Wrap-up from discussion on freezing choices for calculations: virtual corrections and QED emissions

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Genuine weak and lineshape corrections

- Z-boson propagator
- \succ Scan for sin² θ_{eff}
- > QED FSR/ISR/IFI

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Genuine weak and lineshape corrections

- Defined five benchmark points i.e. EW schemes which differ by input parameters and/or formalisms for calculating corrections.
- Compared are three different codes:
 - Powheg_ew,
 - MCSANC,
 - Dizet FF + wt^{EW} (TauSpinner)
- Plans to have also QCD NLO for the final tables.

Program	QCD	EW	EW scheme	Comments
Powheg_ew	LO	LO	$\alpha(0) v0$	pole mass, fixed Γ_Z
		LO, NLO, NLO+HO	$\alpha(0) v 1$	
		LO, NLO, NLO+HO	G_{μ}	
		LO, NLO, NLO+HO	$\sin^2 \theta_{eff} v 1$	
		LO, NLO, NLO+HO	$\sin^2 \theta_{eff} v2$	
	NLO	NLO+HO	G_{μ}	pole mass, fixed Γ_Z
MCSANC	LO	LO, NLO, NLO+HO	$\alpha(0) v 1$	pole mass, fixed Γ_Z
		LO, NLO, NLO+HO	G_{μ}	
Dizet FF+wt ^{EW}	MC event	LO, NLO+HO	$\alpha(0) v0$	on-shell mass, running Γ_Z^1

EW schemes: input parameters

SM fundamental relation used to calculate EW LO parameters for different schemes (on-shell mass).

Completed since last meeting!

Parameter	$(\alpha(0), G_{\mu}, M_Z)$	$(\alpha(0), M_W, M_Z)$	(G_{μ}, M_Z, M_W)	$(\alpha(0), s_W^2, M_Z)$	(G_{μ}, s_W^2, M_Z)
	$\alpha(0) v 0$	$\alpha(0) v 1$	G_{μ}	$\sin^2_{eff} v1$	sin_{eff}^2 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
$G_{\mu} ({ m GeV^{-2}})$	$1.1663787 \cdot 10^{-5}$	$1.1254734 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$	$1.09580954 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$
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
$\frac{G_{\mu} M_{z}^{2} \cdot 16c_{W}^{2} s_{W}^{2}}{\sqrt{2.8\pi \cdot \alpha}} = 1.0$	$\rightarrow s_W^2, M_W$	$ ightarrow G_{\mu}, s_W^2$	$ ightarrow lpha, s_W^2$	$ ightarrow G_{\mu}, m_W$	$ ightarrow lpha, m_W$
$s_W^2 = 1 - m_W^2 / m_Z^2$					
$\alpha_s(M_Z)$	0.120178900000	0.120178900000	0.120178900000	0.120178900000	0.120178900000

$$s_W^2 = 1 - m_W^2 / m_Z^2$$
 $G_\mu = \frac{\pi \alpha}{\sqrt{2} M_W^2 s_W^2}$

EW schemes: input parameters

SM fundamental relation used to calculate EW LO parameters for different schemes (pole mass).

Completed since last meeting!

