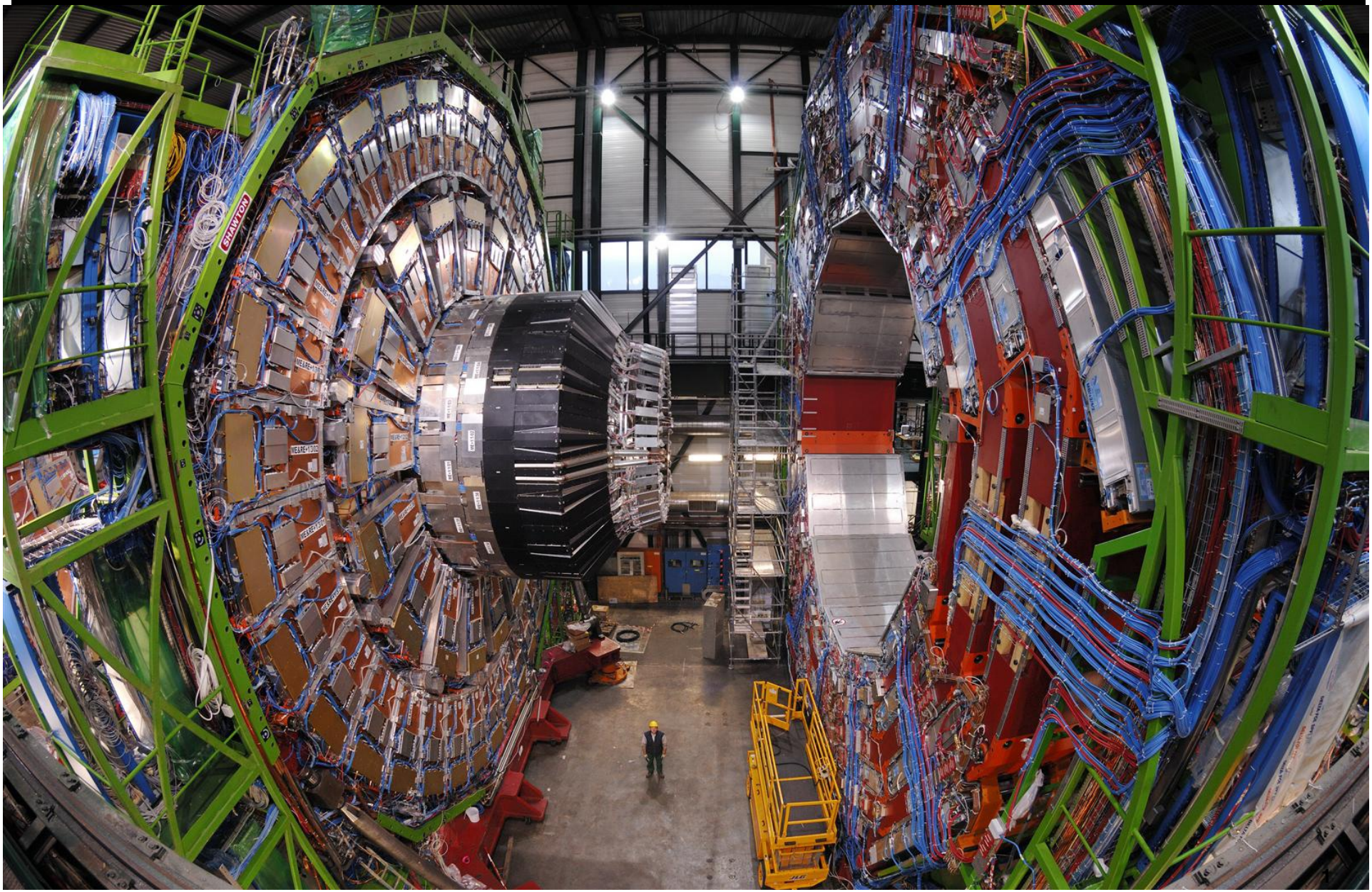
CMS SUSY Searches, David Stuart (UC Santa Barbara)



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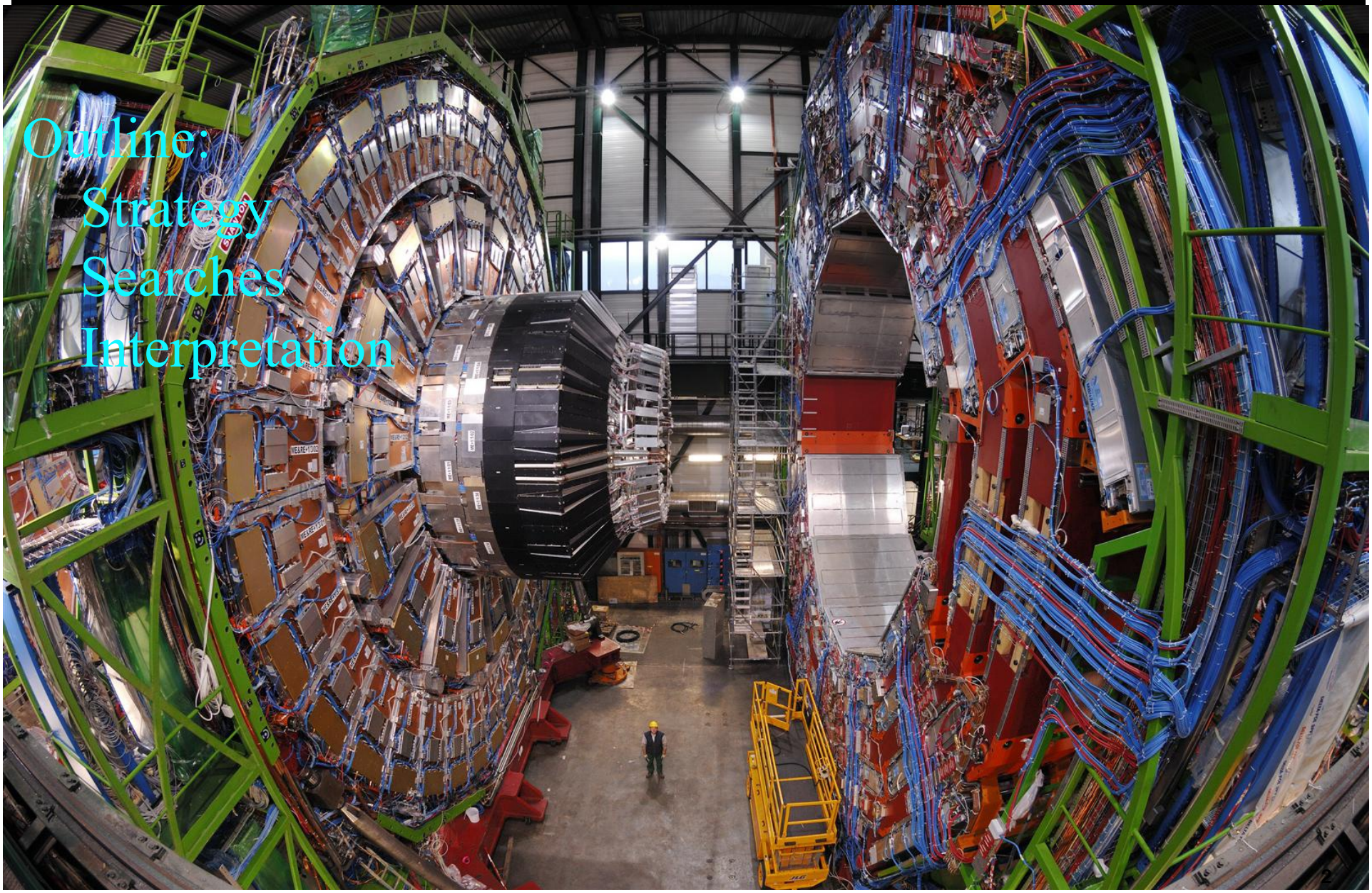


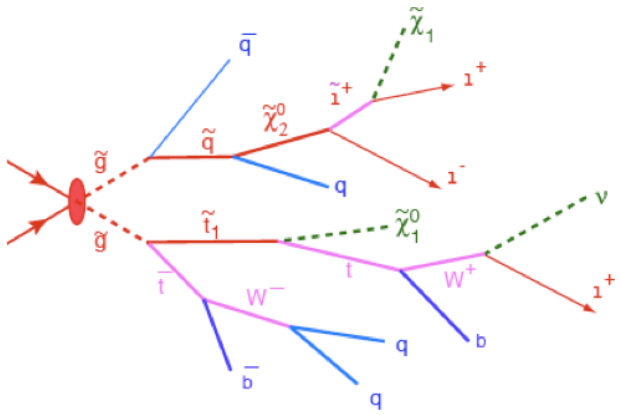
Outline:

- Strategy
- Searches
- Interpretation

Strategy:

Strongly produced heavy particles

Large missing energy and large jet activity



Backgrounds from:

Physics: Standard Model processes that give similar signatures (tails).
External: Beam-halo and cosmic ray muons, beam-gas interactions.
Instrumental effects: Noise, mis-calibration, bugs.

Strategy:

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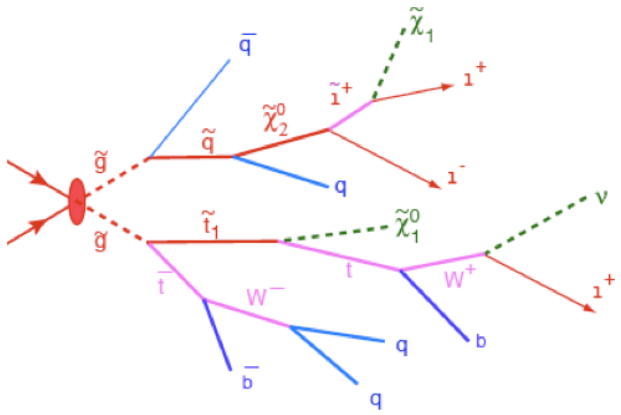

Backgrounds from:

Physics: Standard Model processes that give similar signatures (tails).
External: Beam-halo and cosmic ray muons, beam-gas interactions.
Instrumental effects: Noise, mis-calibration, bugs.

Design for a discovery

⇒ Search broadly and quickly

⇒ Simple signatures

⇒ Data-driven backgrounds. Don't trust simulation to the 10^{-6} level

Strategy: Search broadly and quickly with simple signatures

Search Modes

- 0 leptons
- 1 lepton
- OS dilepton
- SS dilepton
- ≥ 3 leptons
- γ+lepton
- di-photon

Signatures are ≈ MET + jets + X

Strategy: Search broadly and quickly with simple signatures

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Signatures are ≈ MET + jets + X

Sub-sets in these with e.g., b's, τ's.

Each analysis uses multiple, cross-checking background prediction methods.

Strategy: Search broadly and quickly with simple signatures

Search Modes

- 0 leptons
- 1 lepton
- OS dilepton
- SS dilepton
- ≥ 3 leptons
- γ+lepton
- di-photon
- RPV or long-lived ← Non-MET based searches not covered in this talk

Signatures are ≈ MET + jets + X

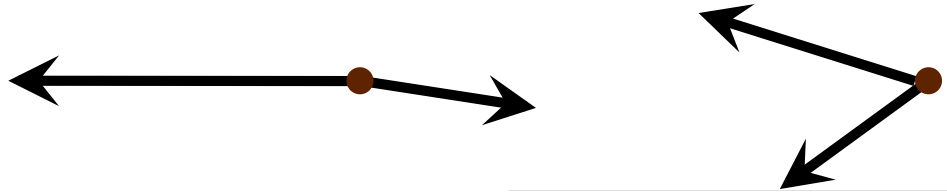
Sub-sets in these with e.g., b's, τ's.

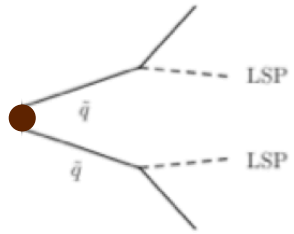
Each analysis uses multiple, cross-checking background prediction methods.

All-hadronic searches with α_T

All-hadronic search is challenging due to QCD backgrounds: $\sigma^*\varepsilon \approx \infty^*0$
α_T is designed to be a QCD killer; inefficient but fast.

E.g., Di-jets

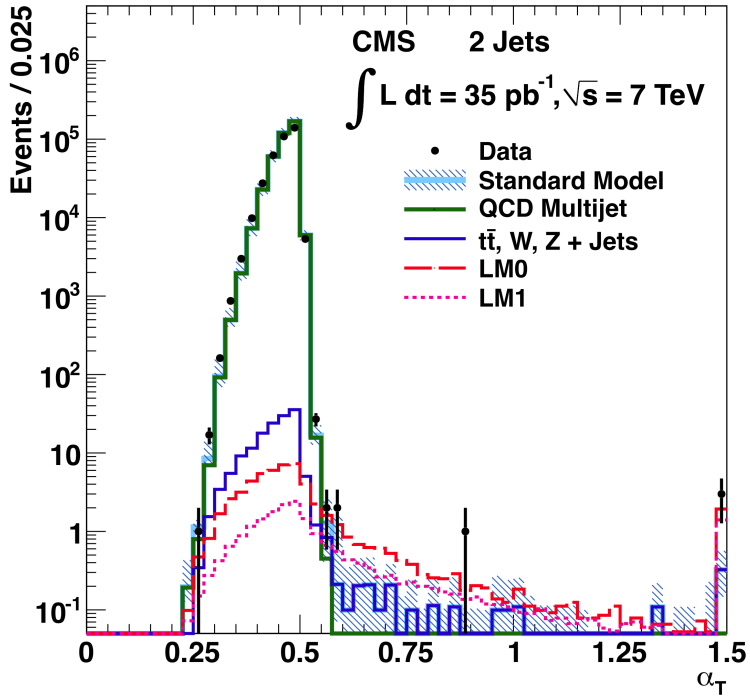




$$\alpha_T \equiv \frac{p_{T2}}{M_T}$$

$$M_T = \sqrt{2p_{T1}p_{T2}(1-\cos\Delta\phi)}.$$

$$\alpha_T = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$



$\alpha_T \leq 0.5$ for mis-measured QCD

All-hadronic searches with α_T

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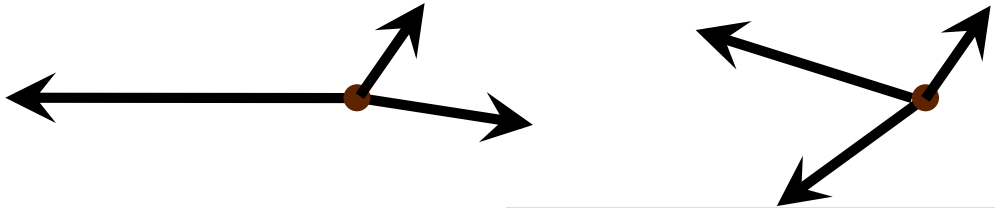
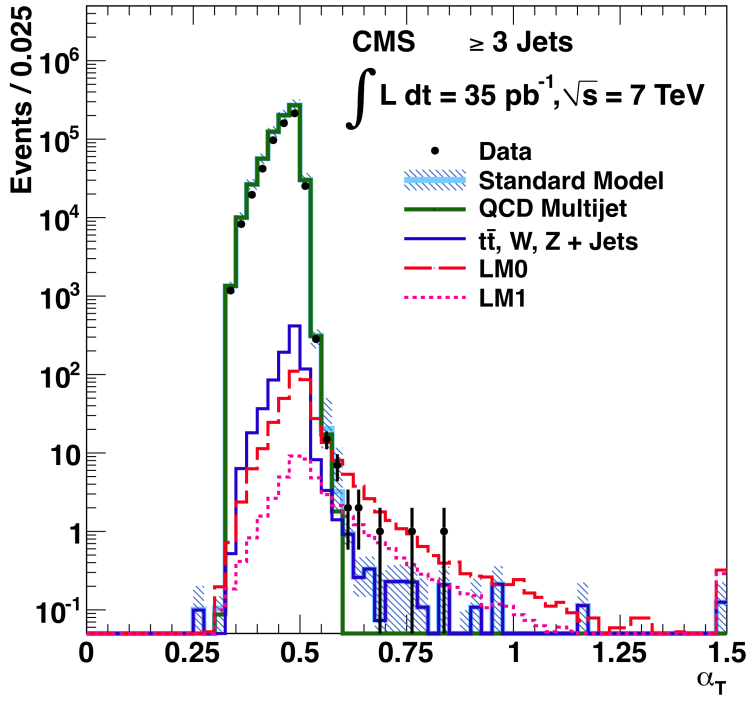
Turn >2 jets
into 2 pseudo-jets



$$\Delta H_T = p_{T\text{pseudojet 1}} - p_{T\text{pseudojet 2}}$$

$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}$$

$\alpha_T \leq 0.5$ for mis-measured QCD



All-hadronic searches with α_T

Search for high pT jets, high HT and α_T>0.55

2 jets, E_T>100 $|\eta|$<2.5

Additional jets with E_T>50 $|\eta|$<3

HT > 350

Event cleaning cuts, e.g.,
- Dead calorimeter cells
- “Baby jets”

