Monte Carlo Generators for SM signals and backgrounds

Mauro Moretti

Dept. of Phys. and INFN Ferrara

DIS2009 Madrid, 26-30 April, 2009

Outline

- LO matrix element generators and matching with QCD Parton Shower
- Matching NLO calculations with Parton Shower
- QCD NLO calculations and implementation in MC programs
- Electroweak corrections and generators
- First attempts to the inclusion of QCD and EW corrections for precision physics: the case of charged Drell-Yan process
- LO matrix element generators and matching with QED Parton Shower
- Summary

Apologize for omitting several important contributions

Motivations

- Top pair production, Drell-Yan, many gauge bosons production in association with hard, light jets $\Rightarrow$ crucial for SM studies
- Backgrounds to BSM searches $\Rightarrow$ large number of hard jets and leptons, missing E_T
  1. gluinos production and decay: Jets ($n \geq 4$) and missing E_T
  2. excited top states (composite models, kaluza klein excitations) production and decay: $t\bar{t}WWqq$ final states, four leptons four jets and missing E_T or lower number of leptons and larger number of jets
- Understunding as accurate as possible of associate production of a large number of jets, heavy quarks and EWK gauge bosons required

SM signals

Avaliable for all the most relevant standard model signals:

1. LO + multi-jets interfaced to PS
2. NLO MC

- N-jets
- W^*, Z^* NNLO; NLO$_{EW}$ (+ QED PS); soft gluon resummation NLL, NNLL;
- $\bar{t}t$ (NLO large); soft gluon resummation
- H (gluon fusion) NLO; NNLO soft gluon resummation NLL; N.B. *everything (in MC)* in $m_t \to \infty$ limit, situation much less satisfactory for $m_H \geq 2m_t$
- H (Weak Bosons Fusion) (no NLO matched with PS)

Many, but not all, relevant backgrounds known to NLO, strong progresses in this field however

LO matrix element event generators

- Many (hard) jets final states are not well described by traditional Parton Shower event generators (e.g. HERWIG and PYTHIA) and matrix element generators are needed
- example: the statistical significance of the $t\bar{t}H(\to b\bar{b})$ channel at LHC has been lowered after complete simulations with matrix element event generators instead of plain Pyhtia
- Now we have the technology for the calculation of exact Leading Order (LO) multiparton processes of essentially arbitrary complexity

available LO generators

- ACERMC, ALPGEN, CompHEP, GRACE, MADEVENT, HELAC/PHEGAS, NJETS, PHANTOM, SHERPA, VECBOS, OMEGA, WIZARD
- some of them can deal with every SM final state, while others are designed for particular channels
- recent activity by few teams (essentially at present ALPGEN, ARIADNE, HELAC, MADEVENT and SHERPA) in combining consistently matrix element predictions with Parton Shower, in order to exploit at the same time the positive features of matrix element and parton shower description

- Usually matrix element event generators are used to produce parton-level unweighted events which are then used as input for the shower evolution and hadronization given by a parton shower programme
- Generating final states with QCD partons, we need parton level cuts, and the final results will depend on these unphysical cuts and will DIVERGE in the soft/collinear limit IRRESPECTIVELY of the cuts applied at analysis level.
- Moreover if we put together, after showering, samples obtained with different parton-level multiplicities we meet the "double counting" problem: the same jet multiplicity can be obtained from different parton-level multiplicities. We need a resolution cutoff to separate the region covered by the matrix element and the one covered by the parton shower
- the problem has been studied for e^+e^- collisions and proved that the dependence on the cutoff can be shifted at NLL level by using matrix elements reweighted with Sudakov form factors (giving the probability of no further emissions) and vetoed parton shower (algorithm known as CKKW procedure)

CKKW for hadronic collisions

- A recipe has been proposed few years ago by F. Krauss, but no formal proof of NLL accuracy exists up to now.
- Indipendent proposal by M.L. Mangano, based on the idea of parton-jet matching (so called MLM prescription). Events are rejected *after the shower* if the PS produces jets "harder" than the ME ones. Sudakov reweighting is not analytic but induced by the veto procedure. The "interplay" of the ME with PS is kept minimal (no need to modify the shower).
- Extension of the CKKW algorithm to the dipole cascade model of parton evolution implemented in `ARIADNE` (Lavesson and Lonnblad)
- Recent activity has been devoted to the comparison between different implementations of CKKW matching in order to quantify the differences and understand their origin

