# Forward nucleon tagging at EIC 

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## Outline

- EIC physics with (far-)forward nucleon tagging - protons with Roman Pots
- neutrons with Zero Degree Calorimeter
- Interaction Region integration
- Requirement and considerations for the measurements


## EIC physics and measurements



## Physics with forward tagging

- Defining exclusive reactions in ep/eA:
-ep: reconstruction of all particles in (diffractive) event including scattered proton with wide kinematics coverage
$\bullet$ eA: identify with rapidity gap. need wide rapidity coverage [ HCal for $\mathrm{I}<\eta<4$ ]
- Identifying coherence of nucleus in diffractive eA: with neutrons from nucleus break-up

- Sampling target in $e^{+3} \mathrm{He}$, d with spectator tagging
- Accessing event geometry in semi-inclusive eA with evaporated nucleons




## Forward protons in diffraction



- Scattered with ~O(mrad): Need a detector close to the beam - Roman Pot to detect
- Large angle (high-t) acceptance mainly limited by beam aperture $\left[t \sim \mathrm{pT}^{2} \sim \mathrm{p}^{2} \theta^{2}\right]$
- Small angle (low-t) acceptance limited by beam envelop ( $\sim<10 \sigma_{\text {beam }}$ )
- Reconstruction resolution limited by
- beam angular divergence ( $\sim$ O( $100 \mu \mathrm{rad})$ ), emittance
- uncertainties in beam offset, crossing, transport, detector alignment, vertex reconstruction resolution
- at RHIC
- $\delta \mathrm{p} / \mathrm{p} \sim 0.005$
- $\delta \mathrm{t} / \mathrm{t} \sim 0.03 / \sqrt{\mathrm{t}}$
- in addition, effect of crab crossing (expected to be << beam divergence) need to be simulated


## Roman Pot system at RHIC



## Exclusive diffraction tagging with RP at RHIC



R. Sikora at Diffraction and Low-x 2018

## EIC: Impact of proton acceptance in RP

## Measurement





Physics observable (cross-section vs impact parameter)

limited lower $\mathrm{P}_{\mathrm{T}}$-acceptance
limited higher $\mathrm{P}_{\mathrm{T}}$-acceptance



## Requirement:

$\int \mathrm{L}_{\text {int }}=10 \mathrm{fb}^{-1}$
$0.18<\mathrm{p}_{\mathrm{t}}(\mathrm{GeV})<1.3$
$0.03<|\mathrm{t}|\left(\mathrm{GeV}^{2}\right)<1.6$
$\int \mathrm{L}_{\text {int }}=10 \mathrm{fb}^{-1}$
$0.44<\mathrm{P}_{\mathrm{T}}(\mathrm{GeV})<1.3$
$\int \mathrm{L}_{\text {int }}=10 \mathrm{fb}-1$
$0.18<\mathrm{P}_{\mathrm{T}}(\mathrm{GeV})<0.8$

## Forward neutrons from nucleus break-up

Diffractive physics in eA

- Measure spatial gluon distribution in nuclei
- Reaction: $\mathrm{e}+\mathrm{Au} \rightarrow \mathrm{e}^{\prime}+\mathrm{Au}^{\prime}+\mathrm{J} / \psi, \phi, \rho$

- Physics requires forward scattered nucleus needs to stay intact
- Veto incoherent diffraction with break-up (evaporated) neutron detection
- discussions on additional requirements: M Baker's talk



## Requirements

- Need at $+/-4$ mrad beam element free region before the zero degree calorimeter for $100 \%$ acceptance to detect the breakup neutrons at 100 GeV
- Evaporated neutrons can be utilized to reconstruct collisions geometry $\rightarrow$ precision neutron energy with good reconstruction resolution with complete coverage


## Spectator protons in ${ }^{3} \mathrm{He}, \mathrm{d}$



- Crucial for identifying processes with a neutron "target" $[\mathrm{e}(\mathrm{p})+\mathrm{n}]$ in light ions - d, ${ }^{3} \mathrm{He}$
- Spectator neutron can be identified by a calorimeter at beam rapidity (zero degree calorimeter)
- Tagging spectator protons from d, ${ }^{3} \mathrm{He}$
- Relying on separation from magnetic rigidity $\left(B_{r}\right)$ changes ${ }^{3} \mathrm{He}: \mathrm{p}=3 / 2: 1 \mathrm{~d}: \mathrm{p}=2: 1$
- Momentum spread mainly due to Fermi motion + Lorentz boost


