CMS Search for New Physics in Events with Same-Sign Dileptons and Jets

Ryan Kelley, on behalf of the CMS Collaboration
University of California, San Diego

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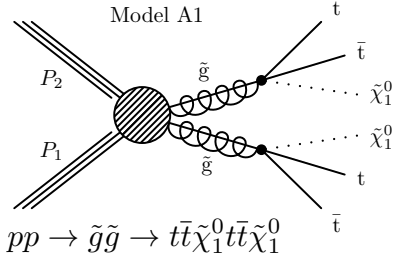
Why Same-Sign Dileptons?

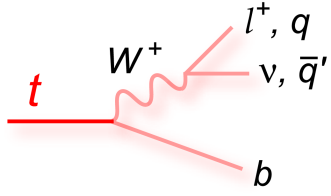
- **Same-Sign Dileptons → an electron and/or muon pair with the same electric charge in the final state**
  - $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$
- **Genuine same-sign dileptons (SS) are rare in the Standard Model (SM)**
  - EWK processes ($\alpha_W < \alpha_S$)
  - Examples (ℓ = e or μ): $pp \to t\bar{t}W^+;\ W^+ \to \ell^+\nu;\ t \to \ell^+\nu b$
    $pp \to W^-Z;\ W^- \to \ell^-\nu;\ Z \to \ell^+\ell^-$
- **Example signature → many new physics models involve pair production of Majorana particles**
  - classic example is gluino pair production from SUSY
  - can produce OS/SS lepton pairs in equal numbers
  - show up as **excess** w.r.t SM alone
- **This analysis presents a general search sensitive to a wide range of models that produce SS dileptons.**

$$pp \to \ell^{\pm}\ell^{\pm} + X$$

Supersymmetry (SUSY)



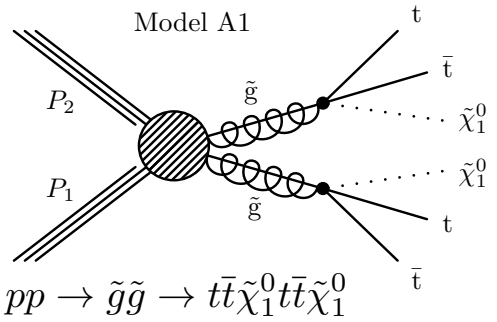
$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$



Search Strategy

- **Counting Experiment → look for:**
  - Same-sign lepton pairs (electrons, muons)
  - Hadronic activity → jets
    - Expect significant hadronic activity
      - strong production → e.g. gluino production
    - N_{jets} = count # jets,
    - N_{bjets} = count of jets originating from b-quarks (b-tagged),
    - H_T = scalar sum of transverse momenta (p_T) of selected jets.
  - Missing Transverse Energy (E_T^{miss})
    - Dark matter candidates suggest a weakly-interacting and massive particle (WIMP)
      → sizable missing E_T^{miss}

Supersymmetry (SUSY)



$$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$$

gluino production
4W+4b+2LSP

Event Selections

- L_{int} = 19.5 fb^{-1} at √s = 8 TeV collisions
- **Same-sign isolated leptons (e/μ)**
  - **high p_T analysis** → both leptons with p_T > 20 GeV used to suppress the most background.
  - **low p_T analysis** → both leptons with p_T > 10 GeV to give sensitivity to models with compressed spectra.
- **≥ 2 jets with p_T > 40 GeV**
- **24 search regions regions for each analysis (48 total)**
  - maximize statistical sensitivity to many models.
  - 3 bins in N_{bjets}
    - 10's place represent the N_{bjets}
    - (e.g. SR0x = 0 N_{btags}, SR1x = 1 N_{btags}, SR2x ≥ N_{btags})
  - 2 bins in N_{jets}
    - 2-3 jets and ≥ 4 jets
  - 2 bins E_T^{miss}
    - [50-120] and ≥ 120 GeV
  - 2 bins H_T
    - [200-400] and ≥ 400 GeV

SR01-08: N_{bjets} = 0

SR11-18: N_{bjets} = 1

SR21-28: N_{bjets} ≥ 2

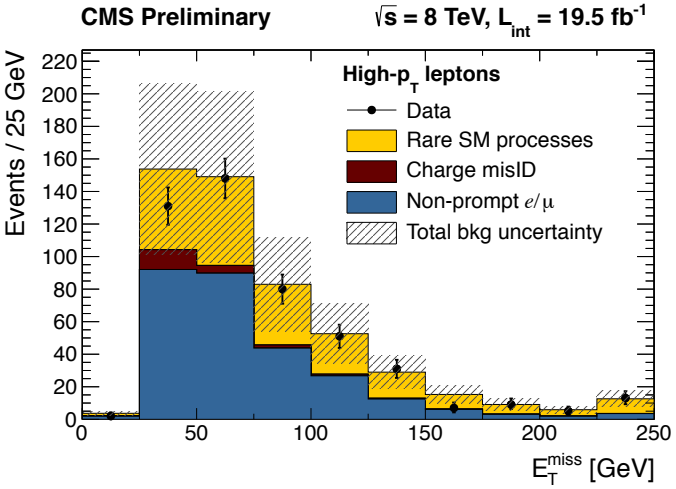
Summary of Search Regions

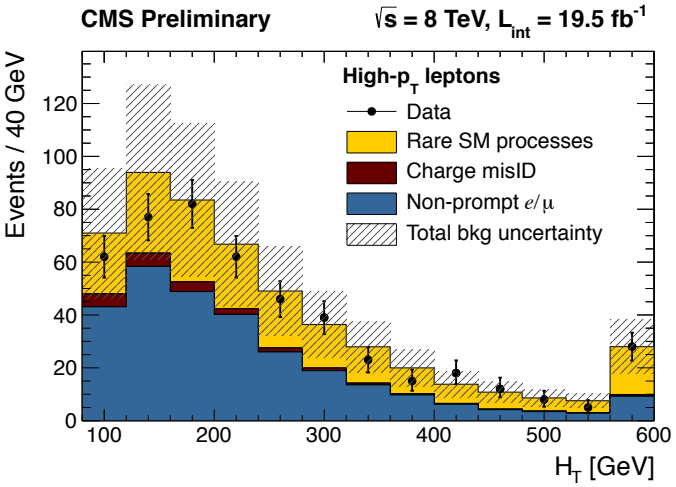
$N_{\text{b-jets}}$	E_T^{miss} (GeV)	N_{jets}	$H_T \in [200, 400]$ (GeV)	$H_T > 400$ (GeV)
$= 0$	50-120	2-3	SR01	SR02
		≥ 4	SR03	SR04
	> 120	2-3	SR05	SR06
		≥ 4	SR07	SR08
$= 1$	50-120	2-3	SR11	SR12
		≥ 4	SR13	SR14
	> 120	2-3	SR15	SR16
		≥ 4	SR17	SR18
≥ 2	50-120	2-3	SR21	SR22
		≥ 4	SR23	SR24
	> 120	2-3	SR25	SR26
		≥ 4	SR27	SR28

Background Sources

source	examples
• **Genuine Same-sign dileptons (Rare)** ▪ arise from rare SM processes ▪ Estimate from simulation ▪ ~ 30-60% of the estimated background	$t\bar{t}W,\ t\bar{t}Z,\ WZ$
• **Non-prompt lepton backgrounds** ▪ **From heavy flavor decays (b/c)**, hadron misID, decays in flight, photon conversions. ▪ "tight/loose" (data driven) ○ extrapolation in isolation ○ measure TL ratio in control region ○ apply to data sideband region ▪ ~ 35-65% of the estimated background	$t\bar{t} \to \ell\nu jjbb; b \to \ell + X$ $W \to \ell\nu + j;\ j \to \ell + X$
• **Opposite-sign dileptons with one charge mis-identified** ▪ negligible for mouns ▪ MisID rate measured with Z→ee events (data driven) ▪ < 5% of estimated background	$t\bar{t} \to \ell\nu b\ell\nu b$ $Z/\gamma^\star \to e^+e^-$

