Towards a more accurate treatment of QED radiative corrections in exclusive semileptonic *B*-meson decays.

Joint Workshop on |Vub| and |Vcb| 2009

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Review

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Why bother about photonic FSR?

- QED effects yield corrections to the strength of the semileptonic weak interaction vertex.
- All charged final- and initial states couple to photons, change of kinematic.

- Hard work @ B-Factories yielded very precise data-sets. Measurements gained sensitivity to radiation loss due to FSR.
- Currently used method not entirely satisfactory: PHOTOS was never designed to provide high-precision results in the B-meson sector. Not clear how to address theoretical uncertainties without explicitly calculating $\mathcal{O}(\alpha)$ corrections.
- $|V_{\mathrm{us}}|$ extraction through KL3 decays profited from improved understanding of FSR effects.

Phys. Rev. D 79, 012002 (2009) BaBar Collaboration

Annals of Physics, V 322, 11 (2005), Troy Andre

Universal soft corrections: PHOTOS.

- In the soft limit ($k \longrightarrow 0$) QED corrections are universal and large.
- PHOTOS: $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha^2)$ algorithm based on factorizing out photonic corrections.

Comput. Phys. Commun. 66 (1991),
Comput. Phys. Commun. 79 (1994).

$$\left| \mathcal{M}_0^0 + \mathcal{M}_1^{\frac{1}{2}} + \mathcal{M}_0^1 + \ldots \right|^2$$

$$\approx \quad \prod_i P(k_i, \Omega) \left| \mathcal{M}_0^0 \right|^2$$

The 20-30% rule:

Theoretical uncertainties are assessed by comparing Born and PHOTOS corrected Monte Carlo. 20-30% of the difference in the extracted central values are assigned as uncertainty.

$\mathcal{M}_j^i$ matrix element of $\mathcal{O}(\alpha^i)$ and with j real photons in the final state.

Universal soft corrections: Yennie-Frautschi-Suura Kernel

- Based on resummation of soft limit ($k \longrightarrow 0$).
- Separation of real and virtual amplitudes into YFS form factor: $e^{Y(\Omega)}$
- Reorganization of original perturbative series into infrared subtracted expansion of squared amplitudes: $\tilde{\beta}_i^j$

$$\left| \mathcal{M}_0^0 + \mathcal{M}_1^{\frac{1}{2}} + \mathcal{M}_0^1 + \ldots \right|^2$$

Annals Phys.13 379-452 (1961),YFS
JHEP12 018 (2008), Marek Schönherr

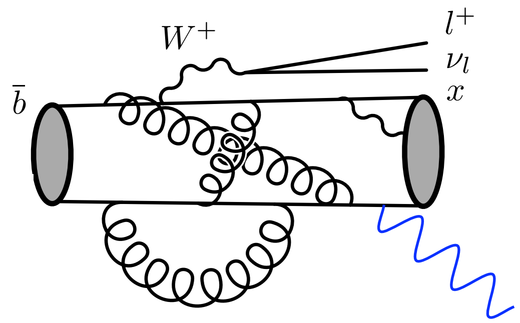
$$= \quad e^{Y(\Omega)} \prod_0^i \tilde{S}(k_i, \Omega) \left(\tilde{\beta}_0^0 + \tilde{\beta}_0^1 + \sum_i \frac{\tilde{\beta}_1^1(k_i)}{\tilde{S}(k_i)} + \ldots \right)$$

$\tilde{\beta}_0^0 = \mathcal{M}_0^0 \mathcal{M}_0^{0\,\dagger}$ $\quad \tilde{\beta}_i^j$ infrared subtracted matrix elements.

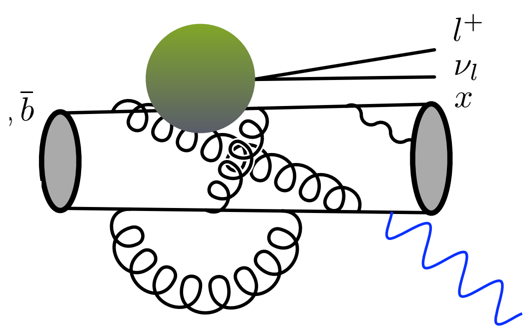
Next step to increase precision: going beyond the soft limit and treat semileptonic processes explicit at $\mathcal{O}(G_{\mathrm{F}}\, \alpha)$.

