Search for compressed SUSY in hadronic final states with the CMS detector

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on behalf of the CMS collaboration
(Uni Hamburg)

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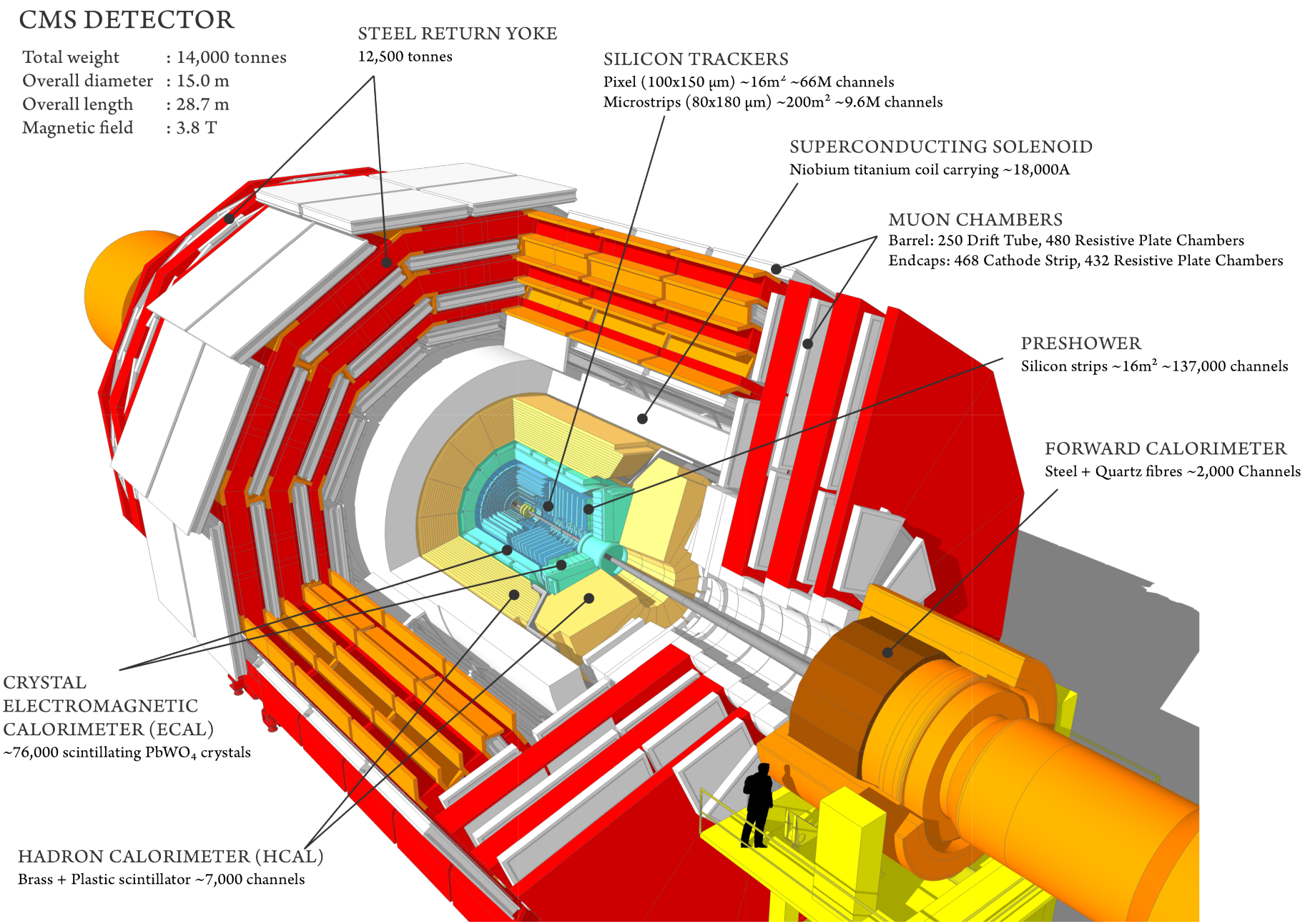
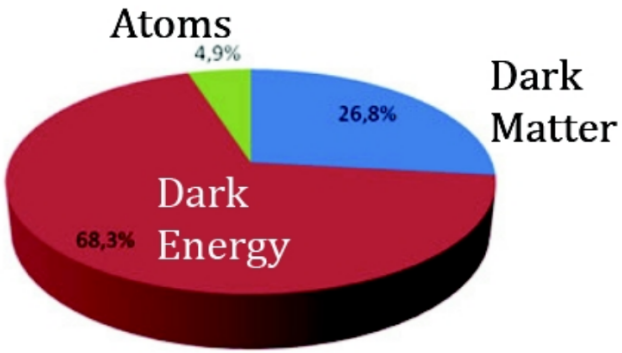
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

