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ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

INFN Gruppo Collegato di Cosenza Istituto Nazionale di Fisica Nucleare

Measurement of inclusive DDIS in EIC and determination of DPDFs with EIC Pseudodata

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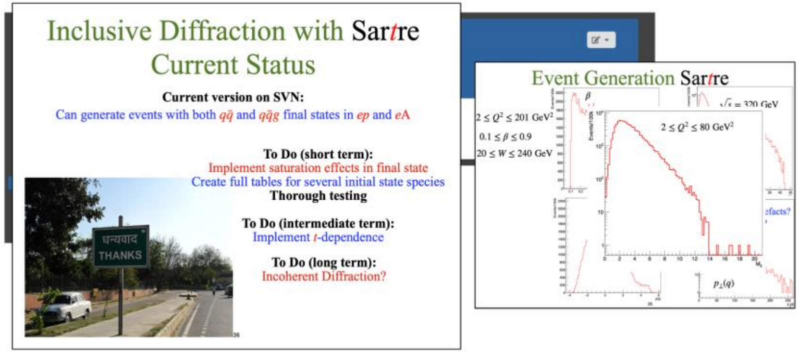
Jan. 23, 2025

ePIC collaboration meeting

Outline:

- Motivation
- What has been so far
- What is the plan for future

Early Science - Inclusive diffraction



Inclusive DDIS in eP/eA process:

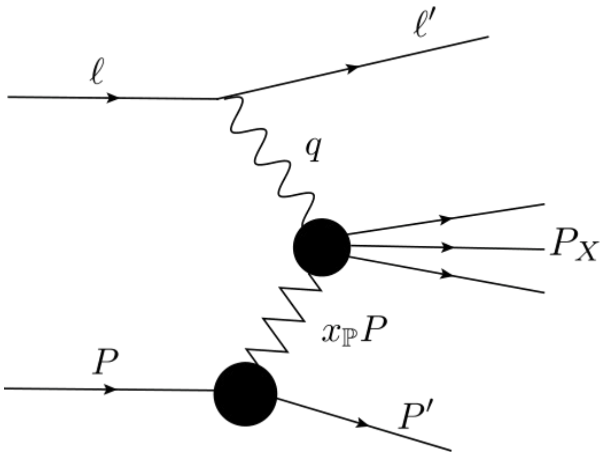
$$Q^2 = -q^2 = (l' - l)^2 \qquad y = \frac{P.q}{P.l} \qquad x = \frac{Q^2}{2P.q}$$

$$x_{\mathbb{P}} = \frac{2(P - P').q}{P.q} \qquad \beta = \frac{Q^2}{2(P - P').q} = \frac{x}{x_{\mathbb{P}}}$$

Triple differential Cross section

$$\frac{d\sigma^{ep\to epX}}{d\beta dQ^2 dx_{\mathbb{P}}} = \frac{2\pi\alpha^2}{\beta Q^4}[1 + (1 - y)^2]\sigma_r^{D3}(\beta, Q^2; x_{\mathbb{P}})$$

$$\sigma_r^{D3}(\beta, Q^2; x_{\mathbb{P}}) = F_2^{D3}(\beta, Q^2; x_{\mathbb{P}}) - \frac{y^2}{1 + (1 - y)^2} F_L^{D3}(\beta, Q^2; x_{\mathbb{P}})$$



Using the factorization theorem on Fracture functions

$$F_k^{D3}(\beta, Q^2; x_{\mathbb{P}}) = \sum_i \mathcal{F}_i^{D3}(\beta, Q^2; x_{\mathbb{P}}) \otimes C_{ki}(\beta, Q^2, \alpha_S)$$

Fracture functions: An Improved description of inclusive hard processes in QCD Phys. Lett. B 323, 201 (1994)

