THE UPPER ENERGY LIMIT OF CHPT IN PION PHOTOPRODUCTION

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OUTLOOK

- Introduction
- Observable Structure
- Multipole Description
- Results
- Summary and future

INTRODUCTION

INTRODUCTION

- High quality data make obsolete previous experiments
- Most accurate experiment for the cross section
- Experiment designed to pin down P waves: photon asymmetry
- We are in a perfect situation to test CHPT

OBSERVABLE STRUCTURE

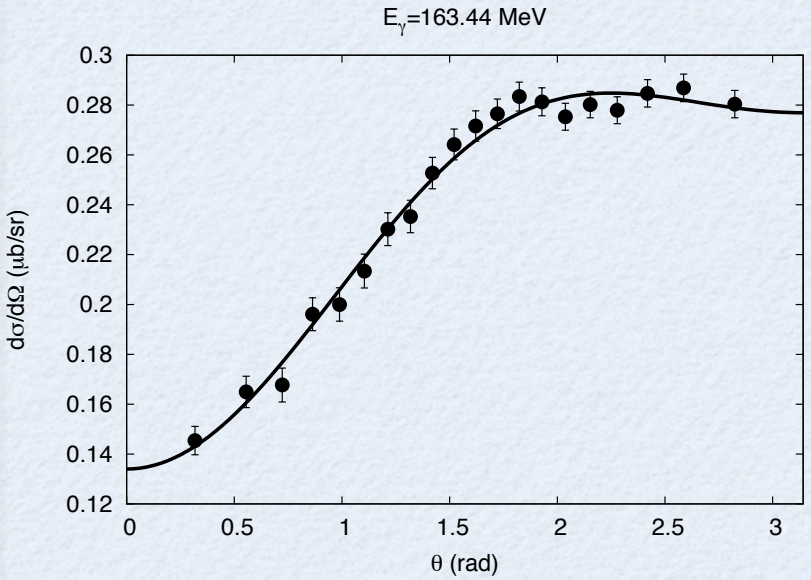
OBSERVABLE EXPANSION

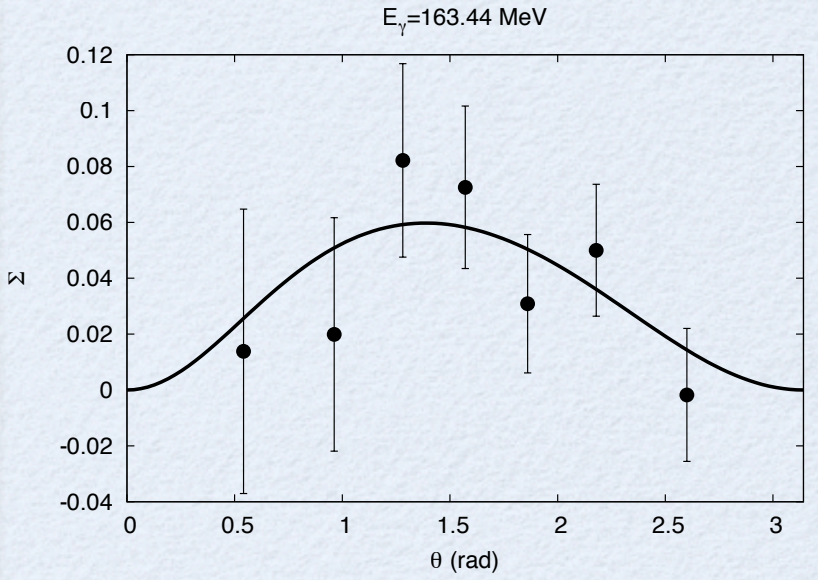
$$W_T(W,\theta) \equiv T_0(W) + T_1(W)\mathcal{P}_1(\theta) + T_2(W)\mathcal{P}_2(\theta) + T_3(W)\mathcal{P}_3(\theta) + T_4(W)\mathcal{P}_4(\theta)$$

$$W_S(W,\theta) \equiv [S_0(W) + S_1(W)\mathcal{P}_1(\theta) + S_2(W)\mathcal{P}_2(\theta)]\sin^2\theta$$