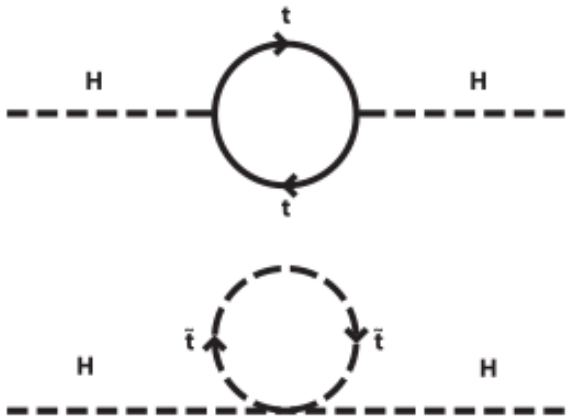
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Supersymmetry: An Elegant Extension of the SM

- SUSY:
  - Can provide dark matter candidate
  - Solving hierarchy problem by canceling large SM mass contributions to Higgs mass
    - ★ Mainly driven by third generation contribution → **light** $\tilde{t}$, $\tilde{b}$
  - and more...
- Light SUSY partners at TeV scale favored



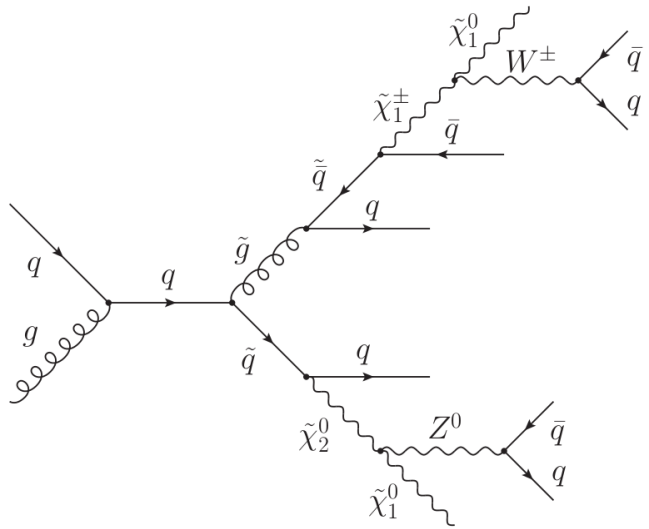


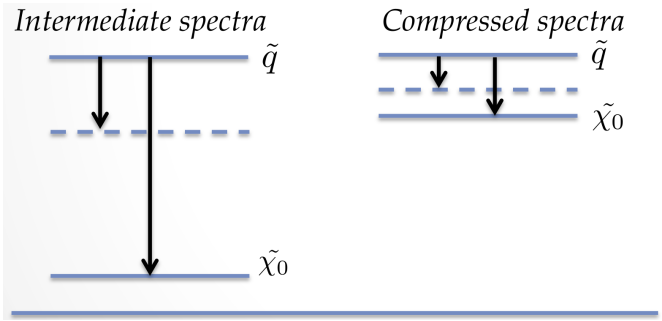
Difficulty: Exact SUSY realization unknown

Look for variety of final states!

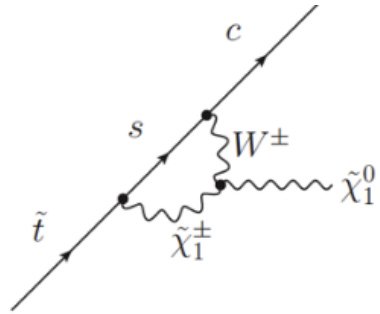
SUSY Search Strategies

- Various generic searches (traditional):
  - Final states: Jets + MET, leptons, photons
- If initially produced particles close in mass to LSP($\tilde{\chi}^0$)$\rightarrow$Compressed Spectra:
  - Small amount of visible energy in final state $\rightarrow$ small p_T, H_T, MET
  - Hard to distinguish between SM processes and SUSY signal events! ("hidden SUSY")





