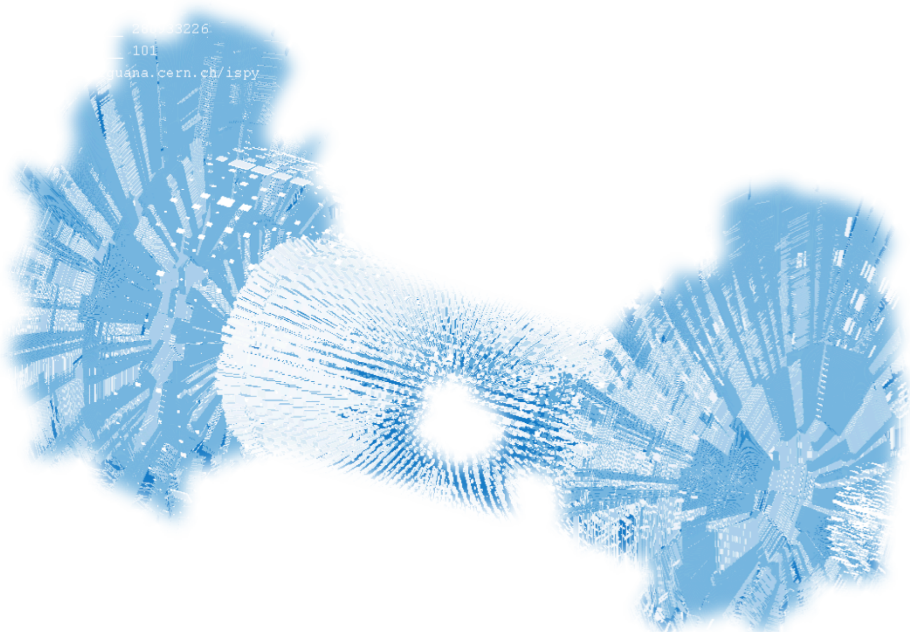
Searches for SUSY in events with 3rd generation particles at CMS

On behalf of the CMS Collaboration



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DESY

ICHEP 2012, 05 July 2012,
Melbourne, Australia

HELMHOLTZ ASSOCIATION

ICHEP2012 Melbourne

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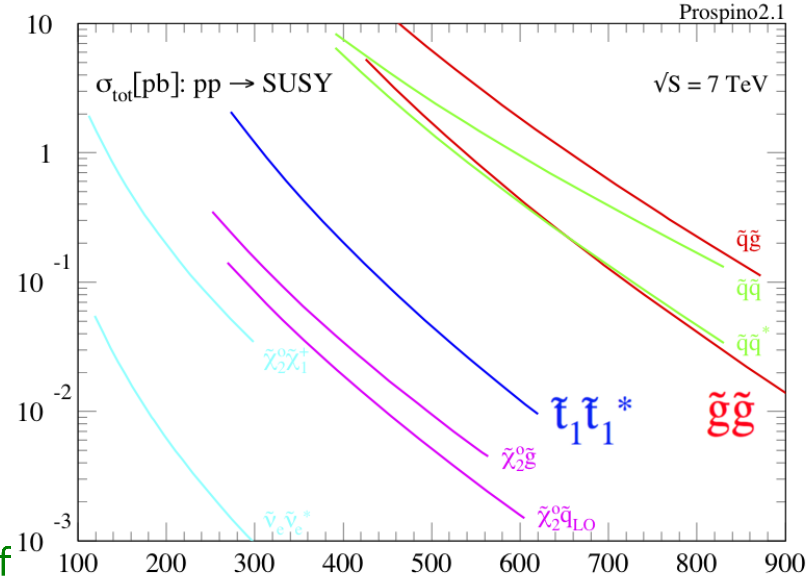
SUSY in the 3rd Generation

- SUSY can solve many problems intrinsic to SM:
  - Hierarchy problem
  - Unification of forces at a high energy scale
- If R-parity is conserved: Lightest SUSY particle (LSP) is stable
  → natural Dark Matter (DM) candidate
- In the third generation SUSY particles → sizeable mixing
  $\tilde{t}_1$ and $\tilde{b}_1$ are lighter than the other squarks
  $\tilde{\tau}_1$ is lighter than the other sleptons

→ **3rd generation sfermions:**
- **Can be relatively light**
- **Can be produced in pairs with high cross section or appear in the gluino cascade decay**
- Produce *b, t or τ* in their decay

→ Good prospects for experimental observation of 3rd generation SUSY particles



$m_{avarage}$ [GeV]

Searching for 3rd Generation SUSY in CMS*

- Search for Supersymmetry in Final States with a **Single Lepton, B-jets,** and Missing Transverse Energy in Proton-Proton Collisions at $\sqrt{s}$ = 7 TeV – PAS-SUS-11-028

- Search for supersymmetry in events with a **single lepton** and jets using templates PAS-SUS-11-027

- NEW Search for physics beyond the standard model in events with **tau leptons** in the presence of multijets and large momentum imbalance in pp collisions at $\sqrt{s}$= 7 TeV PAS-SUS-12-004

- NEW Search for new physics in events with **same-sign dileptons and b-tagged jets** in pp collisions at **$\sqrt{s}$=8 TeV** CMS-SUS-12-017

- NEW Search for new physics in events with **b-quark jets** and missing transverse energy in pp collisions at $\sqrt{s}$=7 TeV PAS-SUS-12-003

☛ For Alpha$_{Tb}$ and M_{T2b} analyses → see Seema Sharma`s talk!

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

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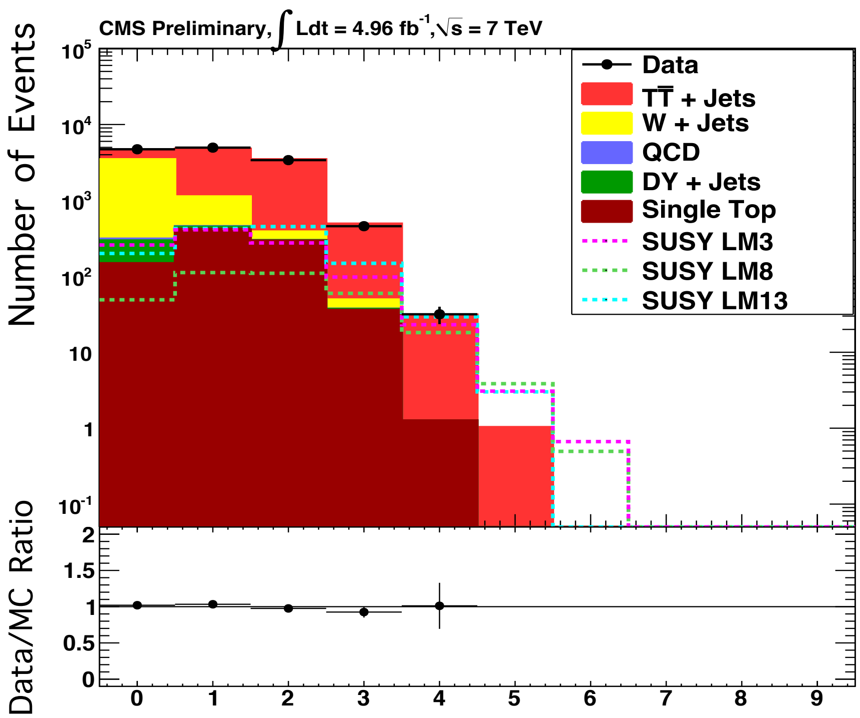
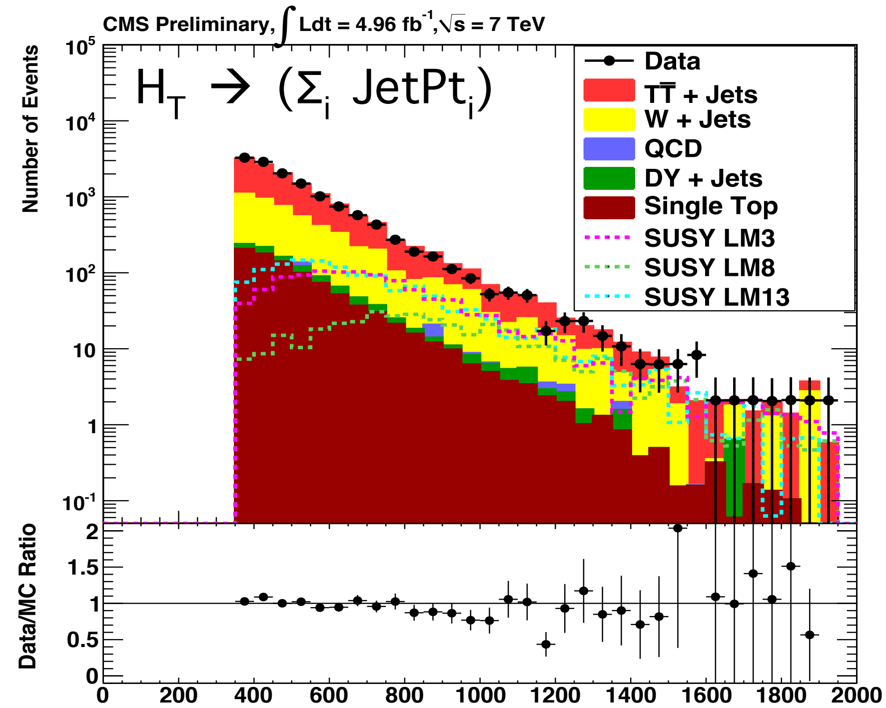
Search for SUSY in Final States with a Single Lepton, B-jets, and Missing Transverse Energy in Proton-Proton Collisions at $\sqrt{s}$ = 7 TeV

PAS-SUS-11-028

☞ The analysis is performed in three channels according to the number of b-tags: **exactly one b-tag, exactly two b-tags and three or more b-tags.**



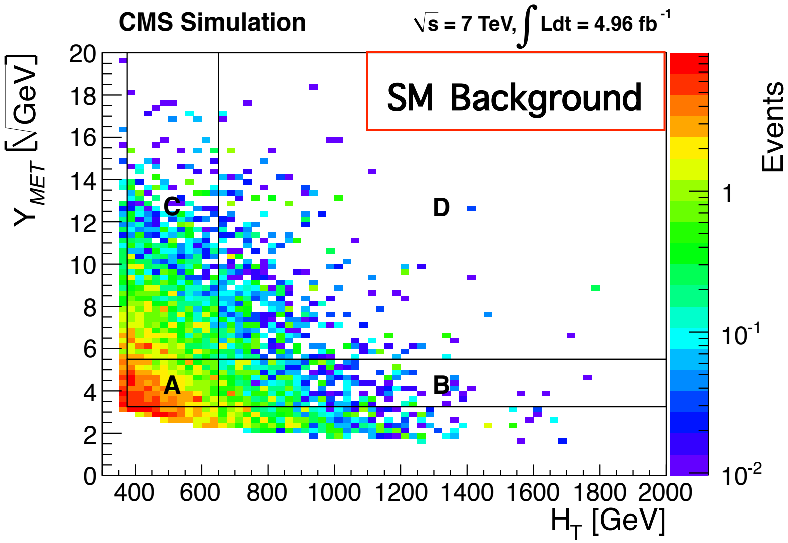


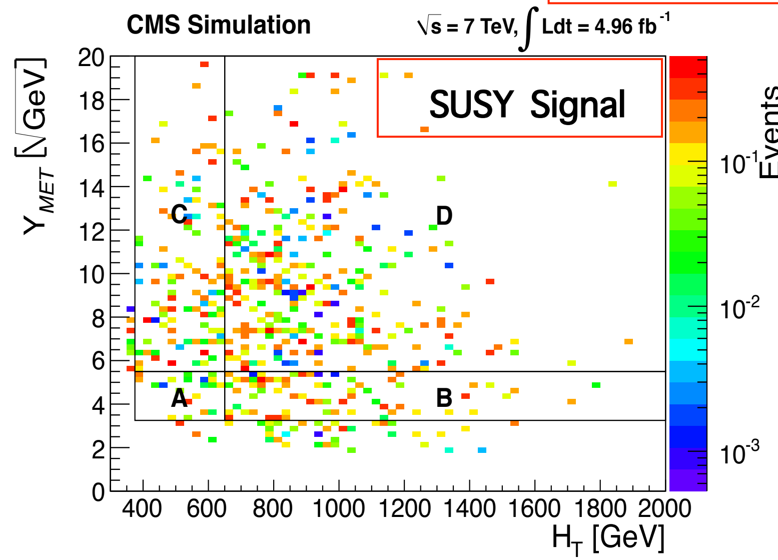
☞ H_T > 375 GeV, Njets ≥ 4 and one exact isolated lepton (e, μ) (left)

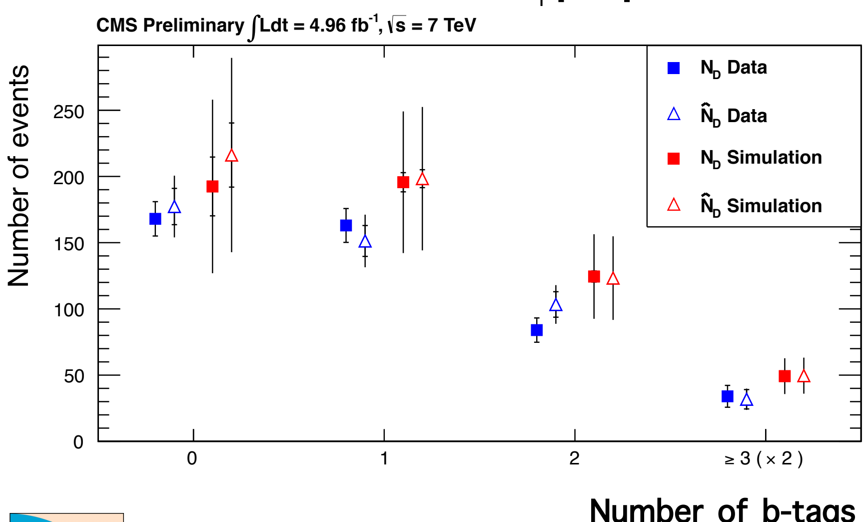
→ **Nbjets ≥ 1 required for H_T plot (right)**

Background Estimation Method - Factorization

MET Significance → Y_{MET} = MET/√ HT





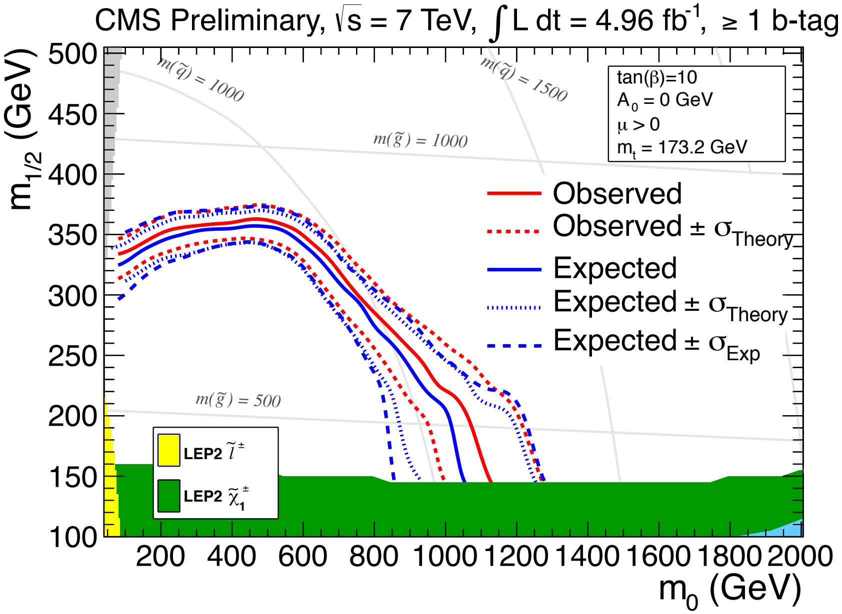


☞ The measured and the predicted number of events in signal region (D) are in good agreement.

