In Search of New Physics
or
Why We Need to Talk More!

Harrison B. Prosper

Florida State University

WHEPP XIV, IIT Kanpur, India

10 December, 2015

Outline

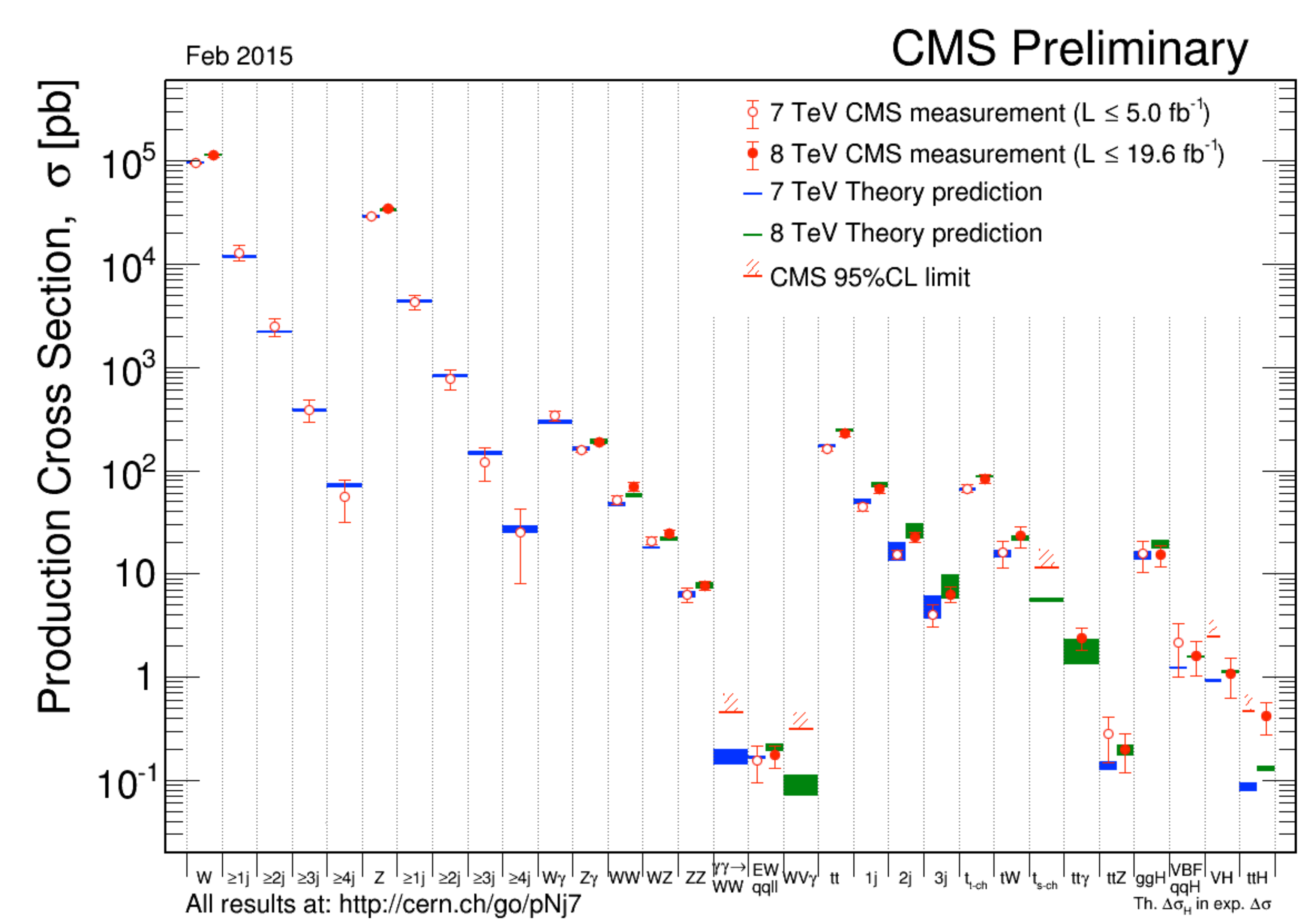
* Introduction
* LHC Run I – A Random Stroll
* LHC Run II – Early Results
* Opportunities and Challenges
* Final Remarks

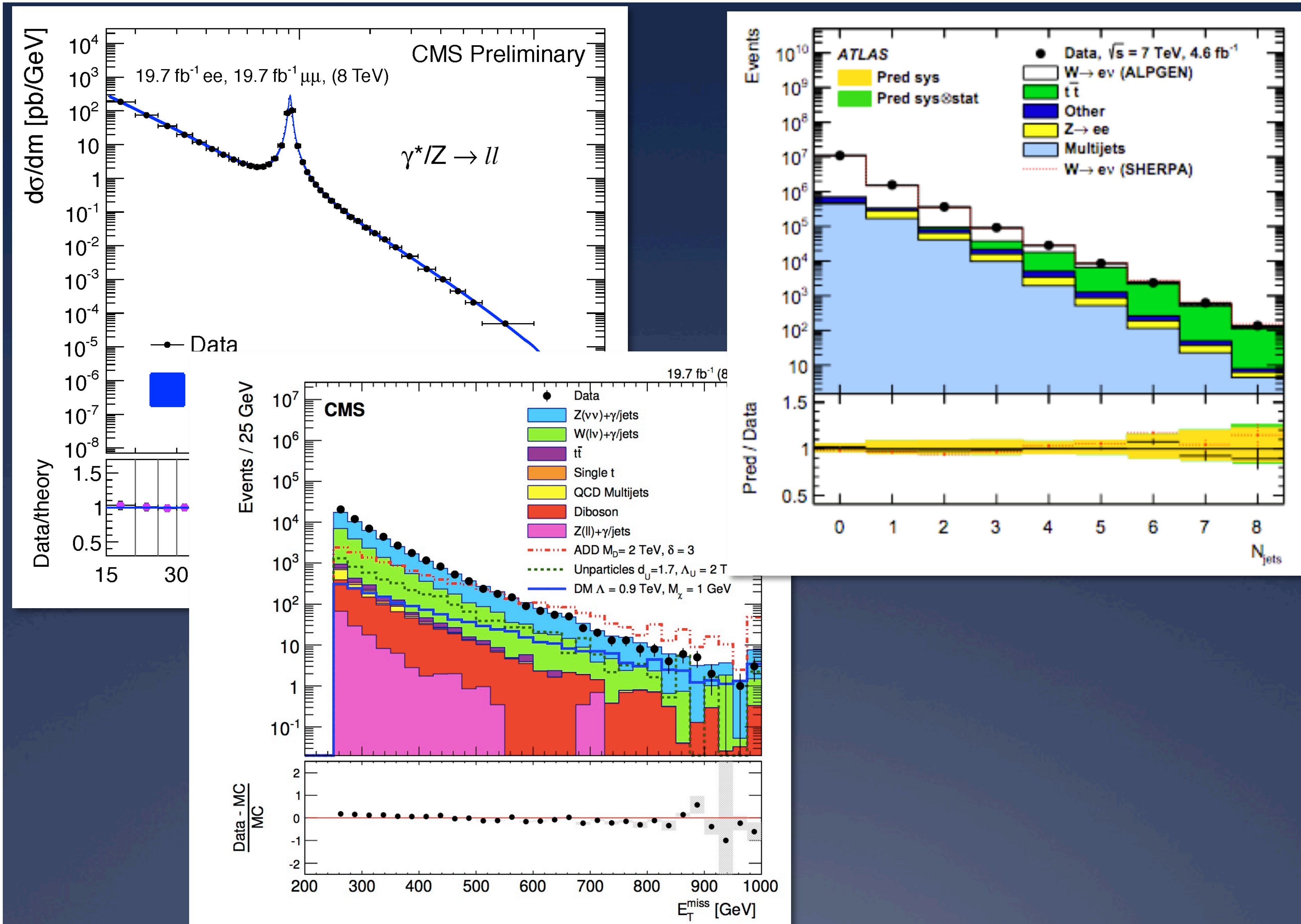
Outline

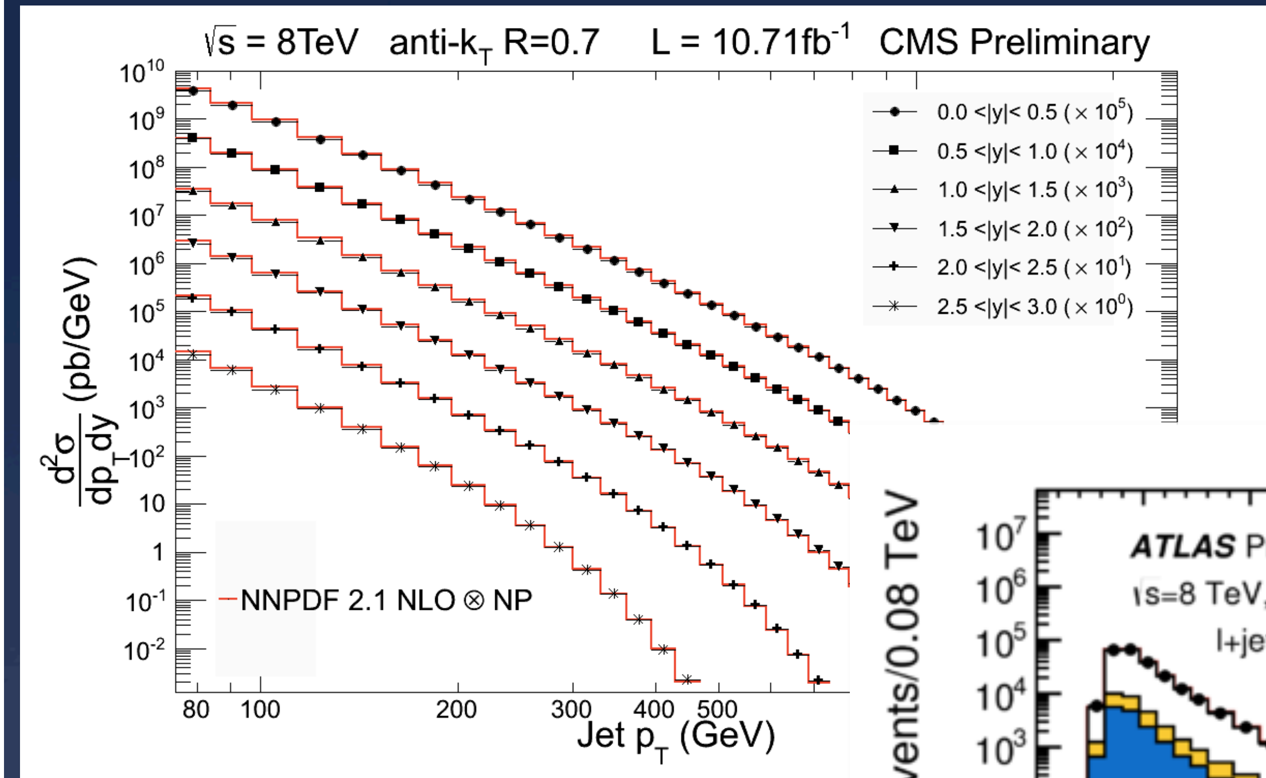
* **Introduction**
* LHC Run I – A Random Stroll
* LHC Run II – Early Results
* Opportunities and Challenges

