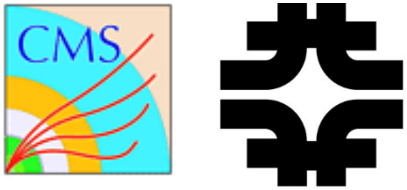
Searches for BSM Physics with the CMS Experiment



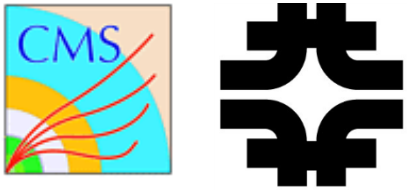
Christos Leonidopoulos

LPC, Fermilab

Implications of LHC results for TeV-scale physics

29 Aug-2 Sep 2011, CERN, Geneva

Searches for BSM(*) Physics with the CMS Experiment



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(*) Review of Exotica results presented at EPS and LP11
No Higgs or SUSY discussed here

Implications of LHC results for TeV-scale physics
29 Aug-2 Sep 2011, CERN, Geneva

Outline

- Summary of searches carried out with 2011 data
  - Including a list of signatures on which CMS is working on
- Explicit (obvious) question
  - What else is there? What are we forgetting?
- Goal: give an idea of "mainstream" channels under consideration
  - Details discussed in parallel sessions (when time allows)
  - Links given to public analysis notes

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

“No New Physics”

“No New Physics (yet)”

Reactions

Reactions

"1 fb^{-1} down, 2999 fb^{-1} to go"

D. Gross, EPS11

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"These numbers [exclusion limits] are terrifying"

G. Altarelli, EPS11

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"1 fb^{-1} down, 2999 fb^{-1} to go"

D. Gross, EPS11

"These numbers [exclusion limits] are terrifying"

G. Altarelli, EPS11

"What can we learn from the phenomenal success of the Standard Model in the first LHC results?"

S. Dimopoulos

An Apology to Theorists

- Several results with exclusion limits assume SSM cross sections (“best case” scenario)
  - This obviously does not tell us the full story
  - We are working on improving the way we present our results (a difficult task)

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- Several results with exclusion limits assume SSM cross sections ("best case" scenario)
  - This obviously does not tell us the full story
  - We are working on improving the way we present our results (a difficult task)
- An experimentalist's view
  - In my opinion, exclusions limits (albeit useful) should not be our first priority
    - In the sense that all "mainstream" searches are *constantly* monitored
    - Even if BSM cross section of search channel is 1/2, 1/5, 1/10, ... smaller than in SSM, New Physics will (eventually) be discovered

An Apology to Theorists

- Several results with exclusion limits assume SSM cross sections ("best case" scenario)
  - This obviously does not tell us the full story
  - We are working on improving the way we present our results (a difficult task)
- An experimentalist's view
  - Our priority should be to make sure there is "no stone left unturned"
    - Focus on unusual topologies, neglected decay channels, etc
    - Specify what is not being analyzed (i.e. not popular) or recorded (i.e. by the trigger)

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)
- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ
- More extra dimensions:
  - mono-jet, mono-photon, black holes
- Fourth generation
  - Heavy bottom-like and top-like quarks
- "Weird" stuff: stopped (or slow) HSCP

Resonances (aka: Z'-like) and Extra Dimensions

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)

- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ

- More extra dimensions:
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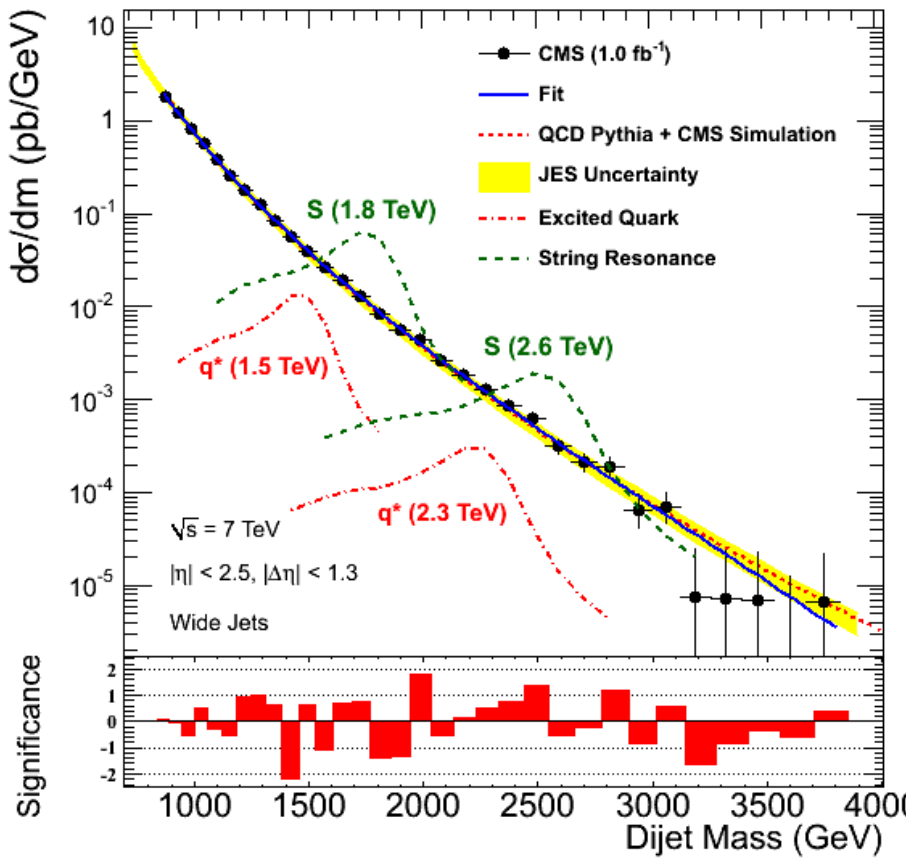
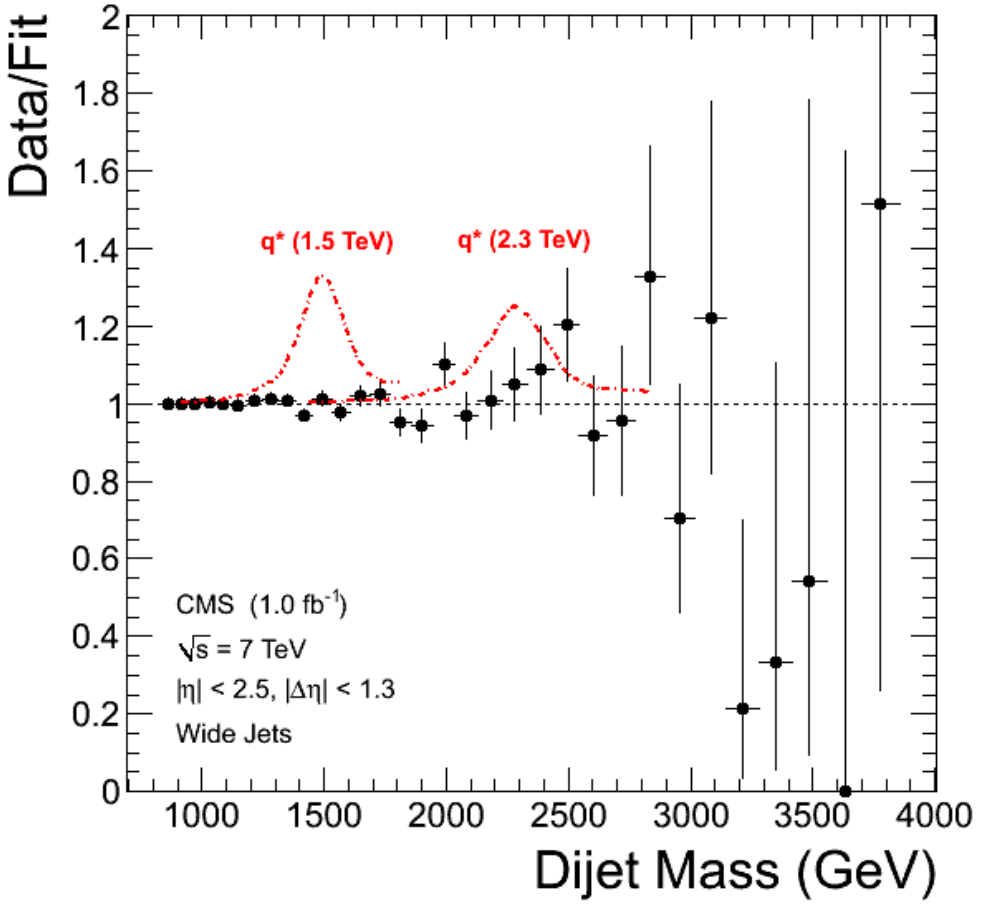
- Fourth generation
  - Heavy bottom-like and top-like quarks