Loose Control Region





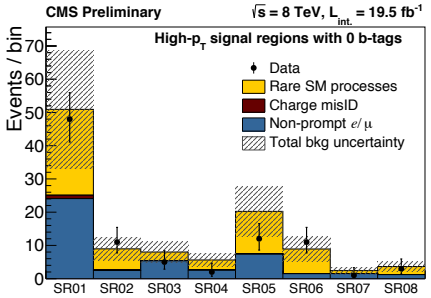
Results

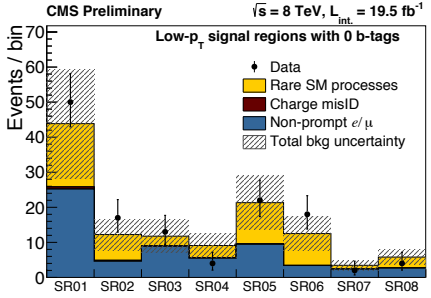
- **Results and Background Predictions**
  - good agreement in data vs. prediction.
  - both high and low lepton p_T results.
- **No observed excess over SM background predictions.**

- **Results used to interpret several models that predict same-sign events.**
  - simplified SUSY Models (SMS)
  - set upper limits on cross sections
  - provide exclusion curves in the parameter space
- Search regions and high/low p_T lepton selections determined on a **per model basis**.

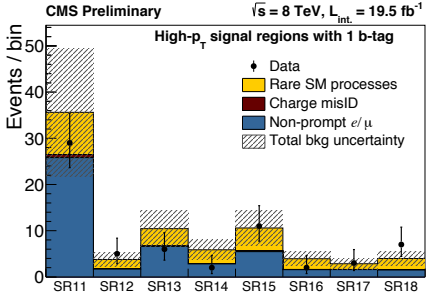
high p_T analysis | **low p_T analysis**

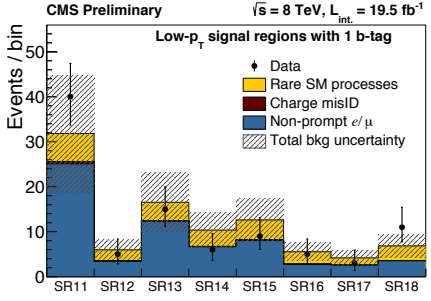
N_{bjets} = 0 (SR01-08)



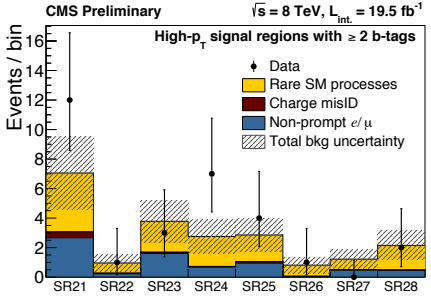


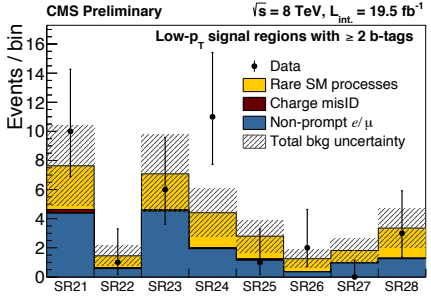
N_{bjets} = 1 (SR11-18)





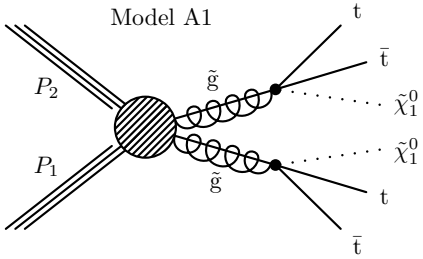
N_{bjets} ≥ 2 (SR21-28)

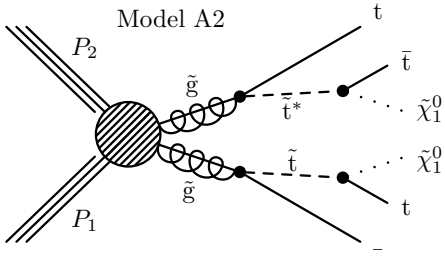


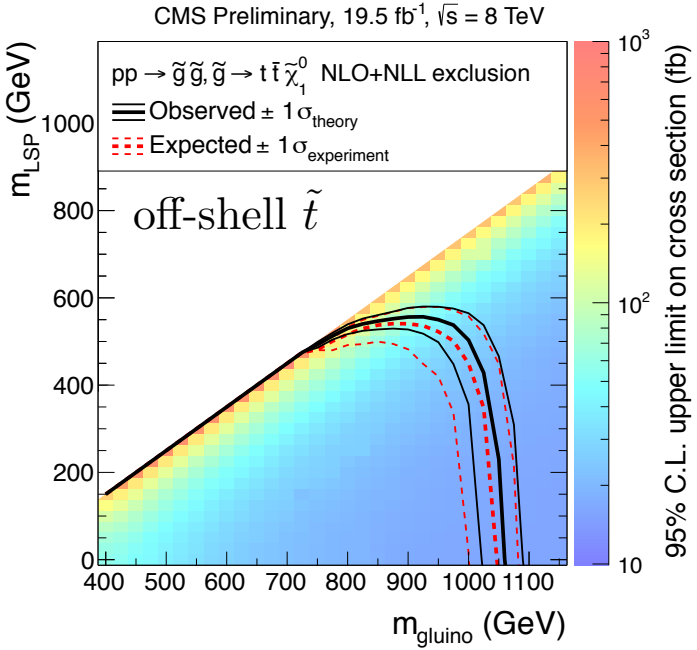


Gluino-mediated Stop Production

- Stop is off-shell (left) and on-shell (right) stops.
- Using high p_T leptons and ≥ 2 N_{bjets} search regions (SR21-28).

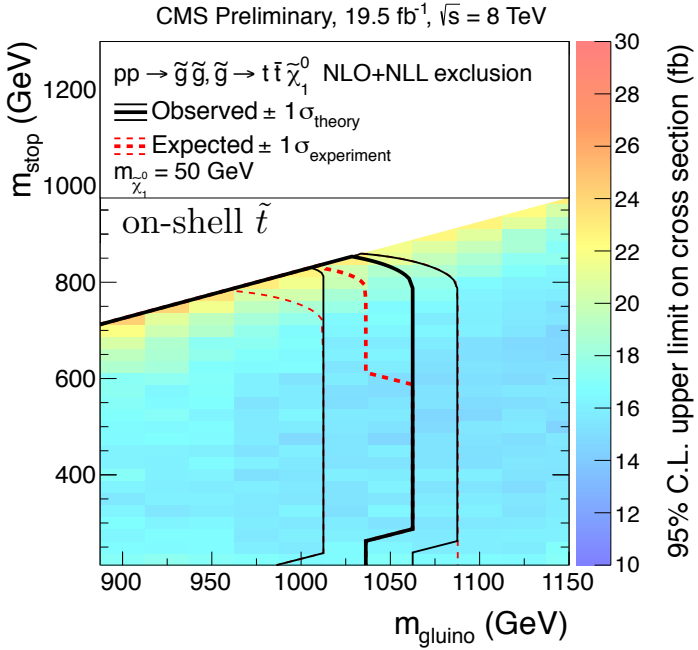






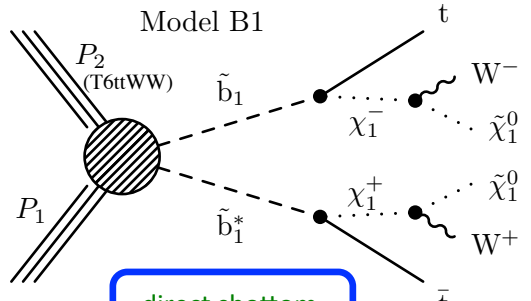
gluino production
4W+4b+2LSP

$2 \times (\tilde{g} \to t\bar{t}\tilde{\chi}_1^0)$
A1: off-shell $\tilde{t}_1$
A2: on-shell $\tilde{t}_1$