Short-distance and phenomenological long-distance model connected.

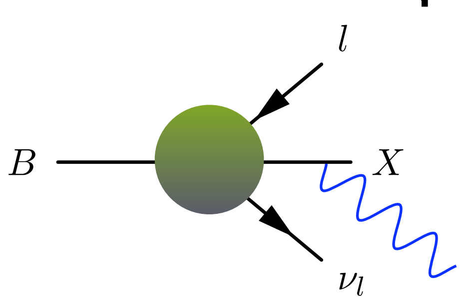
$$b \longrightarrow x\, l\, \nu_l$$



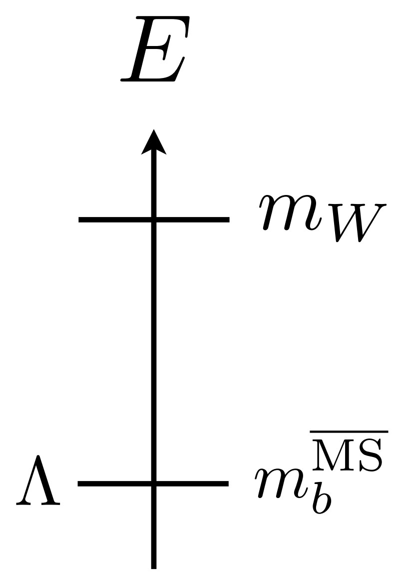
Fermi Theory



Phenomenological picture



$$B \longrightarrow X\, l\, \nu_l$$



$$\mathcal{L}_{\mathrm{SM}}(W, Z, \gamma, g)$$

$$\downarrow$$

$$\langle X\, l\, \nu_l(\gamma) | \mathcal{L}_{\mathrm{eff}} | B \rangle = G_{\mathrm{F}} \sum_n c_n \, \langle X\, l\, \nu_l(\gamma) | \mathcal{O}_n | B \rangle$$

Virtual loop momenta exceed expansion scale $q^2 = (p_l + p_\nu) \rightarrow$ yields corrections from short distance picture in Wilson coefficients of local expansion.

Photonic corrections within $k^2 < \Lambda^2$ & $\Lambda^2 < m_B^2$ can be modeled calculating QED corrections to a phenomenological weak Lagrangian.

Short-distance and long-distance correction to weak decay coupling.

Total rate change due to radiative corrections: $\Gamma = \Big(1 + \delta_{SD} + \delta_{LD}\Big)\Gamma^{\text{Born}} \times \eta_{QCD}$

LL of SD correction known from calculation of Sirlin.

$$\boxed{\delta_{SD} = \frac{2\alpha}{\pi}\log\left(\frac{m_Z}{\Lambda}\right)}$$

