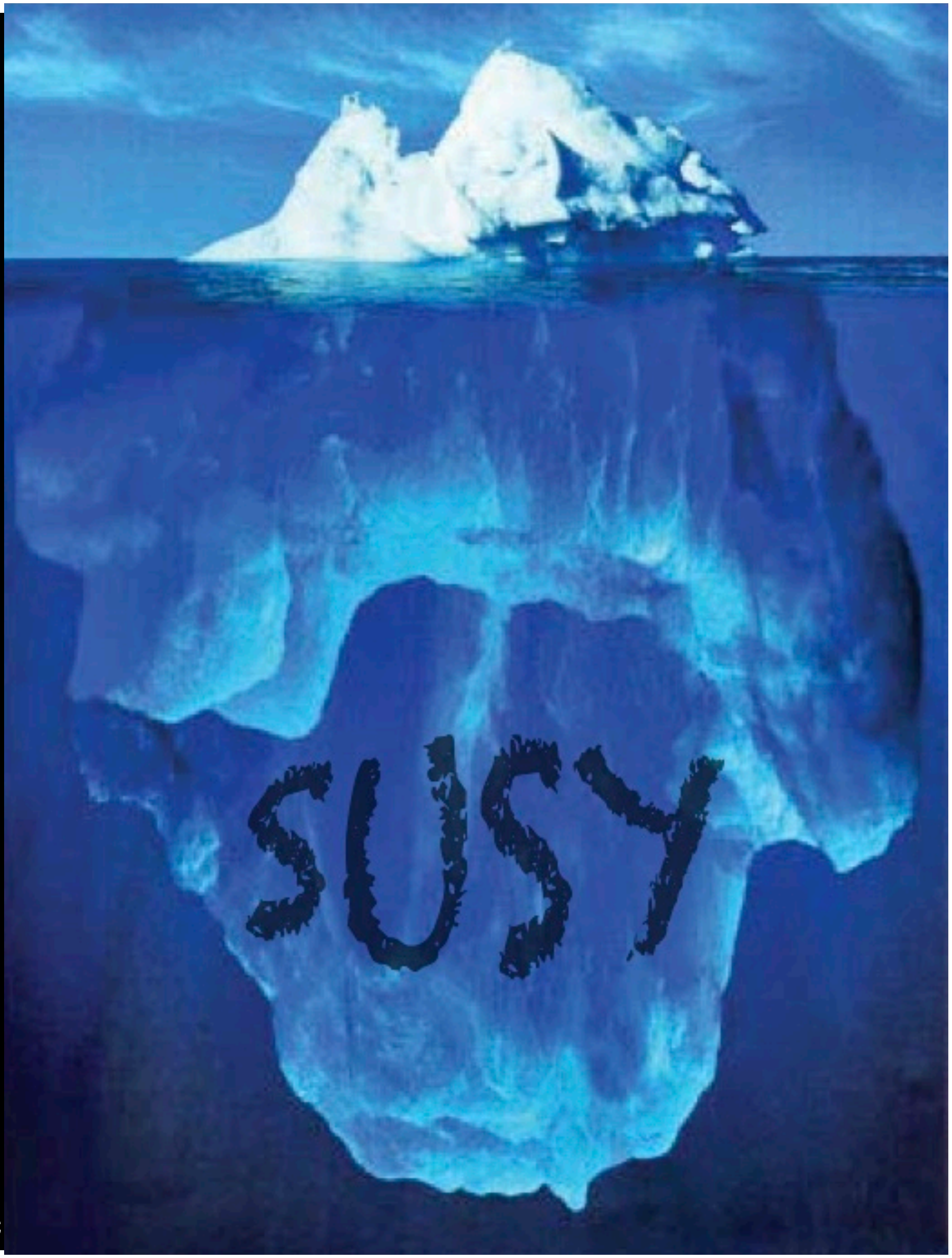
SUSY Status Report

David Stuart
UC Santa Barbara



SUSY Status Report?

SUSY Status Report?

Not yet.

SUSY Status Report?

Not yet. Check back next year.

SUSY Status Report? – a perturbative answer, 0^{th} order

"Squarks and gluinos excluded up to 1000 GeV…"

is a common sound bite.

SUSY Status Report? – a soundly bitten answer

“Squarks and gluinos excluded up to 1000 GeV…”

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NEWS SCIENCE & ENVIRONMENT

Aug 27: **LHC results put supersymmetry theory 'on the spot’**

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.

SUSY Status Report? – a perturbative answer, 1st order

Hadroproduction covered up to 500 or 1000 GeV

SUSY Status Report? – a reasonable answer

$\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ covered up to *maybe* 500 or 1000 GeV

SUSY Status Report? – a reasonable answer

$\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ covered up to maybe 500 or 1000 GeV

stop pair production unprobed so far.

Workshop on Searches for Supersymmetry at the LHC
LNBL, October 19-21

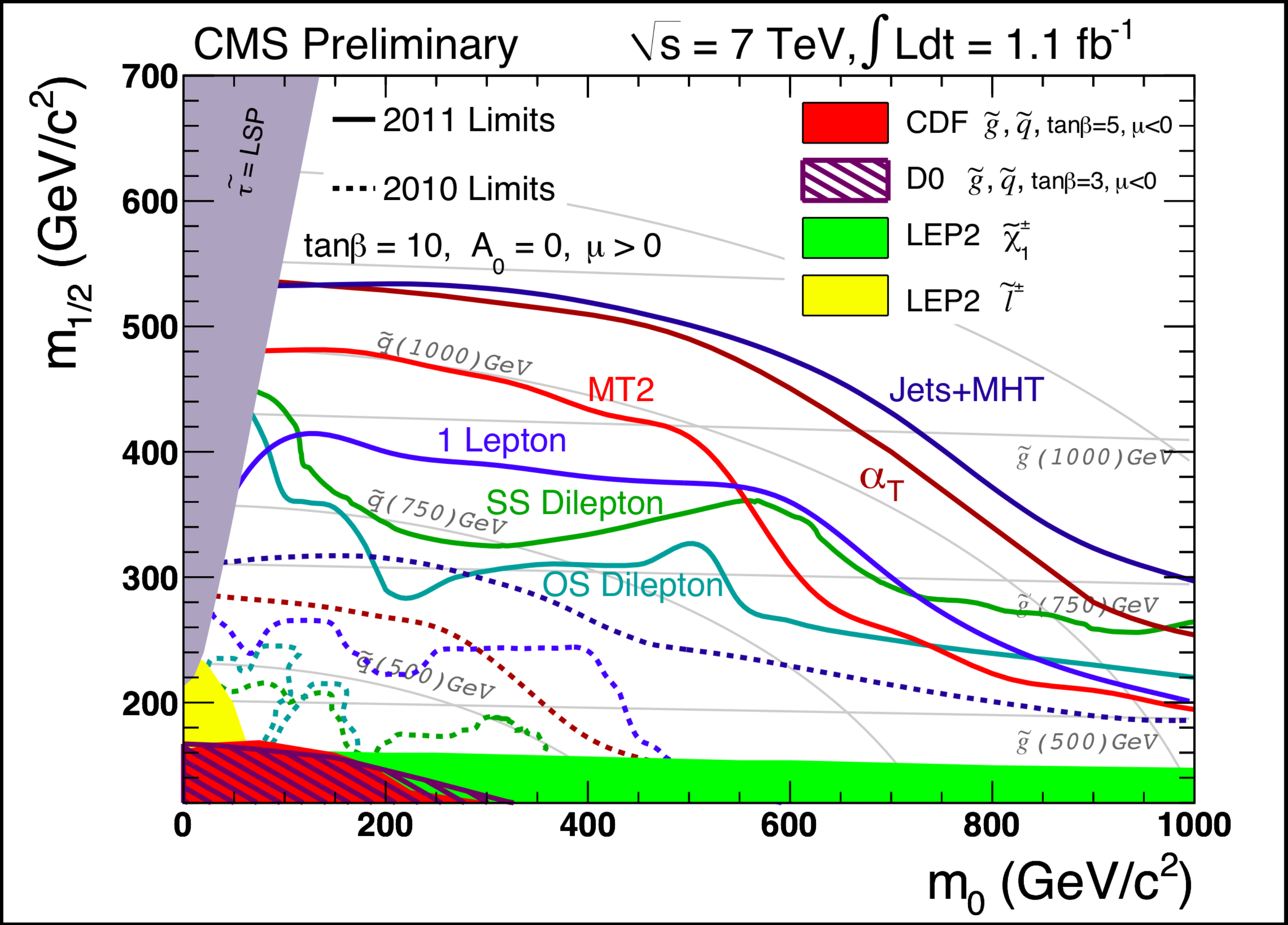
Outline

1. *Some* experimental results

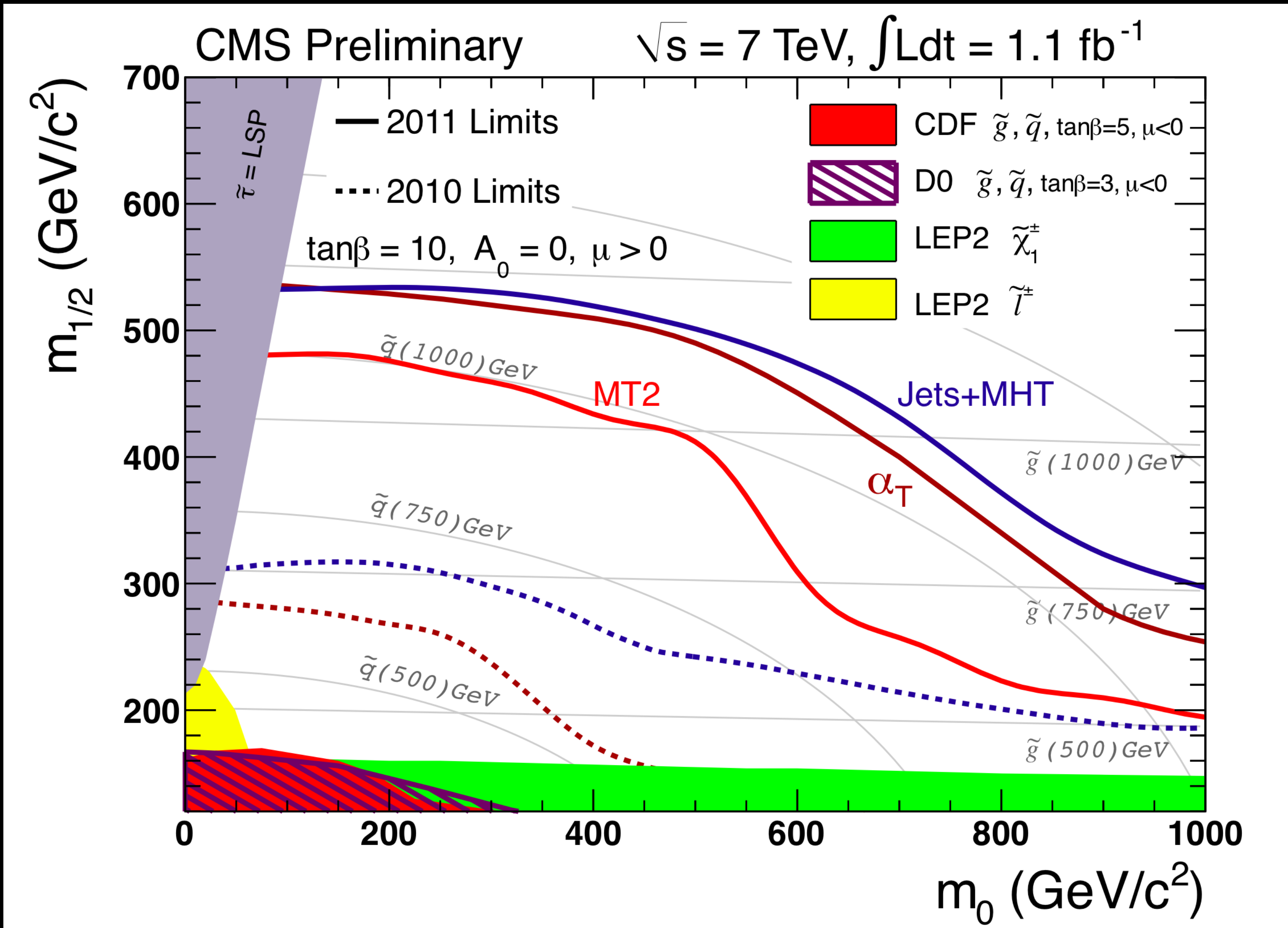
2. Theoretical issues and ideas

3. Outlook

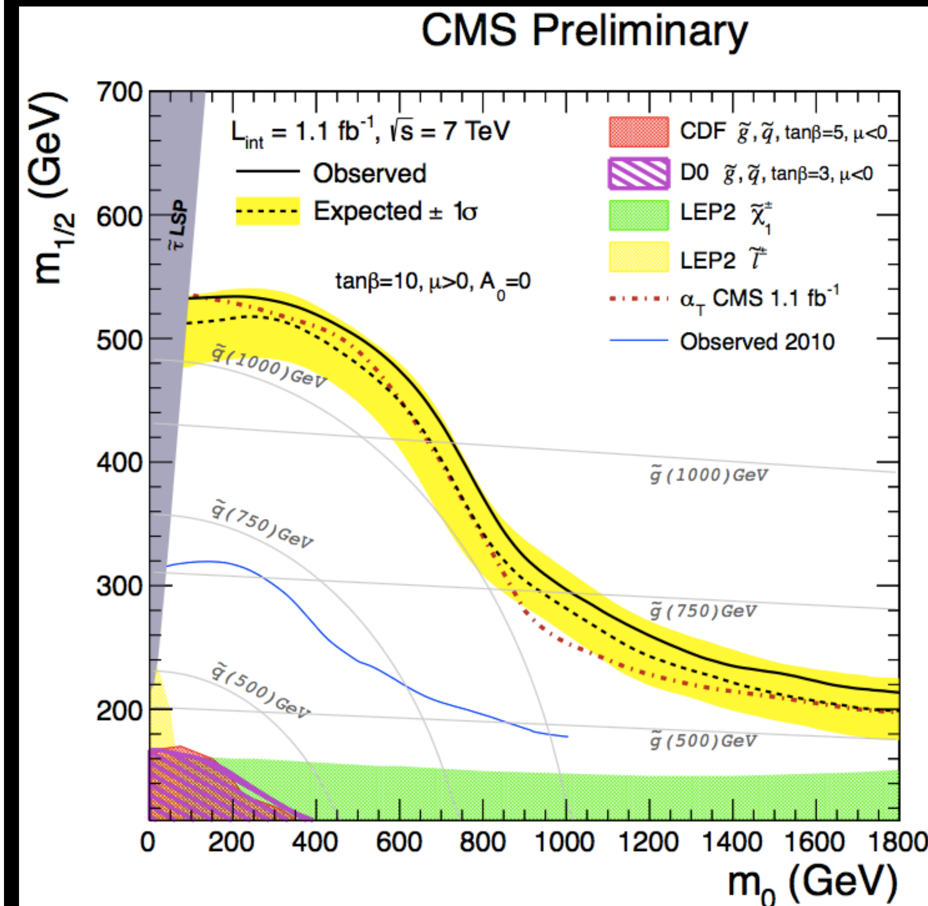
Some experimental results…

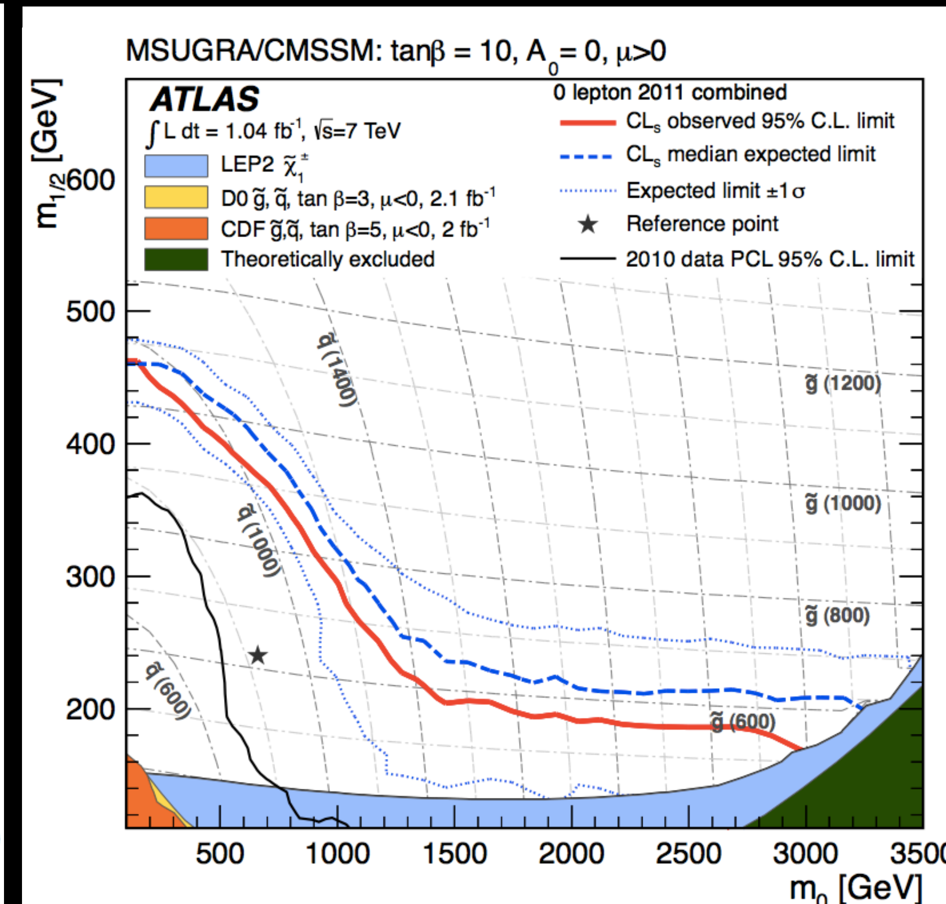


All-hadronic searches:



All-hadronic searches: Compare CMSSM limits





Small difference at low m0, ±1σ bands differ at high m0.

