MONTE CARLO EVENT GENERATION WITH RADIATIVE QED PROCESSES IN DEEP-INELASTIC SCATTERING

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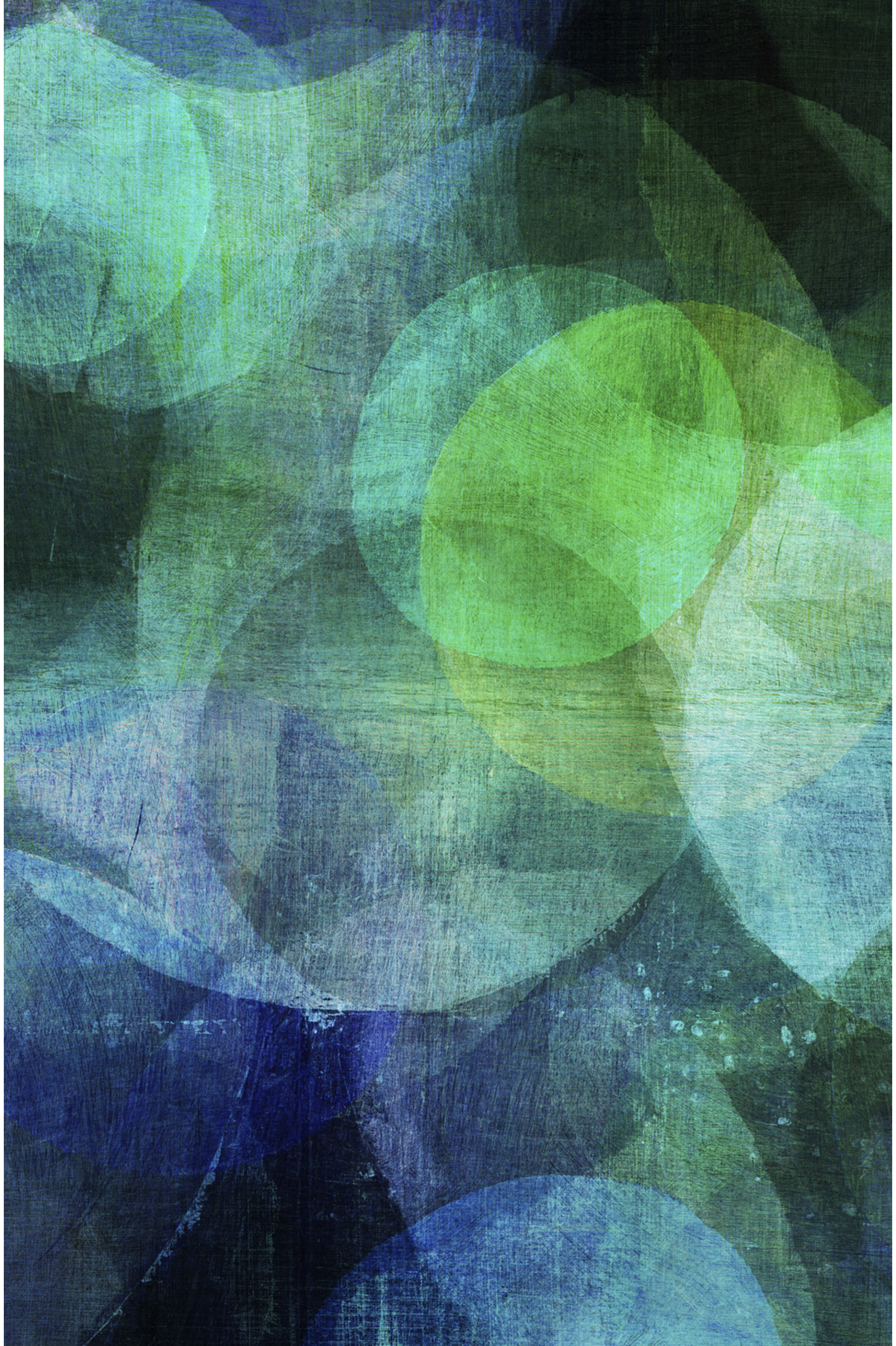
December 20, 2017



CONTENTS

- Radiative corrections : features and impact.
- The DJANGOH generator for radiative events.
- Results for inclusive and semi-inclusive corrections.

INTRODUCTION TO RADIATIVE CORRECTION

Measure FFs, PDFs, by comparing data with theoretical predictions :

$$\sigma_{\exp} = \sigma_{theory}\left[F_n\left(x,Q^2\right)\right]$$

High precision = knowledge of higher order corrections :

$$\sigma_{theory} = \sigma^{(0)}\left[F_n\right] + \alpha_{em}\sigma^{(1)}\left[F_n\right] + \dots$$

<u>Experimental problem :</u>

<u>cannot distinguish radiative photon from non-radiative ones…</u>

UNFOLDING

Determination of the true cross-sections from the measured ones :

$$d\sigma^{obs}(p,q) = \int \frac{d^3k}{2k^0} R(l,l',k)\, d\sigma^{true}(p,-q,k)$$

Radiator function

Typical answer : an iterative solution !

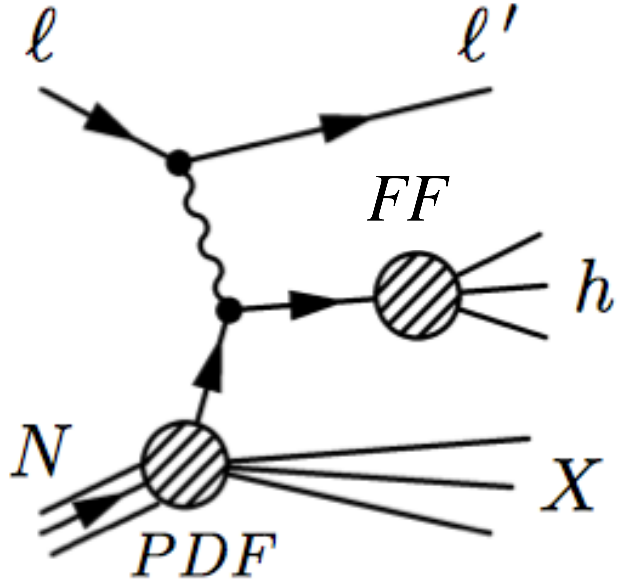
But, ill defined :
- no unique solution
- large uncertainties
- numerically unstable

However, with partial functioning : $R(l,l',k) = \frac{I}{k \cdot l} + \frac{F}{k \cdot l'} + \frac{C}{\tilde{Q}^2}$

- Initial state radiation : k.l small for $\sphericalangle(l_{in},\gamma) \to 0$
- Final state radiation : k.l' small for $\sphericalangle(l_{out},\gamma) \to 0$
- Compton peak : Q^2 small for $p_T(l_{out}) \sim p_T(\gamma)$

RADIATIVE QED CORRECTIONS IN DIS/SIDIS

One of COMPASS goals : measurement of hadron multiplicities for Fragmentation Functions (FFs) extraction.



DIS = Deep-Inelastic Scattering (Inclusive)

SIDIS = Semi-Inclusive Deep-Inelastic Scattering (Observation of at least one hadron in the final state)

Impact on SIDIS data :

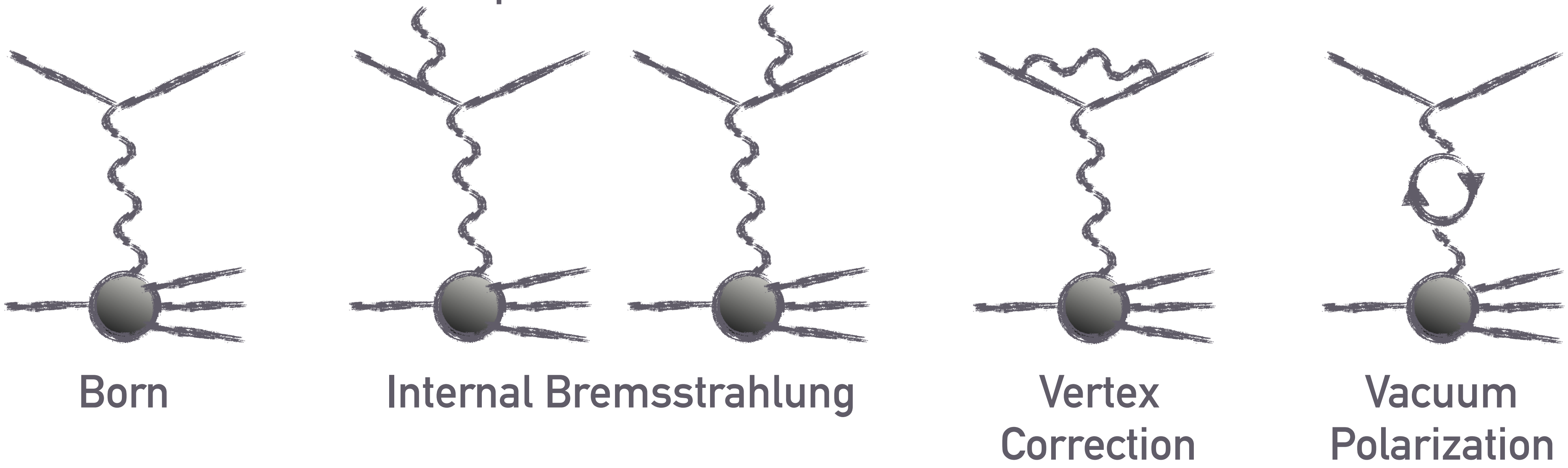
Difference between the hadronic and leptonic kinematic variables

→ some hadrons fall into the wrong kinematic bin.

Correction factor to multiplicities → 'redirects' those hadrons.