S. Höche et al.

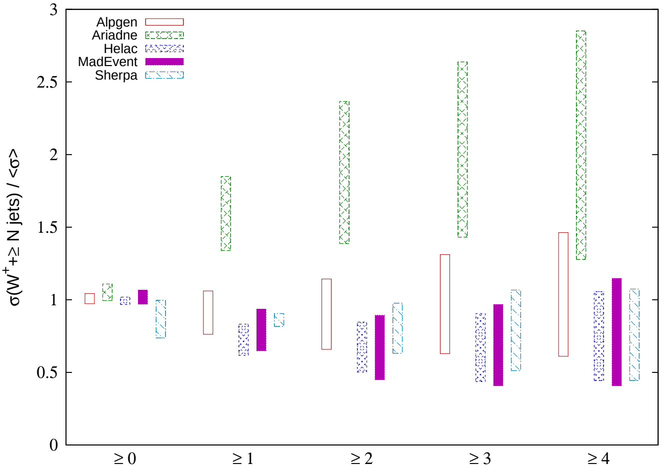


Figure: Range of variation for the LHC cross-section rates of the five codes, normalized to the average value of the default settings for all codes in each multiplicity bin.

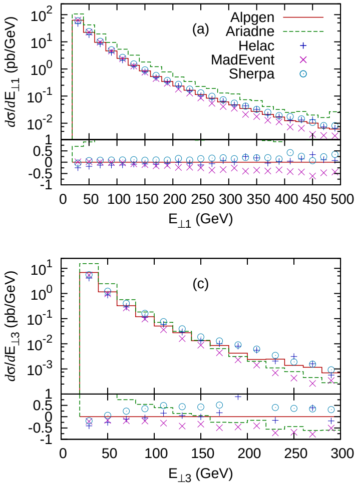


Figure: Inclusive $E_{\perp}$ spectra of the leading 4 jets at the LHC (pb/GeV). In all cases the full line gives the ALPGEN results, the dashed line gives the ARIADNE results and the "+", "x" and "o" points give the HELAC , MADEVENT and SHERPA results respectively.

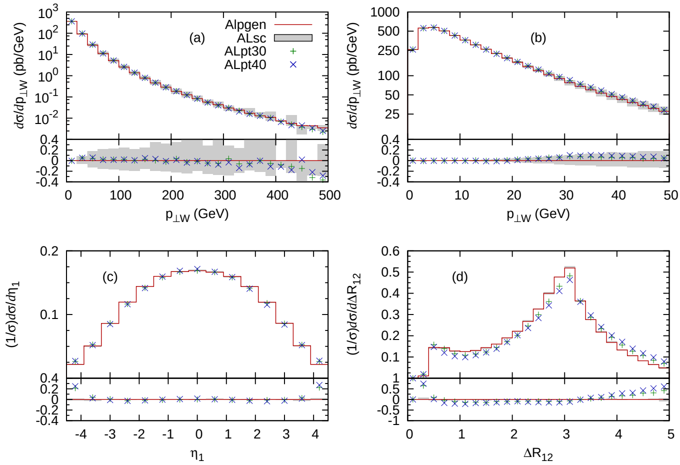
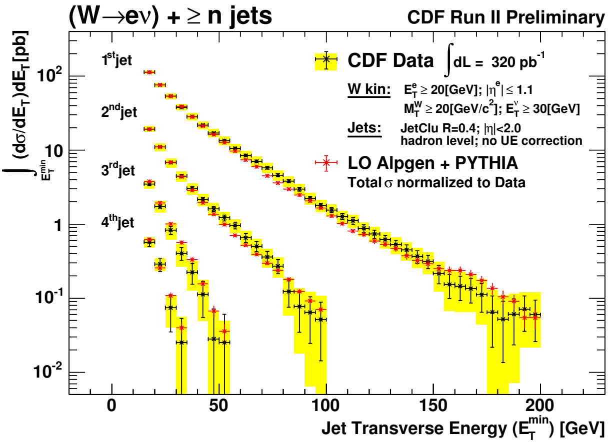
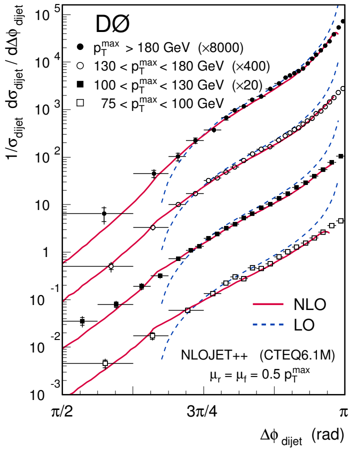


