



Prospects for measurements of H/Z production cross section ratios using CMS

Run II data

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Motivation I

→ General motivation is to study the production dynamics in hh collisions

→ Difference expected between quark and gluon processes

→ Processes involving W & Z boson production are one of the best understood processes at hadron colliders

→ $W \rightarrow l\nu$, $Z \rightarrow ll$, ($l=e,\mu$) are among the cleanest final states experimentally

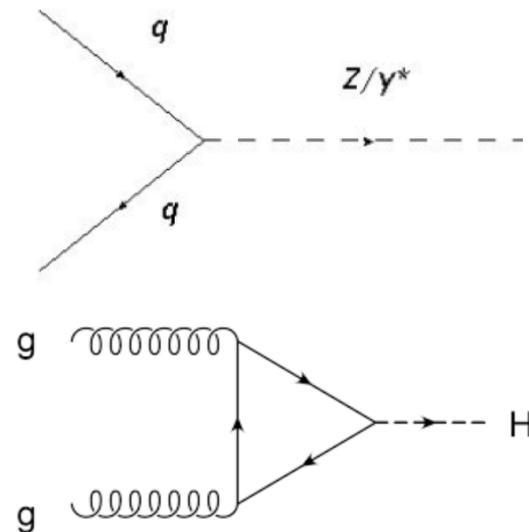
→ Allows study of QCD production mechanisms

→ But, only precision for quark induced process

→ An alternate is to use Higgs to study gluon induced processes [1,2]

→ For gg, H is a color singlet state coupling to gluons

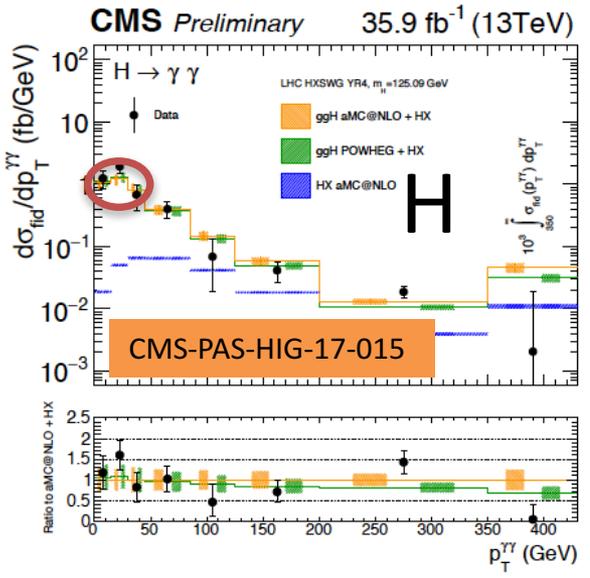
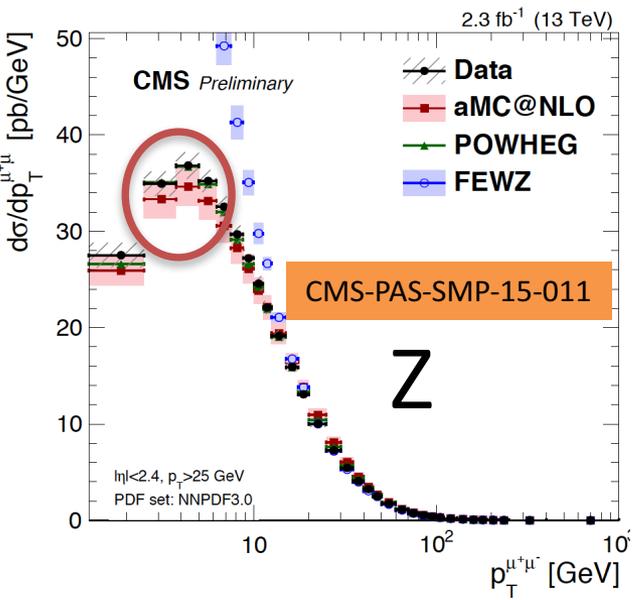
→ $H \rightarrow 4l$ is low background, allows good kinematic reconstruction of H



[1] P. Cipriano et al, Physical Review D 88 (2013), no. 9,097501.

[2] H. Van Haeve, doi:10.1051/epjconf/20159010004.

Motivation II



While similar mass scales (90 vs 125 GeV), the difference of initial state dynamics give very different rising behavior at low p_T

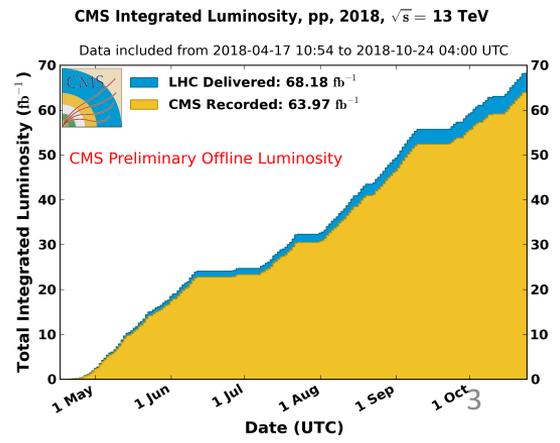
→ Z p_T peaks ~ 4 GeV whereas H ~ 25 GeV

→ DY/H ratio measurement can highlight the production dynamics difference

- Aim to compare the production mechanism at the same process scale
- Partially eliminating systematic effects

→ Run II proton data taking is done

- 2016-2018 CMS recorded ~ 145 /fb data



Observables of interest

- Sensitive to hard radiations
 - Jet multiplicity, jet p_T , boson p_T (large values)
- Sensitive to soft radiations
 - boson p_T (small values), p_T^{bal} , JBB

$$p_T^{\text{bal}} \equiv \left| \sum_{\text{jets}} \vec{p}_T(\text{jet}) + \vec{p}_T(\text{B}) \right|$$

$$\text{JBB} \equiv \left| \sum_{\text{jets}} \vec{p}_T(\text{jet}) \right| - p_T(\text{B}).$$



- Sensitive to:
 - Hadronic activity outside jet acceptance
 - Central parton radiation that is not clustered in a jet
- JBB conserves the sign of the difference

Generator Level Study

Z → 2l selection

- Pair of opposite sign same flavor leptons (e^+e^- , $\mu^+\mu^-$)
 - $p_T > 25$ GeV, $|\eta| < 2.4$
 - $115 < M_{ll} < 135$ GeV

