Inevitability of reweighting at LHC Monte Carlo simulation

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Outline

- Drell-Yan like processes at LHC
- LHC simulation with ATLAS software and inevitability of reweighting
- Existing precision MC tools for Drell-Yan production
- Drell-Yan like processes in SANC
- Reweighting technique and general requirements on reweighting tool
- PDF reweighting as simple example
- Conclusions

Drell-Yan like processes at LHC. Motivation

- Drell-Yan processes have clear signature and large cross-section and contribute to the background in many searches for new physics
- Precision study of DY will be used to define more accurate the parton density functions, for luminosity monitoring and to specify the values of M_W, $\sin^2\theta^{eff}$, Γ_W
- Required theoretical precision $< 1\%$
- To gain the required accuracy it is necessary to take into account EW and QCD corrections at least at NLO and their interplay

LHC simulation. Full chain

The full chain simulation of Drell-Yan events in ATLAS is realised within **Athena** framework and includes several steps:

- Generation
- Simulation (through **GEANT4**)
- Digitization
- Reconstruction
- Creation of AOD (Analysis Object Data) files

The usual running time $\sim$ 10 min/event

LHC simulation. MC generation

There are many MC generators with various levels of tunes which have an interface in Athena or are planned to have one soon

https://twiki.cern.ch/twiki/bin/view/AtlasProtected/McGeneratorsForAtlas

Most usefull and well tuned Monte Carlo programs for generation of Drell-Yan events at LHC:

- **PYTHIA** (**LO + parton showers**)
  + **Photos** (**multi-photon FSR**)
- **MC@NLO** (**NLO QCD**)
  + **HERWIG** (**parton showers**)
  (+ **Photos**)

LHC simulation. Missing contributions

The following contributions required to achieve the desired precision of 1% are missing in the standard ATLAS MC simulations:

- **NNLO QCD corrections** ($\mathcal{O}(\alpha_s^2)$)
- **complete NLO EW corrections** ($\mathcal{O}(\alpha)$)
- **mixed EW/QCD corrections** ($\mathcal{O}(\alpha\alpha_s)$)

We need the MC generator combining these corrections

In addition we need the improved PDFs

Reweighting

- The validation of new MC generators requires much time
- Due to this we need to study the possibility to include NNLO QCD and NLO EW corrections to DY processes into MC simulation in an approximate way by multiplying probabilities of events by certain weights.
- These weights force the Monte Carlo output to agree with certain observables. This technique is called event reweighting.

Precision MC tools

NLO EW:

- WGRAD2, ZGRAD2 (U. Baur et al.)
- HORACE (C. Carloni Calame et al.)
- SANC (SANC group)
- SANC+WINHAC (S. Jadach et al.)

NNLO QCD:

- FEWZ (K. Melnikov and F. Petriello)

Drell-Yan processes in SANC

SANC modules for neutral and charged currents Drell-Yan processes include the **complete NLO EW** corrections.
We take into account two types of subprocesses:

- quark-quark interaction (qq):

$$p[q] + p[\bar{q}] \to X + \{\gamma, \mathbf{Z}\} \to X + \ell^+ + \ell^-(+\gamma)$$
$$p[q] + p[\bar{q}'] \to X + \{\mathbf{W}^\pm\} \to X + \ell^\pm + \nu_\ell(+\gamma)$$

- photon-quark interaction $(\gamma\mathrm{q})$:

$$p[\gamma] + p[q] \to X' + q + \{\gamma, \mathbf{Z}\} \to X + \ell^+ + \ell^-$$
$$p[\gamma] + p[q] \to X' + q' + \{\mathbf{W}^\pm\} \to X + \ell^\pm + \nu_\ell$$

$\ell = e, \mu, \tau$

$q = u, d, c, s, b$

Photon-induced subprocesses

A. Arbuzov and R. Sadykov, Eur.Phys.J.C54:451-460,2008

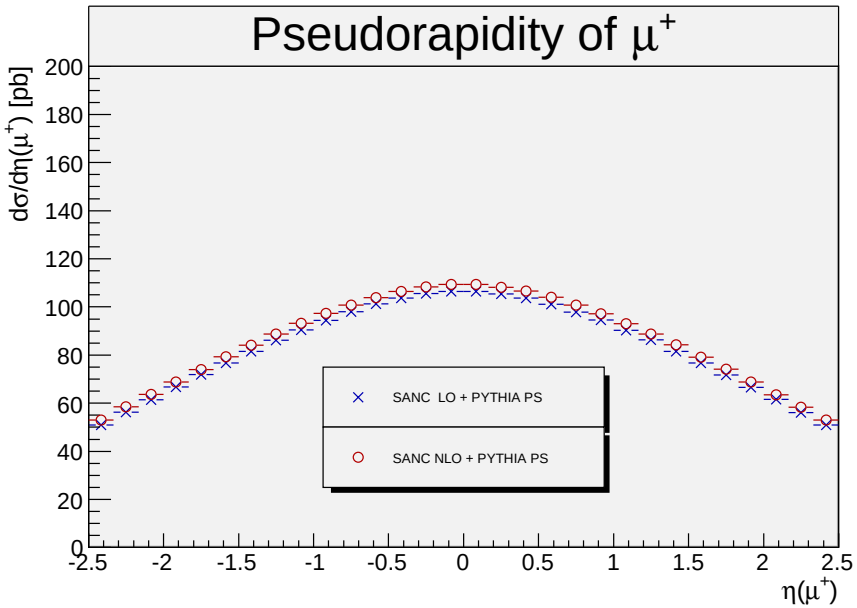
$p_{T,l} \geq$ GeV	25	50	100
	$\sigma_0(pb)$		
DK	**2112.2(1)**	**13.152(1)**	**0.9452(1)**
SANC	**2112.2(1)**	**13.151(1)**	**0.9451(1)**
	$\delta_{\gamma q}(\%)$		
DK	**0.071(1)**	**5.24(1)**	**13.10(1)**
SANC	**0.074(1)**	**5.24(1)**	**13.09(1)**

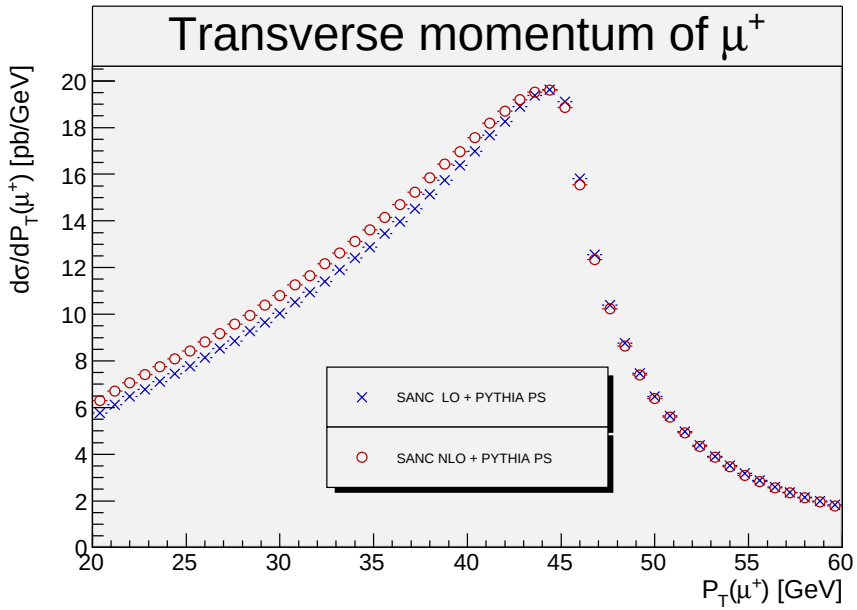
$p_{T,l} \geq$ GeV	200	500	1000
	$\sigma_0(pb)$		
DK	**0.11511(2)**	**0.0054816(3)**	**0.00026212(1)**
SANC	**0.11511(2)**	**0.0054813(1)**	**0.00026211(1)**
	$\delta_{\gamma q}(\%)$		
DK	**16.44(2)**	**14.30(1)**	**11.89(1)**
SANC	**16.43(1)**	**14.30(1)**	**11.90(1)**

