Prospects for measuring H to Z cross section ratios

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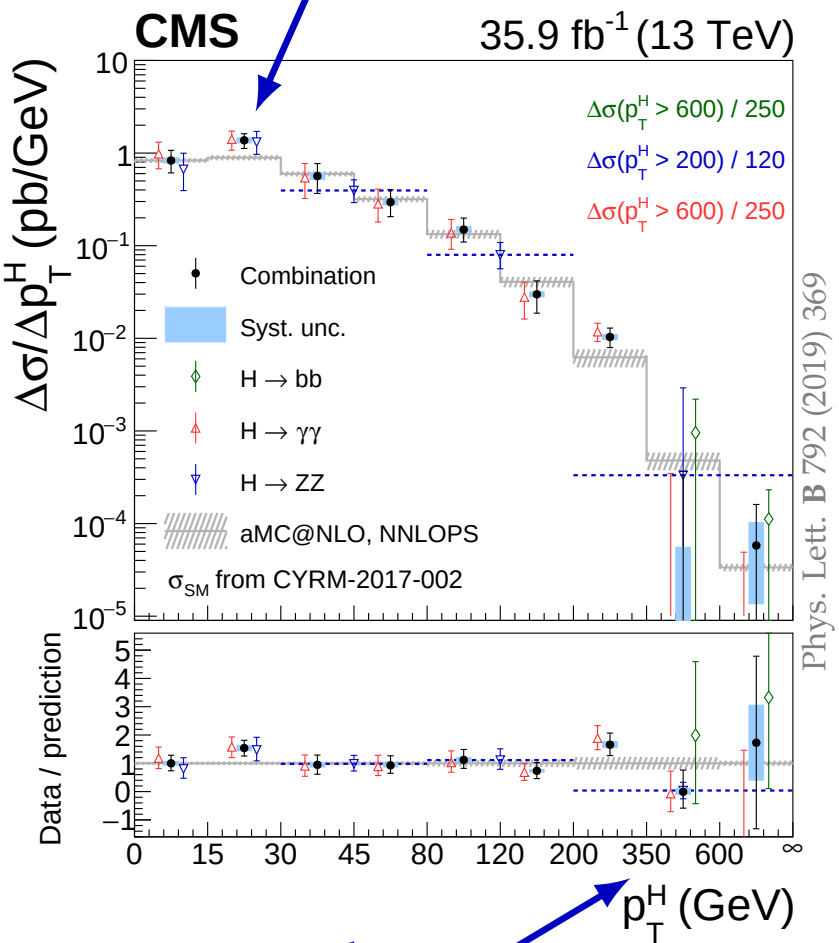
Low-x workshop in Nicosia – August 27, 2019

Where does the Higgs p_T come from?

Peak at 20 GeV

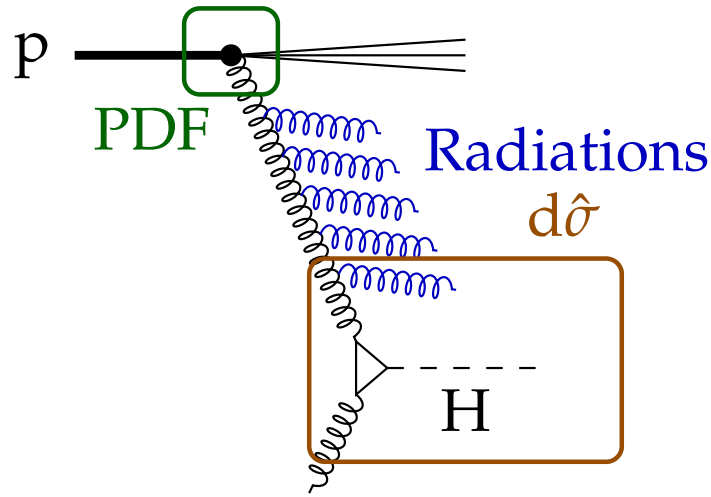


Large values

Where does the Higgs p_{T} come from?