$$\sigma_T(W,\theta) \equiv \frac{q_\pi}{k_\gamma} W_T(W,\theta)$$

$$\Sigma(W,\theta) \equiv -\frac{W_S(W,\theta)}{W_T(W,\theta)}$$





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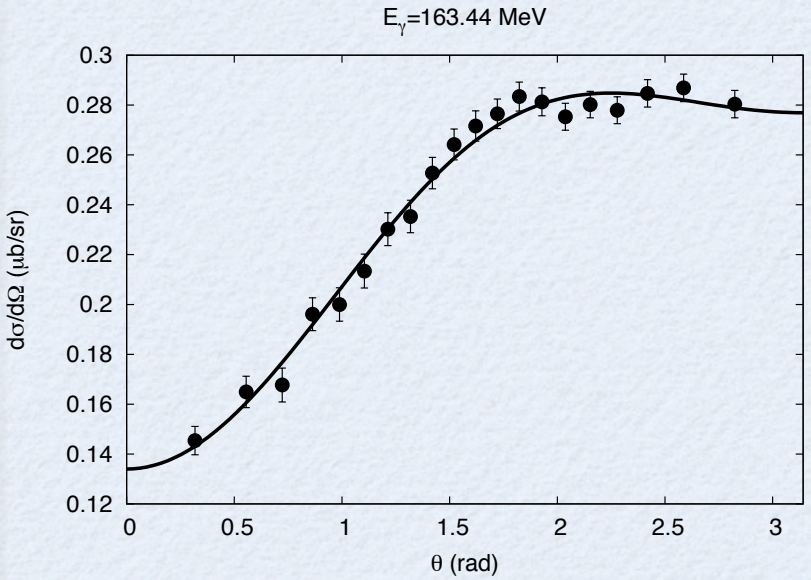

