Search for Supersymmetry
with Jets and Missing Transverse Momentum in pp Collisions at 13 TeV at CMS

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on behalf of the CMS collaboration

ICHEP16
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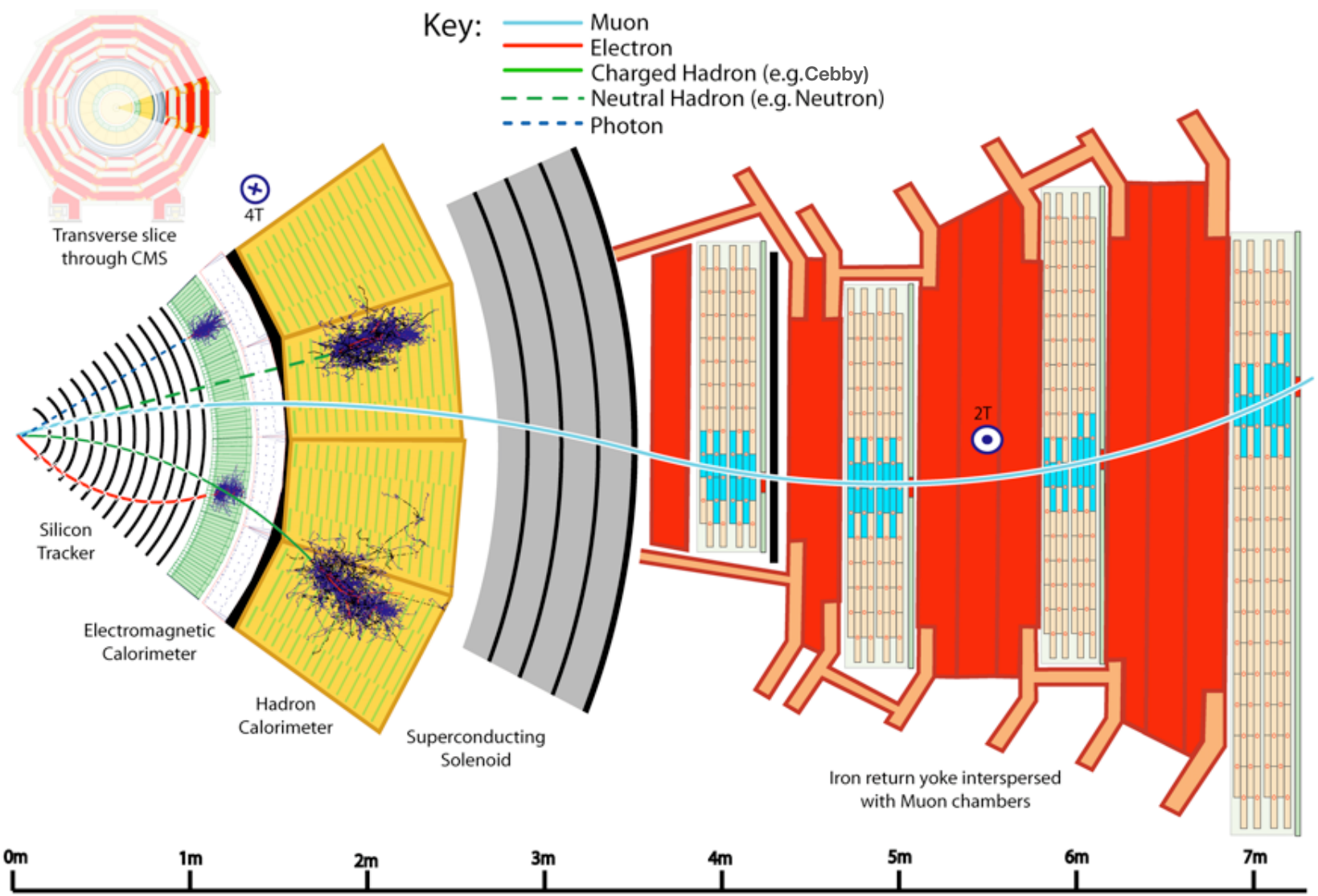
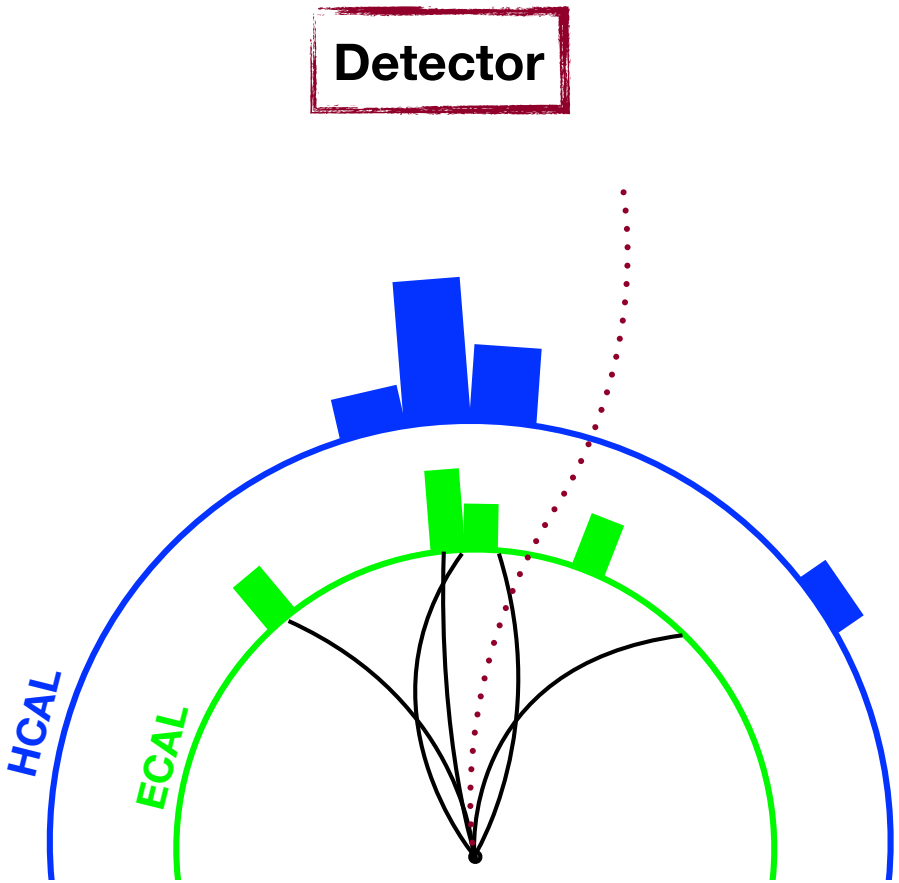
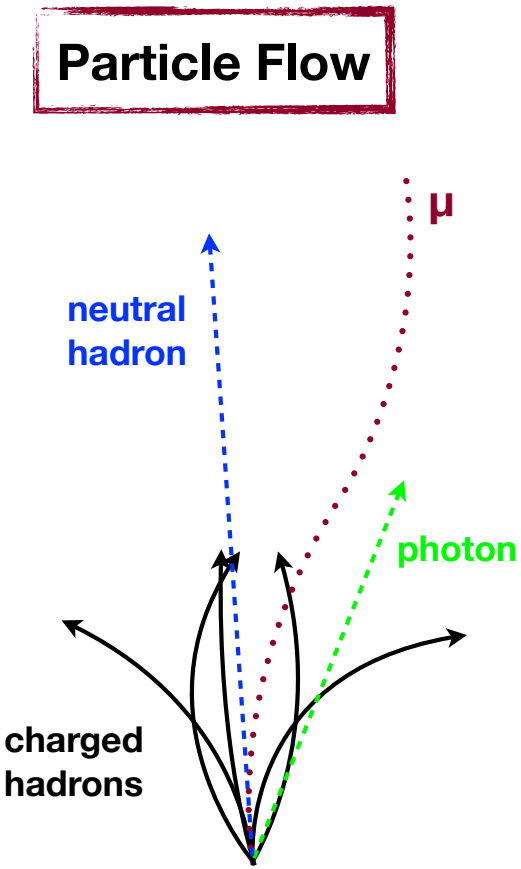
The Compact Muon Solenoid



