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Impact of the Δ(1232) in $\gamma + p \to \pi^0 p$ in χPT.

Lloyd W. Cawthorne
Judith A. McGovern

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29th of June 2015

Importance of D-waves

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Working to energies approaching Δ(1232)

$\gamma+p \to \pi^0 p$

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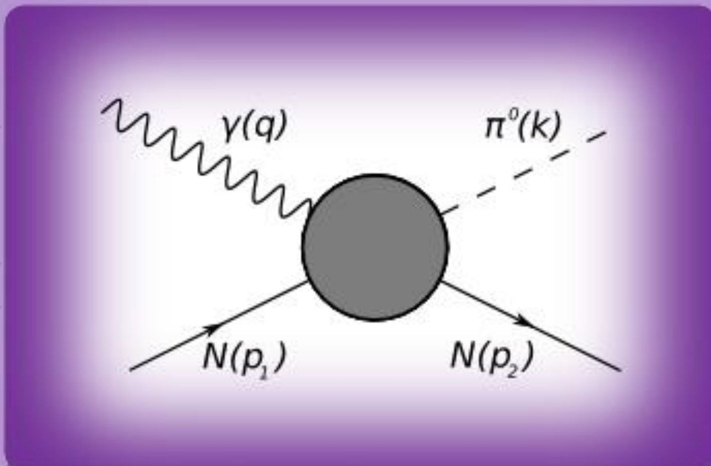

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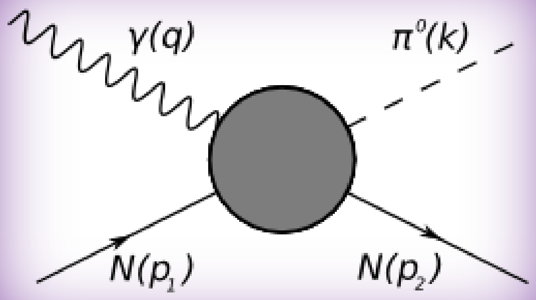

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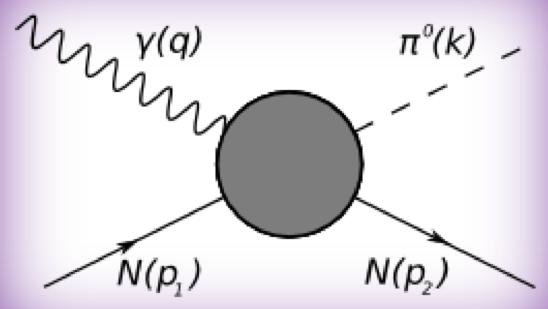

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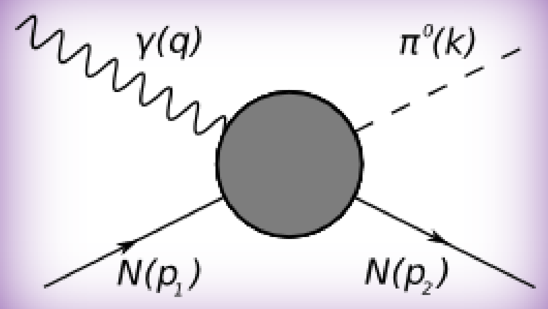

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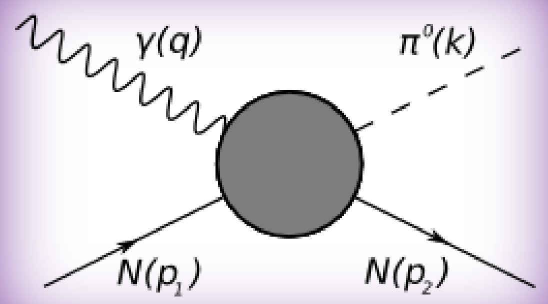

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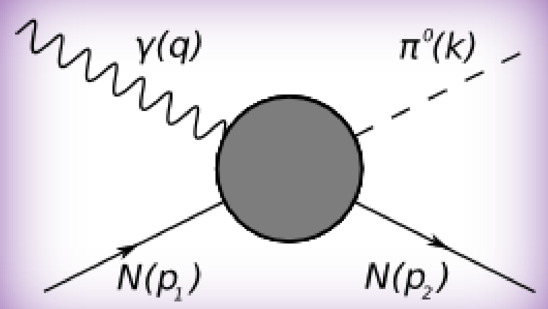

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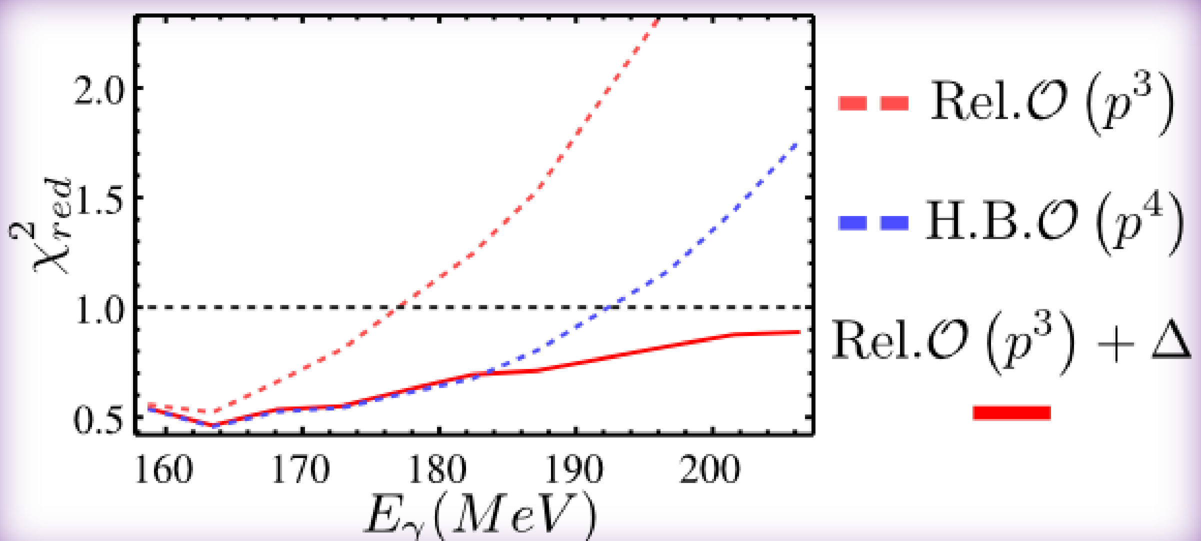

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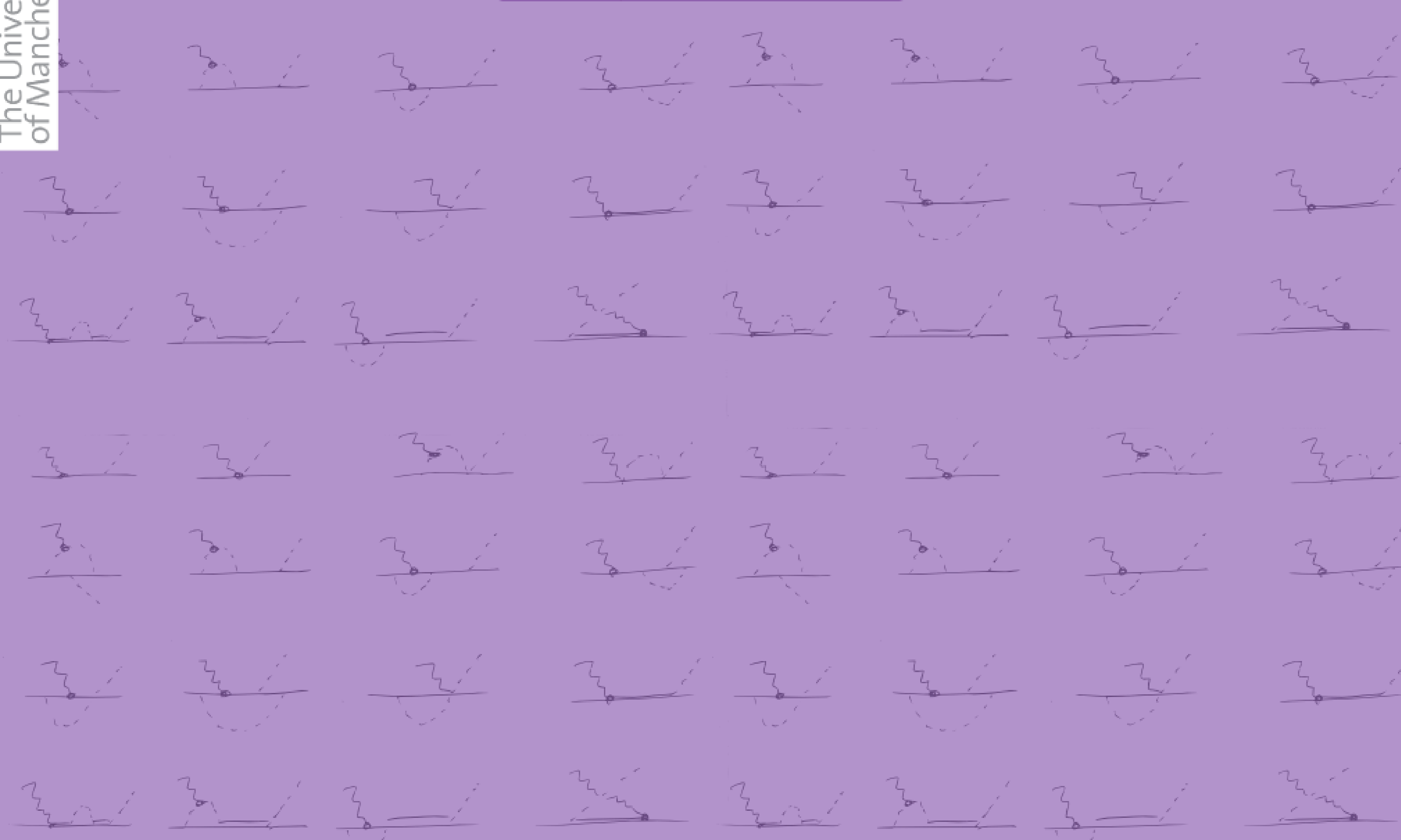

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4th order LECs used:

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We extract the relativistic D-waves to construct a hybrid theory.

We expect D-waves to be supressed in the HB description.

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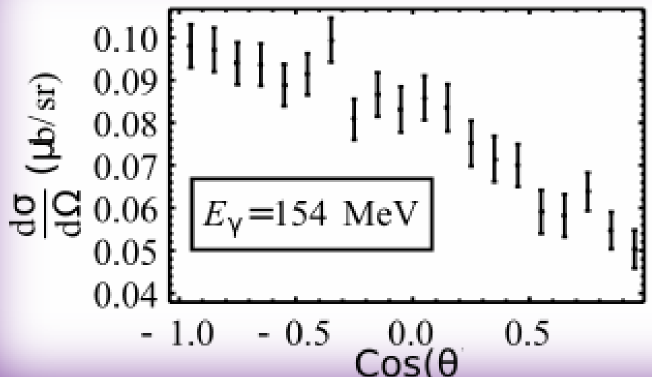

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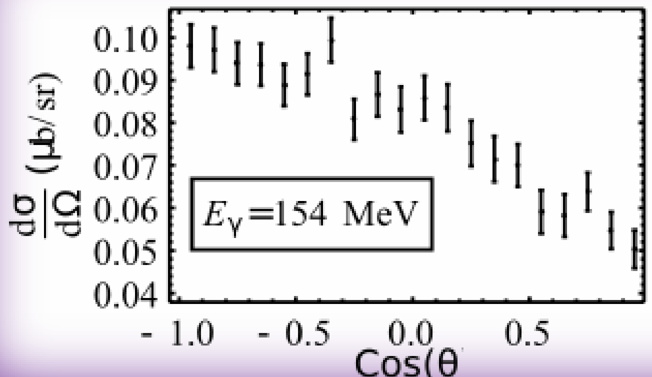

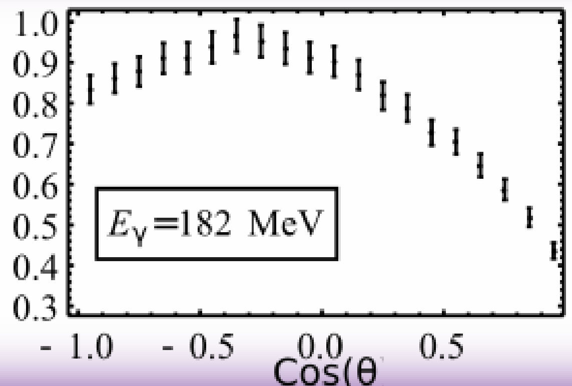

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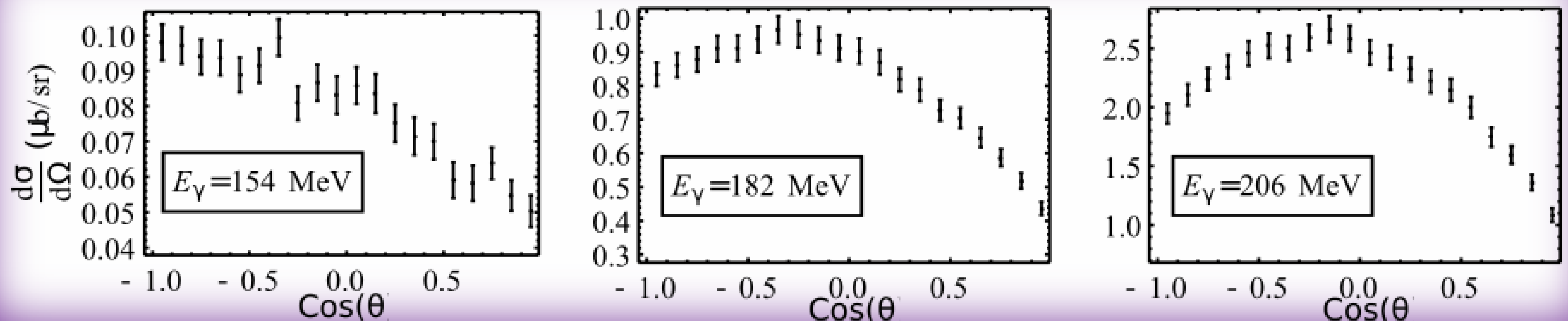

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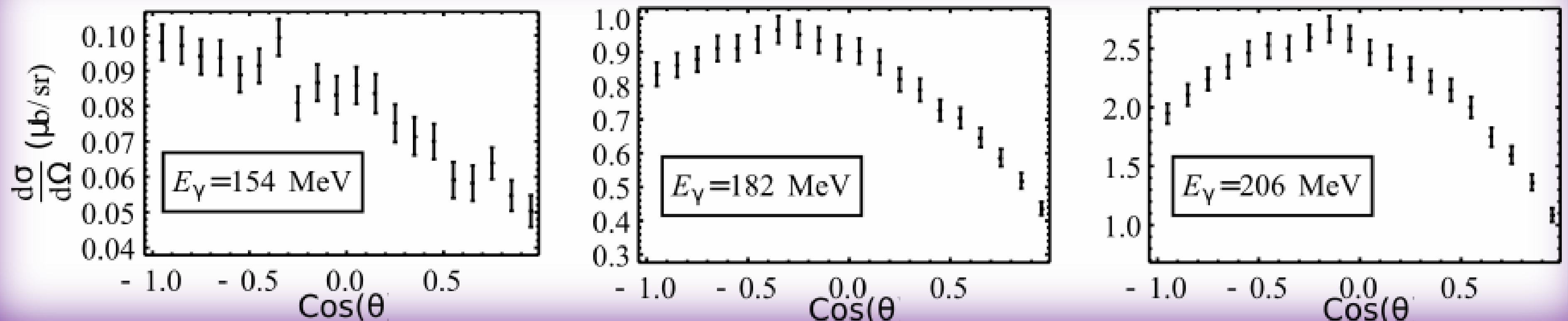

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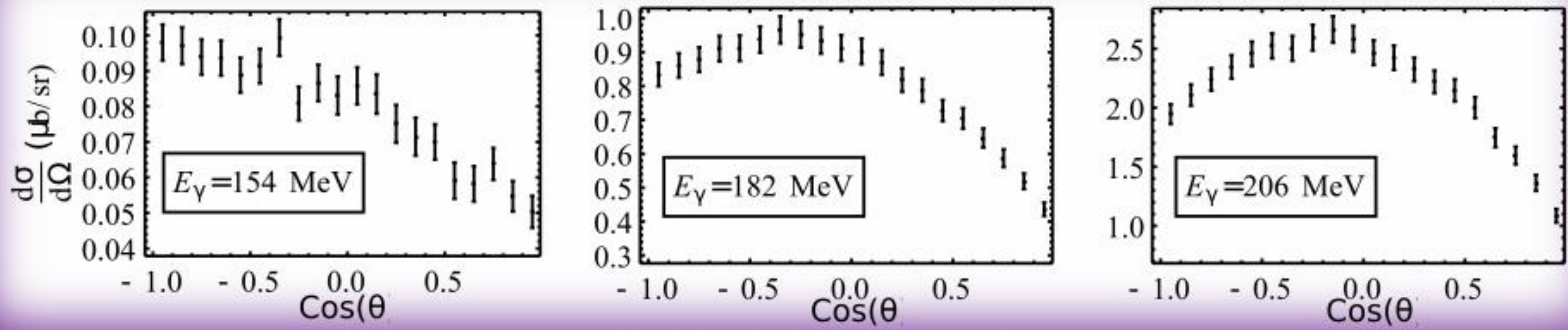

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$$\Sigma = \frac{d\sigma^\perp - d\sigma^\parallel}{d\sigma^\perp + d\sigma^\parallel} = \frac{|\vec{k}_\pi|\sin^2\theta}{2|\vec{q}_\gamma|}\left(\frac{d\sigma}{d\Omega_{cm}}\right)^{-1}\left(|P_3|^2 - |P_2|^2 + ...\right)$$

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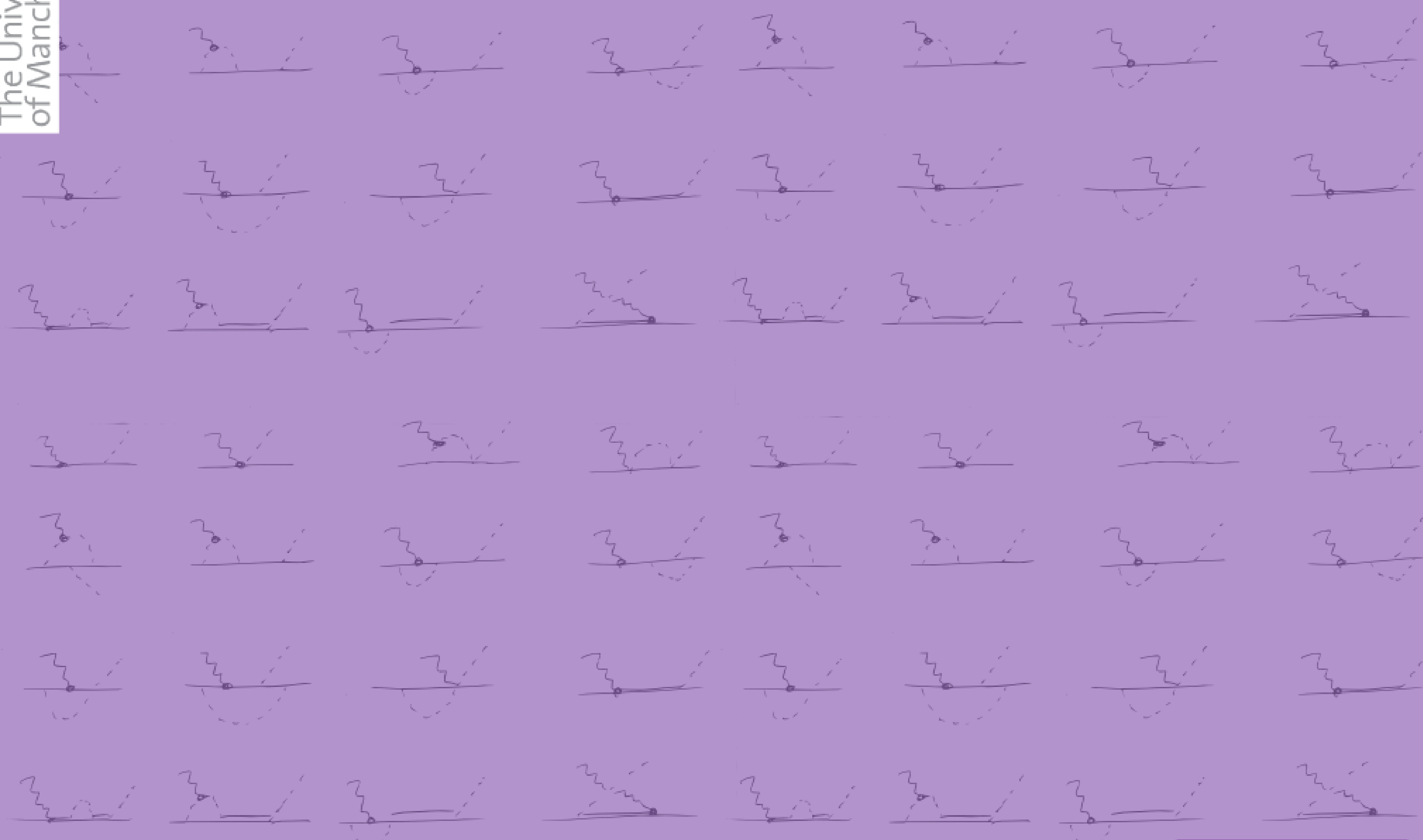
Interference from D-waves might not be.

Fernández-Ramírez, et al. (2009) Phys. Rev. C.

Effects of D-waves (and higher)



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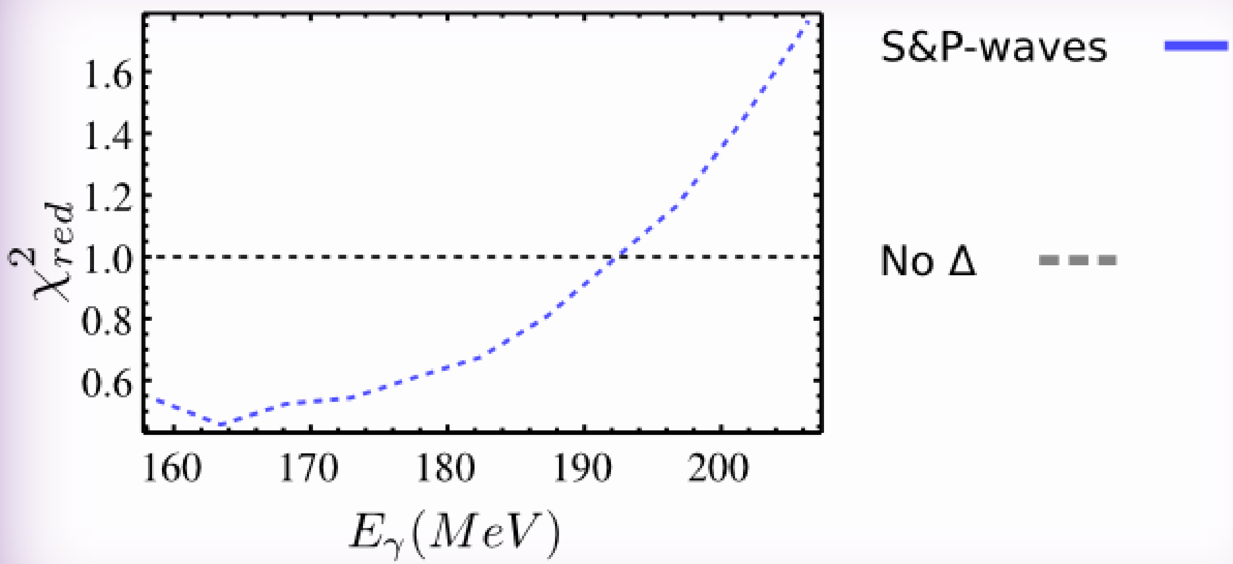

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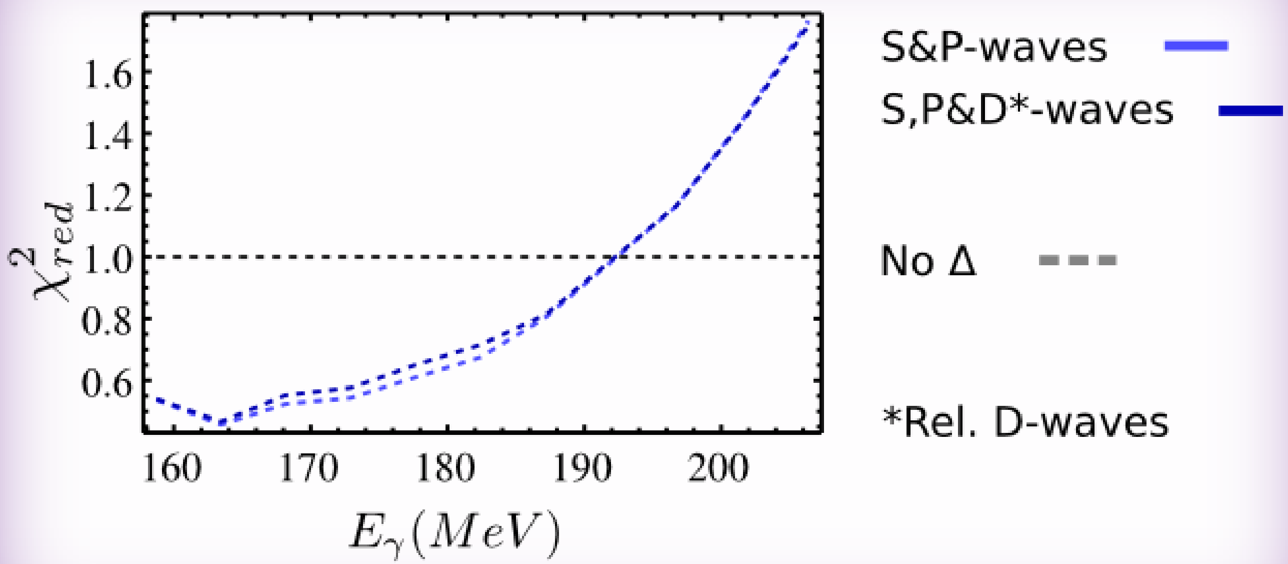

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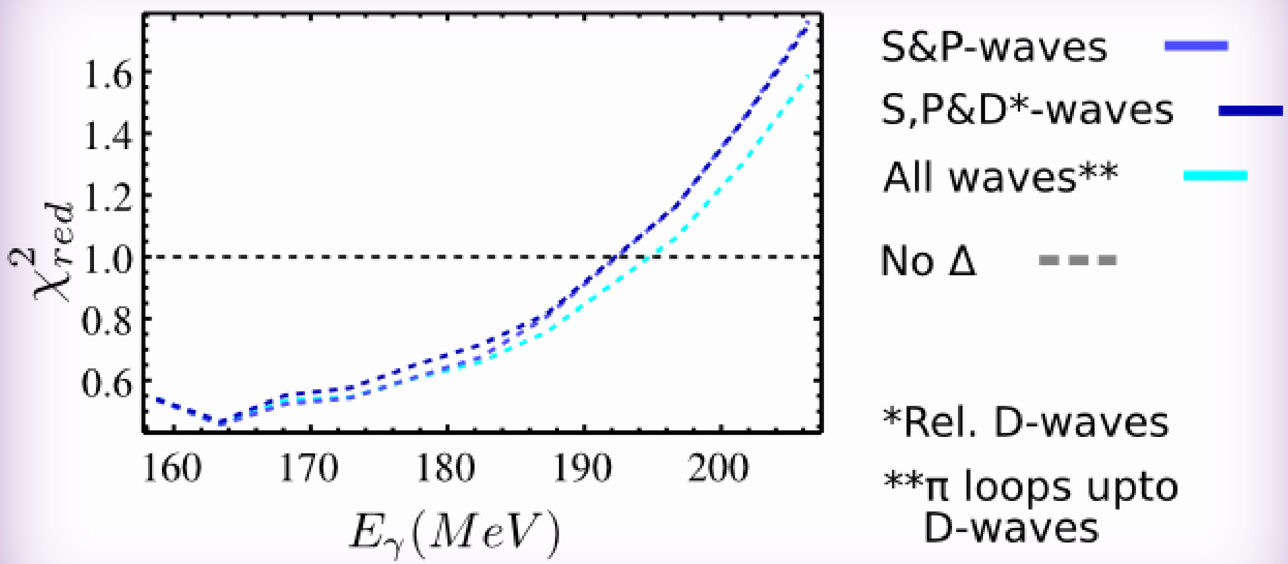

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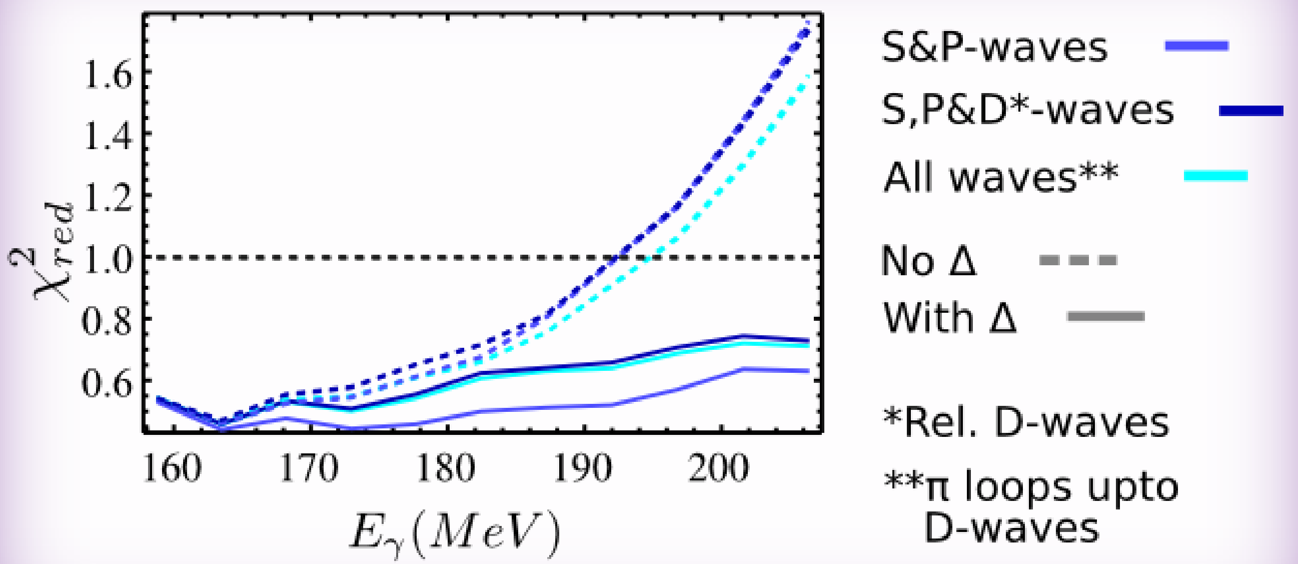

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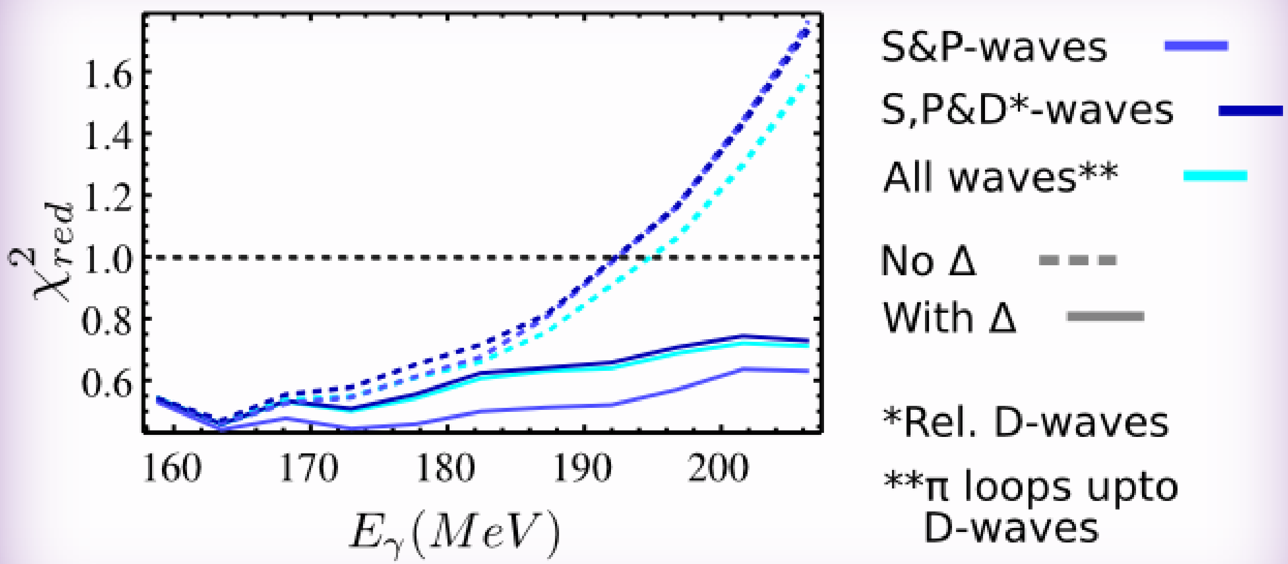

