Search for SUSY in hadronic final states with the α_T variable at CMS

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for the CMS collaboration

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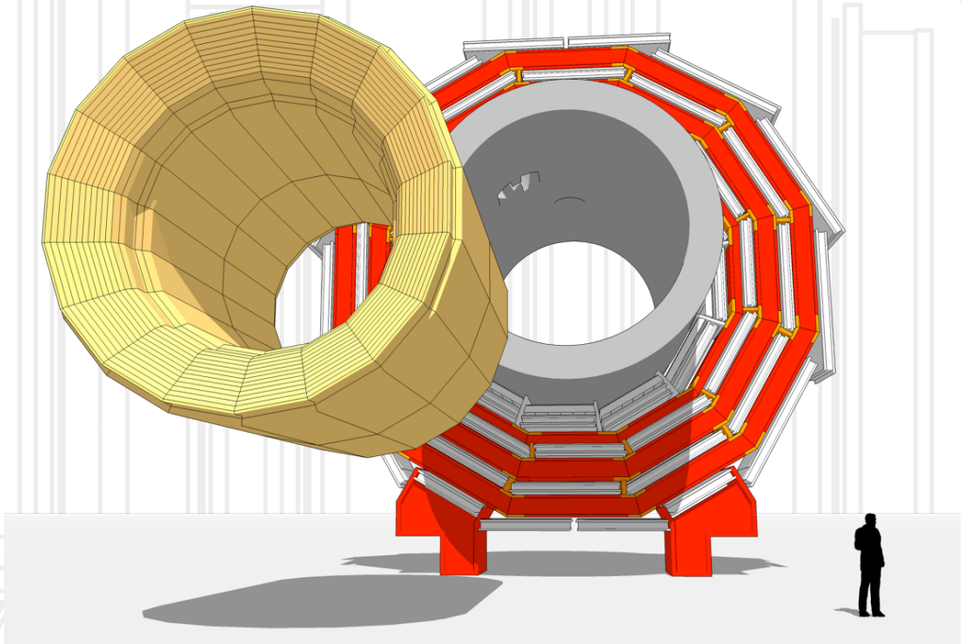
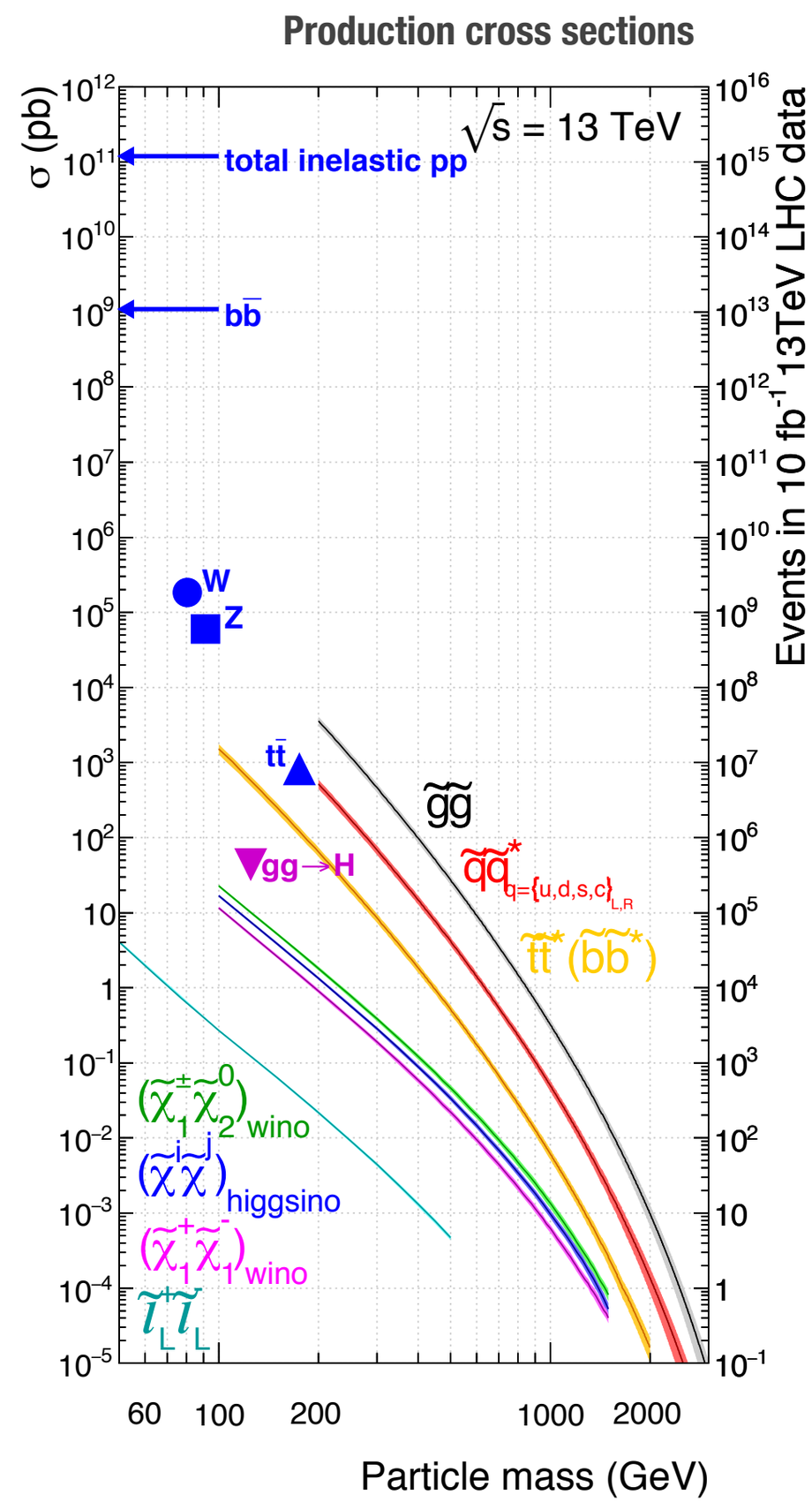
https://indico.cern.ch/event/443176/sessions/175282/#20160704



Search for SUSY in hadronic final states with the α_T variable at CMS

- **Hadronic final states**
  - jets and missing energy
  - events with a lepton or photon are vetoed
- **The α_T variable**
  - A dimensionless variable used to reject QCD multijet events

- Related talks: CMS searches in hadronic final states with other variables
  - **MT2:** *Search for supersymmetry in hadronic final states with the MT2 variable* by Mario Masciovecchio, today
  - **Razor:** *Inclusive searches for SUSY using the razor variables in CMS* by Javier Mauricio Duarte, tomorrow
  - **MHT:** *Search for supersymmetry in the multijet and missing transverse momentum channel in pp collisions at 13 TeV* by Kevin Pedro, tomorrow



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SUSYSMSSummaryPlots13TeV

Run 2 SUSY searches with the α_T variable

SUS-15-005	2.2 fb^{-1} 13 TeV	CDS:2114880	Dec 2015

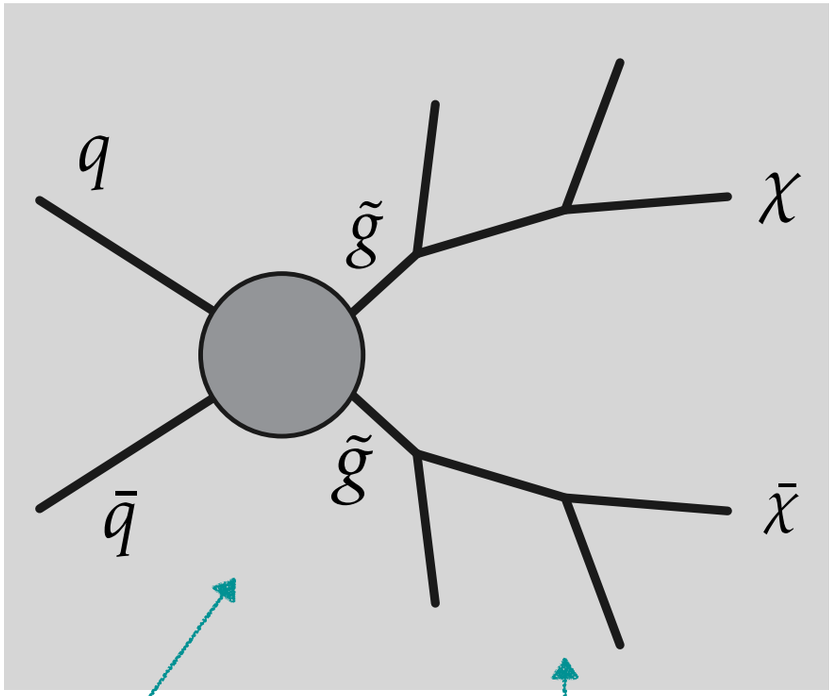
Run 1 SUSY searches with the α_T variable

