Divers topics on EW virtual corrections

E. Richter-Was (IF UJ, Krakow)

- **Predictions for ΔA_4 (EW) with experimental binning. TauSpinner + Dizet 6.45**
- **Factorizing QCD from EW corrections.**
- **Draft v05 status**

Status of the YR draft (v04)

Recently updated

Contents

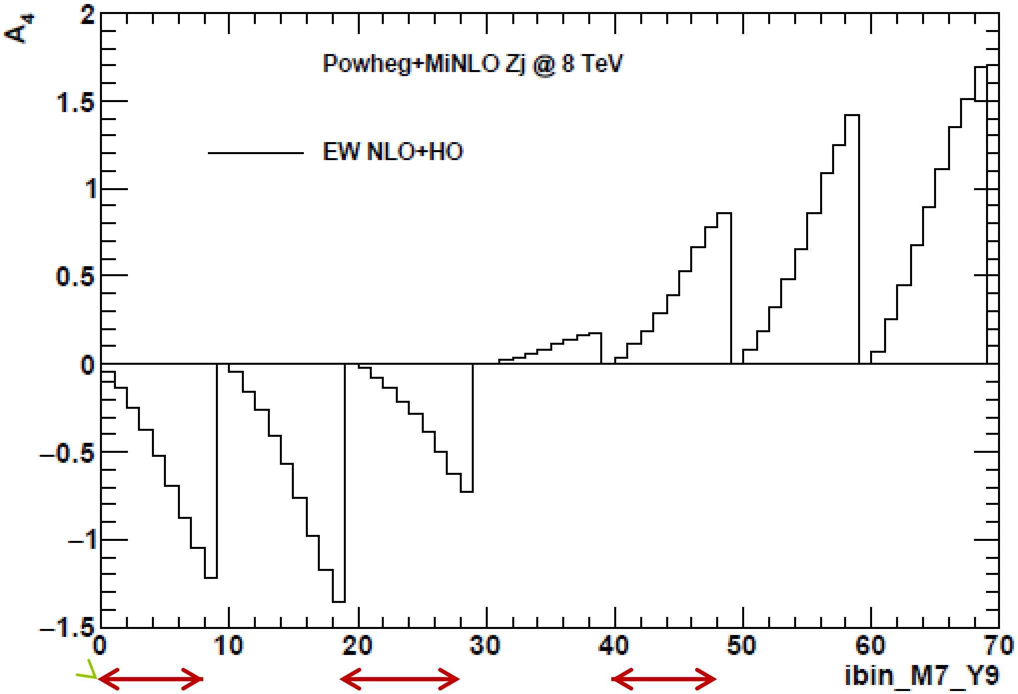
The ΔA_4(EW) in the full phase-space

- **Experimental binning**

Table 29: The binning in M_{bin}, Y_{bin} for tabulating A_4 sensitivity to $\sin^2\theta_W^{eff}$.

Observable	Bin thresholds
M_{bin}	[60, 66, 76, 86, 96, 106, 116, 150] GeV
Y_{bin}	[0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6]

Should start at 50 GeV, but I have no events below 60 GeV



m_{ll} = 60-66 GeV   76-86 GeV   96-106 GeV

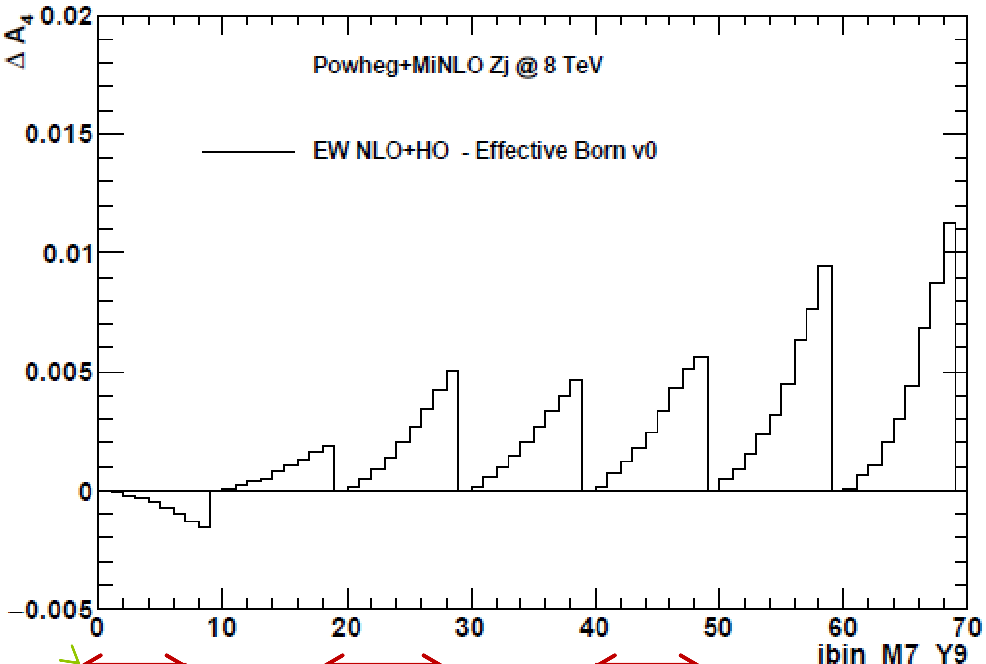
Dizet v6.45

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0
M_Z (GeV)	91.1876
$1/\alpha(M_Z)$	0.0077549256
$\alpha(M_Z)$	128.9503020
G_μ (GeV^{-2})	$1.1663787 \cdot 10^{-5}$
M_W (GeV)	80.358935
s_W^2	0.223401084
$\sin^2\theta^\ell_{eff}$	0.231499
$\sin^2\theta^u_{eff}$	0.231392
$\sin^2\theta^d_{eff}$	0.231265
$\sin^2\theta^b_{eff}$	0.232733

The ΔA_4(EW) in the full phase-space

- **EW NLO+HO vs Effective Born v0**

Effective Born *v0*
$\alpha = 1/128.950302$ $s_W^2 = 0.231499$ $\rho_{\ell f} = 1.0$



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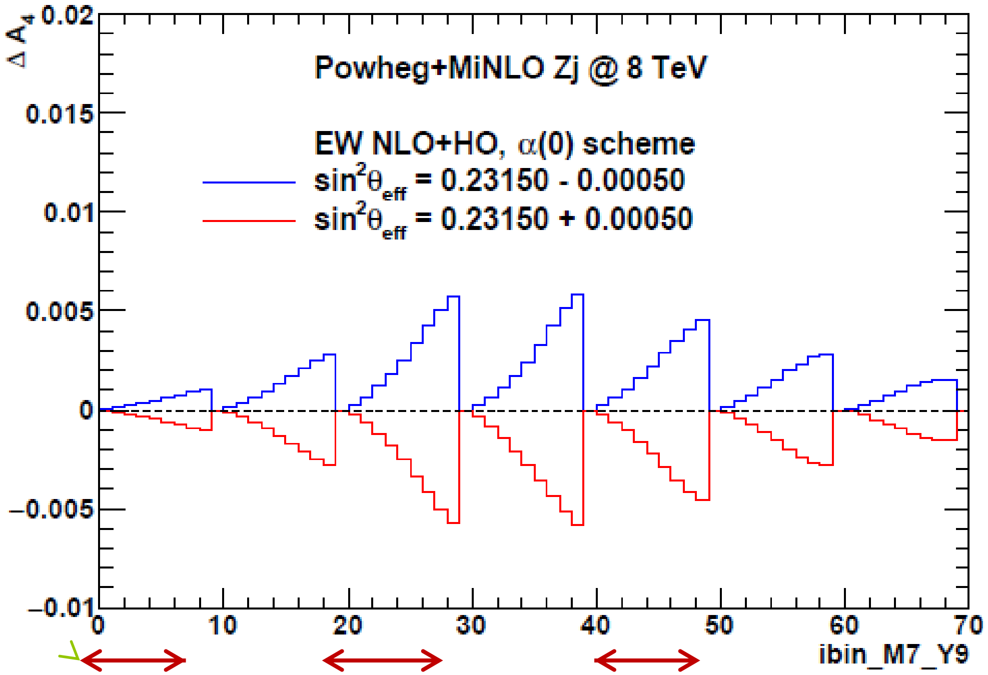
The ΔA_4(EW) in the full phase-space

- **EW NLO+HO vs Effective Born v0**

Effective Born *v0*
$\alpha = 1/128.9503022$ $s_W^2 = 0.231499$
$s_W^2 = s_W^2 + \delta_v$



m_{ll} = 60-66 GeV 76-86 GeV 96-106 GeV

EW NLO+HO, $\alpha(0)$ scheme

$$v_\ell = (2\cdot T_3^\ell - 4\cdot q_\ell\cdot(s_W^2\cdot\mathcal{K}_\ell(s,t) + \delta_V))/\Delta,$$

$$v_f = (2\cdot T_3^f - 4\cdot q_f\cdot(s_W^2\cdot\mathcal{K}_f(s,t) + \delta_V))/\Delta,$$

$$vv_{\ell f} = \frac{1}{v_\ell\cdot v_f}[(2\cdot T_3^\ell)(2\cdot T_3^f) - 4\cdot q_\ell\cdot(s_W^2 + \cdot\mathcal{K}_f(s,t) + \delta_V)(2\cdot T_3^\ell) - 4\cdot q_f\cdot(s_W^2\cdot\mathcal{K}_\ell(s,t) + \delta_V)(2\cdot T_3^f) + (4\cdot q_\ell\cdot s_W^2)(4\cdot q_f\cdot s_W^2)\mathcal{K}_{\ell f}(s,t) + 2\cdot(4\cdot q_\ell))(4\cdot q_f\cdot)\cdot s_W^2\cdot\mathcal{K}_{\ell f}(s,t)\cdot\delta_V]\frac{1}{\Delta^2}.$$

δ_v = ±0.00050

The A_4 in the full phase-space

Powheg+MiNLO events with EW NLO+HO corrections (TauSpinner + Dizet 6.45)

Table 30: The A_4 caculated including full EW corrections, in experimental bins M_{bin}, Y_{bin}. *Updated with* `Dizet 6.45` *form factors.*

M_{bin}, Y_{bin}	$\sin^2\theta_W^{eff} = 0.23100$	$\sin^2\theta_W^{eff} = 0.23150$	$\sin^2\theta_W^{eff} = 0.23200$	Δ_P	Δ_M
1 , 1	-0.04712	-0.04716	-0.04720	0.00004	-0.00004
1 , 2	-0.13503	-0.13515	-0.13528	0.00012	-0.00012
1 , 3	-0.24463	-0.24485	-0.24506	0.00021	-0.00021
1 , 4	-0.37830	-0.37862	-0.37893	0.00032	-0.00032
1 , 5	-0.52417	-0.52461	-0.52505	0.00044	-0.00045
1 , 6	-0.69617	-0.69676	-0.69735	0.00059	-0.00059
1 , 7	-0.87865	-0.87940	-0.88013	0.00074	-0.00075
1 , 8	-1.04540	-1.04630	-1.04719	0.00089	-0.00090
1 , 9	-1.22346	-1.22447	-1.22548	0.00100	-0.00101
2 , 1	-0.04599	-0.04610	-0.04621	0.00011	-0.00011
2 , 2	-0.15099	-0.15133	-0.15168	0.00035	-0.00035
2 , 3	-0.25526	-0.25587	-0.25648	0.00061	-0.00061
2 , 4	-0.41167	-0.41258	-0.41349	0.00091	-0.00091
2 , 5	-0.56949	-0.57077	-0.57204	0.00127	-0.00128
2 , 6	-0.76368	-0.76537	-0.76705	0.00168	-0.00169
2 , 7	-0.97291	-0.97501	-0.97710	0.00209	-0.00210
2 , 8	-1.17256	-1.17506	-1.17755	0.00249	-0.00250
2 , 9	-1.35532	-1.35813	-1.36092	0.00279	-0.00281
3 , 1	-0.02223	-0.02245	-0.02267	0.00022	-0.00022
3 , 2	-0.07747	-0.07815	-0.07884	0.00068	-0.00068
3 , 3	-0.13806	-0.13926	-0.14046	0.00120	-0.00120
3 , 4	-0.20723	-0.20904	-0.21085	0.00181	-0.00181
3 , 5	-0.28220	-0.28473	-0.28726	0.00253	-0.00253
3 , 6	-0.38354	-0.38690	-0.39024	0.00335	-0.00335
3 , 7	-0.49968	-0.50390	-0.50810	0.00421	-0.00421
3 , 8	-0.61852	-0.62357	-0.62861	0.00504	-0.00505
3 , 9	-0.72616	-0.73188	-0.73758	0.00571	-0.00572
4 , 1	0.00742	0.00721	0.00691	0.00030	-0.00021
4 , 2	0.02350	0.02285	0.02204	0.00081	-0.00065
4 , 3	0.04065	0.03950	0.03811	0.00139	-0.00114
4 , 4	0.06283	0.06111	0.05904	0.00207	-0.00172
4 , 5	0.08847	0.08604	0.08324	0.00280	-0.00243
4 , 6	0.11597	0.11267	0.10908	0.00359	-0.00330
4 , 7	0.14134	0.13709	0.13271	0.00438	-0.00424
4 , 8	0.16457	0.15941	0.15424	0.00517	-0.00516
4 , 9	0.18159	0.17575	0.16990	0.00585	-0.00584
5 , 1	0.03252	0.03232	0.03213	0.00020	-0.00020
5 , 2	0.11502	0.11441	0.11380	0.00061	-0.00061
5 , 3	0.19154	0.19047	0.18940	0.00107	-0.00107
5 , 4	0.28932	0.28773	0.28612	0.00160	-0.00160
5 , 5	0.39524	0.39303	0.39083	0.00220	-0.00220
5 , 6	0.52786	0.52499	0.52213	0.00287	-0.00286
5 , 7	0.66747	0.66395	0.66042	0.00353	-0.00352
5 , 8	0.77857	0.77447	0.77035	0.00411	-0.00411
5 , 9	0.86671	0.86218	0.85764	0.00454	-0.00453

m_{ll} = 86-96 GeV

Table 31: The A_4 caculated including full EW corrections, in experimental bins M_{bin}, Y_{bin}. Continuation of Table 30: *Updated with* `Dizet 6.45` *form factors.*

M_{bin}, Y_{bin}	$\sin^2\theta_W^{eff} = 0.23100$	$\sin^2\theta_W^{eff} = 0.23150$	$\sin^2\theta_W^{eff} = 0.23200$	Δ_P	Δ_M
6 , 1	0.08041	0.08027	0.08013	0.00014	-0.00014
6 , 2	0.18749	0.18705	0.18660	0.00044	-0.00044
6 , 3	0.32530	0.32454	0.32378	0.00076	-0.00076
6 , 4	0.48828	0.48715	0.48602	0.00113	-0.00113
6 , 5	0.65712	0.65557	0.65402	0.00155	-0.00155
6 , 6	0.85586	0.85389	0.85191	0.00198	-0.00197
6 , 7	1.08547	1.08313	1.08078	0.00235	-0.00234
6 , 8	1.24701	1.24433	1.24165	0.00268	-0.00267
6 , 9	1.42075	1.41796	1.41516	0.00280	-0.00279
7 , 1	0.07507	0.07498	0.07489	0.00009	-0.00009
7 , 2	0.25610	0.25582	0.25553	0.00028	-0.00028
7 , 3	0.44532	0.44484	0.44435	0.00049	-0.00049
7 , 4	0.67565	0.67494	0.67423	0.00071	-0.00071
7 , 5	0.89229	0.89135	0.89041	0.00095	-0.00094
7 , 6	1.11025	1.10907	1.10788	0.00119	-0.00119
7 , 7	1.35502	1.35364	1.35226	0.00139	-0.00138
7 , 8	1.51281	1.51129	1.50975	0.00153	-0.00153
7 , 9	1.69631	1.69481	1.69330	0.00151	-0.00150

Δ_P, Δ_M correspond to ΔA_4 due to $\delta_V = \pm 0.00050$

The A_4 in the full phase-space

Powheg+MiNLO events with Effective EW Born corrections (TauSpinner)

Table 32: The A_4 caculated with Effective Born v0, in experimental bins M_{bin}, Y_{bin}.