Light Stop Searches



$$\Delta m = m(\tilde{t}) - m(\tilde{\chi}_1^0)$$

$\Delta m < m(W)$ | $m(W) < \Delta m < m(t)$ | $\Delta m > m(t)$

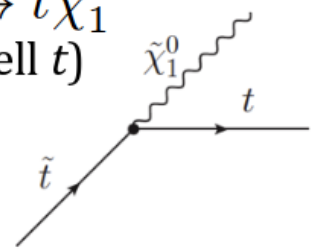
4-body | 3-body | 2-body

$m(\tilde{t}) < m(\tilde{\chi}_1^0)$
violates assumed spectrum

$\tilde{t} \to bW^* \tilde{\chi}_1^0$ (off-shell W)

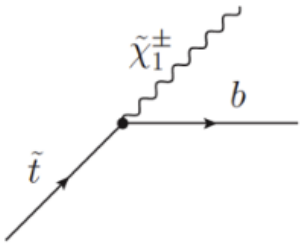
$\tilde{t} \to bW \tilde{\chi}_1^0$ (off-shell t)

$\tilde{t} \to t\tilde{\chi}_1^0$ (on-shell t)



$\tilde{t} \to c\tilde{\chi}_1^0$ (by loops)

$\tilde{t} \to b\tilde{\chi}_1^{\pm} \to bW^{\pm(*)}\tilde{\chi}_1^0$ (has extra mass parameter)