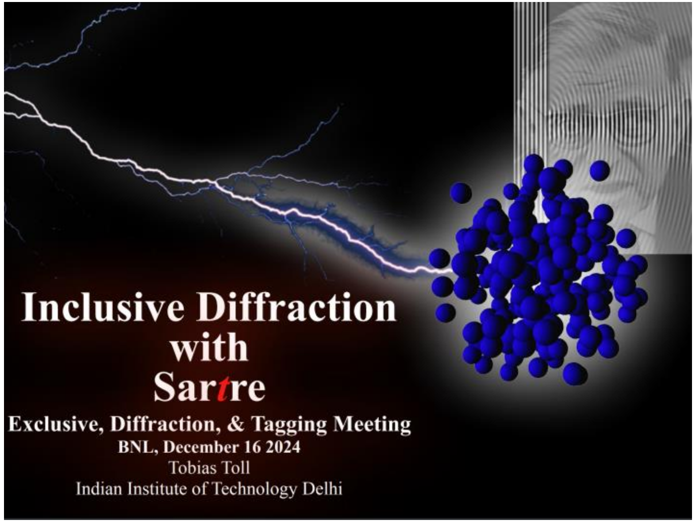
Monte Carlo Event Generators:

- We are going to use RAPGAP for event generation
- Event generation based on 10 fb^{-1}= 10^7 nb^{-1} luminosity and sigma = 4.22 nb:
-

  number of events:

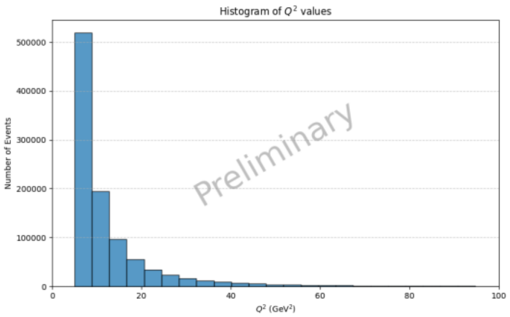
  4.22 (nb) * 10^7 (nb^{-1}) =~ 4.2x10^7 events
- 42 million events as mock data.
- 42 million events as MC data, totaling 84 million events.
- Proton momentum : 100 GeV
- Electron momentum : 10 GeV
- SARTRE for ep and eA inclusive, beta soon(?) Tobias Toll talk @ Exclusive, Diff. and tagging WG
- Then we can have a nice comparison between these two

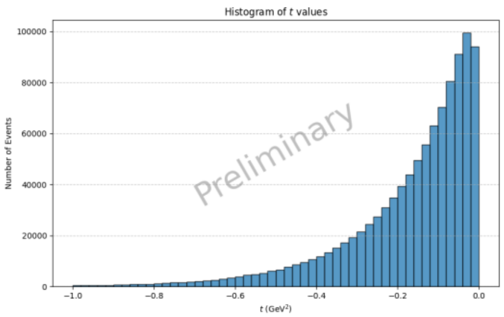
https://indico.bnl.gov/event/25025/contributions/100107/attachments/59181/101676/SartreInclusiveDiffraction.pdf

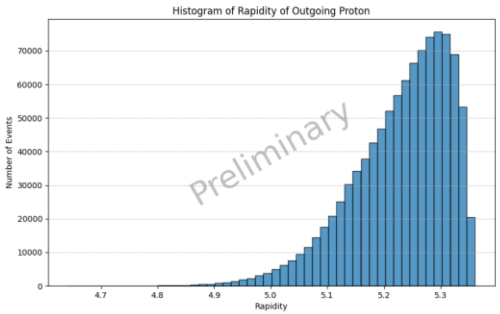


Control distributions:

- **Q^2 Distribution**:
- **t Distribution**:
- **Rapidity of Outgoing Proton**:
- **Overall**:
    - Dominant forward-scattering component with minimal momentum transfer, characteristic of diffractive and elastic processes

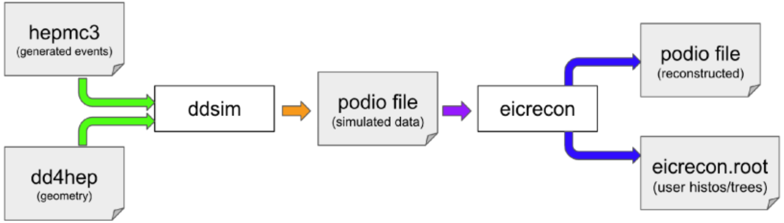






Update on event generation:

- The workflow of detector simulation and reconstruction needs HepMC3 format
- We found out that the version 3.310 of RAPGAP with HepMC support has a bug, in some events there are more than 2 particles designated as beam!
- We are in contact with Hannes Jung about this




```
E 2 11 28
U GEV MM
W 1.0000000000000000000000e+00
A 0 GenCrossSection 4.22617769e+03 1.23955151e+01 -1 -1
A 0 GenPdfInfo 11 2212 3.07580054e-01 5.40348813e-02 6.64962981e+01 -3.07580042e+00 5.40348816e+00 252 10041
A 0 alphaQCD -1
A 0 alphaQED -1
A 0 event_scale 66.4963
A 0 mpi -1
A 0 random_states 0
A 0 signal_process_id 0
A 0 signal_process_vertex 0
P 1 0 11 1.7763568394002505e-15 0.0000000000000000e+00 -9.9999999999999609e+00 1.0000000013005049e+01 5.1000000000000004e-04 4
P 2 1 23 2.4461285218615494e+00 -6.3292634422228229e+00 -4.7382444723232906e+00 1.4134295707586053e+00 -8.1545262274720809e+00 3
P 3 1 11 -2.4461285218615494e+00 6.3292634422228264e+00 -5.2617555276767298e+00 8.5865704422463729e+00 5.1000000000000004e-04 1
P 4 0 2212 -1.7763568394002505e-15 3.5527136788005009e-15 1.0000000000000000e+02 1.0000440165609162e+02 9.3827000000000005e-01 4
P 5 4 990 1.6697379176052896e-01 -2.8478672883558431e-03 1.4687212367650162e+01 1.4686291195575638e+01 -2.3440650310167599e-01 3
P 6 4 21 2.7739710433714315e-01 1.0555810530099841e-01 1.0997649207188017e+01 1.1001052652471973e+01 -0.0000000000000000e+00 3
P 7 4 2212 -1.6697267947604644e-01 2.8477799149158045e-03 8.5312233960207607e+01 8.5317556820736741e+01 9.3827000000000005e-01 1
P 8 4 21 -4.5373307959223674e-02 -7.2619797935561059e-02 3.6628929682694622e+00 3.7301631669989908e+00 6.9999998807907104e-01 2
P 9 2 1 3.5291873685974604e+00 -5.2447542032833976e+00 7.5698783562734562e-01 6.3753071077930450e+00 3.3000000000000002e-01 3
P 10 9 1 3.5291873685974604e+00 -5.2447542032833976e+00 7.5698783562734562e-01 6.3753071077930450e+00 3.3000000000000002e-01 2
P 11 0 21 2.6442149021873207e-01 -5.6189047227182543e-02 2.4018956585142837e+00 2.5163820598665572e+00 6.9999998807907104e-01 4
P 12 0 -1 -1.1351332572460775e+00 -9.5854821236685406e-01 3.1271913558982938e+00 3.4778683073892824e+00 3.3000000000000002e-01 4
```

Afterburner will complain here

Conclusions and Future Directions

- We are working with RAPGAP v3.310 and waiting for SARTRE to be ready for inclusive diffraction.
- We believe that using RAPGAP/SARTRE inclusive events provide a good comparison that gives us insight into early science study.
- We think that a neural network parameterization, combined with new pseudodata from ePIC, will improve the precision and reliability of DPDF extraction beyond current limits.
- Progress on fitting code and ROOT analysis scripts is ongoing.

Thank You!

