The W boson mass determination: theory perspective

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Pomeriggio tematico su M_W

`U. Roma 1`

Roma

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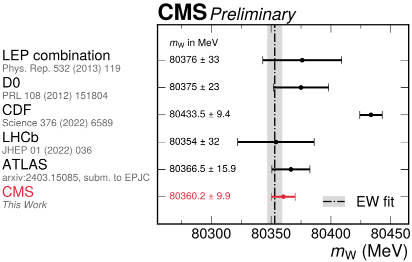
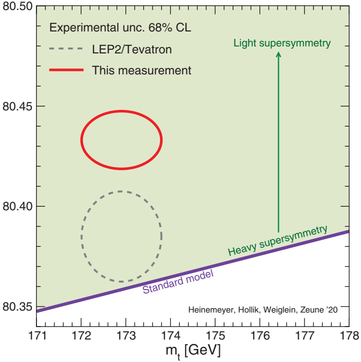
The physics case for the W mass

- The m_W mass measurement is one of the cornerstones of the SM precision program at colliders
- From the theory side, there are two lines of research, one linked to the measurement itself and one linked to the prediction in the SM (or beyond) to interpret the measurement



[CMS-SMP-23-002, '24]



[CDF collaboration, Science 376 (2022) 6589, 170-176]

Theory aspects of the M_W determination at the LHC

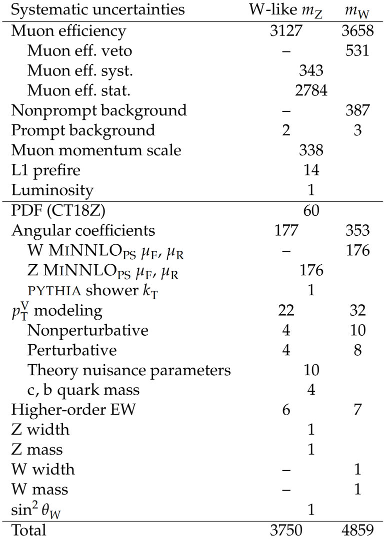
The importance of an accurate theory framework

- M_W determination at hadron collider is performed indirectly by measuring observables that are strongly sensitive to W mass
- That makes it heavily dependent on having a refined theory framework
- This fact is reflected in the uncertainty budget of the currently available determination
- A huge effort from the theory community contributes directly to the exp. effort.

- **ATLAS** $\rightarrow m_W = 80366.5 \pm 9.8_{\mathrm{stat}} \pm 12.5_{\mathrm{exp}}\ \mathrm{MeV}$
- **CMS** $\rightarrow m_W = 80360 \pm 2.4_{\mathrm{stat}} \pm 9.6_{\mathrm{syst.}}\ \mathrm{MeV}$
- **LHCb** $\rightarrow m_W = 80354 \pm 23_{\mathrm{stat}} \pm 10_{\mathrm{exp}} \pm 17_{\mathrm{theory}} \pm 9_{\mathrm{PDF}}\ \mathrm{MeV}$
- **CDF II** $\rightarrow m_W = 80433.5 \pm 6.4_{\mathrm{stat}} \pm 6.9_{\mathrm{exp+mod.\ syst.}}\ \mathrm{MeV}$
- **D0** $\rightarrow m_W = 80375.5 \pm 11_{\mathrm{stat}} \pm 20_{\mathrm{exp+mod.\ syst.}}\ \mathrm{MeV}$

The importance of an accurate theory framework

- CMS → $m_W = 80360 \pm 2.4_{\mathrm{stat}} \pm 9.6_{\mathrm{syst.}}\ \mathrm{MeV}$

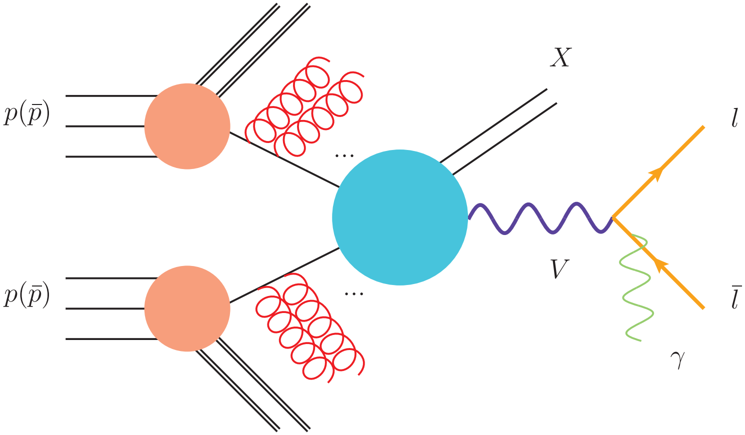


<table>
<tr><th>Systematic uncertainties</th><th>W-like m_Z</th><th>m_W</th></tr>
<tr><td>Muon efficiency</td><td>3127</td><td>3658</td></tr>
<tr><td>Muon eff. veto</td><td>–</td><td>531</td></tr>
<tr><td>Muon eff. syst.</td><td colspan="2">343</td></tr>
<tr><td>Muon eff. stat.</td><td colspan="2">2784</td></tr>
<tr><td>Nonprompt background</td><td>–</td><td>387</td></tr>
<tr><td>Prompt background</td><td>2</td><td>3</td></tr>
<tr><td>Muon momentum scale</td><td colspan="2">338</td></tr>
<tr><td>L1 prefire</td><td colspan="2">14</td></tr>
<tr><td>Luminosity</td><td colspan="2">1</td></tr>
<tr><td>PDF (CT18Z)</td><td colspan="2">60</td></tr>
<tr><td>Angular coefficients</td><td>177</td><td>353</td></tr>
<tr><td>W MiNNLO$_{\mathrm{PS}}$ μ_F, μ_R</td><td>–</td><td>176</td></tr>
<tr><td>Z MiNNLO$_{\mathrm{PS}}$ μ_F, μ_R</td><td colspan="2">176</td></tr>
<tr><td>PYTHIA shower k_T</td><td colspan="2">1</td></tr>
<tr><td>p_T^V modeling</td><td>22</td><td>32</td></tr>
<tr><td>Nonperturbative</td><td>4</td><td>10</td></tr>
<tr><td>Perturbative</td><td>4</td><td>8</td></tr>
<tr><td>Theory nuisance parameters</td><td colspan="2">10</td></tr>
<tr><td>c, b quark mass</td><td colspan="2">4</td></tr>
<tr><td>Higher-order EW</td><td>6</td><td>7</td></tr>
<tr><td>Z width</td><td colspan="2">1</td></tr>
<tr><td>Z mass</td><td colspan="2">1</td></tr>
<tr><td>W width</td><td>–</td><td>1</td></tr>
<tr><td>W mass</td><td>–</td><td>1</td></tr>
<tr><td>$\sin^2 \theta_W$</td><td colspan="2">1</td></tr>
<tr><td>Total</td><td>3750</td><td>4859</td></tr>
</table>

The Drell-Yan process

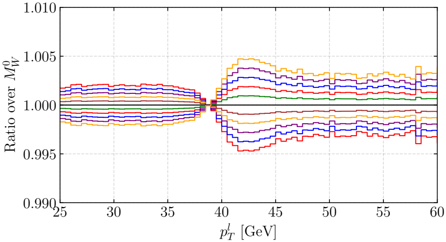
- Proton dynamics (Parton Distribution Function, intrisic k_T)
- Hard scattering process (higher order corrections: QCD, EW, QCDxEW)
- Z to W information transfer

Theoretical elements



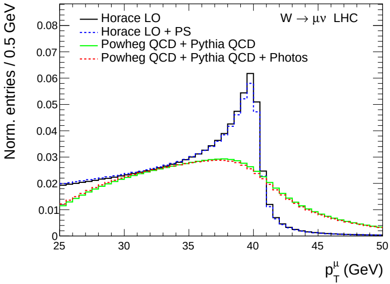
Template fitting

- Observables sensitive to the W mass: p_T^l, M_T^W, $p_T(missing)$
- Template distributions generated within a theoretical framework and for different M_W hypothesis → fit to data
- Theoretical and modelling uncertainties of the templates → uncertainty on the extracted value of M_W



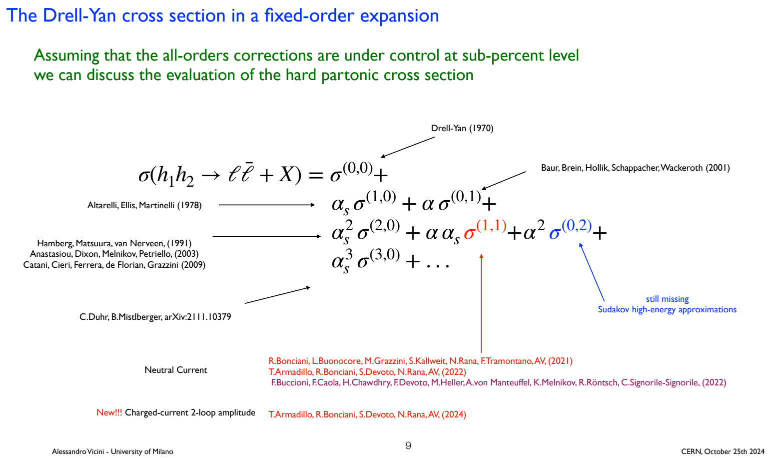
$M_W^0 = 80.385$

p_T^l shape templates from 80.355 GeV to 80.435 GeV



QCD

Overview of theoretical calculations for Drell-Yan



The Drell-Yan cross section in a fixed-order expansion

Assuming that the all-orders corrections are under control at sub-percent level
we can discuss the evaluation of the hard partonic cross section

Drell-Yan (1970)

Baur, Brein, Hollik, Schappacher, Wackeroth (2001)

$$\begin{aligned}\sigma(h_1h_2 \to \ell\bar{\ell} + X) = {} & \sigma^{(0,0)} + \\ & \alpha_s\,\sigma^{(1,0)} + \alpha\,\sigma^{(0,1)} + \\ & \alpha_s^2\,\sigma^{(2,0)} + \alpha\,\alpha_s\,\sigma^{(1,1)} + \alpha^2\,\sigma^{(0,2)} + \\ & \alpha_s^3\,\sigma^{(3,0)} + \ldots\end{aligned}$$

Altarelli, Ellis, Martinelli (1978)

Hamberg, Matsuura, van Nerveen, (1991)
Anastasiou, Dixon, Melnikov, Petriello, (2003)
Catani, Cieri, Ferrera, de Florian, Grazzini (2009)

C.Duhr, B.Mistlberger, arXiv:2111.10379

still missing
Sudakov high-energy approximations

Neutral Current

R.Bonciani, L.Buonocore, M.Grazzini, S.Kallweit, N.Rana, F.Tramontano, AV, (2021)
T.Armadillo, R.Bonciani, S.Devoto, N.Rana, AV, (2022)
F.Buccioni, F.Caola, H.Chawdhry, F.Devoto, M.Heller, A.von Manteuffel, K.Melnikov, R.Röntsch, C.Signorile-Signorile, (2022)

New!!! Charged-current 2-loop amplitude

T.Armadillo, R.Bonciani, S.Devoto, N.Rana, AV, (2024)

Alessandro Vicini - University of Milano

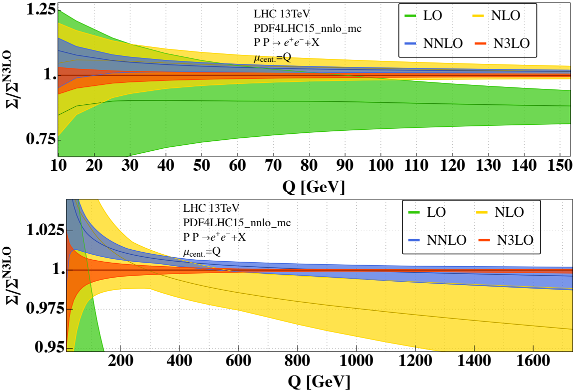
9

CERN, October 25th 2024

[A. Vicini at the LHCb implications workshpp 2024]

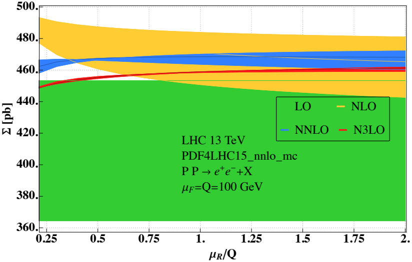
https://indico.cern.ch/event/1423686/contributions/6139381/attachments/2954730/5195179/Vicini-SMprecision.pdf

$m_{l^+l^-}$ @ N3LO-QCD

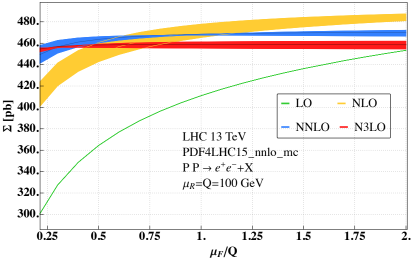


- Note: N3LO PDFs availables only at the approximate level
- Estimation of Missing Higher Order Uncertainties via scale variation yields per-mille level uncertainty. NNLO and N3LO bands do not overlap.

