Inclusive SUSY Particle Searches with Jets and MET (CMS)

On behalf of the CMS collaboration

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SUSY 2014 – Manchester, England

Production of SUSY Particles at the LHC

At the LHC SUSY can show up in manifold ways

→ cover various production and decay channels

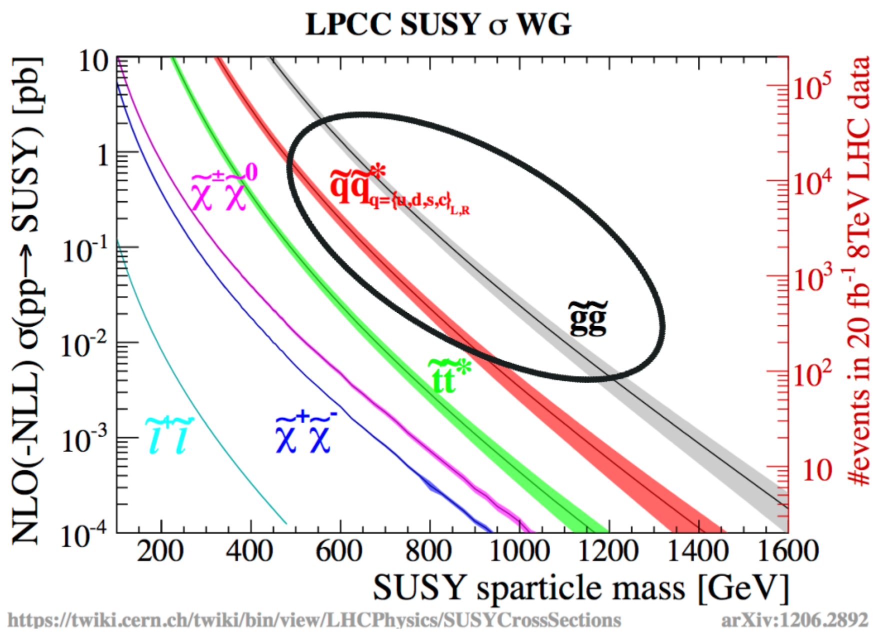
Inclusive analyses target wide range of SUSY phase space

→ use complementary methods

High production cross section of gluinos and light squarks

→ sizeable rate expected at 8 TeV

→ main target of inclusive searches

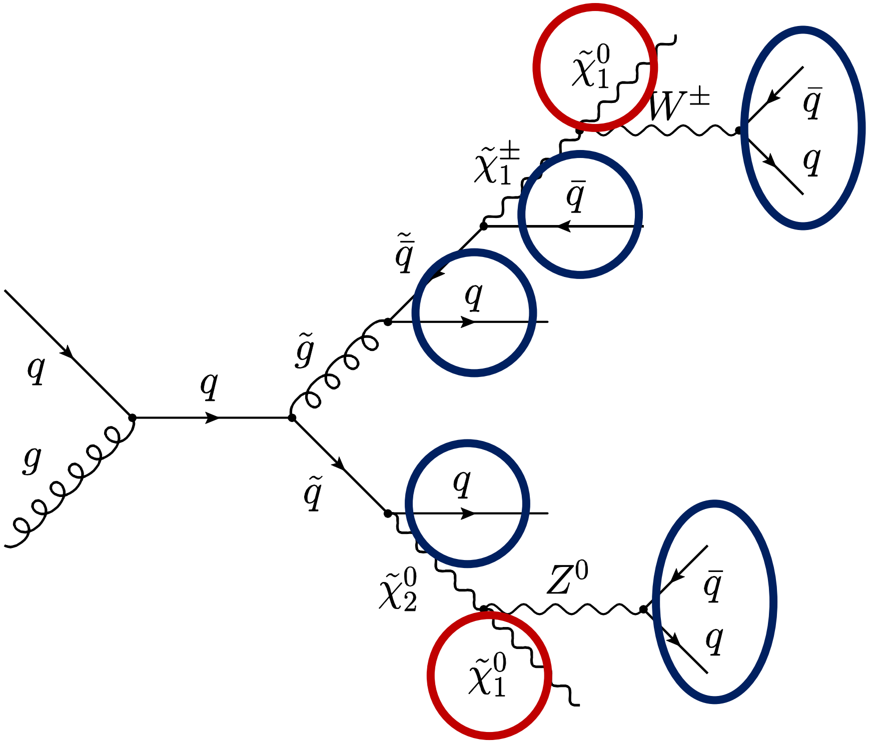


SUSY signatures

Parent particles often decay via cascades

→ R-parity conservation: production of quarks + stable lightest SUSY particle (LSP)

- R-parity violating models: Talk by H. Saka on Monday



- **Signature:**
  - Multijets with large total jet energy
  - Missing transverse energy from undetected LSPs
- **Main backgrounds:**
  - Z + jets → νν + jets
  - W + Jets → lν + jets
  - tt
  - QCD multijet

Overview

1. **Introduce different analyses** performed within CMS
   - ➢ Based on total available dataset at 8 TeV

