A new take on resolved-photon PDFs

Particle-level PDF fitting with MC-tuning tools

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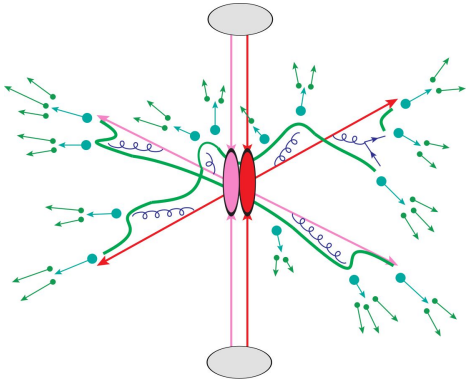
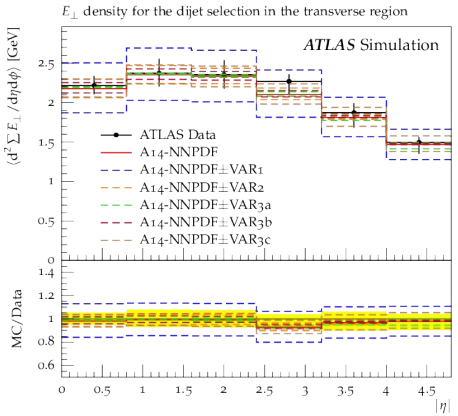
MC-tuning a PDF?

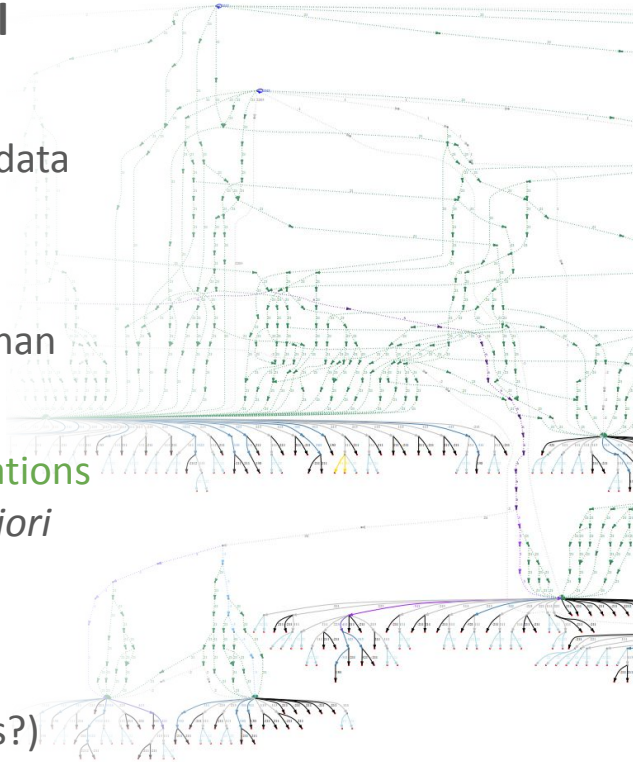
- **“Could you fit a PDF as part of your MC tune?”**
  - — Zoltan Nagy, DESY seminar question, ~2009!
  - My answer was “no”; I’ll show it should have been “yes”
- **Two views of PDFs:**
  - as fundamental properties of nature (or at least of hadrons),
  - and as an ingredient for MC modelling.
- **The first is anyway framed by the perturbative ingredient**
  - Have to deconvolve data wrt fixed-order matrix-elements
  - Typically forces massless-parton approx ⟶ FONLL, etc.
  - Also limitations in the final-state: jet-parton equivalence, etc.
- **Alternative would be to match to a particle-level MC**
  - Historically intractable, but technology has evolved
  - Showing a prototype today, very interested in feedback!





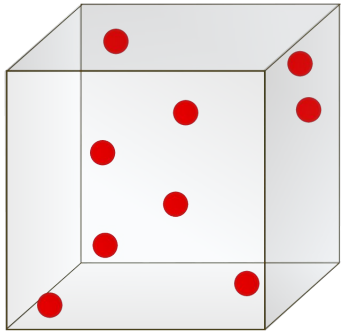
Empirical PDFs via parton-shower MC

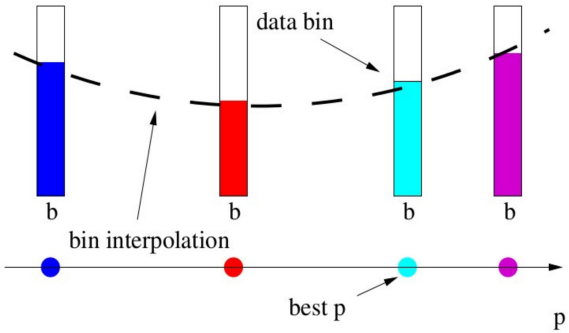
- **Plan: fit empirical "modelling PDFs" using particle-level shower+hadronization event generators**
  - PDF fitting ⇒ iterative minimization of the (PDFs ⊗ ME) - data difference. Already non-trivial: adding a full shower/hadronisation with O(1M) events is crazy…?
  - But desirable: with a good FS tune, access to more data than that with transfer functions or parton/jet safety.
  - Modern ME+SHG generators at >LO can include PDF variations as weights on a single run. Can trial 100s or 1000s of *a priori* PDF variations (modulo caveats)
    - Can view as similar to APPLgrid or FastNLO cachings
    - (Scale-variation weights⟶ scale-compensating PDFs?)