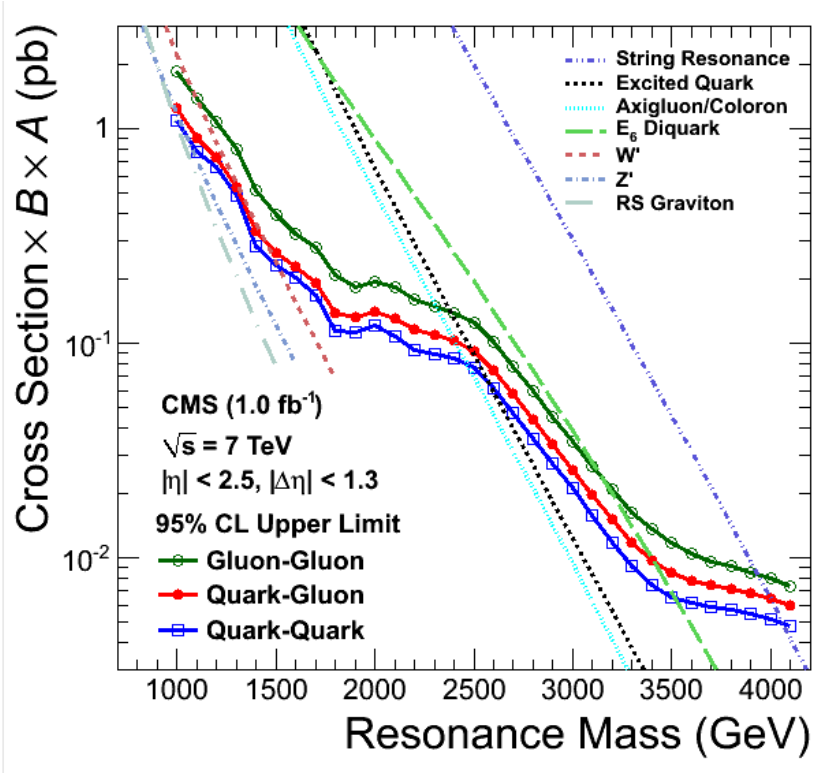
- "Weird" stuff: stopped (or slow) HSCP

Resonances: dijets





Resonances: limits with dijets

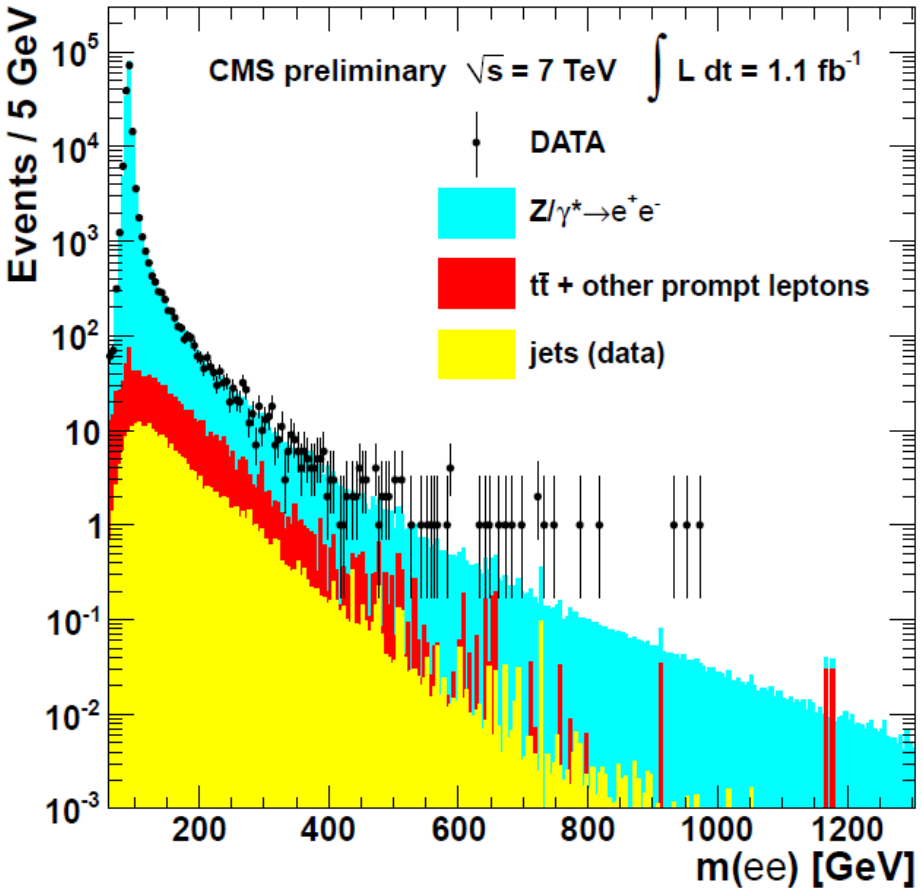


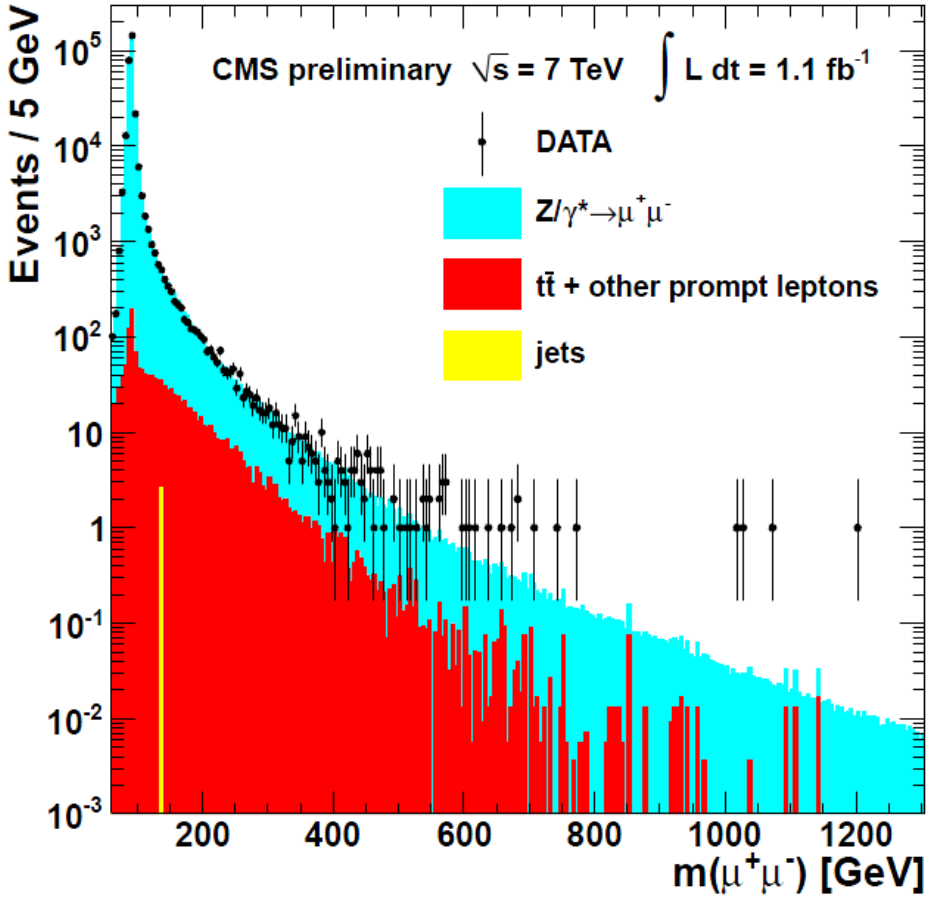
Derived limits for several models, with excluded masses up to 4 TeV

Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

arXiv.1107.4771
(submitted to PLB)
EXO-11-015

Resonances: dielectrons, dimuons

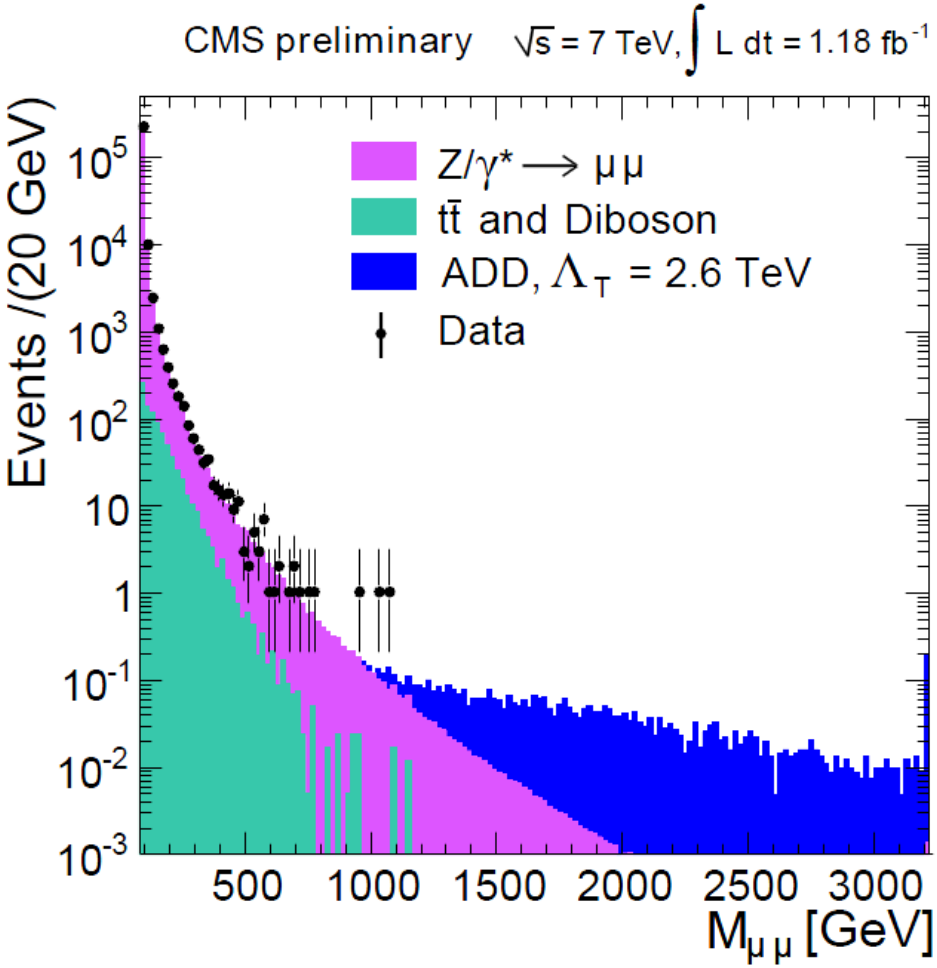




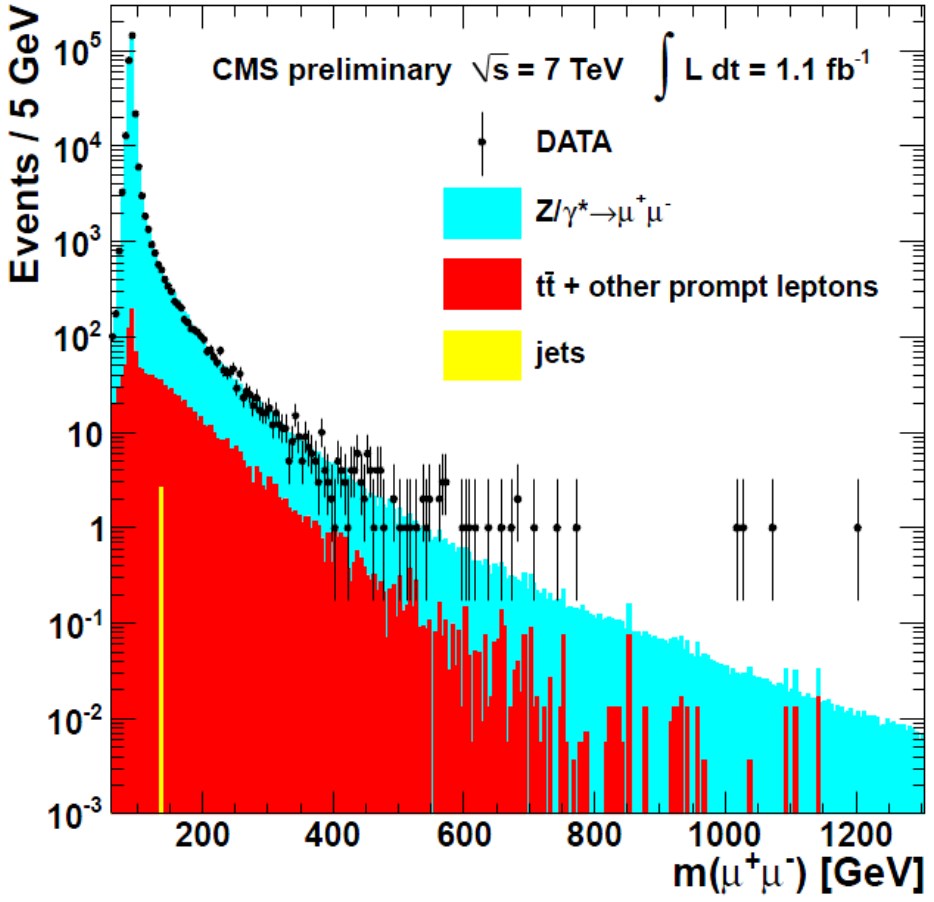
ee

$\mu\mu$

Extra dimensions in dimuons

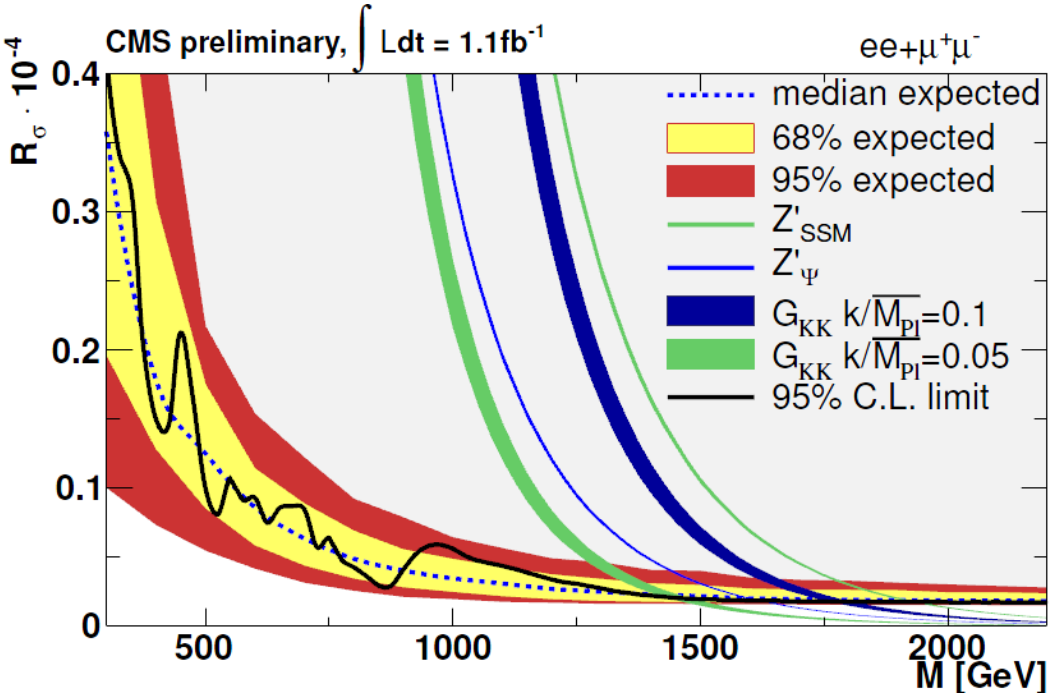


$\mu\mu$



$\mu\mu$

Limits with dimuons, dielectrons



Λ_T [TeV] (GRW)	M_s [TeV] (HLZ)					
	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
ADD k-factor: 1.0						
2.62	2.58	3.12	2.62	2.36	2.20	2.08
2.56	2.58	3.10	2.56	2.27	2.09	1.95
ADD k-factor: 1.3						
2.70	2.72	3.22	2.70	2.44	2.28	2.16
2.66	2.72	3.20	2.66	2.37	2.17	2.02

EXO-11-019

Z'_{SSM}: 1940 GeV

Z'_{ψ}: 1620 GeV

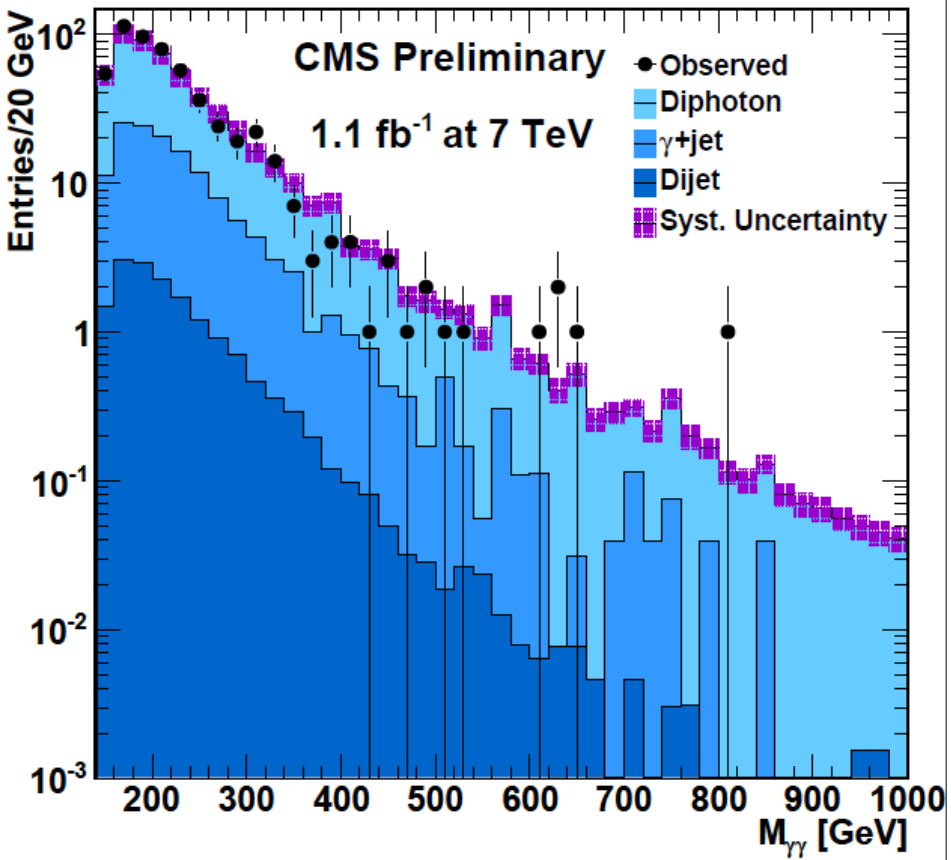
KK: 1450 GeV ($\frac{k}{M}$ =0.05)

