(Hall A) SoLID Run Group Proposal E12-11-007A: A Precision Measurement of Inclusive g_2^n and d_2^n with SoLID on a Polarized ^{3}He Target at 8.8 and 11 GeV

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For the SoLID Collaboration

JLab PAC 48, August 2020

Review Committee: Jian-Ping Chen, Haiyan Gao (Chair), Cynthia Keppel, Axel Schmidt

Spokespersons: Ye Tian, Chao Peng

Duke UNIVERSITY

SoLID SOLENOIDAL LARGE INTENSITY DEVICE

Review Process and Decision

- Initial review on June 9, 2020 during the SoLID collaboration meeting and the committee raised a number of questions
- Two follow-up reviews took place on June 18 and June 20, 2020 of the revised proposal
- The review committee decided to endorse it enthusiastically as a run group proposal on June 20, 2020 and the committee
  - Recognizes the significance of the proposed physics
  - Believes it will further enhance the impact of the SoLID program on the neutron spin physics.

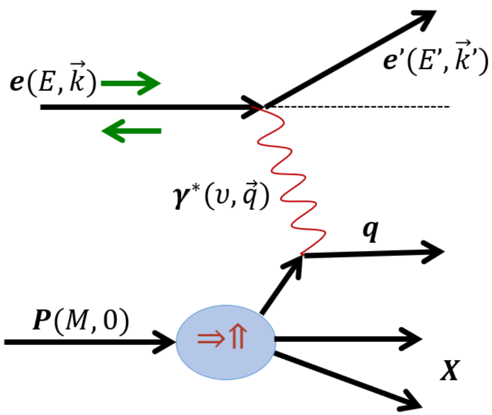
Physics Motivation: Neutron Spin Structure

- Spin-dependent structure functions
  - g_1 relates to the polarized parton distribution functions
  - g_2 carries information of quark-gluon interaction

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

  - leading twist related to g_1 by Wandzura-Wilczek relation

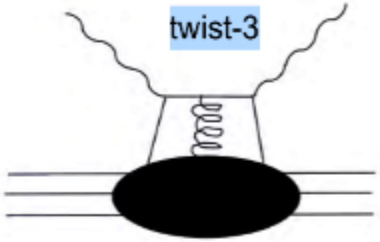
$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$



- x^2 moment of higher twists contribution $\bar{g}_2(x,Q^2)$

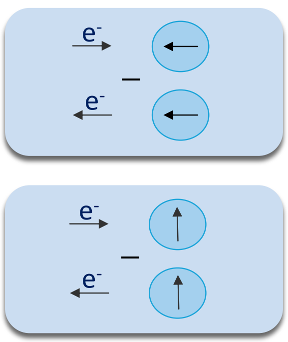
$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2{}^{WW}(x,Q^2)]dx$$
$$= \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$

- ✓ Calculable on the Lattice.
- ✓ A clean way to access twist-3 contribution
- ✓ Impact of high x data because of weighting



Parasitic with SoLID SIDIS-^{3}He Experiments

- SoLID SIDIS layout without changes
- E12-10-006: Transversely polarized ^{3}He target
- E12-11-007: Longitudinally polarized ^{3}He target
- Polarized luminosity with 15 uA current: 1e^{36} cm^{-2}s^{-1}

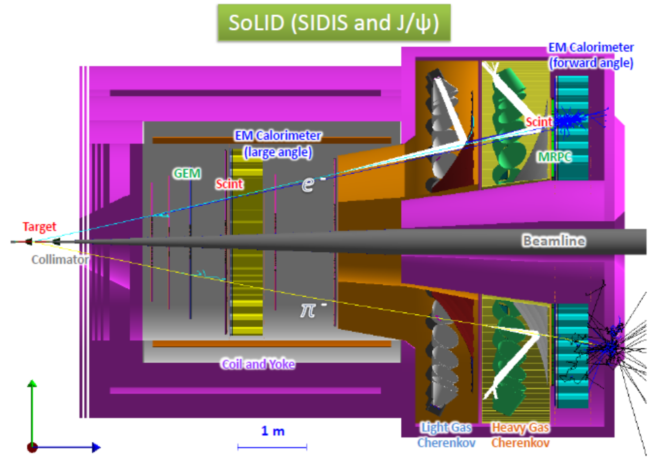


E12-11-007:

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}}$$

E12-10-006:

