SM@LHC
EW Summary
11.4.2014

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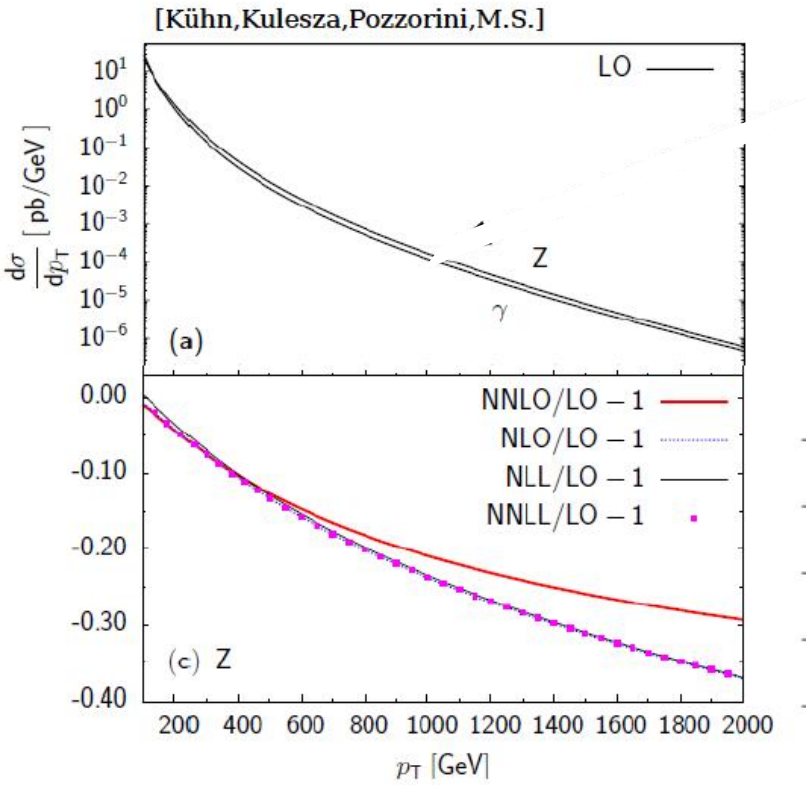
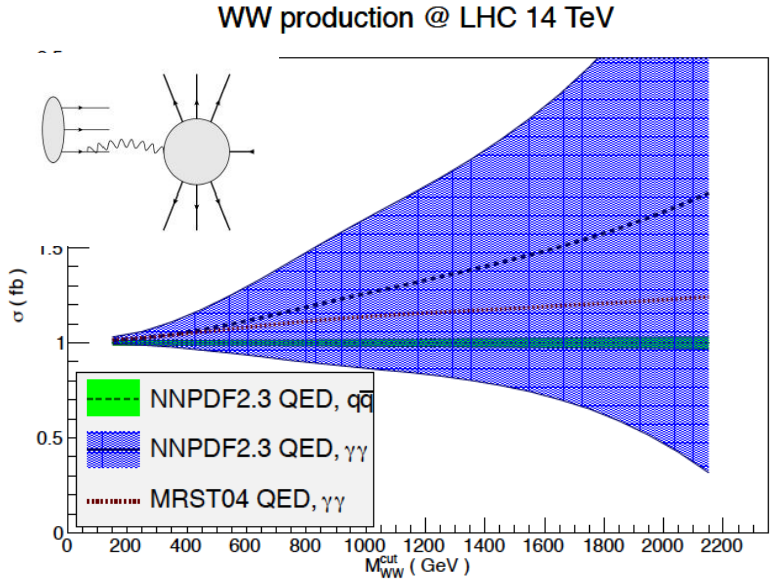
EW NLO corrections for V/VV

► Sizable EW corrections for most scattering processes at TeV range
→ input from experiments?

