A_1^n and g_1^n from polarized eHe3 DIS with double spectator tagging

Win Lin Stony Brook University

EIC Early Science Workshop 04/25/2025





Center for Frontiers in Nuclear Science



Double spectator tagging



Friščić et al. Neutron Spin Structure from e-3He Scattering with Double Spectator Tagging at the Electron-Ion Collider. Phys. Lett. B 2021

Comparison of Aⁿ extracted from inclusive (blue band) vs tagged (black square) measurements

5x41 GeV, $\mathscr{L} = 100 \text{ fb}^{-1}$ (per nucleon)



A_1^n from $A_1^{^{3}\text{He}}$

Nuclear effect:

- Spin depolarization
- Blinding
- Fermi motion
- Off-shell effect
- Non-nucleonic degrees of freedom
- Nuclear shadowing and anti-shadowing

DOI: https://doi.org/10.1103/PhysRevC.70.065207 DOI: https://doi.org/10.1103/PhysRevC.65.064317

(For
$$10^{-4} \le x \le$$

$$F_2^{^{3}\text{He}}[A_1^{^{3}\text{He}} - 2(F_2^p/F_2^{^{3}\text{He}})P_pA_1^p(1 - 0.014/(2P_p))]$$

$$P_nF_2^n(1 + 0.056/P_n)$$

 $A_{1}^{n} =$

TABLE X. Total uncertainties for A_1^n .

$\langle x \rangle$	0.33	0.47	0.60
Statistics	0.024	0.027	0.048
Experimental syst.	0.004	0.003	0.004
$\Delta A_1^{n,\mathrm{ir}}$	0.012	0.013	0.015
$\Delta A_1^{n,\mathrm{er}}$	0.002	0.002	0.003
F_{2}^{p}, F_{2}^{d}	0.006	0.008	+0.005
			-0.010
Nuclear effect	0.001	0.000	0.009
A_1^p	0.001	0.005	0.011
P_n, P_p	+0.005	+0.009	+0.018
*	-0.012	-0.020	-0.037





$A_1^n \operatorname{from} A_1^{^3\operatorname{He}}$

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 $A_{1}^{n} =$

$$P_n F_2^n (1 + 0.056/P_n)$$

correction due to $\Delta(1232)$ in ³He wave function







Data comparison



Aⁿ₁ exacted using this model
 agrees with HERA data



Double spectator tagging



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Spectator tagging

- Track reconstruction is not ready for e³He events, so currently:
- Define proton track: at least one hit per plane per detector (either RP or OMD)
- If there are two proton tracks, then the event is tagged as *en* scattering.





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- Define proton track: at least one hit per plane per detector (either RP or OMD)
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Tagging efficiency

– Overall uniform with bin efficiency $\gtrsim 80\%$



												_
									1	0.833	1	
								0.739	0.938	0.667	1	 6
							0.803	0.844	0.887	0.706		
					0.917	0.839	0.824	0.831	0.843	0.776	1	 0
				0.867	0.856	0.827	0.826	0.834	0.849	0.806	0.6	
			0.821	0.841	0.845	0.852	0.848	0.833	0.838	0.808	0.75	 0
		0.837	0.841	0.84	0.831	0.833	0.82	0.84	0.826	0.809	1	
0.864	0.846	0.842	0.847	0.838	0.845	0.836	0.841	0.826	0.827	0.808	0.842	
0.843	0.839	0.845	0.819	0.821	0.847	0.828	0.822	0.829	0.793	0.821	1	_
0.823	0.828	0.845	0.863	0.847	0.856	0.839	0.845	0.835	0.849	0.867	1	
0.863	0.847	0.839	0.822	0.846	0.844	0.84	0.843	0.84	0.829	1		
0.843	0.845	0.834	0.838	0.832	0.83	0.811	0.845	0.852	0.895			
0.848	0.846	0.839	0.832	0.84	0.842	0.83	0.855	1				 0
0.839	0.858	0.858	0.804	0.865	0.786	0.794						
0.843	0.828	0.838	0.834	0.83	0.894							 0
0.874	0.852	0.837	0.849	0.893								
0.828	0.824	0.842	0.667									 10
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Tagging purity

