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Determining the standard model backgrounds of a search for new physics with jets and missing transverse momentum in 13 TeV pp collisions at the LHC

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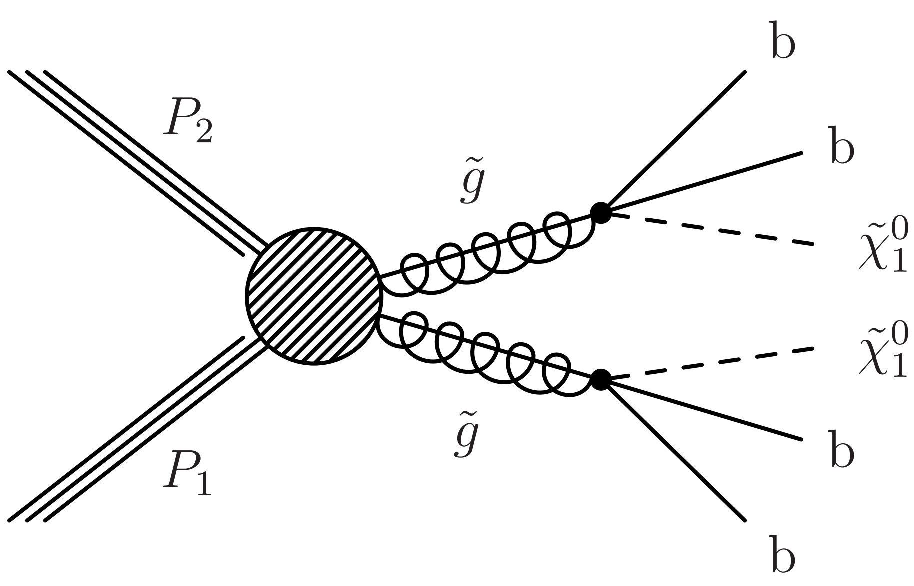
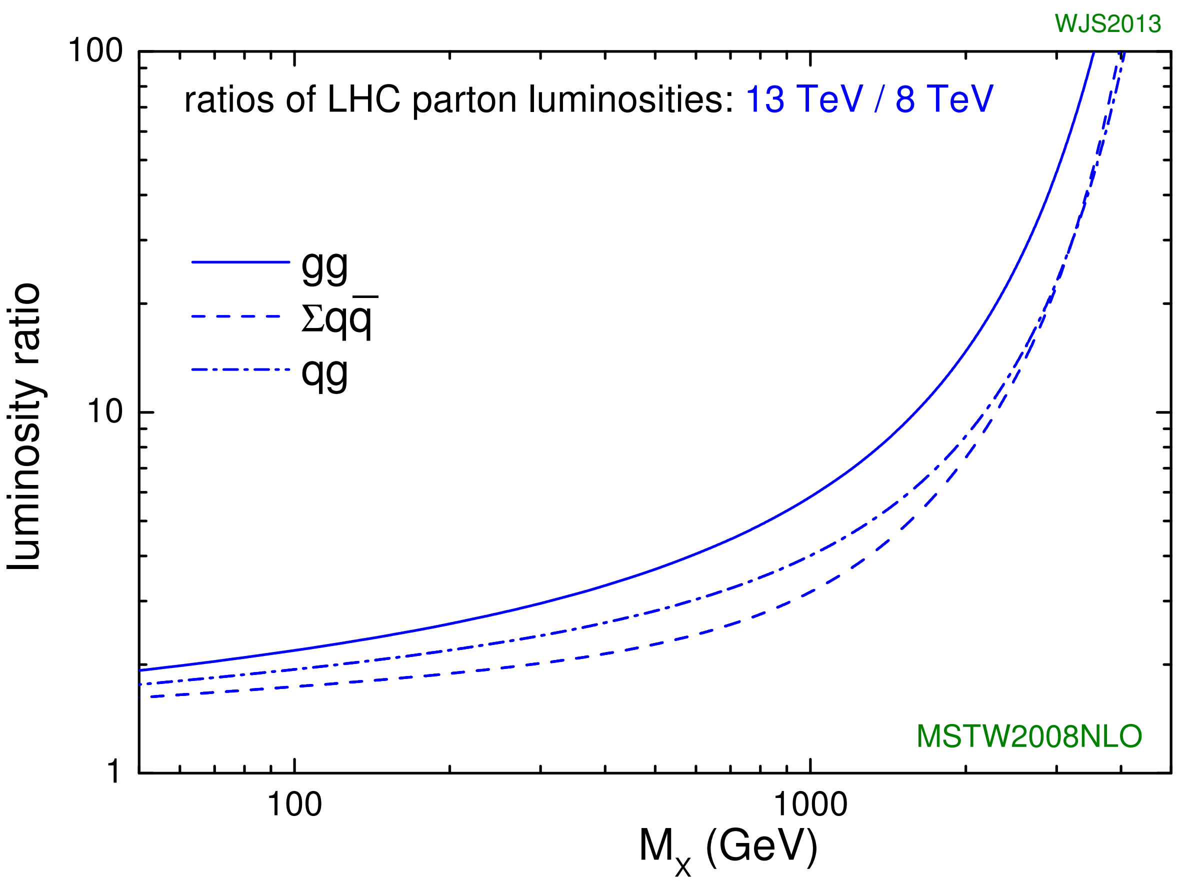
Searching for supersymmetry at the LHC

- Supersymmetry (SUSY) is an elegant extension of the standard model that solves the hierarchy problem and provides a candidate for dark matter
- SUSY production via the strong force has the highest cross section at the LHC
- Under R-parity conservation SUSY decays to pairs of weakly interacting neutralinos
- If natural SUSY exists it should be produced with a significant cross section increase during Run 2