H → 4l selection

- all sets of four leptons ($4e$, $2e2\mu$, 4μ)
 - p_T greater than 5, 7, 10, 20 GeV
 - $|\eta| < 2.4$
- Pair leptons to find two Z bosons
 - $40 < M_{ll}^1 < 120$ GeV, $M_{ll}^2 > 12$ GeV

Jet selection

- Anti k_T jets ($R = 0.4$)
- $p_T > 30$ GeV, $|\eta| < 4.7$
- $\Delta R(j,l) > 0.4$

Process	Dataset name	$\sigma \times BR (\times \epsilon_{filter})$	N_{events}
DY	amcatnlo + pythia8 (FXFX)	5765.4 pb	27×10^6
gg → H → 4l	powheg2 + JHUGenV7011 + pythia8	12.18 fb	942 508
VBF → Hqq → 4l	powheg2 + JHUGenV7011 + pythia8	1.044 fb	496 885
$W^+(H \rightarrow 4l)$	powheg2-minlo-HWJ + JHUGenV7011 + pythia8	0.232 fb	299 710
$W^-(H \rightarrow 4l)$	powheg2-minlo-HWJ + JHUGenV7011 + pythia8	0.147 fb	200 000
Z(H → 4l)	powheg2-minlo-HZJ + JHUGenV7011 + pythia8	0.668 fb	494 864
$t\bar{t}(H \rightarrow 4l)$	powheg2 + JHUGenV7011 + pythia8	0.393 fb	492 273

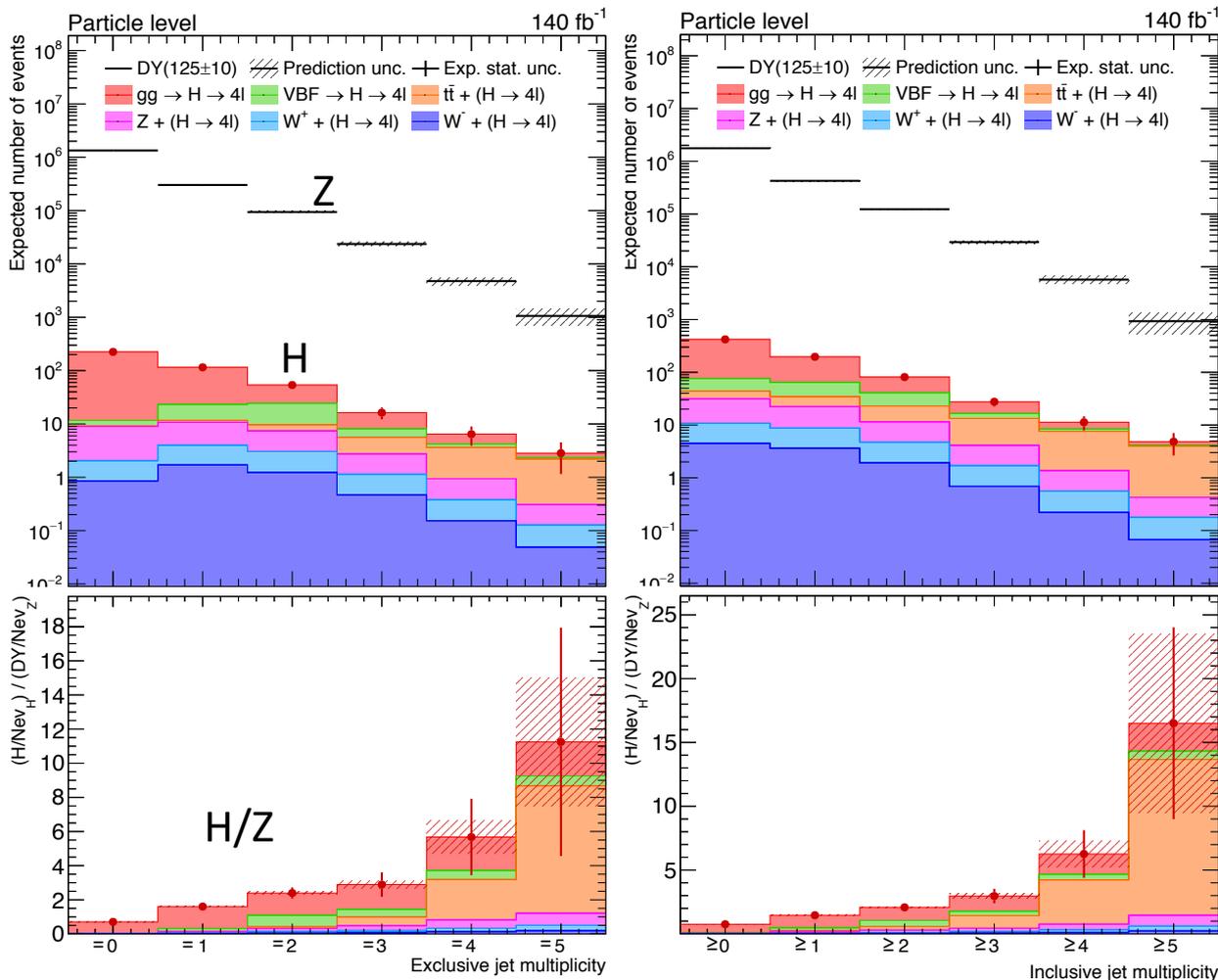
jet multiplicity

Yields are normalized to expected number of events at 140 /fb

Ratios show the shape differences.

