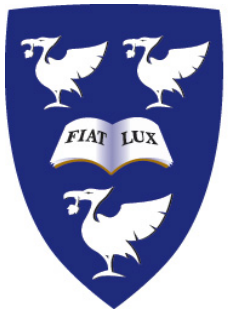
Precision NC and CC Drell-Yan - HO EW Corrections from an experimenter's view -



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and
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PPSC20: PRECISION MODELLING OF HADRON STRUCTURE AT HIGHEST ENERGIES

Les Houches Workshop, 9.6.2013

Points for discussion

1) EW parameters (and Vcs sensitivity) and choice of W partial width

2) EW parameters in Monte Carlo's and new methodology

3) Application of missing HO EW corrections (factored versus additive)

→ choice of nominal correction and evaluation of systematics

4) Photon-induced contributions

→ current procedure

→ measurement proposals?

1) Input parameters and EW schema

- Nominal EW schema for CC and NC Drell Yan : Gmu schema

$$\frac{1}{\alpha_G} = \frac{\sqrt{2} G_\mu M_W^2}{\pi} \left(1 - \frac{M_W^2}{M_Z^2}\right); \quad \sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

- Use for cross checked for NC DY : alpha(Mz) schema

Update of EW parameters:

❖ PDG 2012 change : Mw = 80.385 GeV (80.403), W width 2.085 GeV (2.0910) and 'a Higgs' mass of 125 GeV

❖ scrutinize SM QCD and EW tests!

→ use SM theory as strict as possible, i.e. using ONLY measured masses and ONE constant as input BUT CALCULATE ALL OTHER values

✓ PDG2012 predictions, but partial widths calculated for alpha_s=0.120

✓ ZFITTER package update from Sabine and Tord Riemann (private comm.)
ZFITTER v.6_44beta (Jan 2013), D. Bardin et al., CPC 133 (2001) 229,
A. Arbuzov et al., CPC 174 (2006) 728-758

➔ Cross checks showed excellent agreement between PDG2012 predictions and ZFITTER

➔ New : use an EW set in agreement with nominal NNLO alpha_s=0.118

W partial width

SM best partial width contains full (QED FSR and missing HO EW) HO EW corrections for inclusive cross sections is:

$\Gamma_W(l\nu) = 226.36$ MeV

If we like to evaluate missing HO EW corrections for W decay (kinematic dependencies) then we have to use e.g. SANC, and then we have to use the LO partial width

$\Gamma_W(l\nu) = 227.27$ MeV

➔ thus we can control the missing HO EW corrections

(‘missing HO EW ‘ == all NLO EW corrections except QED FSR, QED FSR correction is done via PHOTOS and unfolded ATLAS DY data are corrected for QED FSR)

➔ very good agreement between SANC and PHOTOS for QED FSR : "QED Bremsstrahlung in decays of electroweak bosons” A. B. Arbuzov, R. R. Sadykov, Z. Was [arXiv:1212.6783] ➔ missing HO EW from SANC is ‘matched’ to PHOTOS QED FSR correction

Remaining SM parameters

M_Z = 91.1876(0) GeV
M_W = 80.385(15) GeV
M_H = 125(0) GeV
m_t = 173.5(1) GeV
gf=1.1663787d-5
Caluclated by SANC : stw^2 = 0.2228972252391828
alphaG= 7.562395636697338 48E-003
vec_up= 0.4056074066028846 3
vec_dn= -0.7028037033014422 6
vec_le= -0.1084111099043269 0
Widths : PDG2012 [partial widths zfitter alpha_s corrected from PDG12]
Γ_Z(ll) = 84.000 MeV Γ_W(lnu) = 227.27 MeV
Γ_Z = 2494.9 MeV Γ_W = 2090.6 MeV
PDG2012 uses CKM fitter results, but consistent with UTfitter results [Note: using FEWZ, one has to use Vus=Vcd=0.2252D0,
but for MCFM and DYNNLO we do NOT use this constraint]
Vud = 0.97427 Vus = 0.22534 Vub = 0.00351
Vcd = 0.22520 Vcs = 0.97344 Vcb = 0.0412
Vtd = 0.00867 Vts = 0.0404 Vtb = 0.999146