– Overall uniform with bin purity $\gtrsim 90\,\%$



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							1	1	1		l .
						1	1	1	1		0
					0.966	0.991	1	1			
			1	0.985	0.97	0.981	0.992	1	1		0
		0.958	0.953	0.962	0.954	0.972	1	1	1		
	0.944	0.949	0.956	0.961	0.967	0.979	0.983	0.981	1		0
0.92	0.936	0.939	0.949	0.955	0.962	0.984	0.993	1	1		
2 0.936	0.936	0.938	0.943	0.958	0.973	0.983	0.987	1	1		0
9 0.927	0.96	0.934	0.942	0.964	0.973	0.97	0.97	1	1		
2 0.92	0.923	0.939	0.94	0.956	0.975	0.968	0.991	1	1		١٧
6 0.927	0.924	0.954	0.923	0.947	0.955	0.974	0.994	1			0
0.919	0.922	0.922	0.937	0.943	0.961	0.979	1				ľ
0.91	0.92	0.928	0.942	0.946	0.973	1					0
7 0.913	0.907	0.96	0.932	0.964							
7 0.914	0.915	0.924	0.937								0
8 0.911	0.908	0.893									
7 0.931	1		I								0
			1								
•	I I		<u> </u>	1			I				• ()
	0.92 2 0.936 9 0.927 2 0.92 3 0.927 9 0.927 9 0.919 1 0.91 1 0.91 7 0.913 7 0.914 8 0.911 7 0.931	0.944 0.92 0.936 0.936 0.936 0.936 0.936 0.927 0.936 0.927 0.923 0.919 0.923 0.919 0.922 0.911 0.922 0.913 0.907 0.914 0.915 0.915 0.908 0.911 1	0.958 0.944 0.949 0.92 0.936 0.939 0.92 0.936 0.938 0.92 0.936 0.938 0.927 0.96 0.934 0.927 0.923 0.939 0.927 0.924 0.939 0.910 0.922 0.924 0.911 0.922 0.928 0.911 0.907 0.928 0.911 0.9015 0.924 0.911 0.908 0.893 0.911 0.908 0.893 1 0.911 1	1 0.958 0.953 0.92 0.944 0.949 0.956 0.92 0.936 0.939 0.949 0 0.927 0.96 0.934 0.942 0 0.927 0.923 0.939 0.942 0 0.927 0.923 0.939 0.942 0 0.927 0.923 0.939 0.942 0 0.927 0.924 0.934 0.942 0 0.927 0.923 0.939 0.942 0 0.927 0.924 0.954 0.923 0 0.919 0.922 0.922 0.937 0 0.913 0.907 0.966 0.932 1 0.911 0.920 0.924 0.937 1 0.931 1 0.933 0.933 1 1 1 10 10	1 0.985 0.958 0.953 0.962 0.944 0.949 0.956 0.961 0.92 0.936 0.939 0.949 0.955 0.936 0.939 0.949 0.956 0.958 0.927 0.936 0.938 0.949 0.958 0.927 0.961 0.934 0.943 0.958 0.927 0.923 0.939 0.942 0.964 0.910 0.922 0.923 0.934 0.943 0.911 0.922 0.922 0.937 0.943 0.911 0.922 0.923 0.934 0.942 0.911 0.915 0.924 0.937 0.943 0.931 1 0.934 0.937 0.944 10 0.911 0.915 0.924 0.937 0.931 1 0.933 0.937 0.943	0.966 1 0.985 0.97 0.954 0.953 0.962 0.954 0.92 0.936 0.939 0.949 0.955 0.962 0 0.92 0.936 0.939 0.949 0.955 0.962 0 0.92 0.936 0.938 0.949 0.955 0.962 0 0.927 0.936 0.938 0.943 0.958 0.973 0 0.927 0.926 0.938 0.943 0.956 0.973 0 0.927 0.926 0.938 0.943 0.956 0.973 0 0.927 0.923 0.939 0.941 0.956 0.975 0 0.927 0.924 0.954 0.923 0.947 0.955 0 0.919 0.922 0.928 