Beam Normal Single Spin Asymmetry in the N-to-Δ Transition

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for the Q-weak Collaboration

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Overview

$$B_{\mathrm{n}} = M_{\mathrm{kin}} \left[\frac{\frac{\epsilon_{\mathrm{reg}}}{P} - \sum_{i=1}^{4} B_{\mathrm{bi}} f_{\mathrm{bi}}}{1 - \sum_{i=1}^{4} f_{\mathrm{bi}}} \right] \tag{1}$$

$$B_{n} = M_{total} \left[\frac{\frac{\epsilon_{reg}}{P} - \sum_{i=1}^{4} B_{bi} f_{bi}}{1 - \sum_{i=1}^{4} f_{bi}} \right] \tag{2}$$

$$\epsilon_{reg} = \epsilon_{raw} - \sum_{i=1}^{5} \left(\frac{\partial \epsilon_{raw}}{\partial T_i} \right) \Delta T_i \tag{3}$$

$$M_{total} = M_{RC} M_{Det} M_{Q^2} M_{\phi} \tag{4}$$

$$B_{\mathrm{n}} = M_{\mathrm{RC}} M_{\mathrm{Det}} M_{\mathrm{Q}^2} M_{\phi} \left[\frac{\frac{\epsilon_{\mathrm{reg}}}{P} - B_{\mathrm{Al}} f_{\mathrm{Al}} - B_{\mathrm{BB}} f_{\mathrm{BB}} - B_{\mathrm{QTor}} f_{\mathrm{QTor}} - B_{\mathrm{el}} f_{\mathrm{el}}}{1 - f_{\mathrm{Al}} - f_{\mathrm{BB}} - f_{\mathrm{QTor}} - f_{\mathrm{el}}} \right] \tag{5}$$

$$B_{\mathrm{n}} = M_{\mathrm{kin}} \left[\frac{\frac{\epsilon_{\mathrm{reg}}}{P} - B_{\mathrm{Al}} f_{\mathrm{Al}} - B_{\mathrm{BB}} f_{\mathrm{BB}} - B_{\mathrm{QTor}} f_{\mathrm{QTor}} - B_{\mathrm{el}} f_{\mathrm{el}}}{1 - f_{\mathrm{Al}} - f_{\mathrm{BB}} - f_{\mathrm{QTor}} - f_{\mathrm{el}}} \right] \tag{6}$$

$$\frac{\epsilon_{reg}}{P} = \frac{(1 - f_{total})}{M_{kin}} B_n + B_{el} f_{el} + others \tag{7}$$

$$\frac{(1 - f_{total})}{M_{kin}} B_n = \frac{\epsilon_{reg}}{P} - B_{el} f_{el} - others \tag{8}$$

$$B_n = \frac{\frac{\epsilon_{reg}}{P} - B_{Al} f_{Al} - B_{BB} f_{BB} - B_{QTor} f_{QTor} - B_{el} f_{el}}{1 - f_{Al} - f_{BB} - f_{QTor} - f_{el}} \tag{9}$$

- $\epsilon_{reg} = \epsilon^{in}_{reg} M_{\phi}$, ϵ^{in}_{reg} is the measured asymmetry
- $B_{Al} = \epsilon^{Al}_{reg} M_{\phi}/P$, $\epsilon^{Al}_{reg} = (\epsilon^{DS-Al}_{reg} + \epsilon^{US-Al}_{reg})/2$
- f_{Al}, measured
- $B_{BB} = 0 \pm 0.313$ ppm, AncELOG 122
- f_{BB}, measured
- $B_{Qtor} = 0 \pm 10$ ppm
- f_{QTor}, measured
- $B_{el} = \sqrt{\frac{Q^2_{in}}{Q^2_{el}}} B^{el}_T$, B^{el}_T is Buddhini's final asymmetry. Will change after calculation from Gorchtein. Mark D. has preliminary no. but not finalized yet.
- f_{el}, simulation

$$B_n = M_{RC} M_{Det} M_{Q^2} \left[\frac{\frac{\epsilon_{reg}}{P} - B_{Al} f_{Al} - B_{BB} f_{BB} - B_{QTor} f_{QTor} - B_{el} f_{el}}{1 - f_{Al} - f_{BB} - f_{QTor} - f_{el}} \right] \tag{10}$$

- $\epsilon_{reg} = \epsilon_{reg}^{in} M_\phi$, ϵ_{reg}^{in} is the measured asymmetry
- $B_{Al} = \epsilon_{reg}^{Al} M_\phi / P$, $\epsilon_{reg}^{Al} = (\epsilon_{reg}^{DS-Al} + \epsilon_{reg}^{US-Al})/2$
- f_{Al}, measured
- $B_{BB} = 0$
- f_{BB}, measured
- $B_{Qtor} = 0$
- f_{QTor}, measured
- $B_{el} = \sqrt{\frac{Q^2_{in}}{Q^2_{el}}} B_T^{el}$, B_T^{el} is Buddhini's final asymmetry. Will change after calculation from Gorchtein
- f_{el}, simulation
- M_{RC}, needs update
- M_{Det}, needs update
- M_{Q^2}?, probably we should change it to M_θ as we will be quoting numbers at $\theta = 8.3$ degrees. But need to know the uncertainty on θ.

