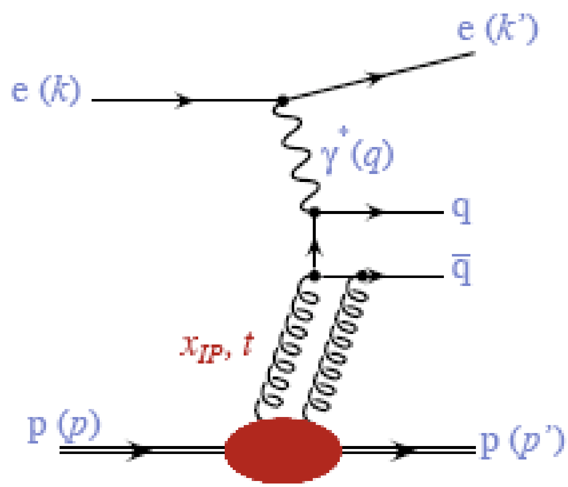
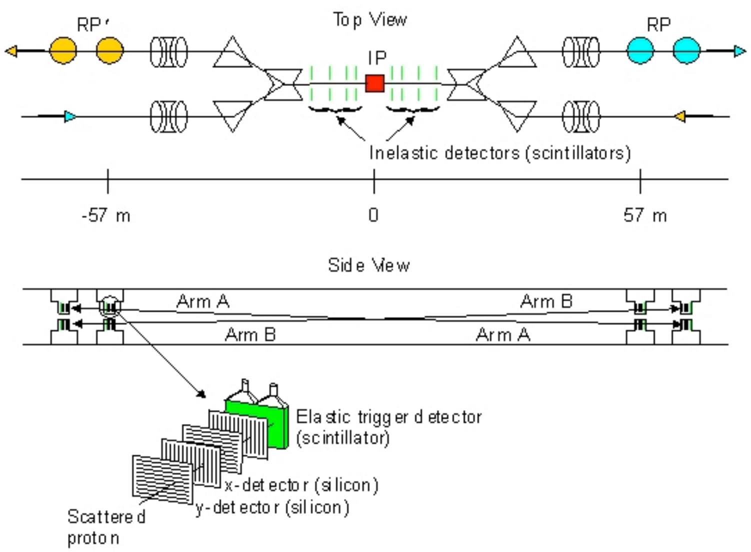
Measuring Diffraction at the EIC

Exclusive process: eA → e A
or
Inclusive process: eA → e + V + X, where “+” is a rapidity gap



Scattering angles of p (A) are small

Principle of the Measurement I



- Protons/Nuclei are scattered at very small scattering angle θ^*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without breaking accelerator vacuum

Beam transport equations relate measured position at the detector to scattering angle.

$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{pmatrix}$$

x_0, y_0: Position at Interaction Point
Θ^*_x Θ^*_y : Scattering Angle at IP
x_D, y_D : Position at Detector
Θ^x_D, Θ^y_D : Angle at Detector

Principle of the Measurement II

1. Hence, the known parameters of the accelerator lattice can be used to calculate the deflection y^* and the scattering angle θ_y^* at the interaction point, knowing the deflection y and angle at the at the detector.

2. Proton momenta are not parallel, the angular spread is given by the beam angular divergence, which limits the smallest angle that can be measured:

$$\theta = \sqrt{\frac{\varepsilon}{6\pi\beta^*}}$$

3. The beam size at the collision point is given by:

$$\sigma_{x,y} = \sqrt{\frac{\varepsilon\beta^*}{6\pi}}$$

4. At a point where the phase advance from the interaction point is Ψ and the betatron function is β, *y* is given by:

$$y = \sqrt{\frac{\beta}{\beta^*}}\left(\cos\Psi + \alpha^* \sin\Psi\right)y^* + \sqrt{\beta\beta^*}\sin\Psi\theta_y^*,$$

