Unitarized models of VV scattering at the LHC. From 7 to 14 TeV.

What if no Higgs shows up?

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Implications of LHC results for TeV-Scale physics – CERN 26-30 March 2012

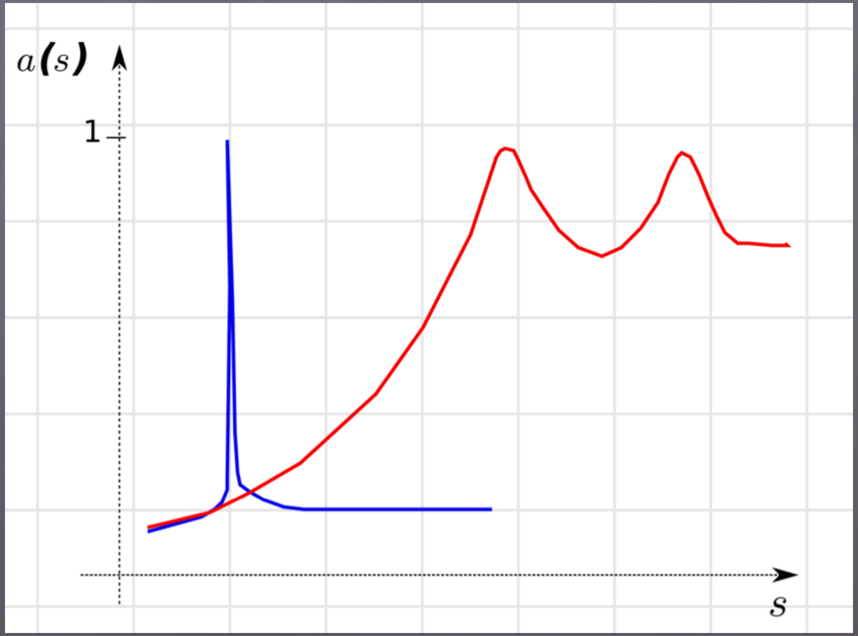
Outline

Update on results presented by A. Ballestrero at the WG1 September meeting

- Brief introduction
- Recall implementation of unitarized models of Vector Boson Scattering (VBS) in the event generator PHANTOM with complete 2→6 m.e.
- Review results at 14 TeV: combining all channels it appears likely unitarized model could be detected as an excess of events compared to SM predictions
- Present results at 7, 8 and 10 GeV: only some model will be within reach. Energy is crucial. Limits on relevant parameters can be set

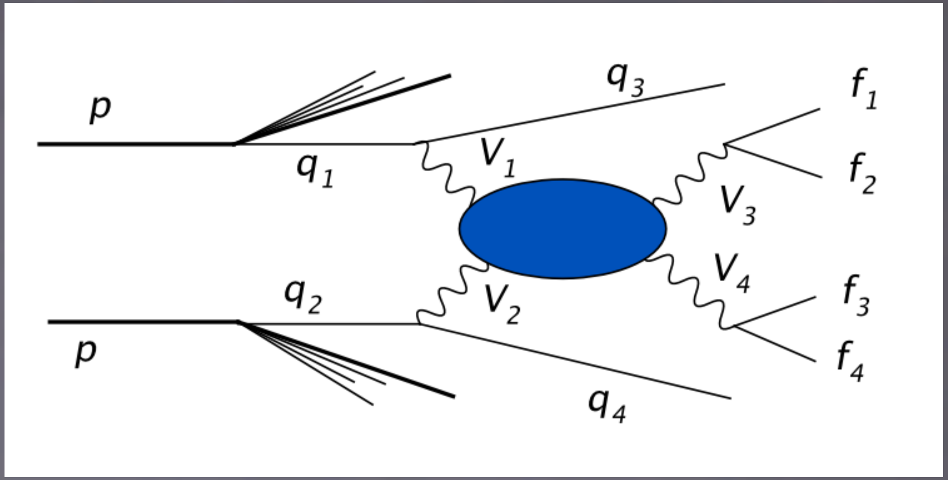
If the Higgs is found: VBS amps predicted to remain small
Ultimate test of SM description of EWSB

If the Higgs is NOT found: VBS amps grow with s at "threshold"
Nothing in the SM to tame this growth
In the absence of new physics violate unitarity ~1.7 TeV
Best hunting ground for hints of new physics of EWSB
Expect resonances as in ππ physics



VBS is not the only Weak process in which unitarity is violated
In all other cases the violation happens at larger cm partonic energy

LHC:2j+VV



PDF → dσ/dM_{VV} decreases at large M_{VV}
Look for possible increases in VV+2j production wrt SM
Large gauge cancellations between scattering and non scattering diagrams

VV → 2j+2l semileptonic channels. VV mass can be reconstructed.
"Large" rate, Large bkg: QCD V+4j (NLO BlackHat), tt(+jets)

VV → 4l leptonic channels (NLO Zeppenfeld,Greiner). If more than one neutrino VV mass cannot be reconstructed.
"Small" rate, Small bkg: O(α_s^2) mimics signal, tt(+jets)

Large separation between tag jets and centrality of VV decay products improve signal/background

Effective lagrangian: a tool to parametrize the unknown

$$\Sigma(x) = \exp\left(\frac{i\sigma^a\omega^a(x)}{v}\right)$$

ω^a a =1,2,3 are Goldstone bosons. In Unitary Gauge $\omega^a = 0$, $\Sigma = 1$

$$\Sigma \to U_L(x)\Sigma U_Y^\dagger(x),$$

$$U_L(x) = \exp\left(\frac{i\beta^a(x)\sigma^a}{2}\right), \qquad U_Y(x) = \exp\left(\frac{i\beta_Y(x)\sigma^3}{2}\right)$$

$$\begin{aligned}\mathcal{L} =& \frac{v^2}{4}\,\mathrm{Tr}[(D_\mu\Sigma)^\dagger(D^\mu\Sigma)] - \frac{1}{4}G^a_{\mu\nu}G^{\mu\nu,a} - \frac{1}{4}W^i_{\mu\nu}W^{\mu\nu,i} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}\\ &+ i\,\bar{Q}_L\not{D}Q_L + i\,\bar{Q}_R\not{D}Q_R + i\,\bar{L}_L\not{D}L_L + i\,\bar{L}_R\not{D}L_R\\ &- (\bar{Q}_L\Sigma M_Q Q_R + \bar{L}_L\Sigma M_L L_R + \mathrm{h.c.}).\end{aligned}$$

Non linear
σ-model
NonRenormalizable
in d=4

$$\mathcal{L}_4 = \alpha_4\mathrm{Tr}[V^\mu, V^\nu]^2$$
$$\mathcal{L}_5 = \alpha_5\mathrm{Tr}[V_\mu, V^\mu]^2$$
$$V_\mu = (D_\mu\Sigma)\Sigma^\dagger$$

Only two dimension-4 operators which respect EW and custodial symmetry
They modify the SM quartic vertices
Higher dimensional operators suppressed by inverse powers of Λ, the large energy scale of new physics

$$A^{(1)}(s,t,u) = \frac{s}{v^2}$$

Master Amplitudes

$$A^{(2)}(s,t,u) = 4\alpha_4 \frac{t^2+u^2}{v^4} + 8\alpha_5 \frac{s^2}{v^4} + \frac{1}{16\pi^2}\left[\frac{10s^2+13(t^2+u^2)}{18v^4} + \frac{s^2}{2v^4}\ln\left(\frac{\mu^2}{-s}\right) + \frac{t(s+2t)}{6v^4}\ln\left(\frac{\mu^2}{-t}\right) + \frac{u(s+2u)}{6v^4}\ln\left(\frac{\mu^2}{-u}\right)\right],$$

Amps of definite isospin

$$\begin{aligned} A_0(s,t,u) &= 3A(s,t,u) + A(t,s,u) + A(u,s,t), \\ A_1(s,t,u) &= A(t,s,u) - A(u,s,t), \\ A_2(s,t,u) &= A(t,s,u) + A(u,s,t). \end{aligned}$$

$$A(\omega^+\omega^- \to zz) = \frac{1}{3}A_0(s,t,u) - \frac{1}{3}A_2(s,t,u)$$

$$A_{IJ}(s) = \frac{1}{2}\int_{-1}^{1} \mathrm{d}\cos\theta \, P_J(cos\theta) A_I(s,t,u),$$

Partial wave expansion

eg:

$$A_{00}(s) = 2\frac{s}{v^2} + \left[\frac{8}{3}\left(7\alpha_4(\mu) + 11\alpha_5(\mu)\right) + \frac{1}{16\pi^2}\left(2\ln\left(\frac{\mu^2}{-s}\right) + \frac{7}{9}\ln\left(\frac{\mu^2}{s}\right) + \frac{11}{54}\right)\right]\frac{s^2}{v^4}$$

$$\ln(-s) = \ln s - i\pi, \text{ when } s > 0$$

$$\mathrm{Im}\, A_{IJ}^{(2)}(s) = \frac{1}{32\pi}|A_{IJ}^{(1)}(s)|^2$$

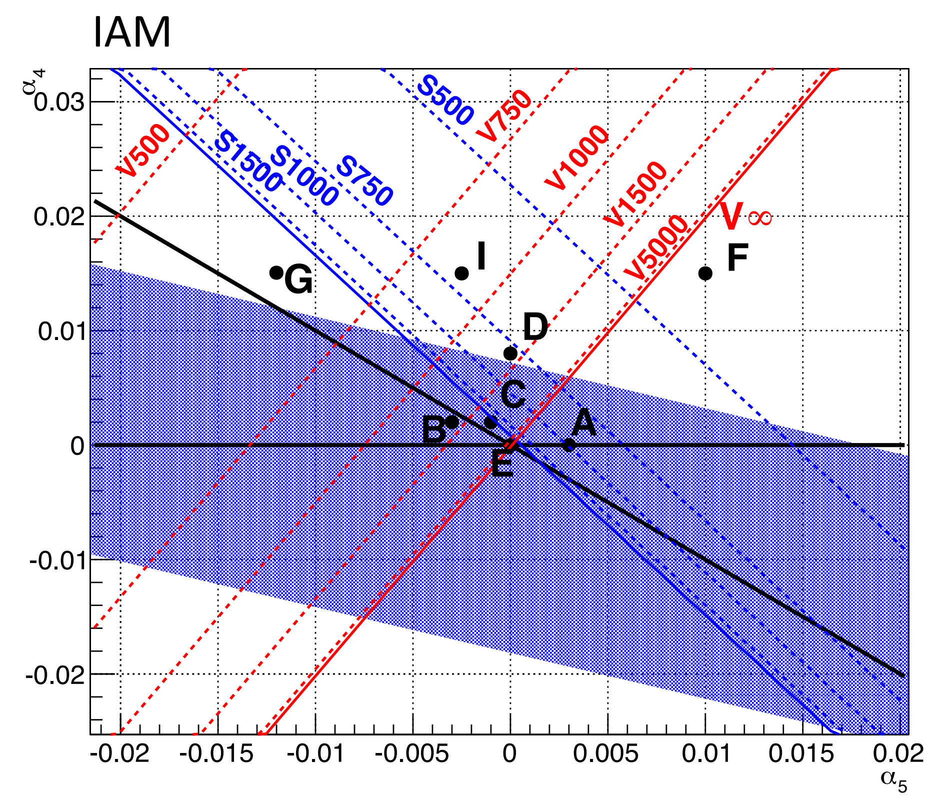
$T^\dagger T = -i\,(T - T^\dagger)$

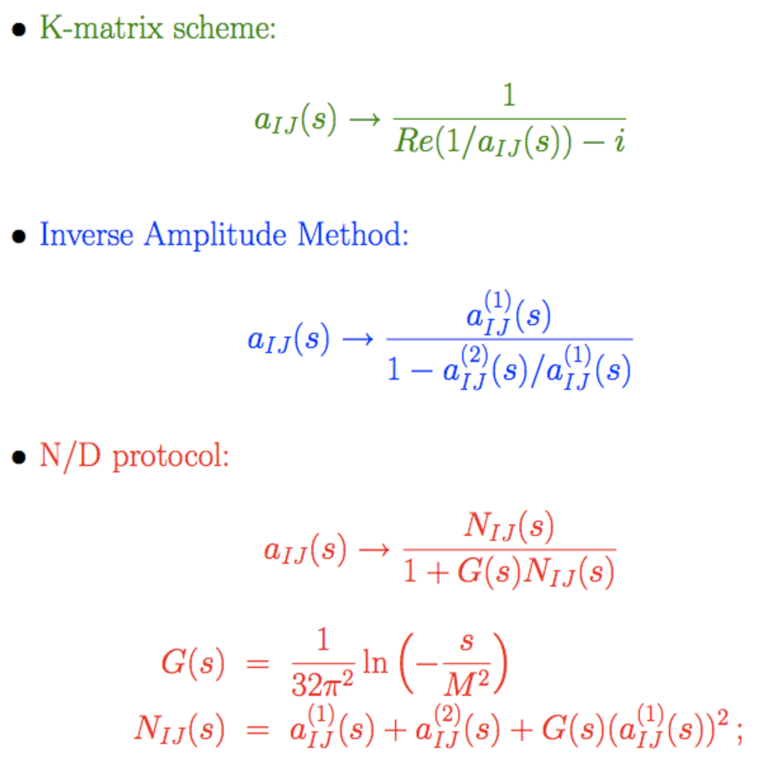
Amplitudes still grow indefinitely as s → ∞. Need unitarization procedure

