QCD at the Forward Physics Facility @ CERN

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The Forward Physics Facility @ CERN

* Exploit beams of particles produced in the interactions points at the LHC, propagating in the direction tangent to the beam line.

* Let the beam propagating for some distance, until they interact with the material of one or more detectors.

Questions:

- at which angle positioning the detector(s) ? ($6 \lesssim \eta \lesssim 10$)
- how far from the IP ? ($\sim$ 500 m near ATLAS IP or less near CMS IP)
- which detection technology and materials ?
- besides exploiting *pp* HL-LHC runs, shall one consider *pA* and *AA* runs ?

$\Rightarrow$ The answers partly depend on the physics one wants to explore, partly on the morphology of the experimental environment.

Experience built on top of experiments active during Run-3 will help (Faser-ν, FASER....).

Characterizing the beam

* At distance far enough from the interaction point, after optical elements, the beam is composed by neutrinos and muons.

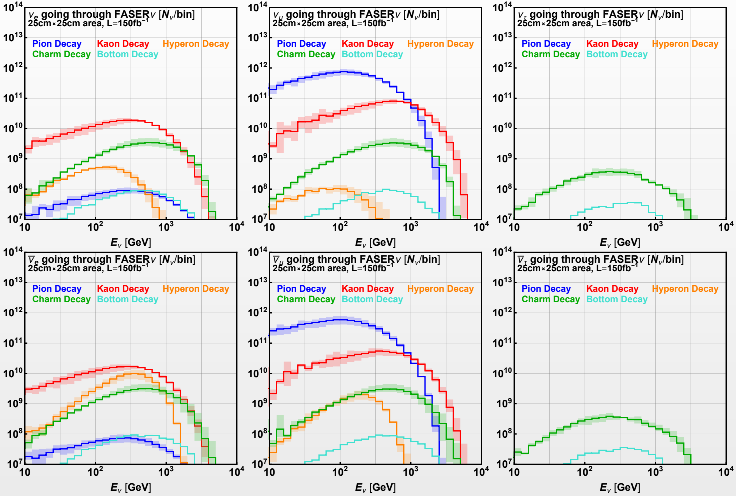
* Neutrinos come mainly from the decays of various mesons and baryons (light-flavoured and heavy-flavoured) produced at the IP.

* How to characterize the beam ?

⇒ Predictions for
the energy and angular spectra of the ν_e, ν_μ, ν_τ components,
accompanied by uncertatinties of perturbative and non-perturbative nature.

A-posteriori complication:
ν could oscillate and disappear during propagation!

Examples of MC predictions of forward ($\nu+\bar{\nu}$) fluxes



Estimated number of neutrinos impinging on the transverse area of the FASER-ν detector.

Uncertainty band: envelope of the central predictions of different MC.

How to estimate a more reliable uncertainty band ?

Non-perturbative effects potentially affecting predictions for ν beams at the FPF

* Modelling of PDFs (at various stages of the simulation)
* Modelling of MPI (partly perturbative)
* Modelling of hadronization (including color reconnection effects)
* Heavy-quark treatment/mass values/interpretation
* Factorization framework
* Modelling of diffraction

$\Rightarrow$ Models and tunes implemented in MC event generators
$+$ non-perturbative parameters in the hard-scattering

Long-standing issue: difficulties to simultaneously reproduce the experimental charged particle multiplicities (and other observables) at small and large pseudorapidities.

Parton Distribution Functions

$*$ Forward ν production in pp collisions implies sensitivity to PDFs in the regions $10^{-8} \lesssim x \lesssim 10^{-5}$ and $10^{-1} \lesssim x \lesssim 1$

$*$ These are the regions where present PDF fits are less constrained!

$*$ Partly constrained by LHCb heavy-flavour production data ($2 < y < 4.5$), but PDFs still extrapolated to the more extreme x values.

Questions:

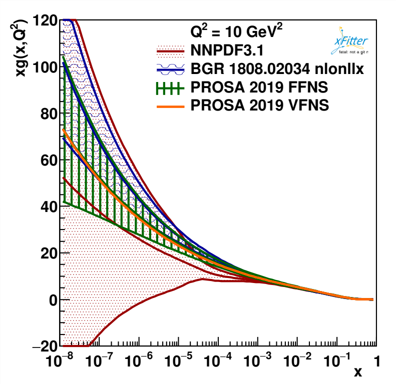
$*$ Is the DGLAP formalism in collinear factorization appropriate enough to describe proton content at low x, low Q^2 ?