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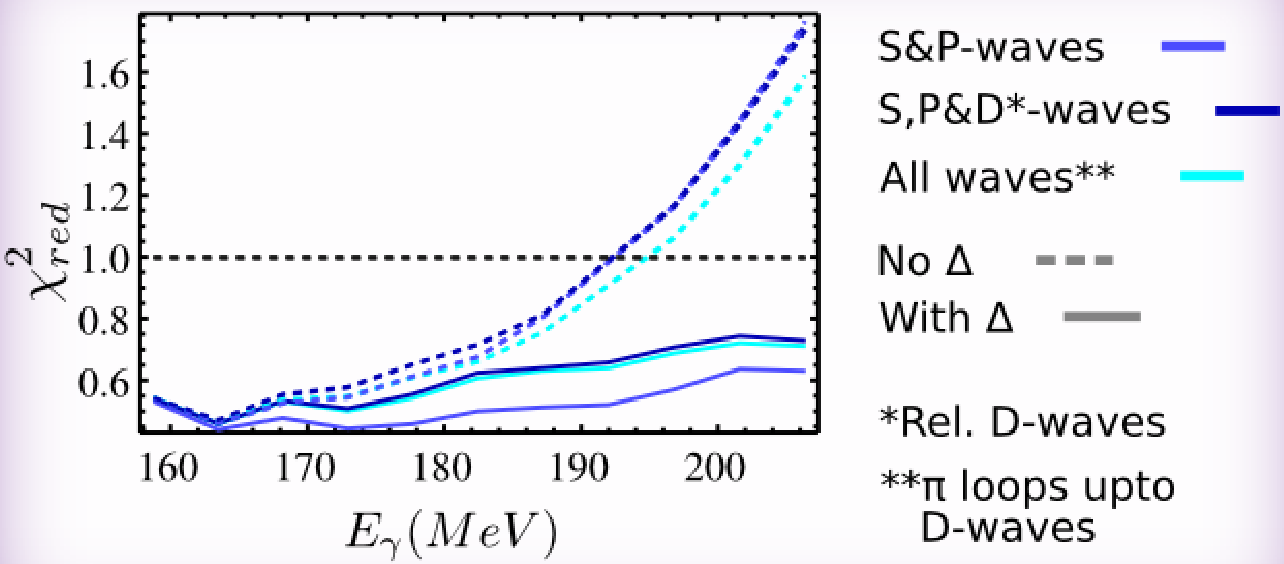

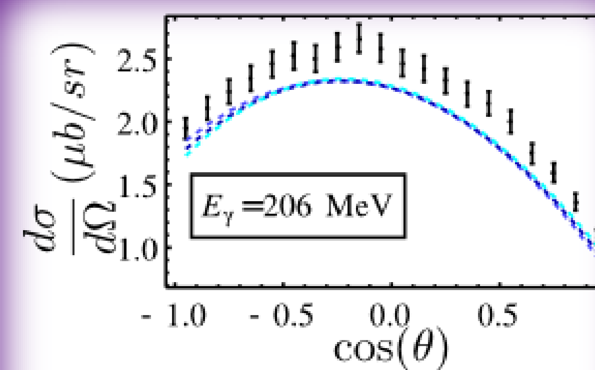

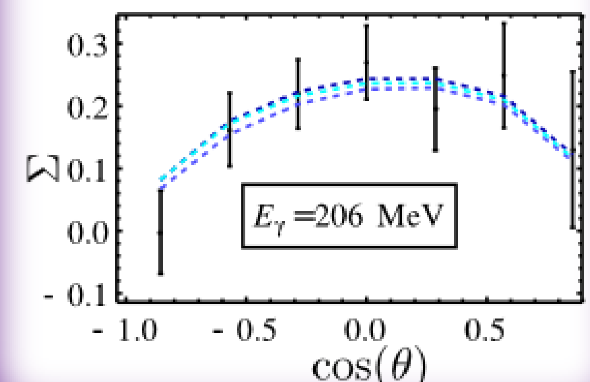

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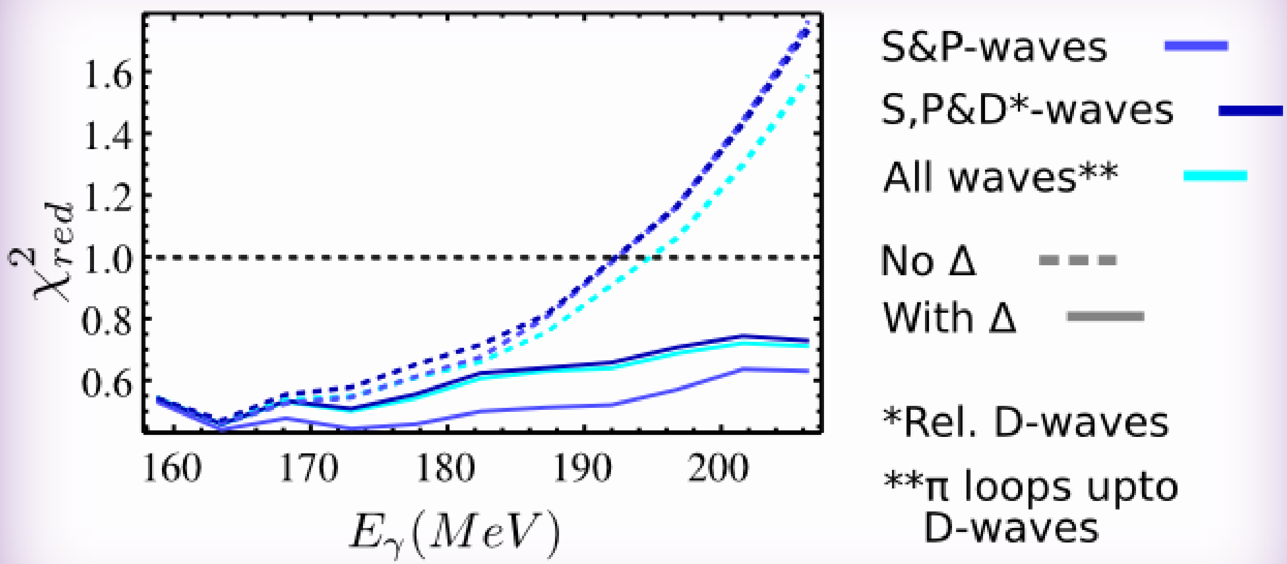

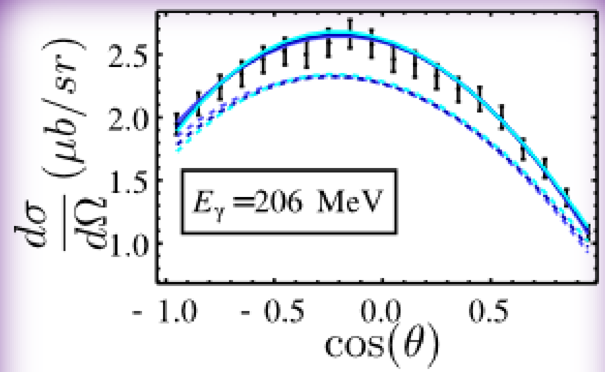

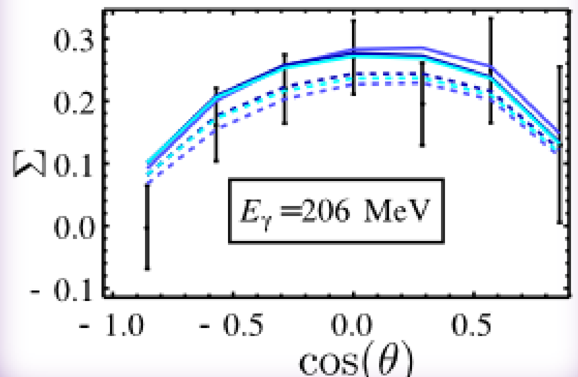

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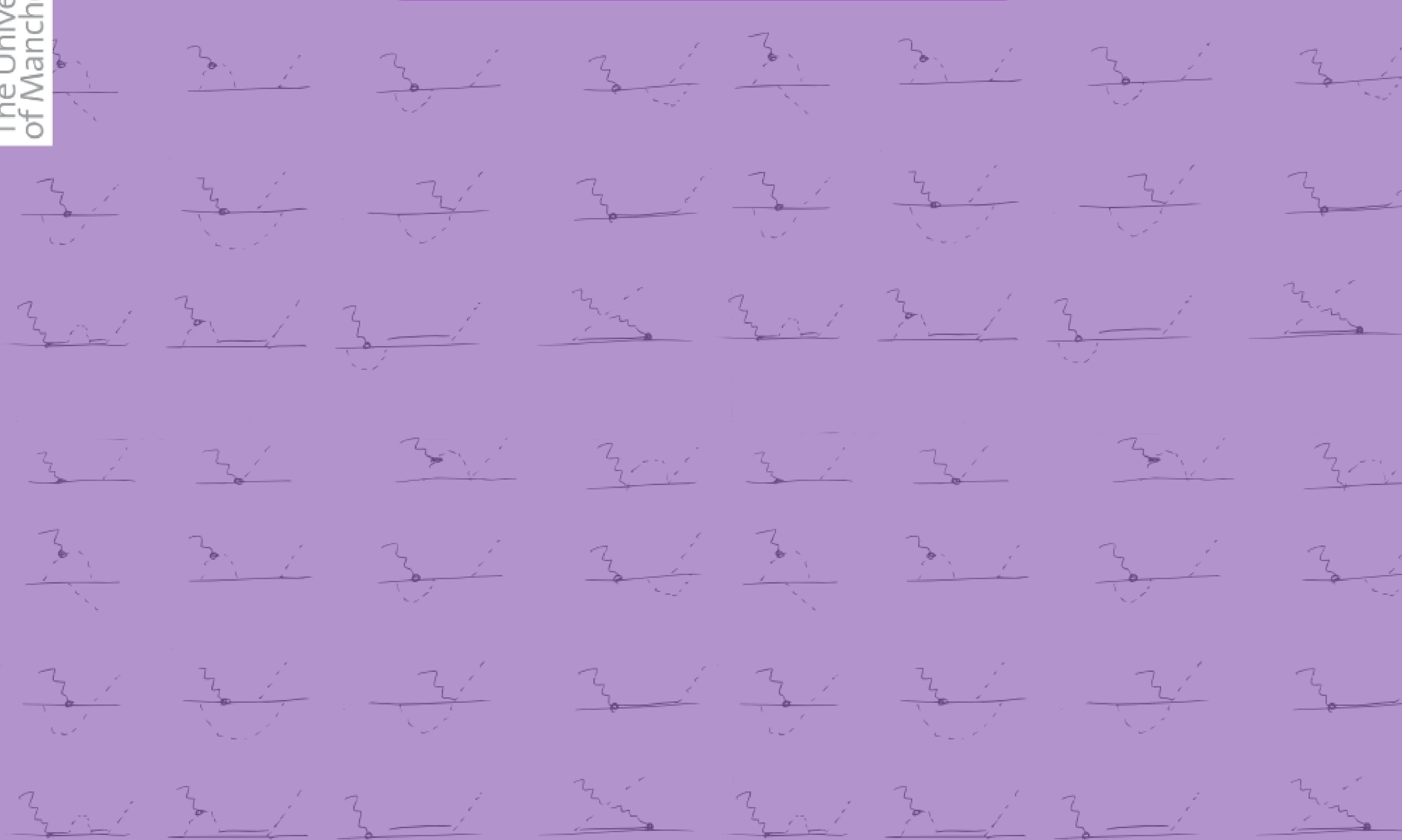

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$$P \approx \delta^2$$

Propagator: $$S_\Delta(\omega \sim M_\pi) \propto \frac{1}{\Delta_M \pm \omega}$$

Pascalutsa, et al. (2006), Phys. Rev. D

Working to higher energies

One can include π loop diagrams containing a Δ propogator.

Close to threshold: $\omega \sim M_\pi \approx 140 MeV$ SB scale: $\Lambda_{SB} \approx 700 MeV$

Mass difference: $\Delta_M = m_\Delta - m_N \approx 290 MeV$ $M_\pi \ll \Delta_M$

Two scales:

$$P = \frac{M_\pi}{\Lambda} \approx 0.2$$

$$\epsilon = \frac{\Delta_M}{\Lambda} \approx 0.4$$

$$\delta \approx \frac{\Delta_M}{\Lambda} \approx \left(\frac{M_\pi}{\Lambda}\right)^{1/2}$$

$$P \approx \delta^2$$

Propagator: $S_\Delta(\omega \sim M_\pi) \propto \frac{1}{\Delta_M \pm \omega}$ scales as δ^{-1}

Pascalutsa, et al. (2006), Phys. Rev. D

Two energy regimes

Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Pascalutsa, et al. (2006) Phys. Rev. D

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Pascalutsa, et al. (2006) Phys. Rev. D

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Propagator:

$$S_\Delta \left(\omega \sim \Delta_M\right) \propto \frac{1}{\Delta_M + i\mathrm{Im}\Sigma_\Delta - \omega}$$

Pascalutsa, et al. (2006) Phys. Rev. D

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

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Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Self energy: Σ_Δ

Propagator:

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Pascalutsa, et al. (2006) Phys. Rev. D

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Propagator:

$$S_\Delta\left(\omega \sim \Delta_M\right) \propto \frac{1}{\Delta_M + i\mathrm{Im}\Sigma_\Delta - \omega}$$

Self energy: Σ_Δ

given by:

Pascalutsa, et al. (2006) Phys. Rev. D

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Propagator:

$$S_\Delta\left(\omega \sim \Delta_M\right) \propto \frac{1}{\Delta_M + i\mathrm{Im}\Sigma_\Delta - \omega}$$

Self energy: Σ_Δ

given by:

scales as: δ^3

Pascalutsa, et al. (2006) Phys. Rev. D

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Self energy: Σ_Δ

given by:

scales as: δ^3

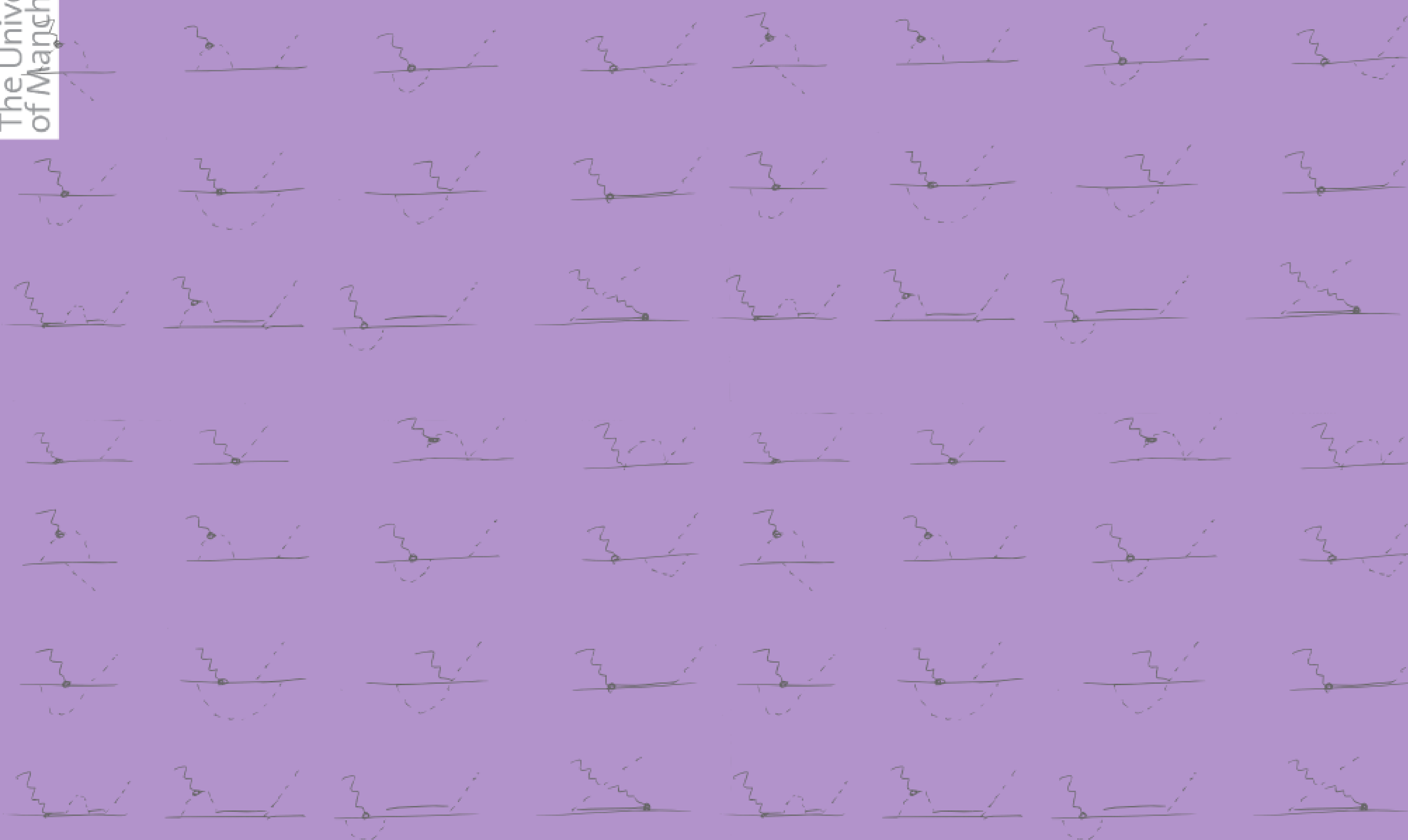
Propagator:

$$S_\Delta\left(\omega \sim \Delta_M\right) \propto \frac{1}{\Delta_M + i\mathrm{Im}\Sigma_\Delta - \omega}$$

$S_\Delta(\omega \sim \Delta_M)$ scales as: δ^{-3}

Pascalutsa, et al. (2006) Phys. Rev. D

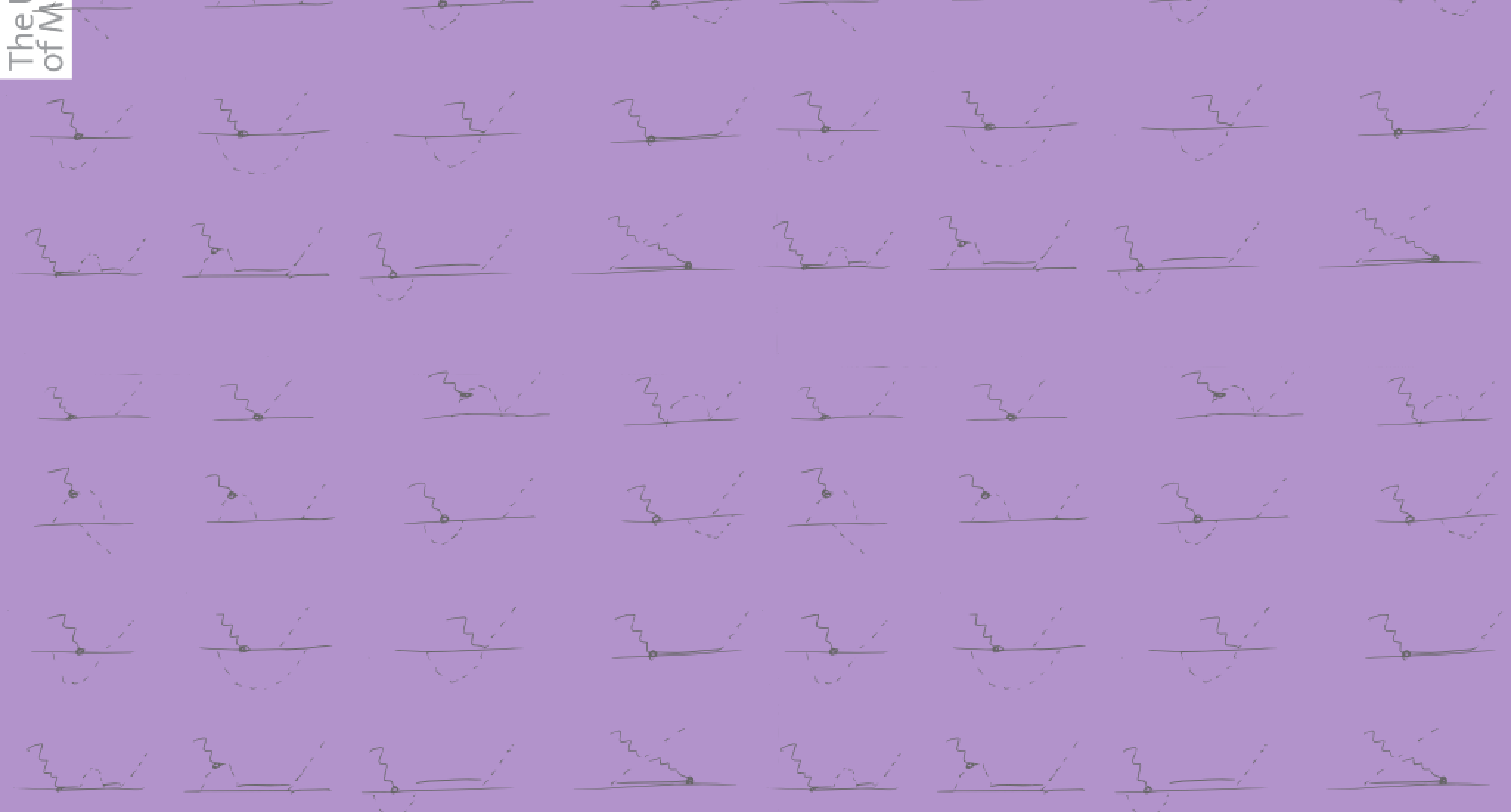
γNΔ vertex corrections



Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

γNΔ vertex corrections

Order of diagrams changes with energy.



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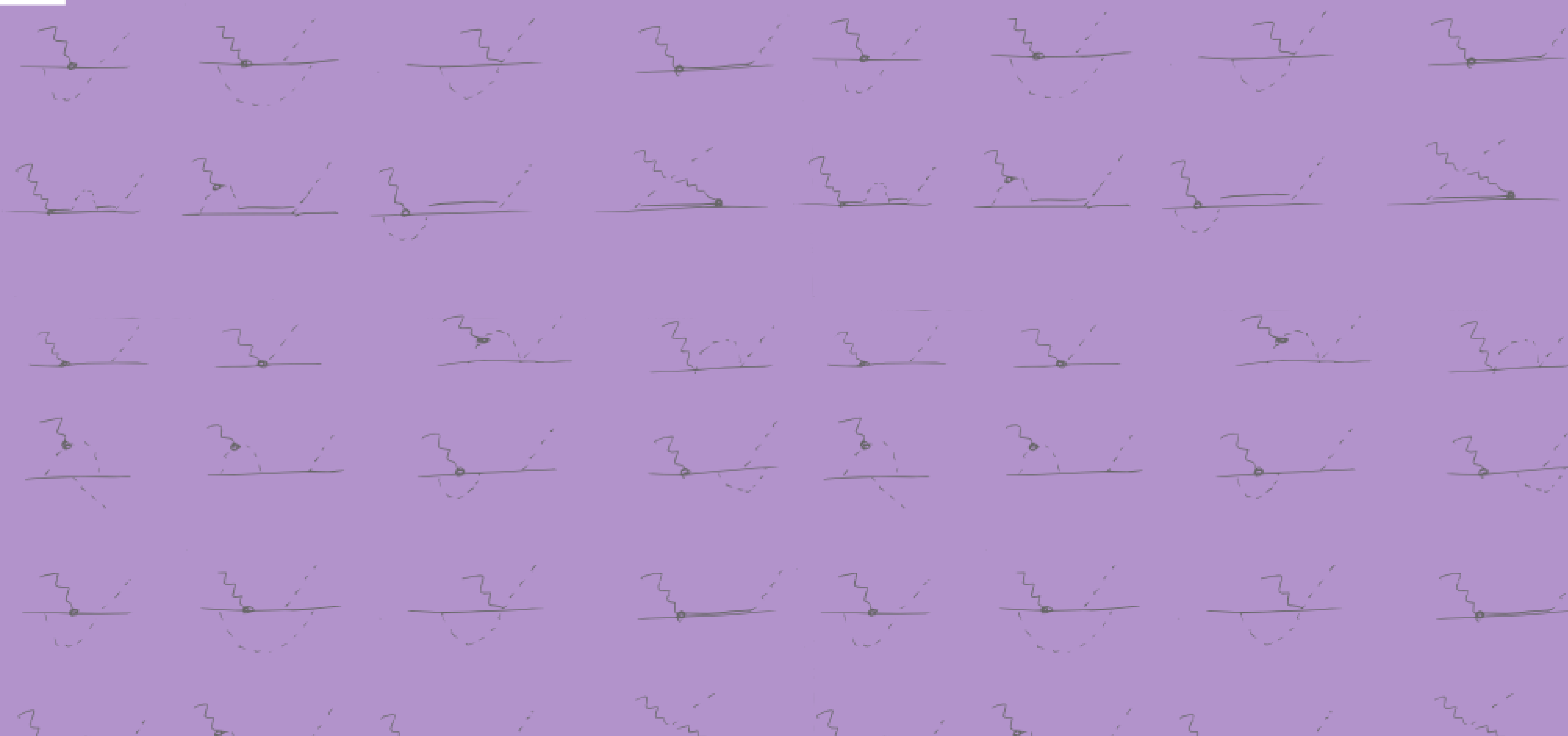

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

γNΔ vertex corrections

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Tree level:

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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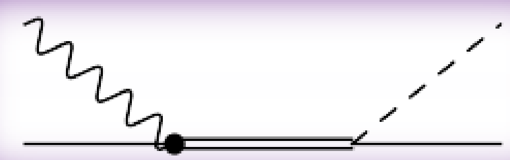

$$\omega \sim M_\pi \quad eP^2\delta^{-1} \longrightarrow e\delta^3$$

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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γNΔ vertex corrections

Order of diagrams changes with energy.

Tree level:

$$\omega \sim M_\pi \quad eP^2\delta^{-1} \longrightarrow e\delta^3$$

$$\omega \sim \Delta_M \quad eP^2\delta^{-3} \longrightarrow e\delta^{-1}$$

$$eP^2\delta^{-1} \longrightarrow e\delta^3$$

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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$$eP^2\delta^{-1} \longrightarrow e\delta^3$$

$$eP^2\delta^{-1} \longrightarrow e\delta$$

Loop corrections:

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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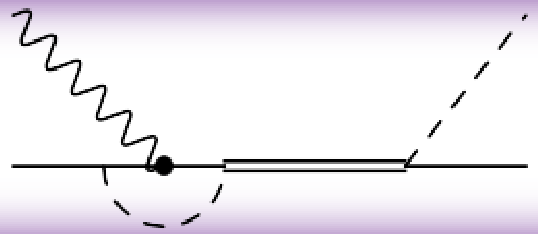
$eP^2\delta^{-1} \longrightarrow e\delta^3$

$eP^2\delta^{-1} \longrightarrow e\delta$

Loop corrections:



McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

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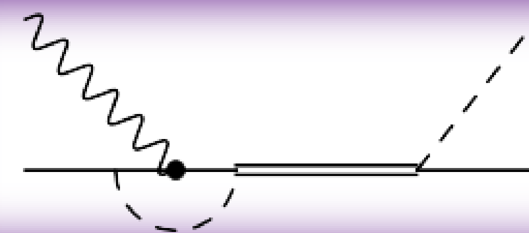

$\omega \sim M_\pi \quad eP^3\delta^{-1} \longrightarrow e\delta^5$

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

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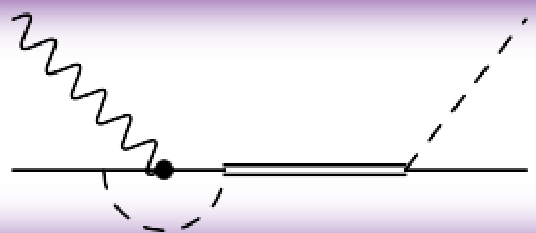
$\omega \sim \Delta_M \quad eP^2\delta^{-3} \longrightarrow e\delta^{-1}$

$eP^2\delta^{-1} \longrightarrow e\delta^3$

$eP^2\delta^{-1} \longrightarrow e\delta$

Loop corrections:

$\omega \sim M_\pi \quad eP^3\delta^{-1} \longrightarrow e\delta^5$



$eP^4\delta^{-1} \longrightarrow e\delta^6$

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

Impact of the Δ(1232) in $\gamma+p \rightarrow \pi^0 p$ in χPT.

γNΔ vertex corrections

Order of diagrams changes with energy.

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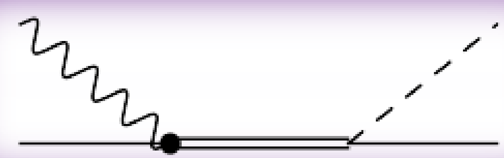

$\omega \sim M_\pi \quad eP^2\delta^{-1} \longrightarrow e\delta^3$

$\omega \sim \Delta_M \quad eP^2\delta^{-3} \longrightarrow e\delta^{-1}$

$eP^2\delta^{-1} \longrightarrow e\delta^3$

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Loop corrections:

$\omega \sim M_\pi \quad eP^3\delta^{-1} \longrightarrow e\delta^5$

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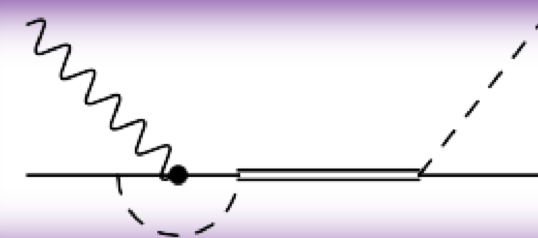

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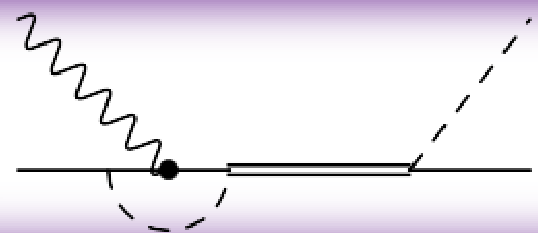
Loop corrections:



$\omega \sim M_\pi \quad eP^3\delta^{-1} \longrightarrow e\delta^5$

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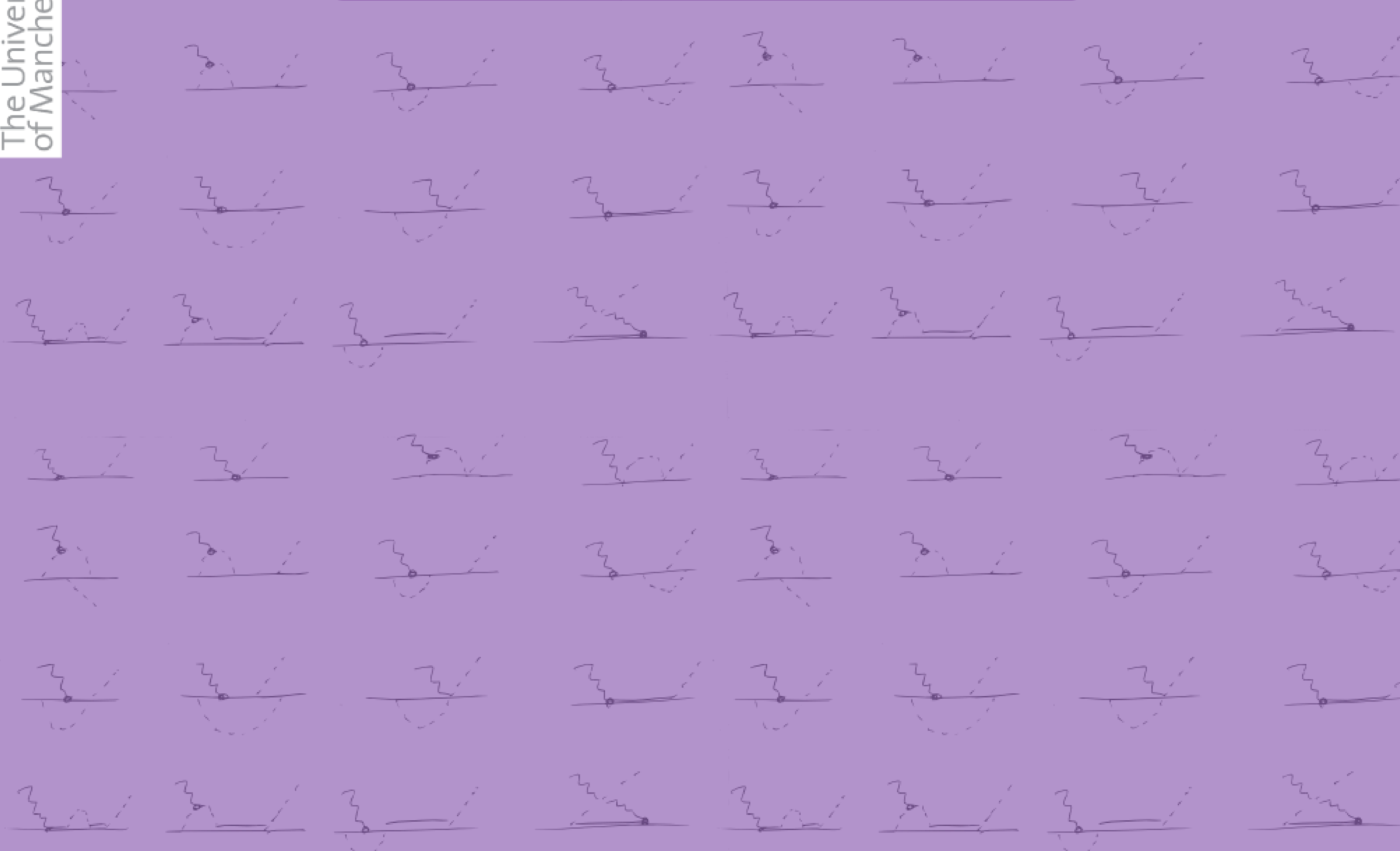
McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

Effects of γNΔ vertex corrections



Effects of γNΔ vertex corrections

The corrections are implemented by scaling the coupling constants with energy

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McGovern, et al. (2013) Eur. Phys. J.

