How large are Electroweak Radiative Corrections at High Energies?

all results are preliminary

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1 – Introduction

- In the past few years calculations of electroweak (EW) radiative corrections at high energies ($\gg M_{W,Z}$) have been performed for a number of processes
  - ☞ $f'\bar{f} \to \ell'\ell$ (Kühn et al.)
  - ☞ $p\overset{(-)}{p} \to \ell^\pm\nu$, $p\overset{(-)}{p} \to \ell^+\ell^-$ (UB, D. Wackeroth, Dittmaier and Krämer)
  - ☞ prompt photon and Zj production at hadron colliders (Kühn et al.)
  - ☞ di-boson production (Accomando et al., Hollik and Meier)
  - ☞ inclusive jet production at hadron colliders (Norton et al.)
  - ☞ $p\overset{(-)}{p} \to t\bar{t}$ (Norton et al., Kühn et al.)

- These calculations show that EW corrections become large and negative at high energies, due to the presence of Sudakov-like logarithms ($(\alpha/\pi)\log(\hat{s}/M^2_{W,Z})$).
- Where are these logarithms coming from?
  - ☞ IN QED, these logarithms cancel between virtual and real corrections (KLN theorem); observables which are inclusive over soft final states (ie. photons) are infrared safe (Bloch-Nordsieck (BN) theorem)
  - ☞ In the EW case, the incoming $q'\bar{q}$ system does have a non-zero $SU(2)\times U(1)$ charge, and, due to the non-abelian character of the gauge group, the BN-theorem is violated
    (remark: In QCD the BN-theorem is also violated, but one sums/averages over colors. This effectively restores the BN-theorem)

- ☞ Furthermore, since the EW symmetry is broken and the massive W and Z bosons decay, the real EW radiative corrections (ie. W and Z radiation) lead to a different final state, and thus are often ignored

- The existing calculations thus are applicable to exclusive searches/reactions

- However, in experiment, one rarely considers exclusive reactions; in most cases processes are (semi-)inclusive

- Real EW corrections (W and Z radiation) thus have to be included in the calculation.

- This results in a partial compensation of the large negative corrections originating from the Sudakov-like logarithms

- So, how large are EW radiative corrections when realistic experimental conditions are taken into account?

