Resolved-Photon PDFs at Particle Level

PDF fitting (and future UE tuning) via a chain of event modelling machinery

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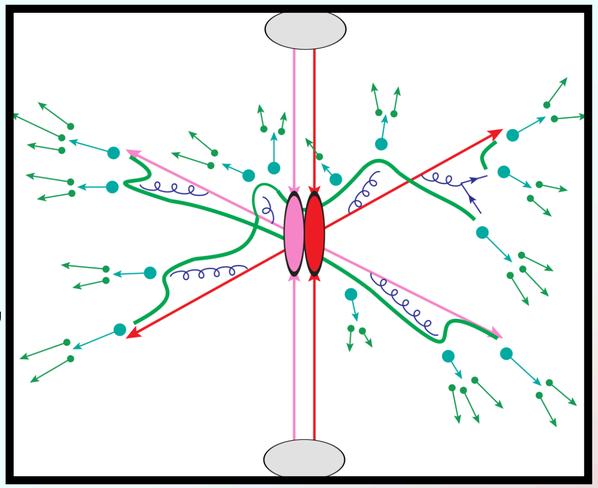
Can you MC-tune a PDF?

Why?

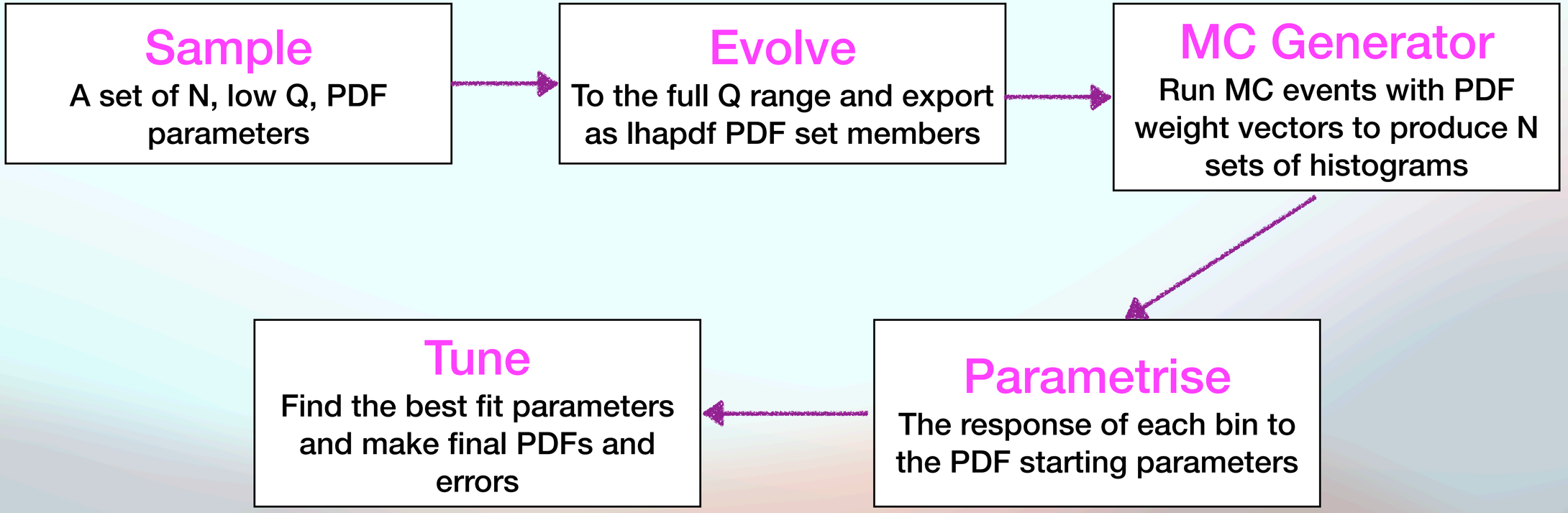
Two ways of doing PDFs



- Typically, fit PDFs via minimisation of the **(PDF x ME) - data** difference, step by step. This is already difficult - adding shower/hadronization models on top of this makes it all the more difficult.
- Several potential advantages to including shower & hadronisation in a PDF fit - more datasets, PDFs being directly useful to MC generation.
- We can do this by matching PDFs to particle level MC generators.
- While this would have been historically difficult, it may no longer be the case! We can now use PDF-weight-variation mechanisms in generators to get MC predictions from randomly sampled PDFs. Can look at 1000s of random PDFs in one MC run.
- I am showing off our ongoing attempt!

