Phenomenology of Fundamental Interactions

Giancarlo Ferrera

(for the group: S. Forte, A. Vicini, G. Bozzi, E. Nocera, S. Carrazza, E. Mariani)

Università and INFN Milano

Consiglio di Sezione INFN – June 24th 2013

Outline

Overview

RT21

Project title: Phenomenology of Fundamental Interactions
National Organizer: Giuseppe Degrassi

Subgroups: Genova Milano Roma III
International collaborations: BNL, USA CERN, CH Ioffe Institute, St.Petersburg, RU ITP Karlsruhe, DE LAL, Orsay, FR LAPTH, Annecy, FR LPTHE, Paris, FR Moscow State University, Moscow, RU Niels Bohr Institute, DK PNPI, Gatchina, RU RTW, Aachen, DE State University of New York at Buffalo, USA TU Muenchen, DE University of Barcellona, ES University of Buenos Aires, RA University of Edinburgh, UK University of Freiburg, DE University of Granada, ES University of Grenoble, FR University of London, UK University of Manchester, UK University of Paris 11, FR University of Santiago de Compostela, ES University of Southampton, UK University of Strasbourg, FR University of Vienna, A

Milano

Name	Position	INFN Position	Time percentage
Giuseppe Bozzi	Assegnista	Associato	100
Stefano Carrazza	Dottorando	Associato	100
Giancarlo Ferrera	Ricercatore	Associato	100
Stefano Forte	Prof. Ordinario	Associato	100
Elisa Mariani	Dottorando	Associato	100
Emanuele Roberto Nocera	Dottorando	Associato	100
Alessandro Vicini	Ricercatore	Associato	100

Activity

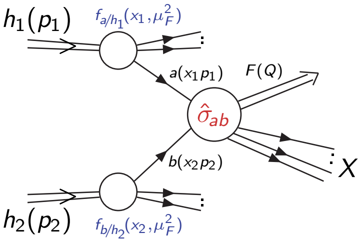
Milano:
The Milano group has been very actively involved in the analysis of the first LHC data, in particular through its direct involvement in the Higgs working group (of which Ferrera and Forte are working group convenors). On top of the contribution of Forte, Ferrera and Vicini as authors of the "Handbook of LHC cross-sections 2" (which has appeared as a CERN yellow report in 2012), both staff and students have given significant contributions to various topics related to collider physics. Worth mentioning are the contributions to the development of NNPDF parton sets (Forte, Carrazza), to soft-gluon resummation and its application to Higgs production (Ferrera, Forte), and to the development of dedicated Monte Carlo studies for LHC processes (Bozzi, Vicini). Work has alos been performed on polarized parton distributions (Forte, Nocera).

Publications (2012): 33 (12 from MI)
Talks (2012): 17 (14 from MI)
Thesis (2012): 6 (3 from MI)

Theoretical introduction (in one slide)

QCD Factorization

$$h_1(p_1) + h_2(p_2) \;\rightarrow\; F(Q) + X$$



The framework: QCD factorization formula

$$\sigma_{h_1 h_2}(p_1, p_2) = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2 \, f_{a/h_1}(x_1, \mu_F^2)\, f_{b/h_2}(x_2, \mu_F^2)\, \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2; \mu_F^2) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{Q}\right)^p$$

- $f_{a/h}(x, \mu_F^2)$: Non perturbative universal parton densities (PDFs), $\mu_F \sim Q$. Measured from experiments at a given scale μ_0 Evolution to μ_F calculable in pQCD through DGLAP equation.
- $\hat{\sigma}_{ab}$: Hard scattering cross section. Process dependent, calculable with a perturbative expansion i the strong coupling $\alpha_S(Q) \sim 1/(\beta_0 \ln Q^2/\Lambda_{QCD}^2) \sim 0.1$ (for $Q = m_H, m_W, m_Z, m_t, p_T^{jet}, \cdots$).

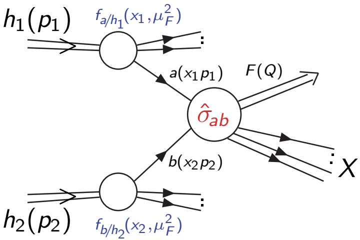
$$\hat{\sigma}_{ab} = \hat{\sigma}_{ab}^{(0)} + \alpha_S(\mu_R^2)\, \hat{\sigma}_{ab}^{(1)} + \alpha_S^2(\mu_R^2)\, \hat{\sigma}_{ab}^{(2)} + \mathcal{O}(\alpha_S^3)\,.$$

- $\left(\frac{\Lambda_{QCD}}{Q}\right)^p$ (with $p \leq 1$): Non perturbative power-corrections (higher-twist).

