A toolset for parton densities

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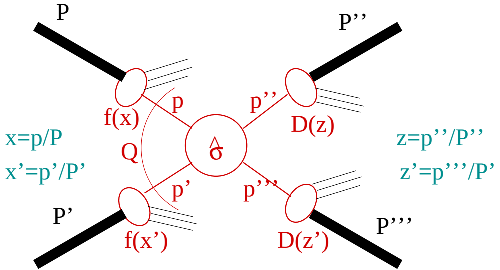
LHC08 Meet, TIFR Mumbai

March 26, 2008

Factorization (1)

Semi-inclusive process $H + H' \to H'' + H'''$+anything with single large scale ($P \sim P' \sim P'' \sim P''''$) computed in perturbative QCD through a factorization formula.



$$d\sigma = f_{p|H}(x, Q^2) f_{p'|H'}(x', Q^2) \otimes d\hat{\sigma} \otimes \mathcal{D}_{H''|p''}(z, Q^2) \mathcal{D}_{H'''|p'''}(z', Q^2)$$

If factorization holds then f and $\mathcal{D}$ are universal.

Factorization (2)

$$d\sigma = f_{p|H}(x,\mu^2) f_{p'|H'}(x',\mu^2) \otimes d\hat{\sigma} \otimes \mathcal{D}_{H''|p''}(z,Q^2)\mathcal{D}_{H'''|p'''}(z',Q^2)$$

Parton distribution functions	$f_{p\|H}$
Hard scattering cross section	$d\hat{\sigma}$
Fragmentation functions	$\mathcal{D}_{H\|p}$
Factorization scale	μ^2
Renormalization scale (virtuality)	Q^2
Delta functions and phase space integrals	$\otimes$

Formulation also applicable for less inclusive processes $H + H' \to H''$+anything and $H + H' \to$ *jets* or $H + H' \to$leptons+anything, $e^+ + e^- \to H$+anything, *etc.*.

Universality

When factorization holds then parton densities and fragmentation functions are **universal**. All experiments with fixed initial H from which parton p is extracted give information on the same $f_{p|H}(x,\mu^2)$.

Since universality holds, **global analysis** of all factorisable cross sections can be performed to extract a best fit value for $f_{p|H}(x,\mu^2)$. Similar analysis also possible for $\mathcal{D}_{H|p}(z,\mu^2)$.

When reliable results for $f_{p|H}(x,\mu^2)$ and $\mathcal{D}_{H|p}(z,\mu^2)$ are available, reliable **predictions** for unmeasured processes can be made.

New measurements can be eventually incorporated into the parton density fits.

Universality in QED

The Lagrangian of QED depends on two bare parameters, the bare mass of the electron and the bare coupling of the electron

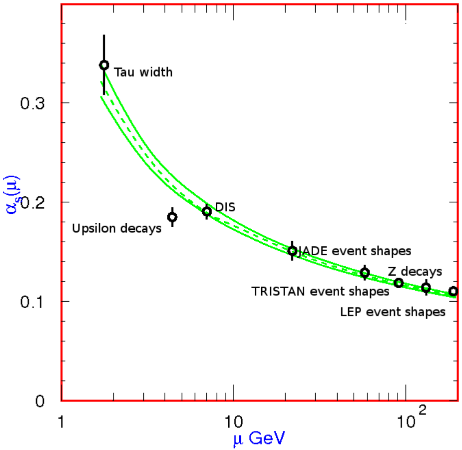
$$\mathcal{L}_{QED}(m_b, g_b).$$

All predictions of QED depend on these two bare parameters and the renormalization scale of the process computed μ_R.

The bare parameters are eliminated in favour of renormalized parameters m and g, which are defined through appropriate low measurements. This is called renormalization and its analogue in QED includes the notion of factorization.

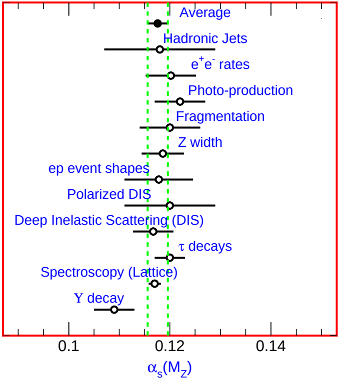
One makes a "global fit" of measurements from precision experiments in QED to extract the values of m and g. The predictability of QED consists of being able to use the same m and g for all experiments: universality.

Running of α_s



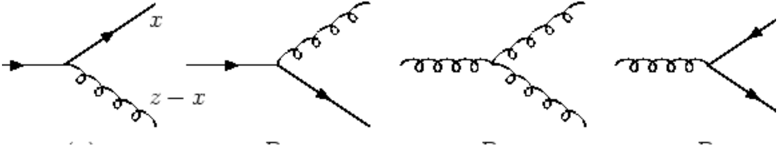
Scale invariance is broken in QCD, resulting in scale $\Lambda_{\overline{MS}}$, and giving rise to running of α_s.

