Ratios of Higgs Cross Sections at 14 TeV and 8 TeV

Jonathan Walsh, UC Berkeley

work with Iain Stewart, Frank Tackmann, and Saba Zuberi - 1307.1808

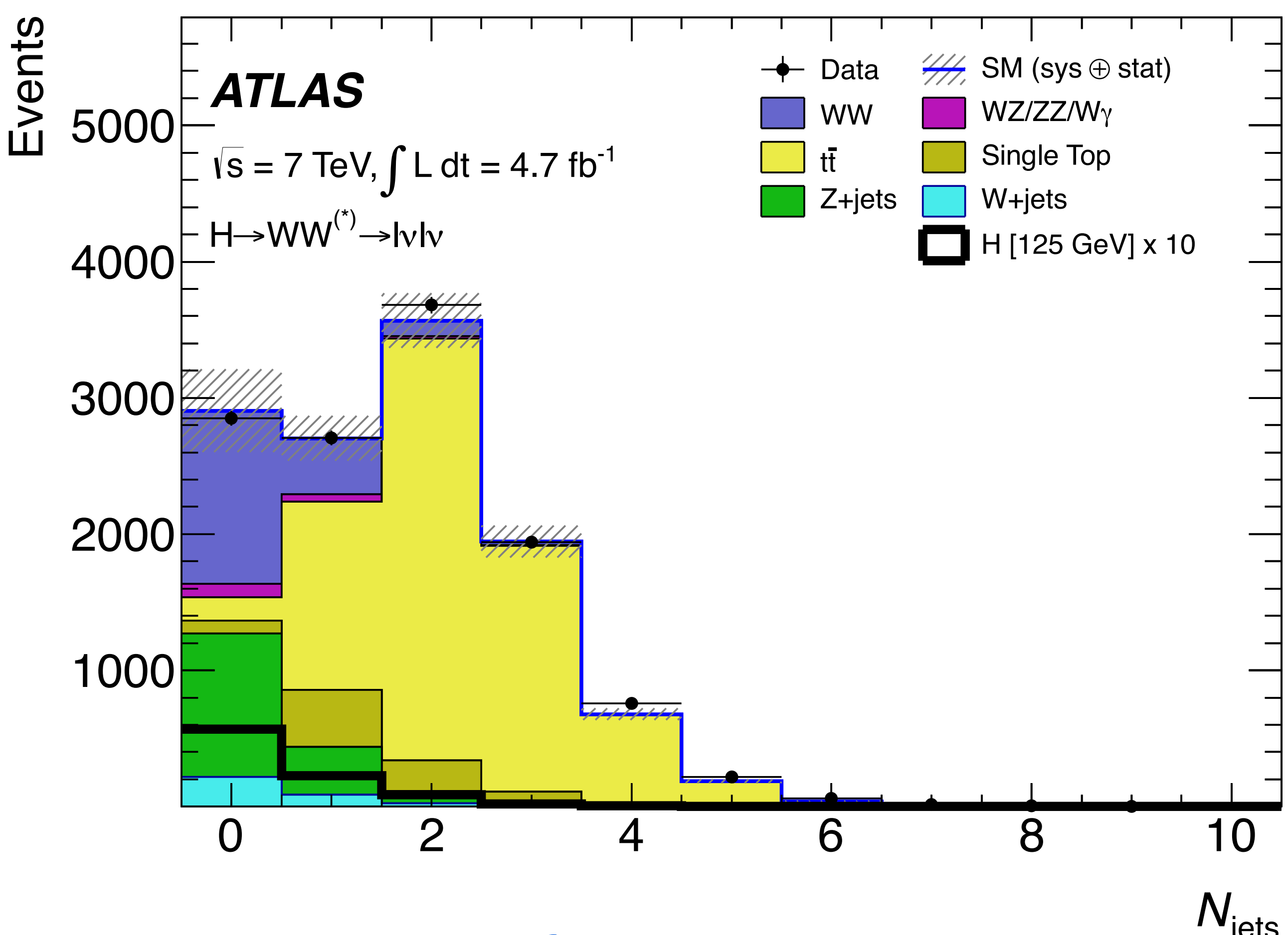
with many thanks to Frank Tackmann for providing runs for this talk

BERKELEY LAB

THE UNIVERSITY OF CALIFORNIA 1868 LET THERE BE LIGHT

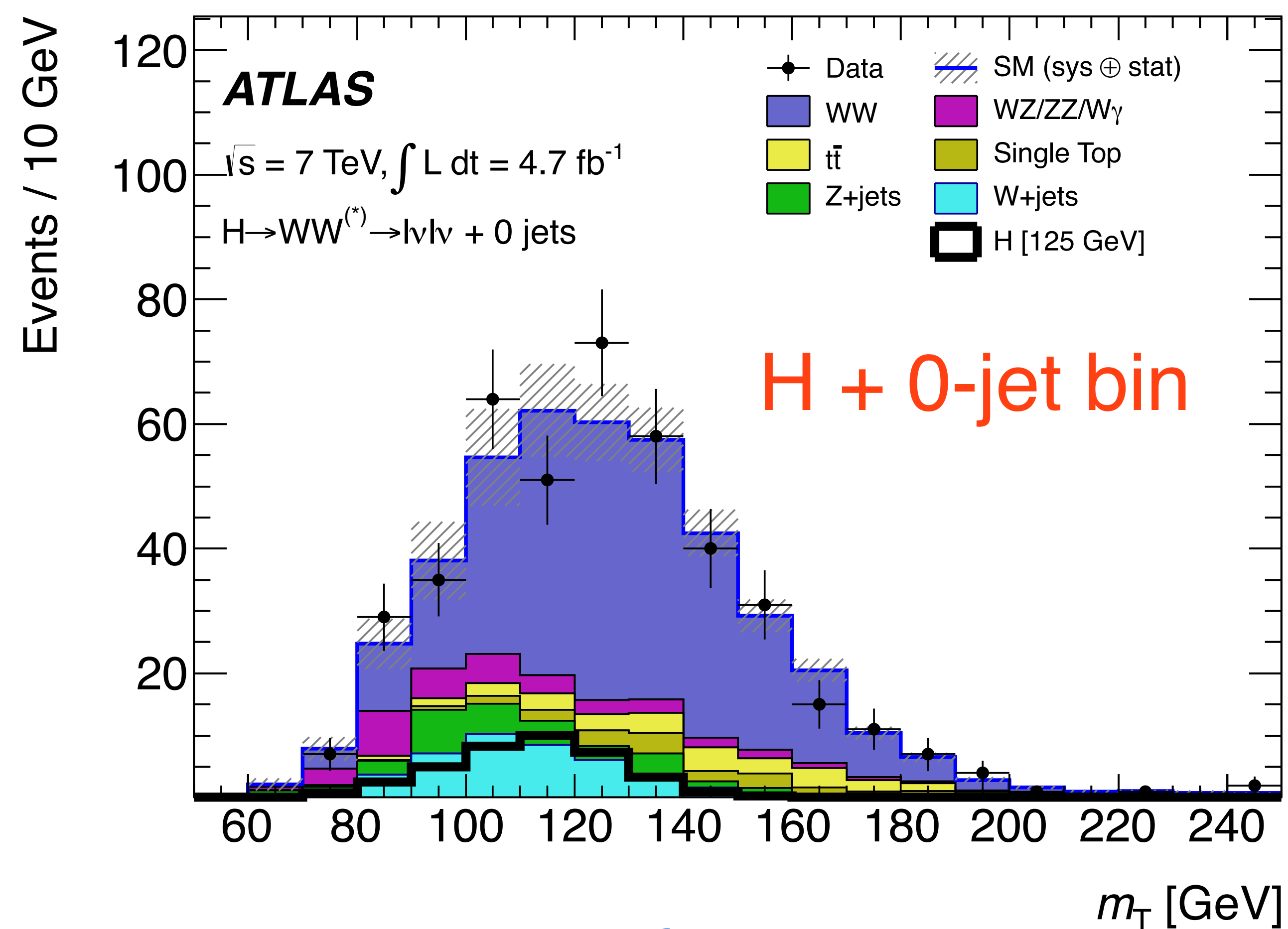
Demands for Precision QCD in Higgs Cross Sections

$H \to WW \to 2l + 2\nu$



before cuts

No mass peak in this channel



after cuts

"The systematic uncertainties that have the largest impact on the sensitivity of the search are the theoretical uncertainties associated with the signal."

from ATLAS, 1206.0756

Demands for Precision QCD in Higgs Cross Sections

Leading systematic uncertainties

Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
PDF model (signal only)	8	-
QCD scale (acceptance)	4	-
Jet energy scale and resolution	4	2
W+jets fake factor	-	5
WW theoretical model	-	5
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	26	-
2-jet incl. ggF signal ren./fact. scale	15	-
Parton shower/ U.E. model (signal only)	10	-
b-tagging efficiency	-	11
PDF model (signal only)	7	-
QCD scale (acceptance)	4	2
Jet energy scale and resolution	1	3
W+jets fake factor	-	5
WW theoretical model	-	3