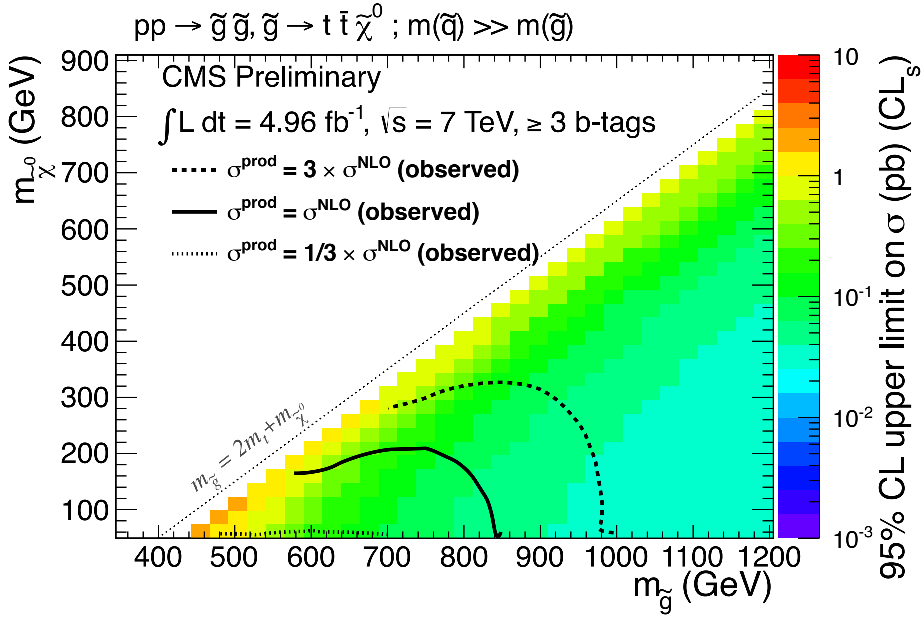
Interpretation of the results

PAS-SUS-11-028

cMSSM



Simplified Model



☞ Limits are set using the **CLs method with a test statistic given by a profile likelihood ratio.**

☞ The limits are based on **≥1 btag** and **≥3 btag** for cMSSM and SMS models, respectively.

PAS-SUS-11-028

☑ No deviation from the SM has been found

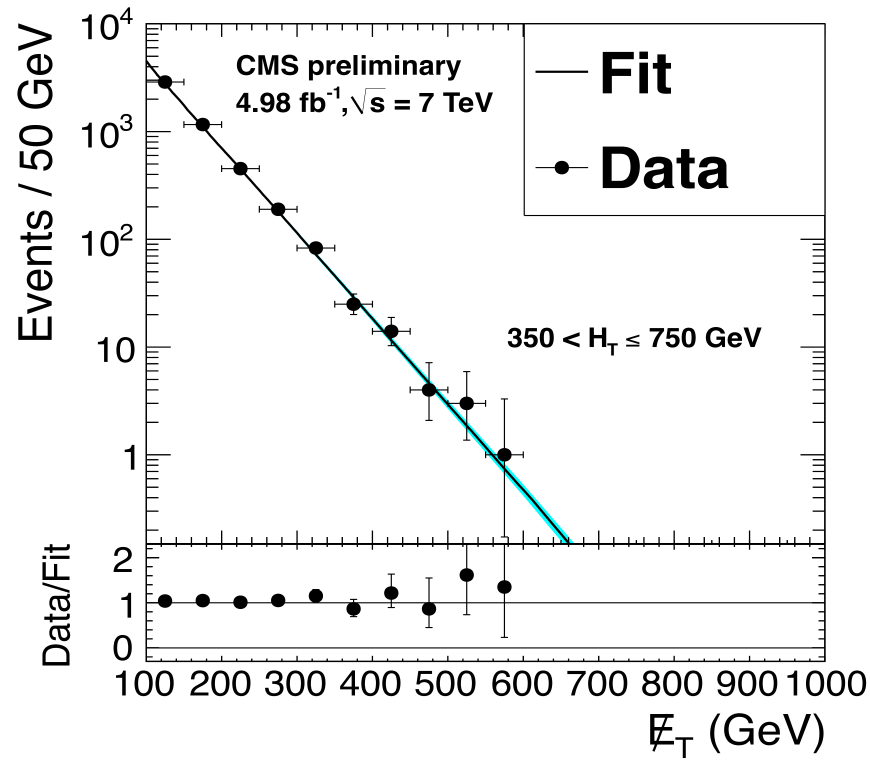
☑ Upper limits have been set on production cross-sections for both models.

☞ The analysis is done as a function of **the number of identified b-quark (<u>including 0-btag</u>) jets** in the event.

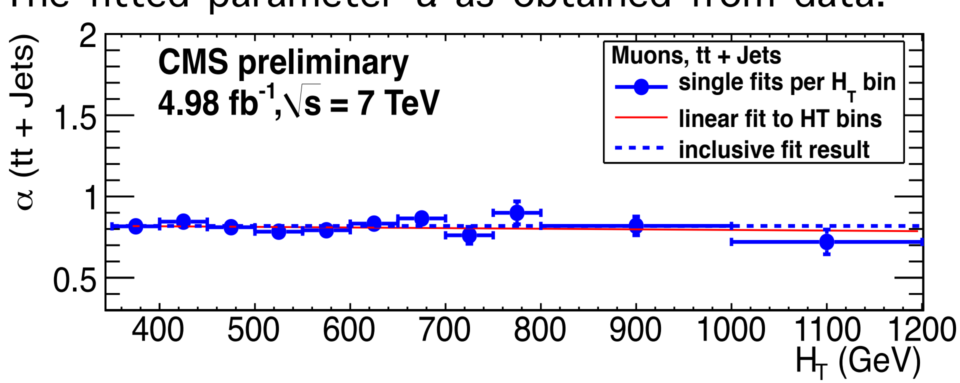
Methodology for Background Estimation

The dominant SM backgrounds (Wjets, TTjets) can be obtained from data:

- Use hadronic component of events
- Fit the parameters of a model for the genuine MET in a control region defined by H_T
- Apply individual MET models for W^+jets, W^-jets and TTjets
- Use W+jets/TTJets ratios for events with 0,1 or ≥2 tagged bjets determined using template fit.



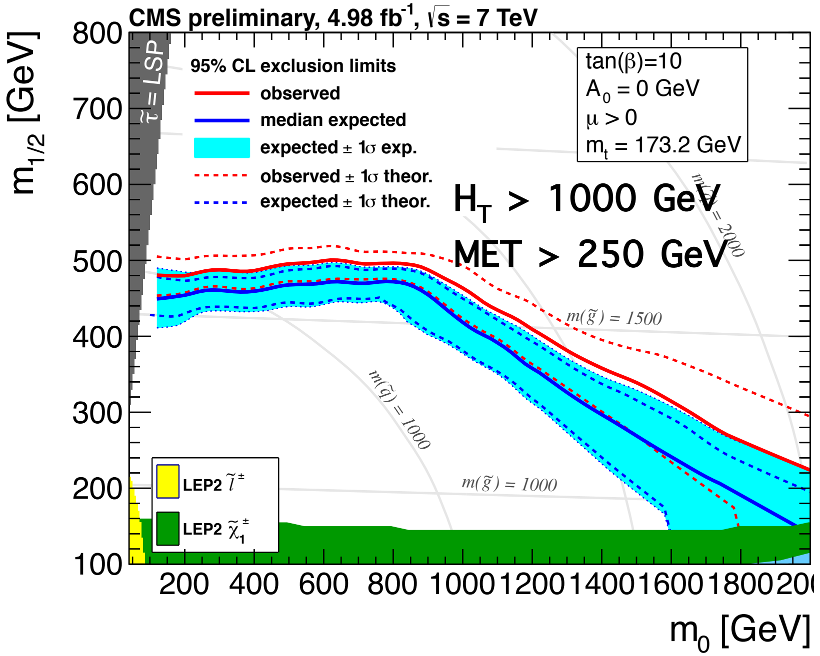
The fitted parameter *α* as obtained from data:



Interpretation of the results

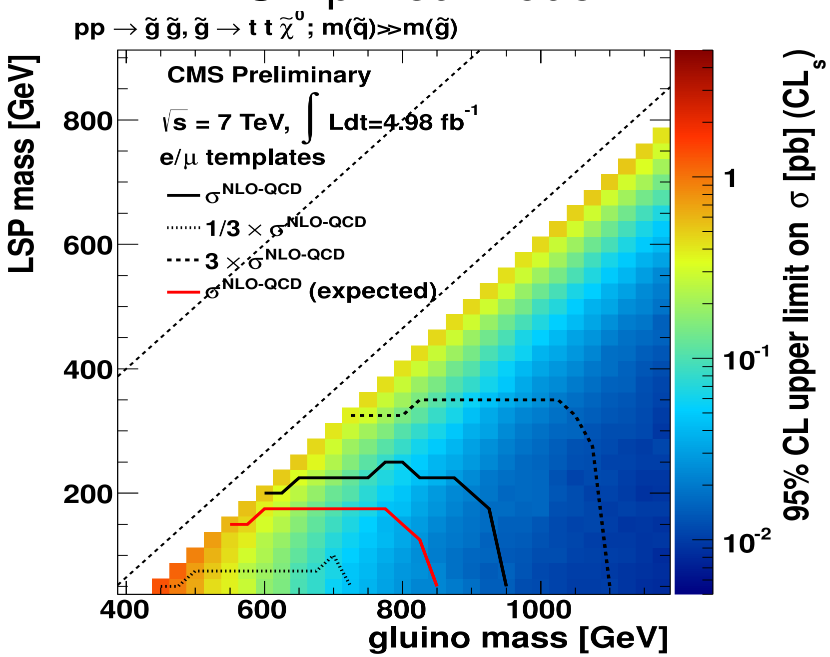
PAS-SUS-11-027

cMSSM



☞ The observed and expected median limits are based on **all btags bins** (0,1,2 btag).

Simplified Model



☞ The signal region is defined by HT > 750 GeV and MET > 250 GeV with **at least 2 b-jet bin.**

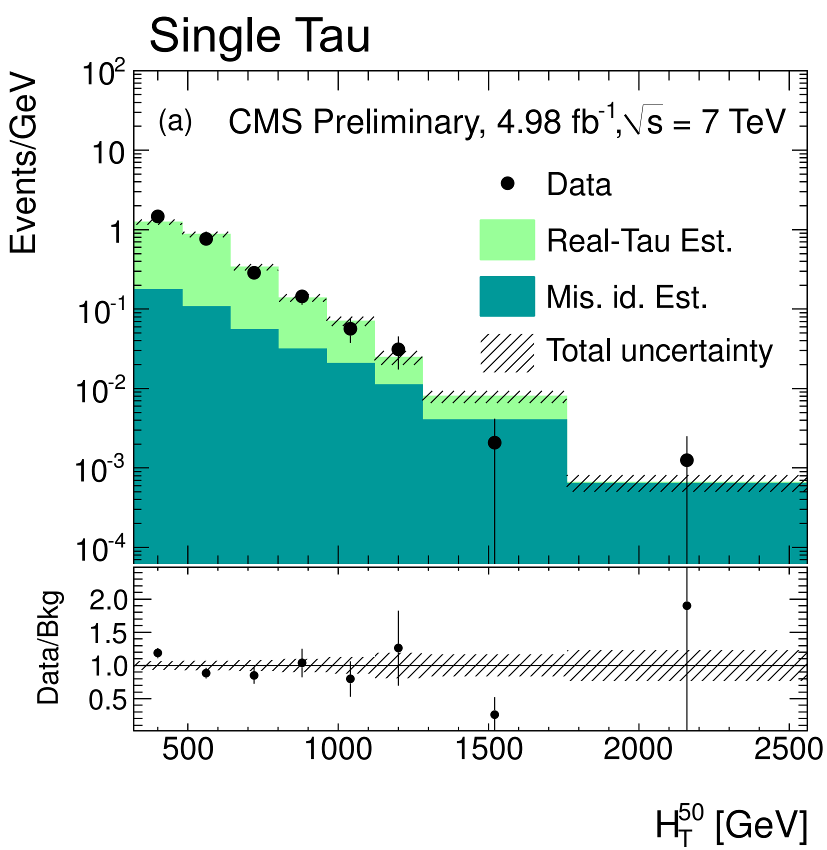
☑ No excess has been observed

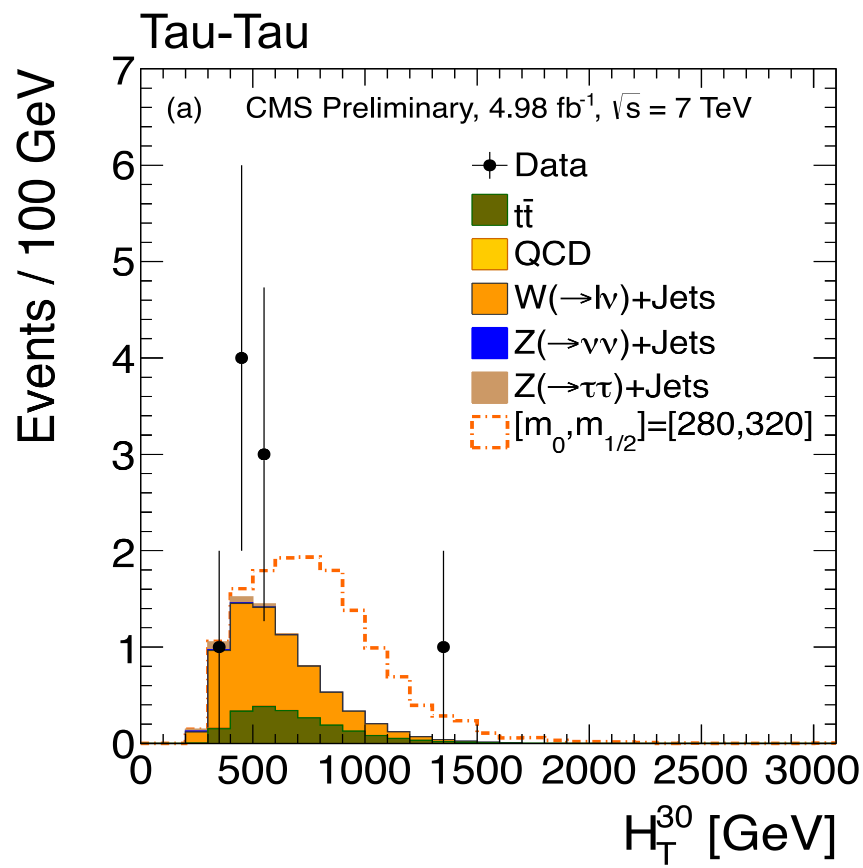
☑ The simplified model is excluded using the ≥ 2 b-jet bin.