Parameter	$(\alpha(0), G_{\mu}, M_Z)$	$(\alpha(0), M_W, M_Z)$	(G_{μ}, M_Z, M_W)	$(\alpha(0), s_W^2, M_Z)$	(G_{μ}, s_W^2, M_Z)
	$\alpha(0) v0$	$\alpha(0) v 1$	G_{μ}	\sin^2_{eff} v1	sin_{eff}^2 v2
M_Z (GeV)	91.15348	91.15348	91.15348	91.15348	91.15348
Γ_Z (GeV)	2.494266	2.494266	2.494266	2.494266	2.494266
Γ_W (GeV)	2.085	2.085	2.085	2.085	2.085
$1/\alpha$	137.035999139	137.035999139	132.3572336357709	137.035999139	128.84133952
α	0.007297353	0.007297353	0.007555311	0.007297353	0.007761484
G_{μ} (GeV ⁻²)	$1.1663787 \cdot 10^{-5}$	$1.126555497 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$	$1.09663005 \cdot 10^{-5}$	$1.1663787 \cdot 10^{-5}$
M_W (GeV)	80.91191	80.35797	80.35797	79.90895881	79.90895881
s_W^2	0.21208680	0.22283820939	0.22283820939	0.231499	0.231499
$\frac{G_{\mu} \cdot M_z^2 \cdot 16c_W^2 s_W^2}{\sqrt{2} \cdot 8\pi \cdot \alpha} = 1.0$	$\rightarrow s_W^2, M_W$	$ ightarrow G_{\mu}, s_W^2$	$ ightarrow lpha, s_W^2$	$ ightarrow G_{\mu}, m_W$	$ ightarrow lpha, m_W$
$s_W^2 = 1 - m_W^2 / m_Z^2$					
$\alpha_s(M_Z)$	0.120178900000	0.120178900000	0.120178900000	0.120178900000	0.120178900000

$$s_W^2 = 1 - m_W^2 / m_Z^2$$
 $G_\mu = \frac{\pi \alpha}{\sqrt{2} M_W^2 s_W^2}$

EW schemes: input parameters

To complete, we defined also masses for fermions which are used in all codes.

Parameter	Mass (GeV)	Description
m _e	5.1099907e-4	mass of electron
m_{μ}	0.1056583	mass of muon
m_{τ}	1.7770500	mass of tau
m_u	0.0620000	mass of up-quark
m _d	0.0830000	mass of down-quark
m_c	1.5000000	mass of charm-quark
m_s	0.2150000	mass of strange-quark
m_b	4.7000000	mass of bottom-quark
m _t	173.0	mass of top quark
m_H	125.0	mass of Higgs boson

Table 12: Values of fermions and Higgs boson massed used for calculating EW corrections.

Pseudo-observables at Z-pole

Table to go into Section 2, started working on it.



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

Parameter	$(\alpha(0), G_{\mu}, M_Z)$	$(\alpha(0), M_W, M_Z)$	(G_{μ}, M_Z, M_W)	$(\alpha(0), s_W^2, M_Z)$	(G_{μ}, s_W^2, M_Z)
	$\alpha(0) v 0$	$\alpha(0) v 1$	G_{μ}	\sin^2_{eff} v1	sin_{eff}^2 v2
M_Z (GeV)	91.1876	91.1876	91.1876	91.1876	91.1876
$1/\alpha(M_Z)$	0.0077549256				
$\alpha(M_Z)$	128.9503020				
$G_{\mu} ({ m GeV^{-2}})$	$1.1663787 \cdot 10^{-5}$		$1.1663787 \cdot 10^{-5}$		$1.1663787 \cdot 10^{-5}$
M_W (GeV)	80.358935	80.385	80.385		
s_W^2	0.223401084	0.22289722	0.22289722		
$\sin^2 \theta_{eff}^{\ell}$	0.231499			0.231499	0.231499
$\sin^2 \theta^u_{eff}$	0.231392				
$\sin^2 \theta_{eff}^d$	0.231265				
$\sin^2 \Theta_{eff}^{b'f}$	0.232733				
	•				

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

Dizet v6.45

Observables (distributions): Tables and plots

What used so far:

Example

	EW order	$m_{ee} = 89 - 93 \text{ GeV}$	$m_{ee} = 80 - 100 {\rm GeV}$	$m_{ee} = 70 - 120 \text{ GeV}$
Powheg_ew	NLO+HO/LO			
$\alpha(0)$ v1		1.06325	1.06374	1.06435
G_{μ}		0.99104	0.99229	0.99284
MCSANC	NLO+HO/LO			
$\alpha(0)$ v1		1.051194	1.066182	1.066778
G_{μ}		0.992299	0.992740	0.993295
PowhegZj+ <i>wt^{EW}</i>	NLO+HO/LO			
$\alpha(0) v0$		0.96452	0.96611	0.96757
$\alpha(0)$ v1		1.06506	1.06580	1.06640
G_{μ}		0.99167	0.99223	0.99289

We stay with this format for a now, **no decision made to change !** However, as **everybody will provide also results in form of histograms**, they can be Produced in desired bins later.

