CLAS12 Exclusive $\omega(782)$ Meson Analysis Update

Zhaozhong Shi

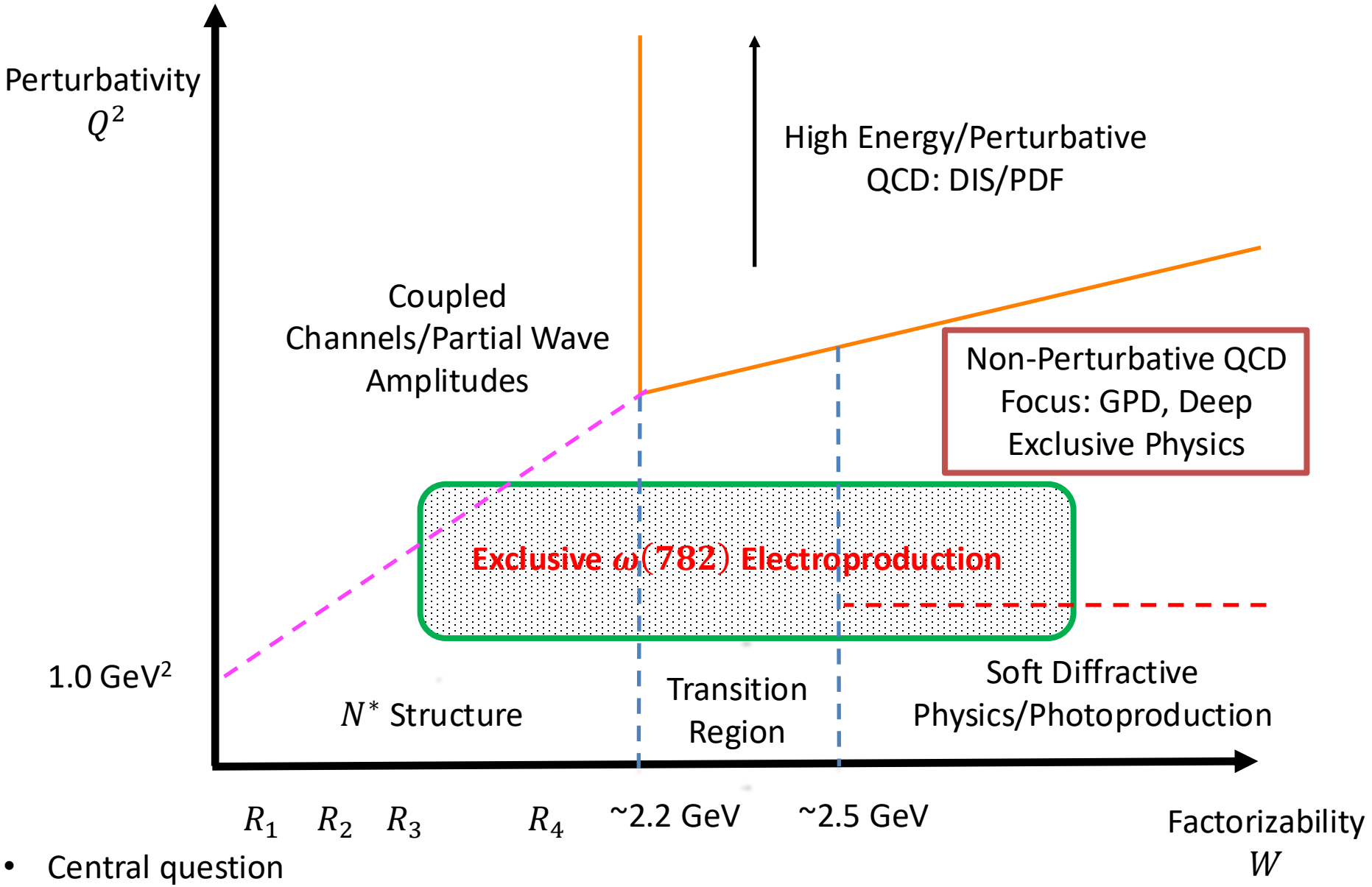
11/18/2026

Overview

- Three Main references for This talk:
  - Bil Li's ω PhD thesis
  - CLAS6 ω paper
  - Andrey Kim's CLAS12 π^0 BSA measurement

