UNIVERSITÀ DEGLI STUDI
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Precision extraction of MW from observables at hadron colliders

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HO10 Theory Institute
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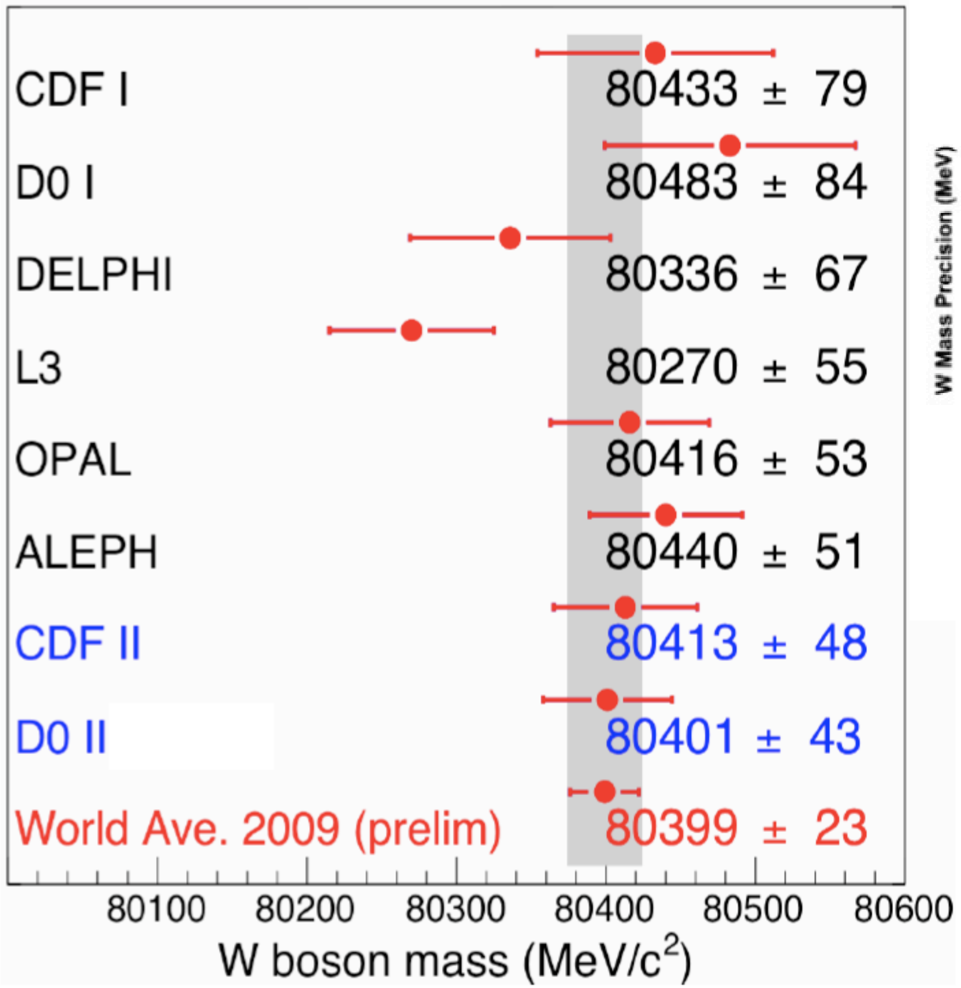
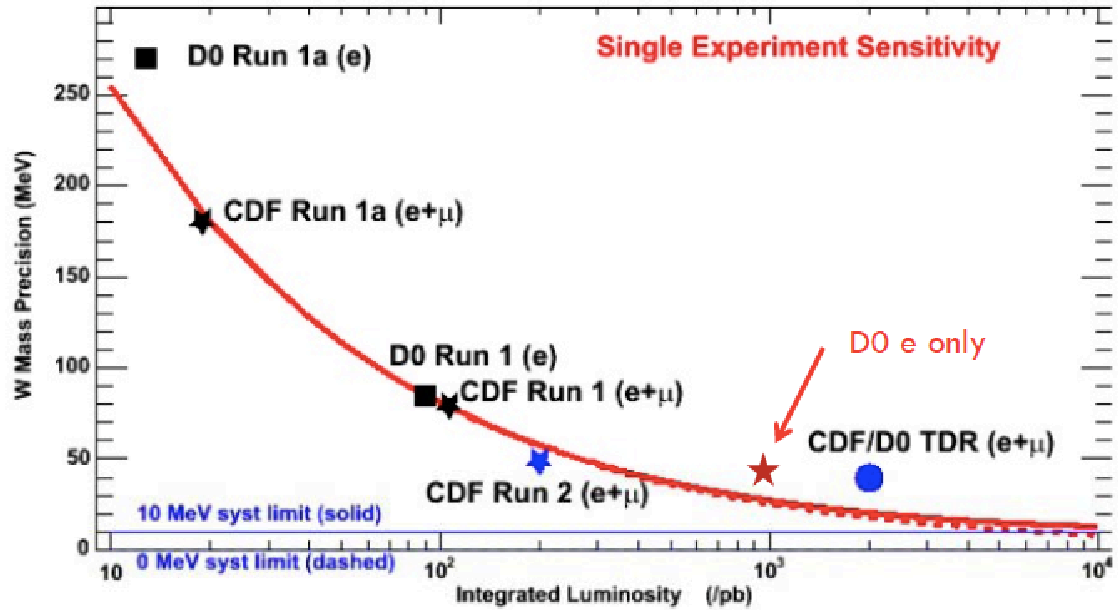
Thanks to: G.Bozzi, C.M.Carloni Calame,
G. Ferrera, S.Alioli, E. Re, A.Mueck, D.Wackeroth
all the other participants to the W mass workshop

Relevance of a precise W mass measurement





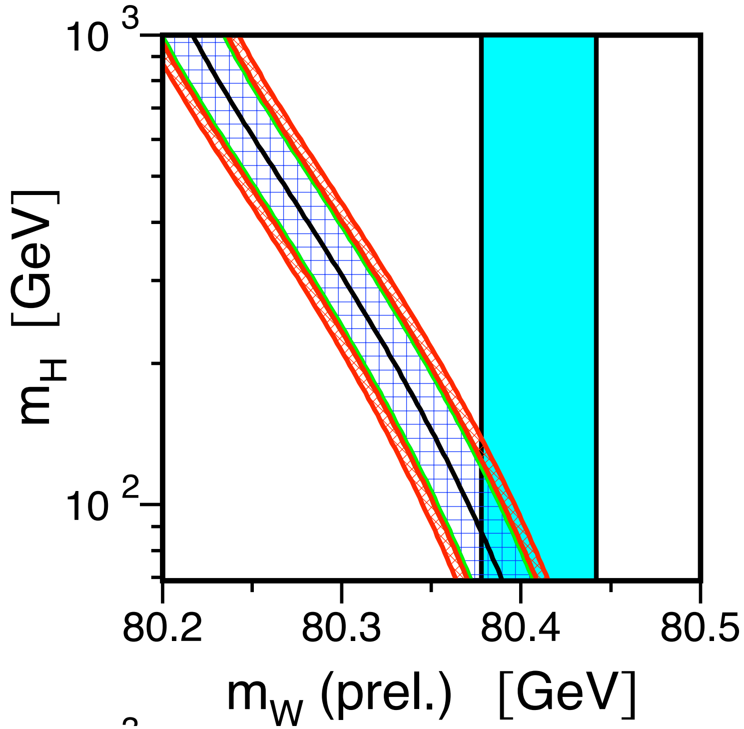
Tevatron has collected 600.000 $W \to \mu\nu$ events

Final Tevatron error on MW:~15 MeV ? J.Zhu, arXiv:0907.3239

LHC with 1 fb^{-1} and a total (no cuts) xsec of ~10 nb will collect 10 M of Ws
potential for an even more accurate measurement at the LHC?

Relevance of a precise W mass measurement

Sensitivity to the precise value of the Higgs boson mass or e.g. to SUSY particles

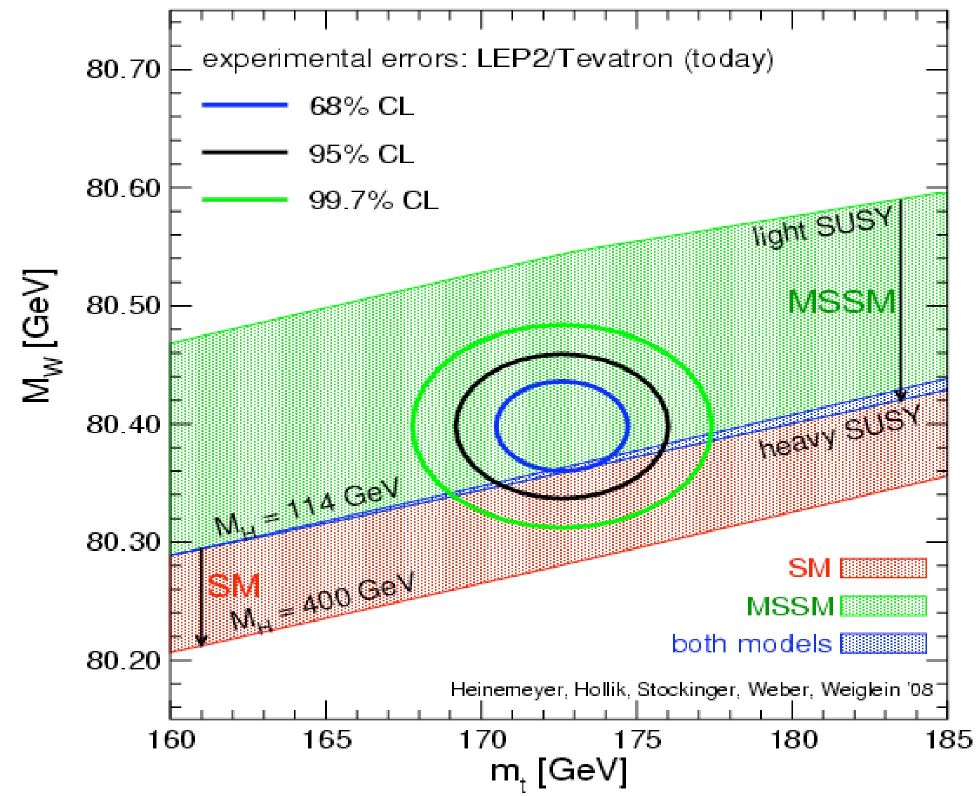


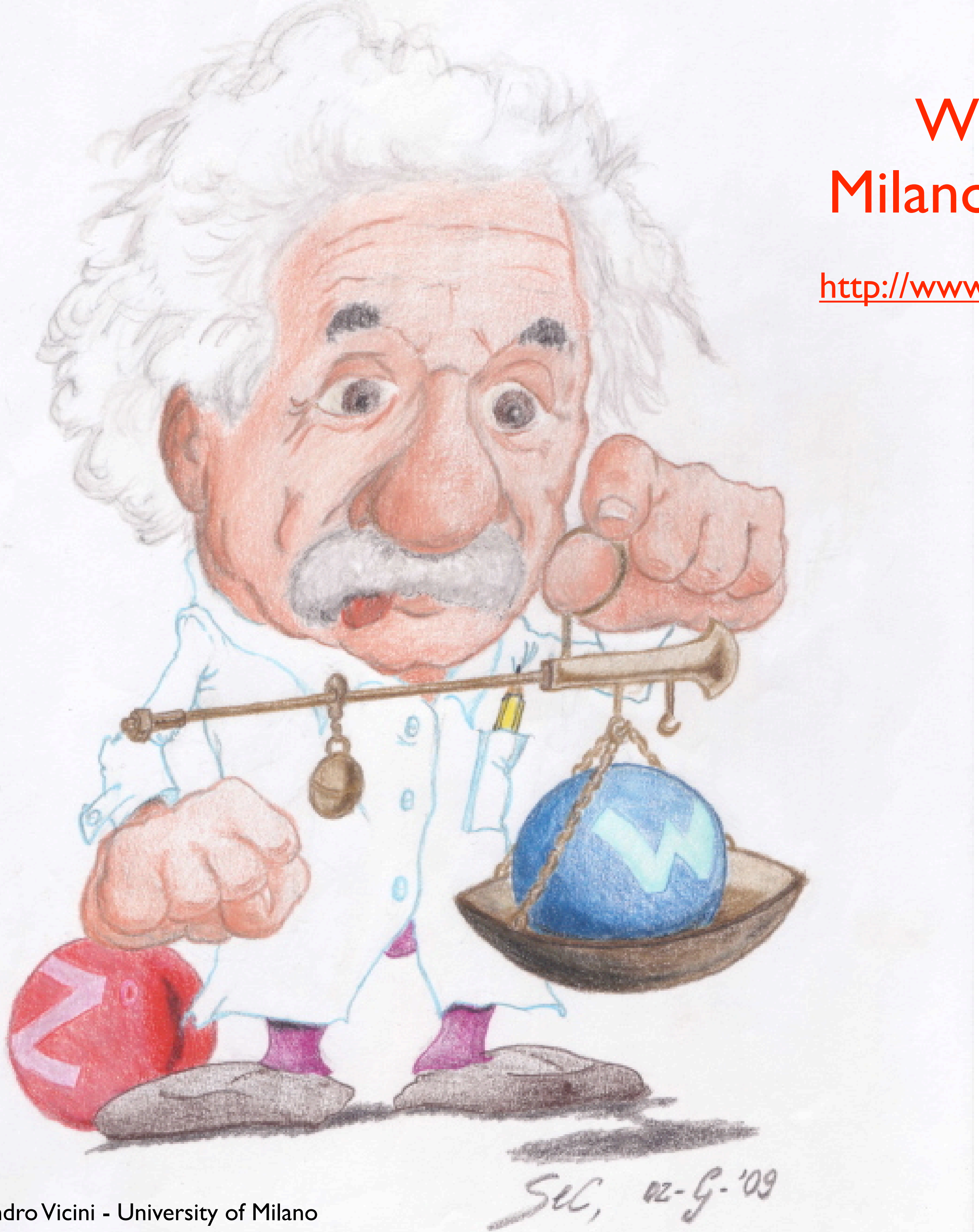
Awramik, Czakon, Freitas, Weiglein Degrassi, Gambino, Passera, Sirlin

$$M_W = M_W^0 - 0.0581\,\ln\left(\frac{M_H}{100\text{ GeV}}\right) - 0.0078\ln^2\left(\frac{M_H}{100\text{ GeV}}\right) - 0.085\left(\frac{\alpha_s}{0.118}-1\right)$$
$$- 0.518\left(\frac{\Delta\alpha_{had}^{(5)}(M_Z^2)}{0.028}-1\right) + 0.537\left(\left(\frac{m_t}{175\text{ GeV}}\right)^2-1\right)$$

$$m_W = m_W\left(\Delta r^{SM,MSSM}\right)$$

$$\Delta r^{SM,MSSM} = \Delta r^{SM,MSSM}\left(m_t, m_H, m^{SUSY}, \ldots\right)$$





W mass workshop
Milano, March 17-18 2009

http://wwwteor.mi.infn.it/~vicini/wmass.html

Outline

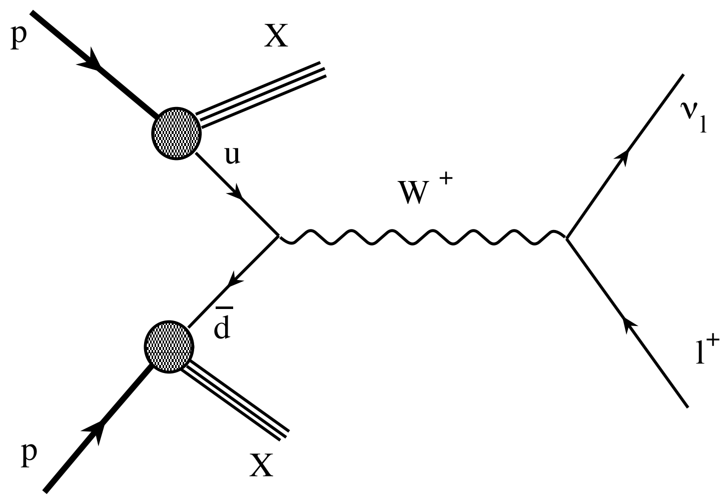
- measurement of MW (probably) at the 15 MeV level   at the Tevatron
- measurement of this pseudo-observable heavily involves theoretical ingredients

