Searches for SUSY in compressed scenarios with the CMS detector

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on behalf of the CMS Collaboration

50th Rencontres de Moriond EW

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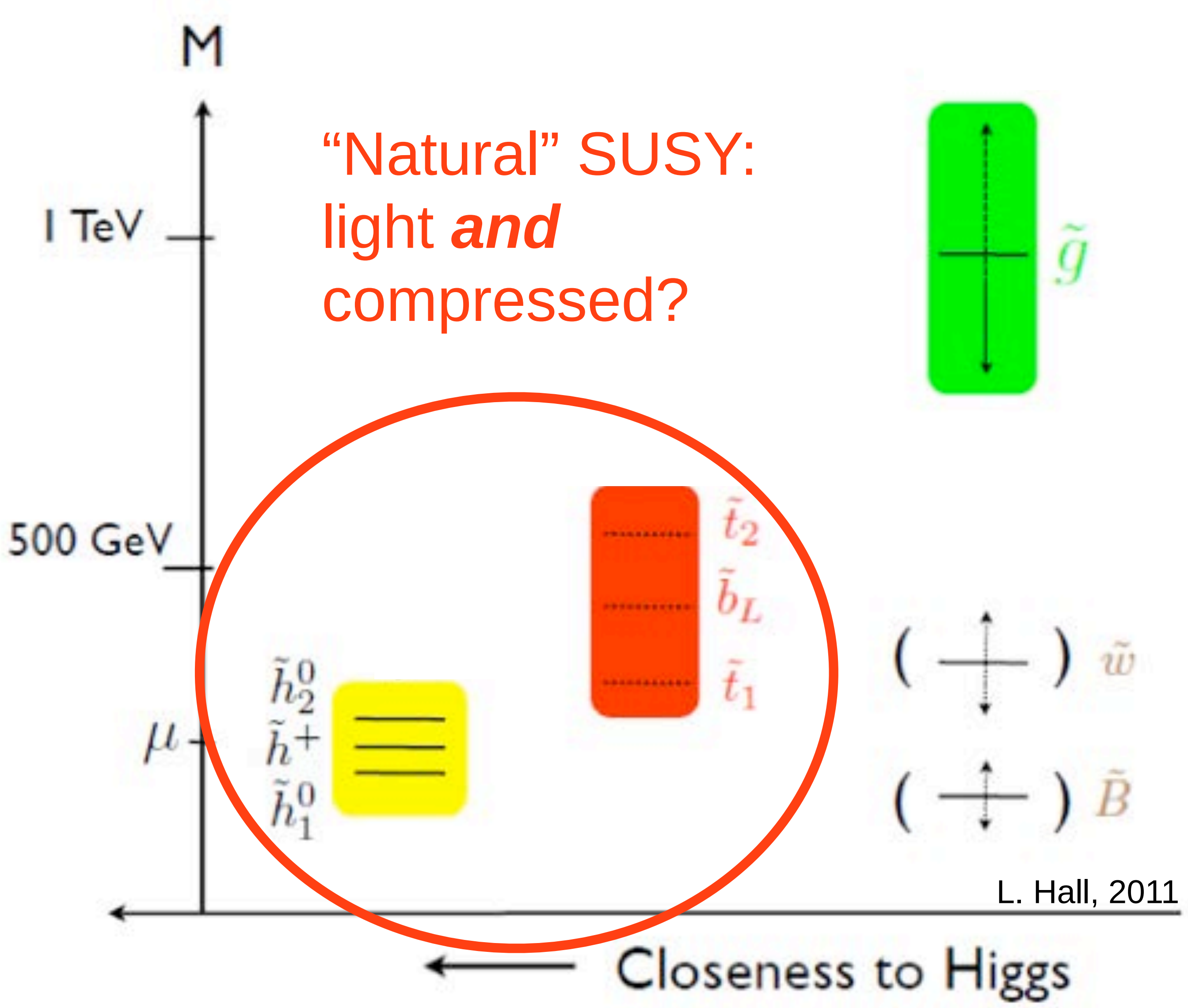
Why compressed scenarios?

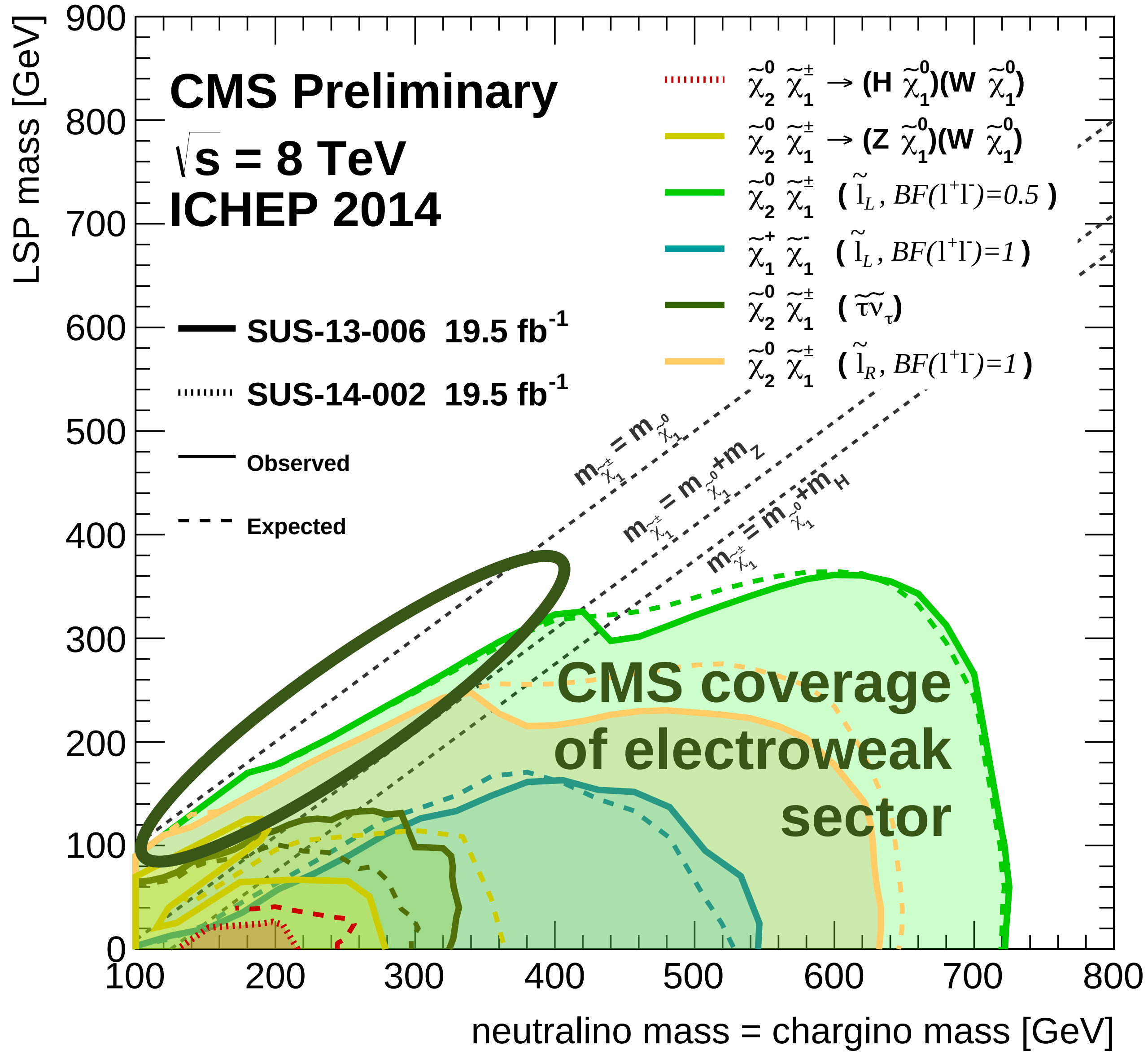
Discovery of Higgs boson motivates a “natural” SUSY parameter space

Strong coverage for $m_{LSP} \approx 0$ GeV, ***weak coverage of compressed (“natural”) scenarios***

Experimentally challenging: low acceptance due to soft decay products, rely on ISR or VBF

SUSY can provide ***correct relic density*** assuming co-annihilation of sparticles with small Δm



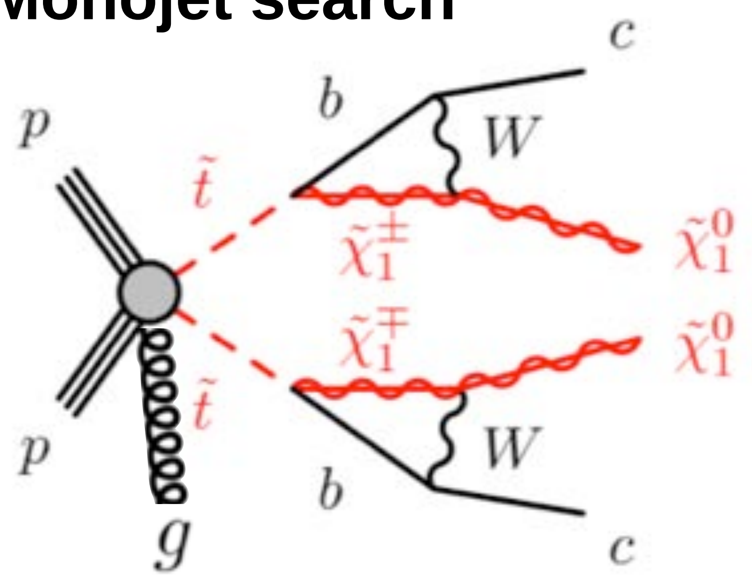


Scope: three analyses targeting compressed mass spectra

Third-generation squarks via ***hadronic final states***; electroweak sector via ***VBF + di-lepton***

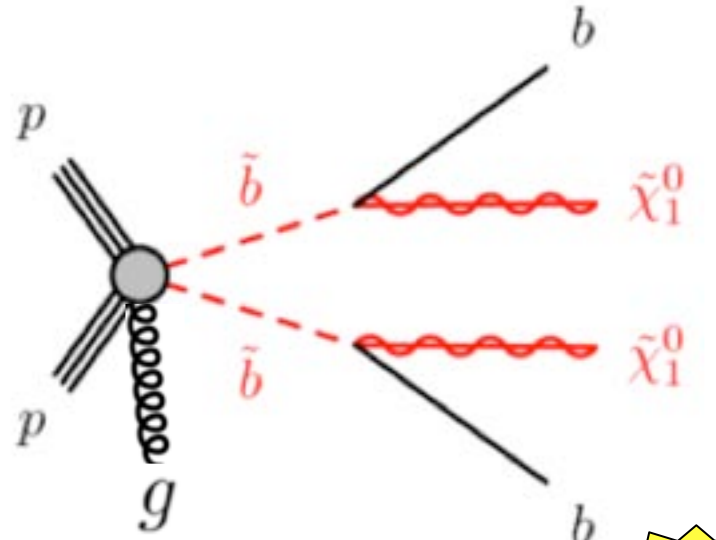
Simplified models comprising two or three sparticles, analyses target the compressed regions

