Search for color supersymmetric partners at CMS

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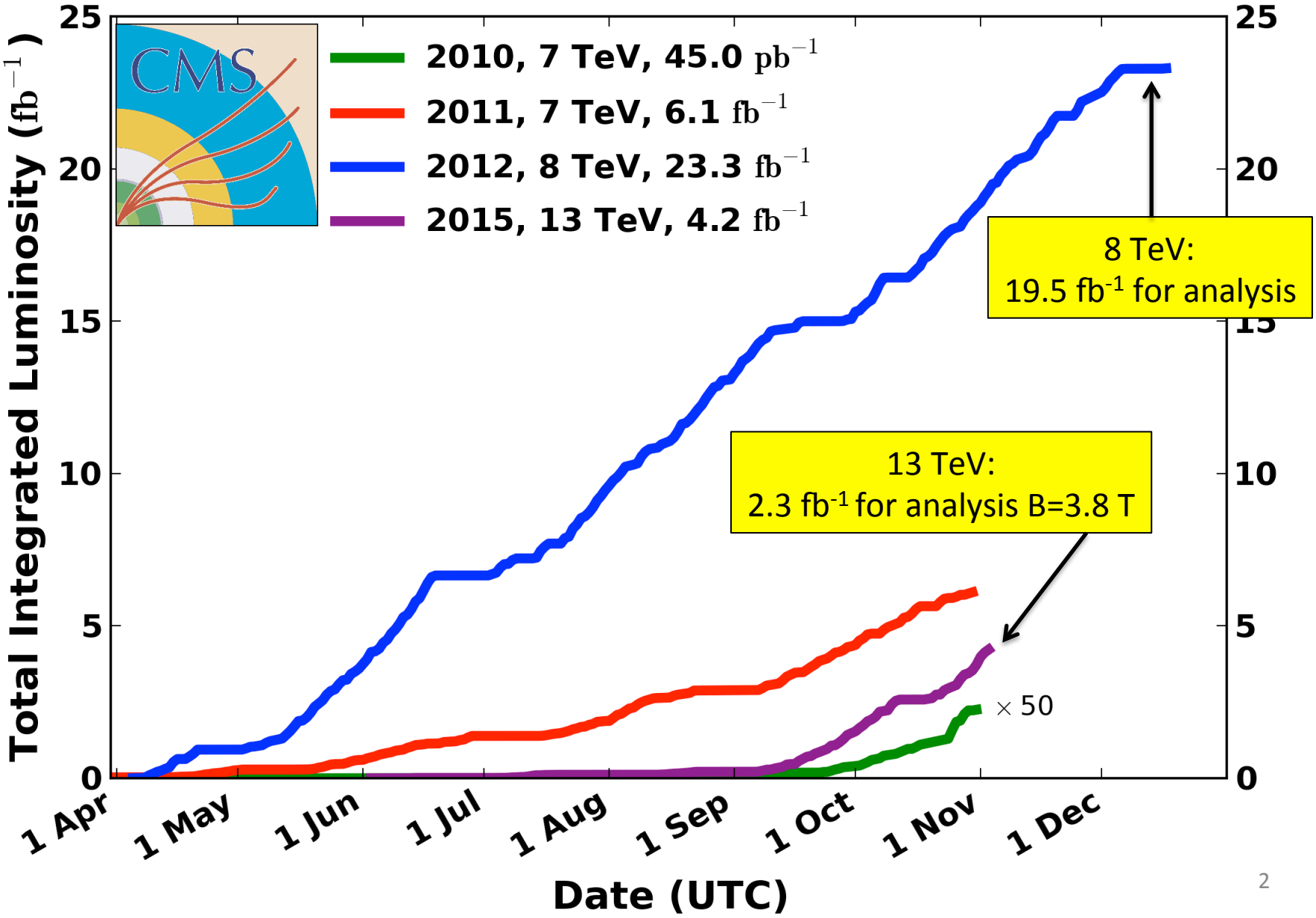
CMS Integrated Luminosity, pp

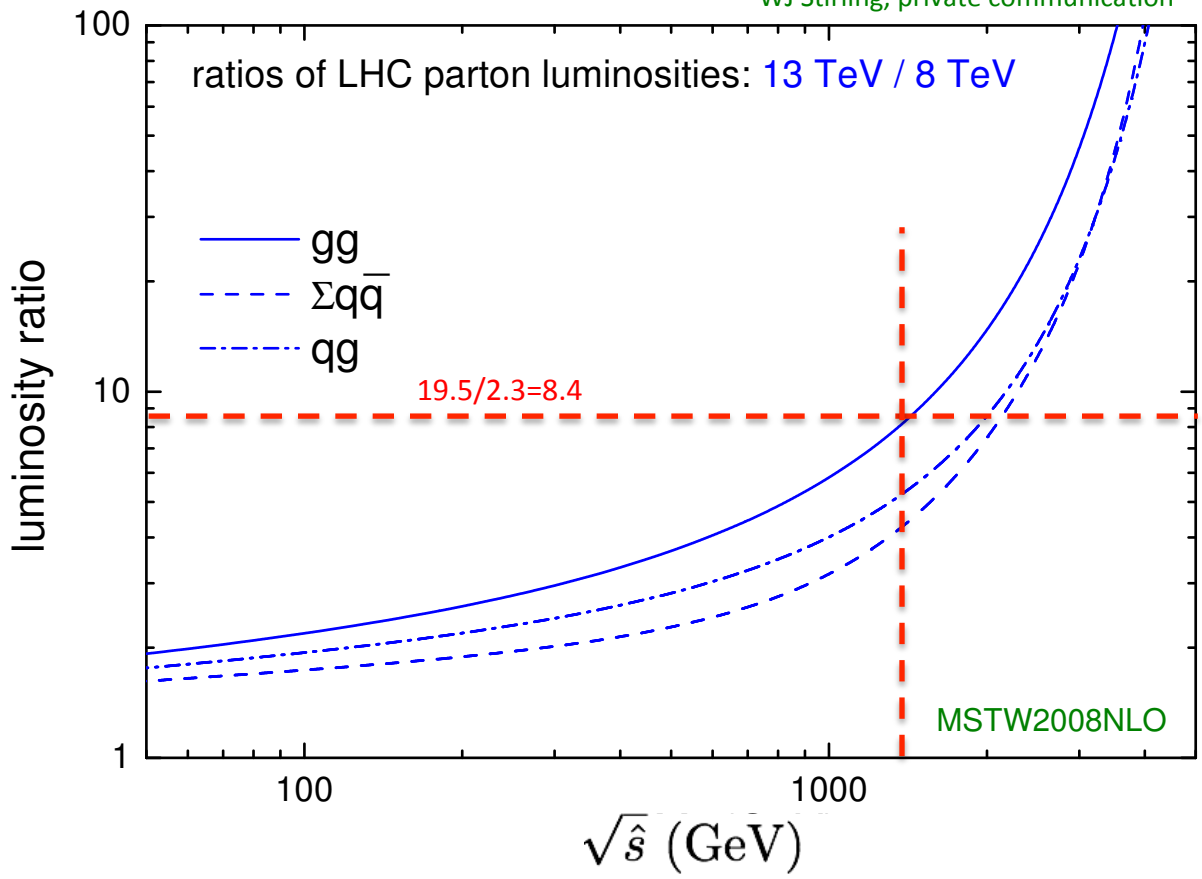


2.3 fb^{-1} @ 13 TeV vs. 19.4 @ 8 TeV

$$\frac{d\sigma(pp \to X)}{d\hat{s}} = \sum \frac{dL_{ij}}{d\hat{s}} \hat{\sigma}(ij \to X)$$

$$\frac{dL_{ij}}{d\hat{s}} = \frac{1}{1+\delta_{ij}} \frac{1}{\hat{s}} \int_\tau^1 \frac{dx}{x} [f_i(x) f_j(\frac{\tau}{x}) + f_i(\frac{\tau}{x}) f_j(x)] \qquad \tau \equiv \frac{\hat{s}}{s}$$