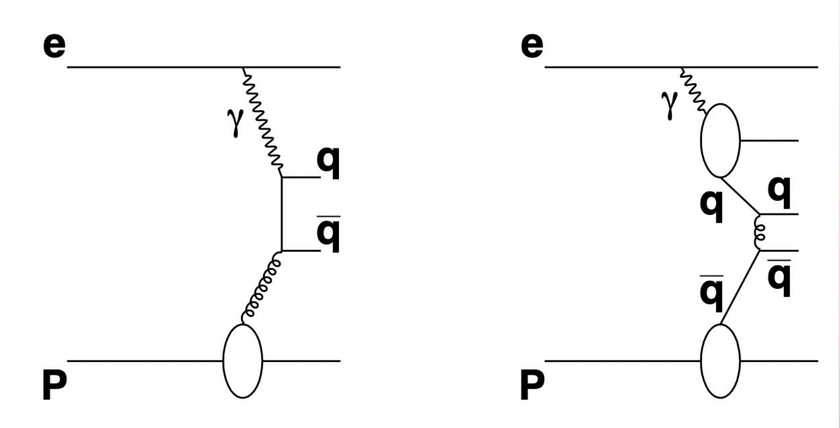
PDF fitting with ME+PS MC

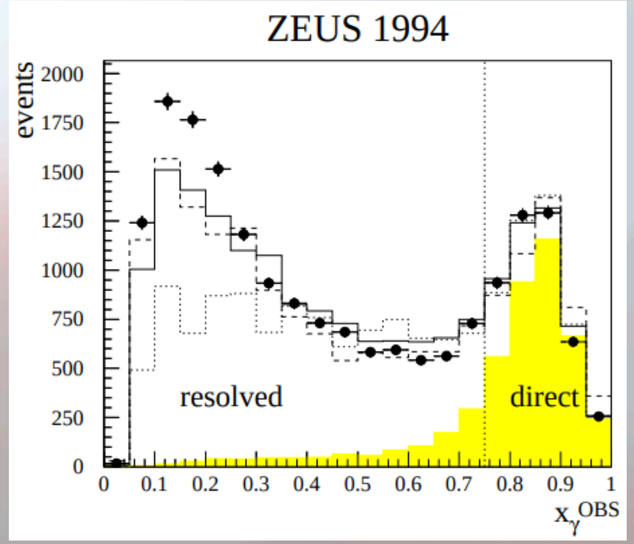
Our Procedure



The Resolved Photon

- $\gamma \rightarrow q\bar{q}$ allows for virtual photon to acquire QCD structure (with hadronic features)
- There are no valence quarks, as the initial structure is from the EM charge. i.e. $e \rightarrow \gamma$ via the Weizacker-Williams approximation
- Can access this in ee, ep, eA, AA → Relevant to the EIC!





[arXiv:hep-ex/9710018]

Why Resolved Photon?

Our testbed

- Major activity at HERA since the last public photon PDFs ~ 2004 CJK fit. No photon PDFs on lhapdf since 1996 Schuler & Sjöstrand.
- Existing Photon PDFs in lhapdf don’t have errors.
- More ep data available.
- Modern Proton PDF sets ⇒ coupled extraction of better Photon PDFs (in theory)
- New photon PDFs (with error sets) with HERA and LEP datasets becomes immediately useful to the EIC.

Parametrization and Evolution of PDFs

SAL Parametrisation [hep-ph/0507091, DIS05]

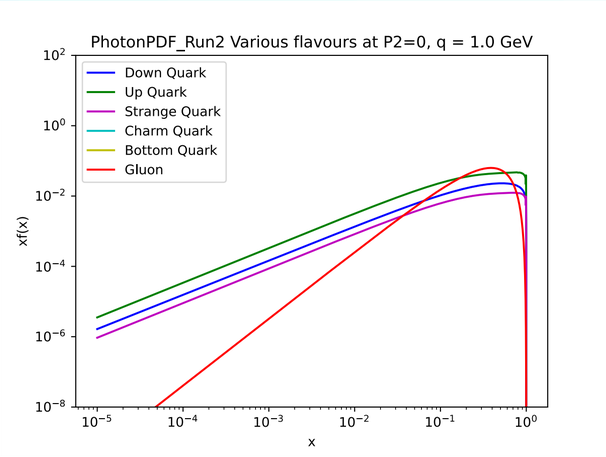
- We begin with a parametrisation from SAL, consisting of point-like and hadronic terms.
- No c,b components. These are turned on later in the evolution at the appropriate scales.
- Using APFEL for DGLAP evolution of PDFs, starting from Q=1GeV.

$$f_q(x) = f_{\bar{q}}(x) = e_q^2 A^{\mathrm{PL}} \frac{x^2 + (1-x)^2}{1 - B^{\mathrm{PL}} \ln(1-x)} + f_q^{\mathrm{HAD}}(x)$$

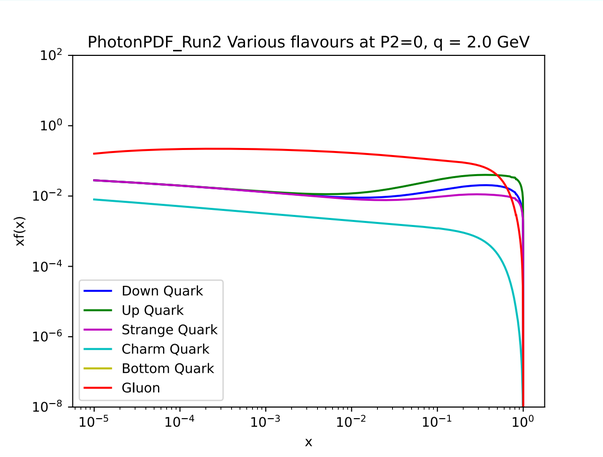
$$f_u^{\mathrm{HAD}}(x) = f_d^{\mathrm{HAD}}(x) = A^{\mathrm{HAD}} x^{B^{\mathrm{HAD}}} (1-x)^{C^{\mathrm{HAD}}}$$

$$f_s^{\mathrm{HAD}}(x) = 0.3 f_d^{\mathrm{HAD}}(x)$$

$$f_G^{\mathrm{HAD}}(x) = A_G^{\mathrm{HAD}} x^{B_G^{\mathrm{HAD}}} (1-x)^{C_G^{\mathrm{HAD}}}$$



PDFs before DGLAP evolution



PDFs evolved up to Q^2= 2GeV

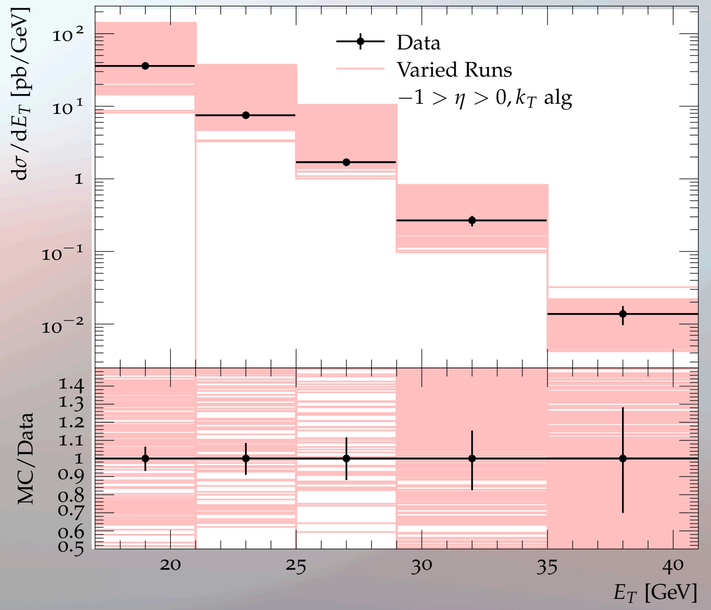
A^{PL}	3.0	5.0
B^{PL}	2.5	3.0
A^{HAD}	0	0.9
B^{HAD}	-2.0	-0.5
A_G^{HAD}	0	0.1
B_G^{HAD}	-2.0	-0.5