All-hadronic searches: Different cuts and variables

arXiv:1109.6572; arXiv:1110.2299

Different search modes
Different kinematic variables
Different kinematic regimes

$M_{eff} \approx$ sum of all p_T

Signal Region	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100

Signal region	7j55	8j55	6j80	7j80
Jet p_T	> 55 GeV		> 80 GeV	
Jet $\|\eta\|$	< 2.8			
ΔR_{jj}	> 0.6 for any pair of jets			
Number of jets	≥ 7	≥ 8	≥ 6	≥ 7
$E_T^{miss}/\sqrt{H_T}$	> 3.5 GeV$^{1/2}$			

All-hadronic searches: Backgrounds

arXiv:1109.6572; arXiv:1110.2299

	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\text{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	$32.3 \pm 2.6 \pm 6.9$	$25.5 \pm 2.6 \pm 4.9$	$209 \pm 9 \pm 38$	$16.2 \pm 2.2 \pm 3.7$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.4 \pm 4.0 \pm 6.7$	$22.6 \pm 3.5 \pm 5.6$	$349 \pm 30 \pm 122$	$13.0 \pm 2.2 \pm 4.7$	$2.1 \pm 0.8 \pm 1.1$
$t\bar{t}$+ single top	$3.4 \pm 1.6 \pm 1.6$	$5.9 \pm 2.0 \pm 2.2$	$425 \pm 39 \pm 84$	$4.0 \pm 1.3 \pm 2.0$	$5.7 \pm 1.8 \pm 1.9$
QCD multi-jet	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.73 \pm 0.14 \pm 0.50$	$2.10 \pm 0.37 \pm 0.82$
Total	$62.4 \pm 4.4 \pm 9.3$	$54.9 \pm 3.9 \pm 7.1$	$1015 \pm 41 \pm 144$	$33.9 \pm 2.9 \pm 6.2$	$13.1 \pm 1.9 \pm 2.5$
Data	58	59	1118	40	18

Signal region	7j55	8j55	6j80	7j80
Multi-jets	26 ± 5.2	2.3 ± 0.7	19 ± 4	1.3 ± 0.4
$t\bar{t} \to q\ell, \ell\ell$	10.8 ± 6.7	$0^{+4.3}$	6.0 ± 4.6	$0^{+0.13}$
W + jets	0.95 ± 0.45	$0^{+0.13}$	0.34 ± 0.24	$0^{+0.13}$
Z + jets	$1.5^{+1.8}_{-1.5}$	$0^{+0.75}$	$0^{+0.75}$	$0^{+0.75}$
Total Standard Model	39 ± 9	$2.3^{+4.4}_{-0.7}$	26 ± 6	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3
$N^{95\%}_{\text{BSM,max}}$	26.0	11.2	16.3	6.0
$\sigma^{95\%}_{\text{BSM,max}} \times \epsilon$/fb	19.4	8.4	12.2	4.5
p_{SM}	0.30	0.36	0.49	0.16

All-hadronic searches: Varied cuts and variables

arXiv:1109.2352; arXiv:1107.1279; PAS-SUS-11-004; PAS-SUS-11-005

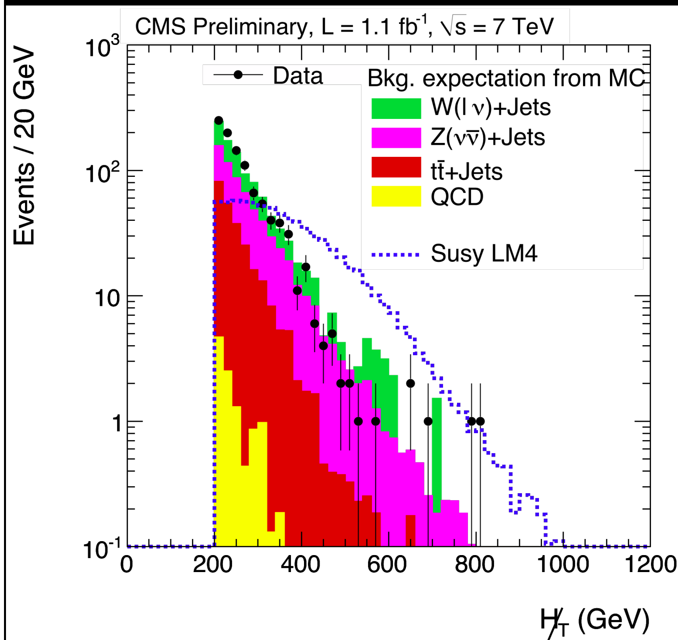
Different search modes
Different kinematic variables
Different kinematic regimes

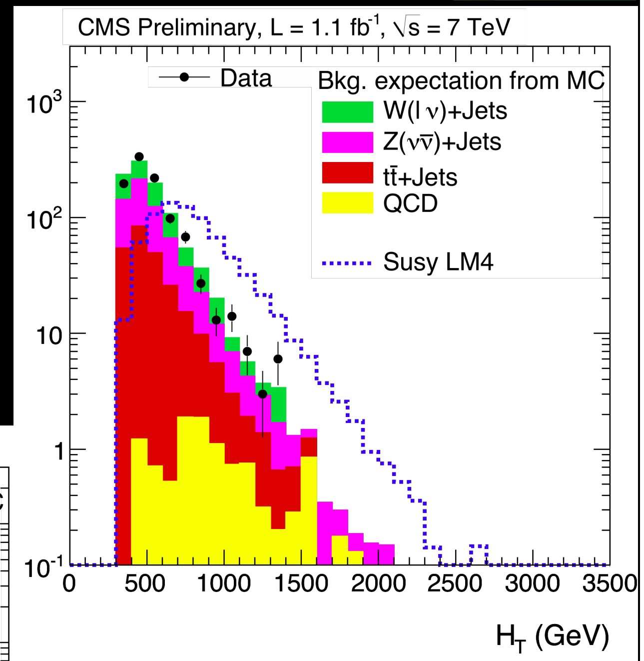
HT ≈ sum of jet p_Ts

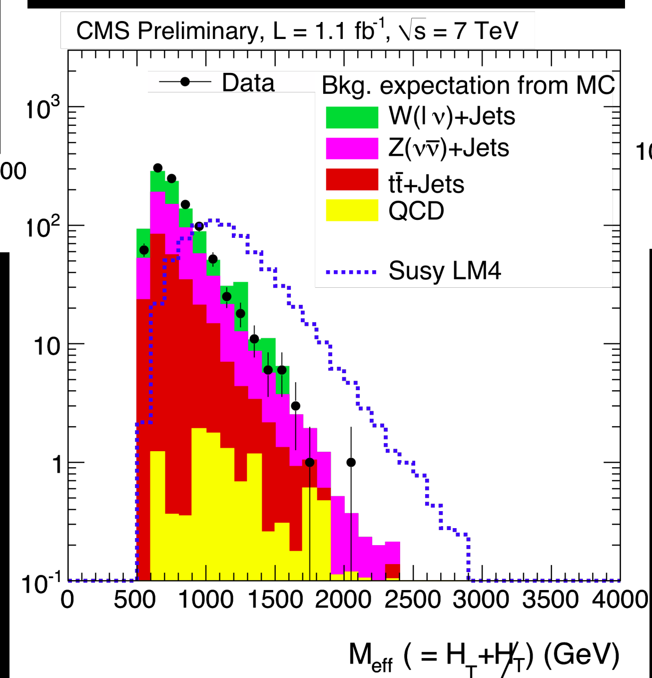
	Baseline HT>300 MET>200	Baseline ≥ 3jets p_T>50	Baseline ≥ 3jets $\Delta\phi$ cuts	Baseline ≥ 3jets $\Delta\phi$ cuts e/μ veto	Medium HT>500 MET>350	High H_T HT>800 MET>200	High $\not{H}_T$ HT>800 MET>500
Data	6377	3408	1640	986	78	70	3
Sum SM MC	6406	3227	1709	987	95	83	7.5
QCD multijet (PYTHIA)	1143	549	11.4	11.3	0.3	6.9	0.0
$Z(\nu\bar{\nu})$+jets (MG)	1370	481	387	386	46.3	29	4.2
$W(\ell\nu)$+jets (MG)	2963	1365	784	346	37.5	28	2.9
$t\bar{t}$ (MG)	930	832	527	244	11.3	18	0.4
LM4 (PYTHIA)	1477	1179	942	742	318	304	54

All-hadronic searches: Kinematic comparisons

arXiv:1109.2352; arXiv:1107.1279; PAS-SUS-11-004; PAS-SUS-11-005

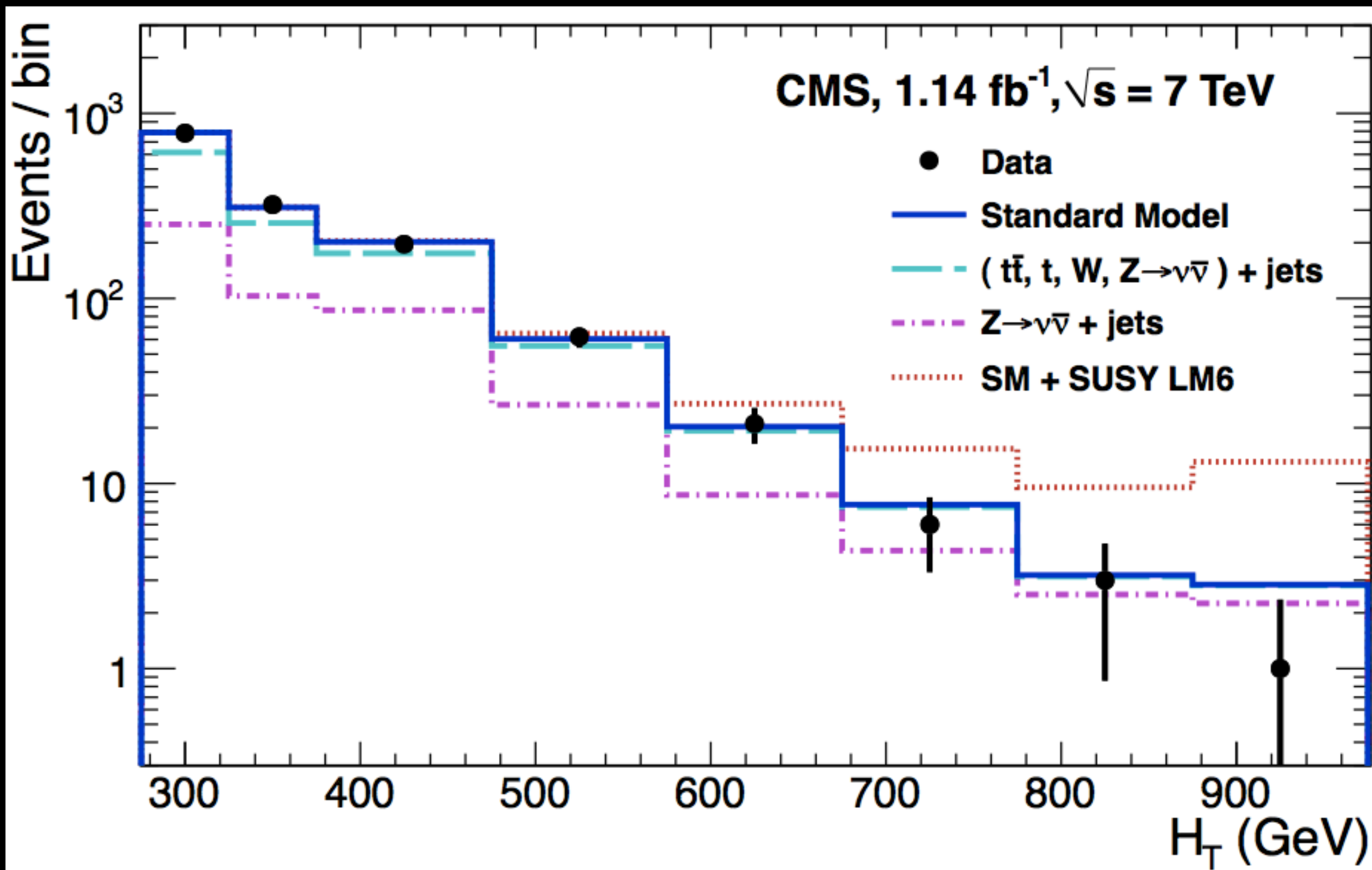






All-hadronic searches: Using the shape

arXiv:1109.2352, alphaT analysis



b-hadronic searches: Loosen kinematic cuts

ATLAS-CONF-2011-098

At least 3 jets, with p_T>130,50,50 (cf. 130,130)

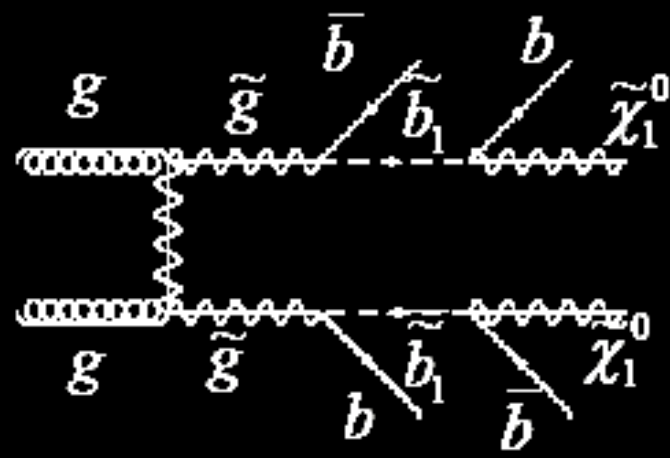
Lepton veto

b-tag jets with p_T>50

MET>130, $\Delta\phi$(jet,MET)>0.4

MET/m_{eff} > 0.25

m_{eff} > 500 or 700 (cf. 1000)



Sig. Reg.	Data (0.83 fb^{-1})	Top	W/Z	QCD	Total
3JA (1 btag m_{eff} >500 GeV)	361	221^{+82}_{-68}	121 ± 61	15 ± 7	356^{+103}_{-92}
3JB (1 btag m_{eff} >700 GeV)	63	37^{+15}_{-12}	31 ± 19	1.9 ± 0.9	70^{+24}_{-22}
3JC (2 btag m_{eff} >500 GeV)	76	55^{+25}_{-22}	20 ± 12	3.6 ± 1.8	79^{+28}_{-25}
3JD (2 btag m_{eff} >700 GeV)	12	$7.8^{+3.5}_{-2.9}$	5 ± 4	0.5 ± 0.3	$13.0^{+5.6}_{-5.2}$

b-hadronic searches: Kinematic comparisons

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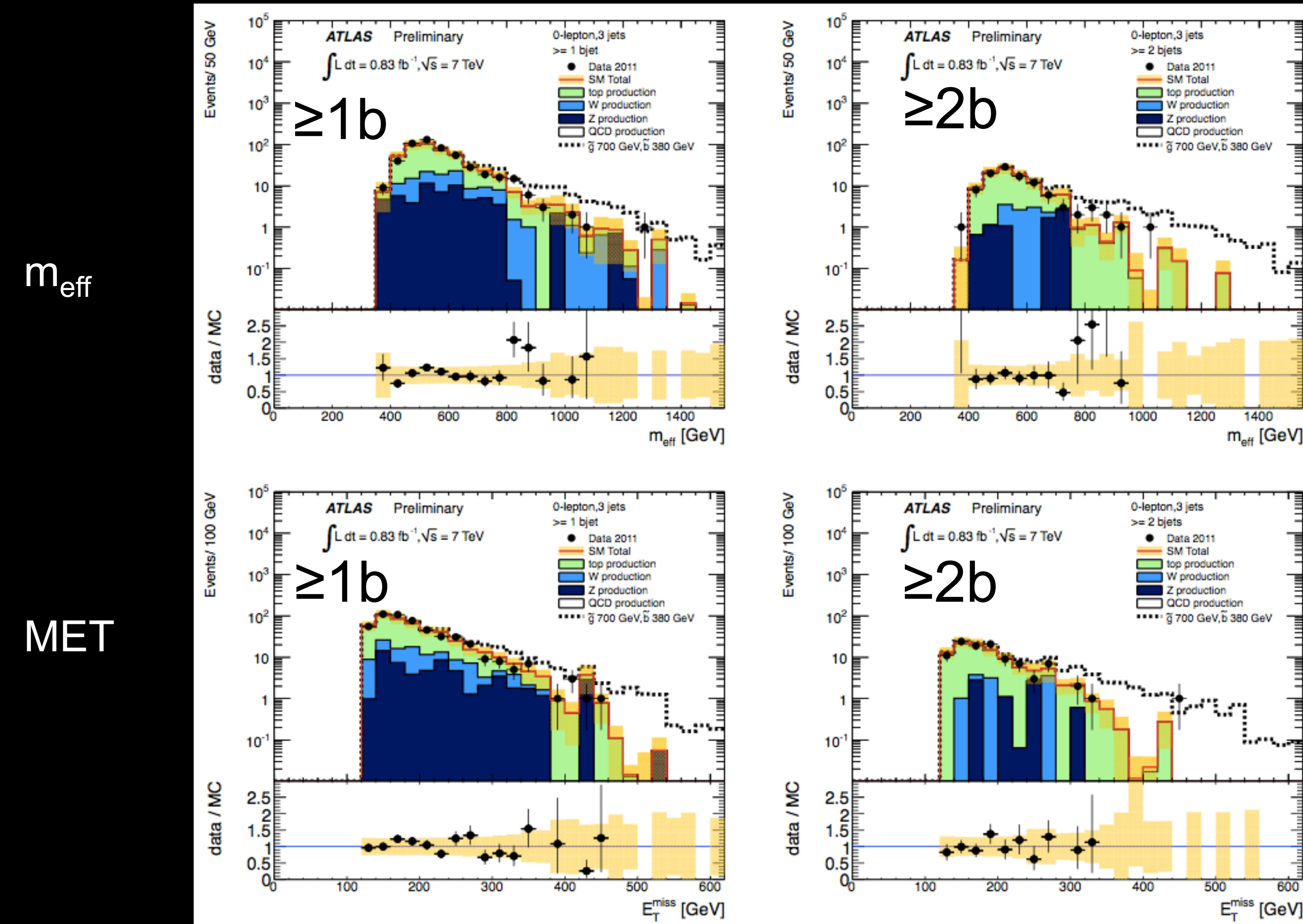

b-hadronic searches: Varied cuts and variables

PAS-SUS-11-005, PAS-SUS-11-006

<u>HT and MET Search</u>

≥3 jets, with p_T>50

Lepton veto

b-tag jets with p_T>30

MET>200, $\Delta\phi$ (normalized) > 4

HT > 350 (loose) or 500 (tight)