Monojet search



$\tilde{t} \rightarrow c\chi^0$

Monojet / dijet searches

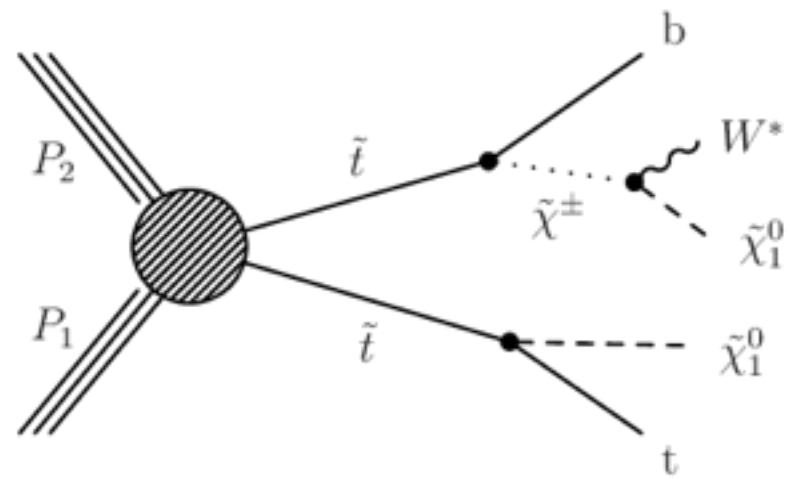


New

$\tilde{b} \rightarrow b\chi^0$

Dijet search

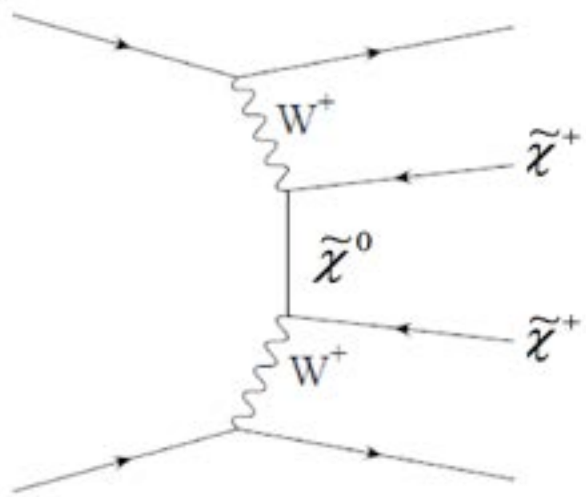
New



$\tilde{t} \rightarrow t\chi^0$ or $b\chi^{\pm}$; various Br

Search in ℓℓjj final state via VBF

New



$\chi^{\pm}\chi^0$ production, with $\tilde{\tau}$ NLSP

Latest results summarised in:
CMS-SUS-14-001
CMS-PAS-SUS-14-005

"Classic" monojet search repurposed for SUSY

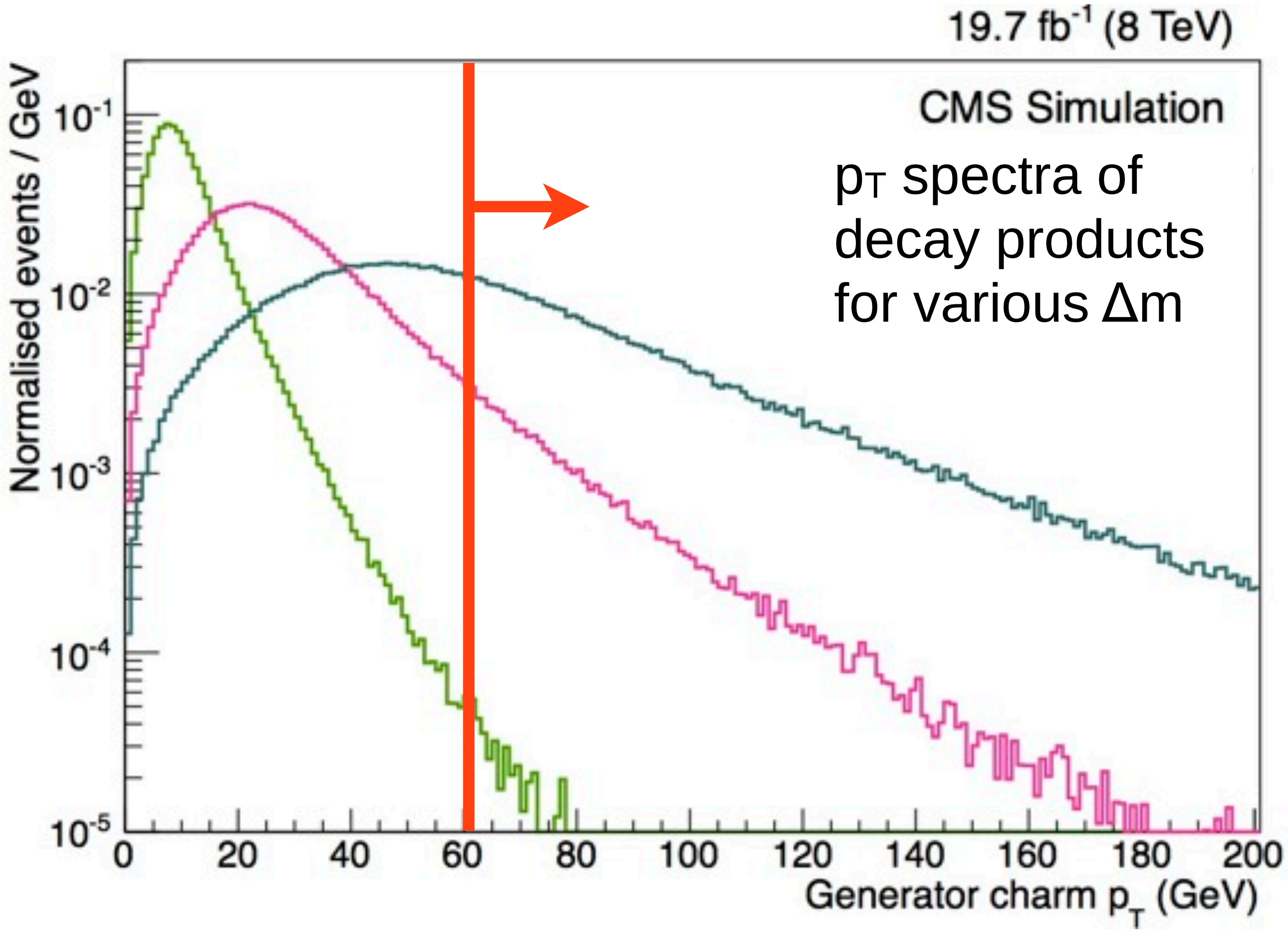
Acceptance for mass-degenerate spectra ($\Delta m \approx 0$) if recoiling against hard ISR

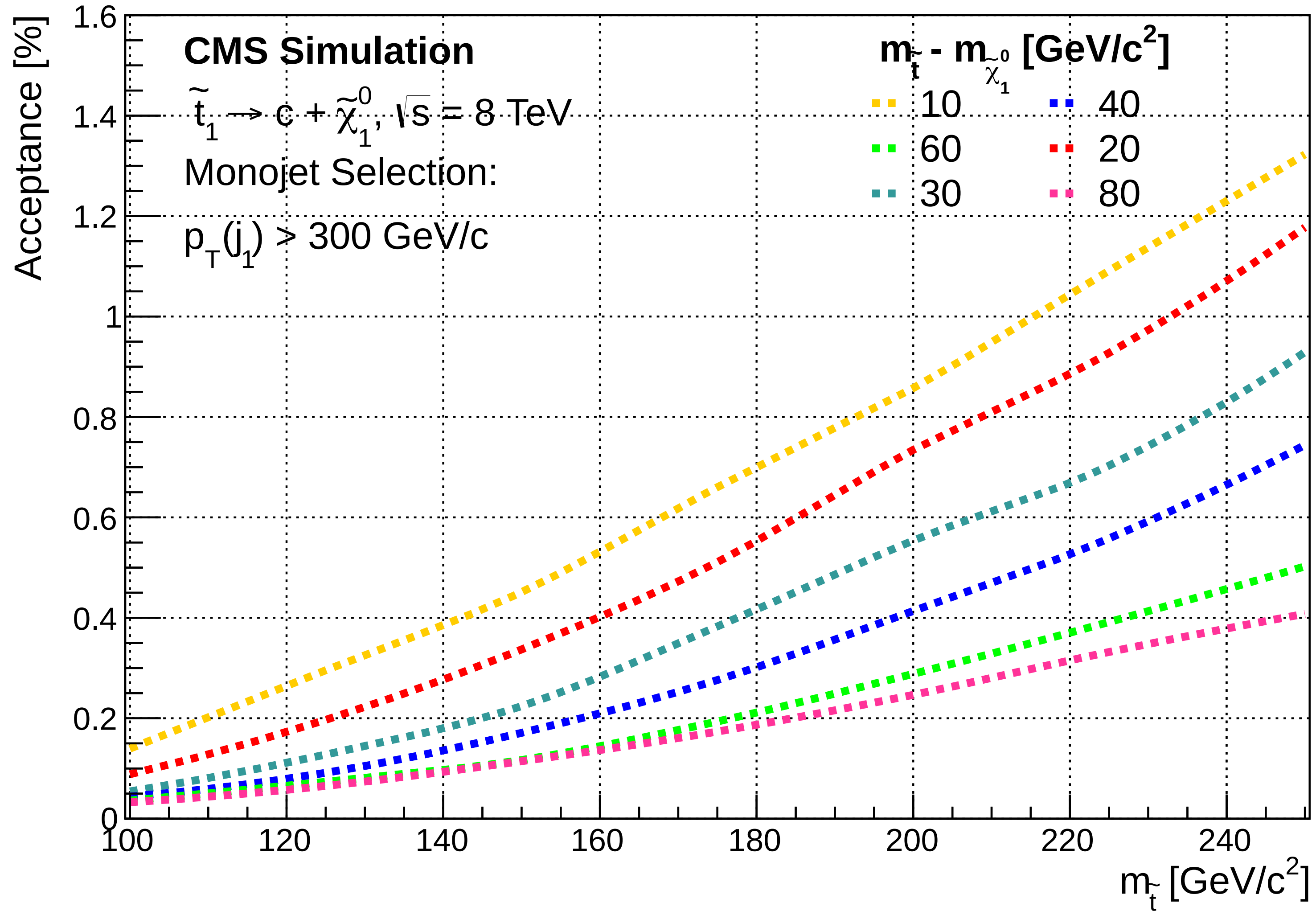
al la "classic" monojet, require significant p_T^{miss} and a hard lead jet

Then ***tune event selection*** to accommodate (soft) SM particles from SUSY decay chain

- As before, allow 2nd jet (ISR *or* decay)
- Raise 2nd jet threshold: to maintain "monojet" topology at larger Δm
- Discriminating variable lead jet p_T defines signal regions (rather than p_T^{miss})