2. **Discuss model interpretations**
   - ➢ Simplified models
   - ➢ pMSSM

Multijet + MET search

<u>Generic search based on:</u>

Jet multiplicity

N_{jets} = 3-5, 6-7, ≥ 8

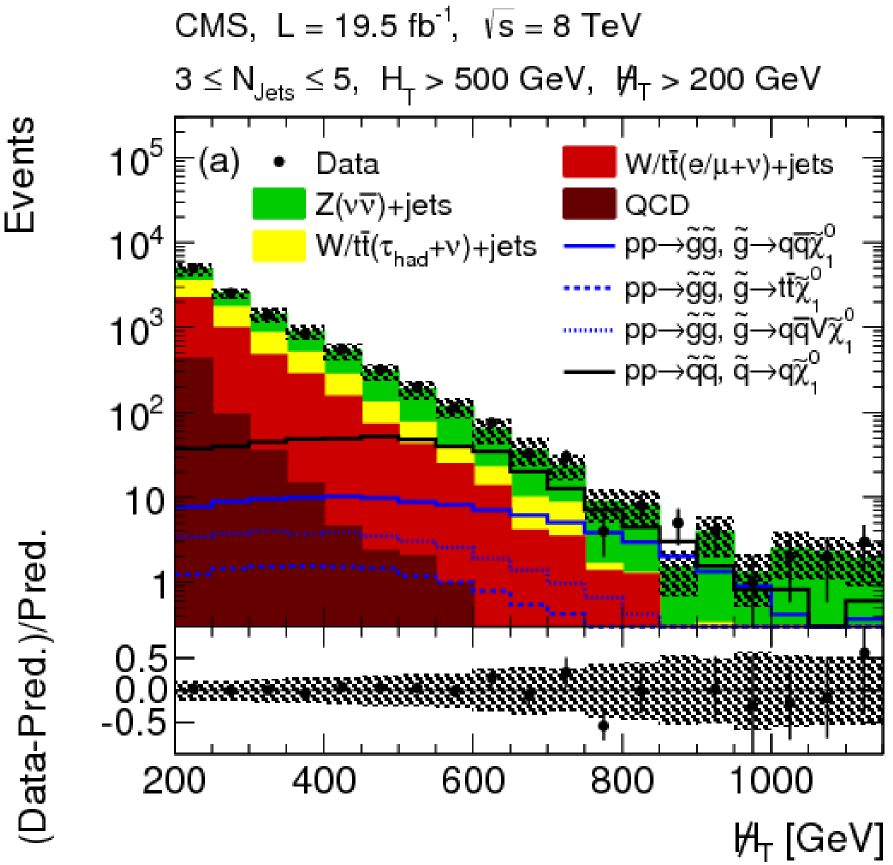
Scalar sum of jet energy

$H_T = \sum_{jets} p_T$

Missing transverse energy

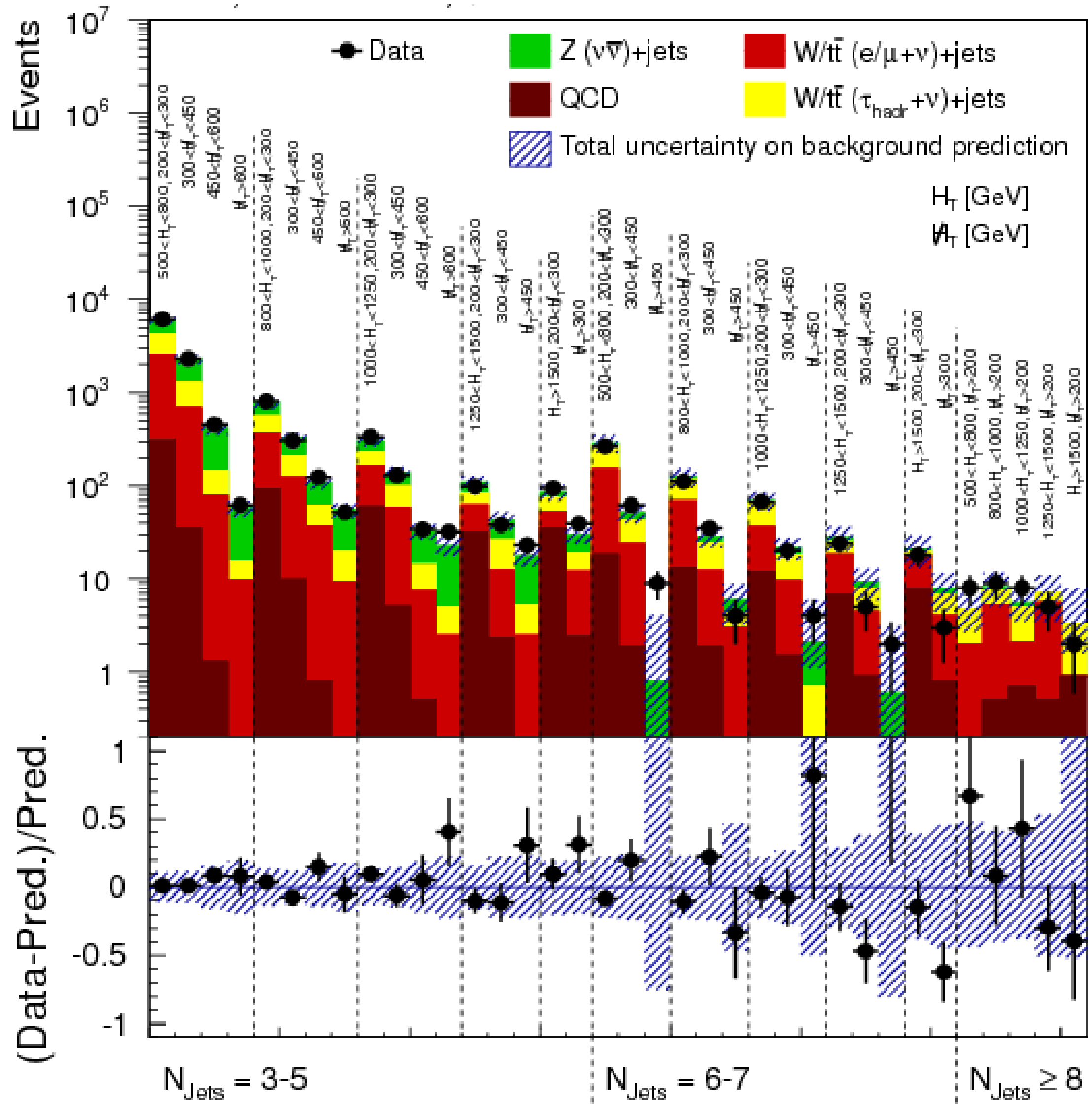
$MHT = | -\sum_{jets} \vec{p}_T |$

JHEP 06 (2014) 055
arXiv:1402.4770



- <u>No</u> b-tag requirement
- $\Delta\Phi$(MHT, jet$_{123}$) > 0.5, 0.5, 0.3
  - reject events with fake missing energy caused by mismeasured jets
- Reject events with isolated e or μ
  - reduce W+jets and tt background

Results - Multijet + MET search



Background processes estimated from data

No significant deviation between observed data and predicted background

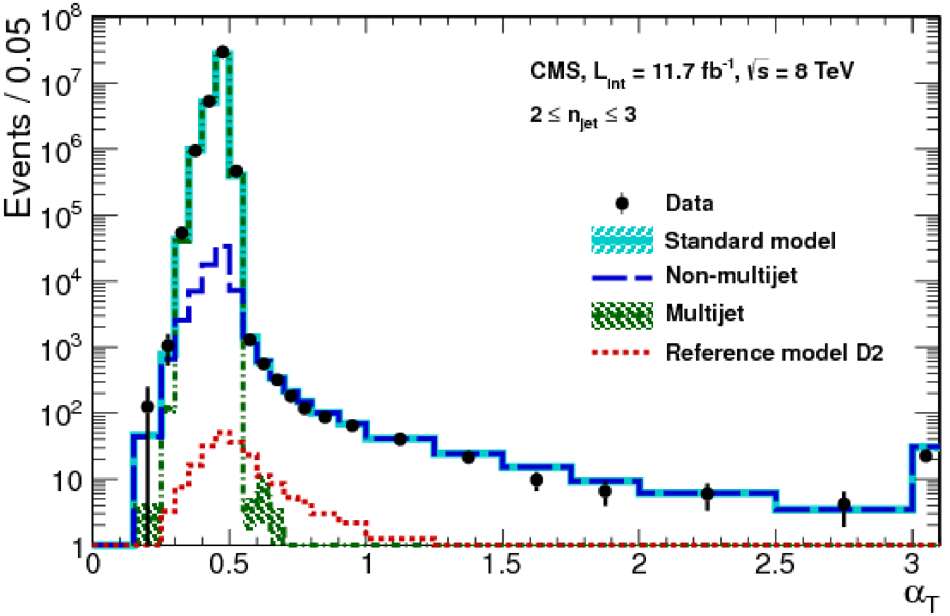
α_T + Jets search

- Inclusive search based on kinematic variable α_T
  - Dijet events: $\alpha_T = \frac{E_T^{j_2}}{M_T}$
  - Multijet events: cluster jets into two pseudo-jets

EPJC 73 (2013) 2568
arXiv:1303.2985

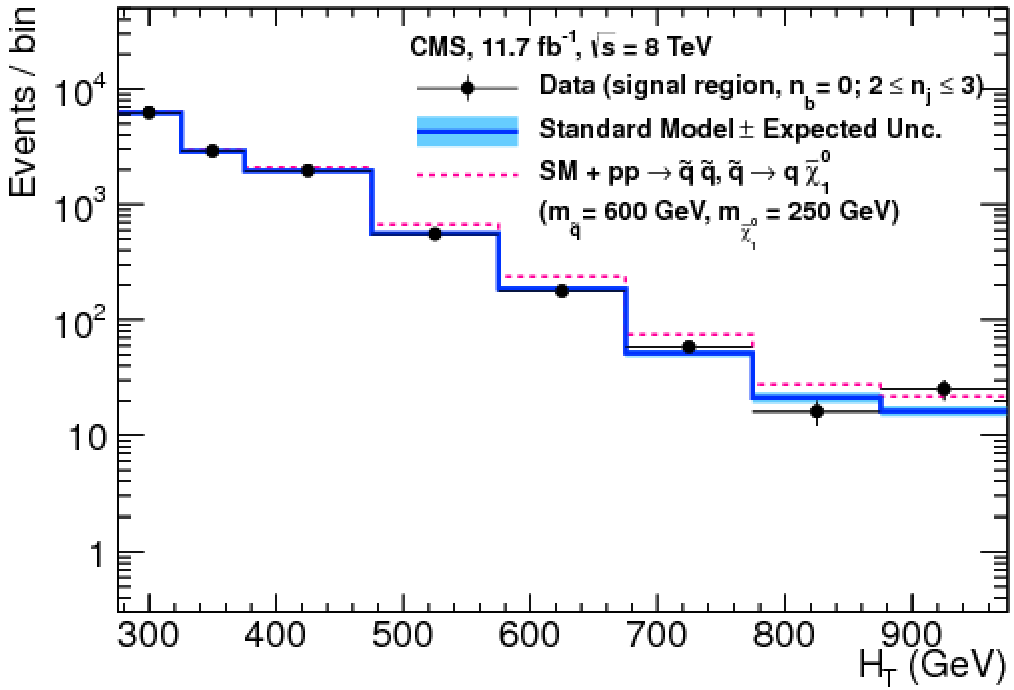
- <u>Basic Idea:</u>
  - $\alpha_T = 0.5$: perfect dijet event
  - $\alpha_T < 0.5$: events with mismeasured jets
  - $\alpha_T > 0.5$: events with genuine MET