<u>HT and MT2 Search</u>

≥4 jets, with p_T>150,100,40,40

Lepton veto

b-tag jets with p_T>50

MT2>150, $\Delta\phi$(jet,MET)>0.4

HT > 650

b-hadronic searches: Results

PAS-SUS-11-005, PAS-SUS-11-006

HT and MET Search

≥3 jets, with p_T>50

Lepton veto

b-tag jets with p_T>30

MET>200, $\Delta\phi$ (normalized) > 4

HT > 350

	$(H_T, E_T^{miss}) > (350, 200)$ GeV		$(H_T, E_T^{miss}) > (500, 300)$ GeV	
	≥ 1 b-jets	≥ 2 b-jets	≥ 1 b-jets	≥ 2 b-jets
Data	155	30	20	5
Total SM	183 ± 5	35.7 ± 1.3	25.1 ± 1.6	4.54 ± 0.37
$t\bar{t}$	122 ± 2	28.9 ± 0.7	14.7 ± 0.8	3.49 ± 0.24
Single top	4.54 ± 0.38	0.77 ± 0.09	0.59 ± 0.15	0.12 ± 0.04
W+Jets	17.0 ± 2.1	1.21 ± 0.45	4.20 ± 1.28	0.42 ± 0.28
$Z \rightarrow \nu\bar{\nu}$	22.5 ± 0.5	2.23 ± 0.10	4.25 ± 0.20	0.43 ± 0.04
$Z/\gamma^* \rightarrow \ell^+\ell^-$	0.17 ± 0.17	0.01 ± 0.01	0	0
Diboson	0.69 ± 0.07	0.10 ± 0.02	0.10 ± 0.02	0.006 ± 0.002
QCD	16.4 ± 3.9	2.5 ± 0.9	1.28 ± 0.40	0.08 ± 0.01
SUSY LM9	147 ± 5	60.0 ± 2.5	27.7 ± 2.2	10.1 ± 1.0

b-hadronic searches: Results

PAS-SUS-11-005, PAS-SUS-11-006

HT and MET Search

≥3 jets, with p_T>50
Lepton veto
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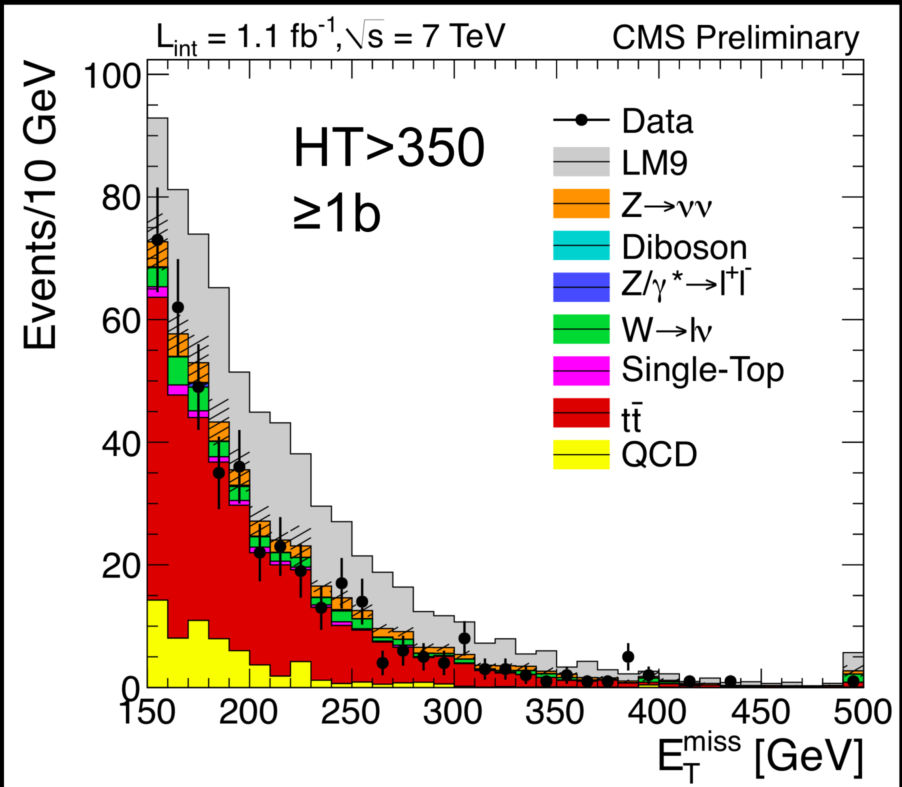
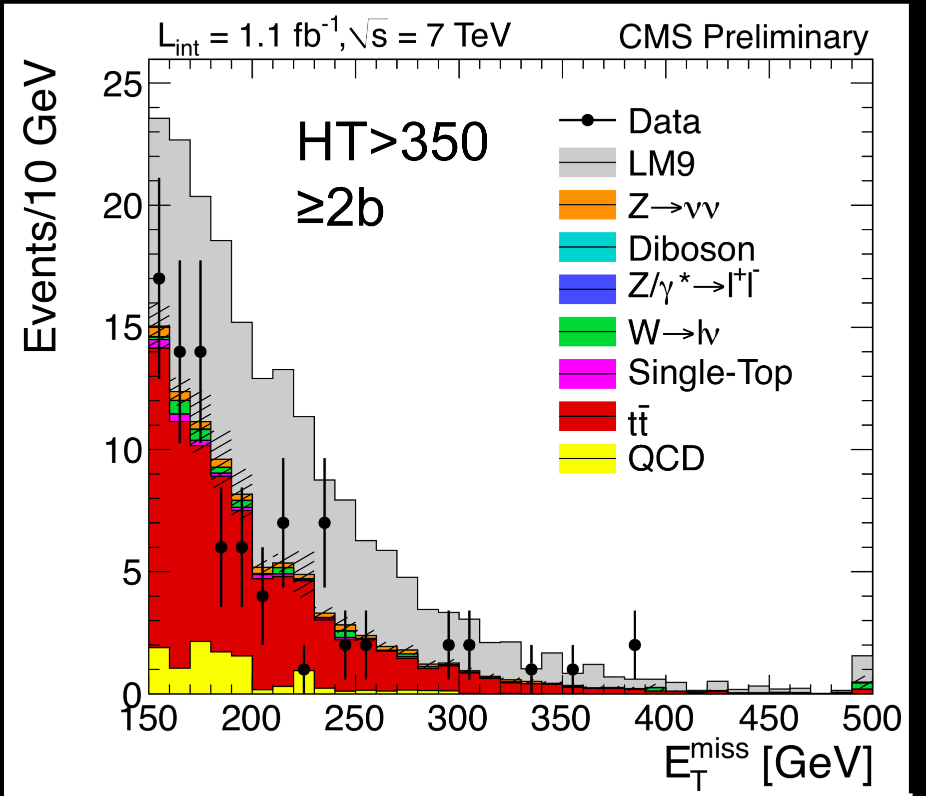
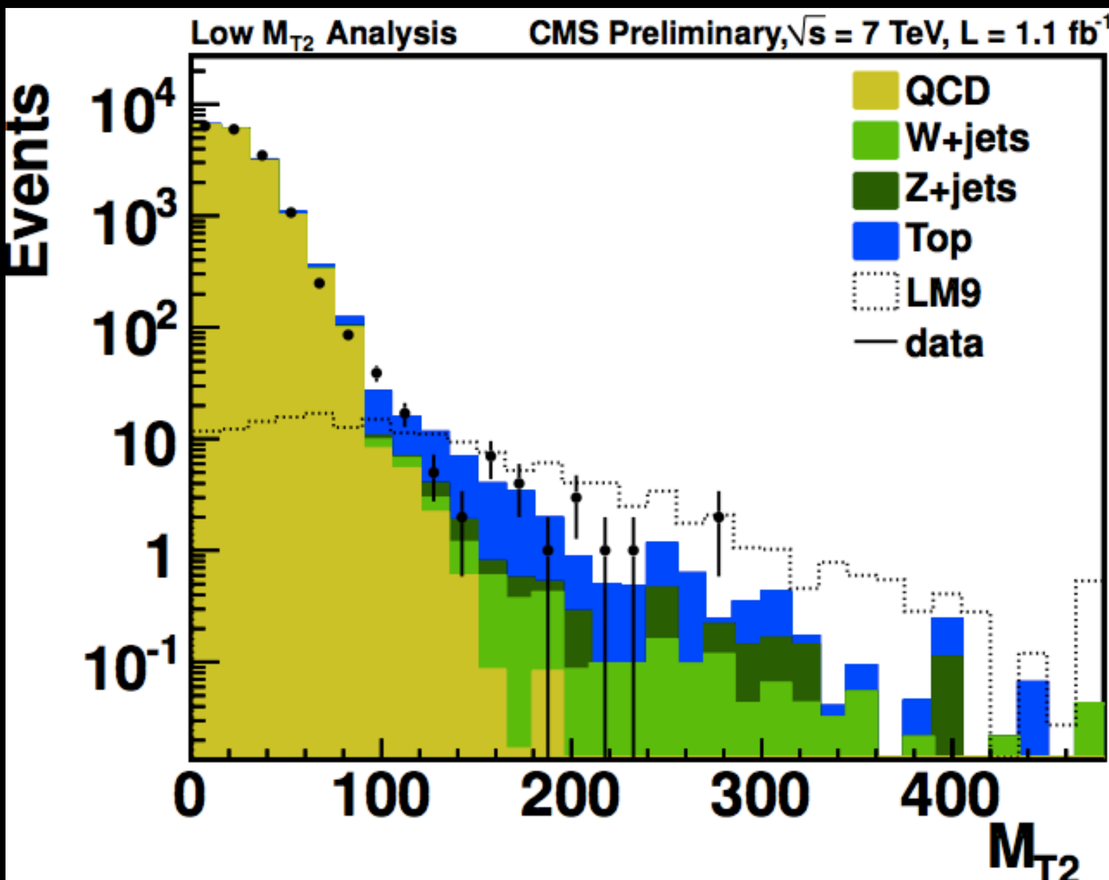




b-hadronic searches: Results

PAS-SUS-11-005, PAS-SUS-11-006



HT and MT2 Search

≥4 jets, with p_T>150,100,40,40

Lepton veto

b-tag jets with p_T>50

MT2>150, $\Delta\phi$(jet,MET)>0.4

HT > 650

b-hadronic searches: Limits

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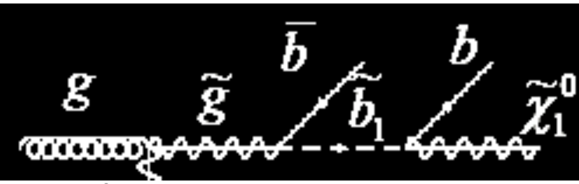

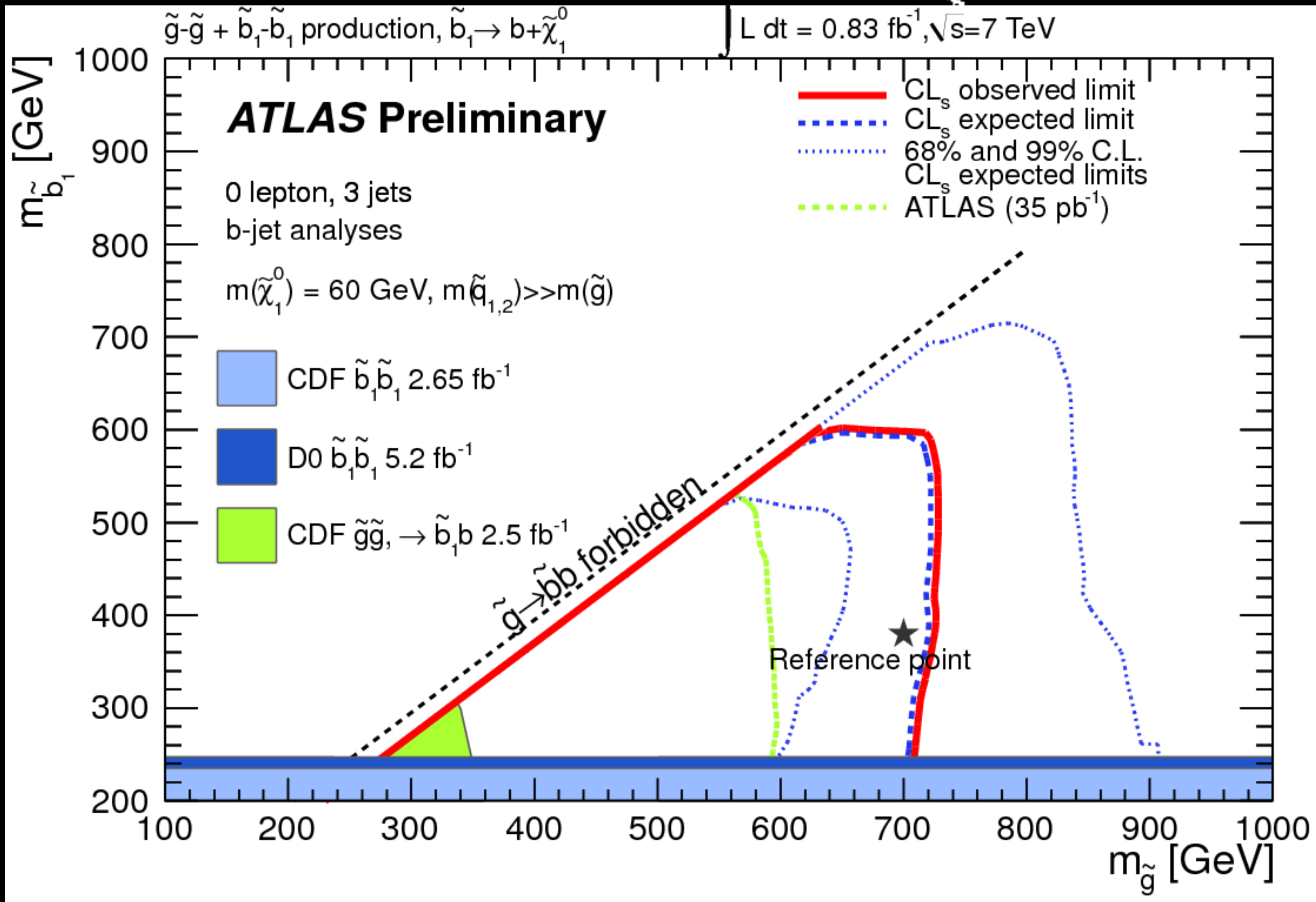

b-hadronic searches: Limits

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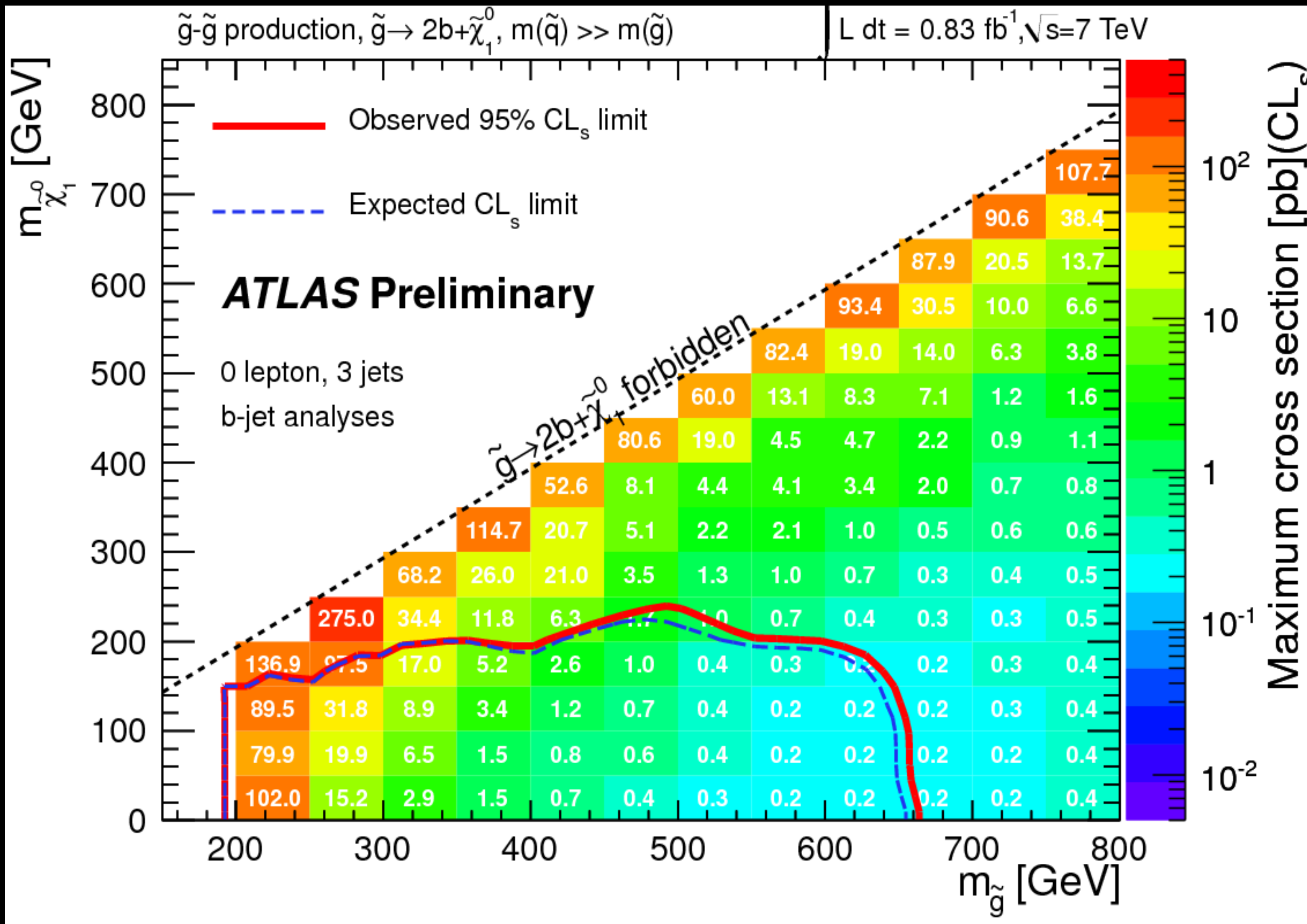
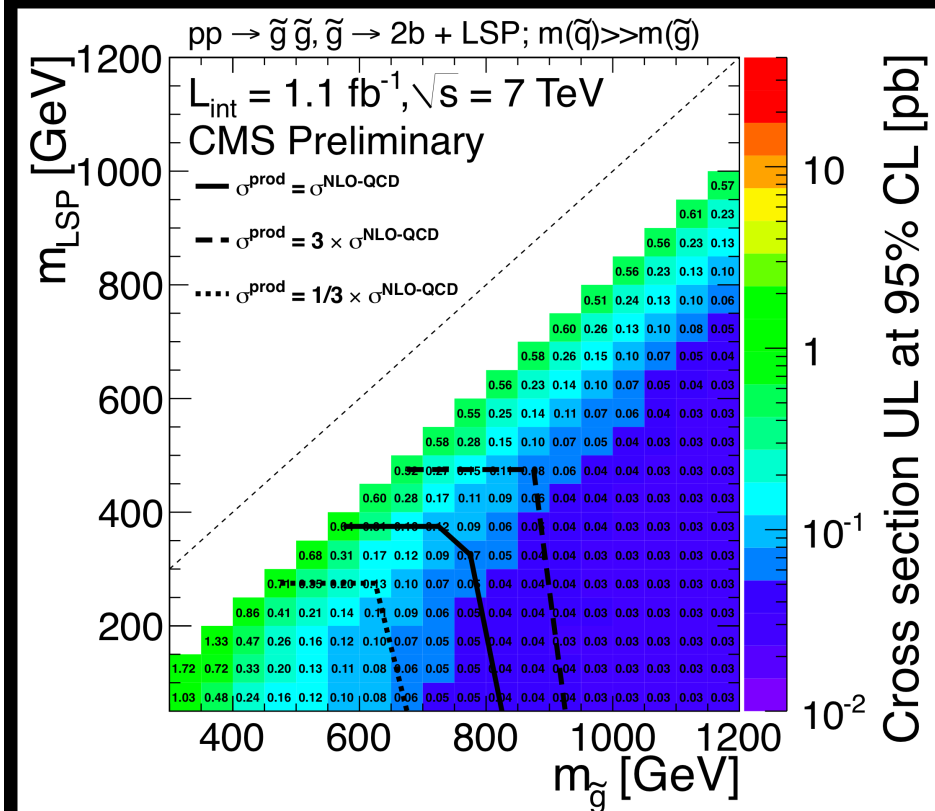