Nucl. Phys. B196, 83 (1982)
A. Sirlin

$$\sqrt{1+\delta_{SD}} = 1.007$$

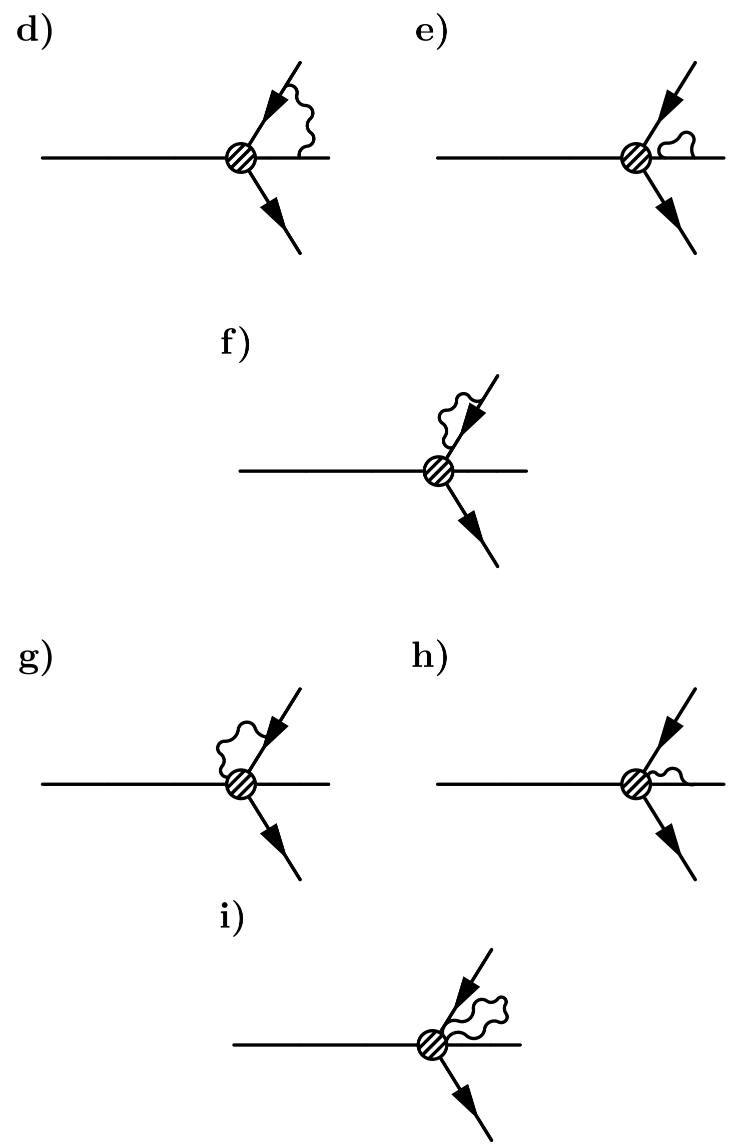
Change extracted CKM matrix elements from exclusive channels by
$1/\sqrt{1+\delta_{SD}+\delta_{LD}}$

η_{QCD} decay mode dependent QCD correction. δ_{LD} and corrections for initial- and final states from simulation at $\mathcal{O}(\alpha)$ of phenomenological model.

Decays of interests:

heavy to heavy	heavy to light
$B \to Dl\nu$	$B \to \pi l\nu$
$B \to D^* l\nu$	$B \to \rho l\nu$
$B \to D^{**}\, l\,\nu$	$B \to \omega l\nu$

Involved loops.



- In order to retain decay mode independent in our treatement of the loop integration, we neglect the photonic contribution to q^2 in the form factors and pull them in front of the arising integrals.
- The contribution of the photon 4-momenta to the Lorentz structure of hadronic current however is fully included.
- Vertex couplings are obtained from minimal coupling of the photon field to the weak Lagrangian.
- Arising IR divergencies regulated through small photon mass or dimensional regulator.
- UV divergencies show up. Several approaches (dimensional regularization, Pauli-Villars, Euclidian cut-off) could be applied.

A word on renormalization and regularization.

- Short-distance result of Sirlin took care of renormalization of the weak coupling G_F and matching it to the muon decay constant.
- No further renormalization is needed to calculate corrections of $\mathcal{O}(G_\mathrm{F}\,\alpha)$.

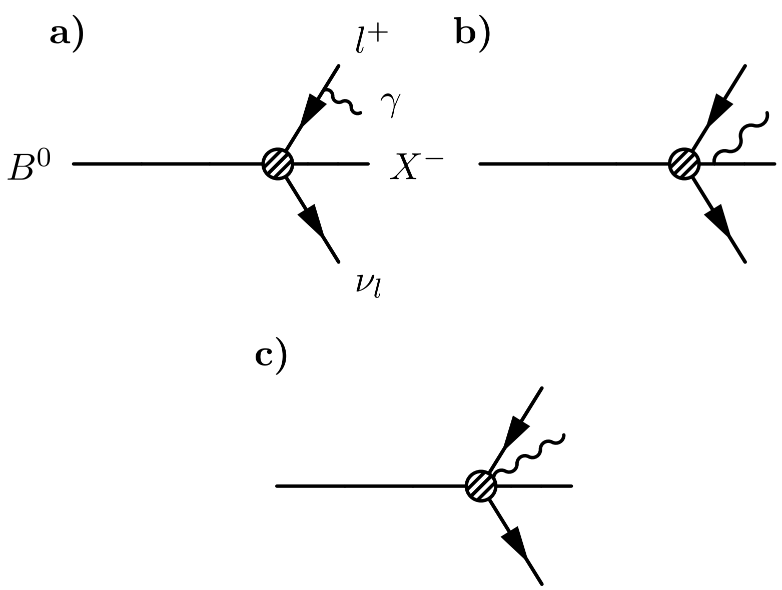
Nucl. Phys. B196, 83 (1982)
A. Sirlin

- IR divergencies cancel away when real emissions are included.
- UV divergencies in loop integrals in the short-distance picture are regularized using a Pauli-Villar-like approach.
- Long-distance result is matched to short-distance picture by Pauli-Villar approaches. Matching causes negligible impact on partial rates, but influence total integration results.