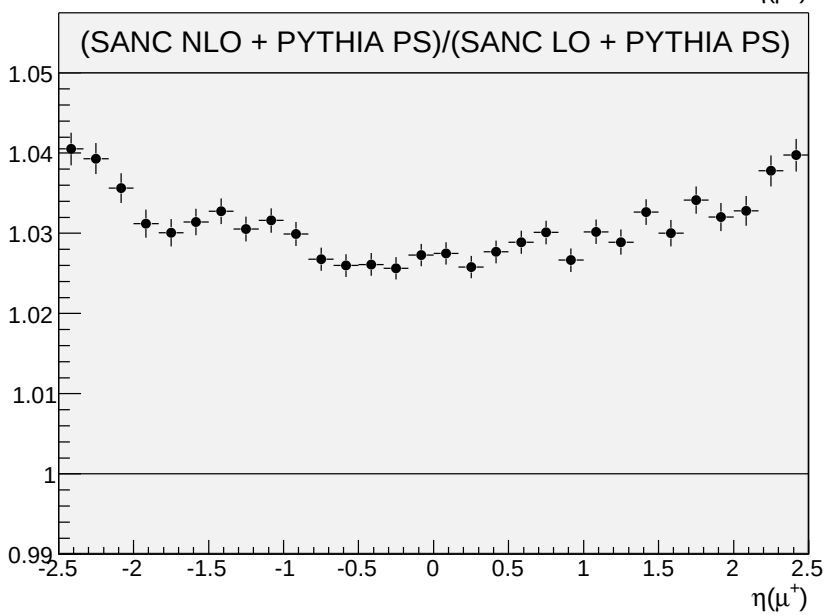
Drell-Yan processes in SANC

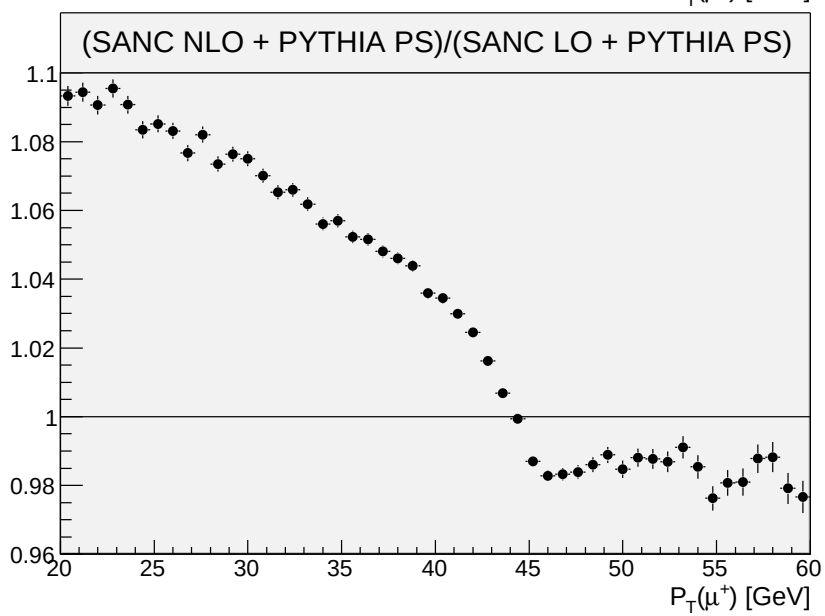
- **SANC** Monte-Carlo generators for neutral and charged current Drell-Yan processes produce unweighted events with help of **FOAM** algorithm
- The transfer of information between **SANC** Monte Carlo generator and the general purpose event generators **PYTHIA** and **HERWIG** is organized via data files containing the event kinematics in the standard Les Houches Accord format

$pp \to Z/\gamma \to \mu^+\mu^-$ (α-scheme)