0.942 0.946 0.973 1 0.911 0.907 0.964 0.937 0.964 0.973 1 0.911 0.907 0.926 0.937 0.947 0.947 0.913 0.915	1 0.966 0.991 0.966 0.991 1 0.985 0.977 0.981 0.944 0.949 0.953 0.962 0.954 0.972 0.92 0.936 0.939 0.949 0.955 0.962 0.984 2 0.936 0.938 0.949 0.955 0.962 0.984 2 0.936 0.938 0.949 0.955 0.962 0.984 2 0.936 0.938 0.949 0.955 0.962 0.984 2 0.936 0.938 0.949 0.955 0.962 0.984 2 0.937 0.936 0.938 0.943 0.956 0.973 0.983 3 0.919 0.922 0.923 0.937 0.943 0.964 0.973 1 4 0.911 0.922 0.924 0.937 0.943 0.964 1 1 7 0.913 0.907 0.924 0.937 1 1 1 7 0.931 1 1 <	1 1 1 1 1 1 0.966 0.991 1 0.966 0.991 1 0.97 0.981 0.992 0.944 0.949 0.953 0.962 0.954 0.972 1 0.92 0.936 0.939 0.949 0.955 0.962 0.984 0.993 2 0.936 0.936 0.939 0.949 0.955 0.962 0.984 0.983 2 0.936 0.938 0.949 0.955 0.962 0.984 0.983 2 0.936 0.938 0.943 0.958 0.973 0.983 0.983 3 0.927 0.96 0.938 0.942 0.964 0.973 0.974 0.994 4 0.919 0.922 0.927 0.943 0.941 0.955 0.974 0.994 5 0.911 0.922 0.928 0.942 0.946 0.973 1 1 7 0.913 0.907 0.924 0.937 0.943	1 1 1 1 1 1 1 1 1 1 0.966 0.991 1 1 0.966 0.991 1 1 0.94 0.958 0.962 0.954 0.972 1 1 0.92 0.936 0.939 0.956 0.961 0.962 0.973 0.983 0.981 0.92 0.936 0.939 0.949 0.955 0.962 0.984 0.993 1 0.92 0.936 0.939 0.949 0.955 0.962 0.984 0.993 1 0.92 0.936 0.938 0.943 0.955 0.962 0.984 0.993 1 0.936 0.936 0.942 0.964 0.973 0.977 0.977 1 0.910 0.922 0.923 0.947 0.946 0.975 0.968 0.991 1 1 0.917 0.924 0.924 0.942 0.946 0.975 1 1 1 1 0.91 <td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0.966 0.991 1 1 1 0.97 0.981 0.992 1 1 0.958 0.953 0.962 0.974 0.972 1 1 1 0.944 0.949 0.956 0.961 0.967 0.979 0.983 0.981 1 1 0.944 0.949 0.956 0.962 0.974 0.979 0.983 0.981 1 2 0.920 0.936 0.939 0.949 0.955 0.962 0.984 0.993 1 1 2 0.936 0.938 0.943 0.955 0.963 0.977 0.977 1 1 1 2 0.927 0.964 0.939 0.944 0.955 0.973 0.974 0.994 1 1 4 0.919 0.922 0.924 0.943 0.961 0.979 1 1</td> <td>$\begin{array}{cccccccccccccccccccccccccccccccccccc$</td>	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0.966 0.991 1 1 1 0.97 0.981 0.992 1 1 0.958 0.953 0.962 0.974 0.972 1 1 1 0.944 0.949 0.956 0.961 0.967 0.979 0.983 0.981 1 1 0.944 0.949 0.956 0.962 0.974 0.979 0.983 0.981 1 2 0.920 0.936 0.939 0.949 0.955 0.962 0.984 0.993 1 1 2 0.936 0.938 0.943 0.955 0.963 0.977 0.977 1 1 1 2 0.927 0.964 0.939 0.944 0.955 0.973 0.974 0.994 1 1 4 0.919 0.922 0.924 0.943 0.961 0.979 1 1	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$