Error bars show the expected stat unc at 140/fb, shaded bar corresponds to the stat unc of MC samples

Would have enough stat to measure up to 4 (5) jets

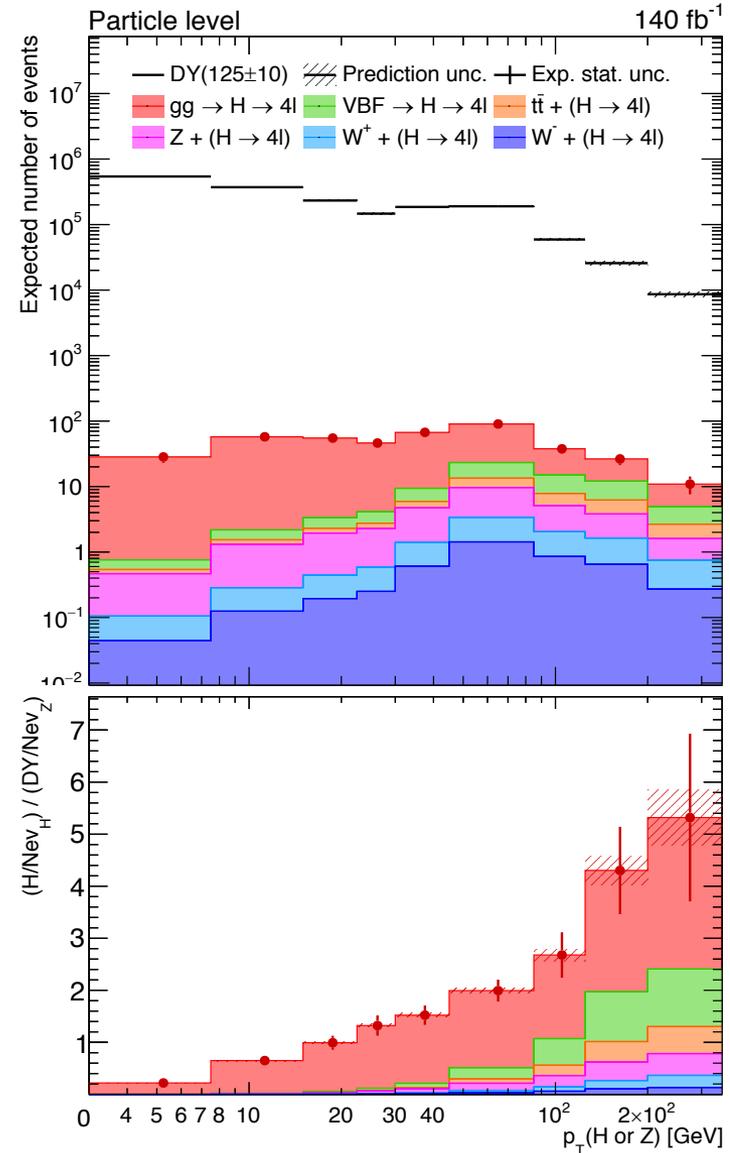
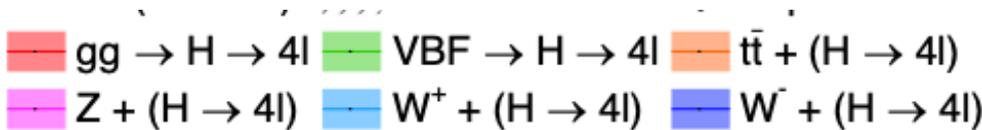


Ratio increasing with jet mult.

Boson transverse momentum

p_T of the H and the Z boson differs :

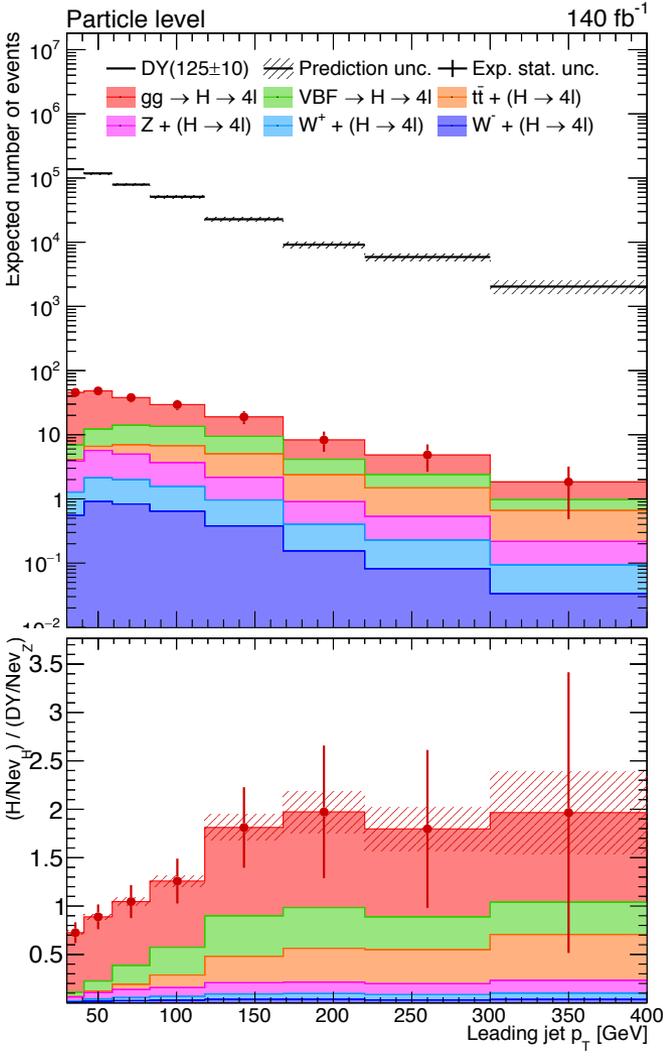
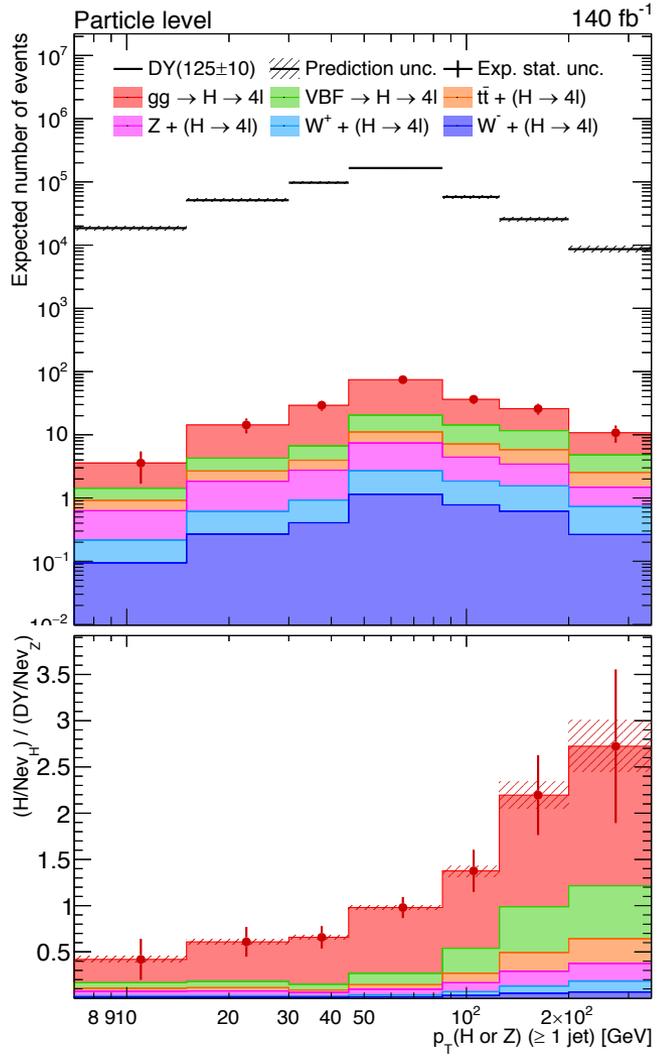
- For $gg \rightarrow H$, harder H boson p_T compared to the Z due to emission difference (color factor,...) between gluons and quarks
- For other production mechanisms the H boson p_T is harder than the Z because of existence of other particles
- Binning inspired by the existing H measurements



