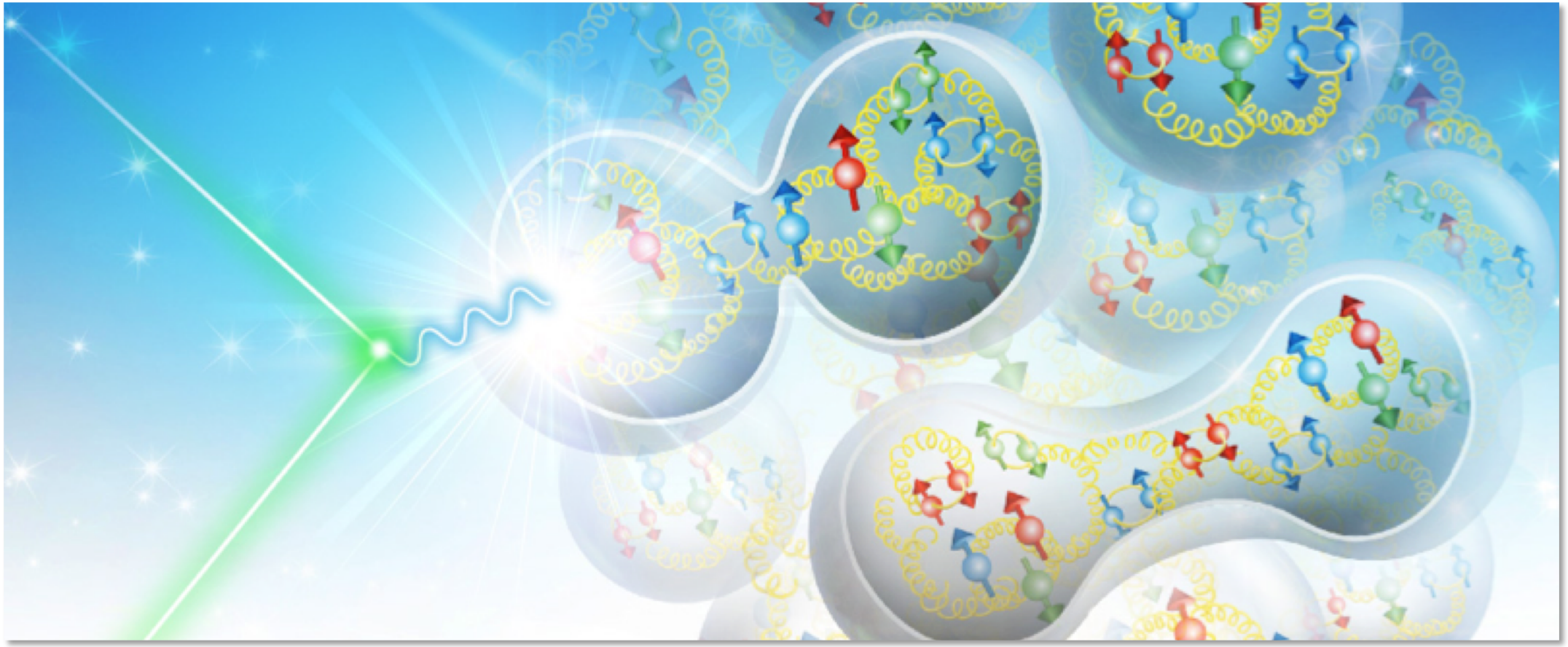
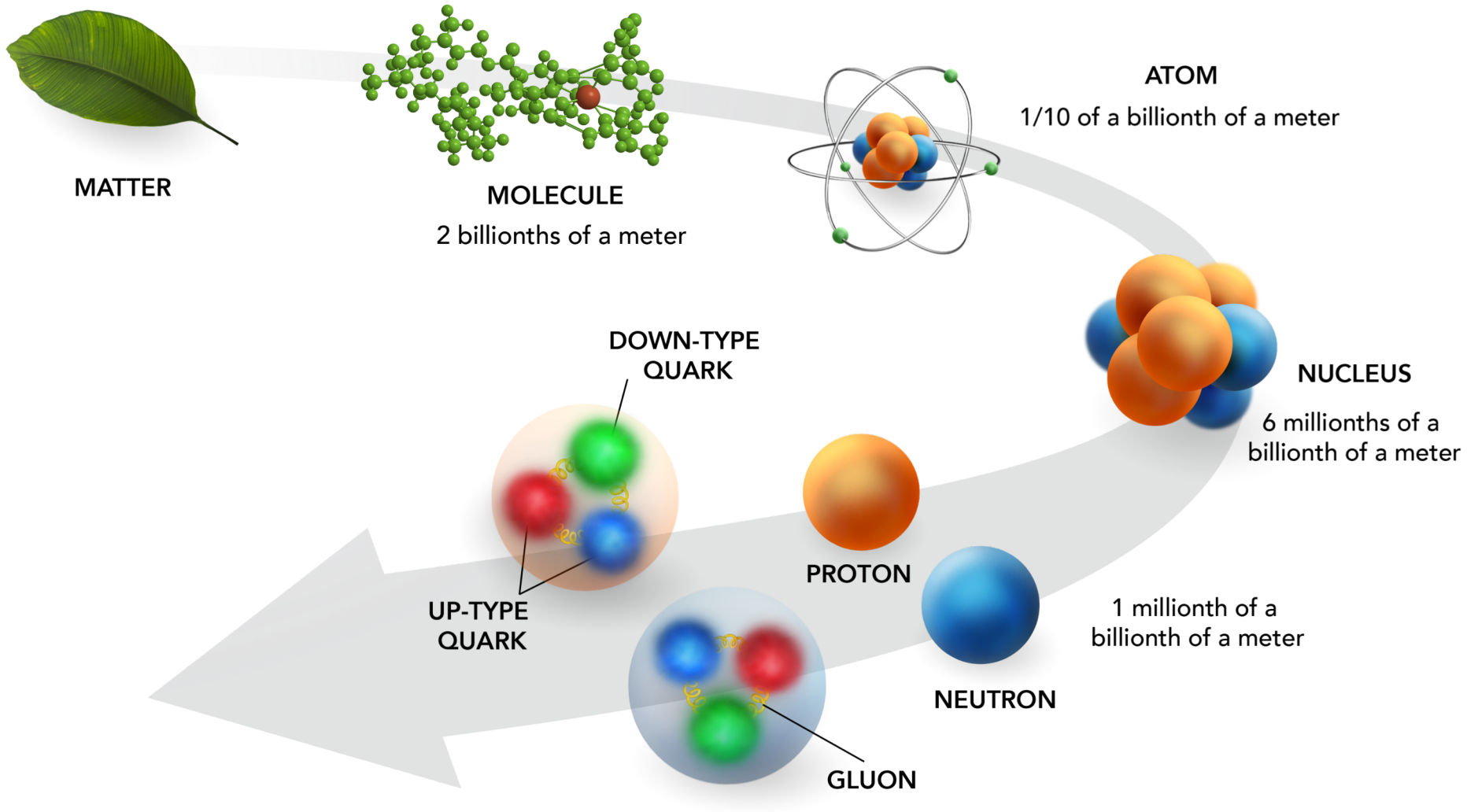
Deeply Learning Deep-Inelastic Scattering Kinematics



