Pomeron dynamics as a probe of nuclear structure

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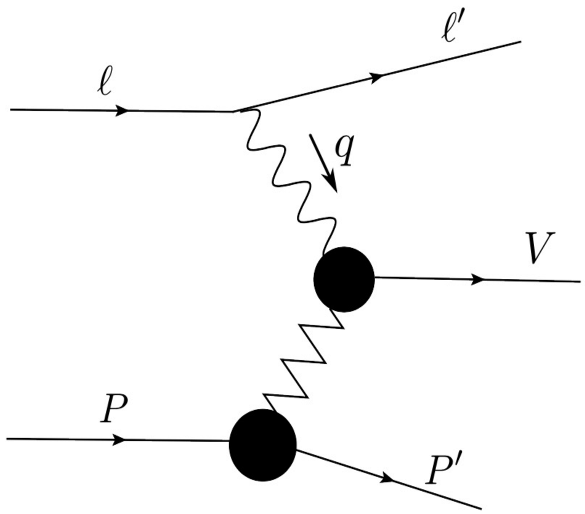
EIC 2nd Detector workshop, CFNS Dec. 6th-8th, 2022

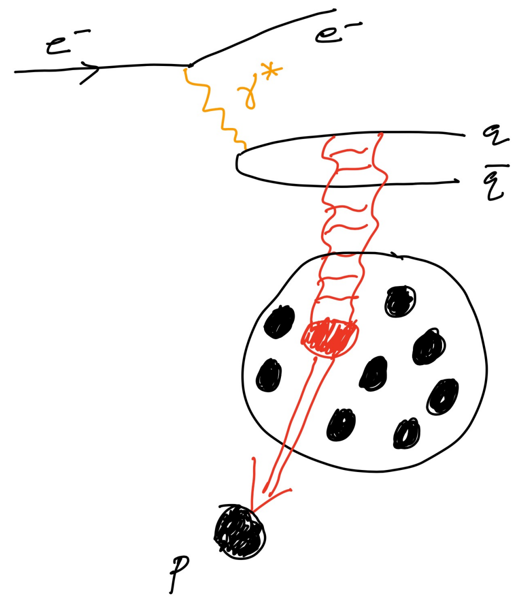
Part I: Ask not what the Pomeron can do for nuclear structure….
but what nuclear structure can do for the Pomeron

Ballistic protons as a measure of rare parton fluctuations

Lappi, Mantysaari, RV, PRL 114 (2015) 8 082301



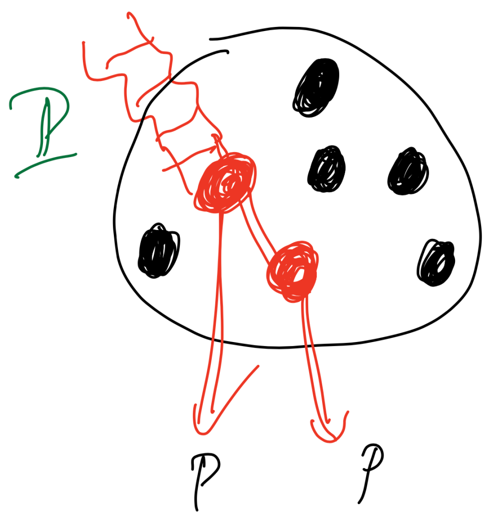
$$q^2 \equiv -Q^2 \equiv (\ell - \ell')^2$$
$$t \equiv (P' - P)^2$$
$$W^2 \equiv (P + q)^2$$
$$x_{\mathbb{P}} \equiv A \frac{(P - P') \cdot q}{P \cdot q} = A \frac{m_V^2 + Q^2 - t}{W^2 + Q^2 - m_A^2}$$
$$\nu \equiv \frac{P \cdot q}{m_A} \approx \frac{P \cdot q}{A m_N}.$$



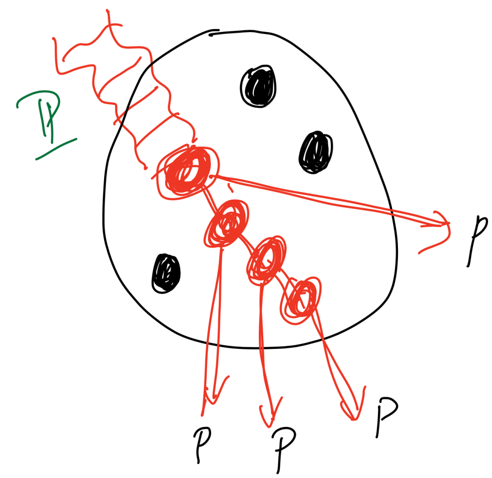
Incoherent diffractive vector meson production