  $\rightarrow$very effective discriminant against QCD multijet background



Results - α_T + Jets search

- Select events with α_T > 0.55 categorized in bins of
  - $H_T \geq 275$ GeV
  - N_{jets} = 2-3, ≥ 4
  - $N_{b\text{-tags}}$ = 0, 1, 2, 3, ≥ 4



- All results compatible with SM expectation

M_{T2} hadronic search

- Utilizes kinematic variable

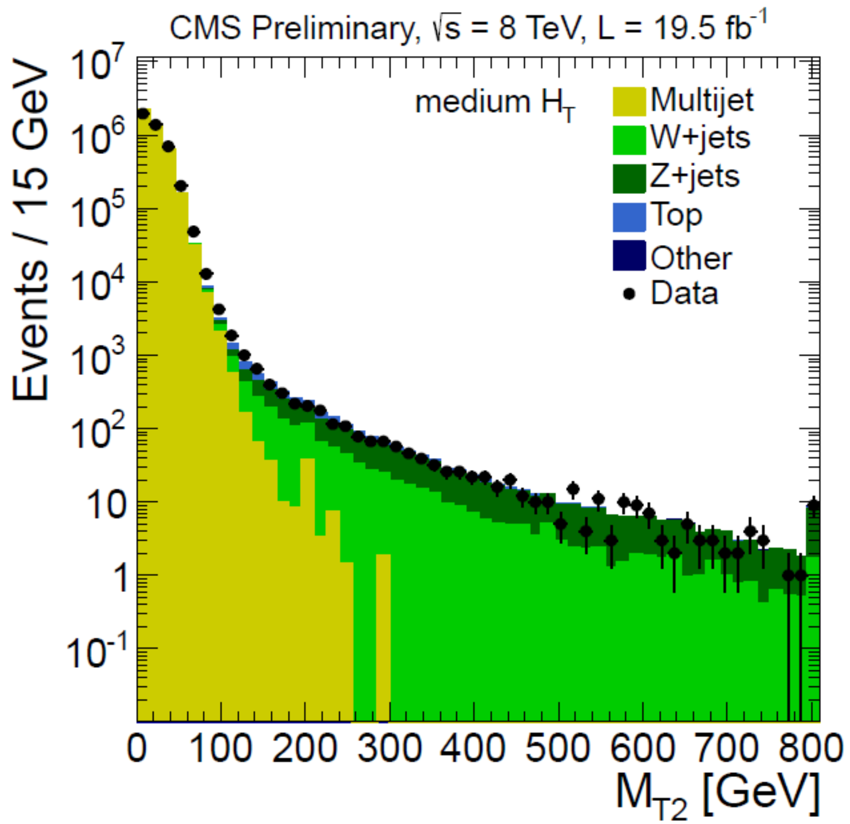
  M_{T2} = *stransverse mass*

  → generalization of transverse mass

PAS-SUS-13-019

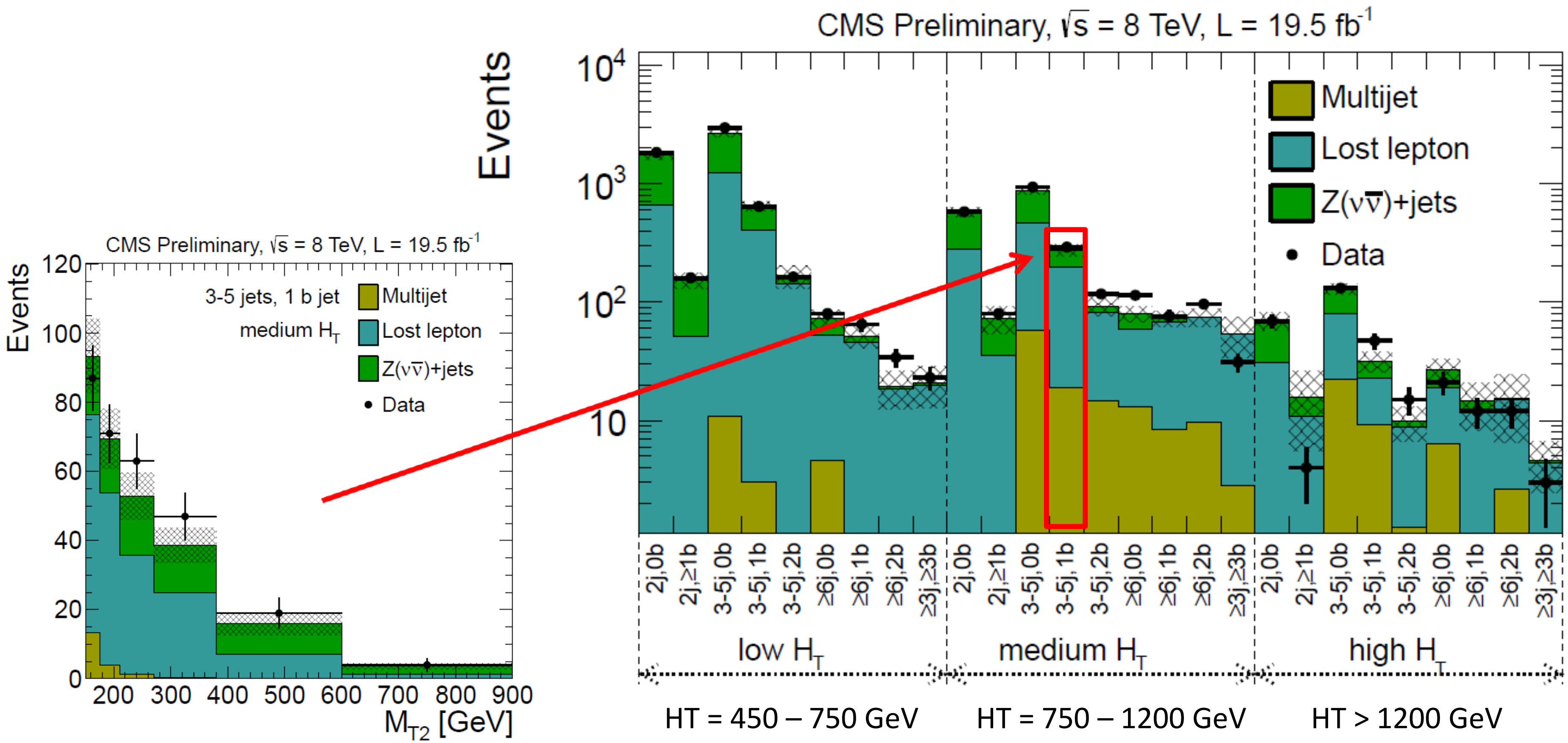
$$M_{T2}(m_{\tilde{\chi}}) = \min_{\vec{p}_T^{\tilde{\chi}(1)} + \vec{p}_T^{\tilde{\chi}(2)} = \vec{p}_T^{miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

- Events categorized according to
  - H_T = 450 – 750 GeV, 750 – 1200 GeV, ≥ 1200 GeV
  - N_{Jets} = 2, 3-5, ≥ 6
  - $N_{b\text{-tags}}$ = 0, 1, 2, ≥ 3