PDF fitting with PS MC surrogates

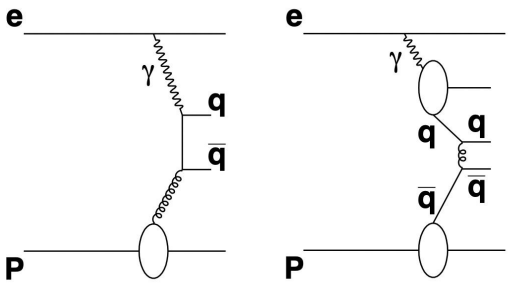
- **MC shower/MPI/hadronisation tuning suggests an alternative approach to parton-level fits:**
  - **sample** a set of *N* low-*Q* PDF-function param vectors ⇒
  - **evolve** into full range of *Q*, and export as an **LHAPDF error set with randomly sampled members**
  - **produce and analyse large MC-event sets**, using PDF weight vectors to produce *N* sets of statistically convergent histograms (automatic in Rivet)
  - **parametrise the response of each bin to the PDF form parameters** (using e.g. the Professor MC tuning interpolations) ⇒ surrogate PDF ⊗ ME ⊗ PS
  - use the fast parametrisations as proxies for full MC runs **⇒ usual iterative fit to reference data**



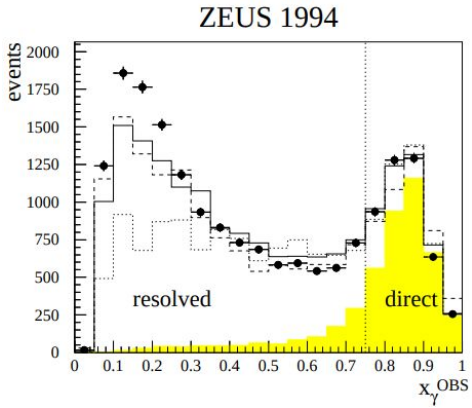


Resolved-photon PDFs

- **A specific application: resolved-photon PDFs**
  - $\gamma \rightarrow q\,q$ allows virtual photon (e.g. in *ep* , *eA* and *AA* — QED enhanced in high-*Z* ultraperipheral collisions) to acquire **hadron-like QCD structure and constituents**
  - NB. no valence quarks, initial structure driven by EM charge



- **EIC is a particular reason to return to photon PDFs**
  - Major activity at HERA, particularly pre-2000
  - PDF error sets developed after e.g. 1996 Schuler-Sjostrand fit: no public resolved-photon sets with error estimation
  - More data, and improved proton PDFs ⇒ **coupled extraction**
  - **⇒ making new resolved-photon PDFs with the most complete LEP and HERA datasets is immediately useful**



Resolved photon PDF strategy

- **Start from SAL parametrisation** [hep-ph/0507091, DIS05]
  - avoid virtuality dependence and VMD effects for now: focus on (quasi-)real via equivalent-photon approximation and (x,Q^2) dependence
  - SAL $x < 0.01$ dominated by Gribov factorization — using $F_2^{\gamma} \sim 0.43\alpha\, F_2^{p}$: 122/286 points. Skip/avoid
  - PDF evolution with APFEL cf. "anomalous" splitting

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

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

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

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

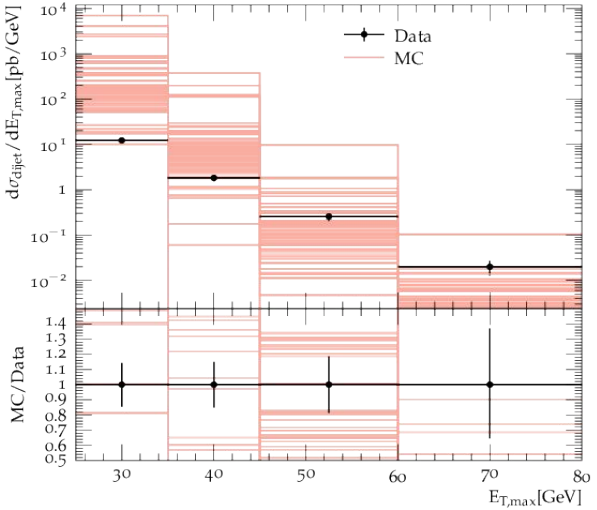
- **Use Sherpa MC generator 3.0.0alpha**
  - Direct and resolved dijet *ep* photoproduction
  - LO ME, CKKW merging of up to one extra jet
  - Weighted variations on random PDF members