KK: 1780 GeV ($\frac{k}{M}$ =0.1)

Exclusion limits for SSM, superstring-inspired, RS KK (1.5-2 TeV, as well as ADD models for several parameters (2-3 TeV)

EXO-11-039

Resonances: diphotons



EXO-11-038

Exclusion limits on RS gravitons (800-1800 GeV) and several ADD models (2.2-3.6 TeV)

Effective Planck scale (TeV) in ADD

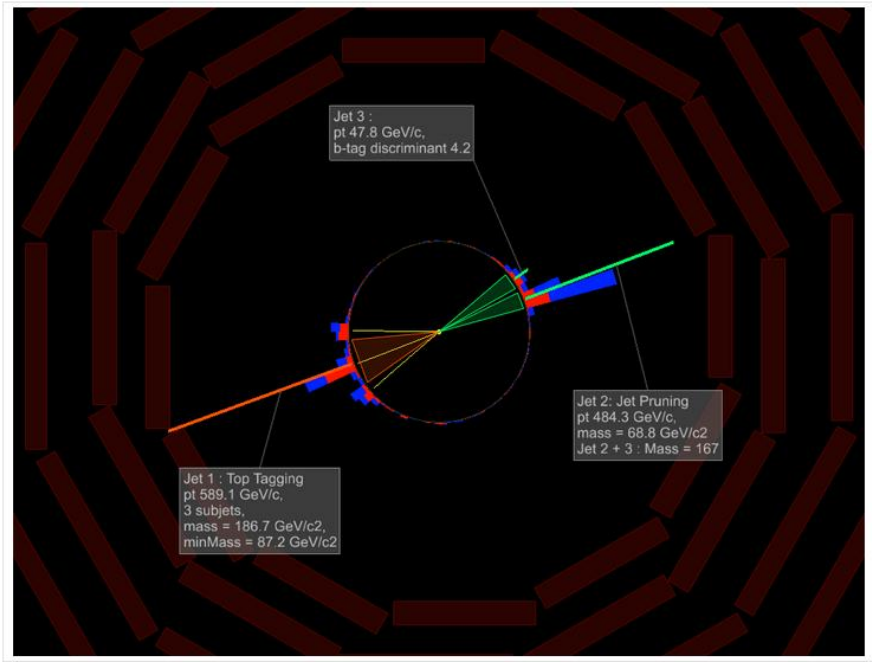
K factor	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
1.0	3.2	3.4	2.8	2.6	2.4	2.2
1.6	3.5	3.7	3.1	2.8	2.6	2.4

RS gravitons: Mass (TeV)

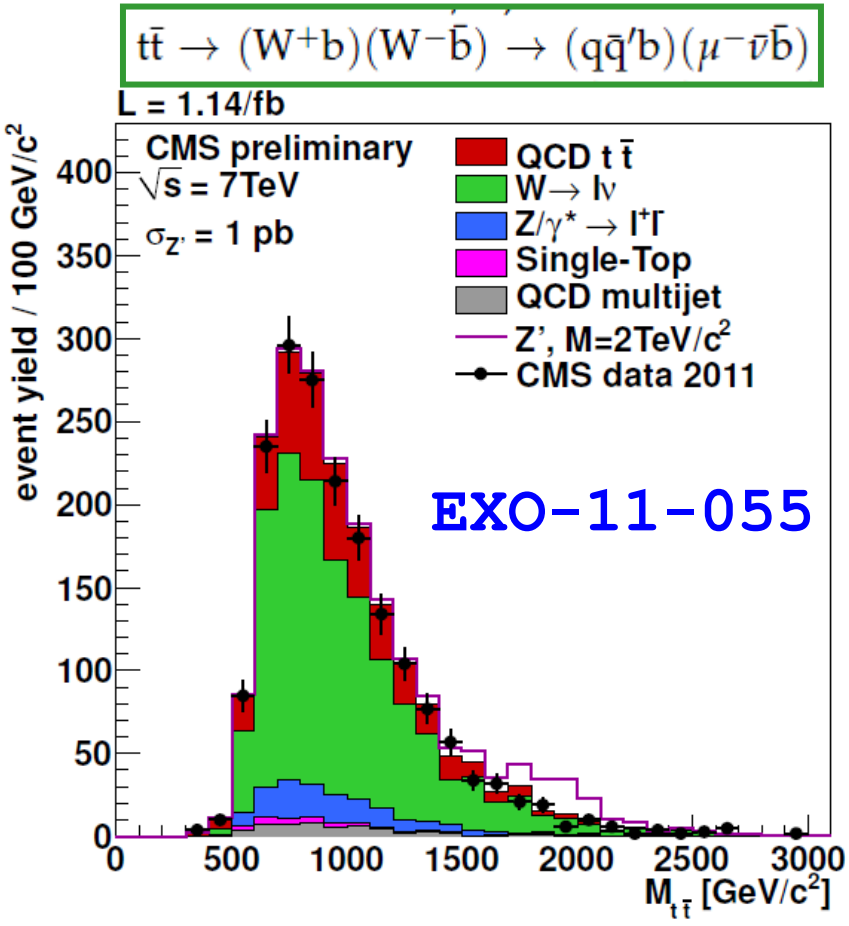
$\tilde{k}$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11
M_1 [TeV]	0.77	1.05	1.20	1.31	1.41	1.49	1.57	1.63	1.69	1.74	1.78

Resonances: $t\bar{t}$

Boosted all-hadronic final state



EXO-11-006



Z'_{SSM}: 1.1 TeV
KK: 1.0-1.5 TeV

Z'_{topcolor}: 805-935, 960-1060 GeV

Exclusion limits on SSM (1.1 TeV), KK (1.0-1.5 TeV) and topcolor models

“Non-Resonances” (aka: W'-like)

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)

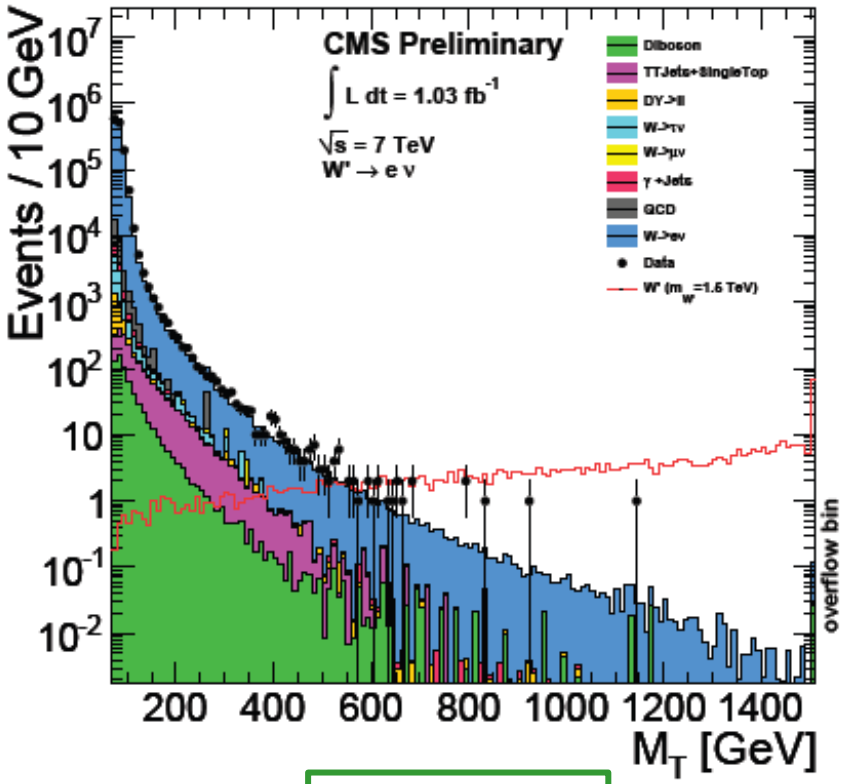
- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ

- More extra dimensions:
  - mono-jet, mono-photon, black holes

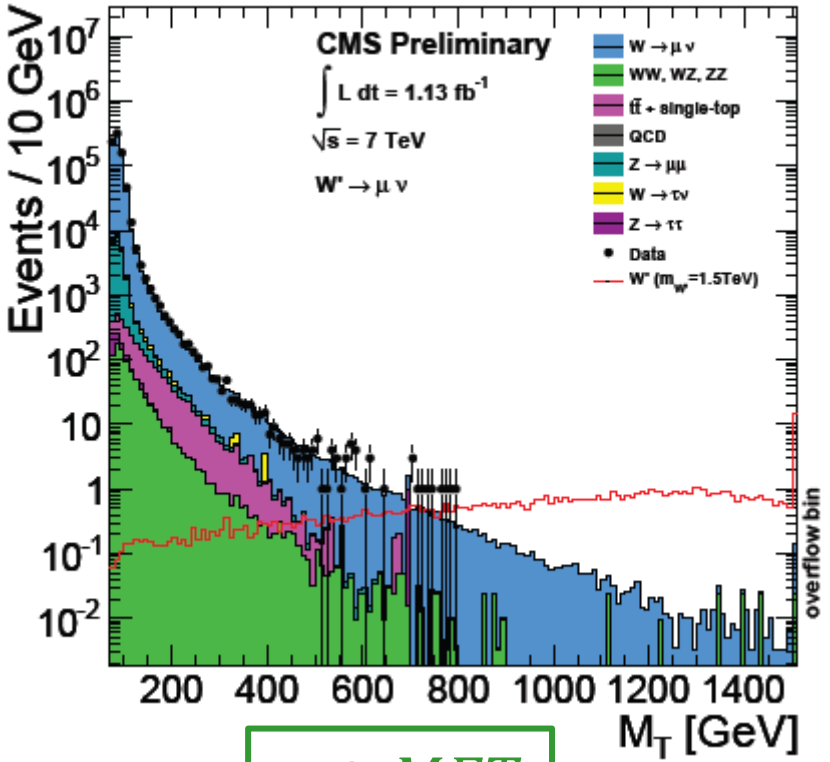
- Fourth generation
  - Heavy bottom-like and top-like quarks

- "Weird" stuff: stopped (or slow) HSCP

$W' \to \ell\nu\ (\ell = e, \mu)$



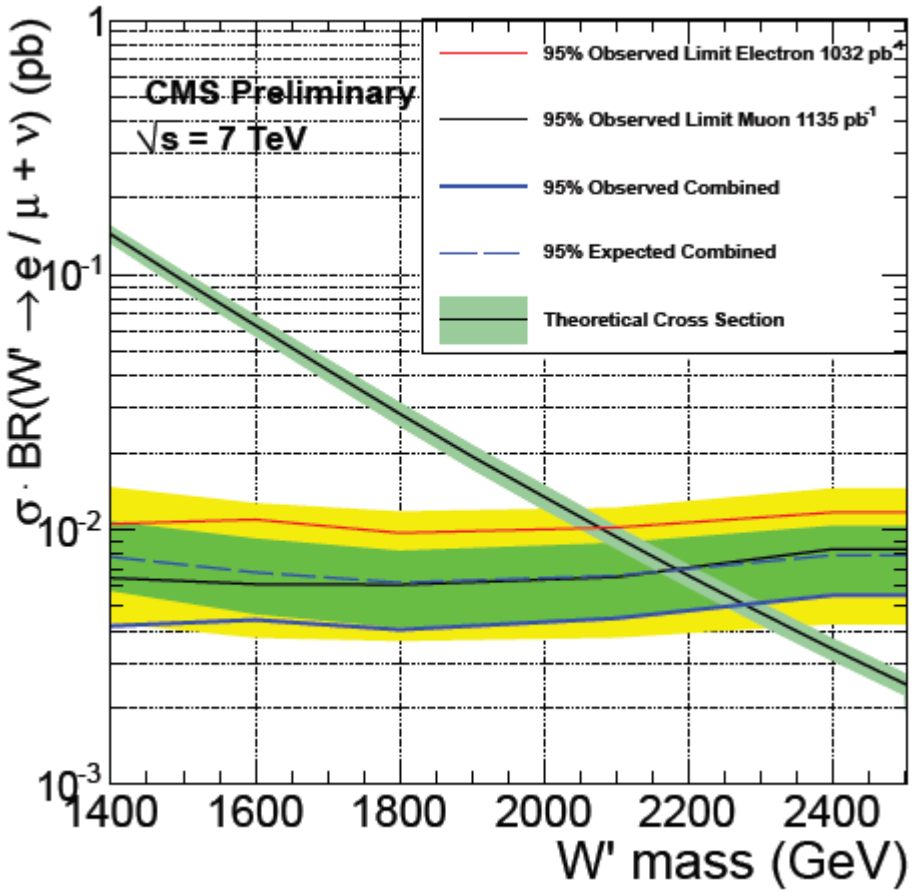
$e + MET$



$\mu + MET$

$$M_T = \sqrt{2 \cdot (p_T^{\mu} \cdot c) \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\mu,\nu})}$$