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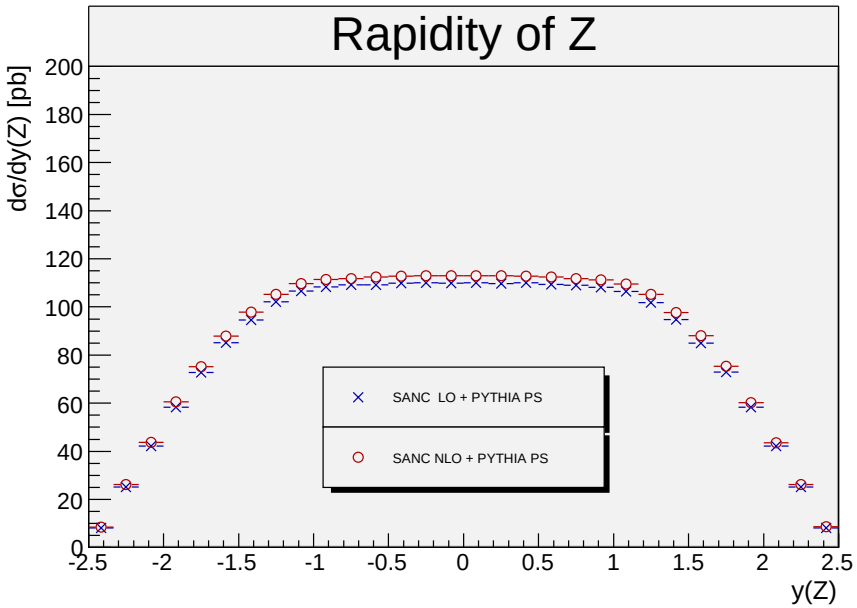
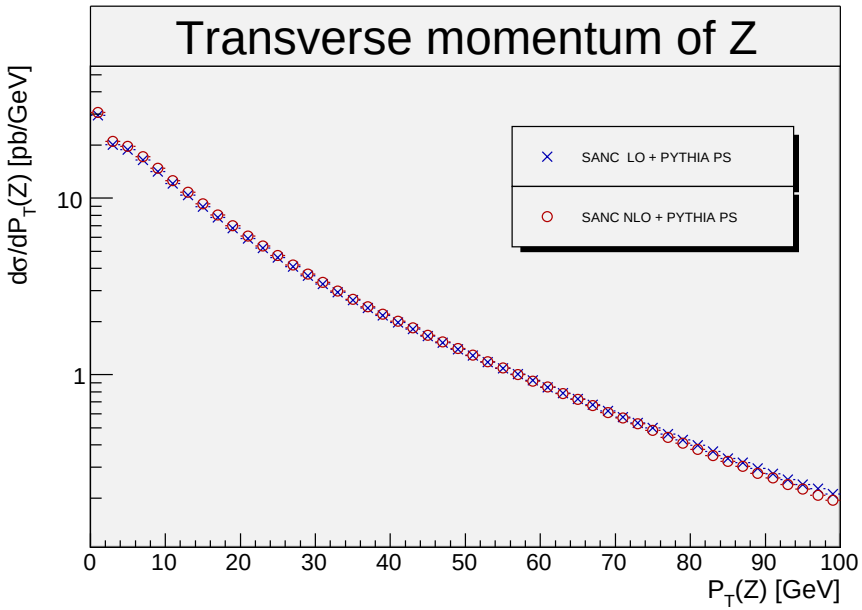
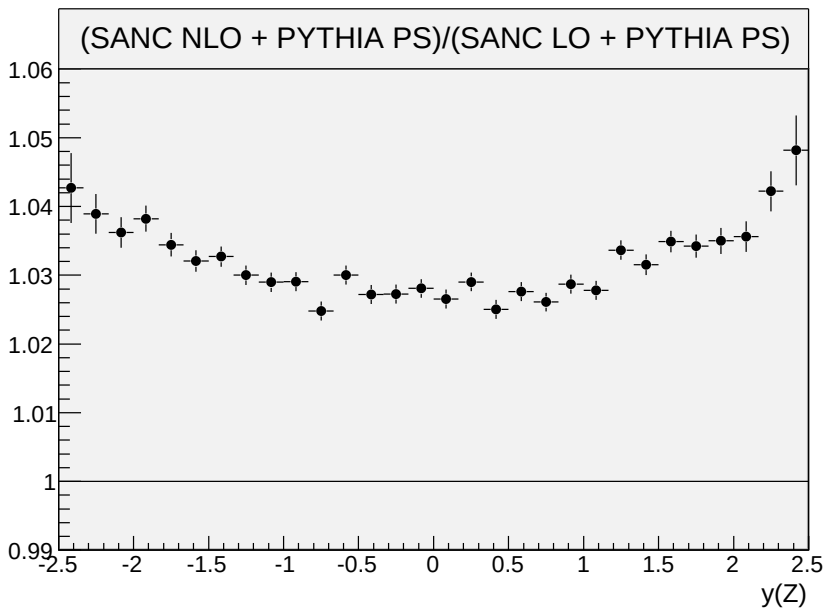
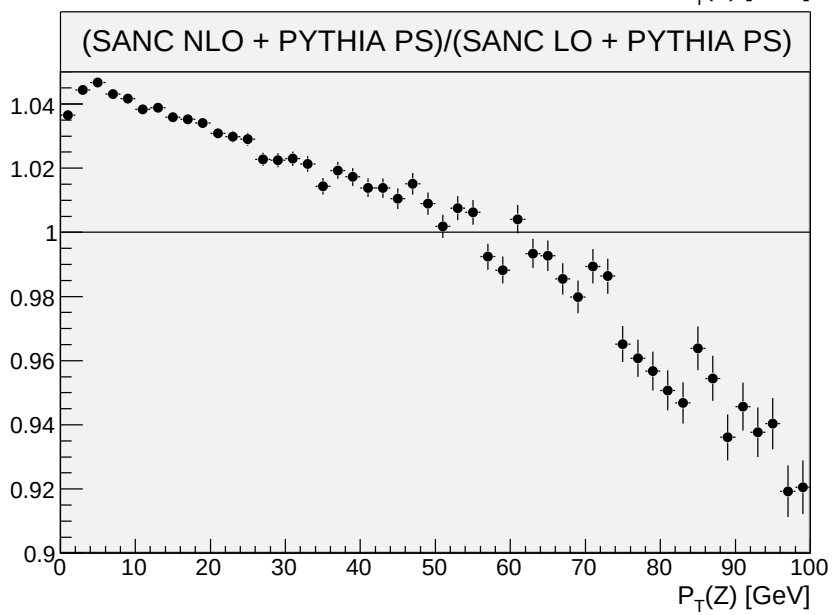
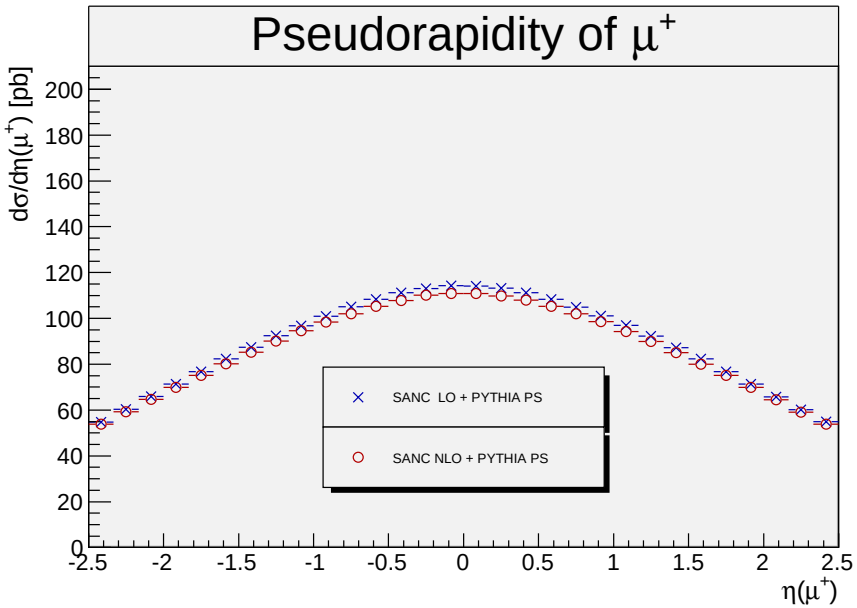


