

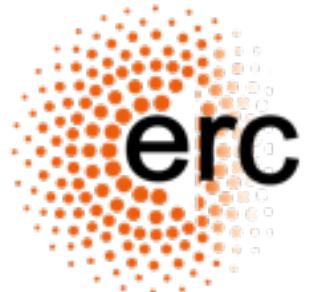
Differential Distributions for Precision Higgs Physics

Bernhard Mistlberger

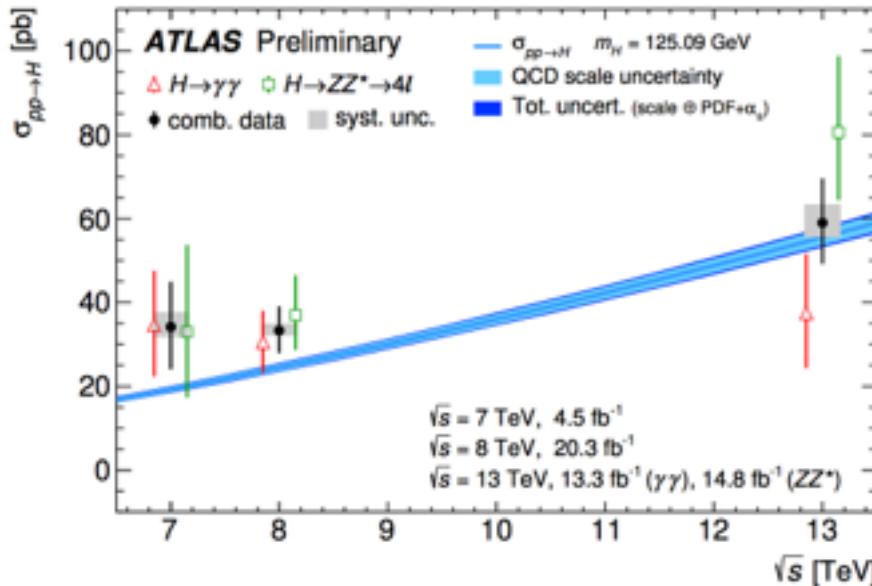


In collaboration with

Babis Anastasiou, Simone Lionetti, Andrea Pelloni, Caterina Specchia



LHC for Higgs Precision



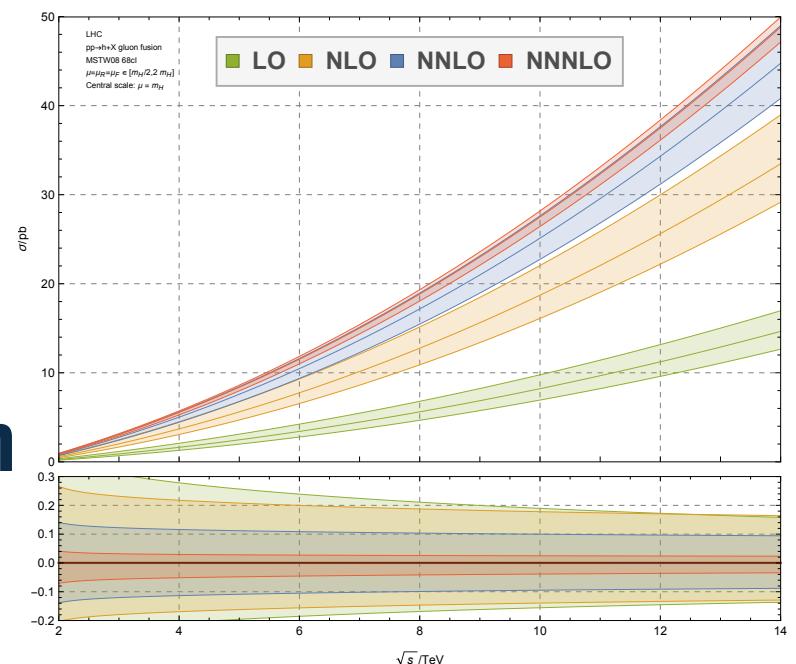
Run II+ : Data, Data, Data

We require precise measurement
and precise prediction

Pinn down Higgs properties

Prime example: Total Cross Section

Couplings, Branching Ratios



[ADDFGHL - N3LO Team]