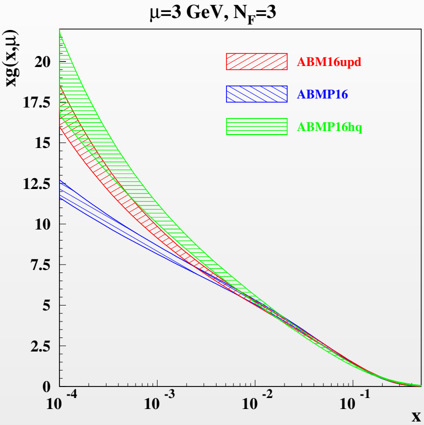
$*$ How to model higher-twist effects ?

$*$ Do we need to switch to more general factorization and evolution frameworks including gluon saturation ?

$\Rightarrow$ Partial overlap with x regions explorable at EIC (large x) and LHeC (small x).

Recent results on gluon PDFs





* Comparison between NLO PDF fits incorporating or not LHCb open heavy flavour data (left).
* Effects of cuts of inclusive DIS data on the ABMP gluon distribution (right).

Multiple Partonic Interactions

* Interactions at lower x with respect to the hard-scattering. Tame the divergences in perturbative $2 \rightarrow 2$ scatterings.
* Dual Parton Scattering often modelled with pocket formulas using σ_{eff} parameter.

Questions:

- How to go beyond the present treatment ?
- PDFs in MPI ?
- rescattering (and non-trivial color flows) in MPI ?
- how to implement color reconnection effects (many color strings overlapping in physical space) ?

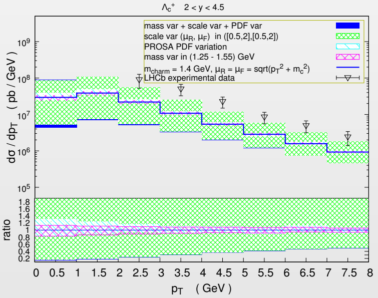
Hadronization

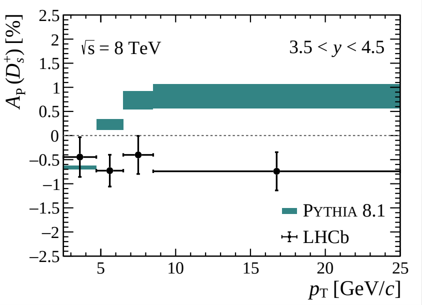
∗ String and cluster hadronization mechanisms available in Monte Carlo event generators.

∗ Color connections and reconnection effects.

∗ Questions:
up to which extent is it meaningful to apply the results of fits of e^+e^- data to *pp* collisions (gluon jets/initial state hadrons) ?

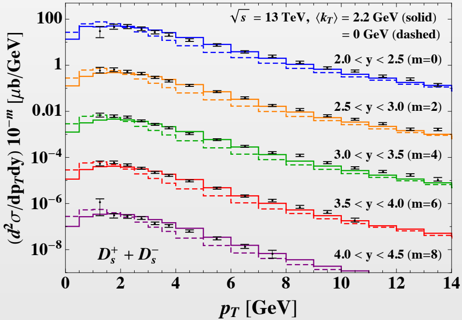
⇒ Asymmetries in forward production of mesons with opposite charge may give hints on beam remnant effects in the hadronization mechanisms.





Primordial k_T

- Introduced in MC generators in collinear factorization, to account for Fermi motion of partons confined in the proton.
- Average $\langle k_T \rangle$ value tuned to experimental data (Drell-Yan production at low p_T).
- The result may depend on the perturbative accuracy of the simulation: a large intrinsic $\langle k_T \rangle$ can mimic missing higher-order perturbative effects!



Question:

Is it enough to improve the accuracy of the computation in the collinear factorization framework (e.g. NNLO, better PDFs/FFs, etc...), or shall we go beyond collinear factorization ?

Conclusions

$*$ Characterizing and quantifying the non-perturbative uncertainties affecting forward ν beams is crucial to be able to use these beams for further SM and BSM studies (e.g. ν oscillations and nuclear PDF extraction from ν-induced DIS in the detector).

$*$ Measuring/inferring the beam composition at different angles and energies will allow for a better understanding of non-perturbative mechanisms.

$*$ Open issue:

how to distinguish the relative role of different non-perturbative mechanisms ?

Modifying one element can compensate for the effect of other missing ones!

$\Rightarrow$ Importance of the sinergy between different experiments.

Next discussion opportunities on the FPF

* Talks in the Snowmass CPM-meeting session #138
  "Synergy of Astroparticle and Collider Physics" tomorrow.

* FPF Kickoff Meeting, via zoom on November 9-10, 2020:

  https://indico.cern.ch/event/955956/overview

  - Registrations open.
  - Snowmass inter-frontier participation:
    SM/BSM/astroparticle and collider phenomenologists
  - Call for abstracts from these communities open until October, 25th.

  ⇒ Discussions and work in preparation of the Snowmass report
  and a practical proposal for the facility.

Thank you for your attention!