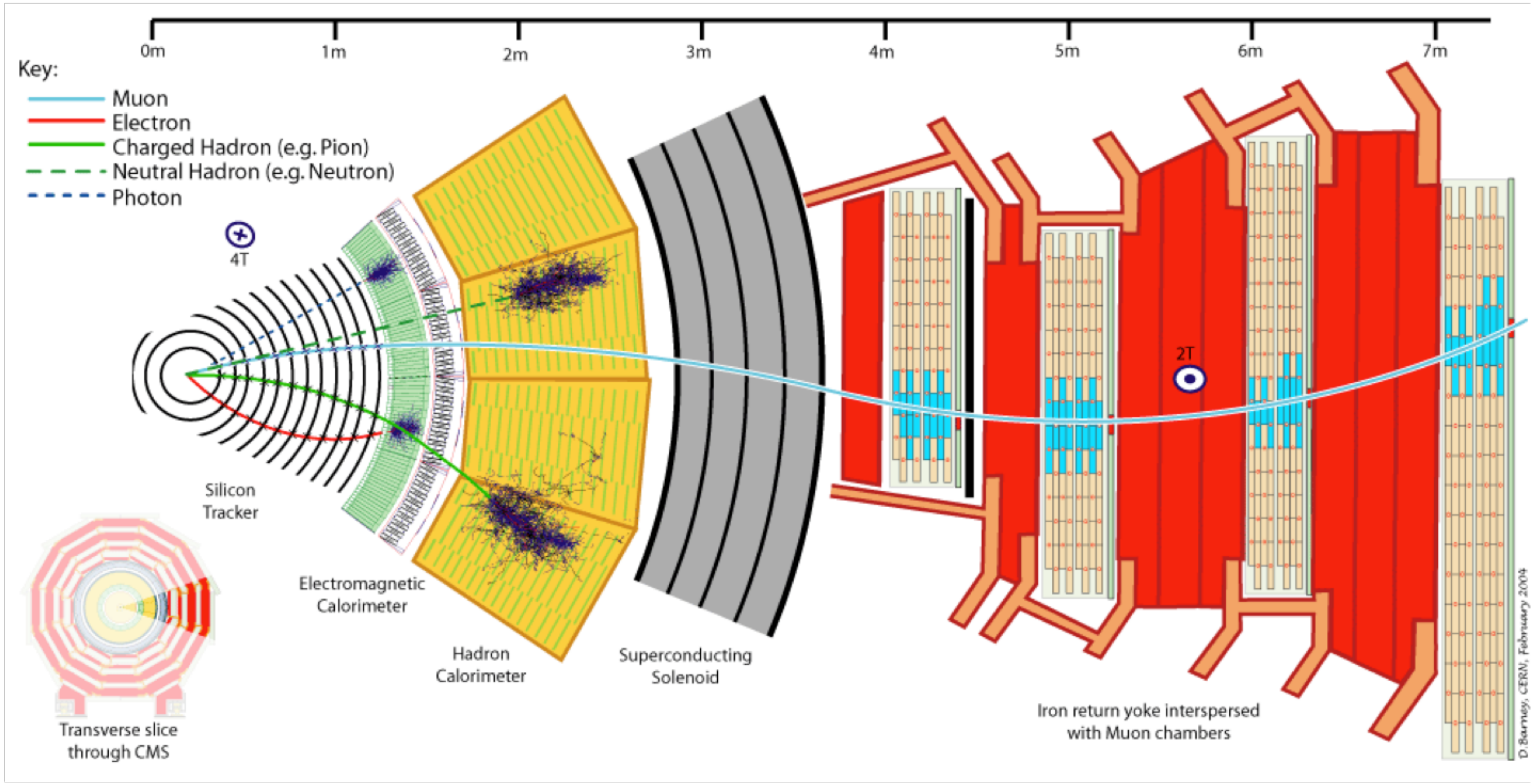


Simplified SUSY model: gluino pair production



The Compact Muon Solenoid (CMS)

- CMS is a general purpose detector designed to search for new particles produced in proton proton collisions at the LHC
- It consists of a series of sub detectors built around a 4 Tesla solenoid that are exploited to reconstruct the particles produced in each collision event
- Due to its comprehensive coverage of all angles the missing momentum in each collision event can be accurately determined

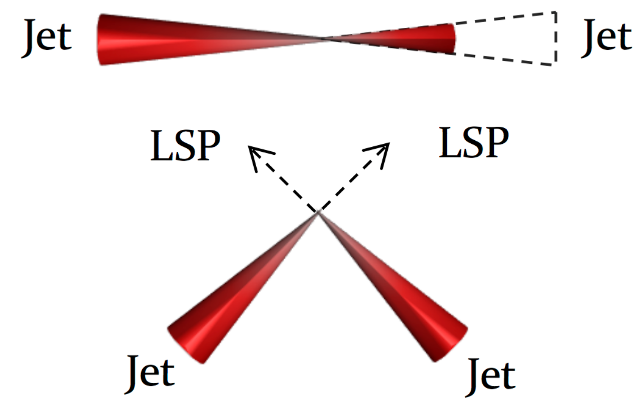


Analysis strategy

- **Inclusive search for new physics with missing energy**
  - All hadronic jets + missing energy signatures vetoing leptons or photons
  - Consider all jet and b-tag multiplicities ($n_{jet} \geq 1$, $n_b \geq 0$)
  - Low threshold on jet activity
    - $H_T \equiv \Sigma\, p_T^{jet} > 200$ GeV, $H_T^{miss} \equiv -\Sigma\, \underline{\mathbf{p}}_T^{\,jet} > 130$ GeV
  - Thresholds maintained through a suite of dedicated triggers
- **Robust analysis**
  - Suppress QCD multijet background with tight cuts on dedicated variables: α_T, $\Delta\phi^*$
  - Data-driven estimation of the other backgrounds
- **Sensitivity**
  - Binning in n_{jet}, n_b, H_T and H_T^{miss}
  - Categorising based on n_{jet} topologies