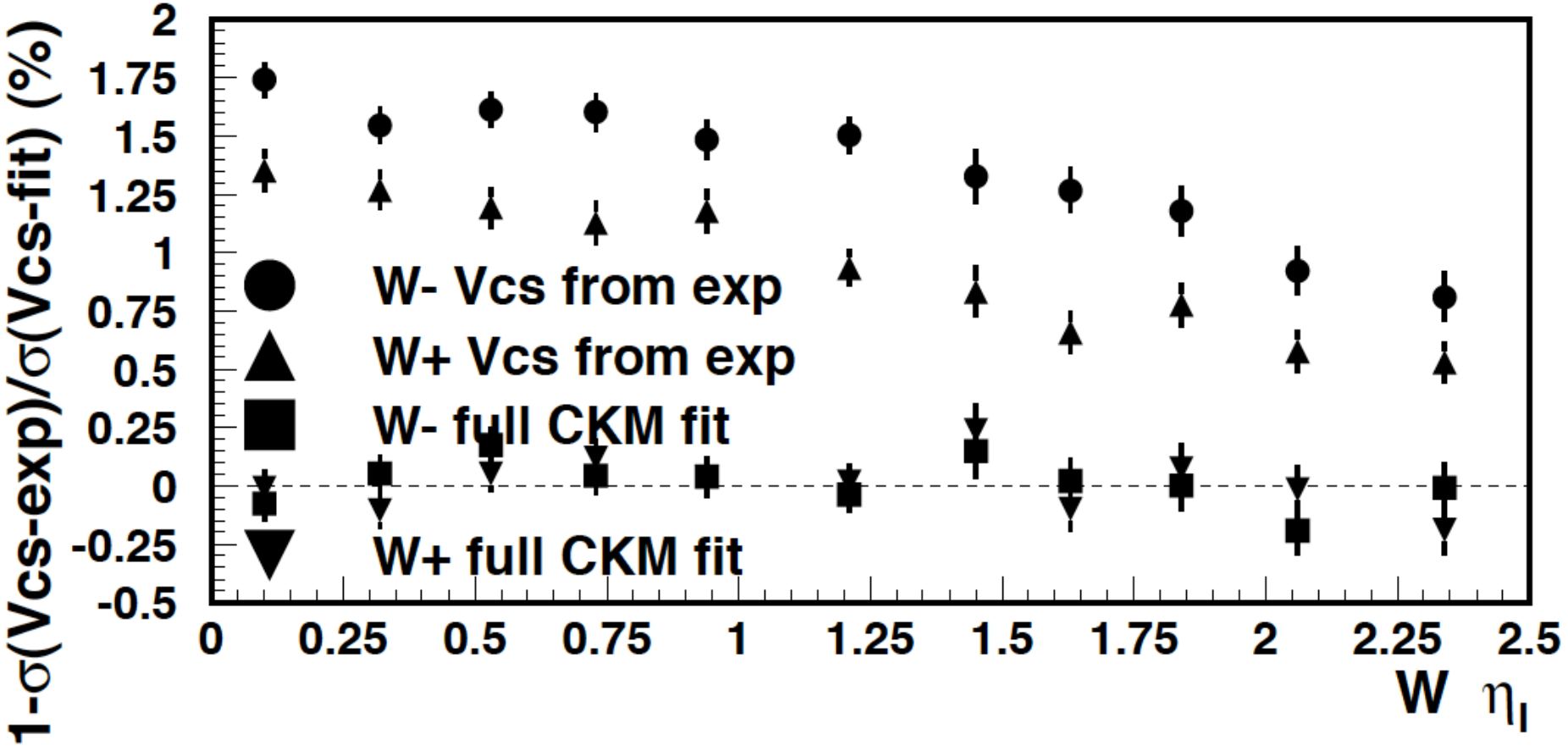
Effects of CKM value choice

➔ Case study : Use of exp. determined CKM values versus fitted values

➔ Deviations are largest for use of exp. Vcs value, Vcs=1.006+-0.023, evaluated w.r.t. use of fitted Vcs but experimental CKM values otherwise

❖ checked CKM fitter and UT fitter results → consistent values with much smaller errors, but fits assume strict SM and unitarity for all generations

❖ effect on W- and W+ predictions are in the 0.8% to 1.7% range and eta-dependent



2) EW parameters in Monte Carlo's and new methodology

- NEW method used for Z' ATLAS-CONF-2013-017 mass-dependent k-factors:

$$\sigma_{(NNLO\_QCD+NLO\_EW)} = k_{HO\_QCD\_EW} \times \sigma_{MC}$$

with

σ_{MC} **: obtained from Pythia or Powheg**

$$k_{HO\_QCD\_EW} = \frac{\sigma_{(NNLO\_QCD+NLO\_EW)}}{\sigma_{MC}} \quad \textbf{: fit}$$

➔ forces the generated Monte Carlos to consistent EW scheme and PDF choice (before cuts and before QED FSR)

Nominal application of missing HO EW corrections to form $\sigma_{(NNLO\_QCD+NLO\_EW)}$

➔ **use FEWZ NC DY and full additive EW** correction in ONE calculation ➔ **cross checked with MCSANC (and also for yz in peak region)**

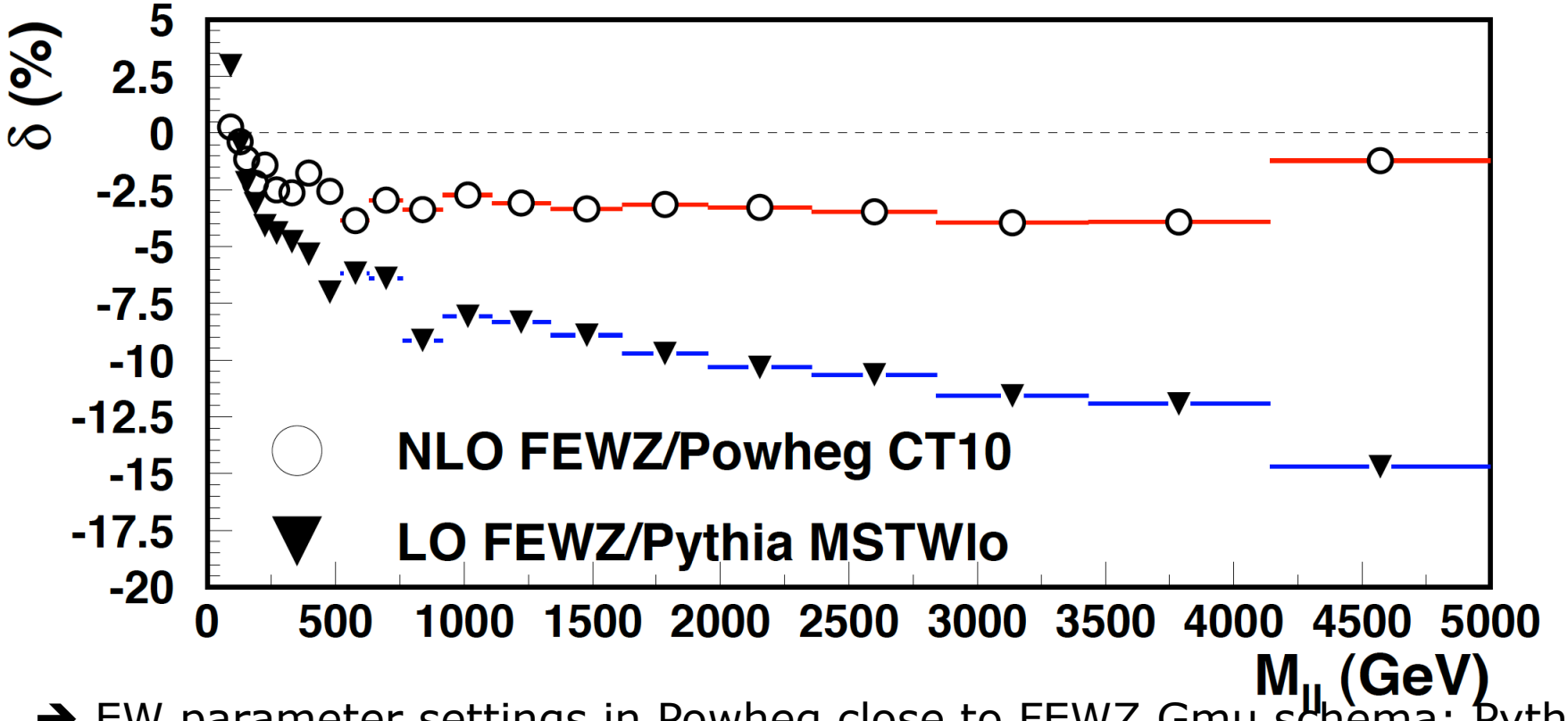
➔ **use DYNNLO and SANC for CC DY (and W' searches) in additive approach**