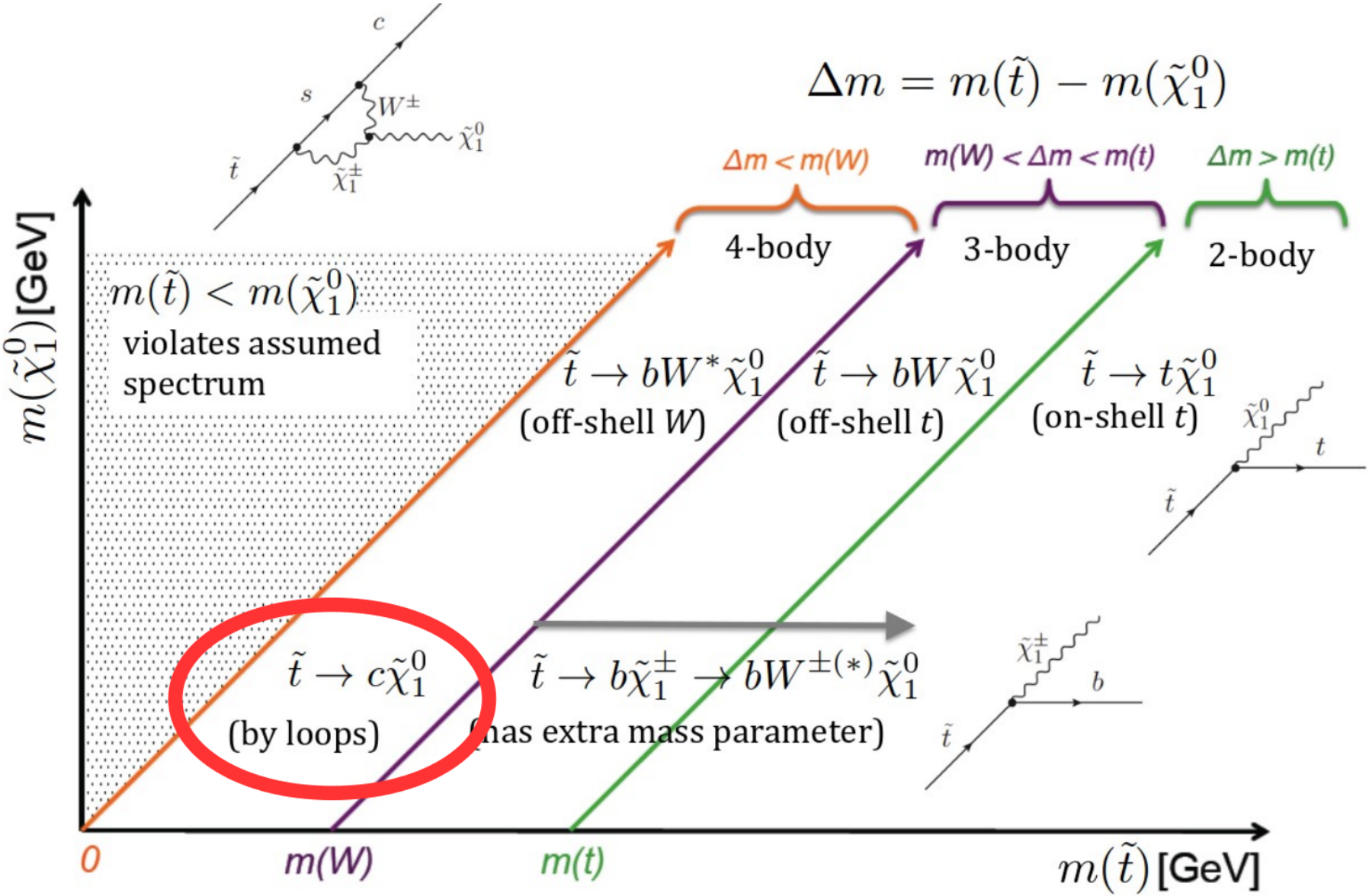


$m(\tilde{\chi}_1^0)$ [GeV]

0 | $m(W)$ | $m(t)$

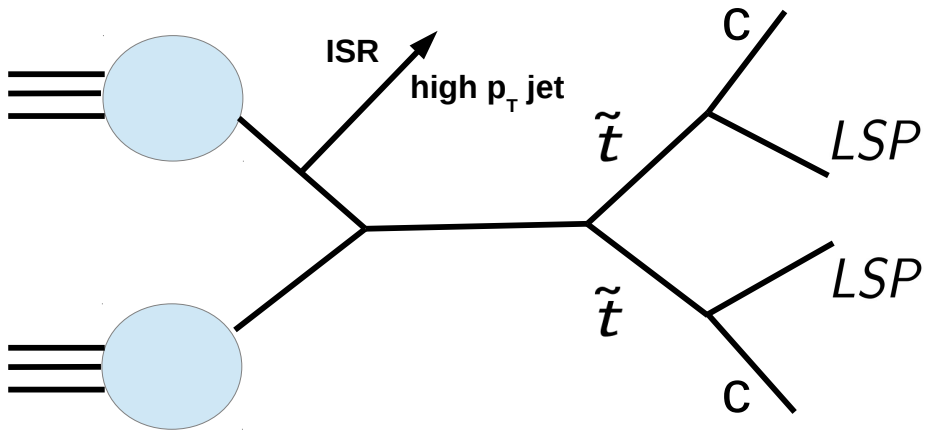
$m(\tilde{t})$ [GeV]

Light Stop Searches



Compressed SUSY Search Strategy

- Soft final state $\rightarrow$ classical high H_T, MET etc. searches not sensitive
- Focus not on SUSY decay products but on associated produced particles
  $\rightarrow$ initial state radiation (ISR) boosting decay products!
- Final state: High p_T Jet (ISR) + MET (LSP)



CMS Search for: $\tilde{t} \to c\tilde{\chi}^0$ and $\tilde{b} \to b\tilde{\chi}^0$

"Searches for third-generation squark production in fully hadronic final states in proton-proton collisions at $\sqrt{s} = 8$ TeV"

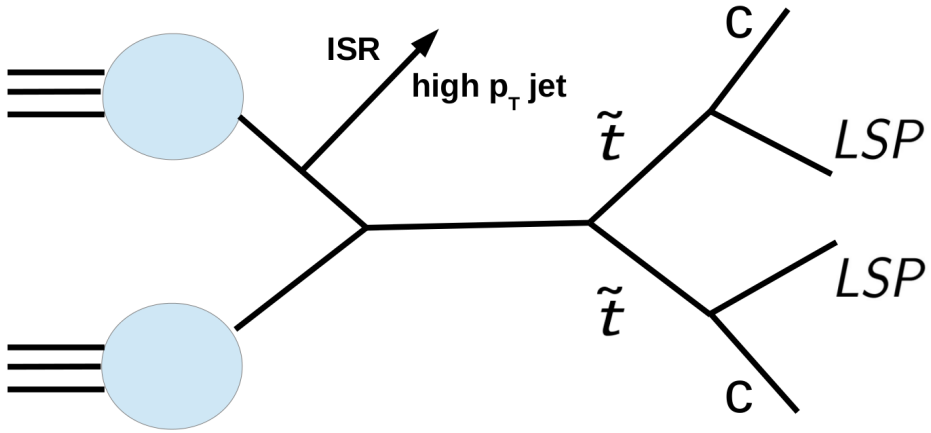
Published: JHEP06(2015)116 (Jun 17, 2015)
Combination of three analysis including
Monojet Search

