MODELING SOFT GLUONS AND FIDUCIAL CROSS SECTIONS: NEW PHYSICS OR OLD QCD?

Patrick Meade Yang Institute for Theoretical Physics Stony Brook University

Based on: D. Curtin, P. Jaiswal, PM 1206.6888 D. Curtin, P. Jaiswal, PM, P. Tien 1304.7011 D. Curtin, PM, P. Tien 1406.xxxx (wednesday night EDT) PM, H. Ramani, M. Zeng 1406.xxxx

A LONG AND WINDING TALE...

THE AUTHORITATIVE EDITION

Moby-Dick

THE WHALE 150TH ANNIVERSARY EDITION



HERMAN MELVILLE WITH A NEW INTRODUCTION BY HERSHEL PARKER

THE NORTHWESTERN-NEWBERRY EDITION

Is new physics the theorists white whale?

A LONG AND WINDING TALE...

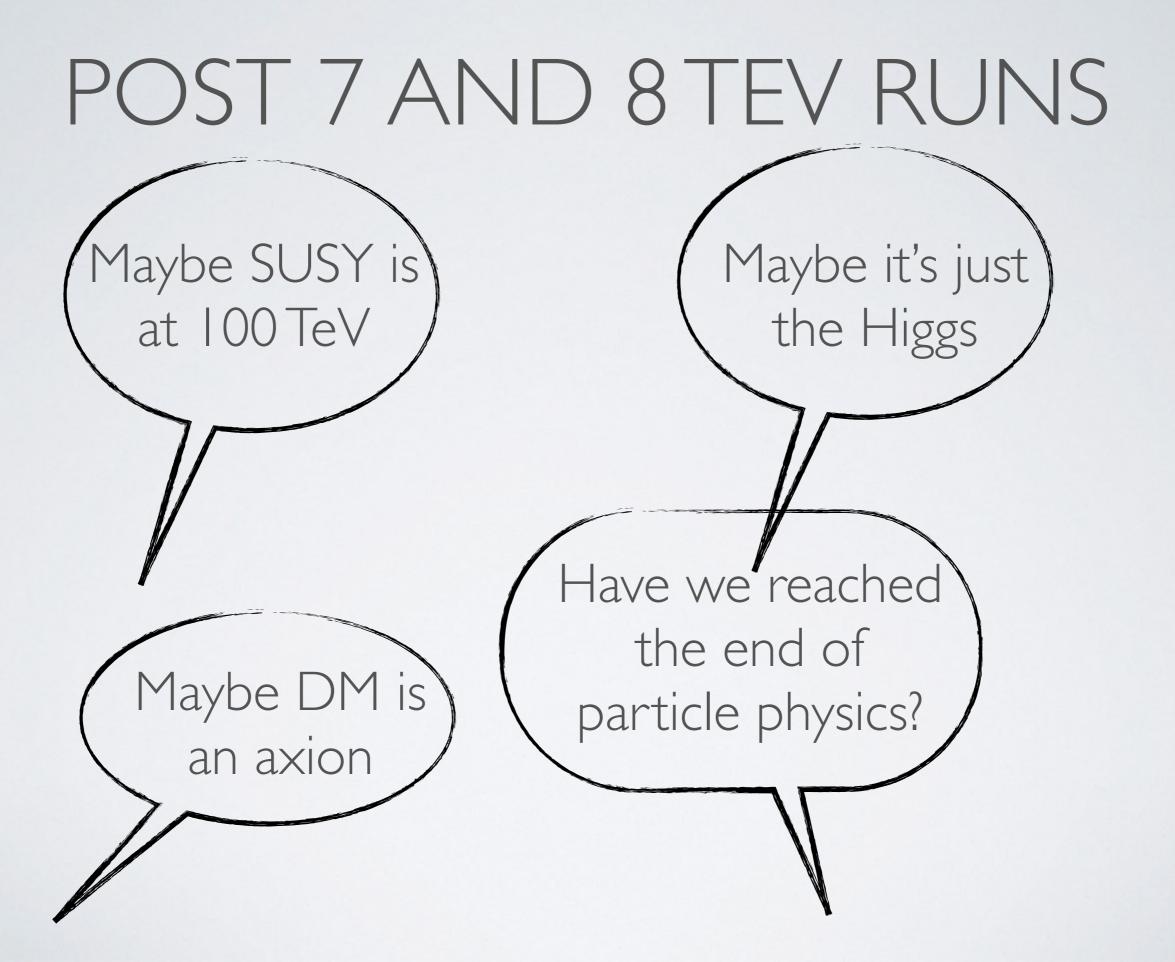


WHAT THEORISTS WERE SAYING PRE LHC



A LONG AND WINDING TALE...





A LONG AND WINDING TALE...







Model ADD $G_{KK} + g/q$ ADD non-resonant $\ell \ell \gamma \gamma$ ADD QBH $\rightarrow \ell q$ ADD BH high N_{irk} ADD BH high $\sum p_T$ ASI $G_{KK} \rightarrow \ell \ell$ ASI $G_{KK} \rightarrow ZZ \rightarrow \ell \ell q q / \ell \ell \ell \ell$	ℓ, γ − 2γ or 2e, μ 1 e, μ 2μ (SS) ≥ 1 e, μ	Jets 1-2j - 1j -	Emiss T Yos	∫£ dt[ft 4.7	1 Mass limit		£ dt = (1.0 - 20.3) fb ⁻¹	Reference
ADD non-resonant $\ell \ell / \gamma \gamma$ ADD QBH $\rightarrow \ell q$ ADD BH high N_{ink} ADD BH high $\sum p_T$ AS1 $G_{RK} \rightarrow \ell \ell$	2γ or 2e, μ 1 e, μ 2 μ (SS)	- 1 j		4.7				
ADD QBH $\rightarrow \ell q$ ADD BH high N_{ink} ADD BH high $\sum p_T$ AS1 $G_{RK} \rightarrow \ell \ell$	1 e.μ 2 μ (SS)	1 j	-		Mp 4.37 TeV		n = 2	1210.4491
ADD BH high N_{irk} ADD BH high $\sum p_T$ RS1 $G_{RK} \rightarrow \ell \ell$	2 µ (SS)	-		4.7	Ms 4.18 TeV		# = 3 HLZ NLO	1211.1150
ADD BH high $\sum p_T$ AS1 $G_{KK} \rightarrow \ell \ell$		-	-	20.3	M _a 5.2 TeV	4	a = 6	1311.2006
$RS1 G_{KK} \rightarrow \ell \ell$	≥ 1 e.µ		-	20.3	M _{ah} 5.7 Te	eV.	n = 6, M _D = 1.5 TeV, non-rot BH	1308.4075
		≥ 2 j	-	20.3	M _{sh} 6.2	TeV	n = 6, Mp = 1.5 TeV, non-rot BH	ATLAS-CONF-20
SI Guy = 77 - Hanille	2 c. µ	-	-	20.3	Groc mass 2.47 TeV		$k/\overline{M}_{cv} = 0.1$	ATLAS-CONF-20
IOI OKA - XX - IIIQUIIII	2 or 4 e. µ	2 j or -	-	1.0	G _{KK} mass 845 GeV		$k/\overline{M}_{Pl} = 0.1$	1203.0718
$G_{KK} \rightarrow WW \rightarrow \ell \nu \ell \nu$	2 e.µ	_	Yes	4.7	Groc mass 1.23 TeV		$k/\overline{M}_{cr} = 0.1$	1208.2880
	-	4 b	-					ATLAS-CONF-20
	10.0	> 1 b. > 1J/3	Zi Yos					ATLAS-CONF-20
			-					1209,2535
		_	Voc					ATLAS-CONE-20
	-		105					
		-	-					ATLAS-CONF-20
$SM Z' \rightarrow \tau \tau$	2 7	-	-		Z' mass 1.9 TeV			ATLAS-CONF-20
$SM W' \rightarrow \ell r$	1 e,µ	-	Yes	20.3	W' mass 3.28 TeV			ATLAS-CONF-20
$GM W' \rightarrow WZ \rightarrow \ell \nu \ell' \ell'$	3 e.µ	-	Yes	20.3	W mass 1.52 TeV			ATLAS-CONF-20
$RSM W'_R \rightarrow tb$	1 c, µ	2 b, 0-1 j	Yes	14.3	Wilmase 1.84 TeV			ATLAS-CONF-20
2 qqqq	-	2 j	-	4.8	٨	7.6 TeV	$\eta = +1$	1210.1718
3 gg({	2 e. µ	-		5.0	٨	13	1.9 TeV 914 1	1211.1150
		≥ 1 b, ≥ 1 j	Yes	14.3	A 3.3 TeV		C - 1	ATLAS-CONF-20
				10.5			and the set of the set of the	
							4-7	ATLAS-CONF-20
FI D9 operator	-	1 J, ≤ 1 J	Yes	20.3	M, 2.4 TeV		at 90% CL for m(x) < 100 GeV	1309.4017
icalar LQ 1 st gen	2 e	≥2j	-	1.0	LQ mass 660 GeV		$\beta = 1$	1112.4028
Scalar LQ 2 nd gen	2μ	≥ 2 j	-	1.0	LQ mass 685 GeV		$\beta = 1$	1203.3172
icalar LQ 3 rd gen	1 e, μ, 1 τ	1 b, 1 j	-	4.7	LQ mass 534 GeV		$\beta = 1$	1303.052
Actor-like quark $TT \rightarrow Ht + X$	1.0.0	> 2 h > 4 i	Ves	14.3	T mass 700 GoV		T in (T.B) doublet	ATLAS-CONF-20
								ATLAS CONF 20
			-					ATLAS-CONF-20
			Mag					ATLAS-CONF-20
			105					100000000000
	1γ	1 j	-	20.3	q" mass 3.5 TeV		only u^* and d^* , $\Lambda = m(q^*)$	1309.3230
Excited quark $q^* \rightarrow qg$	-	2 j	-	13.0	q" mass 3.84 TeV		only v^* and d^* , $\Lambda = m(q^*)$	ATLAS-CONF-20
excited quark $b^* \rightarrow Wt$	1 or 2 e, µ	1 b, 2 j or 1	i Yes	4.7	b" mass 870 GeV		left-handed coupling	1301.1583
excited lepton $\ell^* \rightarrow \ell \gamma$	2 e.µ. 1 y	-	-	13.0	/* mass 2.2 TeV		A = 2.2 TeV	1308.1364
RSM Majorana v	2 e,µ	2 j	-	2.1	N ^o mass 1.5 TeV		$m(W_R) = 2$ TeV, no mixing	1203.5420
		-	-					ATLAS-CONF-20
		-						1210.5070
		-	-					1301.5272
	_	_	_					1207.6411
ngenous monopolos		_		2.0			prosenter, gr - 180	-207.0411
	SM $W' \rightarrow \ell \nu$ GM $W' \rightarrow WZ \rightarrow \ell \nu \ell' \ell''$ RSM $W''_R \rightarrow t\bar{b}$ 21 qqqq 21 qqq(21	uik RS $g_{KK} \rightarrow t\bar{t}$ 1 e, μ $3/Z_2$ ED2 e, μ ED2 γ SM $Z' \rightarrow \ell \ell$ 2 e, μ SM $Z' \rightarrow tr$ 2 τ SM $Z' \rightarrow tr$ 2 τ SM $W' \rightarrow \ell r$ 1 e, μ GM $W' \rightarrow WZ \rightarrow \ell r \ell' \ell''$ 3 e, μ RSM $W'_R \rightarrow tb$ 1 e, μ I qood-A qott2 e, μ A uott2 e, μ (SS)FT D5 operator-FT D9 operator-calar LQ 1" gen2 ecalar LQ 2" gen2 μ calar LQ 3" gen1 e, μ , 1 τ lector-like quark $TT \rightarrow Ht + X$ 1 e, μ lector-like quark $RB \rightarrow Zb + X$ 2 e, μ loctor-like quark $BB \rightarrow Wt + X$ 2 e, μ (SS)kotted quark $q^* \rightarrow qq$ 1 γ kotted quark $b^* \rightarrow Wt$ 1 or 2 e, μ kotted quark $b^* \rightarrow Wt$ 1 or 2 e, μ RSM Majorana r 2 e, μ Iggs triplot $H^{1+} \rightarrow \ell \ell$ 2 e, μ (SS)huit-charged particles-tagnetic monopoloes-	uk RS $g_{KK} \rightarrow t\bar{t}$ 1 $e,\mu \ge 1 b, \ge 1 JG$ $3/Z_2 \in D$ $2 e,\mu$ ED 2γ SM $Z' \rightarrow \ell\ell$ $2 e,\mu$ SM $Z' \rightarrow \ell\ell$ $2 e,\mu$ SM $Z' \rightarrow t\bar{t}$ $2 t$ SM $Z' \rightarrow t\bar{t}$ $2 t$ GM $W' \rightarrow WZ \rightarrow \ell \nu \ell' \ell'$ $3 e,\mu$ RSM $W'_R \rightarrow t\bar{b}$ $1 e,\mu$ 1 $qqqq$ $-2j$ 1 $qqqq$ $-2j$ 1 $qqq\ell$ $2 e,\mu$ 2 e,μ -1 1 $qqqq$ $-12j$ FT D5 operator $-14j \le 1j$ FT D9 operator $-14j \le 1j$ calar LQ 2^{rd} gen $2e \ge 2j$ calar LQ 2^{rd} gen $2e \ge 2j$ calar LQ 3^{rd} gen $1 e, \mu, 1\tau$ 1 $b, 1j$ ector-like quark $TT \rightarrow Ht + X$ $1 e, \mu \ge 2 b, \ge 4j$ bector-like quark $BB \rightarrow Zb + X$ $2e, \mu \ge 2b$ bector-like quark $BB \rightarrow Wt + X$ $2e,\mu$ $2 t$ $2b$ $xolted quark q' \rightarrow qq$ 1γ $xolted quark b' \rightarrow Wt$ $1 \text{ or } 2e,\mu$ $xolted quark b' \rightarrow Wt$ $1 \text{ or } 2e,\mu$ $2 t e,\mu$ $2 t$ $2 t e,\mu$ $2 t $	uk RS $g_{KK} \rightarrow t\bar{t}$ 1 $e,\mu \ge 1$ $b,\ge 1$ $J/2$ YOS $3/Z_2$ ED $2e,\mu$ $ -$ ED 2γ $-$ YOSSM $Z' \rightarrow \ell\ell$ $2e,\mu$ $ -$ SM $Z' \rightarrow t\bar{t}$ $2r$ $ -$ SM $W' \rightarrow WZ \rightarrow \ell\nu$ $\ell'\ell'$ $3e,\mu$ $-$ YesSSM $W'_R \rightarrow t\bar{b}$ $1e,\mu$ $2b,01j$ YesRSM $W'_R \rightarrow t\bar{b}$ $1e,\mu$ $2b,01j$ RSM $W'_R \rightarrow t\bar{b}$ $1e,\mu$ $2b,01j$ Yes TDS operator $ 1J, \leq 1j$ Yes TDS operator $ 1J, \leq 1j$ FT D9 operator $ 1J, \leq 1j$ Yes $2e,\mu$ $22j$ $-$ calar LQ 2^{rd} gen $2e$ $22j$ calar LQ 3^{rd} gen $2e$ $22j$ calar LQ 3^{rd} gen $2e$ $22j$ calar LQ 3^{rd} gen $1e,\mu,1\tau$ $1b,1j$ calar LQ 3^{rd} gen $1e,\mu,1\tau$ $1b,23j$ YesYes $2e,\mu$ $2b,24j$ Vector-like quark $TT \rightarrow Ht + X$ $1e,\mu$ $2b,24j$ YesYes $2e,\mu$ $2b,-1j$ Vector-like quark $BB \rightarrow Wt + X$ $2e,\mu$ $2b,21j$ Vector-like quark $BB \rightarrow Wt + X$ $2e,\mu$ $2b,-1j$ Vector quark $d^{r} \rightarrow qg$ 1γ $1j$ $-$ Noted quark $d^{r} \rightarrow qg$ $1c,2e,\mu$ $1p$	uk RS $g_{0K} \rightarrow t\bar{t}$ 1 $e, \mu \ge 1b, \ge 1J/2$ Yos 14.3 $3^{2}/Z_{2}$ ED $2e, \mu = -$ - 5.0 ED $2\gamma = -$ Yos 4.8 SM $Z' \rightarrow t\ell$ $2e, \mu = -$ - 20.3 SM $Z' \rightarrow tr$ $2\tau = -$ - 19.5 SM $W' \rightarrow tr$ $2e, \mu = -$ - 19.5 SM $W' \rightarrow tr$ $1e, \mu = -$ Yes 20.3 GM $W' \rightarrow WZ \rightarrow tr t''$ $3e, \mu = -$ Yes 20.3 RSM $W'_{R} \rightarrow t\bar{b}$ $1e, \mu = 2b, 0.1j$ Yes 14.3 H qapa - $2j = -$ 4.8 H qapa - $2i = -5.0$ 14.3 H apt(L $2e, \mu = 2b, 0.1j$ Yes 14.3 H apt(L $2e, \mu = 5.0 = 1j$ Yes 14.3 H apt(L $2e, \mu = 5.0 = 1j$ Yes 10.5 FT D5 operator - $1.2j$ Yes 10.5 FT D9 operator - $1.2j$ Yes 10.5 FT D9 operator - $1.4, 1\tau$ $1.0 t_{2} = 1j$ Yes 1.3 cotar LQ 2rd gen	uk RS pc \rightarrow rr 1 e, $\mu \ge 1$ b, ≥ 1 J/2; Yos 14.3 6xx mass 0.52.0 TeV $j^2/2$; ED 2 e, μ - 5.0 Compact scale R ⁻¹ 1.41 TeV ED 2 γ - Yos 4.8 Compact scale R ⁻¹ 1.41 TeV SM $Z' \rightarrow tri 2 r. \mu - - 10.5 Z' mass 2.86 TeV SM V' \rightarrow tri 1 e, \mu - Yes 20.3 W' mass 1.9 TeV SM W'_{0} \rightarrow tri 1 e, \mu 2 b, 0-1 J Yes 20.3 W' mass 1.42 TeV SM W'_{0} \rightarrow tri 1 e, \mu 2 b, 0-1 J Yes 20.3 W' mass 1.42 TeV SM W'_{0} \rightarrow tri 1 e, \mu 2 b, 0-1 J Yes 20.3 W' mass 1.42 TeV SM W'_{0} \rightarrow tri 2 e, \mu - Yes 20.3 W'''' mass 1.42 TeV I equal - (1 e, \mu, 1 for the triant t$	uk RS $g_{DX} \rightarrow t\bar{t}$ 1 4 $e_{\mu} \ge 1b_{2} \ge 1d_{2}$ Yos 14.3 to xmass 0.52.0 TeV 1/2; ED 2 $e_{\mu} \mu$ - - 0.50 SM $Z' \rightarrow tr$ 2 $e_{\mu} \mu$ - - 0.50 2.50 TeV SM $Z' \rightarrow tr$ 2 $e_{\mu} \mu$ - - 2.50 TeV SM $Z' \rightarrow tr$ 2.6 2.50 TeV SM $Z' \rightarrow tr$ 2.60 TeV 2.60 TeV SM $Z'' \rightarrow tr$ 2.60 TeV 2.60 TeV SM $Z'' \rightarrow tr$ 2.60 TeV 2.60 TeV SM $Z'' \rightarrow tr$ 2.60 TeV 2.60 TeV 1.60 Colspan= 2.60 TeV 2.60 TeV 1.60 Colspan= 2.	uk RS pp: \neg fr 1 e, $\mu \ge 1$ b, $\ge 1/2$ W = 4.30 per etable per etable