## Tagging spectator protons with Roman Pots




- Unambiguously identified $e^{+} p$ event vs $\mathrm{e}+\mathrm{n}$ event in $\mathrm{e}+{ }^{3} \mathrm{He}$ $1 p+1 n$ vs $2 p=30 \%$ vs $22 \%$ (DPMJetIII)
- Common detector RP be utilized for tagging forward proton from diffraction and the spectator protons from ${ }^{3} \mathrm{He}, \mathrm{d}$ ?
- measurement can be done with RPs + forward detectors + ZDC
- Shown distribution at fixed RP locations at eRHIC IR
- Detectors (location, size) can be configured to optimize the acceptance
- Acceptance for spectators with PT kick needs to be considered/simulated


## Controlling collision geometry in e-A?


d : in medium traveling length
R : distance from involved nucleon to the center of nucleus
b : impact parameter
$\mathrm{N}_{\mathrm{n}}$ : number of neutrons in forward region




## collision geometry selected by forward neutrons




EPJA 50 I 89 (20|4) L.Zheng, JHL, E. Aschenauer

- Forward neutrons dominantly correlated with collision geometry
- Zero Degree Calorimeter ( $\theta<\sim 4 \mathrm{mrad}$ ) can be used to count the forward neutrons
- More detailed study including nuclear shadowing effect in progress [BeAGLE]


## IR design at eRHIC

As simulated for High Divergence without cooling


- Integrating requirements for hadron beam direction
- Forward Detector (6-20 mrad)
- Neutron detector ZDC (0 to 4 mrad)
- Roman Pots (sensitive I to 5 mrad )
- electron and hadron polarimetry at separate IR @ IP-I2


## Proton acceptance with eRHIC


$P_{T}$ acceptance for forward scattered protons from exclusive reactions


- Plots:HD (high divergence) mode
- Acceptance gap between RP and BO will be further optimized

Accept $0.3<\mathrm{pT}_{\mathrm{T}}<1.3 \mathrm{GeV}$ and higher $\rightarrow$ Low $\mathrm{PT}_{\mathrm{T}}$-part can be filled in with HA (high acceptance, smaller beam divergence) running mode

## Proton acceptance with JLEIC

IR Layout


Two forward charged hadron detector regions:
_ Region 1: Small dipole covering scattering angles from 0.5 up to a few degrees (before quads)

- Region 2: Far forward, up to one degree, for particles passing through (large aperture) accelerator quads. Use second dipole for precision measurement. (Hi Res)

R. Yoshida Polarized Light lons at EIC 2018
acceptance proton at 100 GeV



## Roman Pots at EIC: considerations

- Integral part of IR design
- beam divergence, aperture limit, multiple running mode/beam parameters
- optimized location for optimal performance and acceptance
- Coverage
- need to measure diffractive protons in beam envelop - aperture limit with full $\varphi$ acceptance
- need wide coverage in momentum for tagging spectator protons from light ions
- "grey" area in acceptance: between RP+forward spectrometer and main tracker (20-~50 mrad)
- Operation
- operation no disturbance to the beam, routine operation
- run simultaneously with normal operation for high luminosity sampling (ref: RHIC, LHC)
- Detector technology
- tracking silicon/pixel + timing/triggering counter (ref: latest development at LHC)
- potential space constraint for full $\varphi$ coverage in horizontal: 2d-move
- geometrical configuration/size for maximal coverage for various energies


## Summary

- Forward nucleon tagging crucial part of EIC physics
- Requirements for detecting forward nucleons are being integrated in the IR design
- The IR with the forward detector system can cover physics needs for wide ranges of nucleon energies in ep and eA (50-275 GeV/nucleon)
- More detailed simulation and detector design study with further optimization underway


## backup

## Nucleon spatial imaging: <br> Deeply Virtual Compton Scattering




Current data: Limited and mainly unpolarized data at low-x



- exclusive process with forward proton measured
- evolution of impact parameter transformed from measured $t$


## $P_{t}$ resolution for recoil protons (eRHIC)

- B0 magnet [100 GeV/c beam energy @ $\mathrm{p}_{\mathrm{t}} \sim 1.3 \mathrm{GeV} / \mathrm{c}$ (worst case)]
( $\sim 1.3 T$ field, $\sim 1.2 \mathrm{~m}$ long; 4 Si stations with $\sim 20 \mu \mathrm{~m}$ resolution; Kalman filter)
- $\sim 30 \mathrm{MeV} / \mathrm{c}$ without IP vertex constraint
- $\sim 15 \mathrm{MeV} / \mathrm{c}$ with reasonable assumptions about beam envelope size at the IP
- Roman Pots [275 GeV/c beam energy]
(2 stations $\sim 30 \mathrm{~m}$ from IP, 20 cm apart, $\sim 20 \mu \mathrm{~m}$ resolution; matrix transport)
- $\sim 20 \mathrm{MeV} / \mathrm{c}$ at $\varphi \sim 0$ degrees (recoil in horizontal plane)
- $\sim 10 \mathrm{MeV} / \mathrm{c}$ at $\varphi \sim 90$ degrees (recoil in vertical plane)

NB: these estimates do not include beam divergence at the IP