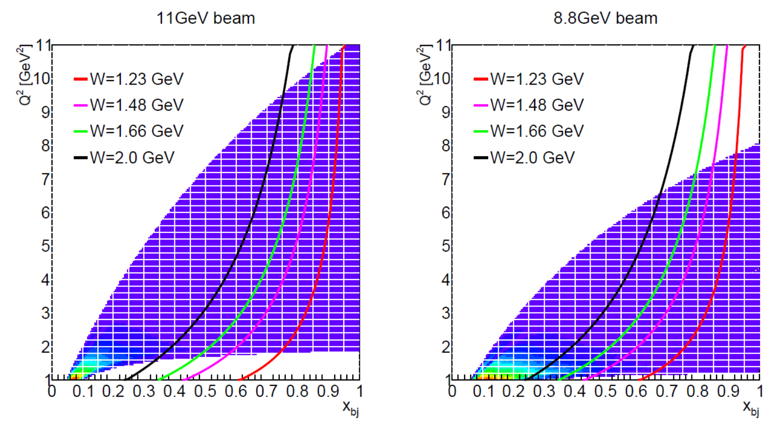
$$A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$



$$\Delta\sigma_{\parallel,\perp} = 2\sigma_0 A_{\parallel,\perp}$$

$$g_1 = \frac{MQ^2}{4\alpha^2}\frac{\nu E}{(E-\nu)(2E-\nu)}\left[\Delta\sigma_{\parallel} + \tan\frac{\theta}{2}\Delta\sigma_{\perp}\right],$$

$$g_2 = \frac{MQ^2}{4\alpha^2}\frac{\nu^2}{2(E-\nu)(2E-\nu)}\left[-\Delta\sigma_{\parallel} + \frac{E+(E-\nu)\cos\theta}{(E-\nu)\sin\theta}\Delta\sigma_{\perp}\right]$$



More than 15 kHz free trigger space with 100 kHz DAQ limit

Dedicated singles charged particle trigger rate: 103 kHz/10 = 10.3 kHz

Reusable random coincidence trigger rate: 69 kHz

Total rate estimated to be less than 85 KHz

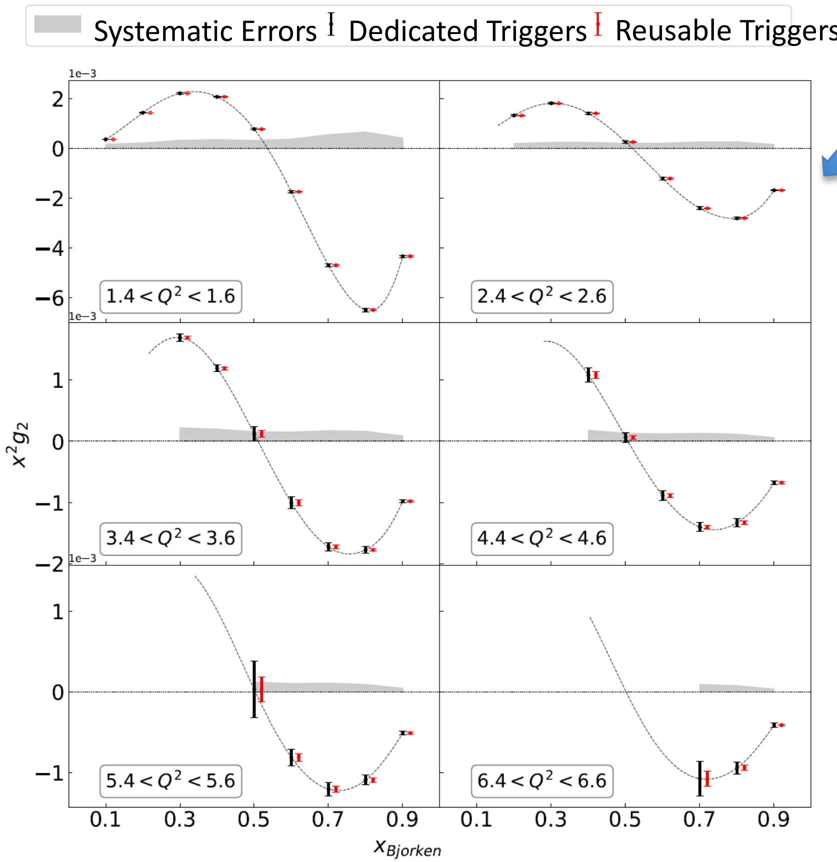
(Addressed also in Ay (E12-11-108A/E12-10-006A))