➔ **use factored approach for systematics**

➔ ON TOP of NNLO QCD + NLO EW for NC DY : real W,Z radiation and photon-induced contribution (with cuts) w.r.t. PDF

NC DY : Matching of QCD cross sections to MC

- To match the different EW parameter schemes in the MC to external programs ➔ form ratio at same QCD order (LO EW) and use same PDF
- FEWZ Gmu EW schema calculations (LO EW) done at either NLO or LO QCD and using same PDF as used for the MC generation (a common PDG based input set is used for ALL MC generations!)



➔ EW parameter settings in Powheg close to FEWZ Gmu schema; Pythia OFF

3) Methodology $\sigma_{(NNLO\_QCD+NLO\_EW)}$

Various methods, how to obtain $\sigma_{(NNLO\_QCD+NLO\_EW)}$ (numerator of k)

a) **NC DY :** use FEWZ 3.1.b2 and calculate the combined (additive) NNLO QCD + NLO EW effects in ONE calculation

b) **Construct $\sigma_{(NNLO\_QCD+NLO\_EW)}$ → method for NC and CC DY**
using several external programs:

i) NNLO QCD prediction per bin : using FEWZ or DYNNLO for NNLO QCD directly (caveat : for low and high masses use FEWZ, for W diff. predictions use DYNNLO)

OR use pure QCD k-factors (ZWPROD or VRAP) and apply to LO/NLO QCD FEWZ prediction per bin

ii) HO EW $\boldsymbol{\delta_{MISS}}$: HORACE, SANC (or FEWZ for NC), but renormalize LO QCD obtained results for missing HO EW corrections higher order QCD cross section

$$\delta_{MISS} = \frac{\sigma_{HO\_EW\_LO\_QCD} - \sigma_{LO\_QCD}}{\sigma_{LO\_QCD}} = k_{EW} - 1$$

Methodology … cont'd

Practical formulas, how it may work for NC and CC DY,

fully factored ansatz (note, any photon induced contribution has to be added for the fiducial cuts in the NC DY case or as a PDF dep. factor)

$$\sigma_{(NNLO\_QCD+NLO\_EW)} = k_{QCD} \times k_{EW} \times \sigma_{QCD\_in\_bin}$$

with

$$\sigma_{QCD\_in\_bin} = \sigma_{LO\_QCD\_PDF1,EW1} \quad \text{(DYNNLO,FEWZ)}$$

$$k_{QCD} = \sigma_{NNLO\_QCD} / \sigma_{LO\_QCD\_PDF1} \quad \text{(VRAP,ZWPROD:ratio robust w.r.t. EW schema)}$$

$$k_{EW} = \sigma_{HO\_EW,EW1} / \sigma_{LO\_QCD,EW1} \quad \text{(SANC, HORACE: ratio robust w.r.t. PDF and c.m.s. energy)}$$

additive ansatz (for the construction of EW corrected NNLO QCD, BUT using NNLO PDF for all orders of QCD!)

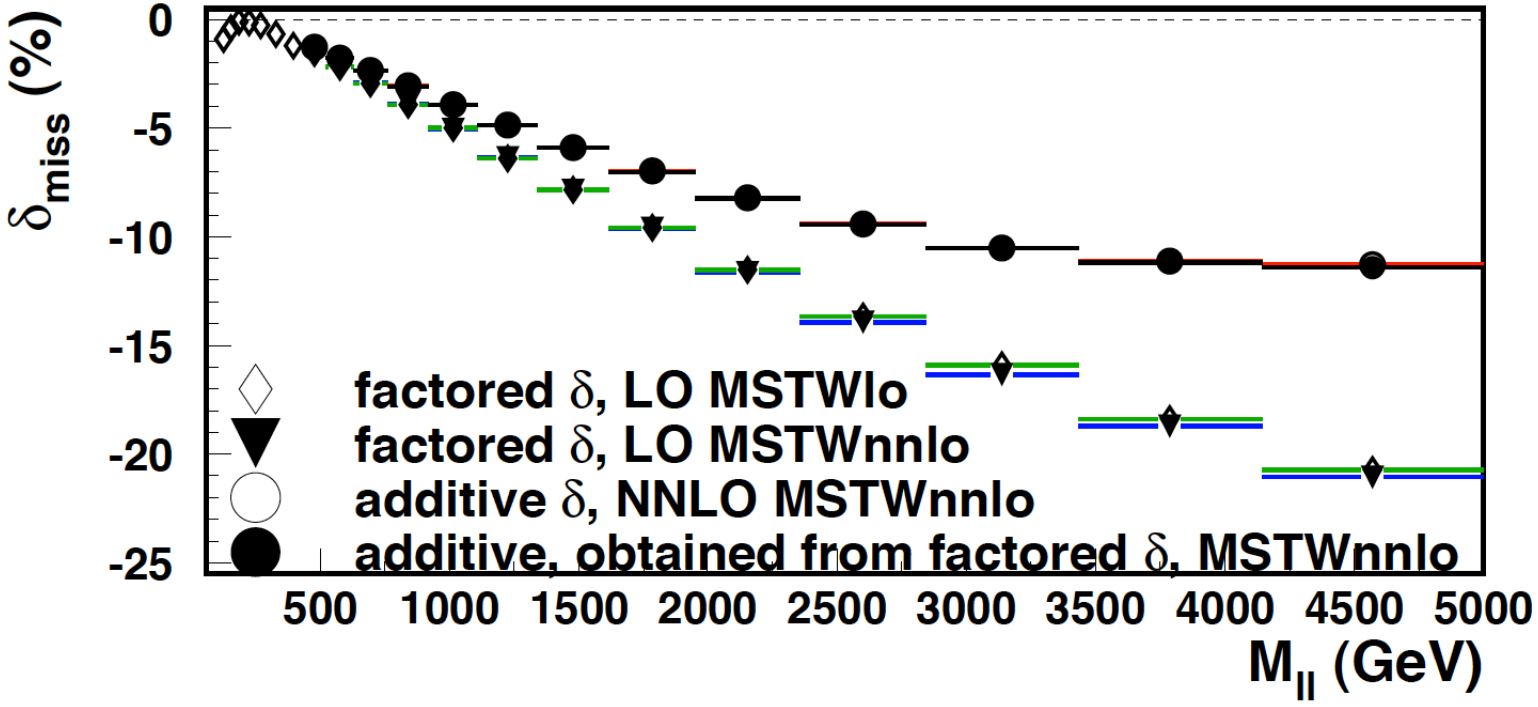
$$\sigma_{(NNLO\_QCD,NNLOPDF,EW)} - \sigma_{(NNLO\_QCD,NNLOPDF)} = \sigma_{(LO\_QCD,NNLOPDF,EW)} - \sigma_{(LO\_QCD,NNLOPDF)}$$