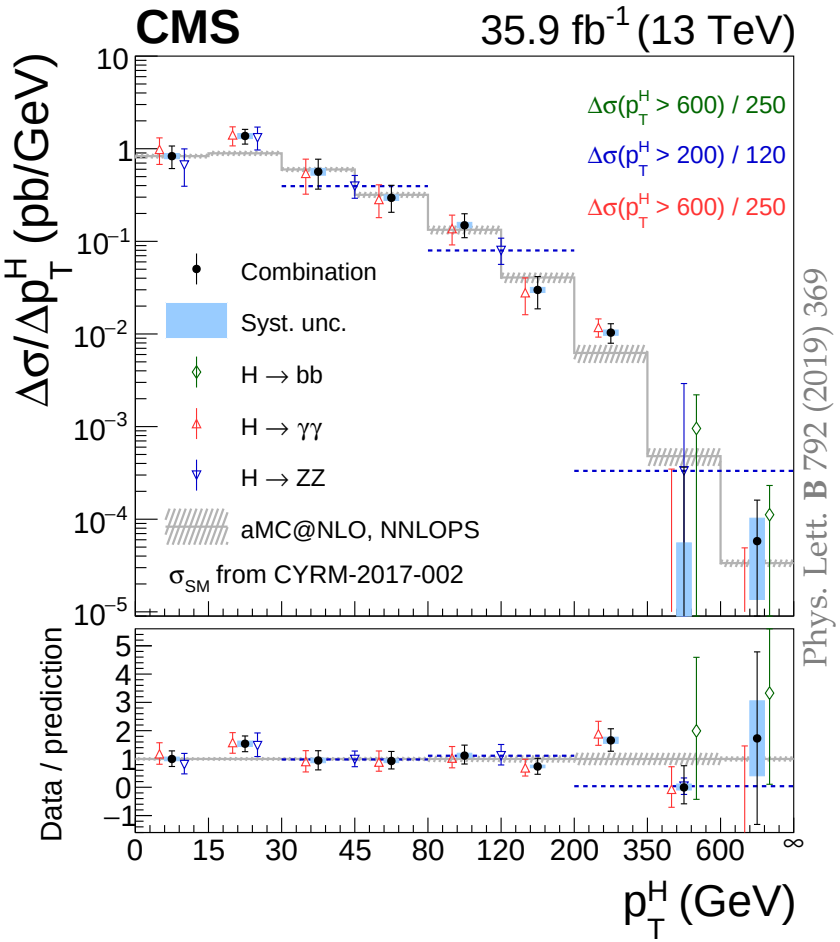
Factorization theorem: no explicit p_{T} dependence!

$$\mathrm{d}\sigma(\mathrm{pp} \to \mathrm{H}) = \mathrm{PDF} \otimes \mathrm{PDF} \otimes \mathrm{d}\hat{\sigma}(\mathrm{gg} \to \mathrm{H})$$



The p_{T} dependence comes from (not always hard) radiations.

The p_T dependence comes from radiations



soft hard

Experimental validation

Drell-Yan is very useful:

- Color singlet, clean final state and large cross section
- Dominant production mode is quark-induced: $q\bar{q} \to Z$

What about gluons?

- Higgs production is mostly gluon-induced: $gg \to H$
- Color singlet, clean final state (four leptons) and small cross section

Questions:

- How do variables sensitive to radiations compare between Higgs and Z?
- Can we measure the difference in Run II data?

