Update on Dizet 6.21 vs Dizet 6.45 in KKMC-hh

S.A. Yost

The Citadel

with assistance from Z. Wąs, IFJ-PAN, Kraków

June 4, 2020

KKMC-hh is a collaboration with S. Jadach, B.F.L. Ward and Z. Wąs.

Computational resources provided by IFJ-PAN, Kraków.

KKMC-hh with Dizet 6.21 vs Dizet 6.45

- Last month, I presented a table with some comparisons between Dizet 6.21 and 6.45 using results from a 7.5 billion event run.
- The comparisons focused on A_4 *defined* as $\frac{8}{3}A_{FB}$ calculated in the full phase space.
- The following table showed some changes that were larger than may have been expected.
- There has not been time to rerun the results (and the farm was dismantled), and we are still going through KKMC-hh to see if this could be due to some bug in the implementation.
- One possible issue: the Dizet 6.21 results were with old parameters – some of the difference could have been due to that.
- For now, I will look at Dizet directly, and show some comarisons made using the interface to KKMC-hh.

Comparisons of A_4 for Dizet 6.21 and 6.45

$A_4 = \frac{8}{3} A_{FB}$ is calculated in the full phases space with complete (KKMC best) photonic corrections. ΔISR is the difference in A_4 with ISR on minus ISR off, with IFI off in both cases. ΔIFI is the difference in A_4 with IFI on minus IFI off. These numbers are based on analyzing a 7.5G event sample.

	DIZET	$60 < M_{ll} < 81$	$81 < M_{ll} < 101$	$101 < M_{ll} < 150$	$60 < M_{ll} < 120$	$89 < M_{ll} < 93$
A_4 (best)	6.45	$-0.28422(4)$	$0.07725(2)$	$0.57409(5)$	$0.05596(2)$	$0.08255(3)$
	6.21	$-0.28986(4)$	$0.08039(2)$	$0.58284(9)$	0.05827(2)	$0.08771(3)$
Difference		$(5.64 \pm 0.05) \times 10^{-3}$	$-(3.14 \pm 0.03) \times 10^{-3}$	$-(8.35 \pm 0.07) \times 10^{-3}$	$-(2.31 \pm 0.02) \times 10^{-3}$	$-(5.16 \pm 0.04) \times 10^{-3}$
Δ ISR	6.45	$(0.4 \pm 5.9) \times 10^{-4}$	$(3.6 \pm 2.6\ ) \times 10^{-5}$	$-(8.6 \pm 0.9) \times 10^{-4}$	$(0.7 \pm 2.3) \times 10^{-5}$	$(1.7 \pm 3.9) \times 10^{-5}$
	6.21	$(1.2 \pm 0.6) \times 10^{-4}$	$(3.72 \pm 0.02) \times 10^{-3}$	$-(1.64 \pm 0.9) \times 10^{-3}$	$(3.29 \pm 0.02) \times 10^{-3}$	$(5.76 \pm 0.04) \times 10^{-3}$
Δ IFI	6.45	$(4.8 \pm 0.6) \times 10^{-4}$	$(\ 3.0 \pm 0.1) \times 10^{-4}$	$-(6.15 \pm 0.04) \times 10^{-3}$	$(1.3 \pm 0.1) \times 10^{-4}$	$(1.7 \pm 0.2) \times 10^{-4}$
	6.21	$(4.3 \pm 1.1) \times 10^{-4}$	$(5.4 \pm 1.3) \times 10^{-5}$	$-(6.11 \pm 0.03) \times 10^{-3}$	$-(9.2 \pm 1.7) \times 10^{-5}$	$-(2.2 \pm 0.2) \times 10^{-4}$

What Dizet Provides

Dizet provides a set of form factors that can be used in an improved Born approximation for the hard process, starting with the Born amplitude*

$$\mathcal{M}_{\mathrm{Born}} = \frac{1}{s}(\bar{u}\gamma^{\mu}v)_i\left(\bar{v}\gamma_{\mu}u\right)_f\{q_i q_f + v_i v_f \chi_Z(s)\} + \frac{\chi_z(s)}{s}\Big\{(\bar{u}\gamma^{\mu}v)_i\left(\bar{v}\gamma_{\mu}\gamma^5 u\right)_f v_i a_f \chi_Z(s) + (\bar{u}\gamma^{\mu}\gamma^5 v)_i\left(\bar{v}\gamma_{\mu}u\right)_f a_i v_f + (\bar{u}\gamma^{\mu}\gamma^5 v)_i\left(\bar{v}\gamma_{\mu}\gamma^5 u\right)_f a_i a_f\Big\}$$

with

$$\chi_z(s) = \frac{G_\mu M_Z^2 \Delta^2}{8\pi\alpha(0)\sqrt{2}} \frac{s}{s - M_Z^2 + i\Gamma_Z M_Z} \quad , \qquad \Delta = 4\sin\theta_w \cos\theta_W \quad ,$$

$$v_{i,f} = \frac{1}{\Delta}\left(2T_3^{i,f} - 4q_{i,f}\sin^2\theta_W\right) \quad , \qquad a_{i,f} = \frac{2T_3^{i,f}}{\Delta} \quad .$$

*This descriptions is from a Jan. 2020 CERN FCC presentation by Z. Wąs.