$W' \to \ell\nu\ (\ell = e, \mu)$

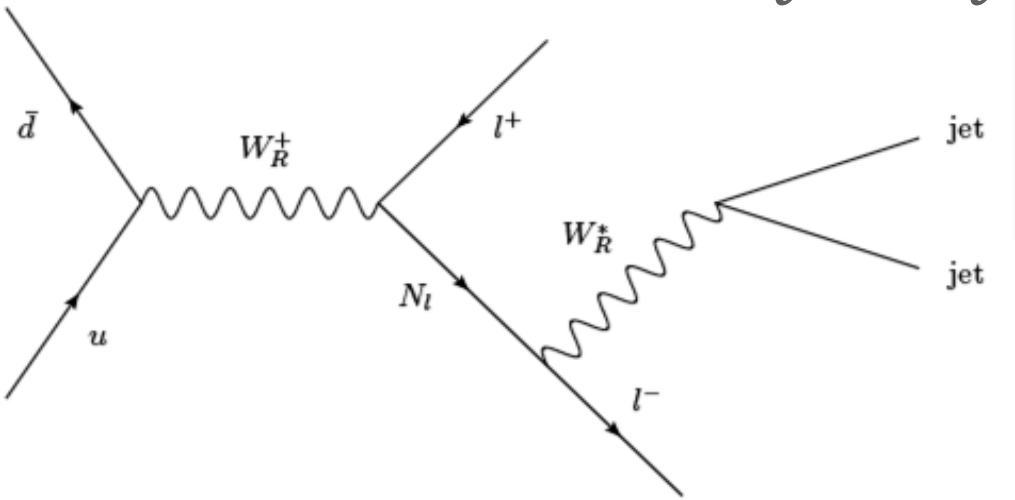


Significant improvement over 2010 result in SSM model (1.58 TeV → 2.27 TeV)

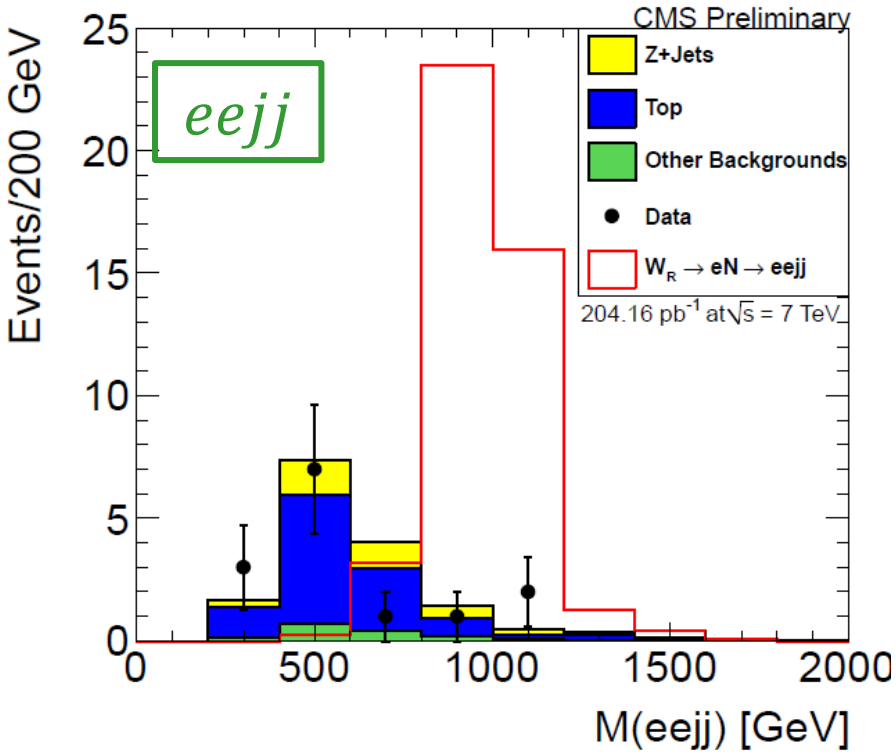
W'_{SSM}: 2.27 TeV

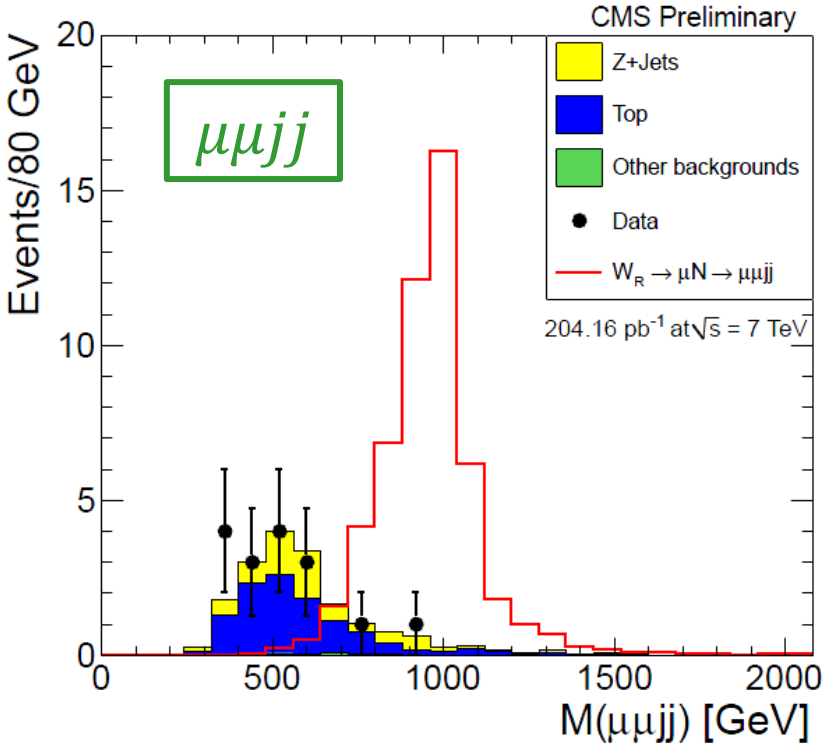
EXO-11-024

$W' \to \ell N_\ell , N_\ell \to qq'\ell'$

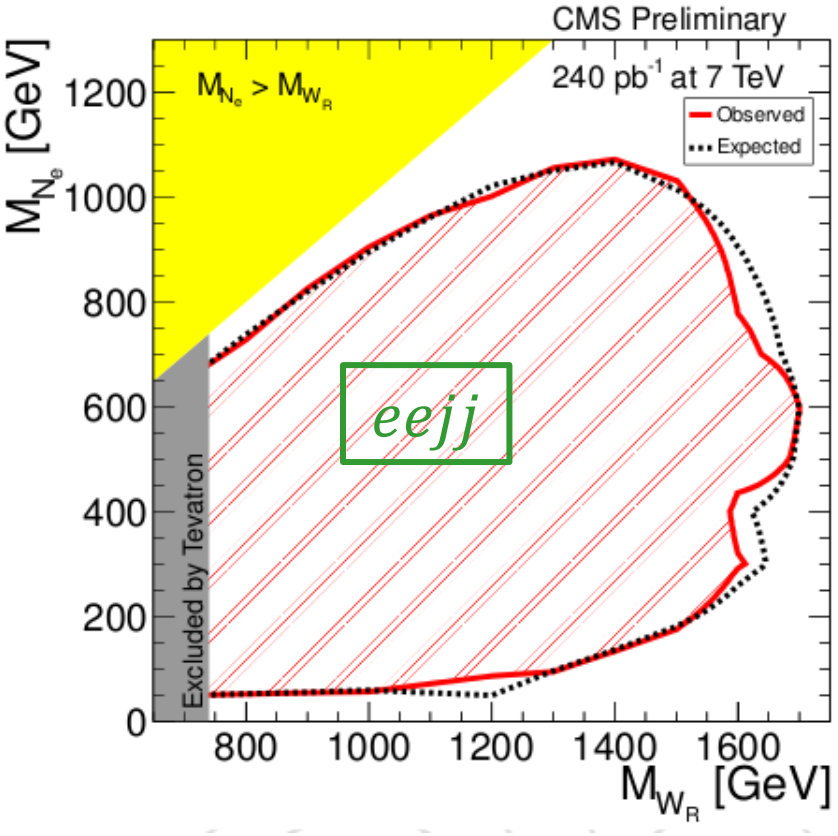


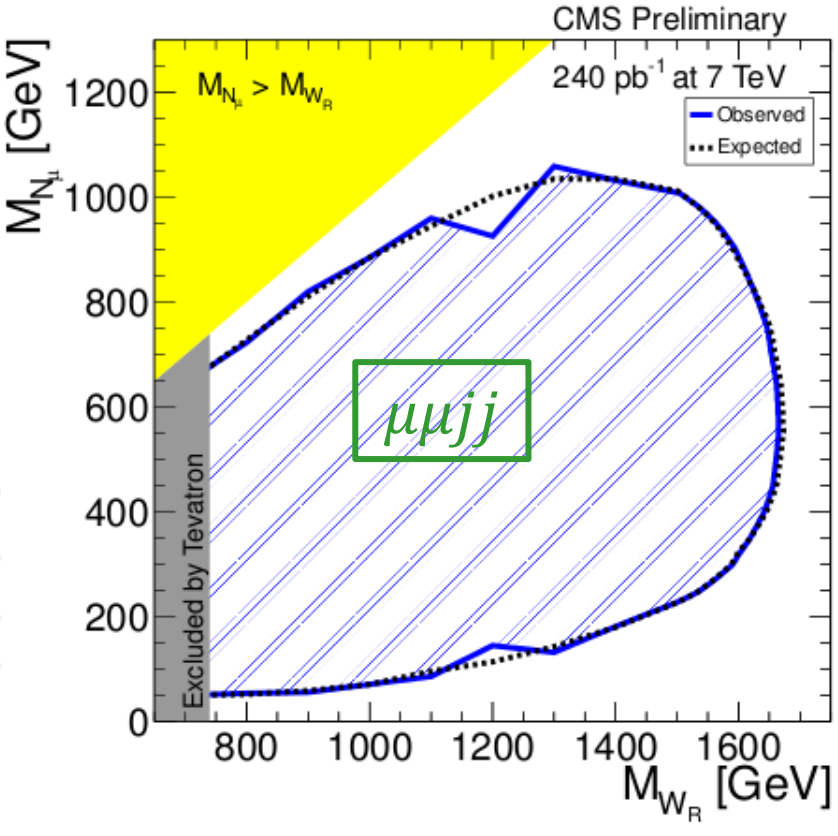
See G. Senjanovic's seminar at CERN (01-AUG-11)





$W' \to \ell N_\ell , N_\ell \to qq'\ell'$



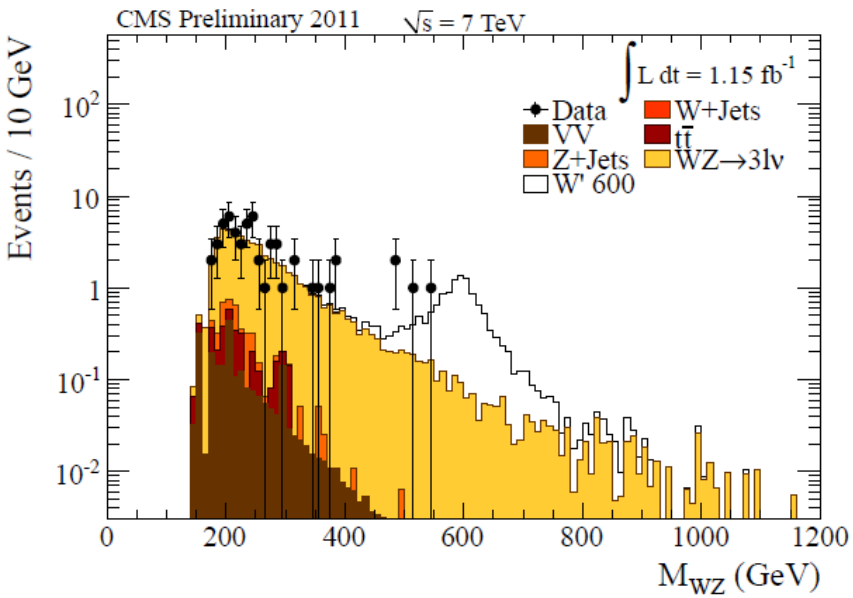


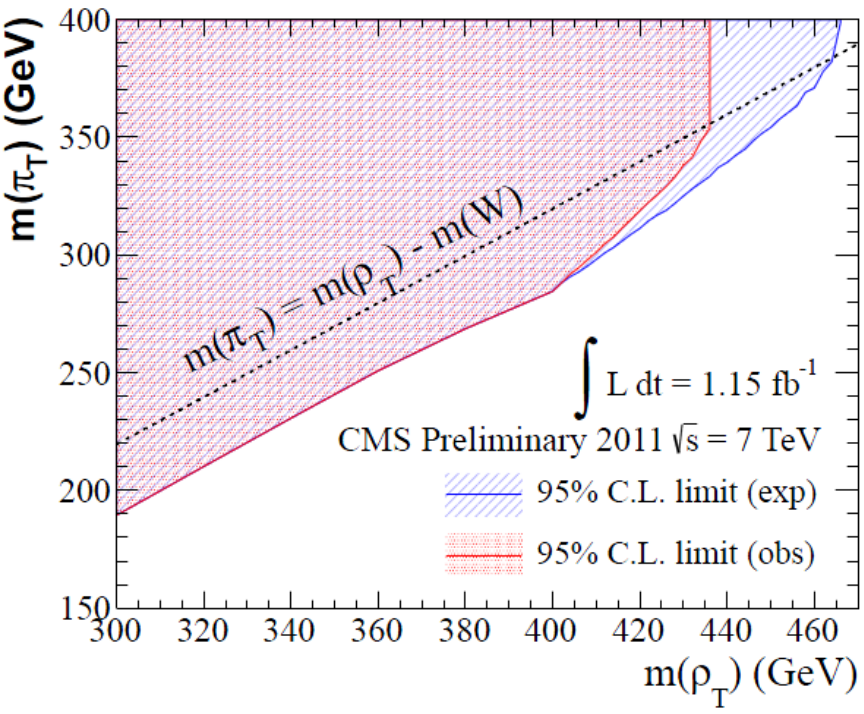
W'_{SSM}: extends to 1.7 TeV

EXO-11-002

Significant improvement over TeVatron limit (780 GeV → 1.7 TeV)