RADIATIVE QED CORRECTIONS IN DIS/SIDIS

Born level and one-loop corrections (so-called o(α) corrections) :



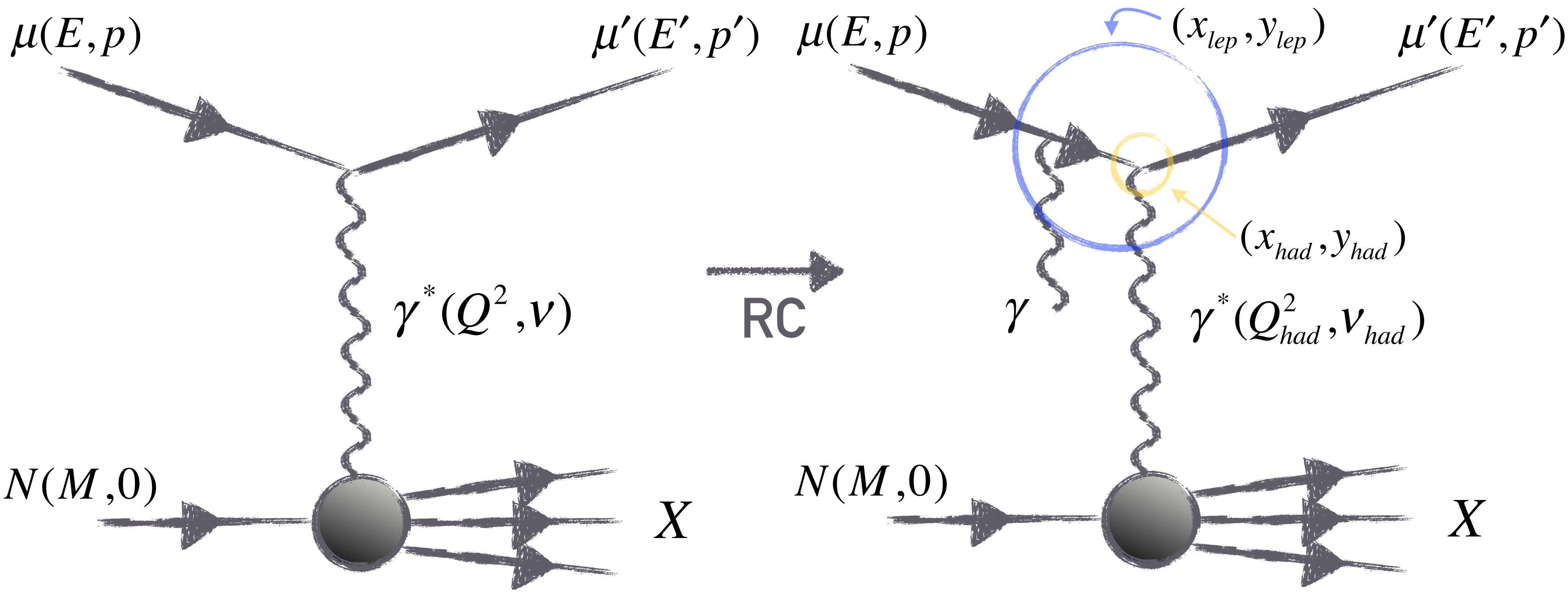
Measurement of DIS cross-section : Inclusive radiative corrections

$$\eta(x,y) = \frac{\sigma_{Born}(x,y)}{\sigma_{Born+o(\alpha)}(x,y)} = \frac{\sigma_{1\gamma}(x,y)}{\sigma_{measured}(x,y)}$$

Measurement of SIDIS cross-section : Semi-Inclusive radiative corrections

$$\eta^{h^\pm}(x,y,z) = \frac{M^{h^\pm}_{Born}(x,y,z)}{M^{h^\pm}_{Born+o(\alpha)}(x,y,z)} = \frac{M^{h^\pm}_{1\gamma}(x,y,z)}{M^{h^\pm}_{measured}(x,y,z)}$$

DEFINITION OF A RADIATIVE EVENT



SIDIS = Semi-Inclusive DIS (obs. of one hadron of the final state)

$$x \stackrel{lab}{=} \frac{Q^2}{2M\nu} \qquad y \stackrel{lab}{=} \frac{E-E'}{E} = \frac{\nu}{E} \qquad z \stackrel{lab}{=} \frac{E_h}{\nu}$$

Radiative event
=
Event containing a real radiated photon

RC @ COMPASS

Used program for RC calculation : TERAD composed by Dubna group (A.A.Akhundov, et al., Fortschr. Phys. 44 (1996) 373).

However, still do not know where the radiative photon goes…

→ need a radiative event generator

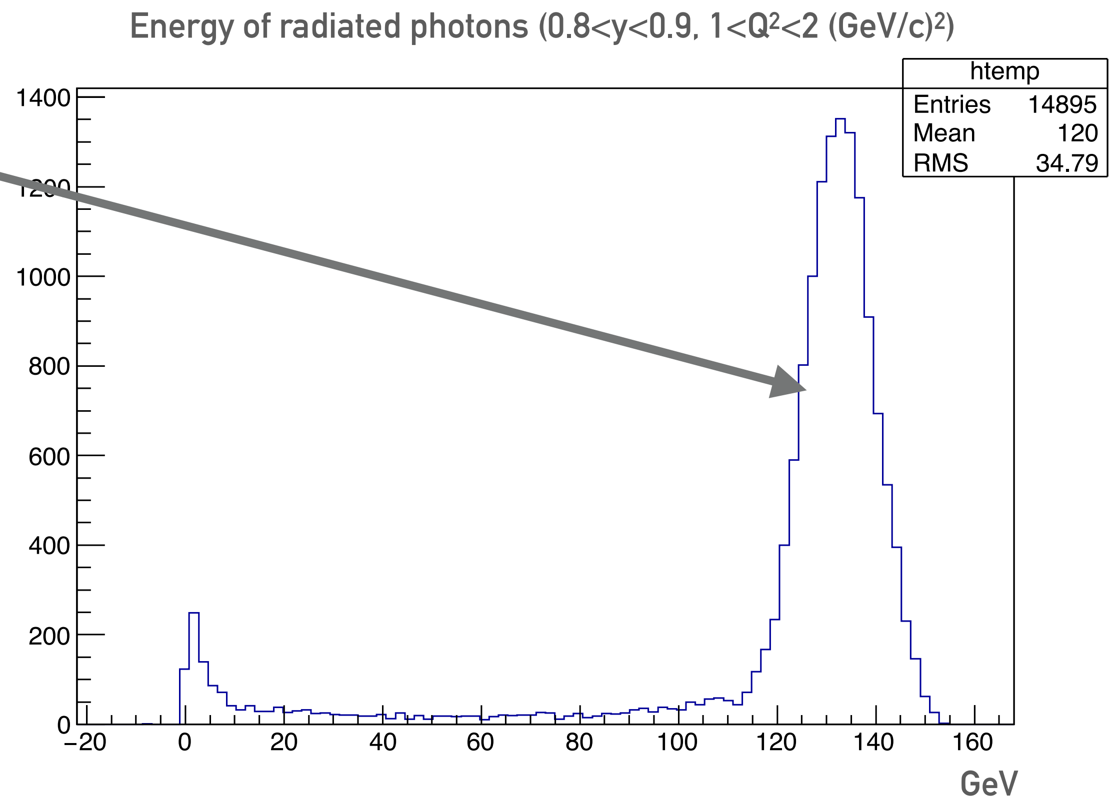
COMPASS used RADGEN generator (I.Akushevich, H.Böttcher, D.Ryckbosch, arXiv:hep-ph/9906408) in previous analyses.

FINDING THE BEST RC GENERATOR

RADGEN : high amount of hard photons (high energy photons)

Naïve thinking : in theory, more soft than hard photons.

But : MC simulation + RADGEN do not describe COMPASS data : hard photons leading to high production of electrons not seen in COMPASS data..



Can we find a better MC generator ?