SUS-14-006	18.5 fb^{-1} 8 TeV	arXiv:1605.08993 (submitted to PLB)	May 2016
SUS-12-028	11.7 fb^{-1} 8 TeV	EPJC 73 (2013) 2568	Mar 2013
SUS-11-022	4.98 fb^{-1} 7 TeV	JHEP 01 (2013) 077	Oct 2012
SUS-11-003	1.14 fb^{-1} 7 TeV	PRL 107 (2011) 221804	Sep 2011
SUS-10-003	35 pb^{-1} 7 TeV	PLB 698 (2011) 196	Jan 2011

http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/ALPHAT.html

SUSY production at LHC

A typical SUSY production at LHC predicted by SUSY models with conserved R-parity



Each cascade decay chain ends with the LSP, invisible and causes missing transverse momentum (MET)

SUSY particles will be pair-produced

Each SUSY particle successively decays to another SUSY particle and SM particle (the cascade decay)

The final states contain large MET, jets, and possibly leptons or photons

Simplified Model Spectra (SMS)

A ***SMS*** contains two (or three) new particles in addition to the SM particles

- new particles are named after sparticles with the same quantum numbers, e.g., gluinos, neutralinos
- the heavier particles are produced in pair. Each decay chain ends with the lighter particle (LSP).
- the masses of the new particles are the only new parameters if the couplings are specified by a particular SUSY model.
- relevant for "*natural*" SUSY models, in which only a few particles are light enough to be produced at LHC

http://dx.doi.org/10.1103/PhysRevD.88.052017

An example of SMS

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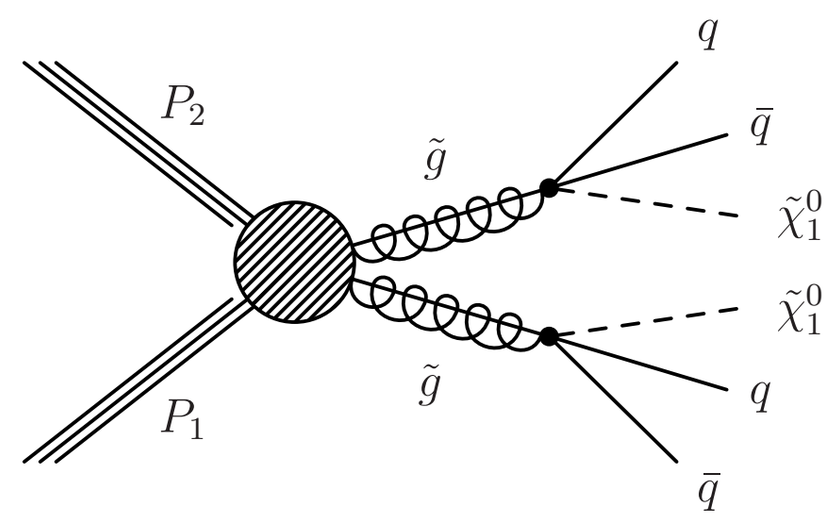


We use the data to exclude the possible range of the masses of the new particles in SMS as long as the data agrees with the SM predictions

Common variables used to define search regions or categories

HT - a measure of how energetic the event was

$$H_{\mathrm{T}} = \sum_{i \in \mathrm{jets}} \left| \vec{p}_{\mathrm{T}i} \right|$$

MET - sensitive to the presence of invisible particles and their total p_{T}

$$\vec{E}_{\mathrm{T}}^{\mathrm{miss}} = \vec{\not{E}}_{\mathrm{T}} = -\sum_{i \in \mathrm{particles}} \vec{p}_{\mathrm{T}i}$$

MHT - alternative to MET, defined only by jet p_{T}

$$\vec{H}_{\mathrm{T}}^{\mathrm{miss}} = \vec{\not{H}}_{\mathrm{T}} = -\sum_{i \in \mathrm{jets}} \vec{p}_{\mathrm{T}i}$$

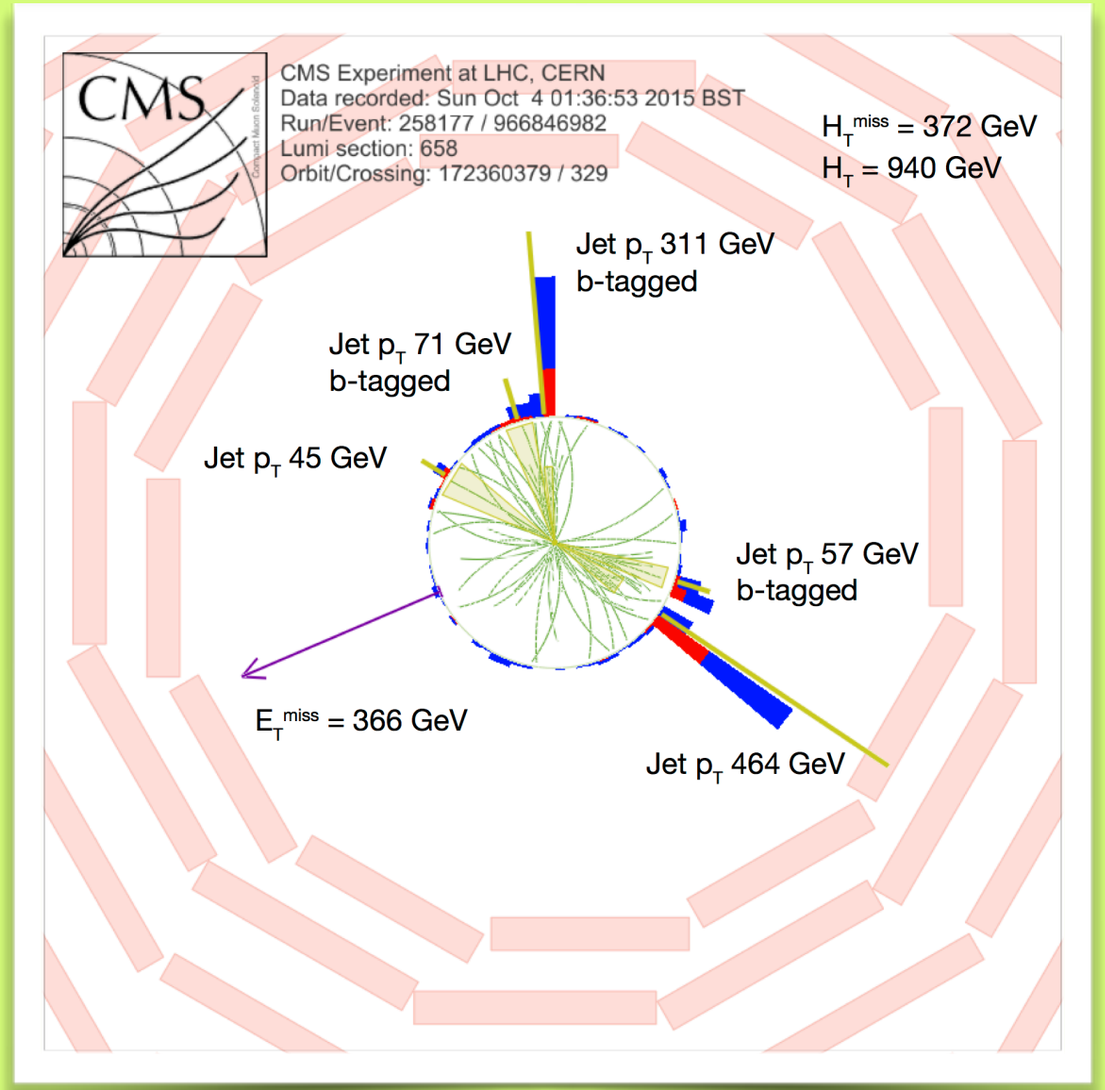
$$H_{\mathrm{T}}^{\mathrm{miss}} = \not{H}_{\mathrm{T}} = \left| \vec{H}_{\mathrm{T}}^{\mathrm{miss}} \right| = \left| \vec{\not{H}}_{\mathrm{T}} \right|$$