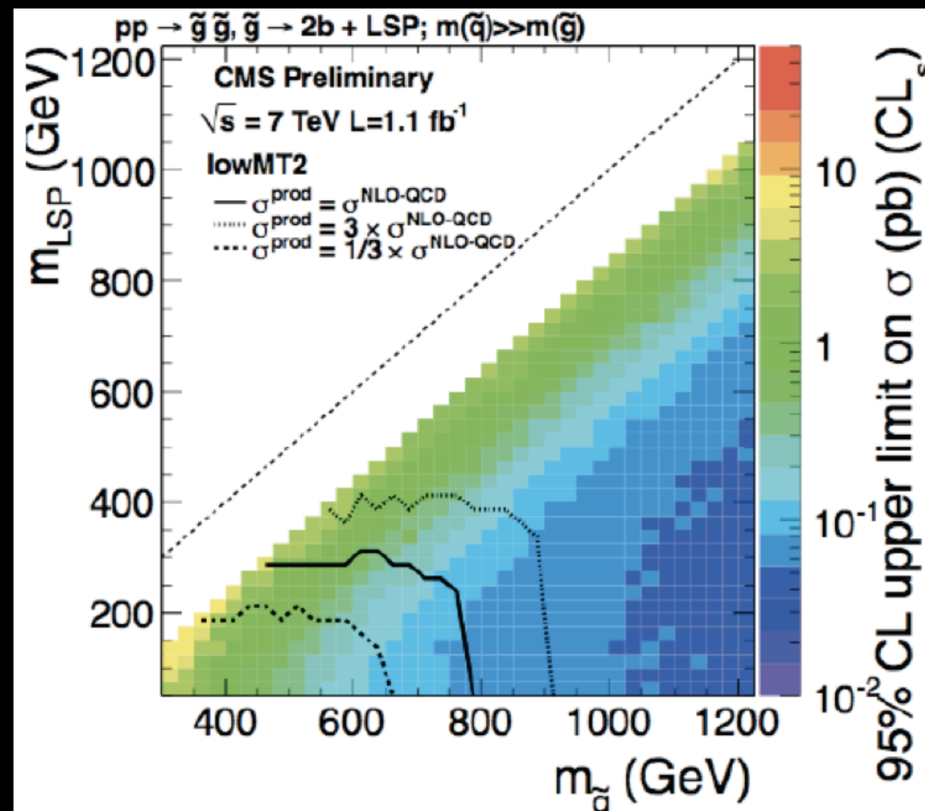
b-hadronic searches: Limits

PAS-SUS-11-005, PAS-SUS-11-006

HT and MET Search



HT and MT2 Search



Multilepton searches

PAS-SUS-11-013

Fedor Ratnikov (KIT)
Richard Gray (Rutgers)

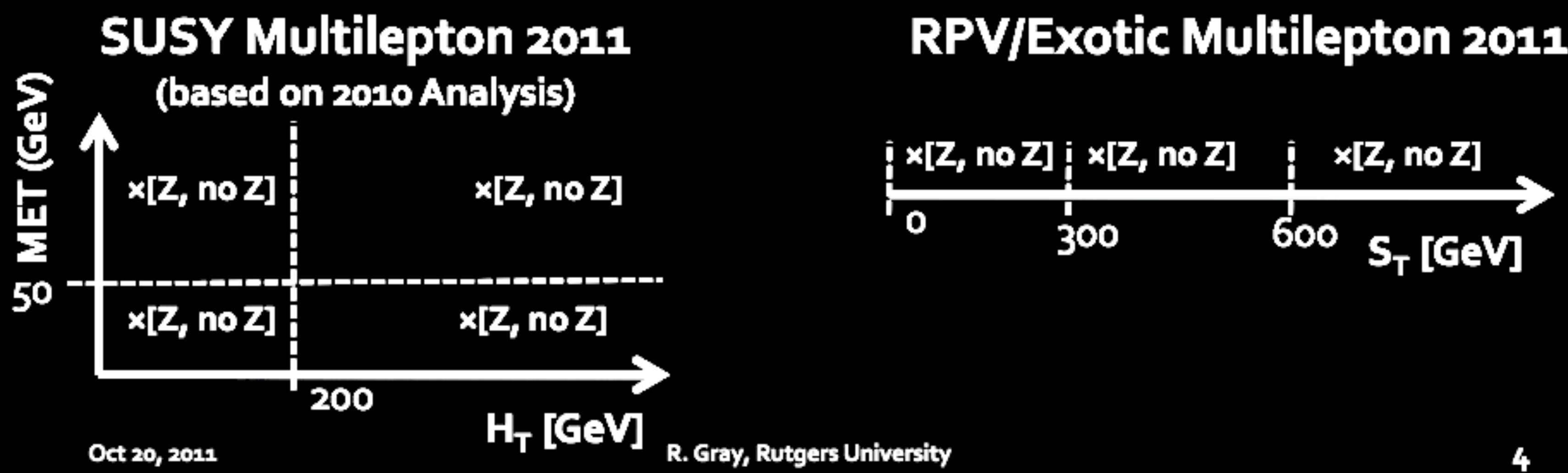
Low background SUSY search,
including EWK gaugino pair-production

or

RPV

Separate search into multiple *exclusive* boxes by:

3 or 4 leptons; # taus; on/off-Z OSOF pairs; kinematics, HT and MET or ST (=m_{eff})



Multilepton searches

PAS-SUS-11-013

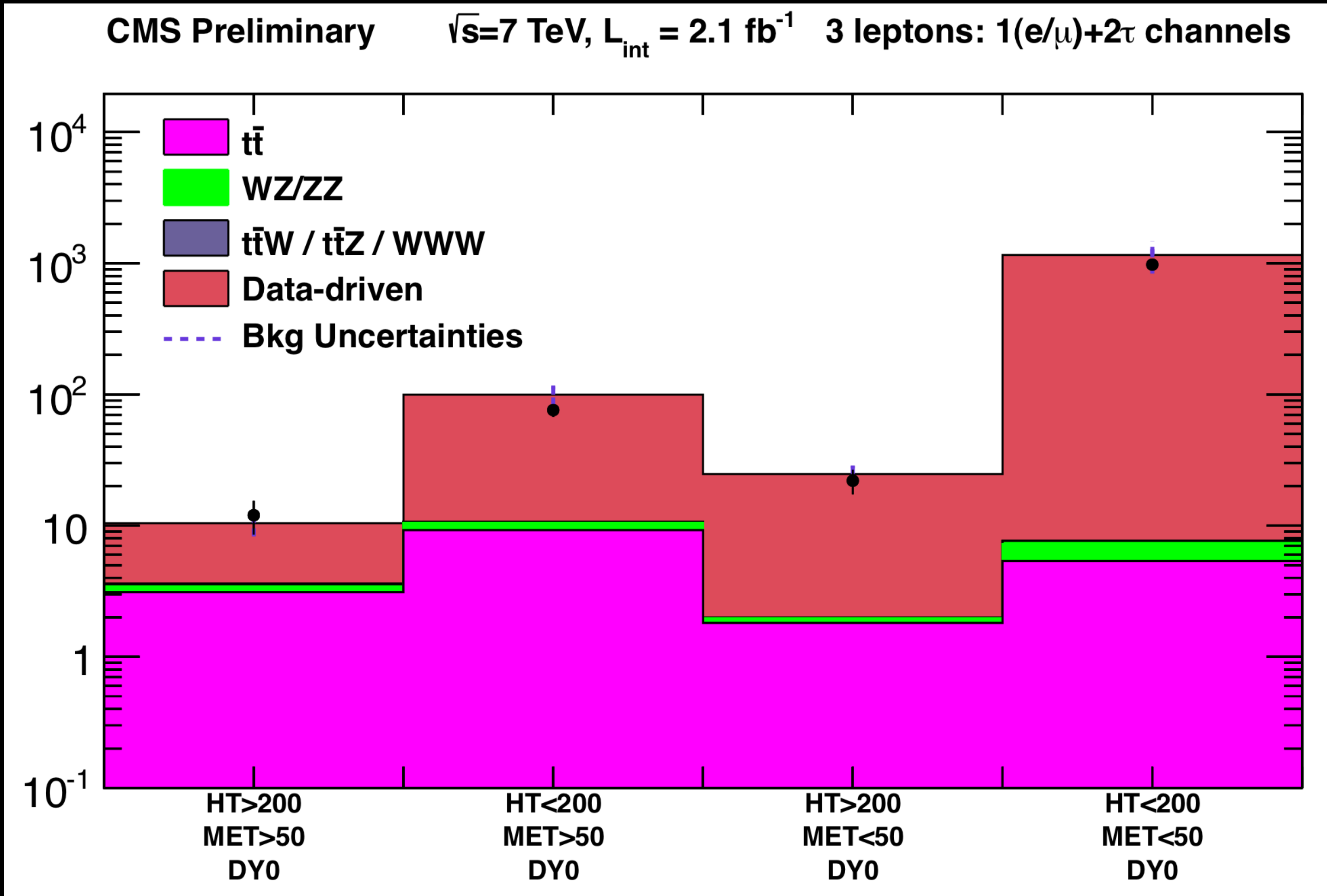
53 exclusive regions

Selection	N(τ)=0 obs	N(τ)=0 expected SM	N(τ)=1 obs	N(τ)=1 expected SM	N(τ)=2 obs	N(τ)=2 expected SM
≥FOUR Lepton Results						
MET>50,H_T >200,noZ	0	0.003 ± 0.002	0	0.01 ± 0.05	0	0.30 ± 0.22
MET>50,H_T >200, Z	0	0.06 ± 0.04	0	0.13 ± 0.10	0	0.15 ± 0.23
MET>50,H_T <200,noZ	1	0.014 ± 0.005	0	0.22 ± 0.10	0	0.59 ± 0.25
MET>50,H_T <200, Z	0	0.43 ± 0.15	2	0.91 ± 0.28	0	0.34 ± 0.15
MET<50,H_T >200,noZ	0	0.0013 ± 0.0008	0	0.01 ± 0.05	0	0.18 ± 0.07
MET<50,H_T >200, Z	1	0.28 ± 0.11	0	0.13 ± 0.10	0	0.52 ± 0.19
MET<50,H_T <200,noZ	0	0.08 ± 0.03	4	0.73 ± 0.20	6	6.9 ± 3.8
MET<50,H_T <200, Z	11	9.5 ± 3.8	14	5.7 ± 1.4	39	21 ± 11
THREE Lepton Results						
MET>50,H_T >200,no-OSSF	2	0.87 ± 0.33	21	14.3 ± 4.8	12	10.4 ± 2.2
MET>50,H_T <200,no-OSSF	4	3.7 ± 1.2	88	68 ± 17	76	100 ± 17
MET<50,H_T >200,no-OSSF	1	0.50 ± 0.33	12	7.7 ± 2.3	22	24.7 ± 4.0
MET<50,H_T <200,no-OSSF	7	5.0 ± 1.7	245	208 ± 39	976	1157 ± 323
MET>50,H_T >200,noZ	5	1.9 ± 0.5	7	10.8 ± 3.3	–	–
MET>50,H_T >200, Z	8	8.1 ± 2.7	10	11.2 ± 2.5	–	–
MET>50,H_T <200,noZ	19	11.6 ± 3.2	64	52 ± 13	–	–
MET<50,H_T >200,noZ	5	2.0 ± 0.7	24	26.6 ± 3.3	–	–
MET>50,H_T <200, Z	58	57 ± 21	47	44.1 ± 7.0	–	–
MET<50,H_T >200, Z	6	8.2 ± 2.0	90	119 ± 14	–	–
MET<50,H_T <200,noZ	86	82 ± 21	2566	1965 ± 438	–	–
MET<50,H_T <200, Z	335	359 ± 89	9720	7740 ± 1698	–	–
Totals 4L	13.0	10.4 ± 3.8	20.0	7.8 ± 1.5	45	30 ± 12
Totals 3L	536	539 ± 94	12894	10267 ± 1754	1086	1291 ± 324

Multilepton searches

PAS-SUS-11-013

Diboson and ttbar from MC. Fake contributions measured in data.



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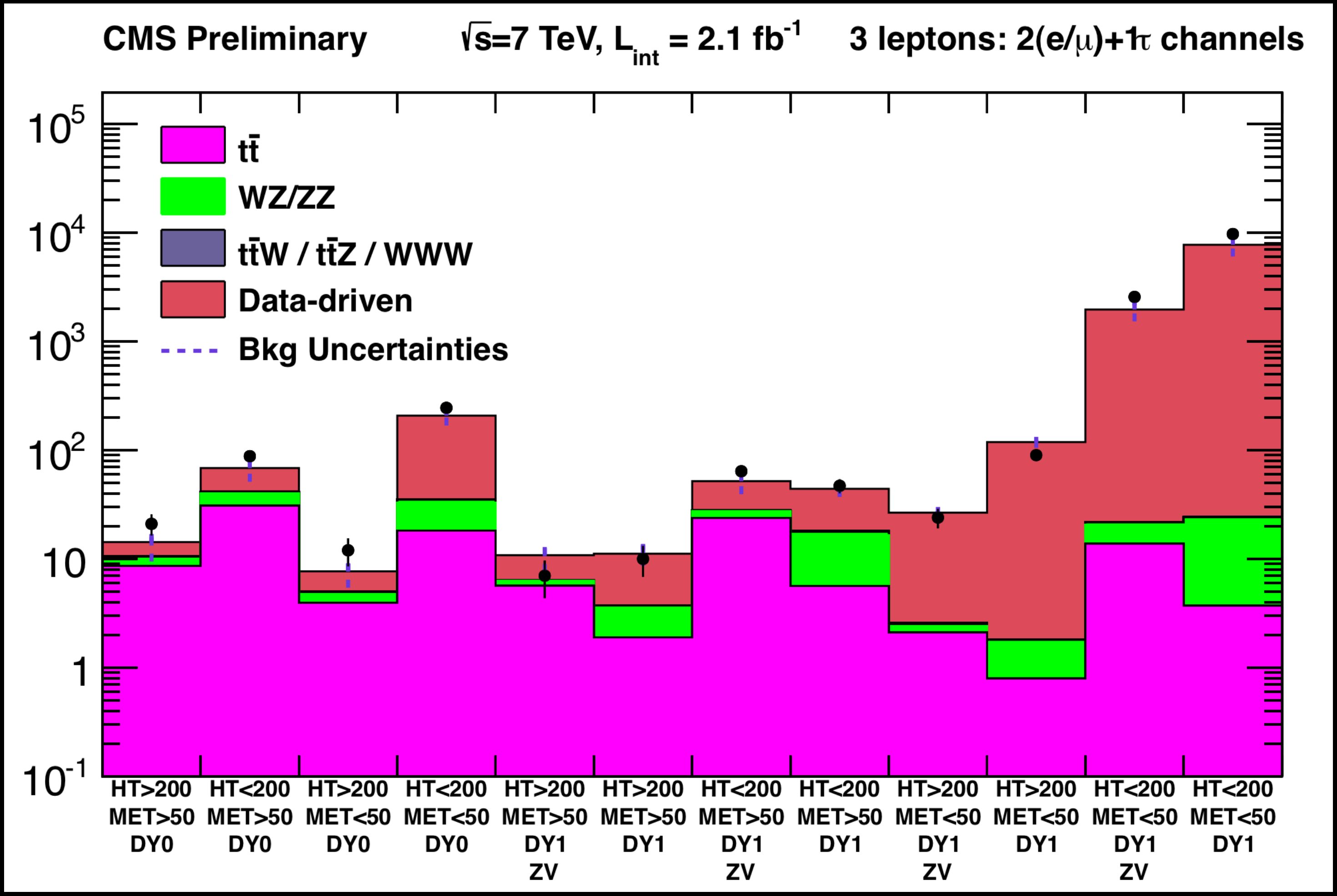