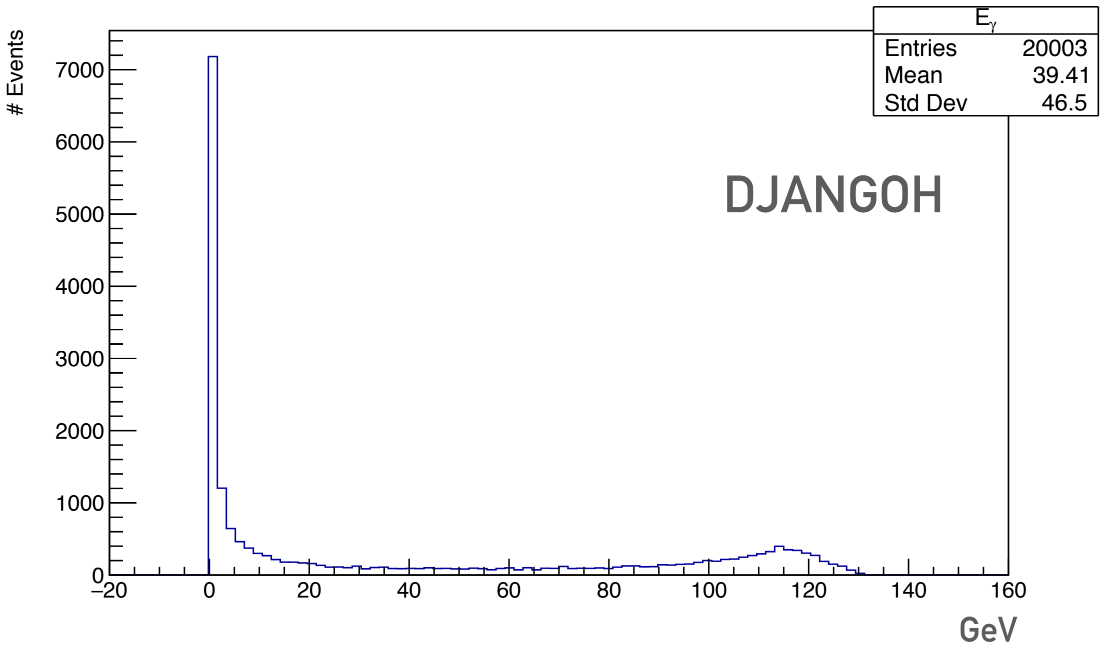
DJANGOH

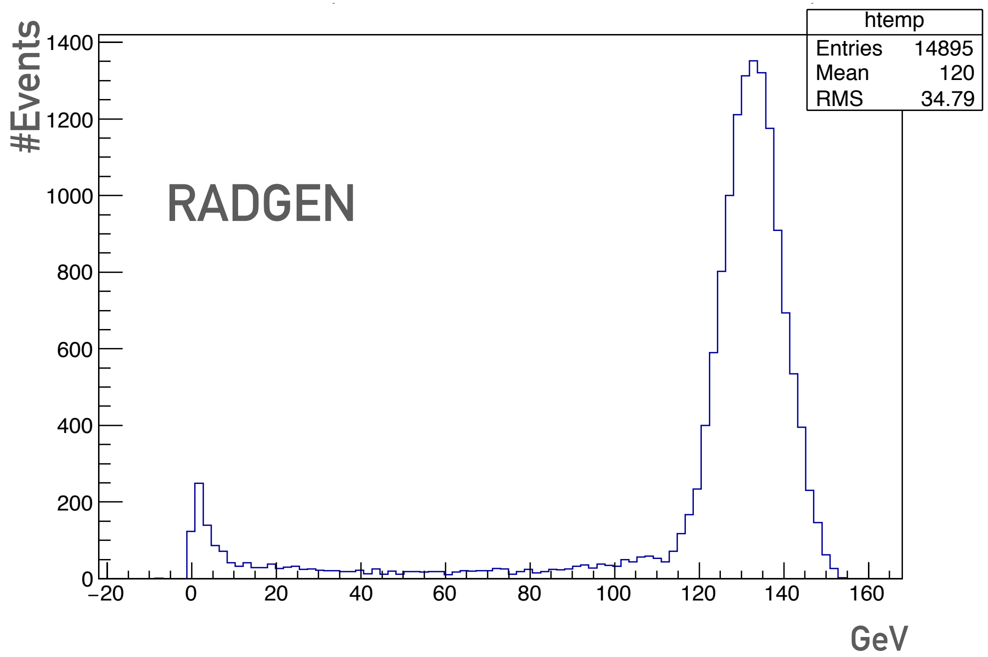
DJANGOH, concatenation of DJANGO and HERACLES :

- Event generator for neutral/charged current ep interactions at HERA by H. Spiesberger (http://wwwthep.physik.uni-mainz.de/~hspiesb/djangoh/djangoh.html, arXiv:1309.5327). Will be used for EIC (arXiv:1309.5327v1)
- Simulates DIS including both QED and QCD radiative effects.
- Includes single photon emission from lepton/quark line, self energy corrections and complete set of one-loop weak corrections (o(α) corrections).
- Includes also the background from radiative elastic scattering $\mu p \rightarrow \mu p \gamma$.
- Capable of obtaining hadronic final state via the use of JETSET.
- Modified to work for μp interactions.
- Uses exact calculations and no approximations.
- FORTRAN framework.

DJANGOH/RADGEN COMPARISON

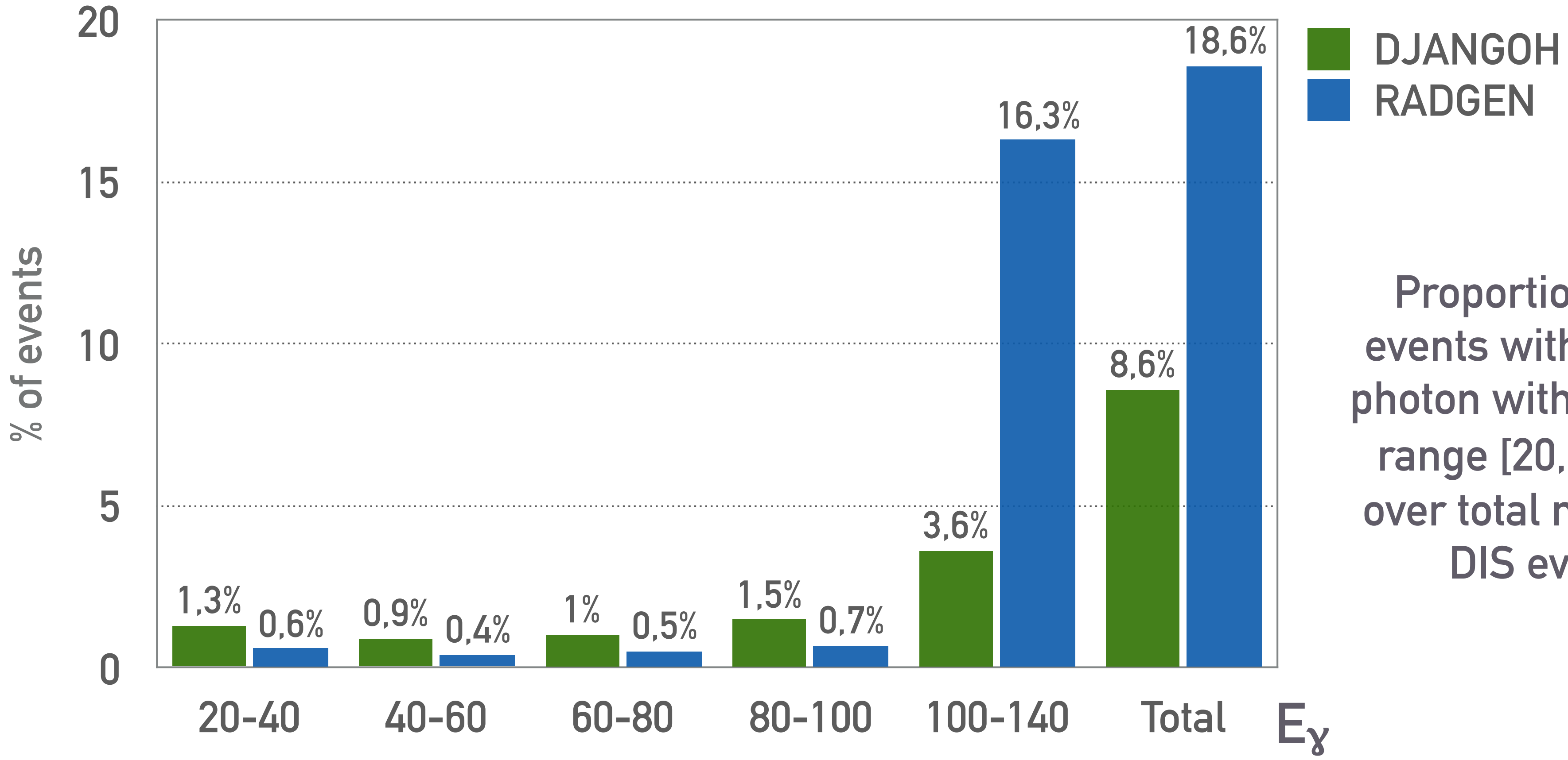
Energy of radiated photons ($0.8<y<0.9$, $1<Q^2<2$ $(GeV/c)^2$)





First observation : ▸ DJANGOH produces **more soft photons than hard photons**

DJANGOH/RADGEN COMPARISON



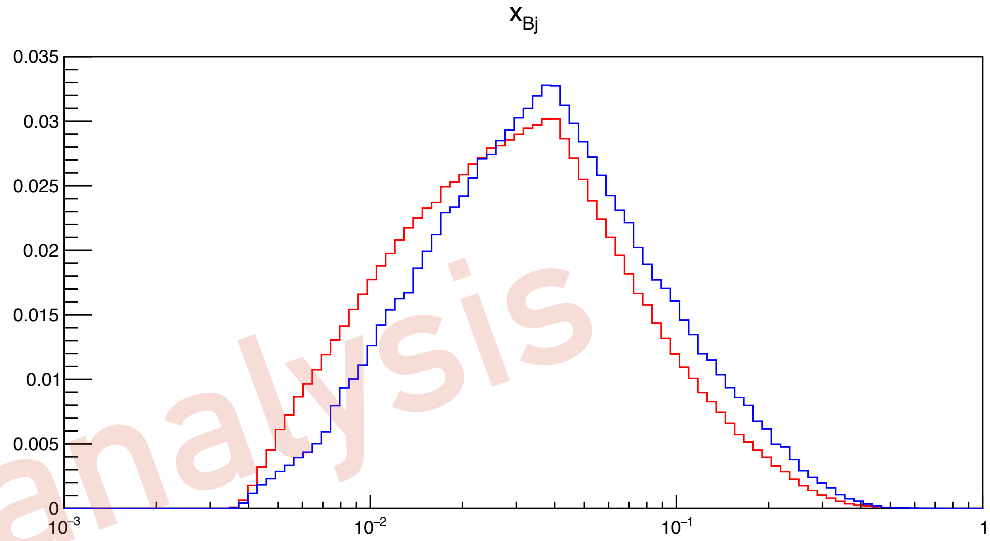
Proportion of DIS events with radiated photon with energy in range [20,140] GeV over total number of DIS events.

