E97-110: Small Angle GDH

Experimental Status Report

Jaideep Singh

University of Virginia

on the behalf of the Spokespeople: J.P. Chen, A. Deur, F. Garibaldi

Thesis Students: J. Singh, ***Dr. Vincent Sulkosky, PhD*** , and J. Yuan

and the rest of YOU, the Hall A Collaboration

Hall A Collaboration Meeting

CC Auditorium, June 22, 2007

GDH sum rule $\left(Q^2 = 0\right)$

First derived in the mid-1960's by **G**erasimov and **D**rell & **H**earn, the sum rule for spin-***I*** particles is based on the following ***modest yet robust arguments:***

$$\boxed{\int_{\nu_{\rm th}}^{\infty} \boldsymbol{\sigma}_{\rm A}(\nu) - \boldsymbol{\sigma}_{\rm P}(\nu)\, \frac{d\nu}{\nu} \;=\; -2\pi^2 \alpha_{\rm em}\,(2m_I)\left[\frac{\mu/e\hbar}{I} - \frac{Z}{M}\right]^2}$$

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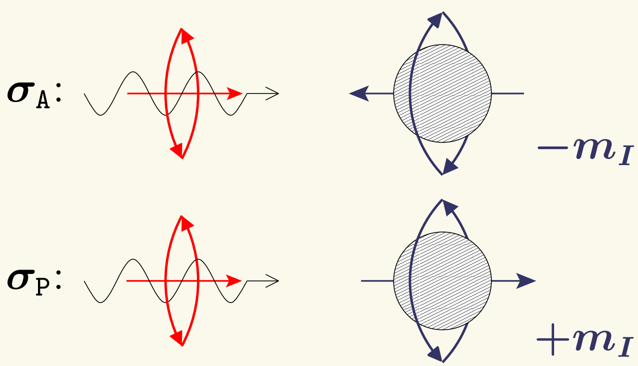

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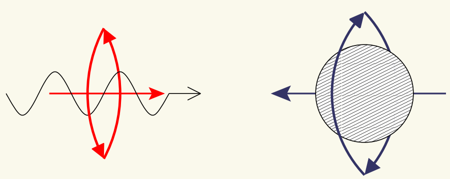
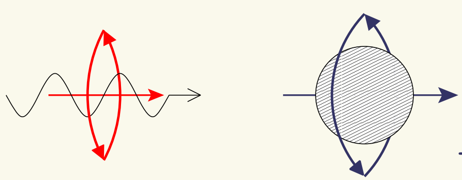
$\sigma_{\rm A}$:



$-m_I$

$\sigma_{\rm P}$:



$+m_I$

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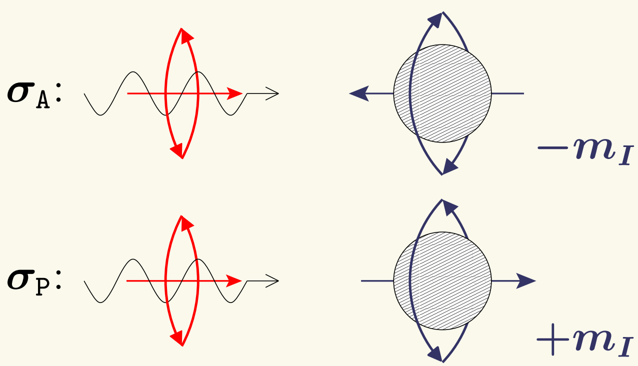
total particle m.m.

point-like m.m. is the charge-to-mass ratio



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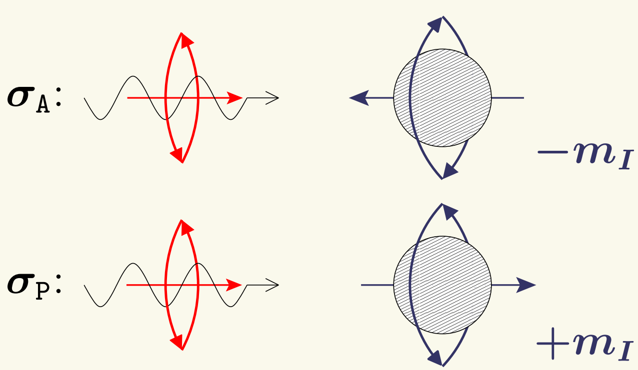

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$I_{\text{GDH}} = -233.16\ \mu$b for the Neutron

$I_{\text{GDH}} = -497.95\ \mu$b for ^{3}He

Generalization for $Q^2 > 0$ $(I = 1/2)$

$$\boxed{\int_{\nu_{\mathtt{th}}}^{\infty} \frac{K'(\nu, Q^2)}{K'(\nu, 0)} \left[2\sigma_{\mathtt{TT}} + (0 \text{ or } 1) \left(\frac{Q}{\nu} \right) 2\sigma_{\mathtt{LT}} \right] \frac{d\nu}{\nu} = -2\pi^2 \alpha_{\mathtt{em}} \mathcal{M}\left(Q^2\right)}$$

Generalization for $Q^2 > 0$ $(I = 1/2)$

LHS: **Experimentally measureable** via polarized inclusive electron scattering from a polarized target

$$\boxed{\int_{\nu_{\mathrm{th}}}^{\infty} \frac{K'(\nu, Q^2)}{K'(\nu, 0)} \left[2\sigma_{\mathrm{TT}} + (0 \text{ or } 1) \left(\frac{Q}{\nu} \right) 2\sigma_{\mathrm{LT}} \right] \frac{d\nu}{\nu} \quad = -2\pi^2 \alpha_{\mathrm{em}} \mathcal{M}(Q^2)}$$

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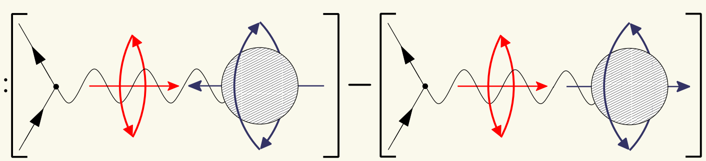
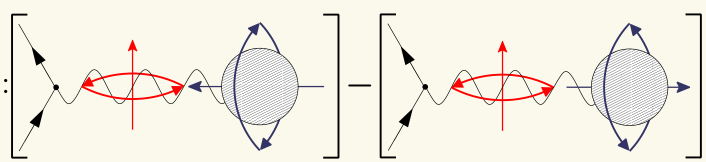
$2\sigma_{\text{TT}}$:



$2\sigma_{\text{LT}}$:



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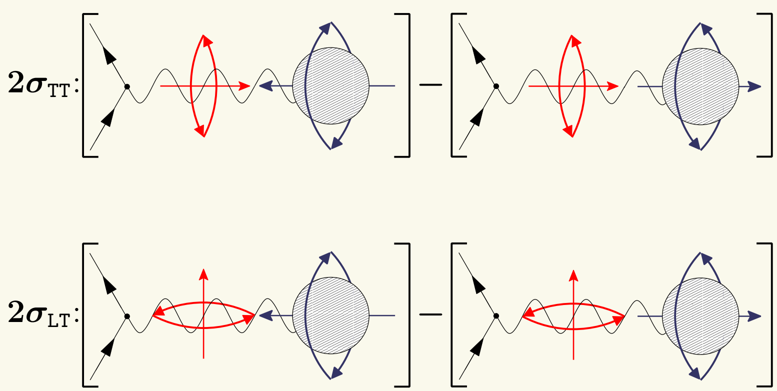

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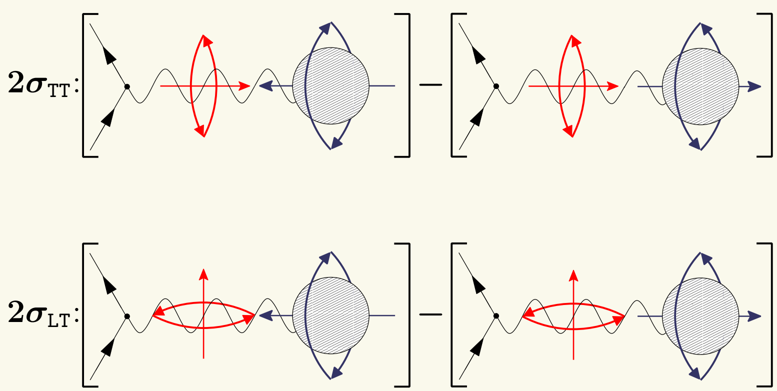

Low Q^2 expansion of the elastic-subtracted virtual forward Compton amplitude:

$$\mathcal{M}(Q^2) = \left(\frac{\kappa}{M}\right)^2 + Q^2 \left.\frac{d\mathcal{M}}{dQ^2}\right|_{Q^2=0} + \cdots$$

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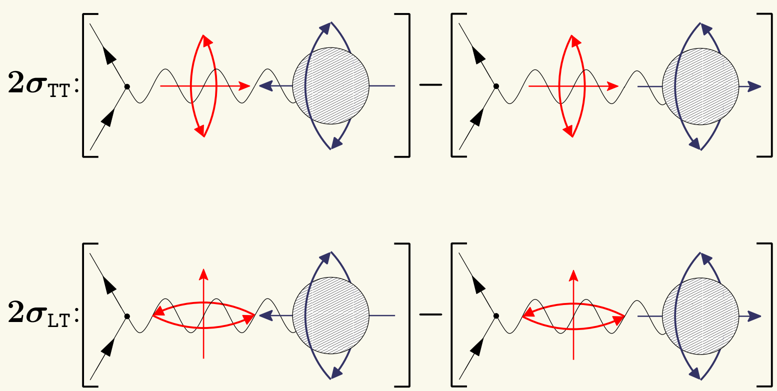

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slope from Chiral Perturbation Theory

Generalization for $Q^2 > 0$ $(I = 1/2)$

"=": Science!