ATLAS-CONF-2012-158

dominant contribution:
perturbative QCD
scale uncertainties

$$\delta\sigma_{0\,\mathrm{jet}} = 16.5\%$$

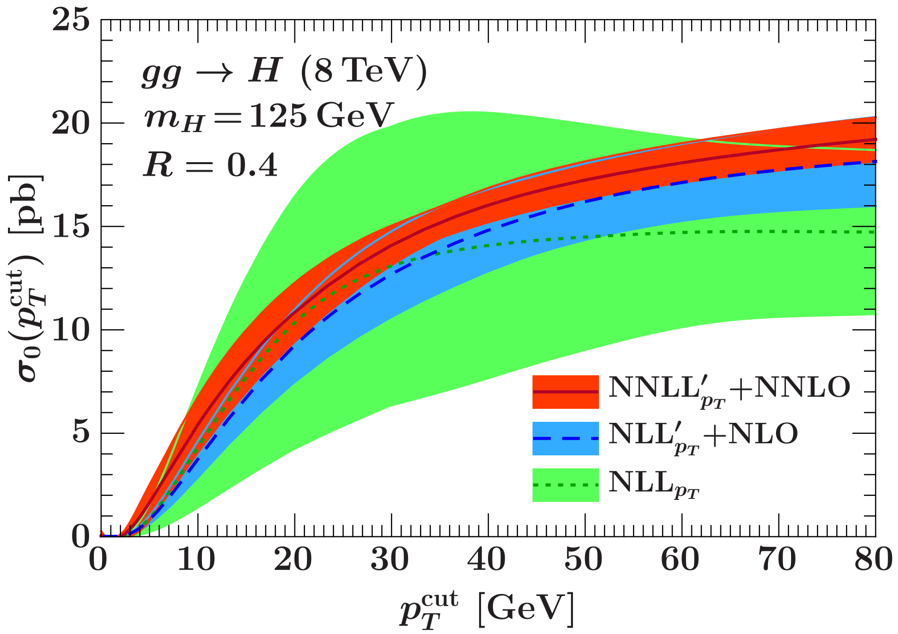
$$\delta\sigma_{1\,\mathrm{jet}} = 30\%$$

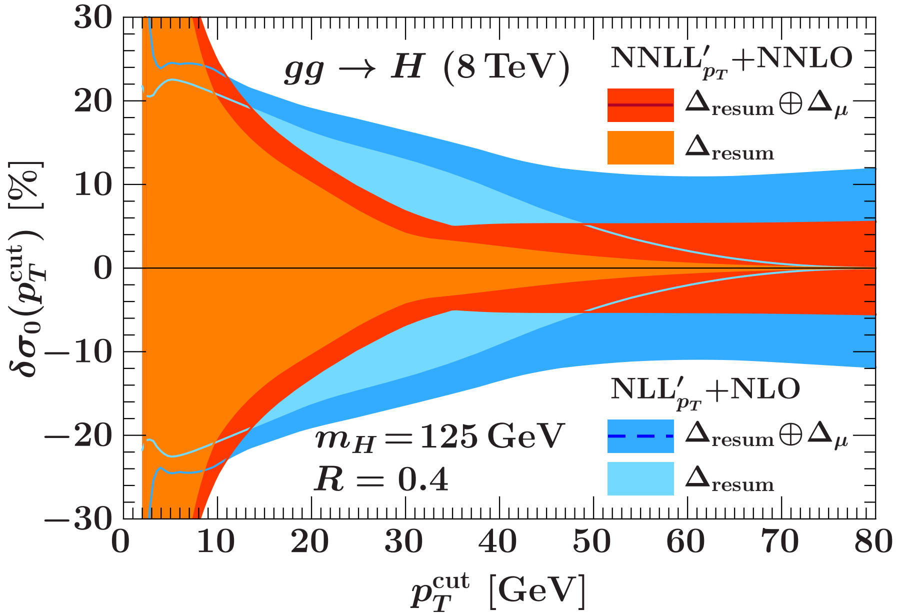
"The systematic uncertainties that have the largest impact on the sensitivity of the search are the theoretical uncertainties associated with the signal."

from ATLAS, 1206.0756

Overview of the H + 0-jet Calculation

$\sigma_0(p_T^{\text{cut}})$





Make a prediction for the resummed+matched (NNLL' + NNLO) H + 0-jet cross section:

Use a factorization theorem for the cross section:

- Global/local veto bootstrap *in each function*
- New calculations in SCET

Focus on uncertainty estimates on the result:

- Makes the prediction robust
- Many scales, sources of uncertainty

Jet algorithm clustering effects are theoretically interesting, phenomenologically important

H + 0-jet Cross Section

$$\sigma(p_T^{\rm cut}) \sim H_{gg}(\mu)\left[B_a(p_T^{\rm cut},\mu,\nu) \times B_b(p_T^{\rm cut},\mu,\nu) \times S(p_T^{\rm cut},\mu,\nu)\right] + \sigma_{ns}(\mu)$$

virtuals known to NNLO
can add m_b, EW corrections
(sum largely cancels)

$$B_a = B_a^G + \Delta B_a^{\rm clus}$$

Logarithms known to NNLO through RGE
Finite log(R) dependence calculated by us
(finite means $p_T^{\rm cut}$ independent)
Remaining finite terms fit via MCFM

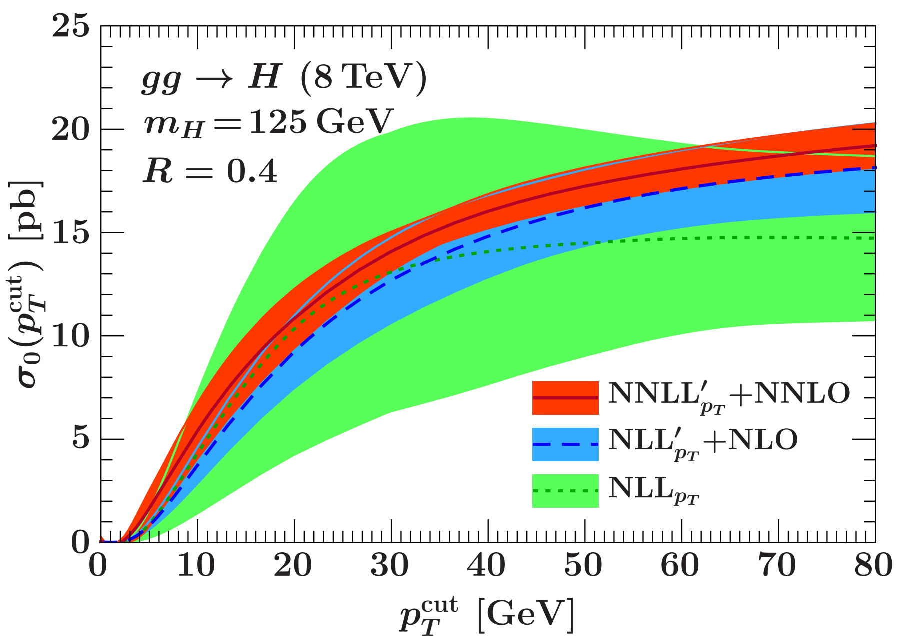
$$S = S^G + \Delta S^{\rm clus}$$

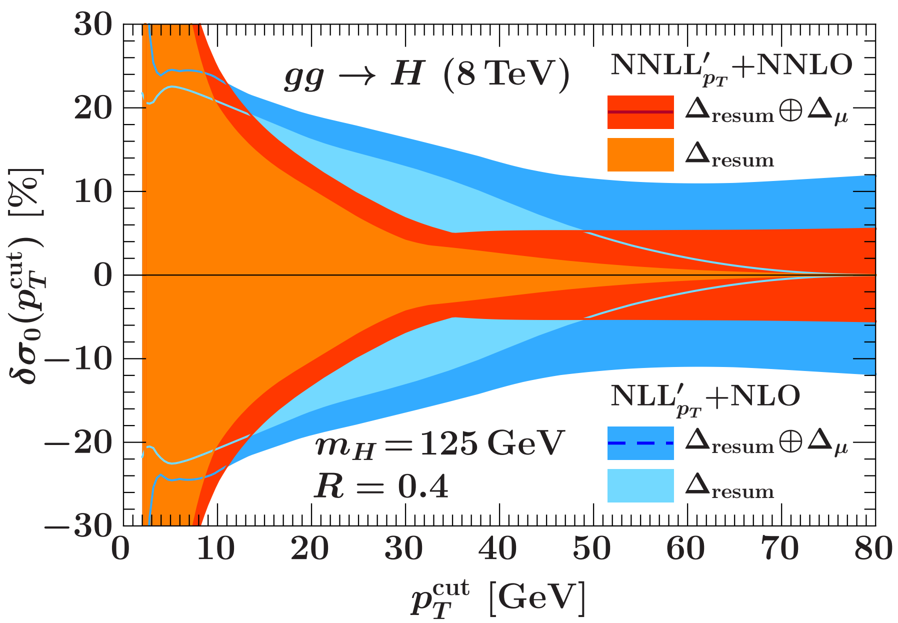
Fully calculated to NNLO
(allows for precision predictions for E_T)

Fit to NNLO from MCFM
fit for several R values
for the MSTW PDFs
would like to vary m_H, PDFs

H + 0-jet Results

0-jet cross section
resummed convergence





rates with uncertainties:

R = 0.4:

$$p_T^{cut} = 25 \text{ GeV} : \sigma_0 = 12.67 \pm 1.22 (9.6\%)$$
$$p_T^{cut} = 30 \text{ GeV} : \sigma_0 = 14.09 \pm 0.96 (6.8\%)$$

R = 0.5:

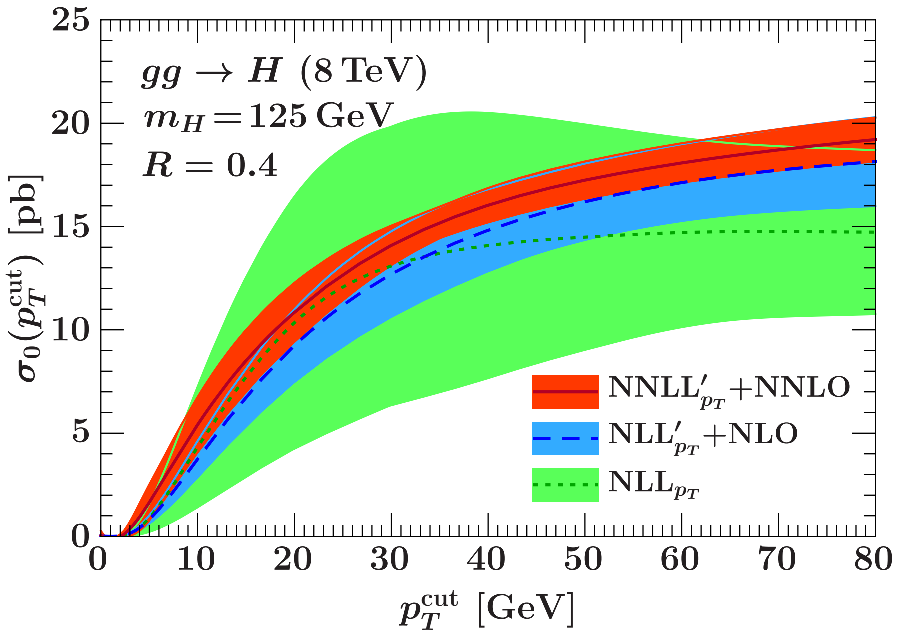
$$p_T^{cut} = 25 \text{ GeV} : \sigma_0 = 12.40 \pm 1.12 (9.0\%)$$
$$p_T^{cut} = 30 \text{ GeV} : \sigma_0 = 13.85 \pm 0.87 (6.3\%)$$