*Only a selection of the available mass limits on new states or phenomena is shown.

ATLAS Exotics S Status: April 2014	earch	es^ -	95%		xclusion $\int \mathcal{L} dt = (1.0 - 20.3)$	TLAS Prelimin $fb^{-1} \sqrt{s} = 7, 81$
Model	ℓ, γ	Jets	E_{T}^{miss}	∫£ dt[fb ⁻¹	Mass limit	
ADD $G_{KK} + g/q$	-	1-2 j	Yes	4.7	4.37 TeV a = 2	
ADD non-resonant (1/yy	2γ or 2e, μ		-	4.7	4.18 TeV n = 3 HLZ NLP	
ADD QBH $\rightarrow \ell q$	1 e.µ	1 j	-	20.3	a 5.2 TeV a = 6	
ADD BH high N_{trk} ADD BH high $\sum p_T$ RS1 $G_{RK} \rightarrow \ell\ell$ RS1 $G_{RK} \rightarrow ZZ \rightarrow \ell\ell qq/\ell\ell\ell$ RS1 $G_{RK} \rightarrow WW \rightarrow \ell r\ell r$ Ruk RS $G_{RK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	2 µ (SS)	-	-	20.3	5.7 TeV	
ADD BH high $\sum p_T$	≥1 <i>e</i> ,µ	≥2j	-	20.3	6.2 TeV	
RS1 $G_{KK} \rightarrow \ell \ell$	2 c, µ	-	-	20.3	× mass 2.47 TeV	
RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell \ell q q / \ell \ell \ell \ell$	2 or 4 e, µ	2 j or -	-	1.0	x mass 845 GeV	
RS1 $G_{KK} \rightarrow WW \rightarrow \ell \nu \ell \nu$	2 e, µ	-	Yos	4.7	x mass 1.23 TeV	
	-	4 b	-		x mass 590-710 GeV	-201
Bulk RS $g_{KK} \rightarrow t\bar{t}$		≥ 1 b, ≥ 1J/	2j Yos		x 17858	-AS-CONF-201
S ¹ /Z ₂ ED	2 e, µ	-	-		(x) ≈ R ⁻¹	1209.2535
UED	2γ	-	Yes	4.8	mpact. scale R ⁻¹	ATLAS-CONF-201
SSM $Z' \rightarrow \ell \ell$	2 e, µ	-	-	20.3	mass	ATLAS-CONF-201
2 SSM $Z' \rightarrow \tau \tau$	2 7	-	-	19.5	mass	ATLAS-CONF-201
SSM $Z' \rightarrow \tau \tau$ SSM $W' \rightarrow t r$ EGM $W' \rightarrow WZ \rightarrow t r t''$	1 e, µ	-	Yes	20.3		ATLAS-CONF-201
$\frac{2}{8} EGM W' \rightarrow WZ \rightarrow \ell_V \ell' \ell'$	3 e.µ	-	Yes	20.3		ATLAS-CONF-201
LRSM $W'_{\mu} \rightarrow t\bar{b}$	1 c.µ	2 b, 0-1 j	Yes			ATLAS-CONF-20
Cl qqqq	-	2 j			7.6 TeV a = +1	1210.1718
Cl qqll	2 e, µ	-1			13.9 TeV 9LL = -1	1211.1150
Cloutt	2 e, µ /**				3.3 TeV C = 1	ATLAS-CONF-201
	2.0,0			. (
EFT D5 operator					131 GeV at 90% CL for m(χ) < 80 0	
EFT D9 operator					2.4 TeV at 90% CL for m(χ) < 100	GeV 1309.4017
Scalar LO ***					660 GeV β = 1	1112.4028
Ser.					685 GeV β = 1	1203.3172
					mass 534 GeV ß = 1	1303.0526
				.4.3	mass 790 GeV T in (T.S) doublet	ATLAS-CONF-201
					mass. 670 GeV isospin singlet	ATLAS CONF-201
		, d	-05		mass 725 GeV B in (B,Y) doublet	ATLAS-CONF-201
		≥1b,≥1	Yes		mass 720 GeV B in (T,B) doublet	ATLAS-CONF-201
	*		1 100			
	1γ	1 j	-		mass 3.5 TeV only u^* and d^* , $\Lambda = m(q^*)$	
	-	2 j	-	13.0	mass 3.84 TeV only o^* and d^* , $\Lambda = m(q^*)$	
~ WL	1 or 2 e, µ	1 b, 2 j or 1	1 Yes		mass 870 GeV left-handed coupling	1301.1583
$an t' \rightarrow t\gamma$	2 e.µ. 1 γ	-	-	13.0	mass 2.2 ToV A = 2.2 ToV	1208.1364
«RSM Majorana »	2 e, µ	2 j	-	2.1	mass 1.5 TeV m(Wg) - 2 TeV, no mixin	9 1203.5420
Type III Seesaw	2 e.µ	-	-	5.8	mass 245 GeV (V _e)=0.065, V _p =0.063, V	=0 ATLAS-CONF-201
Higgs triplet H ^{±±} → <i>l</i> ℓ Multi-charged particles	2 e, µ (SS)	-		4.7	mass 409 GeV DY production, RR(H**	(/)-1 1210.5070
Multi-charged particles	-	-	-	4.4	ill-charged particle mass 490 GeV DY production, q = 4e	1301.5272
Magnetic monopoles	-	-	-	2.0	mopole mass 862 GeV DY production, [g] = 1gp	1207.6411
	.6	7 Told	15	e TeV		
	V8 =	7 TeV	¥2 = 1	8 TeV	10 ⁻¹ 1 ¹⁰ Mass scale	

*Only a selection of the available mass limits on new states or phenomena is shown.

 LAS Exotics S tus: April 2014	carcin	- 63	33 /		LACIUSION		1	$\mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1}$	4S Prelimina $\sqrt{s} = 7, 8 \text{ Te}$
Model	ℓ, γ	Jets	E ^{miss} T	∫£ dt[fb	-1]	Mass limit	,		Reference
ADD $G_{KK} + g/q$	-	1-2 j	Yes	4.7	Mp		4.37 TeV	n = 2	1210.4491
ADD non-resonant ((/)yy	2y or 2e, µ	-	-	4.7	Ms		4.18 TeV	# = 3 HLZ NLO	1211.1150
ADD QBH $\rightarrow \ell q$	1 e.µ	1 j	-	20.3	Ma		5.2 TeV	# - 6	1311.2006
ADD BH high Nork	2 µ (SS)	-	-	20.3	Ma		5.7 TeV	$n = 6, M_O = 1.5$ TeV, non-rot BH	1308.4075
ADD BH high $\sum p_T$	$\geq 1 e. \mu$	≥2j	-	20.3	Mak		6.2 TeV	$n=6, M_D=1.5$ TeV, non-rot BH	ATLAS-CONF-2014-0
RS1 $G_{KK} \rightarrow \ell \ell$	2 c, µ	-	-	20.3	G _{KK} mass		2.47 TeV	$k/\overline{M}_{PI} = 0.1$	ATLAS-CONF-2013-0
RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell \ell q q / \ell \ell \ell \ell$	2 or 4 e, µ	2 j or -	-	1.0	G _{KK} mass	845 GeV		$k/\overline{M}_{Pl} = 0.1$	1203.0718
$RS1\ G_{KK} \to WW \to \ell \nu \ell \nu$	2 e, µ	-	Yos	4.7	G _{KK} mass	1.23 TeV		$k/\overline{M}_{PY} = 0.1$	1208.2690
Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	-	4 b	-	19.5	G _{KK} mass	590-710 GeV		$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-0

It must be at higher mass scales!!!