$W'(\rho_{TC}) \rightarrow WZ \rightarrow 3\ell\nu\ (\ell = e, \mu)$





W'_{SSM}: 784 GeV

ρ_{TC}: 382 GeV ($M_{\pi_{TC}} = \frac{3}{4} M_{\rho_{TC}}$-25 GeV)

ρ_{TC}: 436 GeV ($M_{\rho_{TC}} < M_{\pi_{TC}} + M_W$)

EXO-11-041

First search after TeVatron; Exclusion limits on SSM (784 GeV) and techni-color models (382-436 GeV)

(More) Large Extra Dimensions

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)
- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ
- More extra dimensions:
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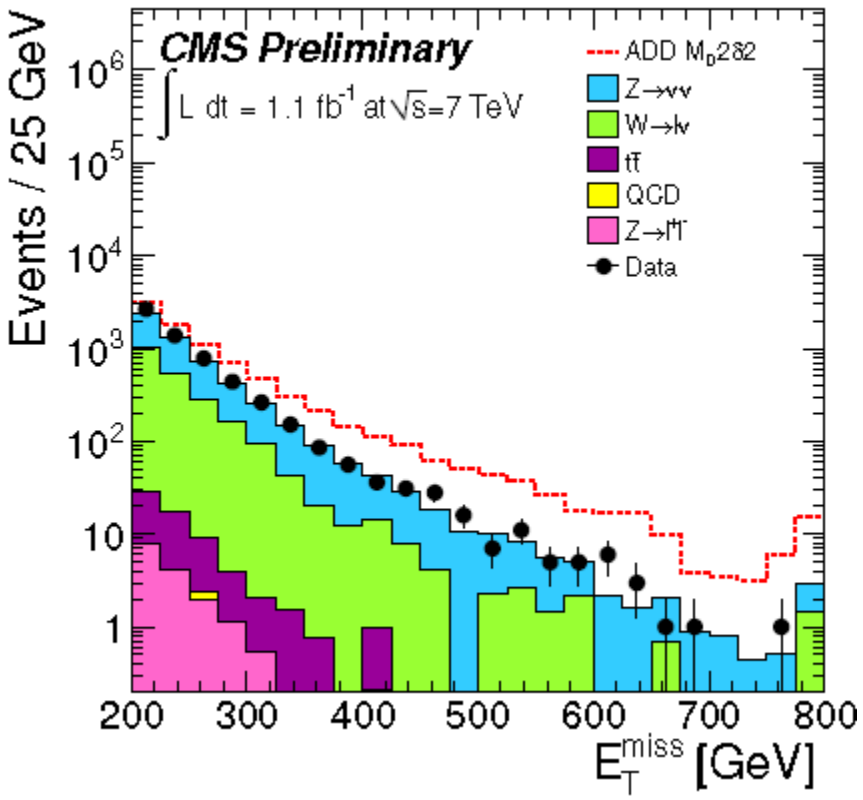
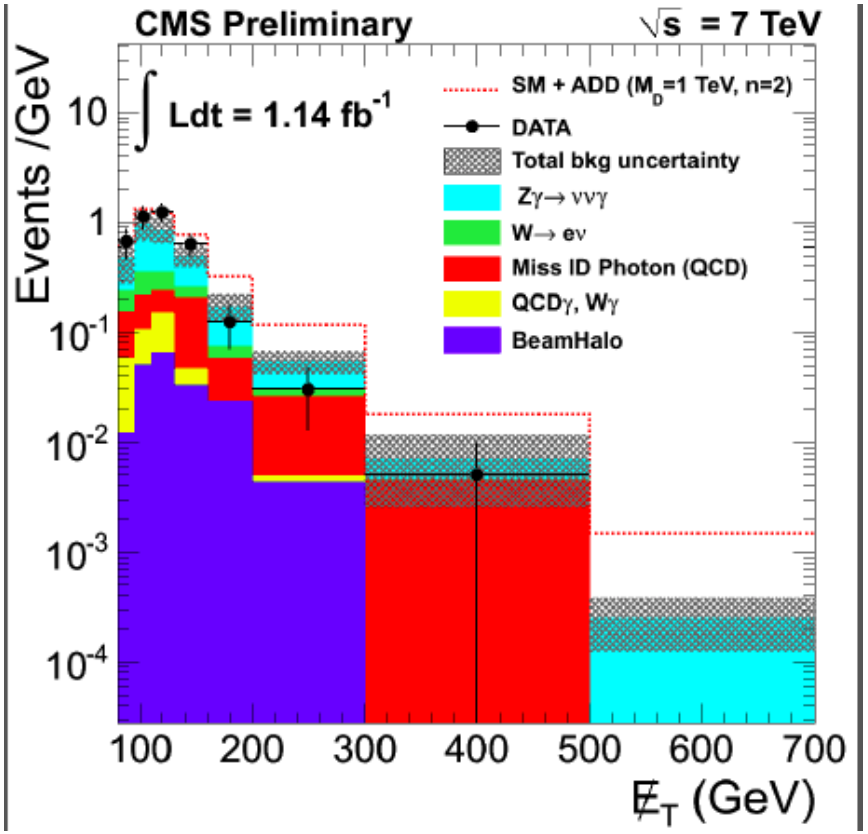
- Fourth generation
  - Heavy bottom-like and top-like quarks
- "Weird" stuff: stopped (or slow) HSCP

(Mono)Jet + ME_T, $\gamma + ME_T$





Jet +MET

γ + MET

Limits with (mono)jet/γ + ME_T

δ	K factor	$E_T^{miss} > 350$ GeV Exp. Limit	Obs. Limit
2		3.72	3.67
3		3.00	2.96
4		2.68	2.66
5		2.44	2.41
6		2.27	2.25
2	1.5	4.10	4.03
3	1.5	3.25	3.21
4	1.4	2.83	2.80
5	1.4	2.57	2.55
6	1.4	2.39	2.36

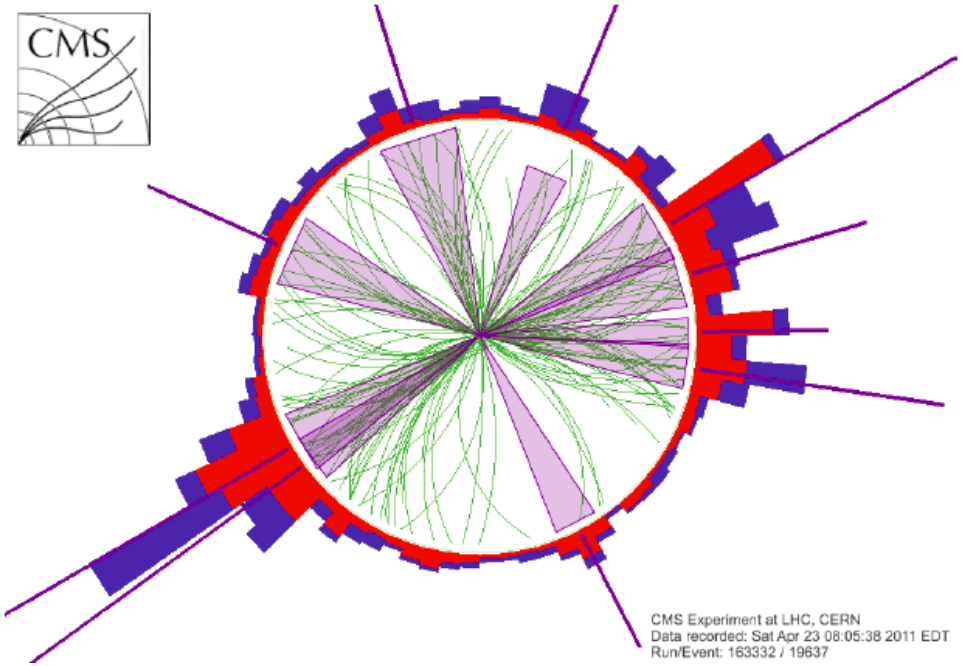
EXO-11-059

Exclusions limits on ADD models for several parameters (1-4 TeV)

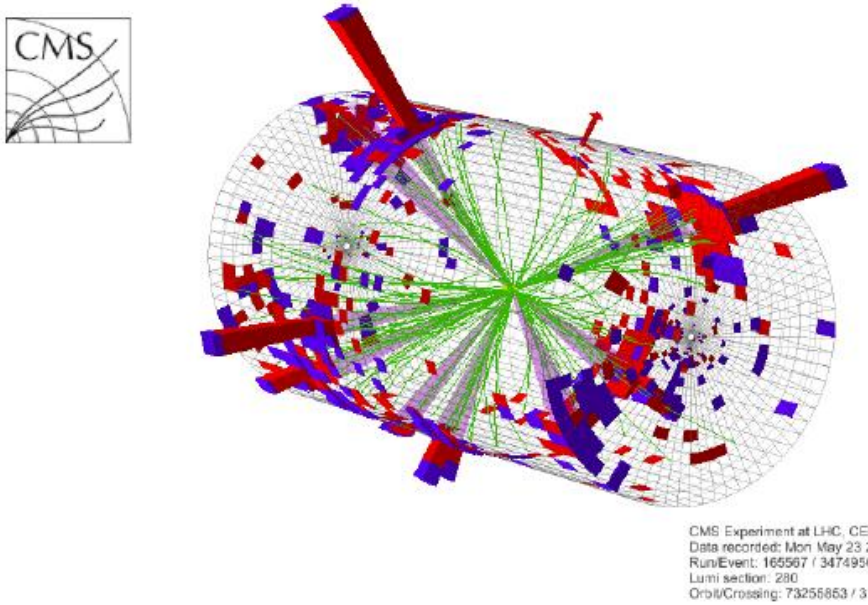
n	k-factor	Exp. Limit [TeV]	Obs. Limit, [TeV]
2	-	1.17	1.03
3	-	1.20	1.07
4	-	1.24	1.12
5	-	1.27	1.16
6	-	1.31	1.21
2	2.0	1.45	1.31
3	1.7	1.38	1.25
4	1.5	1.36	1.26
5	1.4	1.37	1.26
6	1.3	1.38	1.29

