Excesses at the dawn of Run 2

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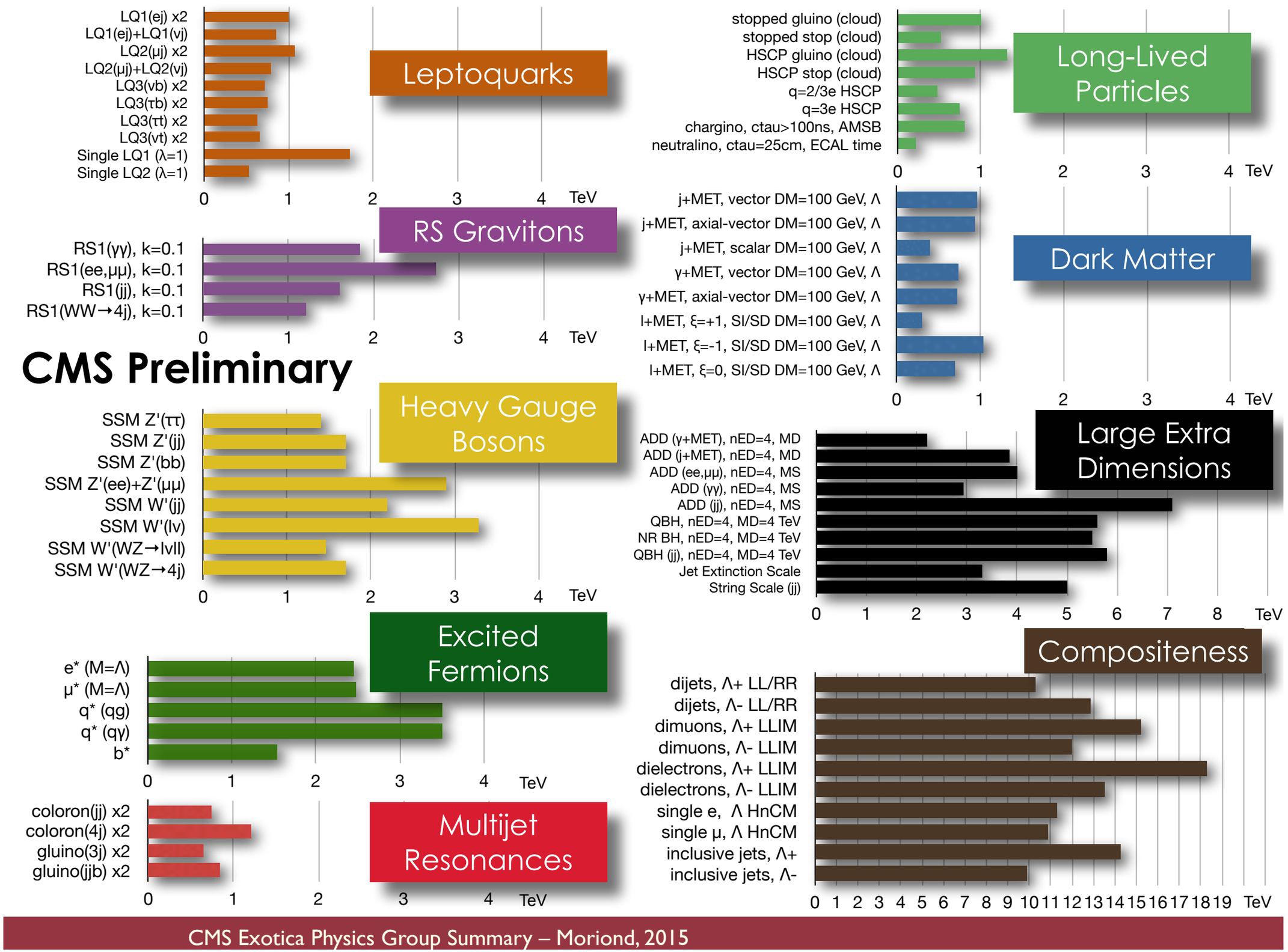
MC4BSM, May 18th, Fermilab

Run 1: SM remains a huge success



CMS Exotica Physics Group Summary – Moriond, 2015

yet there are a few anomalies out there

(focusing on the high-pT results)

- CMS eejj, ev jj “leptoquark excess”, 2.4/2.6σ, CMS PAS EXO-12-041
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- ATLAS SS dileptons + b-jets + MET, 2.5σ, 1504.04605

…

with so many things measured at the LHC, there must be some deviations

most will shrink in time with more data

deviations that persist are looked at seriously.. analysis are redone independently

results are scrutinized for months, sometimes even longer

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maybe its the beginning of new physics!! we **are** in this business to look for new phenomena, after all!
who cares if its a 'motivated' model?

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very difficult, even for a particle we EXPECTED and KNEW where to look

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Can we really discovery something totally unexpected?

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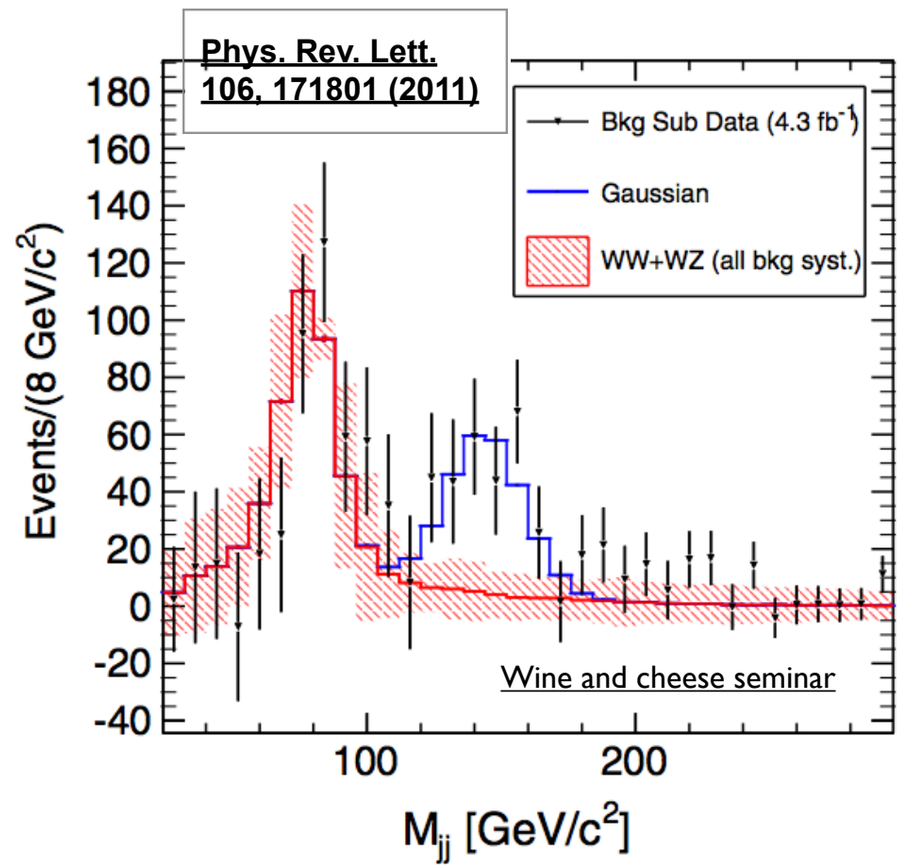
so grab anomalies, explore what can explain them

finally, don’t let the fact that “no paper exists with that particle/final state” be an excuse for the experimenters

even if the anomaly fades, efforts point out weaknesses/problems in search strategies

example: W+jj
(CDF, 2011)



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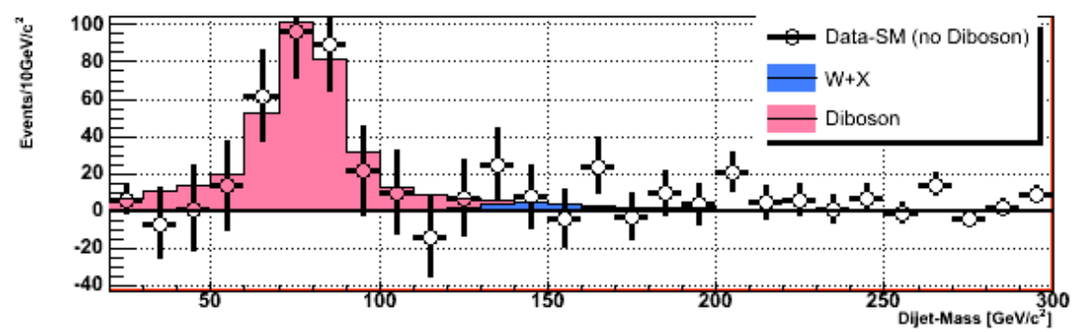
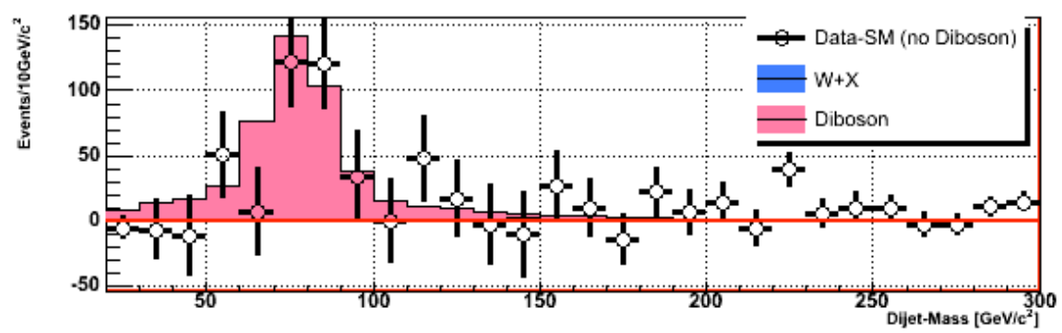


e



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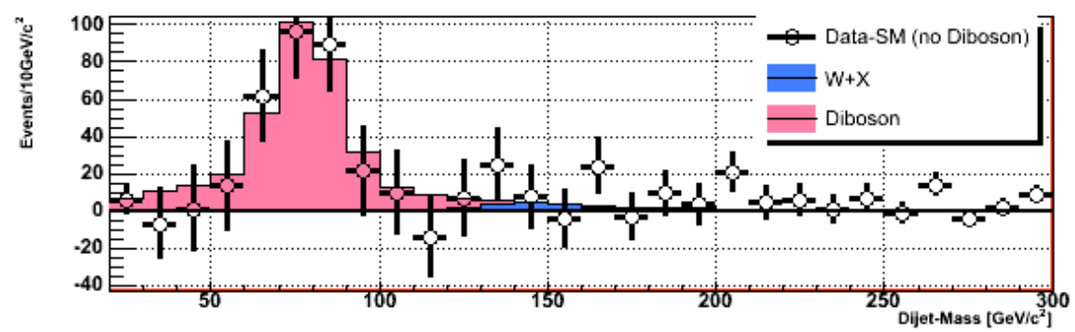

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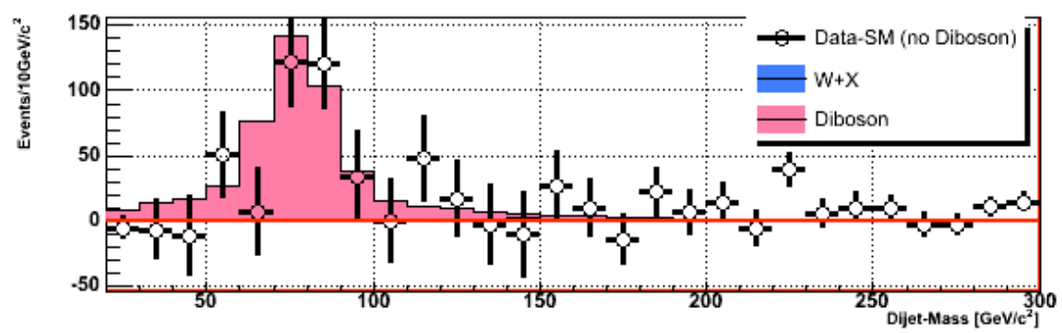

and motivate new ones, **either for full model or components** (ex. dark photon)