PAS-SUS-11-027

Search for physics SUSY in events with tau leptons in the presence of multijets and large momentum imbalance in pp collisions at √s= 7 TeV PAS-SUS-12-004

☞The analysis is performed with one or more hadronically decaying τ-leptons, highly energetic jets and large momentum imbalance in the final state.

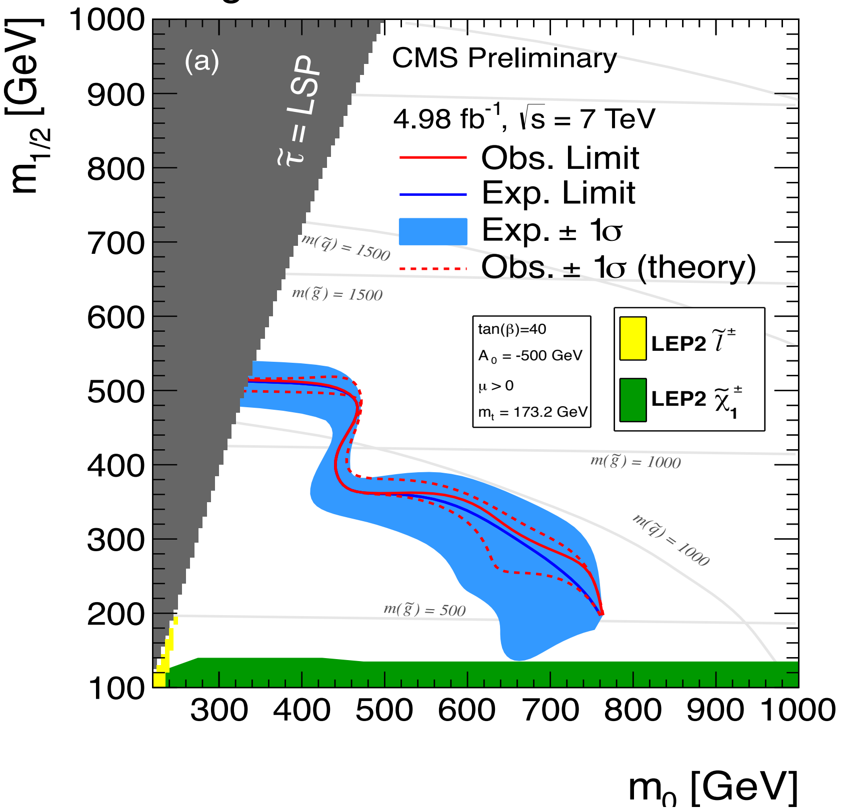




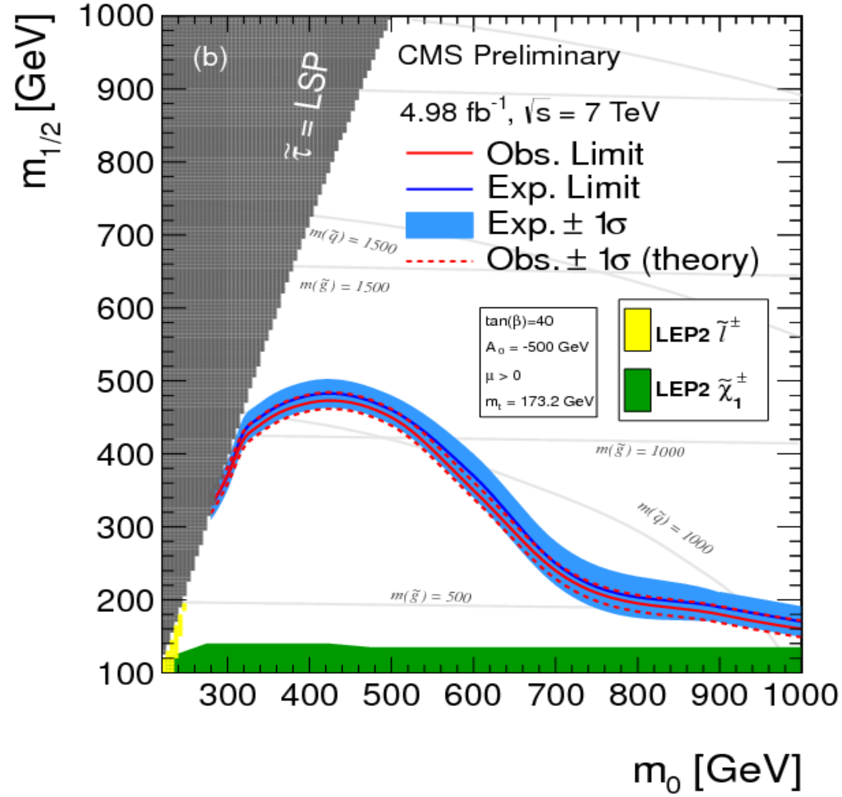
Interpretation of the results

cMSSM

Single τau



τau-τau



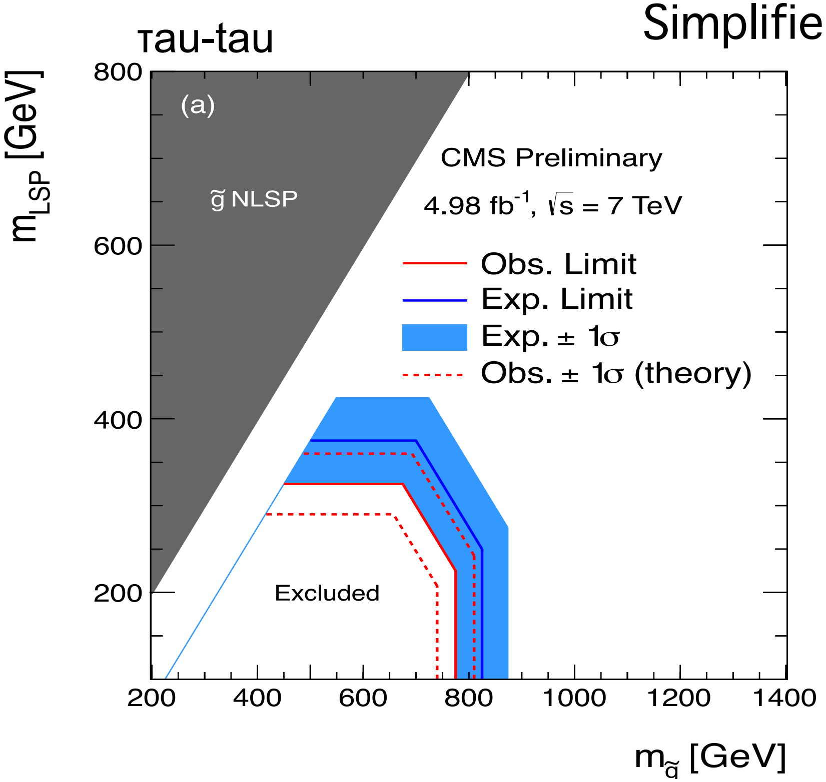
- ☑ Single tau analysis sensitive to lower m_0
- ☑ Tau-tau analyses sensitive to higher m_0

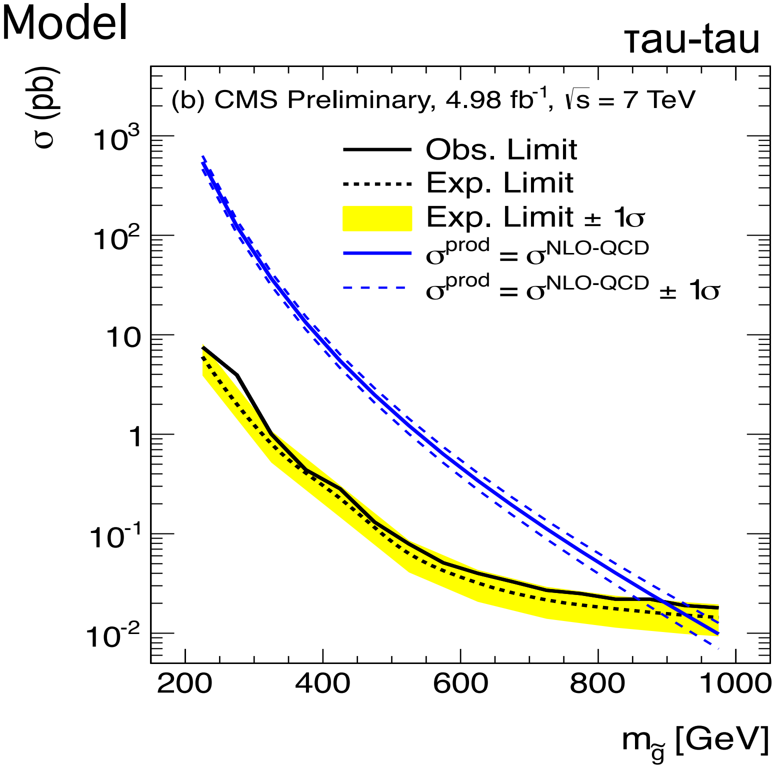
PAS-SUS-12-004

Interpretation of the results

PAS-SUS-12-004

Simplified Model





☞ 95% CL cross section upper limits for the limits on the mass of the gluino and the LSP (left) and cross section upper limits as a function of gluino mass in the GMSB

☑ No excess beyond the SM expectations has been found for both single and di-tau final states.

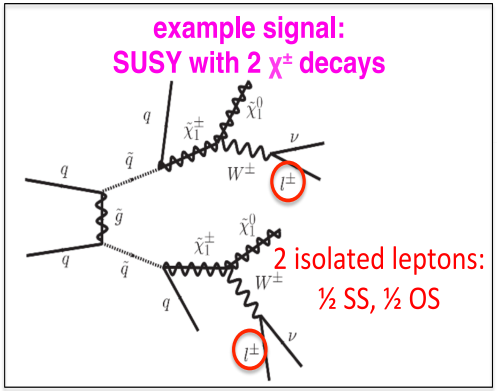
PAS-SUS-12-004

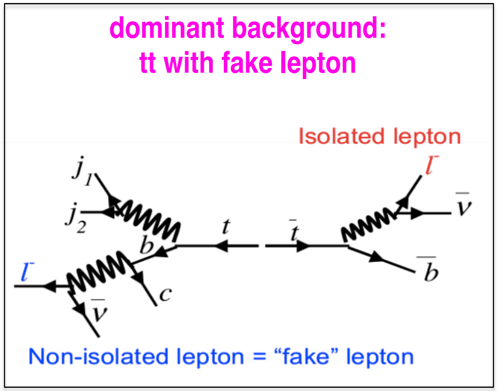
Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at $\sqrt{s}$= 8 TeV

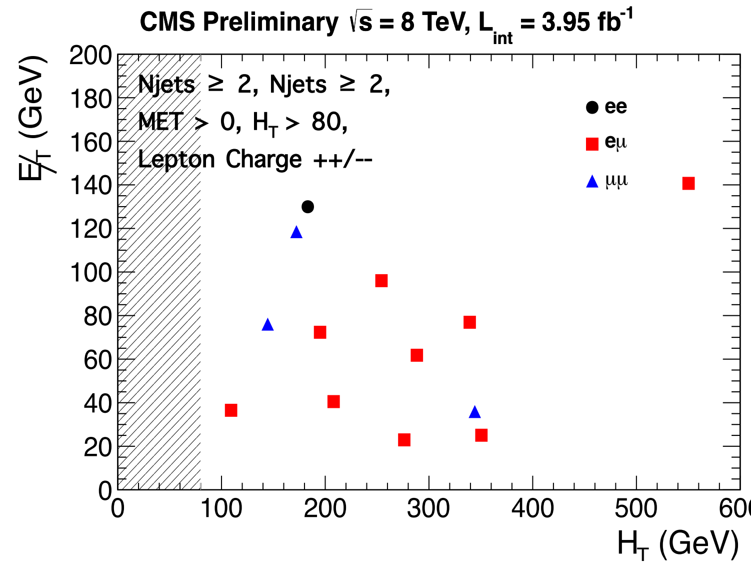
PAS-SUS-12-017

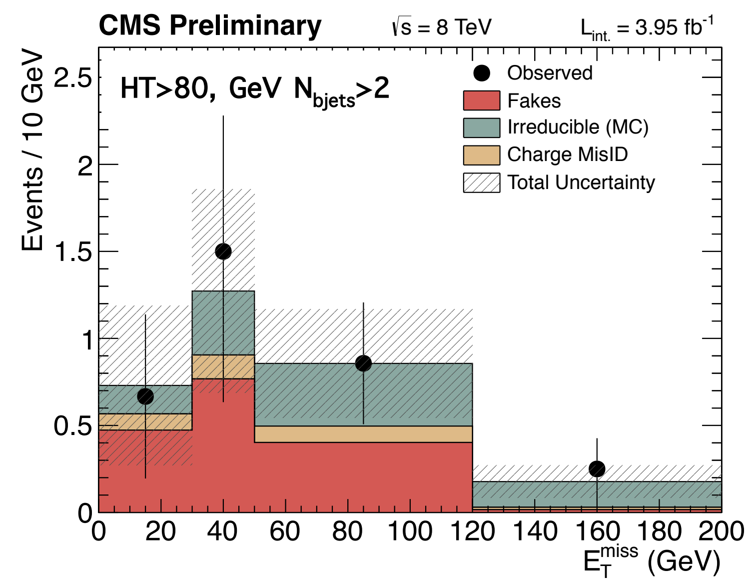
Dominant SM backgrounds:

- ttbar with "fake" leptons → fake ratio / isolation extrapolation
- Charge mis-reconstruction → use Z`s for charge
- Rare SM processes with high $P_{T\ l}$ leptons and bjets → estimate from MC









Background Estimation

☞ Define pre-selection regions in **MET - H_T**

- ✓ Validate data-driven background estimates with ~10-100 events

☞ Define search regions by adding **MET, H_T** requirements ->Data driven techniques