$m_{l^+l^-}$ @ N3LO-QCD



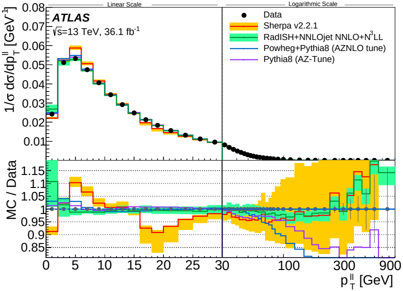
Only μ_R variation

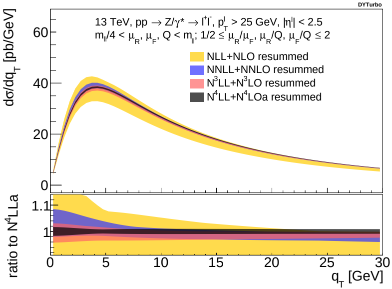


Only μ_F variation

- Note: N3LO PDFs availables only at the approximate level
- Estimation of Missing Higher Order Uncertainties via scale variation yields per-mille level uncertainty. NNLO and N3LO bands do not overlap.

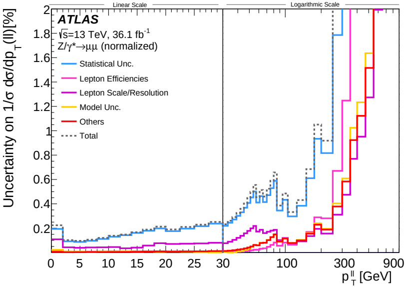
$p_T^{l^+l^-}$ in Drell-Yan

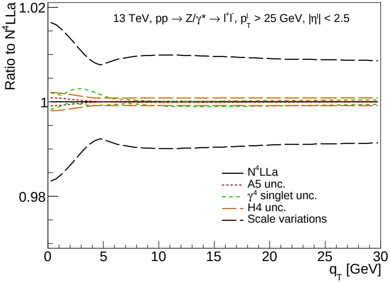




- The measurements of the tranverse distribution of the vector boson is a classic benchmark for collider predictions
- It is a test of our description of the transverse dynamic of the process → important for the M_W determination
- The neutral current process is used as a standard candle, to tune Monte Carlo parton showers and in some M_W determination to improve the theory prediction

$p_T^{l^+l^-}$ in Drell-Yan

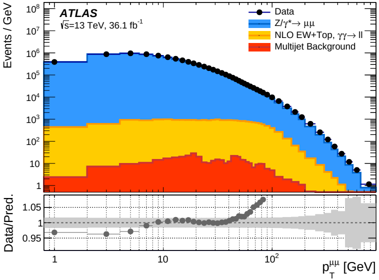




- Experimentally less than 1% uncertainty for $p_T^{l^+l^-} \lesssim 300$ GeV (left)
- Estimation of Missing Higher Order Uncertainties (MHOUs) crucial for the comparison with the data (right)

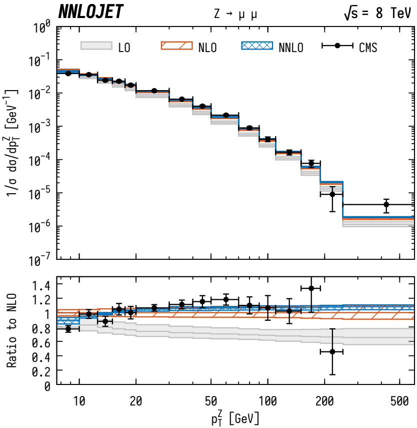
Higher order corrections do matter

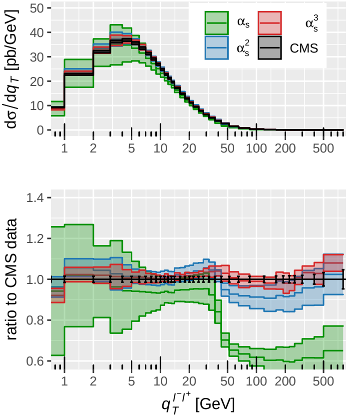
- The data line is obtained with the **POWHEG — BOX** event generator
- The **POWHEG-BOX** curve on the right is only $\mathcal{O}(\alpha_s)$ at high $p_T^{l^+l^-}$
- Sizable deviation from the data at high pt → without a proper estimation of theory uncertainties this could have been interpreted as a BSM effect



- Computation and inclusion of higher corrections is fundamental for Drell-Yan phenomenology

The high-$p_T^{l^+l^-}$ region

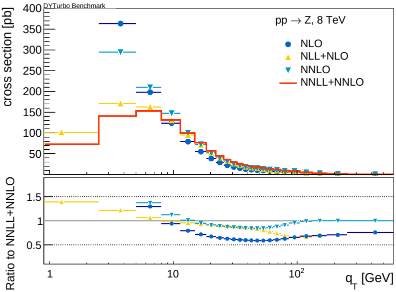




- State of the art results are $\mathcal{O}(\alpha_s^3)$ (NNLO for $p_T^{l^+l^-}$)
- NNLOJet [Gehrmann-De Ridder, Gehrmann, Glover, Huss, morgan, Walker, ’15-’17]
- MCFM [Boughezal, Campbell, Ellis, Focke, Giele, Liu, Petriello, ’15; Neumann and Campbell ’22, ’23]

The low $p_T^{l^+l^-}$ region

- The low $p_T^{l^+l^-}$ region is trickier to handle
- Double logarithmic leftovers from the real-virtual cancellation of infrared and collinear divergences $\sim -\frac{1}{2}\ln^2 \frac{p_T^{l^+l^-}}{m_{l^+l^-}}$
- These logarithms spoil the perturbative accuracy of the predictions as $p_T^{l^+l^-} \to 0$



[Camarda et al, '19, 1910.07049]

- The resummation of the large logs of $p_T^{l^+l^-}$ is needed
- $\ln O(p_T^{l^+l^-}) = \sum_n \mathcal{O}(\alpha_s^n L^{n+1}) + \mathcal{O}(\alpha_s^n + L^n) + \mathcal{O}(\alpha_s^n L^{n-1})$, with $L = \ln \frac{p_T}{m_{l^+l^-}}$

Transverse momentum resummation

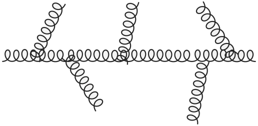
- The limit of low transverse momentum is tricky because it is a vectorial quantity, $\vec{p}_T^{\,l^+l^-}$
- Two possibilities to get $\vec{p}_T^{\,l^+l^-} \rightarrow \vec{0}$

Sudakov limit

[L. Rottoli, EWWG meeting '24]

- $(p_T^{l^+l^-})^2 \sim k_{t,i}^2 \ll m_{l^+l^-}^2$
- There no phase space left for gluon emissions
- Exponential suppression

$\vec{k}_T$ cancellation between multiple emissions



[L. Rottoli, EWWG meeting '24]

- $\sum_{i=1}^{n} \vec{k}_{t,i} \simeq \vec{0}$
- Power suppression

Two approaches

- impact parameter space approach (most widely used)
- direct space approach

Impact-parameter space approach

The crucial observation is that in the impact-parameter space, the condition of the conservation of the transverse momentum is cast in factorized form

$$\delta^2\left(\vec{\mathrm{p}}_T^{\,l^+l^-} - \sum_{i=1}^{n} \vec{\mathrm{k}}_{t,i}\right) = \int d^2 b \, \frac{1}{4\pi^2} e^{i\vec{\mathrm{b}}\cdot\vec{\mathrm{p}}_T} \prod_{i=1}^{n} e^{-i\vec{\mathrm{b}}\cdot\vec{\mathrm{k}}_{t,i}}$$

- It is then possible to rewrite the multiple emissions as an exponential
- One then moves back to direct space with an inverse transform

$$\begin{aligned}\sigma &= \sigma_0 \int d^2\vec{\mathrm{p}}_T \int \frac{d^2\vec{\mathrm{b}}}{4\pi^2} e^{-i\vec{\mathrm{b}}\cdot\vec{\mathrm{p}}_T} \sum_{n=0}^{\infty} \frac{1}{n!} \prod_{i=1}^{n} \int [dk_i] \, |\mathcal{M}(k_i)|^2 \left(e^{-i\vec{\mathrm{b}}\cdot\vec{\mathrm{k}}_{t,i}} - 1\right) \\ &= \sigma_0 \int d^2\vec{\mathrm{p}}_T \int \frac{d^2\vec{\mathrm{b}}}{4\pi^2} e^{-i\vec{\mathrm{b}}\cdot\vec{\mathrm{p}}_T} e^{-R_{NLL}(L)}\end{aligned}$$

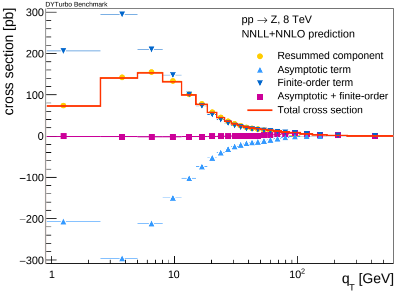
with

$$-R_{NLL}(L) = -L g_1(\alpha_s L) - g_2(\alpha_s L) \quad , \quad L = \frac{m_{l^+l^-}\, b}{b_0} \quad , \quad b_0 = 2e^{-\gamma_E}$$

Used in many calculations and codes, and with a variety of formalisms (QCD, SCET, TMD)

Matching the resummed and fixed order results

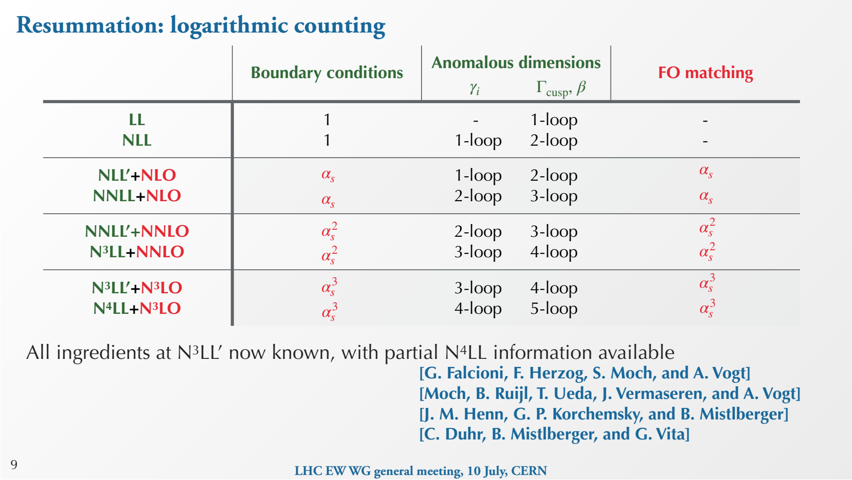
- Final goal: build a prediction which is valid across the full $p_T^{l^+l^-}$ spectrum
- How: match the resummed (low p_T region) and the fixed-order (high p_T region)
- Problem: avoid double counting of the logs that are in both results → subtraction
- Problem: avoid having the resummed prediction affecting the spectrum in p_T range where the resummation is not justified → modified logs, scale profiling (SCET)