FOX

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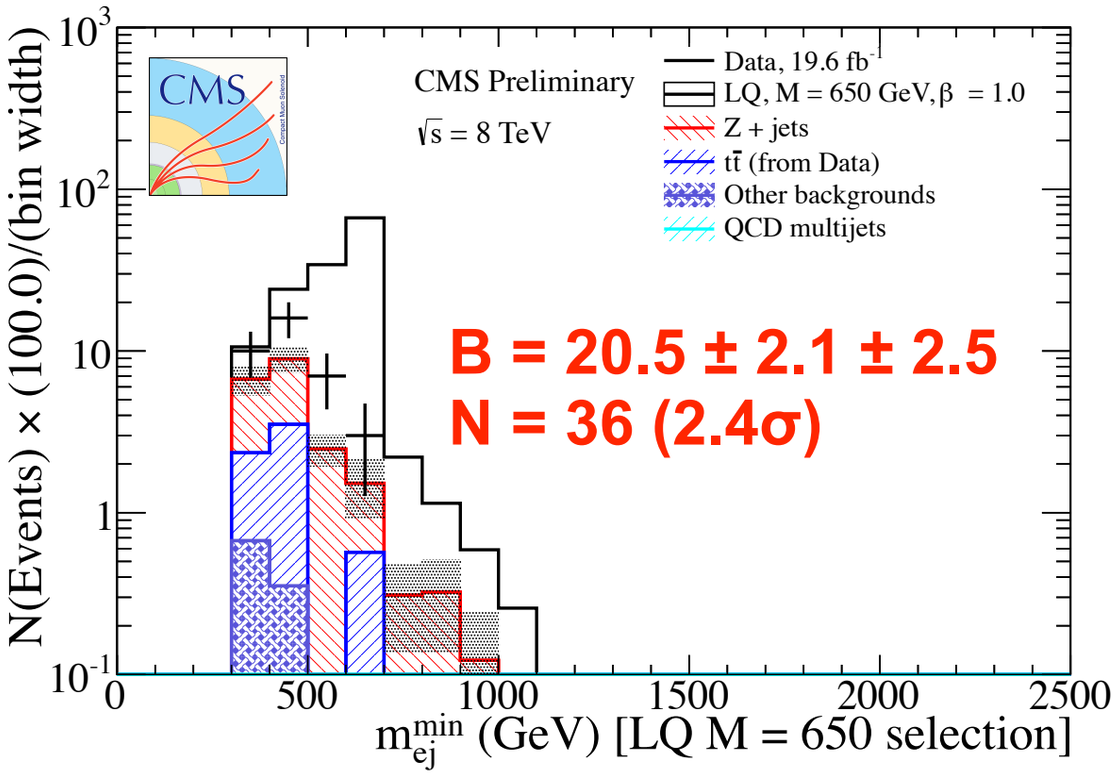
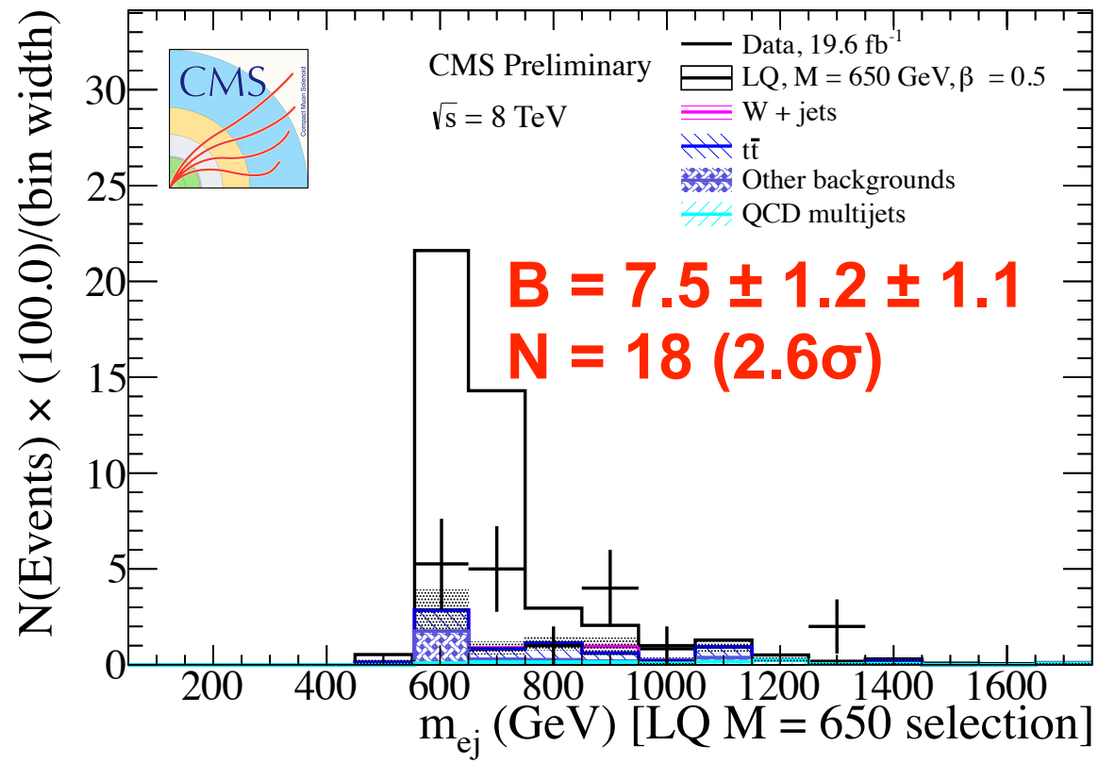
eejj and e\nu jj “leptoquark” searches





2+ jets, p_T > 125/45 GeV, |η| < 2.4. No muons

2 electrons, p_T > 45 GeV, |η| < 2.5

optimized using S_T, m_{ee}, m_{ej}

1 electron, MET > 55 GeV

jet, electron isolated from MET

optimized using S_T,MET, $m_{T,ev}$

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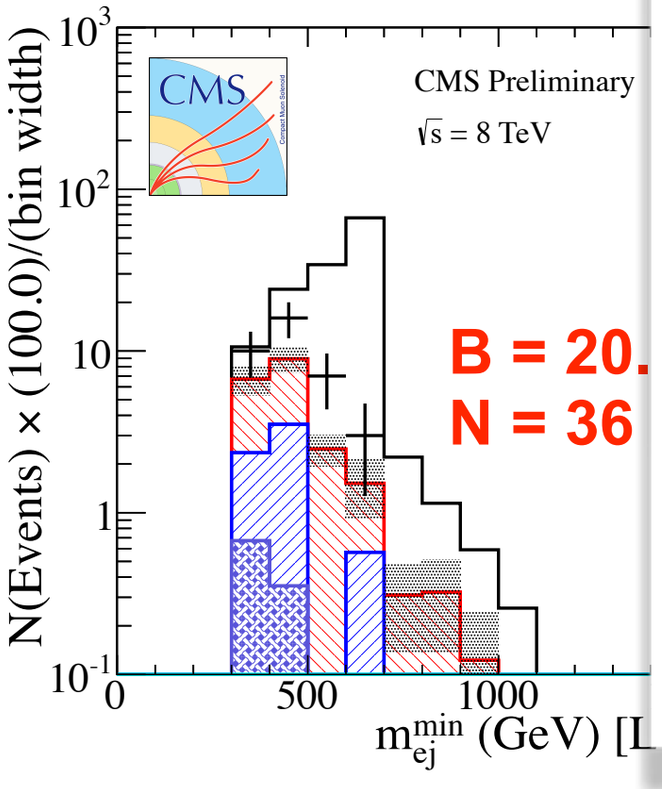

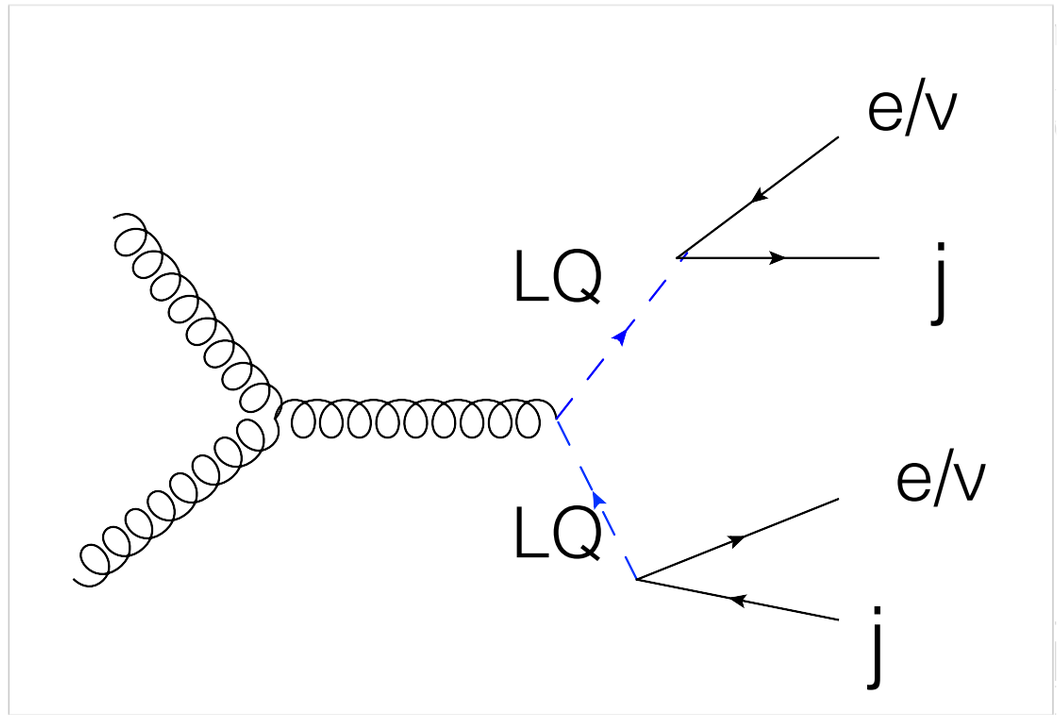

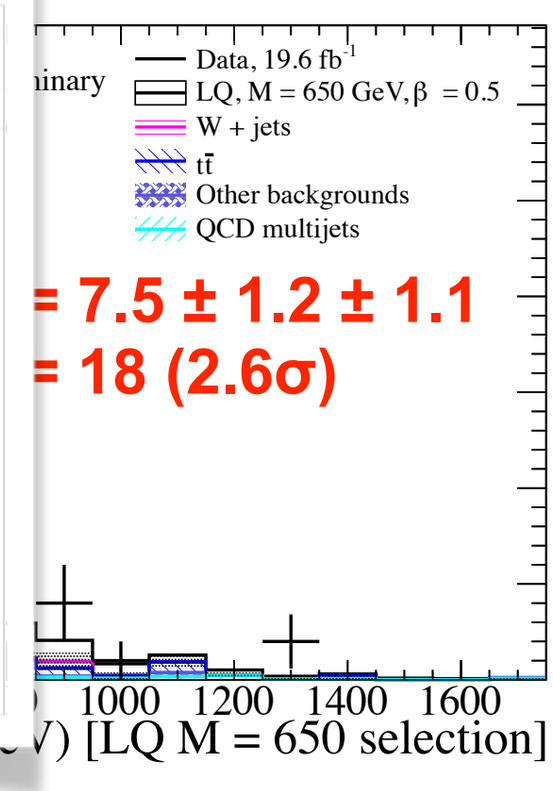

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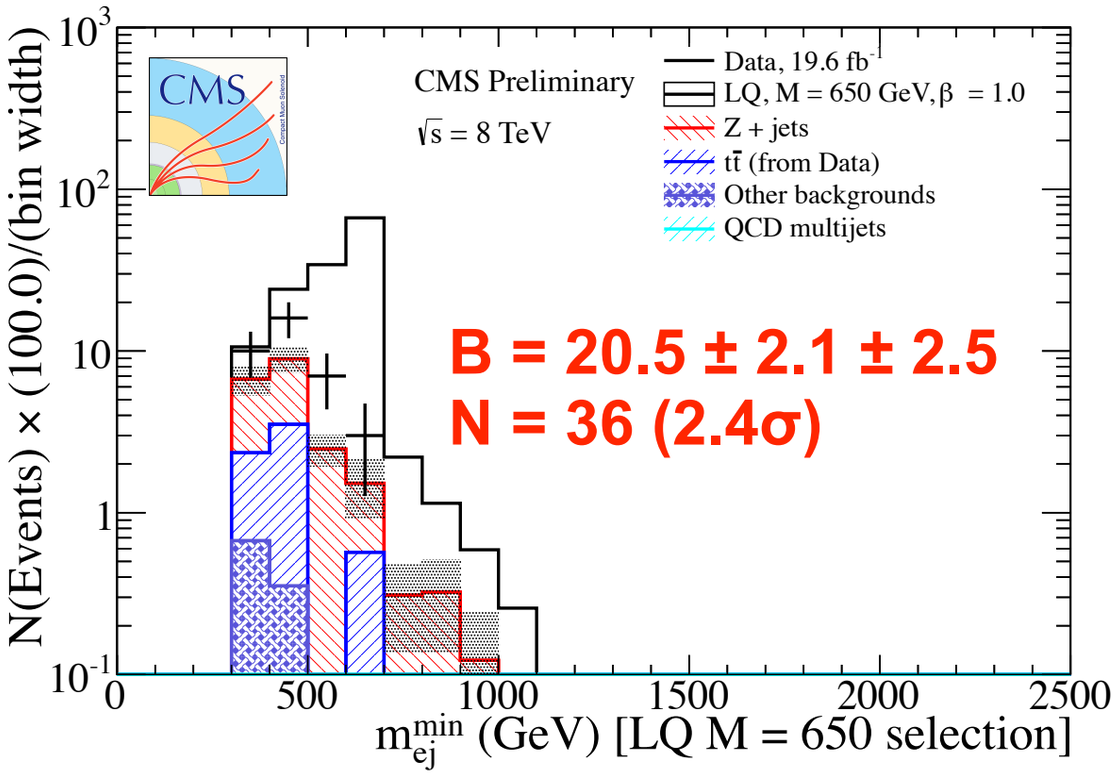