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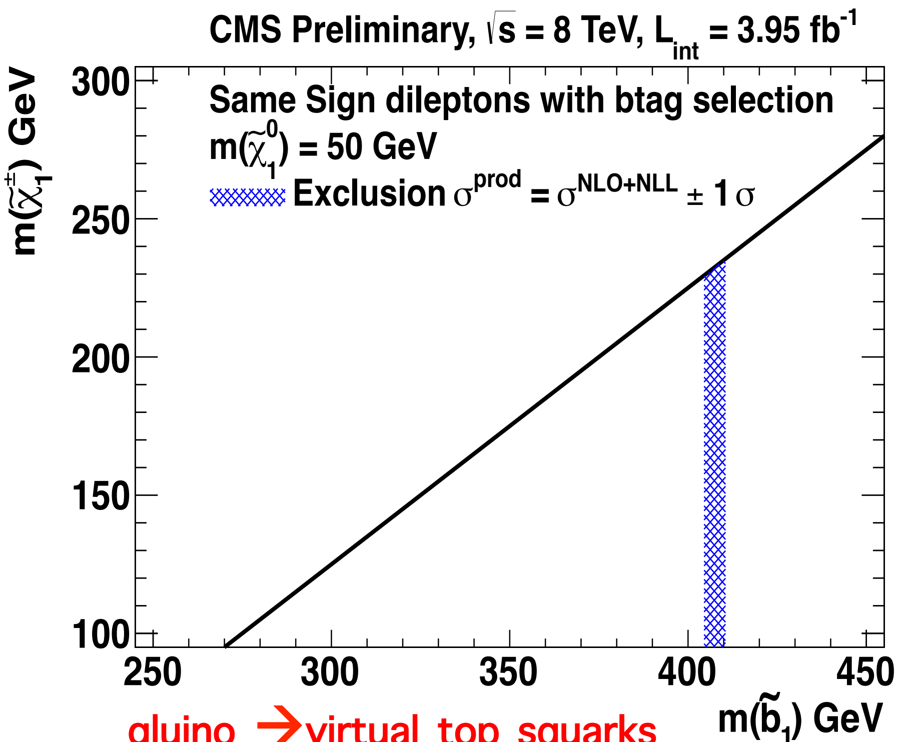
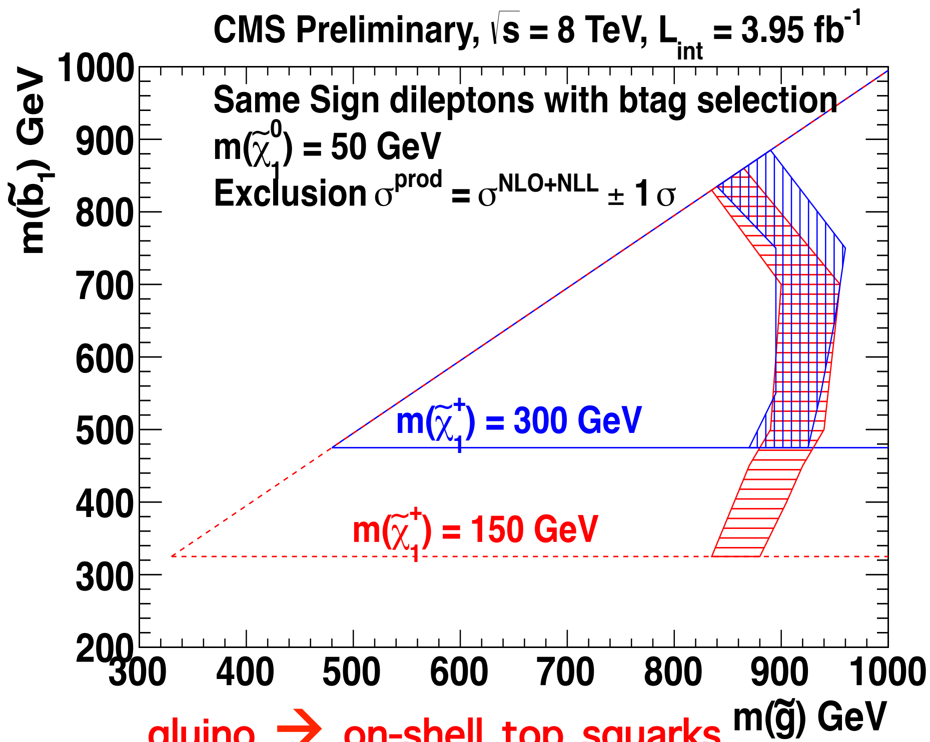
Interpretation of the results

PAS-SUS-12-017

Simplified Model



gluino → virtual top squarks



gluino → on-shell top squarks

☞Gluinos have been excluded with masses up to approximately 900 GeV

☞Lower limit on the bottom squark mass of 407 GeV.

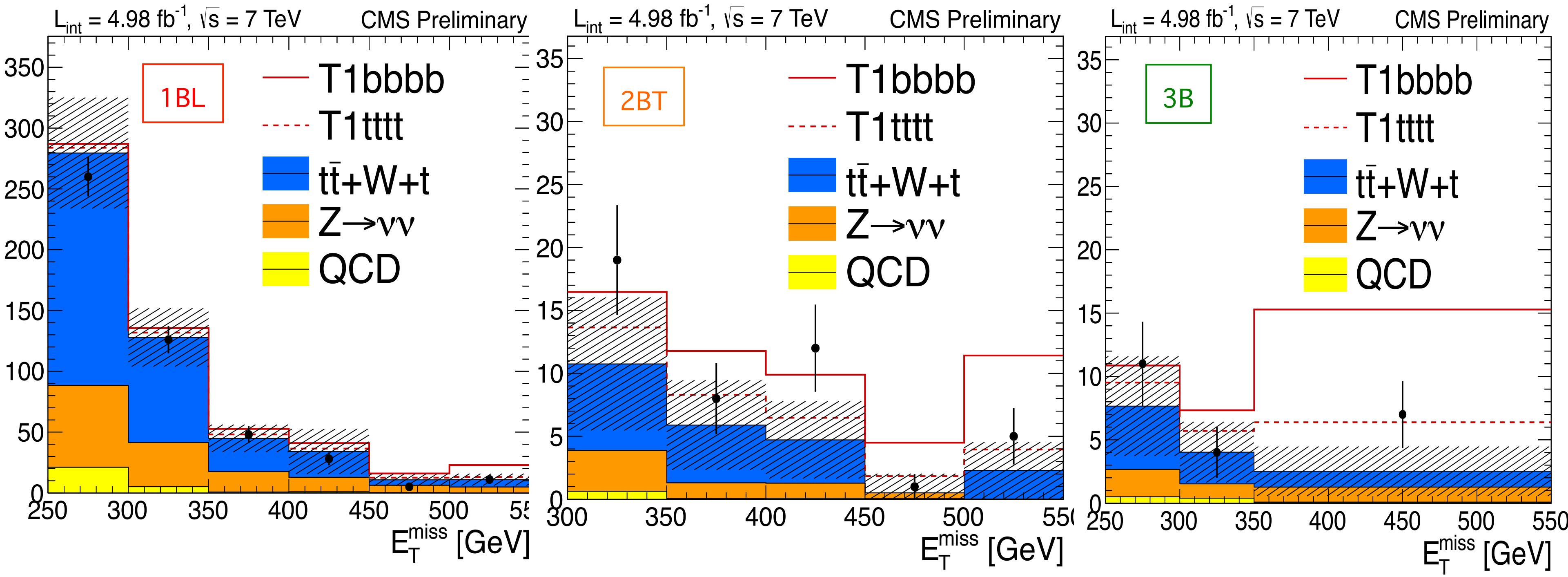
PAS-SUS-12-017

→ For multiple bottom final states → see Pablo Arbol`s talk!

Search for new physics in events with b-quark jets and missing transverse energy in pp collisions at $\sqrt{s}$ = 7 TeV

PAS-SUS-12-003

☞The SM background estimates from the data-based background procedures in comparison with the observed number of events in data.



1BL → 1B-Loose selection

HT > 400 GeV, MET > 250 GeV

Nbjets ≥ 1

2BT → 2B-Tight selection

HT > 600 GeV, MET > 300 GeV

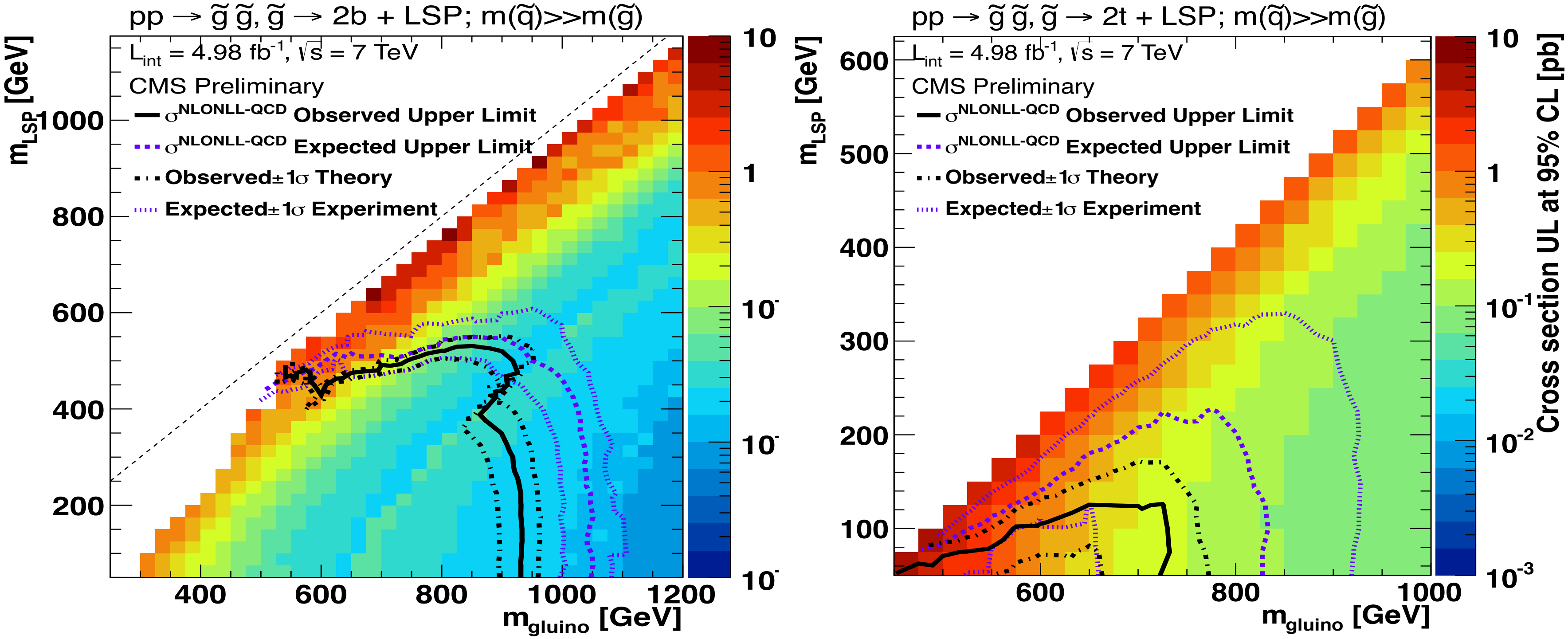
Nbjets ≥ 2

3B → 3B selection

HT > 400 GeV, MET > 200 GeV

Nbjets ≥ 3

Simplified Models



☞ 95% CL observed **cross section upper limits for multi top and bottom quarks final states.**

☑ No excess beyond the SM expectations

PAS-SUS-12-003

☑ Set limits on new physics in the context of the b-jet rich simplified model

Summary

☞ Variety of searches for SUSY events with 3rd generation squarks and sleptons

☞ Exploring signatures with heavy quarks or tau leptons using **L = 4.98/fb data at √s= 7 TeV (2011)** **and** **L = 3.95/fb data at √s= 8 TeV (2012)** in the CMS Collaboration

- ☑ 1 lepton + 1 and 3 bjets → cMSSM and simplified model (multiple top quarks)
- ☑ 1 lepton + 0,1,2 bjets → cMSSM and simplified model (multiple top quarks)
- ☑ 1 or 2 tau leptons → GMSB scenario and simplified model (multiple tau leptons)
- ☑ 2 lepton (SS) + 2 bjets → cMSSM and simplified model (multiple top quarks)
- ☑ 0 lepton + 1,2,3 bjets → cMSSM and simplified models (multiple top and bottom quarks)

✓ No significant excess observed over SM expectations → Limits on the masses of the sparticles in a various SUSY scenarios

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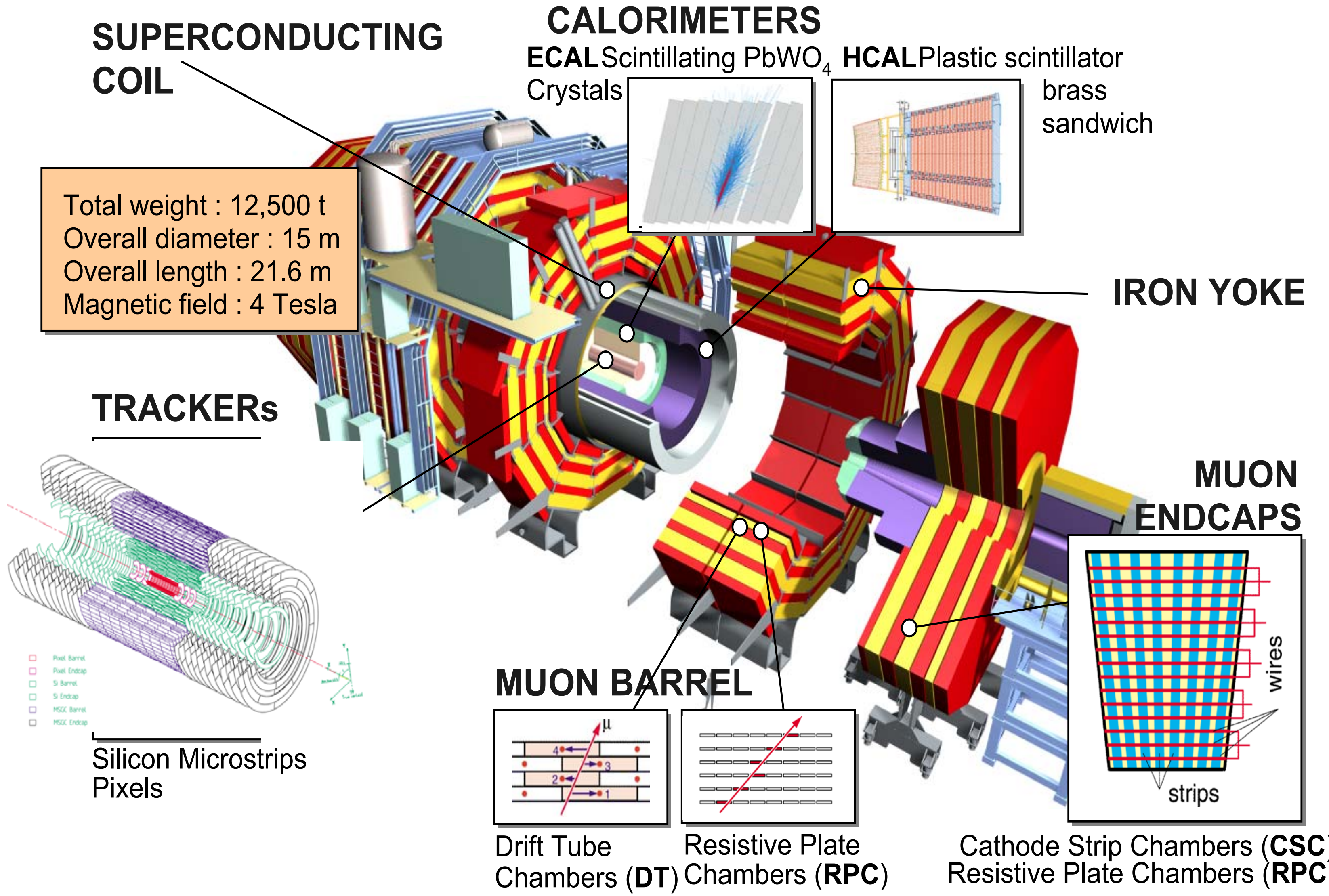
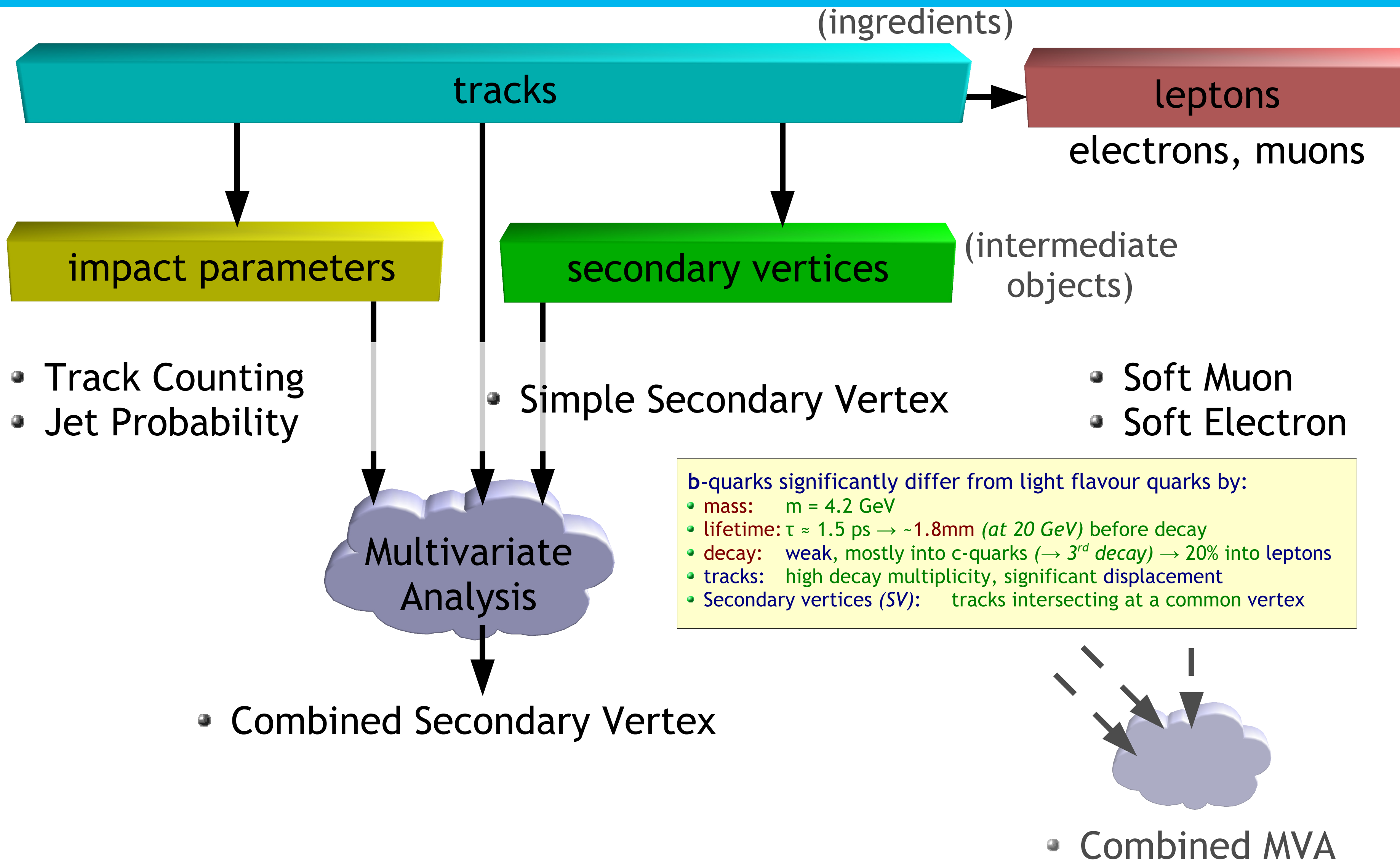
BACKUP