M_{bin}, Y_{bin}	$\sin^2\theta_W^{eff} = 0.23100$	$\sin^2\theta_W^{eff} = 0.23150$	$\sin^2\theta_W^{eff} = 0.23200$	Δ_P	Δ_M
1 , 1	-0.04709	-0.04713	-0.04716	0.00004	-0.00004
1 , 2	-0.13492	-0.13503	-0.13514	0.00011	-0.00011
1 , 3	-0.24443	-0.24462	-0.24482	0.00019	-0.00020
1 , 4	-0.37801	-0.37831	-0.37860	0.00029	-0.00029
1 , 5	-0.52369	-0.52409	-0.52450	0.00040	-0.00041
1 , 6	-0.69549	-0.69604	-0.69657	0.00054	-0.00054
1 , 7	-0.87772	-0.87840	-0.87908	0.00068	-0.00068
1 , 8	-1.04412	-1.04494	-1.04576	0.00082	-0.00082
1 , 9	-1.22195	-1.22288	-1.22379	0.00091	-0.00093
2 , 1	-0.04604	-0.04615	-0.04625	0.00010	-0.00010
2 , 2	-0.15122	-0.15155	-0.15188	0.00033	-0.00033
2 , 3	-0.25571	-0.25629	-0.25686	0.00057	-0.00058
2 , 4	-0.41223	-0.41309	-0.41395	0.00086	-0.00086
2 , 5	-0.57033	-0.57154	-0.57274	0.00120	-0.00121
2 , 6	-0.76484	-0.76644	-0.76802	0.00158	-0.00160
2 , 7	-0.97431	-0.97630	-0.97826	0.00197	-0.00198
2 , 8	-1.17431	-1.17667	-1.17901	0.00234	-0.00236
2 , 9	-1.35734	-1.35998	-1.36260	0.00262	-0.00264
3 , 1	-0.02243	-0.02264	-0.02285	0.00021	-0.00021
3 , 2	-0.07801	-0.07866	-0.07932	0.00065	-0.00065
3 , 3	-0.13899	-0.14015	-0.14129	0.00115	-0.00115
3 , 4	-0.20869	-0.21043	-0.21216	0.00173	-0.00174
3 , 5	-0.28436	-0.28678	-0.28920	0.00242	-0.00242
3 , 6	-0.38640	-0.38961	-0.39281	0.00320	-0.00321
3 , 7	-0.50327	-0.50731	-0.51133	0.00402	-0.00404
3 , 8	-0.62293	-0.62776	-0.63257	0.00481	-0.00483
3 , 9	-0.73141	-0.73688	-0.74233	0.00545	-0.00547
4 , 1	0.00725	0.00703	0.00681	0.00022	-0.00022
4 , 2	0.02298	0.02229	0.02155	0.00074	-0.00069
4 , 3	0.03972	0.03851	0.03721	0.00130	-0.00121
4 , 4	0.06141	0.05962	0.05769	0.00193	-0.00179
4 , 5	0.08642	0.08398	0.08135	0.00263	-0.00245
4 , 6	0.11317	0.10997	0.10656	0.00341	-0.00320
4 , 7	0.13780	0.13372	0.12951	0.00422	-0.00407
4 , 8	0.16030	0.15539	0.15042	0.00497	-0.00492
4 , 9	0.17675	0.17115	0.16560	0.00555	-0.00559
5 , 1	0.03233	0.03214	0.03195	0.00019	-0.00019
5 , 2	0.11426	0.11368	0.11310	0.00058	-0.00058
5 , 3	0.19031	0.18930	0.18829	0.00101	-0.00101
5 , 4	0.28747	0.28596	0.28444	0.00151	-0.00151
5 , 5	0.39271	0.39063	0.38854	0.00208	-0.00208
5 , 6	0.52438	0.52167	0.51897	0.00271	-0.00271
5 , 7	0.66295	0.65962	0.65630	0.00332	-0.00333
5 , 8	0.77326	0.76938	0.76551	0.00387	-0.00388
5 , 9	0.86079	0.85652	0.85226	0.00426	-0.00427

Table 33: The A_4 caculated Effective Born v0, in experimental bins M_{bin}, Y_{bin}. Continuation of Table 32:

M_{bin}, Y_{bin}	$\sin^2\theta_W^{eff} = 0.23100$	$\sin^2\theta_W^{eff} = 0.23150$	$\sin^2\theta_W^{eff} = 0.23200$	Δ_P	Δ_M
6 , 1	0.07990	0.07977	0.07963	0.00013	-0.00013
6 , 2	0.18659	0.18618	0.18577	0.00041	-0.00041
6 , 3	0.32375	0.32304	0.32233	0.00071	-0.00071
6 , 4	0.48585	0.48479	0.48374	0.00105	-0.00105
6 , 5	0.65382	0.65238	0.65094	0.00144	-0.00144
6 , 6	0.85126	0.84943	0.84761	0.00183	-0.00183
6 , 7	1.07892	1.07675	1.07458	0.00217	-0.00217
6 , 8	1.23912	1.23665	1.23418	0.00247	-0.00247
6 , 9	1.41110	1.40854	1.40599	0.00256	-0.00256
7 , 1	0.07496	0.07488	0.07479	0.00008	-0.00008
7 , 2	0.25547	0.25521	0.25496	0.00025	-0.00025
7 , 3	0.44422	0.44378	0.44334	0.00044	-0.00044
7 , 4	0.67355	0.67291	0.67228	0.00064	-0.00064
7 , 5	0.88920	0.88836	0.88751	0.00085	-0.00085
7 , 6	1.10575	1.10469	1.10362	0.00106	-0.00106
7 , 7	1.34808	1.34684	1.34561	0.00123	-0.00123
7 , 8	1.50391	1.50256	1.50120	0.00136	-0.00136
7 , 9	1.68489	1.68358	1.68226	0.00131	-0.00132

Δ_P, Δ_M correspond to ΔA_4 due to $\delta_V = \pm 0.00050$

The A_4 in the full phase-space

EW NLO+HO - Effective Born (TauSpinner + Dizet 6.45)

Table 34: The ΔA_4 for $\Delta \sin^2\theta_W = +0.00050$, estimated with full EW corrections and Effective Born v0, in experimental bins M_{bin}, Y_{bin}. *Updated with* `Dizet 6.45` *form factors.*

M_{bin}, Y_{bin}	ΔA_4 (full EW)	ΔA_4 (Effective v0)
1 , 1	0.00004	0.00004
1 , 2	0.00012	0.00011
1 , 3	0.00021	0.00019
1 , 4	0.00032	0.00029
1 , 5	0.00044	0.00040
1 , 6	0.00059	0.00054
1 , 7	0.00074	0.00068
1 , 8	0.00089	0.00082
1 , 9	0.00100	0.00091
2 , 1	0.00011	0.00010
2 , 2	0.00035	0.00033
2 , 3	0.00061	0.00057
2 , 4	0.00091	0.00086
2 , 5	0.00127	0.00120
2 , 6	0.00168	0.00158
2 , 7	0.00209	0.00197
2 , 8	0.00249	0.00234
2 , 9	0.00279	0.00262
3 , 1	0.00022	0.00021
3 , 2	0.00068	0.00065
3 , 3	0.00120	0.00115
3 , 4	0.00181	0.00173
3 , 5	0.00253	0.00242
3 , 6	0.00335	0.00320
3 , 7	0.00421	0.00402
3 , 8	0.00504	0.00481
3 , 9	0.00571	0.00545
4 , 1	0.00030	0.00022
4 , 2	0.00081	0.00074
4 , 3	0.00139	0.00130
4 , 4	0.00207	0.00193
4 , 5	0.00280	0.00263
4 , 6	0.00359	0.00341
4 , 7	0.00438	0.00422
4 , 8	0.00517	0.00497
4 , 9	0.00585	0.00555
5 , 1	0.00020	0.00019
5 , 2	0.00061	0.00058
5 , 3	0.00107	0.00101
5 , 4	0.00160	0.00151
5 , 5	0.00220	0.00208
5 , 6	0.00287	0.00271
5 , 7	0.00353	0.00332
5 , 8	0.00411	0.00387
5 , 9	0.00454	0.00426

Table 35: The ΔA_4 for for $\Delta \sin^2\theta_W = +0.00050$, estimated with full EW corrections and Effective Born v0, in experimental bins M_{bin}, Y_{bin}. *Updated with* `Dizet 6.45` *form factors.*

M_{bin}, Y_{bin}	ΔA_4 (full EW)	ΔA_4 (Effective v0)
6 , 1	0.00014	0.00013
6 , 2	0.00044	0.00041
6 , 3	0.00076	0.00071
6 , 4	0.00113	0.00105
6 , 5	0.00155	0.00144
6 , 6	0.00198	0.00183
6 , 7	0.00235	0.00217
6 , 8	0.00268	0.00247
6 , 9	0.00280	0.00256
7 , 1	0.00009	0.00008
7 , 2	0.00028	0.00025
7 , 3	0.00049	0.00044
7 , 4	0.00071	0.00064
7 , 5	0.00095	0.00085
7 , 6	0.00119	0.00106
7 , 7	0.00139	0.00123
7 , 8	0.00153	0.00136
7 , 9	0.00151	0.00131

ΔA_4 due to δ_V = +0.00050

Factorizing QCD: Reweighting technique

Reweighting possible because of Drell-Yan factorisation properties, Mirkes et al. arXiv:9406381.

Method follows technique developed for TauSpinner program (for LHC!), arXiv:1201.0117; 1802.05459

Define per event electroweak weight $wt^{EW} = \sigma^{new}_{Born}/\sigma^{old}_{Born}$

$$wt^{EW} = \frac{d\sigma_{Born+EW}(x_1, x_2, \hat{s}, \cos\theta^*, s_W^2)}{d\sigma_{Born}(x_1, x_2, \hat{s}, \cos\theta^*, s_W^2)}$$

$$d\sigma_{Born}(x_1, x_2, \hat{s}, \cos\theta^*, s_W^2) = \sum_{q_f, \bar{q}_f} [f^{q_f}(x_1, ...) f^{\bar{q}_f}(x_2, ...) d\sigma_{Born}^{q_f \bar{q}_f}(\hat{s}, \cos\theta^*, s_W^2) + f^{q_f}(x_2, ...) f^{\bar{q}_f}(x_1, ...) d\sigma_{Born}^{\bar{q}_f q_f}(\hat{s}, -\cos\theta^*, s_w^2)]$$

x_1, x_2, $\cos\theta^*$ (symmetrised) calculated using 4-momenta of outgoing leptons; asymmetry in sign of $\cos\theta^*$ from average over PDFs

Allows to reweight MC event generated with any EW LO scheme to

- Improved Born Approximation including:
  - EW loop corrections to propagators
  - EW loop corrections to vector couplings without boxes
  - EW Loop corrections with boxes
- Effective Born with LEP with improved norm. parametrisation

Different rest frames (reminder)

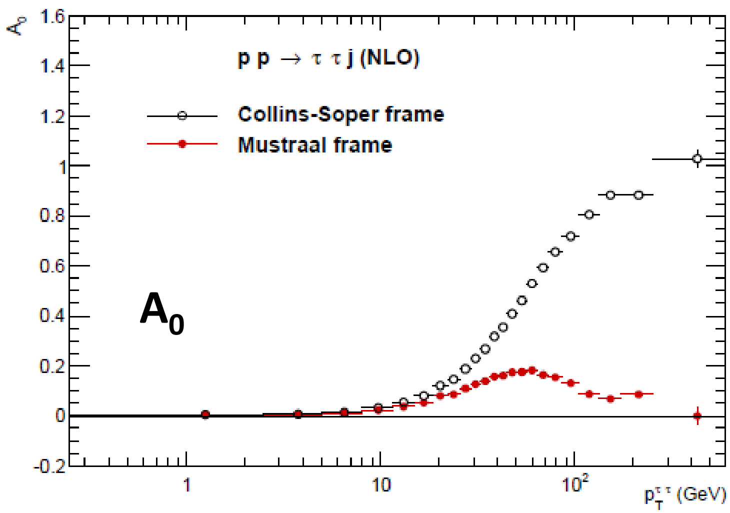
- **Polar and azimuthal angle are defined in the rest-frame of outgoing leptons. But how?**
  1) **Collins-Soper frame: used for Ais 8 TeV measurement. All Ais non-zero at high pT.**
  2) **Mustraal frame: proven in 80's (F.A.Berends at al. Comp. Phys. Com 29(1983) 185) that for qqbar->Z->ll and single spin-1 emission in initial state (gluon or photon) matrix element can be presented as weighted sum of Borns. Addapted (ERW&ZW, Eur. Phys. J C76 (2016) 473) to pp case and added definition of azimuthal angle. Only A4 non-zero at high pT.**
  3) **$\cos\theta^*$ frame: used in precision calculations for LEP to minimise some higher order corrections to optimal observables (eg. asymmetries).**
- **Any of those frames can be used for Ais definition or calculating wt_{sw2}, wt_{EWloop} . For now, for measurement we use (1) and for calculating weights we use (3).**

