

The Monte Carlo event generator **WINHAC** for single **W** production **IN HAdronic Collisions**

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Outline:

- Introduction.
- Why is FSR in W production processes important?
- The YFS exponentiation in leptonic W decays.
- The Monte Carlo event generator **WINHAC**.
- Numerical results – parton level.
- Numerical results – hadron level.
- Conclusions and outlook.

▷ W. Placzek & S. Jadach, hep-ph/0302065;

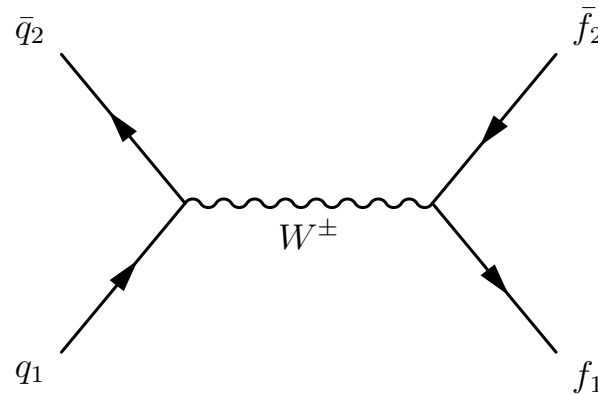
→ <http://cern.ch/placzek>

Why to investigate W -boson production processes?

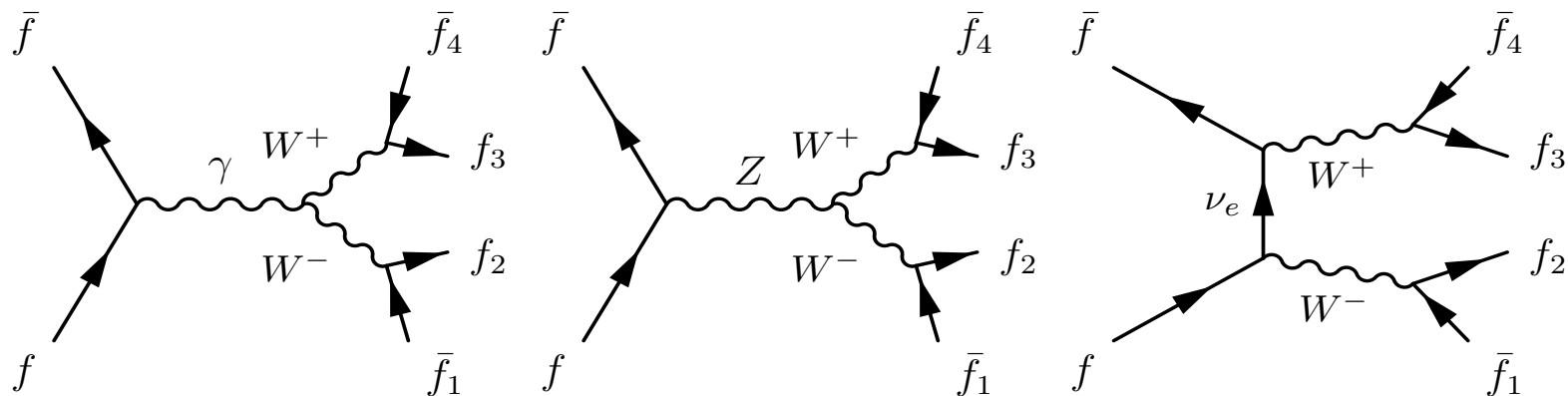
- To measure the Standard Model (SM) parameters, e.g. M_W , Γ_W
 - ▷ PDG 2002: $\Delta M_W = 39 \text{ MeV}$, $\Delta \Gamma_W = 42 \text{ MeV}$,
while: $\Delta M_Z = 2.1 \text{ MeV}$, $\Delta \Gamma_Z = 2.3 \text{ MeV}$.
- To test the SM, in particular its non-Abelian nature through triple and quartic gauge-boson couplings (TGC: WWV and QGC: WWV_1V_2).
- To get better constraints on the **Higgs boson mass**
 - ▷ Indirectly from SM fits
 - Requirements: $\Delta M_W \approx 0.7 \times 10^{-2} \Delta m_t$ (for equal weights in χ^2 tests)
⇒ LHC: $\Delta M_W \approx 15 \text{ MeV}$ ($\Delta M_W / M_W \approx 0.02\%$)
- To search for “**new physics**”, e.g. anomalous TGCs and QGC, etc.
- To measure parton distribution functions (PDF) and parton luminosities at **LHC**.
- Background for other processes, e.g. **Higgs boson** production.

Basic processes:

▷ **Single W :** $q_1 + \bar{q}_2 \longrightarrow W^\pm \longrightarrow f_1 + \bar{f}_2$



▷ **W -Pair:** $f + \bar{f} \longrightarrow W^-W^+ \longrightarrow f_1 + \bar{f}_2 + f_3 + \bar{f}_4$ ($f = e, q$)



W -boson mass and width measurement:

▷ Final-state radiation (FSR) distorts W -resonance line-shape

→ FSR reduces the effective W mass reconstructed from final fermion 4-momenta

Example:

Z -line shape from Z -pair production

[Beenakker, Berends & Chapovsky, PLB435 (1998) 233.]

(resummed – with soft-photon exponentiation)

▷ Z -peak distortions from FSR:

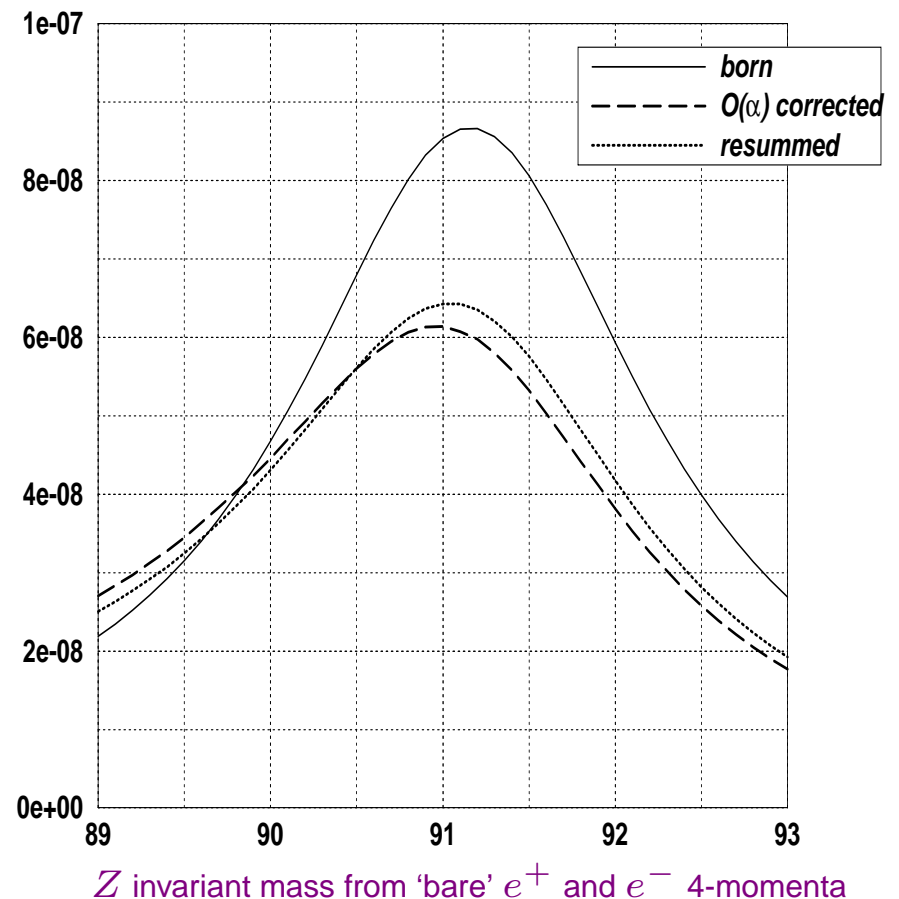
- $\mathcal{O}(\alpha)$:

$$\Delta M_{peak} = -196 \text{ MeV}, \quad \kappa_{peak} = 0.70$$

- resummed:

$$\Delta M_{peak} = -111 \text{ MeV}, \quad \kappa_{peak} = 0.74$$

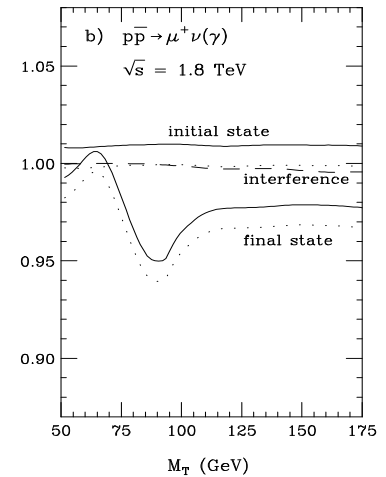
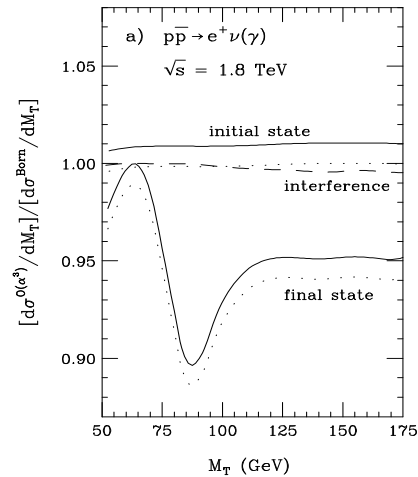
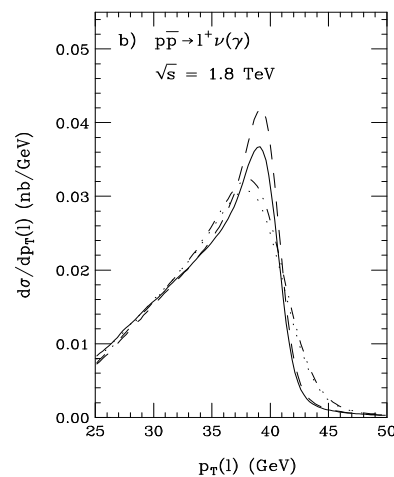
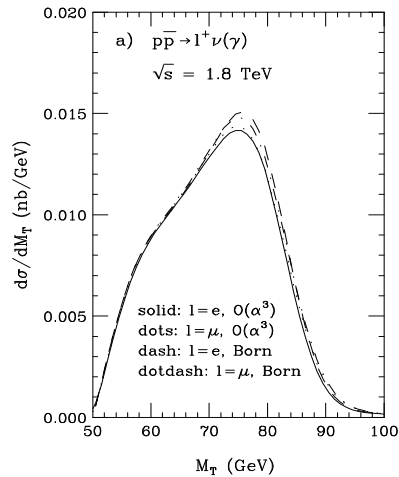
→ W -peak distortions $\approx \frac{1}{2}$ of the above.



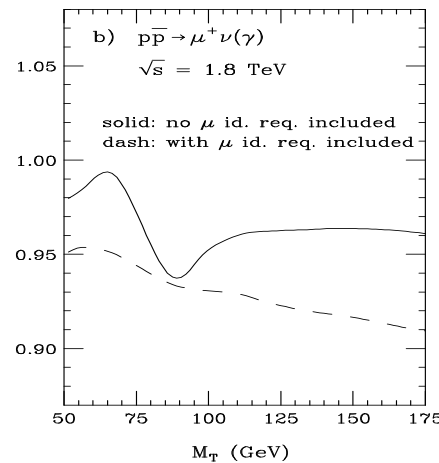
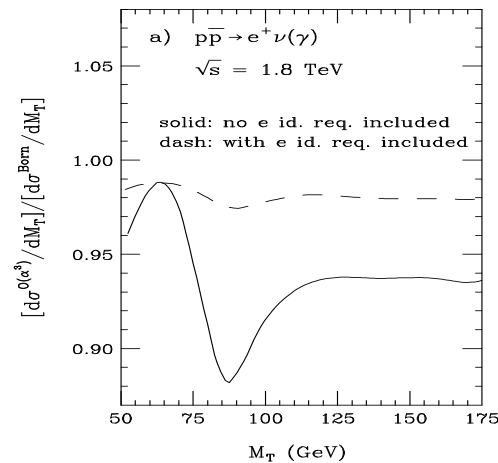
Why is FSR in W production processes important?