Compact Muon Solenoid (CMS) Experiment



B-Tagging Schema



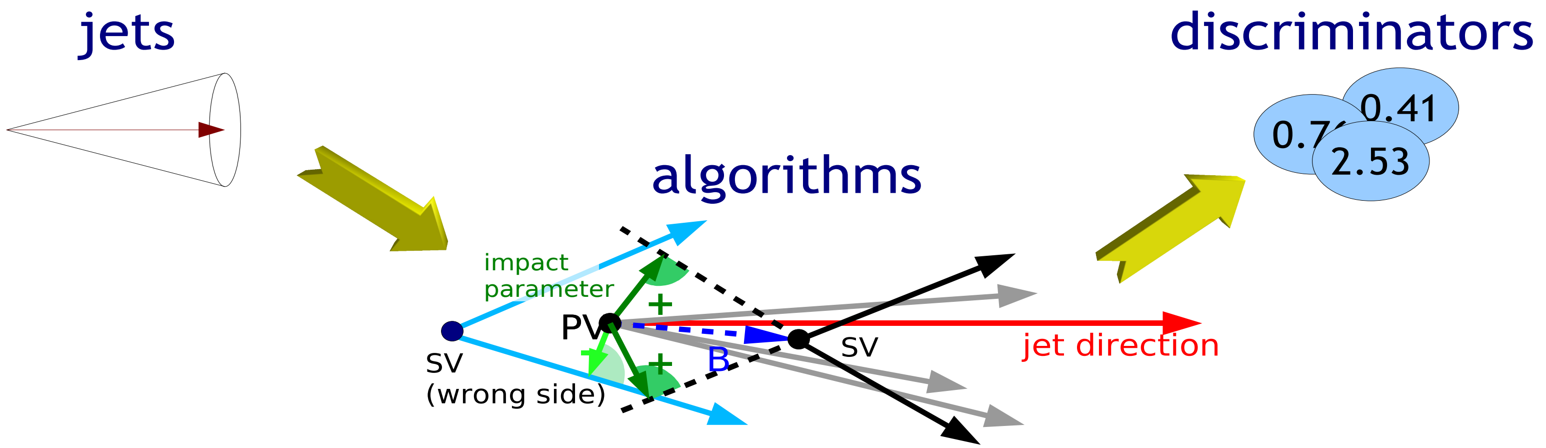
b-quarks significantly differ from light flavour quarks by:

- mass: m = 4.2 GeV
- lifetime: $\tau \approx$ 1.5 ps → ~1.8mm *(at 20 GeV)* before decay
- decay: weak, mostly into c-quarks *(→ 3^{rd} decay)* → 20% into leptons
- tracks: high decay multiplicity, significant displacement
- Secondary vertices *(SV)*: tracks intersecting at a common vertex

B-Tagging Algorithm

"Track Counting" algorithm: This is a very simple tag, exploiting the long lifetime of B hadrons. It calculates the signed impact parameter significance of all good tracks, and orders them by decreasing significance. Its b tag discriminator is defined as the significance of the N'th track. It comes in two variations for N = 2 (high efficiency) or N = 3 (high purity).

"Combined Secondary Vertex" algorithm: This sophisticated and complex tag exploits all known variables, which can distinguish b from non-b jets. Its goal is to provide optimal b tag performance, by combining information about impact parameter significance, the secondary vertex and jet kinematics.



PAS-SUS-11-028

- Factorization method (also called ABCD method) is used:
- Hypothesis: H_T and Y_{MET} are **not strongly correlated**

$$k := \frac{N_A \times N_D}{N_B \times N_C} \qquad \hat{N}_D := k \frac{N_B \times N_C}{N_A}$$

K≠1 to account for correlation where K is taken from MC

1.20 ± 0.13

Control regions / Signal region

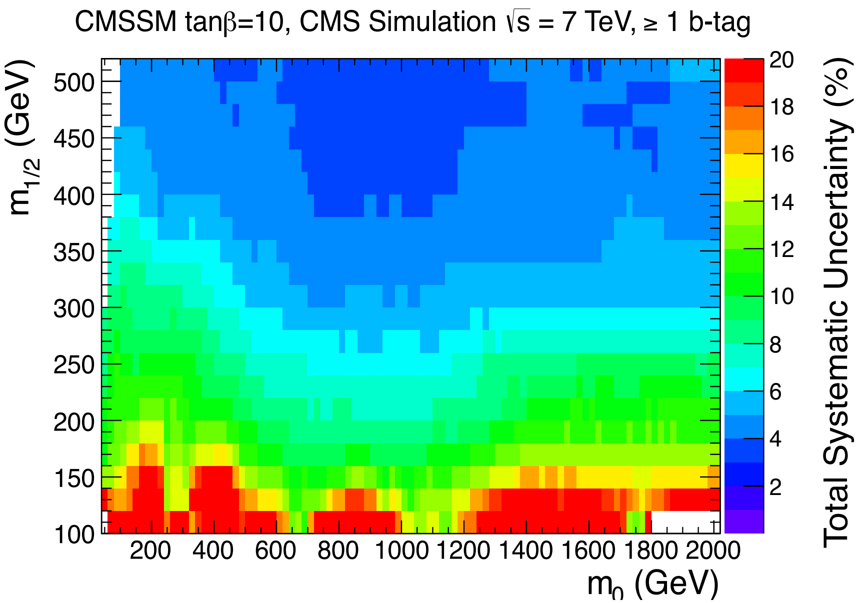
	Regions Boundaries H_T	Y_{MET}
Control regions	A: $375 < H_T < 650$	$3.25 < Y_{MET} < 5.5$
Control regions	B: $650 < H_T$	$3.25 < Y_{MET} < 5.5$
Control regions	C: $375 < H_T < 650$	$5.5 < Y_{MET}$
Signal region	D: $650 < H_T$	$5.5 < Y_{MET}$

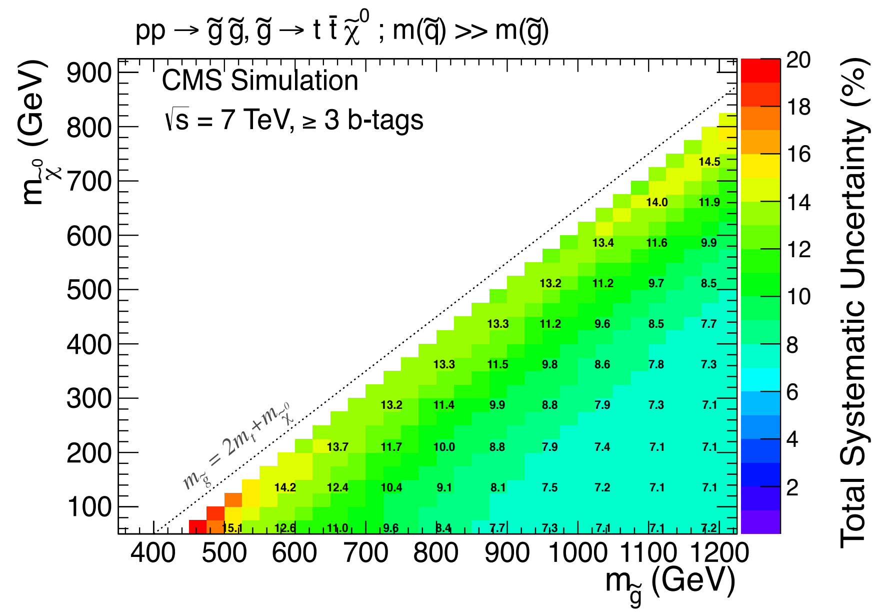
Variation	$\Delta\kappa$ (0 b-tags)	$\Delta\kappa$ (1 b-tag)	$\Delta\kappa$ (2 b-tags)	$\Delta\kappa$ ($\geq$ 3 b-tags)	$\Delta\kappa$ ($\geq$ 1 b-tags)
JES	±7.5%	±2.2%	±1.4%	±4.0%	±1.5%
JER	±4.2%	±1.7%	±1.8%	±5.5%	±1.1%
p_T lepton	±0.6%	±1.5%	±0.7%	±1.2%	±0.7%
Uncl. energy	±3.1%	±0.3%	±0.7%	±0.8%	±0.4%
Pile-up	±1.7%	±0.5%	±1.1%	±0.9%	±0.8%
B-tag SF	±0.3%	±0.1%	±0.1%	±0.1%	±0.0%
Mis-tag SF	±0.0%	±0.1%	±0.0%	±0.1%	±0.1%
Cross-sect. var.	±3.4%	±1.0%	±2.0%	±1.4%	±0.4%
0b-data	±10.0%	±10.0%	±10.0%	±10.0%	±10.0%
Total syst. uncert.	±14.1%	±10.6%	±10.5%	±12.3%	±10.3%
Stat. error	±11.8%	±4.9%	±4.6%	±6.2%	±3.3%

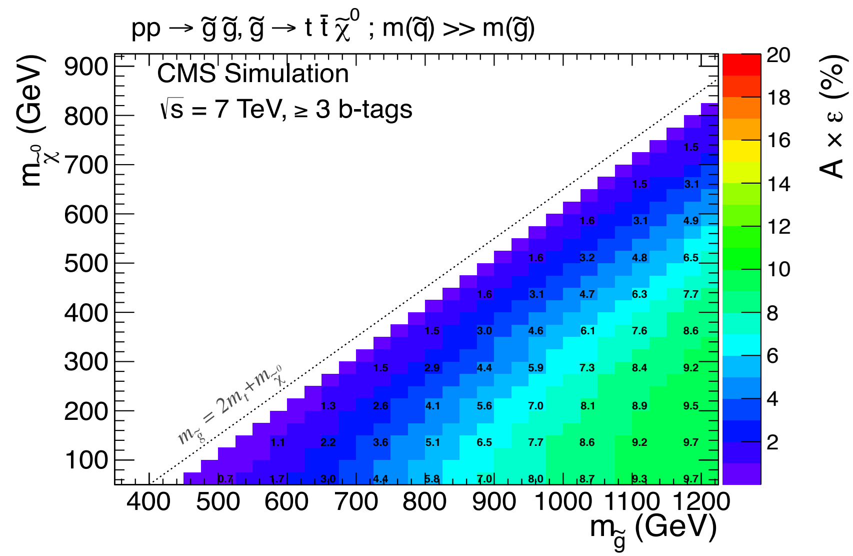
Variation	ΔN_D (0 b-tags)	ΔN_D (1 b-tag)	ΔN_D (2 b-tags)	ΔN_D ($\geq$ 3 b-tags)	ΔN_D ($\geq$ 1 b-tags)
JES	±26.3 %	±20.9 %	±17.9 %	±17.1 %	±19.6 %
JER	±7.7 %	±6.1 %	±7.0 %	±9.5 %	±6.7 %
p_T lepton	±2.3 %	±1.8 %	±2.0 %	±2.2 %	±1.9 %
Uncl. energy	±2.1 %	±0.3 %	±0.3 %	±0.3 %	±0.3 %
Pile-up	±0.2 %	±0.7 %	±0.3 %	±0.2 %	±0.5 %
B-tag SF	±2.3 %	±0.9 %	±3.8 %	±7.4 %	±1.5 %
Mis-tag SF	±1.9 %	±0.6 %	±1.1 %	±5.7 %	±1.2 %
Model uncert.	±16.0 %	±16.0 %	±16.0 %	±16.0 %	±16.0 %
Lep. trig. & ID	±3.0 %	±3.0 %	±3.0 %	±3.0 %	±3.0 %
Lumi. uncert.	±2.2 %	±2.2 %	±2.2 %	±2.2 %	±2.2 %
Total uncert.	±32.2 %	±27.3 %	±25.7 %	±27.3 %	±26.6 %
Stat. error	±8.4 %	±3.4 %	±3.1 %	±4.3 %	±2.2 %