DJANGOH produces less hard photons than RADGEN

Motivated implementation in MC chain and further tests

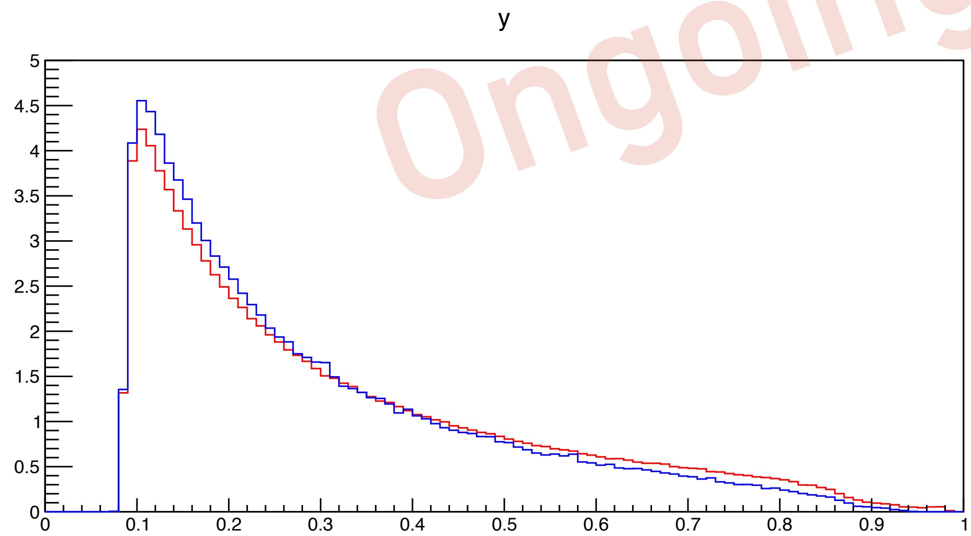
RECONSTRUCTED MONTE-CARLO

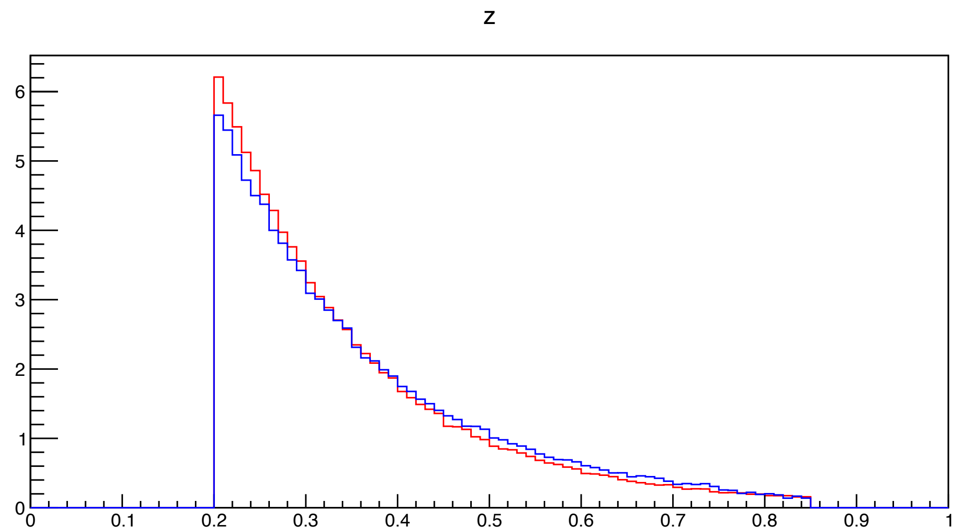
Comparison between real Data and MC for x, y and z.
Ok for y and z, still some problems with x (not enough low x events) : under investigation !



Real Data — MC

Ongoing analysis





INCLUSIVE RADIATIVE CORRECTIONS

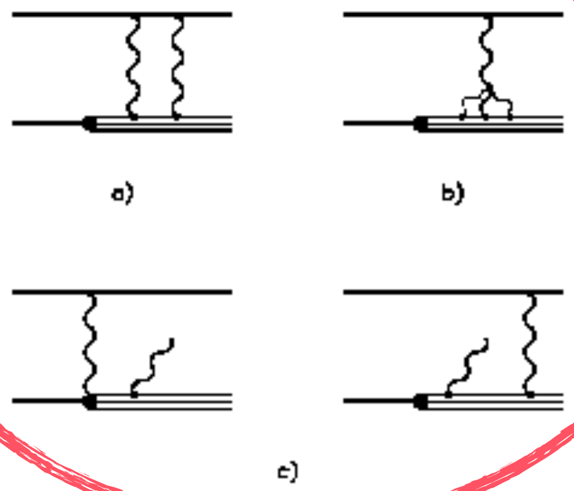
- To fix the definition of radiative correction :

$$\eta(x,y) = \frac{\sigma_{Born}(x,y)}{\sigma_{Born+o(\alpha)}(x,y)} = \frac{\sigma_{1\gamma}(x,y)}{\sigma_{measured}(x,y)}$$

- This definition will be used in the following.

- o(α) corrections for DJANGOH, o(α) and some hadron currents corrections for TERAD.

- TERAD uses parametrization for structure functions. Same F_2 and R used in DJANGOH.

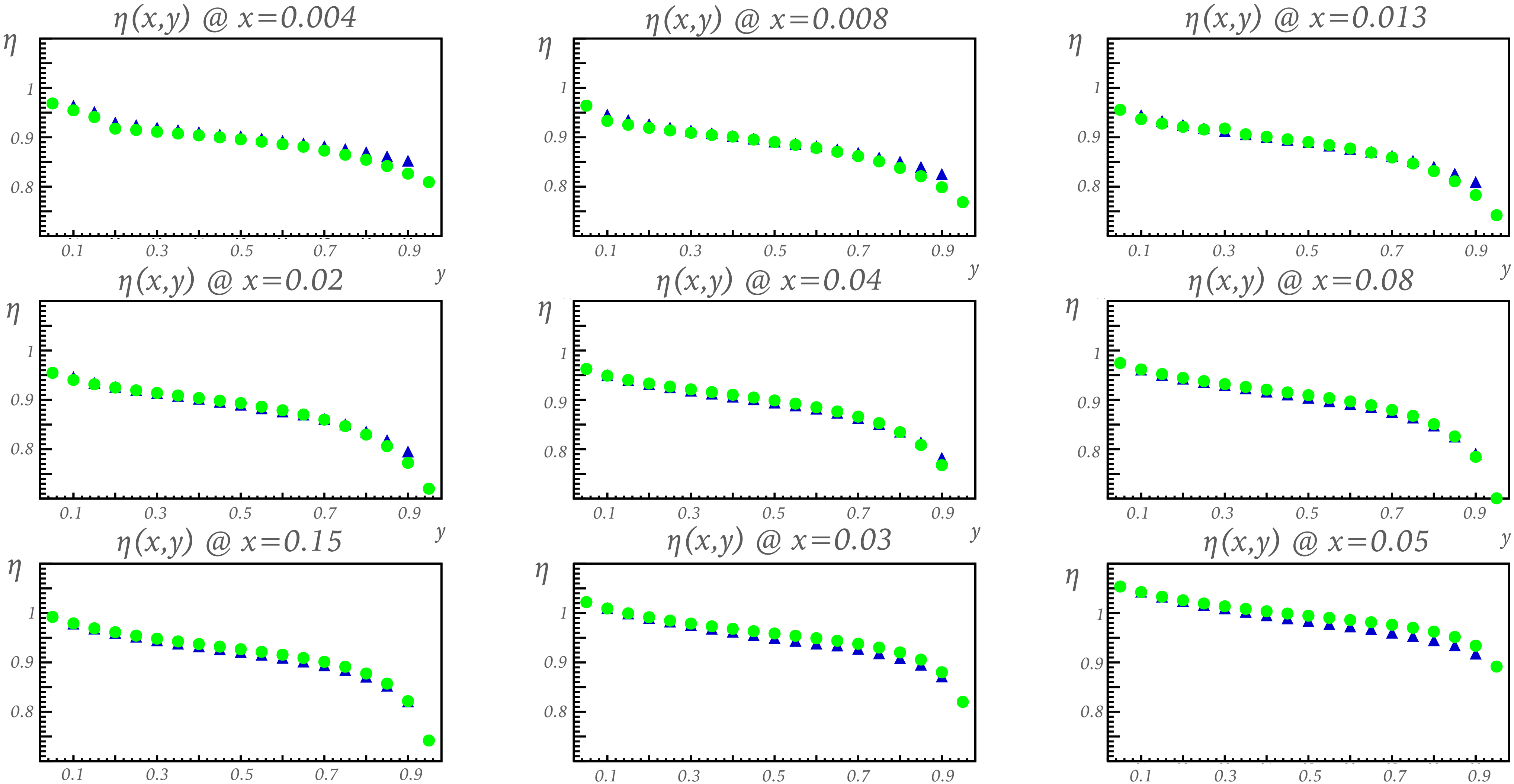


INCLUSIVE CORRECTIONS

$$\eta(x,y) = \frac{\sigma_{Born}(x,y)}{\sigma_{Born+o(\alpha)}(x,y)} = \frac{\sigma_{1\gamma}(x,y)}{\sigma_{measured}(x,y)}$$

Inclusive radiative corrections for TERAD ● and DJANGOH ▲.

Corrections within 10%, going to 40% at high y. Discrepancy smaller than 3%.