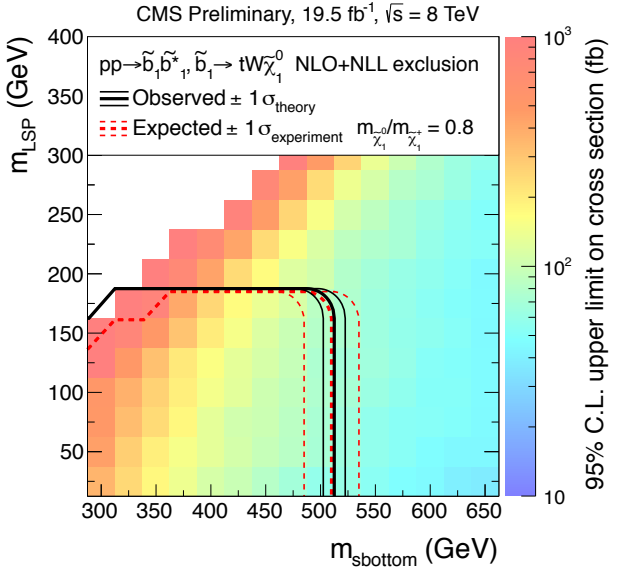
Direct Sbottom-Pair Production

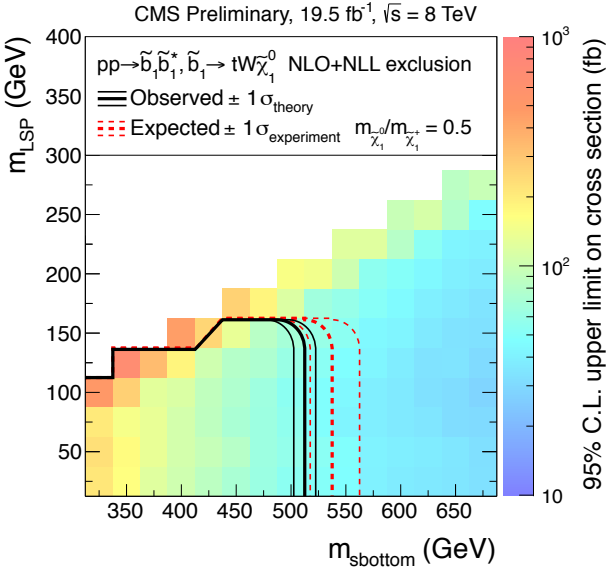
- Using = 1 and ≥ 2 N_{bjets} search regions (SR11-18, SR21-28).
- lower p_T Leptons used:
  - bottom left: $m_{sbottom}$ vs m_{LSP}, x = 0.8 → lower p_T leptons
- High p_T Leptons used:
  - center: $m_{sbottom}$ vs m_{LSP}, x = 0.5
  - bottom right: $m_{sbottom}$ vs $m_{chargino}$, m_{LSP} = 50 GeV