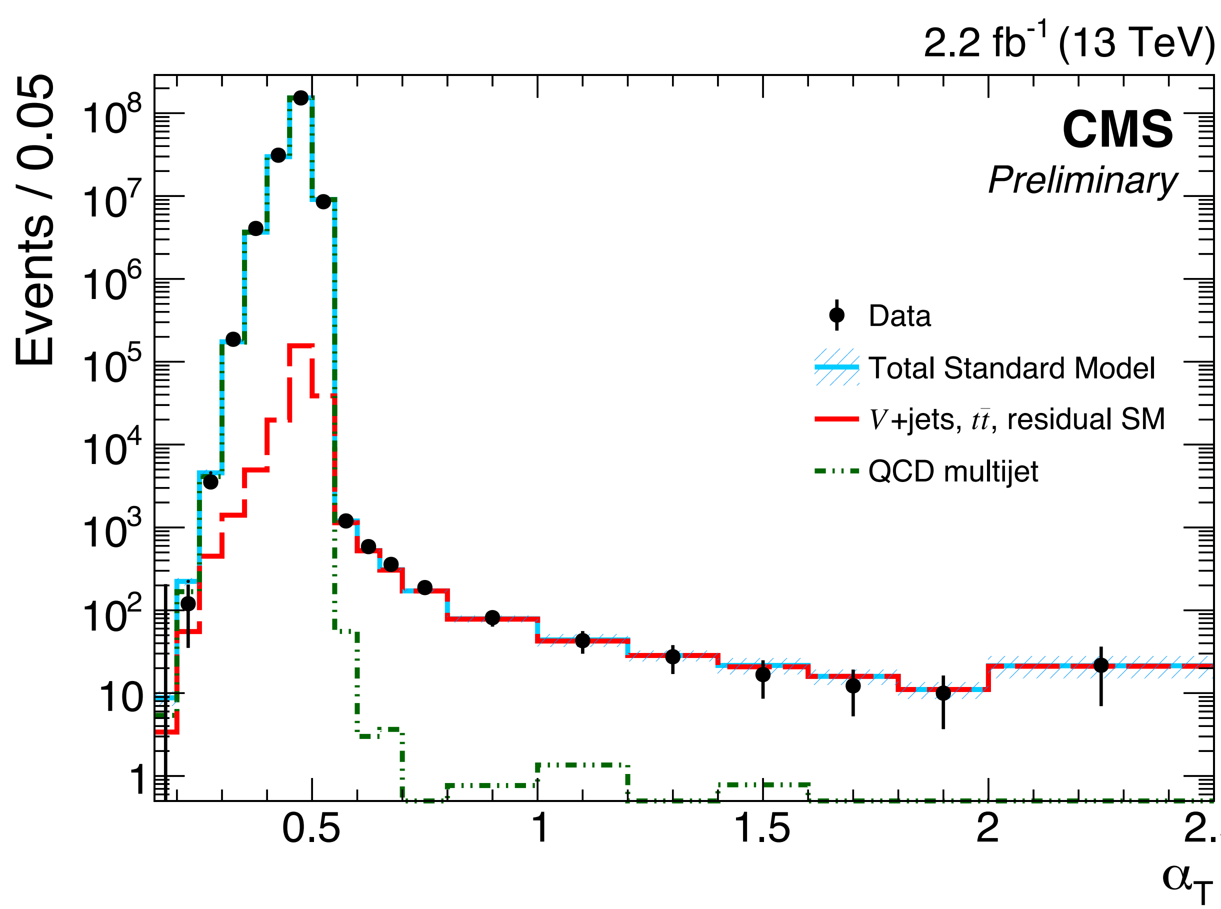
Variables for QCD multi-jet background control

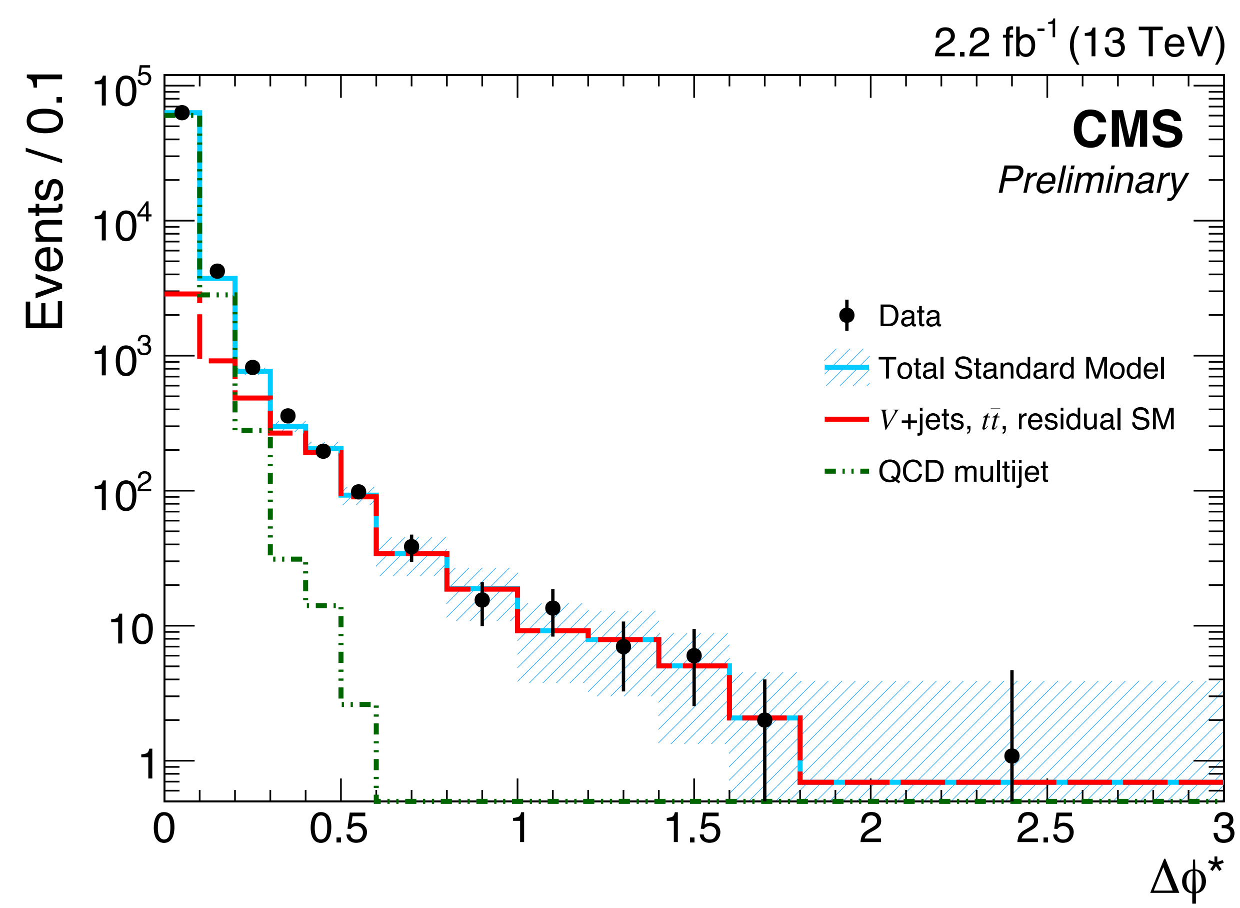
- α_T and $\Delta\phi^*$ separate processes with genuine missing energy from those with fake missing energy caused by detector mismeasurement



$$\alpha_T = \frac{1}{2} \times \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (H_T^{miss})^2}} \quad \dagger$$

$\Delta\phi^*$ = minimum azimuthal angle between jet and H_T^{miss} computed without the jet