Boson + 1 jet: Boson & jet transverse momentum 140 /fb

→ When an extra jet is accompanying the boson, p_T is shifted to higher values due to recoil

→ Differences between H and Z visible as in the 0 jet case.



Boson + 1 jet: JBB & P_Tbal

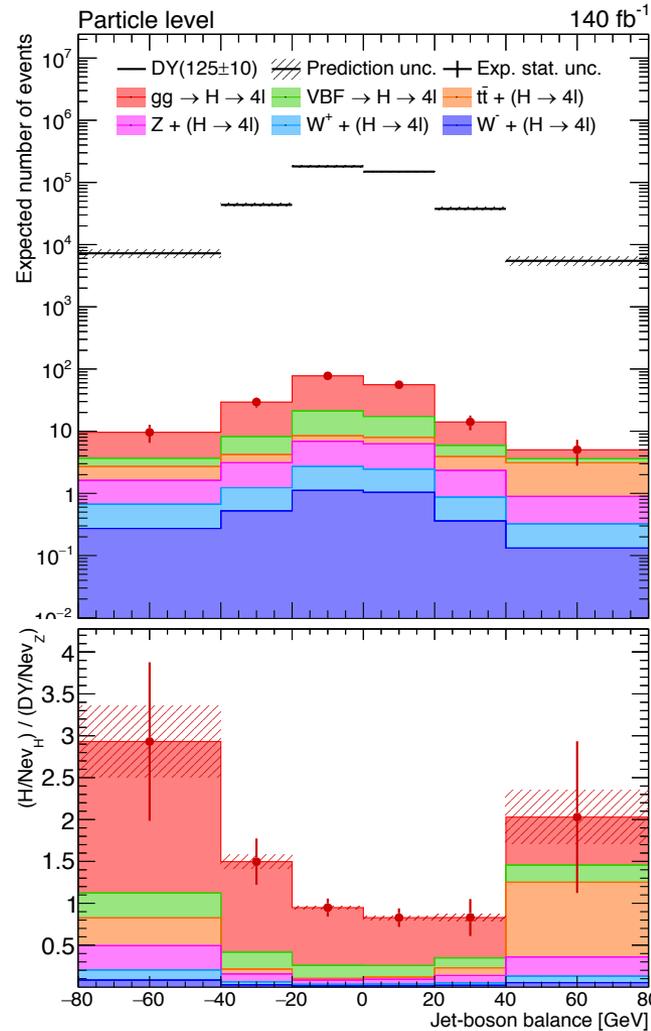
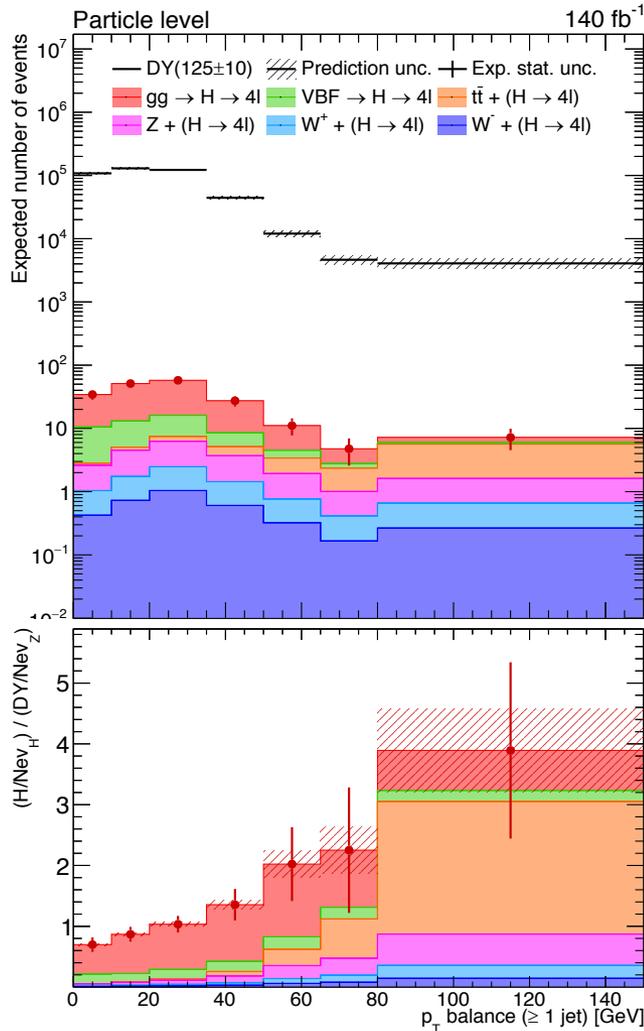
$$p_T^{\text{bal}} \equiv \left| \sum_{\text{jets}} \vec{p}_T(\text{jet}) + \vec{p}_T(B) \right|$$

$$\text{JBB} \equiv \left| \sum_{\text{jets}} \vec{p}_T(\text{jet}) \right| - p_T(B).$$

To study undetected radiations two new observables are defined

Effects coming from extra jets (in acceptance) cancel out

Remaining effects mainly due to different production mechanisms





SUMMARY

- First study based on MC to show the feasibility of H/Z ratio
- Effects of gluon / quark ISR visible in various observables
- Additional particles for some production mechanisms affect the sensitivity
 - As seen for quark induced H production mechanisms (like VBF..)
 - JBB & $P_{t,bal}$ eliminate some of the effects from extra particles/jets
- Run II data is there- just waiting for us to analyze 😊



THANK YOU!