$\Delta\phi$ - the azimuthal angle between jet p_{T} and MHT (or MET)

$$\Delta\phi_i = \Delta\phi(\vec{p}_{\mathrm{T}i}, \vec{H}_{\mathrm{T}}^{\mathrm{miss}})$$

Jet multiplicity n_{jet}

b-jet multiplicity n_{b}



an event with large MET and multiple hight-pT jets

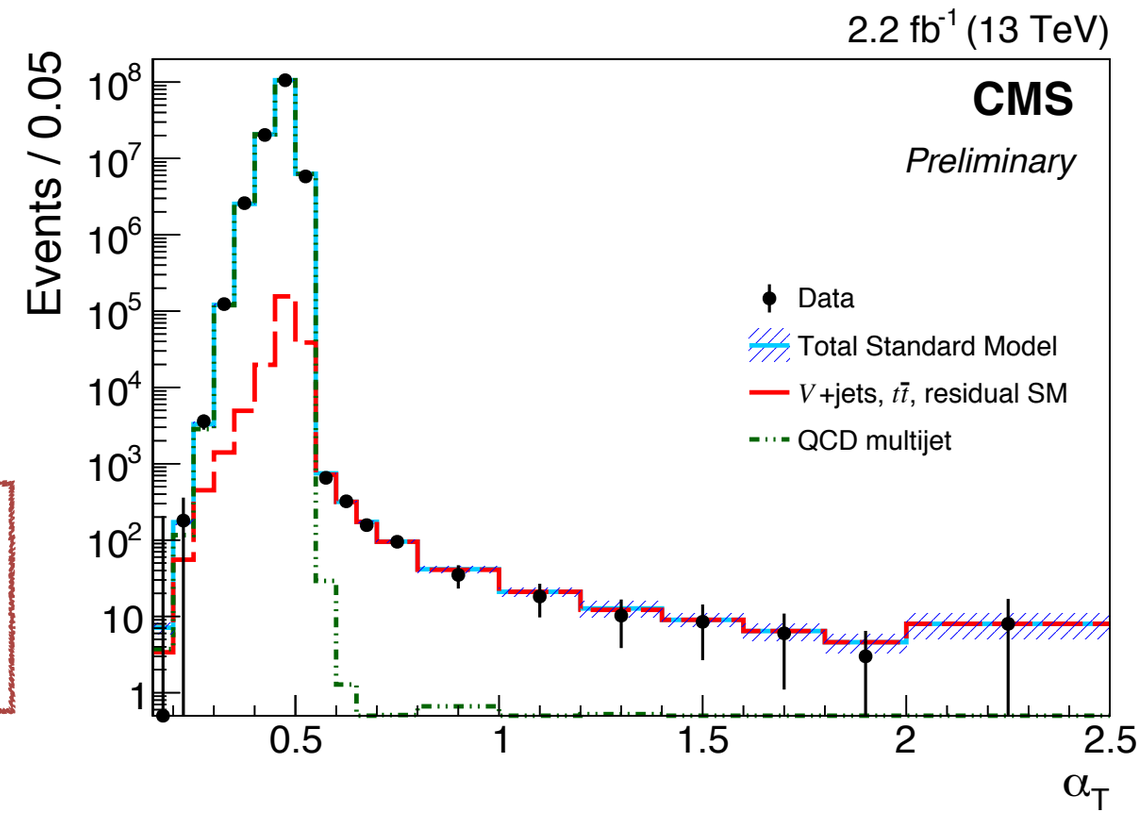
Two dedicated variables to suppress QCD events

α_T

$$\alpha_T = \frac{\sum_i E_T^{j_i} - \Delta E_T}{2\sqrt{\left(\sum_i E_T^{j_i}\right)^2 - H_T^{miss\,2}}}$$

ΔE_T: the jets in the event are combined into two ***pseudo-jets*** such that ΔE_T, the difference in E_T of two pseudo-jets, is minimized

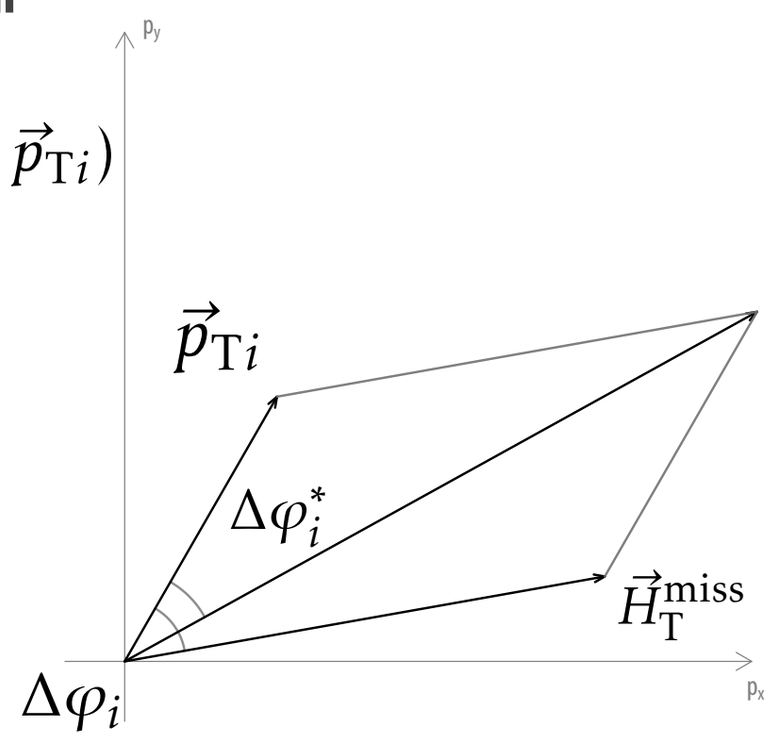
$\alpha_T \leq 0.5$ for QCD events, α_T can be greater than 0.5 for events with invisible particles

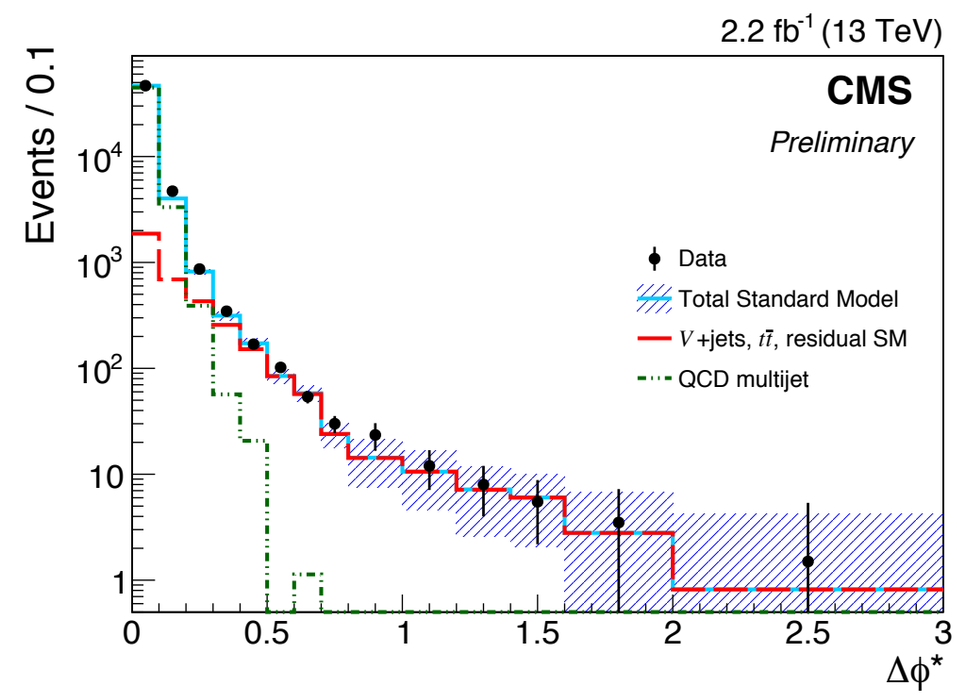


$\Delta\phi^*_{min}$: minimum biased delta phi

$$\Delta\phi^* = \min_{i \in \text{jets}} \Delta\phi(\vec{p}_{Ti}, \vec{H}_T^{miss} + \vec{p}_{Ti})$$