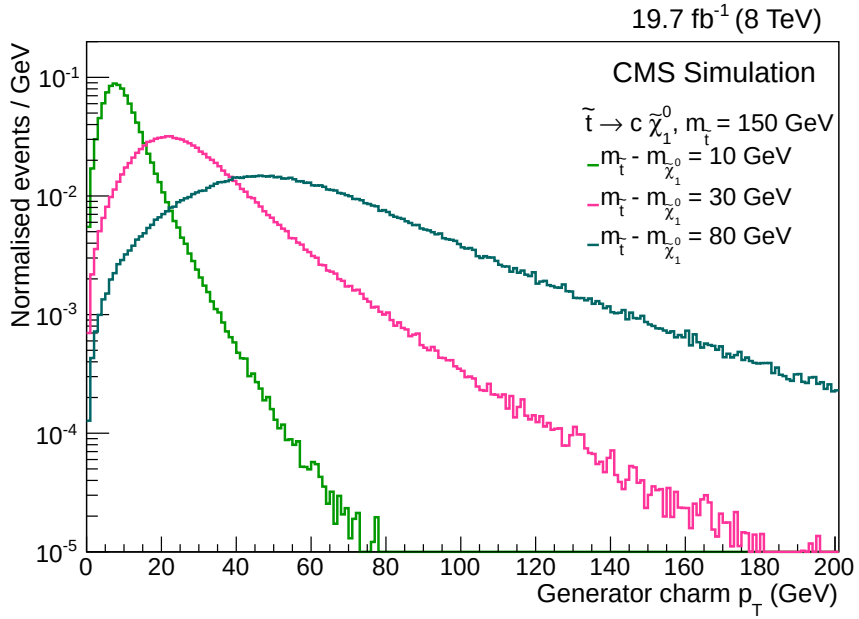
- Analyzing 19.7 fb^{-1} of $\sqrt{s} = 8$ TeV for $\tilde{t}$ & $\tilde{b}$ pair production, assuming 100% branching fraction to $c\tilde{\chi}^0$ or $b\tilde{\chi}^0$ interpreted in the context of simplified models

- Note this is an optimization of "arXiv:1408.3583 (2014): Search for dark matter, extra dimensions, and unparticles in monojet events in proton-proton collisions at $\sqrt{s} = 8$ TeV"
  - Increased threshold on N_{jets}
  - Define search regions: Highest jet p_{T}, not p_{T}^{miss}

Event Selection

- Trigger 1: $p_{\mathrm{T}}^{miss} > 120$ GeV
- Trigger 2: $p_{\mathrm{T}}^{j1} > 80$ GeV & $p_{\mathrm{T}}^{miss} > 105$ GeV
- $p_{\mathrm{T}}^{j1} > 110$ GeV, $|\eta| < 2.4$, $\not{E}_{\mathrm{T}} > 250$ GeV
- $N_{\mathrm{jets}} \leq 2$, jets: $p_{\mathrm{T}} > 60$ GeV, $|\eta| < 4.5$
- Veto: Iso e, μ, τ, $\Delta\phi(\vec{p}_{\mathrm{T}}^{j1}, \vec{p}_{\mathrm{T}}^{j2}) > 2.5$
  (Selecting invisible final state: Veto soft jets while reject QCD dijet events)