BACK-UP

Generator Level Study

- Rivet based study, particle level
- Expected event yields at 140 /fb

Z → 2l selection

- Pair of opposite sign same flavor leptons (e^+e^- , $\mu^+\mu^-$)
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H → 4l selection

- all sets of four leptons (4e, 2e2 μ , 4 μ)
 - p_T greater than 5, 7, 10, 20 GeV
 - $|\eta| < 2.4$
- Pair leptons to find two Z bosons
 - Opposite sign same flavor (e^+e^- , $\mu^+\mu^-$)
 - $\Delta R(l, l) > 0.1$
 - $40 < M_{ll}^1 < 120$ GeV, $M_{ll}^2 > 12$ GeV

Jet selection

- Anti k_T jets ($R = 0.4$) using fast-jet in Rivet
- $p_T > 30$ GeV, $|\eta| < 4.7$
- $\Delta R(j, l) > 0.4$

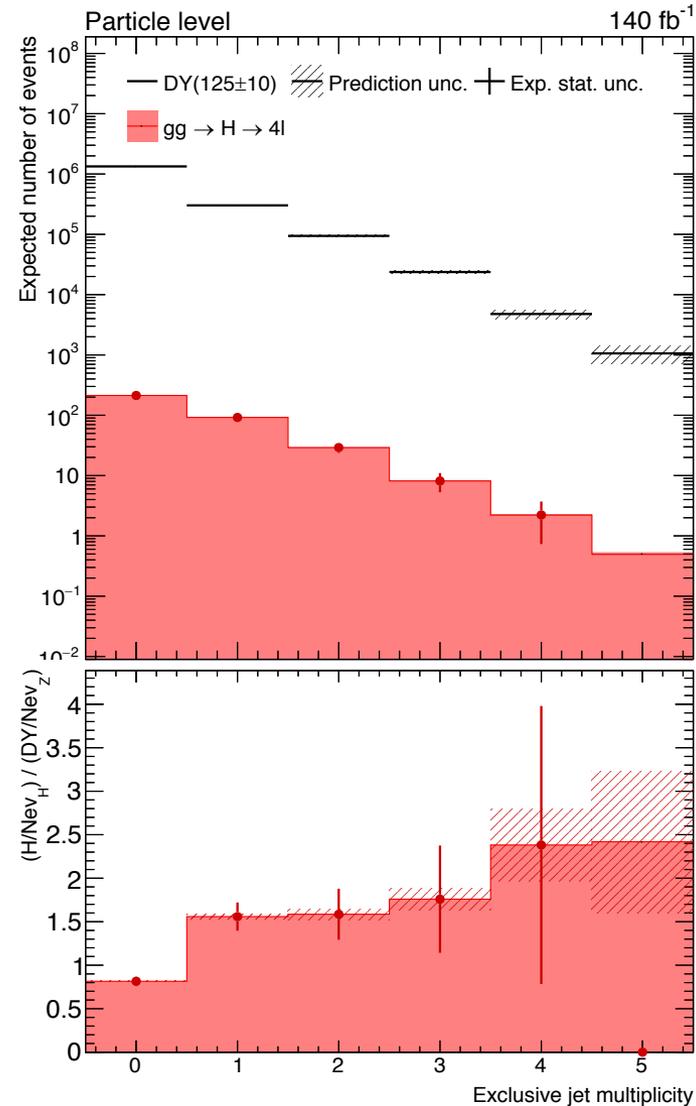
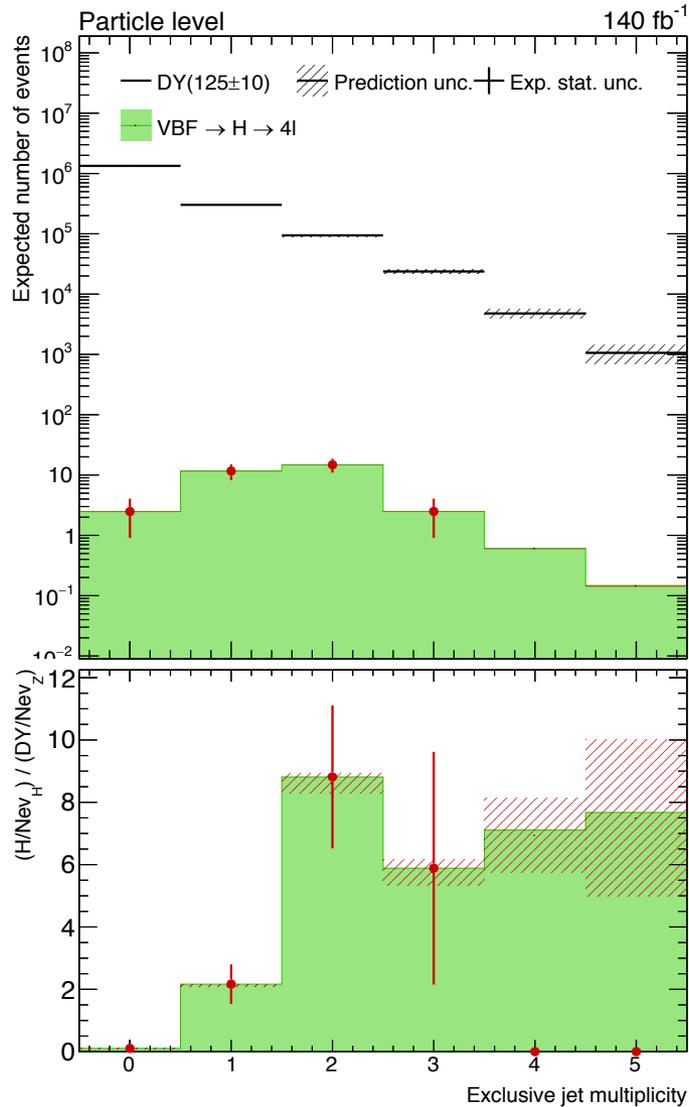
Process	Dataset name	$\sigma \times BR (\times \epsilon_{\text{filter}})$	N_{events}
pp → Z + X → 2l + X	/DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8/[1]	5765.4 pb	27×10^6
gg → H → 4l	/GluGluHToZZTo4LM125_13TeV_powheg2_JHUGenV7011.pythia8/[1]	12.18 fb	942 508
qq → ZZqq → Hqq → 4lqq	/VBF_HToZZTo4LM125_13TeV_powheg2_JHUGenV7011.pythia8/[2]	1.044 fb	496 885
q \bar{q} → W ⁺ H → W ⁺ ZZ → 4l + X	/WplusH_HToZZTo4LM125_13TeV_powheg2-minlo-HWJ_JHUGenV7011.pythia8/[1]	0.232 fb	299 710
q \bar{q} → W ⁻ H → W ⁻ ZZ → 4l + X	/WminusH_HToZZTo4LM125_13TeV_powheg2-minlo-HWJ_JHUGenV7011.pythia8/[1]	0.147 fb	200 000
q \bar{q} → ZH → ZZZ → 4l + X	/ZH_HToZZ_4LFilter_M125_13TeV_powheg2-minlo-HZJ_JHUGenV7011.pythia8/[1]	0.668 fb	494 864
gg → ttH → ttZZ → 4l + X	/ttH_HToZZ_4LFilter_M125_13TeV_powheg2_JHUGenV7011.pythia8/[1]	0.393 fb	492 273