The angle between jet p_T and MHT that is calculated without the jet





An overall search procedure in hadronic final states

- Define ***search (signal) region (SR)***

  - high signal-to-background ratio
    - high hadronic activity and large missing energy
      e.g., cuts on HT, n_{jet}, MHT, α_T, $\Delta\phi^*$
    - no lepton or photon (**vetos**)
  - primary SM background processes: Z(→νν) + jets, top pair, W(→lν) + jets, QCD
  - **blind analysis**: do not analyze data in the search region until later

- Define ***control regions (CR)***

  - by inverting the veto or as sidebands
  - used to predict background
  - dominated by specific SM processes

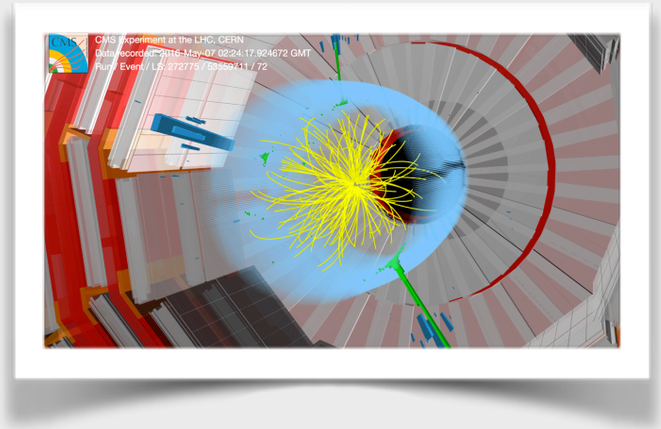
CRs and dominant SM processes:
- double lepton: Z(→ll) + jets
- single photon: γ + jets
- single lepton: W(→lν) + jets, top pair
- sideband of cuts: QCD

- Define ***categories***

  - events in the SR are categorized in **bins** of HT, n_{jet}, n_b, MHT

- Analyze data in CR: compare with MC
- Predict background in each category in the SR

  - validate the predictions, e.g., closure test



- Analyze data in the SR (***unblind***)

  - compare the data in the SR with the prediction

- Interpret the results in SMS unless a significant discrepancy is observed in the comparison

  - place exclusion limits on cross sections and masses,
    e.g., asymptotic formula [1] and CL_S method

[1] EPJ C71 (2011) 1554

SUS-15-005: overview

- **CMS-PAS-SUS-15-005**
- 2.2 fb^{-1}, pp collisions, 2015, LHC Run 2
- Use α_T and $\Delta\phi^*_{min}$ to suppress QCD to a negligible level
- **Search region**: low n_{jet}, HT thresholds
- **Categorization**: bins of n_{jet}, n_b, HT, MHT
- **Interpretations**: T1tttt, T1bbbb, T1qqqq

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-15-005/index.html

Search region

- n_{jet} (p_T > 40 GeV) ≥ 1
- lead jet p_T > 100 GeV
- HT > 200 GeV, MHT > 130 GeV
- MHT/MET < 1.25
- $\Delta\phi^*$min > 0.5
- α_T > 0.52 ~ 0.65 only for HT < 800 GeV

Categorization

- n_{jet} bins
  - **monojet bins**: n_{jet} = 1
  - **asymmetric jet bins**: n_{jet} ≥ 2
    lead jet p_T > 100 GeV
    2nd lead jet p_T between 40 and 100 GeV
  - **symmetric jet bins**: n_{jet} ≥ 2
    lead and 2nd lead jets with p_T > 100 GeV
- each n_{jet} bin further in bins of n_b, HT, MHT

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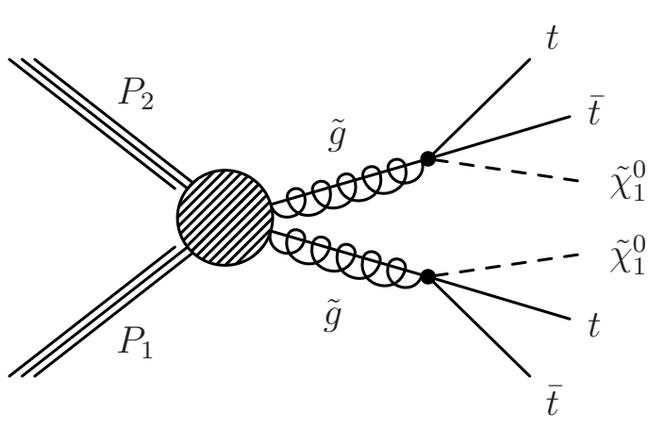

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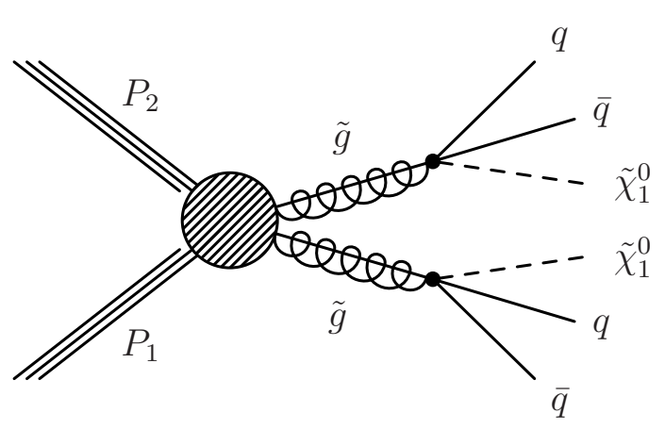

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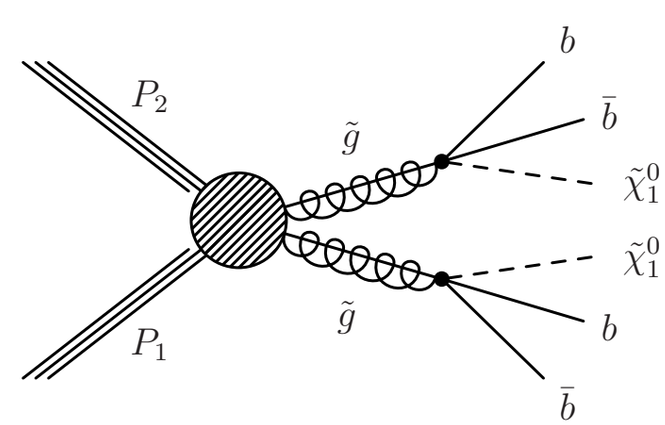


SUS-15-005: detailed definitions of event selection and categorization

Search region

Table from CMS-PAS-SUS-15-005

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

Baseline selection:	
Jets selection	Select jets satisfying $p_T > 40$ GeV and $\|\eta\| < 3$
Forward jet veto	Veto events containing jet satisfying $p_T > 40$ GeV and $\|\eta\| > 3$
Lepton/photon vetoes	$p_T > 10$ GeV and $\|\eta\| < 2.5$ for leptons, $p_T > 25$ GeV and $\|\eta\| < 2.5$ for photons
Lead jet acceptance	$p_T > 100$ GeV and $\|\eta\| < 2.5$
Second jet acceptance	$p_T > 100$ GeV (symmetric), $40 < p_T < 100$ GeV (asymmetric), $p_T < 40$ GeV (monojet)
Energy sums	$H_T > 200$ GeV and $H_T^{miss} > 130$ 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, ≥5 (both symmetric and asymmetric)
n_b binning	0, 1, 2, ≥ 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 $H_T < 800$ GeV)
QCD suppression	$\Delta\phi^*_{min} > 0.5$
QCD suppression	$H_T^{miss}/E_T^{miss} < 1.25$

