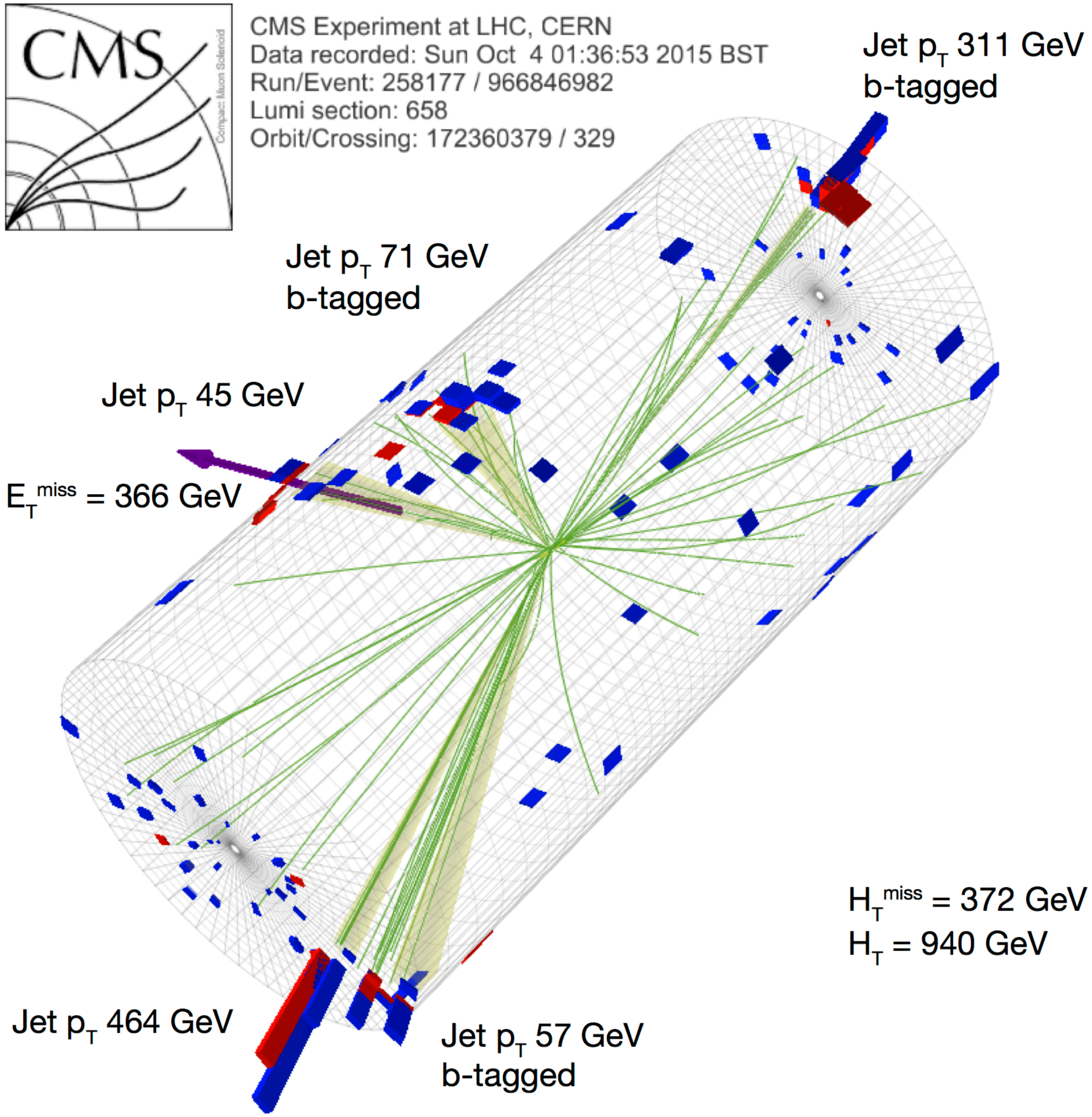
Search for new physics in the multijet and missing transverse momentum channel in $\sqrt{s} = 13$ TeV pp collisions with the α_T variable

Dominic Smith for the CMS collaboration

17th December 2015

Outline

- Introduction
  - Overview
- Analysis Strategy
- Control Regions
  - Background Estimation
- Systematic Uncertainties
- Results and Interpretations



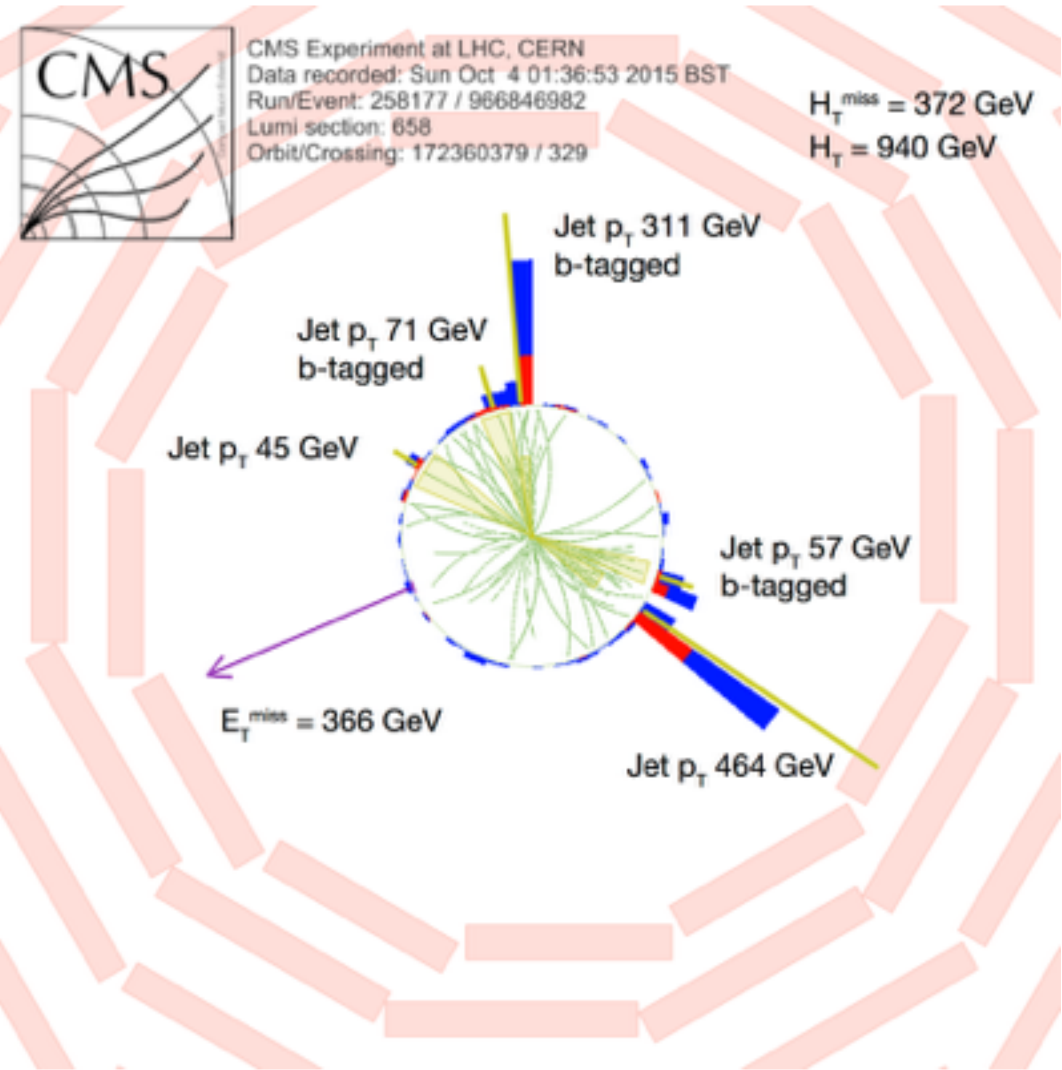
Preliminary Result
Soon to appear in CDS: **SUS-15-005**

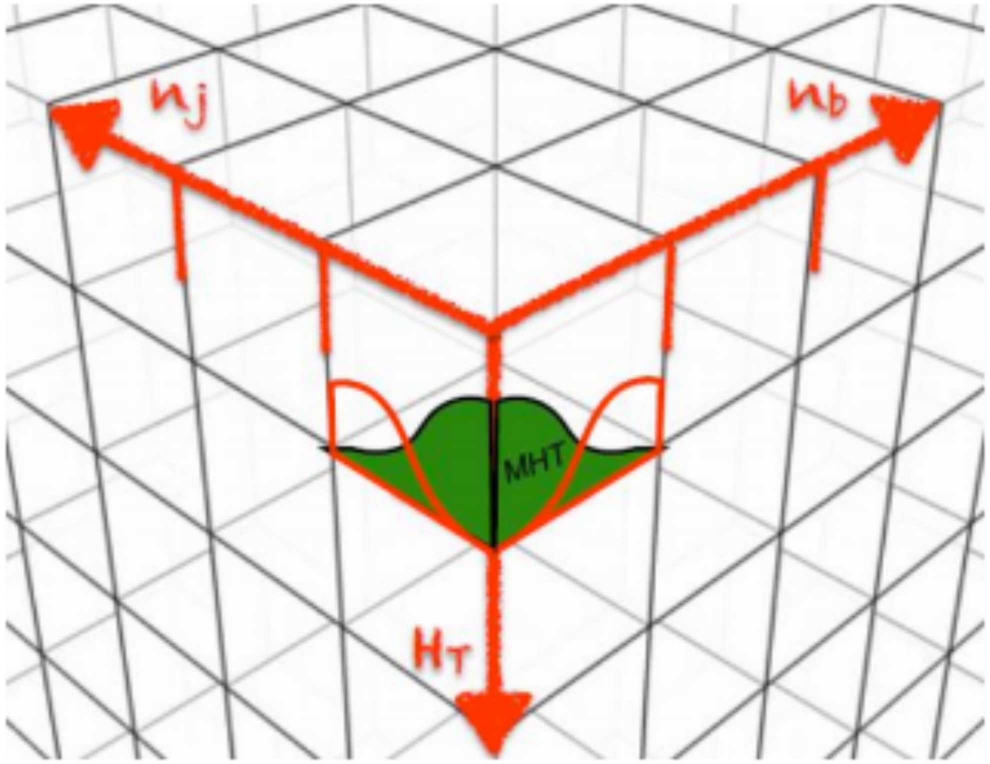
Introduction
Overview

- Target pair production of gluinos and squarks in hadronic final states

- R-parity conserving SUSY
  - Cascade decays to LSP
  - **Jets + missing energy final states**