[1] RunIIFall17MiniAOD-94X_mc2017_realistic_v10-v1

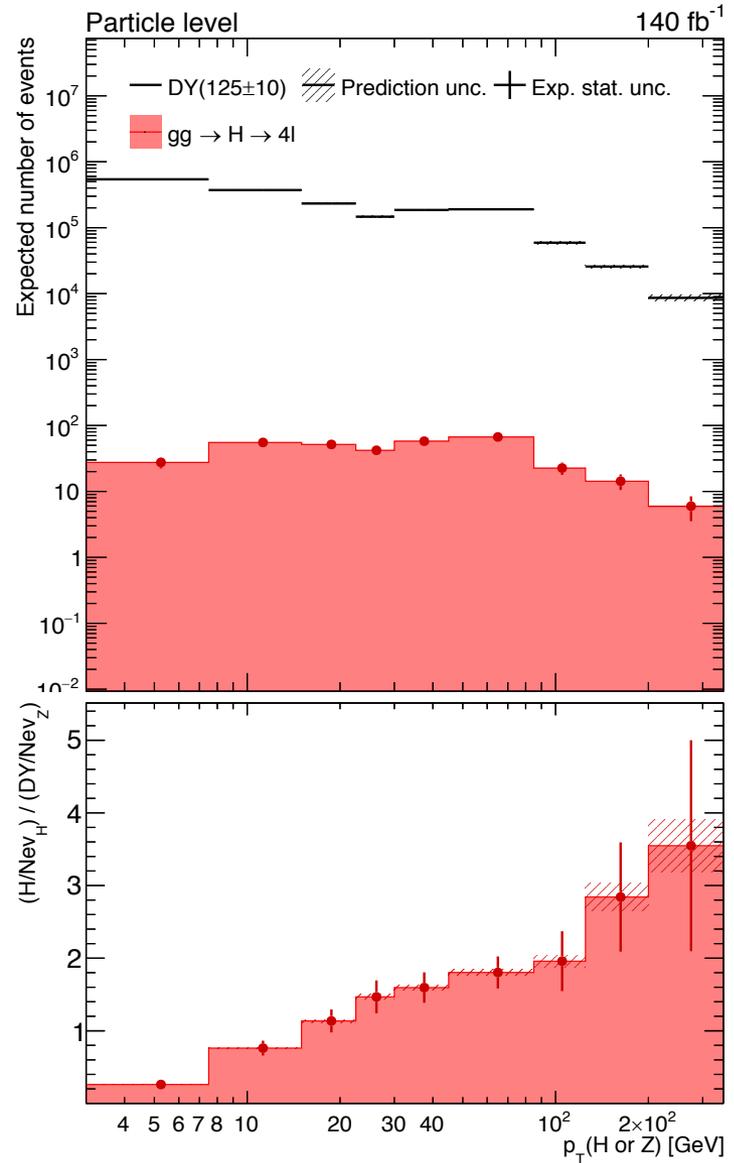
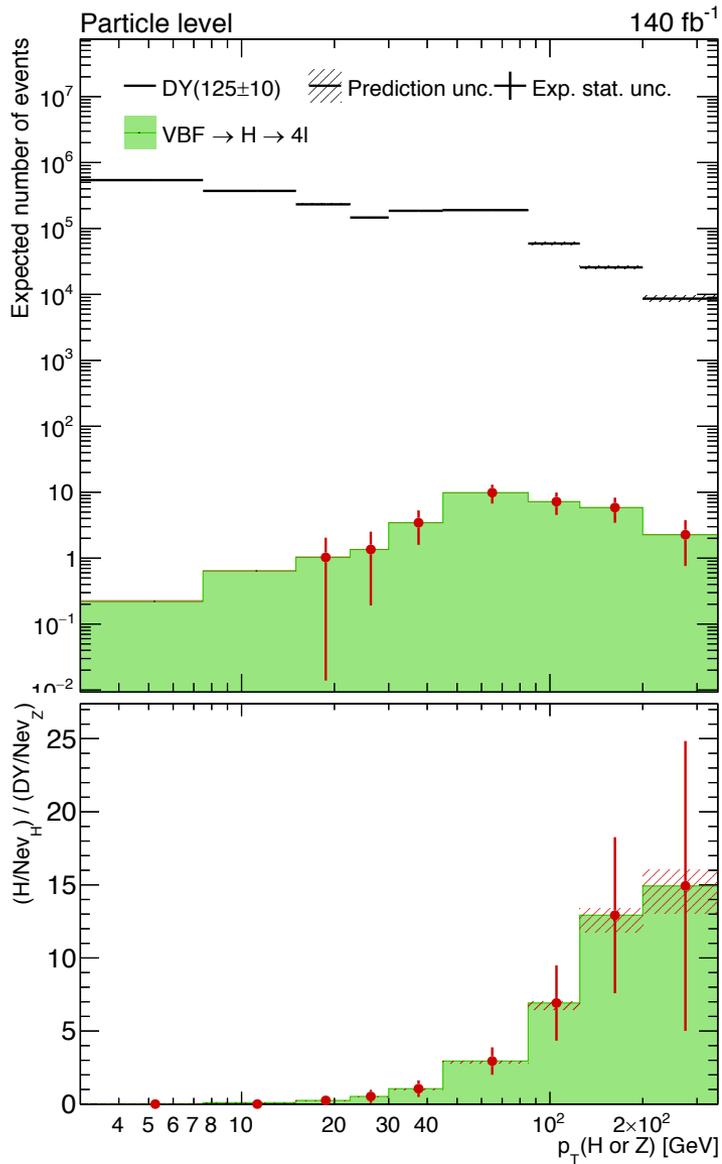
[2] RunIIFall17MiniAOD-94X_mc2017_realistic_v10-v2

Table 1: List of samples used in this Note.