Heavy	Vector-like quark $TT \rightarrow Wb + X$ Vector-like quark $BB \rightarrow Zb + X$ Vector-like quark $BB \rightarrow Wt + X$	2 e, µ	≥ 1 b, ≥ 3 ≥ 2 b ≥ 1 b, ≥ 1	-	14.3 14.3 14.3	T mans 670 GeV B mass 725 GeV B mans 720 GeV	isospin singlet B in (B.Y) doublet B in (T,B) doublet	ATLAS CONF 2013 060 ATLAS-CONF-2013-056 ATLAS-CONF-2013-051
20	Excited quark $q^* \rightarrow q\gamma$	1γ	1 j	-	20.3	q" mass 3.5 TeV.	only u^* and d^* , $\Lambda = m(q^*)$	1309.3230
ê.ê	Excited quark q [*] → qg	-	2 j	-	13.0	q" mass 3.84 TeV	only v^* and d^* , $\Lambda = m(q^*)$	ATLAS-CONF-2012-148
SE.	Excited quark b* Wt	1 or 2 e, µ	1 b, 2 j or 1	i Yes	4.7	b" mass 870 GeV	left-handed coupling	1301.1583
2	Excited lepton $\ell^* \rightarrow \ell \gamma$	2 e.µ. 1 y	-	-	13.0	P mass 2.2 TeV	A = 2.2 TeV	1308.1364
	LRSM Majorana v	2 e,µ	2 j	-	2.1	N ^o mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e.µ	-	-	5.8	N ^a mass 245 GeV	$ V_{e} =0.055, V_{\mu} =0.063, V_{e} =0$	ATLAS-CONF-2013-019
2	Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$	2 e, µ (SS)			4.7	H11 mass 409 GeV	DY production, IIR($\mathcal{H}^{i+} \rightarrow \ell \ell$)=1	1210.5070
ð	Multi-charged particles	-	-	-	4.4	multi-charged particle mass 490 GeV	DY production, q = 4e	1301.5272
	Magnetic monopoles	-	-	-	2.0	monopole mass 862 GeV	DY production, $ g = 1g_D$	1207.6411
		√s =	7 TeV	√s = 8	8 TeV	10 ⁻¹ 1 1	⁰ Mass scale [TeV]	

"Only a selection of the available mass limits on new states or phenomena is shown.

LET'S MAKE SURE NOT TO LEAVE ANY SCALE BEHIND!



A ALEXANDER AND A CONTRACTOR

LET'S MAKE SURE NOT TO LEAVE ANY SCALE BEHIND!



*Not just a commentary on the USA being left behind on the Energy Frontier

THE ONLY NEW PHYSICS WE'VE FOUND SO FAR IS THE HIGGS

Is there anything else lurking at the EW scale? (remember the CDF Wjj saga...)

It's difficult to go after this scale... It runs contrary to deep ingrained desire of BSM experimentalists **not** to trust theorists and do everything in a "data-driven" manner

DATA-DRIVEN SEARCHES...



DATA-DRIVEN SEARCHES...

- Based on being able to separate signal and control regions
 - What if there isn't a good place where the signal isn't?
 - Assumes shapes extrapolate almost perfectly, don't trust MCs for normalizations...
 - If there are exceptions, this doesn't just have dire consequences for searches, but for the Higgs as well in principle!

ARE THERE ANY POTENTIAL DISCREPANCIES IN THE DATA?

- some discrepancies:²
 - p_T of the individual top quarks in $t\bar{t}$
 - p_T of the leptons in W^+W^-
- difficult to describe both minimum bias (MB) and underlying event (UE) data with the same tune
- http://mcplots.cern.ch
 - a good overview of the distributions and comparisons (for many event generators and tunes)

²There are some disagreements between ATLAS and CMS on which ones.

ARE THERE ANY POTENTIAL DISCREPANCIES IN THE DATA?

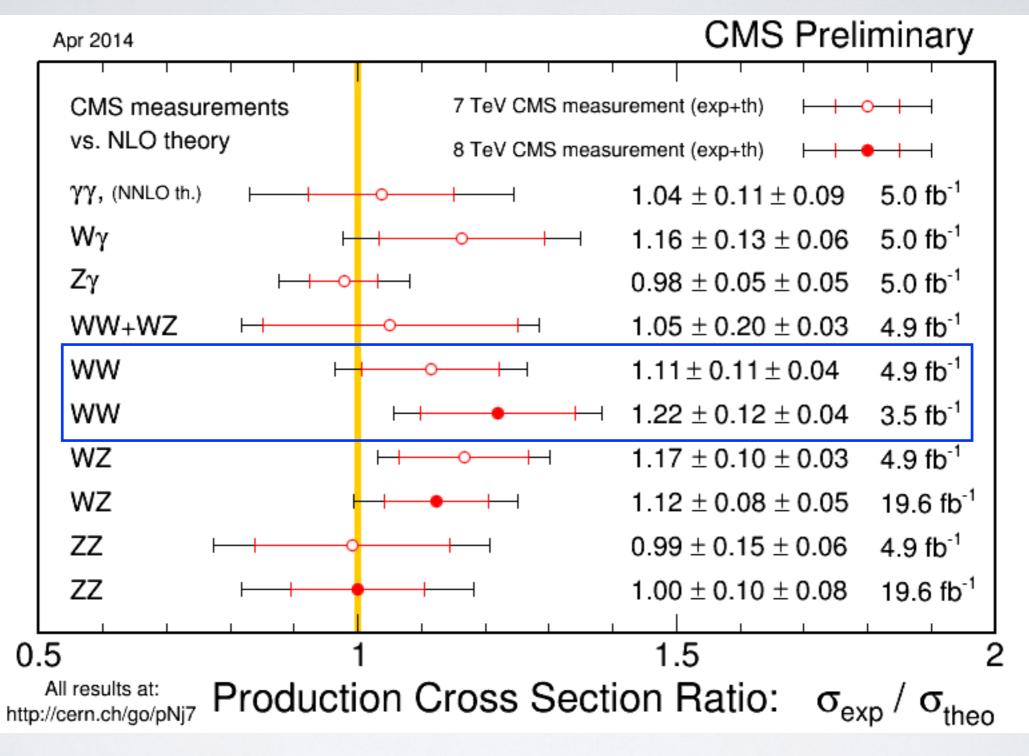
- some discrepancies:²
 - p_T of the individual top quarks in $t\bar{t}$
 - p_T of the leptons in W^+W^-
- difficult to describe both minimum underlying event (UE) data with the put this on his slide...
- http://mcplots.cern.ch
 - a good overview of the distributions and comparisons (for many event generators and tunes)

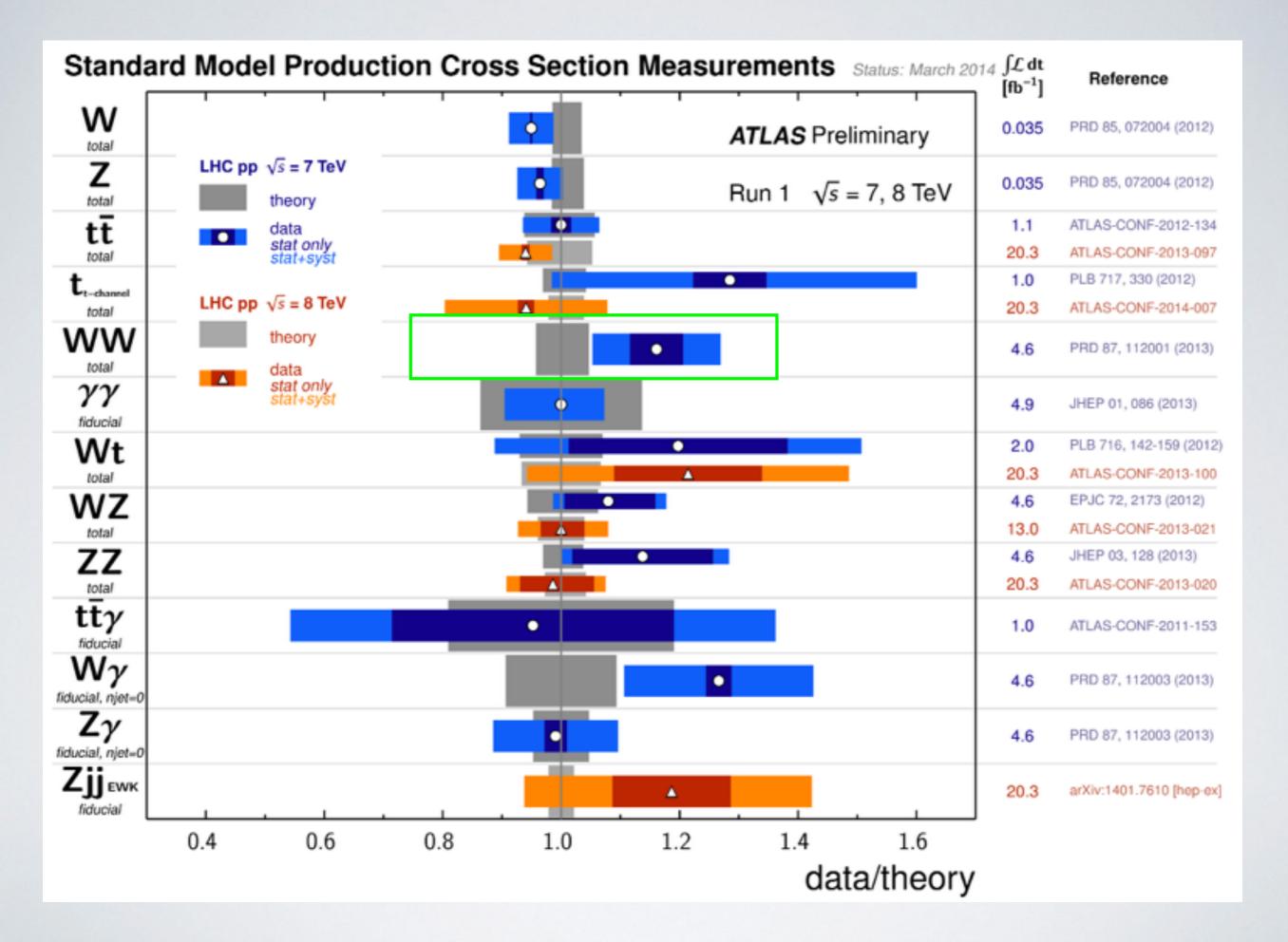
S. Mrenna Talk

*I didn't pay him to

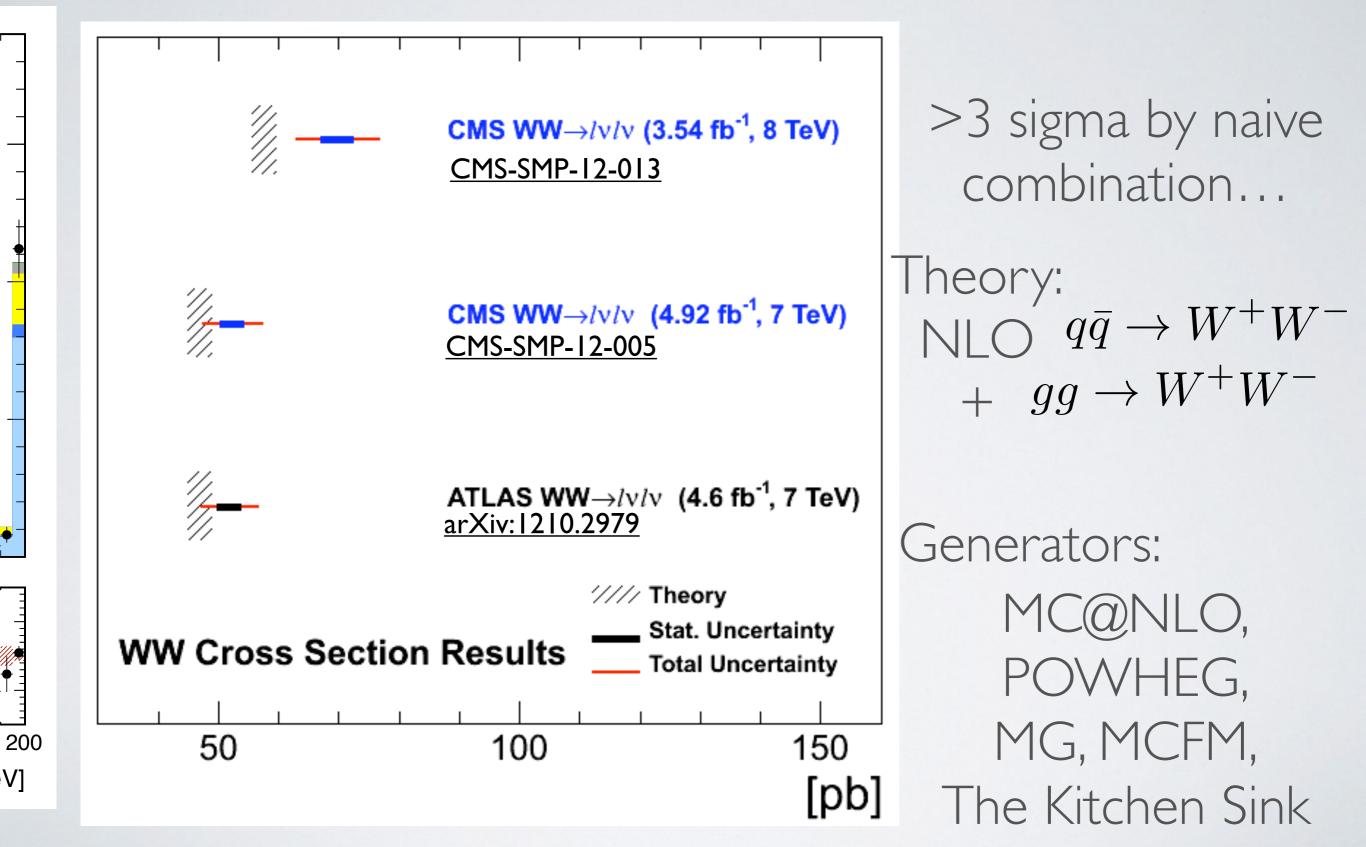
²There are some disagreements between ATLAS and CMS on which ones.