[Camarda et al, '19, 1910.07049]

- Note: one needs a numerical control of less than $\mathcal{O}(1\%)$ in order for the matching to work

Accuracy table



Resummation: logarithmic counting

	Boundary conditions	Anomalous dimensions		FO matching
		γ_i	$\Gamma_{\text{cusp}}, \beta$	
LL	1	-	1-loop	-
NLL	1	1-loop	2-loop	-
NLL′+NLO	α_s	1-loop	2-loop	α_s
NNLL+NLO	α_s	2-loop	3-loop	α_s
NNLL′+NNLO	α_s^2	2-loop	3-loop	α_s^2
N^{3}LL+NNLO	α_s^2	3-loop	4-loop	α_s^2
N^{3}LL′+N^{3}LO	α_s^3	3-loop	4-loop	α_s^3
N^{4}LL+N^{3}LO	α_s^3	4-loop	5-loop	α_s^3

All ingredients at N^{3}LL′ now known, with partial N^{4}LL information available

[G. Falcioni, F. Herzog, S. Moch, and A. Vogt]
[Moch, B. Ruijl, T. Ueda, J. Vermaseren, and A. Vogt]
[J. M. Henn, G. P. Korchemsky, and B. Mistlberger]
[C. Duhr, B. Mistlberger, and G. Vita]

9

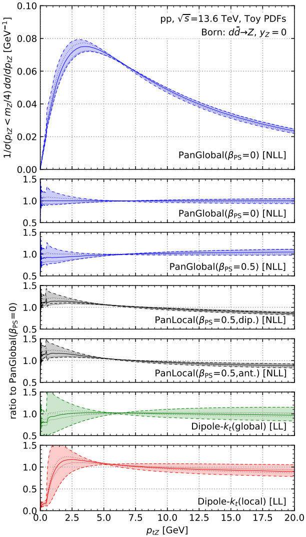
LHC EW WG general meeting, 10 July, CERN

See the talk by L. Rottoli at LHC EW WG for a comprehensive overview and more detail about the theoretical calculations

https://indico.cern.ch/event/1400204/

Monte carlo event generators

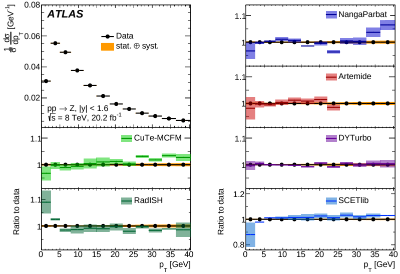
- Log resummation can also be achieved with Parton Shower Monte Carlo
- However, the logarithmic accuracy of currently widely used showers is considered to be LL
- Work ongoing to raise the accuracy of the showers, see for instance the work of the Panscales collaboration, which developed the first validated NLL shower
- Another approach, pursued by the GENEVA collaboration, is to combine analytic resummation with a Parton shower [Alioli et al.]



[Panscales 2207.09467]

Comparison with the data

- Qualitatevely good agreements between the codes and the data at 8 TeV from ATLAS



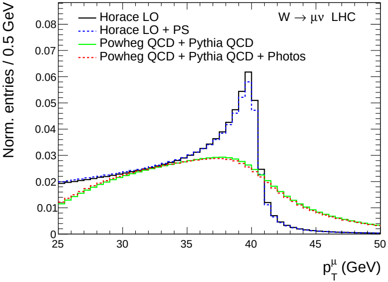
[ATLAS '23, 2309.09318]

- Different description at low p_T due to different NP effects
- Differences in the transition region between the FO and resummed results
- Differences in the estimation of MHOUs
- Benchmarking program in the EW WG (again see the talk by Rottoli)

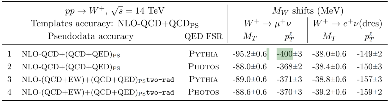
QED/EW

QED, EW and QCDxEW effects

- Huge impact from QED and mixed QCDxEW on the M_W determination
- In [Carloni Calame et al.] QCDxEW included with a factorized ansatz
- Need a full calculation to estimate the missing effects, and the corresponding matched tools (e.g. [Buonocore et al, 2404.15112])



[Carloni Calame et al, '16]



	$pp \to W^+$, $\sqrt{s} = 14$ TeV Templates accuracy: NLO-QCD+QCD$_{\mathrm{PS}}$		M_W shifts (MeV)			
			$W^+ \to \mu^+\nu$		$W^+ \to e^+\nu$(dres)	
	Pseudodata accuracy	QED FSR	M_T	p_T^ℓ	M_T	p_T^ℓ
1	NLO-QCD+(QCD+QED)$_{\mathrm{PS}}$	Pythia	-95.2±0.6	-400±3	-38.0±0.6	-149±2
2	NLO-QCD+(QCD+QED)$_{\mathrm{PS}}$	Photos	-88.0±0.6	-368±2	-38.4±0.6	-150±3
3	NLO-(QCD+EW)+(QCD+QED)$_{\mathrm{PS}}$`two-rad`	Pythia	-89.0±0.6	-371±3	-38.8±0.6	-157±3
4	NLO-(QCD+EW)+(QCD+QED)$_{\mathrm{PS}}$`two-rad`	Photos	-88.6±0.6	-370±3	-39.2±0.6	-159±2

Impact of full mixed QCDxEW corrections on M_W

- A lot of theory activity on this topic in the past few years
- Estimation of the effect on the M_W extraction for OS production and in the pole approximation [Behring et al., PRD103 (2021) 11, 113002]
- Study the impact by looking at the decorrelation between the corrections in W and Z production

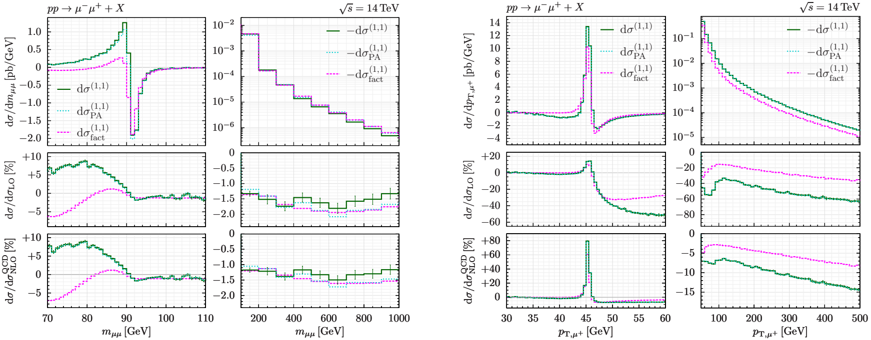
- Simple model that correlates the W and Z processes, $m_W^{\mathrm{meas}} = \frac{\langle p_\perp^{l,W} \rangle^{\mathrm{meas}}}{\langle p_\perp^{l,Z} \rangle^{\mathrm{meas}}} \, m_Z \, C_{\mathrm{th}}$, with $C_{\mathrm{th}} = \frac{m_W^{input}}{m_Z^{input}} \frac{\langle p_\perp^{l,Z} \rangle^{\mathrm{th}}}{\langle p_\perp^{l,W} \rangle^{\mathrm{th}}}$
- If one modified the theoretical framework, in first approximation one has

$$\frac{\delta m_W^{\mathrm{meas}}}{m_W^{\mathrm{meas}}} = \frac{\delta C_{\mathrm{th}}}{C_{\mathrm{th}}} = \frac{\delta \langle p_\perp^{l,Z} \rangle^{\mathrm{th}}}{\langle p_\perp^{l,Z} \rangle^{\mathrm{th}}} - \frac{\delta \langle p_\perp^{l,W} \rangle^{\mathrm{th}}}{\langle p_\perp^{l,W} \rangle^{\mathrm{th}}}.$$

- Use this formula to estimate the M_W shift
- $\delta m_W^{meas} = -17 \pm 2$ MeV with ATLAS-inspire cuts; $\delta m_W^{meas} = -1 \pm 5$ MeV with a “tuned” set of cuts
- Estimation not fully supported by other theorists

Complete mixed QCDxEW corrections in NC DY

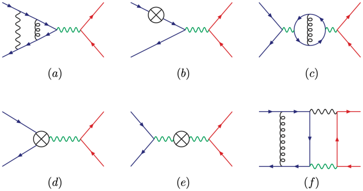
- Complete, fully off-shell mixed QCDxEW calculation for neutral current Drell-Yan [Bonciani et al., PRL 128 (2022) 1, 012002]



- Pole approximation confirmed to work very well at the resonance
- No factorization below the resonance peak
- Charged-current Drell-Yan still being worked out by the relevant groups

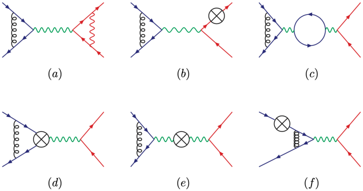
Complete QCDxEW corrections in CC DY

- Semi-analytic results with power series expansions
- Very difficult, weak bosons with different masses; no gauge invariance separation as in NC DY between ISR-QED and FSR-QED beyond LL



(a) (b) (c)

(d) (e) (f)



(a) (b) (c)

(d) (e) (f)

- Complete, fully off-shell mixed QCDxEW calculation for neutral current Drell-Yan [Armadillo et al., 2405.00612]
- Will be made available via `MATRIX`

Non perturbative effects

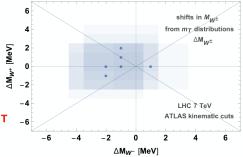
Intrinsic K_T for M_W

- Study of flavor-dependent intrisic K_T on the W mass extraction at the LHC [Bacchetta et al., PLB788 (2019) 542-545]
- Compare flavor-independent vs flavor-dependent intrinsic K_t using template fitting

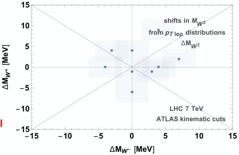
	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	0	-1	-2	-2	3	-3
2	0	-6	0	-2	0	-5
3	-1	9	0	-2	4	-10
4	0	0	-2	-2	-4	-10
5	0	4	1	-1	-3	-6
6	1	0	2	-1	4	-4
7	2	-1	2	-1	0	-8
8	0	2	8	1	7	8
9	0	4	-3	-1	0	7

TABLE I: ATLAS 7 TeV

ATLAS m_T



ATLAS p_{Tl}

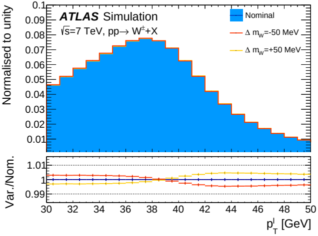


- m_T: at most a few MeV shift; p_T^l / p_T^ν up to $\mathcal{O}$(10-15) MeV shift

[Plots from G. Bozzi talk at LPC workshop connection between the LHC and the EIC, '19]

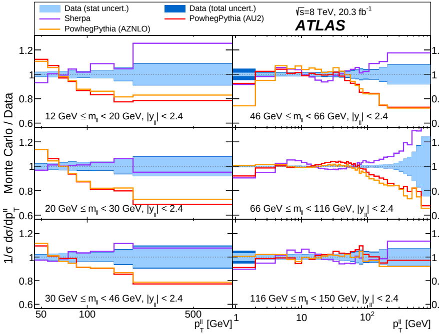
P_T^Z vs P_T^W

The relation between the Z and the W



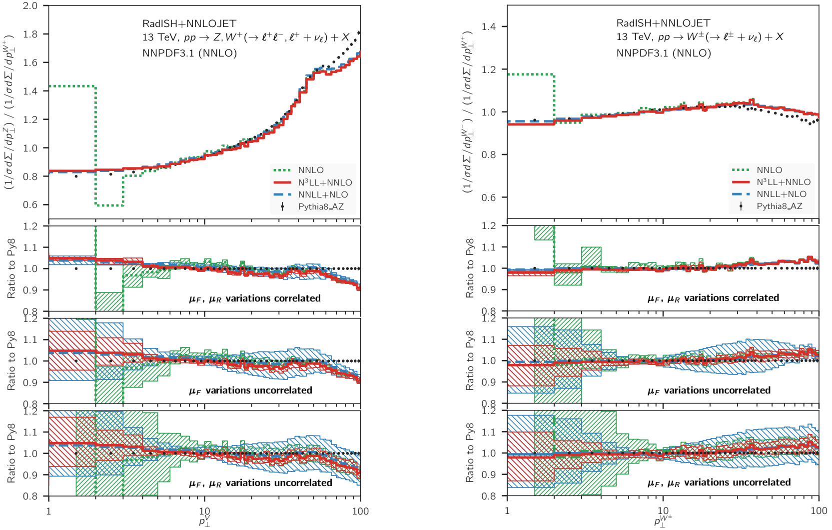
- The measurement of the W mass is performed using a template-fit approach.
- it depends on the theory models encoded in the tools (Monte Carlo event generators) used to produce the templates.
- One element that therefore enters these predictions is the *non-perturbative tune* of the Parton Shower (PS).