$$A_{\text{ep}} = R_{\text{total}} \left[\frac{\frac{A_{\text{msr}}}{P} - \sum_{i=1}^{4} A_{\text{bi}} f_{\text{bi}}}{1 - \sum_{i=1}^{4} f_{\text{bi}}} \right] \tag{11}$$

$$A_{\text{msr}} = A_{\text{raw}} + A_T + A_L + A_{\text{reg}} \tag{12}$$

$$R_{\text{total}} = R_{\text{RC}} R_{\text{Det}} R_{\text{Bin}} R_{Q^2} \tag{13}$$

$$A_{\text{ep}} = R_{\text{RC}} R_{\text{Det}} R_{\text{Bin}} R_{\text{Q}^2} \left[\frac{\frac{A_{\text{msr}}}{P} - A_{\text{Al}} f_{\text{Al}} - A_{\text{BB}} f_{\text{BB}} - A_{\text{QTor}} f_{\text{QTor}} - A_{\text{in}} f_{\text{in}}}{1 - f_{\text{Al}} - f_{\text{BB}} - f_{\text{QTor}} - f_{\text{el}}} \right] \tag{14}$$

Q-weak First Result 2

	Correction Value [ppb]		Contribution to ΔA_{ep} [ppb]
Normalization Factors Applied to $A_{\rm raw}$			
Beam Polarization 1/P	-21		5
Kinematics $R_{\rm total}$	5		9
Background Dilution $1/(1\text{-}f_{\rm total})$	-7		-
Asymmetry Corrections			
Beam Asymmetries $\kappa A_{\rm reg}$	-40		13
Transverse Polarization κA_T	0		5
Detector Linearity κA_L	0		4
Backgrounds	$\kappa P f_{\rm bi} A_{\rm bi}$	$\delta(f_{\rm bi})$	$\delta(A_{\rm bi})$
Target windows (Al)	-58	4	8
Beamline scattering (BB)	11	3	23
Other neutral bkg (QTor)	0	1	<1
Inelastics (in)	1	1	<1

Table: Summary of corrections and the associated systematic uncertainty, in parts per billion. The table shows the contributions of normalization factors on A_{raw}, then the properly normalized contributions from other sources. Background correction terms listed here include only $R_{tot} f_i A_i/(1 - f_{tot})$ uncertainties in A_{ep} due to dilution fraction and background asymmetry uncertainties are noted separately.

Beam Normal Single Spin Asymmetry 2

Input parameters			
Measured regressed asymmetry (A_M^{in})	5.127 ± 0.455 ppm (Det. acpt. correcte		
Beam polarization (P)	0.875 ± 0.009		
Detector acceptance correction	0.9938		
Background corrections			
Quantity	Asymmetry (A_{bi}) [ppm]	Dilution (f_{bi})	Correction $c_i = \kappa P A_{bi} f_{b}$ [ppm]
Target windows (b1)	9.185 ± 1.279	0.033 ± 0.002	1.364
Beamline scattering (b2)	2.239 ± 6.843	0.018 ± 0.001	0.180
Other neutral bkg. (b3)	0.000 ± 0.200	0.024 ± 0.010	0.000
Elastic asymmetry (b4)	-4.885 ± 0.093	0.701 ± 0.070	-13.809
Other corrections			
Radiative correction (R_{RC})	1.010 ± 0.004		
Detector bias (R_{Det})	0.998 ± 0.001		
Q^2 acceptance (R_{Q^2})	1.000 ± 0.012		

Table: Summary of input quantities.

Overview

Frame 61

$$A_{ep} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right]\left[\frac{\varepsilon G_E^{p\gamma} G_E^{pZ} + \tau G_M^{p\gamma} G_M^{pZ} - (1-4\sin^2\theta_W)\varepsilon' G_M^{p\gamma} G_A^Z}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}\right] \tag{15}$$

$$\varepsilon = \frac{1}{1+2(1+\tau)\tan^2\frac{\theta}{2}}, \varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}, \tau = \frac{Q^2}{4M} \tag{16}$$

$$G_{E,M}^{pZ} = (1-4\sin^2\theta_W) G_{E,M}^{p\gamma} - G_{E,M}^{n\gamma} - G_{E,M}^{s} \tag{17}$$

$$\frac{A_{ep}}{A_0} = \left[\frac{\varepsilon G_E^{p\gamma}(Q_W^p G_E^{p\gamma} - G_E^{n\gamma} - G_E^s) + \tau G_M^{p\gamma}(Q_W^p G_M^{p\gamma} - G_M^{n\gamma} - G_M^s) - (1-4\sin^2\theta_W)\varepsilon' G_M^{p\gamma} G_A^Z}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}\right] \tag{18}$$

$$\frac{A_{ep}}{A_0} = Q_W^p \left[\frac{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}\right] + \left[(-1)\frac{\varepsilon G_E^{p\gamma} G_E^{n\gamma} + \tau G_M^{p\gamma} G_M^{n\gamma}}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}\right] + \left[(-1)\frac{(1-4\sin^2\theta_W)\varepsilon' G_M^{p\gamma} G_A^Z}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}\right] \tag{19}$$