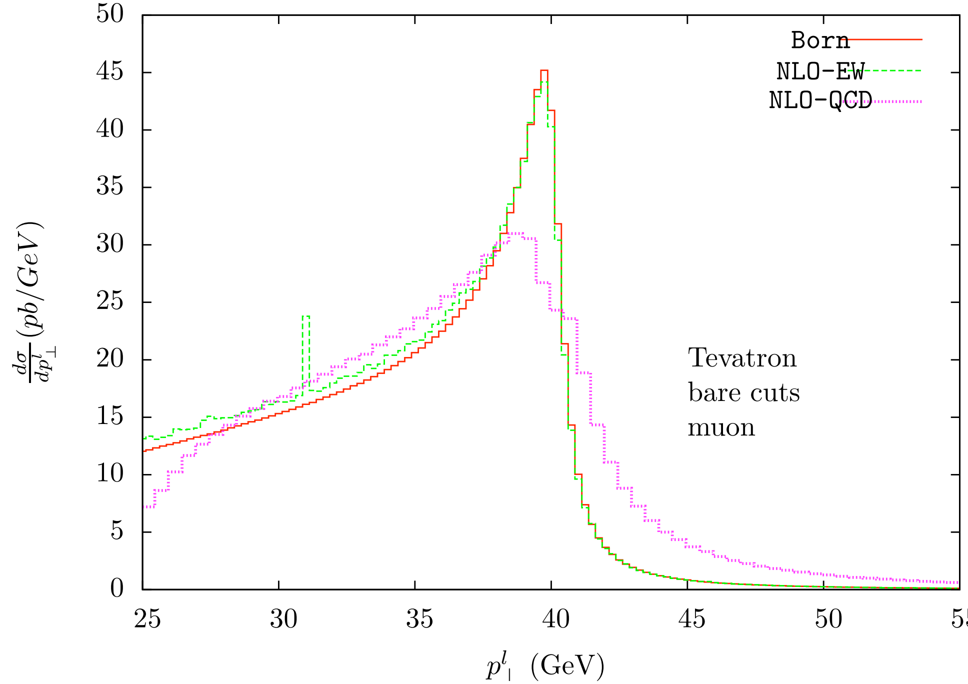
- classification of the impact of different classes of radiative corrections
  in terms of shifts of the final value of MW
- estimate of different sources of theoretical uncertainty
  to obtain a final theoretical systematic error on MW

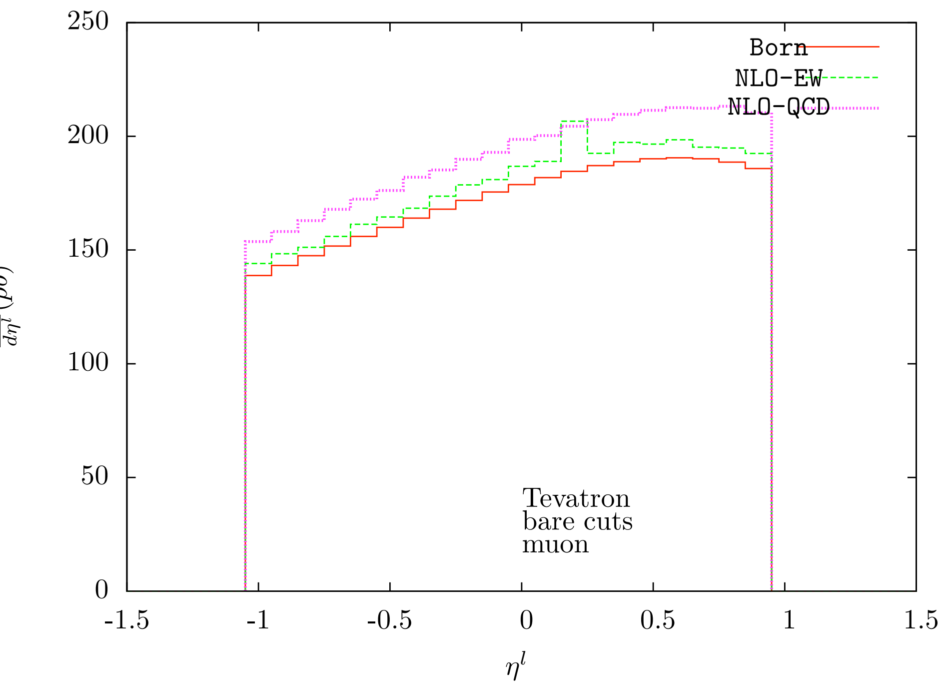
- fixed order calculations provide the first basic estimates
  but
  a realistic simulation shows which effects survive after e.g.
  convolution with multiple gluon/photon emission
  smearing of lepton momenta or photon recombination

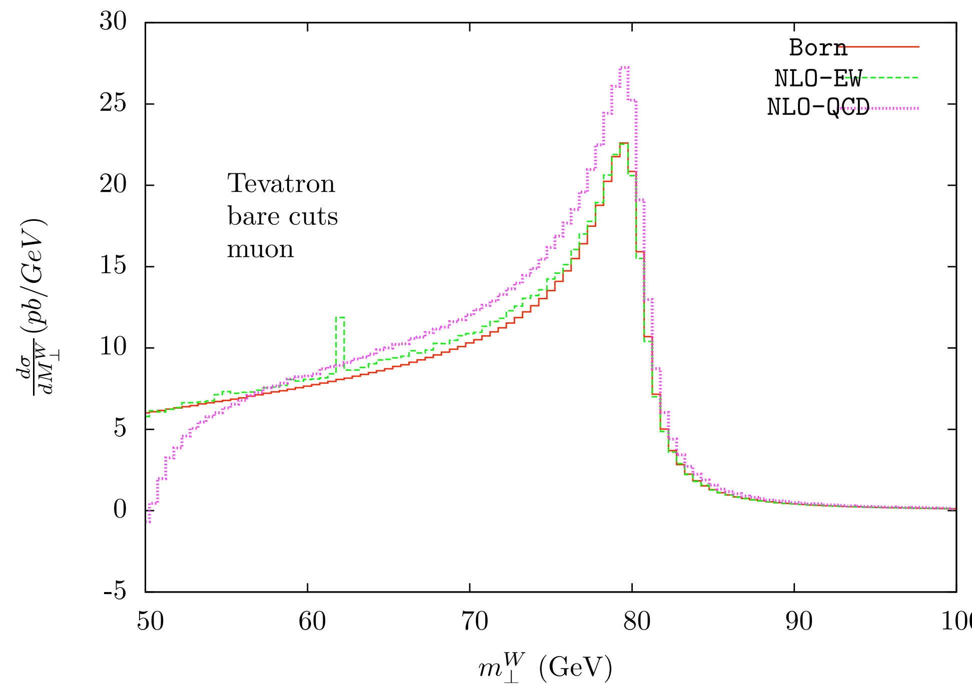
  - change of EW input scheme, use of factorized expressions, higher orders
  - combination of QCD+EW corrections
  - QCD corrections by different codes
  - PDF uncertainties

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

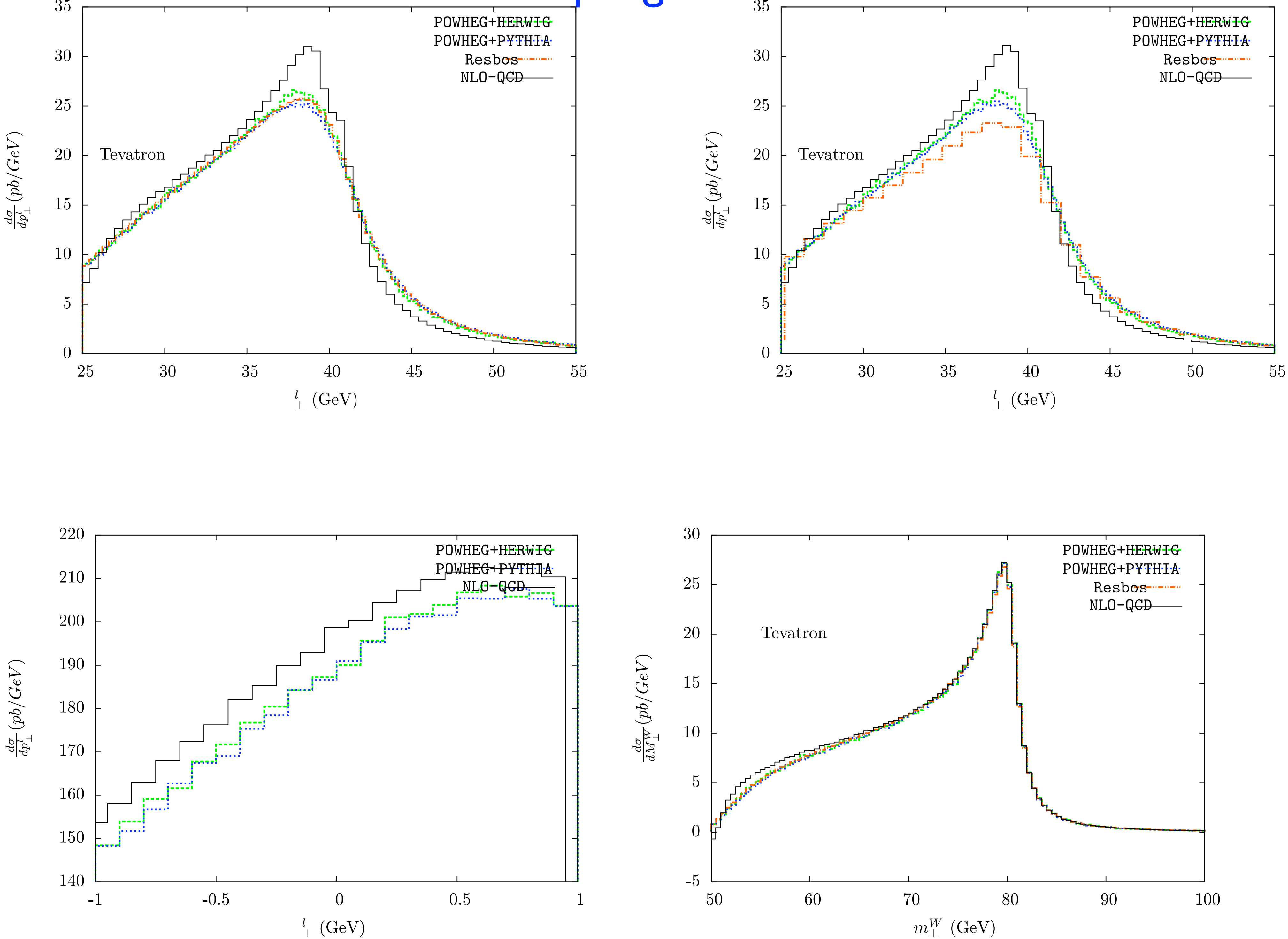




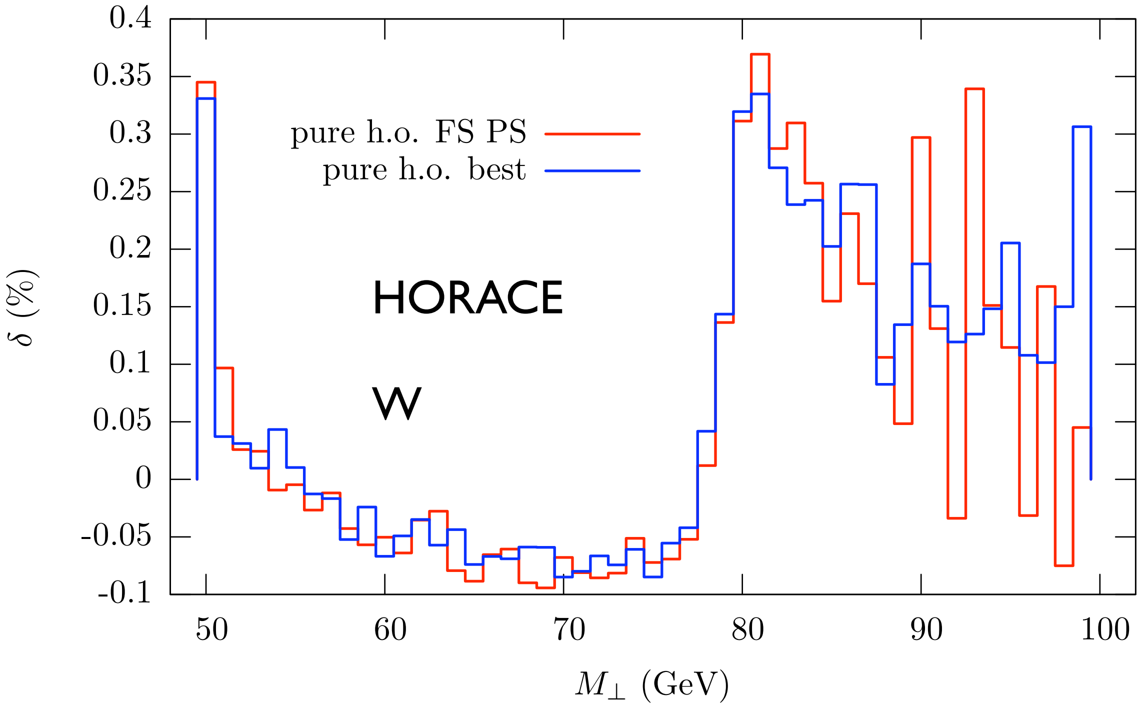




The effect of initial state multiple gluon emission



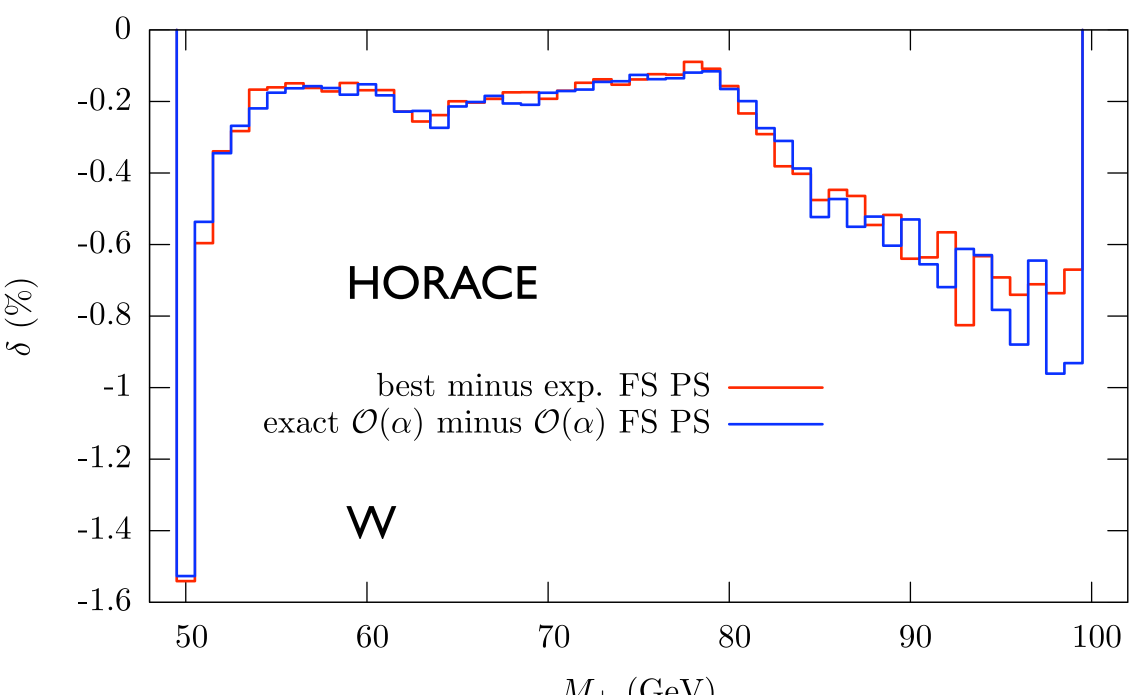
The effect of multiple photon emission and of subleading EW terms

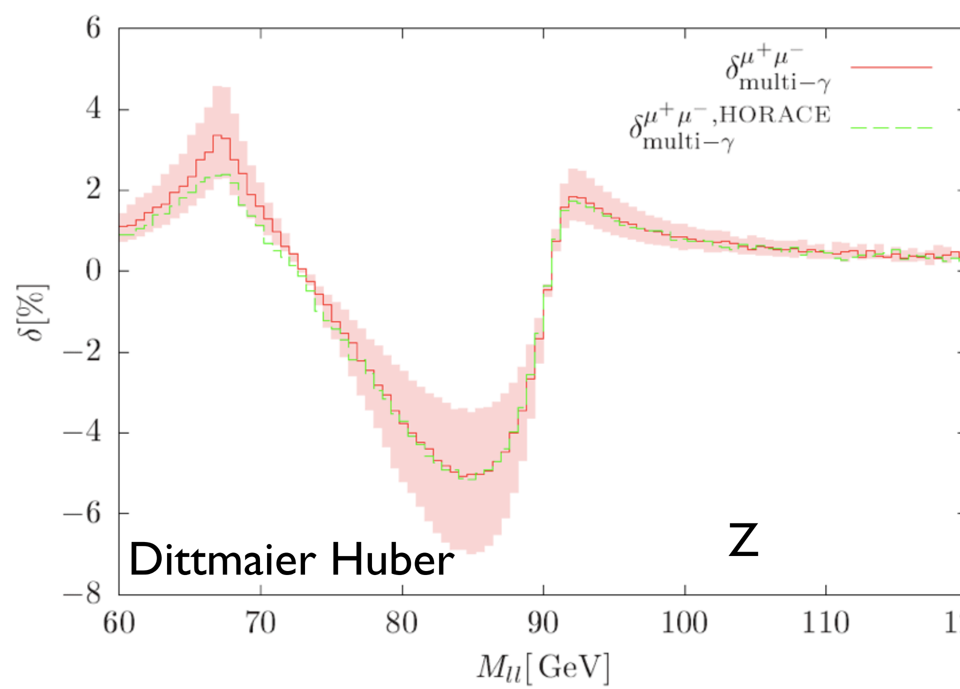


Effects of multiple photon emission studied

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)

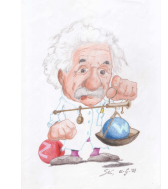
The W mass is defined starting from the pole, in the complex plane, of the W propagator

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.