What Dizet Provides

Dizet inserts factors as shown:

$$\mathcal{M}_{\text{Born}} = \frac{1}{s}(\bar{u}\gamma^{\mu}v)_i\left(\bar{v}\gamma_{\mu}u\right)_f\left\{\frac{q_i q_f}{2-\left(1+\Pi_{\gamma\gamma}(s)\right)}+V_{if}\chi_Z(s)\right\}$$
$$+\rho_{if}(s,t)\frac{\chi_Z(s)}{s}\Big\{(\bar{u}\gamma^{\mu}v)_i\left(\bar{v}\gamma_{\mu}\gamma^5u\right)_f v_i a_f\chi_Z(s)+(\bar{u}\gamma^{\mu}\gamma^5v)_i\left(\bar{v}\gamma_{\mu}u\right)_f a_i v_f$$
$$+(\bar{u}\gamma^{\mu}\gamma^5v)_i\left(\bar{v}\gamma_{\mu}\gamma^5u\right)_f a_i a_f\Big\}$$

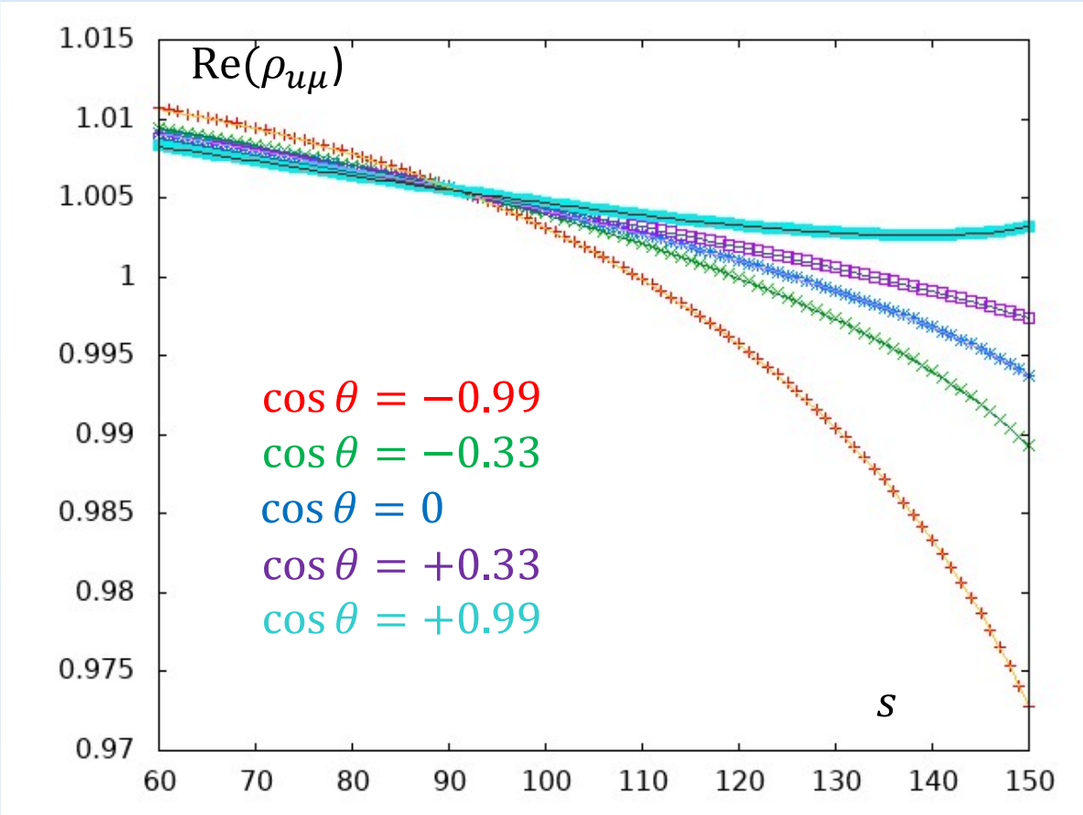
with