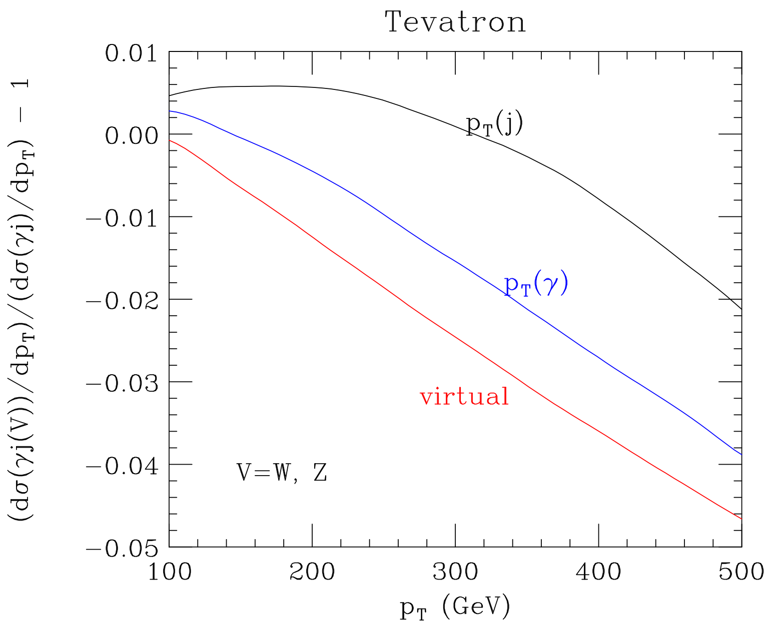
2 – Prompt Photon Production

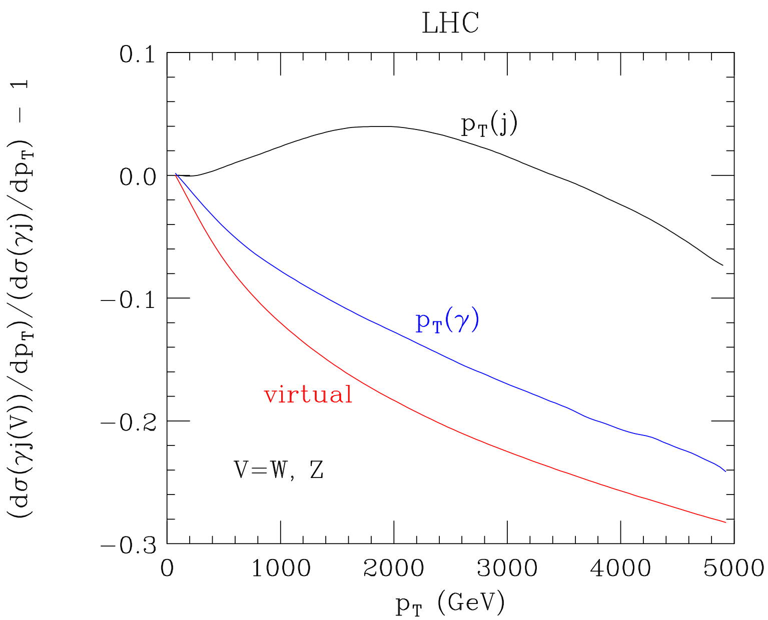
- LO process: $p \overset{(-)}{p} \to \gamma j$
- typical CDF/DØ selection criteria:
  - ☞ require a hard ($p_T(\gamma) > 10$ GeV), isolated ($\Delta R > 0.4$) photon
  - ☞ some analyses also require the missing E_T in the event to be small ($\not{p}_T < 20$ GeV) to reject events with large calorimeter noise
  - ☞ there is no restriction on the number of jets or leptons in the event
- The one-loop NLL weak corrections have a very compact form and can easily be included in a γj parton level MC program (Kühn et al.) they agree at the percent level with the full weak one-loop corrections

- Real EW radiative corrections: $W\gamma j$ and $Z\gamma j$ production
- To find out how big these are begin by imposing cuts only on the photon and jet:

$$p_T(\gamma),\, p_T(j) > 25\,(50)\text{ GeV} \quad \text{at Tevatron (LHC)},$$
$$|\eta(\gamma)|,\, |\eta(j)| < 2.5 \qquad \Delta R(\gamma, j) > 0.4$$

