Università degli Studi di Milano

INFN Istituto Nazionale di Fisica Nucleare

EW higher order corrections and EW scheme uncertainties: a fitting exercise

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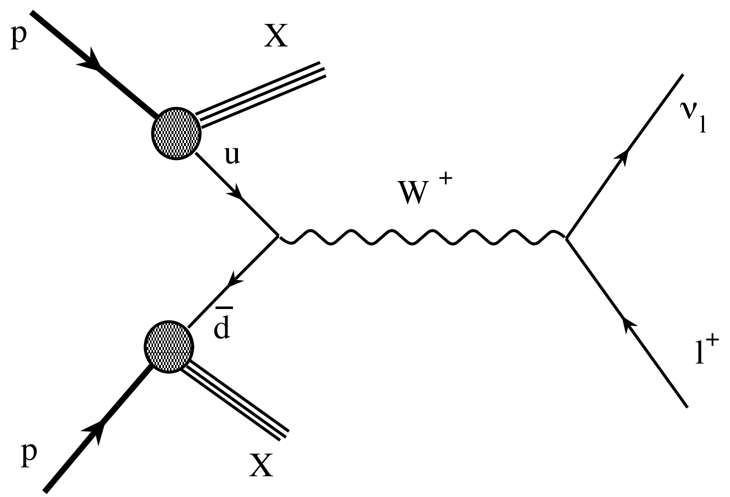
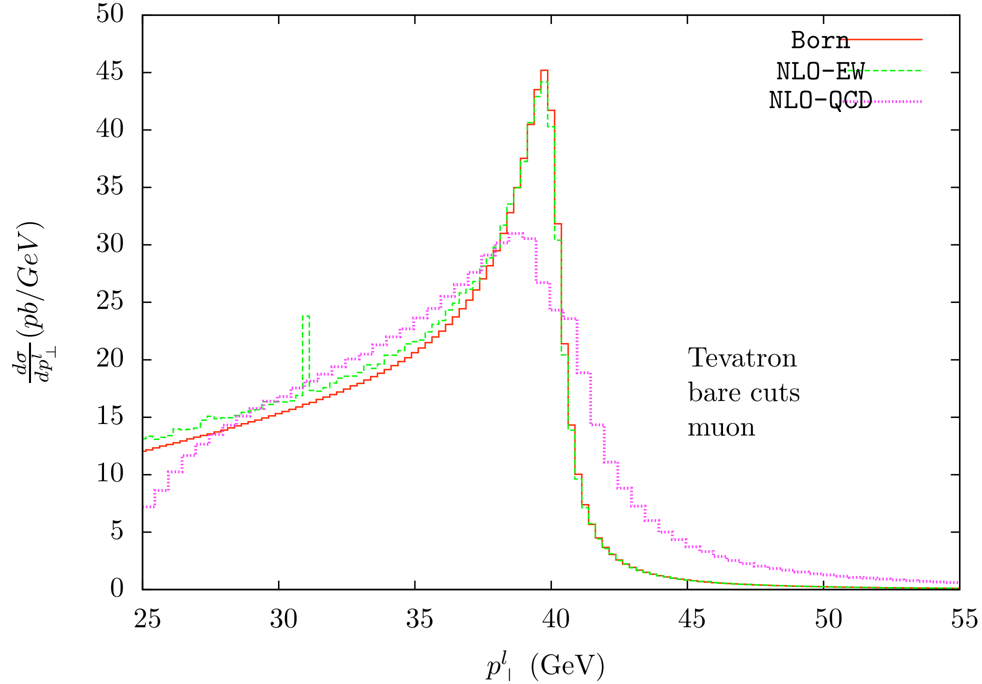
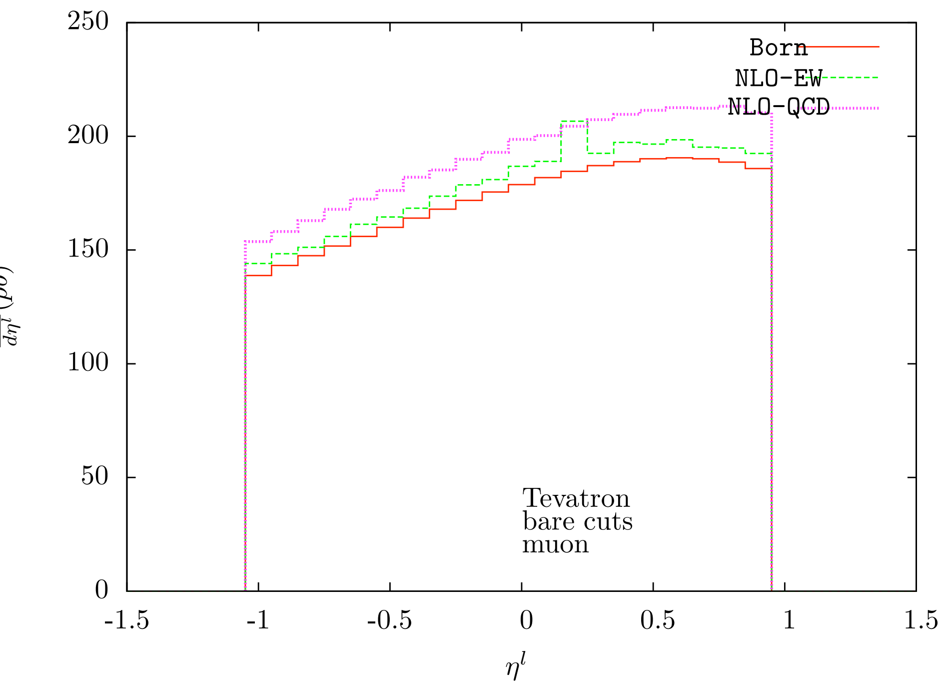
W mass workshop
Fermilab, October 5th 2010

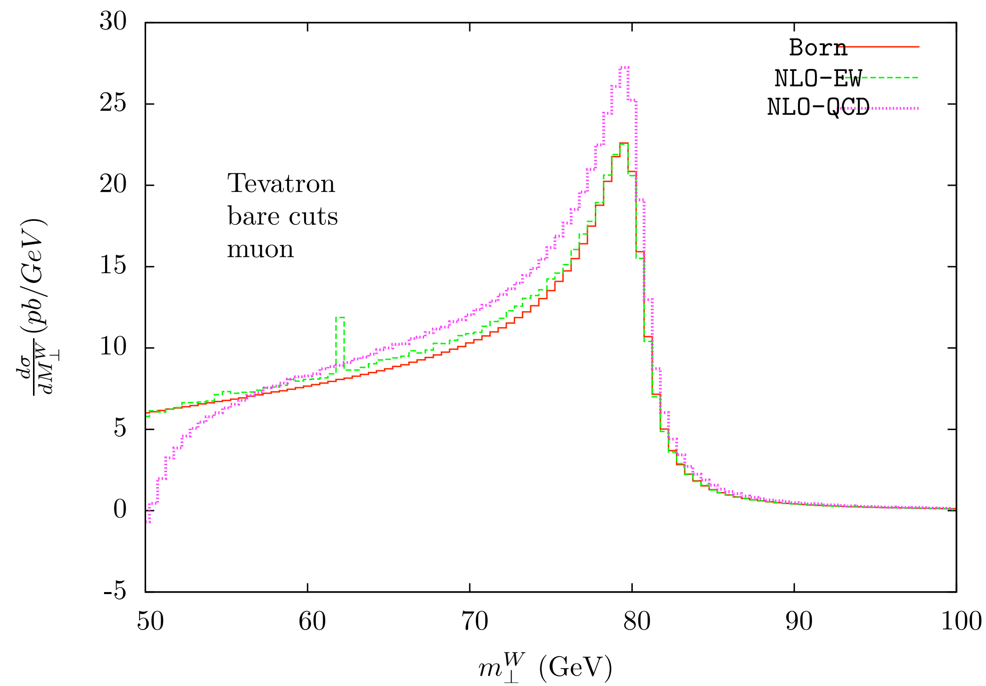
in collaboration with C.M.Carloni Calame

The Drell-Yan process at fixed (NLO) order (α_0 input scheme)

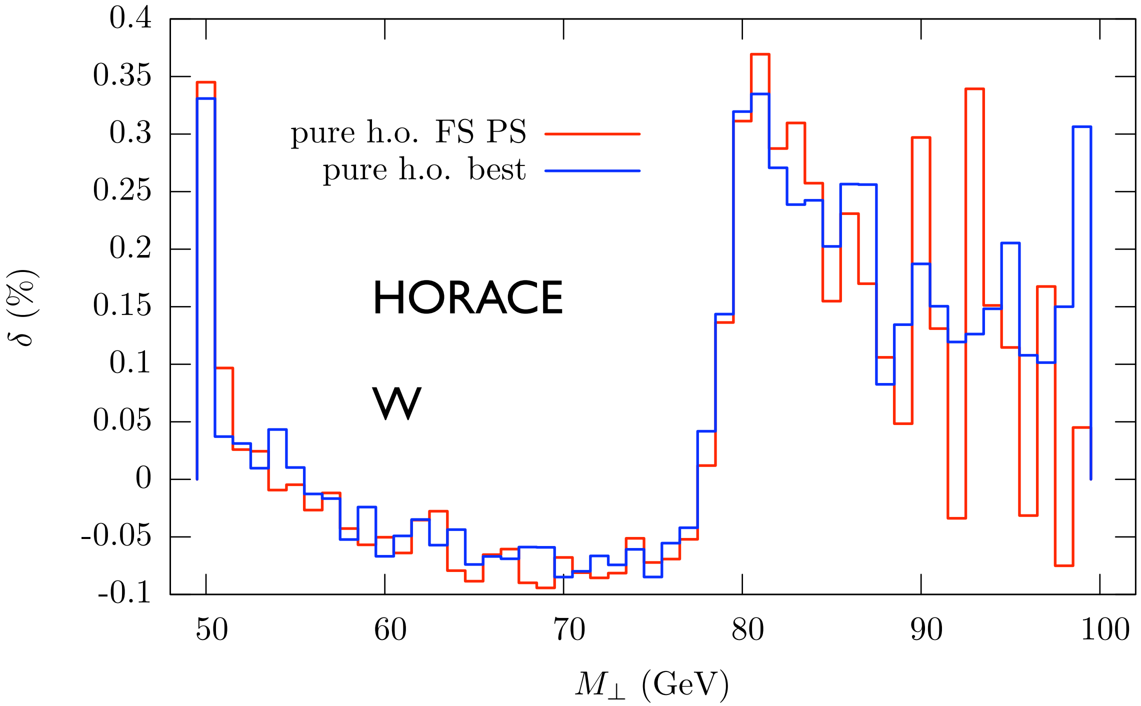








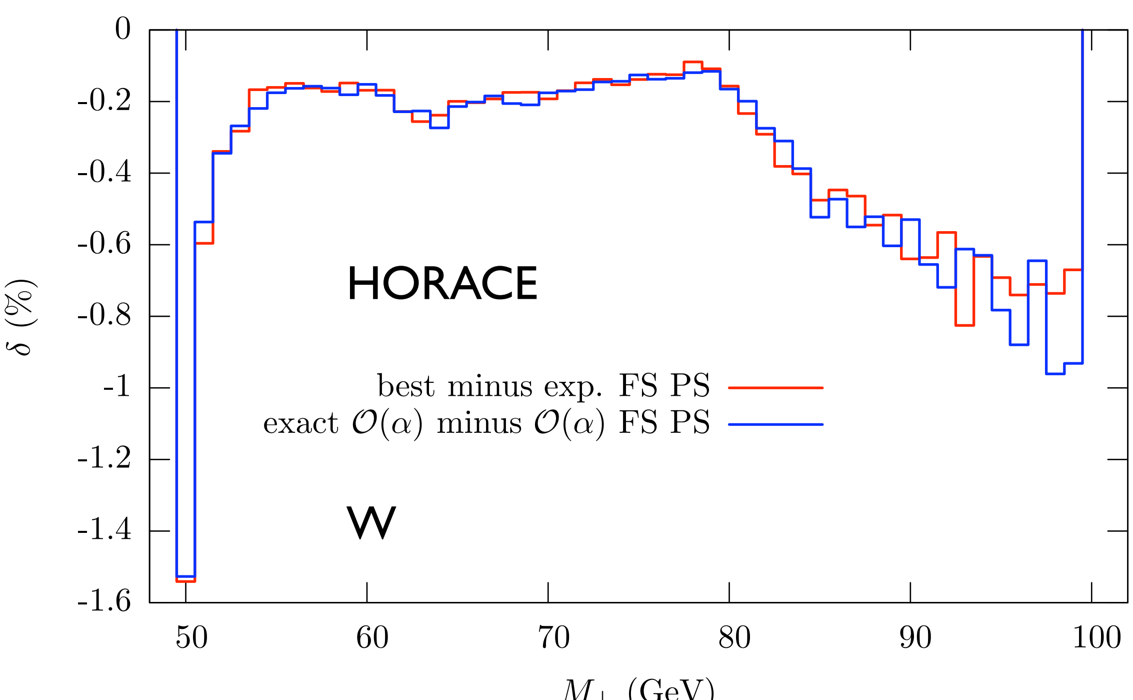
The effect of multiple photon emission and of subleading EW terms