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

Radiative corrections and simulation tools: QCD matching



ALPGEN
M.L.Mangano et al., JHEP **0307**, 001 (2003)

LO-QCD matched with HERWIG QCD Parton Shower   MLM prescription

SHERPA
F. Krauss et al., JHEP **0507**, 018 (2005)

LO-QCD matched with QCD Parton Shower   CCKW algorithm

MADGRAPH/MADEVENT
T.Stelzer, W.F.Long, Comp.Phys.Commun.81 (1994) 357, F.Maltoni, T.Stelzer, JHEP 02 (2003) 027

LO-QCD matched with QCD Parton Shower   MLM prescription

Resbos
C.Balazs and C.P. Yuan, Phys.Rev. **D56** (1997) 5558

NLO-QCD matched with resummation of NLL and NNLL of log(p_T^W/m_W)

MC@NLO
S. Frixione and B.R.Webber., JHEP **0206**, 029 (2002)

NLO-QCD matched with the HERWIG QCD Parton Shower

POWHEG
P.Nason, JHEP **0411** 040 (2004)   S.Frixione, P.Nason, C.Oleari, JHEP **0711** 070 (2007)

NLO-QCD matched with any vetoed QCD Parton Shower

BCDFG
G.Bozzi, S.Catani, D.De Florian, G.Ferrera, M.Grazzini, Nucl.Phys.**B815** (2009) 174

NLO-QCD matched with resummation of NLL of log(p_T^W/m_W)
(factorized prescription, explicit dependence on the resummation scale)

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) JHEP 0710:109 (2007)	HORACE

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

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

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 $MW-MW_0$ 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

Validation of the template-fitting procedure

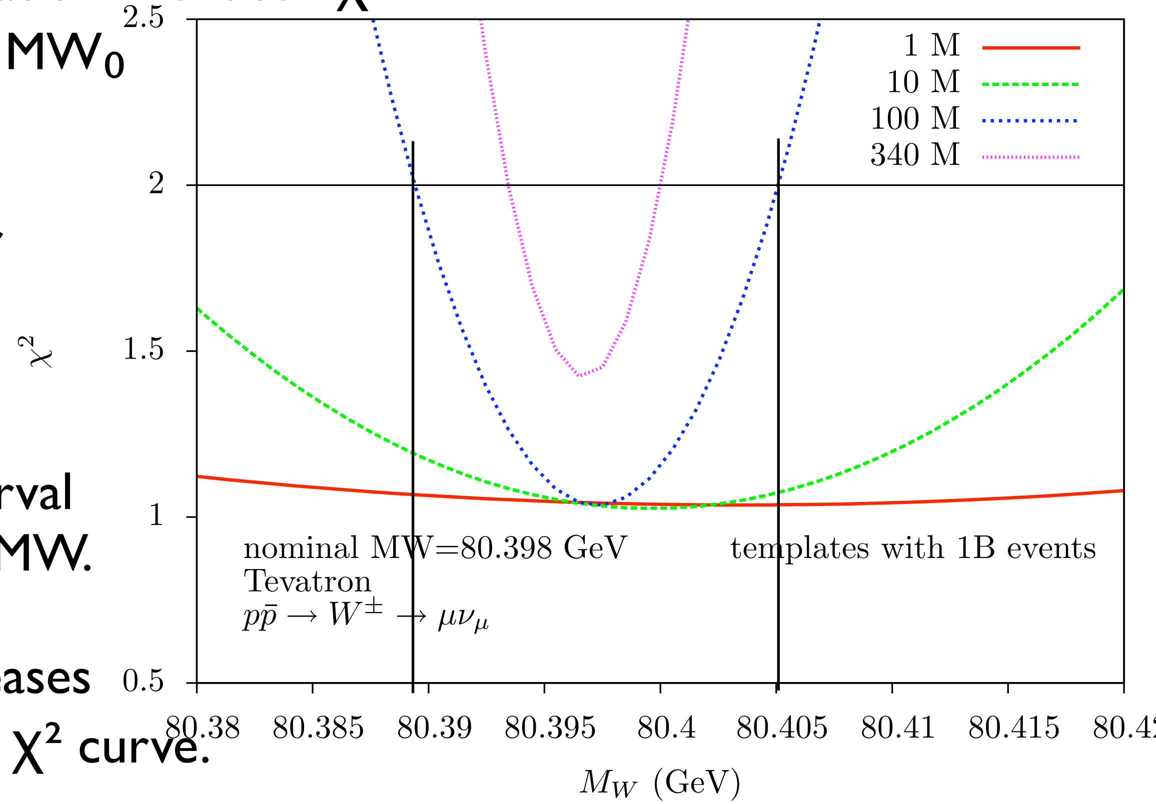
In this template-fitting procedure,
the reduced χ^2 is never close to one because the distributions are "by construction" different

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

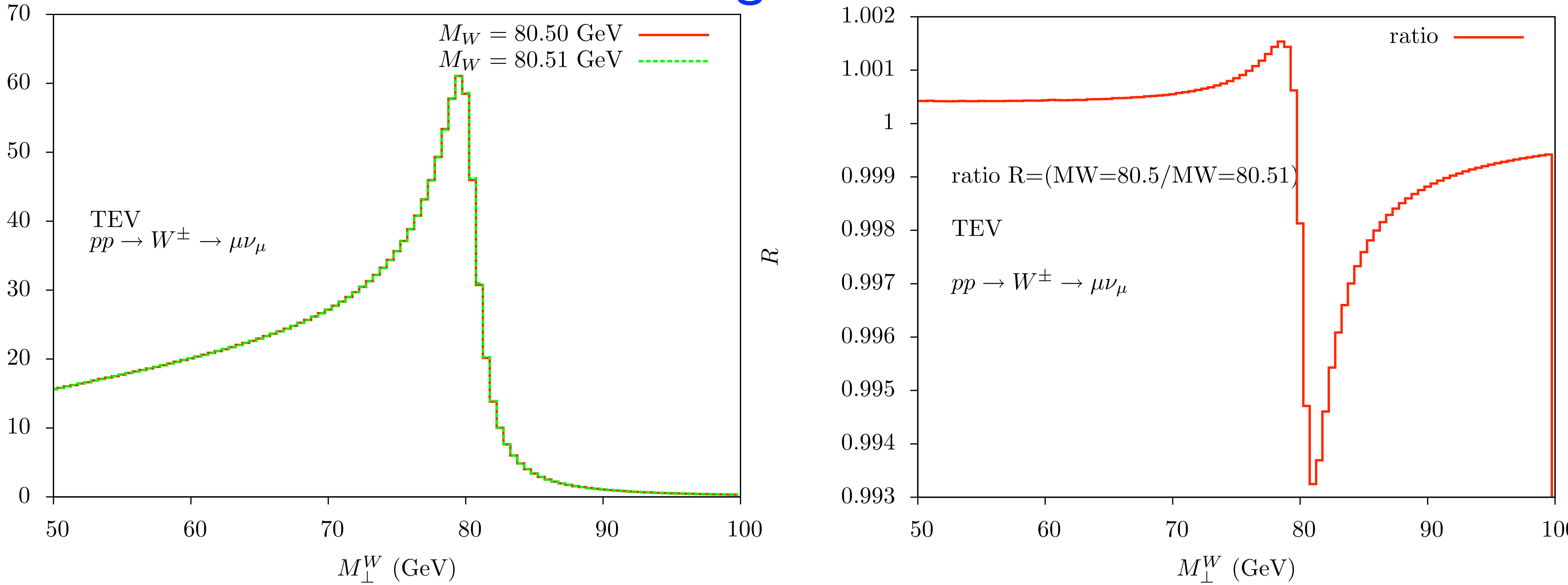
In the case of Born pseudo-data,
the $\Delta\chi^2 = 1$ MW points fix the 68% C.L. interval
associated to the estimate of the preferred MW.

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

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 HORACE formula and the input-scheme dependence

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

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

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

This formula has to be compared with a fixed order expression, where the precise sharing of 0- and 1-photon events can be slightly different

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

The HORACE formula and its impact on the MW measurement

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

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

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,

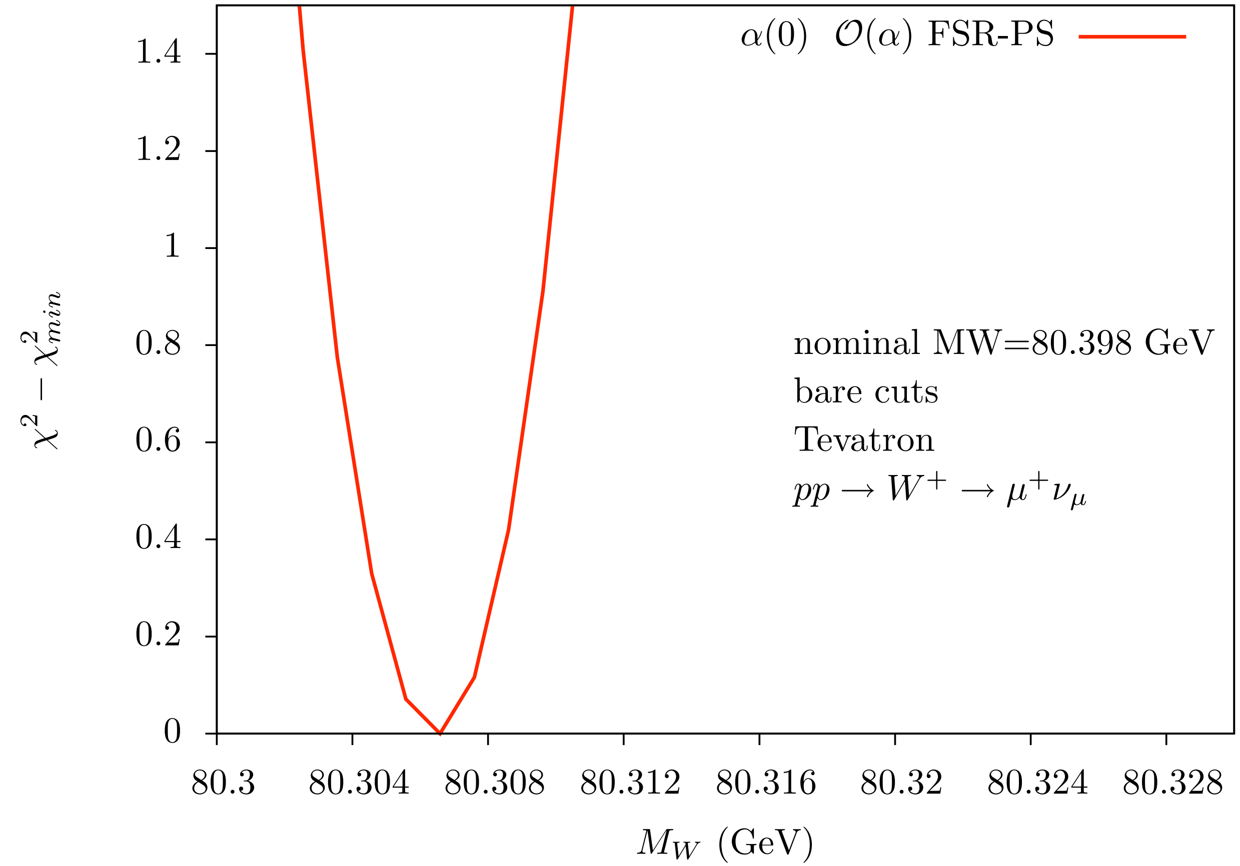
Therefore the χ^2 of the fit that exhibits a corresponding variation,

but also the precise MW determination is affected.

EW higher orders in the α_0 scheme

Born templates 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



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The FSR QED Parton Shower
truncated at $O(\alpha)$
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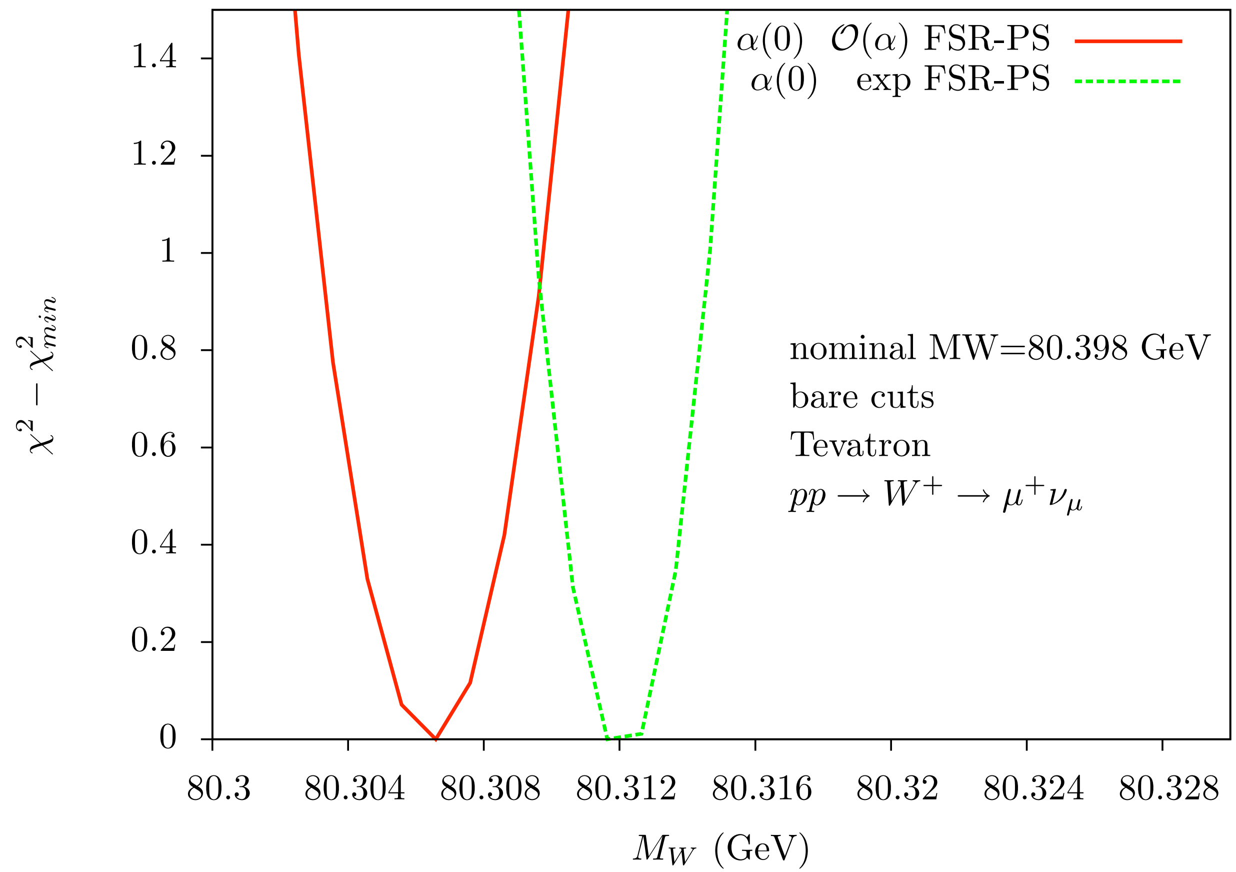
The FSR QED Parton Shower
to all orders
yields an additional shift of +6 MeV