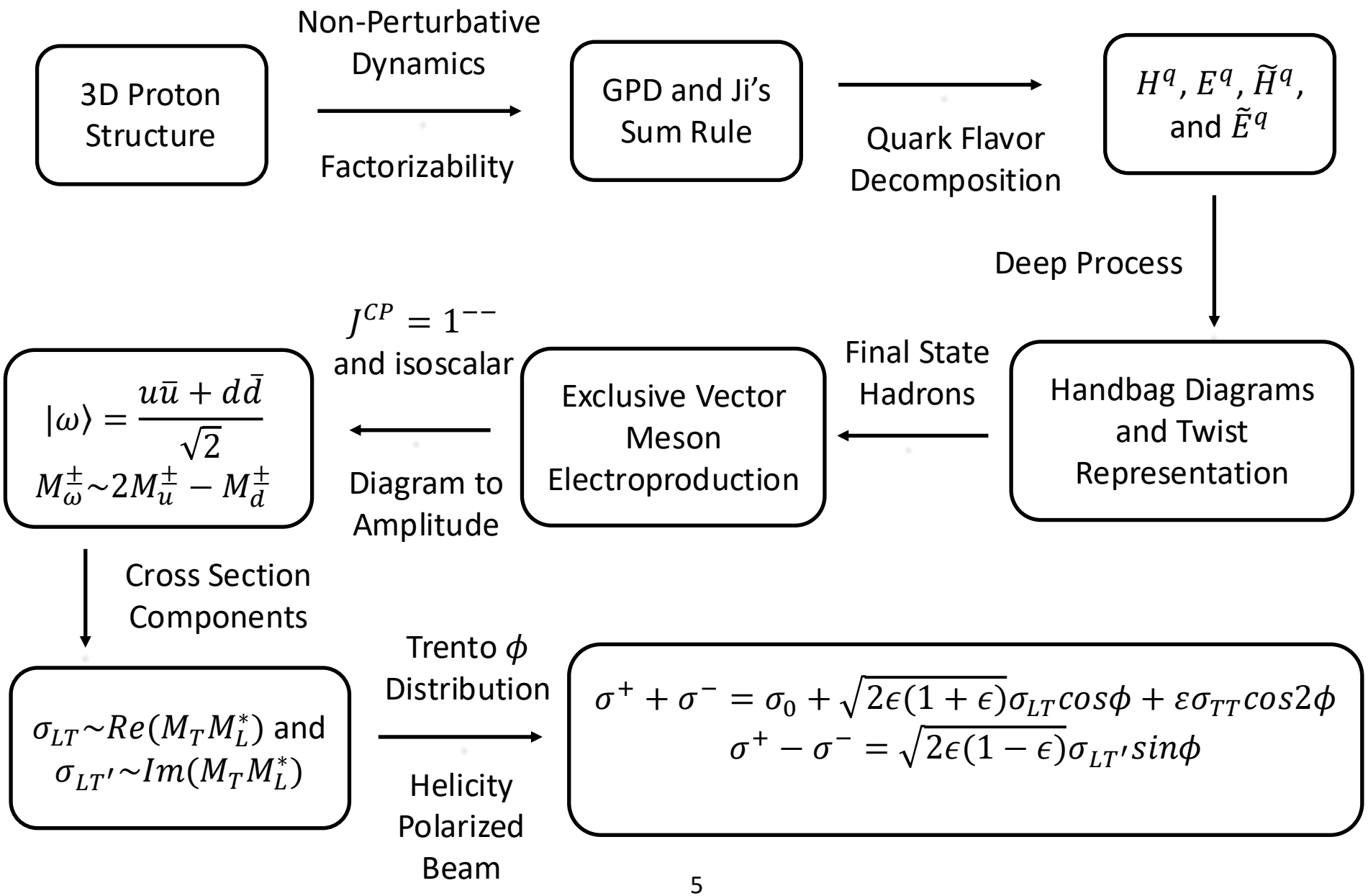
The Physics

Physics of Exclusive $\omega(782)$ Meson

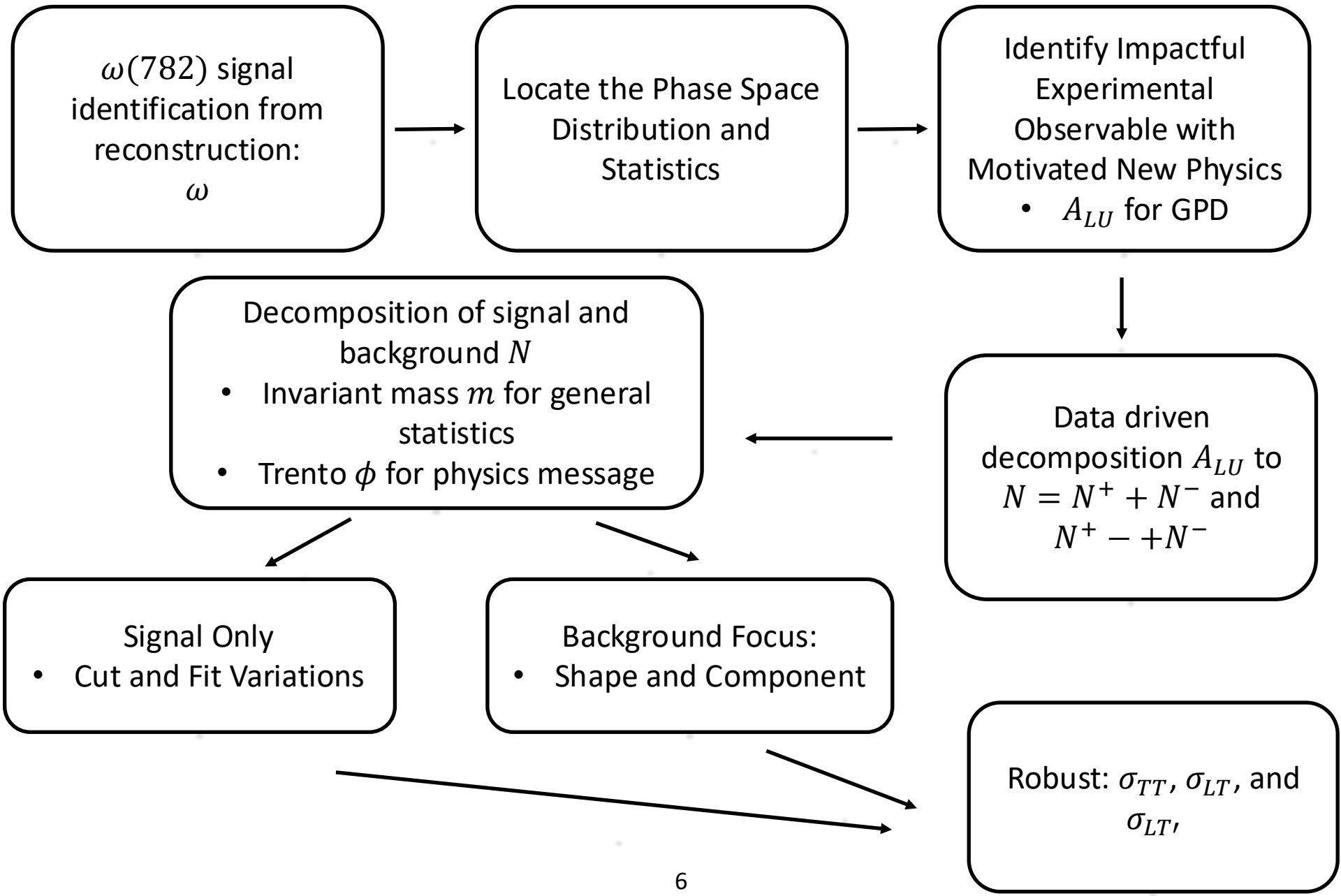


- Central question

GPD and Deep Process Physics

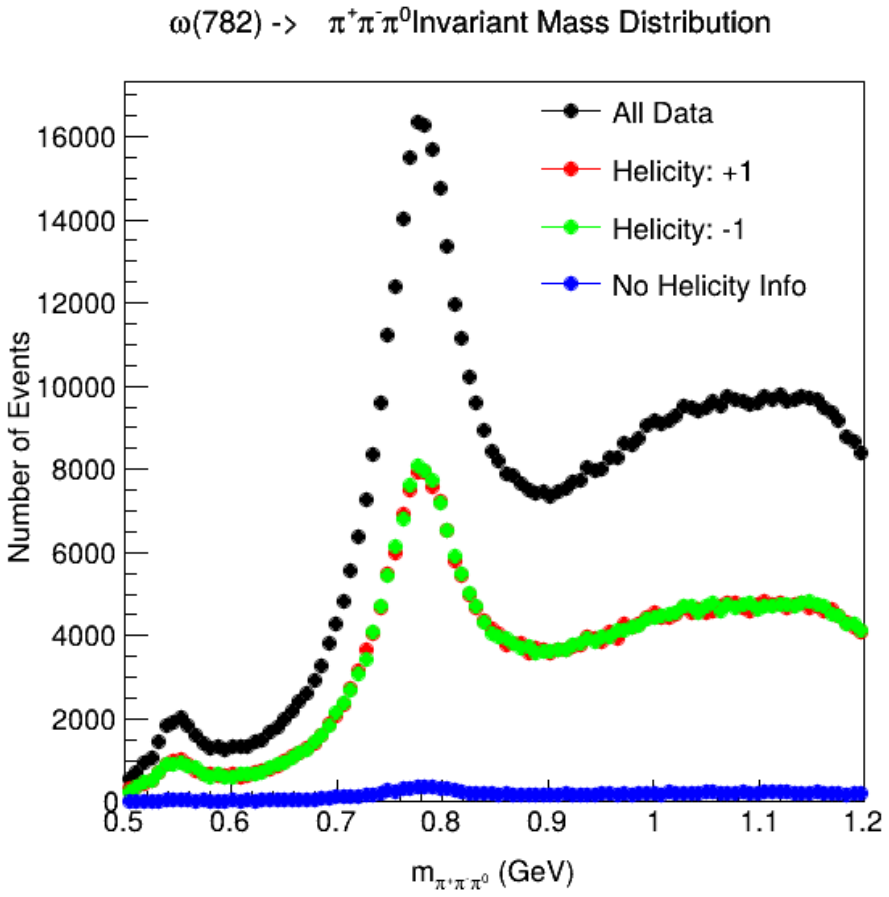


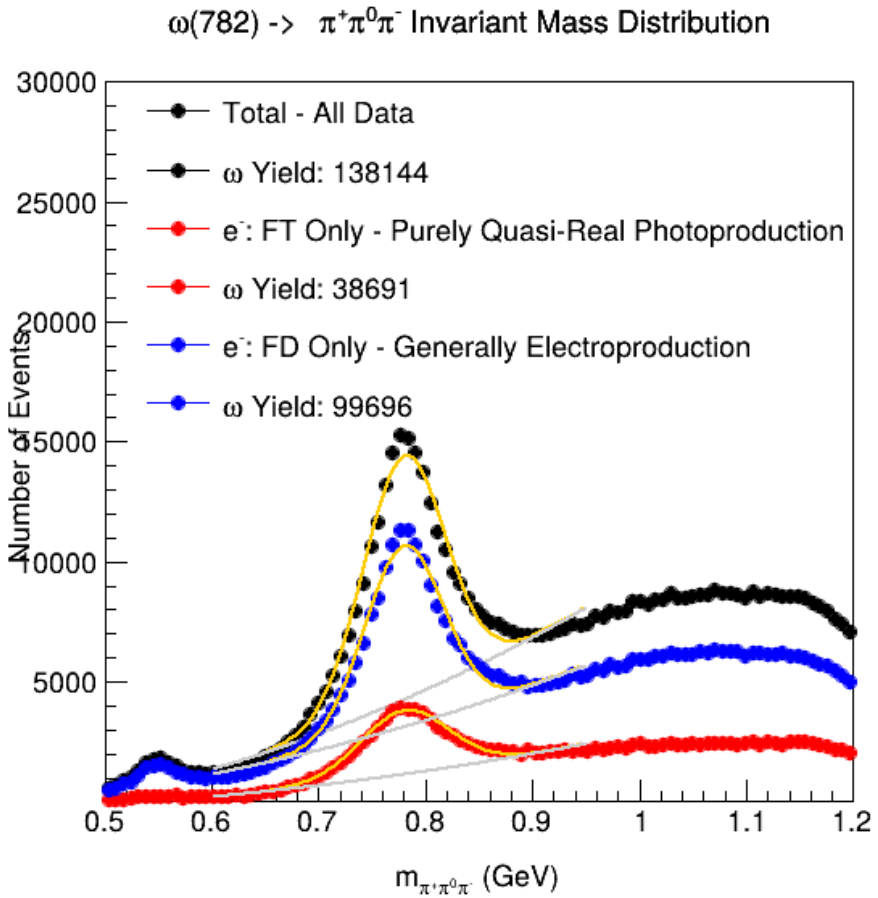
Analysis Procedures and Strategies



The Analysis

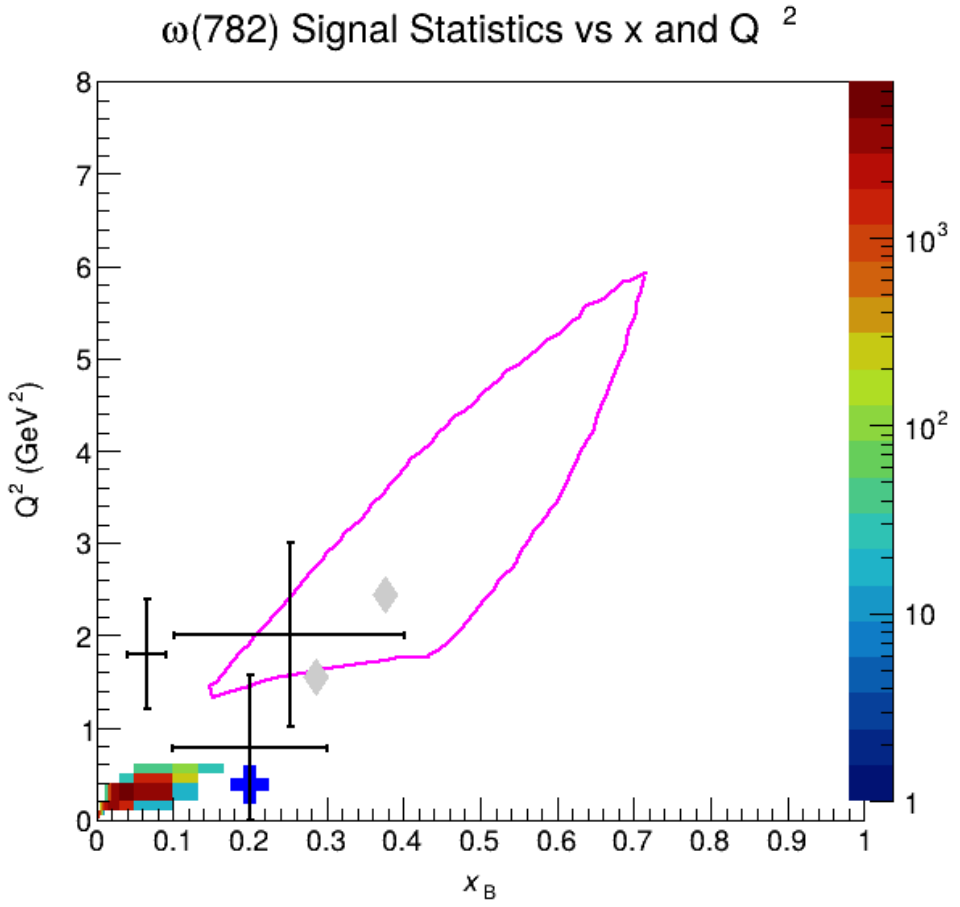
Global Statistics FT and FD based

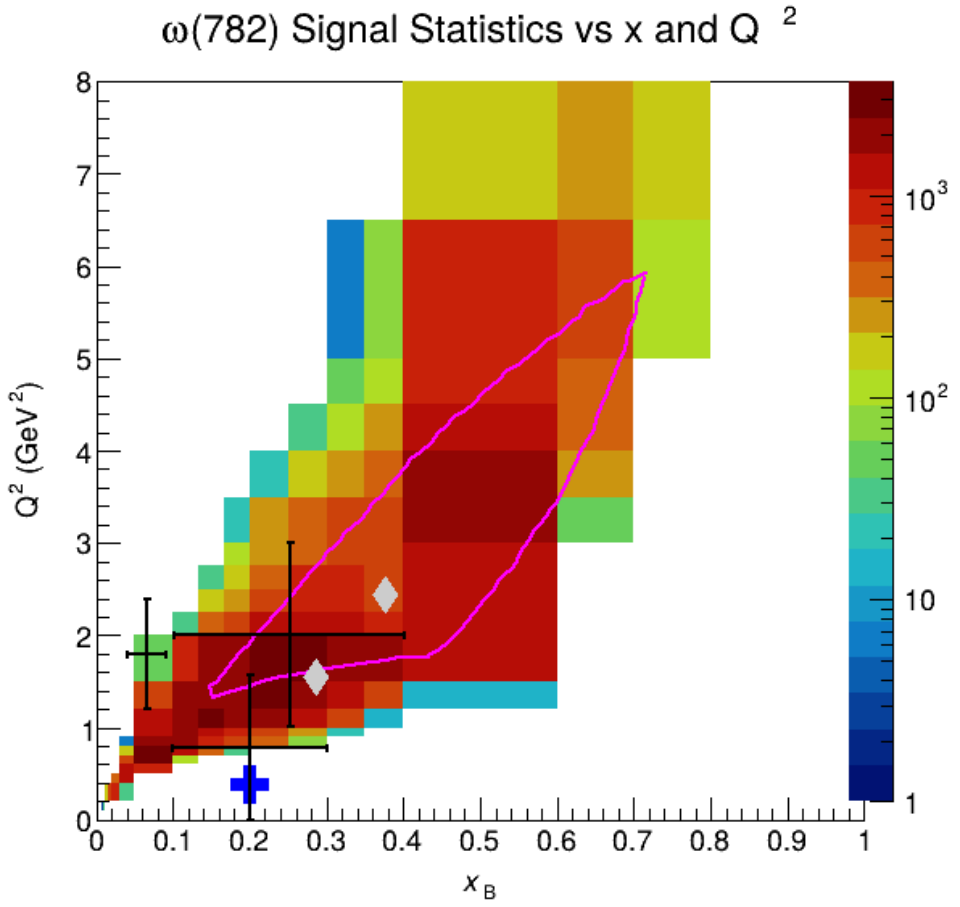




- Current presentation focus purely on Fall 2018 RG-A datasets
- We have statistics do $\omega(782)$ BSA measurement
  - Best statistical error: maximum signal statistical significance
  - Most stable and robust results: separation from signal to background
- How to best handle signal and background as you always have background?