Markus Diefenthaler

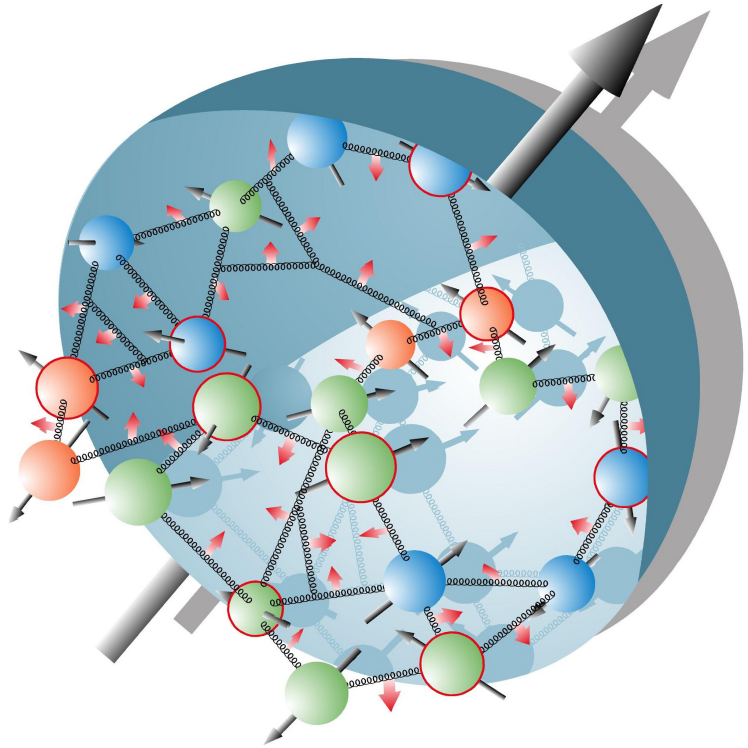
Jefferson Lab

Building blocks of matter

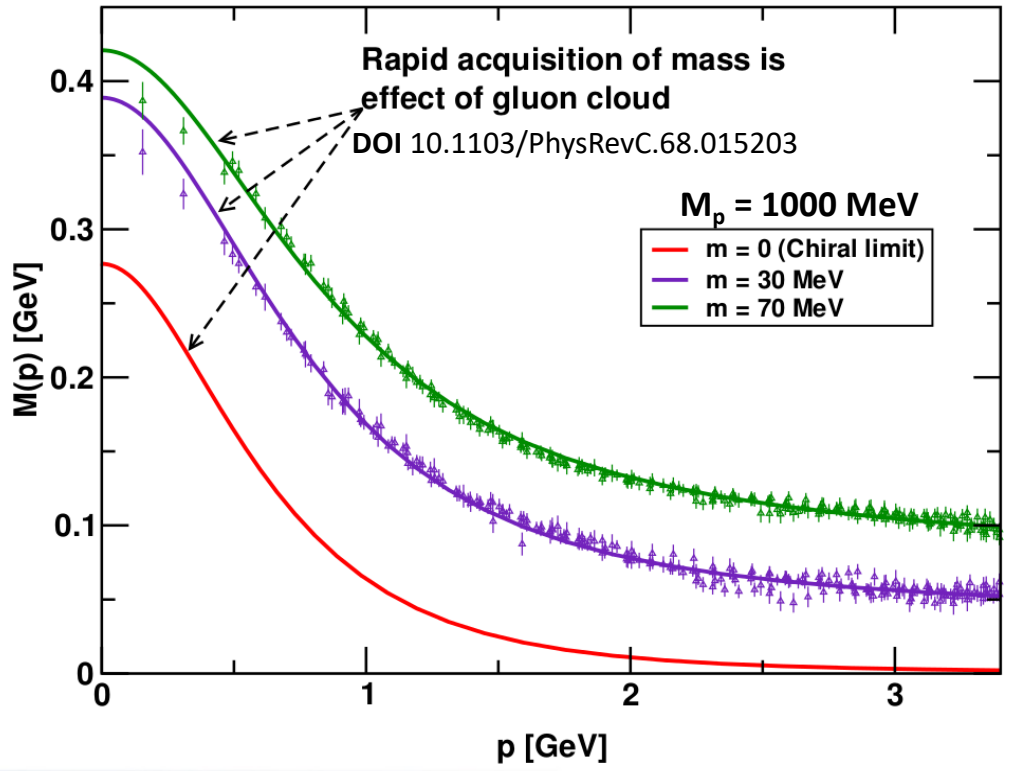


The dynamical nature of nuclear matter

Nuclear Matter Interactions and structures are inextricably mixed up



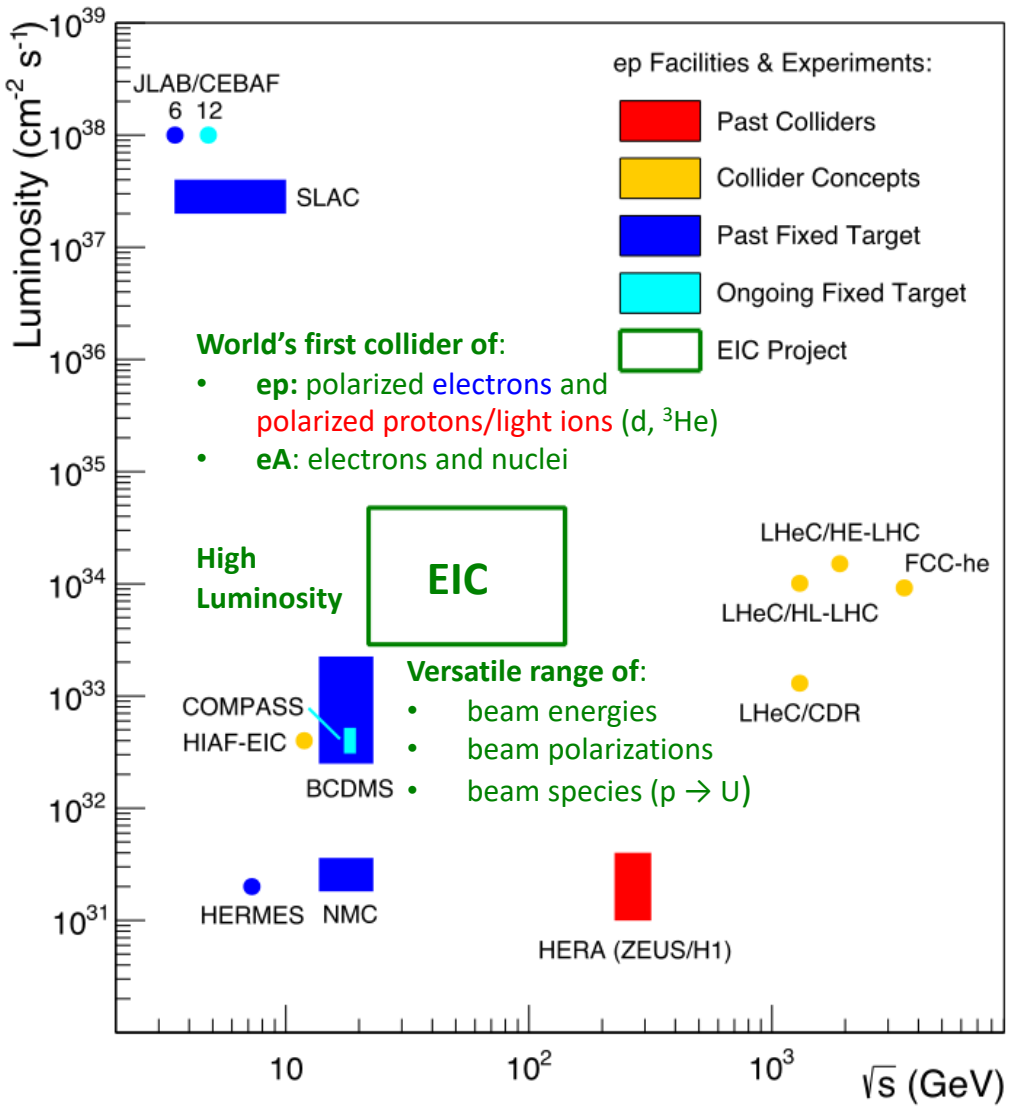