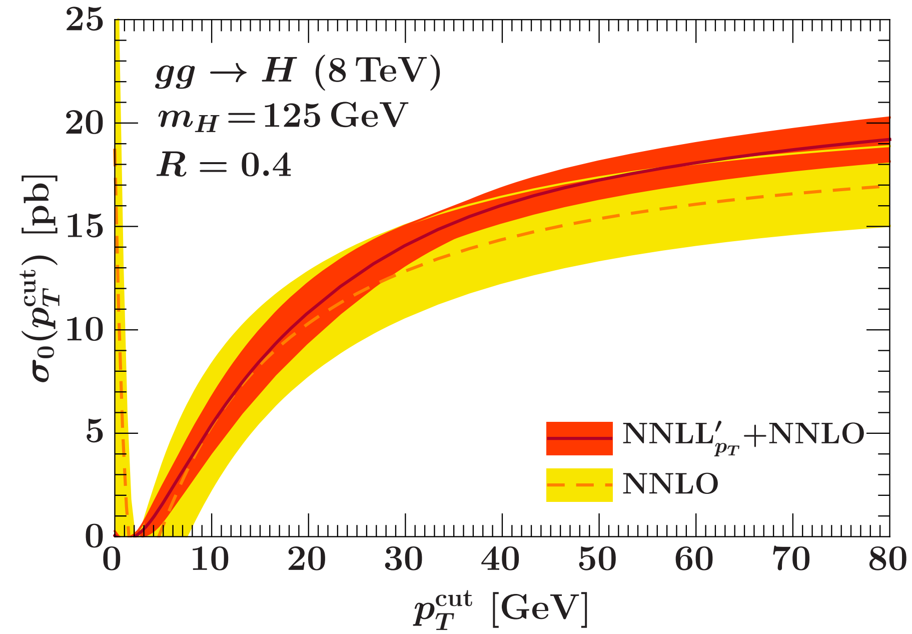
compare to 17%!

H + 0-jet Results

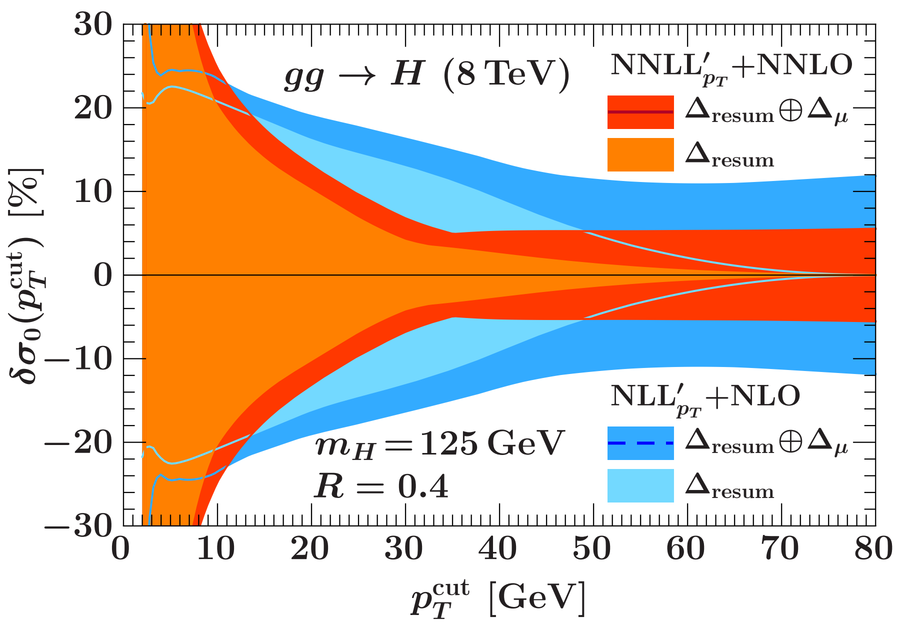
0-jet cross section resummed convergence

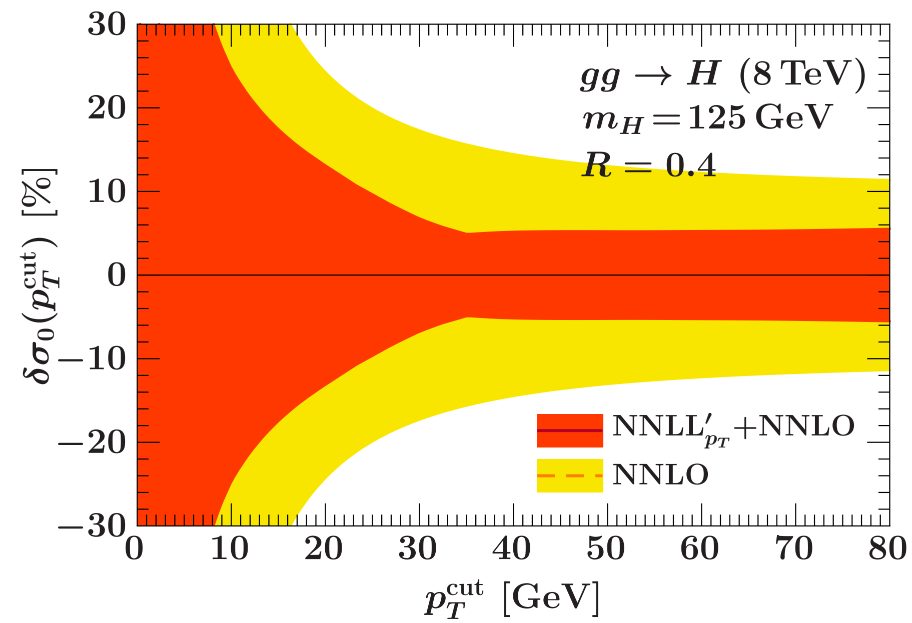
0-jet cross section compared to fixed order





cross sections





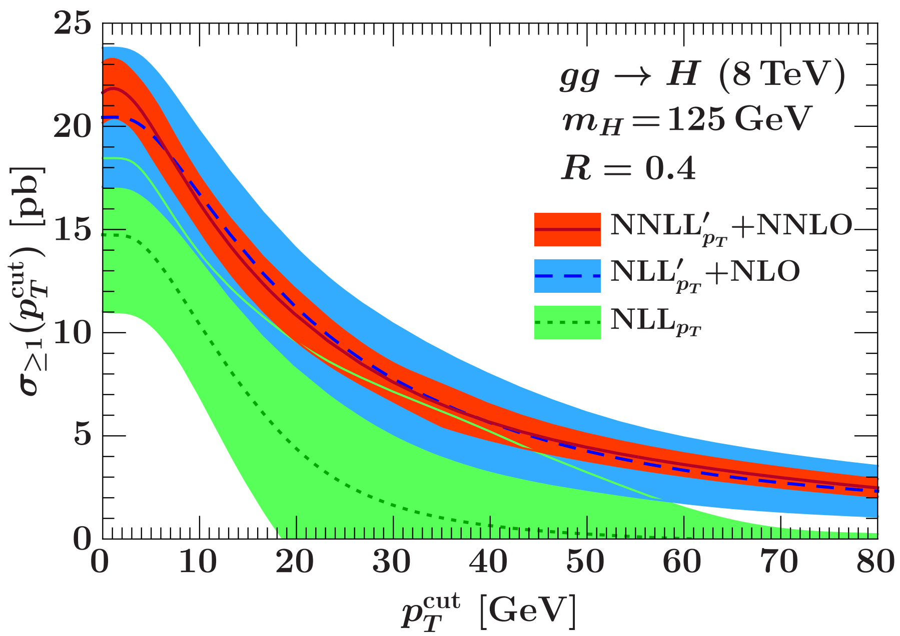
uncertainties

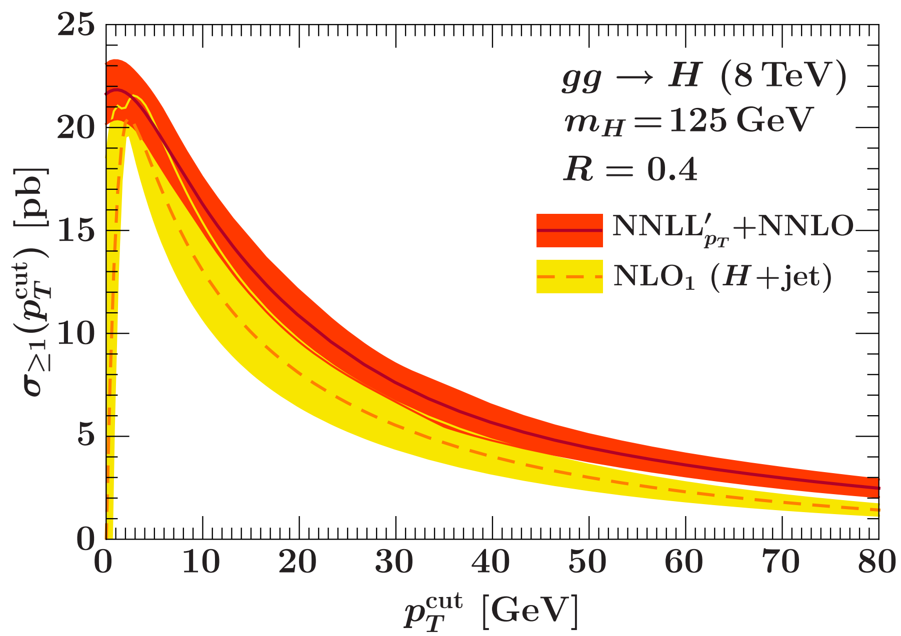
Inclusive 1-jet Cross Section, 0-jet Efficiency

