW Sudakov logarithms

GENEVA

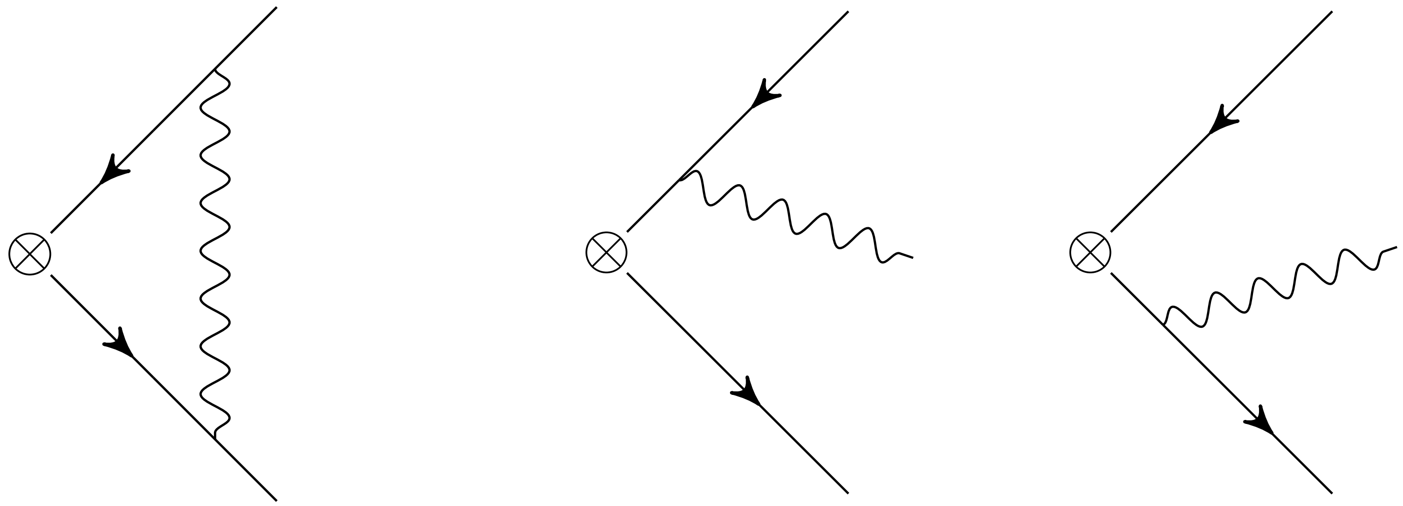
Fully exclusive MC with NNLL / NNLO accuracy



Resummation of EW Sudakov logarithms

Electroweak Sudakov logarithms arise from exchanges of electroweak gauge bosons

Consider example of qq production

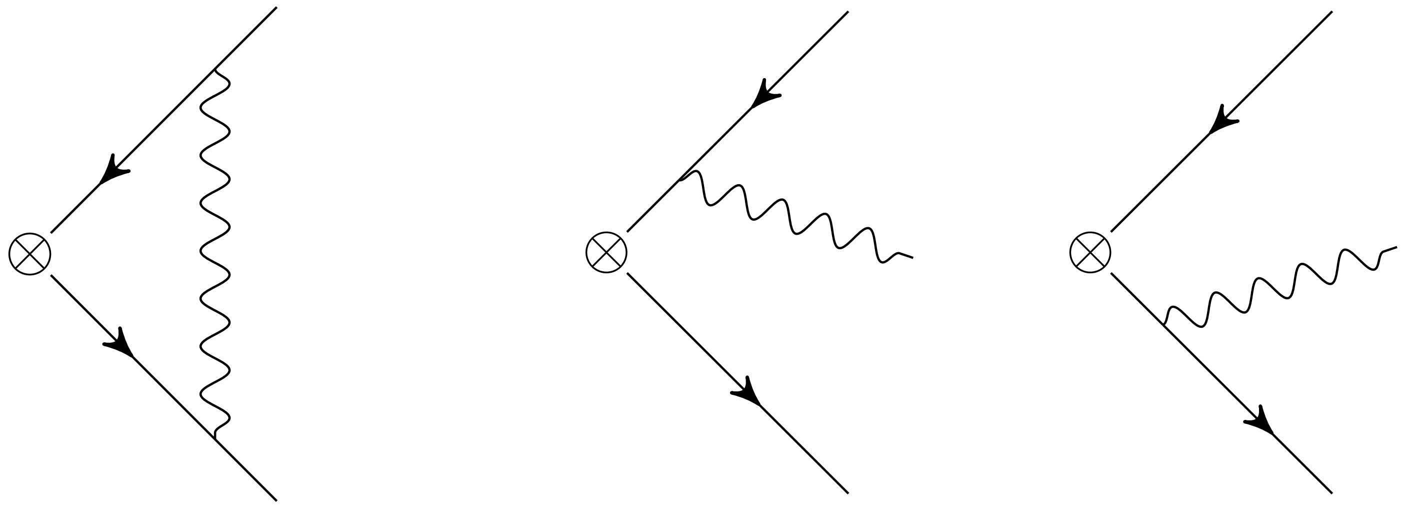


Have contributions from virtual and real emission

For massless gauge boson, get IR divergences in both virtual and real that cancel by KLN

Electroweak Sudakov logarithms arise from exchanges of electroweak gauge bosons

Consider example of qq production



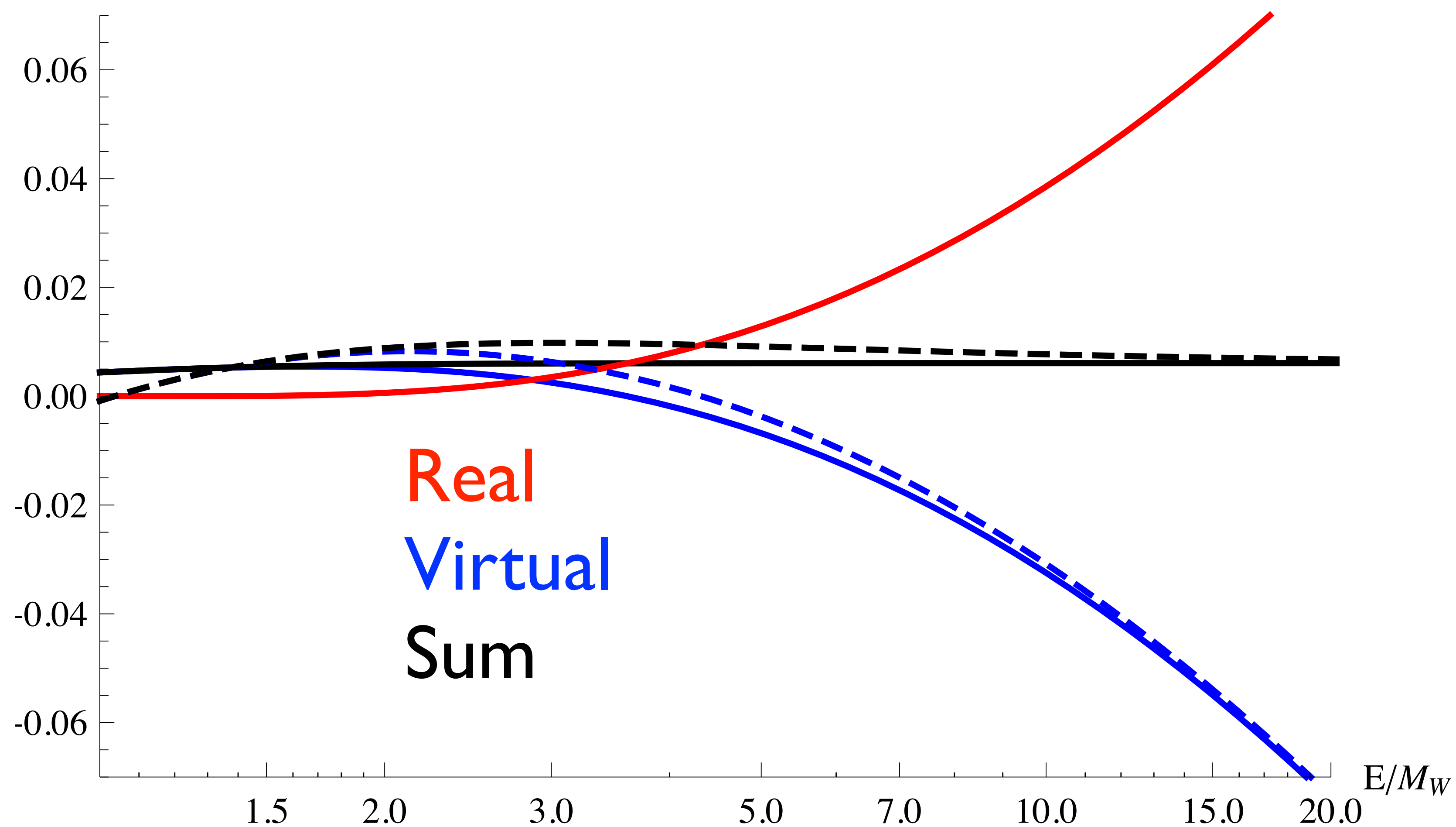
Have contributions from virtual and real emission