▷ Hadron colliders: M_W from W transverse mass M_T or final-lepton p_T

→ Tevatron: $\mathcal{O}(\alpha)$ radiative corrections [Baur, Keller & Wackerth, PRD59 (1998) 013002]



BARE vs. CALO acceptances



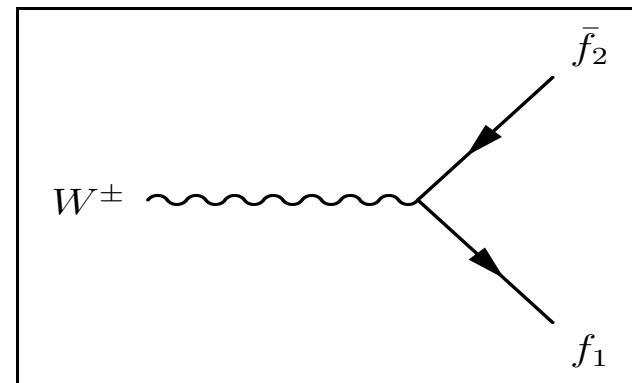
FSR effects are large and acceptance dependent ⇒ MC event generator needed

W -boson decay:

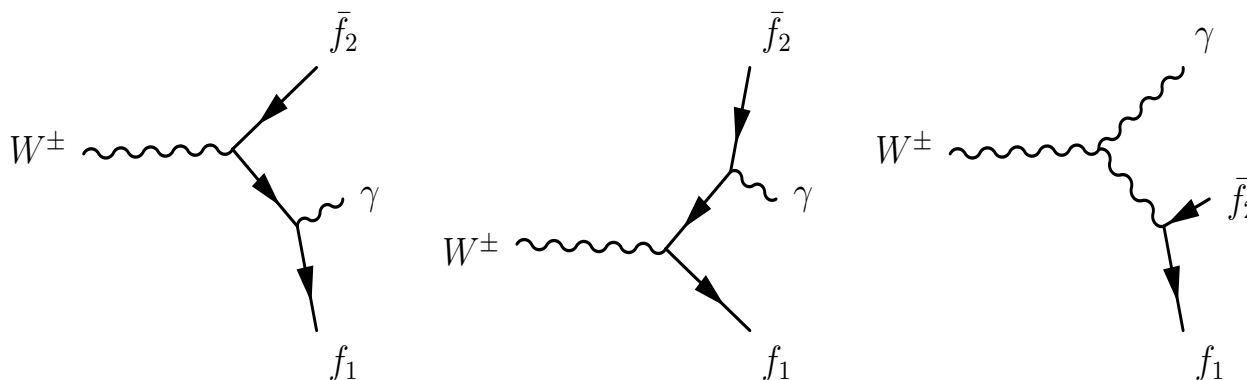
▷ Born-level process: $W^\pm \longrightarrow f_1 + \bar{f}_2$,
 where $f_1, f_2 \in SU(2)_L$ doublets with $I_3^{f_1} = -I_3^{f_2}$.

Basic difference with Z -boson decay:

W is charged \Rightarrow different electric charge flow and
 photon radiation from W -boson line



▷ Single photon radiation (in unitary gauge):



In actual processes:

▶ W -bosons in the intermediate state $\rightarrow W$ width must be included (preferably
 through the complex-pole definition)

▷ Photon emission from intermediate W -boson line

→ Partial-fraction decomposition of W propagators:

$$\frac{1}{Q^2 - M_W^2 + iM_W\Gamma_W} \times \frac{1}{Q'^2 - M_W^2 + iM_W\Gamma_W} = \underbrace{\frac{1}{k^2 + 2kQ'} \frac{1}{Q'^2 - M_W^2 + iM_W\Gamma_W}}_{\leftarrow \text{radiative production}} + \underbrace{\frac{1}{Q^2 - M_W^2 + iM_W\Gamma_W} \frac{1}{k^2 - 2kQ}}_{\text{radiative decay} \rightarrow}$$

⇒ Radiative corrections can be decomposed into:

- a) radiative corrections to W production,
- b) radiative corrections to W decay,
- c) their interferences (non-factorizable).

▷ In resonance W production the non-factorizable corrections are negligible

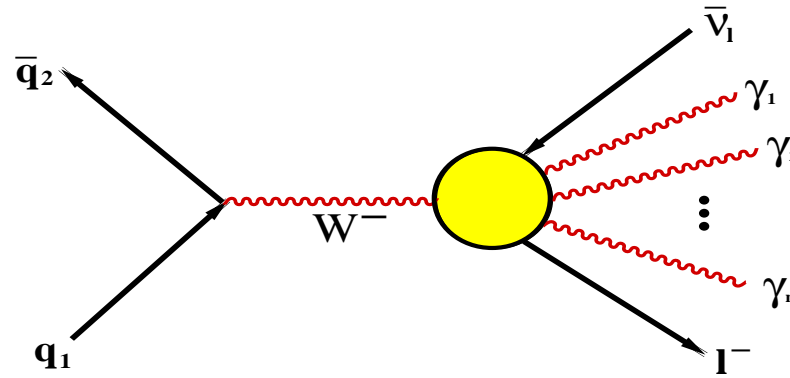
→ corrections to W -production and W -decay stages can be treated separately!

Here we investigate radiative corrections to leptonic W decays

▷ Single W -boson production in hadron collisions

- We consider the process:

$$q_1(p_1) + \bar{q}_2(p_2) \longrightarrow W^\pm(Q) \longrightarrow l(q_l) + \nu(q_\nu) + \gamma(k_1) + \dots + \gamma(k_n), \quad (n = 0, 1, \dots)$$



▶ $\mathcal{O}(\alpha)$ Yennie–Frautschi–Suura (YFS) exponentiated cross section:

$$\sigma_{\text{YFS}}^{\text{tot}} = \sum_{n=0}^{\infty} \int \frac{d^3 q_l}{q_l^0} \frac{d^3 q_\nu}{q_\nu^0} \rho_n^{(1)}(p_1, p_2, q_l, q_\nu, k_1, \dots, k_n),$$

where

$$\rho_n^{(1)} = e^{Y(Q, q_l; k_s)} \frac{1}{n!} \prod_{i=1}^n \frac{d^3 k_i}{k_i^0} \tilde{S}(Q, q_l, k_i) \theta(k_i^0 - k_s) \delta^{(4)} \left(p_1 + p_2 - q_l - q_\nu - \sum_{i=1}^n k_i \right) \\ \times \left[\bar{\beta}_0^{(1)}(p_1, p_2, q_l, q_\nu) + \sum_{i=1}^n \frac{\bar{\beta}_1^{(1)}(p_1, p_2, q_l, q_\nu, k_i)}{\tilde{S}(Q, q_l, k_i)} \right].$$

▷ More details:

• **YFS FormFactor** – gauge-invariant resummation of IR contributions:

$$Y(Q, q_l; k_s) = \underbrace{2\alpha\Re B(Q, q_l; m_\gamma)}_{\text{virtual photons}} + \underbrace{2\alpha\tilde{B}(Q, q_l; m_\gamma, k_s)}_{\text{real photons}};$$

where

$$B(Q, q; m_\gamma) = \frac{i}{8\pi^3} \int \frac{d^4k}{k^2 - m_\gamma^2 + i\varepsilon} \left(\frac{2q - k}{k^2 - 2kq + i\varepsilon} - \frac{2Q - k}{k^2 - 2kQ + i\varepsilon} \right)^2,$$

$$\tilde{B}(Q, q; m_\gamma, k_s) = -\frac{1}{8\pi^2} \int_{k^0 < k_s} \frac{d^3k}{k^0} \left(\frac{q}{kq} - \frac{Q}{kQ} \right)^2,$$

▷ **Four-momentum transfer between charged particles:**

$$t = (Q - q_l)^2 = \left(q_\nu + \sum_i k_i \right)^2 \geq 0$$

→ Different t domain than in production or scattering processes!

▷ We calculated this YFS formfactor in any Lorentz frame and for arbitrary particle masses → numerically stable representations!

! Special care had to be taken for the cases of $t = 0$ and W -rest frame (to avoid numerical instabilities).

▷ The virtual-photon IR function for $t > 0$ reads:

$$2\alpha\Re B(Q, q; m_\gamma) = \frac{\alpha}{\pi} \left\{ [\nu A(Q, q) - 1] \ln \frac{m_\gamma^2}{Mm} + \frac{1}{2} A_1(Q, q) - \nu A_3(Q, q) \right\},$$

$$A(Q, q) = \frac{1}{\lambda} \ln \frac{\lambda + \nu}{Mm},$$

$$A_1(Q, q) = \frac{M^2 - m^2}{t} \ln \frac{M}{m} - \frac{2\lambda^2}{t} A(Q, q) - 2,$$

$$\begin{aligned} A_3(Q, q) = & A(Q, q) \ln \frac{2\lambda}{Mm} + \frac{1}{\lambda} \left[\frac{1}{4} \left(\ln \frac{\lambda + \nu}{M^2} + 2 \ln \frac{\lambda - \nu + M^2}{t} \right) \ln \frac{\lambda + \nu}{M^2} \right. \\ & + \frac{1}{4} \left(\ln \frac{\lambda + \nu}{m^2} - 2 \ln \frac{\lambda + \nu - m^2}{m^2} \right) \ln \frac{\lambda + \nu}{m^2} \\ & \left. + \frac{1}{2} \ln \eta \ln(1 + \eta) - \frac{1}{2} \ln \zeta \ln(1 + \zeta) + \Re \text{Li}_2(-\eta) - \Re \text{Li}_2(-\zeta) \right], \end{aligned}$$

$$\nu = Qq, \quad \lambda = \sqrt{(\nu - Mm)(\nu + Mm)}, \quad Q^2 = M^2, \quad q^2 = m^2, \quad M > m,$$

$$t = M^2 + m^2 - 2\nu, \quad Mm \leq \nu < \frac{1}{2} (M^2 + m^2),$$

$$\eta = \frac{m^2 t}{2\lambda(2\lambda + \nu - m^2)}, \quad \zeta = \frac{\lambda + \nu}{m^2} \eta.$$

▷ The real-photon IR function for $t > 0$ reads:

$$\tilde{B}(Q, q; m_\gamma, k_s) = \frac{\alpha}{\pi} \left\{ \left[\nu A(Q, q) - 1 \right] \ln \frac{4k_s^2}{m_\gamma^2} - \frac{M^2}{2} A_4(Q, Q) - \frac{m^2}{2} A_4(q, q) - \nu A_4(Q, q) \right\}$$

$$A_4(p, p) = \frac{1}{p^2 \beta} \ln \frac{1 - \beta}{1 + \beta}, \quad \beta = \frac{|\vec{p}|}{p^0},$$

$$A_4(Q, q) = \frac{1}{\kappa} \left\{ \ln \left| \frac{V^2}{t} \right| \sum_{i=0}^1 (-1)^{n+1} [X(z_i; y_1, y_4, y_2, y_3) + R(z_i)] \right\},$$

$$R(z) = Y_{14}(z) + Y_{21}(z) + Y_{32}(z) - Y_{34}(z) + \frac{1}{2} X(z; y_1, y_2, y_3, y_4) X(z; y_2, y_3, y_1, y_4),$$

$$Y_{ij}(z) = 2Z_{ij}(z) + \frac{1}{2} \ln^2 \left| \frac{z - y_i}{z - y_j} \right|, \quad Z_{ij}(z) = \Re \text{Li}_2 \left(\frac{y_j - y_i}{z - y_i} \right),$$

$$X(z; a, b, c, d) = \ln \left| \frac{(z - a)(z - b)}{(z - c)(z - d)} \right|, \quad z_0 = \frac{|\vec{q}|}{T}, \quad z_1 = \frac{|\vec{Q}|}{T} - 1;$$

$$y_1 = -\frac{1}{2T} \left[T + \Omega - \frac{\omega\delta + \kappa}{t} V \right], \quad y_2 = y_1 - \frac{\kappa V}{tT},$$

$$y_3 = -\frac{1}{2T} \left[T - \Omega + \frac{\omega\delta + \kappa}{V} \right], \quad y_4 = y_3 + \frac{\kappa}{TV};$$

$$\kappa = \sqrt{(\omega^2 - t)(\delta^2 - t)}, \quad \delta = M - m, \quad \omega = M + m,$$

$$T = \sqrt{\Delta^2 - t}, \quad V = \Delta + T, \quad \Delta = Q^0 - q^0, \quad \Omega = Q^0 + q^0.$$

- The non-IR YFS functions:

- a) 0 real hard photons:

$$\bar{\beta}_0^{(1)}(p_1, p_2, q_l, q_\nu) = \bar{\beta}_0^{(0)}(p_1, p_2, q_l, q_\nu) \left[1 + \delta^{(1)}(Q, q_l, q_\nu) \right]$$

where: $\bar{\beta}_0^{(0)} = \frac{1}{8s} \frac{1}{(2\pi)^2} \frac{1}{12} \sum |\mathcal{M}^{(0)}|^2$ ← Born-like contribution

- ▶ $\mathcal{O}(\alpha)$ electroweak virtual corrections:

$$\delta^{(1)}(Q, q_l, q_\nu) = \delta_{\text{EW}}^v(Q, q_l, q_\nu; m_\gamma) - 2\alpha \Re B(Q, q_l; m_\gamma)$$

- ▶ In the released version only QED-like corrections included:

[based on: Marciano & Sirlin, PR **D8** (1973) 3612]

$$\delta_{\text{QED}}^{(1)}(Q, q_l) = \frac{\alpha}{\pi} \left(\ln \frac{M}{m_l} + \frac{1}{2} \right)$$

→ Version with EW corrections (from D. Bardin et al.) to be released soon (this week?)

