Spectator proton tagging in e/p + $^3$He

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Outline

• **Spectator**, forward proton tagging for eRHIC and RHIC: What’s involved

• Utilizing Roman Pot detectors in
  • $e^+{}^3\text{He}$ at EIC
  • $p^+{}^3\text{He}$ at STAR/RHIC
Forward protons in the key measurements for EIC

- Diffractive proton in exclusive Deeply Virtual Compton Scattering (DVCS) process (ep → eγp): access to the spatial distribution of partons in the transverse plane: GPD (polarized, unpolarized)

- Spectator protons in polarized e+^3He in inclusive DIS for polarized neutron structure function g_1^n(x,Q^2) and flavor separation in semi-inclusive DIS

- ...
Forward protons in current and future RHIC physics

- Protons in elastic $p+p$: studying structure of Pomeron (and Odderon)
- Inelastic diffractive protons in central process: $p+p \rightarrow p + M_X + p$ to study constituent gluonic degree of freedom
- Spectator protons in polarized $p + ^3He$
- ...

...
Forward protons

• Scattered with $\sim O(\text{mrad})$: Need Roman Pot to detect
• Large angle (high-$t$) acceptance mainly limited by magnet aperture
• Small angle (low-$t$) acceptance limited by beam envelop ($\sim 10\sigma$)
• Reconstruction resolution limited by
  – beam angular divergence ($\sim O(50\mu\text{rad})$)
  – uncertainties in vertex ($x,y,z$) and transport
Tagging spectators in $^3$He

- Crucial for identifying processes with a neutron “target” \([e(p)+n]\) in \(e(p)+^3He\)
- Spectator neutron (<~3 mrad) can be measured by ZDC
- Tagging spectator protons from $^3$He
  - Relying on separation from magnetic rigidity ($B_r$) changes
    
    $^3$He: $p = 3/2:1$
  - No need to reconstruct momentum but need clean identification
    - position+directional measurement desirable
- Can a common detector be utilized for tagging forward proton from DVCS and the spectator protons from $^3$He?
Simulation

• Event: DPMJET III with FLUKA implemented
  • Simulated internuclear cascades in spectator pre-fragments and break-up of excited nuclei
  • $e(5) + ^3\text{He}(100) \ 0 < Q^2 < 20 \text{ GeV}^2$ (spectator distributions depend on $^3\text{He}$ energy)

• Beam transport: HECTOR (beam simulator)
  • with the “latest” EIC Optics
  • with current RHIC Optics (with DX): for $p + ^3\text{He}$

• Detector: Roman Pot (RP)
  • 4 sided (2 Up/Down 2 Left/Right) active area of 10cm x 7cm (flexible)
  • RP at 20m for EIC
  • RP at 15.3m for RHIC

• Using a common setup used for detecting diffractive protons in DVCS
  (See http://www.rhic.bnl.gov/~jhlee/proton_tagging_in_DVCS.pdf)
Spectator protons from $^3\text{He}$

- Momentum smearing mainly due to Fermi motion + Lorentz boost
- Angle $\lesssim 3\text{mrad} (>99.9\%)$
IP configuration for eRHIC (December 22, 2010)

Combined function:
0.92 m, 3.60 T, 19 T/m
θ=4 mrad
IP configuration for eRHIC (December 22, 2010)
• Spectator proton acceptance in RP ~ 90% with the assumed design
Unambiguously identified e+p event vs e+n event:
1 p + 1 n vs 1 p + 1 p = 30% vs 22%
\( Q^2 \) vs \( x \) in e\(^+\)\(^3\)He (DPMJET III)

- RP acceptance: No significant bias in \( Q^2-x \)
Forward Proton Tagging at STAR/RHIC

- Roman Pot detectors to measure forward scattered protons in diffractive processes
  - Staged implementation to cover wide kinematic coverage
    - Phase I (Installed): for low-t coverage
    - Phase II (planned): for higher-t coverage
Roman Pots at STAR (Phase I)

- Phase I: 8 Roman pots at ±55.5, ±58.5m from the IP
- Require special beam tune: large $\beta^*$ (21m for $\sqrt{s}=200$ GeV) for minimal angular divergence
- Successful run in 2009: Analysis in progress focusing on small-$t$ processes ($0.002<|t|<0.03$ GeV$^2$)

Beam transport simulation using Hector
Roman Pots (Phase II)

- Phase II: 8(12) Roman Pots at ±15 and ±17m
- Planned to be implemented in 2011-2012
- Doesn’t require special beam optics: main set-up for central DPE processes requiring wide-t coverage and high-luminosity
- $2\pi$ coverage in $\phi$ will be limited due to machine constraint (incoming beam)
Current “Design” for RP Phase II

...for CF flange interface to DX-D0 chamber. Alternatively, can extend strongback and kinematics to accommodate CF flange interface in DX-D0 chamber to keep Roman Pot design the same at both stations. Alternatively, can redesign RP brackets at RF(601). A type frame will be required in place of existing Roman Pot support pedestal to avoid interference with RF beam components. Adding a screen can be simple to complex depending on requirements. The most simple rf-screen will be a perforated sheet of copper pressed to an oval upon box closure. The simplest rf-shield design will only rounds the longitudinal sharp inside corners.
RHIC after DX z~15m
Spectator proton from $^3$He with the current RHIC optics

- The same RP configuration with the current RHIC optics (at $z \sim 15m$ between DX and D0)
- Acceptance $\sim 98\%$
“Spectator” proton from deuteron with the current RHIC optics

- Rigidity (d:p = 2:1)
- The same RP configuration with the current RHIC optics (at z ~ 15m between DX and D0)
- Detector size and position can be optimized for optimal acceptance
Summary

• Spectator tagging necessary for identifying target nucleon in e/p+\(^3\)He

• Deflected spectator protons due to different rigidity can be detected using Roman Pots

• A common detector system ("forward proton spectrometer") can be utilized for measuring diffractive protons and spectator protons in \(^3\)He

• Currently assumed detector design can be optimized for better acceptance and efficiency

• High luminosity and background effects in p+\(^3\)He need to be studied
“protons, protons, $^3$He...”

"Particles, particles, particles."