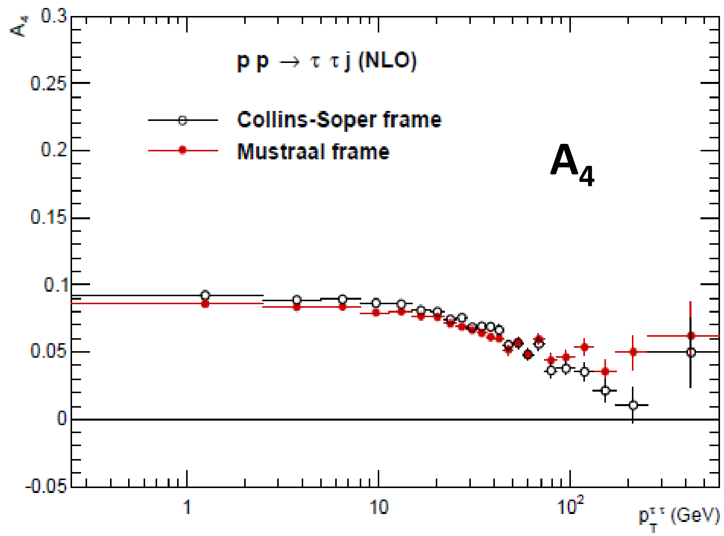
A_i's in different rest frames

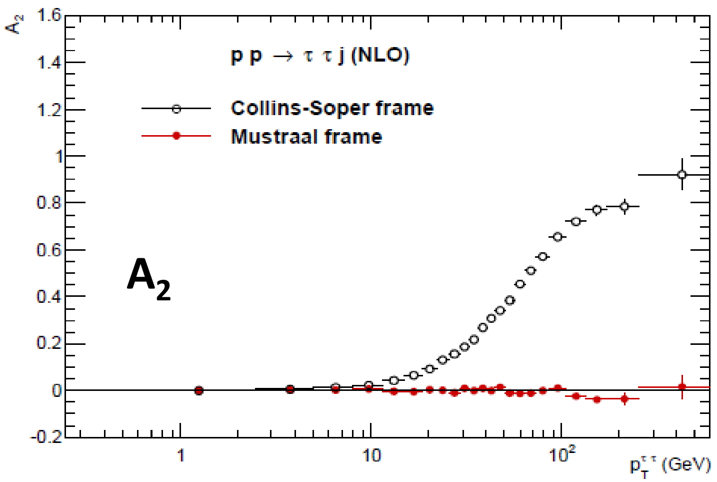
Black: Collins-Soper frame

Red: Mustraal frame

ERW & Z. Was
arXiv:1605.05450







MC events generated with Powheg+MiNLO Zj (NLO)

In Mustraal frame, NLO QCD event has „Born-like" angular correlations of leptons from Z decay. Preferred frame to factorise EW and QCD corrections. Remaining A_i's close to zero.

How sensitive is A_{fb} to rest frame used for calculating wt^{EW}

Table 24: The difference in forward-backward asymmetry, ΔA_{FB} around Z-pole, m_{ee} = 89 - 93 GeV. The difference is calculated using $\cos\theta^{CS}$ to define forward and backward hemisphere. The EW weight is calculated with $\cos\theta^{*}$, $\cos\theta^{Mustraal}$ or $\cos^{CS}$.
Updated with Dizet 6.45 *form factors.*

Corrections to A_{FB} ($89 < m_{ee} < 93$ GeV)	$wt^{EW}(\cos\theta^{*})$	$wt^{EW}(\cos\theta^{ML})$	$wt^{EW}(\cos\theta^{CS})$
A_{FB}(EW/QCD corr. to m_W) - A_{FB}(EW LO $\alpha(0)$)	-0.02076	-0.02091	-0.02080
A_{FB}(EW/QCD corr. to $\chi(Z),\chi(\gamma)$) - A_{FB}(EW LO $\alpha(0)$)	-0.02047	-0.02062	-0.02051
A_{FB}(EW/QCD FF no boxes) - A_{FB}(EW LO $\alpha(0)$)	-0.03491	-0.03517	-0.03497
A_{FB}(EW/QCD FF with boxes) - A_{FB}(EW LO $\alpha(0)$)	-0.03489	-0.03516	-0.03496
A_{FB}(Eff. v0) - A_{FB}(EW/QCD FF with boxes)	0.00039	0.00037	0.00039
A_{FB}(Eff. v1) - A_{FB}(EW/QCD FF with boxes)	0.00042	0.00038	0.00042
A_{FB}(Eff. v2) - A_{FB}(EW/QCD FF with boxes)	0.00022	0.00024	0.00022

δA_{fb}^{frame} = 20 10-5

Shift in predicted $A_{fb}(M_Z)$ by 20 10-5 $\rightarrow \Delta \sin^2\theta_w^{eff}$ = ~ 10 10-5
We can take it as proxy for systematics uncertainties from QCD corrections.
Should fall into same category as PDFs uncertainties.

Summary

- **Started preparing Tables with binned ΔA_4 (EW)**
  - **Quantify difference between EW NLO+HO corrections and Effective Born**
  - **Next step will be to compare with those presented by Aleko.**
    Not straighforward, because I don't have 13 TeV samples generated consistently with setup of CMS pseudodata.

- **To which extend we can factorise EW and QCD corrections**

- **Draft v05 status**
  - **No comments nor contributions received!**

SPARES slides

Z-boson propagator

For now we took pragmatic approach: use defaults of each code:

- **Powheg_ew and MCSANC: pole-mass and fixed width propagator**
  - **Not clear to me if implementation includes N_Z modification to couplings (?)**
  - **If yes, how it is share between ga, gf couplings, does it affect sin2weff interpretation (?)**
  - **If not included, does it count for „missing HO corrections" (?)**

- **wt^{EW} : calculated with on-shell masses and running width propagator, as it is standard used by Zfitter+Dizet**

We should keep it in mind, that ones we reach precision of the comparisons which might be sensitive to the effect of $\chi(s)$ implementation.

It should be discussed as component of theoretical uncertainties of the predictions.

Z-boson propagator

Running width, on-shell M_Z, Γ_Z

$$\chi_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot s / M_Z}$$

Fixed width, on-shell M_Z, Γ_Z

$$\chi'_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot M_Z}.$$

Equivalent to [dashed box]

shifted M_Z, Γ_Z, scaled by N_Z

$$\begin{aligned}
\chi_Z(s) &= N'_Z \frac{1}{s - {M'_Z}^2 + i\Gamma'_Z M'_Z} \\
M'_Z &= \frac{M_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}} \\
\Gamma'_Z &= \frac{\Gamma_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}} \\
N'_Z &= \frac{(1 - i \cdot \Gamma_Z / M_Z)}{(1 + \Gamma_Z^2 / M_Z^2)} = \frac{(1 - i \cdot \Gamma'_Z / M'_Z)}{(1 + {\Gamma'_Z}^2 / {M'_Z}^2)}
\end{aligned}$$

Shifted M_Z, Γ_Z, no scaling N_Z

$$\begin{aligned}
\chi_Z(s) &= \frac{1}{s - {M'_Z}^2 + i\Gamma'_Z M'_Z} \\
M'_Z &= \frac{M_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}} \\
\Gamma'_Z &= \frac{\Gamma_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}}
\end{aligned}$$

Z-boson propagator

Reference: LEP convention: running width propagator, nominal M_Z, Γ_Z

Table 15: Ratio of the cross-section σ alculated with different form Z-boson propagator, integrated over specified mass windows. Shown in case of EW LO and EW NLO+HO predictions with $O(\alpha(0)$ v0 EW scheme.

σ (Fixed/Running)	$90.5 < m_{ee} < 91.5$ GeV	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW LO					
with M_Z, Γ_Z shift, no scaling	1.00087	1.00087	1.00062	1.00086	1.00071
no M_Z, Γ_Z shift, no scaling	0.99620	1.00074	0.99716	0.99977	1.00392
EW NLO+HO					
with M_Z, Γ_Z shift, no scaling	1.00113	1.00085	1.00043	1.00083	1.00075
no M_Z, Γ_Z shift, no scaling	0.99746	1.00122	0.99719	1.00013	1.00392

Table 16: Difference in A_{fb} calculated wiht different form of Z-boson propagator, integrated over specified mass windows. Shown in case of EW LO and EW NLO+HO predictions with $O(\alpha(0)$ v0 EW scheme.

ΔA_{fb} (Running - Fixed)	$90.5 < m_{ee} < 91.5$ GeV	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW LO					
with M_Z, Γ_Z shift, no scaling	-0.00048	-0.00047	-0.00047	-0.00047	-0.00030
no M_Z, Γ_Z shift, no scaling	-0.00006	-0.00026	-0.00012	-0.00040	-0.00005
EW NLO+HO					
with M_Z, Γ_Z shift, no scaling	-0.00053	-0.00053	-0.00052	-0.00053	-0.00024
no M_Z, Γ_Z shift, no scaling	-0.00007	-0.00030	-0.00026	-0.00048	-0.00004

Blue box: **used by LHC experiments** → **for A_{fb} and around Z-pole very close to LEP convention**

Red box: **used by Powheg_ew**

Virtual EW corrections

wt^{EW} : TauSpinner + Dizet 6.45

wt^{EW}

MC events
EW LO

Arbitrary
EW setup

- $\alpha(0)$ v0: LO, NLO+HO
- $\alpha(0)$ v1: LO
- G_μ: LO
- $\sin^2_{eff}$: LO

Powheg_ew: QCD LO

- $\alpha(0)$ v0: LO
- $\alpha(0)$ v1: LO, NLO, NLO+HO
- G_μ: LO, NLO, NLO+HO
- $\sin^2_{eff}$: LO, NLO, NLO+HO

MCSANC: QCD LO

- $\alpha(0)$ v1: LO, NLO, NLO+HO
- G_μ: LO, NLO, NLO+HO

EW schemes: benchmark input parameters

SM relation used to calculate EW LO parameters for different schemes. On-shell mass.

LEP-legacy (column $(\alpha(0), G_\mu, M_Z)$) — **LHC-paradigm** (column (G_μ, M_Z, M_W)) — **New scheme** (column (G_μ, s_W^2, M_Z))

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0	$(\alpha(0), M_W, M_Z)$ $\alpha(0)$ v1	(G_μ, M_Z, M_W) G_μ	$(\alpha(0), s_W^2, M_Z)$ $\sin^2_{eff}$ v1	(G_μ, s_W^2, M_Z) $\sin^2_{eff}$ v2
M_Z (GeV)	91.1876	91.1876	91.1876	91.1876	91.1876
Γ_Z (GeV)	2.4952	2.4952	2.4952	2.4952	2.4952
Γ_W (GeV)	2.085	2.085	2.085	2.085	2.085
$1/\alpha$	137.035999139	137.035999139	132.23323	137.035999139	128.744939484
α	0.007297353	0.007297353	0.007562396	0.007297353	0.007767296
G_μ (GeV^{-2})	$1.1663787 \cdot 10^{-5}$	$1.1254734 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$	$1.09580954 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$
M_W (GeV)	80.93886	80.385	80.385	79.93886984	79.93886984
s_W^2	0.2121517	0.2228972	0.2228972	0.231499	0.231499
$\frac{G_\mu \cdot M_Z^2 \cdot 16 c_W^2 s_W^2}{\sqrt{2} \cdot 8\pi \cdot \alpha} = 1.0$; $s_W^2 = 1 - m_W^2/m_Z^2$	$\rightarrow s_W^2, M_W$	$\rightarrow G_\mu, s_W^2$	$\rightarrow \alpha, s_W^2$	$\rightarrow G_\mu, m_W$	$\rightarrow \alpha, m_W$
$\alpha_s(M_Z)$	0.120178900000	0.120178900000	0.120178900000	0.120178900000	0.120178900000

$$s_W^2 = 1 - m_W^2/m_Z^2$$

$$G_\mu = \frac{\pi\alpha}{\sqrt{2} M_W^2 s_W^2}$$

Pseudo-observables at Z-pole: benchmarks

„Best predictions" in each EW scheme, i.e. EW NLO+HO

	Dizet v6.45		Powheg_ew, MCSANC		Powgeh_ew
Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0	$(\alpha(0), M_W, M_Z)$ $\alpha(0)$ v1	(G_μ, M_Z, M_W) G_μ	$(\alpha(0), s_W^2, M_Z)$ $\sin^2_{eff}$ v1	(G_μ, s_W^2, M_Z) $\sin^2_{eff}$ v2
M_Z (GeV)	91.1876	91.1876	91.1876	91.1876	91.1876
$1/\alpha(M_Z)$ $\alpha(M_Z)$ G_μ (GeV^{-2})	0.0077549256 128.9503020 $1.1663787 \cdot 10^{-5}$		??? $1.1663787 \cdot 10^{-5}$		??? $1.1663787 \cdot 10^{-5}$
M_W (GeV) s_W^2	80.358935 0.223401084	80.385 0.22289722	80.385 0.22289722		???
$\sin^2\theta^\ell_{eff}$ $\sin^2\theta^u_{eff}$ $\sin^2\theta^d_{eff}$ $\sin^2\theta^b_{eff}$	0.231499 0.231392 0.231265 0.232733		???	0.231499	0.231499 ???

Experiments measure observables: cross-sections, asymmetries, distributions.
We need predictions to interpret these measurements.
For now, only TauSpinner + Dizet provides predictions for LEP-style pseudo-observables.

$\sin^2_W{}^{eff}$ at NLO in G_μ scheme

H Results from analytical programs

From S. Dittmaier

Table 34: The $\sin^2\theta_W^{eff}$ predictions in EW G_μ scheme.

$\sin^2\theta_W^{eff}$	EW LO	EW NLO	EW NLO+HO	Comments
lepton	0.222897222523918	0.232355798367449		
neutrino	0.222897222523918	0.232000993322481		
up-quark	0.222897222523918	0.232255993583881		
down-quark	0.222897222523918	0.232137725235559		
bottom-quark	0.222897222523918	0.233727423384525		

Dizet v6.45

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0
$\sin^2\theta^{\ell}_{eff}$	0.231499
$\sin^2\theta^{u}_{eff}$	0.231392
$\sin^2\theta^{d}_{eff}$	0.231265
$\sin^2\theta^{b}_{eff}$	0.232733

Effective Born

Can we parametrise Effective Born to bring it closer to EW LO+HO Improved Born Approximation?

