Updates to HVQMNR module

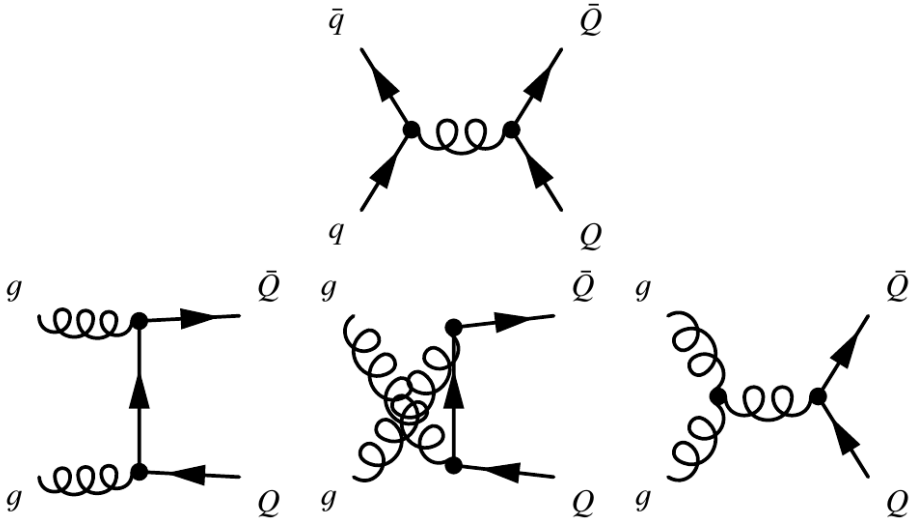
Oleksandr Zenaiev

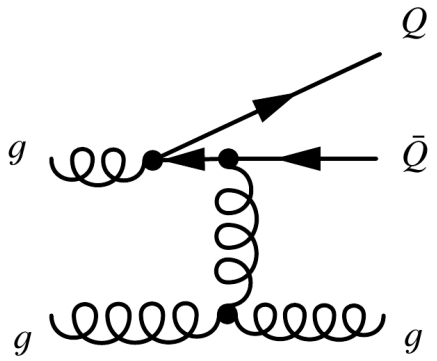
xFitter meeting, Oxford
10.03.2015

Overview

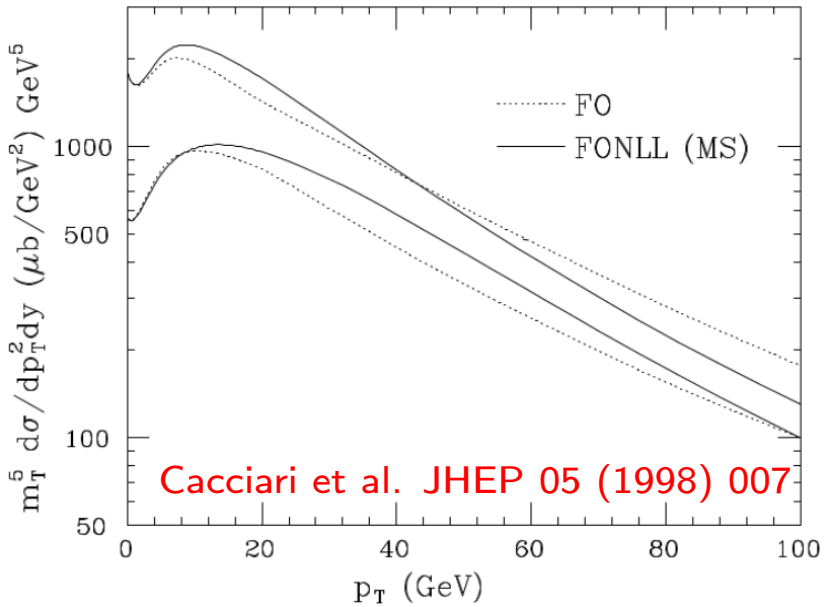
- MNR calculations and their usage
  - PROSA studies of low x gluons and applications for athmospheric neutrino flux calculaions
- Implementation of MNR in xFitter [HERAFitter-1.2.0]: called 'HVQMNR' there
- Re-implementation using theory interface [xFitter-2.?.?]
- Overview of possible future applications

