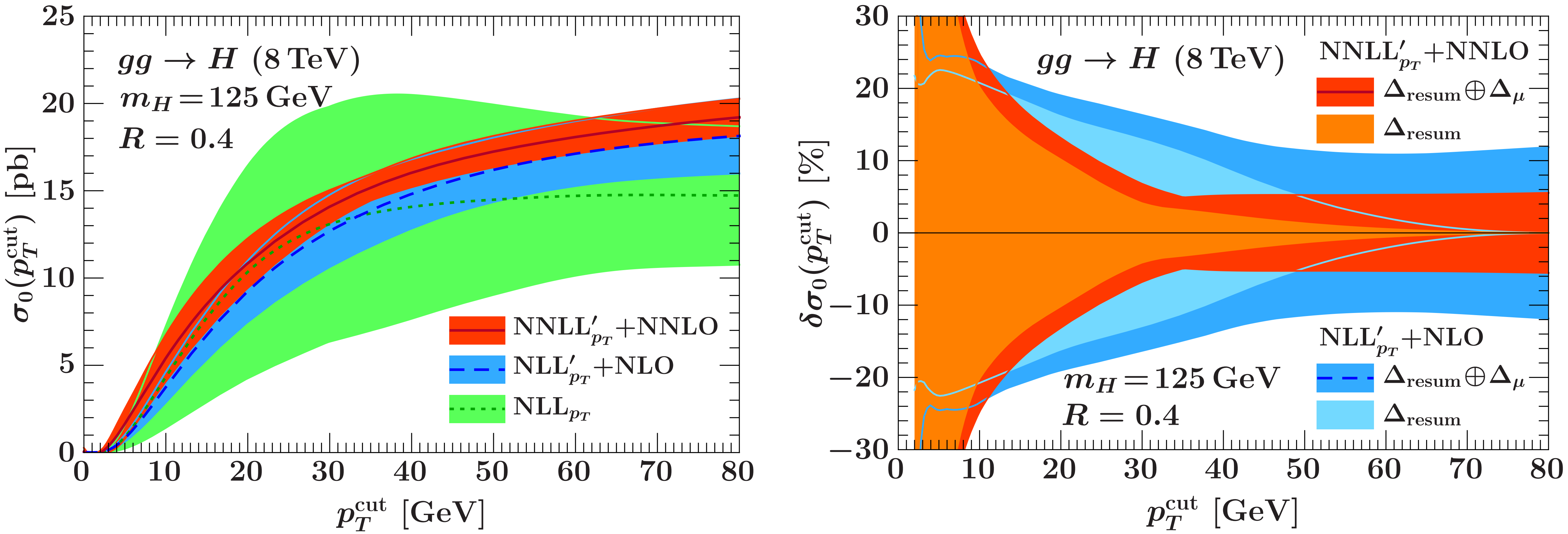
Combining Resummed Jet Bin Predictions

Jonathan Walsh, UC Berkeley

work with

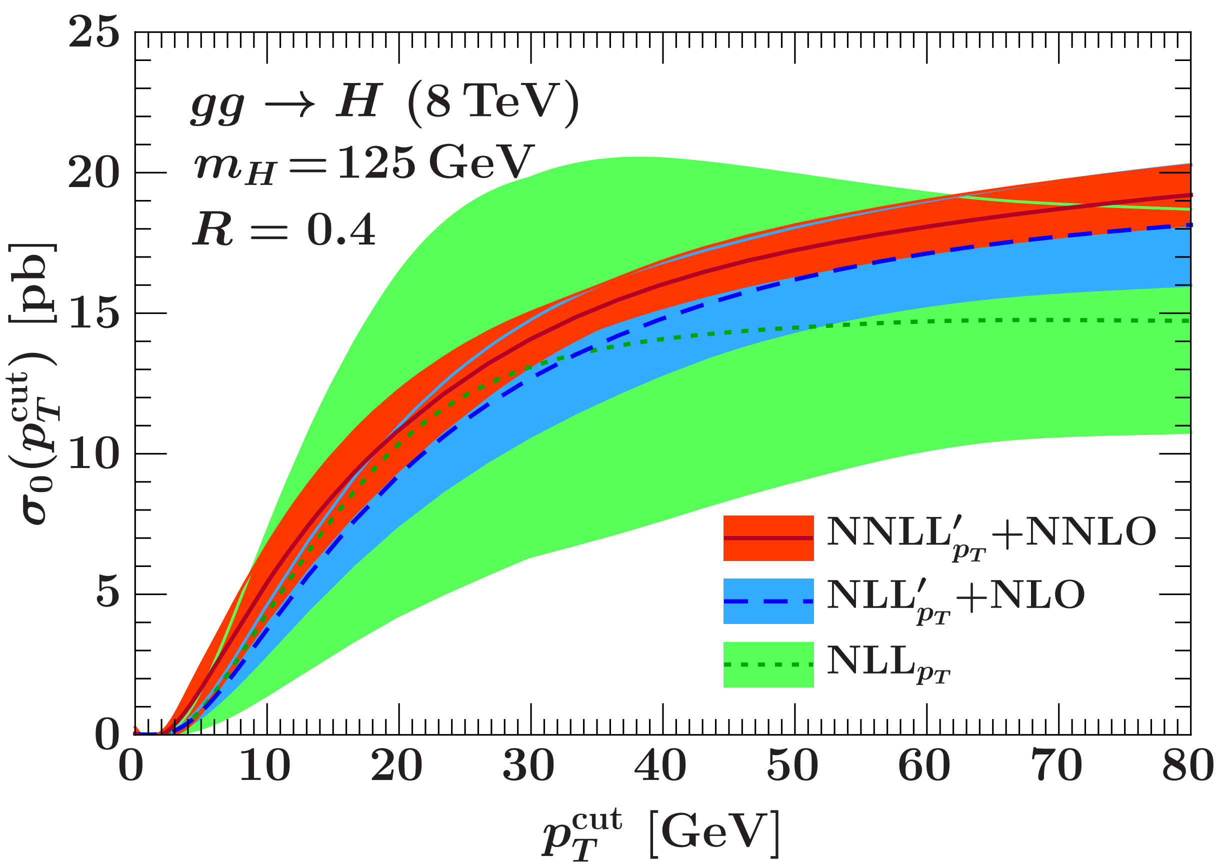
Radja Boughezal, Xiaohui Liu, Frank Petriello, and Frank Tackmann - 1312.4535

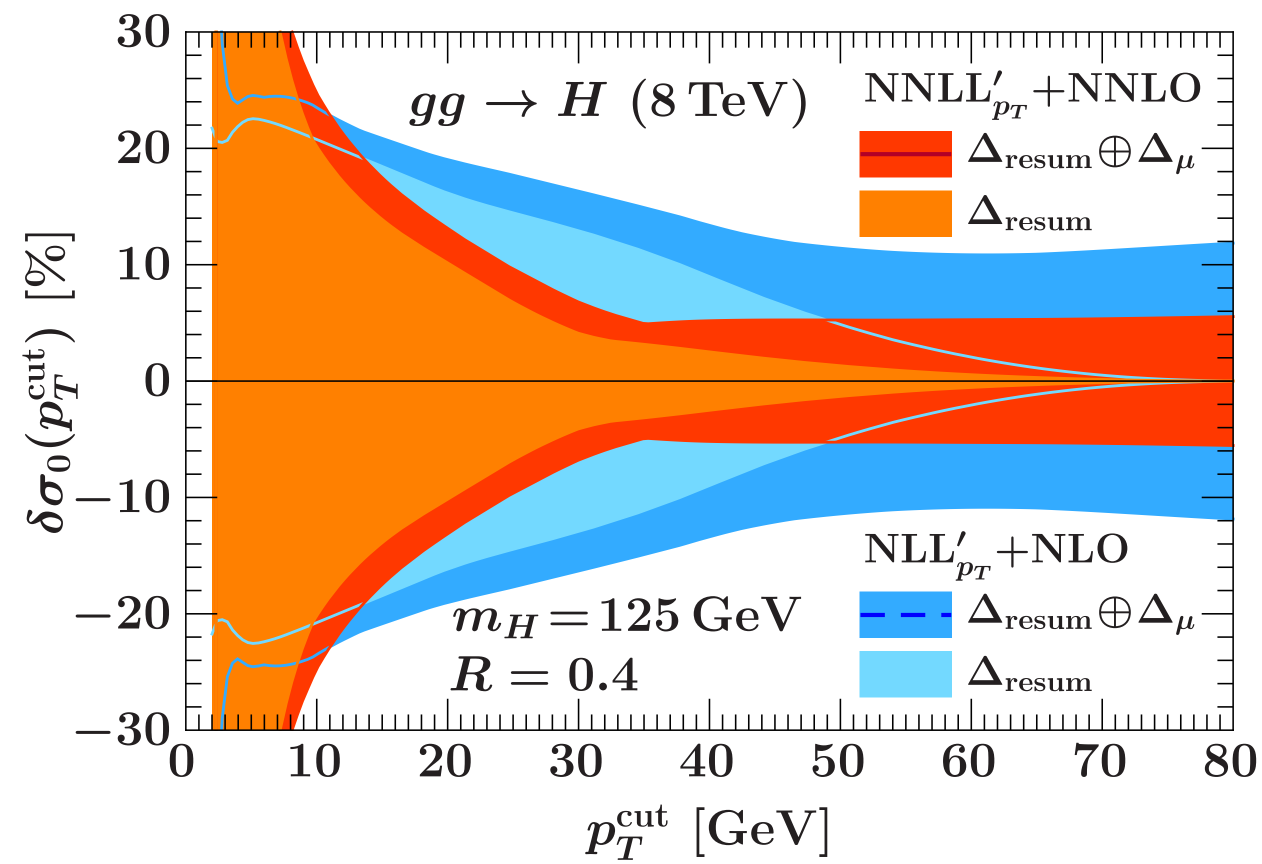
see also Frank Tackmann's talk and
Iain Stewart, Frank Tackmann, JW, Saba Zuberi - 1307.1808
Xiaohui Liu, Frank Petriello - 1210.1906, 1303.4405