Dominates for $1/R_A^2 \lesssim |t| \lesssim 1/R_p^2$

Ballistic proton as a measure of centrality

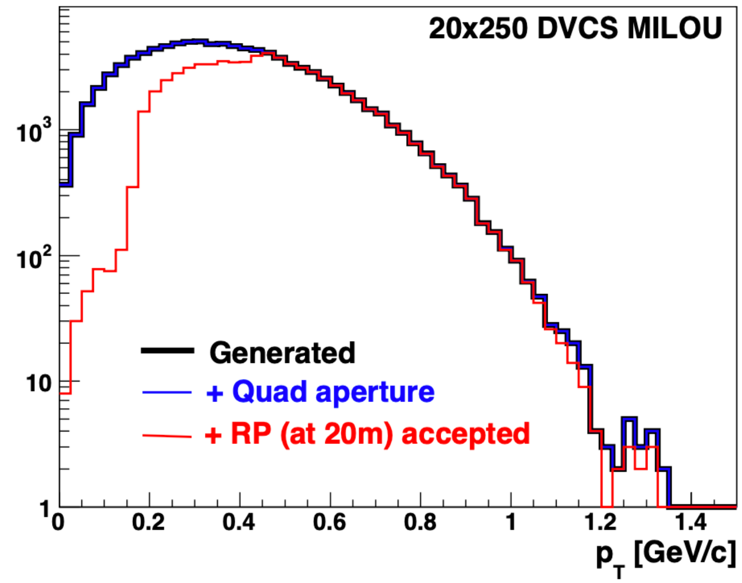


More typical "min-bias" event

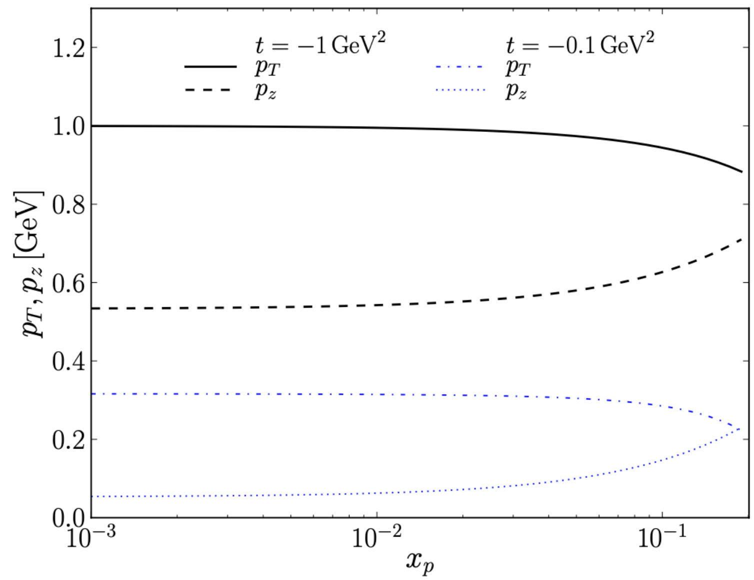


Rare high multiplicity event

Ballistic proton as a measure of centrality



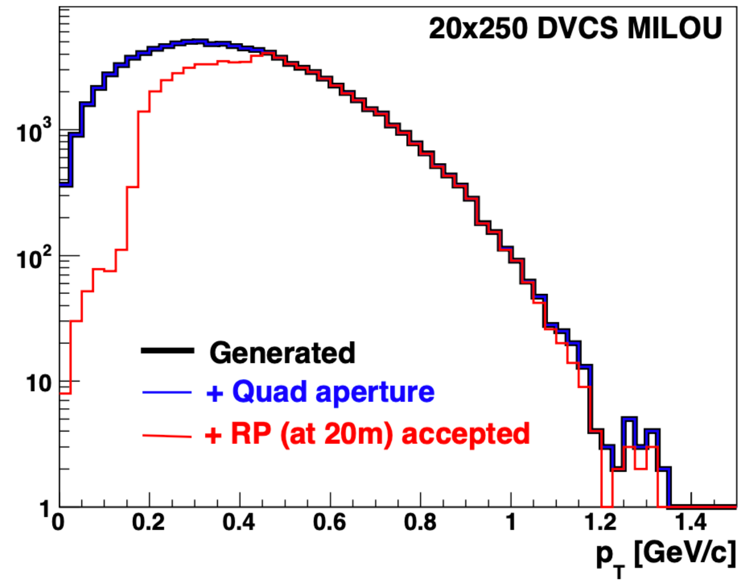
Acceptance for protons in e+p in a Roman pot detector
EIC detector study (courtesy E. Aschenauer, cerca 2014)