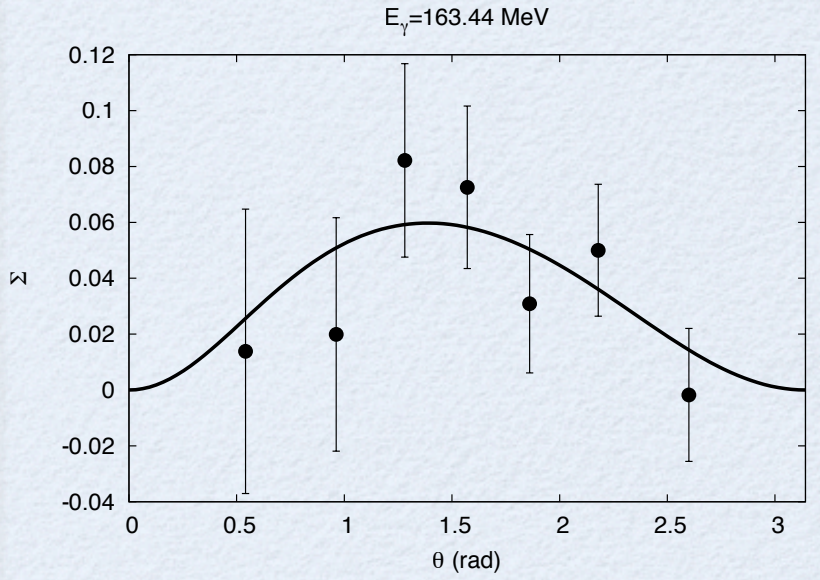

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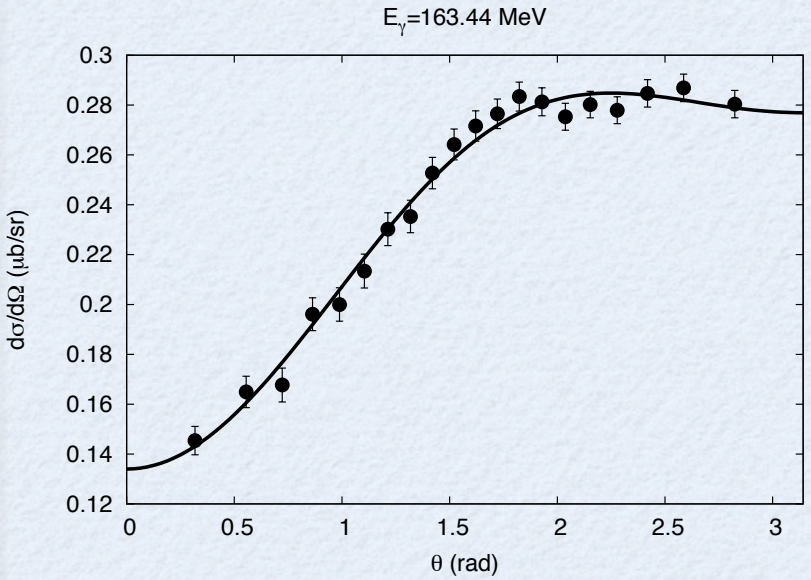

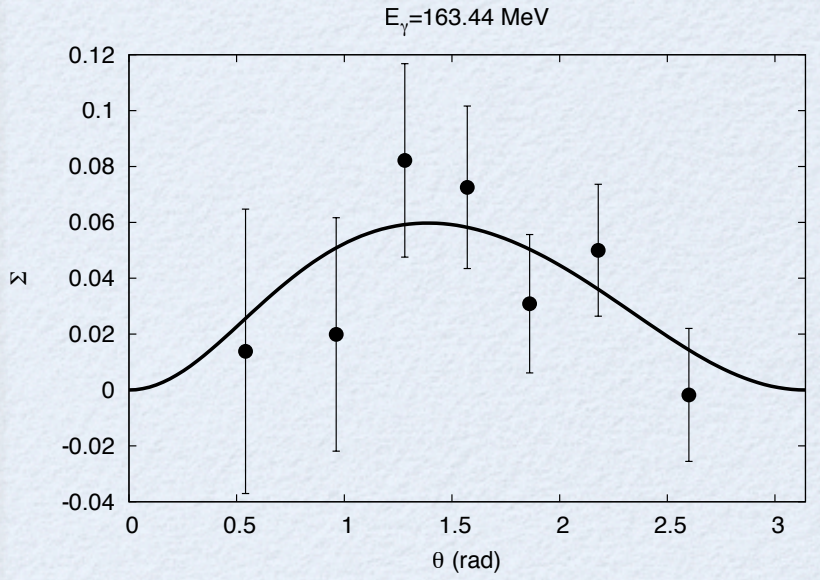

MULTIPOLE STRUCTURE

$$
\begin{aligned}
T_0 &= S \times S + P \times P + D \times D + F \times F + \ldots \\
T_1 &= S \times P + P \times D + D \times F + F \times G + \ldots \\
T_2 &= S \times D + P \times P + D \times D + P \times F + \ldots \\
T_3 &= P \times D + \ldots \\
T_4 &= D \times D + \ldots
\end{aligned}
$$

$$
\begin{aligned}
S_0 &= P \times P + S \times D + \ldots \\
S_1 &= P \times D + \ldots \\
S_2 &= D \times D + \ldots
\end{aligned}
$$

MULTIPOLE STRUCTURE

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

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

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

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

$$T_4 = D \times D + \ldots$$

$$S_0 = P \times P + S \times D + \ldots$$

$$S_1 = P \times D + \ldots$$

$$S_2 = D \times D + \ldots$$

MULTIPOLE STRUCTURE

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

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$$S_0 = P \times P + S \times D + \ldots$$

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MULTIPOLE STRUCTURE

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$$S_1 = P \times D + \ldots$$

$$S_2 = D \times D + \ldots$$

MULTIPOLE DESCRIPTION

MULTIPOLE DESCRIPTION

- Empirical
- HBCHPT

  Bernard, Kaiser, Meißner, Z. Phys. C70, 483 (1996); EPJA11, 209 (2001)
- BCHPT

  Hilt, Scherer, Tiator, private communication (2012)

- Energy range?