- To tune the PS, precisely measured observables are needed.
- A prime target is the transverse momentum distribution of the Z ($l\bar{l}$).



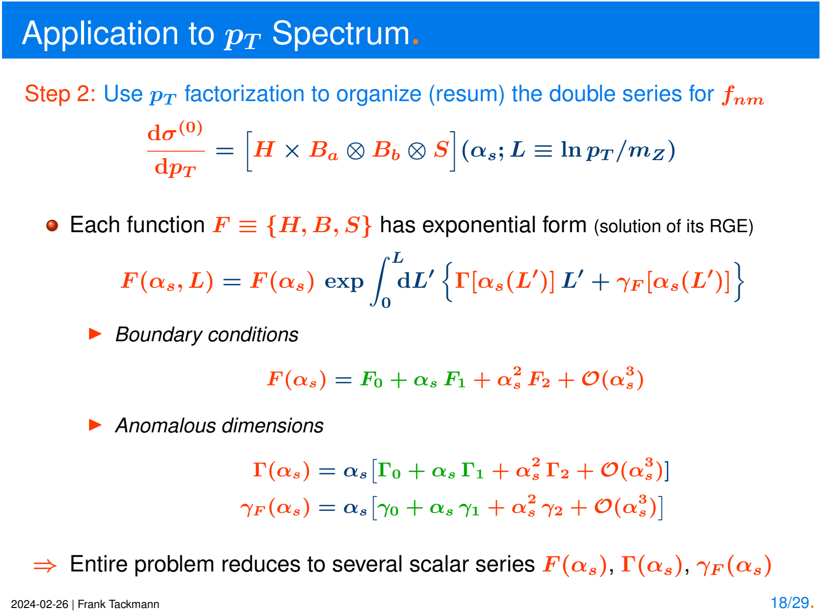
[ATLAS 1512.02192]

The ratio in QCD



[Bizon et al. '19, 1905.05171]

Theory nuisance parameters



Application to p_T Spectrum.

Step 2: Use p_T factorization to organize (resum) the double series for f_{nm}

$$\frac{d\sigma^{(0)}}{dp_T} = \Big[H \times B_a \otimes B_b \otimes S\Big](\alpha_s; L \equiv \ln p_T/m_Z)$$

- Each function $F \equiv \{H, B, S\}$ has exponential form (solution of its RGE)

$$F(\alpha_s, L) = F(\alpha_s)\ \exp \int_0^L dL' \Big\{\Gamma[\alpha_s(L')]\, L' + \gamma_F[\alpha_s(L')]\Big\}$$

  - *Boundary conditions*

$$F(\alpha_s) = F_0 + \alpha_s F_1 + \alpha_s^2 F_2 + \mathcal{O}(\alpha_s^3)$$

  - *Anomalous dimensions*

$$\Gamma(\alpha_s) = \alpha_s\big[\Gamma_0 + \alpha_s \Gamma_1 + \alpha_s^2 \Gamma_2 + \mathcal{O}(\alpha_s^3)\big]$$
$$\gamma_F(\alpha_s) = \alpha_s\big[\gamma_0 + \alpha_s \gamma_1 + \alpha_s^2 \gamma_2 + \mathcal{O}(\alpha_s^3)\big]$$

⇒ Entire problem reduces to several scalar series $F(\alpha_s)$, $\Gamma(\alpha_s)$, $\gamma_F(\alpha_s)$

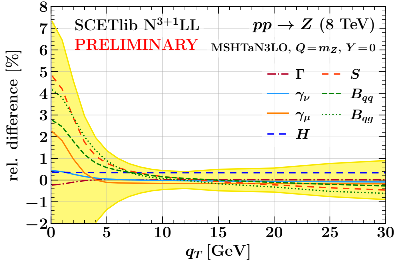
2024-02-26 | Frank Tackmann

18/29.

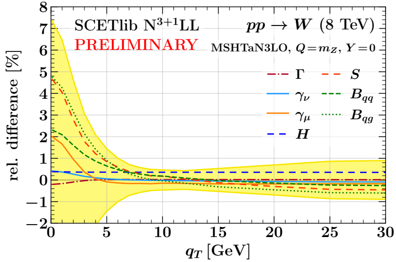
Theory nuisance parameters

TNP Uncertainties in Drell-Yan p_T Spectrum.

relative impact for Z p_T



relative impact for W p_T



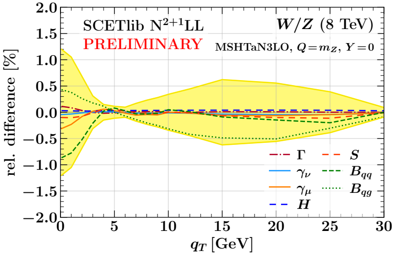
- N^{3+1}LL: Full N^{4}LL resummation with highest-order boundary conditions and anomalous dimensions as TNPs
- Important caveats:
  - Beam boundary conditions B_{qj}: Using $f_n = (0 \pm 2) \times f_n^{\mathrm{true}}$
  - Hard boundary conditions H: No singlet corrections (enter only Z not W)
  - DGLAP splitting functions are noncusp anom. dimensions, not varied here

✓ Correlations across p_T and between W and Z are correctly captured

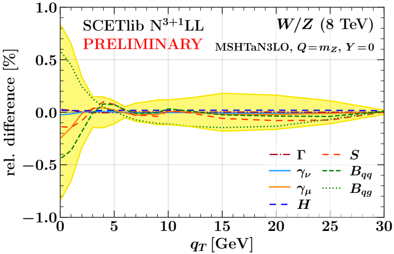
Theory nuisance parameters

TNP Uncertainties in Drell-Yan p_T Spectrum.

relative impact for W/Z



relative impact for W/Z



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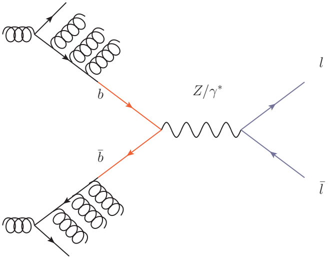
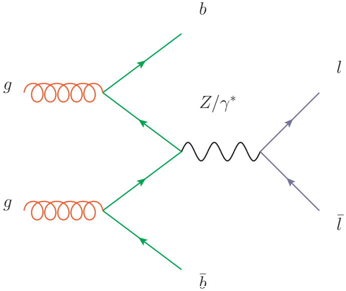
Bottom quark effects in NC-DY and their impact on M_W



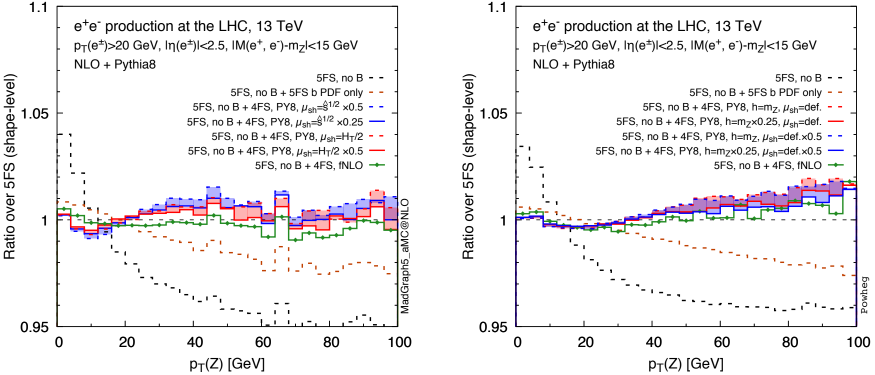
- 5FS – the bottom quark is massless
- A bottom PDF is defined
- log resummation via DGLAP
- no mass effects in the phase space from bottom quarks



- 4FS – the bottom is massive
- no bottom PDF
- no resummation
- mass effects taken into account

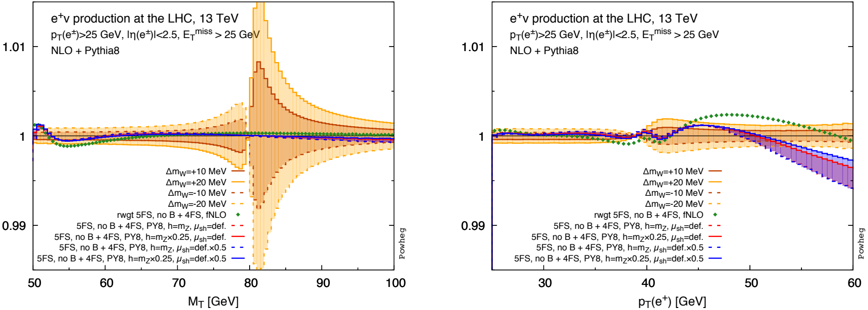
- Impact on M_W via P_T^Z-p_T^W?
- how to merge the two calculations?

An improved prediction of $p_T^{l\bar{l}}$



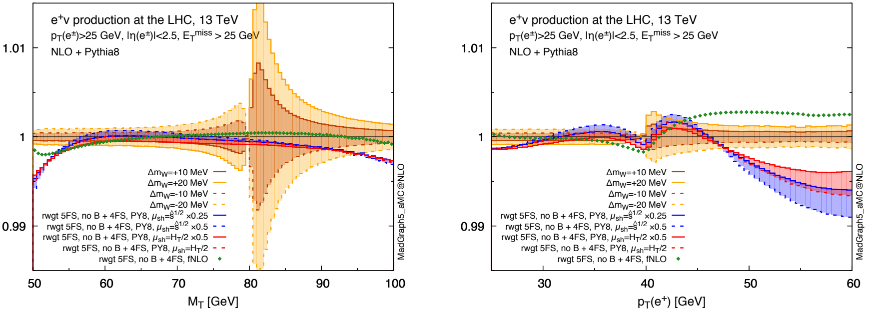
- 5FS b-contribution: non-trivial shape, the two contributions are of the same order of magnitude at large p_T, while at low p_t gluon splitting from light-quark induced processes dominates.
- Non-trivial shape distortion.
- Effects after merging of the order of $\mathcal{O}(\pm 1\%)$ for `MG5_aMC@NLO`, $\mathcal{O}(\pm 0.5\%)$.

The templates



- Templates generation with both the POWHEG-BOX and `MG5_aMC@NLO` at NLO+PS in the 5FS.
- Different shape of the Jacobian peak for $p_T^{l^\pm}$ in the two Monte Carlos.
- Largest effects from the reweighting outside the canonical fit window.