Backup slides

Neural Network Approach to Parameterization

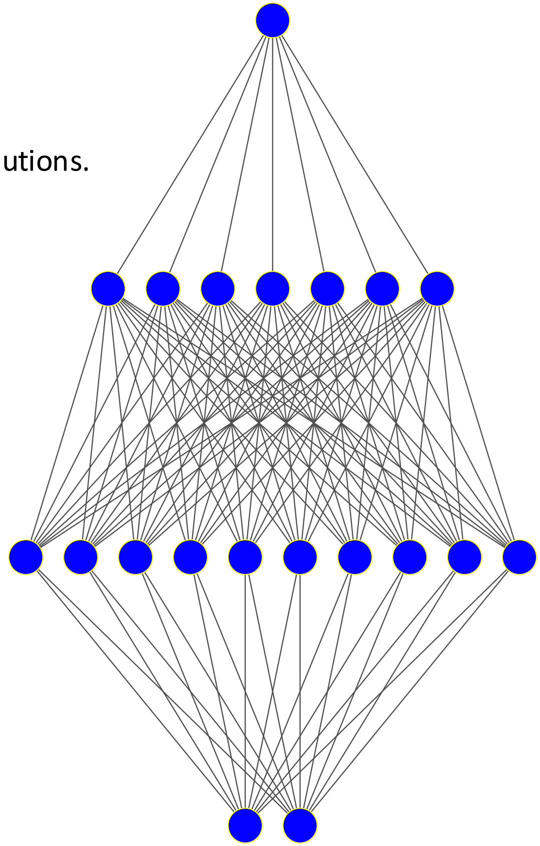
- **A Feed-forward neural network** with two hidden layers used to parametrize diffractive distributions.
- Benefits of using NNs: flexibility, no need for strict theoretical assumptions.

$$\beta\mathcal{F}_q^D(\beta, Q_0^2; x_{\mathbb{P}}) = \mathcal{W}(x_{\mathbb{P}})(NN_1(\beta, Q_0^2) - NN_1(1, Q_0^2))^2$$

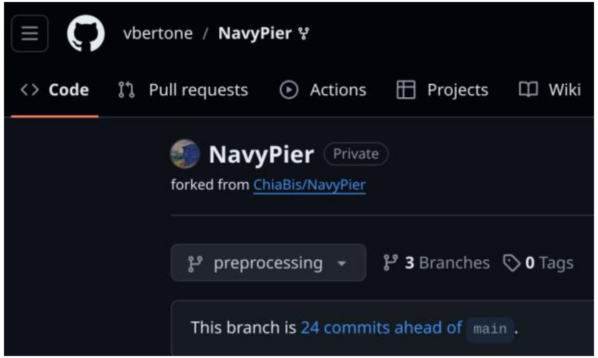
$$\beta\mathcal{F}_g^D(\beta, Q_0^2; x_{\mathbb{P}}) = \mathcal{W}(x_{\mathbb{P}})(NN_2(\beta, Q_0^2) - NN_2(1, Q_0^2))^2$$

$$Q_0^2 = 2 \text{ GeV}^2$$

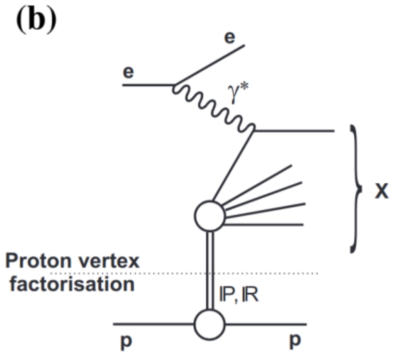
$$\mathcal{W}(x_{\mathbb{P}}) = x_{\mathbb{P}}^{w_1}(1 - x_{\mathbb{P}})^{w_2}(1 + w_3 x_{\mathbb{P}}^{w_4})$$



DPDF analysis: Computational Tools



- **Code Name**: NavyPier
- **Programming Language**: C++
- **Based On**: APFEL++
- Used for **DGLAP evolution** and **convolution integrals**.
- **Core Functionalities**:
  - **DGLAP Evolution**: Solves equations related to PDFs using APFEL++.
  - **Convolution Integrals**: Computes integrals using APFEL++.
  - **Parameterization**: Utilizes a feed forward NN library NNAD.
- **Optimization Tool**: Uses Google's **CERES Solver** to minimize the chi-squared function.
- **Uncertainty Estimation**: Implements the Monte Carlo replica method.