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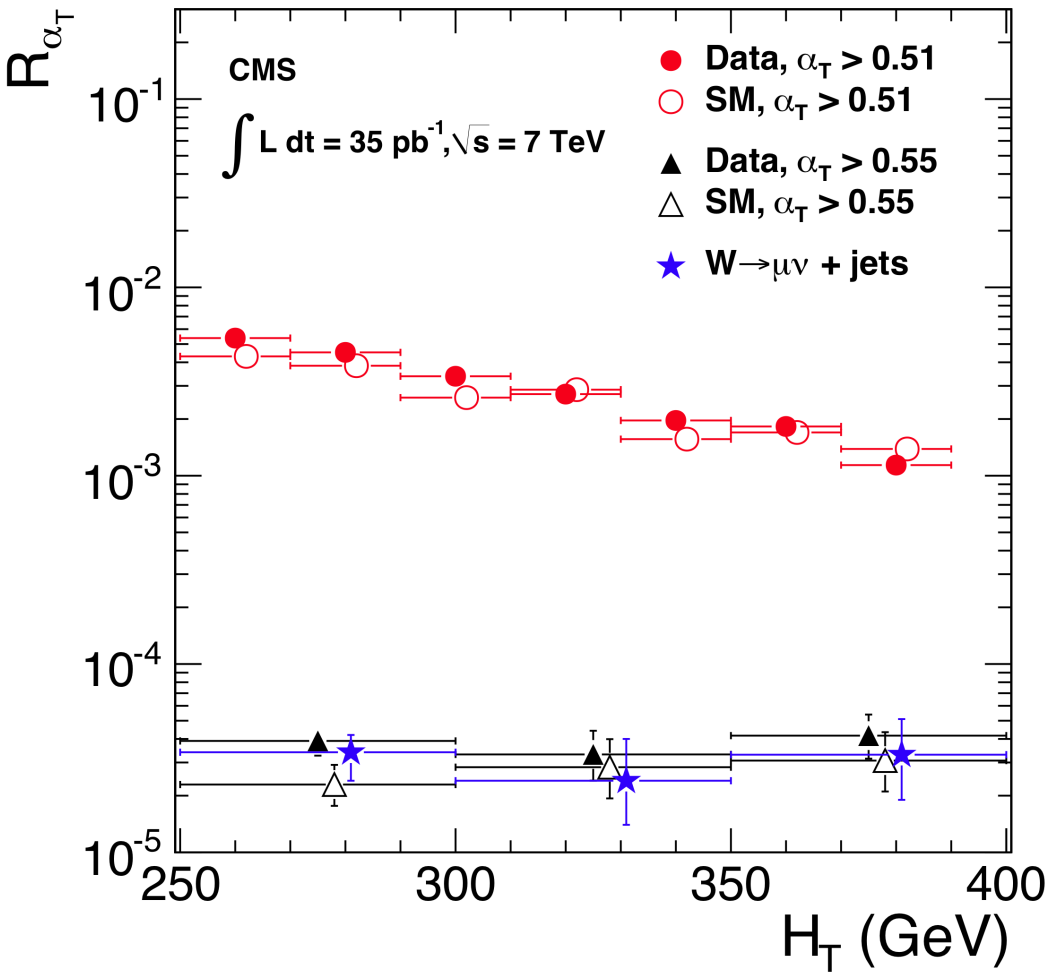
Predict high HT background by extrapolating R from low HT.
- QCD ≈ exponential
- True MET = flat

W & ttbar from μ control

$Z\rightarrow\nu\nu$ from γ+jets



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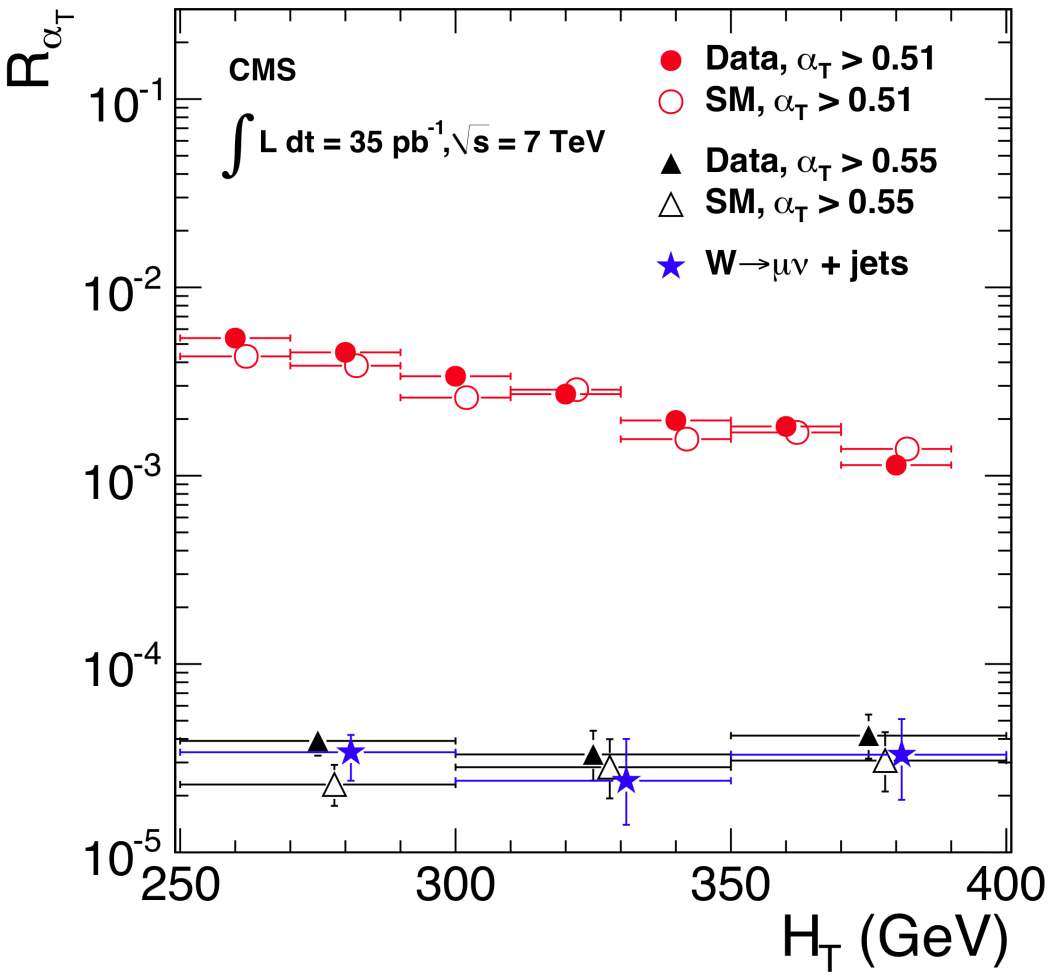
$Z\rightarrow\nu\nu$ from γ+jets

Predict $9.4^{+4.8}_{-4.0}$ (stat) ± 1.0 (syst)

Observe 13



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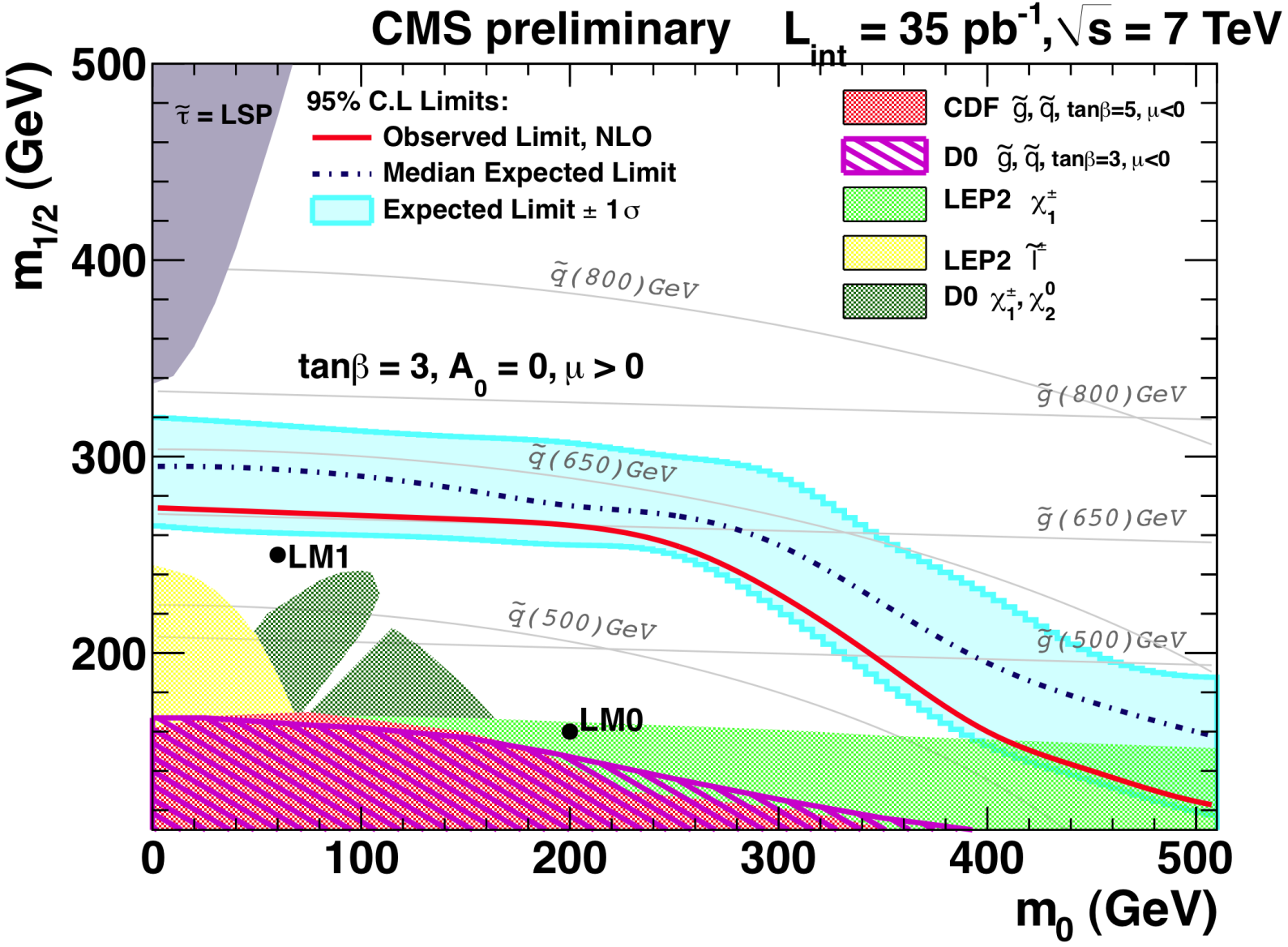

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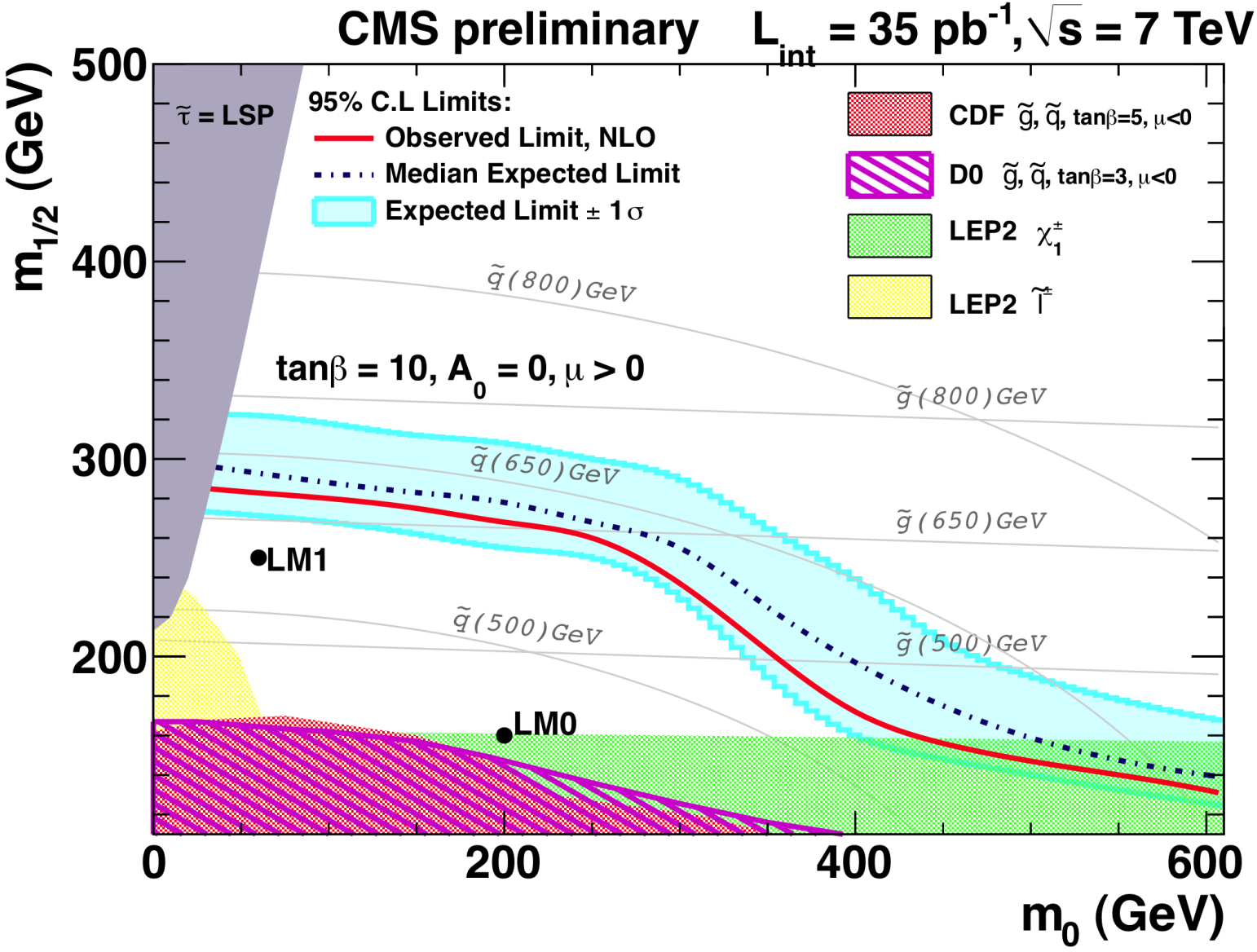