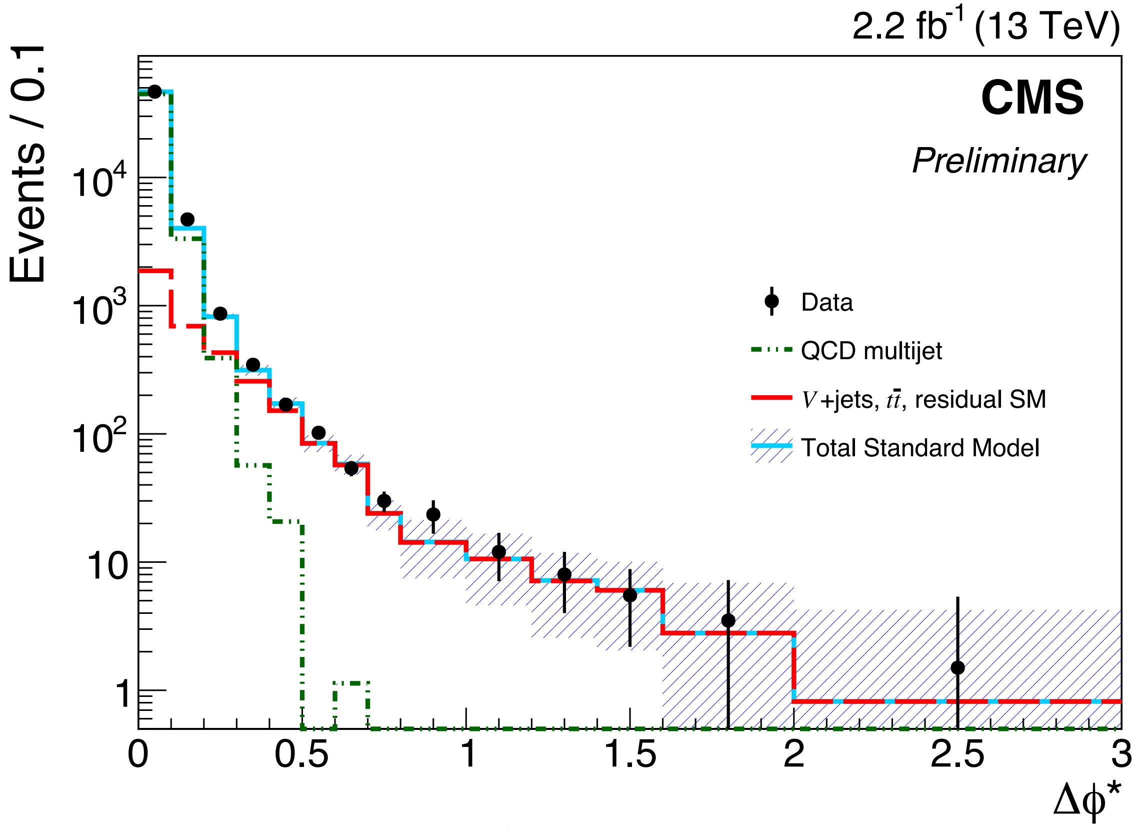
- Key analysis principles
  - Dedicated triggers for high acceptance
  - Low thresholds on jet activity
  - Consider all jet/ b-tag multiplicities
  - Four dimensional binning in n_{jet}, n_b, H_T, MHT to maximise coverage





Analysis Strategy

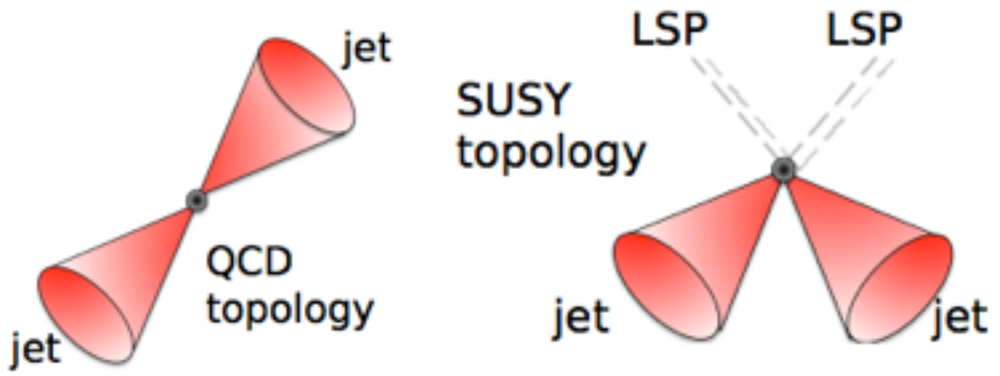
- To suppress multijets
  - With α_T and $\Delta\phi^*$
  - Utilise control samples for backgrounds
- Discriminating variables provide sensitivity to variety of models
  - Binning in n_{jet}, n_b, H_T, MHT



- $\Delta\phi^*_j = \Delta\phi\left(\vec{p_{Tj}}, -\sum_{i\neq j}\vec{p_{Ti}}\right)$
- Aim to find events where MHT in same direction as mis-measured jet
- Mis-measured jets and jets with significant neutrino component peak at low values

Di-Jet

$$\alpha_T = \frac{E_T^{j_2}}{M_T}$$

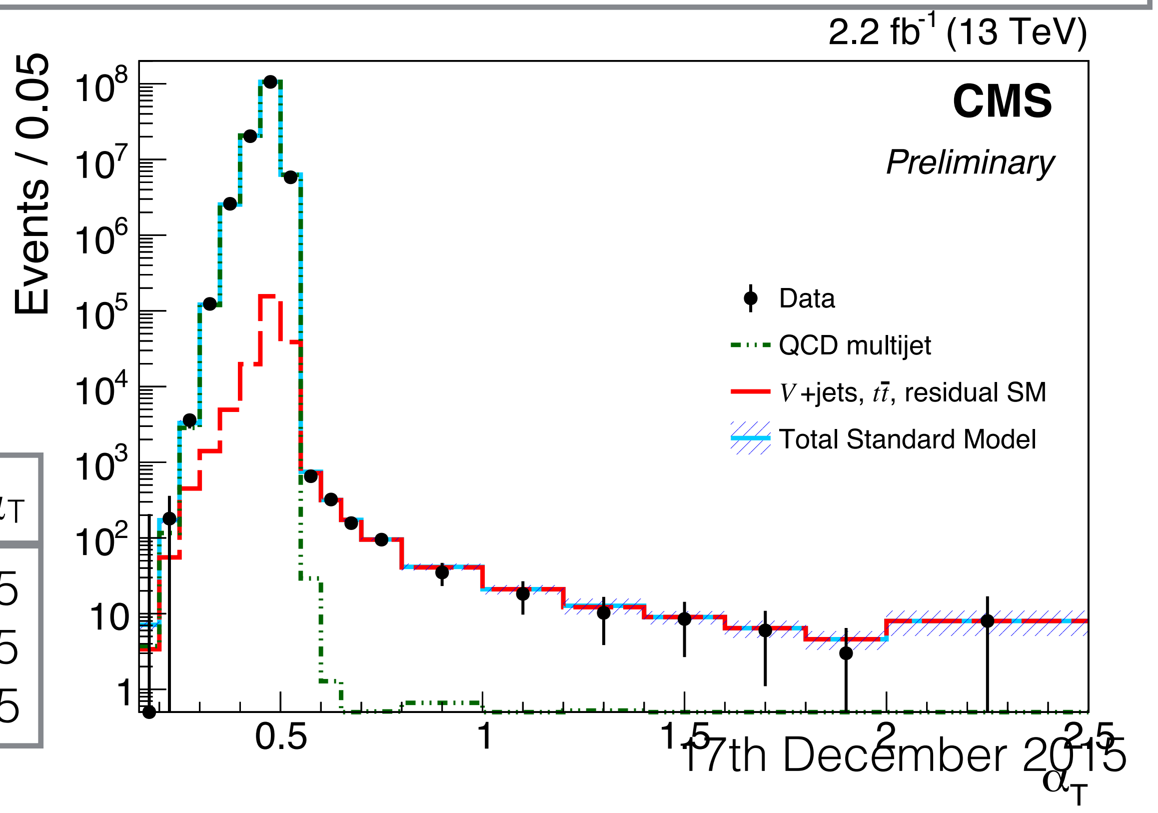


Multi-Jet

$$\alpha_T = \frac{1}{2} \times \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - H_T^{miss\,2}}}$$

α_T

- back-to-back events: 0.5
- "unbalanced" events: < 0.5
- genuine MET events: > 0.5

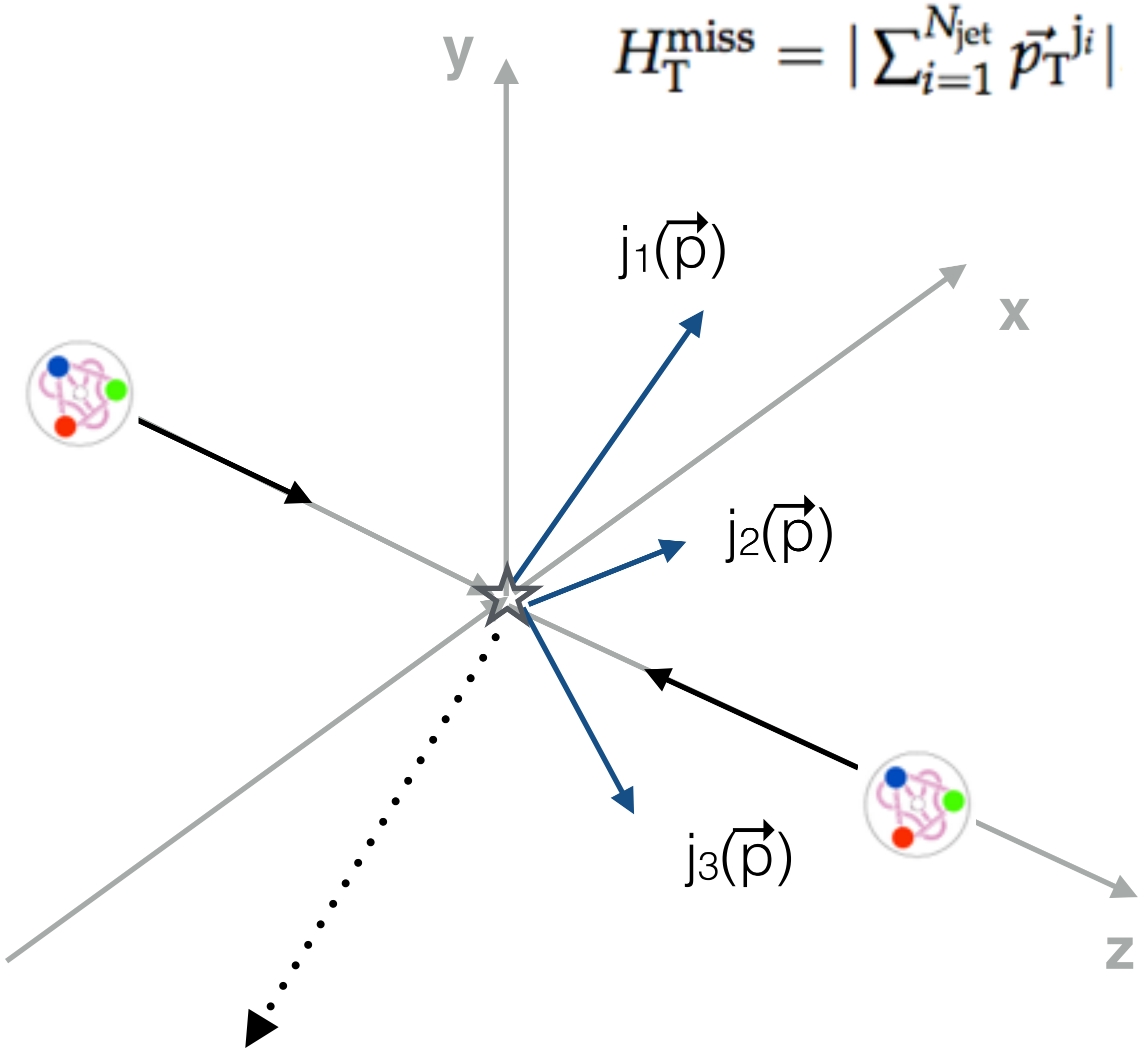


Analysis Strategy
Selection

$$H_T = \sum_{i=1}^{n_{jet}} E_T^{j_i}$$

$$H_T^{miss} = \left| \sum_{i=1}^{N_{jet}} \vec{p}_T^{\,j_i} \right|$$

- Baseline Selection:
  - Veto all leptons including leptonic taus (+1 prong taus)
  - $N_{jet} >= 1$
  - Leading jet $p_T > 100$ GeV, $|\eta| < 2.5$
  - Sub-leading jet $p_T > 40$ GeV, $|\eta| < 3$
  - $H_T > 200$ GeV
  - MHT > 130 GeV
  - MHT/MET < 1.25