Unitarized Model Implementation in PHANTOM

Unitarized models modify the amplitudes in such a way that unitarity is satisfied keeping the same low energy behaviour

In the K-matrix scheme specific resonances (scalar vector or tensor) can be added to $a_{IJ}(s)$, while IAM and N/D prescriptions produce different resonances depending on the specific values of α_4 and α_5 . N/D has additional parameters.





- K-matrix scheme:

$$a_{IJ}(s) \to \frac{1}{Re(1/a_{IJ}(s)) - i}$$

- Inverse Amplitude Method:

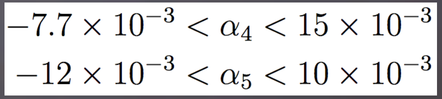
$$a_{IJ}(s) \to \frac{a^{(1)}_{IJ}(s)}{1 - a^{(2)}_{IJ}(s)/a^{(1)}_{IJ}(s)}$$

- N/D protocol:

$$a_{IJ}(s) \to \frac{N_{IJ}(s)}{1 + G(s)N_{IJ}(s)}$$

$$G(s) = \frac{1}{32\pi^2}\ln\left(-\frac{s}{M^2}\right)$$
$$N_{IJ}(s) = a^{(1)}_{IJ}(s) + a^{(2)}_{IJ}(s) + G(s)(a^{(1)}_{IJ}(s))^2\,;$$

α_4 and α_5 constrained in the range (Eboli et al hep-ph/0606118)



$$-7.7\times10^{-3} < \alpha_4 < 15\times10^{-3}$$
$$-12\times10^{-3} < \alpha_5 < 10\times10^{-3}$$

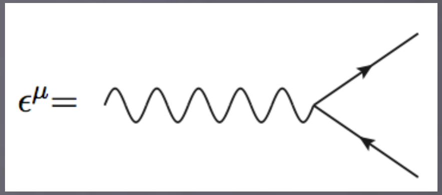
De Vecchi: unitarity & causality
Van der Bij

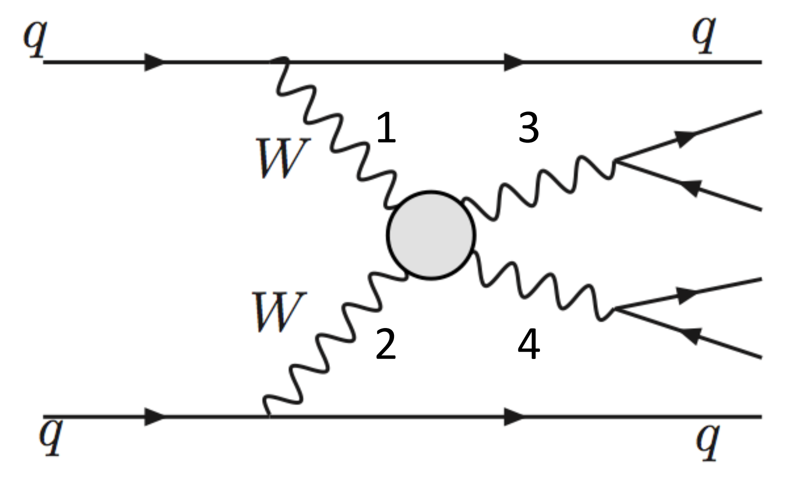
Off-shell implementation

- Needed for LHC beyond EVBA approximation, keep control of tag jets
- Proposed by Chanowitz hep-ph/9512358
- Implemented by Kilian et al. in WHIZARD
- Implemented independently in PHANTOM

Elastic amplitudes are embedded as modifications of quartic vertices
s,t,u are identified with appropriate contractions of polarization vectors
Exact phase between scattering and non scattering diagrams is preserved

$$s^2 = 2p_1 \cdot p_2 \; 2p_3 \cdot p_4 \approx 4M_{V_1}M_{V_2}M_{V_3}M_{V_4} \; g_{\mu\nu}g_{\rho\sigma} \; \epsilon_1^\mu \epsilon_2^\nu \epsilon_3^\rho \epsilon_4^\sigma$$
$$t^2 = 2p_1 \cdot p_3 \; 2p_2 \cdot p_4 \approx 4M_{V_1}M_{V_2}M_{V_3}M_{V_4} \; g_{\mu\rho}g_{\nu\sigma} \; \epsilon_1^\mu \epsilon_2^\nu \epsilon_4^\rho \epsilon_4^\sigma$$
$$u^2 = 2p_1 \cdot p_4 \; 2p_2 \cdot p_3 \approx 4M_{V_1}M_{V_2}M_{V_3}M_{V_4} \; g_{\mu\sigma}g_{\nu\rho} \; \epsilon_1^\mu \epsilon_2^\nu \epsilon_3^\rho \epsilon_4^\sigma$$

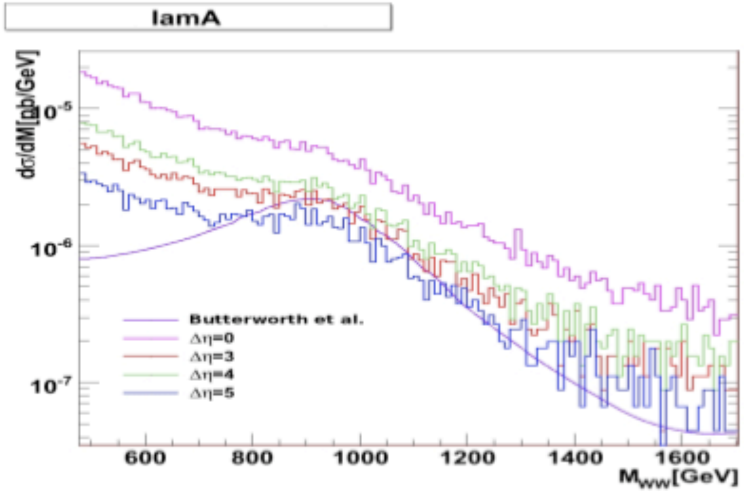




Comparison with EVBA

Results for Unitarization Models

Comparison with previous study (Butterworth et al, hep-ph/0201098) based on on-shell amplitudes and EVBA.



$2j\mu^{\pm}e^{\mp}\nu\bar{\nu}$

$\Delta\eta(jj) > 4$

no top processes

scenario	α_4	α_5
IAM A	0.0	0.003
IAM B	0.002	-0.003
IAM D	0.008	0.0

IAM determines resonances depending on chiral coeff:

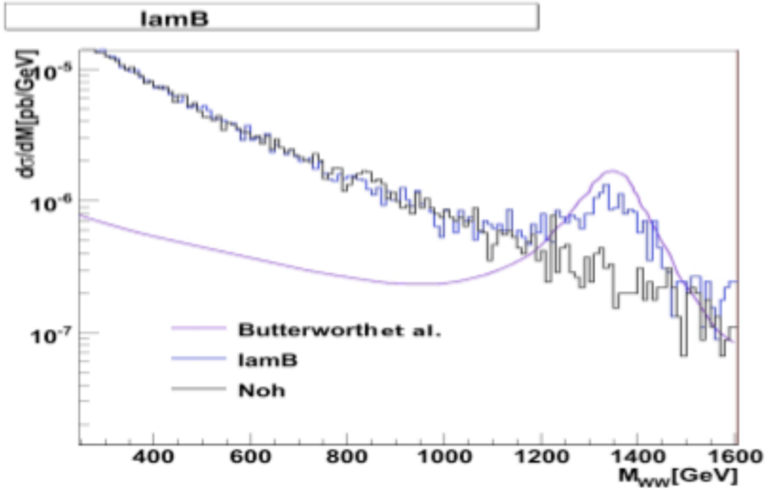
IAMA 1 TeV scalar

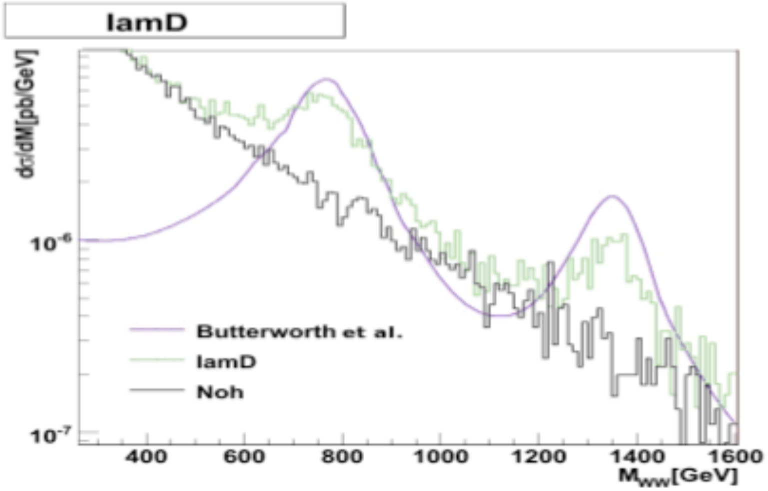
IAMB 1.4 vector

IAMD 0.8 scal 1.4 vect

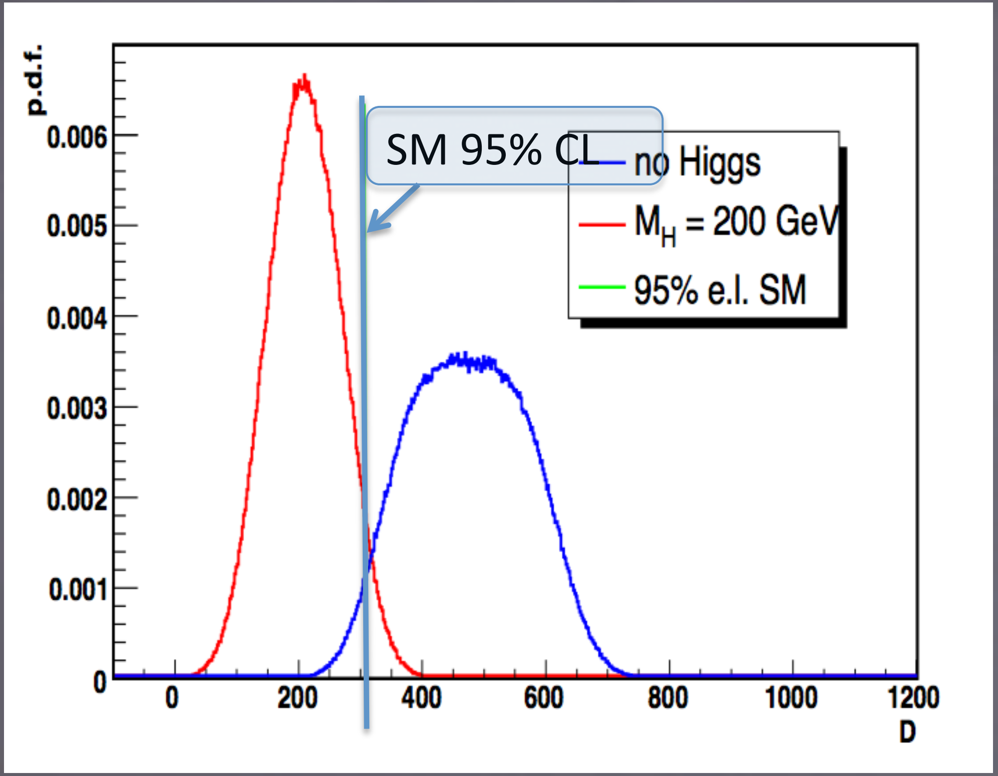
VV mass not measured

offpeak as important as peak





Method: Probability Beyond the Standard Model @ 95% CL (PBSM95%CL)