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They restore Watson's theorem.

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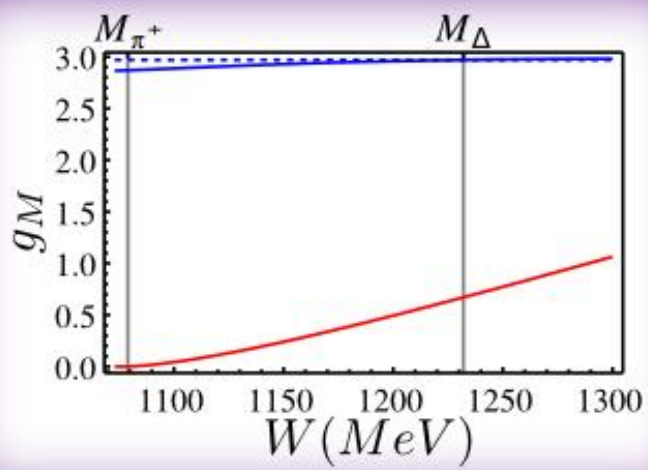
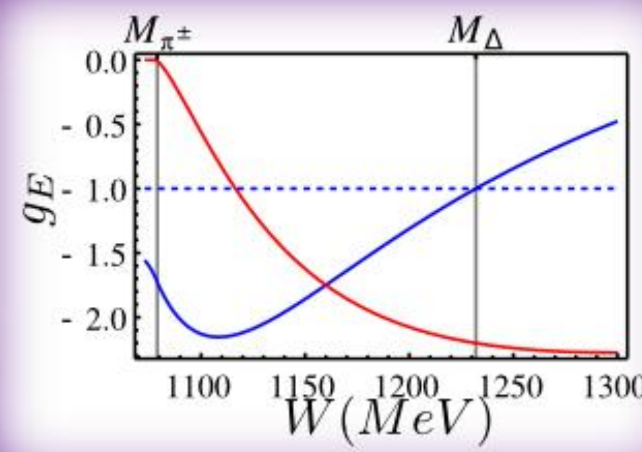


Re: (solid blue line)

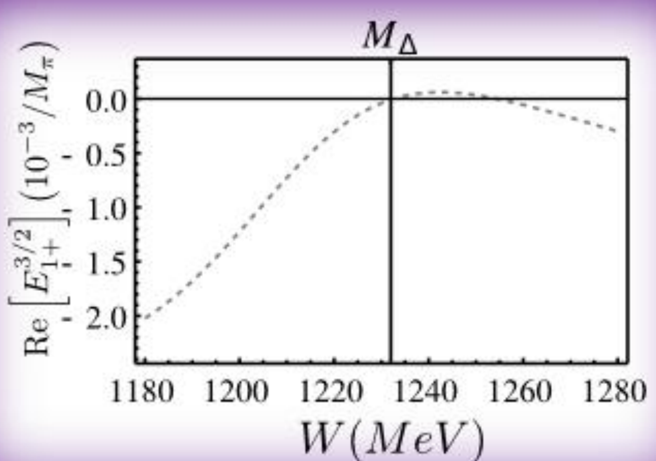
Im: (solid red line)

No corrections: (dashed blue line)

McGovern, et al. (2013) Eur. Phys. J.

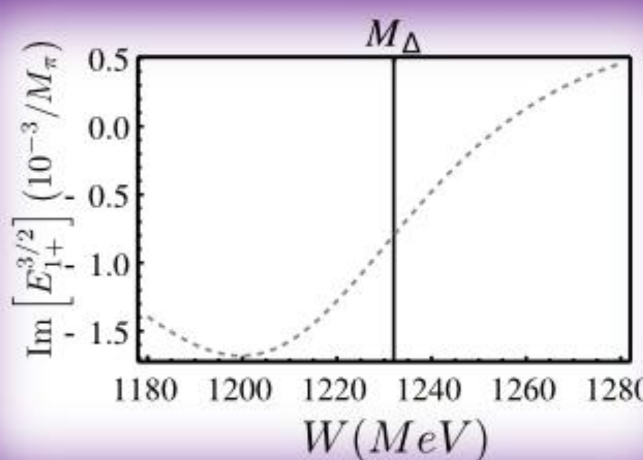


They restore Watson's theorem.



MAID: (dashed grey line)

Pascalutsa, et al. (2006) Phys. Rev. D



Impact of the Δ(1232) in $\gamma+p \to \pi^0 p$ in χPT.

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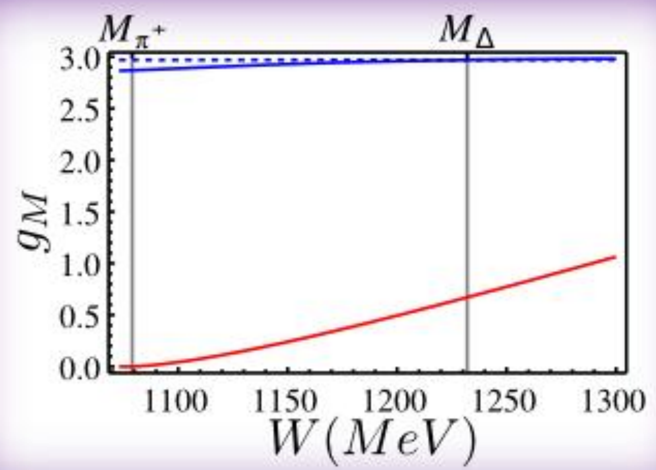
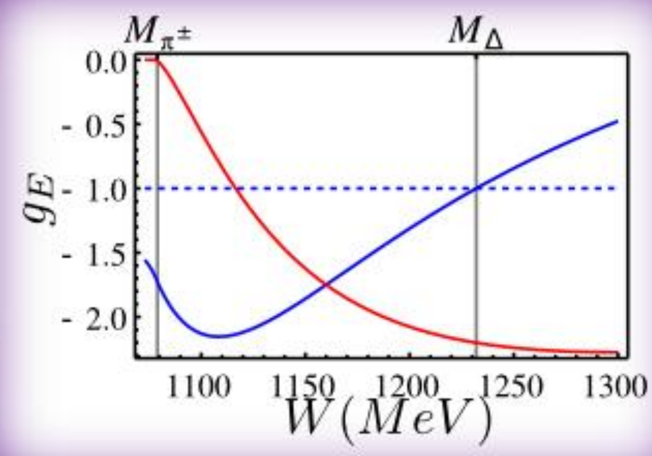


Re:

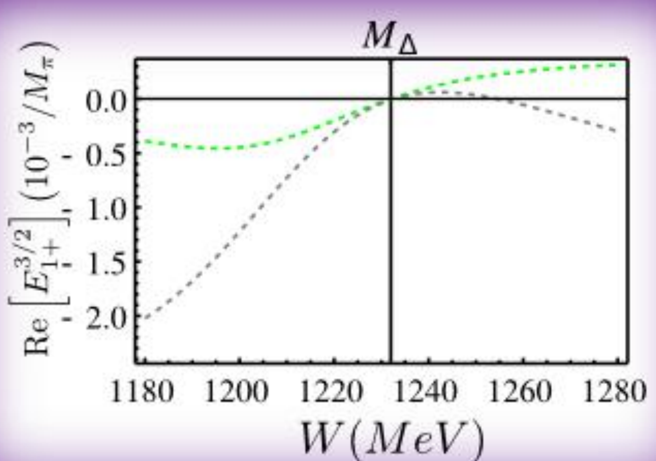
Im:

No corrections:

McGovern, et al. (2013) Eur. Phys. J.



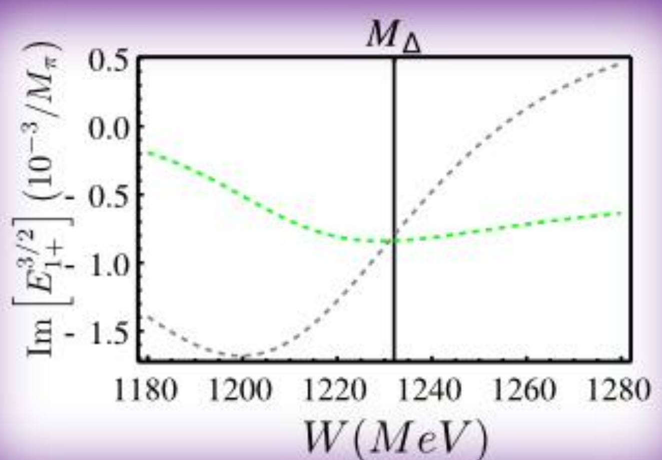
They restore Watson's theorem.



MAID:

Δ:

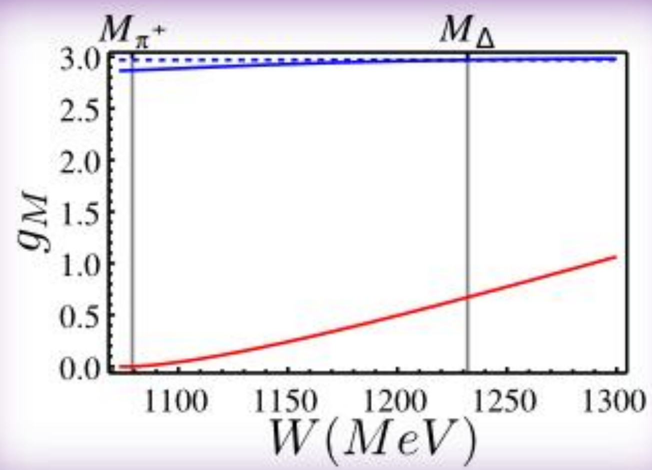
Pascalutsa, et al. (2006) Phys. Rev. D



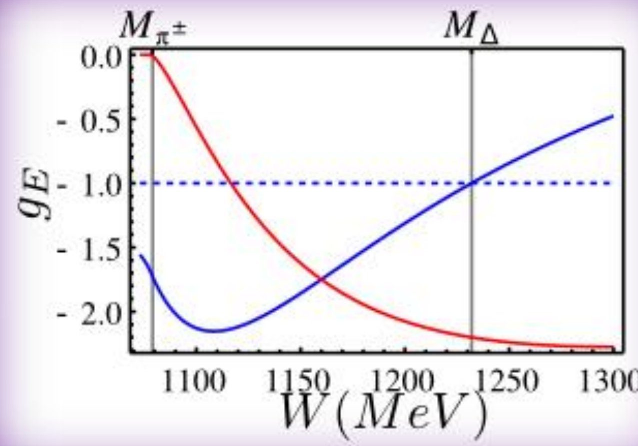
Impact of the Δ(1232) in $\gamma + p \to \pi^0 p$ in χPT.

Effects of γNΔ vertex corrections

The corrections are implemented by scaling the coupling constants with energy

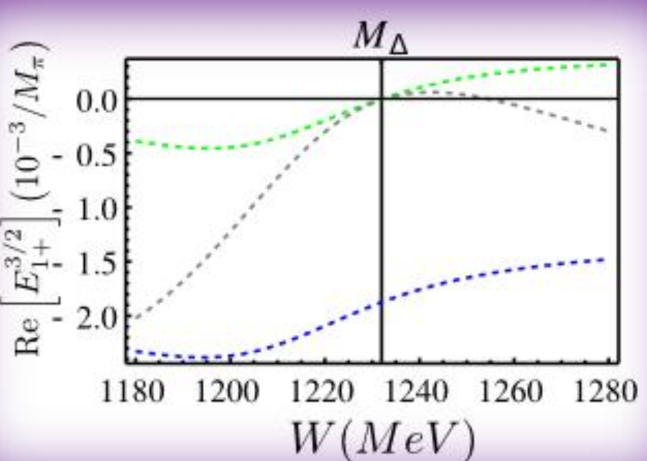


Re:
Im:
No corrections:

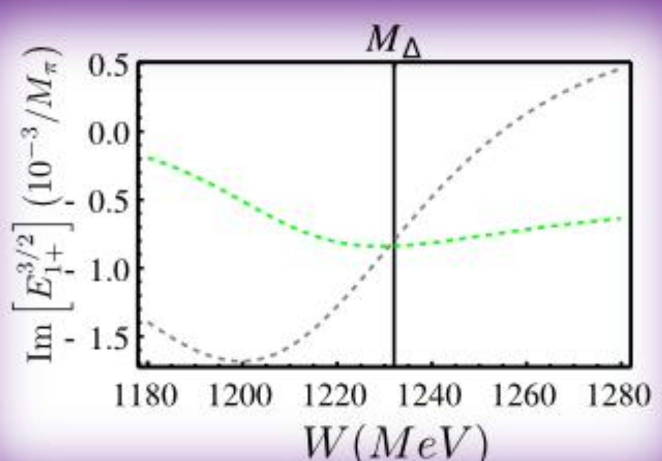


McGovern, et al. (2013) Eur. Phys. J.

They restore Watson's theorem.



MAID:
Δ:
Δ+Tree:



Pascalutsa, et al. (2006) Phys. Rev. D

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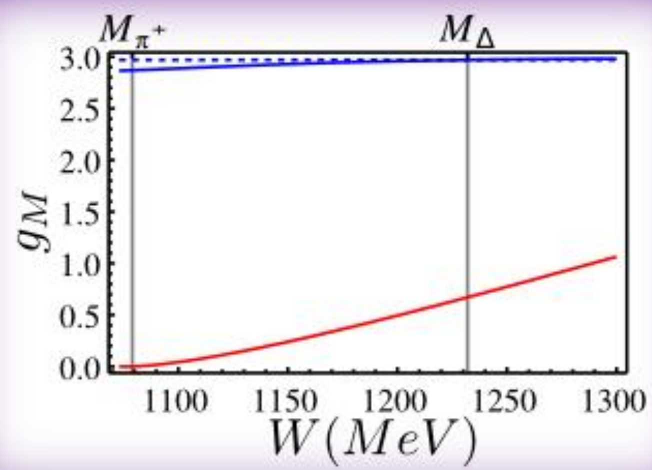
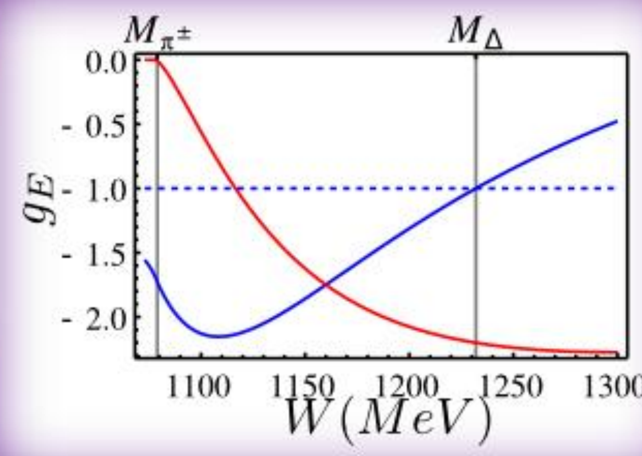


Re:

Im:

No corrections:

McGovern, et al. (2013) Eur. Phys. J.



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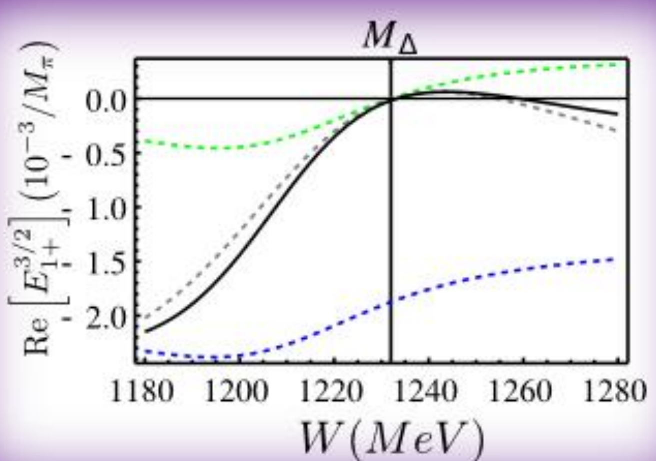


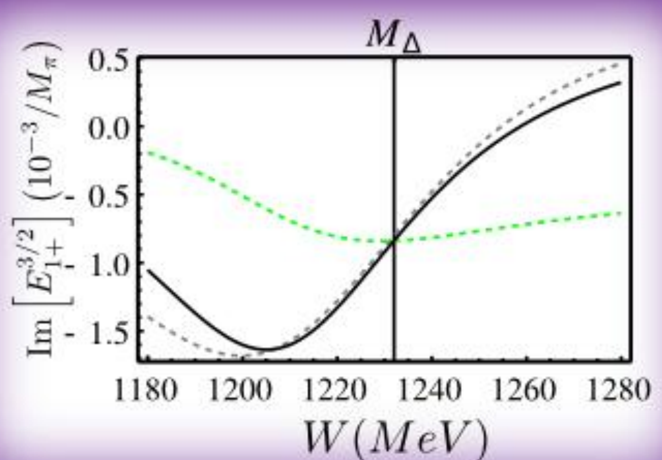
MAID:

Δ:

Δ+Tree:

Δ+Tree +V.C.:

Pascalutsa, et al. (2006) Phys. Rev. D



Results from corrections

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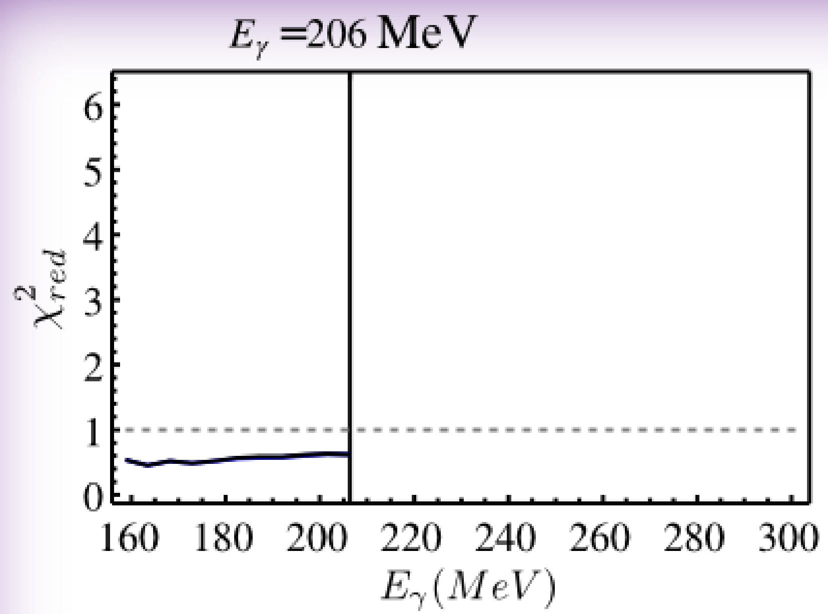
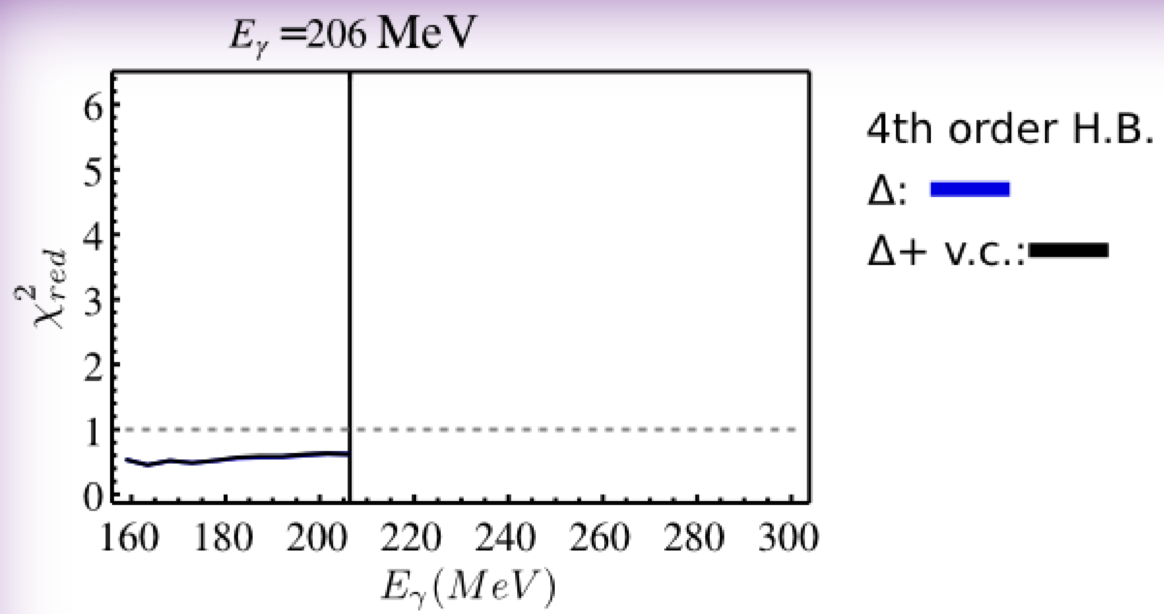


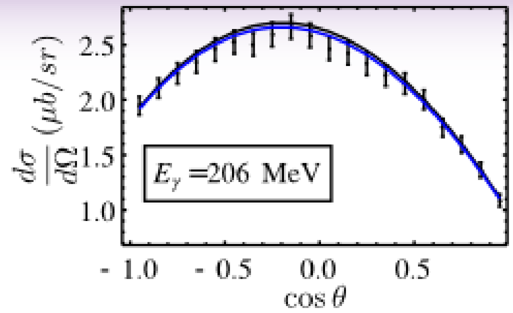
4th order H.B.

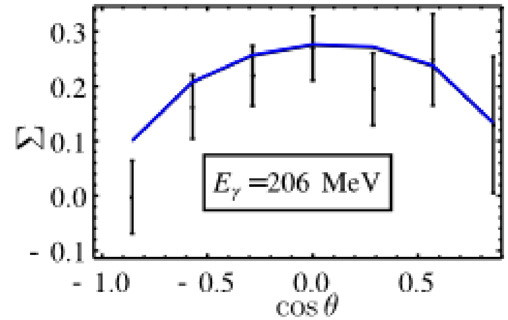
Δ:

Δ+ v.c.:

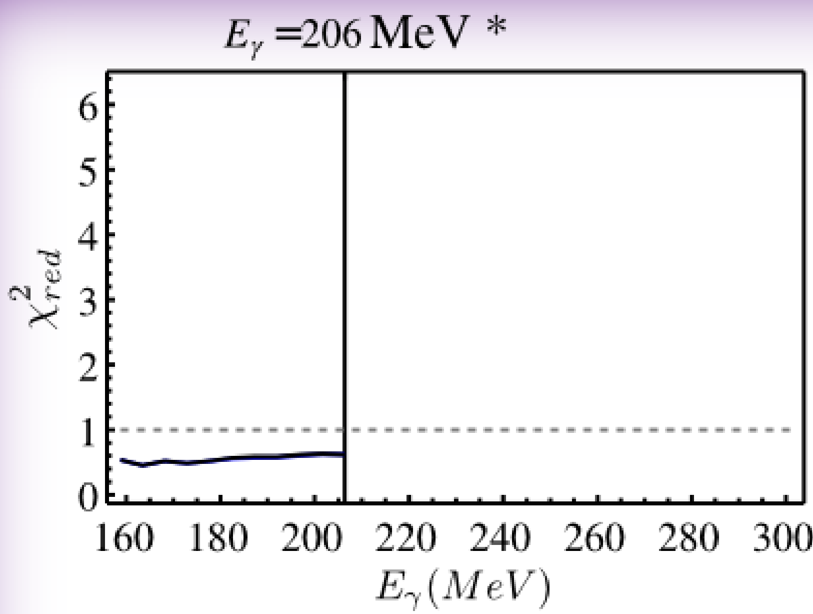
Results from corrections







Results from corrections

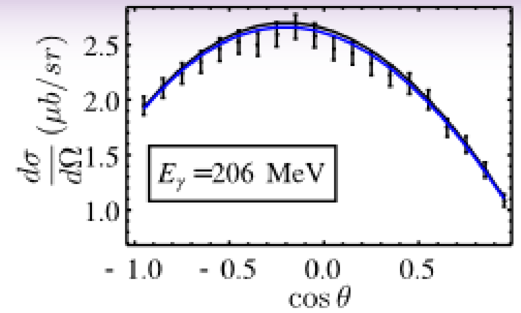


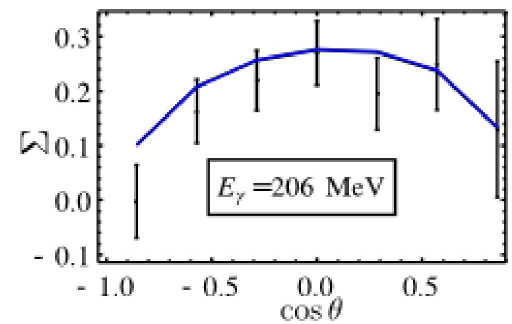
4th order H.B.

Δ:

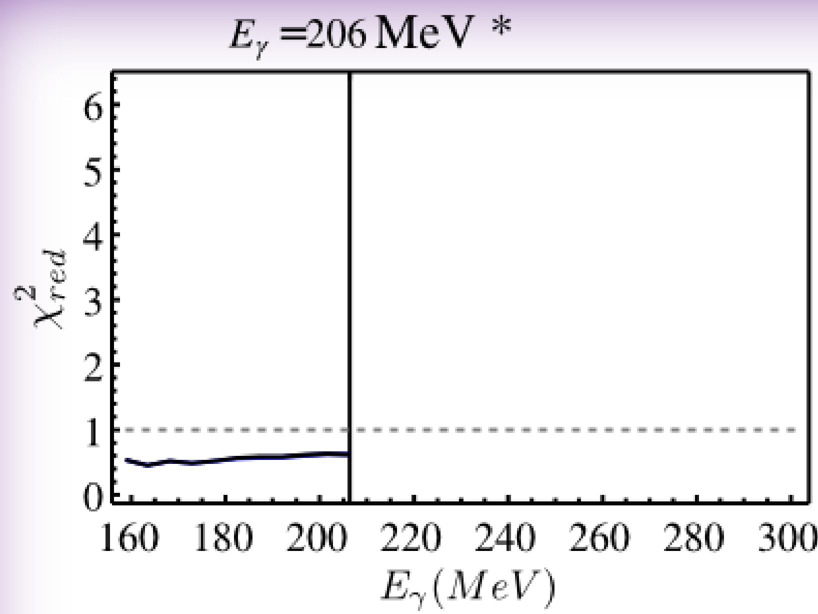
Δ+ v.c.:

*Fix LECs at 206 MeV.





Results from corrections

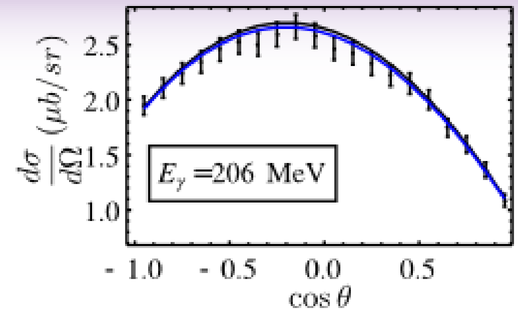


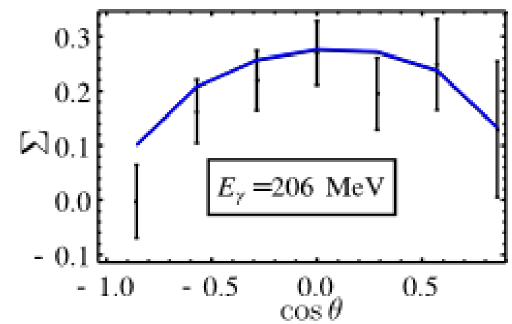
4th order H.B.

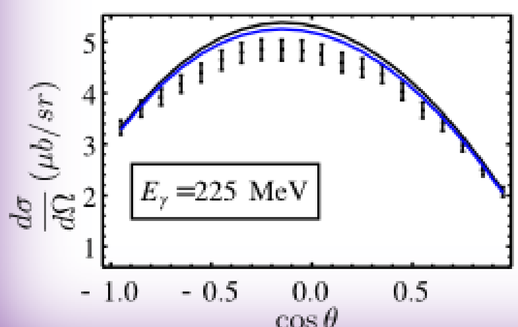
Δ: (blue line)

Δ+ v.c.: (black line)

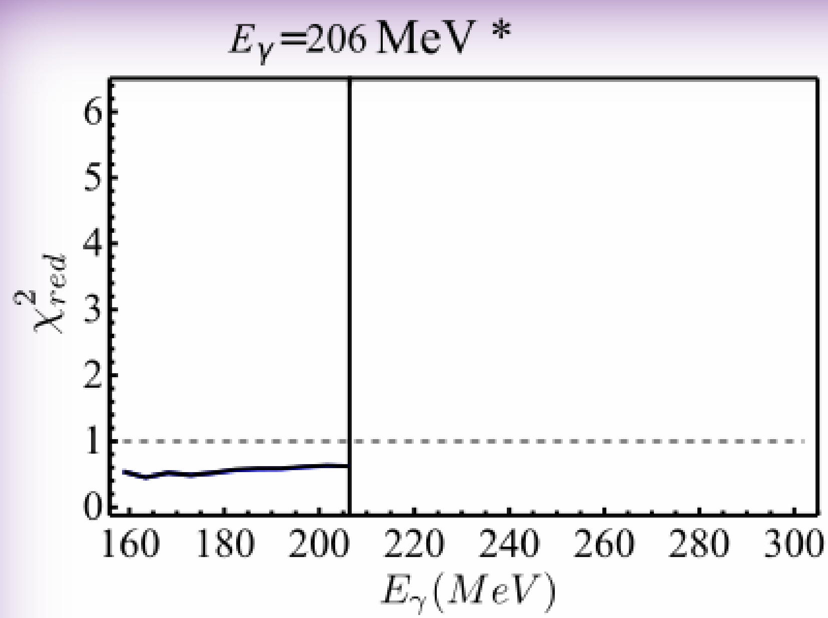
*Fix LECs at 206 MeV.







Results from corrections

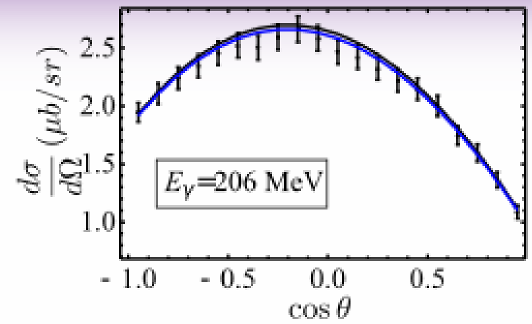


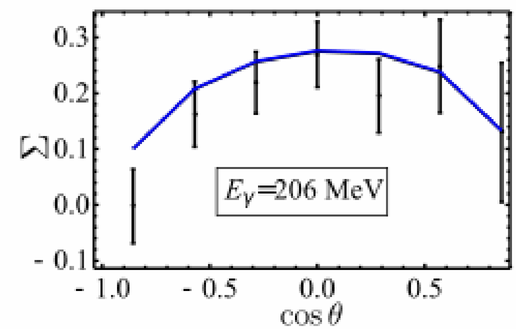
4th order H.B.