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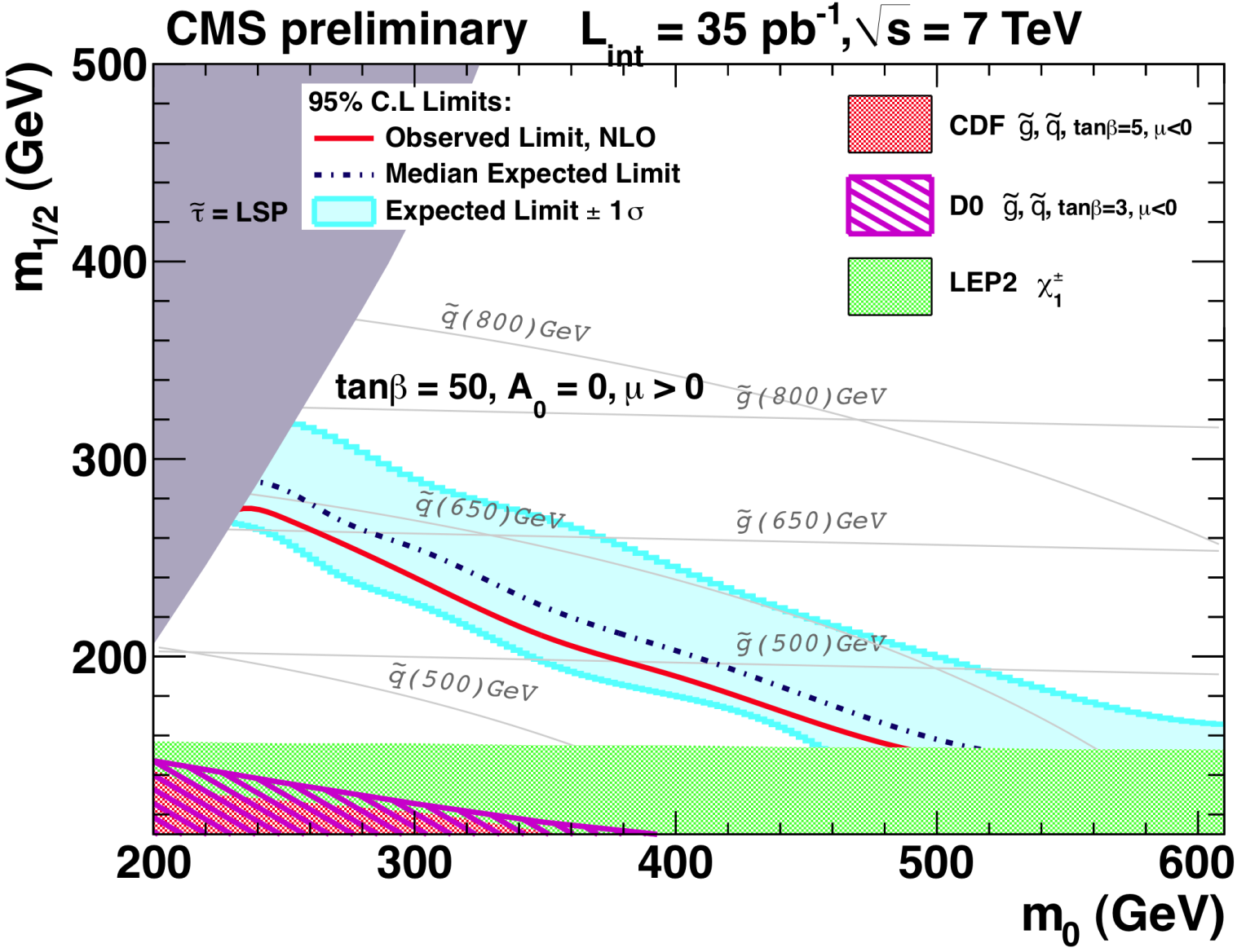


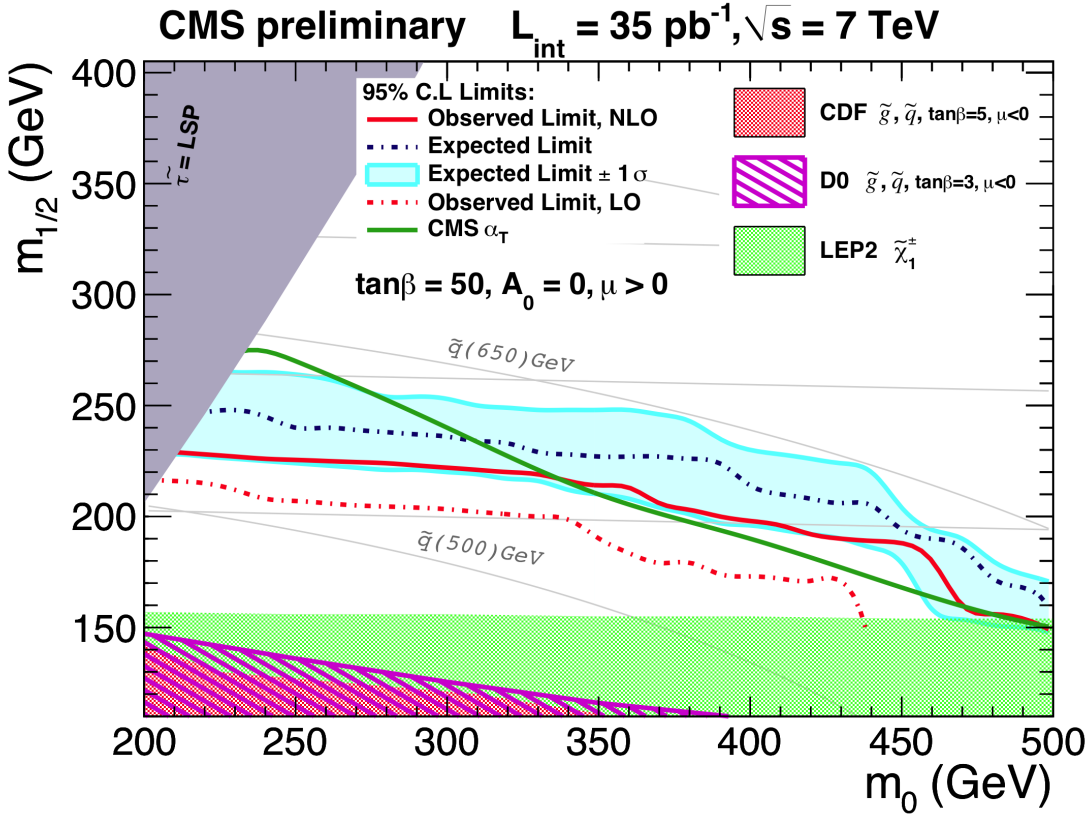
Limits in less constrained models discussed later.

All-hadronic searches with α_T + b-tag

α_T is a quick QCD killer; b-tagging is a quick EWK killer.
⇒ Enhance early discovery potential.

Similar selection (+ b-tag); Similar background prediction method.

Predict $0.33^{+0.43}_{-0.33}$ (stat) ± 0.13 (syst); Observe 1 event



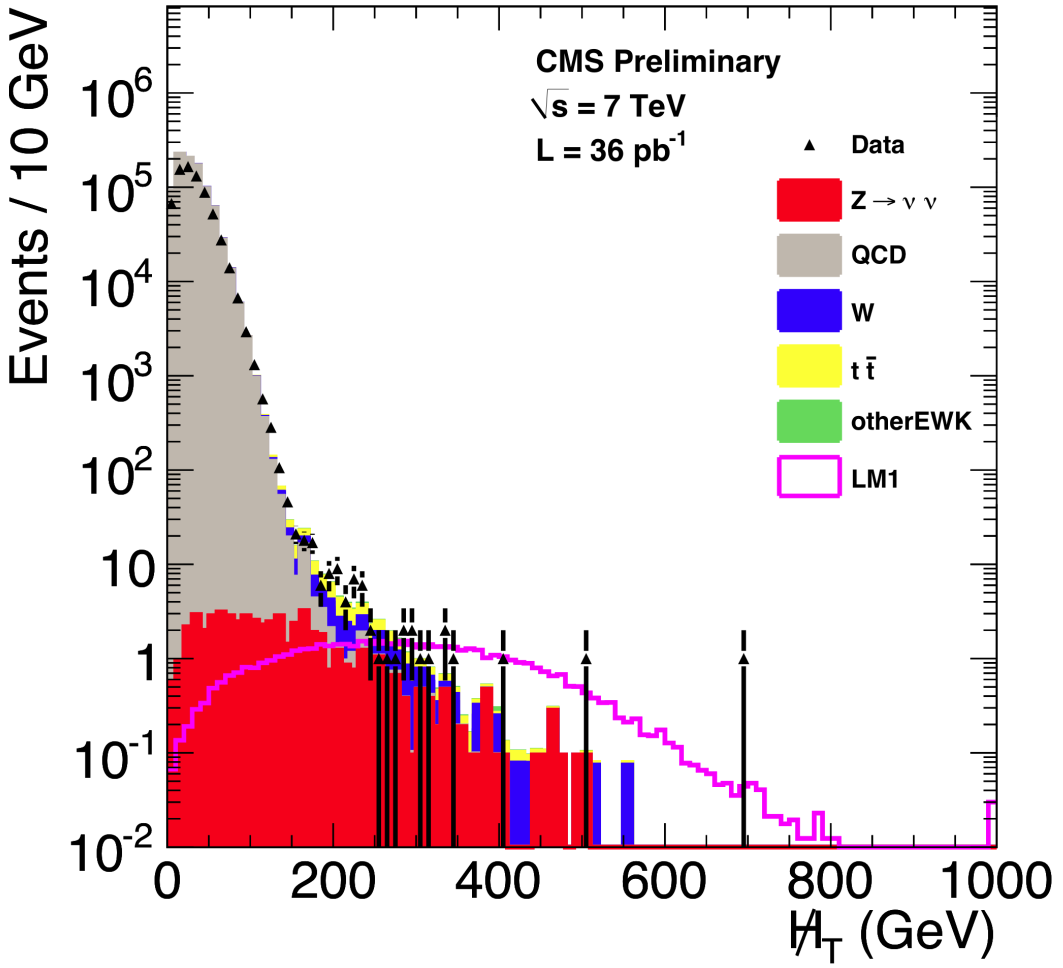
All-hadronic searches with MHT

Search for high pT jets, high HT and high MHT (= vector sum of jets)

3 jets, E_T>50 $|\eta|$<2.5

HT > 350 and MHT > 150

Event cleaning cuts.



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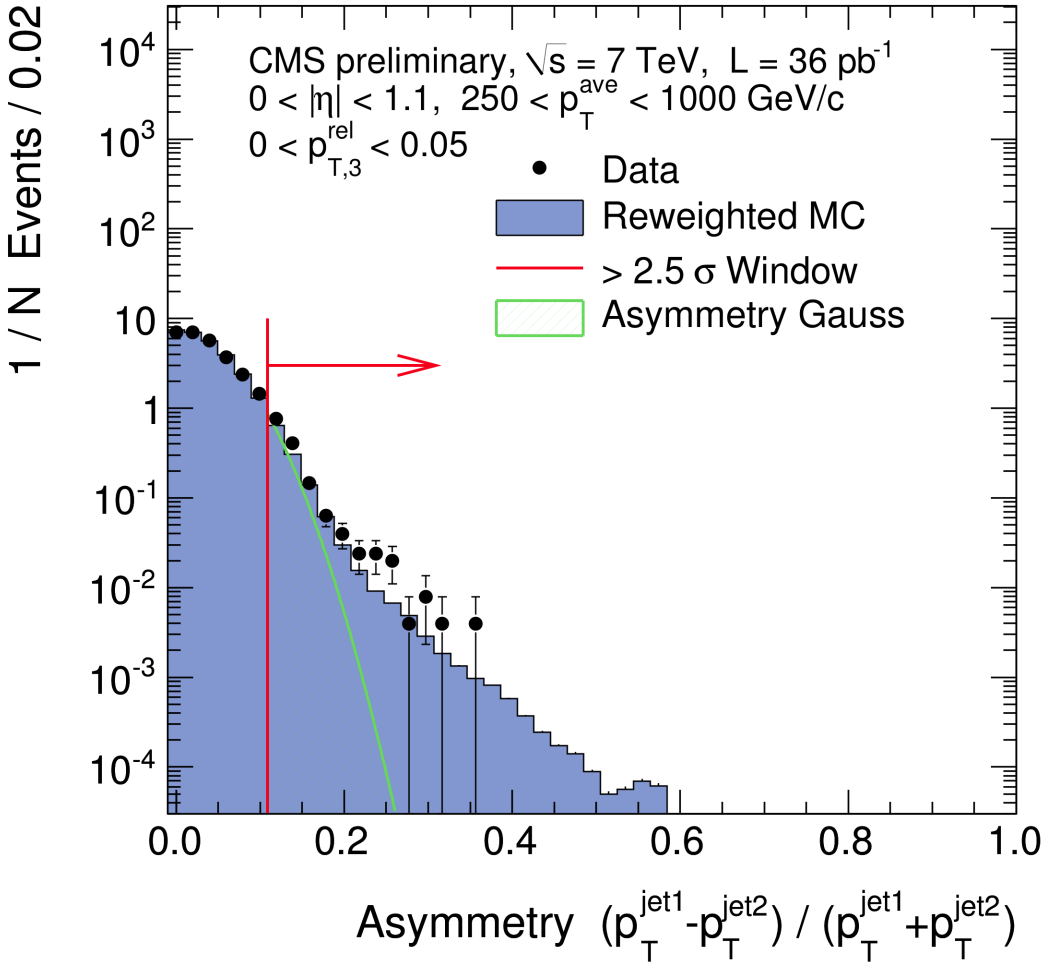
Predict each bkgd separately

- QCD: rebalance & smear
- W & ttbar from μ control
- $Z \rightarrow \nu\nu$ from γ+jets and $Z \rightarrow \mu\mu$



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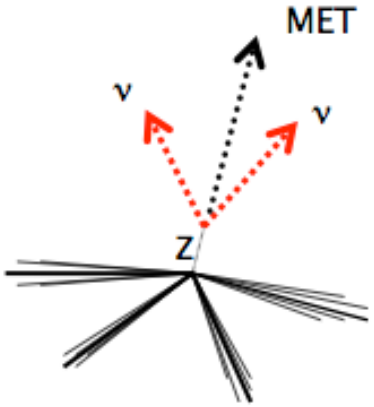
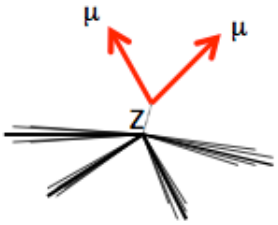
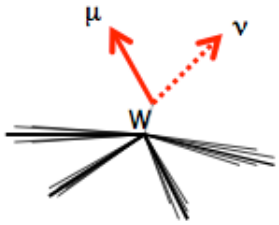
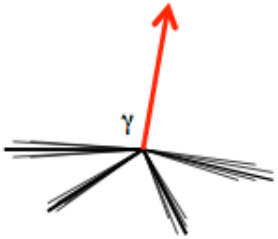




Z → ll + jets
Strength: very clean
Weakness: low statistics



W → lν + jets
Strength: larger statistics
Weakness: background from SM and SUSY



γ + jets
Strength: large statistics and clean at high E_T
Weakness: background at low E_T, theoretical errors

All-hadronic searches with MHT

Search for high pT jets, high HT and high MHT (= vector sum of jets)

3 jets, E_T>50 |η|<2.5

HT > 350 and MHT > 150

Event cleaning cuts.