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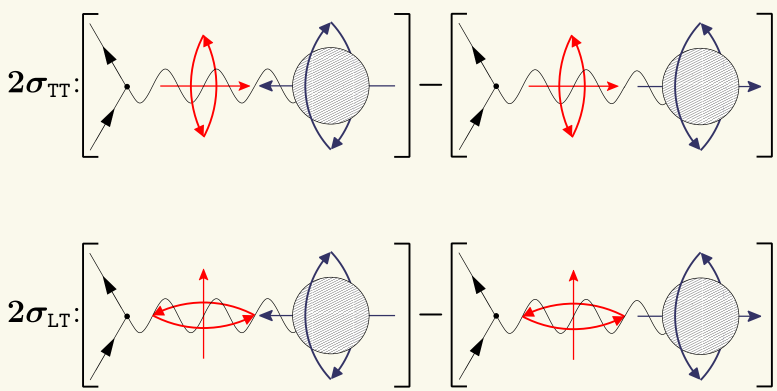

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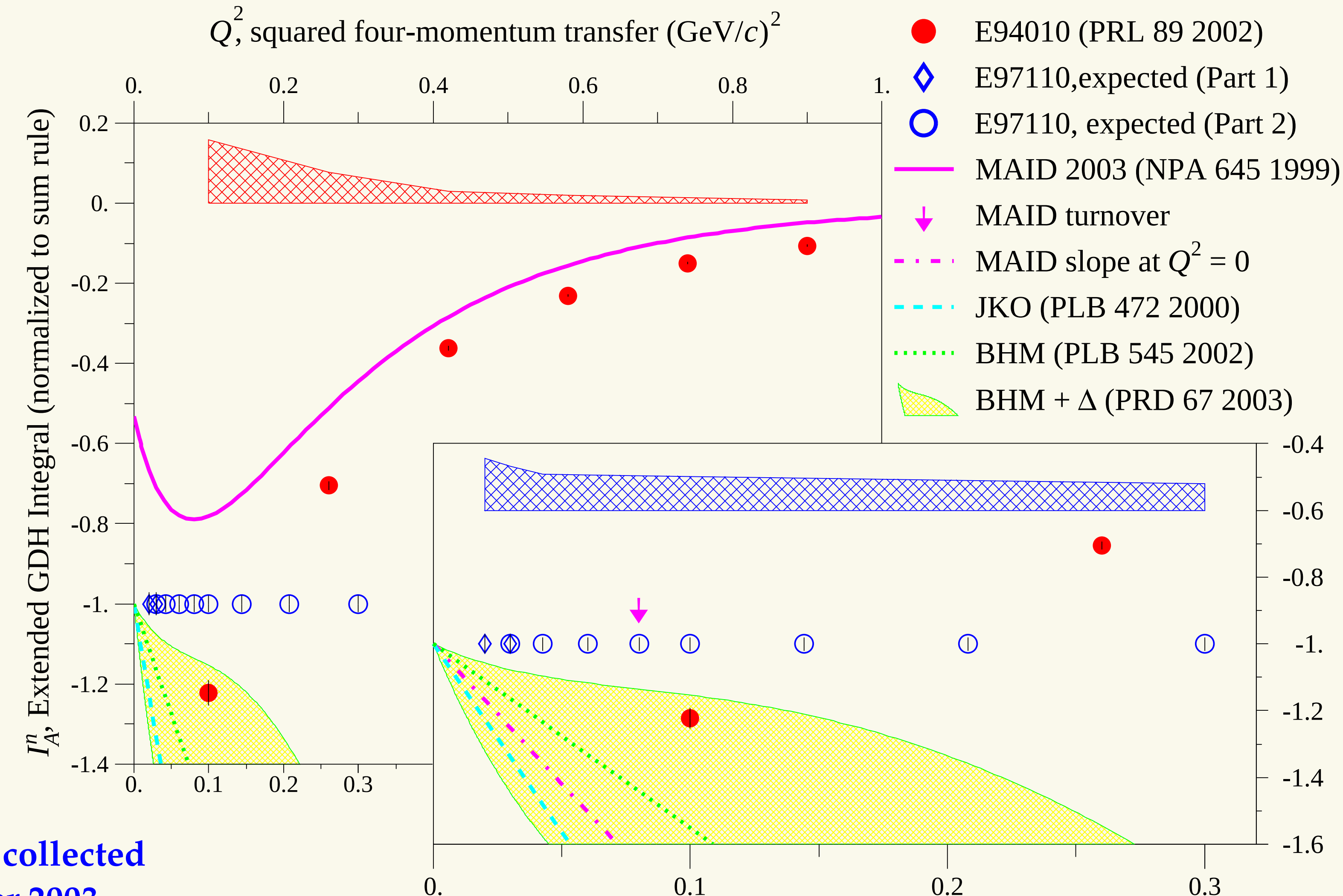
The spin structure of ^{3}He and the Neutron at low Q^2



Data was collected in summer 2003

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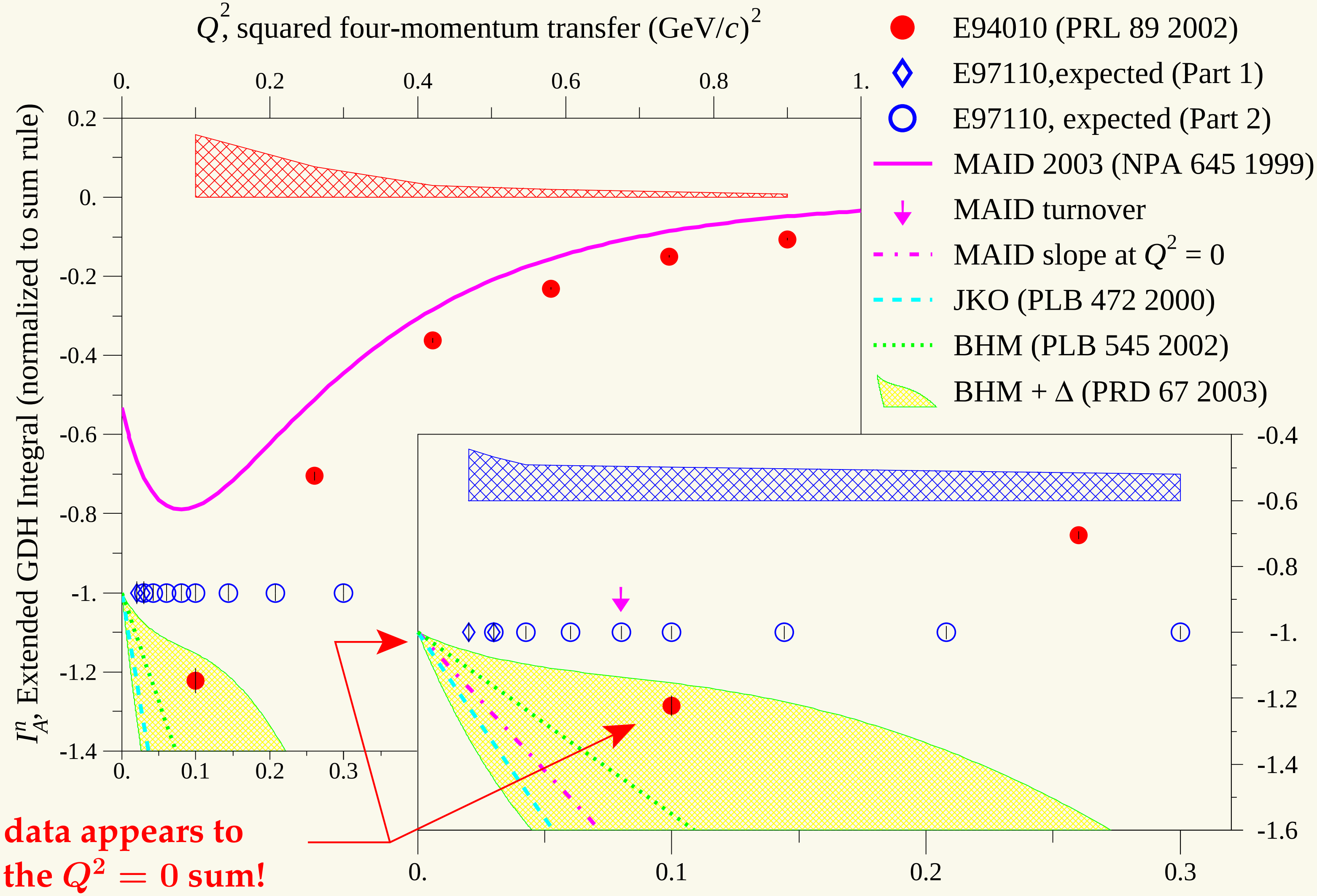
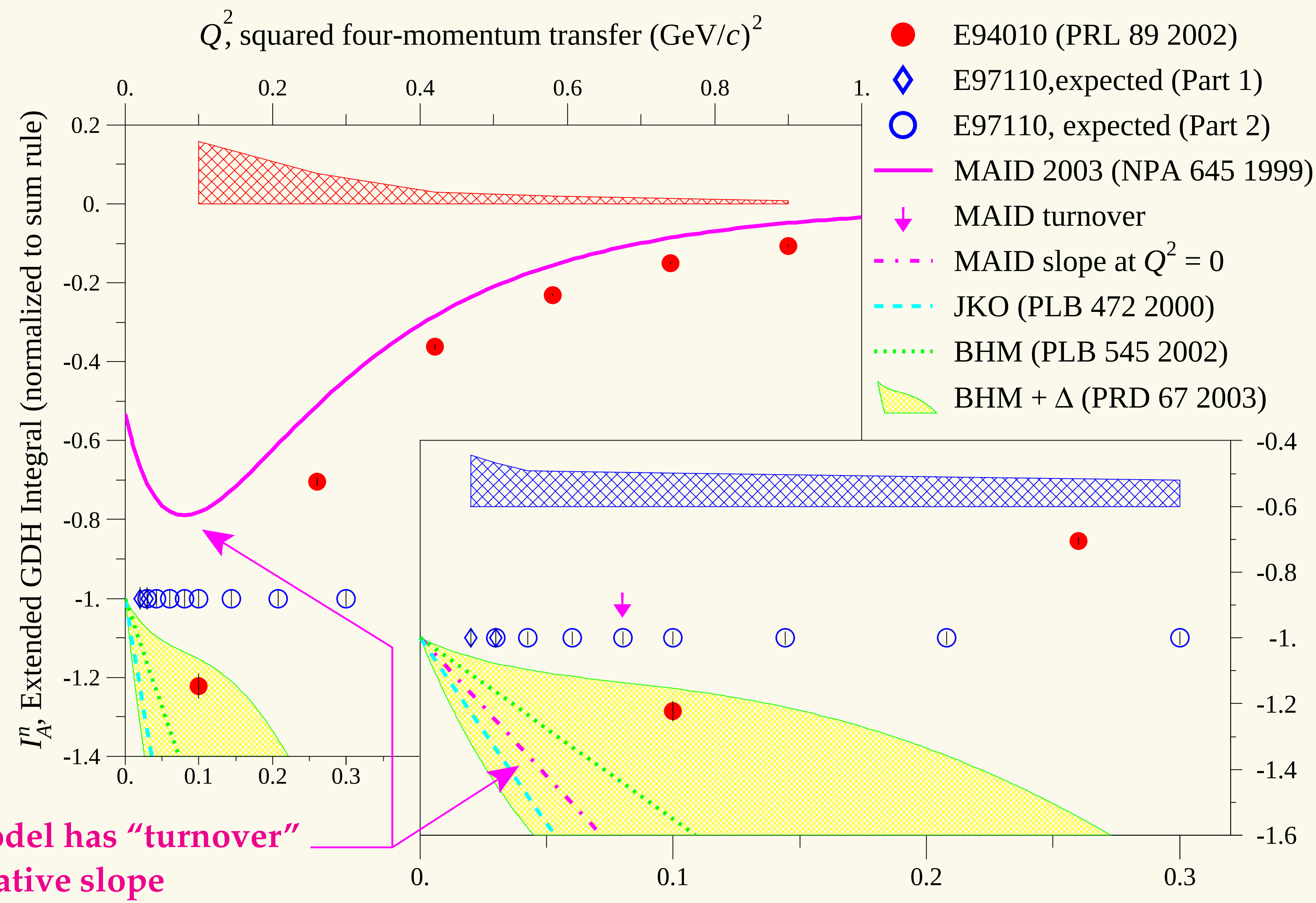