Fully differential massive $O(\alpha_s^3)$ calculaions for HQ production in hadron collisions
M. Mangano, P. Nason, G. Ridolfi Nucl. Phys. B373 (1992) 295





+ other NLO corrections

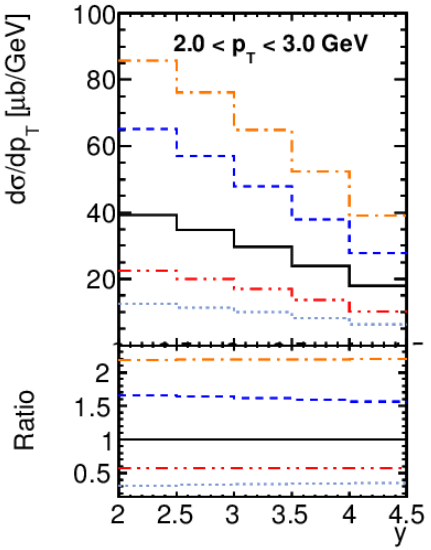


- at high p_T can be matched with ZM calculaions: FONLL and other GM-VFNS variants
- equivalent to FONLL at low p_T
- recent NNLO by Mitov et al. not yet available for c, b

  $\Rightarrow$ MNR remain one of the most reliable at low p_T up-to-date

PROSA Coll., arXiv:1503.04581 **"Impact of heavy-flavour production cross sections measured by the LHCb experiment on parton distribution functions at low x"**

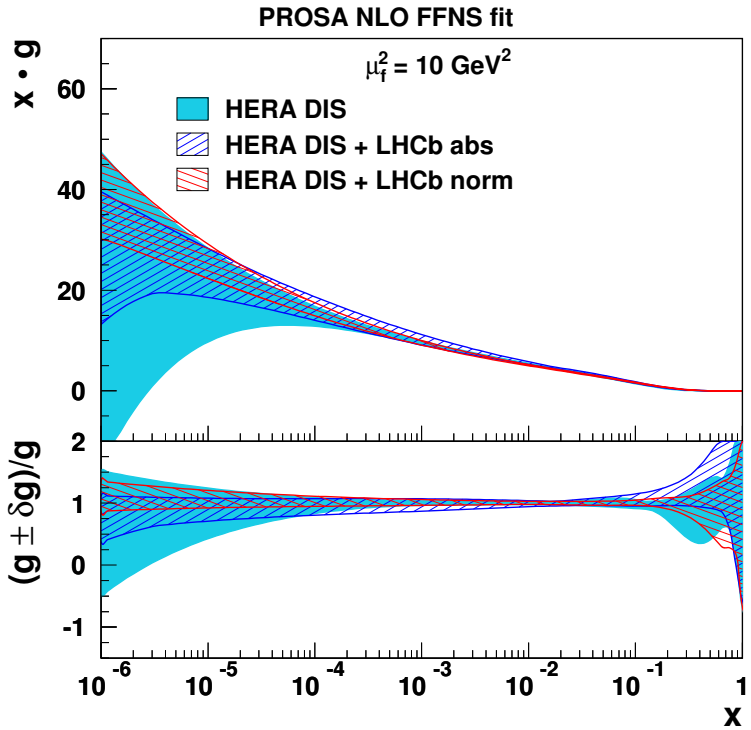
- LHCb measured:
  - charm $0 < p_T < 8$ GeV, $2 < y < 2.5$ [NPB871 (2013) 1]
  - beauty $0 < p_T < 40$ GeV, $2 < y < 2.5$ [JHEP 1308 (2013) 117]
- **PROSA (Proton Structure Analyses in Hadronic Collisions):** QCD analysis of these data
- *Crucial* reduction of NLO theory uncertainty for y shape
- Improved gluon and sea-quark distributions up to $x \gtrsim 5 \times 10^{-6}$