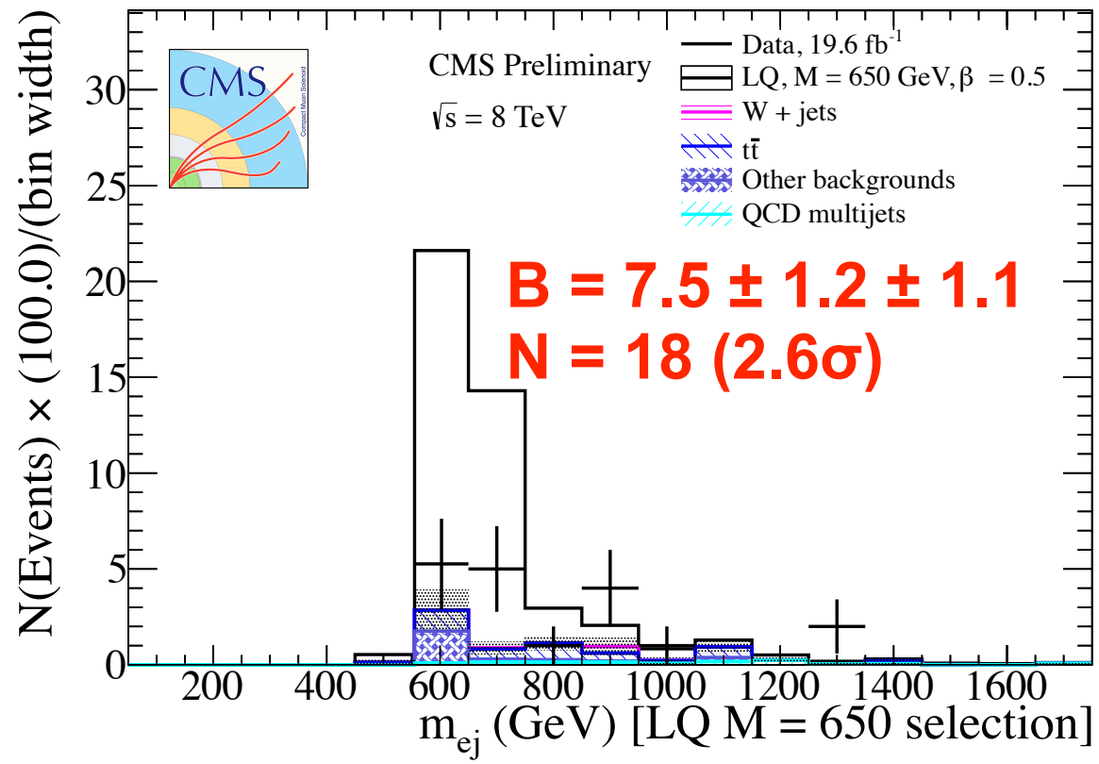

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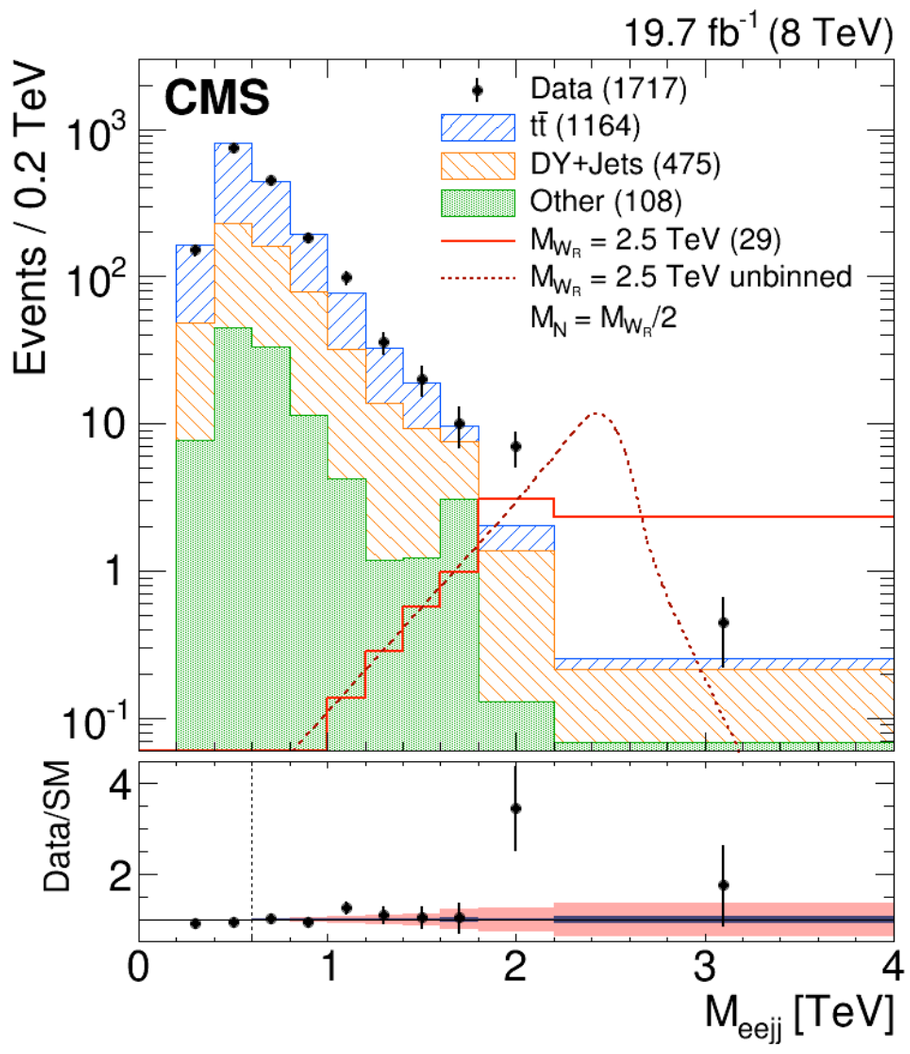
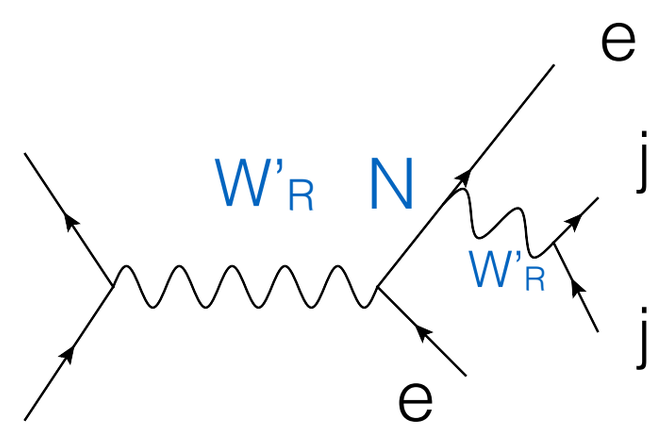




1.8-2.2 TeV bin:

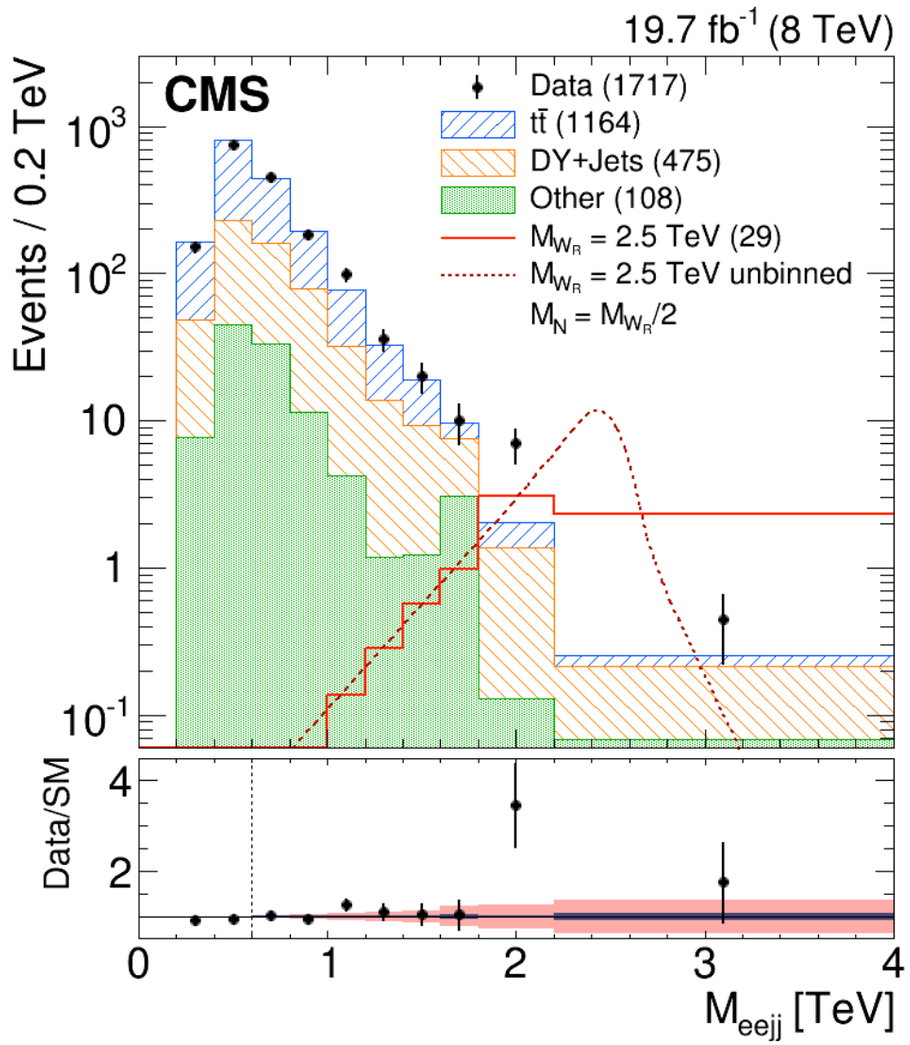
14 events, ~4 expected

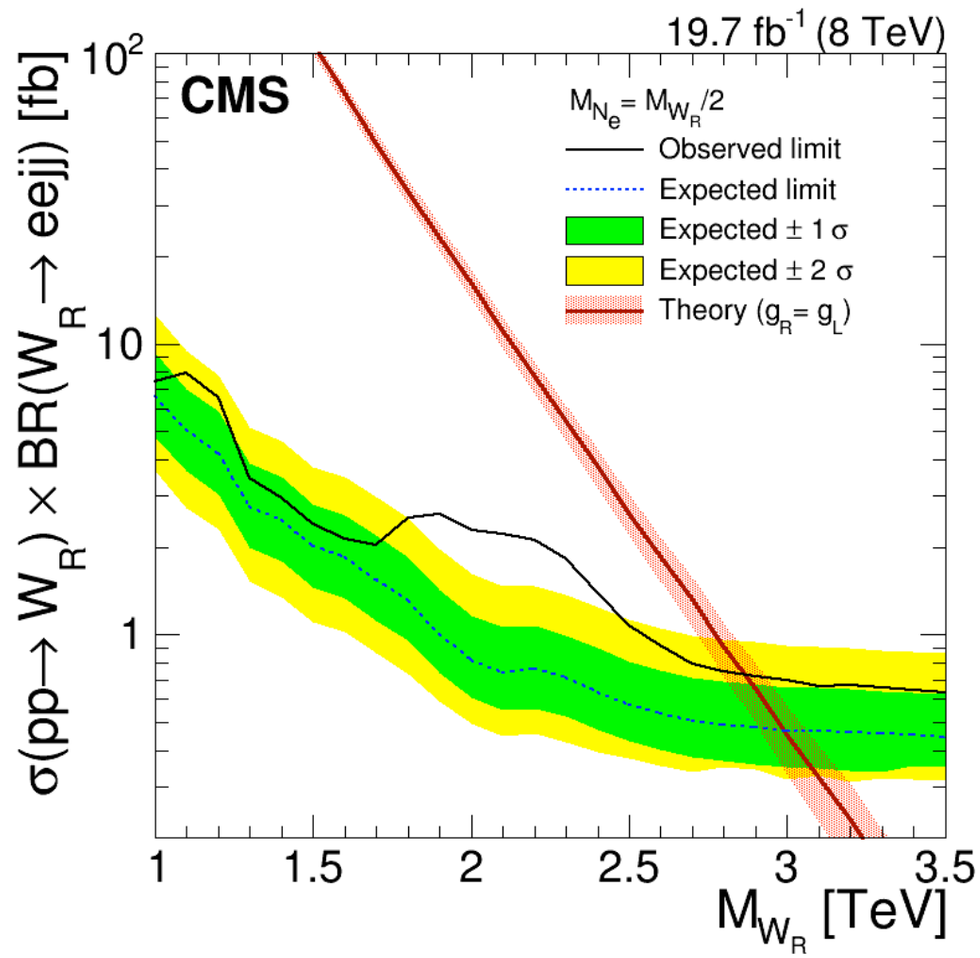
2.8σ

2 jets, p_T > 40 GeV, 2 electrons p_T > 60 (40) GeV

for events with m_{ee} > 200 GeV, form m_{eejj}

1407.3683





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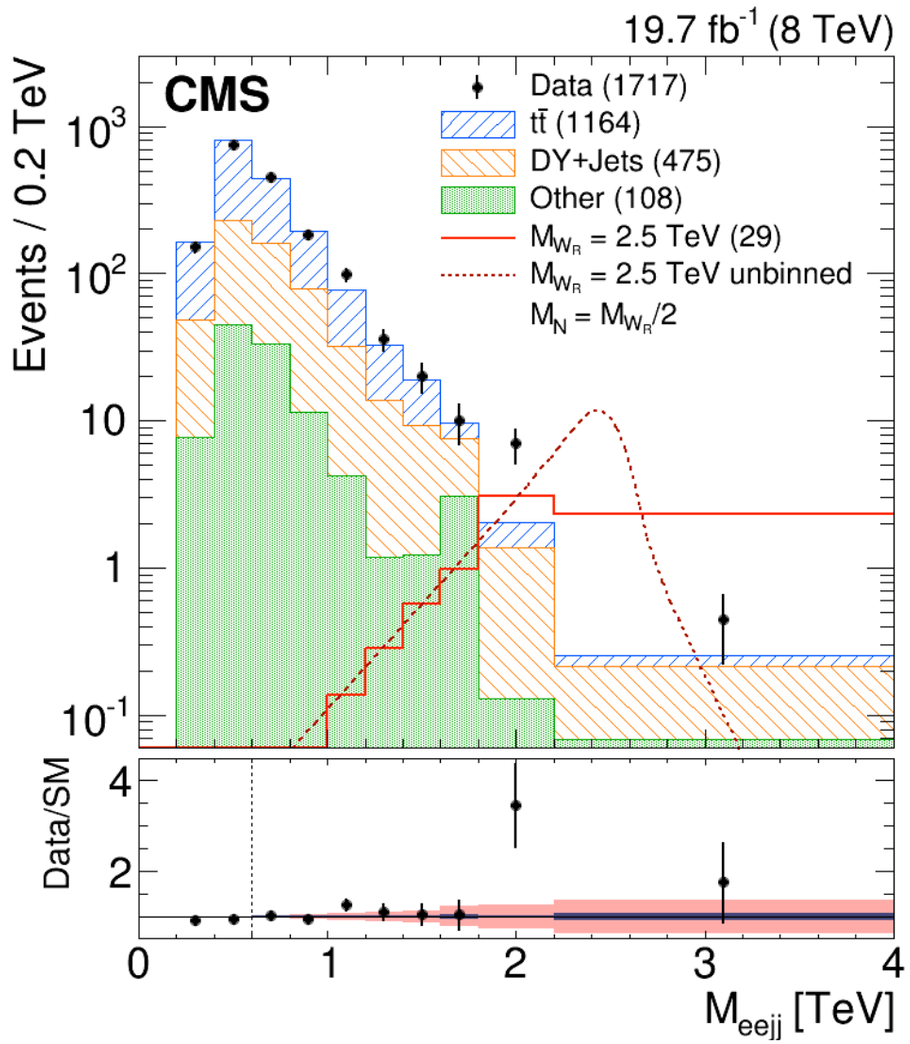

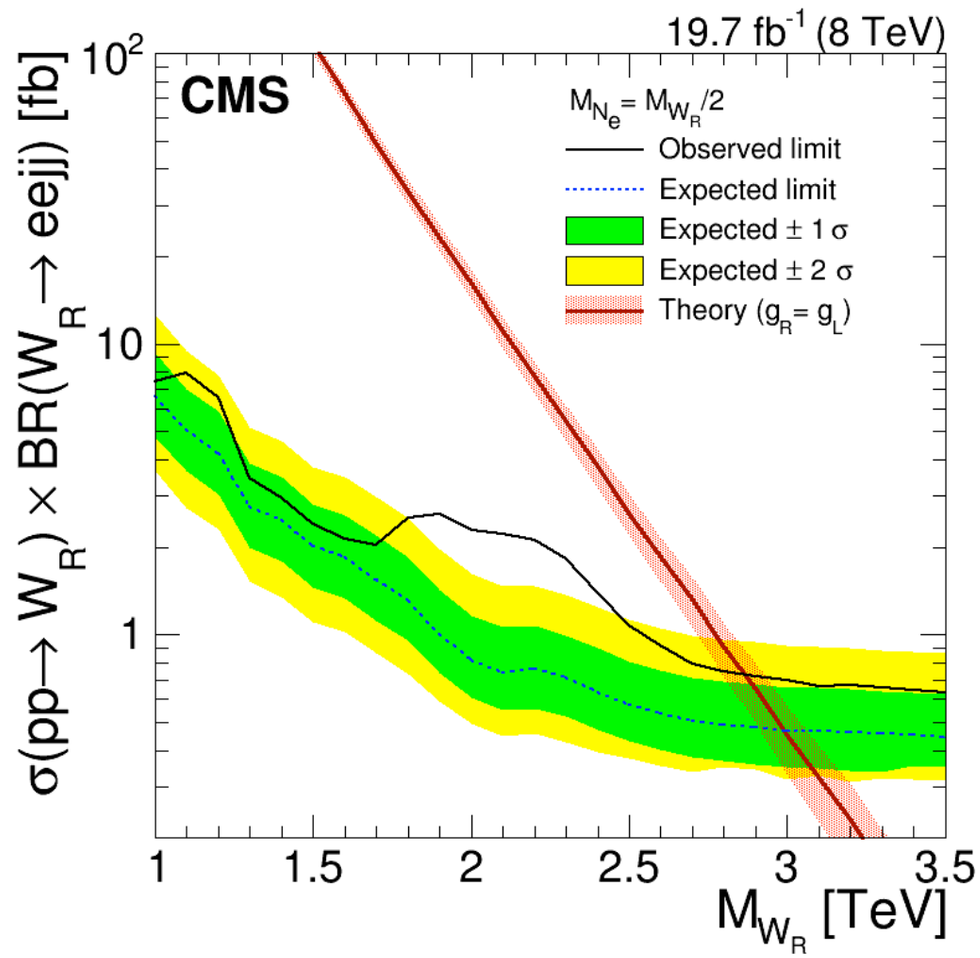

This excess does not appear to be consistent with $W_R \to eN_e$ decay. We examined additional distributions for events with $1.8 < M_{eejj} < 2.2$ TeV, including the mass distributions M_{ejj} (for both the leading and subleading electrons), M_{ee}, and M_{jj}, as well as the p_T distributions for each of the final state particles. In this examination, we find no compelling evidence in favor of the signal hypothesis over the assumption of an excess of SM background events in this region.

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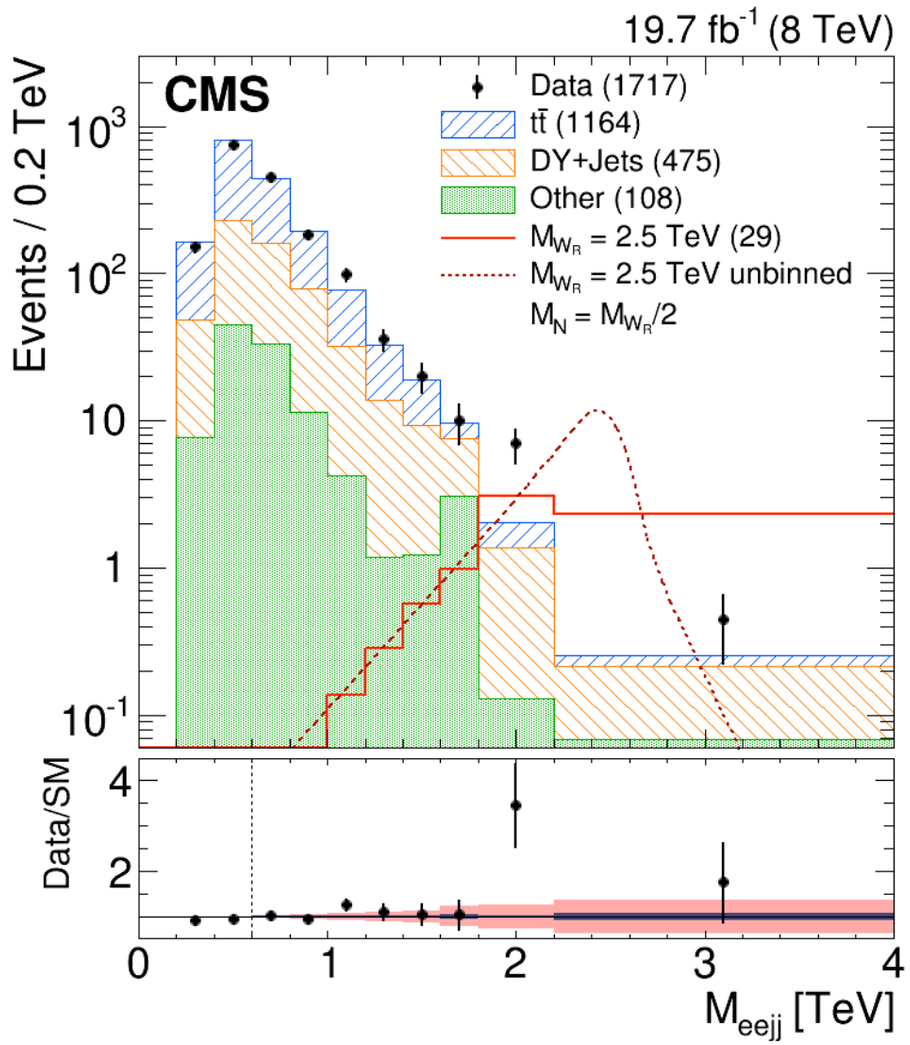