UNITARY CUSP

$$E_{0+} = e^{i\delta_0}\left[A_0 + i\beta q_+/m_{\pi^+}\right] ; W > W_{thr}(\pi^+ n)$$
$$E_{0+} = e^{i\delta_0}\left[A_0 - \beta\,|q_+|\,/m_{\pi^+}\right] ; W < W_{thr}(\pi^+ n)$$

$$\beta = E_{0+}(\gamma p \to \pi^+ n) \times a(\pi^+ n \to \pi^0 p)$$

$$a(\pi^- p \to \pi^0 n) = -(0.122 \pm 0.002)/m_{\pi^+}$$
$$a(\pi^+ \to \pi^0 p) = -a(\pi^- p \to \pi^0 n)$$
$$E_{0+}(\gamma p \to \pi^+ n) = (28.06 \pm 0.27 \pm 0.45) \times 10^{-3}/m_{\pi^+}$$

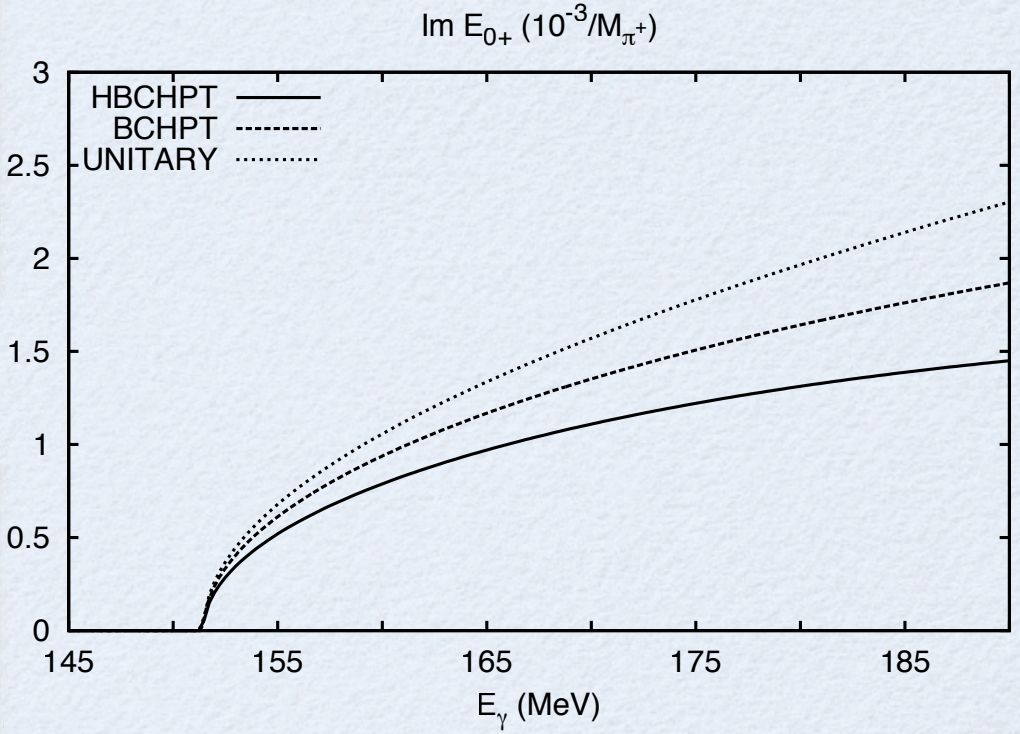
UNITARITY

$$\mathrm{Im}\, E_{0+}(W) = \beta \frac{q_{\pi+}(W)}{m_{\pi+}}$$

$\beta = 3.44 \times 10^{-3}/m_{\pi+}$ Unitary

$\beta = 2.72 \times 10^{-3}/m_{\pi+}$ HBCHPT

$\beta = 3.10 \times 10^{-3}/m_{\pi+}$ BCHPT



BCHPT: Hilt, Scherer, Tiator, private communication

EMPIRICAL FIT

- Taylor expansion in the partial waves + S wave cusp
- Unitarity is respected in the S wave
- 8 parameters (2 per partial wave)
- P waves are real
- D waves: Born terms

$$E_{0+}(W) = E_{0+}^{(0)} + E_{0+}^{(1)} \frac{k_\gamma^{lab}(W) - k_{\gamma,thr}^{lab}}{m_{\pi+}} + i\beta \frac{q_{\pi+}(W)}{m_{\pi+}}$$