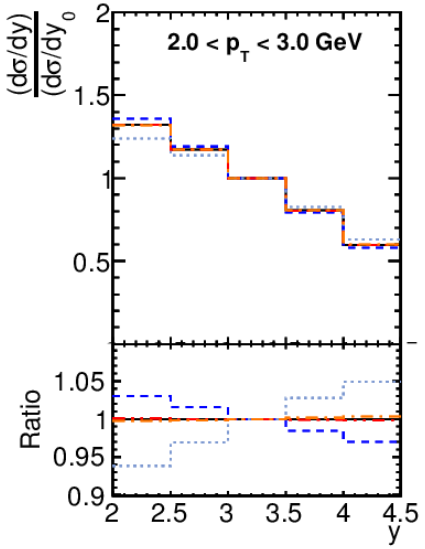


PROSA,
EPJ C75 (2015) 396

https://prosa.desy.de

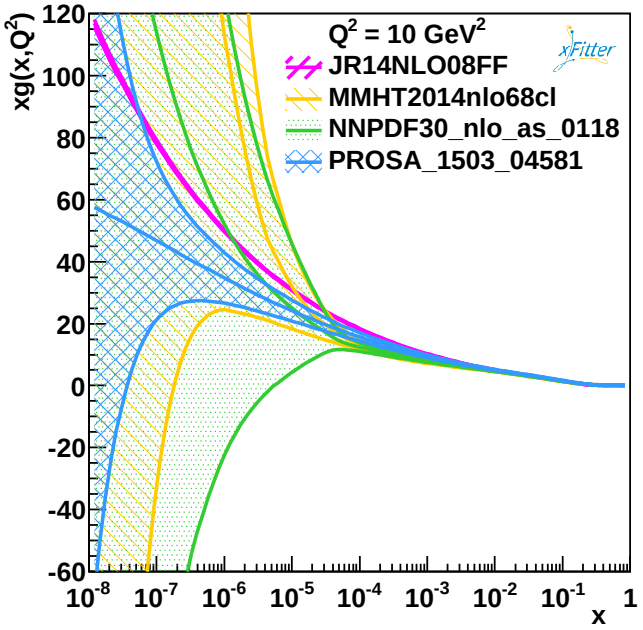
Similar studies by R. Gauld et al. 1506.08025, 1610.09373