The MC results are smeared for statistical fluctuations and for theoretical uncertainties: flat distribution ± 30% (Parton distributions, NLO contributions …)
UNLESS THEY CAN BE MEASURED IN DIFFERENT KINEMATIC REGIONS eg: tt, 4jV
The fraction of BSM distribution beyond the 95% SM line is the PBSM95%CL

QCD Corrections ~10%, x_q~10^{-1}-10^{-2} pdf uncertainties ~5% Larger for QCD(α_s^4) 4jV, gg

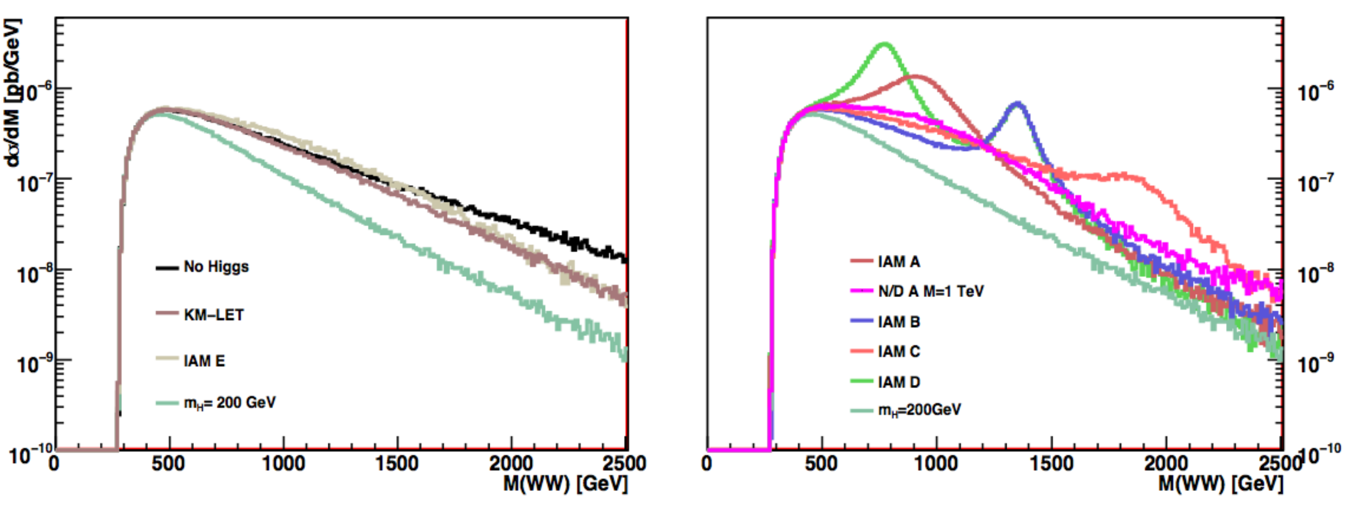
Results at 14 TeV for Unitarized Models

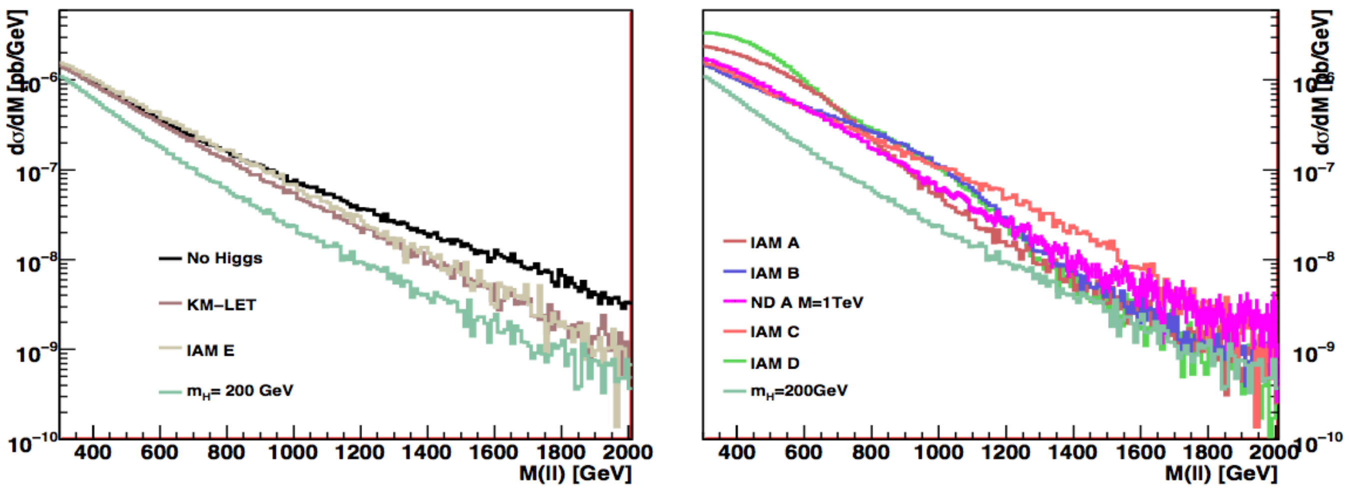
arXiv:1112.1171, jhep
Ballestrero,Franzosi,Oggero,EM

$$2jW^+W^- \rightarrow 2j\ell^+\ell^-\nu\bar{\nu}$$

Cuts in spares. Used ΔR for jets
MVA can do more. Boosted fat jets

IAM A: m_s = 1 TeV
IAM B: m_v = 1.4 TeV
IAM C: m_v = 1.9 TeV
IAM D: m_s = 0.8 TeV,
m_v = 1.4 TeV
IAM E: no res 1loop
KM-LET: no res tree
KM method
N/D: m_s = 1 TeV





No Higgs
not significantly
different from
IAM E, KM-LET
at LHC energies

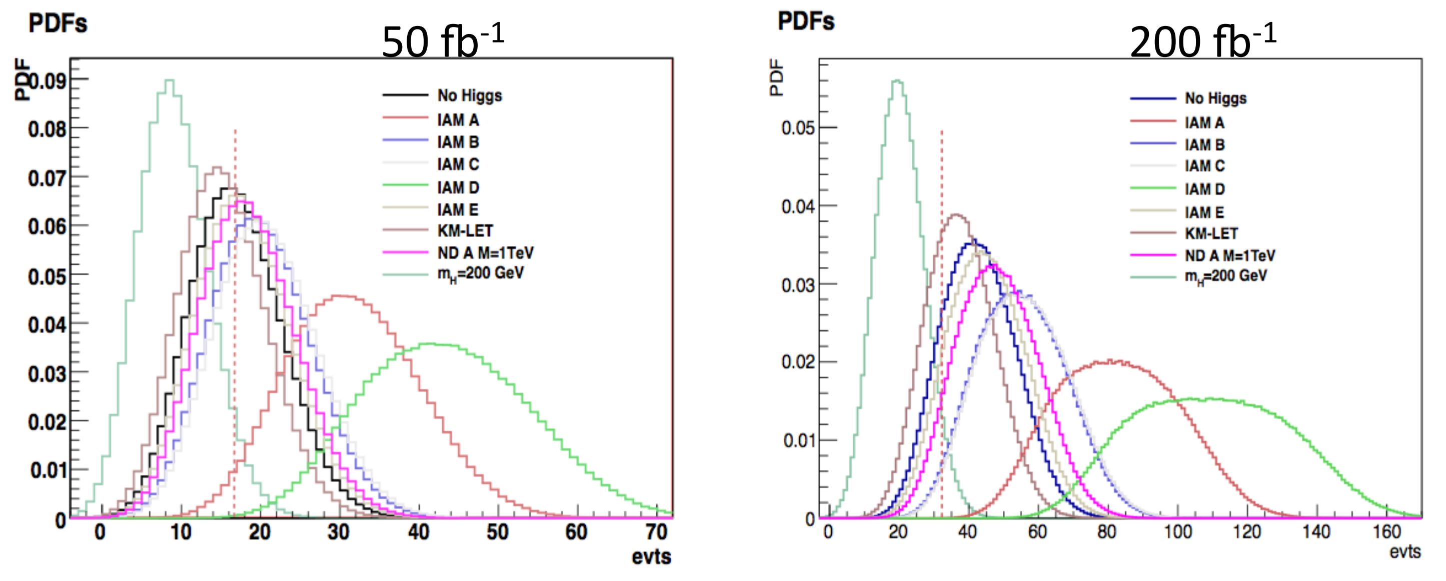
MadEvent for tt+jets

Other channels exist
and can be combined

$2jW^+W^- \to 2j\ell^+\ell^-\nu\bar{\nu}$

In fb $M_{cut} = M_{min}(ll)$

M_{cut}	no-H	KM	IAMA	IAMB	IAMC	IAMD	IAME	N/D	SM	$t\bar{t}jj$
300	.337	.303	.631	.400	.412	.867	.355	.367	.179	.173
400	.212	.186	.413	.274	.277	.547	.224	.240	.100	.0890
500	.139	.115	.246	.190	.187	.304	.142	.150	.0577	.0407
600	.0968	.0724	.132	.130	.126	.160	.0897	.0931	.0332	.0215
700	.0696	.0461	.0658	.0862	.0858	.0898	.0571	.0568	.0217	.0138



IAM A: m_s = 1 TeV
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IAM D: m_s = 0.8 TeV,
m_v = 1.4 TeV
IAM E: no res 1loop
KM-LET: no res tree
KM method
N/D: m_s = 1 TeV

$L(\text{ fb}^{-1})$	M_{cut}	no-H	KM	IAMA	IAMB	IAMC	IAMD	IAME	N/D
50	300	49.4%	37.8%	97.2%	68.5 %	71.6%	99.9%	55.4%	59.2 %
200	400	82.5%	68.4 %	100%	97.2 %	97.5%	100%	87.2%	91.8 %