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Electron kinematic reconstruction





- Use MC info to find
 reconstructed electrons
- BeAGLE does not include radiative effect
- Currently using "electron method" only

11

A_1^n for early science

$$A_1(x,Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{\parallel}}{D(1 + \eta\xi)} - \frac{\eta A_{\perp}}{d(1 + \eta\xi)}$$

-
$$\mathscr{L} = 8.65 \text{ fb}^{-1}, P_e = P_n = 70\%$$

– Data split evenly between A_{\parallel} and A_{\perp}

$$\delta A_{\parallel,\perp} = \frac{1}{\sqrt{NP_eP_N}}$$

- Bin A_1 calculated from: Doi: 10.2172/824895
- Statistical uncertainty only, correction not yet applied





g_1^n for early science

$$A_1(x,Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{\parallel}}{D(1 + \eta\xi)} - \frac{\eta A_{\perp}}{d(1 + \eta\xi)}$$

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-
$$A_1 \approx g_1/F_1$$

- F_1 taken from <u>HERAPDF20_LO_EIG</u>







Extract α_s via A_1^p and A_1^n

EIC Early Science Timeline

	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization			
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A			
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS			
YEAR 3	e+p	e+p 10 x 130 4.95 - 5.33		LONG	TRANS and/or LONG			
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG			
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG			
Note: the eA luminosity is per nucleon								

$$\begin{array}{c} A_1^n \\ g_1^n \end{array} \qquad \bullet \qquad \begin{array}{c} A_1^p \\ g_1^p \\ g_1^p \end{array}$$



Bjorken integral:

$$\Gamma_1^{p-n} \equiv \int_0^{1^-} (g_1^p - g_1^n) \, dx$$

At finite Q² values:

$$\Gamma_1^{p-n}(\alpha_S) = \Gamma_1^{p-n}(Q^2) = \sum_{\tau>0} \frac{\mu_{2\tau}^{p-n}(\alpha_S)}{Q^{2\tau-2\tau}}$$





Extract α_s via A_1^p and A_1^n

EIC can be a significant contributor to the global extraction of $\alpha_{\rm s}$:

- Global PDF fits

Cerci et al. Extraction of the strong coupling with HERA and EIC

inclusive data. Eur. Phys. J. C 2023

Using BJSR

Kutz et al. High precision measurements of α_s at the future EIC.

Phys. Rev. D 2024

$$\begin{array}{c} A_1^n \\ g_1^n \end{array} \qquad \bullet \qquad \begin{array}{c} A_1^p \\ f_1 \\ g_1^p \\ g_1^p \end{array}$$



P. A. Zyla et al. (Particle Data Group), Review of Particle Physics. PTEP 2020





Slides+ : analysis QA



Analysis status & QA checklist

https://docs.google.com/presentation/d/1nSJGFxWLkfE6dPkI-VMcOyVpJWkmOTN0UgKXCCFTUqQ/edit?slide=id.g34d71ddcf31_0_