THERE'S MORETO IT!





Results (CMSUAL'ÉVIDENCE''



WW CROSS SECTION

- In principle the LHC makes 8 measurements highly sensitive to the WW cross section
 - SM WW at CMS7, ATLAS7, CMS8) ATLAS8
 - h→WW at CMS7, ATLAS7, CMS8, ATLAS8
- What's the status? Every reported* measurement is higher than the SM

NOT JUST THE SM GROUPS

Control Region estimates at 8TeV-ATLAS

Estimate	Nobs	$N_{\rm bkg}$	N _{sig}	N_{WW}	N_{VV}	$N_{t\bar{t}}$	N_t	N_{Z/γ^*}	N_{W+jets}
WW									
$N_{\text{jet}} = 0$	2224	1970 ± 17	31 ± 0.7	1383 ± 9.3	100 ± 6.8	152 ± 4.4	107 ± 4.3	68 ± 10	160 ± 3.6
$N_{\rm iet} = 1$	1897	1893 ± 17	1.9 ± 0.3	752 ± 6.8	88 ± 5.5	717 ± 9.5	243 ± 6.7	37 ± 7.5	56 ± 2.5

Full luminosity @ 8 TeV!

Discrepancy **must** exist with full lumi when SM groups publish

NOT The Nobel Prize in Physics 2013

Control R

Nobs	N_{b}
2224	1970
1897	1893
	2224

Ful

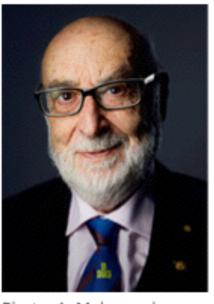


Photo: A. Mahmoud François Englert Prize share: 1/2



Photo: A. Mahmoud Peter W. Higgs Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

Discrepancy **must** exist with full lumi when SM groups publish

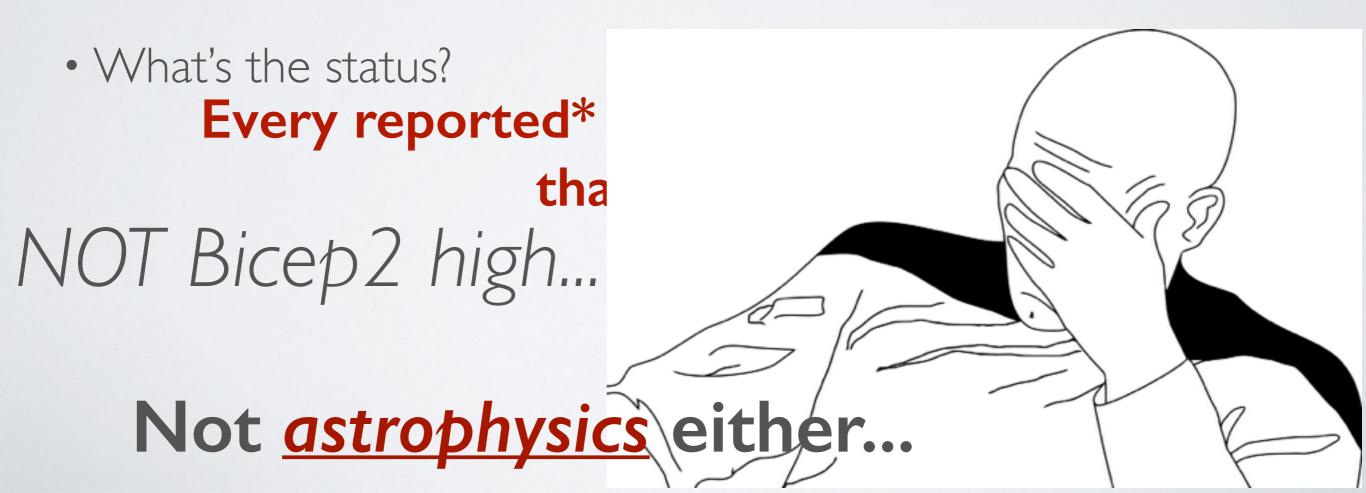
١T	LAS	
γ*	N _{W+jets}	
± 10 ± 7.5	160 ± 3.6 56 ± 2.5	

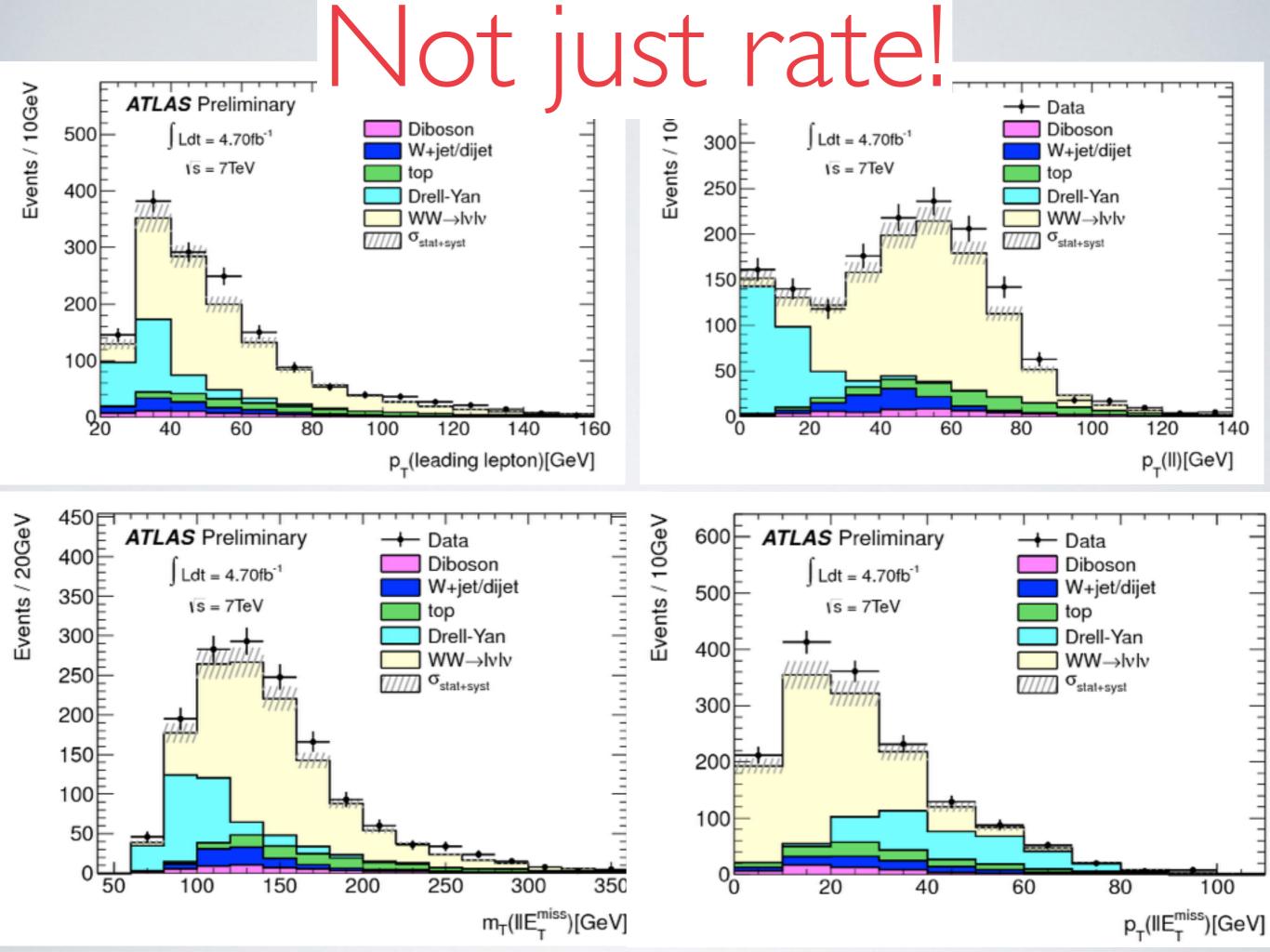
WW CROSS SECTION

- In principle the LHC makes 8 measurements highly sensitive to the WW cross section
 - SM WW at CMS7, ATLAS7, CMS8) ATLAS8
 - h→WW at CMS7, ATLAS7, CMS8, ATLAS8
- What's the status? **Every reported* measurement is higher** than the SM NOT Bicep2 high... only a few sigma

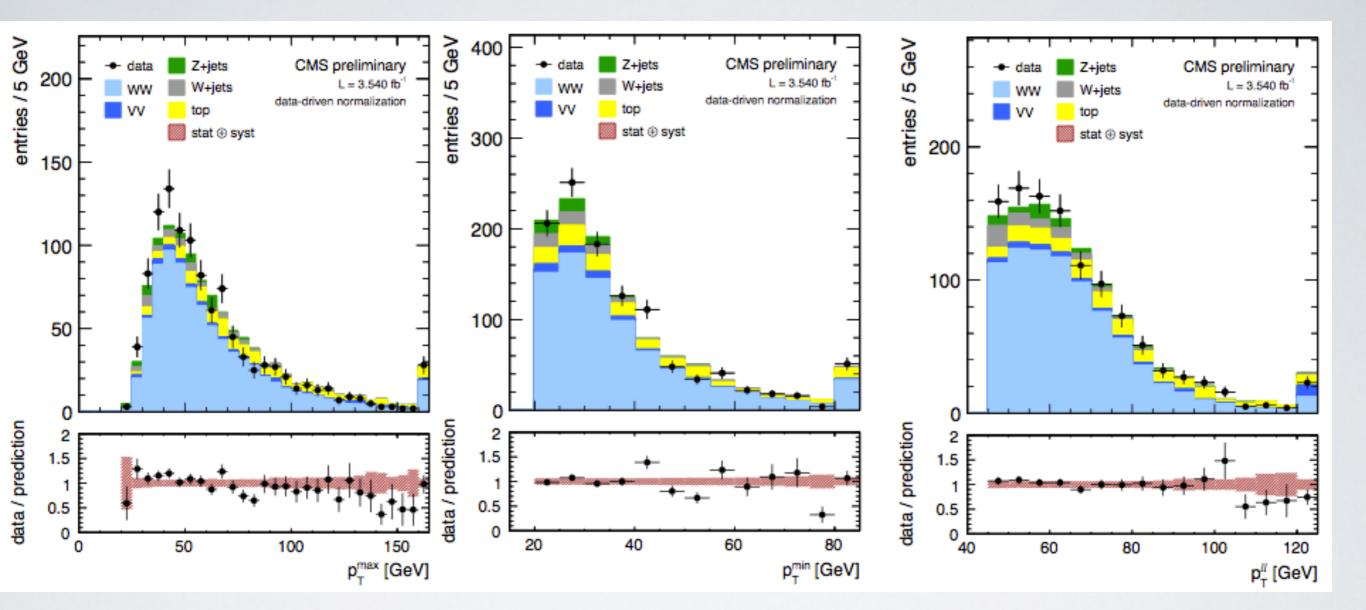
WW CROSS SECTION

- In principle the LHC makes 8 measurements highly sensitive to the WW cross section
 - SM WW at CMS7, ATLAS7, CMS8)ATLAS8
 - h→WW at CMS7, ATLAS7, CMS8, ATLAS8





CMS8

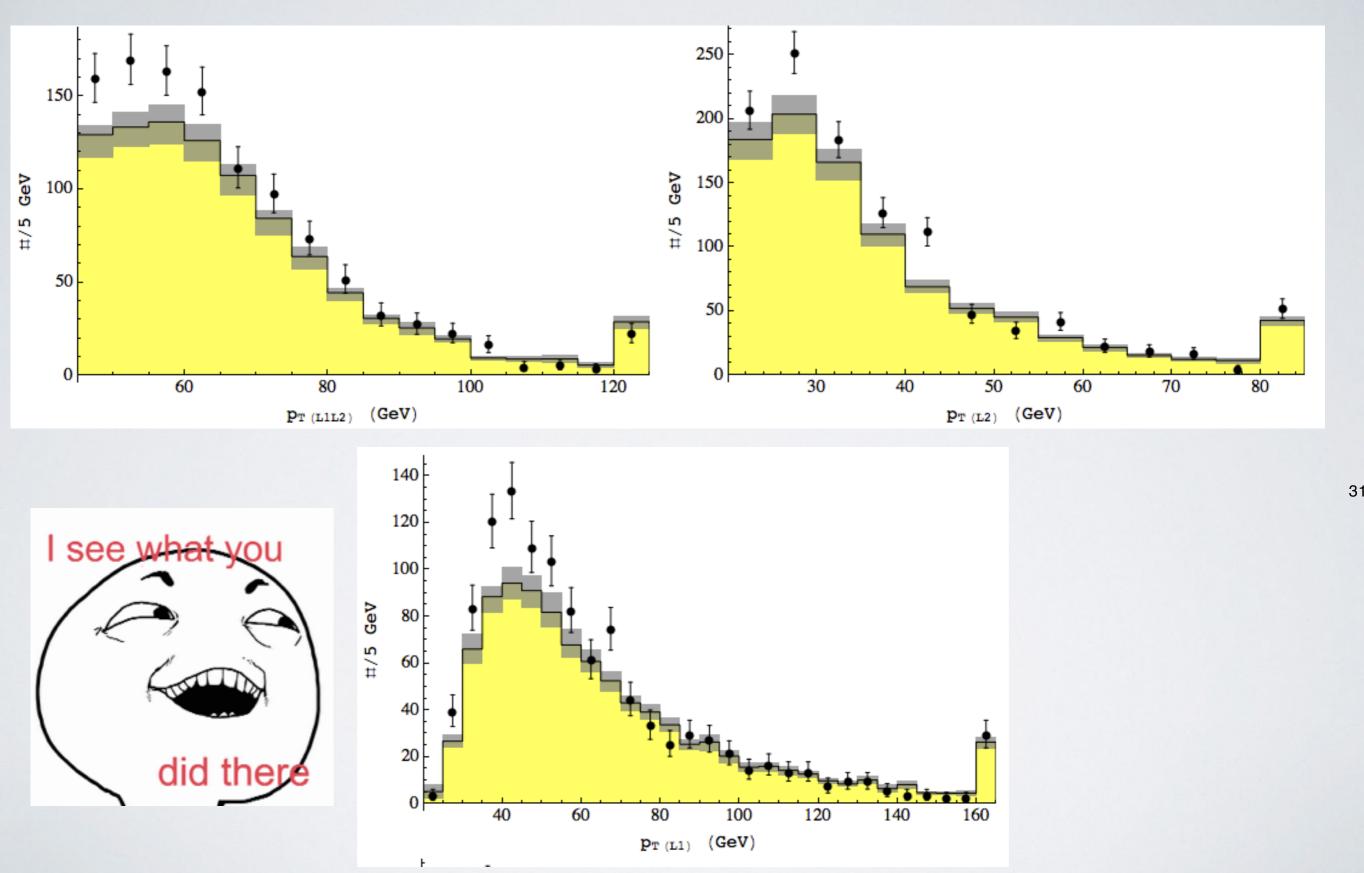


Looks pretty good...