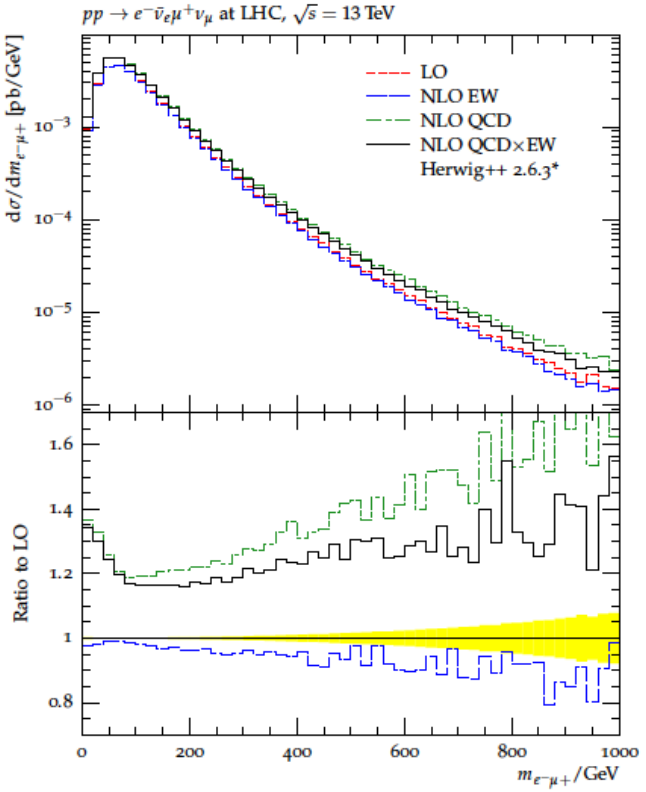
Presently only with jet veto
→ Moving towards 2-loop ($\alpha\alpha_s$)





► Photon-induced processes:
Modern NNPDF replaces MSTW2004qed
Uncertainties for high energies
→ need input from WW high-mass DY...

EW NLO corrections for V/VV



- Demand for generators that combine NLO QCD and EW

First implementations available: EW k-factor, with jet vetoes

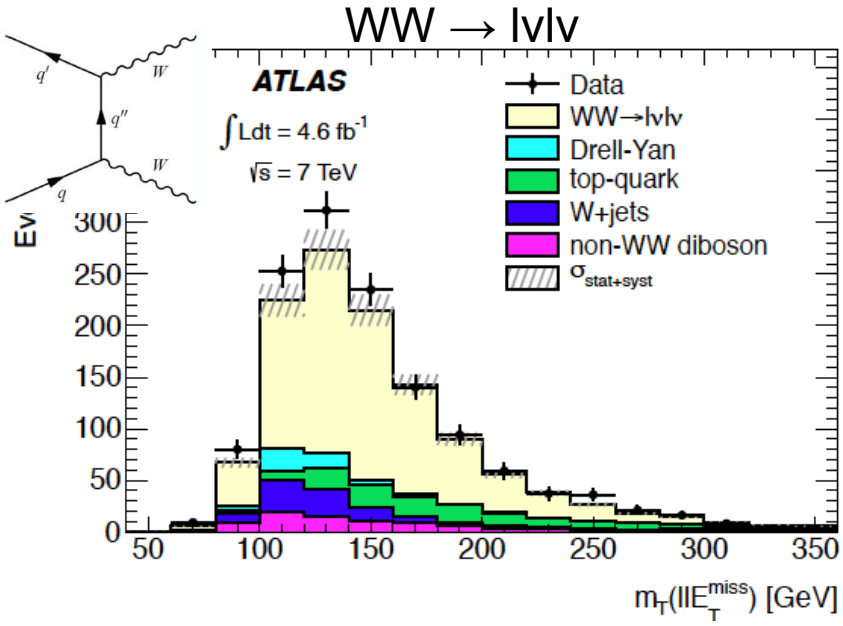
- Les-Houches wishlist for W/Z processes