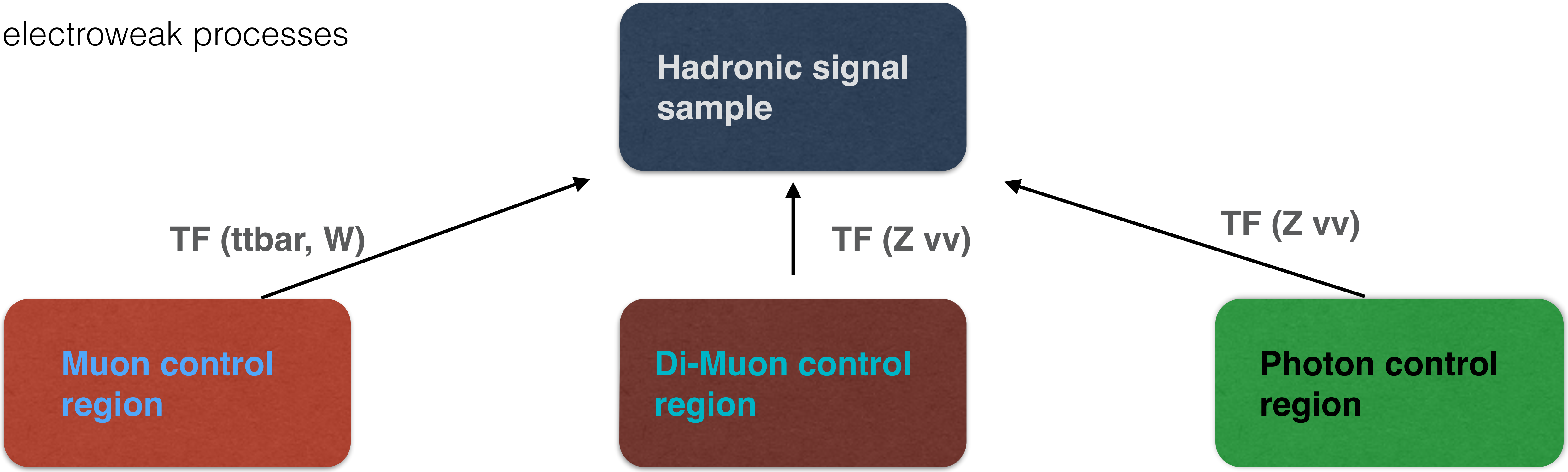
Categorisation

Monojet:	$p_T(j_2) < 40$ GeV
Asymmetric:	$40 < p_T(j_2) < 100$ GeV
Symmetric:	$p_T(j_2) > 100$ GeV

Control Regions
Background estimations

- Estimate the backgrounds in Signal Region
- n_{jet}, n_{b}, H_T binning identical to signal region
- Rely on transfer factors for estimations of electroweak processes

$$N^{\mathrm{signal}}_{\mathrm{pred}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}}) = \overset{\text{TF}}{\boxed{\frac{N^{\mathrm{signal}}_{\mathrm{MC}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})}{N^{\mathrm{control}}_{\mathrm{MC}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})}}} \times N^{\mathrm{control}}_{\mathrm{obs}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})$$



Hadronic signal sample

TF (ttbar, W)

TF (Z vv)

TF (Z vv)

Muon control region

Di-Muon control region

Photon control region

- Remaining multijet background assessed using QCD enriched sideband

- Systematic uncertainties on transfer factor derived from closure tests
  - Designed to probe potential biases from specific physics processes

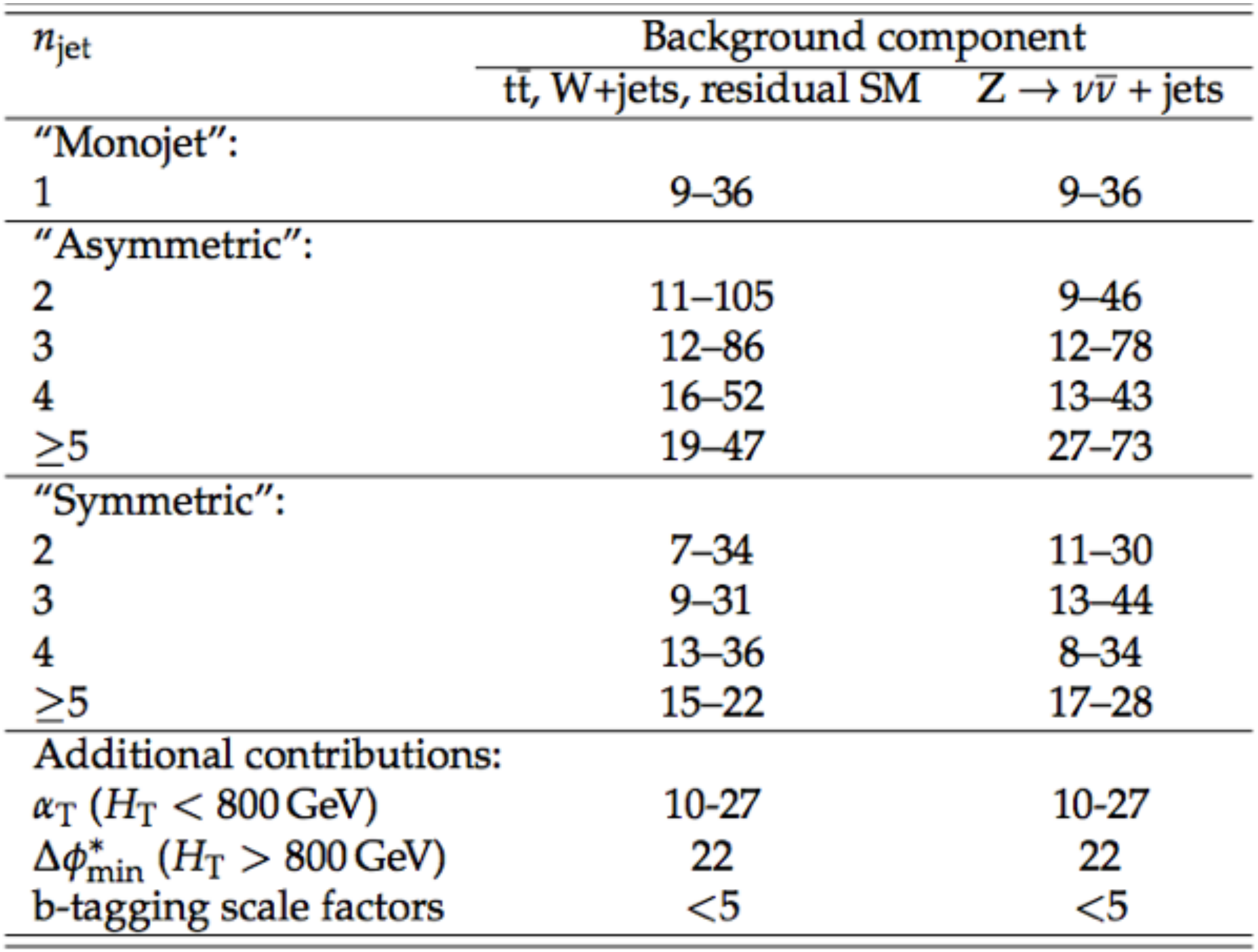
Systematic Uncertainties

- Electroweak background systematics:
    - TF uncertainties: 10-40% (sym/mono), 10-100% (asym)
        - Uncorrelated in (n_{jet}, n_b, H_T)

- Multijet systematics

  from background predictions

  dealt with separately

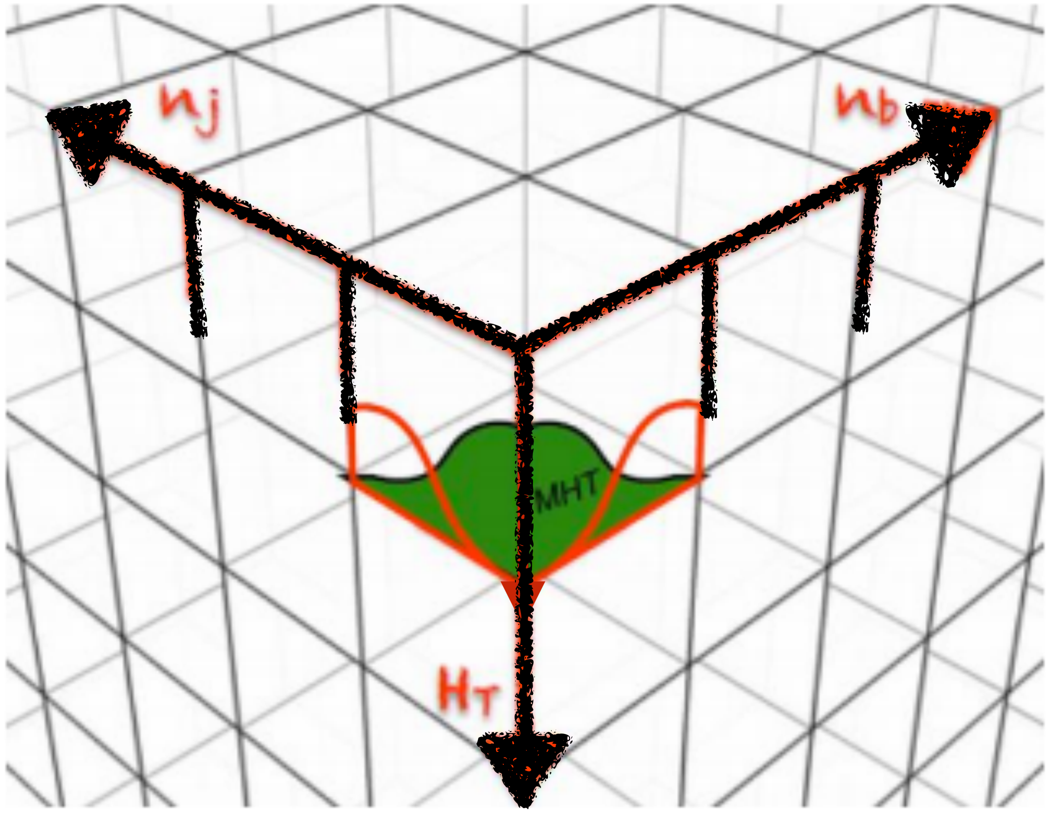


n_{jet}	Background component	
	$t\bar{t}$, W+jets, residual SM	$Z \to \nu\bar{\nu}$ + jets
"Monojet":		
1	9–36	9–36
"Asymmetric":		
2	11–105	9–46
3	12–86	12–78
4	16–52	13–43
$\geq$5	19–47	27–73
"Symmetric":		
2	7–34	11–30
3	9–31	13–44
4	13–36	8–34
$\geq$5	15–22	17–28
Additional contributions:		
α_T ($H_T < 800\,\text{GeV}$)	10-27	10-27
$\Delta\phi^*_{\text{min}}$ ($H_T > 800\,\text{GeV}$)	22	22
b-tagging scale factors	<5	<5

Results

Statistical treatment

- Binned likelihood model of signal and control region observations
  - Correlation and statistical uncertainties propagated throughout via dedicated parameters
  - Signal contamination accounted for
- Systematics uncertainties are encoded as log-normal nuisances
  - Transfer factor systematics are uncorrelated in n_{jet}, H_T, n_b
- Limits computed with the asymptotic CLs method