The templates



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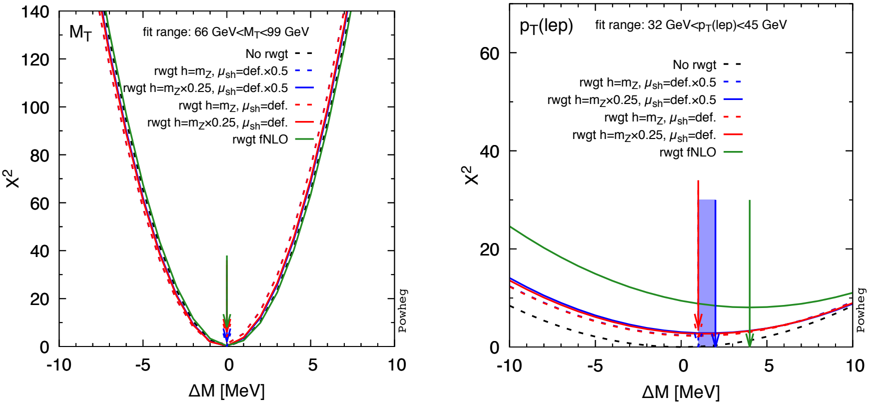
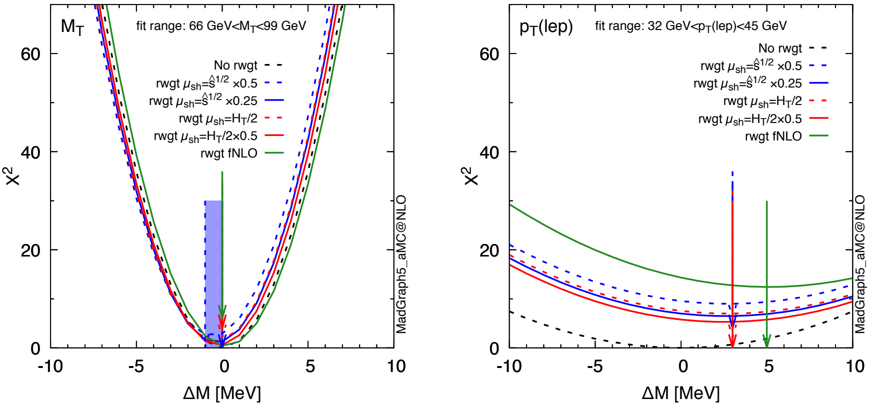
Shift on the W mass measurement



- Granularity of 1 MeV.
- Positive sign shift, at most reaching +5 MeV.
- Quite similar effect in POWHEG-BOX and in `MG5_aMC@NLO`.

Shift on the W mass measurement



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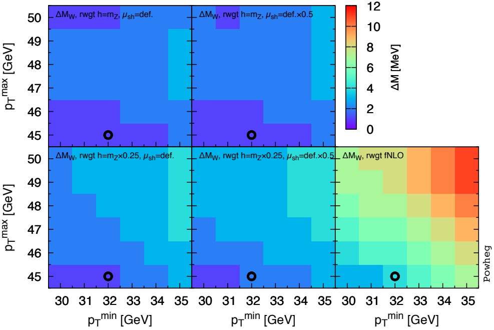
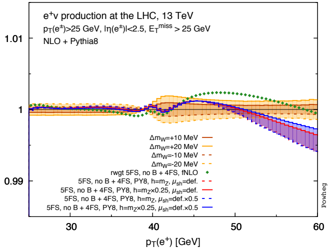
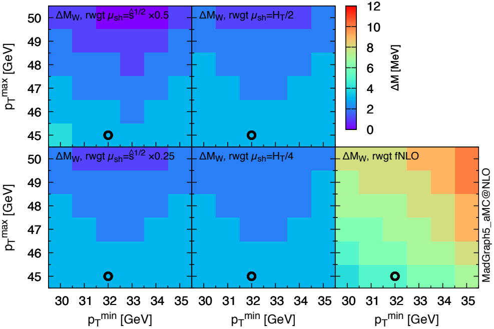
Dependence of the shift on the fit window

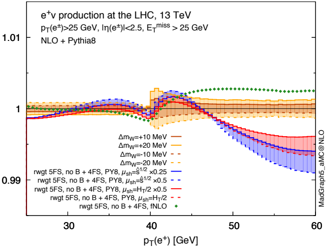




- Non-negligible dependence on the fit window due to the non-trivial shape of the reweighting function.

Dependence of the shift on the fit window





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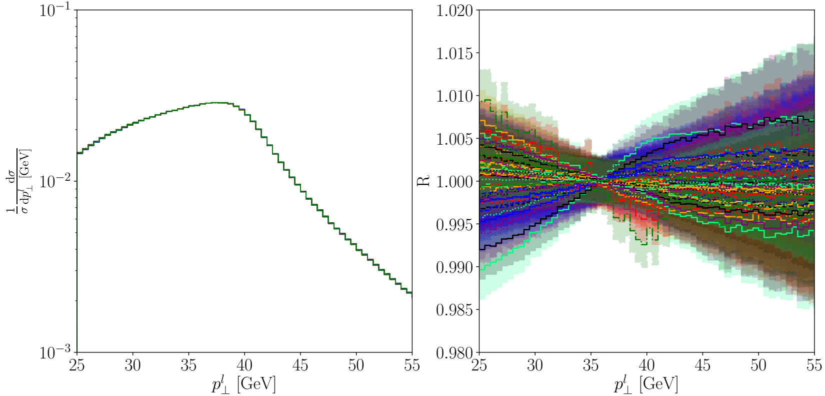
PDF uncertainties

Aspects of PDF uncertainties

- Three sets of uncertainties linked to PDFs:
  1. Uncertainty in the PDFs from the experimental uncertainty of the dataset used in the fit
  2. Different fit methodologies (i.e. differences between PDF sets of different collaborations)
  3. Theoretical uncertainties of the predictions used in PDF fits. Concerning Missing Higher Order Uncertainties (MHOUs), their inclusion has started to be addressed systematically in the past few years ([L. A. Harland-Lang, R. S. Thorne – 1811.08434], [R. A. Khalek et al. (NNPDF) – 1906.10698] + more recent papers).

PDF uncertainty on p_T^l



Previous studies for M_W

- Tevatron collaborations [0707.0085,0708.3642,0908.0766,1203.0275,1203.0293,1307.7627].
- Comprehensive study on the PDF uncertainty on M_T^W using modern matched MCs (see also [Bozzi, Rojo, Vicini – 1104.2056]), however with inaccurate M_T^W modeling.
- Subsequent study on p_T^l presented in [Bozzi, Citelli, Vicini – 1501.05587] and extended to the study of a high-rapidity lepton in [Bozzi, Citelli, Vesterinen, Vicini – 1508.06954].

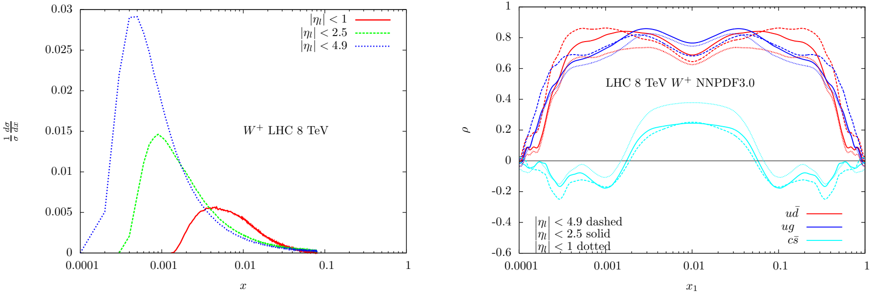
Prescription for the estimation of the uncertainty in those studies

- Generate M_W-templates using the central replica of the NNPDF set.
- $\chi^2_{k,r} = \sum_{i \in bins} (\mathcal{T}_{0,k} - \mathcal{D}_r)^2_i / \sigma^2_i$.
- Fit other NNPDF replicae; compute the standard deviation of the M_W corresponding to minima of the replica χ^2 and take it as a proxy of the PDF uncertainty.
- Neglect the value of the χ^2.
- Fixed fit range, $p^l_\perp \in [29, 49]$ GeV.

- ATLAS [1701.07240], [Kotwal PRD 98, 033008].
- Other recent studies: [E. Manca, O. Cerri, N. Foppiani, L. Rolandi – 1707.09344], [L. Bianchini and G. Rolandi – 1902.03028], [S. Farry, O. Lupton, M. Pili, M. Vesterinen – 1902.04323], [M. Hussein, J. Isaacson, J. Huston – 1905.00110] + the experimental papers

The role of LHCb

- According to the η_l cuts, the cross section is dominated by different range of x
- Anti-correlation at large and small x between between $p_T^l = 40.5$ GeV and the sea-quark parton luminosities
- These luminosities are also the most uncertain → potential of LHCb measurements in reducing the PDF uncertainties when combined with ATLAS/CMS ones



[Bozzi et al., PRD91 (2015) 11, 113005]

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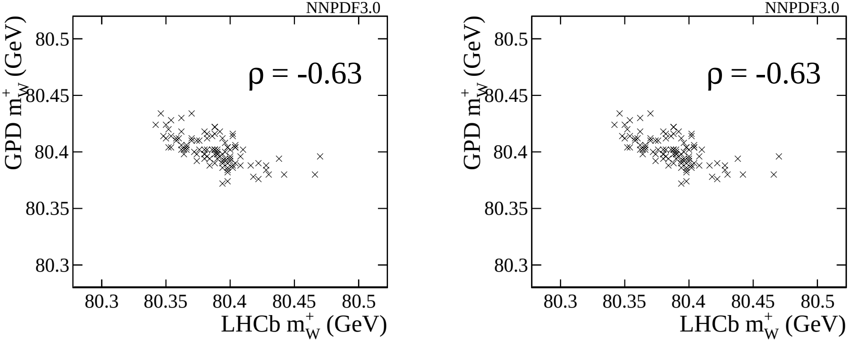


[Bozzi et al., EPJC(2015) 12, 601]

Non-trivial structure of PDF uncertainties

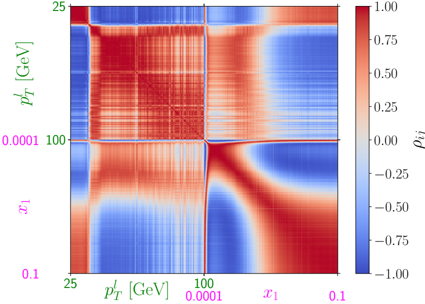
- Study the impact of including the PDF uncertainty directly in the M_W template fit ($\sim$ profiling used by the recent ATLAS and CMS determination)
- Include non-trivial correlations between bins

$$\chi^2_{k,min} = \sum_{(r,s)\in bins} (\mathcal{T}_{0,k} - \mathcal{D}^{exp})_r \left(C^{-1}\right)_{rs} (\mathcal{T}_{0,k} - \mathcal{D}^{exp})_s$$

$$C = \Sigma_{PDF} + \Sigma_{stat} + \Sigma_{MC} + \Sigma_{exp,syst}$$

$$(\Sigma_{PDF})_{rs} = \langle (\mathcal{T} - \langle \mathcal{T} \rangle_{PDF})_r (\mathcal{T} - \langle \mathcal{T} \rangle_{PDF})_s \rangle_{PDF}$$

$$\langle \mathcal{O} \rangle_{PDF} \equiv \frac{1}{N_{cov}} \sum_{l=1}^{N_{cov}} \mathcal{O}^{(l)}$$

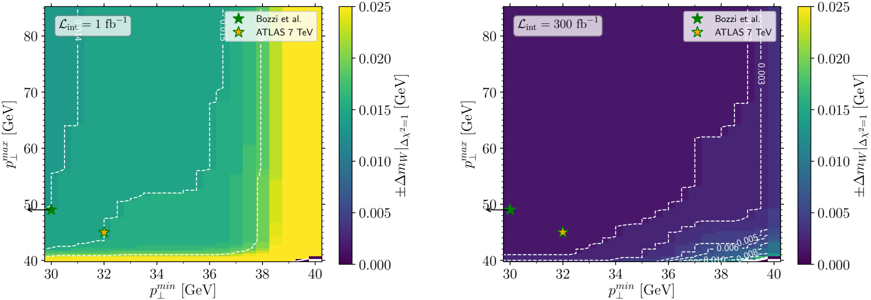


$$\rho_{ij} = \frac{\langle (\mathcal{O}_i - \langle \mathcal{O}_j \rangle_{PDF}) \ (\mathcal{O}_j i - \langle \mathcal{O}_i \rangle_{PDF}) \rangle_{PDF}}{\sigma_i \sigma_j}$$

[EB and A. Vicini, PRL126 (2021) 4, 041801]

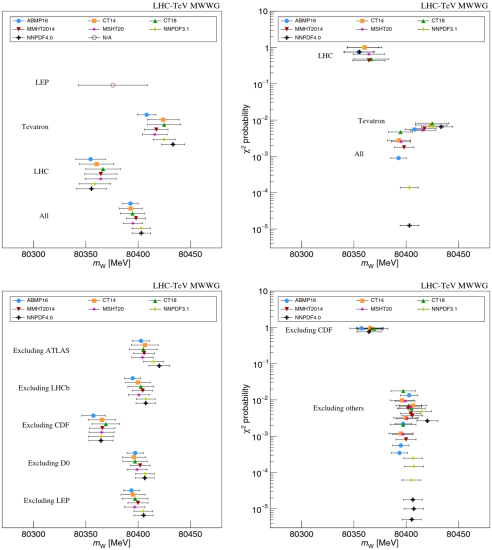
Non-trivial structure of PDF uncertainties

- Potential reduction in the PDF uncertainties if uncertainties on the measurements such as stat. uncertainty sufficiently low



- Profiling/in-situ constraint used in the most recent measurements
- Open questions about "tolerance factors" etc.