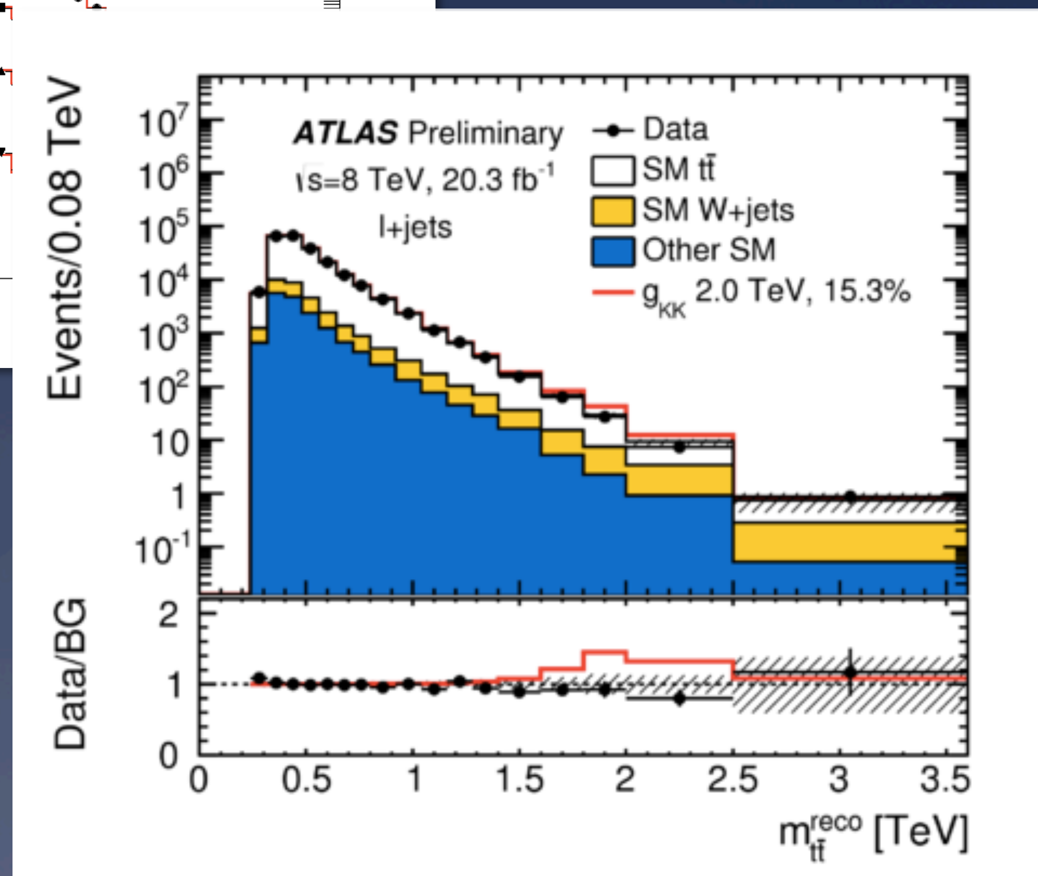
Introduction

- The discovery of the Higgs boson at the LHC was a remarkable achievement.
- But, equally remarkable is the astonishing reaffirmation of the predictive power of the Standard Model.
- The disappointing corollary is the complete absence of <u>compelling</u> evidence of new physics at the LHC, so far.
- Nevertheless, there is still hope that we shall not be disappointed by the end of Run II.
- But, we could still be unlucky: finding no obvious resonances, but just a set of subtle spectral deviations.


CMS Preliminary
Feb 2015
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
7 TeV Theory prediction
8 TeV Theory prediction
CMS 95%CL limit
W ≥1j ≥2j ≥3j ≥4j Z ≥1j ≥2j ≥3j ≥4j Wγ Zγ WW WZ ZZ γγ→WW EW qqll WVγ tt 1j 2j 3j t-ch tW s-ch ttγ ttZ ggH VBF qqH VH ttH
Th. ΔσH in exp. Δσ
All results at: http://cern.ch/go/pNj7


CMS Preliminary
19.7 fb^{-1} ee, 19.7 fb^{-1} μμ, (8 TeV)
$\gamma^*/Z \to ll$
dσ/dm [pb/GeV]
Data
Data/theory
ATLAS
Data, $\sqrt{s}$ = 7 TeV, 4.6 fb^{-1}
Pred sys
Pred sys⊗stat
W→ eν (ALPGEN)
t t̄
Other
Z→ ee
Multijets
W→ eν (SHERPA)
Events
Pred / Data
N_{jets}
CMS
19.7 fb^{-1} (8
Data
Z(νν)+γ/jets
W(lν)+γ/jets
tt̄
Single t
QCD Multijets
Diboson
Z(ll)+γ/jets
ADD M_D= 2 TeV, δ = 3
Unparticles d_U=1.7, Λ_U = 2 T
DM Λ = 0.9 TeV, M_χ = 1 GeV
Events / 25 GeV
Data - MC / MC
E_T^{miss} [GeV]


√s = 8TeV anti-k$_T$ R=0.7 L = 10.71fb^{-1} CMS Preliminary
0.0 <|y|< 0.5 (× 10^5)
0.5 <|y|< 1.0 (× 10^4)
1.0 <|y|< 1.5 (× 10^3)
1.5 <|y|< 2.0 (× 10^2)
2.0 <|y|< 2.5 (× 10^1)
2.5 <|y|< 3.0 (× 10^0)
NNPDF 2.1 NLO ⊗ NP
$\frac{d^2\sigma}{dp_T dy}$ (pb/GeV)
Jet p$_T$ (GeV)


ATLAS Preliminary
√s=8 TeV, 20.3 fb^{-1}
l+jets
Data
SM $t\bar{t}$
SM W+jets
Other SM
g$_{KK}$ 2.0 TeV, 15.3%
Events/0.08 TeV
Data/BG
$m_{t\bar{t}}^{reco}$ [TeV]

Introduction

- Ordinarily, the remarkable level of agreement between observations and predictions should be cause for celebration.
- But, that is not what we were hoping for in 2008!
- Run II, however, has only just started, and hope remains a rational stance.
- The fact that WHEPP is still going strong (XIV) suggests that many of you agree.

Outline

* Introduction
* **LHC Run I – A Random Stroll**
* LHC Run II – Early Results
* The LHC and Beyond – Opportunities and Challenges

LHC Run I – A Random Stroll

Let "N" Thousand Flowers Bloom!

$$N \rightarrow \chi_0$$

Compositeness

Large extra dimensions

Heavy neutrinos

Di-boson resonances

Di-jet resonances

Braneworlds

Microscopic black holes

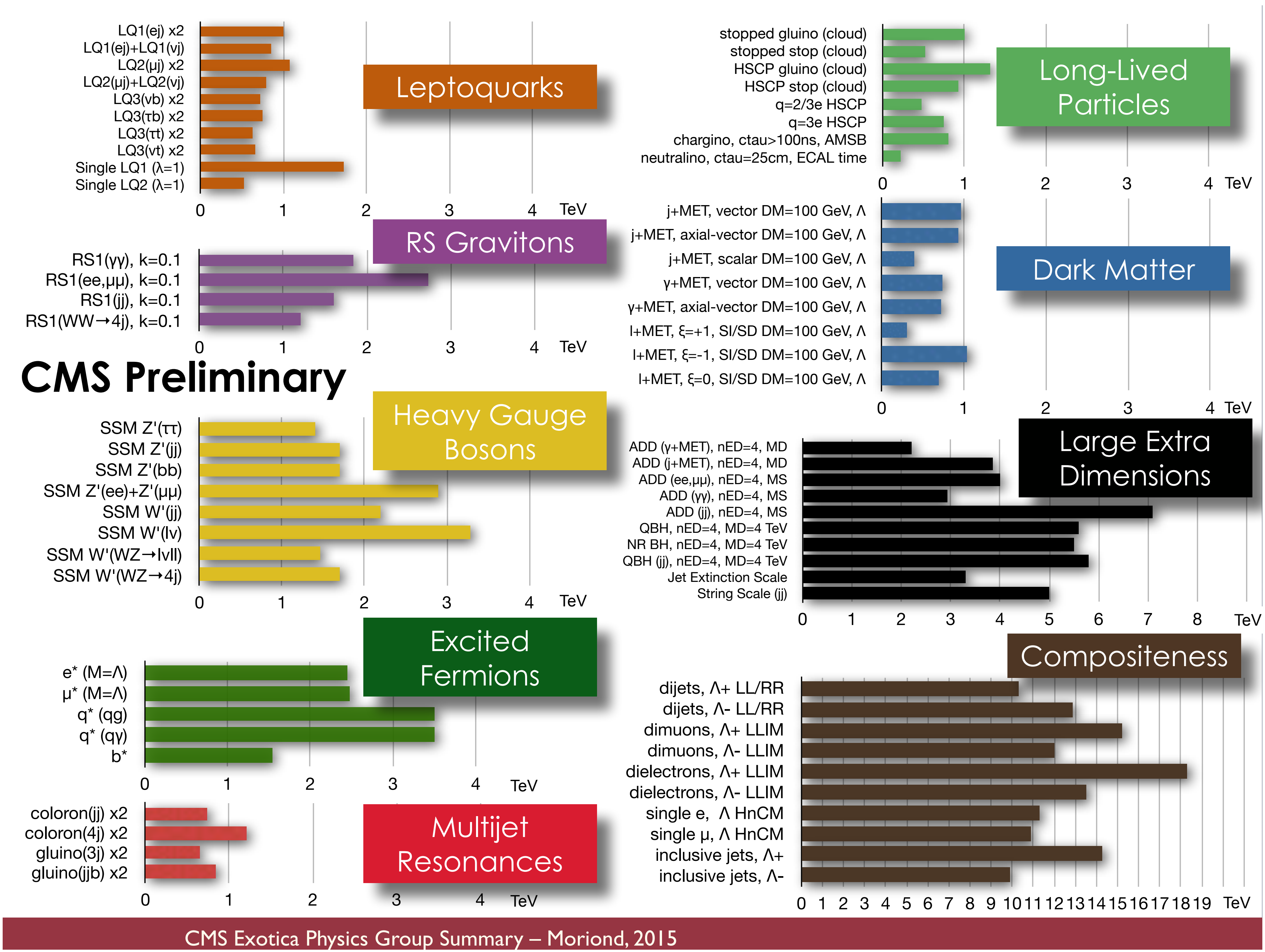
Supersymmetry

Leptoquarks

Walking, crawling, semi-comatose Technicolor

Strings

Excited fermions



CMS Preliminary
Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(νj)
LQ2(μj) x2
LQ2(μj)+LQ2(νj)
LQ3(νb) x2
LQ3(τb) x2
LQ3(τt) x2
LQ3(νt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
0 1 2 3 4 TeV
RS Gravitons
RS1(γγ), k=0.1
RS1(ee,μμ), k=0.1
RS1(jj), k=0.1
RS1(WW→4j), k=0.1
0 1 2 3 4 TeV
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(bb)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lν)
SSM W'(WZ→lνll)
SSM W'(WZ→4j)
0 1 2 3 4 TeV
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ)
b*
0 1 2 3 4 TeV
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
0 1 2 3 4 TeV
Long-Lived Particles
stopped gluino (cloud)
stopped stop (cloud)
HSCP gluino (cloud)
HSCP stop (cloud)
q=2/3e HSCP
q=3e HSCP
chargino, ctau>100ns, AMSB
neutralino, ctau=25cm, ECAL time
0 1 2 3 4 TeV
Dark Matter
j+MET, vector DM=100 GeV, Λ
j+MET, axial-vector DM=100 GeV, Λ
j+MET, scalar DM=100 GeV, Λ
γ+MET, vector DM=100 GeV, Λ
γ+MET, axial-vector DM=100 GeV, Λ
l+MET, ξ=+1, SI/SD DM=100 GeV, Λ
l+MET, ξ=-1, SI/SD DM=100 GeV, Λ
l+MET, ξ=0, SI/SD DM=100 GeV, Λ
0 1 2 3 4 TeV
Large Extra Dimensions
ADD (γ+MET), nED=4, MD
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
ADD (jj), nED=4, MS
QBH, nED=4, MD=4 TeV
NR BH, nED=4, MD=4 TeV
QBH (jj), nED=4, MD=4 TeV
Jet Extinction Scale
String Scale (jj)
0 1 2 3 4 5 6 7 8 TeV
Compositeness
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dielectrons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 TeV
CMS Exotica Physics Group Summary – Moriond, 2015