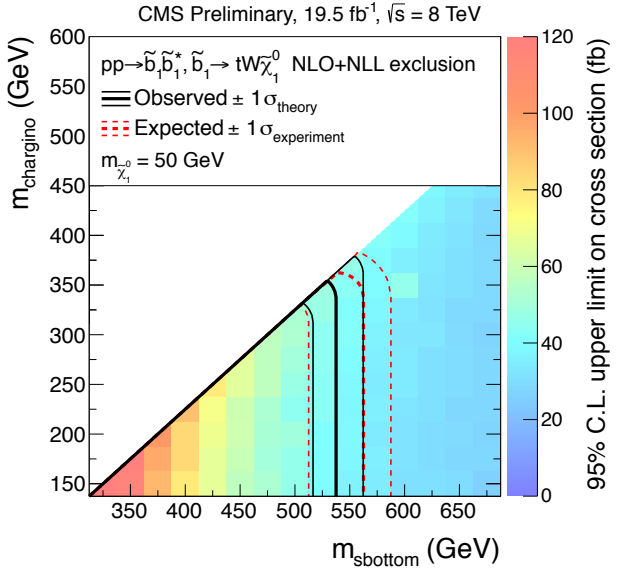


$$x = \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\chi}_1^+}}$$

direct sbottom production
4W+2b+2LSP

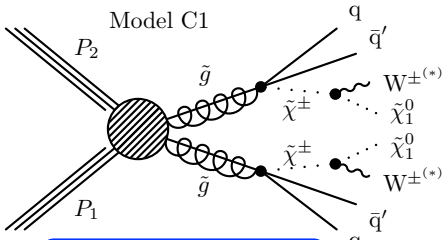




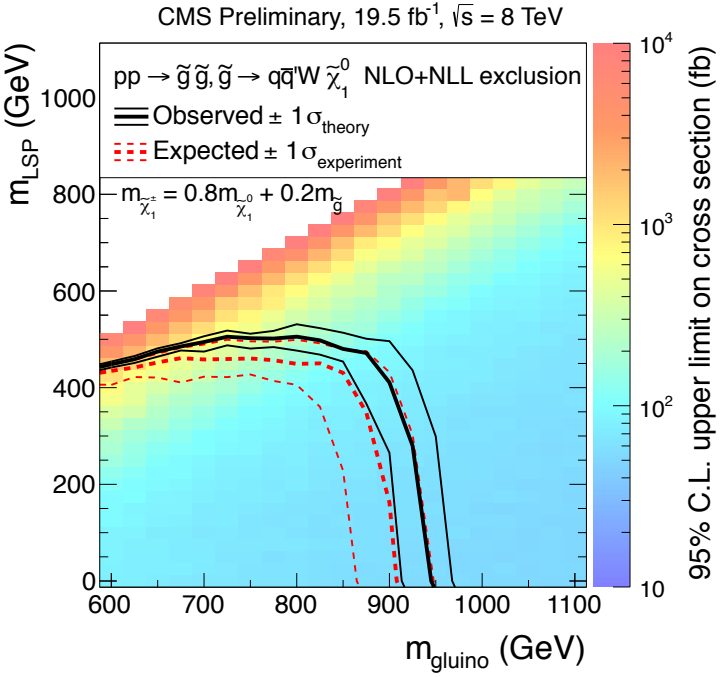


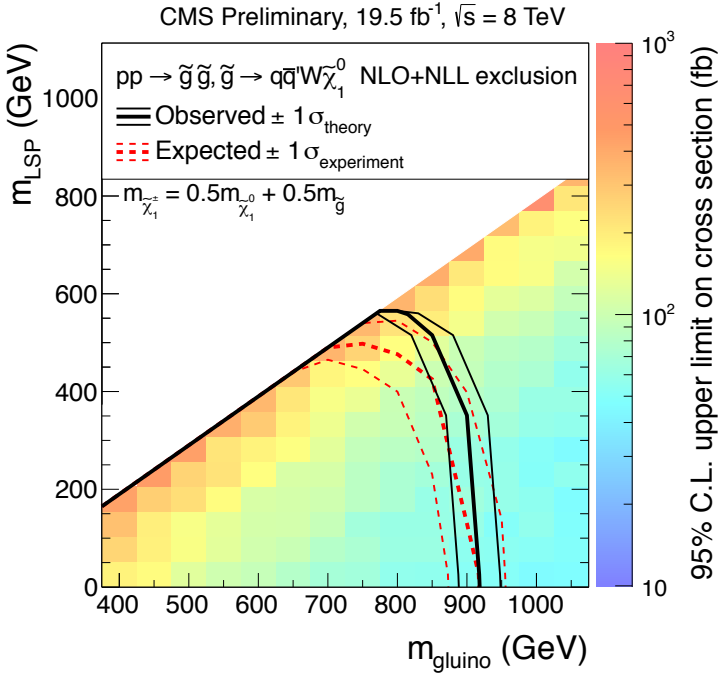
Gluino Mediated Light Squark Production

- Using = 0 N_{bjets} search regions (SR01-08).
- m_{gluino} vs m_{LSP}
- 2 scenarios for fixed relationship between chargino, LSP, and gluino masses
  - left: $m_{chargino} = 0.8m_{LSP} + 0.2m_{gluino}$ → low p_T leptons
  - right: $m_{chargino} = 0.5m_{LSP} + 0.5m_{gluino}$ → high p_T leptons



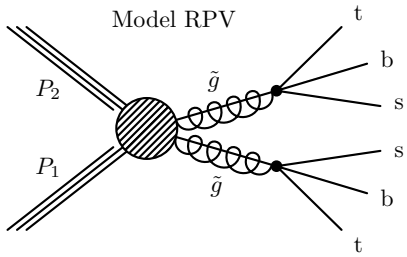
gluino production
2W+2LSP





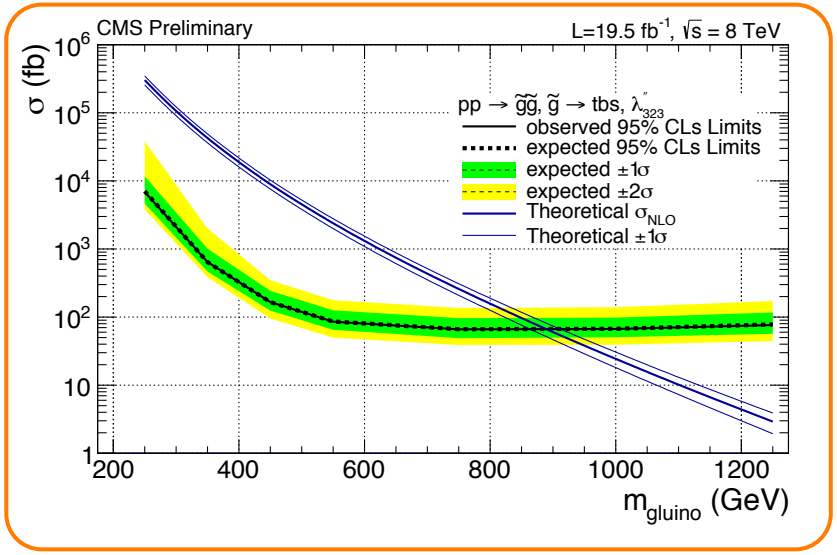
Additional Models

- Additional Search regions designed for R-Parity violating SUSY models and same-sign top production
  - All use high p_T lepton selection
- RPV gluino → tbs 95% CL σ_{UL} (bottom right)
- Same Sign top production 95% CL σ_{UL} = 0.72 pb
- SM 4-top production 95% CL σ_{UL} = 49 fb
  - using ≥ 2 N_{bjets} search regions (SR21-28)



RPV Model
2W+4b

N_{jets}	$N_{b\text{-}jets}$	E_T^{miss} (GeV)	H_T (GeV)	charge	SR
≥ 2	≥ 0	> 0	> 500	++/−−	RPV0
≥ 2	≥ 2	> 0	> 500	++/−−	RPV2
≥ 2	= 1	> 30	> 80	++/−−	SStop1
≥ 2	= 1	> 30	> 80	++ only	SStop1++
≥ 2	≥ 2	> 30	> 80	++/−−	SStop2
≥ 2	≥ 2	> 30	> 80	++ only	SStop2++

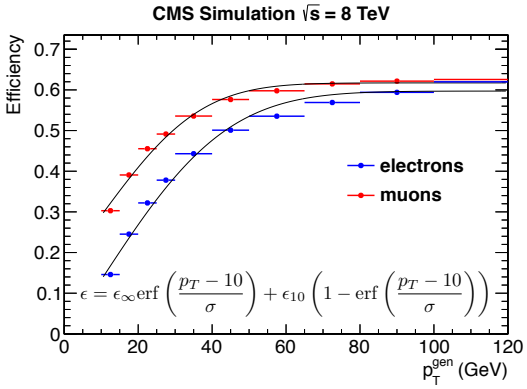


Signal Acceptance Parameterization

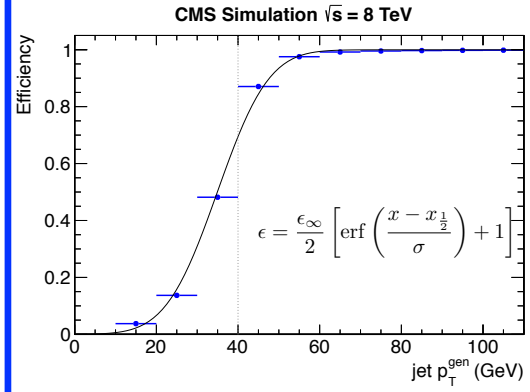
- Use to get an approximate acceptance for any New Physics model
  - defined w.r.t generator level
  - good to within 30% of using full detector simulation/reconstruction
- Parameters for the fit functions are provided in PAS [1] (and backup)

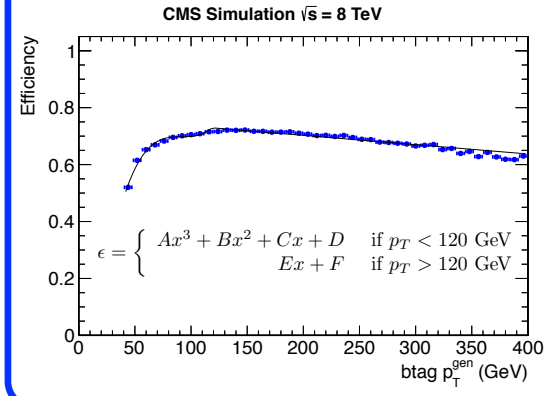
[1] CMS-PAS-SUS-13-013: http://cds.cern.ch/record/1563301

Lepton Efficiency



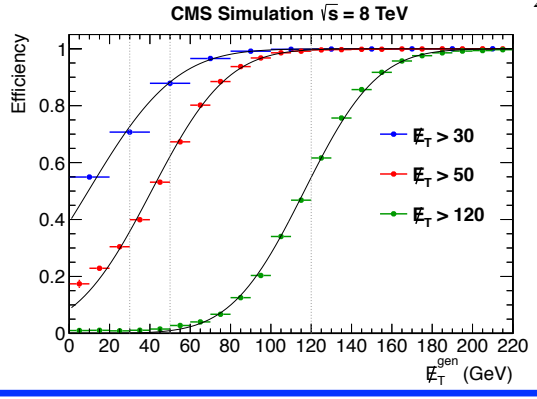
Jet and b-tag Efficiency

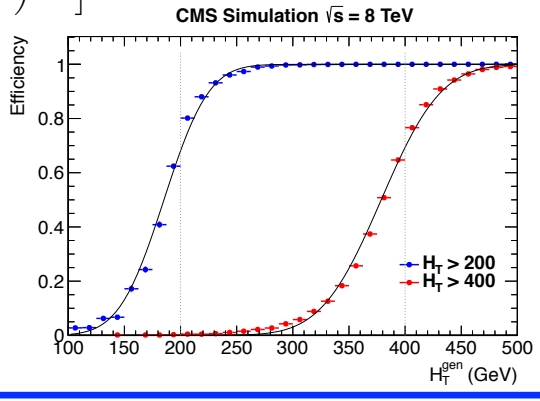




H_T and E_T^{miss} Efficiency

$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$





Summary

- **We searched for new physics in events with a same-sign lepton pair and jets in pp collisions at 8 TeV using a dataset corresponding to 19.5 fb^{-1}.**
- **We observe no evidence for new physics.**
  - We interpret the results in the context of several SUSY models of stop and sbottom production.
  - We set an upper limit on the cross-section for same-sign top and SM four top production.
- We provide a parameterization of the signal acceptance to allow for the interpretation of the observed experimental limits in the context of a broad range of models.