Scattered proton transverse and longitudinal momentum in target rest frame

Protons in the 400 MeV – 1 GeV range can be identified as ballistic
Since energy and momentum transport in this case is localized in the nucleus,
multiplicity is likely sensitive measure of centrality

Ballistic proton as a measure of centrality



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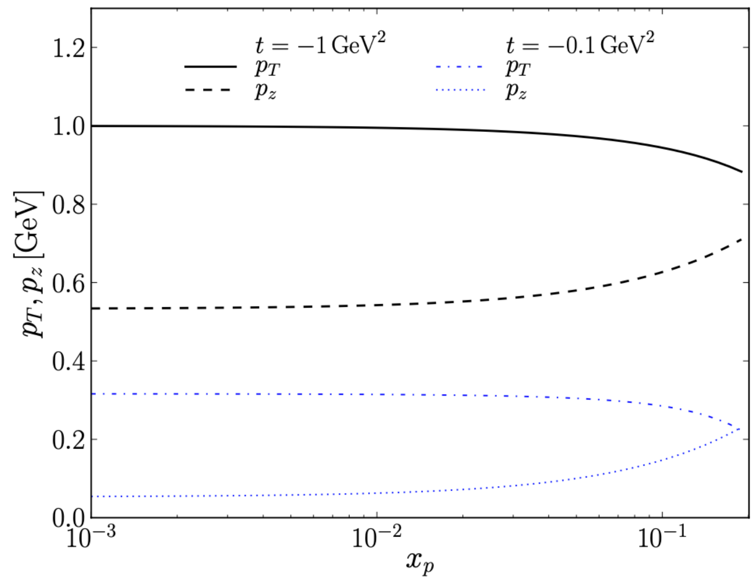

Scattered proton transverse and longitudinal momentum in target rest frame

More challenging for nuclei. Does a comparable study exist? BeAGLE?
Evaporation protons/neutrons (implementing FLUKA) likely not as good a measure of centrality

Centrality dependence of incoherent exclusive vector mesons

Study within the framework of the dipole model:

Imaginary part of dipole-nuclear amplitude:

$$\mathcal{A}(x_{\mathbb{P}}, Q^2, \mathbf{\Delta}_T) = \int \mathrm{d}^2\mathbf{r}_T \int \frac{\mathrm{d}z}{4\pi} \int \mathrm{d}^2\mathbf{b}_T \times \underbrace{[\Psi_V^* \Psi](r, Q^2, z)}_{\text{Overlap of VM wave-fn with dipole wave fn.}} e^{-i\mathbf{b}_T\cdot\mathbf{\Delta}_T} 2\, N_A(\mathbf{r}_T, \mathbf{b}_T, x_{\mathbb{P}})$$

Simple independent scattering approximation: $N_A = 1 - S_A$ with $S_A(\mathbf{r}_T, \mathbf{b}_T, x_{\mathbb{P}}) = \prod_{i=1}^{A} S_p(\mathbf{r}_T, \mathbf{b}_T - \mathbf{b}_{Ti}, x_{\mathbb{P}})$

IPSat model

$$\exp\left(-\frac{\pi^2}{2N_c}\mathbf{r}_T^2 \alpha_s(\mu^2) x g(x, \mu^2) T_p(\mathbf{b}_T)\right)$$

Average over nucleon positions in nucleus: $\langle \mathcal{O}(\{\mathbf{b}_{Ti}\})\rangle_{\mathrm{N}} \equiv \int \prod_{i=1}^{A} \left[\mathrm{d}^2\mathbf{b}_{Ti} T_A(\mathbf{b}_{Ti})\right] \mathcal{O}(\{\mathbf{b}_{Ti}\})$

Woods-Saxon dist.