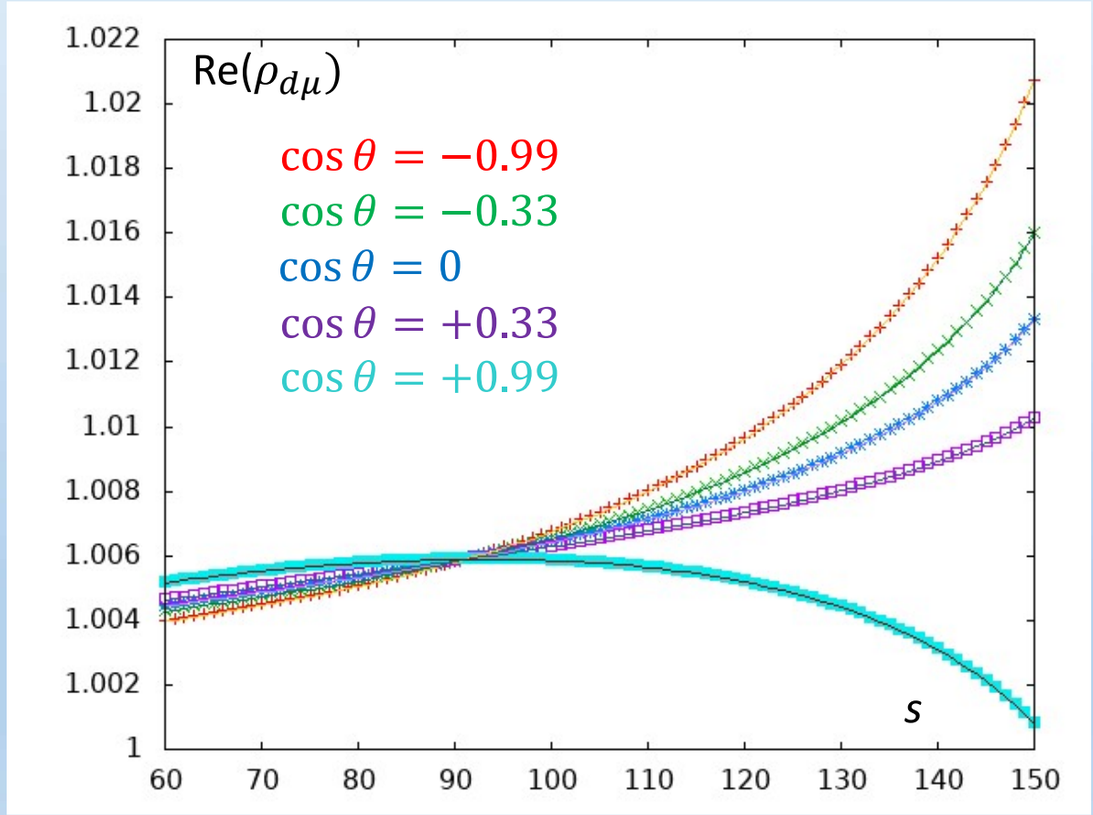
$$v_{i,f}=\frac{1}{\Delta}\left(2T_3^{i,f}-4q_{i,f}\,K_{i,f}(s,t)\sin^2\theta_W\right)\quad,\qquad a_{i,f}=\frac{2T_3^{i,f}}{\Delta}\quad,$$

$$V_{if}=\frac{4}{\Delta^2 v_i v_f}\left\{T_3^i T_3^f-\sin^2\theta_W\left(q_i K_f(s,t)+q_f K_i(s,t)\right)+4\sin^4\theta_W\, q_i q_f K_{if}(s,t)\right\}.$$

$\rho_{u\mu}$ and $\rho_{d\mu}$ for Dizet 6.21 and Dizet 6.45

The dotted lines are made using Dizet 6.21, and the solid lines are from Dizet 6.45 in all plots. $\cos\theta$ is calculated in the quark CM frame. Only real parts are shown. There is no apparent version dependence.