PDF parameter sampling ranges (approximate)

Sherpa MC and Analysis in Rivet

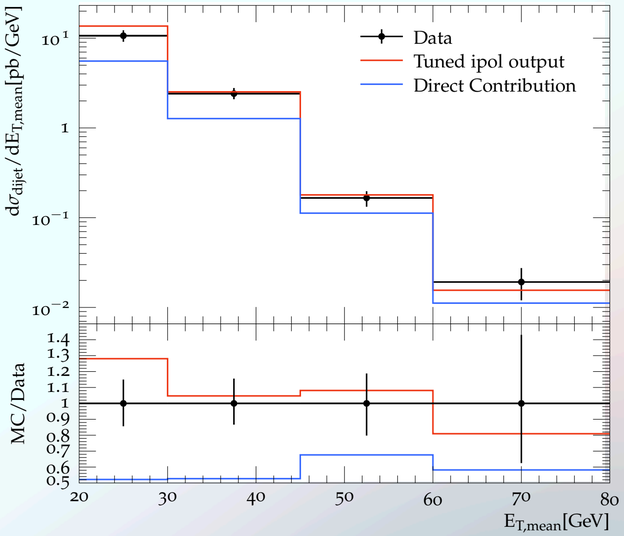
- Using Sherpa 3.0.0 beta - latest master version
- LO ME + PS (CKKW merging of up to 3 extra jets - depending on analysis)
- Sherpa e-p - one run of 15M events in direct mode (parallelised and rivet-merged)
- Sherpa e-p 300 resolved results (from varied PDFs) in one run - using the PDF_VARIATIONS mode in Sherpa
- Sherpa runs ee - direct and single resolved modes are currently running fast.
- Double-resolved is difficult at the moment due to slow run times (Investigating) →Implement later in the chain once the first tune has been done, and during a finer sampled rerun.

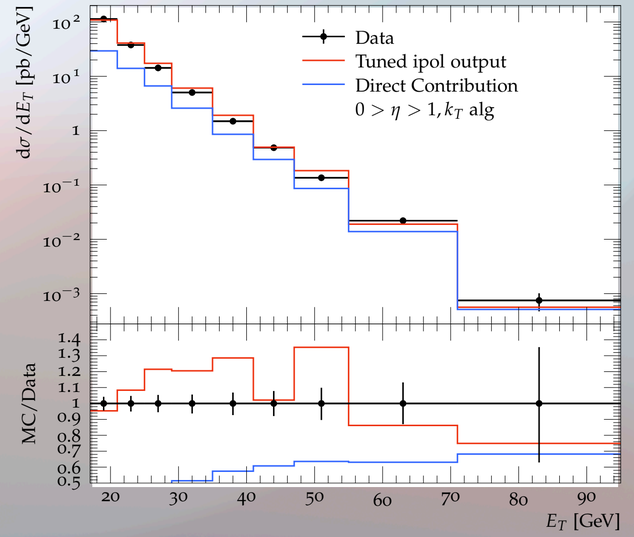
- H1_2002_I581409 - New! Dijet cross sections in photo production
- ZEUS_2012_I1116258 - Inclusive Jet photo production
- ZEUS_1997_I450085 - Dijet cross sections in photo production
- ZEUS_2007_I756660 - New! - 3/4 jets FS in photoproduciton
- ZEUS_2003_I613625 - New! - Dijet angular distribution in photo production of charm
- OPAL_2003_I611415 - Dijet Photoproduction



Tuning with Professor

- 6 free parameters
- Weights primarily on resolved part of the distributions
- Adding new shape-fitting, where the histograms are normalised to area before fitting - useful where clear > LO contribution is missing - or where cross sections/ direct-process modelling is problematic.
- Last time we floated all the norms using meta-params in the fit. Now, Professor's norm-mode ⇒ allow most histos to be fitted regularly, constraining the normalisation.
- Also focusing on weighting the tuning on UE-insensitive bins (high momentum/high jet invariant mass)