Results

Symmetric categories

Monojet: $p_T(j_2) < 40$ GeV

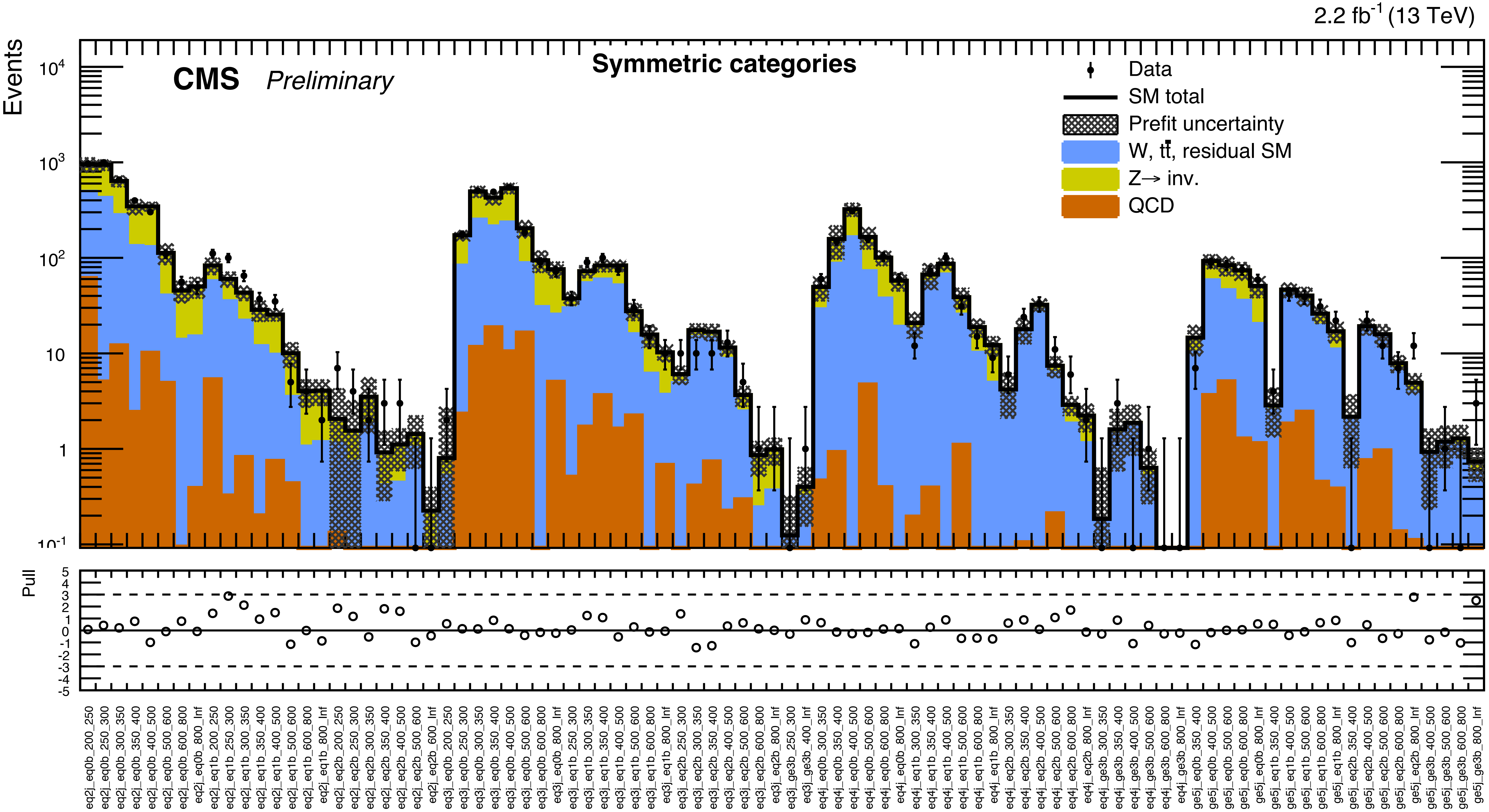
Asymmetric: $40 < p_T(j_2) < 100$ GeV

Symmetric: $p_T(j_2) > 100$ GeV

		H_T (GeV)							
	(n_{jet}, n_b)	200-250	250-300	300-350	350-400	400-500	500-600	600-800	800-∞
Data	(2, 0)	968	997	657	398	301	110	56	49
SM post-fit	(2, 0)	969.9 ± 51.2	996.4 ± 36.2	656.8 ± 25.1	395.5 ± 18.7	312.3 ± 16.4	107.3 ± 10.6	53.1 ± 6.2	47.2 ± 6.4
SM pre-fit	(2, 0)	943.9 ± 134.2	938.4 ± 148.4	627.9 ± 86.0	341.4 ± 61.3	329.1 ± 38.4	105.2 ± 24.3	43.8 ± 12.2	44.4 ± 11.4
Data	(2, 1)	111	100	65	37	35	5	4	2
SM post-fit	(2, 1)	104.2 ± 9.5	87.1 ± 8.1	54.9 ± 6.0	33.4 ± 4.4	26.4 ± 2.8	8.1 ± 1.6	4.2 ± 1.2	3.4 ± 0.9
SM pre-fit	(2, 1)	80.9 ± 16.0	57.9 ± 11.1	40.8 ± 7.3	26.8 ± 5.7	24.1 ± 3.7	9.5 ± 2.7	4.0 ± 1.4	3.7 ± 1.3
Data	(2, 2)	7	4	2	3	3	0	0	–
SM post-fit	(2, 2)	4.6 ± 1.8	2.7 ± 1.2	3.0 ± 1.3	1.5 ± 0.7	1.4 ± 0.4	1.0 ± 0.5	0.2 ± 0.2	–
SM pre-fit	(2, 2)	1.1 ± 2.3	0.8 ± 1.9	3.4 ± 2.0	0.7 ± 0.8	1.1 ± 0.5	1.3 ± 0.8	0.2 ± 0.2	–
Data	(3, 0)	2	176	505	491	547	185	90	72
SM post-fit	(3, 0)	1.4 ± 1.4	175.8 ± 13.3	504.3 ± 26.5	484.8 ± 20.5	541.3 ± 24.0	189.0 ± 15.3	89.9 ± 8.2	71.0 ± 7.2
SM pre-fit	(3, 0)	0.0 ± 2.4	173.6 ± 26.2	491.8 ± 63.6	421.9 ± 58.6	499.2 ± 65.1	195.4 ± 36.8	89.5 ± 23.7	68.0 ± 11.6
Data	(3, 1)	–	38	90	100	76	30	15	10
SM post-fit	(3, 1)	–	38.1 ± 4.1	82.0 ± 7.4	93.7 ± 7.0	79.3 ± 6.8	27.3 ± 3.6	15.2 ± 2.8	9.6 ± 1.6
SM pre-fit	(3, 1)	–	37.9 ± 6.3	70.5 ± 11.1	81.2 ± 11.9	79.2 ± 11.6	26.4 ± 5.9	15.3 ± 4.1	9.2 ± 2.0
Data	(3, 2)	–	10	10	10	13	5	1	1
SM post-fit	(3, 2)	–	6.9 ± 1.5	15.3 ± 2.3	15.8 ± 2.1	12.0 ± 1.8	3.6 ± 0.7	0.8 ± 0.3	1.0 ± 0.3
SM pre-fit	(3, 2)	–	5.9 ± 1.7	17.5 ± 3.2	16.4 ± 3.0	11.3 ± 2.2	3.4 ± 1.0	0.8 ± 0.3	0.9 ± 0.3
Data	$(3, \geq 3)$	–	0	–	–	1	–	–	–
SM post-fit	$(3, \geq 3)$	–	0.1 ± 0.2	–	–	0.5 ± 0.2	–	–	–
SM pre-fit	$(3, \geq 3)$	–	0.0 ± 0.3	–	–	0.4 ± 0.2	–	–	–
Data	(4, 0)	–	–	60	148	308	157	104	60
SM post-fit	(4, 0)	–	–	57.4 ± 7.5	149.5 ± 14.3	309.1 ± 16.5	156.9 ± 12.4	102.2 ± 9.6	56.6 ± 6.2
SM pre-fit	(4, 0)	–	–	48.8 ± 14.1	163.1 ± 65.7	301.0 ± 46.9	155.8 ± 36.3	96.5 ± 19.1	52.8 ± 11.3
Data	(4, 1)	–	–	12	72	101	31	15	9
SM post-fit	(4, 1)	–	–	15.3 ± 2.7	71.5 ± 8.5	94.5 ± 7.6	34.2 ± 4.3	18.1 ± 2.6	11.3 ± 1.8
SM pre-fit	(4, 1)	–	–	19.9 ± 6.3	67.1 ± 19.0	84.6 ± 11.7	36.9 ± 8.3	18.4 ± 4.3	11.6 ± 2.5
Data	(4, 2)	–	–	6	24	34	11	6	2
SM post-fit	(4, 2)	–	–	4.6 ± 1.5	21.6 ± 3.8	33.5 ± 3.8	8.1 ± 1.6	3.1 ± 0.6	2.1 ± 0.5
SM pre-fit	(4, 2)	–	–	3.6 ± 2.0	17.2 ± 5.8	31.9 ± 5.0	7.3 ± 2.1	2.8 ± 0.7	2.1 ± 0.6
Data	$(4, \geq 3)$	–	–	0	3	0	1	0	0
SM post-fit	$(4, \geq 3)$	–	–	0.2 ± 0.3	2.1 ± 0.9	1.2 ± 0.6	0.7 ± 0.3	0.1 ± 0.1	0.1 ± 0.0
SM pre-fit	$(4, \geq 3)$	–	–	0.0 ± 0.4	1.5 ± 1.1	1.5 ± 0.8	0.6 ± 0.4	0.0 ± 0.1	0.0 ± 0.0
Data	$(\geq 5, 0)$	–	–	–	7	89	84	75	59
SM post-fit	$(\geq 5, 0)$	–	–	–	10.3 ± 2.6	88.1 ± 9.1	81.3 ± 8.2	74.4 ± 7.0	58.3 ± 6.6
SM pre-fit	$(\geq 5, 0)$	–	–	–	15.3 ± 5.9	86.1 ± 13.1	78.1 ± 20.0	71.0 ± 14.4	46.2 ± 12.8
Data	$(\geq 5, 1)$	–	–	–	4	42	39	31	21
SM post-fit	$(\geq 5, 1)$	–	–	–	3.0 ± 1.0	43.3 ± 5.0	38.9 ± 4.6	27.8 ± 3.2	20.0 ± 3.3
SM pre-fit	$(\geq 5, 1)$	–	–	–	2.5 ± 1.5	44.1 ± 8.0	38.9 ± 8.7	25.3 ± 5.6	15.8 ± 3.5
Data	$(\geq 5, 2)$	–	–	–	0	22	12	7	12
SM post-fit	$(\geq 5, 2)$	–	–	–	1.4 ± 0.8	20.1 ± 3.2	14.6 ± 2.3	7.7 ± 1.2	6.6 ± 1.3
SM pre-fit	$(\geq 5, 2)$	–	–	–	2.1 ± 1.3	18.8 ± 4.1	15.4 ± 3.8	7.6 ± 1.9	4.6 ± 1.2
Data	$(\geq 5, \geq 3)$	–	–	–	–	0	1	0	3
SM post-fit	$(\geq 5, \geq 3)$	–	–	–	–	0.7 ± 0.5	1.2 ± 0.5	1.3 ± 0.4	1.1 ± 0.4
SM pre-fit	$(\geq 5, \geq 3)$	–	–	–	–	0.7 ± 0.7	1.2 ± 0.7	1.4 ± 0.5	0.8 ± 0.3

Results

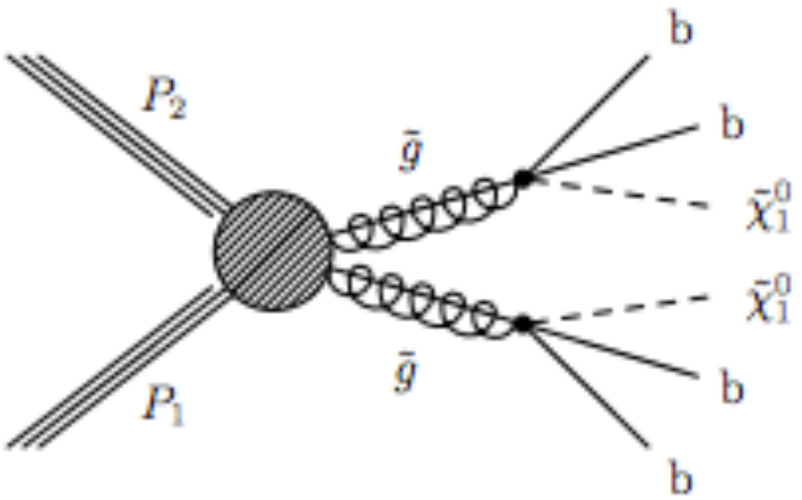
Symmetric categories



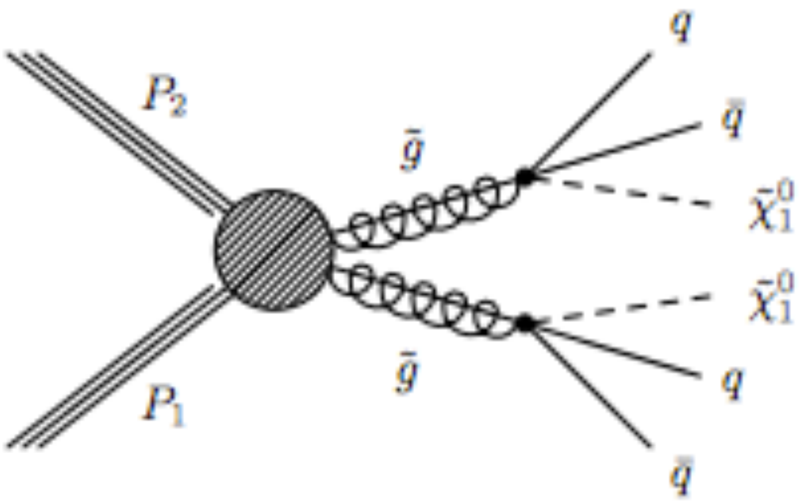
Results

SUSY Interpretation

- Search interpreted in the framework of simplified models (SMS)
    - Direct cascade with 100% branching fractions
- 2 gluino pair-produced models are considered
    - T1bbbb: gluino → b b + LSP
    - T1qqqq: gluino → q q + LSP