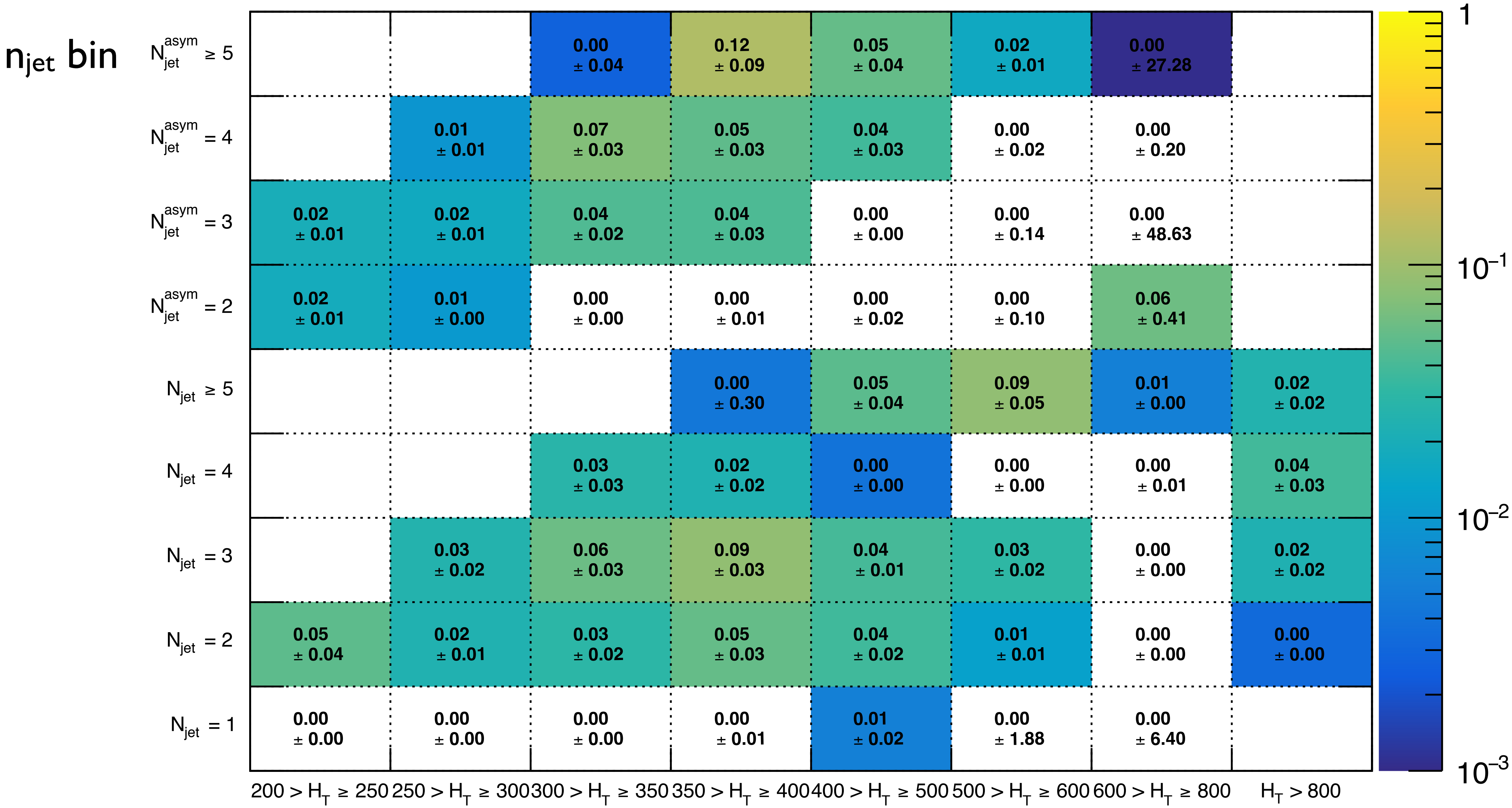


† For a pseudo dijet system with pseudo jet p_T difference: ΔH_T

Remaining QCD background

- After applying appropriate cuts the remaining QCD background is determined to be negligible through a data driven study

Predicted QCD yield divided by remaining SM background yield



Data driven background estimation methods for processes with genuine missing energy

- Left with non-multijet Standard Model backgrounds
  - In association with lost leptons: $t\bar{t}$, W+jets
  - Irreducible: Z decaying to neutrinos
- Define single muon, double muon and single photon control samples
- Emulate the missing energy by ignoring the leptons when calculating variables
- An extrapolation of yields from one control sample to signal region via appropriate transfer factors in Monte Carlo (MC) simulation

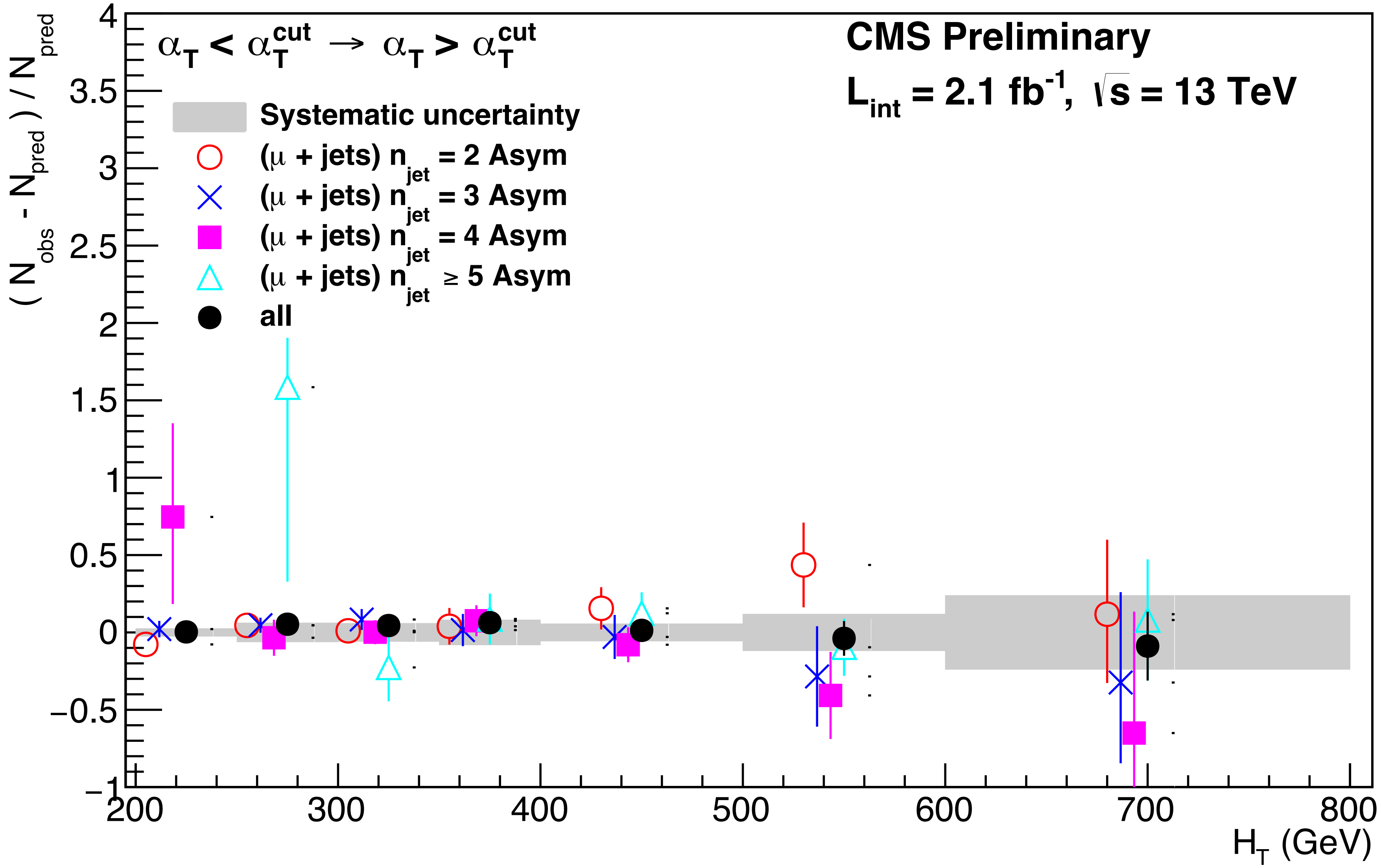
$$N_{\mathrm{pred}}^{\mathrm{signal}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}}) = \frac{N_{\mathrm{MC}}^{\mathrm{signal}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})}{N_{\mathrm{MC}}^{\mathrm{control}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})} \times N_{\mathrm{obs}}^{\mathrm{control}}(n_{\mathrm{jet}}, n_{\mathrm{b}}, H_{\mathrm{T}})$$