$$\sigma_{(NNLO\_QCD+NLO\_EW)} = \sigma_{NNLO\_QCD}\left(1+\delta_{MISS}^{rescaled}\right) = \sigma_{NNLO\_QCD}\left(1+\frac{\sigma_{LO\_QCD,EW}-\sigma_{LO\_QCD}}{\sigma_{NNLO\_QCD}}\right)$$

NC DY : Factored versus additive miss EW

- rescale EW correction based on LO QCD (full triangles) to NNLO QCD (full circles) ➔ excellent agreement with EW corrections calculated based on NNLO QCD (open circles), using the additive application of the loop corrections, but using NNLO PDF for all orders of QCD!

➔ method applicable for NC and CC current, and in principle no need to run FEWZ NNLO QCD + EW… (but nice to control the method)

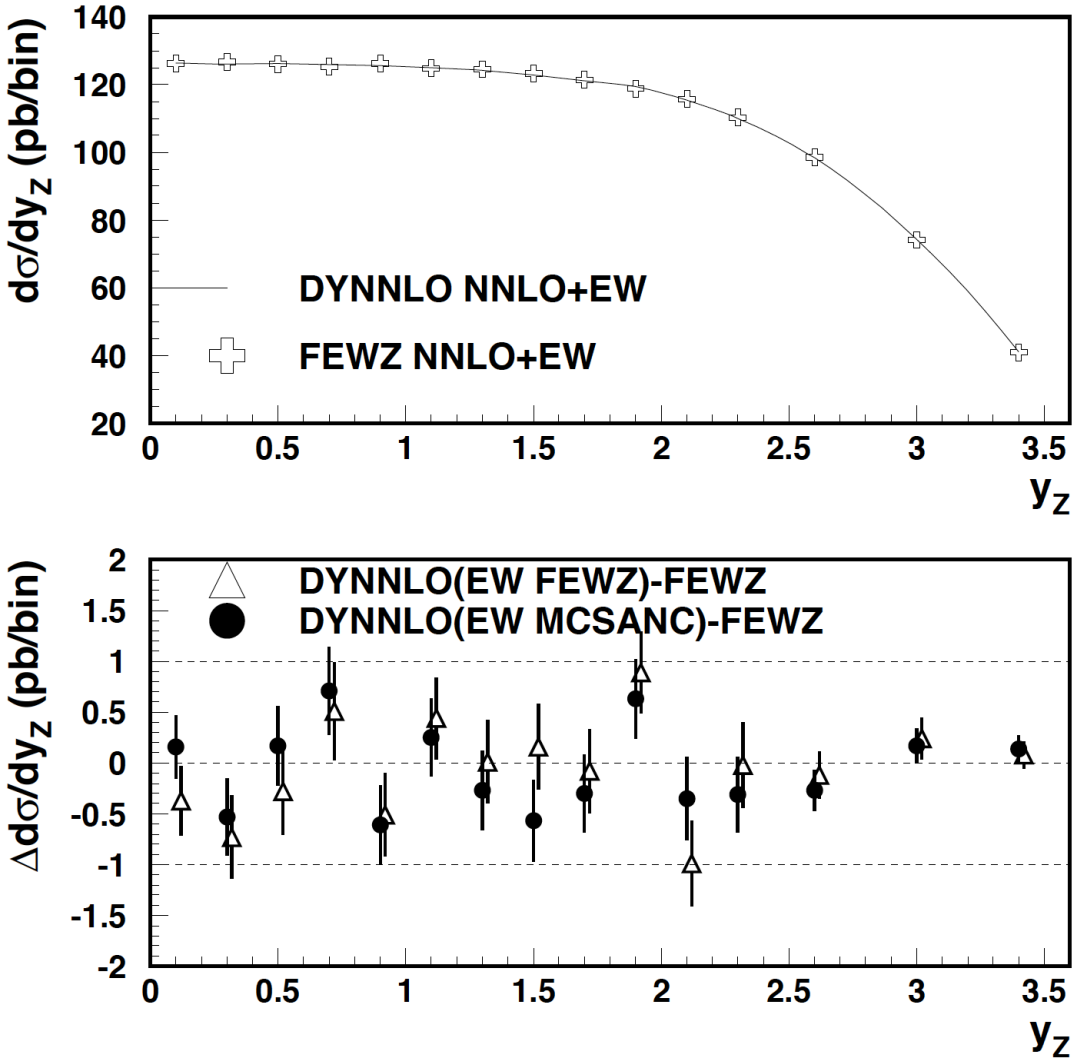


example: 8 TeV Z' search calculations ➔expected to work well for 1d distributions ➔issues may arise for pT and strong phase space cut regions (where LO QCD fails)

NC DY : 66-116 GeV NNLO QCD+NLO missing EW predictions for yz

High precision
NC DY yZ predictions using
either missing EW (FEWZ) or missing EW (MCSANC)
applied in additive way to the NNLO QCD DYNNLO y_Z prediction

→ method works and can be used also for CC DY
→ using there also additive vs factored results



LO predictions

$M_{ll} > 50\,\text{GeV}, \quad p_{\text{T},l^\pm} > 25\,\text{GeV}, \quad |y_{l^\pm}| < 2.5,$ arXiv:0911.2329v2

$\text{pp} \to l^+l^- + X$ at $\sqrt{s} = 14\,\text{TeV}$ Table 1

MRST2004QED

G_μ ; scales=M_Z (!)