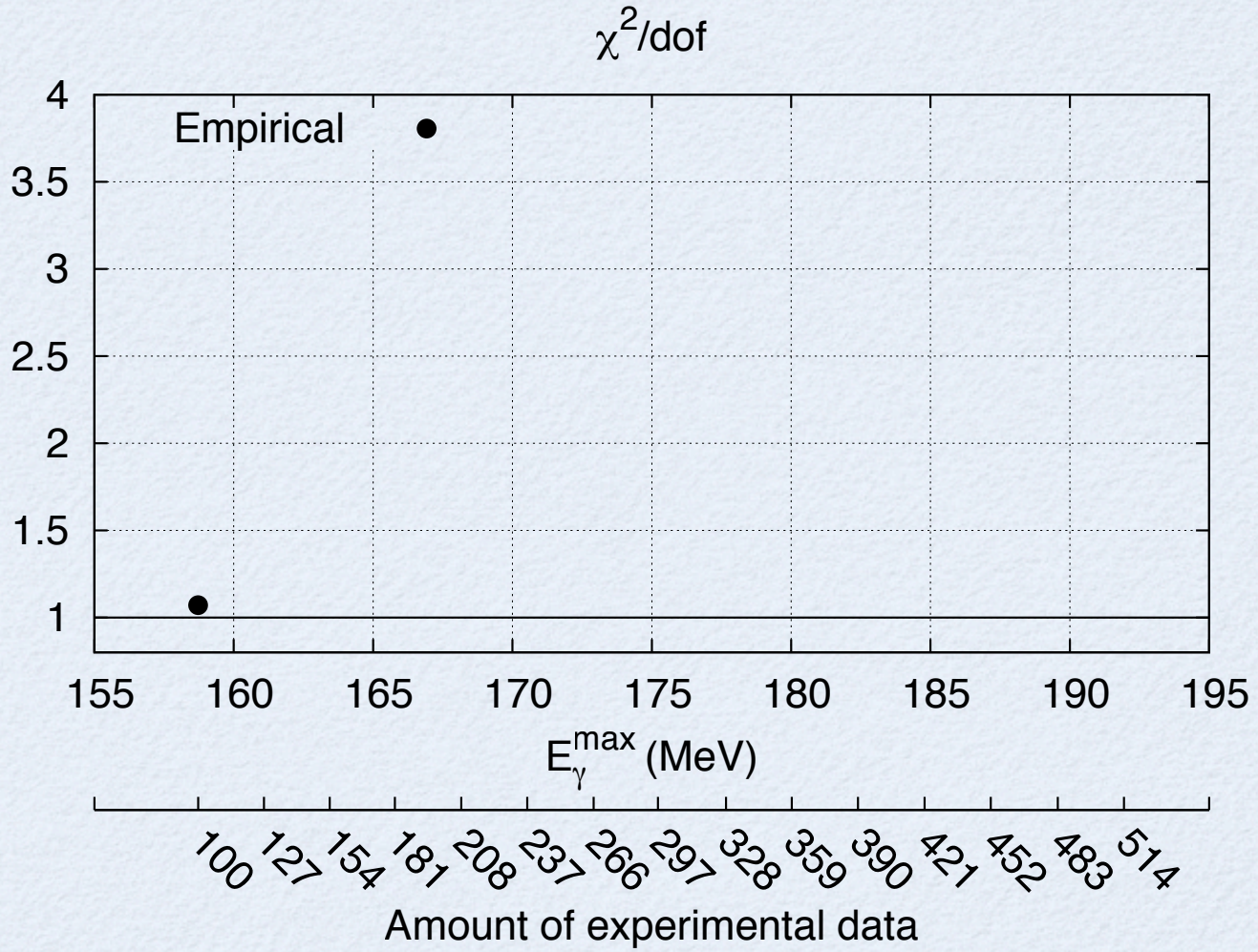
$$P_i(W) = \frac{q_{\pi^0}(W)}{m_{\pi+}} \left(P_i^{(0)} + P_i^{(1)} \frac{k_\gamma^{lab}(W) - k_{\gamma,thr}^{lab}}{m_{\pi+}} \right)$$