Control regions

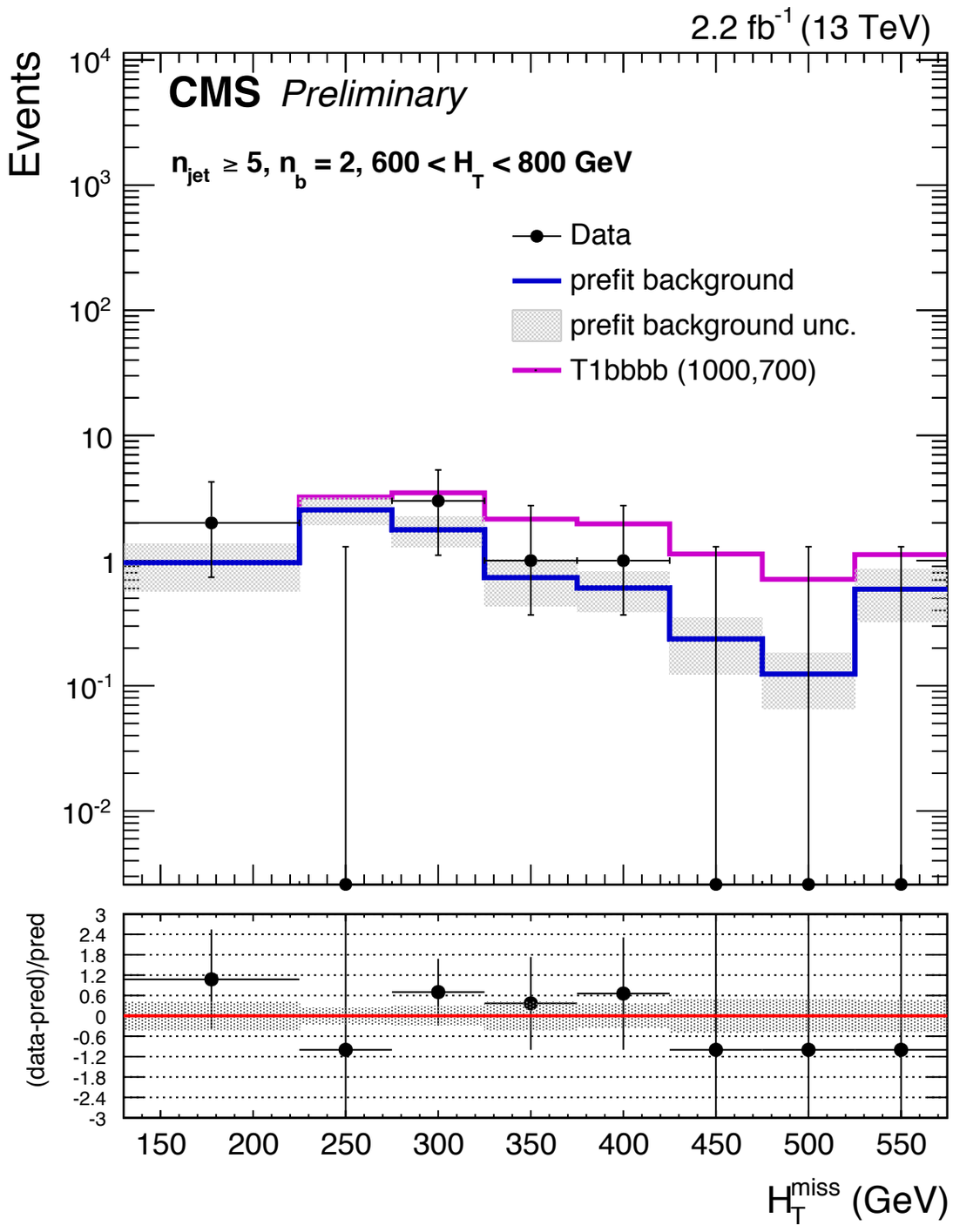
Single muon: one isolated muon with M_T compatible with the W mass

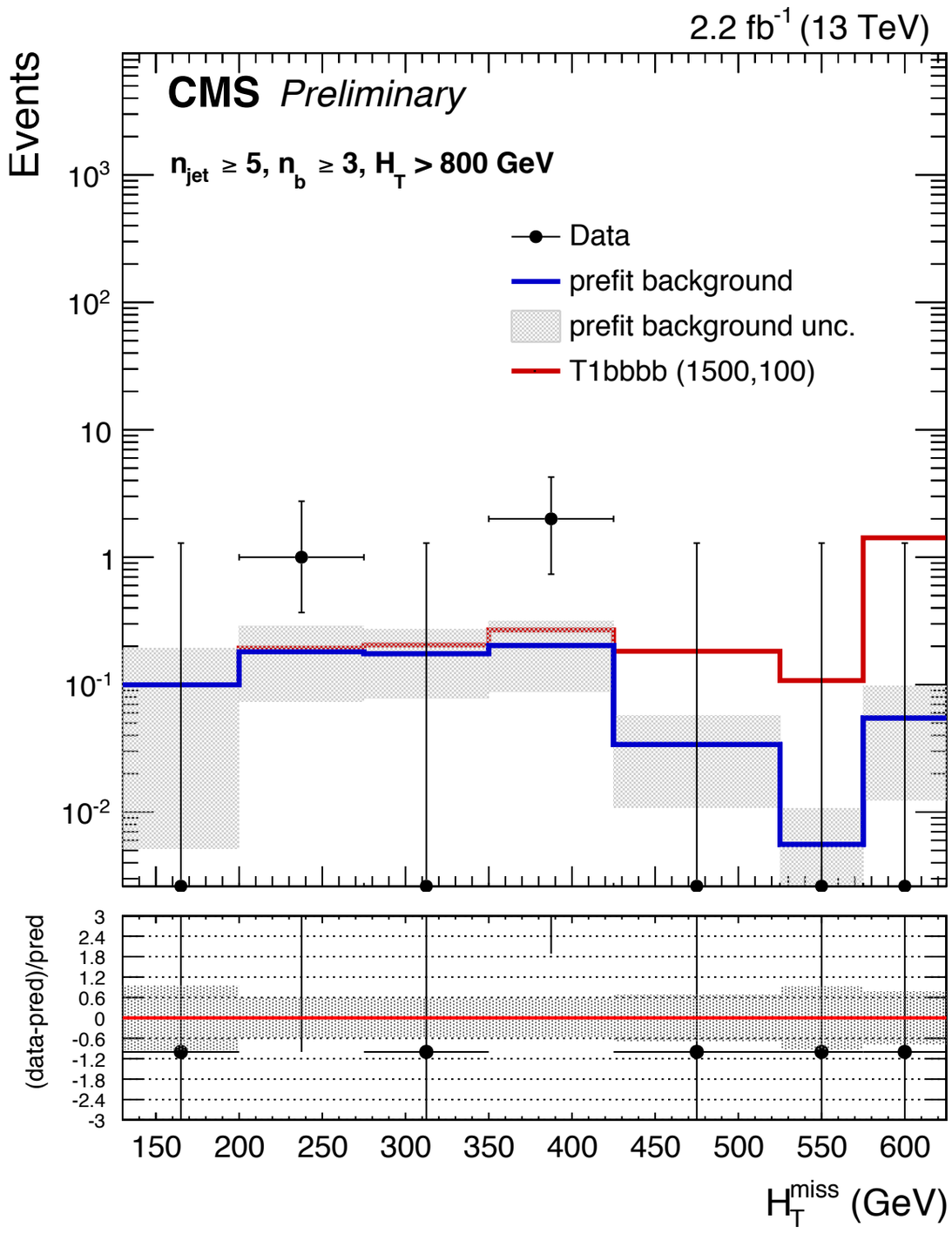
Double muon: two isolated muons with the dimuon mass compatible with the Z mass

Single photon: one isolated photon and $H_T > 400$ GeV

Hadronic: sideband of MHT/MET, $\Delta\phi^*_{min}$ cuts

SUS-15-005: data in search region and prediction





The data and the prediction (labeled as “prefit background”) in the MHT bins in two n_{jet}, n_b, HT bins