M_{ll}/GeV	50–∞	100–∞	200–∞	500–∞	1000–∞	2000–∞
σ_0/pb	738.733(6)	32.7236(3)	1.48479(1)	0.0809420(6)	0.00679953(3)	0.000303744(1)
$\sigma_0\|_{\text{FS/PS}}/\text{pb}$	738.773(6)	32.7268(3)	1.48492(1)	0.0809489(6)	0.00680008(3)	0.000303767(1)
$\delta_{\gamma\gamma,0}/\%$	0.17	1.15	4.30	4.92	5.21	6.17
$\delta^{\text{rec}}_{q\bar{q},\text{phot}}/\%$	−1.81	−4.71	−2.92	−3.36	−4.24	−5.66
$\delta^{\mu^+\mu^-}_{q\bar{q},\text{phot}}/\%$	−3.34	−8.85	−5.72	−7.05	−9.02	−12.08
$\delta^{\mu^+\mu^-}_{\text{multi}-\gamma}/\%$	$0.073^{+0.027}_{-0.024}$	$0.49^{+0.18}_{-0.15}$	$0.17^{+0.06}_{-0.05}$	$0.23^{+0.07}_{-0.06}$	$0.33^{+0.09}_{-0.08}$	$0.54^{+0.13}_{-0.12}$
$\delta_{q\bar{q},\text{weak}}/\%$	−0.71	−1.02	−0.14	−2.38	−5.87	−11.12
$\delta_{\text{h.o.weak}}/\%$	0.030	0.012	−0.23	−0.29	−0.31	−0.32
$\delta^{(2)}_{\text{Sudakov}}/\%$	−0.00046	−0.0067	−0.035	0.23	1.14	3.38
$\delta_{q/\bar{q}\gamma,\text{phot}}/\%$	−0.11	−0.21	0.38	1.53	1.91	2.34
$\delta^{\text{rec}}_{\gamma\gamma,\text{phot}}/\%$	−0.0060	−0.032	−0.11	−0.14	−0.16	−0.23
$\delta^{\mu^+\mu^-}_{\gamma\gamma,\text{phot}}/\%$	−0.011	−0.058	−0.22	−0.30	−0.39	−0.59
$\delta_{\gamma\gamma,\text{weak}}/\%$	0.000045	0.00056	−0.025	−0.14	−0.31	−0.64
$\delta_{\text{QCD}}/\%$	4.0(1)	13.90(6)	26.10(3)	21.29(2)	8.65(1)	−11.93(1)

photon induced

weak

to be added : NLO photon induced (photon-quark contribution, not in FEWZ 3.1.)

'Benchmark' FEWZ 3.1.b2
→ I could reproduce exactly those numbers within 0.2% for photon-induced and weak contributions (c.f. also FEWZ 3.1. paper).
→ Perform calculations for Atlas cuts and bins !
→ISSUE : how to ADD?

Benchmarking and systematics … cont'd

I made a qualitative cross check with S Dittmaier paper as guidance,arXiv: 0911.2329v2, Table 1, calculations at scale Mz, PDF: MRST2004qed, LO QCD, c.m.s.=14 TeV, using FEWZ EW, 8 TeV, approximate bin limits as in Dittmaier paper (bin with * means M>116 GeV for FEWZ instead of M>100 GeV as for Dittmaier)

range : mass range as used by Dittmaier, e.g. from 100 GeV to infinity
PW: Dittmaier pure weak (PW) correction
PW': Dittmaier PW + HO PW
Sudakov : Dittmaier Sudakov(2) effects (relevant for very high masses, and indicating potentially further missing HO corrections)
fact : factored results based on LO, using MSTWnnlo, FEWZ+EW
add : additive pure weak effects based on NNLO QCD, using MSTWnnlo, FEWZ+EW
|fact-add| : absolute of difference between factorisation (LO) and additive results

ALL values in %, mass ranges in GeV (inf means infinity)

range	PW	PW'	fact	add	Sudakov	|fact-add|
100-inf	-1.02	-1.00	-0.73*	-0.64	-0.0067	0.09
200-inf	-0.14	-0.37	-0.19	-0.17	-0.035	0.02
500- inf	-2.38	-2.67	-2.00	-1.6	0.23	0.4
1000-inf	-5.87	-6.18	-5.64	-4.35	1.14	1.29
2000-inf	-11.12	-11.44	-12.1	-8.46	3.38	3.64

Observations

- The LO QCD based EW (factored, using FEWZ QCD+EW) results are in very good qualitative agreement with S. Dittmaier results (and also x-checked by SANC)
- The difference between the factored and the additive results seems to be a good, qualitative estimate of missing Sudakov(2) terms.
- However, we need mass-dependent terms, and hence we use the mass-dependent differences between factored and additive approach,

those rises then up to 9% at 4.5 TeV (note, c.m.s. dependence is very weak)