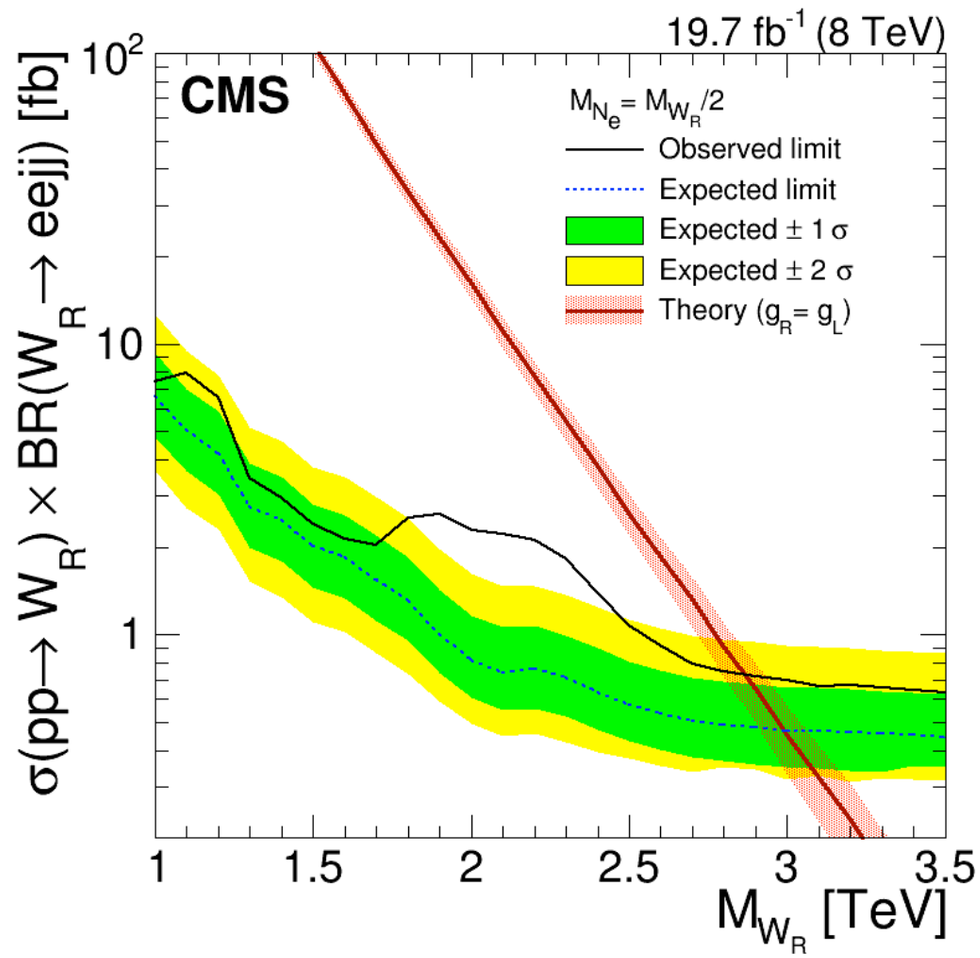

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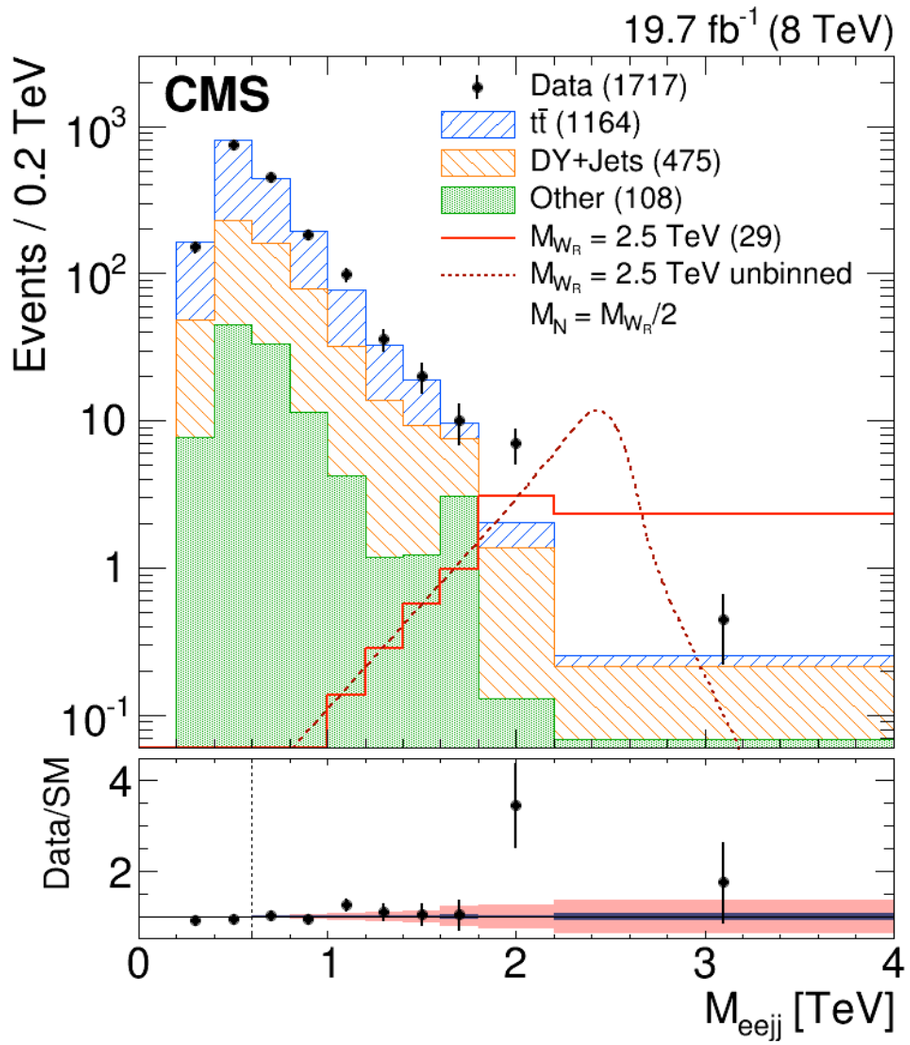

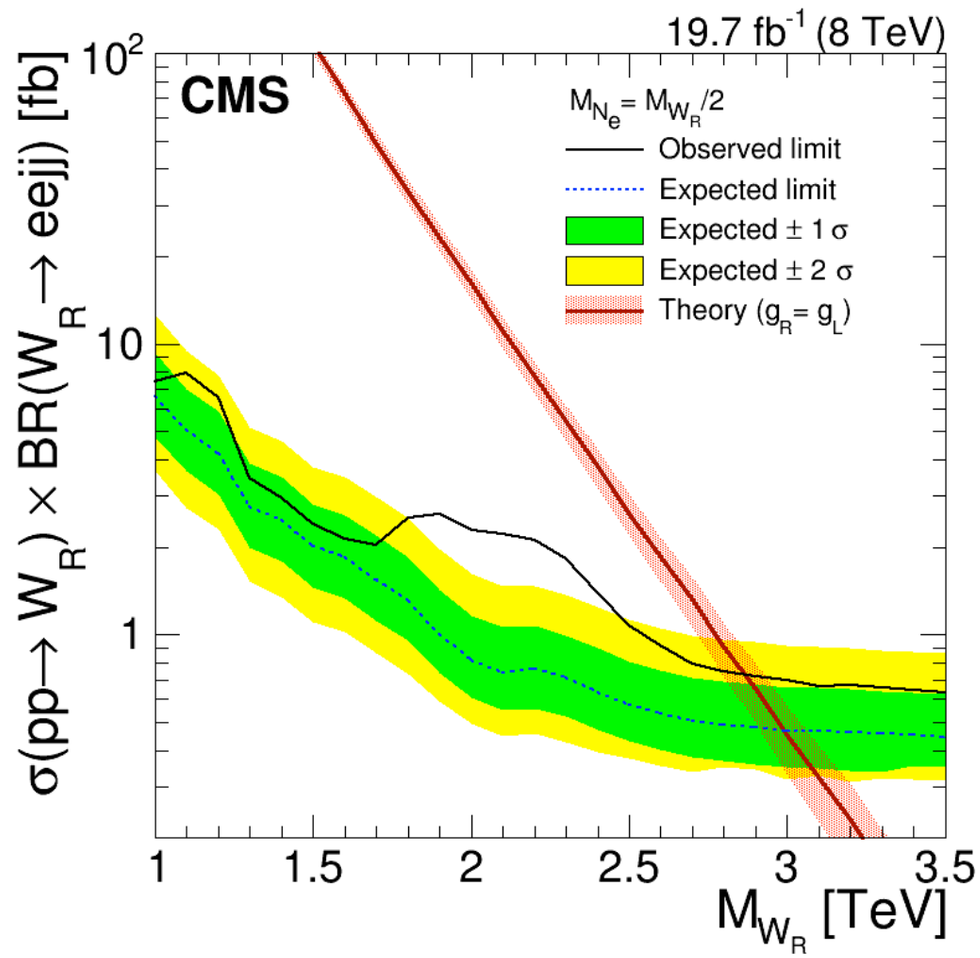

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can 1 model explain all three excesses?

linking the excesses:

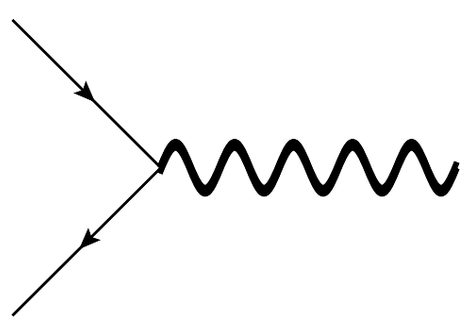
m_{eejj} feature points towards resonant production:

$$pp \to V \to XX$$

decays of X must contain eejj, evjj..

mass fixed; changing the quantum numbers of X, V changes the rate and associated signals

first hurdle: di-jet resonance constraint



need to make sure $\sigma(pp \to V)BR(V \to jj)$ is small

[Dobrescu, Yu 1306.2629]

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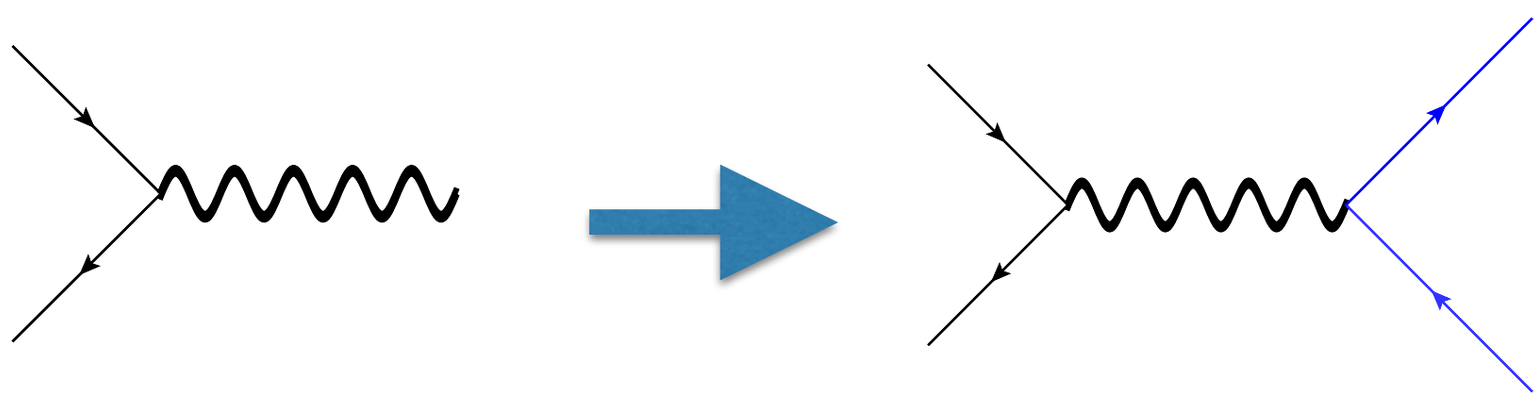

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resonant production of scalar leptoquarks

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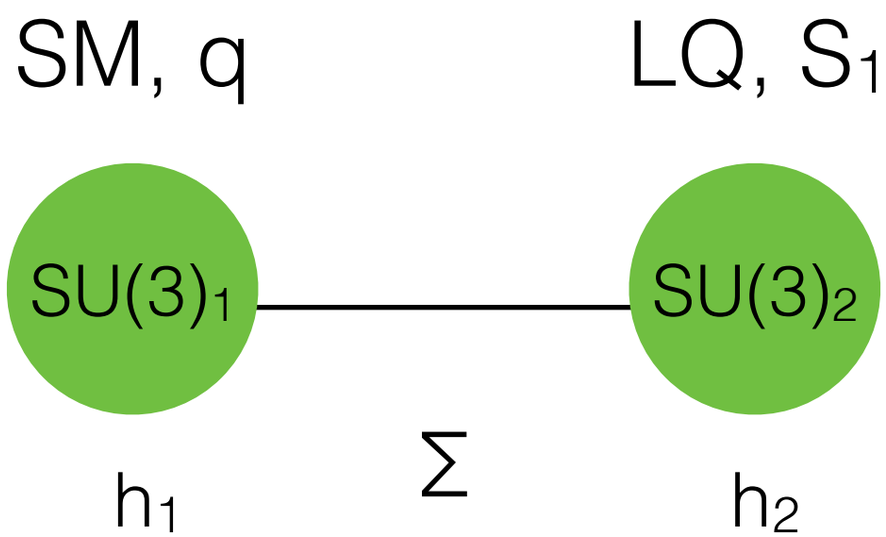

two SU(3) groups in UV, broken to diagonal $SU(3)_c$ by Σ. octet of massive colorons G' remains

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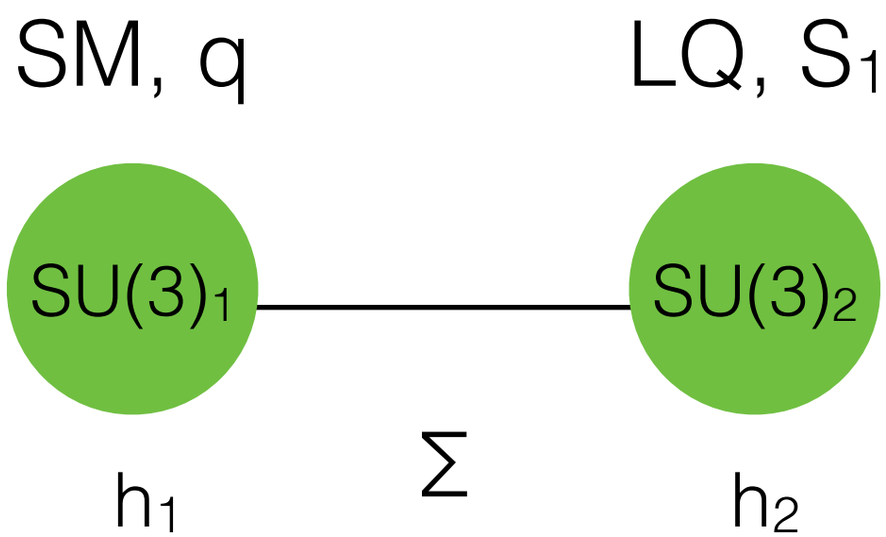