WJ Stirling, private communication



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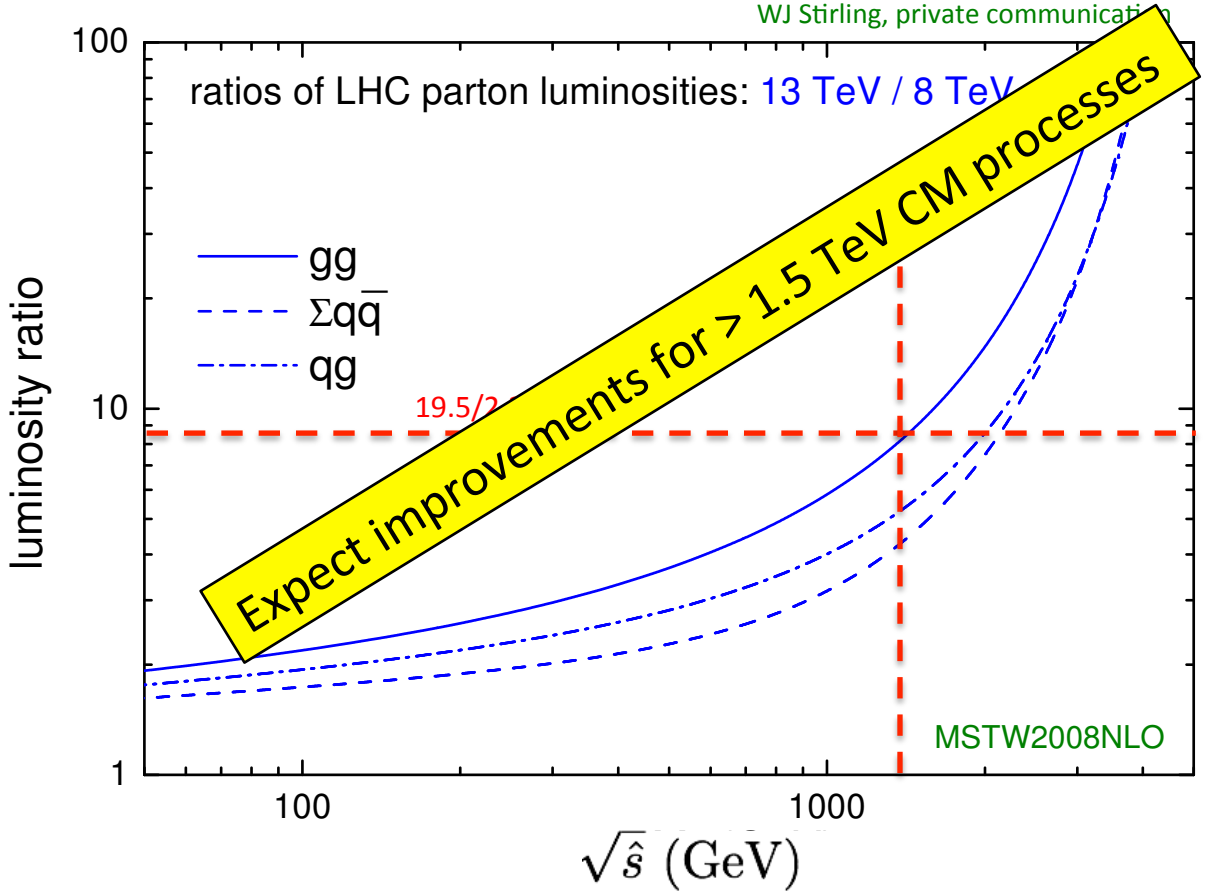
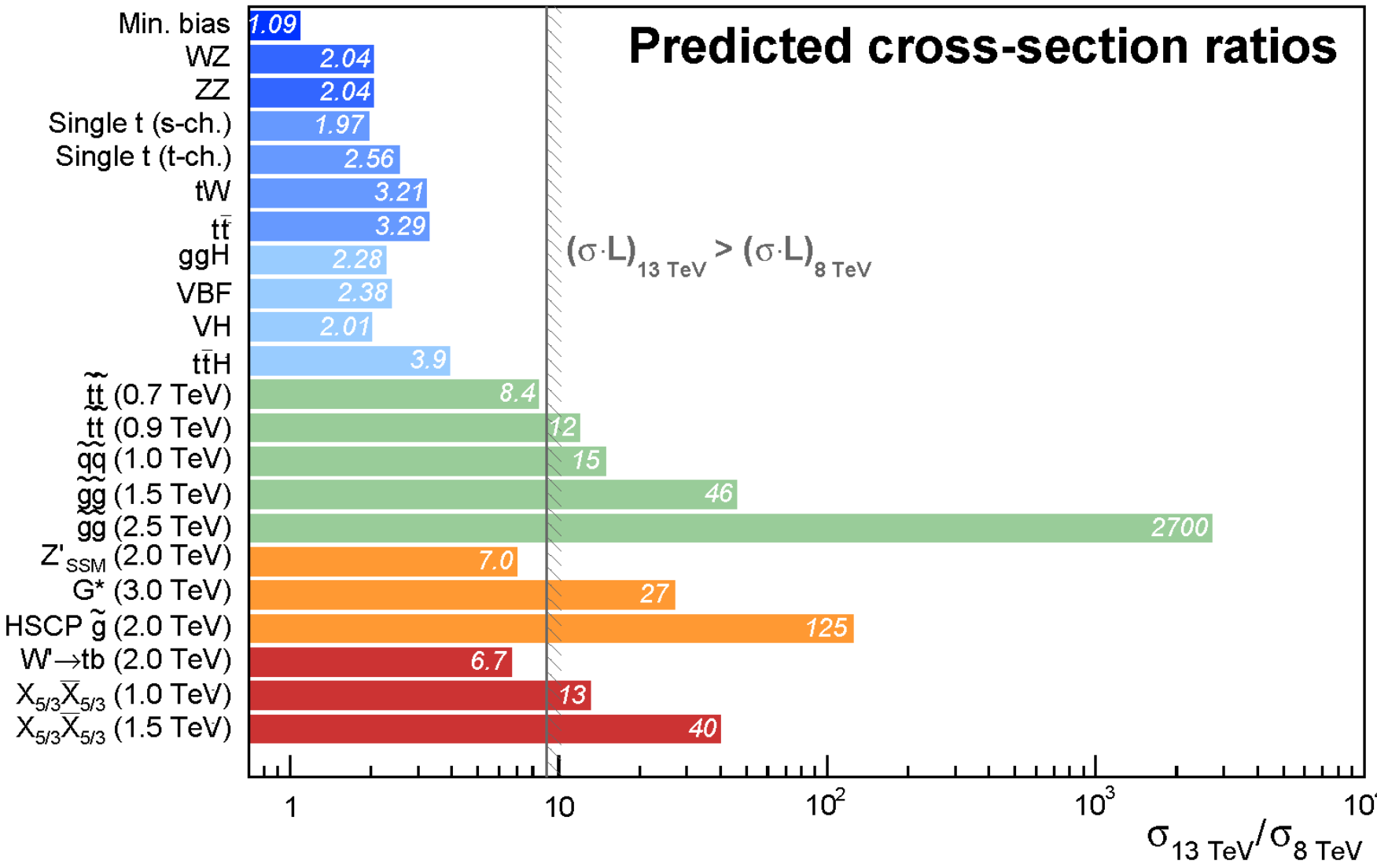
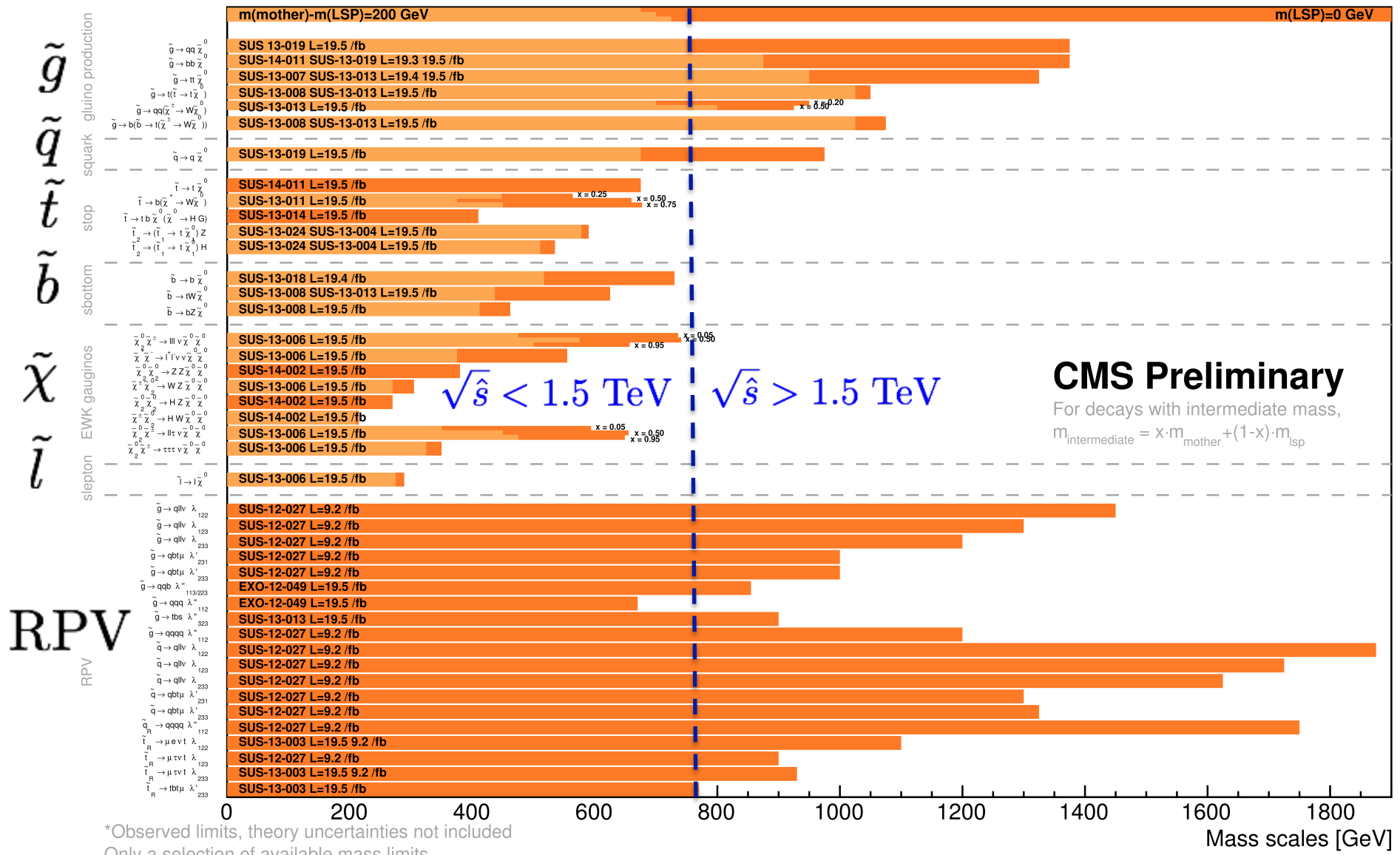



Predicted cross-section ratios
Min. bias
WZ
ZZ
Single t (s-ch.)
Single t (t-ch.)
tW
$t\bar{t}$
ggH
VBF
VH
$t\bar{t}H$
$\tilde{t}\tilde{t}$ (0.7 TeV)
$\tilde{t}\tilde{t}$ (0.9 TeV)
$\tilde{q}\tilde{q}$ (1.0 TeV)
$\tilde{g}\tilde{g}$ (1.5 TeV)
gg (2.5 TeV)
Z'_{SSM} (2.0 TeV)
G* (3.0 TeV)
HSCP $\tilde{g}$ (2.0 TeV)
$W' \rightarrow tb$ (2.0 TeV)
$X_{5/3}\bar{X}_{5/3}$ (1.0 TeV)
$X_{5/3}X_{5/3}$ (1.5 TeV)
1.09
2.04
2.04
1.97
2.56
3.21
3.29
2.28
2.38
2.01
3.9
8.4
12
15
46
2700
7.0
27
125
6.7
13
40
$(\sigma \cdot L)_{13\ TeV} > (\sigma \cdot L)_{8\ TeV}$
1
10
10^2
10^3
10^4
$\sigma_{13\ TeV}/\sigma_{8\ TeV}$