resummed convergence

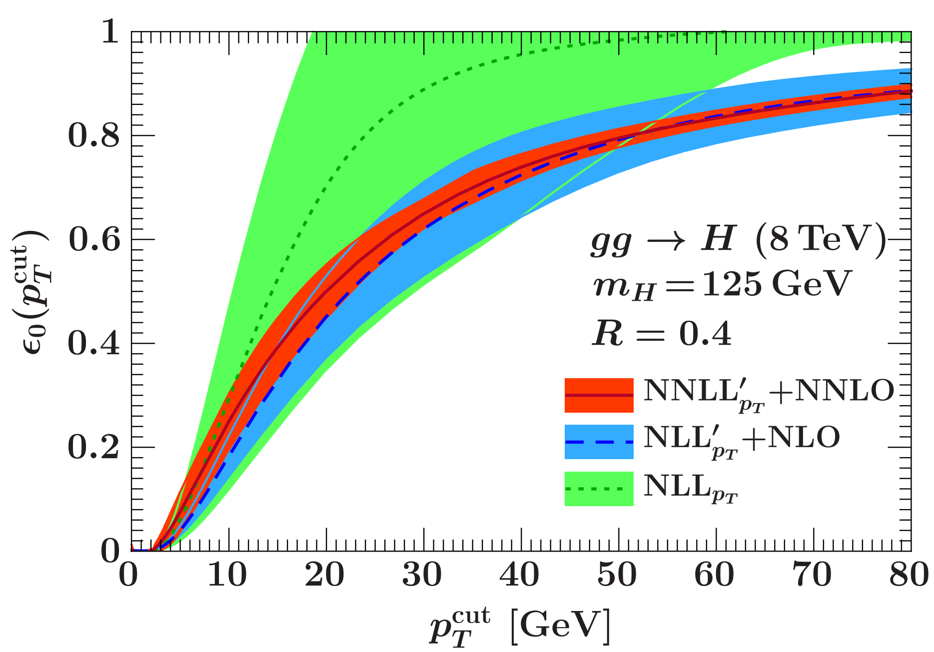
resummed vs. fixed order

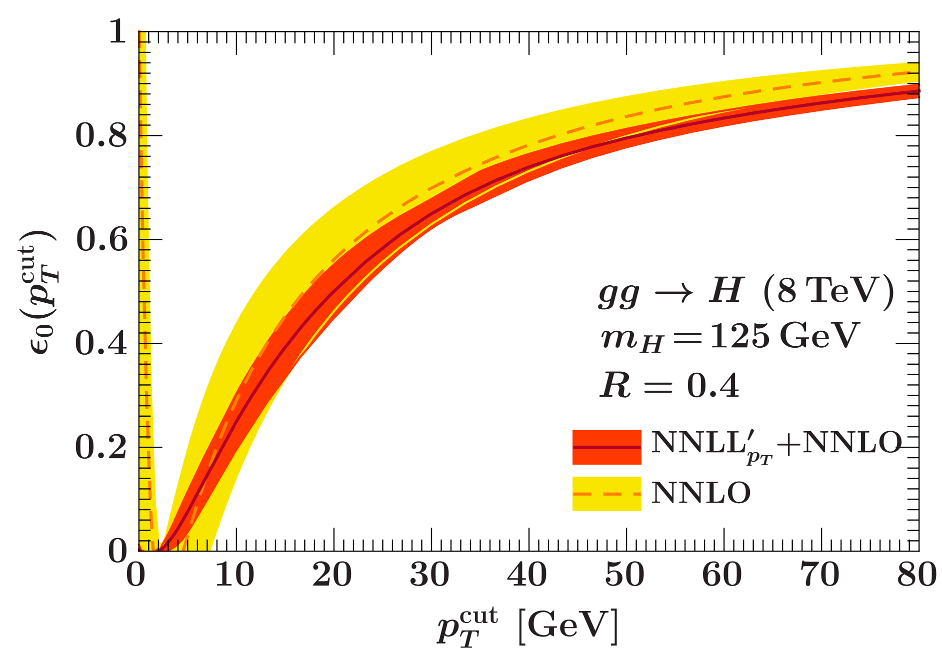
inclusive 1-jet cross section





0-jet efficiency





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, Walsh, Zuberi - 1206.4312, 1307.1808

H + 1 jet

- Liu, Petriello - 1210.1906, 1303.4405
- Liu, Petriello, Tackmann, Walsh (H + 0/1-jet combination) - ongoing