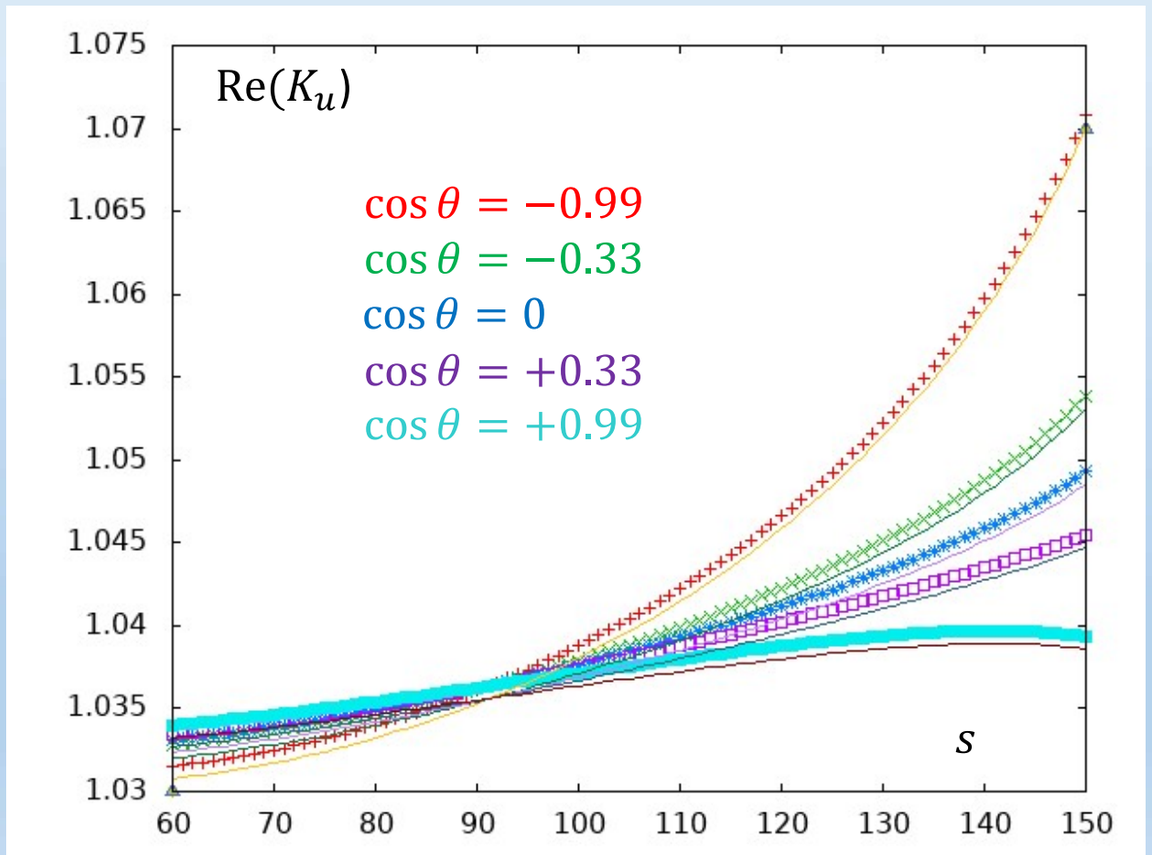


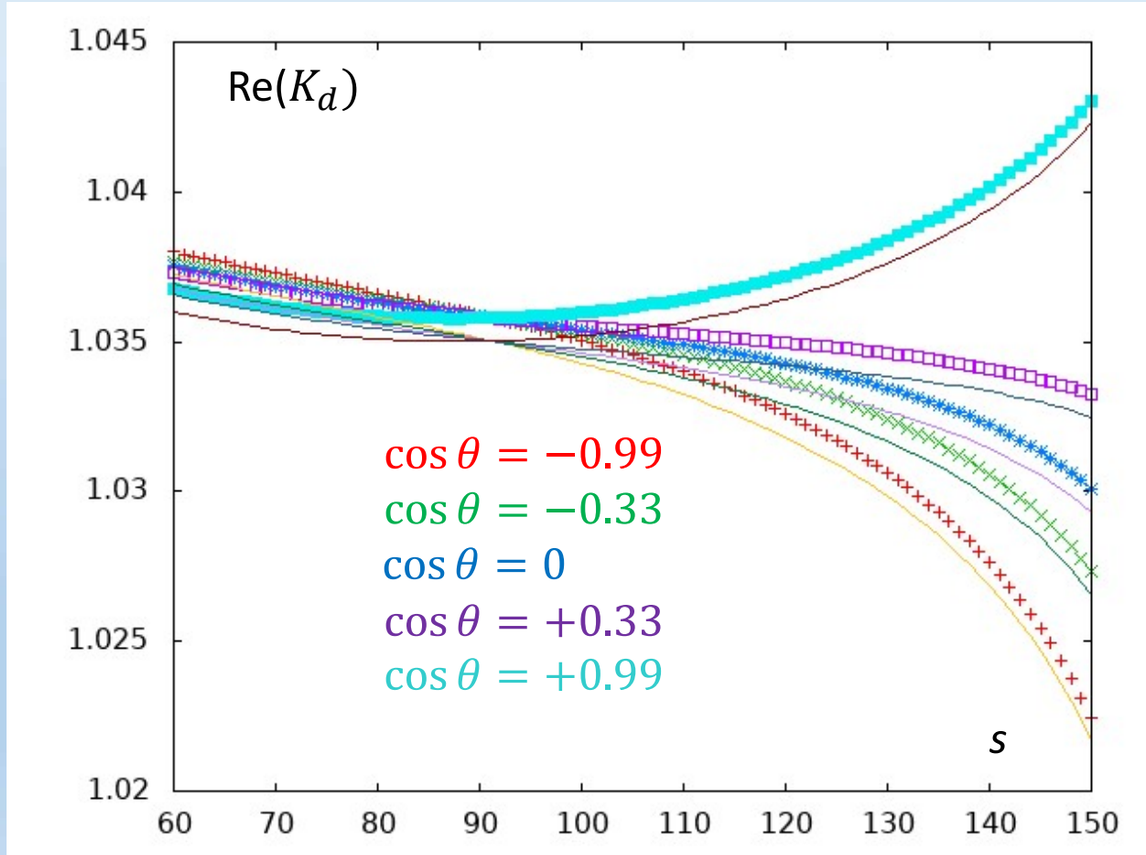
K_u and K_d for Dizet 6.21 and Dizet 6.45

The dotted lines are made using Dizet 6.21, and the solid lines are from Dizet 6.45 in all plots.