Combining the experiments



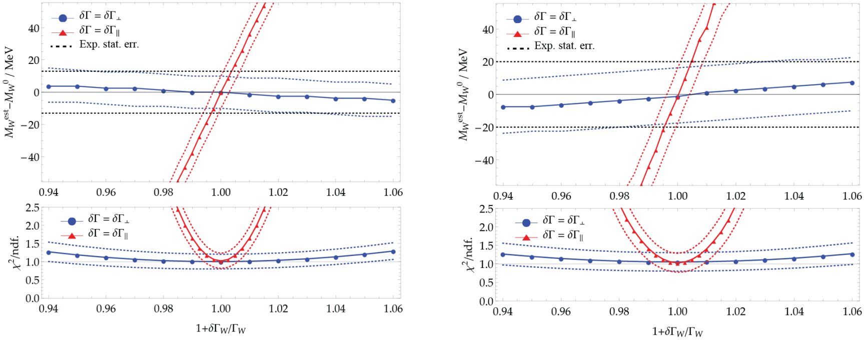
[LHC-TeV MW working group, 2308.09417]

BSM effects in the extraction procedure

SMEFT bias in the extraction procedure

SMEFT bias

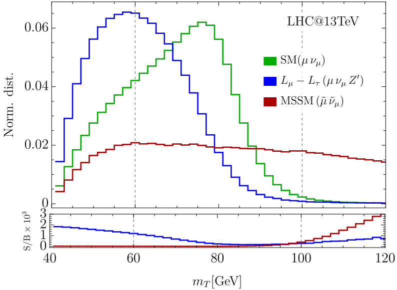
- The extraction is done assuming the SM as the theory describing the Drell-Yan process
- [Bjorn and Trott, '16] studied the impact of SMEFT operators on the procedure

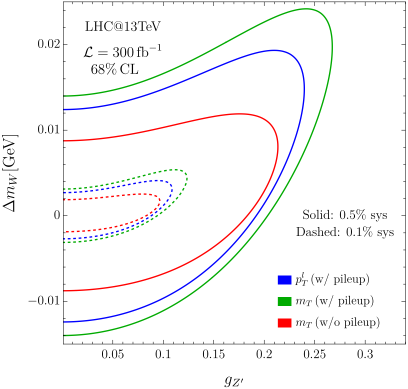


BSM impact on the extraction procedure

SMEFT bias

- More recently [Agashe et al., '23 '24] studied the impact of a variety of BSM signals on the extraction





Theory interpretation

The M_W-M_Z interdependence

The determination of the W mass from the other parameters of the theory is another important consistency test.

M_W calculation

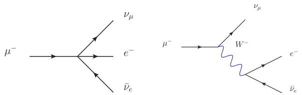
From the matching between the Fermi theory + QED with the SM (or any BSM model)

$$\frac{G_\mu}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2}\left(1+\Delta r\right)$$

It can be re-arranged to obtain the relationship

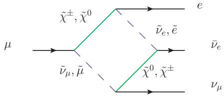
$$M_W^2 = M_Z^2\left(\frac{1}{2}+\sqrt{\frac{1}{4}-\frac{\alpha\pi}{\sqrt{2}G_\mu M_Z^2}\left(1+\Delta_r\right)}\right)$$

Muon decay



BSM contribution to Δr

Δr contains self-energies, vertex corrections, box diagrams ...



The SM prediction

- Higly-accurate SM prediction available since years (full 2-loop EW; higher-order QCD corrections; resummation of reducible terms)
- [Sirlin '80, '84; Sirlin '80, '81; van der Bij, Veltman '84; Barbieri et al. '92-'93; Fleischer et al. '93; Djouadi and Verzegnassi '87; Chetyrkin et al. '95; Consoli et al. '89; Degrassi et al. '96; Degrassi et al. '97; Freitas et al. '00,'03; Awramik et al. '02, Awramik et al. '03, Onischenko et al. 03; Chen et al. '20,'21]

Inputs

PDG 2020

- $1/\hat{\alpha}^{(5)}(M_Z)$ = 127.952
- $\Delta\alpha^{(5)}(M_Z)$ = 0.02766
- $G_F = 1.166378 \times 10^{-5}$ GeV^{-2}
- $M_Z = 91.1876$ GeV
- $M_T = 172.76$ GeV
- $m_b(m_b) = 4.18$ GeV
- $\alpha_s(M_Z) = 0.1179$

Theory uncert.

- $M_W^{SM} = 80.353 \pm 0.004$ GeV [EB et al., EPJC82 (2022) 5, 474; from `FeynHiggs`] (OS scheme)
- $M_W^{SM} = 80.352 \pm 0.003$ GeV [Giardino '22; Degrassi et al., JHEP05 (2015) 154] (mixed scheme)
- (The two calculations are not exactly at the same level though)

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Param uncert.

- M_T, variation of ± 1 GeV $\rightarrow$ changes M_W^{SM} by $\pm$ 6 MeV;
- a shift of ± 0.0010 from the central value $\alpha_S(M_Z) \rightarrow$ change of ± 0.7 MeV in M_W^{SM}
- the uncertainty on M_Z is of ± 0.0021 GeV and its impact on M_W^{SM} is of $\simeq \pm 2.7$ MeV;
- the uncertainty of 0.00007 on the value of $\Delta\alpha^{(5)}_{\rm had}(M_Z)$ yields a variation of $\simeq$ 1.2 MeV;
- varying the Higgs mass by 1 GeV $\rightarrow$ shift of $\simeq$ 0.4 MeV.

M_W measurement and new physics models

- After the CDF measurement, many articles have been published discussing BSM perspectives, both from perspective of using explicit BSM models or a framework such as SMEFT (list not updated after 2022 ...)

BSM Landscape

- SM+Singlet extension [Sakurai et al., 2204.04770]
- SM+Triplet extension [Addazi et al., 2204.10315, Ghost et al., 2205.05041; Kanemura et al., 2204.07511; Perez et al., 2204.07144]
- Superweak SM [Péli et al, 2204.07100]
- Nonlocal SM [Krasnikov, 2204.06327]
- Simple Extension of the SM [2205.08215]
- 2HDMs [Abouabid et al., 2204.12018; Ahn et al, 2204.06485; Applequist et al., 2205.03320; Arcadi et al, 2204.08406; Babu et al., 2204.05303; Bahl et al., 2204.05269; Botella et al., Fan et al., 2204.03693; Ghorbani et al., 2204.09001; Heo et al., 2204.06505; Kim 2205.01437; Kim et al., 2205.0170; Lee et al., 2204.10338; Song et al., 2204.04805; Zhu et al., 2204.03767; Zhu et al., 2204.04688]
- N2HDM [Biekötter et al.,2204.05975]
- GUT [Evans et al., 2205.03877; Senjanovic et al., 2205.05022; Wilson, 2204.07970]
- SUSY models [Athron et al., 2204.05285; Du et al., 2204.04286; Sun et al., 2204.06234; Tang et al. 2204.04356; Zheng et al., 2204.06541]

M_W measurement and new physics models

- After the CDF measurement, many articles have been published discussing BSM perspectives, both from perspective of using explicit BSM models or a framework such as SMEFT (list not updated after 2022 ...)

BSM Landscape

- Neutrinos [Arias-Aragon et al., 2204.04672; Batra et al., 2204.11945; Blennow et al. 2204.04559; Borah et al., 2204.08266; Chakraberty et al., 2206.11771; Cheng et al., 2204.05031; Chowdhury et al., 2204.08390; Coy et al., 2110.09126; Dong, 2205.04253; Dcruz et al., 2205.02217; Faraggi et al., 2204.11974; Ghoshal et al., 2204.07138; Heeck, 2204.10274; Liu et al., 2204.04834; Ma, 2205.09794; Popov et al., 2204.08568; Van Dong, 2205.04253; Yang et al., 2204.11871]
- String theory [Barman et al., 2205.01699; Basiouris et al., 2205.00758; Heckman et al., 2204.05302]
- Vector-like fermions [Cao et al., 2204.09477; Chowdhuri et al., 2205.03917; Crivellin et al. 2204.05962; Dermisek et al., 2204.13272; Kawamura et al., 2205.10480; Lee at al., 2204.05024; Li et al., 2205.02205; Nagato et al., 2204.07411]
- Extra vectors [Allanach et al., 2205.12252 ; Cai et al, 2204.11570; Di Luzio et al., 2204.05945; Endo et al., 2204.05965; Nagao et al., 2206.15256; Rizzo, 2206.09814; Thomas et al., 2205.01911; Zeng et al., 2204.09487]
- Leptoquarks [Bhaskar et al, 2204.09031; Cheung et al., 2204.05942; He, 2205.02088]
- Georgi-Machacek [Chen et al., 2204.12898; Du et al., 2204.05760; Mondal, 2204.07844]
- $U(1)_{L_{mu}-L_{\tau}}$ [Baek, 2204.09585]
- Little Higgs [Ramirez et al., 2205.10420]

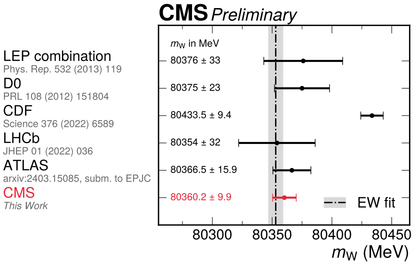
M_W measurement and new physics models

- After the CDF measurement, many articles have been published discussing BSM perspectives, both from perspective of using explicit BSM models or a framework such as SMEFT (list not updated after 2022 ...)

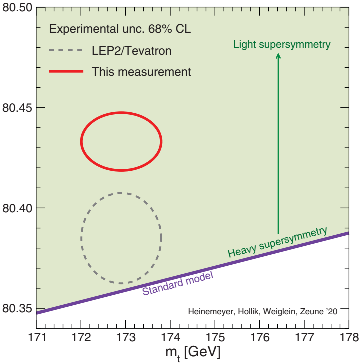
BSM Landscape

- Composite Higgs [Cacciapaglia et al., 2204.04514, Frandsen et al., 2207.01465]
- Composite vectors [Xue, 2205.14957]
- Dark sectors [Borah et al., 2204.09671; Cheng et al., 2204.10156; Du et al., 2204.09024; Kawamura et al., 2204.07022; Kim et al., 2205.04016; Wang et al., 2205.00783; Wojcik, 2205.11545; Zeng, 2203.09462 ; Zhang et al., 2204.08067]
- Axion models [Lazarides et al., 2205.04824]
- Colored scalars [Carpenter et al., 2204.08546]
- 3-3-1 [Van loi et al., 2206.10100]
- $SU(2)_L \times SU(2)_R$ [Afoni, 2205.12237]
- Low-energy implications [Cirigliano et al., 2204.08440; Tran Tan et al., 2204.11991]
- EW fits (most with BSM interpretations; different levels of sophistication) [Athron et al., 2204.03996; Asadi et al., 2204.05283; Balkin et al., 2204.05992; De Blas et al., 2204.04204; Fan et al., 2204.04805; Lu et al., 2204.03796; Gu et al., 2204.05296; Paul et al., 2204.05267; Strumia 2204.04191]
- (More) Global fits [EB et al. 2204.05260; D'Alise et al., 2204.03686; Gupta et al., 2204.13690]

to CDR or not to CDF?