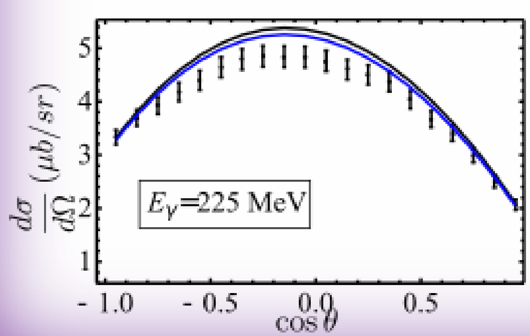
Δ:

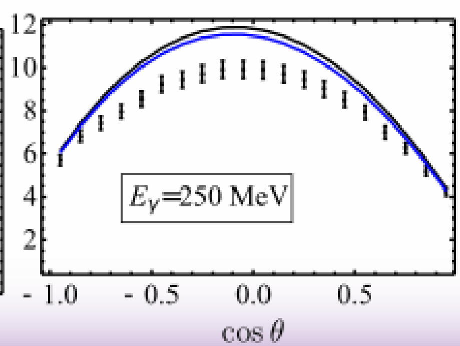
Δ+ v.c.:

*Fix LECs at 206 MeV.









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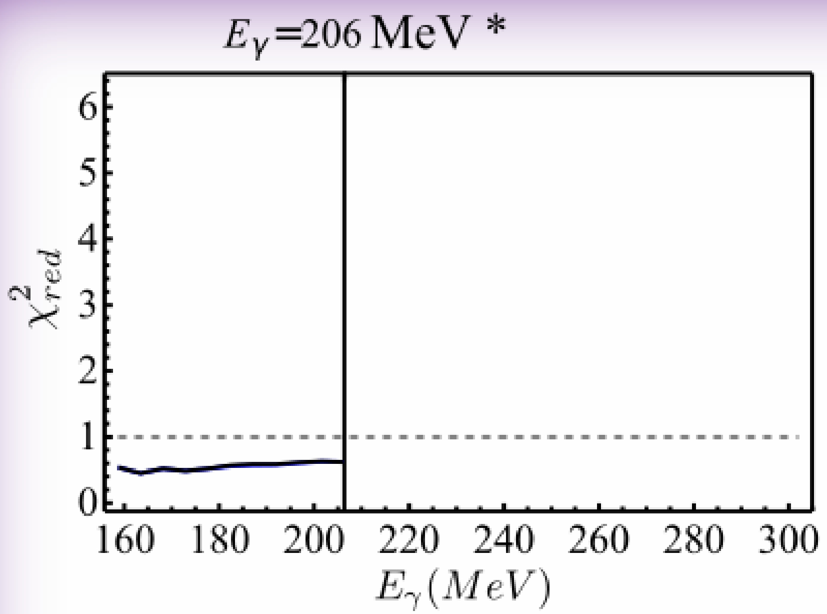

4th order H.B.

Δ: (blue)

Δ+ v.c.: (black)

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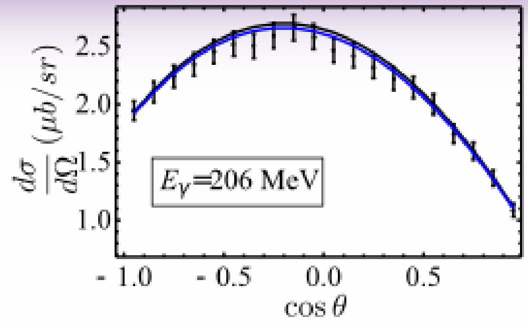

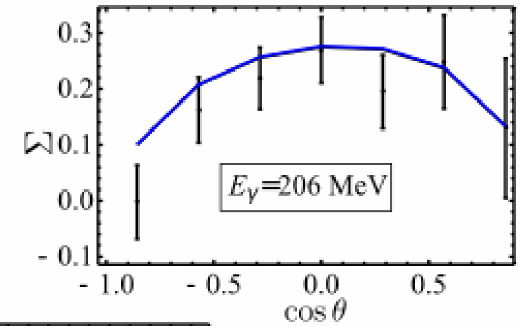

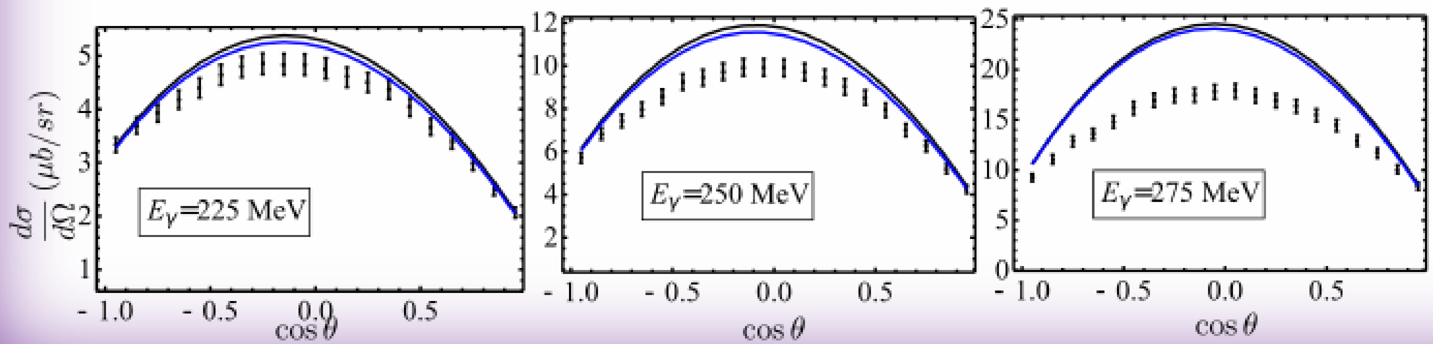

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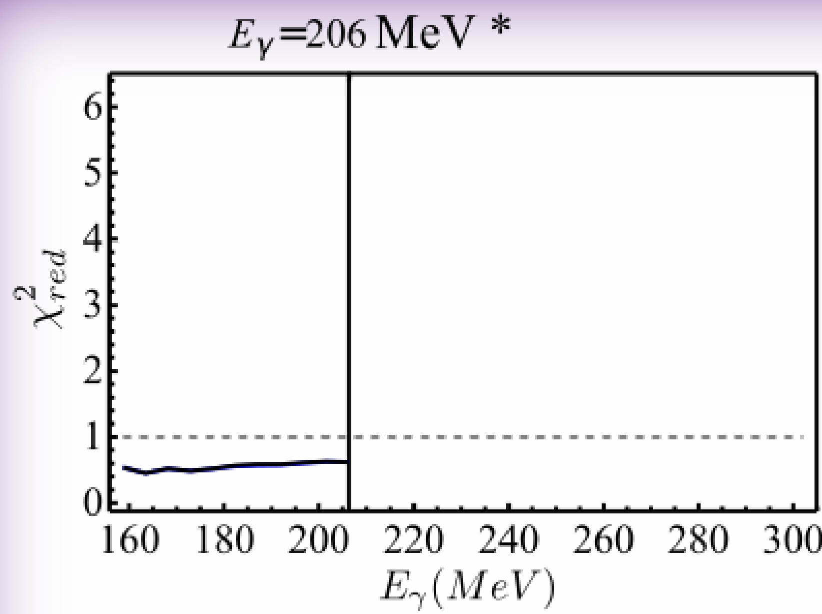

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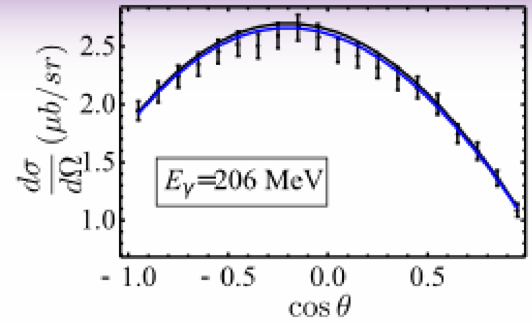
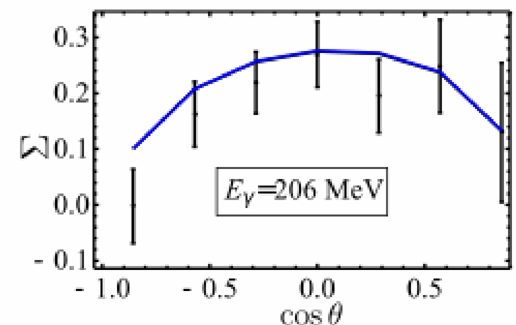
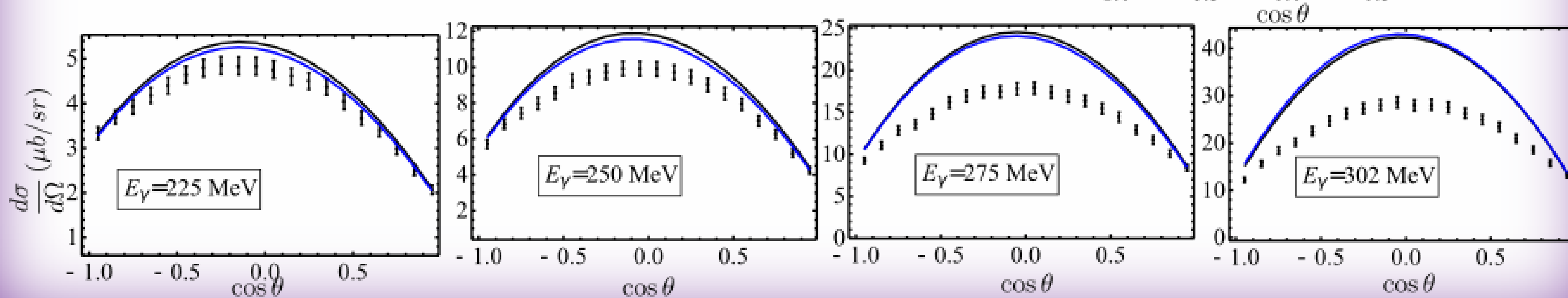
Δ: (blue line)

Δ+ v.c.: (black line)

*Fix LECs at 206 MeV.







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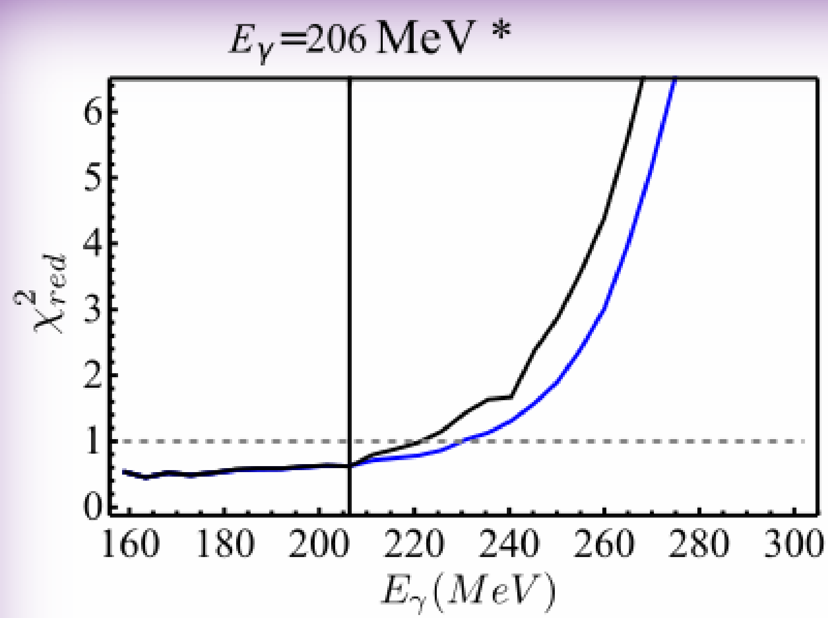

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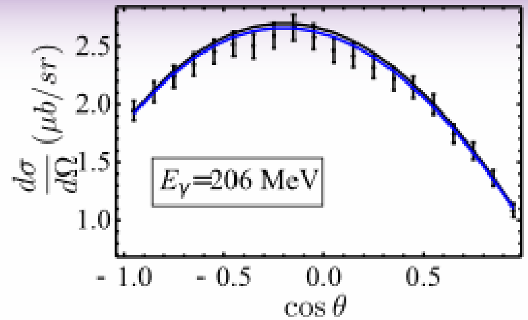
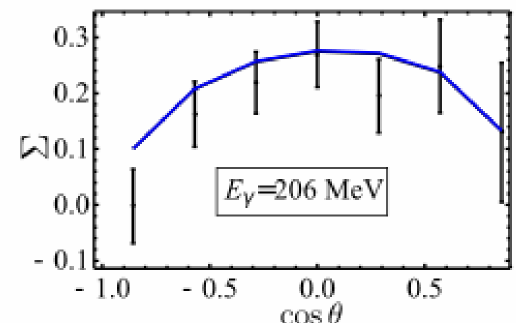
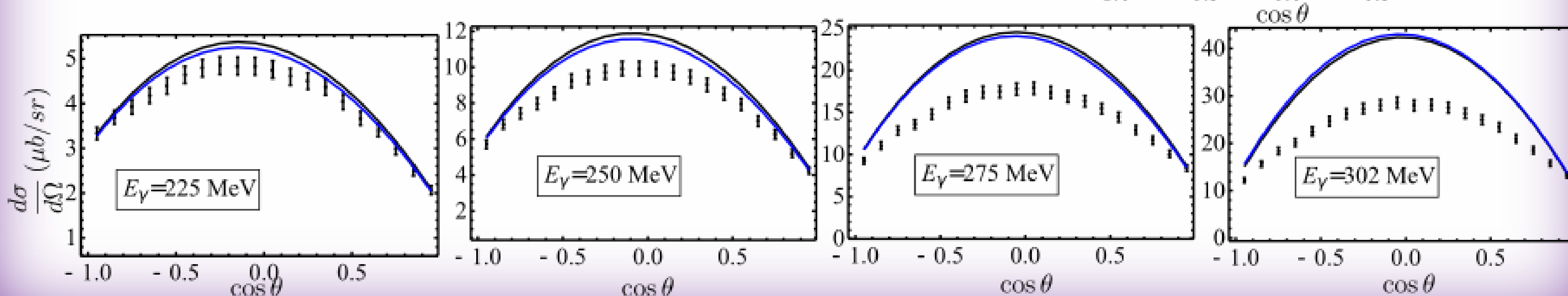
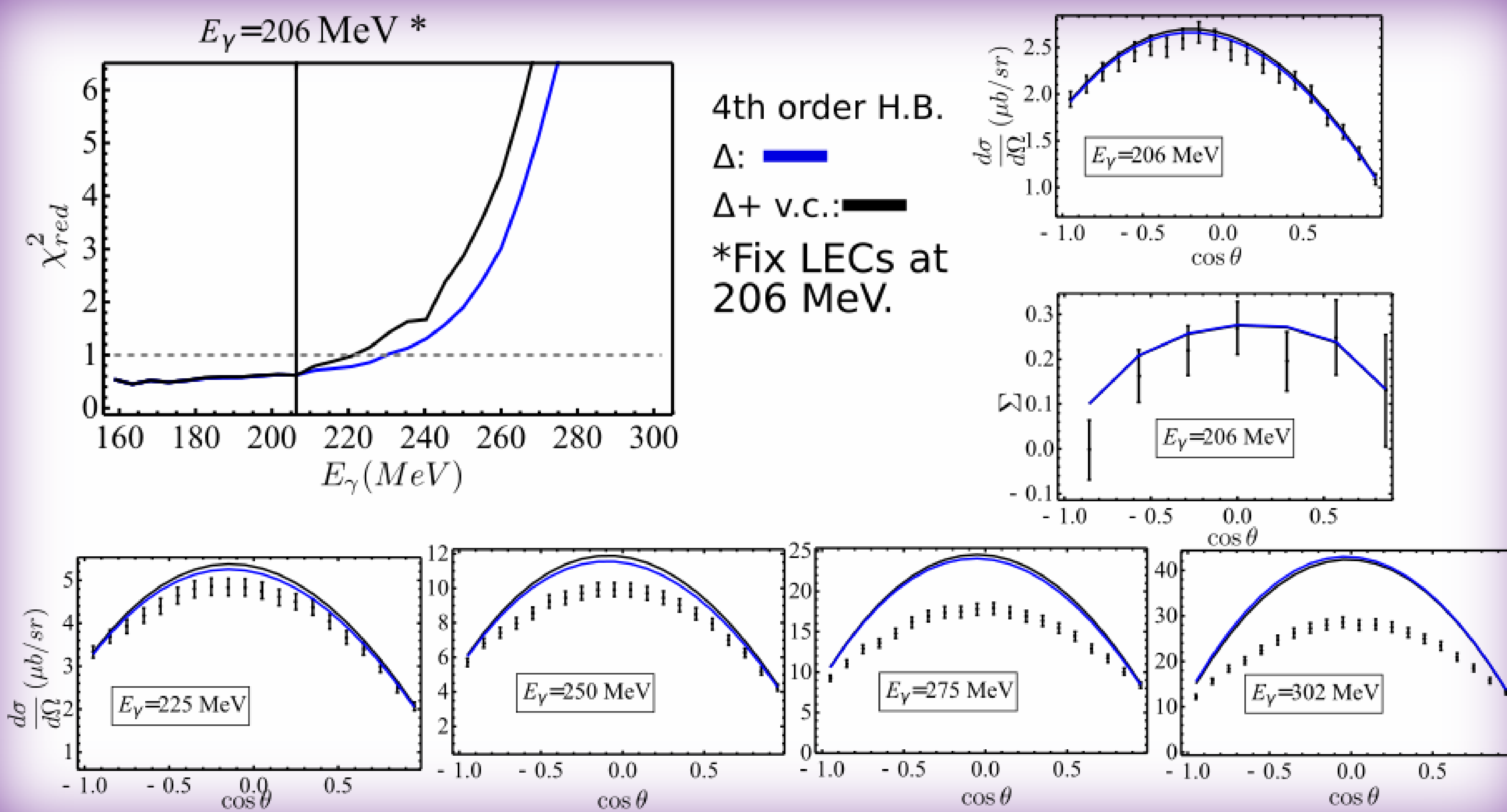






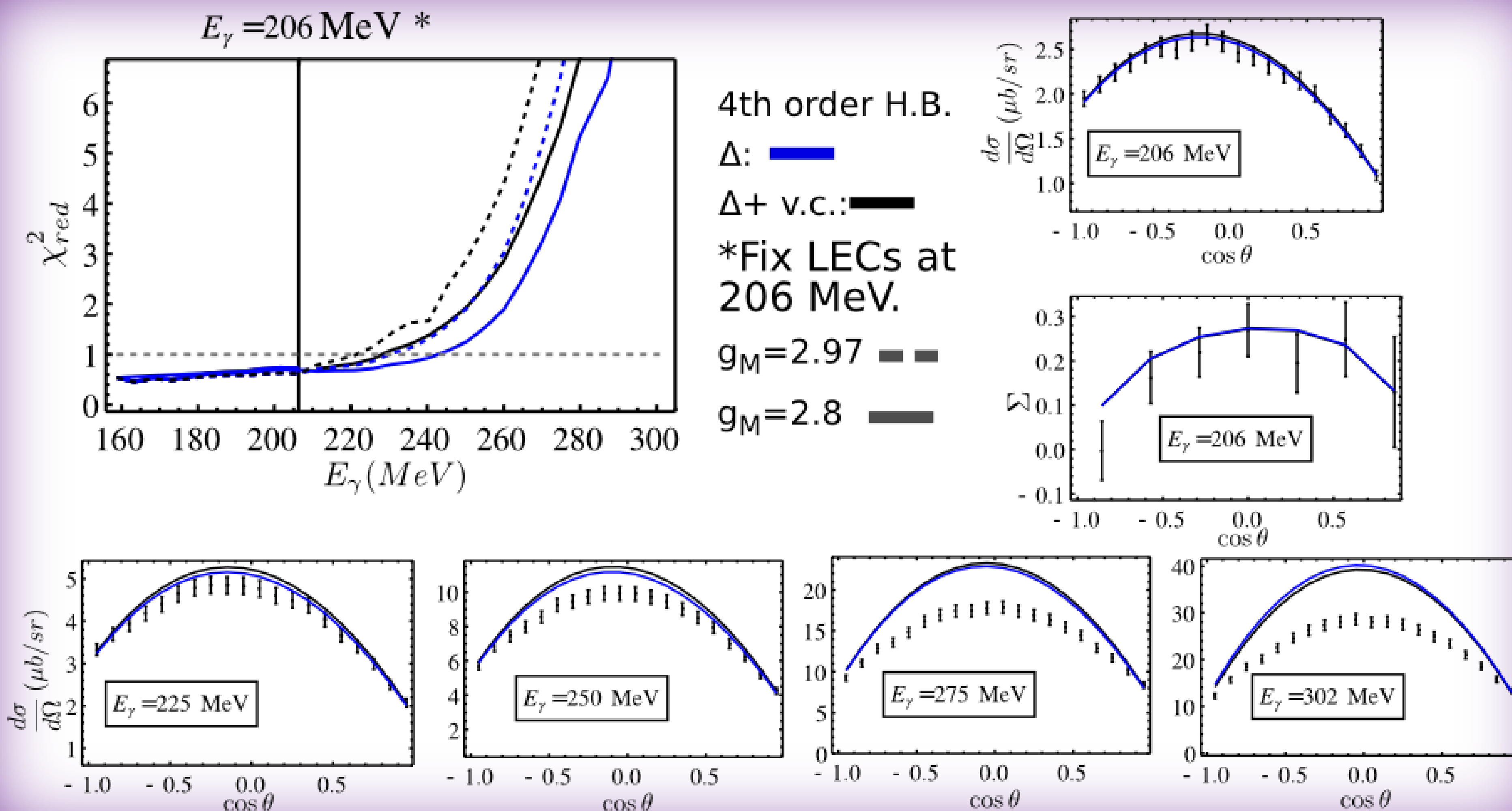
Results from corrections



We are overestimating the data. Can we do better?

Impact of the $\Delta(1232)$ in $\gamma + p \to \pi^0 p$ in χPT.

Varying g_M



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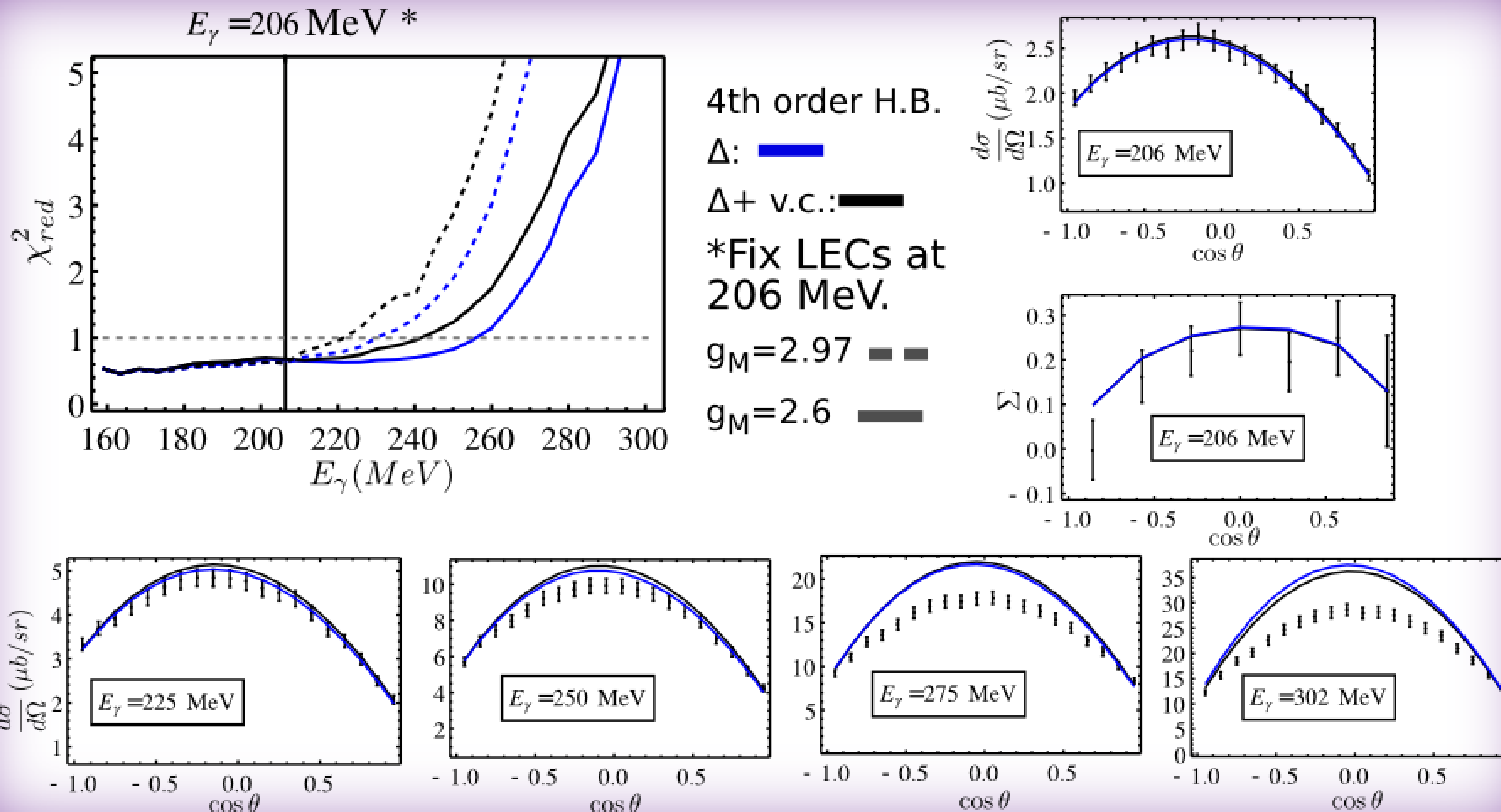

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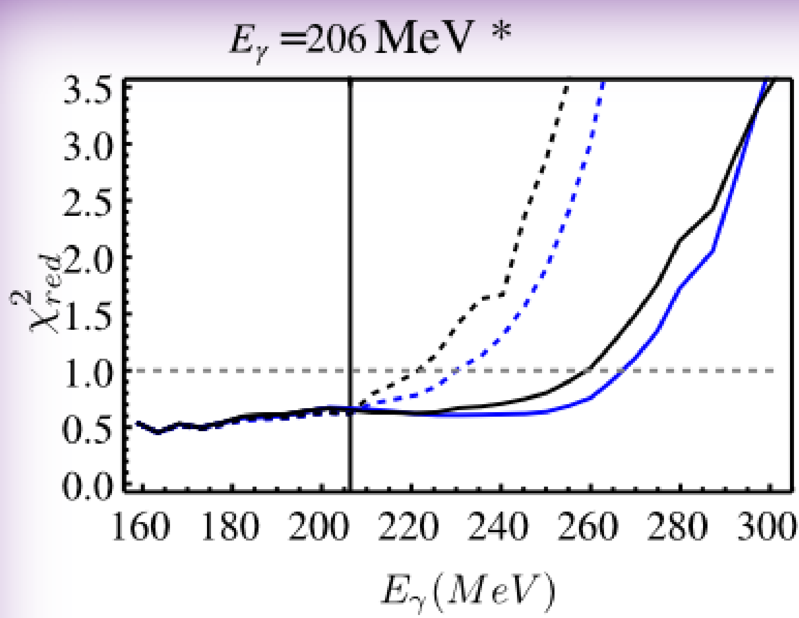


4th order H.B.

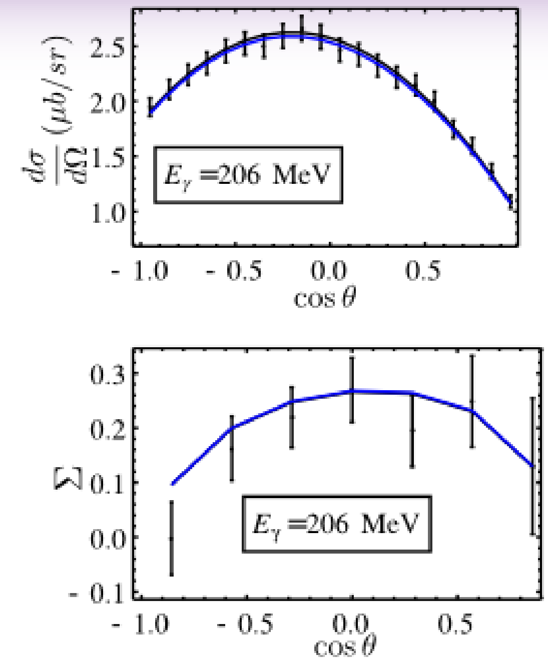
Δ:

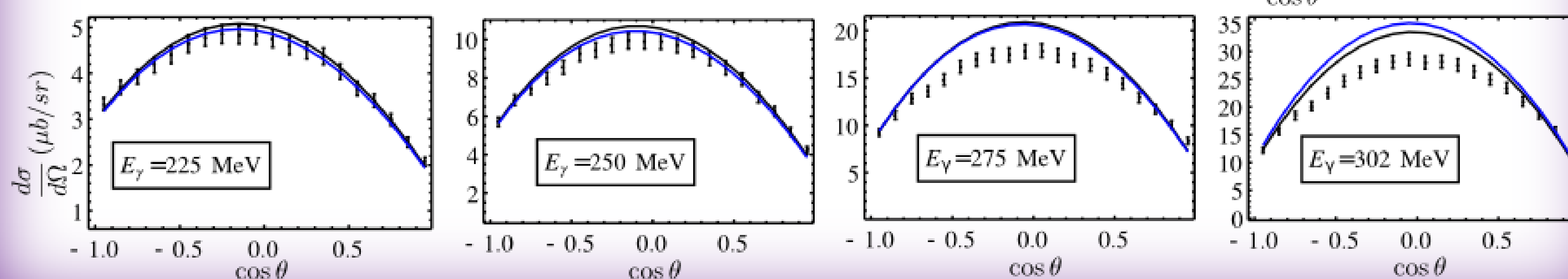
Δ+ v.c.:

*Fix LECs at 206 MeV.

g_M=2.97

g_M=2.4





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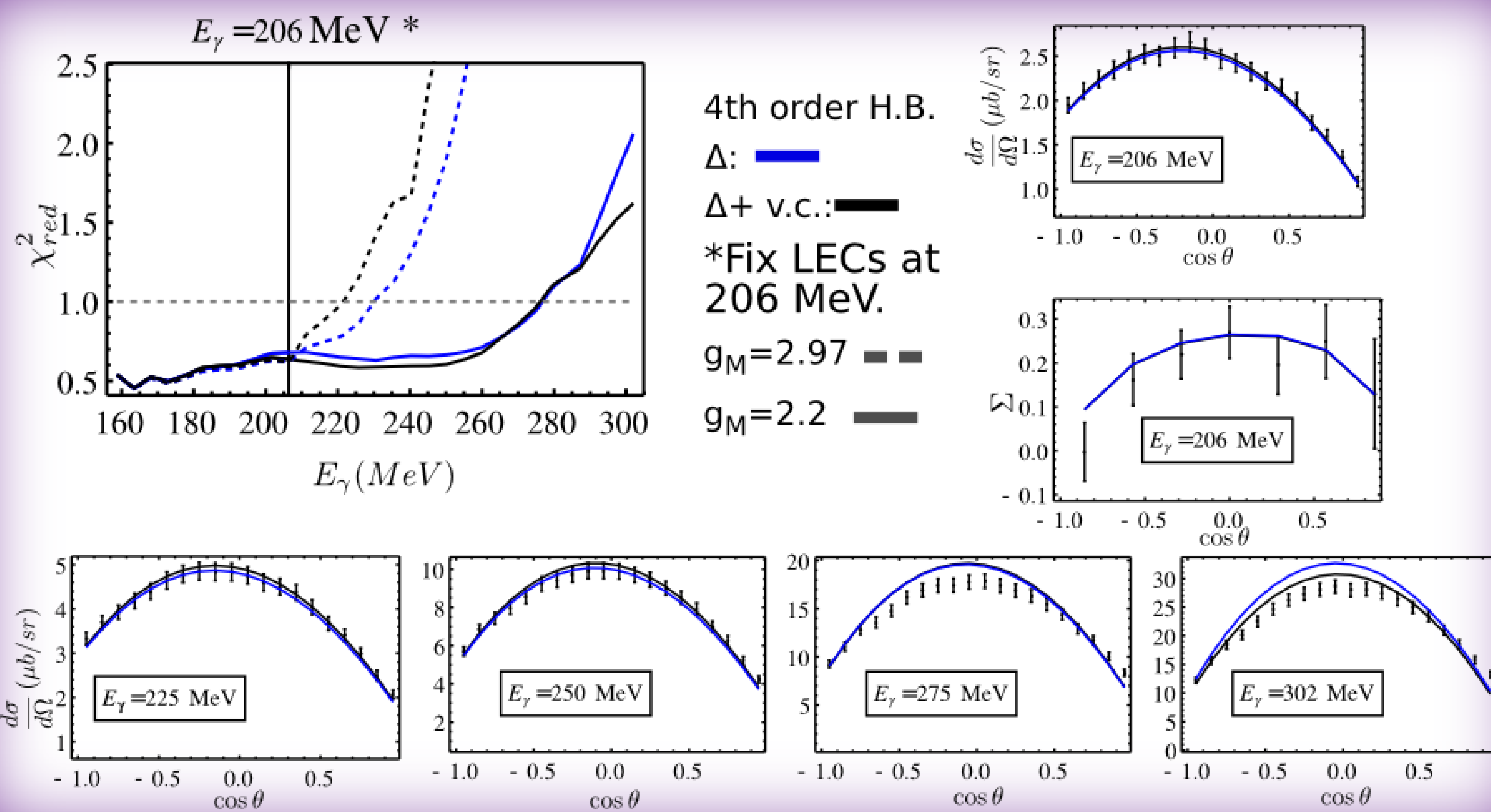