Table 4: The EW parameters used for: (i) the EW LO $\alpha(0)$ v0 scheme, (ii) effective Born spin amplitude around the Z-pole. The $G_\mu = 1.1663887 \cdot 10^{-5}$ GeV^{-2}, $M_Z = 91.1876$ GeV and $\mathcal{K}_f, \mathcal{K}_e, \mathcal{K}_{\ell f} = 1$.

.

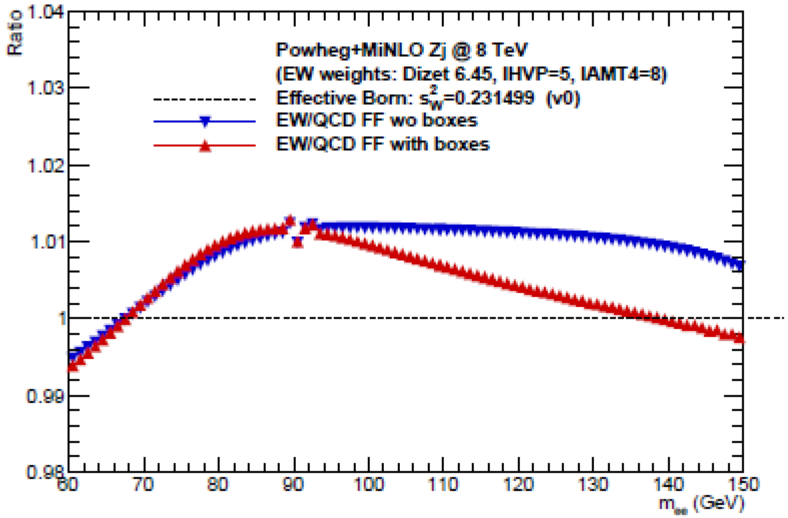
EW LO $\alpha(0)$ scheme	Effective Born *v0*	Effective Born *v1*	Effective Born *v2*
$\alpha = 1/137.03599$ $s_W^2 = 0.21215$ $\rho_{\ell f} = 1.0$	$\alpha = 1/128.9503022$ $s_W^2 = 0.231499$ $\rho_{\ell f} = 1.0$	$\alpha = 1/128.9503022$ $s_W^2 = 0.231499$ $\rho_{\ell f} = 1.005$	$\alpha = 1/128.9503022$ ${s_W^2}^{\ell} = 0.231499$ ${s_W^2}^{up} = 0.231392$ ${s_W^2}^{down} = 0.231265$ $\rho_{\ell up} = 1.005403$ $\rho_{\ell down} = 1.005889$

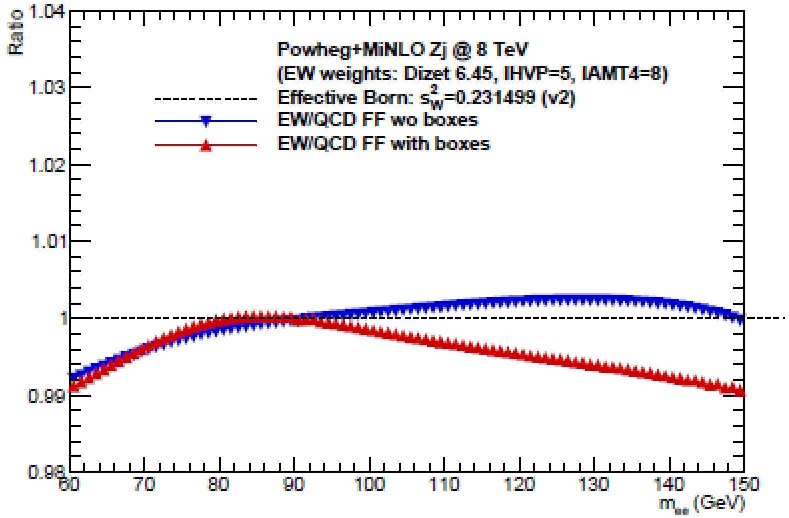
Dizet v6.45

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0
M_Z (GeV)	91.1876
$1/\alpha(M_Z)$ $\alpha(M_Z)$ G_μ (GeV^{-2})	0.0077549256 128.9503020 $1.1663787 \cdot 10^{-5}$
M_W (GeV) s_W^2	80.358935 0.223401084
$\sin^2\theta^{\ell}_{eff}$ $\sin^2\theta^{u}_{eff}$ $\sin^2\theta^{d}_{eff}$ $\sin^2\theta^{b}_{eff}$	0.231499 0.231392 0.231265 0.232733

Effective Born

Can we parametrise Effective Born to bring it closer to EW LO+HO Improved Born Approximation?

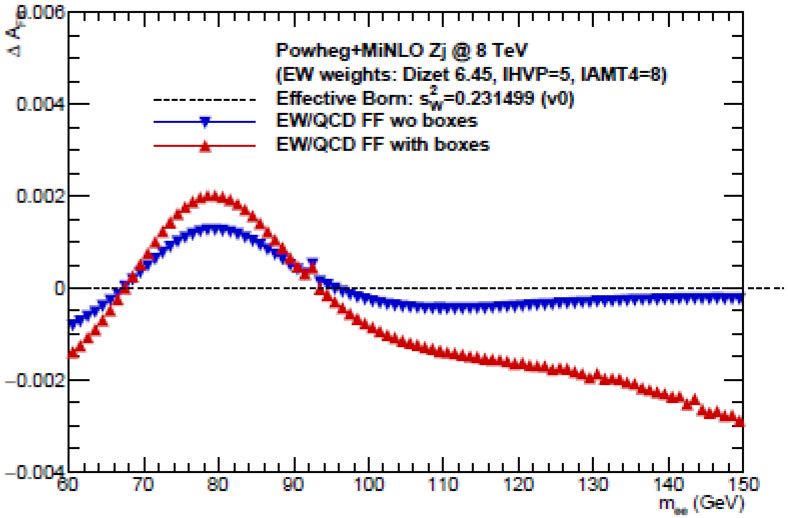


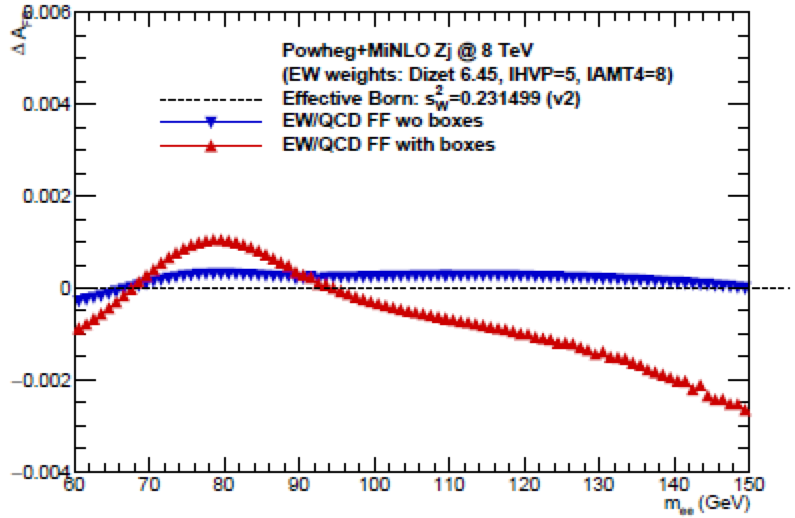


$\sigma^{ref}(NLO+HO)/\sigma(effect.)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
Effective v0	1.01142	1.00411	1.01135	1.00627
Effective v1	1.00130	0.99780	1.00132	0.99800
Effective v2	0.99989	0.99701	0.99987	0.99654

Effective Born

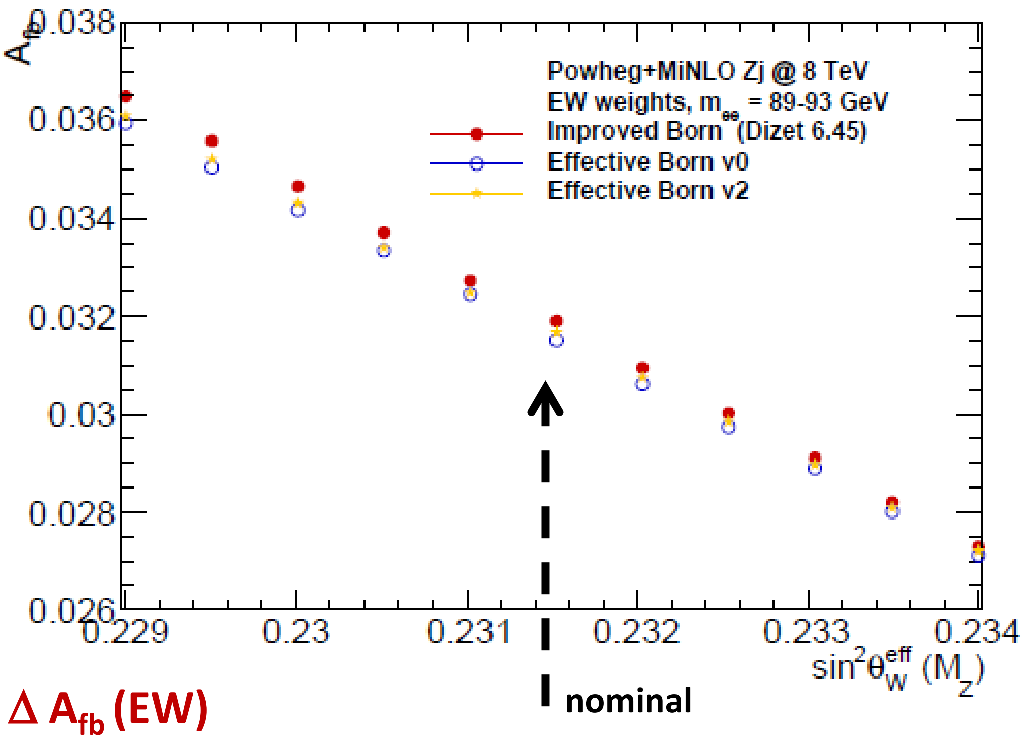
Can we parametrise Effective Born to bring it closer to EW LO+HO Improved Born Approximation?





$A_{fb}^{ref}(NLO+HO) - A_{fb}(effect.)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
Effective v0	0.00039	0.00104	0.00042	-0.00153
Effective v1	0.00042	0.00068	0.00042	-0.00094
Effective v2	0.00022	0.00052	0.00024	-0.00087

$\sin^2\theta_{eff}$ scan for A_{FB} and A_4



Effective Born v0	Effective Born v1	Effective Born v2
$\alpha = 1/128.9503022$	$\alpha = 1/128.9503022$	$\alpha = 1/128.9503022$
$s^2_W = 0.231499$	$s^2_W = 0.231499$	$s^{2\ \ell}_W = 0.231499$ $s^{2\ up}_W = 0.231392$ $s^{2\ down}_W = 0.231265$
$\rho_{\ell f} = 1.0$	$\rho_{\ell f} = 1.005$	$\rho_{\ell up} = 1.005403$ $\rho_{\ell down} = 1.005889$

Dizet v6.45

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0
M_Z (GeV)	91.1876
$1/\alpha(M_Z)$	0.0077549256
$\alpha(M_Z)$	128.9503020
G_μ (GeV^{-2})	$1.1663787 \cdot 10^{-5}$
M_W (GeV)	80.358935
s^2_W	0.223401084
$\sin^2\theta^\ell_{eff}$	0.231499
$\sin^2\theta^u_{eff}$	0.231392
$\sin^2\theta^d_{eff}$	0.231265
$\sin^2\theta^b_{eff}$	0.232733

Δ A_{fb} (EW)

$A^{ref}_{fb}(NLO+HO) - A_{fb}(effect.)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
Effective v0	0.00039	0.00104	0.00042	-0.00153
Effective v1	0.00042	0.00068	0.00042	-0.00094
Effective v2	0.00022	0.00052	0.00024	-0.00087

EW NLO+HO corrections vs „Effective Born v0"

- **Shift in predicted $A_{fb}(M_Z)$ by 40 10-5 → $\Delta \sin^2\theta_w^{eff}$ = ~ 20 10-5**
- **Different slope for $A_{fb}(\sin^2\theta_W^{eff}(M_Z))$**

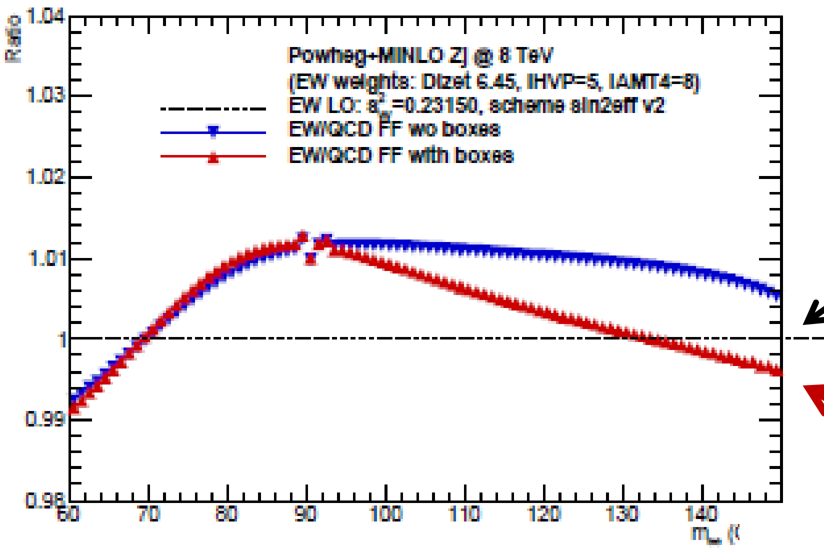
σ(EW)/σ(LO) „expected" for different EW schemes

Ref: NLO+HO with $\alpha(0)$ scheme, Dizet 6.45 form-factors, wt^{EW} from TauSpinner

EW LO

$\sigma^{ref}(NLO+HO)/\sigma(LO)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW scheme $\alpha(0)$) v0	0.96510	1.04695	0.96632	0.96508
EW scheme $\alpha(0)$) v1	1.06558	1.09892	1.06613	1.06202
EW scheme G_μ	0.99211	1.02321	0.99264	0.98884
EW scheme $\sin^2\theta_{eff}$ v2	1.01141	1.00293	1.01132	1.00572

Using Dizet 6.45 form-factors and wt^{EW}, table above presents expected size of EW corrections in different EW schemes.