Systematic Uncertainty Estimate

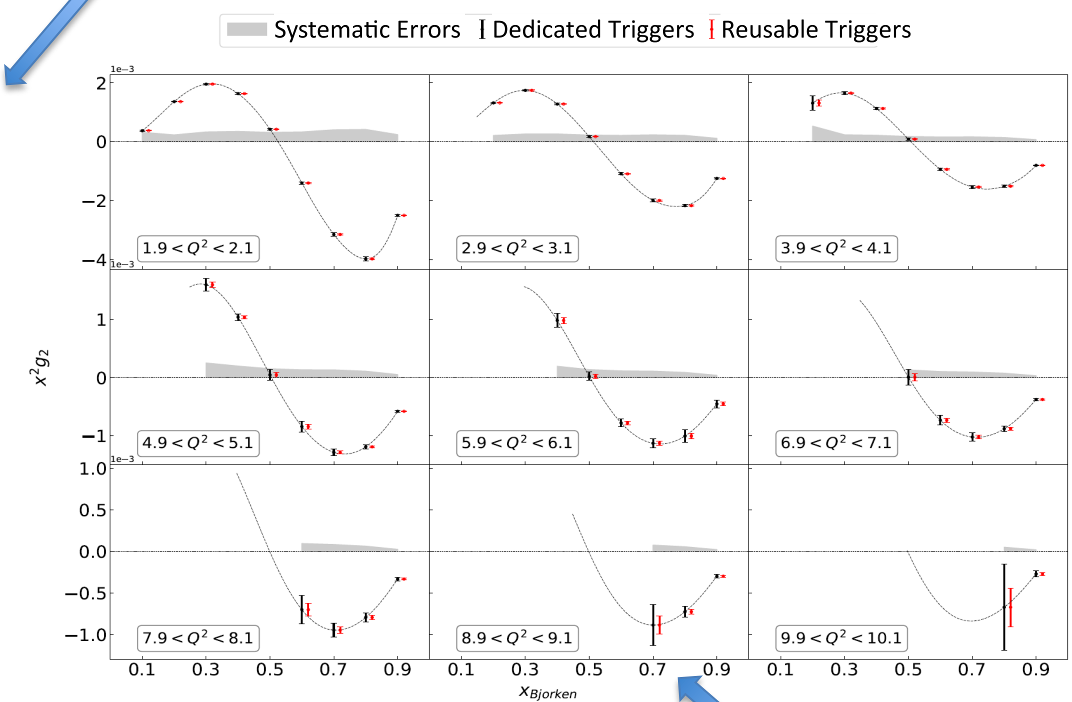
Source	Systematic Uncertainty
Cross Sections	
Detector acceptance	5.0%
Detector efficiencies	3.0%
Target density	2.0%
Beam charge	1.0%
Background subtraction	3.0%
Asymmetries	
Dilution effects	$< 1.0\%$
Beam polarization	$< 2.0\%$
Target polarization	3.0%
Charge asymmetry	$< 10^{-4}$
Pion asymmetry	$< 5 \times 10^{-4}$
Unfolding Procedure	
Nuclear corrections	$\sim 5.0\%$
Radiative corrections	$\sim 3.0\%$
Physics Results	
Cross sections	$< 10.0\%$
g_2 syst.	$\sim 10^{-3}$-10^{-4}
d_2 stat.	$\sim 3 \times 10^{-4}$
d_2 syst. (11 GeV)	$\sim 5 \times 10^{-4}$
d_2 syst. (8.8 GeV)	$\sim 8 \times 10^{-4}$