$$\frac{1}{(k-p)^2+i\epsilon} \to \frac{1}{(k-p)^2+i\epsilon} - \frac{1}{(k-p)^2-\Lambda^2+i\epsilon}$$

- Proposed recipe for uncertainty: Matching uncertainty by varying cut-off +/- 1 GeV. NNLO correction of magnitude of NLO x α.

Involved emissions.



Follow two Ansätze:

- 1. Model emissions direct from weak Lagrangian. Yields form factor model independent expressions and neglects k dependencies of q^2.
- 2. The emission diagrams including the full k dependency yields form factor model dependent expressions. These can be obtained (up to structure dependent contributions) by exploiting gauge invariance and the Ward identity of QED.

The IR divergency can either be addressed via a photon mass or via dimensional regularization.

BLOR and Sherpa: two tools to study radiative effects.

BLOR is derived from KLOR, a NLO QED MC generator that simulates radiative corrections to KL3 decays originally written by Troy Andre.

Annals of Physics, V 322, 11 (2005), Troy Andre

In this talk: $B \to D$ partial and total rate predictions
and $B \to \pi$ total rate predictions.

Work is in progress for remaining channels.

Sherpa is an all purpose MC generator, that incorporates the YFS kernel approach and allows easy inclusion of virtual and real matrix elements.

JHEP 0902:007,2009

Work in progress to obtain corrections.