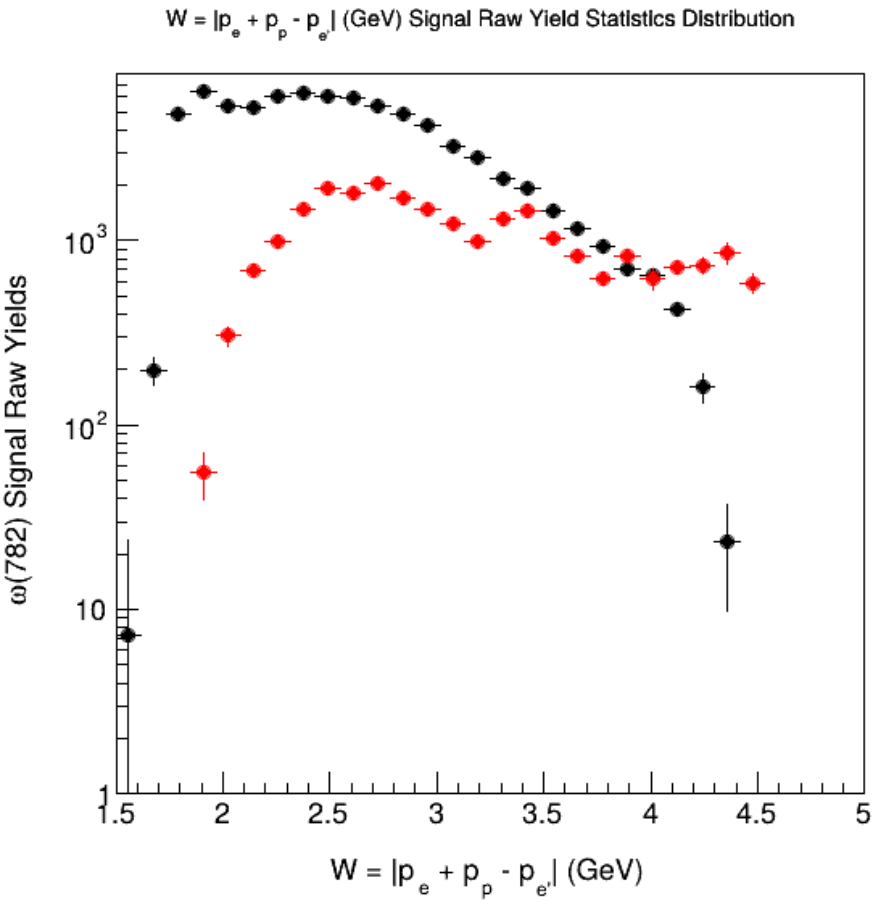
FT and FD Separated Data in x_B and Q^2

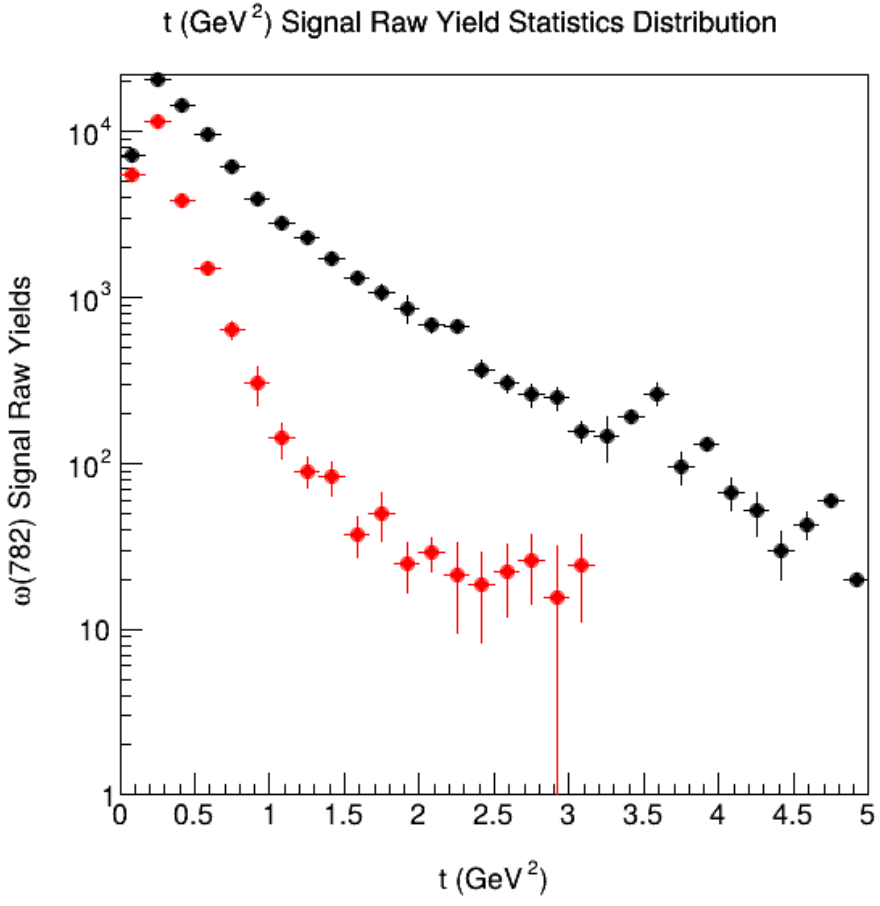




- Simply reject FT data if we want to do large Q^2 studies fit into DPWG priorities
- Also convenient for efficiency correct since now focusing one detector FD

FT and FD W and t distribution





- Similar W coverage for the **FT** and **FD** detector systems
- The FD generally provide us with a large coverage in higher |t|

Three Levels of Measurements for ω BSA

Level 1 – Explore the Existence of Possibility

- Obtain Trento ϕ distribution of
- Focus on signal optimization only interpretation of the modulation



Level 2 – Establish the Robustness of the Observables

- Also work on the background to look at pure background observables and contribution



Level 3 — Extract Meaningful Physics Message

- First step is to validate existing physics expectation
- Second step is to check deviation from expectation after everything is solidly validated

Evidences

CLAS12 π^0 BSA Paper Style



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Letter

Beam spin asymmetry measurements of deeply virtual π^0 production with CLAS12

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10.1016/j.physletb.2024.138459 ↗

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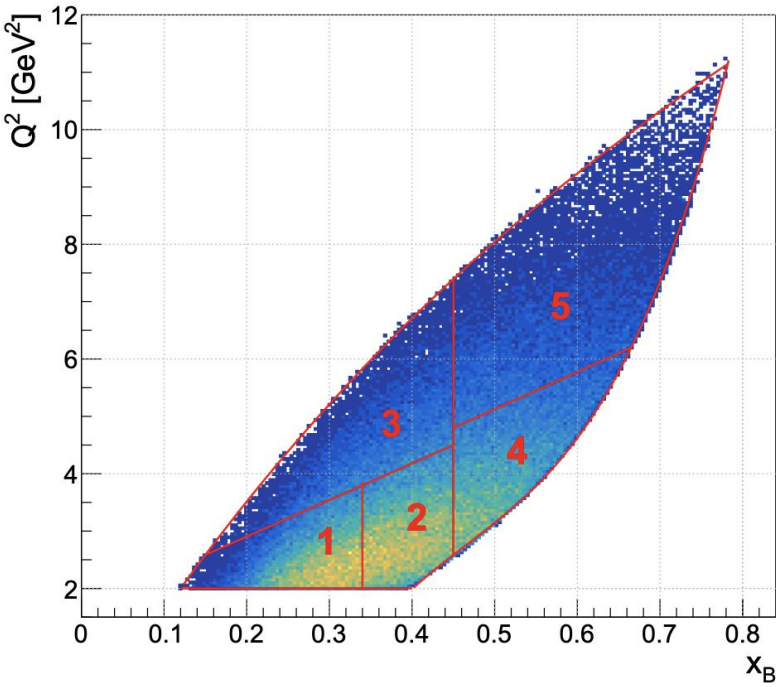


FIG. 4. Distribution of Q^2 versus x_B. The red lines represent the bin boundaries, and the bin numbering is given.

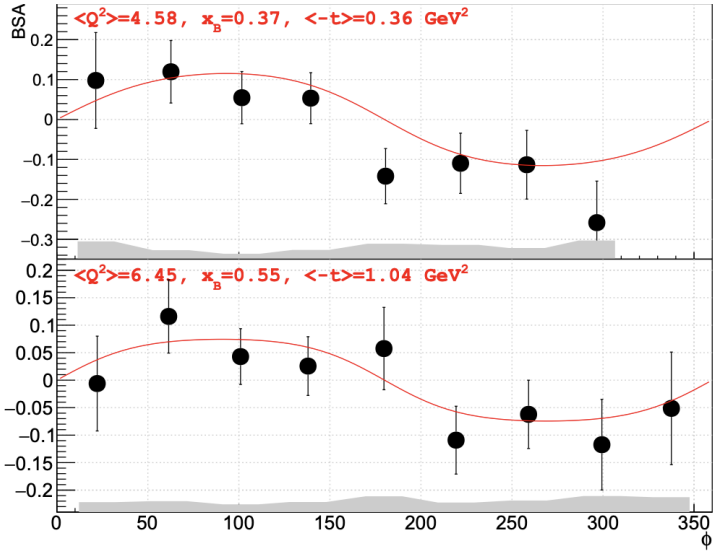
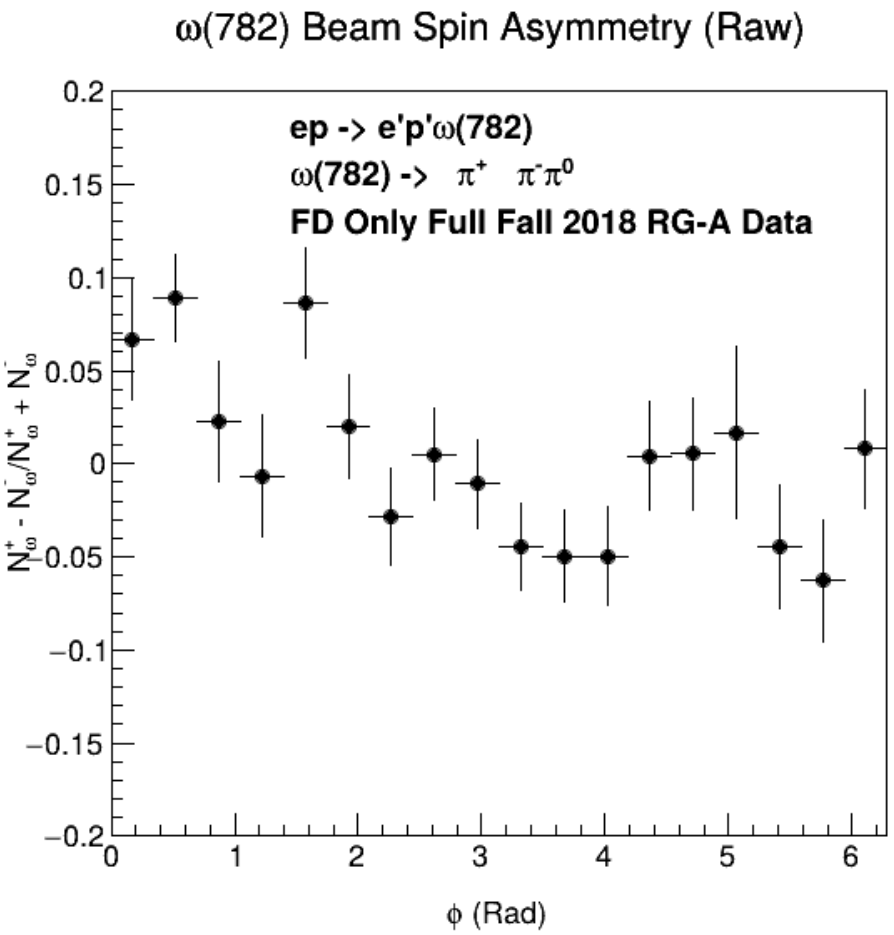


FIG. 5. Beam spin asymmetry as a function of ϕ for two representative kinematic bins. The vertical error bars show the statistical uncertainty of each point. The gray bands represent systematic uncertainties of the BSA measurements. The red lines show the fit with functional form of Eq. (1).