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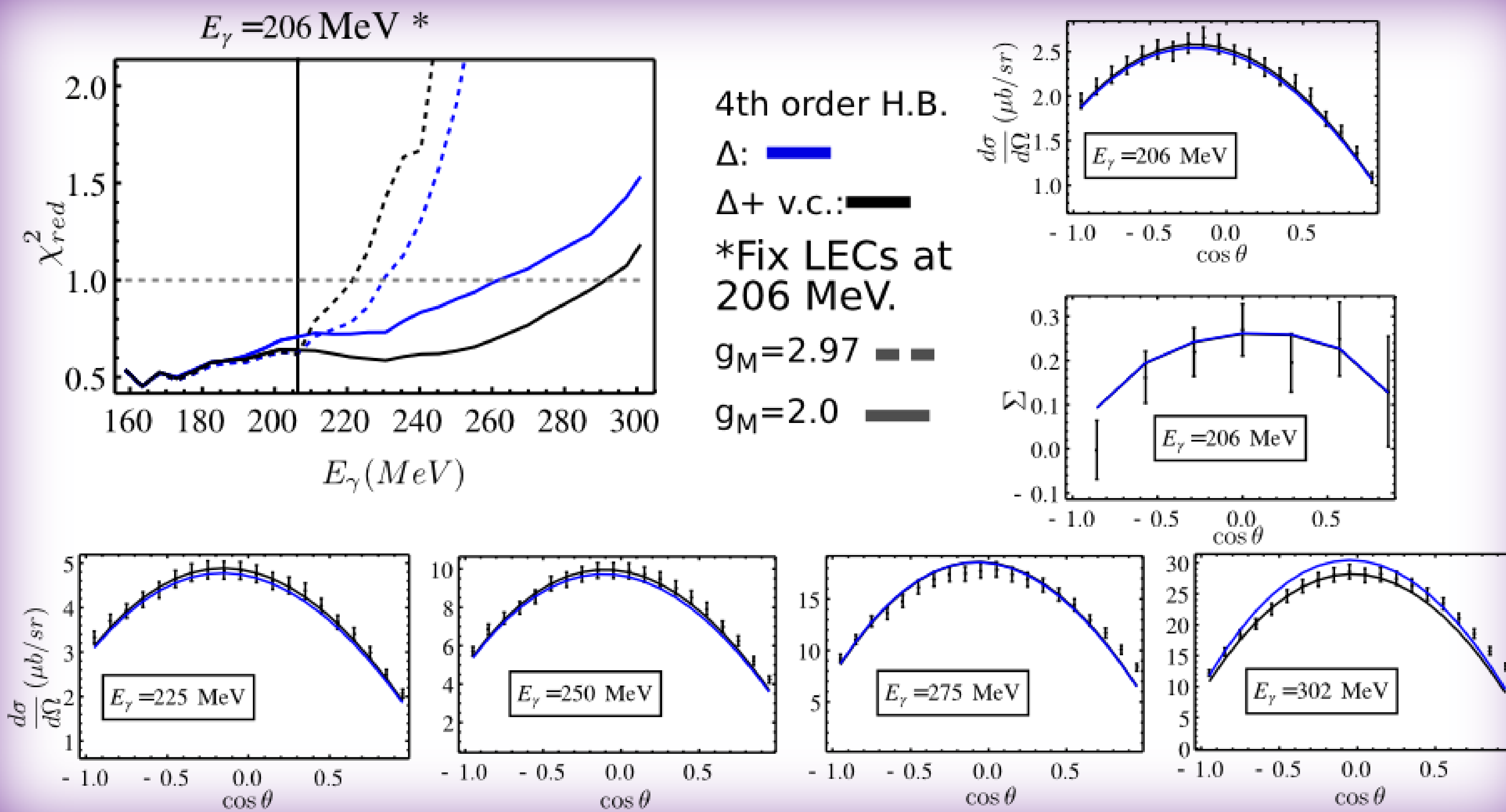

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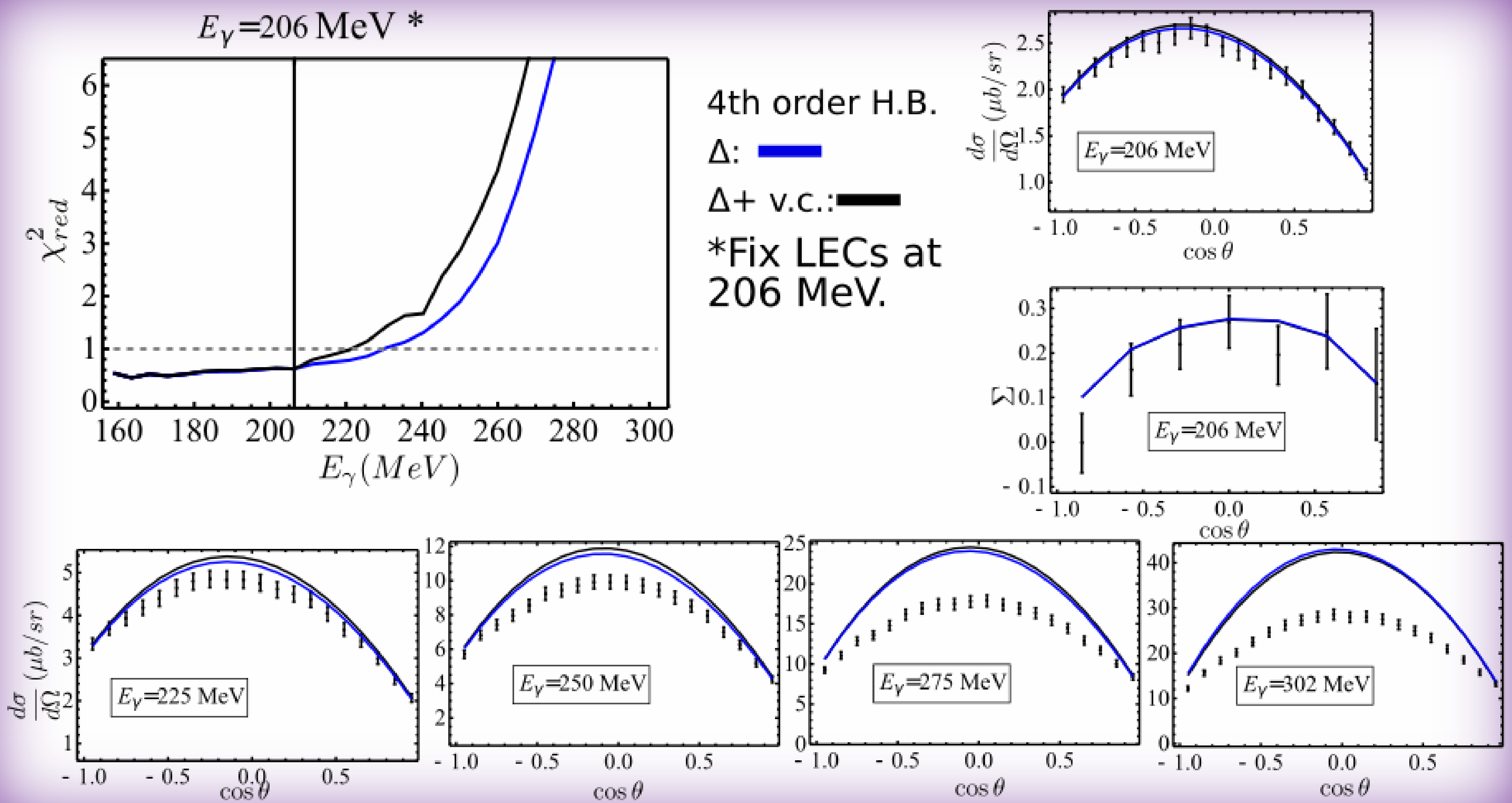

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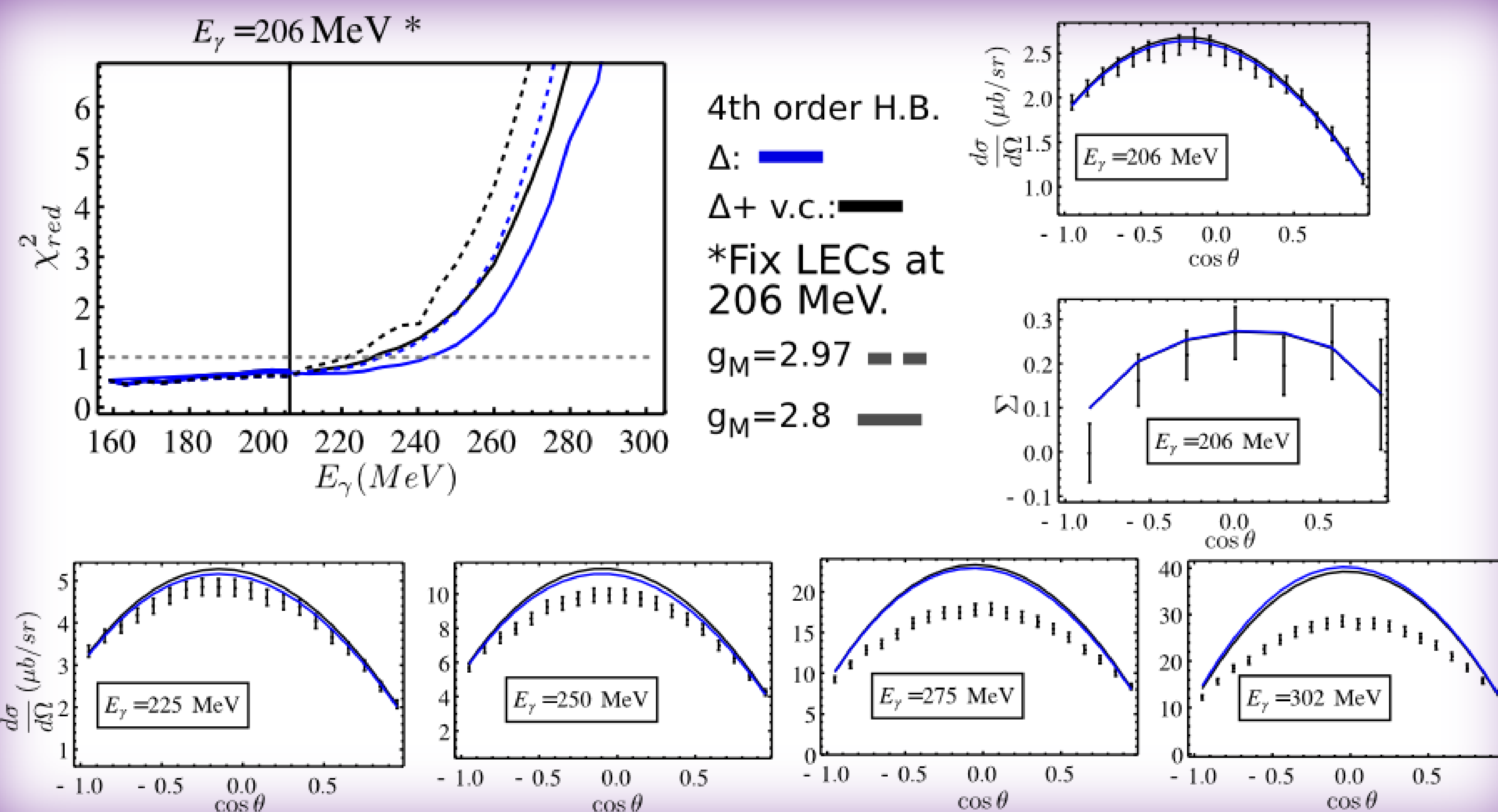

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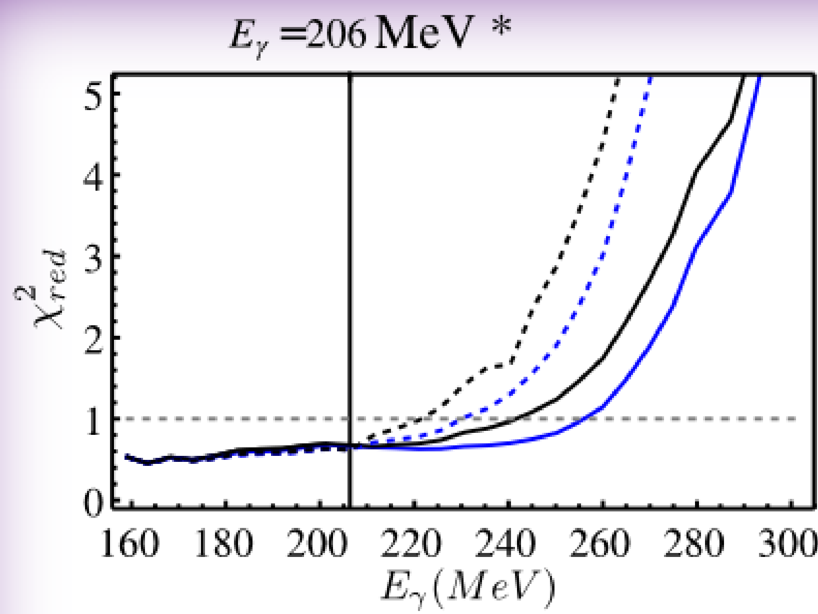


4th order H.B.

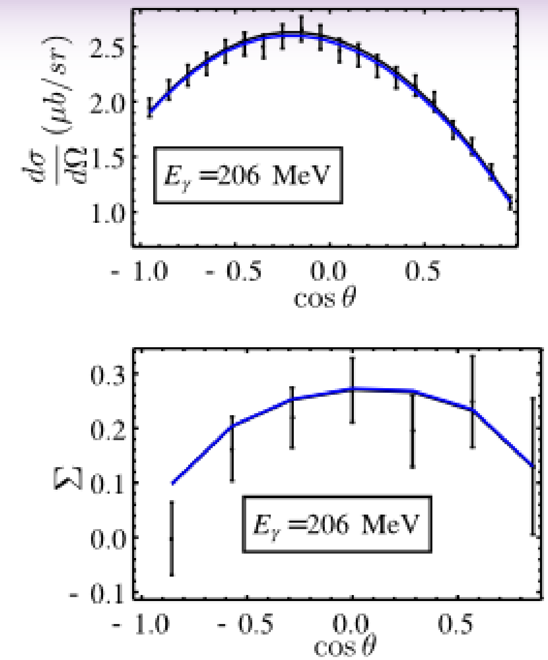
Δ: (blue line)

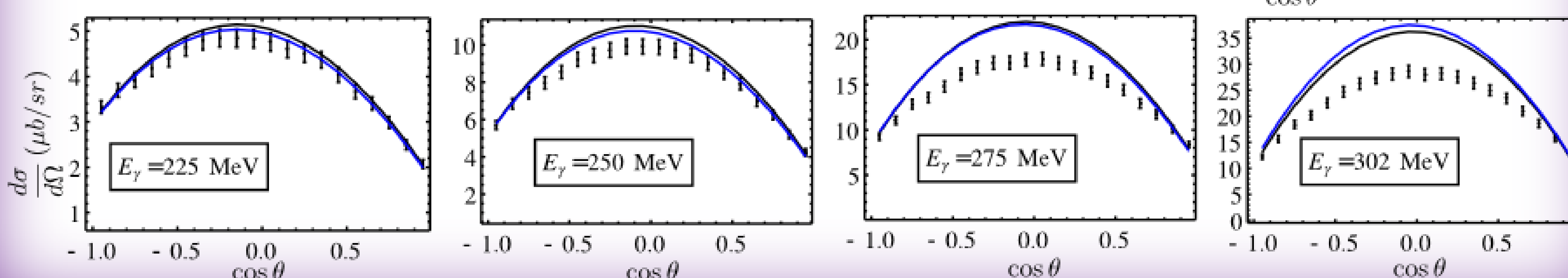
Δ+ v.c.: (black line)

*Fix LECs at 206 MeV.

g_M=2.97 (dashed)

g_M=2.6 (solid)





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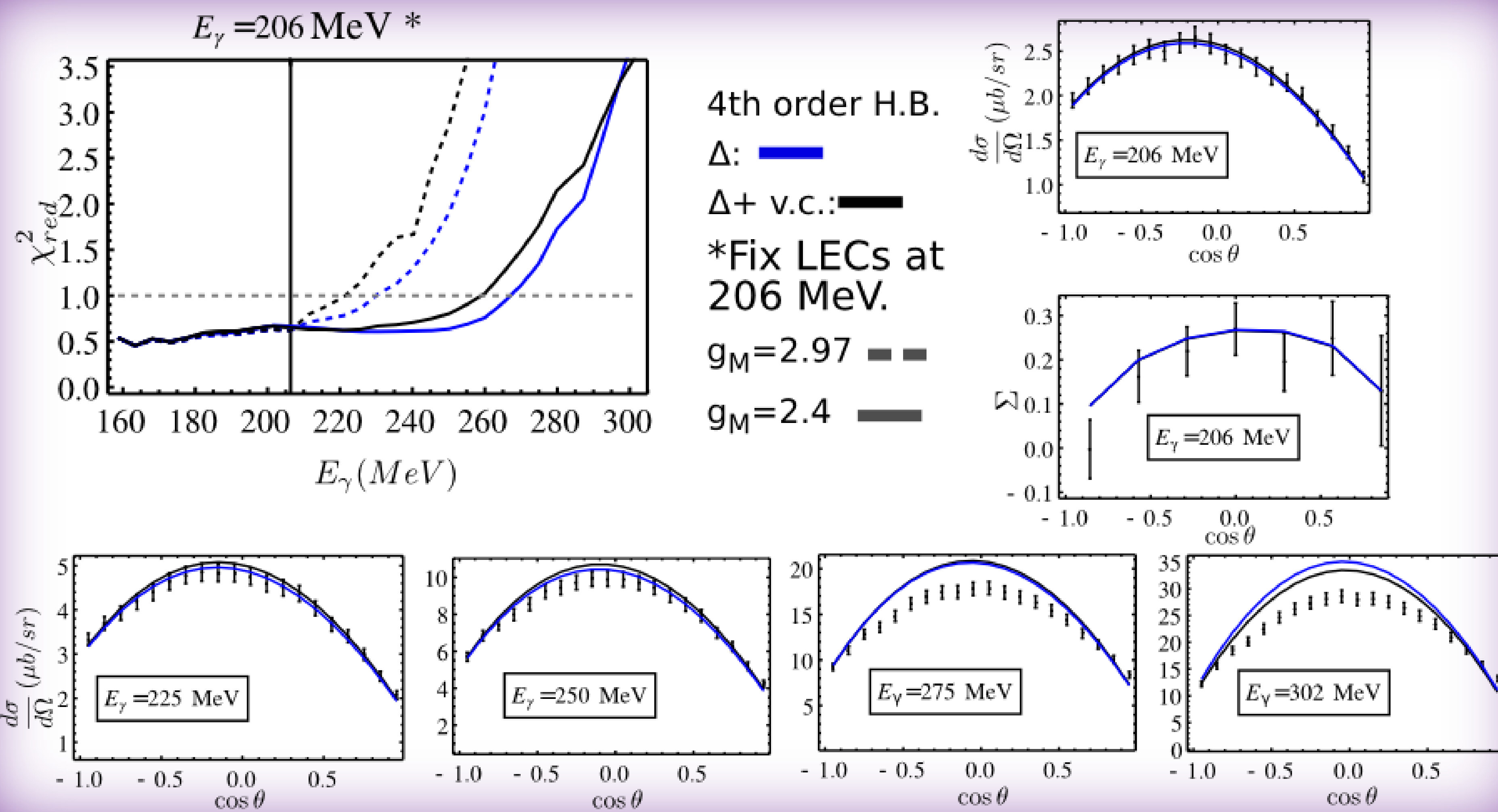
Varying g_M



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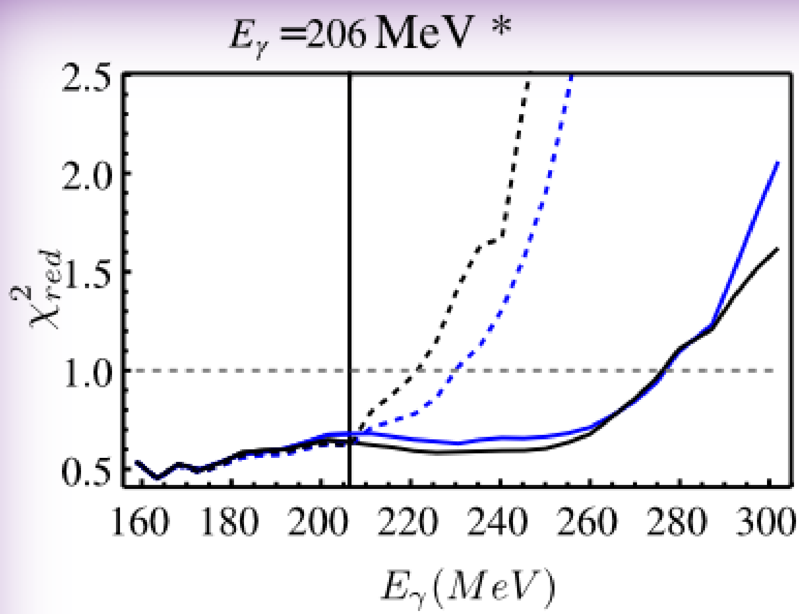


4th order H.B.

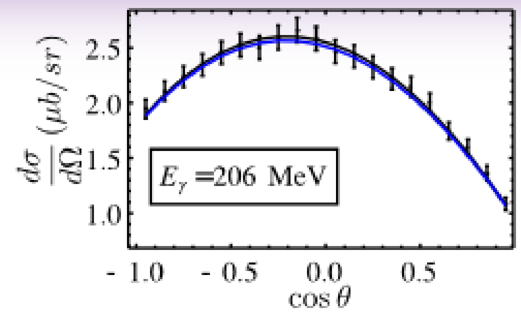
Δ:

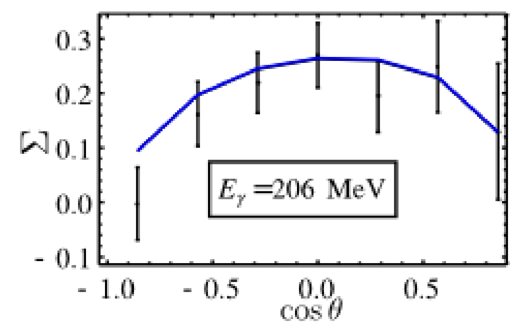
Δ+ v.c.:

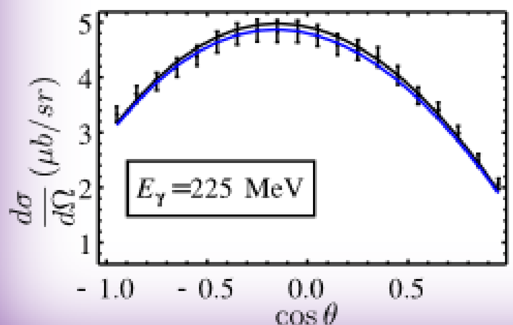
*Fix LECs at 206 MeV.

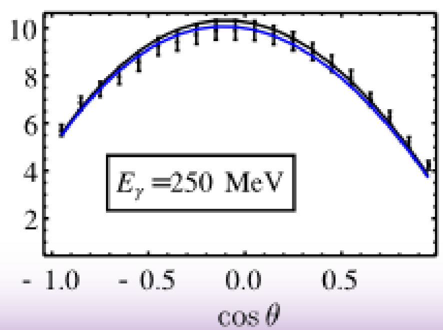
g_M=2.97

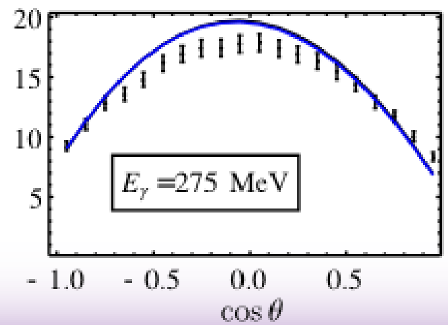
g_M=2.2

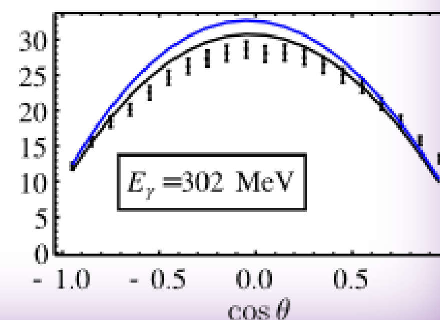












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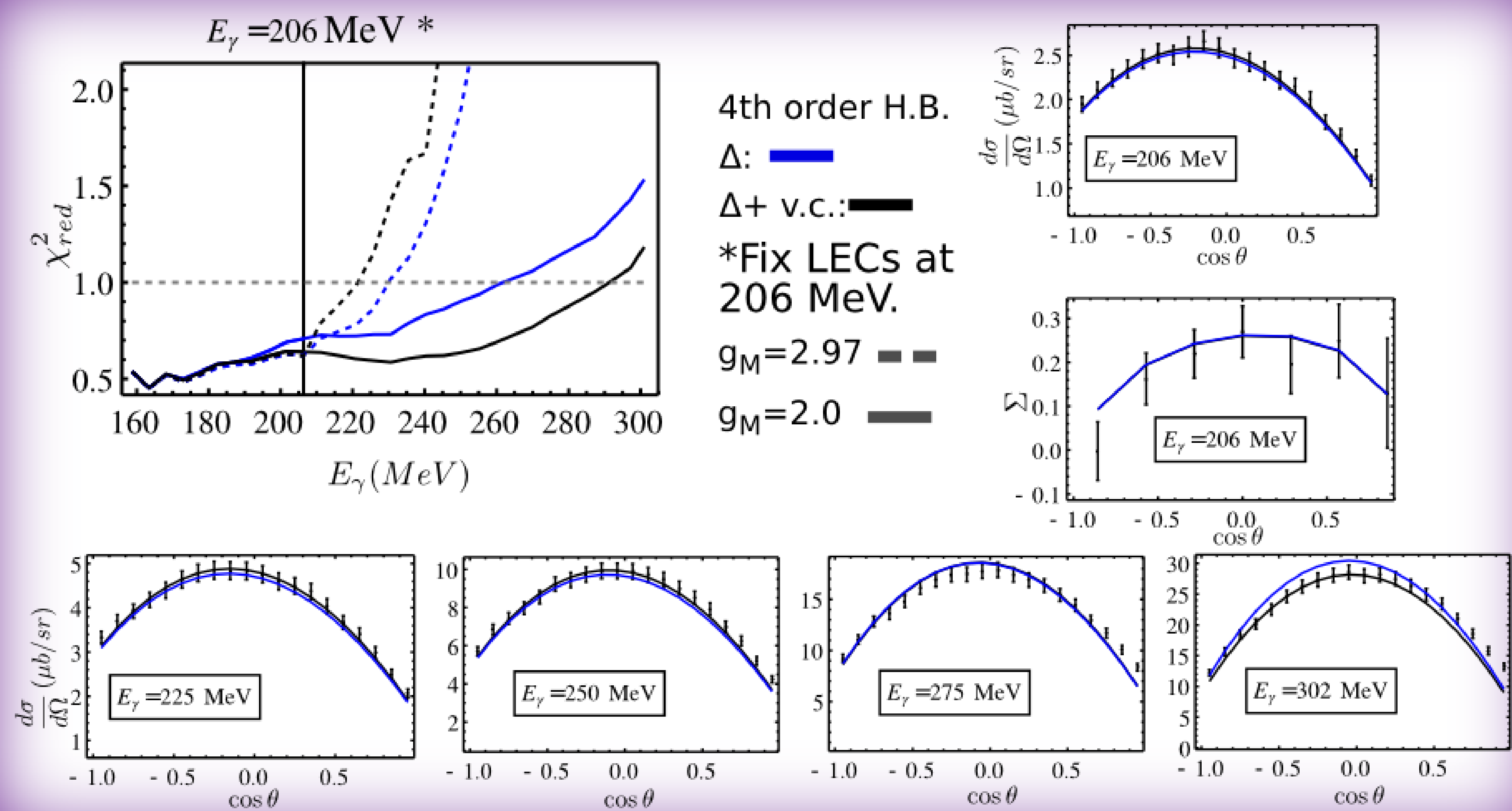
Varying g_M