EXO-11-058

Black Holes

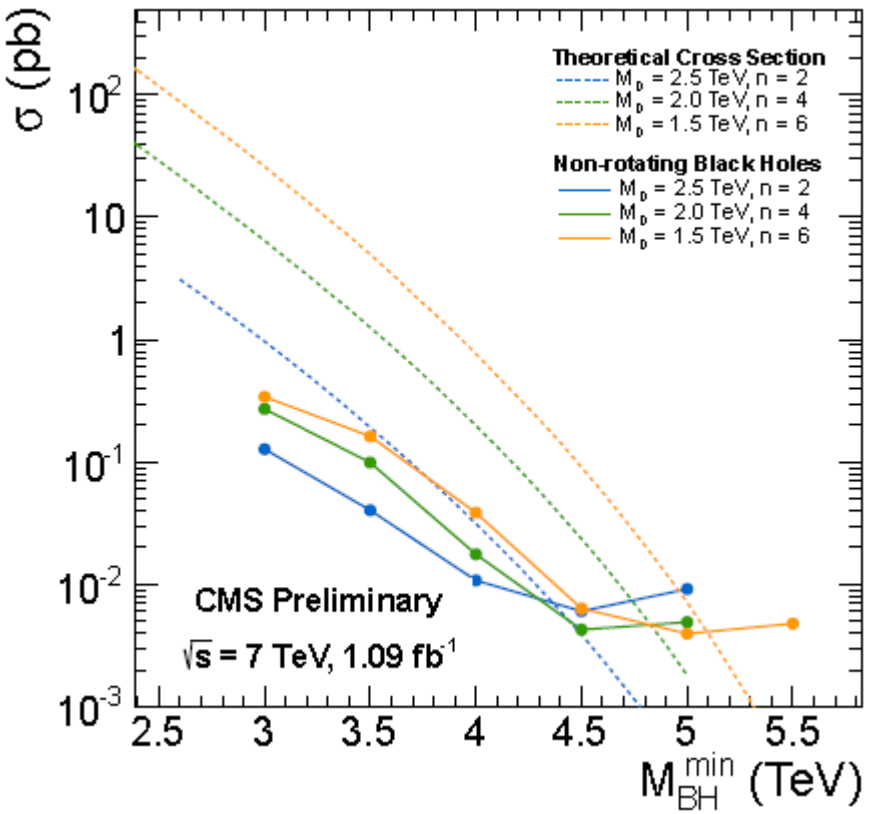


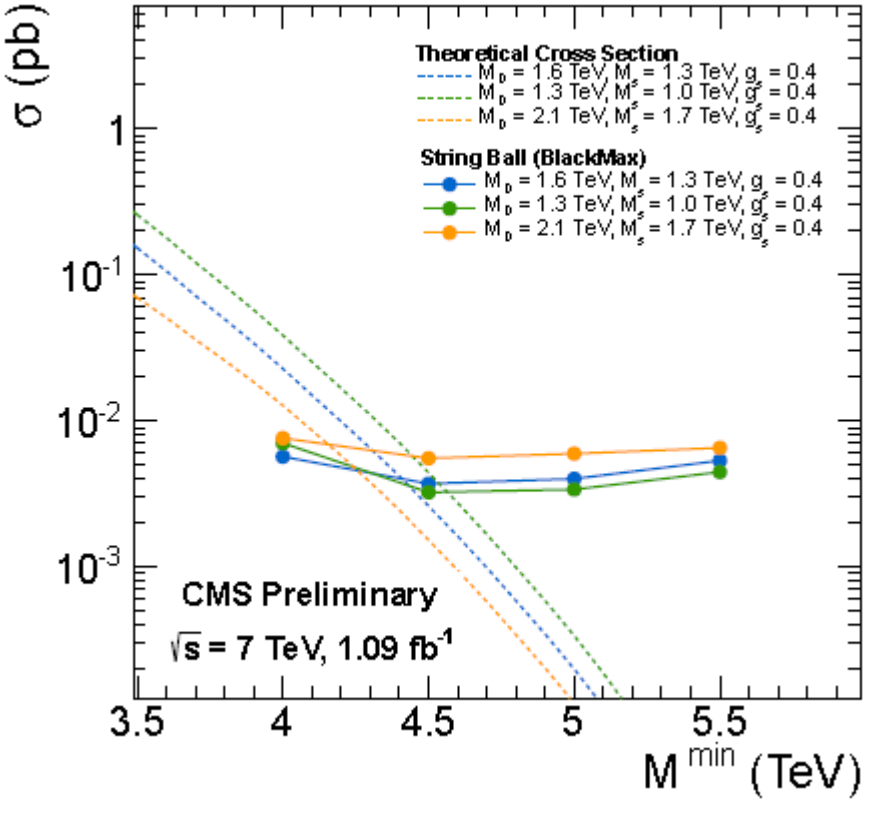
$$N = 10, S_T = 1.1 \text{ TeV}$$



$$N = 9, S_T = 2.5 \text{ TeV}$$

Limits on Black Holes





Black Holes: 4 – 5 TeV

String balls: 4.1 – 4.5 TeV

EXO-11-071

Exclusions limits on ADD (4-5 TeV)
and string ball (4.1-4.5) models

Fourth Generation

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)
- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ
- More extra dimensions:
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- Fourth generation
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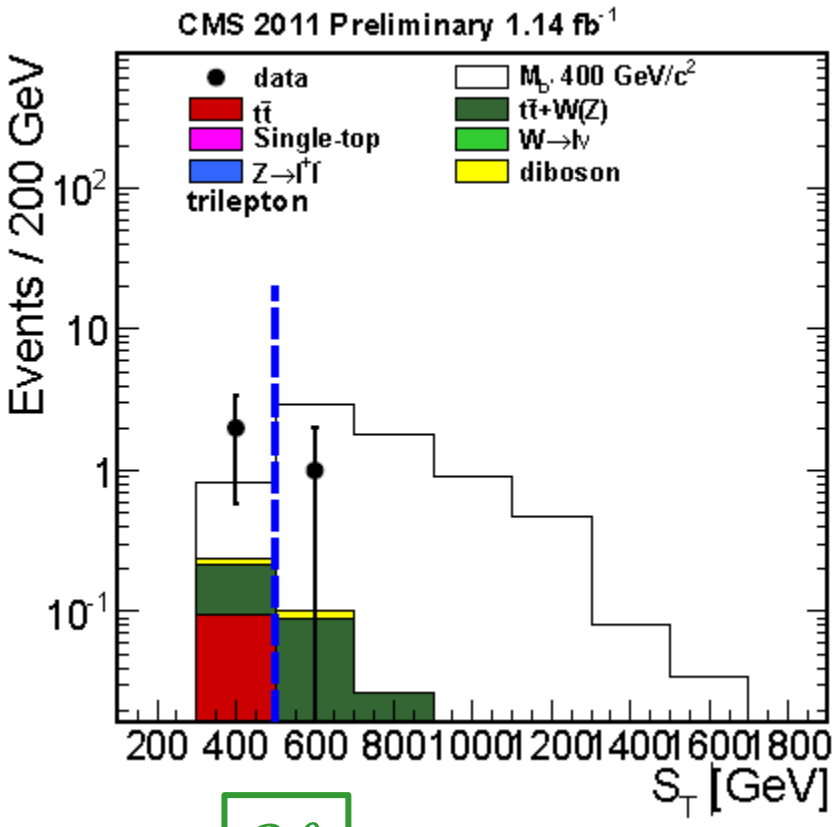
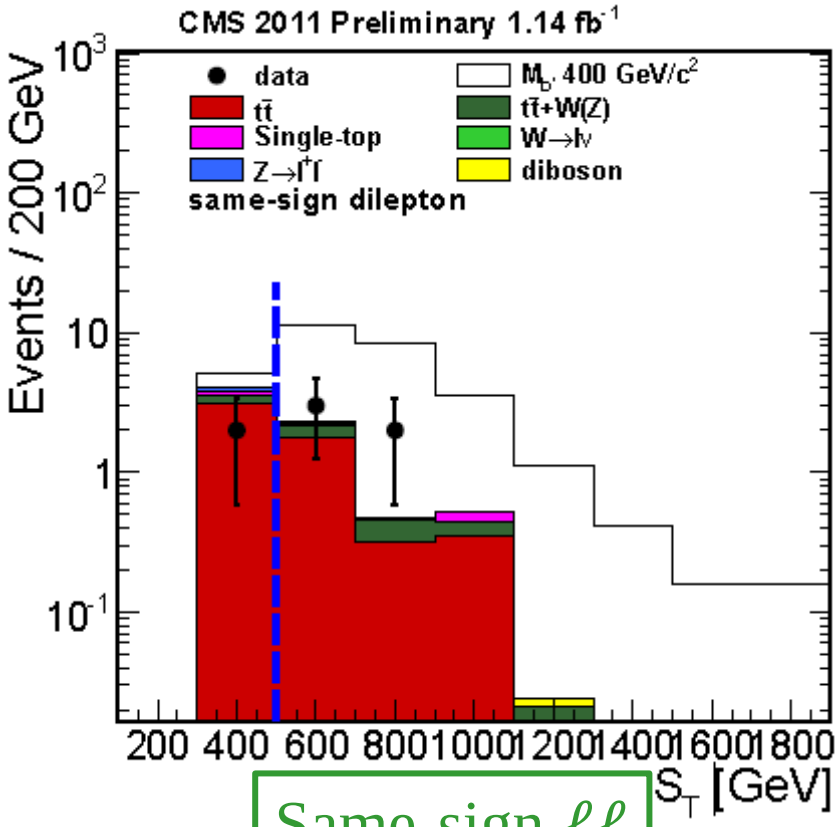
Heavy new bottom-like quark





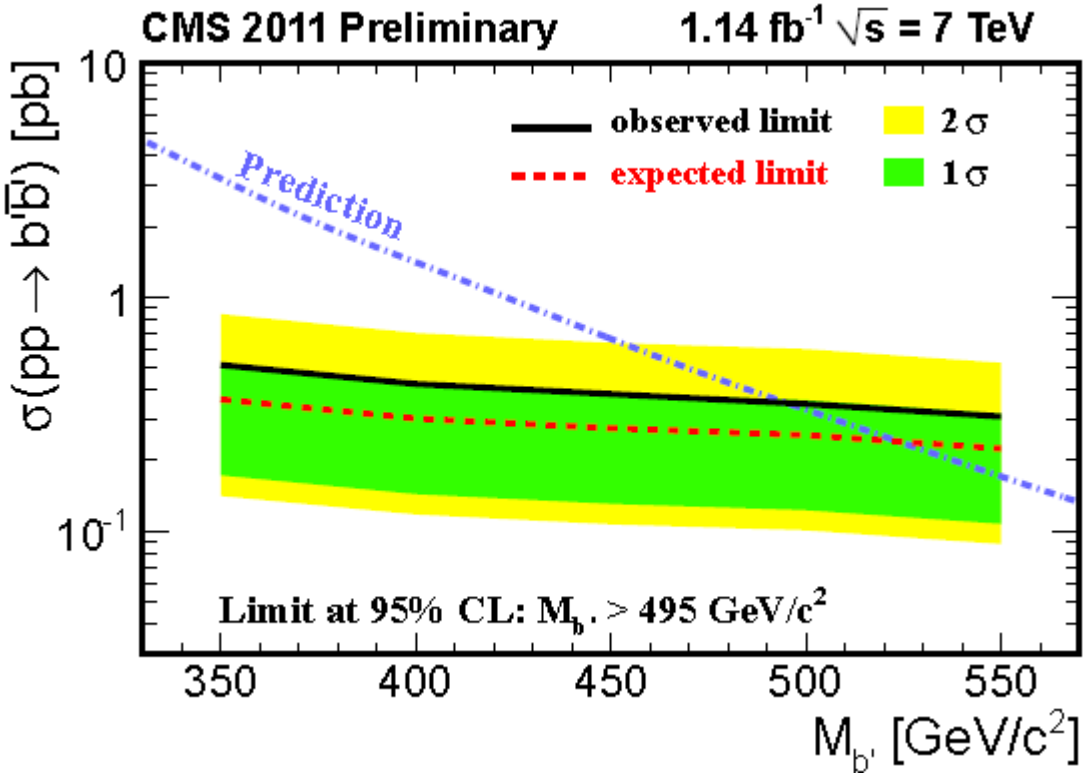
3ℓ

Same-sign $\ell\ell$

$$\sum p_T(\text{jets}) + \sum p_T(\text{leptons}) + \not{E}_T$$

$$b'\bar{b}' \to tW^-\bar{t}W^+ \to bW^+W^-\bar{b}W^-\bar{W}^+$$

Heavy new bottom-like quark



$M_{b\prime}$: 495 GeV **EXO-11-036**

Significant improvement over 2010 result
(361 → 495 GeV)

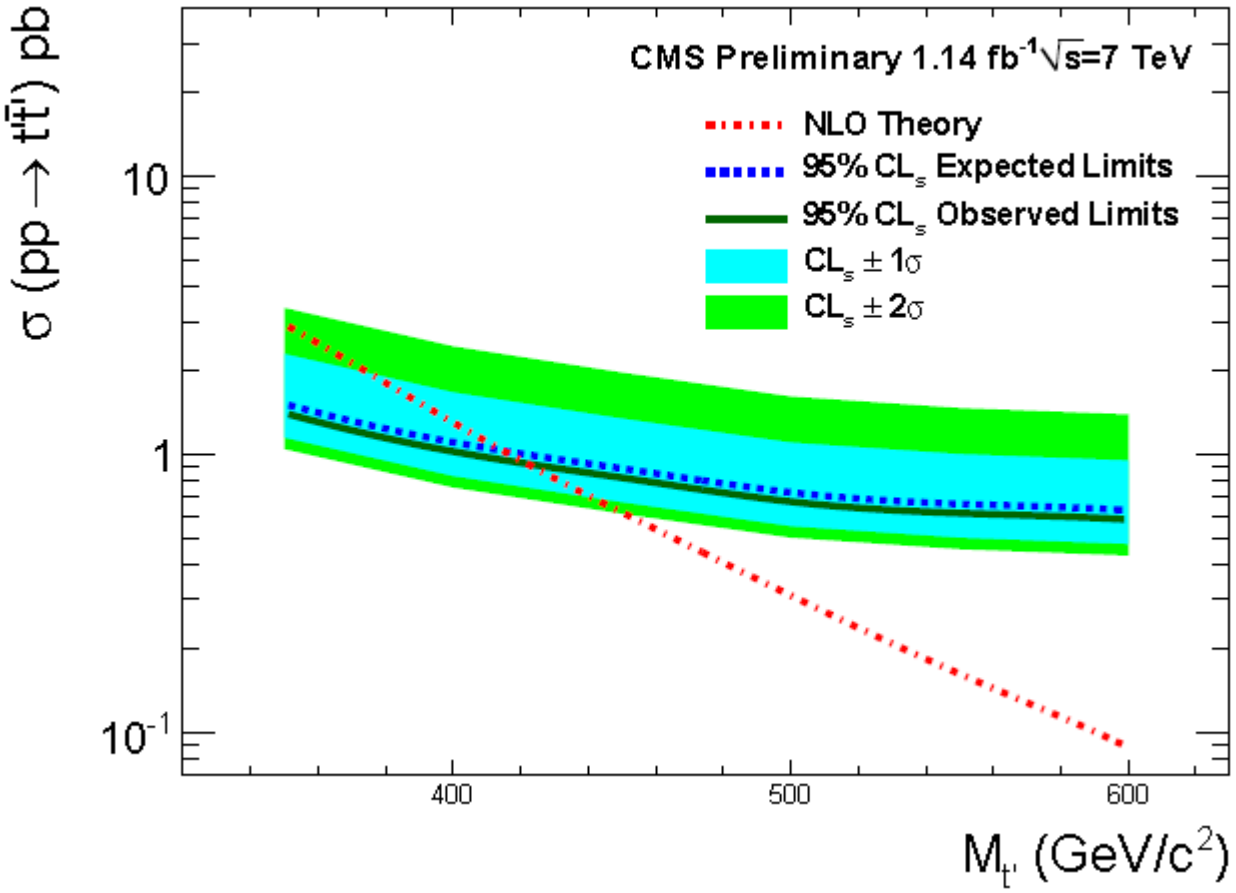
Heavy new top-like quark

- Two analyses assuming heavy top decays exclusively to *b*-quark and a *W*
  - Full leptonic
  - Lepton + jets

- Third analysis assuming heavy top decays to (SM) top and a *Z*

Heavy new top-like quark #1

$$t'\bar{t}' \rightarrow bW^+\bar{b}W^- \rightarrow b\bar{\ell}^+\nu\,\bar{b}\ell^-\bar{\nu}$$