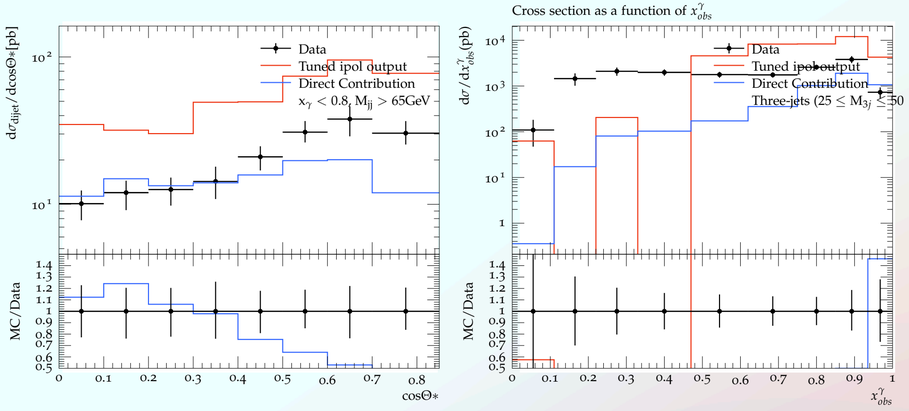


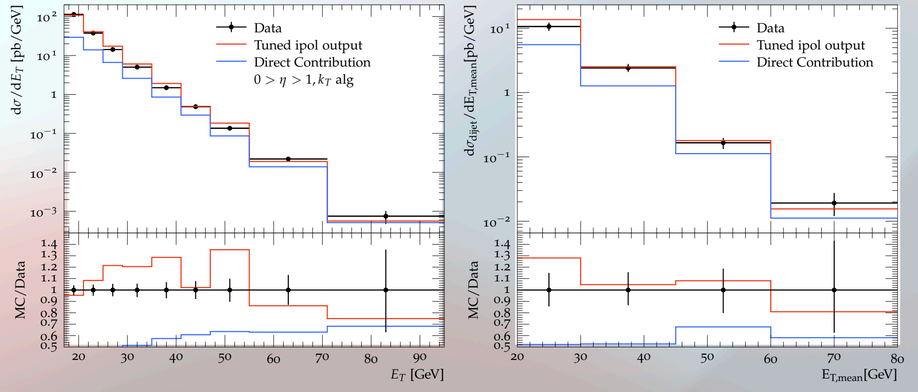


Current PDF Results & Errors

IPOL and Tuning

- Predominantly weighting on resolved areas
- Weights on “high momentum/ high invariant mass” bins - currently judging by eye ~ > 20 GeV - should refine!
- Removing areas with weird ipol-issues & direct mis-modelling
- “Decent” results so far - mostly battling high resolved cross sections, rather than low!! - potentially a problem with how we are using APFEL.

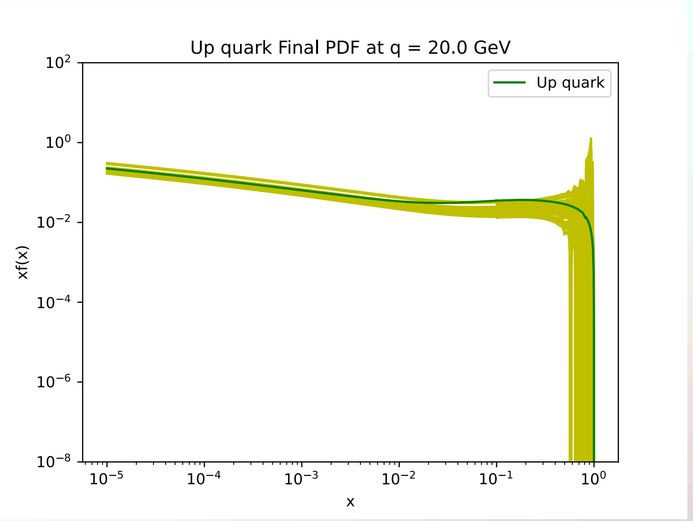


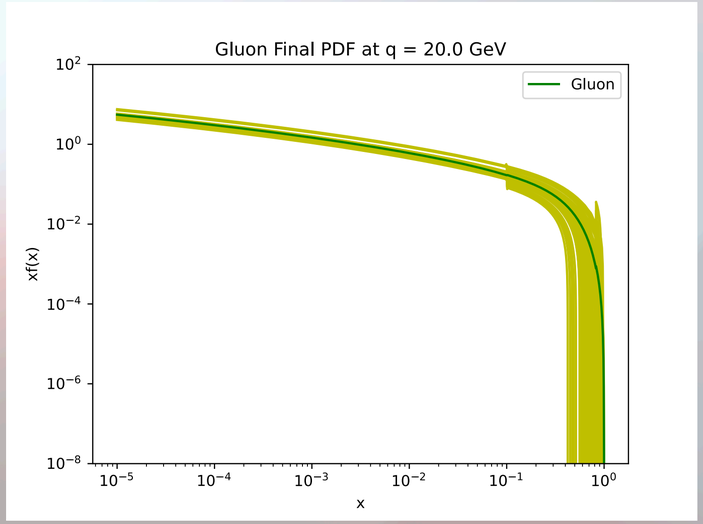


Current PDF Results & Errors

Final PDFs and errors

- Using replica sets for errors - resample reference data from error bars -> refit the ipols to each smeared reference data set to obtain multiple tunes - supply as (non 0000) member PDFs.
- Nominal fit now mostly central in the band - except for high x.
- Can do better? Using covariance matrix from the initial tunes to inform our next set of PDF variations - and derive error bands from those.
- Clear charge separation of u and d. Mass suppression of c and b also works (these are not parametrised, just switched on in APFEL at the appropriate Q^2.
- Errors are large at the moment. More data needs to be added in?





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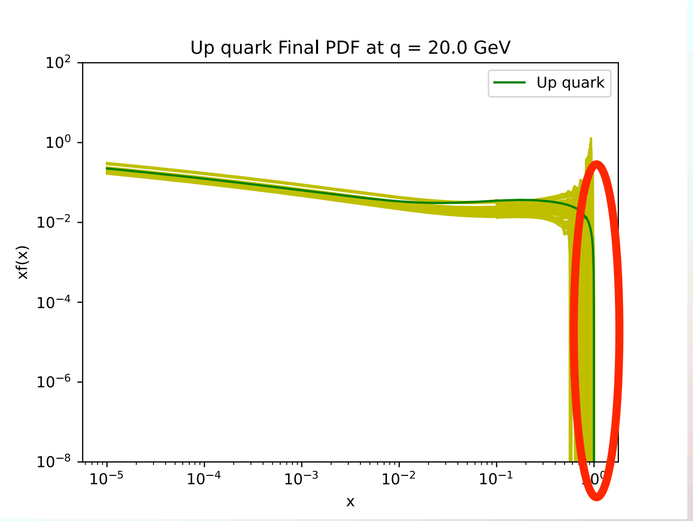