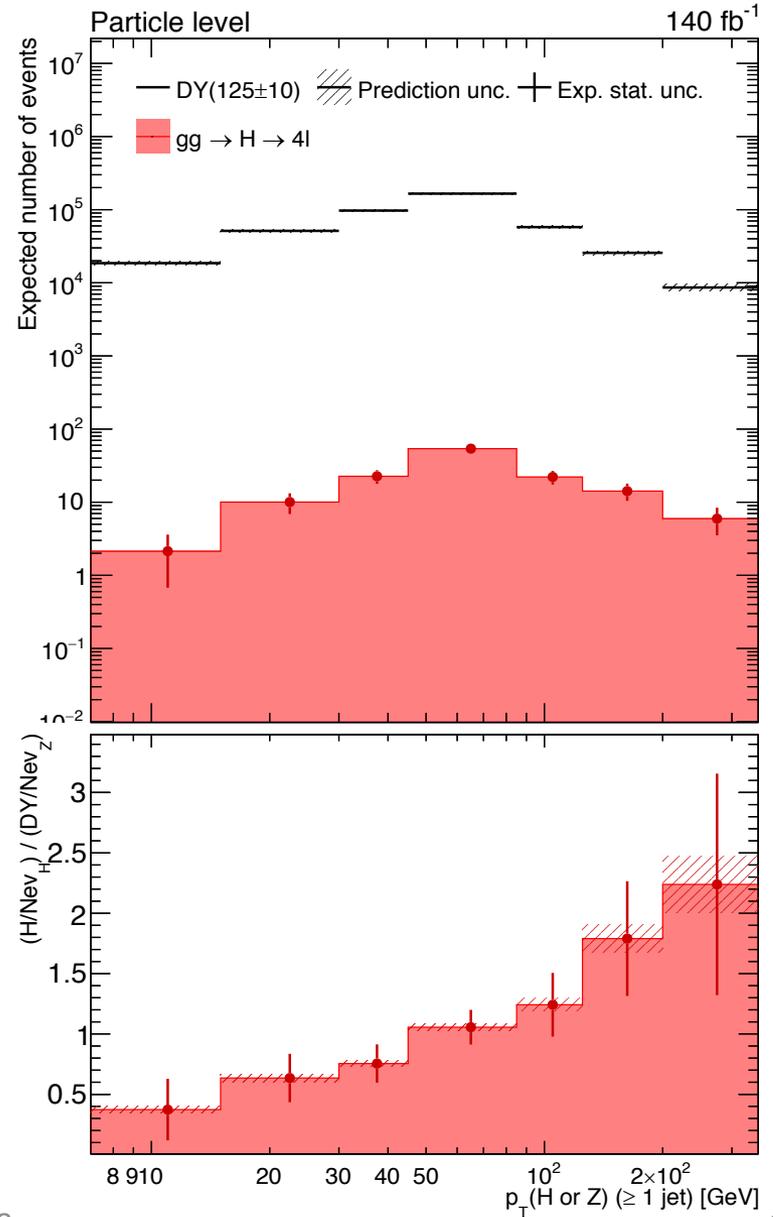
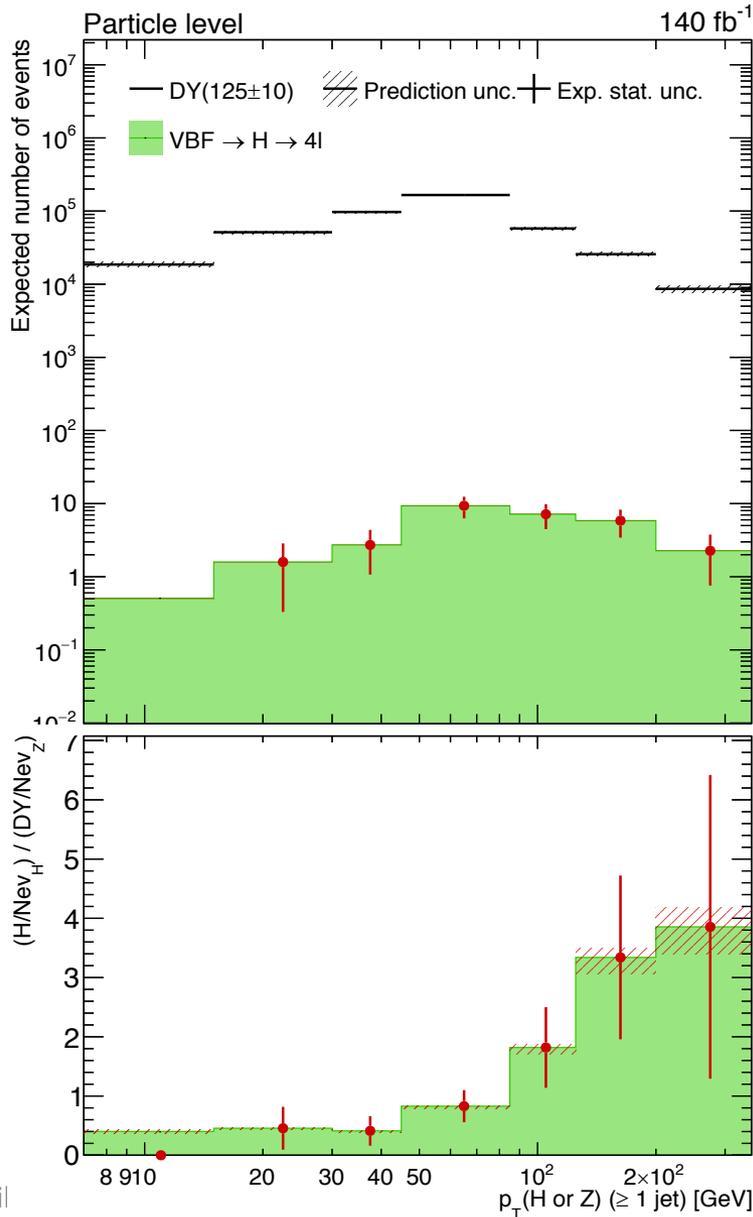
jet multiplicity, VBF vs ggH