Projections – x^2g_2

Assumed 55% target polarization, 85% beam polarization, 0.17 nitrogen dilution



8.8 GeV

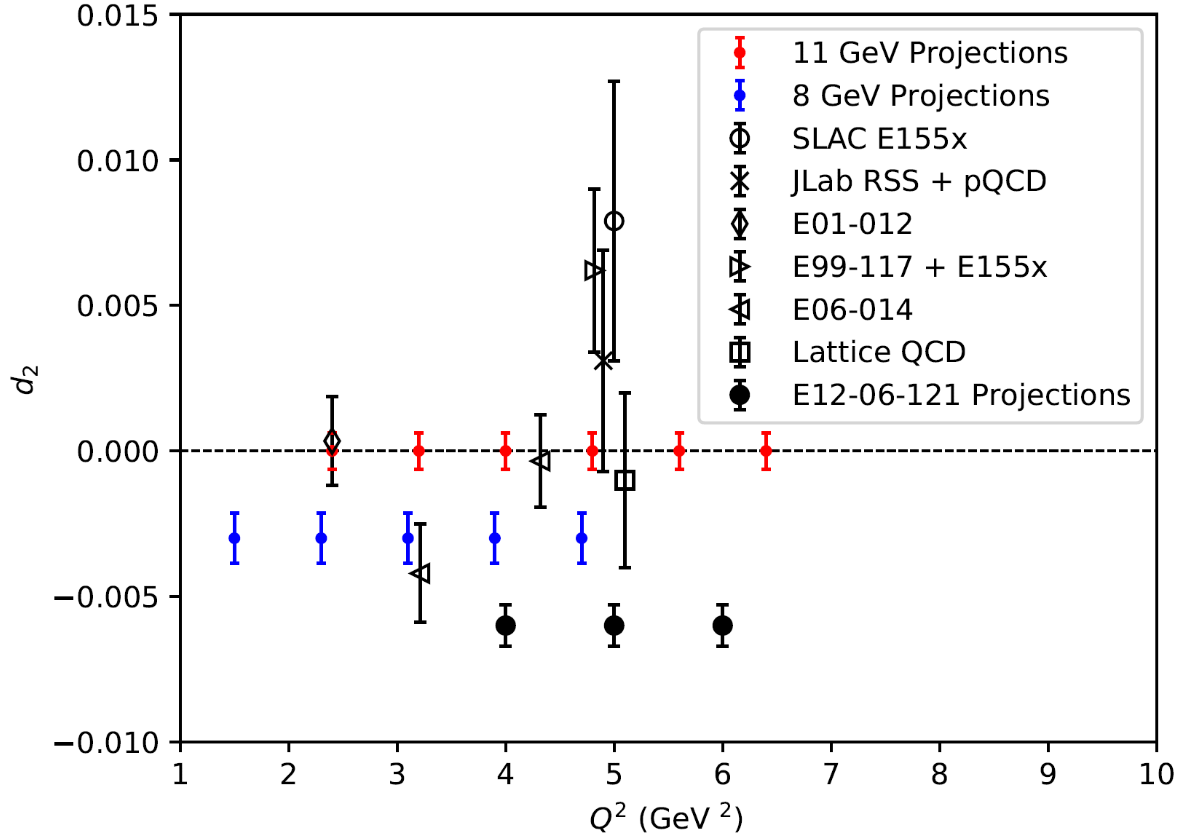


11.0 GeV

- Dedicated triggers assumes a prescale factor of 10
- F_2 from New Muon Collaboration (NMC) parameterization
- $R = g^n_1/F^n_1$ from SLAC