Particle Flow Event Reconstruction





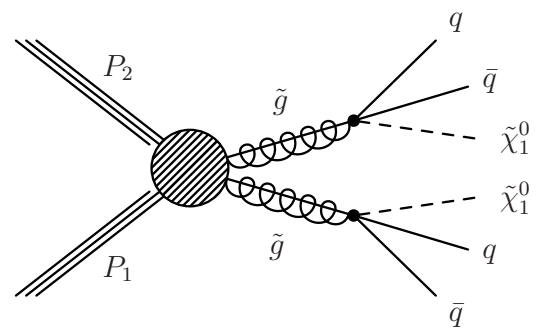
Jets = clustered particles (anti-k_T, R=0.4), **E_T^{miss} = vectorial sum of all particles p_T**

H_T = scalar sum of jet transverse momenta, **H_T^{miss} = ME_T with jets**

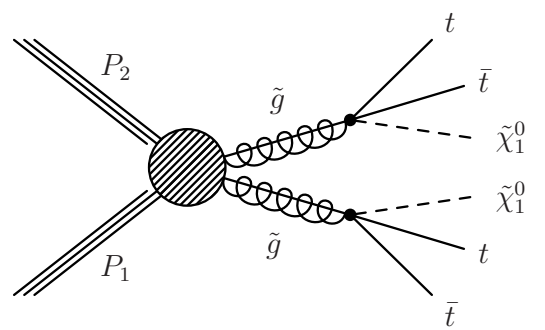
Looking for SUSY in Hadronic Final States

- Aiming for **direct** production of gluinos and squarks
  - Strong production → **high** σ
- **Largest** BR to SM quarks + LSP
  - **Many** jets/b-jets
  - High E_T^{miss}: scan the **tails**
- **Different** models → different topologies
  - Need to be sensitive to **many** possible final states

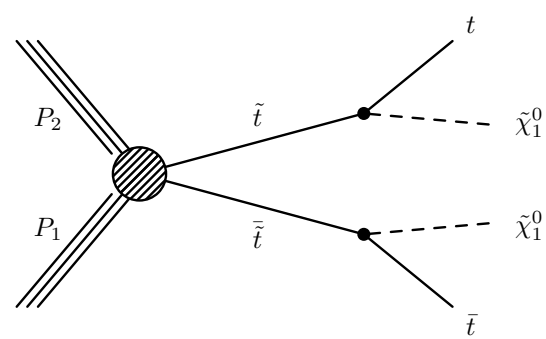
Some typical hadronic SUSY events:



4 jets + E_T^{miss}



≤12 jets + E_T^{miss} (4 b-jets)



≤6 jets + E_T^{miss} (2 b-jets)

Four Independent Searches

- Historically, four CMS all-hadronic SUSY searches:

H_T and H_T^{miss}
SUS-16-014
12.9 fb^{-1} **NEW!**

M_{T2}
SUS-16-015
12.9 fb^{-1} **NEW!**

α_T
SUS-16-016
12.9 fb^{-1} **NEW!**

Razor
SUS-15-004
2.1 fb^{-1}

Common strategy:
veto leptons
look for lots of jets
and lots of E_T^{miss}

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2.1 fb^{-1}
Coming soon!

Common strategy:
veto leptons
look for lots of jets
and lots of E_T^{miss}

The Strategies at a Glance

- H_T and H_T^{miss}

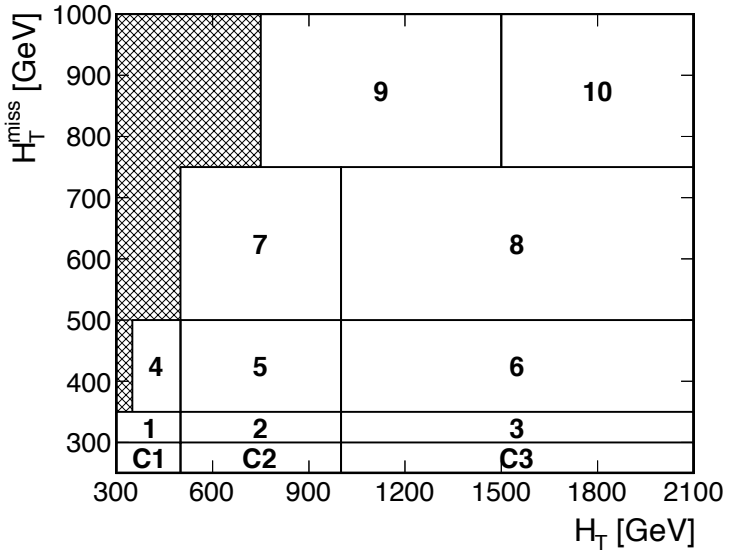
"A canonical jets+E_T^{miss} search"

Search variable: H_T^{miss}

Binned in jet and b-jet multiplicity (4×4):

N_j : 3-4, 5-6, 7-8, 9+
N_b : 0, 1, 2, 3+

In each of the 16 jet multiplicity regions bin in H_T and H_T^{miss}:



The Strategies at a Glance

- H_T and H_T^{miss}
- M_{T2}

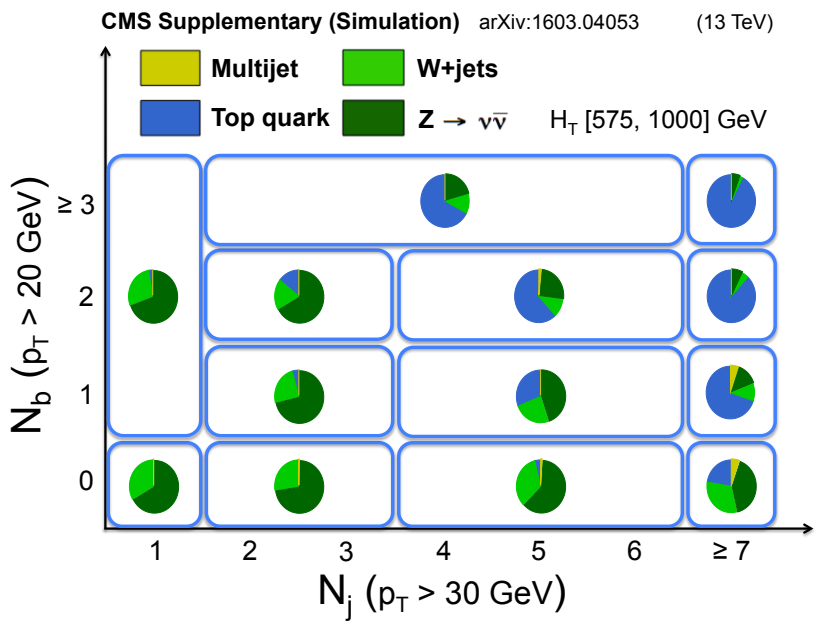
"Optimized for pair-produced new physics with WIMPs"

Search variable: M_{T2} ('stransverse mass', E_T^{miss}-like)

Binned in H_T, N_j and N_b

H_T : 200, 450, 575, 1000, 1500+ GeV
N_j : 1, 2-3, 4-6, 7+
N_b : 0, 1, 2, 3+

In each (H_T x N_j x N_b) region, look at **tails** of M_{T2}



The Strategies at a Glance

- H_T and H_T^{miss}
- M_{T2}
- α_T

"Maximal QCD rejection"

Search variable: H_T^{miss}

Trigger and preselection based on α_T variable

Require leading jet with $p_{T,1} > 100$ GeV

In dijet events:
$\alpha_T = p_{T,2} / M_T$

Depending on subleading jet, classify as:

symmetrical ($p_{T,2} > 100$ GeV)
asymmetrical ($40 < p_{T,2} < 100$ GeV)
monojet ($p_{T,2} < 40$ GeV)

Binned in H_T, N_j and N_b

H_T : 200, 250, 300, 350, 400, 500, 600, 800+ GeV
Nj : 1, 2, 3, 4, 5+
N_b : 0, 1, 2, 3+

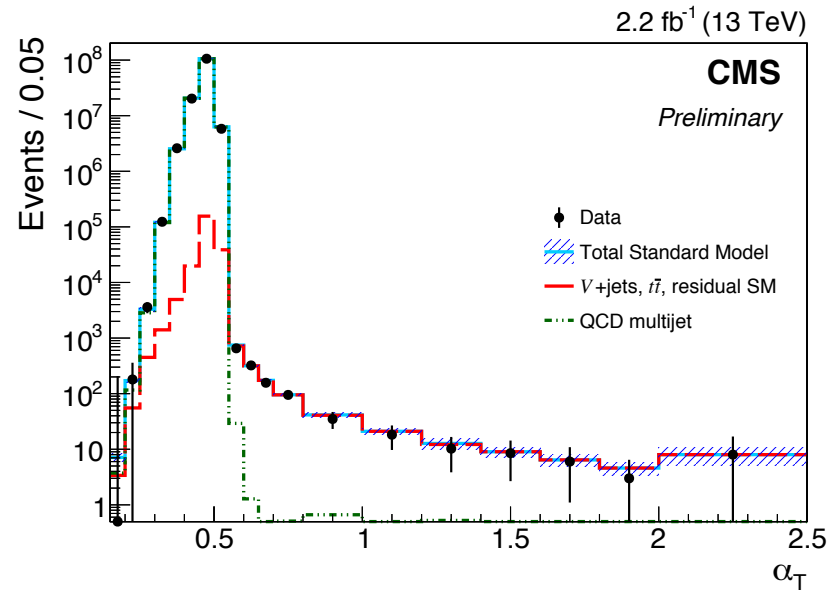
In each (H_T x N_j x N_b) region, look at **tails** of H_T^{miss}

Three Main Backgrounds

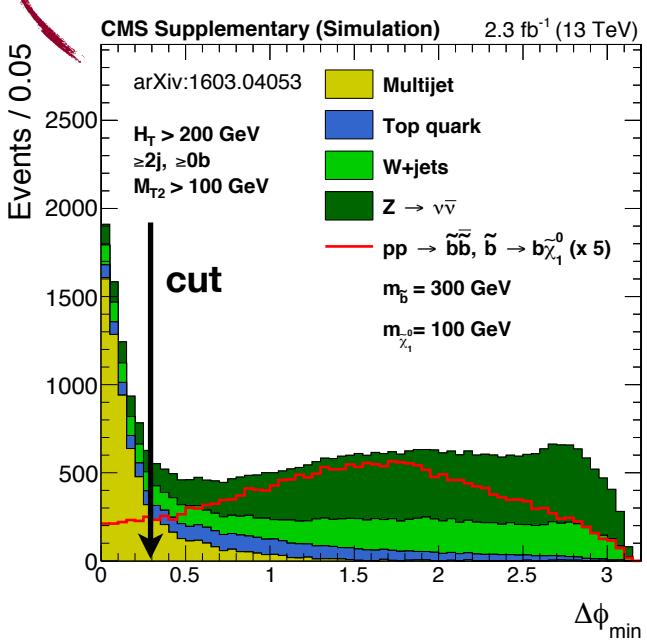
- **QCD** multijet events
  - **Instrumental** E_T^{miss}: mismeasurement of one of the jets
  - Typically pointing in the **direction** of a jet
- Events with **W→lν** decays ('lost lepton')
  - **Authentic** E_T^{miss} from neutrino
  - Out of acceptance, non-isolated, or mis-identified lepton; or hadronic τ
- Events with **Z→νν** decays ('invisible Z')
  - **Authentic** E_T^{miss} from neutrinos
  - Main **irreducible** background

Highest Cross-Section Background: QCD

- Search variables are 'QCD-killers'
  - Tails mostly QCD-free



- **Further** suppression:
  - E_T^{miss} not pointing in direction of a jet
  - $E_T^{miss}/H_T^{miss} \sim 1$