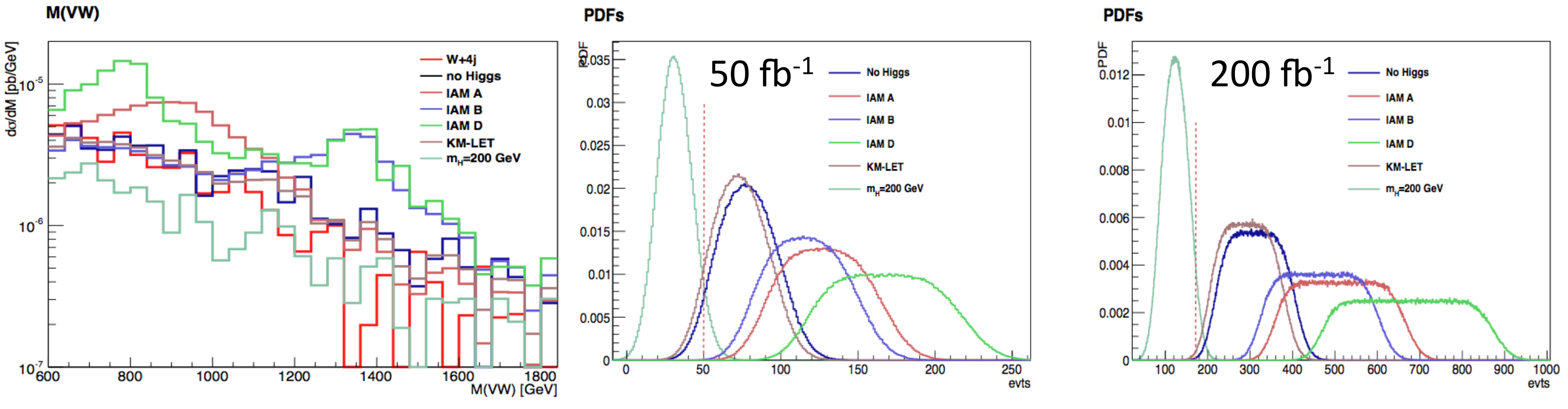
$4j\ell\nu$ channel

In fb　M_{cut} = $M_{min}(j_c j_c l\nu)$　70 GeV < $M(j_c j_c)$ < 100 GeV

Large BR(WV→2jlv), Large QCD bkg　$p_z(\nu)$ reconstructed

MadEvent for W4j and tt+jets

M_{cut}	no–Higgs	KM–LET	IAM A	IAM B	IAM D	SM	$W+4j$	$t\bar{t}+2j$
600	2.36	2.23	3.66	3.04	5.46	1.048	2.03	.432
800	1.558	1.46	2.56	2.32	3.36	.618	1.15	.167
1000	.966	.877	1.13	1.76	1.90	.338	0.62	.0617
1200	.526	.478	.414	1.26	1.27	.188	0.30	.0264

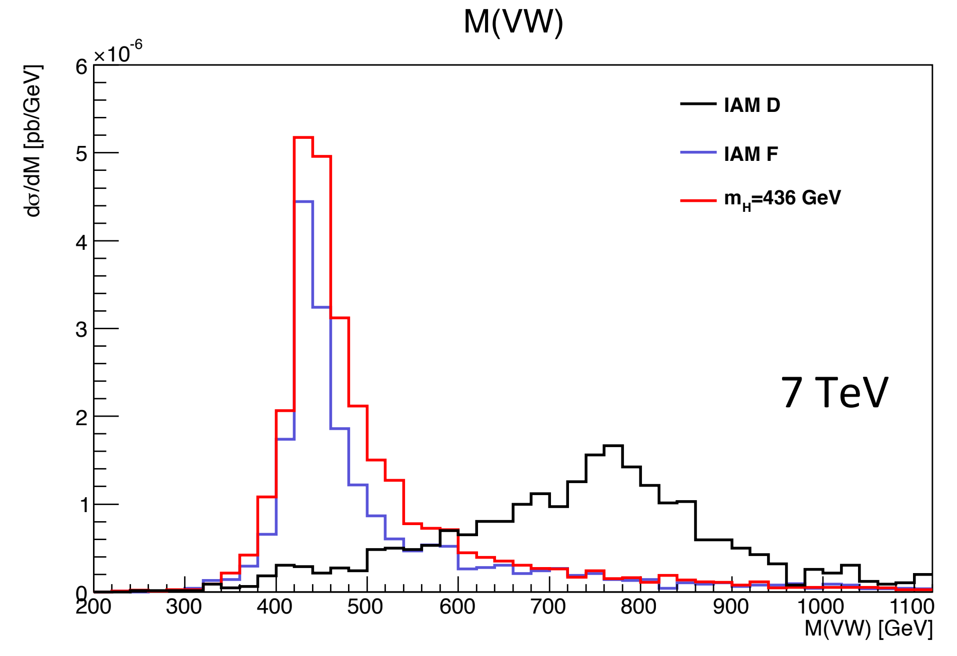


$L(\text{ fb}^{-1})$	M_{cut} (GeV)	no–Higgs	KM–LET	IAM A	IAM B	IAM D
50	800	94.51%	91.03%	99.99%	99.97%	100%
200	800	99.93%	99.64%	100%	100%	100%

Better channel IF bkg can be controlled

Results at lower energies: 7,8,10 TeV

Ballestrero,Franzosi, EM
arXiv:1203.2771



IAM F: scalar m_s = 436 GeV
IAM D: scalar+vector
m_s = 0.8 TeV, m_v = 1.4 TeV

Examined
IAM E: no resonance
IAM G: vector m_v = 0.6 TeV
IAM J: scalar+vector, m_s = m_v = 1 TeV

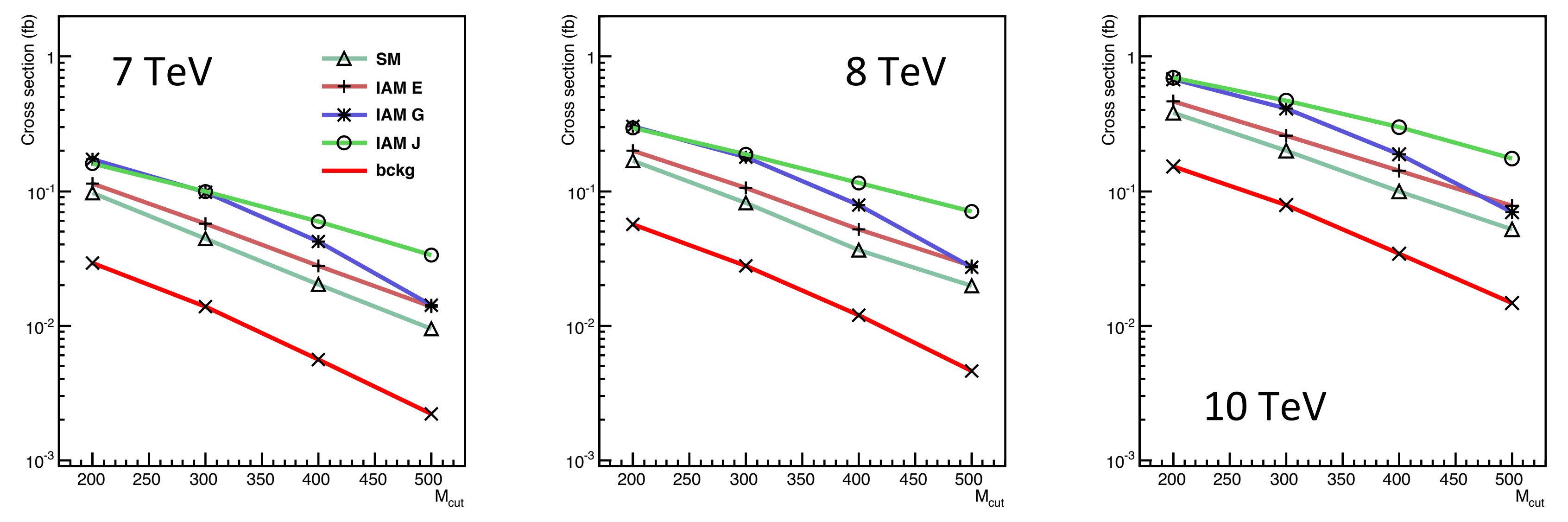
2jW+W- → 2j2l2v 2j3lv 4jlv all channels can be combined
Cut-based preliminary study at parton level

Results at lower energies: 7,8,10 TeV

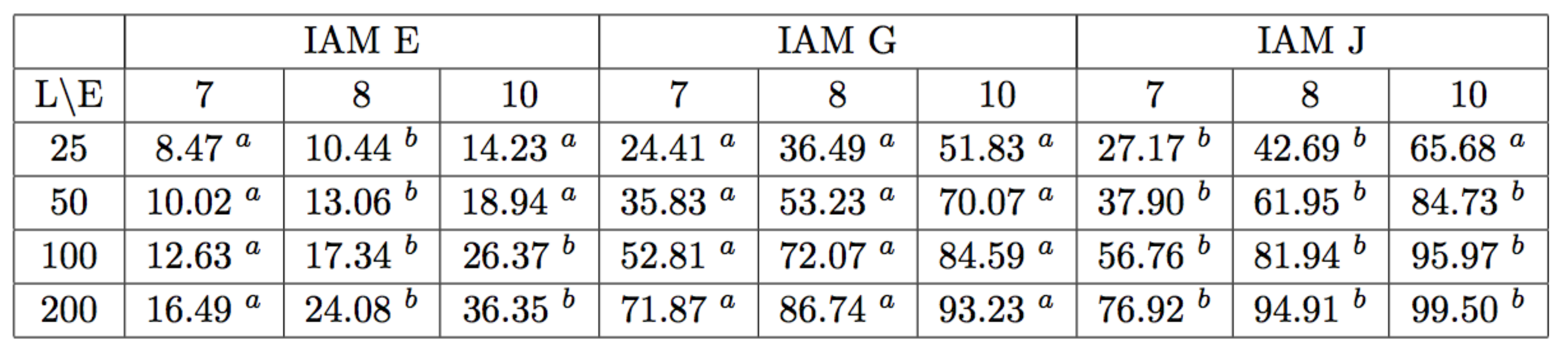
IAM E: no resonance
IAM G: vector m_v = 0.6 TeV
IAM J: scalar+vector, m_s = m_v = 1 TeV

$$2jW^+W^- \to 2j\ell^+\ell^-\nu\bar{\nu}$$

Cross section in fb M_{cut} = M_{min}(ll)



PBSM95%CL

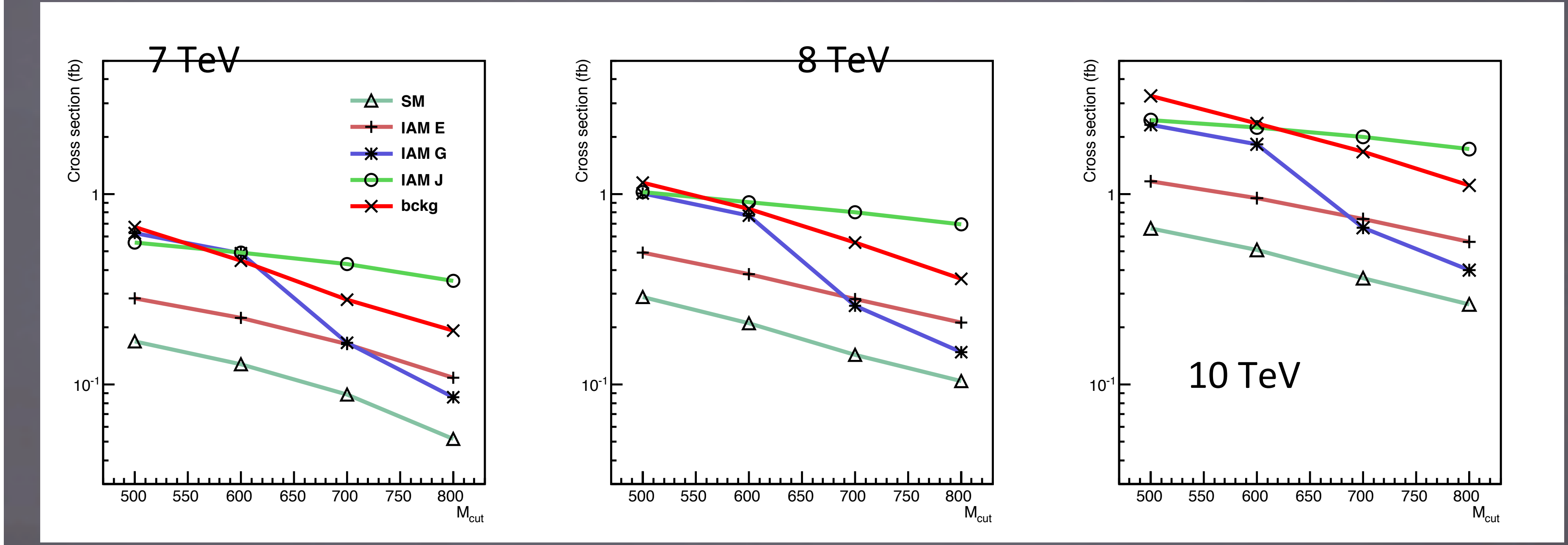


	IAM E			IAM G			IAM J		
L\E	7	8	10	7	8	10	7	8	10
25	8.47 ^{a}	10.44 ^{b}	14.23 ^{a}	24.41 ^{a}	36.49 ^{a}	51.83 ^{a}	27.17 ^{b}	42.69 ^{b}	65.68 ^{a}
50	10.02 ^{a}	13.06 ^{b}	18.94 ^{a}	35.83 ^{a}	53.23 ^{a}	70.07 ^{a}	37.90 ^{b}	61.95 ^{b}	84.73 ^{b}
100	12.63 ^{a}	17.34 ^{b}	26.37 ^{b}	52.81 ^{a}	72.07 ^{a}	84.59 ^{a}	56.76 ^{b}	81.94 ^{b}	95.97 ^{b}
200	16.49 ^{a}	24.08 ^{b}	36.35 ^{b}	71.87 ^{a}	86.74 ^{a}	93.23 ^{a}	76.92 ^{b}	94.91 ^{b}	99.50 ^{b}