SEMI-INCLUSIVE RADIATIVE CORRECTIONS

- To fix the definition of radiative correction :

$$\eta^{h^\pm}(x,y,z) = \frac{M^{h^\pm}_{Born}(x,y,z)}{M^{h^\pm}_{Born+o(\alpha)}(x,y,z)}$$

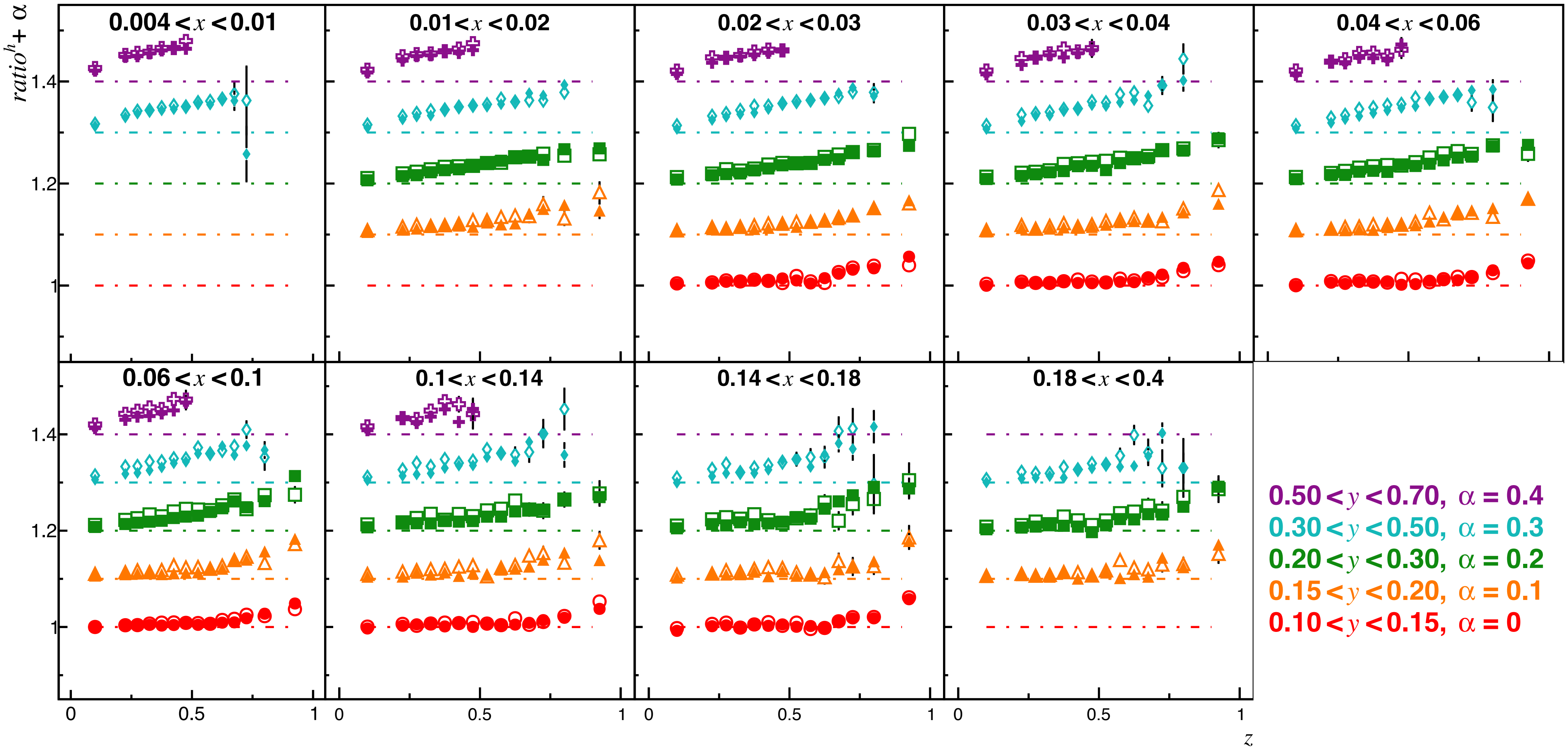
- This definition will be used in the following.
- 'True' DJANGOH used with PDFs and no parametrization for SFs : comparison with TERAD will be difficult.

SEMI-INCLUSIVE CORRECTIONS

$$\eta^{h^{\pm}}(x,y,z) = \frac{M^{h^{\pm}}_{Born}(x,y,z)}{M^{h^{\pm}}_{Born+o(\alpha)}(x,y,z)}$$

Semi-Inclusive radiative correction for DJANGOH.
Mean correction of 5%, goes to 10% at high z high y.

○ negative hadrons
● positive hadrons

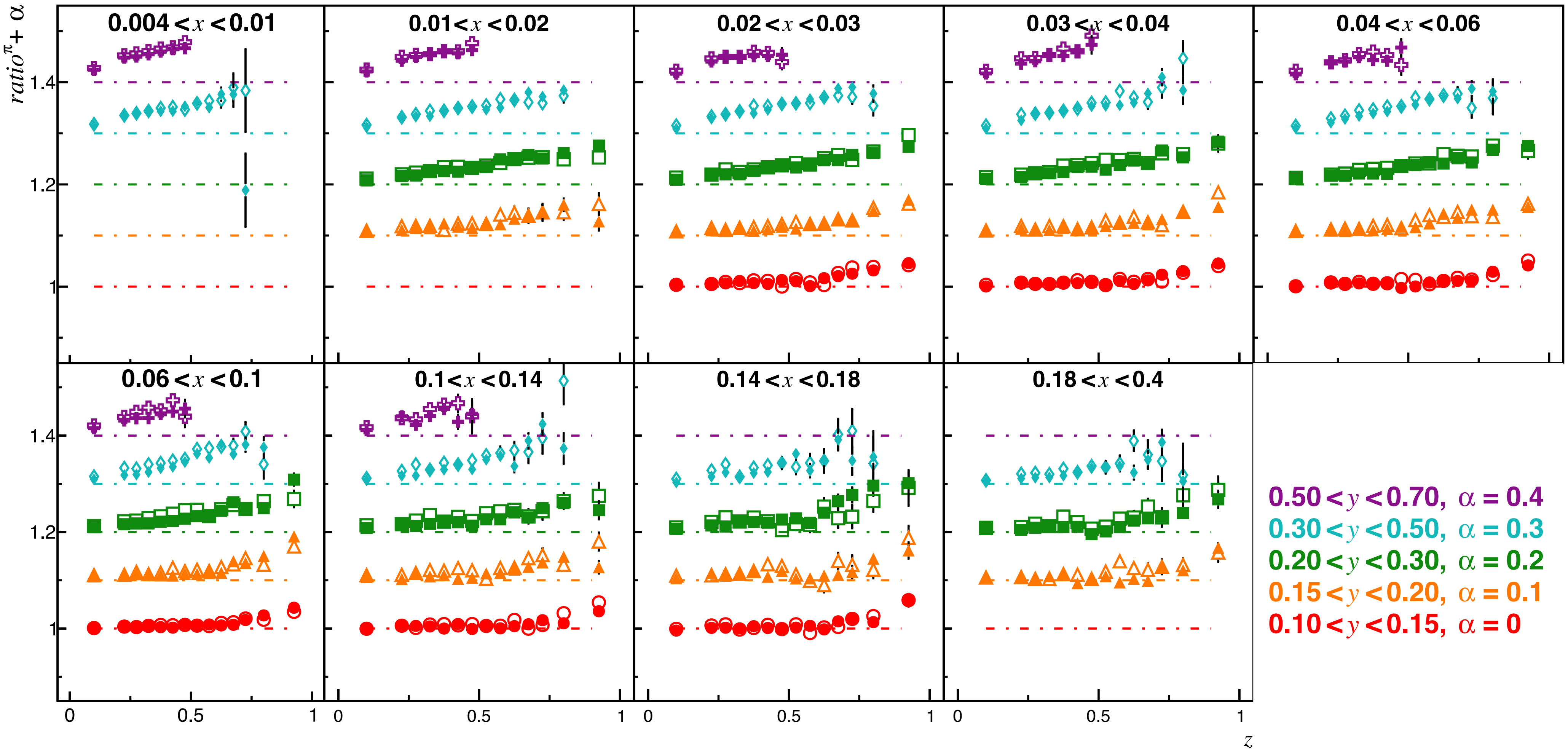


SEMI-INCLUSIVE CORRECTIONS

$$\eta^{\pi^{\pm}}(x,y,z) = \frac{M^{\pi^{\pm}}_{Born}(x,y,z)}{M^{\pi^{\pm}}_{Born+o(\alpha)}(x,y,z)}$$

Semi-Inclusive radiative correction for DJANGOH.
Mean correction of 5%, goes to 10% at high z high y.