Predict each bkgd separately

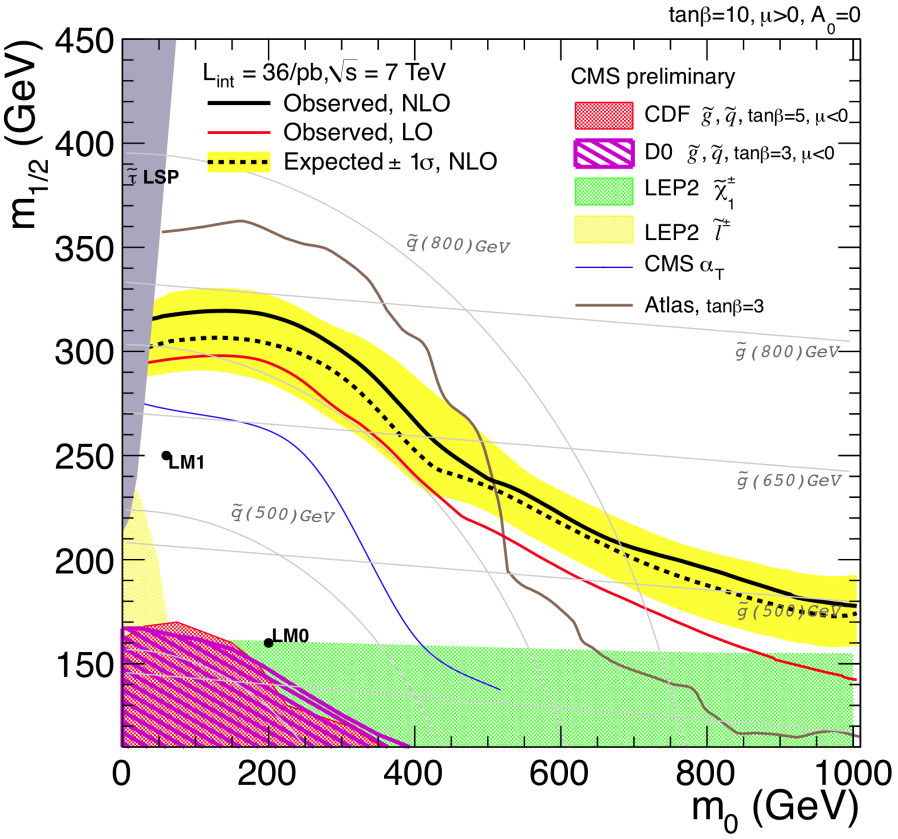
QCD: rebalance & smear

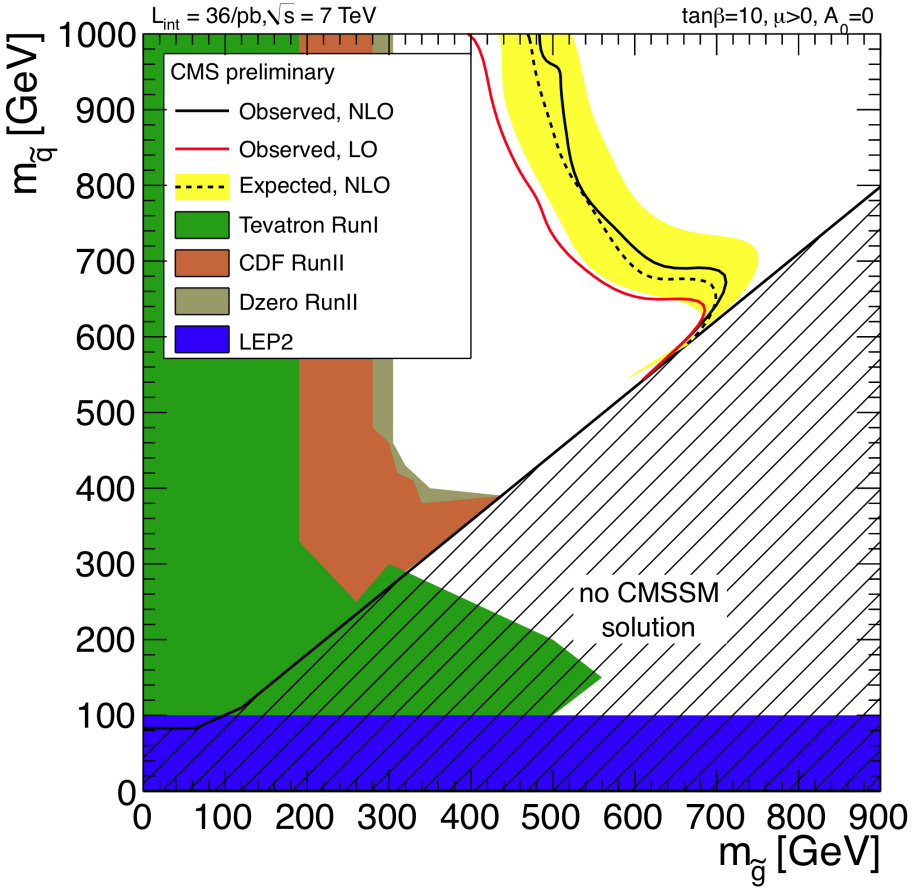
W & ttbar from μ control

Z→νν from γ+jets and Z→μμ

Method	Baseline		High-$\not{H}_T$ ($\not{H}_T > 250$ GeV/c)		High-H_T ($H_T > 500$ GeV/c)	
$Z \to \nu\bar{\nu}$ from γ+jets	26.3	±4.8	7.1	±2.2	8.4	±2.3
$t\bar{t}/W \to e, \mu$+X lost-lepton method	33.0	±8.1	4.8	±1.9	10.9	±3.4
$t\bar{t}/W \to \tau_{had}$+X method	22.3	±4.6	6.7	±2.1	8.5	±2.5
QCD Rebalance+Smear method	29.7	±15.2	0.16	±0.10	16.0	±7.9
QCD factorization method	25.2	±13.4	0.4	±0.3	17.3	±9.4
Total data-driven background	111.3	±18.5	18.8	±3.5	43.8	±9.2
Observed in 36 pb^{-1} of data	111		15		40	
95% CL limit on signal events	40.4		9.6		19.6	

All-hadronic searches with MHT





“Razor” search: threshold production

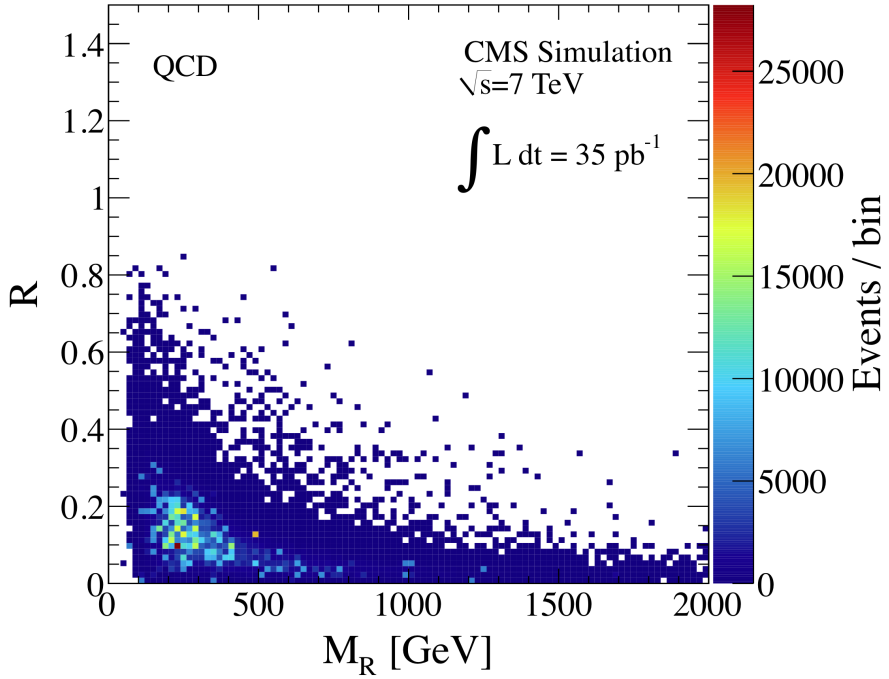
arXiv:1006.2727

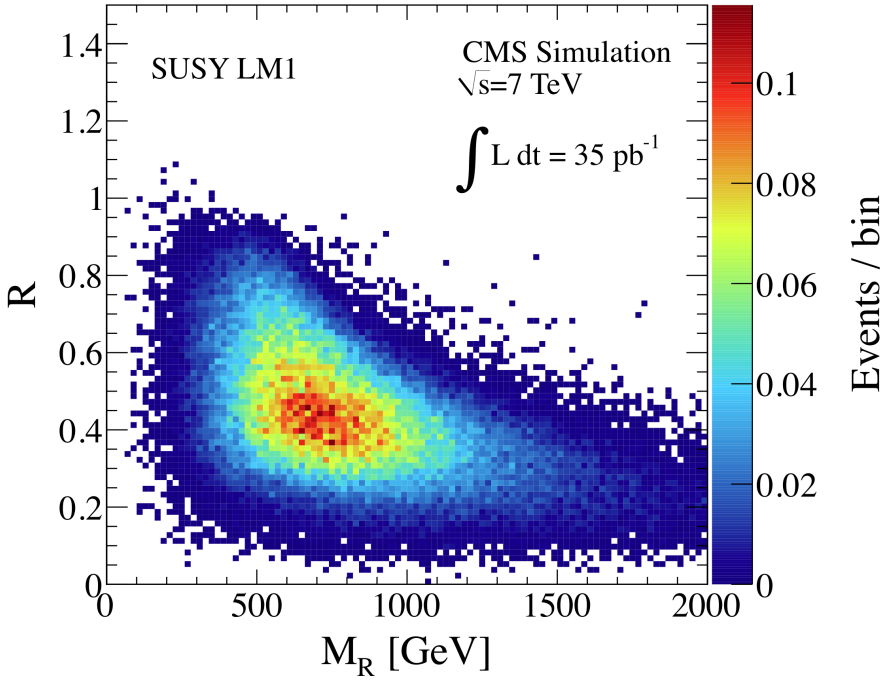
Introduce “razor” variables, M_R and R, that characterize massive pair-production.

Form two hemispheres and boost back to rest frame and calculate mass: $M_R \sim \frac{M_{squark}^2 - M_{\chi}^2}{M_{squark}}$

Define $R \equiv M_R^T / M_R$ that ≈ measures threshold production (centrality).

R>0.45 rejects QCD, then massive pair production would peak in ≈ MR.



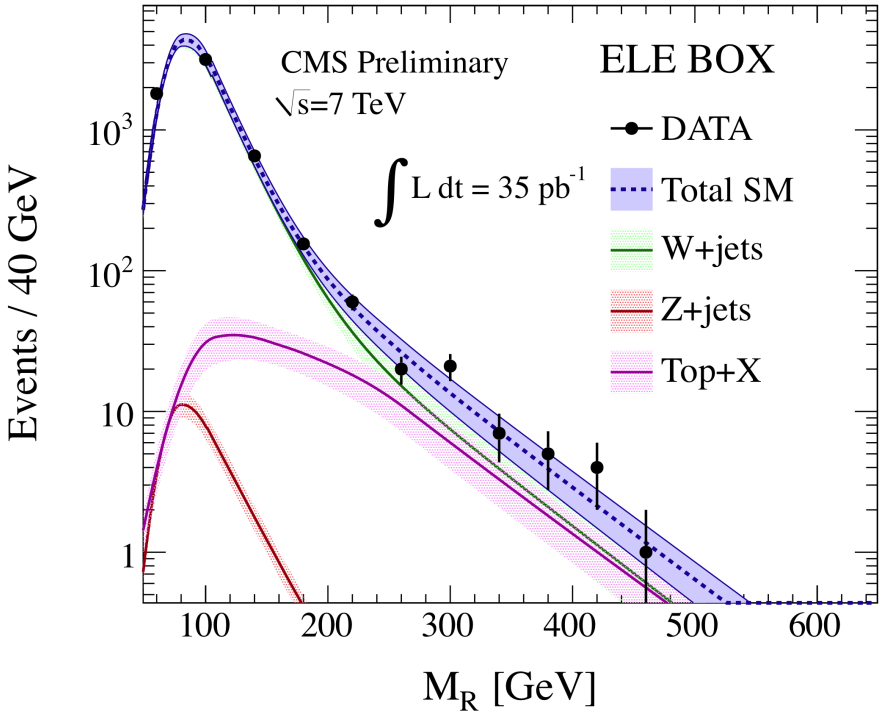


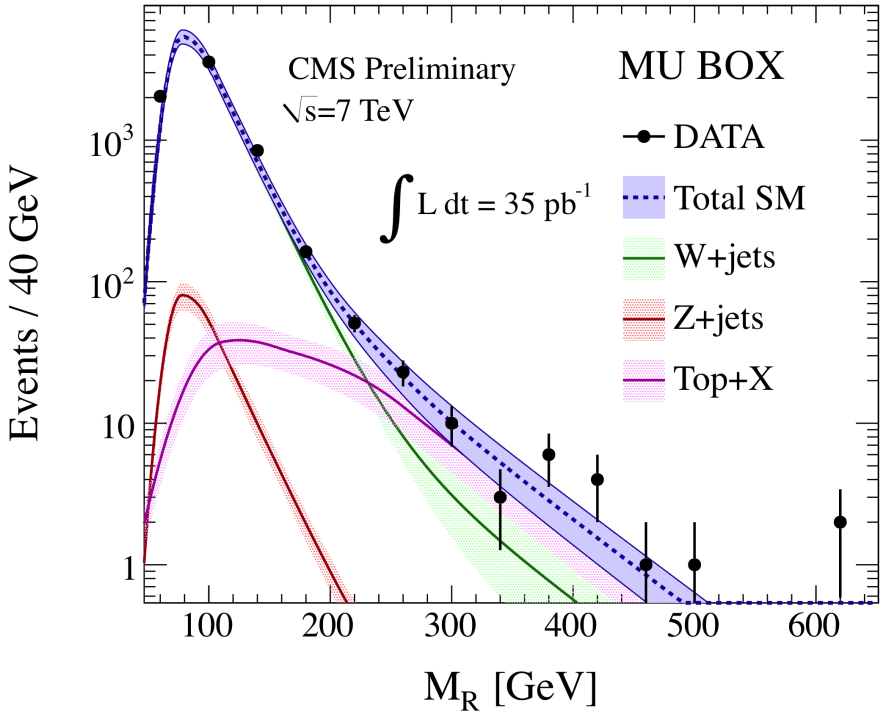
“Razor” search: threshold production

SM backgrounds (low mass) fall exponentially with M_R.

Measure them in control samples with BR and efficiency constraints from MC.

These shapes predict the lost lepton and $W \rightarrow \tau\nu$ background shapes in the hadronic mode.





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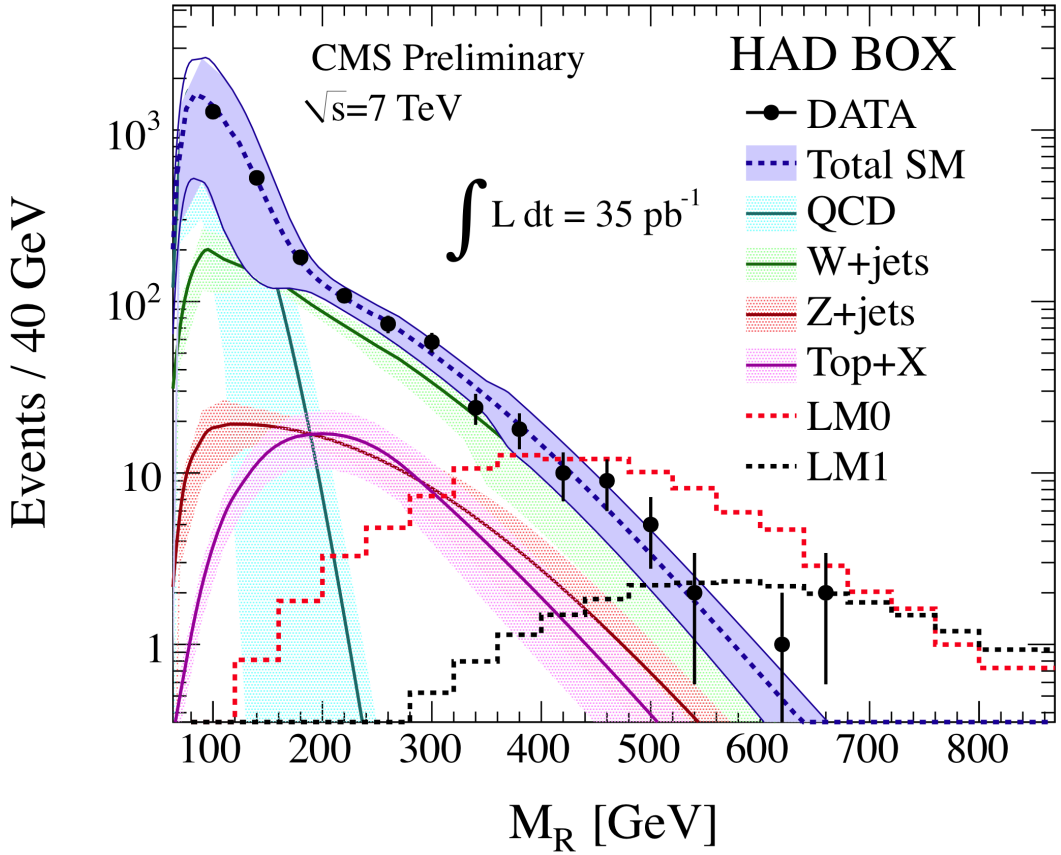
SM backgrounds (low mass) fall exponentially with M_R.

