QCD activities: overview

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4th FPF meeting, 1 Feb 2022

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Overview

- Prospects for QCD studies are very promising, and a wide range of contributions promised/provided for the white paper!

- White paper chapter will be organised in terms of key physics themes. Will present (brief) summary here. Some detailed talks to follow.
- Many thanks to all the contributors to this white paper and previous meetings. Results + plots taken liberally from these.

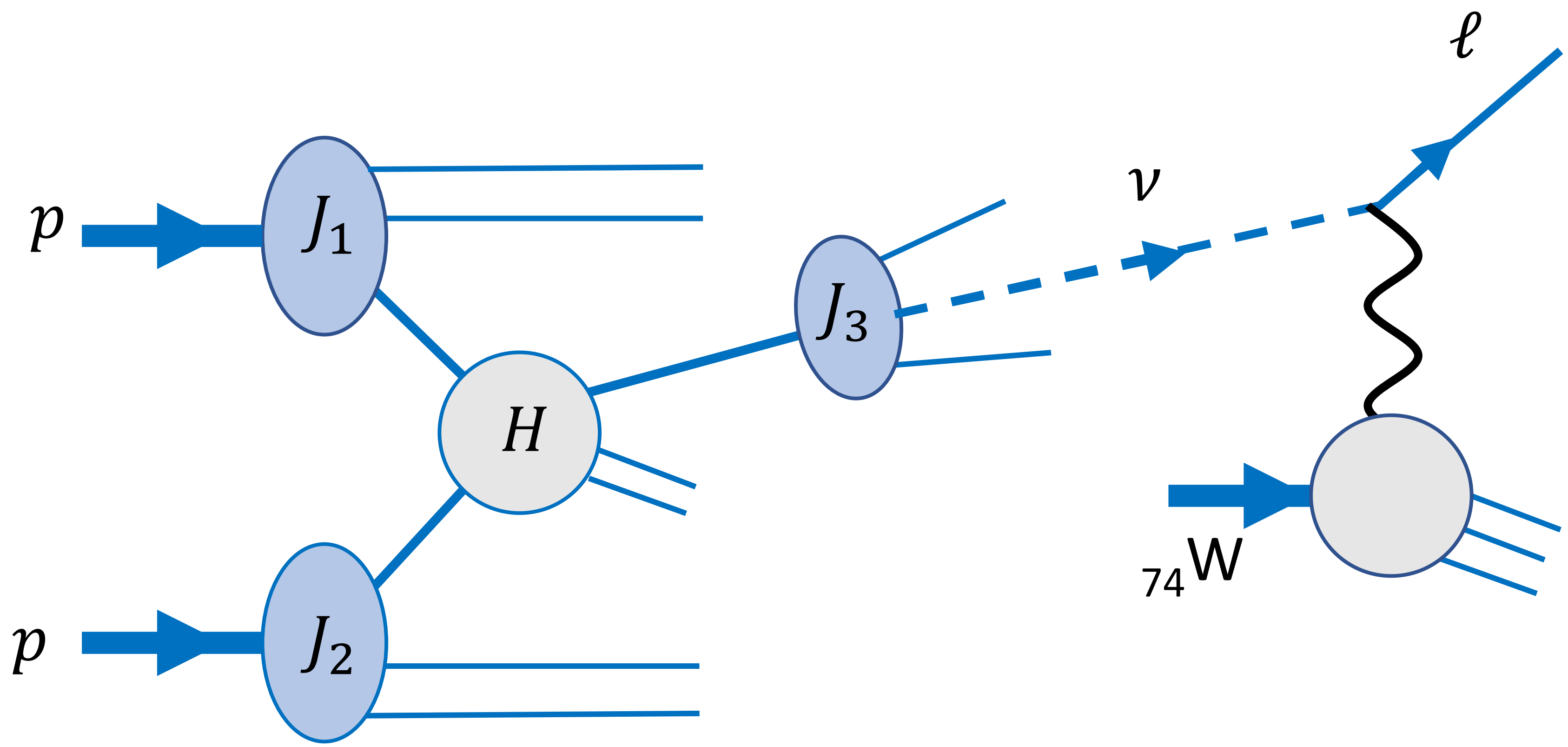
QCD@FPF

- Wide range of QCD studies relating to:

★ **Forward particle production** mechanisms in the central detector.

and/or

★ **Neutrino induced DIS** scattering at FPF.



- Both aspects can provide new understanding of QCD physics, complementary to ongoing LHC (…) programme.

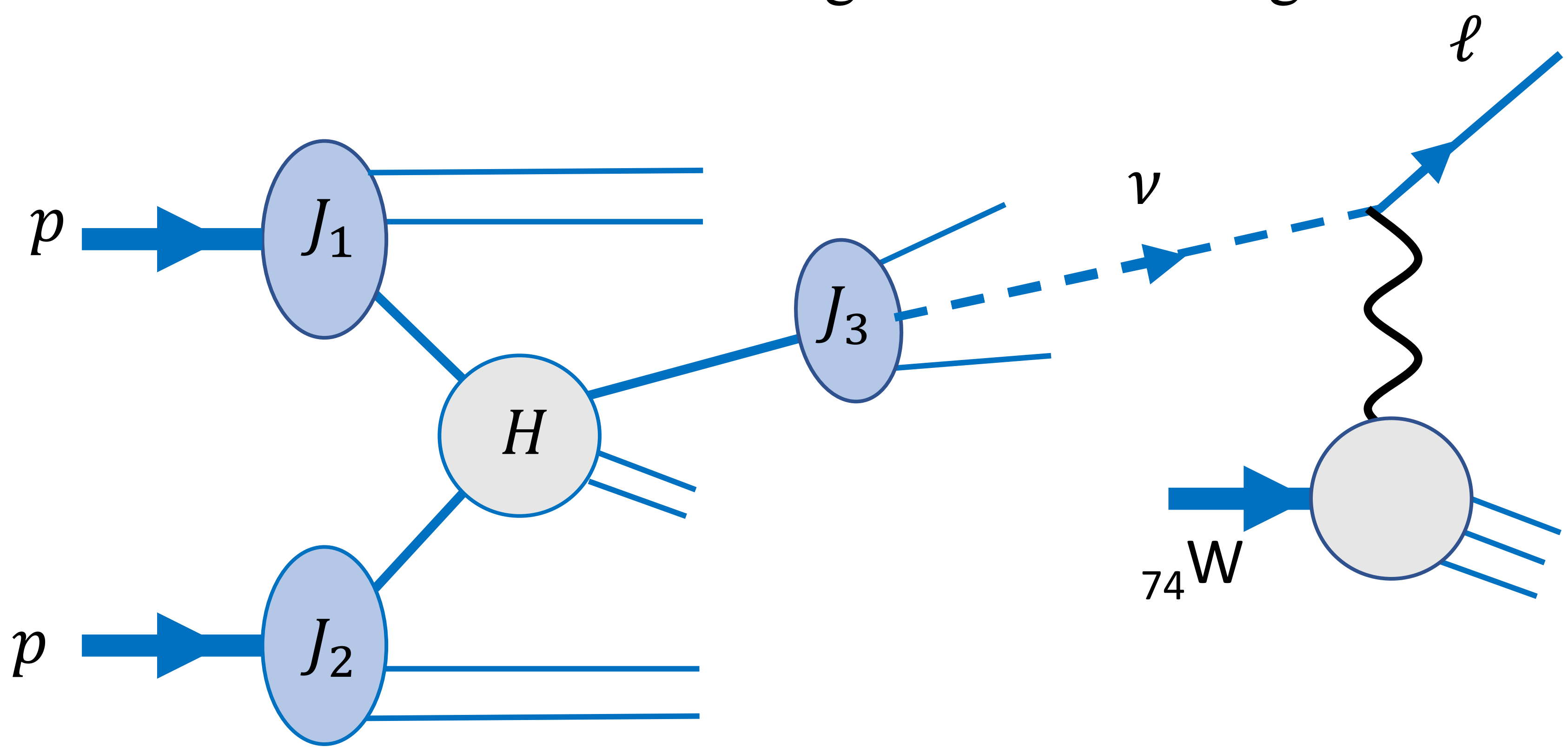
- Range of areas:

★ pp physics in the forward region: BFKL & saturation physics

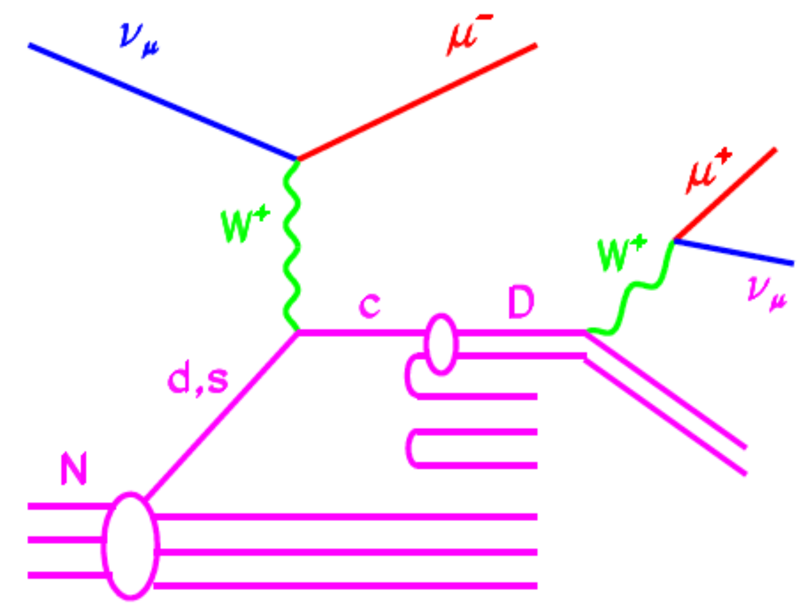
★ Neutrino-induced DIS: a probe of proton and nuclear PDFs.