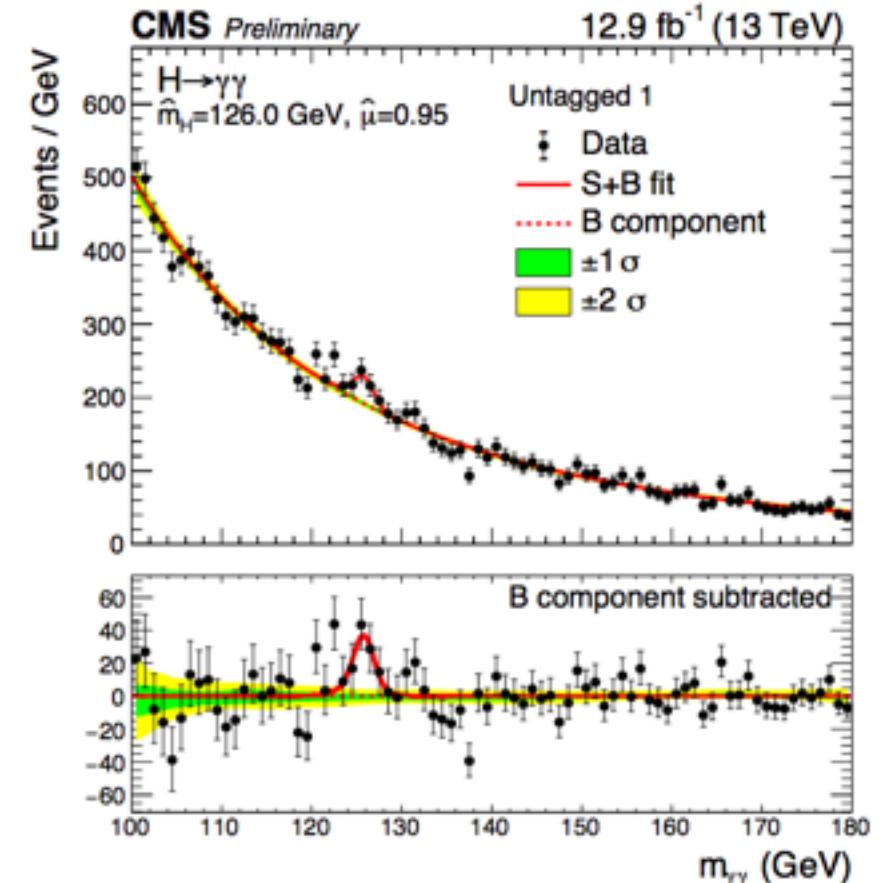
LHC for Higgs Precision

**Actual measurement:
Fiducial Volumes!**

Table 1: The summary of the selection criteria that define the fiducial regions.

	diphoton baseline	VBF enhanced	single lepton
Photons		$ \eta < 1.37$ or $1.52 < \eta < 2.37$ $p_T^{\gamma_1} > 0.35 m_{\gamma\gamma}$ and $p_T^{\gamma_2} > 0.25 m_{\gamma\gamma}$	
Jets	-	$p_T > 30 \text{ GeV}$, $ y < 4.4$ $m_{jj} > 400 \text{ GeV}$, $ \Delta y_{jj} > 2.8$ $ \Delta\phi_{\gamma\gamma,jj} > 2.6$	-
Leptons	-	-	$p_T > 15 \text{ GeV}$ $ \eta < 2.47$

[ATLAS]



**Wanted: Precision predictions for
observables as close to experimental
outcome as possible.**

Differential Cross Sections

Complicated final state phase space at high orders

Current Status: NNLO (H , $H+J$)

Going to NNLO: Many new techniques

Ideally: Compute
fully differential N3LO corrections

- Sector decomposition
- Non-Linear Mappings
- qT
- FKS+
- N-Jettiness
- Antenna
- Colourful
- Projection-To-Born
- ...

Differential Cross Sections

Complicated final state phase space at high orders

Current Status: NNLO (H , $H+J$)

Going to NNLO: Many new techniques

Ideally: Compute
fully differential N3LO corrections

- Sector decomposition
- Non-Linear Mappings
- qT
- FKS+
- N-Jettiness
- Antenna
- Colourful
- Projection-To-Born
- ...