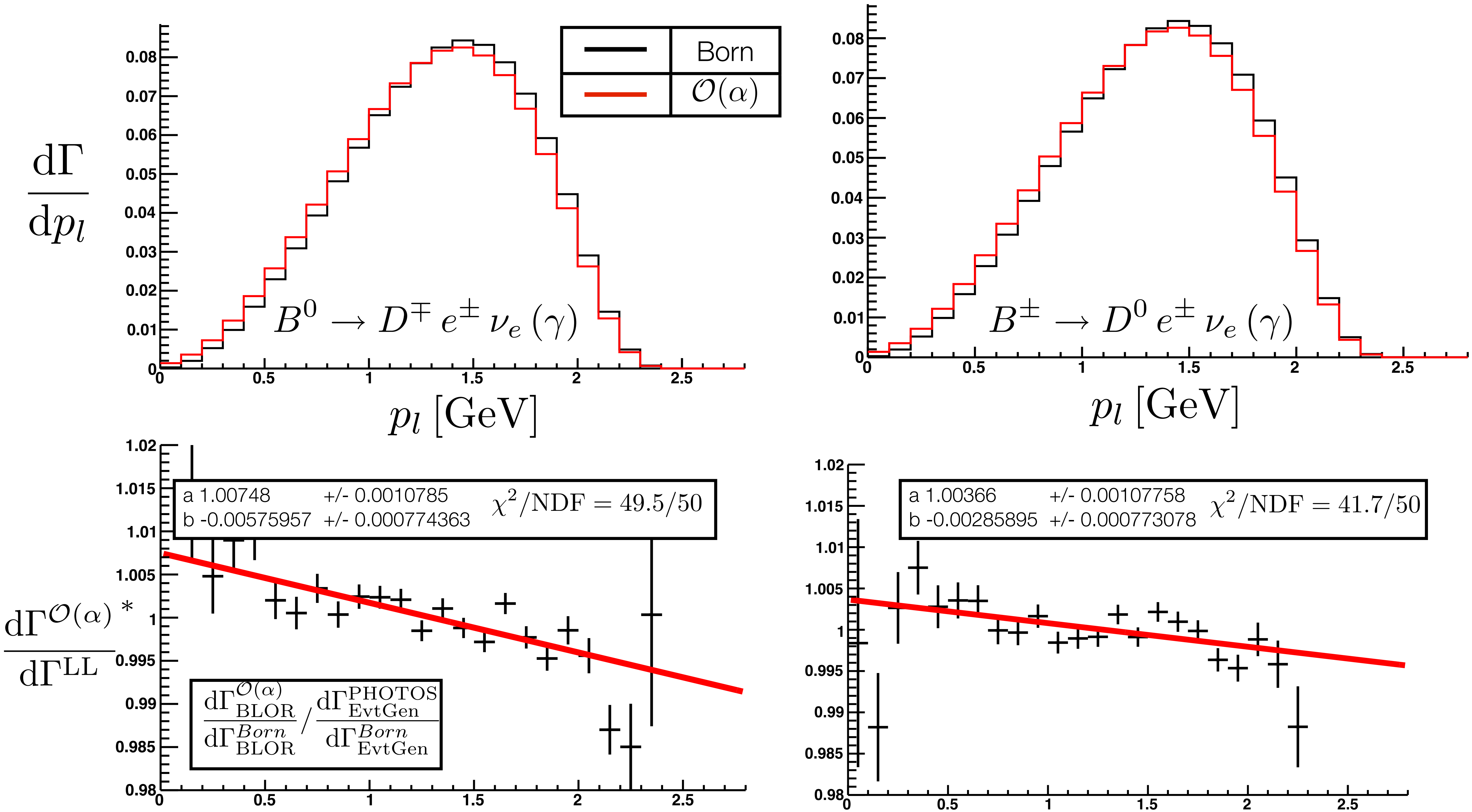
BLOR

Results for partial rates: $B \to D$

preliminary

Tuples are available at SLAC: /a/sulky53/AWG74/florian/awg

* = compared with PHOTOS' v. 2.13 (interference enabled).



BLOR
Results for partial rates: $B \to D$

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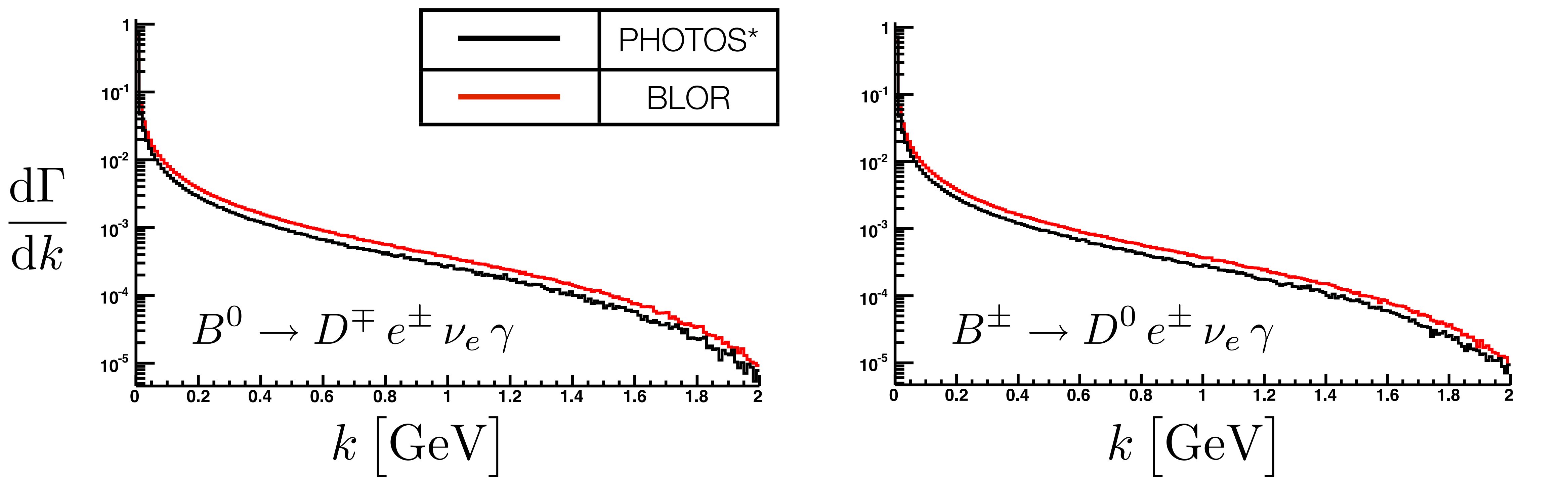


PHOTOS seems to produce not enough hard photons.

Results for corrections to total rates: $B \to D$

preliminary

* = averaged.