Precise predictions for σ depend on good knowledge of both $\hat{\sigma}_{ab}$ and $f_{a/h}(x, \mu_F^2)$

QCD Factorization

$$h_1(p_1) + h_2(p_2) \;\rightarrow\; F(Q) + X$$



The framework: QCD factorization formula

$$\sigma_{h_1 h_2}(p_1,p_2) = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2\, f_{a/h_1}(x_1,\mu_F^2)\, f_{b/h_2}(x_2,\mu_F^2)\, \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2; \mu_F^2) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{Q}\right)^p$$

- $f_{a/h}(x,\mu_F^2)$: Non perturbative universal parton densities (PDFs), $\mu_F \sim Q$. Measured from experiments at a given scale μ_0 Evolution to μ_F calculable in pQCD through DGLAP equation.
- $\hat{\sigma}_{ab}$: Hard scattering cross section. Process dependent, calculable with a perturbative expansion i the strong coupling $\alpha_S(Q) \sim 1/(\beta_0 \ln Q^2/\Lambda^2_{QCD}) \sim 0.1$ (for $Q = m_H, m_W, m_Z, m_t, p_T^{jet}, \cdots$).

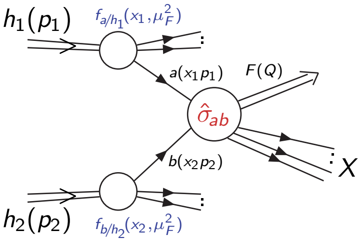
$$\hat{\sigma}_{ab} = \hat{\sigma}^{(0)}_{ab} + \alpha_S(\mu_R^2)\,\hat{\sigma}^{(1)}_{ab} + \alpha_S^2(\mu_R^2)\,\hat{\sigma}^{(2)}_{ab} + \mathcal{O}(\alpha_S^3)\,.$$

- $\left(\frac{\Lambda_{QCD}}{Q}\right)^p$ (with $p \leq 1$): Non perturbative power-corrections (higher-twist).

Precise predictions for σ depend on good knowledge of both $\hat{\sigma}_{ab}$ and $f_{a/h}(x,\mu_F^2)$

QCD Factorization

$$h_1(p_1) + h_2(p_2) \;\to\; F(Q) + X$$



The framework: QCD factorization formula

$$\sigma_{h_1 h_2}(p_1, p_2) = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2\, f_{a/h_1}(x_1, \mu_F^2)\, f_{b/h_2}(x_2, \mu_F^2)\, \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2; \mu_F^2) + \mathcal{O}\left(\frac{\Lambda_{QCD}}{Q}\right)^p$$

- $f_{a/h}(x, \mu_F^2)$: Non perturbative universal parton densities (PDFs), $\mu_F \sim Q$. Measured from experiments at a given scale μ_0 Evolution to μ_F calculable in pQCD through DGLAP equation.
- $\hat{\sigma}_{ab}$: Hard scattering cross section. Process dependent, calculable with a perturbative expansion i the strong coupling $\alpha_S(Q) \sim 1/(\beta_0 \ln Q^2/\Lambda_{QCD}^2) \sim 0.1$ (for $Q = m_H, m_W, m_Z, m_t, p_T^{jet}, \cdots$).

$$\hat{\sigma}_{ab} = \hat{\sigma}_{ab}^{(0)} + \alpha_S(\mu_R^2)\, \hat{\sigma}_{ab}^{(1)} + \alpha_S^2(\mu_R^2)\, \hat{\sigma}_{ab}^{(2)} + \mathcal{O}(\alpha_S^3)\,.$$

- $\left(\frac{\Lambda_{QCD}}{Q}\right)^p$ (with $p \leq 1$): Non perturbative power-corrections (higher-twist).

Precise predictions for σ depend on good knowledge of both $\hat{\sigma}_{ab}$ and $f_{a/h}(x, \mu_F^2)$

Parton Distribution Functions (Carrazza, Forte, Nocera)

Inclusion of open-charm and $W^{\pm}$ production data in a polarized PDF extraction via Bayesian reweighting

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects

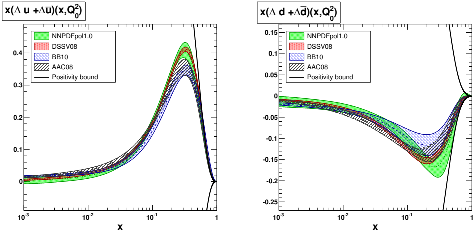
Emanuele R. Nocera
in collaboration with R.D. Ball, S. Forte, A. Guffanti, G. Ridolfi and J. Rojo