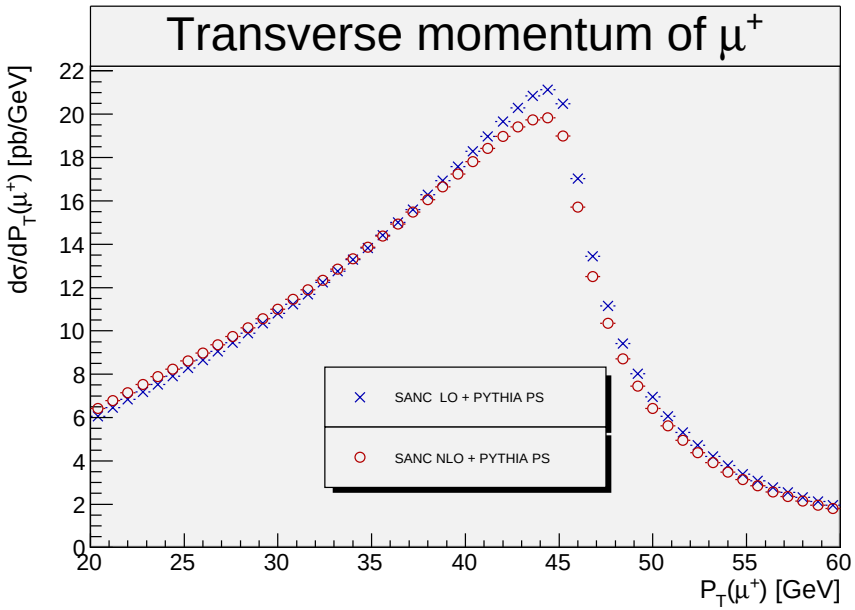


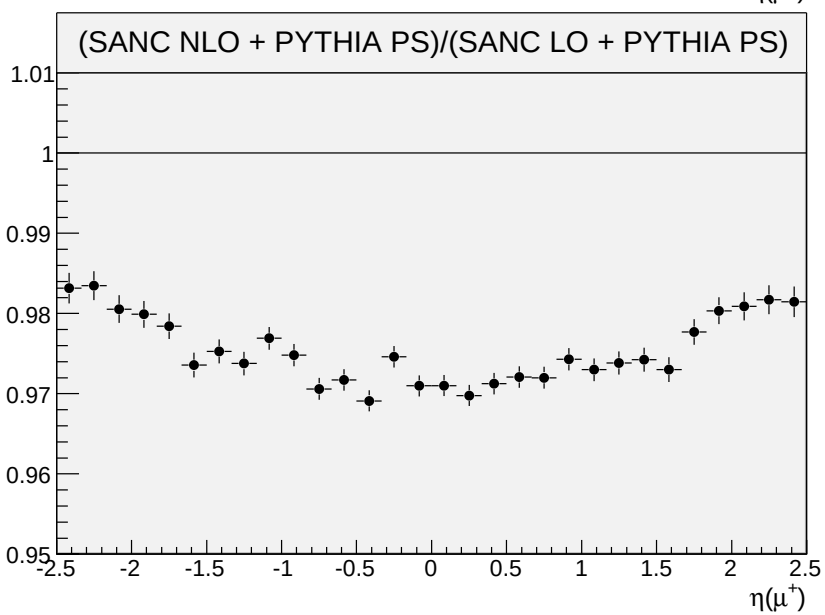


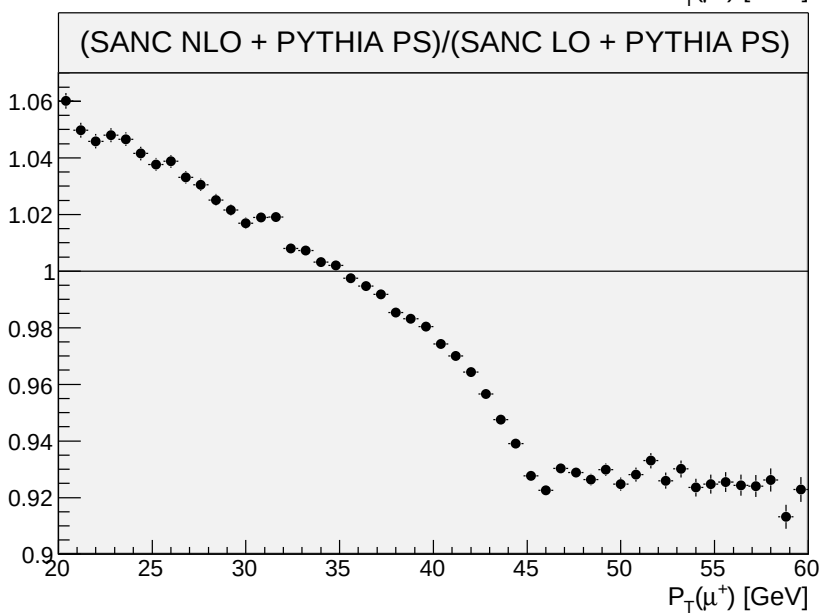


$pp \to Z/\gamma \to \mu^+\mu^-$ (G_F-scheme)