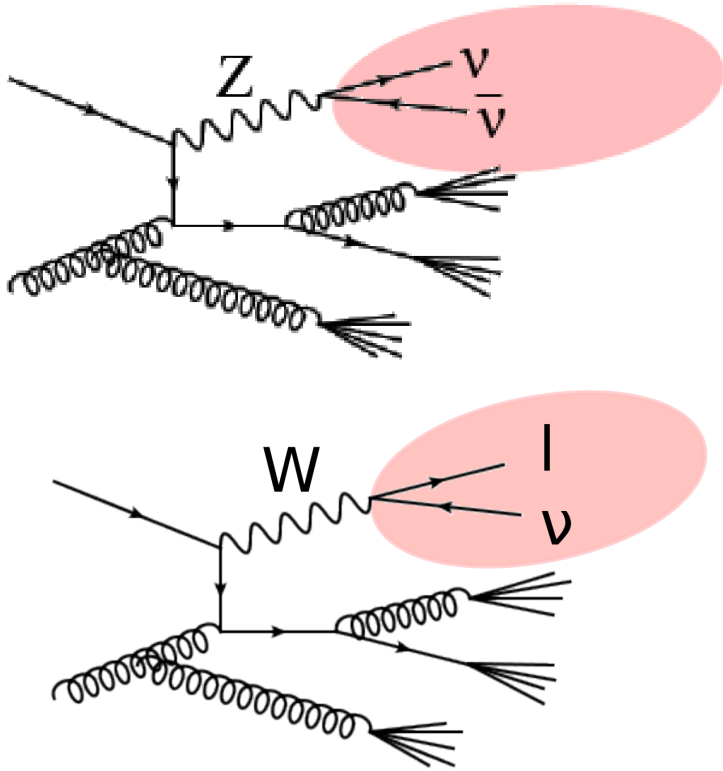


Search regions: $p_{\mathrm{T}}^{j1} > 250, 300, 350, 400, 450, 500, 550$ GeV

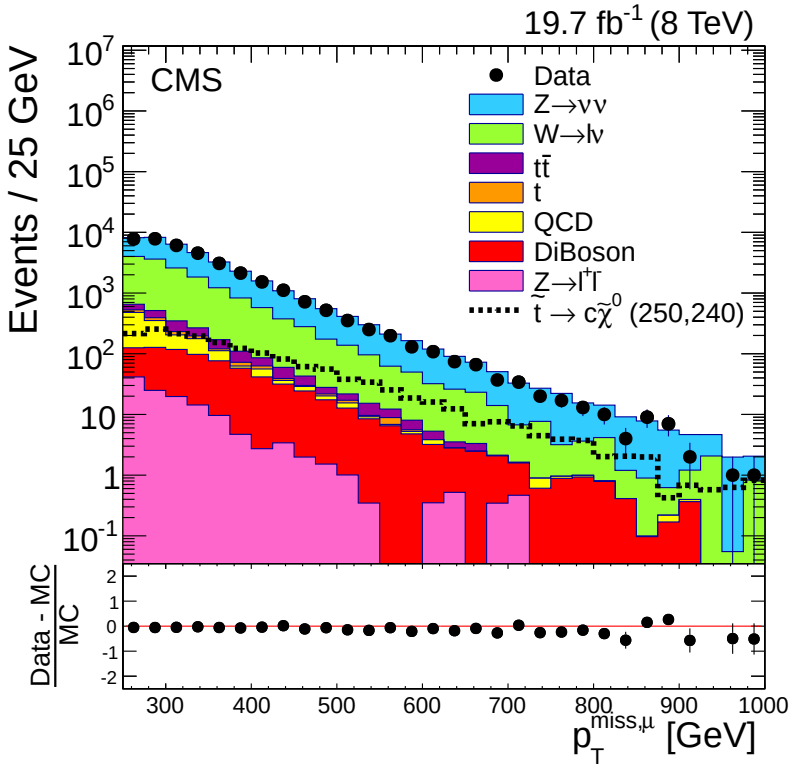
SM Background Estimation Strategy

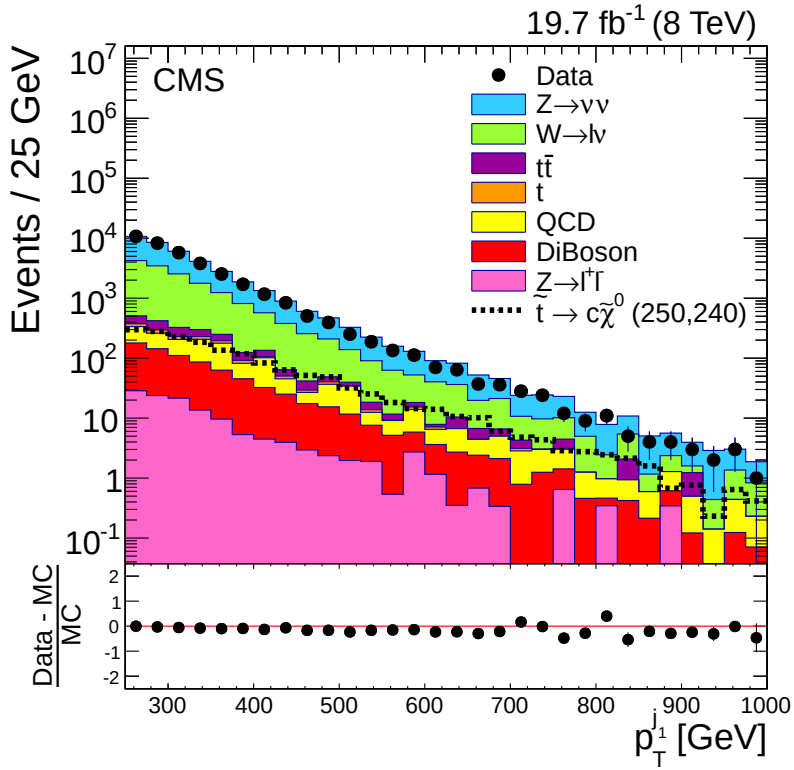
- Prominent background processes:
  $Z \to \nu\bar{\nu}$ + jets (irreducible, largest) & $W \to l\nu$ + jets (lost-lepton)
- Data driven estimation: Select control-sample (N^{obs}) of di-muon events ($Z \to \nu\bar{\nu}$ + jets), single-muon events (W + jets) in data