As $\theta \to 0$, $\varepsilon \to 1$, and $\tau \ll 1$

Frame 71

$$A_{Q-weak} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] Q_W^p \left[\frac{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}\right] = \tag{20}$$

$$A_{hadronic} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] Q_W^n \left[\frac{\varepsilon G_E^{p\gamma} G_E^{n\gamma} + \tau G_M^{p\gamma} G_M^{n\gamma}}{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}\right] = \tag{21}$$

$$A_{axial} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] G_A^e \left[\frac{(1 - 4\sin^2\theta_W)\varepsilon' G_M^{p\gamma} G_A^Z}{\varepsilon(G_E^{p\gamma})^2 + \tau(G_M^{p\gamma})^2}\right] = \tag{22}$$

$$A_{ep} = A_{Q-weak} + A_{hadronic} + A_{axial} = \tag{23}$$

$$Q_W^p = (1 - 4\sin^2\theta_W) \tag{24}$$

$$\frac{A_{ep}}{A_0} = \left[Q_W^p + Q^2 B(Q^2, \theta)\right] \tag{25}$$

$$A_{ep} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] \left[Q_W^p + B(Q^2, \theta)\right] = A_0 \left[Q_W^p + B(Q^2, \theta)\right] \tag{26}$$

$$A_{ep} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] \left[Q_W^p + Q^2 B(Q^2, \theta)\right] = A_0 \left[Q_W^p + Q^2 B(Q^2, \theta)\right] \tag{27}$$

$$\begin{gathered} A_{ep} = A_0 \left[Q_W^p + B(Q^2, \theta)\right] \\ A_0 = \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha} \end{gathered} \tag{28}$$

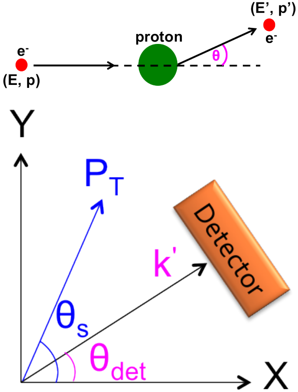
Beam Normal Single Spin Asymmetry (BNSSA)

Measured asymmetry

$$A_M = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = -B_n \vec{P_T} \cdot \hat{n} = -B_n P_T \sin(\phi_{det} - \phi_s)$$

where $\hat{n} = \frac{\vec{k} \times \vec{k'}}{|\vec{k} \times \vec{k'}|}$ and $\vec{P_T}$ is transverse polarization and B_n is BNSSA.

- Measured asymmetry has a small azimuthal dependence.



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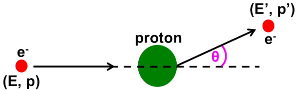

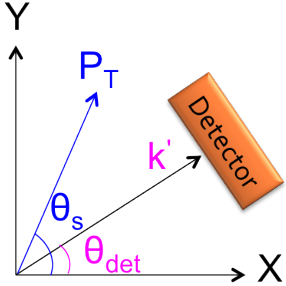

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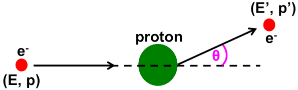

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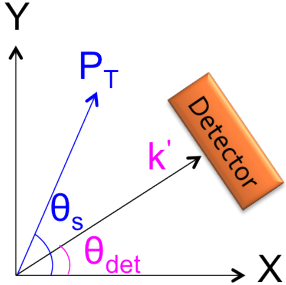

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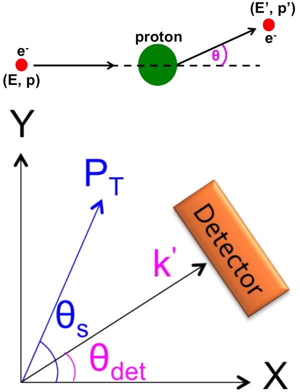