- b) 1 real hard photon:

$$\bar{\beta}_1^{(1)}(p_1, p_2, q_l, q_\nu, k) = \frac{1}{16s} \frac{1}{(2\pi)^5} \frac{1}{12} \sum |\mathcal{M}^{(1)}|^2 - \tilde{S}(Q, q_l, k) \bar{\beta}_0^{(0)}(p_1, p_2, q_l, q_\nu),$$

where: $\tilde{S}(Q, q_l, k) = -\frac{\alpha}{4\pi^2} \left(\frac{Q}{kQ} - \frac{q_l}{kq_l} \right)^2$ ← soft-photon factor

▷ Matrix elements:

$$\mathcal{M}^{(0)}(\sigma_1, \sigma_2; \tau_1, \tau_2) = \frac{1}{Q^2 - M_W^2 + iM_W\Gamma_W} \sum_{\lambda} \mathcal{M}_P^{(0)}(\sigma_1, \sigma_2; \lambda) \mathcal{M}_D^{(0)}(\lambda; \tau_1, \tau_2)$$

$$\mathcal{M}^{(1)}(\sigma_1, \sigma_2; \tau_1, \tau_2, \kappa) = \frac{1}{Q^2 - M_W^2 + iM_W\Gamma_W} \sum_{\lambda} \mathcal{M}_P^{(0)}(\sigma_1, \sigma_2; \lambda) \mathcal{M}_D^{(1)}(\lambda; \tau_1, \tau_2, \kappa)$$

▶ Spin amplitudes in Weyl-spinor representation [cf. Hagiwara & Zeppenfeld, NP **B274** (1986) 1]:

a) Born-level W production:

$$\mathcal{M}_P^{(0)}(\sigma_1, \sigma_2; \lambda) = -\frac{ieVf_1f_2}{\sqrt{2}s_W} \omega_{-\sigma_1}(p_1) \omega_{\sigma_2}(p_2) \sigma_2 S(p_2, \epsilon_W^*(Q, \lambda), p_1)_{-\sigma_2, \sigma_1}^-$$

b) Born-level W decay:

$$\mathcal{M}_D^{(0)}(\lambda; \tau_1, \tau_2) = -\frac{ieCVf_1f_2}{\sqrt{2}s_W} \omega_{-\tau_1}(q_1) \omega_{\tau_2}(q_2) \tau_2 S(q_1, \epsilon_W(Q, \lambda), q_2)_{\tau_1, -\tau_2}^-$$

c) W decay with single real-photon radiation:

$$\begin{aligned} \mathcal{M}_D^{(1)}(\lambda; \tau_1, \tau_2, \kappa) = & -\frac{ie^2CVf_1f_2}{\sqrt{2}s_W} \omega_{-\tau_1}(q_1) \omega_{\tau_2}(q_2) \tau_2 \\ & \times \left\{ \left(\frac{Qf_1 q_1 \cdot \epsilon_{\gamma}^*}{k \cdot q_1} - \frac{Qf_2 q_2 \cdot \epsilon_{\gamma}^*}{k \cdot q_2} - \frac{Q_W Q \cdot \epsilon_{\gamma}^*}{k \cdot Q} \right) S(q_1, \epsilon_W(Q, \lambda), q_2)_{\tau_1, -\tau_2}^- \right. \\ & + \frac{Qf_1}{2k \cdot q_1} S(q_1, \epsilon_{\gamma}^*(k, \kappa), k, \epsilon_W(Q, \lambda), q_2)_{\tau_1, -\tau_2}^- - \frac{Qf_2}{2k \cdot q_2} S(q_1, \epsilon_W(Q, \lambda), k, \epsilon_{\gamma}^*(k, \kappa), q_2)_{\tau_1, -\tau_2}^- \\ & \left. - \frac{Q_W k \cdot \epsilon_W}{2k \cdot Q} S(q_1, \epsilon_{\gamma}^*(k, \kappa), q_2)_{\tau_1, -\tau_2}^- + \frac{Q_W \epsilon_W \cdot \epsilon_{\gamma}^*}{2k \cdot Q} S(q_1, k, q_2)_{\tau_1, -\tau_2}^- \right\} \end{aligned}$$

→ Spin amplitudes evaluated numerically for arbitrary fermion masses!

- Monte Carlo algorithm for multiphoton radiation:

- ▷ Lorentz frame choice for low-level MC generation

- ▶ Our previous MC generators:

- a) ISR in annihilation processes → initial-beams CMS

- b) FSR in neutral boson decays → final-state fermion-pair CMS

- c) Bhabha scattering → electron/positron Breit frames

- ▶ W -boson decay → W -rest frame (seems most natural)

- ▷ Construction of MC algorithm:

- Step-by-step simplification of the YFS formula for the cross section, compensated with appropriate MC weights – until Poissonian distribution is reached.

- Generation of random variables and evaluation of compensating weights – in the opposite way to the above simplification process.

- Construction of a MC event in terms of particle flavours and 4-momenta.

- ▷ MC event generator **WINHAC version 1.11**: → <http://cern.ch/placzek>

- Full-hadron level (**Tevatron/LHC**): quark x and Q^2 generated with the help of self-adapting MC sampler **Foam** according to PDFs from **PDFLIB** package.

• **Basic tests at the parton level**

▷ Test of spin amplitudes and MC algorithm:

→ To reproduce Born-level and $\mathcal{O}(\alpha)$ results from the YFS exponentiation

a) **Born cross section:**

$$\sigma_0^{\text{WH}} = \int \frac{d^3 q_l}{q_l^0} \frac{d^3 q_\nu}{q_\nu^0} \rho_0^{(0)} e^{-Y}$$

$$\sigma_0^{\text{An}} = \frac{\alpha^2 \pi |V_{ij}|^2}{36 s_W^4} \times \frac{s}{(s - M_W^2)^2 + M_W^2 \Gamma_W^2}$$

Calculation	σ_0^{tot} [nb]		
	e	μ	τ
Analytical	8.8872	8.8872	8.8872
WINHAC	8.8869 (2)	8.8873 (2)	8.8808 (2)

b) $\mathcal{O}(\alpha)$ corrected cross section:

$$\sigma_1^{\text{WH}} = \int \frac{d^3 q_l}{q_l^0} \frac{d^3 q_\nu}{q_\nu^0} \delta^{(4)}(p_1 + p_2 - q_l - q_\nu) \bar{\beta}_0^{(0)} \left[1 + \delta_{\text{QED}}^{(1)} + Y \right]$$

$$+ \int \frac{d^3 q_l}{q_l^0} \frac{d^3 q_\nu}{q_\nu^0} \frac{d^3 k}{k^0} \delta^{(4)}(p_1 + p_2 - q_l - q_\nu - k) \left[\bar{\beta}_1^{(1)} + \tilde{S} \bar{\beta}_0^{(0)} \right] \theta(k^0 - k_s),$$

$$\delta_1^{\text{An}} = \frac{\alpha}{\pi} \left(\frac{77}{24} - \frac{\pi^2}{3} \right) \approx 1.89 \times 10^{-4}$$

Calculation	$\delta_1 = \sigma_1^{\text{tot}} / \sigma_0^{\text{tot}} - 1$		
	e	μ	τ
WINHAC	$-1.5 (3) \times 10^{-4}$	$-2.2 (3) \times 10^{-4}$	$-0.3 (2) \times 10^{-4}$

► Hard photon spectrum at $\mathcal{O}(\alpha)$

$$\delta_1^h(k_0) = \frac{1}{\sigma_1^{\text{tot}}} \int_{E_0} dE_\gamma \frac{d\sigma_1}{E_\gamma} \times 100\%$$

$$E_0 = k_0 \times E_{\text{CM}}/2, \quad E_{\text{CM}} = 90 \text{ GeV}$$

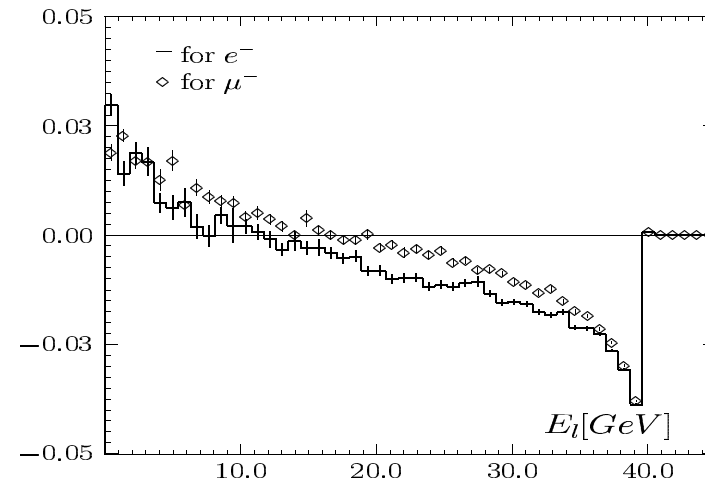
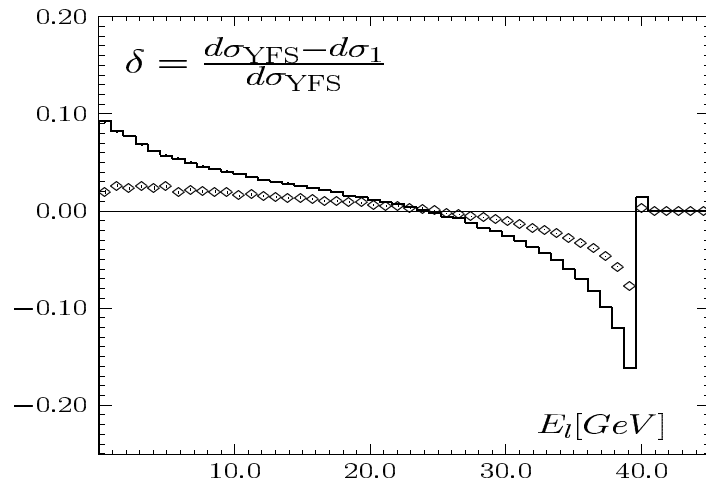
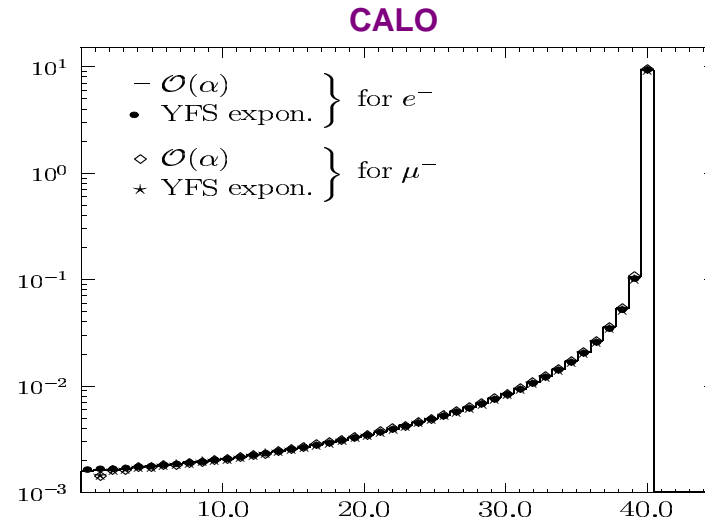
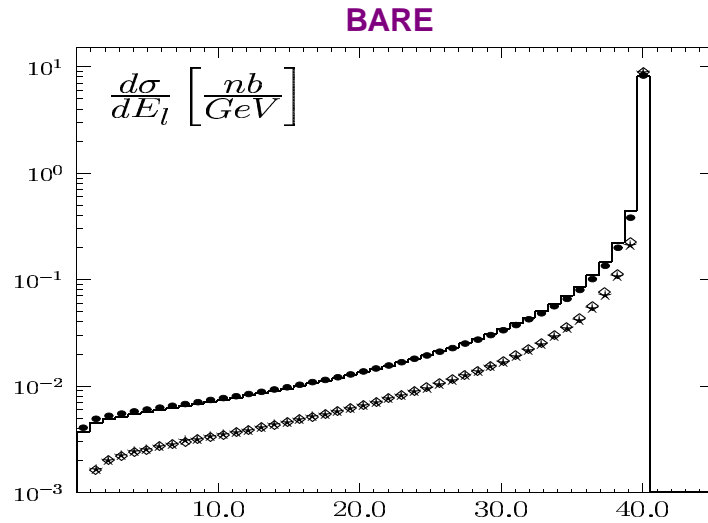
B&K: Berends & Kleiss, ZP C27 (1985) 365