Observed properties such as mass and spin emerge out of the complex system



Ultimate goal Understand how matter at its most fundamental level is made

To reach goal precisely image quarks and gluons and their interactions

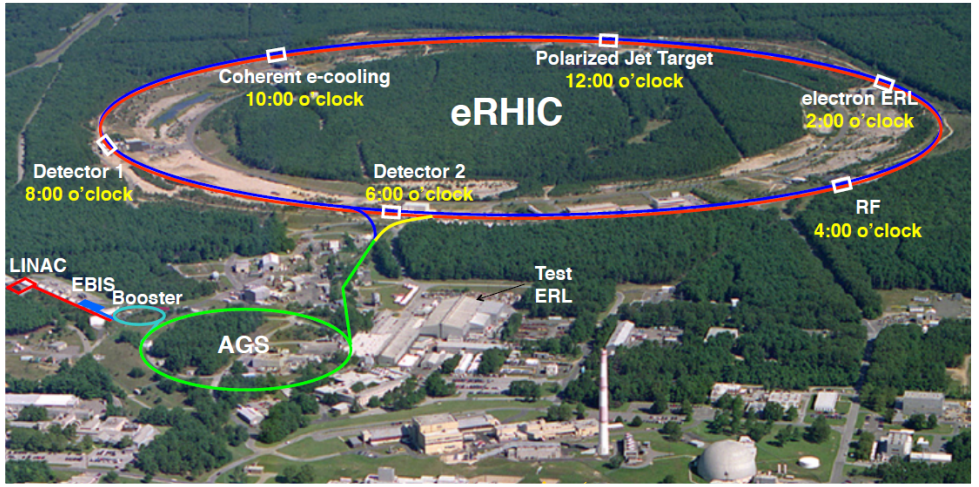
The Electron-Ion Collider: Frontier accelerator facility in the U.S.