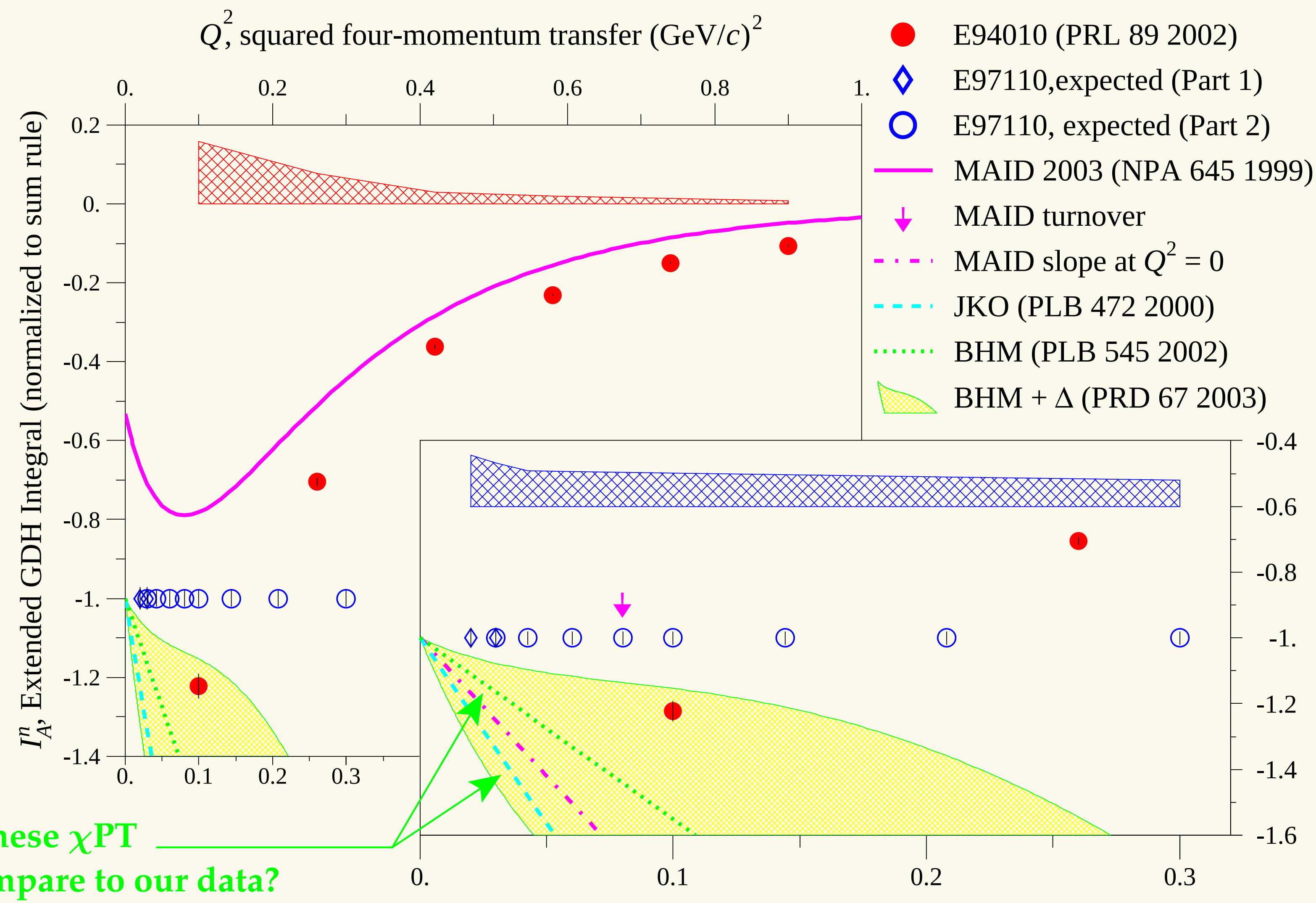
The "old" data appears to overshoot the $Q^2 = 0$ sum!

The spin structure of ^{3}He and the Neutron at low Q^2



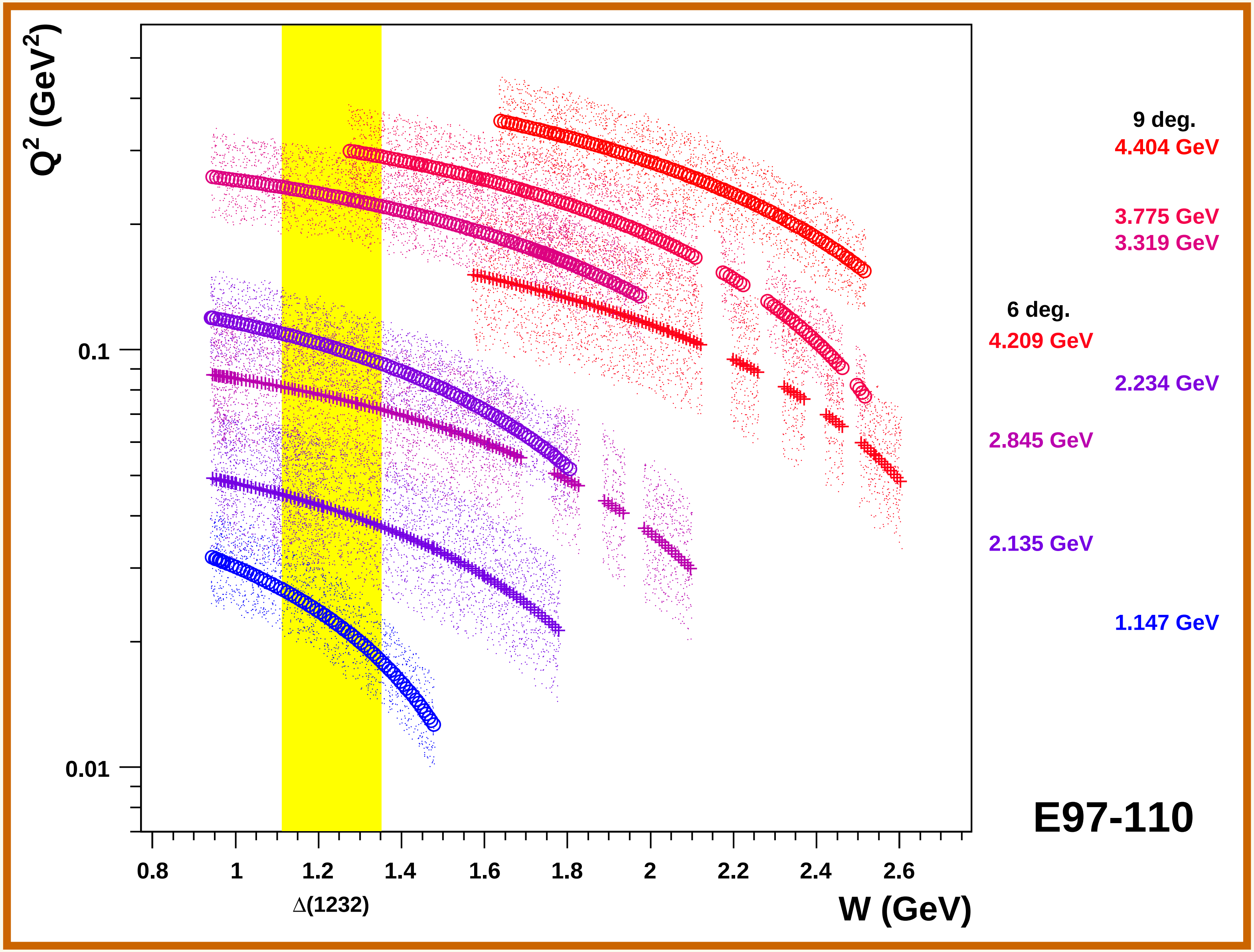
MAID model has "turnover" and a negative slope

The spin structure of ^{3}He and the Neutron at low Q^2



How do these χPT slopes compare to our data?

Kinematic Coverage



Asymmetries 1/8

$$\boldsymbol{A}_{\mathtt{phys}} = \left[\frac{\left(\frac{\boldsymbol{N}_+}{\boldsymbol{Q}_+ \cdot \boldsymbol{L}_+}\right) - \left(\frac{\boldsymbol{N}_-}{\boldsymbol{Q}_- \cdot \boldsymbol{L}_-}\right)}{\left(\frac{\boldsymbol{N}_+}{\boldsymbol{Q}_+ \cdot \boldsymbol{L}_+}\right) + \left(\frac{\boldsymbol{N}_-}{\boldsymbol{Q}_- \cdot \boldsymbol{L}_-}\right)} \right] \times \frac{\mathbf{1}}{\boldsymbol{P}_{\mathtt{b}} \cdot \boldsymbol{P}_{\mathtt{t}} \cdot \boldsymbol{d}_{\mathtt{N_2}} \cdot \boldsymbol{d}_{\mathtt{glass}}}$$

- good e^- count
- charge
- livetime
- beam pol.
- target pol.
- N_2 dilution
- glass dilution

Asymmetries 2/8

$$A_{\text{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\text{b}} \cdot P_{\text{t}} \cdot d_{\text{N}_2} \cdot d_{\text{glass}}}$$

- **good e^- count**
- charge
- livetime
- beam pol.
- target pol.
- N_2 dilution
- glass dilution

"standard" trigger and PID cuts
relatively loose acceptance cuts

Asymmetries 3/8

$$A_{\mathtt{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\mathtt{b}} \cdot P_{\mathtt{t}} \cdot d_{\mathtt{N_2}} \cdot d_{\mathtt{glass}}}$$

- good e^- count
- **charge**
- livetime
- beam pol.
- target pol.
- N_2 dilution
- glass dilution

only 10% of the runs have a charge asymmetery of > 200 ppm

Asymmetries 4/8

$$A_{\text{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\text{b}} \cdot P_{\text{t}} \cdot d_{\text{N}_2} \cdot d_{\text{glass}}}$$

- good e^- count
- charge
- **livetime**
- beam pol.
- target pol.
- N_2 dilution
- glass dilution

only 15% of the runs have a deadtime $> 10\%$

Asymmetries 5/8

$$A_{\mathrm{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\mathtt{b}} \cdot P_{\mathtt{t}} \cdot d_{\mathtt{N_2}} \cdot d_{\mathtt{glass}}}$$

- good e^- count
- charge
- livetime
- **beam pol.**
- target pol.
- N_2 dilution
- glass dilution

Moller corrected w/Hall C bleedthrough:

6 degrees	68%
9 degrees	75%
overall	71%

Still need to check bleedthrough correction with Compton where available!