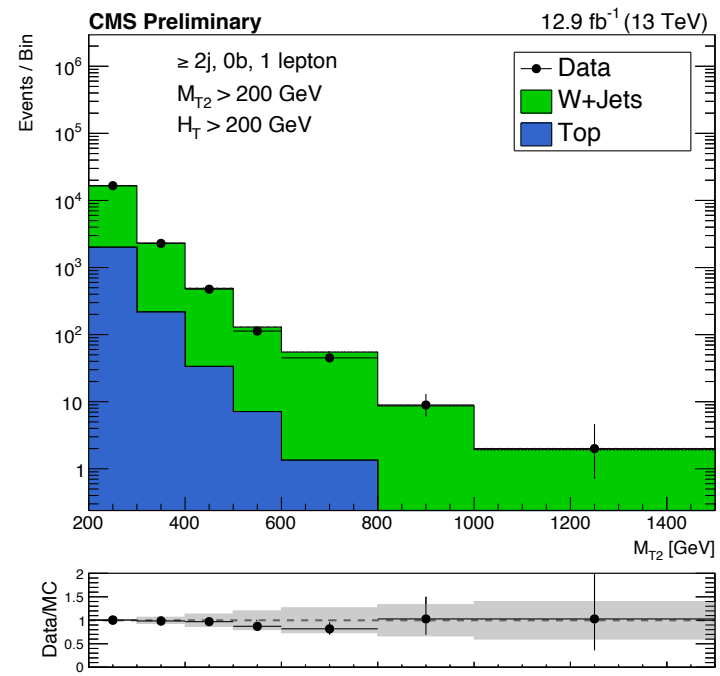


- **Residual** QCD evaluated from control regions
  - H_T/H_T^{miss} and M_{T2} : inverting $\Delta\phi(E_T^{miss}$,jet)
  - α_T : inverting E_T^{miss}/H_T^{miss}

‘Lost’ Lepton from W Decay

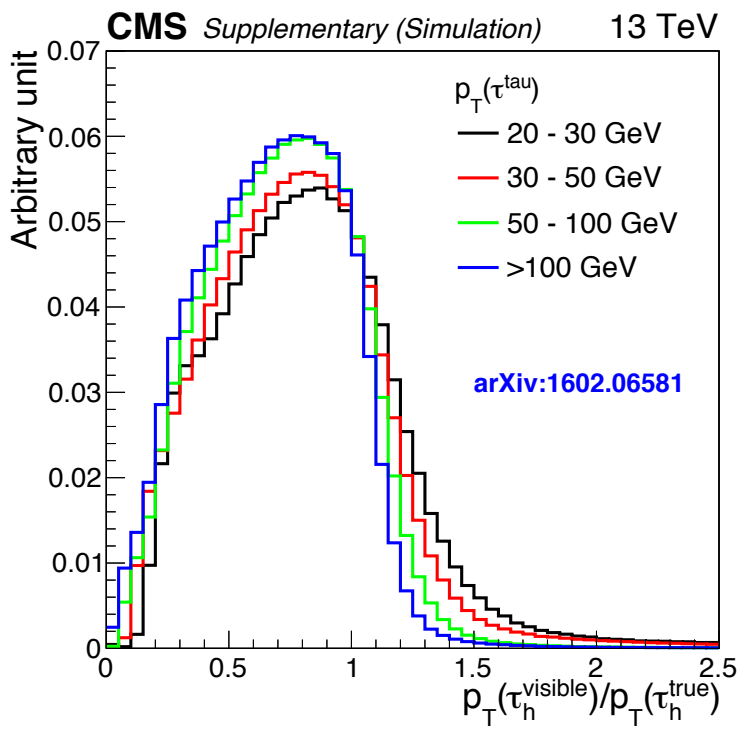
- **Main suppression**: tighten lepton veto
- Some residual events pass selection:
  - Outside of detector **acceptance**
  - **Non-isolated** leptons
  - Reconstruction/ID failures
- Data **control region** with exactly one e/μ
  - Then multiply by probability of ‘losing’ it

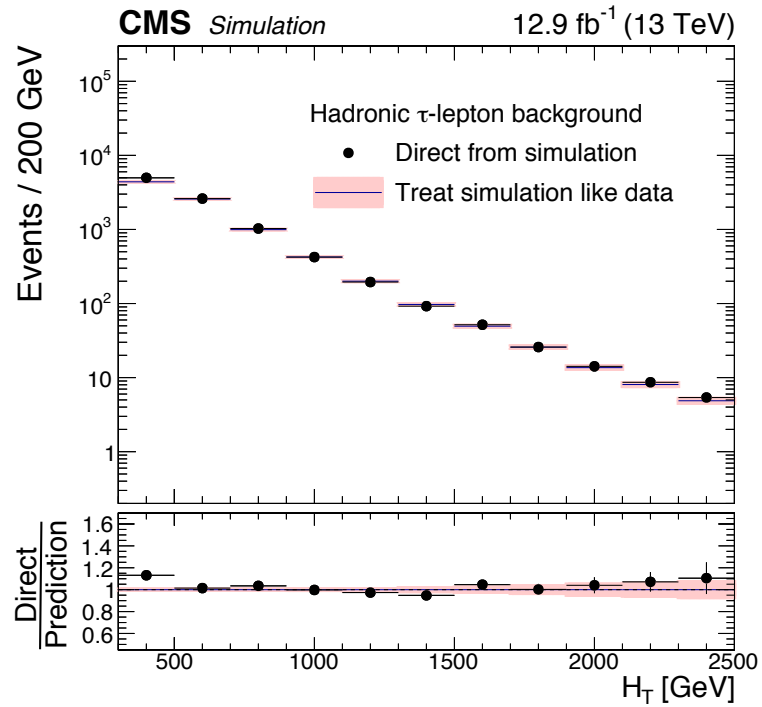
Example:
M_{T2} in single-lepton control region (lepton removed)