Mode	$1+\delta_{SD}+\delta_{LD}$	$\sigma_{\text{matching}+\alpha^2}+\sigma_{\text{stat.}}$	$\sqrt{1+\delta_{SD}+\delta_{LD}}$	$\sigma_{\text{matching}+\alpha^2}+\sigma_{\text{stat.}}$
$B^{\pm} \to D^0\, e^{\pm}\, \nu\, (\gamma)$	1.01417	0.00104282 +/-0.000213	1.00706	0.000517756 +/-0.000106
$B^0 \to D^{\mp}\, e^{\pm}\, \nu\, (\gamma)$	1.02774	0.00062951 +/-0.000241	1.01377	0.00031048 +/-0.000120
$B \to D\, e\, \nu\, (\gamma)^{*}$	**1.02096**	**0.000609048 +/-0.000161**	**1.01042**	**0.000301856 +/-0.000080**
$B^{\pm} \to D^0\, \mu^{\pm}\, \nu\, (\gamma)$	1.01424	0.00105136 +/-0.000121	1.00709	0.000521975 +/-0.000061
$B^0 \to D^{\mp}\, \mu^{\pm}\, \nu\, (\gamma)$	1.02795	0.000629207 +/-0.000164	1.01388	0.000310298 +/-0.000081
$B \to D\, \mu\, \nu\, (\gamma)^{*}$	**1.02109**	**0.000612629 +/-0.000102**	**1.01049**	**0.000303621 +/-0.000050**

Results for corrections to total rates: $B \to \pi$

preliminary

* = averaged.

Mode	$1 + \delta_{SD} + \delta_{LD}$	$\sigma_{\text{matching}+\alpha^2} + \sigma_{\text{stat.}}$	$\sqrt{1 + \delta_{SD} + \delta_{LD}}$	$\sigma_{\text{matching}+\alpha^2} + \sigma_{\text{stat.}}$
$B^\pm \to \pi^0 \, e^\pm \, \nu \, (\gamma)$	1.0141	0.000696777 +/- 0.00027	1.00703	0.000345958 +/- 0.000133
$B^0 \to \pi^\mp \, e^\pm \, \nu \, (\gamma)$	1.06696	0.000482716 +/-0.00048	1.03294	0.000233662 +/- 0.000236
$B \to \pi \, e \, \nu \, (\gamma)$ *	**1.04053**	**0.000423826 +/- 0.00028**	**1.02006**	**0.000208737 +/- 0.000135**
$B^\pm \to \pi^0 \, \mu^\pm \, \nu \, (\gamma)$	1.01446	0.000700383 +/-0.00022	1.00721	0.000347686 +/-0.000171
$B^0 \to \pi^\mp \, \mu^\pm \, \nu \, (\gamma)$	1.06717	0.000481688 +/-0.00047	1.03304	0.000233142 +/- 0.000223
$B \to \pi \, \mu \, \nu \, (\gamma)$ *	**1.04082**	**0.000425018 +/- 0.00026**	**1.0202**	**0.000209309 +/- 0.000141**

Summary and Conclusions.

- Total rate enhancement of charmed and pion decays agree good for charged B-mesons. Small corrections to extracted values of CKM matrix elements.
- Partial rate results between PHOTOS and BLOR agree on a percent level.
- However: Hard to draw an error bar in partial rates, the ‘truth’ might be in between.
- Therefore marrying both approaches within SHERPA is appealing: universal soft corrections to all orders and the hard limit will give a more precise insight.

Backup slides.

Points of improvements.