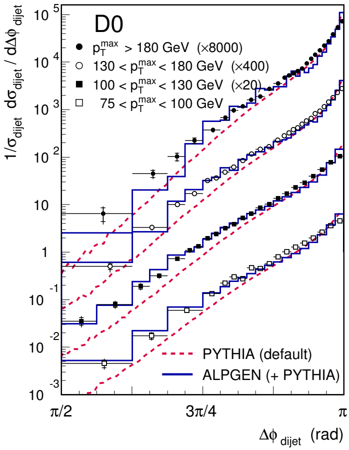
Figure: ALPGEN systematics at the LHC. (a) and (b) show the $p_\perp$ spectrum of the W, (c) shows the pseudo-rapidity distribution of the leading jet, (d) shows the ΔR separation between the two leading jets. The full line is the default settings of ALPGEN , the shaded area is the range between two different scale choiches for α_S, while the points represent two different choiches of matching parameters.

validation against Tevatron data



validation against Tevatron data





LO Generators a few words of warning

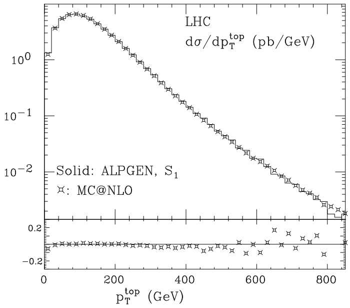
- All generators include a width for heavy unstable particles (top, W, Z and H). This breaks EWK gauge invariance. Usually negligible effects but it can lead to strong unphysical effects.
- Higgs in gluon fusion always in $m_t \to \infty$ (at least partially) limit. $P_T > m_t$ unreliable
- If the ME account for the production of heavy particles, non resonant contribution are lost (even if particles are subsequently decayed), and spin correlation of decay products in some codes are retained (in the infinitely narrow width limit) and lost in others. Non resonant contribution can be accounted calculating the ME for the final state after the decay at the price of lowering the amount of additional final state jets avaliable.

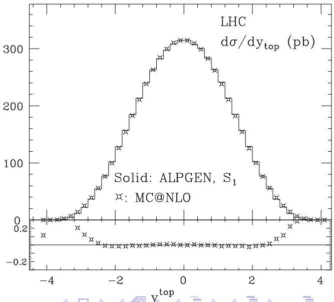
matching NLO calculations and Parton Shower

- One drawback of the CKKW algorithm is the lack of virtual corrections $\Rightarrow$ even if the hard radiation is well described according to the matrix elements, the cross section accuracy is still LO
- another subject of intense activity is the matching of a complete NLO calculation with the Parton Shower
- several proposals, but up to now only one implementation: `MC@NLO`, running for many relevant final states
- main idea: subtract from the Parton Shower its $\mathcal{O}(\alpha)$ expansion and replace it with the NLO calculation
- negative weights appear
- proposal of an alternative algorithm by P. Nason able to avoid negative weights. The code `POWHEG` is working for vector boson pairs and heavy flavours. Work is in progress to allow external user to input phase space and NLO amplitudes in `POWHEG` making authomatic the transition from NLO calculation to NLO+PS