$$F_{2/L}^{D(4)}(\beta, Q^2; x_{I\!P}, t) = \sum_i \int_\beta^1 \frac{dz}{z} C_{2/L,i}\left(\frac{\beta}{z}\right) f_i^D(z, Q^2; x_{I\!P}, t),$$

$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i(\beta = x/x_{I\!P}, Q^2)$$

parameterized by NNs

$$f_{I\!P,I\!R}(x_{I\!P}, t) = A_{I\!P,I\!R} \frac{e^{B_{I\!P,I\!R}\, t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}},$$

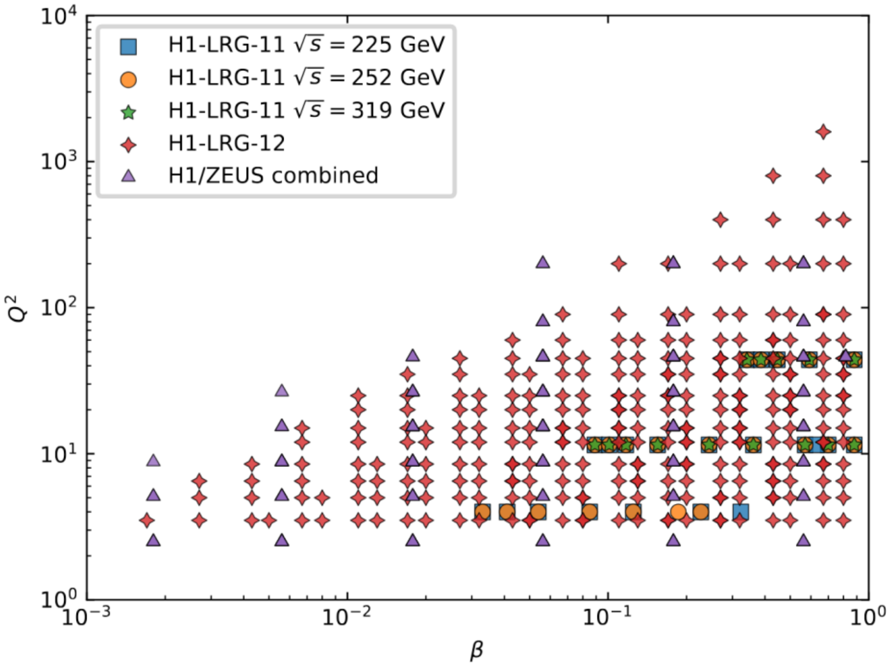
Update on fitting code:

Standard Pomeron-Reggeon approach is added to the fitting code, (testing)

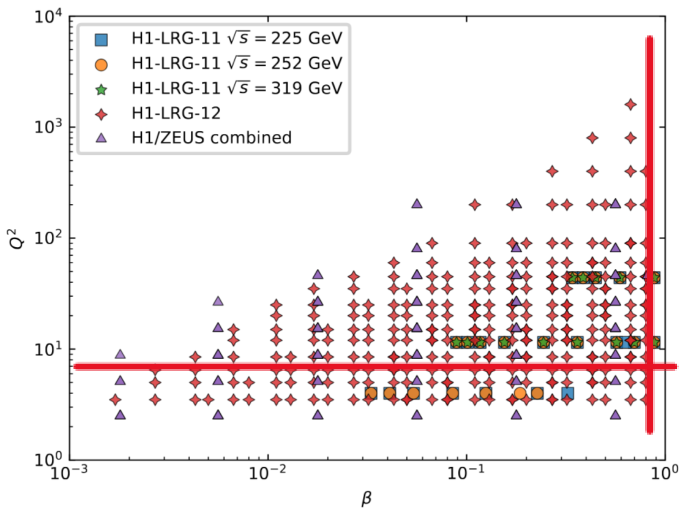
```
    double xp = 0.003; // this is for substitution in A_P see hep-ex/0606004 eq. (14) and below
    // Calculate the quantity
    double denom_A_Pom = (-((std::pow(xp, 2 * alpha_val)) / std::exp(B_val)) + (std::exp((B_val * m_val * m_val * xp *
(std::pow(xp, (2 * m_val * m_val * xp * xp * alpha_val) / (-1 + xp))));
    double A_Pom = ((std::pow(xp, -2 + 2 * alpha0_val)) * (B_val - 2 * alpha_val * std::log(xp))) / denom_A_Pom;

    // we are going to multiply the flux factor by xPom, because the observable we are interested in is xPom*sigma_red
    return std::vector<double>{
    // Expression
    xp_val * A_Pom * ( xp_pow_1_minus_2_alpha0 * (-(xp_alpha_term / exp_B) + common_exp / xp_alpha_common)) / denom
    ,

    // Derivatives
    // Derivative w.r.t. B
```