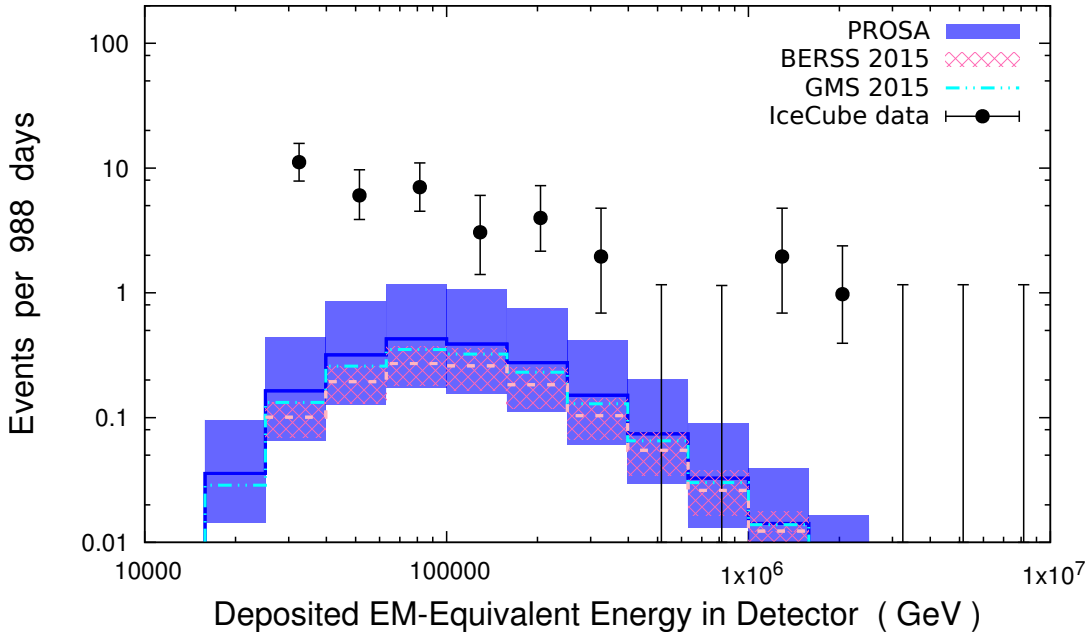




Garzelli et al., arXiv:1611.03815 **"Prompt neutrino fluxes in the atmosphere with PROSA parton distribution functions"**

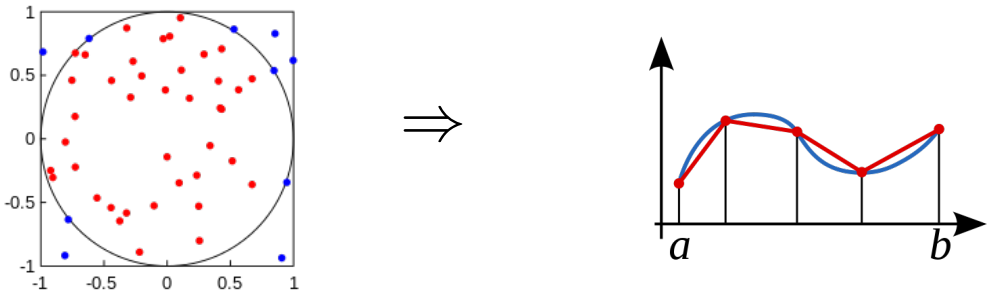
- First demonstration how HQ forward hadro-production data can contsrain low-x gluon
  $\Rightarrow$ message for global PDF analyses
- Application: predictions for prompt atmosphere ν fluxes
  $\Rightarrow$ background for very high energy cosmic ν





PROSA, arXiv:1611.03815

Strategy of MNR calculations implementation in xFitter (HERAFitter)



- PDF fit typically requires several thousands of iterations to converge
- MNR calculations (one-particle inclusive variant) as implemented originally in the FORTRAN code by the authors require about several hours to calculate one set of predictions for one of considered LHCb datasets
- Possible workarounds:
  - "fast" techniques (K-factors): do not allow changing parameters of calculations (scales, masses, fragmentation)
  - **"smart" implementation of MNR calculations: MC intregration ⇒ nested loops with separation of the most time consuming parts in the top loop(s)**
    ⇒ available since HERAFitter 1.2.0

Details of MNR calculations implementation in xFitter

- only single-particle inclusive variant is implemented
- 3 loops for LO (p_T, y, y') + 1 more for real NLO corrections (t_3) $\Rightarrow$ parton-level cross sections $\sigma(p_T, y)$
- 1 loop for each point to apply fragmentation (z), if needed $\Rightarrow$ hadron-level cross sections $\sigma_H(p_T, y)$
- some coefficients in calculations are computed one time and stored (approach is similar to "fast" techniques)
- number of iterations in integration loops have been adjusted for this particular datasets; another phase space and/or binning will need their readjustment
- scales μ_r, μ_f are parametrised as $\mu^2 = Ap_T^2 + Bm_Q^2 + C$ (in principle, *any* parametrisation is possible: just modify the routine)
- heavy-quark masses m_Q can be treated as free parameters
- fragmentation function: Kartvelishvili or Peterson with (possibly) fitted parameter + special treatment for D^0, D^+ which partially originate from D^{*+}, D^{*0} as described in [JHEP09 (2003) 006]
- **timing: $\sim$1s** (charm LHCb dataset, Intel Core i7-3520M)
- **memory usage: 10 MB**
- **inaccuracy: <1%** (can be improves further at the price of CPU/memory usage)