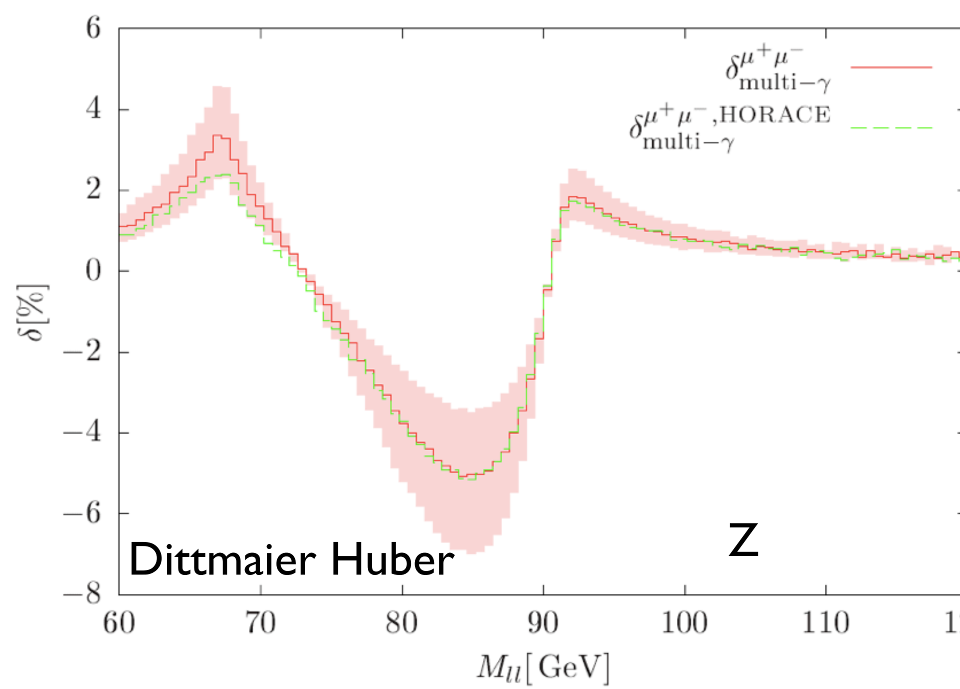


Effects of multiple photon emission studied

HORACE : full all orders QED Parton Shower

W-ZGRAD, Dittmaier-Huber:
final state structure function approach





The W mass as pseudo-observable

The W mass is not a property of measured (final state) particles, but
it is rather an input parameter of the Lagrangian which can be chosen
to maximize the agreement theory-data for some given distributions.

If we want to measure MW, in the SM, in the gauge sector, it is possible to use as inputs

(α, m_W, m_Z) (G_μ, m_W, m_Z) but not (α, G_μ, m_Z)

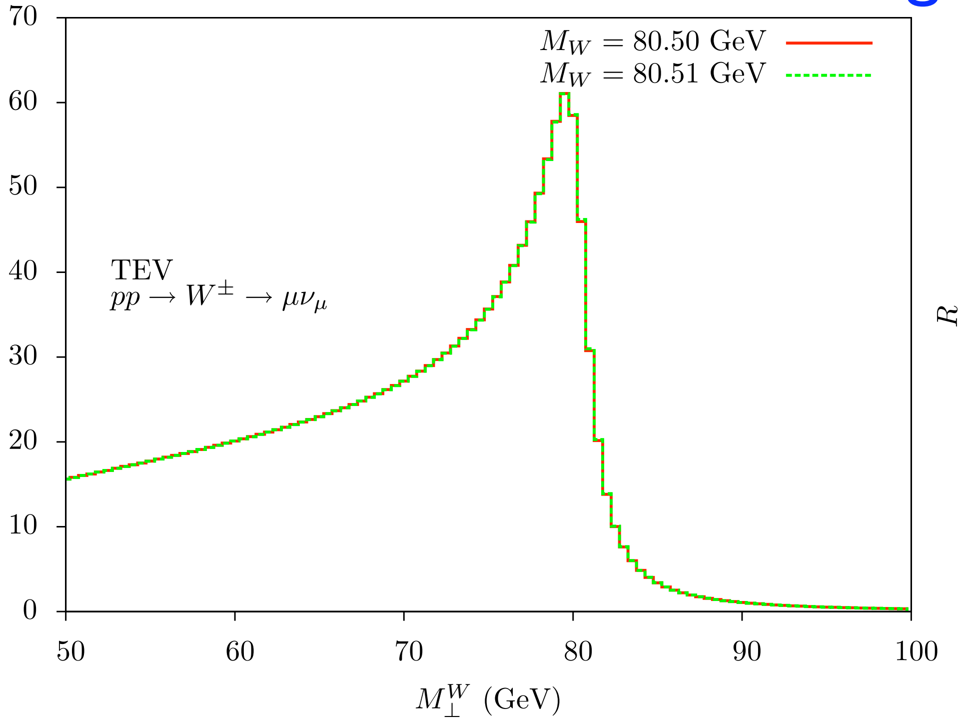
The W mass is defined starting from the pole, in the complex plane, of the W propagator

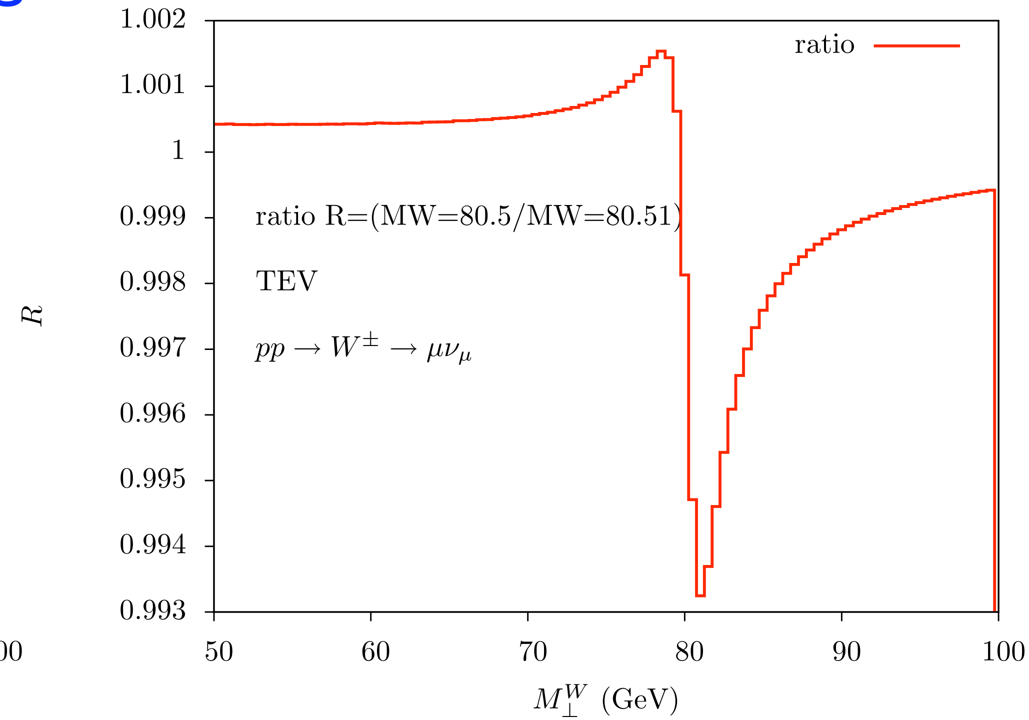
Since the final state neutrino escapes detection, it is not possible to reconstruct all the components of the W momentum (and therefore its virtuality).
It is possible to infer the value of the transverse components of the neutrino
provided one has an excellent understanding of initial state QCD+QED radiation

The lepton and the missing transverse momentum and transverse mass distributions
have a jacobian peak about the W mass.
The peak of distributions provides a strong sensitivity to the value of MW.

$$M_\perp^W = \sqrt{2 p_\perp^l p_\perp^\nu \ (1 - \cos\phi_{l\nu})}$$

Estimate of MW shift due to higher order corrections in the fit





The ratio of two distributions generated with nominal MW which differ by 10 MeV shows a deviation from unity at the level of few per mil, with non trivial shape

If we aim at measuring MW with 10-15 MeV of error, are we able to control the shape of the distributions and the theoretical uncertainties at the few per mil level?

Not all the radiative corrections have the same impact on the MW measurement not all the uncertainties are equally bad on the final error

The template-fitting procedure

A distribution computed with a given set of radiative corrections and
with a given value MW_0
is treated as a set of pseudo-data

The templates are prepared in Born approximation, using 100 values of MW_i
Each template is compared to the pseudo-data and a distance is measured

$$\chi_i^2 = \sum_{j=1}^{N_{bins}} \frac{\left(O_j^{data} - O_j^{templ=i}\right)^2}{\left(\sigma_j^{data}\right)^2} \qquad\qquad i = 1, \ldots, N_{templ}$$

The template that minimizes the distance is considered as the "preferred one"
and the value of MW, used to generate it, is the "measured" MW

The difference $MW\text{-}MW_0$ represents the shift induced on the measurement of the W mass
by including that specific set of radiative corrections

The distributions used in the evaluation of χ^2_i in general do not have the same normalization.
It is also possible to compare distributions that have been normalized to their respective xsecs,
to appreciate the role of the shape differences

The HORACE formula:
exact O(α) matched with multiple photon radiation

$$d\sigma^{\infty}_{matched} = \Pi_S(Q^2) F_{SV} \sum_{n=0}^{\infty} d\hat{\sigma}_0 \frac{1}{n!} \prod_{i=0}^{n} \left(\frac{\alpha}{2\pi} P(x_i)\, I(k_i)\, dx_i\, d\cos\theta_i\, F_{H,i} \right)$$

$$F_{SV} = 1 + \frac{d\sigma^{\alpha,ex}_{SV} - d\sigma^{\alpha,PS}_{SV}}{d\sigma_0} \qquad F_{H,i} = 1 + \frac{d\sigma^{\alpha,ex}_{H,i} - d\sigma^{\alpha,PS}_{H,i}}{d\sigma^{\alpha,PS}_{H,i}}$$

The matched HORACE formula is based on the all-orders QED Parton Shower structure

The presence of the overall Sudakov form factor guarantees the "semi-classical" limit
The Sudakov form factor contains the (IR) LL virtual corrections

The exact O(α) accuracy is reached by adding

finite (no IR-div) soft+virtual effect in the overall factor F_SV
exact (vs. eikonal) hard matrix element effects to every photon emission F_H,i

EW input schemes

$$\frac{G_\mu}{\sqrt{2}} = \frac{g^2}{8 m_W^2}\,(1+\Delta r)$$

$$\alpha_\mu^{tree} = \frac{\sqrt{2}}{\pi} G_\mu m_W^2 \sin^2\theta_W$$

$$\alpha_\mu^{1l} = \frac{\sqrt{2}}{\pi} G_\mu m_W^2 \sin^2\theta_W\,(1-\Delta r)$$

$$\alpha_0 \;:\qquad \sigma = \alpha_0^2\sigma_0 + \alpha_0^3(\sigma_{SV}+\sigma_H)$$

$$G_\mu\ I \;:\qquad \sigma = (\alpha_\mu^{tree})^2\sigma_0 + (\alpha_\mu^{tree})^2\alpha_0(\sigma_{SV}+\sigma_H) - 2\Delta r(\alpha_\mu^{tree})^2\sigma_0$$

$$G_\mu\ II \;:\qquad \sigma = (\alpha_\mu^{1l})^2\sigma_0 + (\alpha_\mu^{1l})^2\alpha_0(\sigma_{SV}+\sigma_H)$$

the three input schemes differ by $O(\alpha^2)$ terms

the change of scheme yields a different overall normalization
but also
the sharing of 0- and of 1-photon events is different in the 2 Gmu schemes
the same in α_0 and Gmu-II schemes