But let's start with a bit of differential

General Idea - Higgs Differential

Derive a flexible framework for
differential Higgs boson cross sections

Explicit Goal: **N3LO**

Be able to compute fiducial cross sections
for realistic final states

$$\begin{aligned} P P \rightarrow h \rightarrow 4l \\ P P \rightarrow h \rightarrow \gamma\gamma \end{aligned}$$

Be inclusive w.r.t. additional radiation

Rely on analytic computation

Exploit what we learned from computing inclusive N3LO

General Idea - Higgs Differential

Master-Formula for differential cross section

$$\frac{d\sigma}{d\mathcal{O}} \sim \int d^d p_h dx dy f(x) f(y) \frac{\partial \hat{\sigma}}{\partial p_h} \mathcal{J}_{\mathcal{O}}(p_h)$$

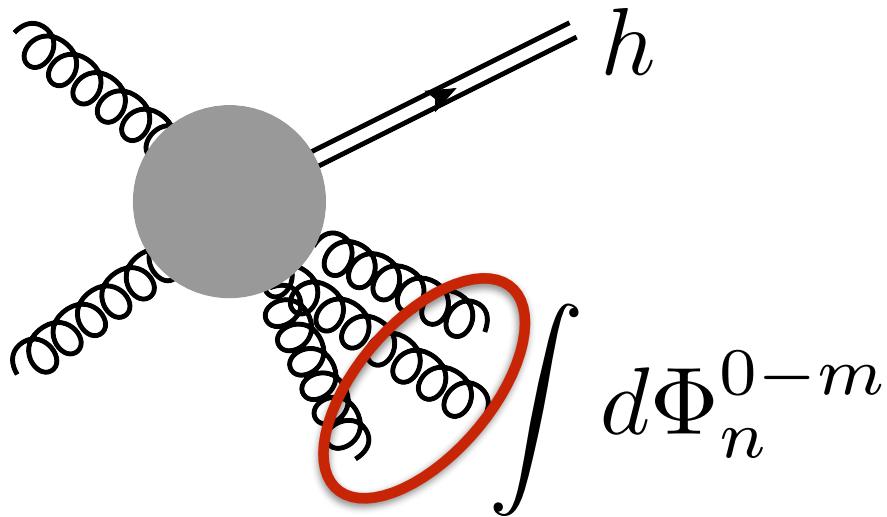
Observable depending
on Higgs momentum

Measurement Function

For Example

$$\mathcal{J}_{\mathcal{O}}(p_h) = \theta(p_T < 50 GeV)$$

Phase - Space Factorisation



Integrate only radiation

Higgs properties: Y