For massive W, IR divergences regulated by $\log(m_W^2/s)$, and generally have two powers per power of alpha

Both virtual and real sensitive to $\log(m_W^2/s)$

The numerical effect of EW Sudakov logarithms becomes large at high energies

For J→qq production



For E » 10m$_V$, each contributions becomes large

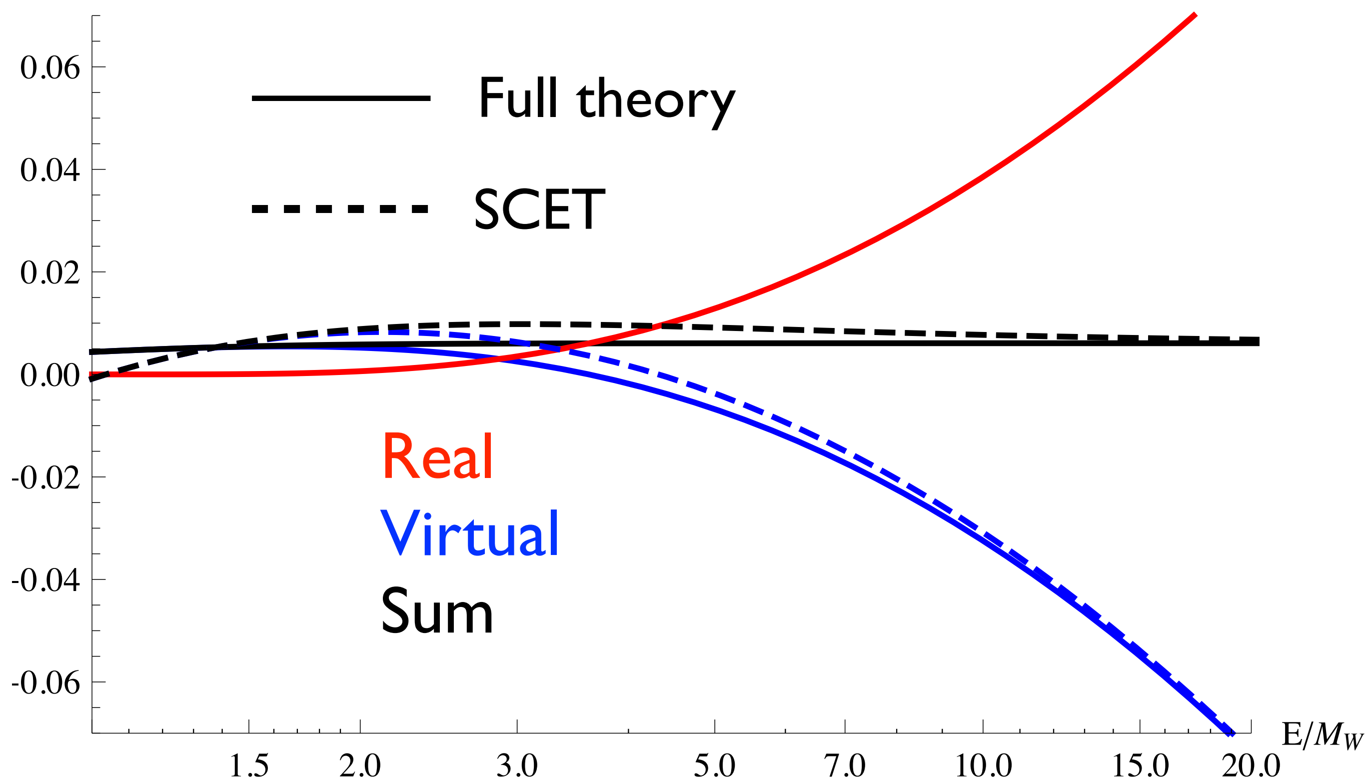
Most observables are not fully inclusive, such that EW Sudakov logarithms remain

$$\sigma_T = \frac{\alpha_W}{2\pi}\left(G_R - G_V\right)\widehat{\sigma}_0\left\{\ln^2 r + 3\ln r + \ldots\right\}$$

Process	G_V	G_R	$G_R - G_V$
Inclusive **ff(V)**	N CF	N C_F	**0**
Any fermion **ff**	N C_F	0	**-N C_F**
Specified f's **$f_i f_j$(V)**	1/2(1 - δ_{ij}/N)	$C_F\,\delta_{ij}$	**1/2(1 - N δ_{ij})**

Furthermore, since initial pp state not SU(2) singlet, EW Sudakov logs don't cancel even in fully inclusive case

SCET makes calculation of EW Sudakov logarithms much easier than in full theory



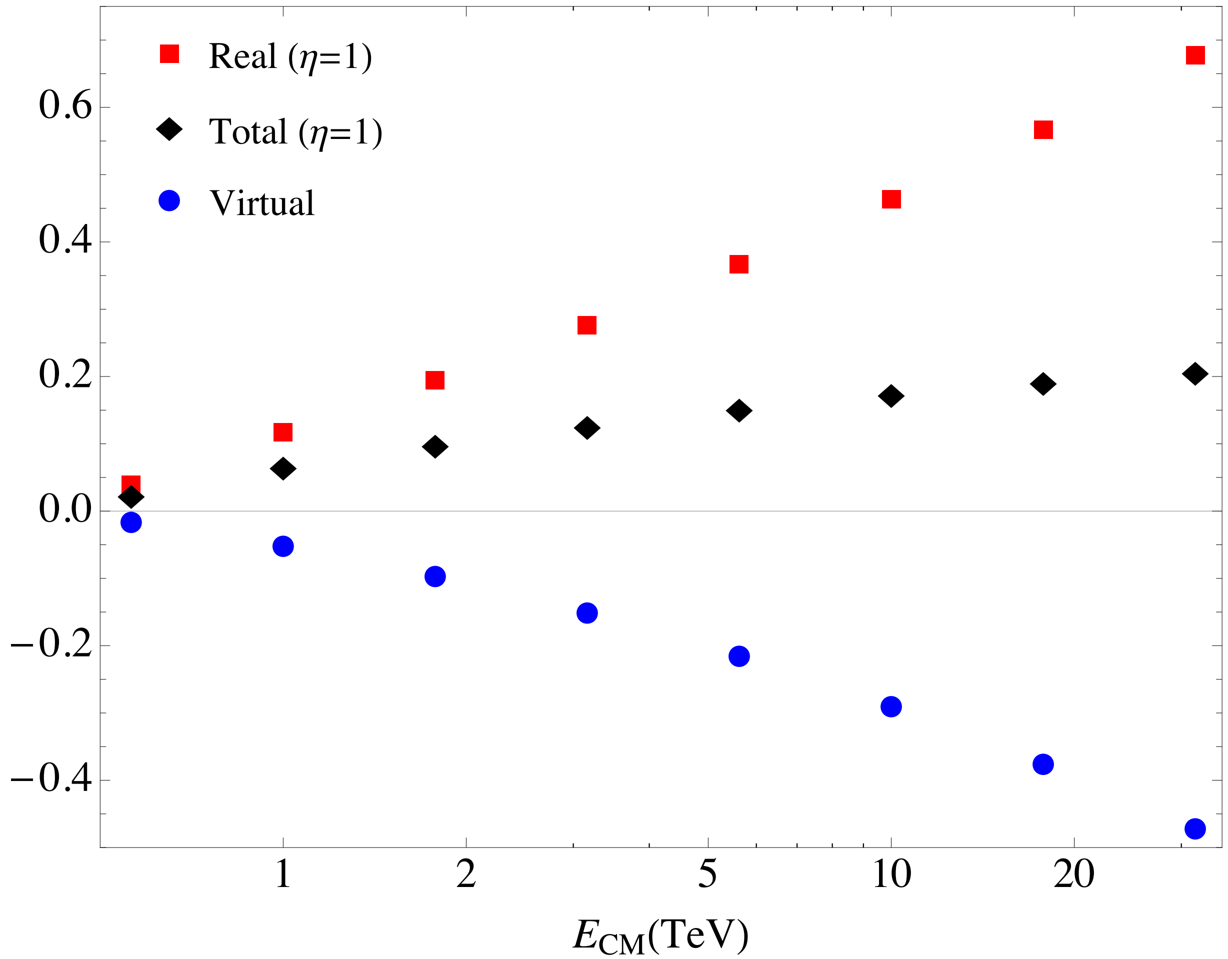
Virtual requires a loop diagram with multiple scales in a broken gauge theory (quite difficult)