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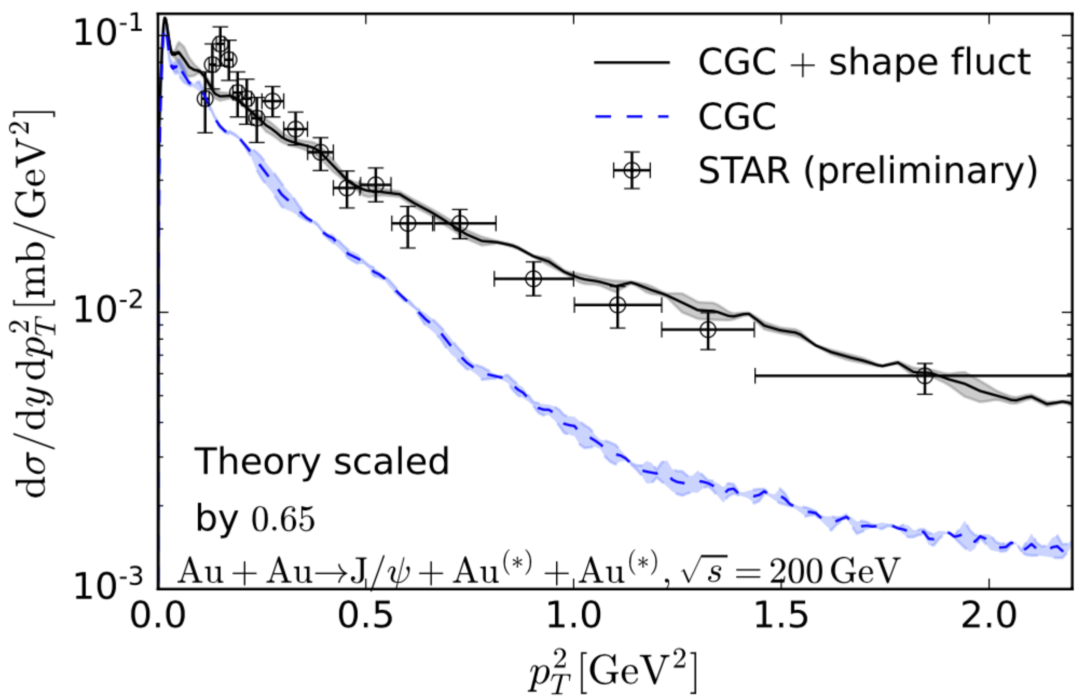
IPSat model

$$\exp\left(-\frac{\pi^2}{2N_c}\mathbf{r}_T^2 \alpha_s(\mu^2) x g(x, \mu^2) T_p(\mathbf{b}_T)\right)$$

Incoherent exclusive VM cross-section: $\underbrace{< |\mathcal{A}|^2 >_N}_{\text{Total}} - \underbrace{|< \mathcal{A} >_N|^2}_{\text{Coherent}}$

UPC studies of incoherent exclusive VM production



Salazar,Schenke,Mantysaari, PRD 106 (2022) 7 074019

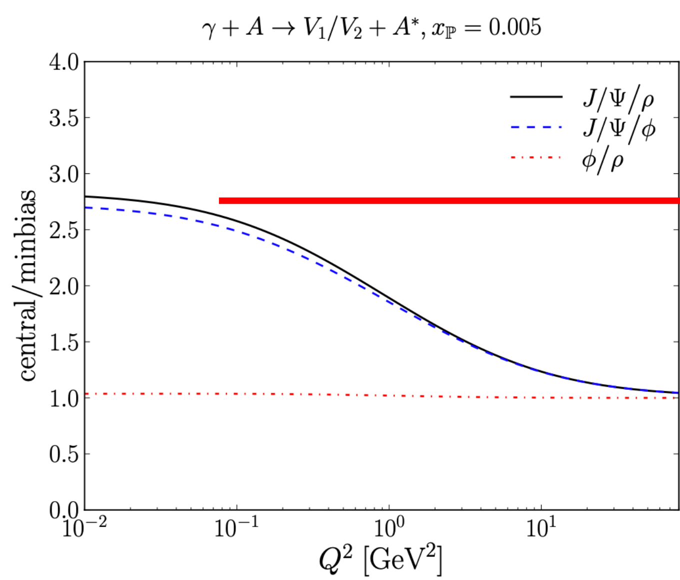
Hot spot fluctuations: see also Demerci, Lappi, Schlichting, arXiv:2206.05207

Supersized "oomph"

Double ratio:

$$\frac{\sigma(\gamma^* A \to V_1 A^*) \Big/ \sigma(\gamma^* A \to V_2 A^*)\Big|_{\text{central}}}{\sigma(\gamma^* A \to V_1 A^*) \Big/ \sigma(\gamma^* A \to V_2 A^*)\Big|_{\text{minimum bias}}}$$

Uncertainties in VM wave-function and overall normalization minimized



$$\propto \frac{Q^4_{S,central}}{Q^4_{S,min.bias}}$$

Interesting interplay between
color transparency and color opacity

Lappi, Mantysaari, Venugopalan, PRL 114 (2015) 8 082301

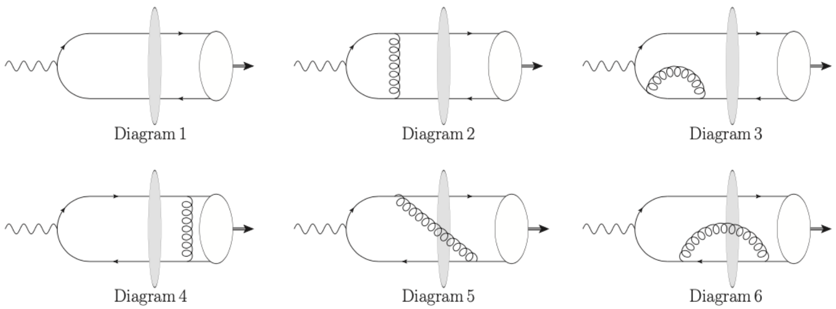
Some naïve comments

What is the status of the treatment of "ballistic" knock-out reactions in nuclear reaction theory
- especially In large nuclei?