HBCHPT

- S and P waves up to $O(q^4)$
- D waves: Born terms
  (up to order $O(q^4)$ another LEC appears in E_{2-} but it can be ignored)
- 5 LECs which are fitted to data
  - a_1 and a_2 associated to S wave
  - ξ_1 associated to $P_1=3E_{1+}+M_{1+}-M_{1-}$
  - ξ_2 associated to $P_2=3E_{1+}-M_{1+}+M_{1-}$
  - b_p associated to $P_3=2M_{1+}-M_{1-}$

RESULTS

χ^2/DOF DEPENDING ON MAX ENERGY/AMOUNT OF DATA



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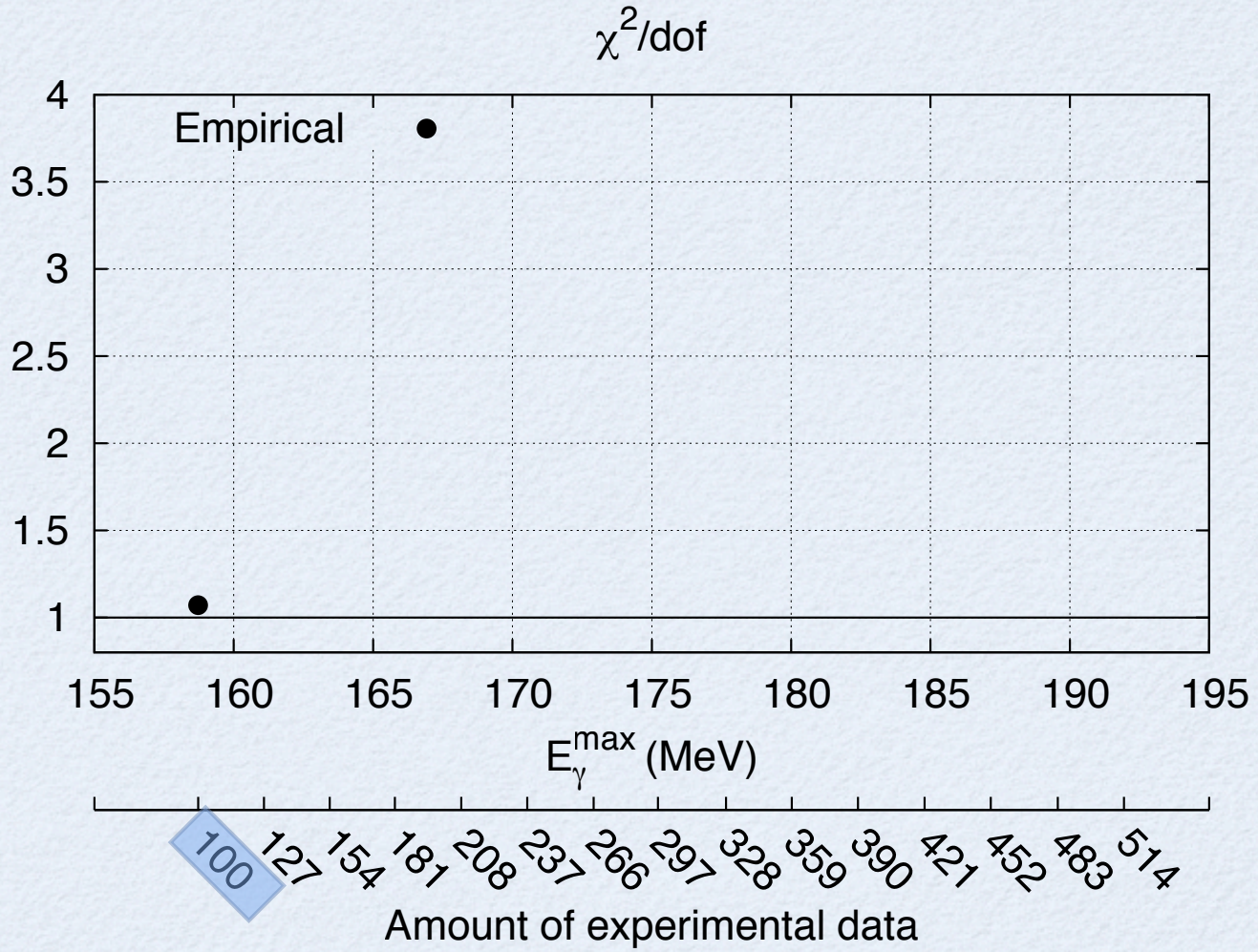