Percent-level signal acceptance





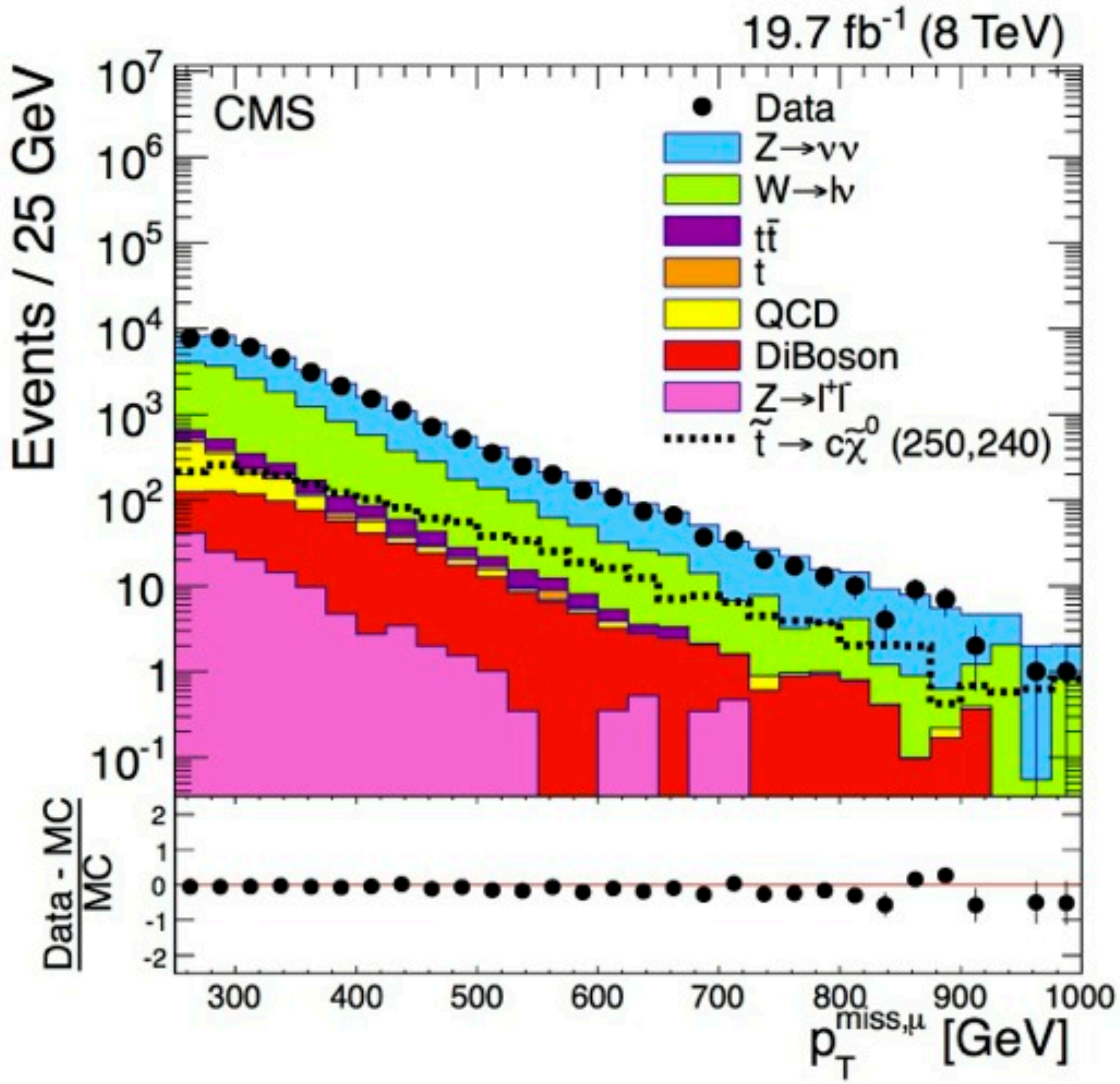
Monojet search: backgrounds

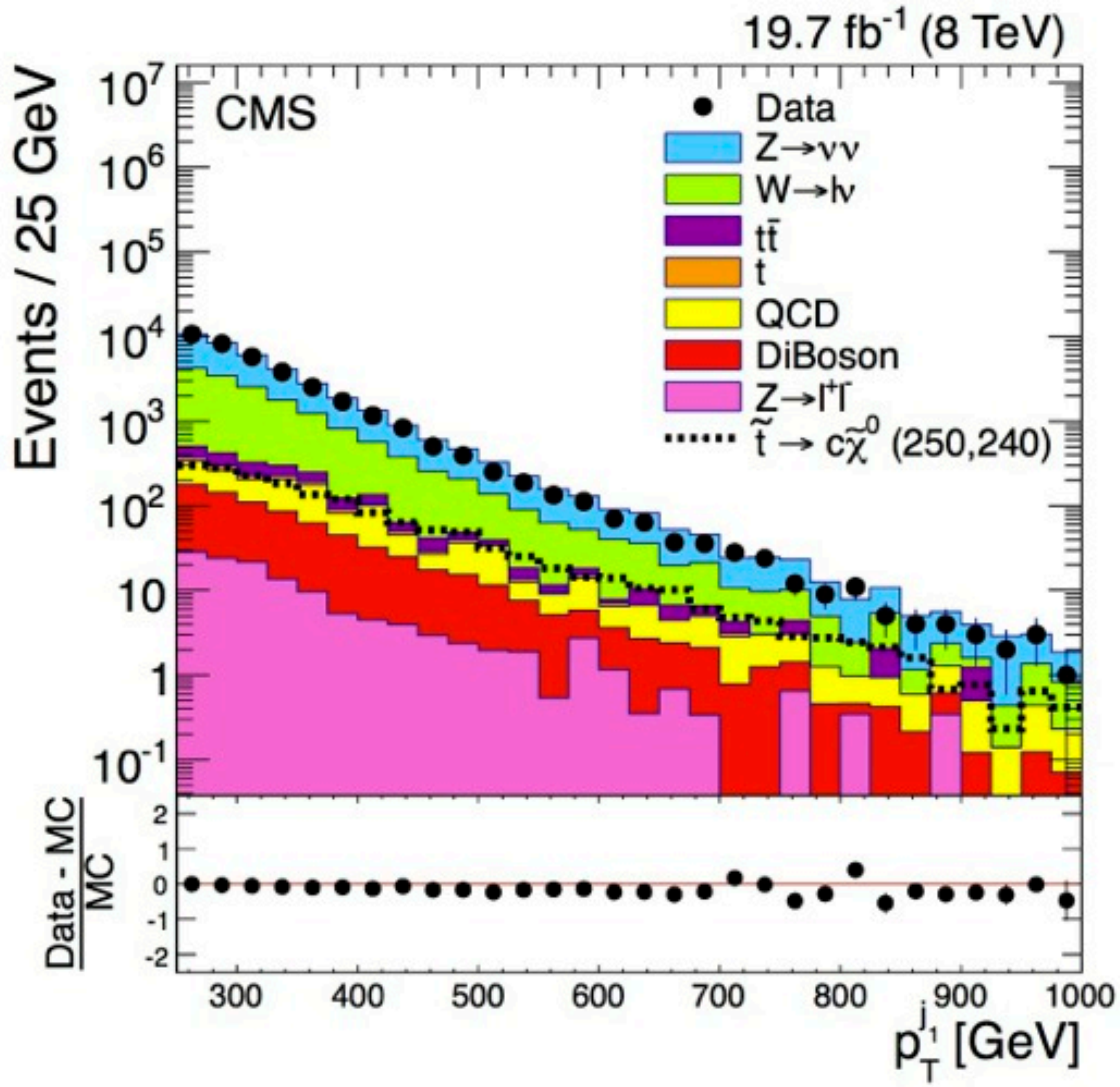
Z(→νν) + jets: use Z(→μμ) + jets sample and transfer factors (5-19% uncertainty)

W(→ℓν) + jets: use W(→μν) + jets sample and transfer factors (6-12%)

QCD: from simulation with normalisation to data in $\Delta\phi(j_1,j_2)$ sideband (~60%)

$t\bar{t}$ and diboson: taken from simulation, validated in eμ control sample (50%)





Monojet search: result and interpretation

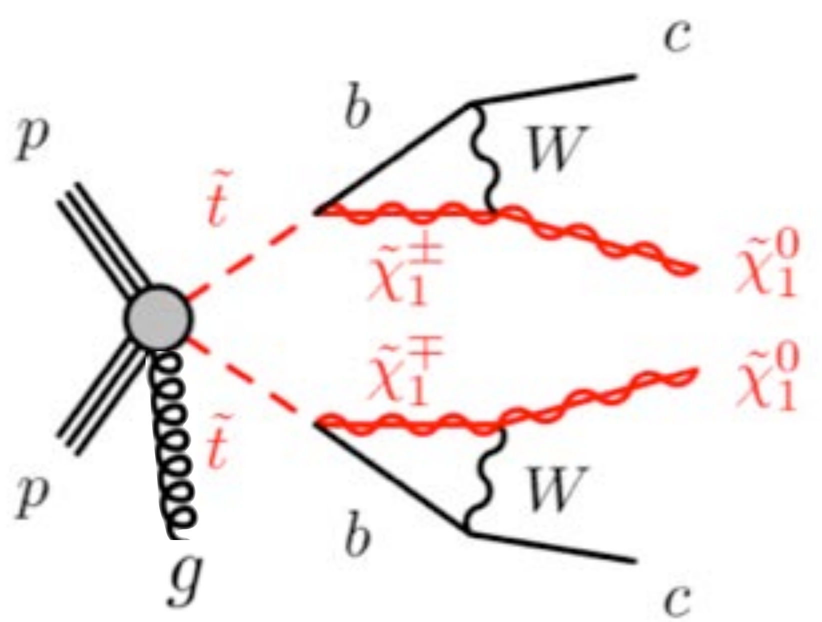
Result compatible with SM, so interpret with compressed model of stop → charm,LSP

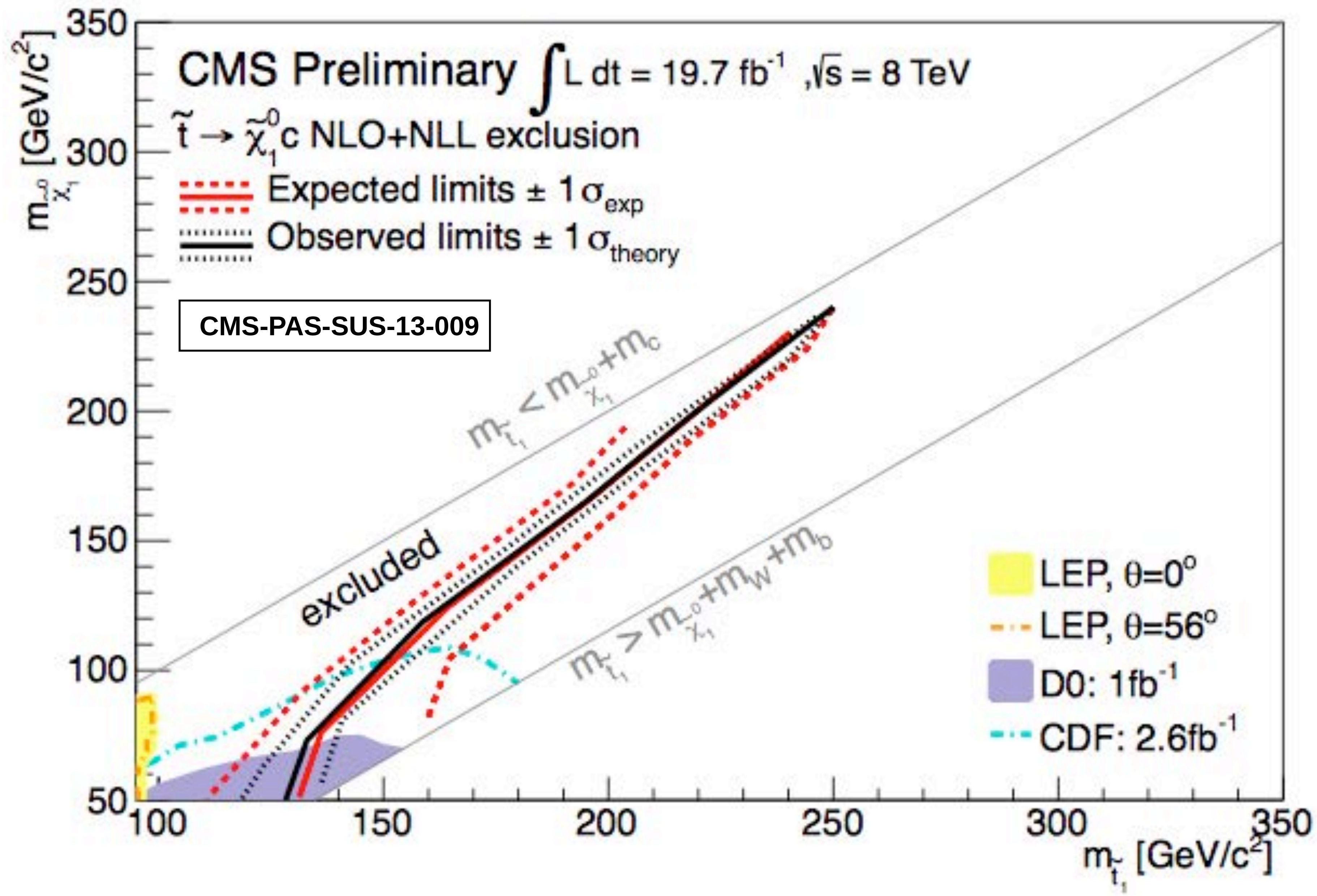
Sensitivity weakens for larger $m_{\tilde{t}}$ and Δm (harder decay products)

Other final states (leptons, multijets) provide complementary coverage at larger Δm

Analysis result (syst. dominated)