Università degli studi di Milano & INFN, sezione di Milano

Parc Chanot Marseille - April, 23 2013

NNPDF

The NNPDFpol1.0 parton set at $Q_0^2 = 1$ GeV^2



DSSV08
[arXiv:0904.3821]
DIS+SIDIS+pp (π^0/jet)

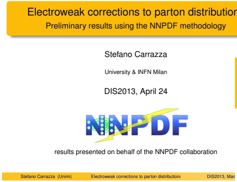
BB10
[arXiv:1005.3113]
DIS only

AAC08
[arXiv:0808.0413]
DIS+pp (π^0)

$\Delta u + \Delta\bar{u}$ and $\Delta d + \Delta\bar{d}$

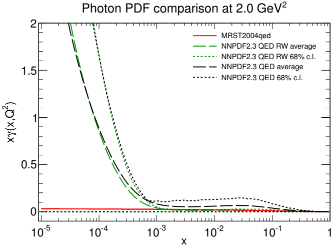
- Central values in reasonable agreement with those of other parton sets (best with DSSV08, slightly worse with AAC08, worst with BB10)
- Uncertainties slightly larger for NNPDF than for other sets, especially DSSV08 (notice that DSSV08 fit is based on a much wider dataset)
- Where no data or theoretical constraints are available, uncertainties are larger (flexibility of the Neural Network)

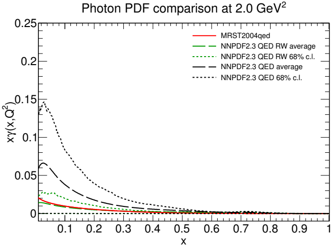
Parton Distribution Functions (Carrazza, Forte, Nocera)



Final photon PDF (preliminary)

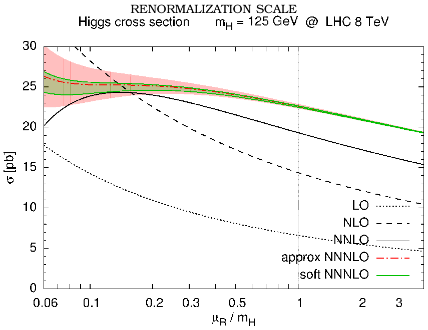
- Final unweighted photon PDF
  - constrained at **small** and **central/large-x**.
  - achieved good precision for **LHC predictions**.





Higher order QCD corrections (Bozzi,Forte, GF, Mariani)

THE N^{3}LO PREDICTION SCALE DEPENDENCE



- SCALE DEPENDENCE SIGNIFICANTLY FLATTENED BY N^{3}LO CORRECTION
- N-SOFT (RESUMMED RESULT) HAS SIMILARLY WEAK SCALE DEP. FOR HIGH SCALES, BUT STRONG SCALE DEP. FOR LOW SCALES
- PREVIOUS COLLINEAR IMPROVEMENTS (Catani, de Florian, Grazzini, Nason, 2003) INEFFECTIVE
- SMALL x TERMS STABILIZE SCALE DEP. @ VERY LOW $\mu_R \lesssim 0.2$

Higher order QCD corrections (Bozzi,Forte, GF, Mariani)

Single-Top in t-channel at NNLO

Elisa Mariani[a,b]

in collaboration with

Fabio Maltoni[a], Sven-Olaf Moch[c], Marco Zaro[a]

[a] Center for Cosmology, Particle Physics and Phenomenology (CP3), Université Catholique de Louvain
[b] Universitá degli Studi di Milano [c] Deutsches Elektronensynchrotron DESY

About t-channel...

In our analyses, we concentrate on t-channel...Why?

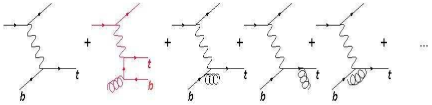
1. t-channel has the largest cross-section @LHC(Tevatron)!

$$\sigma^{t-ch}_{t(\bar{t})} > \sigma^{s-ch}_{t(\bar{t})}, \sigma^{tW}_{t(\bar{t})}$$

2. NLO QCD corrections are small ($\sim 5\%$), so $\sigma^{t-ch}_{t(\bar{t})}$ may become one of the most precisely predicted observables in Top Physics..