Department of Energy

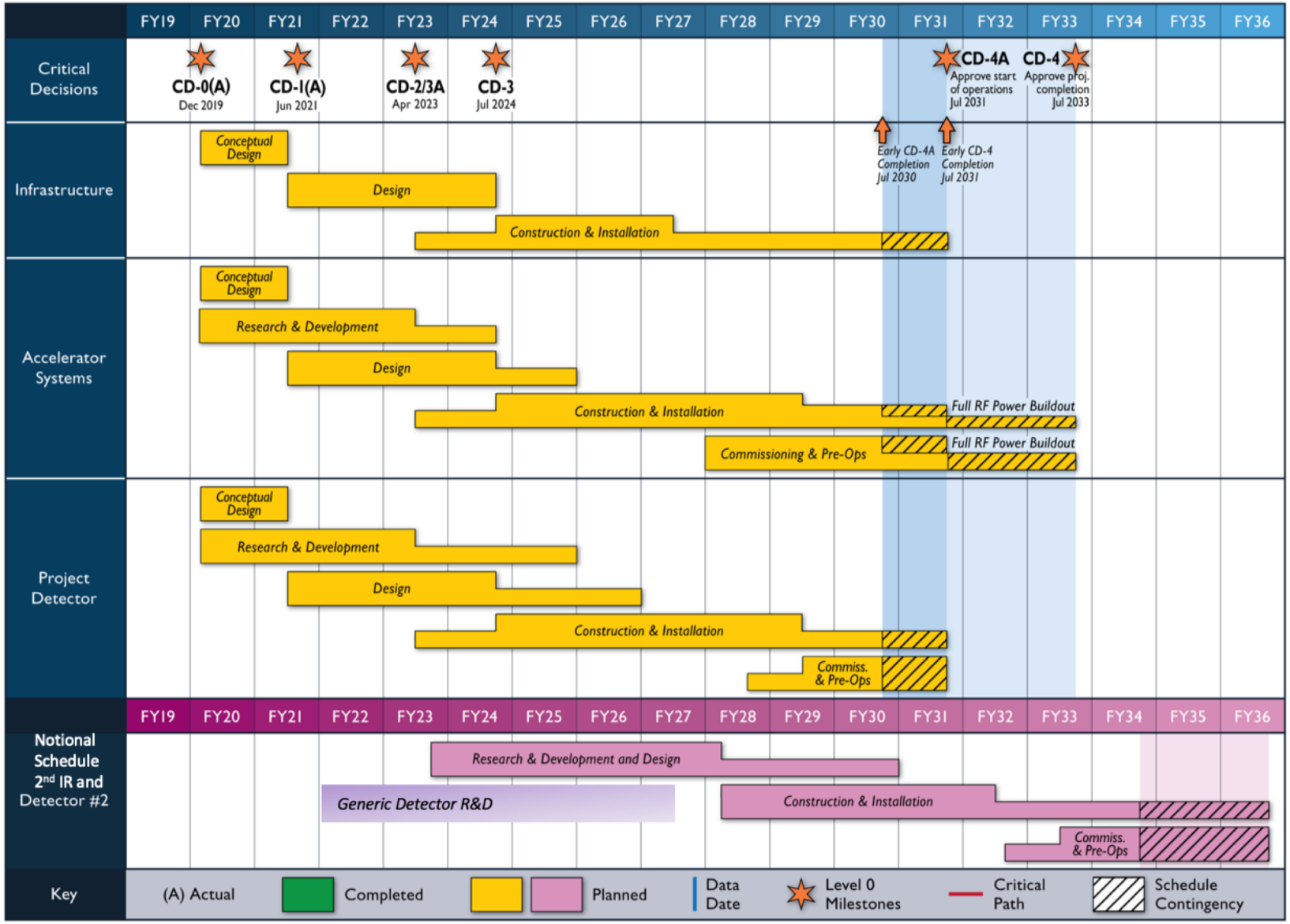
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020



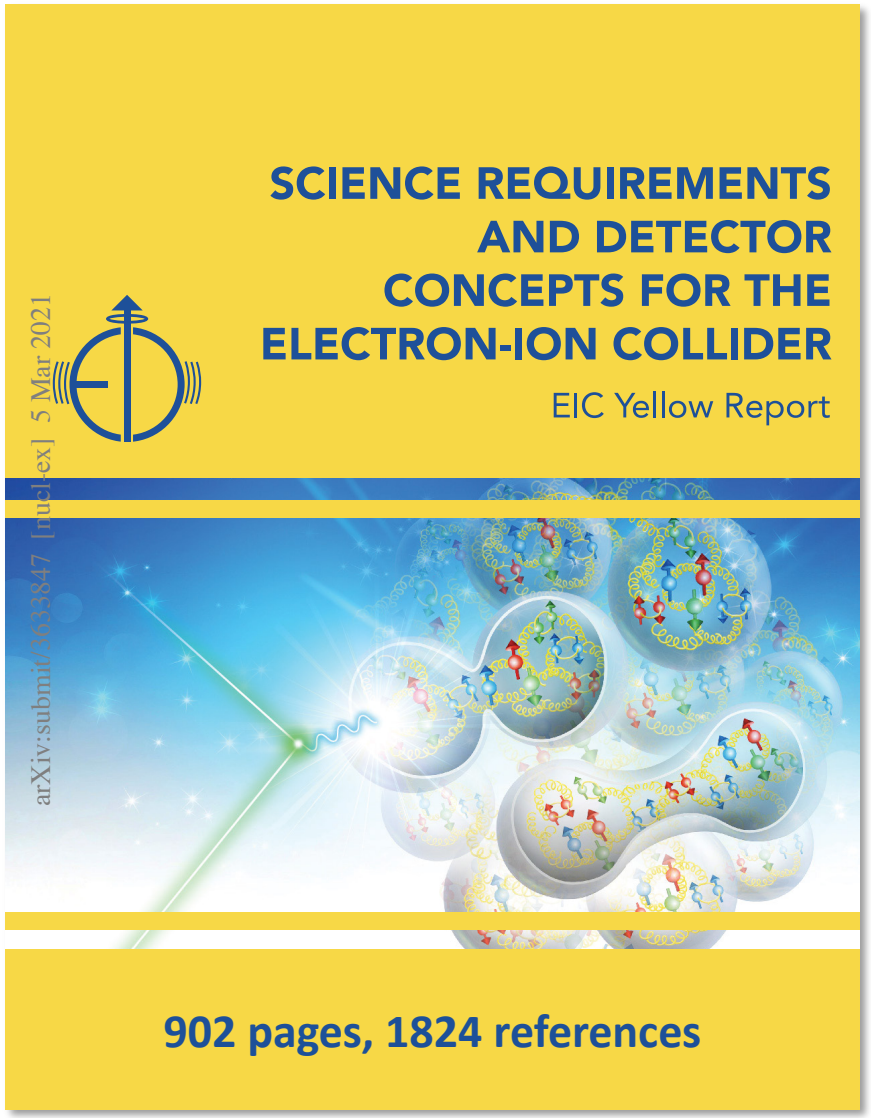
Brookhaven National Laboratory and Jefferson Lab will be host laboratories for the EIC Experimental Program. Leadership roles in the EIC project are shared.