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$$\alpha_0 \;:\quad \sigma = \alpha_0^2\sigma_0 + \alpha_0^3(\sigma_{SV} + \boxed{\sigma_H})$$

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The HORACE formula and its impact on the MW measurement

$$d\sigma^{\infty}_{matched} = \Pi_S(Q^2) F_{SV} \sum_{n=0}^{\infty} d\hat{\sigma}_0 \frac{1}{n!} \prod_{i=0}^{n} \left(\frac{\alpha}{2\pi} P(x_i)\, I(k_i)\, dx_i\, d\cos\theta_i\, F_{H,i} \right)$$

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in the matched HORACE formula the change of input scheme affects:

the overall couplings of the Born cross-section $d\sigma_0$ and

the F_SV factor

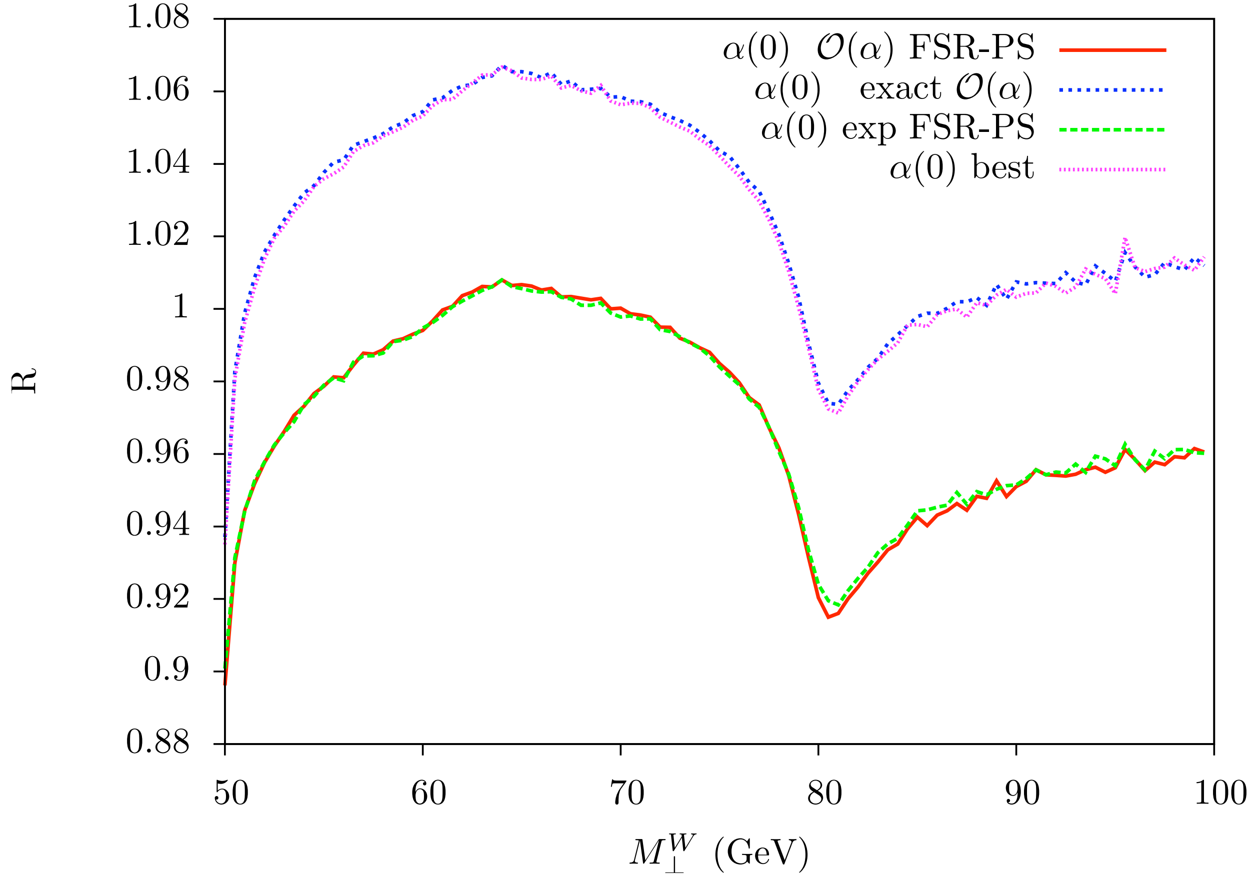
in both cases it modifies the overall normalization of the cross section

the sharing of 0-, 1-, 2-,.... photon events remains the same in all the input schemes and therefore the shape of the distributions (relevant for MW) remains the same

The input scheme changes differ at $O(\alpha^2)$ and modify mostly the normalization of the cross section,

Therefore the χ^2 of the fit exhibits a corresponding variation.

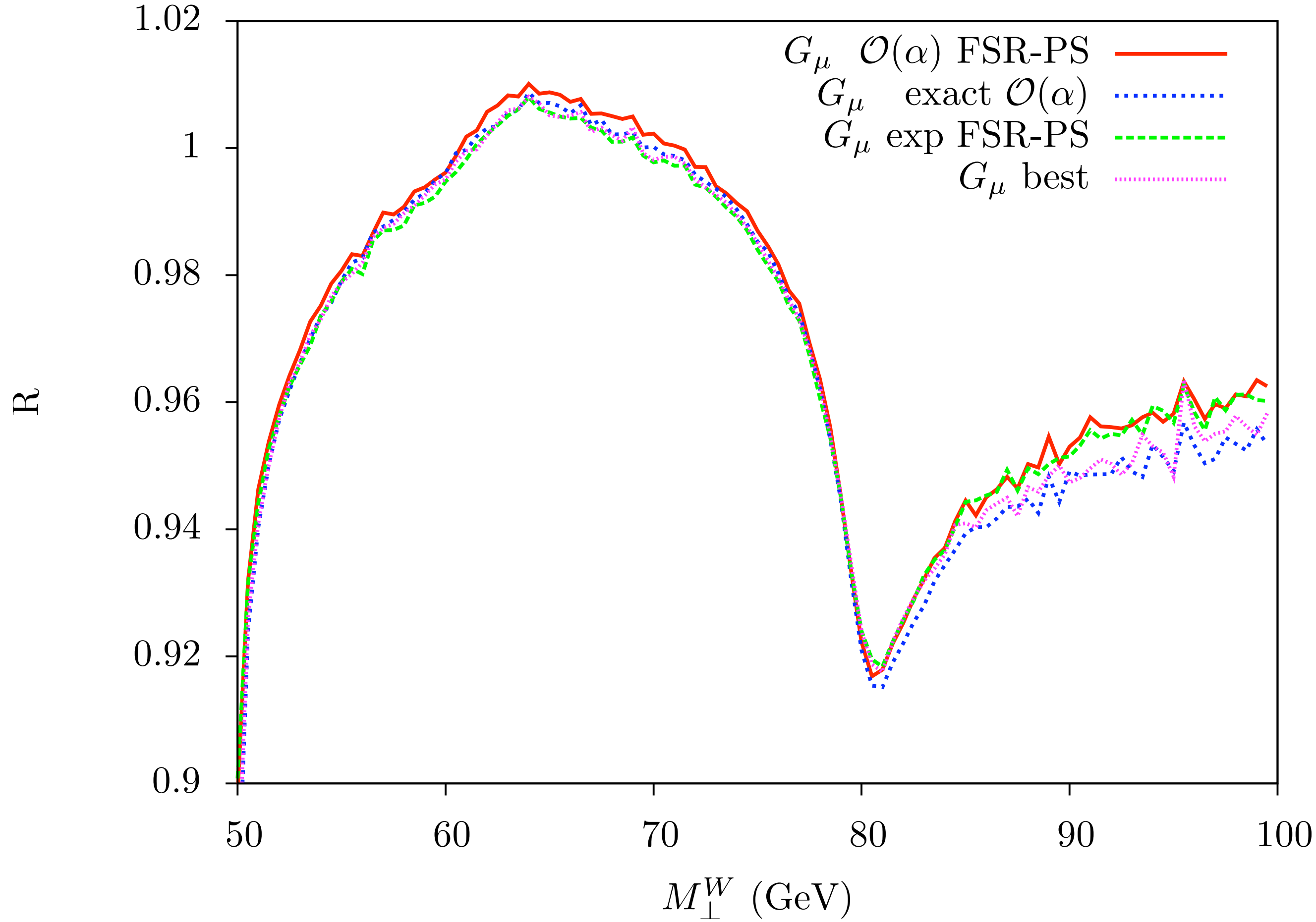
EW higher orders in the α_0 scheme: percentual effect (in unit Born)



The 2 lower curves are obtained with FSR QED Parton Shower

The 2 upper curves show the effect of the 1-loop virtual corrections

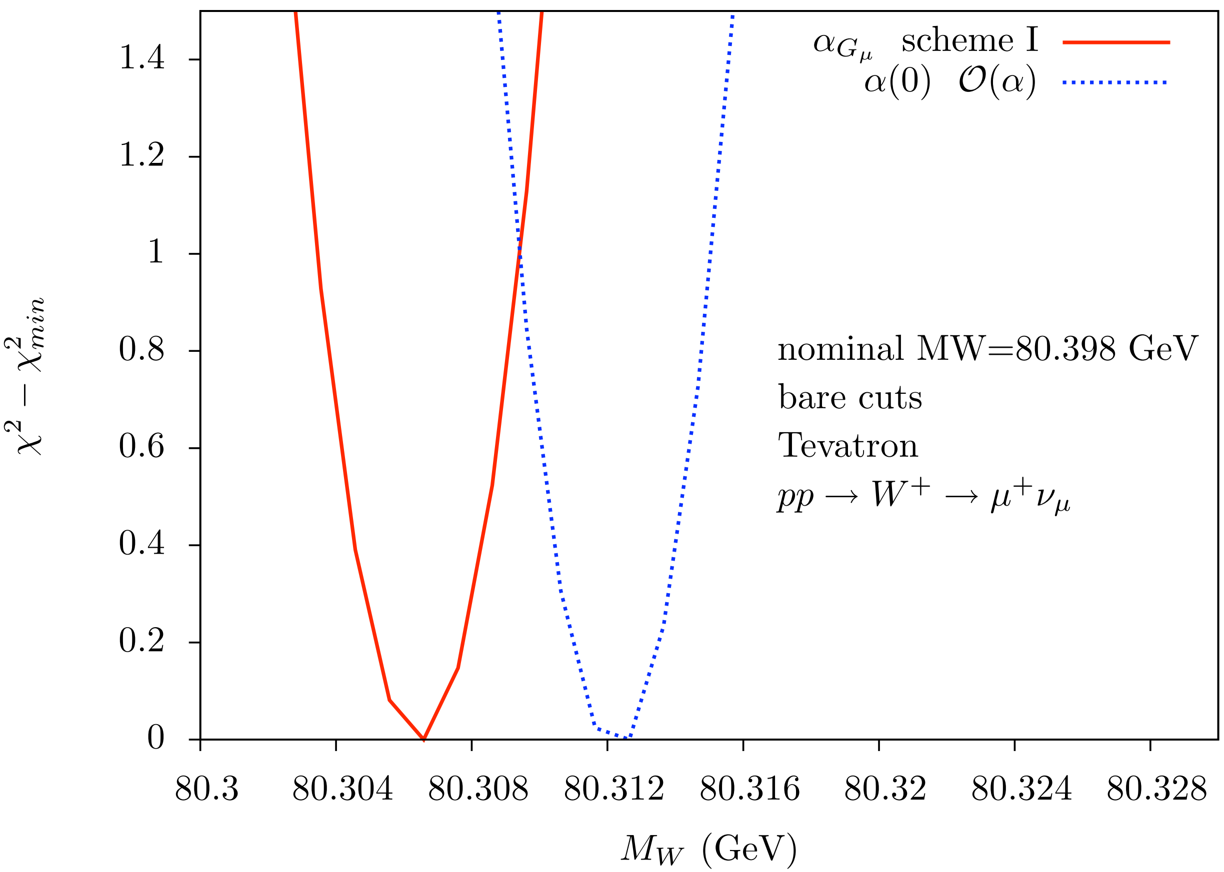
EW higher orders, Gmu scheme: percentual effect (in unit Born)