○ negative pions
● positive pions

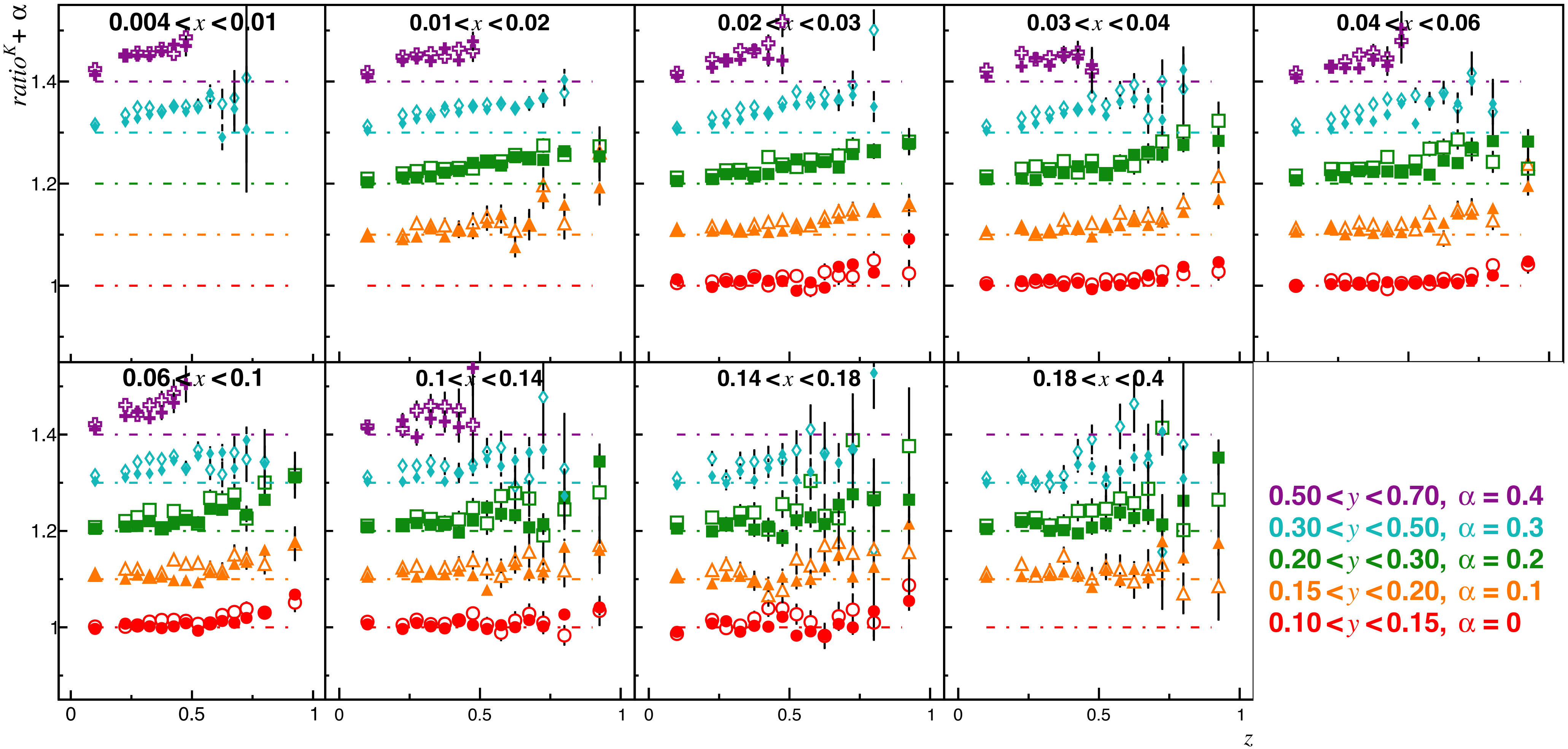


SEMI-INCLUSIVE CORRECTIONS

$$\eta^{K^\pm}(x,y,z) = \frac{M^{K^\pm}_{Born}(x,y,z)}{M^{K^\pm}_{Born+o(\alpha)}(x,y,z)}$$

Semi-Inclusive radiative correction for DJANGOH.
Mean correction of 5%, goes to 10% at high z high y.

○ negative kaons
● positive kaons



WORK STILL IN PROGRESS

- Comparison with TERAD is difficult for semi-inclusive :
  - TERAD : special parametrization of SFs.
  - DJANGOH : SFs extracted from PDFs.
- Possible investigation : apply a correction to extracted SFs to match TERAD SFs.

- Comparison of MC and COMPASS data
  - Tuning of MC

CONCLUSION & PROSPECTS

- RCs needed for cross-sections. Impact of these corrections on SIDIS are not negligible : corrections goes up to 40%, average at ~10% for inclusive, up to 10%, average at ~5% for semi-inclusive.
- Inclusive corrections calculated by DJANGOH consistent with TERAD inclusive corrections : discrepancy smaller than 3%.
- TDJANGOH : C++ wrapper of DJANGOH, can be used easily as physics generator MC simulation as in TGEANT.
- Production of MC with DJANGOH as event generator has begun for 2016 setup, hopefully giving better agreement than RADGEN.

BACKUP

QED CORRECTIONS TO F_2

- Typically quark line radiation corrections
- Negligible except at extremely large Q^2 and large x (see next slide)
- Often not subtracted inside the parametrization, thus already taken into account.
- Decided not to use it in DJANGOH for those reasons. Thus o(α) corrections does not take into account quark line radiation corrections.

INCLUSIVE CORRECTIONS

H. Spiesberger,
QED Radiative Corrections for Parton Distributions
hep-ph/9412286

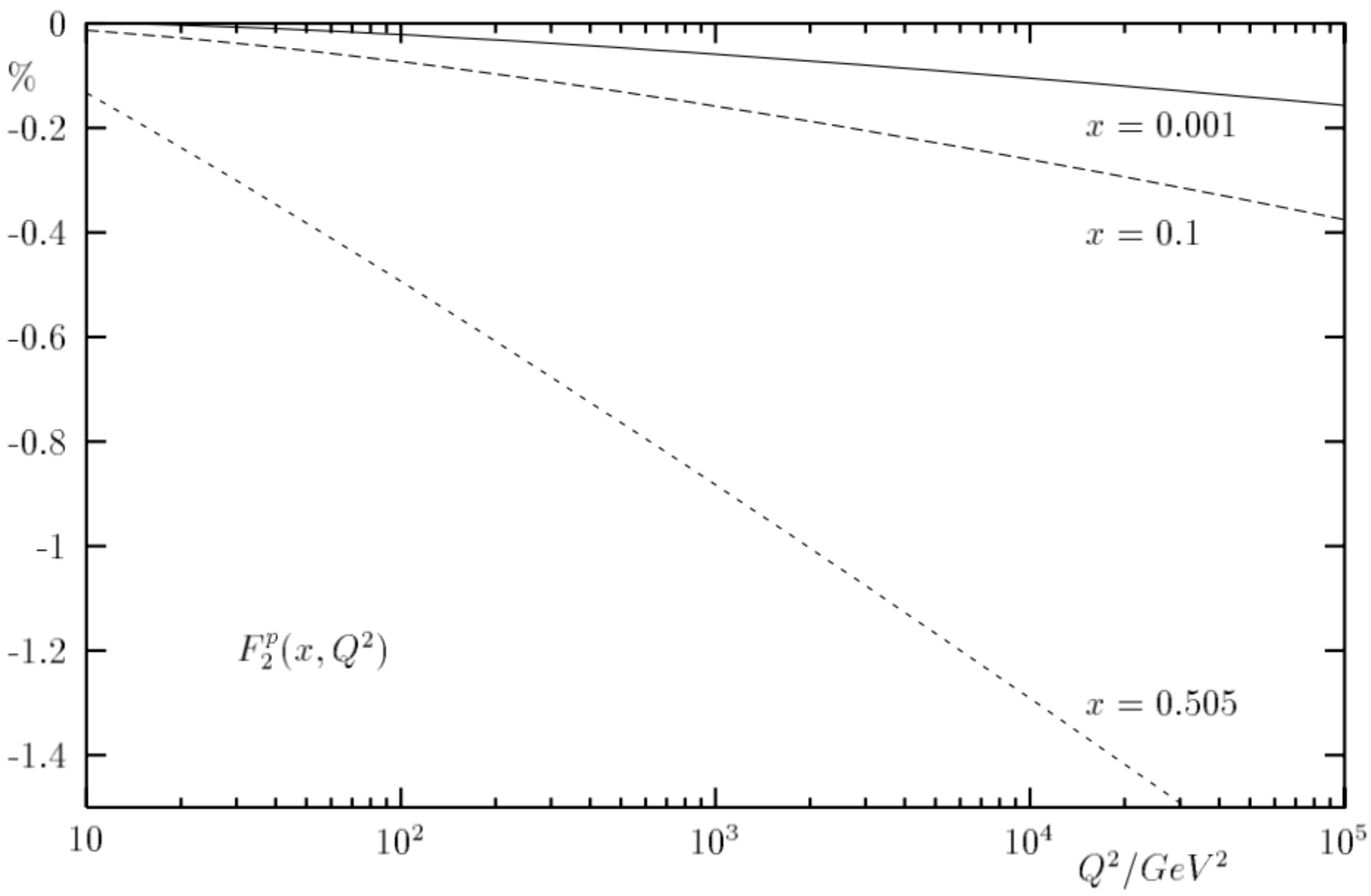
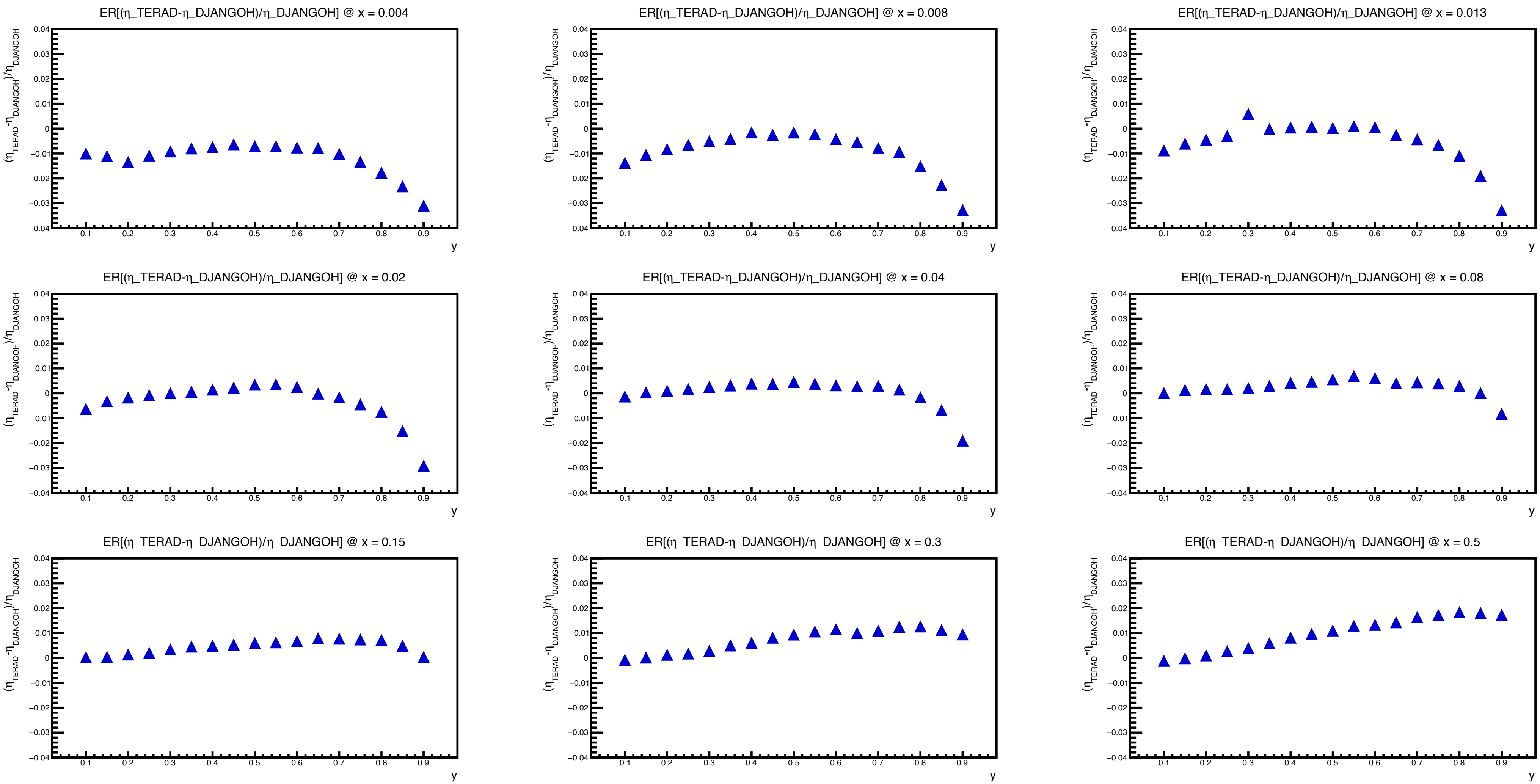