Backup

Search Regions

search region	# b-tagged jets	$\not{E}_T$	# jets	H_T
SR0		30 if $H_T < 500$ else 0	2	80
SR1	≥ 0	50-120	2-3	200-400
SR2				> 400
SR3			≥ 4	200-400
SR4				> 400
SR5		> 120	2-3	200-400
SR6				> 400
SR7			≥ 4	200-400
SR8				> 400
SR10		30 if $H_T < 500$ else 0	2	80
SR11	$= 1$	50-120	2-3	200-400
SR12				> 400
SR13			≥ 4	200-400
SR14				> 400
SR15		> 120	2-3	200-400
SR16				> 400
SR17			≥ 4	200-400
SR18				> 400
SR20		30 if $H_T < 500$ else 0	2	80
SR21	≥ 2	50-120	2-3	200-400
SR22				> 400
SR23			≥ 4	200-400
SR24				> 400
SR25		> 120	2-3	200-400
SR26				> 400
SR27			≥ 4	200-400
SR28				> 400
SR30 SR31 (++)	≥ 2	> 30	≥ 2	> 80
SR32 SR33	≥ 0 ≥ 2	> 0	≥ 2	> 500
SR34 SR35 (++)	$= 1$	> 0	≥ 2	> 80

- Search Regions expanded to be sensitive to a broad range of signatures
- Made exclusive to allow for statistical combination
  - Contrast to HCP: inclusive regions and $N_{btags} \geq 2$.
  - binned in N_{btags}
    - SR0-8: no N_{btags} req
    - SR10-18: $N_{btags} = 1$
    - SR20-28: $N_{btags} \geq 2$
  - Three baseline regions
    - loose MET and H_T cuts
  - General SUSY search regions binned in H_T, MET, and N_{jets}
  - Same-sign top.
  - R-parity violation (RPV)
- Low p_T same except
  - H_T 200 GeV → 250 due to H_T trigger turn on
  - Only defined for SRs 0-28

Results Tables

SR	low-p_T Expected	low-p_T Observed	high-p_T Expected	high-p_T Observed
1	44 ± 16	50	51 ± 18	48
2	12 ± 4	17	9.0 ± 3.5	11
3	12 ± 5	13	8.0 ± 3.1	5
4	9.1 ± 3.4	4	5.6 ± 2.1	2
5	21 ± 8	22	20 ± 7	12
6	13 ± 5	18	9 ± 4	11
7	3.5 ± 1.4	2	2.4 ± 1.0	1
8	5.8 ± 2.1	4	3.6 ± 1.5	3
11	32 ± 13	40	36 ± 14	29
12	6.0 ± 2.2	5	3.8 ± 1.4	5
13	17 ± 7	15	10 ± 4	6
14	10 ± 4	6	5.9 ± 2.2	2
15	13 ± 5	9	11 ± 4	11
16	5.5 ± 2.0	5	3.9 ± 1.5	2
17	4.2 ± 1.6	3	2.8 ± 1.1	3
18	6.8 ± 2.5	11	4.0 ± 1.5	7
21	7.6 ± 2.8	10	7.1 ± 2.5	12
22	1.5 ± 0.7	1	1.0 ± 0.5	1
23	7.1 ± 2.7	6	3.8 ± 1.4	3
24	4.4 ± 1.7	11	2.8 ± 1.2	7
25	2.8 ± 1.1	1	2.9 ± 1.1	4
26	1.3 ± 0.6	2	0.8 ± 0.5	1
27	1.8 ± 0.8	0	1.2 ± 0.6	0
28	3.4 ± 1.3	3	2.2 ± 1.0	2

SR	Expected	Observed
RPV0	38 ± 14	35
RPV2	5.3 ± 2.1	5
SStop1	160 ± 59	152
SStop1++	90 ± 32	92
SStop2	40 ± 13	52
SStop2++	22 ± 8	25

Model	Model parameter	Analysis	Signal Regions used
A1		high-p_T	21–28
A2	$m_{\chi_1^0} = 50$ GeV	high-p_T	21–28
B1	$m_{\chi_1^0} = 50$ GeV	high-p_T	11–18, 21–28
B1	$x = m_{\chi_1^0}/m_{\chi_1^\pm} = 0.5$	high-p_T	11–18, 21–28
B1	$x = m_{\chi_1^0}/m_{\chi_1^\pm} = 0.8$	low-p_T	11–18, 21–28
B2	$m_{\chi_1^0} = 50$ GeV, $m_{\chi_1^\pm} = 150$ GeV	high-p_T	21–28
B2	$m_{\chi_1^0} = 50$ GeV, $m_{\chi_1^\pm} = 300$ GeV	high-p_T	21–28
C1	x = 0.5	high-p_T	01–08
C1	x = 0.8	low-p_T	01–08
RPV		high-p_T	RPV2
$pp \to t\bar{t} + t\bar{t}$		high-p_T	SStop1, SStop2
$pp \to t\bar{t}$		high-p_T	SStop1++, SStop2++
$pp \to t\bar{t}t\bar{t}$		high-p_T	21–28

Red = 0b, Blue = 1b, Green = ≥ 2b

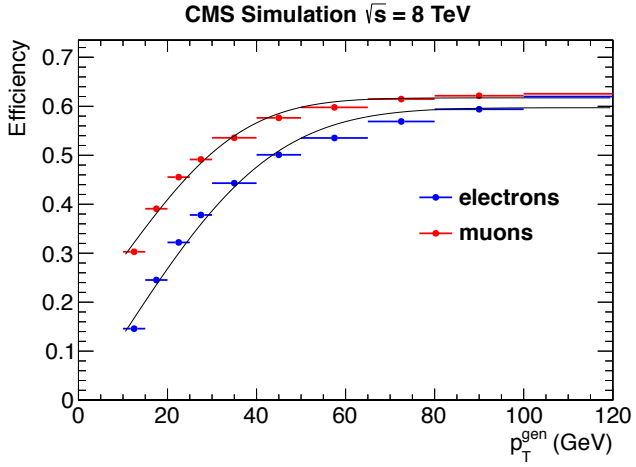
Signal Acceptance Parameterization

- Acceptance model defined w.r.t status 3 generator level using T1tttt.