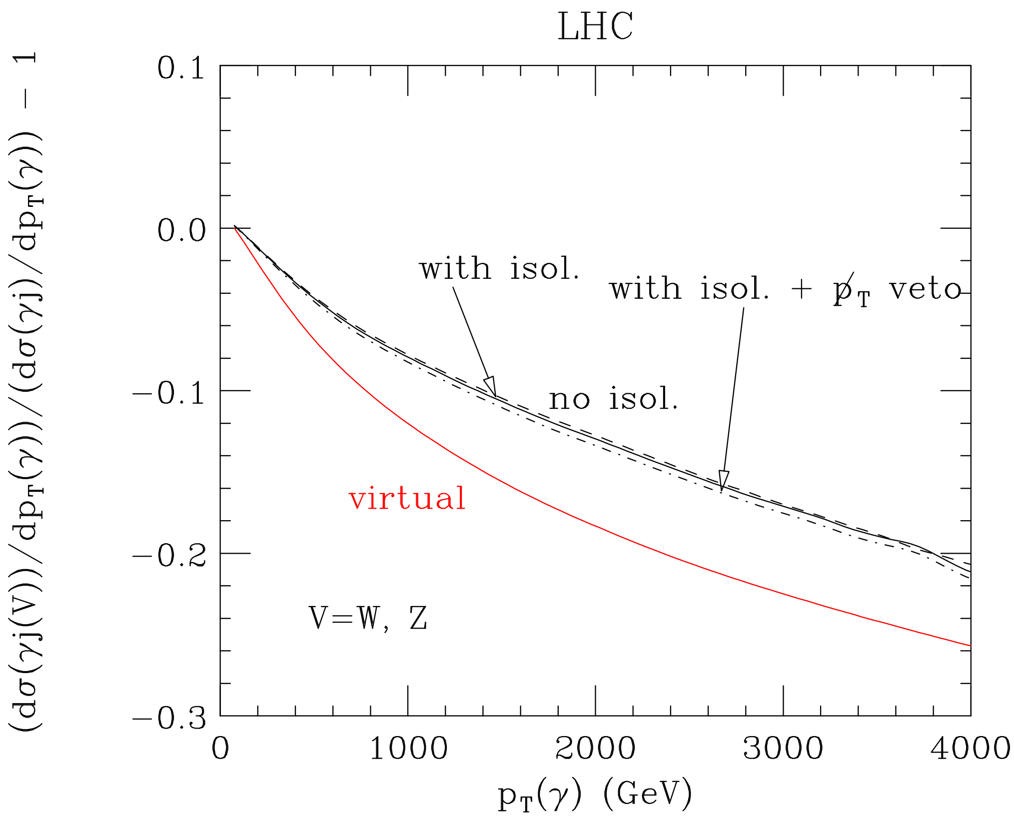
- No W and Z decays are included at this point.
- This gives the maximum possible effect of the real EW radiative corrections
- only include NLL weak one-loop corrections (i.e. photonic corrections are not included)





- At LO, the $p_T(\gamma)$ and $p_T(j)$ distributions are equal, but this is not the case for $W\gamma j$ production
- Tevatron: the $V\gamma j$ ($V = W,\ Z$) differential cross section approaches 0.5% (2.5%) at large $p_T(\gamma)$ ($p_T(j)$)
- LHC: the $V\gamma j$ differential cross section approaches 5% (22%) at large $p_T(\gamma)$ ($p_T(j)$)

- the one-loop EW corrections are a few percent at most at the Tevatron, but can reach $20 - 30\%$ at the LHC
- real W, Z emission may reduce the effect of the $\mathcal{O}(\alpha)$ 1-loop radiative corrections somewhat for the $p_T(\gamma)$ distribution, and substantially for the $p_T(j)$ distribution
- for the $p_T(\gamma)$ distribution at the LHC they are of the same size as the $\mathcal{O}(\alpha_s^2)$ corrections (at large $p_T(\gamma)$)
- however, the $p_T(j)$ distribution is not a good observable as there can be additional jets in the event from gluon bremsstrahlung or $V \to jj$
- Now add W, Z decays and require that photon is isolated from W, Z decay products (except ν): $\Delta R(\gamma, j) > 0.4$, $\Delta R(\gamma, \ell) > 0.4$ (This assumes that selection criteria for prompt photon events at the LHC will be similar to those used at the Tevatron)
- focus on LHC