Can this be implemented in BeAGLE and other nuclear event generators ? Would be especially important to model this as a function of $x_{Pomeron}$ – reflecting dependence on coherence length

What is the fraction of evaporation versus knockout as a function of momentum transfer? What is the status of ZDC measurements as a benchmark for centrality. Collective wisdom from UPC studies

NLO CGC amplitude $\mathcal{A}_{NLO}$ for exclusive VM production now available. Sensitive to dipole and double dipole correlators

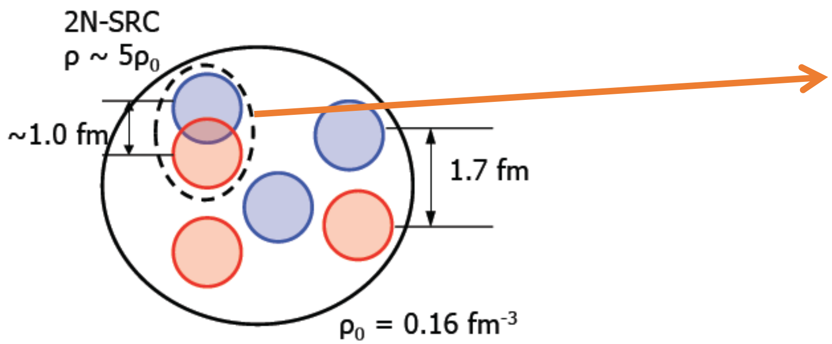


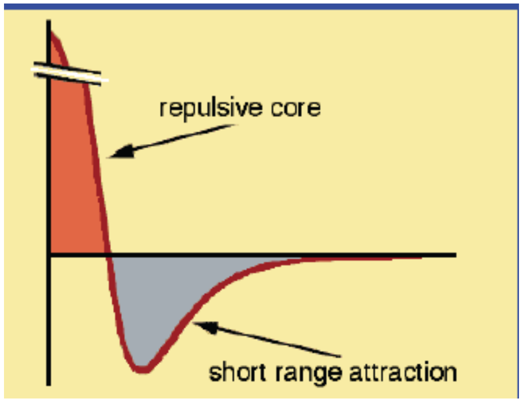
However quantitative NLO studies and impact parameter dependence (crucial for incoherent diffraction) not available yet

Access to largest possible t (small impact parameters) will reduce systematic uncertainties in the theoretical treatments

Light VM:
Boussarie,Grabovsky,Ivanov,Szymannowski,Wallon, PRL 119 (2017) 7 072002
Heavy VM:
Mantysaari,Penttala, JHEP 08 (2022) 247

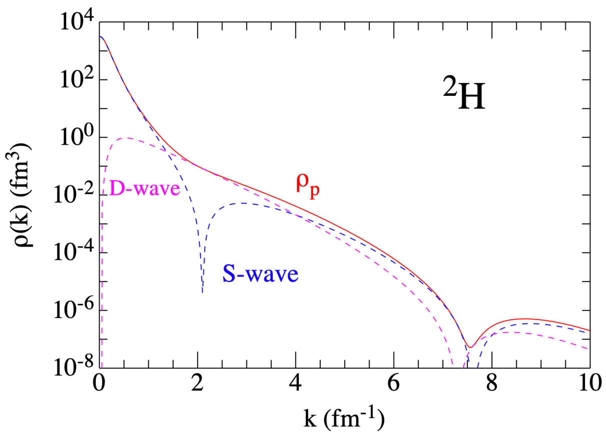
Part II: Ask what the Pomeron can do for nuclear structure





Center for Frontiers in Nuclear Science

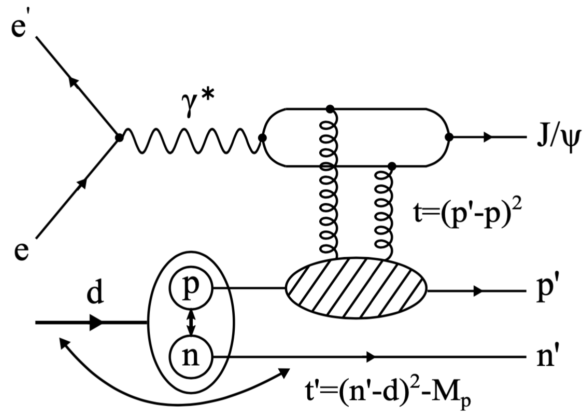
2018 workshop: Short-range nuclear correlations at the EIC https://indico.bnl.gov/event/4343/