- Errors:
  - Error bars - statistic errors
  - Shades - systematic errors

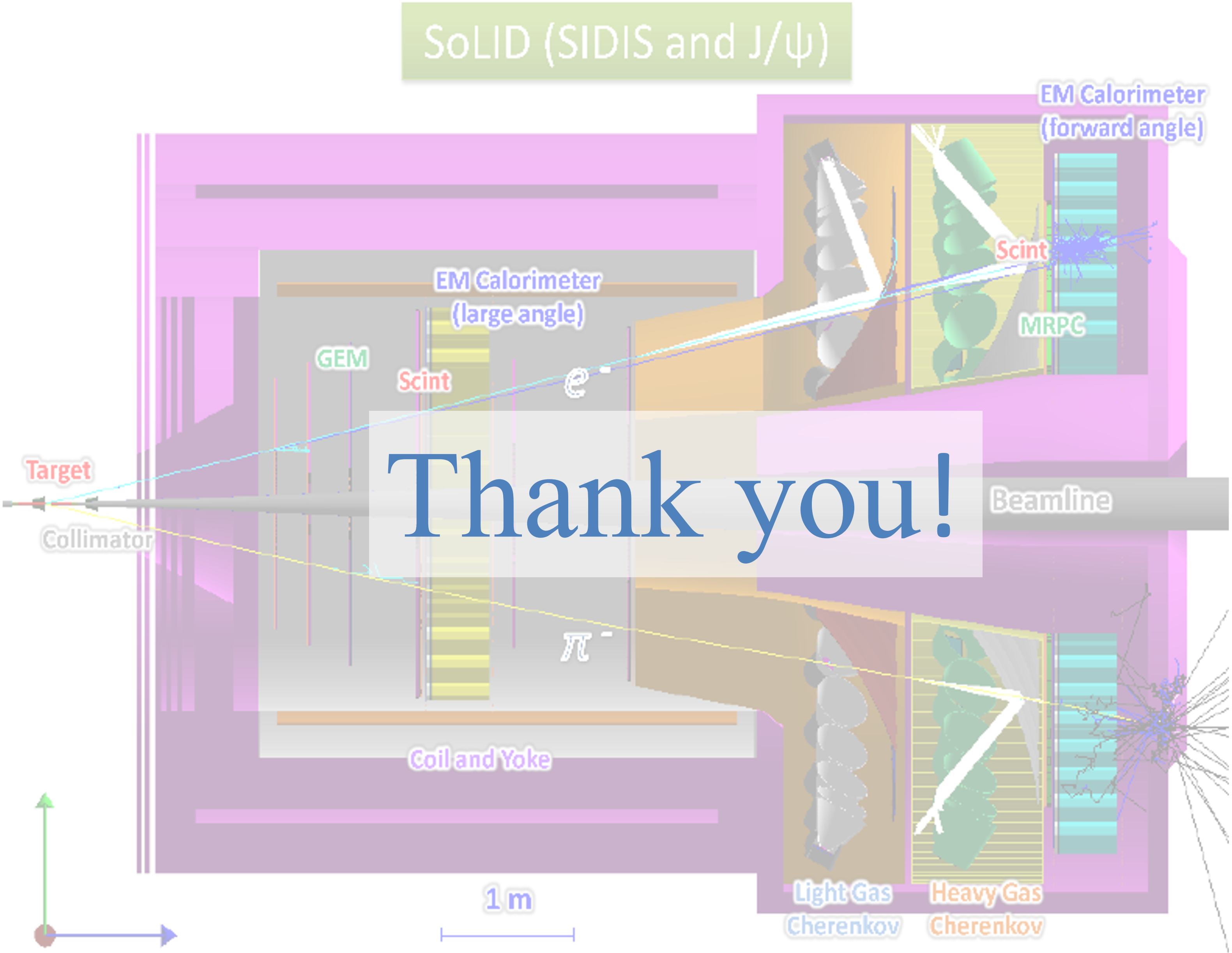
Projections – d_2



- ✧ Results from dedicated triggers (prescale factor 10)
- ✧ Statistic and systematic errors combined
- ✧ Systematic errors dominate
- ✧ Require $x_{min} > 0.4$ to obtain d_2
- ✧ d_2 for $Q^2 < 6.5$ GeV^2

- ❖ E12-11-007A: a parasitic measurement with approved SoLID ^{3}He experiments E12-10-006 and E12-11-007 to extract g_2^n at $x > 0.1$ and $1.5 < Q^2 < 10$ GeV^2, and d_2^n for $Q^2 < 6.5$ GeV^2
- ❖ The proposed dataset provides an opportunity to better understand the twist-3 matrix element $d_2^n(Q^2)$, therefore the associated quark-gluon correlations within the neutron
- ❖ Q^2 evolution of $d_2(Q^2)$ provides a direct test of Lattice QCD predictions.

Thank you!


SoLID (SIDIS and J/ψ)
EM Calorimeter
(forward angle)
Scint
MRPC
EM Calorimeter
(large angle)
GEM
Scint
e⁻
Target
Collimator
Beamline
π⁻
Coil and Yoke
1 m
Light Gas
Cherenkov
Heavy Gas
Cherenkov

Backup slides

TAC Comments---2 main questions

1. **Pair symmetric backgrounds may be significant for the lower (x, Q^2) bins in the singles trigger. It isn't clear if those backgrounds had been considered, and what the systematic impact would be on the extracted physics quantities. (Likely more of an impact on $g_2^n(x, Q^2)$ than on d_2 given the x^2 weighting in the integral for the latter.) Perhaps vertex cuts are capable of suppressing this background?**

- The background "mis-identified" electrons from e^+e^- pair production **mainly come from π^0 decay** (15% of charged-singles trigger are pair produced electrons).
- For the SoLID spectrometer, we expect to reduce the contamination from this background to the 1% level by rejecting triggers with coincident positron and electron events consistent with pair production. Conservatively, **1% systematic errors** are estimated for those pair symmetric backgrounds.