Asymmetries 6/8

$$A_{\mathrm{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)}\right] \times \frac{1}{P_{\mathrm{b}} \cdot P_{\mathrm{t}} \cdot d_{\mathrm{N_2}} \cdot d_{\mathrm{glass}}}$$

- good e^- count
- charge
- livetime
- beam pol.
- **target pol.**
- N_2 dilution
- glass dilution

Water NMR and EPR calibrations differ by 15% relative. There may be a subtle effect due to the fringe fields of the septum magnet. We are trying to track down the source of this difference.

Asymmetries 7/8

$$A_{\mathrm{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\mathtt{b}} \cdot P_{\mathtt{t}} \cdot d_{\mathtt{N_2}} \cdot d_{\mathtt{glass}}}$$

- good e^- count
- charge
- livetime
- beam pol.
- target pol.
- **N$_2$ dilution**
- glass dilution

can be as low as 85% at low beam energy and high ν

analysis by: Xiaohui Zhan (MIT)

Asymmetries 8/8

$$A_{\mathtt{phys}} = \left[\frac{\left(\frac{N_+}{Q_+ \cdot L_+}\right) - \left(\frac{N_-}{Q_- \cdot L_-}\right)}{\left(\frac{N_+}{Q_+ \cdot L_+}\right) + \left(\frac{N_-}{Q_- \cdot L_-}\right)} \right] \times \frac{1}{P_{\mathtt{b}} \cdot P_{\mathtt{t}} \cdot d_{\mathtt{N_2}} \cdot d_{\mathtt{glass}}}$$

- good e^- count
- charge
- livetime
- beam pol.
- target pol.
- N_2 dilution
- **glass dilution**

can be as low as 50% at low beam energy and high ν

analysis by: Xiaohui Zhan (MIT)

Unpolarized Cross Sections 1/5

$$\boldsymbol{\sigma_0 = \left[\frac{N_0}{(Q_0 e) L_0 \rho \epsilon_{\texttt{det}}}\right] \times \frac{1}{(\Delta Z \Delta\Omega \Delta E_{\texttt{f}})}}$$

- good e^- count
- charge
- livetime
- target density
- detector eff.
- acceptance

Unpolarized Cross Sections 2/5

$$\sigma_0 = \left[\frac{N_0}{(Q_0 e) L_0 \rho \epsilon_{\mathtt{det}}}\right] \times \frac{1}{(\Delta Z \Delta \Omega \Delta E_{\mathtt{f}})}$$

- **good e^- count**
- charge
- livetime
- target density
- detector eff.
- acceptance

“standard” trigger and PID cuts
relatively tight acceptance cuts
N_2 reference cell subtraction
empty reference cell subtraction
“kinematic” matching
V. Sulkosky and R. Feuerbach

Unpolarized Cross Sections 3/5

$$\sigma_0 = \left[\frac{N_0}{(Q_0 e) L_0 \rho \epsilon_{\mathtt{det}}}\right] \times \frac{1}{(\Delta Z \Delta \Omega \Delta E_{\mathtt{f}})}$$

- good e^- count
- charge
- livetime
- **target density**
- detector eff.
- acceptance

cell	**avg (amg)**	**fill−p.b. (rel.)**
Proteus	6.869	-0.4%
Penelope	8.900	-0.8%
Priapus	8.723	-1.8%

creanalysis of PB data by: Vladimir Nelyubin (UVa)

Unpolarized Cross Sections 4/5

$$\sigma_0 = \left[\frac{N_0}{(Q_0 e) L_0 \rho \epsilon_{\mathtt{det}}}\right] \times \frac{1}{(\Delta Z \Delta\Omega \Delta E_{\mathtt{f}})}$$

- good e^- count
- charge
- livetime
- target density
- **detector eff.**
- acceptance

PID efficiencies done by Hai-jiang Lu (USTC)
VDC multitrack identification in progress by Jing Yuan (Rutgers)

Unpolarized Cross Sections 5/5

$$\sigma_0 = \left[\frac{N_0}{(Q_0 e) L_0 \rho \epsilon_{\mathtt{det}}} \right] \times \frac{1}{(\Delta Z \Delta \Omega \Delta E_{\mathtt{f}})}$$

- good e^- count
- charge
- livetime
- target density
- detector eff.
- **acceptance**

A lot of progress has been made by Vince Sulkosky, but we still have some issues to work out.

Kinematic Matching

Goal: To insure that the $A_{\mathtt{phys}}$ and σ_0 are extracted for the same ν and average scattering angle $\langle \theta_{\mathtt{sc}} \rangle$

- Apply “loose” cuts to get more statistics for $A_{\mathtt{phys}}$

Kinematic Matching

Goal: To insure that the $A_{\mathtt{phys}}$ and σ_0 are extracted for the same ν and average scattering angle $\langle\theta_{\mathtt{sc}}\rangle$

- Apply “loose” cuts to get more statistics for $A_{\mathtt{phys}}$
- Calculate $A_{\mathtt{phys}}$ per ν bin

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- Apply "loose" cuts to get more statistics for $A_{\mathtt{phys}}$
- Calculate $A_{\mathtt{phys}}$ per ν bin
- For each ν bin, using the $A_{\mathtt{phys}}$ sample, calculate $\langle\theta_{\mathtt{sc}}\rangle$

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- Apply "loose" cuts to get more statistics for $A_{\mathtt{phys}}$
- Calculate $A_{\mathtt{phys}}$ per ν bin
- For each ν bin, using the $A_{\mathtt{phys}}$ sample, calculate $\langle\theta_{\mathtt{sc}}\rangle$
- Apply tighter cuts to select a "super-clean" subset of $A_{\mathtt{phys}}$ sample for the σ_0 analysis

Kinematic Matching

Goal: To insure that the $A_{\mathtt{phys}}$ and σ_0 are extracted for the same ν and average scattering angle $\langle\theta_{\mathtt{sc}}\rangle$

- Apply "loose" cuts to get more statistics for $A_{\mathtt{phys}}$
- Calculate $A_{\mathtt{phys}}$ per ν bin
- For each ν bin, using the $A_{\mathtt{phys}}$ sample, calculate $\langle\theta_{\mathtt{sc}}\rangle$
- Apply tighter cuts to select a "super-clean" subset of $A_{\mathtt{phys}}$ sample for the σ_0 analysis
- Calculate σ_0 for each ν & $\phi_{\mathtt{tg}}$ bin

Kinematic Matching

Goal: To insure that the $A_{\mathtt{phys}}$ and $\boldsymbol{\sigma}_0$ are extracted for the same $\boldsymbol{\nu}$ and average scattering angle $\langle\boldsymbol{\theta}_{\mathtt{sc}}\rangle$

- Apply “loose” cuts to get more statistics for $A_{\mathtt{phys}}$
- Calculate $A_{\mathtt{phys}}$ per ν bin
- For each ν bin, using the $A_{\mathtt{phys}}$ sample, calculate $\langle\theta_{\mathtt{sc}}\rangle$
- Apply tighter cuts to select a “super-clean” subset of $A_{\mathtt{phys}}$ sample for the σ_0 analysis
- Calculate σ_0 for each ν & $\phi_{\mathtt{tg}}$ bin
- For each $\boldsymbol{\nu}$-$\phi_{\mathtt{tg}}$ bin, using the $\boldsymbol{\sigma}_0$ sample, calculate $\langle\boldsymbol{\theta}_{\mathtt{sc}}\rangle$

Kinematic Matching

Goal: To insure that the A_{phys} and $\boldsymbol{\sigma_0}$ are extracted for the same $\boldsymbol{\nu}$ and average scattering angle $\langle\boldsymbol{\theta}_{\mathrm{sc}}\rangle$

- Apply "loose" cuts to get more statistics for A_{phys}
- Calculate A_{phys} per ν bin
- For each ν bin, using the A_{phys} sample, calculate $\langle\theta_{\mathrm{sc}}\rangle$
- Apply tighter cuts to select a "super-clean" subset of A_{phys} sample for the σ_0 analysis
- Calculate σ_0 for each ν & ϕ_{tg} bin
- For each $\boldsymbol{\nu}$-ϕ_{tg} bin, using the $\boldsymbol{\sigma_0}$ sample, calculate $\langle\boldsymbol{\theta}_{\mathrm{sc}}\rangle$
- For each $\boldsymbol{\nu}$ bin, interpolate $\boldsymbol{\sigma_0}$ along ϕ_{tg} to match $\langle\boldsymbol{\theta}_{\mathrm{sc}}\rangle$ with the corresponding $\langle\boldsymbol{\theta}_{\mathrm{sc}}\rangle$ for the $\boldsymbol{A}_{\mathrm{phys}}$ sample

Some linear algebra, pt. 1

- $\|$ & $\perp$ refer to the target spin para. & perp. to the beam line
- $\boldsymbol{\Delta\sigma}$ is the cross section difference between the target spin pointing “up” vs “down”
- the other stuff is just “kinematic” factors like the beam energy, the energy loss, and the scattering angle

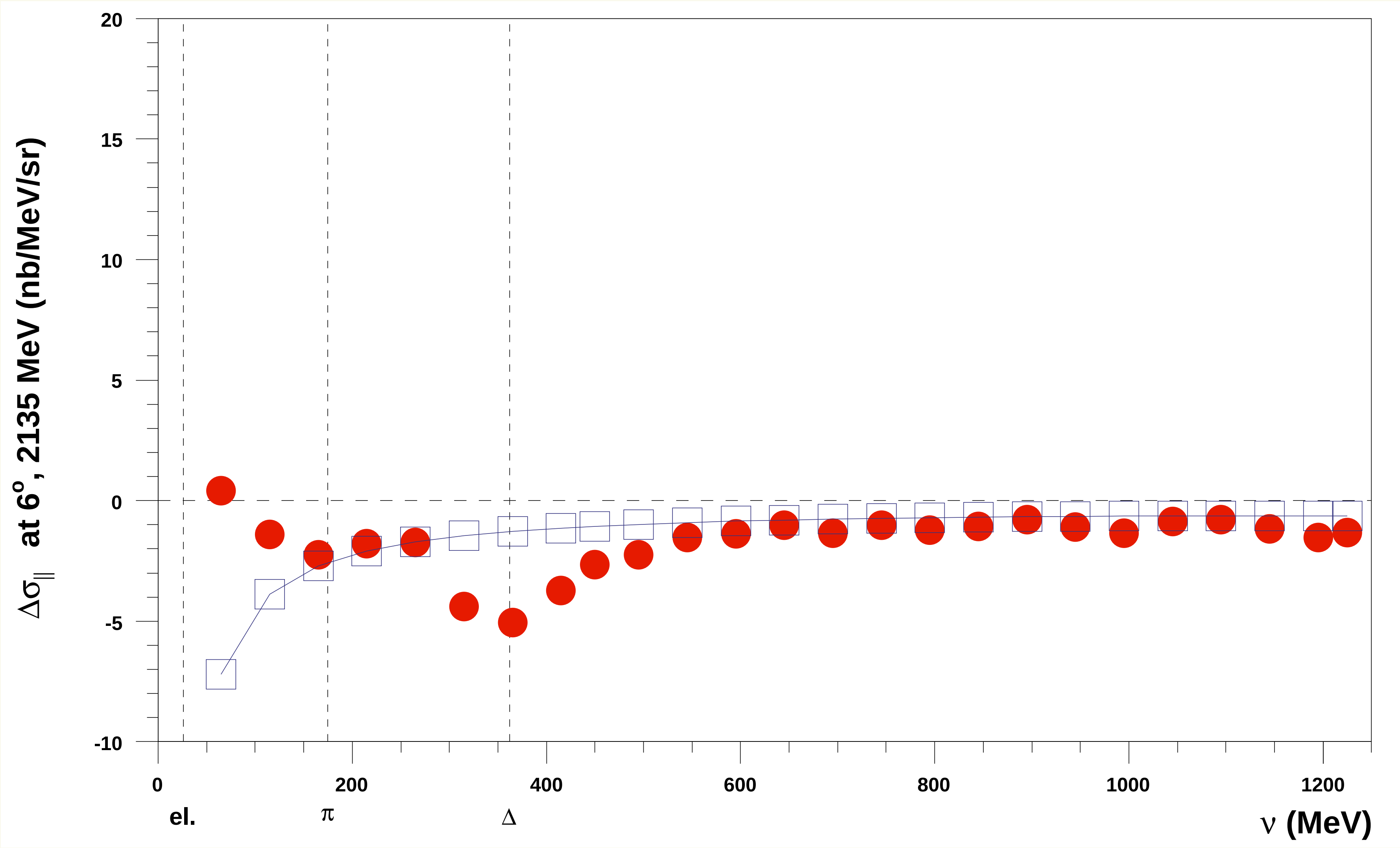
$$\boldsymbol{\Delta\sigma}_{\|,\perp} = \mathbf{2} \times \boldsymbol{A}_{\|,\perp} \times \boldsymbol{\sigma_0}$$