★ pp physics in the forward region: intrinsic charm & PDFs

★ Particle production in the forward region: MC tuning.



CC DIS



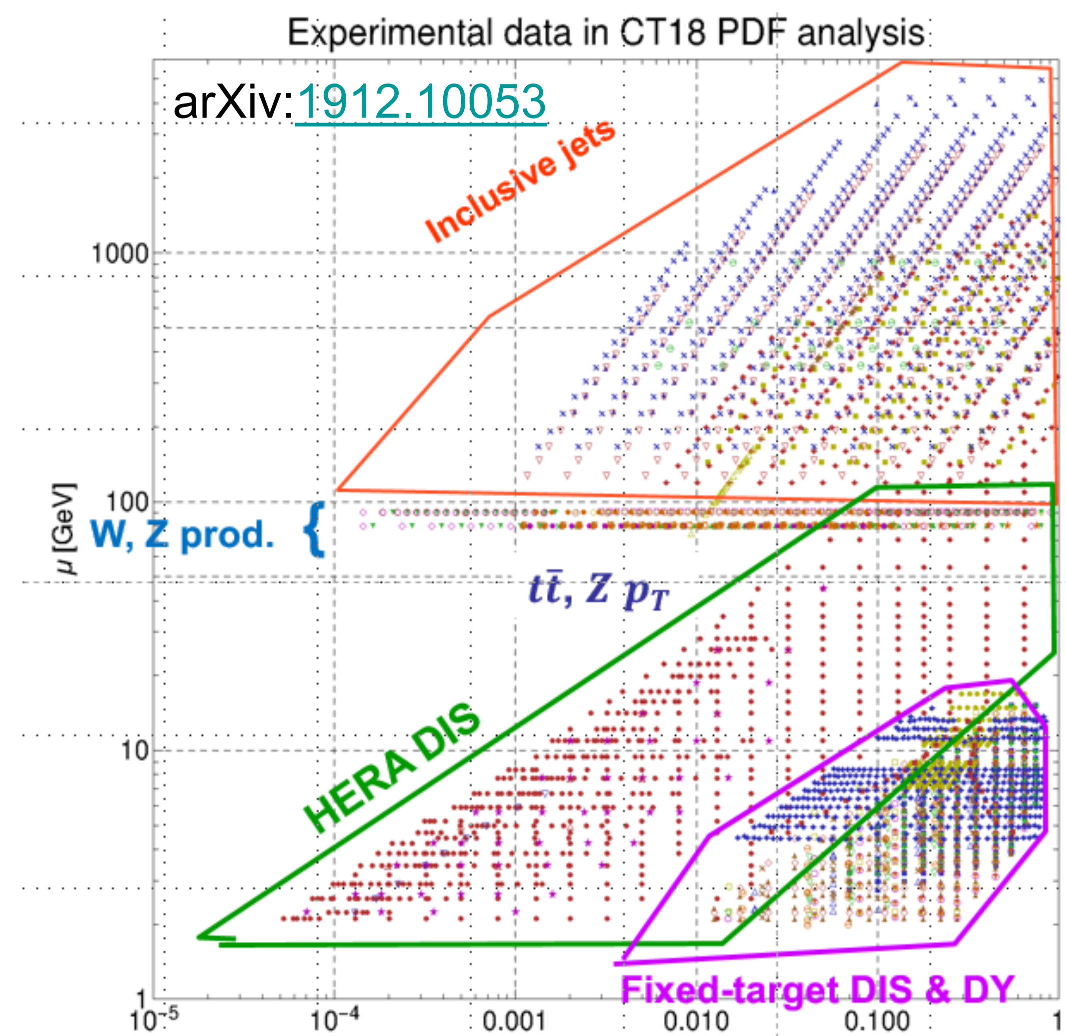
- DIS continues to be a key ingredient in global PDF fits. Neutrino-induced CC DIS an important element in this.

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}y} = N^l \left[y^2 x F_1^l + (1-y)\, F_2^l \mp \left(y - \frac{y^2}{2} \right) x F_3^l \right],$$

$$F_2^{\nu} = 2x(d + s + b + \overline{u} + \overline{c})$$

$$F_2^{\overline{\nu}} = 2x(\overline{d} + \overline{s} + \overline{b} + u + c)$$

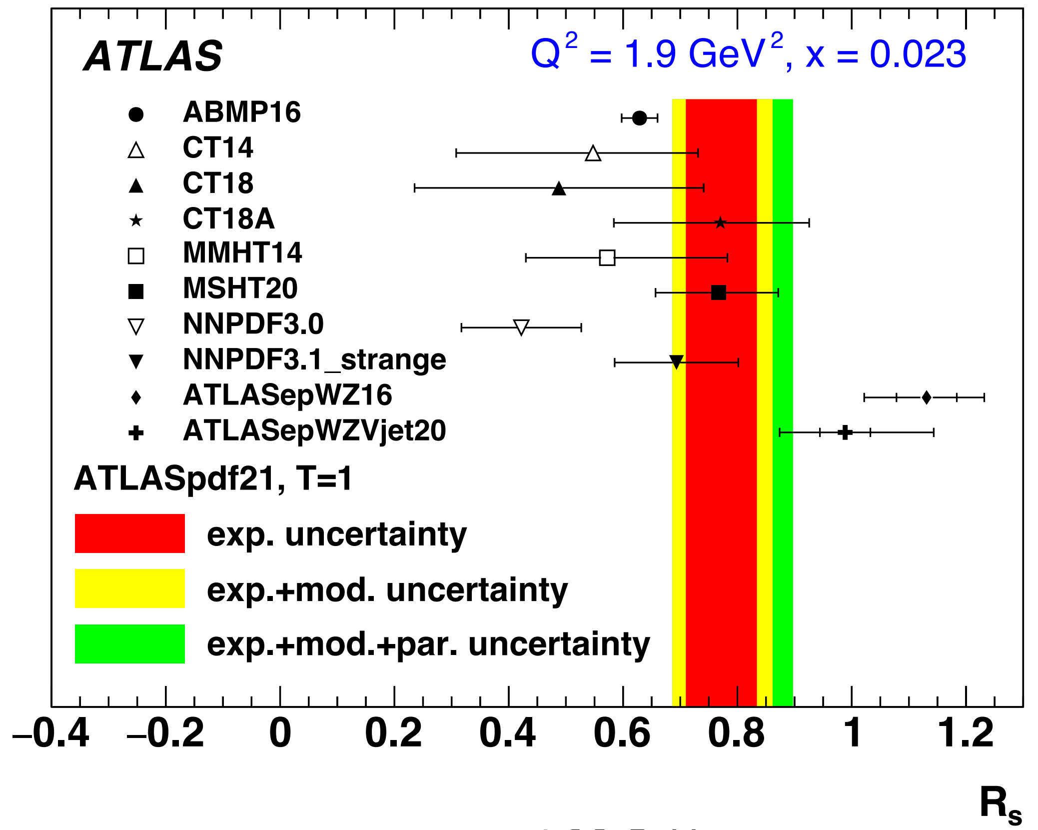
- Key to disentangling nucleon flavour decomposition.