Large logarithms arise from the IR behavior of theory ($m_V \ll p_T$) which can be extracted from SCET in unbroken theory

EW Sudakov logs known for any 2→2 process, both for SM and BSM processes. Only depends on SU(2) charges

For true understanding of EW Sudakov effects, needs to be embedded in MC which includes both virtual and real

Consider gg → t tbar production



- Since gg is SU(2) singlet, no leftover logs in sum of real and virtual
- While both real and virtual get very large corrections, large effects cancel in the sum

Are we usually fully inclusive over real radiation?

For true understanding of EW Sudakov effects, needs to be embedded in MC which includes both virtual and real

Consider gg → t tbar production

Important question that needs to be asked:

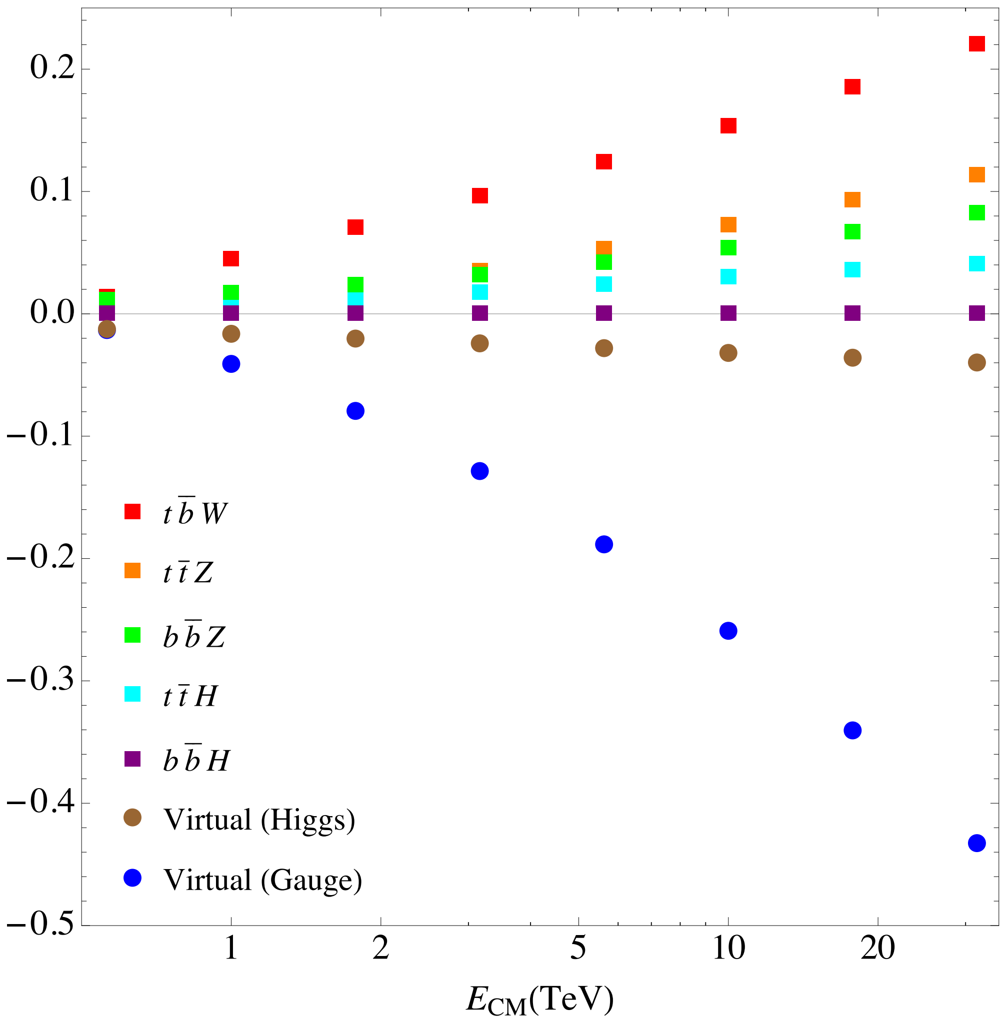
What is the actual experimental signature?
Is extra radiation of gauge bosons included?

Most likely:	tt+(Z→$\nu\nu$)	tb+(W→lν)
Maybe:	tt+(Z→qq?)	
Likely not:	tt+(Z→$\ell\ell$)	bb bbZ

Most of the time, real radiation is partially included

For true understanding of EW Sudakov effects, needs to be embedded in MC which includes both virtual and real

Consider gg → t tbar production



- Different real emission contributions have different forms
- Logarithms will remain in most analyses, and size depends sensitively on details of analysis

Electroweak Sudakov logarithms should be included in MC's to study high energy collisions

In conclusion, EW Sudakov logarithms very important in production of particles at high energy

- EW Sudakov logs become quite large above a few TeV
- This means EW corrections can be much larger than naively expected
- Can be calculated quite easily in SCET, and effects should be included in MC programs

GENEVA

Fully exclusive MC with NNLL / NNLO accuracy

Event generators have many advantages over traditional perturbative* calculations

* 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

Over the past few years there has been dramatic progress in the accuracy of perturbative calculations