What can be done with H+0-jet predictions?

- Use in differential Higgs studies
- Combine with H+1-jet predictions for use in Higgs coupling measurements, e.g. H → WW

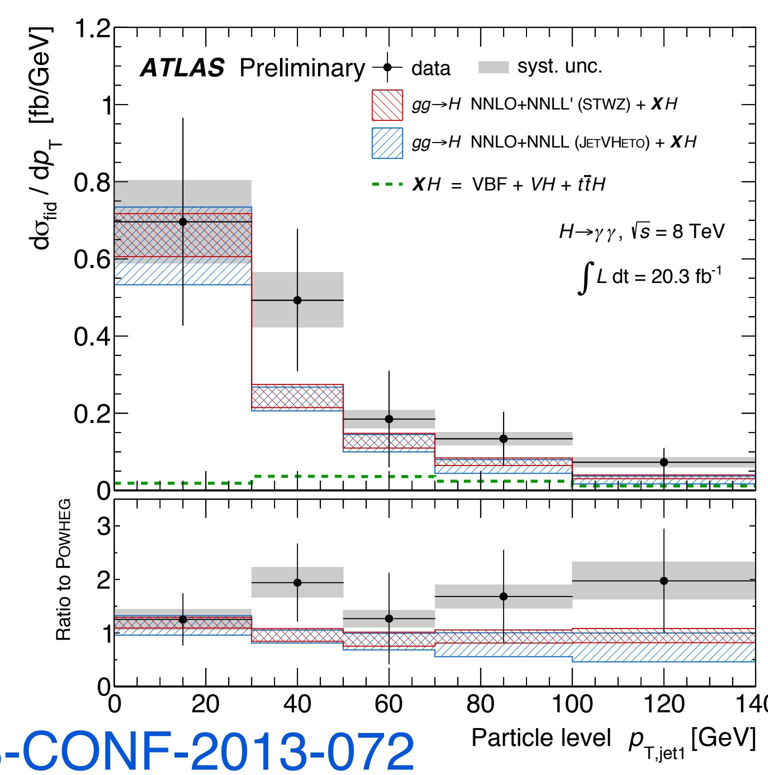




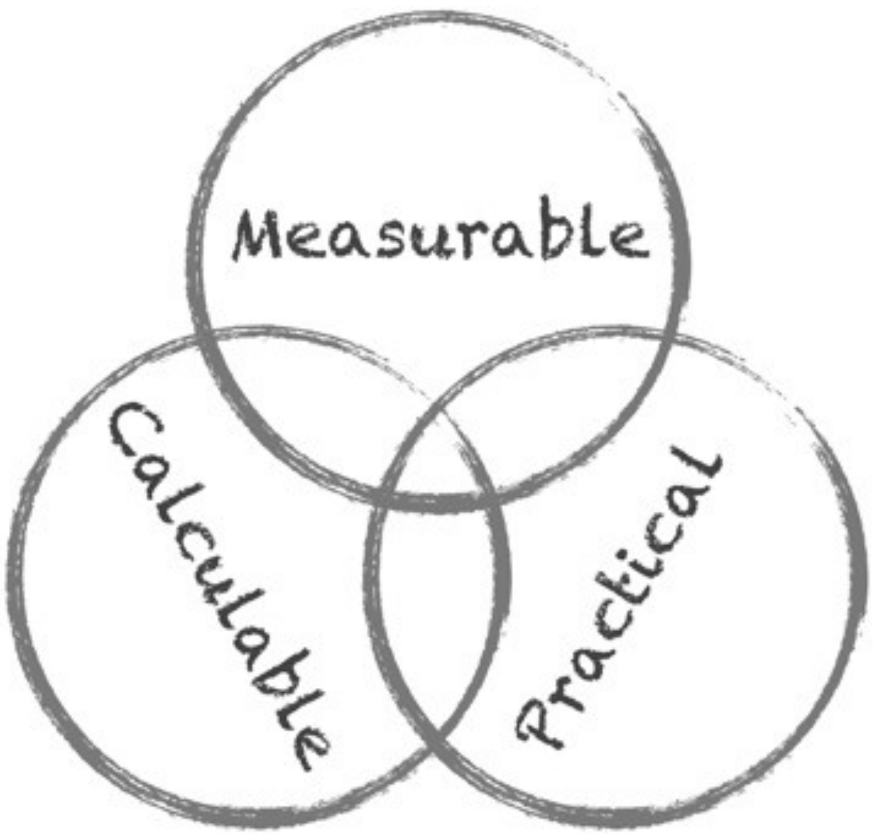
What can be done with H+0-jet predictions?

✓ Use in differential Higgs studies

- Combine with H+1-jet predictions for use in Higgs coupling measurements, e.g. H → WW



ATLAS-CONF-2013-072



✓ Calculable: systematically improvable

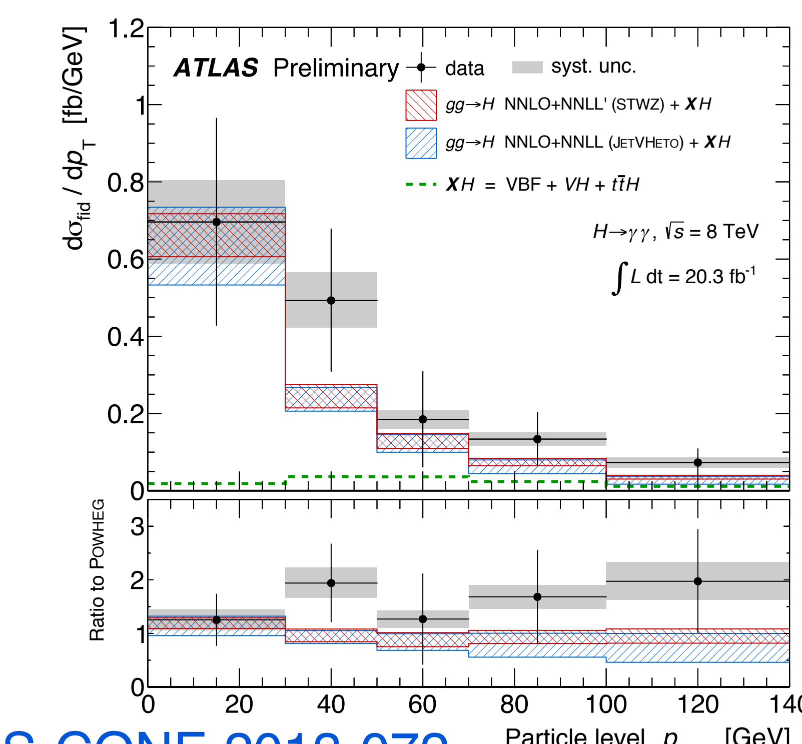
✓ Measurable: integral measurement in Higgs studies across channels

✓ Practical: experiments can directly use our results to lower uncertainties

What can be done with H+0-jet predictions?

