Example Software to Implement nPDF Weighting

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October 1, 2021

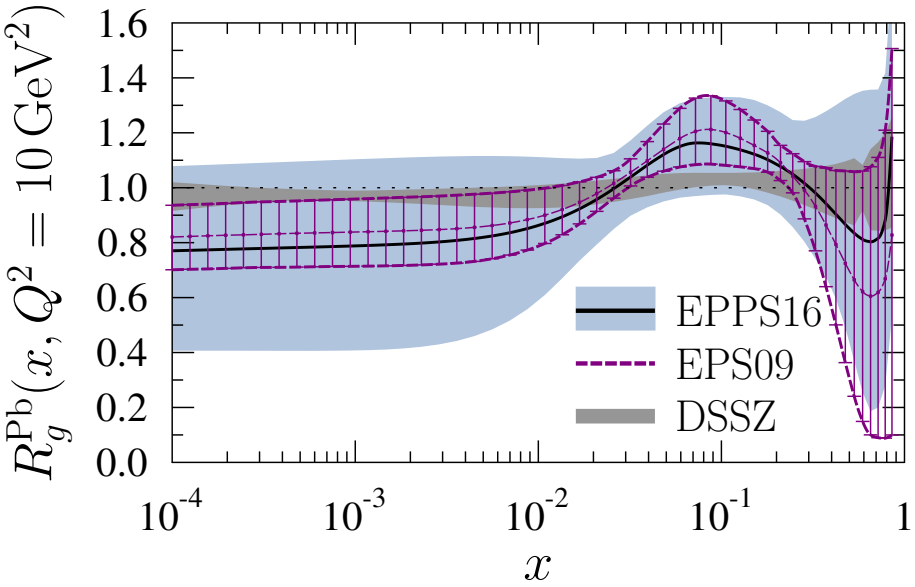
The General Idea

- Simulate e+A rates by weighting e+p MC generated events at analysis time.
- This weighting will **only** modify rates and is only good for estimating R_{eA}.
  - no jet fragmentation modification
  - no two-particle correlation broadening
  - etc.
- This is an estimate only. Real MCs sample the PDFs for the hard scattering calculation.

Nuclear PDF (nPDF) Fitting

- PDF $\phi_i^p(x, Q^2)$ fitting follows from the factorization theorem
- $d\sigma^{ep\to hX} \propto d\hat{\sigma}^{\gamma^* f_i \to f_i} \otimes \phi_i^p(x, Q^2) \otimes D_i^h(z)$
- nPDF fit data from nuclear targets starting with $\phi_i^p(x, Q^2)$ and finding the nuclear modification

$$R_i^A(x, Q^2) = \frac{\phi_i^A(x, Q^2)}{A\phi_i^p(x, Q^2)}$$



Comparison of nuclear modification of 3 different nPDFs from EPPS16 paper

Example EPS09

- EPS09: K. J. Eskola, H. Paukkunen and C. A. Salgado, "EPS09 - a New Generation of NLO and LO Nuclear Parton Distribution Functions," JHEP04(2009) 065
- The fortran (and c++ version it turns out) code and all LO and NLO grids are available from

  `https://www.jyu.fi/science/en/physics/research/highenergy/urhic/npdfs/eps09`
- Uses `CTEQ6.1M` proton PDF – ideally this is what you run for the MC generator

Example EPS09

- There is a single method

  `EPS09(order, pset, A, x, Q, ruv, rdv, ru, rd, rs, rc, rb, rg)`

  - `order` $= 1$ (LO), 2 (NLO)
  - `pset` $= 1$ (central value), 2 & 3 ($\pm 1\sigma$), etc. (31 sets total)
  - `A, x, Q` = atomic mass, x and $\sqrt{Q^2}$ of the partonic collision.
  - It returns `ruv, rud, ru, rd, rs, rc, rb, rg` = u, d, $\bar{u}$, $\bar{d}$, $s + \bar{s}$, $c + \bar{c}$, $b + \bar{b}$ and g nuclear modification factor $R_i^A(x, Q^2)$

EPS09 C++ Wrapper

```
13  class AUEPS {
14
15   public:
16
17    /**
18     * @brief Constructor
19     * @brief A - the nuclear mass
20     */
21    AUEPS(int A, int order=1) : _A(A), _order(order) {}
22
```

```
28    /**
29     * @brief Return the LO modification factor for a given parton,
30     *        error set, x, and Q values
31     * @param parton - the pdg id of the parton to evaluate
32     *           21) gluon
33     *           1) d valence
34     *           2) u valence
35     *          -1) bar(d)
36     *          -2) bar(u)
37     *        (-)3) (bar)s
38     *        (-)4) (bar)c
39     *        (-)5) (bar)b
40     * @param set - the error set
41     *           1) central values
42     *           2,3) +/- 1 sigma uncertainties
43     *           4,5) +/- 2 sigma uncertainties
44     *           ...
45     *           30,31) +/- 15 sigma uncertainties
46     * @param x - the energy fraction the parton carries of the
47     *            projectile or target
48     * @param Q - the sqrt(Q^2) of the interaction
49     */
50    double pdfmod(int parton, int set, double x, double Q);
```

- `pdfmod` simply calls the EPS09 fortran code and returns the appropriate nPDF modification for the requested parton.

Applying nPDF Weights

- The nuclear modification is determined from `pdfmod` for an event.
- If one loops over e+p events and adds a weight of 1 for rate histograms, these would represent the e+p rates.

```
hjetpt_ep->Fill(jetpt)
```

- If one loops over e+p events and adds a weight from `pdfmod`, these would represent the e+A rates.

```
double weight = pdfmod(...);
hjetpt_eA->Fill(jetpt,weight);
```

- Nuclear modification to the rate is then the ratio of the two histograms

```
hReA = hjetpt_eA->Clone(...);
hReA->Divide(hjetpt_ep);
```

$$R_{eA} = \frac{\text{unweighted rate histogram}}{\text{weighted rate histogram}}$$

LHAPDF

- The fortran versions (prior to ver. 6) had EPS09 interface
- The current C++ version has EPPS16, nNNPDF nCT15 versions of nPDFs
- LHAPDF is available on RHIC machines. Not sure if it part of ECCE offline environment and I didn't check.
- But, in principle, that is a general interface that we could use. Though I don't have too much experience coding with that.