The curves obtained with FSR QED Parton Shower
are close to the
exact 1-loop and to the matched calculation
thanks to the input choice

EW input schemes

Born templates Gmu scheme with 10 billions of events: maximal accuracy 2 MeV



At O(α)

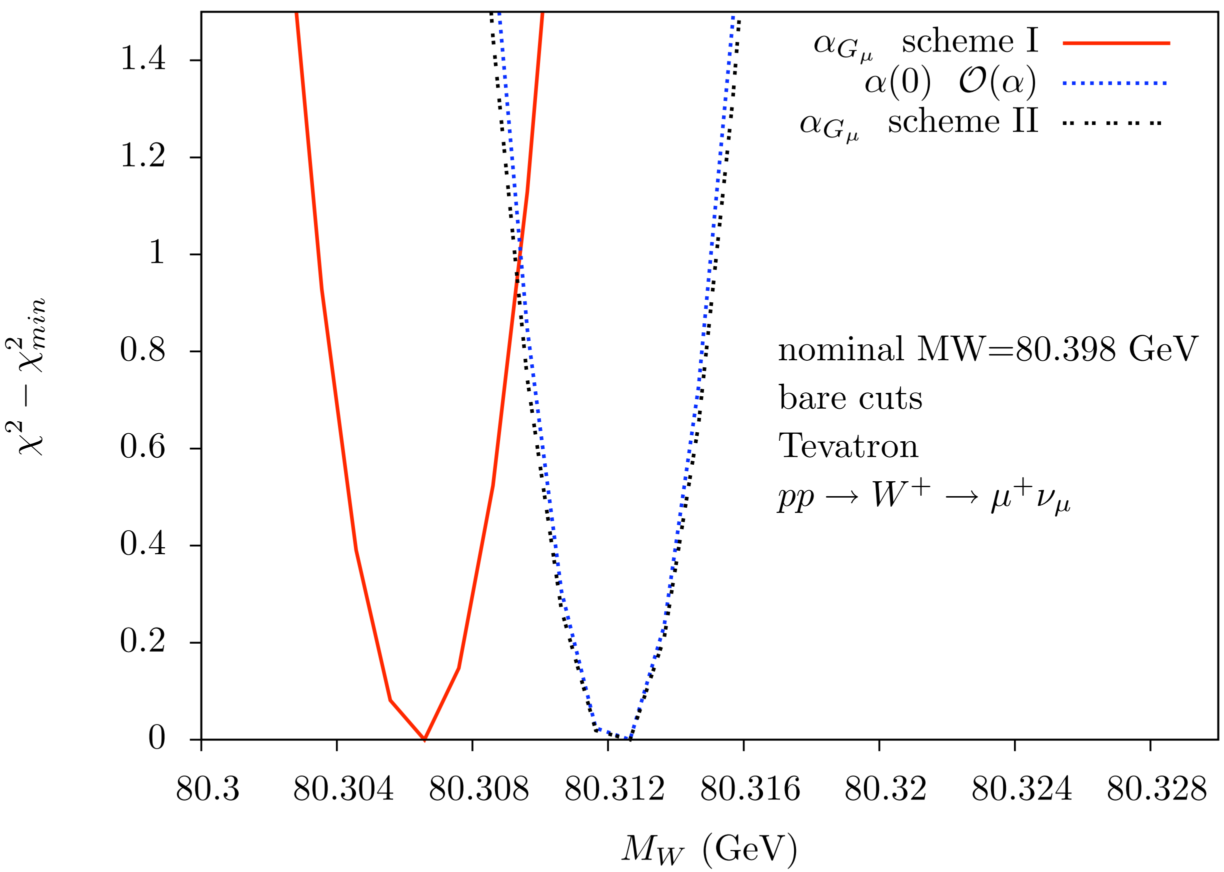
using α_0 or Gmu-I schemes

(different 0- and 1-photon sharing)

yields a change of MW of 6 MeV

EW input schemes

Born templates Gmu scheme with 10 billions of events: maximal accuracy 2 MeV

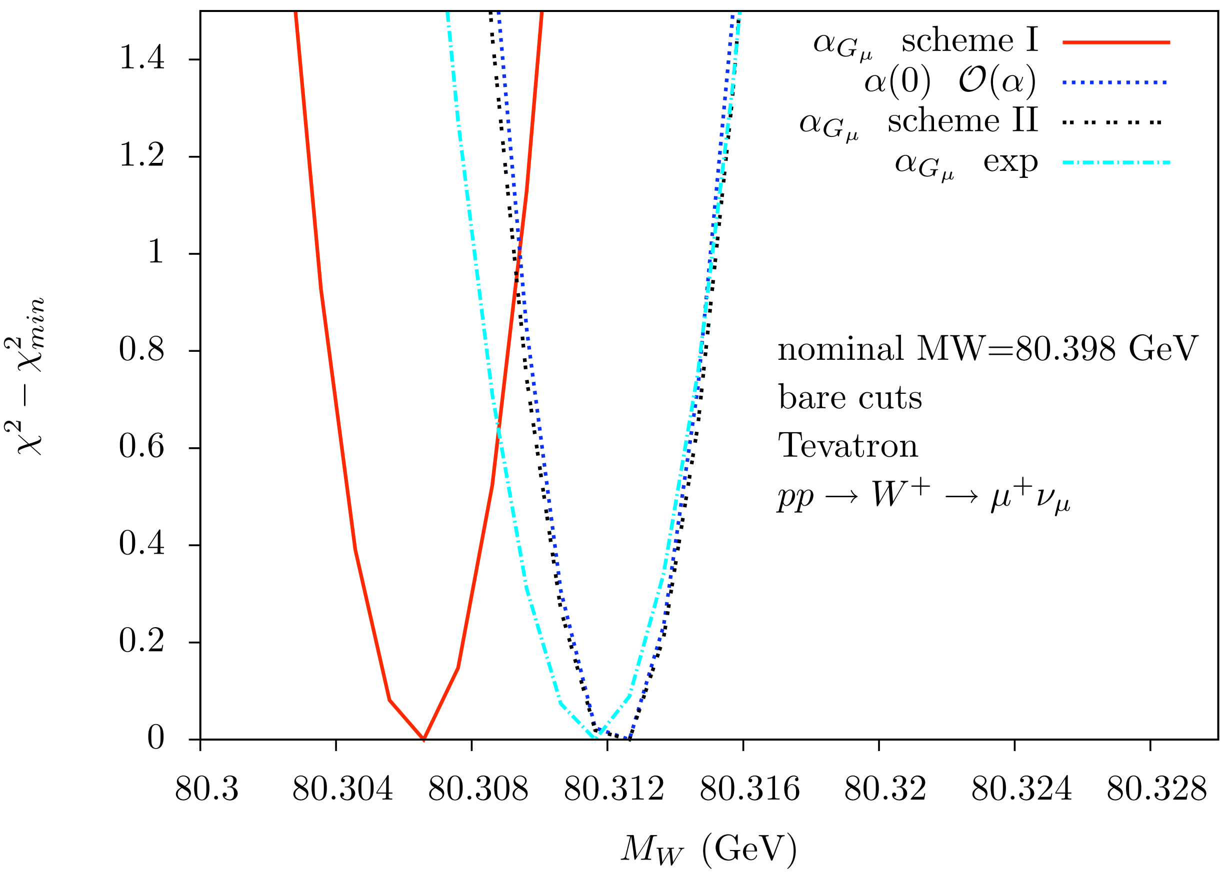


At $O(\alpha)$
using α_0 or Gmu-I schemes
(different 0- and 1-photon sharing)
yields a change of MW of 6 MeV

At $O(\alpha)$
using α_0 or Gmu-II scheme
(same 0- and 1-photon sharing as α_0)
there is no extra shift in MW

EW input schemes

Born templates Gmu scheme with 10 billions of events: maximal accuracy 2 MeV



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In the Gmu-I scheme
O(α) and best approximation
differ by 5 MeV

EW input schemes

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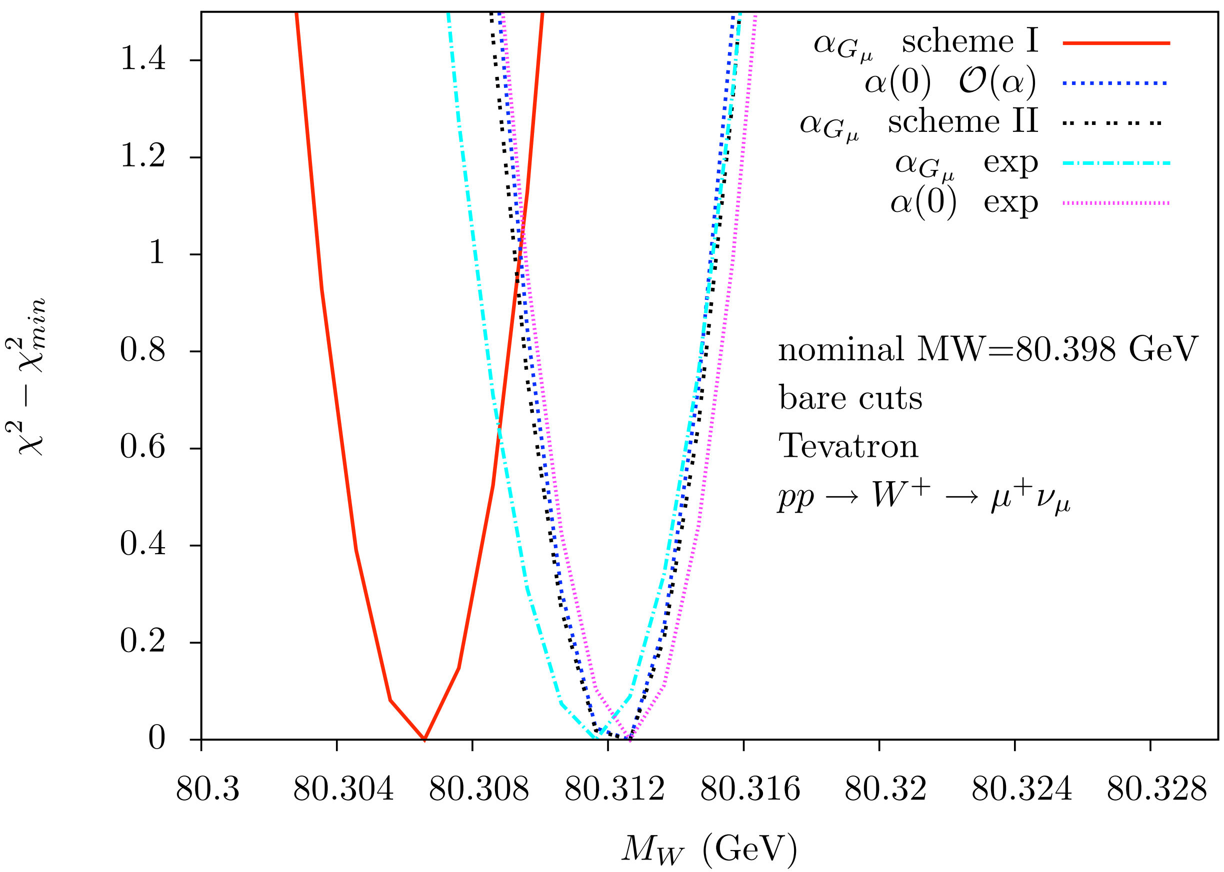