- For each region: several adjoining M_{T2} bins defined

Results - M_{T2} hadronic search



- Event yield in each region summed over respective M_{T2} spectrum

→ Observed data events consistent with predicted background

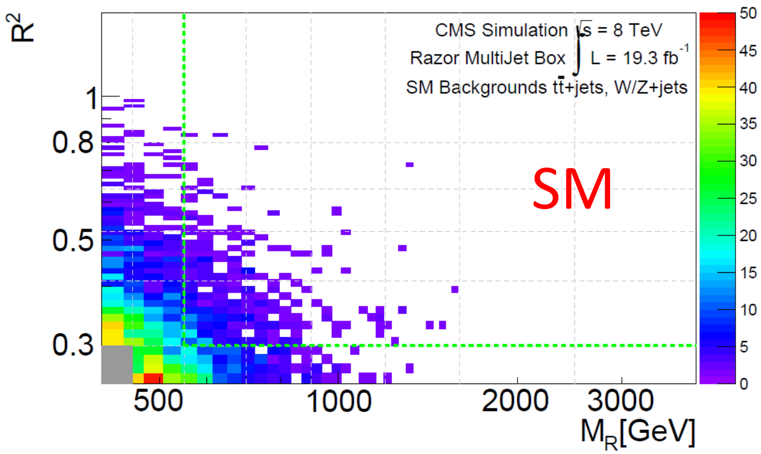
PAS-SUS-13-004

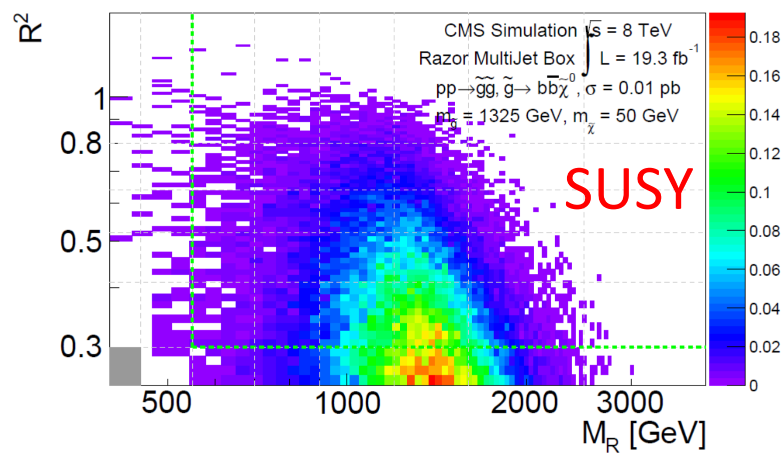
- Based on kinematic *razor* variables

$$R \equiv \frac{M_T^R}{M_R} \qquad M_R \equiv \sqrt{(p_{j_1} + p_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

  - Defined in terms of dijet topology
  - Multijet events → map event into dijet structure

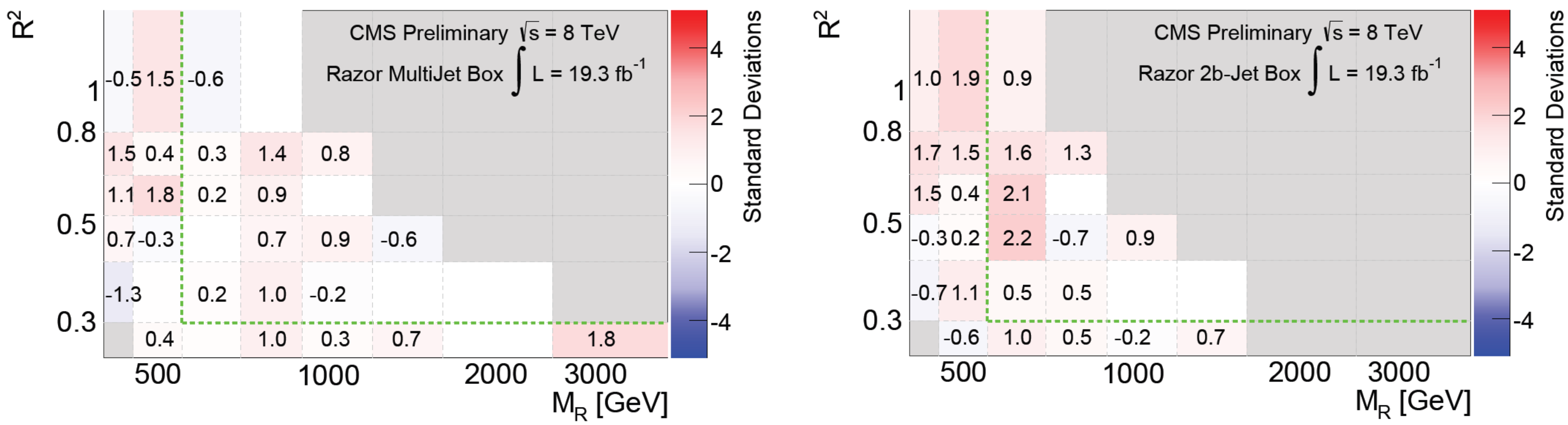




→ Search for peaking signal in $R^2 - M_R$ plane

Results - search using razor variables

- Search based on events with at least 1 b-tagged jet
  - Categorized in various *boxes* according to lepton multiplicites + jet/b-jet multiplicities