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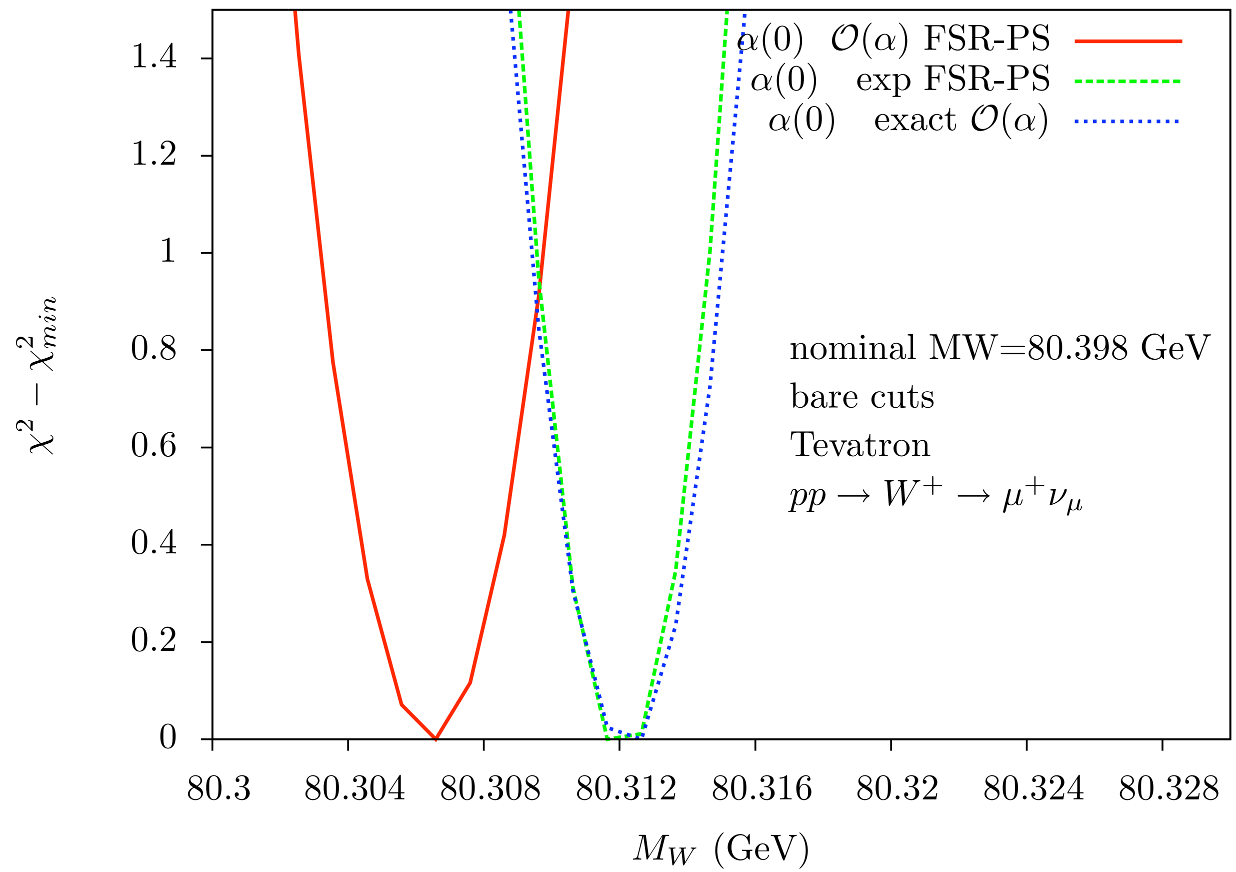
The exact matrix element at O(α)
and
O(α) FSR QED PS prediction
differ by +6 MeV (subleading EW)



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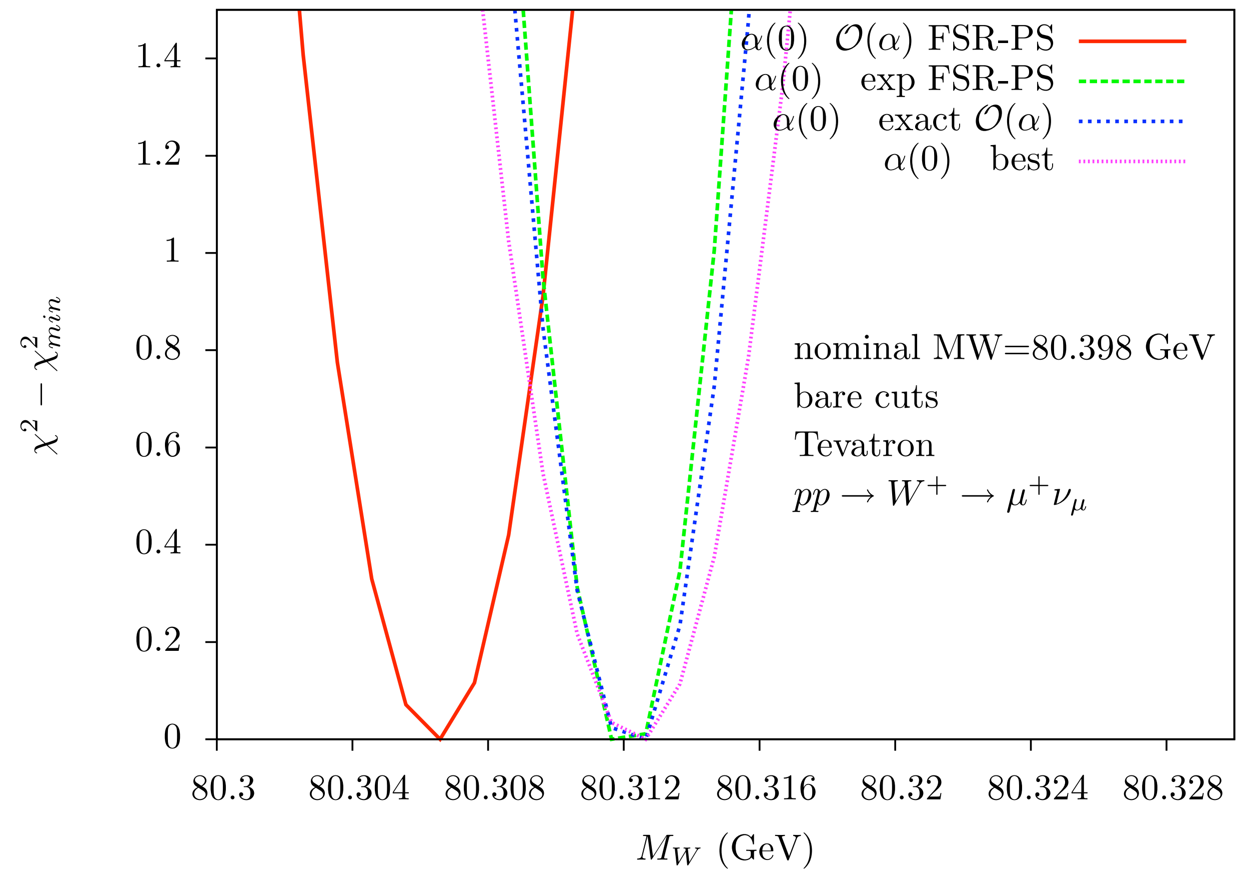
The exact matrix element at $O(\alpha)$
and
$O(\alpha)$ FSR QED PS prediction
differ by +6 MeV (subleading EW)

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



EW input schemes

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

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

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

$$\begin{aligned}
\alpha_0\ &: \qquad \sigma = \alpha_0^2\sigma_0 + \alpha_0^3(\sigma_{SV}+\sigma_H)\\
G_\mu\ I\ &: \qquad \sigma = (\alpha_\mu^{tree})^2\sigma_0 + (\alpha_\mu^{tree})^2\alpha_0(\sigma_{SV}+\sigma_H) - 2\Delta r(\alpha_\mu^{tree})^2\sigma_0\\
G_\mu\ II\ &: \qquad \sigma = (\alpha_\mu^{1l})^2\sigma_0 + (\alpha_\mu^{1l})^2\alpha_0(\sigma_{SV}+\sigma_H)
\end{aligned}$$

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

EW input schemes

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

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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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G_\mu \ II :& \quad \sigma = (\alpha_\mu^{1l})^2 \boxed{\sigma_0} + (\alpha_\mu^{1l})^2 \alpha_0 (\boxed{\sigma_{SV}} + \boxed{\sigma_H})
\end{aligned}$$

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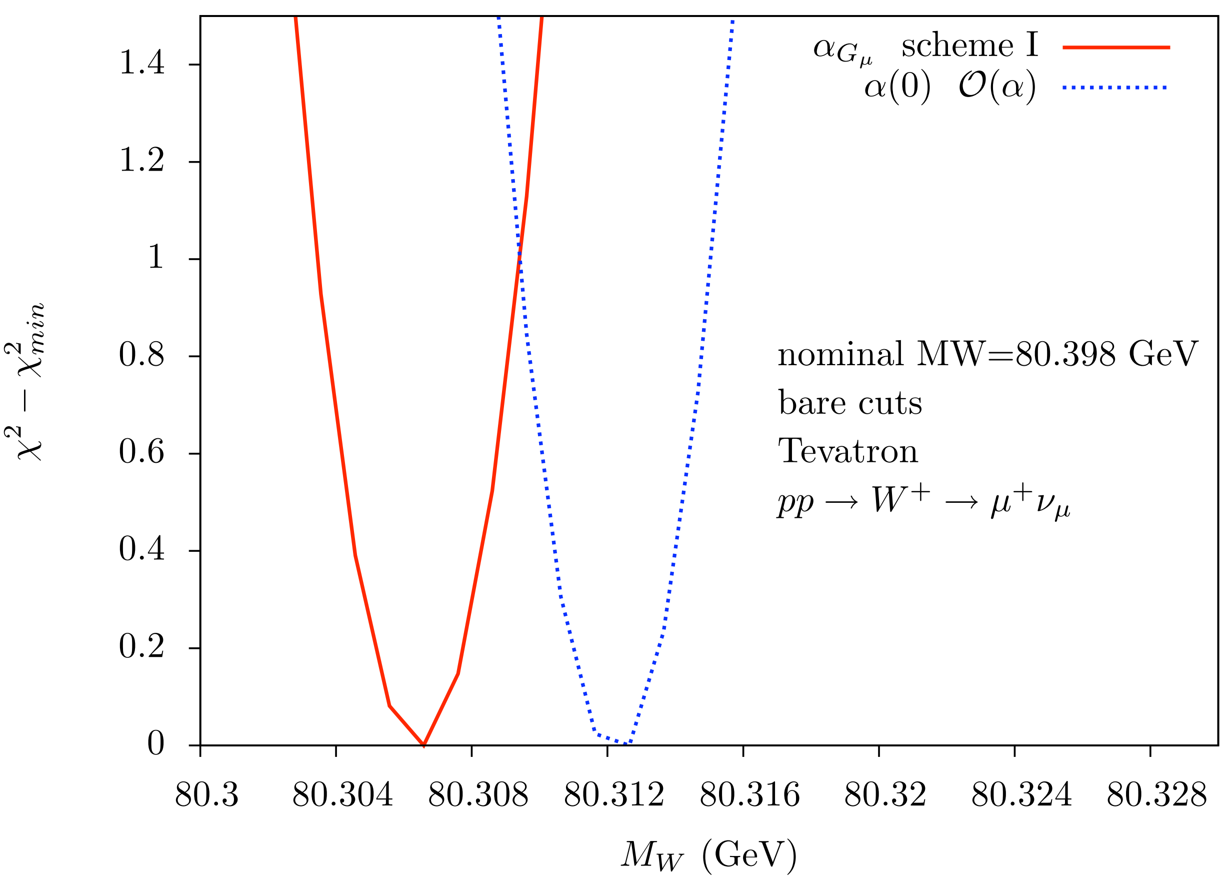
the sharing of 0- and of 1-photon events is different in the 2 Gmu schemes
the same in α_0 and Gmu-II schemes

EW input schemes

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



At O(α)

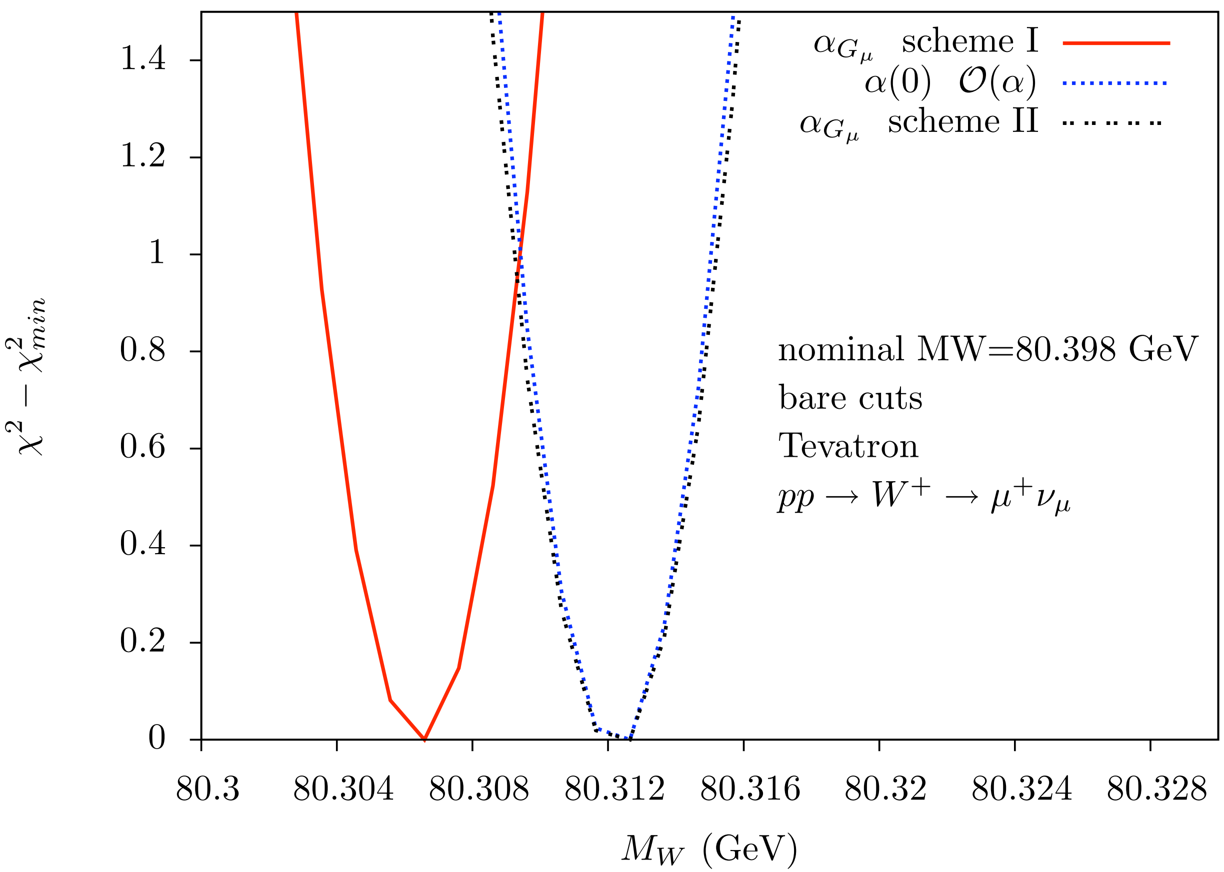
using α_0 or Gmu-I schemes

(different 0- and 1-photon sharing)