CC DIS

$$R_s \equiv \frac{s(x,Q^2)+\bar{s}(x,Q)}{\bar{u}(x,Q)+\bar{d}(x,Q)}$$

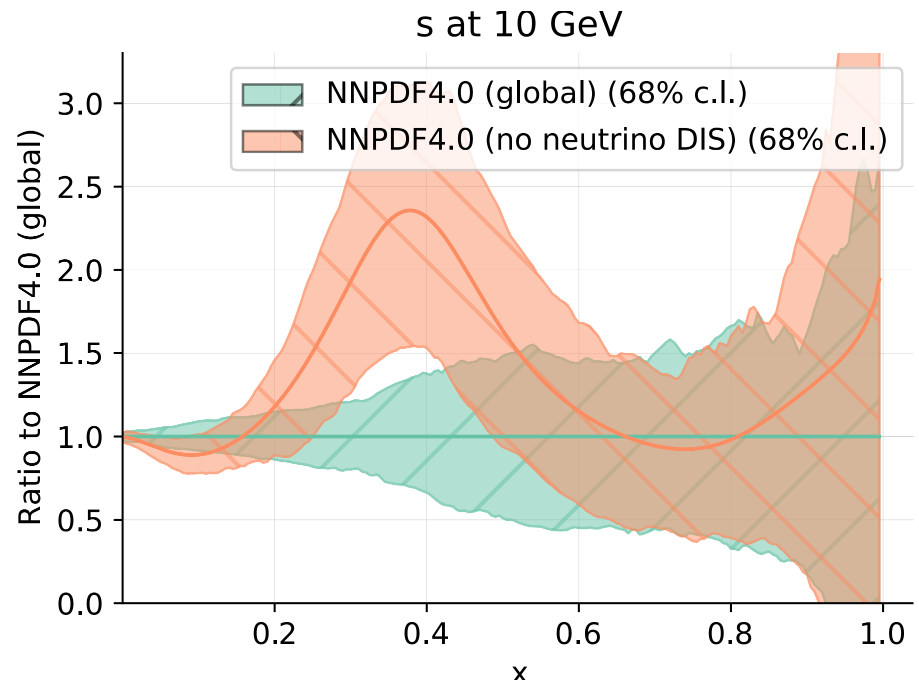
- Strangeness 'puzzle': some degree of tension. between LHC (W,Z) constraints on proton strangeness and DIS.
- To some extent reduced in more recent fits, but difference in pulls remain. CC DIS still important constraint.



- FPF provides significant new information:

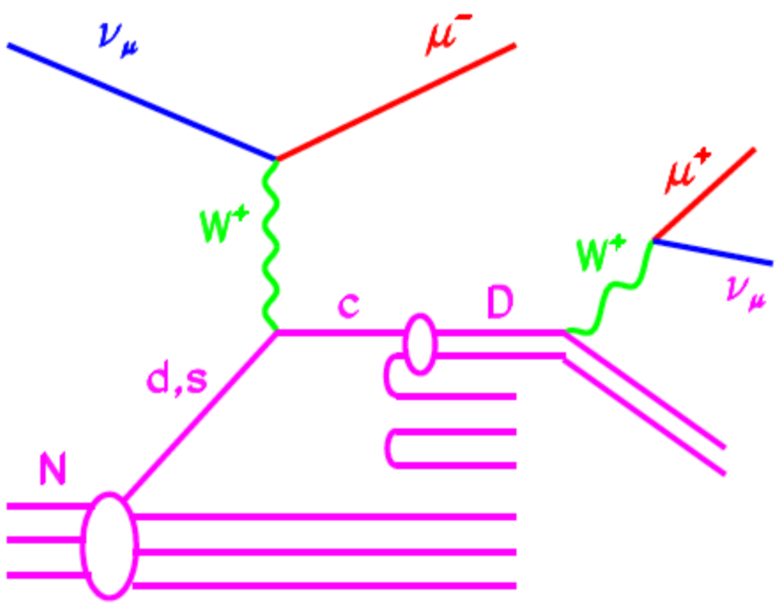
  ★ Extended coverage/higher energy regime.

  ★ Multiple charm tagging methods ($D \to \mu$ branching key uncertainty in existing data).



- Can help to further disentangle this question!

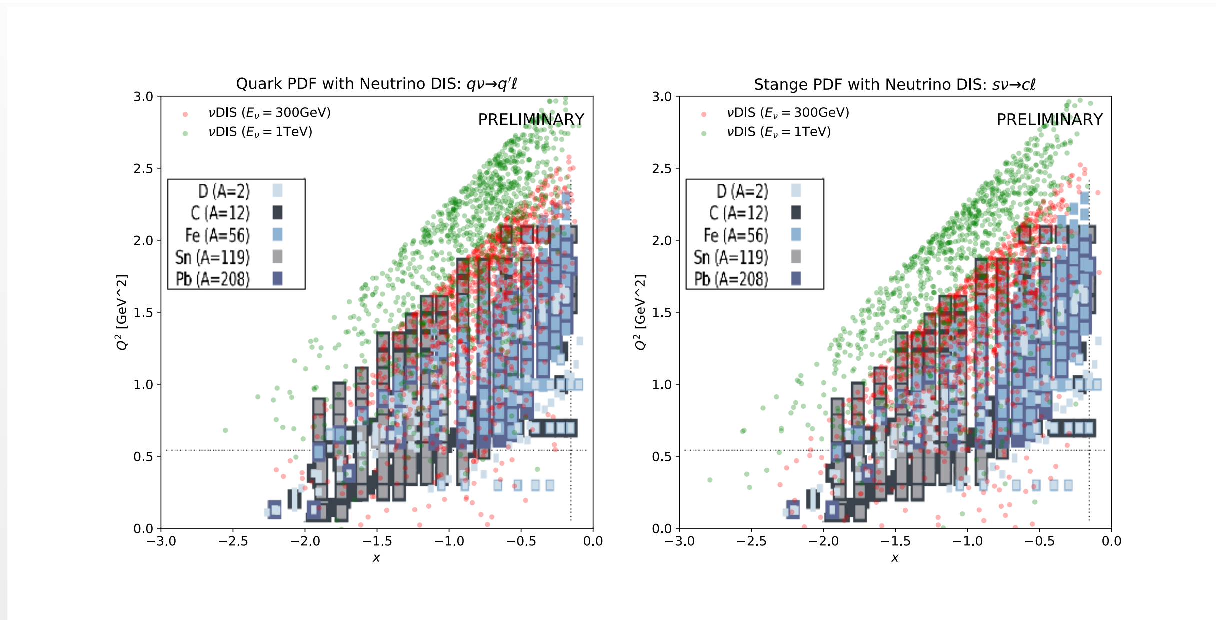
CC DIS



- Previous fixed-target neutrino-induced DIS on fixed nuclear targets. FPF of course no different.

  $\Rightarrow$ Either constrain proton PDFs (w/ nuclear corrections) or nuclear PDFs directly.

- Flavour structure and strangeness in particular less constrained in nuclear PDFs, and less LHC W,Z data here $\Rightarrow$ potential for even greater impact.