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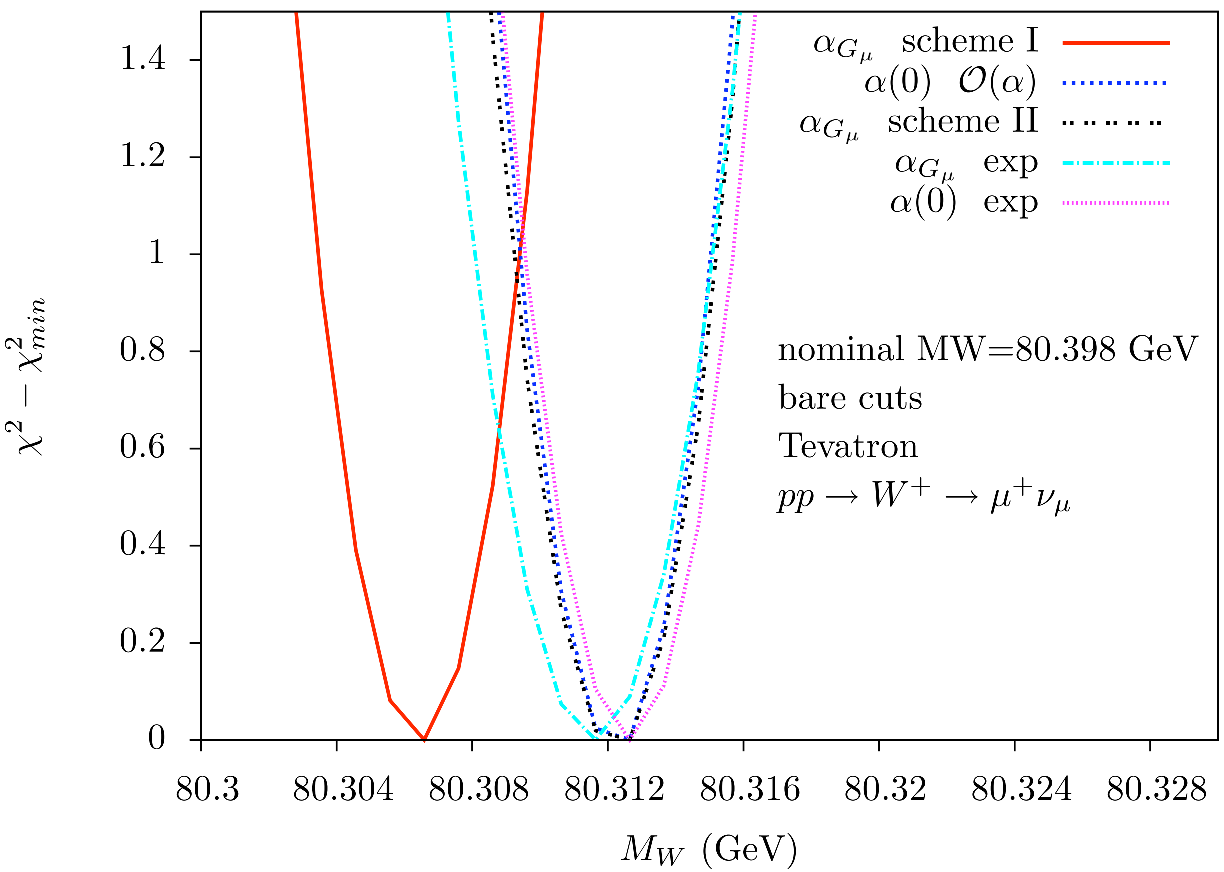
In the Gmu-I scheme
O(α) and best approximation
differ by 5 MeV

In the best approximation
α_0 or Gmu-I schemes
differ by 2 MeV
(different normalization)

EW input schemes

Born templates Gmu scheme with 10 billions of events: maximal accuracy 2 MeV



Good stability of the matched formula against scheme changes

Different schemes may yield at most a change of the χ^2 of the fit

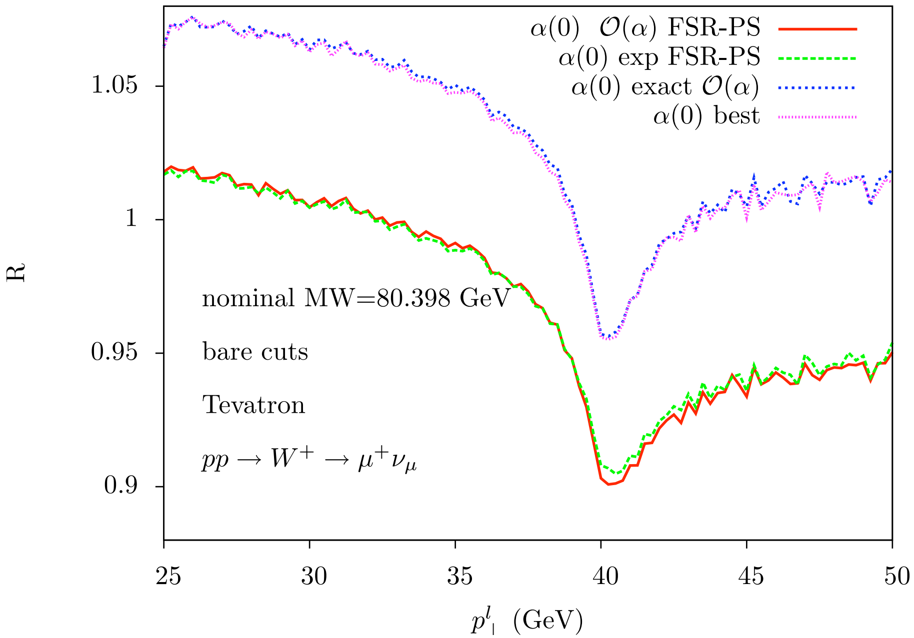
At O(α)
using α_0 or Gmu-I schemes
(different 0- and 1-photon sharing)
yields a change of MW of 6 MeV

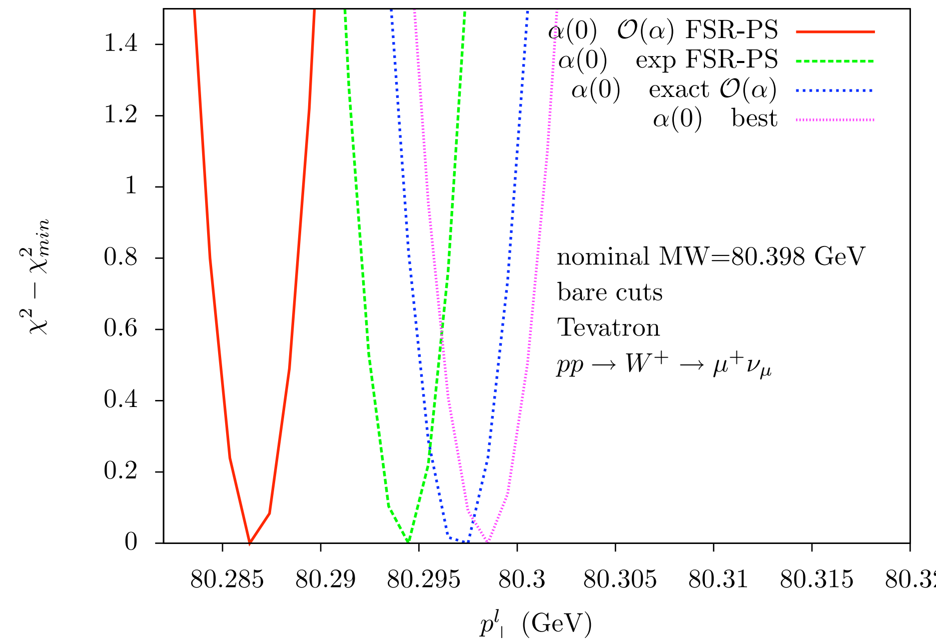
At O(α)
using α_0 or Gmu-II scheme
(same 0- and 1-photon sharing as α_0)
there is no extra shift in MW

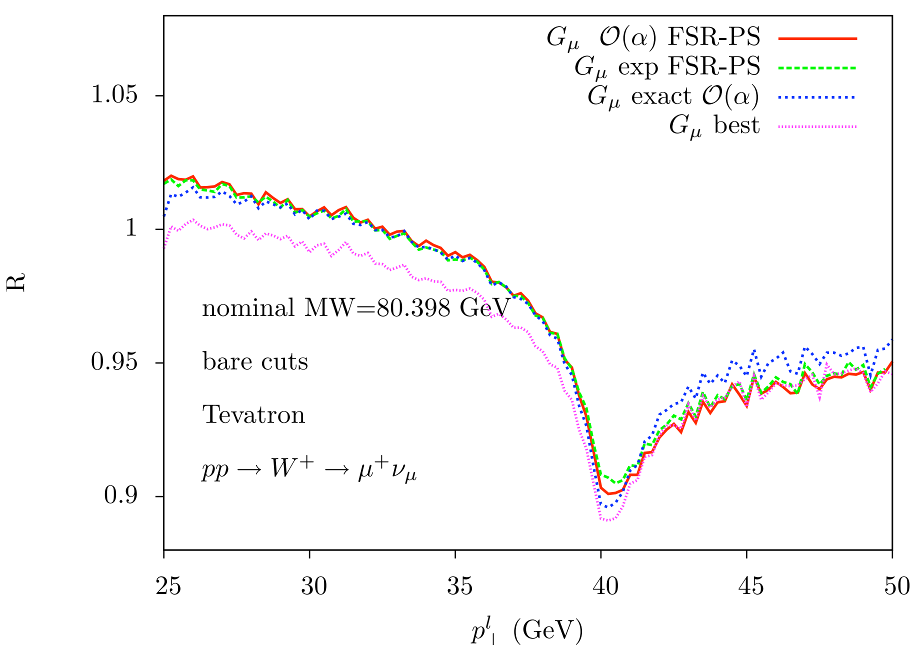
In the Gmu-I scheme
O(α) and best approximation
differ by 5 MeV

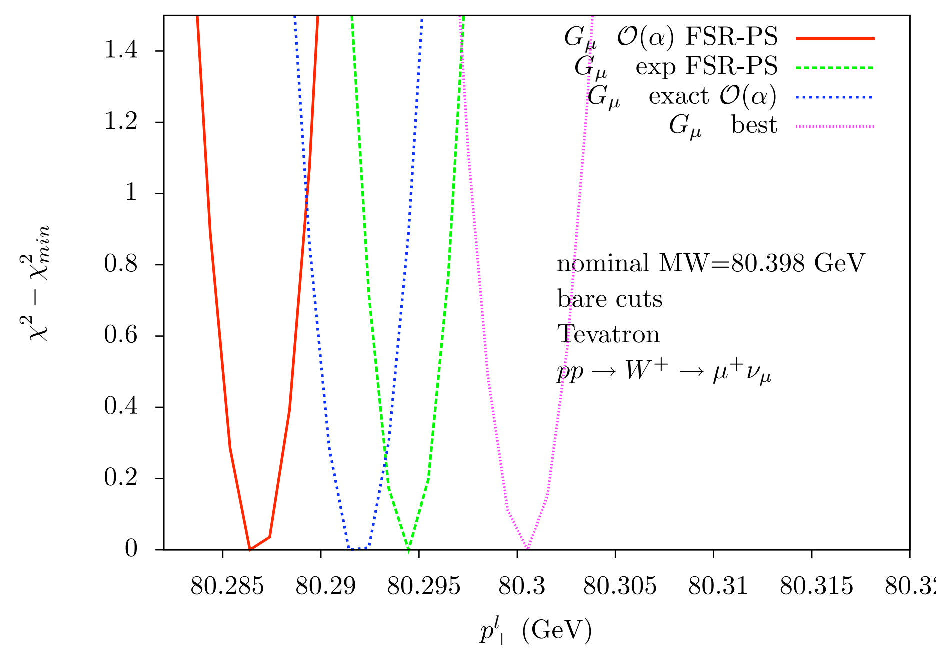
In the best approximation
α_0 or Gmu-I schemes
differ by 2 MeV
(different normalization)

EW input schemes: lepton transverse momentum distribution









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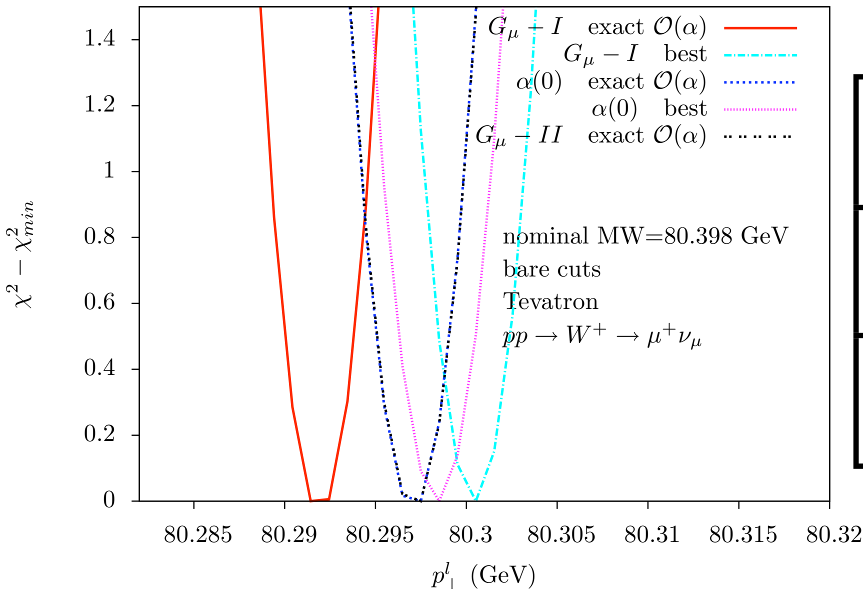


	truncated O(α) QED-PS	all orders QED-PS	exact O(α)	best
α_0 scheme	-112 MeV	-104 MeV	-101 MeV	-100 MeV
Gmu scheme	-112 MeV	-104 MeV	-107 MeV	-98 MeV

Good stability of the matched formula against scheme changes:
the best approximation shows a sensitivity to the scheme choice reduced by a factor 3 w.r.t. to the fixed O(α) result.