Monojet search	SM Pred.	Obs.
$p_T^{j1} > 250$ GeV	35900±1500	36600
$p_T^{j1} > 300$ GeV	17400±800	17600
$p_T^{j1} > 350$ GeV	8060±440	8120
$p_T^{j1} > 400$ GeV	3910±250	3900
$p_T^{j1} > 450$ GeV	2100±160	1900
$p_T^{j1} > 500$ GeV	1100±110	1000
$p_T^{j1} > 550$ GeV	563±71	565





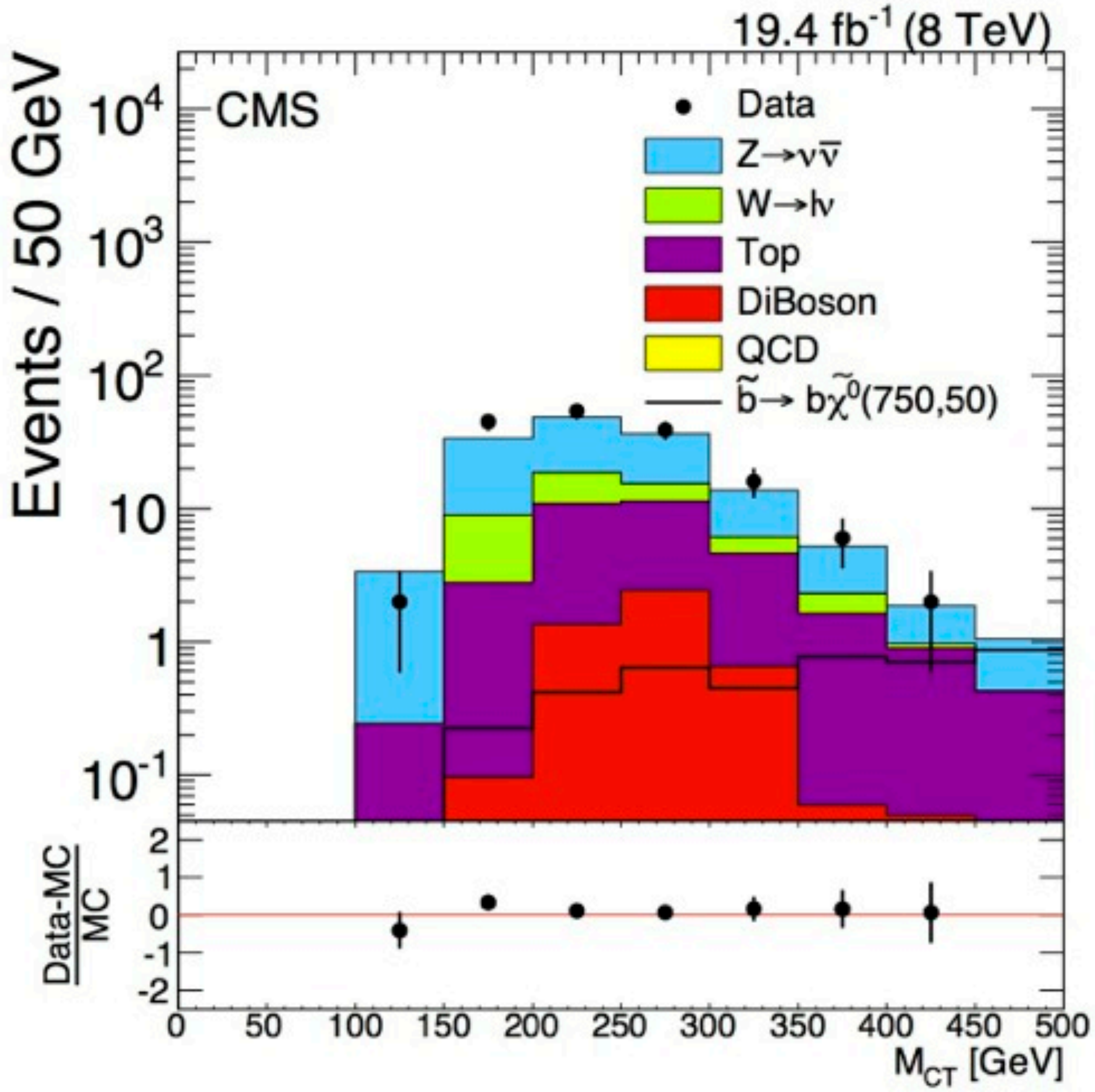
Dijet search with b-tags

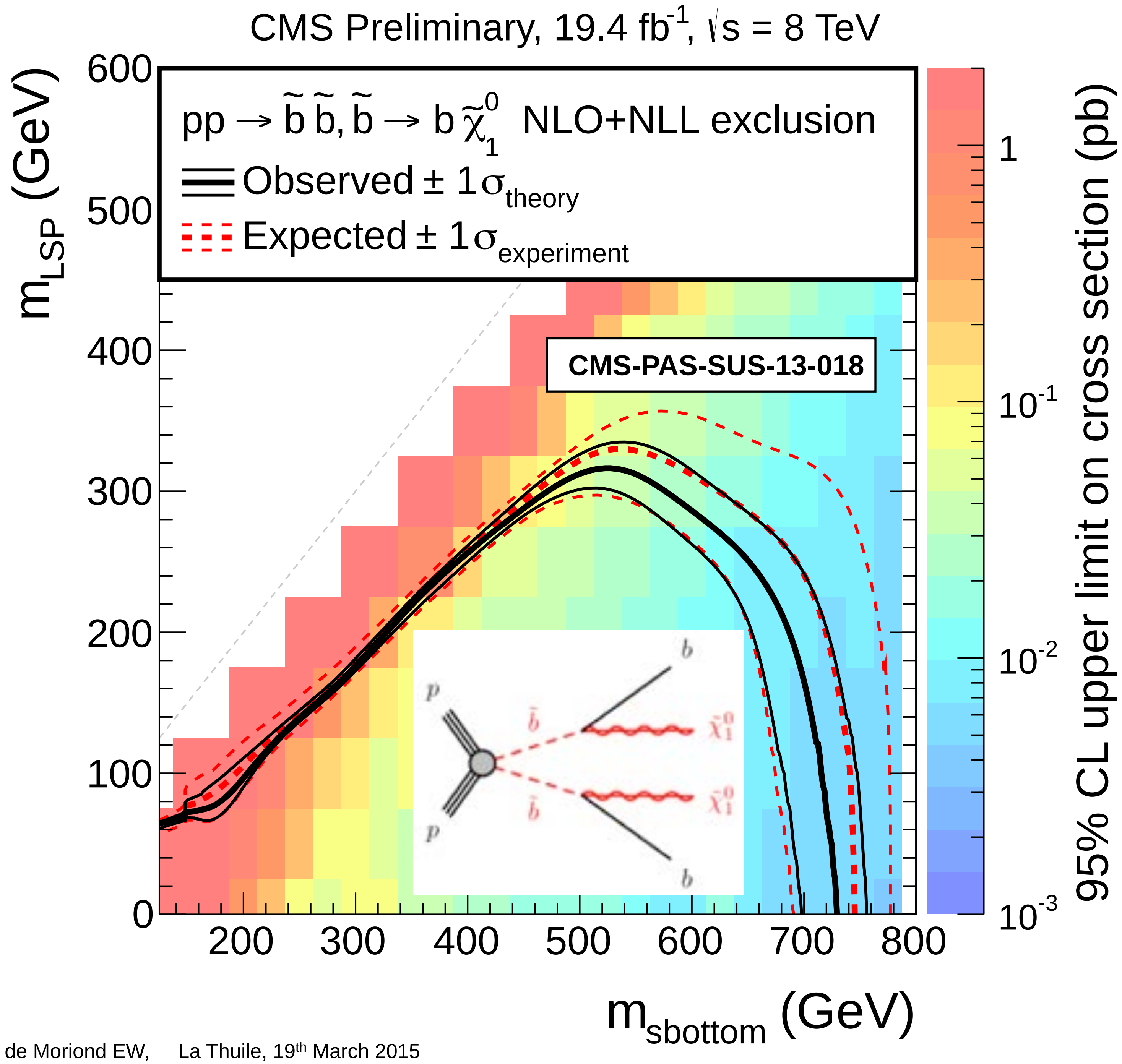
Analysis *specifically* targets sbottom pair-production with $\tilde{b} \rightarrow b\chi^0$ and $\Delta m > \sim 100$ GeV

Event selection: two jets, ≥1 b-tag, HT > 250 GeV, $p_T^{miss} > 175$ GeV, $\Delta\varphi(\text{jet}, p_T^{miss}) > 0.5$

Eight signal regions defined by N_{btag} and M_{CT} variable

For $\Delta m < \sim 100$ GeV: jets below threshold → ***require boost against ISR***





Dijet search with b-tags: new “ISR” search regions

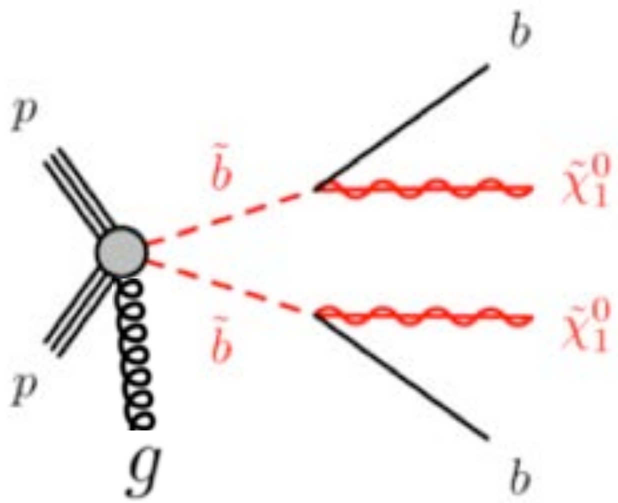
New!

Define two new signal regions and ***tune original selection to accommodate ISR***

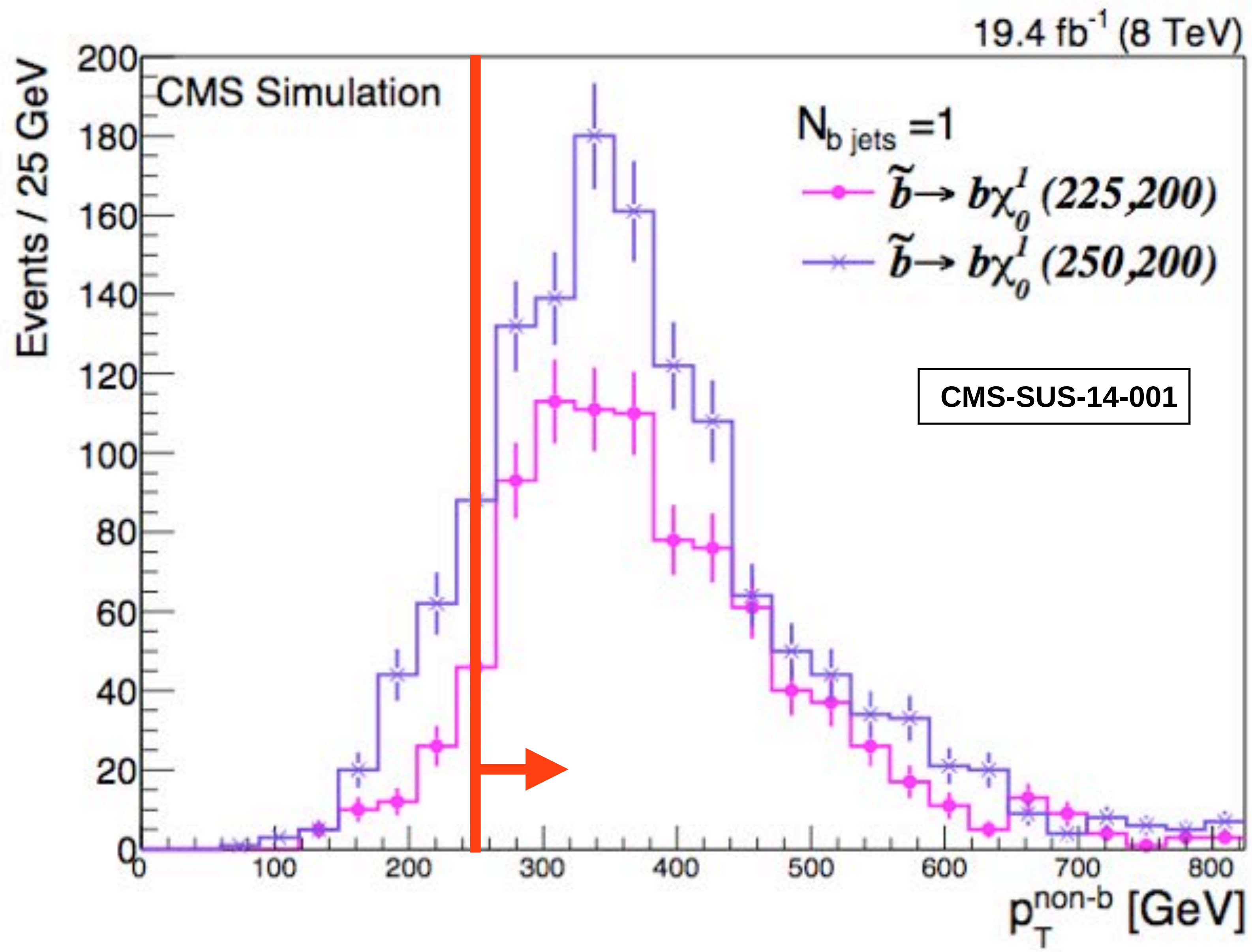
Selection: allow a third jet, b-tag veto for lead jet, tighter p_T^{miss} requirement, $p_T^{non\text{-}b}$ > 250 GeV