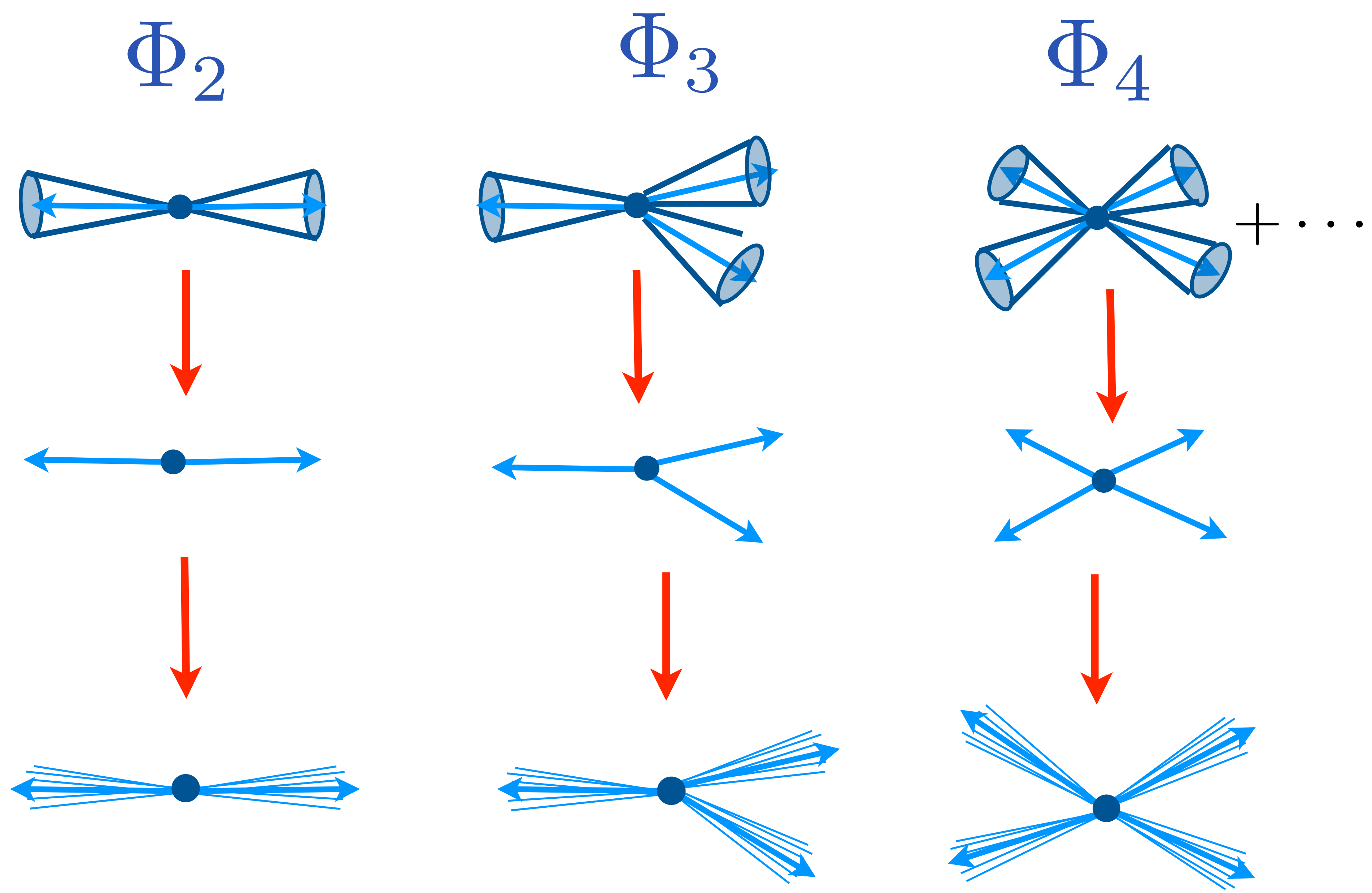
- Only a few years ago, NLO calculations required serious amount of work by dedicated groups
- By now, NLO calculations completely standard, and can be performed by anybody using automated code
- NLO is what LO was a few years ago
- Much progress is made on NNLO calculations, and the tools are approaching general applicability
- We are even starting to see the first NNNLO calculations appearing

To implement experimental acceptances, need fully exclusive events, as produced by parton shower algorithms

- Matching of LO calculations with a parton shower is completely standard and included in automatic codes
- Matching NLO calculations is somewhat automatic (requires to implement the NLO calculations in a particular way)
- Very little available to match NNLO calculations with parton showers

Main idea of Geneva is to calculate physical jet cross-sections. This works to any order in perturbation theory

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



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

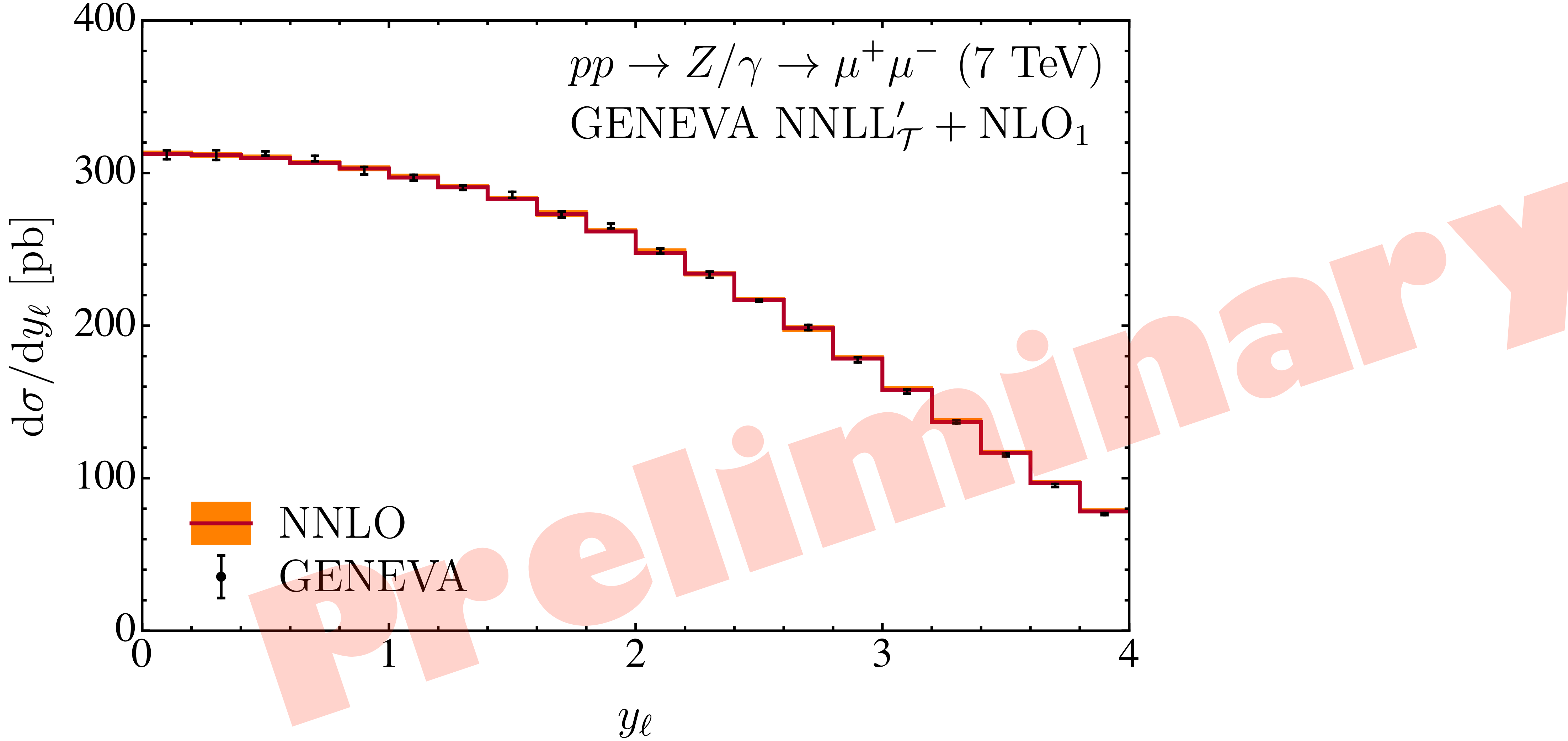
Use the full power of SCET to obtain exclusive jet distributions that are correct to given fixed order and resummation accuracy

Fixed Order Z+0	Fixed order Z+1	Fixed order Z+2	Resummation Z
NNLO	NLO	LO	NNLL'

No other generator on the market with this level of accuracy

In the remainder of the talk, I will show you some results from GENEVA that are fresh off the press