Tables and plots

What used so far: range 60-200 GeV with 1 GeV binning. Histograms: total cross-sections, forward - backward cross-sections, and for convenience also A_{FB}

Example Ratio G_{NIC+10}/G_{IC} 1.15 1.05 EW soheme: a(0) v1 EW coheme: G. 1.04 SANC: QCD LO, EW NLO+HO/LO SANC: QCD LO, EW NLO+HO/LO OCD LO, EW NLOHHOLO 1.03 1.1 1.02 1.05 0.99 0.95 m., (GeV) m_{er} (GeV) .**₽**004 Poo 0.998 0.998 0.996 0.996

Status of the draft: Section 2 & Appendix: A-G

- Completed setup for bechmark configurations
- Updated several tables to Dizet v6.45 + benchmark points specifications. Will continue on it during next weeks.
- Started receiving updates from MCSANC: synchronizing with benchmarks specifications.
- We should try to
 - Conclude discussion on the Z-boson propagator
 - Add at least 2 more points to validate scan in sin_{eff}^2

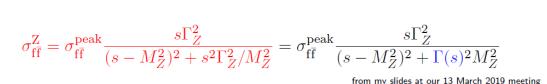
- Discussed since fall last year, problem in nutshell
 - LEP1 legacy (Dizet+Zfitter, experiments):
 - use running width in the Born propagator
 - form-factors calculated with pole-mass/fixed width (internally converted), applied to Born with on-shell mass/running width
 - see references: hep-ex/0509008, 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

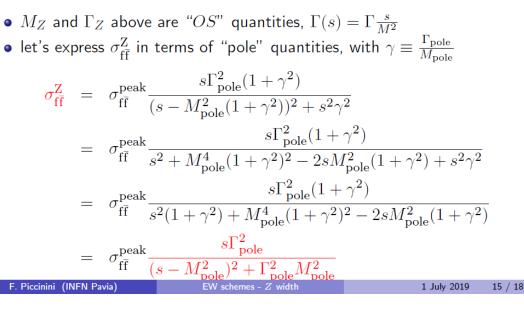
Is that a concern for $sin^2\theta_{eff}$ measurement at LHC ?

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?

idea behind running width





$$\mu \bigvee_{\overrightarrow{q}} \bigvee_{k} \bigvee_{q} \bigvee_{q}$$

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

But the propagator in ME is of the form

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

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

including photon exchange

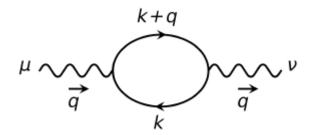
$$\begin{aligned} \frac{d\sigma_0^{\gamma}}{d\Omega} &= \frac{\alpha^2 Q_f^2 N_c}{4s} (1 + \cos^2 \vartheta) \\ \frac{d\sigma_0^{\gamma Z}}{d\Omega} &= -\frac{\alpha^2 Q_f N_c}{4\sqrt{2} s_{\theta}^2 c_{\theta}^2 s} \operatorname{Re}(\chi(s)) [g_V^e g_V^f (1 + \cos^2 \vartheta) + 2 g_A^e g_A^f \cos \vartheta] \\ \frac{d\sigma_0^Z}{d\Omega} &= -\frac{\pi \alpha^2 N_c}{32 s_{\theta}^4 c_{\theta}^4 s} |\chi(s)|^2 [f(g_V^{e,f}, g_A^{e,f})(1 + \cos^2 \vartheta) + g(g_V^{e,f}, g_A^{e,f}) \cos \vartheta] \\ \chi(s) &= \frac{s}{(s - M_Z^2) + i\Gamma_Z M_Z} \end{aligned}$$