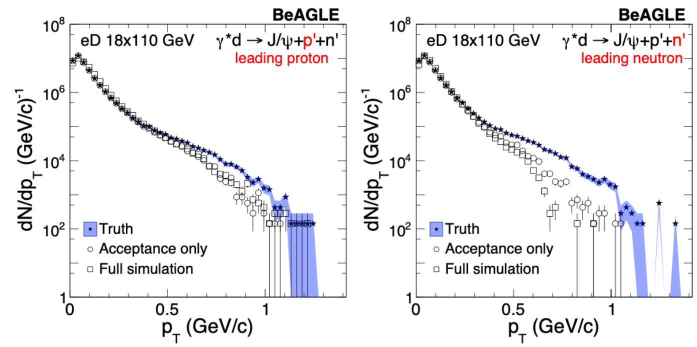


(from Wiringa's talk)

Exclusive VM production as probe of gluon structure of NN-potential

Nucleon as spectator





K. Tu et al., PLB 811 (2020) 135877

"Hard" NN scattering

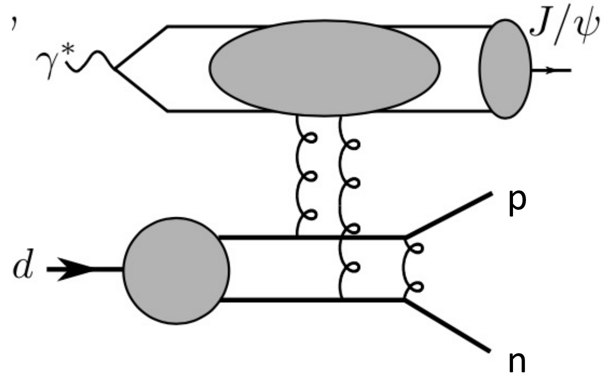


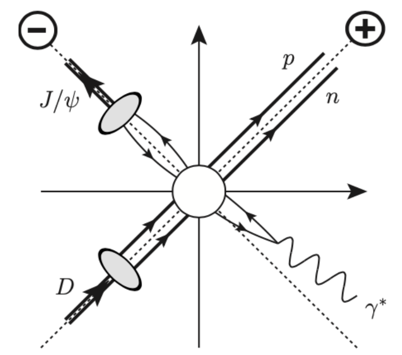
Fig. from EIC Yellow report

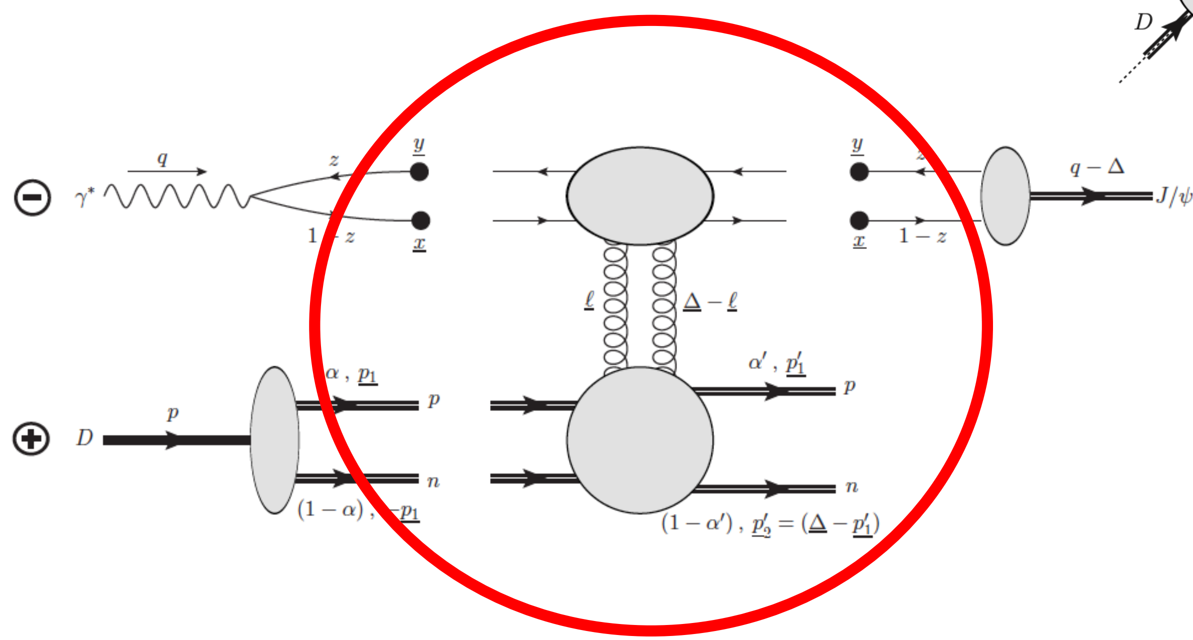
Miller, Sievert, Venugopalan, PRC93, 045202 (2016)