Higgs as a "gluon trigger" first proposed in Phys. Rev. **D** 88, 097501

Monte-Carlo setup

Event generation:

- aMC@NLO with PYTHIA8 for Drell-Yan
- POWHEG + JHUGEN with PYTHIA8 for Higgs
- CP5 tune and NNPDF 3.1

Cuts that mimic existing CMS analyses:

Z boson:

- e^+e^- or $\mu^+\mu^-$ pairs
- Lepton $p_T > 25\,\text{GeV}$
- Lepton $|\eta| < 2.4$
- $115 < M_{ll} < 135\,\text{GeV}$

Jets:

- Anti-k_T with $R = 0.4$
- $p_T > 30\,\text{GeV}$, $|\eta| < 4.7$
- $\Delta R(\text{jet}, \text{lepton}) > 0.4$

Higgs boson:

- Four leptons: $2(e^+e^-)$, $2(\mu^+\mu^-)$ or $e^+e^-\mu^+\mu^-$
- Lepton $p_T > 5(7), 7, 10, 20\,\text{GeV}$
- Lepton $|\eta| < 2.4$
- Pair leptons to make two Z bosons with $40 < M_{ll,1} < 120\,\text{GeV}$ and $M_{ll,2} > 12\,\text{GeV}$

Variables of interest

For measured jets:

- Boson p_{T}
- Number of jets
- Jet p_{T}

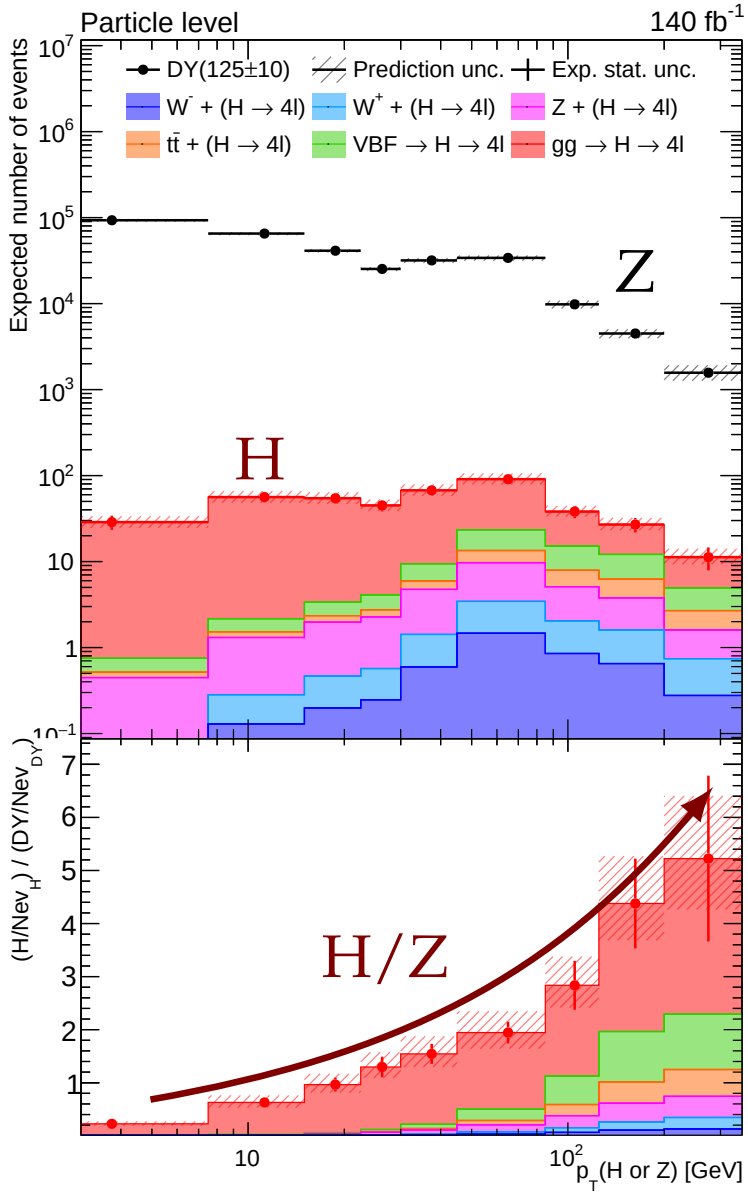
For radiation other than selected jets:

- Boson p_{T}
- p_{T} balance: $p_{\mathrm{T}}^{\mathrm{bal}} \equiv \left| \sum_{\mathrm{jets}} \vec{p}_{\mathrm{T}}(\mathrm{jet}) + \vec{p}_{\mathrm{T}}(\mathrm{B}) \right|$
- Jet-boson balance: $\mathrm{JBB} \equiv \left| \sum_{\mathrm{jets}} \vec{p}_{\mathrm{T}}(\mathrm{jet}) \right| - p_{\mathrm{T}}(\mathrm{B})$

CMS measurement for Z: EPJ **C** (2018) 78:965

Results: Reading the plots

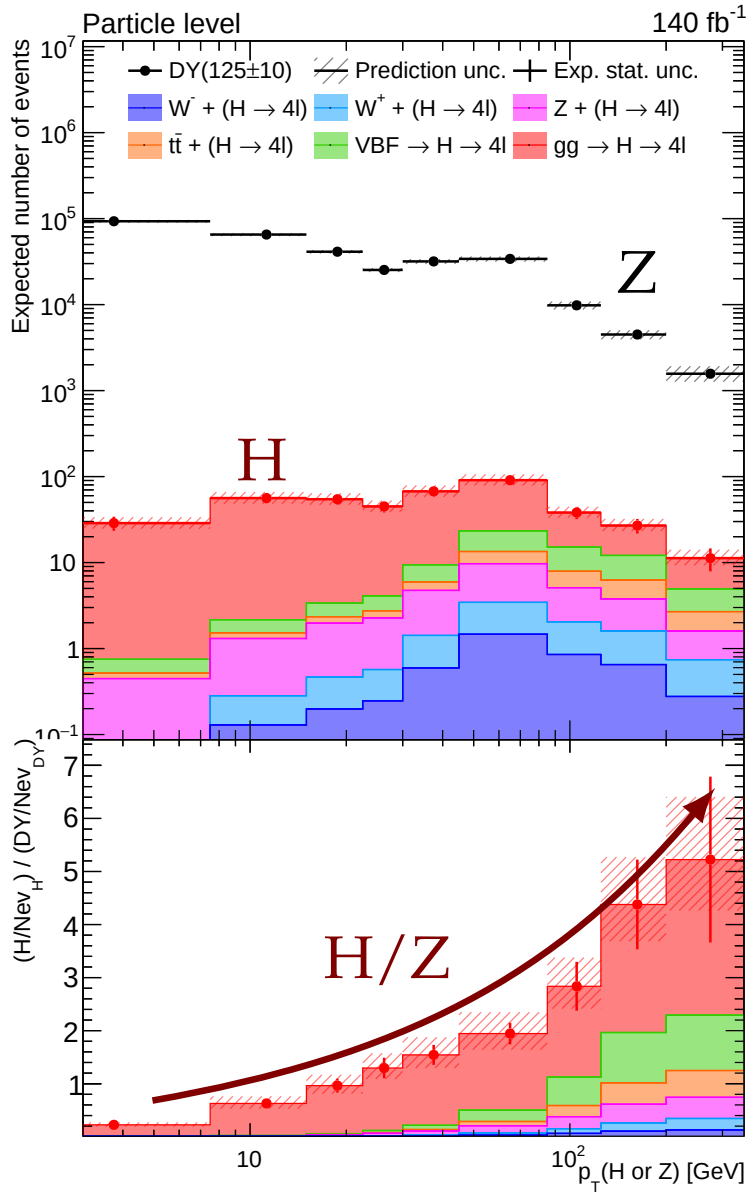
- Expected number of events for 140 fb^{-1}
- Higgs breakdown by production mechanism
  - Prediction uncertainty (stat, scale, PDF)
  - Expected stat. error in Run II data
  - $gg \to H \to 4l$, $VBF \to H \to 4l$, $t\bar{t} + (H \to 4l)$
  - $Z + (H \to 4l)$, $W^+ + (H \to 4l)$, $W^- + (H \to 4l)$
- Higgs to Z ratio (normalized)
- **No data**, this is a MC-only study



Results: Boson p_{T} (Higgs or Z)