T1bbbb

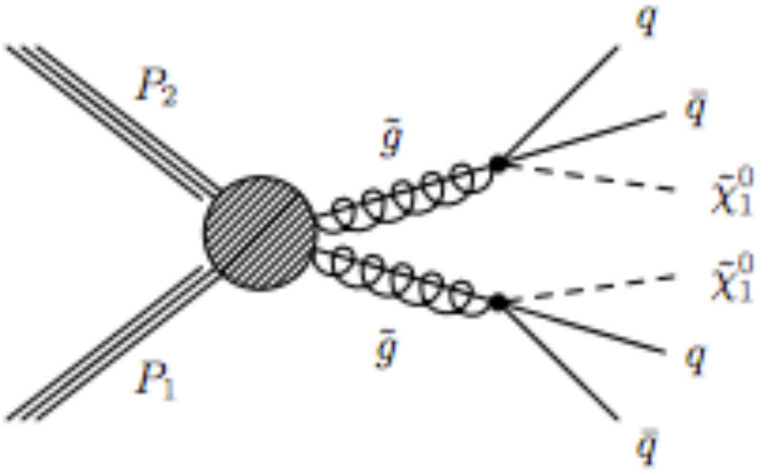


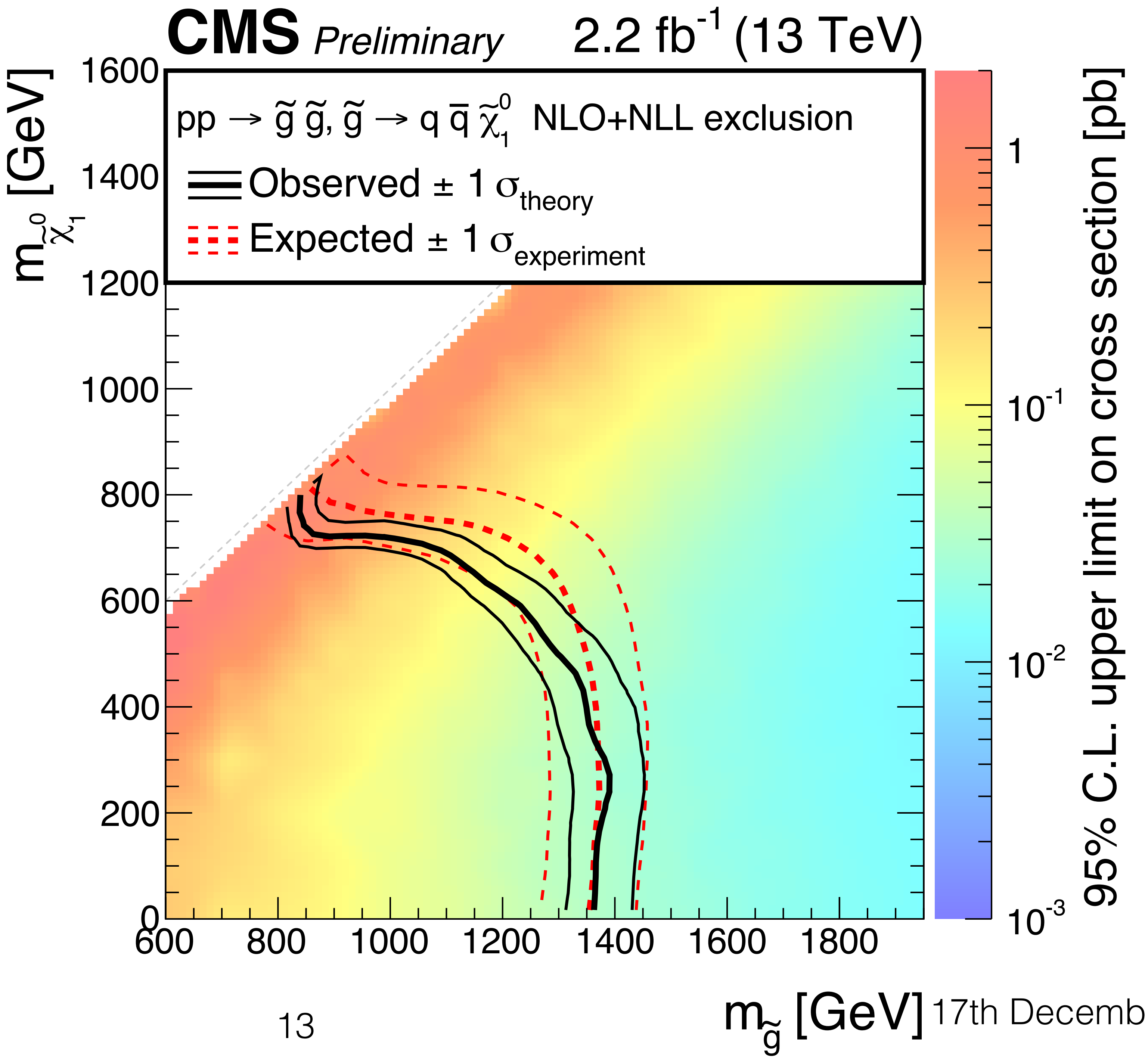
T1qqqq

Results
Scan

- Expected/ observed exclusion are in reasonable agreement
- At low m_{LSP}, we exclude up to m_{Gluino} ≃ **1.4 TeV**