  State-of-the-art NLO QCD+EW has not yet arrived at LHC experiments

  Some guideline for which regime EW corrections are expected to be relevant

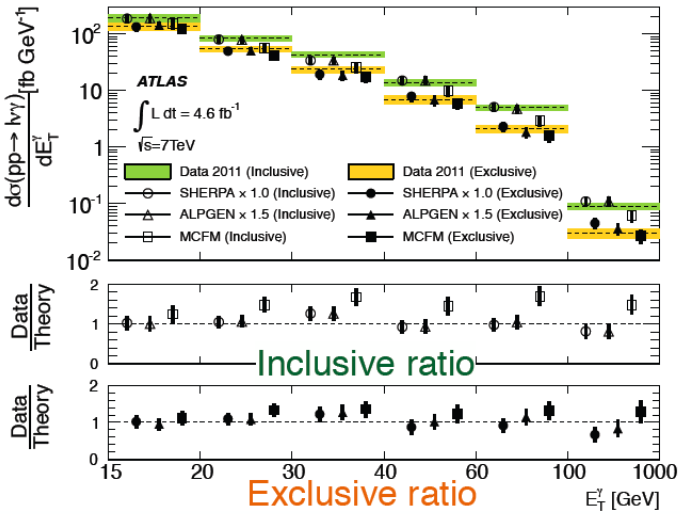
Process	State of the Art	Desired
V	$d\sigma$(lept. V decay) @ NNLO QCD $d\sigma$(lept. V decay) @ NLO EW	$d\sigma$(lept. V decay) @ NNNLO QCD and @ NNLO QCD+EW NNLO+PS
$V + j(j)$	$d\sigma$(lept. V decay) @ NLO QCD $d\sigma$(lept. V decay) @ NLO EW	$d\sigma$(lept. V decay) @ NNLO QCD + NLO EW
VV'	$d\sigma(V$ decays) @ NLO QCD $d\sigma$(on-shell V decays) @ NLO EW	$d\sigma$(decaying off-shell V) @ NNLO QCD + NLO EW
$gg \to VV$	$d\sigma(V$ decays) @ LO QCD	$d\sigma(V$ decays) @ NLO QCD
$V\gamma$	$d\sigma(V$ decay) @ NLO QCD $d\sigma$(PA, V decay) @ NLO EW	$d\sigma(V$ decay) @ NNLO QCD + NLO EW
$Vb\bar{b}$	$d\sigma$(lept. V decay) @ NLO QCD massive b	$d\sigma$(lept. V decay) @ NNLO QCD + NLO EW, massless b
$VV'\gamma$	$d\sigma(V$ decays) @ NLO QCD	$d\sigma(V$ decays) @ NLO QCD + NLO EW
$VV'V''$	$d\sigma(V$ decays) @ NLO QCD	$d\sigma(V$ decays) @ NLO QCD + NLO EW
$VV' + j$	$d\sigma(V$ decays) @ NLO QCD	$d\sigma(V$ decays) @ NLO QCD + NLO EW
$VV' + jj$	$d\sigma(V$ decays) @ NLO QCD	$d\sigma(V$ decays) @ NLO QCD + NLO EW
$\gamma\gamma$	$d\sigma$ @ NNLO QCD + NLO EW	q_T resummation at NNLL matched to NNLO

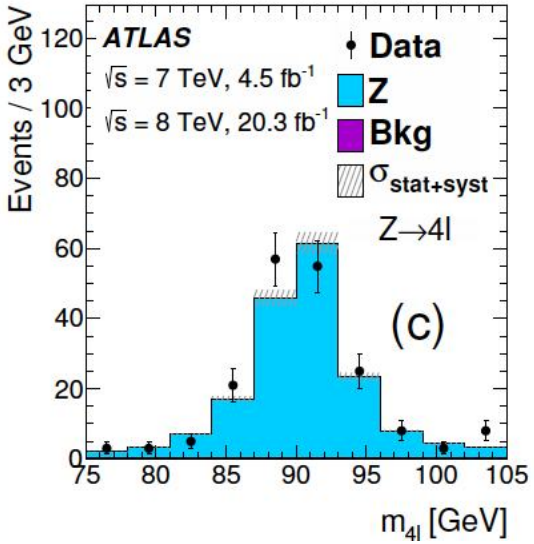
Progress in DiBoson cross sections

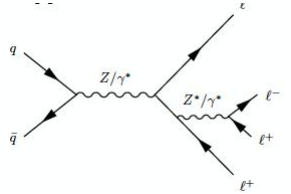


- 1-2 σ excess in WW (and WZ, Wγ) events at ATLAS/CMS.
  Not in TGC relevant region
  → Eagerly awaiting 8TeV results..