EW LO sin2eff v2

EW NLO+HO $\alpha(0)$ v0

σ(EW)/σ(LO) „expected” for different EW schemes

Ref: NLO+HO with α(0) scheme, Dizet 6.45 form-factors, wt^{EW} from TauSpinner

$\sigma^{ref}(NLO+HO)/\sigma(LO)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
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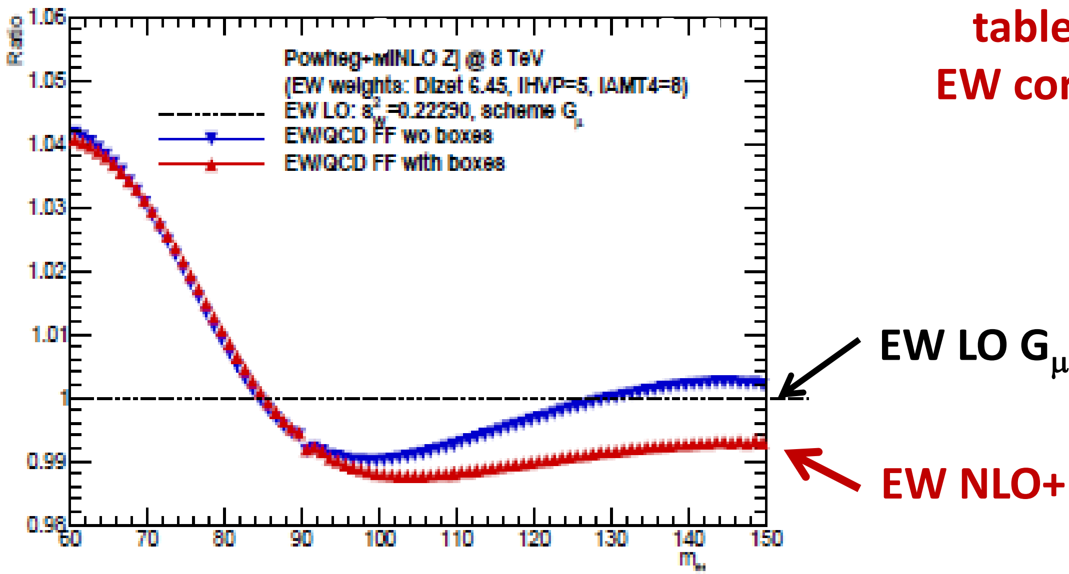
EW scheme $\sin^2\theta_{eff}$ v2	1.01141	1.00293	1.01132	1.00572

EW LO



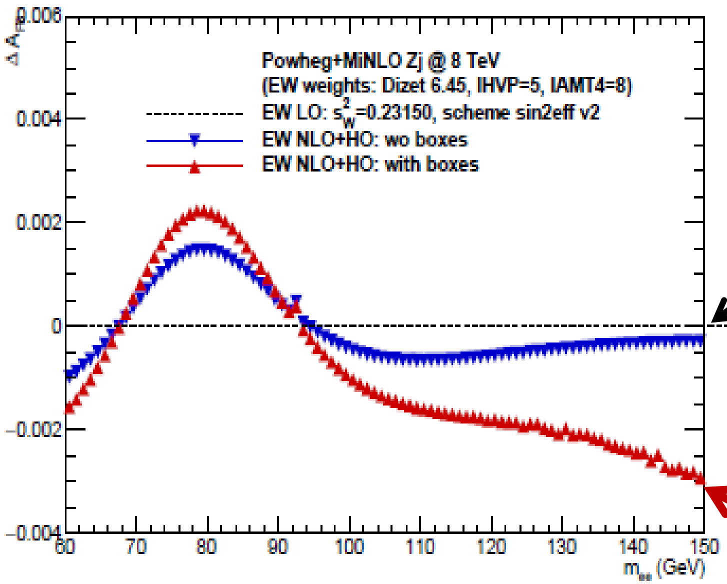
Using Dizet 6.45 form-factors and wt^{EW}, table above presents expected size of EW corrections in different EW schemes.

Δ A_{fb}(EW) „expected” for different EW schemes

Ref: NLO+HO with α(0) scheme, Dizet 6.45 form-factors, wt^{EW} from TauSpinner

EW LO

$A_{fb}^{ref}(NLO+HO) - A_{fb}(LO)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW scheme α(0)) v0	-0.03489	-002880	-0.03514	-0.01334
EW scheme α(0)) v1	-0.01508	-0.01104	-0.01515	-0.00684
EW scheme G_μ	-0.01507	-0.01104	-0.01514	0.00684
EW scheme $\sin^2\theta_{eff}$ v2	-0.00039	0.00115	-0.00046	-0.00171



EW LO sin2eff v2

EW NLO+HO α(0) v0

Using Dizet 6.45 form-factors and wt^{EW}, table above presents expected size of EW corrections in different EW schemes.

Δ A_{fb}(EW) „expected" for different EW schemes

Ref: NLO+HO with $\alpha(0)$ scheme, Dizet 6.45 form-factors, wt^{EW} from TauSpinner

EW LO

$A_{fb}^{ref}(NLO+HO) - A_{fb}(LO)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
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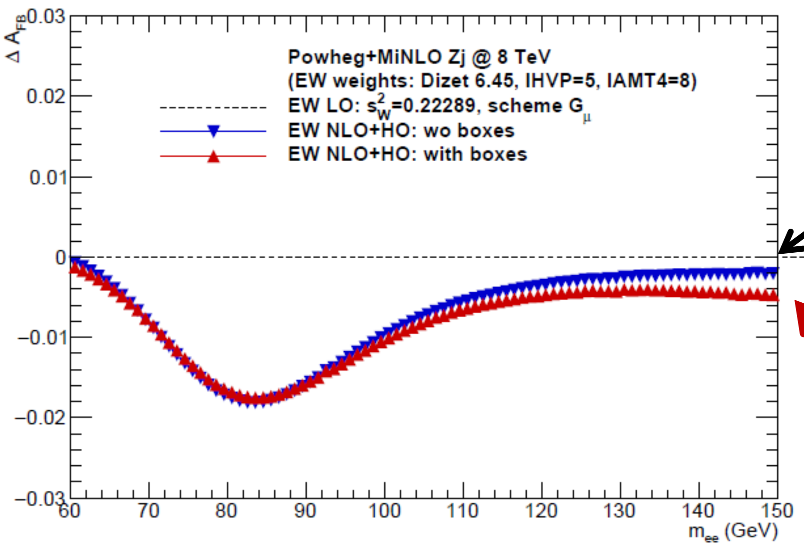
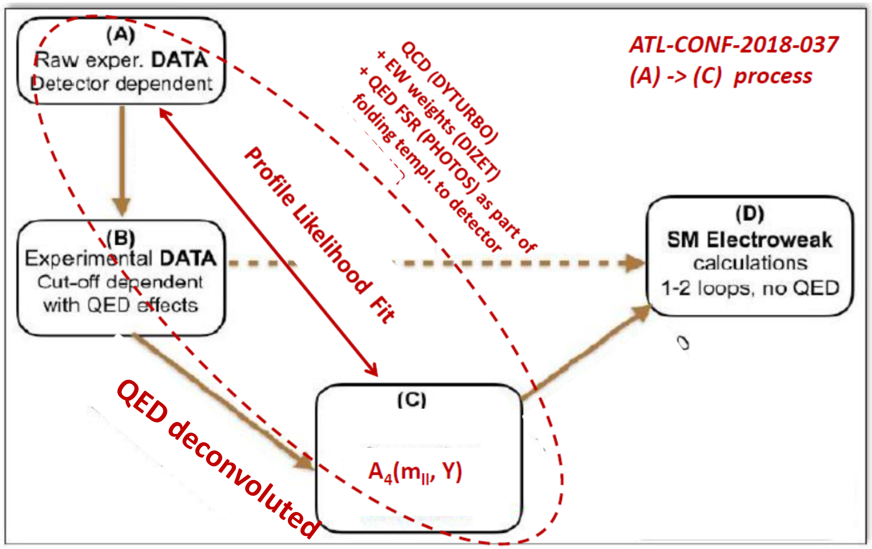


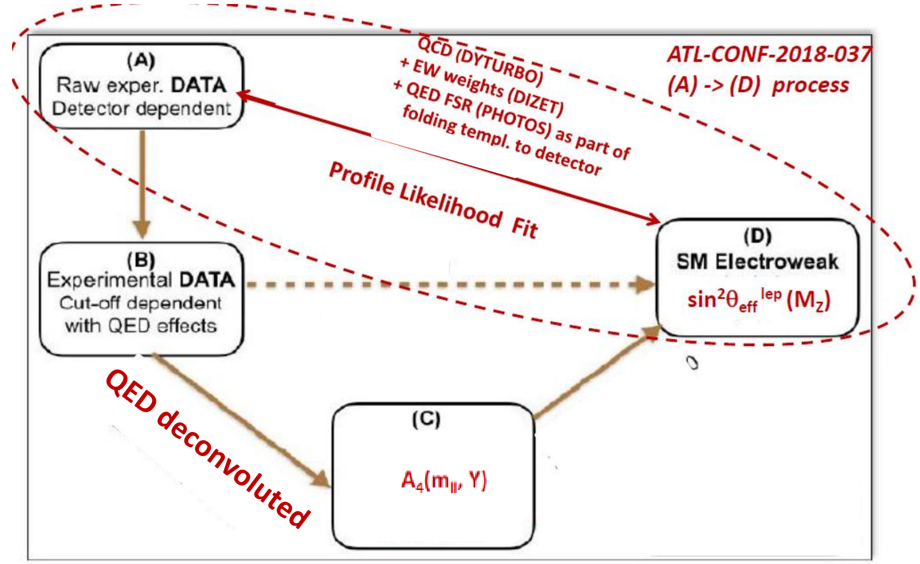
EW LO G_μ

EW NLO+HO $\alpha(0)$ v0

Using Dizet 6.45 form-factors and wt^{EW}, table above presents expected size of EW corrections in different EW schemes.

Electroweak Pseudo-Observables at LHC: the meeting point between data and theory





$$N^n_{\mathrm{exp}}(A,\sigma,\theta) = \left\{ \sum_{j=0}^{N_{\mathrm{bins}}} \sigma_j \times L \times \left[t^n_{8j}(\beta) + \sum_{i=0}^{7} A_{ij} \times t^n_{ij}(\beta) \right] \right\} \times \gamma^n + \sum_{B}^{\mathrm{bkgs}} T^n_B(\beta),$$

$$A_{4,j}(\sin^2\theta^{\ell}_{\mathrm{eff}},\ \theta) = a_j(\theta) \times \sin^2\theta^{\ell}_{\mathrm{eff}} + b_j(\theta)$$

Electroweak Pseudo-Observables at LHC: the meeting point between data and theory

ATL-CONF-2018-037

	$70 < m^{\ell\ell} < 80$ GeV			$80 < m^{\ell\ell} < 100$ GeV				$100 < m^{\ell\ell} < 125$ GeV		
$\lvert y^{\ell\ell}\rvert$	$0-0.8$	$0.8-1.6$	$1.6-2.5$	$0-0.8$	$0.8-1.6$	$1.6-2.5$	$2.5-3.6$	$0-0.8$	$0.8-1.6$	$1.6-2.5$
Central value (NNLO QCD)	−0.0870	−0.2907	−0.5970	0.0144	0.0471	0.0928	0.1464	0.1045	0.3444	0.6807
ΔA_4 (NNLO - NLO QCD)	0.0003	0.0010	0.0021	−0.0001	−0.0005	−0.0009	−0.0015	−0.0007	−0.0022	−0.0041
ΔA_4 (EW)	0.0008	0.0028	0.0056	0.0002	0.0007	0.0015	0.0026	−0.0008	−0.0026	−0.0048
$\Delta \sin^2\theta^{\ell}_{\rm eff}$ (EW)	0.00129	0.00130	0.00133	0.00024	0.00024	0.00025	0.00026	−0.00120	−0.00123	−0.00119
	Uncertainties			Uncertainties				Uncertainties		
Total	0.0035	0.0094	0.0137	0.0007	0.0017	0.0021	0.0021	0.0040	0.0102	0.0140
PDF	0.0034	0.0092	0.0127	0.0007	0.0016	0.0020	0.0019	0.0039	0.0100	0.0131
QCD scales	0.0006	0.0019	0.0052	0.0003	0.0003	0.0004	0.0008	0.0005	0.0022	0.0049

Observables:

cross-sections and asymmetries (A_{FB}, A_4) , unfolded to truth level, in different m_{ll} and y bins.