preliminary modifications of previous plot by F. Kling

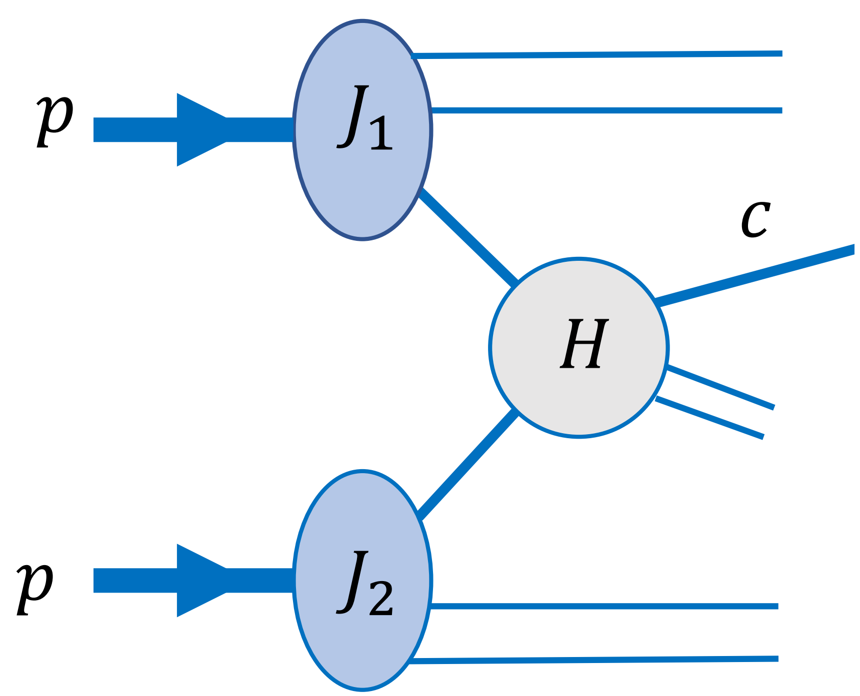
QCD at the extremes

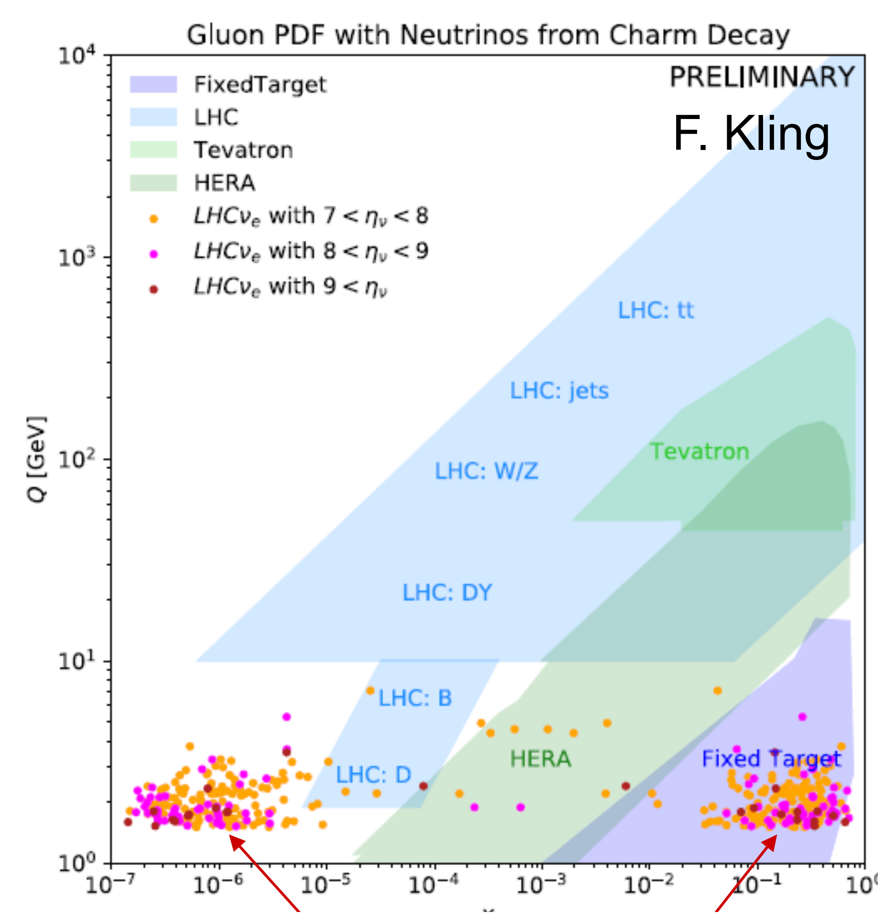
- FPF neutrinos due to far decay of particles produced in far forward region.
- That is, due to both very high and low partonic x. Roughly:

$$x_{\rm low} \gtrsim 5 \times 10^{-8} \qquad\qquad x_{\rm high} \lesssim 0.5$$

- These regimes are both **poorly constrained** and **theoretically challenging**, requiring modifications to ‘standard’ QCD framework.

$\longrightarrow$ FPF data can push into this novel QCD regime

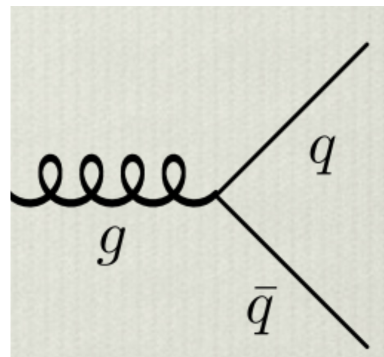


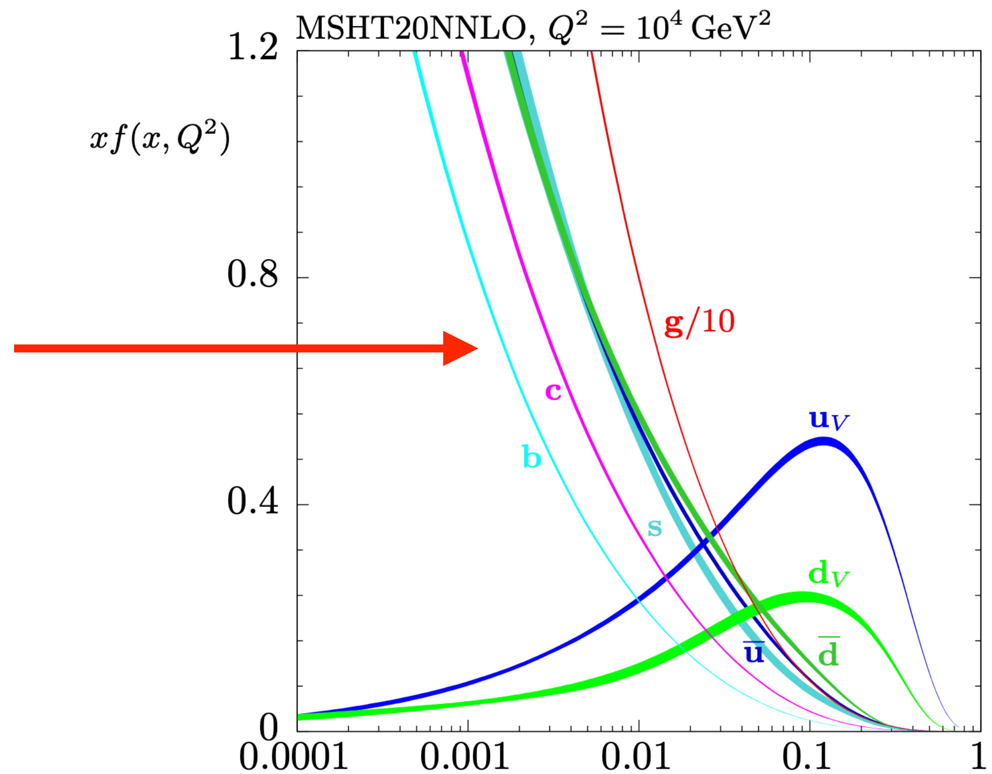


High x and intrinsic charm

- Proton at high scales contains heavy quark content generated by perturbative splittings:

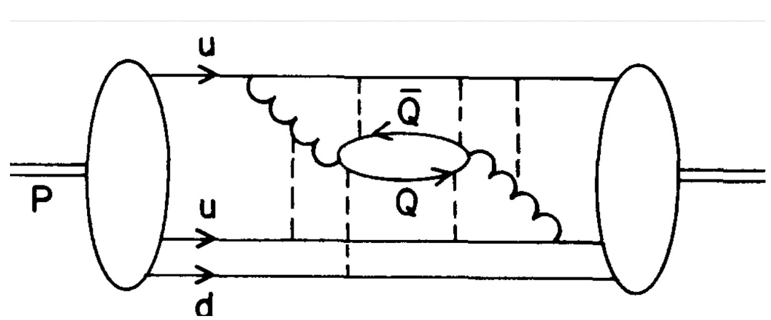
$$b(x,Q^2), \bar{b}(x,Q^2) \sim$$
$$c(x,Q^2), \bar{c}(x,Q^2) \sim$$



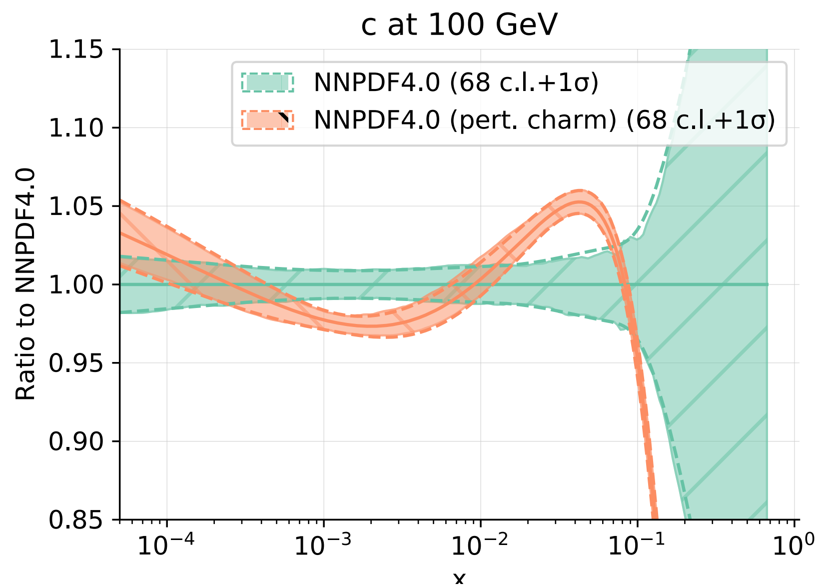


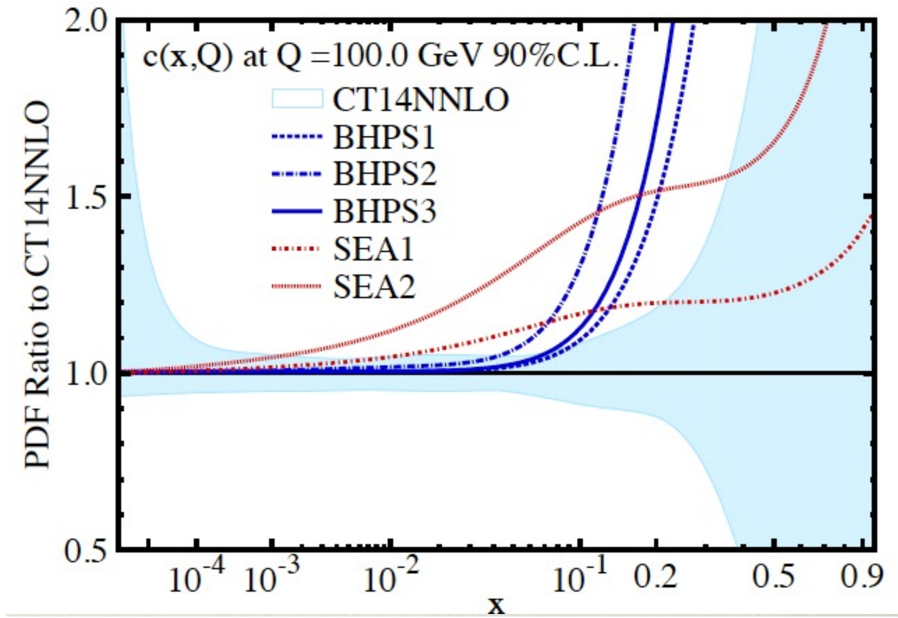
- Predicted by perturbative QCD in terms of other partons.