Allow ISR jet while suppressing backgrounds to improve S/B

Backgrounds: Z(→νν) + jets, W(→ℓν) + jets, $t\bar{t}$



	$N_{\text{b jets}}$	$M_{CT} < 250$	ISR
$Z(\nu\bar{\nu})$ + jets	1	848±12±79	176±24±21
$t\bar{t}$, $W(\ell\nu)$ + jets	1	645±24±57	171±5±25
QCD multijets	1	25.0±9.4±5.2	3.2±0.2±4.6
Rare processes	1	18.0±9.2	5.4±2.7
Total	1	1540±100	356±41
$Z(\nu\bar{\nu})$ + jets	2	60.0±3.4±7.1	6.6±0.4±1.2
$t\bar{t}$, $W(\ell\nu)$ + jets	2	29.0±2.9±5.5	19.0±1.8±3.4
QCD multijets	2	1.9±0.7±0.4	0.4±0.1±0.7
Rare processes	2	1.8±0.9	0.4±0.4
Total	2	93±10	26.0±4.1



Dijet search with b-tags: interpretation $\tilde{b} \rightarrow b\chi^0$

Result compatible with SM expectations, ***addition of "ISR" bins improves reach at low Δm***

Also provide interpretation with monojet search

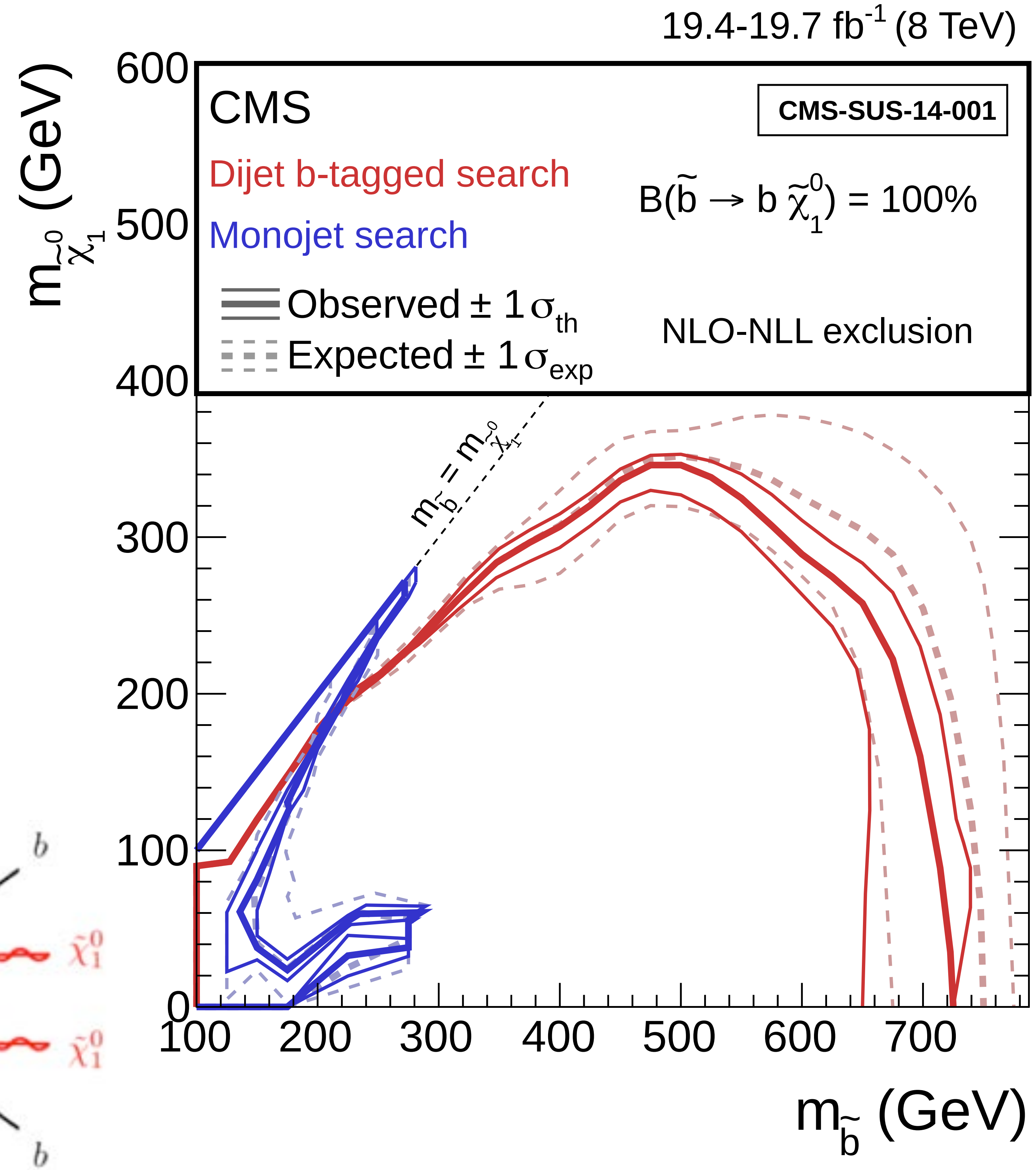
Reach for small Δm is similar to $\tilde{t} \rightarrow c\chi^0$ model

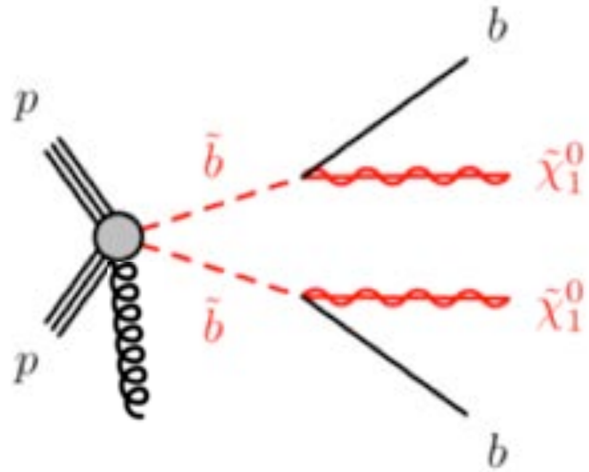
Exclude $m_{\tilde{b}}$ < 200 GeV for all Δm

Exclude $m_{\chi 0}$ < 200 GeV for $m_{\tilde{b}}$ < 700 GeV

Search result

Search regions	$N_{\text{b jets}}$ 1		2	
Dijet b-tagged search	SM Pred.	Obs.	SM Pred.	Obs.
$M_{CT} < 250$ GeV	1540±100	1560	93±10	101
$M_{CT} \in [250, 350]$ GeV	754±68	807	50.0±6.4	55
$M_{CT} \in (350, 450]$ GeV	85±10	101	6.5±1.7	8
$M_{CT} > 450$ GeV	16.0±4.1	23	1.0±0.9	1
ISR	356 ± 41	359	26.0 ± 4.1	28





Stop interpretation: $\tilde{t} \rightarrow t\chi^0$ or $\tilde{t}\ (\rightarrow b\chi^{\pm}) \rightarrow bW^*\chi^0$

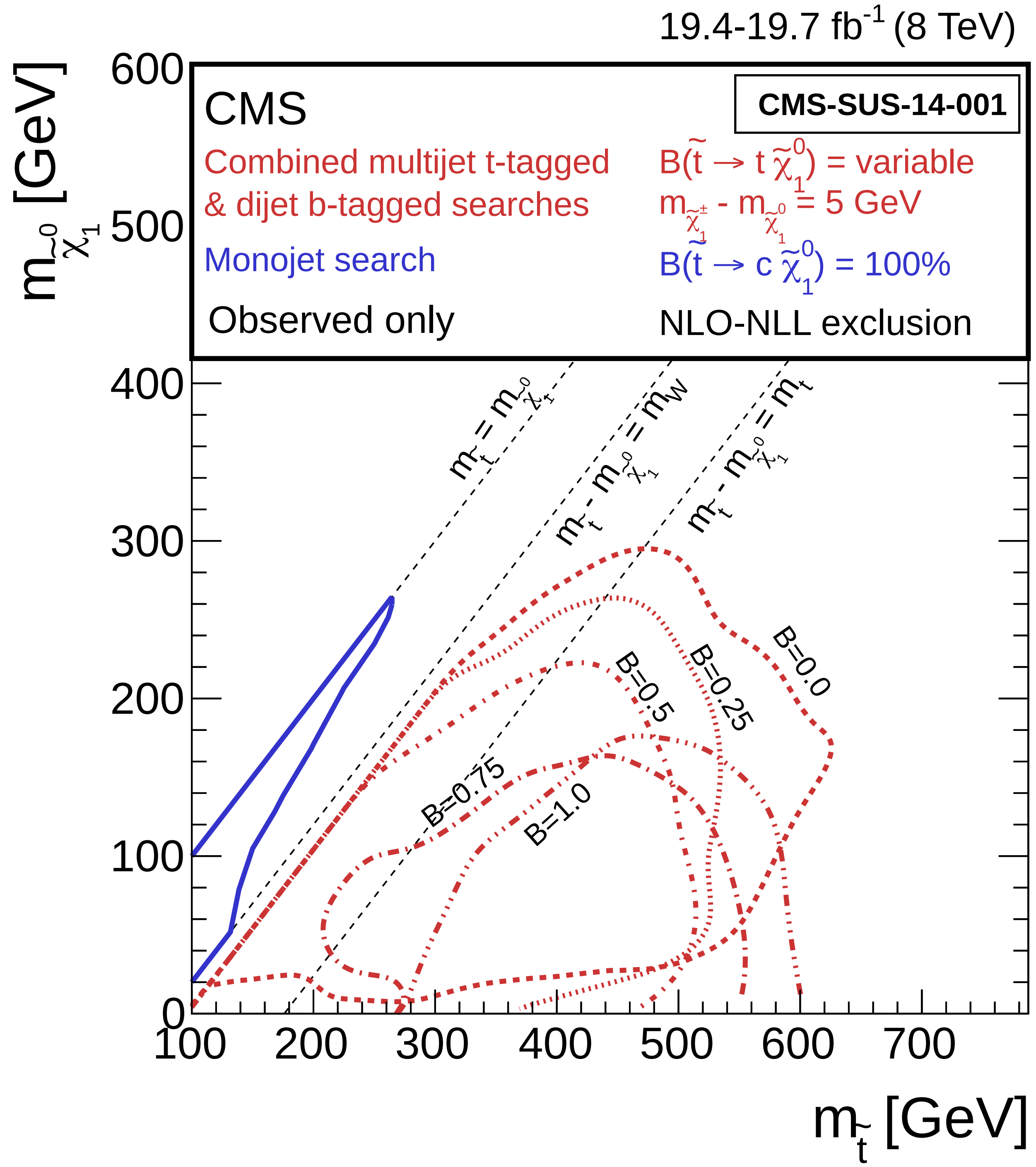
New!