Determination of $\Lambda_{\overline{MS}}$



Precision measurement of $\alpha_S(M_z)$ is one of the strongest constraints on $\Lambda_{\overline{MS}}$.

Evolution equations

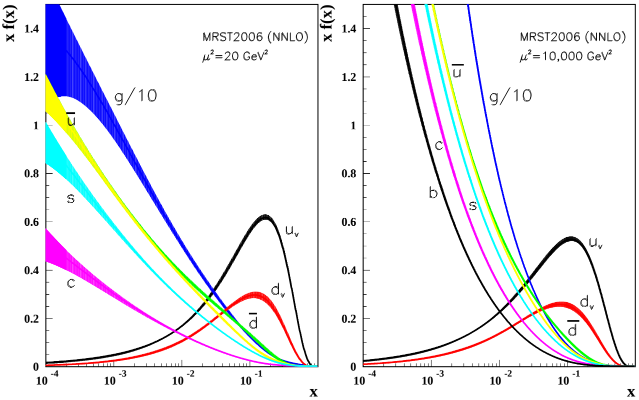


With increasing scale one resolves partons inside partons. At LO, quarks and gluons can mix. Beyond LO quark flavours can mix. The leading-log resummation gives

$$\frac{df_i(x,t)}{dt} = \frac{\alpha_S(t)}{2\pi}\int_x^1 \frac{dz/z}{} P_{ij}(z) f_j\left(\frac{x}{z}\right), \qquad t = \log\left(\frac{Q^2}{\Lambda^2_{\overline{MS}}}\right).$$

Parton densities must soften as scale is increased.

Evolved densities



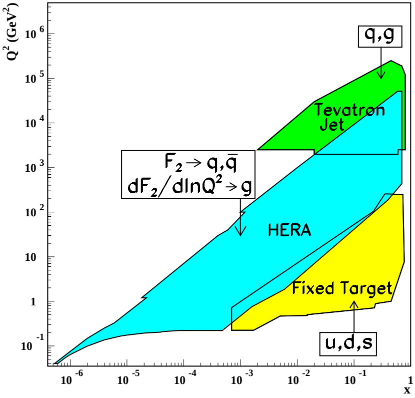
Small-x resummations

When $x \ll 1$, *i.e.*, there are multiple scales in the problem, then one must also resum powers of $\alpha_S(Q^2)\log(1/x)$. In hard processes where $\alpha_S(t) \simeq 0.15$, such resummations become necessary for $x \simeq 0.001$.

At LHC energies, small-x resummations needed whenever particles are produced with mass $M \simeq 10$ GeV. Small-x resummation required for J/ψ and Υ production, and for mass dileptons, but not for W, Z, *etc.*.

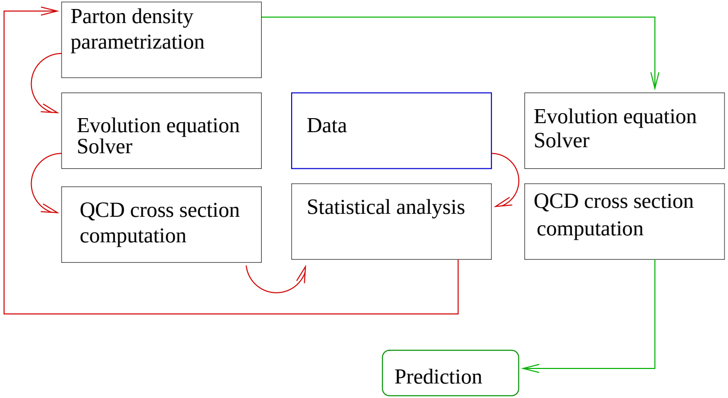
Typical processes of interest in LHC pp do not required small-x resummation, but LHC AA physics does. Colour glass condensation and other such phenomena are of interest in AA physics.

What from where



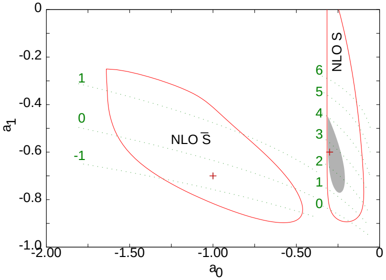
Jets	$q,\ g$
DIS	$q,\ g$
Drell-Yan	$\bar{q}$
Direct photons	g

Fitting procedure



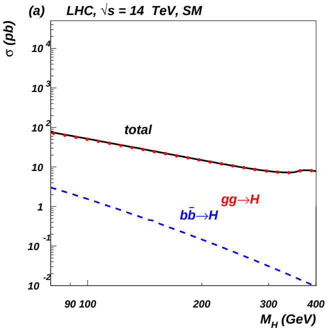
Iterative fitting of parton density parametrizations to experimental data yields a best fit pdf set which is used to give predictions for new experiments.