Lepton Efficiency

$$\epsilon = \epsilon_\infty \mathrm{erf}\left(\frac{p_T - 10}{\sigma}\right) + \epsilon_{10}\left(1 - \mathrm{erf}\left(\frac{p_T - 10}{\sigma}\right)\right)$$

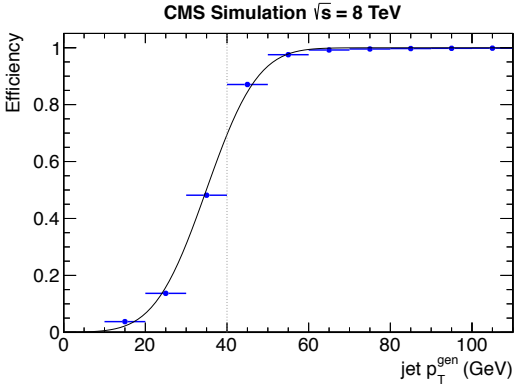
Parameter	Electrons	Muons
ϵ_∞	0.640 ± 0.001	0.673 ± 0.001
ϵ_{10}	0.170 ± 0.002	0.332 ± 0.003
σ	36.94 ± 0.320	29.65 ± 0.382



Jet and b-tag Efficiency

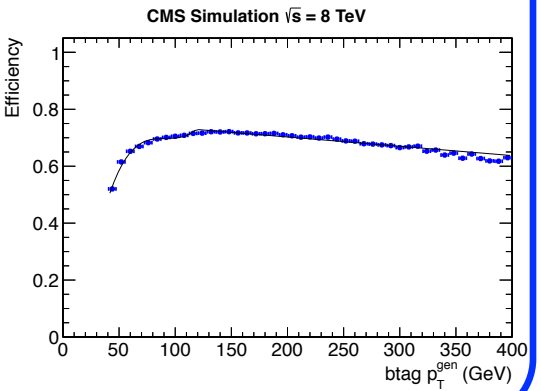
$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$

Parameter	Value
ϵ_∞	1.000 ± 0.001
$x_{1/2}$, GeV	29.81 ± 0.100
σ, GeV	18.75 ± 0.099



$$\epsilon = \begin{cases} Ax^3 + Bx^2 + Cx + D & \text{if } p_T < 120 \text{ GeV} \\ Ex + F & \text{if } p_T > 120 \text{ GeV} \end{cases}$$

Parameter	Value
A	$(1.55 \pm 0.05) \times 10^{-6}$
B	$(-4.26 \pm 0.12) \times 10^{-4}$
C	0.0391 ± 0.0008
D	-0.496 ± 0.020
E	$(-3.26 \pm 0.01) \times 10^{-4}$
F	0.7681 ± 0.0016

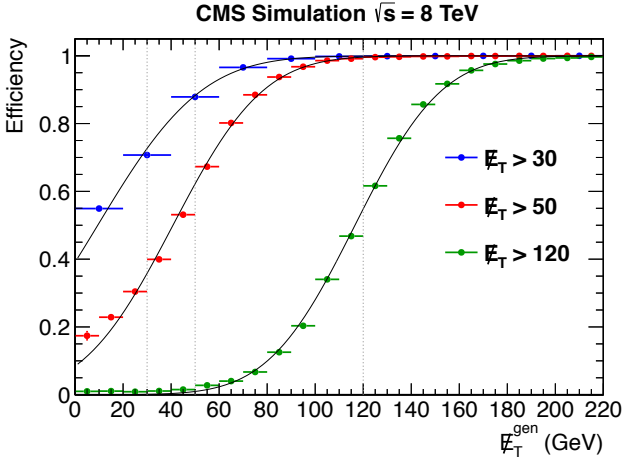


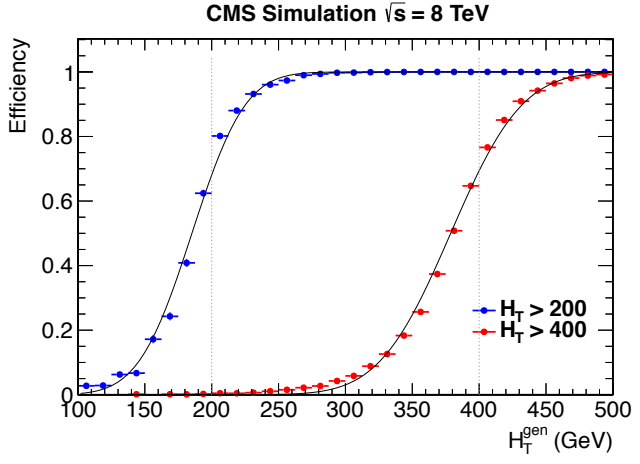
Signal Acceptance Parameterization (2)

H_T and MET Efficiency

$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$

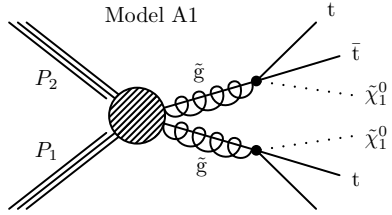
Parameter	H_T		E_T^{miss}		
	> 200 GeV	> 400 GeV	> 30 GeV	> 50 GeV	> 120 GeV
ϵ_∞	0.999 ± 0.001	0.999 ± 0.001	1.000 ± 0.001	1.000 ± 0.001	0.999 ± 0.001
$x_{1/2}$, GeV	185.2 ± 0.4	378.69 ± 0.17	13.87 ± 0.30	42.97 ± 0.14	117.85 ± 0.09
σ, GeV	44.5 ± 0.6	59.41 ± 0.26	42.92 ± 0.34	37.47 ± 0.20	36.90 ± 0.14





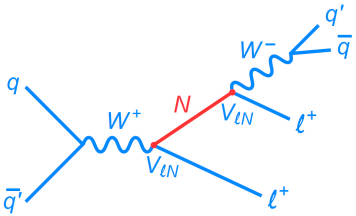
Model Examples

Supersymmetry (SUSY)



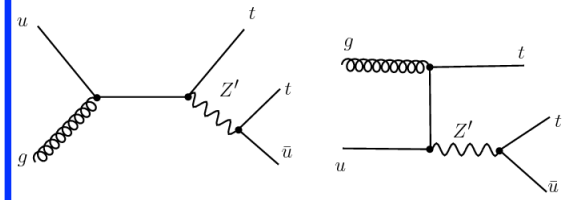
$$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$$

Heavy Majorana Neutrinos



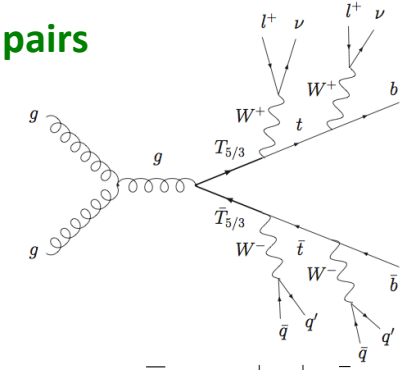
$$pp \to \ell^+ \overline{N} \to \ell^- \ell^- q' \overline{q}$$