Measure them in control samples with BR and efficiency constraints from MC.

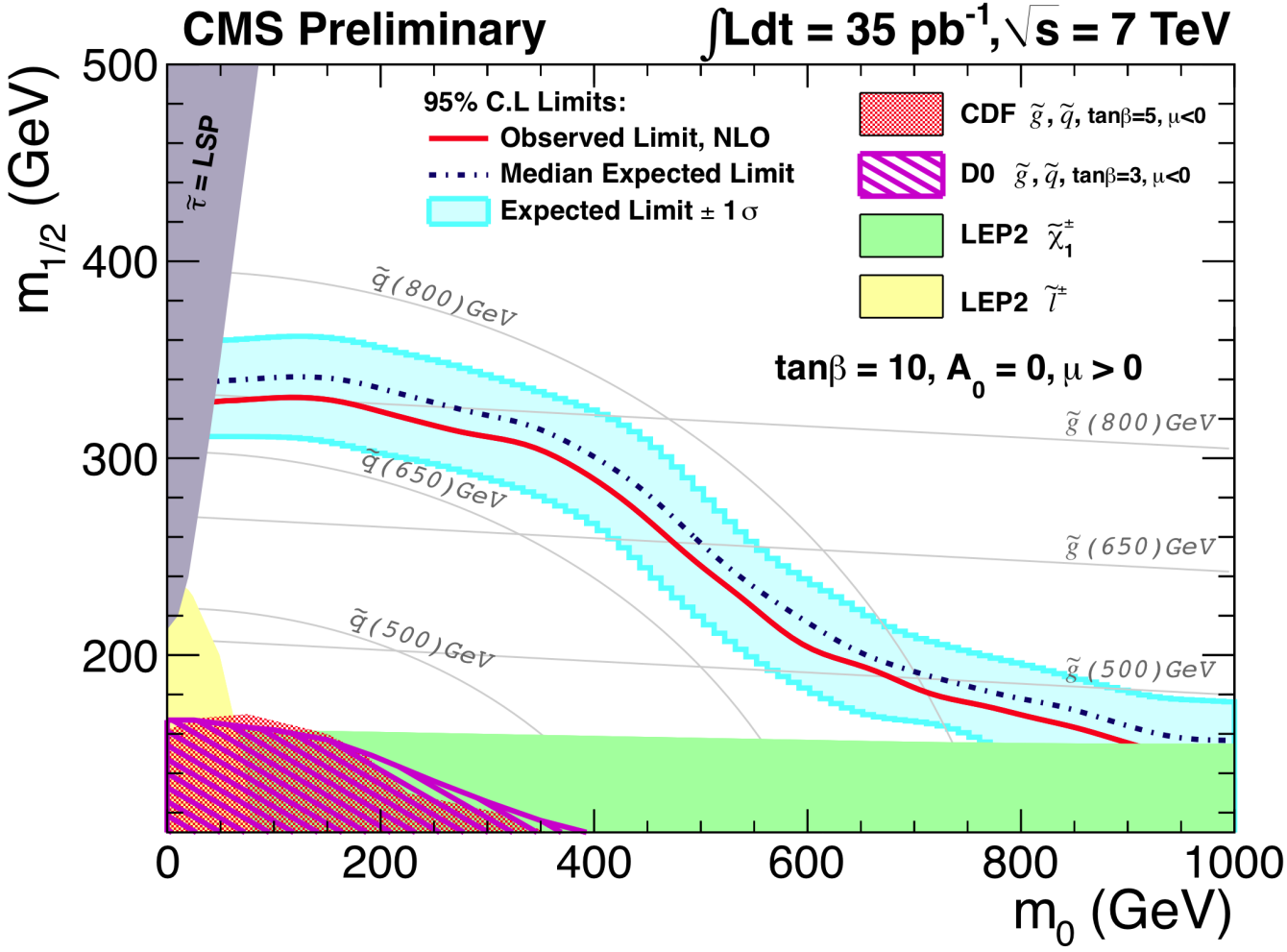
These shapes predict the lost lepton and $W \rightarrow \tau\nu$ background shapes in the hadronic mode. Normalizations fit in $200<M_R<350$ region.



R>0.5	Predicted	Observed
M_R>500 GeV	5.5 ± 1.4	7

“Razor” search: threshold production

Can search in both the hadronic and leptonic boxes, for inclusiveness.

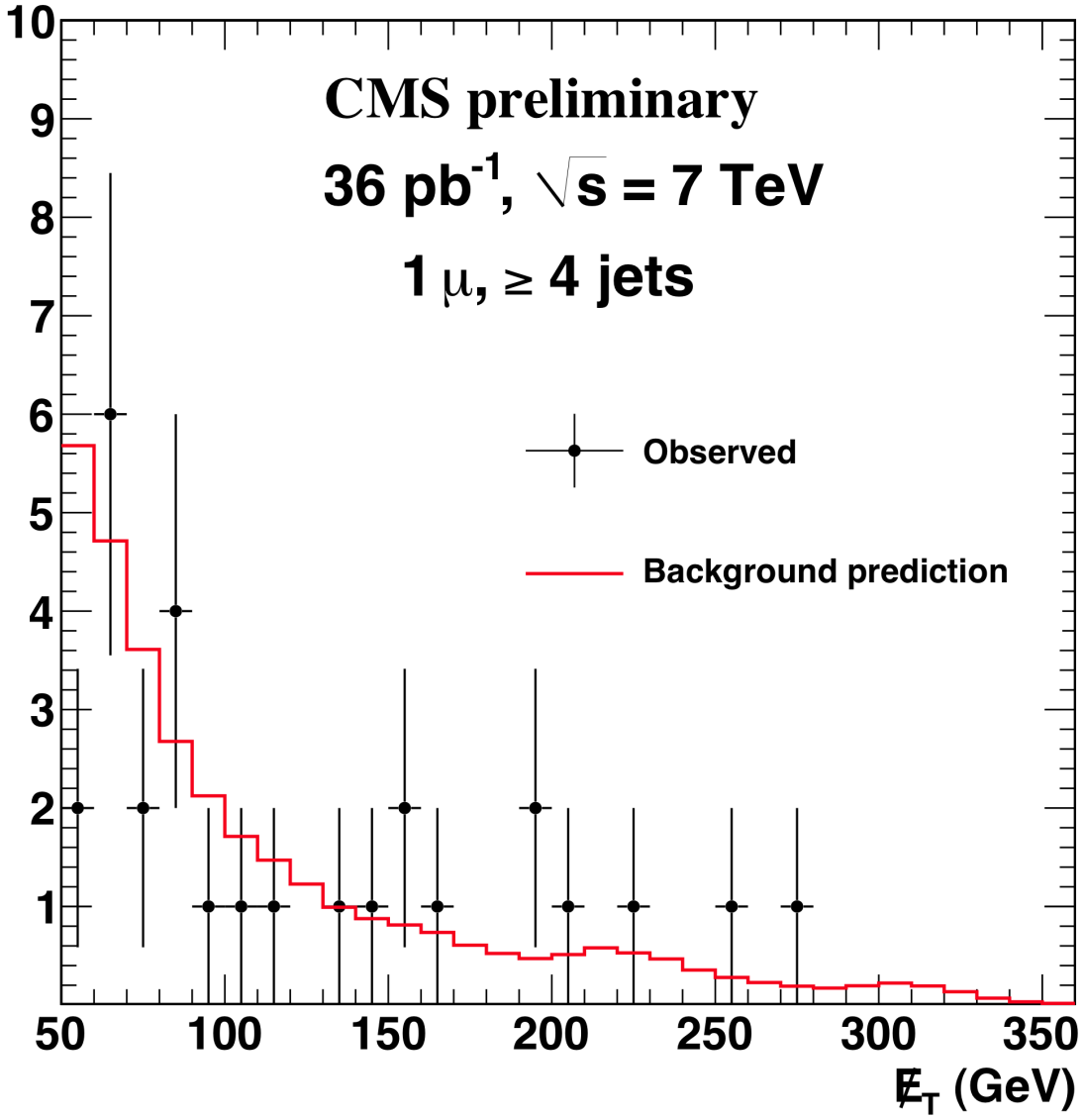


Single lepton + jets + MET search

4 jets, E_T>30 |η|<2.4

HT > 500 and MET > 250

Predict W & ttbar μ pT
μ and ν spectra related.
Threshold effects
Data-derived smearing



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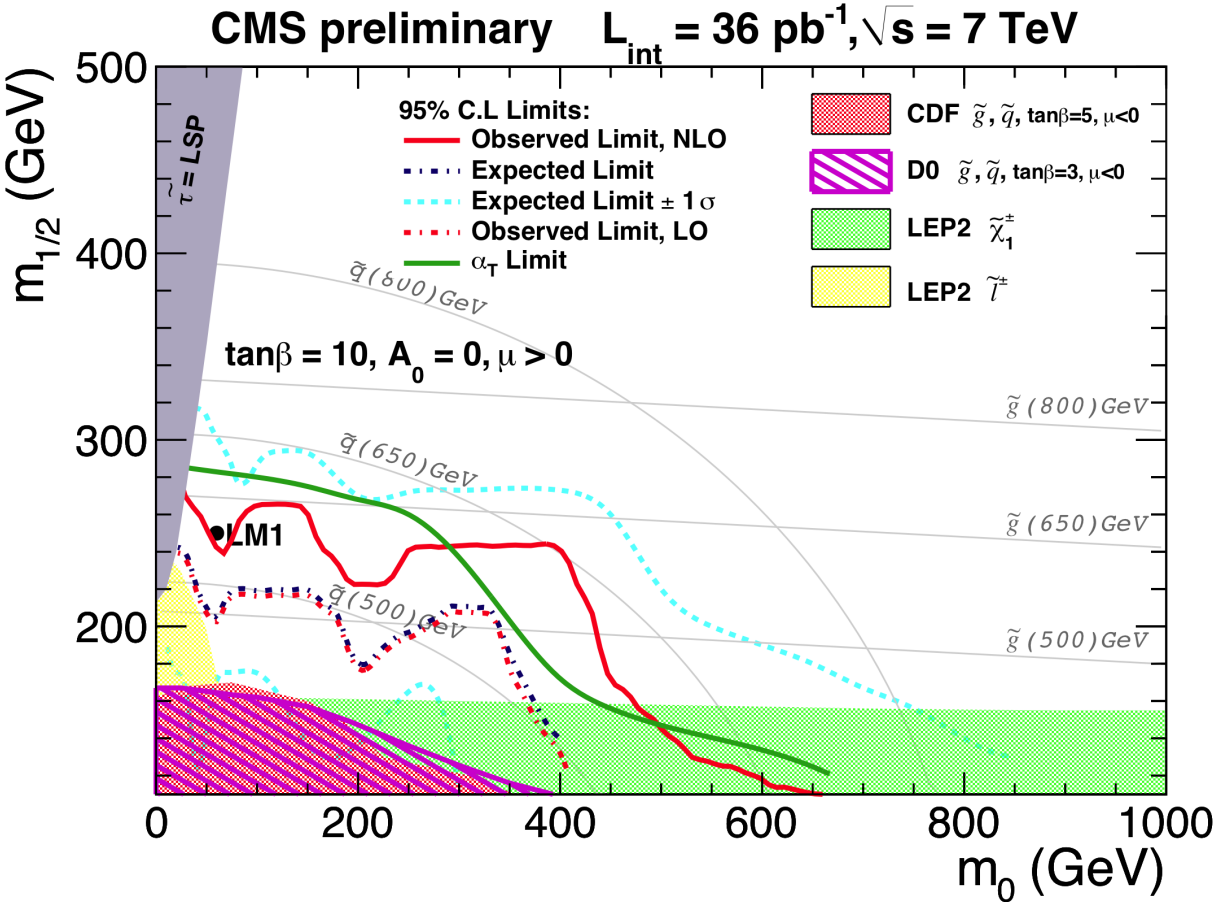
Predict W & ttbar μ pT
μ and ν spectra related.
  Threshold effects
  Data-derived smearing

Predict lost dileptons
from found dileptons

Predict QCD from
Non-isolated sideband

Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0

Single lepton + jets + MET search



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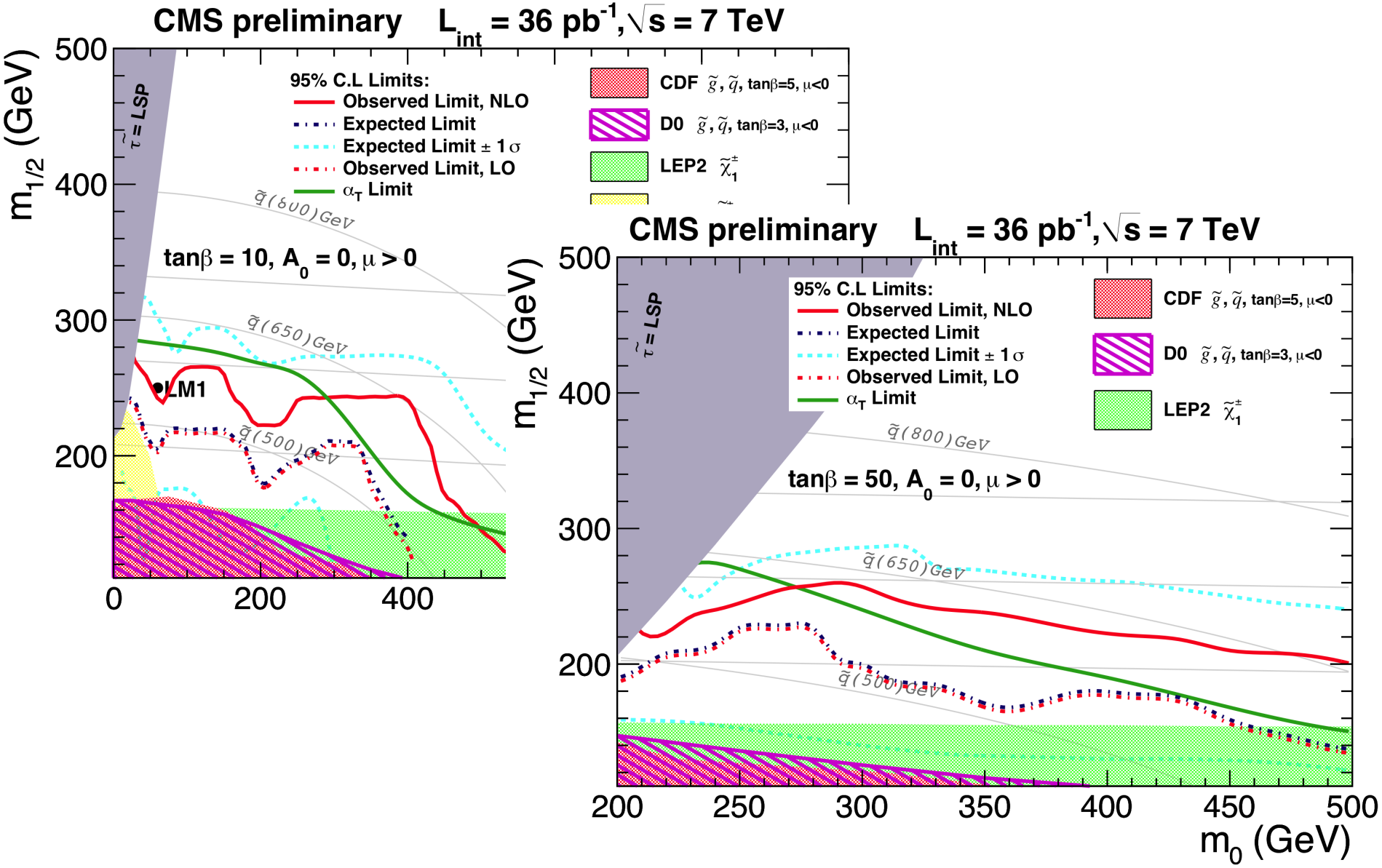