- However for charm quark interesting possibility of 'intrinsic' content, not generated by above perturbative picture.



- Contribution from this intrinsic component currently **open question**.
- Fitted charm included in NNPDF fits, and CT studies within phenomenological models.

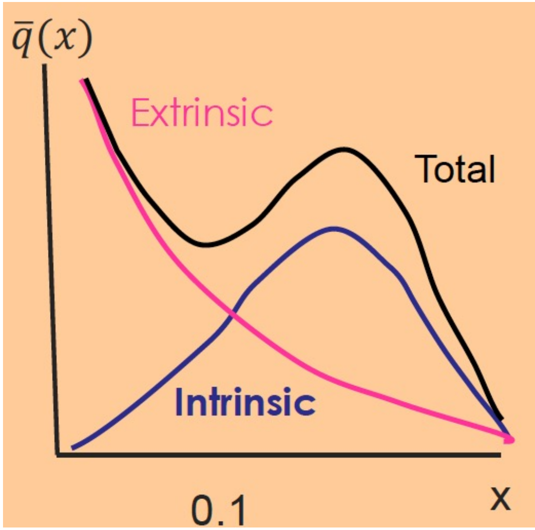




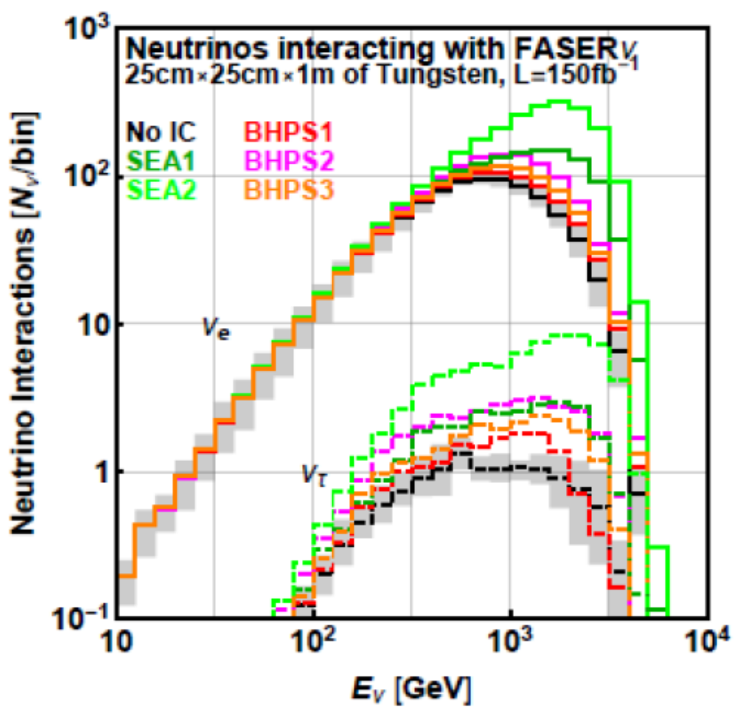
- Some recent evidence from LHCb data on Z+c production.

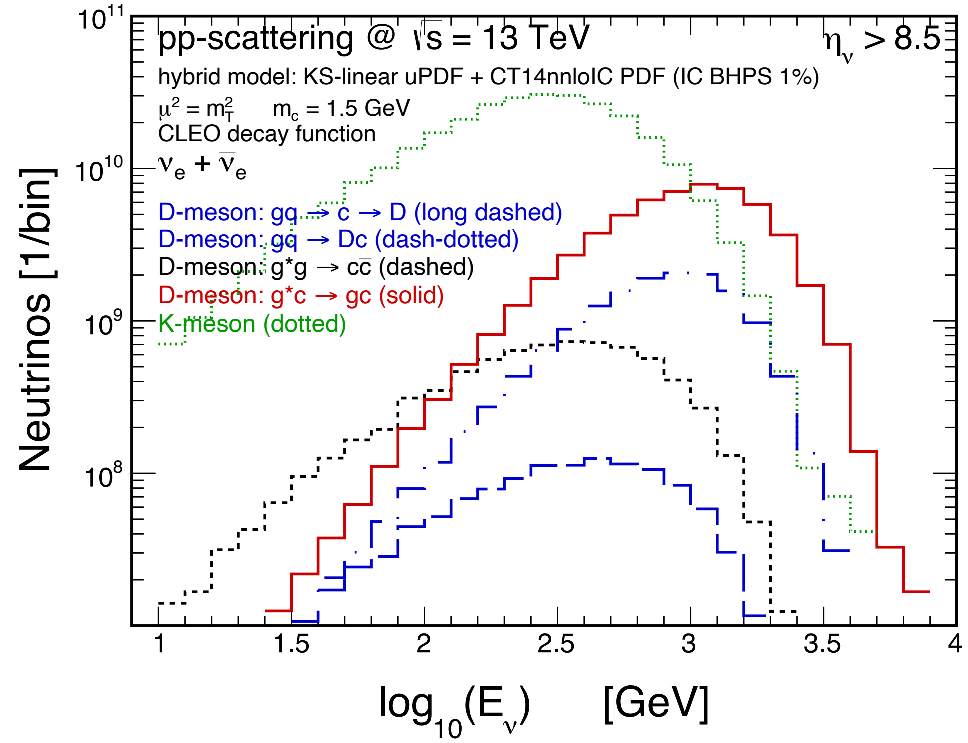
- General expectation: intrinsic content will be enhanced in the high x region.

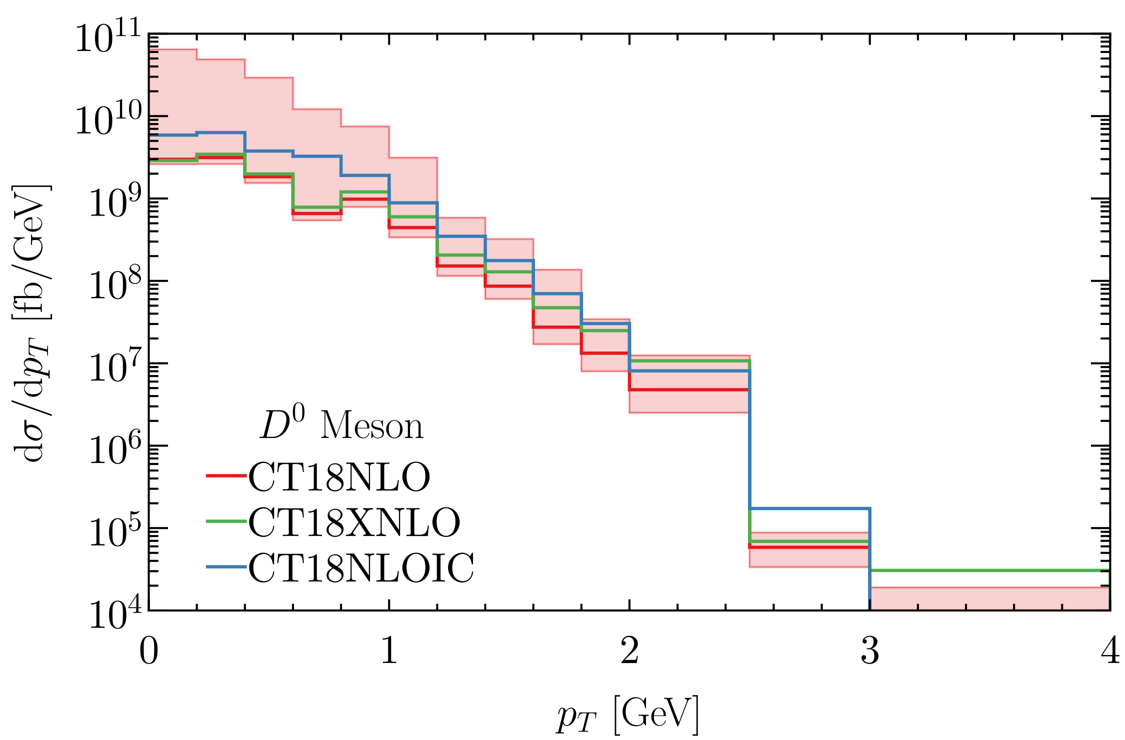
  $\longrightarrow$ FPF data on forward charm production can provide handle on this.