Hadronic τ Decays with Response Functions

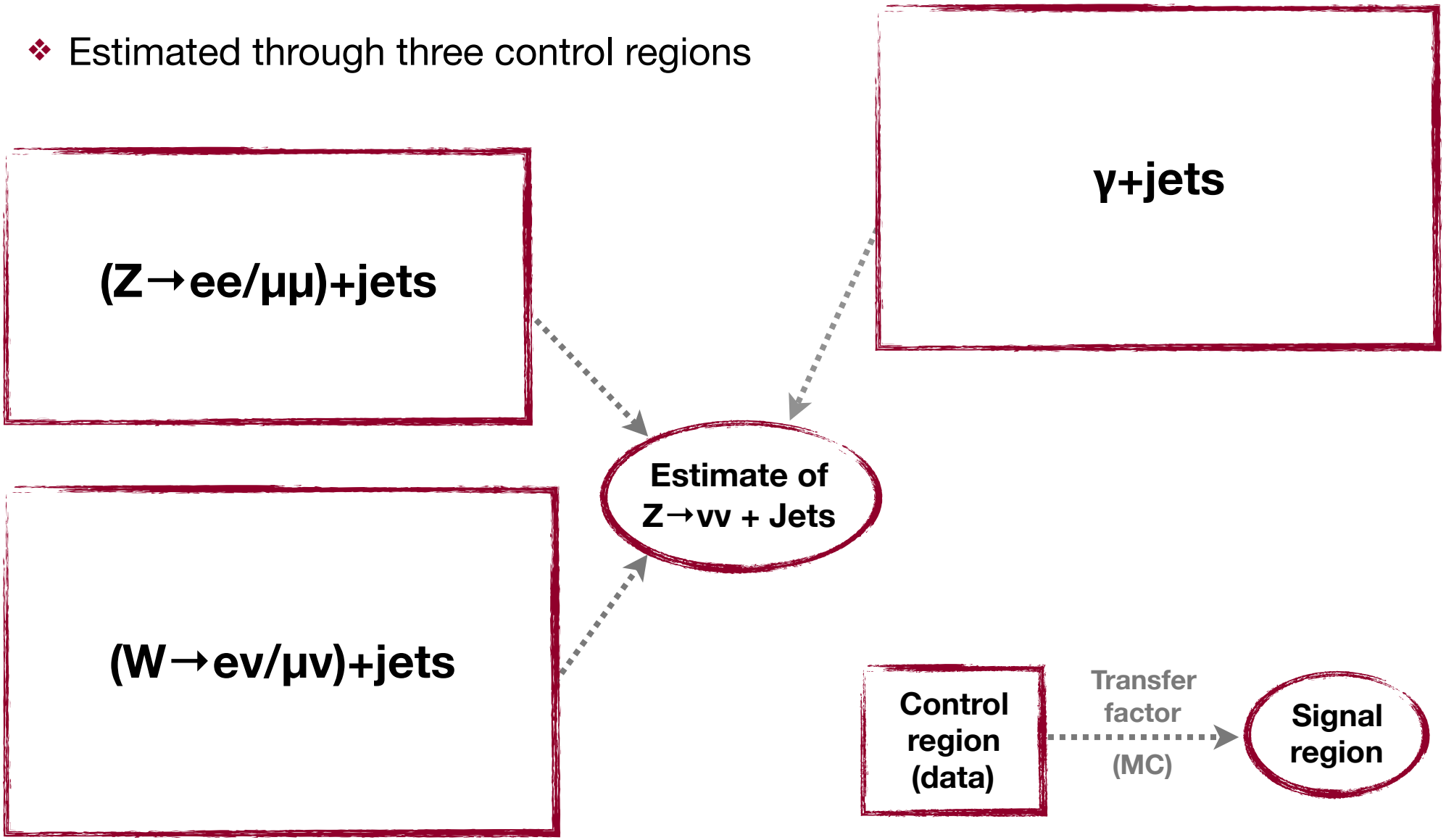
- H_T/H_T^{miss}: **special** treatment of hadronic τ_h
  - Take single-μ events, and smear μ p_T by τ_h **response function**
  - Then **recompute** event kinematics





Main Irreducible Background: Z→νν + Jets

- Estimated through three control regions



Main Irreducible Background: Z→νν + Jets

- Estimated through three control regions

(Z→ee/μμ)+jets

PRO Same process: small uncertainty on transfer factor

CON Low BR, statistically limited

γ+jets

PRO Largest cross-section

CON Different mass/couplings, larger uncertainty on transfer factor

CON Some QCD background

(W→eν/μν)+jets

PRO Background-free

PRO Intermediate cross-section

CON Different mass/couplings, larger uncertainty on transfer factor

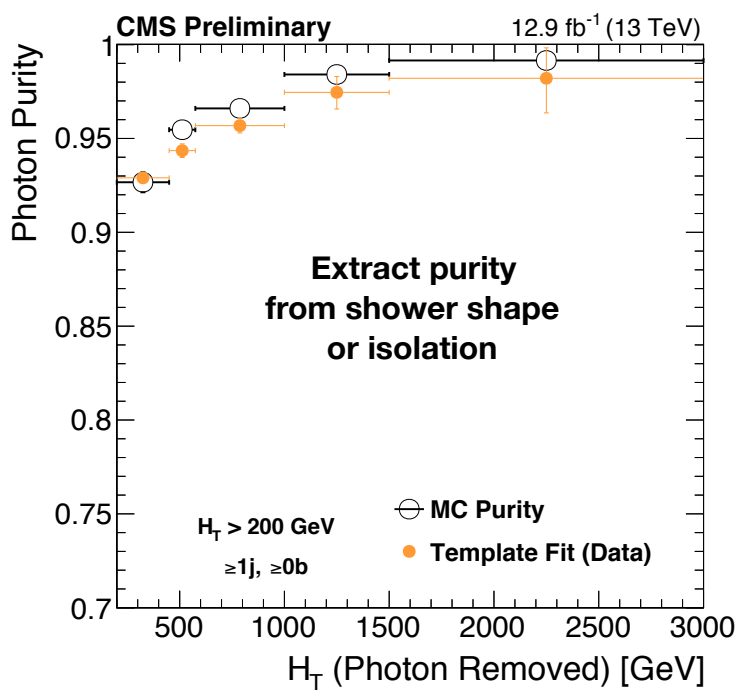
Estimate of Z→νν + Jets

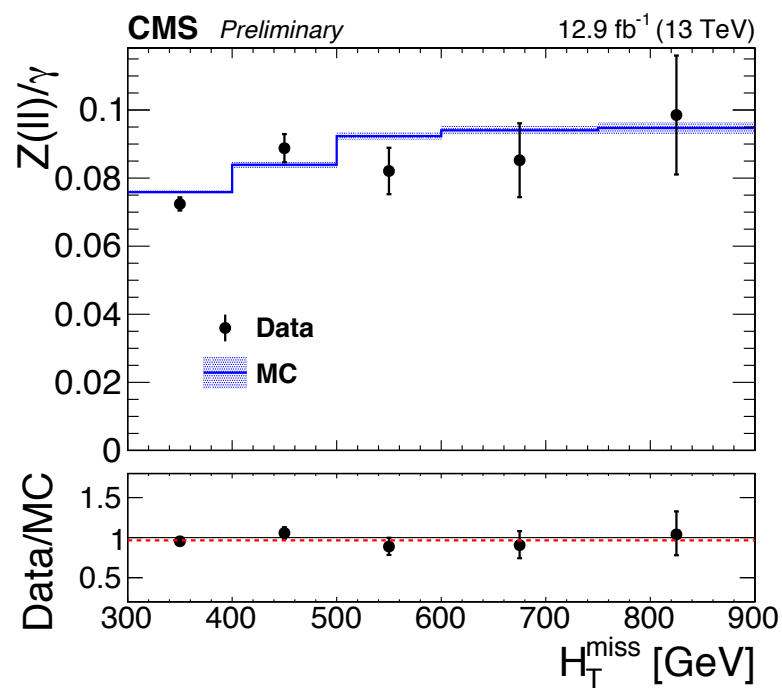
Control region (data) → Transfer factor (MC) → **Signal region**

γ+jets To Estimate (Z→νν)+jets: Two Steps

Events with a photon and jets → (Purity Fit / Remove QCD) → **Events with prompt photon** → (Z/γ Ratio) → **Events with a (Z→νν) and jets**