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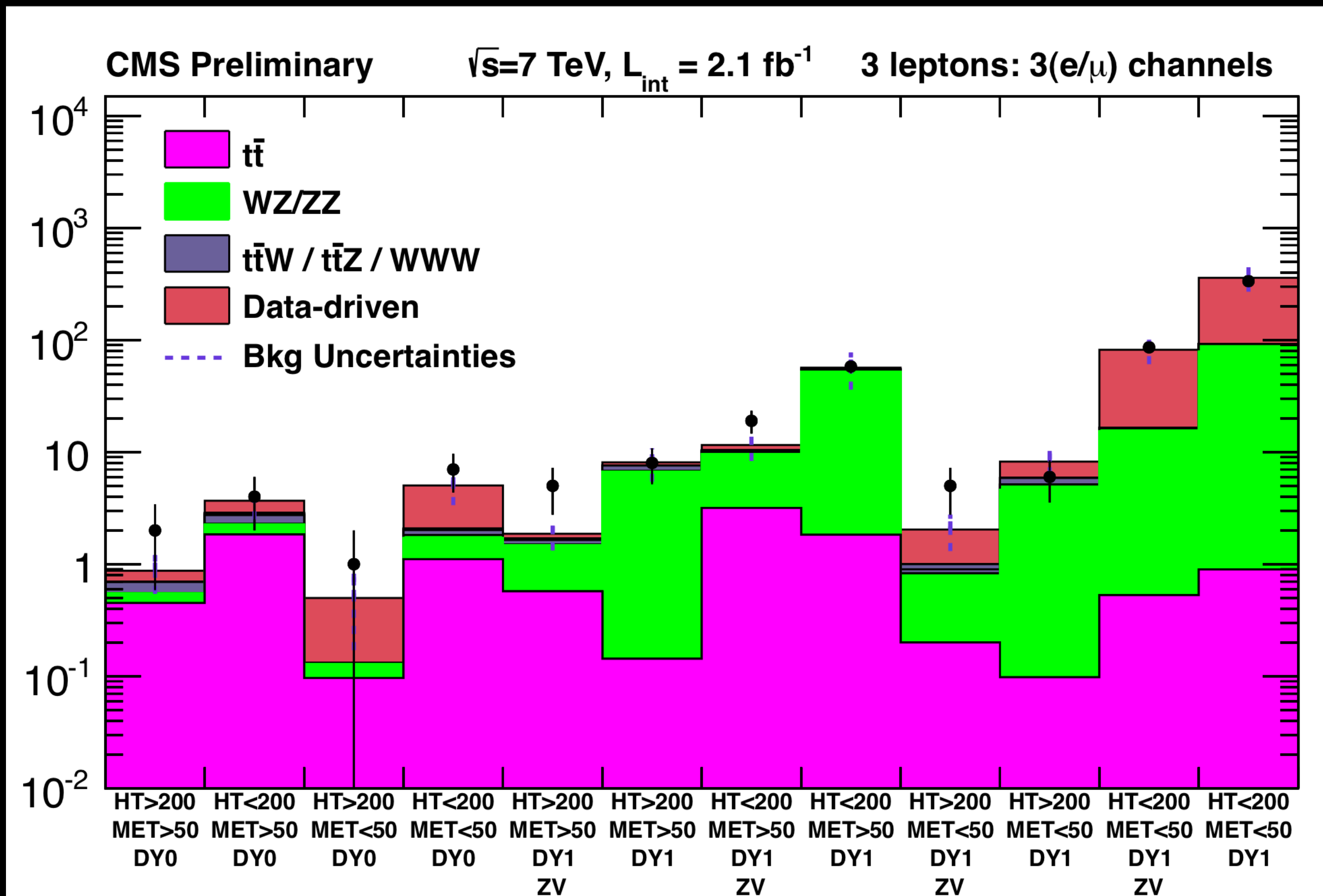
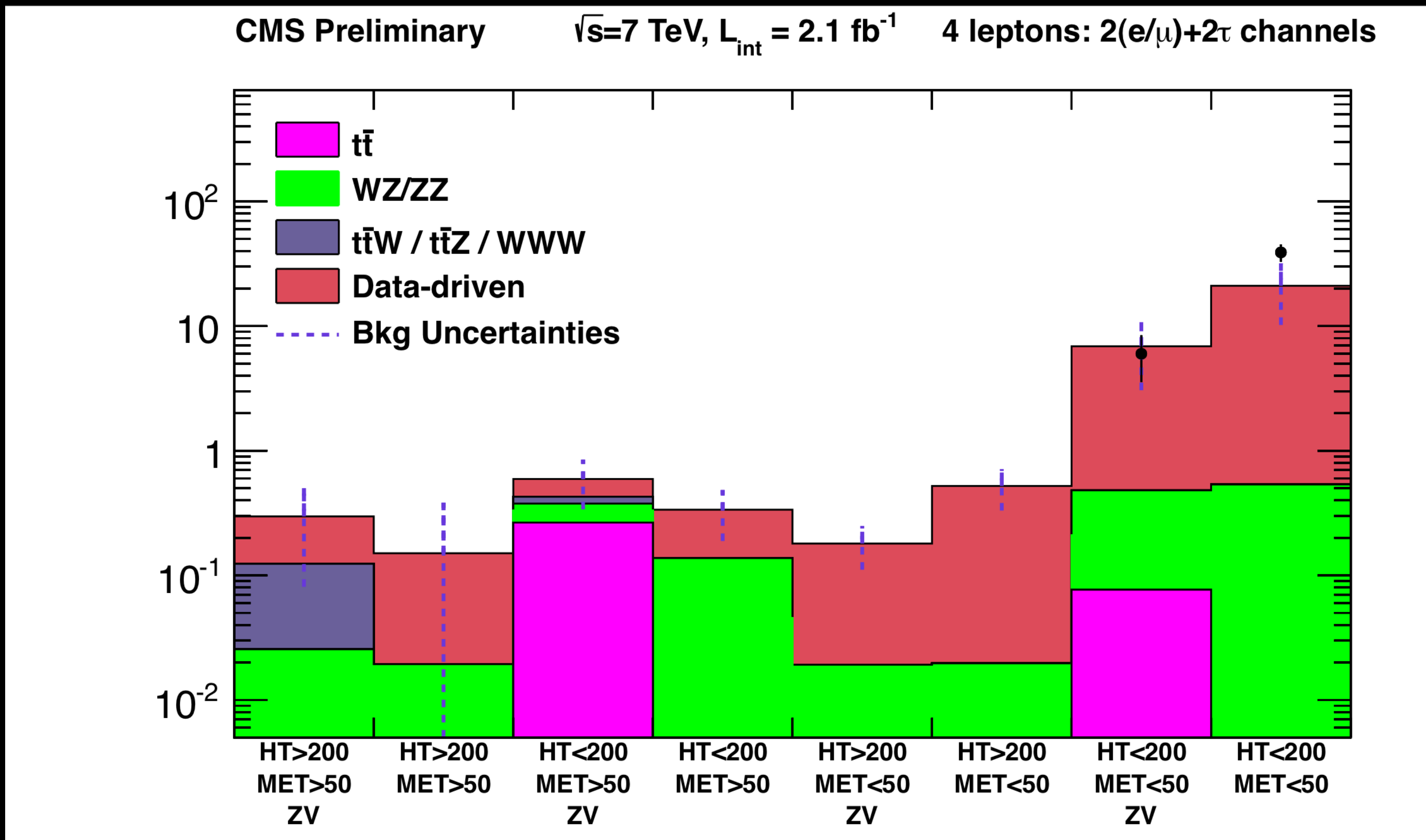


Multilepton searches

PAS-SUS-11-013

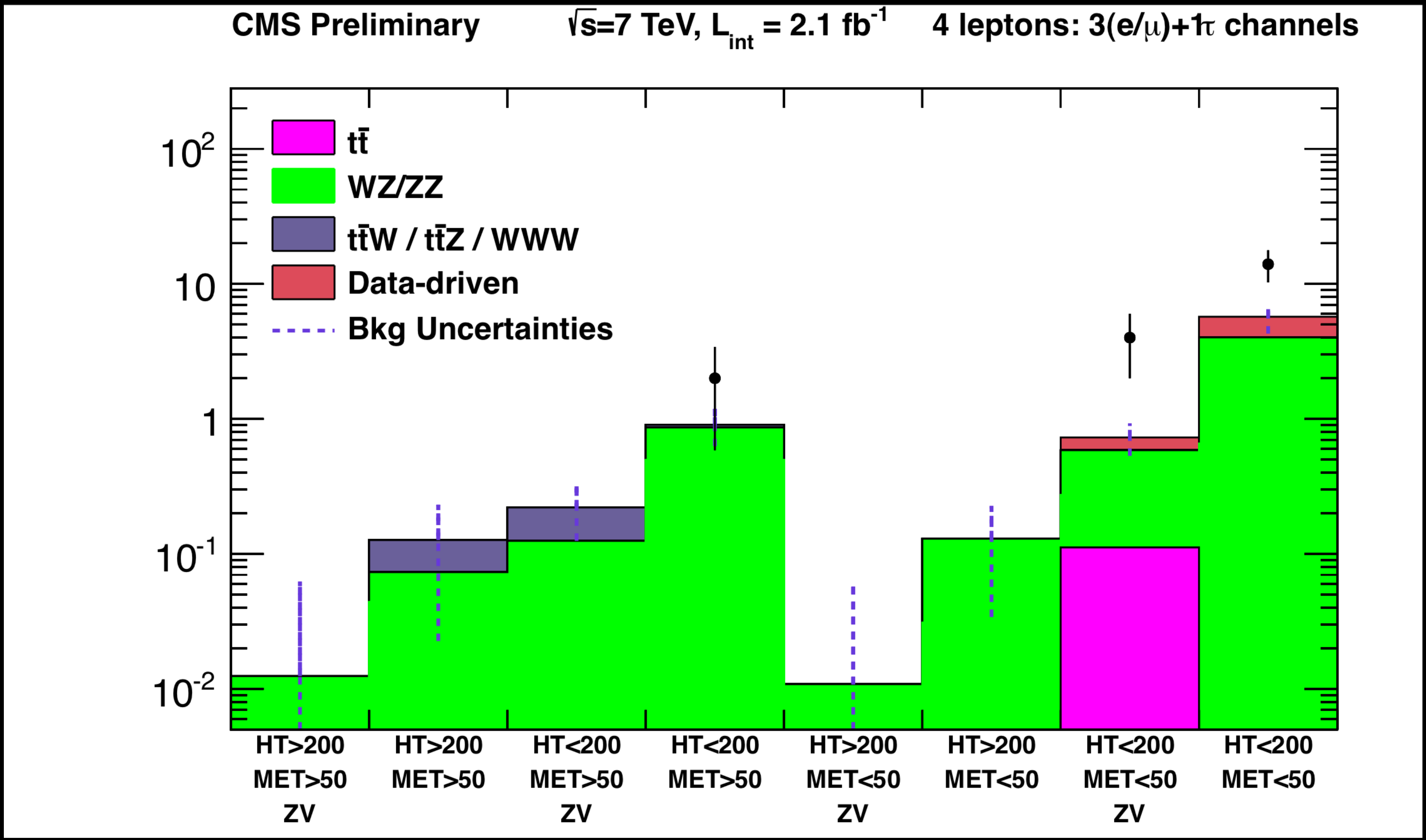
Fake contributions measured in data.



Multilepton searches

PAS-SUS-11-013

4 lepton backgrounds dominated by dibosons; taken from MC.



Multilepton searches

PAS-SUS-11-013

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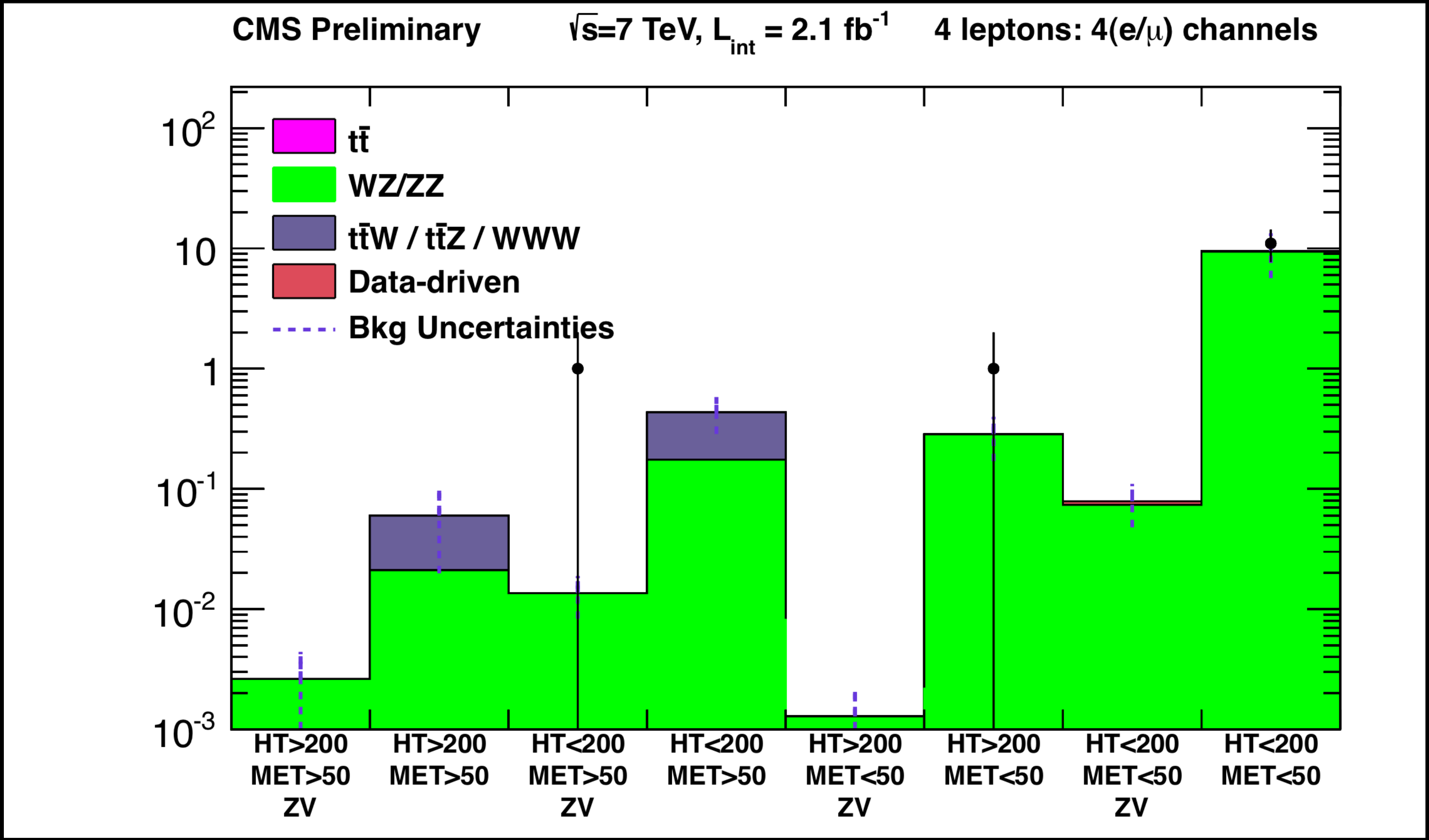
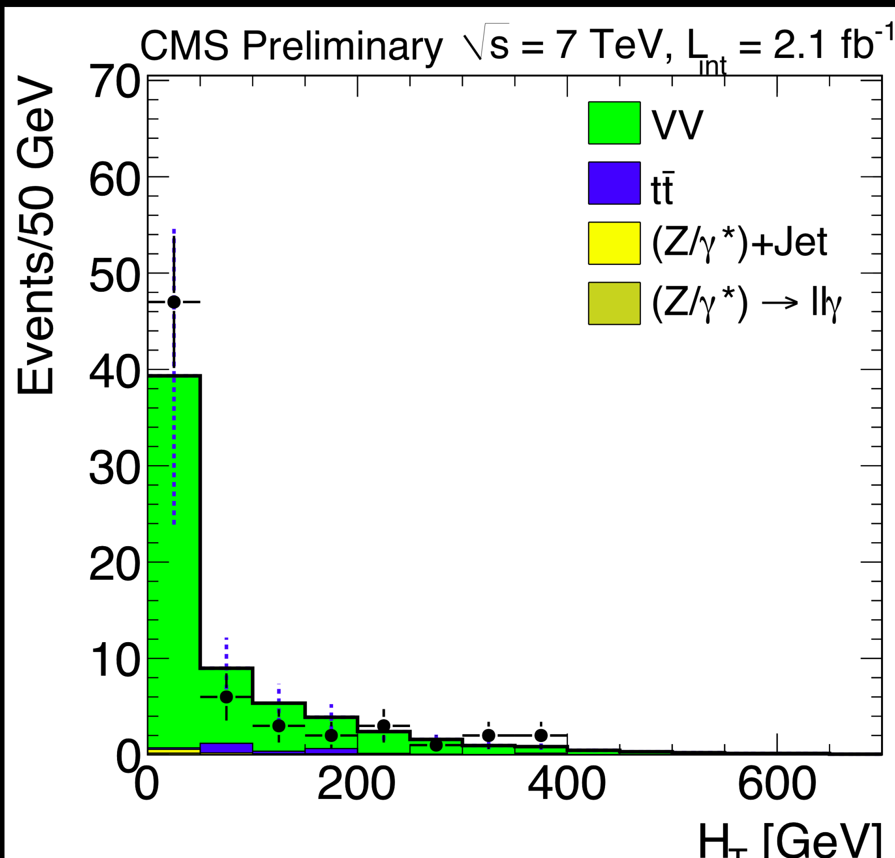
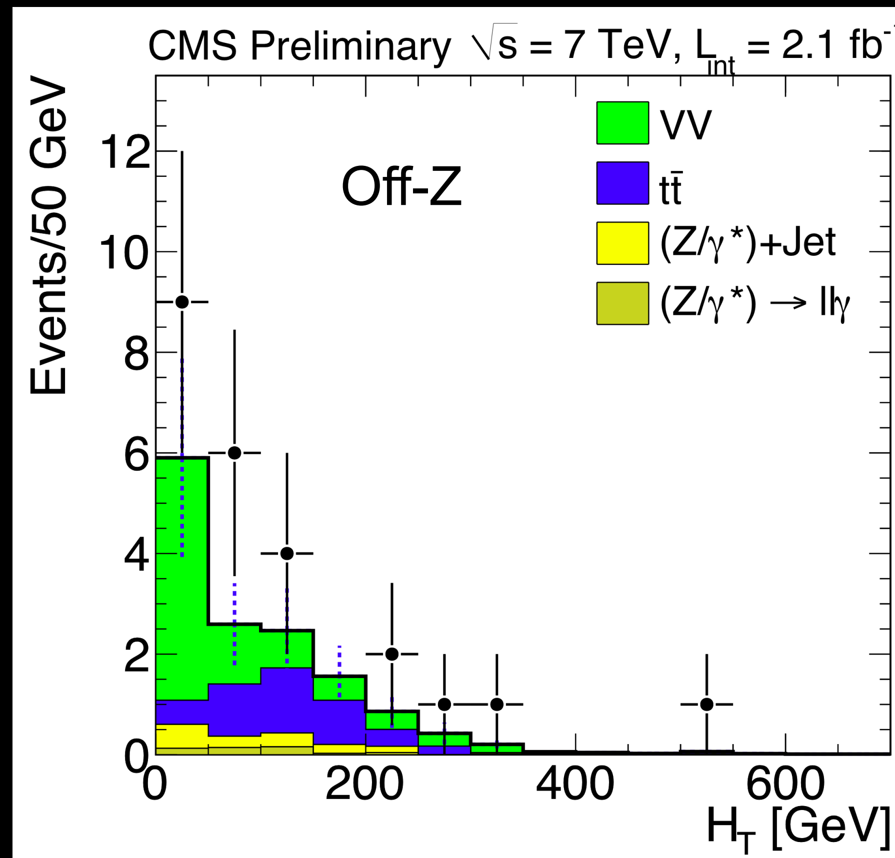


Multilepton searches

PAS-SUS-11-013

Kinematic consistency check: HT (pre-MET cut)