- Wγ description improves with NNLO



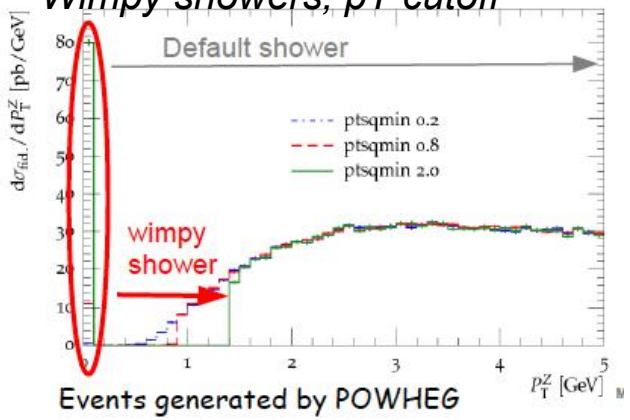




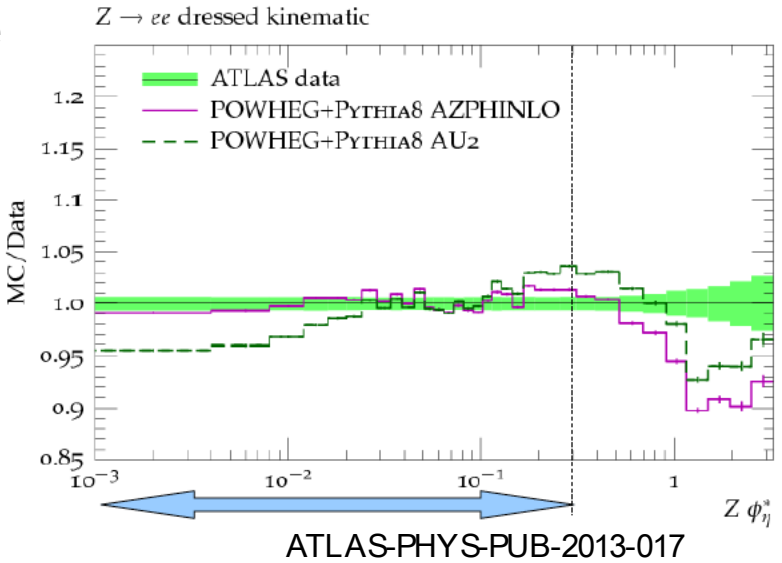
- Z → 4l
  Well under control
  → standard candle
  for H → ZZ

Tuning NLO+PS to ZΦ*/pTZ

Wimpy showers, pT cutoff



- Can achieve 2% precision in low and medium pT(Z) regime



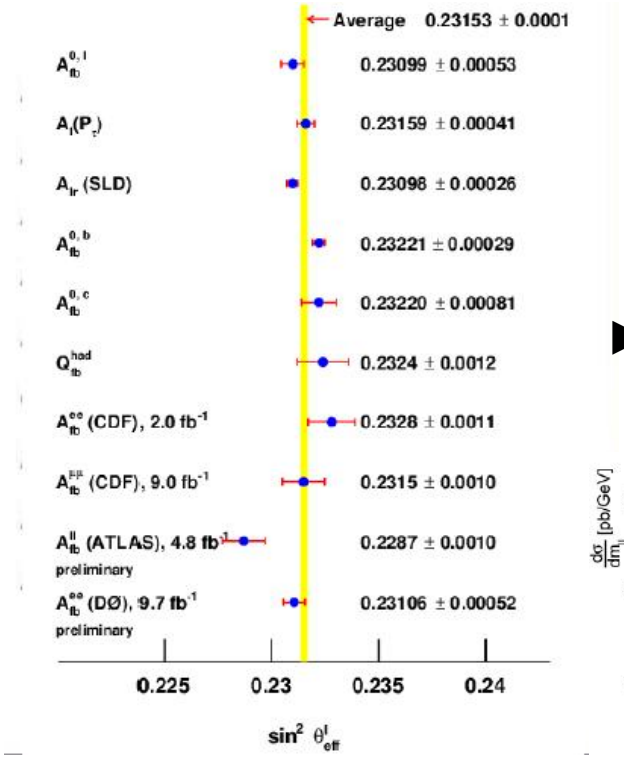
ATLAS-PHYS-PUB-2013-017

- Discussion of parameters suited for tuning: Proton remnants, ISR shower and ME, MPI

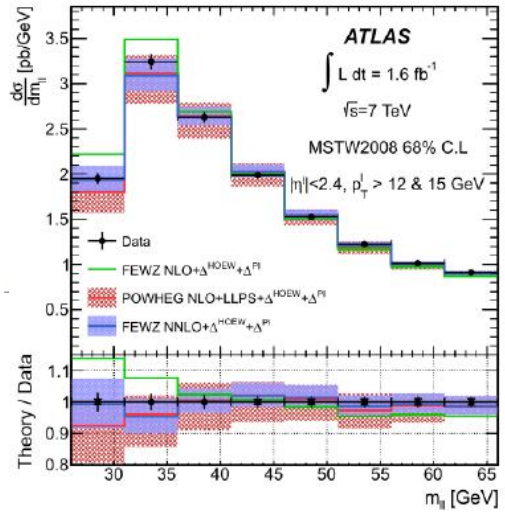
Parameter	PYTHIA8 setting	Variation range	AZPHINLO	AU2-CT10
Primordial kt	BeamRemnants:primordialKThard	1.0 – 2.5	1.74	2.0
ISR cut-off	SpaceShower:pT0Ref	0.5 – 2.5	1.91	2.0
ISR $\alpha_s(M_Z)$	SpaceShower:alphaSvalue	fixed	0.118	0.137
ISR α_s order	SpaceShower:alphaSorder	fixed	2	1
ISR limit	SpaceShower:pTmaxMatch	fixed	1	0
MPI cut-off	MultipartonInteractions:pT0Ref	1.0 – 2.5	1.57	1.70
Parameter	POWHEG setting			
Radiation cut-off	`ptsqmin`	fixed	4	0.8