Five values of cosθ calculated in the CM frame are used. These were calculated for $u\bar{u} \to \mu_+\mu_-$, $d\bar{d} \to \mu_+\mu_-$.

There is a roughly constant shift of -8×10^{-4} from the old to new K-factors.



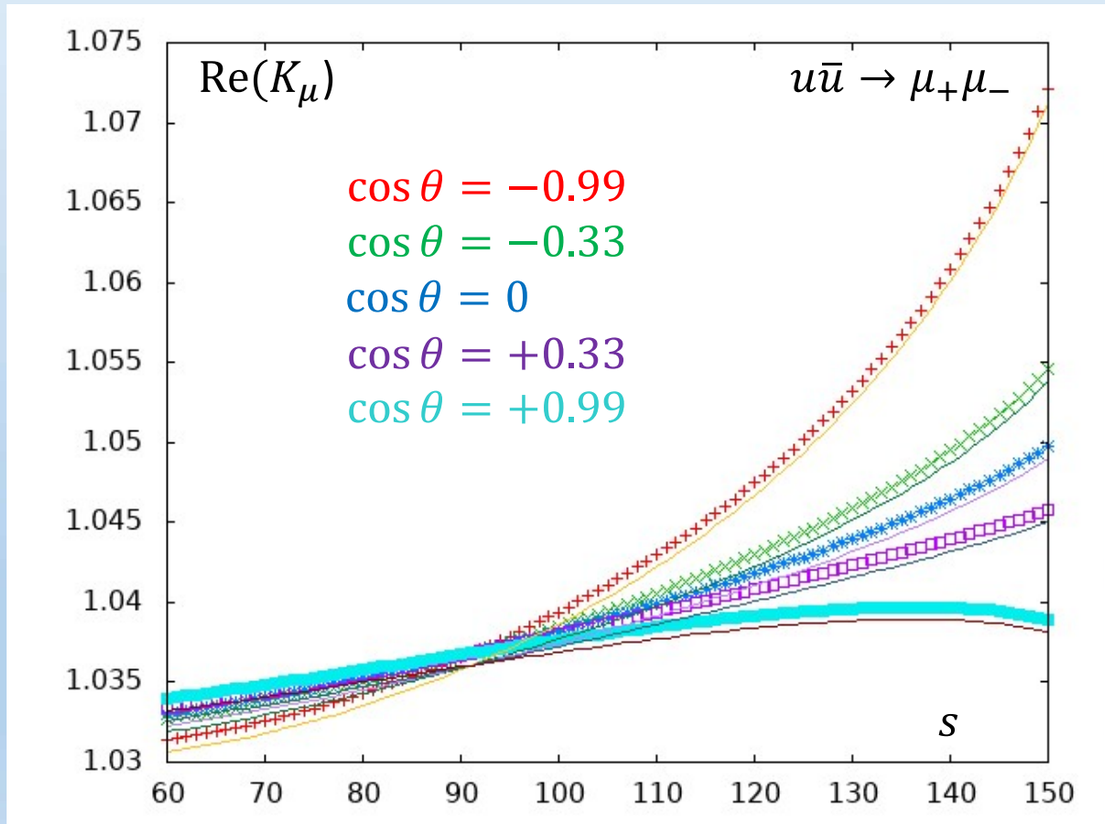


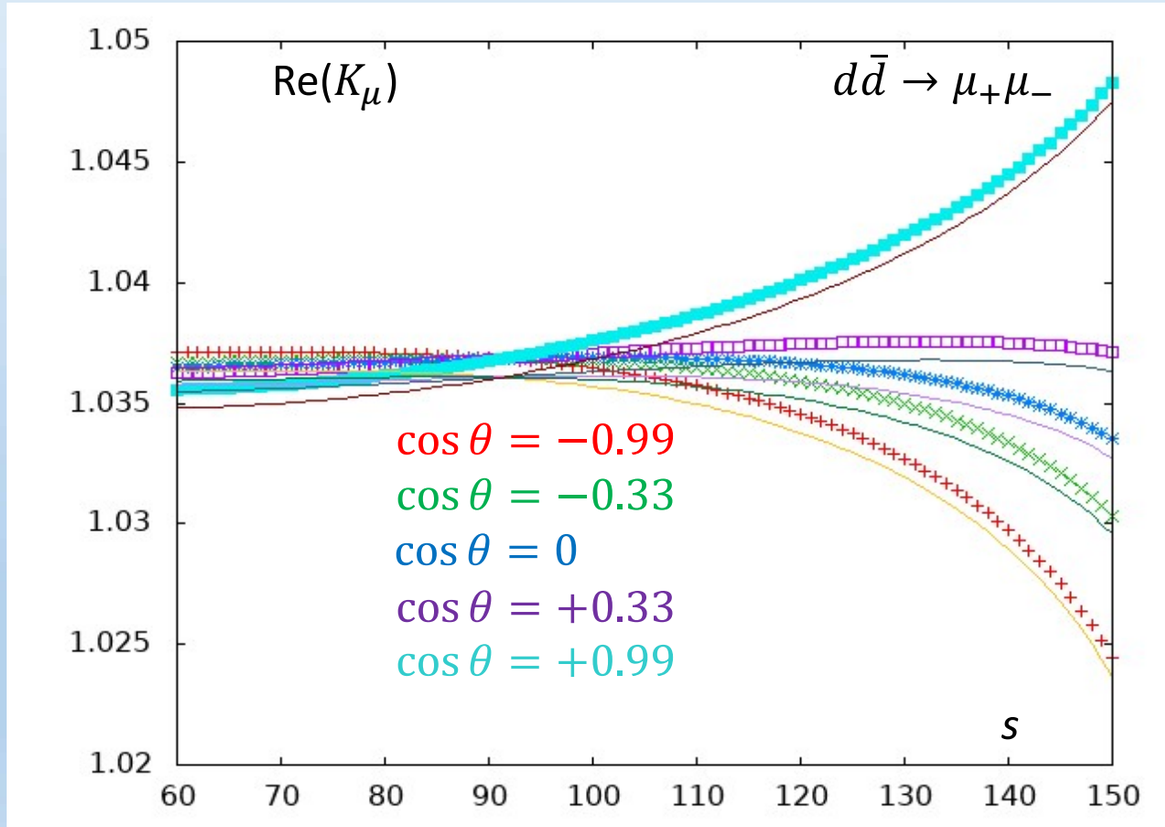
K_μ for Dizet 6.21 and Dizet 6.45

The dotted lines are made using Dizet 6.21, and the solid lines are from Dizet 6.45 in all plots.

Five values of cosθ calculated in the CM frame are used. These were calculated for $u\bar{u} \to \mu_+\mu_-$, $d\bar{d} \to \mu_+\mu_-$.

There is a roughly constant shift of -8×10^{-4} from the old to new K-factors.