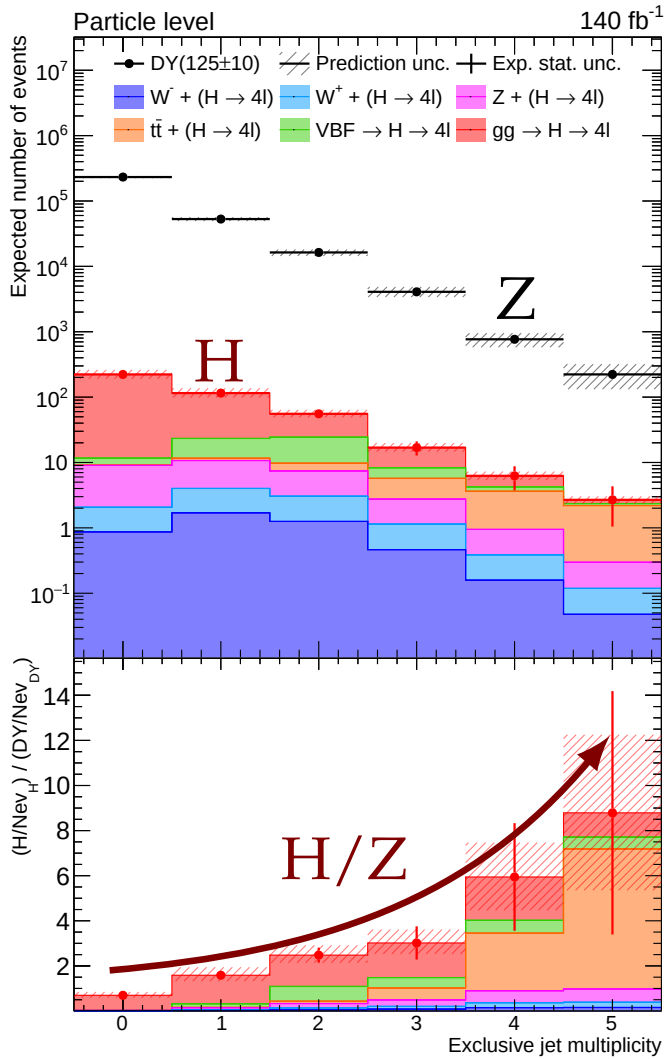
- Sensitive to **hard** jets at **high** p_{T}
- Sensitive to **soft** emissions at **low** p_{T}

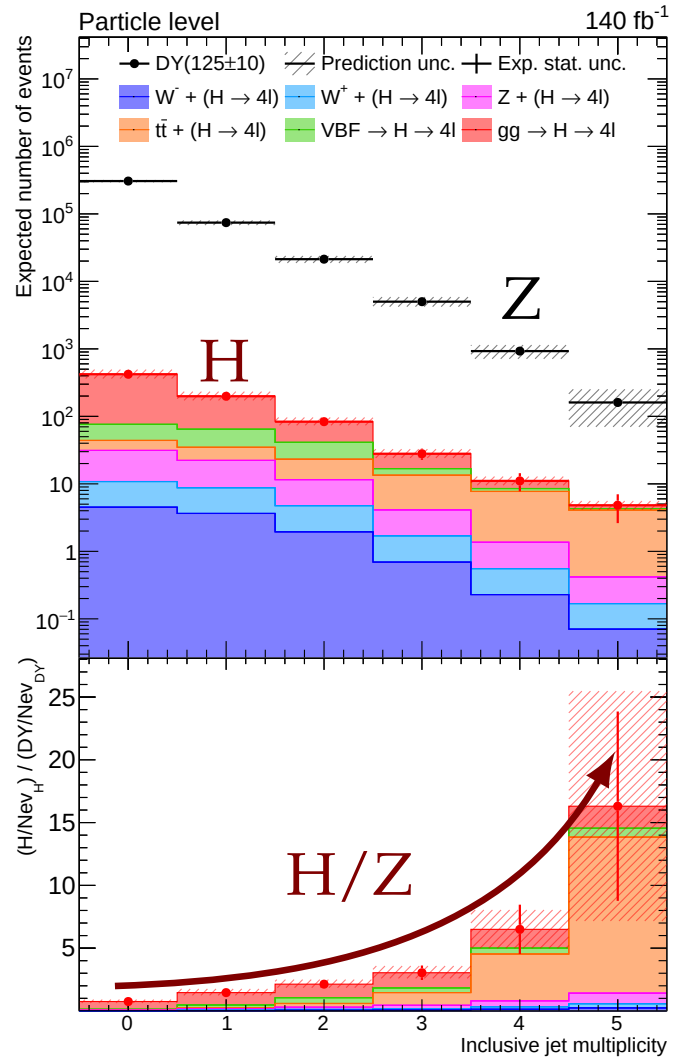
- For gluon fusion, harder H boson p_{T} compared to the Z due to emission difference between gluons and quarks
- For other production mechanisms the Higgs boson p_{T} is harder than the Z because of existence of other particles
- Binning inspired by the existing H measurements