T1qqqq scan



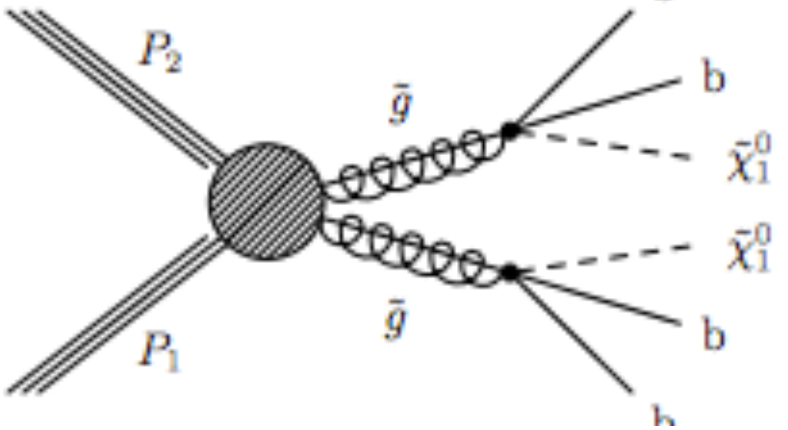


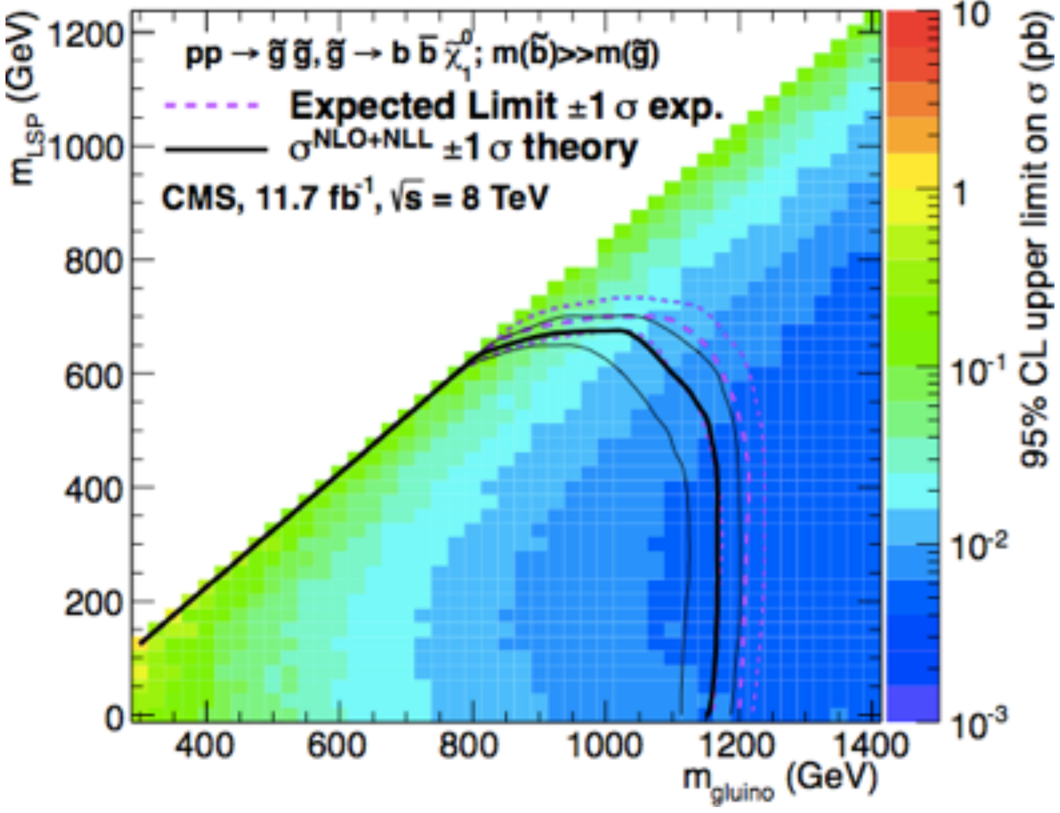
Results

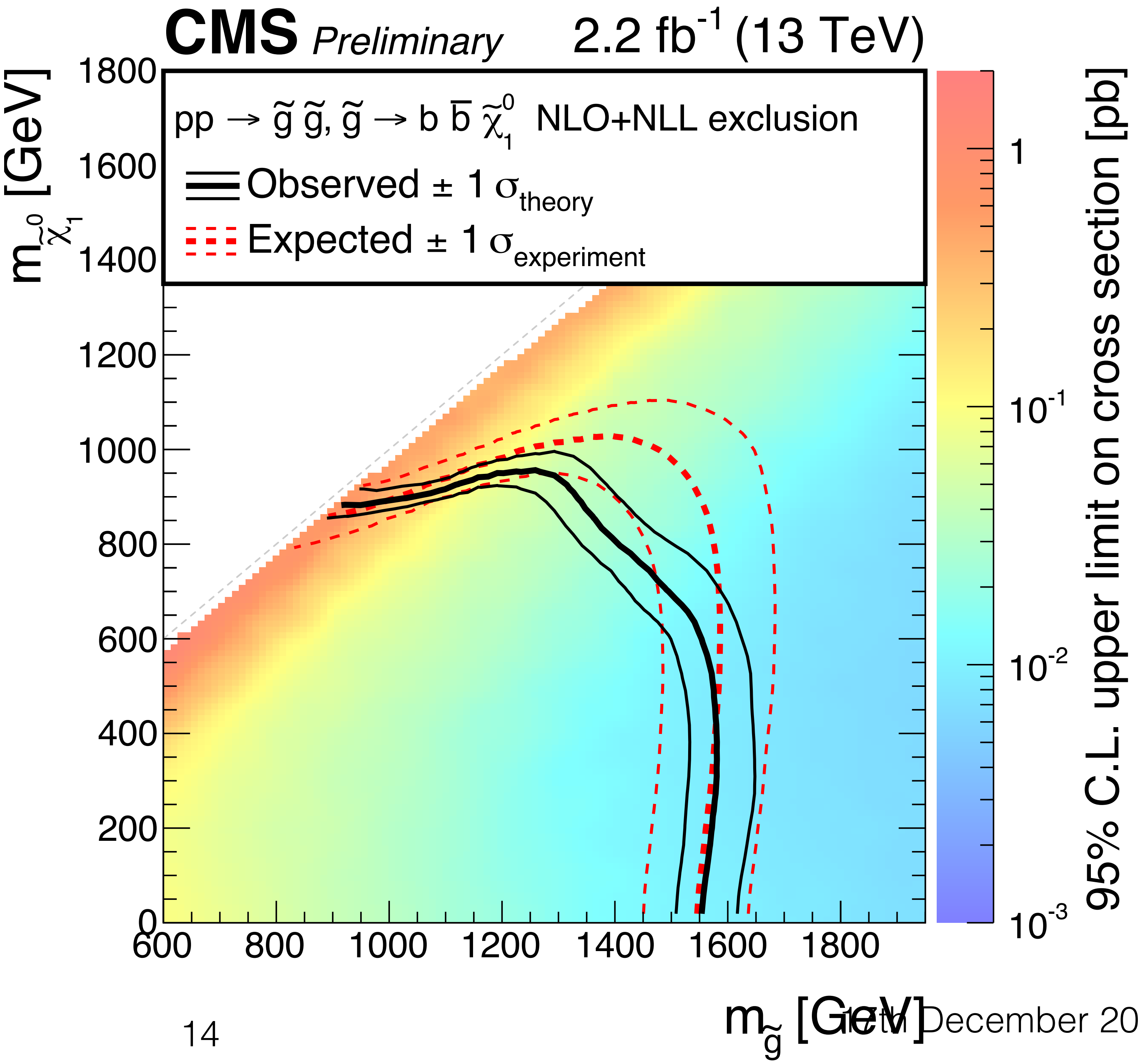
Scan

- Expected/ observed exclusion are in reasonable agreement
- At low m_{LSP}, we exclude up to m_{Gluino} ≃ **1.6 TeV**

T1bbbb scan







Conclusion

- Results of the α_T analysis on the 13 TeV dataset (2.2 fb^{-1}) have been presented
  - Interpreted in the context of SUSY simplified models
- No significant excess is observed and limits are set in the m_{Gluino}, m_{LSP} parameter space
  - For low m_{LSP} masses, m_{Gluino} up to 1.4-1.6 TeV are excluded

- Future studies underway
  - Including additional control samples
  - Utilising modern jet tools to deconstruct complicated final states

Backup

Analysis Strategy

- Triggers:
  - 5 dedicated HT-AlphaT cross-triggers + pure H_T and MHT/MET cross triggers
  - Efficiencies determined in SR-like phase space with lepton reference triggers
  - Triggers near to or in the efficiency plateau after full analysis selection
- Baseline Selection:
  - $N_{jet} >= 1$
  - Leading jet $p_T > 100$ GeV, $|\eta| < 2.5$
  - Sub-leading jet $p_T > 40$ GeV, $|\eta| < 3$
  - $H_T > 200$ GeV
  - MHT > 130 GeV
  - Forward jet veto:
    - $p_T > 40$ GeV, $|\eta| > 3$
  - Isolated track veto:
    - $p_T > 10$ GeV, $|\eta| < 2.5$
  - MHT/MET < 1.25
  - Recommend MET filters

Categorisation

Monojet: $p_T(j_2) < 40$ GeV

Asymmetric: $40 < p_T(j_2) < 100$ GeV

Symmetric: $p_T(j_2) > 100$ GeV

Analysis Strategy

Event Selection

Signal

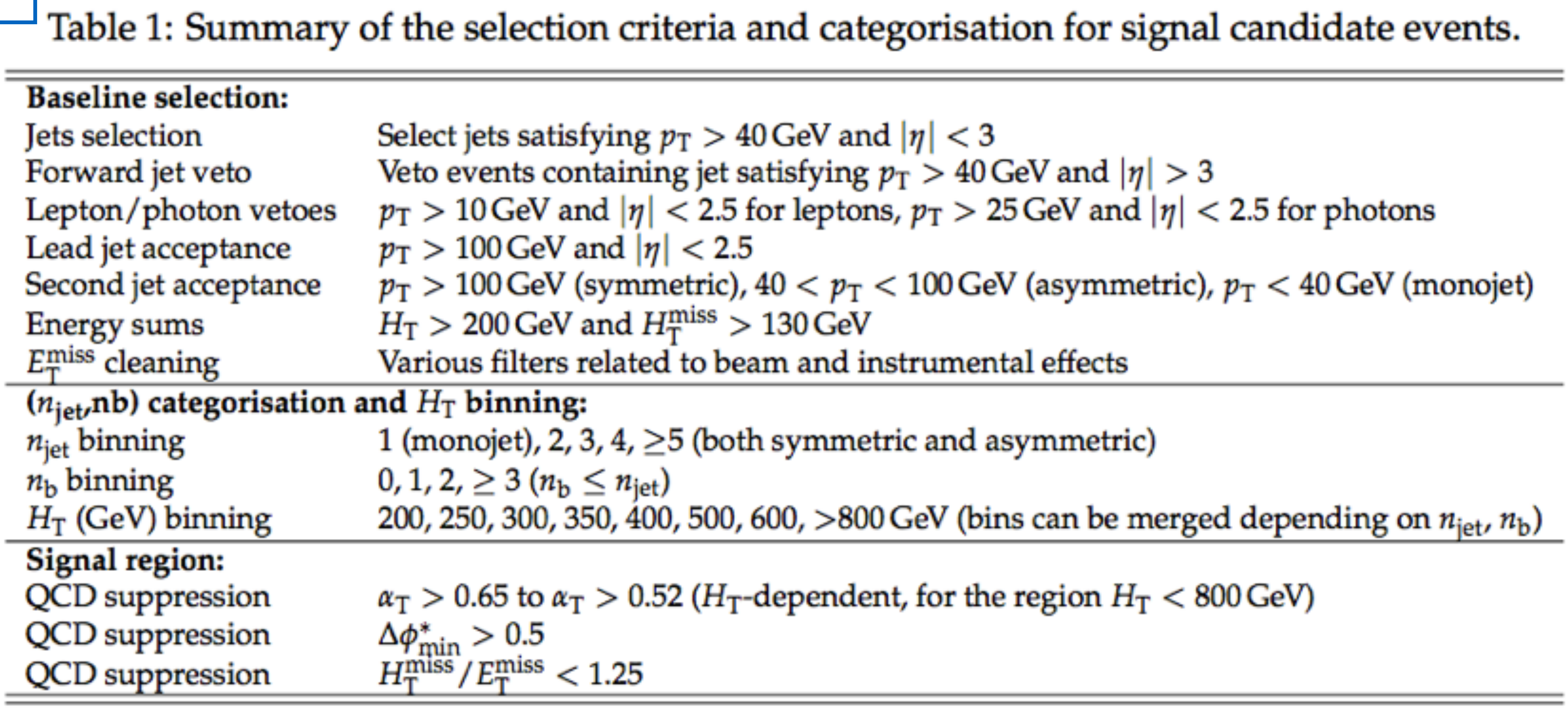


Table 1: Summary of the selection criteria and categorisation for signal candidate events.

Baseline selection:	
Jets selection	Select jets satisfying $p_T > 40\,\mathrm{GeV}$ and $\|\eta\| < 3$
Forward jet veto	Veto events containing jet satisfying $p_T > 40\,\mathrm{GeV}$ and $\|\eta\| > 3$
Lepton/photon vetoes	$p_T > 10\,\mathrm{GeV}$ and $\|\eta\| < 2.5$ for leptons, $p_T > 25\,\mathrm{GeV}$ and $\|\eta\| < 2.5$ for photons
Lead jet acceptance	$p_T > 100\,\mathrm{GeV}$ and $\|\eta\| < 2.5$
Second jet acceptance	$p_T > 100\,\mathrm{GeV}$ (symmetric), $40 < p_T < 100\,\mathrm{GeV}$ (asymmetric), $p_T < 40\,\mathrm{GeV}$ (monojet)
Energy sums	$H_T > 200\,\mathrm{GeV}$ and $H_T^{miss} > 130\,\mathrm{GeV}$
E_T^{miss} cleaning	Various filters related to beam and instrumental effects
(n_{jet},nb) categorisation and H_T binning:	
n_{jet} binning	1 (monojet), 2, 3, 4, $\geq$5 (both symmetric and asymmetric)
n_b binning	$0, 1, 2, \geq 3$ ($n_b \leq n_{jet}$)
H_T (GeV) binning	200, 250, 300, 350, 400, 500, 600, >800 GeV (bins can be merged depending on n_{jet}, n_b)
Signal region:	
QCD suppression	$\alpha_T > 0.65$ to $\alpha_T > 0.52$ (H_T-dependent, for the region $H_T < 800\,\mathrm{GeV}$)
QCD suppression	$\Delta\phi^*_{min} > 0.5$
QCD suppression	$H_T^{miss}/E_T^{miss} < 1.25$

Muon and Photon CRs

- One (two) muon with $p_T > 30$ GeV, $|\eta| < 2.1$, or one photon $p_T > 200$ GeV
- Relative isolation requirement
- M_T (M_{ll}) cut compatible with W (Z) mass
- ΔR(lepton, jet) > 0.5 or ΔR(photon, jet) >1.0

MHT dimension

- Variables connected to the scale of the event (such as HT) show bias in Data/MC due to missing higher-order corrections
- Binning MHT distribution in HT can mitigate bias - ‘scale anchoring’
  - Designed to minimise the effects of missing theory higher-order corrections in MC
- Fit a linear function to Data/ MC(MHT) in each (Njet, nb, HT) bin in the control regions
- Use pull of linear term of function to determine level of bias
- Uncertainties on the fit parameters are used to determine the alternative templates in the SR

QCD Predictions

- Main background rejected by α_T, $\Delta\phi^*$ cuts, MHT/MET
- Sources of QCD contamination come from:
  - Large fluctuations in jet energy mis-measurements (rely on α_T, $\Delta\phi^*$)
  - Instrumental effects (inefficiencies, noise). Rely on MET filters, α_T, $\Delta\phi^*$
  - Jets below threshold (40 GeV) conspiring to high MHT (MHT/MET)
  - Heavy flavour leptonic decays ($\Delta\phi^*$)

- Residual contamination assessed using MHT/MET sideband (> 1.25)
- Construct MC ratio of multijet events passing and failing MHT/MET requirement: R
  - Obtain predicted data counts of QCD in sideband (use mu + jets to estimate EWK backgrounds)
  - Product of ratio and predicted data counts, gives predicted QCD in signal region (vs N_{jet}, H_T)
- Ratio is validated in $\Delta\phi^*$ sideband
- Contamination at percent level

MC Corrections from sidebands

- Correct the MC normalisation (e.g. due to limited perturbative orders in cross section calculation)

  via sidebands in, HT, MHT/ MET

- In closure tests, the transfer factor usually maps control regions with different background compositions
  - Any bias in the yields of the specific processes do not necessarily cancel out

- In the photon control region, using HT binned LO G+jets sample:
  - Derive correction from a 350 < HT < 400 GeV sideband
  - k-factor = (data - MCQCD)/MCGJets