Differential cross sections

- Tevatron and LHC updates on $\sin^2\Theta_W$

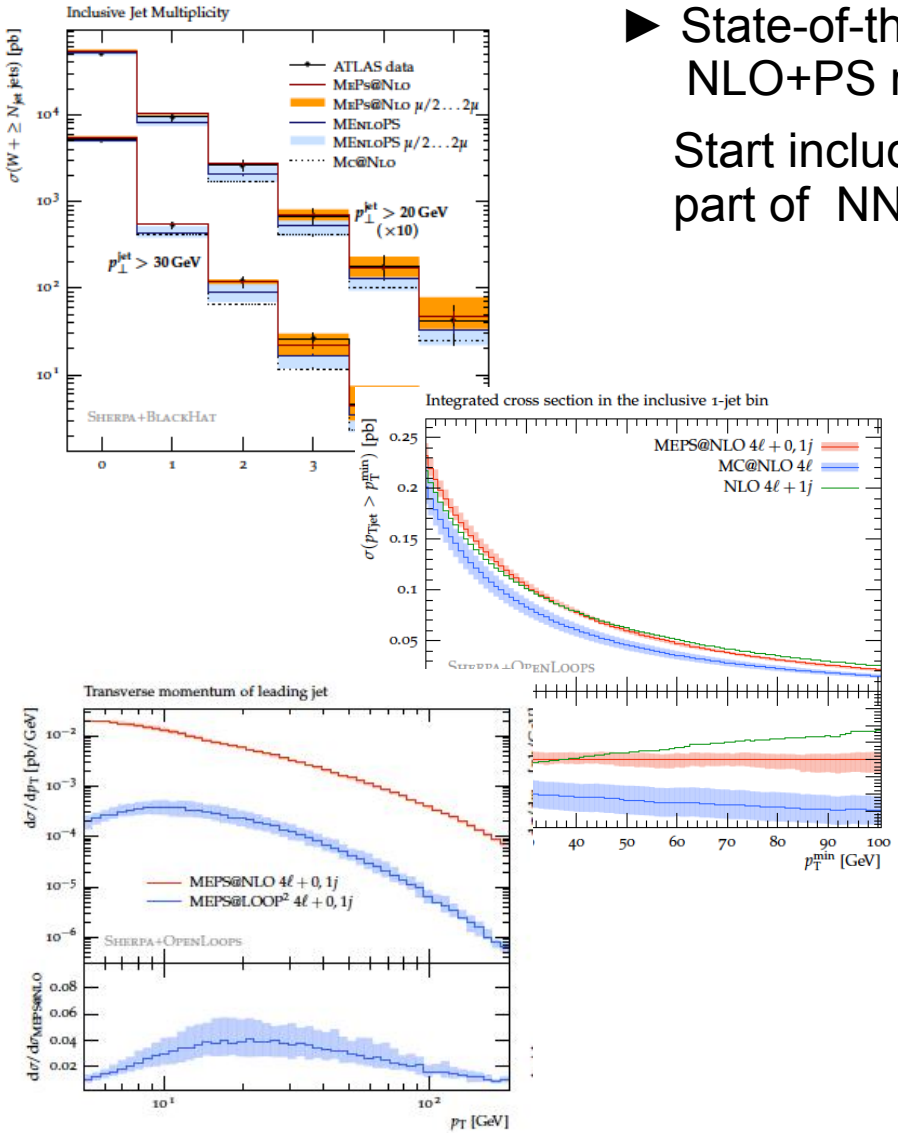


- DY mass spectrum at ATLAS and CMS



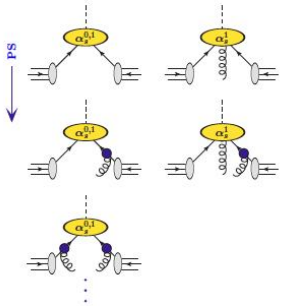
- Discussion: Comparison/combination of measurements between experiments
  - Common LHC fiducial region? (allow to sacrifice some sensitivity wrt. official measurement)
  - Common definitions of final state objects (e.g. bare, dressed leptons) as a baseline for generator comparisons?

State-of-the-art V, VV,VVV simulation



► State-of-the art: Multijet merging of NLO+PS matched simulations

Start including finite gauge-invariant part of NNLO contributions



► Discussion:

How to exploit huge recent progress in NLO+matching+merging in the signal **and** background simulations?