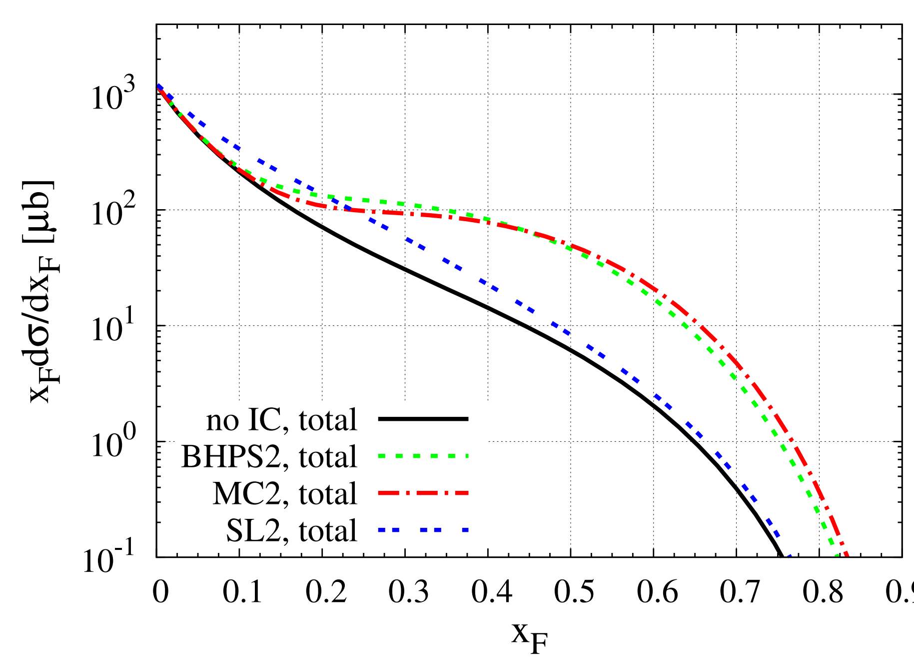


- Forward charm production key probe of intrinsic charm, via impact on neutrino flux. Can shed light on this issue.





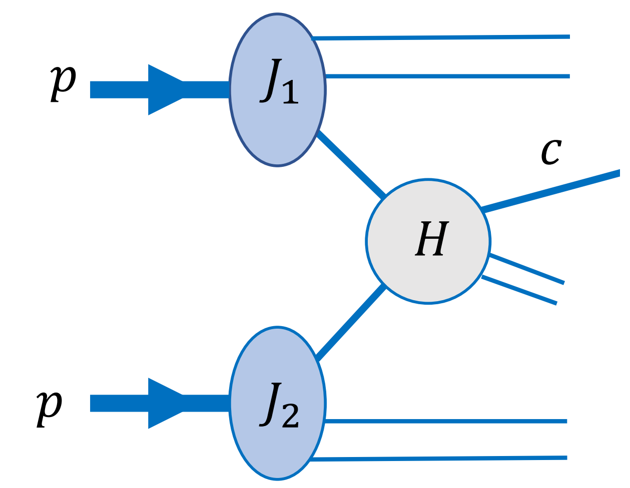




- Range of feasibility studies in white paper.

Forward production & low x physics

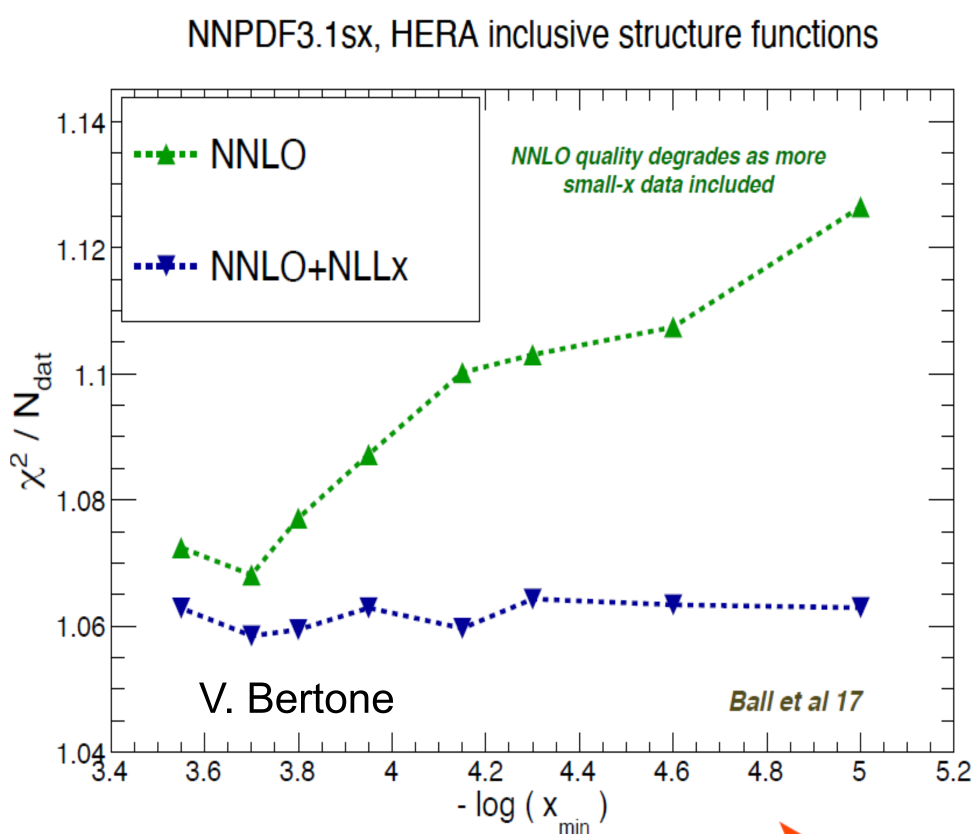
- For generic production processes in the high energy (i.e. low x) regime a range of novel QCD effects come into play.



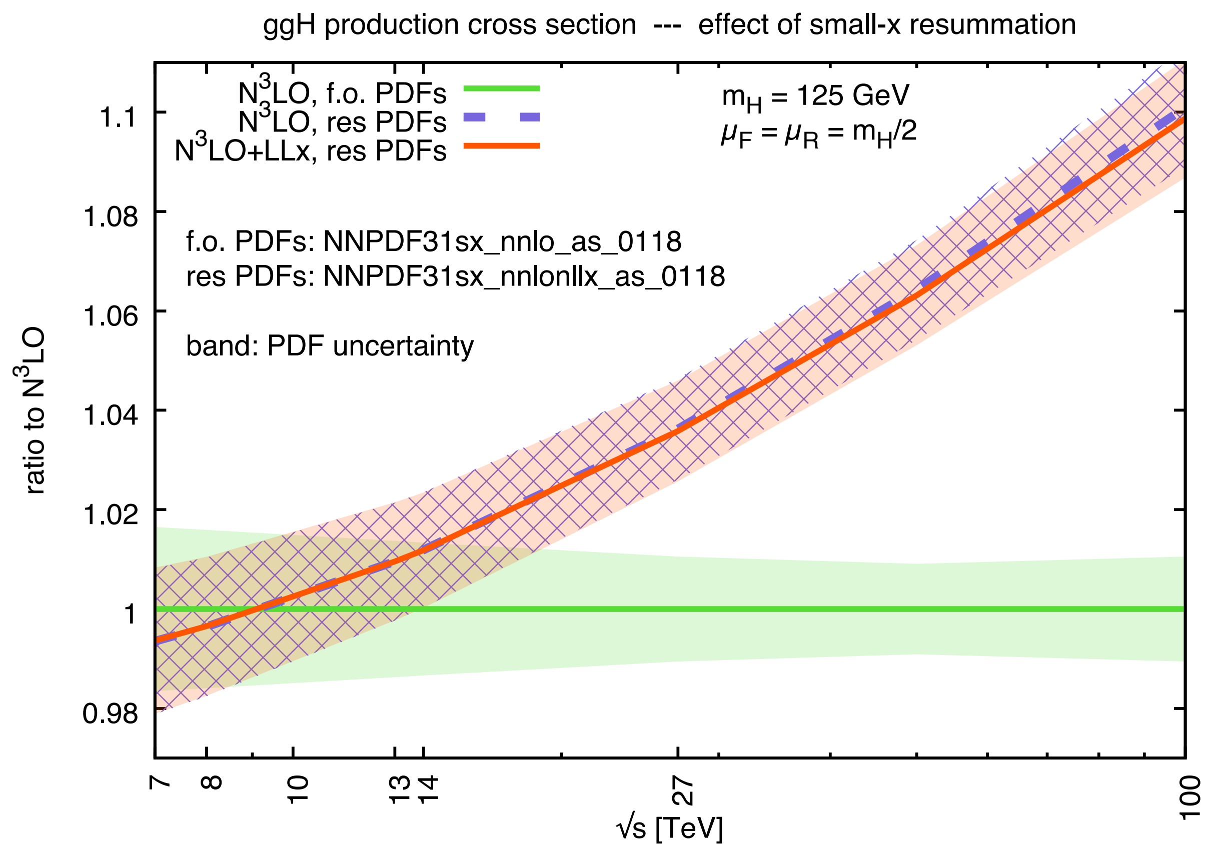
★ Low x and BFKL :

- For $\alpha_s \ln \frac{1}{x} \sim 1$ fixed order pQCD becomes unreliable and resummation required $\rightarrow$ move beyond DGLAP framework to BFKL based one.