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

- 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

 F. Piccinini (INFN Pavia)
 EW schemes - Z width
 1 July 2019
 16 / 18

idea behind running width



$$\begin{split} M_{OS}^2 &= M_{\rm pole}^2 \left(1 + \frac{\Gamma_{\rm pole}^2}{M_{\rm pole}^2} \right) \\ \Gamma_{OS}^2 &= \Gamma_{\rm pole}^2 \left(1 + \frac{\Gamma_{\rm pole}^2}{M_{\rm pole}^2} \right) \end{split}$$

Mathematically formulas for $\chi(s)$ are equivalent, ones M_z , Γ_z , N_z are properly implemented.

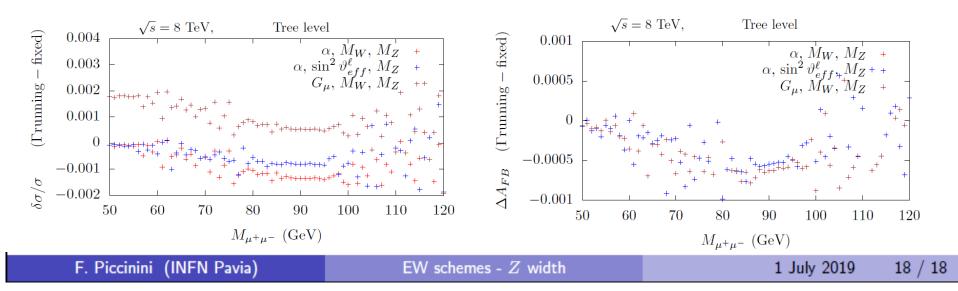
At the Z-pole both formulas should lead to same calculated cross-section.

$$\begin{split} \chi'_{Z}(s) &= \frac{1}{s(1+i\cdot\Gamma_{Z}/M_{Z}) - M_{Z}^{2}} \\ &= \frac{(1-i\cdot\Gamma_{Z}/M_{Z})}{s(1+\Gamma_{Z}^{2}/M_{Z}^{2}) - M_{Z}^{2}(1-i\cdot\Gamma_{Z}/M_{Z})} \\ &= \frac{(1-i\cdot\Gamma_{Z}/M_{Z})}{(1+\Gamma_{Z}^{2}/M_{Z}^{2})} \frac{1}{s - \frac{M_{Z}^{2}}{1+\Gamma_{Z}^{2}/M_{Z}^{2}} + i\cdot\frac{\Gamma_{Z}M_{Z}}{1+\Gamma_{Z}^{2}/M_{Z}^{2}}} \\ &= N_{Z} \frac{1}{s - M_{Z}'^{2} + i\Gamma_{Z}'M_{Z}'} \\ M_{Z}' &= \frac{M_{Z}}{\sqrt{1+\Gamma_{Z}^{2}/M_{Z}^{2}}} \\ N_{Z} &= \frac{\Gamma_{Z}}{\sqrt{1+\Gamma_{Z}^{2}/M_{Z}^{2}}} \\ N_{Z} &= \frac{(1-i\cdot\Gamma_{Z}/M_{Z})}{(1+\Gamma_{Z}^{2}/M_{Z}^{2})} = \frac{(1-i\cdot\Gamma_{Z}'/M_{Z}')}{(1+\Gamma_{Z}'^{2}/M_{Z}'^{2})} \end{split}$$

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

PRELIMINARY

PRELIMINARY



At Z-pole, predictions for σ and A_{FB} are not the same, difference of 0.15% for ratio of cross-sections and 5 10⁻⁴ for ΔA_{FB} . Looks like residuum scaling factor 1/(1+i γ) is missing, was it intentional?

Some differences for cross-sections between both formulas for $\chi(s)$, for observables outside the Z-pole were indeed discussed already at LEP1 times, considered not relevant for the precision of the measurements there. The "running width" model was observed as agreeing better with measured Z lineshape.