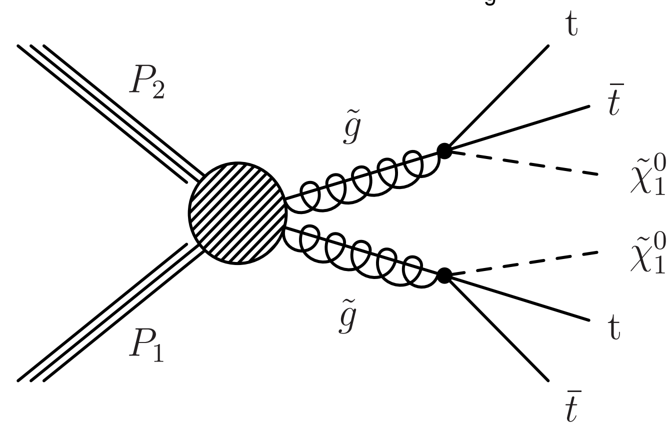
PAS-SUS-11-028

☞ Systematical uncertainties for cMSSM and simplified model









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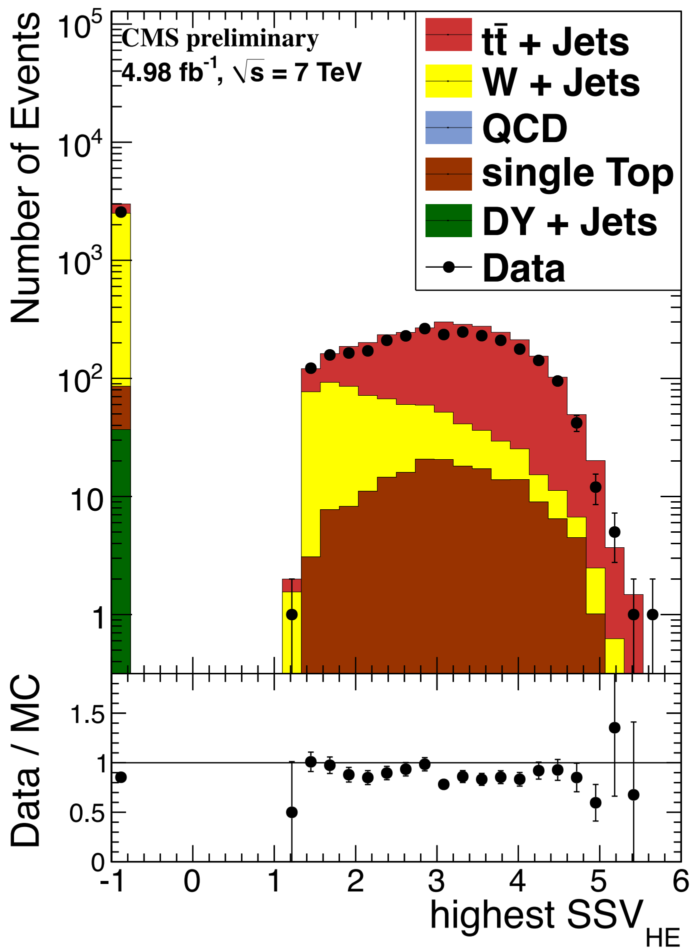

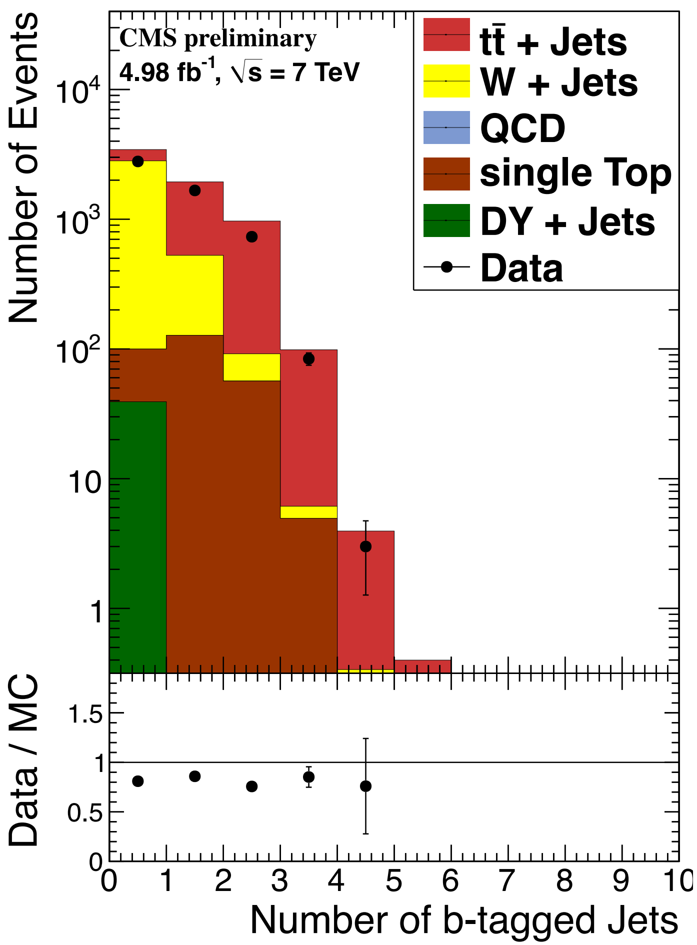

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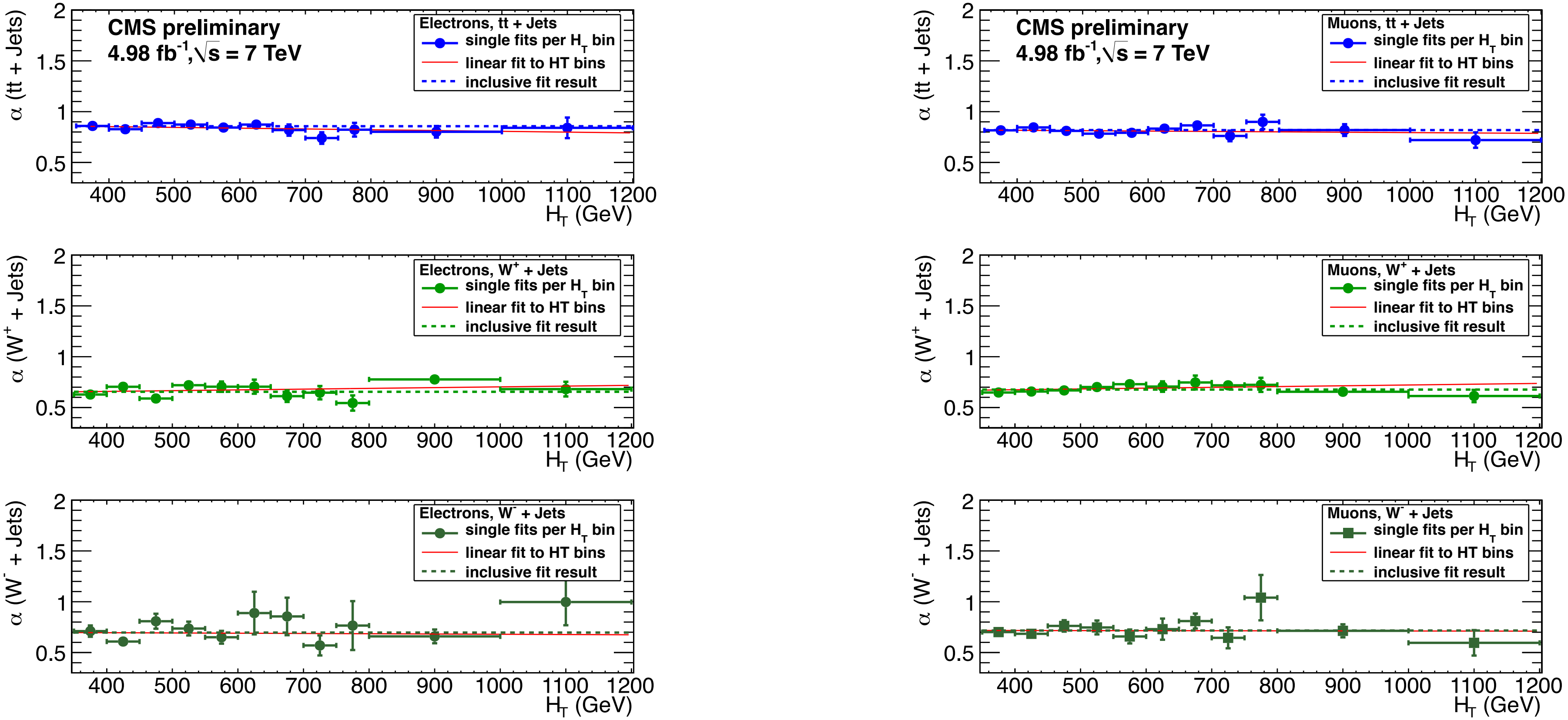
PAS-SUS-11-027

- It is the complete MET model for an HT interval/bin.

$$\mathcal{M}_i(x) \sim x \exp(-\alpha x^{0.5}) \times (1 + \mathrm{erf}(x; b_0 + b_1 H_{T,i}, c_0 + c_1 H_{T,i})) \times (1 - \mathrm{erf}(x; b_0 + b_1 H_{T,i+1}, c_0 + c_1 H_{T,i+1})).$$



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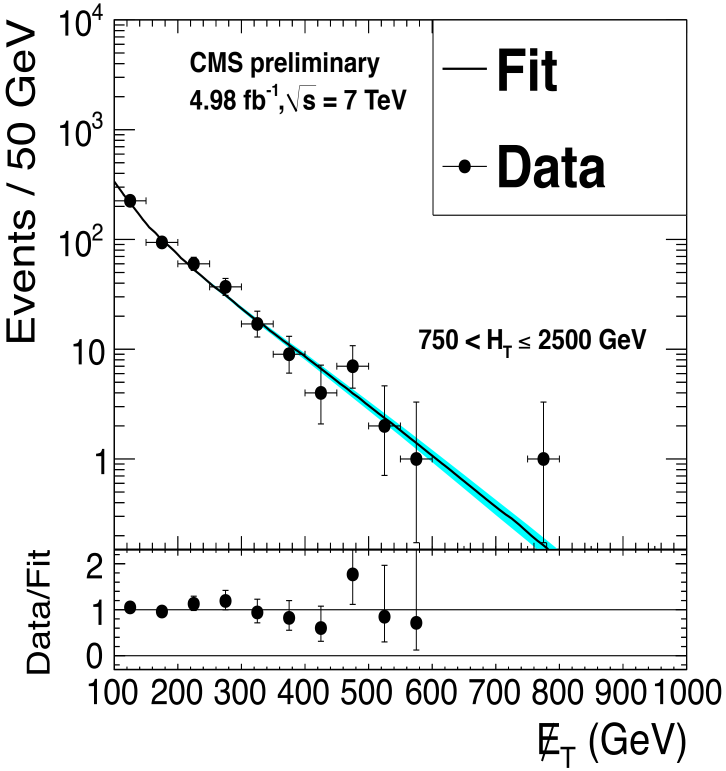
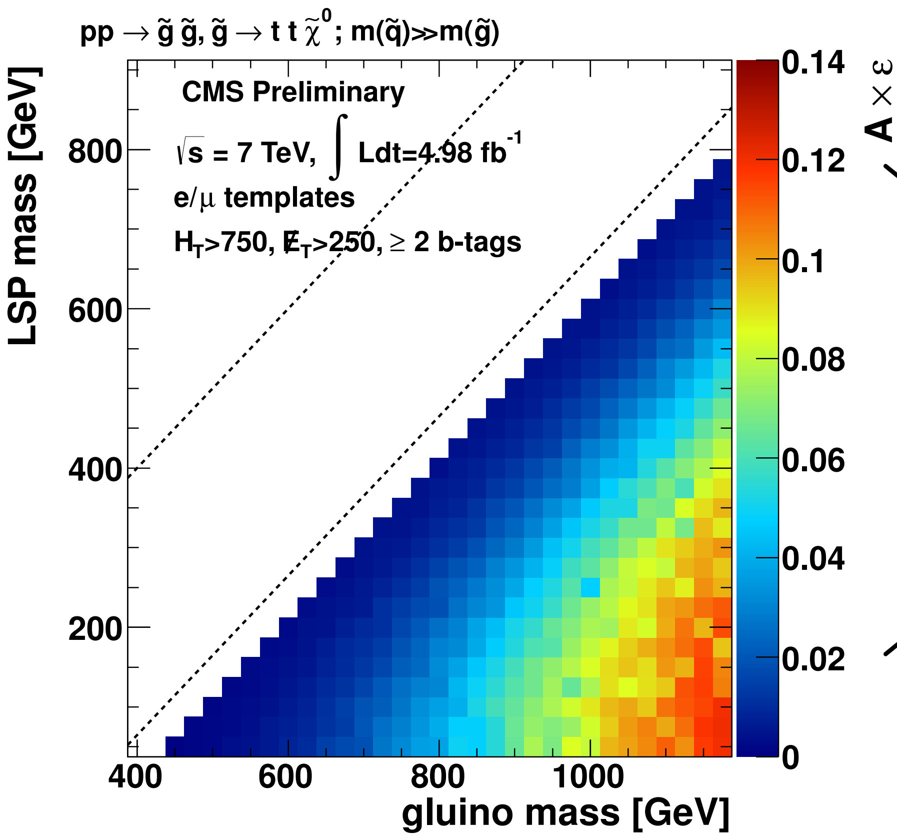
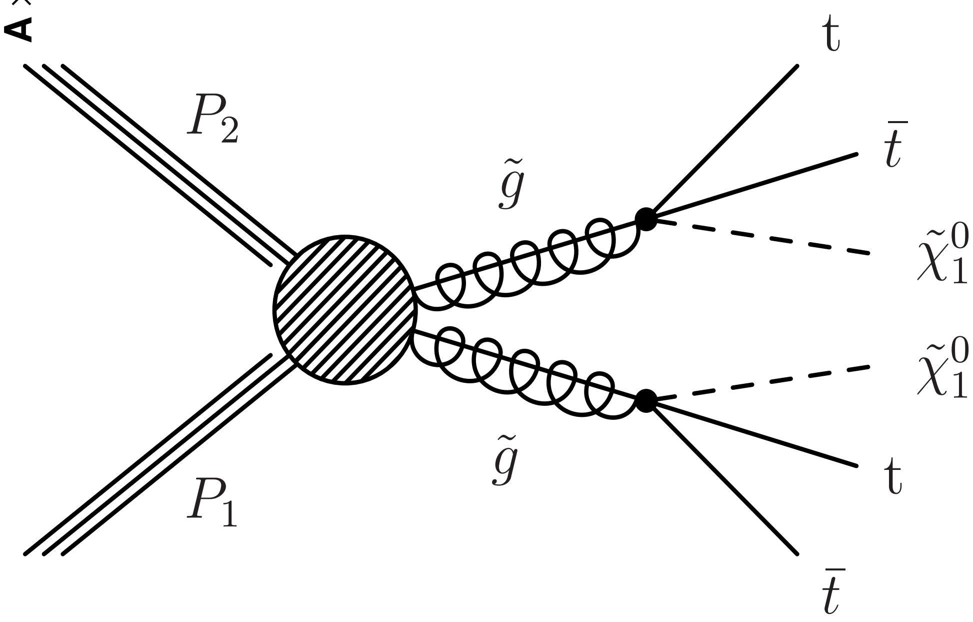