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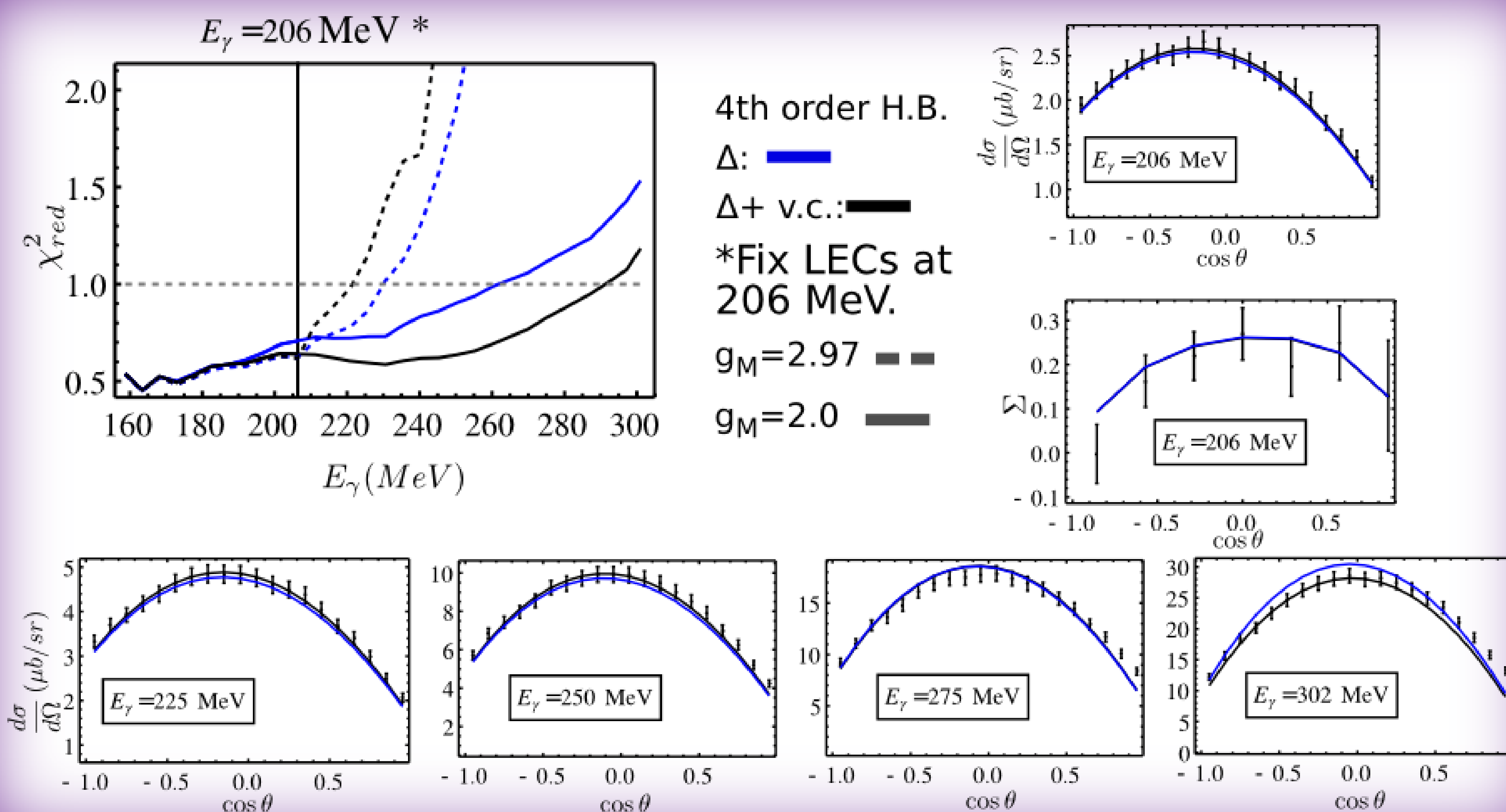
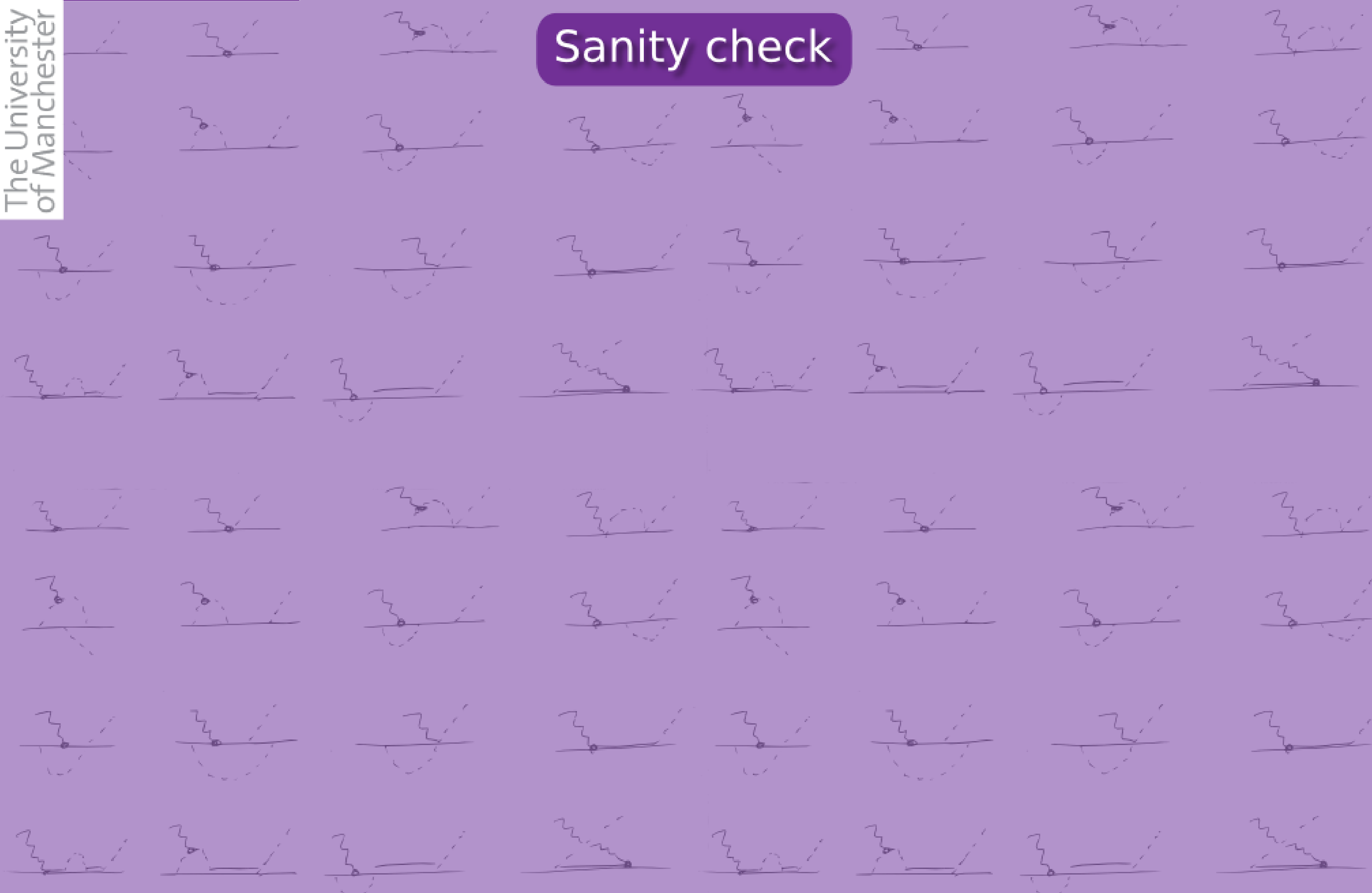


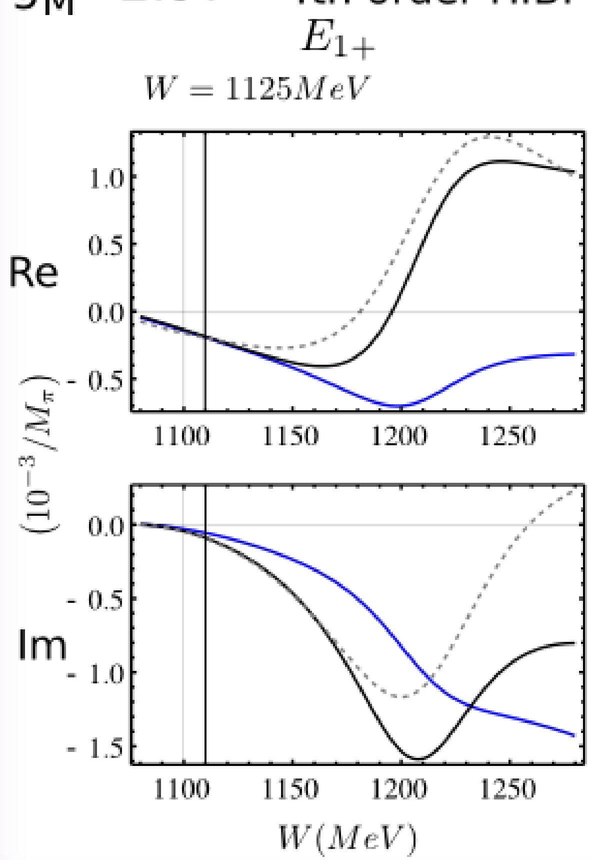
Are we free to vary g_M so much?

Sanity check



Sanity check

$g_M = 2.97$ 4th order H.B. Δ: (blue) Δ+ v.c.: (black) MAID: (grey dashed)

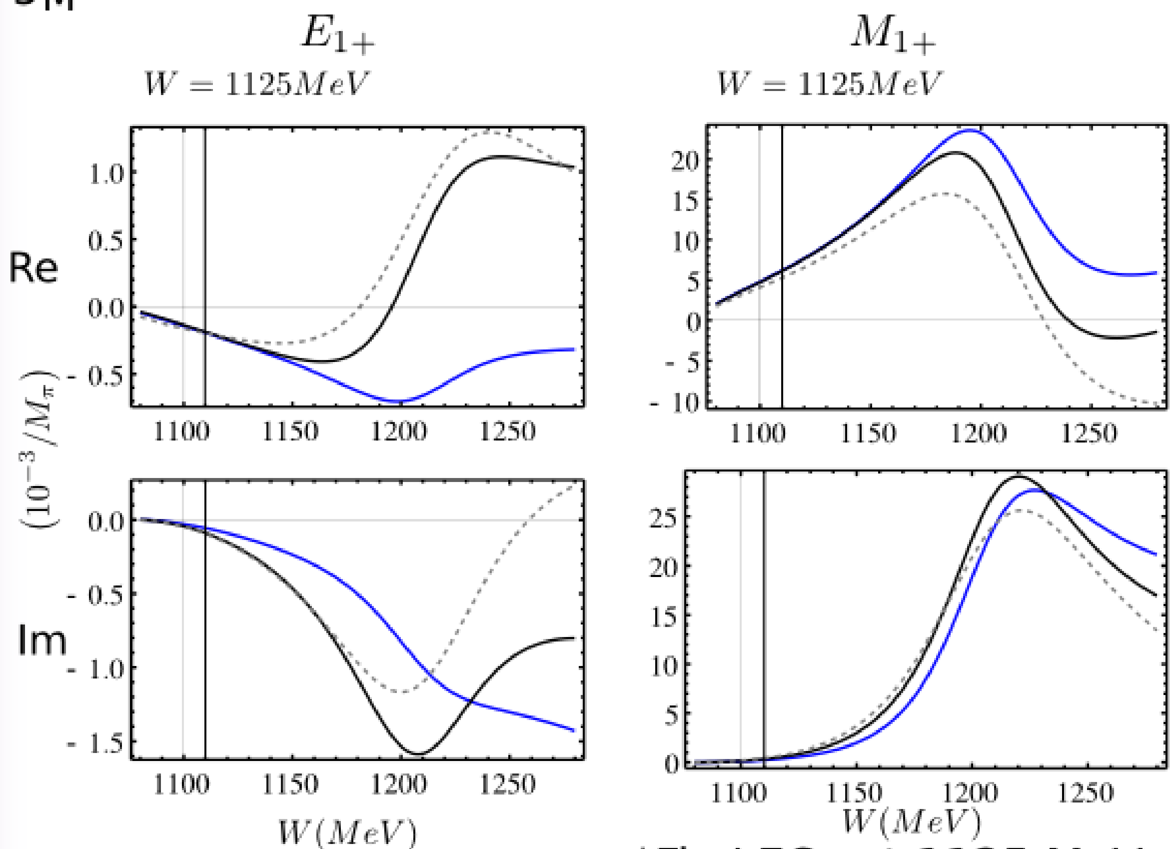


*Fix LECs at 1125 MeV.

Impact of the Δ(1232) in $\gamma+p \rightarrow \pi^0 p$ in χPT.

Sanity check

g_M=2.97 4th order H.B. Δ: Δ+ v.c.: MAID:



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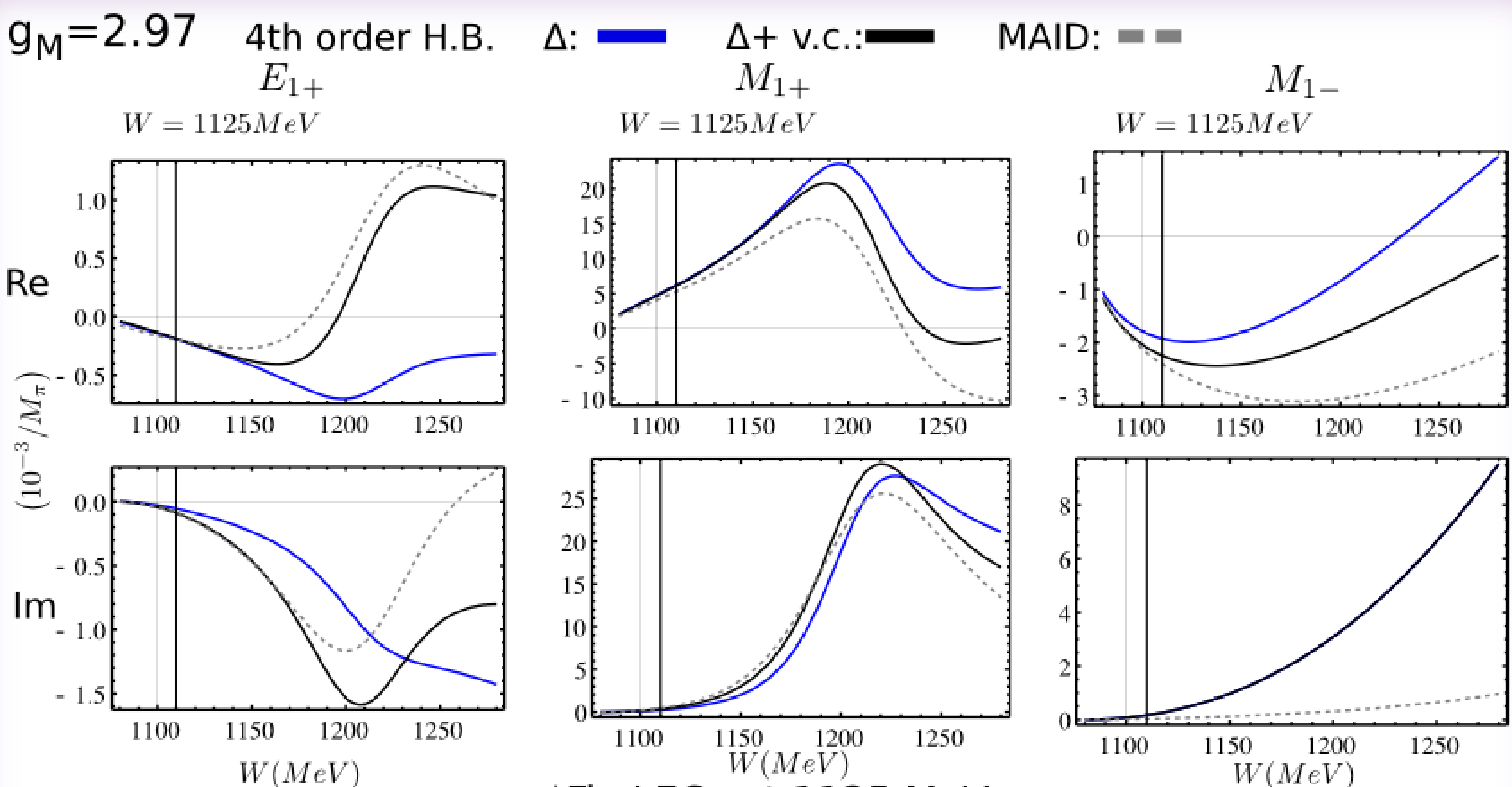

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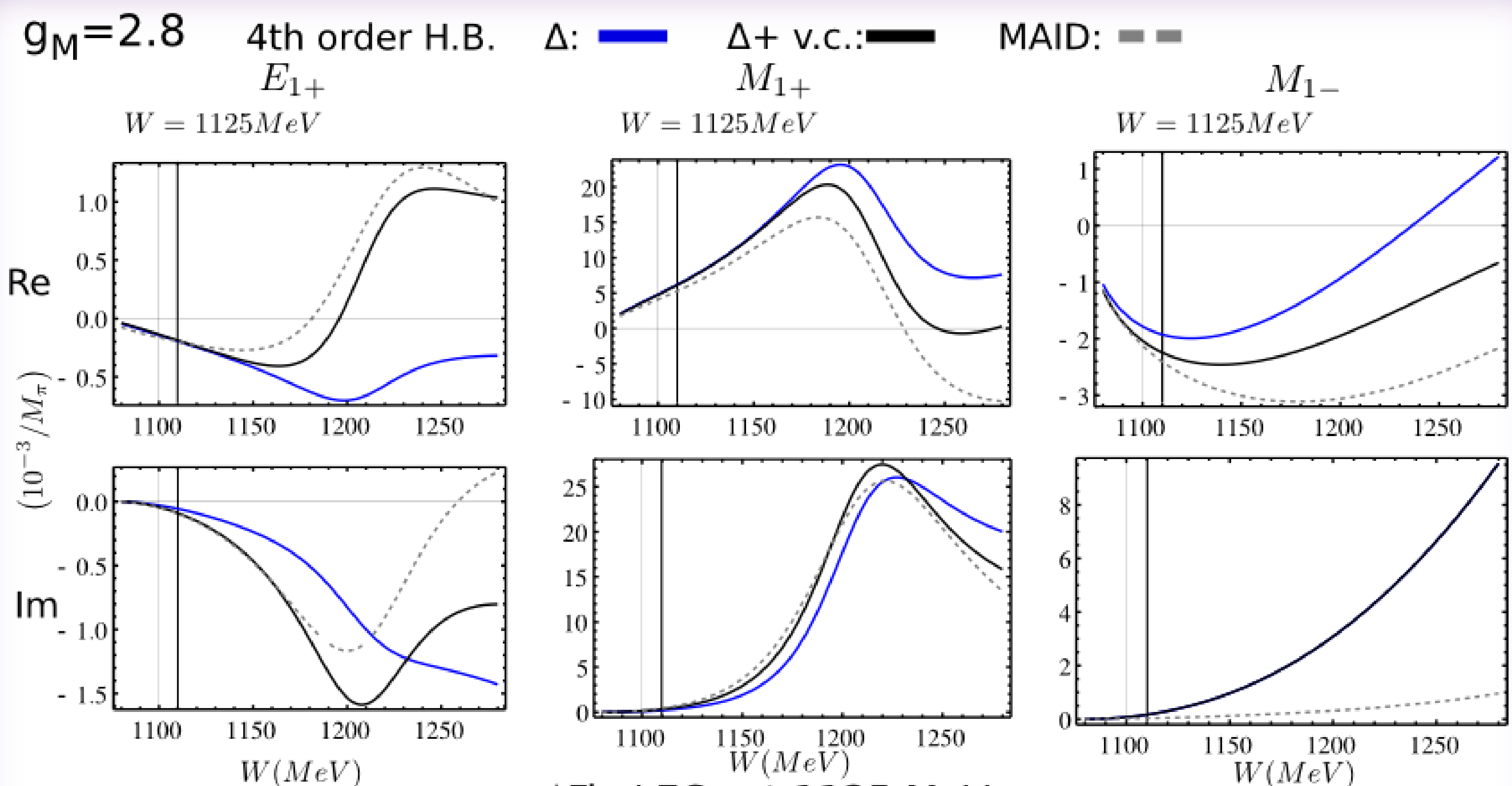

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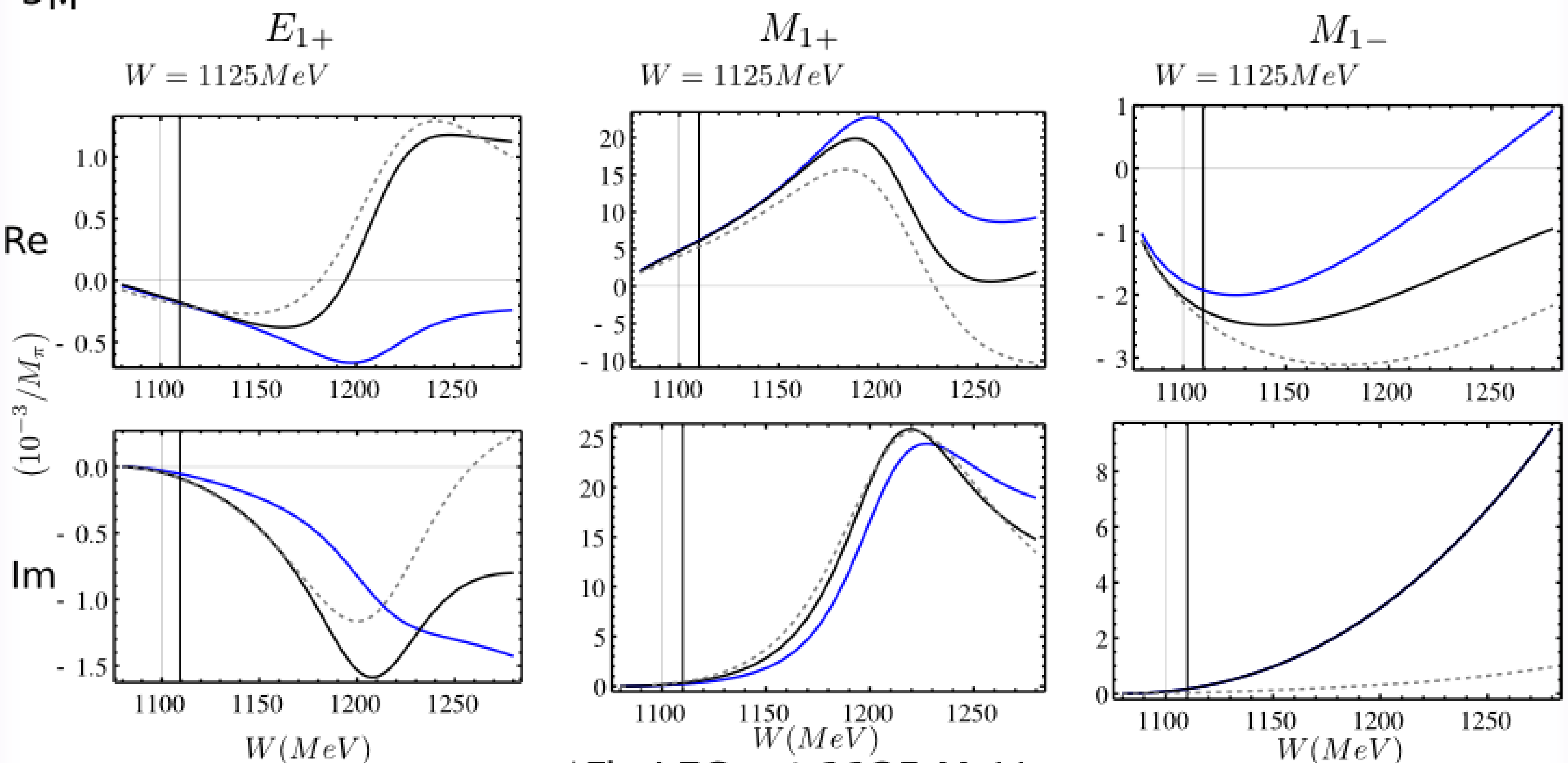
g_M=2.6 4th order H.B. Δ: Δ+ v.c.: MAID:



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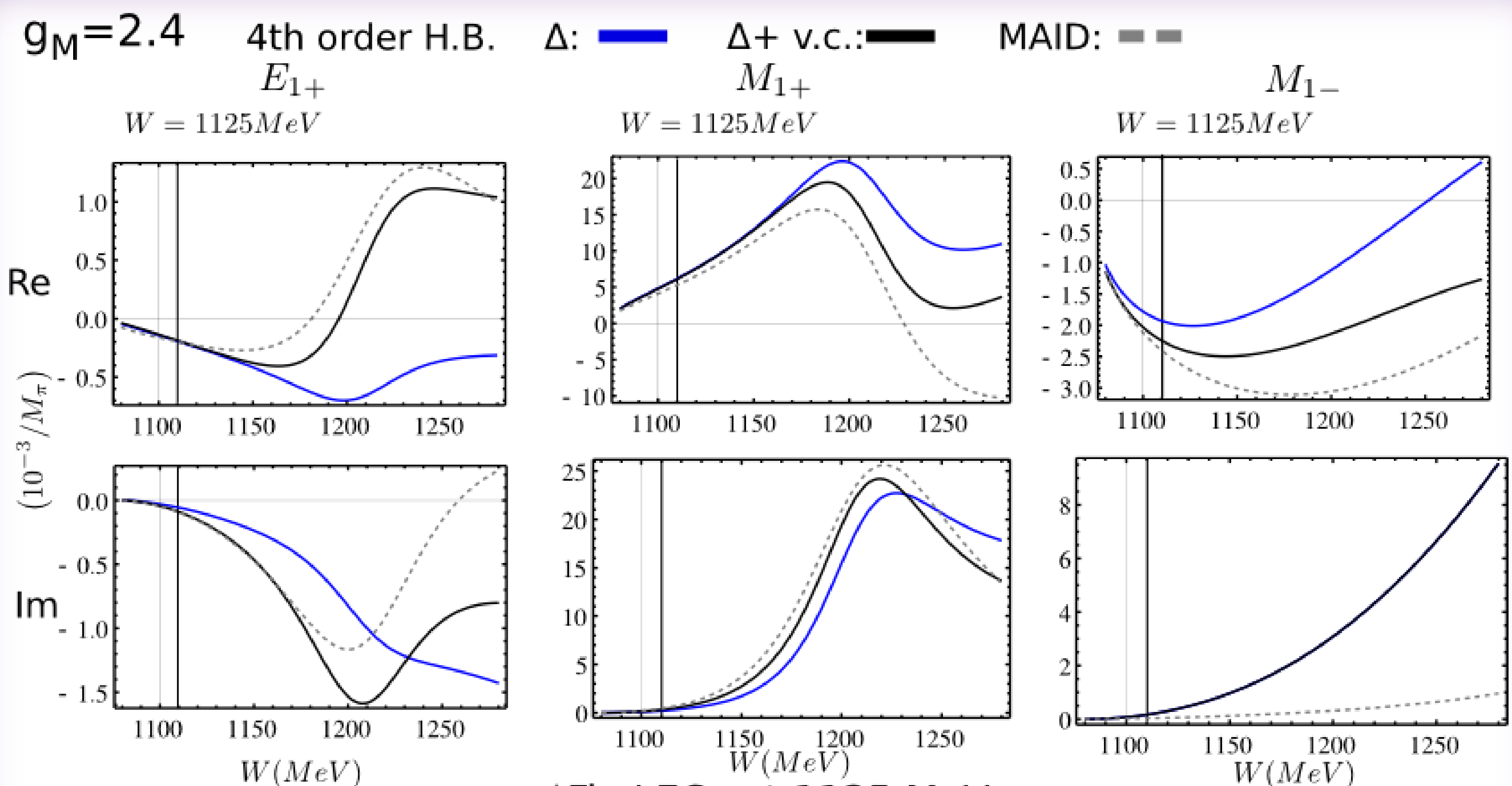

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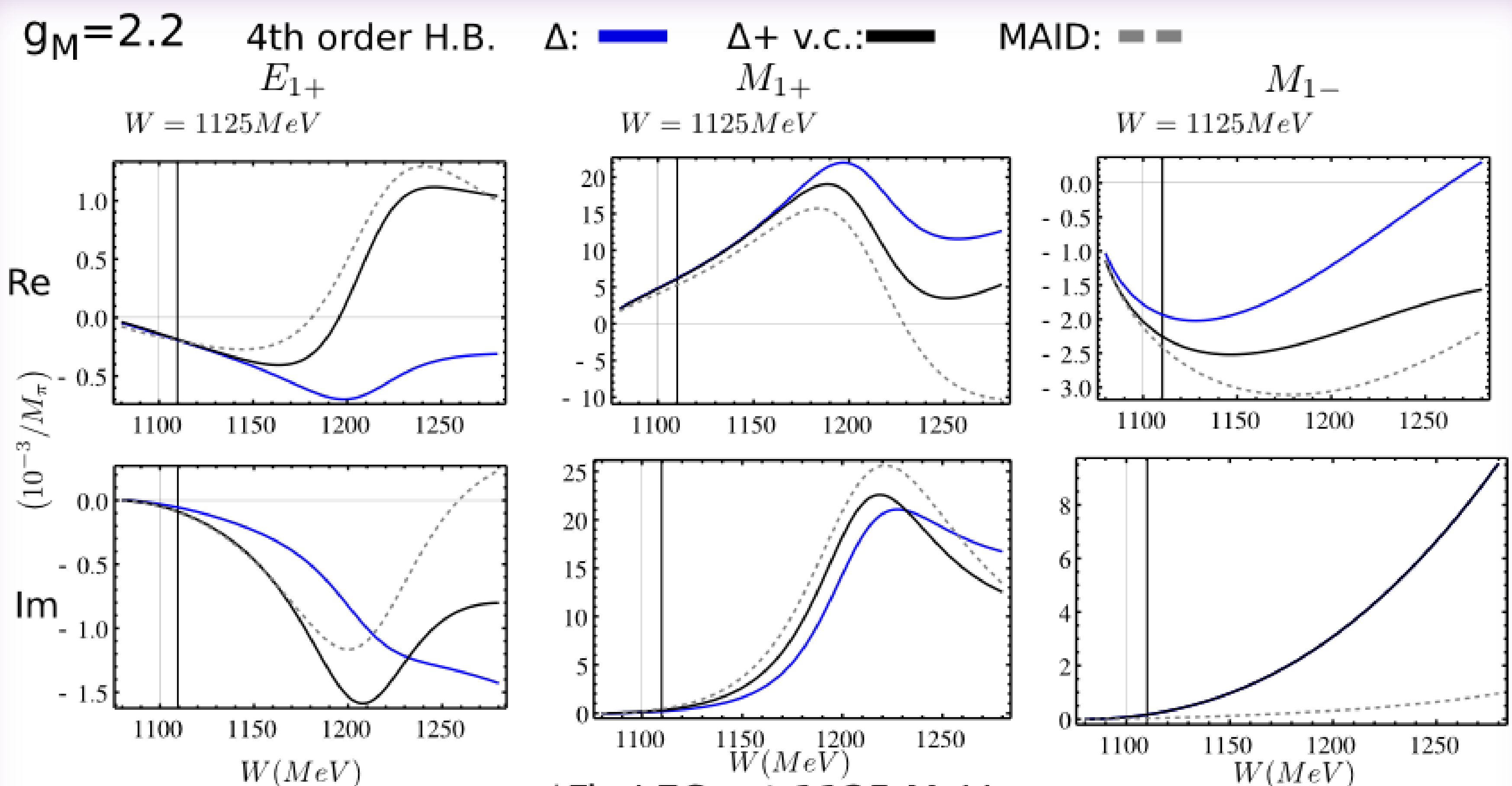

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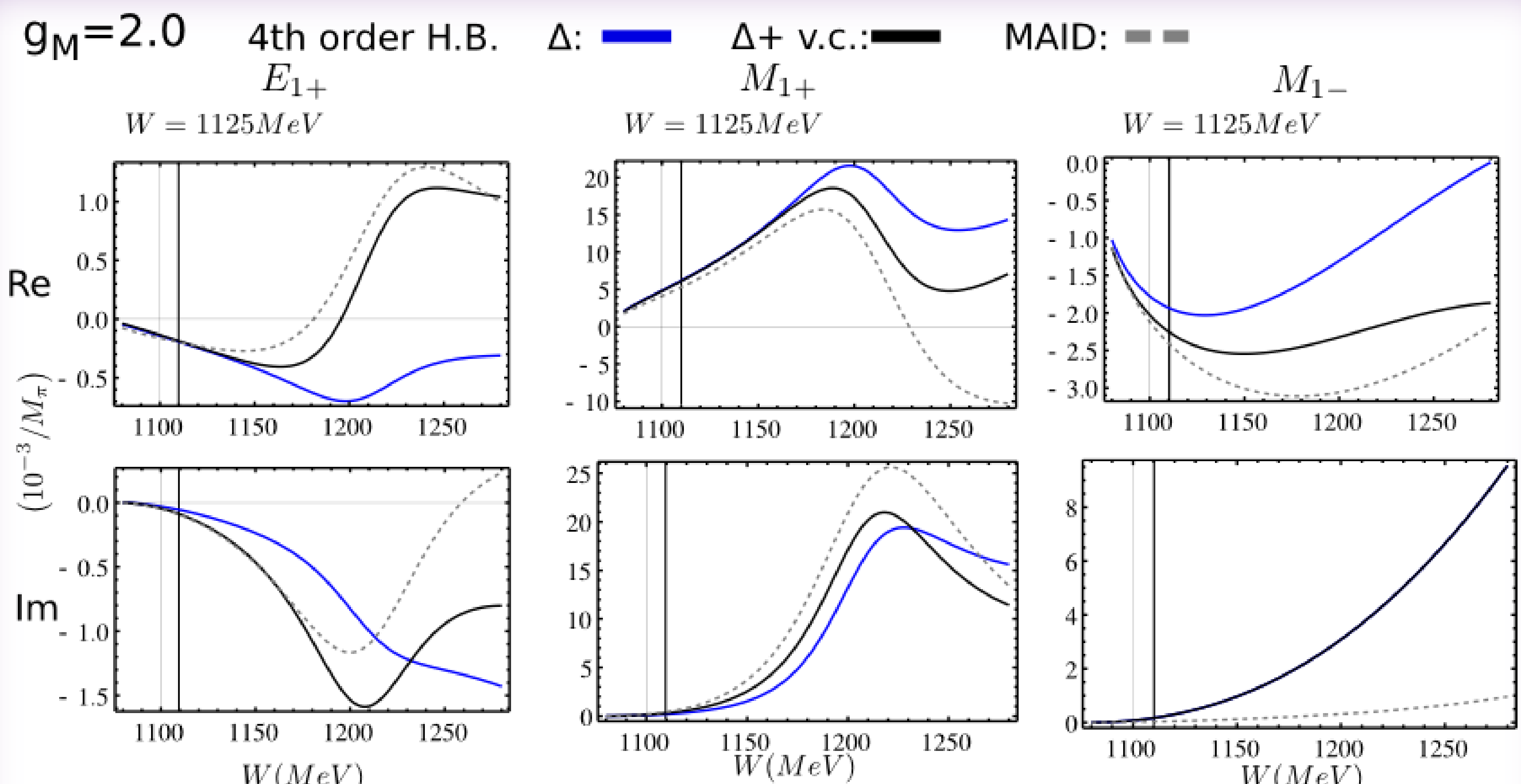

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Summary

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Thank you to David Hornidge for providing us with the data and the STFC for funding this work.

Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Lloyd W. Cawthorne
Judith A. McGovern

The University of Manchester

lloyd.cawthorne@postgrad.manchester.ac.uk

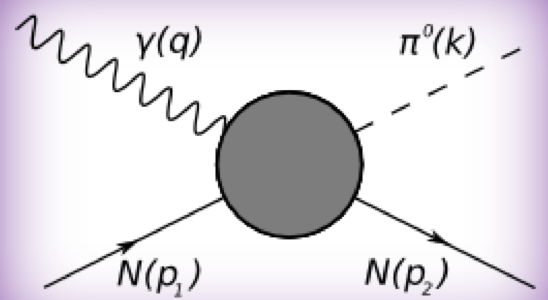
29th of June 2015

Importance of D-waves

Working to energies approaching Δ(1232)

Impact of the Δ(1232) in $\gamma+p \to \pi^0 p$ in χPT.