We also have the BSA $A_{LU}(\phi)$

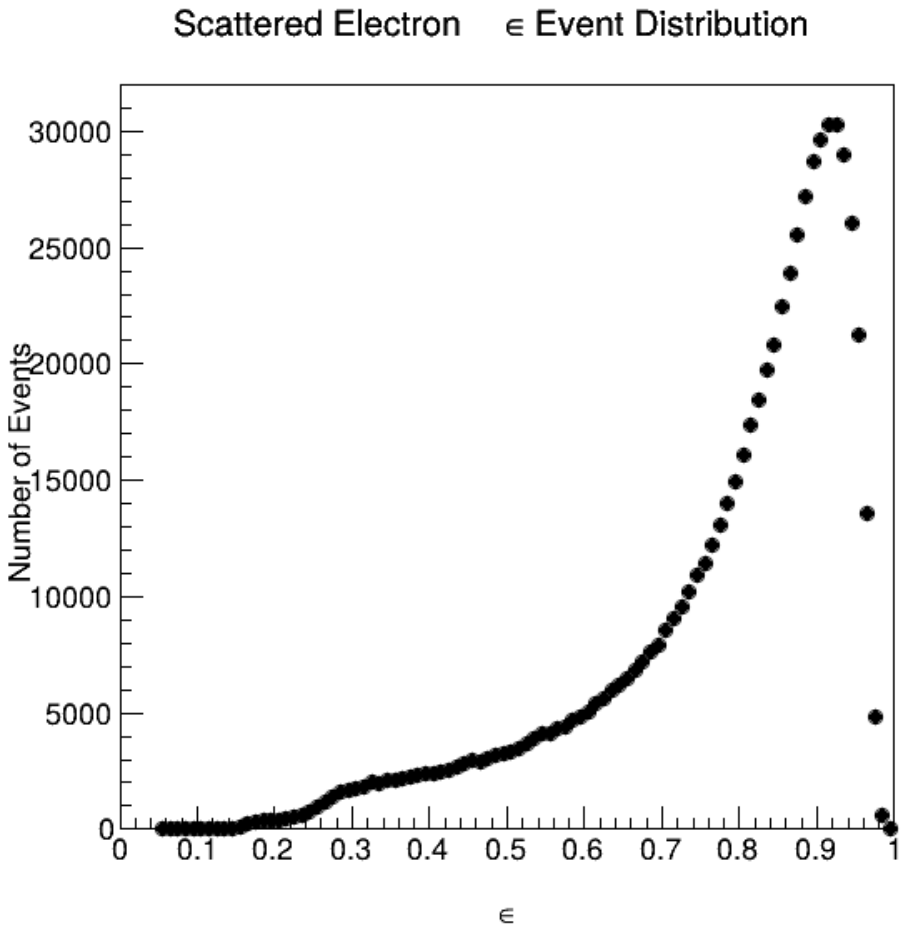
- I would say it is too large in statistical uncertainties despite systematically good to do a meaningful fit of before discussing the parameter set below
  - To the leading order this is good for systematic uncertainties
  - I have also a slide with the fitted parameters
  - Also going down differential may be even more challenging

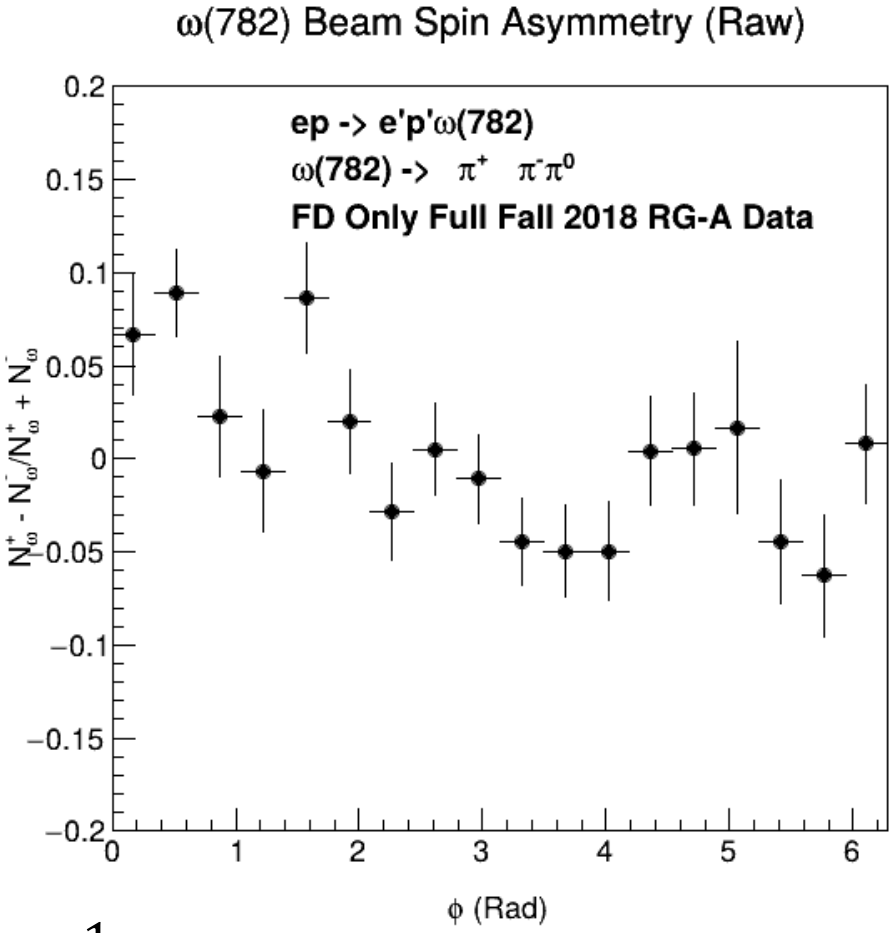


- Instead, as mentioned before, we will decompose the numerator $\sigma^+ - \sigma^-$ as $N^+ - N^-$ and denominator $\sigma^+ + \sigma^-$ as $N^+ + N^-$ first to look for stable assuming small dependence on the Trento ϕ

$$A_{LU}(\phi) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{N^+ - N^-}{N^+ + N^-} = \frac{\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'} sin\phi}{\sigma_0 + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT} cos\phi + \varepsilon\sigma_{TT} cos2\phi}$$

Direct Fit Over Integrated Bin for Parameter Extraction

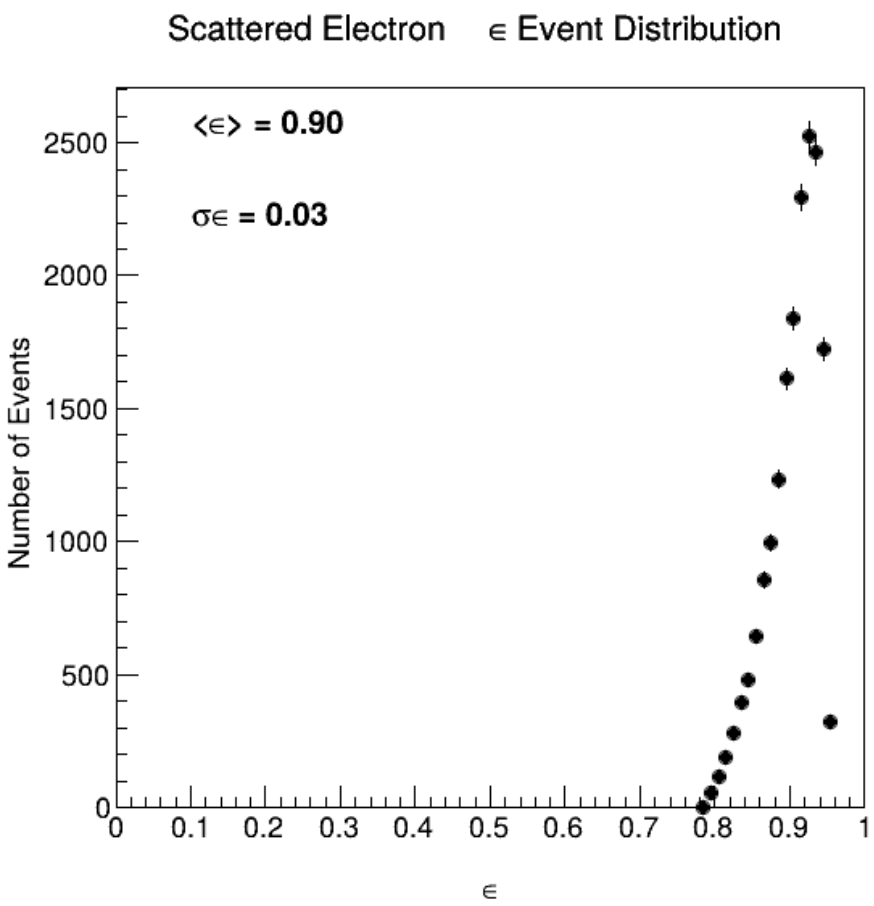


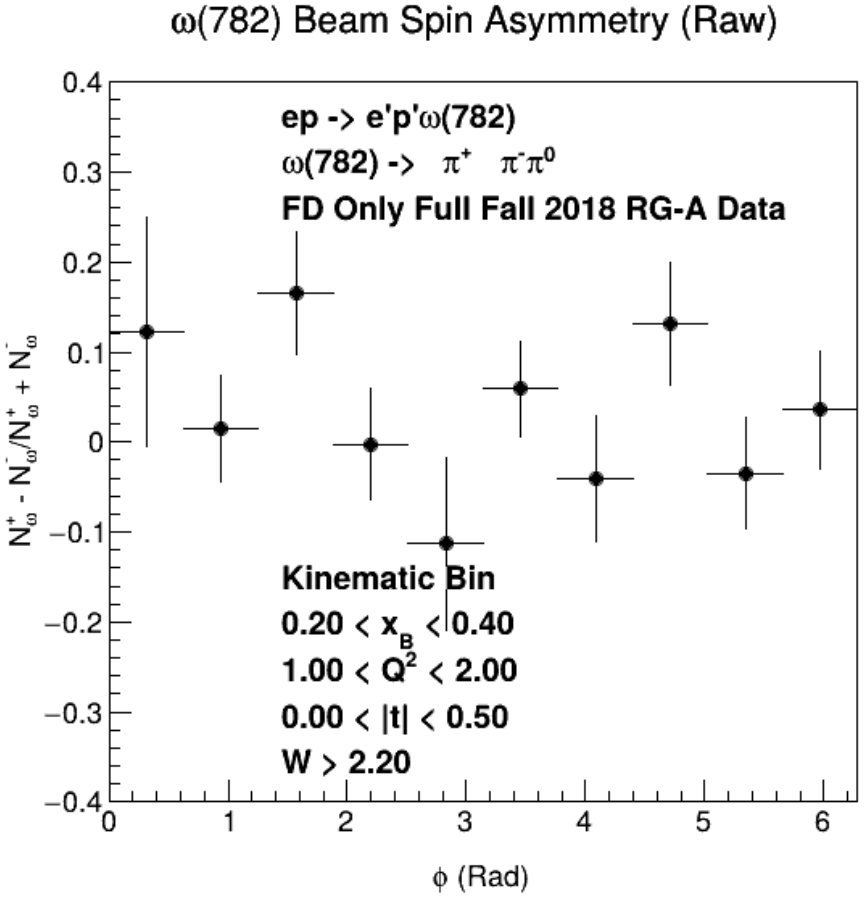


$$\epsilon = \frac{1}{1 + 2(1 + \frac{\upsilon^2}{Q^2})tan^2\frac{\theta_c}{2}}$$