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

$\sqrt{s}$ = 7 TeV | $\sqrt{s}$ = 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$ 100-440 GeV	$m(\tilde{q})$-$m(\tilde{\chi}_1^0)$<10 GeV	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 780 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0-1 e,μ	2-6 jets	Yes	20	$\tilde{g}$ 1.26 TeV	$m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1507.05525
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	$\tan\beta$ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 110-167 GeV, 230-460 GeV	$m(\tilde{\chi}_1^\pm)$ = 2$m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-191 GeV, 210-700 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 250 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 124-361 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$ 482 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	2<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to q\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 870 GeV	$m(\tilde{\chi}_1^0)$=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

10^{-1} — 1 — **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Searching for Resonances

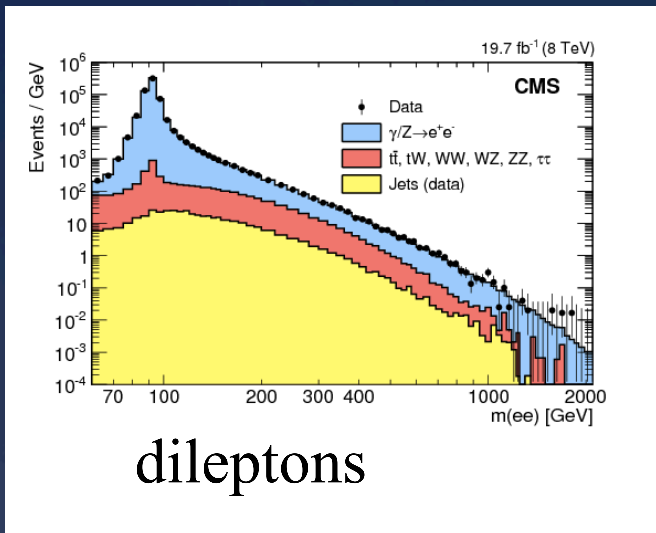
Resonances, such as

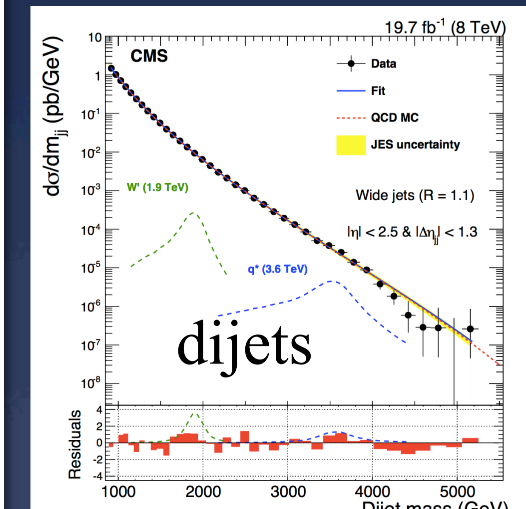
* excited quarks
* W and Z primes
* Randall-Sundrum gravitons
* Axigluons,

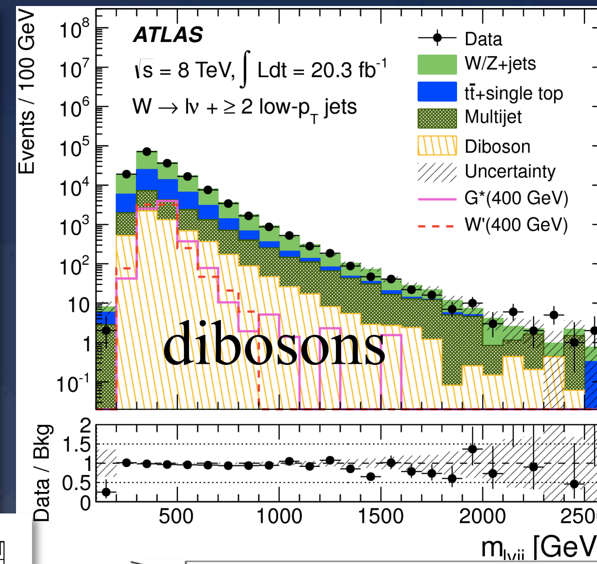
to name but a few, are a generic prediction of many models of beyond the SM physics.

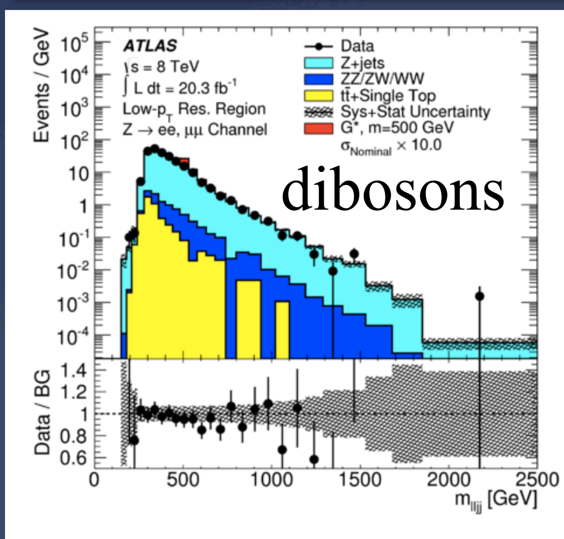
A systematic search for resonances should be a priority.

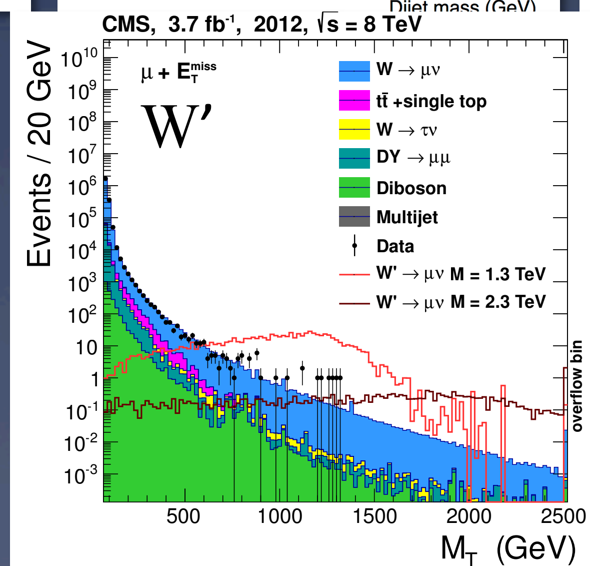
Searching for Resonances

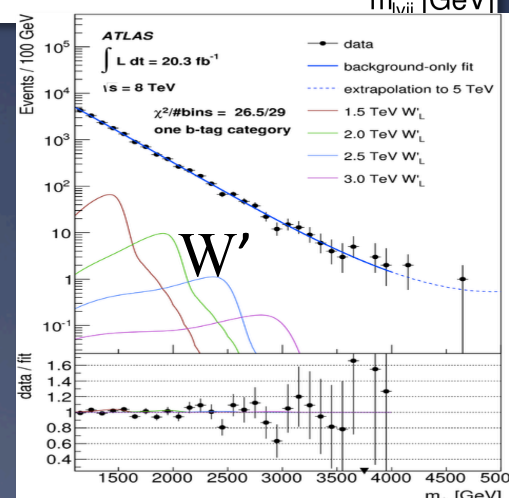












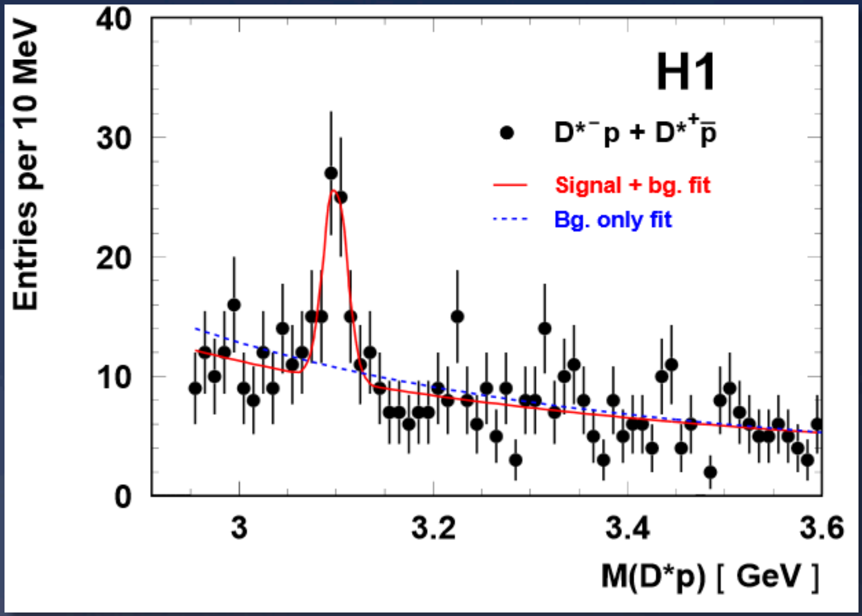
A (Cautionary) Tale of Resonances

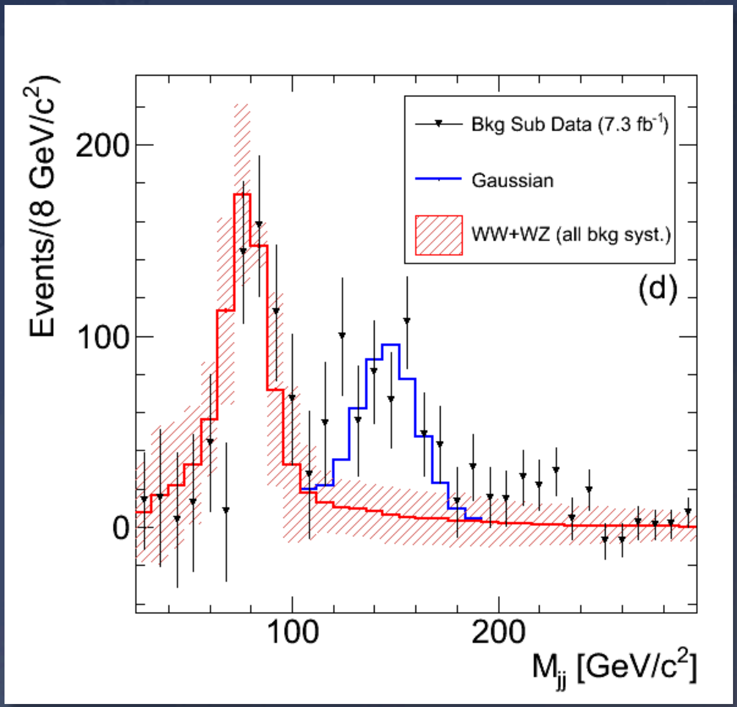
- Today, no discovery in our field is more convincing than observing a peak, especially if narrow, on top of a smooth monotonic background.