k_0	e		μ	
	WINHAC	B&K	WINHAC	B&K
0.01	19.69 (3)	19.7	10.11 (2)	10.1
0.05	11.61 (2)	11.6	5.92 (1)	5.9
0.10	8.31 (2)	8.3	4.22 (1)	4.2
0.15	6.47 (2)	6.5	3.27 (1)	3.3
0.20	5.23 (1)	5.2	2.63 (1)	2.6
0.30	3.61 (1)	3.6	1.80 (1)	1.8
0.40	2.57 (1)	2.6	1.27 (1)	1.3
0.50	1.84 (1)	1.8	0.91 (1)	0.9
0.60	1.29 (1)	1.3	0.63 (1)	0.6
0.70	0.86 (1)	0.9	0.42 (1)	0.4
0.80	0.52 (1)	0.5	0.25 (1)	0.2
0.90	0.24 (1)	0.2	0.11 (1)	0.1

WINHAC reproduces very well Born and $\mathcal{O}(\alpha)$ calculations!

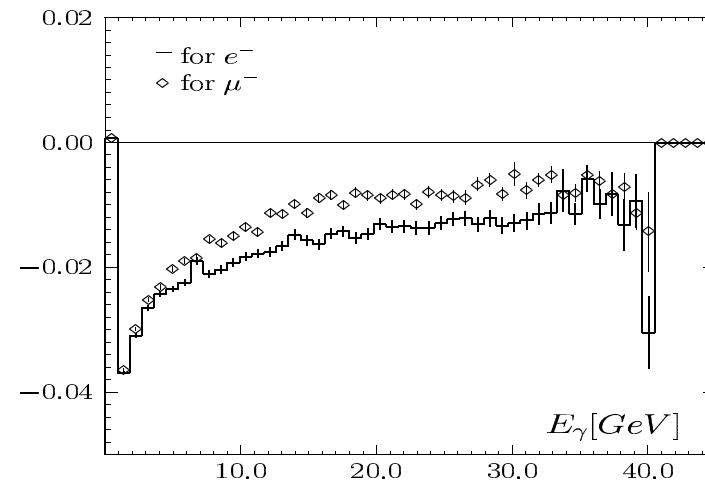
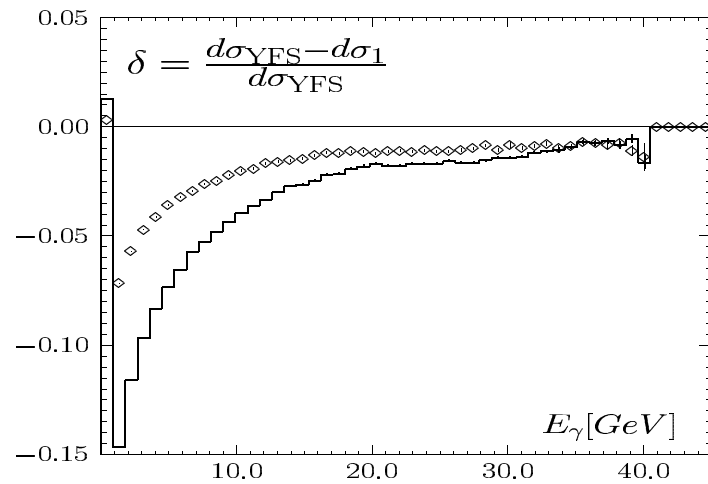
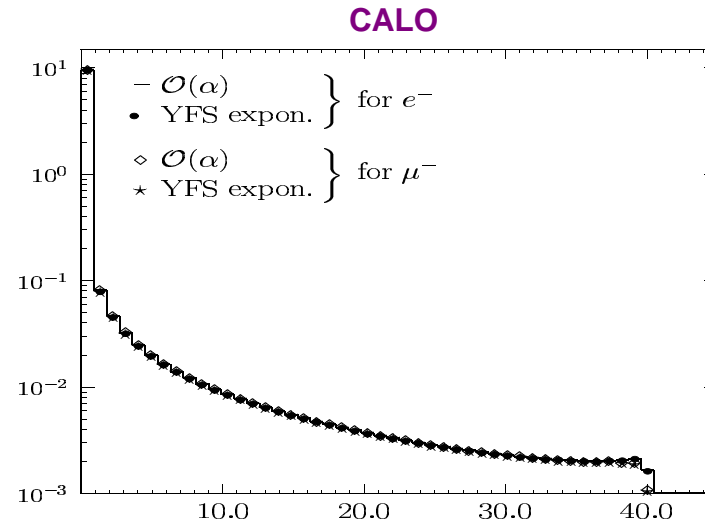
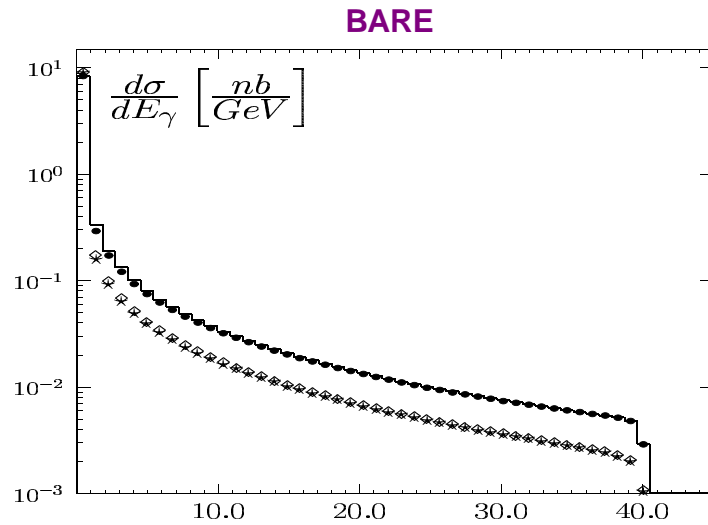
• Parton level distributions – higher-order FSR effects:

▷ Charged-lepton energy E_l



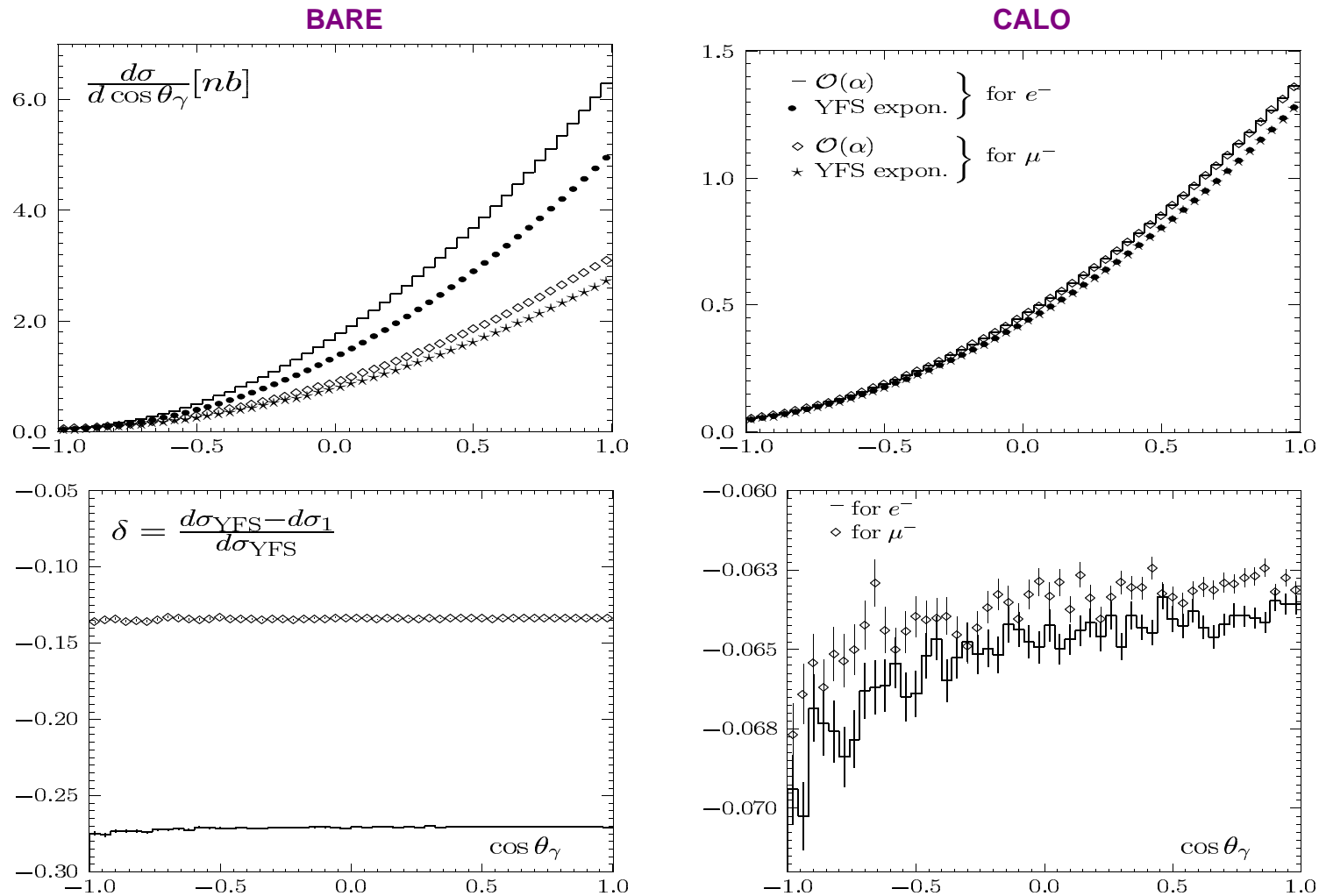
CALO: Photons recombined with charged lepton if $\angle(l, \gamma) \leq 5^\circ$.

▷ Hardest-photon energy E_γ :



CALO: Photons recombined with charged lepton if $\angle(l, \gamma) \leq 5^\circ$.

▷ Cosine of hardest-photon polar angle $\cos \theta_\gamma$:



CALO: Photons recombined with charged lepton if $\angle(l, \gamma) \leq 5^\circ$.