CMS8



NO EXTRA NORMALIZATION...



CMS 8 TEV 3.5/FB

WW $\rightarrow 2\ell 2\nu$ at 8 TeV: systematics & results



 σ = 69.9 ± 2.8 (stat) ± 5.6 (sys) ± 3.1 (lum) pb NLO prediction (MCFM): 57.25 ($^{+2.35}_{-1.60}$) pb

Already 4% statistical precision About 1.8σ higher than the NLO prediction

It grows at 8 TeV even faster!
$$\sigma(8) \\ \sigma(7) \Big|_{th} = 1.21$$
 $\frac{\sigma(8)}{\sigma(7)} \Big|_{exp} = 1.33$

Upward fluctuations in **all** measurements **Or** a trend?

If a trend... then what explains it??

New Physics

SM calculation wrong "Old QCD?"

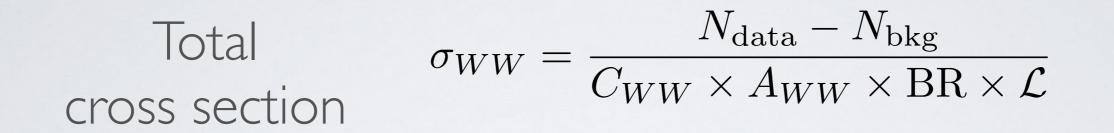
Need around a 20% effect on WW!!

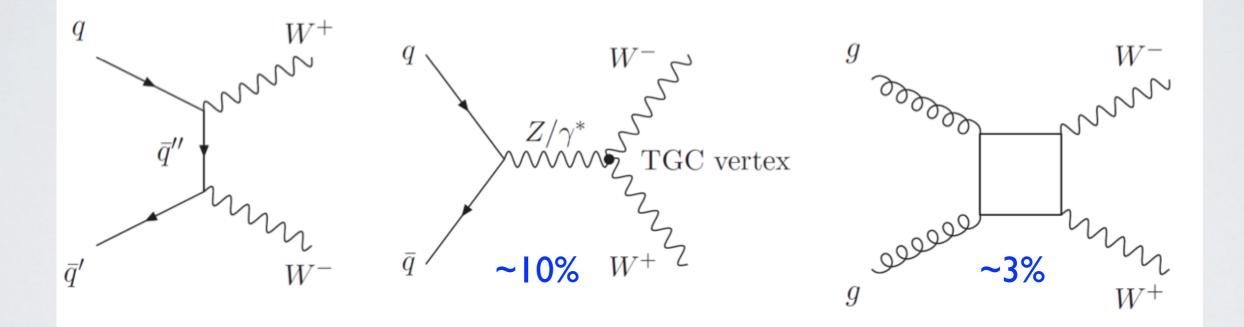
A LONG AND WINDING TALE...



INGREDIENTS FOR AN EXPLANATION

 Need to first understand what it MEANS to measure the WW cross section! **IOCESS**

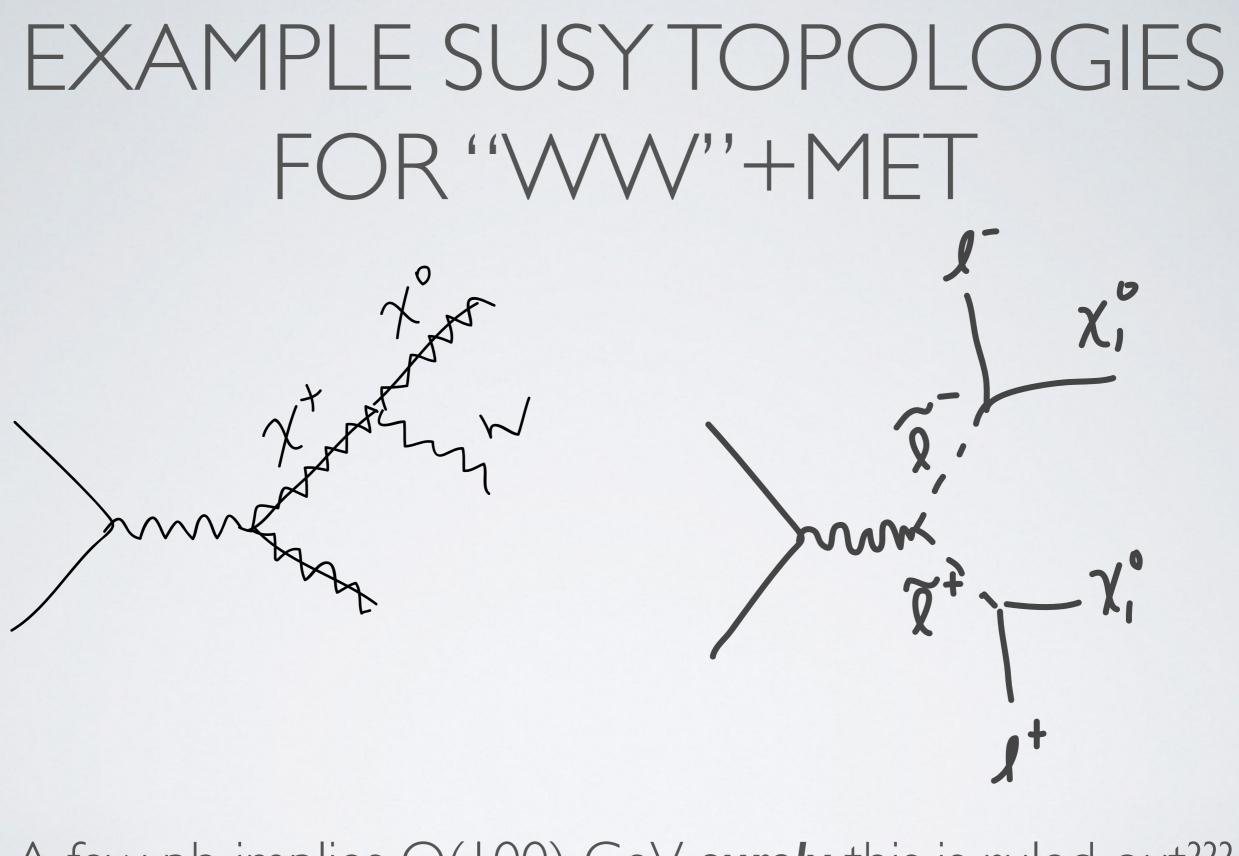




Count opposite sign dileptons + MET in a fiducial region with *a jet veto* and a few other requirements

INGREDIENTS FOR BSM EXPLANATION

- ATLAS and CMS both measure OS dileptons + MET with a jet VETO
- Final state needs to be OS leptons+MET with nothing else essentially
- Does NOT imply there have to be REAL W's
- Need a cross section of a few pb!



A few pb implies O(100) GeV surely this is ruled out???



A few pb implies O(100) GeV surely this is ruled out???

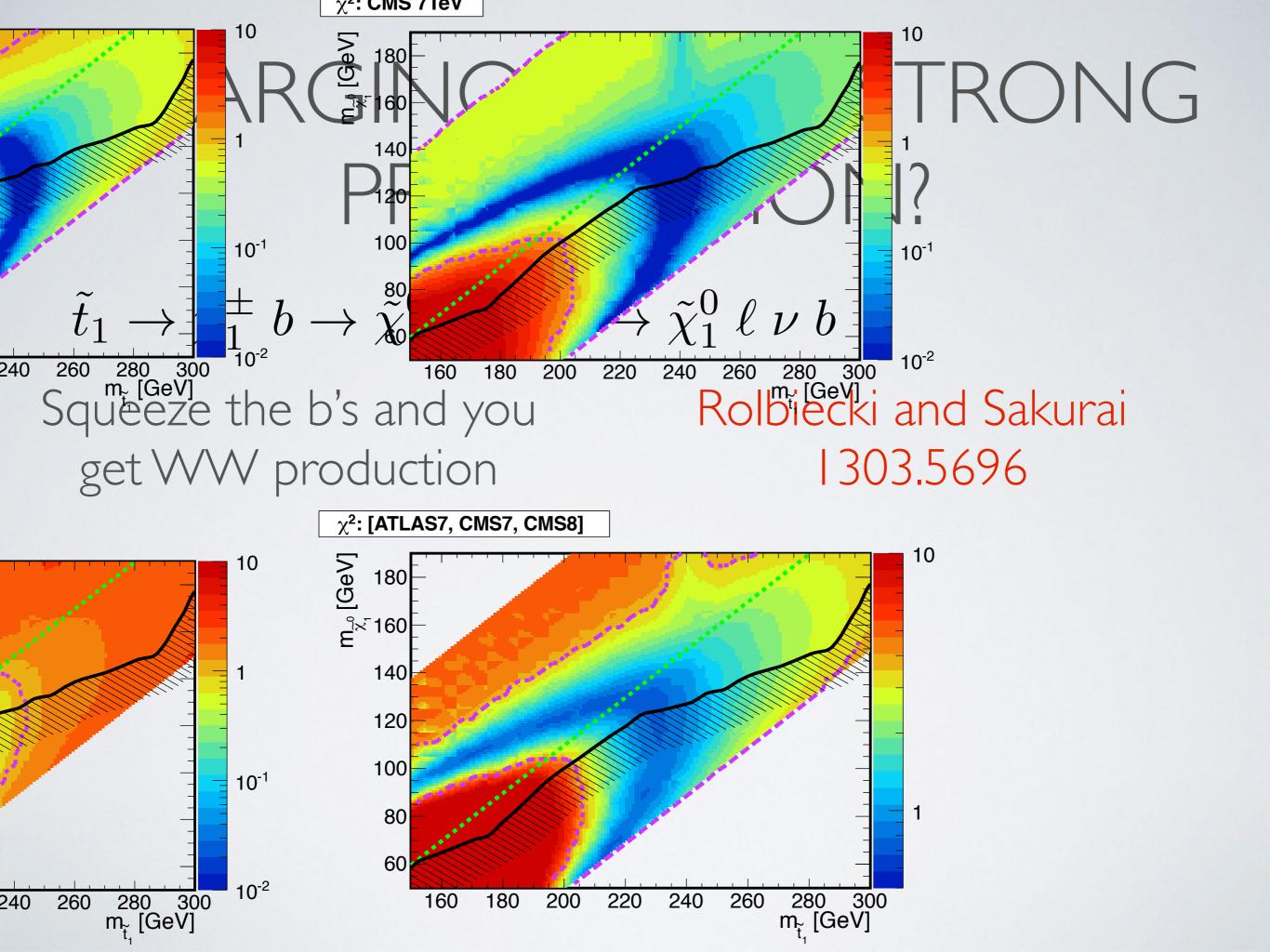
ATLAS 7 - CHARGINOS



BETTER THAN OKAY!

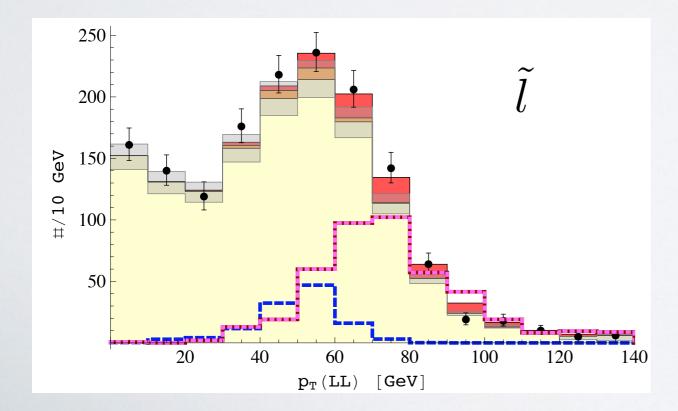
CHARGINOS FROM STRONG PRODUCTION?