- But, we should tread carefully…

Resonances That Aren't!

H1 6σ pentaquarks
hep-ex/0403017

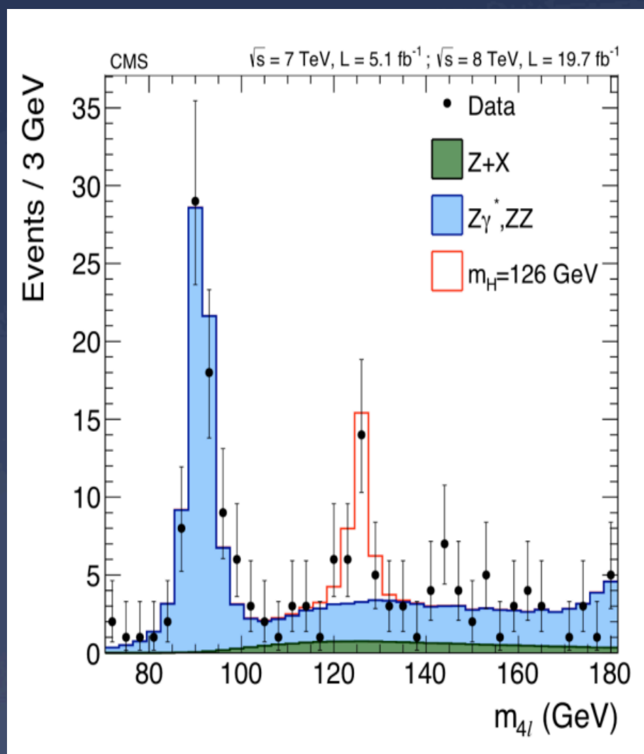


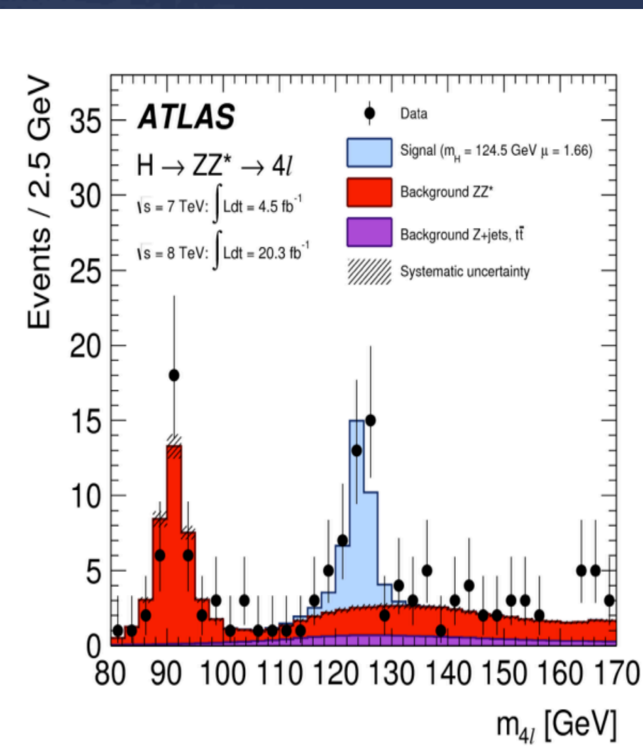


CDF 4σ dijet bump
http://arxiv.org/abs/1104.0699

And Resonances That Are!

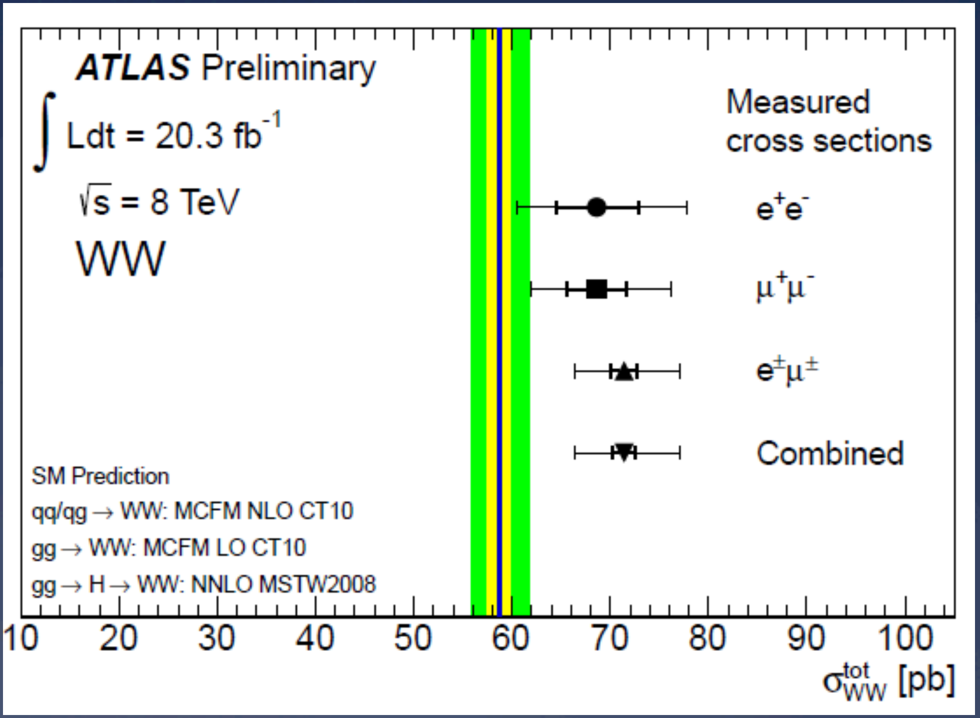
CMS, ATLAS, Higgs boson, $> 5\sigma$





A (Cautionary) Tale of an Excess

- CMS and ATLAS measured a cross section ~20% higher than the NLO SM prediction.

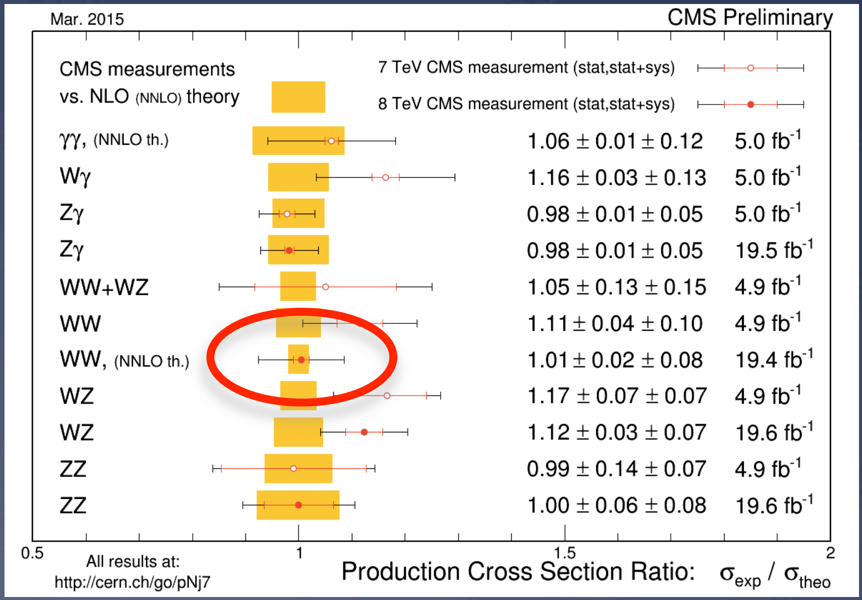


- This exciting result triggered a frenzy of speculation:
  - arXiv:1406.0848
  - arXiv:1406.0858
  - arXiv:1407.4912, etc.

A (Cautionary) Tale of an Excess

- My colleagues Jaiswal and Okui (arXiv:1407.4537), and Meade, Ramani, and Zeng (arXiv:1407.4537) noted that the jet veto cut $p_T > p_{T,veto}$, used by ATLAS and CMS to reduce background from top quark production, renders the NLO calculation inaccurate because terms like $\log^n(M/p_{T,veto})$ now need to be included. Improved calculations brought better agreement.

- Finally, a NNLO calculation of the WW cross section (Phys. Rev. Lett. 113, 212001 (2014)) is found to agree with the measurements:



So How Sure is Sure Enough?

Our field uses a rigid 5σ rule to claim a discovery. But, is this sensible?

Louis Lyons argues perhaps not: http://arxiv.org/pdf/1310.1284v1.pdf.

The point is whether you accept a statistically significant hypothesis H_1 depends on your prior opinion (π) about that hypothesis:

$$\frac{p(H_1 \mid data)}{p(H_0 \mid data)} = \frac{p(data \mid H_1)}{p(data \mid H_0)} \frac{\pi_1}{\pi_0}$$

So How Sure is Sure Enough?