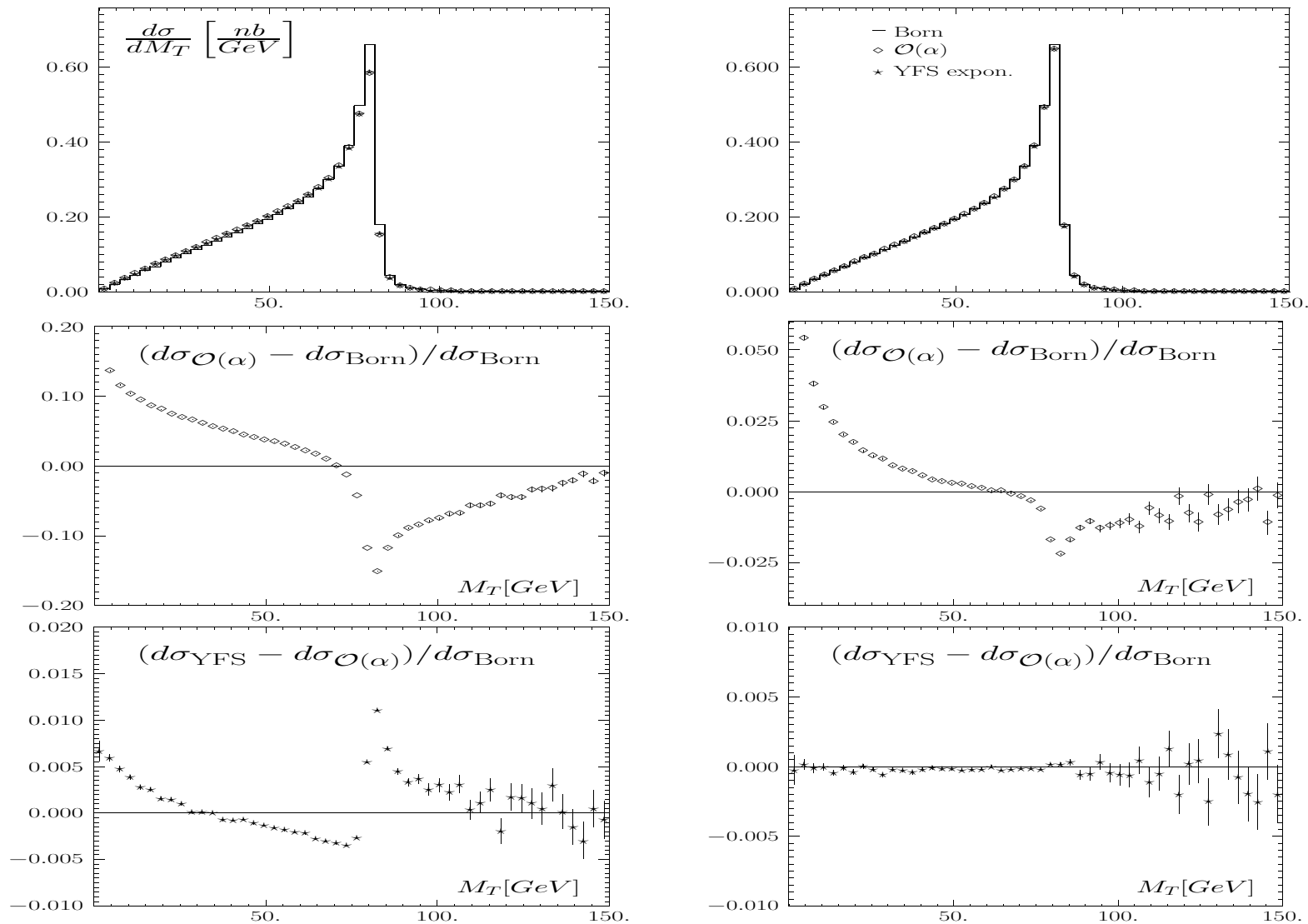
Higher-order QED FSR effects are sizeable and acceptance dependent!

W -boson transverse mass M_T for: $W^+ \rightarrow e^+ \nu_e$

PDF: MRS (G)

BARE

CALO

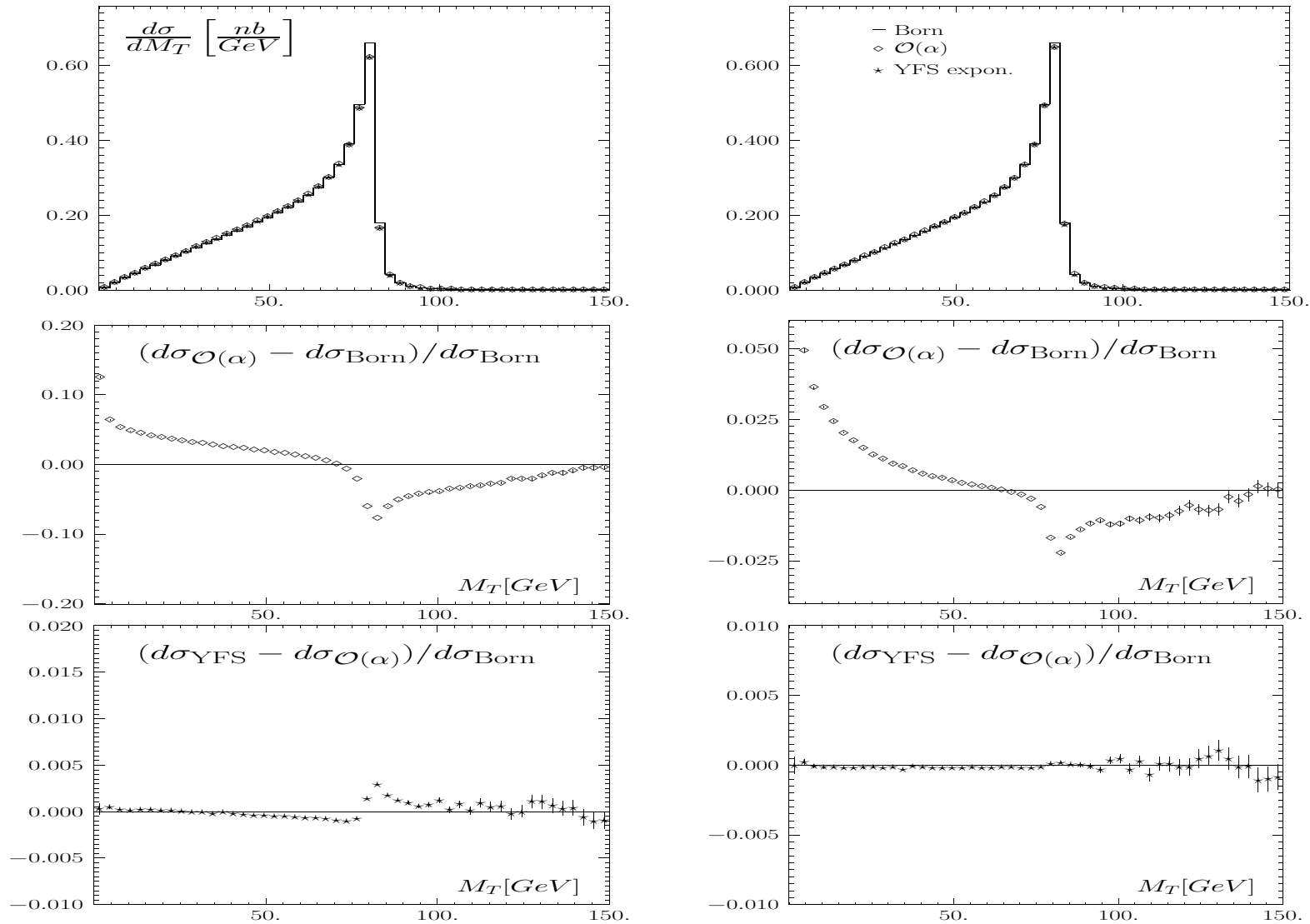


W -boson transverse mass M_T for: $W^+ \rightarrow \mu^+ \nu_\mu$

PDF: MRS (G)

BARE

CALO

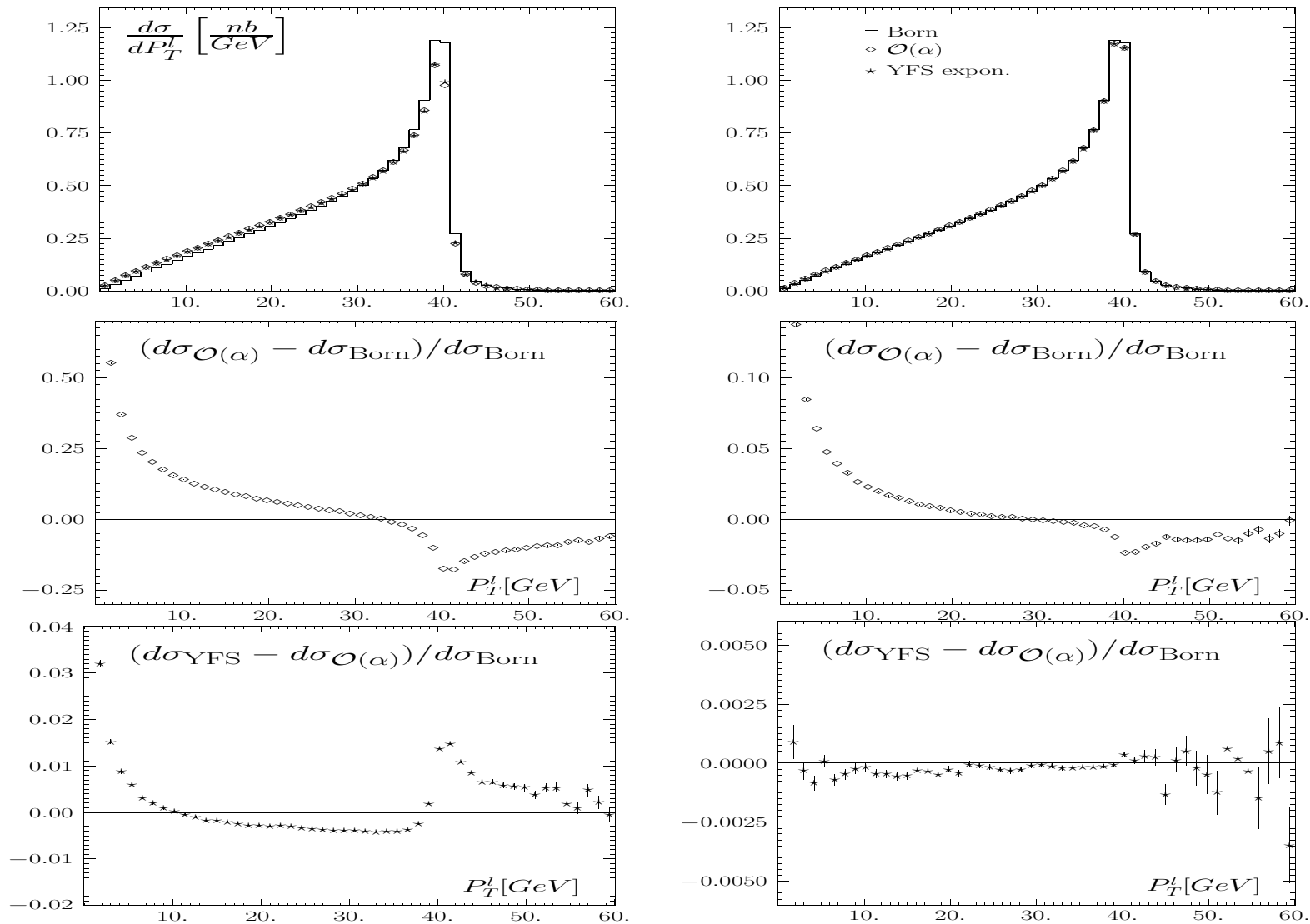


Charged lepton p_T for: $W^+ \rightarrow e^+ \nu_e$

PDF: MRS (G)