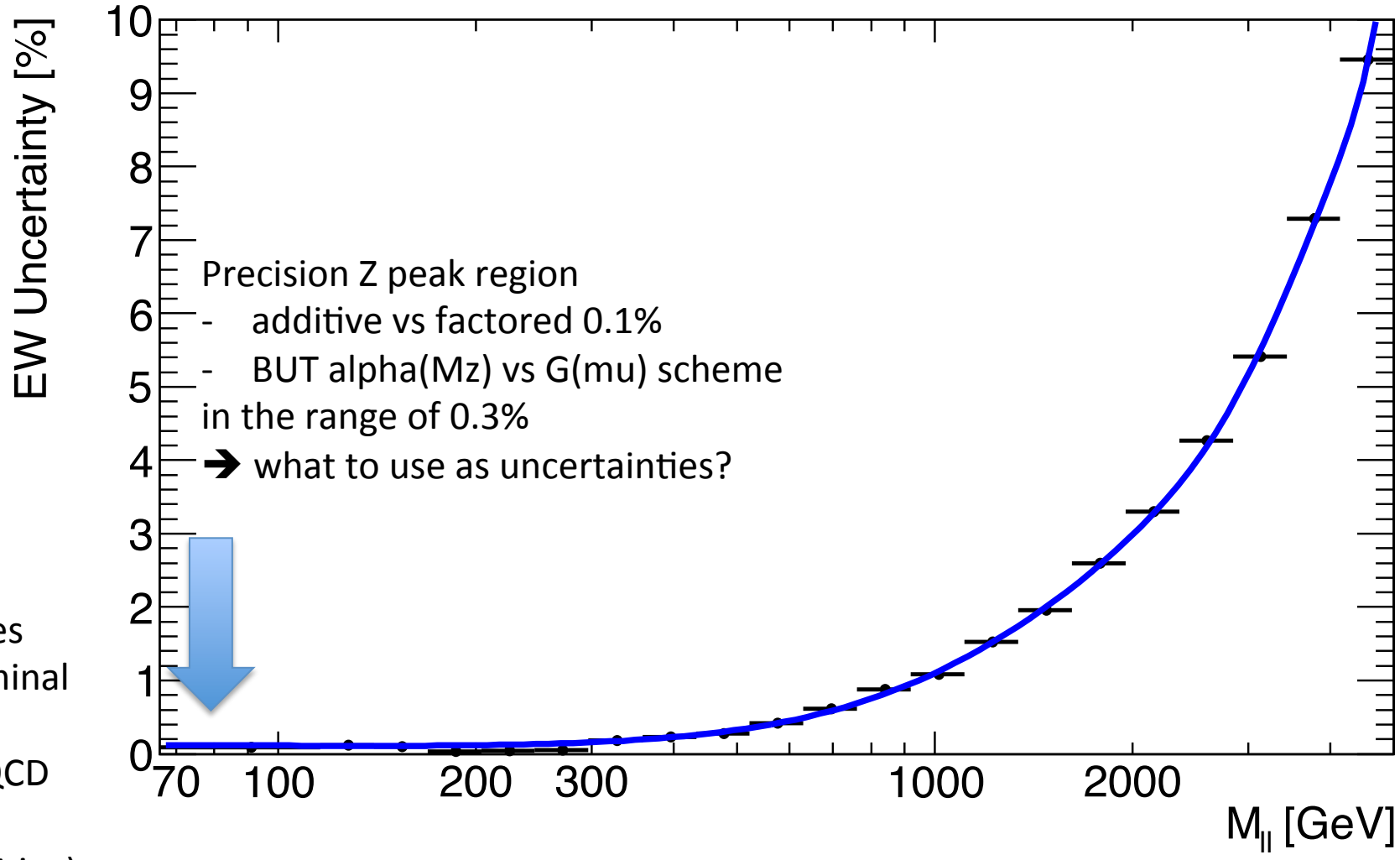
The use of a mass-dependent EW systematics *and not* the 2000-inf (integrated) estimate of the Sudakov(2) terms as done in previous analyses (3.5-4%, assumed constant for all mass bins).

The EW systematics should be symmetric: possible Sudakov effects are positive but a factored application of the LO QCD based evaluated missing HO EW effects would give the full negative variation.

➔ note : Experimenters do NOT like to use 'extremes' for the nominal choice

➔ hence the approach to use additive application as 'mean' (nominal) and apply a symmetric uncertainty

NC DY missing EW ‘systematics’



→ applied as symmetric uncertainties around nominal missing EW corrected QCD prediction (nominal : additive)

4) Photon induced (PI) updated

- Discussion with R Thorne and G Watt at Dec '12 PDF4LHC meeting

➔ new MRST2004qed grid which contains an alternative input model for the photon in the proton obtained by evolution from an effective quark mass, :

➔ model 1 : based on current masses of 6 and 10 MeV

➔ model 2 : based on constituent masses of 300MeV → hence ALWAYS smaller

Max. deviation of model 2 w.r.t.

model 1 is 80% at highest masses

➔ New proposal (also supported by R. Thorne):

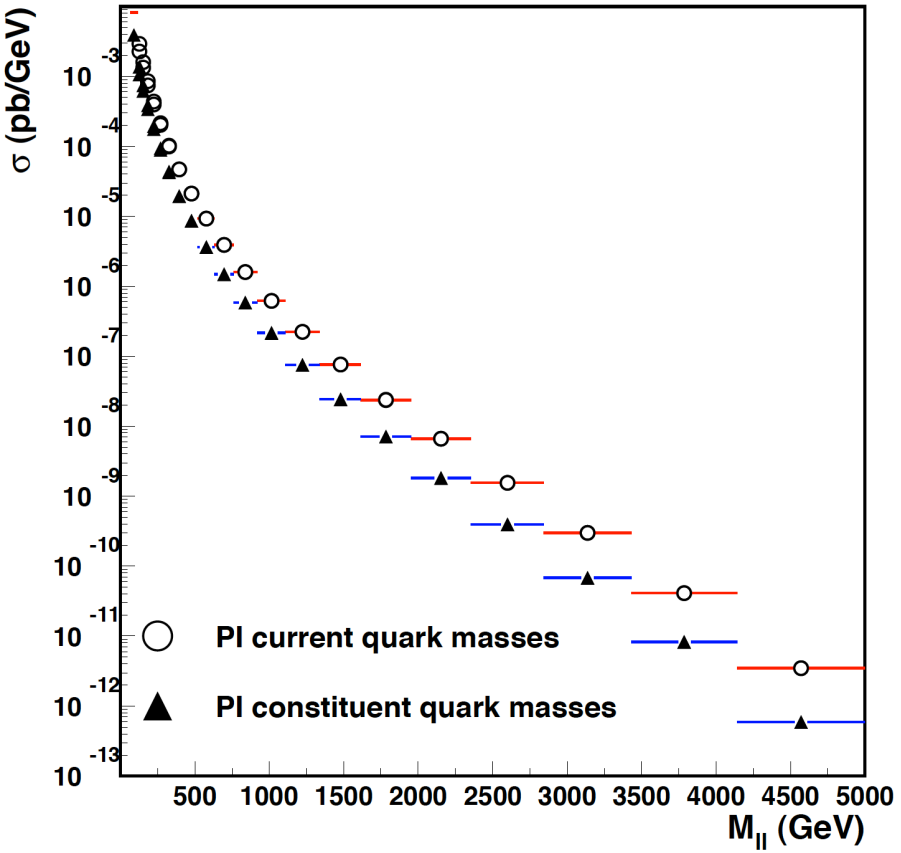
Take the mean of both and use symmetric 'uncertainties'

- Plot : PI with pT>25, $|\eta|<2.5$ for both models

➔plot for 8 TeV for illustration

➔SAME procedure for SM (low mass, high mass and Z peak region NC DY) and Z' searches (NC DY is the background)