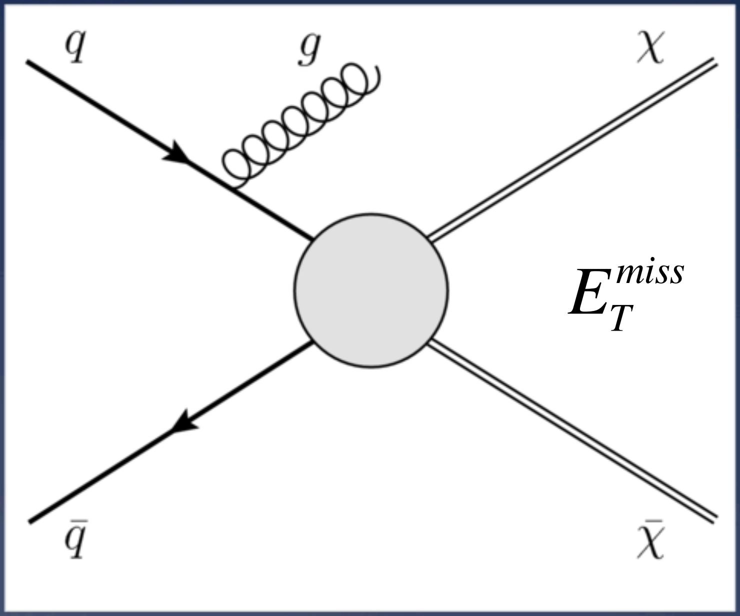
http://arxiv.org/pdf/1310.1284v1.pdf

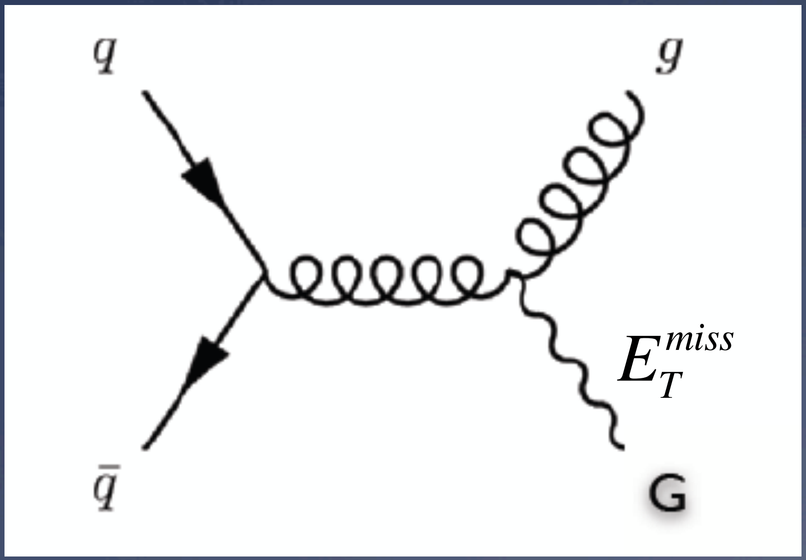
Search	Degree of surprise	Impact	LEE	Systematics	Number of σ
Higgs search	Medium	Very high	Mass	Medium	5
Single top	No	Low	No	No	3
SUSY	Yes	Very high	Very large	Yes	7
B_s oscillations	Medium/low	Medium	Δm	No	4
Neutrino oscillations	Medium	High	$sin^2(2\theta), \Delta m^2$	No	4
$B_s \to \mu\mu$	No	Low/Medium	No	Medium	3
Pentaquark	Yes	High/very high	M, decay mode	Medium	7
$(g-2)_\mu$ anomaly	Yes	High	No	Yes	4
H spin $\neq 0$	Yes	High	No	Medium	5
4^{th} generation q, l, ν	Yes	High	M, mode	No	6
$v_\nu > c$	Enormous	Enormous	No	Yes	>8
Dark matter (direct)	Medium	High	Medium	Yes	5
Dark energy	Yes	Very high	Strength	Yes	5
Grav waves	No	High	Enormous	Yes	7

The Mono X Program

or Clapping With One Hand!

Looking for "nothing" recoiling against something (X = e.g., a jet).





The Mono X Program

Example: 8 TeV ATLAS mono-jet search (1502.01518, 15 Sep 2015) imposed the requirements

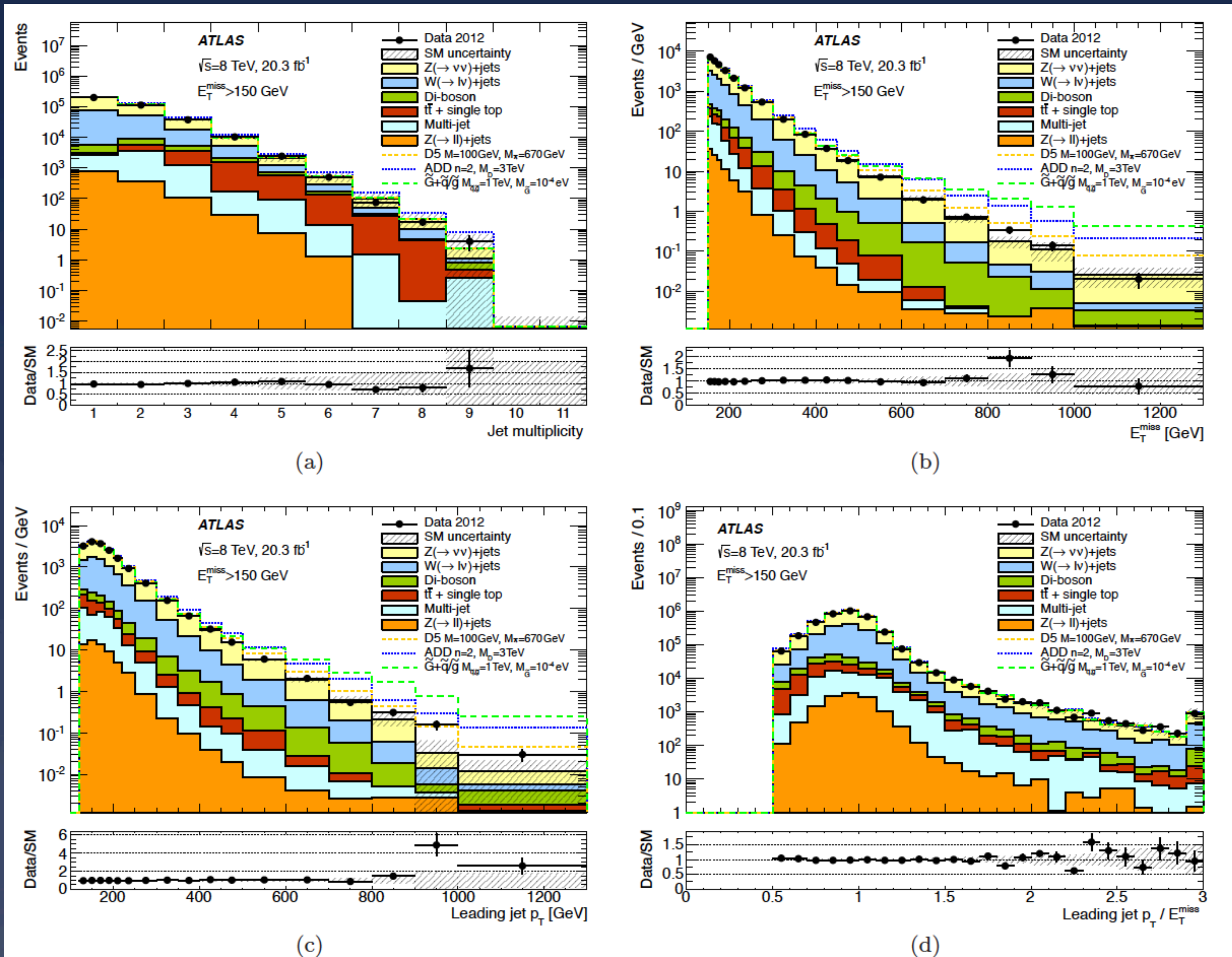
$$p_{Tj} > 30\text{ GeV},\ |\eta_j| < 4.5$$

$$p_{T1} > 120\text{ GeV},\ |\eta_{j1}| < 2.0,\ p_{T1} / E_T^{mis} > 0.5$$

$$\Delta\varphi(\text{jet}, \vec{p}_T^{\,miss}) > 1.0$$

to select mono-jet like events.

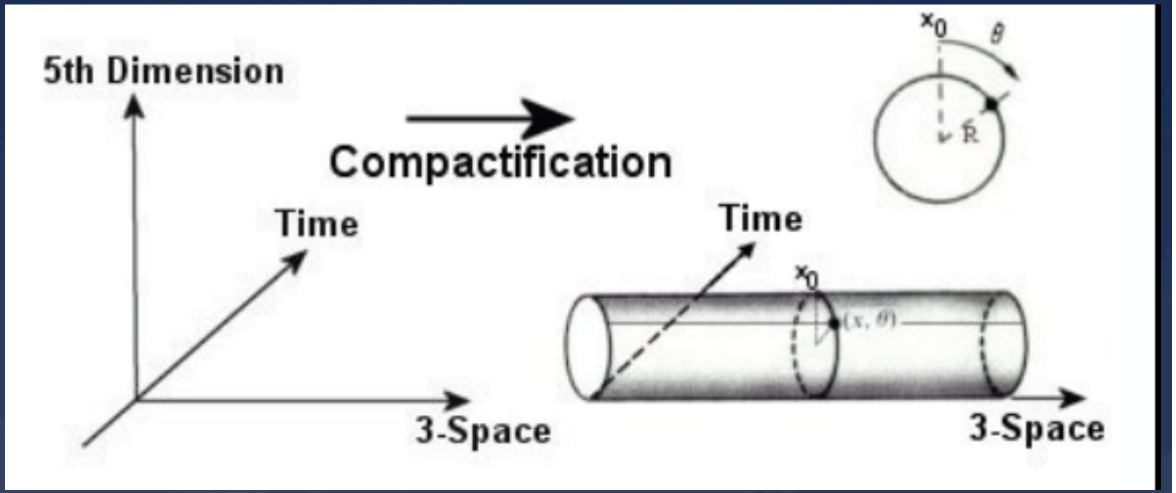
All backgrounds (single-boson, di-boson, top quark) are simulated, except for multi-jets and non-collision events, which are estimated using data-driven methods.