Same-Sign Top Pairs



$$pp \to tt\bar{u}$$

$T_{5/3}$ pairs

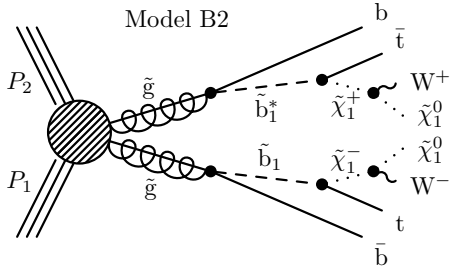


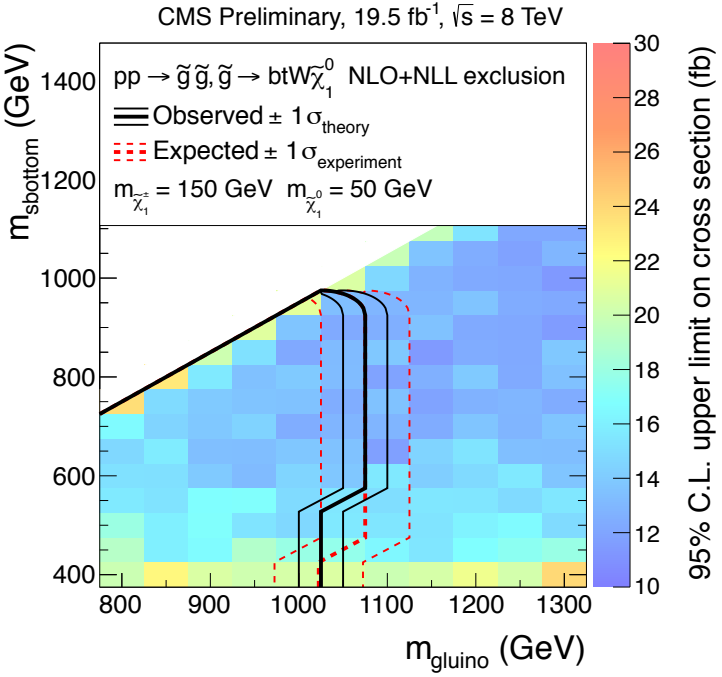
$$pp \to T_{5/3}\overline{T}_{5/3} \to \ell^{\pm}\nu\ell^{\pm}\nu b\bar{b} + \text{jets}$$

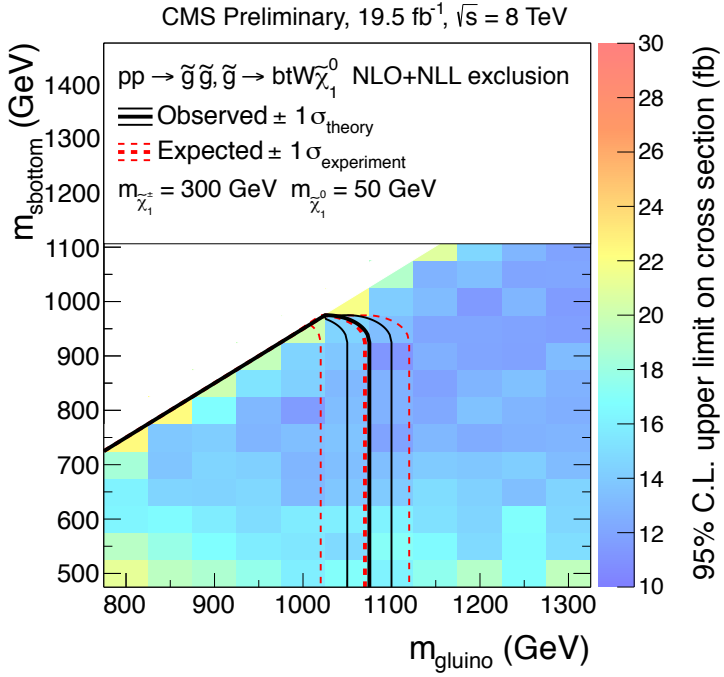
Gluino Mediated Sbottom Production

- Using high p_T leptons and ≥ 2 N_{bjets} search regions (SR21-28).
- m_{gluino} vs $m_{sbottom}$
- $m_{chargino}$ = 150 GeV (left) and 300 GeV (right)
- m_{LSP} held fixed at 50 GeV

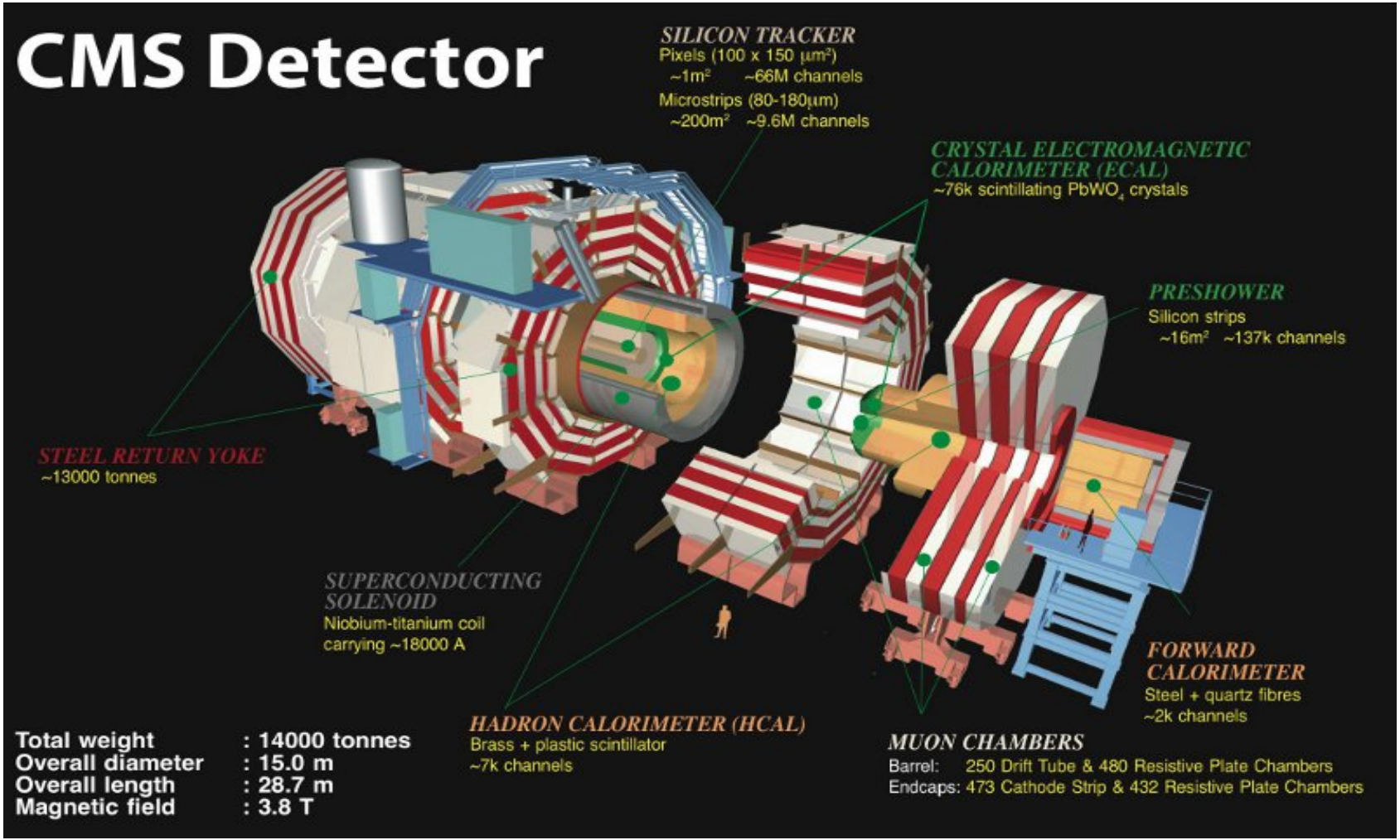
gluino mediated sbottom production
4W+4b+2LSP