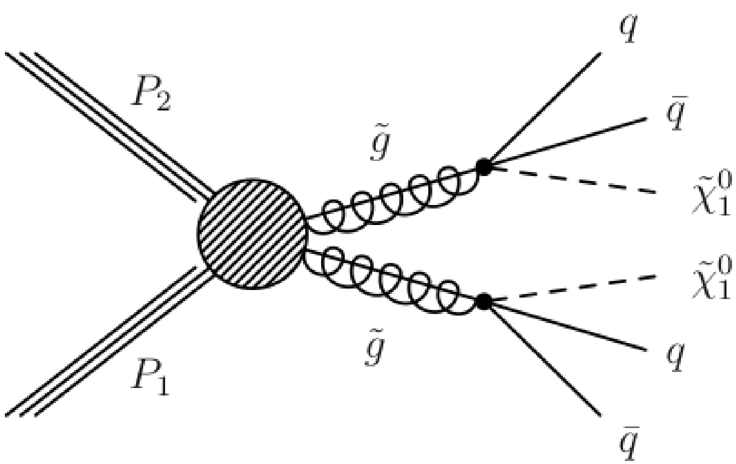


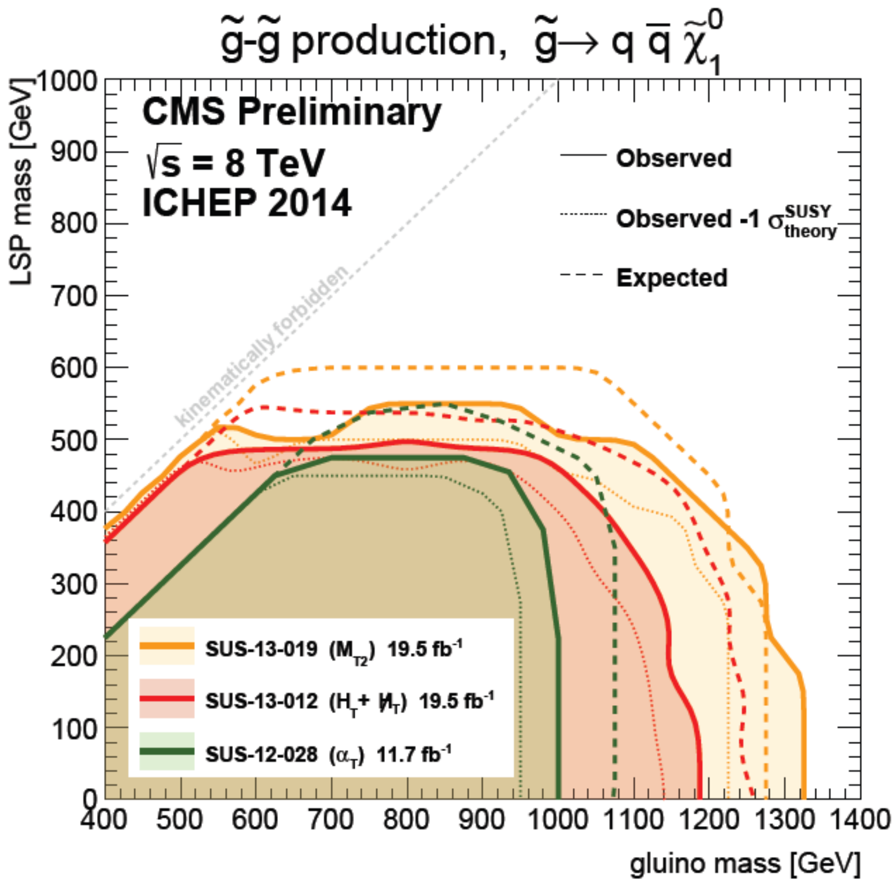
Results in all boxes consistent with SM

Interpretation

Interpret results in terms of simplified models

- include only one possible decay with 100% branching fraction

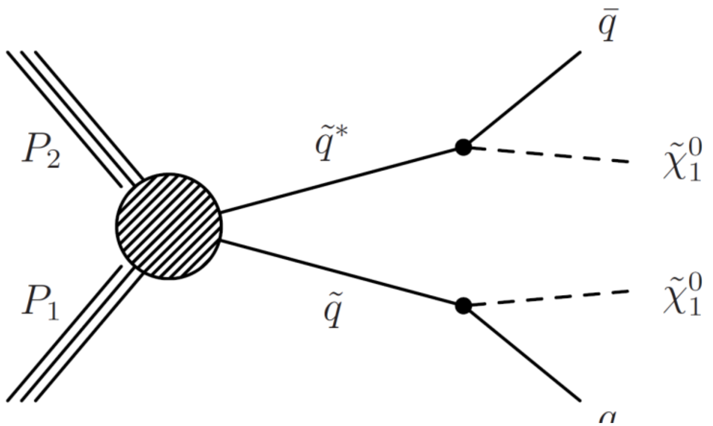


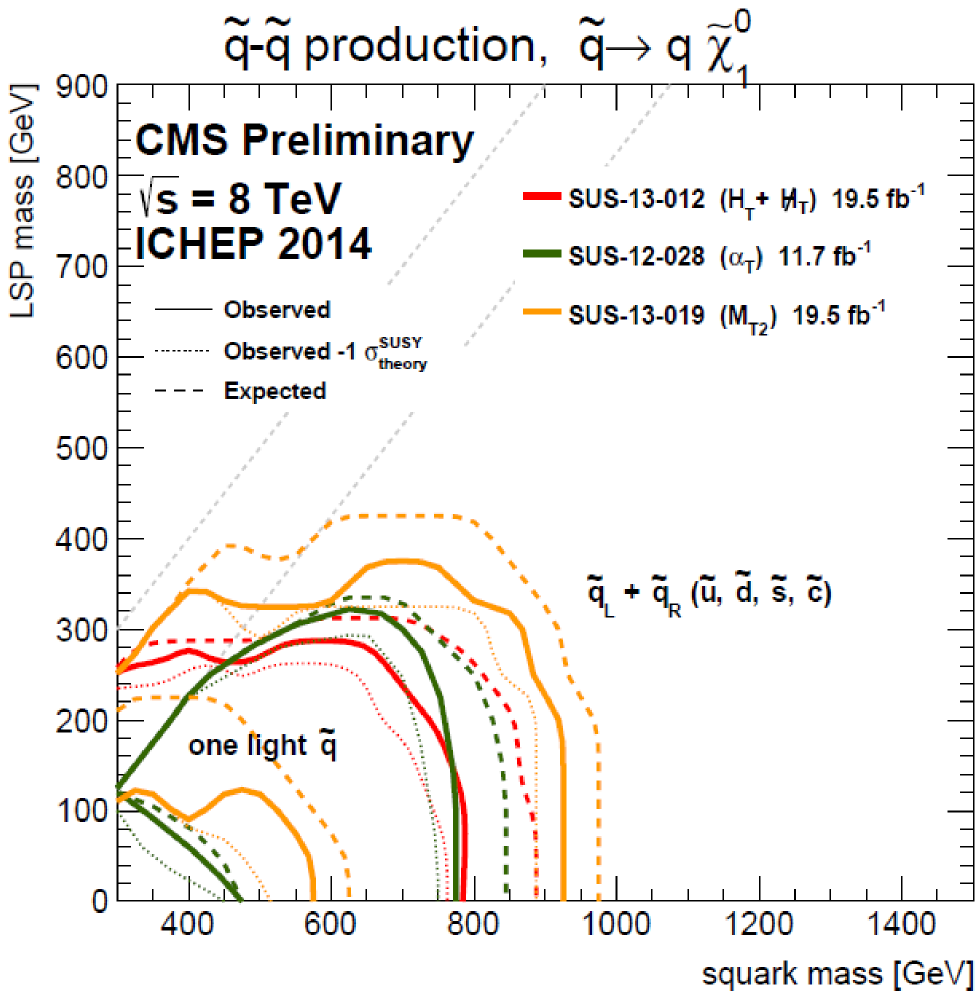


Free parameters: LSP + gluino mass

→ for light LSP: gluinos excluded up to ~ 1.3 TeV

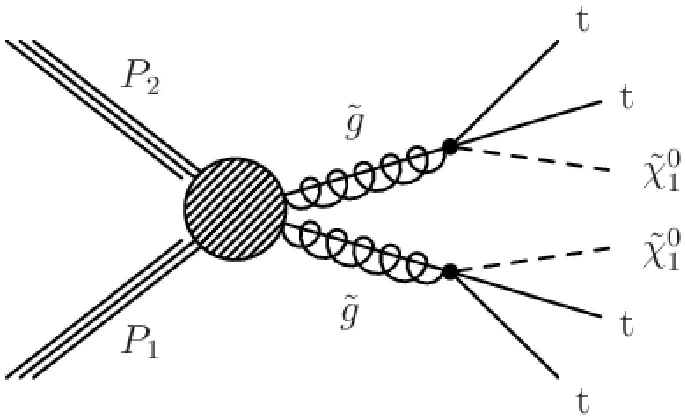
Interpretation





- Limit of ~ 920 GeV for light LSP in case of first two degenerate generations
- Limit of ~ 570 GeV for light LSP in case of only one light flavour