5. Where α^* is the derivative of the betatron function β^* at the interaction point. We have considered a lattice configuration such that α^* is very close to zero. Eq. (4) can be rewritten as:

$$y = a_{11}y^* + L_{eff}\theta_y^*, \quad \text{with} \quad a_{11} = \sqrt{\frac{\beta}{\beta^*}}\left(\cos\Psi + \alpha^* \sin\Psi\right) \quad \text{and} \quad L_{eff} = \sqrt{\beta\beta^*}\sin\Psi$$

6. The optimum experimental condition is $a_{11} = 0$ and L_{eff} as large as possible, as the displacement *y* becomes independent of the coordinate *y** at the IR in the transverse plane of the accelerator, and largest displacements at the detection point are obtained for a given scattering angle. This occurs when Ψ is an odd multiple of π/2. Then, the expression for the *y* coordinate at the detection point simplifies to:

$$\theta^*_{\min} = \frac{d_{\min}}{L_{eff}}, \text{ with } \quad d_{\min} = k\sigma_y + d_0$$

$$y = L_{eff}\theta_y^*,$$

and the scattering angle is determined just from the measurement of the displacement alone. With the above condition satisfied, rays that are parallel to each other at the interaction point are focused onto a single point at the detector, commonly called “parallel-to-point focusing.”

For the measurement of the smallest measurable value of $|t|$, $t_{\mathbf{min}}$, the lattice must be optimized. $t_{\mathrm{min}} = (p\theta^*_{\mathbf{min}})^{\mathbf{2}}$ is determined by the smallest scattering angle measured $\theta^*_{\mathbf{min}}$, whichis given by:

$$t_{\min} = \frac{k^2 \varepsilon\, p^2}{\beta^*}.$$

It follows also that special beam conditions are needed to reach smallest t: $t_{\mathbf{min}}$ is reached by having β* as large as possible and by reducing the *k*-factor and the emittance ε, i.e. by optimizing the beam scraping.

The t_{min} in case of the nucleus

If that p is the total momentum of the nucleaus (A) $p = p_A$

and the momentum per nucleon is $p_0 \Rightarrow p_A = A\, p_0$

For given t_{min} (in the forward direction) life with nuclei is A^2 times harder as comapred with the proton

Consequently measuring exclusive reaction for small t is very difficult for heavy nuclei.

In case of ep or eD collisions the measurement is possible and could be incorporated into the accelerator design

Reconstruction of the Momentum Loss ξ

1. Need to measure vector at the detection point, hence two RPs are needed.

2. For p(A), which scatters with Θ and ξ M_x can be measured:

$$x_1 = a_1 x_0 + L_1 \Theta_x + \eta_1 \xi; \quad \textbf{detection point 1}$$
$$x_2 = a_2 x_0 + L_2 \Theta_x + \eta_2 \xi; \quad \textbf{detection point 2}$$

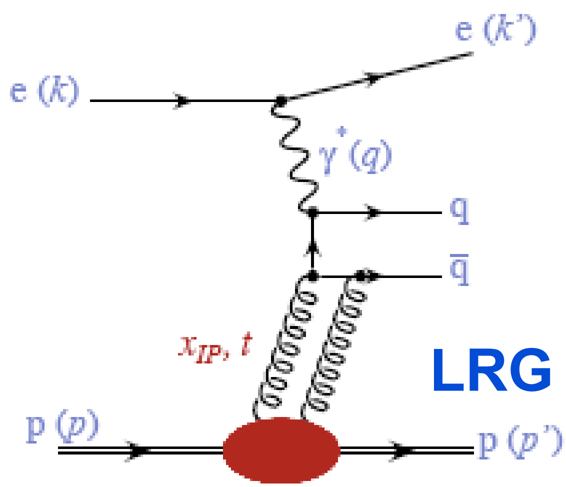
Accelerator transport

$$\begin{pmatrix} \Theta_x \\ \xi \end{pmatrix} = \frac{1}{Det} \begin{pmatrix} \eta_2; & -\eta_1 \\ -L_2; & -\mathrm{L}_1 \end{pmatrix} \begin{pmatrix} x_1 - a_1 x_0 \\ x_2 - a_2 x_0 \end{pmatrix}$$