[CMS-SMP-23-002, '24]



[CDF collaboration, Science 376 (2022) 6589, 170-176]

- Given that the LHC experiments are not confirming the CDF determination, I will show as an example a pre-CDF study

Computation of the W mass in the MSSM

The determination of the W mass from the other parameters of the theory is another important consistency test.

M_W calculation

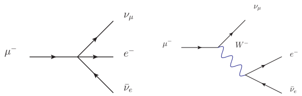
From the matching between the Fermi theory + QED with the MSSM (or the SM or any BSM model)

$$\frac{G_\mu}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2} (1 + \Delta r)$$

It can be re-arranged to obtain the relationship

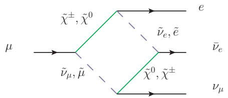
$$M_W^2 = M_Z^2 \left(\frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\alpha \pi}{\sqrt{2} G_\mu M_Z^2} (1 + \Delta_r)} \right)$$

Muon decay



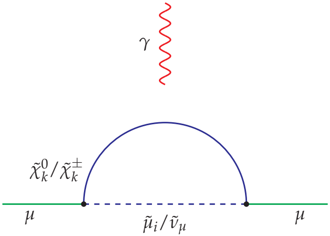
MSSM contribution to Δr

At one loop, Δr contains self-energies, vertex corrections, box diagrams

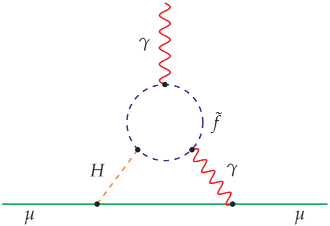


$(g-2)_\mu$ in the MSSM

One loop diagrams



Example of a two loop contribution



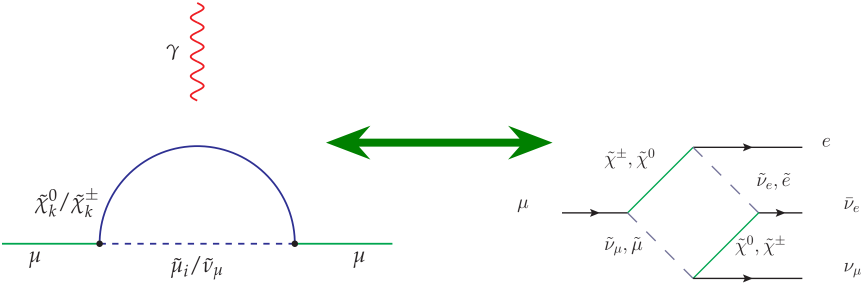
- Approximated formulae for the one loop contribution

$$a_\mu^{\tilde{\chi}^\pm-\tilde{\nu}_\mu} \approx \frac{\alpha\, m_\mu^2\, \mu\, M_2 \tan\beta}{4\pi \sin^2\theta_W\, m^2_{\tilde{\nu}_\mu}} \left(\frac{f_{\chi^\pm}(M_2^2/m^2_{\tilde{\nu}_\mu}) - f_{\chi^\pm}(\mu^2/m^2_{\tilde{\nu}_\mu})}{M_2^2-\mu^2} \right)$$

$$a_\mu^{\tilde{\chi}^0-\tilde{\mu}} \approx \frac{\alpha\, m_\mu^2\; M_1(\mu\tan\beta - A_\mu)}{4\pi\cos^2\theta_W\,(m^2_{\tilde{\mu}_R} - m^2_{\tilde{\mu}_L})} \left(\frac{f_{\chi^0}(M_1^2/m^2_{\tilde{\mu}_R})}{m^2_{\tilde{\mu}_R}} - \frac{f_{\chi^0}(M_1^2/m^2_{\tilde{\mu}_L})}{m^2_{\tilde{\mu}_L}} \right)$$

Our idea

- The lightest electroweakinos and the sleptons are important for both observables
- Is there a correlation between the values assumed by $(g-2)_\mu$ and M_W in the MSSM?
- Moreover, assuming that the $\tilde{\chi}_1^0$ contributes to the observed DM relic density, is there a correlation with specific dark matter mechanisms?



Computational framework and scenarios

We use as baseline the sample obtained in [M. Chakraborti, S. Heinemeyer, I. Saha: EPJC 80 (2020) 10 984; 2103.13043; 2104.03287]

Tools

- Spectrum generator: `SuSpect`
- EWPO, Higgs: `FeynHiggs (mod)`
- Dark matter: `micrOMEGAs`
- Vacuum stability: `Evade`
- Collider constraints: `CheckMATE`
- Higgs constraints: `HiggsSignals`
- $(g-2)_\mu$: `GM2Calc`

Higgsino-like $\tilde{\chi}_1^0$

$100 \text{ GeV} \le \mu \le 1.2 \text{ TeV}$
$1.1 \times \mu \le M_1 \le 10 \times \mu$
$1.1 \times \mu \le M_2 \le 10 \times \mu$
$5 \le \tan\beta \le 60$
$100 \text{ GeV} \le m_{\tilde{l}_L}, m_{\tilde{l}_L} \le 2 \text{ TeV}$

Small value of μ, realized in AMSB

- Heavy third generation squarks, with masses and trilinears chosen to have $m_h = 125$ GeV
- Extra Higgs, first and second generation squarks and gluino heavy
- Other trilinears set to zero

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Wino-like $\tilde{\chi}_1^0$

100 GeV $\leq M_2 \leq$ 1.5 TeV
$1.1 \times M_2 \leq M_1 \leq 10 \times M_2$
$1.1 \times M_2 \leq \mu \leq 10 \times M_2$
$5 \leq \tan\beta \leq 60$
100 GeV $\leq m_{\tilde{l}_L}, m_{\tilde{l}_L} \leq$ 2 TeV

Small value of M_2, realized in AMSB; issues with the OS renormalization of the six $\tilde{\chi}_i^0$ and $\tilde{\chi}_j^\pm$

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Mixed Bino-Wino $\tilde{\chi}_1^0$

$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV}$
$M_1 \leq M_2 \leq 1.1 \times M_1$
$1.1 \times M_1 \leq \mu \leq 10 \times M_1$
$5 \leq \tan\beta \leq 60$
$100 \text{ GeV} \leq m_{\tilde{l}_L} \leq 1.5 TeV$
$m_{\tilde{l}_R} \equiv m_{\tilde{l}_L}$

Bino-Wino Chargino coannihilation

- Heavy third generation squarks, with masses and trilinears chosen to have $m_h = 125$ GeV
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- $(g-2)_\mu$: `GM2Calc`

Bino $\tilde{\chi}_1^0$ with $\tilde{l}$ coannihilation

$100\text{ GeV} \le M_1 \le 1\text{ TeV}$
$M_1 \le M_2 \le 10 \times M_1$
$1.1 \times M_1 \le \mu \le 10 \times M_1$
$5 \le \tan\beta \le 60$
$M_1 \le m_{\tilde{l}_L} \le 1.2 \times M_1$
$M_1 \le m_{\tilde{l}_R} \le 10 \times M_1$

Coannihilation with either the left-handed or the right-handed sleptons

- Heavy third generation squarks, with masses and trilinears chosen to have $m_h = 125$ GeV
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Bino $\tilde{\chi}_1^0$ with $\tilde{l}$ coannihilation

$100\ \text{GeV} \leq M_1 \leq 1\ \text{TeV}$
$M_1 \leq M_2 \leq 10 \times M_1$
$1.1 \times M_1 \leq \mu \leq 10 \times M_1$
$5 \leq \tan\beta \leq 60$
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Coannihilation with either the left-handed or the right-handed sleptons

- Heavy third generation squarks, with masses and trilinears chosen to have $m_h = 125$ GeV
- Extra Higgs, first and second generation squarks and gluino heavy
- Other trilinears set to zero

Collider Constraints on new states

- Same constraints as in [M. Chakraborti, S. Heinemeyer, I. Saha, EPJC 80 (2020) 10, 984, 2103.13043, 2104.03287]
- Focus on collider searches for electroweakinos and sleptons

Process	$\mathcal{L}_{\rm int}$ [fb^{-1}]	Reference
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (\tilde{l}^\pm \nu)(\tilde{l}^+ l^-) \to 3l + \not{E}_T$ $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (l^\pm \tilde{\nu})(\tilde{l}^+ l^-) \to 3l + \not{E}_T$	36.1	[ATLAS EPJC 78 (2018) no.12, 995]
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}^0)(Z\tilde{\chi}^0) \to 3l + \not{E}_T$ $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W\tilde{\chi}^0)(Z\tilde{\chi}^0) \to 2l + jets + \not{E}_T$	36.1	[ATLAS EPJC 78 (2018) no.12, 995]
$\tilde{\chi}_1^+ \tilde{\chi}_1^- \to (W^+ \tilde{\chi}^0)(W^- \tilde{\chi}^0) \to 2l + \not{E}_T$	139	[ATLAS EPJC (2020) no.2, 123]
$\tilde{l}^+ \tilde{l}^- \to (l^+ \tilde{\chi}^0)(l^- \tilde{\chi}^0) \to 2l + \not{E}_T$	36.1 139	[ATLAS EPJC 78 (2018) no.12] [ATLAS EPJC (2020) no.2, 123]
$\tilde{\chi}_1^+ \tilde{\chi}_1^- \to\to (\tilde{l}^+ \nu)(\tilde{l}^+ \nu) \to 2l + \not{E}_T$ $\tilde{\chi}_1^+ \tilde{\chi}_1^- \to\to (l^+ \tilde{\nu})(l^+ \tilde{\nu}) \to 2l + \not{E}_T$	139	[ATLAS EPJC (2020) no.2, 123]
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W^* \tilde{\chi}^0)(Z^* \tilde{\chi}^0) \to 2l + \not{E}_T$ + ISR $\tilde{l}^+ \tilde{l}^- \to (l^+ \tilde{\chi}^0)(l^- \tilde{\chi}^0) \to 2l + \not{E}_T$ + ISR	139 36.1	[ATLAS PRD 101 (2020) 5, 052005]

Other observables

Aside from $(g-2)_\mu$ restricted to have a deviation from the SM within $\pm 2\sigma$ the new value of $\Delta a_\mu = (25.1 \pm 5.9) \times 10^{-10}$, we consider

DM constraints

- Dark matter relic density, imposed as an upper bound
- Direct detection constraints on σ_p^{SI} from XENON

Higgs sector

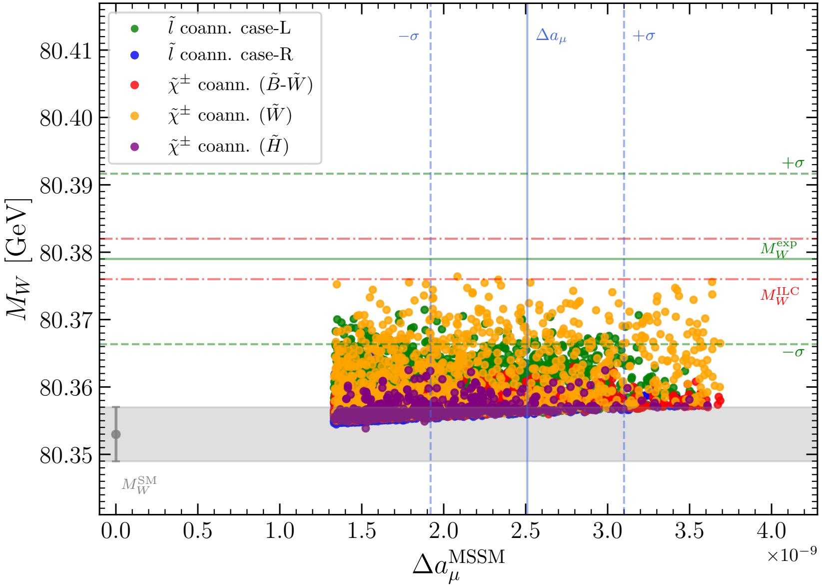
- Higgs mass tuned to 125 GeV
- Higgs properties via `HiggsSignals`