Multilepton searches

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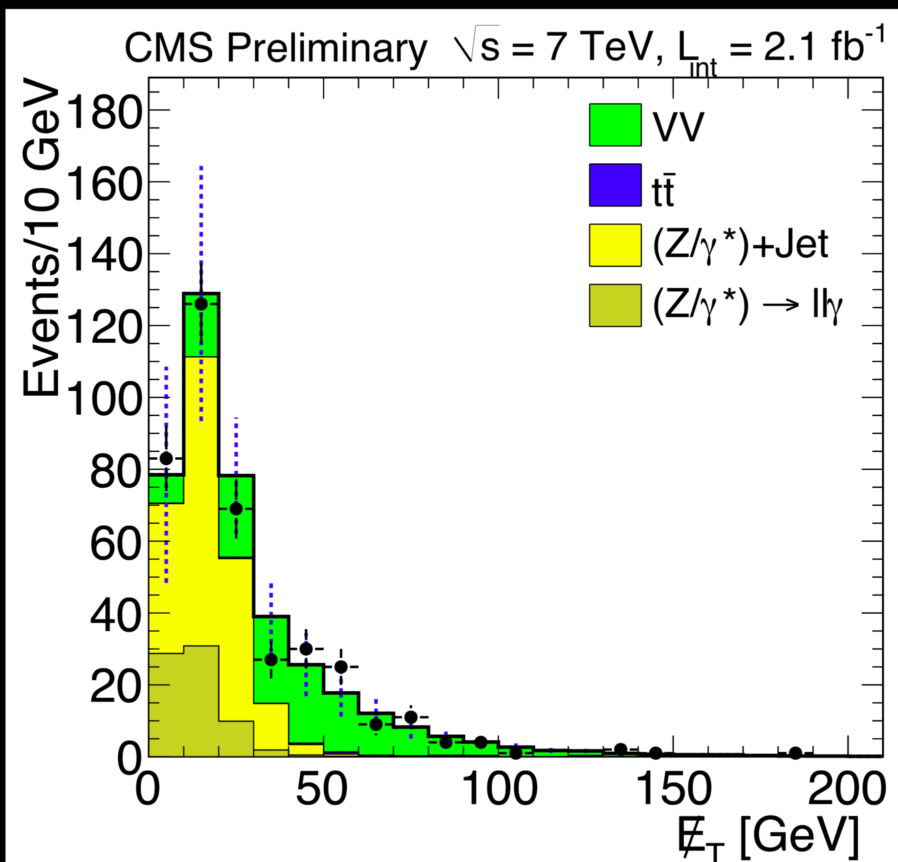
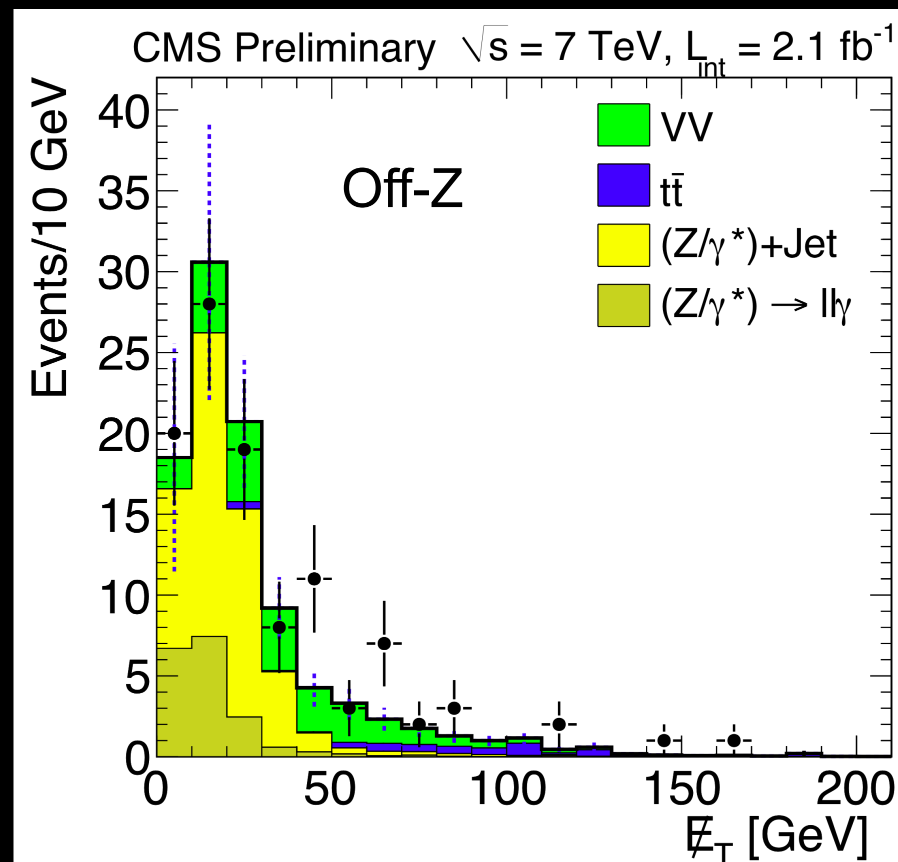
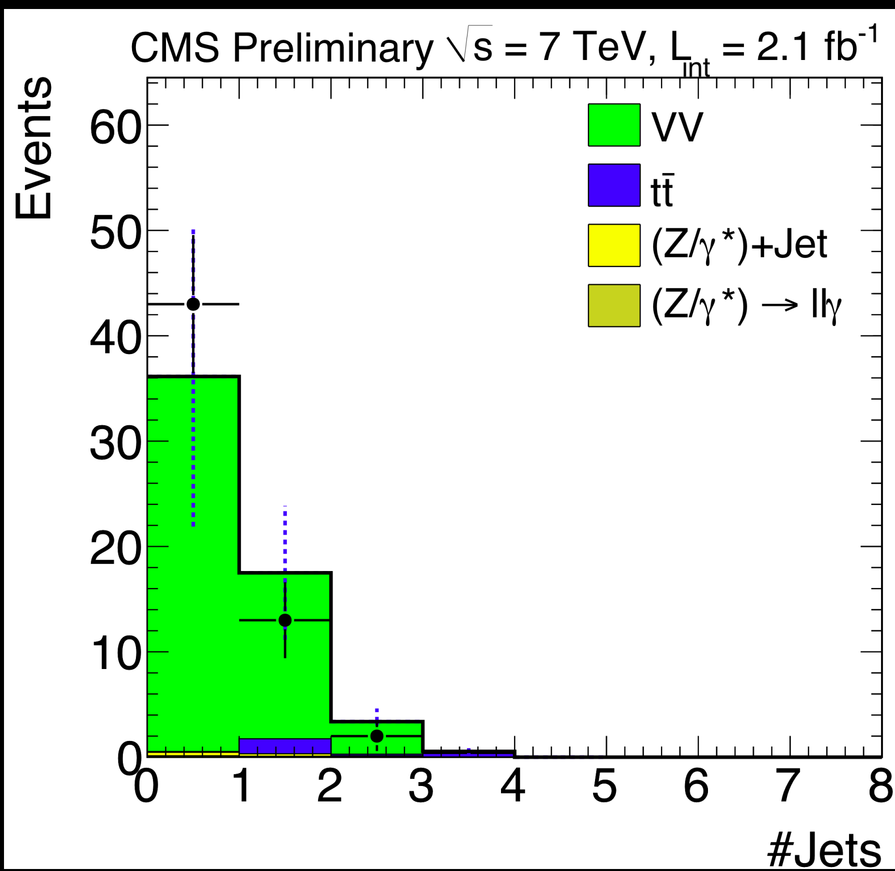


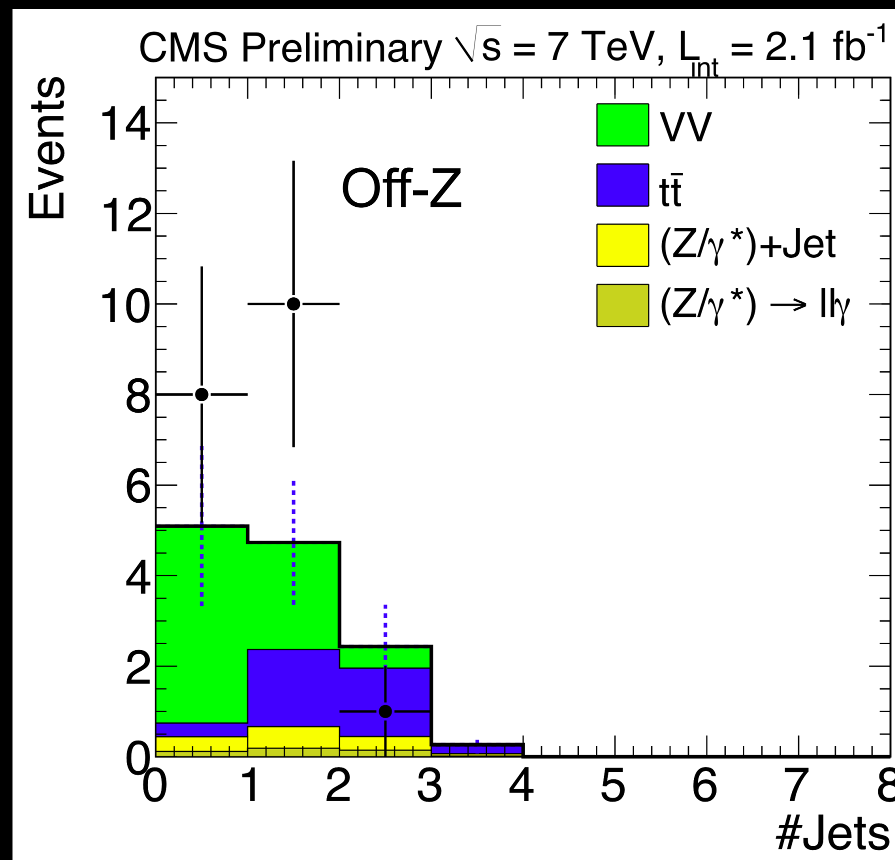


Multilepton searches

PAS-SUS-11-013

Kinematic consistency check: Njet (pT>40) after all cuts





Theory issues: NLO background predictions

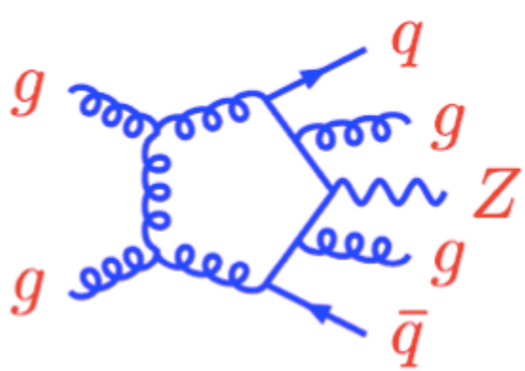
Zvi Bern

NLO Theory for SUSY Searches

October 19, 2011

Zvi Bern, UCLA (on behalf of BlackHat)

BlackHat Collaboration current members:
ZB, L. Dixon, F. Febres Cordero, G. Diana, S. Hoeche, H. Ita, D. Kosower, D. Maitre, K. Ozeren



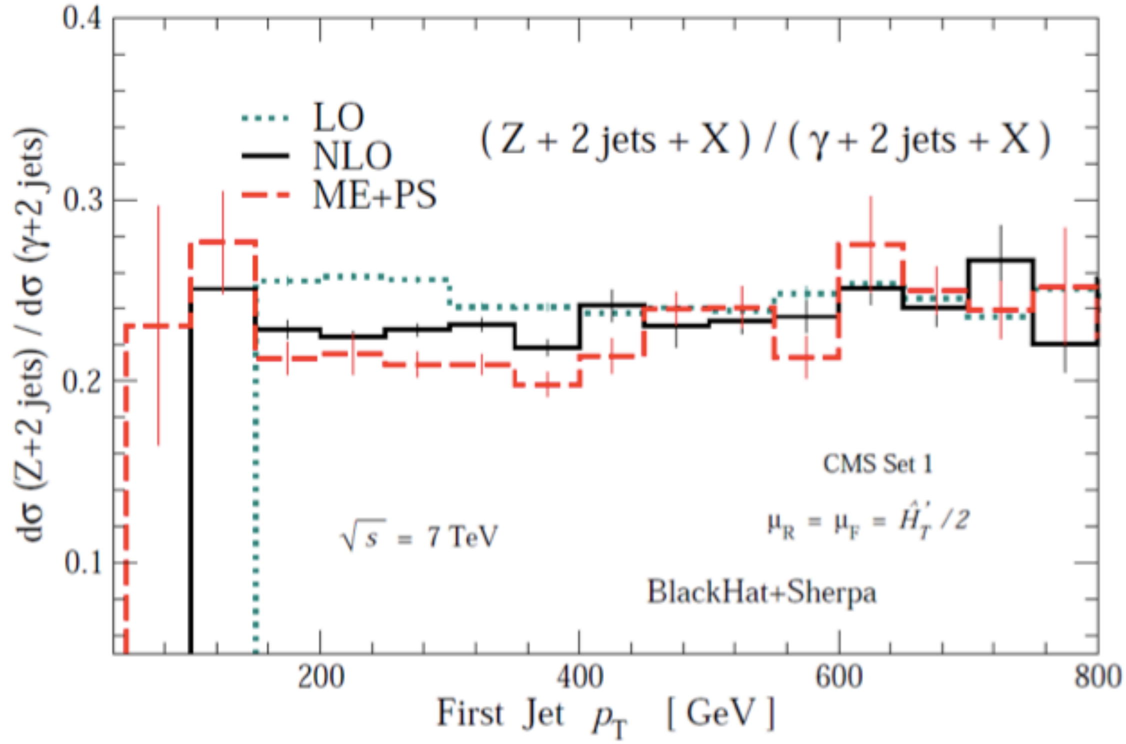
Theory issues: NLO background predictions

Zvi Bern

Will be critical when we start to see excesses

Z/γ ratio

ZB, L. Dixon, F. Febres Cordero, G. Diana, S. Hoeche, H. Ita, D. Kosower, D. Maitre, K. Ozeren



Different theoretical predictions track each other. This conversion directly used by CMS in their estimate of theory uncertainty.

Theory ideas: Compressed spectra

Steve Martin

For study: consider models that generalize mSUGRA by including a "compression factor" c. At the TeV scale:

$$M_1 = \left(\frac{1+5c}{6}\right) M_{\tilde{g}}, \qquad M_2 = \left(\frac{1+2c}{3}\right) M_{\tilde{g}},$$

- $c = 0$ corresponds to mSUGRA.
- $c = 1$ is total compression (gauginos degenerate).

Also take $\tan\beta = 10, \quad \mu > 0,$ and squark masses

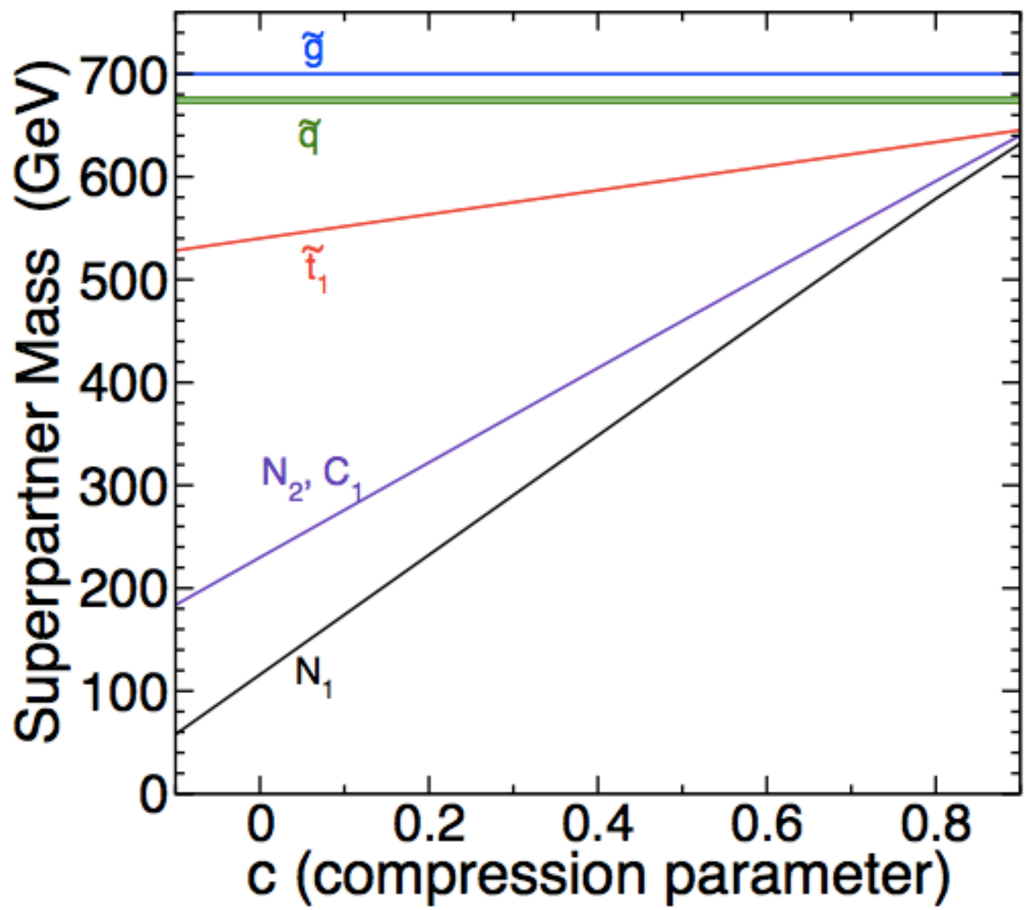
$$M_{\tilde{Q}} = 0.96 M_{\tilde{g}}.$$

Variable input parameters: $M_{\tilde{g}}$ (overall superpartner mass scale) and c (compression factor).