- Basically we take the $\langle\epsilon\rangle$ in our bins and do the fit to get σ_{TT}, σ_{LT}, and $\sigma_{LT'}$
  - But the bin is too broad so a focus kinematics fit makes more sense

x_B, Q^2, t Differential Bins I

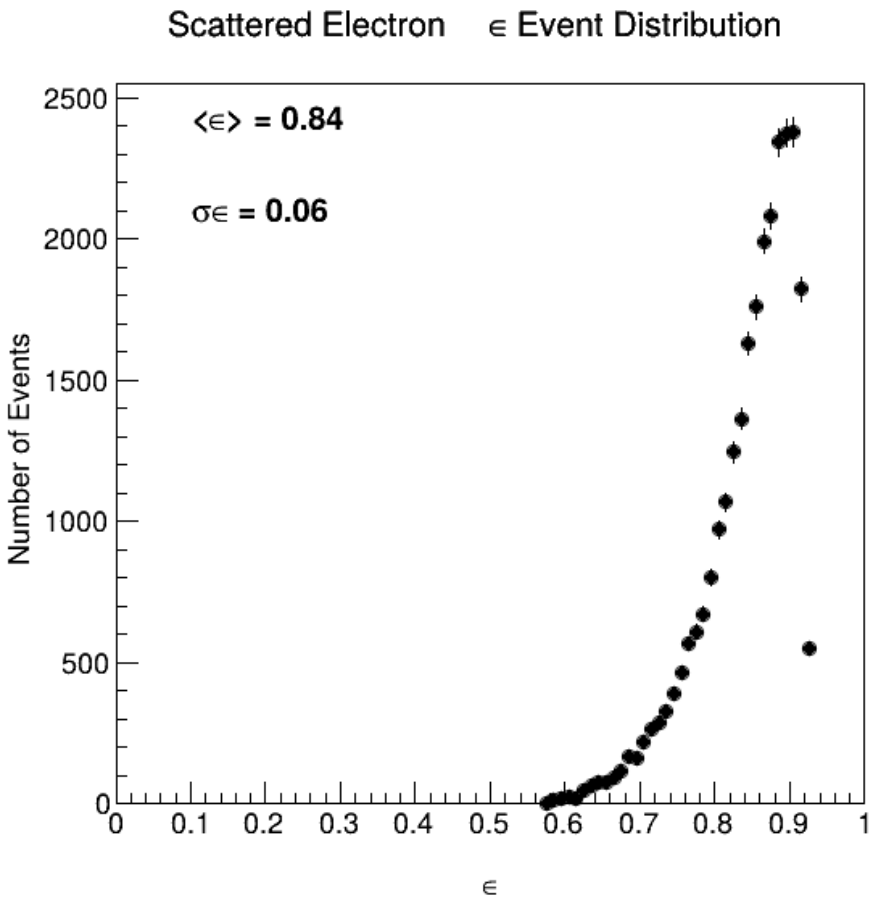


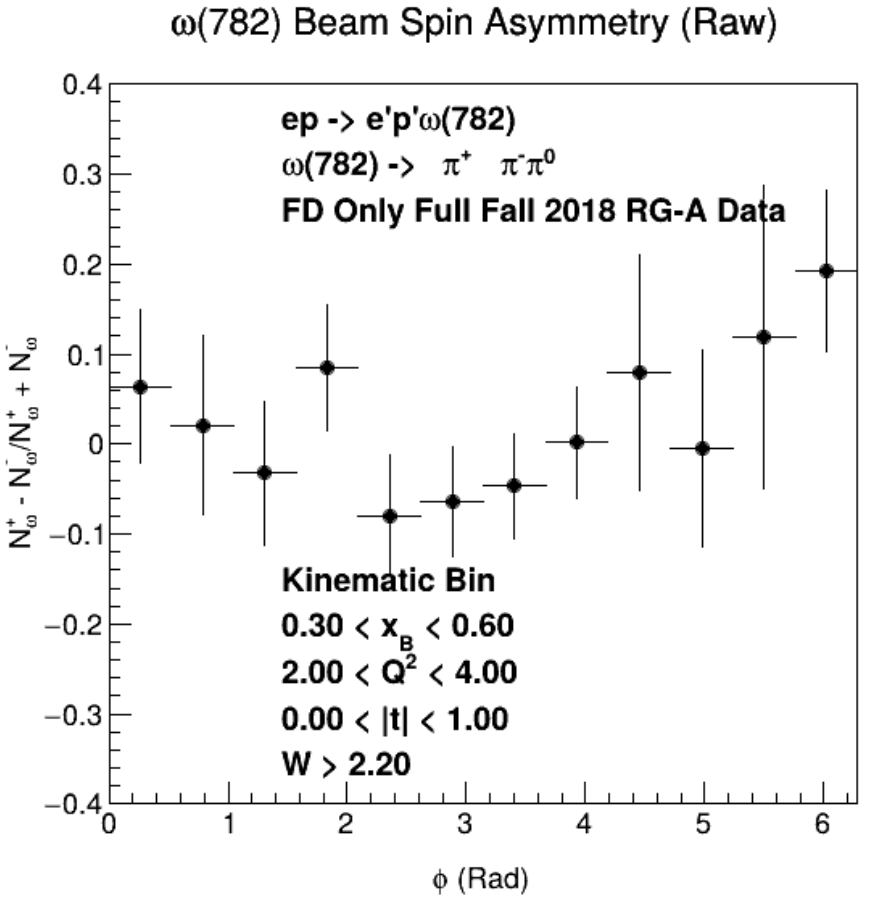


- We now have a meaningful distributions of ϵ and A_{LU}
- However, we are unable to fit to the distribution with a fixed ϵ near 0.90

$$A_{LU}(\phi) = \frac{\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}sin\phi}{\sigma_0 + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}cos\phi + \varepsilon\sigma_{TT}cos2\phi}$$

x_B, Q^2, t Differential Bins II





- We now have a meaningful distribution
- However, we are unable to fit to the distribution with with a fixed ϵ near 0.84

$$A_{LU}(\phi) = \frac{\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}sin\phi}{\sigma_0 + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}cos\phi + \varepsilon\sigma_{TT}cos2\phi}$$

Robustness

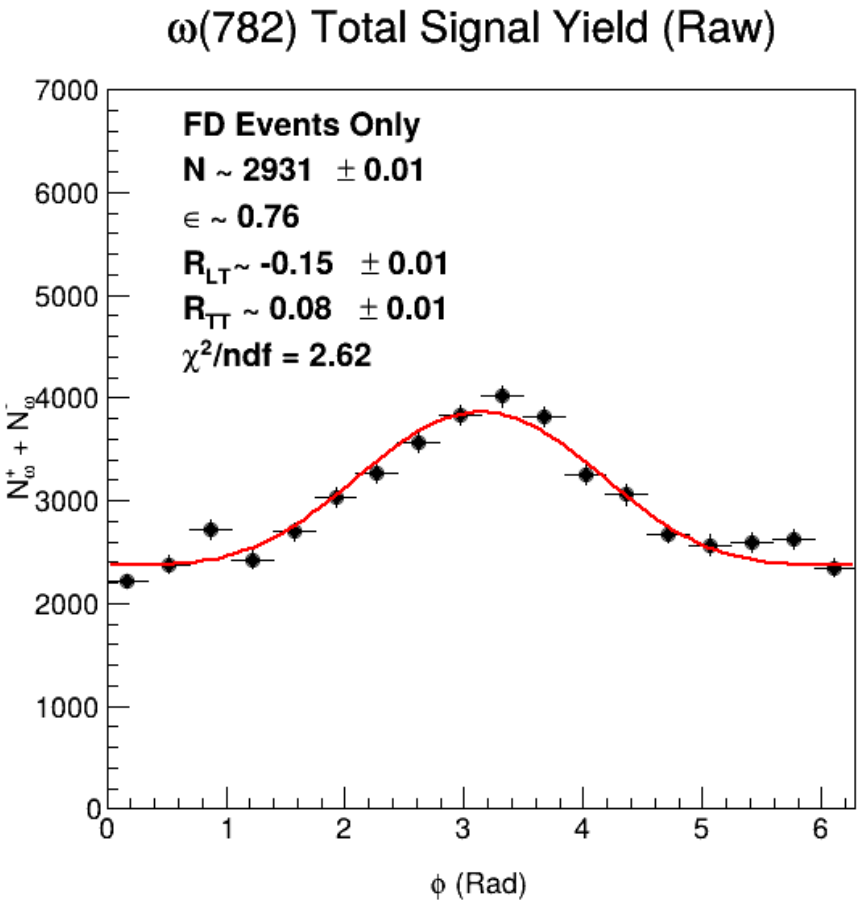
CLAS6 Paper Revisit

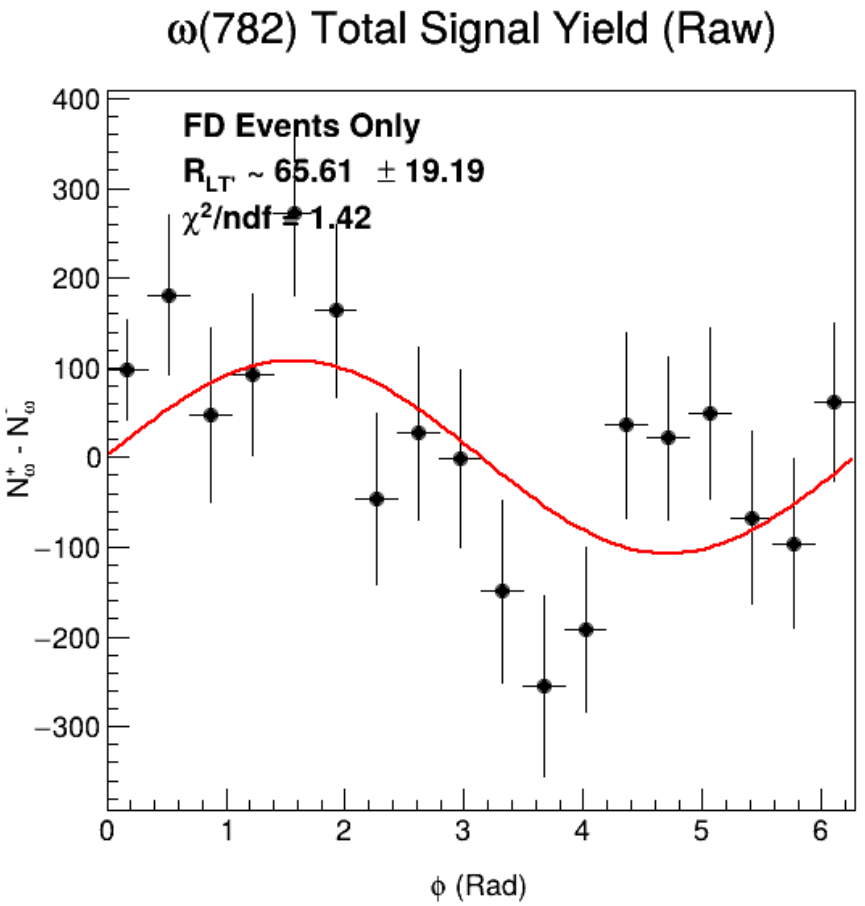
Table 3. Cross-sections $\sigma = \sigma_T + \varepsilon\sigma_L$ and interference terms σ_{TT} and σ_{TL} for the reaction $\gamma^* p \to \omega p$, integrated over $-2.7\ \mathrm{GeV}^2 < t < t_0$. Slope b of $\mathrm{d}\sigma/\mathrm{d}t$ for $-1.5\ \mathrm{GeV}^2 < t < t_0$. Quoted uncertainties are obtained from the addition in quadrature of statistical uncertainties and of point-to-point systematic uncertainties as discussed in sect. 3.1.

x_B	Q^2 (GeV^2)	W (GeV)	ε	t_0 (GeV^2)	$\sigma \pm \Delta\sigma$ (nb)	$\sigma_{TT} \pm \Delta\sigma_{TT}$ (nb)	$\sigma_{TL} \pm \Delta\sigma_{TL}$ (nb)	$b \pm \Delta b$ (GeV^{-2})
0.203	1.725	2.77	0.37	−0.09	536 ± 96	60 ± 87	2 ± 30	2.44 ± 0.18
0.250	1.752	2.48	0.59	−0.15	661 ± 118	156 ± 61	-35 ± 24	1.93 ± 0.16
0.252	2.042	2.63	0.43	−0.14	421 ± 75	104 ± 47	-18 ± 18	2.28 ± 0.16
0.265	2.320	2.70	0.32	−0.14	344 ± 62	58 ± 74	-14 ± 26	1.88 ± 0.17
0.308	1.785	2.21	0.72	−0.25	1139 ± 205	310 ± 122	-175 ± 60	1.23 ± 0.17
0.310	2.050	2.33	0.63	−0.23	551 ± 98	121 ± 42	-66 ± 20	1.90 ± 0.16
0.310	2.350	2.47	0.50	−0.21	395 ± 71	103 ± 41	-49 ± 17	2.03 ± 0.16
0.313	2.639	2.58	0.37	−0.20	287 ± 52	111 ± 48	-9 ± 18	1.90 ± 0.17
0.327	2.914	2.62	0.28	−0.22	226 ± 43	138 ± 84	-46 ± 27	1.87 ± 0.23
0.370	2.050	2.09	0.74	−0.37	1002 ± 180	91 ± 75	-25 ± 39	0.97 ± 0.17
0.370	2.350	2.21	0.65	−0.34	581 ± 104	150 ± 48	-36 ± 23	1.35 ± 0.17
0.370	2.650	2.32	0.55	−0.31	380 ± 68	85 ± 40	-33 ± 17	1.62 ± 0.17
0.370	2.950	2.43	0.43	−0.30	273 ± 49	95 ± 42	-44 ± 17	1.93 ± 0.18
0.378	3.295	2.51	0.31	−0.30	230 ± 42	17 ± 55	-27 ± 19	1.46 ± 0.18
0.429	2.055	1.90	0.81	−0.59	2203 ± 348	54 ± 158	143 ± 85	1.03 ± 0.25
0.430	2.350	2.00	0.74	−0.53	1013 ± 182	181 ± 82	-102 ± 43	0.78 ± 0.22
0.430	2.650	2.10	0.67	−0.49	626 ± 113	90 ± 63	-41 ± 32	0.81 ± 0.22
0.430	2.950	2.19	0.58	−0.46	427 ± 78	56 ± 48	-24 ± 23	0.92 ± 0.23