NNLO accuracy of Z+0jet observables



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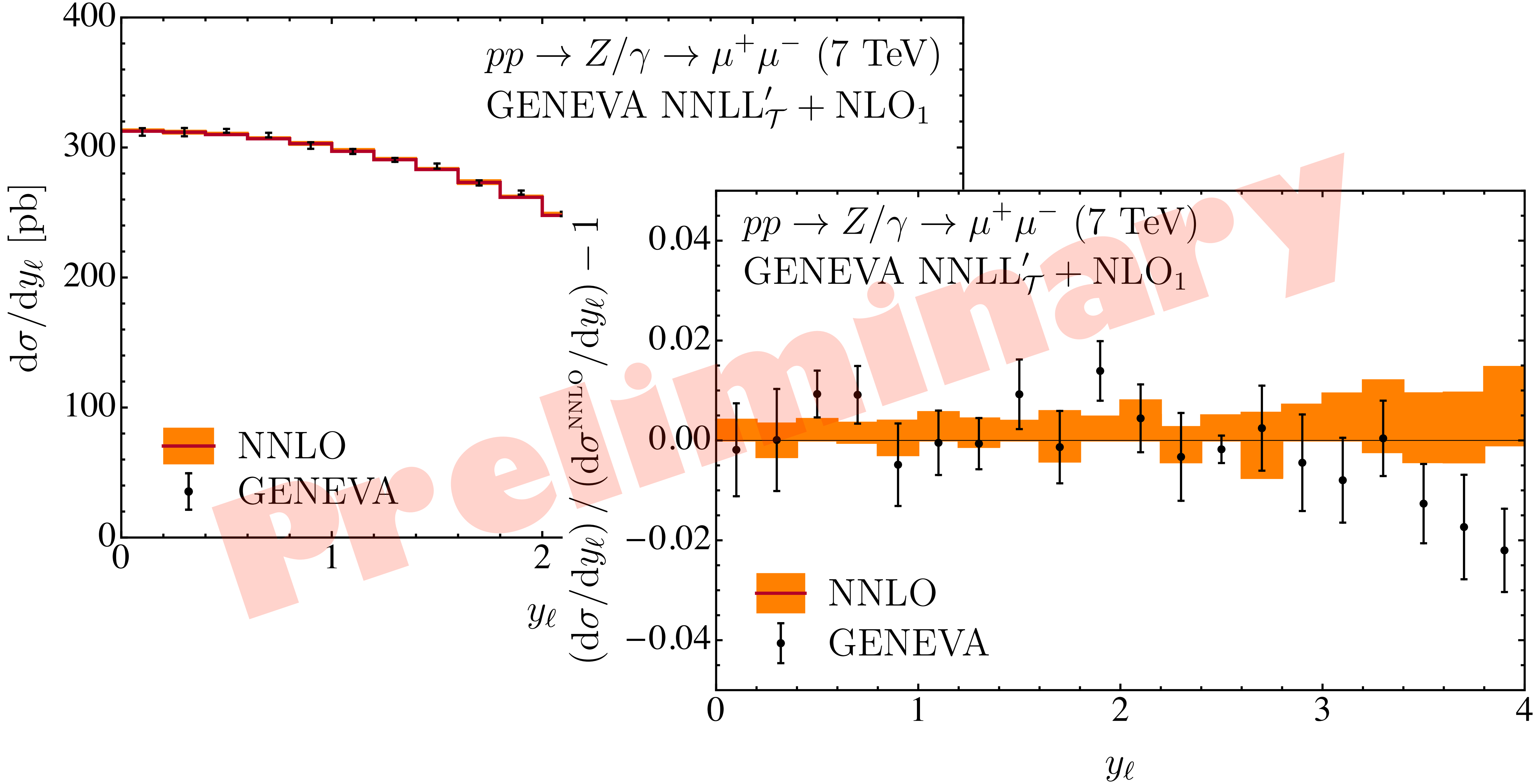

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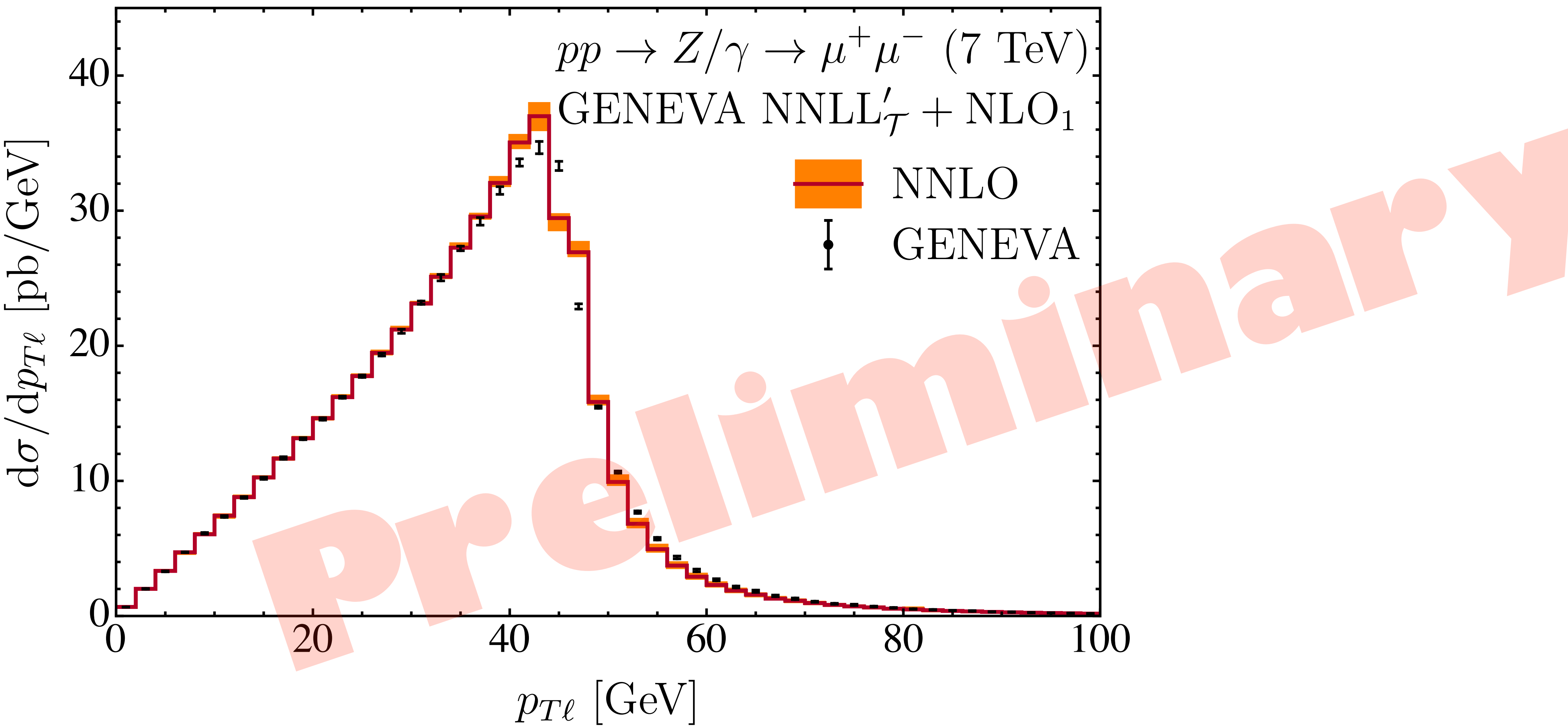

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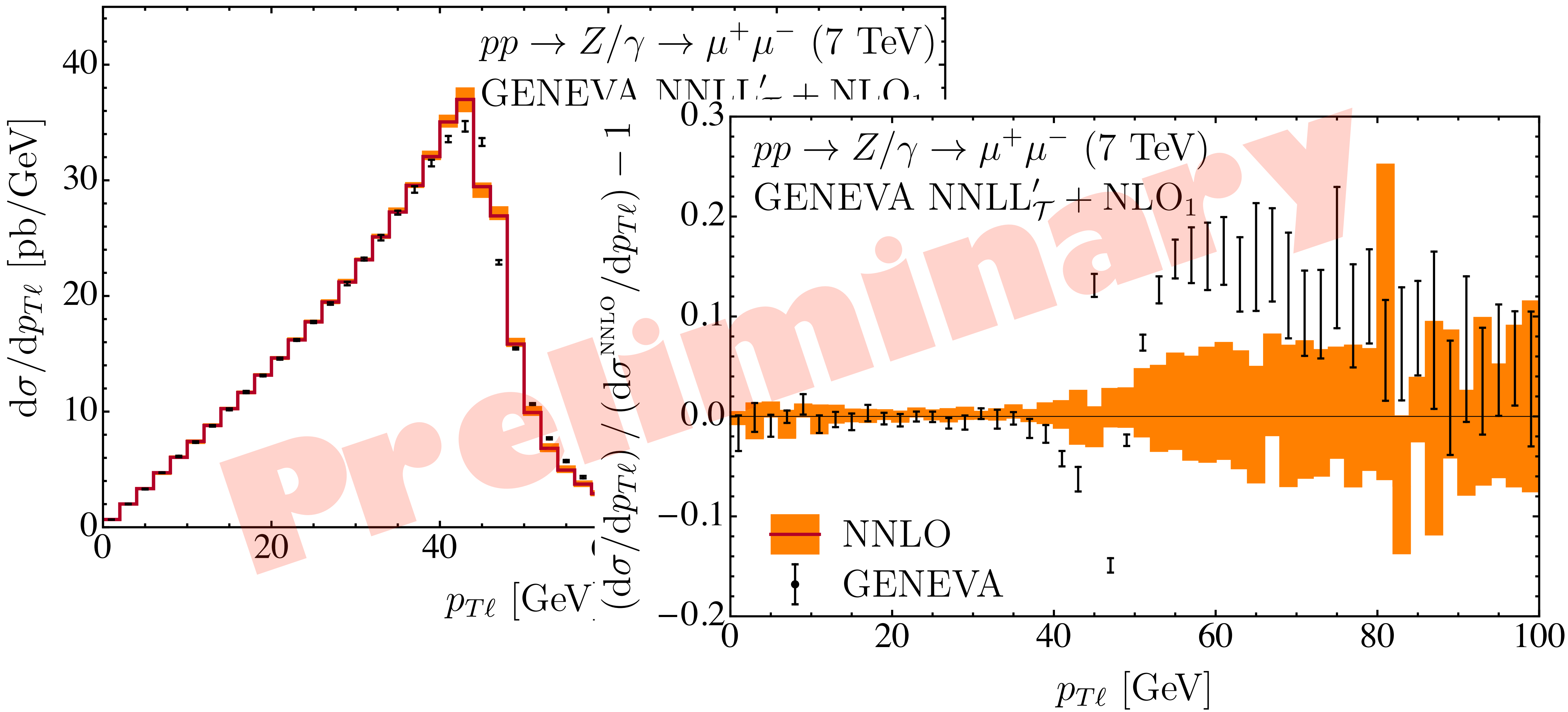