$$M_X = \sqrt{\xi_1 \xi_2 s} \approx 2\xi \cdot p$$

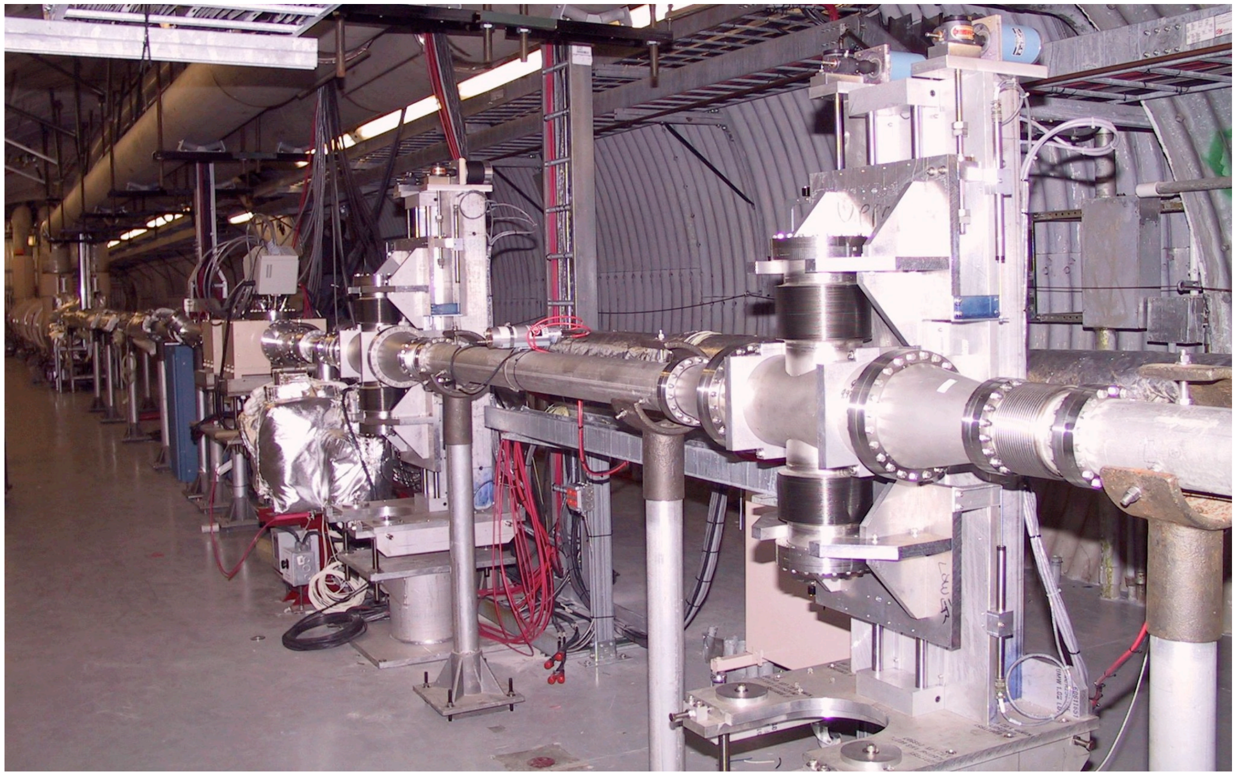
Summary

- Measuring exclusive reactions is very difficult for small |t| in eA case.
- One needs to use large rapidity gap (LRG) technique, and another object (vector meson) to constrain the reaction.
- Incoherent case should be investigated.



Need to know more about the kinematics and the details of the processes of interest to proceed with the detailed design - there is experience at BNL (C-AD and Physics Dept.) to come up with a design.

An example: The pp2pp Experimental Setup



Last but not least: An interesting thing to investigate at EIC, both low and high energy EIC option, is photoproduction of exotics:

$\gamma^{*}p(A) \rightarrow$ E X p(A) with exotic quantum numbers