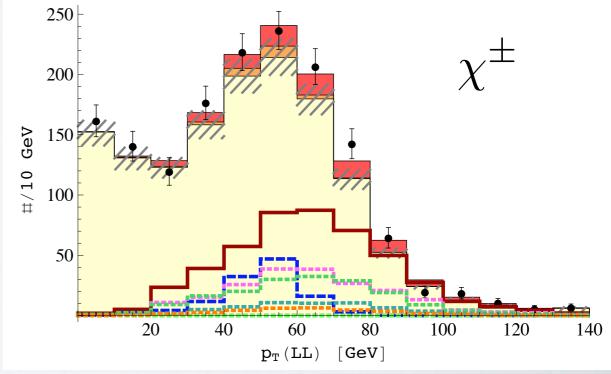
by the Rolbiecki and Sakuran 1303.5696 $\tilde{t}_1 \to \tilde{\chi}_1^{\pm} b \to \tilde{\chi}_1^0 W^{(*)} b \to \tilde{\chi}_1^0 \ell \nu b$



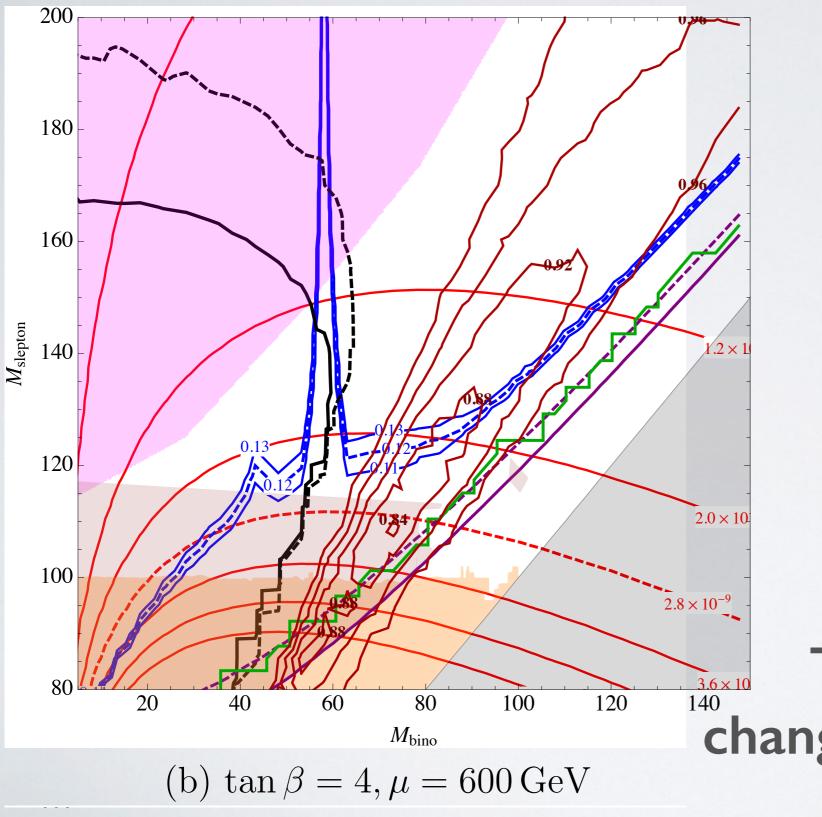
TURNS OUT SLEPTONS FIT JUST AS WELL... ~ 110 GeV $\widetilde{e}, \widetilde{k}, \widetilde{\tau}_{i,k}$ 1304.7011

 $\sim 60 \,\mathrm{GeV} - \chi^{o}$





SLEPTONS DO A LOT MORE!



Bino DM works with light sleptons - BLUE

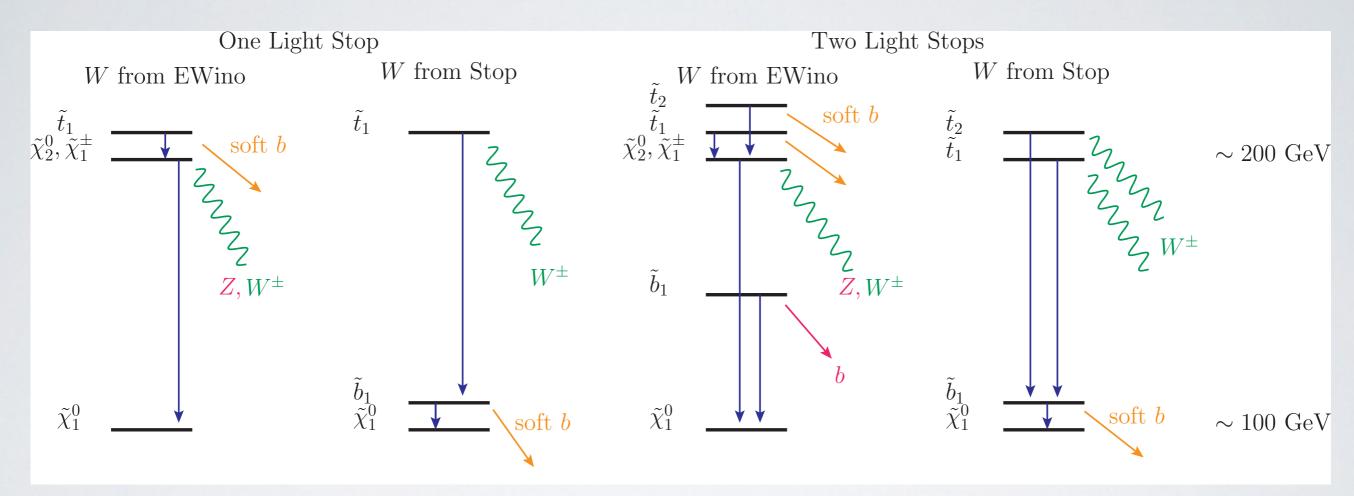
> g-2 anomaly -RED Dashed

WW improvement -RED contours

This model ALSO changes the interpretation of the Higgs!!