Summary of CMS SUSY Results* in SMS framework

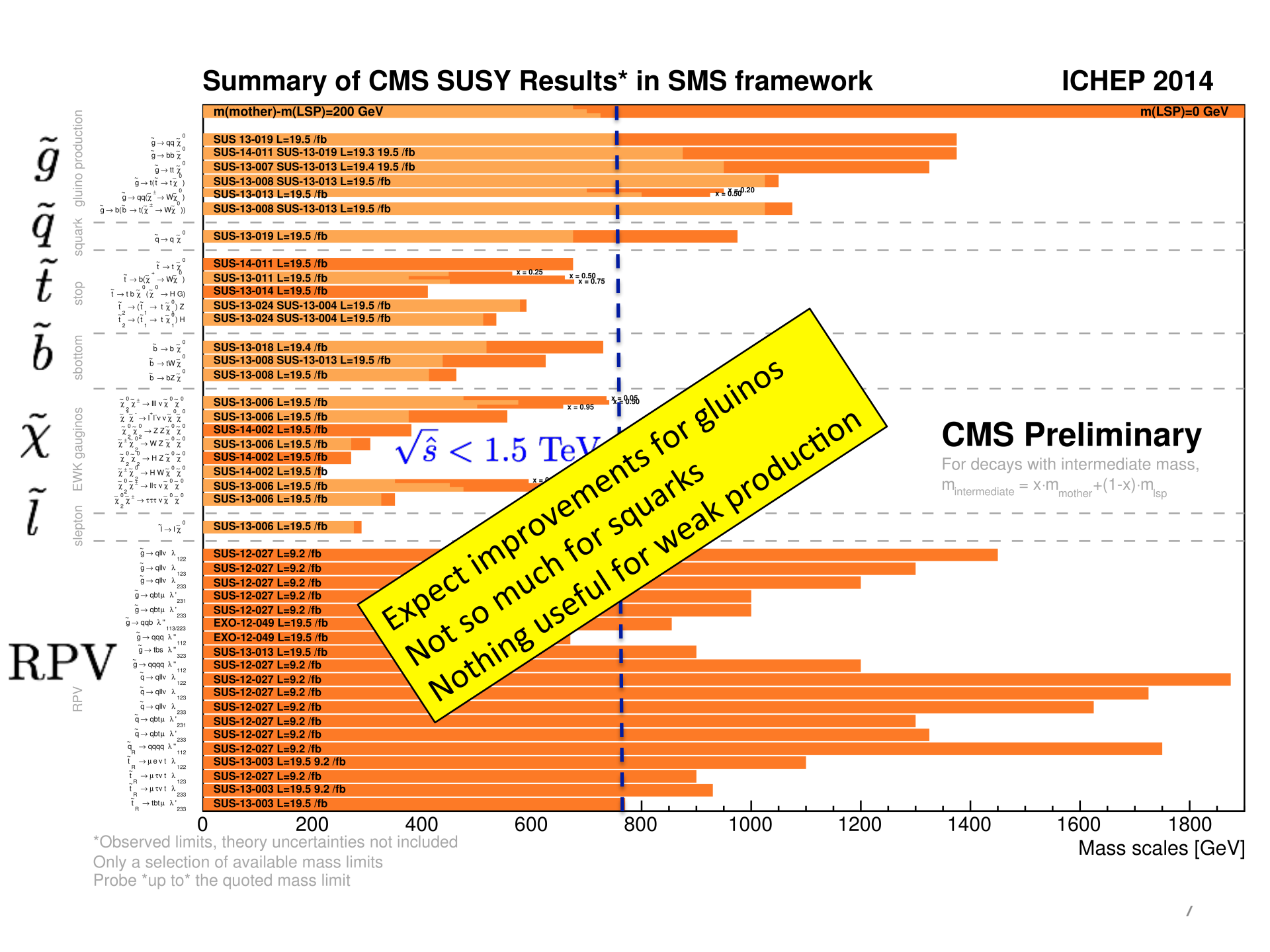
ICHEP 2014



*Observed limits, theory uncertainties not included

Only a selection of available mass limits

Probe *up to* the quoted mass limit


Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-013 L=19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-019 L=19.5 /fb
SUS-14-011 L=19.5 /fb
SUS-13-011 L=19.5 /fb
SUS-13-014 L=19.5 /fb
SUS-13-024 SUS-13-004 L=19.5 /fb
SUS-13-024 SUS-13-004 L=19.5 /fb
SUS-13-018 L=19.4 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-008 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-14-002 L=19.5 /fb
SUS-14-002 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
EXO-12-049 L=19.5 /fb
EXO-12-049 L=19.5 /fb
SUS-13-013 L=19.5 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
$\sqrt{\hat{s}} < 1.5$ TeV
Expect improvements for gluinos
Not so much for squarks
Nothing useful for weak production
CMS Preliminary
For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Searches for strongly produced SUSY particles (R-parity conserving)

- Generic searches
  - 0 leptons + MET + jets
  - 1 lepton + MET + jets
  - 2 same-sign leptons + MET + jets
  - 2 opposite-sign, same flavor, leptons + MET
  - ≥ 3 leptons + MET + jets

- More targeted searches
  - stop pair production (0 leptons, 1 leptons)
  - sbottom pair production

Common themes

- Slice the phase space into many exclusive signal regions to be sensitive to different possible processes with MET + Jets (not only SUSY!)

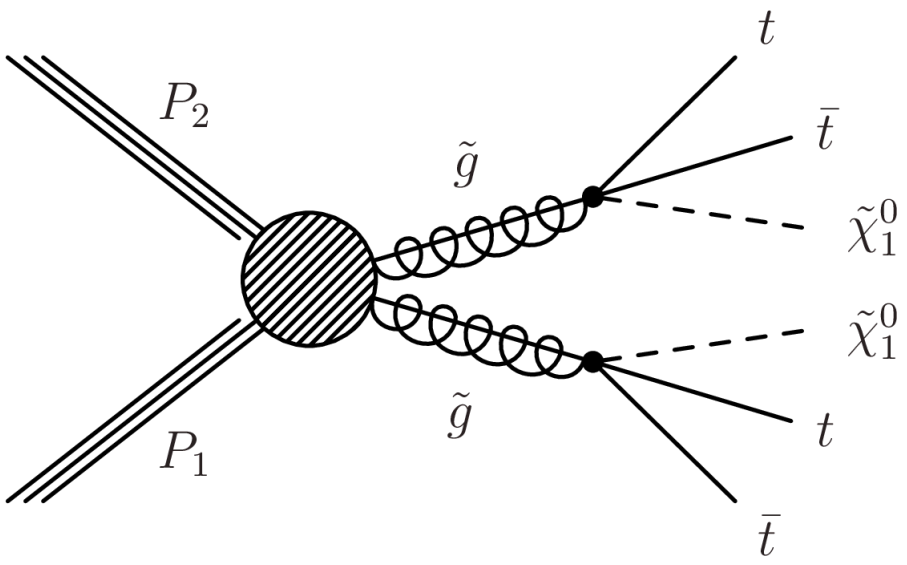
  e.g., bin in MET, N_{jets}, N_{bjets}, H_T
- Often more than one analysis per final state
  - e.g., four independent 0-lepton analyses
- Background determination from control regions to minimize reliance on Monte Carlo modeling
- Interpretation of null results in terms of "simplified models"

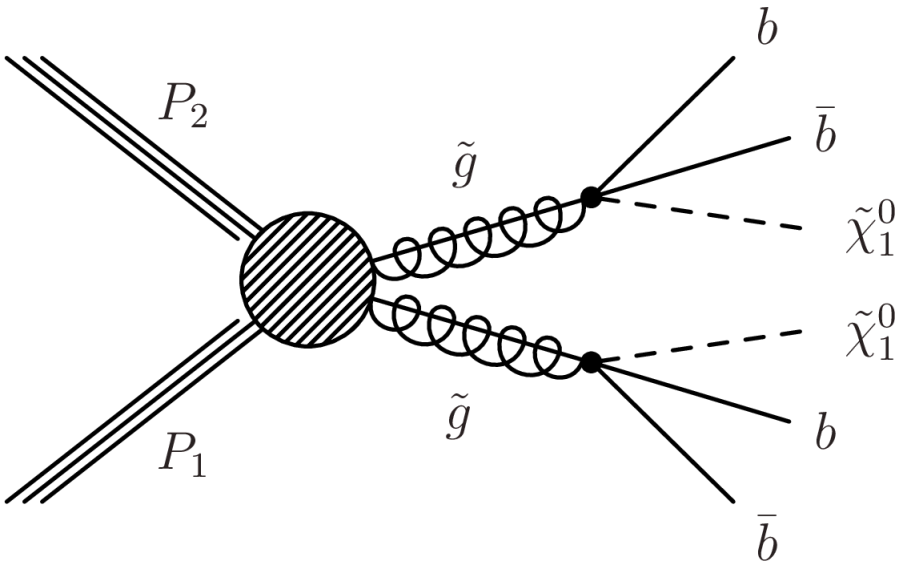
Example of BG determination

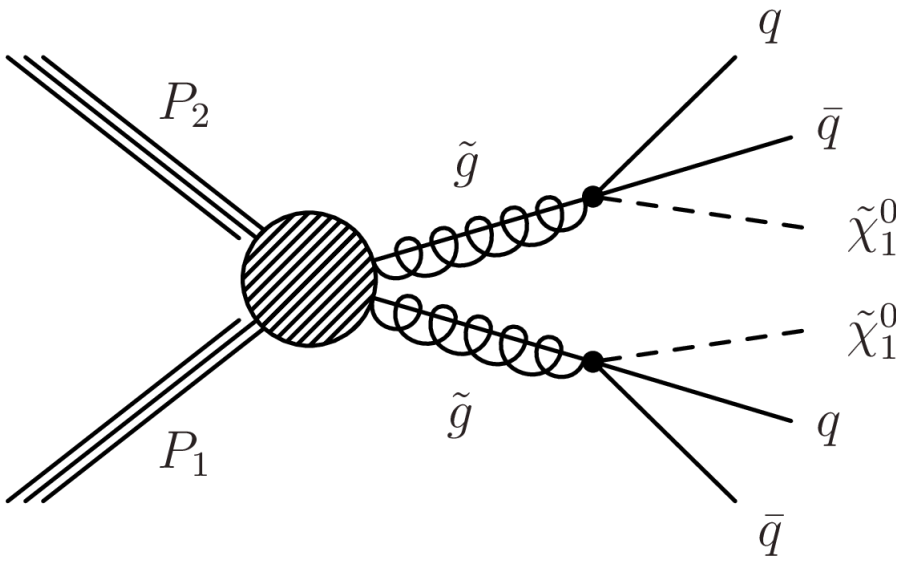
- BG to zero leptons + jets + MET is W+jets and ttbar+jets
  - W decays to lepton neutrino
  - lepton is missed (lost)
  - neutrino gives MET
- Normalize to control region of 1 lepton + jets + MET with identical requirements as zero lepton search
- Use MC only to extrapolate "found lepton" → "lost lepton"
  - include data/MC scale factors for known imperfections of MC

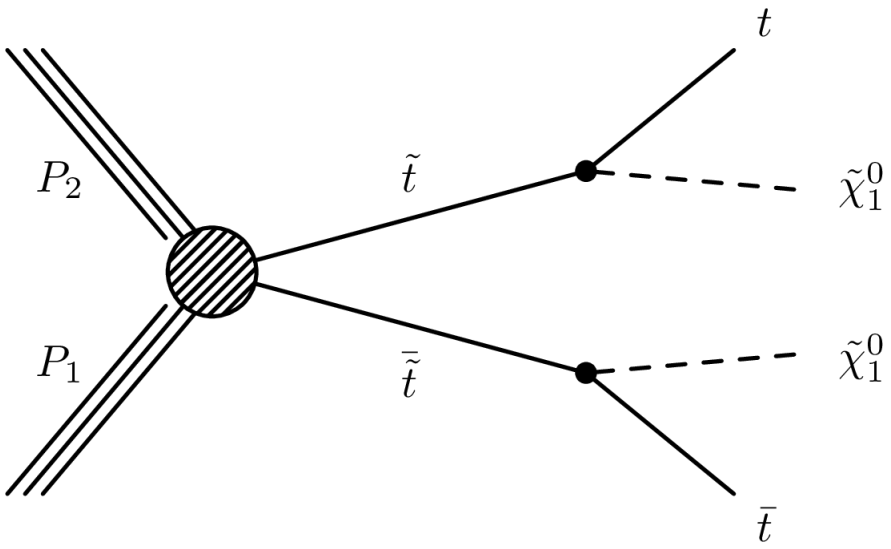
Simplified models

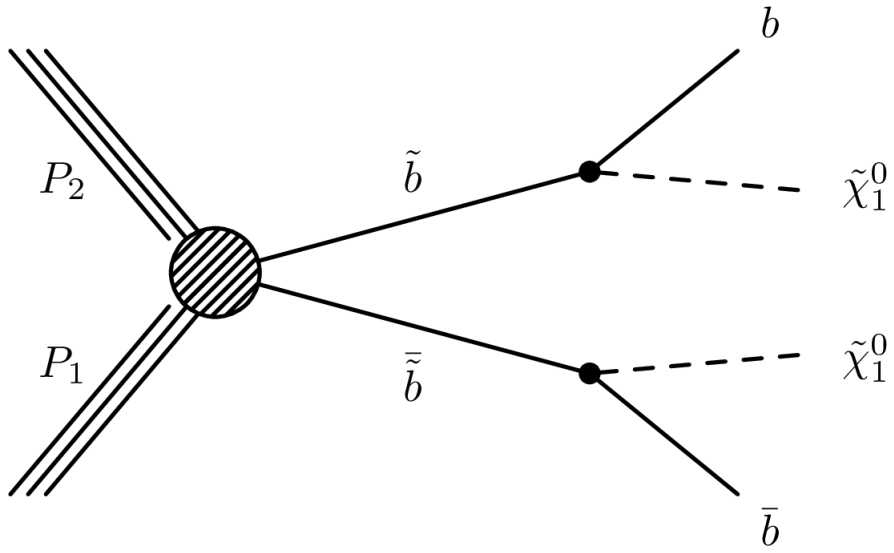
- SUSY particle production
  - gluino pairs or squark pairs
  - simple decay chains, 100% branching ratios
  - one process at a time...ignore other SUSY processes that could be there at the same time
  - try to cover the space of possible signatures
- Used to
  - loosely guide the design of the searches
  - if no excess, used to set ***simplified*** limits on SUSY particles masses