2. **DAQ live-time and front-end deadtime corrections to the extracted absolute cross sections are likely to be significant at the proposed rates. Such corrections could be somewhat complicated to evaluate as they are likely to vary significantly across the SoLID acceptance.**

- Currently, the dead time is set at 100ns, so we would expect **1% at the 100 KHz trigger rate level**. It can be optimized to be even smaller. For the **GEM readout** with high resolution path (300 ns)**, we would expect 3% at 100 KHz trigger rate level**.
- All the above settings will be tested during the SoLID pre-R&D, and they will be addressed for the experiment later. We will follow the development of SoLID DAQ system, and carefully study the systematic uncertainties associated with the DAQ dead-time.

TAC Comments---2 suggestions and 2 clarification

- ✓ **Extraction of g2 from the He3 data at high-x will also be challenging and shouldn't be underestimated. There will be much to learn from the E1206-121 analysis in the next few years. (Again, the d2 integral is generally less sensitive to those systematics.)**

- ✓ **This will also complicate measuring trigger bias in the random coincidences that will be mined for the bulk of the e- inclusive data. The Authors do recognize this trigger bias issue, and plan to monitor/measure the bias by taking 15 kHz of (prescaled) singles triggers on top of the anticipated 85 kHz of coincident triggers required by the parent experiments. The singles data would then be used to tease out and correct for biases in the (e+ random) coincident triggers. The authors are encouraged to negotiate with the parent experiments to take a *statistically significant* portion of dedicated singles-only data, as well as dedicated luminosity scans, instead of relying on the pre-scaled singles data alone. (This would be in addition to taking the prescaled singles data as proposed, of course.) This would benefit the entire Run Group in the end, and should not be too difficult to arrange.**

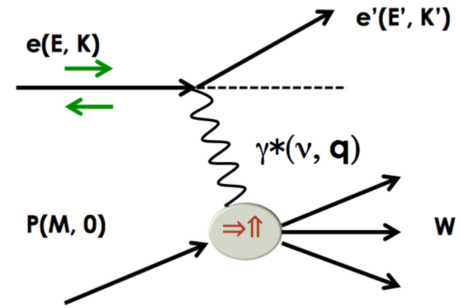
- ✓ **The trigger description section (2.3) in this proposal is somewhat unclear. The discussion begins with a comment that the single electron trigger will be formed through a coincidence of the gas Cherenkov, EM calorimeter, and SPD. But later discussions in the same section seems to use the term 'single e-' trigger when the text and table suggests they mean 'charged singles' trigger. For example, adding up the electron + hadron rates in Table 2.1 suggests that the "single e-" really is just a charged- singles trigger, and that seems consistent with surrounding discussion.**

- ✓ **If the 'single e-' DAQ trigger is just a charged singles trigger, and the 2nd paragraph in Sec. 2.3 is a simply a comment on how electrons will be extracted *offline*, then the discussion makes sense. If the 'single e' trigger requires pion suppression at the trigger level, then assumptions on the sub-detector performance, coincidence windows, and backgrounds should be discussed further.**

Physics Motivation: g_2^n spin structure function

- g_1 related to the polarized parton distribution functions

$$g_1 = \frac{1}{2}\sum_i e_i^2\,\Delta q_i(x) \qquad \Delta q_i(x) = q_i^{\uparrow}(x) - q_i^{\downarrow}(x)$$



- g_2 is zero in the naive parton model

non-zero value carries information of quark-gluon interaction

Ignoring quark mass effect of order $O(m_q/\Lambda_{QCD})$

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

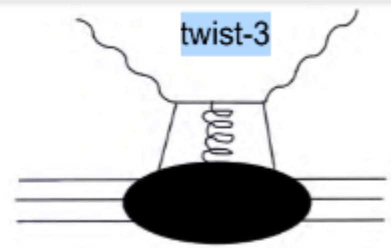
Wandzura-Wilczek relation

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}h_T(y,Q^2) + \zeta(y,Q^2)\right]\frac{dy}{y}$$

quark transverse momentum contribution

twist-3 part which arises from quark-gluon interactions



d_2: the x^2 moment of $\overline{g_2}(x^2,Q^2)$

$$\boxed{d_2(Q^2) = 3\int_0^1 x^2\,[g_2(x,Q^2) - g_2^{ww}(x,Q^2)]dx = \int_0^1 x^2\,[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx}$$

- ✓ Calculable on the Lattice.
- ✓ A clean way to access twist-3 contribution
- ✓ Impact of high x data because of weighting