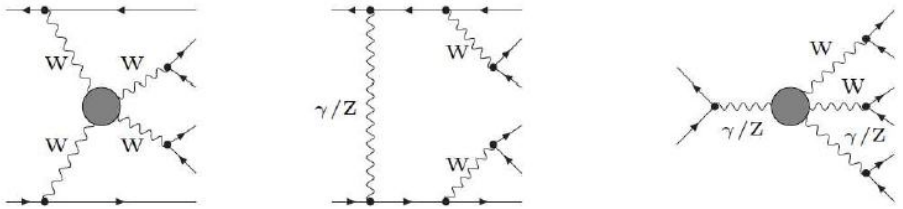
- Precision for various MC application
  - Signal predictions for new processes
  - backgrounds for Higgs/Top/BSM
    → extrapolation from CR to SR
    → nuisance parameter in profile LLH fit
  - unfolding of detector effects
  - Theory reference for xsec measurements

Asymmetry in signal and background precision in Higgs selections

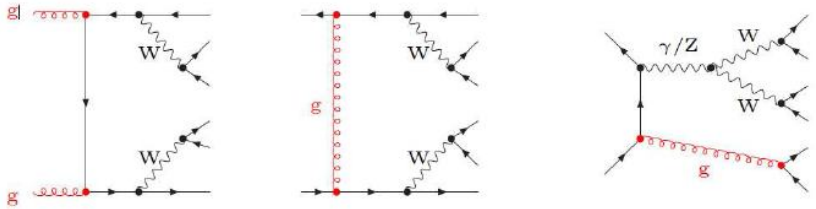
VBS+VBF state of the art simulation

- Impressive progress in recent years
  - precision calculation for VVjj
  - public tools for NLO-QCD+PS

EW channels:

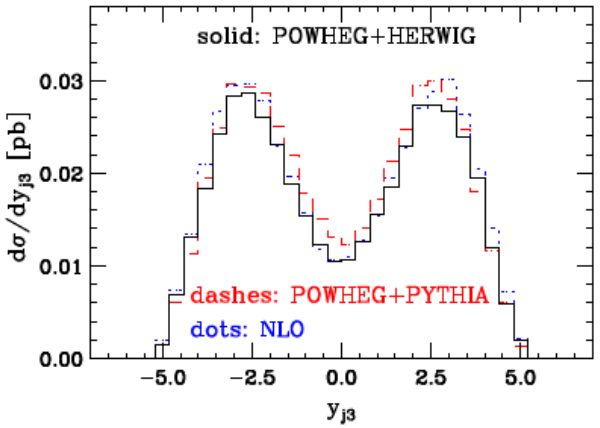


QCD channels:



- VBF: NLO and PS effects on small
  Larger impact on 3rd jet dynamics

Nason, Oleari (2009)



- Open issues in VBS:
  - QCD-induced ZZjj production at NLO+PS
  - NLO+PS VVjj in BSM scenarios
  - EW corrections to VVjj
  - mixing between QCD- and EW induced modes

→ Can develop full potantial only if used by experimentalists!

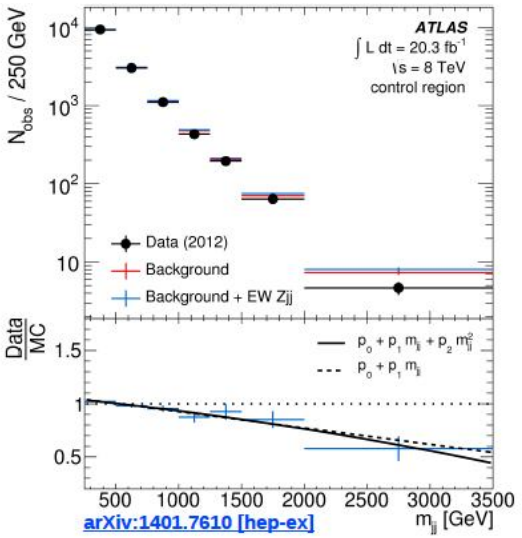
Observation of VBF Z

- Observation of VBF Z in both CMS and ATLAS

8 TeV

$$\sigma_{\mathrm{EW}}^{\mathrm{CMS}} = 226 \pm 26(stat) \pm 35(syst)\mathrm{fb}$$
$$\sigma_{\mathrm{EW}}^{\mathrm{VBFNLO}} = 239\mathrm{fb}$$

$$\sigma_{\mathrm{EW}}^{\mathrm{ATLAS}} = 54.7 \pm 4.6(stat)^{+9.8}_{-10.4}(syst) \pm 1.5(lumi)\mathrm{fb}$$
$$\sigma_{\mathrm{EW}}^{\mathrm{POWHEG}} = 46.1 \pm 0.2(stat)^{+0.3}_{-0.2}(scale) \pm 0.8(pdf) \pm 0.5(model)\mathrm{fb}$$