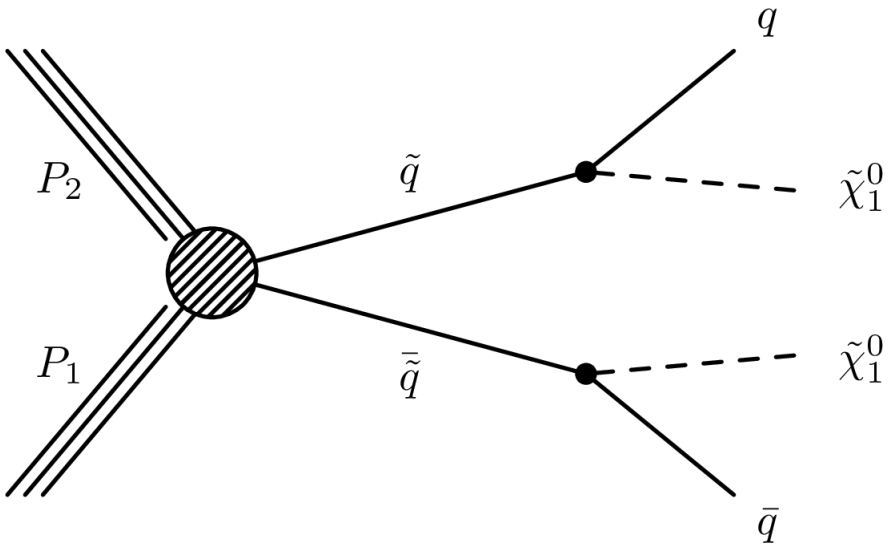

P_2
P_1
$\tilde{g}$
$\tilde{g}$
t
$\bar{t}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
t
$\bar{t}$


P_2
P_1
$\tilde{g}$
$\tilde{g}$
b
$\bar{b}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
b
$\bar{b}$

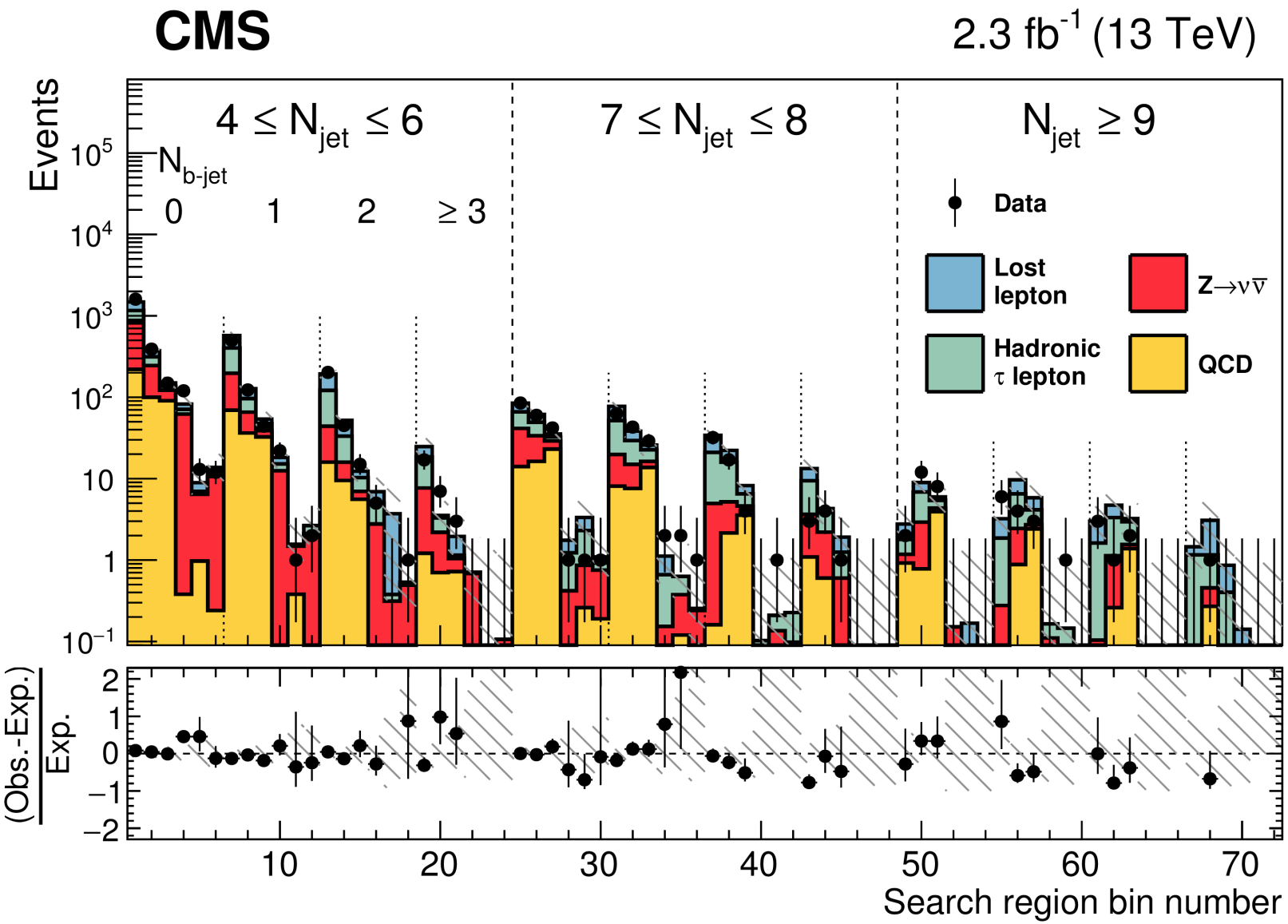

P_2
P_1
$\tilde{g}$
$\tilde{g}$
q
$\bar{q}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
q
$\bar{q}$


P_2
P_1
$\tilde{t}$
$\bar{\tilde{t}}$
t
$\bar{t}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$


P_2
P_1
$\tilde{b}$
$\bar{\tilde{b}}$
b
$\bar{b}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$


P_2
P_1
$\tilde{q}$
$\bar{\tilde{q}}$
q
$\bar{q}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$

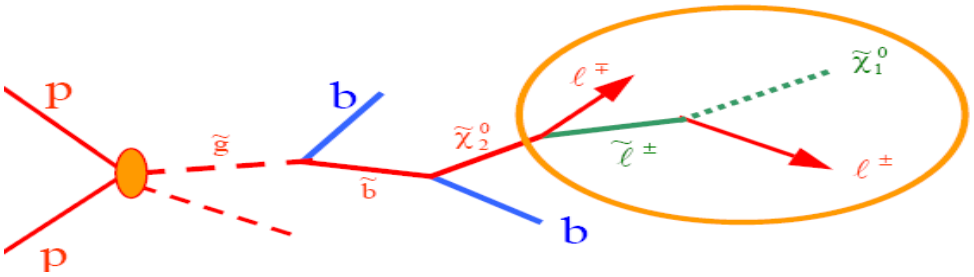
Unfortunately none of our searches showed any excess above SM expectations



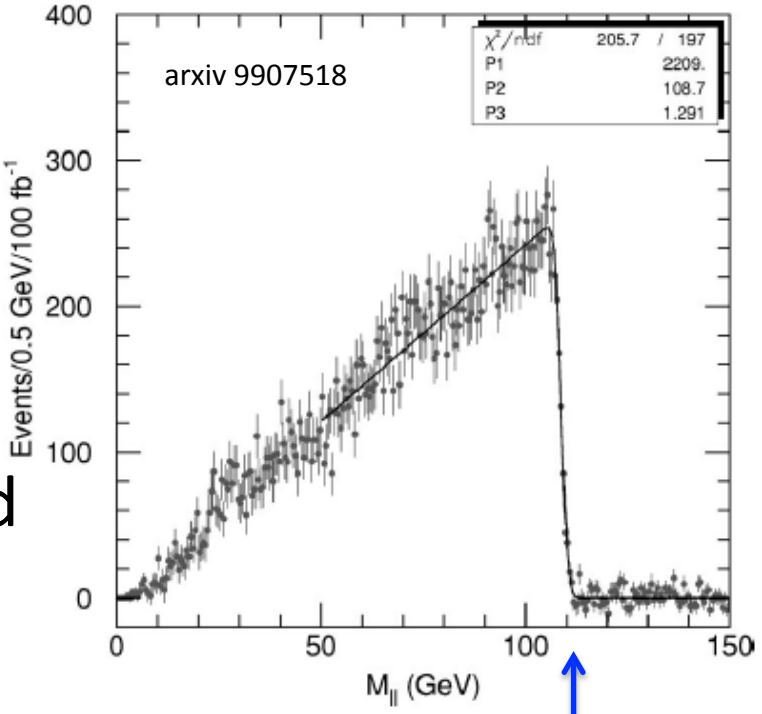
The 72 signal regions of PLB 758 (2016) 152: data vs. prediction