Figure 3: *Q^2 dependence of the QED corrections (in per cent, see text) to the structure function F_2^p for deep inelastic lepton–proton scattering at $x = 0.001$, $x = 0.1$ and $x = 0.505$. Input parton distributions were taken from [12].*

INCLUSIVE CORRECTIONS

$$\eta_T/\eta_D - 1$$

Relative difference between TERAD and DJANGOH. Difference of at most 3%

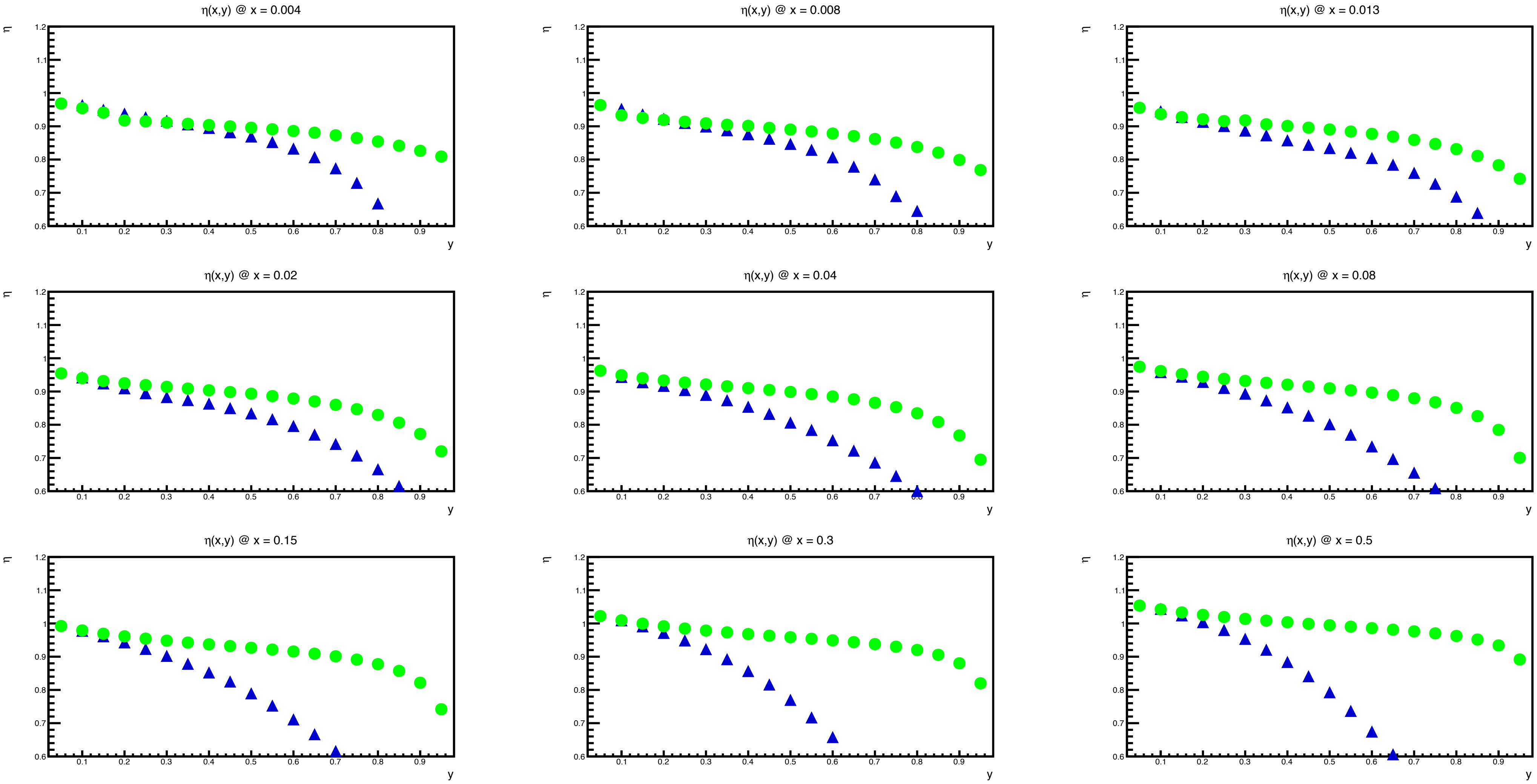


DIGRESSION ON PDF SETS, SF

- Previous results on Inclusive correction show great concordance between DJANGOH and TERAD with TERAD structure functions.
- HOWEVER : for hadronization, DJANGOH needs PDFs and thus cannot use TERAD structure functions for cross-section calculation.
- Game is to find the right PDF set that give structure functions which are not to far from the one from TERAD.
- PROBLEM : for the moment could not find something acceptable.
- ENVISAGED SOLUTION (if time) : might be possible to define a new 'model': use a reasonable set of PDFs and introduce an additional overall correction or scaling factor which gives structure functions in agreement with TERAD structure functions.