BARE

CALO

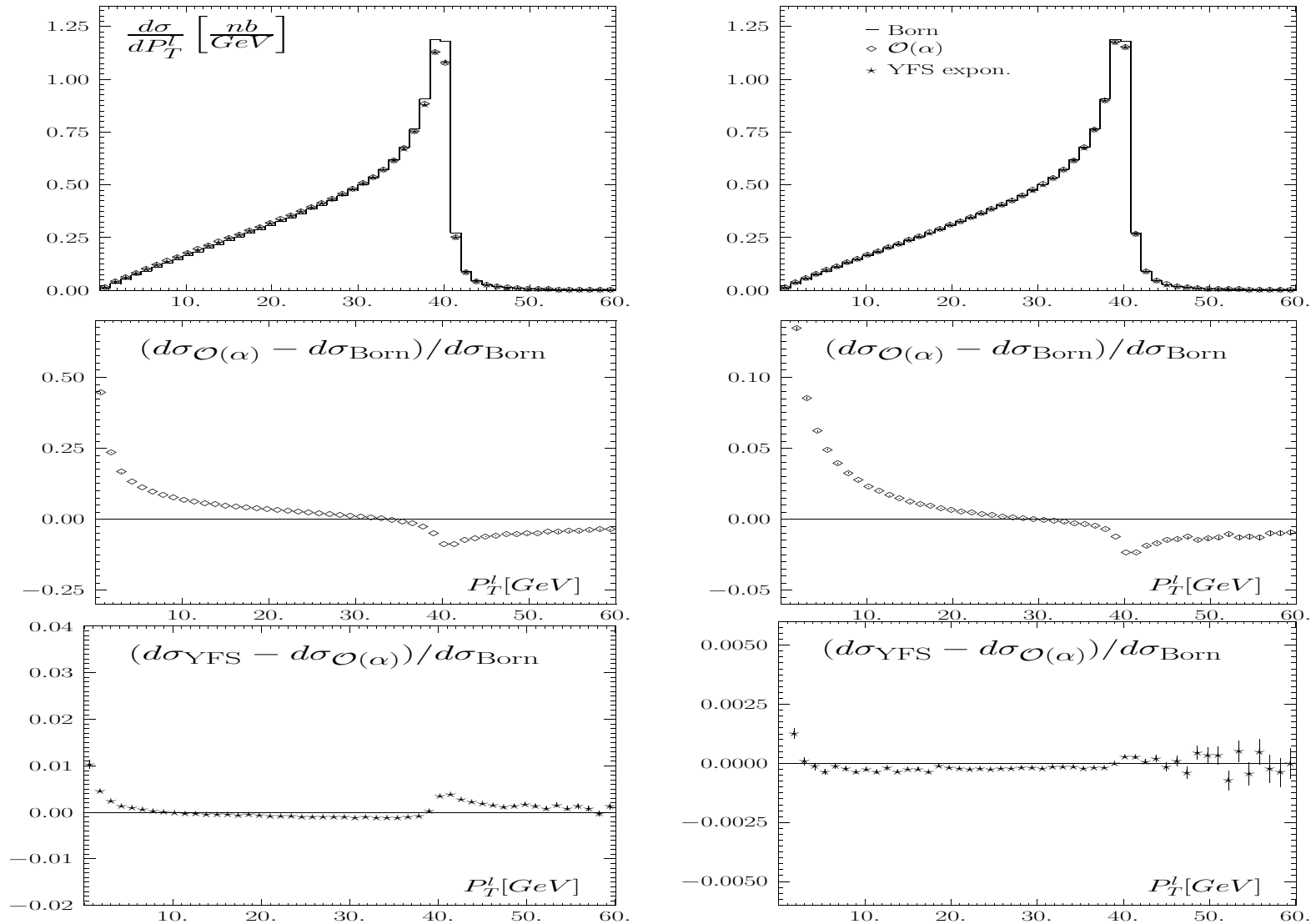


Charged lepton p_T for: $W^+ \rightarrow \mu^+ \nu_\mu$

PDF: MRS (G)

BARE

CALO

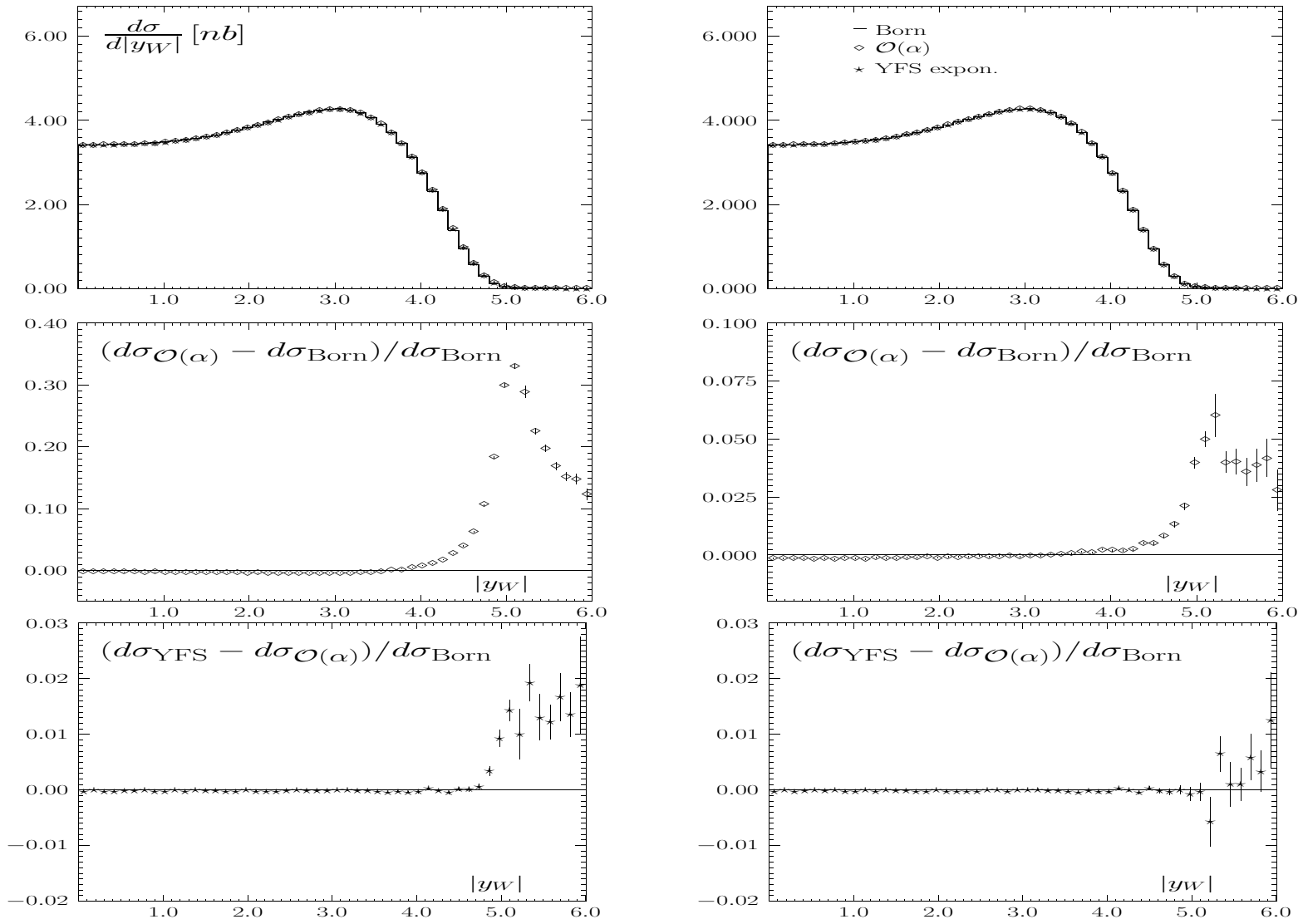


W -boson rapidity y_W for: $W^+ \rightarrow e^+ \nu_e$

PDF: MRS (G)

BARE

CALO

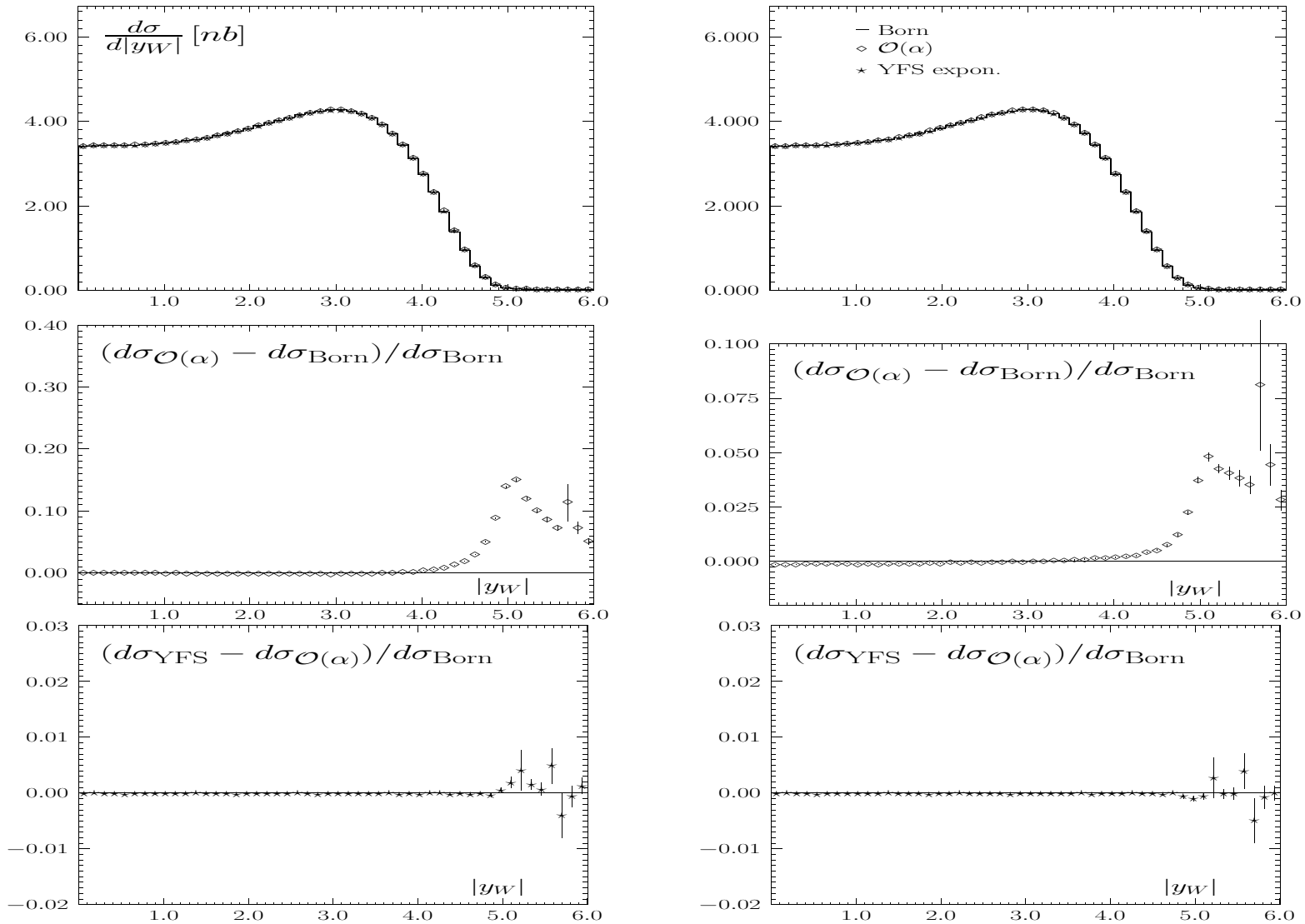


W -boson rapidity y_W for: $W^+ \rightarrow \mu^+ \nu_\mu$

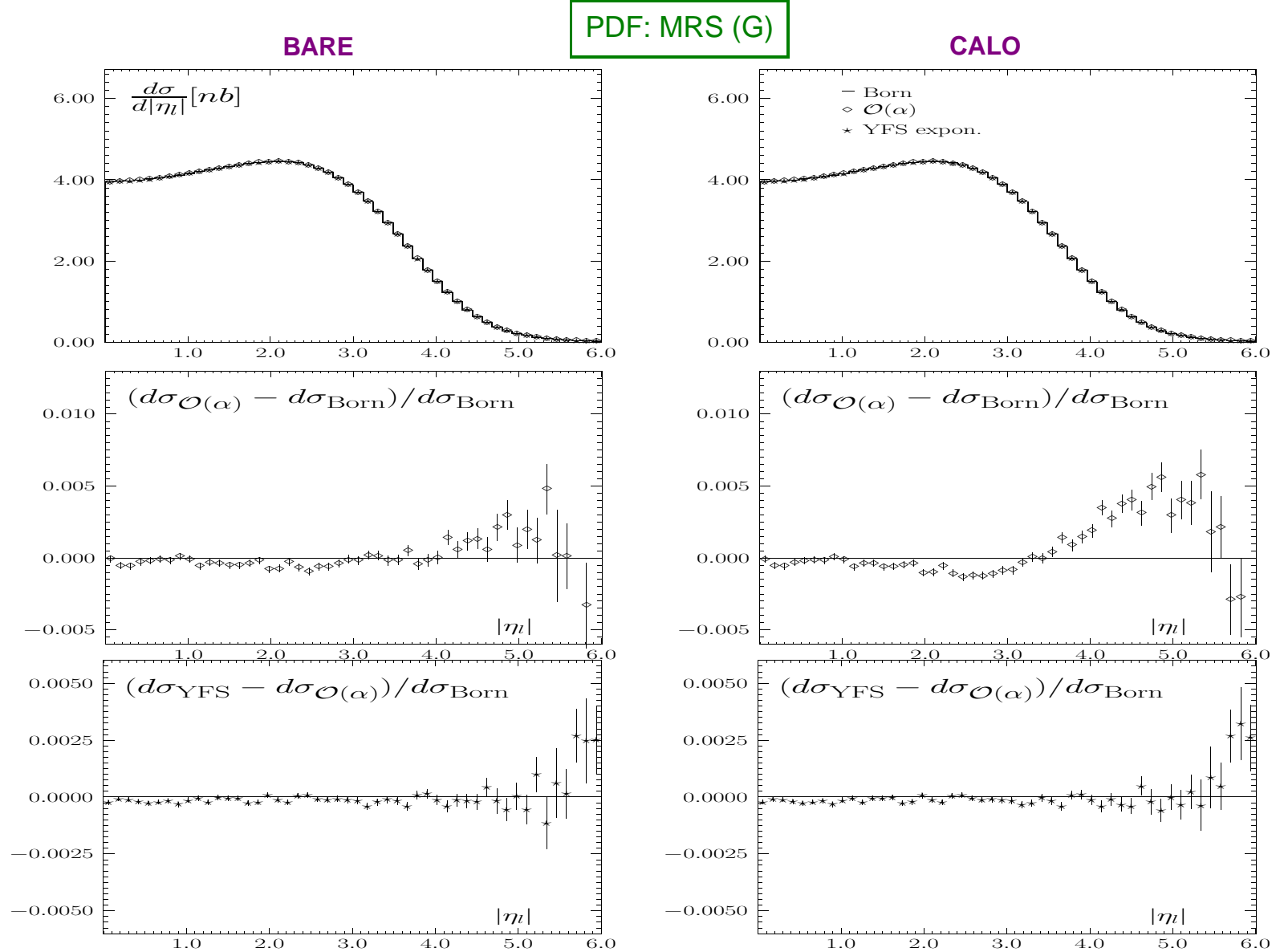
PDF: MRS (G)