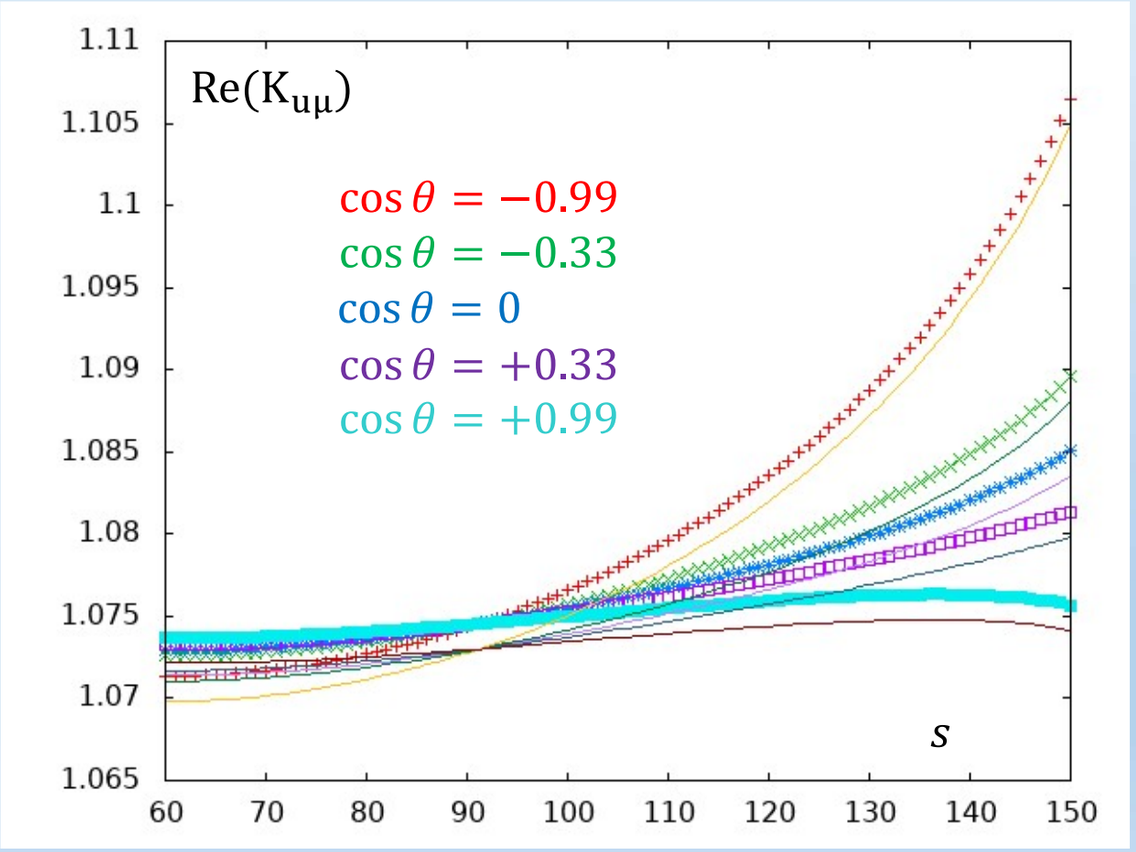


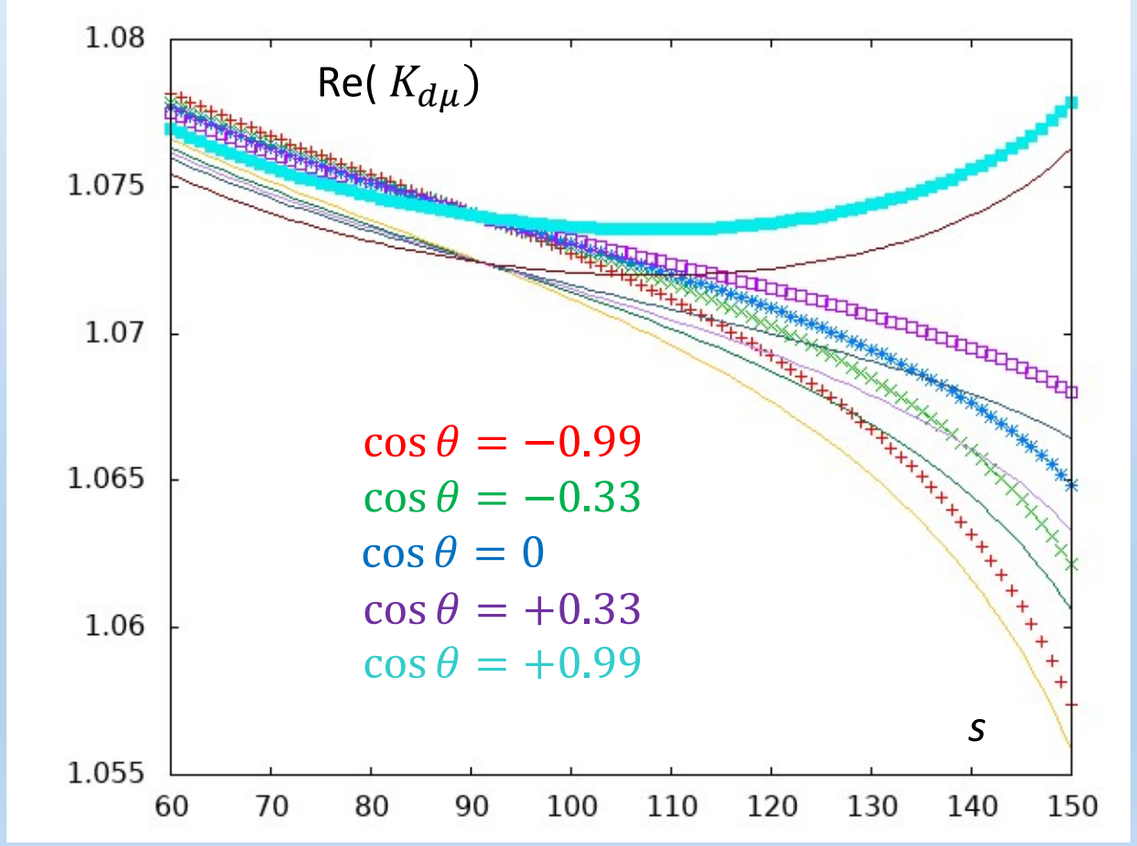
$K_{u\mu}$ and $K_{d\mu}$ for Dizet 6.21 and Dizet 6.45

The dotted lines are made using Dizet 6.21, and the solid lines are from Dizet 6.45 in all plots.