Opposite sign di-lepton + jets + MET search

Two isolated leptons (e or μ)
One w/ p_T>20; other p_T>10

Z-veto (different search)

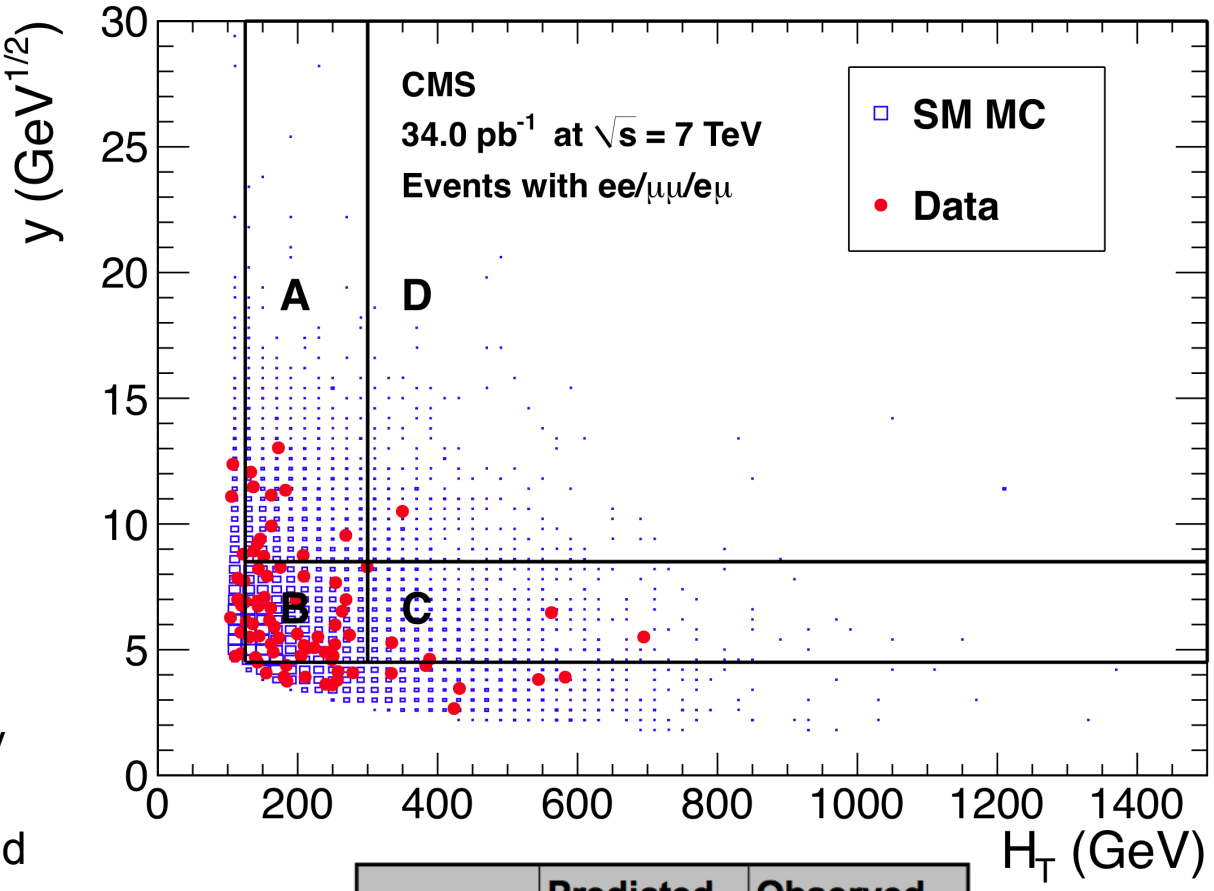
≥ 2 jets, E_T>30 |η|<2.5

HT > 300 GeV
y ≡ MET/√HT > 8.5

Background mostly ttbar.

Two predictions:

1. Extrapolation of HT vs y
2. Lepton spectrum method



	Predicted	Observed
Region D	1.3 ± 0.8	1

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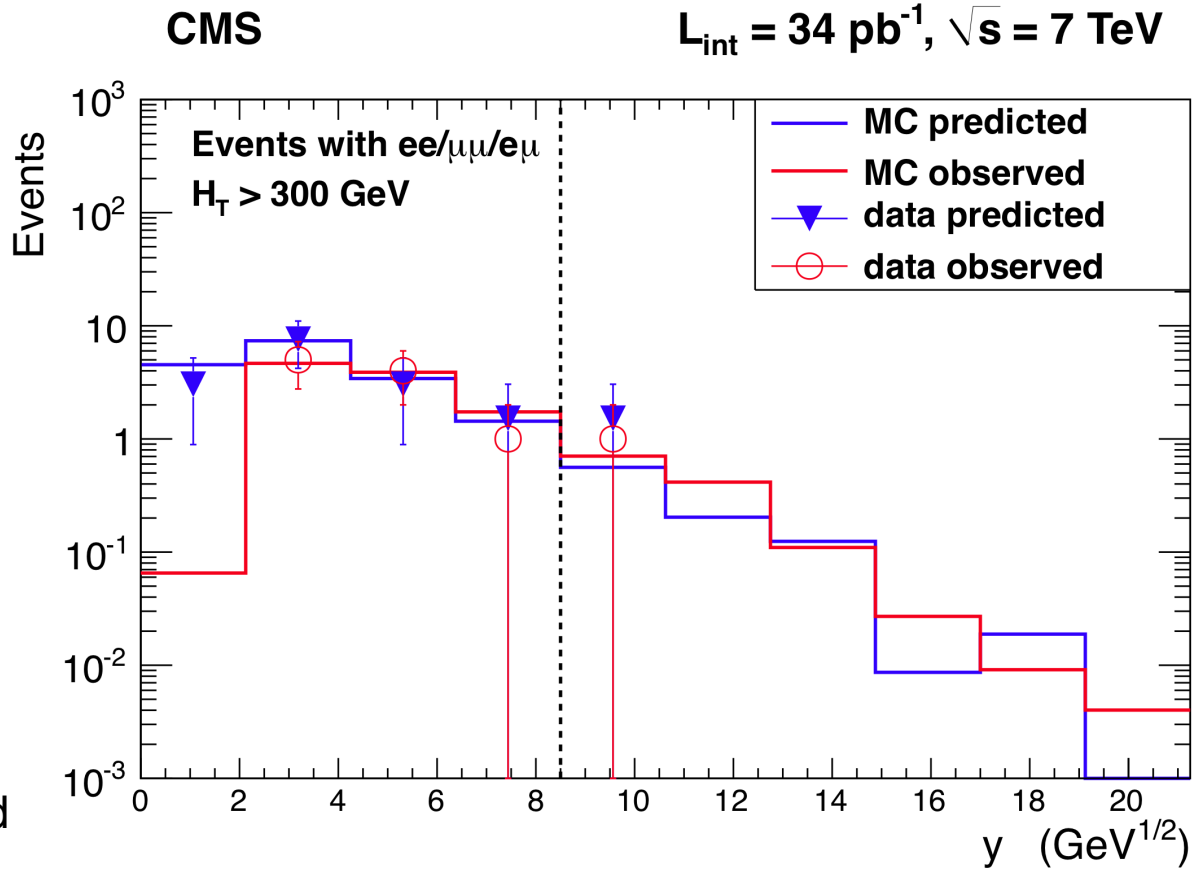

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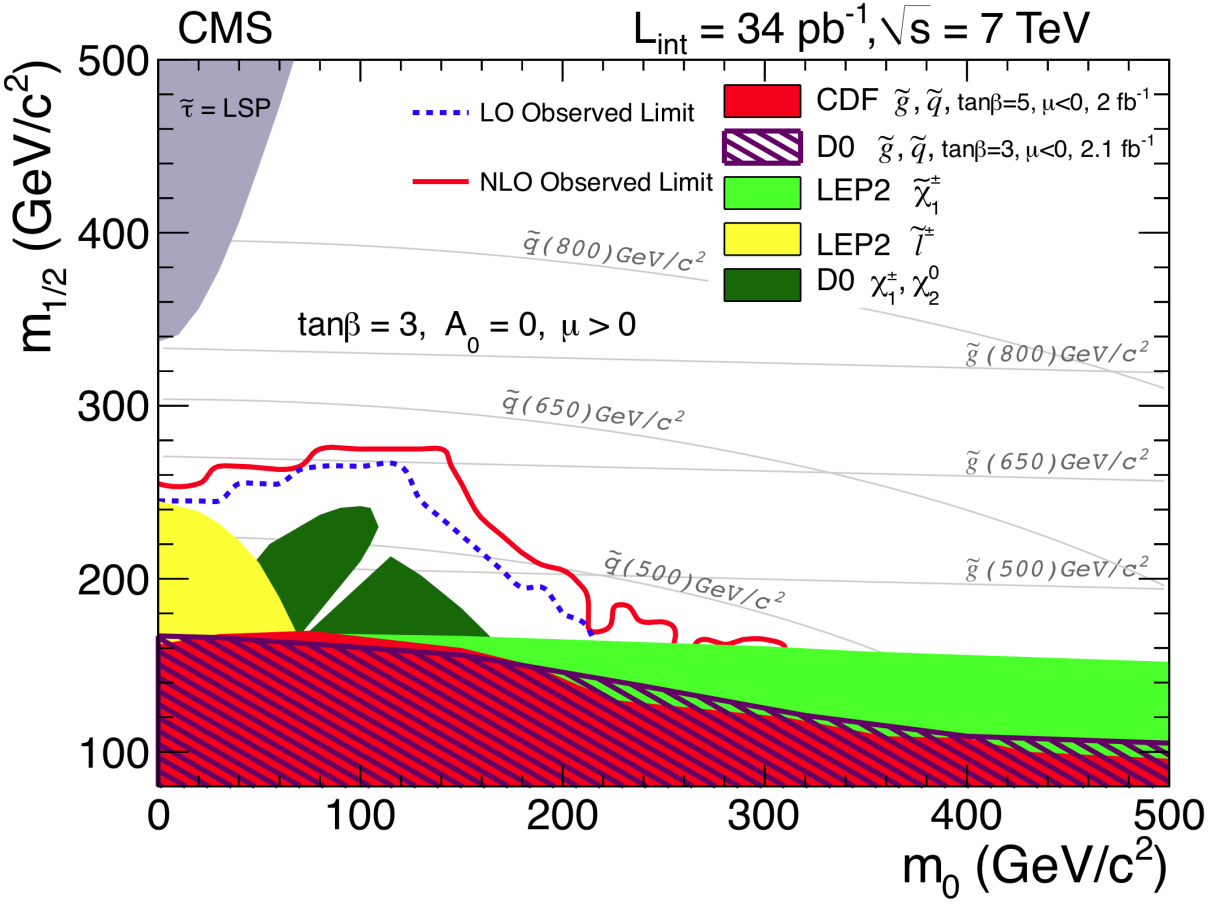


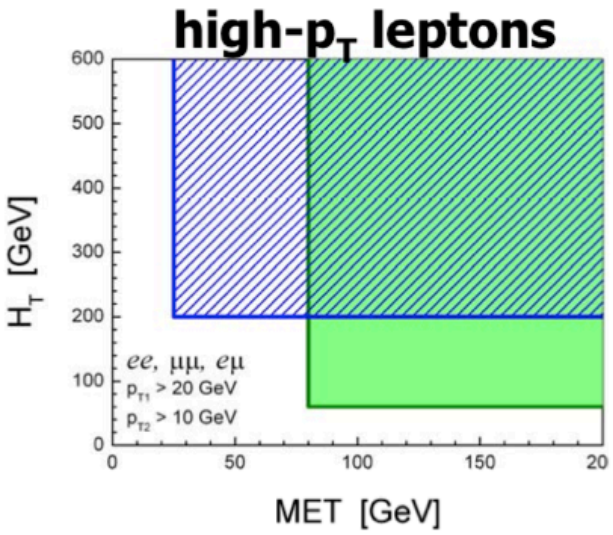
Also obtained results from an opposite-sign, opposite-flavor subtraction

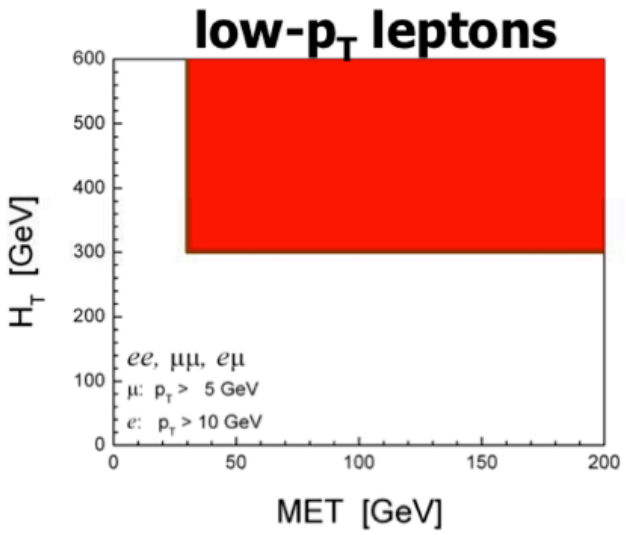
Would reveal a dilepton mass-edge from some SUSY decays.

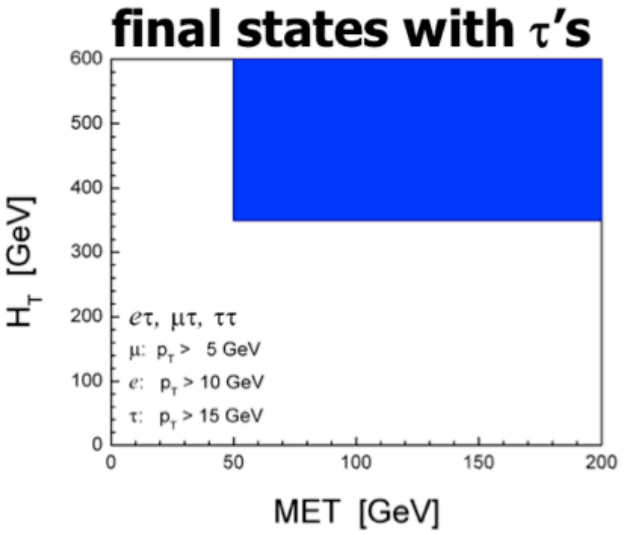
Predict: ee = $0.1^{+1}_{-0.4}$ and μμ = $0.5^{+1.2}_{-0.4}$ and observe no events.

Same sign di-lepton + jets + MET search

Two isolated same-sign leptons, MET and HT, in various combintaions:





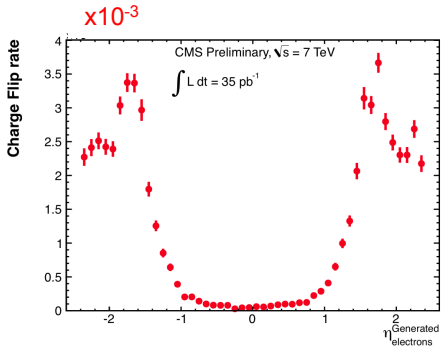


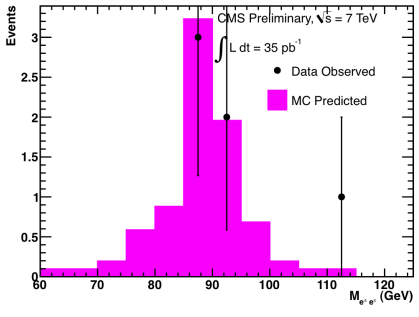
Dominant backgrounds from:

ttbar, with one real and one fake lepton.