$4j\ell\nu$ channel

In fb $M_{cut} = M_{min}(j_c j_c l v)$
70 GeV < $M(j_c j_c)$ < 100 GeV
$p_z(v)$ reconstructed
V+4j measured from sidebands

IAM E: no resonance
IAM G: vector m_v = 0.6 TeV
IAM J: scalar+vector, m_s = m_v = 1 TeV



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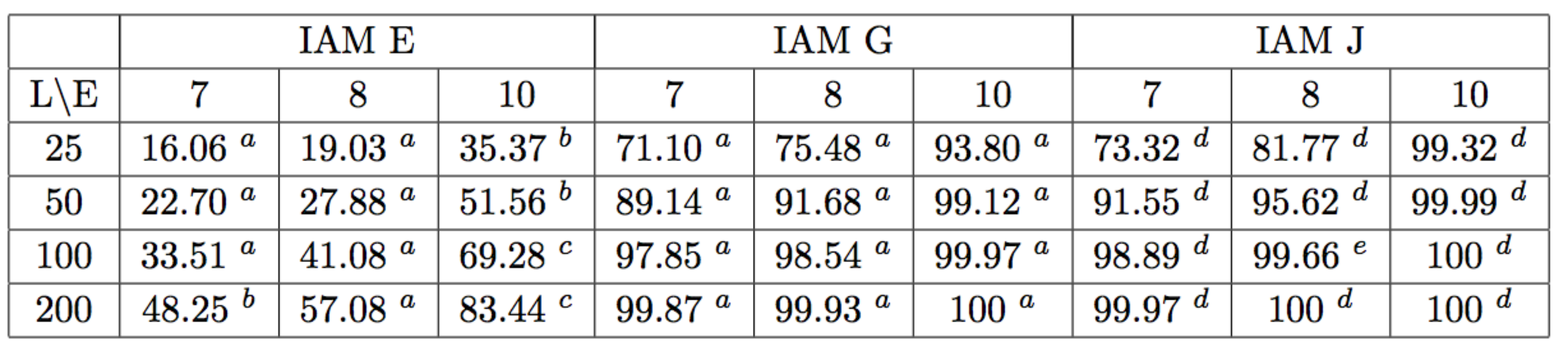
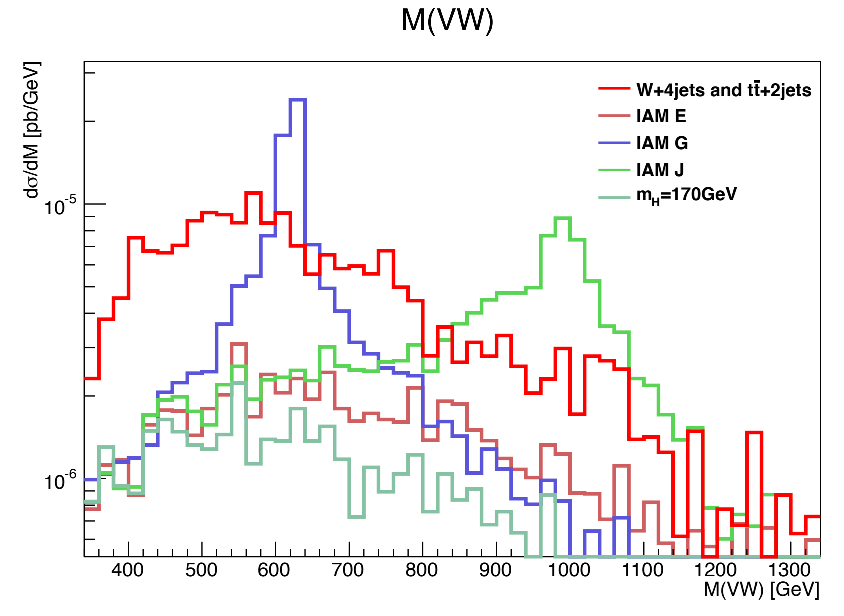
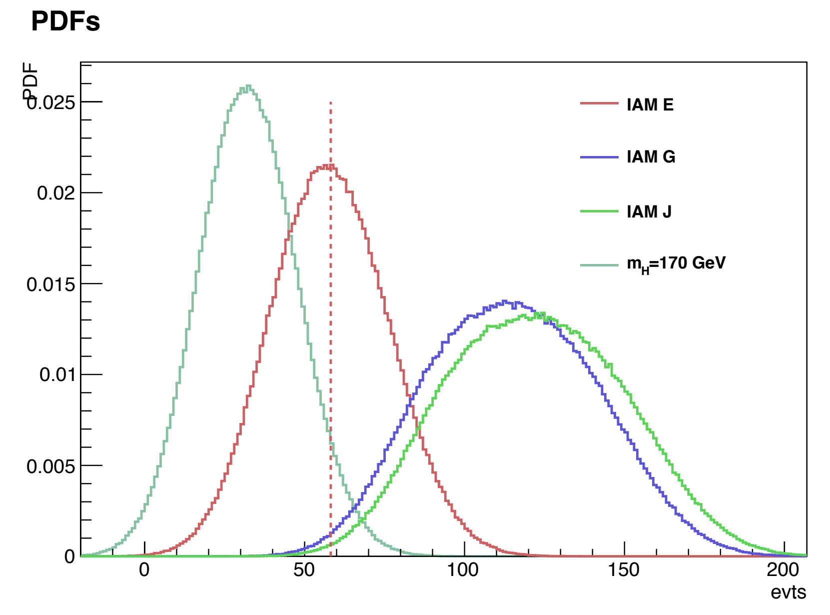


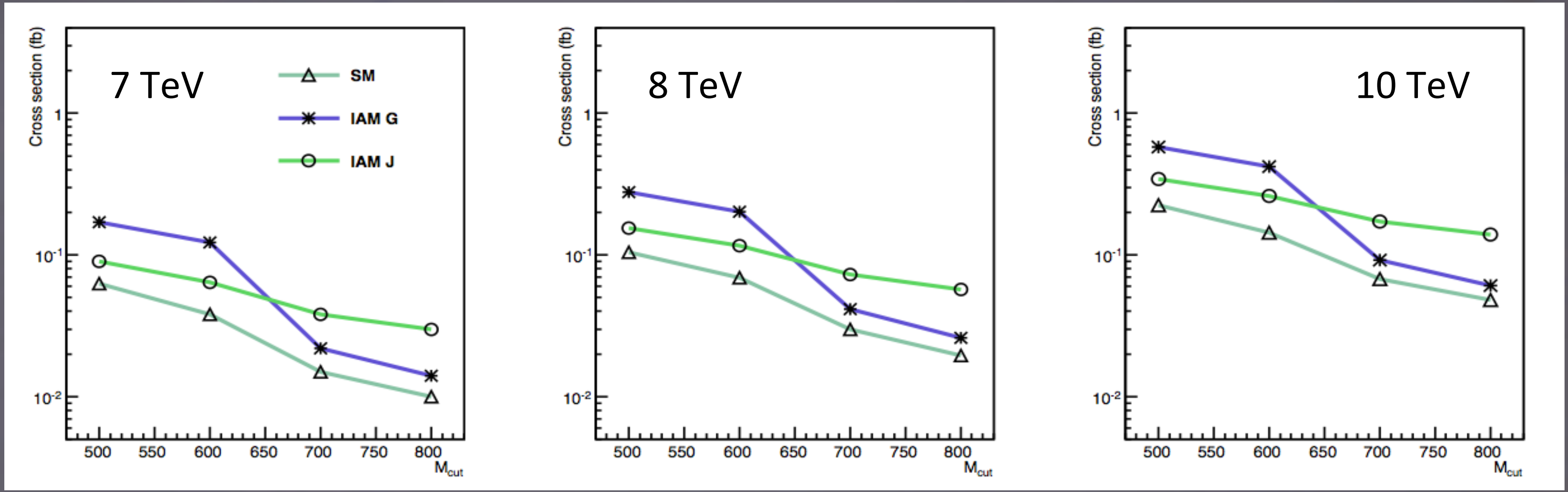
	IAM E			IAM G			IAM J		
L\E	7	8	10	7	8	10	7	8	10
25	16.06 [a]	19.03 [a]	35.37 [b]	71.10 [a]	75.48 [a]	93.80 [a]	73.32 [d]	81.77 [d]	99.32 [d]
50	22.70 [a]	27.88 [a]	51.56 [b]	89.14 [a]	91.68 [a]	99.12 [a]	91.55 [d]	95.62 [d]	99.99 [d]
100	33.51 [a]	41.08 [a]	69.28 [c]	97.85 [a]	98.54 [a]	99.97 [a]	98.89 [d]	99.66 [e]	100 [d]
200	48.25 [b]	57.08 [a]	83.44 [c]	99.87 [a]	99.93 [a]	100 [a]	99.97 [d]	100 [d]	100 [d]