Δ $\sin^2{}_{eff}^{lep}$ (scan) -> ΔA_4(EW, QCD) predicted <-> A4 (measured) -> fitted $\sin^2{}_{eff}^{lep}$ (best)

$\sin^2\theta_{eff}$ scan for A_{FB} and A_4

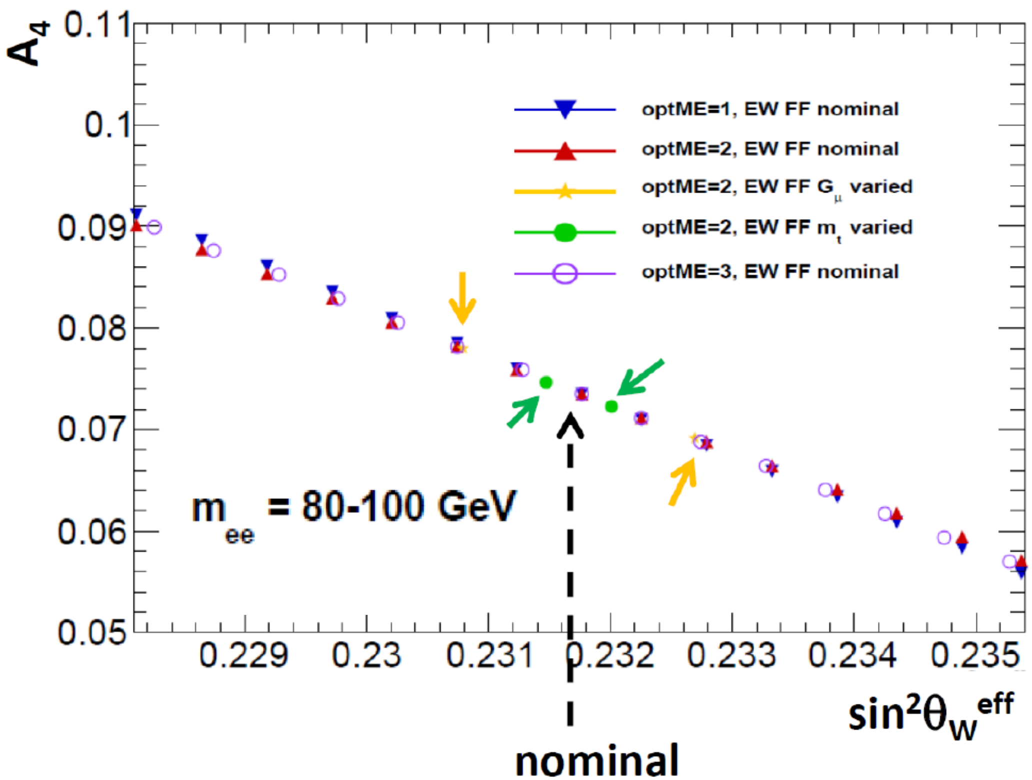
- **This is not a „global fit", but scan targeted to sensitivity to $\sin^2\theta_W^{eff}$**
  - **One should therefore not impose EW LO relations for the scan, namely only $\sin^2\theta_W^{eff}$ should be varied and nothing else. Is this agreed by everyone? See arguments below.**

- **What are options?**
  - **Change input parameter: m_t, m_W, G_μ, recalculated EW corrections, find the „best matching".**
    - **Cons: input parameters for scan outside measured values; it is indirect fit of that parameter not of the $\sin^2\theta_W^{eff}$**
  - **Change $\sin^2\theta_W^{eff}$ by adding δ_v term, propagate to matrix element, find „best matching"**
    - **Cons: going beyond SM in arbitrary manner.**

- **Compare scans between EW LO and EW NLO+HO.**
  - **Each calculation should precisely determine the difference in behaviour of asymmetry versus $\sin^2\theta_W^{eff}$, since $A_{FB}/A_4(\sin^2\theta_W^{eff})$ is sensitive to EW corrections.**

$\sin^2\theta_{eff}$ scan for A_{FB} and A_4

EW corr. with $\alpha(0)$ scheme



Varied m_t, recalculated form-factors

Varied G_μ, recalculated form-factors

Varied δ_V

Varied δ_{s2w}

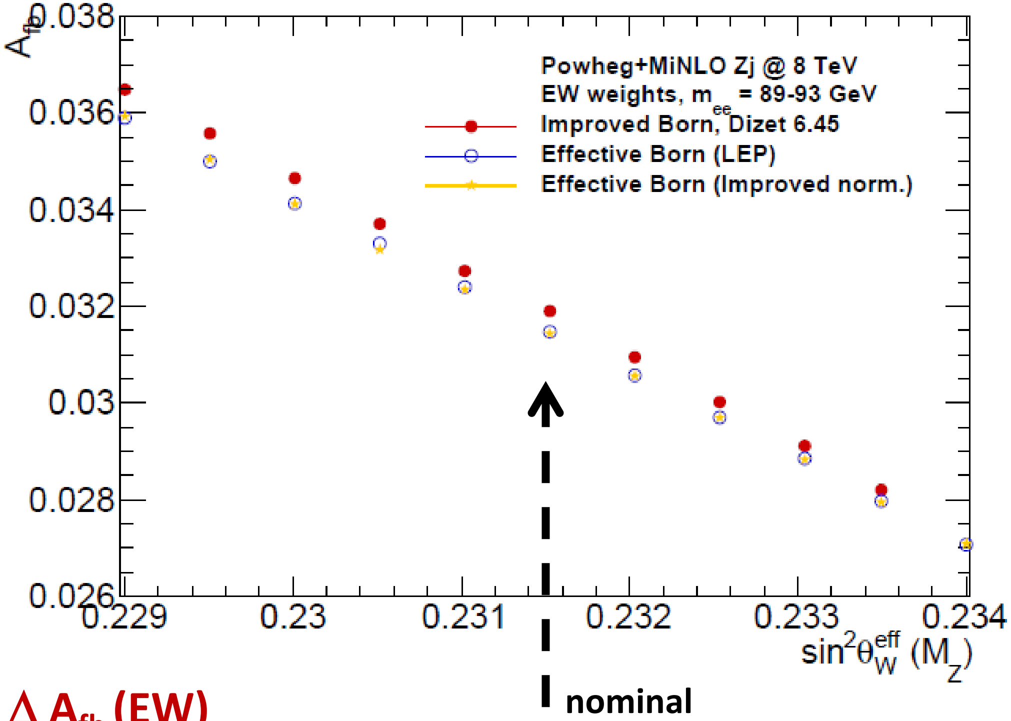
optME=1

$$
\begin{aligned}
v_\ell &= (2\cdot T_3^\ell - 4\cdot q_\ell\cdot(s_W^2+\delta_{S2W})\cdot\mathscr{K}_\ell(s,t))/\Delta,\\
v_f &= (2\cdot T_3^f - 4\cdot q_f\cdot(s_W^2+\delta_{S2W})\cdot\mathscr{K}_f(s,t))/\Delta,\\
vv_{\ell f} &= \frac{1}{v_\ell\cdot v_f}[(2\cdot T_3^\ell)(2\cdot T_3^f)\\
&-4\cdot q_\ell\cdot(s_W^2+\delta_{S2W})\cdot\mathscr{K}_f(s,t)(2\cdot T_3^\ell)\\
&-4\cdot q_f\cdot(s_W^2+\delta_{S2W})\cdot\mathscr{K}_\ell(s,t)(2\cdot T_3^f)\\
&+(4\cdot q_\ell\cdot s_W^2)(4\cdot q_f\cdot s_W^2)\mathscr{K}_{\ell f}(s,t)\\
&+2\cdot(4\cdot q_\ell))(4\cdot q_f\cdot)\cdot s_W^2\cdot\delta_{S2W})\mathscr{K}_{\ell f}(s,t)]\ \frac{1}{\Delta^2}
\end{aligned}
$$

optME=3

$$
\begin{aligned}
v_\ell &= (2\cdot T_3^\ell - 4\cdot q_\ell\cdot(s_W^2\cdot\mathscr{K}_\ell(s,t)+\delta_V))/\Delta,\\
v_f &= (2\cdot T_3^f - 4\cdot q_f\cdot(s_W^2\cdot\mathscr{K}_f(s,t)+\delta_V))/\Delta,\\
vv_{\ell f} &= \frac{1}{v_\ell\cdot v_f}[(2\cdot T_3^\ell)(2\cdot T_3^f)\\
&-4\cdot q_\ell\cdot(s_W^2+\cdot\mathscr{K}_f(s,t)+\delta_V)(2\cdot T_3^\ell)\\
&-4\cdot q_f\cdot(s_W^2\cdot\mathscr{K}_\ell(s,t)+\delta_V)(2\cdot T_3^f)\\
&+(4\cdot q_\ell\cdot s_W^2)(4\cdot q_f\cdot s_W^2)\mathscr{K}_{\ell f}(s,t)\\
&+2\cdot(4\cdot q_\ell))(4\cdot q_f\cdot)\cdot s_W^2\cdot\mathscr{K}_{\ell f}(s,t)\cdot\delta_V]\ \frac{1}{\Delta^2}.
\end{aligned}
$$

$\sin^2\theta_{eff}$ scan for A_{FB} and A_4



Effective Born *LEP*	Effective Born *LEP with improved norm.*
$\alpha = 1/128.8667$ $s_W^2 = 0.23152$ $\rho_{\ell f} = 1.0$	$\alpha = 1/128.8667$ $s_W^2 = 0.23152$ $\rho_{\ell f} = 1.005$

Dizet v6.45

Parameter	$(\alpha(0), G_\mu, M_Z)$ $\alpha(0)$ v0
M_Z (GeV)	91.1876
$1/\alpha(M_Z)$ $\alpha(M_Z)$ G_μ (GeV^{-2})	0.0077549256 128.9503020 $1.1663787 \cdot 10^{-5}$
M_W (GeV) s_W^2	80.358935 0.223401084
$\sin^2\theta^\ell_{eff}$ $\sin^2\theta^u_{eff}$ $\sin^2\theta^d_{eff}$ $\sin^2\theta^b_{eff}$	0.231499 0.231392 0.231265 0.232733

Δ A_{fb} (EW)

$A_{fb}^{ref}(NLO+HO) - A_{fb}(effect.)$	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
LEP	-0.00043	0.00111	0.00046	-0.00158
LEP with improv. norm.	-0.00046	0.00076	0.00047	-0.00099

EW NLO+HO corrections vs „Effective LEP"

- **Shift in predicted $A_{fb}(M_Z)$ by 45 10-5 → $\Delta \sin^2\theta_w^{eff}$ = ~ 20 10-5**
- **Different slope for $A_{fb}(\sin^2\theta_W^{eff}(M_Z))$**

Status of the YR draft (v03)

Recently updated

Contents

Status of the YR draft (v03)

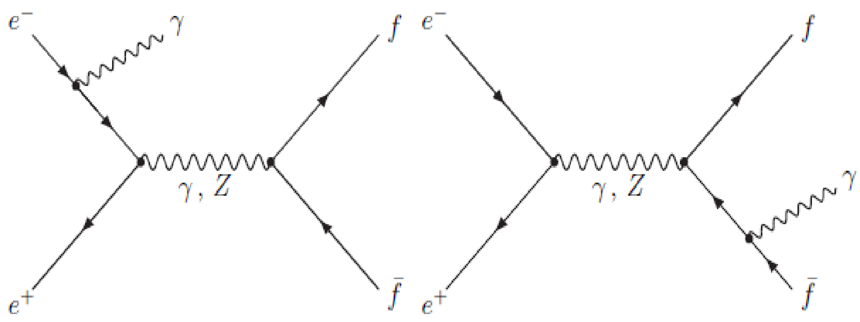
- New since December 2019
  - Appendix from KKMC_hh on QED ISR/IFI
  - Updated TauSpinner + Dizet 6.45 tables/plots
  - Final proposal for mass binning of calculations and how results could be tabulated
- Expected soon:
  - Updates from MCSANC, Powheg_ew:
    - tables, plots, inputs
    - write-up for Appendices
  - Feedback on the content/layout of the draft
- Not settled yet:
  - What is the level of agreement in predictions from different codes and EW schemes.
  - Theory and parametric uncertainties of different EW schemes.
  - Discussion on how to scan $\sin^2\theta_W^{eff}$

LEP legacy: QED (radiative) corrections

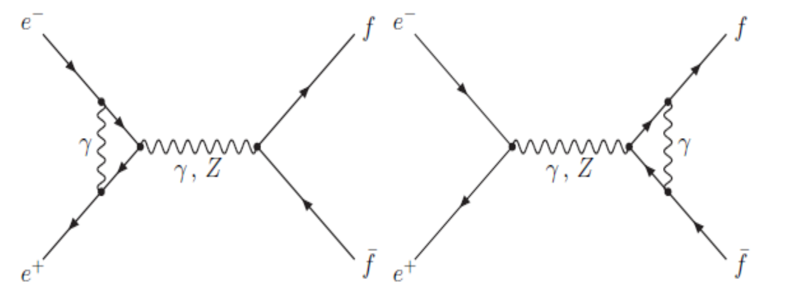
NOT discussed here.

QED FSR can be simulated by PHOTOS (exponentiated multi-photon emission) implemented as after-burner step on already generated event.

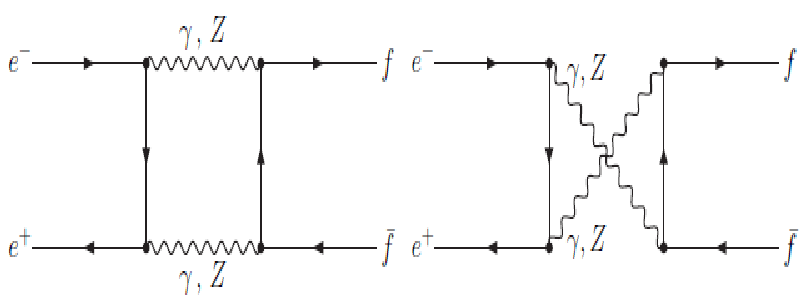
Real emission + pairs creation



Vertex corrections



γγ and γZ box diagrams



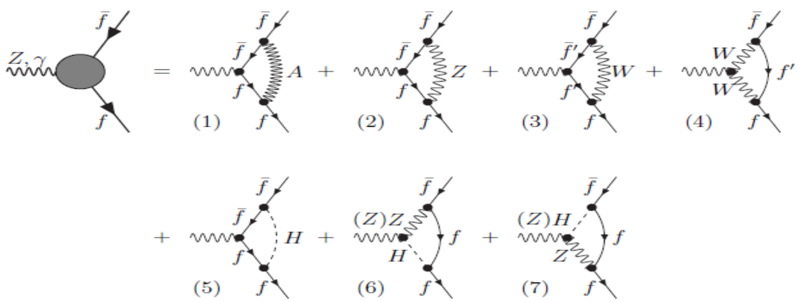
It is QED gauge-invariant set of diagrams (D. Bardin, hep-ph/9908433) which can be factorised out and/or convoluted with QCD corrections.