- CLAS6 Report 4-fold differential bins of cross sections with large errors
- So here we will try to improve the stability better than CLAS6

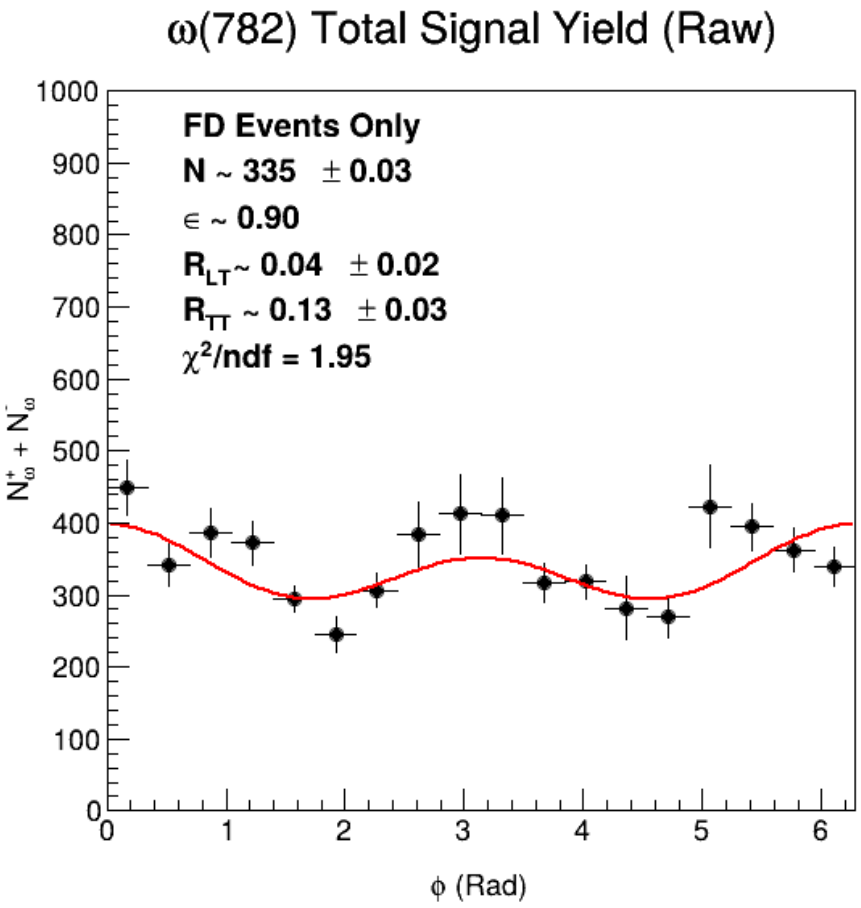
Inclusive $N^+ + N^-$ and $N^+ - N^-$ vs Trento ϕ

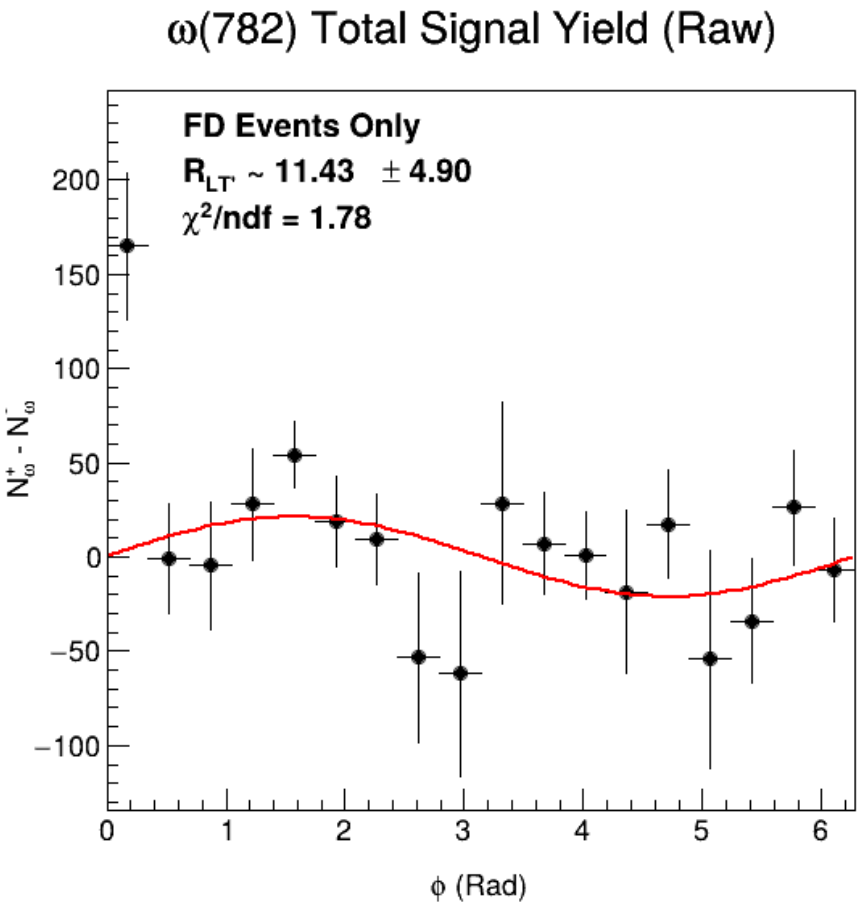




- Motivated by $\sigma^+ + \sigma^- = \sigma_0 + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT} cos\phi + \sigma_{TT}\, \varepsilon\, cos2\phi$
- For sum distribution: $F(\phi) = N\left(1 + \sqrt{2\varepsilon(1+\varepsilon)}R_{LT} cos\phi + R_{TT}\, \varepsilon\, cos2\phi\right)$
- Motivated by $\sigma^+ - \sigma^- = \sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'} sin\phi$
- For difference distribution: $F(\phi) = \sqrt{2\epsilon(1-\epsilon)}R_{LT'} sin\phi$

x_B, Q^2, t Differential Bins I

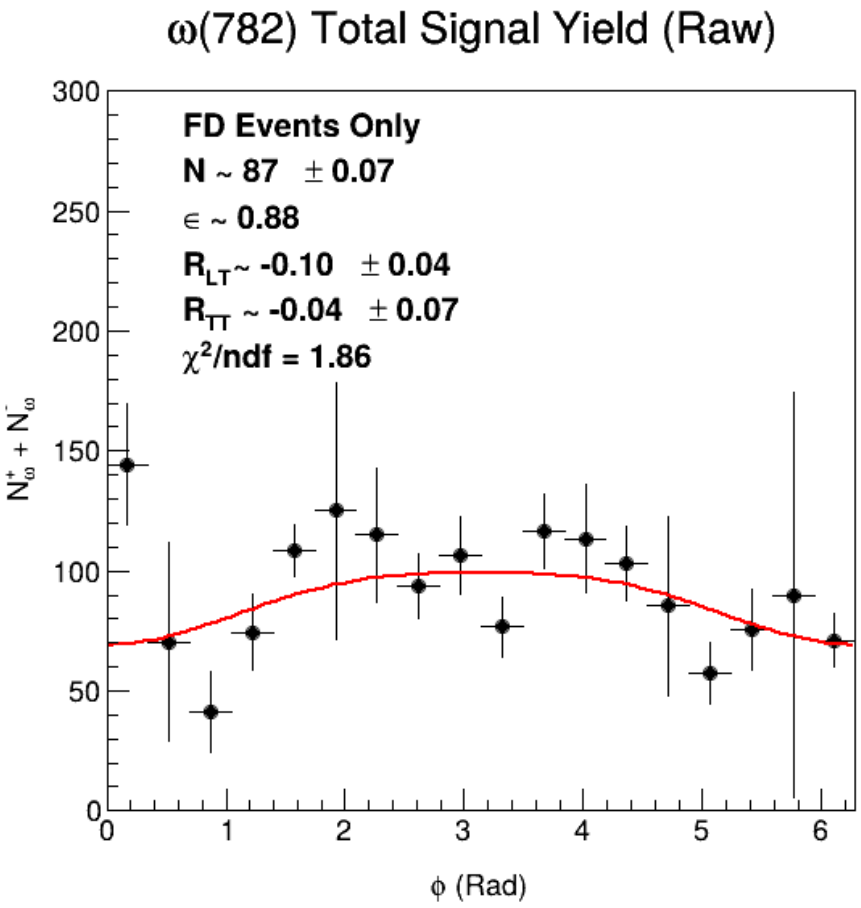


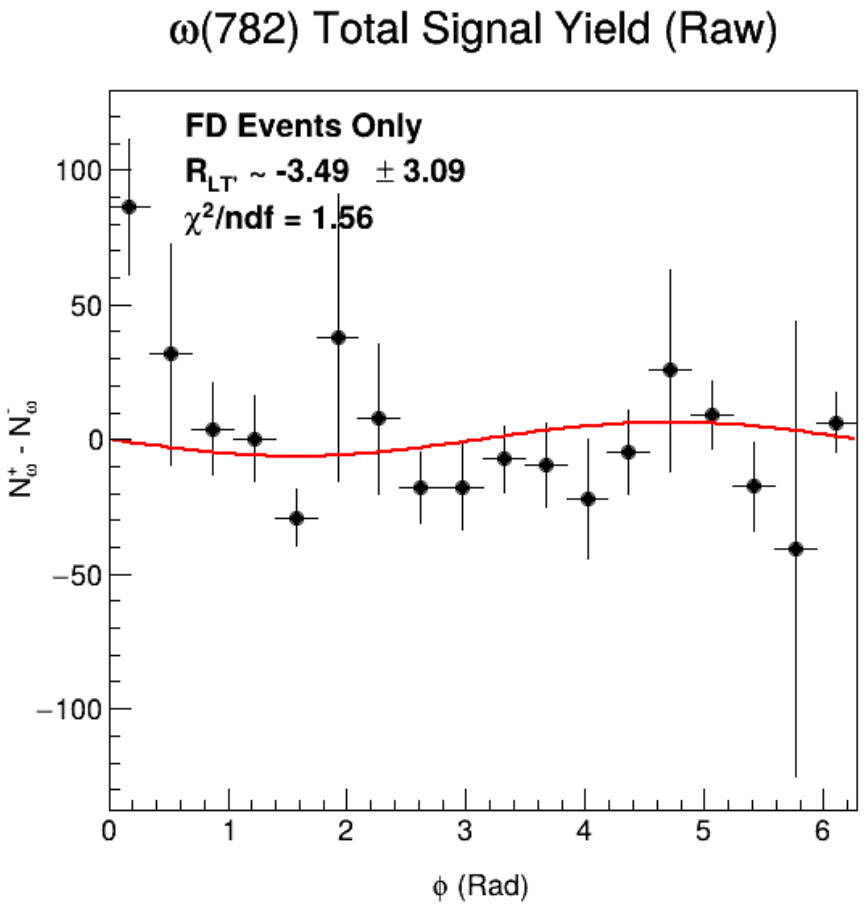


$W > 2.2$ GeV
$1 < Q^2 < 2$ GeV^2
$0.2 < x < 0.4$
$|t| < 0.5$ GeV^2

Ratios	Values
$R_{LT}/R_{TT} = \sigma_{LT}/\sigma_{TT}$	0.29 ± 0.16
$R_{LT'}/(NR_{LT}) = \sigma_{LT'}/\sigma_{LT}$	0.91 ± 0.59