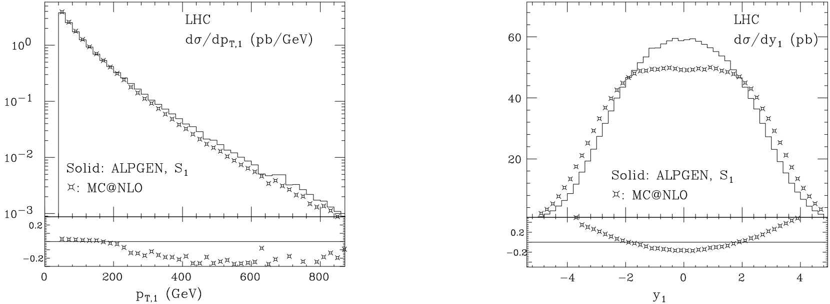
Mangano, M. Moretti, F.P. and Treccani

- Even if a matrix element event generator has a normalization with LO accuracy, it is very interesting to compare its predictions in shapes with the ones by MC@NLO
- Hard radiation (after first jet) should be better described by a matrix element generator
- example of $t\bar{t}$ production





looking at more exclusive distributions



The discrepancy in rapidity seems to be due to the treatment of radiation from heavy flavour radiation in Herwig. The same plot with POWHEG is in agreement with ALPGEN $\Rightarrow$ critical cross checking between different programs is of utmost importance!

QCD NLO calculations and tools

- Very intense activity by several groups in working out missing NLO calculations for processes relevant at LHC
- NLO calculations allows to make more stable predictions with respect to LO ones
- By now all $2 \rightarrow 2$ and many $2 \rightarrow 3$ processes are are known at NLO accuracy. Strong progress towards NLO calculation for arbitrarily complex final states.
- Most of the calculations are implemented in Monte Carlo programs allowing to study distributions with any kind of kinematical cuts
- more on NLO in N. Glover and R. Pittau talks

EW calculations & tools

- Z, W production will be the first signal studied at the LHC (calibration, understunding detectors).
- At peak: M_W
- Al large $M_{ll'}$: new resonances
- 1) $\mathcal{O}(\alpha_S^2) \approx \mathcal{O}(\alpha_{\rm em})$, 2) precision physics program at the LHC $\rightarrow$ need to worry about electroweak corrections!
- Electroweak corrections to W production
  - ⋆ Pole approximation ($\sqrt{\hat{s}} = M_W$)
    - $\rightarrow$ D. Wackeroth and W. Hollik; U. Baur et al.,
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - $\rightarrow$ V.A. Zykunov et al., DK, WGRAD2, ZGRAD2, SANC, HORACE
- Multi-photon radiation

  $\rightarrow$ HORACE WINHAC, ZINHAC SOPHTY, PHOTOS
- In HORACE the complete ew NLO correction has been consistently matched with the QED Parton Shower correction

Combining EW and QCD corrections I

- First attempt: combination of soft-gluon resummation with NLO final-state QED corrections (RESBOS-A)

Cao and Yuan PRL 93 042001 (2004) and `hep-ph/0401171`

- QCD and QED corrections can be combined in a YFS resummation framework, taking into account shower/matrix element matching

B.F.L. Ward and S.A. Yost, Acta Phys. Polon. **B38** (2007) 2395

Combining EW and QCD corrections II

work in progress: Balossini, Carloni Calame, Montagna, M. M., Nicrosini, Fulvio Piccinini, Treccani, Vicini

- our exercise (preliminary results) is based on the following formula

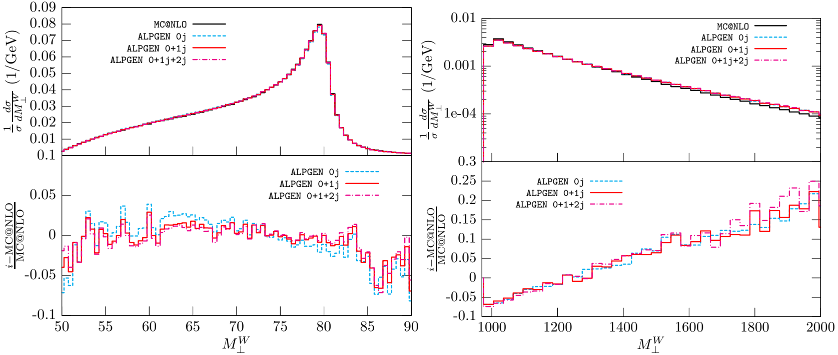
$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{QCD}\oplus\text{EW}} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{best QCD}} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{best EW}} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{Born}}\right\}_{\texttt{HERWIG}\ \text{PS}}$$

- best QCD ⇒ **MC@NLO**, **ALPGEN** (with PS matching according to MLM prescription, `0+1 jet`, `0+1+2 jets`)
- EW part (`HORACE`) is interfaced to **HERWIG** PS (EW ⊕ QCD LL)
  - ⋆ NLO EW is convoluted with QCD LL parton shower ⇒ $\mathcal{O}(\alpha\alpha_s)$ corrections not reliable where hard non log QCD corrections are important (e.g. high $p_\perp$ lepton distribution without cut on the W transverse mass). In this case a two-loop calculation needed for a sound estimate of $\mathcal{O}(\alpha\alpha_s)$ effects

⋆ not suited for true event generation...