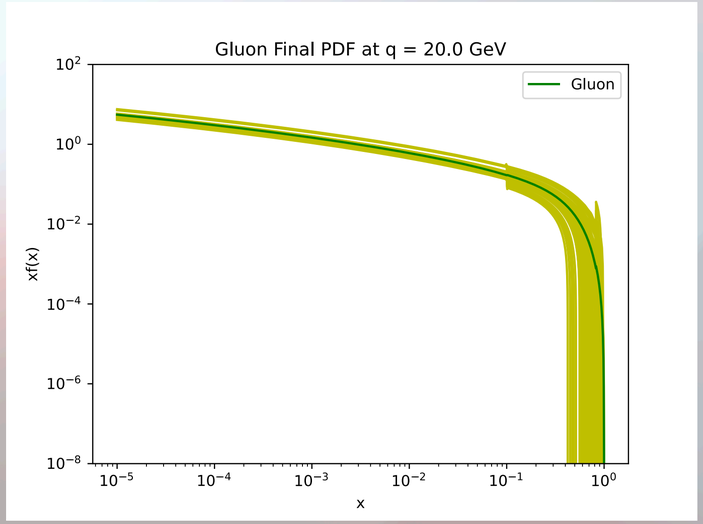

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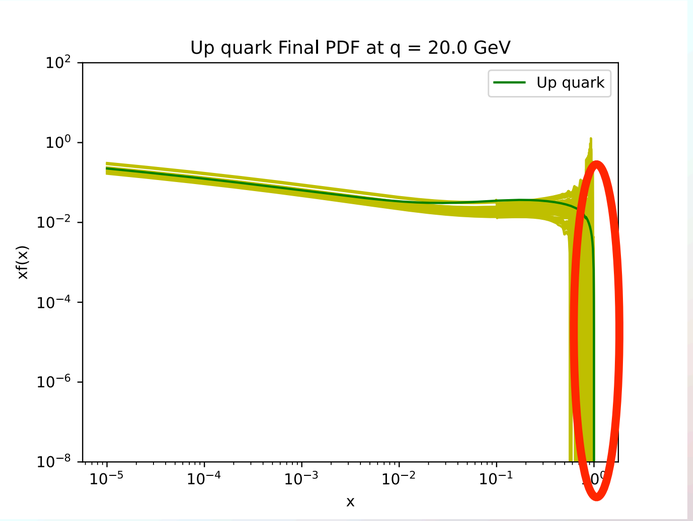

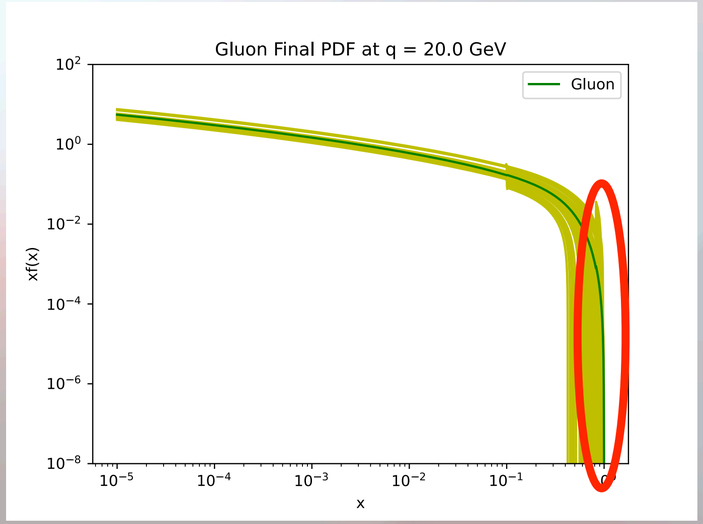

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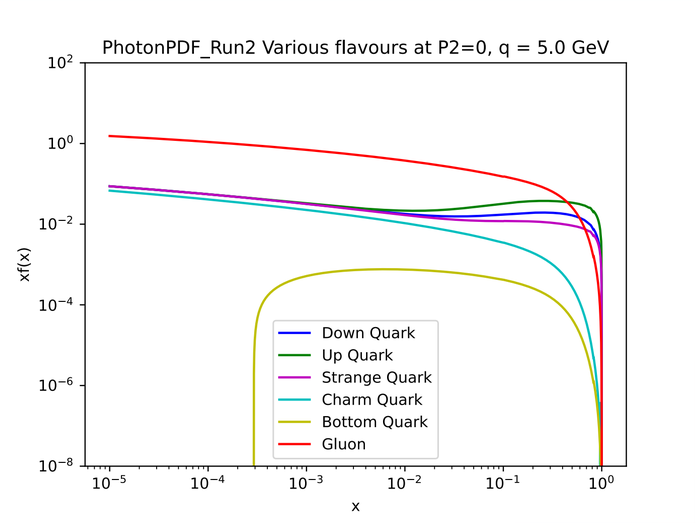