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G' preferentially couples to S_1 $\tan\theta = \frac{h_2}{h_1}$

$$g_s \tan\theta\, \bar{q}\gamma_\mu T^a G'^a_\mu q \qquad i g_s \frac{\xi}{\tan\theta} G'^a_\mu [S_1 T^a \partial^\mu S_1^\dagger - (\partial^\mu S_1) T^a S_1^\dagger]$$

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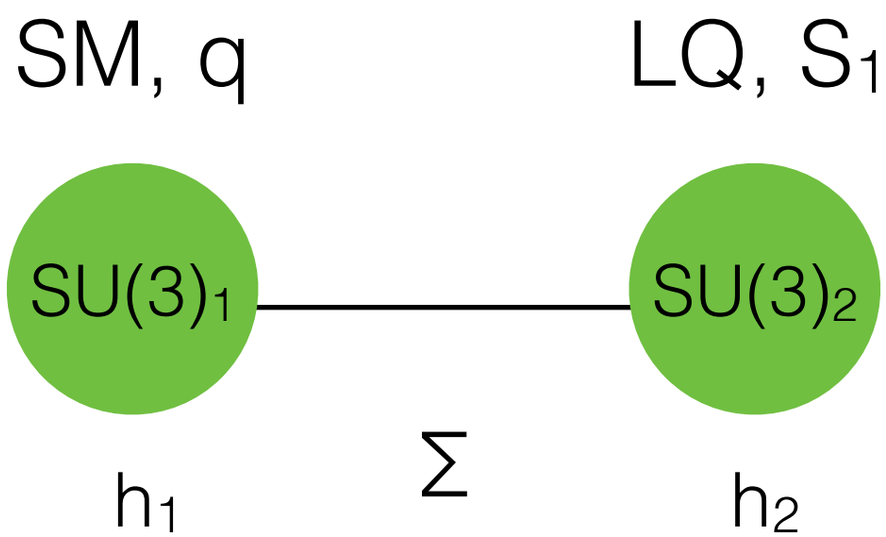

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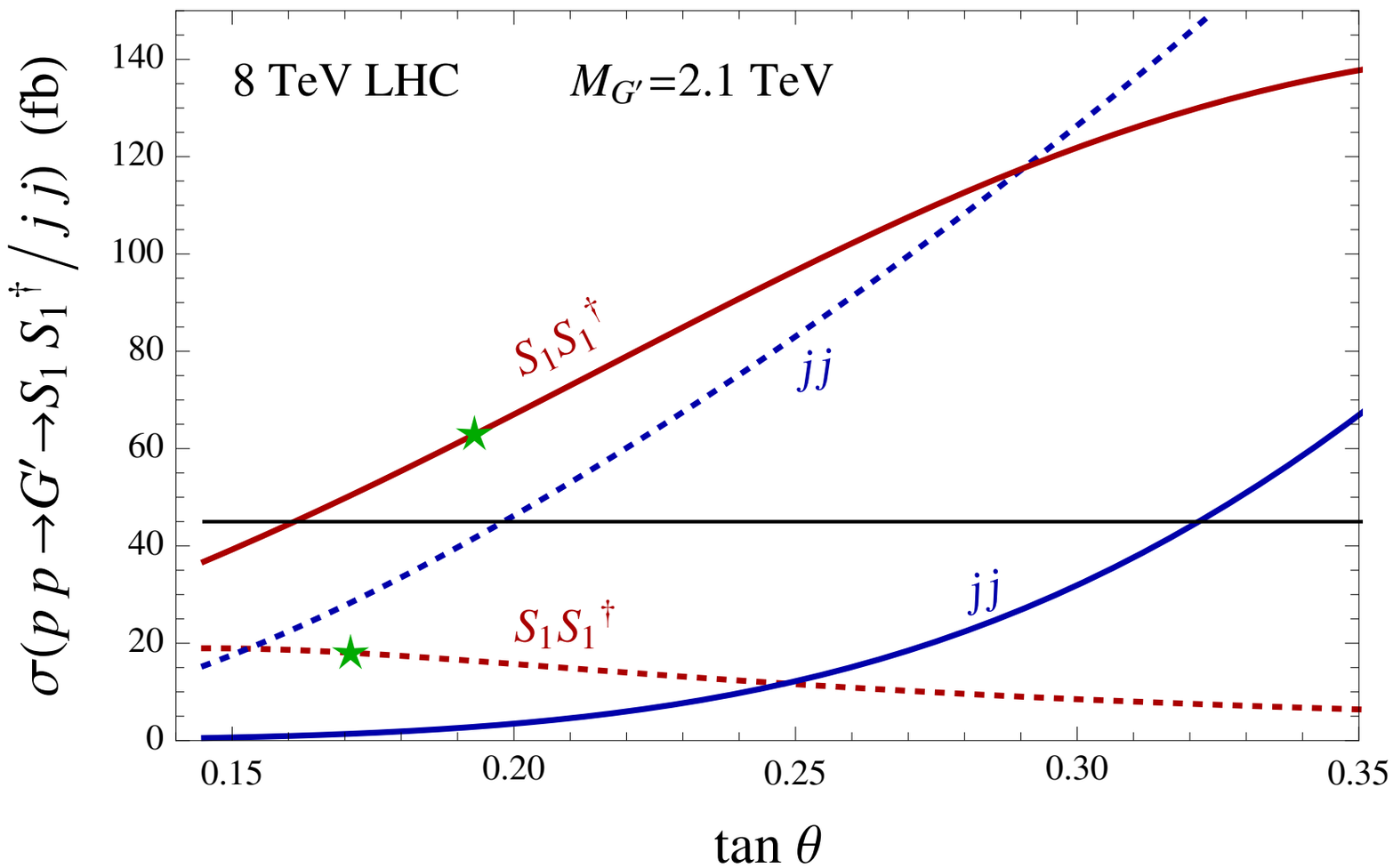
S_1 decays to ej and vj via

$$Q^\dagger L^\dagger \Sigma\, S_1 \to Q^\dagger L^\dagger S_1$$
$$u^c e^c \Sigma\, S_1 \to u^c e^c S_1$$

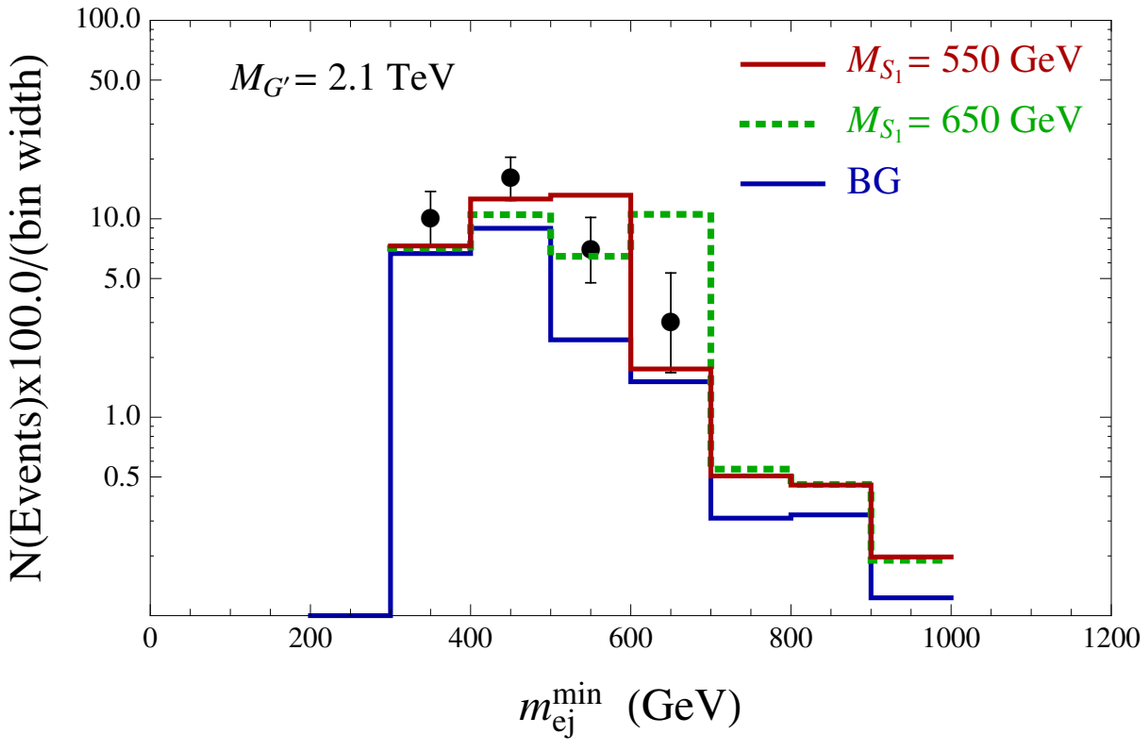
...

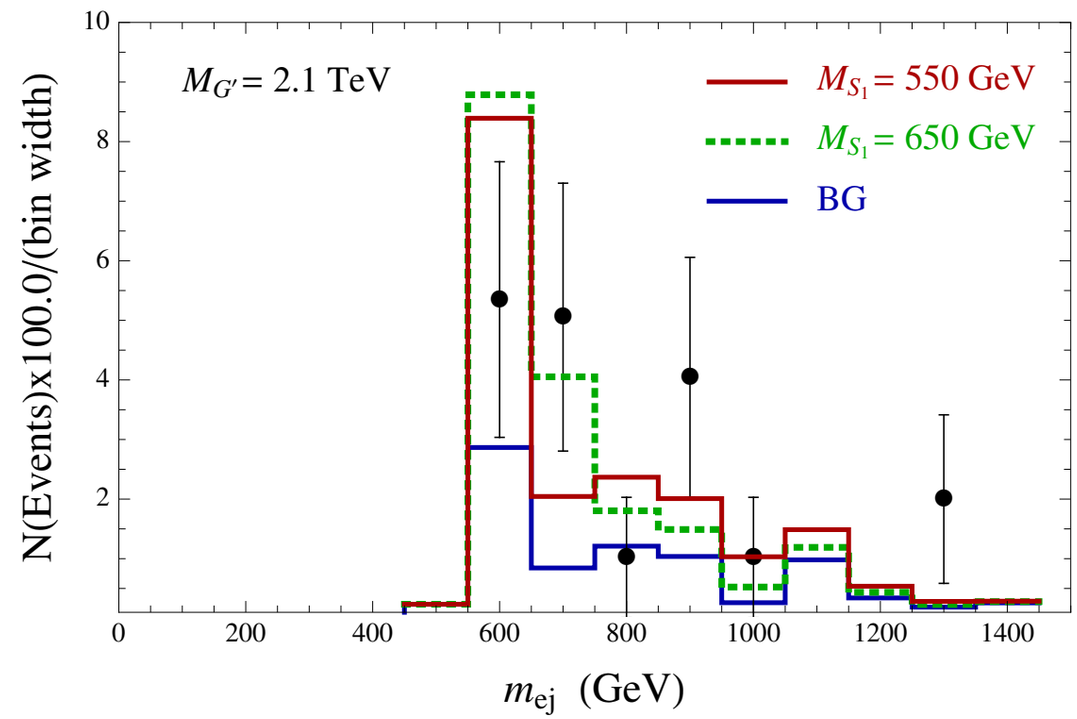
parameters: $M_{G'}$, M_{S1}, ξ, tanθ, BR_{ej}, BR_{vj},



solid: M_{S1} = 550 GeV, ξ = 1, dashed M_{S1} = 650 GeV, ξ = 0.15

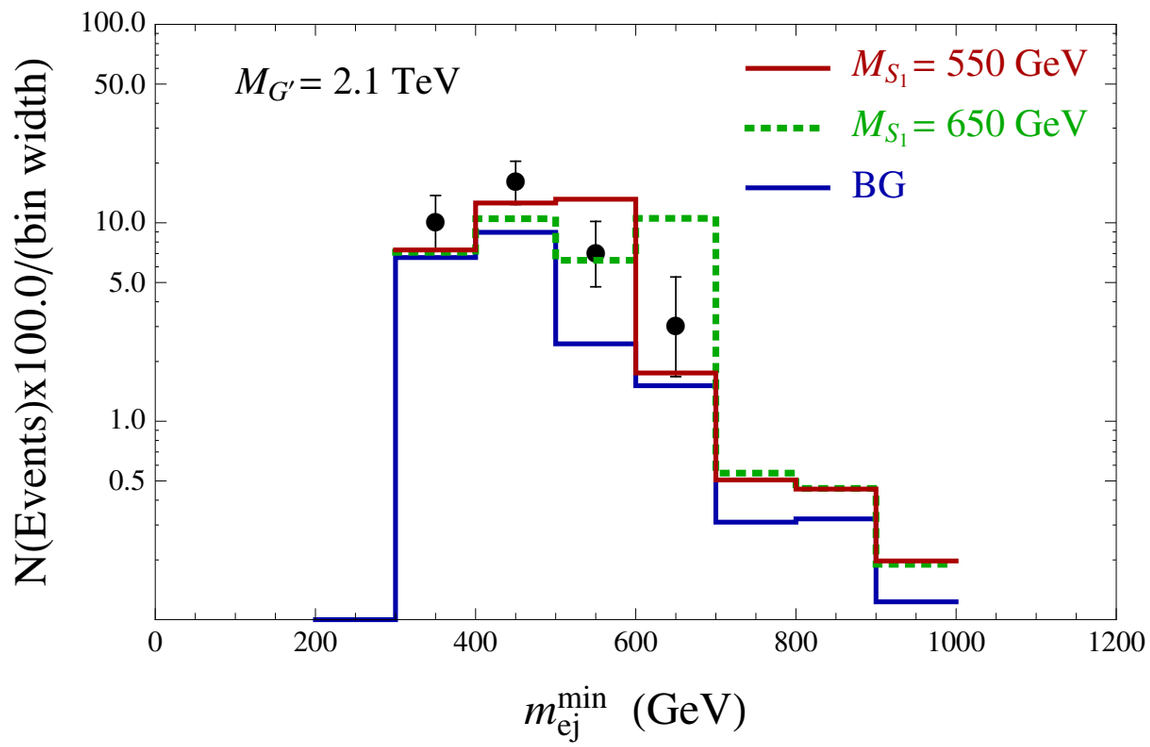
vary parameters for best fit to rate and distribution..
signal efficiency also different than CMS model