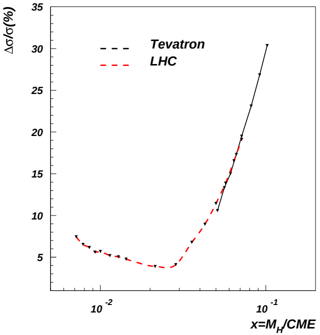
Uncertainties in the fit



Errors in data propagate to errors in fitted parameters. Example: polarized gluon density $\widetilde{g}(x, Q_0^2) = a_0 x^{a_1}(1-x)^{a_2}(1+a_3 x)$ with a_2 and a_3 fixed at the best-fit value. Two different sets give disjoint best-fit and 1σ errors. Grey: fake data, generated with NLO S set, added 10% random noise, errors of 20-30% and refit. Shows effect of improvement in statistics for $g_1(x)$ with $x < 0.1$ and HERA acceptance. Ghosh, SG, Indumathi, Phys.Rev.D62:094012,2000 [hep-ph/0001287]

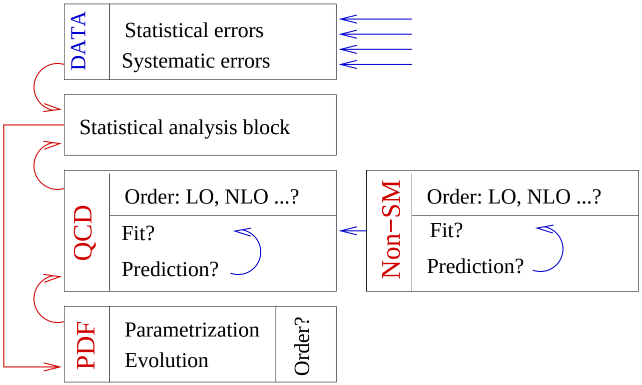
Uncertainties in predictions





Uncertainties in pdfs translate to uncertainties in predictions. The uncertainty in SM Higgs production rate at the LHC is under control. The main uncertainty is from the pdfs. Belyaev, Pumplin, Tung, Yuan, JHEP 0601:069,2006 [hep-ph/0508222]

A scheme


DATA
Statistical errors
Systematic errors
Statistical analysis block
QCD
Order: LO, NLO ...?
Fit?
Prediction?
Non−SM
Order: LO, NLO ...?
Fit?
Prediction?
PDF
Parametrization
Evolution
Order?

Expected behaviour of blocks

DATA block comes with treatment of statistical and systematic errors. Need to define objects called experimental data sets with private methods for treatment of errors. Flexibility is required for adding (and removing) data sets.

QCD block contains SM processes which have as input pdfs and give as outputs cross sections. Each process can be overloaded by order: LO, NLO, and beyond. Also, each contains parameters which control the scale choice. Flexibility is provided by common interfaces which allows processes to be moved between fitted set and predicted set. Re-usability is the main requirement.

Non-SM block is conceptually the same as the QCD block.

STAT block contains methods for treatment of best-fit and errors. Many methods proposed in the last few years for statistical treatment. Urgent need to systematize interface. Re-usability is the main requirement.

PDF block contains standardized definitions of parton densities and their evolution. May be overloaded: x-space and Mellin-moment evolution.

Project definition

- The project is **not** a new pdf fitting scheme.
- It is an attempt to define interfaces to allow inter-operability of programs.
- The main attempt will be to provide standards for data exchange between hadron collider physics programs, probably instantiated as C++ wrappers.
- First (simplest) step of the project: survey available QCD cross sections in order to systematize the **QCD** and **PDF** blocks.
- People involved at present: A. K. Datta, M. Guchait, SG, D. Indumathi, M. C. Kumar, G. Majumder, P. Mathews, V. Ravindran, A. Tripathy, N. Tripathy. Effort on since January.
- Need maximum flexibility for wide acceptance of such a toolbase. A large user forum for discussion of standards would help.

Summary

- In a hadron collider, any computation of inclusive cross section needs pdfs as input. Factorization implies that the pdfs are universal. This leads to a possibility of global analysis of cross sections, and continual improvements in the pdfs as the collider runs.
- Uncertainties in cross sections reflect statistical and systematic uncertainties of experiments, as well as theoretical uncertainties such as computations to finite order (or partial resummations) along with associated problems such as scale uncertainties.
- It is possible (and desirable) to define common interfaces between programs for computations of cross sections which use the factorization formula. A scheme for doing this was outlined.