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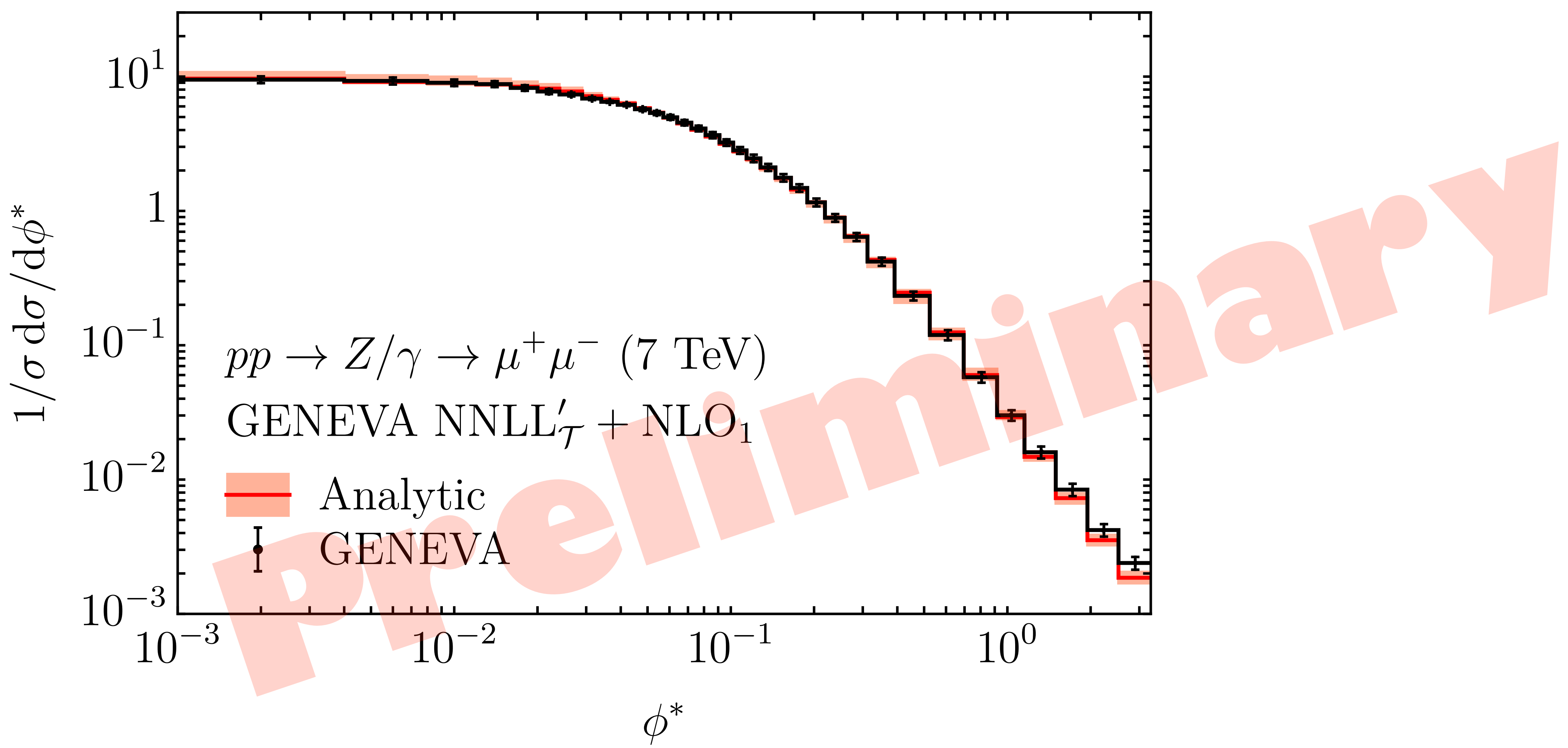
Higher log accuracy of resummed observables



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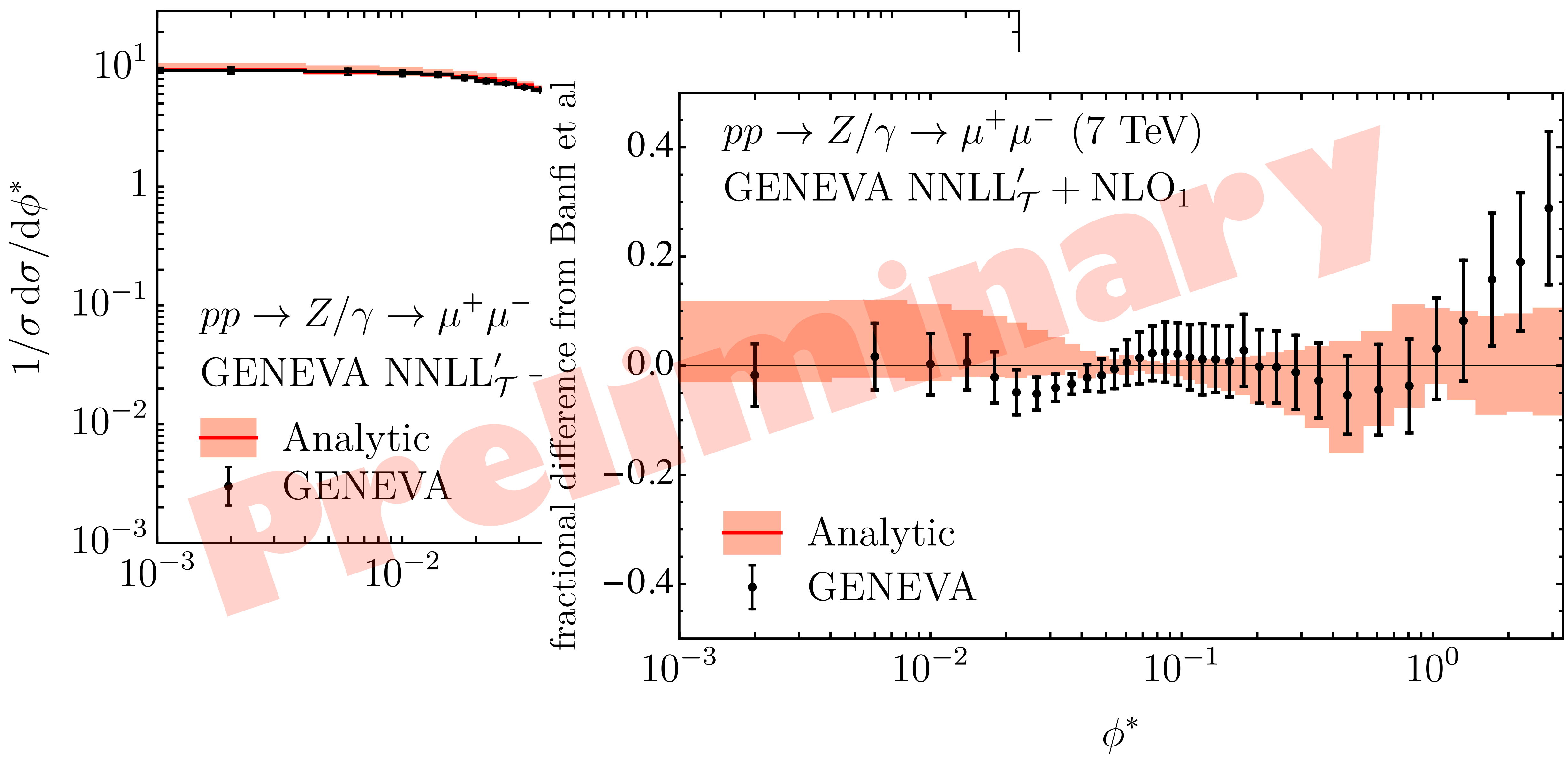