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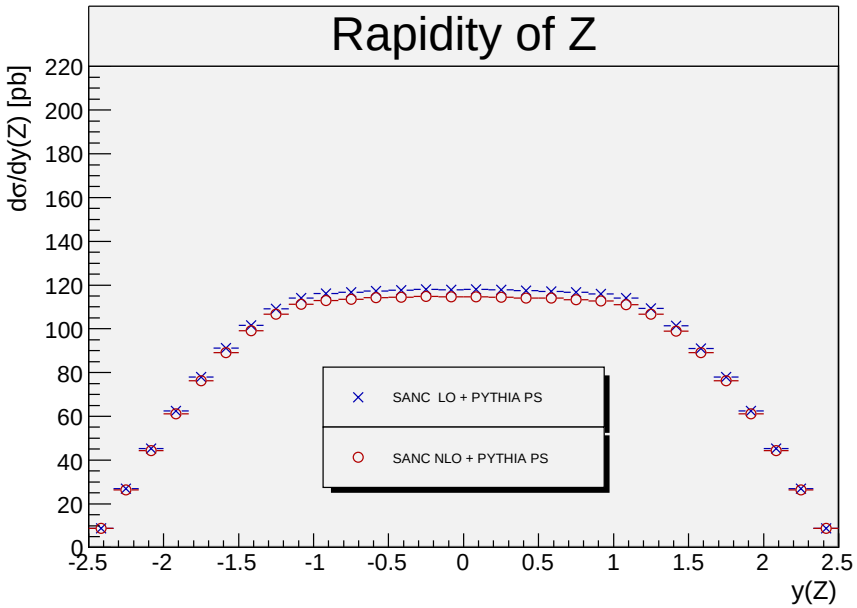
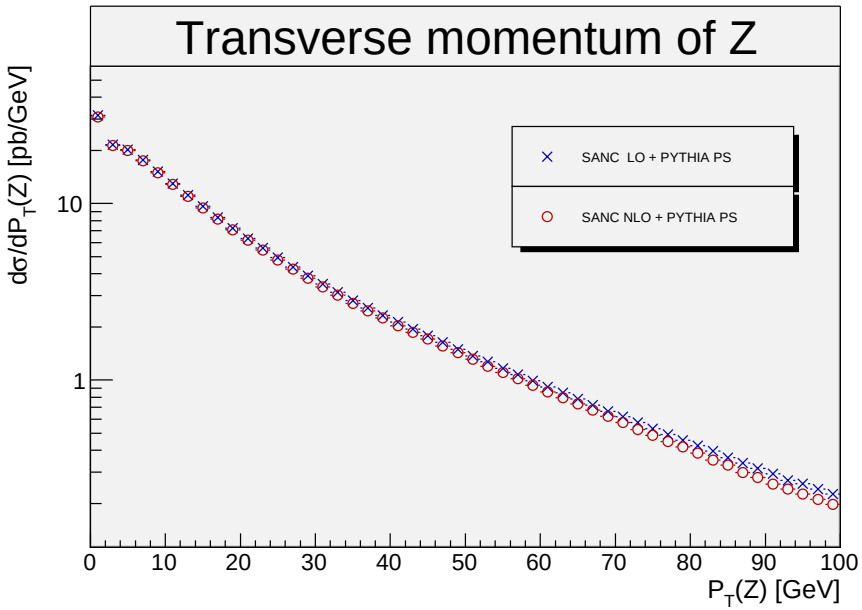
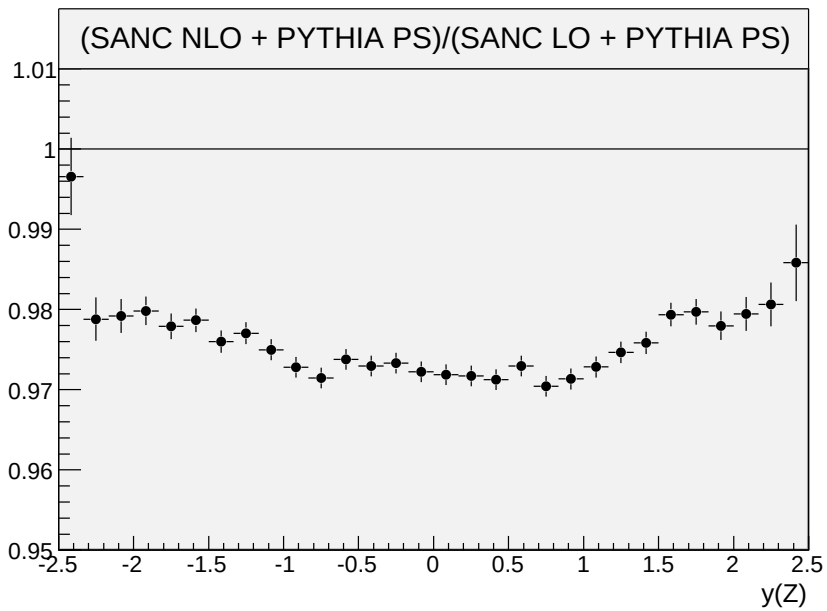
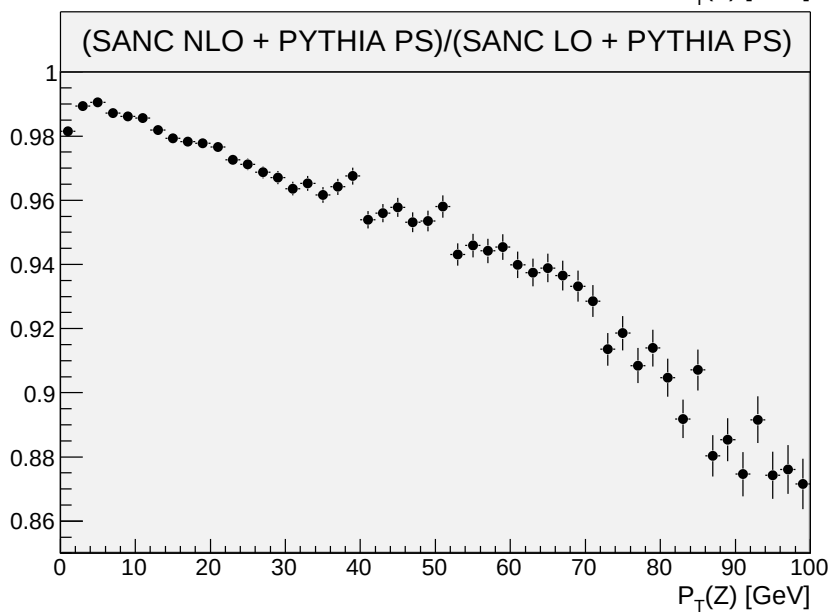
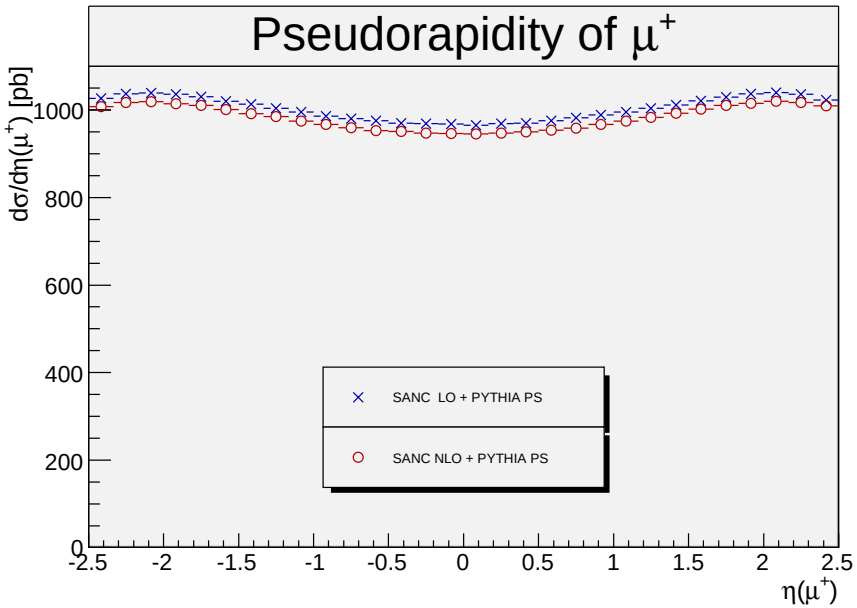