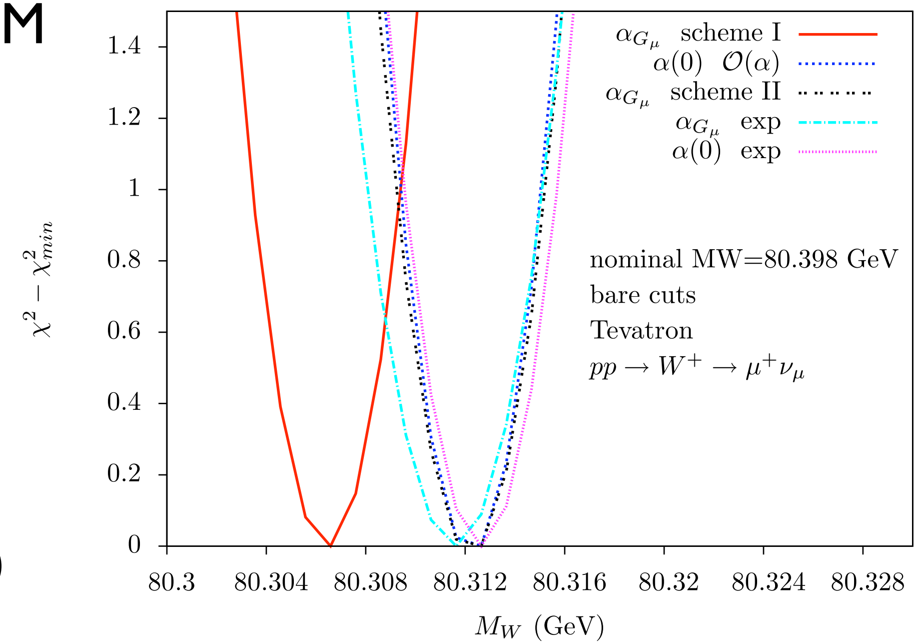
EW input schemes and MW beyond SM

With the SM templates, MW is measured in the SM

A measurement in the MSSM
could in principle yield different results

The difference between SM and MSSM
enters via Δr

The input scheme prescription (Gmu-I vs Gmu-II)
or the fixed order *vs* matched approximations
may or may not yield a different final result



Present uncertainties

CDF uses
Resbos for the QCD simulation
and applies
EW corrections with W/ZGRAD
exact fixed order, no multiple photon

Transverse Mass Fit Uncertainties (MeV)
(CDF, PRL 99:151801, 2007; Phys. Rev. D 77:112001, 2008)

	electrons	*muons*	*common*
W statistics	48	54	0
Lepton energy scale	30	17	17
Lepton resolution	9	3	-3
Recoil energy scale	9	9	9
Recoil energy resolution	7	7	7
Selection bias	3	1	0
Lepton removal	8	5	5
Backgrounds	8	9	0
production dynamics	3	3	3
Parton dist. Functions	11	11	11
QED rad. Corrections	11	12	11
Total systematic	39	27	26
Total	62	60	

Summary of uncertainties

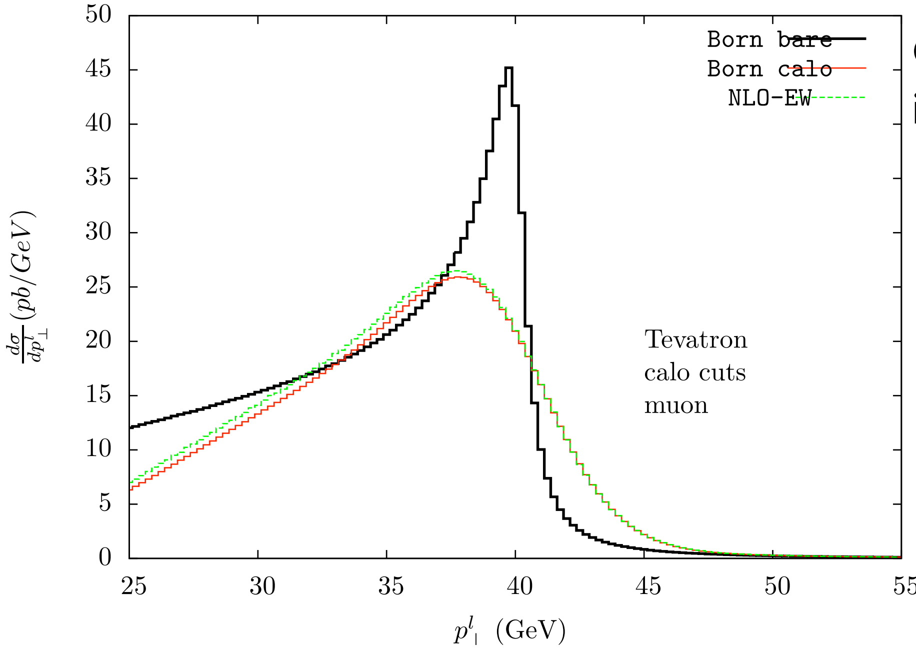
systematic uncertainties

Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not{E}_T$
Experimental			
Electron Energy Scale	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences (material)	4	4	4
Recoil Model	6	12	20
Electron Efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Total	35	37	41
W production and decay model			
PDF	9	11	14
QED	7	7	9
Boson p_T	2	5	2
W model Total	12	14	17
Total	37	40	44
statistical	23	27	23
total	44	48	50

Jan Stark The physics of W and Z bosons, Brookhaven, June 24-25, 2010 46

D0 uses
Resbos for the QCD simulation
and applies
QED corrections with PHOTOS
FSR multiple photon

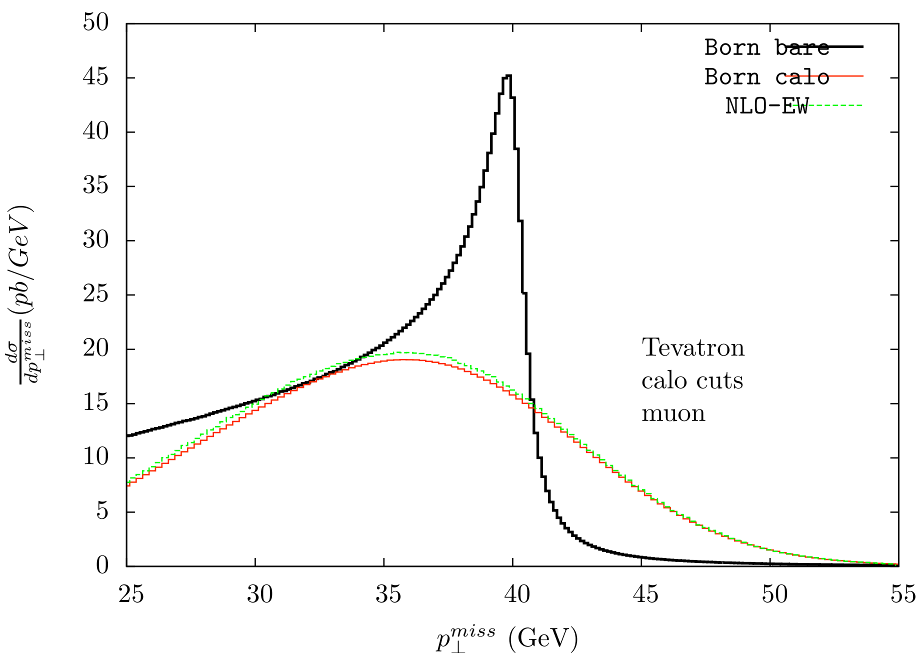
The effect of smearing the momenta and of photon recombination

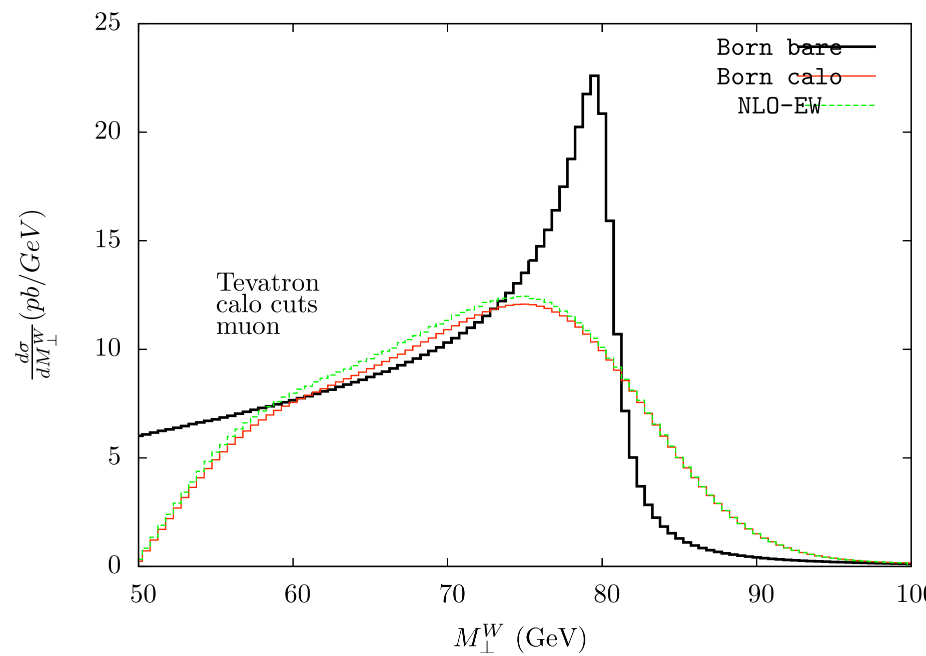


Calorimetric energy deposit
is not pointlike but approximated. by gaussian distribution
→ smearing of the lepton momenta

Photons “close” to the emitting lepton are hardly
disentangled: they are rather merged with the lepton
need to simulate these events by adding photon and
lepton momenta to yield an effective lepton
Effective partial KLN cancellation of FSR collinear logs

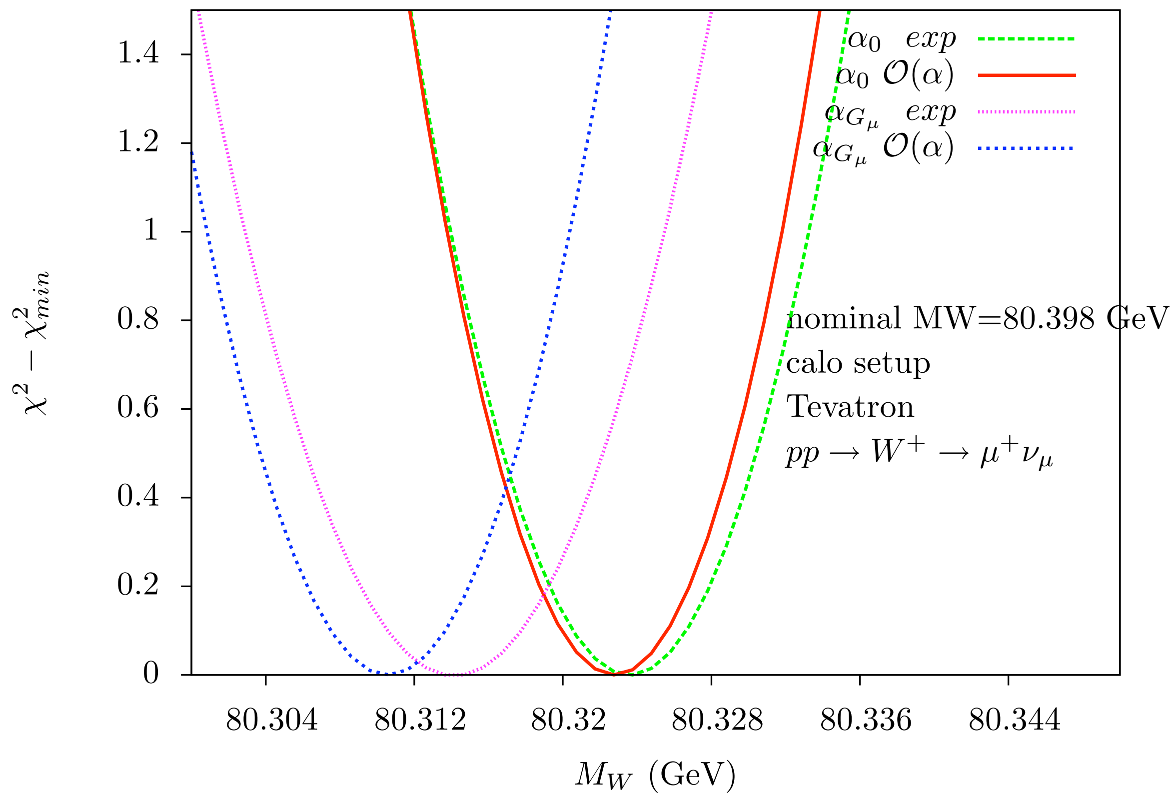
How do the effects of higher order corrections survive
after smearing + recombination?
Effects measured with smeared Born templates