Assume mass-degenerate $\chi^{\pm}$ and χ^0 with Δm = 5 GeV (higgsino- / wino-like χ_1^0)

Various Br are investigated, final states of $bbWW\chi^0\chi^0$ or $bb\chi^0\chi^0$

Combine with a multijet top-tagger search that targets $\Delta m(\tilde{t},\chi^0)$ > 100 GeV

Dijet search drives sensitivity for low $Br(\tilde{t} \rightarrow t\chi^0)$



New search with VBF topology (ℓℓjj final state)

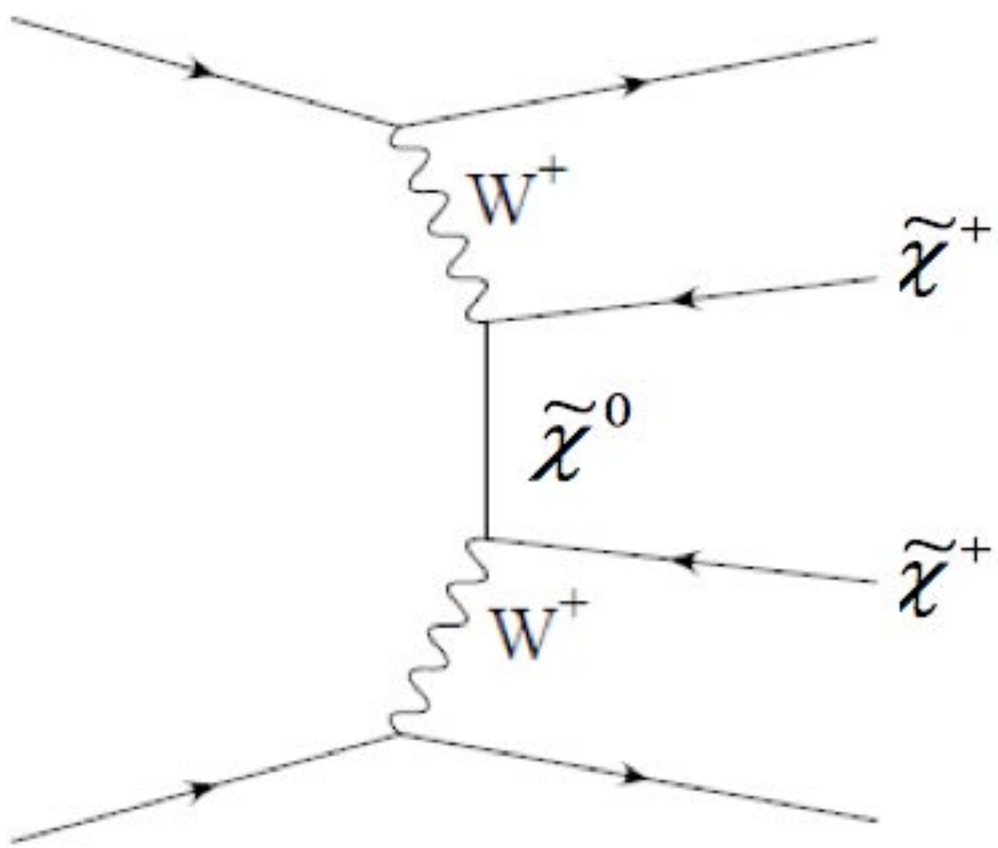
New!

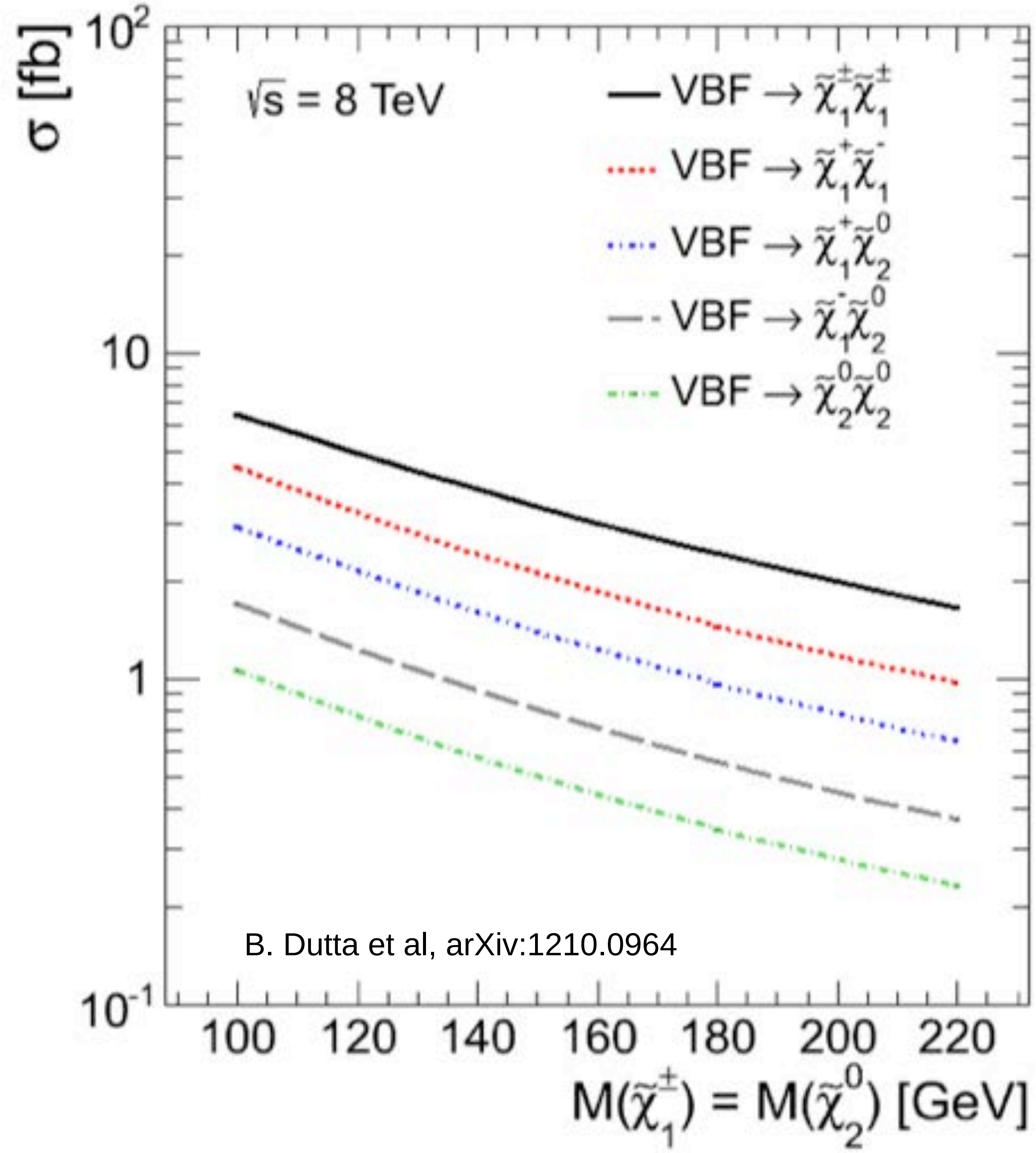
SUSY LSP can provide DM candidate: crucial for effective searches in the electroweak sector

Coverage is weak for compressed electroweak sector, especially with $\tilde{\tau}$ NLSP

VBF topology provides complementary probe to the multilepton searches

Low cross sections $\mathcal{O}$(fb) compensated by ***clean signal region with relatively high S/B***





Search with VBF topology: event selection

Eight channels: eμ, μμ, $\mu\tau_h$, $\tau_h\tau_h$, both opposite- and like-sign charge

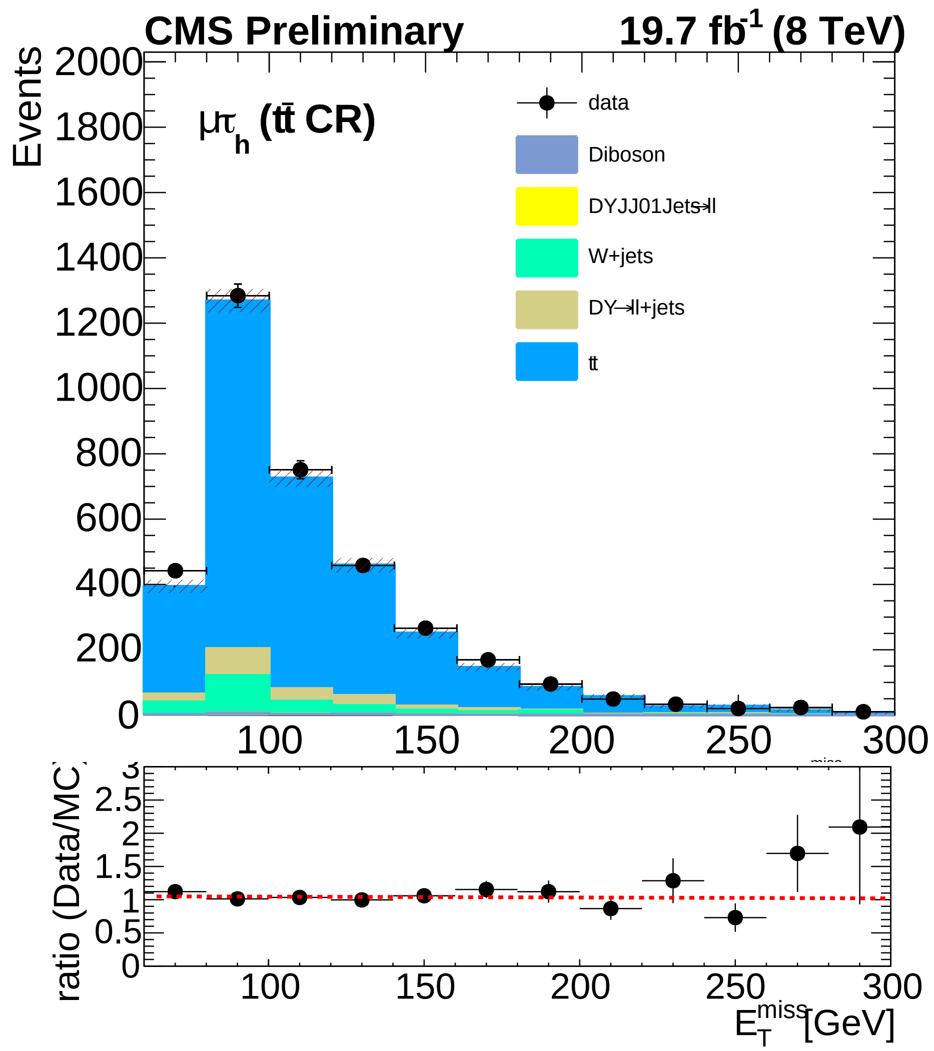
Search for broad enhancement in the tail of m_{jj} spectrum