Results

Asymmetric categories

Monojet: $p_T(j_2) < 40$ GeV

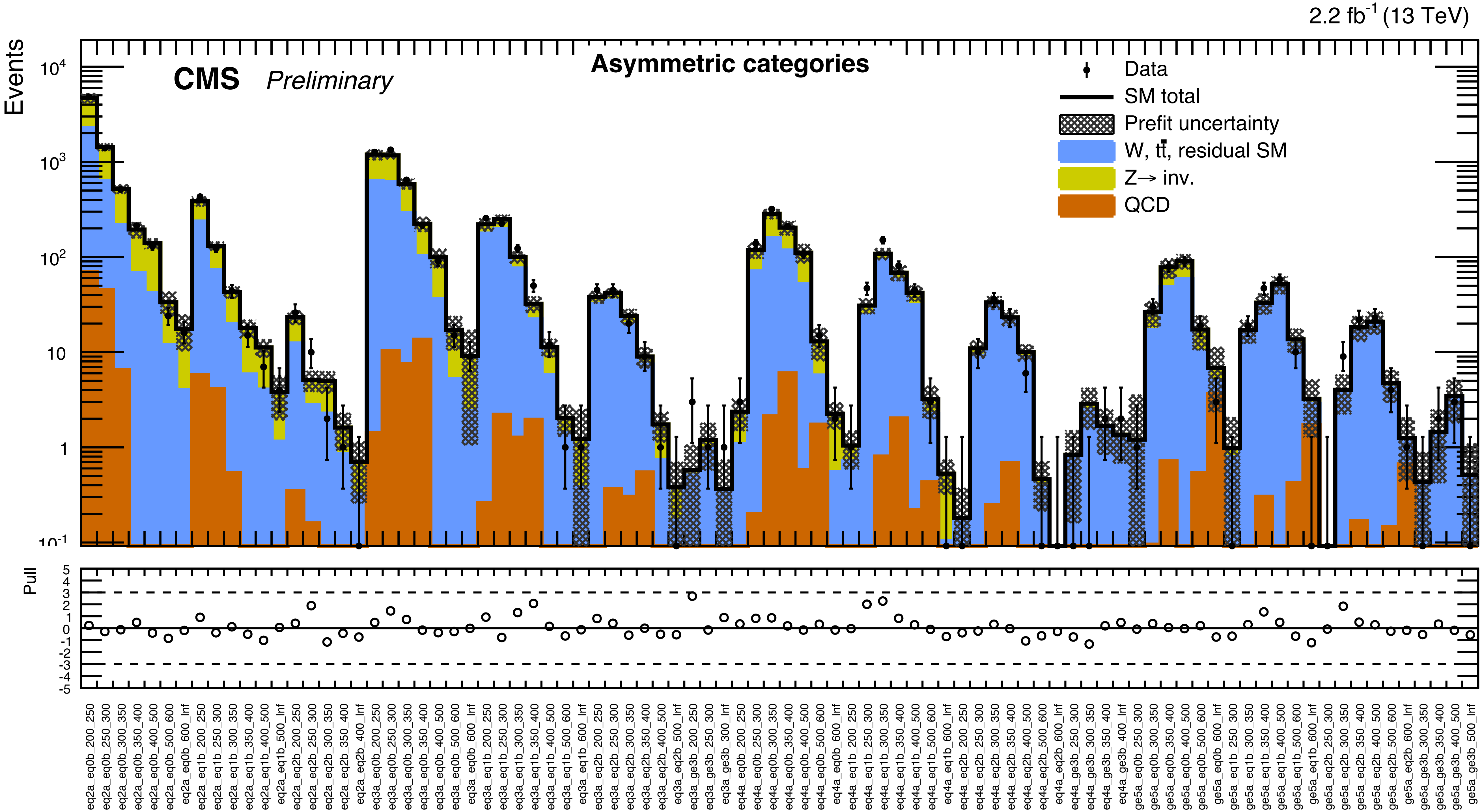
Asymmetric: $40 < p_T(j_2) < 100$ GeV

Symmetric: $p_T(j_2) > 100$ GeV

		H_{T} (GeV)							
	$(n_{\mathrm{jet}}, n_{\mathrm{b}})$	200-250	250-300	300-350	350-400	400-500	500-600	600-800	800-∞
Data	(2a, 0)	4831	1396	512	214	131	24	16	–
SM post-fit	(2a, 0)	4834.3 ± 89.3	1398.3 ± 48.5	512.2 ± 22.6	210.6 ± 13.8	130.3 ± 9.1	27.5 ± 4.2	16.1 ± 3.2	–
SM pre-fit	(2a, 0)	4634.3 ± 533.6	1412.9 ± 113.8	515.3 ± 55.2	193.1 ± 37.4	132.4 ± 20.5	32.7 ± 8.3	16.3 ± 6.6	–
Data	(2a, 1)	431	124	44	15	7	4	–	–
SM post-fit	(2a, 1)	421.4 ± 18.1	125.4 ± 9.0	42.5 ± 4.2	16.9 ± 2.8	9.6 ± 1.5	3.5 ± 1.1	–	–
SM pre-fit	(2a, 1)	372.5 ± 48.7	126.5 ± 12.3	41.8 ± 5.9	17.9 ± 4.3	10.6 ± 2.3	3.6 ± 1.6	–	–
Data	(2a, 2)	26	10	2	1	0	–	–	–
SM post-fit	(2a, 2)	24.3 ± 3.1	5.9 ± 1.2	4.3 ± 1.1	1.4 ± 0.5	0.6 ± 0.4	–	–	–
SM pre-fit	(2a, 2)	21.9 ± 4.1	4.8 ± 1.4	5.0 ± 1.3	1.4 ± 0.7	0.7 ± 0.4	–	–	–
Data	(3a, 0)	1271	1336	647	218	90	15	9	–
SM post-fit	(3a, 0)	1271.0 ± 34.2	1313.0 ± 31.7	642.2 ± 26.5	222.0 ± 18.7	91.1 ± 9.0	15.2 ± 3.8	8.8 ± 2.9	–
SM pre-fit	(3a, 0)	1187.9 ± 165.2	1159.2 ± 103.7	582.2 ± 72.8	220.6 ± 33.7	94.9 ± 20.0	16.3 ± 6.6	8.5 ± 5.4	–
Data	(3a, 1)	256	226	123	50	12	1	1	–
SM post-fit	(3a, 1)	250.9 ± 14.1	238.6 ± 12.3	116.4 ± 8.5	40.9 ± 4.8	11.1 ± 1.9	1.9 ± 0.6	1.1 ± 0.7	–
SM pre-fit	(3a, 1)	217.7 ± 32.0	248.4 ± 24.3	98.4 ± 15.6	32.3 ± 6.0	10.7 ± 2.6	2.1 ± 0.8	1.1 ± 1.0	–
Data	(3a, 2)	45	45	20	9	1	0	–	–
SM post-fit	(3a, 2)	42.8 ± 5.1	43.5 ± 4.0	22.4 ± 3.0	9.5 ± 1.7	1.3 ± 0.4	0.3 ± 0.2	–	–
SM pre-fit	(3a, 2)	38.2 ± 6.9	41.1 ± 5.5	23.0 ± 4.6	9.1 ± 2.2	1.4 ± 0.6	0.4 ± 0.3	–	–
Data	(3a, ≥ 3)	3	1	1	–	–	–	–	–
SM post-fit	(3a, ≥ 3)	1.1 ± 0.5	1.2 ± 0.6	0.5 ± 0.4	–	–	–	–	–
SM pre-fit	(3a, ≥ 3)	0.5 ± 0.5	1.1 ± 0.6	0.2 ± 0.4	–	–	–	–	–
Data	(4a, 0)	3	139	319	211	105	15	2	–
SM post-fit	(4a, 0)	2.1 ± 0.8	135.5 ± 11.3	316.0 ± 14.9	211.9 ± 14.4	104.8 ± 9.4	13.7 ± 3.2	2.1 ± 0.6	–
SM pre-fit	(4a, 0)	1.8 ± 0.8	119.1 ± 21.6	285.6 ± 35.3	204.1 ± 30.7	102.7 ± 22.0	12.5 ± 4.1	2.2 ± 0.8	–
Data	(4a, 1)	1	47	151	81	45	3	0	–
SM post-fit	(4a, 1)	0.9 ± 0.4	40.6 ± 4.8	136.1 ± 10.0	76.0 ± 7.3	41.7 ± 5.0	3.3 ± 1.0	0.5 ± 0.2	–
SM pre-fit	(4a, 1)	0.9 ± 0.4	31.0 ± 7.0	105.4 ± 14.2	66.7 ± 12.8	38.1 ± 7.5	3.3 ± 1.0	0.5 ± 0.2	–
Data	(4a, 2)	0	10	36	22	6	0	0	–
SM post-fit	(4a, 2)	0.2 ± 0.2	10.8 ± 2.0	35.9 ± 4.4	23.0 ± 2.9	8.7 ± 1.4	0.5 ± 0.3	0.1 ± 0.1	–
SM pre-fit	(4a, 2)	0.1 ± 0.2	10.9 ± 2.4	33.4 ± 5.2	22.5 ± 5.4	9.5 ± 2.3	0.5 ± 0.2	0.1 ± 0.1	–
Data	(4a, ≥ 3)	–	0	0	2	2	–	–	–
SM post-fit	(4a, ≥ 3)	–	0.6 ± 0.5	2.2 ± 0.9	1.3 ± 0.6	1.4 ± 0.7	–	–	–
SM pre-fit	(4a, ≥ 3)	–	0.6 ± 0.6	2.9 ± 1.3	1.0 ± 0.7	1.2 ± 0.7	–	–	–
Data	(≥ 5a, 0)	–	1	30	79	91	19	3	–
SM post-fit	(≥ 5a, 0)	–	1.1 ± 1.5	28.9 ± 4.5	80.7 ± 7.7	90.6 ± 8.2	18.2 ± 4.1	4.4 ± 1.4	–
SM pre-fit	(≥ 5a, 0)	–	0.0 ± 3.4	26.5 ± 7.9	80.0 ± 16.4	86.4 ± 13.9	17.8 ± 7.6	6.8 ± 1.9	–
Data	(≥ 5a, 1)	–	0	19	47	58	10	0	–
SM post-fit	(≥ 5a, 1)	–	0.7 ± 0.5	18.3 ± 3.2	42.1 ± 5.4	55.8 ± 5.5	11.3 ± 2.4	2.1 ± 0.8	–
SM pre-fit	(≥ 5a, 1)	–	0.8 ± 1.1	17.1 ± 4.8	32.0 ± 7.4	50.4 ± 10.5	12.9 ± 4.4	3.3 ± 0.8	–
Data	(≥ 5a, 2)	–	0	9	22	23	4	1	–
SM post-fit	(≥ 5a, 2)	–	0.0 ± 0.0	5.9 ± 1.6	20.5 ± 3.6	21.2 ± 3.5	4.5 ± 1.2	0.9 ± 0.4	–
SM pre-fit	(≥ 5a, 2)	–	0.0 ± 0.0	4.0 ± 1.7	17.7 ± 5.0	18.9 ± 4.7	4.8 ± 2.1	1.3 ± 0.4	–
Data	(≥ 5a, ≥ 3)	–	–	0	2	3	0	–	–
SM post-fit	(≥ 5a, ≥ 3)	–	–	0.4 ± 0.3	1.7 ± 0.8	3.3 ± 1.0	0.4 ± 0.4	–	–
SM pre-fit	(≥ 5a, ≥ 3)	–	–	0.2 ± 0.5	1.3 ± 1.1	3.3 ± 1.5	0.4 ± 0.4	–	–