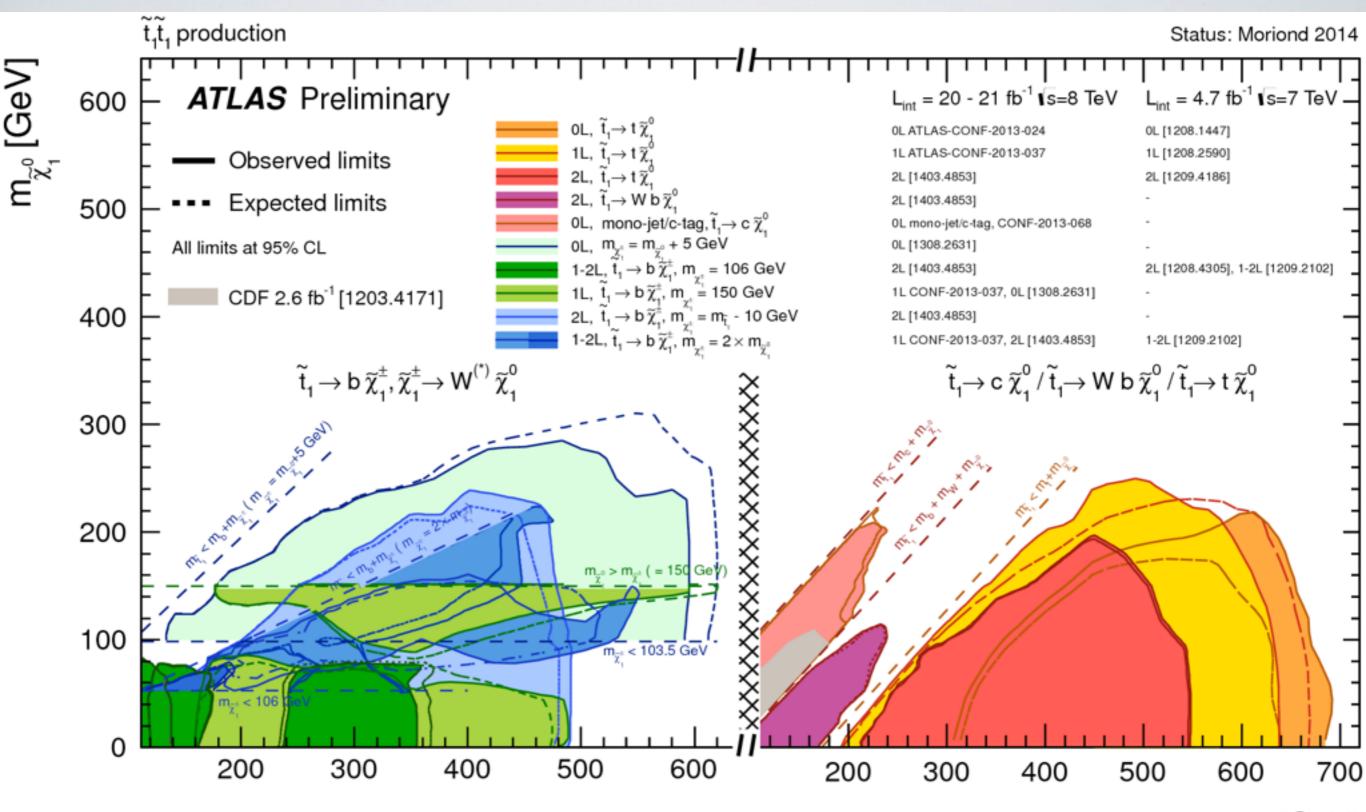
MANY MORE POSSIBILITIES

D. Curtin, PM, P. Tien (1406.xxxx tomorrow morning)

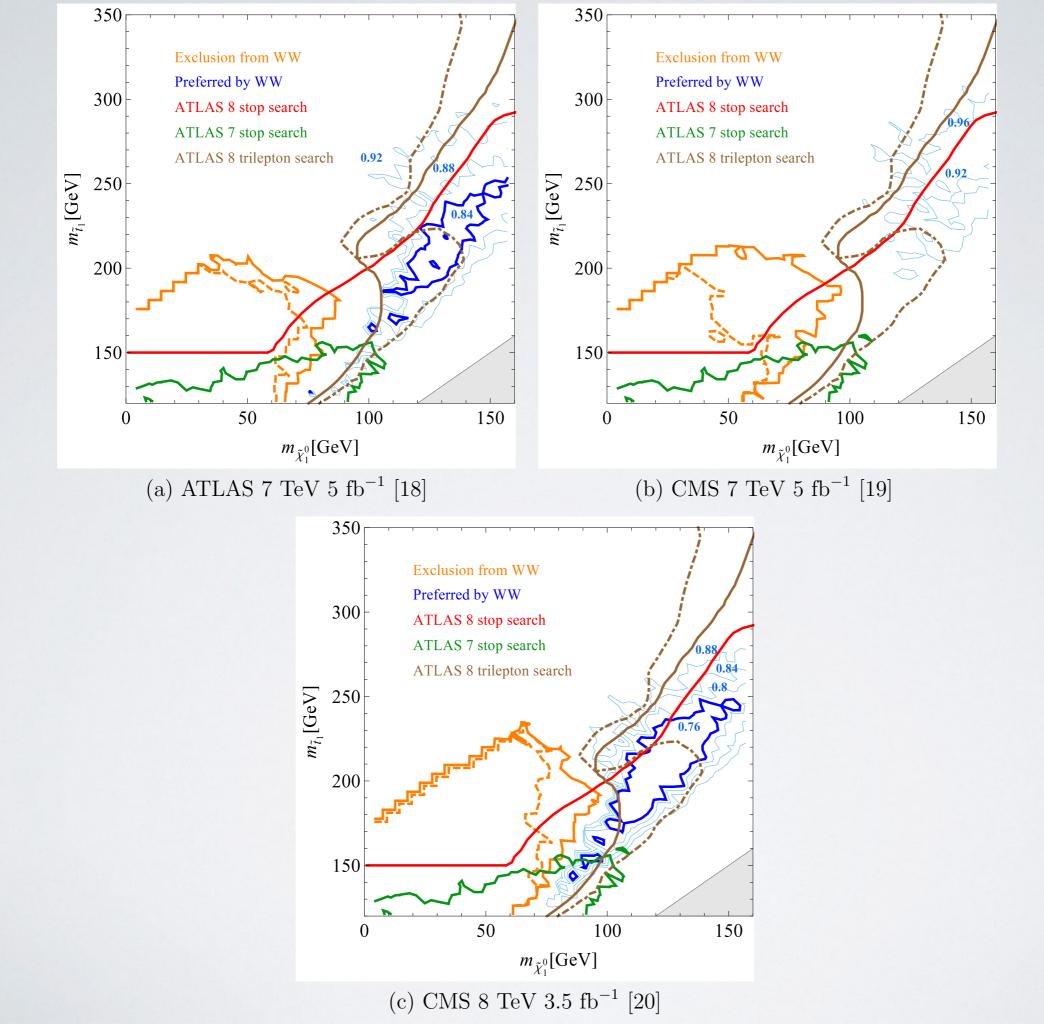


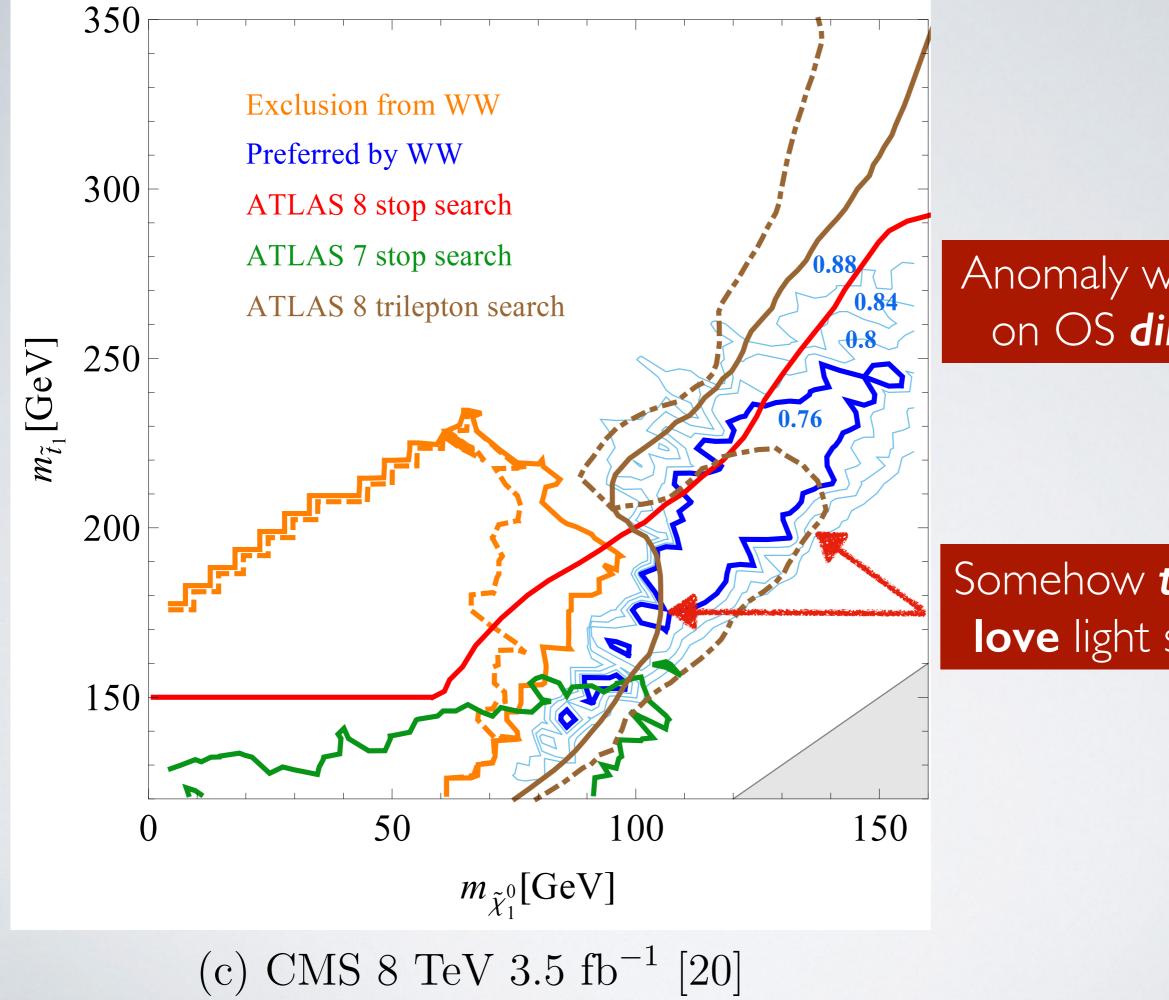
YOU CAN HAVE NATURAL SUSY AS ENVISIONED

SURELY YOU JEST??



 $m_{\tilde{t}_{i}}$ [GeV]



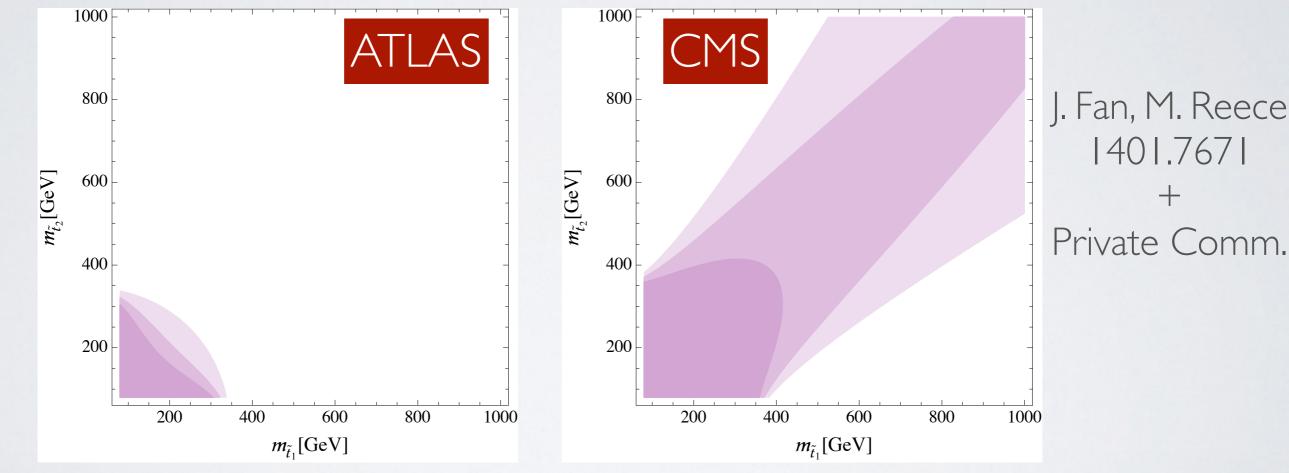


Anomaly was based on OS dileptons

Somehow trileptons love light stops...?

CAVEATS OF COURSE

- Doesn't account for Higgs Mass, but go to D-terms/NMSSM/ model build
- light stops will affect higgs couplings via loops! Status is still uncertain...



MANY POSSIBILITIES...

- Charginos at O(100) GeV
- Sleptons at O(100) GeV
- Stops at O(200) GeV

D. Curtin, P. Jaiswal, PM 1206.6888 Rolbiecki and Sakurai1303.5696 D. Curtin, P. Jaiswal, PM, P.Tien 1304.7011 D. Curtin, PM, P.Tien 1406.xxxx (wednesday night EDT) Kim, Rolbiecki, Sakurai, Tattersall 1406.xxxx (wednesday night EDT)

- All can improve the measurement of the WW cross section compared to the SM!!!!!!
 - Consistent with other LHC Data
 - Can explain DM/g-2
 - Can give a natural SUSY spectra

It just seems easier to do than many other "excesses" top A_{FB} ,multi-muons, CDF Wjj, CDF inclusive signal charged particle

TESTABLE CONSEQUENCES OF NEW PHYSICS

- Charginos lead to SS dileptons
- Sleptons lead to a flavor diagonal excess
- Stops eventually lead to higgs shifts/trileptons/soft b searches
- Important to note that all of these are NP signatures that IMPROVE on the SM as we know it...
 - Other new physics can/is being hidden normally within error bars, even if the parameter space is cut it will be important to look at these possibilities that live in the "space beyond errors…"

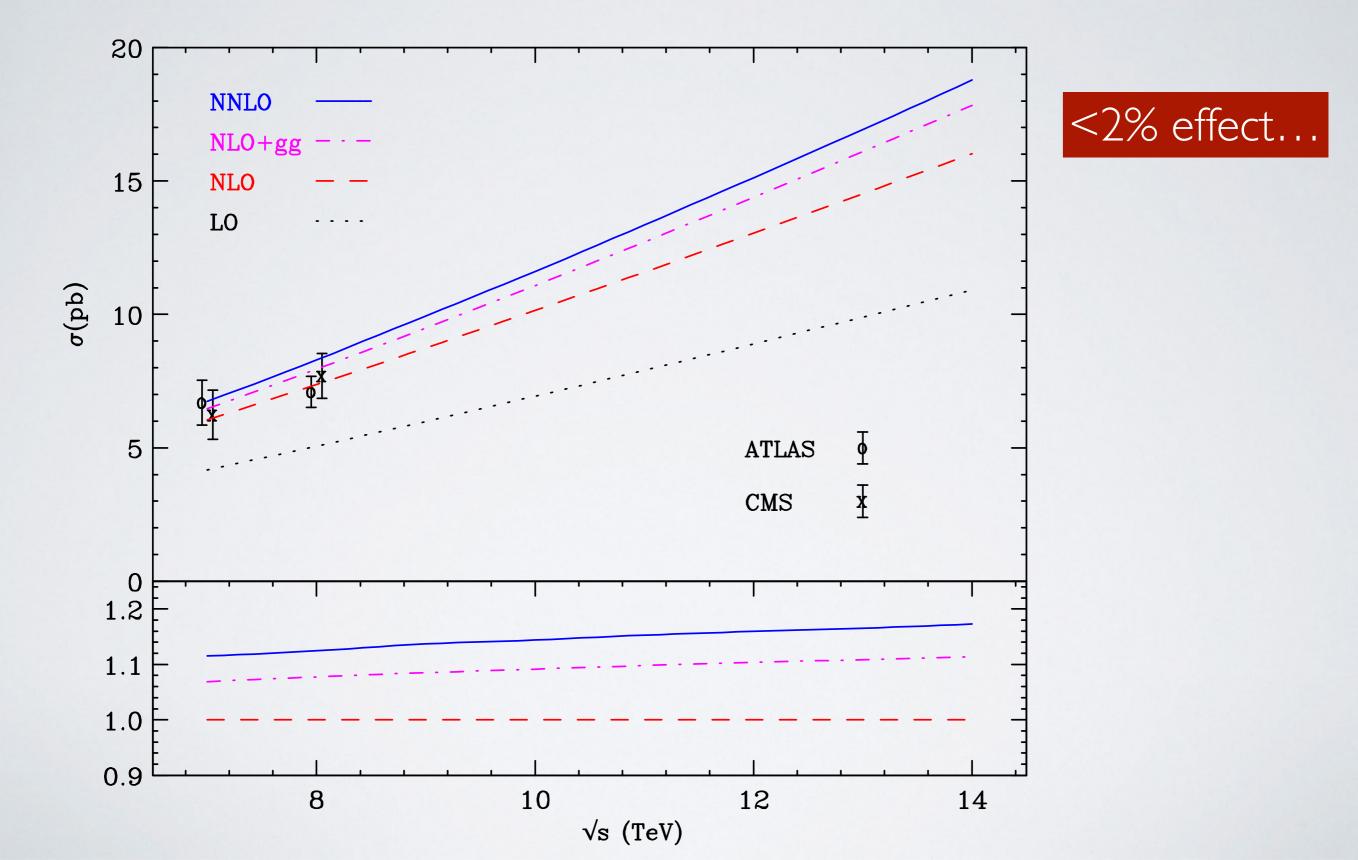
SM/EXPERIMENTAL POSSIBILITIES???

- Backgrounds Wrong Negligible effect?
- WW cross section wrong (k-factors 1.6ish need a 20% NNLO effect, not demonstrated in ZZ very recently)
 - higgs interferes destructively
 - EW NLO reduces as well
- Systematics

WHY DOES $\sigma(pp \rightarrow ZZ)$ AGREE?

|405.22|9 ZZ production at hadron colliders in NNLO QCD

F. CASCIOLI^(a), T. GEHRMANN^(a), M. GRAZZINI^{(a)*}, S. KALLWEIT^(a), P. MAIERHÖFER^(a), A. VON MANTEUFFEL^(b), S. POZZORINI^(a), D. RATHLEV^(a), L. TANCREDI^(a) and E. WEIHS^(a)



HOW DO WE IMPROVE QCD PREDICTION?

- NNLO
- Resummation for WW
 - threshold (S.Dawson et al 1307.3249)
 - pT resummation (Grazzini 0510337, Wang et al, 1307.7520, PM, H. Ramani, M.Zeng to appear)
 - jet veto

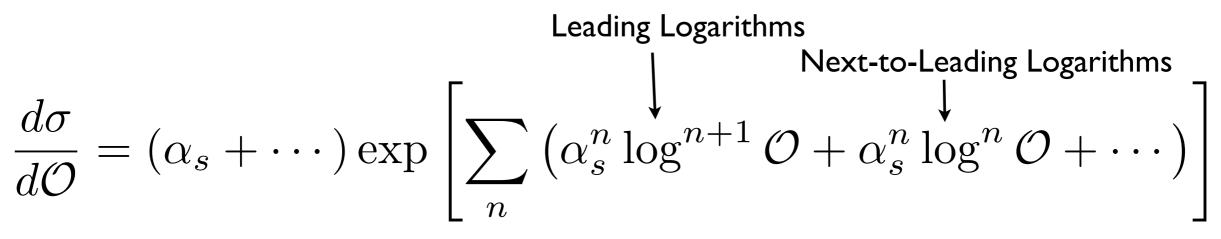
A. Larkoski

 $d\sigma$

 $\overline{d\mathcal{O}}$

Age-old procedure





Resummation Region

Methods of resummation

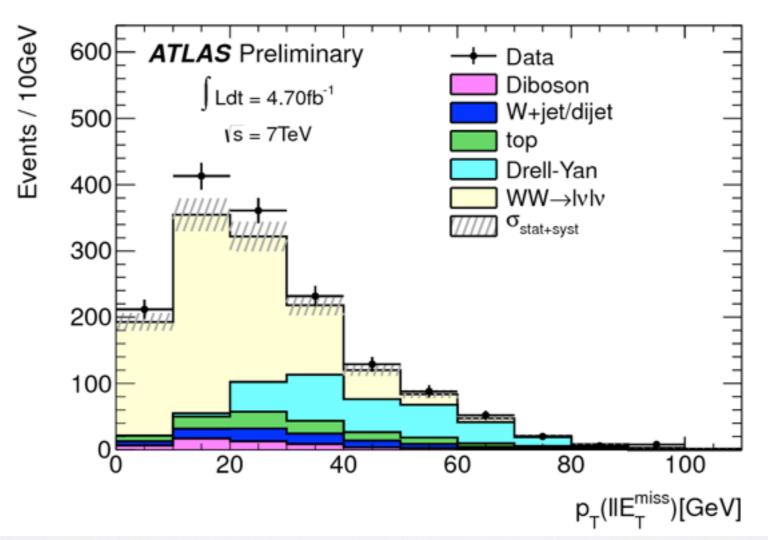
Analytical Effective Theory Methods: Resummaton by renormalization

> Monte Carlo Parton Shower: Numerical approximation to all-orders matrix element