Determination of systematic uncertainties on the remaining non-multijet backgrounds

- To search for significant excesses in hadronic events with missing energy must take account of all systematic uncertainties
- Vary known experimental and theoretical uncertainties by $\pm 1\sigma$ and propagate to the background prediction
  - e.g. jet energy scale uncertainties, lepton simulation efficiency
- Propagate all relevant statistical uncertainties
- Consider uncertainties related to the simulated shape of H_T^{miss}
- Additionally derive data driven systematics that do not rely on simulation to test assumptions and extrapolations in the analysis
  - e.g. α_T extrapolation, Z/photon ratio

Additional data driven systematic uncertainties

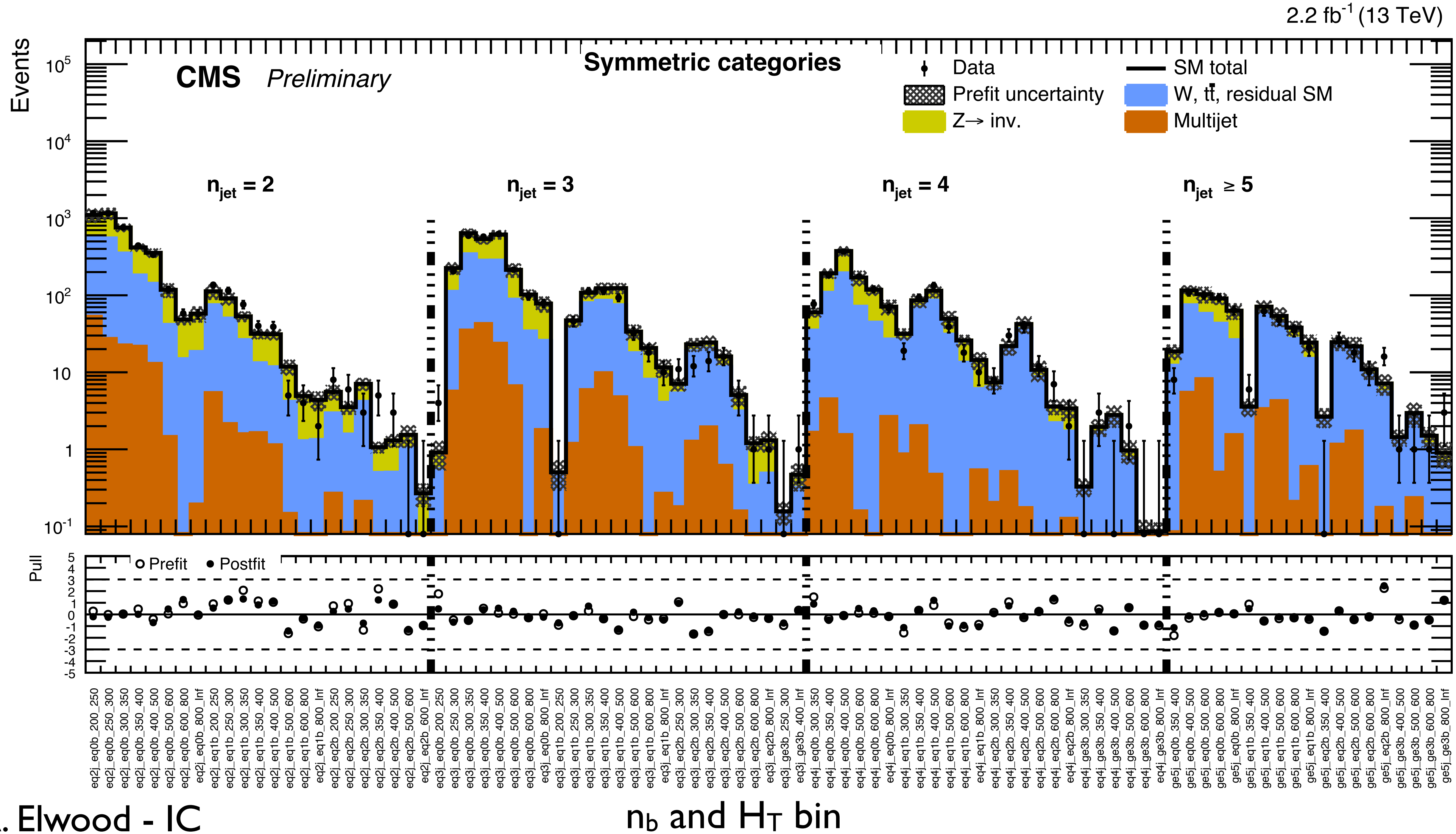
- Use one control (sub-)sample to predict yields in another control (sub-)sample
- E.g. use yields of events with low α_T to predict yields of events with high α_T in the single muon control sample



- A suite of tests are performed, such as using single photon control sample yields to predict the double muon control sample yields