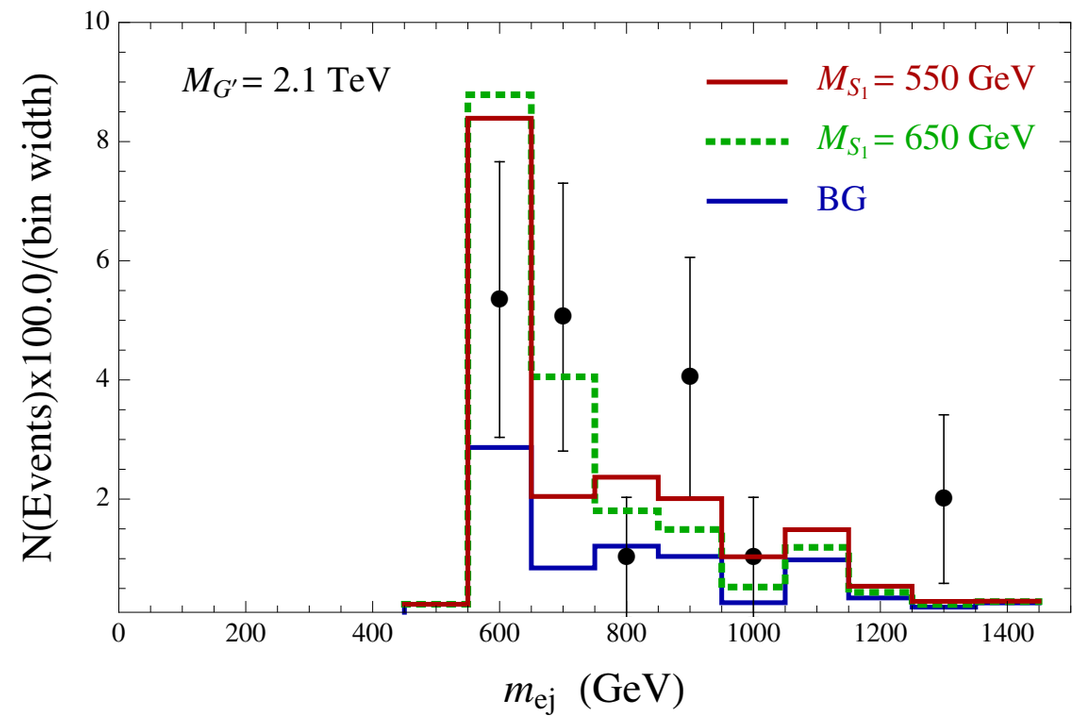




M_{S1} = 550 GeV, σ(G') = 63 fb, BR_{ej} = 0.12, $BR_{\nu j}$ = 0.15

M_{S1} = 650 GeV, σ(G') = 18 fb, BR_{ej} = 0.21, $BR_{\nu j}$ = 0.13





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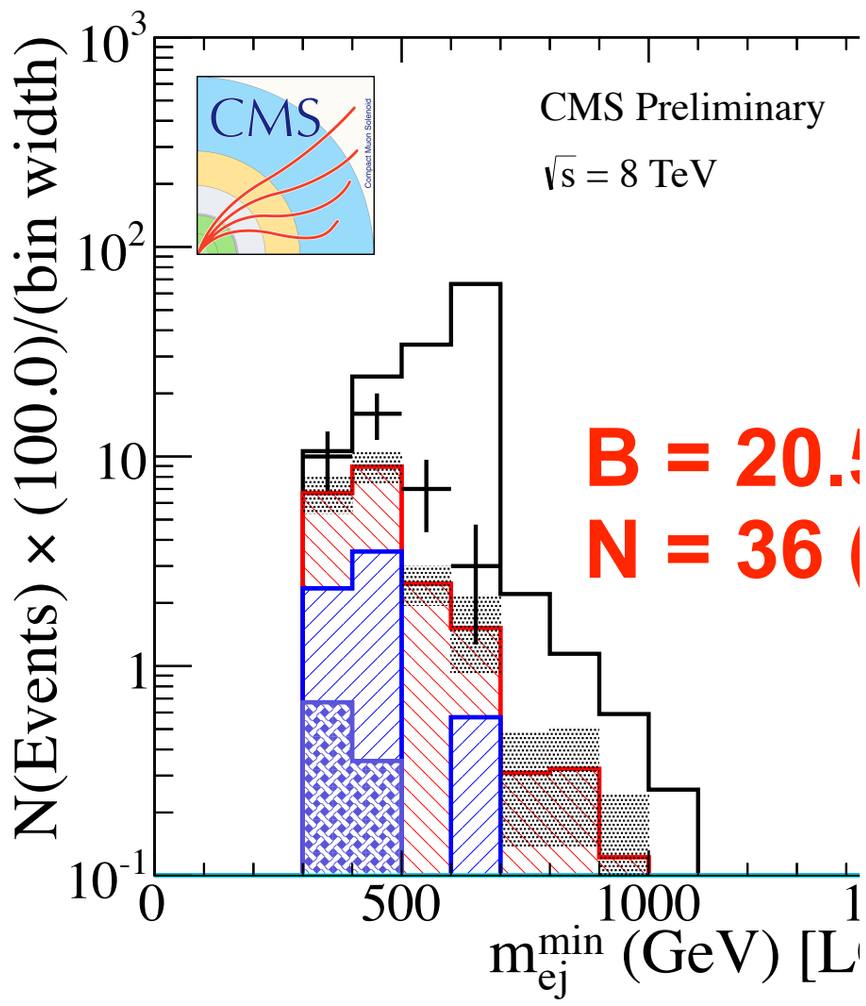
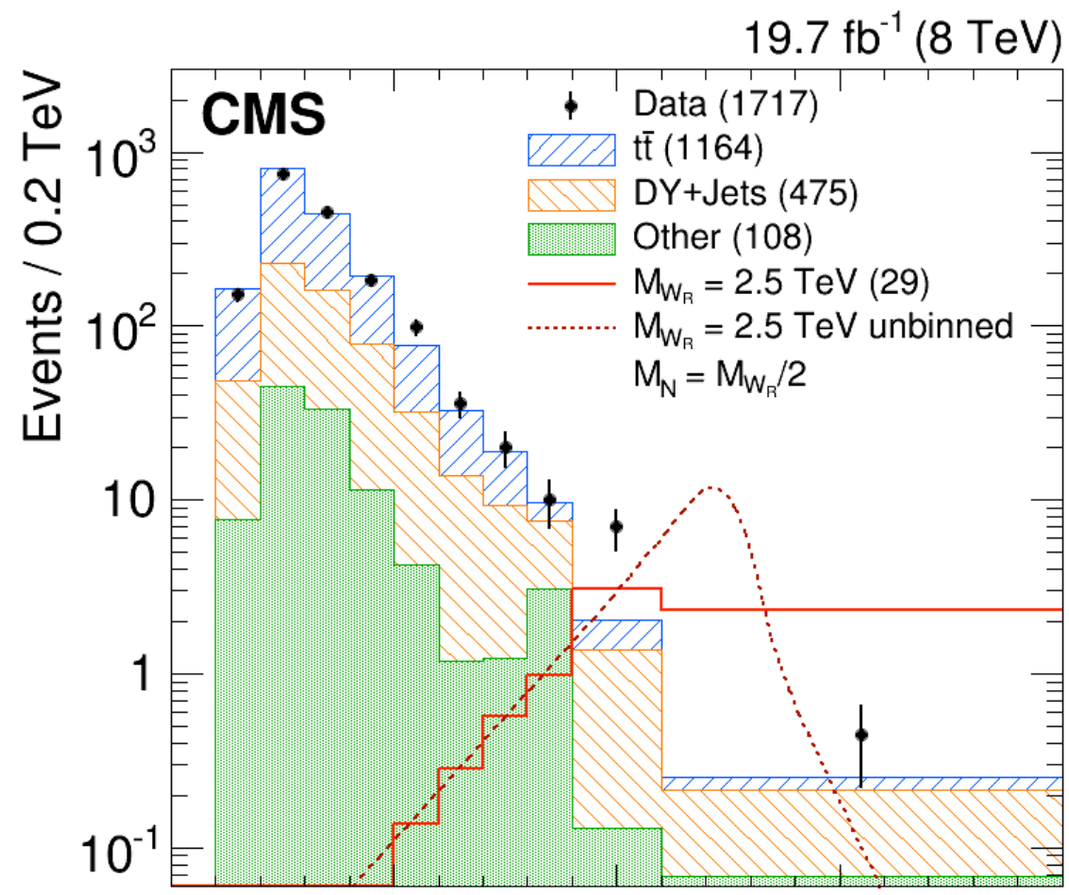
model building components:

- wide resonances
- pair produced states which decay by higher dimension operators

resonant production of more complex objects

ej and eejj peaks may be fit better by more complicated model: pp → ee 4j, or ee 6j

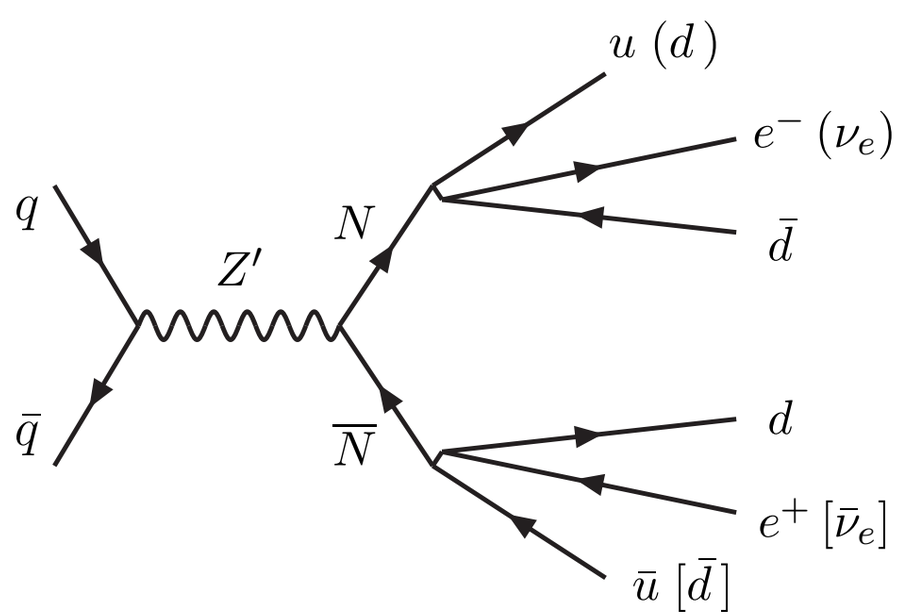


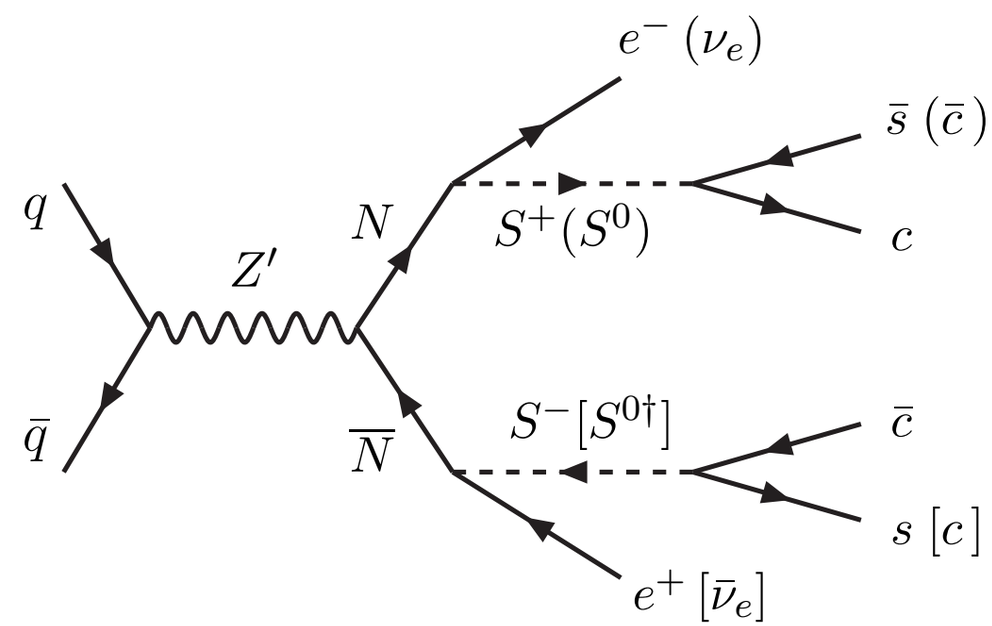


resonant production of more complex objects

[Dobrescu, Martin 1408.1082]