Code-level details

- **Reaction:** 'pp <meson> <variable>'
- **Requires HF_SCHEME = 'FF' or 'FF ABM'**
- **MNR calculations** implemented in files located in separate directory (include original MNR FORTRAN routines)
- **ExtraMinimisationParameters:** scales, masses, fragmentation parameters
- **Option:** constrain ExtraMinimisationParameters (gaussian priors): ConstrVal and ConstrUnc
- **Data files:** 1302.2864, 1306.3663
- **Option for configure '–enable-hvqmnr':** enable/disable this stuff
- **see more** `HVQMNR/README`

Usage of MNR calculaions

To make calculaions for new datasets

- look at the code, modify bin boundaries and/or phase space;
- **adjust number of iterarions in loops to reach needed precision** (likely will require to run original MNR code; or compare with some other sources)
- provide new data files, reaction etc.
- cross check results using:
  - "original" MNR (e.g. `https://www.ge.infn.it/~ridolfi/`)
  - MCFM (`https://mcfm.fnal.gov/`)
  - FONLL, NLO only option available (`http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html`)

Re-implementation using theory interface

New theory interface:

- 'C++ interface' for theoretical calculations in xFitter
- Calculation of each process is realised via singleton class: separate dynamic library, loaded only if required
- Well defined possibility to do something at initilisation, at χ^2 iteration and at calculaion for particular data set: perfectly fits needs of MNR calculaions
- *access to theory parameters (m_c, ...) still to be improved*

MNR calculations are implemented as one base class and two derived classes for charm and beauty

Available in 'theory-interface' branch:
`https://gitlab.cern.ch/fitters/xfitter/tree/theory-interface`
(modified steering files provided in `input_steering/*hvqmnr*_TI`, modified data files available on request)

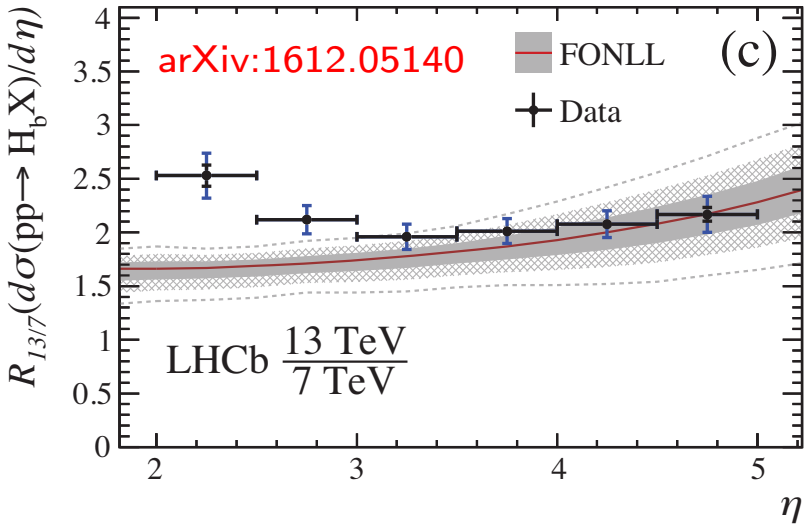
Overview of possible future applications

- Update on low x gluon determination using recent LHCb measurements (charm at 5, 7 and 13 TeV, beauty at 7 and 13 TeV)

  $\Rightarrow$ implementation for corresponding predictions is straightforward

  $\Rightarrow$ this topic becomes interesting, since recent LHCb 13/7 beauty measurement reveal tension with theory [1612.05140]

- Relation to ongoing activities of `TOP++`, `HATHOR`, ...: validate the total cross secion at NLO



Summary

- MNR calculations (single-particle inclusive variant) are available in xFitter for a while
- Predictions for LHCb open charm and beauty data at 7 TeV available out of the box
- Extension to other similar data is straightforward
- Can be used to validate other calculations of the total HQ cross sections at NLO
- Recently these calculaions were re-implemented using new theory interface, will be available in next(?) xFitter release