BARE

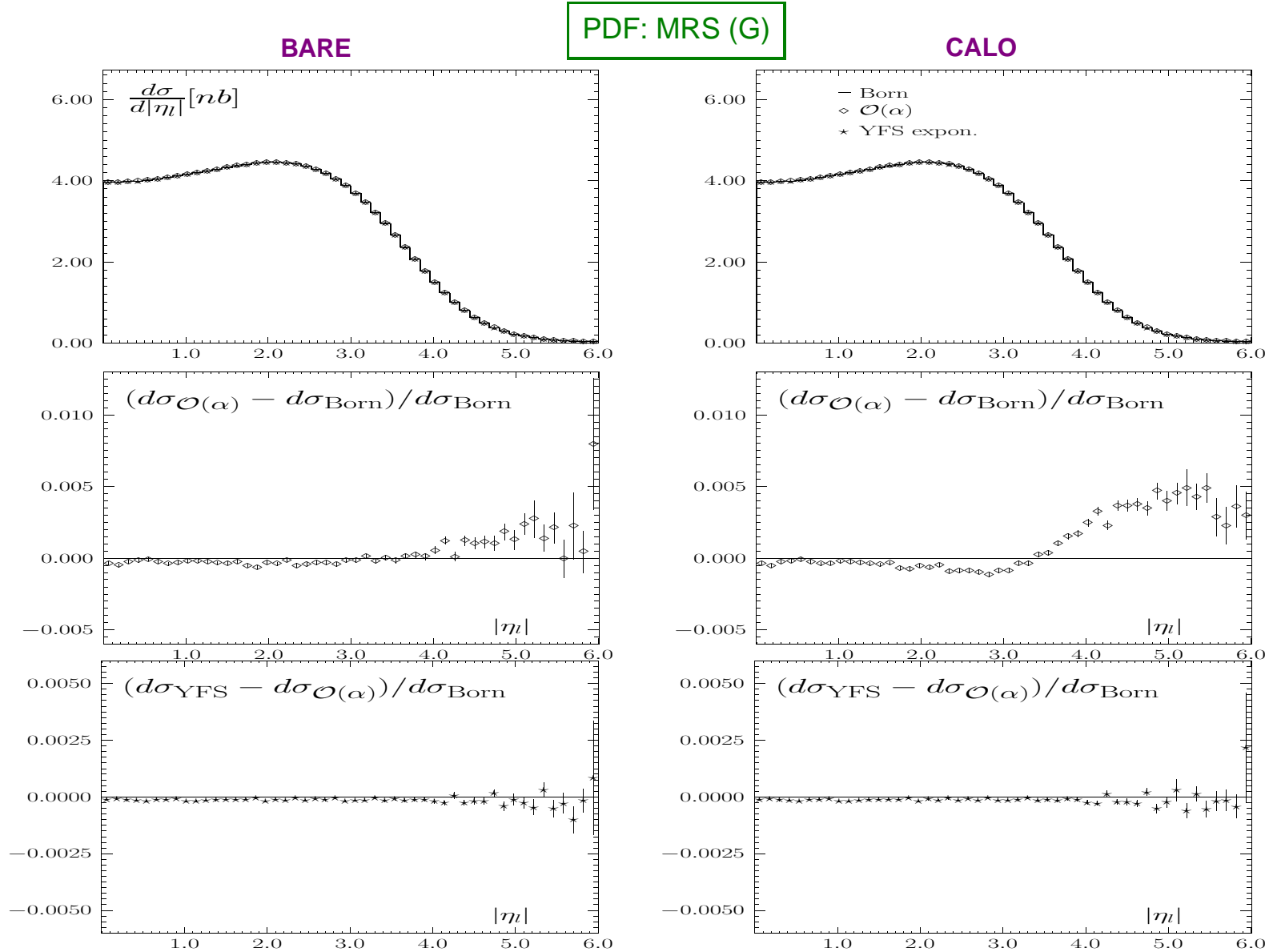
CALO



Charged lepton pseudorapidity η_l for: $W^+ \rightarrow e^+ \nu_e$



Charged lepton pseudorapidity η_l for: $W^+ \rightarrow \mu^+ \nu_\mu$

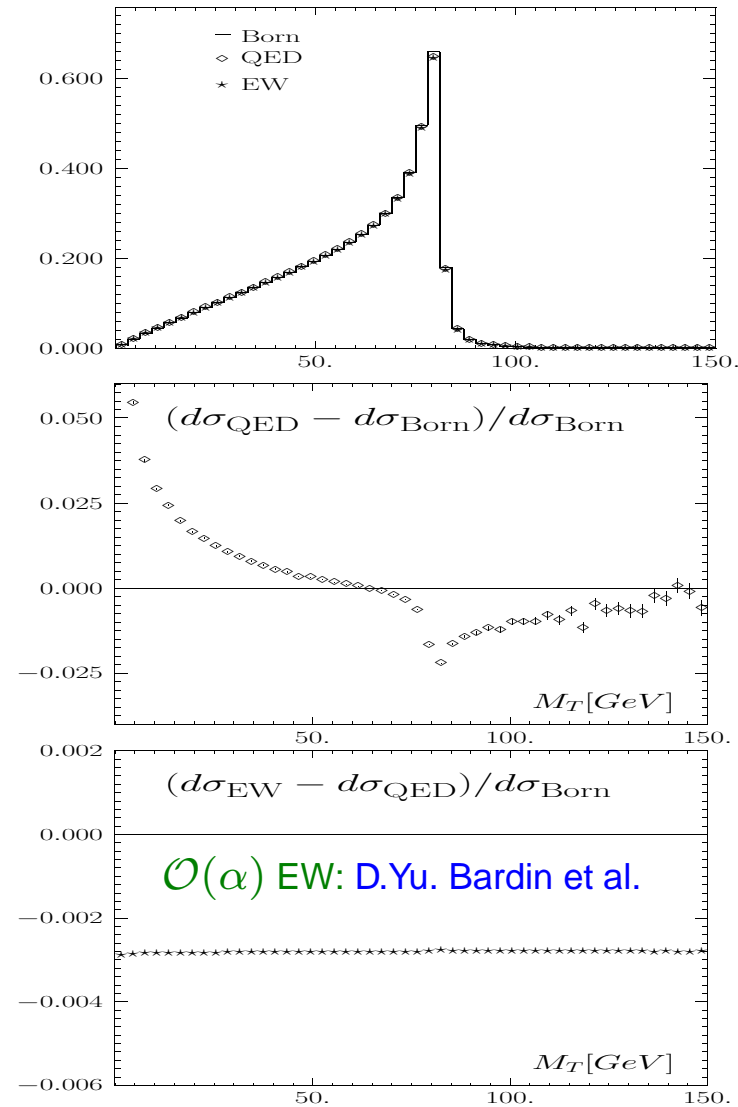
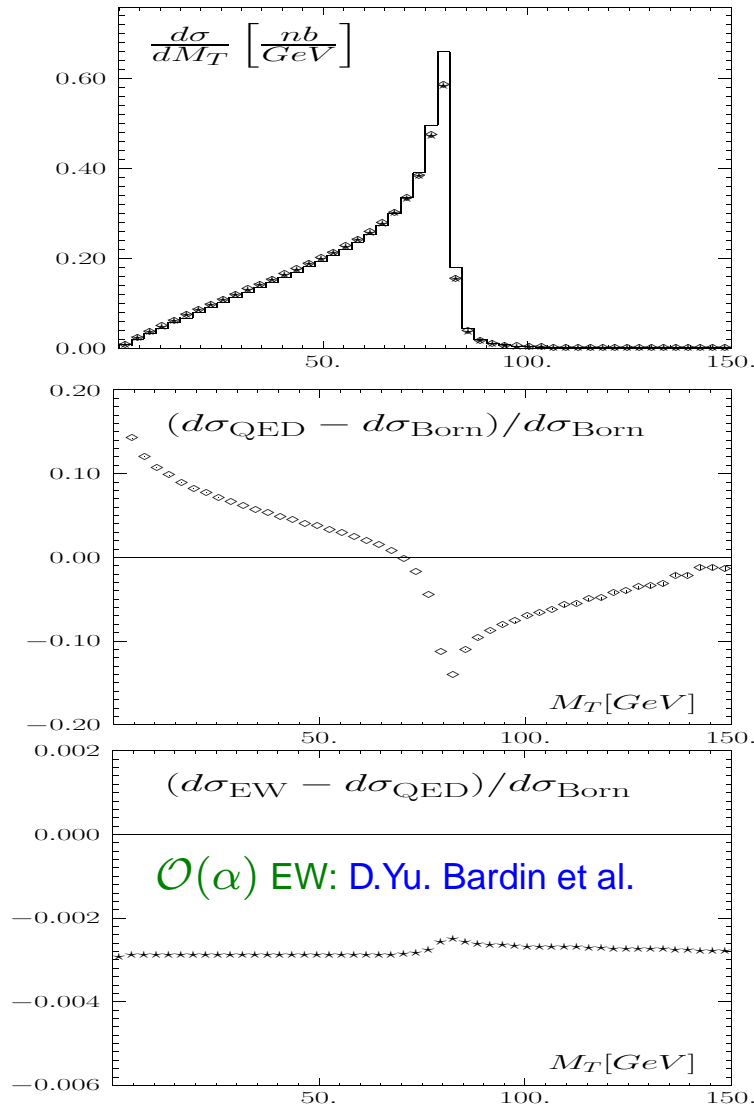


W -boson transverse mass M_T for: $W^+ \rightarrow e^+ \nu_e$

PDF: MRS (G)