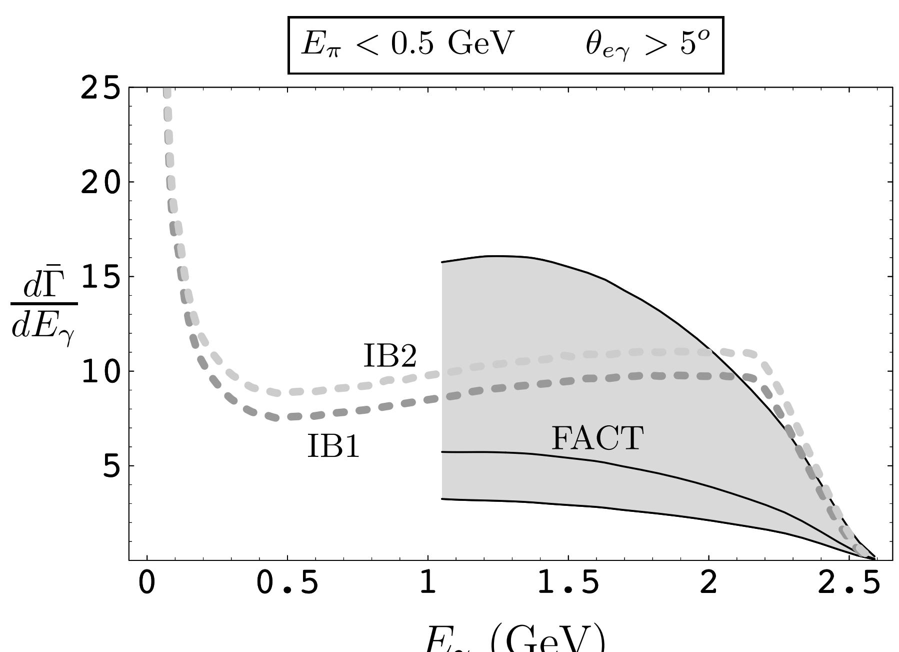
Matching procedure.

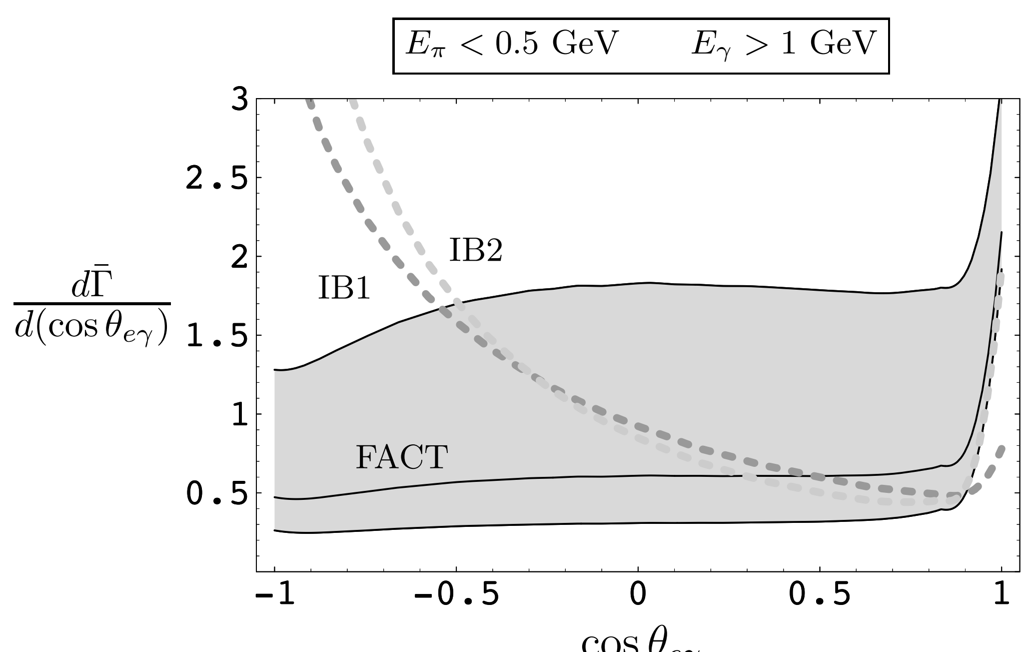
Complete virtual corrections from short distance picture: Further terms depend on strong current, but so far are considered small.

Nucl. Phys. B196, 83 (1982) A. Sirlin

Real emissions in the short distance energy regime: For Endpoint analyses not really problematic, hence contributions are negligible, unless effect enhanced through cuts.

Phys. Rev. D 72, 094021 (2005)





Sherpa, BLOR and PHOTOS at a glance.

		Sherpa	BLOR	PHOTOS
virtual correction	k dependency in FF	approximatively covered	approximatively covered	not covered
	virtual corrections on kinematics	covered	covered	not covered
real emission	k dependency in FF	approximatively covered	covered	not covered
	full emission coupling	covered	covered	not covered
	SD emission	not covered	not covered	not covered
	soft resummation	covered	not covered	covered
	calc. total LD rate change	covered	covered	not covered