x_B, Q^2, t Differential Bins II

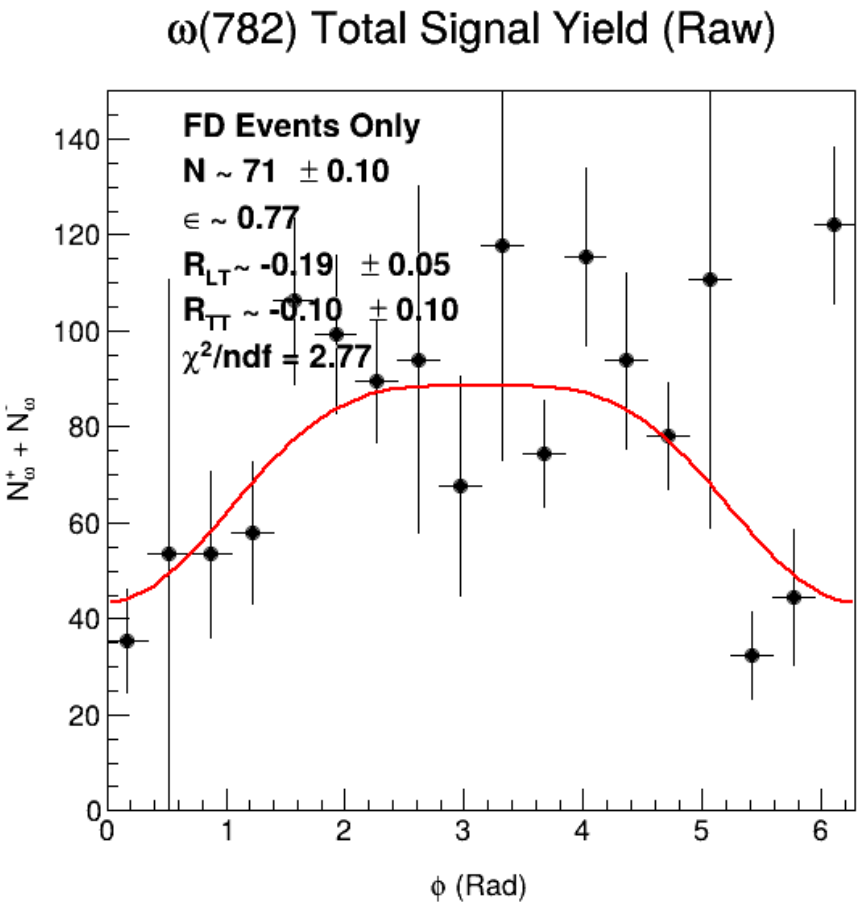


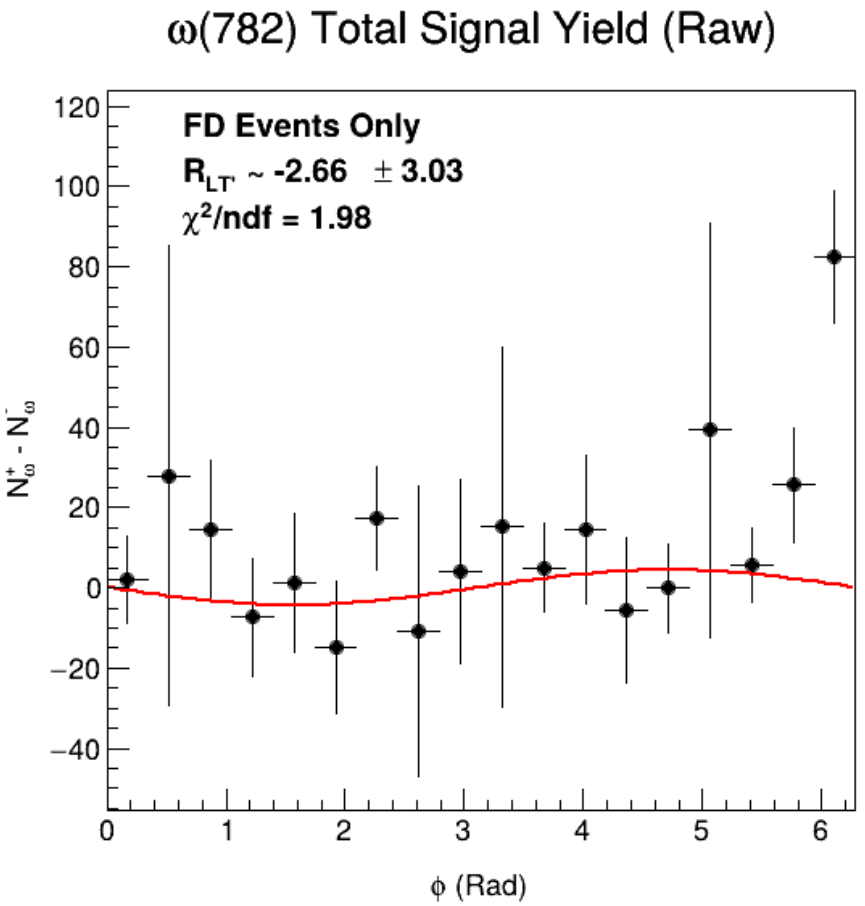


$W > 2.2$ GeV
$2 < Q^2 < 3$ GeV^2
$0.3 < x < 0.5$
$|t| < 0.5$ GeV^2

Ratios	Values
$R_{LT}/R_{TT} = \sigma_{LT}/\sigma_{TT}$	2.64 ± 5.08
$R_{LT'}/(NR_{LT}) = \sigma_{LT'}/\sigma_{LT}$	0.42 ± 0.41

x_B, Q^2, t Differential Bins III

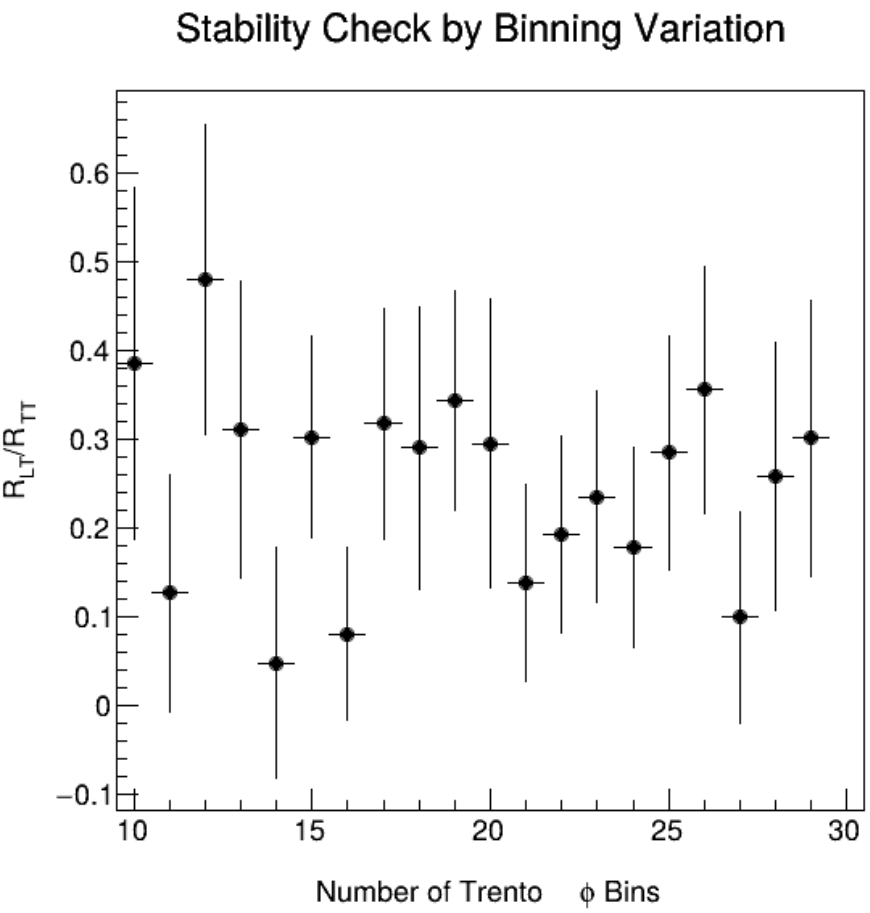


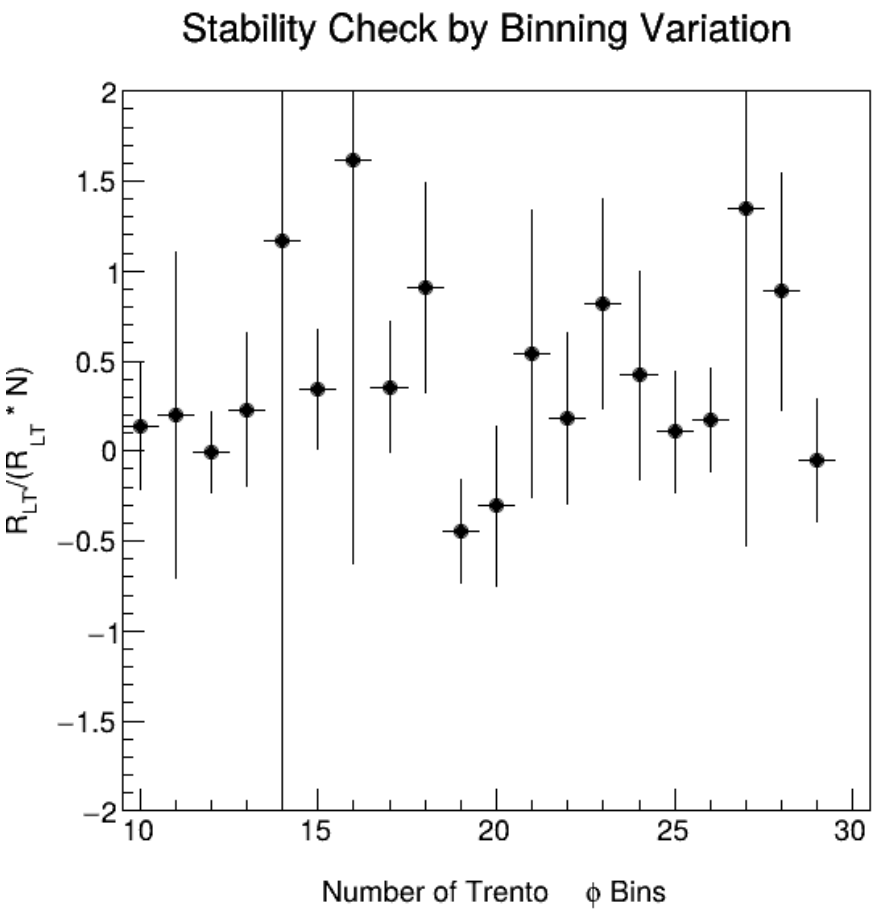


$W > 2.2$ GeV
$Q^2 > 3$ GeV^2
$0.4 < x < 0.6$
$0.5 < |t| < 1.0$ GeV^2

Ratios	Values
$R_{LT}/R_{TT} = \sigma_{LT}/\sigma_{TT}$	1.88 ± 5.08
$R_{LT'}/(NR_{LT}) = \sigma_{LT'}/\sigma_{LT}$	0.42 ± 0.41

Binning Variation





- Overall stable under rebinning
  - Fit is not too bad

Cut Variation

Cut Type	$\lvert m_X^2 - m_p^2 \rvert < (\mathrm{GeV}^2)$	$\lvert m_X^2 - m_\pi^2 \rvert < (\mathrm{GeV}^2)$	$\lvert m_{\gamma\gamma} - m_{\pi^0}^2 \rvert < (\mathrm{GeV})$
Loose	0.3	0.02	0.04
Normal	0.2	0.01	0.025
Tight	0.1	0.005	0.010
LowBkgd	0.05	0.0025	0.005

Cuts	R_{LT}	R_{TT}
Loose	0.16 ± 0.02	0.18 ± 0.03
Nominal	0.04 ± 0.02	0.13 ± 0.03
Tight	-0.06 ± 0.03	0.11 ± 0.07
Low Background	-0.07 ± 0.12	0.33 ± 0.25