yields a change of MW of 6 MeV

EW input schemes

Born templates 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 $O(\alpha)$

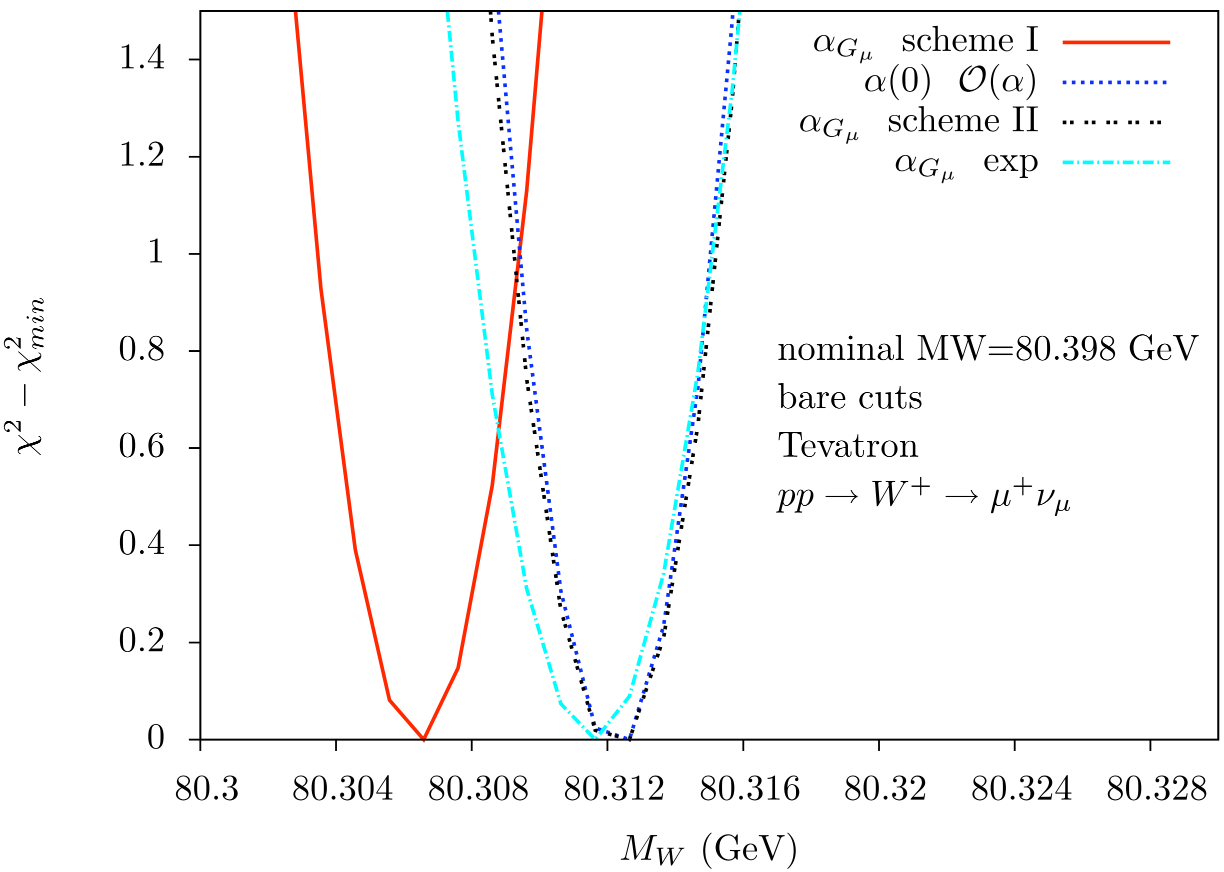
using α_0 or Gmu-II scheme

(same 0- and 1-photon sharing as α_0)

there is no extra shift in MW

EW input schemes

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



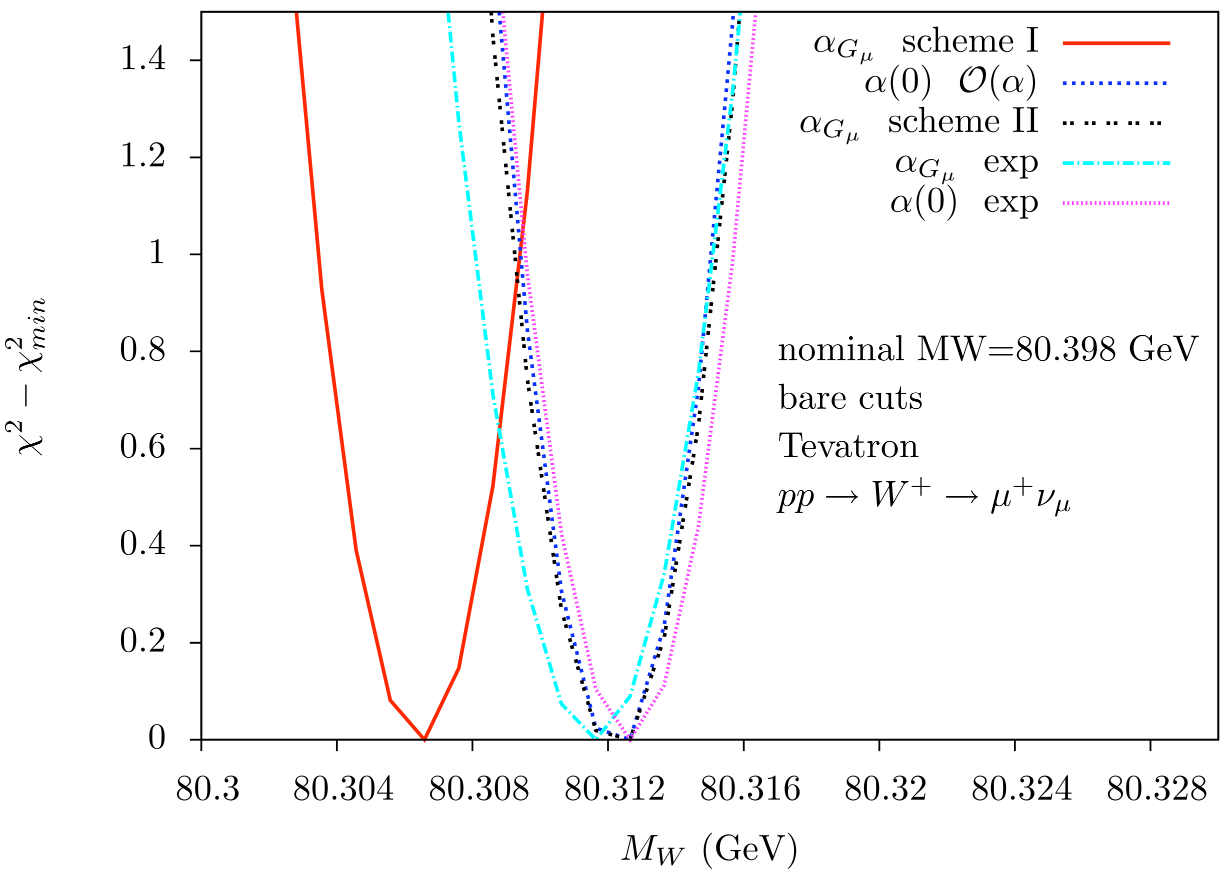
At $O(\alpha)$
using α_0 or Gmu-I schemes
(different 0- and 1-photon sharing)
yields a change of MW of 6 MeV

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

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

EW input schemes

Born templates 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

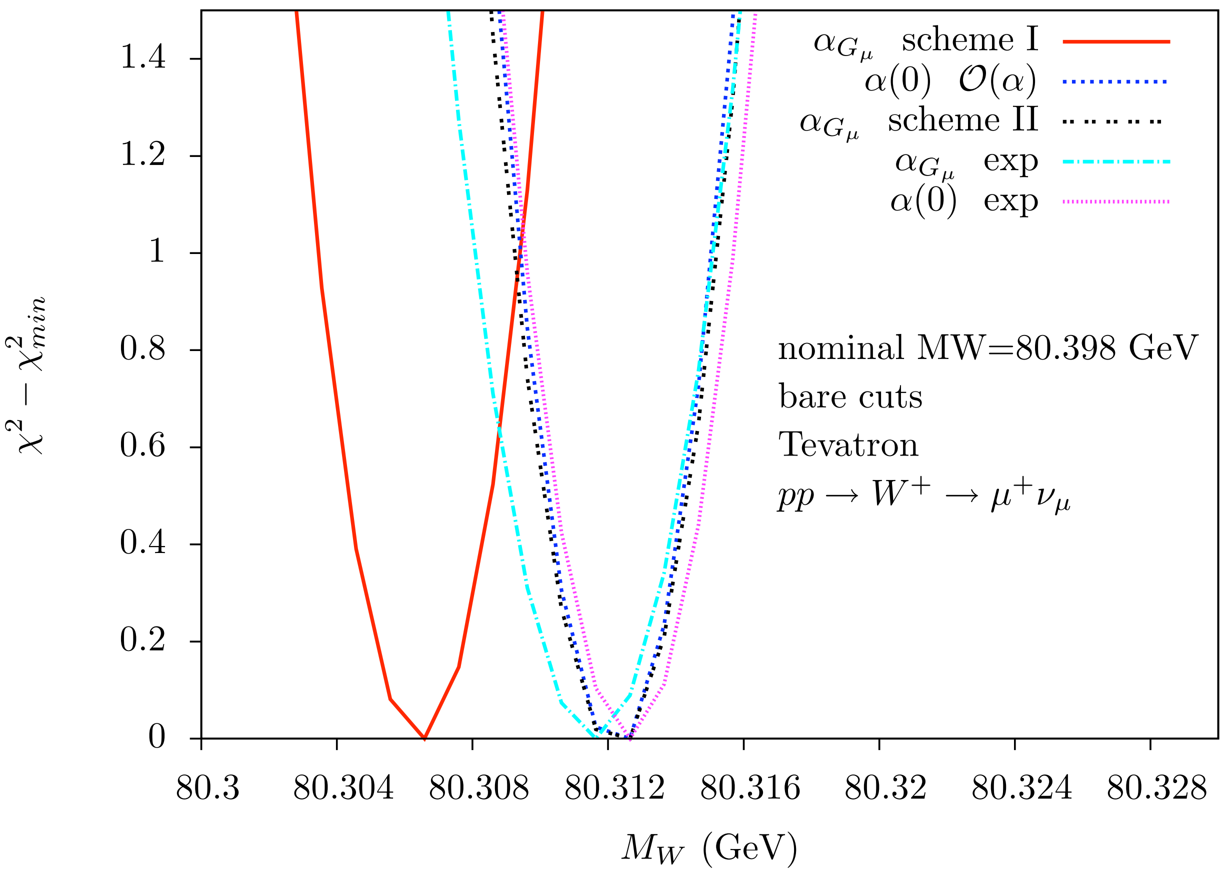
At O(α)
using α_0 or Gmu-II scheme
(same 0- and 1-photon sharing as α_0)
there is no extra shift in MW

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

Born templates 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 $O(\alpha)$
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

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

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

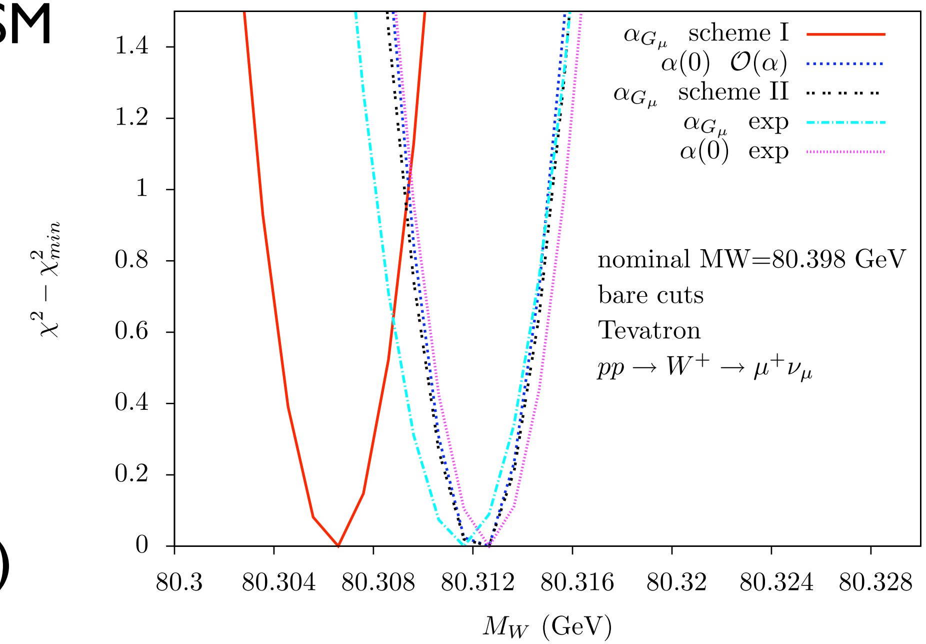
EW input schemes and MW beyond SM

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

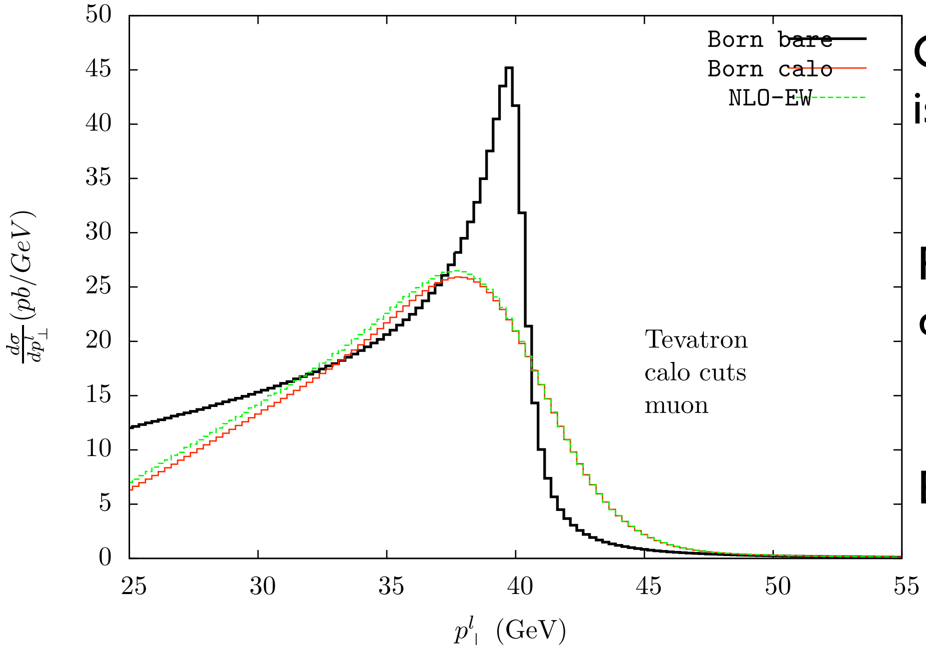
Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not{E}_T$
Experimental			
Electron Energy Scale	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences (material)	4	4	4
Recoil Model	6	12	20
Electron Efficiencies	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

It is possible to reduce the QED uncertainty, by using more complete tools like e.g. HORACE