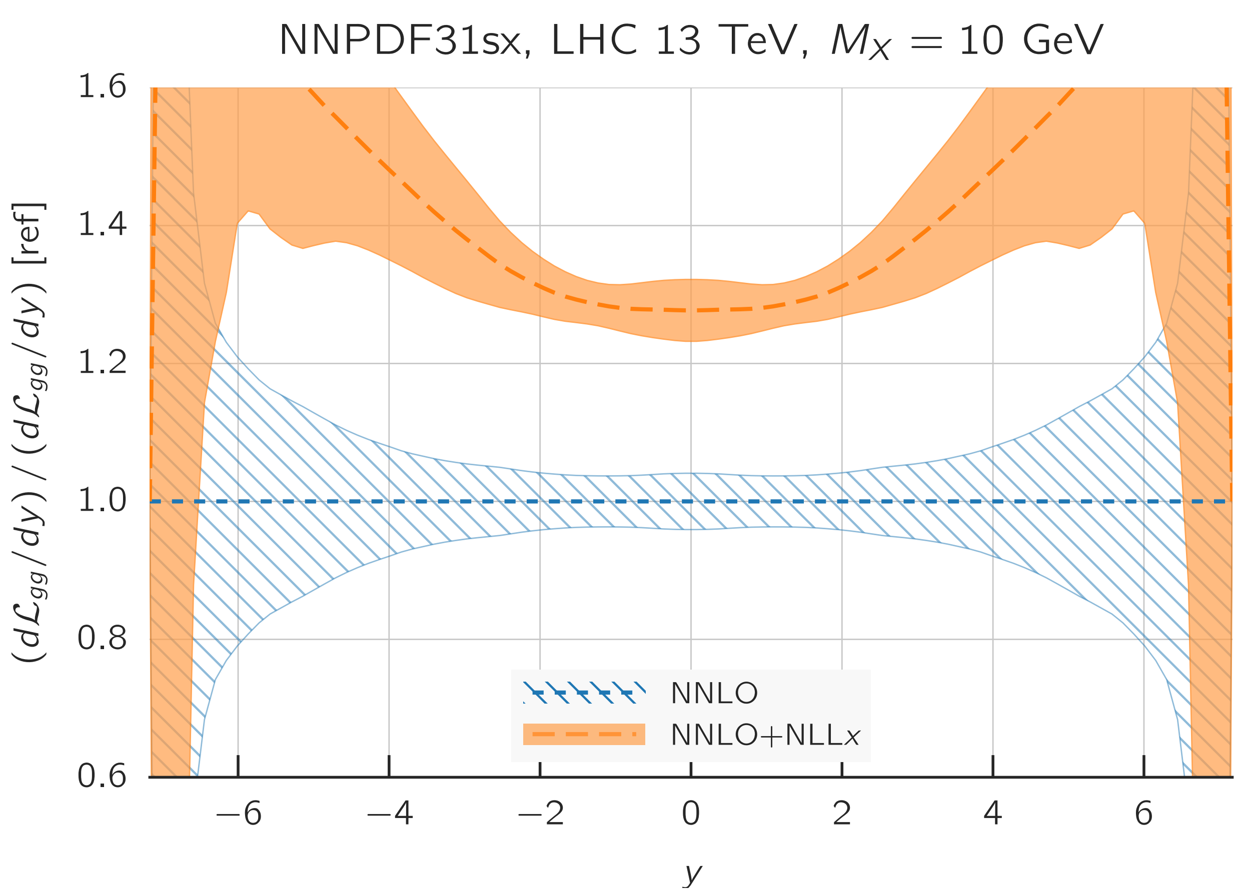
- BFKL resummation of production process and collinear PDF evolution available. Impact on e.g. HERA data seen.



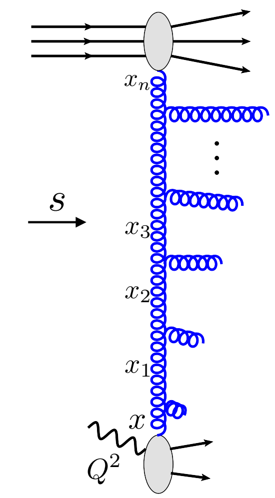
- Impact largest at forward rapidities, whereas can be washed out in inclusive/high scale processes.



- Predictions for forward charm production at FPF highly sensitive to this. Can play key role in studying the effect of such resummation.

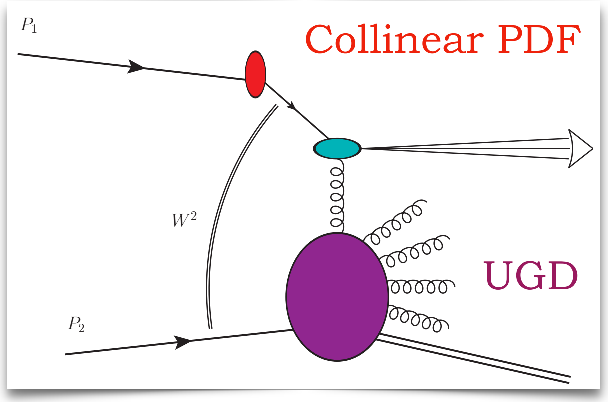


- In this high energy (low x) regime 'standard' collinear factorization not the only way to approach things.
- Forward charm: $k_\perp$ factorization, colour dipole formalism…

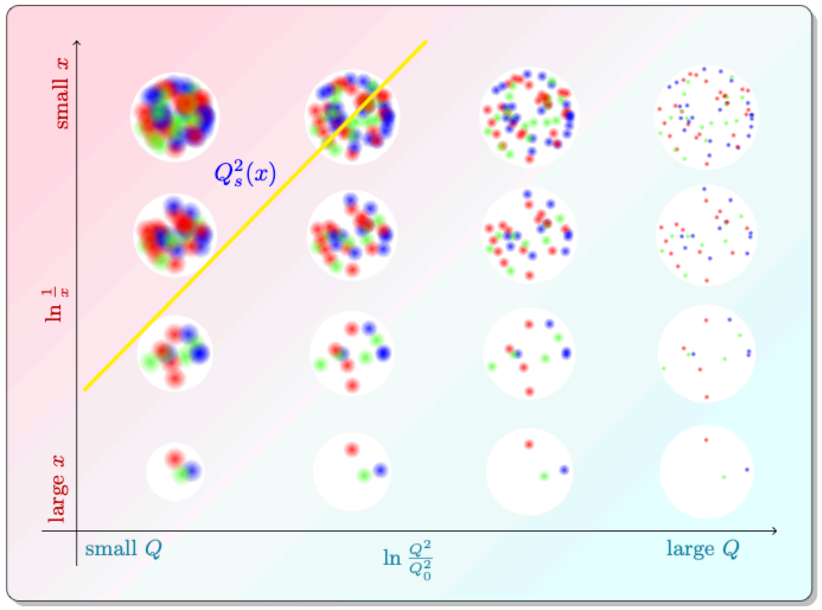


$$\sigma(s) = \int d^2k_{1\perp} \frac{dx_1}{x_1} \mathcal{F}(x_1, k_{1\perp})\, d^2k_{2\perp} \frac{dx_2}{x_2} \mathcal{F}(x_2, k_{2\perp})\, \hat{\sigma}(x_1 x_2 s,\, k_{1\perp},\, k_{2\perp})$$

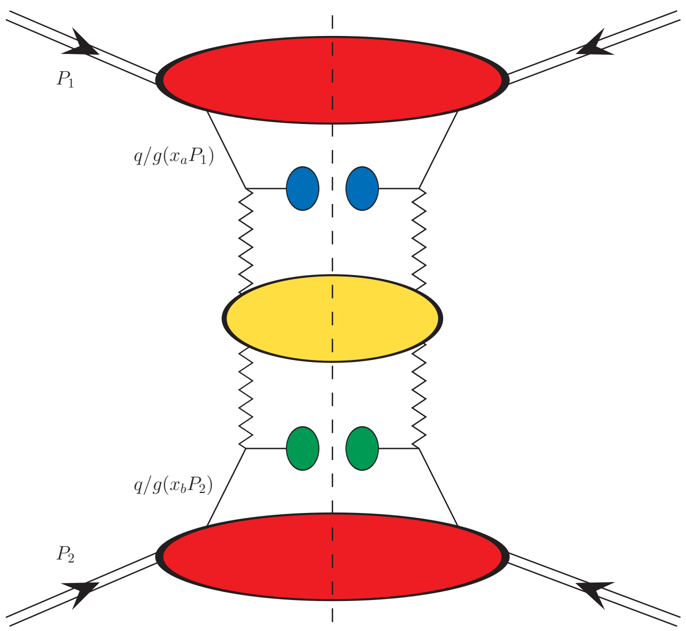
- Inclusive forward charm production: testing ground for different approaches to modelling this regime in QCD.