Kinematic reconstructions	quantity	Reco	Truth	Response (2D)	Purity/bin migration	detector acceptance-only corrected	Unfolding/full correction
(electron,JB, DA,sigma, e-sigma)	Q2						
	х						
	у						
	dQ2/Q2						
	dx/x						
	dy/y						
	e' energy						
	e' theta						
	HFS (E-pz)						
	HFS (pT)						
Event level							
	E-pz (e'+HFS)						
	E/p for calorimeter						
	Calo clusters						
Observable of interest							
	e.g., t,u,etc.						
Detector specific variables	Depends						
PID quantities:	Add when it comes						



Analysis procedure



- EPIC 25.03.1 simulation campaign
- Later scaled to $\mathscr{L} = 8.65 \text{ fb}^{-1}$

Electron identification and kinematic reconstruction was done outside of ElCRecon



eID acceptance

- Use truth information to identify scattered electron from reconstruction
- Use reconstruction information to calculate x and Q^2







eID bin migration

- Use truth information to identify scattered electron from reconstruction
- Use reconstruction information to calculate x and Q^2



									0.5	1.167	1	
								0.826	0.813	1.222		1.4
							0.986	0.898	0.855	1.059		
					1.167	0.996	0.878	0.921	0.986	1.102	1.5	 1.2
				0.781	1.01	0.97	0.972	0.985	0.968	1.129	1.5	
			1.032	0.995	0.985	0.999	1.017	0.926	1.011	0.931	1.5	
		0.982	0.994	0.992	1.013	0.996	0.98	0.979	0.829	1.145	1.5	1
0.84	0.986	0.995	0.993	0.978	0.988	0.95	0.946	0.849	0.825	1.027	1.5	
1.379	1.5	1.5	1.5	1.417	1.31	1.138	1	0.797	0.634	0.714	1.5	 8.0
1.087	1.072	1.073	0.935	0.912	0.772	0.864	0.718	0.476	0.532	1.233	1.5	
1.031	1.029	1.021	1.006	0.919	0.964	0.777	0.606	0.514	0.627	1.5		 06
1.037	1.008	0.983	0.966	0.94	0.811	0.698	0.468	0.564	1.5			0.0
1.01	0.981	0.982	0.91	0.824	0.623	0.416	0.694	1.5		I		
1.263	1.107	1.134	0.887	0.55	0.393	0.897			I			 0.4
0.905	0.963	0.598	0.449	0.388	1.5							
0.752	0.534	0.319	0.376	1.5								 0.2
0.493	0.296	0.263	1.5									•
	<u>.</u>	_			1		_	_	_			-
		1				1	1	1				0
	10 ⁻¹ 1											

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Electron kinematic reconstruction



$$p_{t,h}^{2} = (\sum_{h} p_{x,h})^{2} + (\sum_{h} p_{y,h})^{2} \qquad \delta_{h} = \sum_{h} E_{h} - p_{z,h}$$



Electron kinematic reconstruction



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A_1^n from $A_1^{^{3}\text{He}}$

Nuclear effect:

- Spin depolarization
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effective polarization of n(p) in ³He

DOI: https://doi.org/10.1103/PhysRevC.70.065207 DOI: https://doi.org/10.1103/PhysRevC.65.064317

(For $10^{-4} \le x \le 0.8$)

 $g_1^{^{3}\text{He}} = P_p g_1^n + 2P_p g_1^p - 0.014[g_1^p(x) - 4g_1^n(x)] + a(x)g_1^n(x) + b(x)g_1^p(x)$

nuclear shadowing and anti-shadowing effects



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$A_1^n = \frac{F_2^{^{3}\text{He}}[A_1^{^{3}\text{He}} - 2(F_2^p/F_2^{^{3}\text{He}})P_pA_1^p(1 - 0.014/2P_p)]}{P_nF_2^n(1 + 0.056/P_n)}$





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F_{2}^{p}, F_{2}^{d}	0.006	0.008	$+0.005 \\ -0.010$
Nuclear effect	0.001	0.000	0.009
A_1^p	0.001	0.005	0.011
P_n, P_p	+0.005 -0.012	$+0.009 \\ -0.020$	+0.018 -0.037