$$\begin{pmatrix} \boldsymbol{\Delta\sigma}_{\|} \\ \boldsymbol{\Delta\sigma}_{\perp} \end{pmatrix} = -\mathbf{2\Gamma} \begin{pmatrix} +\cos(\boldsymbol{\alpha}) & +\sin(\boldsymbol{\alpha}) \\ -\sin(\boldsymbol{\alpha}) & +\cos(\boldsymbol{\alpha}) \end{pmatrix} \overleftrightarrow{\boldsymbol{p}}_{\texttt{virt}} \begin{pmatrix} \boldsymbol{\sigma}_{\mathrm{TT}} \\ \boldsymbol{\sigma}_{\mathrm{LT}} \end{pmatrix}$$

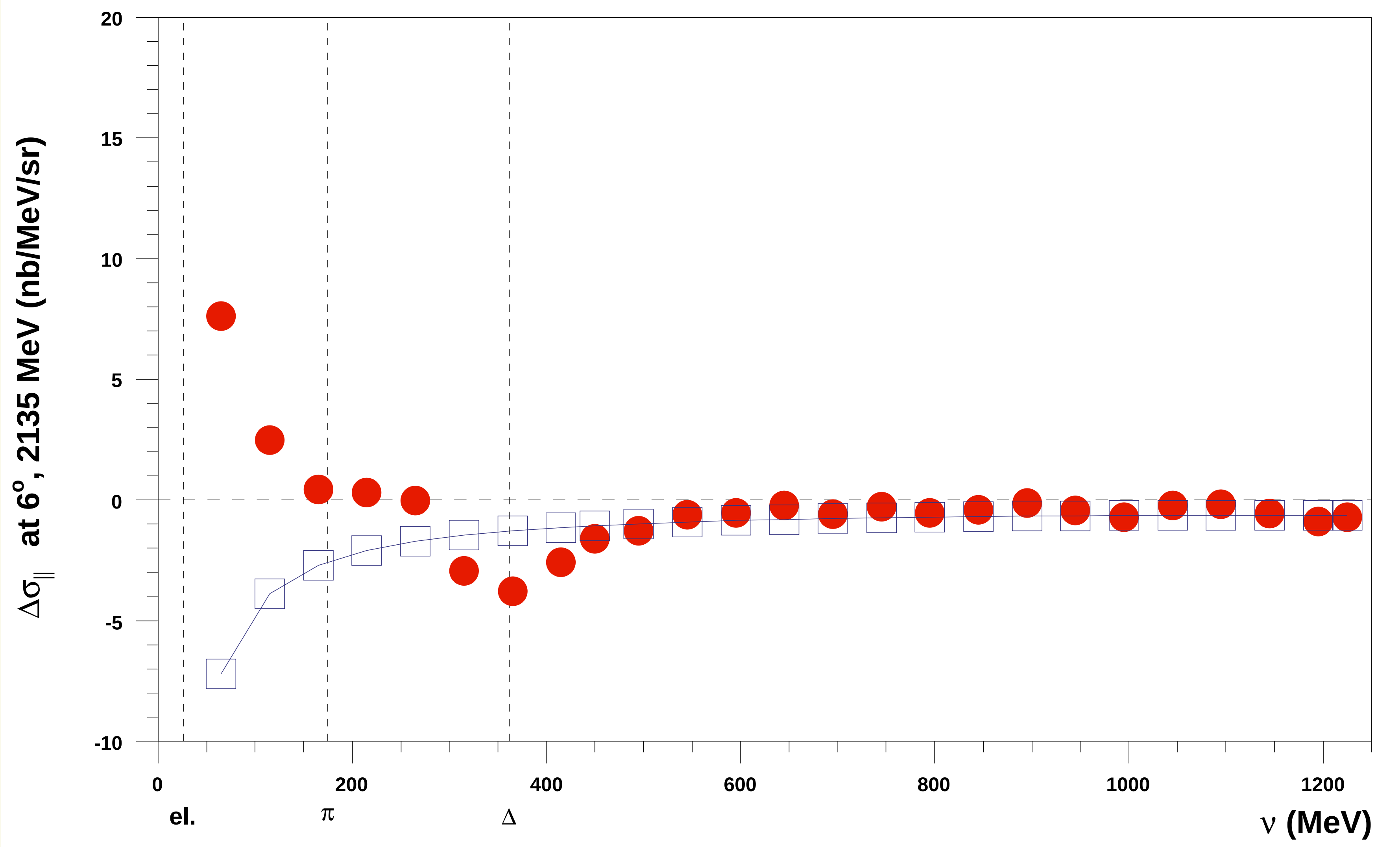
RC Formalism

1. **Radiative Corrections to Elastic and Inelastic ep and μp Scattering**
   L.W. Mo and Y.S. Tsai, *RMP* **41**, 205-235 (1969)
2. **Radiative Corrections to Electron Scatterings**
   Yung-Su Tsai, SLAC-PUB-848, January 1971
3. **Electron scattering at 4^{o} with energies of 4.5-20 GeV**
   S. Stein et. al, *PRD* **12**, 1884–1919 (1975)
4. **Measurement of kinematic and nuclear dependence of $R = \sigma_L/\sigma_T$ in deep inelastic electron scattering**
   S. Dasu, et. al, *PRD* **49**, 5641–5670 (1994)
5. **POLRAD 2.0 FORTRAN code for the Radiative Corrections Calculation to Deep Inelastic Scattering of Polarized Particles**
   I. Akushevich, A. Ilyichev, N. Shumeiko, A. Soroko, and T. Tolkachev
   arXiv:hep-ph/9706516 v1 *26 Jun 1997*