SUS-15-005: interpretations in SMS

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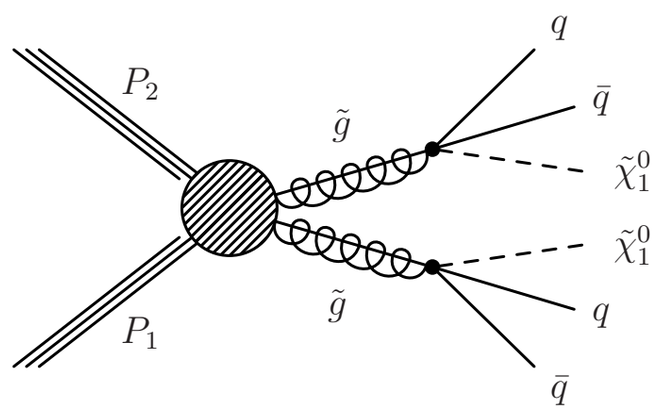

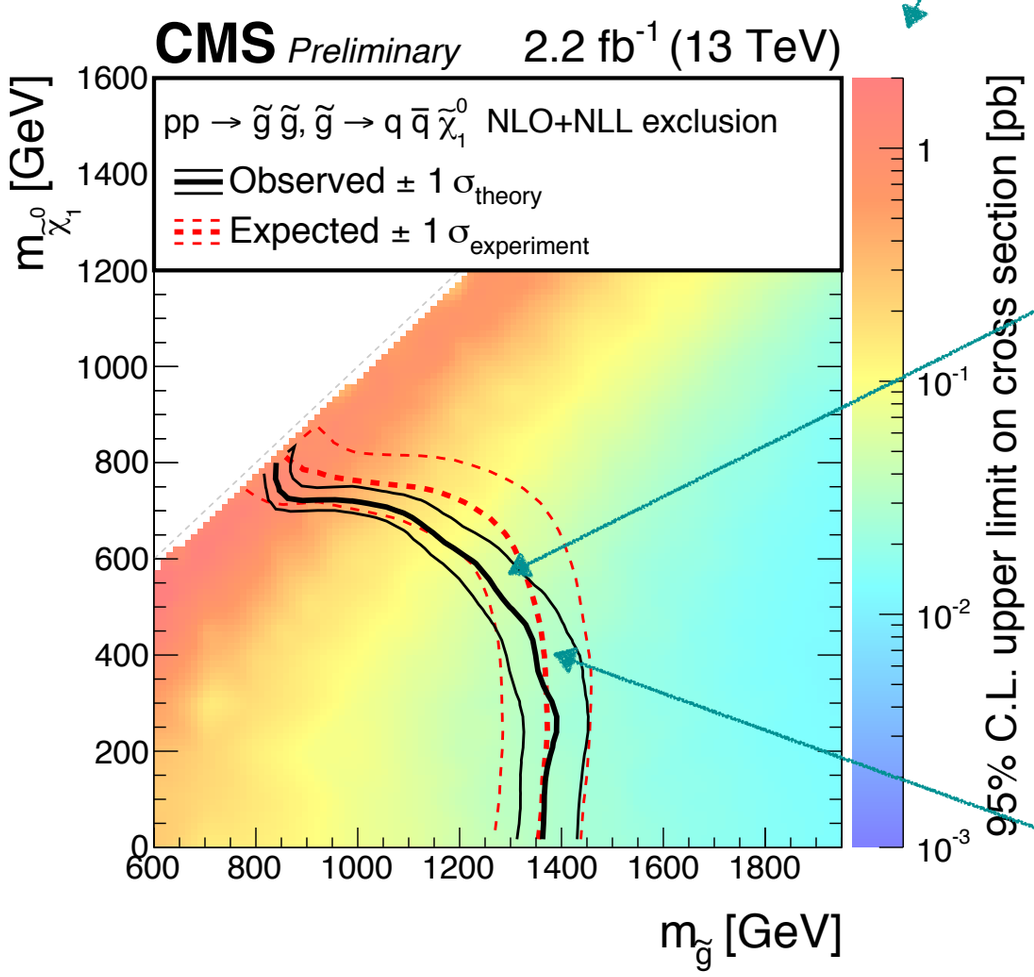

The color scale - the upper limit on the cross section derived from the acceptance, the observed and predicted number of events in the signal region and their uncertainties.

The signal acceptance is evaluated with signal MC samples generated at each point in the grid of the mass plane

The thick black line - the observed lower mass limit, the contour at which the theoretical cross sections calculated in SUSY NLO+NLL intersect with the upper cross section limit.

The thin black lines - the contours at which 1 sigma variations of the theoretical cross sections intersect with the upper cross section limit.

The thick red dotted line - the expected lower mass limit, the contour at which the theoretical cross sections intersect with the expected upper cross section limit, the limit that would be obtained if the predicted number of the events were actually observed

SUS-15-005: interpretations in SMS

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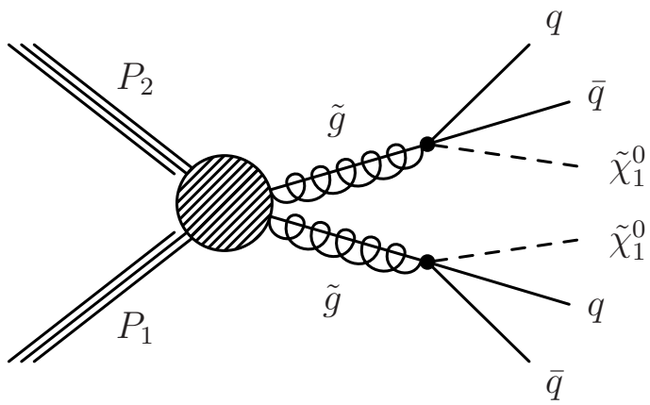

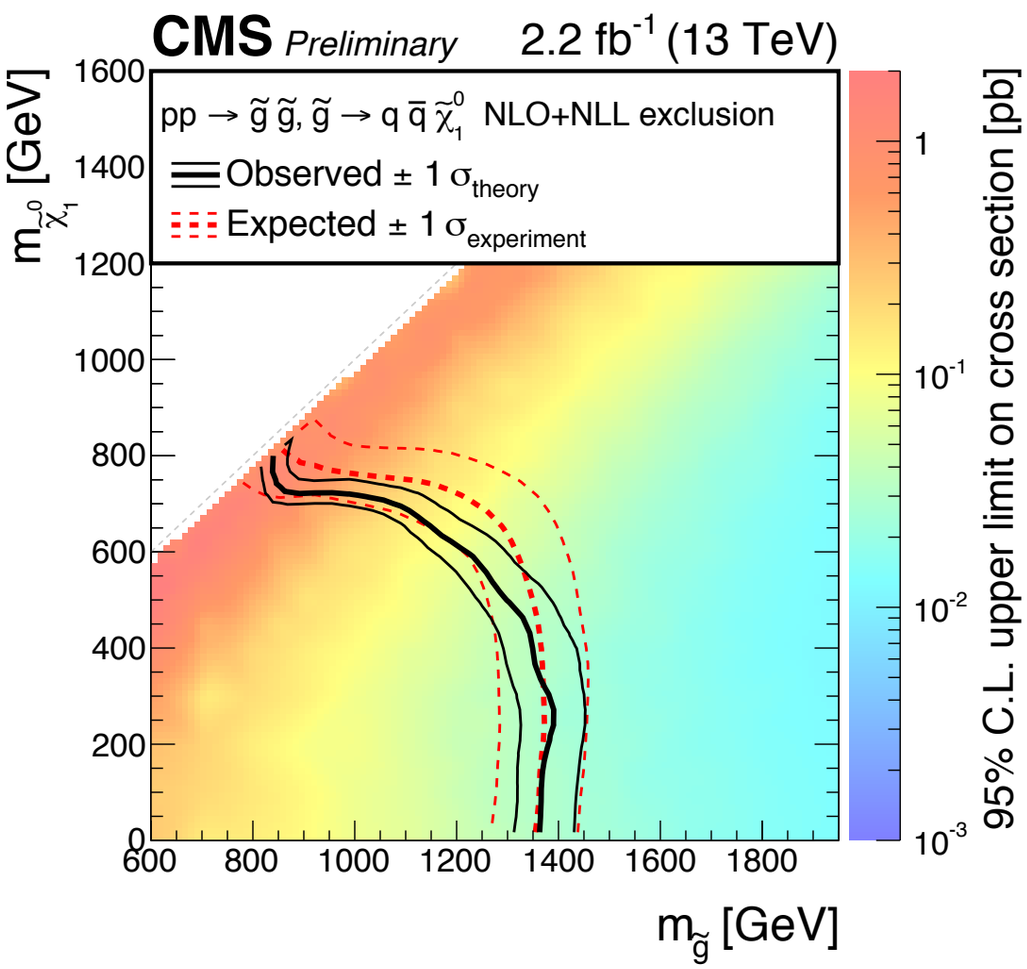

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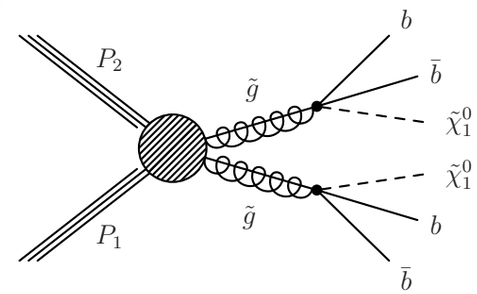