QCD (for τ's)

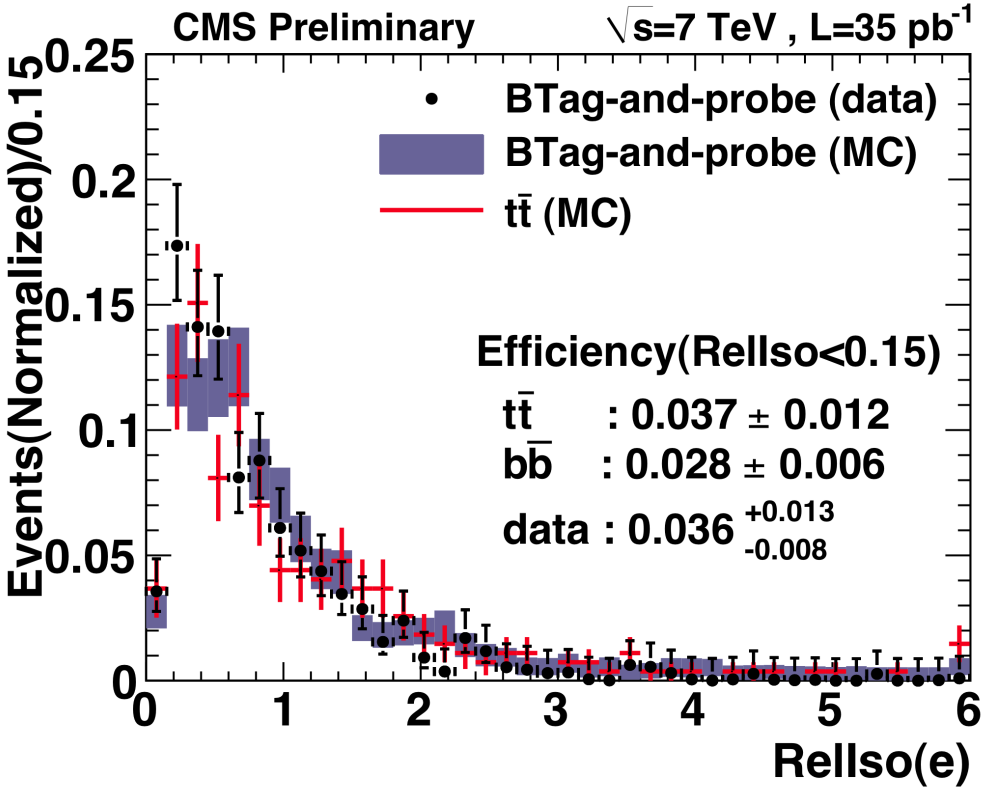
Charge mis-id negligible → (after clean-up cuts)

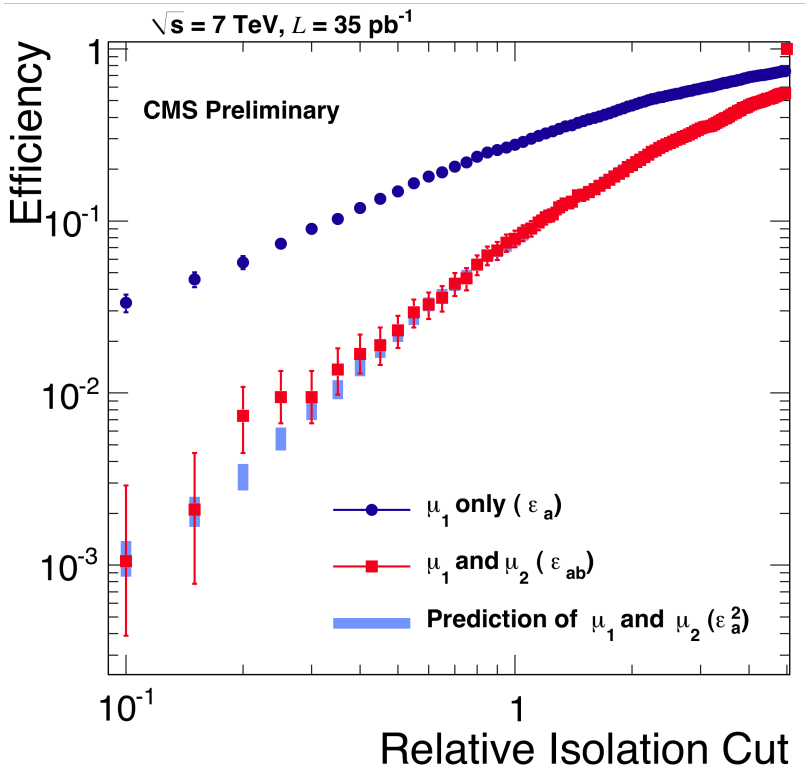




Same sign di-lepton + jets + MET search

Measure ttbar background in isolation side-bands with kinematic reweighting.
Measure QCD background using μ_1 vs μ_2 cut factorization.



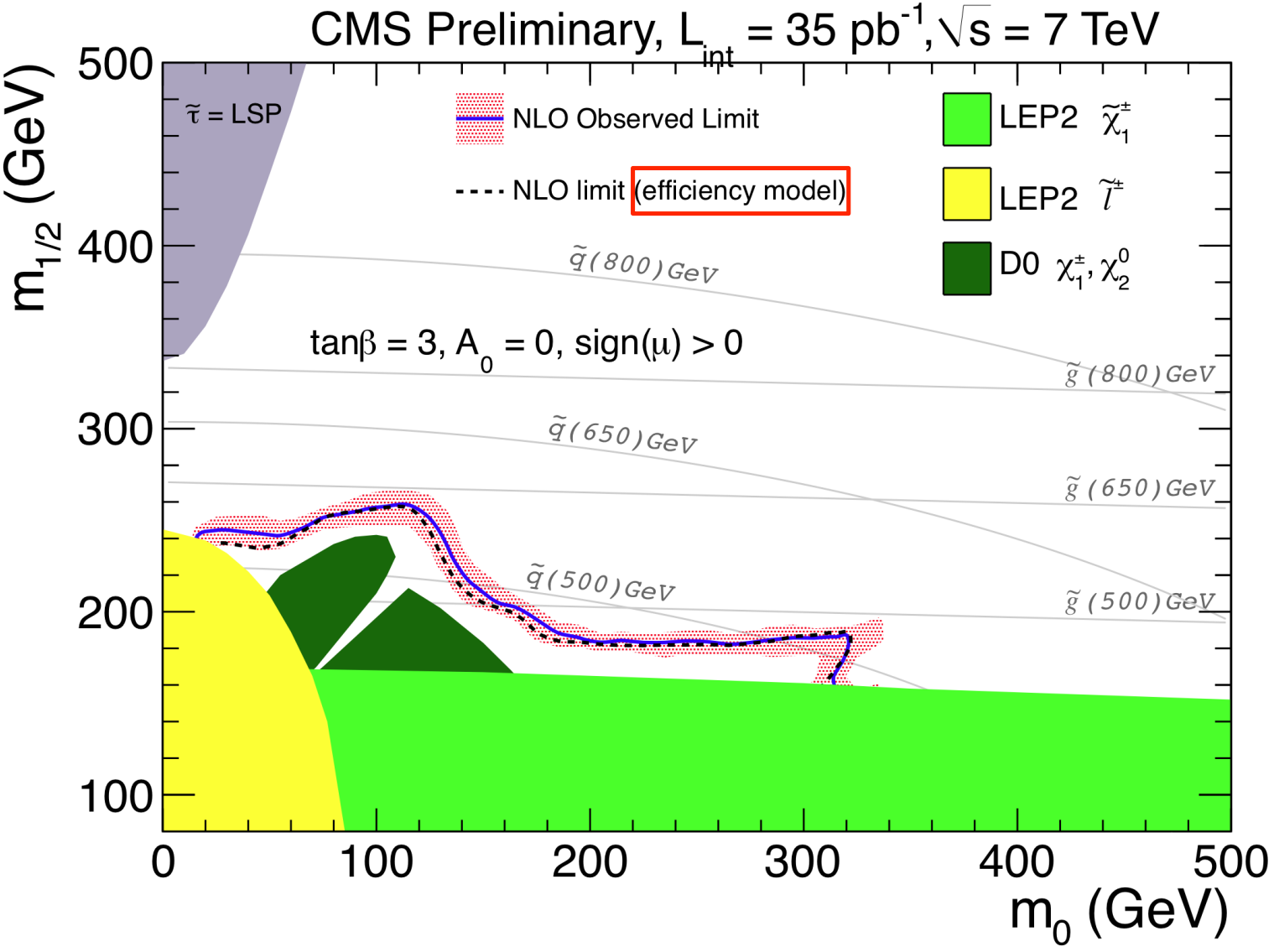


Same sign di-lepton + jets + MET search

Data consistent with predictions in all modes.

	Simulation Only SM BKG		Data Relaxed selection	
Channel	Observed	Predicted	Observed	Predicted
$\tau\tau$	0.08 ± 0.03	0.15 ± 0.15	14	$14.0\pm4.3\pm2.6$
$e\tau$	0.35 ± 0.12	0.30 ± 0.11	1	$0.8\pm0.4\pm0.1$
$\mu\tau$	0.47 ± 0.15	0.49 ± 0.20	2	$2.9\pm0.6\ \pm0.4$

Same sign di-lepton + jets + MET search



Paper includes a simple efficiency model (i.e. for PGS calibrations) and compares full limit to limit with simple model.

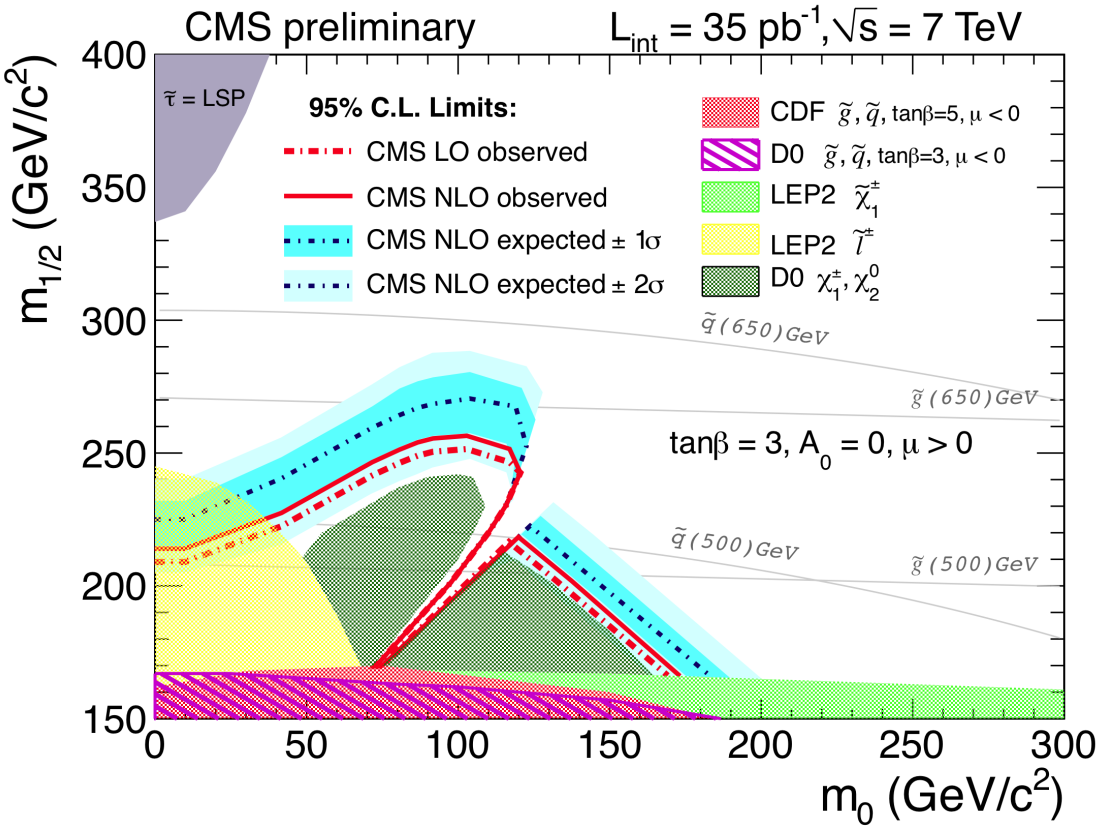
Multi-lepton search

≥ 3 isolated leptons (e, μ, τ or T)
p_T>8, at least one triggerable p_T>15

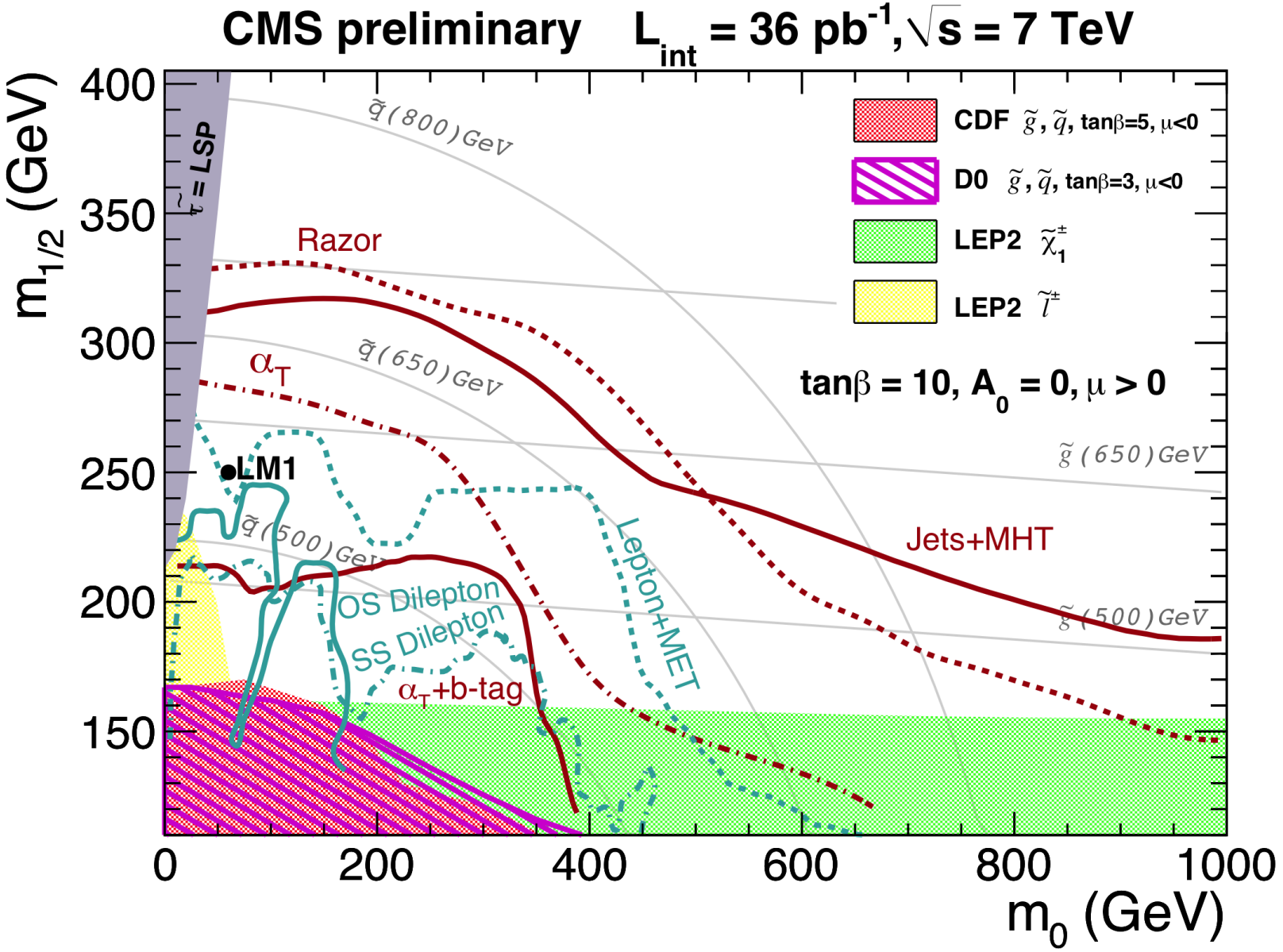
Separately search with:
- HT > 200 GeV
- MET > 50
- Z veto
- 4 leptons
- + others (total 55)

DY + fake bkgd from data
ttbar from MC
diboson from MC

No significant excess,
but some beautiful events.