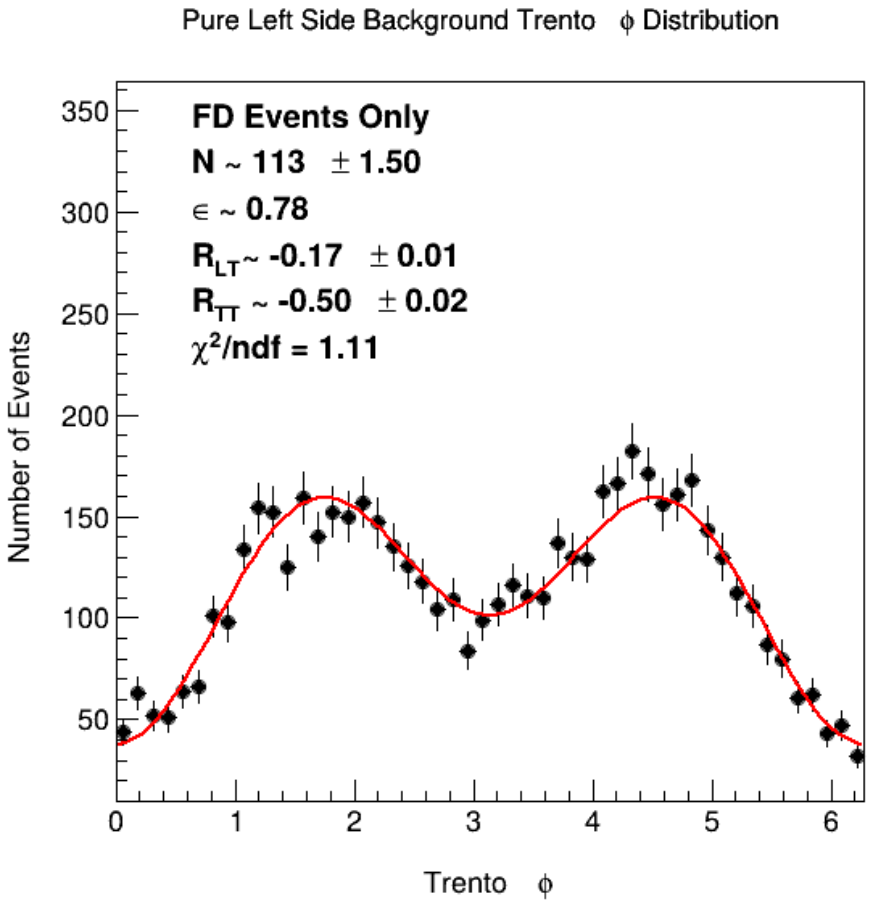
- We also vary cuts and check the stability of
- How can we improve the stability of the signal ω?
  - Efficiency correction with MC
  - Investigate the pure background samples ϕ angle modulation

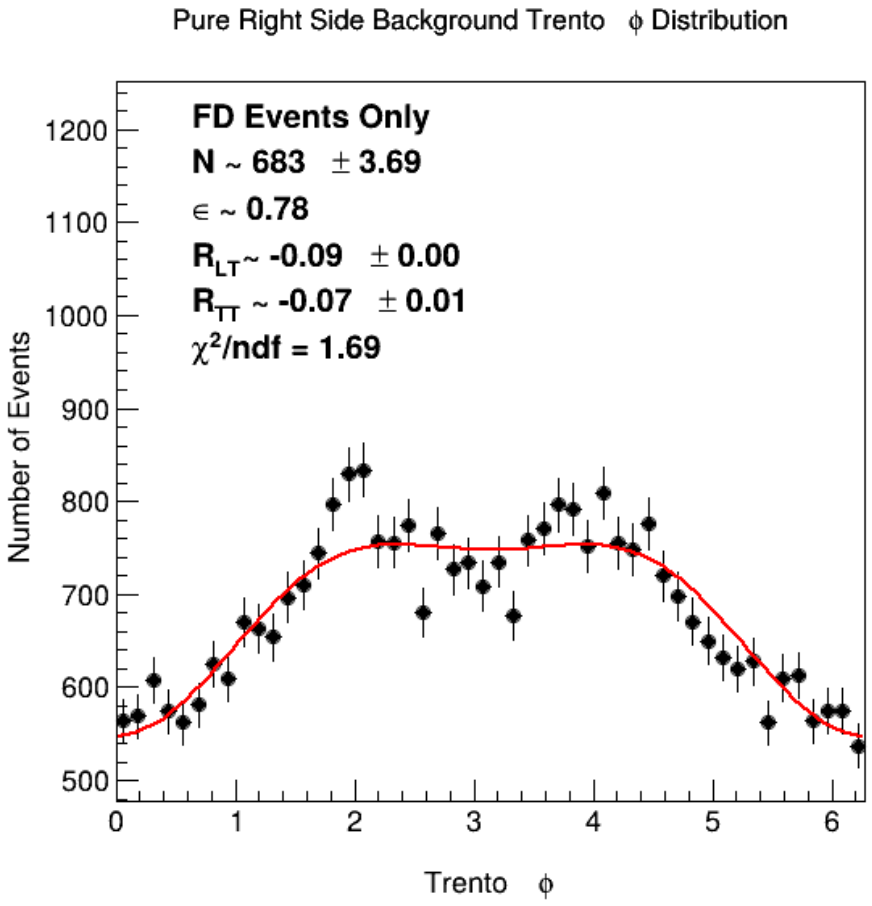
Background

Philosophy: Rather than spending more efforts to ensure the signal is 100% determined correctly from an always mixed signal and background sample, we would like to easily look at the pure background and see its contribution

Left and Right Sideband Choice

Sideband Inspection





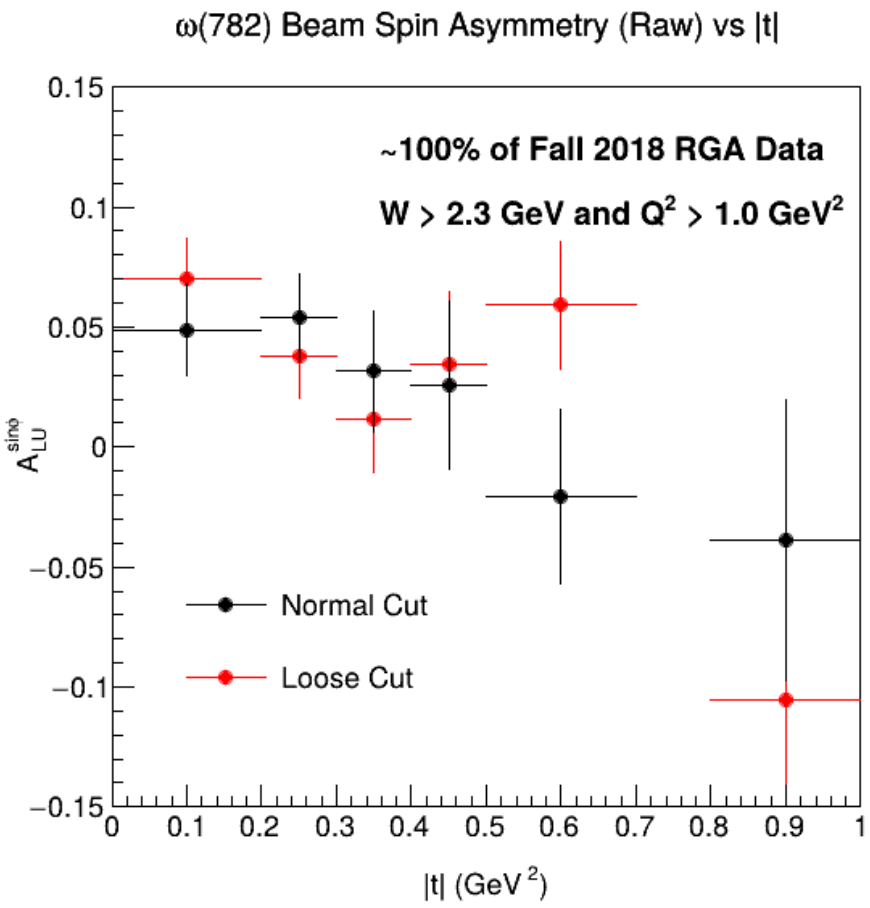
- Overall they have a similar ”M” shape with peaking shape at different regions
- However, the left sideband appear to peak at about $\pi/2$ and $3\pi/2$ dips at π
- The righthand side appear to peak at 2 ($2\pi/3$) and 4 ($4\pi/3$) while still dips at π, which appears to be the contribution of $cos3\phi$ modulation

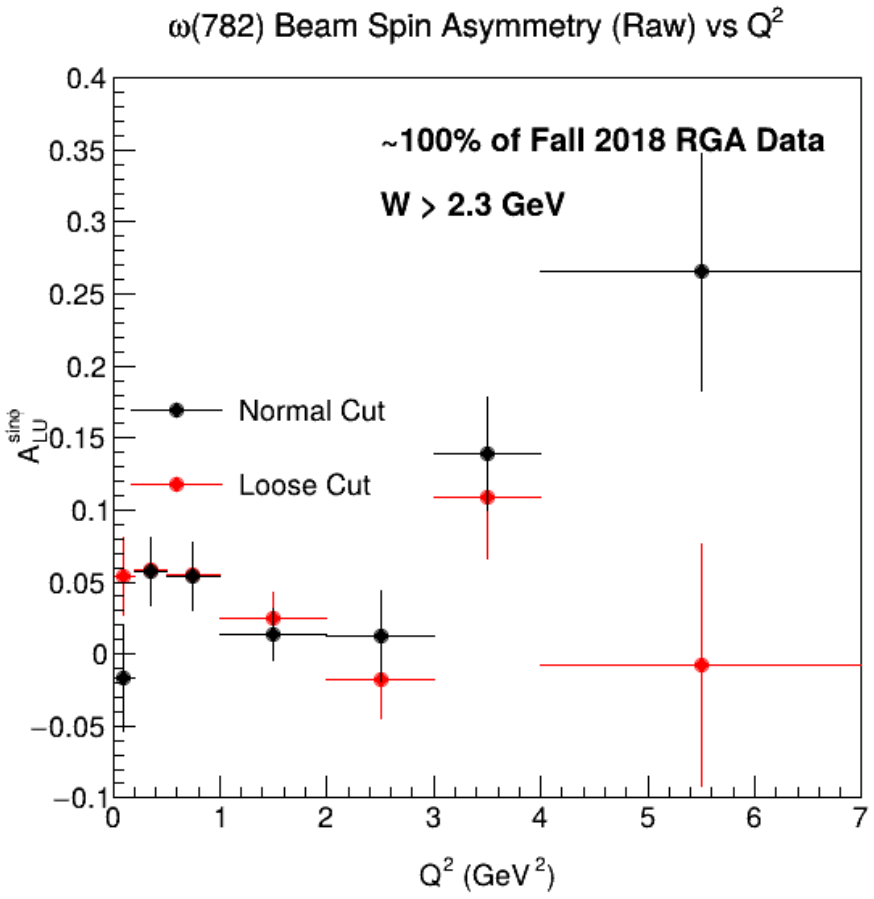
Stability of Pure Left Sideband Background Parameters

Cuts	R_{LT}	R_{TT}	χ^2/ndf
Loose	-0.08 $\pm$ 0.01	-0.53 $\pm$ 0.02	0.95
Nominal	-0.17 $\pm$ 0.01	-0.50 $\pm$ 0.02	1.11
Tight	-0.20 $\pm$ 0.03	-0.47 $\pm$ 0.04	0.77
Low Background	-0.13 $\pm$ 0.04	-0.72 $\pm$ 0.10	1.40

- The background parameters are very stable under signal cuts
- So we may use it as a template to extract the signal in the signal region as the background shape is going to remain stable

Longitudinal Expectation Robustness Check





- Expectation: BSA decreasing feature vs t in terms of this method
  - Existence only? Yes, we have a hint
  - Stable? Perhaps, thoughs robust enough under fit and cut variation for systematics and need more work
  - New Physics? Not there yet?

Summary and To Do List

Summary: Path to CAA

- Focused
- Existence of Trento ϕ modulation ✓
- Robustness and Stability of Parameters σ_{TT}, σ_{LT}, and $\sigma_{LT'}$ ongoing
- Extraction of Physics Messages from the Stable Observables ✗ but will be there
- Next draft will be a with raw signal

To Do List

- MC generator and efficiency studies
- Radiative correction

Thank You