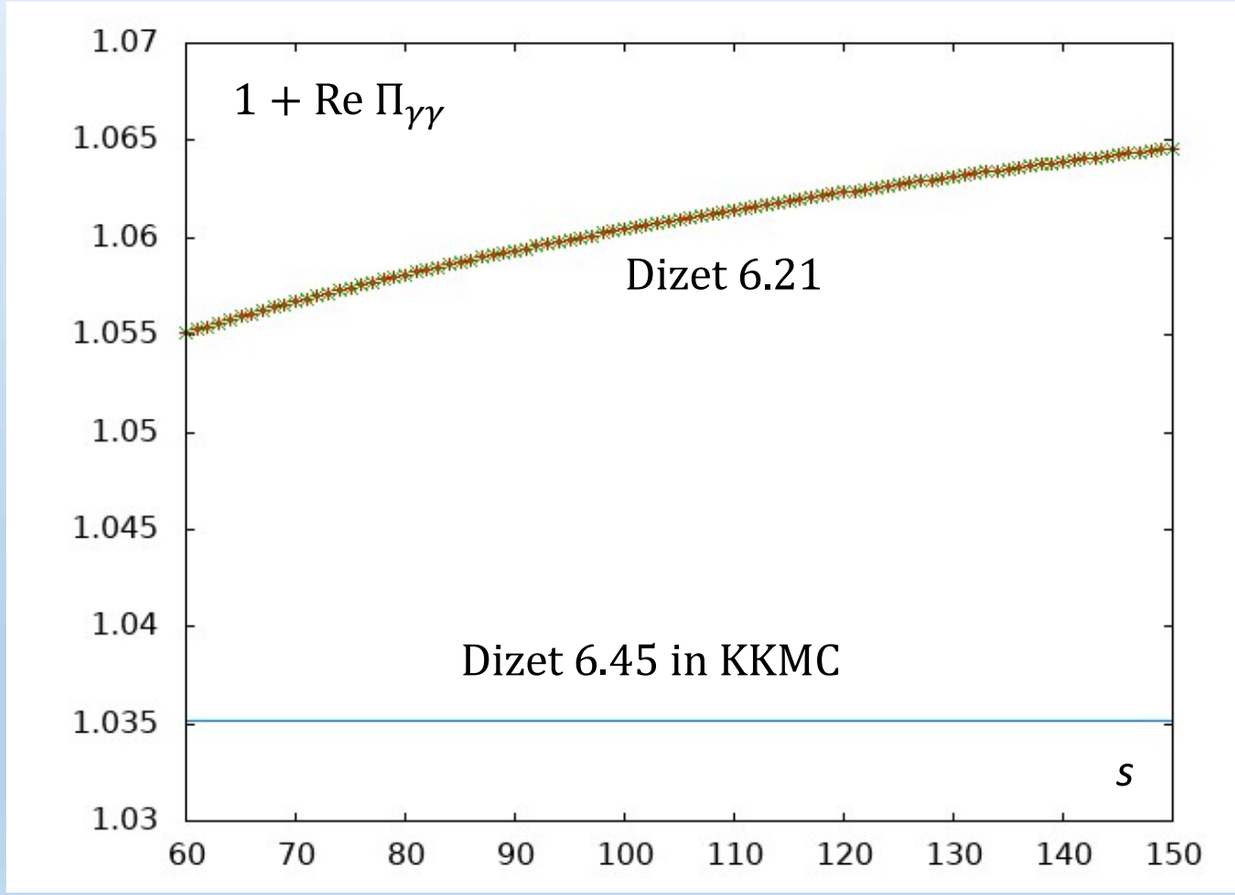
Five values of cosθ calculated in the CM frame are used.

There is a roughly constant shift of -17×10^{-4} from the old to new K-factors.





$1 + \Pi_{\gamma\gamma}$ for Dizet 6.21 and Dizet 6.45



$\Pi_{\gamma\gamma}$ depends only on s. It doesn't depend on the quark flavor. There is a substantial change in this term, and the new value is a constant: $\Pi_{\gamma\gamma} = -0.0351079942$. This is the biggest change between the two versions.

The Dizet 6.21 result appears to be more realistic and consistent with other results. We will need to track down the reason for this difference, which is likely to lie in the interface between Dizet and KKMC.

Summary

The EW form-factors in Dizet changed to varying degrees:

- The shift in ρ_{if} turned out to be negligible.
- The shifts in K_i and K_f were both approximately constant, ~ -0.0008.
- The shift in K_{if} was about twice this, ~ -0.0017.
- $\Pi_{\gamma\gamma}$ had an s-dependent shift considerably larger than either of these. This is likely to be the origin of the unexpectedly large shift in the March-April slides.

The difference in the context of the A_{FB} calculation still needs to be checked. The shift shown last month and in March could have been affected by an older choice of parameters in DIZET 6.21. In the present tests, modern parameters are used in both programs.

Standard Model Parameters

DIZET6.45 uses a scheme $(\alpha(0)v_0)$ with input parameters $G_\mu, \alpha(0), M_Z$. The other EW parameters are then calculated. M_W is calculated with EW corrections. Apart from the top, quark masses are not used by DIZET. The others are parameters for generating ISR in KKMC-hh.

$1/\alpha(0)$	137.035999139	$\alpha_s(M_Z)$	0.1201789
$1/\alpha(M_Z)$	128.950302560	$\alpha_s(m_t)$	0.1094
G_F	1.1663787×10^{-5} GeV^{-2}	$\sin^2(\theta_{\mathrm{W}})$	0.22340108
M_Z	91.1876 GeV	$\sin^2(\theta_{\mathrm{W}})_{\mathrm{eff}}$	0.23149900
Γ_Z	2.4953785 GeV		
M_W	80.3589356 GeV	m_d	4.7 MeV
Γ_W	2.0898823 GeV	m_u	2.2 MeV
M_H	125 GeV	m_s	150 MeV
m_e	510.998928 keV	m_c	4.6 GeV
m_μ	105.658389 MeV	m_b	1.2 GeV
m_τ	1.777 GeV	m_t	173.0 GeV

Red: input

Blue: output

(corrected)