EW corrections impact after smearing and recombination

calo Born templates with 1 billions of events: maximal accuracy 4 MeV
calo setup: smeared lepton momenta (at tree level no recombination)



In the α_0, best w.r.t. fixed $O(\alpha)$ results differ by 1 MeV
In the Gmu-I scheme best w.r.t. fixed $O(\alpha)$ results differ by 4 MeV

Conclusions

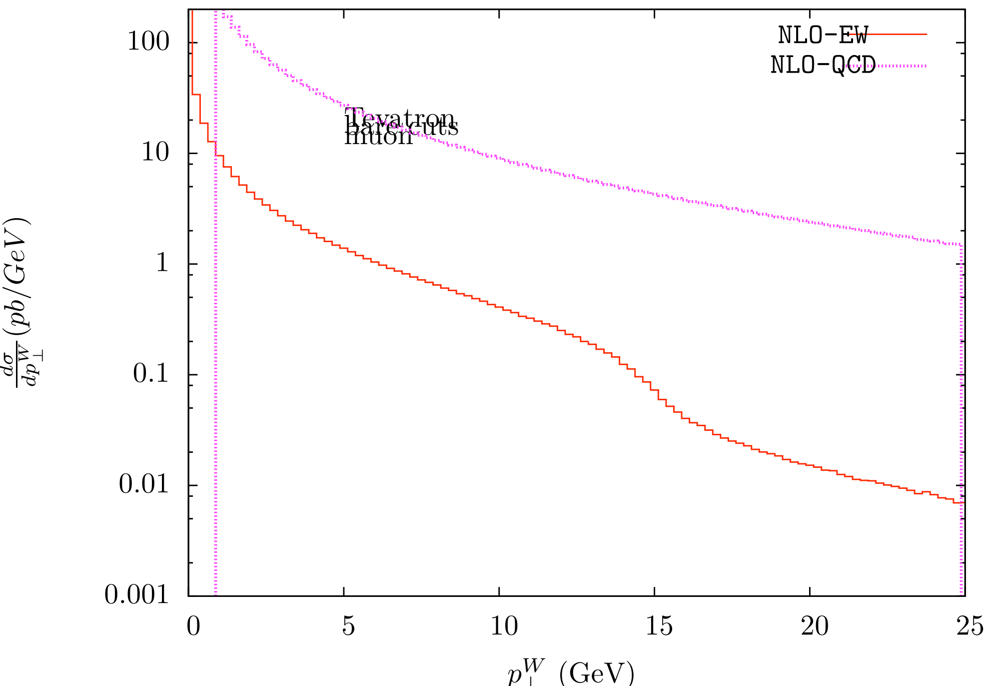
Final state one-photon emission yields the bulk of the ME shift due to EW corrections

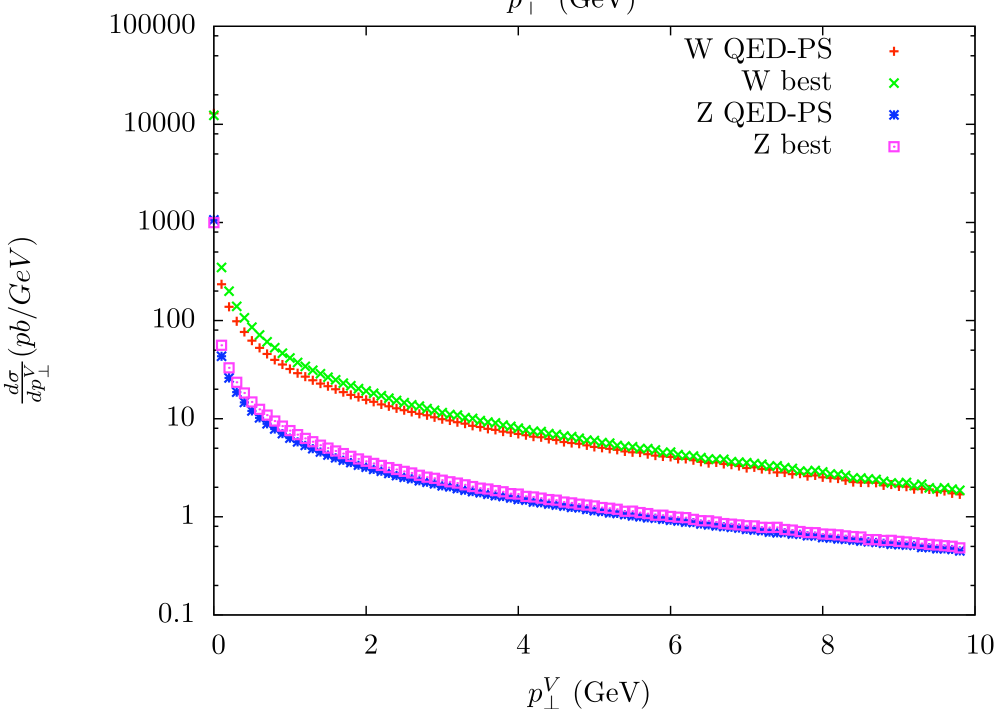
The effect of the inclusion of multiple photon radiation
is about 10% of the $O(\alpha)$ emission and with opposite sign

The effect of the EW, sub-leading $O(\alpha)$ terms is between 5 and 10% of the leading terms
and depends on the chosen EW input scheme

The matched formula by HORACE
- includes the exact $O(\alpha)$ corrections and the multiple photon radiation
- shows a good stability under EW input scheme changes (shift at the 2 MeV level)

QED induced W(Z) transverse momentum





The uncertainty on ptW directly translates into an uncertainty on the final MW value.

Photon radiation yields a tiny gauge boson transverse momentum.

This momentum is different in the CC and NC channels because of the different flavor structure.

The "non-final state" component differs in the 2 cases by 54 (Z) - 33 (W) = 21 MeV

$\langle p_\perp^V \rangle =$

Z	FSR-PS	0.409	GeV
Z	best	0.463	GeV
W	FSR-PS	0.174	GeV
W	best	0.207	GeV

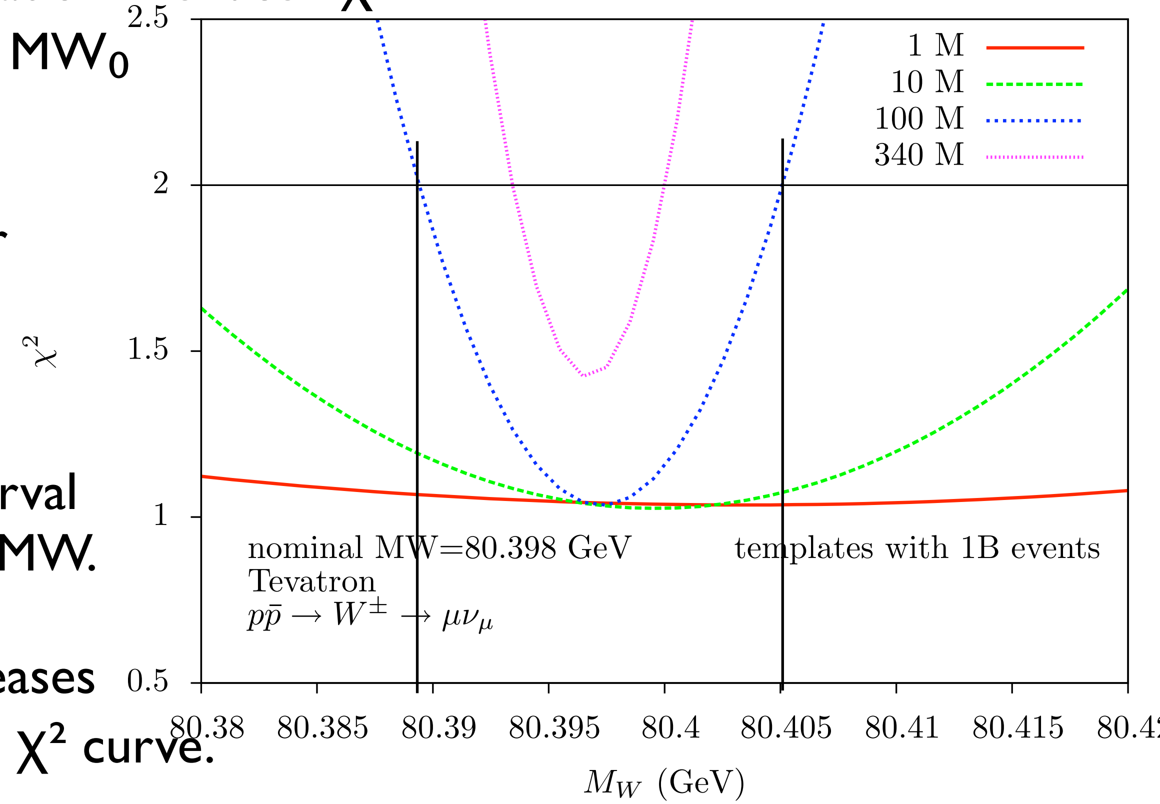
The fit of the non perturbative QCD parameters is done on the Z transverse momentum and it is necessary to properly remove the EW corrections to the NC channel

In the simulation of the CC channel the relevant EW corrections are then applied

Validation of the template-fitting procedure

In this template-fitting procedure,
the reduced χ^2 is never close to one because the distributions are "by construction" different

Fit pseudo-data computed in Born approximation reduced $\chi^2 \sim 1$
The fit should exactly find the nominal value MW_0
used to generate the Born pseudo-data



The accuracy of the fit depends on the error
associated to each bin of the pseudo-data

In the case of Born pseudo-data,
the $\Delta\chi^2 = 1$ MW points fix the 68% C.L. interval
associated to the estimate of the preferred MW.

A larger number of pseudo-data events increases
the accuracy of the prediction, shrinking the χ^2 curve.