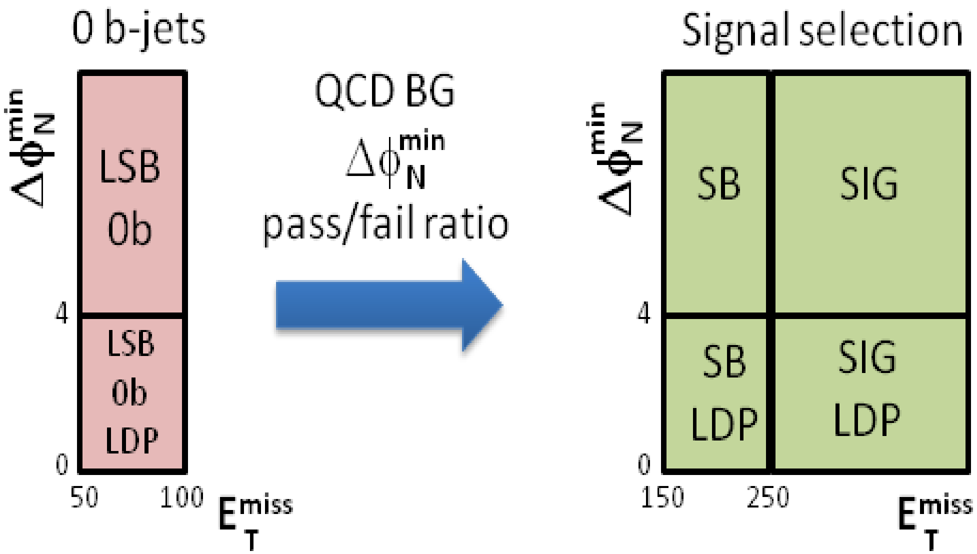
Source	μ channel total	μ 0-tag	μ $\geq$ 1-tag	e channel total	e 0-tag	e $\geq$ 1-tag
Jet and E_T^{miss} scale	6.0 %	7.5 %	7.2 %	3.1 %	5.6 %	2.1 %
W polarization (1), $\pm$10%	0.5 %	0.6 %	0.1 %	1.3 %	1.8 %	0.2 %
W^- polarization (2), $\pm$5%	0.3 %	0.5 %	0.1 %	0.5 %	0.5 %	0.2 %
W^+ polarization (2), $\pm$5%	0.1 %	0.2 %	0.1 %	0.1 %	0.1 %	0.1 %
W polarization (3), $\pm$ 10%	0.0 %	0.1 %	0.0 %	0.5 %	0.6 %	0.2 %
vary lep. eff. at low p_T	0.4 %	0.3 %	0.6 %	0.6 %	1.3 %	0.7 %
vary lep. eff. in endcaps	0.2 %	0.2 %	0.1 %	0.6 %	0.8 %	0.4 %
vary pile-up	0.1 %	0.1 %	0.2 %	0.3 %	1.5 %	0.4 %
Non-leading bkg $\pm$ 50%	0.7 %	0.4 %	0.4 %	4.0 %	3.0 %	6.2 %
dilep. contr $\pm$ 50%	0.1 %	0.5 %	0.7 %	0.6 %	1.2 %	0.6 %
σ($t\bar{t}$), $\pm$ 32%	1.2 %	2.3 %	1.6 %	0.7 %	1.8 %	2.0 %
σ(W+jets), $\pm$ 32%	1.3 %	2.9 %	2.3 %	2.6 %	1.6 %	2.8 %
exponent $t\bar{t}$ $\pm$ 10%	1.6 %	0.2 %	5.3 %	1.8 %	0.3 %	4.8 %
exponent W^++jets $\pm$ 10%	3.5 %	4.4 %	1.3 %	3.6 %	4.6 %	1.5 %
exponent W^-+jets $\pm$ 10%	0.7 %	0.8 %	0.3 %	0.9 %	1.4 %	0.9 %
α slope $t\bar{t}$	11.0 %	2.4 %	29.3 %	14.8 %	5.0 %	34.3 %
α slope W^++jets	15.9 %	20.6 %	6.0 %	16.5 %	22.2 %	5.1 %
α slope W^-+jets	4.9 %	8.2 %	2.0 %	5.6 %	8.7 %	0.5 %
Variation of Erfc.	4.1 %	4.6 %	2.9 %	3.1 %	3.2 %	2.7 %

Source	μ channel total	μ 0-tag	μ 1-tag	μ $\geq$ 1-tag	μ $\geq$ 2-tag	e channel total	e 0-tag	e 1-tag	e $\geq$ 1-tag	e $\geq$ 2-tag
W+jets/$t\bar{t}$ ratio	2.9 %	2.1 %	6.1 %	4.8 %	2.4 %	1.1 %	2.4 %	2.6 %	2.3 %	2.3 %
b-tagging efficiency $\pm 1\sigma$	2.0 %	1.5 %	2.2 %	1.3 %	5.1 %	2.2 %	1.6 %	0.8 %	1.7 %	3.6 %
mistag rate $\pm 1\sigma$	0.4 %	0.4 %	0.7 %	0.9 %	0.6 %	0.3 %	0.4 %	0.4 %	0.2 %	0.1 %

PAS-SUS-11-027







$$\Delta\phi_{\mathrm{N}}^{\mathrm{min}} \equiv \min(\Delta\phi_i / \sigma_{\Delta\phi,i})$$

$$\sigma_{T_i}^2 \approx \sum_n (\sigma_{p_{\mathrm{T}},n} \sin\alpha_n)^2$$

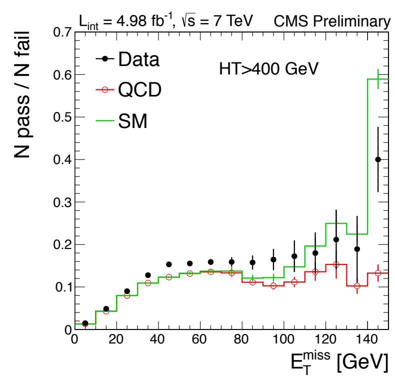
$$\sigma_{\Delta\phi,i} = \arctan(\sigma_{T_i} / E_{\mathrm{T}}^{\mathrm{miss}})$$

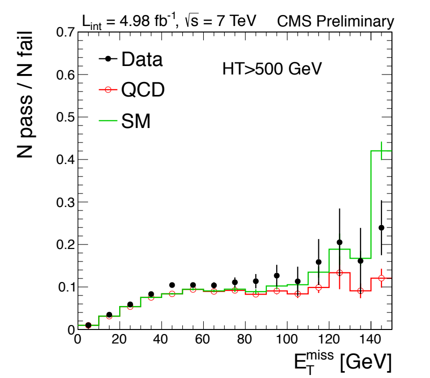
SB=Side Band, LSB=Low Side Band
LDP=Low Delta Phi, SIG=Signal

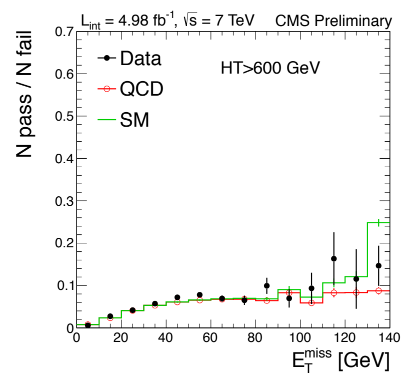
QCD background

$$N_{SIG}^{QCD} = \frac{N_{LSB}}{N_{LSB-LDP}} \times (N_{SIG-LDP} - N_{SIG-LDP}^{top,MC} - N_{SIG-LDP}^{EW,MC}),$$

$$N_{SB}^{QCD} = \frac{N_{LSB}}{N_{LSB-LDP}} \times (N_{SB-LDP} - N_{SB-LDP}^{top,MC} - N_{SB-LDP}^{EW,MC}),$$







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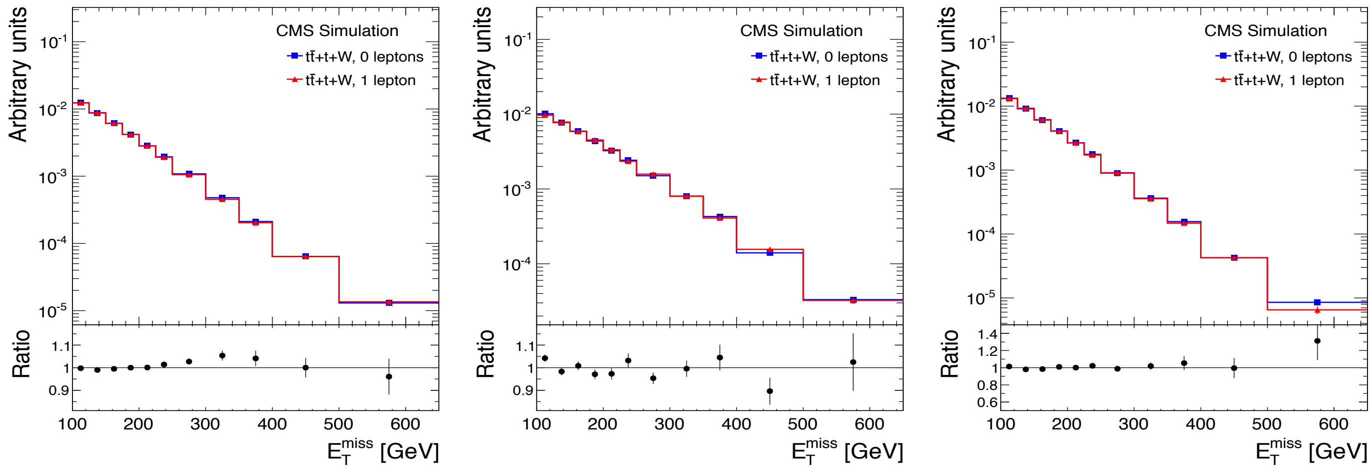
PAS-SUS-12-003

Top and W+jets background (nominal)

$$N_{SIG}^{top+W} = \frac{N_{SIG-SL}}{N_{SB-SL}} \times (N_{SB} - N_{SB}^{Z\rightarrow\nu\bar{\nu}} - N_{SB}^{QCD} - N_{SB}^{other,MC}).$$



Z +jets background

Z→μμ-to-νν replacement

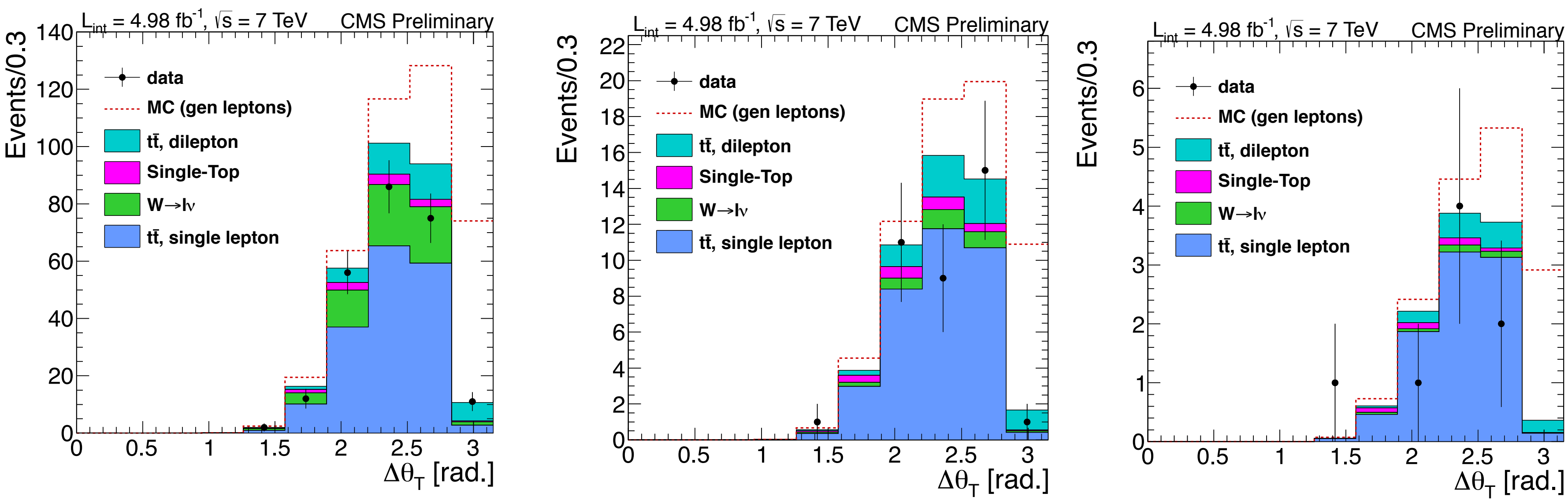
$$BR(Z \rightarrow \nu\bar{\nu})/BR(Z \rightarrow \mu^+\mu^-) = 5.95 \pm 0.02$$

$$\epsilon = \mathcal{A} \cdot \epsilon_{trig} \cdot \epsilon^2_{\ell\,reco} \cdot \epsilon^2_{\ell\,sel},$$

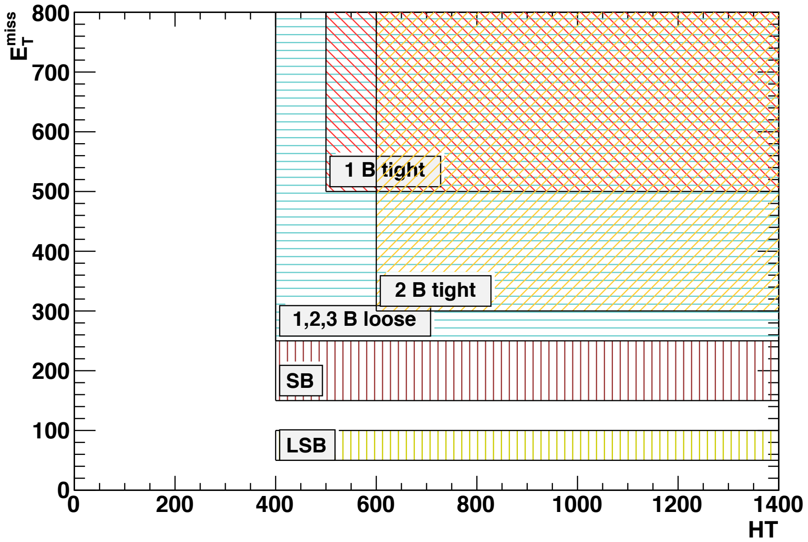
	1BL	1BT	2BL	2BT	3B
Scale factors	20 (17)	20 (17)	61 (49)	61 (49)	105 (144)
$Z \rightarrow \ell^+\ell^-$ background	8 (10)	8 (10)	8 (10)	8 (10)	8 (10)
Acceptance	3 (3)	8 (6)	3 (3)	4 (4)	3 (3)
Lepton selection efficiency	4 (5)	4 (5)	4 (5)	4 (5)	4 (5)
Trigger efficiency	5 (5)	5 (5)	5 (5)	5 (5)	5 (5)
MC closure	19 (11)	19 (11)	19 (11)	19 (11)	19 (11)
Total	30 (24)	30 (25)	65 (52)	65 (52)	107 (145)

Top and W+jets background (E_T^{miss}-reweighting)

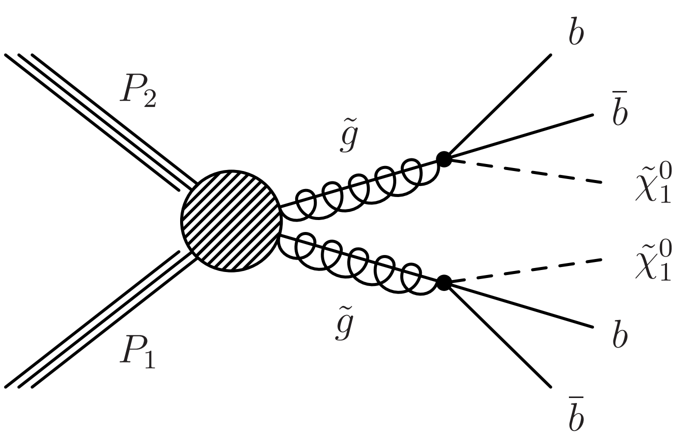
1. top or W+jets events in which exactly one W decays into an e or μ, or into a τ that decays into an e or μ, while the other W (if any) decays hadronically;
2. top or W+jets events in which exactly one W decays into a hadronically-decaying *τ,* while the other W (if any) decays hadronically;
3. tt events in which both W bosons decay into an e, *μ* or *τ,* with the *τ* decaying either leptonically or hadronically.