$\gamma+p \to \pi^0 p$



Has been studied using χPT since the early 90s.

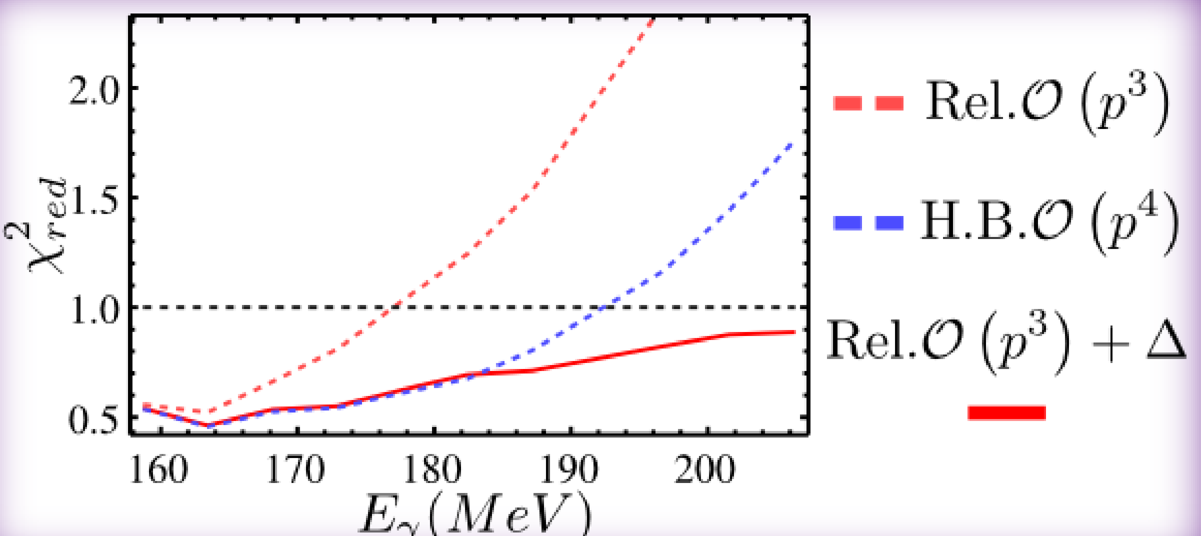
Requires the inclusion of pion loops for an adequate description.

More physics required to go beyond the threshold region.

More accurate studies can be performed thanks to data from MAMI.

$$\frac{d\sigma}{d\Omega} \qquad \Sigma = \frac{d\sigma^{\perp} - d\sigma^{\parallel}}{d\sigma^{\perp} + d\sigma^{\parallel}}$$

Hornidge et al (2013) PRL



Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Hybrid calculations.

4th order heavy baryon description.

Calculated for S and P-waves, up to L=1.

Bernard et al, (1996) Z. Phys; (2001) Eur. Phys. J.

3rd order covariant theory.

No truncation of angular momentum.

Can extract D-waves and beyond.

Bernard et al, (1992) Nucl. Phys. B; (1994) Phys. Rep.

4th order LECs used:

$$E_{0+}^{ct} = ea_2\omega^3 + ea_1\omega M_\pi^2$$

$$P_1^{ct} = \frac{eg_A|\vec{k}_\pi|\omega^2}{m_N\,(4\pi F_\pi)^3}\xi_1$$

$$P_2^{ct} = \frac{eg_A|\vec{k}_\pi|\omega^2}{m_N\,(4\pi F_\pi)^3}\xi_2$$

$$P_3^{ct} = e|\vec{k}_\pi|b_P\left(\omega - \frac{M_\pi^2}{2m}\right)$$

We extract the relativistic D-waves to construct a hybrid theory.

We expect D-waves to be supressed in the HB description.

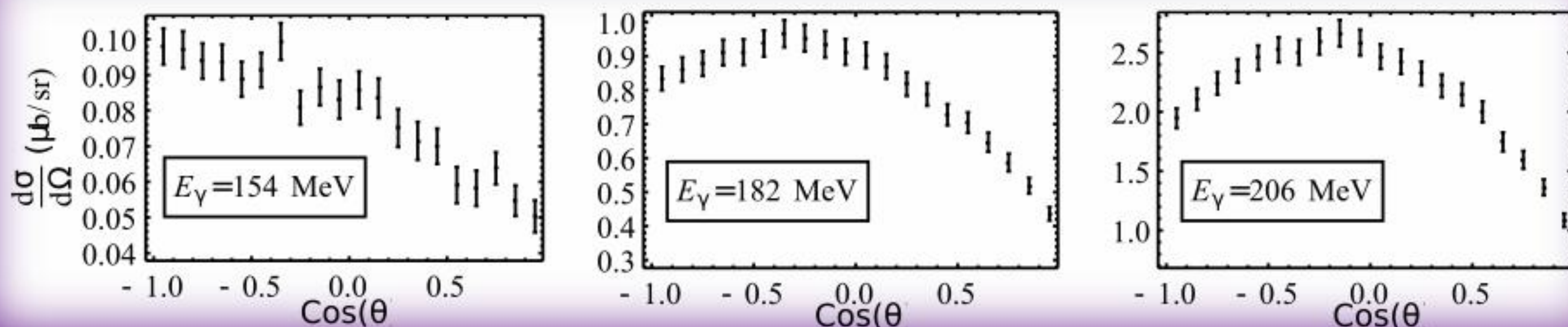
Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Details of Observables

$$\frac{|\vec{q_\gamma}|}{|\vec{k_\pi}|}\frac{d\sigma}{d\Omega_{cm}} = A + B\cos\theta + C\cos^2\theta + \ldots$$

Increasing energy allows access to more multipoles, changing the shape.

Looking at the data from MAMI:



Hornidge et al, (2013) PRL

$$\Sigma = \frac{d\sigma^\perp - d\sigma^\parallel}{d\sigma^\perp + d\sigma^\parallel} = \frac{|\vec{k}_\pi|\sin^2\theta}{2|\vec{q}_\gamma|}\left(\frac{d\sigma}{d\Omega_{cm}}\right)^{-1}\left(|P_3|^2 - |P_2|^2 + \ldots\right)$$

How important are D-waves? (and higher?)

$$\frac{|\vec{q}_\gamma|}{|\vec{k}_\pi|}\frac{d\sigma}{d\Omega_{cm}} = T_0(W) + T_1(W)\mathcal{P}_1(\theta) + T_2(W)\mathcal{P}_2(\theta) + T_3(W)\mathcal{P}_3(\theta) + \ldots$$

$$T_0 = S\times S + P\times P + D\times D + \ldots$$

$$T_1 = S\times P + P\times P + D\times F + \ldots$$

$$T_2 = S\times D + P\times P + D\times D + P\times F\ldots$$

$$T_3 = P\times D + \ldots \quad T_4 = D\times D + \ldots$$

D-wave amplitudes are small.

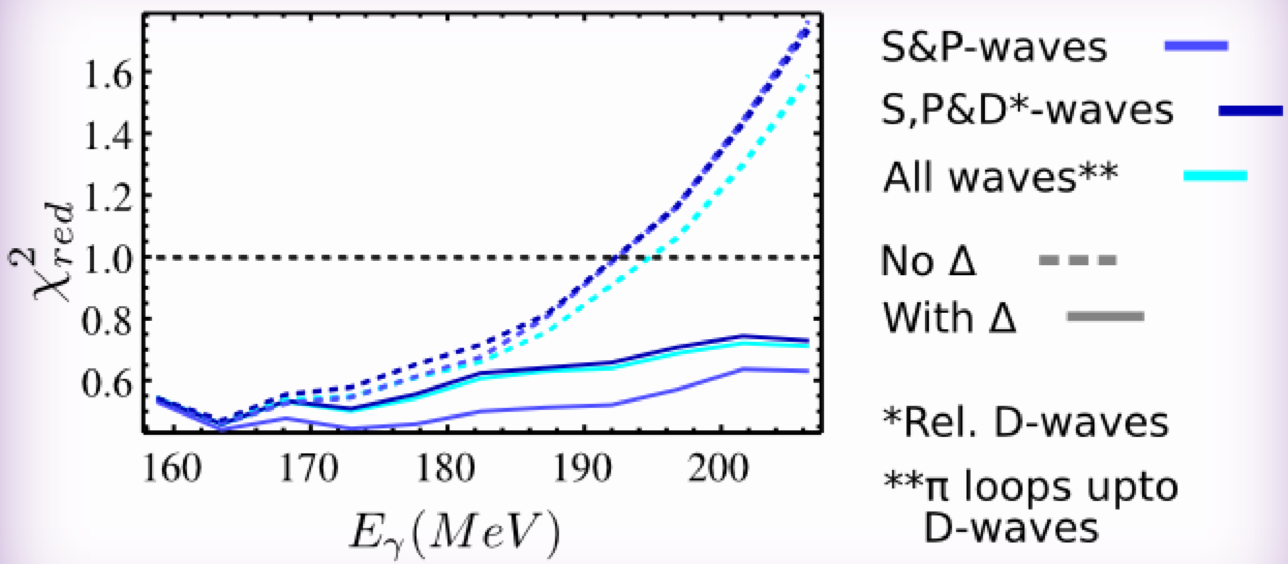
Interference from D-waves might not be.

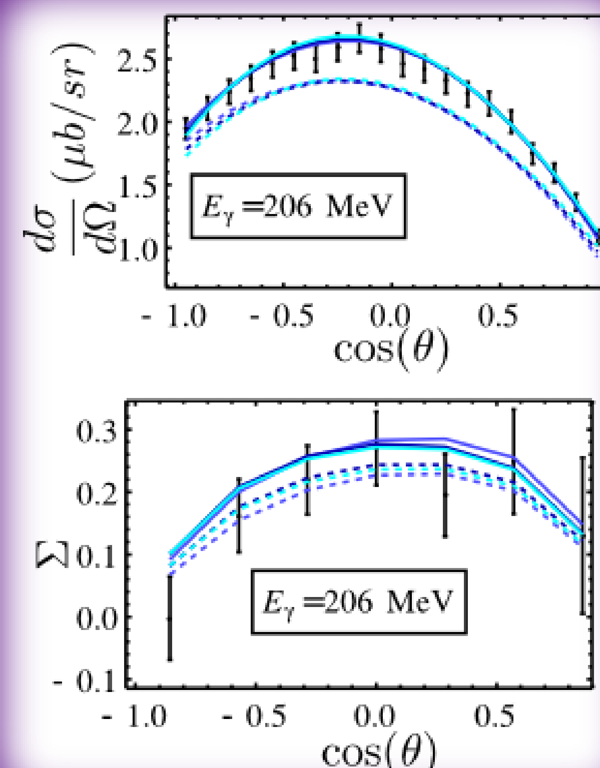
Fernández-Ramírez, et al. (2009) Phys. Rev. C.

Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Effects of D-waves (and higher)

The effects of D-waves (and beyond) are small.





The small effect of L=2 states (and above) are dwarfed by the Δ.

Working to higher energies

One can include π loop diagrams containing a Δ propogator.

Close to threshold: $\omega \sim M_\pi \approx 140 MeV$ SB scale: $\Lambda_{SB} \approx 700 MeV$

Mass difference: $\Delta_M = m_\Delta - m_N \approx 290 MeV$ $M_\pi \ll \Delta_M$

Two scales:

$$P = \frac{M_\pi}{\Lambda} \approx 0.2$$

$$\epsilon = \frac{\Delta_M}{\Lambda} \approx 0.4$$

$$\delta \approx \frac{\Delta_M}{\Lambda} \approx \left(\frac{M_\pi}{\Lambda}\right)^{1/2}$$

$$P \approx \delta^2$$

Propagator: $S_\Delta(\omega \sim M_\pi) \propto \frac{1}{\Delta_M \pm \omega}$ scales as δ^{-1}

Pascalutsa, et al. (2006), Phys. Rev. D

Impact of the Δ(1232) in $\gamma + p \to \pi^0 p$ in χPT.

Two energy regimes

Close to threshold: $\omega \sim M_\pi$ $P \approx \delta^2$

Close to resonance: $\omega \sim \Delta_M$

Scales change: $P = \frac{\omega}{\Lambda} \approx \frac{\Delta_M}{\Lambda} = \delta$

Propagator:

$$S_\Delta \left(\omega \sim \Delta_M\right) \propto \frac{1}{\Delta_M + i\mathrm{Im}\Sigma_\Delta - \omega}$$

Self energy: Σ_Δ

given by:

scales as: δ^3

$S_\Delta(\omega \sim \Delta_M)$ scales as: δ^{-3}

Pascalutsa, et al. (2006) Phys. Rev. D

Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

γNΔ vertex corrections

Order of diagrams changes with energy.

Tree level:

$\omega \sim M_\pi \quad eP^2\delta^{-1} \longrightarrow e\delta^3$

$\omega \sim \Delta_M \quad eP^2\delta^{-3} \longrightarrow e\delta^{-1}$

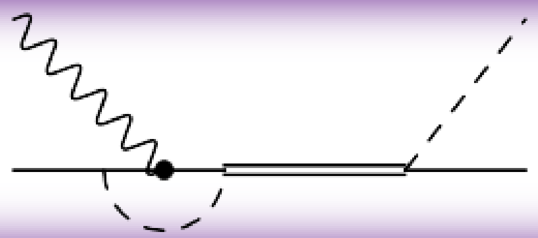
$eP^2\delta^{-1} \longrightarrow e\delta^3$

$eP^2\delta^{-1} \longrightarrow e\delta$

Loop corrections:

$\omega \sim M_\pi \quad eP^3\delta^{-1} \longrightarrow e\delta^5$

$\omega \sim \Delta_M \quad eP^3\delta^{-3} \longrightarrow e\delta^0$



$eP^4\delta^{-1} \longrightarrow e\delta^6$

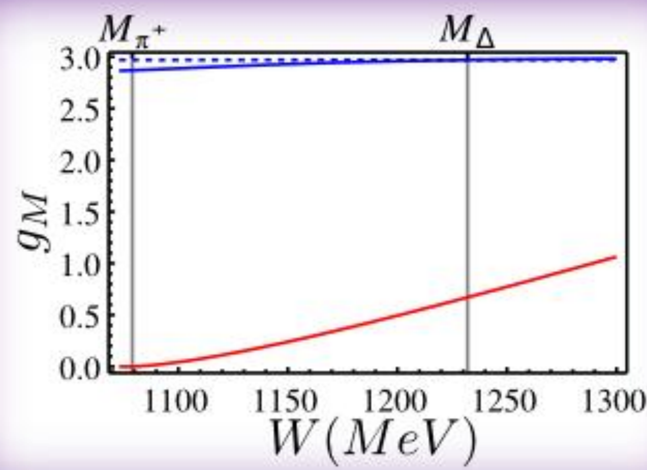
$eP^4\delta^{-3} \longrightarrow e\delta$

McGovern, et al. (2013) Eur. Phys. J; Pascalutsa, et al. (2006) Phs. Rev. D

Impact of the Δ(1232) in $\gamma+p \to \pi^0 p$ in χPT.

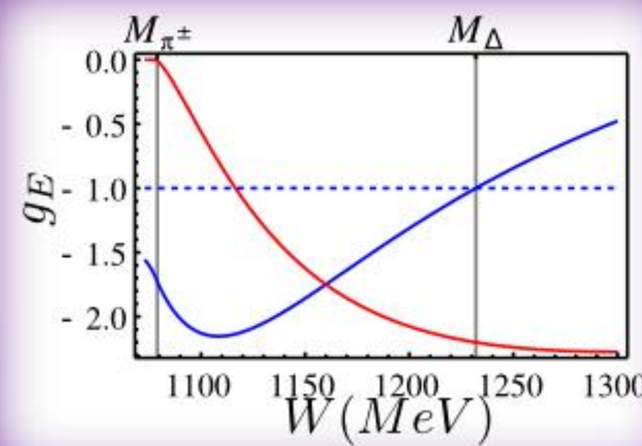
Effects of γNΔ vertex corrections

The corrections are implemented by scaling the coupling constants with energy

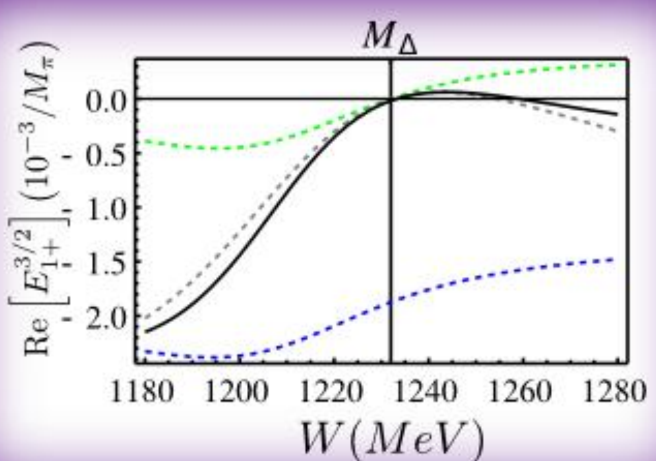


Re:
Im:
No corrections:

McGovern, et al. (2013) Eur. Phys. J.

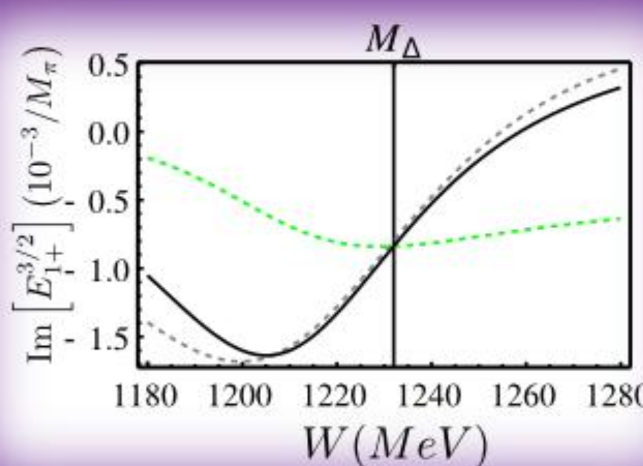


They restore Watson's theorem.

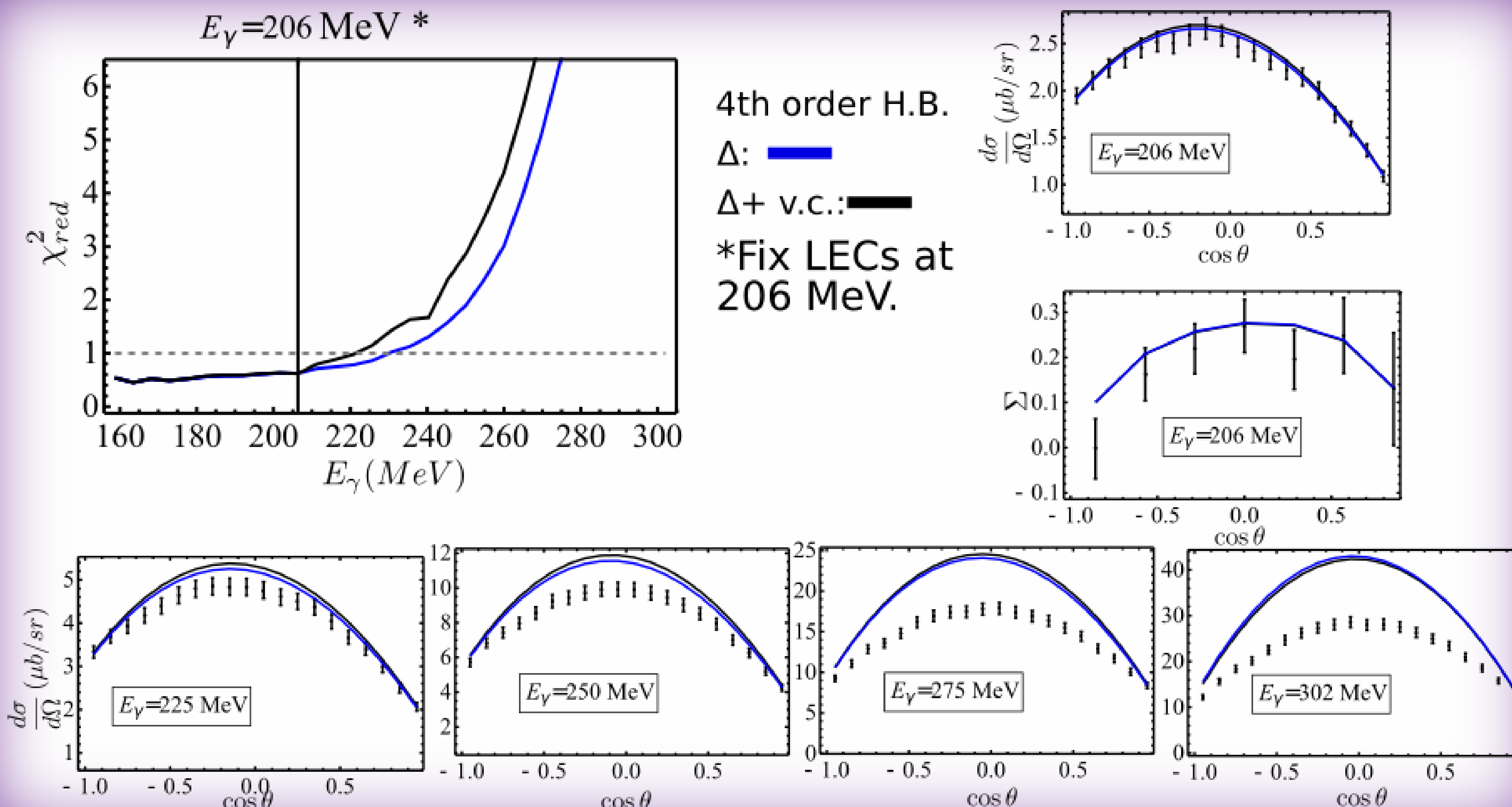


MAID:
Δ:
Δ+Tree:
Δ+Tree +V.C.:

Pascalutsa, et al. (2006) Phys. Rev. D



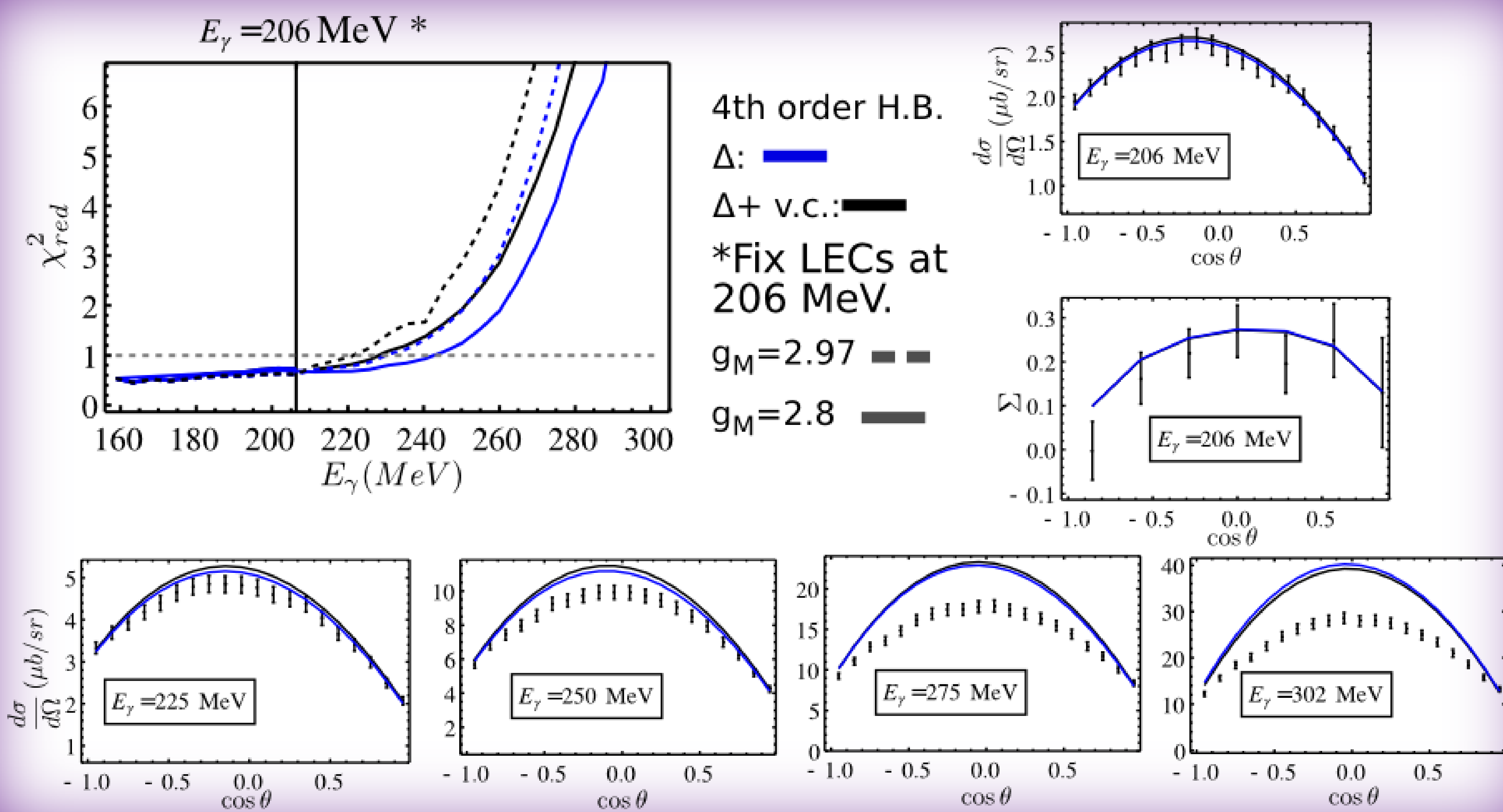
Results from corrections



We are overestimating the data. Can we do better?

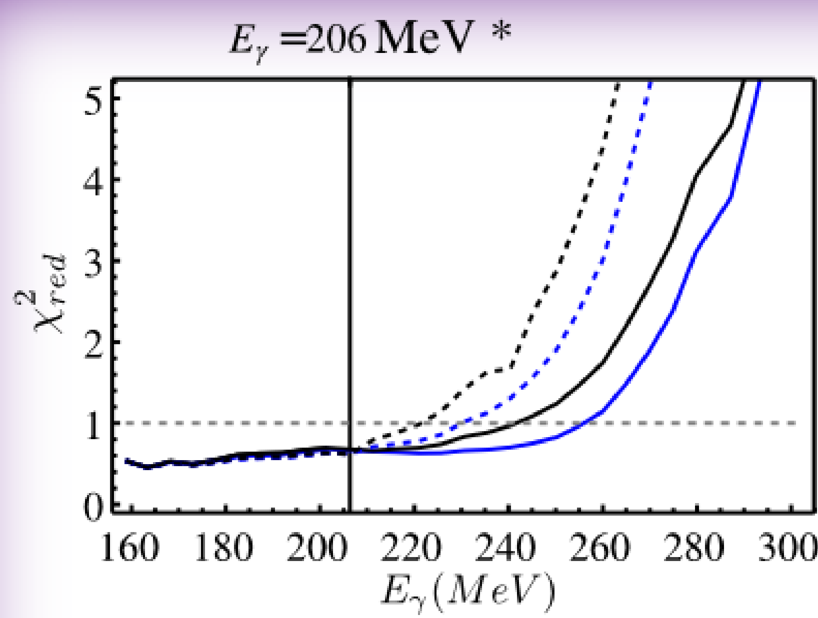
Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Varying g_M



Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Varying g_M



4th order H.B.

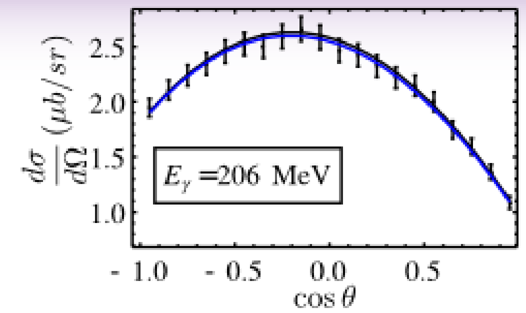
Δ: (blue line)

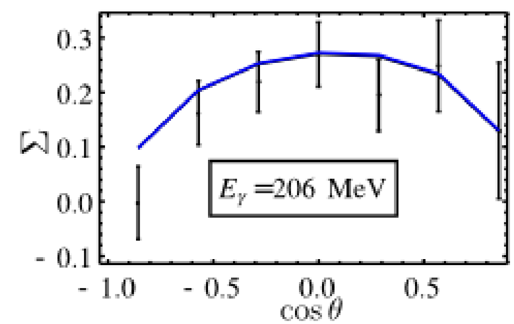
Δ+ v.c.: (black line)

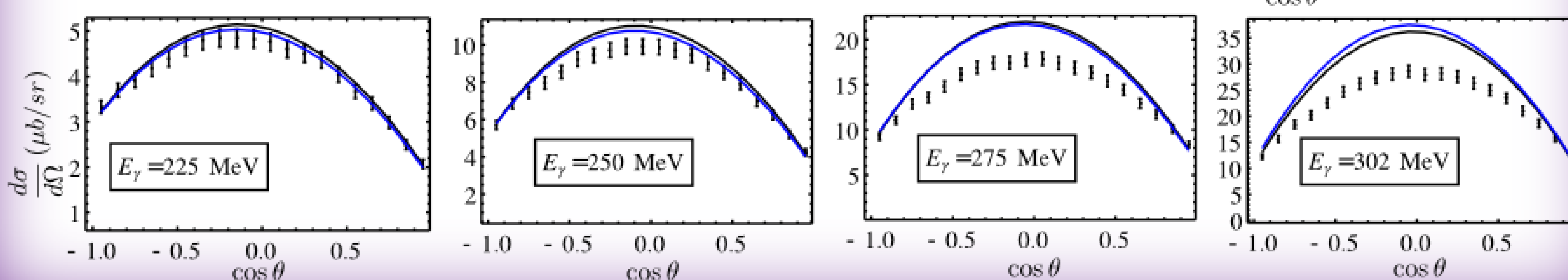
*Fix LECs at 206 MeV.

g_M=2.97 (dashed)

g_M=2.6 (solid)

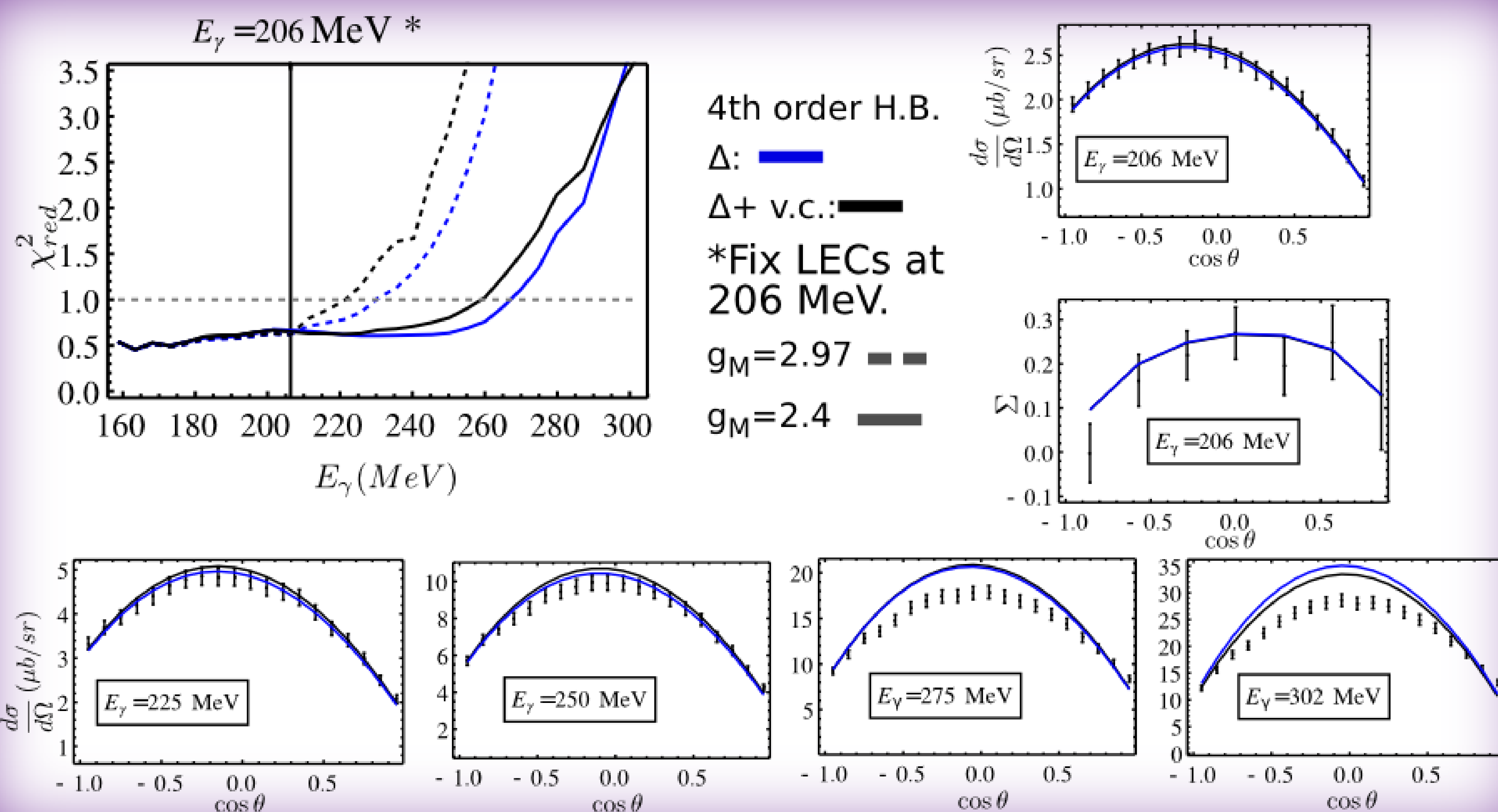






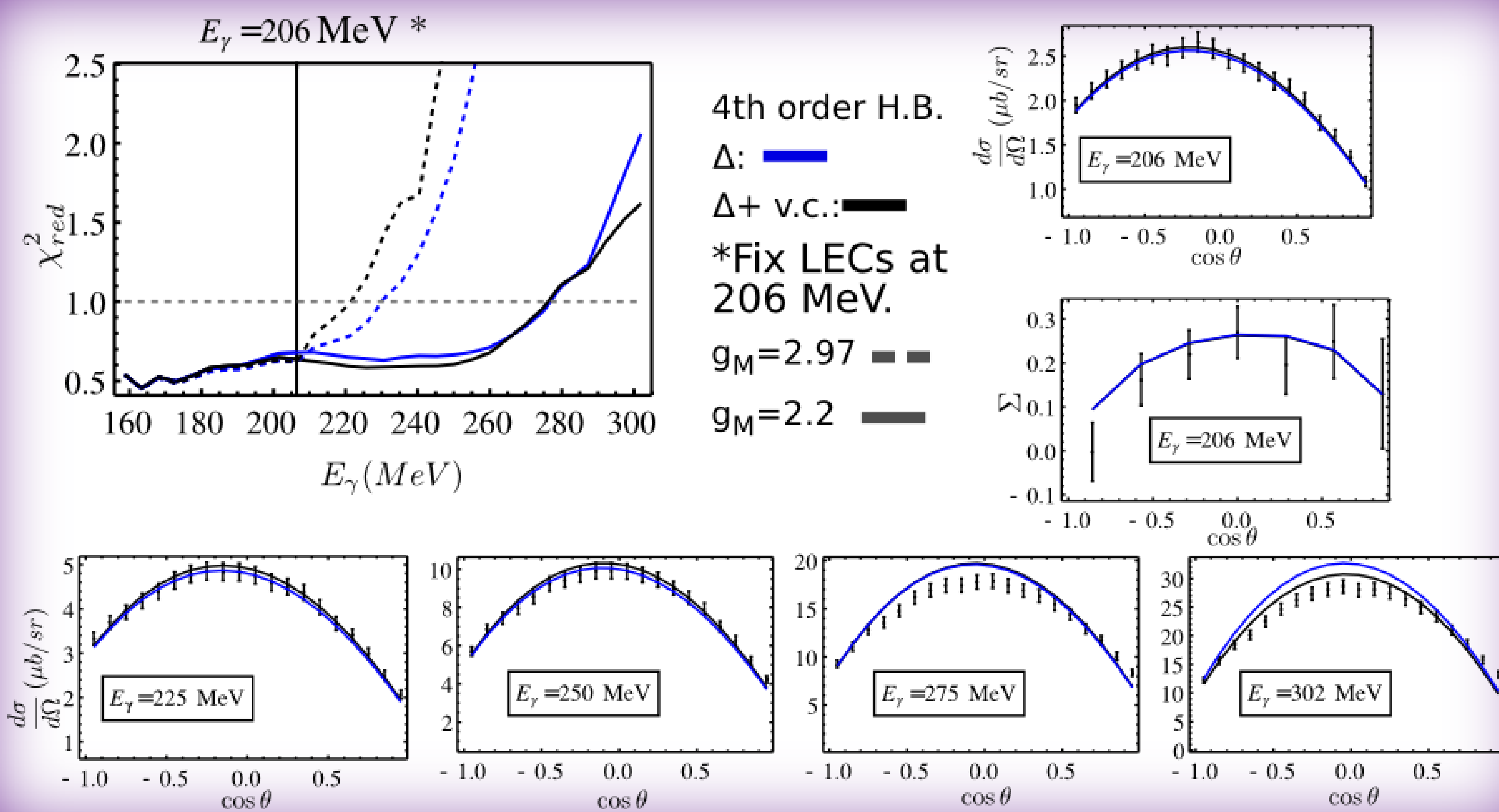
Impact of the Δ(1232) in $\gamma + p \to \pi^0 p$ in χPT.