(Remove photon to emulate Z→νν)

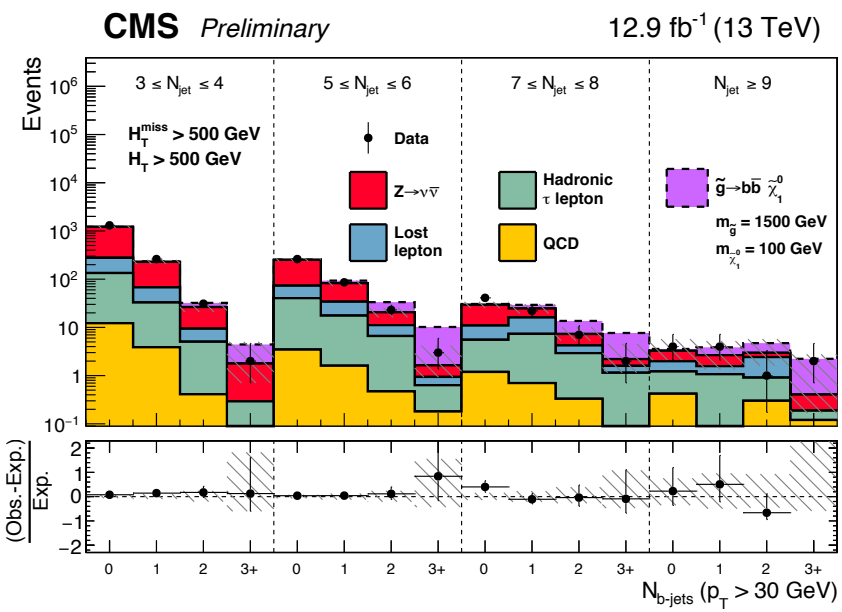




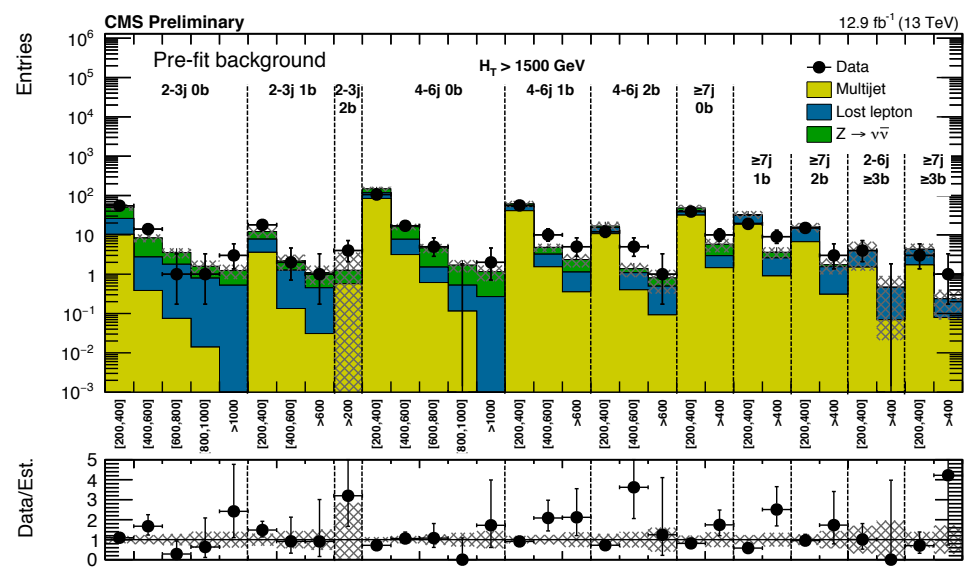
Comparing the Background Estimates to Data

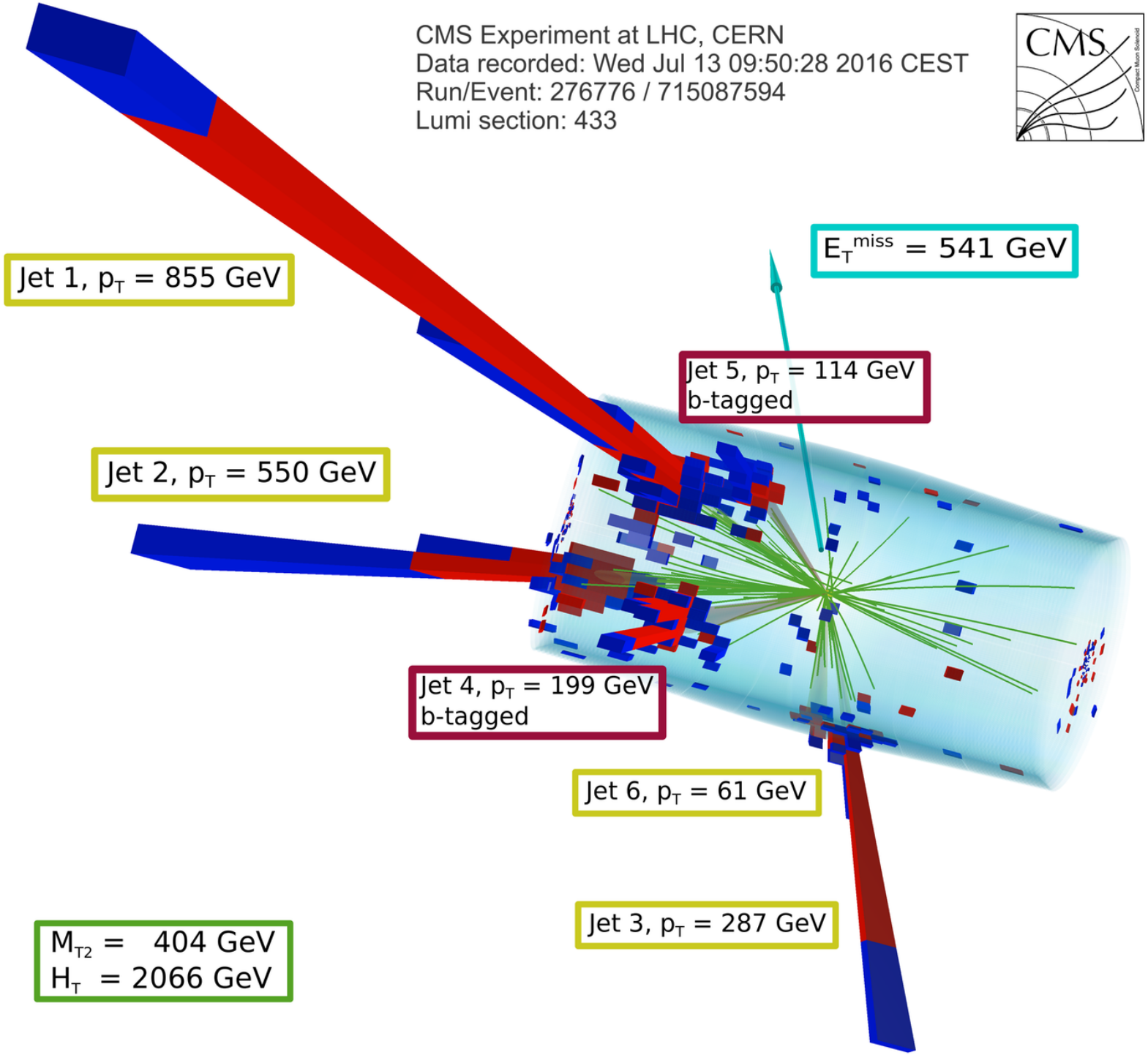
- **Compare** background estimates to data in signal regions
  - Look for excesses in **tails** of search variables
- **No significant** excess over background predictions