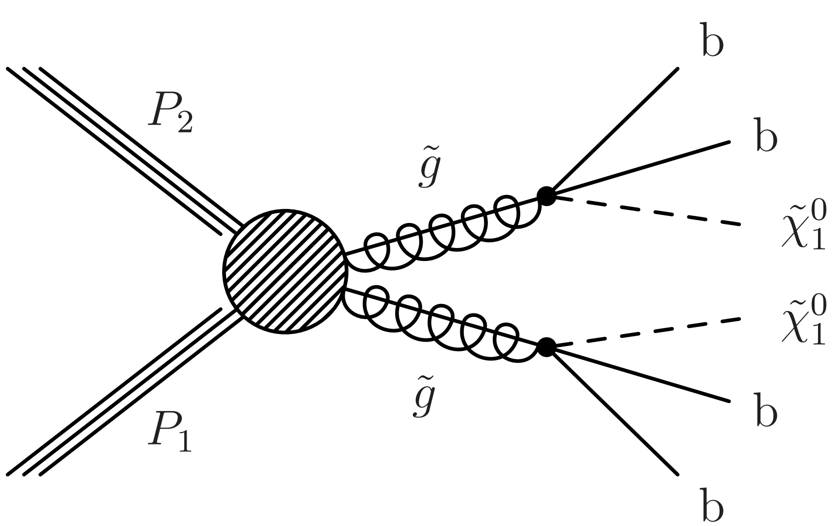
Results

- The background prediction is carried out using 2.2 fb^{-1} of 13 TeV collision data collected by CMS across all n_{jet}, n_b and H_T analysis bins
- Overall the data agrees well with the background only hypothesis with no statistically significant pulls

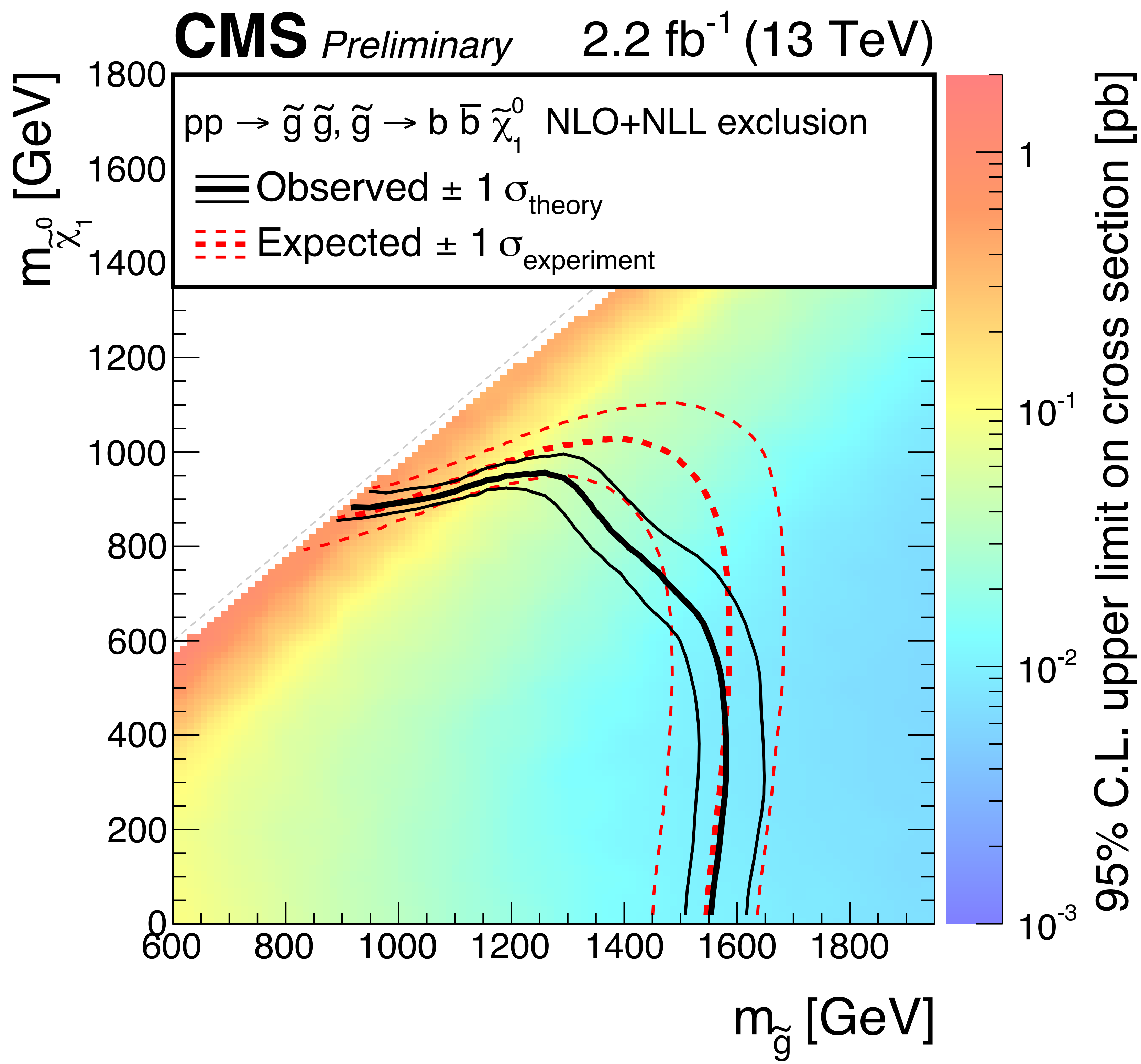


Interpretation

- In the absence of any observed signal a limit is set on the production of supersymmetric particles
- These interpretations are performed on SUSY models with simplified topologies



T1bbbb model



Extend beyond 8 TeV result, in which we excluded up to: m_{gluino} > 1400 GeV , m_{LSP} > 750 GeV

Conclusions

- A generic search for new physics with missing energy signatures that aims to be robust and data driven has been presented
- The QCD multi-jet background is reduced to a negligible level with cuts on dedicated variables
- Remaining Standard Model backgrounds with genuine missing energy, and their systematic uncertainties, are predicted with data driven methods
- No excess of events above the predicted Standard Model backgrounds is observed
- This result is used to set limits on the production of new physics processes
- For the T1bbbb simplified SUSY model limits we exclude up to: $m_{gluino} > 1550$ GeV , $m_{LSP} > 900$ GeV