A partly disappearing excess: opposite sign-same flavor leptons + MET

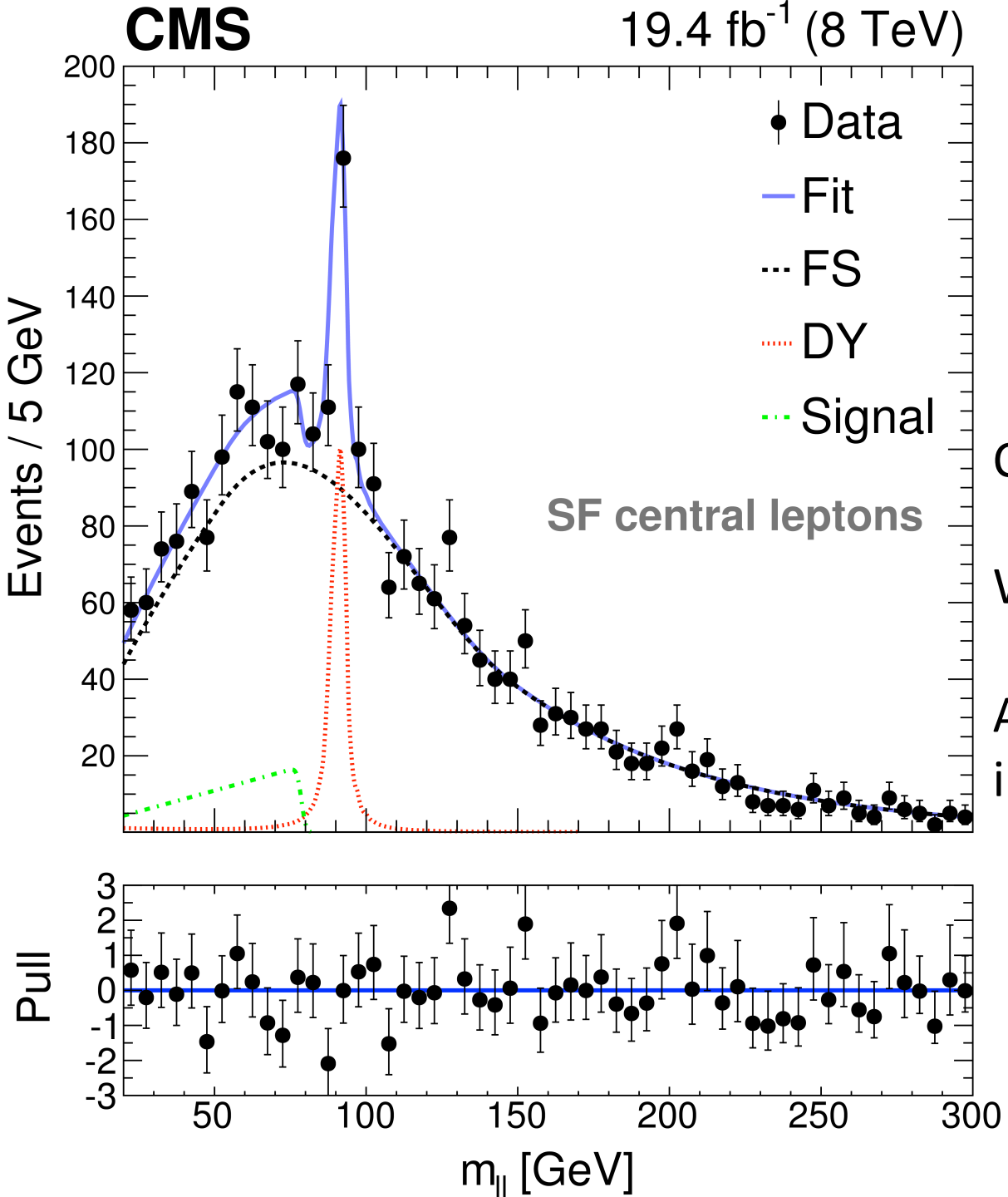
- A "classic" SUSY signature



- Two leptons of opposite sign and same flavor
- The invariant mass of the pair has a kinematical edge and a triangular shape from phase space



$$M(\chi_2)\sqrt{1-\frac{M(\tilde{\ell})}{M(\chi_2)}}\sqrt{1-\frac{M(\chi_1)}{M(\tilde{\ell})}}$$

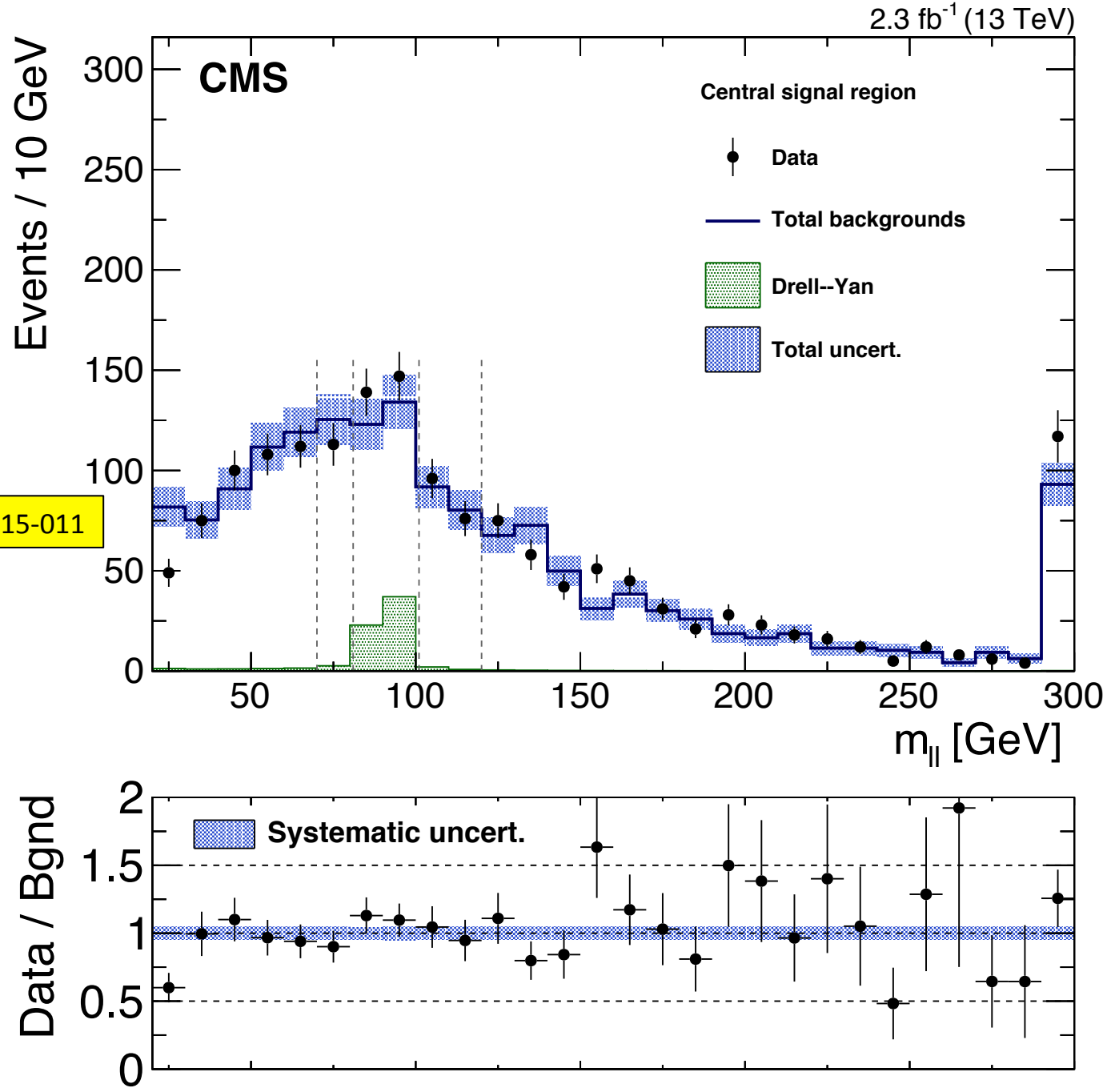


JHEP04(2015)124

Can you see a triangle?