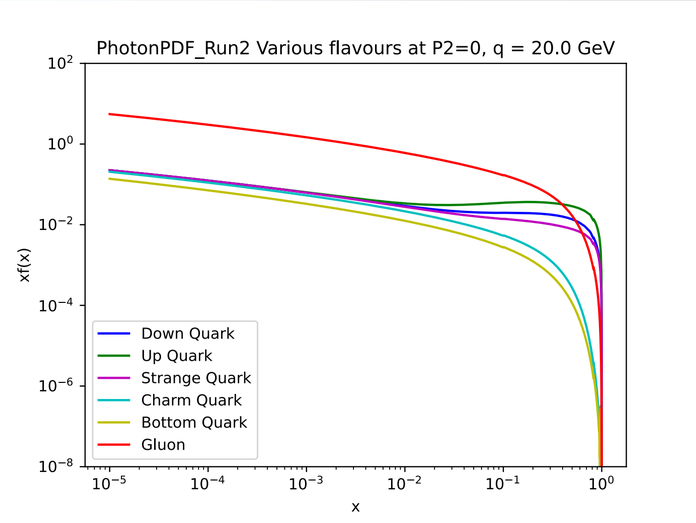

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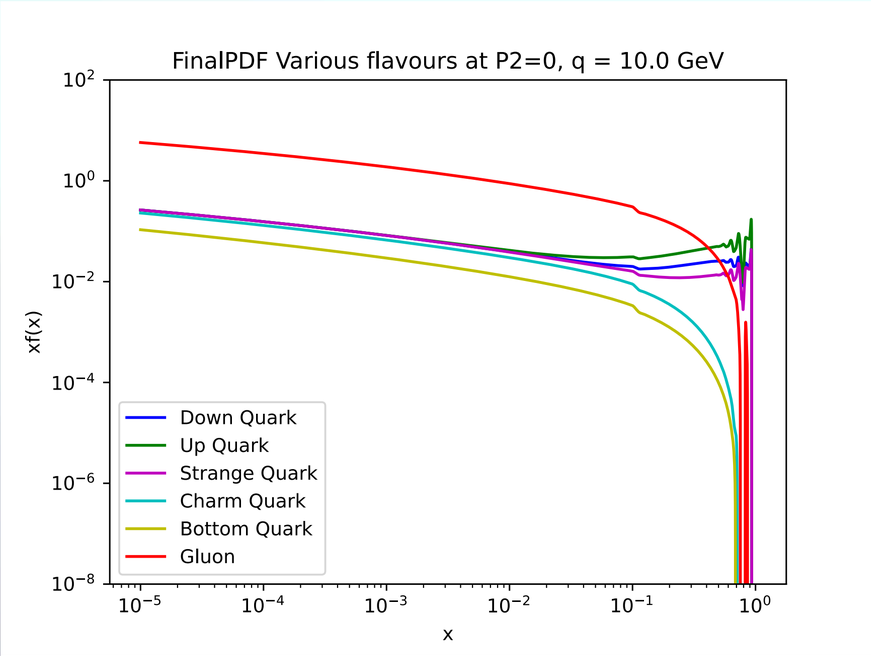
Comparing to last year - and APFEL issues?

- Last time out, we had issues with wiggles at high x, as well as step artefacts. We oversampled in x to fix any interpolation issues.
- Step issues still there. And occasionally the wiggles still resurface.
- Not sure how to fix! Suggestions welcome! Perhaps a different DGLAP evolution tool?



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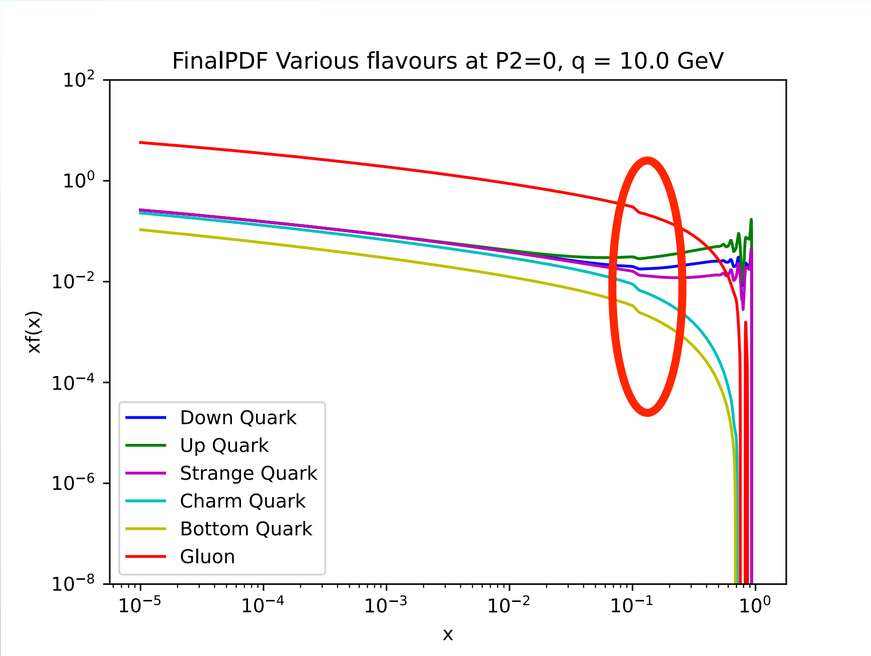

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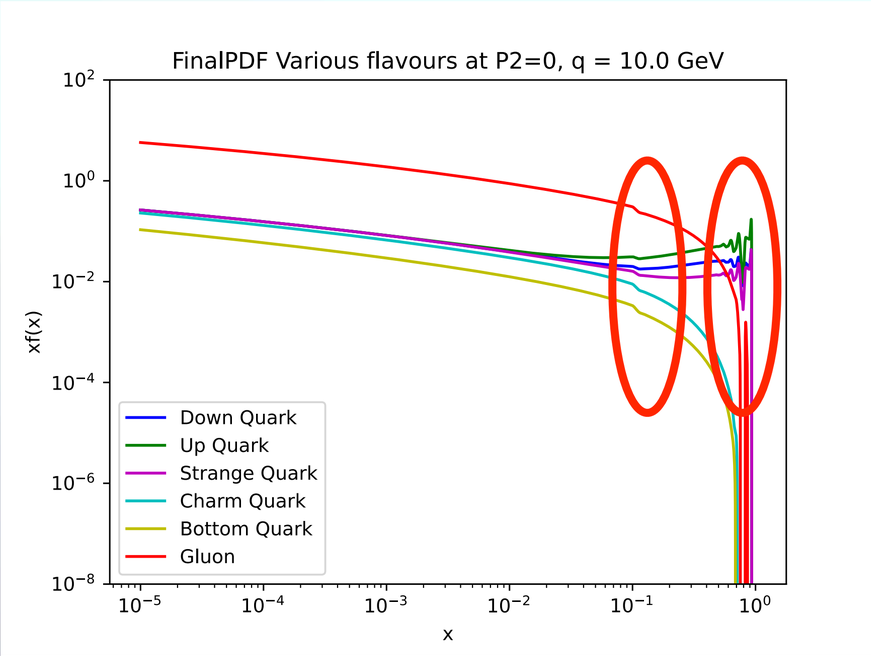