Theory ideas: Compressed spectra

Steve Martin

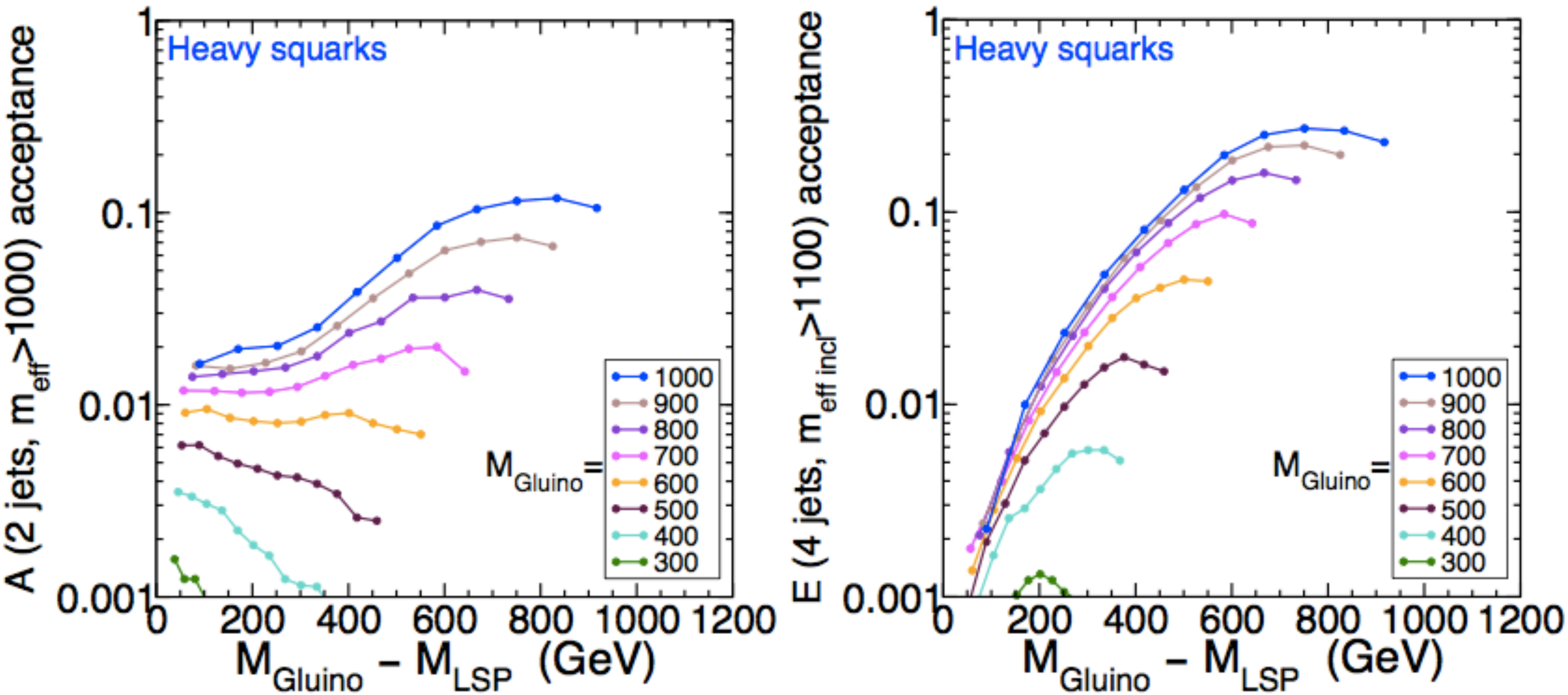
Masses of important superpartners, as a function of c, for $M_{\tilde{g}} = 700$ GeV:



Theory ideas: Compressed spectra

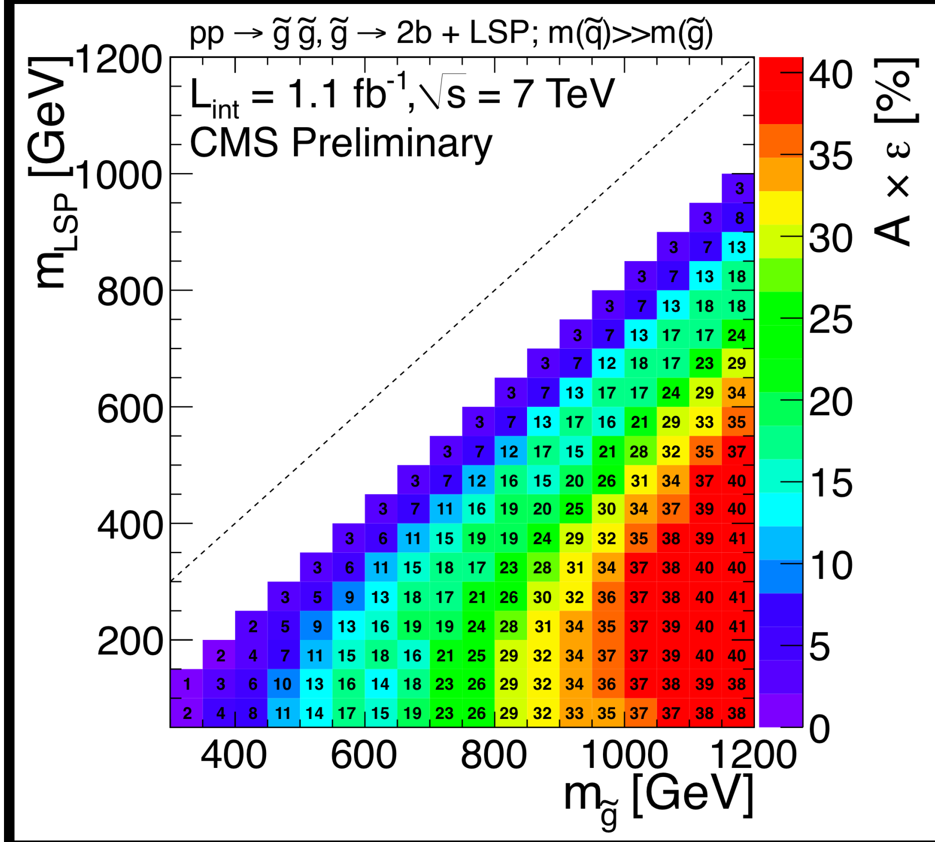
Steve Martin

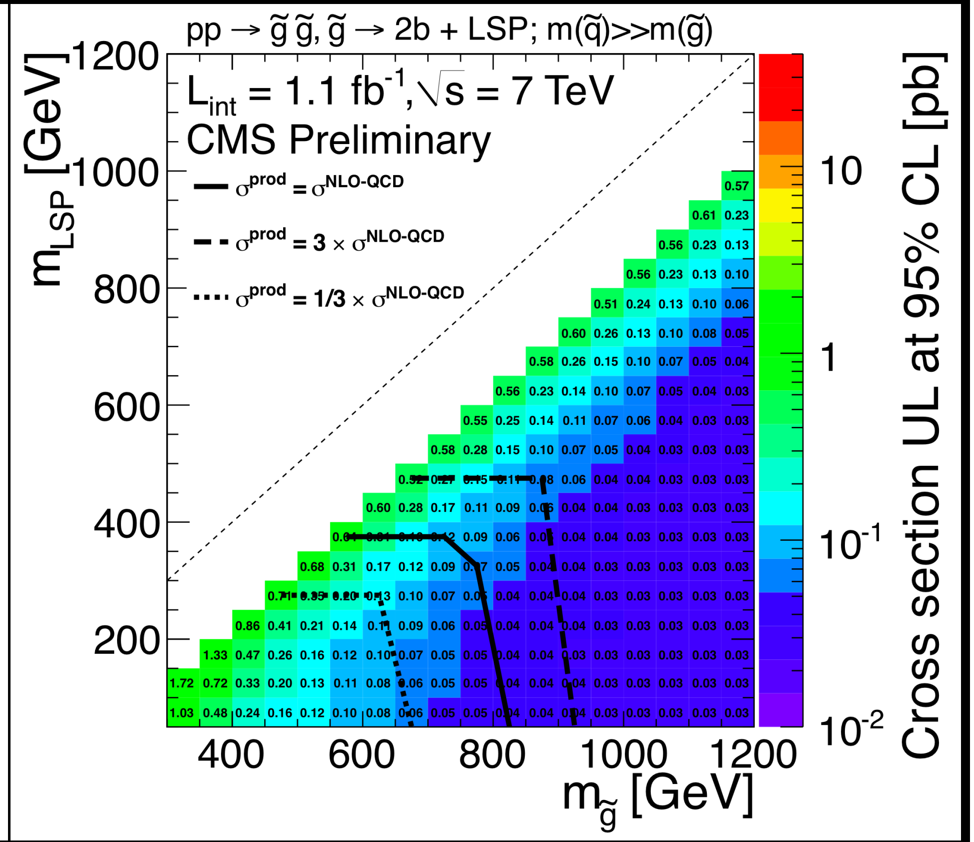
For low compression, signal E (4 jets, inclusive m_{eff}) wins, but as the compression increases, B (3 jets) and then A (2 jets) take over.



Theory ideas: Compressed spectra

Limits collapse for LSP mass above a couple hundred GeV.
Efficiency at low Δm is low and uncertain.





Theory ideas: Compressed spectra

Steve Martin

Suggestions:

- Require fewer jets (or lower p_T threshold for subleading jets), but sum over more of them in defining m_{eff},

  AND/OR

- Choose lower cut on m_{eff} (750 GeV?), and a higher cut on $E_T^{\text{miss}}/m_{\text{eff}}$ (0.35?) to compensate.

- Collect more data and be patient. . .

Theory ideas: GGM

David Shih

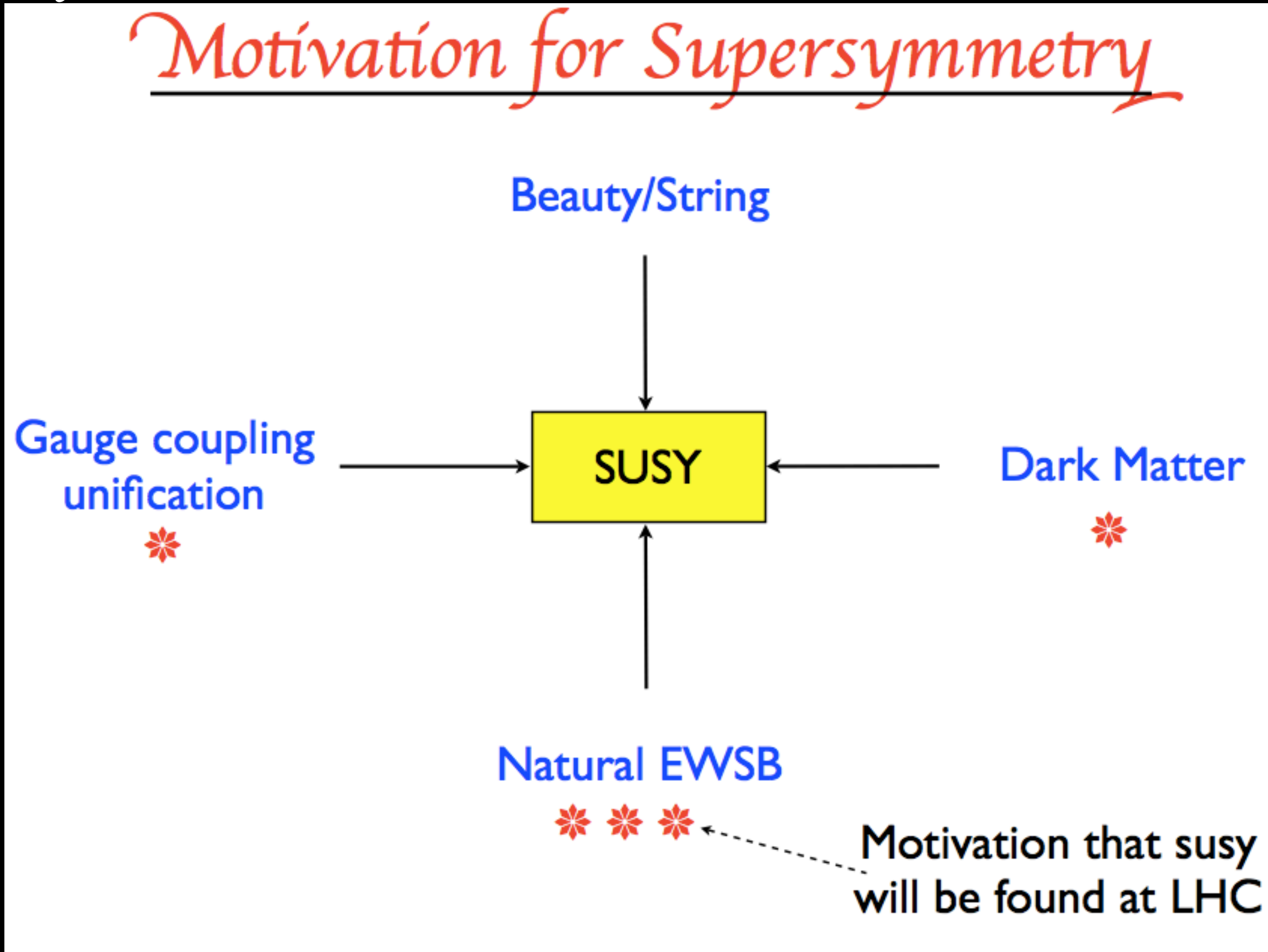
NLSP Collider Signatures

- In GGM, the NLSP can be (almost) anything in the MSSM

NLSP type	Relevant final states (+MET)
bino	$\gamma\gamma$, γ+jets
wino	$\gamma\ell$, $\gamma\gamma$, γ+jets, ℓ+jets, jets
Z-rich Higgsino	$Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell'^+\ell'^-)$, jets
h-rich Higgsino	b-jets, jets
slepton	SS dileptons, multileptons, jets
squark/gluino	jets
stop	SS dileptons, b-jets, ℓ+jets, $\ell + b$-jets, $t\bar{t}$, jets
sbottom	b-jets, jets

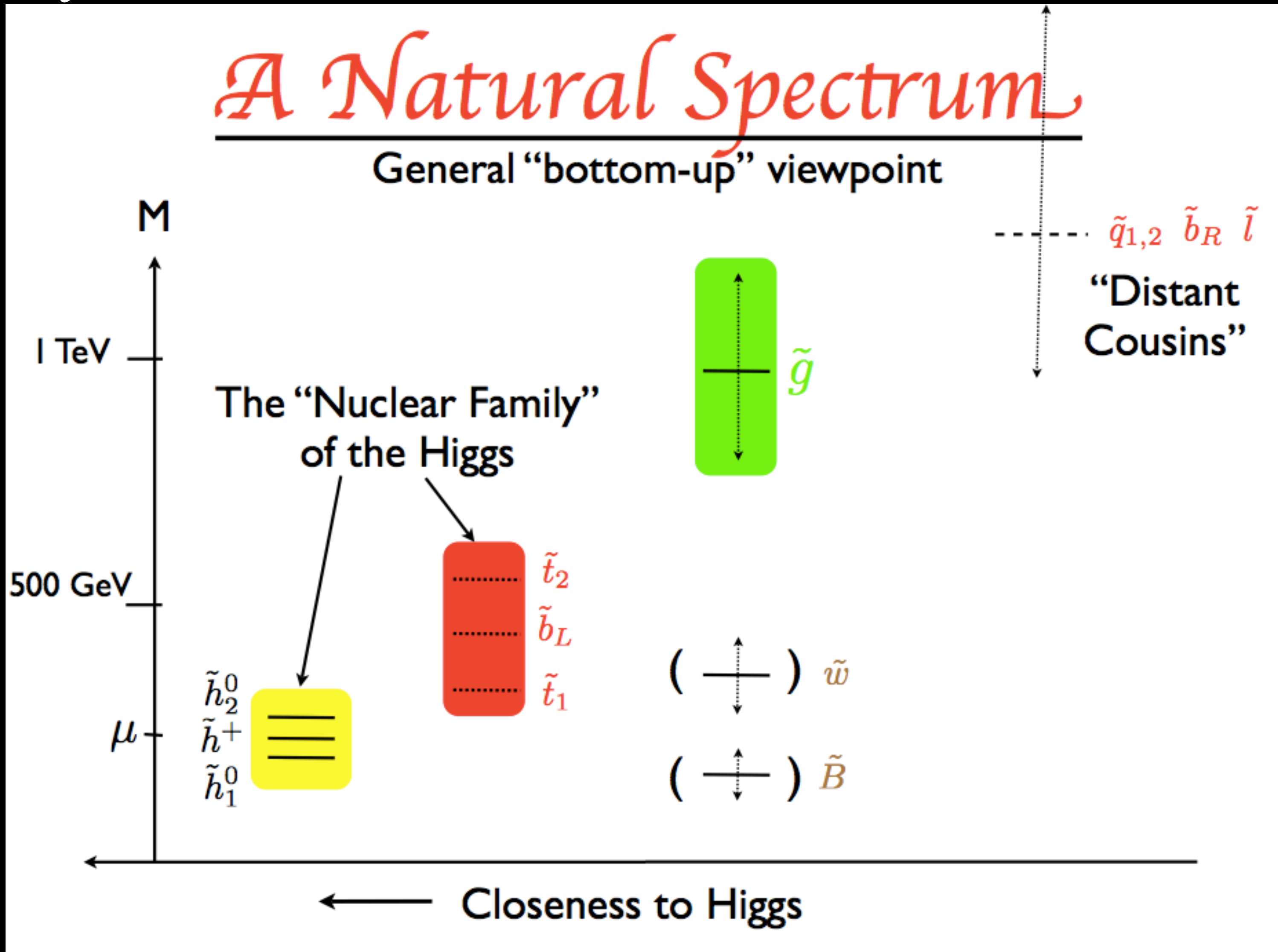
Theory ideas: Naturalness

Lawrence Hall



Theory ideas: Naturalness

Lawrence Hall

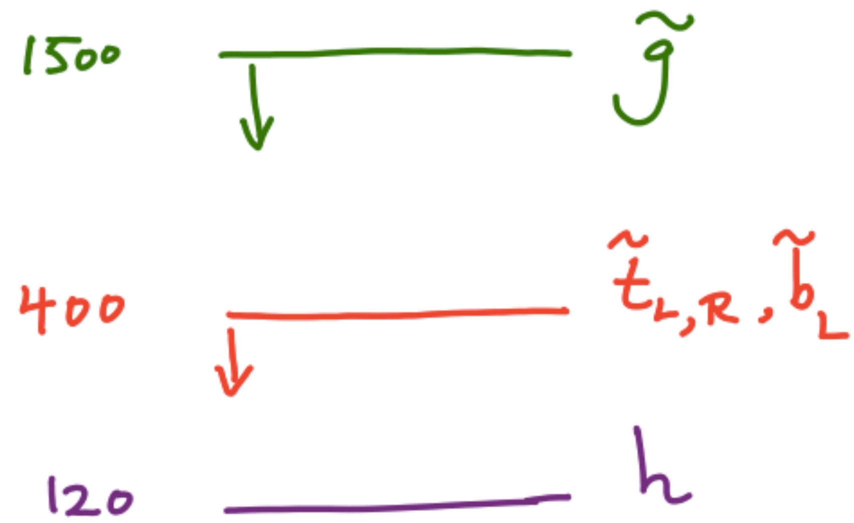


" 'Natural spectrum' is 15-20 years old"; "We already bought something like this after LEP"

Theory ideas: Naturalness

Nima Arkani-Hamed

SUSY Bull's Eye

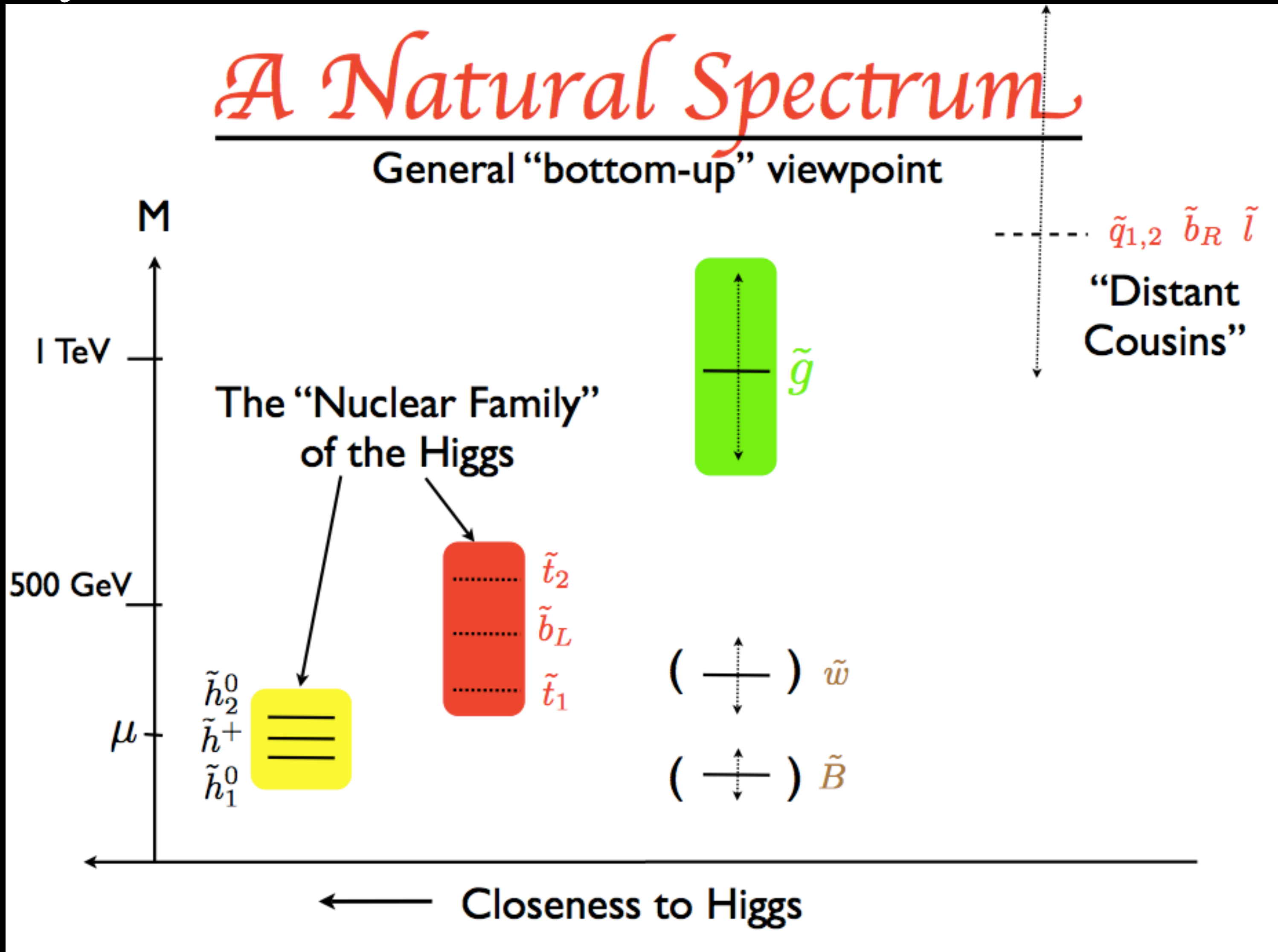


No wiggle room. Limits: sharply quantify tuning.