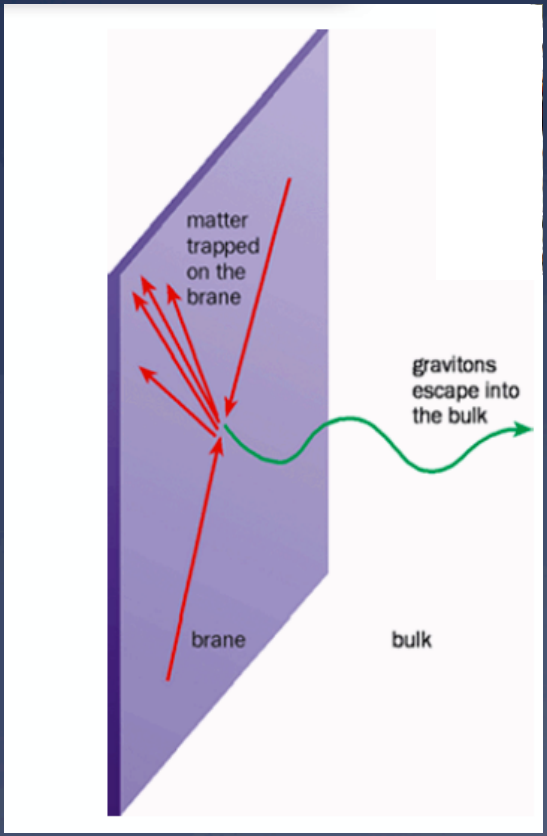


ATLAS 1502.01518, 15 Sep 2015

The Mono X Program

Arkani-Hamed
Dimopoulos
Dvali

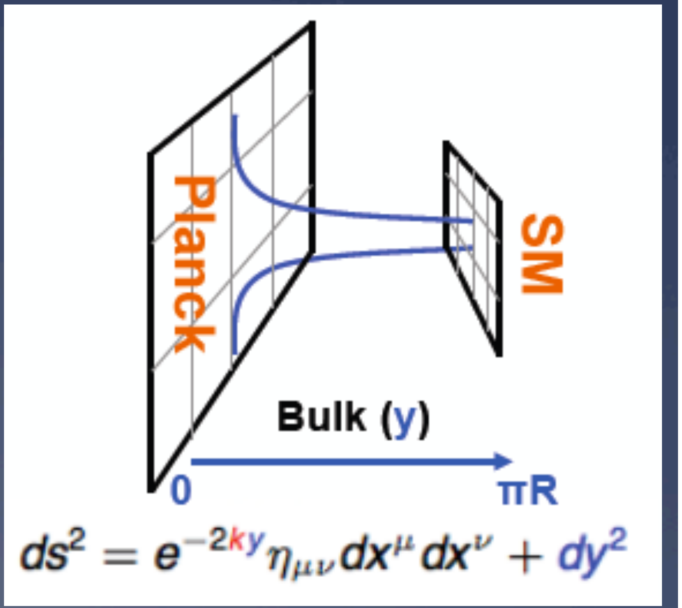




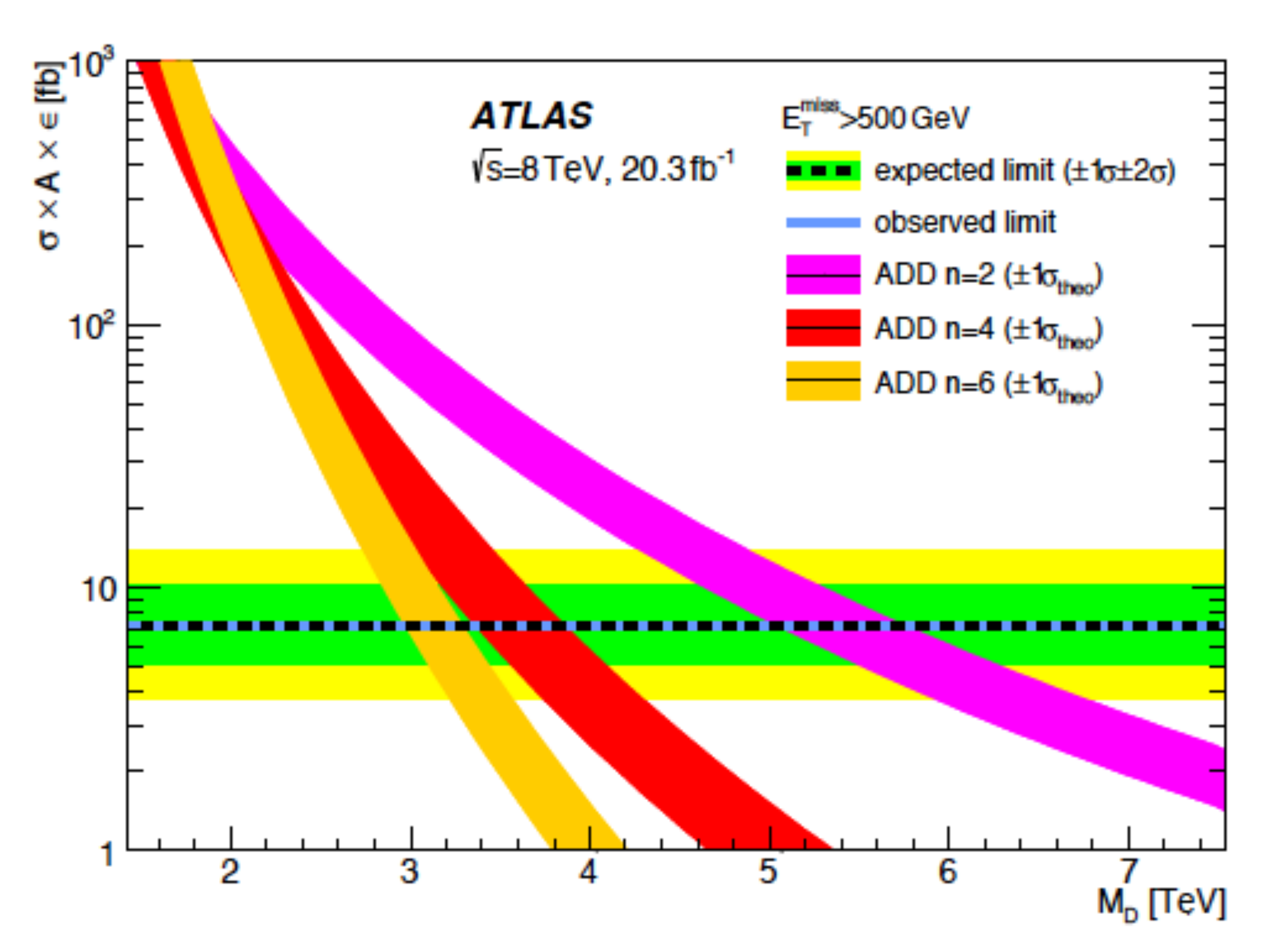
Randall
Sundrum

ADD $M_{Pl} \sim M_{EWK}^{1+n/2} R^{n/2}$

RS $M_{Pl} \sim \Lambda e^{k\pi R}$



The Mono X Program

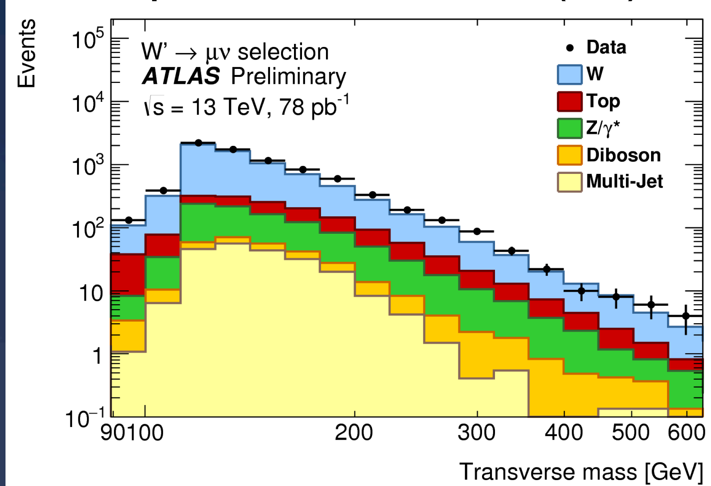


Outline

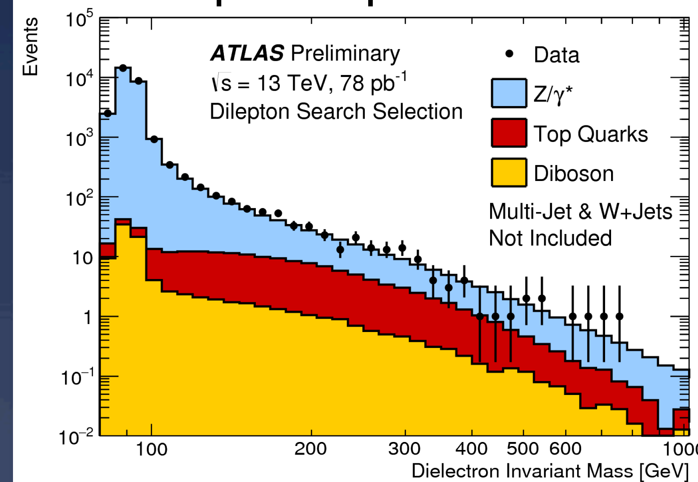
* Introduction
* LHC Run I – A Random Stroll
* **LHC Run II – Early Results**
* Opportunities and Challenges

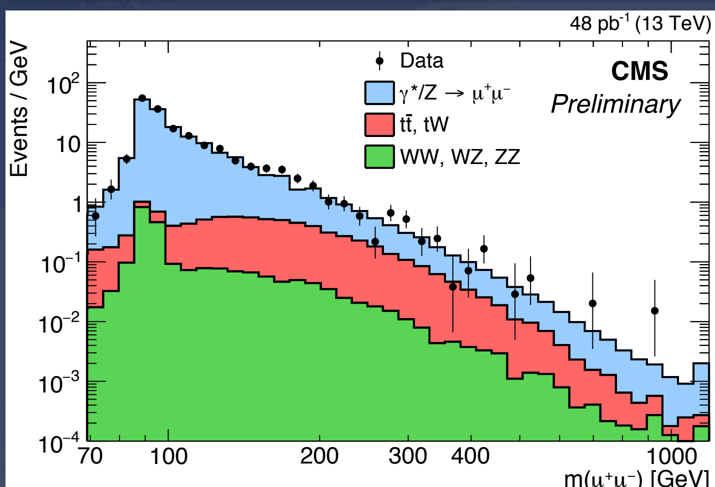
Early Commissioning Results

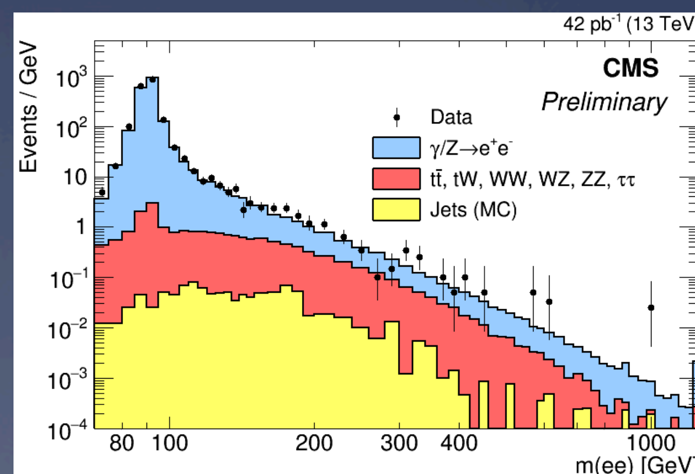
lepton+MET mass (W')