Whenever there's factorization, there's evolution, and whenever there's evolution there's resummation G.Sterman

Fixed-Order Region

TRANSVERSE MOMENTUM RESUMMATION



Given the jet veto, this **all** is dependent on soft QCD Need this to get things right like W mass measurements (D0 used Collins, Soper, Sterman formalism to attain precision)

DIFFERENCES W/ PARTON SHOWER ResBos WEBSITE

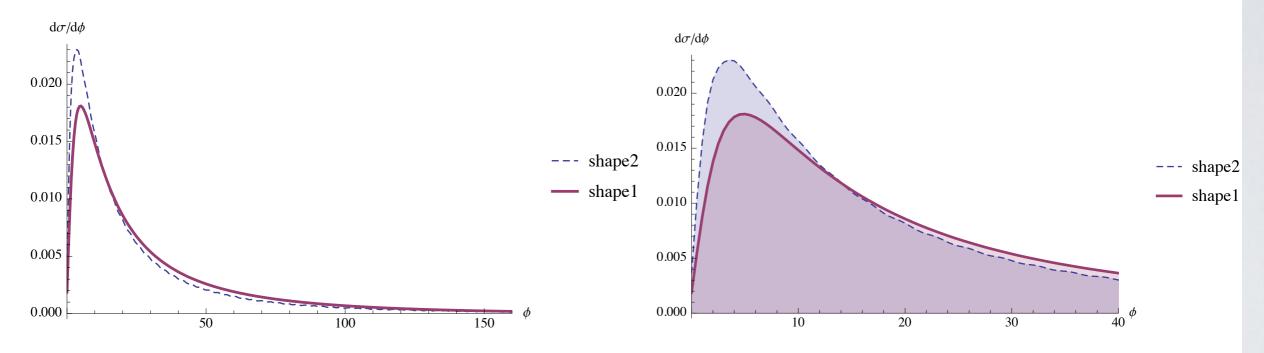
Analytical Q _T resummation	Parton showering programs (Pythia, MC@NLO, Sherpa)			
 evaluate(s) effects of multiple parton radiation in hadronic scattering 				
 applies to a restricted class of processes and observables (e.g., lepton distributions in Drell-Yan-like processes); inclusive with respect to hadronic radiation 	 apply to a wide range of observables; exclusive with respect to hadronic radiation 			
 is proved to all orders in the QCD coupling by special factorization theorems devised for each qualified observable 	 no factorization proofs for individual observables 			
 streamlined computation of higher-order corrections and high-p_T 	 beyond the leading order, radiative contributions and high-p_T tails may be 			
contributions	difficult to implement			
 NLO Q_T resummation formulated in 1979-1997; 	 modern showering programs approach NLO accuracy 			
modern Q _T resummation approaches NNLO accuracy				
• resummation of all logarithms $ln Q_T^2/Q^2$	• resummation of leading logarithms $ln Q_T^2/Q^2$			
 nonperturbative contributions are constrained by invoking their universality in the considered class of processes 	 nonperturbative scattering is evaluated in one of several available models 			
 more strict and precise; relies on first principles of perturbative QCD 	 more flexible; more parameters to tune to describe various hadronic scattering effects 			

Transverse momentum resummation changes shape not cross section!

CAN'T DO THIS SOLELY ANALYTICALLY -FIDUCIAL G_{Fid} = G_{Fid}

 $\sigma_{fid} = \sigma_{total} \epsilon.A.Br$

However if resummation causes a shape difference...



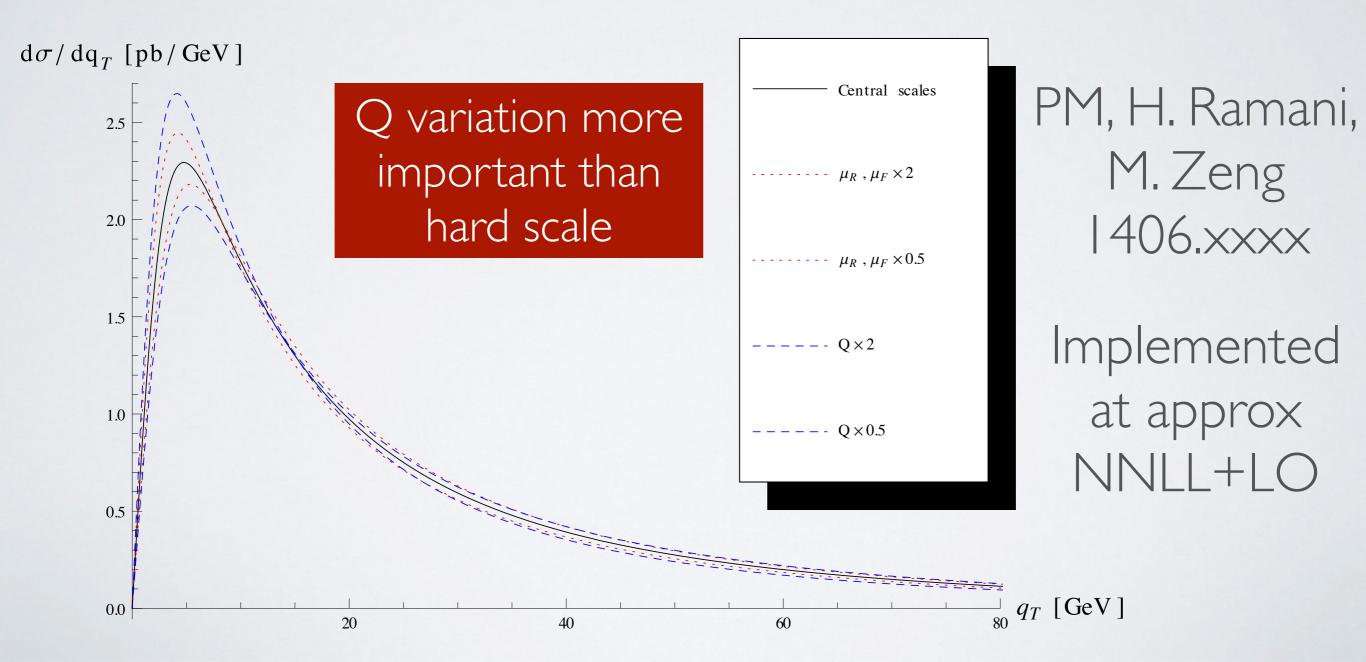
Full Phase-space. Both curves Normalized to unity. Shape effect translates to different Fiducial cross-section

CAN GET LARGE SHAPE DIFFERENCES FROM MATCHING IN RESUMMATION

- There are various different ways to do transverse momentum resummation, typically you don't work in qT you work in "b" space - problem is how to deal with small qT
 - Work in qT space directly in some approx (Dokshitzer and others)
 - CSS formalism cut off b space softly (ResBos uses this)
 - CDG formalism play with contour integral in b space
 - others as well

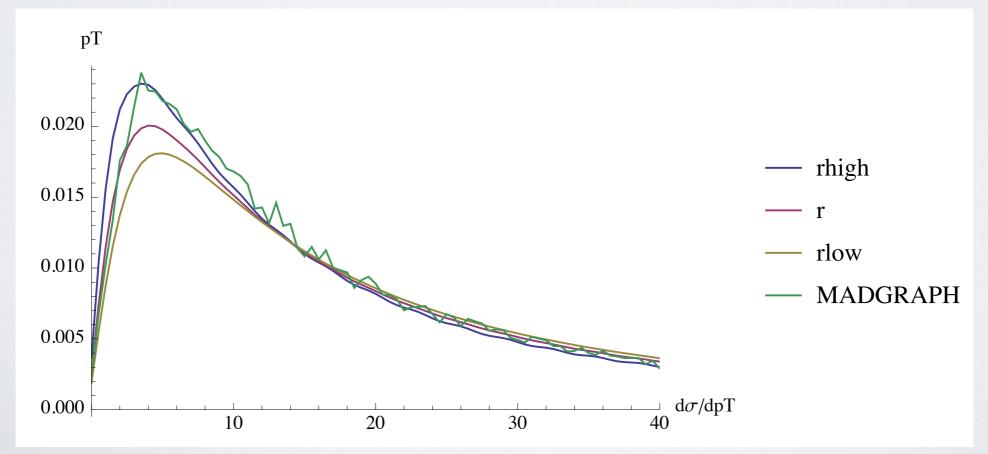
CAN GET LARGE SHAPE DIFFERENCES FROM MATCHING IN RESUMMATION

• We use CDG formalism, in this there is a matching/ resummation scale Q between fixed order and resummation



THE PROBLEM WITH TRANVSERSE MOMENTUM RESUMMATION AND COLLIDERS

- We don't have events, we've summed over all our gluons!
- There isn't an ''unfolded'' WW pt from experiments
- Have to come up with a proxy to get to fiducial cross section... come up with proxy, reweight MC events a la the Higgs group to see if underlying differences persist!



FIDUCIAL CROSS SECTION EFFECTS EXAMPLE

Cut-flow vs reweighted events

Cut	%	
exactly 1 pair of oppositely charged leptons +MET	0	
p_t and η cuts on leptons	0.06%	
mll cuts	-0.32%	
$E_{TMiss,rel}$	1.16%	
Jet Veto	8.37%	
p_{Tll}	8.50%	

PRELIMINARY 8 TEV RESULTS

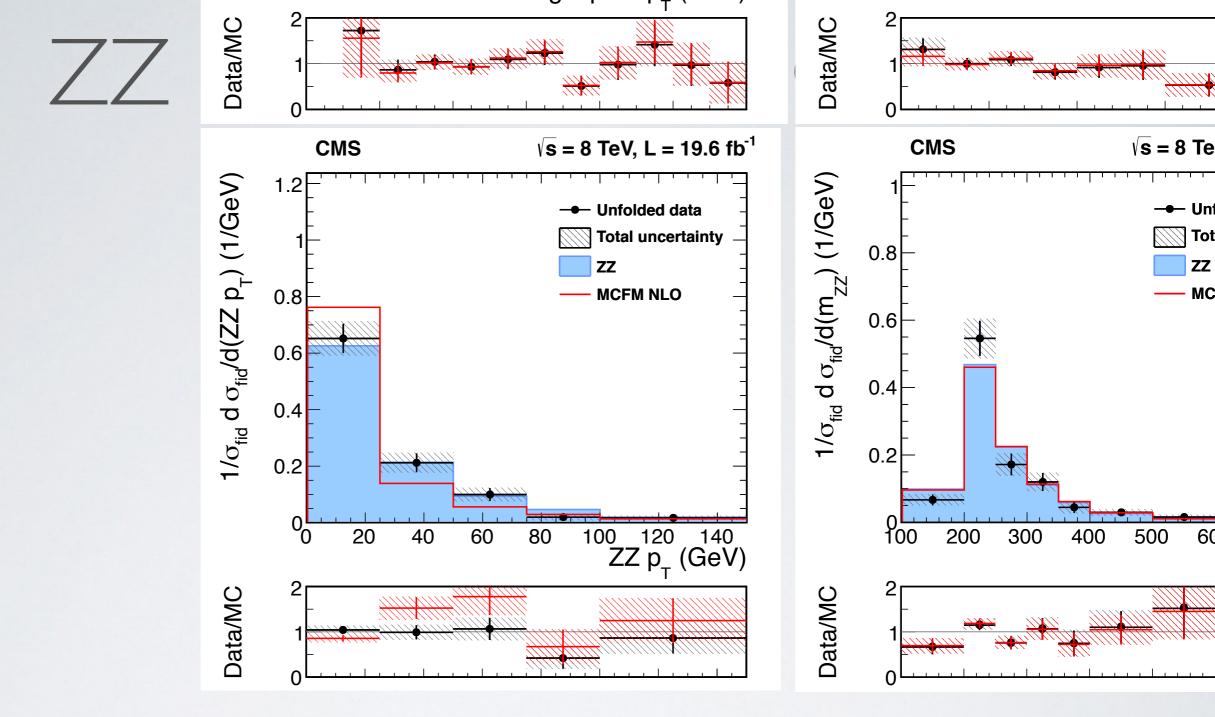
MC	Percentage Increase Q=mW/2	Percentage Increase Q=mW	Percentage Increase Q=2mW
Powheg+Pythia	4.05	0.16	-5.35%
aMC@NLO +Herwig	8.50	2.98	-0.82
Madgraph +Pythia	-1.13	-5.94	-8.88

 μ_{res}

 μ_{res}

 μ_{res}

Transverse Momentum Resummation can have an effect, but it should be UNIVERSAL...



The agreement between PowHEG and ZZ is very good

Correlation then with PowHEG and resummation in WW is crucial

EXPLORING JET VETO EFFECTS DIRECTLY?

- Jet veto scale ~25-30 GeV introduces a new scale in the problem, and hence logs
- A number of groups have investigated this for Higgs/Drell-Yan

Banfi, Salam, Zanderighi/Stewart, Tackmann, Walsh, Zuberi and others

- This should be studied directly for SM WW
 - Similar to Banfi et al 1203.5773 comparison between HqT and jet vetoes

CONCLUSIONS...

- There could be BSM right around the corner: understand WW!!!!
 - Charginos, Sleptons, Stops all can fit better than the SM, or certainly exist at low energies!!!!!!!!!!
 - Can **also** set new bounds better than experimentalists using SM cross sections!
 1304.7011
- Important to get QCD predictions/MC as accurate as possible to push back on experimentalists
 - Transverse momentum resummation can have an effect on WW, but it can go both wa and we have to understand the best scale choice
 - jet veto resummation or joint pt/eta resummation would be useful to investigate
 - Experimentalists need to care just as much about background shapes as signal
- Crucially important to get EW scale correct before pushing higher, as it can have serious implications for Higgs physics! Experimentalists also tend not to revisit things...