H + 2 jets

- Gangal, Tackmann (fixed order uncertainties) - 1302.5437

VH + 0 jets

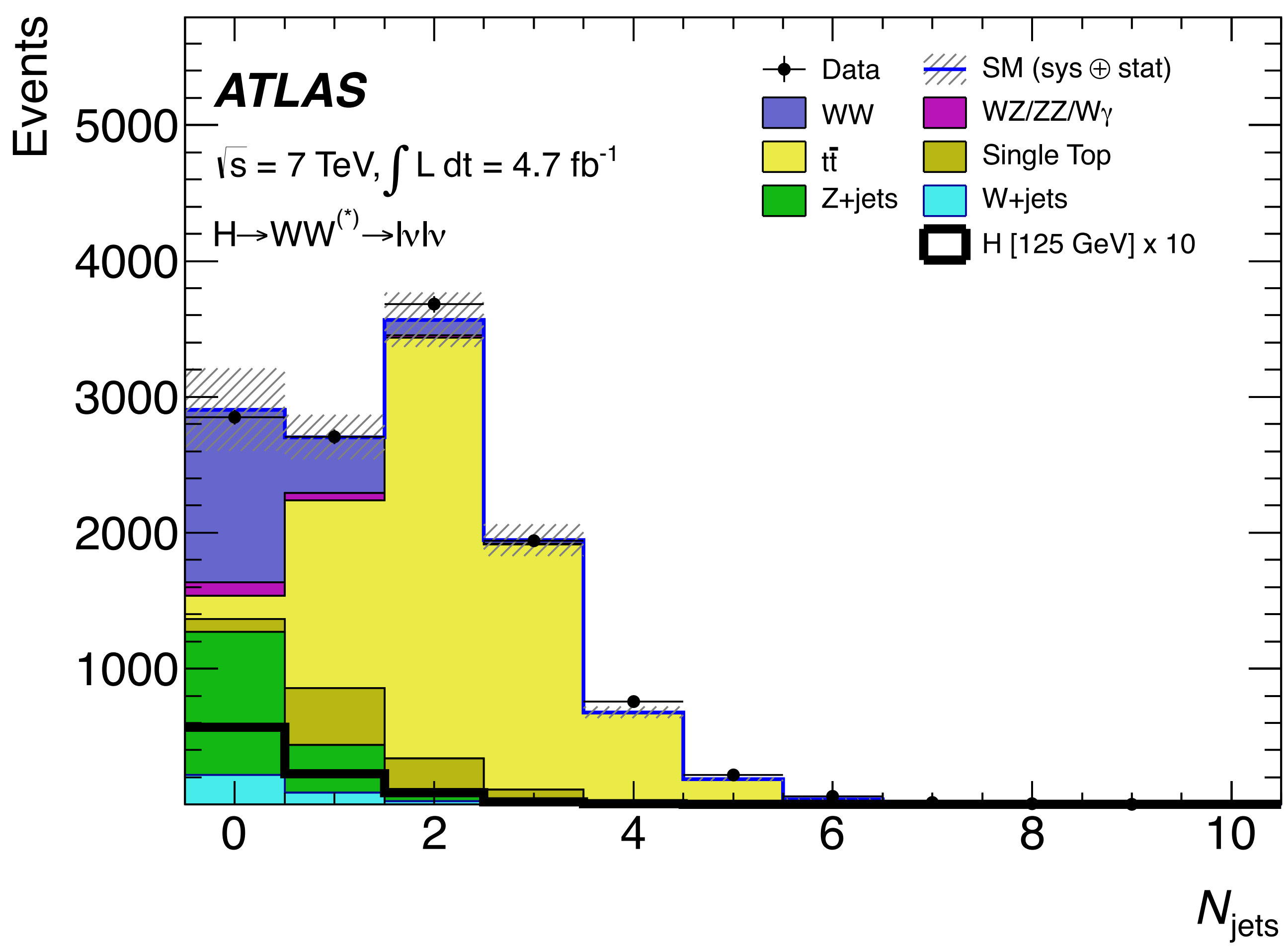
- Li, Li, Shao - 1309.5015

clustering effects

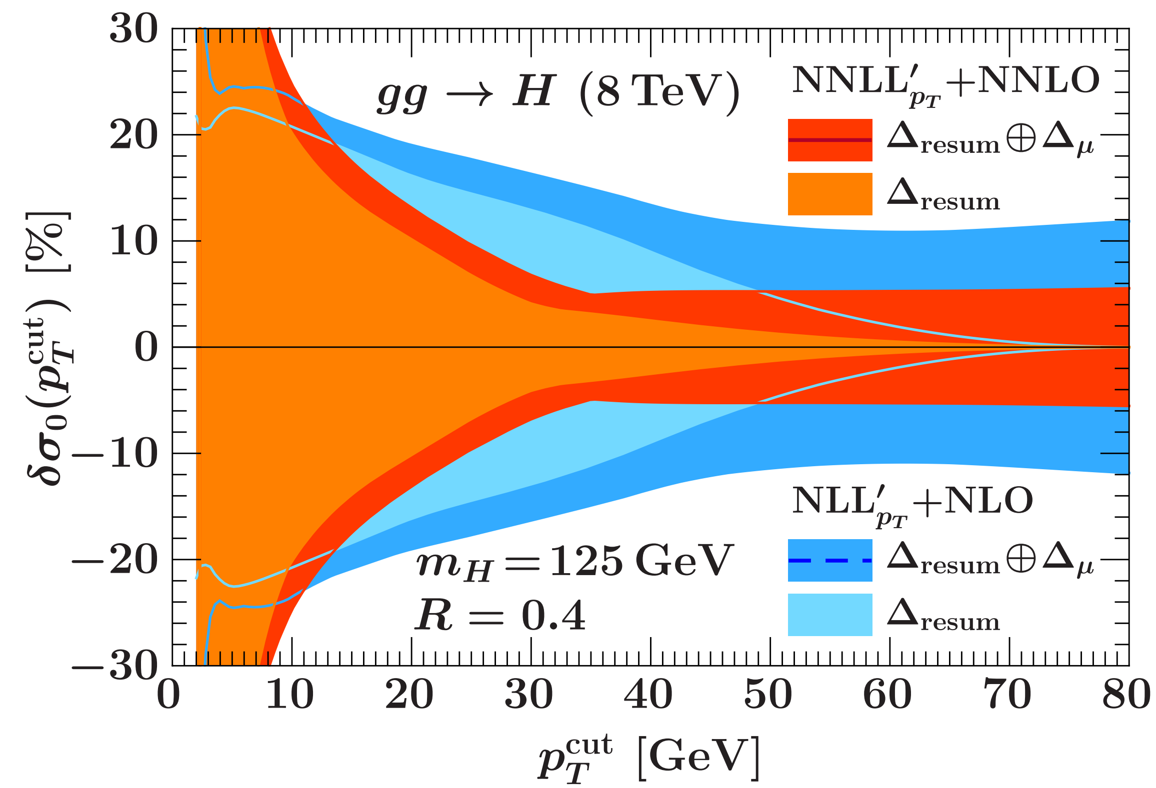
- Alioli, Walsh - ongoing

Jet Veto Thresholds

H→WW→2l+2ν



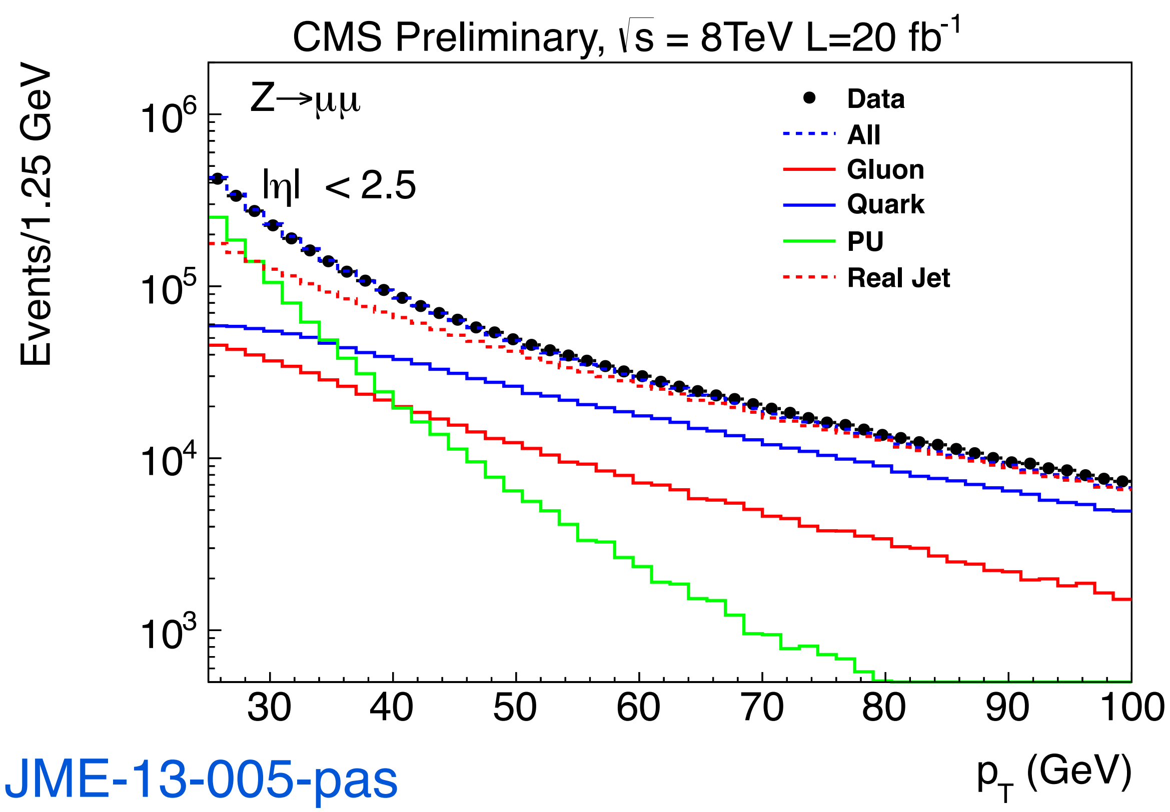
yikes! ←



thresholds governed by two considerations:

poorly measured jets at low p_T < p_T cut < poor background discrimination

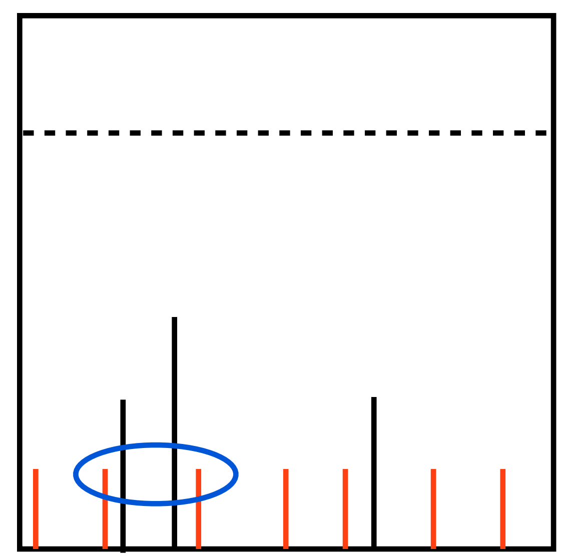
Jet Veto Thresholds



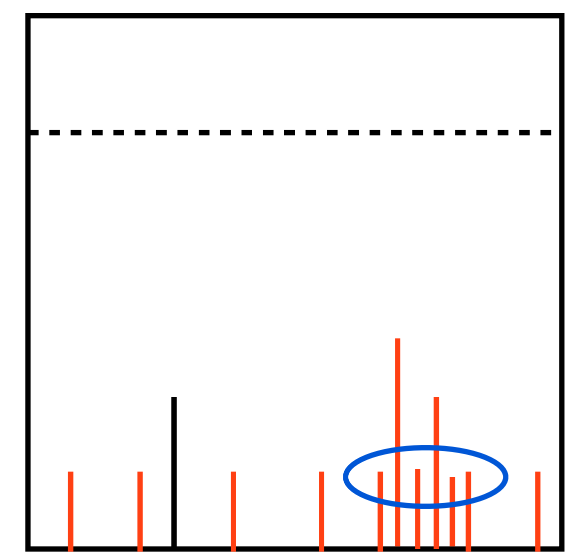
JME-13-005-pas

pileup corrections essential for
precision measurements
in vetoed rates

two types of pileup effects on jet bins



threshold effect



pileup jets

thresholds governed by two considerations:

poorly measured jets at low p_T < p_T cut < poor background discrimination

Bin Migration Effects from Pileup: Uncertainties

covariance matrices
resummed and fixed order parts

$$C\big(\{\sigma_{\geq 0}, \sigma_0, \sigma_{\geq 1}\}\big) = C_\mu + C_{\rm resum}\,,$$

$$C_\mu = \begin{pmatrix} \Delta_{\rm tot}^2 & \Delta_{\rm tot}\Delta_{\mu 0} & \Delta_{\rm tot}\Delta_{\mu\geq 1} \\ \Delta_{\rm tot}\Delta_{\mu 0} & \Delta_{\mu 0}^2 & \Delta_{\mu 0}\Delta_{\mu\geq 1} \\ \Delta_{\rm tot}\Delta_{\mu\geq 1} & \Delta_{\mu 0}\Delta_{\mu\geq 1} & \Delta_{\mu\geq 1}^2 \end{pmatrix},$$

$$C_{\rm resum} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta_{\rm resum}^2 & -\Delta_{\rm resum}^2 \\ 0 & -\Delta_{\rm resum}^2 & \Delta_{\rm resum}^2 \end{pmatrix},$$

allows for control over
correlations between jet bins

pileup corrections are:

1. purely uncorrelated
2. anti-correlated between jet bins

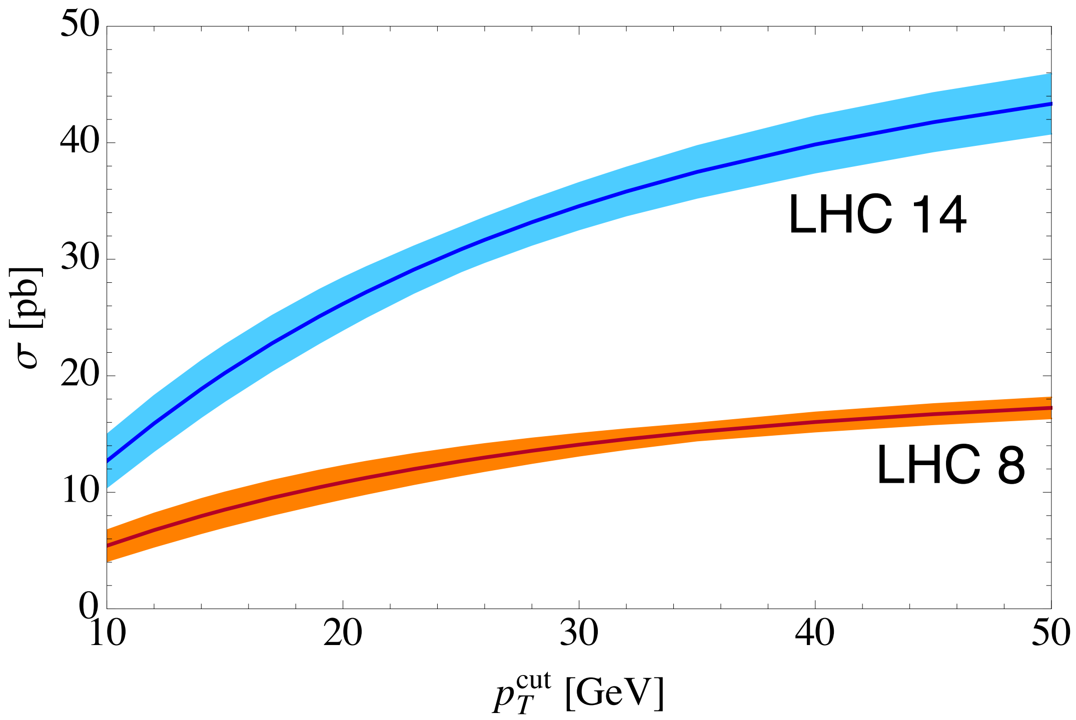
$$C_{\rm pileup}(\sigma_0, \sigma_{\geq 1}) = \begin{pmatrix} \Delta_{\rm pu}^2 & -\Delta_{\rm pu}^2 \\ -\Delta_{\rm pu}^2 & \Delta_{\rm pu}^2 \end{pmatrix}$$

threshold and pileup jet effects have
separate kinematic dependence, e.g.:
on veto scale, steepness of 0-jet rate

would be interesting to see the size of
these terms at LHC8, LHC14, hi lumi LHC
can be estimated from MC (for theorists)

Ratios of Cross Sections

NNLL’ + NNLO for different E_{cm}

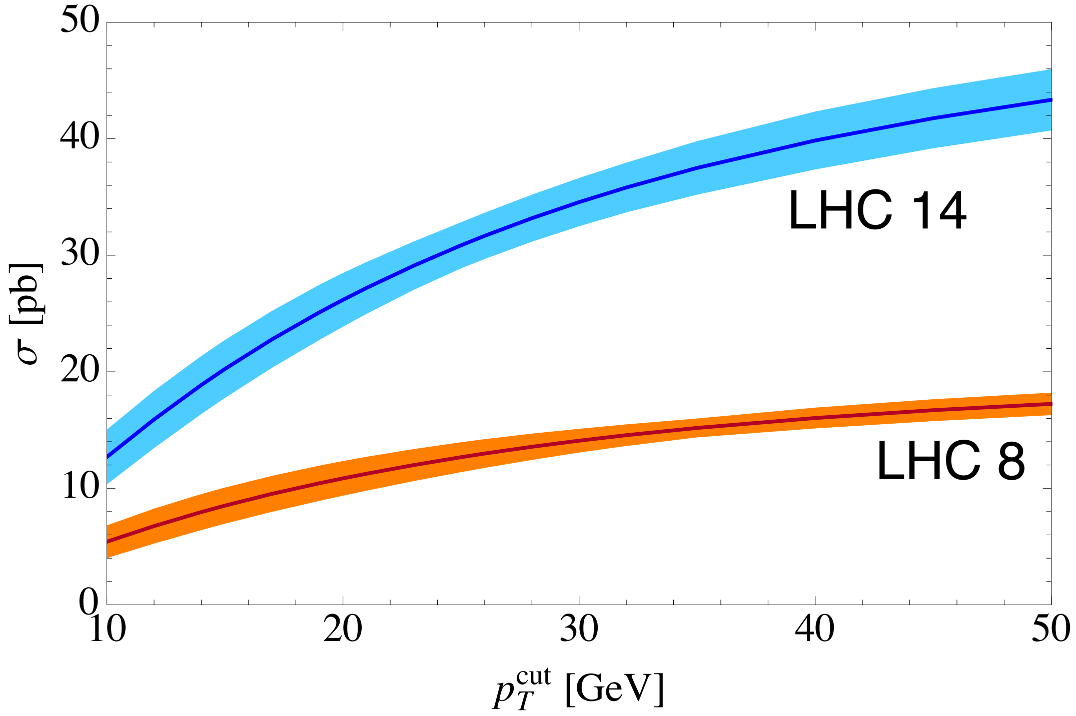


Can we probe veto threshold effects more sensitively with ratios of rates?

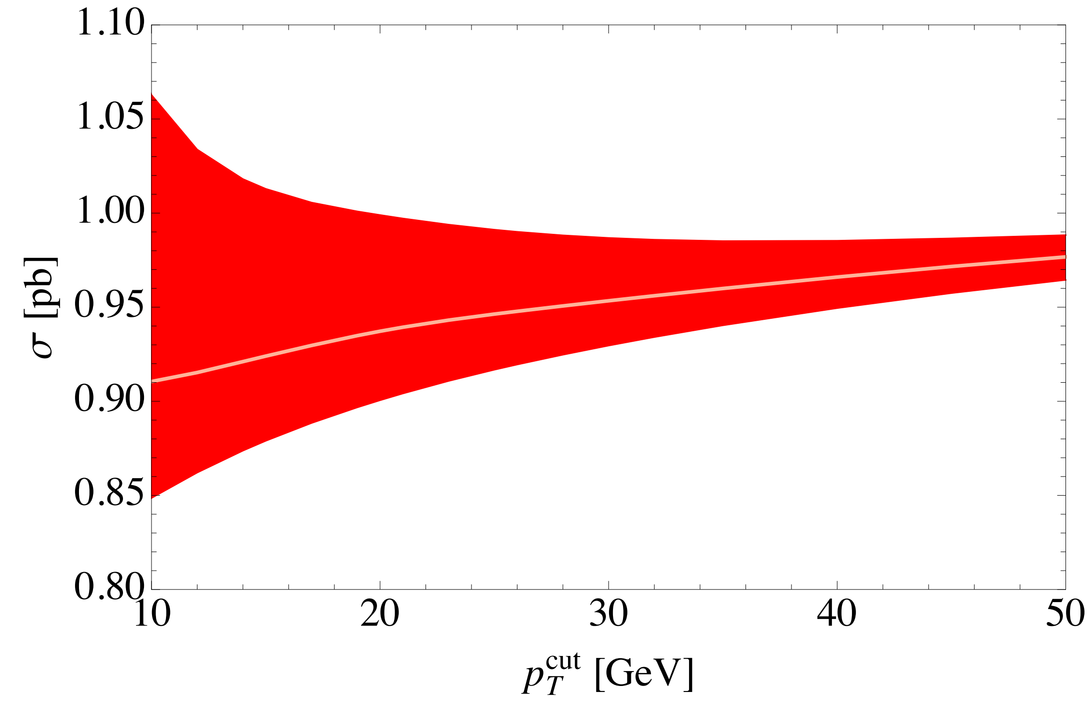
pileup, luminosities,
higher order corrections

Ratios of Cross Sections

NNLL' + NNLO for different E_{cm}



scaled ratio of [14 TeV] / [8 TeV]



rescaled by the inverse ratio of LO cross sections

Can we probe veto threshold effects more sensitively with ratios of rates?

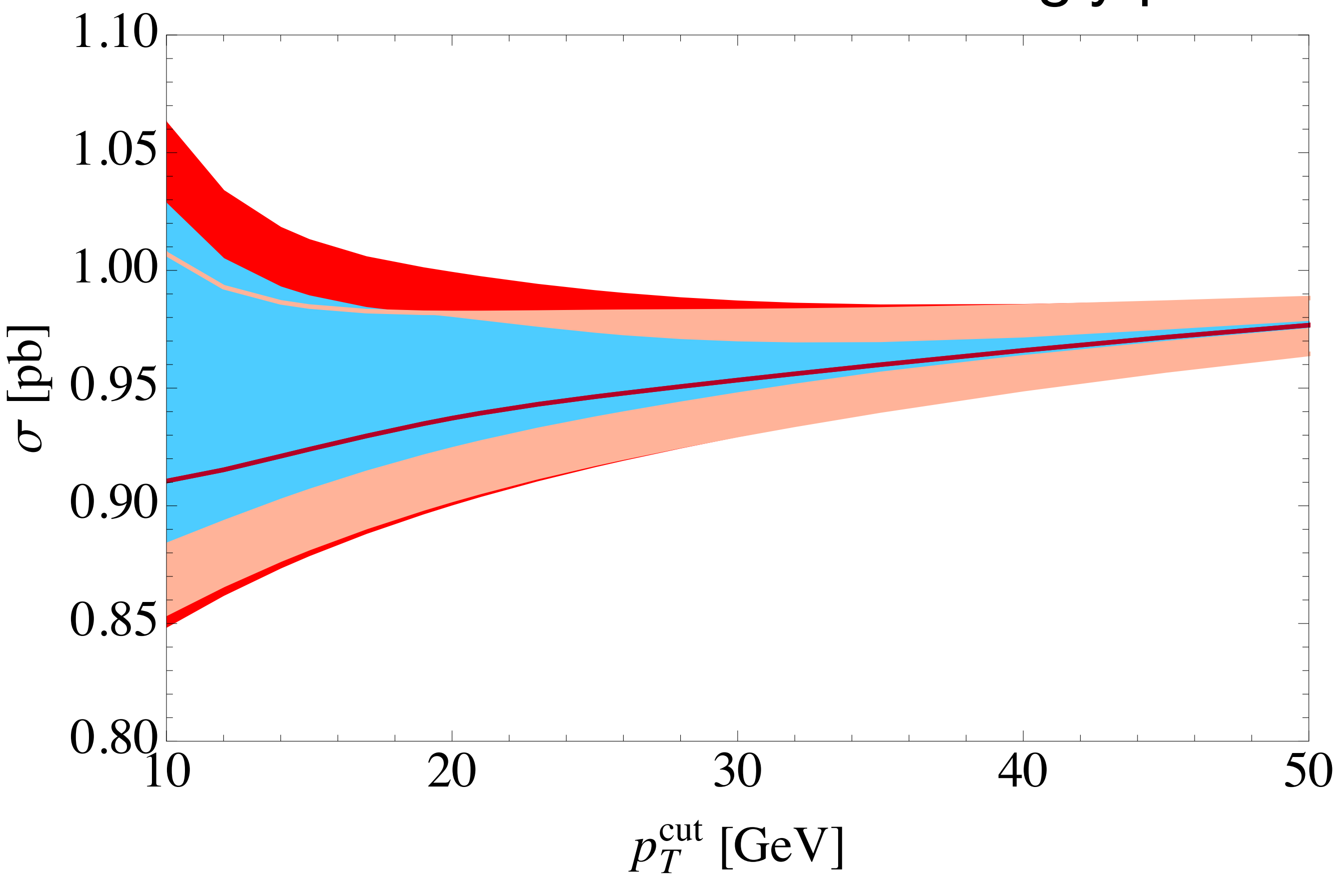
pileup, luminosities, higher order corrections

$$\frac{\sigma_0^{[14]}(30\ \mathrm{GeV})}{\sigma_0^{[8]}(30\ \mathrm{GeV})} = 0.953^{+0.034}_{-0.024}$$