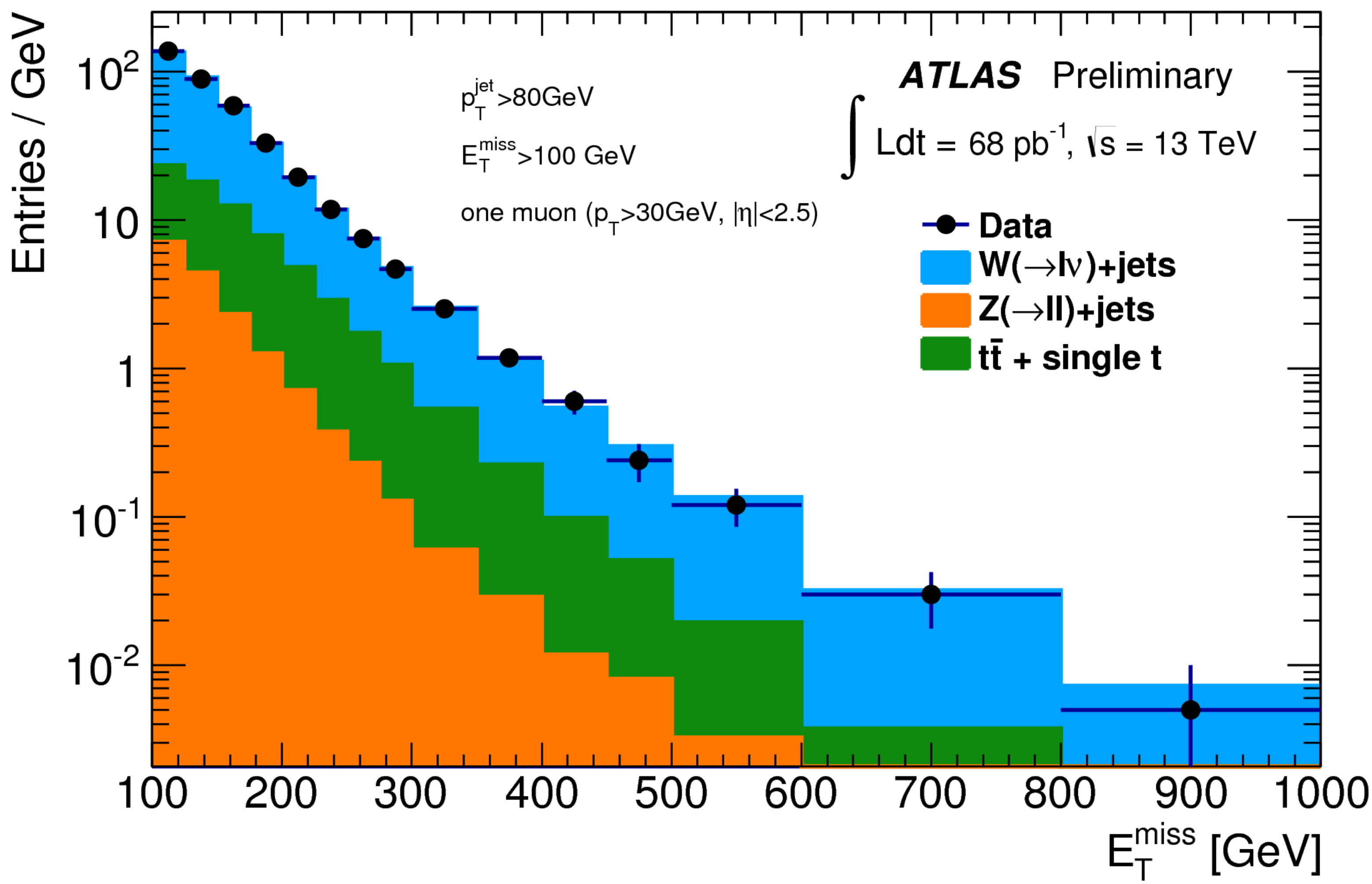
di-lepton spectrum







ATLAS@13 TeV: Breathtaking!



Resonance Searches – Round 2

CMS search for a narrow resonance in dijet mass spectrum

$p_T > 30\ \text{GeV}$

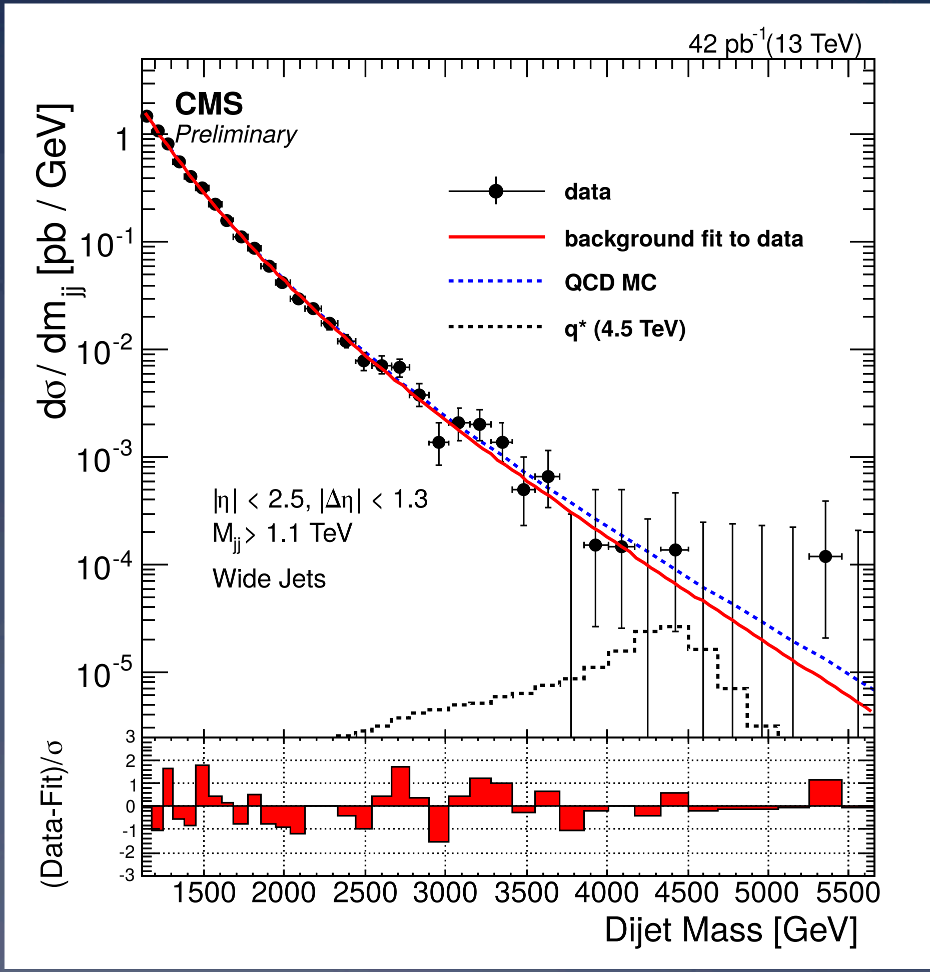
$|\eta_j| < 2.5$

$|\Delta\eta_{jj}| > 1.3$

$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} < 1.1$

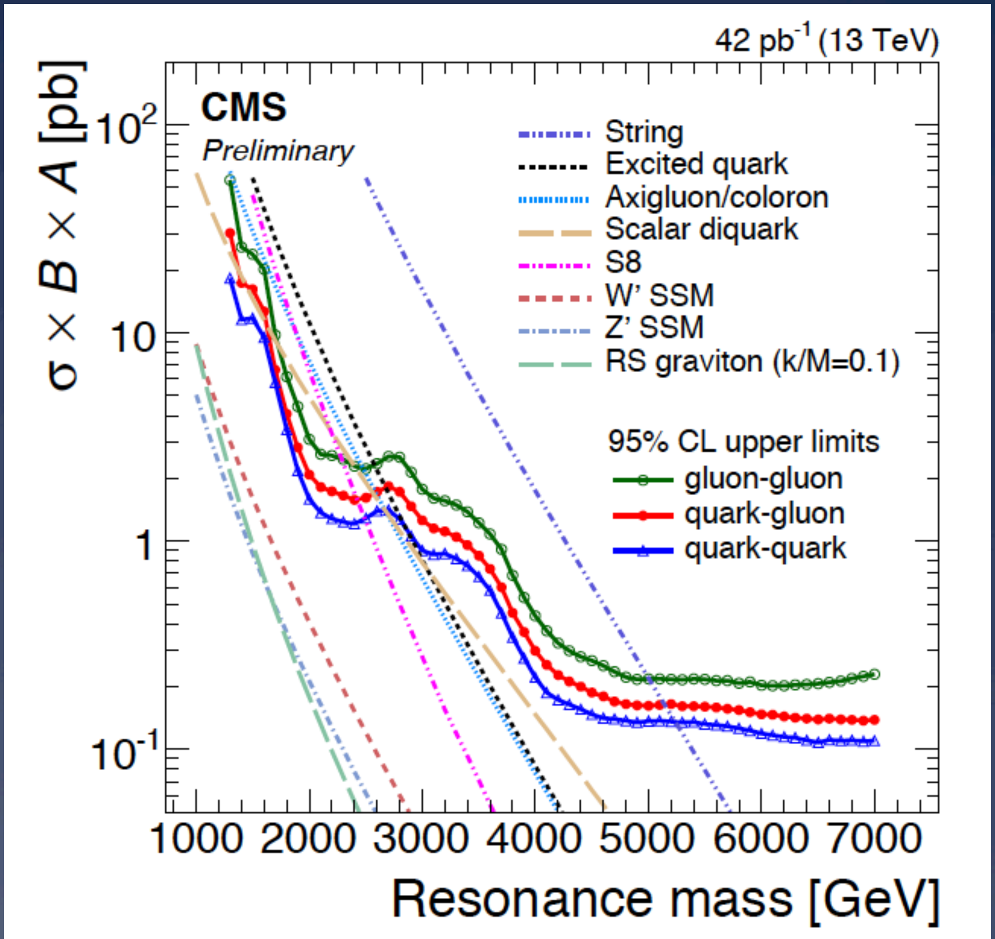
Background modeled with

$$\frac{d\sigma}{m_{jj}} = p_1(1-x)^{P_2}\, x^{-p_3}$$



Resonance Searches – Round 2

- As expected, this search can be used to set limits on many models:
- But, yet again, the Standard Model reigns supreme!



A 2.9 TeV Di-Electron Event

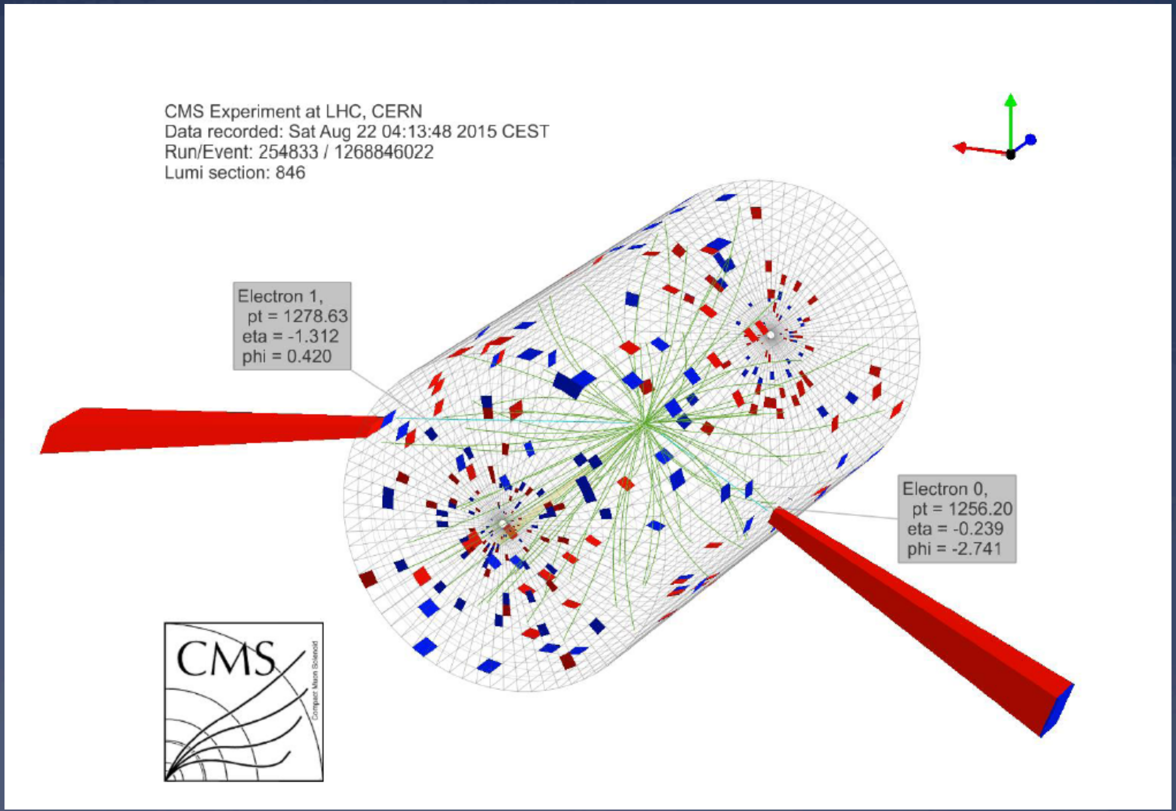
p_{T1} = 1.28 TeV, $\eta_1 = -1.31$, $\varphi_1 = 0.42$