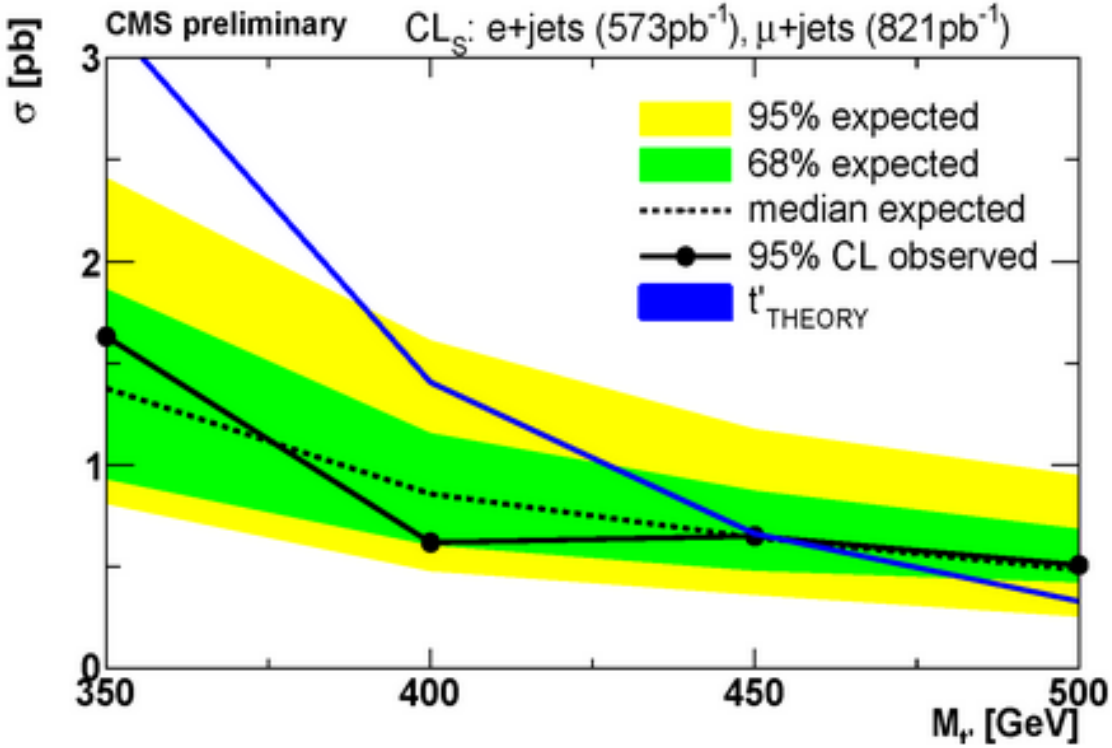


$M_{t\prime}$: 422 GeV

EXO-11-050

Heavy new top-like quark #2

$$t'\bar{t}' \rightarrow WbW\bar{b} \rightarrow \ell\nu bq\bar{q}\bar{b}$$

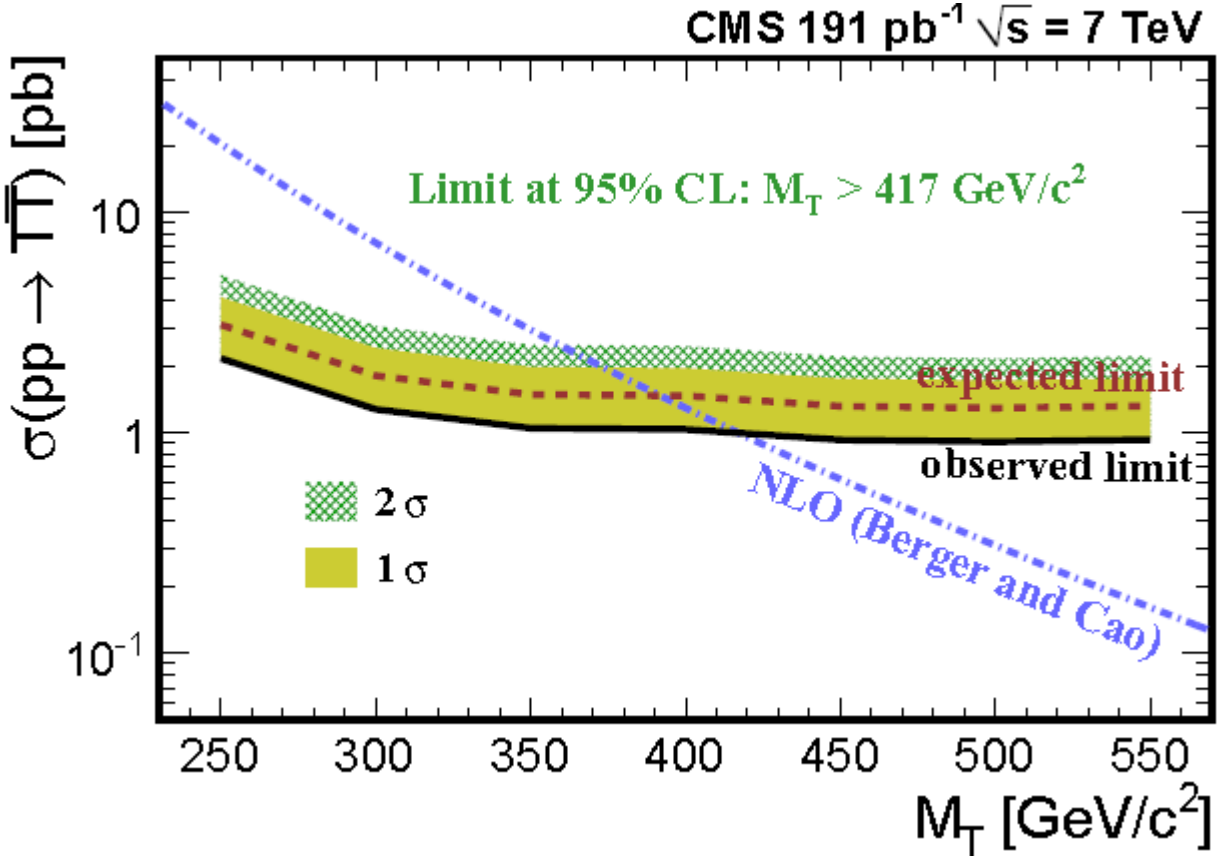


$M_{t\prime}$: 450 GeV

EXO-11-051

Heavy new top-like quark #3

$T \rightarrow tZ$



$M_{t\prime}$: 417 GeV

EXO-11-005

Weird Things

CMS: 20 New Results

- Z' (and extra dimensions)
  - dijet, $ee, \mu\mu, \gamma\gamma, t\bar{t}, t\bar{t}$ (boosted)
- W'
  - $e + \nu, \mu + \nu, qq', \ell N_\ell$ (aka: right-handed W), WZ
- More extra dimensions:
  - mono-jet, mono-photon, black holes
- Fourth generation
  - Heavy bottom-like and top-like quarks
- "Weird" stuff: stopped (or slow) HSCP

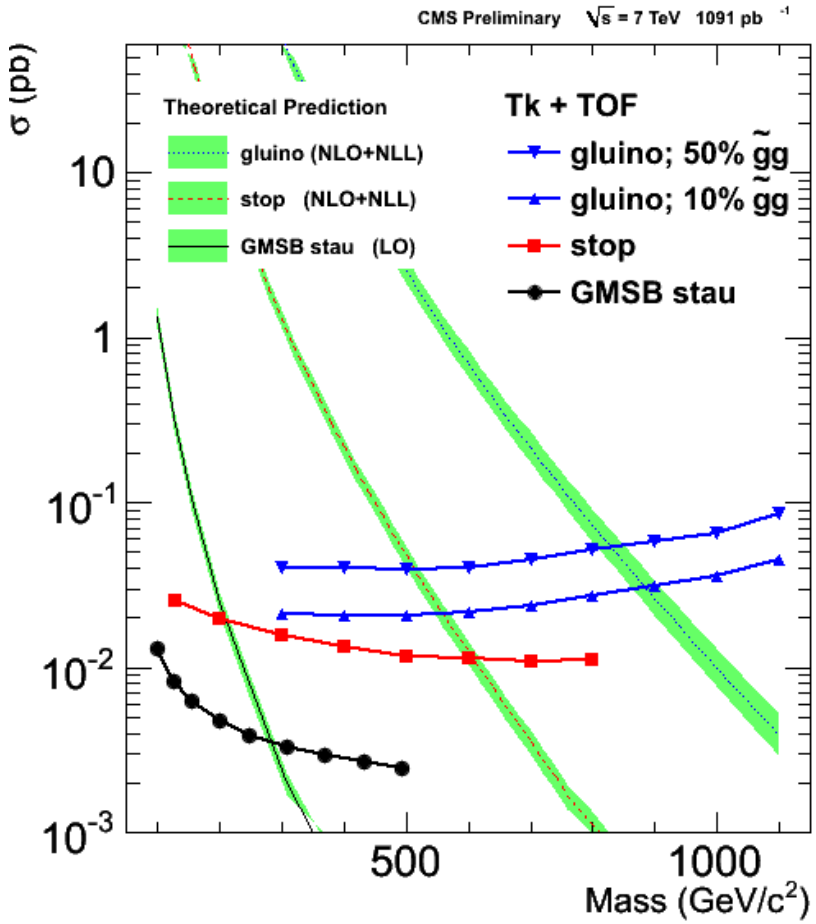
Long-lived particles

Experimental considerations

- Massive charged long-lived particles leaving highly ionizing tracks in the tracker (and muon): identified by dE/dx
- Long-lived, strongly interacting, slow ($\beta<0.4$) particles stopping in the detector and decaying out-of-time
  - Complicated LHC beam structure with gaps sequence allows for a large coverage of particles lifetimes
  - Identified as jets

Complementary analyses: jet-analyses sensitive to slow particles, dE/dx search needs higher β