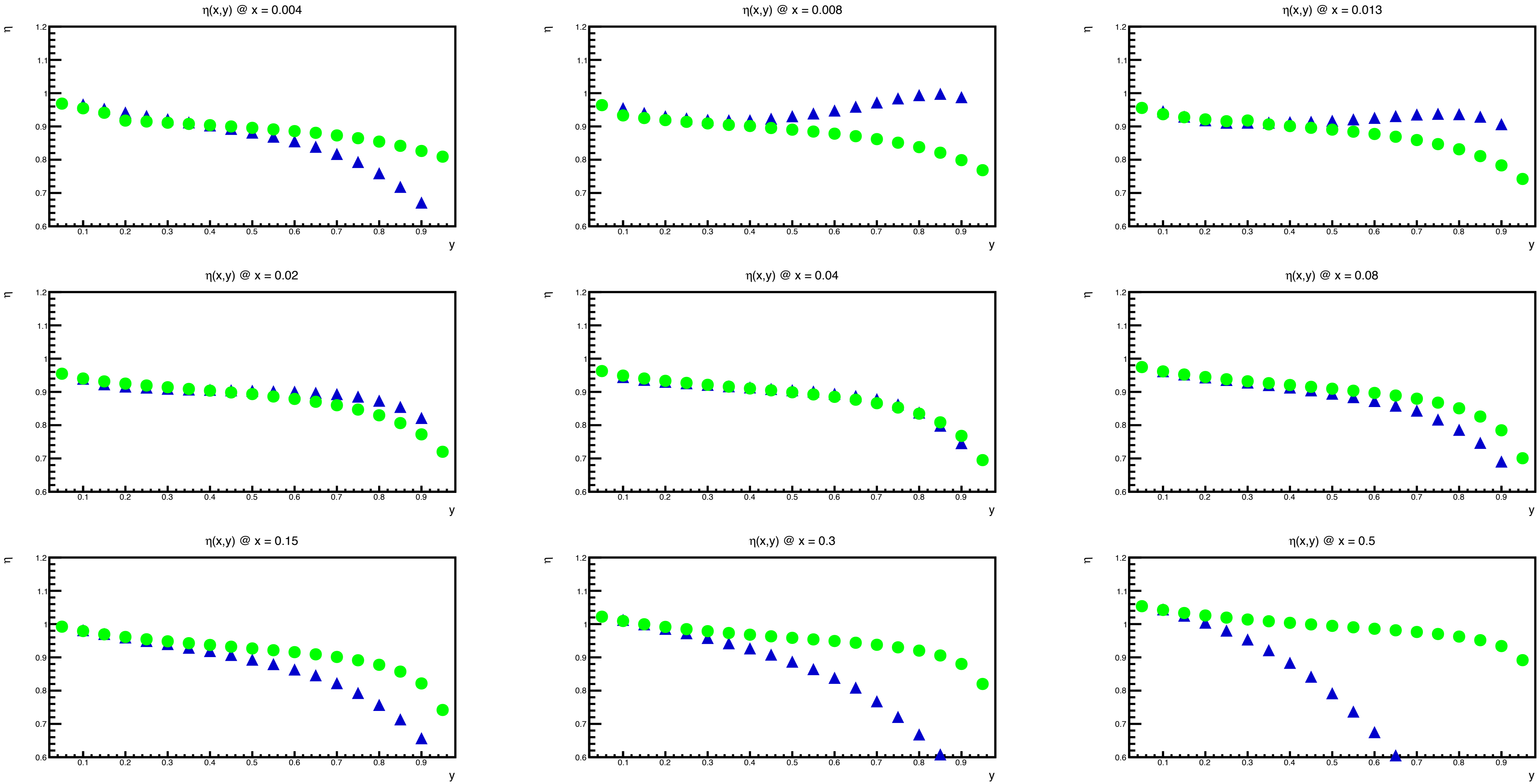
CTEQ6.1

Inclusive radiative corrections for TERAD ● and DJANGOH ▲.



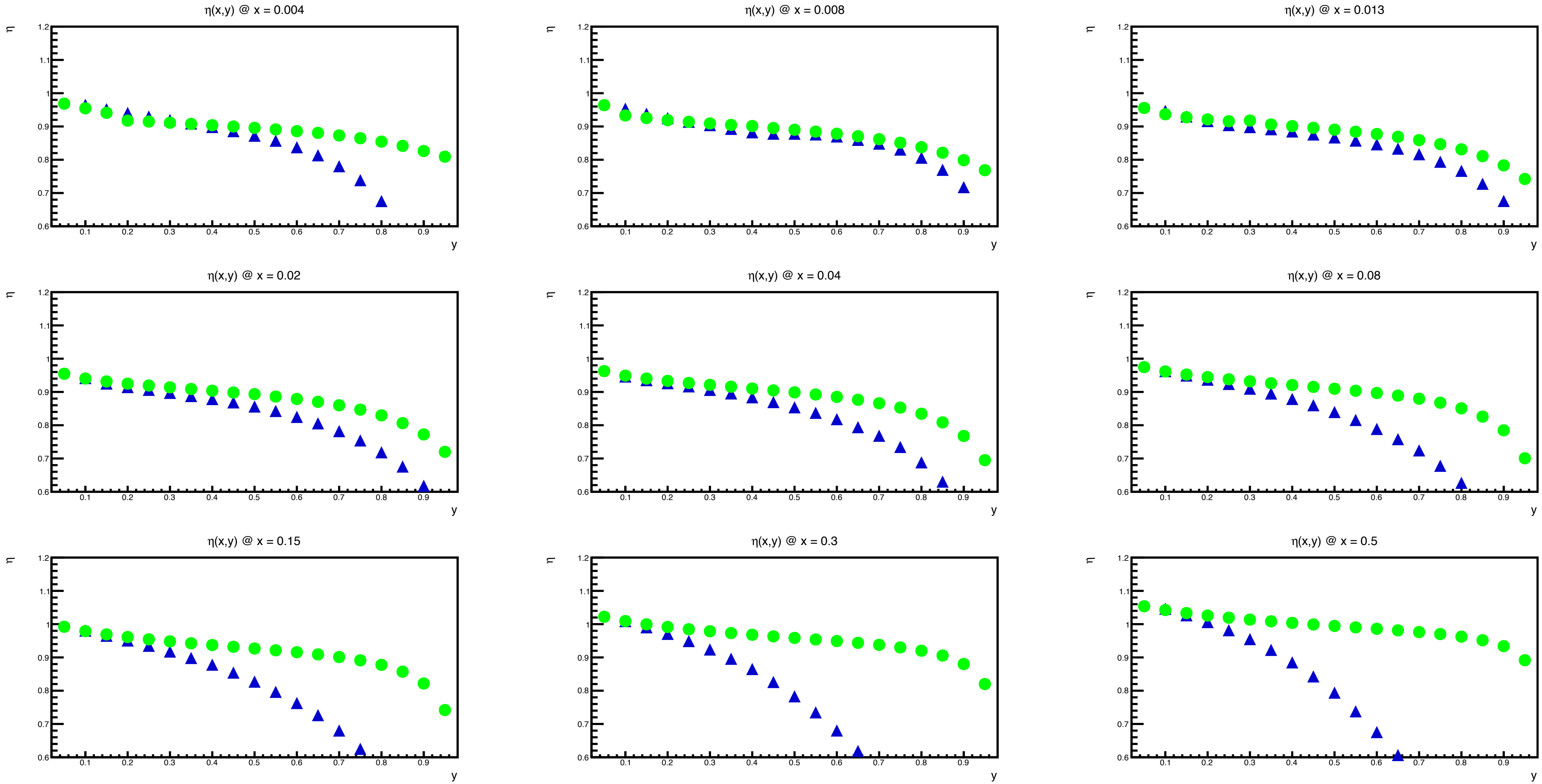
MSTW08

Inclusive radiative corrections for TERAD ● and DJANGOH ▲.



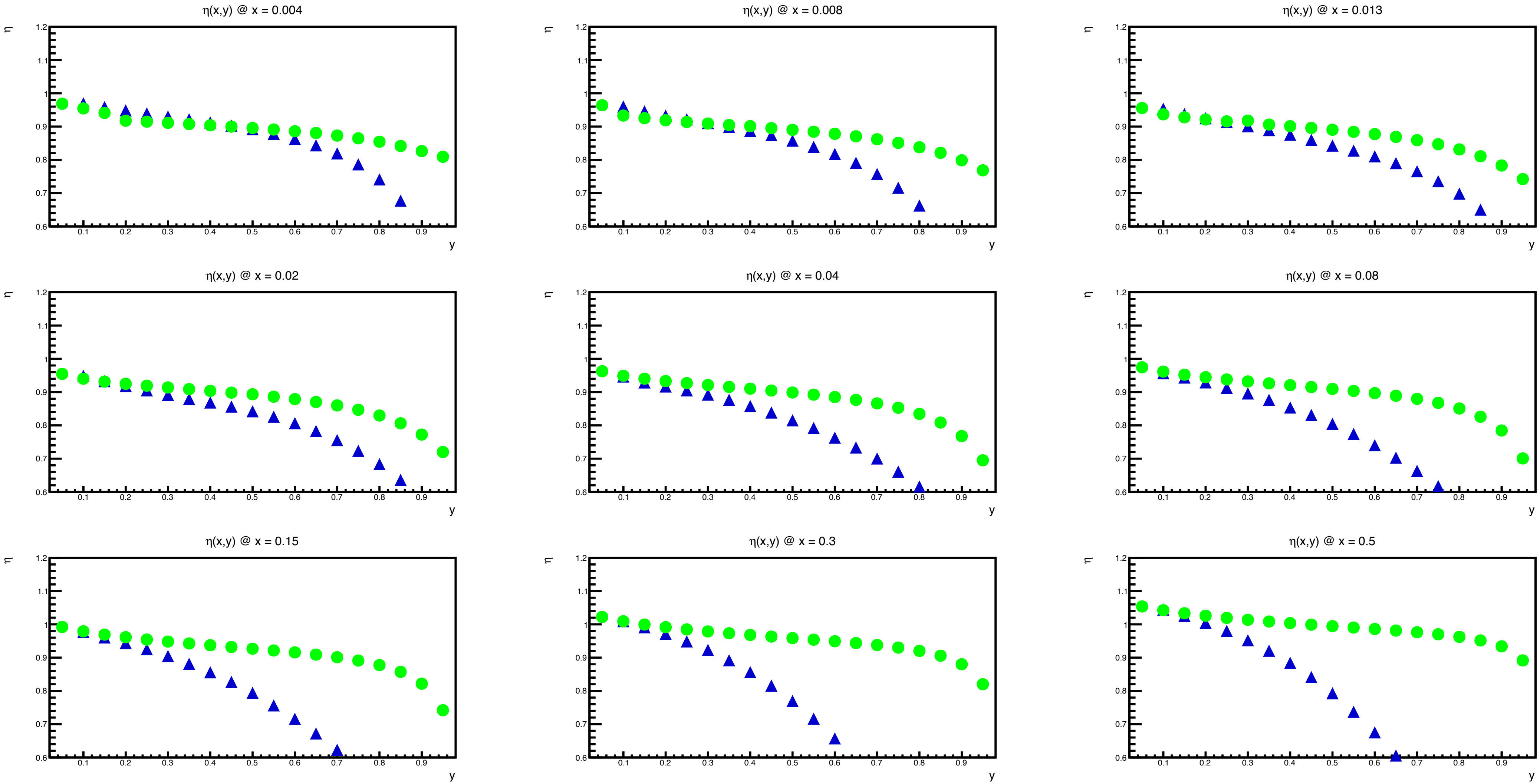
HERAPDF15

Inclusive radiative corrections for TERAD ● and DJANGOH ▲.



NNPDF21DIS

Inclusive radiative corrections for TERAD ● and DJANGOH ▲.



SEMI-INCLUSIVE CORRECTIONS

Semi-Inclusive radiative correction for DJANGOH.
Correction goes from +5% at low y to -10% at high p_T high y.
Strong impact in p_T, stronger than with z.