EIC Timeline: Operations start a decade from now



EIC User Group (EICUG)

Yellow Report Initiative by the EIC User Group

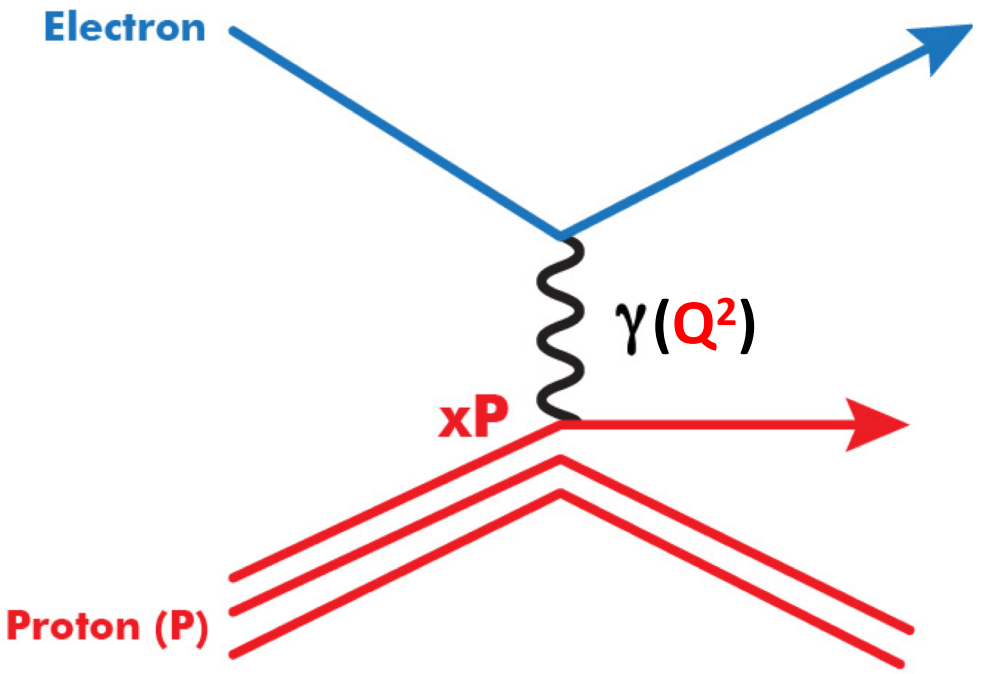


- The **EIC Yellow Report** describes the physics case, the resulting detector requirements, and the evolving detector concepts for the experimental program at the EIC: arXiv:2103.05419
- The studies leading to the EIC Yellow Report were commissioned and organized by the **EIC User Group**.
- The EIC Yellow Report has been important input to the successful DOE CD-1 review and decision.

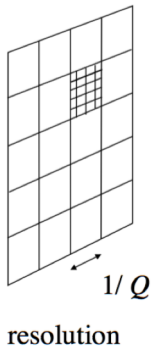
Next Priorities for the EIC User Group

- Formation of the first EIC collaboration.