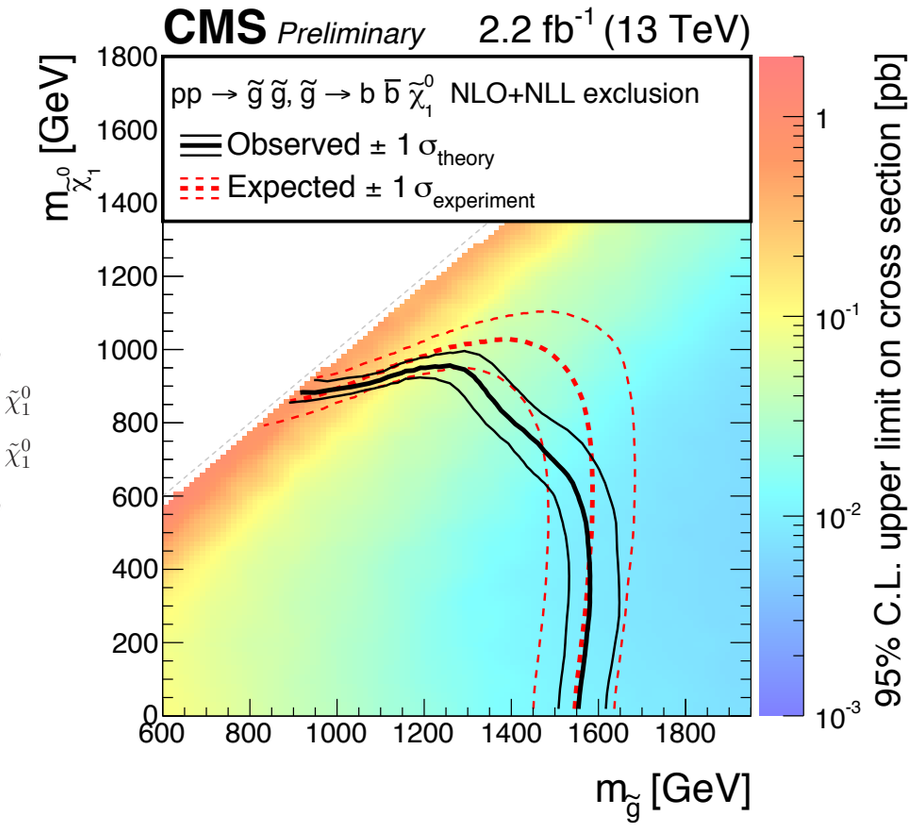

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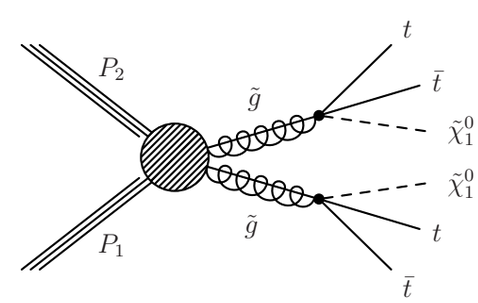

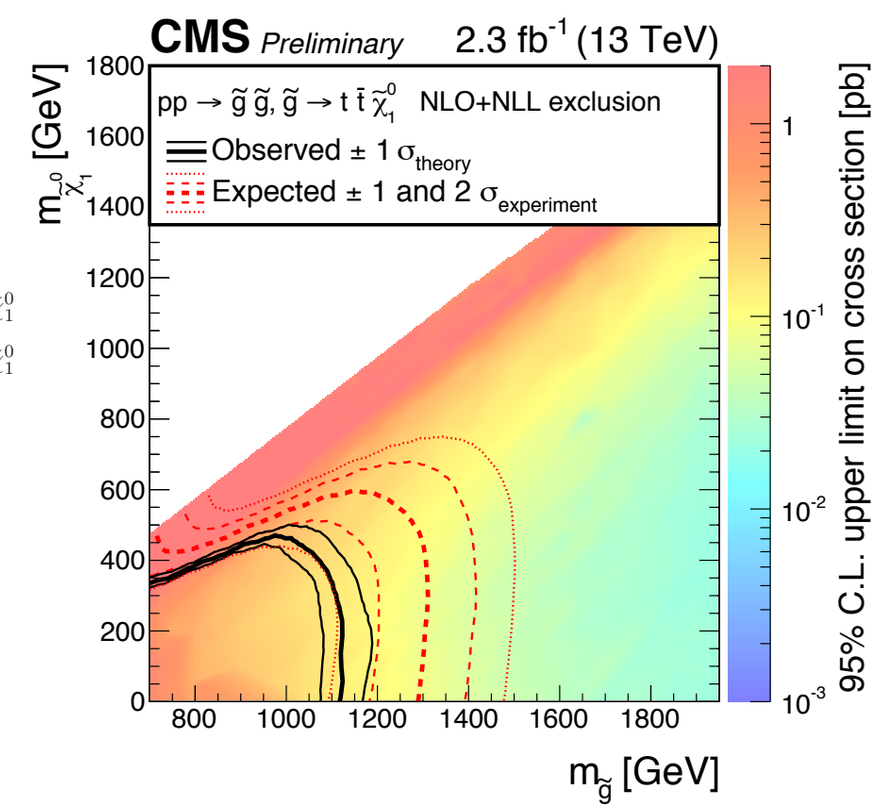

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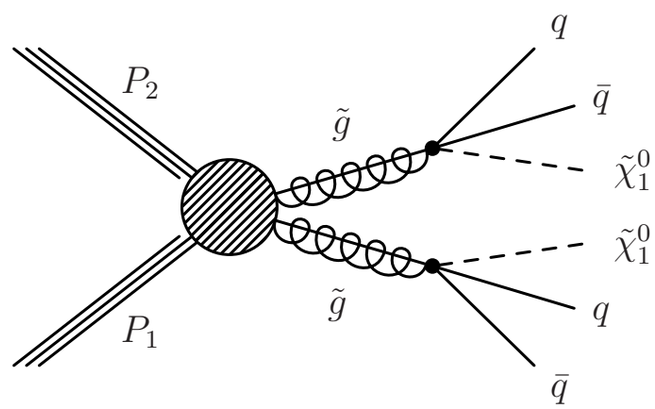