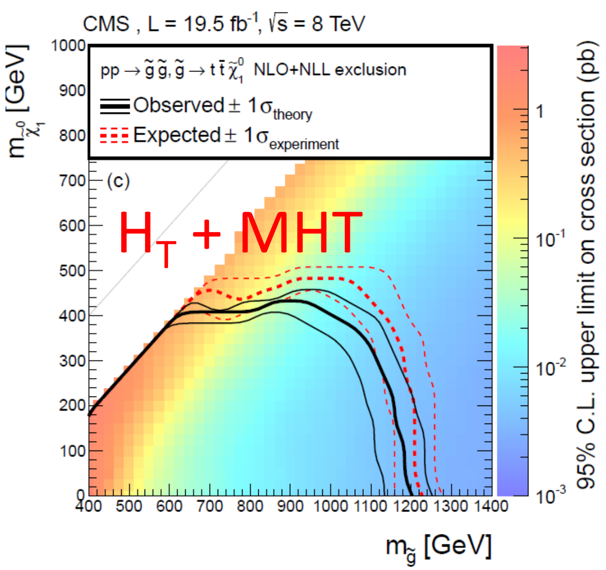
Interpretation

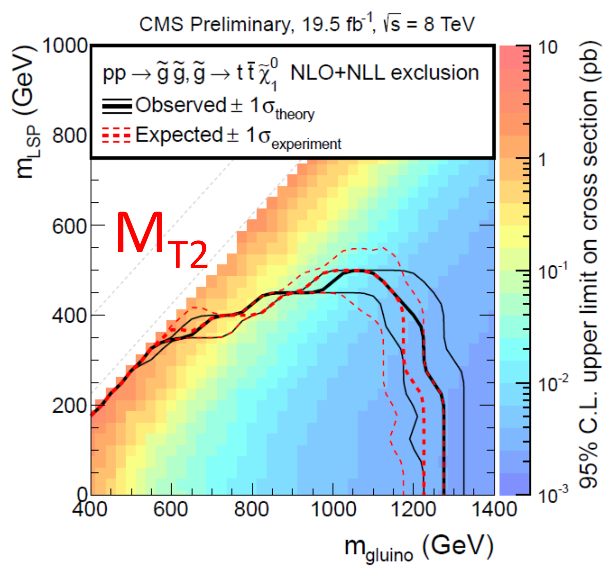


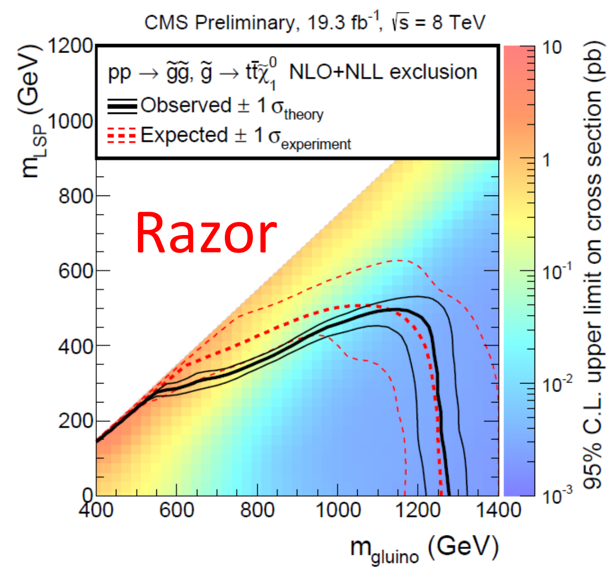
Gluino-mediated third generation searches

– see talk on Friday by N. Strobbe (session: „Precision SUSY“)

Hadronic searches exclude gluinos up to ~1.3 TeV (for light LSP)



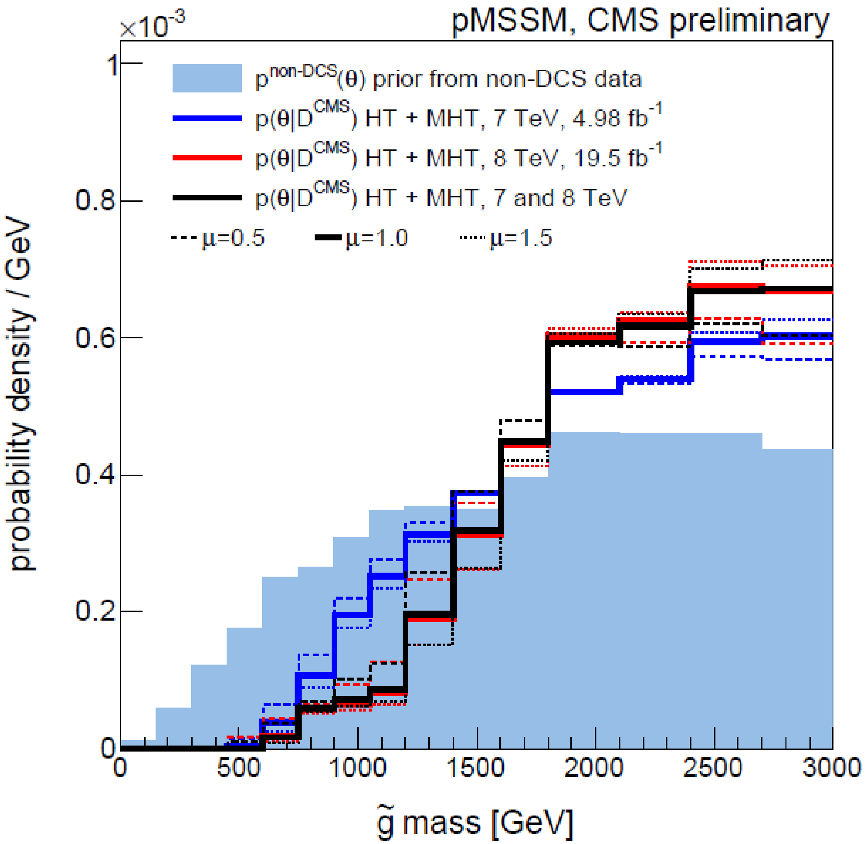




Interpretation

PAS-SUS-13-020

- Phenomenological MSSM
  - 19-dimensional realization of MSSM
- Perform global Bayesian analysis
  - → derive posterior probability densities for model parameters, masses + observables
- Based on pre-CMS data, indirect measurements + CMS search results



→ visible impact of CMS results on e.g. generic gluino

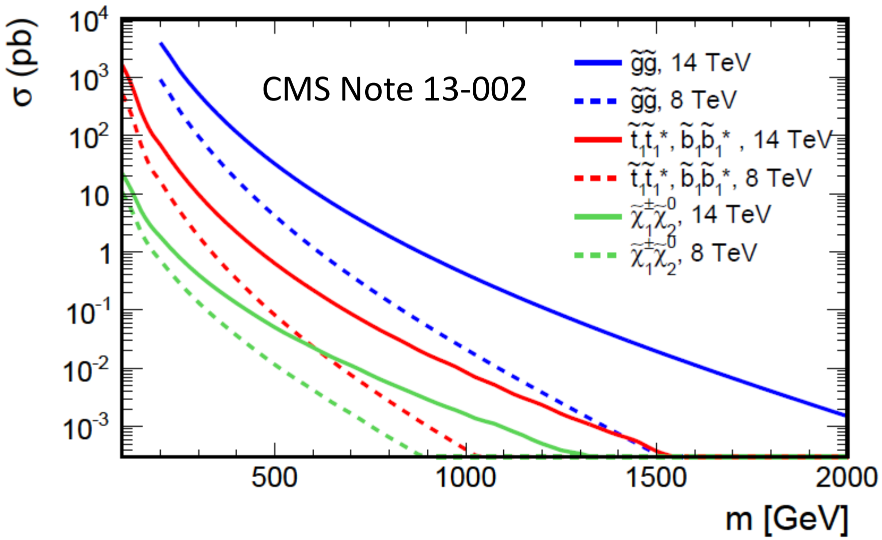
Summary + Outlook

- CMS performs several inclusive SUSY analyses based on final states with jets + MET
  - complementary approaches target natural SUSY
- All observations consistent with standard model expectations
- Results available here:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- BUT: Run II provides higher center-of-mass energy

  → mass reach extended



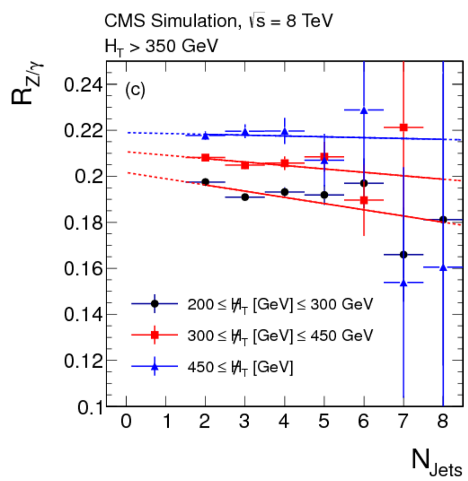
Stay tuned ☺!