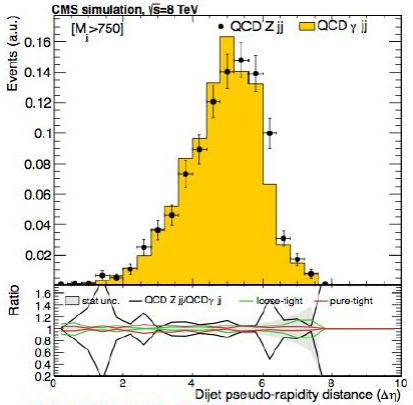


- Need more precise predictions to pin down backgrounds:
  Here: ≥ NLO+PS for OCD Z

- VBF measurements can and should be used to extract limits on TGCs

aTGC	$\Lambda = 6$ TeV (obs)	$\Lambda = 6$ TeV (exp)	$\Lambda = \infty$ (obs)	$\Lambda = \infty$ (exp)
$\Delta g_{1,Z}$	$[-0.65, 0.33]$	$[-0.58, 0.27]$	$[-0.50, 0.26]$	$[-0.45, 0.22]$
λ_Z	$[-0.22, 0.19]$	$[-0.19, 0.16]$	$[-0.15, 0.13]$	$[-0.14, 0.11]$

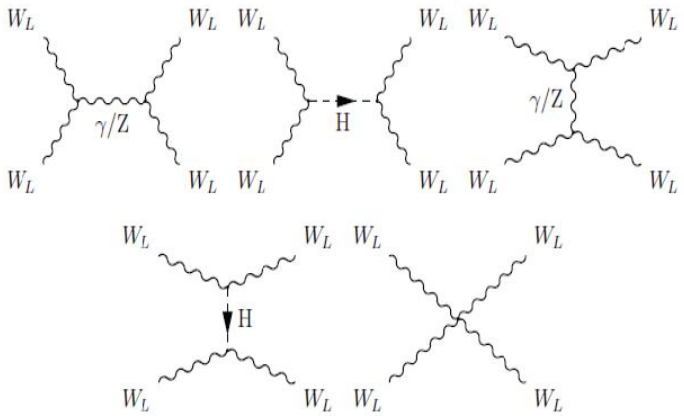
ATLAS, m(jj) > 1TeV search region

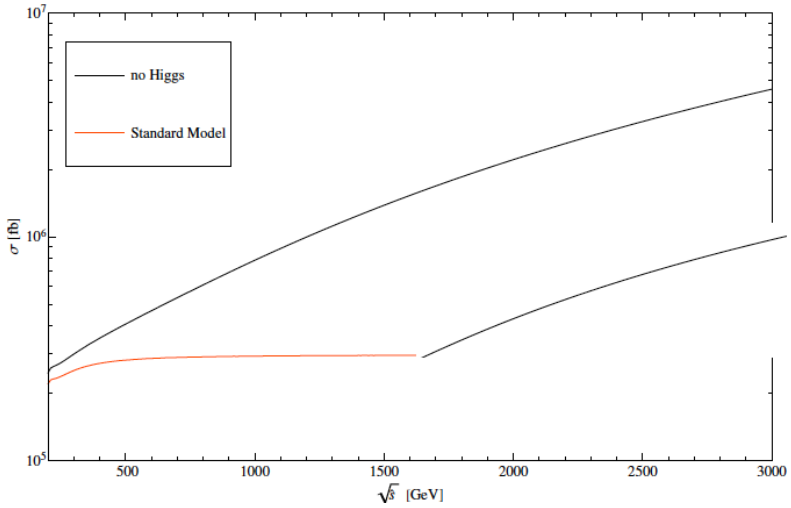


CMS-PAS-FSQ-12-035

aTGCs and aQCDs

- The light weakly coupled Higgs boson unitarises VBS amplitudes but unitarity violations associated with new physics might be just delayed to TeV scale





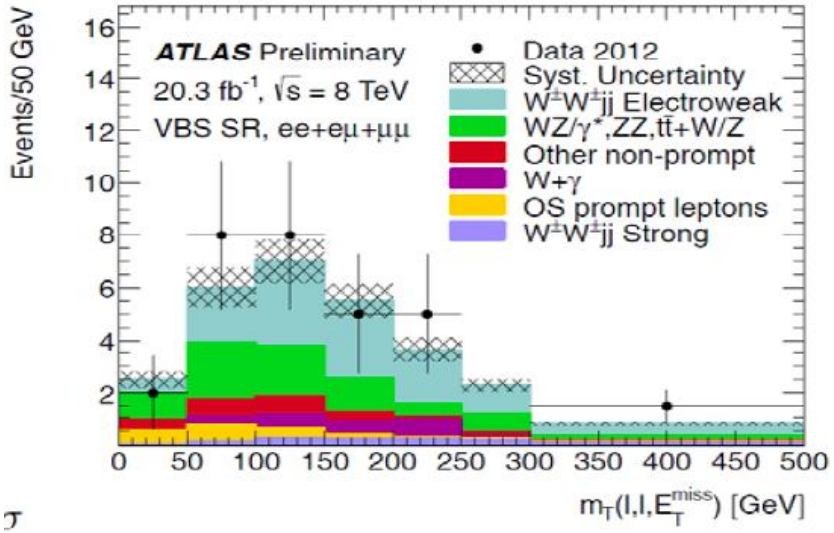
- At the LHC: parametrize new physics as aTGC/aQGC associated with effective Lagrangian