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Overview

Experimental Apparatus

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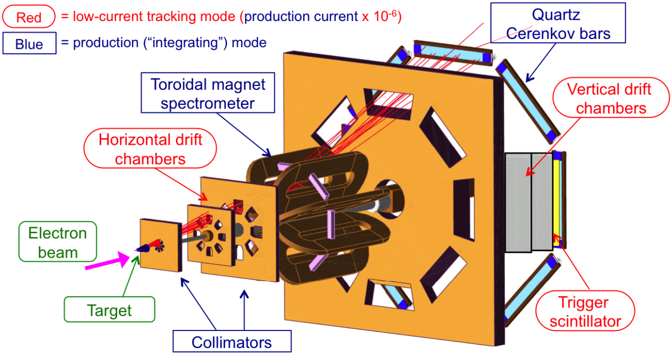
Ebeam = 1.155 GeV
$\langle Q^2 \rangle \sim 0.025\ (\mathrm{GeV/c})^2$
$\langle \theta \rangle \sim 7.9^o \pm 3^o$
ϕ coverage 49% of 2π
Current = 180 μA
Polarization = 89%
Target = 34.4 cm LH_2
Cryopower = 2.5 kW
Luminosity
$2\mathrm{x}1039 \mathrm{s}^{-1}\mathrm{cm}^{-2}$



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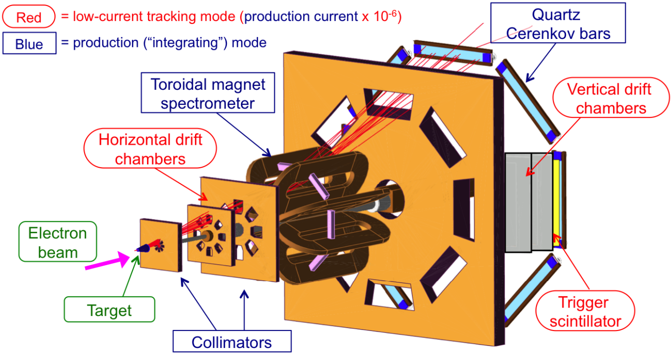

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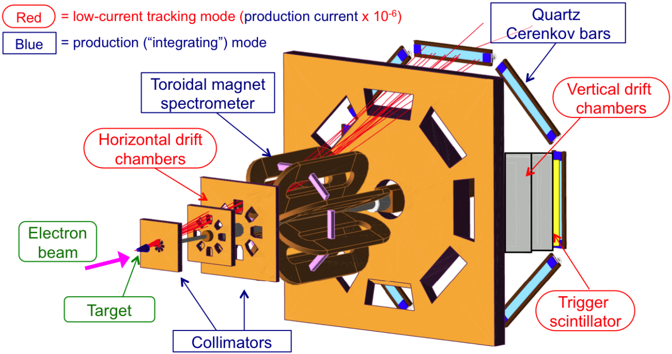

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Overview

Transverse N-to-Δ Data Set

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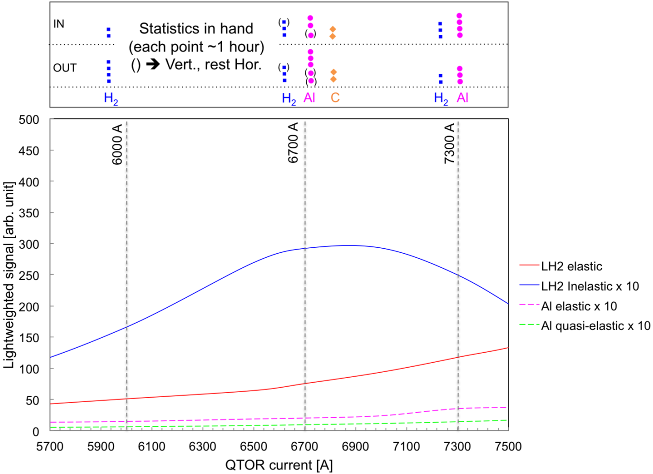

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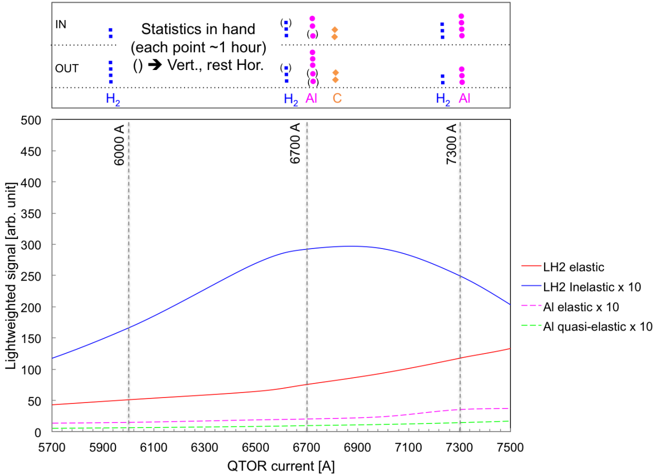