Inputs for M_W

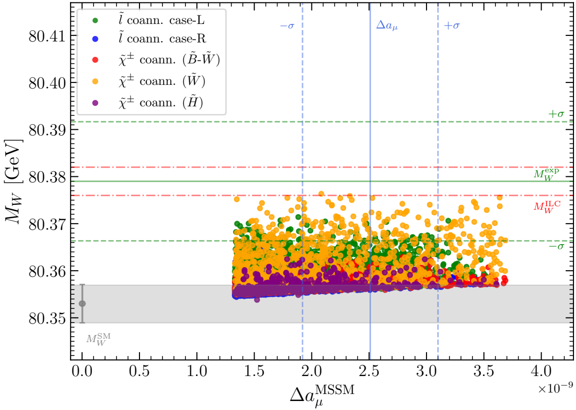
PDG 2020

- $1/\hat{\alpha}^{(5)}(M_Z)$ = 127.952
- $\Delta\alpha^{(5)}(M_Z)$ = 0.02766
- $G_F = 1.166378 \times 10^{-5}$ GeV^{-2}
- $M_Z = 91.1876$ GeV
- $M_T = 172.76$ GeV
- $m_b(m_b) = 4.18$ GeV
- $\alpha_s(M_Z) = 0.1179$

M_W vs $(g-2)_\mu$

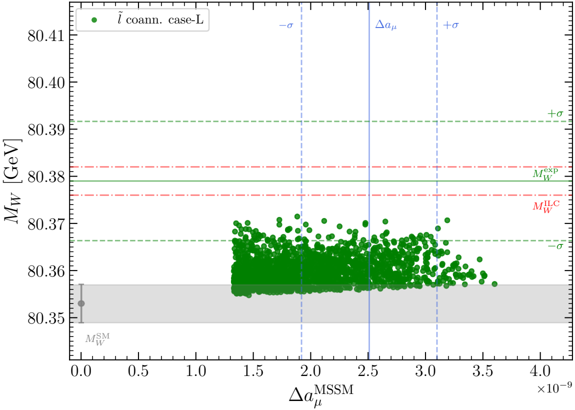

● $\tilde{l}$ coann. case-L
● $\tilde{l}$ coann. case-R
● $\tilde{\chi}^{\pm}$ coann. ($\tilde{B}$-$\tilde{W}$)
● $\tilde{\chi}^{\pm}$ coann. ($\tilde{W}$)
● $\tilde{\chi}^{\pm}$ coann. ($\tilde{H}$)
$-\sigma$
Δa_μ
$+\sigma$
$+\sigma$
M_W^{exp}
M_W^{ILC}
$-\sigma$
M_W^{SM}
M_W [GeV]
80.41
80.40
80.39
80.38
80.37
80.36
80.35
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$\times 10^{-9}$
$\Delta a_\mu^{\mathrm{MSSM}}$

M_W vs $(g-2)_\mu$



- There is a mild correlation between M_W and $(g-2)_\mu$, with interesting patterns arising in connection with DM mechanisms
- The MSSM covers well all the relevant range of Δa_μ
- For these scenarios, M_W is in general below the current exp. average, although many points lie within 1σ

M_W vs $(g-2)_\mu$



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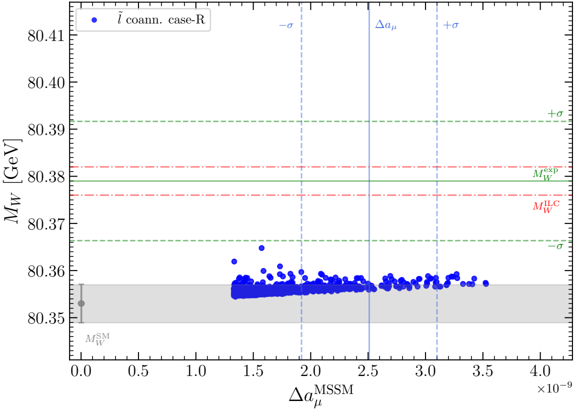

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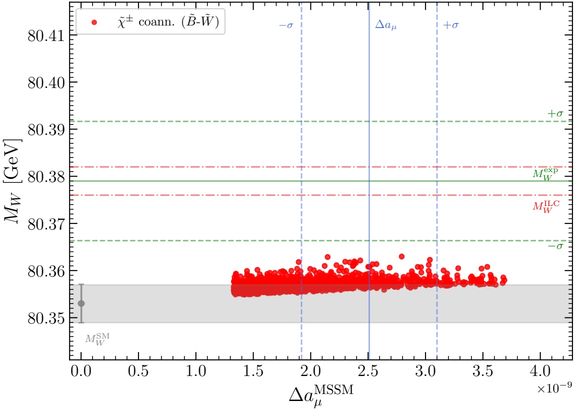

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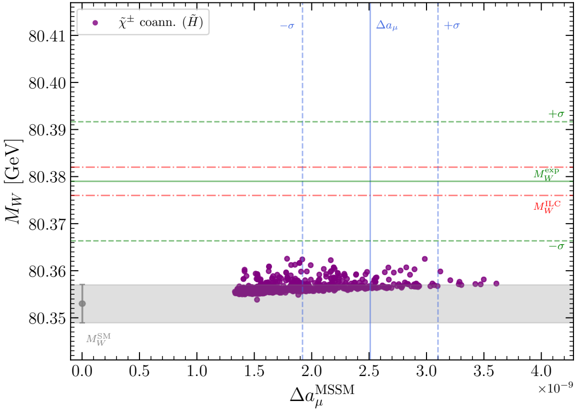

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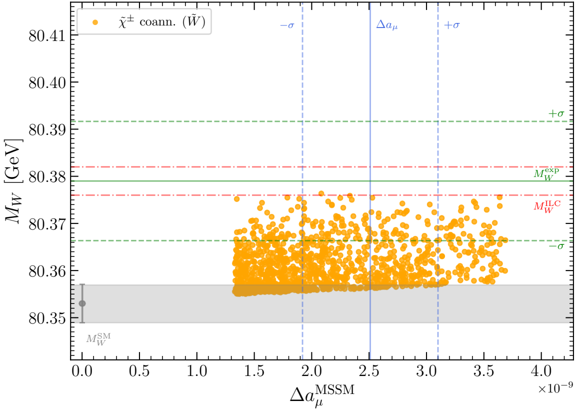
M_W vs $(g-2)_\mu$



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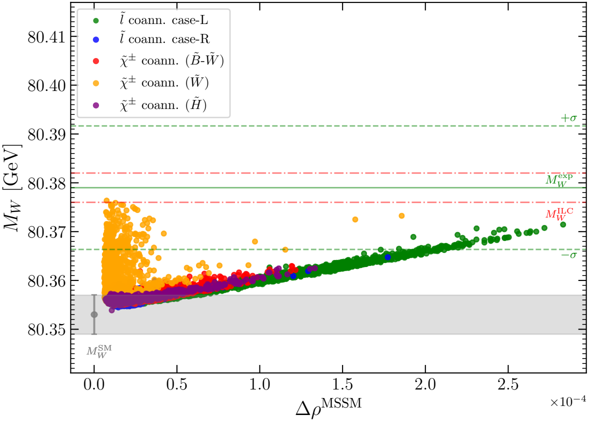
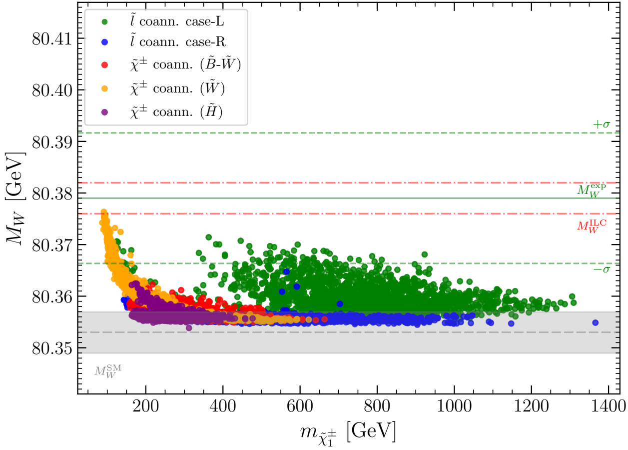
$\Delta\rho$ vs M_W



- For the Wino case, M_W receives the major contributions from the diagrams with charginos and neutralinos

Charginos – M_W vs $m_{\tilde{\chi}_1^\pm}$



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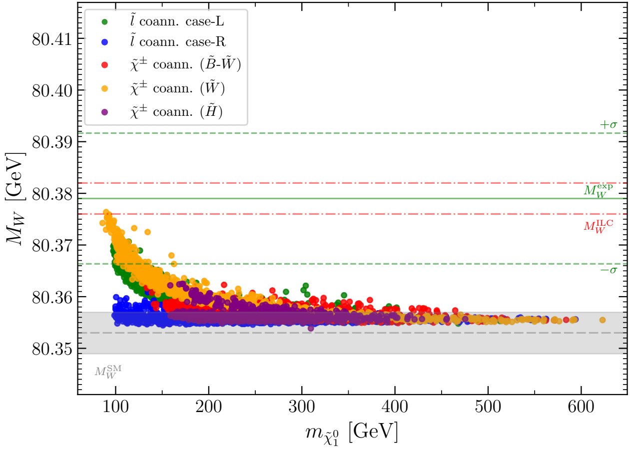
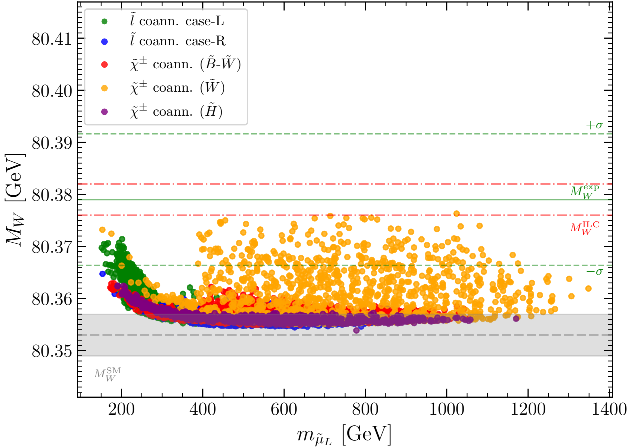
Neutralinos – M_W vs $m_{\tilde{\chi}_1^0}$



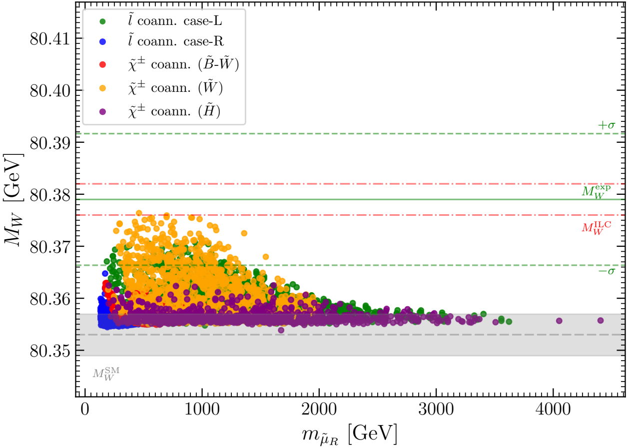
- For the Wino case, M_W receives the major contributions from the diagrams with charginos and neutralinos

Sleptons left – M_W vs $m_{\tilde{\mu}_L}$



- The case-L slepton coann. scenario as expected is characterized by large M_W values and low $\tilde{l}_L$ masses

Sleptons right – M_W vs $m_{\tilde{\mu}_R}$



- The case-R slepton coann. scenario never features a large M_W

Conclusions and outlook

- The Drell-Yan processes represent an important test for SM predictions at colliders
- The precision reached by the LHC experiments is a challenge for the theory community to develop more and more sophisticated calculations
- A proper estimation of the theory uncertainties is required → ongoing work from the theory community
- Theory uncertainty workshop: https://indico.cern.ch/event/1368033/timetable/
- A precise determination of M_W play an important role testing the robustness of the SM, and in probing the parameter space of BSM models