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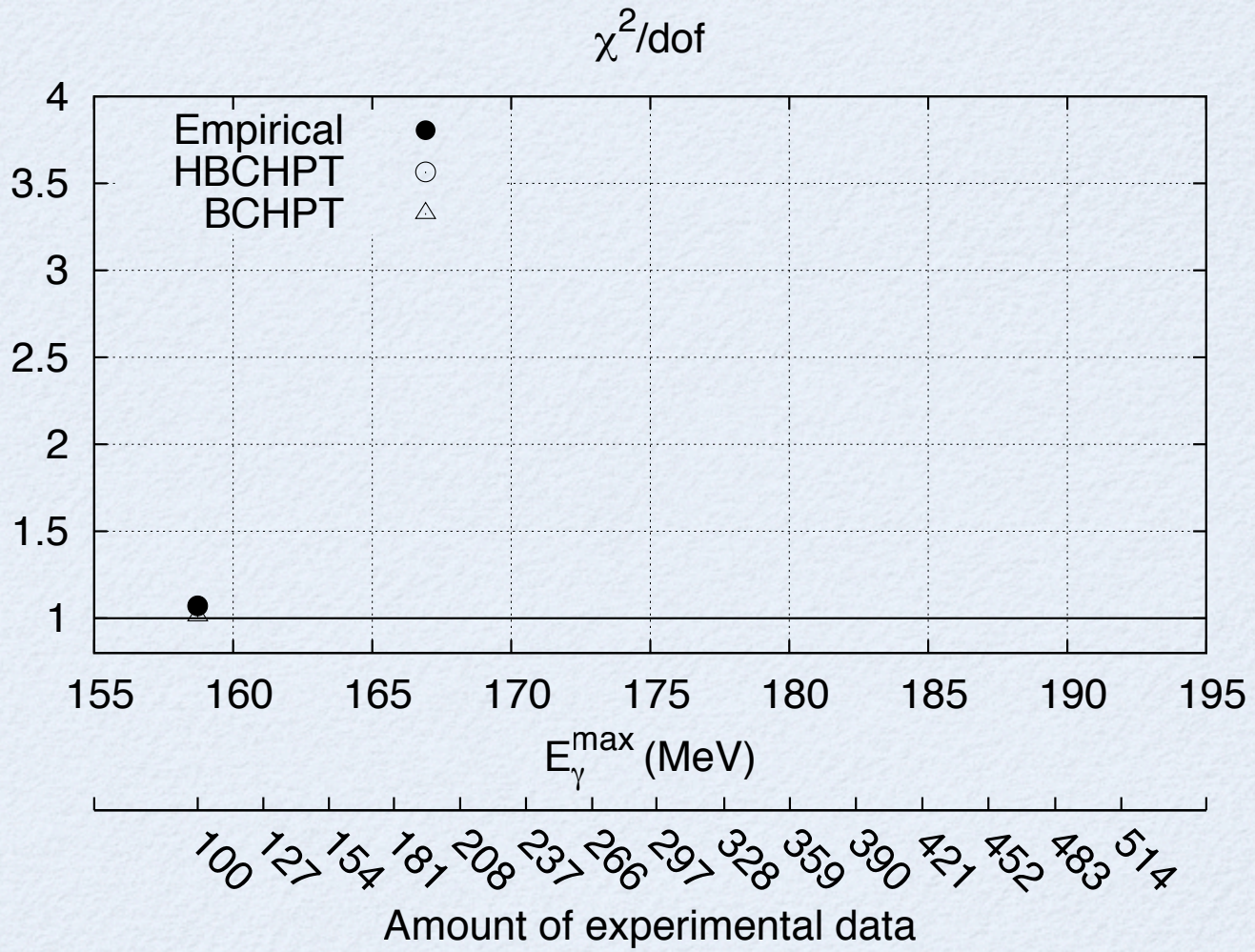