Rapidity

p_T

Transverse
Momentum

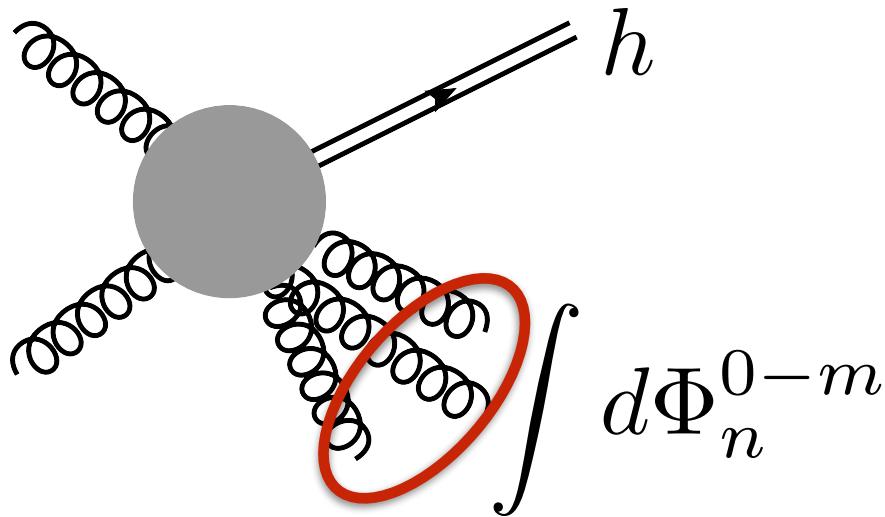
m_h

Mass / Virtuality

ϕ

Azimuthal Angle

Phase - Space Factorisation



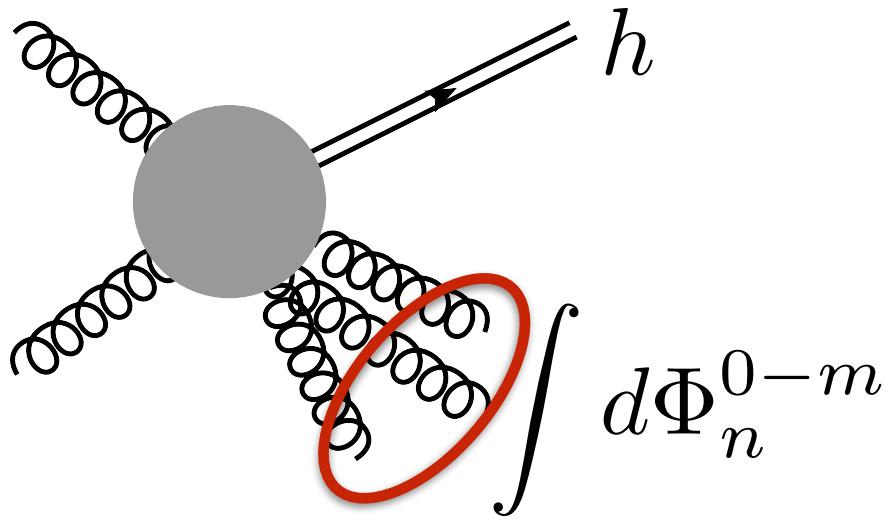
Integrate only radiation

Higgs properties:

3 Variable Problem

Y	Rapidity
p_T	Transverse Momentum
m_h	Mass / Virtuality
ϕ	Azimuthal Angle trivial!

Phase - Space Factorisation



Parametrize:

$$(m_h^2, p_T, Y) \rightarrow (z, x, \lambda)$$

**More convenient
for computation**

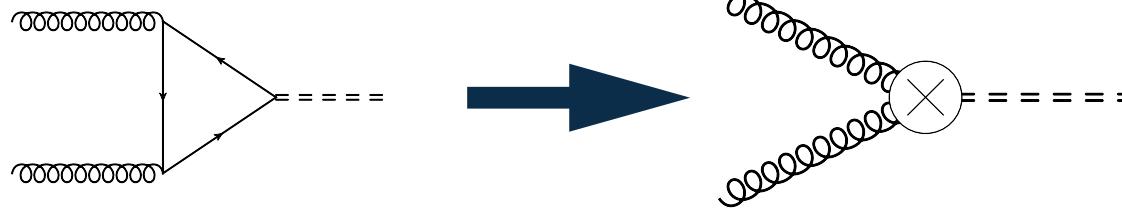
$$\int d\Phi_n \sim \int_0^1 d\lambda dx (\lambda(1-\lambda))^{\frac{d}{2}-1} (1-x)^{\frac{d}{2}-2} (1-x\bar{z}\lambda)^{-\frac{d}{2}} \times \int d\Phi_n^{0-m}$$

Phase-space singularities at the boundaries

Effective Theory

Gluon-Fusion

$$m_t \rightarrow \infty$$



Today's precision standard: NNLO

Anastasiou, Melnikov, Petriello, 2004

qT : Catani, Grazzini

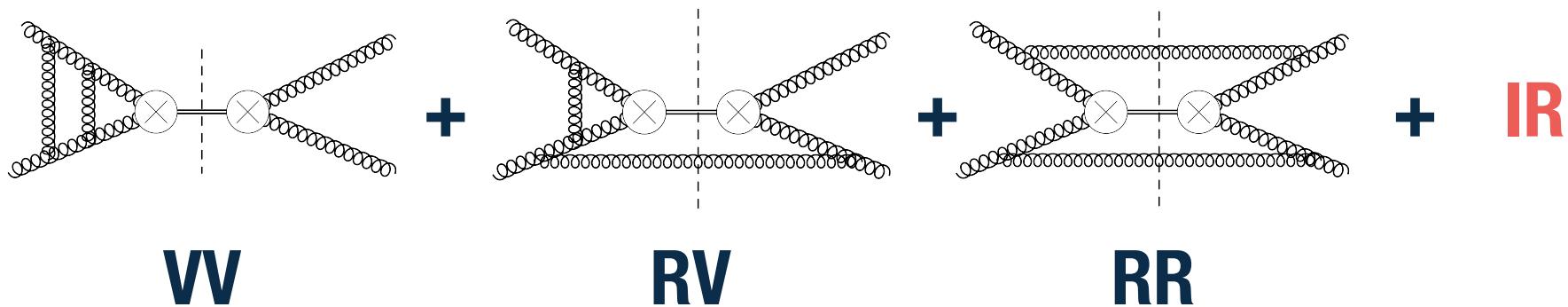
NNLO+PS: Hamilton, Nason, Re, Zanderighi