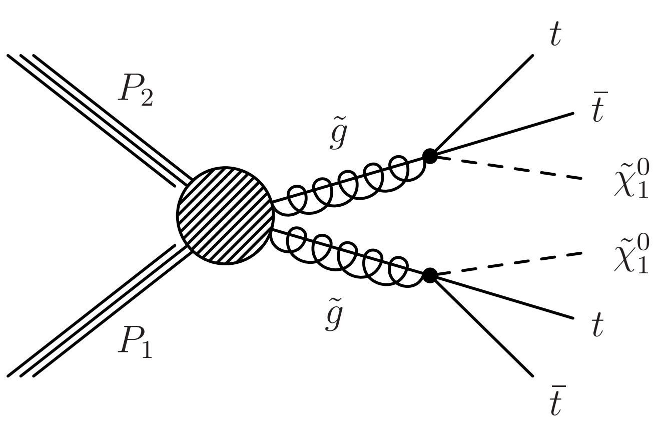


PAS-SUS-12-003



Signal region		H_T (GeV)	E_T^{miss} (GeV)	N_{bjets}
1b-loose	1BL	> 400	> 250	≥ 1
1b-tight	1BT	> 500	> 500	≥ 1
2b-loose	2BL	> 400	> 250	≥ 2
2b-tight	2BT	> 600	> 300	≥ 2
3b	3B	> 400	> 250	≥ 3





PAS-SUS-12-004 (needs to be improved – later!)

Background Estimate for Single Tau Analysis

☞ Several energy corrections will be applied before the computation of HT and MHT.

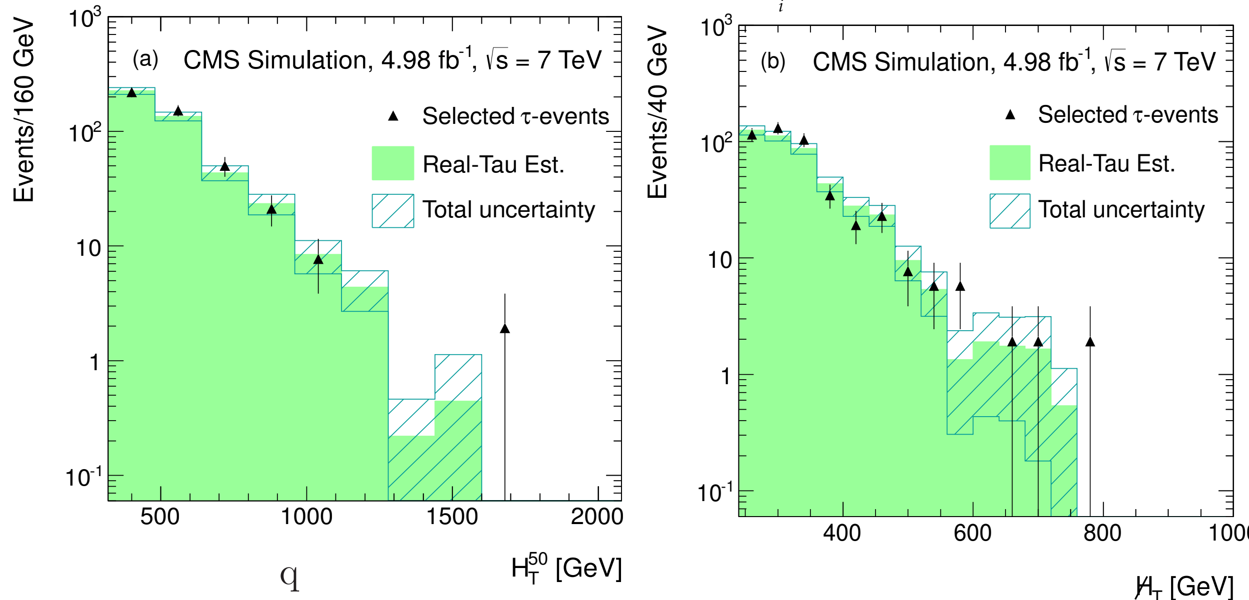
$$f_{event}^{corr} = \frac{p_{\mu}^{W} \times \epsilon_{\tau}^{ID} \times f_{\tau}^{bf(hadr)}}{\epsilon_{\mu}^{reco} \times \epsilon_{\mu}^{iso}}$$

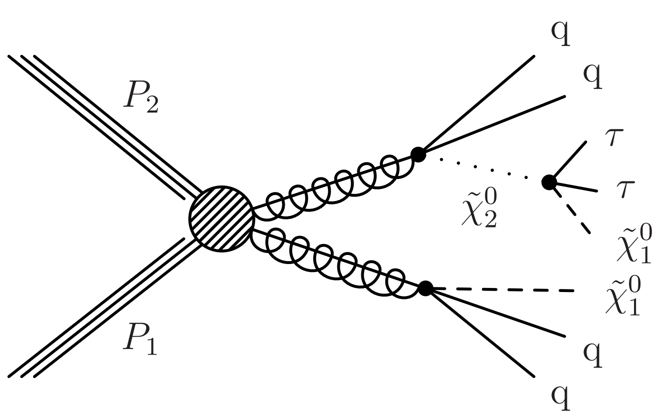
- Muon reconstruction efficiency
- Muon isolation efficiency
- Muons produced in tau decays
- Tau reconstruction efficiency
- Tau hadronic branching fraction

Estimate of Fake-Tau Background

The fake rates f_i of jet i are used as individual events weights in the following form:

$$f_{event}^{corr} = 1 - \prod_{i}(1 - f_i), \quad f_i = f_i(p_{\mathrm{T}}^{i}, \eta^{i})$$





Simplified Model for multi tau states

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PAS-SUS-12-004 (needs to be improved – later!)

Background Estimate for Di-Tau Analysis

We measure correction factors and/or selection efficiencies in control regions (CRs) and use these values to extrapolate to the region where we expect to observe our signal. A novel approach is to use the observed jet multiplicity in each CR along with measured jet $\rightarrow \tau h$ misidentification rate to calculate the yield in the signal regions (SR).

$$N^{SR}_{Background} = N^{CR}_{Background}[\alpha_{\tau\tau}\mathcal{P}(0) + \alpha_{\tau j}\mathcal{P}(1) + \alpha_{jj}\mathcal{P}(2)]$$

tt estimation

$$\begin{aligned} N^{Signal}_{t\bar{t}} &= A_{\tau+j}\frac{N^{CR}_{t\bar{t}}}{P(2\ b\text{-jets})}\varepsilon^{\tau\ \text{iso}}\sum_{N=1}^{\infty}P(N)\sum_{n=1}^{N}C(N,n)f^{n}(1-f)^{N-n} \\ &+ A_{j+j}\frac{N^{CR}_{t\bar{t}}}{P(2\ b\text{-jets})}\sum_{M=2}^{\infty}P(M)\sum_{m=2}^{M}C(M,m)f^{m}(1-f)^{M-m} \end{aligned}$$

Z→νν estimation

$$N^{Signal}_{Z\rightarrow\nu\nu+jets} = \frac{N^{CR}_{Z\rightarrow\mu\mu+jets}}{A^{2}_{\mu}\varepsilon^{2}_{\mu}}\frac{B(Z\rightarrow\nu\nu)}{B(Z\rightarrow\mu\mu)}\frac{\varepsilon^{Trigger}_{\not{H}_{T}}}{\varepsilon^{Trigger}_{\mu\tau}}\varepsilon^{\not{H}_{T}}\sum_{N=2}^{\infty}P(N)\sum_{n=2}^{N}C(N,n)f^{n}(1-f)^{N-n}$$

Z→ττ estimation

$$\begin{aligned} N^{Signal}_{Z\rightarrow\tau\tau} &= N^{CR}_{Z\rightarrow\mu\mu}R\varepsilon^{\not{H}_{T}}\frac{A^{2}_{\tau}\varepsilon^{2}_{\tau}}{A^{2}_{\mu}\varepsilon^{2}_{\mu}} \\ &+ N^{CR}_{Z\rightarrow\mu\mu}R\varepsilon^{\not{H}_{T}}\frac{A^{2}_{\tau}(2\varepsilon_{\tau}(1-\varepsilon_{\tau}))}{A^{2}_{\mu}\varepsilon^{2}_{\mu}}\sum_{N=1}^{\infty}P(N)\sum_{n=1}^{N}C(N,n)f^{n}(1-f)^{N-n} \\ &+ N^{CR}_{Z\rightarrow\mu\mu}R\varepsilon^{\not{H}_{T}}\frac{2A_{\tau}(1-A_{\tau})\varepsilon_{\tau}}{A^{2}_{\mu}\varepsilon^{2}_{\mu}}\sum_{M=1}^{\infty}P(M)\sum_{m=1}^{M}C(M,m)f^{m}(1-f)^{M-m} \\ &+ N^{CR}_{Z\rightarrow\mu\mu}R\varepsilon^{\not{H}_{T}}\frac{(1-A_{\tau})^{2}}{A^{2}_{\mu}\varepsilon^{2}_{\mu}}\sum_{K=2}^{\infty}P(K)\sum_{k=2}^{K}C(K,k)f^{k}(1-f)^{K-k} \end{aligned}$$

W+Jets estimation

$$\begin{aligned} N^{Signal}_{W+jets} &= A_{\tau+j}\frac{N^{\text{After subtraction}}_{W+jets}}{P(0\ b\text{-jets})}\varepsilon^{\tau\ \text{iso}}\sum_{N=1}^{\infty}P(N)\sum_{n=1}^{N}C(N,n)f^{n}(1-f)^{N-n} \\ &+ A_{j+j}\frac{N^{\text{After subtraction}}_{W+jets}}{P(0\ b\text{-jets})}\sum_{M=2}^{\infty}P(M)\sum_{m=2}^{M}C(M,m)f^{m}(1-f)^{M-m} \end{aligned}$$

$$R = \frac{B(Z\rightarrow\tau\tau)B(\tau\rightarrow\tau_{h})}{B(Z\rightarrow\mu\mu)}\frac{\varepsilon^{Trig}_{\not{H}_{T}}}{\varepsilon^{Trig}_{\mu\tau}},$$

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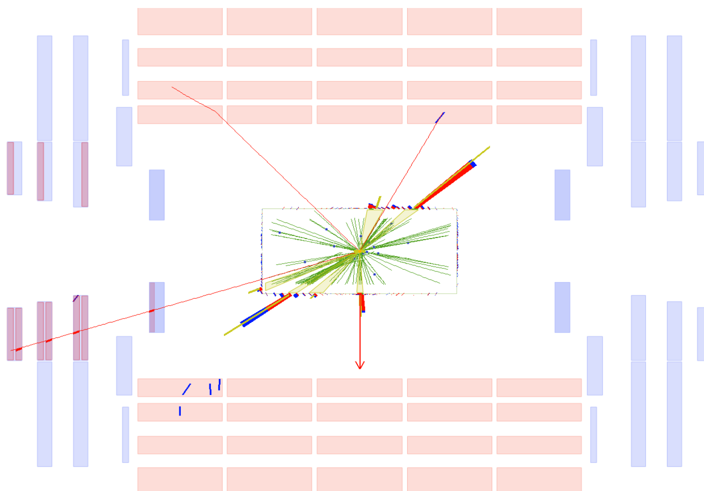
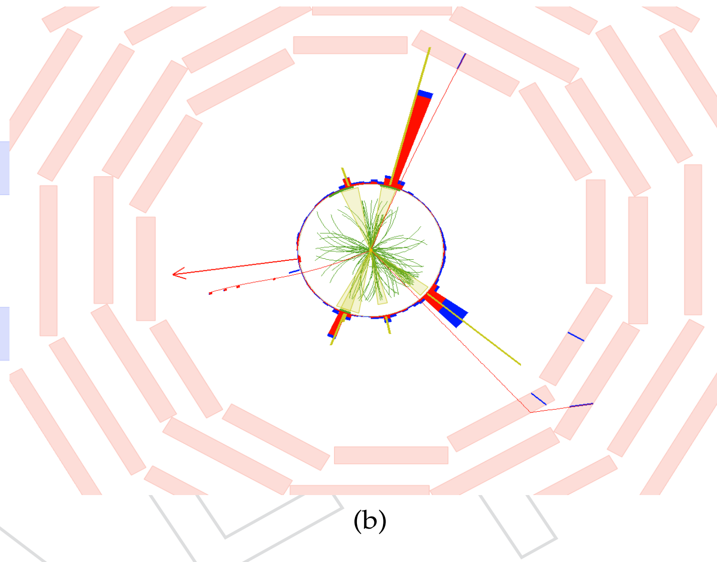
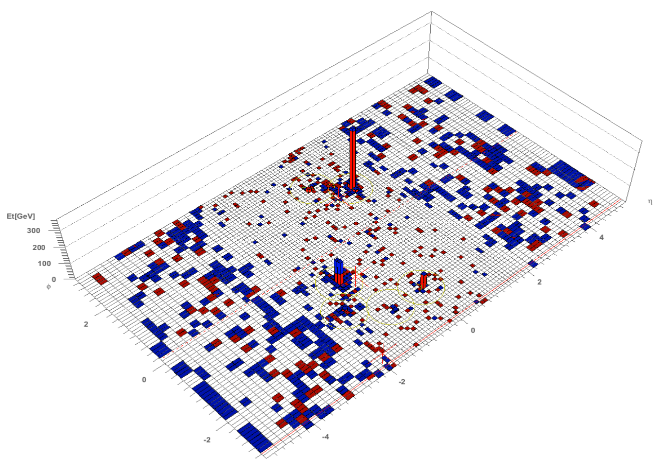
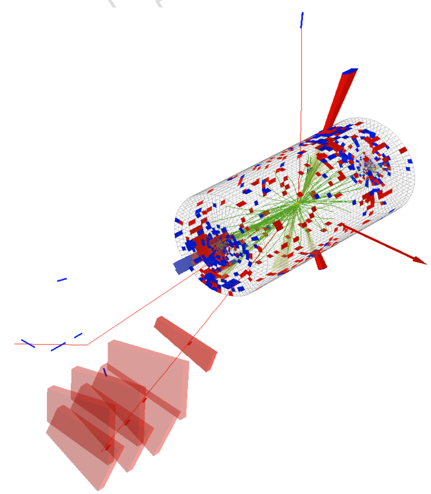


(a)



(b)





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