The templates are not smooth functions, but are generated with a Montecarlo
They also suffer of statistical fluctuations.
We can not arbitrarily increase the number of pseudo-data events,
because we are limited by the number of events used to generate the templates

EW results and tools

$\mathcal{O}(\alpha_S^2) \approx \mathcal{O}(\alpha_{\rm em})$ → Need to worry about EW corrections

W production

Pole approximation	D.Wackeroth and W. Hollik, PRD 55 (1997) 6788	
	U.Baur et al., PRD 59 (1999) 013002	
Exact O(alpha)	V.A. Zykunov et al., EPJC 3 (2001) 9	
	S. Dittmaier and M. Krämer, PRD 65 (2002) 073007	DK
	U. Baur and D.Wackeroth, PRD 70 (2004) 073015	WGRAD2
	A. Arbuzov et al., EPJC 46 (2006) 407	SANC
	C.M.Carloni Calame et al., JHEP 0612:016 (2006)	HORACE
Photon-induced processes	S. Dittmaier and M. Krämer, Physics at TeV colliders 2005	
	A. B.Arbuzov and R.R.Sadykov, arXiv:0707.0423	
Multiple-photon radiation	C.M.Carloni Calame et al.,PRD 69 (2004) 037301, JHEP 0612:016 (2006)	HORACE
	S.Jadach and W.Placzek, EPJC 29 (2003) 325	WINHAC
	S.Brensing, S.Dittmaier, M. Krämer and M.M.Weber, arXiv:0708.4123	DK

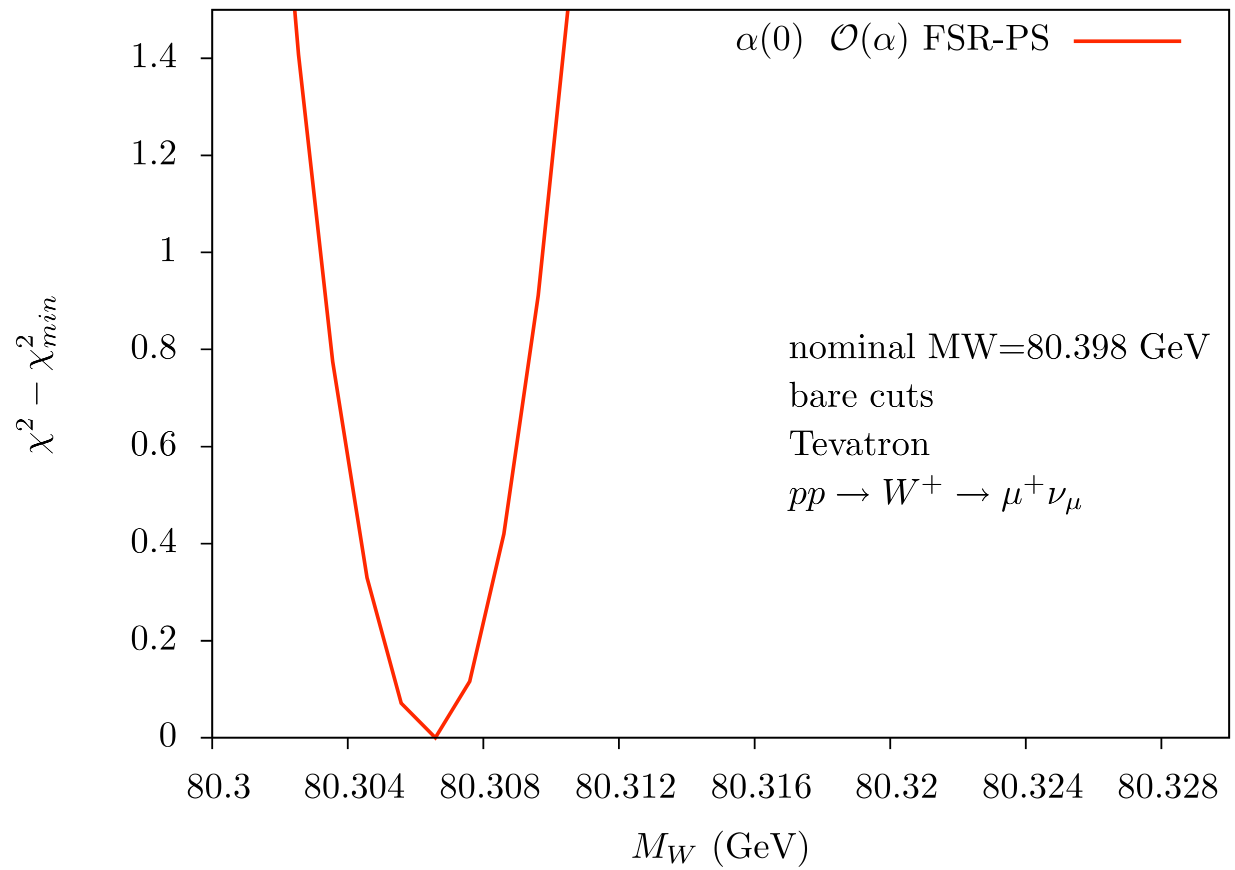
Z production

only QED	U.Baur et al., PRD 57 (1998) 199	
Exact O(alpha)	U.Baur et al., PRD 65 (2002) 033007	ZGRAD2
	V.A. Zykunov et al., PRD75 (2007) 073019	
	C.M.Carloni Calame et al., JHEP 0710:109 (2007)	HORACE
Multiple-photon radiation	C.M.Carloni Calame et al., JHEP 0505:019 (2005)	HORACE
	JHEP 0710:109 (2007)	

EW higher orders in the α_0 scheme

Born templates α_0 scheme with 10 billions of events: maximal accuracy 2 MeV

The FSR QED Parton Shower
truncated at O(α)
yields a change of MW of -92 MeV

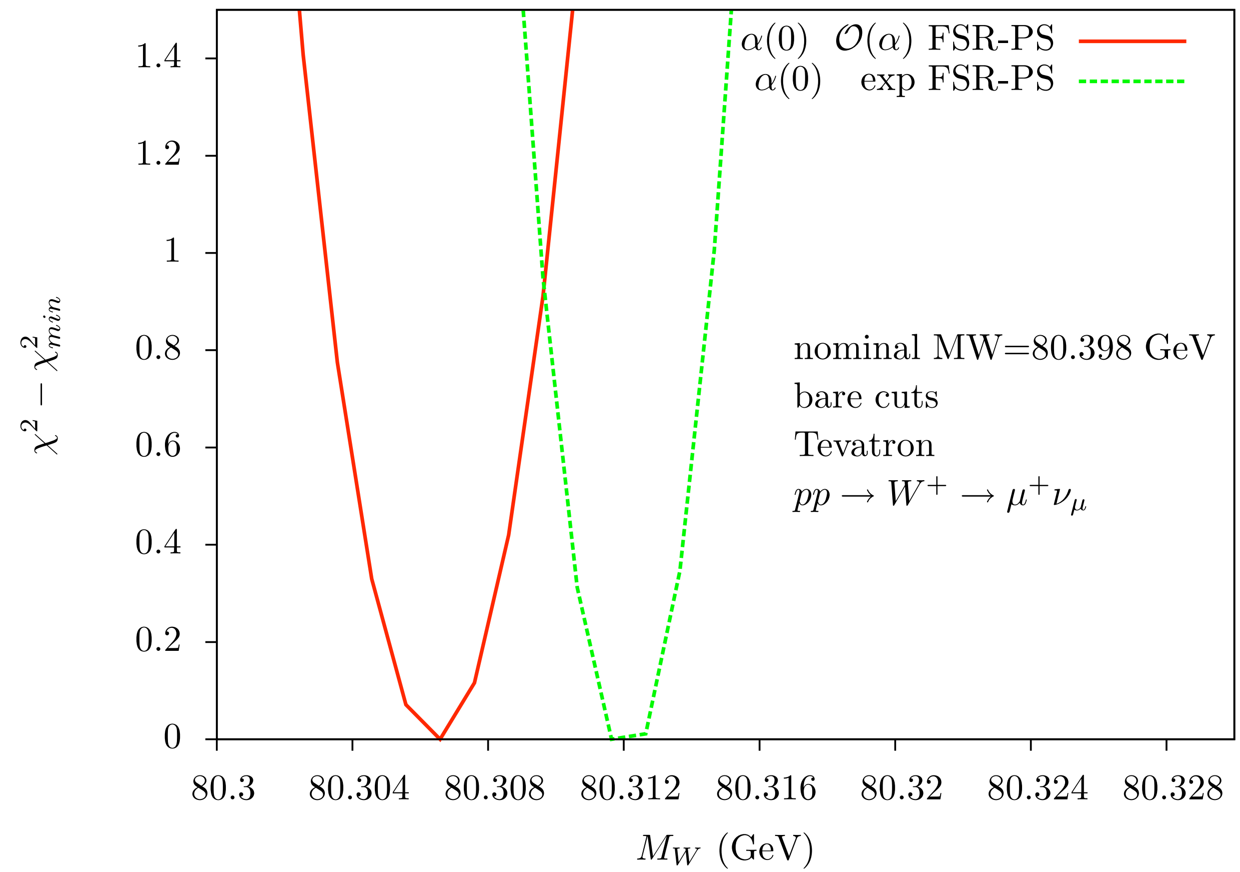


EW higher orders in the α_0 scheme

Born templates α_0 scheme with 10 billions of events: maximal accuracy 2 MeV

The FSR QED Parton Shower
truncated at $O(\alpha)$
yields a change of MW of -92 MeV

The FSR QED Parton Shower
to all orders
yields an additional shift of +6 MeV



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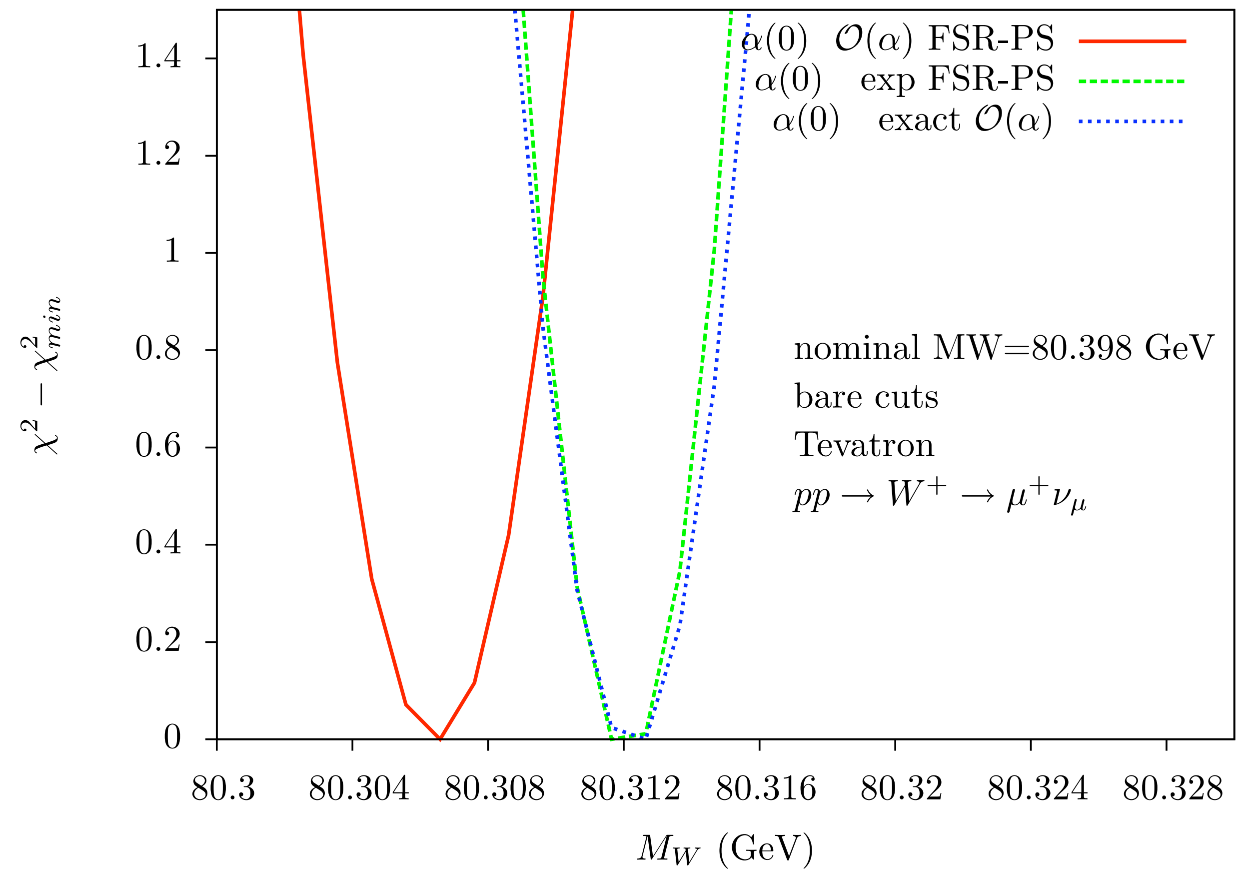
The exact matrix element at O(α)
and
O(α) FSR QED PS prediction
differ by +6 MeV (subleading EW)



EW higher orders in the α_0 scheme

Born templates α_0 scheme with 10 billions of events: maximal accuracy 2 MeV

The FSR QED Parton Shower
truncated at $O(\alpha)$
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The FSR QED Parton Shower
to all orders
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The exact matrix element at $O(\alpha)$
and
$O(\alpha)$ FSR QED PS prediction
differ by +6 MeV (subleading EW)

The best matched results
$O(\alpha)$ + full QED Parton Shower
yields no shift (0 MeV)
w.r.t. the fixed order exact $O(\alpha)$
(which is based on a different formula)
This results is true in the α_0 scheme