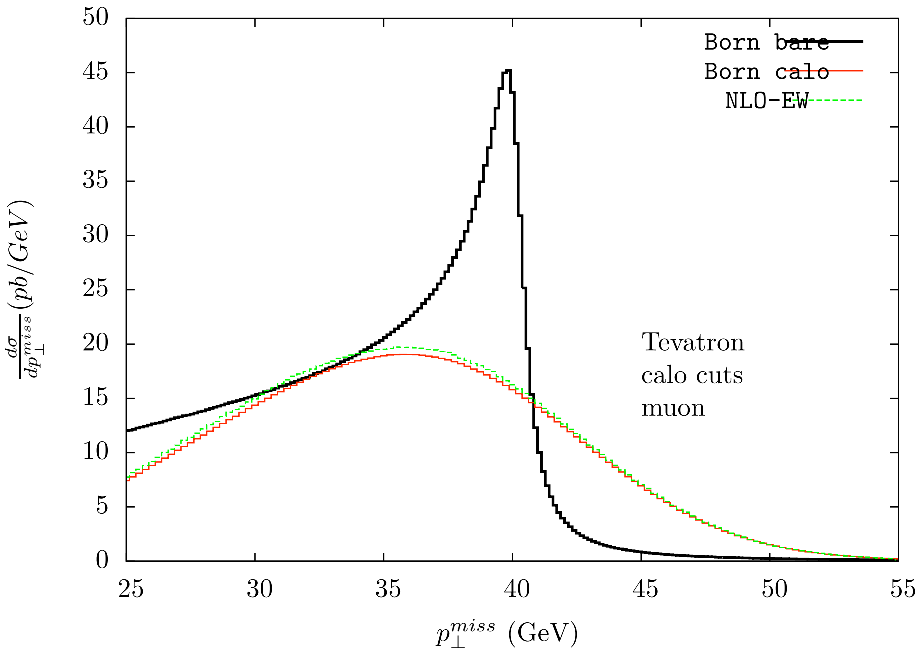
The effect of smearing the momenta and of photon recombination

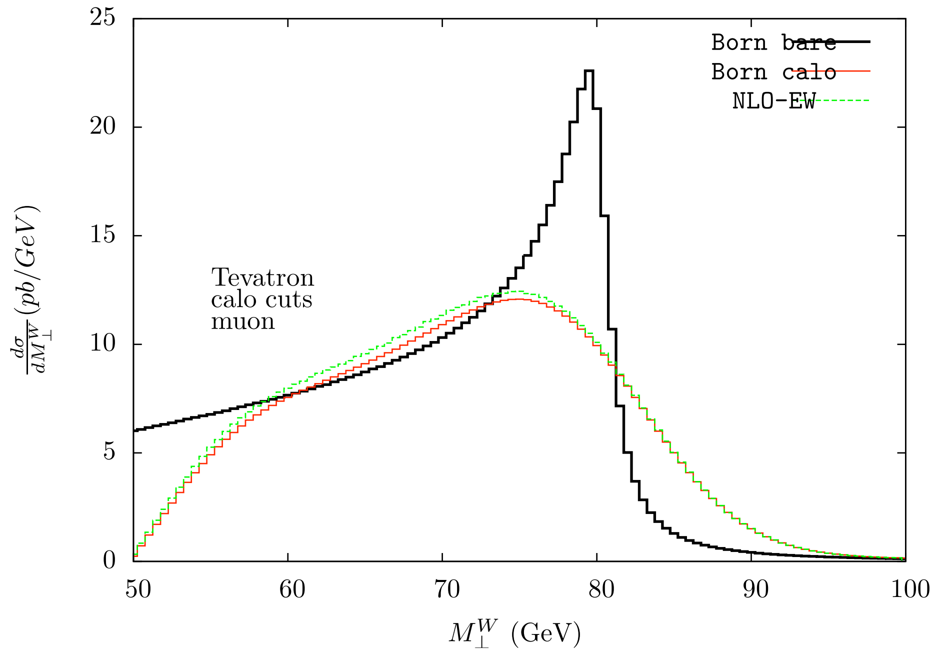


Calorimetric energy deposit
is not pointlike but approximated. by gaussian distribution
→ smearing of the lepton momenta

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

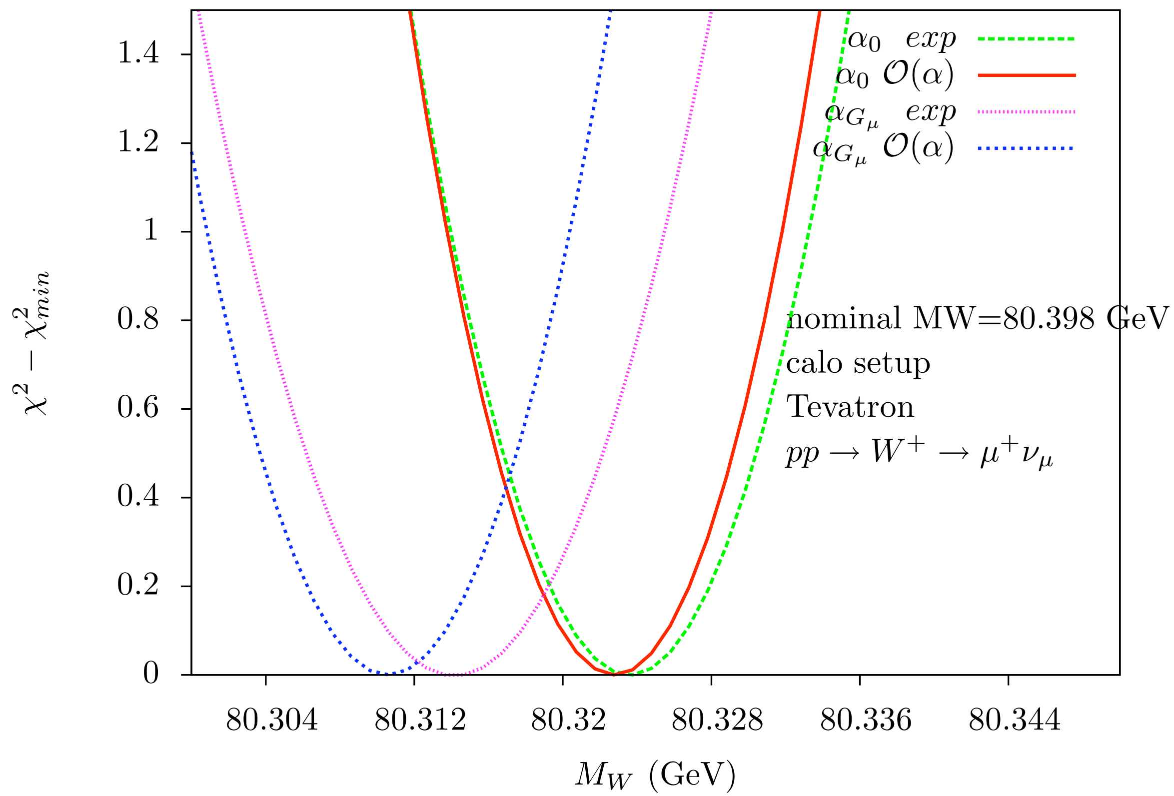
How do the effects of higher order corrections survive after smearing + recombination?
Effects measured with smeared Born templates





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)



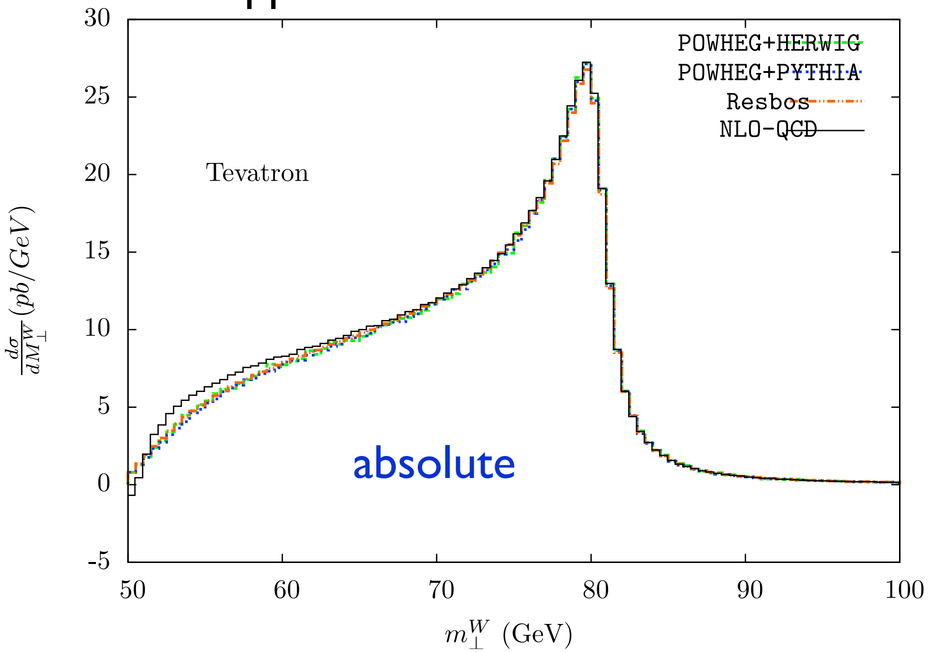
In the α_0, best w.r.t. fixed $O(\alpha)$ results differ by 1 MeV
In the Gmu-I scheme best w.r.t. fixed $O(\alpha)$ results differ by 4 MeV

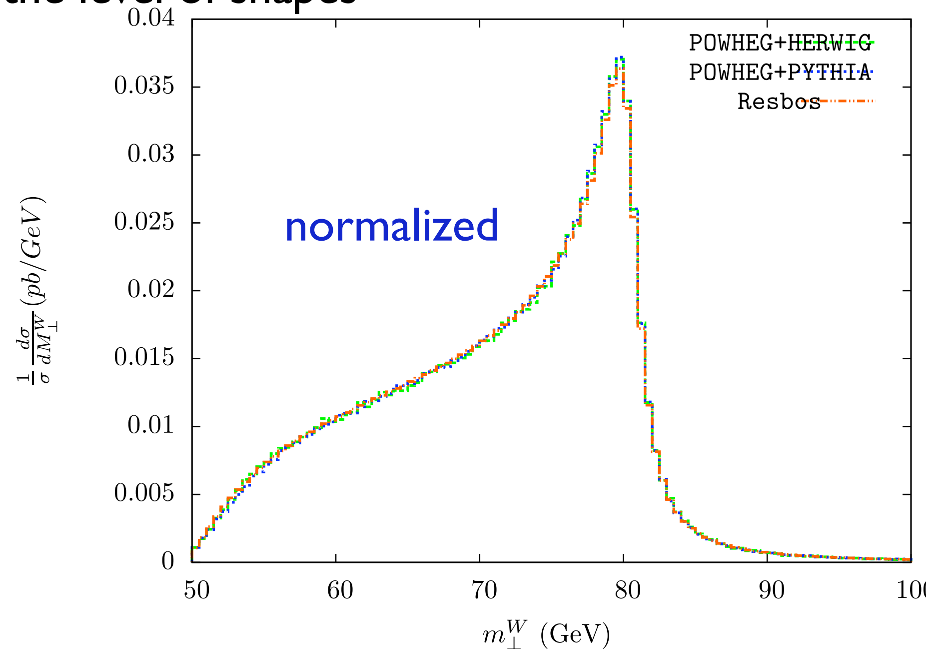
MW and QCD corrections: transverse mass

The perturbative and the non-perturbative content
of POWHEG+HERWIG and POWHEG+PYTHIA are different w.r.t. each other and w.r.t. to Resbos

They share NLO-QCD but differ in the inclusion of subleading higher-orders and in the matching of fixed order with resummed results

Differences appear at the level of normalization and at the level of shapes





Resbos templates: MW=80.398 GeV, 1 billions of calls: maximal accuracy 4 MeV

Fit with "absolute" templates (different normalizations w.r.t. pseudo-data)

POWHEG+HERWIG ΔMW = +18 MeV POWHEG+PYTHIA ΔMW = +18 MeV

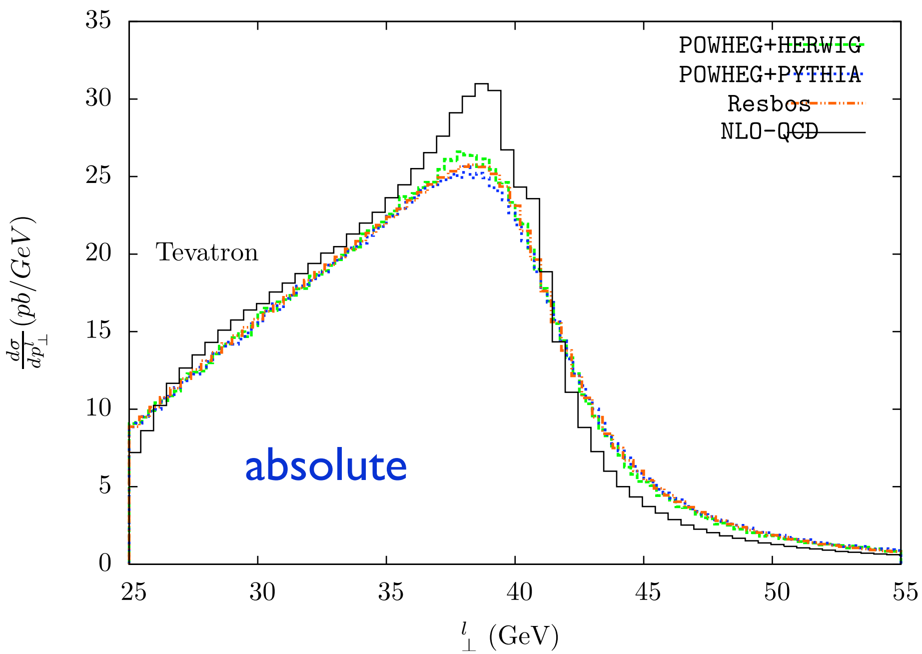
Fit with normalized distributions (templates and pseudo-data each normalized to its cross-section)

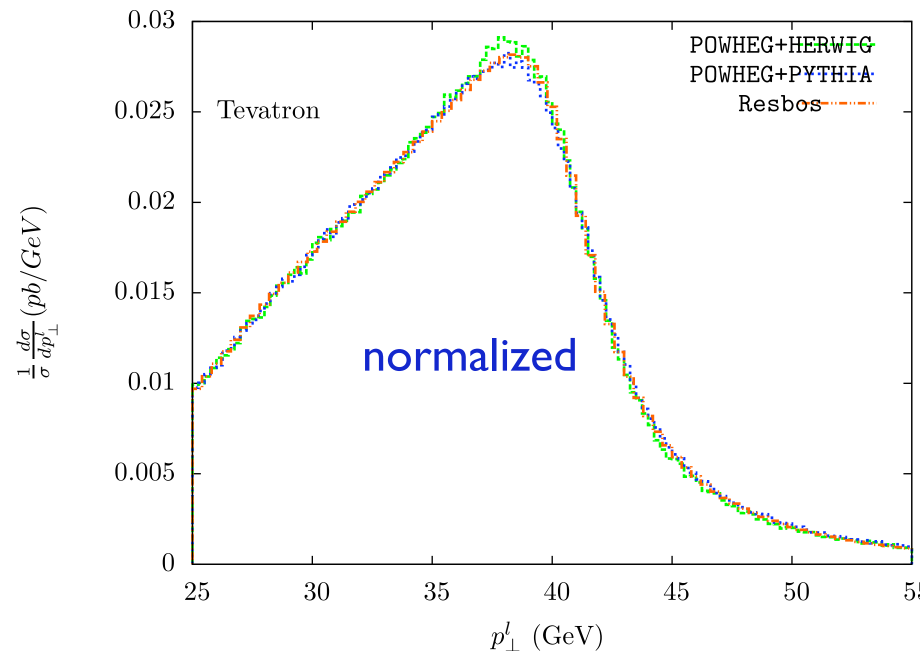
POWHEG+HERWIG ΔMW = + 18 MeV POWHEG+PYTHIA ΔMW = + 18 MeV

Weak sensitivity to the details of multiple gluon radiation

MW and QCD corrections: lepton transverse momentum

The lepton transverse momentum distribution is sensitive to the details of multiple gluon emission (i.e. to the gauge boson transverse momentum)





Resbos templates: MW=80.398 GeV, 1 billions of calls: maximal accuracy 4 MeV

Fit with "absolute" templates (different normalizations w.r.t. pseudo-data)

POWHEG+HERWIG ΔMW = - 48 MeV POWHEG+PYTHIA ΔMW = - 6 MeV

Strong sensitivity to the precise normalization (role of PDFs and choice of non-pert. params)

Fit with normalized distributions (templates and pseudo-data each normalized to its cross-section)