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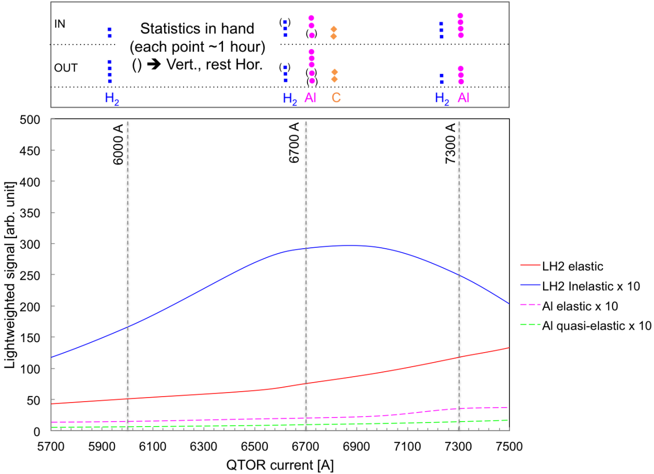

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Transverse Asymmetries for N-to-Δ in Hydrogen

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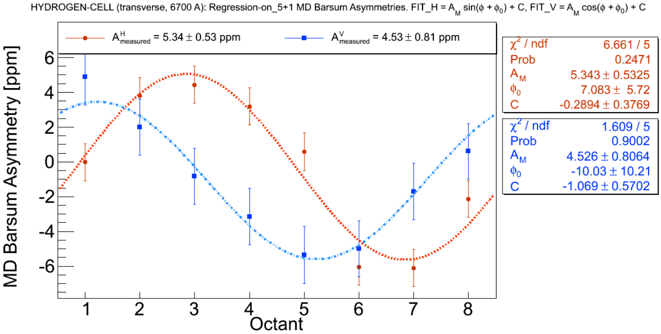

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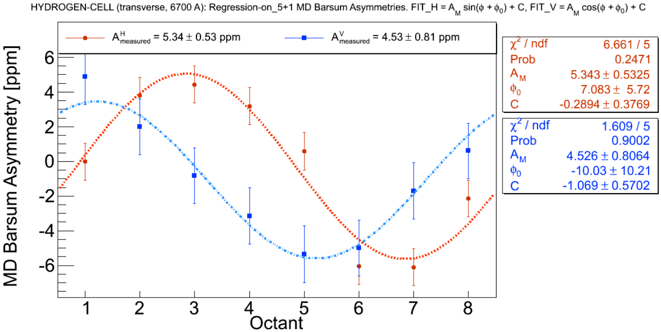

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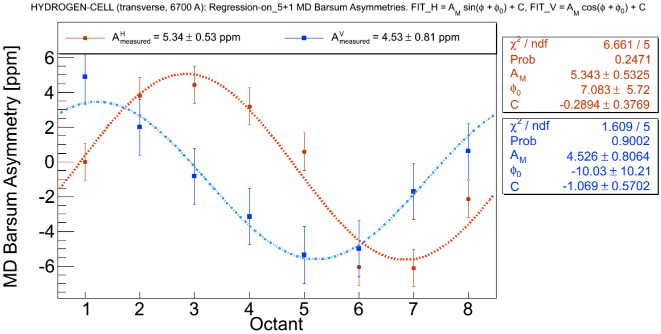

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Summary of Uncertainties

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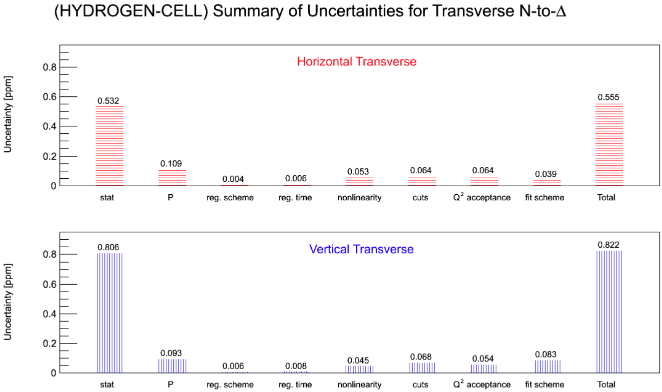

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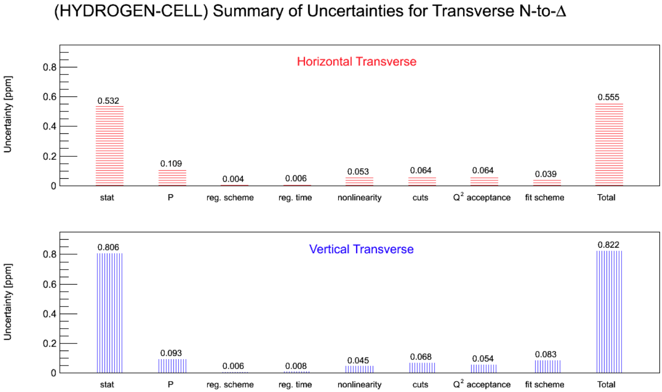