BARE

CALO

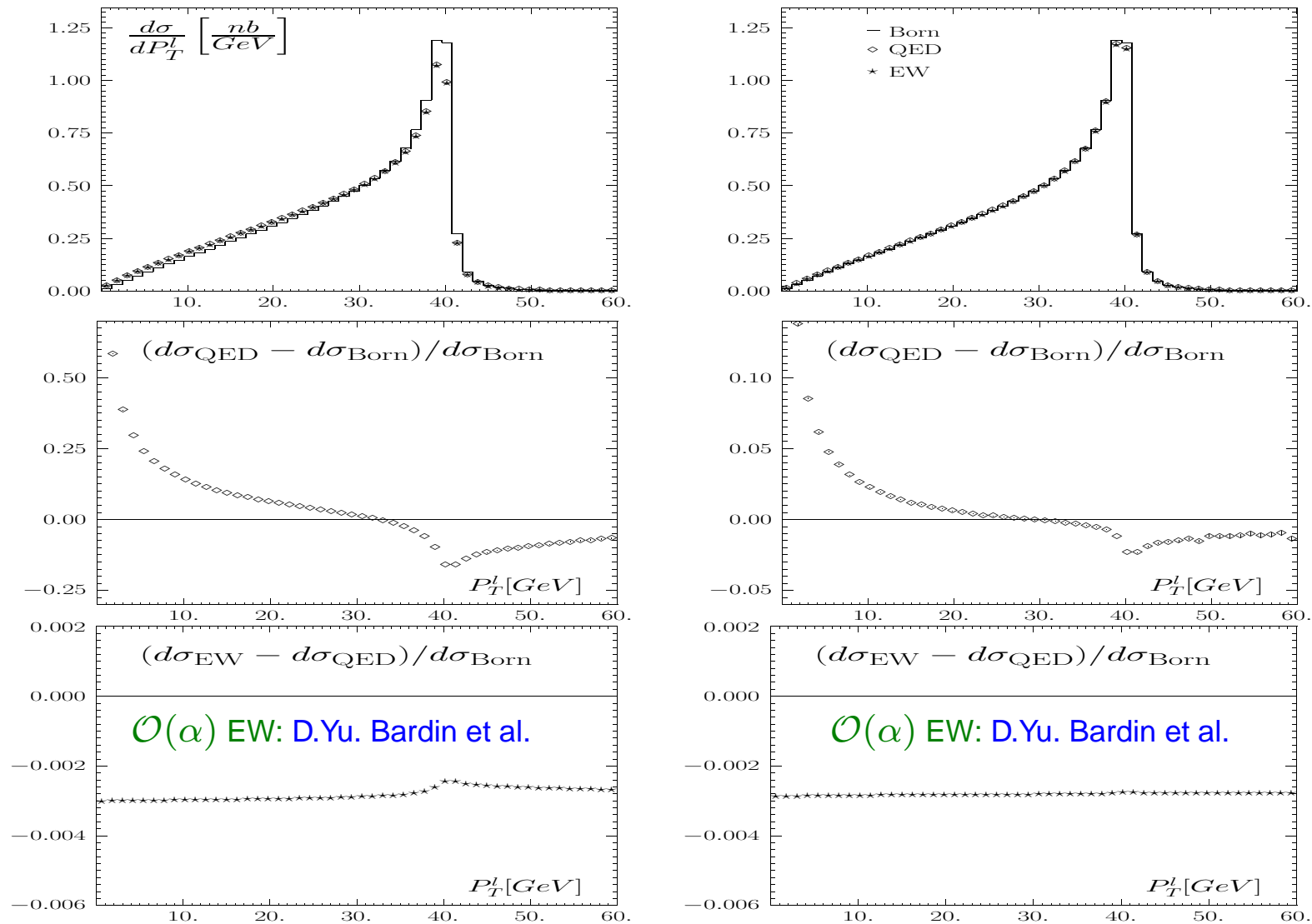


Charged lepton p_T for: $W^+ \rightarrow e^+ \nu_e$

PDF: MRS (G)

BARE

CALO

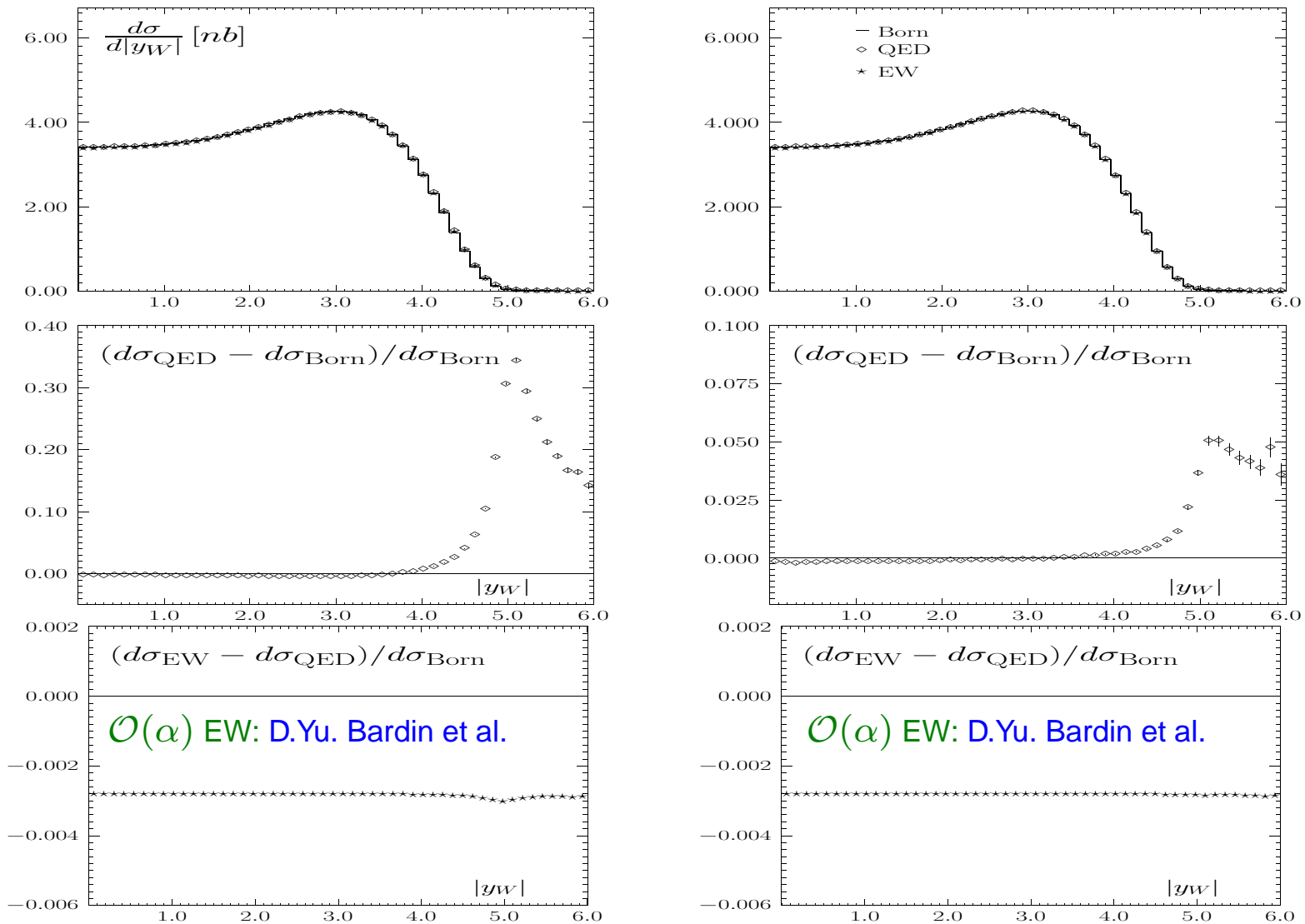


W -boson rapidity y_W for: $W^+ \rightarrow e^+ \nu_e$

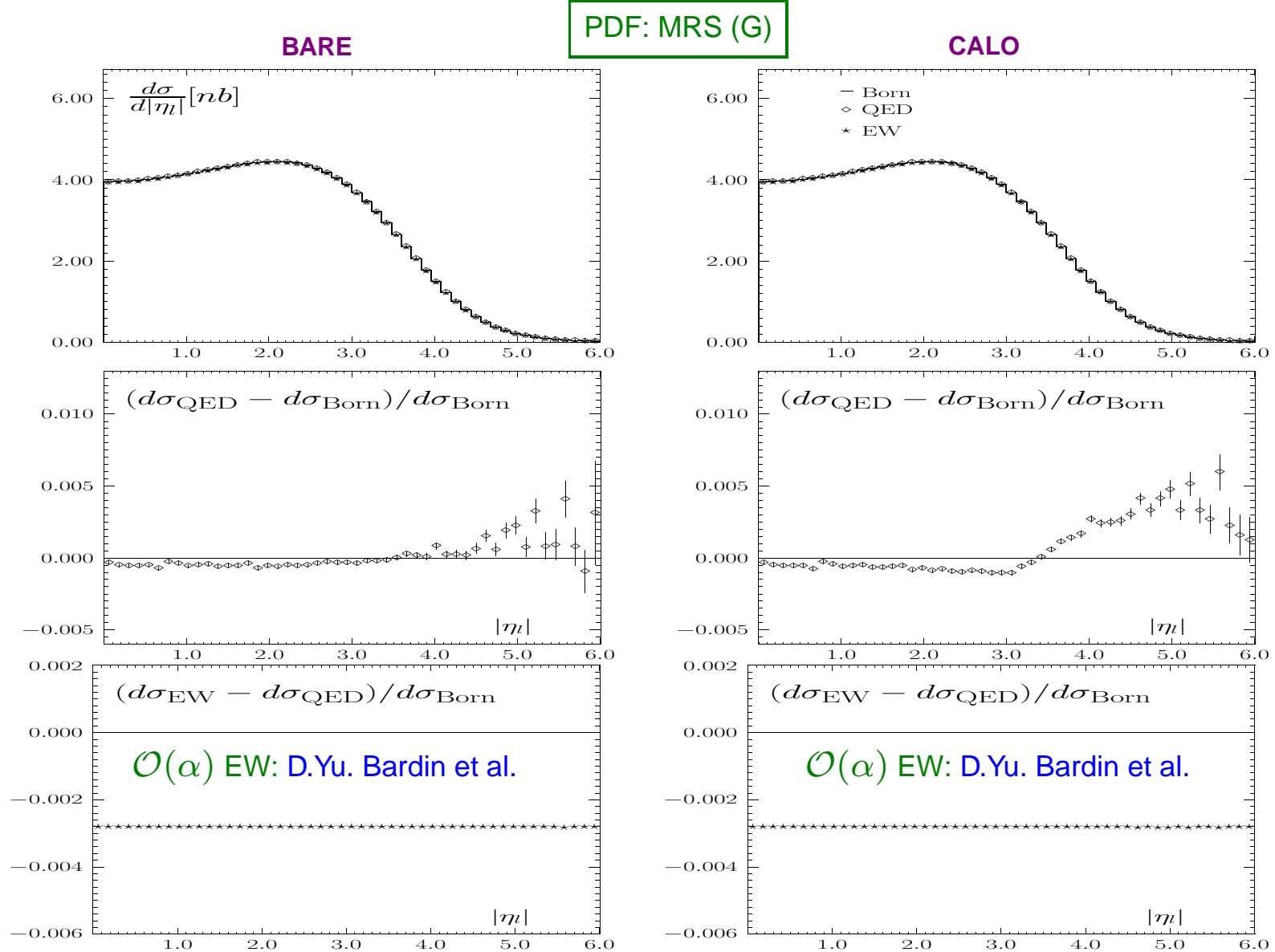
PDF: MRS (G)

BARE

CALO



Charged lepton pseudorapidity η_l for: $W^+ \rightarrow e^+ \nu_e$



Conclusions

- We calculated multiphoton radiation in leptonic W -boson decays in the YFS exclusive exponentiation scheme.
- Appropriate Monte Carlo algorithm has been constructed.
- The above have been implemented in the MC event generator **WINHAC** for single W -boson production in hadronic collisions (Tevatron/LHC).
 - ▷ Acceptance efficiency: $\approx 50\%$
 - ▷ CPU time: $\approx 10,000$ events per second on Pentium IV, 2.4 GHz.
- Cross-checks with independent calculations at the parton level have been performed through $\mathcal{O}(\alpha)$.
- Preliminary results at the hadron level (LHC) have been obtained:
 - ▷ Higher-order FSR corrections (exponentiation) can be important for precision W -boson mass measurement at LHC for BARE-like event selections.
- We also constructed an interface called **WINDEC** for multiphoton leptonic W -decay generator and any external MC program providing single W production in hadron collisions.

... and Outlook

- More tests and comparisons with independent calculations – particularly at the hadron level and with FSR exponentiation.
 - Predictions for the main LHC single- W observables with realistic experimental acceptances.
 - Estimation of effects due to higher-order FSR corrections on the W mass determination at LHC.
 - Inclusion of full $\mathcal{O}(\alpha)$ EW corrections to single W production with leptonic decay.
 - ▷ In collaboration SANC team (D.Yu. Bardin et al., JINR Dubna).
 - Inclusion of QCD effects in W production.
 - Interfacing with hadronization package.
- Similar MC program for single- Z production (and also for VV production).