p_{T2} = 1.26 TeV

$\eta_2 = -1.24$,

$\varphi_2 = -2.74$

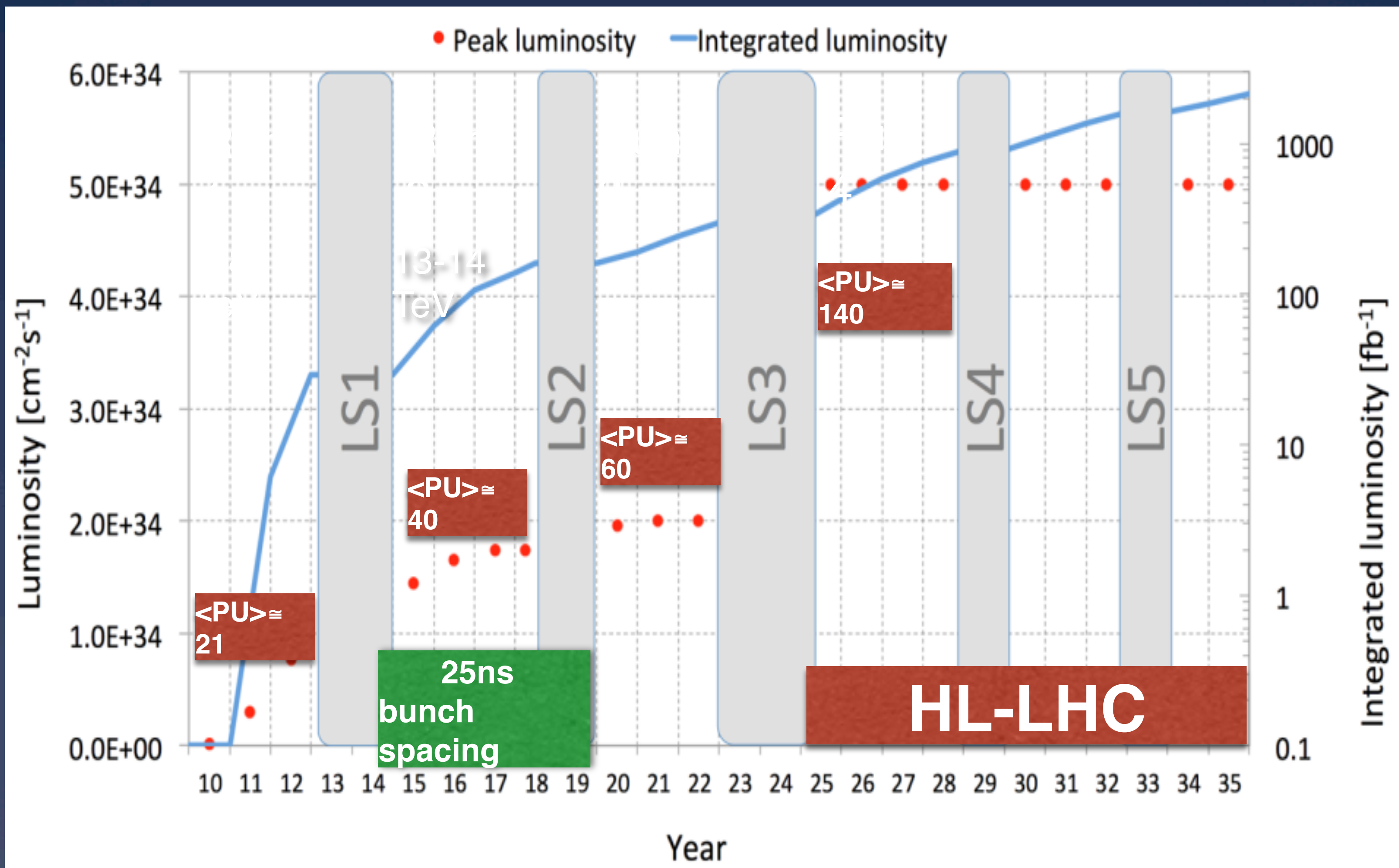
Expected background above 2 TeV 0.007 events



Outline

* Introduction
* LHC Run I – A Random Stroll
* LHC Run II – Early Results
* **Opportunities and Challenges**

Opportunities & Challenges

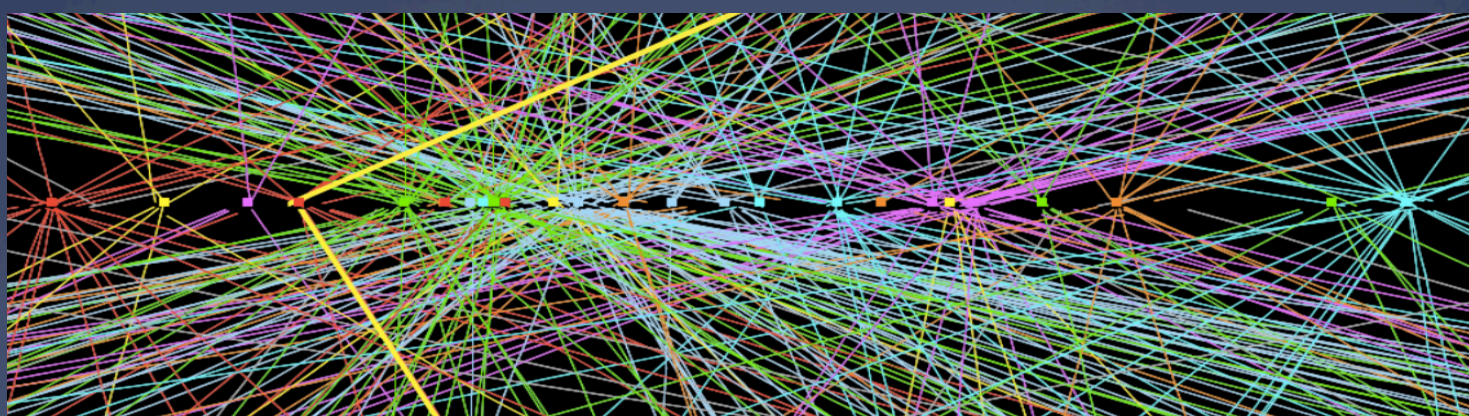


Opportunities & Challenges

* The upgraded LHC and its amazing detectors provide the best chance we have to move the field significantly forward.

* The opportunities for young physicists to make lasting contributions are enormous. They are so precisely because of the many challenges we must face!

* Take, for example, pileup:

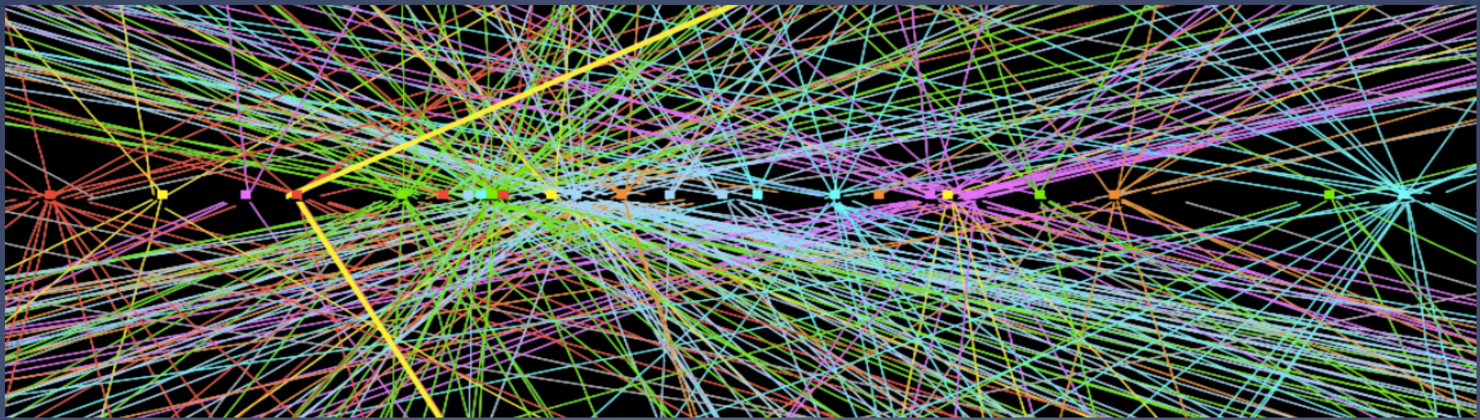


Opportunities & Challenges

At L ~ 1.3 x10^{34} cm^{-2} s^{-1}, find ~140 vertices spread over 5 cm!

$$\mu = \frac{\sigma_{tot} L}{n_b f}$$

μ	average number of events/bunch crossing
σ_{tot}	total inelastic cross section
L	luminosity
n_b	number of bunches
f	bunch collision frequency



Opportunities & Challenges

A Few Experimental Challenges

* Handle data storage at the rate of 6 gigabytes/second
* Trigger efficiently, even at low thresholds
* Mitigate the effects of pileup
* Efficient identification of boosted W, Z, Higgs, top
* Efficient identification of b jets and taus
* High fidelity, yet fast, detector simulation
* Automatic search for deviations from SM

A Couple of Theoretical Physics Challenges (my wish list!)

* Fully automatic high precision predictions for hundreds of SM exclusive final states.
* Precise calculation of multijet cross sections, finally!

Opportunities & Challenges

- Where does our field want to be in 2050?
- We want to be in possession of the New Standard Model.
- However, for that to happen, two things are necessary:
  - We must discover new physics, and
  - we must significantly narrow the divide between theorists and experimentalists: We Need To Talk More.
- But, for the latter to happen, a major cultural shift will be necessary.

Final Remarks

The Standard Model – a complicated Heath Robinson edifice ingeniously put together by brilliant architects and builders – is to be celebrated as a truly magnificent achievement.

But the NSM will be even more extraordinary.

William Heath Robinson
1872 – 1944