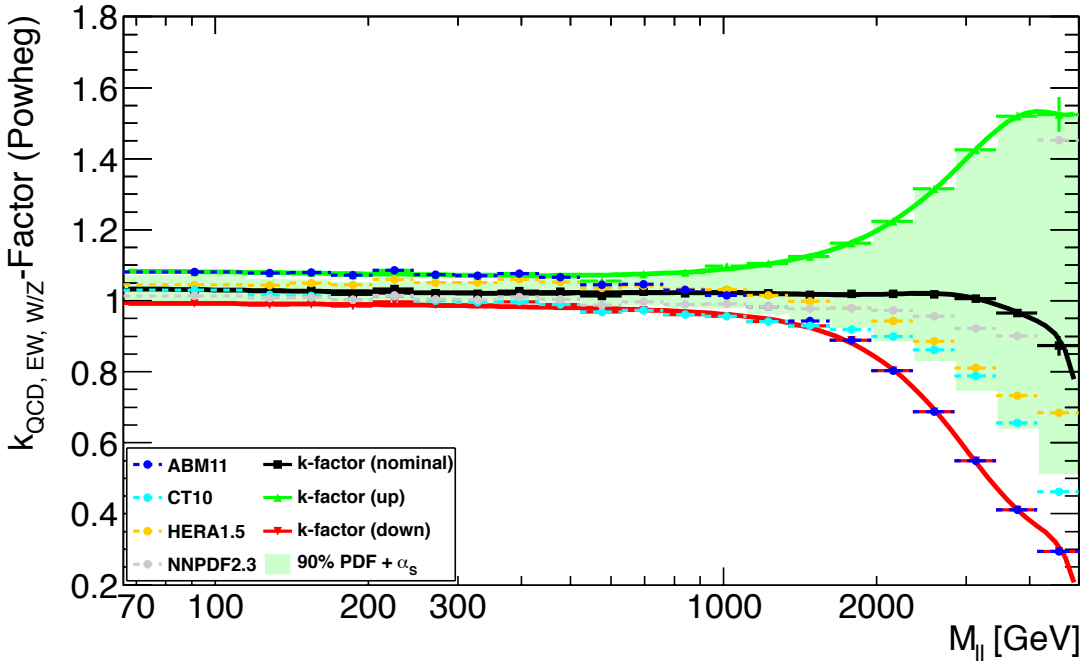
➔ NLO PI : small w.r.t. present errors (few % and scale dep)



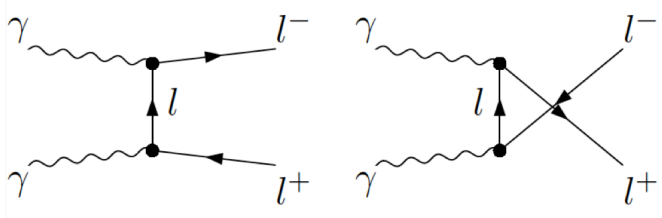
"k-factors" and photon-induced contributions

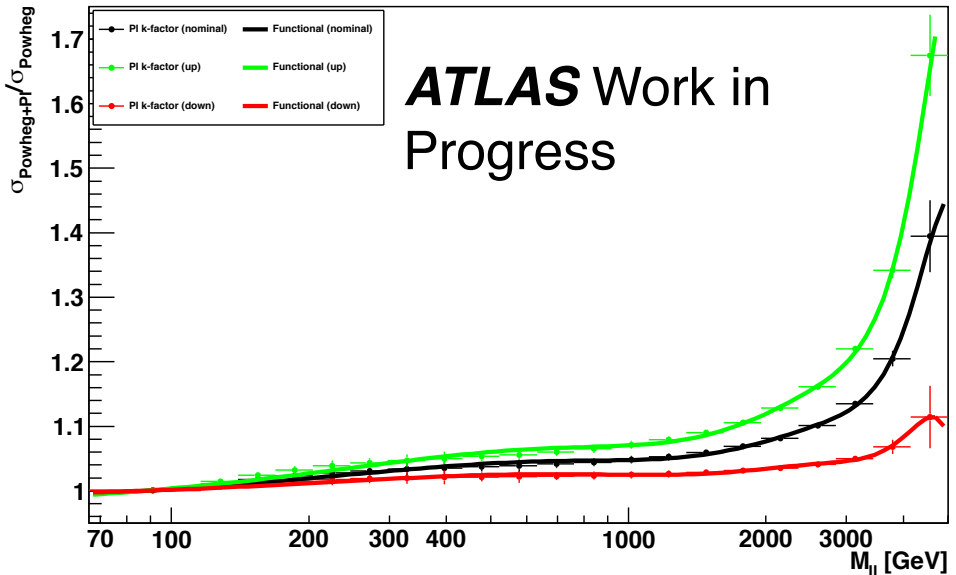
ATLAS-CONF-2013-017
related work

- novel method of "k-factors" : NNLO QCD + NLO EW + real W,Z radiation "k-factor" w.r.t. nominal ATLAS NC DY Powheg MC



- photon-induced contributior w.r.t. nominal "k-factor" reweighted NC DY MC estimated using updated MRST200qed grid (R.Thorne private comm.) <u>with</u> fid. lepton cuts