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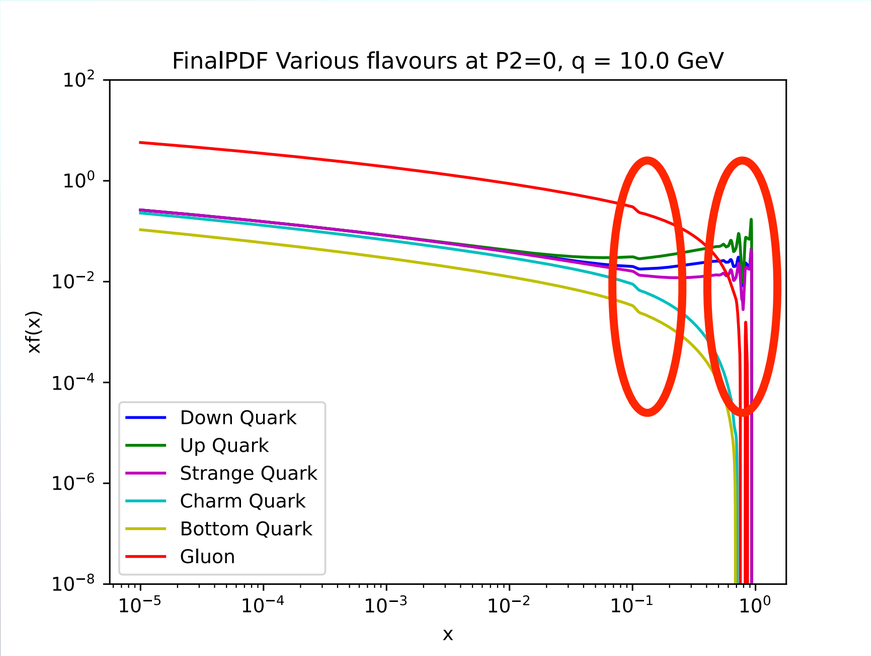

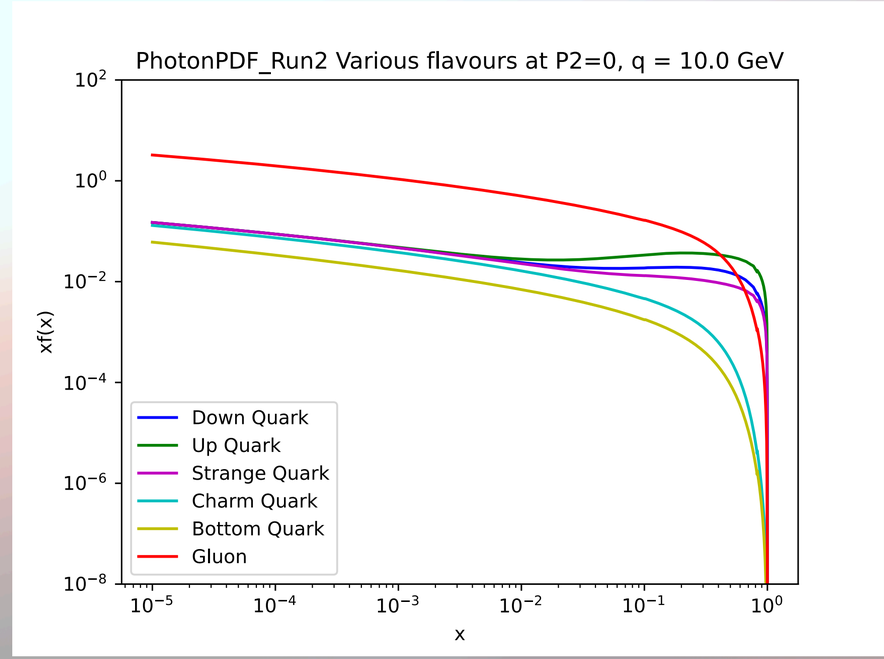

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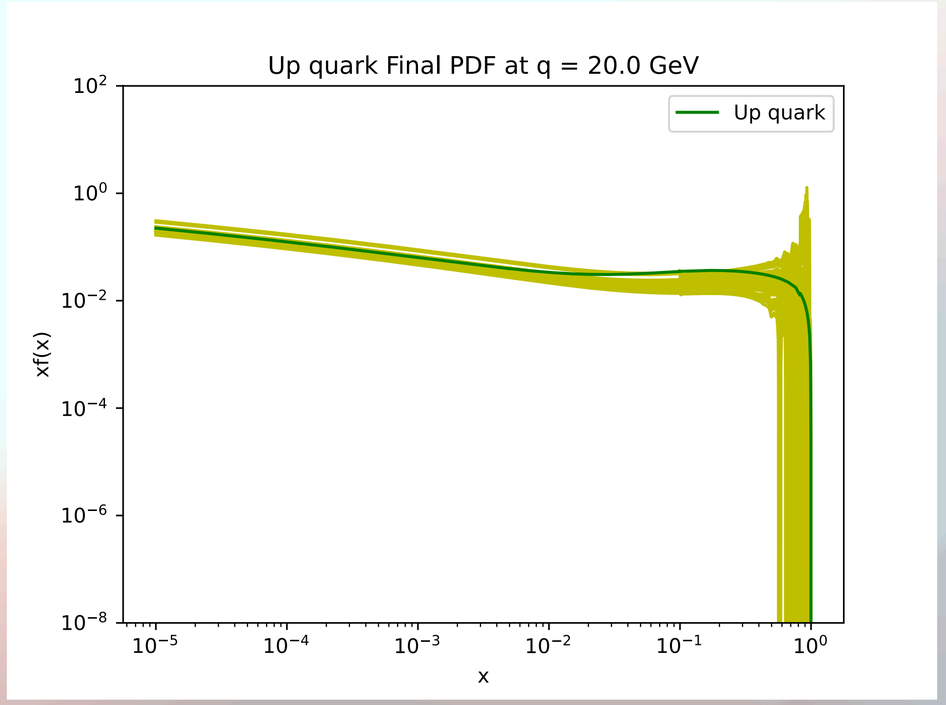