4jlv 10 TeV M(VV) > 500 GeV L = 50 fb^{-1}





$3\ell\nu + 2j$ channel



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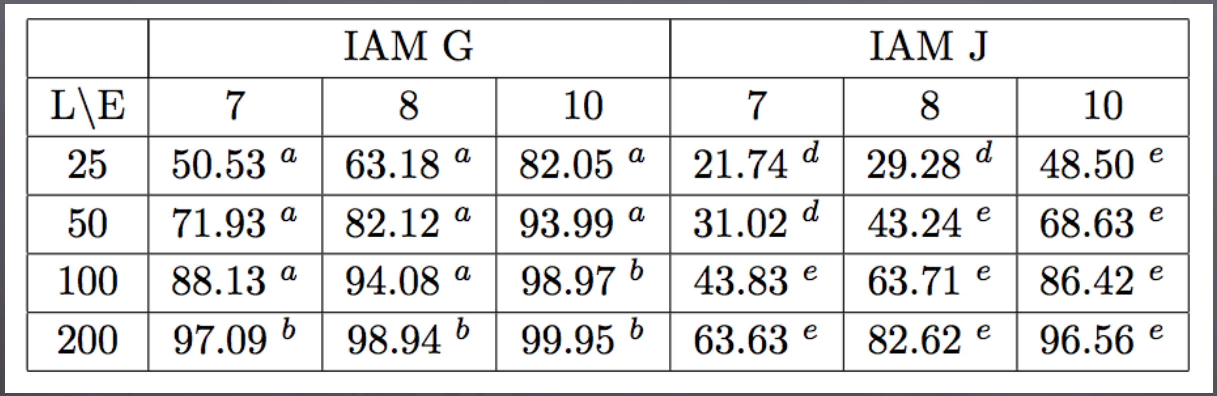
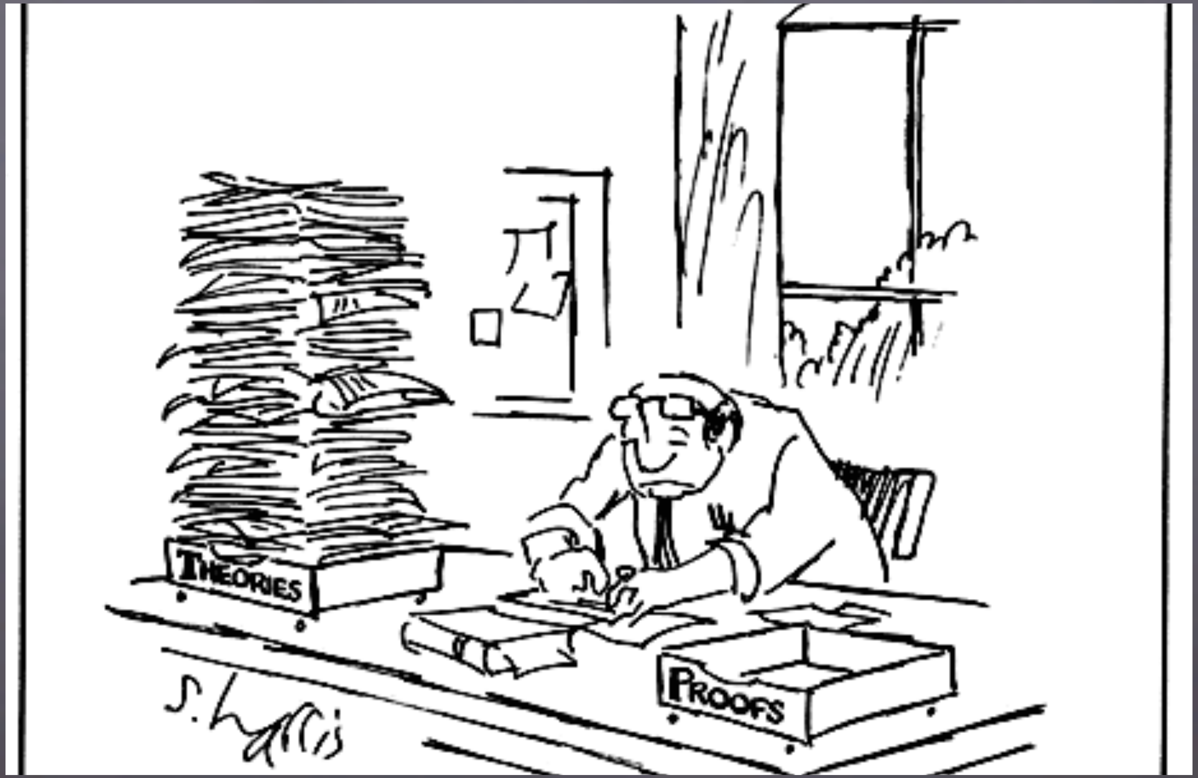


	IAM G			IAM J		
L\E	7	8	10	7	8	10
25	50.53 ^{a}	63.18 ^{a}	82.05 ^{a}	21.74 ^{d}	29.28 ^{d}	48.50 ^{e}
50	71.93 ^{a}	82.12 ^{a}	93.99 ^{a}	31.02 ^{d}	43.24 ^{e}	68.63 ^{e}
100	88.13 ^{a}	94.08 ^{a}	98.97 ^{b}	43.83 ^{e}	63.71 ^{e}	86.42 ^{e}
200	97.09 ^{b}	98.94 ^{b}	99.95 ^{b}	63.63 ^{e}	82.62 ^{e}	96.56 ^{e}

Conclusions

- Whether the Higgs is found or not, VV scattering needs to be explored
- At 14 TeV the outlook is promising
- At 8 TeV some models are within reach, others are not.

  Depending on the unitarization scheme limits on α_4 and α_5 could be derived



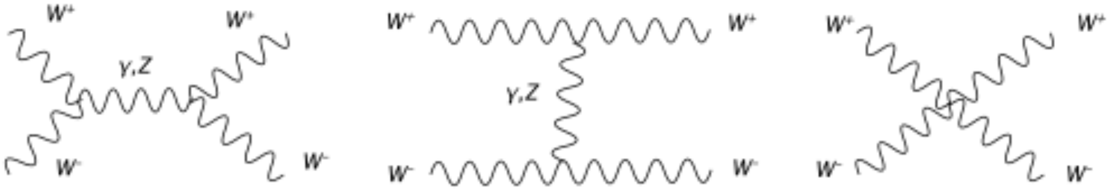
Spares

VV scattering and Unitarity

$$\epsilon_T = \left(0; \pm\frac{1}{\sqrt{2}}, \frac{-i}{\sqrt{2}}, 0\right) \qquad \epsilon_L = \frac{1}{m_W}\left(|\vec{k}|; 0, 0, E_W\right) \qquad \vec{k}//\hat{z}$$

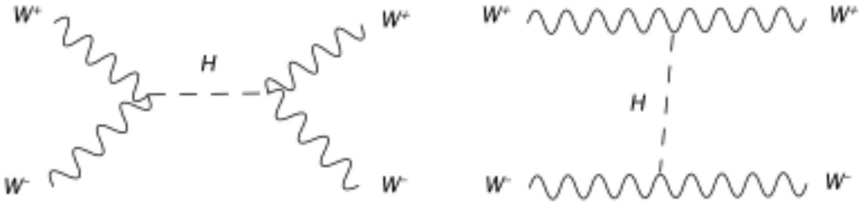
FOR $E_W \gg m_W \qquad \epsilon_L^\mu \approx \frac{k^\mu}{m_W}$

$$\epsilon^L_{W+} \cdot \epsilon^L_{W-} \approx \frac{k_{W+} \cdot k_{W-}}{m_W^2} = \frac{s}{m_W^2} \longrightarrow D_i \propto \frac{k_{W+} \cdot k_{W-}}{m_W^2} \frac{k_{W+} \cdot k_{W-}}{m_W^2} = \frac{s^2}{m_W^4}$$



$\Sigma \propto s$

GAUGE!



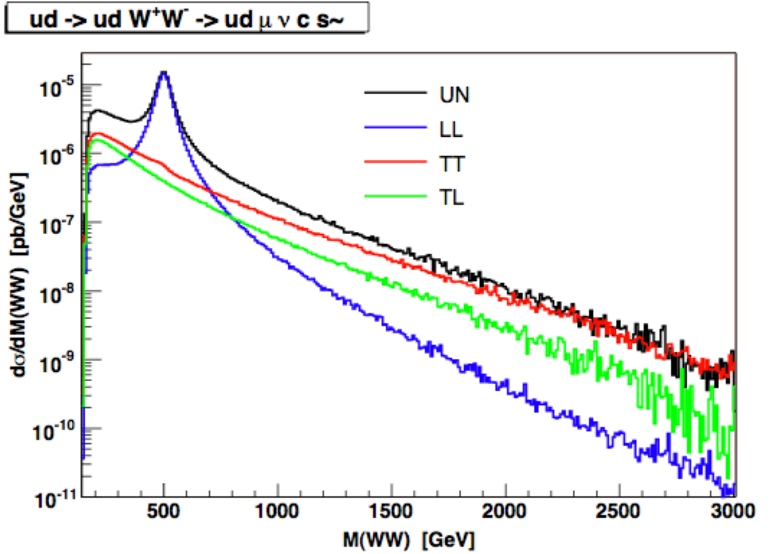
$\Sigma \propto s$

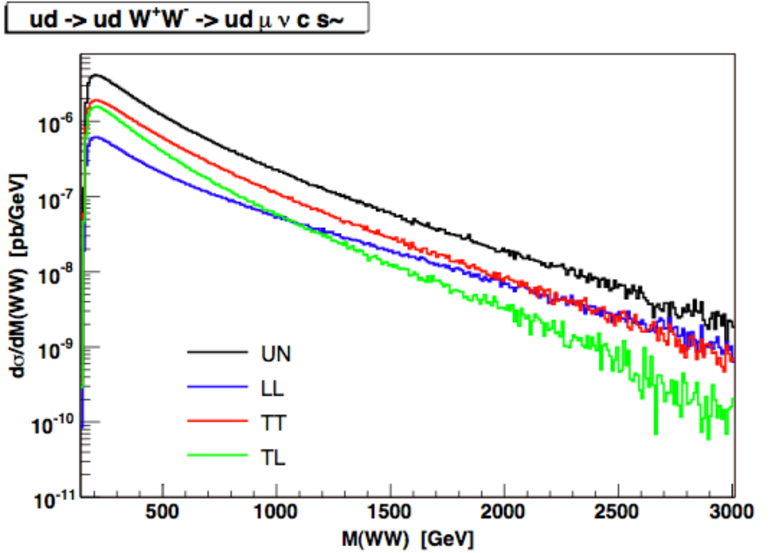
Fermion scattering processes violate unitarity at larger s

$\Sigma_{all} \approx s^0$

Properties of VBF

Contrary to what one expects LL do not dominate at high VV invariant mass





The decrease in the cross section at high invariant masses due to PDF suggests that careful analysis must be performed to evidentiate boson boson scattering effect

The invariant VV mass is the equivalent of the cm energy of the elastic VV scattering

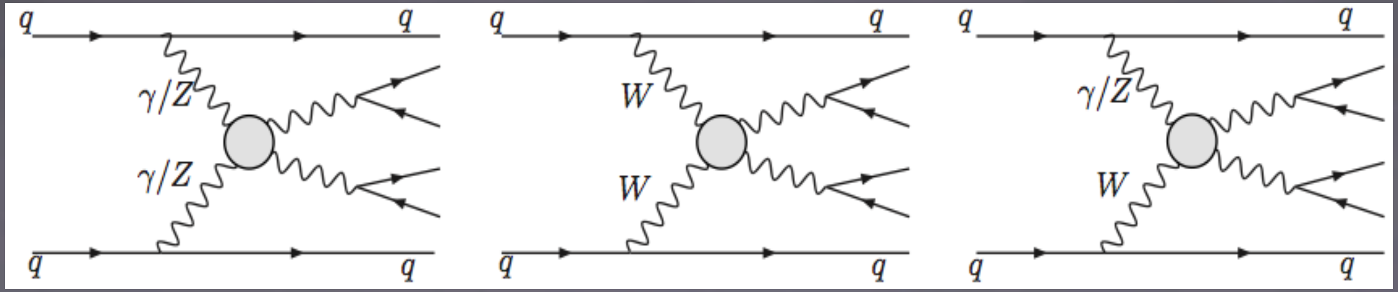
Regions of the order of the TeV or higher in invariant mass
must be examined for effects of alternative EWSB theories.