MCFM: Boughezal et al.

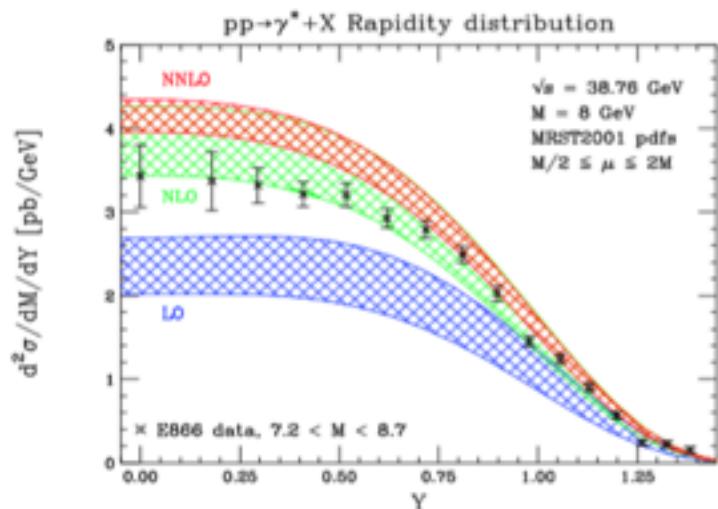
...

+ many electro-weak / mass corrections,
resummations, etc.,

Perturbative Computation at NNLO



Reverse - Unitarity:



Applicable to differential computation

DY - Rapidity Distribution
2003: Anastasiou, Dixon, Melnikov, Petriello

Reverse Unitarity

$\int \frac{d^d p}{(2\pi)^d} \delta_+(p^2) \quad : \quad \text{Constrained Phase-Space!}$
 $\text{Don't integrate over all of it!}$

Replace on-shell constraints with ‘cut-propagator’

Cutkosky’s rule: $\delta_+(q^2) \rightarrow \left(\frac{1}{q^2}\right)_c = \left(\frac{1}{q^2 + i0} - \frac{1}{q^2 - i0}\right)$

Treat cut-propagators as ordinary propagators of loop integrals.

Possibility to use loop-technology:

Integration-by-part, Master Integrals

Reverse Unitarity

Differential Cross Section:

Integrate even **less** than inclusive cross section

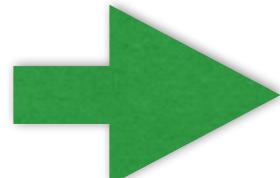
$$\delta(p_T - p_T^0) \delta(Y - Y^0)$$

Inconvenient for Reverse Unitarity.

Any set of variables with a one to one correspondence to p_T and Y will do.

For example: $\delta(2p_1 p_h - w) \delta((p_h - p_1 - p_2)^2 - m)$

Treat constraints as **cut-propagators!**



Master Integrals

Computing Master Integrals

Large variety of technology available

2 Independent Strategies: Direct Computation
Differential Equations

Differential Equations Interlude: $d\vec{M} = A(z, x, \lambda, \epsilon)\vec{M}$

3 dimensionless variables: (z, x, λ)

Alphabet:

$$\begin{aligned} & \{1 - \bar{z}, \bar{z}, 1 - x\bar{z}, 1 - \lambda x\bar{z}, \lambda^2(-(x - 1))x\bar{z}^2 - \bar{z} + 1, \lambda^2 x\bar{z}^2 + \bar{z}(-2\lambda x + x - 1) + 1, \\ & \lambda^2 x^2 \bar{z} (-4\lambda + \lambda^2 \bar{z} + 4) - 2\lambda x(\lambda(\bar{z} - 2) + 2) + 1, 2\lambda^2 x^2 \bar{z} - \sqrt{\lambda^2 x^2 \bar{z} (-4\lambda + \lambda^2 \bar{z} + 4) - 2\lambda x(\lambda(\bar{z} - 2) + 2) + 1} - \dots \end{aligned}$$