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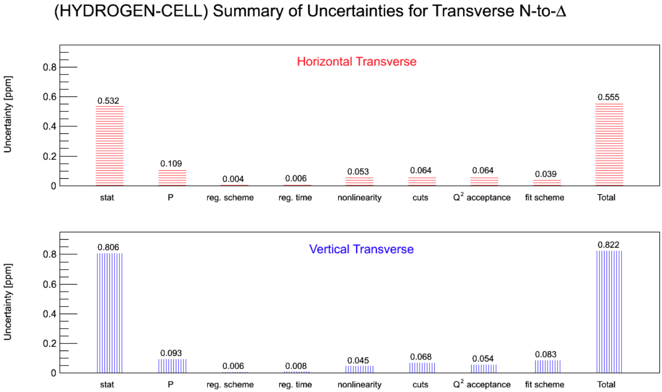

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Overview

Extracting Physics Asymmetry

$$A_{ep} = R_{total} \left[\frac{A_M/P - \sum_{i=1}^{4} f_i A_i}{1 - \sum_{i=1}^{4} f_i} \right]$$

- Polarization
- Multiplicative corrections $R_{total} = R_{RC} R_{Det} R_{Bin} R_{Q^2}$
  Radiative correction R_{RC}
  Detector bias correction R_{Det}
  Bis centering correction R_{Bin}
  Q^2 correction R_{Q^2}
- Background corrections
  Al. window correction A_{b1} = ppm, f_{b1} = , c_{b1} = ppm
  Beamline background A_{b2} = ppm, f_{b2} = , c_{b2} = ppm
  Other neutral A_{b3} = ppm, f_{b3} = , c_{b3} = ppm
  Inelastic correction A_{b4} = ppm, f_{b4} = , c_{b4} = ppm

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  Other neutral $A_{b3} =$ ppm, $f_{b3} =$, $c_{b3} =$ ppm
  Inelastic correction $A_{b4} =$ ppm, $f_{b4} =$, $c_{b4} =$ ppm

Extracting Physics Asymmetry

$$A_{ep} = R_{total}\left[\frac{A_M/P - \sum_{i=1}^{4} f_i A_i}{1 - \sum_{i=1}^{4} f_i}\right]$$

- Polarization
- Multiplicative corrections $R_{total} = R_{RC}R_{Det}R_{Bin}R_{Q^2}$
  Radiative correction R_{RC}
  Detector bias correction R_{Det}
  Bis centering correction R_{Bin}
  Q^2 correction R_{Q^2}
- Background corrections
  Al. window correction $A_{b1} =$ ppm, $f_{b1} =$, $c_{b1} =$ ppm
  Beamline background $A_{b2} =$ ppm, $f_{b2} =$, $c_{b2} =$ ppm
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Quantity	Asymmetry [ppm]		Dilution		Cor. $c_i = A_{bi} f_{bi}$		Ref.
Aluminum window	A_{b1}	8.431 ± 0.985	f_{b1}	0.033 ± 0.002	c_{b1}	0.033 ± 0.002	ELOG 451 (Analysis)[?]
Beamline scattering	A_{b2}	0.000 ± 0.000	f_{b2}	0.033 ± 0.002	c_{b1}	0.033 ± 0.002	DocDB 1655 [?]
Other neutrals	A_{b3}	0.000 ± 0.000	f_{b3}	0.033 ± 0.002	c_{b1}	0.033 ± 0.002	DocDB 1655 [?]
Inelastics	A_{b4}	-5.305 ± 0.166	f_{b4}	0.033 ± 0.002	c_{b1}	0.033 ± 0.002	DocDB 1655 [?]

Table: Background correction table.

Quantity		Value				Referen
Inelastic measured asymmetry	A_M^{in}	4.789 ± 0.844	ppm			This ana
Polarization	P	0.879 ± 0.018				DocDB 16
Aluminum asymmetry	A_{b1}	8.431 ± 0.985	ppm	f_{b1}	0.033 ± 0.002	This ana
QTOR transport channel	A_{b2}	0.000 ± 0.000	ppm	f_{b1}	0.033 ± 0.002	DocDB 16
Beamline background	A_{b3}	0.000 ± 0.000	ppm	f_{b1}	0.033 ± 0.002	DocDB 16
Elastic asymmetry	A_{b4}	-5.305 ± 0.166	ppm	f_{b1}	0.033 ± 0.002	DocDB 16

Table: Input table.

Overview

SUMMARY

Summary

- The uncertainty in measured N-to-Δ transverse asymmetry is dominated by statistics for in hydrogen. Next largest contribution comes from polarization. Most other systematic uncertainties are under control.
- A conservative estimate of extracted physics asymmetry using preliminary background asymmetries and dilutions is $\mathrm{A}^{in}_{PHYS} = 41.05 \pm 7.90$ ppm. Largest contribution in the uncertainties is from elastic dilution.