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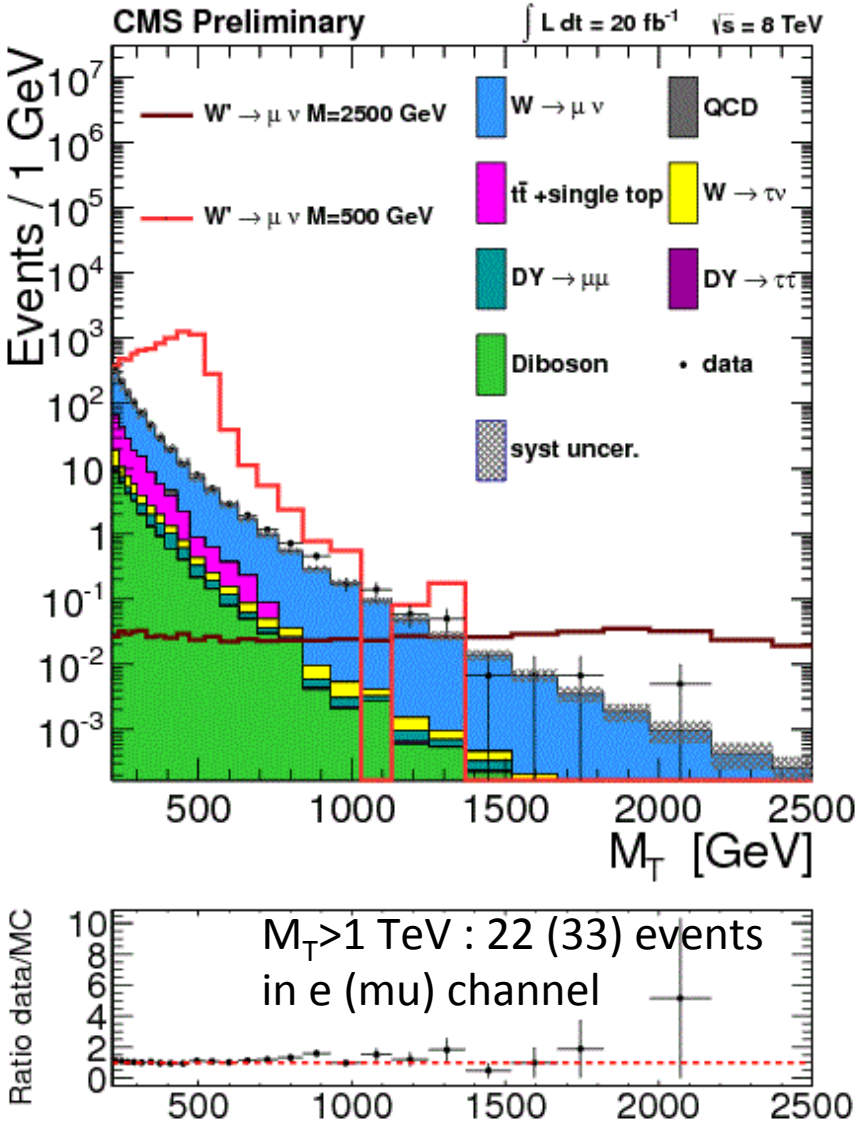
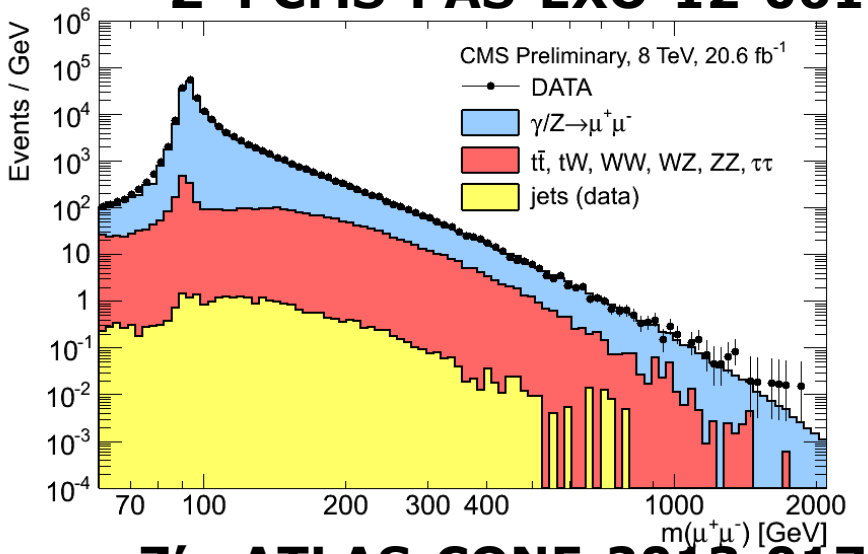
Searches at 8 TeV

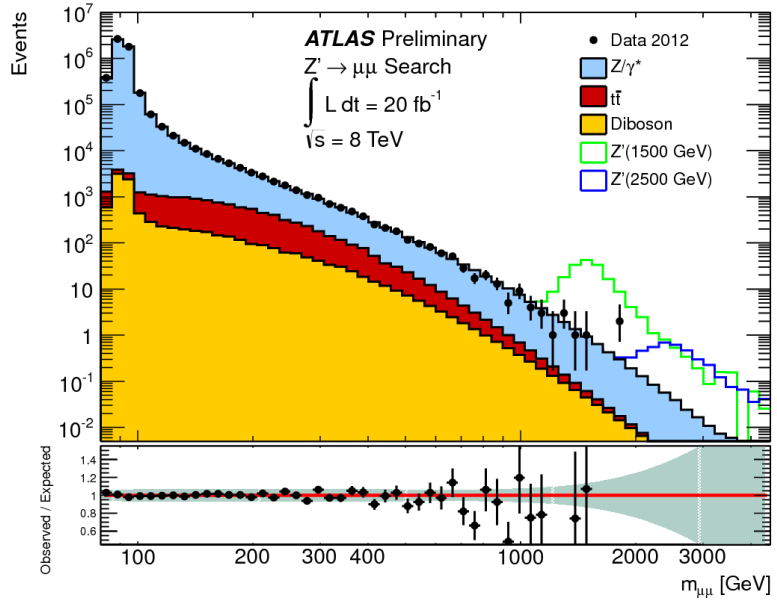
W': CMS-PAS-EXO-12-060



Z' : CMS-PAS-EXO-12-061



Z' : ATLAS-CONF-2013-017



shaded band: mass-dep. bgd. syst.

A wish list for discussion & studies

.. some tasks are already under study also in LPCC and EW experimental and theory WG's

➔ "optimal" choice (and documentation) of EW parameters and SM inputs for *matched* QCD and EW calculations

❖ Precision evaluation of missing HO EW (ISR, interferences, weak) corrections and QED FSR modelling; application of missing HO EW corrections and remaining systematics

❖ Improved modelling of p_T(W,Z) : implementation of resummation into NLO MC models (but e.g also control of resummation scale)

➔ missing HO EW corrections (+systematics) for more complex kinematic variables like phi*(Z), M_T(W), W polarisation

❖ Improved modelling and measurement proposals for non-resonant photon-induced dilepton productions, but also for the NLO gamma-p induced dilepton and W productions

❖ Improved modelling of real W and Z radiation beyond LO approach outlined by U.Baur, arXiv:hep-ph/0611241