Analytic Results at NNLO

Computed partonic cross sections for all channels

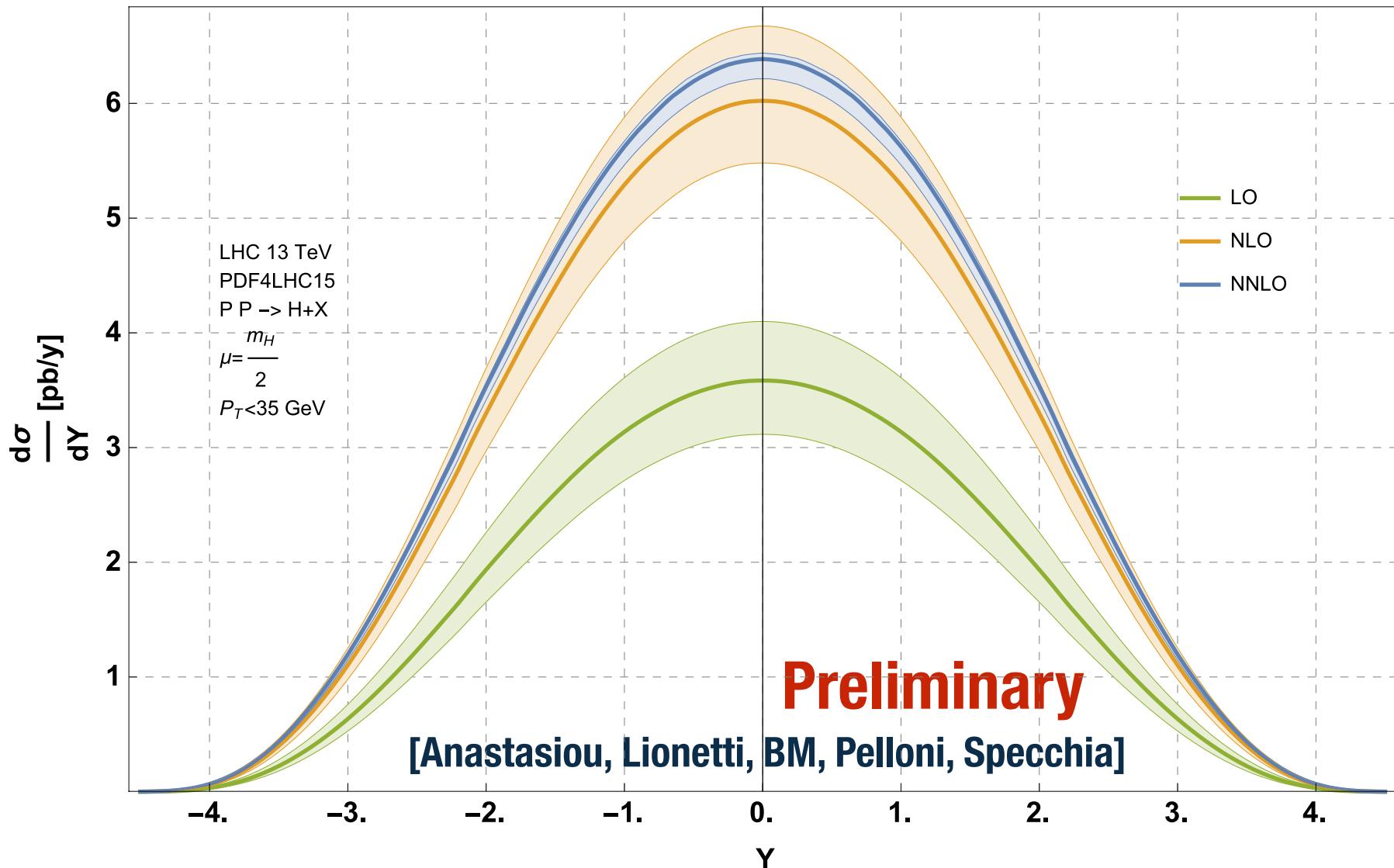
Subtraction of singularities + integration of subtraction terms facilitated by our framework