✓ Use in differential Higgs studies

- Combine with H+1-jet predictions for use in Higgs coupling measurements, e.g. H → WW



ATLAS-CONF-2013-072

Recent Work on (p_T) Jet Vetoes

H + 0 jets

- Banfi, Monni, Salam, Zanderighi - 1203.5773, 1206.4996, 1308.4634
  (also Z + 0 jets)
- Becher, Neubert, Rothen - 1205.3806, 1307.0025
- Stewart, Tackmann, JW, Zuberi - 1206.4312, 1307.1808

H + 1 jet

- Liu, Petriello - 1210.1906, 1303.4405
- Boughezal Liu, Petriello, Tackmann, JW (H + 0/1-jet) 1312.4535

H + 2 jets

- Gangal, Tackmann (fixed order uncertainties) - 1302.5437

VH + 0 jets

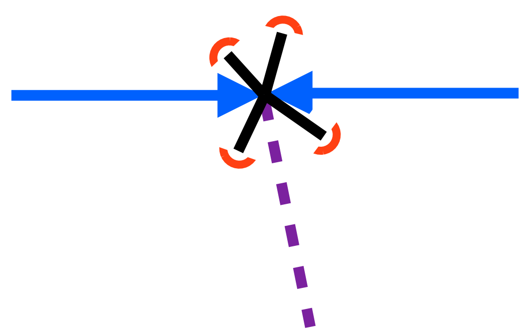
- (Chong Sheng) Li, (Hai Tao) Li, Shao - 1309.5015
- (Ye) Li, Liu - 1401.2149

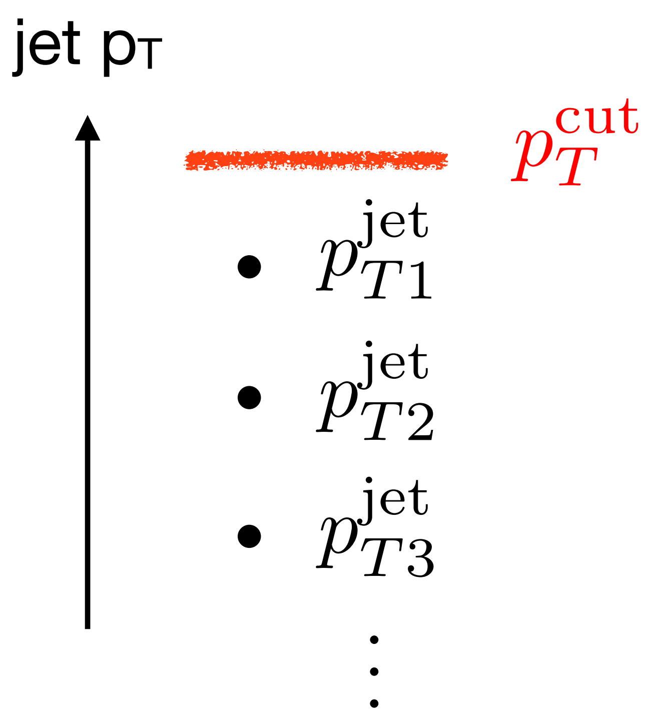
clustering effects

- Alioli, JW - 1311.5234

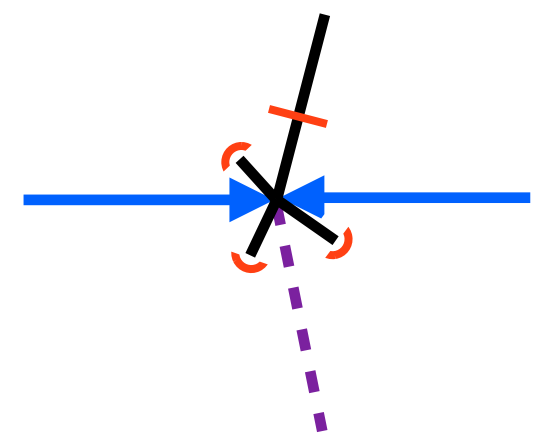
H + 0-jet and H + 1-jet Cross Sections

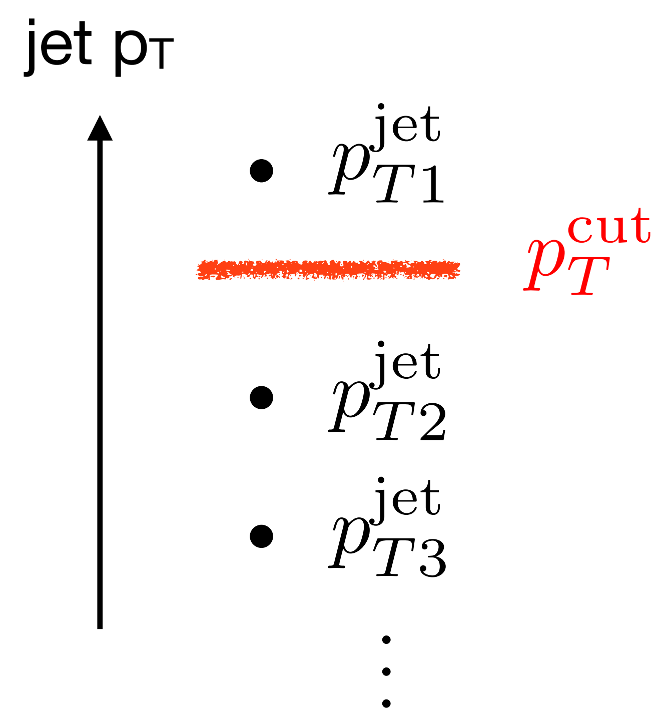
exclusive 0-jet events:
no jets with $p_{TJ} > p_T^{cut}$