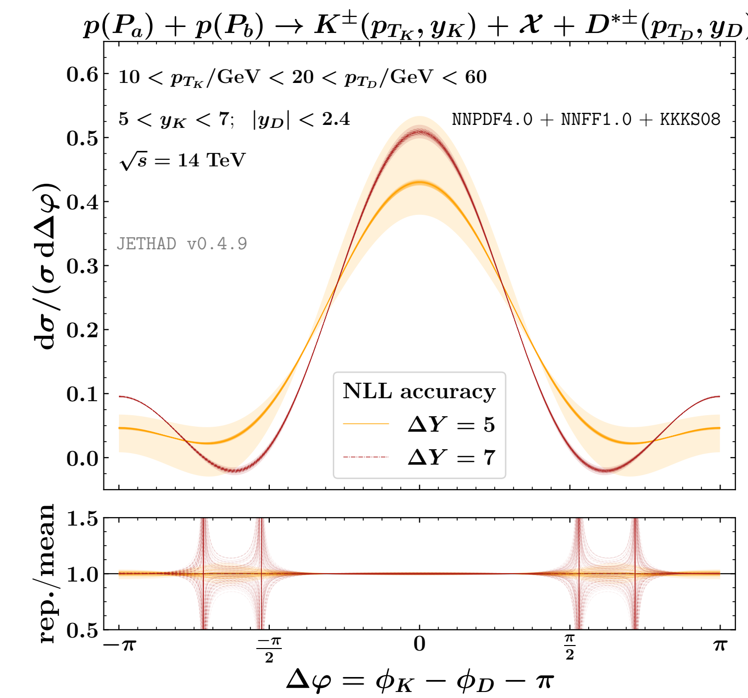
- Additionally connected to physics of saturation: at low x gluon recombination effects expected to become important, modifying gluon density.



- Additional possibility of forward-central events: central particle tagged in ATLAS and forward particle at FPF. Requires precise timing.

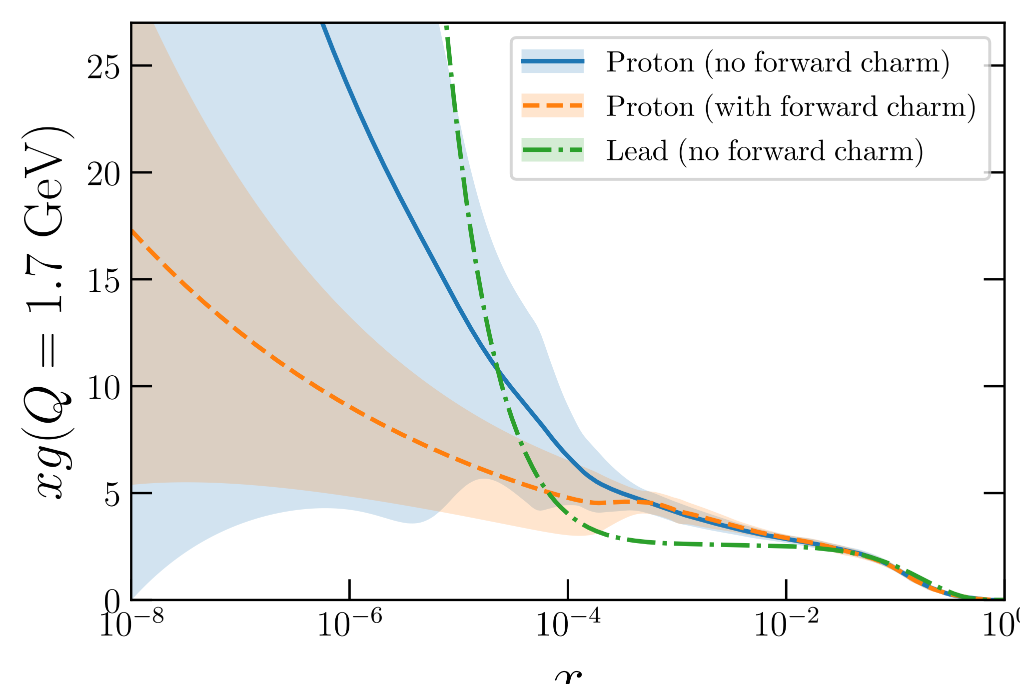


- New observables/ correlations then come into play. Useful extra handle on BFKL effects.



- **Bottom line**: there is significant untested grounded for probing the theoretical framework underlying this low x region that FPF can aim for.

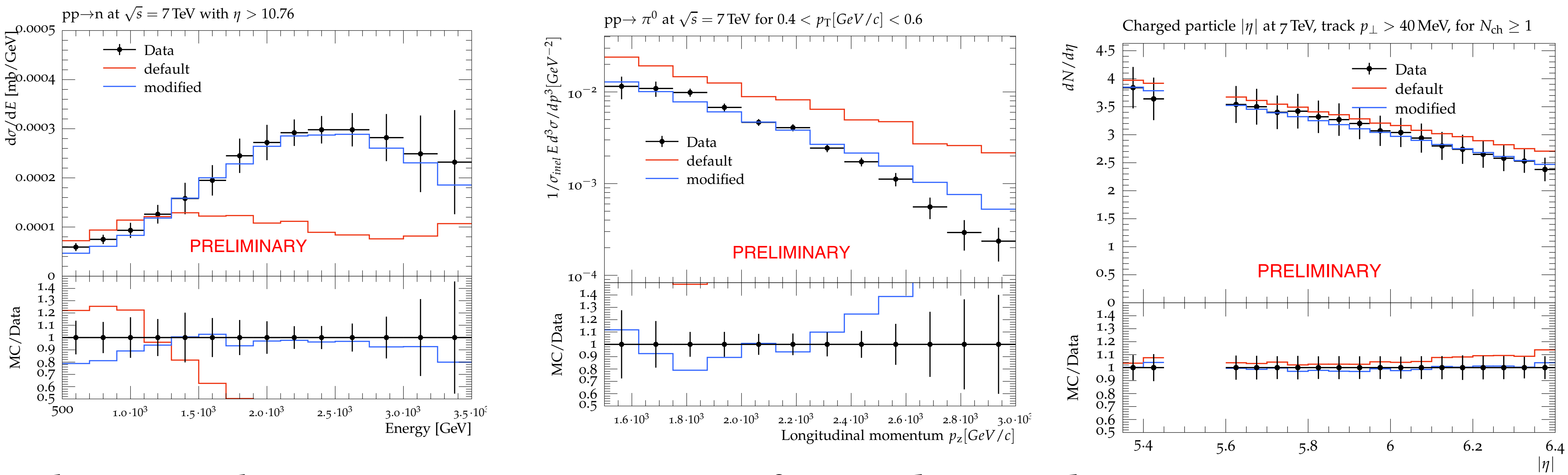
- Note that there is direct interplay in this low x region with PDFs, which are less well constrained in this region.



Forward production & MCs

- FPF neutrino flux not just produced by forward charm production (i.e. pQCD theory), but range of light hadrons.
- Naturally links to general purpose MCs at LHC, and their (non-perturbative) modelling of such production.
- SHERPA, HERWIG & PYTHIA: primary use is for central LHC production. Modelling less constrained/certain in the forward region.

  $\Rightarrow$ Understanding of this region key to FPF physics, and FPF data can help to constrain this.



Above: preliminary PYTHIA tune to forward LHC data.

Summary

- FPF can provide insight into important and unresolved questions of QCD:
  - ★ What is the flavour structure of the proton and nucleons?
  - ★ What is the size of the intrinsic charm content of the proton?
  - ★ How well do we understand the low x QCD regime?
  - ★ How well can we model forward particles production in our general purpose MCs?

- Have summarised some key points here, but not exhaustive: more contained in white paper!