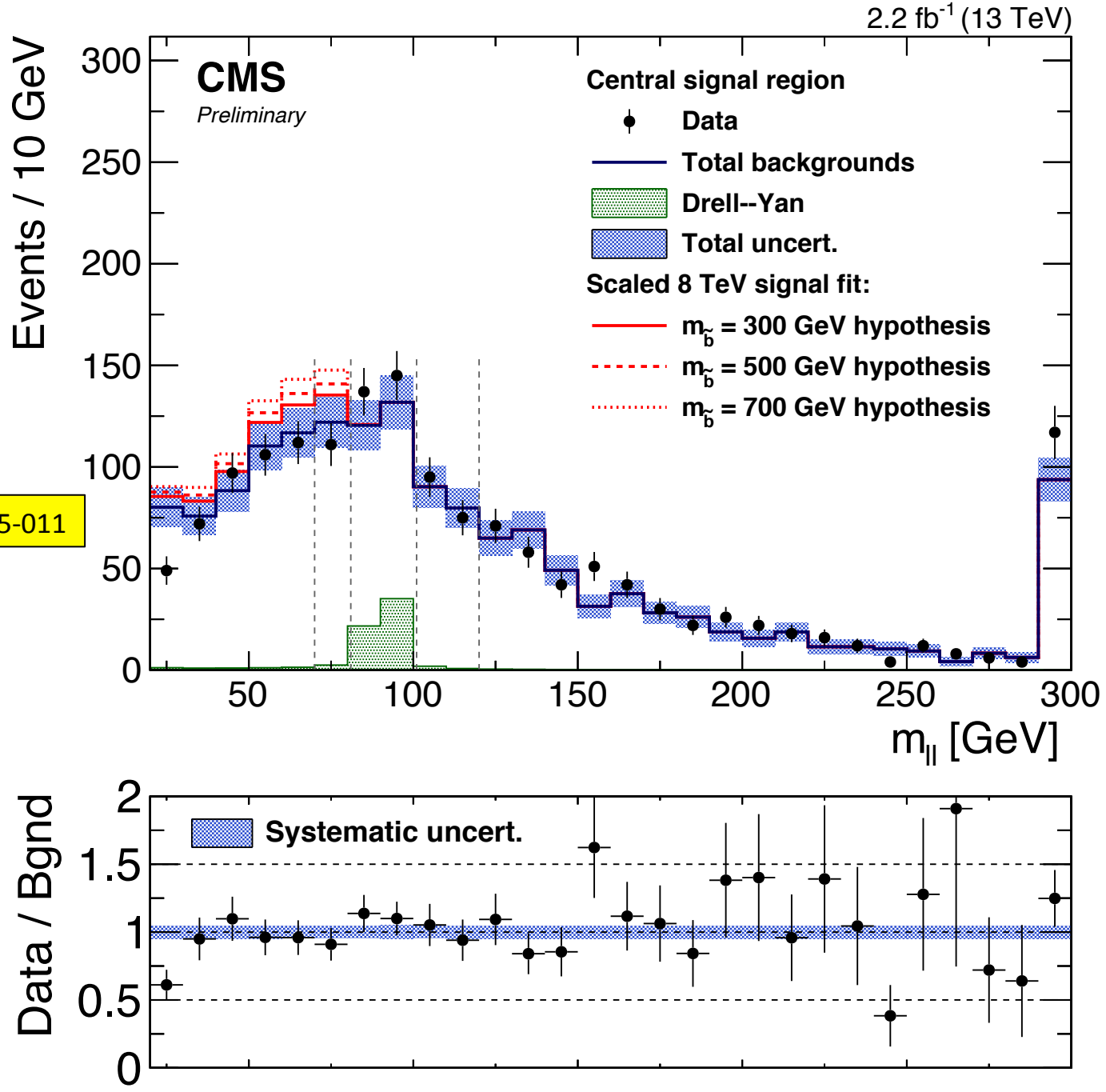
Was ~2.6σ effect

Atlas did not see excess in 8 TeV

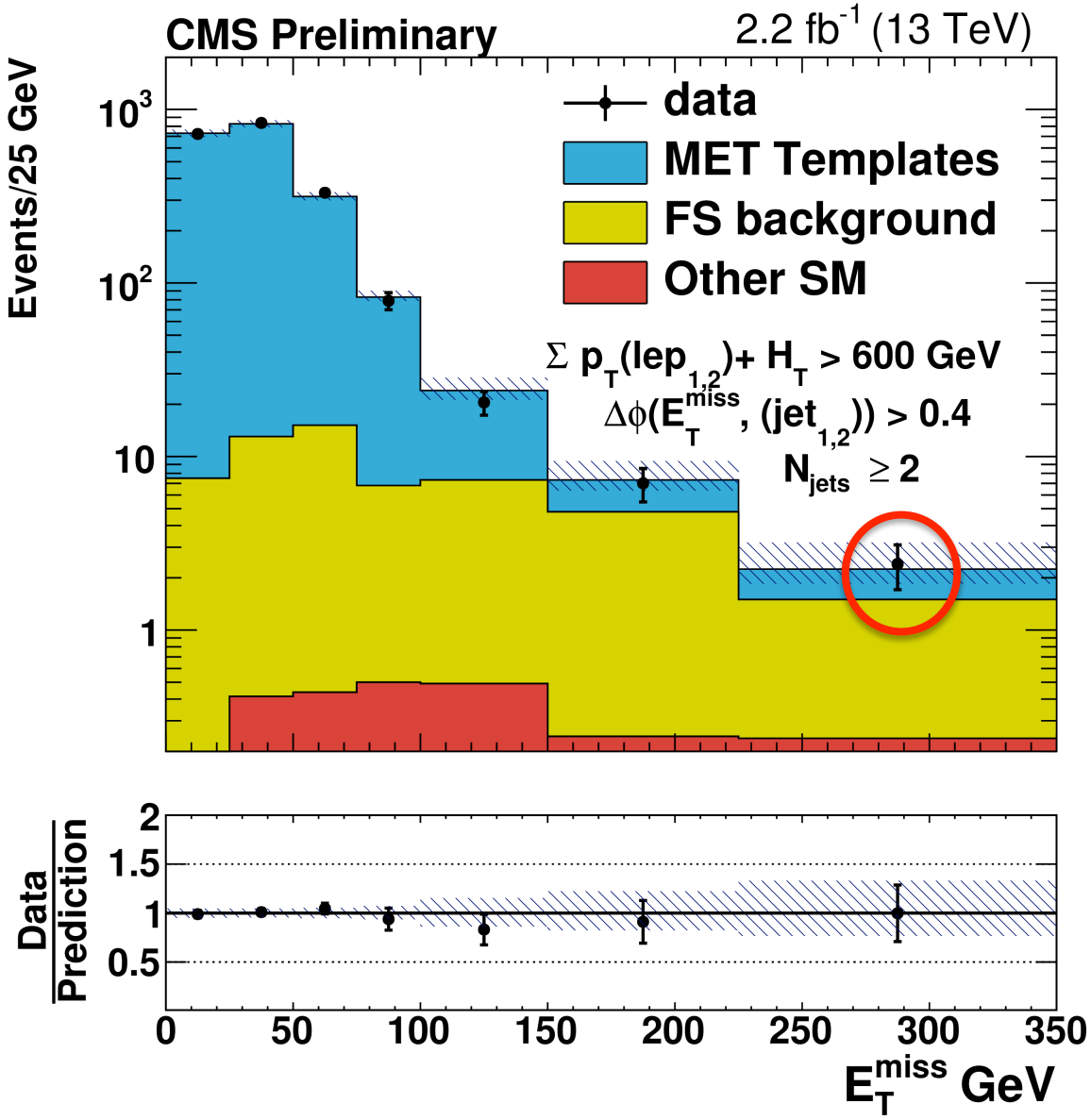


CMS-PAS-SUS-15-011

CMS-PAS-SUS-15-011



Z + jets + MET

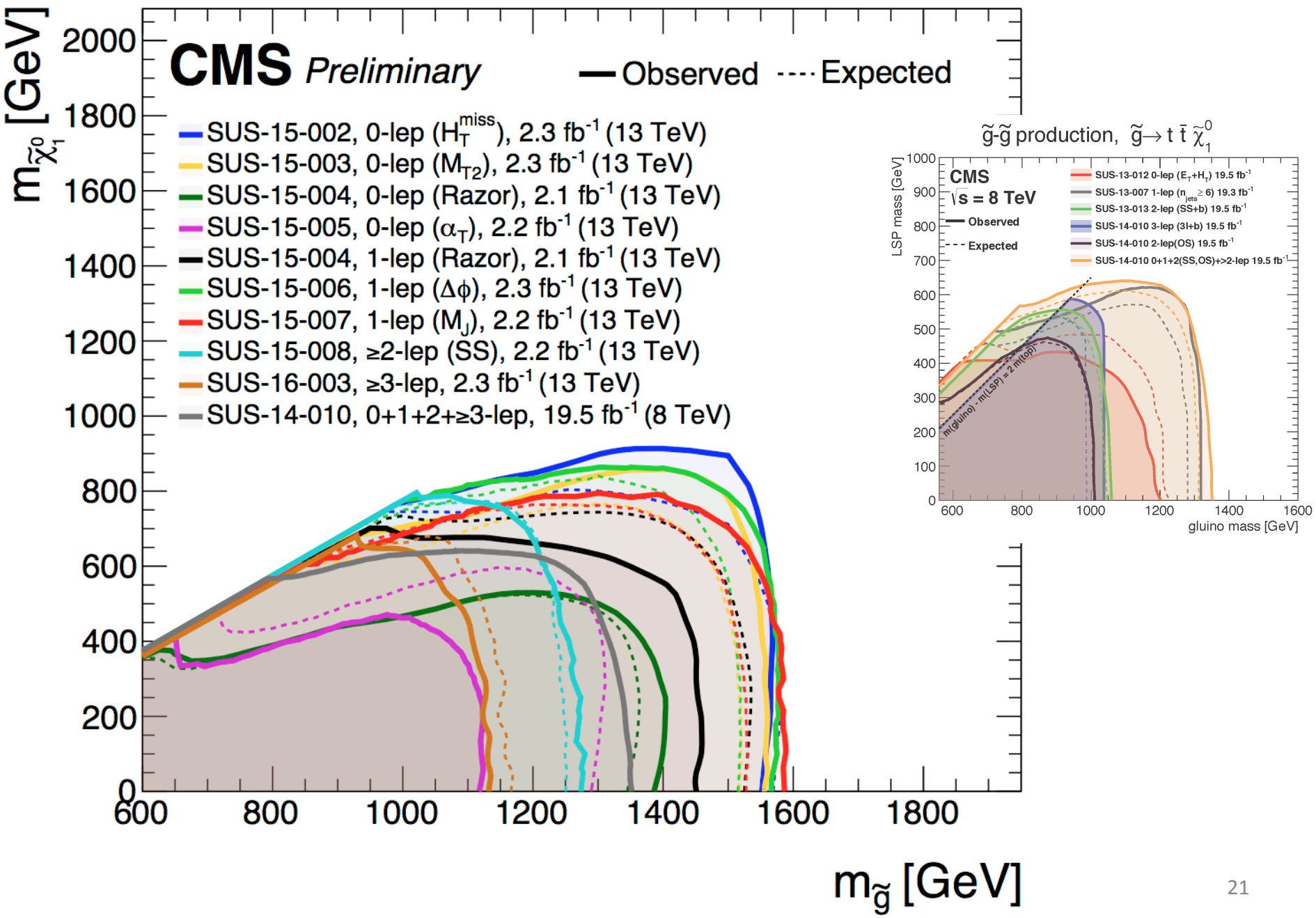