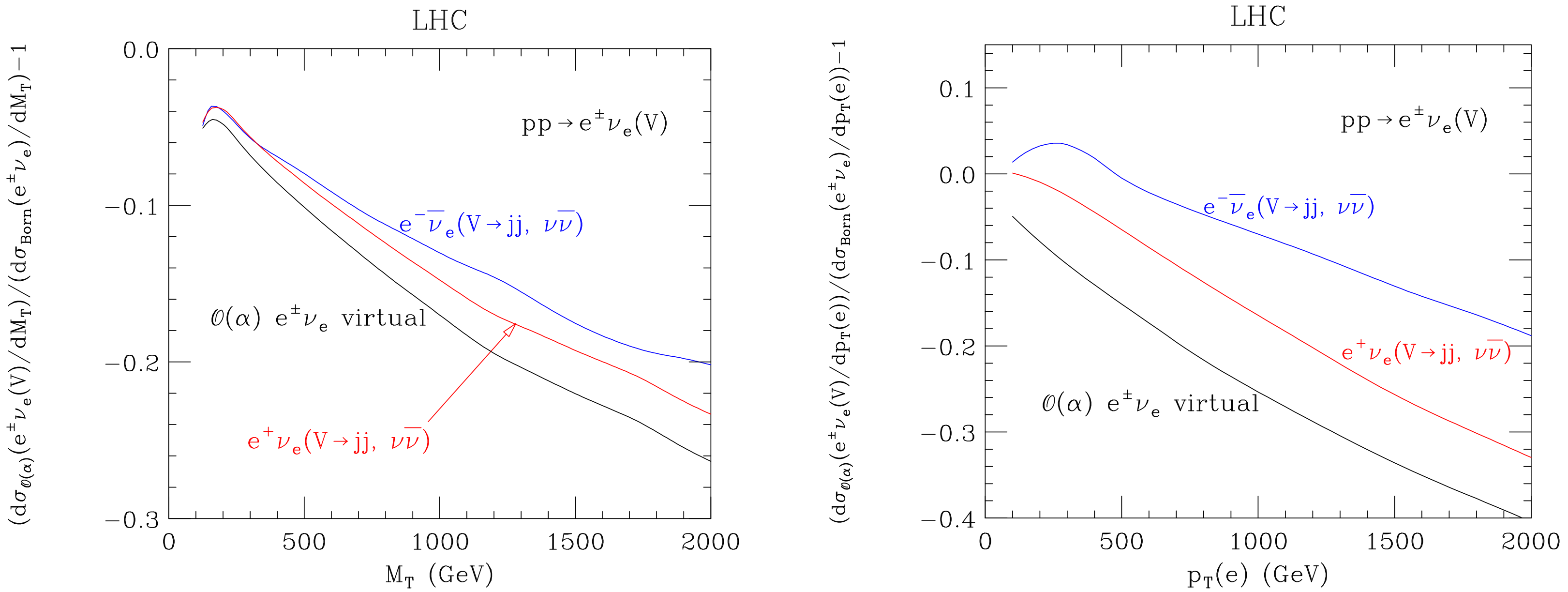


- $\not{p}_T$ veto: require $\not{p}_T < 5\ \mathrm{GeV}^{1/2}\sqrt{\sum p_T}$
- W, Z decay effects hardly change the picture
- Conclusion: real W, Z radiation moderately reduces the effect of the $\mathcal{O}(\alpha)$ one-loop corrections in prompt photon production

3 – Drell-Yan Production

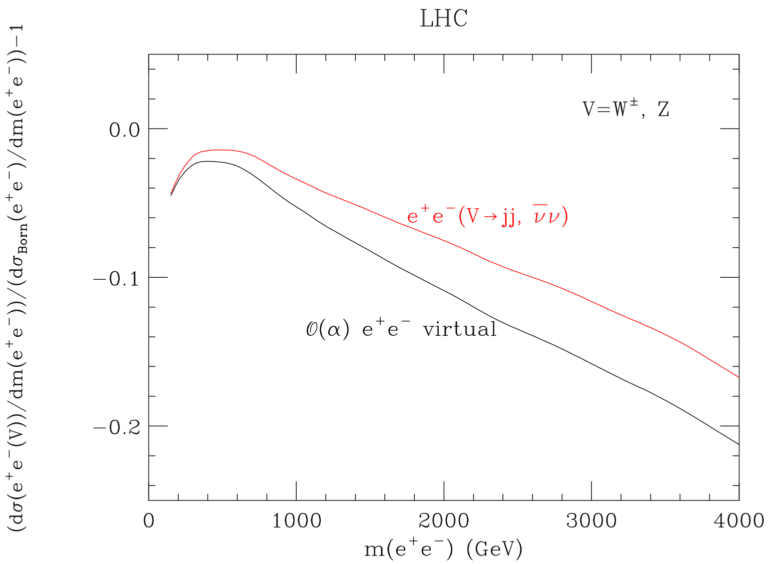
- start with charged channel: $p \overset{(-)}{p} \to \ell\nu$
- used to search for new heavy charged vector bosons
- selection criteria:
  - ☞ one high p_T charged lepton: events with two or more charged leptons are classified as di-boson events
  - ☞ missing transverse momentum $\not{p}_T > 25$ GeV
  - ☞ any number of jets
- real EW radiative corrections: $W^{\pm}\ell\nu$ and $Z\ell\nu$ production (WW, WZ and W, Z bremsstrahlung diagrams)