Large relative momentum transfer between proton and neutron sensitive glue component of short-range NN forces

Pomeron as probe of short-range NN glue potential

At EIC, clean separation of time scales of current and target fragmentation regions in exclusive Onium DIS





Pomeron as probe of short-range NN glue potential

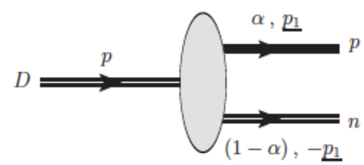
$$\frac{d\sigma^D}{dT\,dt\,dy_1'} = \frac{1}{(4\pi)^3}\frac{\alpha'}{1-\alpha'}\left| \int \frac{d^2r\,dz}{4\pi z(1-z)}\,[\psi^\gamma \psi^{V*}](\underline{r},z)\frac{\alpha_s \pi^2}{2} r_T^2\,\hat{H}^g_{(D)}(x,0,T;t)\right|^2 \qquad \alpha' \equiv p_1'^+/p^+$$

Transition gluon GPD (T-GPD)

$$\hat{H}^g(x,0,T;t) \equiv \int \frac{dr^-}{2\pi p^+}\, e^{ixp^+r^-} \left\langle p(p_1')\, n(p+\Delta-p_1') \middle| F^{+ia}(-\tfrac{r}{2}) F^{+ia}(+\tfrac{r}{2}) \middle| D(p) \right\rangle$$

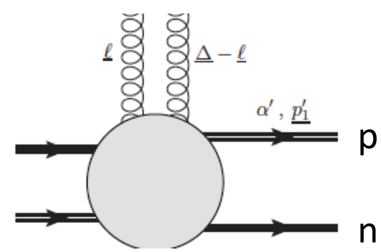
Mom. transfer to deuteron Rel. mom. transfer between nucleons

$$\hat{H}^g_{(D)}(x,0,T;t) = \int \frac{d\alpha}{4\pi\alpha(1-\alpha)}\frac{d^2p_1}{(2\pi)^2}\sum_{\sigma_p\sigma_n}\psi^D_{\sigma_D;\sigma_p\sigma_n}(\underline{p_1},\alpha)$$

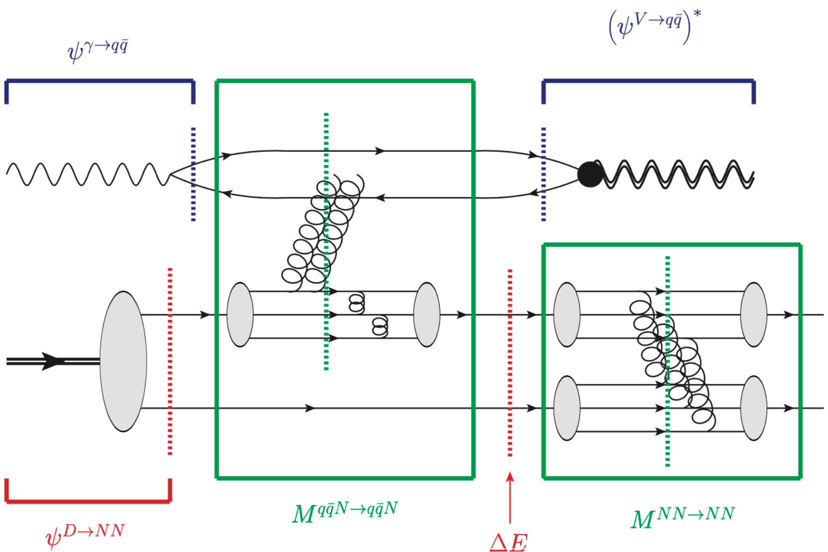


$$\times \left[\int \frac{dr^-}{2\pi p^+}\, e^{ixp^+r^-} \int d\Omega_{NN}\, \langle p_{\sigma_p'}(p_1')\, n_{\sigma_n'}(p+\Delta-p_1')|\, V^-_{NN}\, |NN\rangle \right.$$