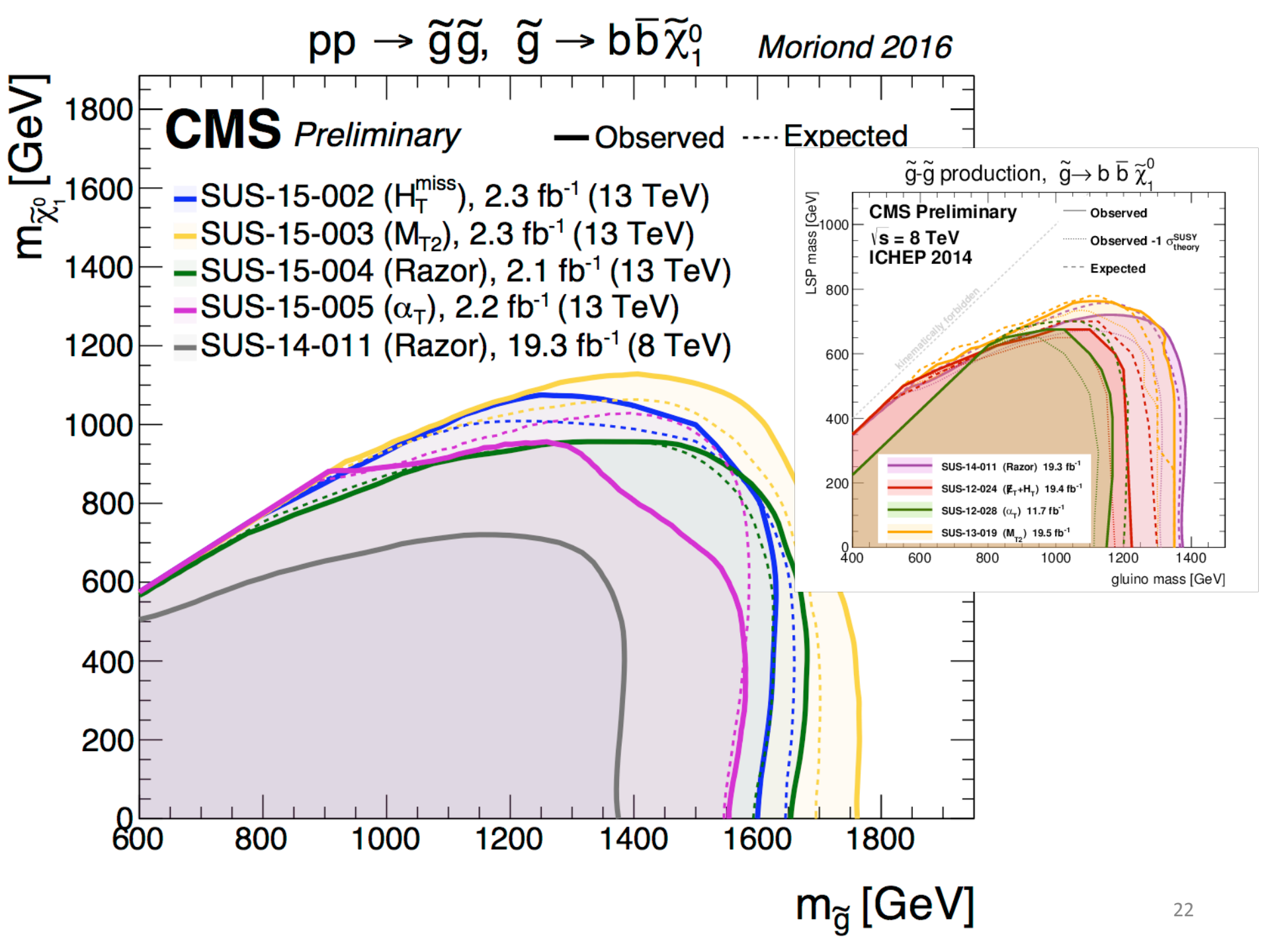
CMS-PAS-SUS-15-011

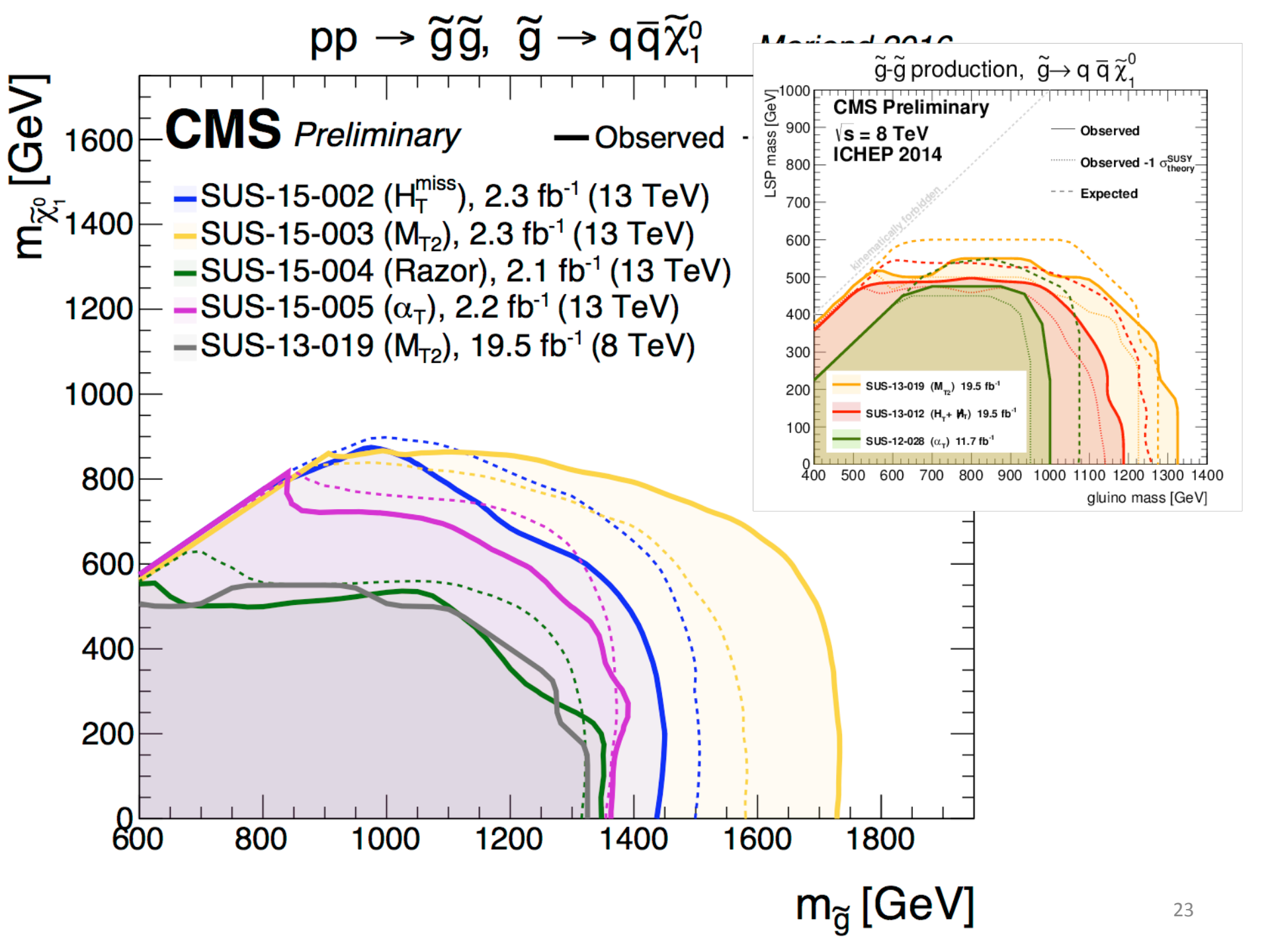
MET>225 GeV, on-Z	
Data	12
Predicted	12 ± 3

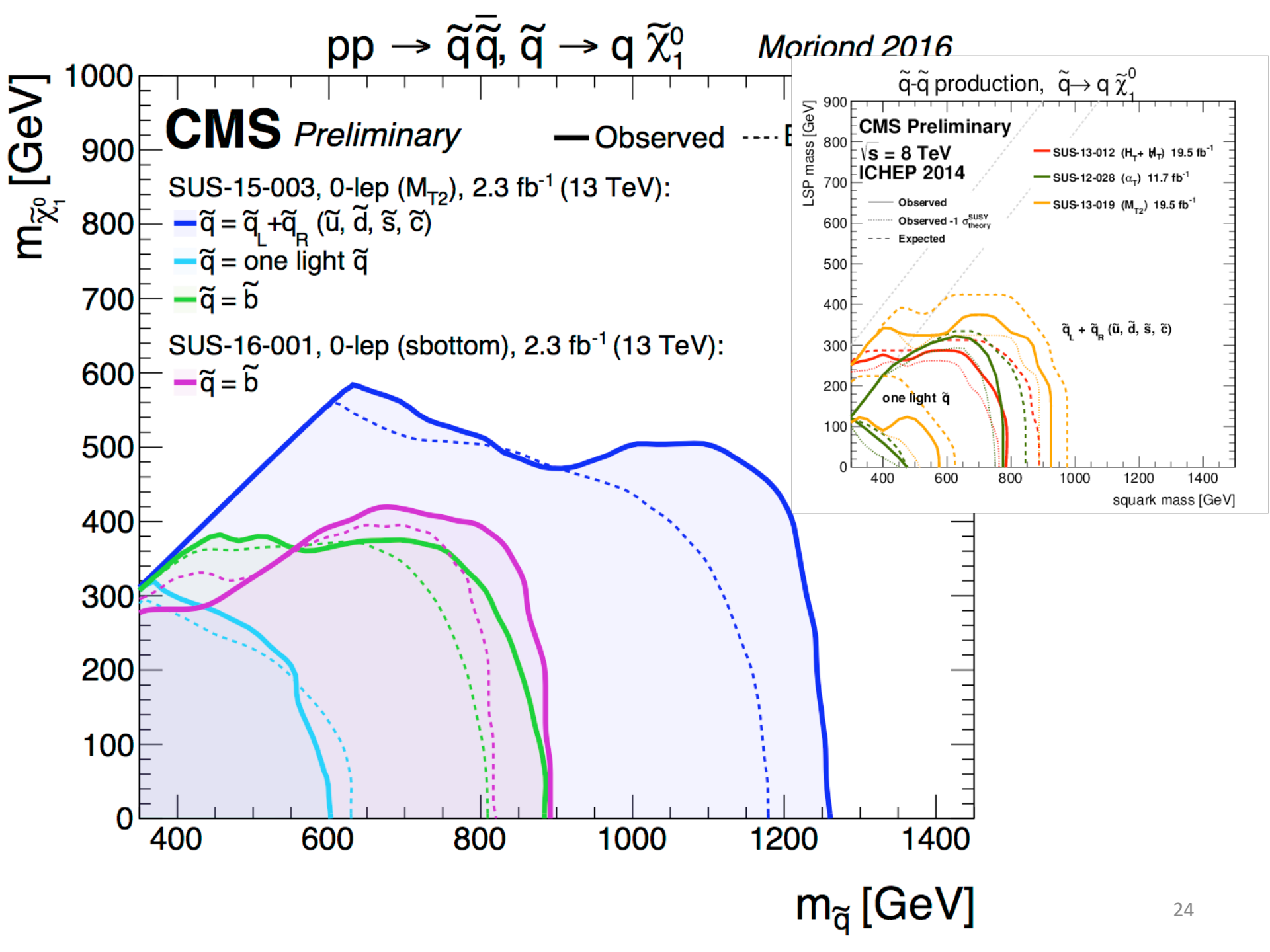
Atlas has excess in very similar kinematical region