Deep-inelastic scattering (DIS) of electrons off protons

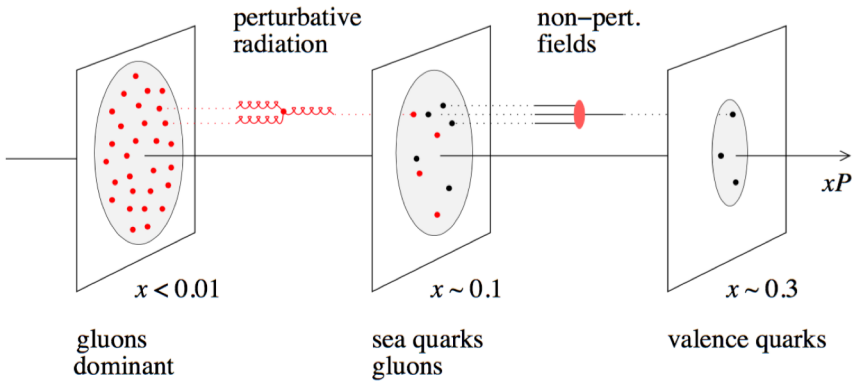


Ability to change Q^2 changes the resolution scale

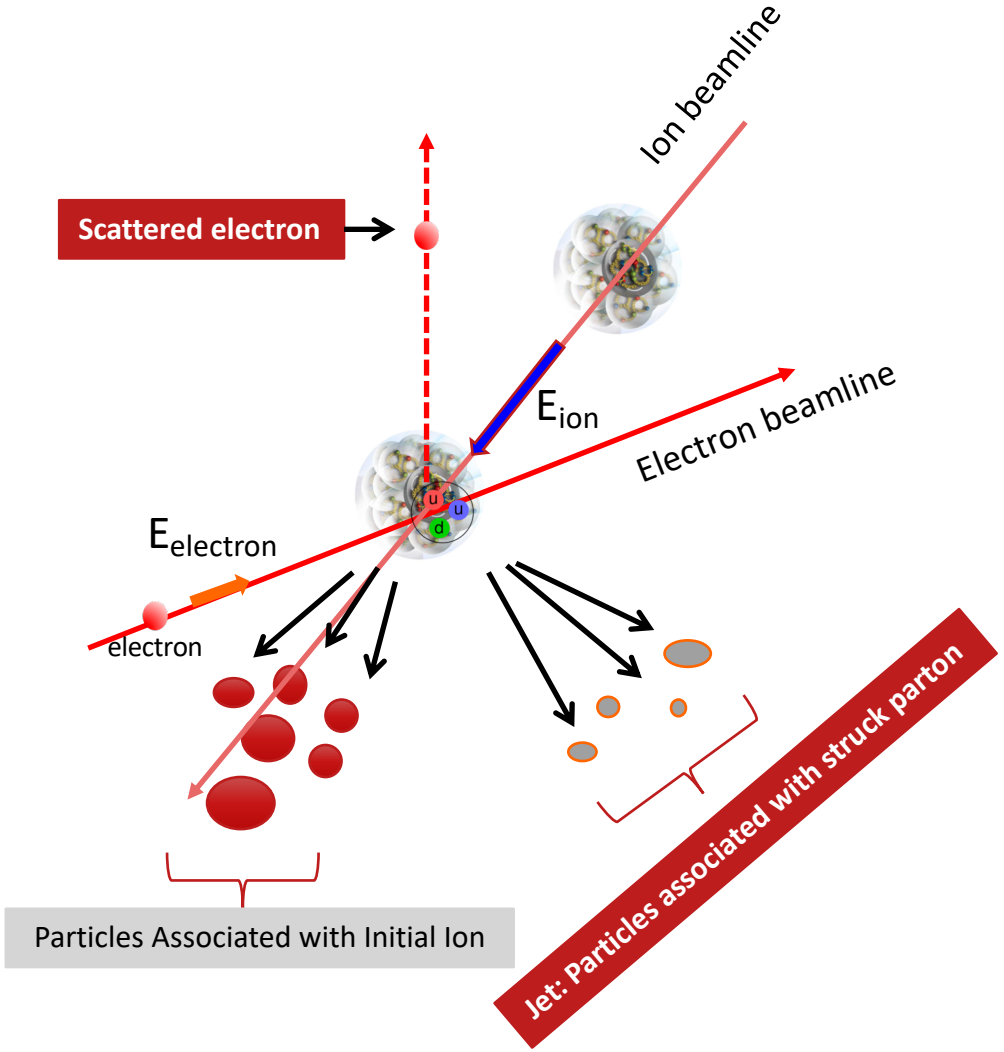


$Q^2 = 400\ GeV^2$
=> 1/Q = 0.01 fm

Ability to change x projects out different configurations where different dynamics dominate



Inclusive DIS Measurements



Kinematics reconstructed from any combination of:

- Energy of the scattered electron
- Angle of the scattered electron
- Energy of the jet
- Angle of the jet

Three analytical reconstruction methods:

Method	Requires	Pro	Contra
Electron (EL)	$E_{l'}$, $\theta_{l'}$	precise	sensitive to QED radiation
Jacques-Blondel (JB)	$\delta_{\mathcal{H}}$, $P_{T,\mathcal{H}}$	resistant to QED radiation	needs precise jet energy measurements
Double Angle (DA)	$\theta_{l'}$, $\gamma_{\mathcal{H}}$	no need for precise jet energy measurements	poor resolution at low x and low Q^2

Deeply Learning DIS Kinematics

https://inspirehep.net/literature/1912344

Slide from Abdullah Farhat (ODU)

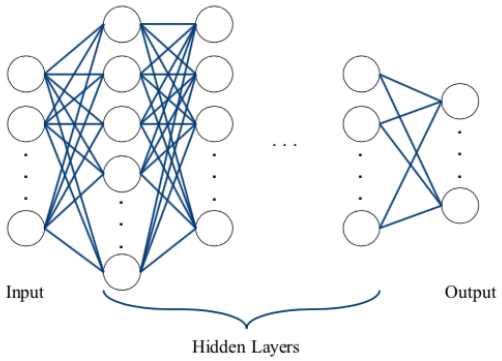
The idea is to build a physics-driven neural network method that combines the quantities determined with the classical methods in a way:

$$Q^2_{NN} = A_{Q^2}(Q^2_{EL}, Q^2_{DA}, Q^2_{JB}) + L_{Q^2}(A_{Q^2}, E_{l'}, \theta_{l'}) + H_{Q^2}(A_{Q^2}, P_{T,H}, \delta_H)$$

And reconstruct x, with Q^2_{NN} as an input, in the form:

$$x_{NN} = A_x(x_{EL}, x_{DA}, x_{JB}) + L_x(A_x, Q^2_{NN}, E_{l'}, \theta_{l'}) + H_x(A_x, Q^2_{NN}, P_{T,H}, \delta_H)$$

Neural networks can be used to reconstruct the kinematics by weighting classical reconstructions and using all four of the measured quantities as corrections.