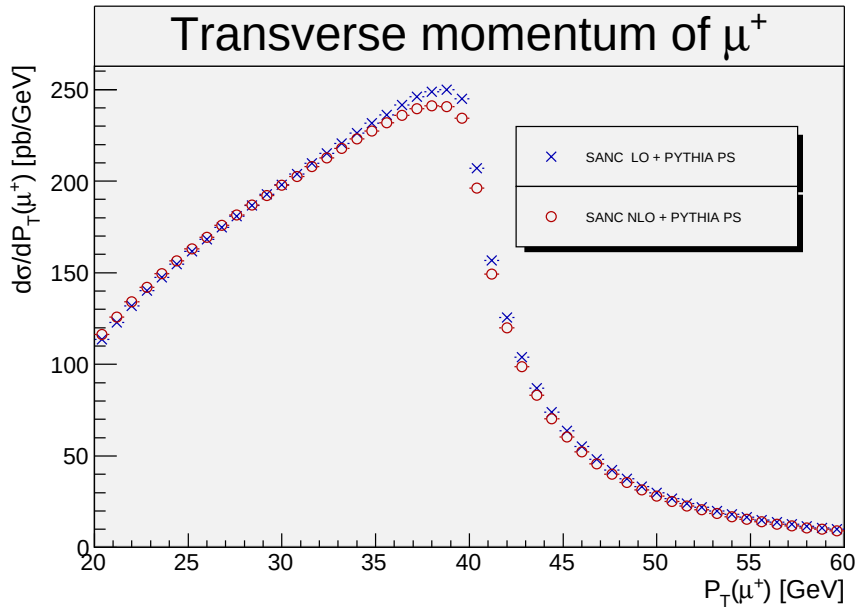


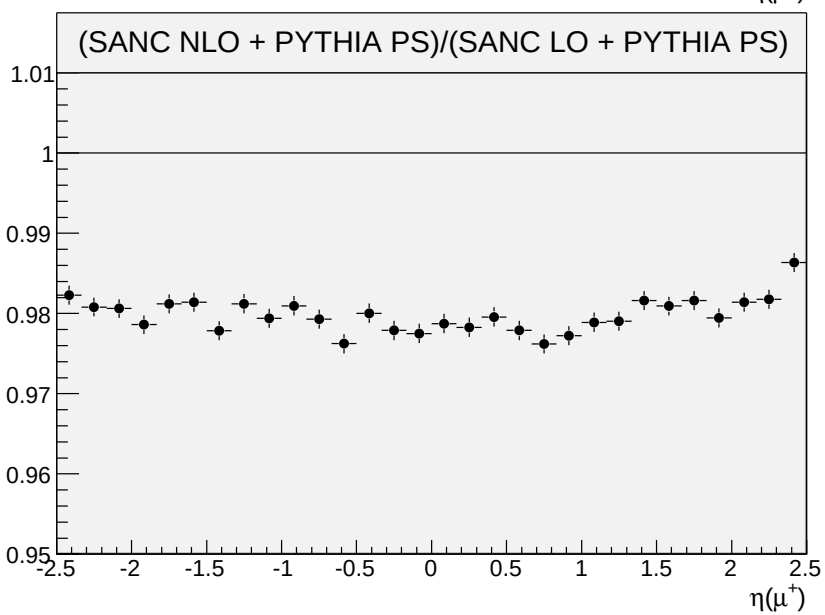


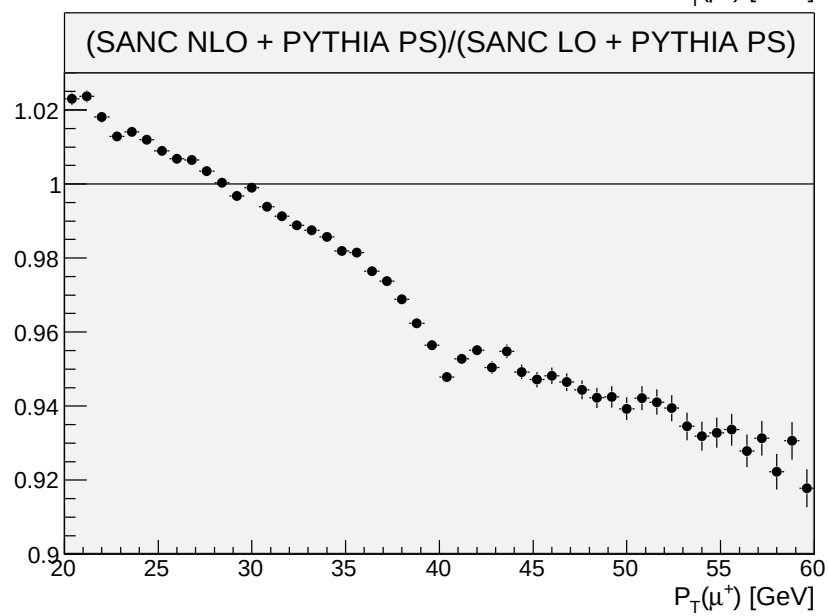


$pp \longrightarrow W^+ \longrightarrow \mu^+\nu_\mu$ (G_F-scheme)









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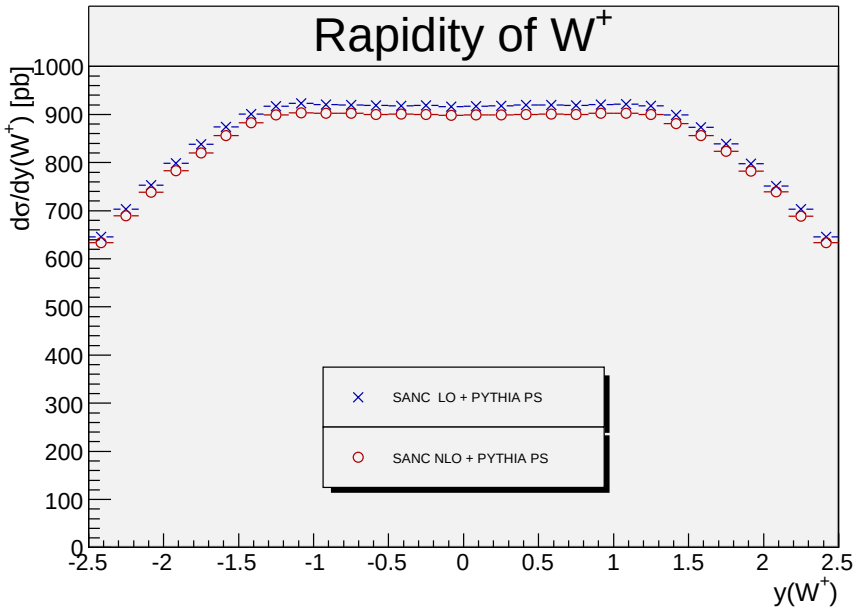