N3LO IR subtraction terms requires $\mathcal{O}(\epsilon)$ for NNLO

Results in form of poly-logarithms

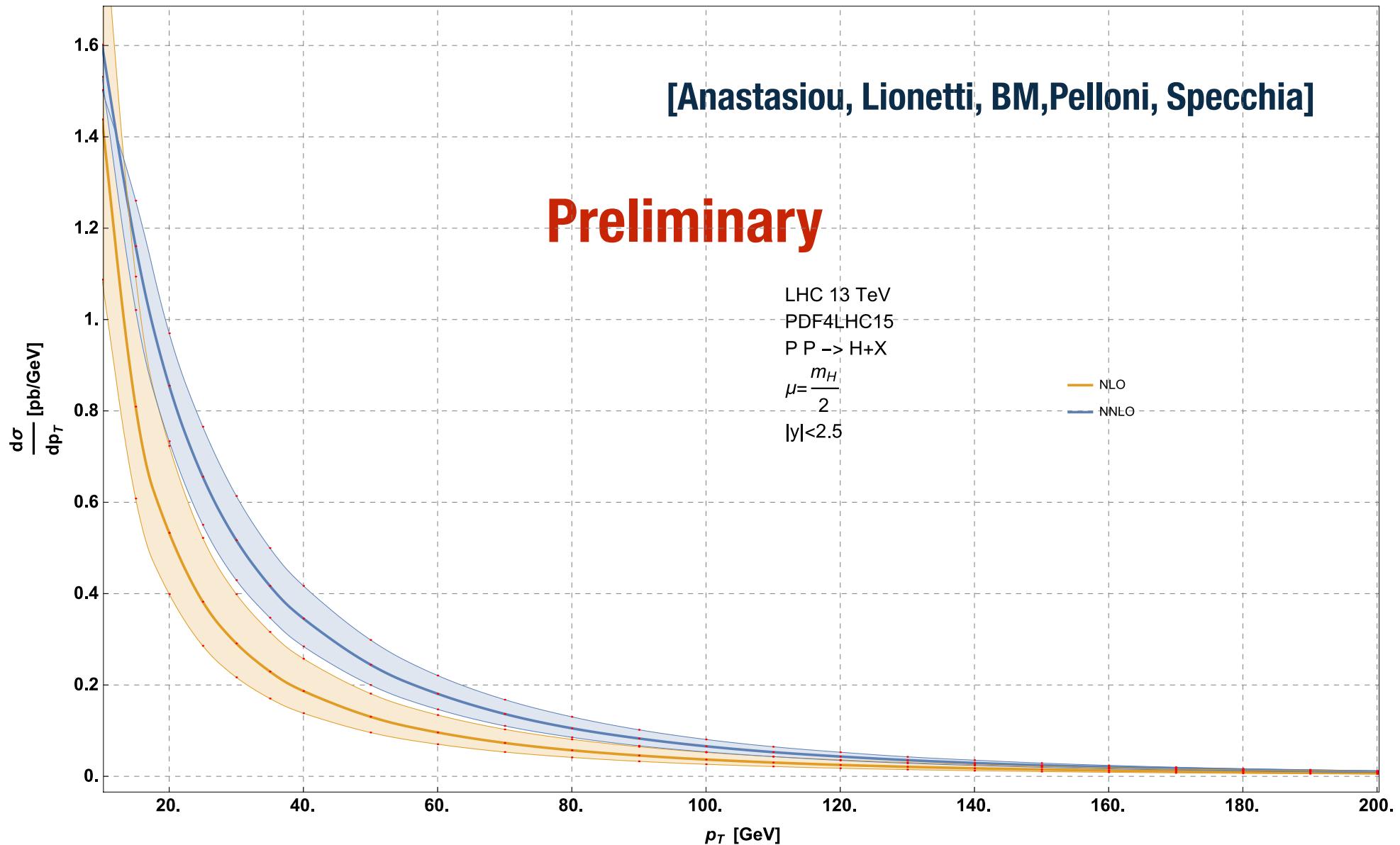
!Numerics!