Diffractive DIS data sets from HERA

- F. D. Aaron et al. [H1 Collaboration],
- Measurement of the diffractive longitudinal structure function *FLD* at HERA. Eur. Phys. J. C **72**, 1836 (2012).
- F. D. Aaron et al. [H1 Collaboration],
- Measurement of the diffractive longitudinal structure function FLD at HERA. Eur. Phys. J. C **71**, 1836 (2011).
- F.D. Aaron et al. [H1 Collaboration],
- Inclusive measurement of diffractive deep-inelastic scattering at HERA. Eur. Phys. J. C **72**, 2074 (2012).
- F.D. Aaron et al. [H1 and ZEUS Collaborations],
- Combined inclusive diffractive cross sections measured with forward proton spectrometers in deep inelastic ep scattering at HERA.
- Eur. Phys. J. C **72**, 2175 (2012).



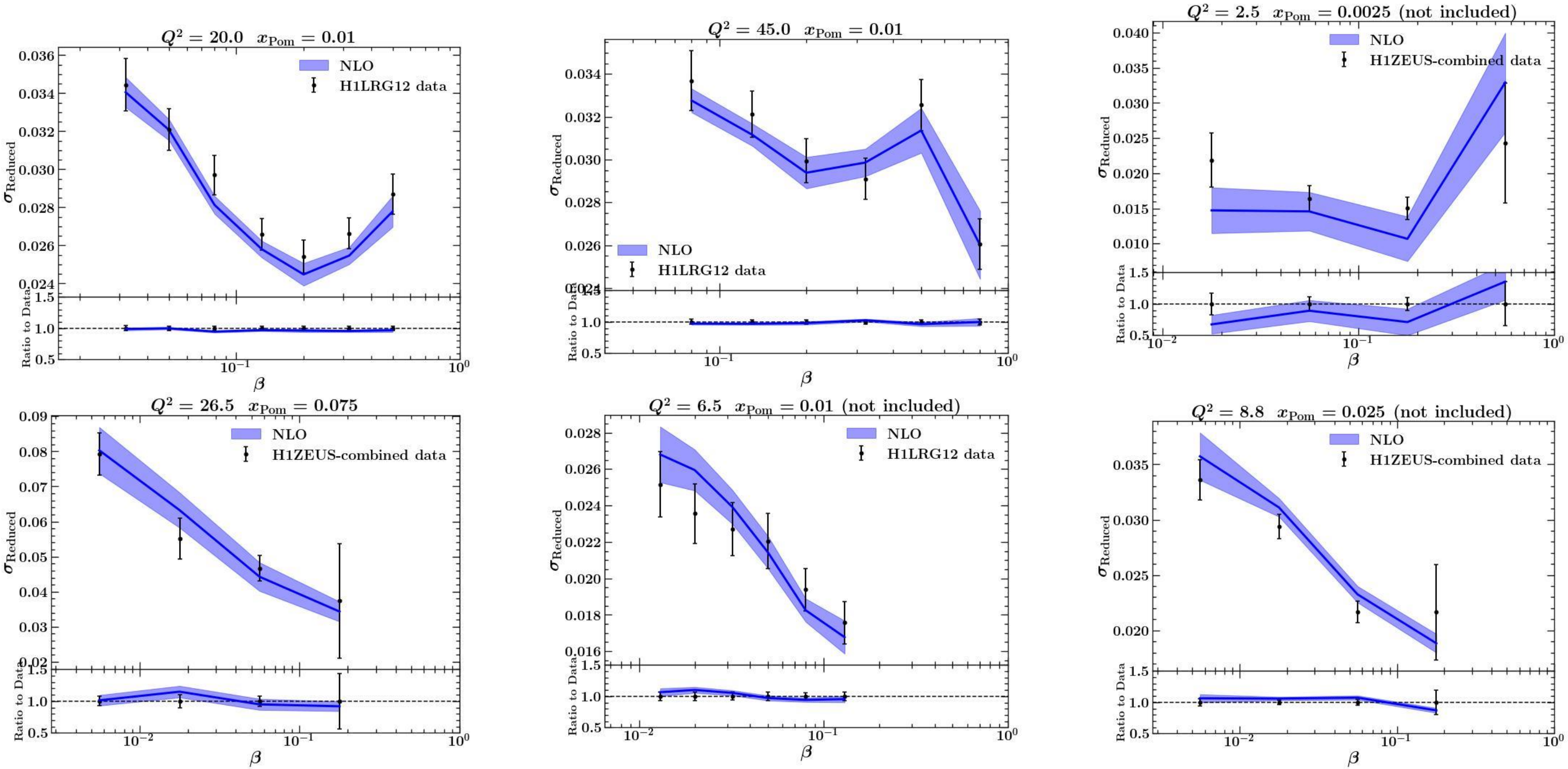
Training the Neural Network



- NN trained using **HERA reduced cross-section data**. NN adjusts weights iteratively, learning the correct mapping between input momentum fraction and DPDFs.