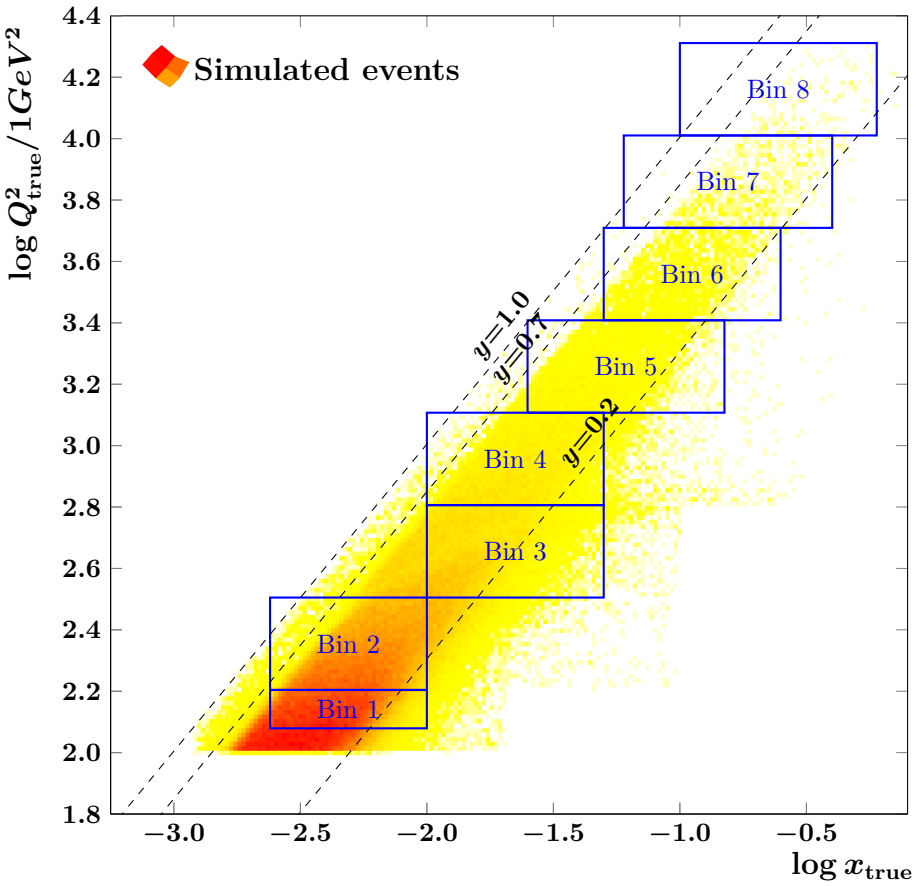
Properties of the DNN

- **Effective**: Universal approximation capability: can approximate any continuous function to arbitrary accuracy
- **Robust**: Increasing the depth of the network (i.e. the number of terms in the sum) necessarily reduces the error
- **Computationally Efficient**: Structure avoids ”vanishing” gradients arising in the backpropagation algorithm

Results for x and Q^2

Slide from Abdullah Farhat (ODU)

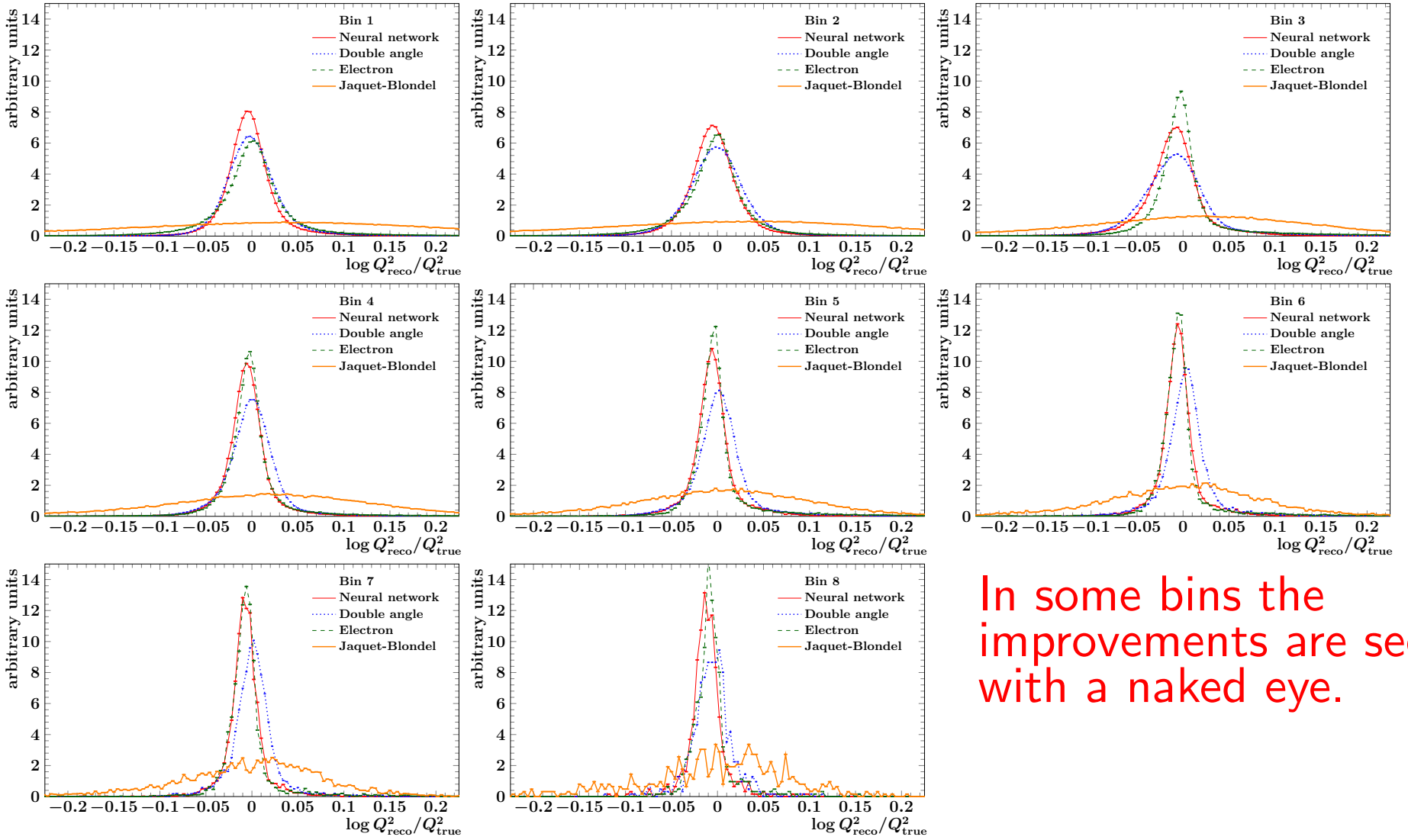
Kinematic phase space at the ZEUS experiment:



Bin	Events	Resolution of $\log x$		Resolution of $\log Q^2/1GeV^2$	
1	301780	**NN: 0.070**	EL: 0.083	**NN: 0.035**	EL: 0.035
		JB: 0.180	DA: 0.103	JB: 0.203	DA: 0.062
2	350530	**NN: 0.069**	EL: 0.082	**NN: 0.040**	EL: 0.043
		JB: 0.167	DA: 0.096	JB: 0.192	DA: 0.064
3	138456	**NN: 0.098**	EL: 0.130	NN: 0.055	**EL: 0.053**
		JB: 0.138	DA: 0.100	JB: 0.150	DA: 0.077
4	74844	**NN: 0.067**	EL: 0.084	**NN: 0.044**	EL: 0.046
		JB: 0.117	DA: 0.077	JB: 0.138	DA: 0.063
5	31043	**NN: 0.064**	EL: 0.091	**NN: 0.036**	EL: 0.041
		JB: 0.102	DA: 0.073	JB: 0.117	DA: 0.053
6	11475	**NN: 0.053**	EL: 0.079	**NN: 0.033**	EL: 0.036
		JB: 0.083	DA: 0.061	JB: 0.100	DA: 0.045
7	3454	**NN: 0.050**	EL: 0.069	**NN: 0.036**	EL: 0.038
		JB: 0.074	DA: 0.055	JB: 0.093	DA: 0.042
8	624	**NN: 0.036**	EL: 0.055	**NN: 0.033**	EL: 0.037
		JB: 0.067	DA: 0.045	JB: 0.095	DA: 0.041

Results for Q^2

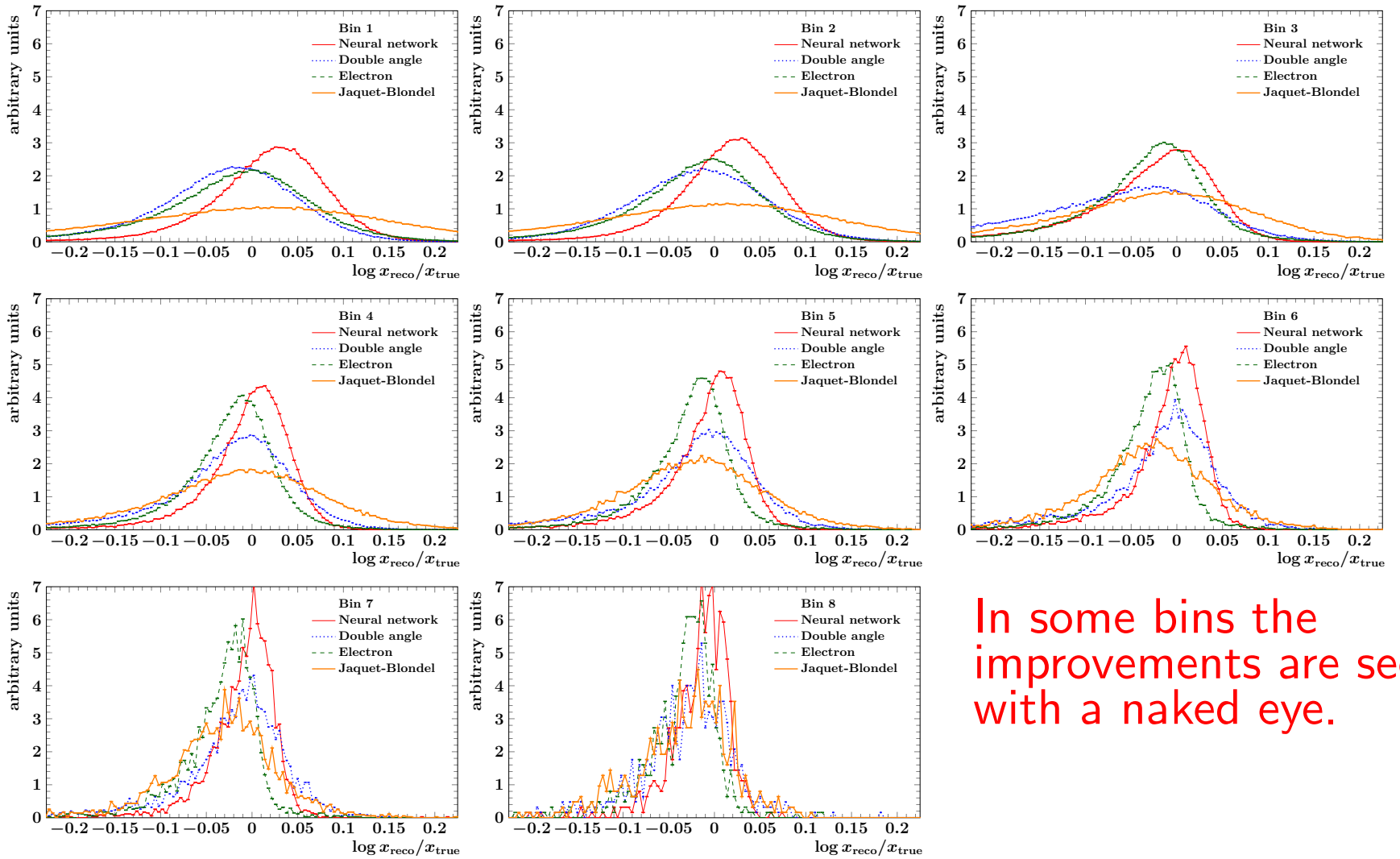
Slide from Abdullah Farhat (ODU)



In some bins the improvements are seen with a naked eye.

Results for *x*

Slide from Abdullah Farhat (ODU)



In some bins the improvements are seen with a naked eye.

Next Steps

We have an approach for **Deeply Learning Kinematics of Inclusive DIS**.

We have agreed upon our next steps:

- **Demonstrate results for EIC project detector** and publish.
- **Deeply Learning Kinematics of Semi-Inclusive DIS**, based on existing approach.
- **Deeply Learning Kinematics of Exclusive Measurements**, based on existing approach.

We have discussed ways to continue our work:

1. Complementary approach to deeply learning kinematics of Inclusive DIS, directly from:
   - Energy of the scattered electron
   - Angle of the scattered electron
   - Energy of the jet
   - Angle of the jet
2. Work out interference with measurements.

Interference

Detector Level

Ground Truth