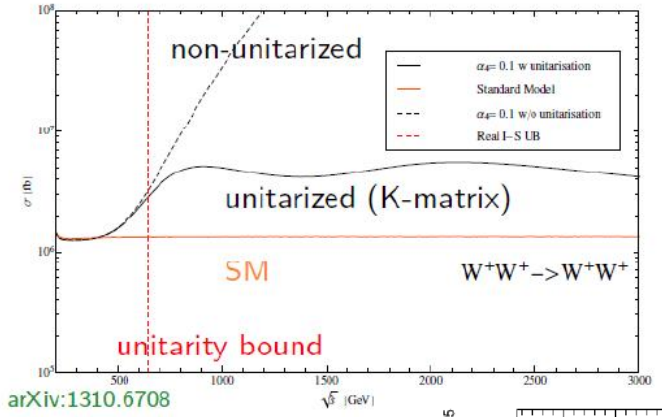
  → need precise measurements and SM theory predictions

- Might be more likely to observe resonant states than aTGCs/aQGCs

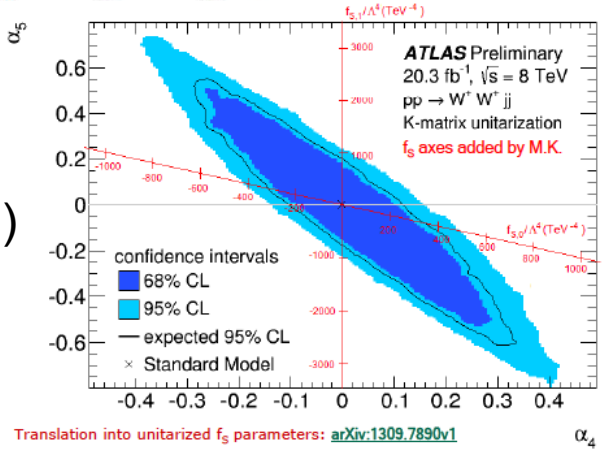
Measuring VVV and VVjj

- First observation of VV → VV scattering (ATLAS) $W^{\pm}W^{\pm} \rightarrow W^{\pm}W^{\pm}$





- Discussion: how to interpret limit on cross section (aQGC)



- CMS: $\sigma(WW\gamma + WZ\gamma)$ < 241 fb (< 3.4 x SM)
- CMS: $\sigma(\gamma\gamma \rightarrow W^+W^-)$ x BR = $2.2_{-2.0}^{+3.3}$ fb ~ 1 s.d.
- ATLAS: $\sigma(pp \rightarrow W^{\pm}W^{\pm}jj\text{-EW})$ x BR = 1.3±0.4±0.2 fb 3.6. s.d.

Parameter	dimension	channel	Λ_{UV} [TeV]	300 fb^{-1}		3000 fb^{-1}	
				5σ	95% CL	5σ	95% CL
$c_{\phi W}/\Lambda^2$	6	ZZ	1.9	34 TeV^{-2}	20 TeV^{-2}	16 TeV^{-2}	9.3 TeV^{-2}
f_{S0}/Λ^4	8	$W^{\pm}W^{\pm}$	2.0	10 TeV^{-4}	6.8 TeV^{-4}	4.5 TeV^{-4}	0.8 TeV^{-4}
f_{T1}/Λ^4	8	WZ	3.7	1.3 TeV^{-4}	0.7 TeV^{-4}	0.6 TeV^{-4}	0.3 TeV^{-4}
f_{T8}/Λ^4	8	$Z\gamma\gamma$	12	0.9 TeV^{-4}	0.5 TeV^{-4}	0.4 TeV^{-4}	0.2 TeV^{-4}
f_{T9}/Λ^4	8	$Z\gamma\gamma$	13	2.0 TeV^{-4}	0.9 TeV^{-4}	0.7 TeV^{-4}	0.3 TeV^{-4}