exclusive 1-jet events:
exactly one jet with $p_{TJ} > p_T^{cut}$

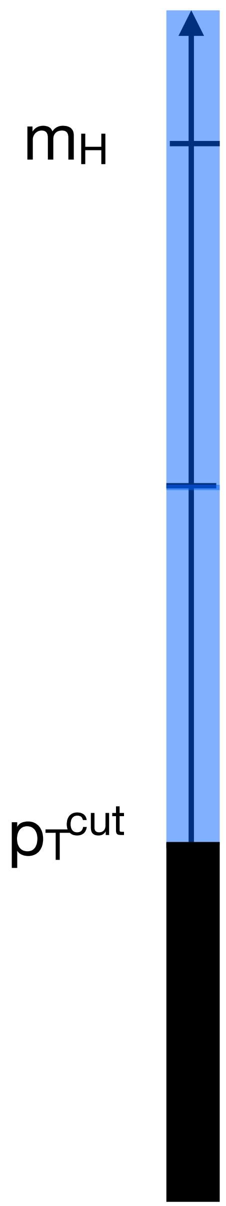




H + 1-jet Cross Section: *Ideal*

exclusive 1-jet cross section

p_{TJ} : leading jet p_T



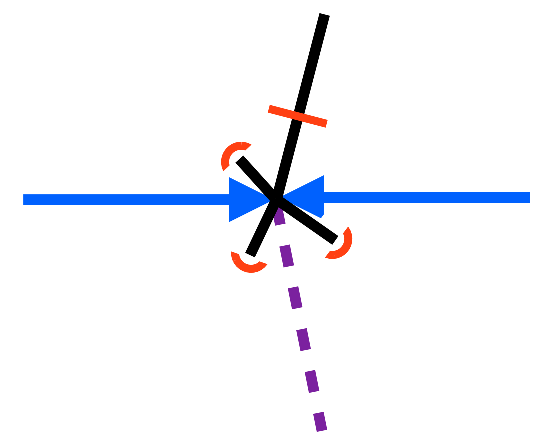
$$p_T^{\rm cut} \ll p_{TJ} \sim m_H$$

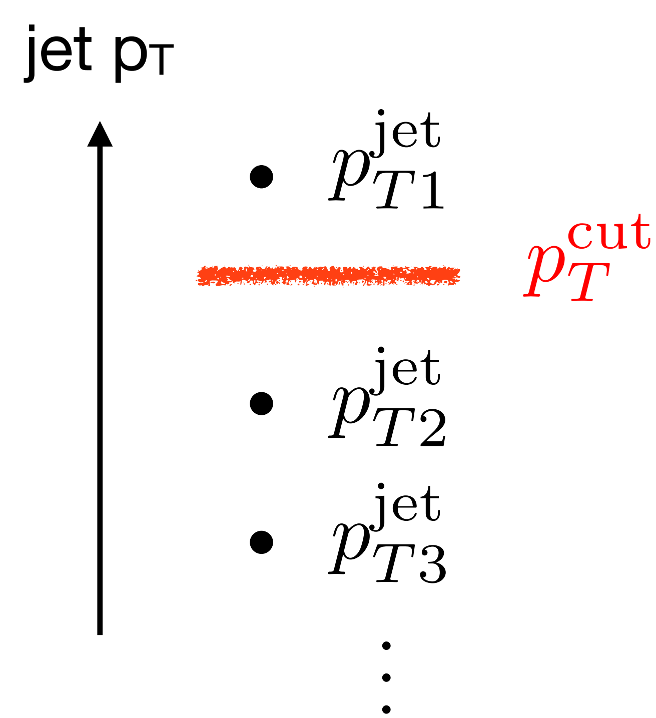
resummation
wanted for all p_{TJ}

$$p_T^{\rm cut} \sim p_{TJ} \ll m_H$$

0-jet region

exclusive 1-jet events:
exactly one jet with $p_{TJ} > p_T^{cut}$

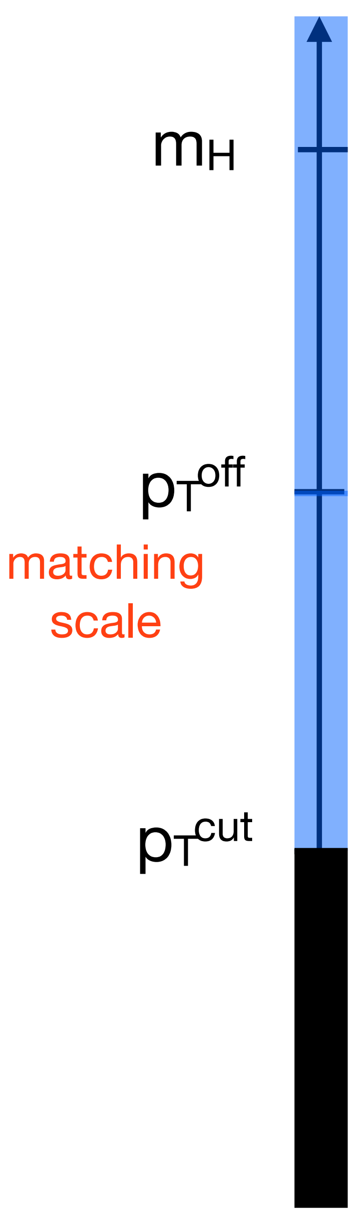




H + 1-jet Cross Section: *Reality*

exclusive 1-jet cross section

p_{TJ} : leading jet p_T



$p_T^{cut} \ll p_{TJ} \sim m_H$ ← Reliable predictions exist

H + 1-jet: Liu, Petriello, 1303.4405, 1210.1906

resummation wanted for all p_{TJ}

$p_T^{cut} \sim p_{TJ} \ll m_H$ ← Soft final state jet framework unclear

cross section peaks at low jet p_T

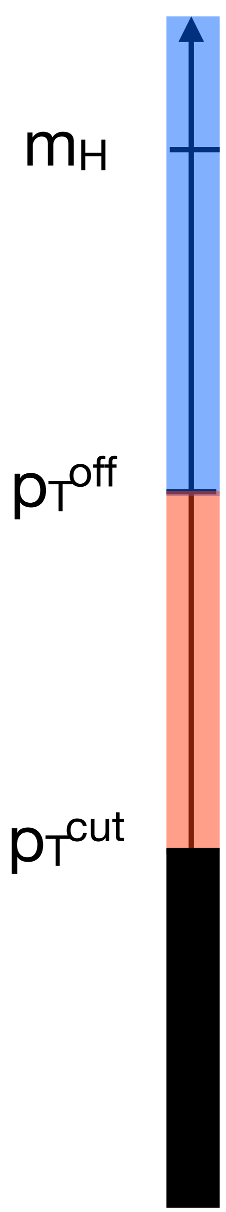
0-jet region

H + 1-jet Cross Section: *Reality*

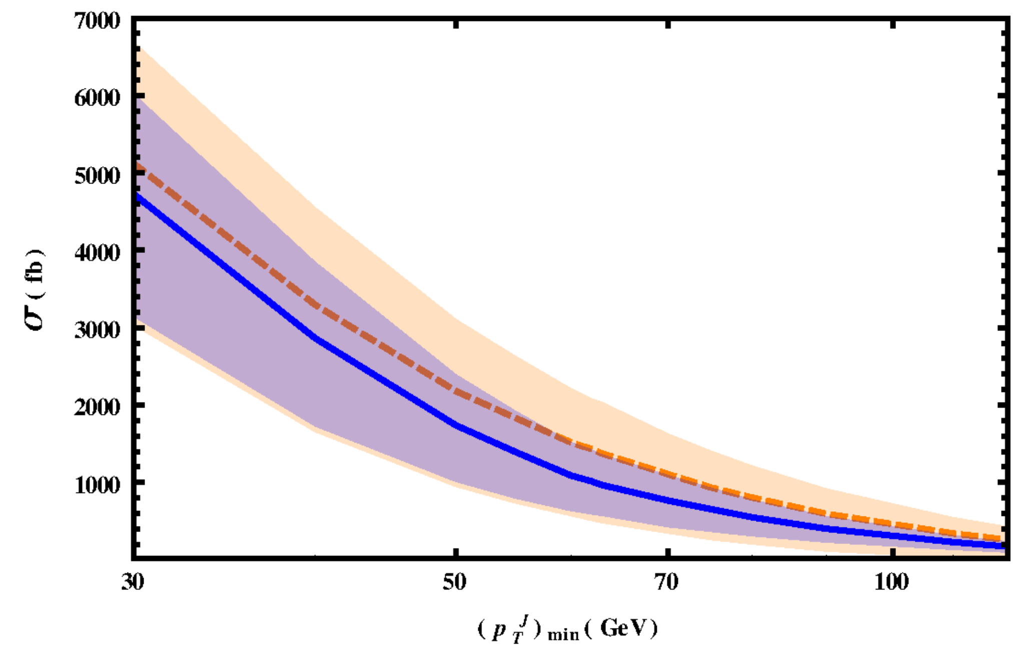
H + 1-jet: Liu, Petriello, 1303.4405, 1210.1906

exclusive 1-jet cross section

p_{TJ} : leading jet p_T



resummed prediction (NLL'+NLO)
find a reduction in uncertainties over NLO



fixed order prediction (NLO)

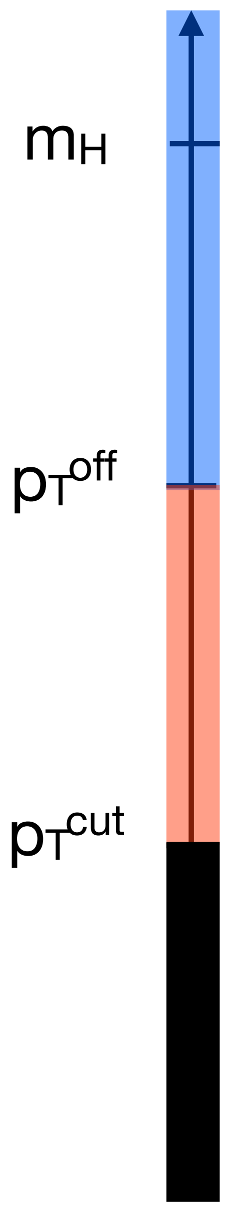
large logarithms remain in the fixed order contributon
$m_H >> p_{TJ} \sim p_T^{cut}$