3. BSM: production of single top quarks by sizeable flavour-changing neutral currents, associated production of a top quark and charged Higgs boson in SUSY

$$\sigma^{t-ch}_{t(\bar{t})} =$$



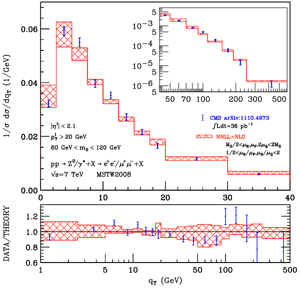
All order resummation (Bozzi,Forte, GF, Mariani)

QCD transverse-momentum resummation for Higgs and Vector Boson production at the LHC

Giancarlo Ferrera
giancarlo.ferrera@mi.infn.it
Università di Milano

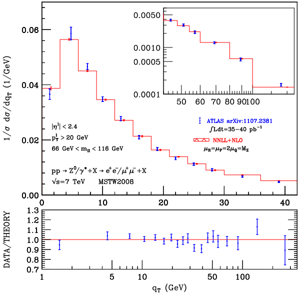
Napoli – March 28th 2013

DY q_T-resummation with V boson decay



CMS data for the Z q_T spectrum compared with NNLL+NLO result.
Scale variation:

$$1/2 \leq \{\mu_F/m_Z, \mu_R/m_Z, \mu_F/\mu_R, 2Q/m_Z, Q/\mu_R\} \leq 2$$



ATLAS data for the Z q_T spectrum compared with NNLL+NLO result.

QCD/EW corrections and Parton Shower studies (Vicini)

Università degli Studi di Milano

INFN Istituto Nazionale di Fisica Nucleare

Montecarlo programs for MW measurement

Alessandro Vicini
University of Milano, INFN Milano

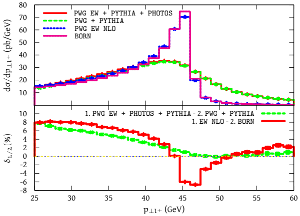
ATLAS workshop on MW measurement

June 13th 2013

Alessandro Vicini - University of Milano CERN, J

NC-DY: QCD+EW effects lepton transverse momentum

Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, arXiv:1302.4606



- the lepton transverse momentum is very sensitive to multiple gluon radiation
- the sharp peak due to EW corrections is reduced by the interplay with the QCD-Parton Shower; factorizable O(αα_s) corrections are at the level of 7%
- an additive prescription to combine QCD+EW effects instead preserves the peak

the fixed-order QCD description of the lepton transverse momentum distribution is poor, a resummation is needed

the combination of NLO-EW effects with multiple gluon emission strongly smears both the NLO-QCD fixed order spectrum and the peaked NLO-EW correction

Alessandro Vicini - University of Milano CERN, June 13th 2013

Theoretical uncertainties on M_W measure (Bozzi, Vicini)

PDF systematics in
M_W and $\sin\theta_W$ precision measurements

giuseppe bozzi
università degli studi di milano

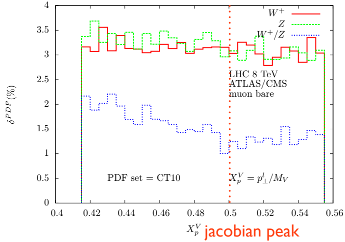
CERN, 17/04/2013

venerdì 21 giugno 13

PDF effect on M_W from lepton p_T

a (very!) preliminary study with DYqT shows that it is possible to partially reduce the PDF uncertainty (e.g. of the quark-gluon luminosity) by studying appropriate ratios of observables which should preserve the sensitivity to MW (in progress)

(Bozzi, Ferrera, Vicini: (very) preliminary!)



DYqT @ NLL+LO QCD accuracy

- W^+ (lepton p_T) distribution sensitive to M_W

- Z (lepton p_T) distribution weakly sensitive to M_W, but probes similar *x*-ranges

The LCM computing laboratory (Vicini)

What is behind the development of these tools

- the computing laboratory LCM (Laboratorio di Calcolo e Multimedia)
  where we have installed a high performance linux cluster
  17 nodes, 120 physical cores, 240 simultaneous processes
  5 GPU Tesla C-2070, 1 GPU Tesla C-1060, 10 GeForce GT440
  for a large fraction funded by INFN

- the intensive use of Mathematica as algebraic manipulation tool to prepare the analytical expressions

- since January 2012 we started a collaboration with NVIDIA (CUDA research and teaching center)
  to develop simulation codes running on GPU (graphics card)

Which skills are behind the development of these tools

- the ability to run long and very long (weeks) MC simulations, with stable, fast, reliable codes

- a good knowledge of Quantum Field Theory, at formal and at phenomenological level

- the ability to define new classes of mathematical functions and to study

Conclusions

- The Milan group of the "Phenomenology of Fundamental Interactions" Specific Initiative (ex RT21) is an active team ($\sim$ 12 papers in 2012) with young members (3 Ph.D. students out of 7 members).
- At present the research of the group is mainly focused on theoretical predictions for the LHC (interactions with ATLAS group of the INFN Milan).
- In this short review some phenomenological results on parton densities (PDFs), QCD/EW fixed-order and resummed perturbative calculations.