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Thank you

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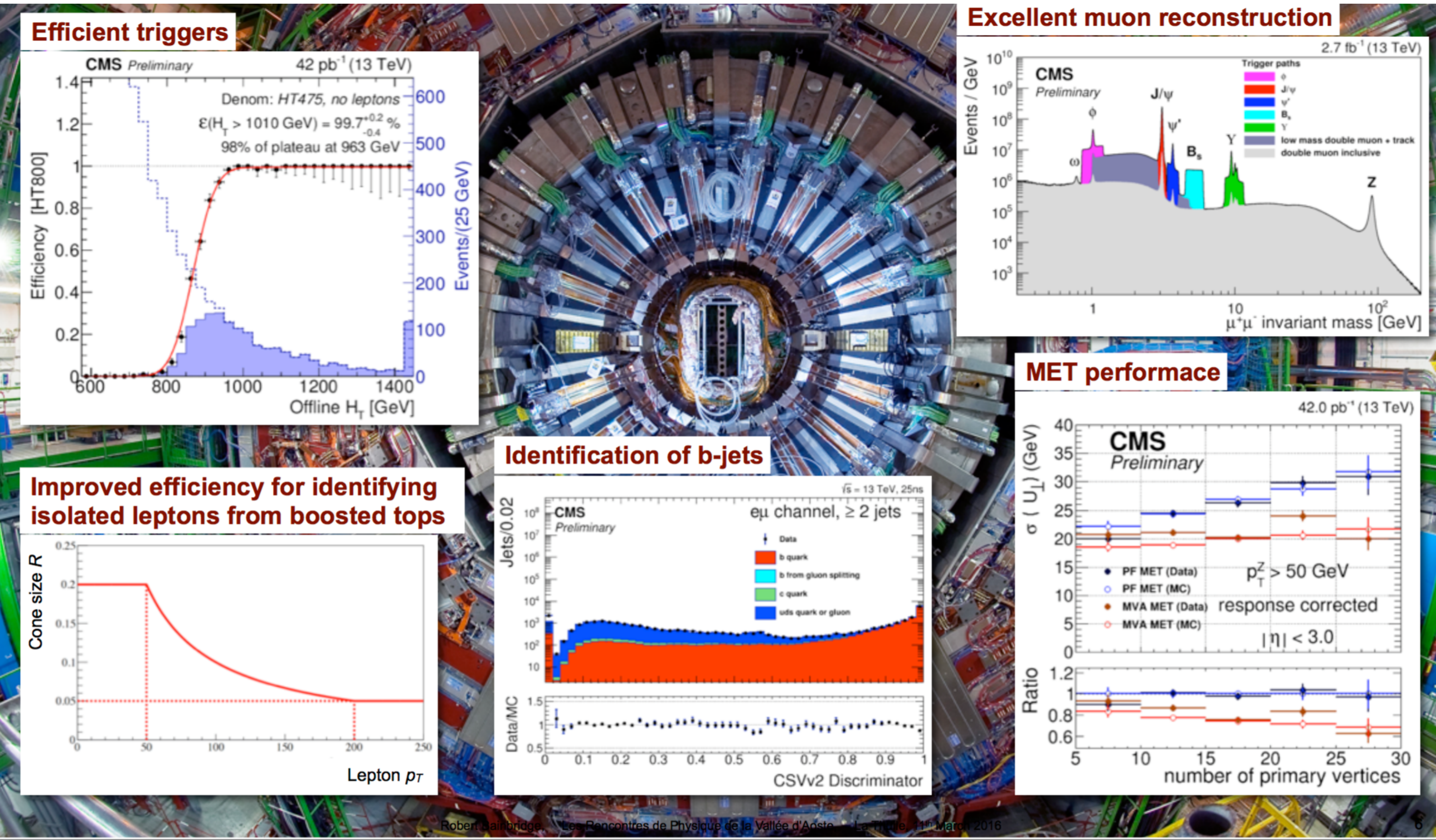
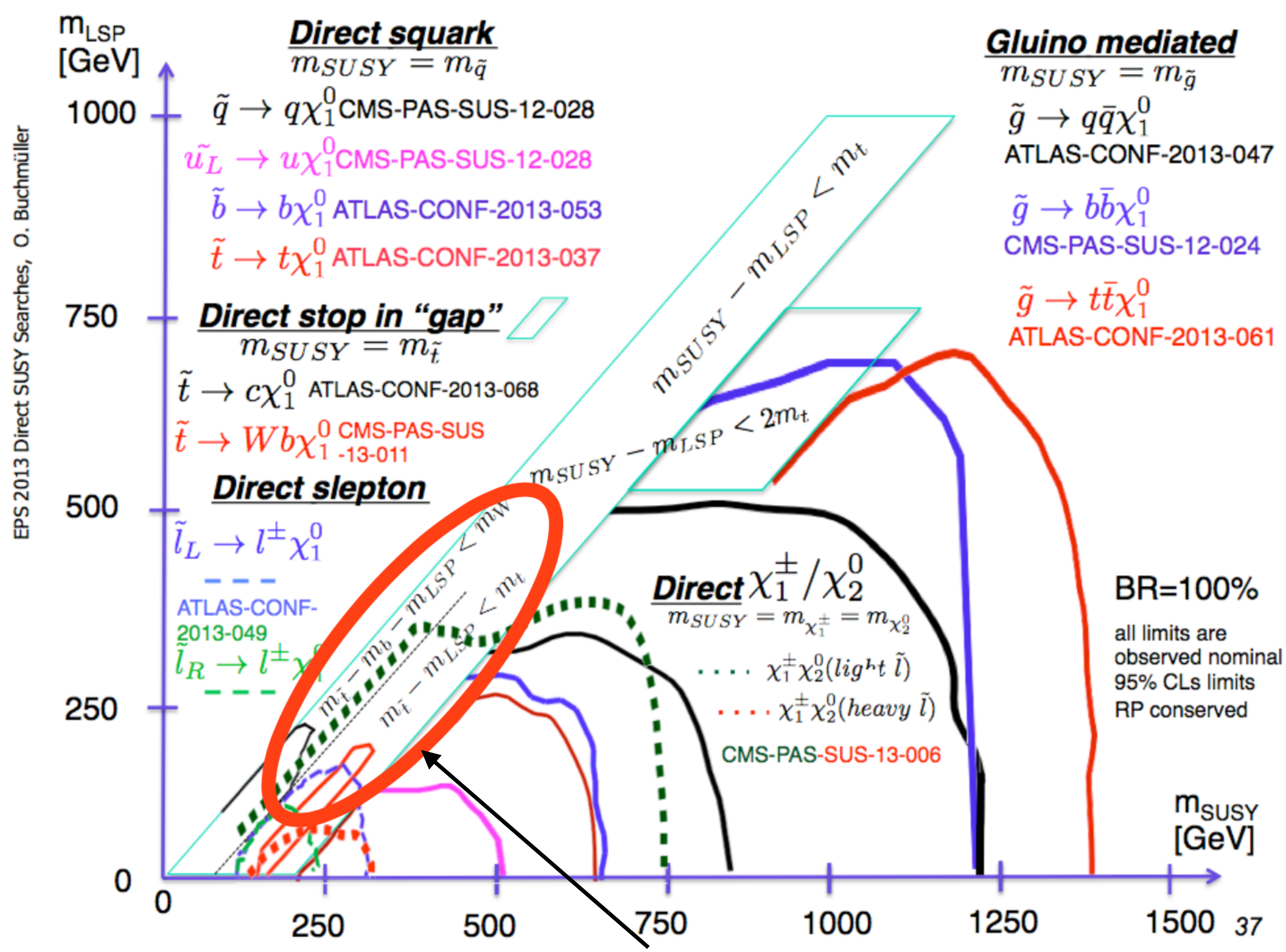
CMS for SUSY searches