0-jet region

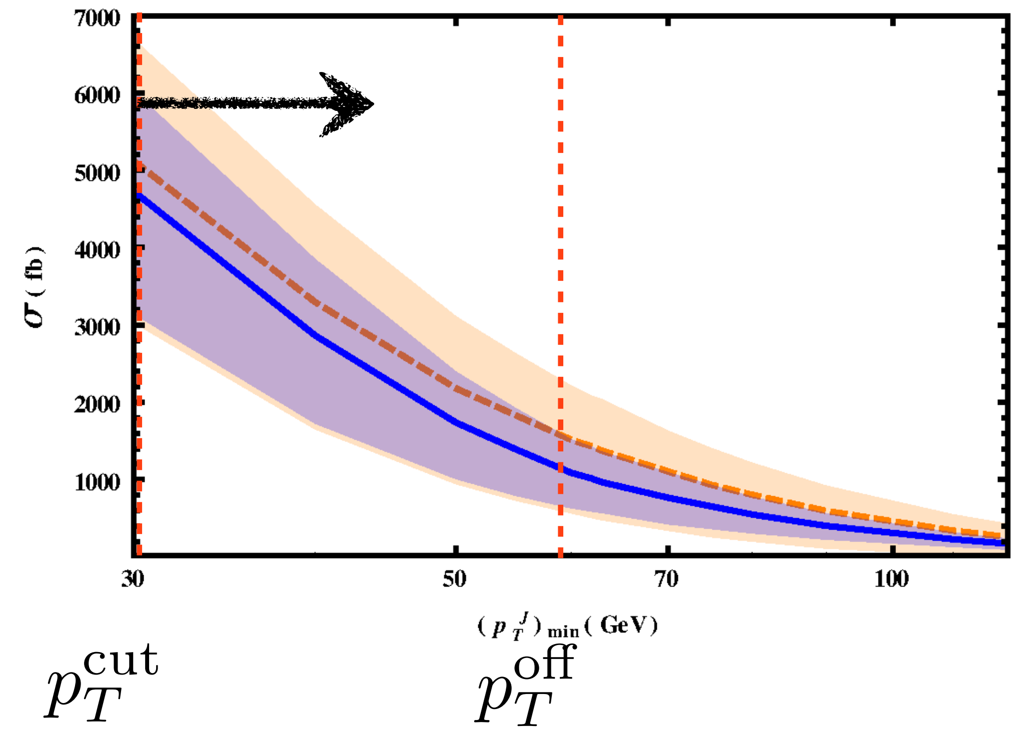
Combining 0-jet and 1-jet Bins

exclusive 1-jet cross section

p_{TJ} : leading jet p_T



resummed prediction (NLL'+NLO)



use the resummed inclusive 1-jet predictions (+ FO correction)

match onto the direct 1-jet resummation at high jet p_T

0-jet region

Bootstrapping from Inclusive 1-jet Resummation

relation for exclusive 1-jet cross section in bin [p_T^{cut}, p_T^{off}]:

$$\sigma_1([p_T^{\rm cut}, p_T^{\rm off}]; p_T^{\rm cut}) = \underbrace{[\sigma_0(p_T^{\rm off}) - \sigma_0(p_T^{\rm cut})]} + \underbrace{[\sigma_{\geq 2}(p_T^{\rm off}, p_T^{\rm cut}) - \sigma_{\geq 2}(p_T^{\rm cut}, p_T^{\rm cut})]}$$

0-jet (1-jet inclusive) terms — will use the 0-jet (inclusive 1-jet) resummation to improve over fixed order

2-jet inclusive terms — will find the (fixed order) 2-jet corrections are small

$p_T^{\rm cut} < p_{TJ} < p_T^{\rm off}$ use 1-jet inclusive resummation + FO correction

$p_T^{\rm off} < p_{TJ}$ resummed prediction (NLL'+NLO) from Boughezal, Liu, Petriello (with/without NNLO virtuals)

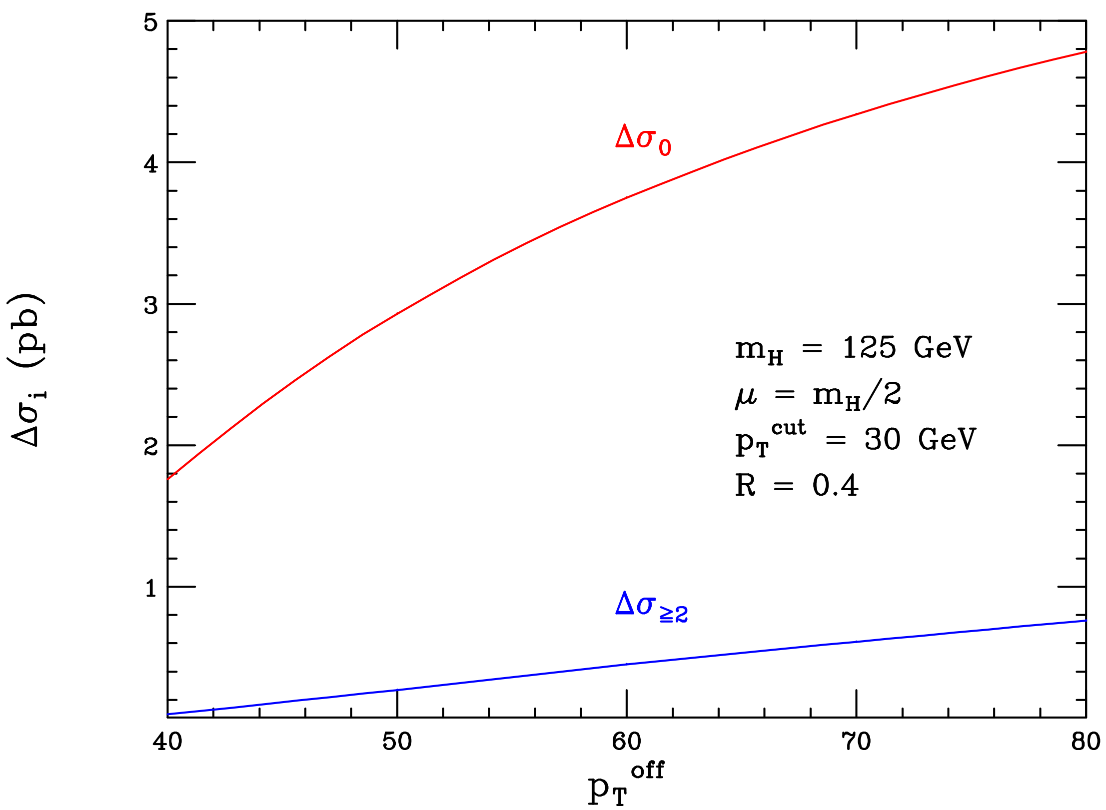
Bootstrapping from Inclusive 1-jet Resummation

relation for exclusive 1-jet cross section in bin [p_T^{cut}, p_T^{off}]:

$$\sigma_1([p_T^{\rm cut}, p_T^{\rm off}]; p_T^{\rm cut}) = \underbrace{[\sigma_0(p_T^{\rm off}) - \sigma_0(p_T^{\rm cut})]} + \underbrace{[\sigma_{\geq 2}(p_T^{\rm off}, p_T^{\rm cut}) - \sigma_{\geq 2}(p_T^{\rm cut}, p_T^{\rm cut})]}$$

0-jet (1-jet inclusive) terms use resummed results (equivalent to inclusive 1-jet)