PHANTOM

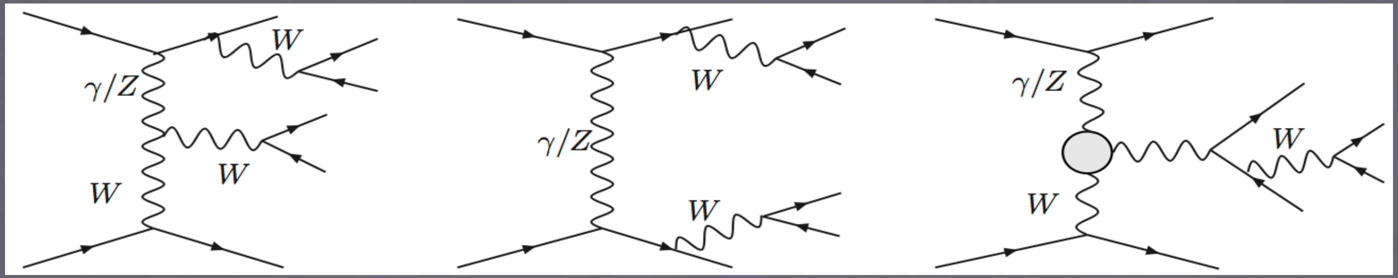
Ballestrero, Belhouari, Bevilacqua, Kashkan, EM
Comp. Phys. Comm. 180 (2009) 401, arXiv:0801.3359

- Tree level dedicated event (LHA Format) generator
- Complete 2→6 $O(\alpha^6)+O(\alpha^4\alpha_s^2)$ matrix elements
- p-p, p-pbar, e+e-
- Exact matrix elements. No production$\otimes$decay or EVBA
- Fast
- One-shot: generates unweighted events for all processes simultaneously
- Efficient: good mapping of phase-space: Multichannel + Vegas

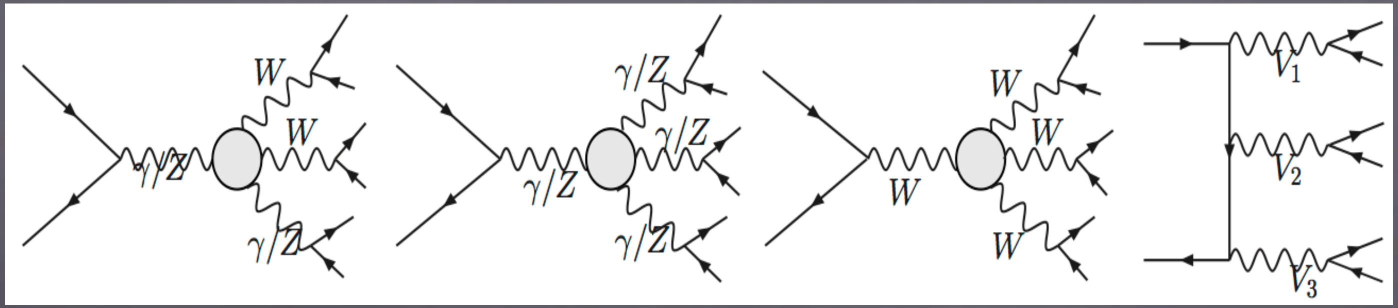
What’s inside PHANTOM: EW



VV scattering



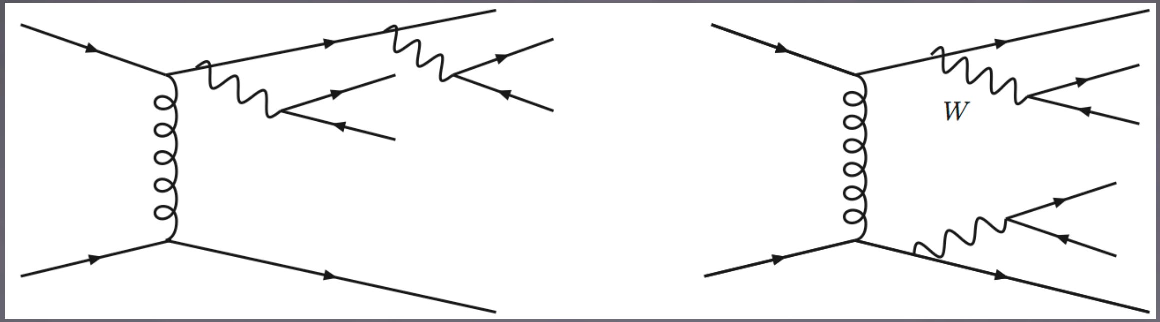
Non scattering 2res.
Single resonant …

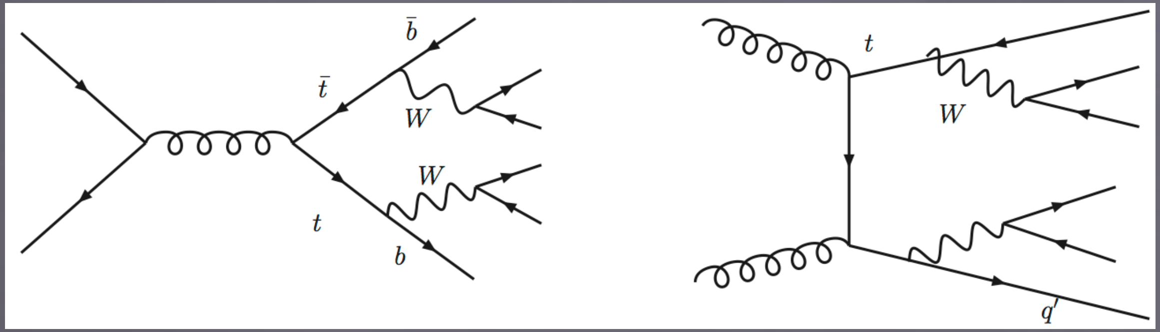


3VB production

FULL GAUGE INVARIANT SET: EXTREME CARE IS NECESSARY IF ANY DIAGRAM IS NEGLECTED
LARGE CANCELLATIONS AMONG GROUPS OF DIAGRAMS

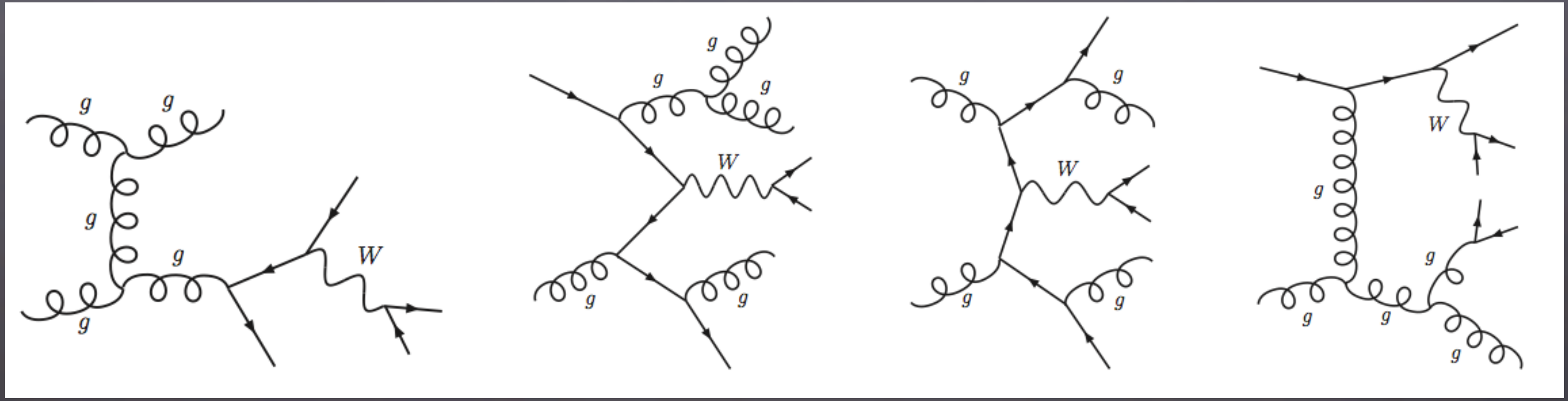
What's inside PHANTOM: EW⊕QCD(α_s^2)





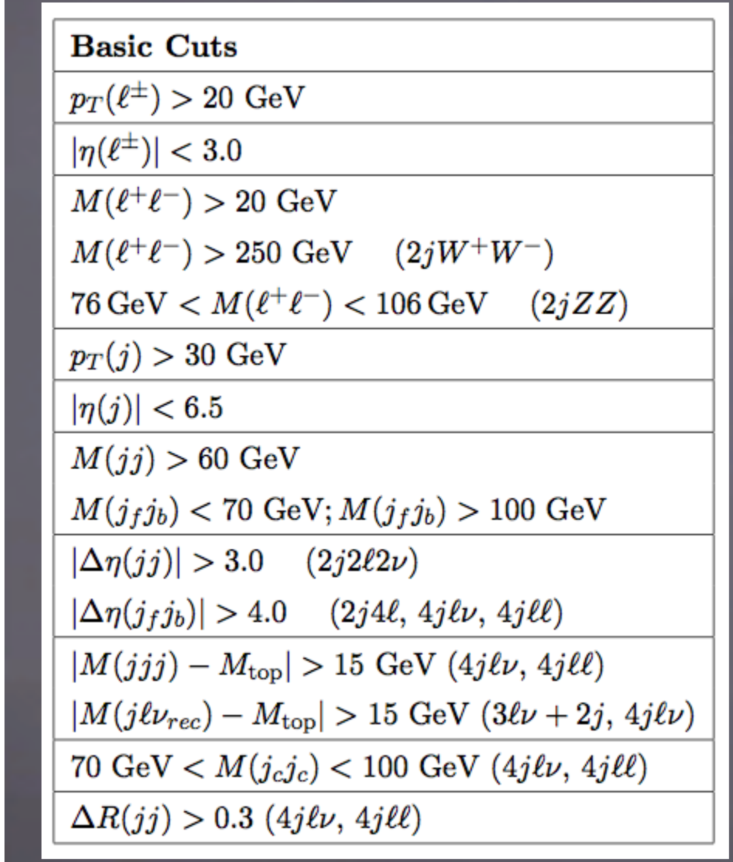
One gluon exchange
Two external gluons
(e.g toptop with full decays)