POWHEG+HERWIG ΔMW ~ - 50 MeV POWHEG+PYTHIA ΔMW ~ +46 MeV

MW and QCD corrections

The different results obtained with POWHEG+(HERWIG_6510, PYTHIA_6.4.16)
in units RESBOS
can be understood in terms of

non-perturbative, model dependent, parameters
- old tunes of the SMC
- old description of the underlying event by HERWIG (use JIMMY instead)

perturbative effects
- different inclusion of NNLO terms (partial vs absent)
- resummation of different subleading logs
  HERWIG vs PYTHIA showers in POWHEG
    vs logs in RESBOS
- different matching prescriptions between fixed order and resummed results

PDF uncertainty: Hessian vs Montecarlo approaches

Hessian (CTEQ, MSTW)

For each of the 5 values compute the *pdf* spread (not necessarily symmetric)

$$(\Delta F^{\alpha_S}_{\rm PDF})_+ = \sqrt{\sum_{k=1}^{n} \{\max\left[\, F^{\alpha_S}(S_k^+) - F^{\alpha_S}(S_0),\ F^{\alpha_S}(S_k^-) - F^{\alpha_S}(S_0),\ 0\right]\}^2},$$

$$(\Delta F^{\alpha_S}_{\rm PDF})_- = \sqrt{\sum_{k=1}^{n} \{\max\left[\, F^{\alpha_S}(S_0) - F^{\alpha_S}(S_k^+),\ F^{\alpha_S}(S_0) - F^{\alpha_S}(S_k^-),\ 0\right]\}^2},$$

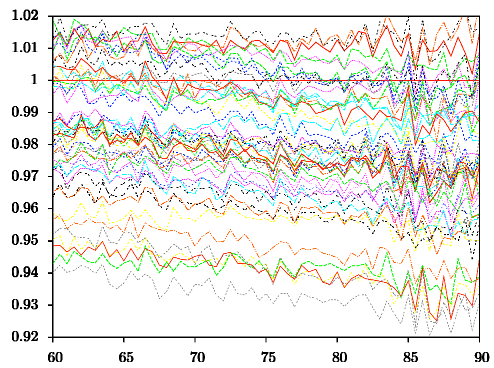
With these Δs one builds a band for the (e.g. transv. mass) distribution
but it is difficult to derive an interval of allowed values for MW

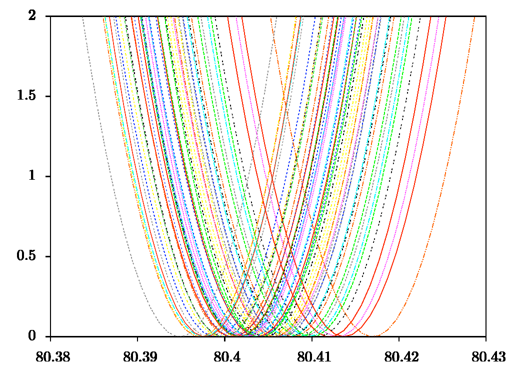
Montecarlo (NNPDF)

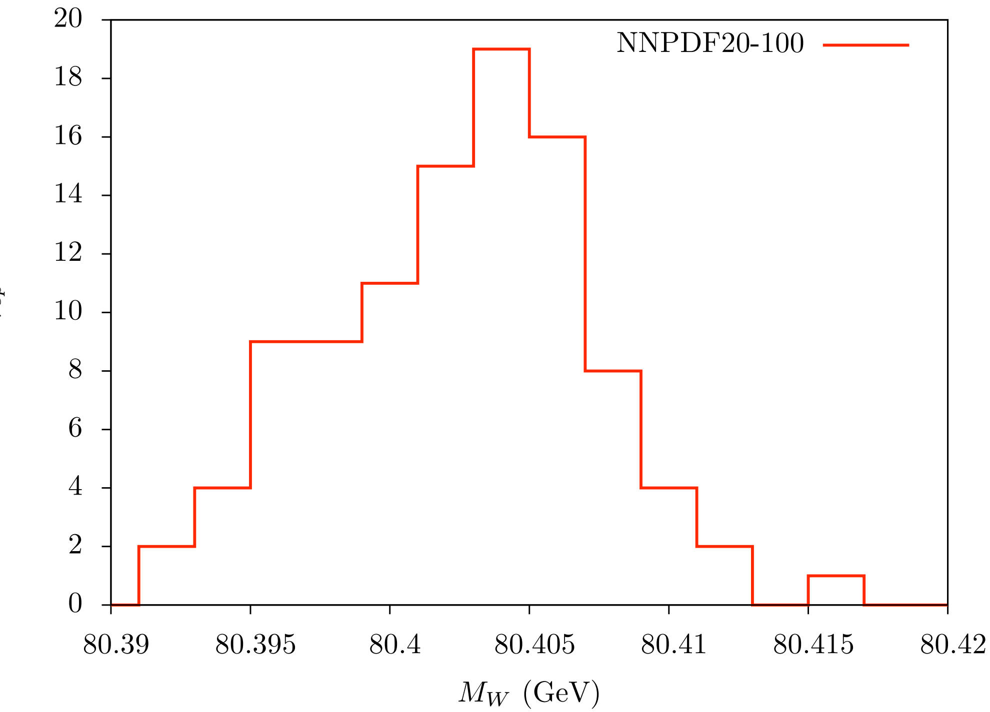
$$\sigma_{\mathcal{F}} = \left(\frac{1}{N_{\rm set}-1}\sum_{k=1}^{N_{\rm set}}\left(\mathcal{F}[\{q^{(k)}\}] - \langle \mathcal{F}[\{q\}]\rangle\right)^2\right)^{1/2}$$

Average and standard deviation of any observable are derived by computing N times its distributions, each time with a different replica.
Since each replica is a representative of the ensemble of allowed (from the data) proton parametrizations we can fit the transverse mass distribution and obtain the corresponding preferred MW

PDF uncertainty: HORACE Born with NNPDF20_100







The transverse mass distribution computed with different replicas have differents shapes and normalizations

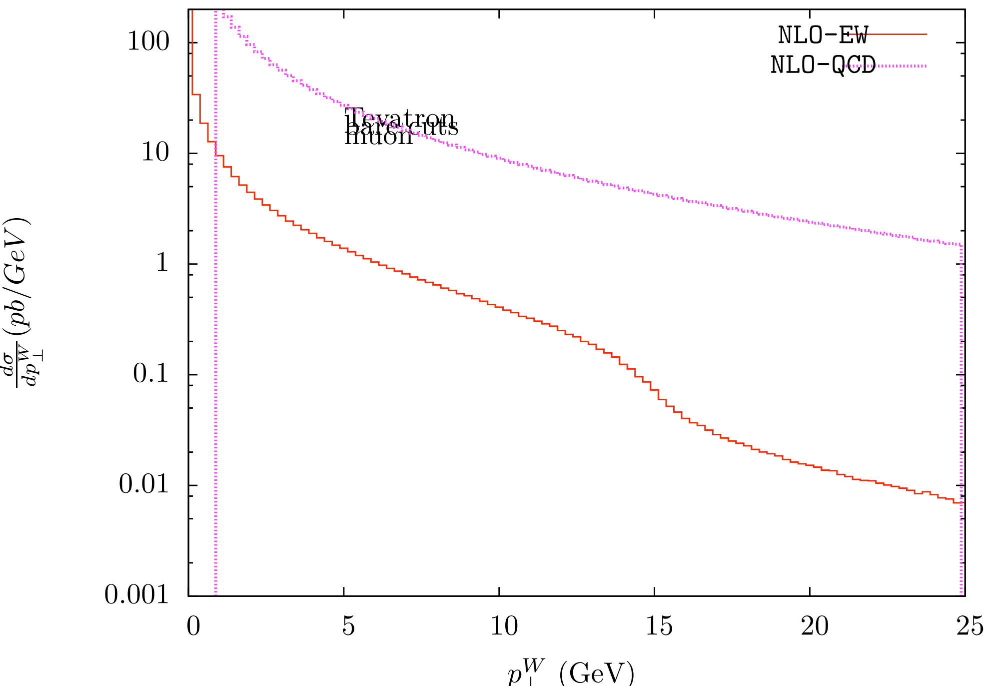
They have been fitted with (HORACE with CTEQ66) templates

The corresponding preferred MW are different

The distribution of the 100 MW values yields
MW = 80.402 +- 0.005 GeV

The choice of the PDF set and of the non pert. parameters to describe soft gluon radiation are correlated

QED induced W(Z) transverse momentum

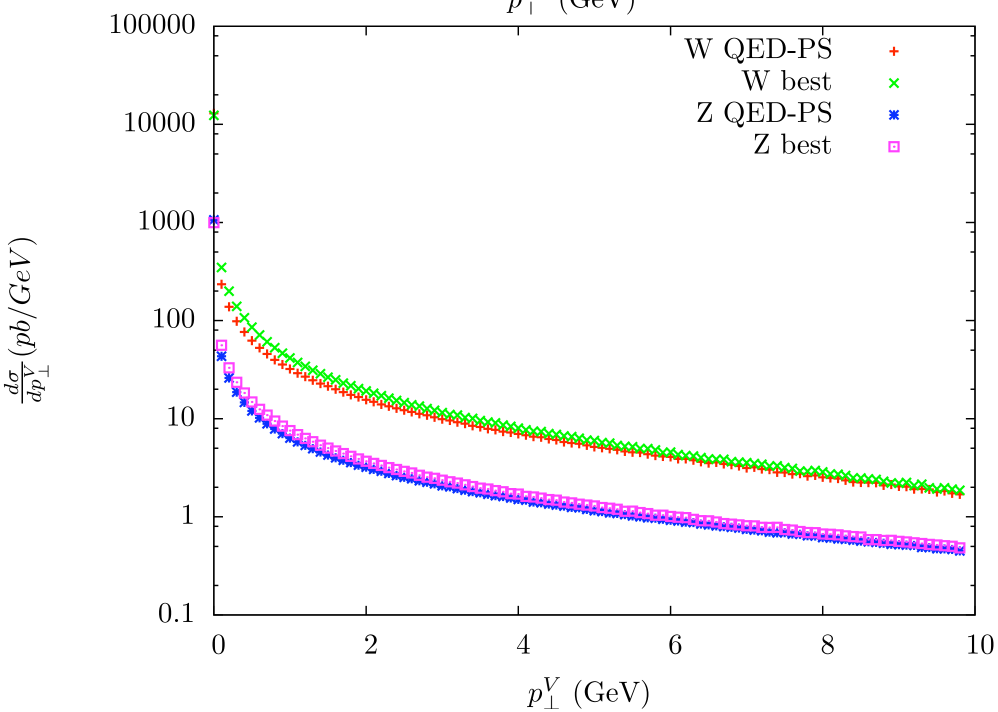


The uncertainty on ptW directly translates into an uncertainty on the final MW value.

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

Combining QCD + EW corrections

G. Balossini, C.M.Carloni Calame, G.Montagna, M.Moretti, O.Nicrosini, F.Piccinini, M.Treccani, A.Vicini, JHEP 1001:013, 2010

factorized prescription

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\otimes EW} = \left(1 + \frac{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{MC@NLO} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{HERWIG\ PS}}{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{LO/NLO}}\right) \times \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW}\right\}_{HERWIG\ PS}$$

additive prescription

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{QCD\oplus EW} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{QCD} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{EW} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{Born}\right\}_{HERWIG\ PS}$$

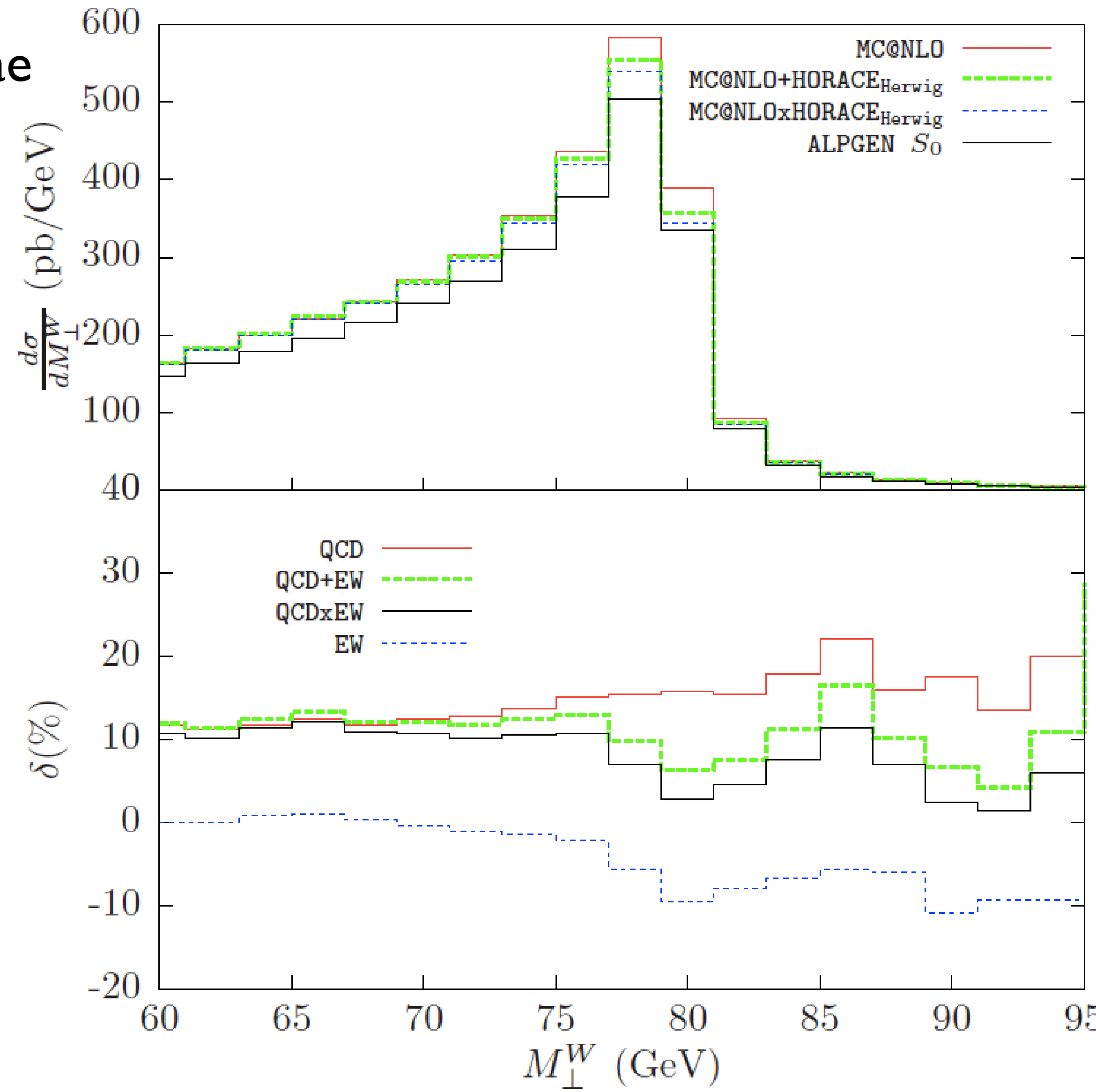
- different inclusion of higher orders $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha\alpha_s)$

the factorized prescription includes the bulk of the reducible $\mathcal{O}(\alpha_s^2)$ terms