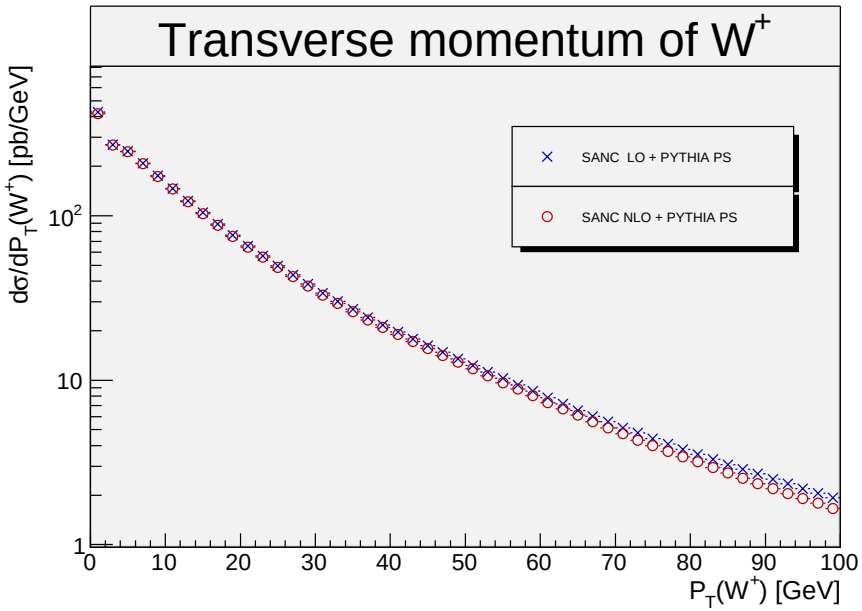

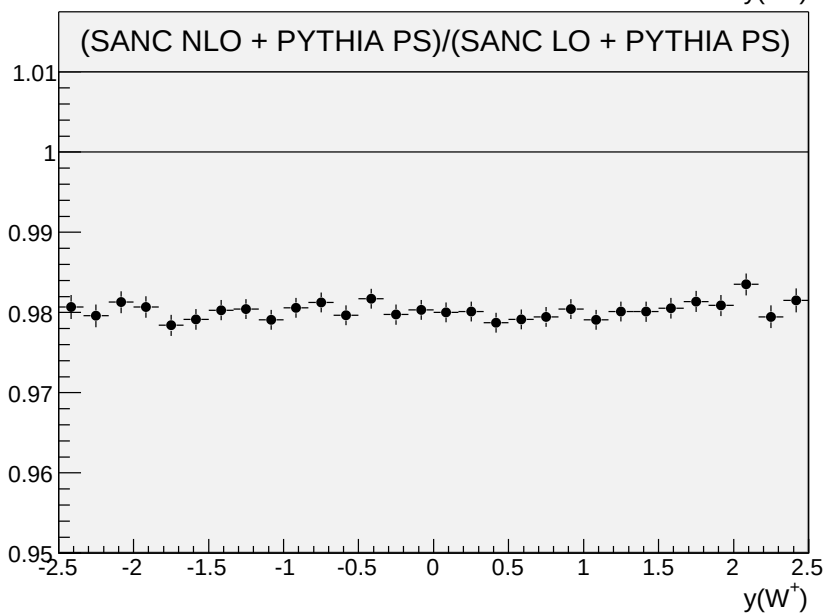

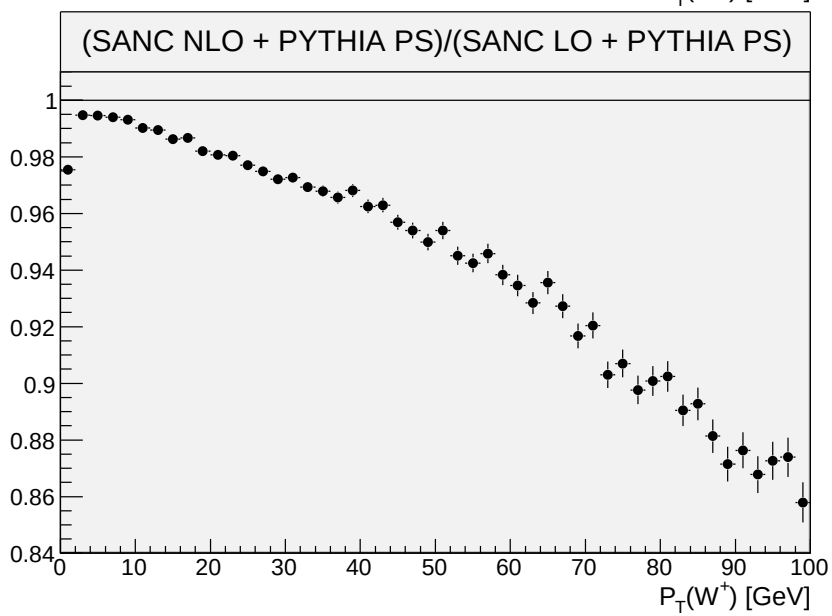

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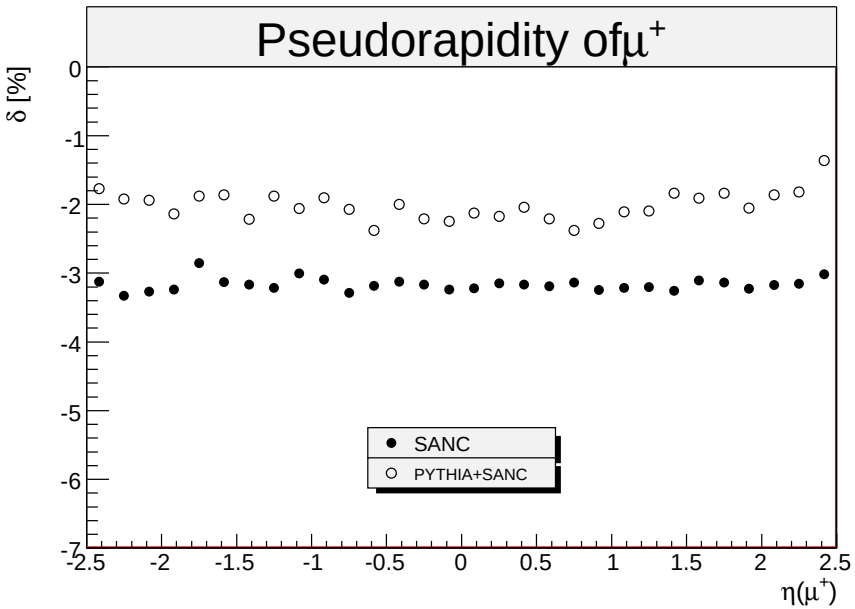
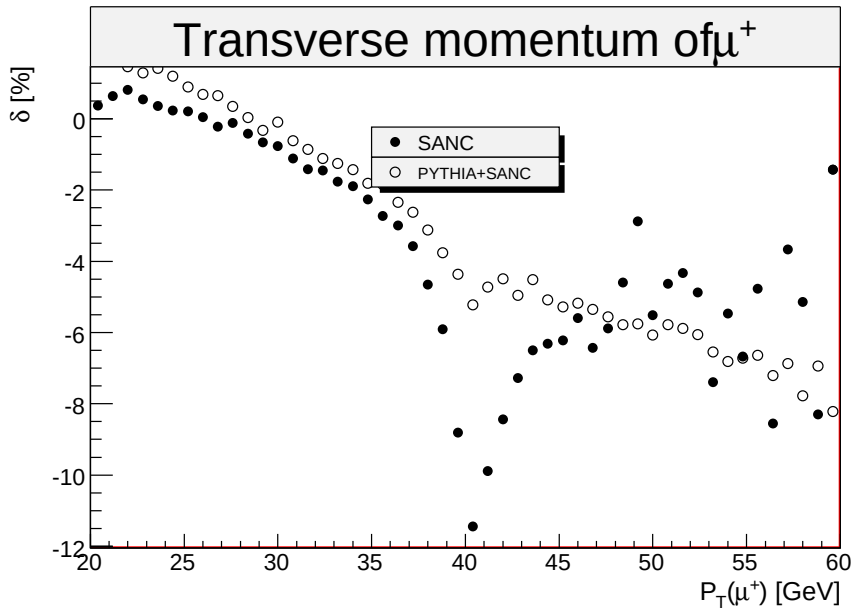




QCD and EW corrections interplay

It is important to combine both QCD and EW corrections consistently at the MC generator level.