Results

Asymmetric categories



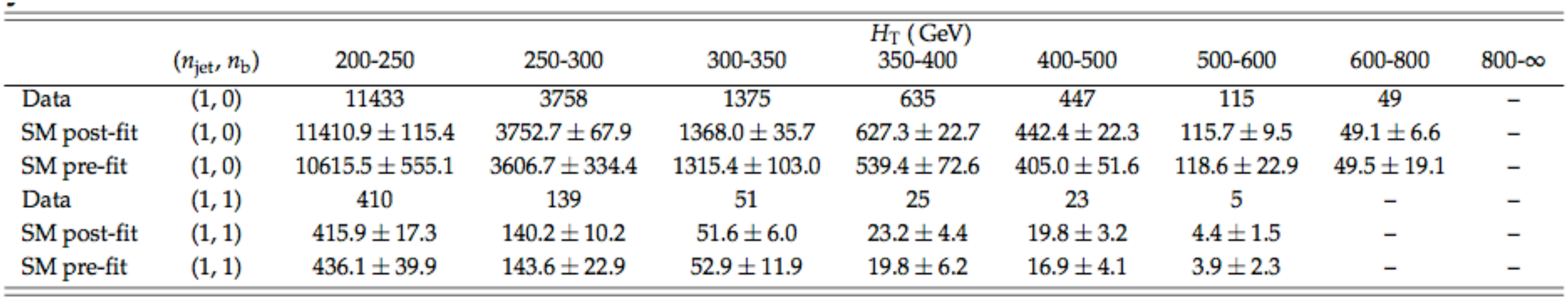
Results

Monojet categories

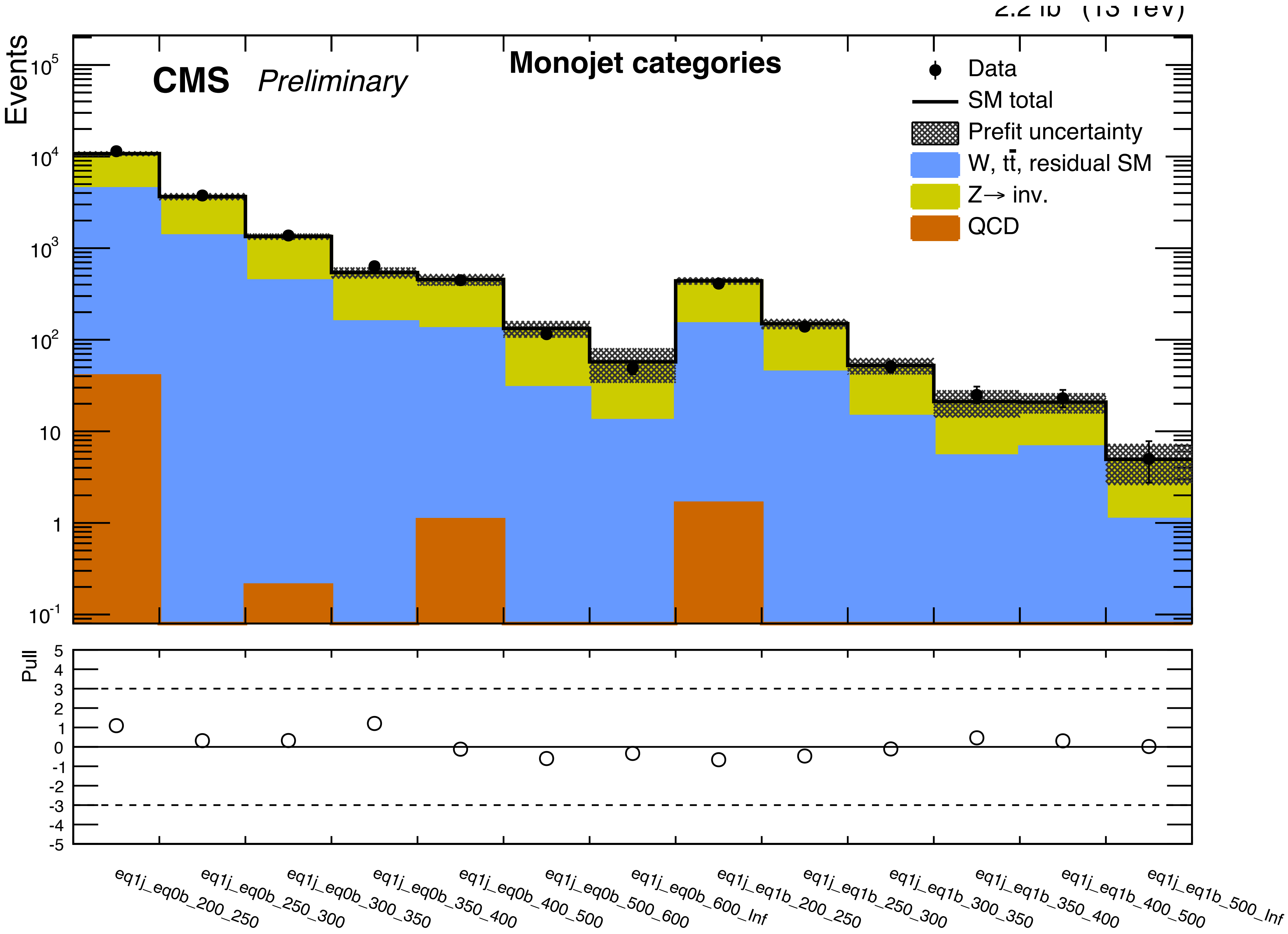
Monojet: **$p_T(j_2) < 40$ GeV**

Asymmetric: $40 < p_T(j_2) < 100$ GeV

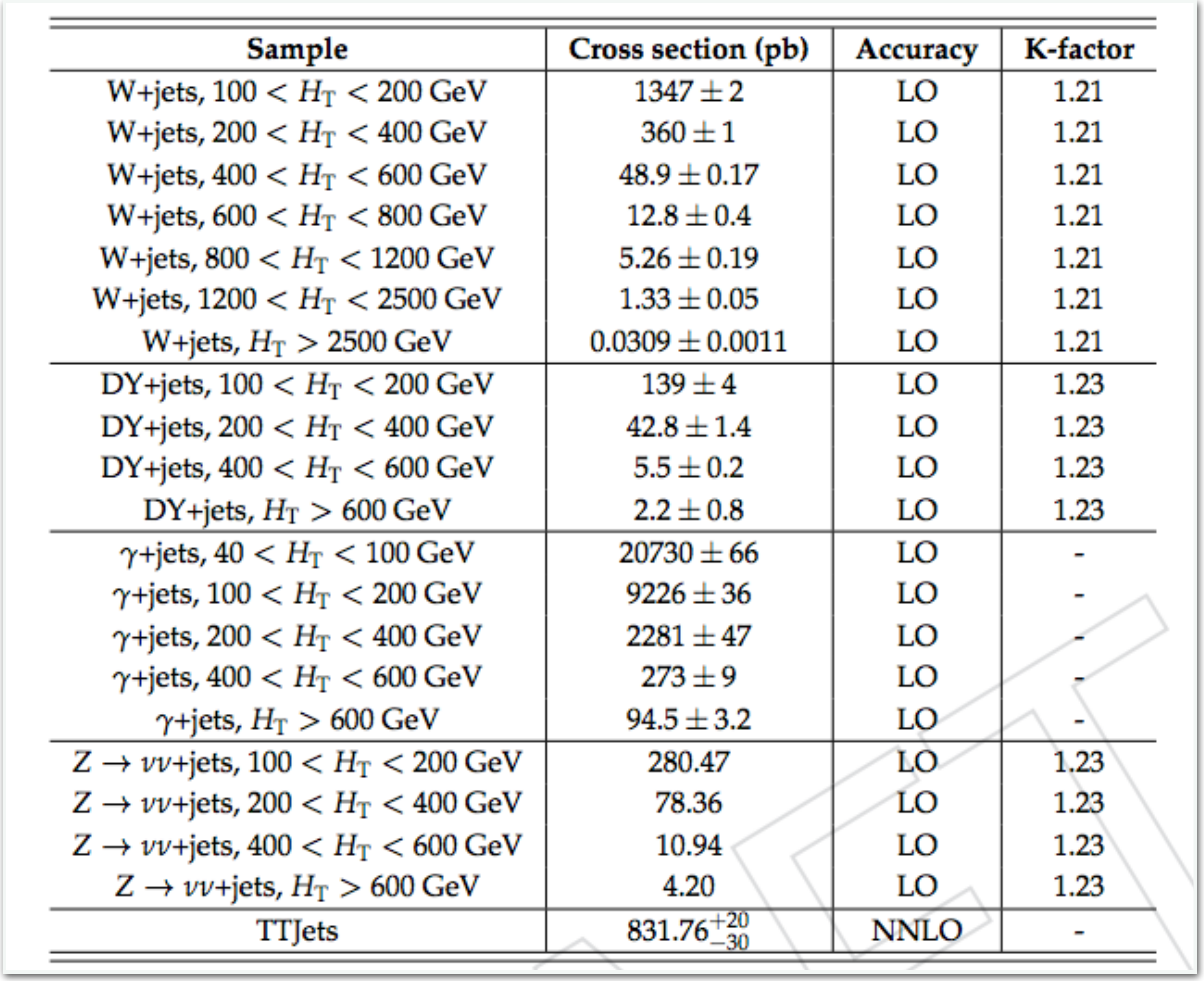
Symmetric: $p_T(j_2) > 100$ GeV



		H_T (GeV)							
	(n_{jet}, n_b)	200-250	250-300	300-350	350-400	400-500	500-600	600-800	800-∞
Data	(1, 0)	11433	3758	1375	635	447	115	49	–
SM post-fit	(1, 0)	11410.9 ± 115.4	3752.7 ± 67.9	1368.0 ± 35.7	627.3 ± 22.7	442.4 ± 22.3	115.7 ± 9.5	49.1 ± 6.6	–
SM pre-fit	(1, 0)	10615.5 ± 555.1	3606.7 ± 334.4	1315.4 ± 103.0	539.4 ± 72.6	405.0 ± 51.6	118.6 ± 22.9	49.5 ± 19.1	–
Data	(1, 1)	410	139	51	25	23	5	–	–
SM post-fit	(1, 1)	415.9 ± 17.3	140.2 ± 10.2	51.6 ± 6.0	23.2 ± 4.4	19.8 ± 3.2	4.4 ± 1.5	–	–
SM pre-fit	(1, 1)	436.1 ± 39.9	143.6 ± 22.9	52.9 ± 11.9	19.8 ± 6.2	16.9 ± 4.1	3.9 ± 2.3	–	–



Samples and Cross-sections



Sample	Cross section (pb)	Accuracy	K-factor
W+jets, $100 < H_T < 200$ GeV	1347 ± 2	LO	1.21
W+jets, $200 < H_T < 400$ GeV	360 ± 1	LO	1.21
W+jets, $400 < H_T < 600$ GeV	48.9 ± 0.17	LO	1.21
W+jets, $600 < H_T < 800$ GeV	12.8 ± 0.4	LO	1.21
W+jets, $800 < H_T < 1200$ GeV	5.26 ± 0.19	LO	1.21
W+jets, $1200 < H_T < 2500$ GeV	1.33 ± 0.05	LO	1.21
W+jets, $H_T > 2500$ GeV	0.0309 ± 0.0011	LO	1.21
DY+jets, $100 < H_T < 200$ GeV	139 ± 4	LO	1.23
DY+jets, $200 < H_T < 400$ GeV	42.8 ± 1.4	LO	1.23
DY+jets, $400 < H_T < 600$ GeV	5.5 ± 0.2	LO	1.23
DY+jets, $H_T > 600$ GeV	2.2 ± 0.8	LO	1.23
γ+jets, $40 < H_T < 100$ GeV	20730 ± 66	LO	-
γ+jets, $100 < H_T < 200$ GeV	9226 ± 36	LO	-
γ+jets, $200 < H_T < 400$ GeV	2281 ± 47	LO	-
γ+jets, $400 < H_T < 600$ GeV	273 ± 9	LO	-
γ+jets, $H_T > 600$ GeV	94.5 ± 3.2	LO	-
$Z \to \nu\nu$+jets, $100 < H_T < 200$ GeV	280.47	LO	1.23
$Z \to \nu\nu$+jets, $200 < H_T < 400$ GeV	78.36	LO	1.23
$Z \to \nu\nu$+jets, $400 < H_T < 600$ GeV	10.94	LO	1.23
$Z \to \nu\nu$+jets, $H_T > 600$ GeV	4.20	LO	1.23
TTJets	831.76^{+20}_{-30}	NNLO	-

Results

Symmetric categories- post fit