Calculated with fixed value of α_{QED}
α_{QED} = 1./137.0359895

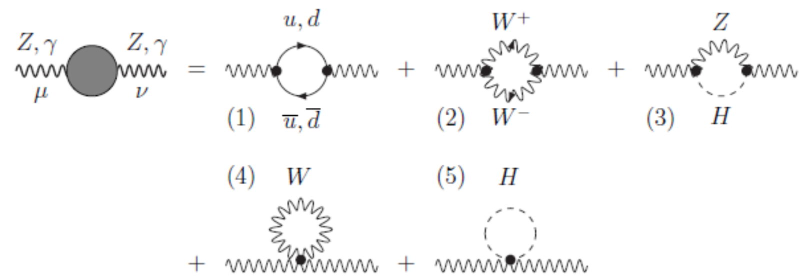
LEP legacy: Genuine EW and lineshape corrections

Also gauge-invariant set of diagrams. Calculated as form-factor corrections to couplings, propagators and masses. Eg. running $\alpha_{QED}(s)$, $\alpha_{QED}(M_Z) = 1./128.86674175$

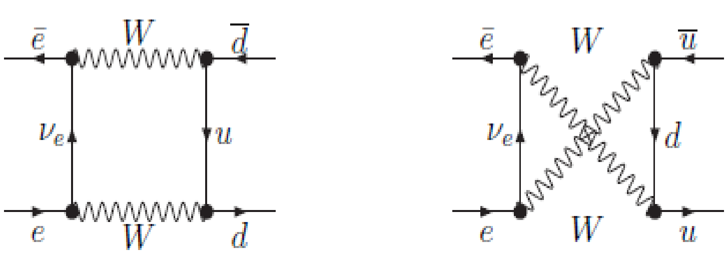
Zff and γ ff vertices



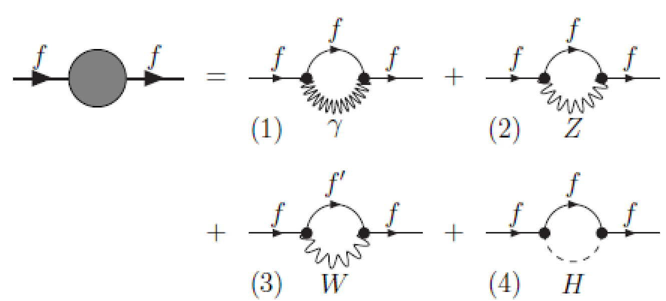
Bosonic self-energies



WW, ZZ boxes (shown only WW diagrams)



Fermionic self-energies



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From Zfitter/Dizet documentation

D. Bardin et al. arXiv:9908433

Zfitter is a **semi-analytical program** for calculating total cross-sections and pseudo-observables (eg. A_{fb}, $\sin^2\theta_W^{eff}$), used by LEP1, and to a lesser degree by LEP2.

DIZET is a library for calculating form-factors and some other corrections. Provides complete EW $O(\alpha)$ weak-loop corrections supplemented with selected higher order terms (eg. vacum polarisation, $\alpha_{QED}(Q^2)$).

For analyses at LEP1, LEP2 used aways in parallel with **MC generators (KoralZ, KoralW)** eg. to evaluate systematics of simplified cuts used in analysis integration.

one loop amplitude

$$\mathcal{A}_Z^{OLA}(s,t) = i\sqrt{2}G_\mu I_e^{(3)} I_f^{(3)} M_Z^2 \chi_Z(s)\rho_{ef}(s,t)\Big\{\gamma_\mu(1+\gamma_5)\otimes\gamma_\mu(1+\gamma_5) - 4|Q_e|s_W^2\kappa_e(s,t)\gamma_\mu\otimes\gamma_\mu(1+\gamma_5) - 4|Q_f|s_W^2\kappa_f(s,t)\gamma_\mu(1+\gamma_5)\otimes\gamma_\mu + 16|Q_eQ_f|s_W^4\kappa_{e,f}(s,t)\gamma_\mu\otimes\gamma_\mu\Big\}. \quad (A.4.75)$$

$$A_\gamma^{OLA} = i\chi_\gamma(s)\alpha(s)\gamma_\mu\otimes\gamma_\mu\,. \quad (2.2.36)$$

Dyson summation leads to the change of α into $\alpha(s)$:

$$\alpha(s) = \frac{\alpha(0)}{1-\Delta\alpha^{\rm fer}(s)} = \frac{\alpha(0)}{1-\Delta\alpha^{(5)}(s)-\Delta\alpha^{t}(s)-\Delta\alpha^{\alpha\alpha_s}(s)}, \quad (2.2.37)$$

Vacuum polarisation corrections

LEP legacy: from Zfitter/Dizet documentation

After some trivial algebra one derives the final expressions:

$$\rho_{ef} = 1+\frac{g^2}{16\pi^2}\Big\{-\Delta\rho_z^F+\mathcal{D}_z^F(s)+\frac{5}{3}B_0^F(-s;M_w,M_w)-\frac{9}{4}\frac{c_w^2}{s_w^2}\ln c_w^2-6+\frac{5}{8}c_w^2\left(1+c_w^2\right)+\frac{1}{4c_w^2}\left(3v_e^2+a_e^2+3v_f^2+a_f^2\right)\mathcal{F}_z(s)+\hat{\mathcal{F}}_w^0(s)+\hat{\mathcal{F}}_w(s)-\frac{r_t}{4}\left[B_0^F(-s;M_w,M_w)+1\right]-c_w^2(R_z-1)\,s\mathcal{B}^d_{WW}(s,t)\Big\}, \quad (A.4.80)$$

$$\kappa_e = 1+\frac{g^2}{16\pi^2}\Big\{-\frac{c_w^2}{s_w^2}\Delta\rho^F-\Pi^F_{Z\gamma}(s)-\frac{1}{6}B_0^F(-s;M_w,M_w)-\frac{1}{9}-\frac{v_e\sigma_e}{2c_w^2}\mathcal{F}_z(s)-\hat{\mathcal{F}}_w^0(s)+(R_z-1)\Big[\frac{|Q_f|}{2}\left(1-4|Q_f|s_w^2\right)\mathcal{F}_z(s)+c_w^2\Big[\hat{\mathcal{F}}_{W_n}(s)-|Q_{f'}|\mathcal{F}_{W_a}(s)+s\hat{\mathcal{B}}^d_{WW}(s,t)\Big]\Big]\Big\}, \quad (A.4.81)$$

$$\kappa_f = 1+\frac{g^2}{16\pi^2}\Big\{-\frac{c_w^2}{s_w^2}\Delta\rho^F-\Pi^F_{Z\gamma}(s)-\frac{1}{6}B_0^F(-s;M_w,M_w)-\frac{1}{9}-\frac{v_f\sigma_f}{2c_w^2}\mathcal{F}_z(s)-\hat{\mathcal{F}}_w(s)+(R_z-1)\Big[\frac{|Q_e|}{2}\left(1-4|Q_e|s_w^2\right)\mathcal{F}_z(s)+c_w^2\Big[\hat{\mathcal{F}}^0_{W_n}(s)-|Q_{e'}|\mathcal{F}_{W_a}(s)+s\hat{\mathcal{B}}^d_{WW}(s,t)\Big]\Big]-\frac{r_t}{4}\left[B_0^F(-s;M_w,M_w)+1\right]\Big\}, \quad (A.4.82)$$

$$\kappa_{ef} = 1+\frac{g^2}{16\pi^2}\Big\{-2\frac{c_w^2}{s_w^2}\Delta\rho^F-2\Pi^F_{Z\gamma}(s)-\frac{1}{3}B_0^F(-s;M_w,M_w)-\frac{2}{9}-\frac{1}{4c_w^2}\Big[\frac{\delta_e^2+\delta_f^2}{s_w^2}(R_w-1)+3v_e^2+a_e^2+3v_f^2+a_f^2\Big]\mathcal{F}_z(s)-\hat{\mathcal{F}}_w^0(s)-\hat{\mathcal{F}}_w(s)-\frac{r_t}{4}\left[B_0^F(-s;M_w,M_w)+1\right]+c_w^2(R_z-1)\Big[\frac{2}{3}-\hat{\Pi}^{\mathrm{bos},F}_{\gamma\gamma}(s)+s\hat{\mathcal{B}}^d_{WW}(s,t)\Big]\Big\}. \quad (A.4.83)$$

interference

Fermionic loops in γ propagator

BOX

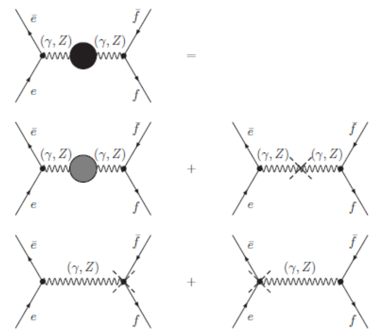


Figure A.11. *Bosonic self-energies and bosonic counter-terms for $e\bar{e} \to (Z,\gamma) \to f\bar{f}$*

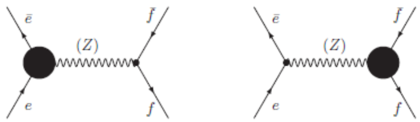


Figure A.10. *Electron (a) and final fermion (b) vertices in $e\bar{e} \to (Z) \to f\bar{f}$*

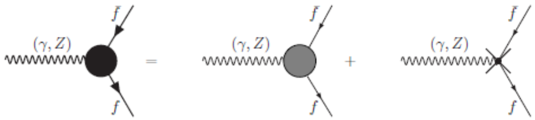


Figure A.6. *Off-shell $Zf\bar{f}$ and $\gamma f\bar{f}$ vertices*

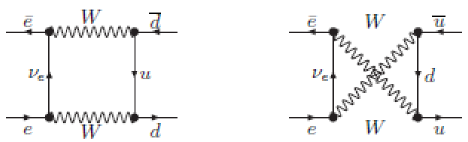


Figure A.7. *The WW boxes*

etc. etc.

Constructing wt^{EW}: EW Improved Born (IBA)

ERW and Z.Was,
arXiv: 1808.08616

$$\mathscr{A}^{Born+EW} = \frac{\alpha}{s}\{ [\bar{u}\gamma^{\mu}vg_{\mu\nu}\bar{v}\gamma^{\nu}u]\cdot(q_\ell\cdot q_f)\cdot\Gamma_{V_\Pi}\cdot\chi_\gamma(s)$$
$$+[\bar{u}\gamma^{\mu}vg_{\mu\nu}\bar{v}\gamma^{\nu}u\cdot(v_\ell\cdot v_f\cdot vv_{\ell f})+\bar{u}\gamma^{\mu}vg_{\mu\nu}\bar{v}\gamma^{\nu}\gamma^5u\cdot(v_\ell\cdot a_f)$$
$$+\bar{u}\gamma^{\mu}\gamma^5vg_{\mu\nu}\bar{v}\gamma^{\nu}u\cdot(a_\ell\cdot v_f)+\bar{u}\gamma^{\mu}\gamma^5vg_{\mu\nu}\bar{v}\gamma^{\nu}\gamma^5u\cdot(a_\ell\cdot a_f)]\cdot Z_{V_\Pi}\cdot\chi_Z(s)\ \}$$

$$\chi_\gamma(s) = 1$$

$$\chi_Z(s) = \frac{G_\mu\cdot M_z^2\cdot\Delta^2}{\sqrt{2}\cdot 8\pi\cdot\alpha}\cdot\frac{s}{s-M_Z^2+i\cdot\Gamma_Z\cdot M_Z}$$

$$v_\ell = (2\cdot T_3^\ell - 4\cdot q_\ell\cdot s_W^2\cdot K_\ell(s,t))/\Delta$$
$$v_f = (2\cdot T_3^f - 4\cdot q_f\cdot s_W^2\cdot K_f(s,t))/\Delta$$
$$a_\ell = (2\cdot T_3^\ell)/\Delta$$
$$a_f = (2\cdot T_3^f)/\Delta$$

$$\Delta = \sqrt{16\cdot s_W^2\cdot(1-s_W^2)}$$

$$Z_{V_\Pi} = \rho_{e,f}(s,t)$$

EW form-factors , functions of $(s,t)=(m_{ll}, \cos\theta)$
Calculated with Dizet 6.21 library.

$$\Gamma_{V_\Pi} = \frac{1}{2-(1+\Pi_{\gamma\gamma}(s))}$$

$$vv_{\ell f} = \frac{1}{v_\ell\cdot v_f}[(2\cdot T_3^\ell)(2\cdot T_3^f) - 4\cdot q_\ell\cdot s_W^2\cdot K_f(s,t)(2\cdot T_3^\ell) - 4\cdot q_f\cdot s_W^2\cdot K_\ell(s,t)(2\cdot T_3^f)$$
$$+(4\cdot q_\ell\cdot s_W^2)(4\cdot q_f\cdot s_W^2 K_{\ell f}(s,t)]\frac{1}{\Delta^2}$$

Vacuum polarisation corrections, used low-energy experiment input.
Warning: problem for analytic continuation

EW schemes: details

EW schemes: come with „on-shell” or „pole” definitions!

Table 44: The EW parameters used at tree-level EW, with on-mass-shell definition (LEP convention).

Parameter	$\alpha(0)$ v0	$\alpha(0)$ v1	G_μ
M_Z	91.1876 GeV	91.1876 GeV	91.1876 GeV
Γ_Z	2.4952 GeV	2.4952 GeV	2.4952 GeV
Γ_W	2.085 GeV	2.085 GeV	2.085 GeV
α	1/137.03599	1/137.03599	1/132.23323
G_μ	$1.1663787 \cdot 10^{-5}$ GeV^{-2}	$1.1254734 \cdot 10^{-5}$ GeV^{-2}	$1.1663787 \cdot 10^{-5}$ GeV^{-2}
M_W	80.93886 GeV	80.385 GeV	80.385 GeV
s_W^2	0.2121517	0.2228972	0.2228972
$\frac{G_\mu \cdot M_z^2 \cdot \Delta^2}{\sqrt{2} \cdot 8\pi \cdot \alpha}$	1.0	1.0	1.0

Runing Γ_Z in Z-propagator

Shift:

- **-30 MeV for M_Z**
- **change on Γ_Z**
- **-0.00006 for s^2w**

Scaling

- **0.99906 for α**

Table 45: The EW parameters used at tree-level EW, with pole definition of the Z, W masses.

Parameter	$\alpha(0)$ v0	$\alpha(0)$ v1	G_μ
M_Z	91.15348 GeV	91.15348 GeV	91.15348 GeV
Γ_Z	2.494266 GeV	2.494266	2.494266 GeV
Γ_W	2.085 GeV	2.085 GeV	2.085 GeV
α	1/137.03599	1/137.03599	1/132.3572336357709
G_μ	$1.1663787 \cdot 10^{-5}$ GeV^{-2}	$1.126555497 \cdot 10^{-5}$ GeV^{-2}	$1.1663787 \cdot 10^{-5}$ GeV^{-2}
M_W	80.91191 GeV	80.35797 GeV	80.35797 GeV
s_W^2	0.21208680	0.22283820939	0.22283820939
$\frac{G_\mu \cdot M_z^2 \cdot \Delta^2}{\sqrt{2} \cdot 8\pi \cdot \alpha}$	1.0	1.0	1.0

Fixed Γ_Z in Z-propagator

Form of the Z-boson propagator

- **Discussed since fall last year, problem in nutshell**
  - **LEP1 legacy (Dizet+Zfitter, experiments):**
    - **use running width in the Born propagator**
    - **form-factors calculated with pole-mass/fixed width (internally converted), applied to Born with on-shell mass/running width**
    - **see references: hep-ex/0509008, hep-ph/9908433**
  - **LEP2, LHC standard**
    - **use complex-mass scheme, pole masses, fixed width propagator**
  - **Zfitter+Dizet v6.42, v6.45, FCCee standard**
    - **stayed with LEP1 convention**

Is that a concern for $\sin^2\theta_{eff}$ measurement at LHC ?