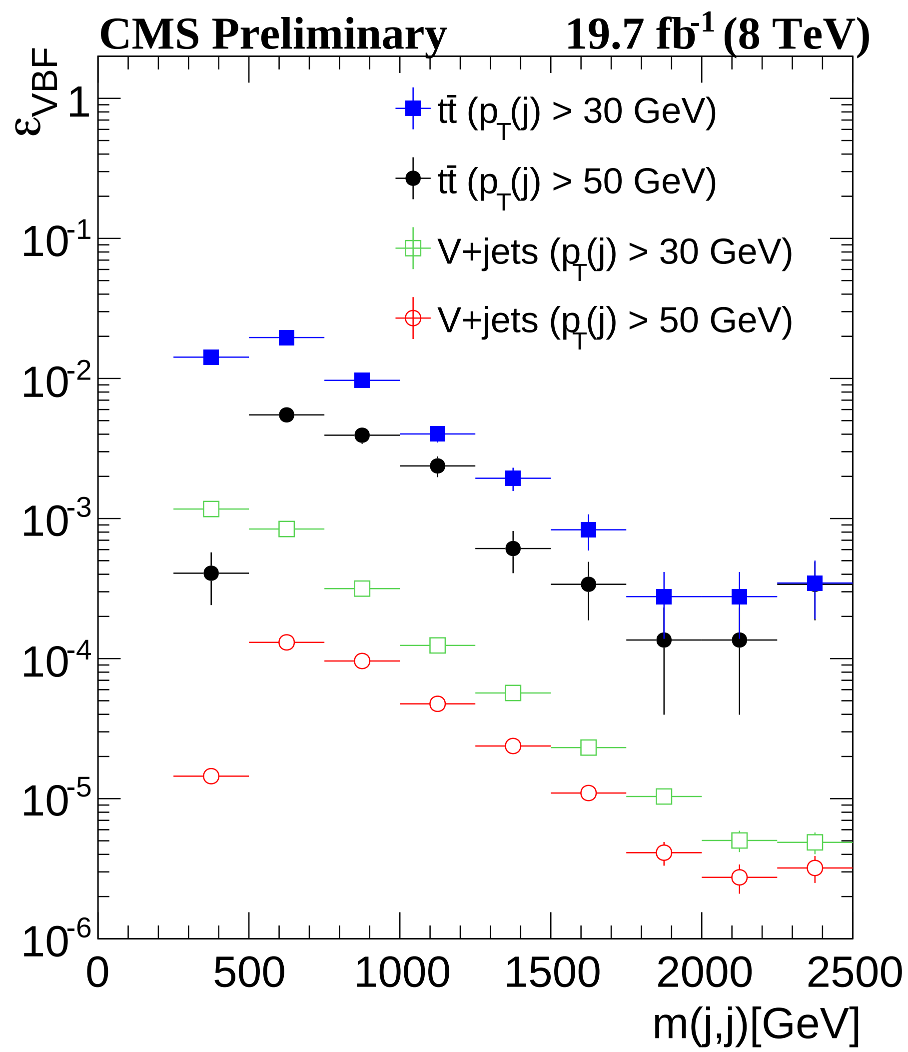
Dedicated di-τ_h trigger and τ_h reconstruction algorithm (~60% eff, 1-5% fake)

Selection: 2 central, isolated leptons, 2 jets with $\Delta\eta > 4.2$, b-tag veto, $p_T^{miss} > 75$, $m_{jj} > 250$ GeV

Various backgrounds (tt, W+jets, $Z\rightarrow\ell\ell$, QCD multijet), composition sensitive to number of τ_h

VBF tag efficiency $\varepsilon_{VBF}(m_{jj})$ measured from data in control samples





Search with VBF topology: result

Result is compatible with SM expectations

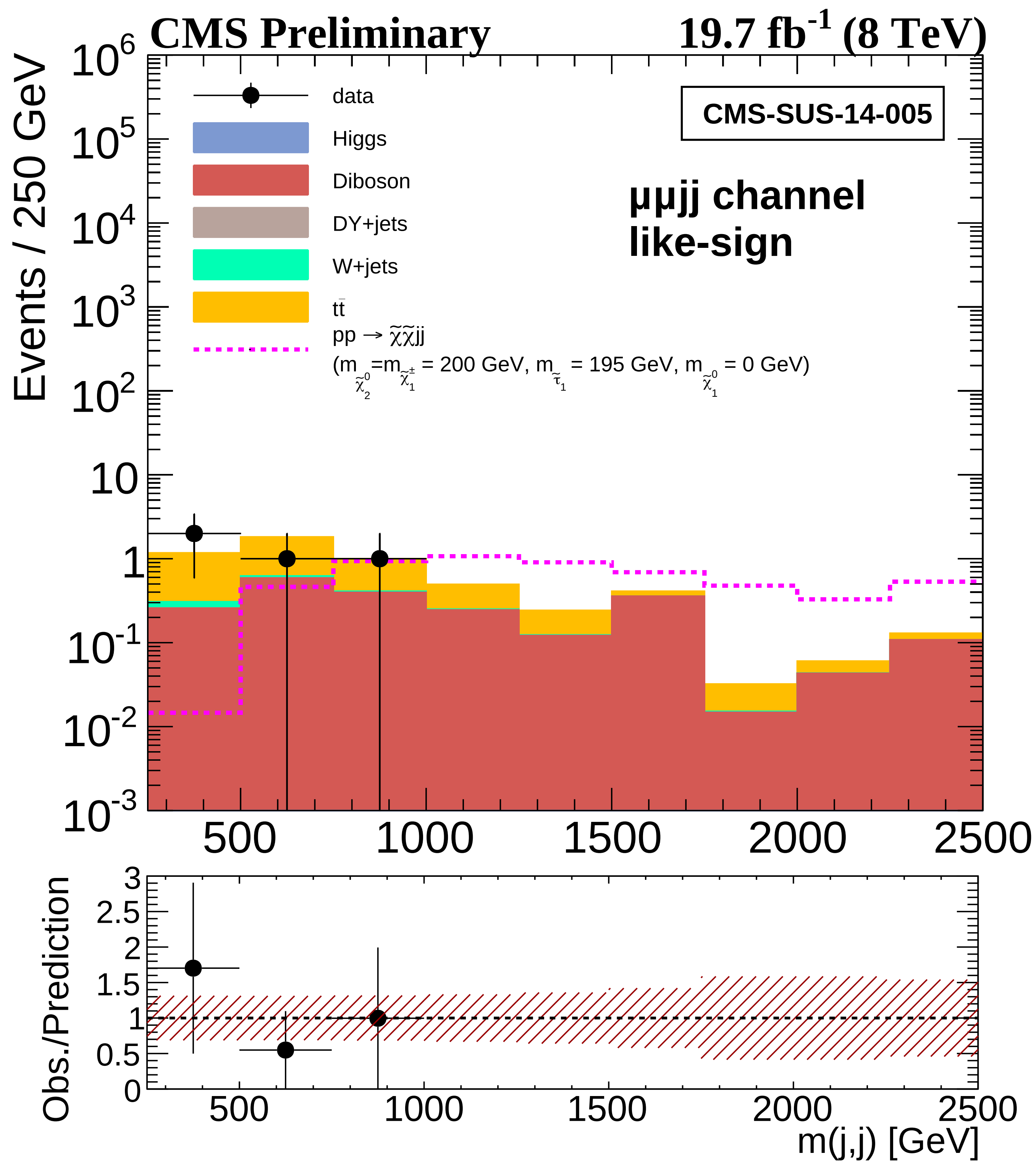
High signal-to-background ratio, esp. for like-sign channels

Result for opposite-sign channels ($\sigma_{stat.}$ only)

Process	$\mu^{\pm}\mu^{\mp}jj$	$e^{\pm}\mu^{\mp}jj$	$\mu^{\pm}\tau_h^{\mp}jj$	$\tau_h^{\pm}\tau_h^{\mp}jj$
DY + jets	4.3 ± 1.7	$3.7\pm^{2.1}_{1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.01	$4.2\pm^{3.3}_{2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0\pm^{2.3}_{2.4}$	11.7 ± 2.8	–
QCD	–	–	–	6.3 ± 1.8
Higgs	1.0 ± 0.1	1.1 ± 0.5	–	1.1 ± 0.1
VBF Z	–	–	–	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1\pm^{4.6}_{4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

Result for like-sign channels ($\sigma_{stat.}$ only)

Process	$\mu^{\pm}\mu^{\pm}jj$	$e^{\pm}\mu^{\pm}jj$	$\mu^{\pm}\tau_h^{\pm}jj$	$\tau_h^{\pm}\tau_h^{\pm}jj$
DY + jets	< 0.01	$0\pm^{1.7}_{0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0\pm^{3.0}_{0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9\pm^{0.4}_{0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5\pm^{0.7}_{0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	–	–	–	< 0.1
QCD	–	–	–	7.6 ± 0.9
Higgs	–	–	–	< 0.01
Total	5.4 ± 0.3	$5.4\pm^{3.5}_{0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9



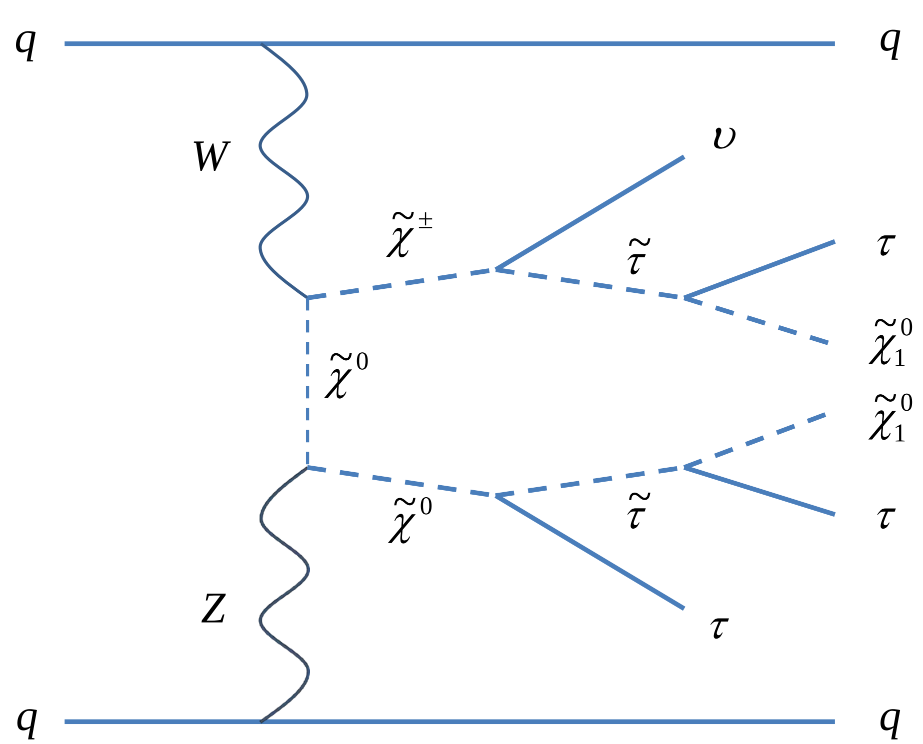
Search with VBF topology: interpretation with light $\tilde{\tau}$