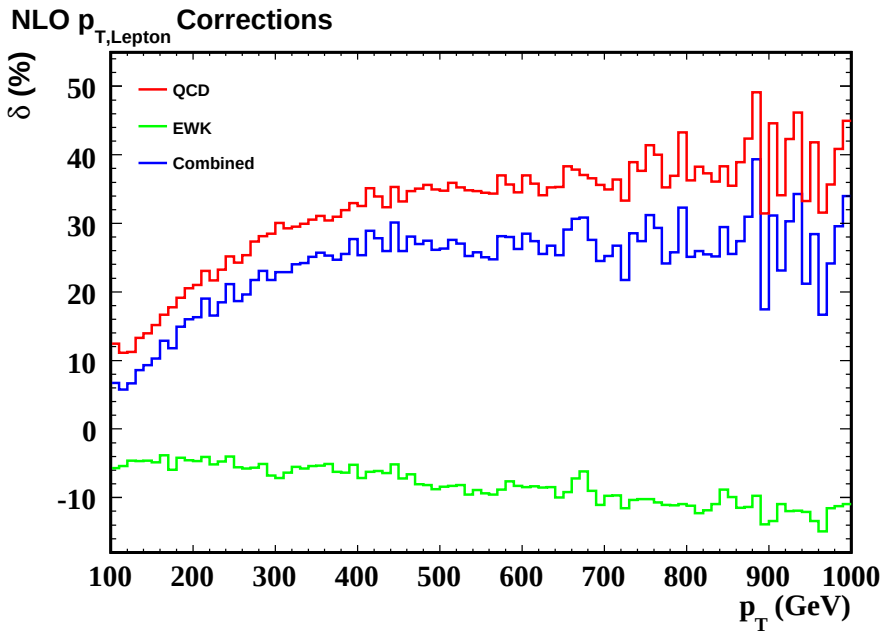
The recent attempts can be found in

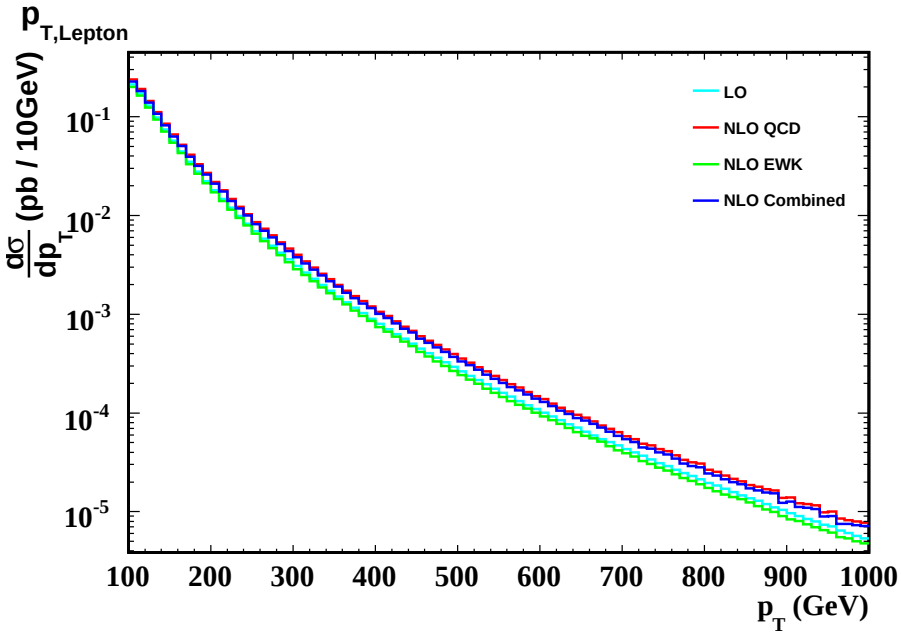
U. Baur et al, arXiv:0803.0678, pp.12-17

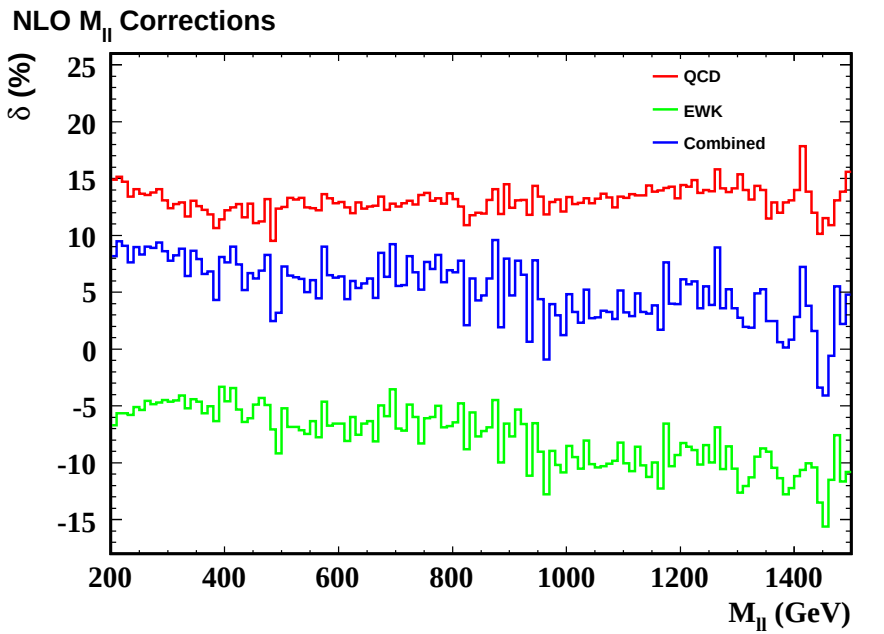
The formula for the combination of QCD and EW effects is given by:

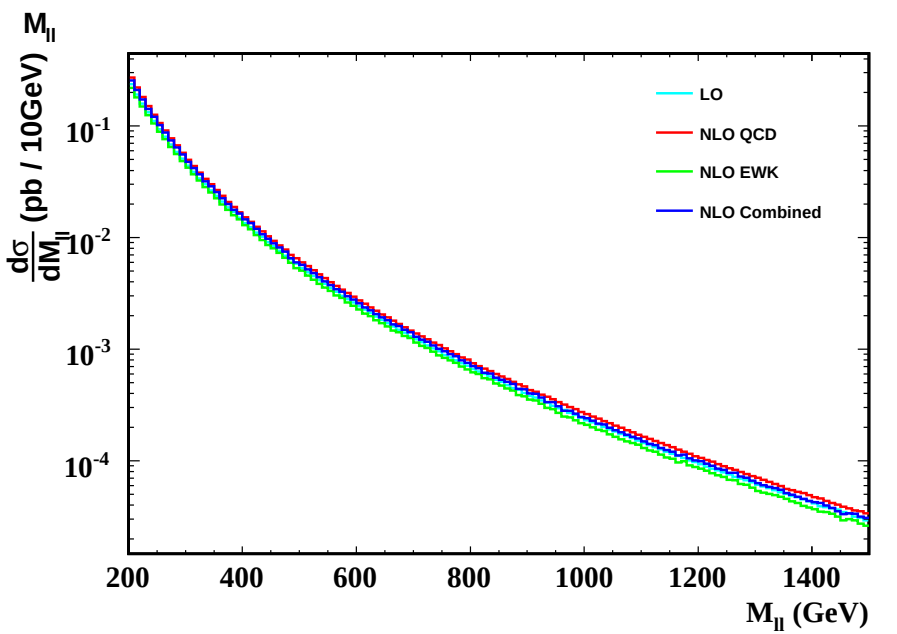
$$\left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\mathrm{QCD}\oplus\mathrm{EW}} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{best QCD}} + \left(\left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{best EW}} - \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{born}}\right)_{\mathrm{HERWIGPS}}$$

QCD&EW interplay (U. Baur et al)









Born-level in Pythia

- In Pythia the running of α is used in hard processes (first order running which is agree with Standard Model α_{M_Z} at the Z^0 mass)
- The gauge boson propagator is proportional to $\frac{1}{s - M^2_{Z,W} + is\Gamma_{Z,W}/M_{Z,W}}$
- The weak mixing angle as used in all Z^0 and $W^{\pm}$masses and couplings $\sin\theta_W = 0.2312$
- The weak mixing angle, as used to derive the vector couplings of fermions to the Z^0 $\sin\theta^{eff}_W = 0.2315$

Reweighting technique and general requirements on reweighting tool

To implement the effects of the required corrections each generated event of the corresponding bin acquires a new weight

$$w = \frac{d^n\sigma^{best}/d\mathcal{O}_1 \ldots d\mathcal{O}_n}{d^n\sigma/d\mathcal{O}_1 \ldots d\mathcal{O}_n}$$

The reweighting tool must be relatively fast and flexible

In general the implementation of reweighting to simulated events is not a trivial task

PDF reweighting as simple example

As a simple example of reweighting one can consider the PDF reweighting

$$w = \frac{d^2\sigma^{PDF_1}/dx_1 dx_2}{d^2\sigma^{PDF_2}/dx_1 dx_2}$$

Conclusions

- To gain the required 1% accuracy it is necessary to take into account NLO EW and NNLO QCD corrections consistently at the event generator level.
- Since the validation of new MC programs requires much time we need to study the possibility to include these corrections into MC simulation in an approximate way by reweighting technique.