Combining QCD + EW corrections

- the factorized and the additive formulae differ by few per cent

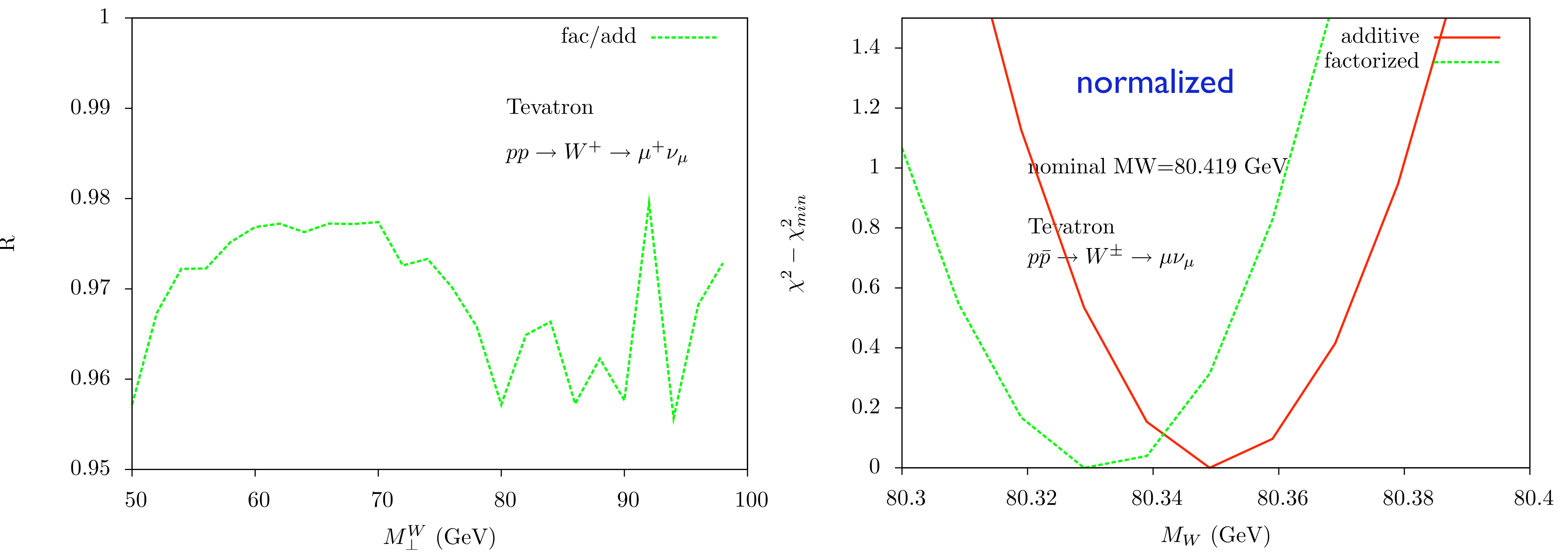
- different inclusion of higher orders $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha\alpha_s)$



- additive prescription: NLO-EW convoluted with HERWIG QCD-PS
- factorized prescription: NLO-EW convoluted with HERWIG QCD-PS + + NLO-EW times (non-log NLO-QCD)

Combining QCD + EW corrections

templates: Resbos, same inputs of the pseudo-data: MW=80.419 GeV, GammaW=2.048 GeV



- in the ratio we observe an offset, mostly due to higher order QCD corrections, and a different shape

- the bulk of the shift (w.r.t. the nominal value) is due to EW corrections

- the different recipes can be translated into a relative MW shift of ~10-20 MeV ? (low statistics)

Summary

Many calculations and many codes available: crucial is the tuning phase

the template fit procedure has been implemented to study
EW corrections (bare and calo Born templates)
QCD and QCD+EW corrections (Resbos templates)

in the EW sector we can classify, in terms of MW shifts
the impact of different perturbative approximations and of theoretical ambiguities:
missing higher orders or different scheme choices induce tiny changes of MW
the factorized HORACE formula exhibits a good stability
exact $O(\alpha)$ matched with multiple photon is needed e.g. to precisely determine pt_W

in the QCD sector we can, in principle, compare how different "best predictions"
(perturbative approximations + matching procedures + (soft+non-pert. models))
differ in terms of MW
In practice, a dedicated work of tuning of soft+non.pert. models is required
before one can attempt to make an estimate of the QCD theoretical uncertainty

two recipes to combine QCD+EW corrections induce differences in MW of O(20 MeV)
(although mostly factorized recipes are presently used)

the PDF uncertainty "alone" induces an uncertainty of +- 5 MeV (68% C.L.)
but there is an interplay with the non-pert. parameters

Work in progress in the framework of the W mass workshop

The Z transverse momentum distribution and the W observables

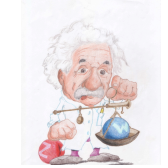
- modeling of soft gluon and non-perturbative effects
  in the Z production case

- extrapolation of this model to the W kinematical region:
  the W transverse momentum distribution is the
  theoretical observable for comparisons

- use of a Montecarlo simulation
  based on the two above ingredients
  to predict in the W case: lepton transverse momentum
  transverse missing momentum
  transverse mass

- a definite improvement has to be obtained in step 1
  (fit of Z observables)
  before any sensible comparison is carried on

Radiative corrections and simulation tools: QCD matching



BCDFG Bozzi, Catani, De Florian, Ferrera, Grazzini

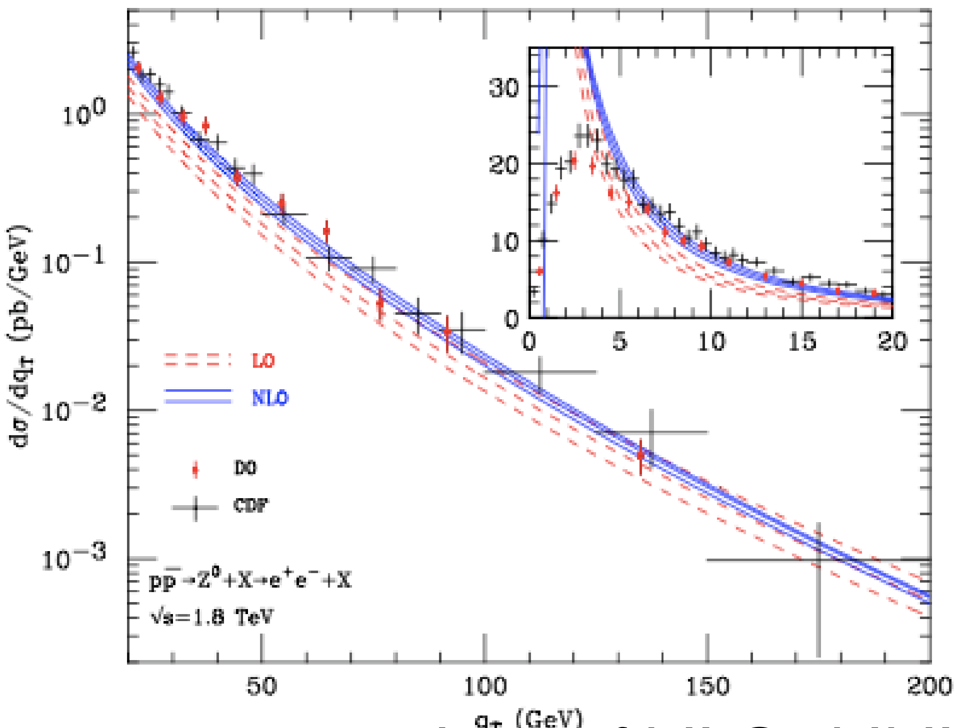
$$\frac{d\hat{\sigma}^{(\mathrm{res.})}_{V\,ab}}{dq_T^2}(q_T, M, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \frac{M^2}{\hat{s}} \int_0^\infty db\, \frac{b}{2}\, J_0(bq_T)\, \mathcal{W}^V_{ab}(b, M, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2)$$

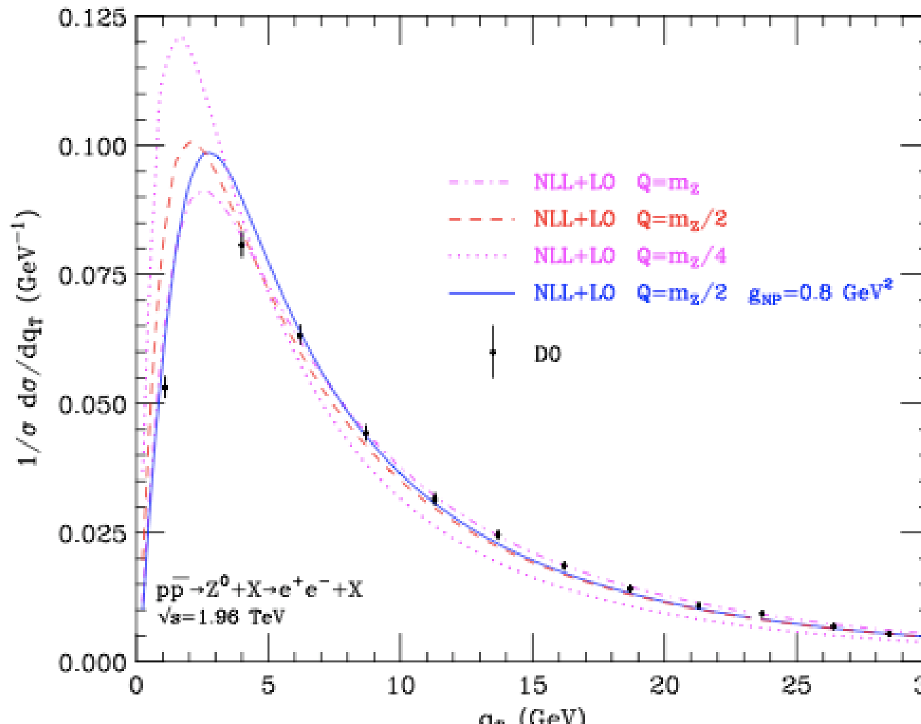
process dependent

$$\mathcal{W}^V_N(b, M; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \mathcal{H}^V_N\left(M, \alpha_S(\mu_R^2); M^2/\mu_R^2, M^2/\mu_F^2, M^2/Q^2\right) \times \exp\{\mathcal{G}_N(\alpha_S(\mu_R^2), L; M^2/\mu_R^2, M^2/Q^2)\} \;,$$

universal

Q is the resummation scale

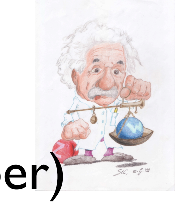




in progress: matching of NLO+NNLL using the recent NNLO results in

Catani, Cieri, Ferrera, de Florian, Grazzini, arXiv:0903.2120

Radiative corrections and simulation tools: QCD matching

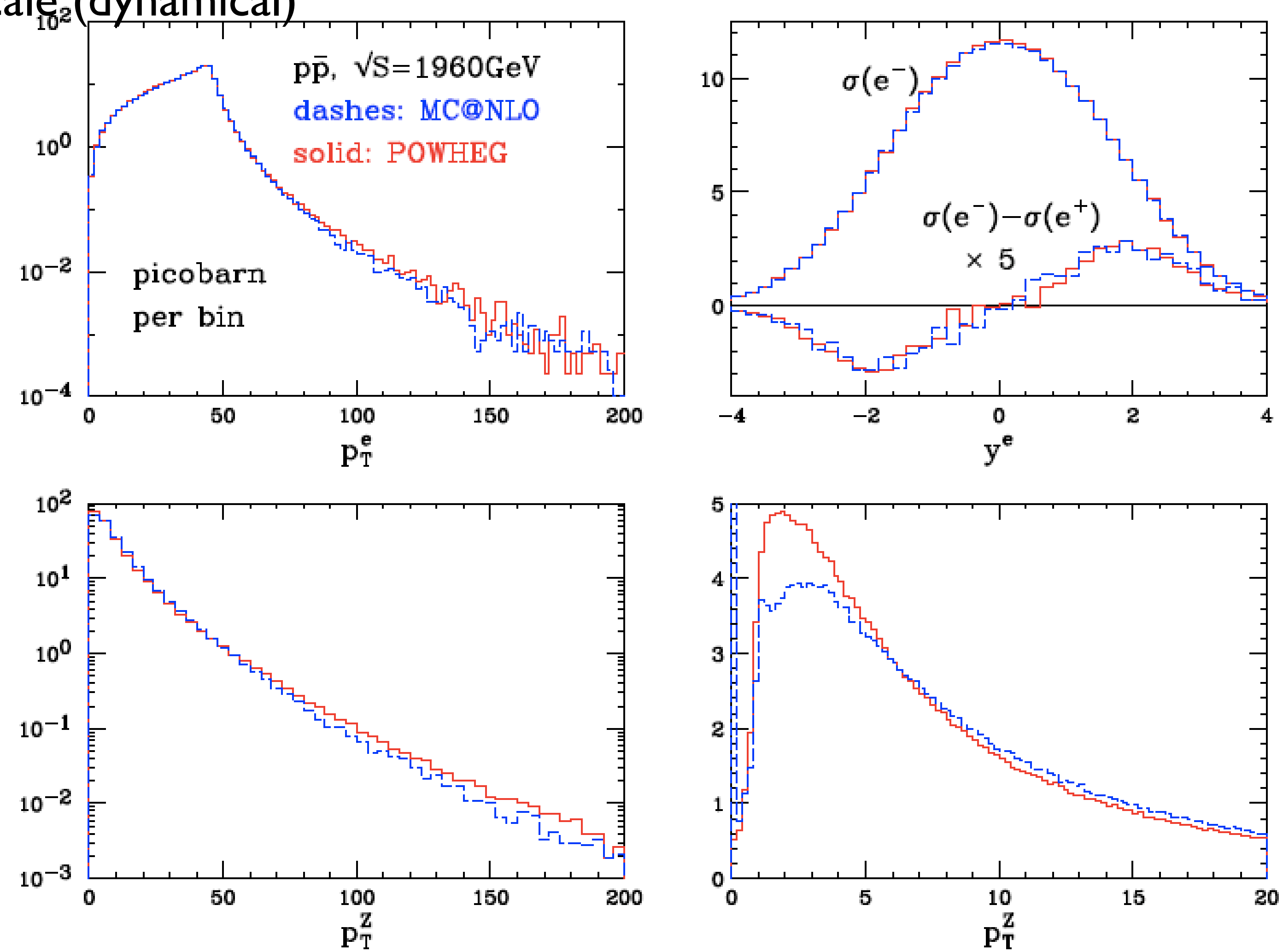


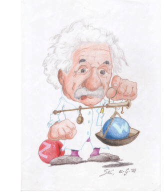
POWHEG (Alioli, Nason, Oleari, Re)

- normalization & hardest emission with NLO accuracy
- rest of the radiation by any vetoed shower, allowed to radiate below the virtuality of the hardest emission
- no matching scale (dynamical)

MC@NLO (Frixione, Webber)

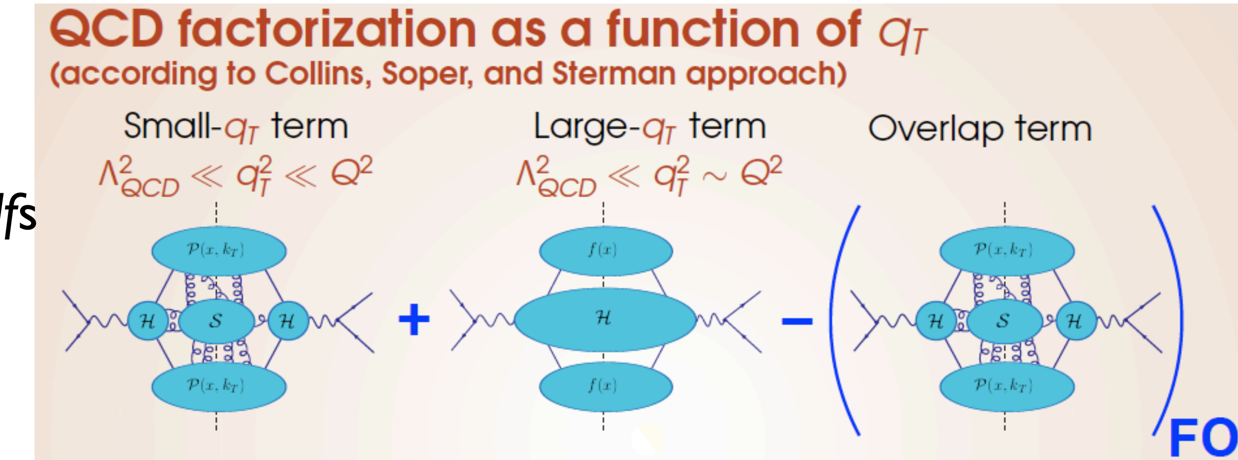
- event generation at NLO
- merging with HERWIG Parton Shower using PS-dependent counterterms
- fixed matching scale





RESBOS

- Finite order: part of the NNLO results
  lepton spin correlation at NLO
- Resummed term *W* at NNLL
  for Sudakov factor and non-collinear *pdfs*
- Two representations of the
  hard-vertex function *H*



matching at the crossing point between resummed and fixed order results