Backup

Multijet + MET search - Background Estimation

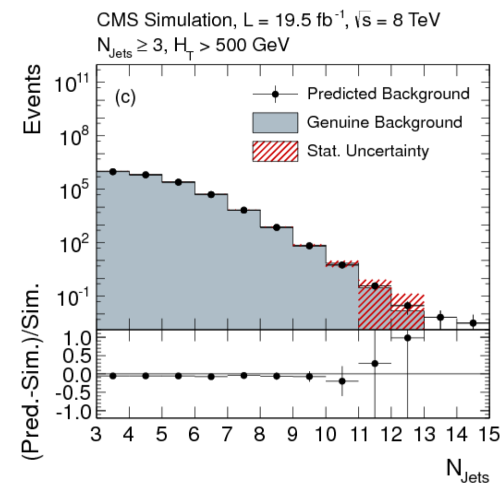
Z + jets:

- use photon control sample
- take ratio of Z/γ events to estimate Z events in signal region



QCD multijet:

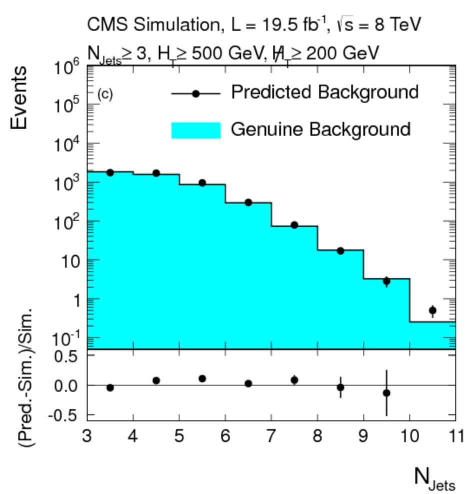
- generate data control sample containing events without missing energy
- smear jet momenta with measured jet response



tt/W+Jets:

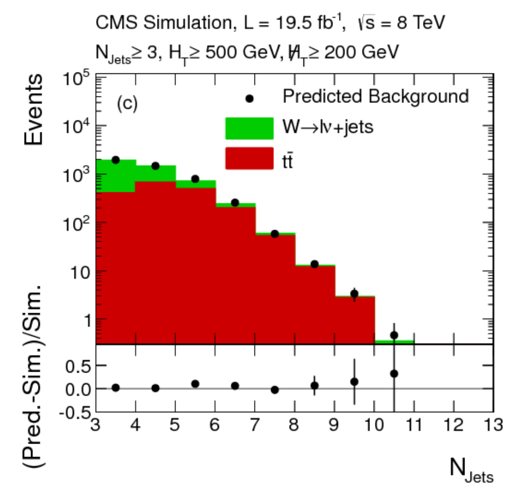
$\tau \longrightarrow had.$

- use μ + jets control sample
- replace μ with jet
- sample jet p_T from τ response

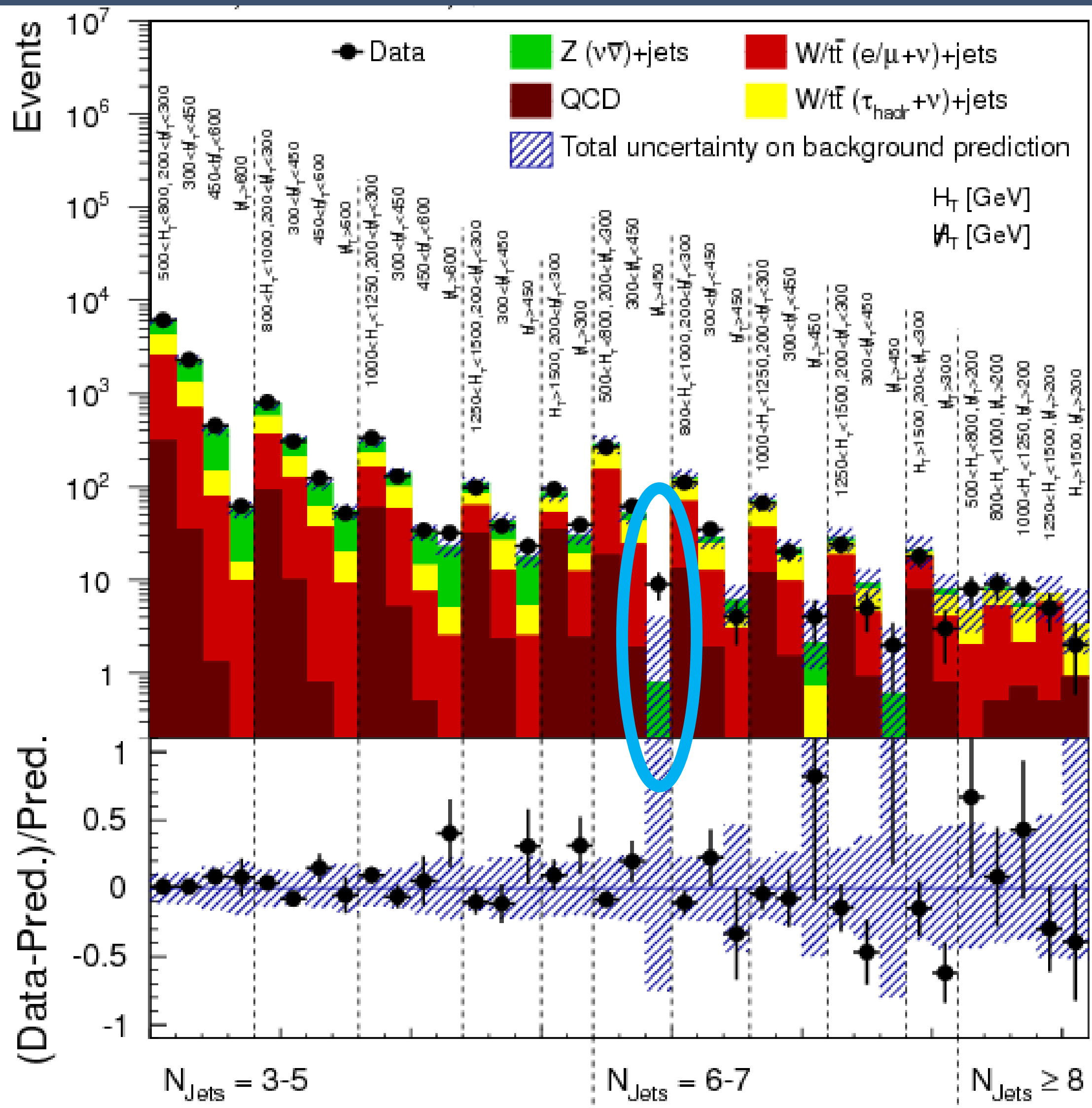


lost-lepton

- use μ + jets control sample
- reweight events with measured lepton inefficiencies



Multijet + MET search - Excess



- Observed events in data: 9
- Predicted background: 0.8 – 0.6 + 3.3

→ p_{local} = 0.05 ~ 1.7σ

But: we search in 36 bins

→ p_{global} = 0.78

→ No significant deviation

α_T - Generalized definition

- <u>αT in multijet events:</u>
  - Characterize mass scale of the event by $H_T = \sum_{i=1}^{n_{\mathrm{jet}}} E_T^{j_i}$
  - Missing energy is estimated by $\not{H}_T = |\sum_{i=1}^{N_{\mathrm{jet}}} \vec{p}_T^{\,j_i}|$
  - Combine jets in the event into two *pseudo-jets*
    - E_T of each pseudo jet is given by scalar sum of E_T from contributing jets
    - Choose combination which **minimizes ΔH_T (= absolute E_T difference of the two pseudo-jets)**