Results: Number of jets

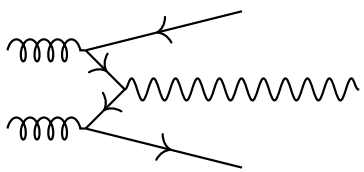
- Sensitive to **hard** jets only
- More jets in Higgs production
- Because of the color factor of gluons, but also specifics of VBF and ttH
- Measure up to 4 (5) jets in Run II data!

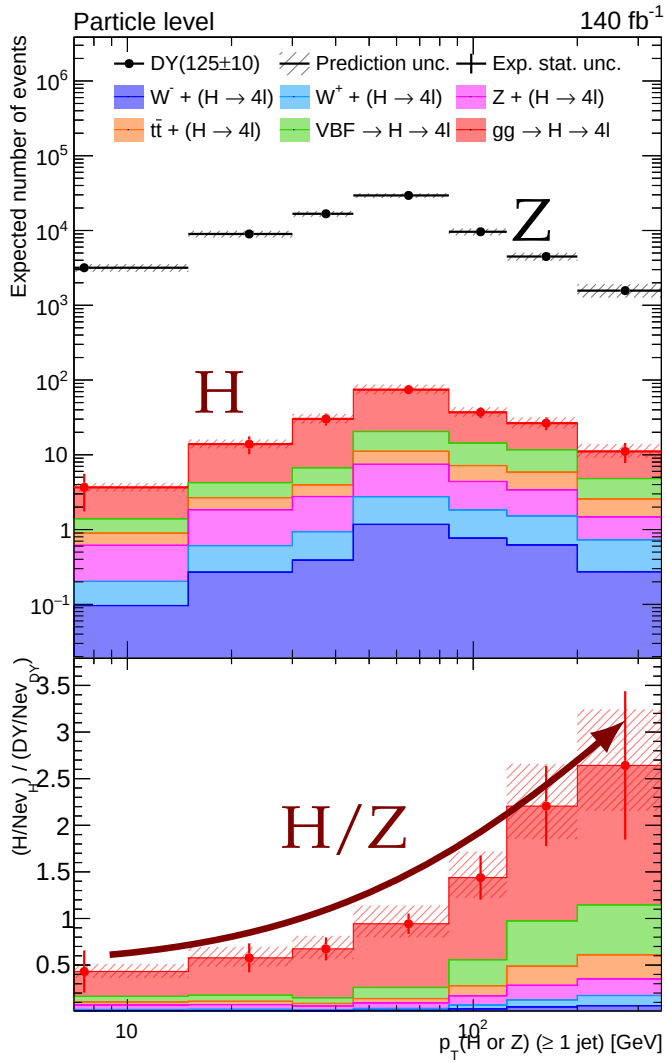


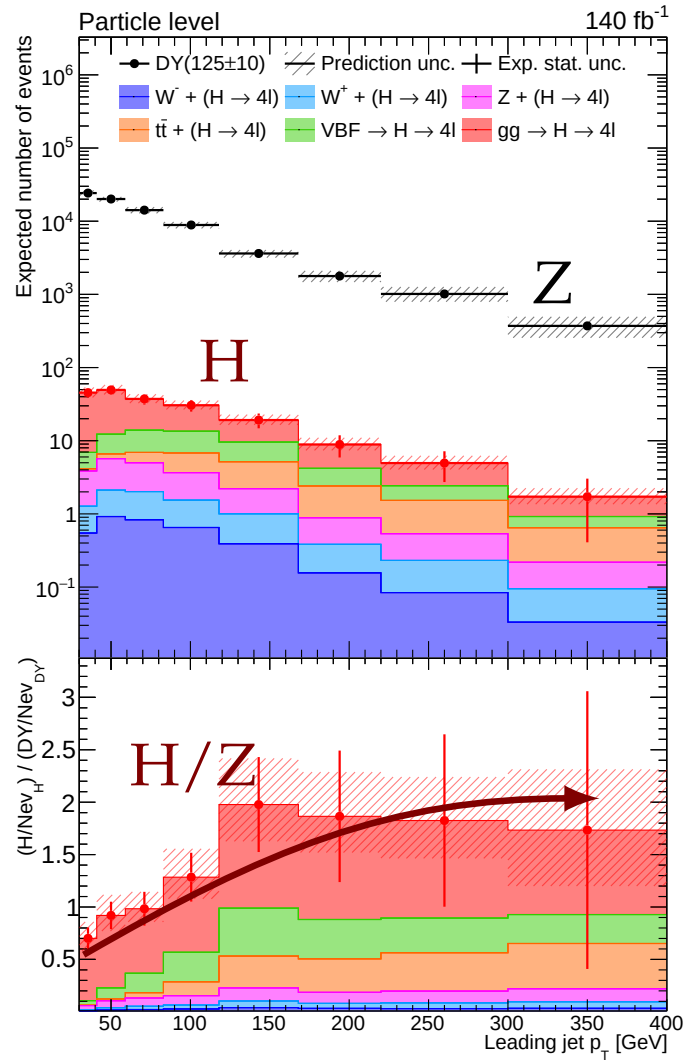


Results: p_T when one jet is present

- When an extra jet is accompanying the boson, p_T is shifted to higher values due to recoil
- Differences between Higgs and Z visible as in the 0 jet case
- Flattening of the ratio for large jet p_T: Z production starts to be dominated by gluon-initiated events with two jets