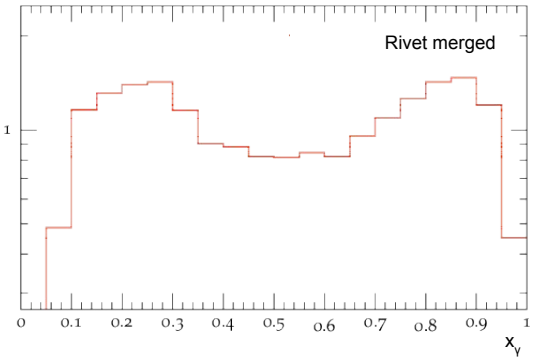
Many thanks to Frank Krauss and Peter Meinzinger for (ongoing) support with trial photon-initiation features in the new Sherpa!

Resolved photon PDF strategy

- **Analyses (in Rivet / implemented for this project)**
  - H1_2002_I581409 (dijet, > 65 bins, new)
  - ZEUS_2001_S4815815 (dijet, > 85 bins)
  - ZEUS_2012_I1116258 (incl jets, > 65 bins)

- Further b- and c-hadron photoproduction analyses implemented, and to be added
- Run 1 x direct analysis, 200 x weighted resolved: scripts to normalize and merge
- 7 params, fitted with weightings biased to low x_γ obs
- Some cross-section issues, resolved in latest Sherpa 3.0.0 alpha ⇒ shape-only fit, floating normalisations with meta-params

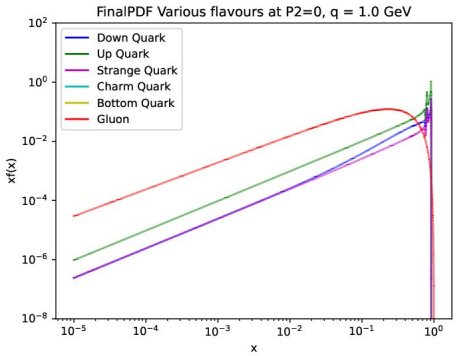




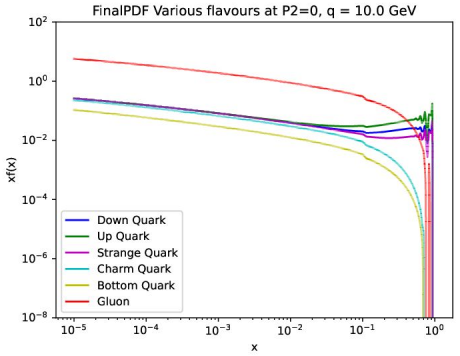
Preliminary results

- **Resulting PDFs**
  - Low-*Q* peaking at high-*x*, i.e. fairly "clean" splitting to *qq* if not direct. Low-*x* structure develops rapidly.
  - Heavier quarks penalised by mass. Charge sensitivity.
    High-*x* oscillations?!
- **Uncertainties**
  - Simplest approach is bootstrapping by resampling ref data from its error bars: re-fit the ipols to each smeared ref dataset → multiple tunes
  - "Eigentunes" →Hessian to come.

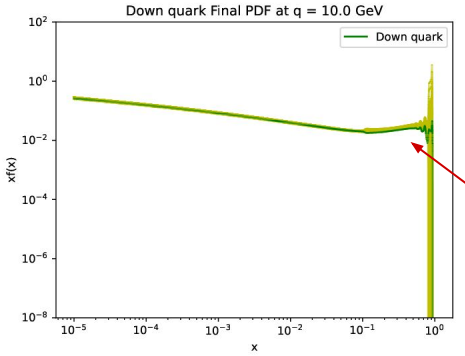
Q = 1 GeV (fit)



Q = 10 GeV (evolved)



Prelim replica uncertainties



fixing known issues with band-step, and asymm nominal!

Summary and outlook

- **MC tuning + latest PS-level MC technology enables PDF fits + uncertainties from particle-level data**
- **Prototype application on resolved-photon PDFs for EIC, via LHAPDF+Sherpa+Rivet+Professor MC tools**
- **More to do! Several issues to fix before release:**
  - add LEP resolved-photon analyses, including both single- and double-resolved processes: PDF variation-index correlation needed, still in development
  - apply cross-section fixes and update to NLO MEs → use absolute cross-sections in the fit
  - add HERA *b*- and *c*-hadron specific analyses to better fix the HF PDF flavours (implemented and in testing)
  - xReconsider parametrisation, cf. high-*x* wobbles.
- **Your feedback is very welcome!!**

SAL PDFs for comparison