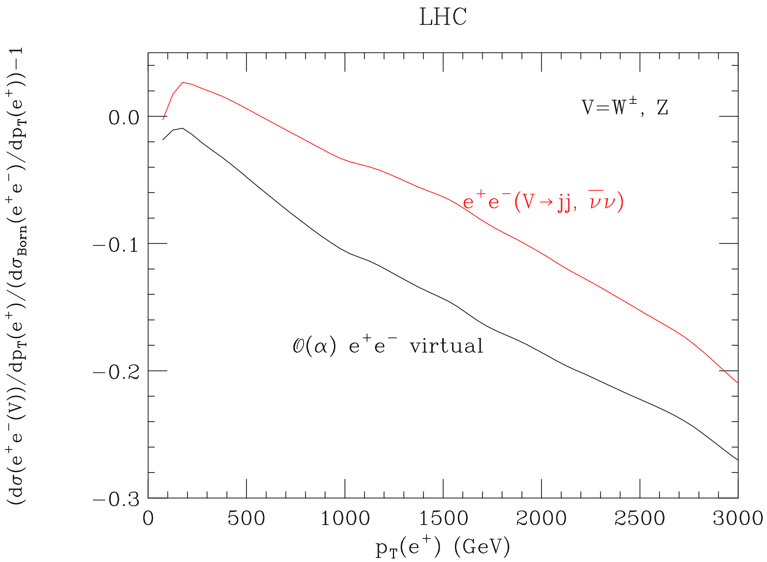
- virtual corrections: full one-loop $\mathcal{O}(\alpha)$ (including photonic corrections)
- focus on LHC and $\ell = e$; recombine photons and electrons for small opening angles
  - ☞ necessary because photons and electrons which are collinear cannot be discriminated
  - ☞ minimizes the effect of the photonic corrections (we are not interested in them)
- for μ final state relative effects are smaller because photonic corrections play a larger role (no recombination with photon; hard photons close to μ are vetoed)
- consider $e\nu$ transverse mass (M_T) and $p_T(e)$ distributions



- The real EW radiative corrections reach 3% (6%) for W^+ (W^-) production in the M_T, and 10% (20%) in the $p_T(e)$ distribution
- They are larger for the $p_T(e)$ distribution because W resonance region is excluded in M_T distribution
- They reduce the effect of the $\mathcal{O}(\alpha)$ one-loop corrections somewhat in the M_T distribution but significantly (up to a factor 2) in the $p_T(e)$ distribution

- Finally look at neutral channel: $p\overset{(-)}{p} \to \ell^+\ell^-$
- used to search for new heavy neutral gauge bosons
- selection criteria:
  - ☞ two same flavor opposite charge high p_T charged leptons: events with three or more are classified as di-boson events
  - ☞ missing transverse momentum $\not{p}_T$ small (we use $< 5\sigma$)
  - ☞ any number of jets
- real EW radiative corrections: $W^\pm\ell^+\ell^-$ and $Z\ell^+\ell^-$ production (WZ, ZZ and W, Z bremsstrahlung diagrams)
- virtual corrections: full one-loop $\mathcal{O}(\alpha)$ (including photonic corrections)
- focus on LHC and $\ell = e$; look at di-lepton invariant mass and $p_T(e)$ distribution





- the real EW corrections reach about 6% at large p_T's and invariant masses

4 – Conclusions

- The size of the EW radiative corrections at hadron colliders depends on the experimental selection criteria
- In (partially) inclusive reactions, real EW radiative corrections may significantly reduce the effect of the $\mathcal{O}(\alpha)$ one-loop corrections
- Details depend on the process considered, and the distribution which is studied.