The effect/was/much smaller than what shown on plots above.

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

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

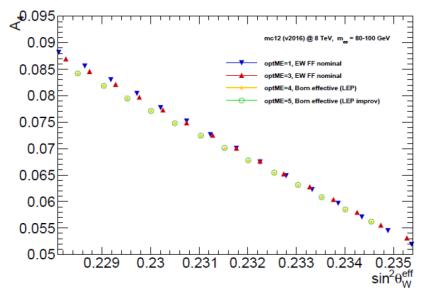
We should keep it in mind, that ones we reach precision of the comparisons which might be sensitive to the effect of $\chi(s)$ implementation.

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

$sin^2\theta_{eff}$ scan for $A_{FB and/or} A4$

Can be done with codes predicting this pseudo-observable explicitly

- It is available with (Dizet FF +wt^{EW})
- Main motivation for Powheg_ew to develop new EW schemes was to have it available as well.
- We should complete this comparison benchmark. Needs at least two additional $\sin^2\theta_{eff}$ points, eg. $\sin^2\theta_{eff} = 0.231499 + 0.00050$ and then predicted slope of the A_{FB}.



Example for A₄ with wt^{EW}

Formulas used for this plot, varied δV

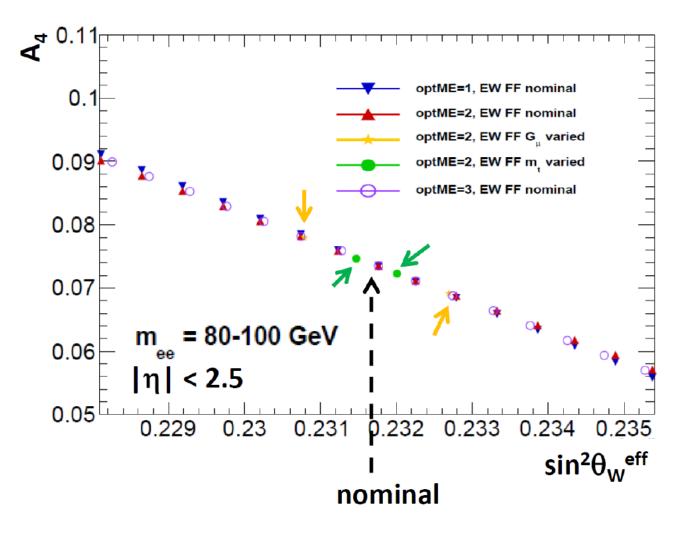
$$\begin{split} v_{\ell} &= (2 \cdot T_{3}^{\ell} - 4 \cdot q_{\ell} \cdot (s_{W}^{2} \cdot K_{\ell}(s, t) + \delta_{V})) / \Delta \\ v_{f} &= (2 \cdot T_{3}^{f} - 4 \cdot q_{f} \cdot (s_{W}^{2} \cdot K_{f}(s, t) + \delta_{V})) / \Delta \\ vv_{\ell f} &= \frac{1}{v_{\ell} \cdot v_{f}} [(2 \cdot T_{3}^{\ell})(2 \cdot T_{3}^{f}) \\ &- 4 \cdot q_{\ell} \cdot (s_{W}^{2} + \cdot K_{f}(s, t) + \delta_{V})(2 \cdot T_{3}^{\ell}) \\ &- 4 \cdot q_{f} \cdot (s_{W}^{2} \cdot K_{\ell}(s, t) + \delta_{V})(2 \cdot T_{3}^{f}) \\ &+ (4 \cdot q_{\ell} \cdot s_{W}^{2})(4 \cdot q_{f} \cdot s_{W}^{2})K_{\ell f}(s, t) \\ &+ 2 \cdot (4 \cdot q_{\ell}))(4 \cdot q_{f} \cdot) \cdot s_{W}^{2} \cdot K_{\ell f}(s, t) \cdot \delta_{V}] \frac{1}{\Delta^{2}} \end{split}$$