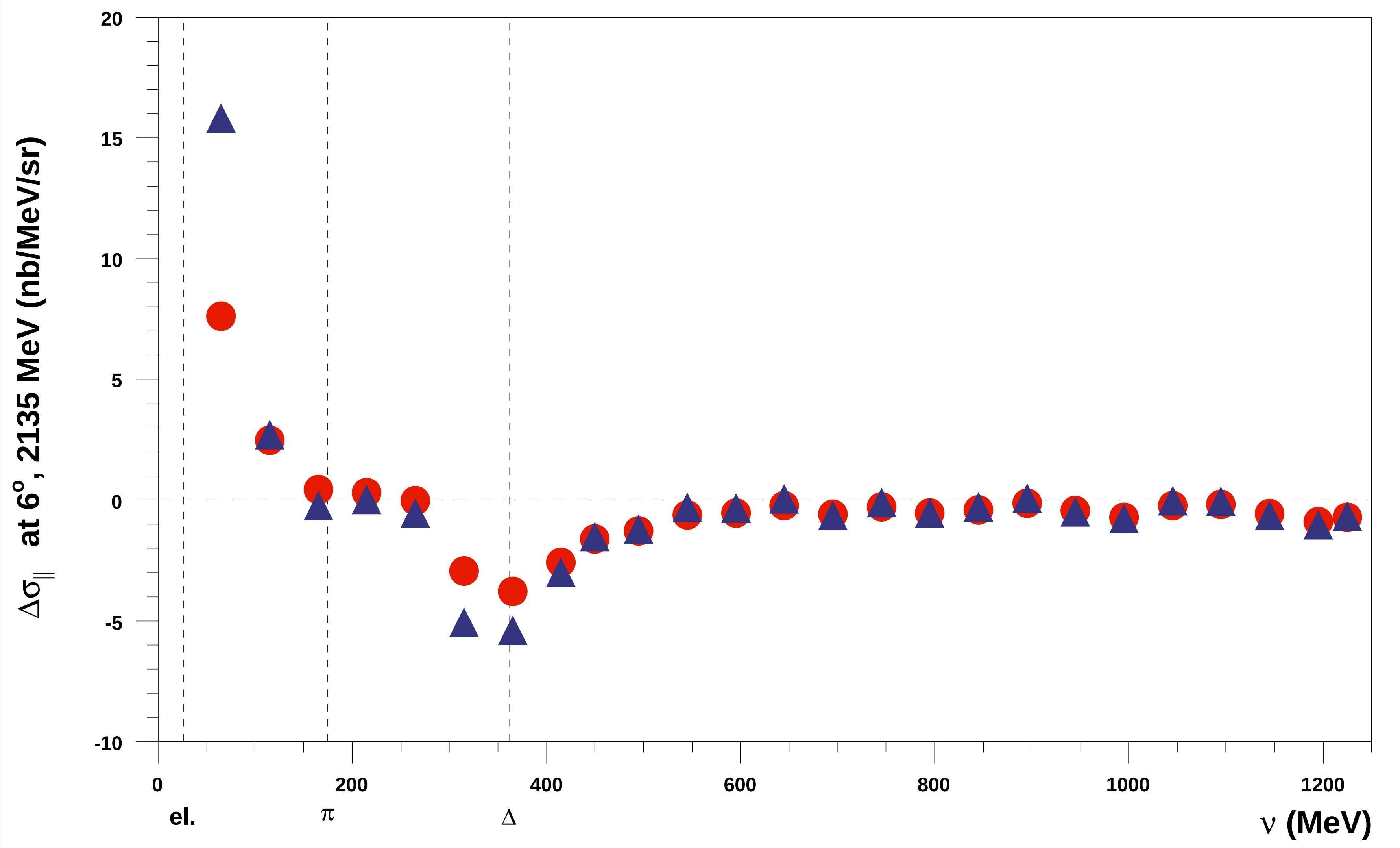
Raw data vs. Elastic tail



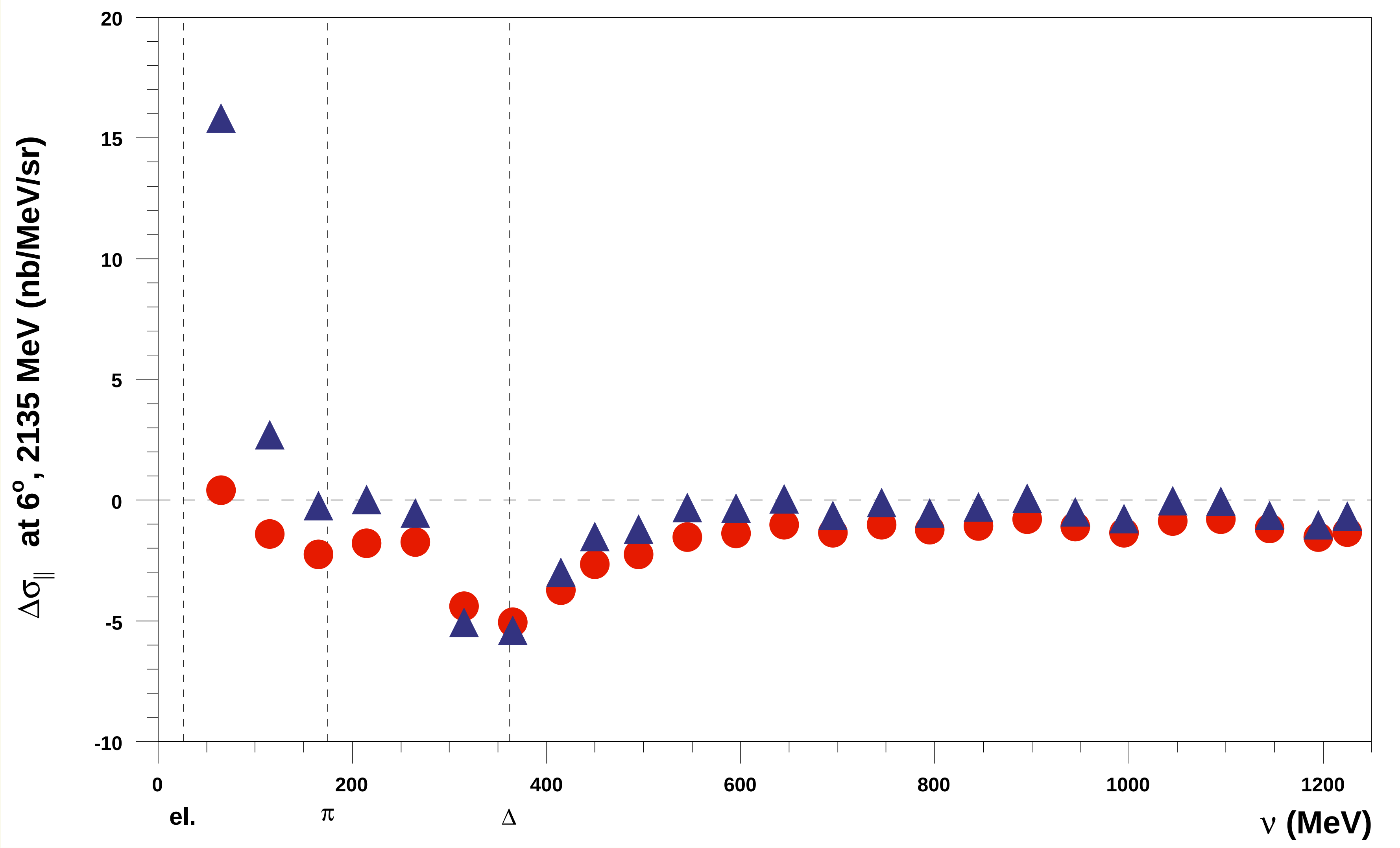
After elastic RC vs. Elastic tail



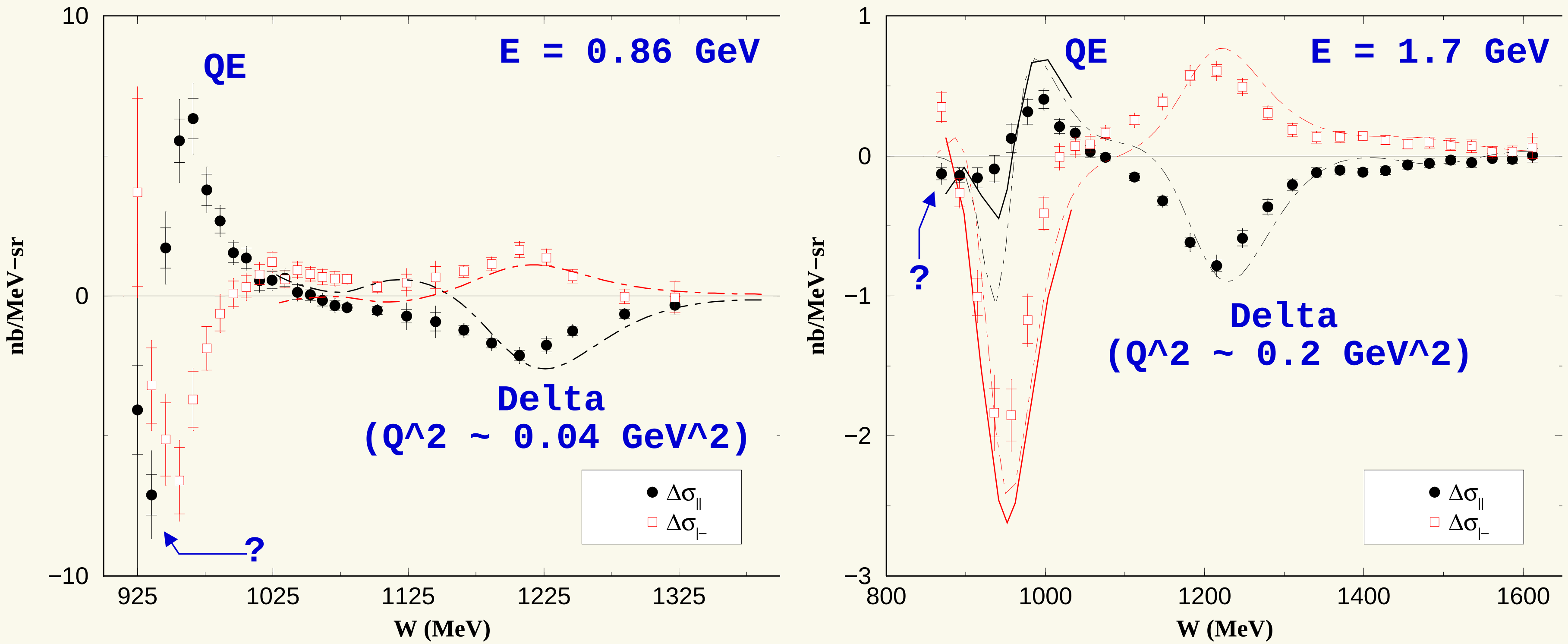
After elastic RC vs. After inelastic RC



After all RC vs. Raw data



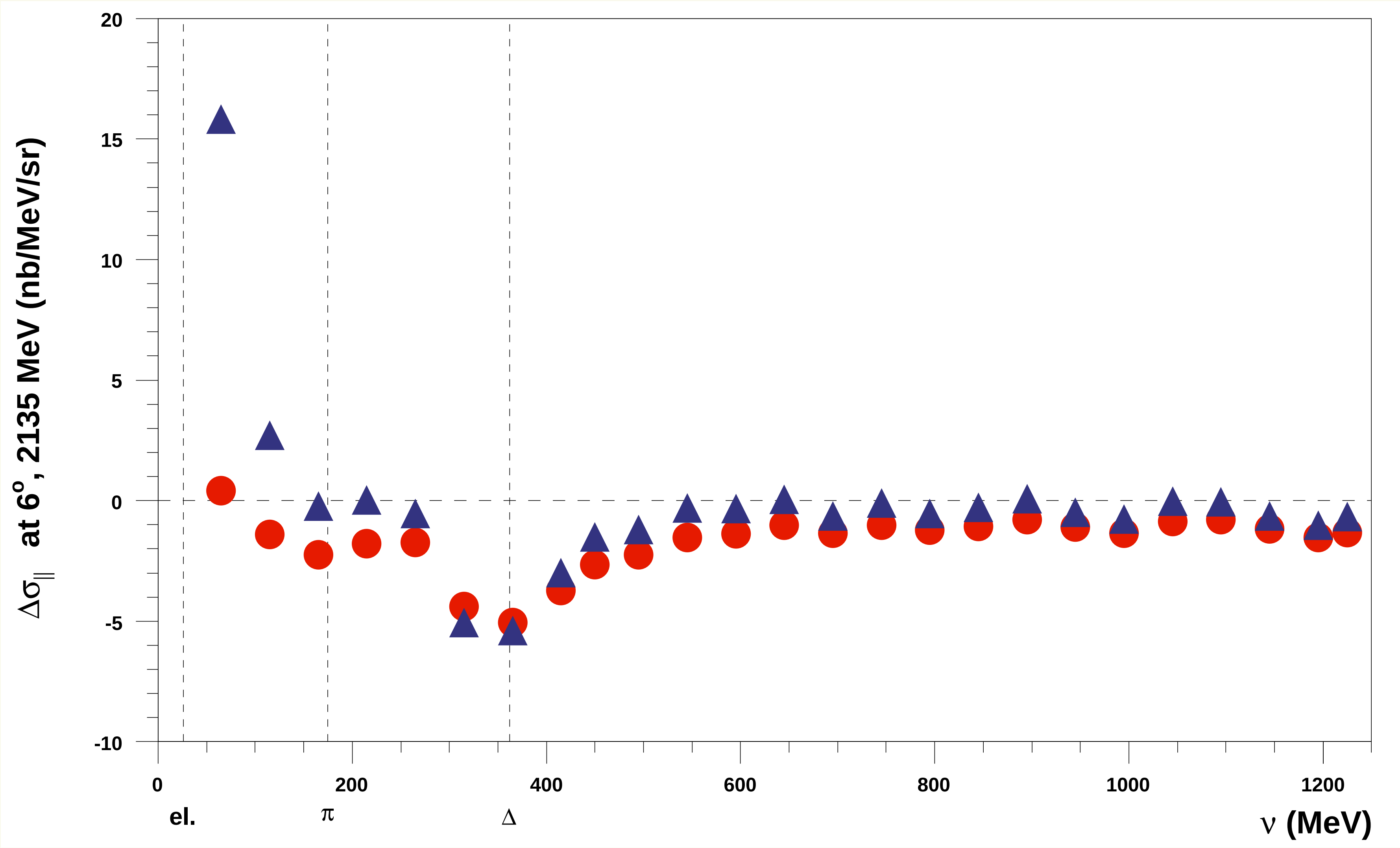
Features in $\Delta\sigma$ from E94010



(from K. Slifer)