pp → Z' → **N$\bar{\mathbf{N}}$**, which can decay 1 → 3 directly, or 1 → 2 → 3





different choices have different phenomenology

N may be SM neutral, or carry hypercharge

resonant production of more complex objects

instead of G', resonant production through $U(1)_B$ Z'..
dijet rate controlled by taking (charge of N) » (charge of q)

N → 3 objects through higher dim. operator

selected by charge of ϕ, field that breaks $U(1)_B$

$$\frac{Q d^c\, L N\, \phi}{\Lambda^3}$$

σ(ee + 4j) = σ(ev + 4j)/2

(adding $\frac{Q^\dagger u^{c\dagger}\, L N\, \phi}{\Lambda^3}, \frac{d^{c\dagger} u^{c\dagger}\, e^c N\, \phi}{\Lambda^3}$ would change this)

parameters: $M_{Z'}$, $g_{Z'}$, M_N, BR(N→ ejjj) = 0.5

4 jets in event means reconstructed eejj and ej are not completely capturing resonances

softened, broadened features → heavier Z', N needed

Alternatively, can have **N** decay in stages

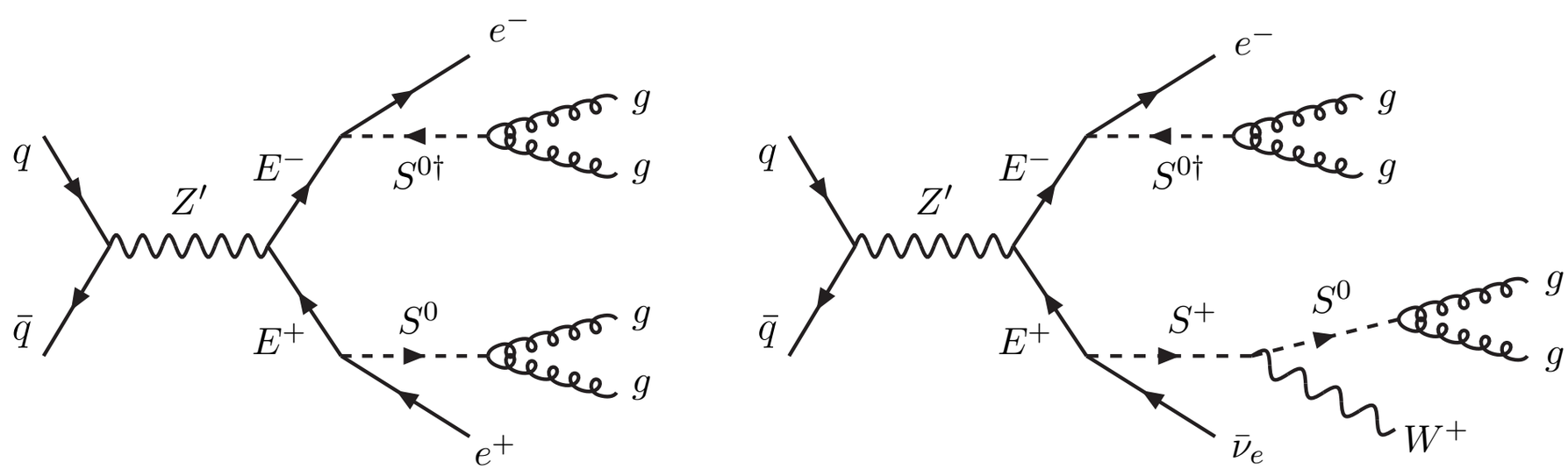
N → L**S**, **S** a new SU(2) doublet $\frac{L(N\phi)S}{\Lambda}$

many possibilities for S decay

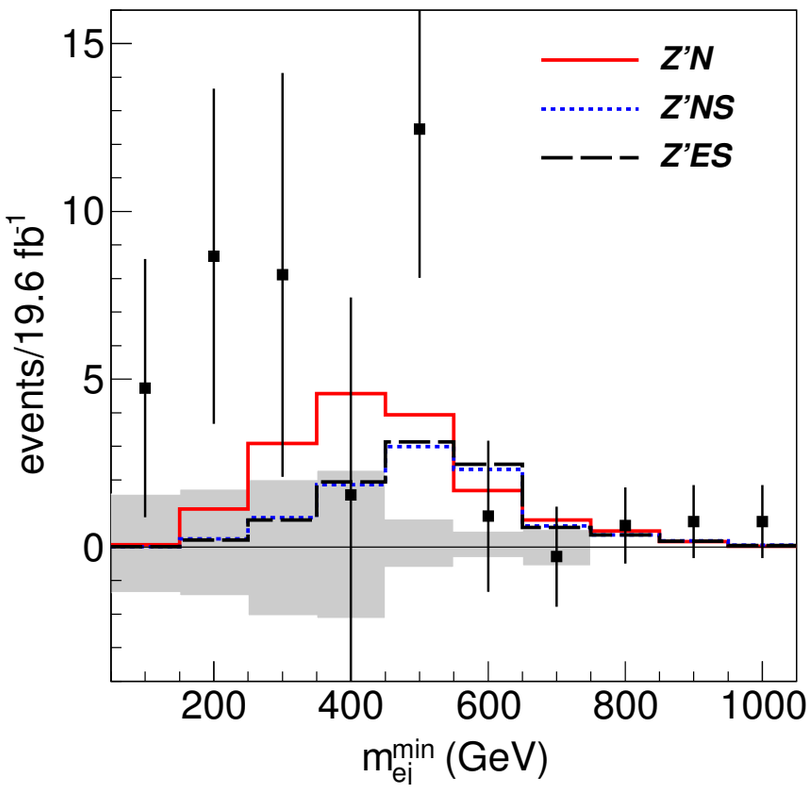
$S \to ff$ from higher dimensional operators
$S \to gg$ from higher dimensional operators
$S^{\pm} \to S^0$ via W emission
…

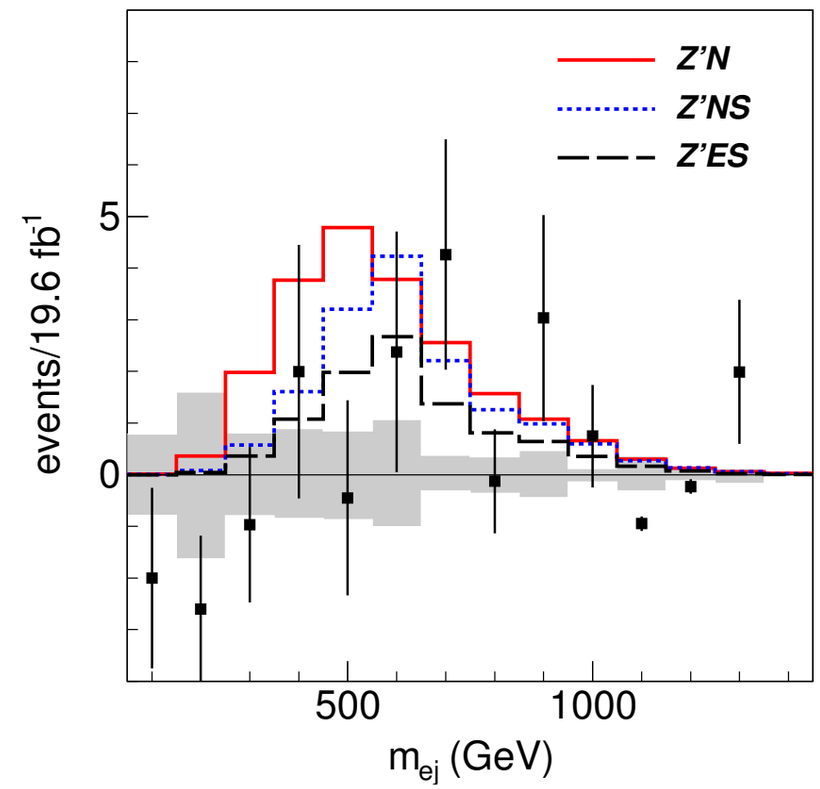
new parameters are M_S, final states of S decay

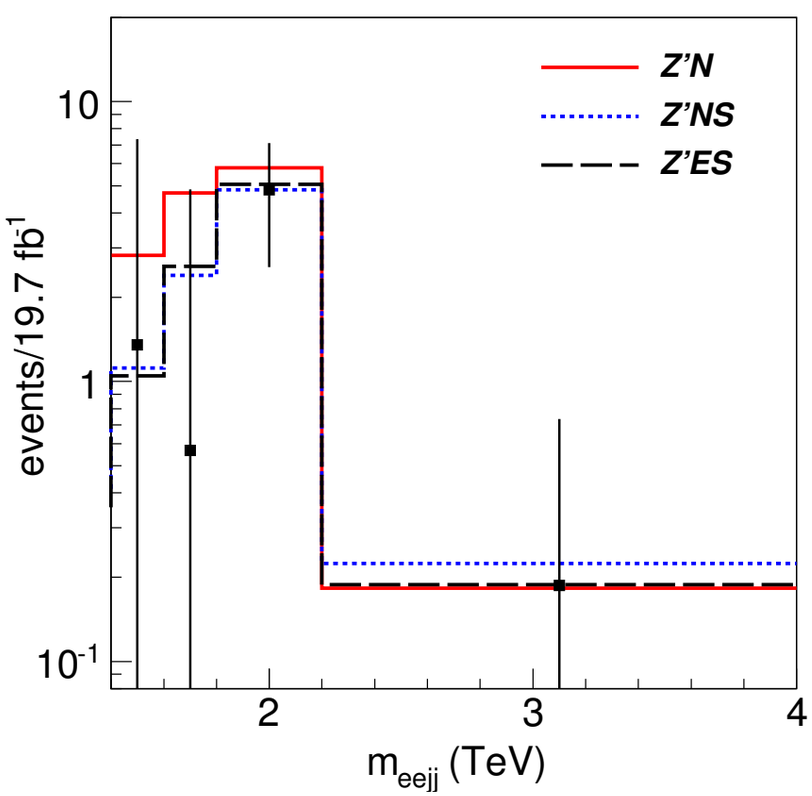
unlike original setup, jets now come from decay of on-shell particles.. possible contributions to ee +6j, +8j



data - SM background







Z'N: $M_{Z'}$ = 2.3 TeV, M_N = 700 GeV

Z'NS: $M_{Z'}$ = 2.4 TeV, M_N = 800 GeV
M_S = 400 GeV

Z'ES: $M_{Z'}$ = 2.4 TeV, M_E = 800 GeV
M_S = 440 GeV, 400 GeV

cross checks and predictions

- feature in $M_{e\nu jj}$
- O(fb) rate in $\nu\nu$ + jj

- excesses in ee + 3+ jets
- within ee + jets, bump in dijets

violation of lepton universality [hints from LHCb? 1409.0882]

confirmation from more data/more experiments.
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other eejj/evjj suggestions:

1408.2456, 1501.04815 (W' and Z'), 1505.00513 (LQ + ν_R)

1408.4508, 1408.5439 (RPV susy)

Conclusions

LHC run 2 about to begin: we have the Higgs, now looking for BSM, best to keep an open mind…

if there's new physics, it will first show up as an 'anomaly'

THANK YOU, and enjoy the rest of MC4BSM