- Data-driven prediction (N):
- $N(Z \to \nu\bar{\nu} + \text{jets}) = \frac{N^{obs} - N^{bkg}}{A \cdot \epsilon} \cdot R$
- $N(W \to l\nu + \text{jets}) = \frac{N^{obs} - N^{bkg}}{A' \cdot \epsilon'}$
  - with N^{bkg} non $Z(\nu\nu)$ or non $W(\mu\nu)$, acceptance (A, A'), efficiencies ϵ, ϵ'
    & R ratio of BR



Combined SM Backgrounds (from MC)





- Comparison of observed events in data to SM bkg distributions (MC) normalized to 19.7 fb^{-1}
- No excess visible

Uncertainties

- $Z \to \nu\bar{\nu}$ + jets estimation (5-19%):
  - 2-17% statistical uncertainty of $Z \to \mu\bar{\mu}$ + jets events (data, MC)
  - 50% on non-Z bkg contribution (MC)
  - 2% PDF
  - 2% hadronization
  - 2% on R
- $W \to l\nu$ + jets estimation (5.7-12.0%):
  - 1-8.6% statistical uncertainty of $W \to \mu\nu$ + jets events (data, MC)
  - 50% on non-W bkg contribution (MC)
  - 4.5-7.1% stat. & syst. (PDF) on acceptance & ϵ'
- QCD method: MC normalized to data in control region $\Delta\phi(\vec{p}_{\mathrm{T}}^{\,j2}, \vec{p}_{\mathrm{T}}^{\,miss}) < 0.3$, uncertainty $\sim 60\%$ (stat. & syst.)
- $t\bar{t}$, single t, di-boson & $Z \to ll$ taken from simulation, uncertainty 50% (stat. & syst.)

Result: Table

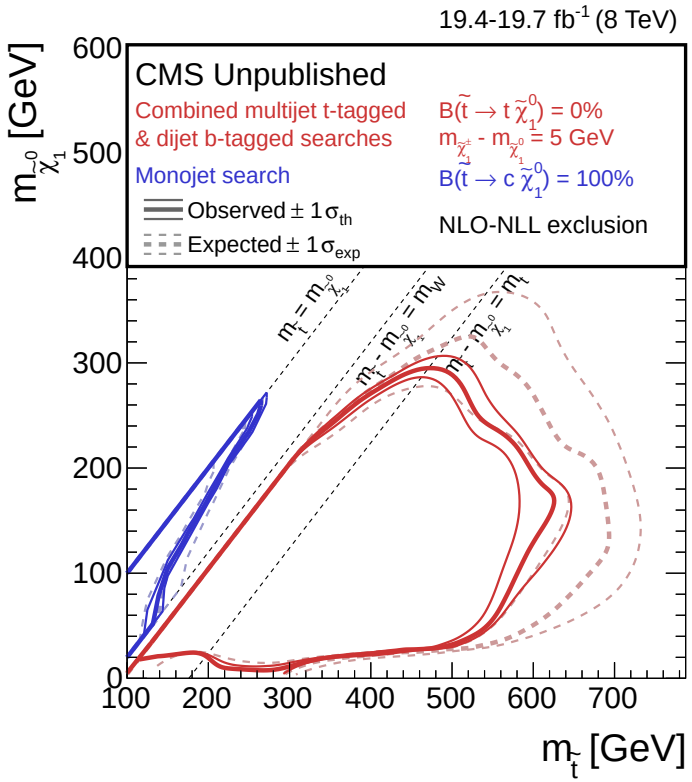
Comparison of data-driven predictions $Z \to \nu\bar{\nu}$ + jets, $W \to \mu\nu$ + jets and other SM bkg predictions using MC validated in data to observed events in 19.7 fb^{-1} data