DISCOVERY → EUPHORIA!

Theory ideas: Naturalness

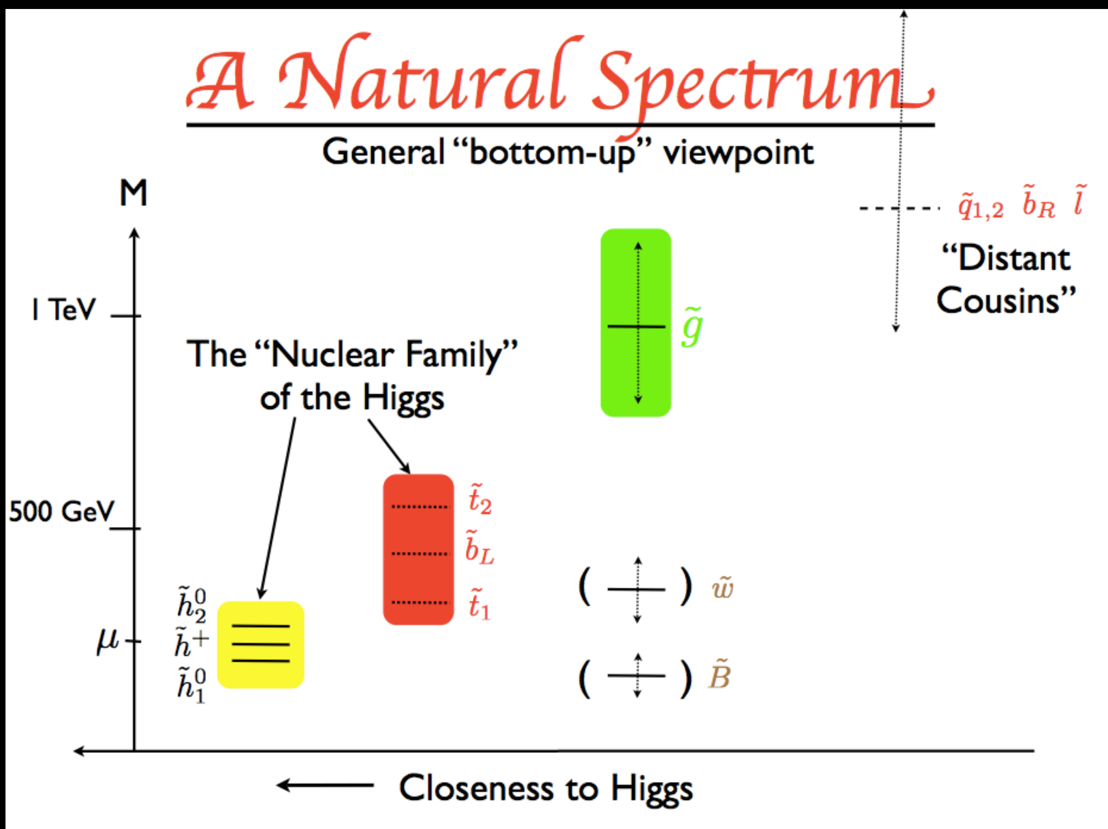
Lawrence Hall



" 'Natural spectrum' is 15-20 years old"; "We already bought something like this after LEP"

SUSY Status Report? – a reasonable answer

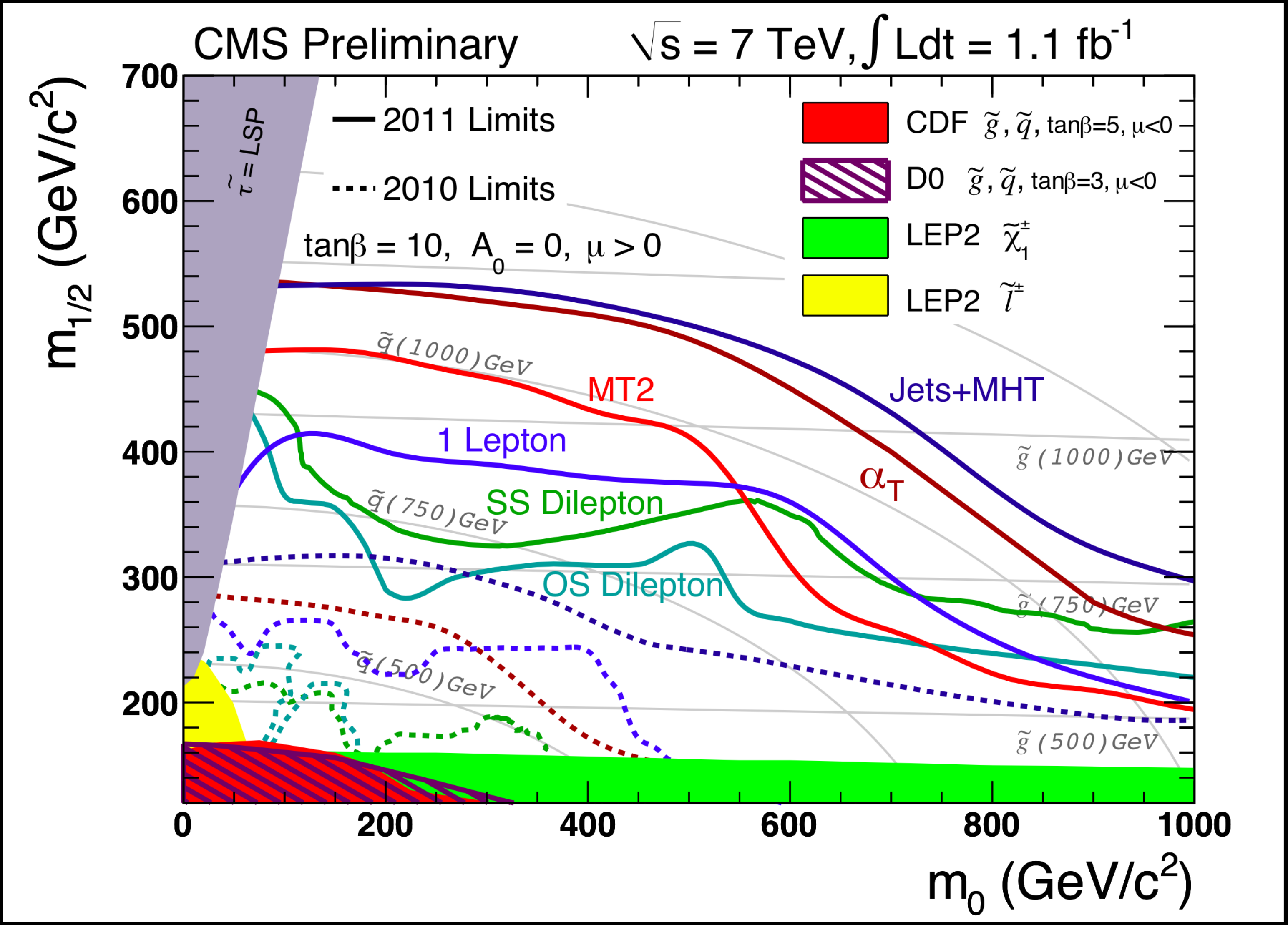
$\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ covered up to maybe 500 or 1000 GeV
stop pair production unprobed so far.



Conclusion

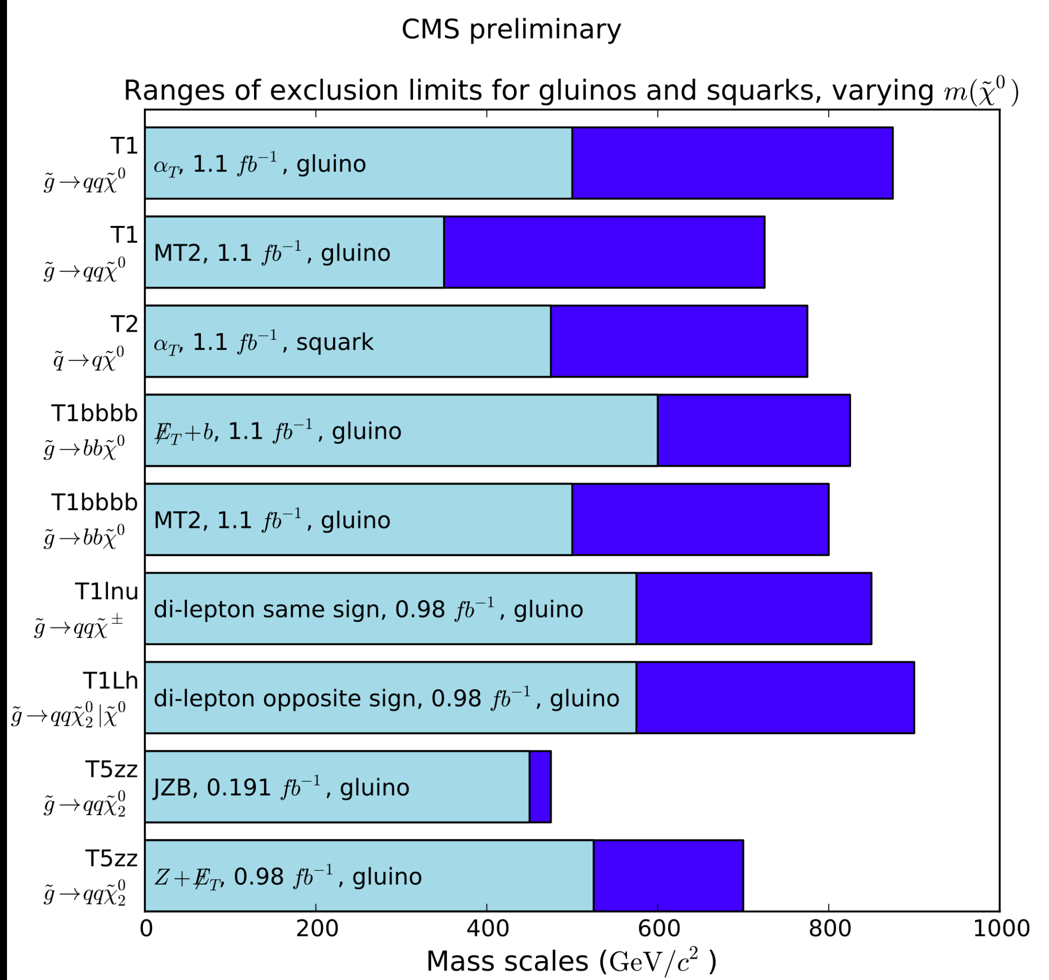
Additional slides…

Conclusion



CMS Preliminary
$\sqrt{s}$ = 7 TeV, $\int$ Ldt = 1.1 fb^{-1}
2011 Limits
2010 Limits
tanβ = 10, A_0 = 0, μ > 0
$\tilde{\tau}$ = LSP
CDF $\tilde{g}, \tilde{q}$, tanβ=5, μ<0
D0 $\tilde{g}, \tilde{q}$, tanβ=3, μ<0
LEP2 $\tilde{\chi}_1^{\pm}$
LEP2 $\tilde{l}^{\pm}$
MT2
Jets+MHT
1 Lepton
α_T
SS Dilepton
OS Dilepton
$\tilde{q}$(1000)GeV
$\tilde{q}$(750)GeV
$\tilde{q}$(500)GeV
$\tilde{g}$(1000)GeV
$\tilde{g}$(750)GeV
$\tilde{g}$(500)GeV
$m_{1/2}$ (GeV/c^2)
m_0 (GeV/c^2)

Conclusion

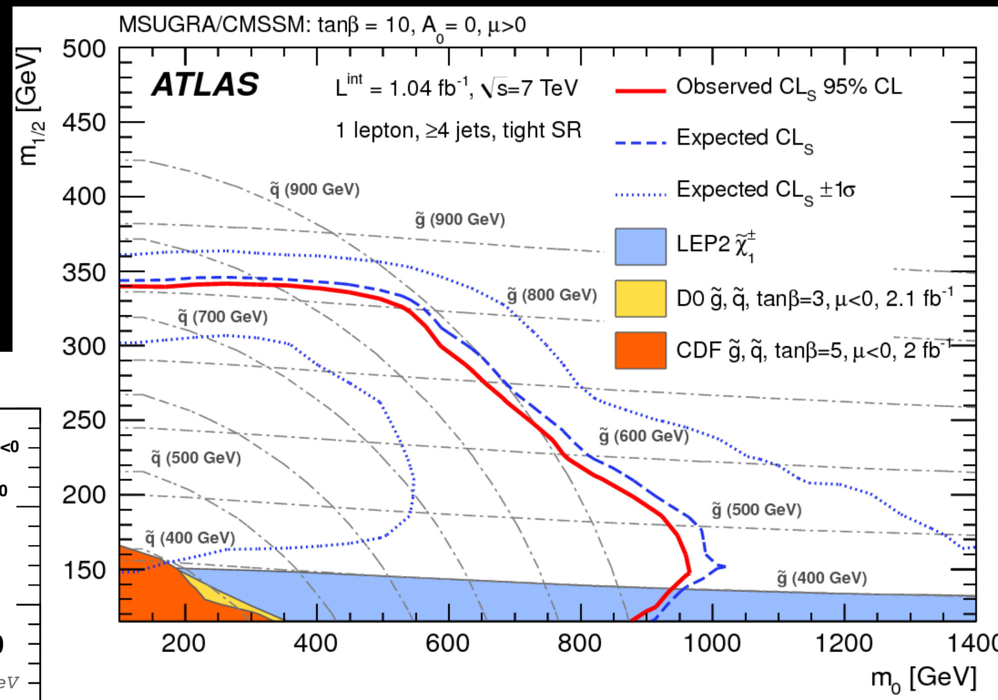


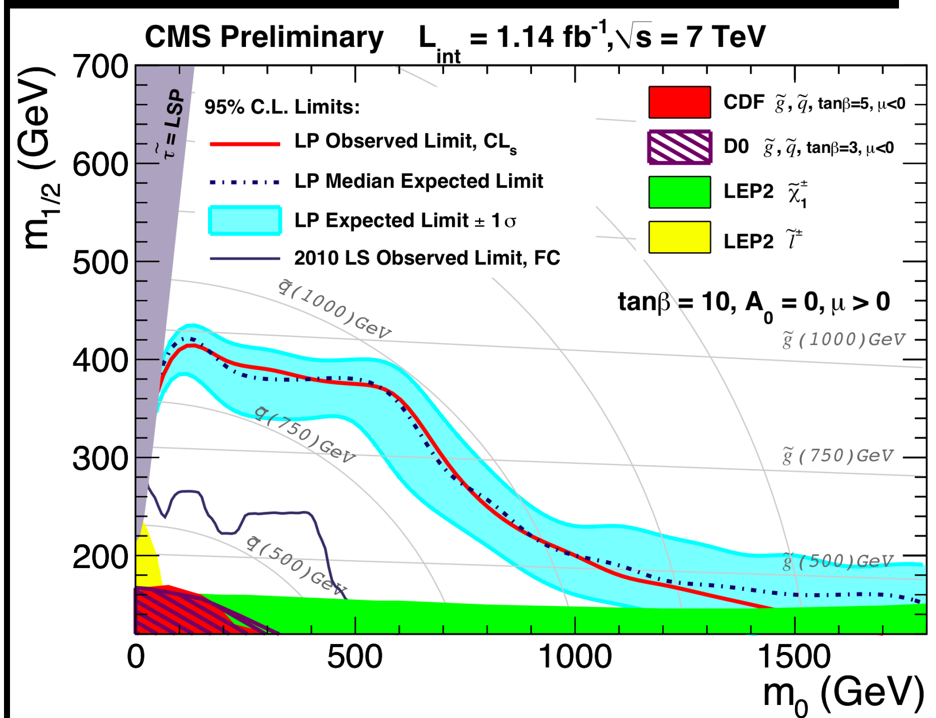
For limits on $m(\tilde{g}), m(\tilde{q}) >> m(\tilde{g})$ (and vice versa). $\sigma^{\mathrm{prod}} = \sigma^{\mathrm{NLO-QCD}}$.

$m(\tilde{\chi}^{\pm}), m(\tilde{\chi}^0_2) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$.

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g}) - 200$ GeV/c^2 (light blue).

Interpretation: PDF uncertainty at high mass






Steve Martin (NIU)