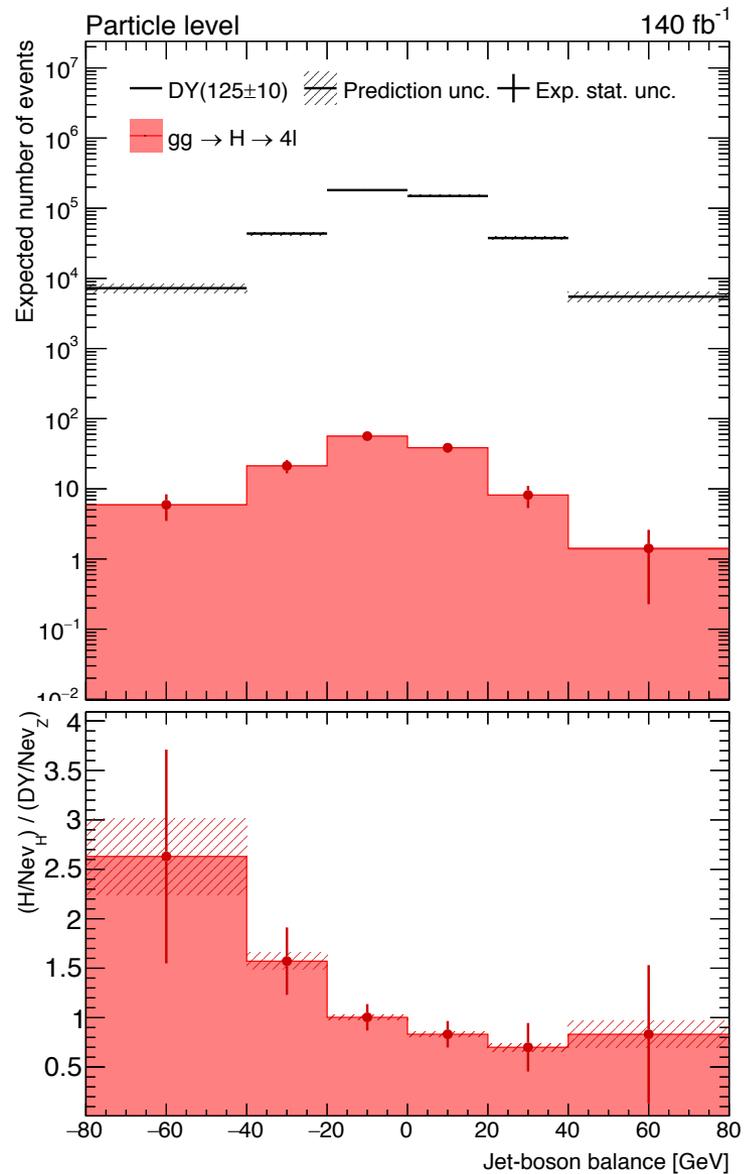
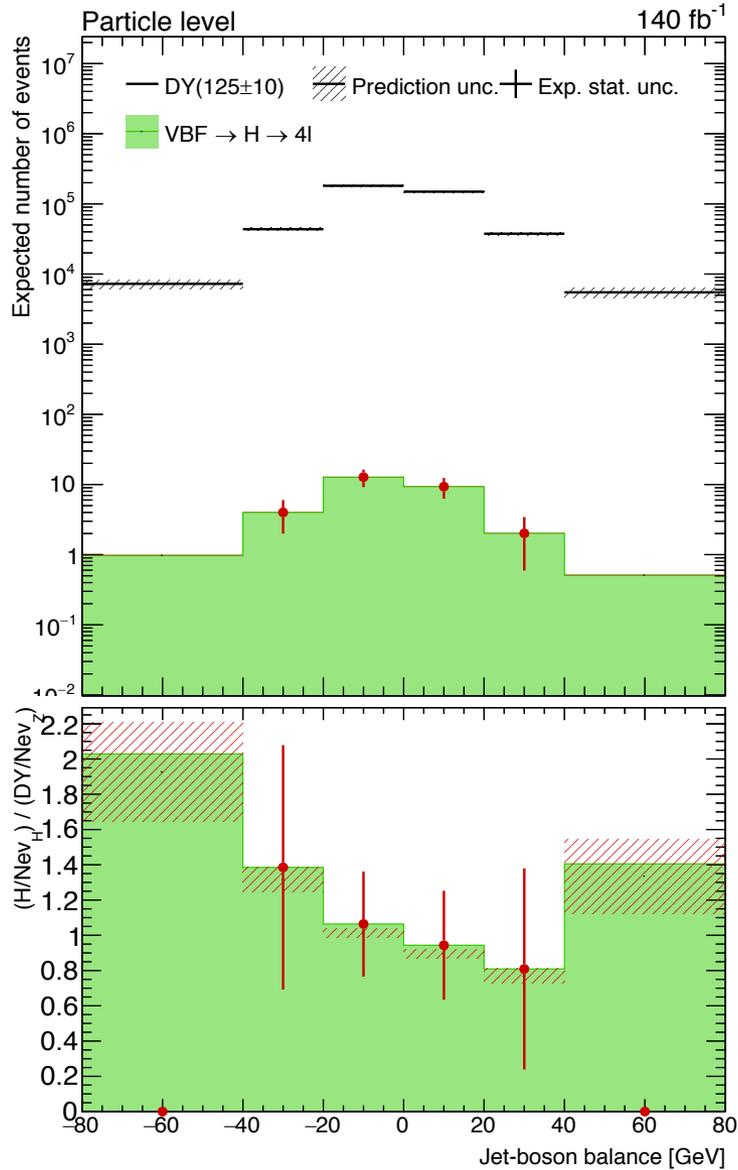
Boson p_T , VBF vs ggH



B + 1j: Boson p_T , VBF vs ggH



B + 1j: JBB



B + 1j: P_T bal