- **Optimization**: Chi-squared minimization between predicted and observed diffractive cross-sections.
- We use H1 Large rapidity gap data and H1/Zeus combined proton spectrometer data.
- Kinematical cuts:
  - $\beta \leq 0.80$
  - $Q^2 > 8.5$ GeV^2 for all the datasets
  - After the cuts we have 301 datapoints
  - Total chi-squared over number of datapoints: 0.88

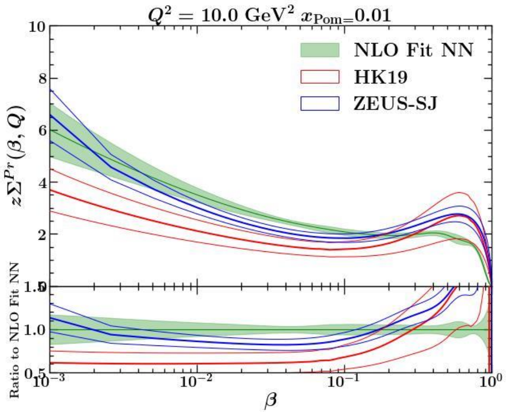
Results

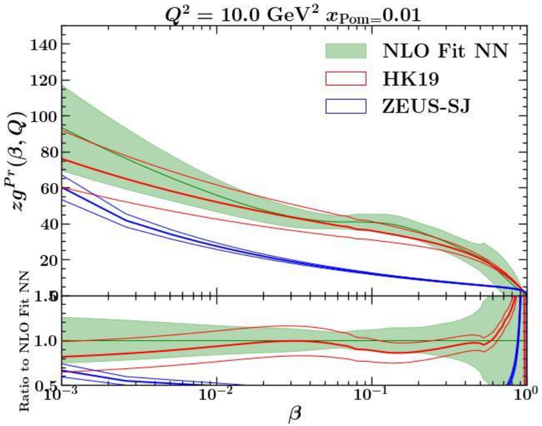
- Fair agreement between **data and NN predictions**.



Results

- NN results show a fair matching with previous DPDF determinations.
- **Monte Carlo method** applied for uncertainty estimation: generating pseudo-datasets (replicas) to calculate central values and uncertainties.





HK19 : PRD99 , 054007 (2019)
ZEUS-SJ: NPB831, 1 (2010)