2-jet inclusive terms use H+2-jet at NLO

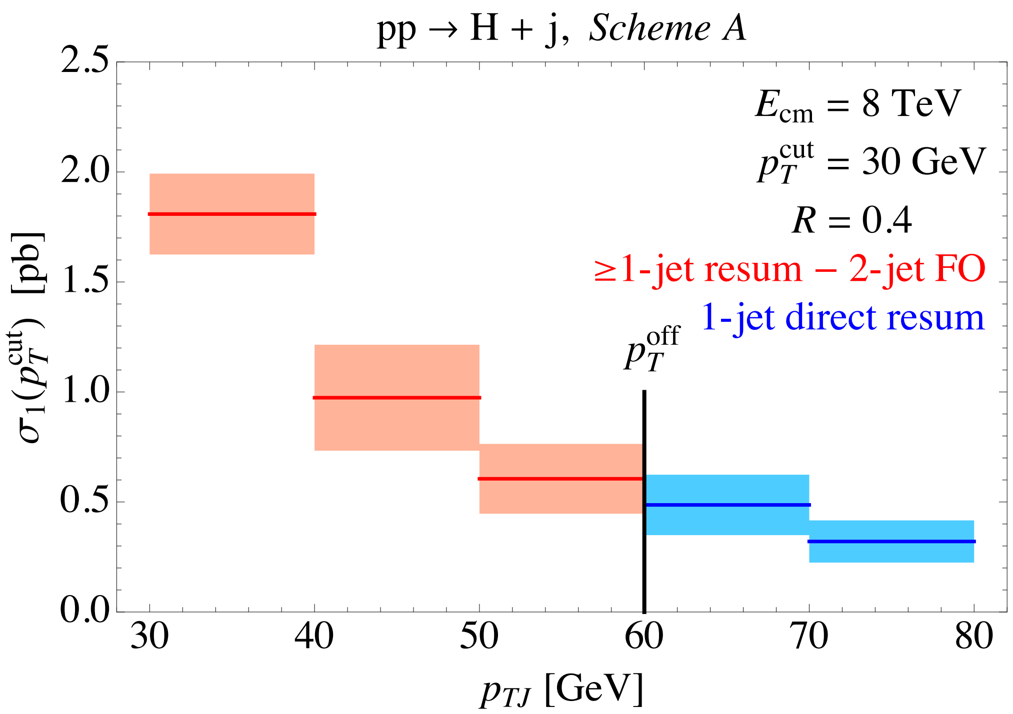


fixed order comparison

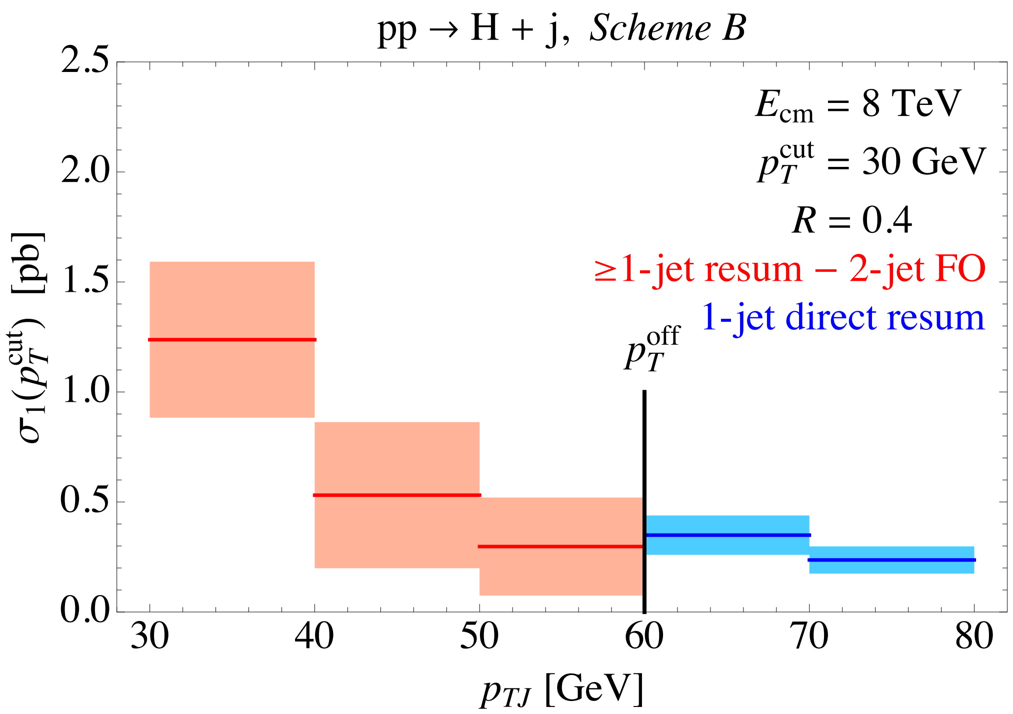
2-jet corrections are small (LO shown)

Testing the Matching

scheme A: π^2 resummation, H + 1j NNLO virtuals



scheme B: no π^2 resummation, H + 1j @ NLO



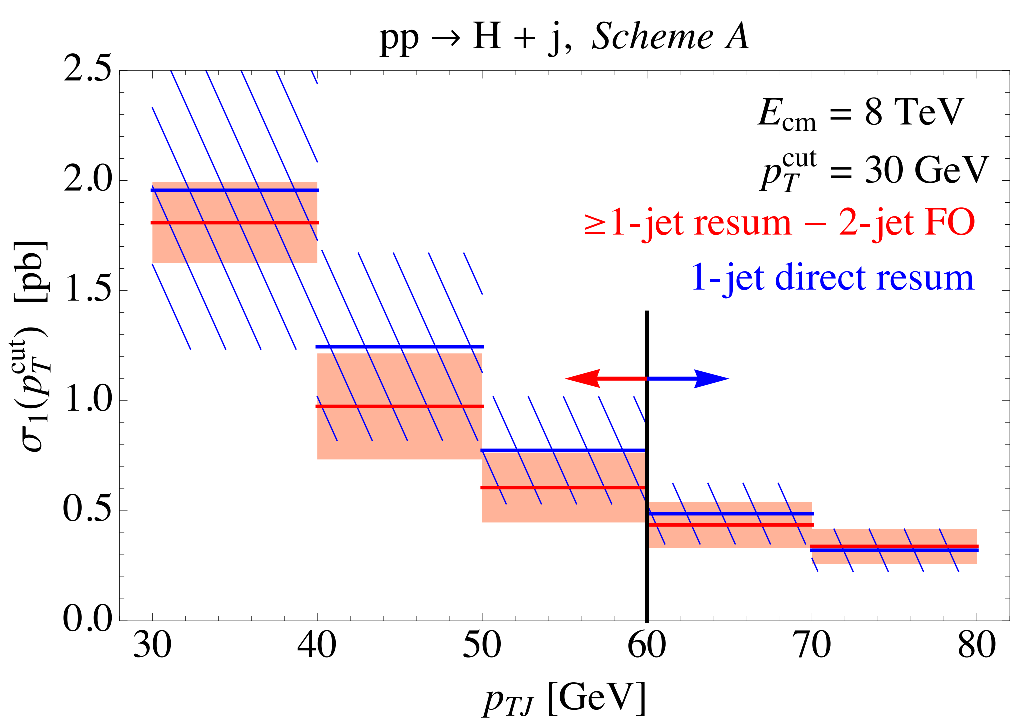
Matching of the "direct" and "indirect" approaches is smooth across p_T^{cut}