Ratios of Cross Sections

$$\sigma_0(p_T^{\rm cut}) = H(m_H) \sum_{i,j} \int dx_a dx_b \left[C_{ij} \otimes f_i \otimes f_j\right](x_a, x_b, p_T^{\rm cut}) U_0(p_T^{\rm cut}) + \sigma_{\rm ns}(p_T^{\rm cut})$$

ratio of 14/8 TeV probes
fixed-order variations more strongly probed



blue: resummation uncertainties
light red: fixed-order uncertainties
red: total uncertainties

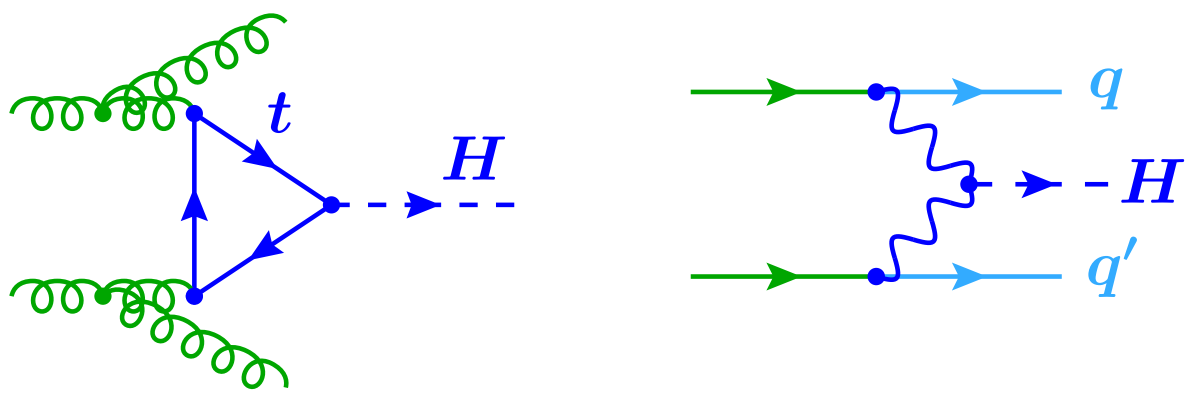
tree level terms
rescale with the luminosities

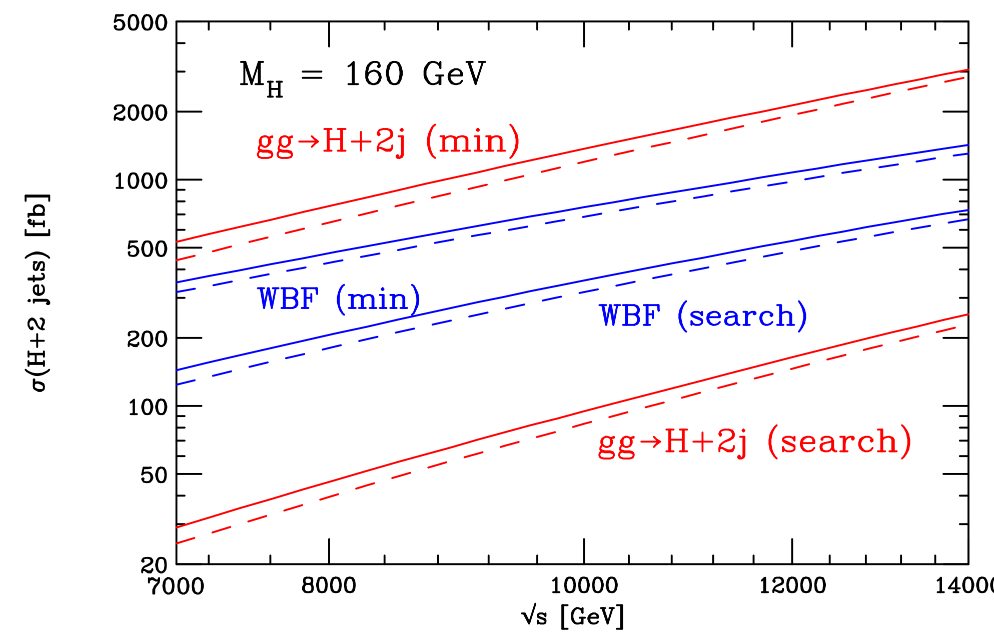
higher order corrections probe
the PDFs in different ways, e.g.:

$$\int_x^1 \frac{dz}{z} P_{gg}\left(\frac{x}{z}\right) f_g(z)$$

we are not close to probing the full PS,
so the luminosity dependence
is the only connection to $E_{\rm cm}$

VBF Contamination from gg Fusion



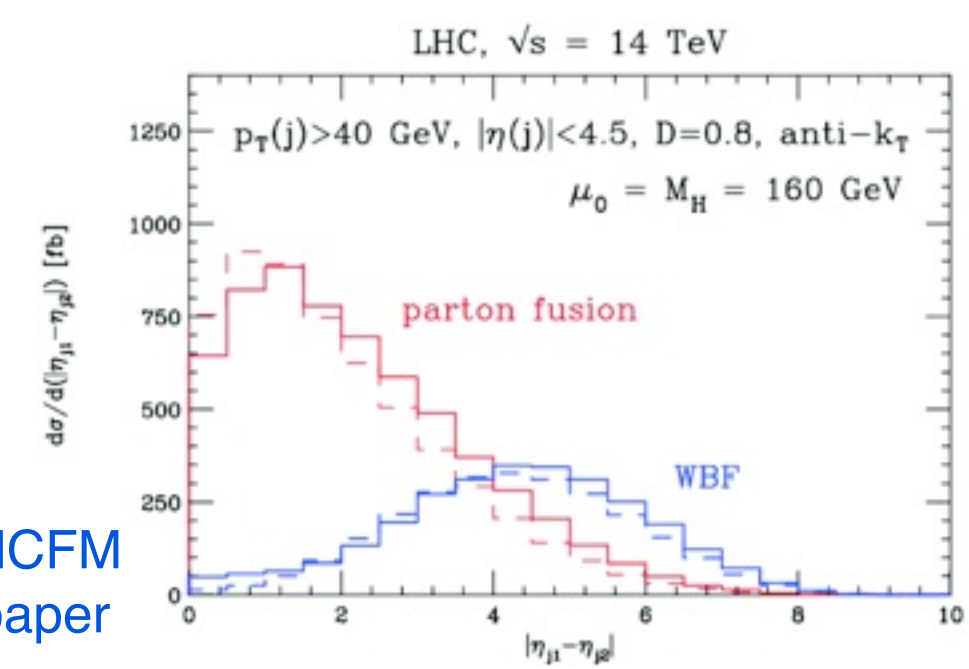


gg fusion contaminates the VBF analysis

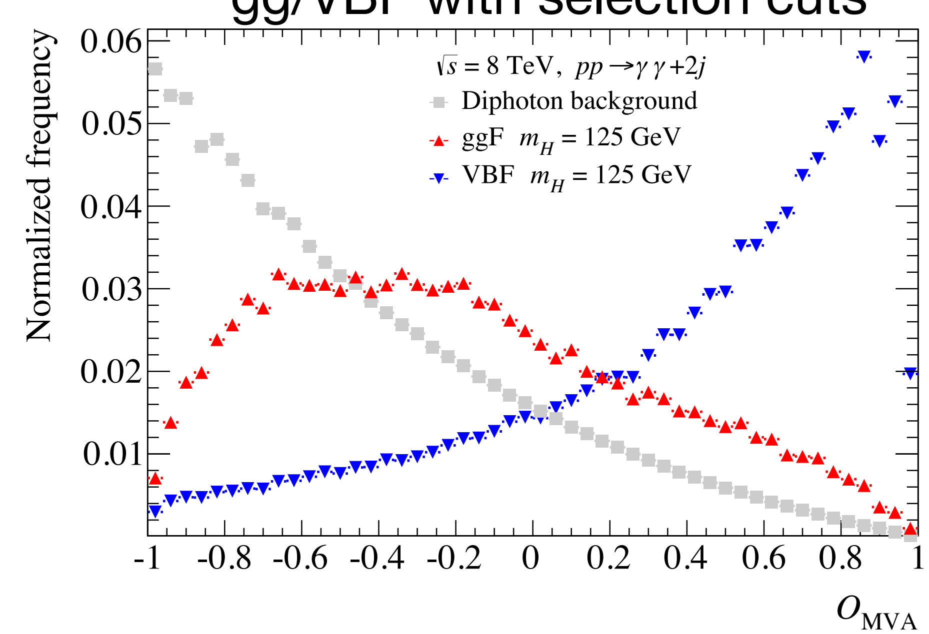
kinematically severe selection cuts induces large scale uncertainties