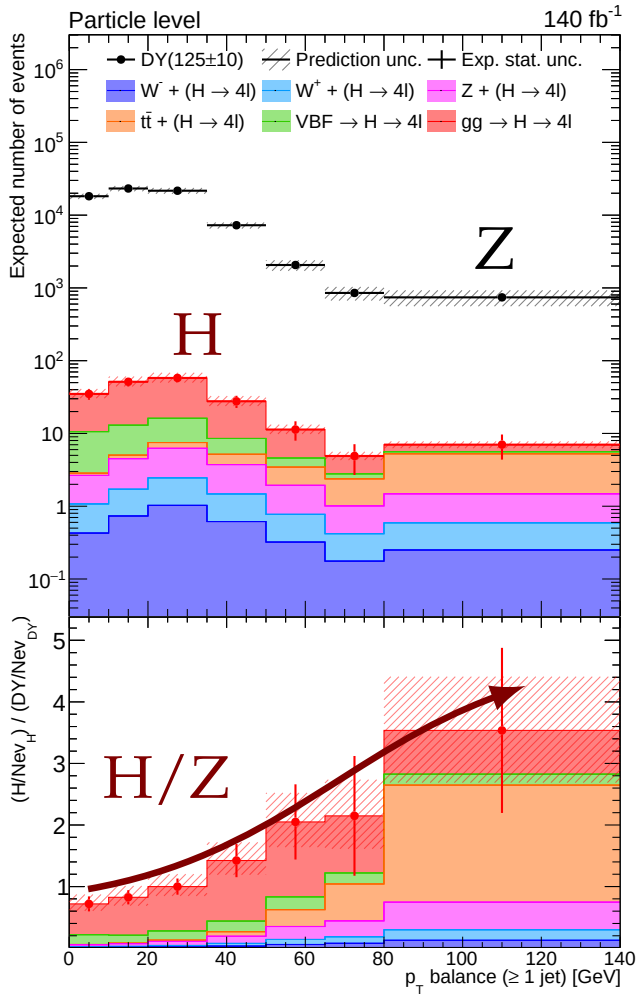


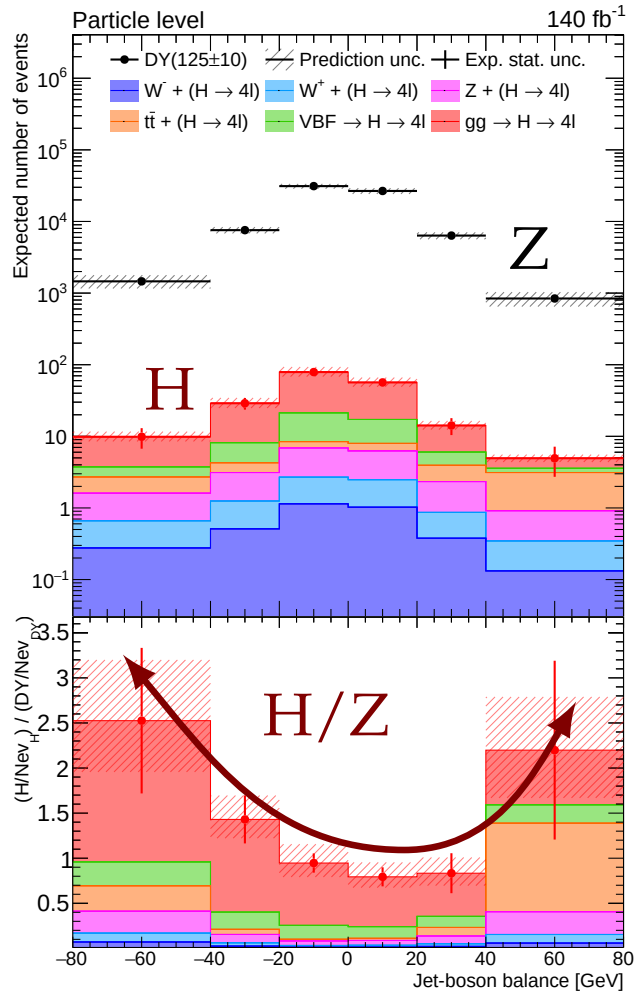
Results: Balance in the transverse plane

$$p_{\mathrm{T}}^{\mathrm{bal}} \equiv \left| \sum_{\mathrm{jets}} \vec{p}_{\mathrm{T}}(\mathrm{jet}) + \vec{p}_{\mathrm{T}}(\mathrm{B}) \right|$$

$$\mathrm{JBB} \equiv \left| \sum_{\mathrm{jets}} \vec{p}_{\mathrm{T}}(\mathrm{jet}) \right| - p_{\mathrm{T}}(\mathrm{B})$$

- To study undetected radiations two new observables are defined [1]
- Effects coming from extra jets (in acceptance) cancel out
- Remaining effects mainly due to different production mechanisms





[1] See EPJ C (2018) 78:965 (SMP-16-015)

Summary

- First study based on MC to show the feasibility of H/Z ratios in Run II
- Variables based on the kinematics of the boson and jets
- Effects of gluon/quark radiations visible in various observables
- Additional particles for some production mechanisms affect the sensitivity
  - As seen for quark induced Higgs production mechanisms (like VBF...)
  - JBB & $p_{\mathrm{T}}^{\mathrm{bal}}$ eliminate some of the effects from extra particles/jets

¿ ?