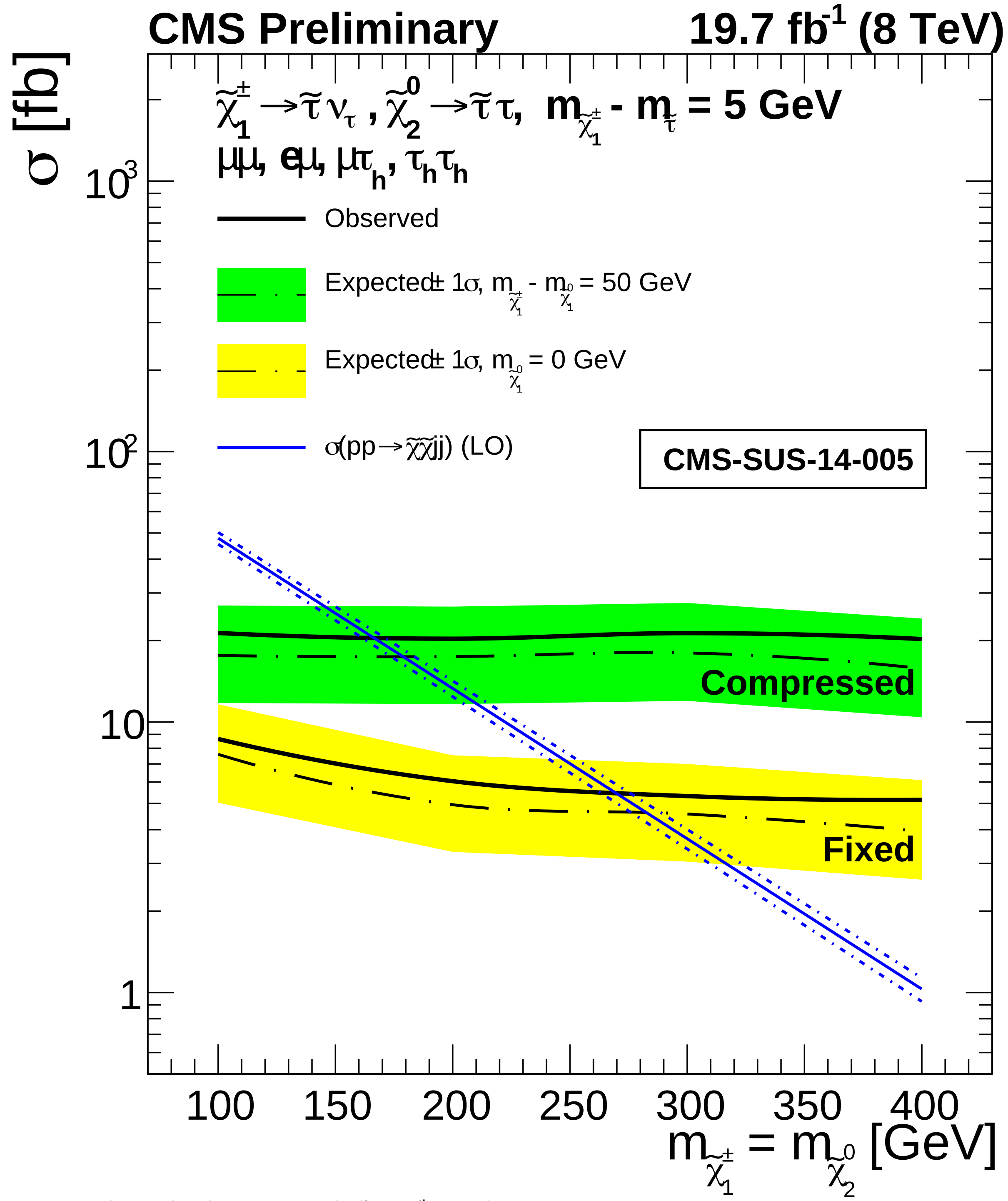
Assume bino-like χ_1^0, mass-degenerate wino-like $\chi_1^\pm$ and χ_2^0, and $\tilde{\tau}$ NLSP (100% Br)

Consider m(χ_1^0) = 0 GeV (fixed) and compressed scenario: m($\chi_1^\pm$) - m(χ_1^0) = 50 GeV

Exclude m($\chi_1^\pm$) = m(χ_2^0) < 170 GeV for compressed scenario assuming m($\chi_1^\pm$) - m($\tilde{\tau}$) = 5 GeV

Search covers new phase space!





Near future

Several additional complementary approaches to compressed spectra (CMS SUSY TWiki)

Further Run 1 analyses in the pipeline (various final states, soft objects, VBF topology, ...)

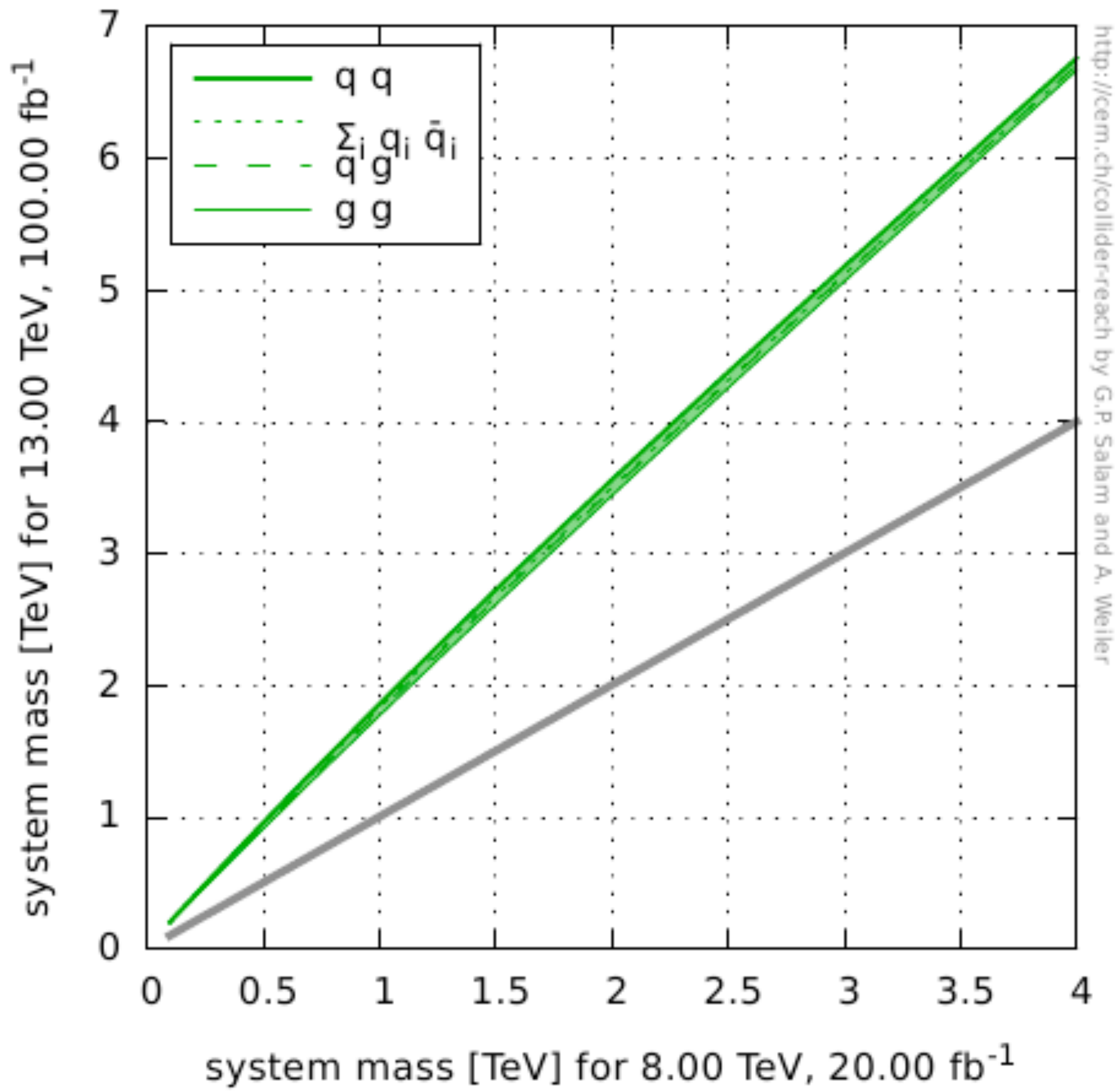
Significant preparations for Run 2 in progress

Huge effort on L1 (cross triggers) and HLT triggers (new dedicated triggers, eg, VBF)

Reconstruction improvements, pileup mitigation

Exploit experience obtained with Run 1 dataset

Reach for 100 fb^{-1} @ 13 TeV based on Run 1



Summary

No sign yet of SUSY: strong exclusions for $m_{LSP} \approx 0$ GeV for coloured and EWK sectors

Weak coverage for compressed scenarios: experimentally challenging due to low acceptance

Extend existing analyses or ***develop new ones*** (eg VBF) to tackle this difficult region

SUSY still hiding in Run 1 data? ***More analyses in the pipeline***...

A lot learned during shutdown on compressed spectra: excellent preparation for Run 2!

If we are to be guided by "natural" SUSY, still have a long way to go (and it will take time)...

Thank you for your attention!

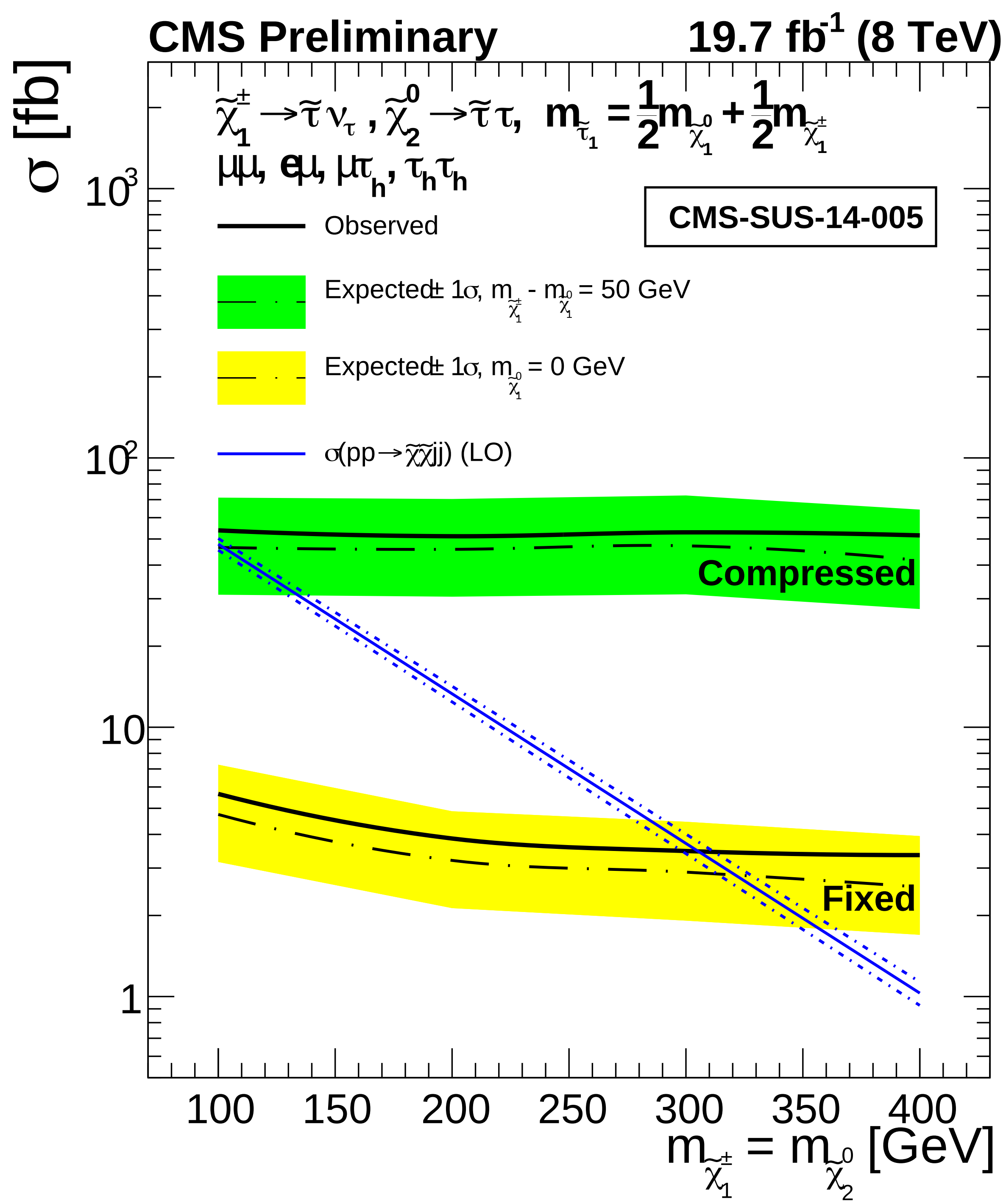
Additional material

Search with VBF topology: interpretation with $\tilde{\tau}$ NLSP

Assume bino-like χ_1^0, mass-degenerate wino-like $\chi_1^\pm$ and χ_2^0, and $\tilde{\tau}$ NLSP (100% Br)

Consider $m(\chi_1^0)$ = 0 GeV (fixed) and compressed scenario: $\Delta m = m(\chi_1^\pm) - m(\chi_1^0)$ = 50 GeV

$\tilde{\tau}$ mass at midpoint between $\chi_1^\pm$ and χ_1^0



CMS coverage of stop and electroweak sector