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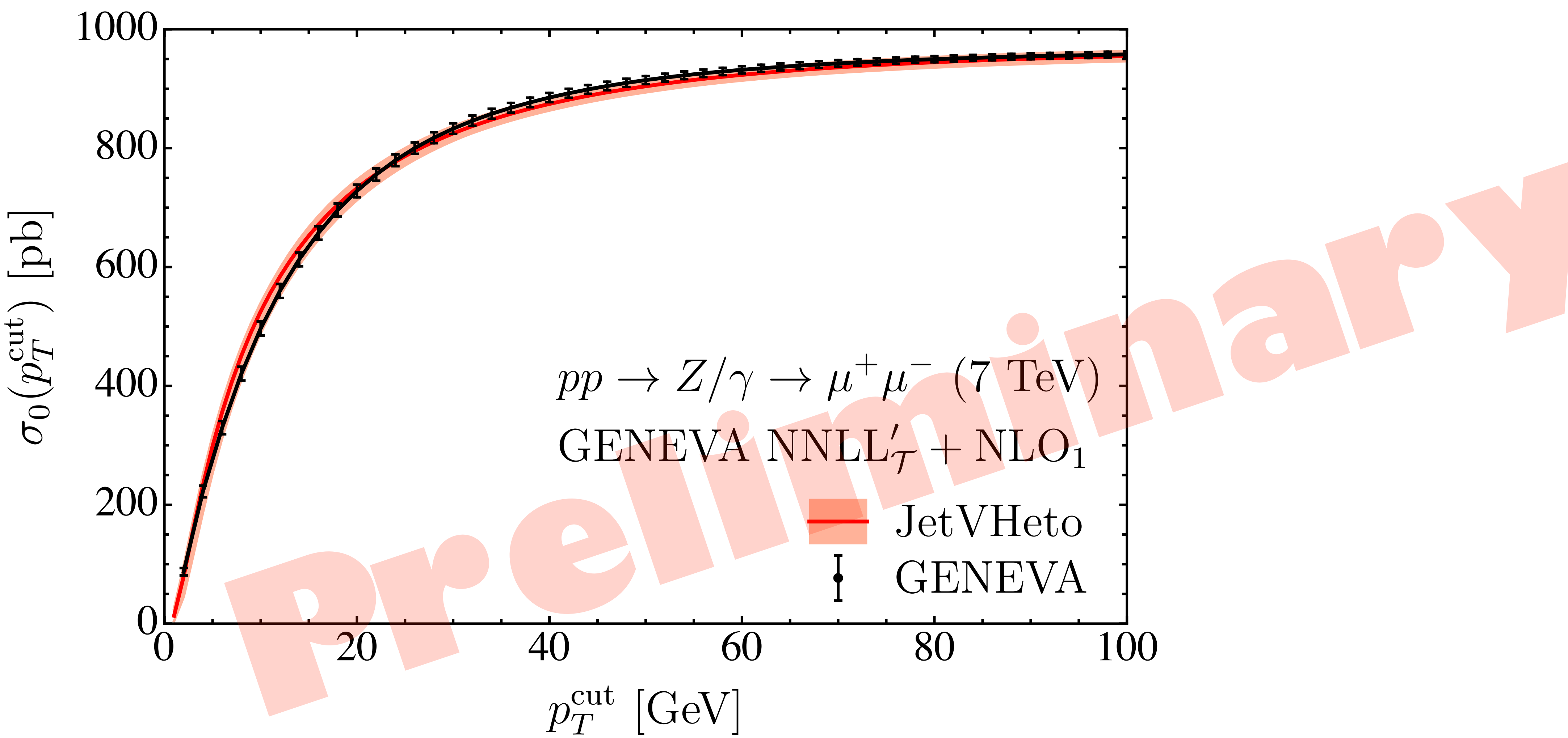

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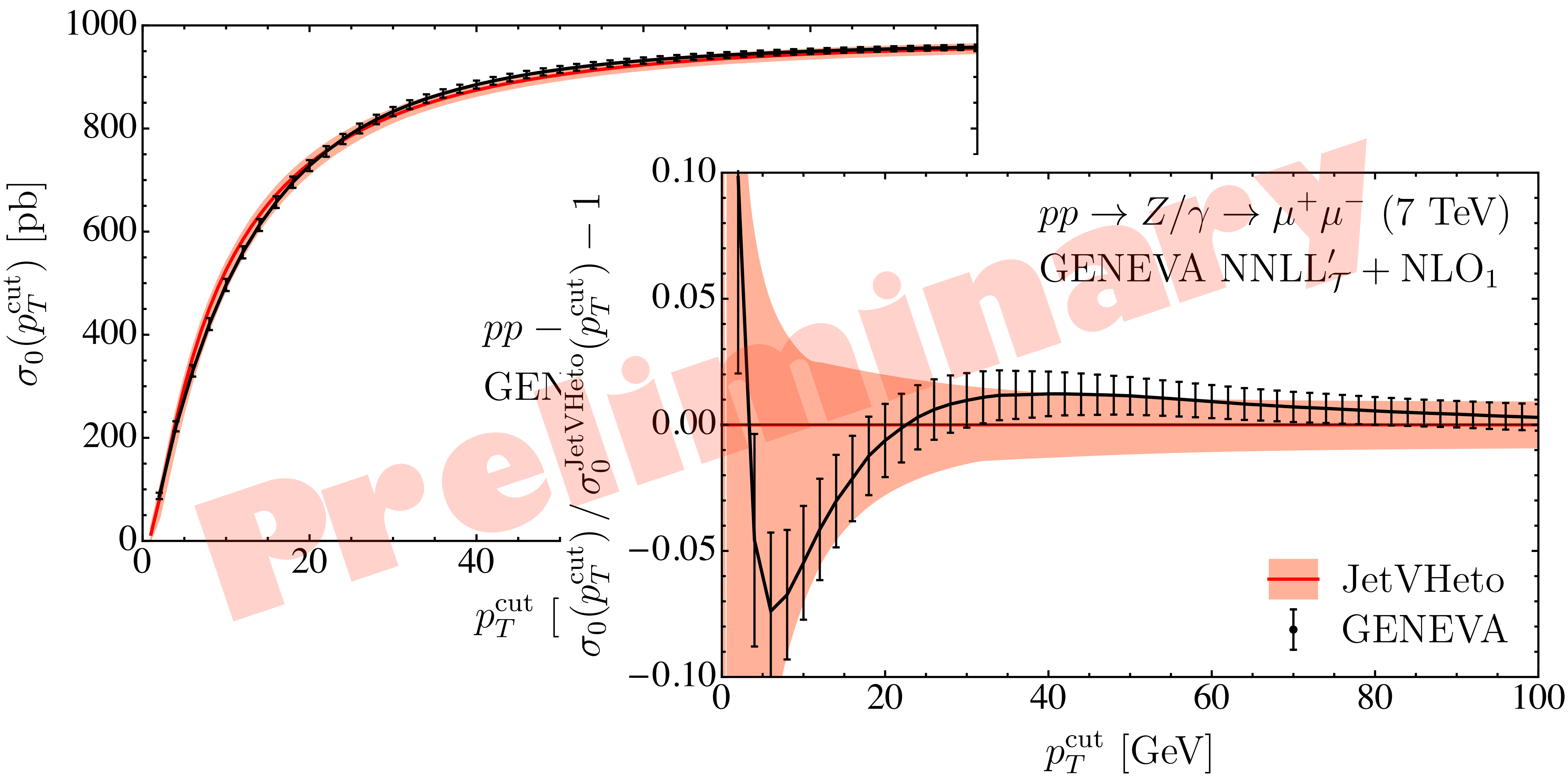