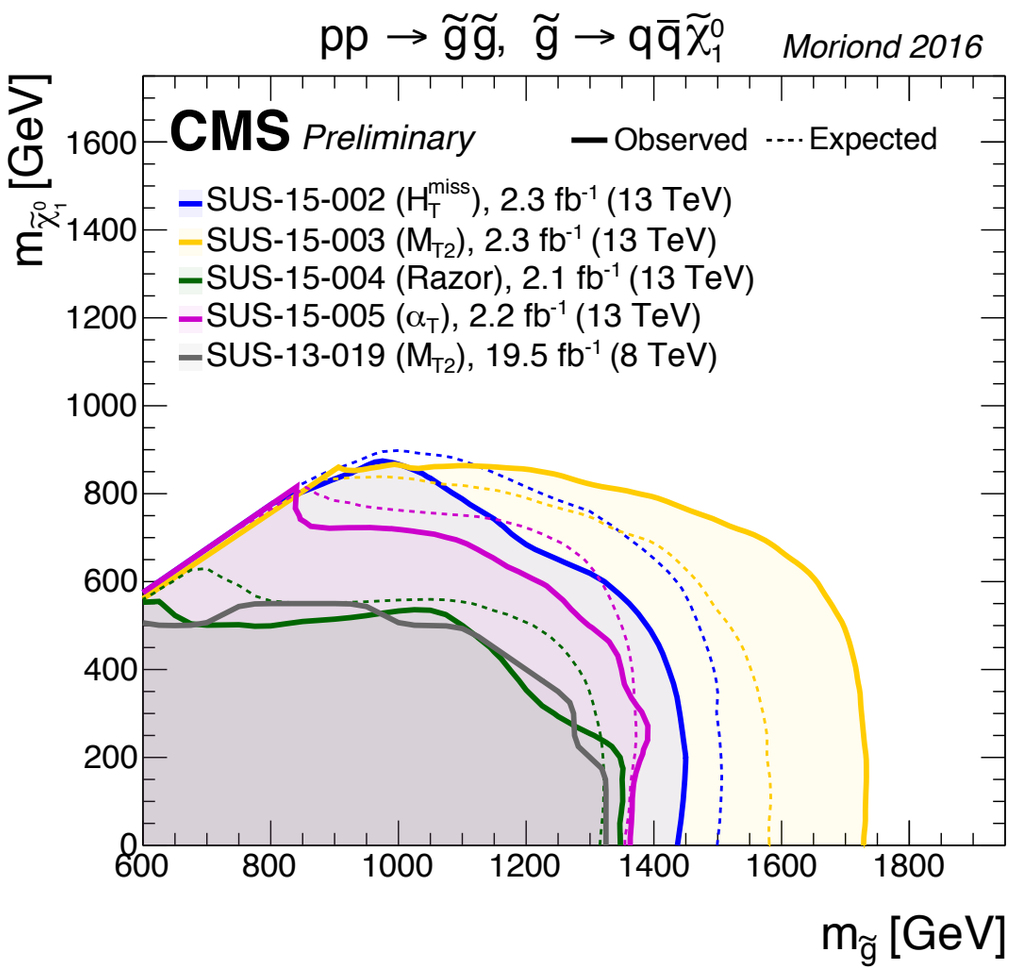

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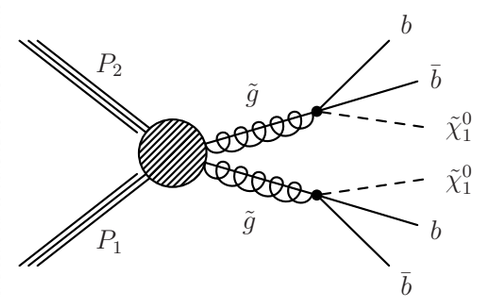

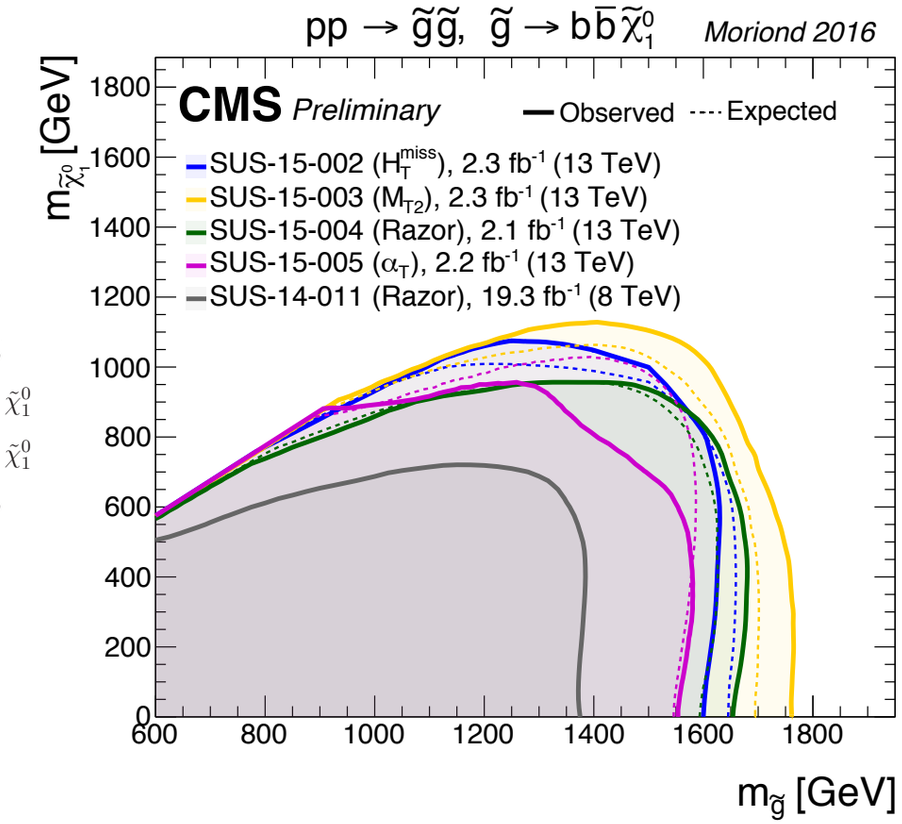

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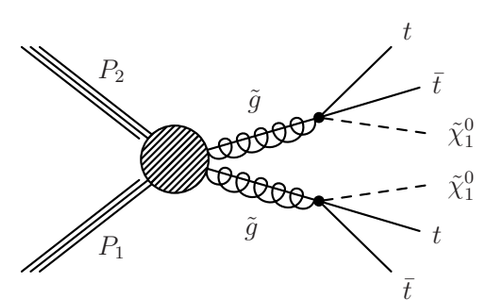

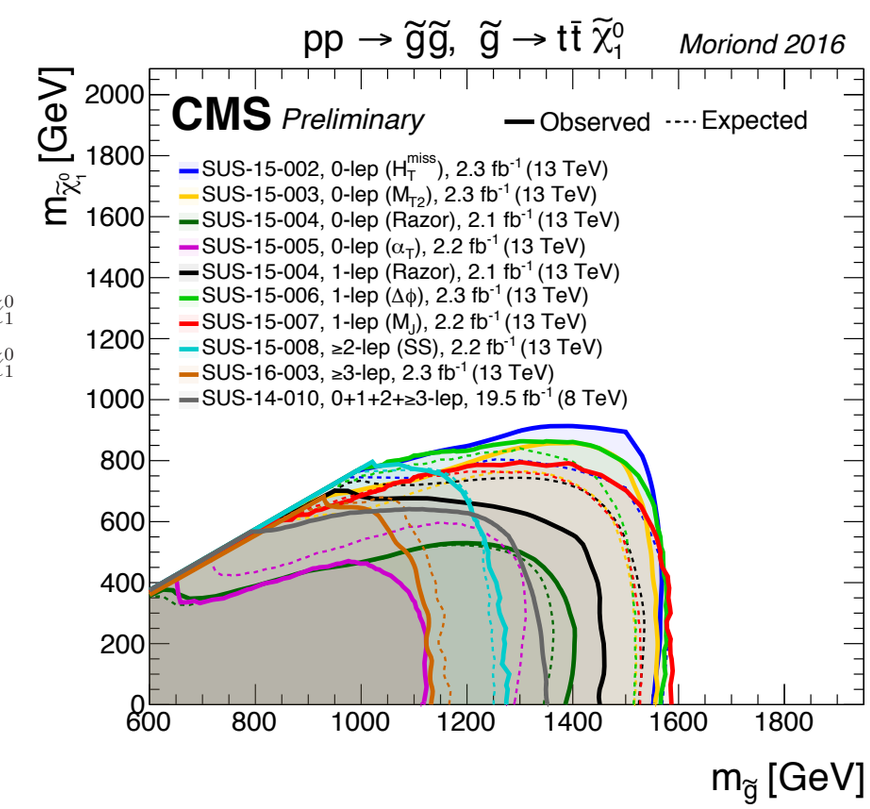

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Summary

- With the variable α_T, we have searched hadronic final states in 2.2 fb^{-1} of data collected with the CMS detector in 2015 for deviations from the standard model prediction. We interpreted the results in SMS for gluinos production and extended the exclusion regions on the mass planes from the Run 1 results.

- The data collection in 2016 has been successful. CMS has recorded 8.2 fb^{-1} of data as of July 3rd. We are actively analyzing these new data and continue searching for signature of production of squarks, gluinos, and other sparticles.

End