scheme A shows significantly reduced uncertainties

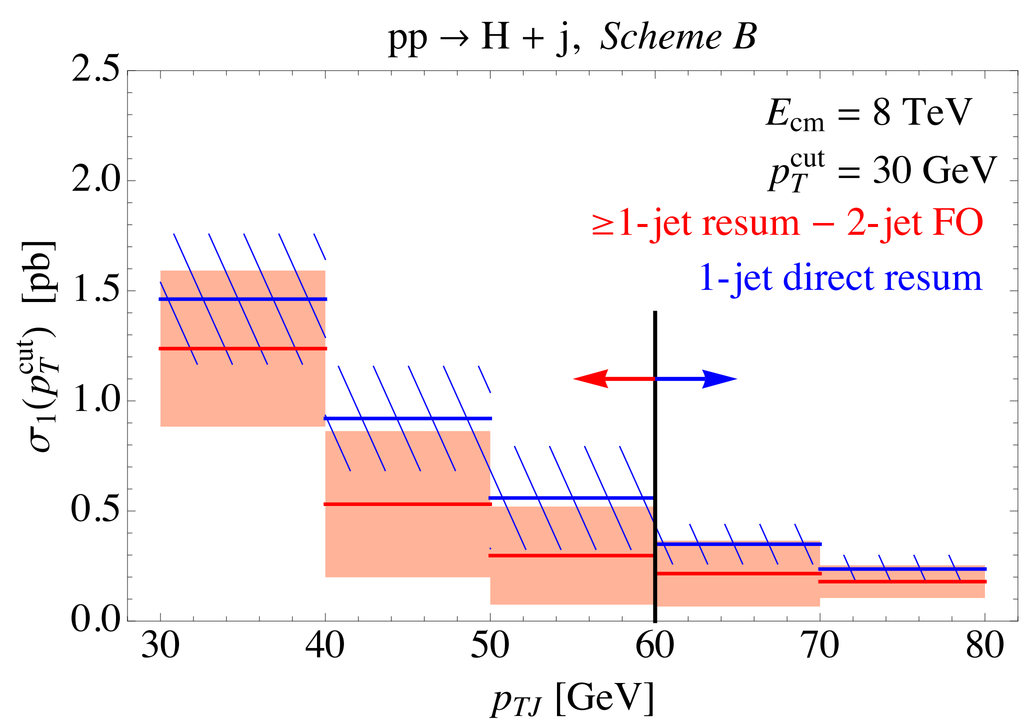
π^2 resummation ⇔ H + 1j NNLO virtuals

Testing the Matching

scheme A: π^2 resummation, H + 1j NNLO virtuals



scheme B: no π^2 resummation, H + 1j @ NLO

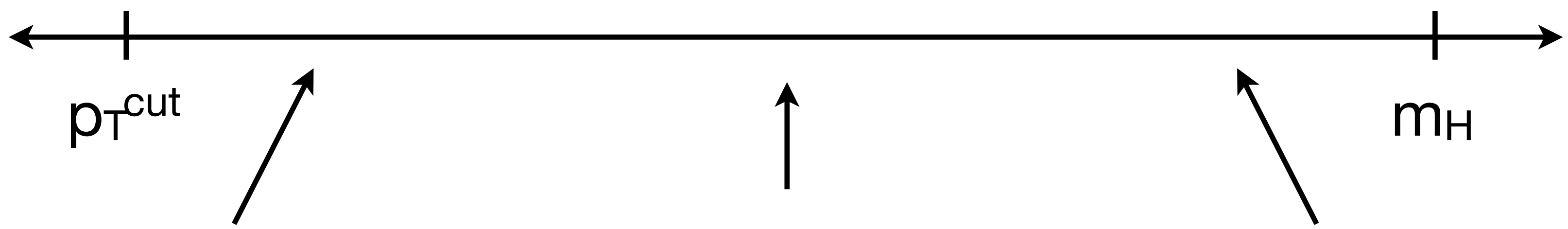


Matching of the “direct” and “indirect” approaches is smooth across p_T^{cut}

scheme A shows significantly reduced uncertainties

π^2 resummation ⇔ H + 1j NNLO virtuals

Testing the Matching

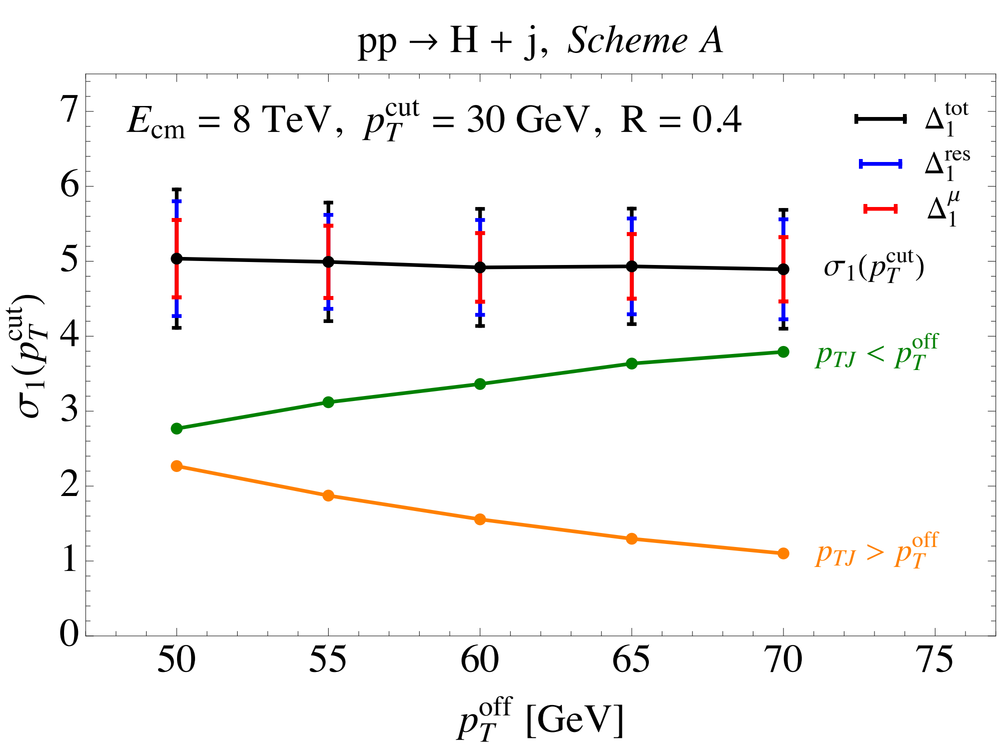


small p_T^{off} :
direct approach increases,
but larger FO contributions

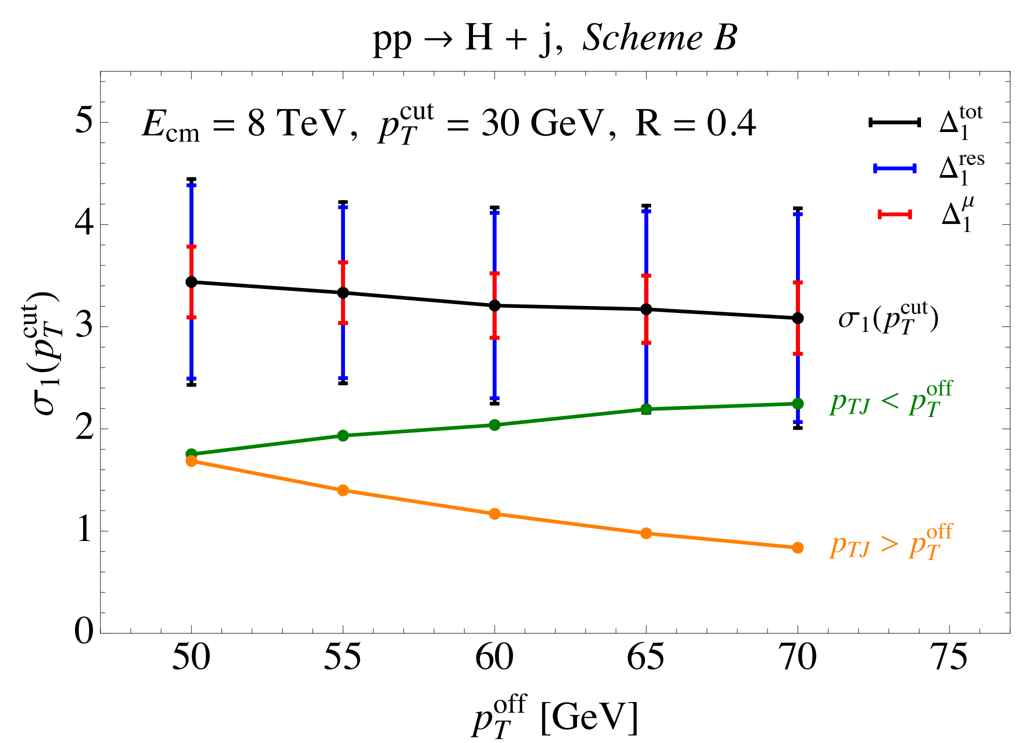
intermediate p_T^{off} :
using each resummed
prediction where it is reliable