NNLO Rapidity Distribution



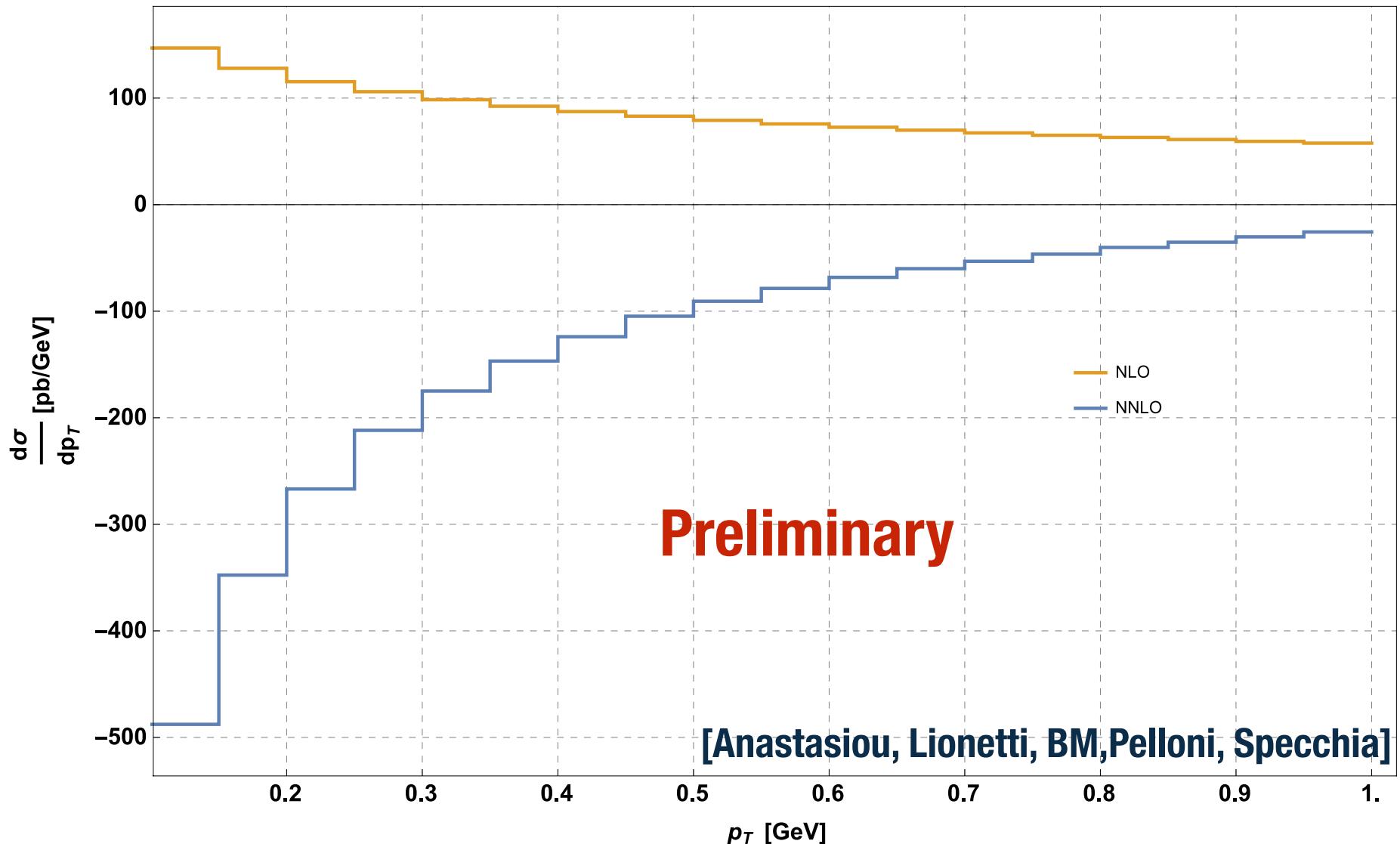
$pT < 35 \text{ GeV}$

NNLO PT Distribution



$|Y| < 2.5$

NNLO PT Distribution



$0.1 \text{ GeV} < p_T < 1 \text{ GeV}$

Conclusions

Framework to produce analytic differential cross sections

First step towards N3LO differential Higgs production

Current status: NNLO + N3LO IR subtraction terms

Flexible method for fiducial predictions comparable to experiment

Useful for other processes: DY