To Do

- Beamline background, detector bias correction, radiative correction etc.
- Update dilution factors.
- Quantify impact of these results on the PV N-to-Δ measurement and talk to theoretician for model calculation.

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Overview

FRAME 1

Overview

FRAME 1

- Item A
- Item B
  - Subitem 1
  - Subtem 2
- Item C

Frame 2

- Item A
- Item B
  - Subitem 1
  - Subtem 2
- Item C

Jump to Theorem 36

FRAME 3

Table: Table

No.	Ordinary	Blue	Pink	Yellow	Green	RCM
			α=0.05			
H=2	95.0	75.3	75.7	79.5	72.0	
H=3	95.6	87.0	87.3	87.6	85.2	
H=4	95.0	91.6	91.9	90.3	90.2	93.3
H=5	95.2	93.5	93.7	91.3	91.8	94.3
H=6	94.9	93.8	94.1	92.6	92.8	94.7

FRAME 3

Table: Table

No.	Ordinary	Blue	Pink	Yellow	Green	RCM
			α=0.5			
H=2	95.0	91.4	91.2	79.5	99.9	
H=3	95.6	95.1	95.1	87.6	95.1	
H=4	95.0	94.8	94.8	90.3	93.5	95.5
H=5	95.2	95.1	95.2	91.3	93.1	95.9
H=6	94.9	94.8	94.8	92.6	93.4	95.5

FRAME 3

Table: Table

No.	Ordinary	Blue	Pink	Yellow	Green	RCM
			α=0.05			
H=2	95.0	75.3	75.7	79.5	72.0	
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H=5	95.2	93.5	93.7	91.3	91.8	94.3
H=6	94.9	93.8	94.1	92.6	92.8	94.7
			α=0.5			
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H=5	95.2	95.1	95.2	91.3	93.1	95.9
H=6	94.9	94.8	94.8	92.6	93.4	95.5

Overview

frame 4

FRAME 4

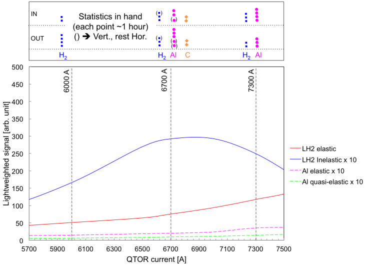

Figure: something

FRAME 4

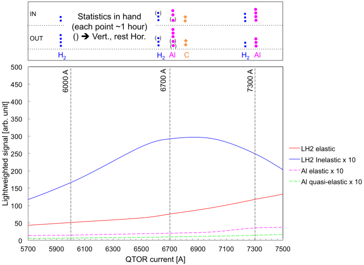

Figure: something

FRAME 4

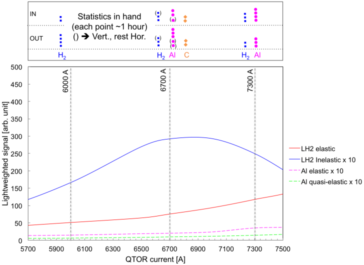

Figure: something

FRAME 4

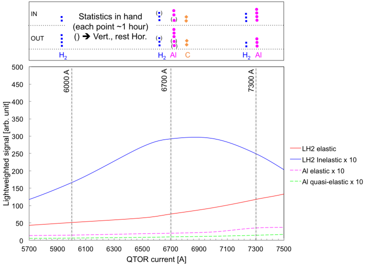

Figure: something

Overview

Frame 6

Some basic formalism about qweak.

$$A_{ep} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right] \left[\frac{\varepsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1 - 4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^Z}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2}\right] \quad (30)$$

$$\varepsilon = \frac{1}{1 + 2(1+\tau)\tan^2\frac{\theta}{2}}, \varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}, \tau = \frac{Q^2}{4M} \quad (31)$$

As $\theta \to 0$, $\varepsilon \to 1$, and $\tau \ll 1$

Frame 7

$$A_{ep} = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\right]\left[Q_W^p + B(Q^2,\theta)\right] = A_0\left[Q_W^p + B(Q^2,\theta)\right] \tag{32}$$

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$$\begin{aligned} A_{ep} &= A_0\left[Q_W^p + B(Q^2,\theta)\right] \\ A_0 &= \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha} \end{aligned} \tag{34}$$

$$\begin{aligned} \sigma &\approx |M_{EM} + M_{weak}|^2 \\ \sigma &\approx |M_{EM}|^2 + 2M_{EM}^* M_{weak} + |M_{weak}|^2 \\ \sigma &\approx |M_{EM}|^2 \end{aligned} \tag{35}$$

Frame 8

$$A_{ep} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \frac{2\Re|M_{EM} \cdot M_{weak}|}{|M_{EM}|^2} \tag{36}$$

$$A_{msr} = \frac{Y_+ - Y_-}{Y_+ + Y_-} \tag{37}$$

$$A_{ep} = \frac{A_{msr} - \sum_i A^i_{false}}{P} \tag{38}$$

$$A_{ep} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \frac{|M^{PV}_{weak}|}{|M_{EM}|} \tag{39}$$