Z-boson propagator

Topic discused in Fulvio's talks at EW meetings on 13.03, 7.05 and 1.07

How to model „resonance"
Is the Breit-Wigner form good enough?

$$\sigma^{Z}_{f\bar{f}} = \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma_Z^2}{(s-M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} = \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma_Z^2}{(s-M_Z^2)^2 + \Gamma(s)^2 M_Z^2}$$

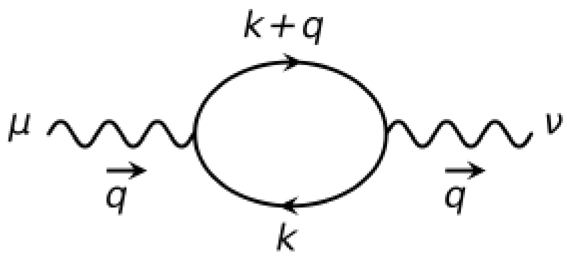
from my slides at our 13 March 2019 meeting

- M_Z and Γ_Z above are "OS" quantities, $\Gamma(s) = \Gamma\frac{s}{M^2}$
- let's express $\sigma^{Z}_{f\bar{f}}$ in terms of "pole" quantities, with $\gamma \equiv \frac{\Gamma_{\text{pole}}}{M_{\text{pole}}}$

$$\begin{aligned}
\sigma^{Z}_{f\bar{f}} &= \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma^2_{\text{pole}}(1+\gamma^2)}{(s-M^2_{\text{pole}}(1+\gamma^2))^2 + s^2\gamma^2} \\
&= \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma^2_{\text{pole}}(1+\gamma^2)}{s^2 + M^4_{\text{pole}}(1+\gamma^2)^2 - 2sM^2_{\text{pole}}(1+\gamma^2) + s^2\gamma^2} \\
&= \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma^2_{\text{pole}}(1+\gamma^2)}{s^2(1+\gamma^2) + M^4_{\text{pole}}(1+\gamma^2)^2 - 2sM^2_{\text{pole}}(1+\gamma^2)} \\
&= \sigma^{\text{peak}}_{f\bar{f}} \frac{s\Gamma^2_{\text{pole}}}{(s-M^2_{\text{pole}})^2 + \Gamma^2_{\text{pole}} M^2_{\text{pole}}}
\end{aligned}$$

F. Piccinini (INFN Pavia) EW schemes - Z width 1 July 2019 15 / 18

idea behind running width



$$\begin{aligned}
M^2_{OS} &= M^2_{\text{pole}}\left(1 + \frac{\Gamma^2_{\text{pole}}}{M^2_{\text{pole}}}\right) \\
\Gamma^2_{OS} &= \Gamma^2_{\text{pole}}\left(1 + \frac{\Gamma^2_{\text{pole}}}{M^2_{\text{pole}}}\right)
\end{aligned}$$

But the propagator in ME is of the form

$$\chi_Z(s) = \frac{1}{s - M_Z^2 + i\cdot\Gamma_Z\cdot s/M_Z}$$

Z-boson propagator

Topic discused in Fuvio talks at EW meetings on 13.03, 7.05 and 1.07

including photon exchange

$$\frac{d\sigma_0^\gamma}{d\Omega} = \frac{\alpha^2 Q_f^2 N_c}{4s}(1+\cos^2\vartheta)$$

$$\frac{d\sigma_0^{\gamma Z}}{d\Omega} = -\frac{\alpha^2 Q_f N_c}{4\sqrt{2}s_\theta^2 c_\theta^2 s}\mathrm{Re}(\chi(s))[g_V^e g_V^f(1+\cos^2\vartheta)+2g_A^e g_A^f\cos\vartheta]$$

$$\frac{d\sigma_0^Z}{d\Omega} = -\frac{\pi\alpha^2 N_c}{32 s_\theta^4 c_\theta^4 s}|\chi(s)|^2[f(g_V^{e,f},g_A^{e,f})(1+\cos^2\vartheta)+g(g_V^{e,f},g_A^{e,f})\cos\vartheta]$$

$$\chi(s) = \frac{s}{(s-M_Z^2)+i\Gamma_Z M_Z}$$

$$\chi(s)_{\mathrm{running}} = \frac{1}{(1+i\gamma)}\chi(s)_{\mathrm{pole}} \qquad \gamma \simeq 0.0274$$

- the couplings, in schemes where $\sin^2\theta$ is connected to M_Z and M_W, get modified when changing from running- to fixed-width scheme
- the relative weights of channels can get modified

!!!

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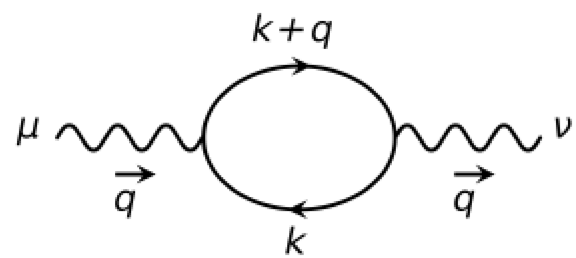
idea behind running width



$$M_{OS}^2 = M_{\mathrm{pole}}^2\left(1+\frac{\Gamma_{\mathrm{pole}}^2}{M_{\mathrm{pole}}^2}\right)$$

$$\Gamma_{OS}^2 = \Gamma_{\mathrm{pole}}^2\left(1+\frac{\Gamma_{\mathrm{pole}}^2}{M_{\mathrm{pole}}^2}\right)$$

Z-boson propagator

Mathematically formulas for χ(s) are equivalent, ones M_Z, Γ_Z, N_Z are properly implemented.

At the Z-pole both formulas should lead to same calculated cross-section.

Running width

$$\chi_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot s / M_Z}$$

→

$$\begin{aligned}
\chi_Z(s) &= \frac{1}{s(1 + i \cdot \Gamma_Z / M_Z) - M_Z^2} \\
&= \frac{(1 - i \cdot \Gamma_Z / M_Z)}{s(1 + \Gamma_Z^2 / M_Z^2) - M_Z^2 (1 - i \cdot \Gamma_Z / M_Z)} \\
&= \frac{(1 - i \cdot \Gamma_Z / M_Z)}{(1 + \Gamma_Z^2 / M_Z^2)} \frac{1}{s - \frac{M_Z^2}{1 + \Gamma_Z^2 / M_Z^2} + i \cdot \frac{\Gamma_Z M_Z}{1 + \Gamma_Z^2 / M_Z^2}}
\end{aligned}$$

$$\begin{aligned}
&= N_Z \frac{1}{s - {M'_Z}^2 + i \Gamma'_Z M'_Z} \\
M'_Z &= \frac{M_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}} \\
\Gamma'_Z &= \frac{\Gamma_Z}{\sqrt{1 + \Gamma_Z^2 / M_Z^2}} \\
N_Z &= \frac{(1 - i \cdot \Gamma_Z / M_Z)}{(1 + \Gamma_Z^2 / M_Z^2)} = \frac{(1 - i \cdot \Gamma'_Z / M'_Z)}{(1 + {\Gamma'_Z}^2 / {M'_Z}^2)}
\end{aligned}$$

Equivalent to running width

Fixed width

$$\chi'_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot M_Z}.$$

Z-boson propagator

Running width, on-shell M_Z, Γ_Z

$$\chi_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot s/M_Z}$$

Fixed width, on-shell M_Z, Γ_Z

$$\chi'_Z(s) = \frac{1}{s - M_Z^2 + i \cdot \Gamma_Z \cdot M_Z}.$$

Equivalent to [dashed box]

shifted M_Z, Γ_Z, scaled by N_Z

$$\begin{aligned}
\chi_Z(s) &= N'_Z \frac{1}{s - {M'_Z}^2 + i\Gamma'_Z M'_Z} \\
M'_Z &= \frac{M_Z}{\sqrt{1 + \Gamma_Z^2/M_Z^2}} \\
\Gamma'_Z &= \frac{\Gamma_Z}{\sqrt{1 + \Gamma_Z^2/M_Z^2}} \\
N'_Z &= \frac{(1 - i \cdot \Gamma_Z/M_Z)}{(1 + \Gamma_Z^2/M_Z^2)} = \frac{(1 - i \cdot \Gamma'_Z/M'_Z)}{(1 + {\Gamma'_Z}^2/{M'_Z}^2)}
\end{aligned}$$

Shifted M_Z, Γ_Z, no scaling N_Z

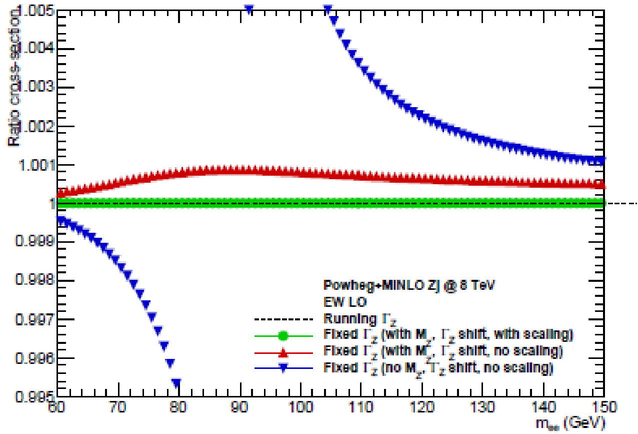
$$\begin{aligned}
\chi_Z(s) &= \frac{1}{s - {M'_Z}^2 + i\Gamma'_Z M'_Z} \\
M'_Z &= \frac{M_Z}{\sqrt{1 + \Gamma_Z^2/M_Z^2}} \\
\Gamma'_Z &= \frac{\Gamma_Z}{\sqrt{1 + \Gamma_Z^2/M_Z^2}}
\end{aligned}$$

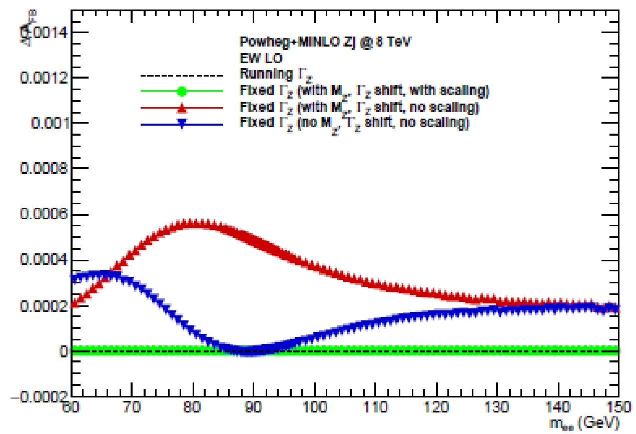
Z-boson propagator

Powheg+MiNLO Zj @ 8 TeV
EW LO
Running Γ_Z
Fixed Γ_Z (with M_Z, Γ_Z shift, with scaling)
Fixed Γ_Z (with M_Z, Γ_Z shift, no scaling)
Fixed Γ_Z (no M_Z, Γ_Z shift, no scaling)

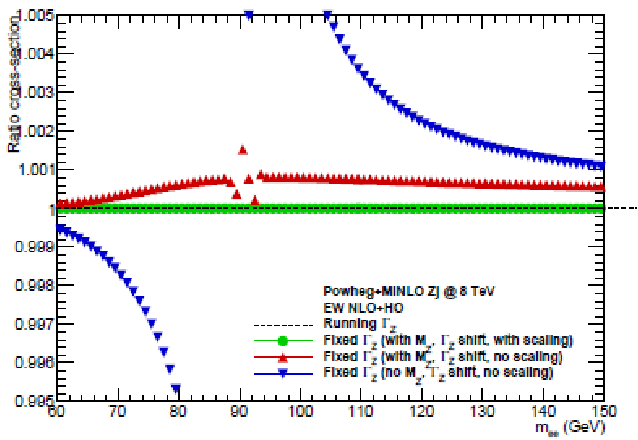
Cross-section ratios | ΔA_{fb}

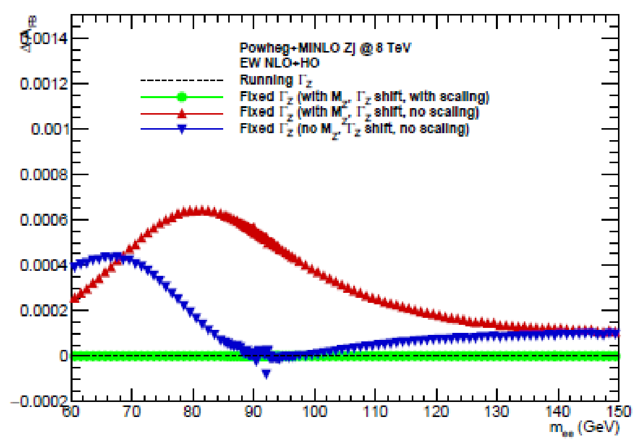
EW LO





EW NLO+HO





Z-boson propagator

Table 15: Ratio of the cross-section σ alculated with different form Z-boson propagator, integrated over specified mass windows. Shown in case of EW LO and EW NLO+HO predictions with $O(\alpha(0)$ v0 EW scheme.

σ (Fixed/Running)	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW LO				
with M_Z, Γ_Z shift, no scaling	1.00087	1.00062	1.00086	1.00071
no M_Z, Γ_Z shift, no scaling	1.00074	0.99716	0.99977	1.00392
EW NLO+HO				
with M_Z, Γ_Z shift, no scaling	1.00085	1.00043	1.00083	1.00075
no M_Z, Γ_Z shift, no scaling	1.00122	0.99719	1.00013	1.00392

Table 16: Difference in A_{fb} calculated wiht different form of Z-boson propagator, integrated over specified mass windows. Shown in case of EW LO and EW NLO+HO predictions with $O(\alpha(0)$ v0 EW scheme.

ΔA_{fb} (Running - Fixed)	$89 < m_{ee} < 93$ GeV	$60 < m_{ee} < 81$ GeV	$81 < m_{ee} < 101$ GeV	$101 < m_{ee} < 150$ GeV
EW LO				
with M_Z, Γ_Z shift, no scaling	-0.00047	-0.00047	-0.00047	-0.00030
no M_Z, Γ_Z shift, no scaling	-0.00026	-0.00012	-0.00040	-0.00005
EW NLO+HO				
with M_Z, Γ_Z shift, no scaling	-0.00053	-0.00052	-0.00053	-0.00024
no M_Z, Γ_Z shift, no scaling	-0.00030	-0.00026	-0.00048	-0.00004