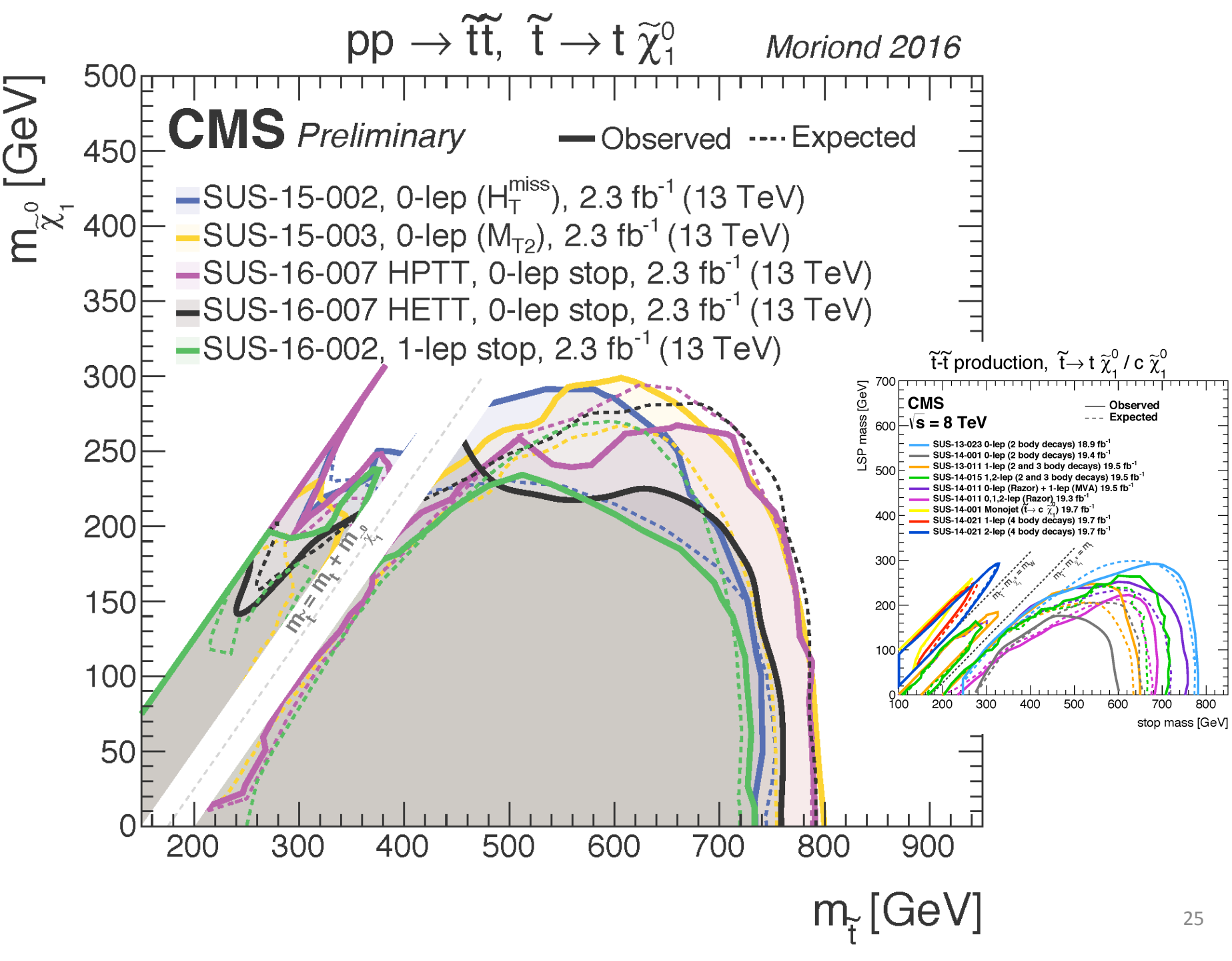
Some simplified model interpretations

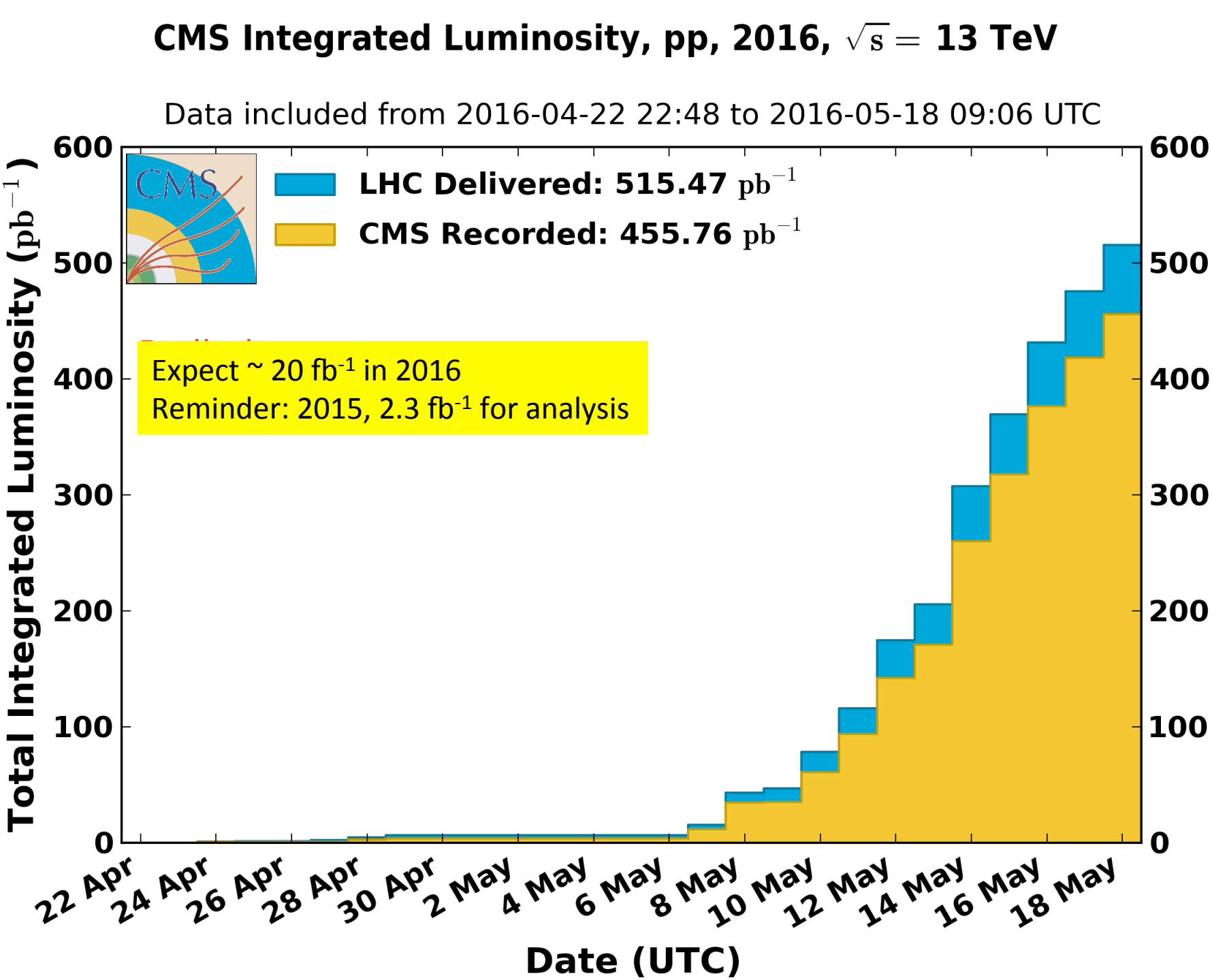

pp → g̃g̃, g̃ → t t̄ χ̃⁰₁
Moriond 2016
CMS Preliminary
Observed
Expected
SUS-15-002, 0-lep (H_T^miss), 2.3 fb⁻¹ (13 TeV)
SUS-15-003, 0-lep (M_T2), 2.3 fb⁻¹ (13 TeV)
SUS-15-004, 0-lep (Razor), 2.1 fb⁻¹ (13 TeV)
SUS-15-005, 0-lep (α_T), 2.2 fb⁻¹ (13 TeV)
SUS-15-004, 1-lep (Razor), 2.1 fb⁻¹ (13 TeV)
SUS-15-006, 1-lep (Δφ), 2.3 fb⁻¹ (13 TeV)
SUS-15-007, 1-lep (M_J), 2.2 fb⁻¹ (13 TeV)
SUS-15-008, ≥2-lep (SS), 2.2 fb⁻¹ (13 TeV)
SUS-16-003, ≥3-lep, 2.3 fb⁻¹ (13 TeV)
SUS-14-010, 0+1+2+≥3-lep, 19.5 fb⁻¹ (8 TeV)
m_χ̃⁰₁ [GeV]
m_g̃ [GeV]
g̃-g̃ production, g̃→ t t̄ χ̃⁰₁
CMS
√s = 8 TeV
Observed
Expected
SUS-13-012 0-lep (E_T+H_T) 19.5 fb⁻¹
SUS-13-007 1-lep (n_jets ≥ 6) 19.3 fb⁻¹
SUS-13-013 2-lep (SS+b) 19.5 fb⁻¹
SUS-14-010 3-lep (3l+b) 19.5 fb⁻¹
SUS-14-010 2-lep(OS) 19.5 fb⁻¹
SUS-14-010 0+1+2(SS,OS)+>2-lep 19.5 fb⁻¹
m(gluino) - m(LSP) = 2 m(top)
LSP mass [GeV]
gluino mass [GeV]


pp → g̃g̃, g̃ → bb̄χ̃⁰₁ Moriond 2016
CMS Preliminary
Observed
Expected
SUS-15-002 (H_T^miss), 2.3 fb⁻¹ (13 TeV)
SUS-15-003 (M_T2), 2.3 fb⁻¹ (13 TeV)
SUS-15-004 (Razor), 2.1 fb⁻¹ (13 TeV)
SUS-15-005 (α_T), 2.2 fb⁻¹ (13 TeV)
SUS-14-011 (Razor), 19.3 fb⁻¹ (8 TeV)
m_χ̃⁰₁ [GeV]
m_g̃ [GeV]
g̃-g̃ production, g̃→ b b̄ χ̃⁰₁
CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Observed -1 σ^SUSY theory
Expected
kinematically forbidden
SUS-14-011 (Razor) 19.3 fb⁻¹
SUS-12-024 (H_T+H_T) 19.4 fb⁻¹
SUS-12-028 (α_T) 11.7 fb⁻¹
SUS-13-019 (M_T2) 19.5 fb⁻¹
LSP mass [GeV]
gluino mass [GeV]


pp → g̃g̃, g̃ → qq̄χ̃₁⁰
CMS Preliminary
Observed
SUS-15-002 (H_T^miss), 2.3 fb⁻¹ (13 TeV)
SUS-15-003 (M_T2), 2.3 fb⁻¹ (13 TeV)
SUS-15-004 (Razor), 2.1 fb⁻¹ (13 TeV)
SUS-15-005 (α_T), 2.2 fb⁻¹ (13 TeV)
SUS-13-019 (M_T2), 19.5 fb⁻¹ (8 TeV)
m_χ̃₁⁰ [GeV]
m_g̃ [GeV]
g̃-g̃ production, g̃→ q q̄ χ̃₁⁰
CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Observed -1 σ^SUSY_theory
Expected
kinematically forbidden
SUS-13-019 (M_T2) 19.5 fb⁻¹
SUS-13-012 (H_T+ MET) 19.5 fb⁻¹
SUS-12-028 (α_T) 11.7 fb⁻¹
LSP mass [GeV]
gluino mass [GeV]


pp → q̃q̃, q̃ → q χ̃⁰₁
Moriond 2016
CMS Preliminary
Observed
SUS-15-003, 0-lep (M_T2), 2.3 fb⁻¹ (13 TeV):
q̃ = q̃_L + q̃_R (ũ, d̃, s̃, c̃)
q̃ = one light q̃
q̃ = b̃
SUS-16-001, 0-lep (sbottom), 2.3 fb⁻¹ (13 TeV):
q̃ = b̃
m_χ̃⁰₁ [GeV]
m_q̃ [GeV]
q̃-q̃ production, q̃ → q χ̃⁰₁
CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Observed -1 σ SUSY theory
Expected
SUS-13-012 (H_T + M_T) 19.5 fb⁻¹
SUS-12-028 (α_T) 11.7 fb⁻¹
SUS-13-019 (M_T2) 19.5 fb⁻¹
q̃_L + q̃_R (ũ, d̃, s̃, c̃)
one light q̃
LSP mass [GeV]
squark mass [GeV]


pp → t̃t̃, t̃ → t χ̃⁰₁
Moriond 2016
CMS Preliminary
Observed
Expected
SUS-15-002, 0-lep (H_T^miss), 2.3 fb⁻¹ (13 TeV)
SUS-15-003, 0-lep (M_T2), 2.3 fb⁻¹ (13 TeV)
SUS-16-007 HPTT, 0-lep stop, 2.3 fb⁻¹ (13 TeV)
SUS-16-007 HETT, 0-lep stop, 2.3 fb⁻¹ (13 TeV)
SUS-16-002, 1-lep stop, 2.3 fb⁻¹ (13 TeV)
m_χ̃⁰₁ [GeV]
m_t̃ [GeV]
m_t̃ = m_t + m_χ̃⁰₁
t̃-t̃ production, t̃→ t χ̃⁰₁ / c χ̃⁰₁
CMS
√s = 8 TeV
Observed
Expected
SUS-13-023 0-lep (2 body decays) 18.9 fb⁻¹
SUS-14-001 0-lep (2 body decays) 19.4 fb⁻¹
SUS-13-011 1-lep (2 and 3 body decays) 19.5 fb⁻¹
SUS-14-015 1,2-lep (2 and 3 body decays) 19.5 fb⁻¹
SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.5 fb⁻¹
SUS-14-011 0,1,2-lep (Razor) 19.3 fb⁻¹
SUS-14-001 Monojet (t̃→ c χ̃⁰₁) 19.7 fb⁻¹
SUS-14-021 1-lep (4 body decays) 19.7 fb⁻¹
SUS-14-021 2-lep (4 body decays) 19.7 fb⁻¹
LSP mass [GeV]
stop mass [GeV]


CMS Integrated Luminosity, pp, 2016, $\sqrt{s} = 13$ TeV
Data included from 2016-04-22 22:48 to 2016-05-18 09:06 UTC
CMS
LHC Delivered: 515.47 pb^{-1}
CMS Recorded: 455.76 pb^{-1}
Expect ~ 20 fb^{-1} in 2016
Reminder: 2015, 2.3 fb^{-1} for analysis
Total Integrated Luminosity (pb^{-1})
0
100
200
300
400
500
600
22 Apr
24 Apr
26 Apr
28 Apr
30 Apr
2 May
4 May
6 May
8 May
10 May
12 May
14 May
16 May
18 May
Date (UTC)

Summary

- Comprehensive program of searches for SUSY ongoing
- Already improved sensitivity to strongly produced SUSY wrt to 2012-12 run with small amount of data in 2015
- Order-of-magnitude increase in luminosity in 2016, more in 2017 and beyond
  - Sensitivity to EWK production as well
- The search continues.....