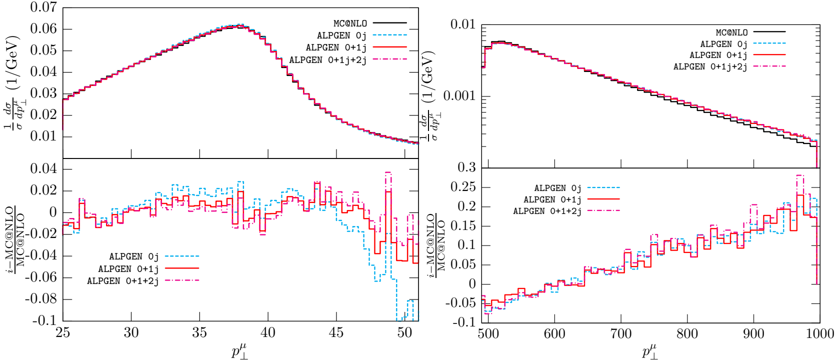
⋆ we consider the charged Drell-Yan process

QCD @ LHC: M_T^W



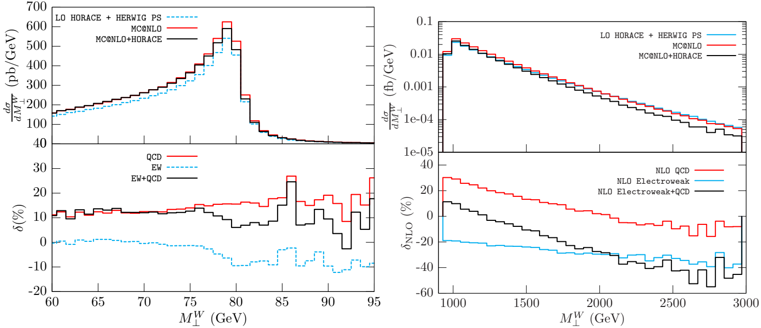
- each distribution normalized to its cross section (shape differences)

QCD @ LHC: $p_\perp^\mu$



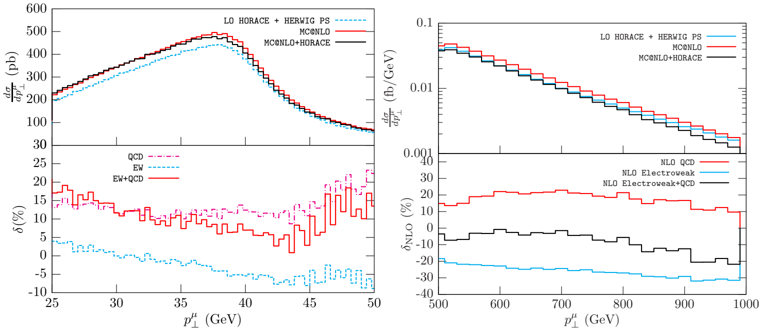
- each distribution normalized to its cross section

⋆ $p_\perp$ (in 0.5 - 1 TeV window) distribution obtained requiring $M_T^W > 1$ TeV



- absolute distributions

QCD $\oplus$ EW @ LHC: $p_\perp^\mu$



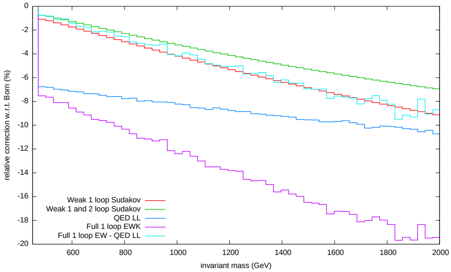
- absolute distributions

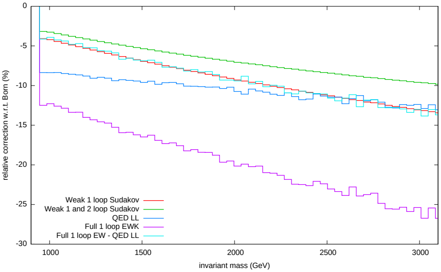
★ $p_\perp$ distribution obtained requiring $M_T^W > 1$ TeV