Varying g_M



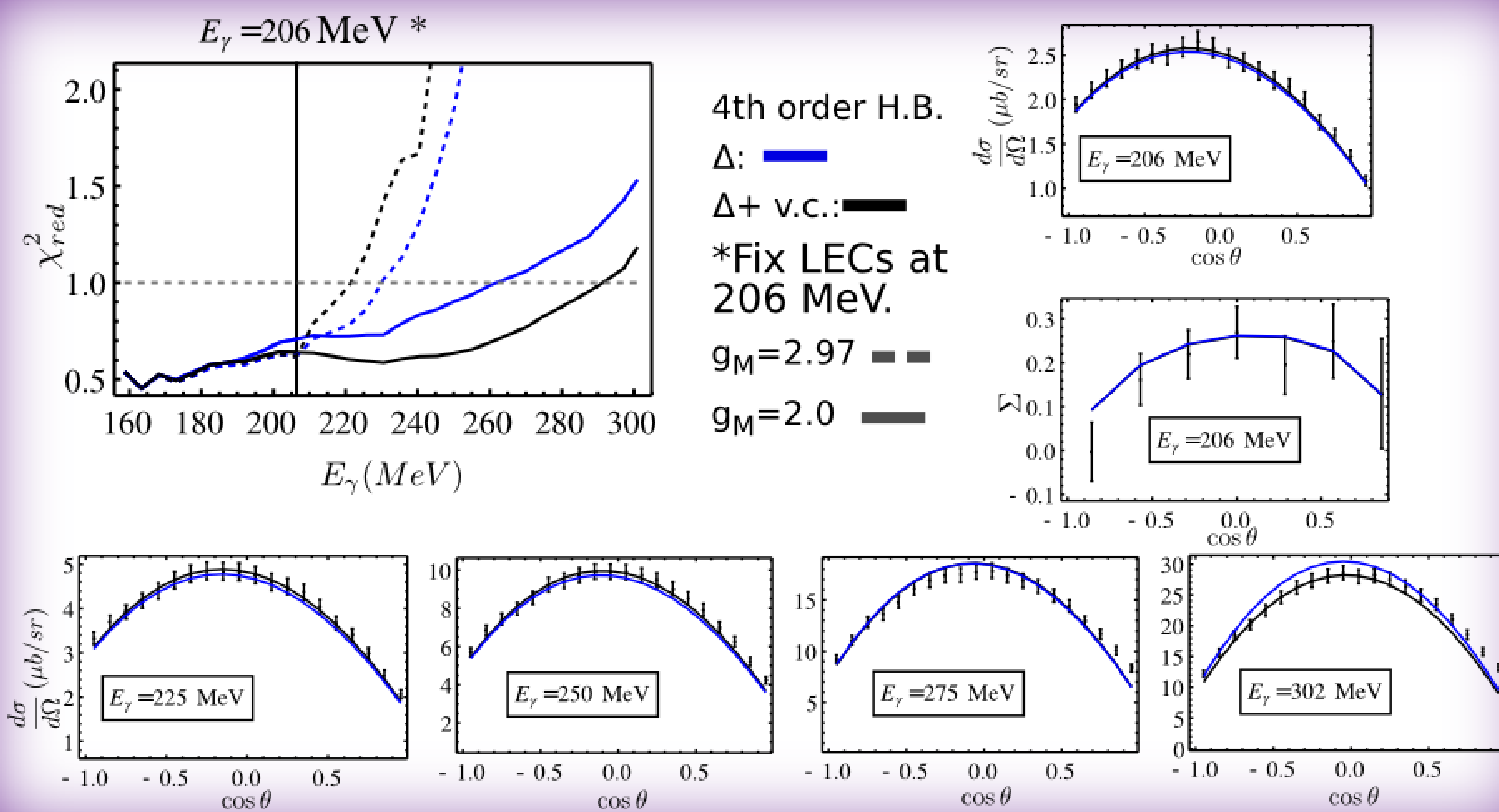
Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Varying g_M



Impact of the Δ(1232) in $\gamma + p \to \pi^0 p$ in χPT.

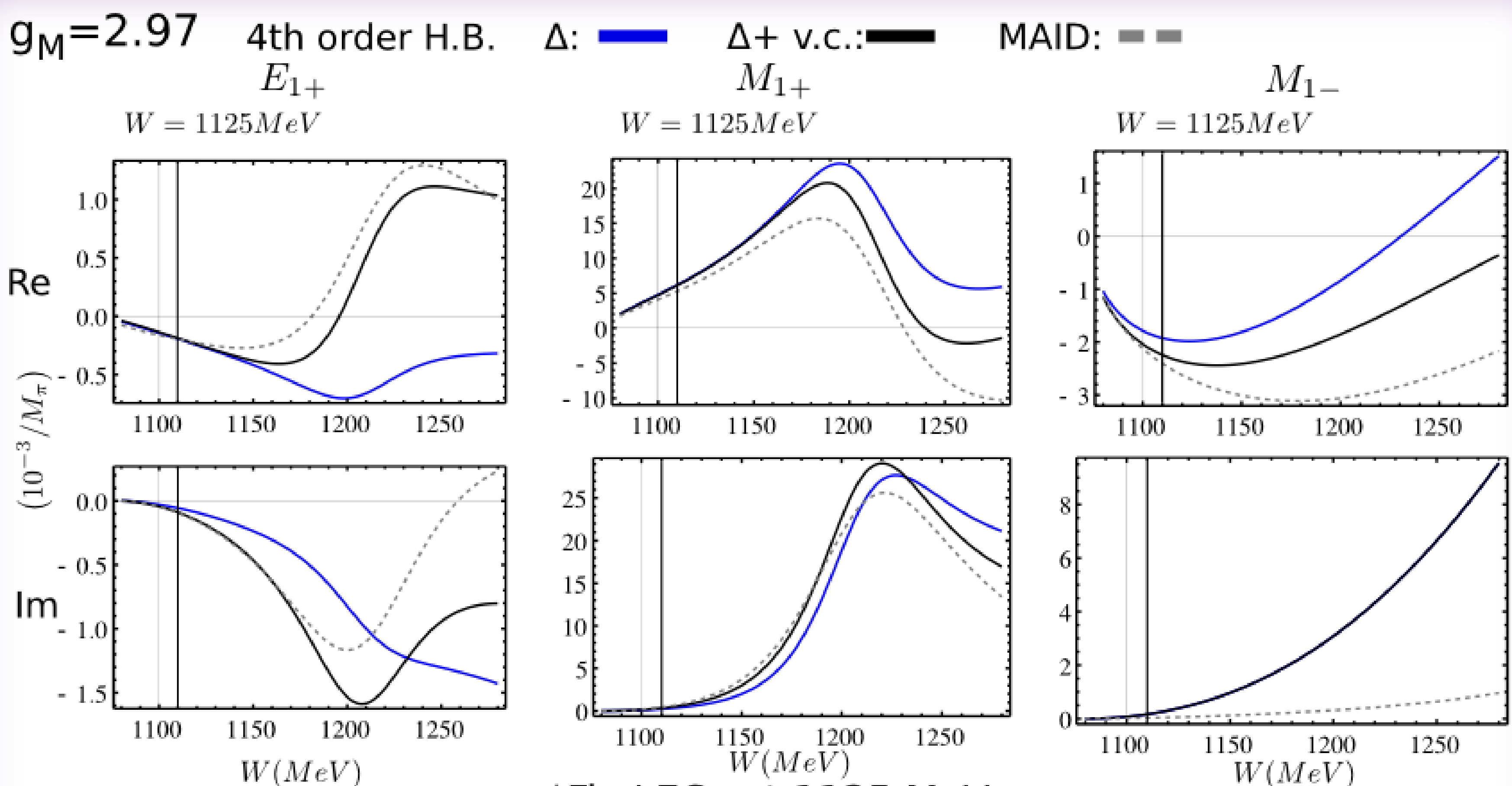
Varying g_M



Are we free to vary g_M so much?

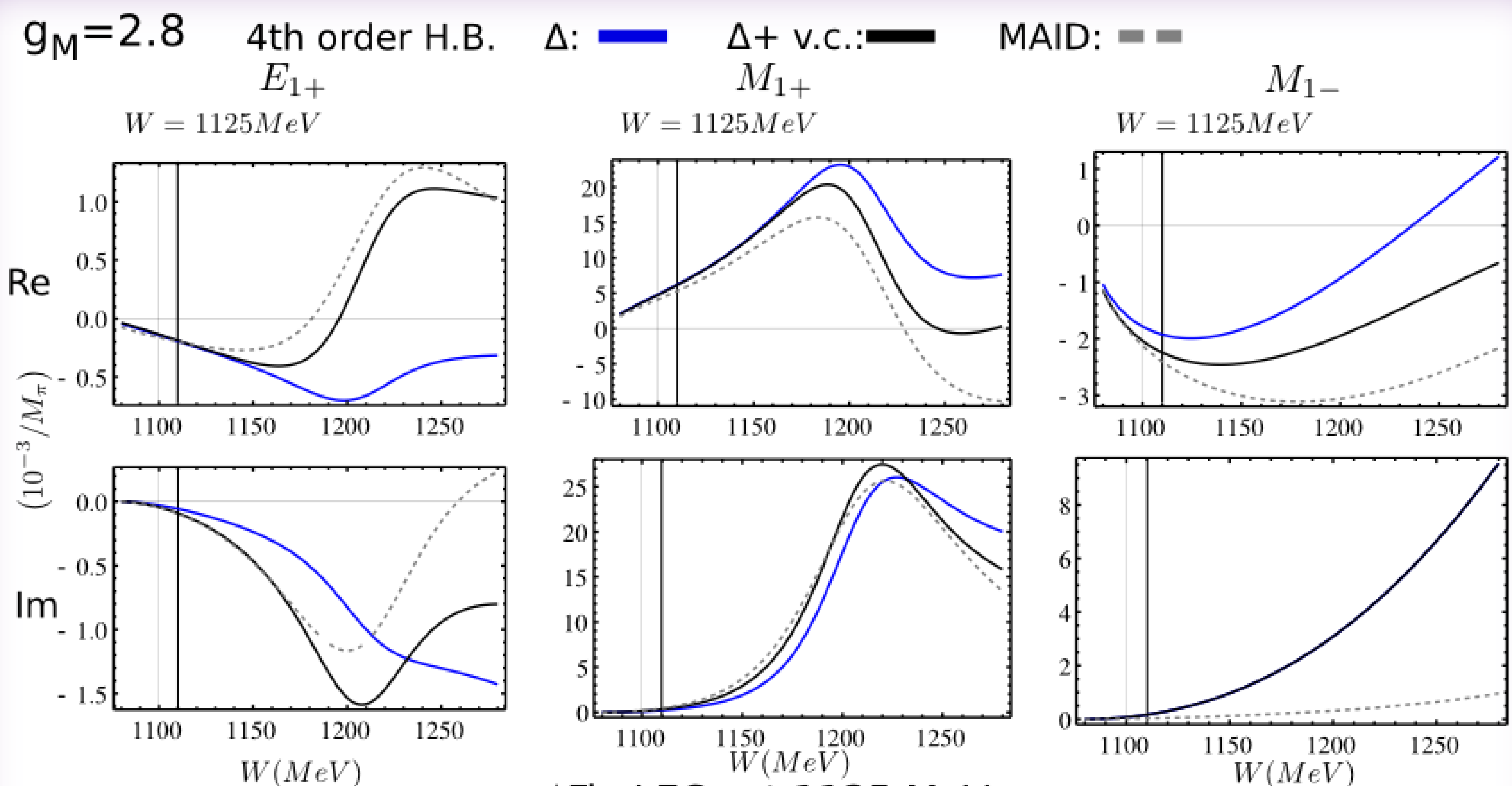
Impact of the Δ(1232) in $\gamma + p \rightarrow \pi^0 p$ in χPT.

Sanity check



*Fix LECs at 1125 MeV.

Sanity check

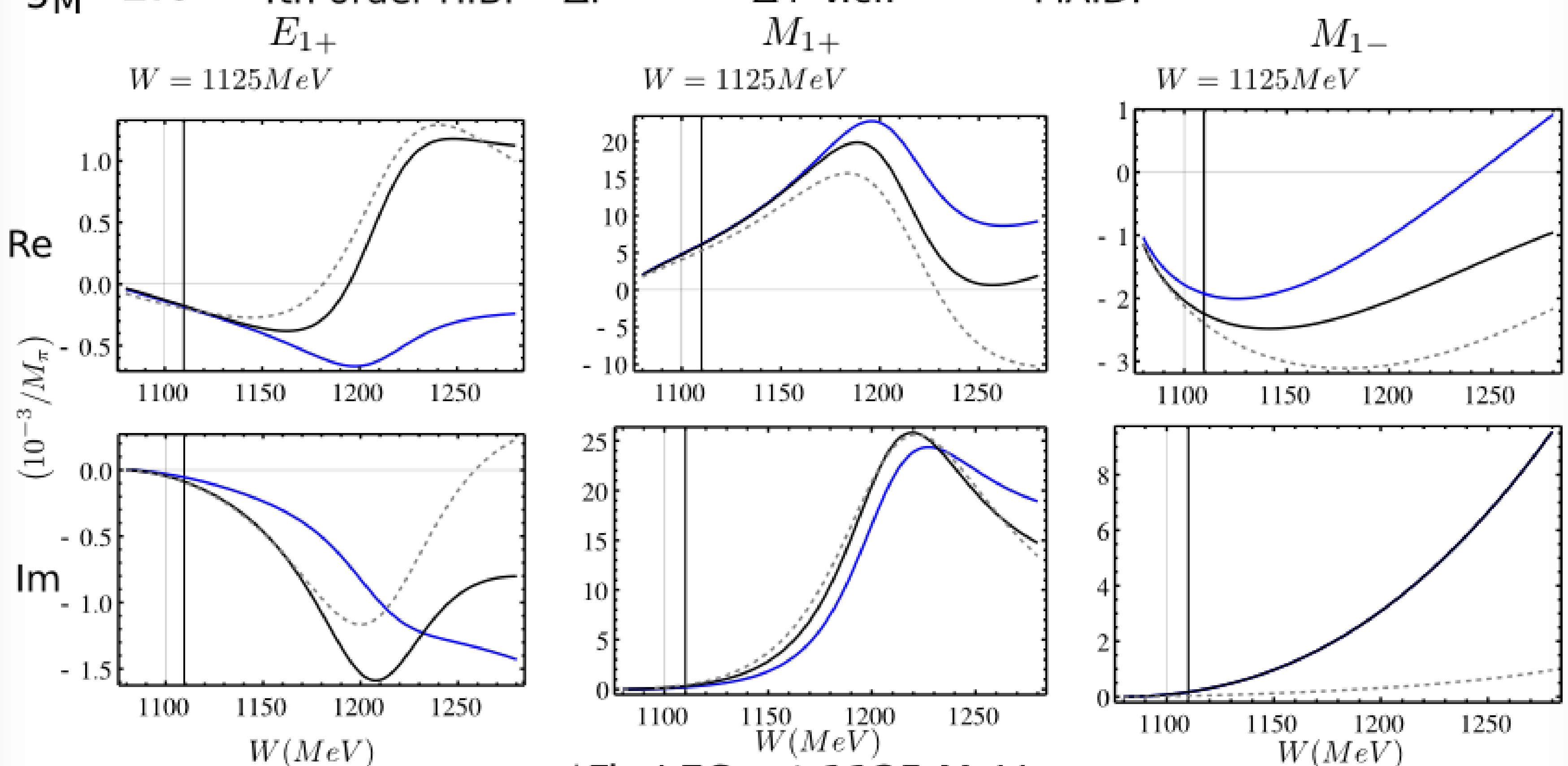


*Fix LECs at 1125 MeV.

Impact of the Δ(1232) in $\gamma+p \rightarrow \pi^0 p$ in χPT.

Sanity check

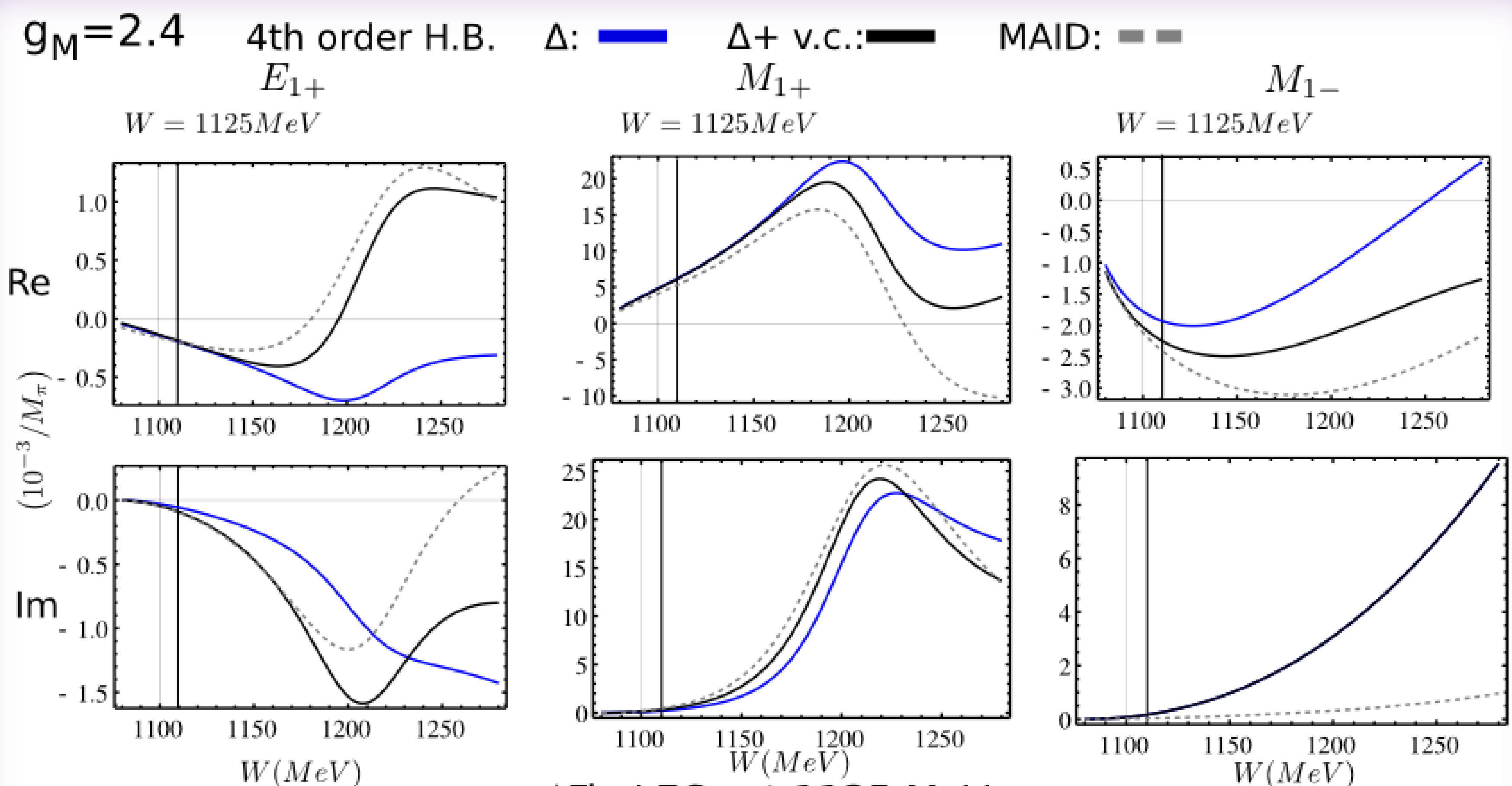
g_M=2.6 4th order H.B. Δ: Δ+ v.c.: MAID:



*Fix LECs at 1125 MeV.

Impact of the Δ(1232) in $\gamma+p \to \pi^0 p$ in χPT.

Sanity check



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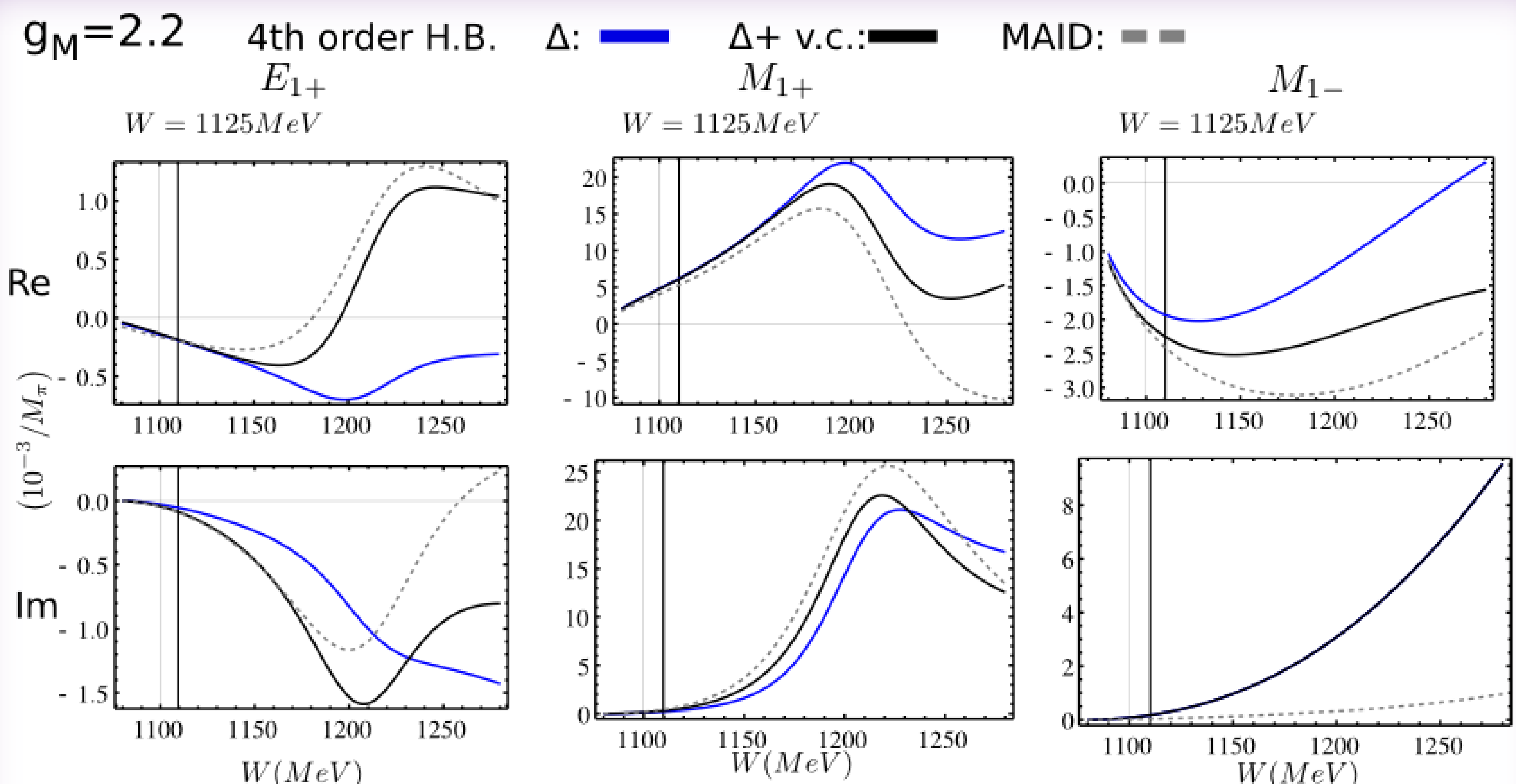
Impact of the Δ(1232) in $\gamma+p \rightarrow \pi^0 p$ in χPT.

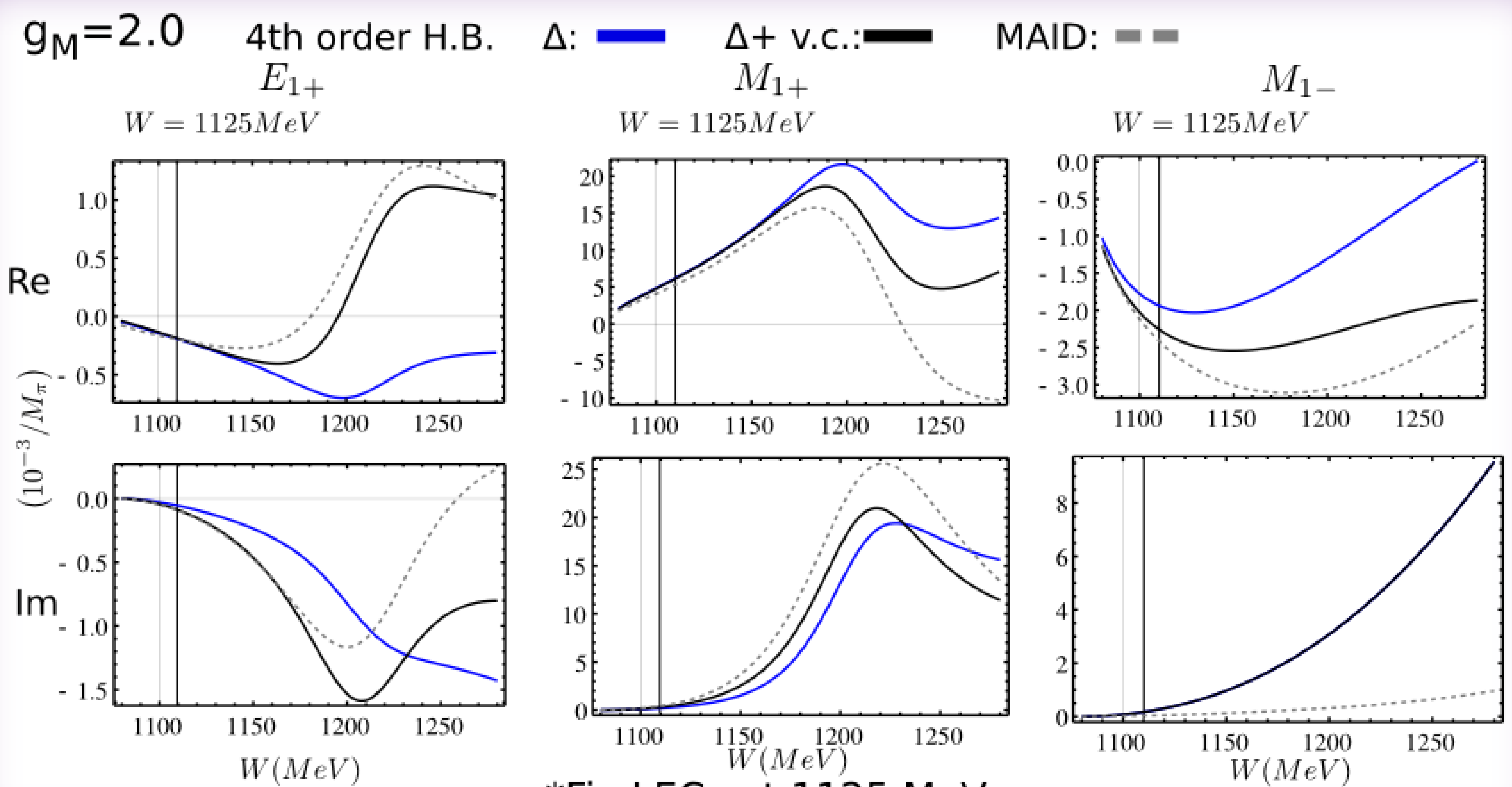
Sanity check



*Fix LECs at 1125 MeV.

Impact of the Δ(1232) in $\gamma+p \rightarrow \pi^0 p$ in χPT.

Sanity check



*Fix LECs at 1125 MeV.

Summary

It is possible to describe neutral pion photoproduction from threshold to energies approaching the Δ(1232) resonance.

D-waves (and higher) do not appear to have a significant impact once the Delta is included. More data on more observables could change this.

Vertex corrections to γNΔ coupling constants show good agreement with data at high energies..

Extend 4th order heavy baryon calculations to all states of angular momentum.

Test theories against data at even higher energies.

Thank you to David Hornidge for providing us with the data and the STFC for funding this work.