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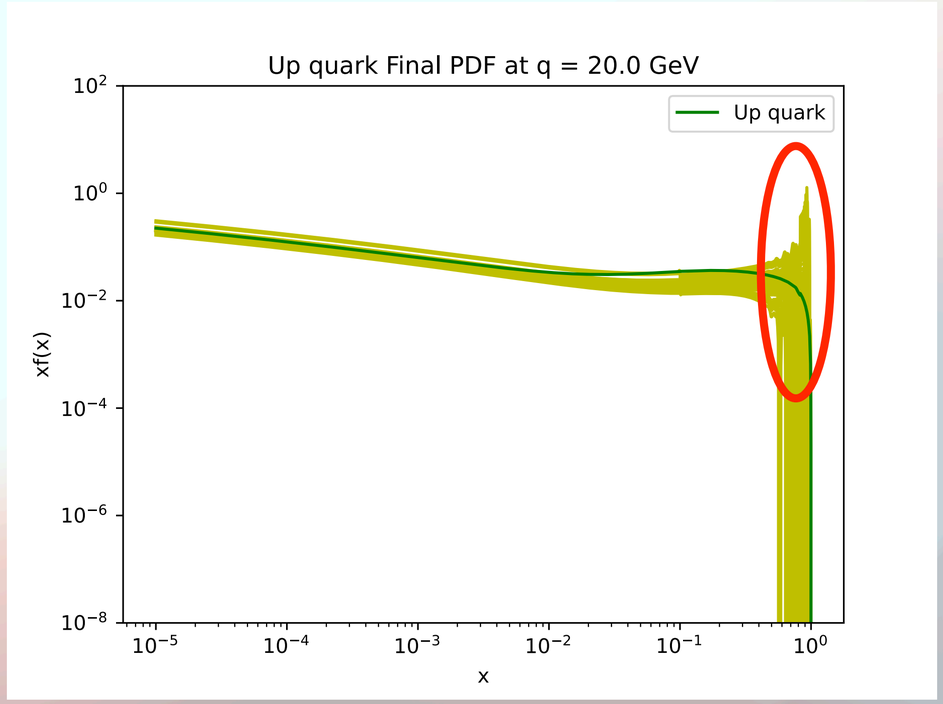

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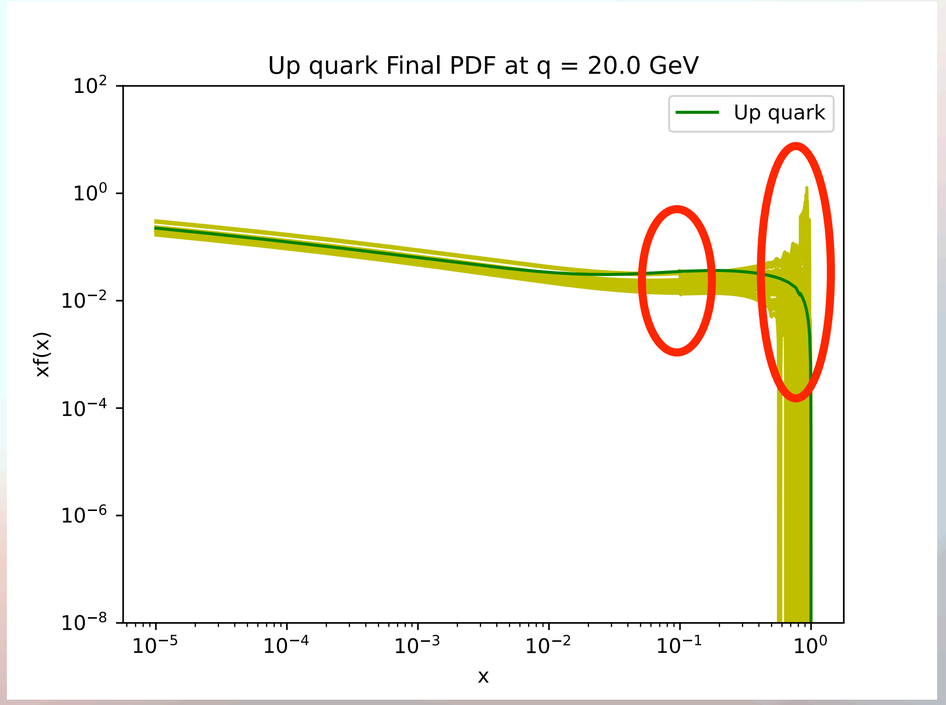

MPI tuning
A Crucial Next Step

- There are MPIs in doubly resolved e-e and resolved e-p processes.
- We can’t simply use p-p MPI tunes for resolved processes in e-p, and similarly for double resolved in e-e. So we need different MPI tunes.
- The data we are using can also constrain this - and we can use the LEP data here without issue.
- And more importantly, we don’t want our PDFs to absorb MPI effects!
- The machinery is already in place, so it seems ideal to do a combined PDF + MPI tune in Sherpa.
- Tune preliminary PDFs with UE-insensitive datapoints -> Use tuned PDF for tuning MPI parameters -> Retune final photon PDF

Conclusions

What we have so far!

- MC tuning with PS + ME generators can give us PDF fits - allows us to produce error sets as well - all @ particle level.
- Hopefully useful to EIC phenomenology efforts when finalised, polished and published!
- The new rivet routines are also potentially useful for other EIC related MC tuning efforts.

Conclusions

What we have to do!

- Fully implement sensitivity to c and b quarks, and incorporate LEP data into an earlier part of the process.
- Deal with errors better - reconsider the current PDF evolution strategies, for smoother PDFs
- Full UE + PDF fits with at least 3 extra parameters.
- Make the move to MC@NLO - accept the longer run times now that prototyping is near-complete.