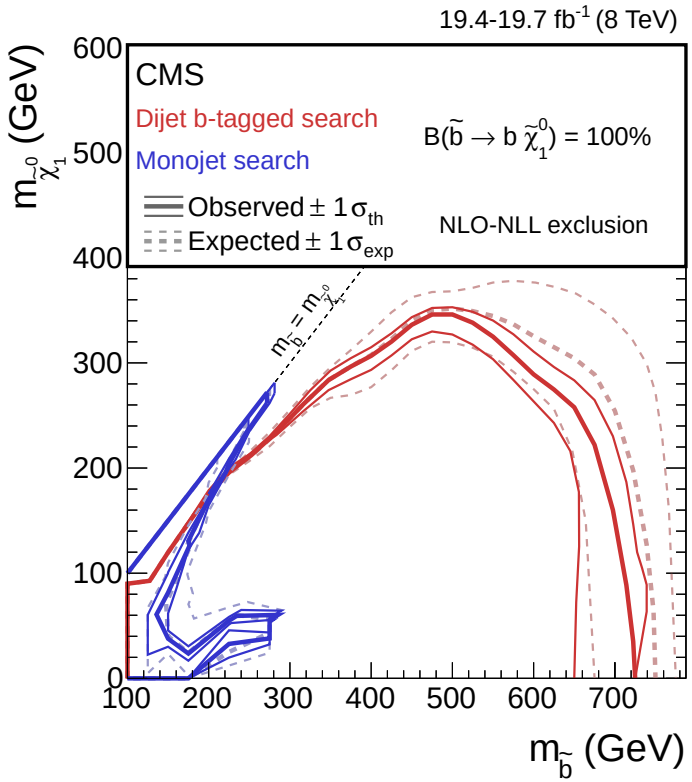
p_T^{j1} [GeV]	> 250	> 300	> 350	> 400	> 450	> 500	> 550
$Z \to \nu\bar{\nu}$	21200 ± 1116	10100 ± 592	4600 ± 325	2250 ± 197	12500 ± 137	663 ± 94	334 ± 65
$W \to \mu\nu$	12300 ± 707	5940 ± 366	2690 ± 180	1250 ± 93	637 ± 53	301 ± 29	150 ± 18
$t\bar{t}$	602 ± 300	344 ± 170	176 ± 89	91 ± 46	48 ± 24	27 ± 14	18 ± 9
$Z \to ll$	127 ± 64	75 ± 38	40 ± 20	25 ± 13	17 ± 8	11 ± 6	7 ± 4
single t	172 ± 86	97 ± 49	49 ± 24	21 ± 10	11 ± 6	5 ± 3	3 ± 2
QCD	786 ± 470	508 ± 310	304 ± 180	162 ± 99	80 ± 49	52 ± 32	28 ± 18
Diboson	639 ± 320	369 ± 180	206 ± 100	113 ± 56	64 ± 32	36 ± 18	21 ± 10
Total SM	35900 ± 1500	17400 ± 800	8060 ± 440	3910 ± 250	2100 ± 160	1100 ± 110	563 ± 71
Data	36600	17600	8120	3900	1900	1000	565

- Combined SM bkg predictions are in good agreement with observed data events for all search regions

Result: Simplified Model (SMS) Interpretation

- SMS produced using Madgraph generator (ISR re-weighted data/sim. differences)
- Uncertainties: Re-weighting, JES, theoretical (PDFs) & luminosity





- 95% CL_s exclusion limit roughly up to 250 GeV for $m_{\tilde{t}}/m_{\tilde{b}} = m_{\tilde{\chi}^0}$

Conclusion

- Results for compressed SUSY searches performed by CMS using 19.7 fb^{-1} data taken at 8 TeV have been presented
- Monojet (ISR) signatures achieve good sensitivity
- No excess of predicted SM bkg and data events observed
- Simplified model 95% CL_s exclusion limits derived excluding 250 GeV $\tilde{t}$ & $\tilde{b}$ masses up to $m_{\tilde{t}} = m_{\tilde{\chi}^0}$ & $m_{\tilde{b}} = m_{\tilde{\chi}^0}$

Additional Material