1. broad Δ peak (defines absolute sign of $\Delta\sigma$)
2. zero-crossing near π-threshold
3. “less” broad QuasiElastic peak with opposite sign
4. “threshold” behaviour with same sign

After all RC vs. Raw data



Some linear algebra, pt. 2

- Γ is the virtual photon "flux"
- α is the lab angle between the target spin and the $\vec{q}$
- $\overleftrightarrow{p}_{\texttt{virt}}$ is the "virtuality" matrix

$$\begin{pmatrix} \Delta\sigma_{\parallel} \\ \Delta\sigma_{\perp} \end{pmatrix} = -2\Gamma \begin{pmatrix} +\cos(\alpha) & +\sin(\alpha) \\ -\sin(\alpha) & +\cos(\alpha) \end{pmatrix} \overleftrightarrow{p}_{\texttt{virt}} \begin{pmatrix} \sigma_{\mathrm{TT}} \\ \sigma_{\mathrm{LT}} \end{pmatrix}$$

Integrand of I_A^3

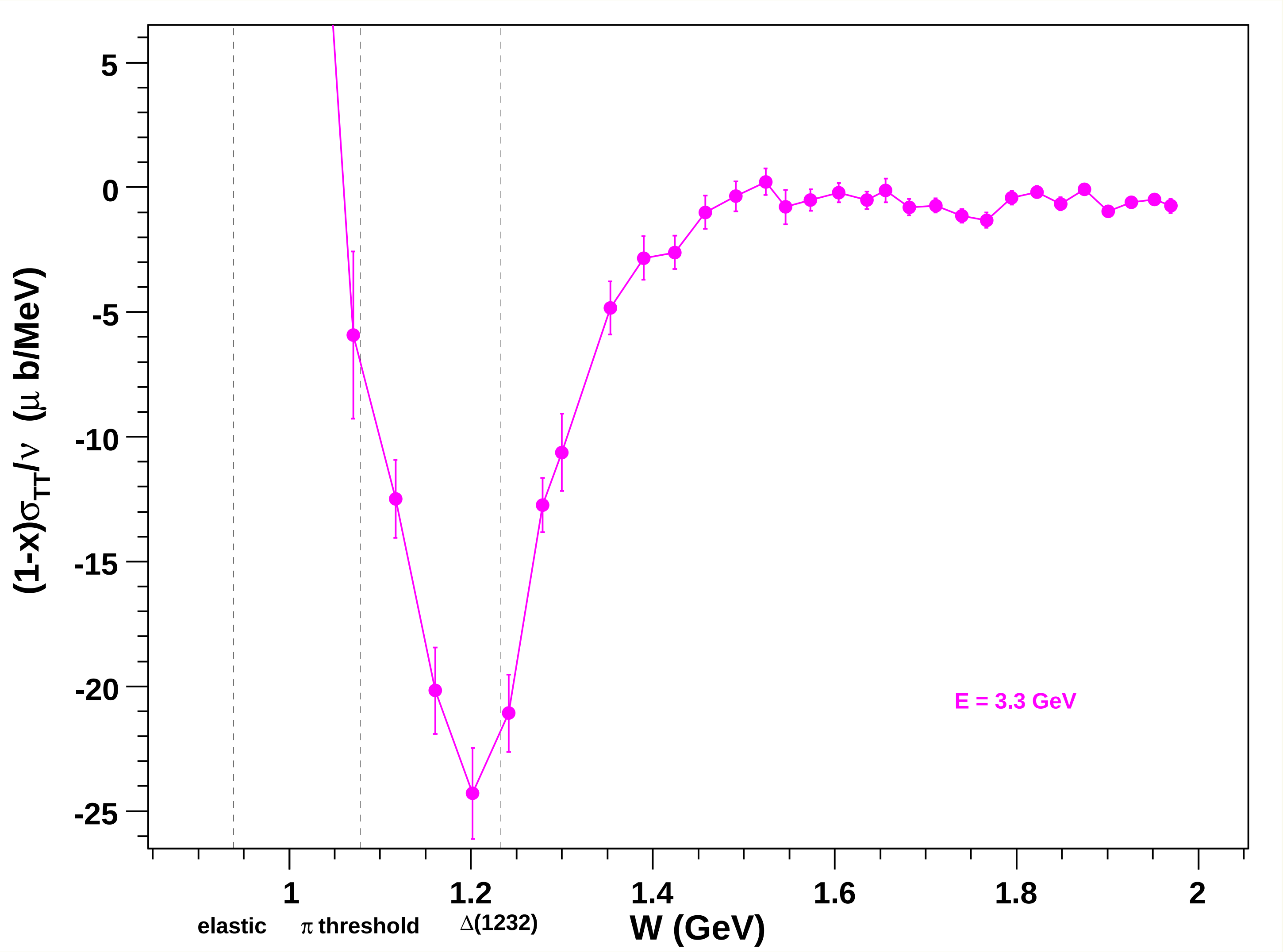
χPT calculations for the slope are given with respect to this for of the generalized integral:

$$I_A^3(Q^2) \quad = \quad \int_{\nu_{\mathtt{tt}}}^{\infty} 2(1-x)\sigma_{\mathtt{TT}}\,\frac{dv}{\nu}$$

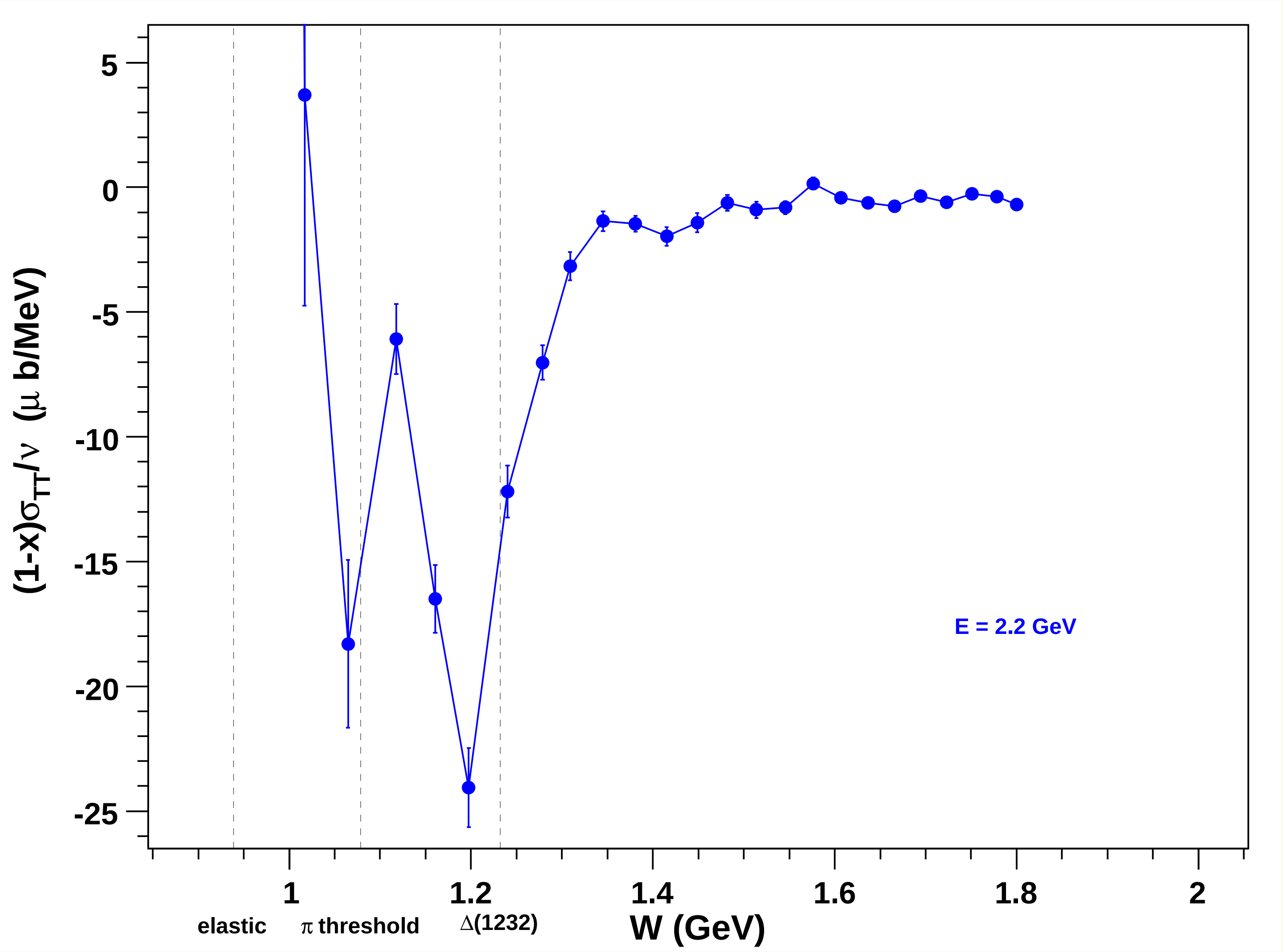
I'm about to show you the integrand at constant energy versus W!

NOTE: These results are preliminary!