What is NOT inside PHANTOM: EW⊕QCD(α_s^4) Use MADEVENT

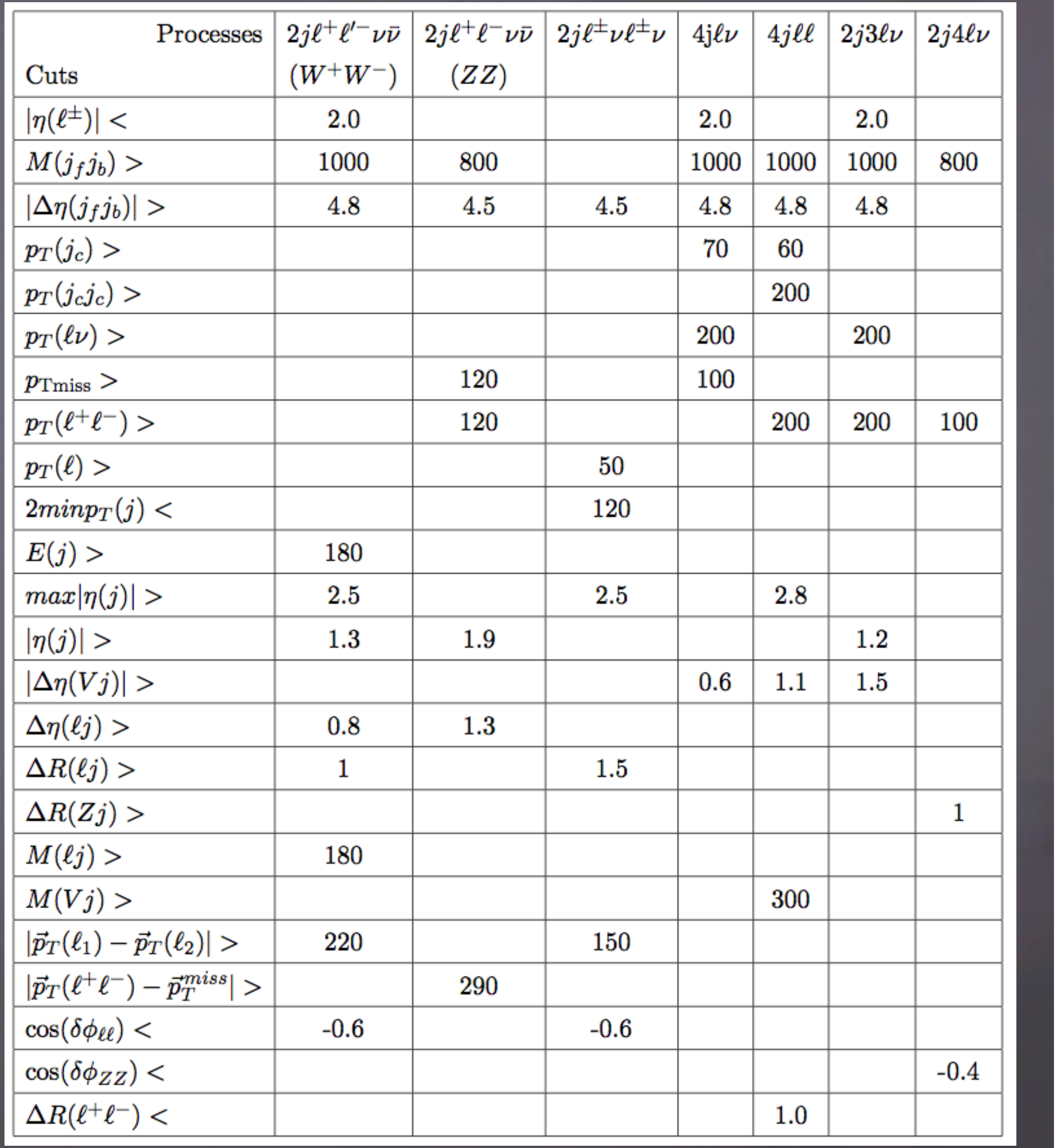


QCD
V+4j

Cuts@14 TeV



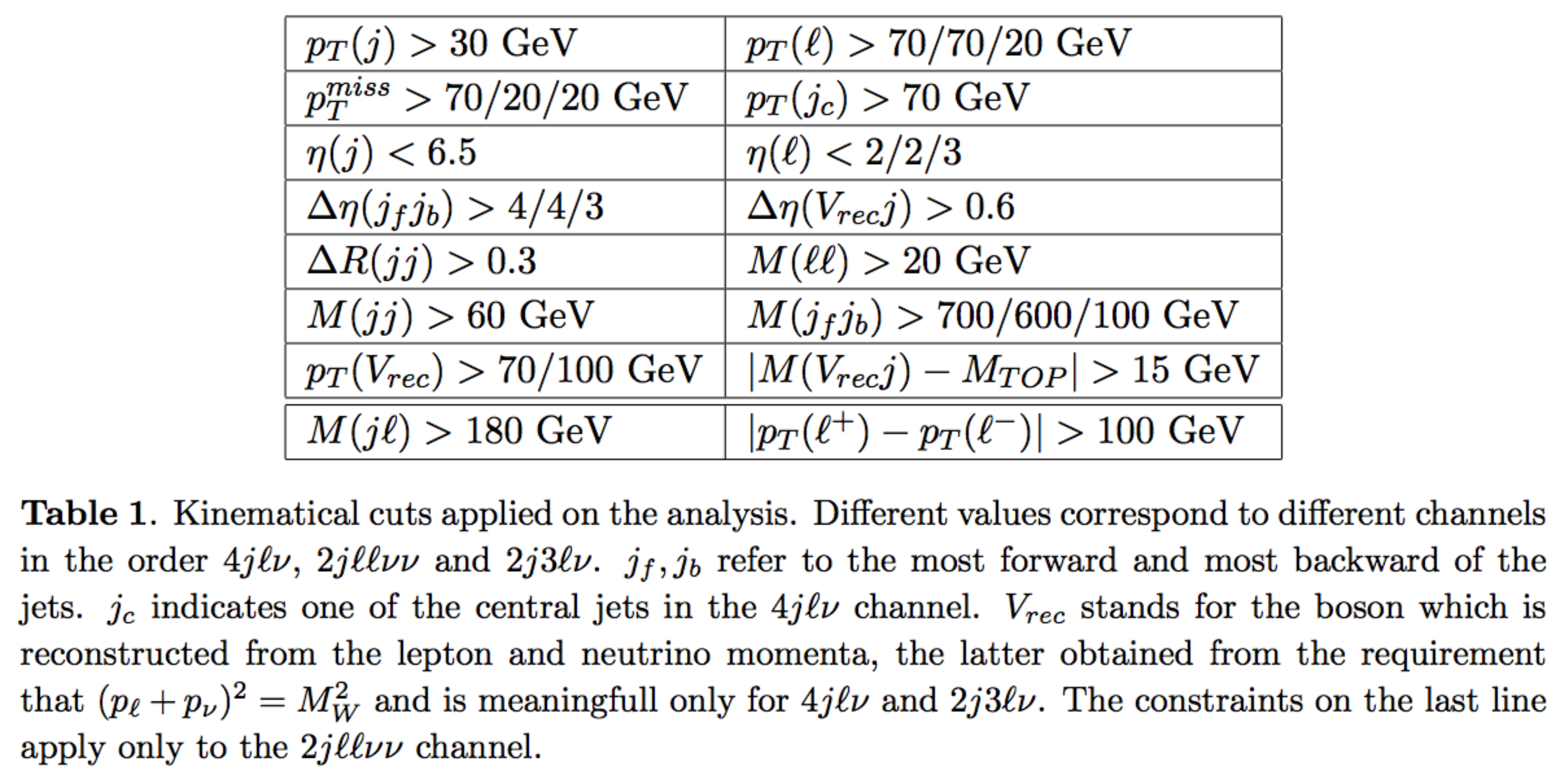
Basic Cuts
$p_T(\ell^\pm) > 20$ GeV
$\lvert\eta(\ell^\pm)\rvert < 3.0$
$M(\ell^+\ell^-) > 20$ GeV $M(\ell^+\ell^-) > 250$ GeV $(2jW^+W^-)$ 76 GeV $< M(\ell^+\ell^-) <$ 106 GeV $(2jZZ)$
$p_T(j) > 30$ GeV
$\lvert\eta(j)\rvert < 6.5$
$M(jj) > 60$ GeV $M(j_fj_b) < 70$ GeV; $M(j_fj_b) > 100$ GeV
$\lvert\Delta\eta(jj)\rvert > 3.0$ $(2j2\ell2\nu)$ $\lvert\Delta\eta(j_fj_b)\rvert > 4.0$ $(2j4\ell,\ 4j\ell\nu,\ 4j\ell\ell)$
$\lvert M(jjj) - M_{\rm top}\rvert > 15$ GeV $(4j\ell\nu,\ 4j\ell\ell)$ $\lvert M(j\ell\nu_{rec}) - M_{\rm top}\rvert > 15$ GeV $(3\ell\nu + 2j,\ 4j\ell\nu)$
70 GeV $< M(j_cj_c) <$ 100 GeV $(4j\ell\nu,\ 4j\ell\ell)$
$\Delta R(jj) > 0.3$ $(4j\ell\nu,\ 4j\ell\ell)$



Processes Cuts	$2j\ell^+\ell'^-\nu\bar\nu$ (W^+W^-)	$2j\ell^+\ell^-\nu\bar\nu$ (ZZ)	$2j\ell^\pm\nu\ell^\pm\nu$	$4\mathrm{j}\ell\nu$	$4j\ell\ell$	$2j3\ell\nu$	$2j4\ell\nu$
$\lvert\eta(\ell^\pm)\rvert <$	2.0			2.0		2.0	
$M(j_fj_b) >$	1000	800		1000	1000	1000	800
$\lvert\Delta\eta(j_fj_b)\rvert >$	4.8	4.5	4.5	4.8	4.8	4.8	
$p_T(j_c) >$				70	60		
$p_T(j_cj_c) >$					200		
$p_T(\ell\nu) >$				200		200	
$p_{\rm Tmiss} >$		120		100			
$p_T(\ell^+\ell^-) >$		120			200	200	100
$p_T(\ell) >$			50				
$2minp_T(j) <$			120				
$E(j) >$	180						
$max\lvert\eta(j)\rvert >$	2.5		2.5		2.8		
$\lvert\eta(j)\rvert >$	1.3	1.9				1.2	
$\lvert\Delta\eta(Vj)\rvert >$				0.6	1.1	1.5	
$\Delta\eta(\ell j) >$	0.8	1.3					
$\Delta R(\ell j) >$	1		1.5				
$\Delta R(Zj) >$							1
$M(\ell j) >$	180						
$M(Vj) >$					300		
$\lvert\vec p_T(\ell_1) - \vec p_T(\ell_2)\rvert >$	220		150				
$\lvert\vec p_T(\ell^+\ell^-) - \vec p_T^{\,miss}\rvert >$		290					
$\cos(\delta\phi_{\ell\ell}) <$	-0.6		-0.6				
$\cos(\delta\phi_{ZZ}) <$							-0.4
$\Delta R(\ell^+\ell^-) <$					1.0		

arXiv:1112.1171

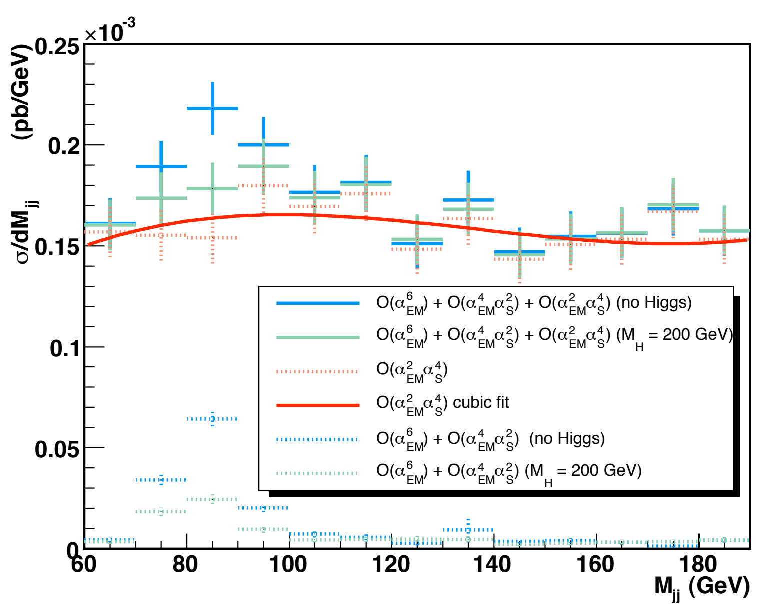
Cuts@7-10 TeV



$p_T(j) > 30$ GeV	$p_T(\ell) > 70/70/20$ GeV
$p_T^{miss} > 70/20/20$ GeV	$p_T(j_c) > 70$ GeV
$\eta(j) < 6.5$	$\eta(\ell) < 2/2/3$
$\Delta\eta(j_f j_b) > 4/4/3$	$\Delta\eta(V_{rec}j) > 0.6$
$\Delta R(jj) > 0.3$	$M(\ell\ell) > 20$ GeV
$M(jj) > 60$ GeV	$M(j_f j_b) > 700/600/100$ GeV
$p_T(V_{rec}) > 70/100$ GeV	$\lvert M(V_{rec}j) - M_{TOP}\rvert > 15$ GeV
$M(j\ell) > 180$ GeV	$\lvert p_T(\ell^+) - p_T(\ell^-)\rvert > 100$ GeV

Table 1. Kinematical cuts applied on the analysis. Different values correspond to different channels in the order $4j\ell\nu$, $2j\ell\ell\nu\nu$ and $2j3\ell\nu$. j_f, j_b refer to the most forward and most backward of the jets. j_c indicates one of the central jets in the $4j\ell\nu$ channel. V_{rec} stands for the boson which is reconstructed from the lepton and neutrino momenta, the latter obtained from the requirement that $(p_\ell + p_\nu)^2 = M_W^2$ and is meaningfull only for $4j\ell\nu$ and $2j3\ell\nu$. The constraints on the last line apply only to the $2j\ell\ell\nu\nu$ channel.

Background fitting from sidebands



→ No NLO, pdf uncertainty

Benchmark comparisons to the SM performed for two scenarios: no-higgs and Silh

✓ no-higgs :

model independent representative at LHC of Strongly Interacting Theories

- One expects predictions similar to those of SIT at LHC:
  - slightly higher than theories with no resonances below 2TeV
  - lower than those with lower mass resonant states
- Pdf strongly depress high VV invariant mass where its predictions are higher than unitary theories
- The No higgs prescription is gauge invariant: corresponds to $m_H \to \infty$ It is however not a consistent theory

✓ Silh:

We have chosen Silh (Strongly Interacting Light Higgs) with $\xi c_H=1$ as representative of the upper limit of model independent lagrangian description of these theories

- The main effect for these processes is the variation of the higgs coupling that correspond to a redefinition of higgs propagator.
- Cancellations are only partial and the model violates unitarity
- The onset of the violation is postponed to a higher scale than in SM

$$\boxed{\frac{1}{p^2-m_H^2} \longrightarrow \frac{1}{1+\xi c_H}\,\frac{1}{p^2-m_H^2}}$$