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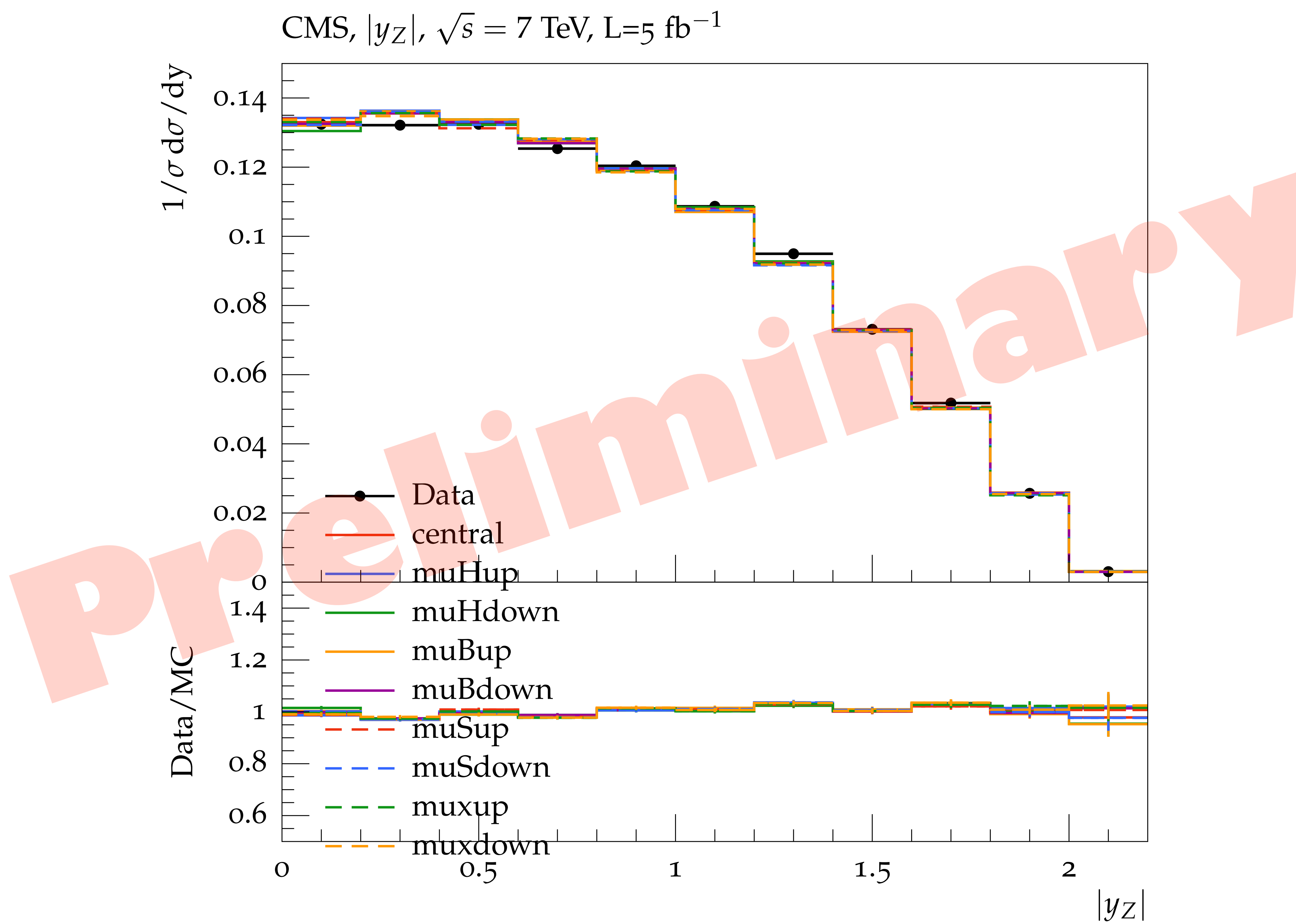
Some data comparisons



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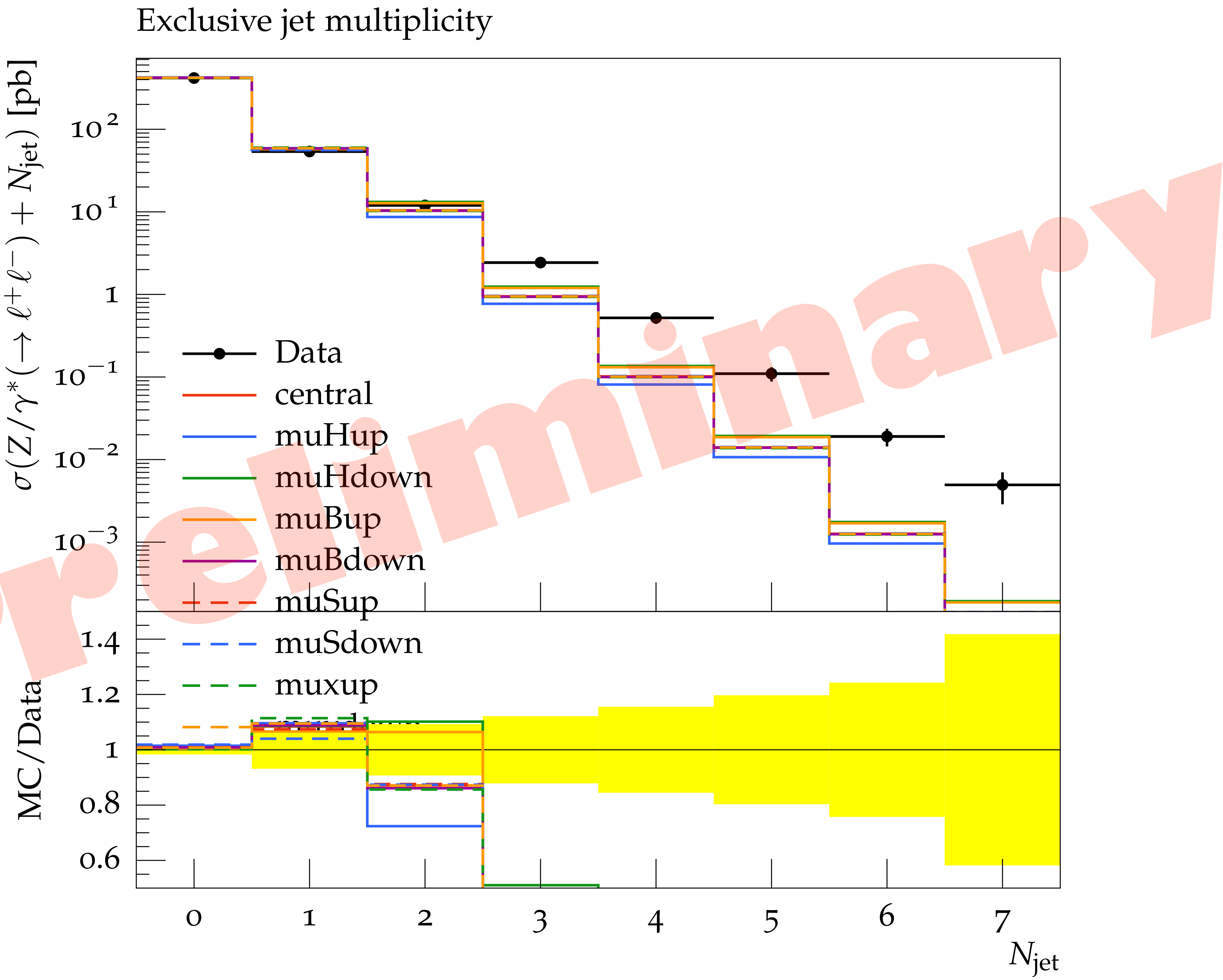

In conclusion, GENEVA is able to produce fully exclusive events with the correct fixed order and resummed accuracy

- GENEVA uses a general concept that is systematically improvable using EFT methods
- It has been applied to Z+jets and reproduces both dedicated fixed order and resummed calculations
- Look forward to extending this to more processes in the future