Heavy Stable Charged Particles

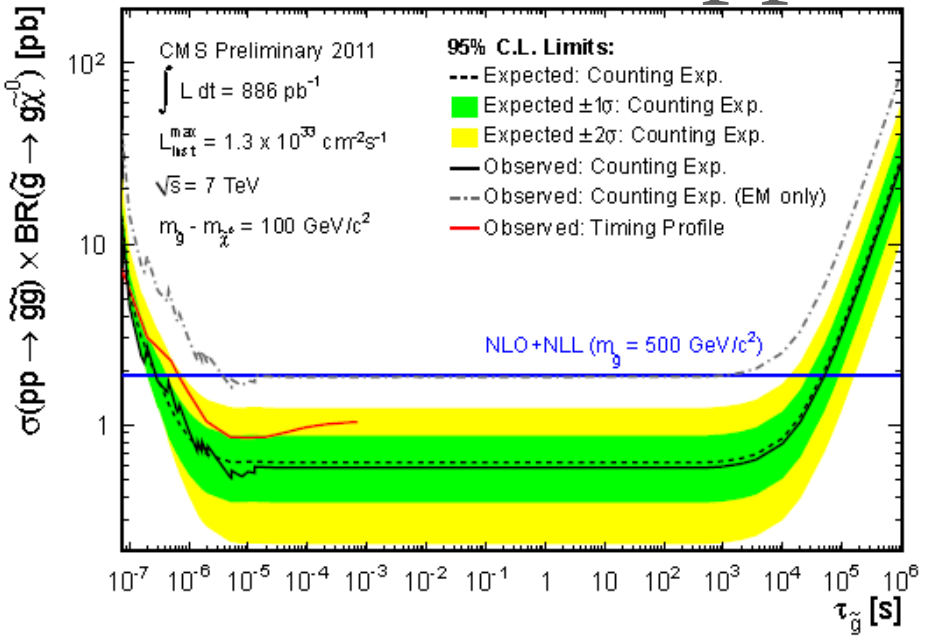


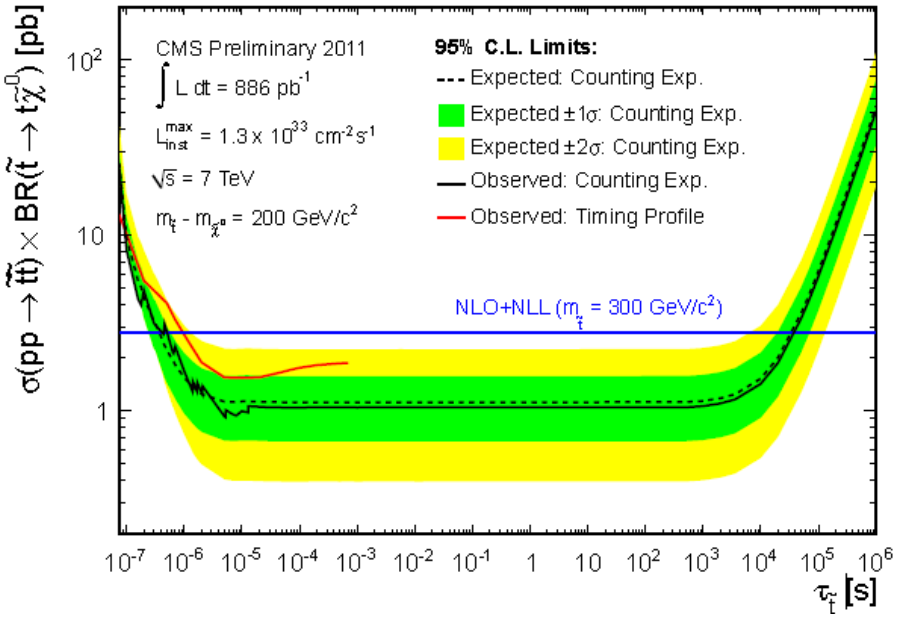
EXO-11-022

gluino: 899 GeV
stop: 620 GeV
stau: 293 GeV

"dE/dx" analysis: exclusion limits on gluinos, stops and staus

Stopped HSCPs



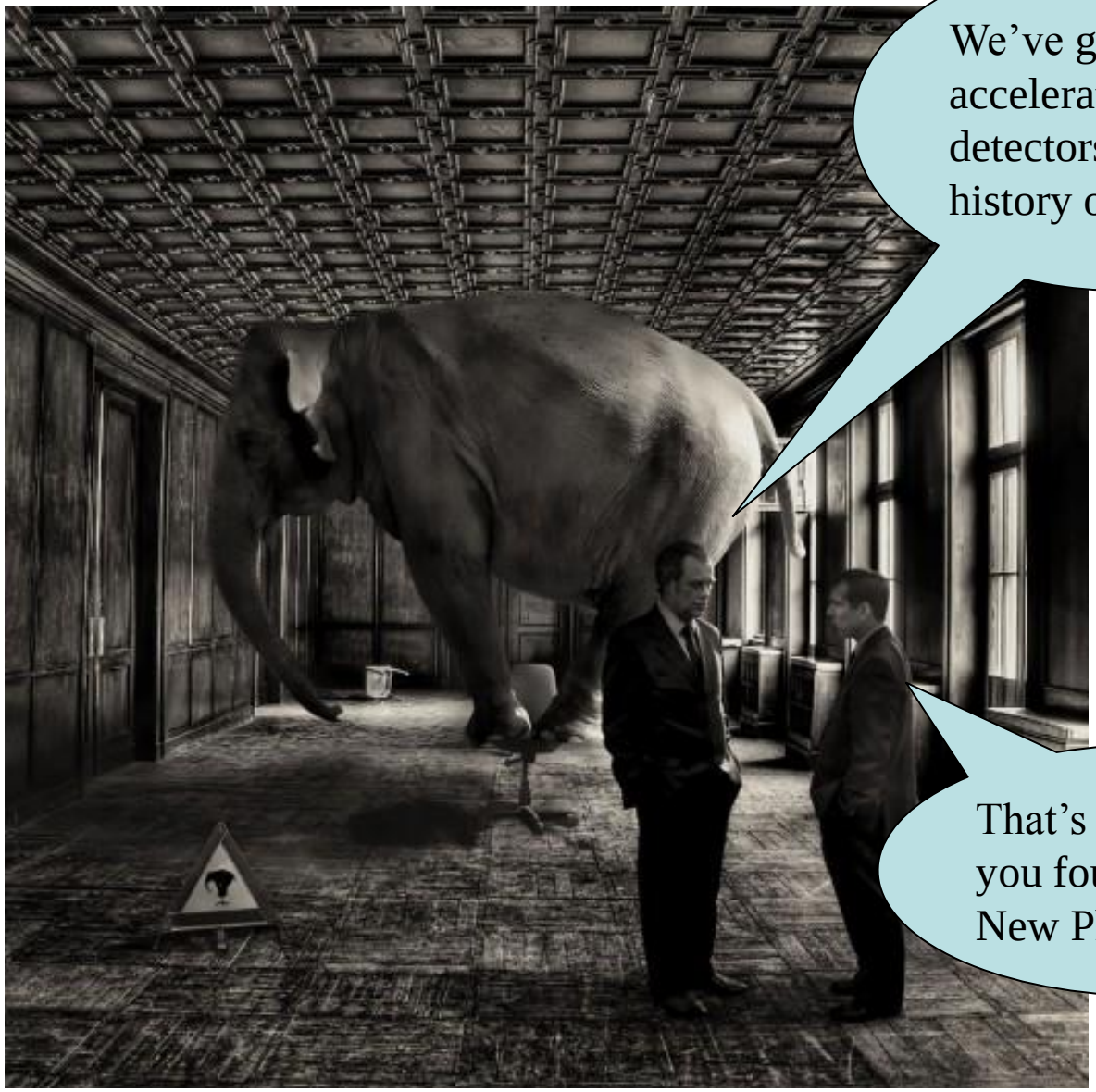


Designed and commissioned special trigger requiring a jet in coincidence with empty beam bunches

gluino: 601 GeV
stop: 337 GeV
Lifetimes: 10 orders of magnitude

EXO-11-020

“No New Physics (yet)”


We've got the best accelerator & detectors in the history of HEP!
That's great. Have you found any New Physics yet?

Where do we go from here

- "Good things come to those who wait"
- "New Physics is too heavy for $\sqrt{s}$ = 7 TeV"
- "Are we looking in the right place?"

“Good things come to those who wait”

- 2011: Very busy and successful year so far
  - Detector, trigger, computing, offline performance: simply outstanding

- These first results are a small demonstration of the potential of the LHC experiments (and the huge preparatory work)

- A large number of channels under scrutiny. IF any of these contains New Physics, we will discover it.

"New Physics is too heavy for $\sqrt{s}$=7 TeV"

- Higher collision energy in 2012?

- If New Physics is (simply) heavier, yes: this is the way to go

- Collision energy: single most important factor for new heavy particles

"New Physics is too heavy for $\sqrt{s}$=7 TeV"

8-to-7 TeV: "Parton luminosity ratios"

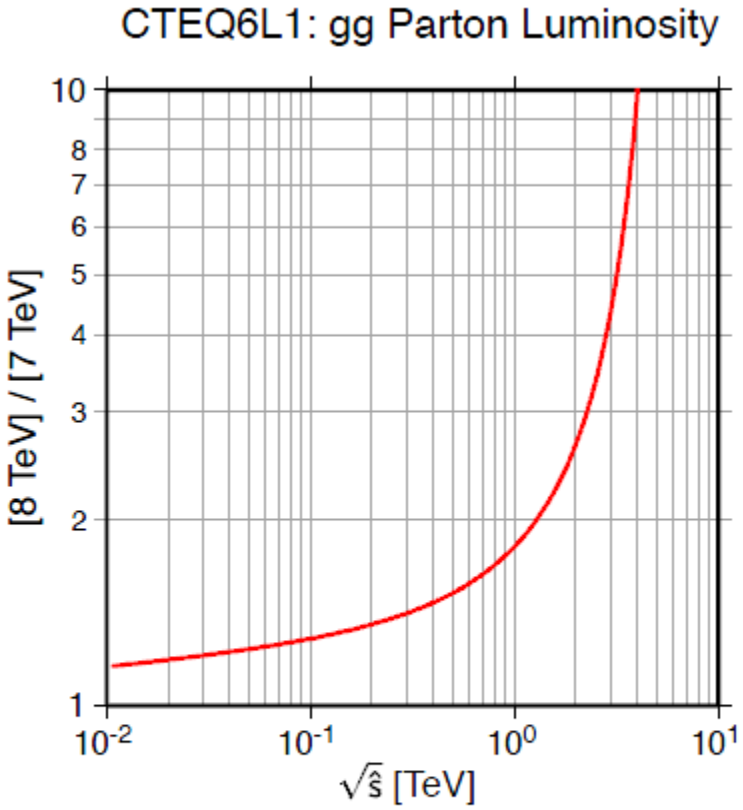


Figure 8: Ratio of parton luminosity for gg interactions in pp collisions at $\sqrt{s} = 8$ TeV to luminosity at 7 TeV (logarithmic scale).

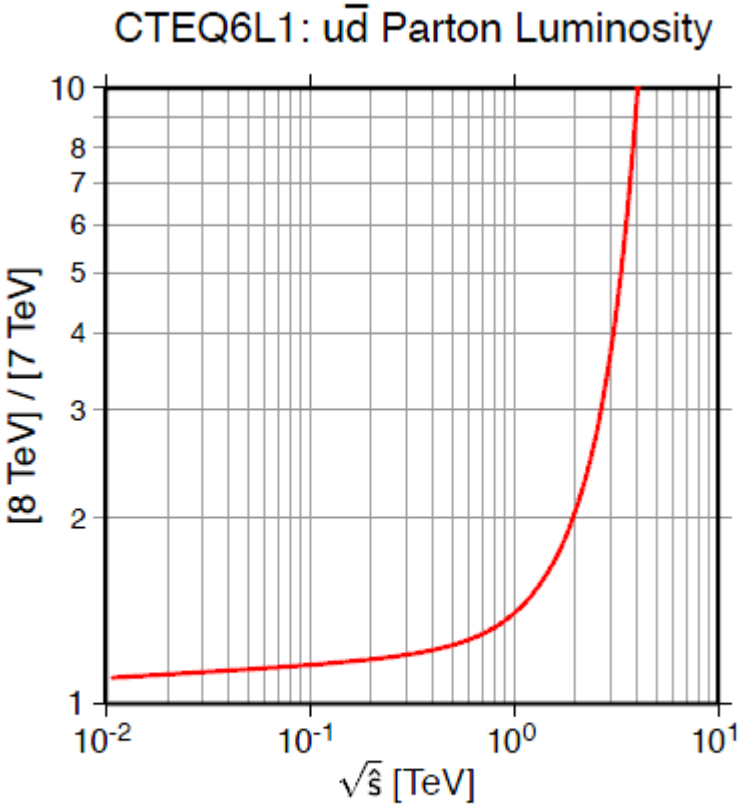


Figure 12: Ratio of parton luminosity for $u\bar{d}$ interactions in pp collisions at $\sqrt{s} = 8$ TeV to luminosity at 7 TeV (logarithmic scale).

Chris Quigg*

arXiv:1101.3201v1 [hep-ph] 17 Jan 2011

"Are we looking in the right place?"

- Adequate coverage of "unusual topologies"?
  - e.g. "hidden valleys" type of physics
- Stopped particles: highlights crucial role of trigger
- If New Physics is contained in collected datasets, there is nowhere to hide. But remember:
  - Only 0.001% of all LHC bunch crossings are recorded
  - The trigger has no "undo" button.

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- If we are neglecting to search in your favorite channel: please let us know
- If we are neglecting to *trigger* on your favorite channel: check with your nearest experimentalist asap.

Summary

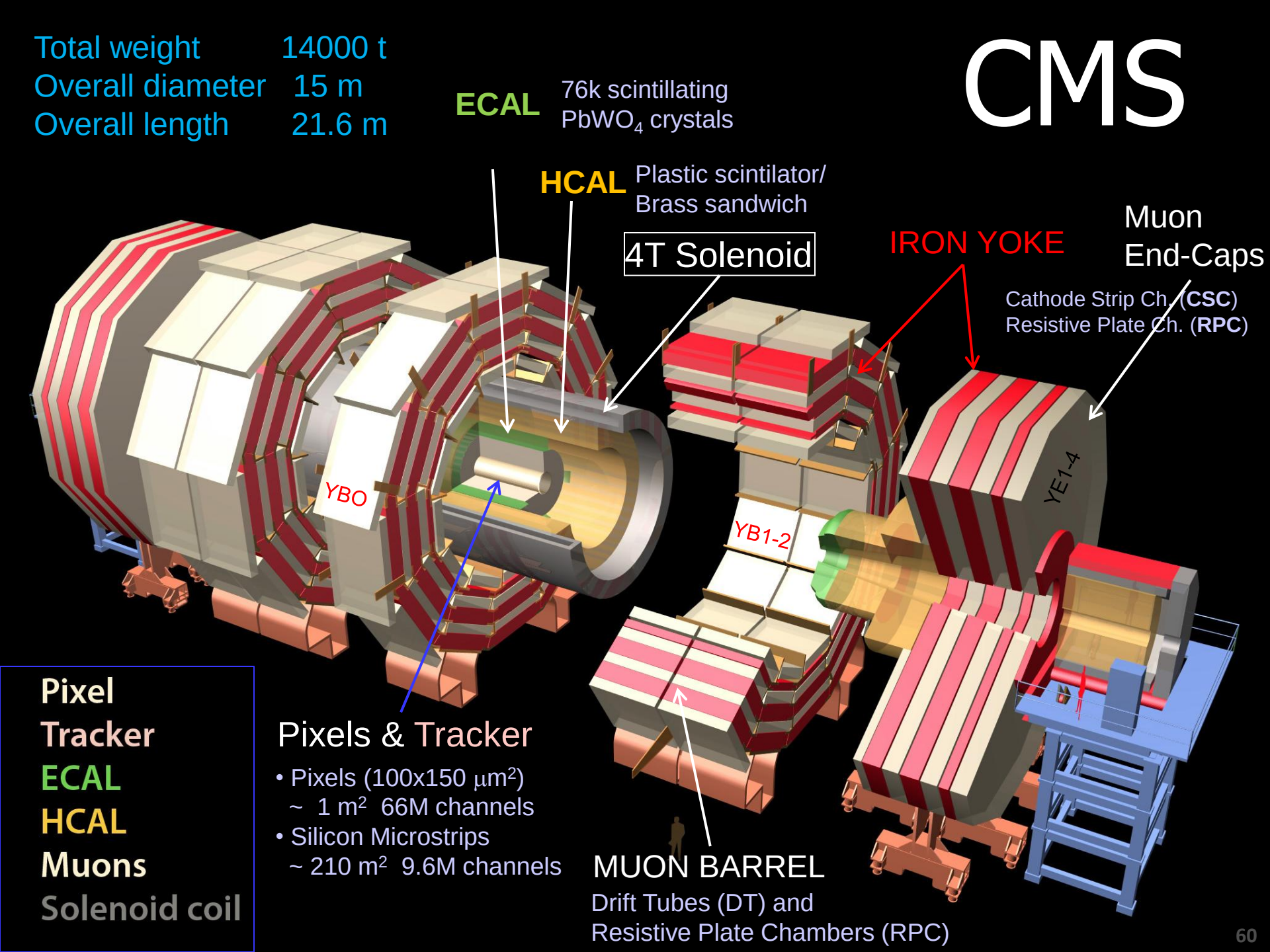
Epilogue

• CMS has made public 20 new results from the analysis of the 2011 data. Excellent detector performance & advanced analysis techniques: very promising for ongoing/future searches

• We are operating state-of-the-art detectors at the most powerful collider in the world. If New Physics is hidden in (very) larger number of channels presented in this workshop, we will get to it (sooner or later).

• We should not forget: 99.999% of all LHC bunch crossings never get a chance to show up in your favorite analysis. Let's make sure New Physics is in the remaining 0.001%.

Backup


Total weight 14000 t
Overall diameter 15 m
Overall length 21.6 m
ECAL
76k scintillating
PbWO4 crystals
CMS
HCAL
Plastic scintilator/
Brass sandwich
4T Solenoid
IRON YOKE
Muon
End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2)
~ 1 m2 66M channels
• Silicon Microstrips
~ 210 m2 9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)