H_T/H_T^{miss}



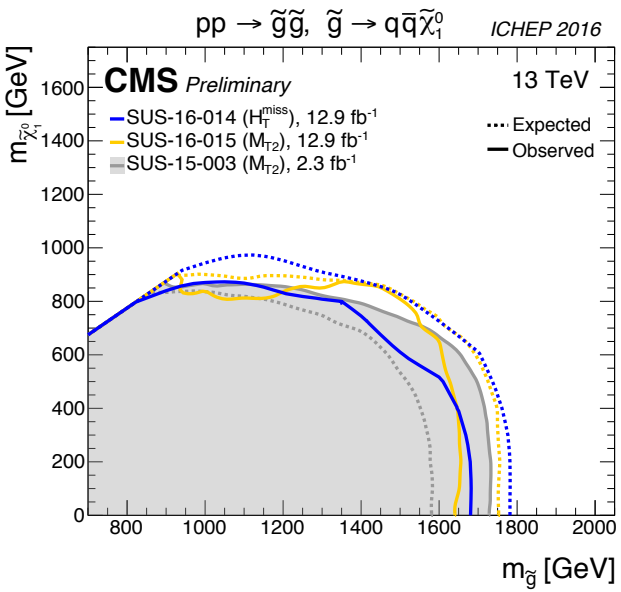
M_{T2}

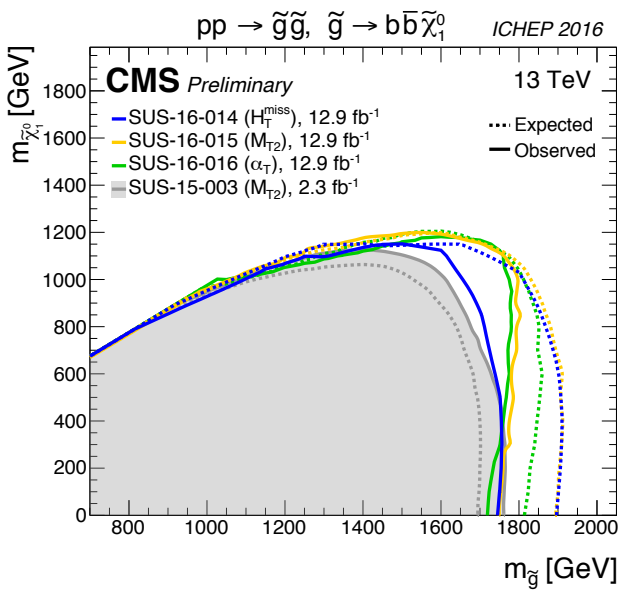


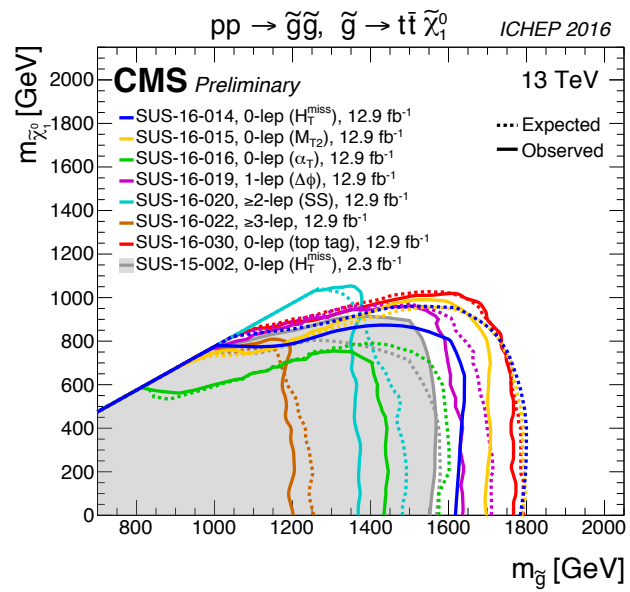

CMS Experiment at LHC, CERN
Data recorded: Wed Jul 13 09:50:28 2016 CEST
Run/Event: 276776 / 715087594
Lumi section: 433
CMS
Jet 1, p_T = 855 GeV
E_T^{miss} = 541 GeV
Jet 5, p_T = 114 GeV
b-tagged
Jet 2, p_T = 550 GeV
Jet 4, p_T = 199 GeV
b-tagged
Jet 6, p_T = 61 GeV
Jet 3, p_T = 287 GeV
M_{T2} = 404 GeV
H_T = 2066 GeV

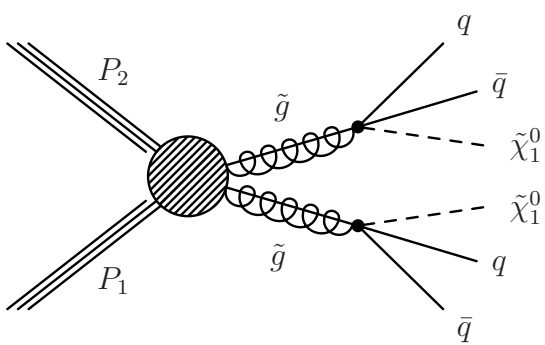
Limits on Direct Gluino Production

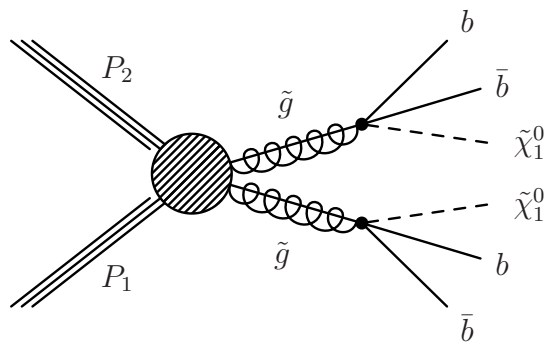
- Excluding **gluinos** up to 1.75 TeV and **neutralinos** up to 1.2 TeV