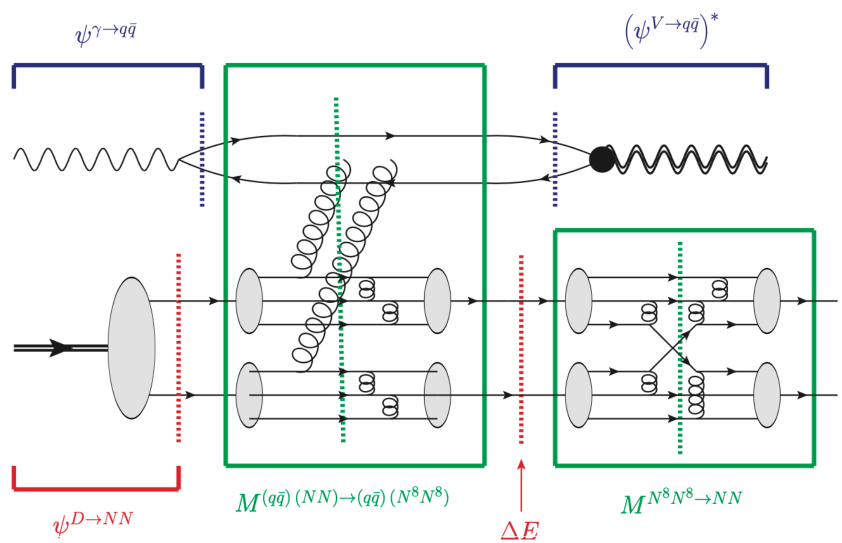
$$\left. \times\, \frac{1}{\Delta E^-} \times \langle NN|\, |F^{+ia}(-\tfrac{r}{2}) F^{+ia}(+\tfrac{r}{2})\, |p_{\sigma_p}(p_1)\, n_{\sigma_n}(p-p_1)\rangle \right]$$



Pomeron as probe of short-range NN glue potential



Hard color-singlet exchange between NN-pair
Landshoff-like mechanism.
State-of the art - Bott, Sterman (2001)



Hard color-octet exchange between NN-pair

$$\frac{d\sigma^{\gamma D\to VNN}}{dT\,dt\,dy} = \frac{1}{\pi^2}\left|\Psi_D(\underline{0},\tfrac{1}{2})\right|^2 \left[\frac{d\sigma^{\gamma N\to VN}}{dT}\right]_{T=-\Delta_T^2} \left[\frac{d\sigma^{NN\to NN}}{dT_{NN}}\right]_{T_{NN}=-p'^2_{1T}}$$

Measurement of l.h.s at EIC at large t ($\approx s_{NN}$) provides novel information on large angle nucleon-nucleon scattering

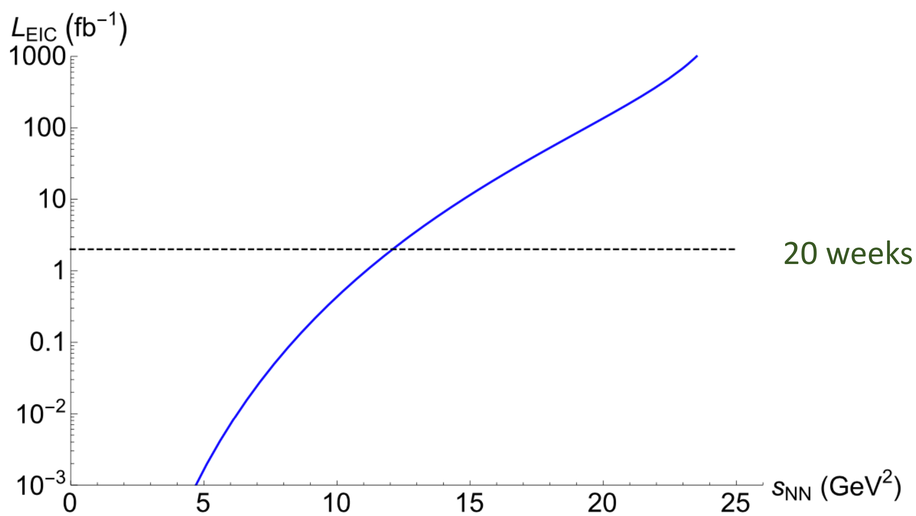
Estimation of rates

$$\frac{d\sigma^{\gamma D\to VNN}}{dT\,dt\,dy} = \frac{1}{\pi^2}\left|\Psi_D(\underline{0},\tfrac{1}{2})\right|^2 \left[\frac{d\sigma^{\gamma N\to VN}}{dT}\right]_{T=-\Delta_T^2} \left[\frac{d\sigma^{NN\to NN}}{dT_{NN}}\right]_{T_{NN}=-p'^2_{1T}}$$

Well-known from models

HERA data

NN elastic scattering data



20 weeks of running at $1.6*10^{32}$/cm^2/sec

(proton-neutron squared c.m. energy)

Notes

Potentially exciting process to simulate and study.

Physics is sensitive to gluon contributions to short-range NN potential

If one can access large relative t, can provide novel insight into nature of point-like multi-quark and glue configurations in light nuclei

Thank you for your attention !