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

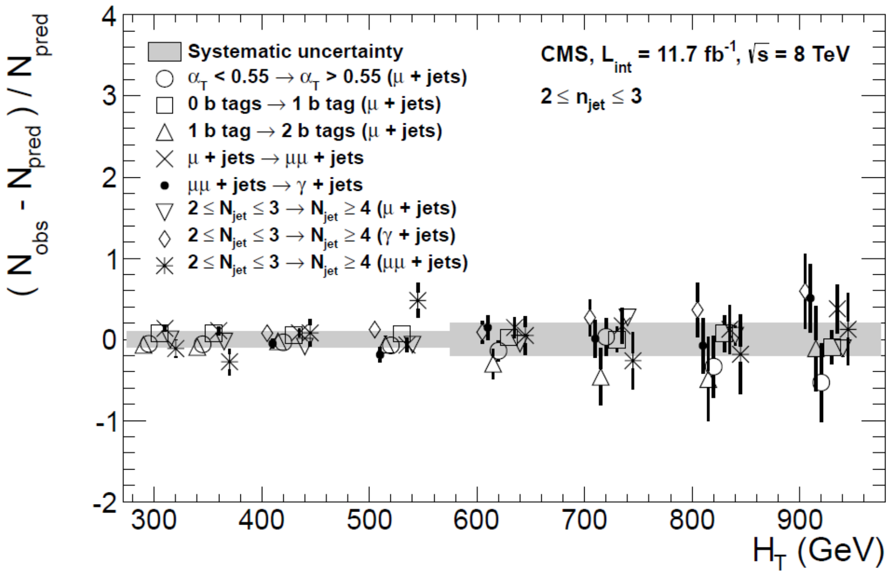
α_T - Background estimation

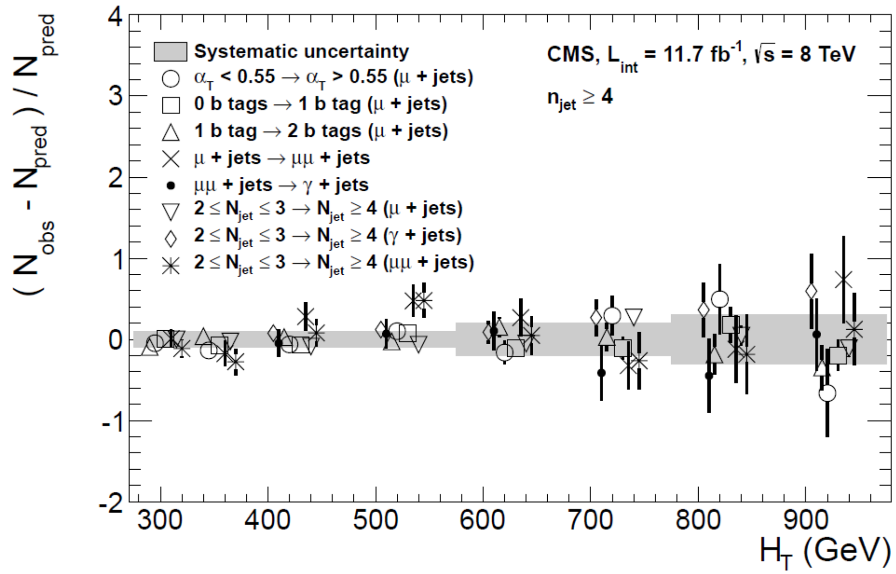
- Define suitable control regions:
  – γ + jets, μ + jets, μμ + jets

$$N_{\rm pred}^{\rm signal} = \frac{N_{\rm MC}^{\rm signal}}{N_{\rm MC}^{\rm control}} \times N_{\rm obs}^{\rm control}$$

- Scale event yields in control regions with correction factors from simulation

Validation tests of transfer factors





M_{T2} – Details definition

- (Susy) event is characterized by decay of primary pair- produced particles into a visible (jets) and an unvisible (LSP) part
- For each decay define transverse mass

$$(M_T^{(i)})^2 = (m^{\text{vis}(i)})^2 + m_{\tilde{\chi}}^2 + 2\left(E_T^{\text{vis}(i)} E_T^{\tilde{\chi}(i)} - \vec{p}_T^{\,\text{vis}(i)} \cdot \vec{p}_T^{\,\tilde{\chi}(i)}\right)$$

$\rightarrow$ can not exceed parent mass

- But: LSPs not accessible individually, only sum (= MET vector) is known

$\rightarrow$ define M_{T2}

  - Choose maximum of M_T^1 and M_T^2
  - Make sure that M_T does not exceed parent mass
    - Perform minimization on trial LSP masses fulfilling MET constraint

$\rightarrow$ M_{T2} has endpoint at mass of primary particle (for correct m_{LSP})

M_{T2} - Clustering multijet events

- MT2 in multijet events:
  - Form two pseudo-jets by reconstructing event hemispheres
  - Choose two initial jet axes
    - Here: defined by axes of (massless) jets with highest invariant dijet mass
  - Associate remaining jets to the one or the other axis by ***hemisphere association method*** (minimal Lund method)
    - Jet k is associated to hemisphere i (and not j), if

$$(E_i - p_i \cos\theta_{ik})\frac{E_i}{(E_i+E_k)^2} \leq (E_j - p_j \cos\theta_{jk})\frac{E_j}{(E_j+E_k)^2}$$

  - After finished association: jet axes are recalculated as sum of all jet momenta associated to one hemisphere

M_{T2} - Background estimation

<u>Similar methods to Multijet + MET analysis:</u>

- ***Multijet background:***
  - factorization procedure:
    - Use control region defined by low M_{T2} and $\Delta\varphi_{min} < 0.2$
    - Extrapolate to signal region with exponential function $r(M_{T2}) = \frac{N(\Delta\phi_{min} \geq 0.3)}{N(\Delta\phi_{min} \leq 0.2)} = \exp(a - b \cdot M_{T2}) + c$
    - Determine a + b via fit to data, determine c from simulation
- ***Lost-lepton background:***
  - use control region with inverted lepton veto (= 1 well identified lepton)
  - Reweight events by propbability to loose lepton due to reconstruction, acceptance, isolation inefficiencies
- ***Z + jets background:***
  - Estimated from photon + jets or Z → ll sample
  - Missing energy mimicked by removing photon (leptons) from event

Razor - Clustering multijet events

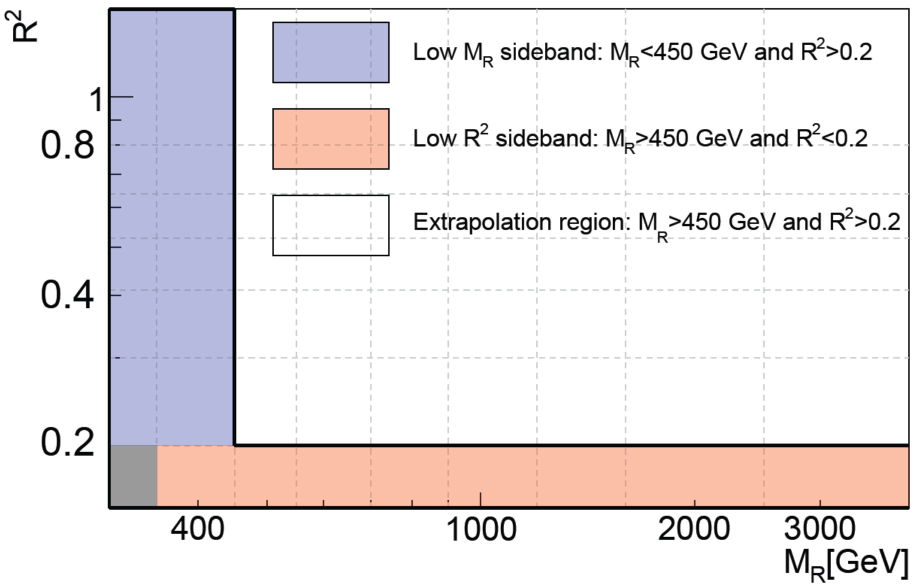
- <u>Razor in multijet events:</u>
- Cluster objects (jets + leptons) into two *megajets*
  - Assign physics objects into one of two non-empty partitions
  - From all possible combinations → select assignment which **minimizes invariant massses of the two megajets summed in quadrature**
  - Megajet four momentum = vector sum of four momenta of assigned physics objects

Razor - Boxes


≥1 b-Jet
Loose Mu && Tight Ele?
MuEle
Tight/Loose Mu?
MuMu
Tight/Loose Ele?
EleEle
Tight Mu && ≥4 Jets?
MuMultiJet
Tight Mu?
MuJet
Tight Ele && ≥4 Jets?
EleMultiJet
Tight Ele?
EleJet
≥4 Jets?
MultiJet
≥2 b-Jets?
2b-Jet
YES
NO

Razor - Background estimation

- Extrapolate from background dominated sidebands at low M_R and R^2 to search region
- Background model: 2D function of M_R and R^2
  - Model is fitted in each box independently but simultaneously for each b-tag multiplicity
  - Shape parameters (n, R_0, M_R^0) to describe potential differences between simulation and data



$$f_{SM}(M_R, R^2) = [b(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n} - 1]e^{-bn(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n}}$$