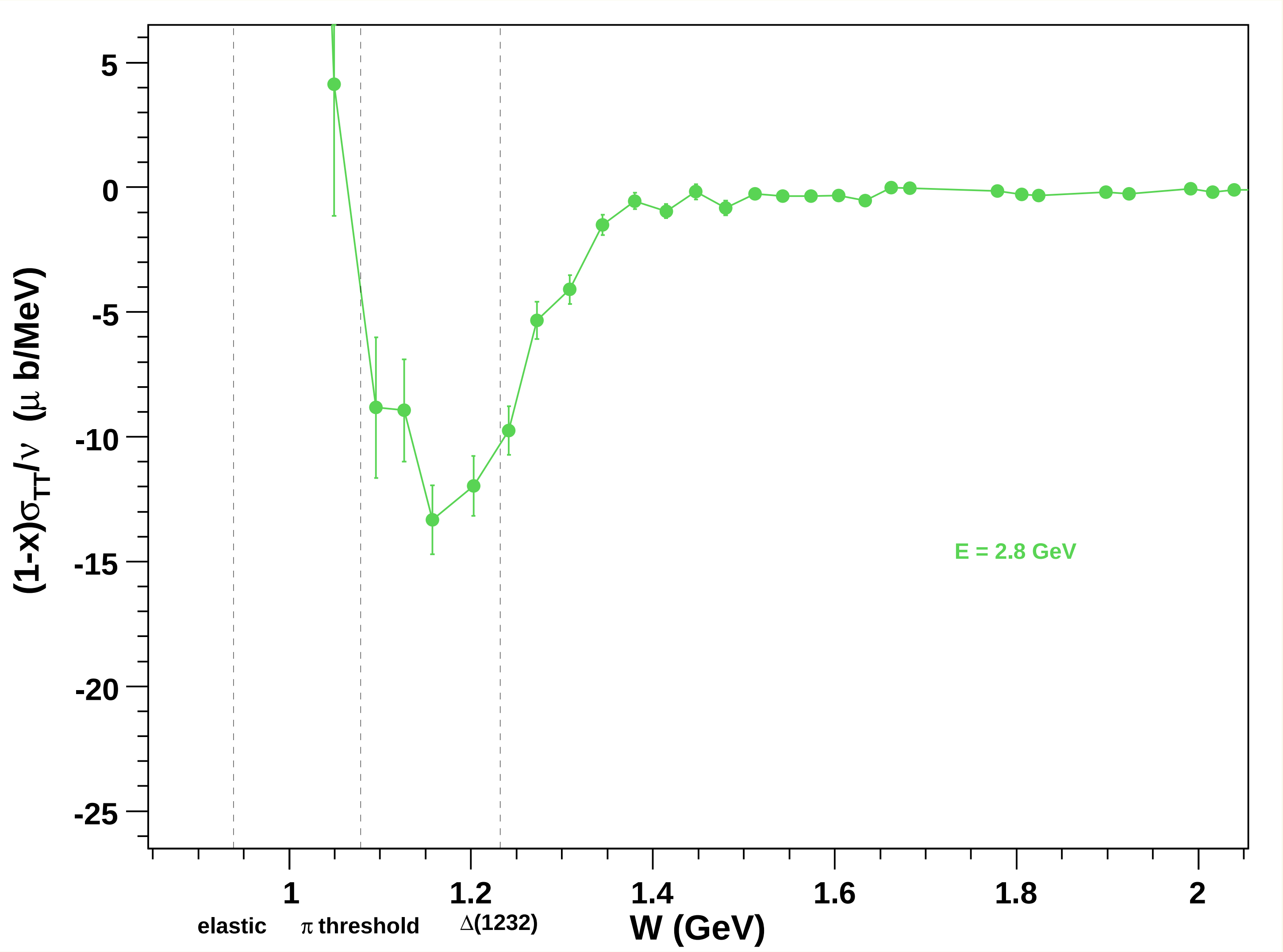
3.3 GeV at 9 deg



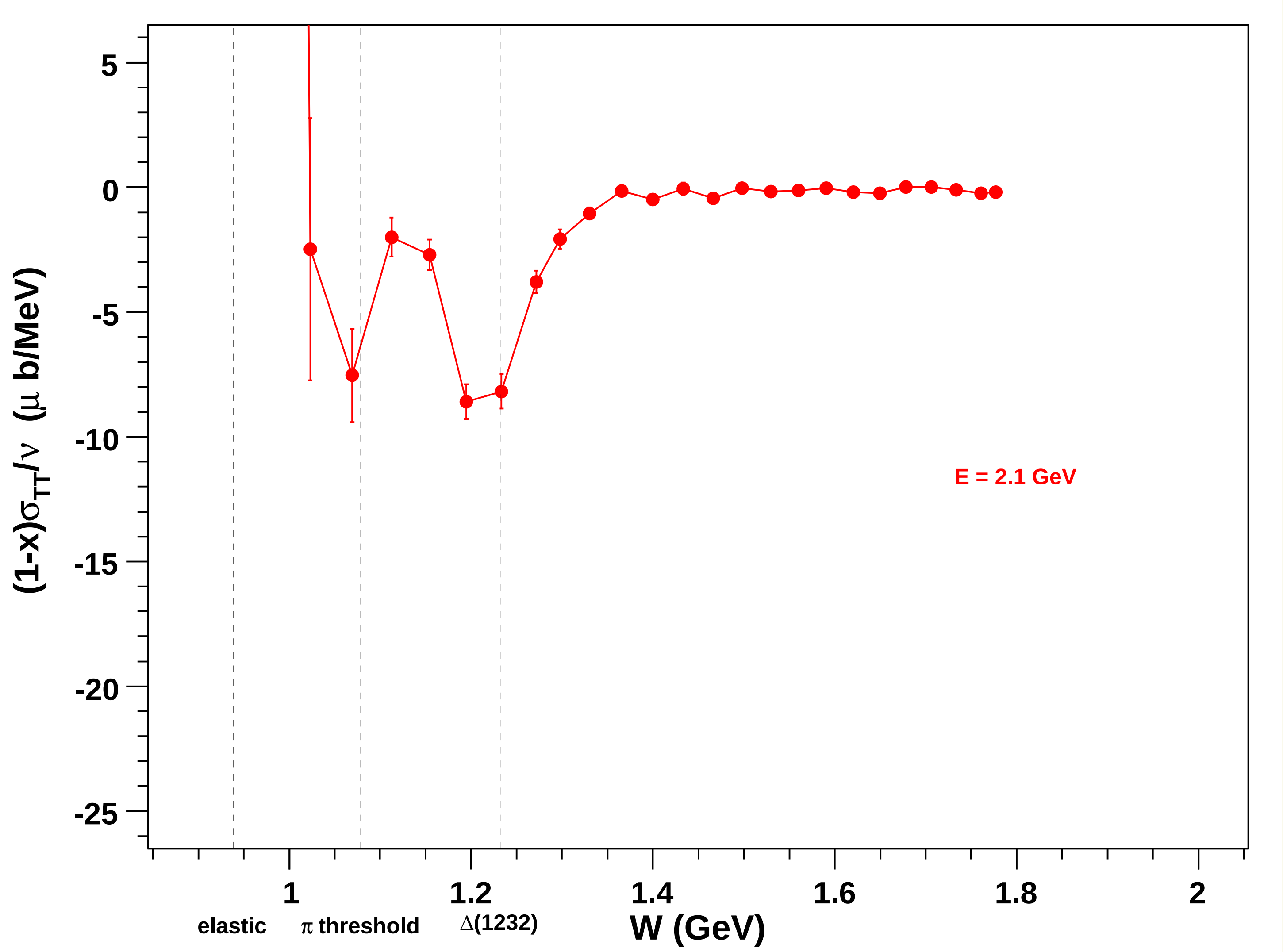
2.2 GeV at 9 deg



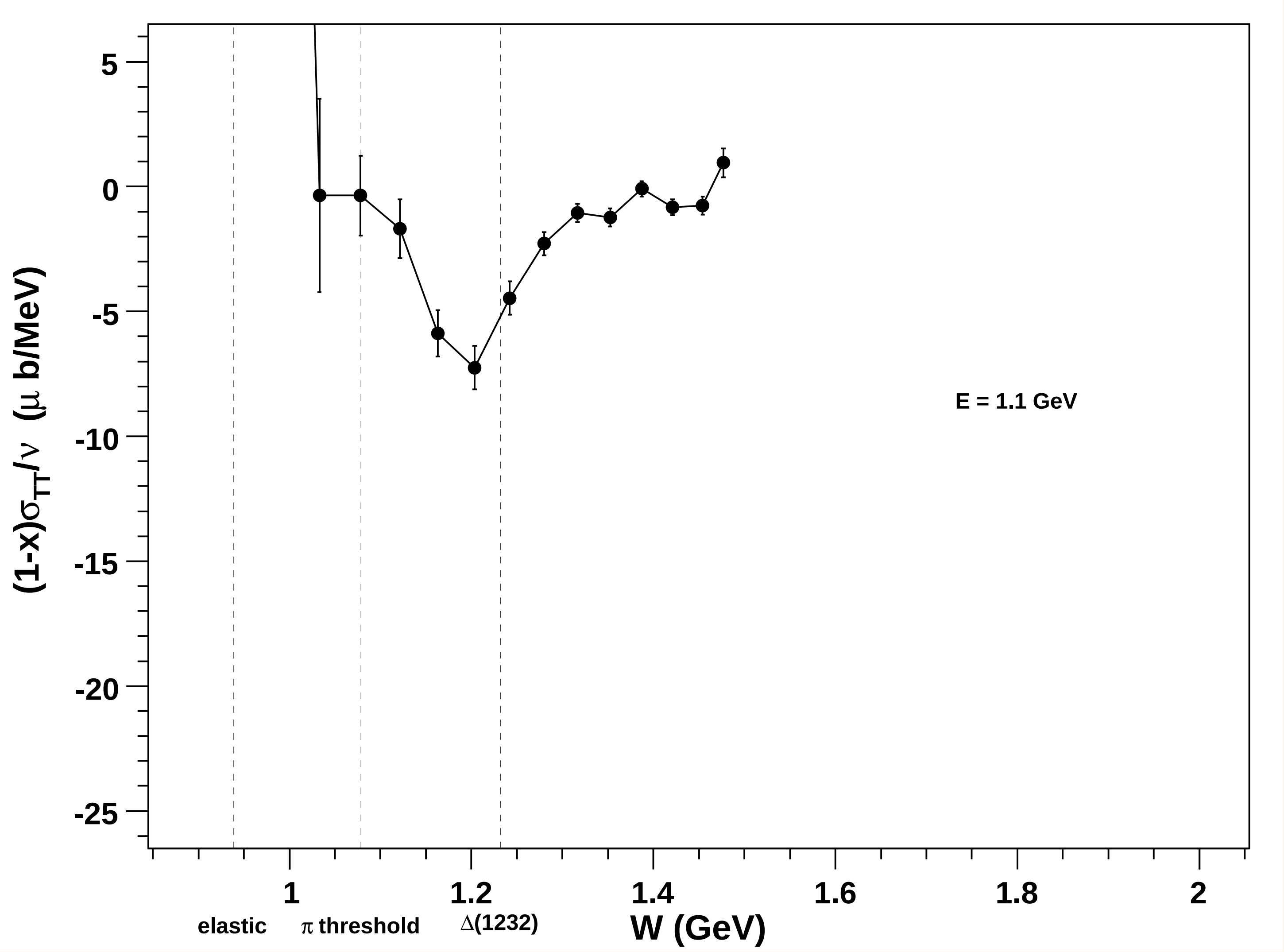
2.8 GeV at 6 deg



2.1 GeV at 6 deg



1.1 GeV at 9 deg



What do we need for the neutron integral?

Goal: Form the generalized integral $I_A(Q^2)$ for the neutron

- Model and subtract quasielastic contribution

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- Extract integrated neutron quantities from integrated ^{3}He quantities
- Estimate the DIS $W > 2$ GeV contribution to the integral

Error Budget, so far (last slide!)

Rad. corr.	?	J. Singh (finite acc./target effects)
Acceptance	7.5%	V. Sulkosky/J. Singh (elastic x-check)
Target pol.	7.5%	J. Singh
Beam Pol.	3.5%	J. Singh (x-check with Compton)
VDC multitracks	2.5%	J. Yuan (in progress)
Target density	2.0%	"done"
Charge	1.0%	"done"
PID cuts/effs	$< 1.0\%$	"done"
dilution factors	$< 1.0\%$	"done"
total syst.	$> \mathbf{12\%}$	*getting there...*
stat. near Δ	tiny	