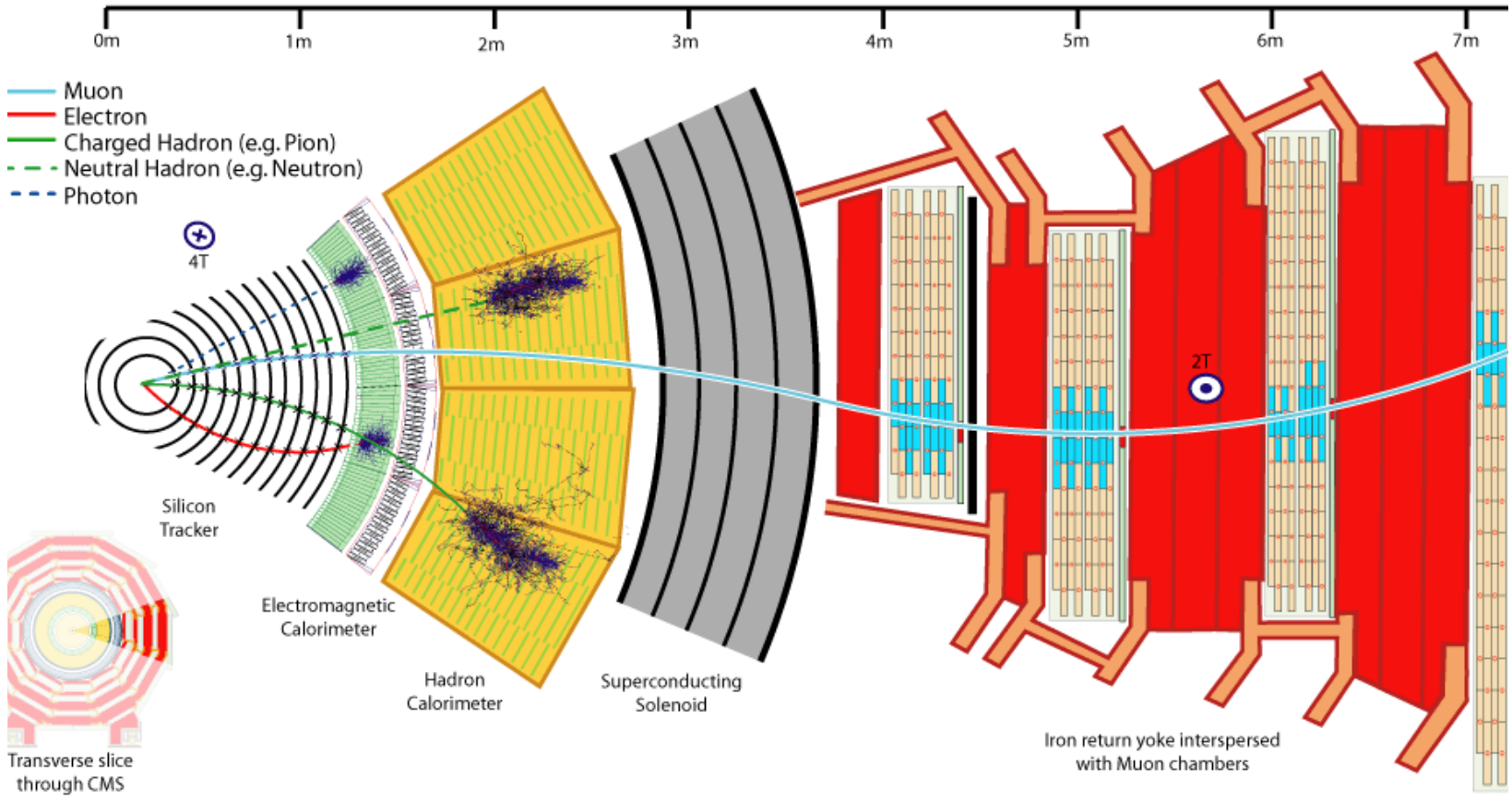




CMS Detector



Reconstructed Objects



SR28

high p_T analysis

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(b \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(\not{b} \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
ZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$t\bar{t}\gamma$	0.00 ± 0.01	0.00 ± 1.08	0.03 ± 0.02	0.03 ± 0.02
$t\bar{t}W$	0.20 ± 0.10	0.26 ± 0.11	0.68 ± 0.16	1.15 ± 0.20
$t\bar{t}Z$	0.02 ± 0.04	0.03 ± 0.05	0.13 ± 0.07	0.18 ± 0.08
$tbZ(Z \to \ell\ell)$	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
$t\bar{t}WW$	0.01 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.05 ± 0.00
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
WZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.00 ± 0.09	0.02 ± 0.04	0.02 ± 0.04
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.02 ± 0.06	0.06 ± 0.07	0.09 ± 0.08	0.17 ± 0.10
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.00 ± 0.01	0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
Total MC	0.27 ± 73.37	0.40 ± 73.38	1.00 ± 73.37	1.67 ± 73.37
SF	0.00 ± 0.46	0.10 ± 0.19	0.44 ± 0.31	0.54 ± 0.37
DF	0.00 ± 0.14	0.00 ± 0.08	0.00 ± 0.10	0.00 ± 0.14
SC	0.03 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	0.09 ± 0.03
SF + DF	0.00 ± 0.37	0.10 ± 0.10	0.44 ± 0.23	0.54 ± 0.25
SF + DF - SC	-0.03 ± 0.02 ± -0.02	0.08 ± 0.10 ± 0.04	0.41 ± 0.23 ± 0.20	0.45 ± 0.25 ± 0.23
Charge Flips	0.02 ± 0.00 ± 0.00	0.00 ± 0.00 ± 0.00	0.02 ± 0.00 ± 0.01	0.03 ± 0.01 ± 0.01
MC Pred	0.27 ± 0.38 ± 0.14	0.40 ± 1.15 ± 0.20	1.00 ± 0.40 ± 0.50	1.67 ± 0.42 ± 0.84
Total Pred	0.25 ± 0.38 ± 0.14	0.48 ± 1.15 ± 0.20	1.43 ± 0.46 ± 0.54	2.16 ± 0.49 ± 0.87
Data	0	1	1	2

low p_T analysis

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(b \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(\not{b} \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
ZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$t\bar{t}\gamma$	0.02 ± 0.03	0.00 ± 1.08	0.02 ± 0.03	0.04 ± 0.04
$t\bar{t}W$	0.25 ± 0.11	0.36 ± 0.12	0.74 ± 0.16	1.36 ± 0.21
$t\bar{t}Z$	0.02 ± 0.04	0.07 ± 0.06	0.15 ± 0.08	0.23 ± 0.09
$tbZ(Z \to \ell\ell)$	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
$t\bar{t}WW$	0.01 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.07 ± 0.00
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
WZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.00 ± 0.09	0.02 ± 0.04	0.02 ± 0.04
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.02 ± 0.06	0.11 ± 0.09	0.13 ± 0.09	0.26 ± 0.11
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.02 ± 0.01
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.00 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
Total MC	0.34 ± 73.37	0.60 ± 73.38	1.13 ± 73.37	2.07 ± 73.37
SF	0.00 ± 0.24	0.46 ± 0.32	0.93 ± 0.37	1.39 ± 0.46
DF	0.00 ± 0.05	0.00 ± 0.08	0.02 ± 0.02	0.02 ± 0.02
SC	0.03 ± 0.01	0.04 ± 0.02	0.05 ± 0.02	0.13 ± 0.04
SF + DF	0.00 ± 0.22	0.46 ± 0.28	0.95 ± 0.37	1.41 ± 0.46
SF + DF - SC	-0.03 ± 0.01 ± -0.02	0.42 ± 0.28 ± 0.21	0.90 ± 0.37 ± 0.45	1.29 ± 0.46 ± 0.64
Charge Flips	0.02 ± 0.00 ± 0.01	0.00 ± 0.00 ± 0.00	0.02 ± 0.00 ± 0.01	0.04 ± 0.01 ± 0.01
MC Pred	0.34 ± 0.38 ± 0.17	0.60 ± 1.15 ± 0.30	1.13 ± 0.40 ± 0.56	2.07 ± 0.44 ± 1.03
Total Pred	0.33 ± 0.38 ± 0.17	1.01 ± 1.18 ± 0.36	2.06 ± 0.54 ± 0.72	3.40 ± 0.63 ± 1.22
Data	0	1	2	3