Campbell, Ellis, Williams 1001.4495

MVA analysis to separate gg/VBF with selection cuts

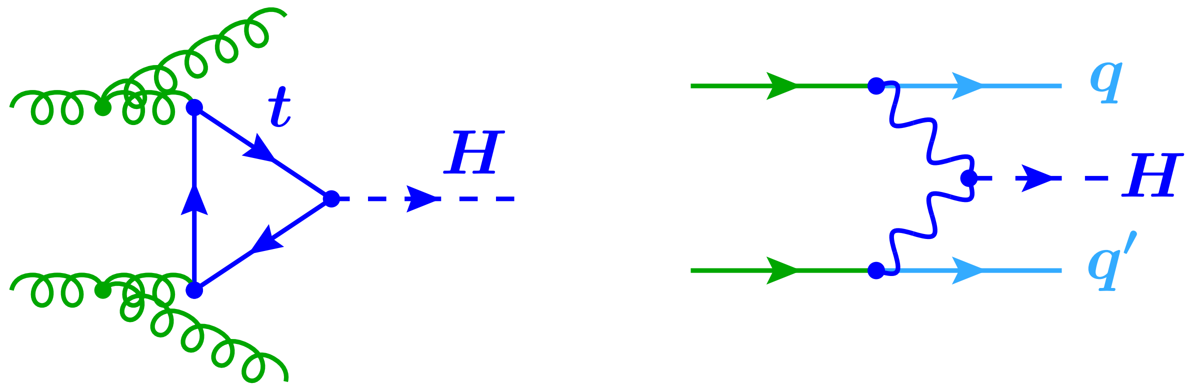


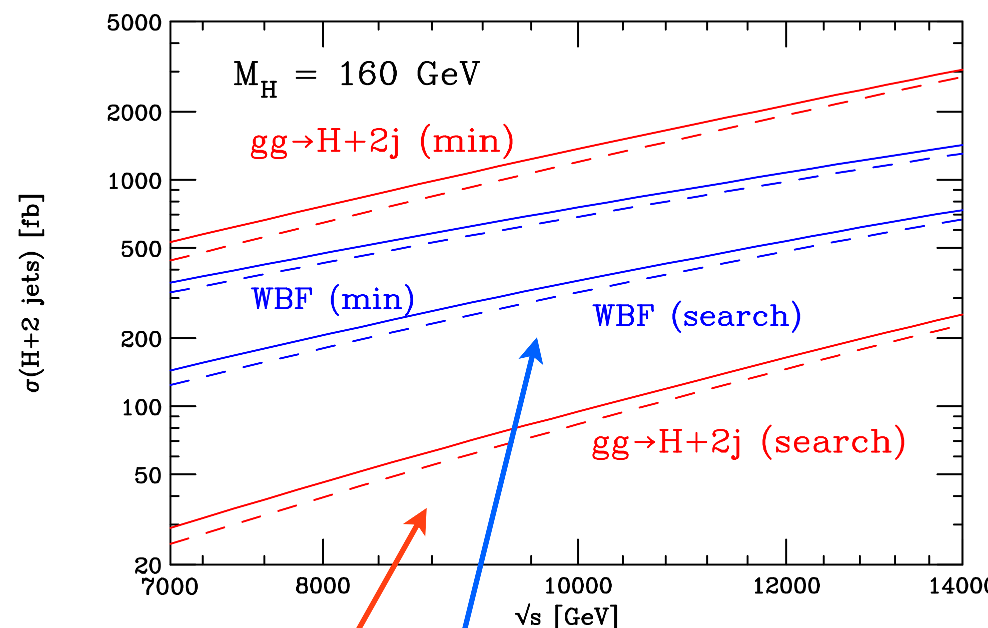
MCFM paper



YR3 fig. 69

VBF Contamination from gg Fusion





Campbell, Ellis, Williams 1001.4495

gg fusion contaminates the VBF analysis

kinematically severe selection cuts induces large scale uncertainties

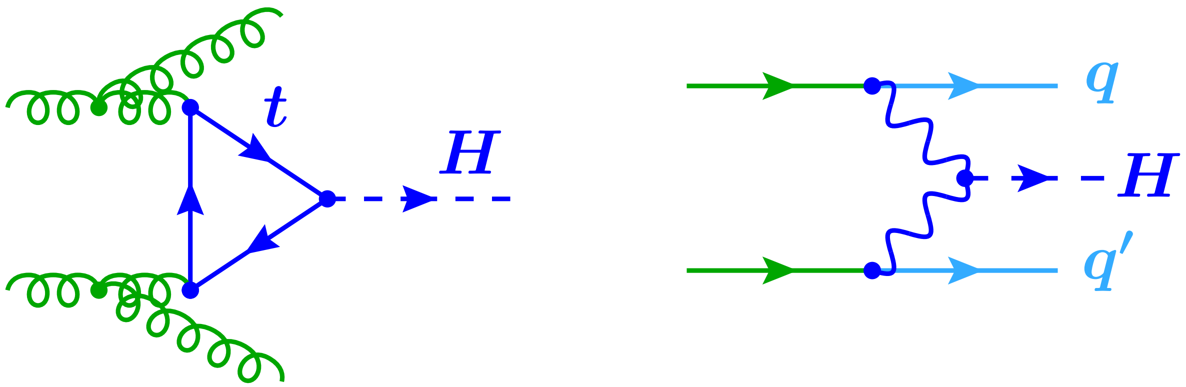
$$\sigma_{\rm obs}(\{v_i\}) = \epsilon_{\rm VBF}(\{v_i\})\sigma_{\rm VBF}(q\bar{q}) + \epsilon_{gg}(\{v_i\})\sigma_{gg}(gg)$$

dominant scaling with gg and q$\bar{\text{q}}$ luminosities

$$\frac{\sigma^{[14]}_{\rm obs}(\{v_i\})}{\sigma^{[8]}_{\rm obs}(\{v_i\})} = \frac{\epsilon^{[14]}_{\rm VBF}(\{v_i\})\sigma^{[14]}_{\rm VBF}(q\bar{q}) + \epsilon^{[14]}_{gg}(\{v_i\})\sigma^{[14]}_{gg}(gg)}{\epsilon^{[8]}_{\rm VBF}(\{v_i\})\sigma^{[8]}_{\rm VBF}(q\bar{q}) + \epsilon^{[8]}_{gg}(\{v_i\})\sigma^{[8]}_{gg}(gg)}$$

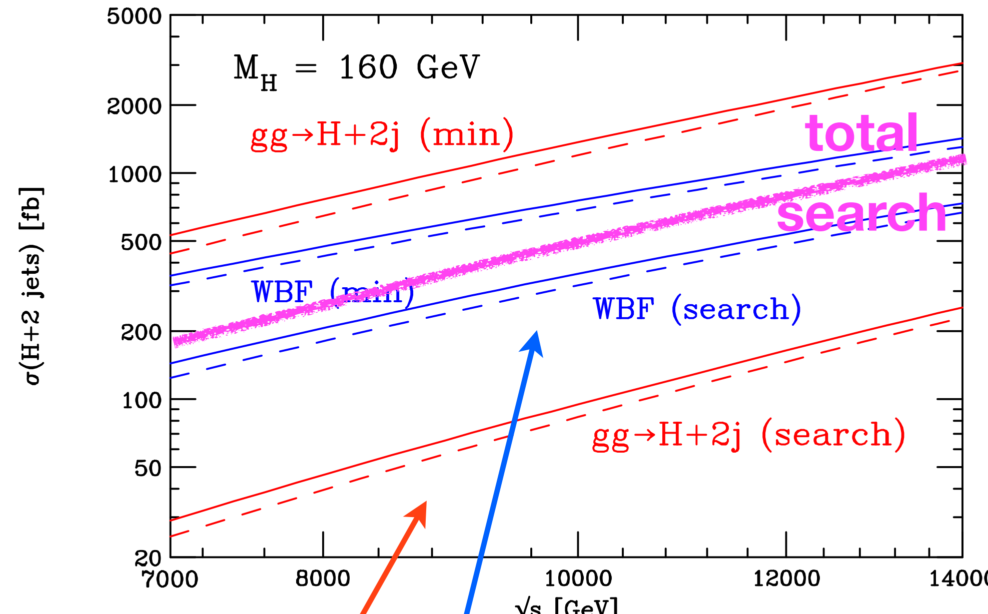
can we use this ratio to lower the uncertainty on the gg contamination?

VBF Contamination from gg Fusion



gg fusion contaminates the VBF analysis

kinematically severe selection cuts
induces large scale uncertainties



Campbell, Ellis, Williams
1001.4495

$$\sigma_{\rm obs}(\{v_i\}) = \epsilon_{\rm VBF}(\{v_i\})\sigma_{\rm VBF}(q\bar{q}) + \epsilon_{gg}(\{v_i\})\sigma_{gg}(gg)$$

dominant scaling with
gg and q$\bar{\text{q}}$ luminosities

$$\frac{\sigma^{[14]}_{\rm obs}(\{v_i\})}{\sigma^{[8]}_{\rm obs}(\{v_i\})} = \frac{\epsilon^{[14]}_{\rm VBF}(\{v_i\})\sigma^{[14]}_{\rm VBF}(q\bar{q}) + \epsilon^{[14]}_{gg}(\{v_i\})\sigma^{[14]}_{gg}(gg)}{\epsilon^{[8]}_{\rm VBF}(\{v_i\})\sigma^{[8]}_{\rm VBF}(q\bar{q}) + \epsilon^{[8]}_{gg}(\{v_i\})\sigma^{[8]}_{gg}(gg)}$$

can we use this ratio to
lower the uncertainty on
the gg contamination?

Conclusions

- Higgs measurements at LHC14 expand the precision program
- Veto thresholds, pileup dependence are interesting issues
  - Can integrate uncertainties with theory predictions
  - Drell-Yan a good testing ground for some of these effects, although higher order corrections much smaller
- Can we understand gg fusion contamination of VBF analysis by comparing 14, 8 TeV measurements?