large p_T^{off} :
indirect approach increases,
but larger FO contributions

scheme A: π^2 resummation, H + 1j NNLO virtuals

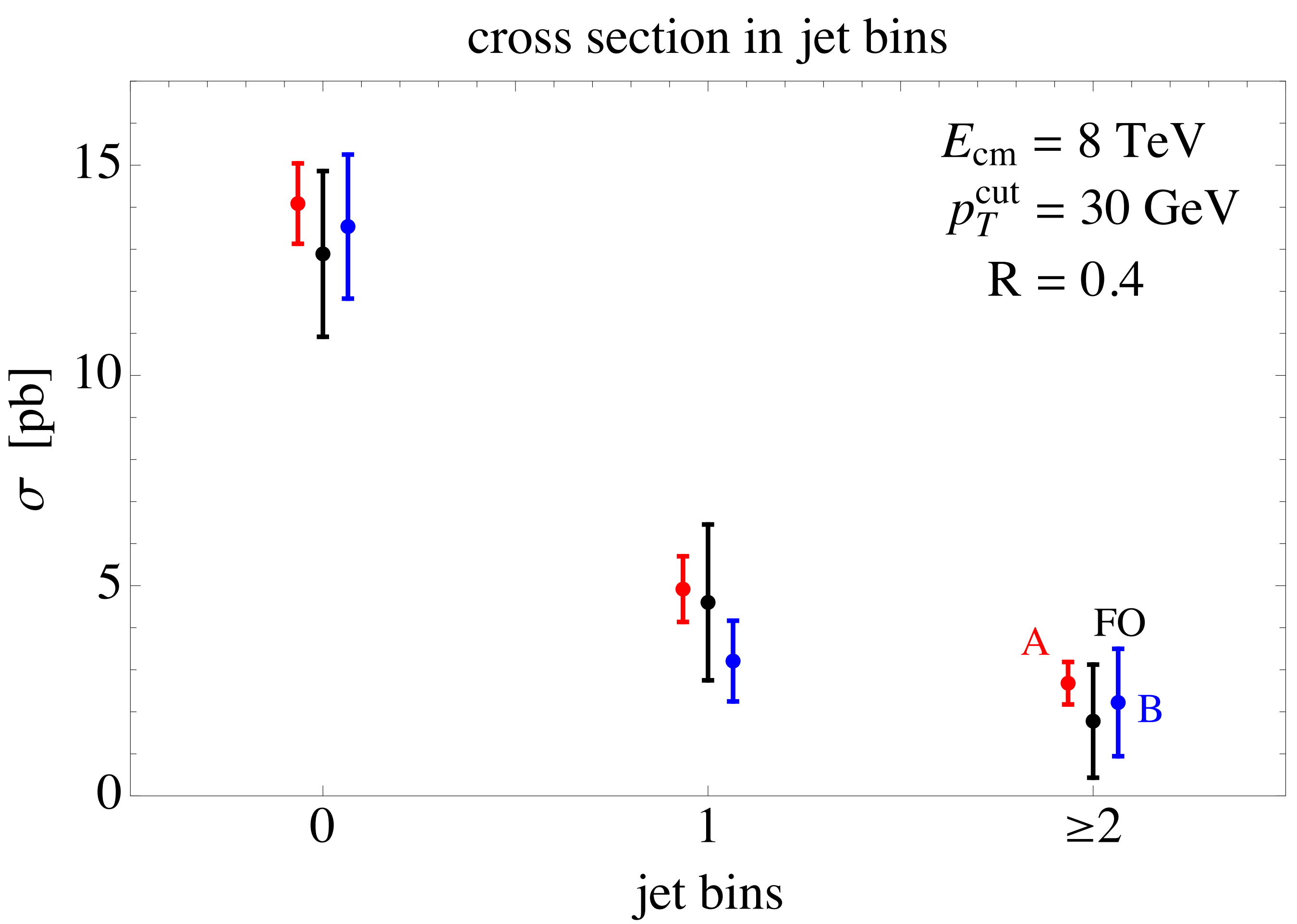


scheme B: no π^2 resummation, H + 1j @ NLO



Matching scale (p_T^{off}) dependence is small

Jet Bin Cross Sections



bin-by-bin uncertainties reduced
by a factor of 2 over FO

cross section in the WW analysis

$$\sigma_{WW} = \epsilon_0^{\rm acc}\sigma_0 + \epsilon_1^{\rm acc}\sigma_1 + \epsilon_{\geq 2}^{\rm acc}\sigma_{\geq 2}$$

acceptances from analysis cuts
(jet bin cuts, leptonic cuts,
reconstruction efficiencies)

need to determine
the theoretical uncertainty
on this cross section

Covariance Matrices

general form of the covariance matrix

$$C = \begin{pmatrix} C_{00} & C_{01} & C_{0\geq 2} \\ C_{01} & C_{11} & C_{1\geq 2} \\ C_{0\geq 2} & C_{1\geq 2} & C_{\geq 2\geq 2} \end{pmatrix}$$

basis of
0, 1, ≥2 jet
cross sections

need a way to parameterize physical sources of uncertainty

Covariance Matrices

general form of the covariance matrix

$$C = \begin{pmatrix} C_{00} & C_{01} & C_{0\geq 2} \\ C_{01} & C_{11} & C_{1\geq 2} \\ C_{0\geq 2} & C_{1\geq 2} & C_{\geq 2\geq 2} \end{pmatrix}$$

basis of 0, 1, ≥2 jet cross sections

need a way to parameterize physical sources of uncertainty

fully correlated

$$C_{\rm y} = \vec{\Delta}_{\rm y} \vec{\Delta}_{\rm y}^T$$

yield uncertainty

anti-correlated 2x2 blocks

$$C_{\rm cut} = \sum_{i,j} \begin{pmatrix} \Delta^2_{ij\,\rm cut} & -\Delta^2_{ij\,\rm cut} \\ -\Delta^2_{ij\,\rm cut} & \Delta^2_{ij\,\rm cut} \end{pmatrix}_{ij}$$

bin migration uncertainty

$$C = C_{\rm y} + C_{\rm cut}$$

this decomposition is completely generic (no built-in assumptions)

and

can be associated with physical sources of uncertainty

Combining Jet Bins

Signal strength: $\mu = \frac{\sigma_{\text{obs}}}{\sigma_{\text{exp}}}$

$$\sigma_{\text{exp}} = \epsilon_0^{\text{exp}} \sigma_0^{\text{exp}} + \epsilon_1^{\text{exp}} \sigma_1^{\text{exp}} + \epsilon_{\geq 2}^{\text{exp}} \sigma_{\geq 2}^{\text{exp}}$$

2-jet term negligible for gg → H → WW

ATLAS measurement of signal strength in H > WW :

$$\begin{aligned} \mu_{\text{obs, 8 TeV}} &= 1.26 \pm 0.24\,(\text{stat.}) \pm 0.21\,(\text{theo. syst.}) \pm 0.14\,(\text{expt. syst.}) \pm 0.06\,(\text{lumi.}) \\ &= 1.26 \pm 0.35. \end{aligned}$$

ATLAS-CONF-2013-030

Combining Jet Bins

Signal strength: $\mu = \frac{\sigma_{\text{obs}}}{\sigma_{\text{exp}}}$

$$\sigma_{\text{exp}} = \epsilon_0^{\text{exp}}\sigma_0^{\text{exp}} + \epsilon_1^{\text{exp}}\sigma_1^{\text{exp}} + \epsilon_{\geq 2}^{\text{exp}}\sigma_{\geq 2}^{\text{exp}}$$

2-jet term negligible for gg → H → WW

$$\frac{\Delta^{\text{th, y}}\mu}{\mu} = \frac{\Delta^{\text{th, y}}\sigma_{\text{exp}}}{\sigma_{\text{exp}}}$$

$$\Delta\sigma_{\text{exp}} = \left[(\epsilon_0^{\text{exp}})^2\Delta_0^2 + (\epsilon_1^{\text{exp}})^2\Delta_1^2 + 2\epsilon_0^{\text{exp}}\epsilon_1^{\text{exp}}\text{cov}(0,1)\right]^{1/2}$$

need to know the correlation between 0-jet, 1-jet bins

Table 13: Leading uncertainties on the signal strength μ for the combined 7 and 8 TeV analysis.

Category	Source	Uncertainty, up (%)	Uncertainty, down (%)
Statistical	Observed data	+21	−21
Theoretical	Signal yield ($\sigma \cdot \mathcal{B}$)	+12	−9
Theoretical	WW normalisation	+12	−12
Experimental	Objects and DY estimation	+9	−8
Theoretical	Signal acceptance	+9	−7
Experimental	MC statistics	+7	−7
Experimental	W+ jets fake factor	+5	−5
Theoretical	Backgrounds, excluding WW	+5	−4
Luminosity	Integrated luminosity	+4	−4
Total		+32	−29

ATLAS-CONF-2013-030

Uncertainties in the H → WW Signal Strength

$$\Delta\sigma_{\rm exp} = \left[(\epsilon_0^{\rm exp})^2\Delta_0^2 + (\epsilon_1^{\rm exp})^2\Delta_1^2 + 2\epsilon_0^{\rm exp}\epsilon_1^{\rm exp}{\rm cov}(0,1)\right]^{1/2}$$

covariance matrices for
ATLAS and CMS parameters:

$$C^{\rm ATLAS} = \begin{pmatrix} 1.49 & -0.39 & 0.20 \\ -0.39 & 0.88 & -0.04 \\ 0.20 & -0.04 & 0.32 \end{pmatrix} {\rm pb}^2$$

$$C^{\rm CMS} = \begin{pmatrix} 0.76 & 0.09 & 0.20 \\ 0.09 & 0.55 & 0.01 \\ 0.21 & 0.01 & 0.32 \end{pmatrix} {\rm pb}^2$$

signal yield uncertainty
on ATLAS signal strength

$$\Delta_{\rm FO}^{\rm th,\,y}\mu = 0.12$$

↓

$$\Delta_{\rm A}^{\rm th,\,y}\mu = 0.07$$

reduction by almost a factor of 2!

the signal yield uncertainty is no
longer a dominant systematic

Conclusions

- A new approach and prediction for the exclusive H+1-jet cross sections that has resummation across the entire phase space
  - Direct resummation of the exclusive 1-jet rate at high jet p_T, indirect resummation using the inclusive 1-jet rate at low jet p_T
- Combined exclusive 0-jet and 1-jet predictions can be used in Higgs analyses
  - Roughly halves uncertainty compared to fixed order, can be directly used in $H \to WW$ signal strength measurement
  - Experiments are evaluating how to best utilize resummed results
  - W/Z+jets an interesting testing ground - more data and more precise predictions can be made

Extra Slides