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Where $\sigma_+ (\sigma_-)$ is the positive (negative) helicity correlated electron-proton scattering cross sections. M_{weak} and M_{EM} are the parity violating and parity conserving electromagnetic scattering amplitudes, respectively

$$Q_W(Z, N) = -2[C_{1u}(2Z + N) + C_{1d}(Z + 2N)] \tag{41}$$

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$$A_N = R_{total}\left[\frac{\frac{A^{in}_M}{P} - \sum_{i=1}^{4} A_{bi} f_{bi}}{1 - \sum_{i=1}^{4} f_{bi}}\right] \tag{42}$$

$$A_{ep} = R_{total}\left[\frac{\frac{A_{msr}}{P} - \sum_{i=1}^{4} A_i f_i}{1 - \sum_{i=1}^{4} f_i}\right] \tag{43}$$

$$R_{total} = R_{RC} R_{Det} R_{Bin} R_{Q^2} \tag{44}$$

$$A_{msr} = A_{raw} + A_T + A_L + A_{reg} \tag{45}$$

$$A_{ep} = R_{RC} R_{Det} R_{Bin}\left[\frac{\frac{A_{msr}}{P} - A_{b1}f_{b1} - A_{b2}f_{b2} - A_{b3}f_{b3} - A_{b4}f_{b4}}{1 - f_{b1} - f_{b2} - f_{b3} - f_{b4}}\right] \tag{46}$$

$$(dA^{in}_{PHYS})_{A^{in}_M} = R_{RC} R_{Det} \frac{dA^{in}_M}{P}\left[\frac{1}{1 - f_{b1} - f_{b2} - f_{b3} - f_{b4}}\right] \tag{47}$$

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$$A_N = R_{total} \left[\frac{\frac{A_M^{in}}{P} - \sum_{i=1}^{4} A_{bi} f_{bi}}{1 - \sum_{i=1}^{4} f_{bi}} \right] \quad (42)$$

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Frame 10

$$(dA^{in}_{PHYS})_{f_{b1}} = R_{RC} R_{Det} df_{b1} \left[\frac{\frac{A^{in}_{M}}{P} - A_{b1}(1 - f_{b2} - f_{b3} - f_{b4}) - A_{b2} f_{b2} - A_{b3} f_{b3} - A_{b4} f_{b4}}{(1 - f_{b1} - f_{b2} - f_{b3} - f_{b4})^2} \right] \tag{53}$$

$$(dA^{in}_{PHYS})_{f_{b2}} = R_{RC} R_{Det} df_{b2} \left[\frac{\frac{A^{in}_{M}}{P} - A_{b1} f_{b1} - A_{b2}(1 - f_{b1} - f_{b3} - f_{b4}) - A_{b3} f_{b3} - A_{b4} f_{b4}}{(1 - f_{b1} - f_{b2} - f_{b3} - f_{b4})^2} \right] \tag{54}$$

$$(dA^{in}_{PHYS})_{f_{b3}} = R_{RC} R_{Det} df_{b3} \left[\frac{\frac{A^{in}_{M}}{P} - A_{b1} f_{b1} - A_{b2} f_{b2} - A_{b3}(1 - f_{b1} - f_{b2} - f_{b4}) - A_{b4} f_{b4}}{(1 - f_{b1} - f_{b2} - f_{b3} - f_{b4})^2} \right] \tag{55}$$

$$(dA^{in}_{PHYS})_{f_{b4}} = R_{RC} R_{Det} df_{b4} \left[\frac{\frac{A^{in}_{M}}{P} - A_{b1} f_{b1} - A_{b2} f_{b2} - A_{b3} f_{b3} - A_{b4}(1 - f_{b1} - f_{b2} - f_{b3})}{(1 - f_{b1} - f_{b2} - f_{b3} - f_{b4})^2} \right] \tag{56}$$

Overview

Rigid body dynamics

- Coriolis acceleration

$$\vec{a}_p = \vec{a}_o + \frac{{}^b d^2}{dt^2}\vec{r} + \boxed{2\vec{\omega}_{ib} \times \frac{{}^b d}{dt}\vec{r}} + \vec{\alpha}_{ib} \times \vec{r} + \boxed{\vec{\omega}_{ib} \times (\vec{\omega}_{ib} \times \vec{r})}$$

- Transversal acceleration
- Centripetal acceleration

Rigid body dynamics

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$$\vec{a}_p = \vec{a}_o + \frac{{}^b d^2}{dt^2}\vec{r} + 2\vec{\omega}_{ib} \times \frac{{}^b d}{dt}\vec{r} + \vec{\alpha}_{ib} \times \vec{r} + \vec{\omega}_{ib} \times (\vec{\omega}_{ib} \times \vec{r})$$

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