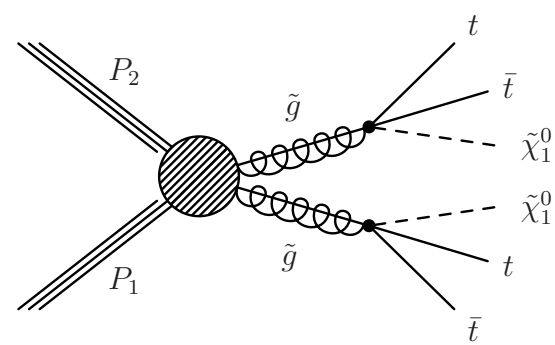






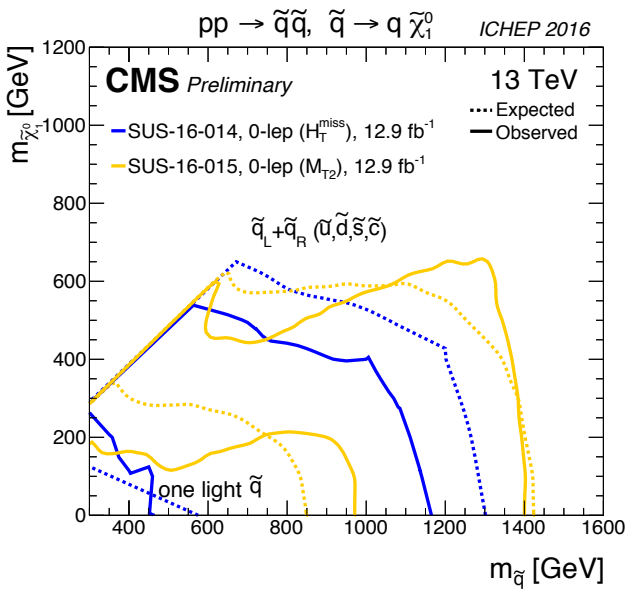


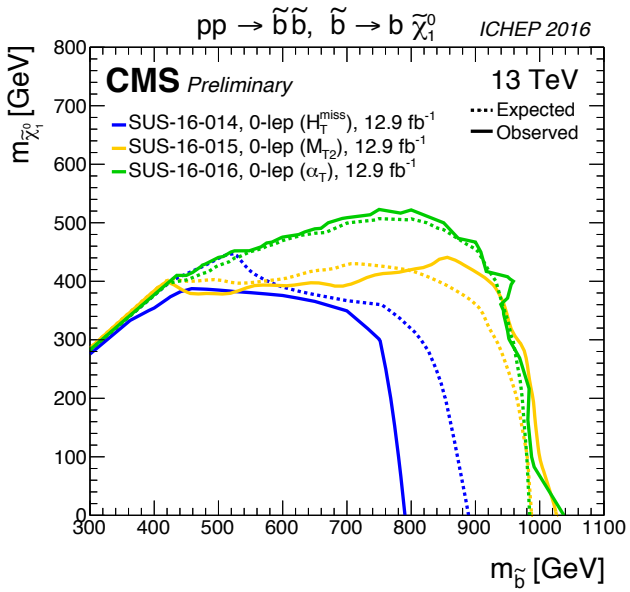


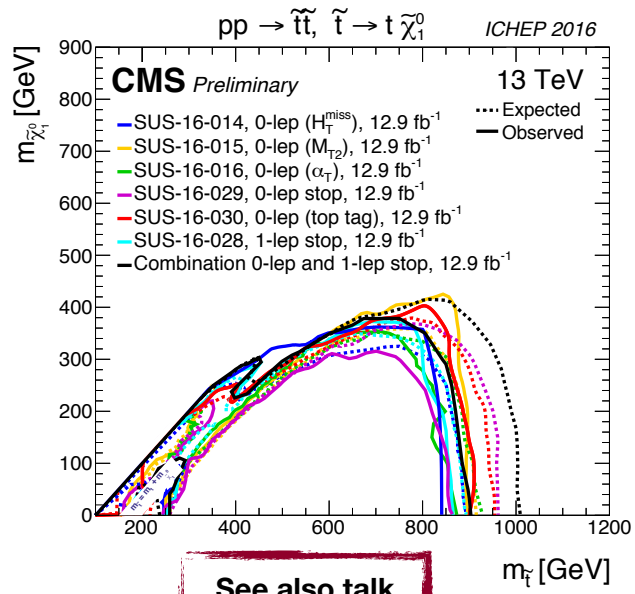


Limits on Direct Squark Production

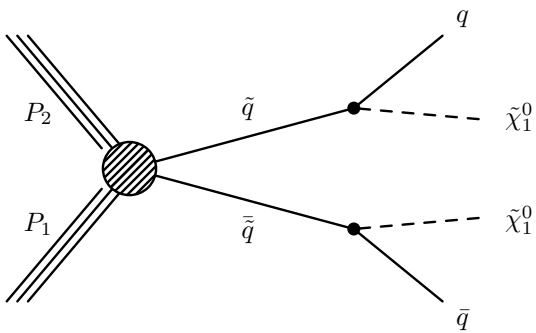
- Excluding **squarks (stops)** up to 1.4 (0.9) TeV and **neutralinos** up to 500 GeV

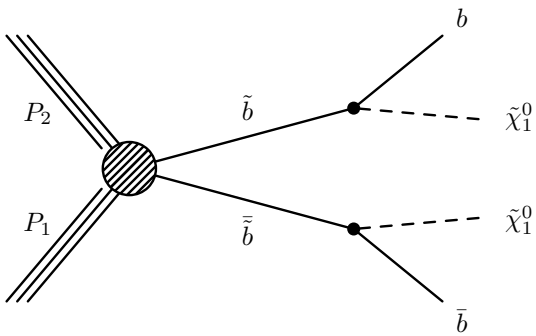


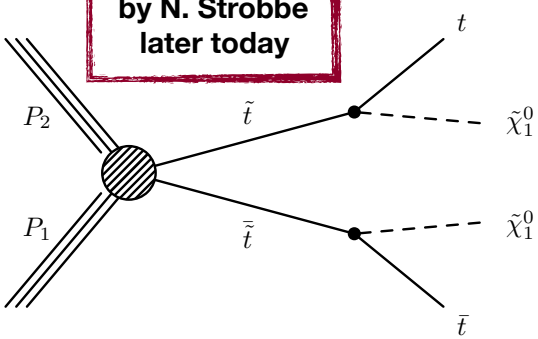




See also talk by N. Strobbe later today







Conclusions

- CMS has a **vast** SUSY-hunting program
- **Inclusive** searches in jets+E_T^{miss} final states
  - Probing **direct** squark and gluino production at the **energy frontier**
- Showed result from **three** searches: H_T/H_T^{miss}, M_{T2}, α_T
  - **Updated** to 12.9 fb^{-1}
- **No significant excess** over background predictions
  - Simplified models: excluding gluino/stop/neutralino up to 1.7/0.9/1.2 TeV
- Will continue searching in the quickly-expanding 13 TeV dataset!