Compressed SUSY

- If SUSY is manifest with small mass splittings we have a compressed spectrum
- This results in decays to soft SM particles and only a small proportion of the MET is visible
- Challenging region that RA1 is well suited to

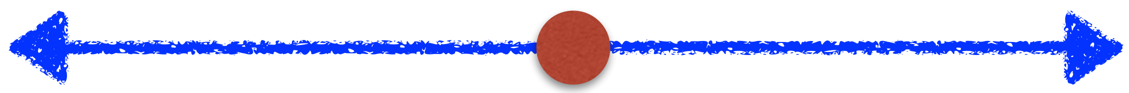


Limits don't extend above $m_{LSP} \approx 300$GeV on the diagonal

What α_T is doing

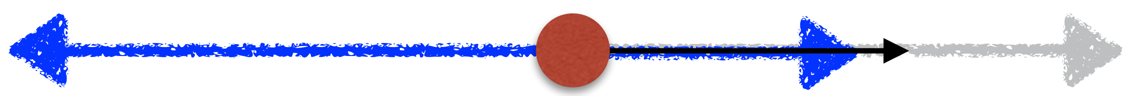
$$\alpha_T = \frac{1}{2} \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}}$$

(1)



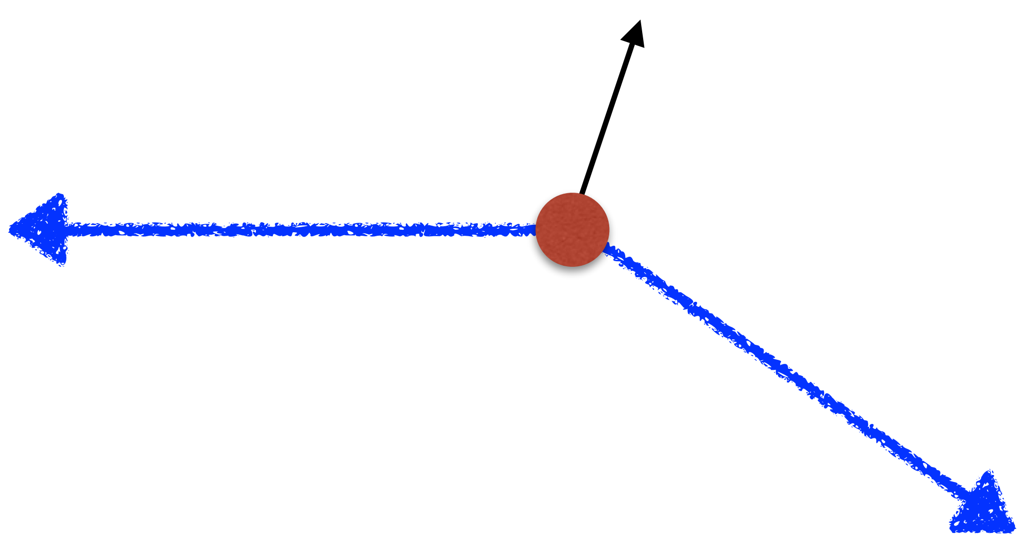
Balanced multijet event:
$\alpha_T = 0.5$

(2)



Mismeasured multijet event:
$\alpha_T < 0.5$

(3)



Genuine missing energy multijet event:
$\alpha_T > 0.5$

QCD background estimation

- Philosophy
  - –QCD is the most difficult background to measure...
  - –Cut hard (AlphaT + dPhi*), assume conservative systematics on negligible contribution

- **QCD estimate**: based on QCD-enriched data sideband, independent per (Njet,HT)
  - –Method relies on QCD-enriched (and signal depleted) sideband: MHT/MET >1.25
  - –Data counts, $\boldsymbol{N^{corr}}$, in sideband corrected to remove non-QCD contribution
    - –New: now use mu+jets control sample to predict the non-QCD background component
  - –Ratio, $\boldsymbol{R_{QCD}}$, of MC QCD events satisfying or failing the MHT/MET < 1.25 requirement
  - –Product of $\boldsymbol{N^{corr}}$ and $\boldsymbol{R_{QCD}}$ gives estimate for QCD contamination vs (Njet,HT)

- **$\boldsymbol{R_{QCD}}$ validation**: ratio from MC is validated in dPhi* data sideband (dPhi* < 0.5)
  - –Construct double ratio R_{QCD}^{data} / R_{QCD}^{MC}: should be unity, independent of dPhi*, Njet, HT

- **QCD in the tails**: check MHT and Nb distributions to ensure no “enrichment”
  - –Distributions taken from MC, integrated over other variables and regions in HT

Normalisation systematic summary (with **all** updates)

Source	Method	Uncertainty on transfer factor			
		μ -> Zinv	μμ->Zinv	γ -> Zinv	μ -> tt+W
JEC	variation of JECs	< 15%	< 10%	< 15%	< 15%
b-tag	variation of b-tag SFs	< 5%	< 2%	< 2%	< 5%
PU	variation of min. bias xs	< 6%	< 4%	< 3%	< 10%
Top p_T	variation of top pT weights	< 20%	< 4%	-	< 5%
Lepton ID/iso/ trigger	variation of lepton SFs	-	-	-	~3%
W polarisation	μ+→μ- closure test	5-10%	-	-	5-50%
$\alpha_T/\Delta\phi^*$ extrapolation	α_T closure test	5-80%	50-80%	-	5-80%
W/Z ratio	μ→μμ closure test	10-30%	-	-	-
Z/g ratio	g→μμ closure test	-	-	10-30%	-
tt/W admixture	0→1 b-tag closure test	-	-	-	10-100%

JEC, b-tag, PU, Top p_T, Lepton ID/iso/trigger: **Fully correlated**

W polarisation, $\alpha_T/\Delta\phi^*$ extrapolation, W/Z ratio, Z/g ratio, tt/W admixture: **Uncorrelated across H_T/jet top. (sym/asym)**