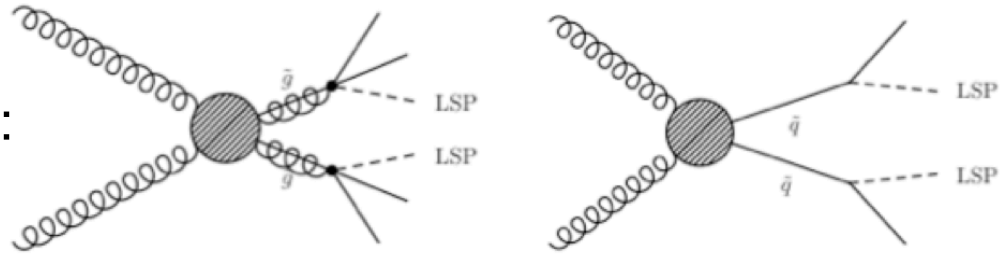


Limits from a broad set of searches on a narrow model

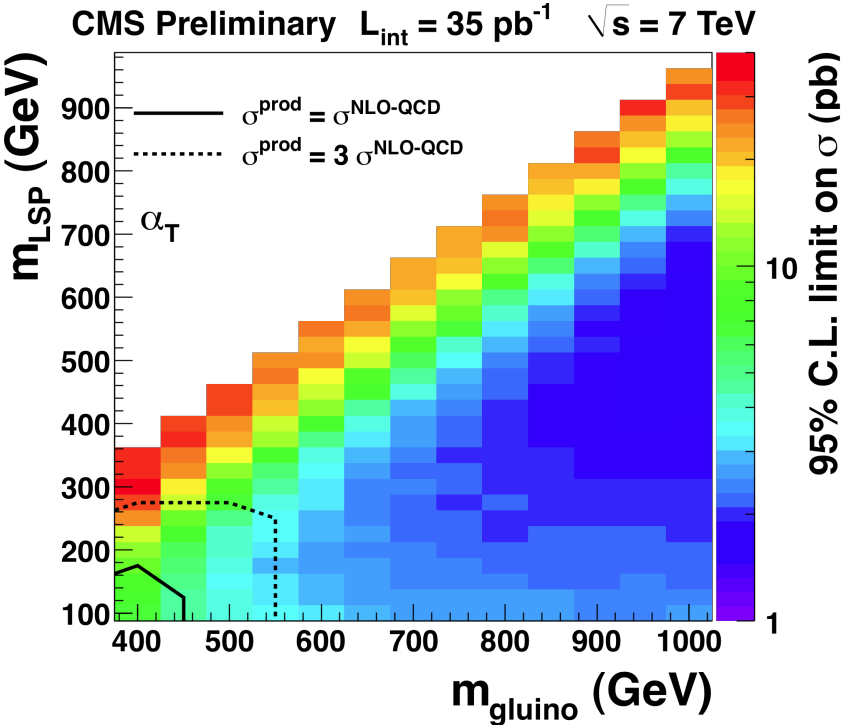


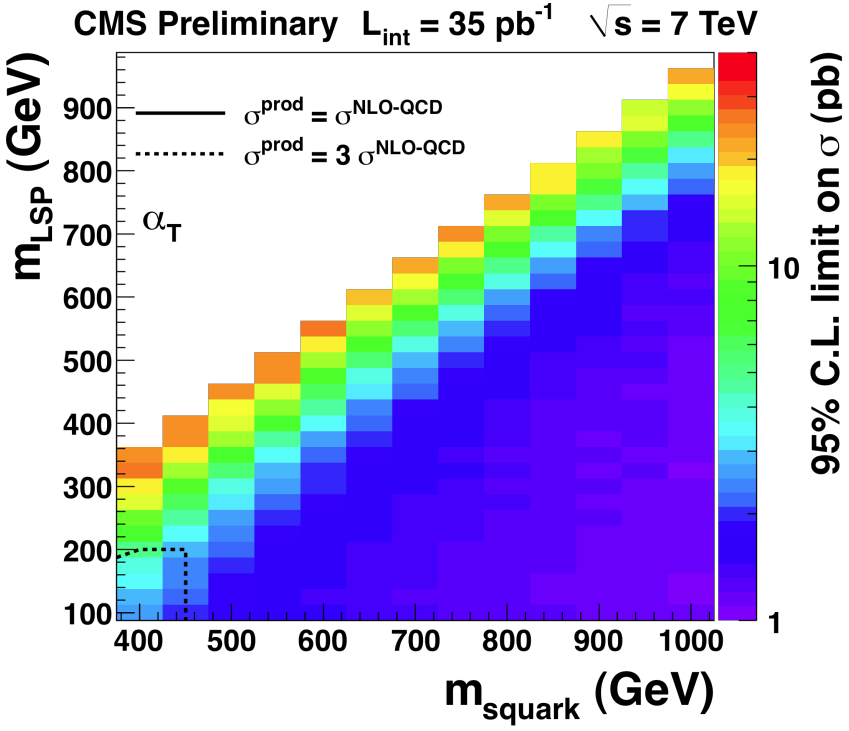
Simplified models, i.e., generalized models

Interpreted hadronic searches
in two simple reference topologies:
gluino & squark pair production
http://www.lhcnewphysics.org



AlphaT limits; no theoretical uncertainties





Simplified models

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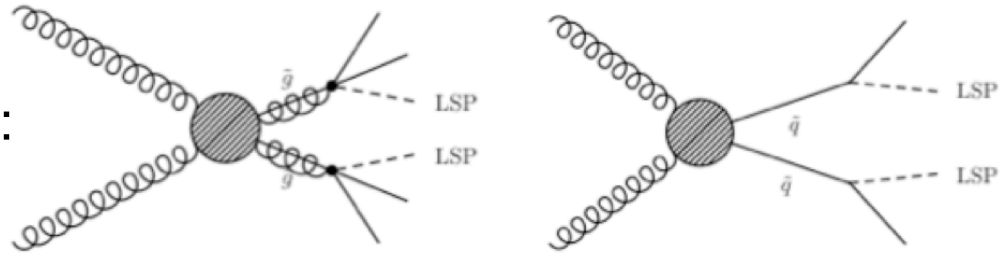
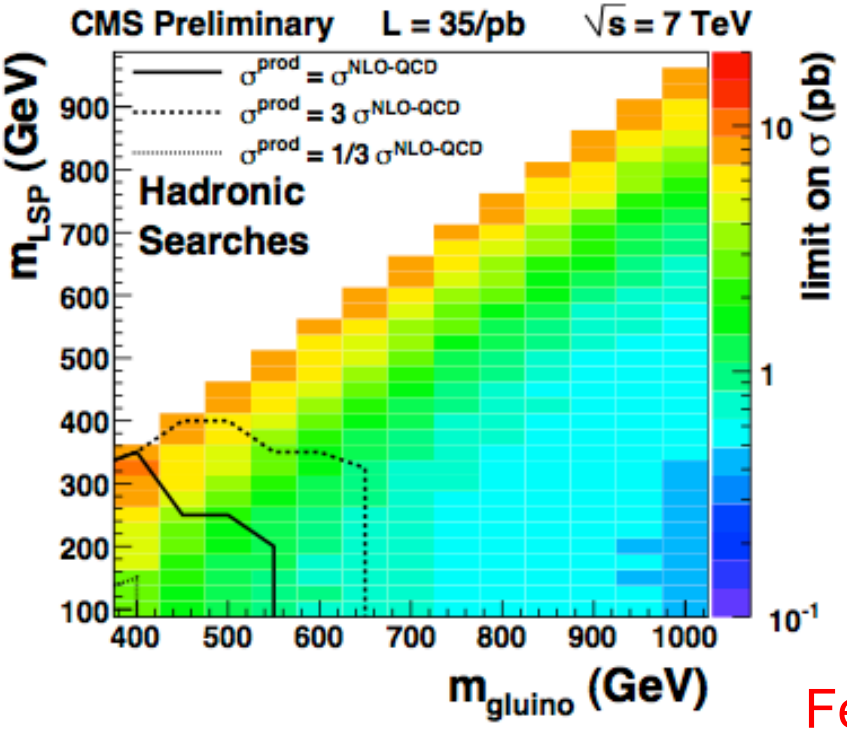
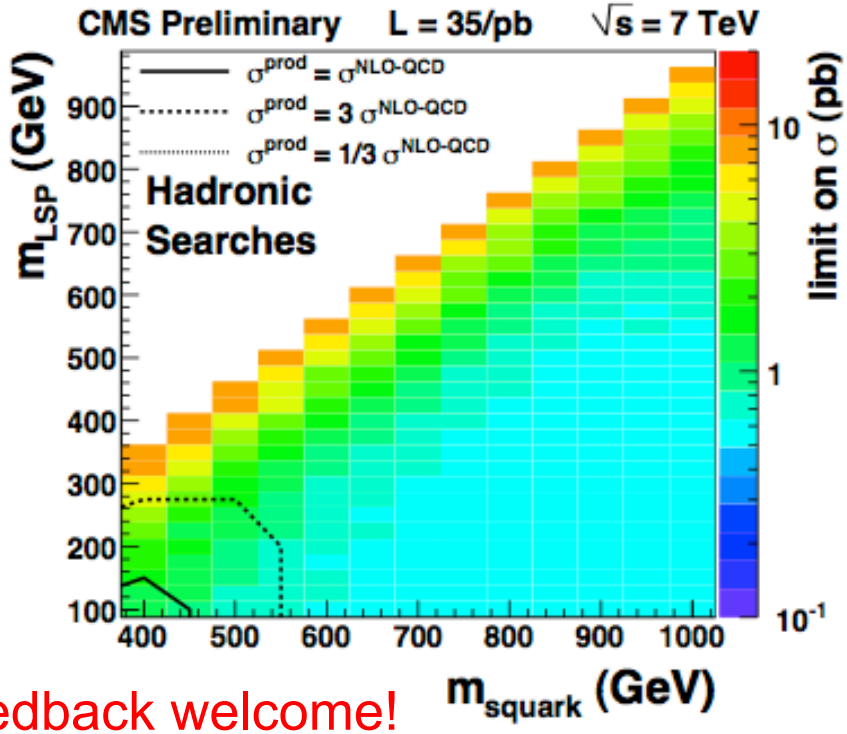


Combined hadronic limits; no theoretical uncertainties

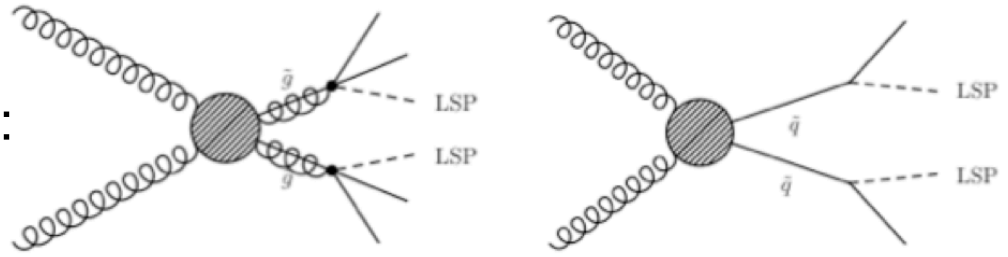




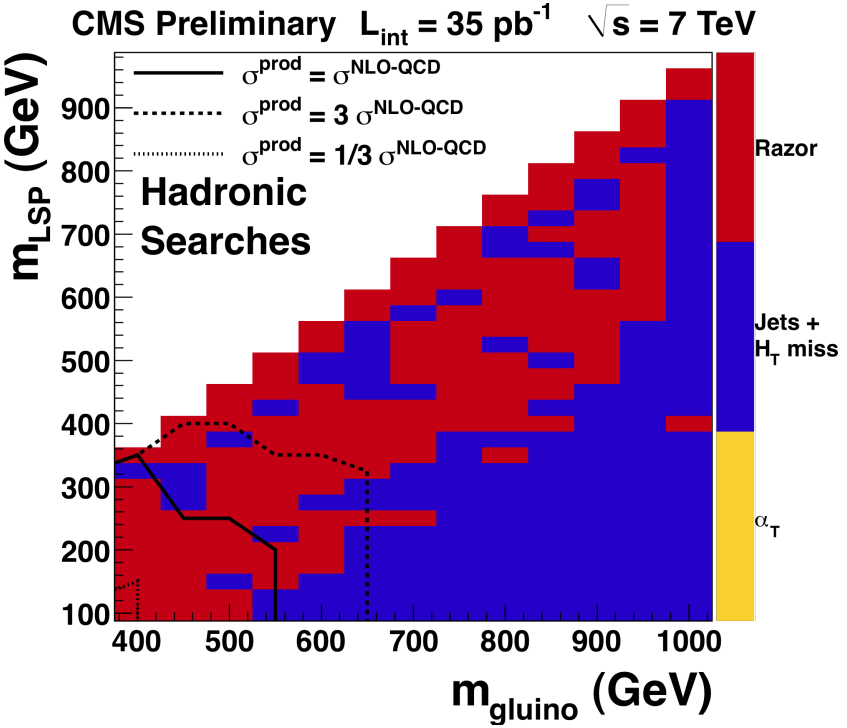
Feedback welcome!

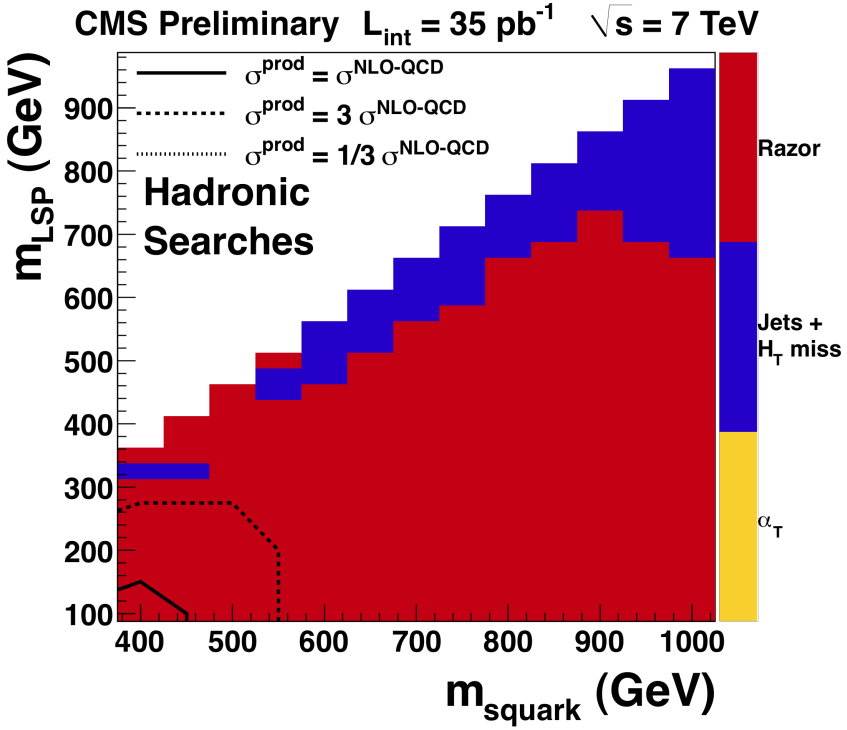
Simplified models

Interpreted hadronic searches
in two simple reference topologies:
gluino & squark pair production
http://www.lhcnewphysics.org



Compared hadronic limits; complementary.





Summary

Details at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Searching for SUSY with a broad set of signatures

Working to present limits results to be broadly interpretable.

Data-driven background predictions:

- Critical for a discovery
- Improve with more data…

Accelerator well tuned, back with high luminosity. Expect > 1 fb^{-1} by summer.

High MHT candidate event from Jets+MHT search