E. Richter-Was, IF JU

CERN, LHC EW precision, 18.10.2019

$sin^2\theta_{eff}$ scan for $A_{FB and/or}$ A4

Example for A₄ with wt^{EW}



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н	KKMC_hh	55
I	HORACE	56

QED emission

- Problem with consistency of Afb because not calculated in the EW schemes.
- Proposal to normalise to "best predictions" of the EW scheme used. It will make Section 3 consistent with Section 2.
- We could also show only △A and ratio of cross-sections with different EW schemes, not the central values.
 - Caveats:
 - LO QCD, reference is LO EW with LUXQED PDF from NNPDF3.1
 - Mass window is 66 to 116 GeV for KKMC-hh (effects smaller near pole)
 - Still need to understand value of A_{FB} quoted by KKMC-hh!

80 < $m_{\mu\mu}$ < 102 GeV	A _{FB} (LO)	∆A(ISR) (10 ⁻⁴)	∆A(IFI) (10 ⁻⁴)	
Total phase space				
MC-SANC	0.0459	-0.4±0.1	-1.8±0.1	\leftarrow EW LO G _µ
Powheg EW	0.0448	0.0±0.6	1.3±0.8	\leftarrow EW LO G_u^{μ}
KKMC-hh	0.0200	-1.8±0.2	0.3±0.1	\leftarrow EW NLO+HO α (0) v1
Fiducial phase space				
MC-SANC	0.0189	-0.3±0.1	-0.4±0.1	
Powheg EW	0.0189	0.1±0.4	0.4±0.4	
KKMC-hh	0.0121	0.3±0.3	1.1±0.1	1

LPCC SM precision EW meeting, 07/05/2019

D. Froidevaux

QED emission

Snapshot of existing comparison results.

Integrated $A_{FB}(LO)$ and difference $\Delta A[QED] = [A_{FB}(LO+QED)-A_{FB}(LO)]$ in green – the numbers from the report of F. Piccinini on Dec 12, 2018

	$A_{FB}(LO)$	$\Delta A[ISR]$	$\Delta A[IFI]$	$\Delta A[q\gamma]$	$\Delta A[\gamma \gamma]$			
			[66-116]					
TV	0.03998(1)	-0.00004(1)	-0.00026(1)	0.00002(1)	-0.00018(1)			
	0.03986(2)	-0.00001(3)						
FV	0.01813(1)	0.00002(1)	-0.00006(1)	0.00000(1)	-0.00002(1)			
	0.01815(3)	0						
			[66-80]					
TV	-0.20465(6)	-0.00019(6)	-0.00076(6)	-0.00181(7)	0.01319(5)			
FV	-0.06969(3)	0.00000(4)	-0.00017(3)	-0.00073(3)	0.00093(3)			
			[80-102]					
TV	0.04496(1)	-0.00004(1)	-0.00018(1)	-0.00000(1)	-0.00008(1)			
	0.04481(2)	0						
FV	0.01891(1)	-0.00003(1)	-0.00004(1)	-0.00000(1)	-0.00000(1)			
	0.01895(3)	-0.00080(6)						
	[102-116]							
TV	0.21388(6)	0.00015(7)	-0.00215(6)	0.00087(7)	-0.00544(6)			
FV	0.09327(4)	0.00004(4)	-0.00064(4)	0.00033(4)	-0.00055(4)			

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LHC EW Precision sub-group meeting, CERN, March 13, 2019

Status of the draft: Section 3 & Appendix: H, I

- Nothing there yet.
- Got collection of plots from KKMC_hh which could go to Appendix H.
- Nice results exist on ISR/FSR/IFI from Powheg_ew and MCSANC in presentions of previous meetings.
- I would like to start putting it into draft, so all is collected in one place. Please send me text/tables/plots as .tex and .eps files.
 Even if there are not final ones, will help converging.