EW⊕QCD for Z production

- ⋆ a similar study on EW⊕QCD is going on also for Z production in the invariant mass tail, in the context of Les Houches 2007
- ⋆ here we are considering also 2-loop weak Sudakov effects

B. Jantzen, S. Pozzorini





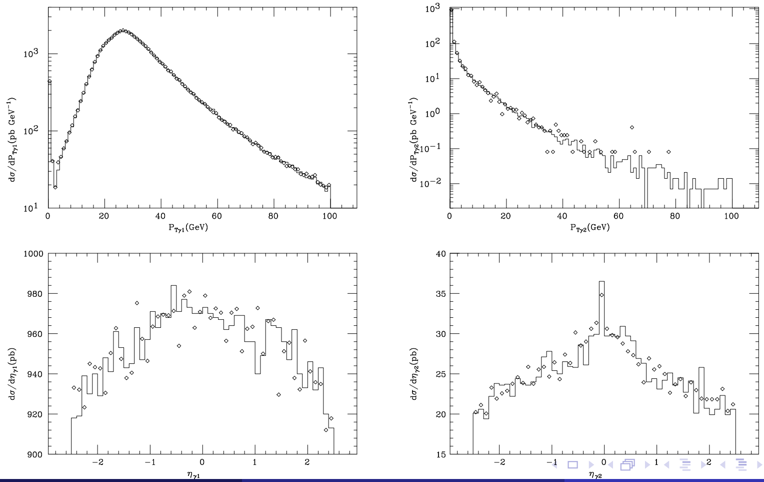
Matching LO and PS, QED

Recently some activity in matching photon radiation off ME and off PS.

- the problem is the same as for QCD: dump IR/Soft divergencies of the ME, avoid double counting of photons from ME and PS
- QED corrections small, however the problem is not only academic $\Rightarrow \gamma\gamma$ background to Higgs searches
  1. irreducible from $pp \to \gamma\gamma$
  2. reducible from $pp \to \gamma +$ jets with a jet mistagged as a photon.
  3. Simulated events in the second sample will contain events overlapping with the first one since they contain photons produced by the PS
- other effects of QED radiation in the simulation of e.m. showers.
- A few result with ALPGEN on $pp \to \gamma + n$-jets: two different samples
  1. $pp \to \gamma + 1$ jet(ME) + PS ($\mathcal{S}_1$)
  2. $pp \to \gamma + 1$ jet(ME) + PS toghether with $pp \to 2\gamma + 1$ jet(ME) + PS and QED matching (a recipe to prevent double counting) ($\mathcal{S}_2$)

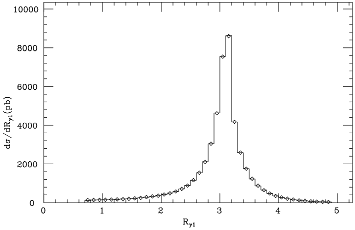
Matching PS and LO ME, QED, preliminary plots

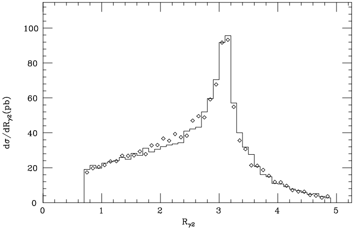
Histogram: $\mathcal{S}_2$; Diamonds $\mathcal{S}_1$



Matching PS and LO ME, QED, preliminary plots

Histogram: $\mathcal{S}_2$; Diamonds $\mathcal{S}_1$





Summary

- Thanks to the efforts of several teams, we have several Monte Carlo programs which will allow us to exploit at best LHC data
- Tevatron data can still be used to further tune the Monte Carlo programs in order to extrapolate their results to the LHC energy range
- The availability of different programs allows to give a sound estimate of the sistematics associated with the theoretical calculations
- For the precision program of LHC running not only QCD but also electroweak corrections need to be carefully considered