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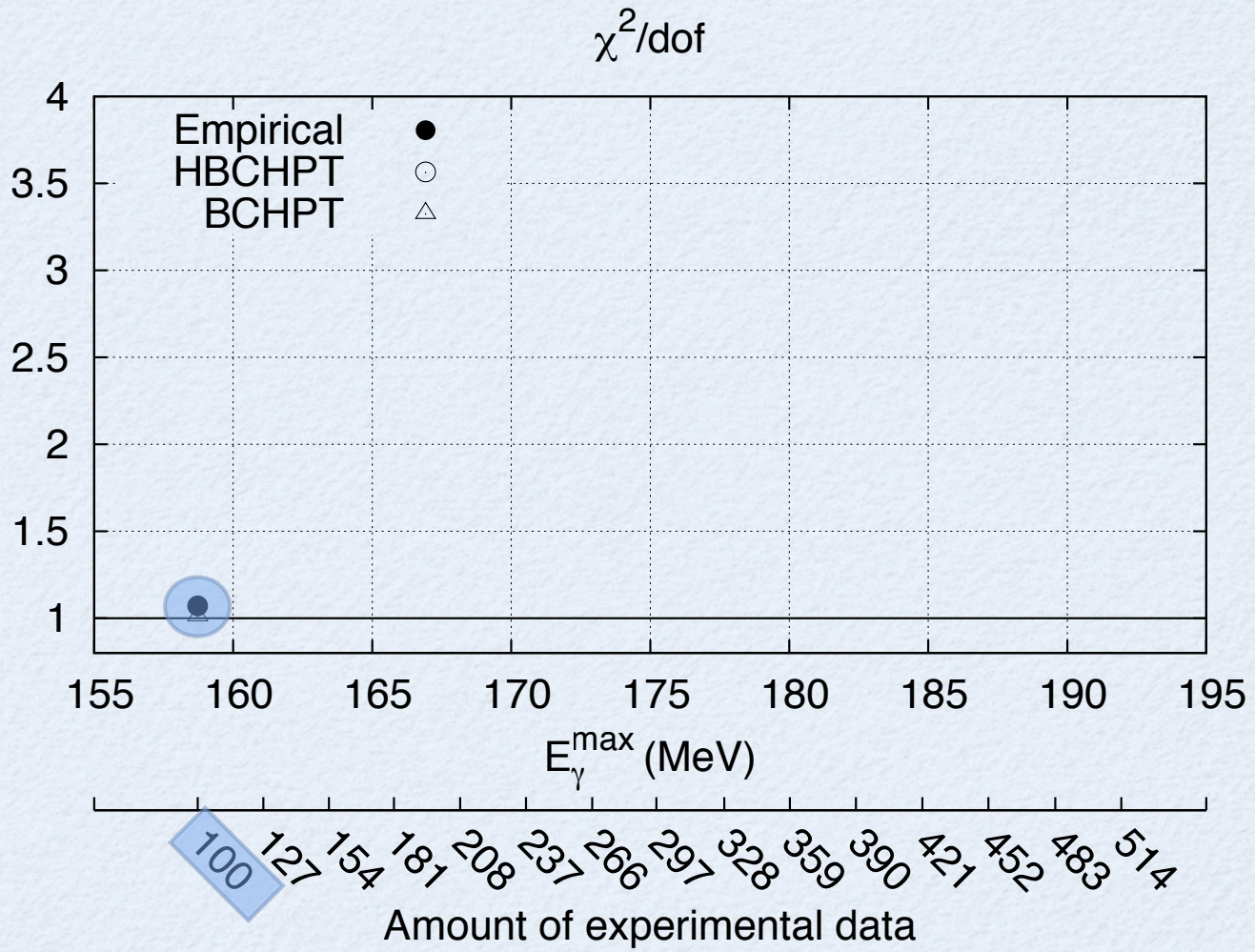

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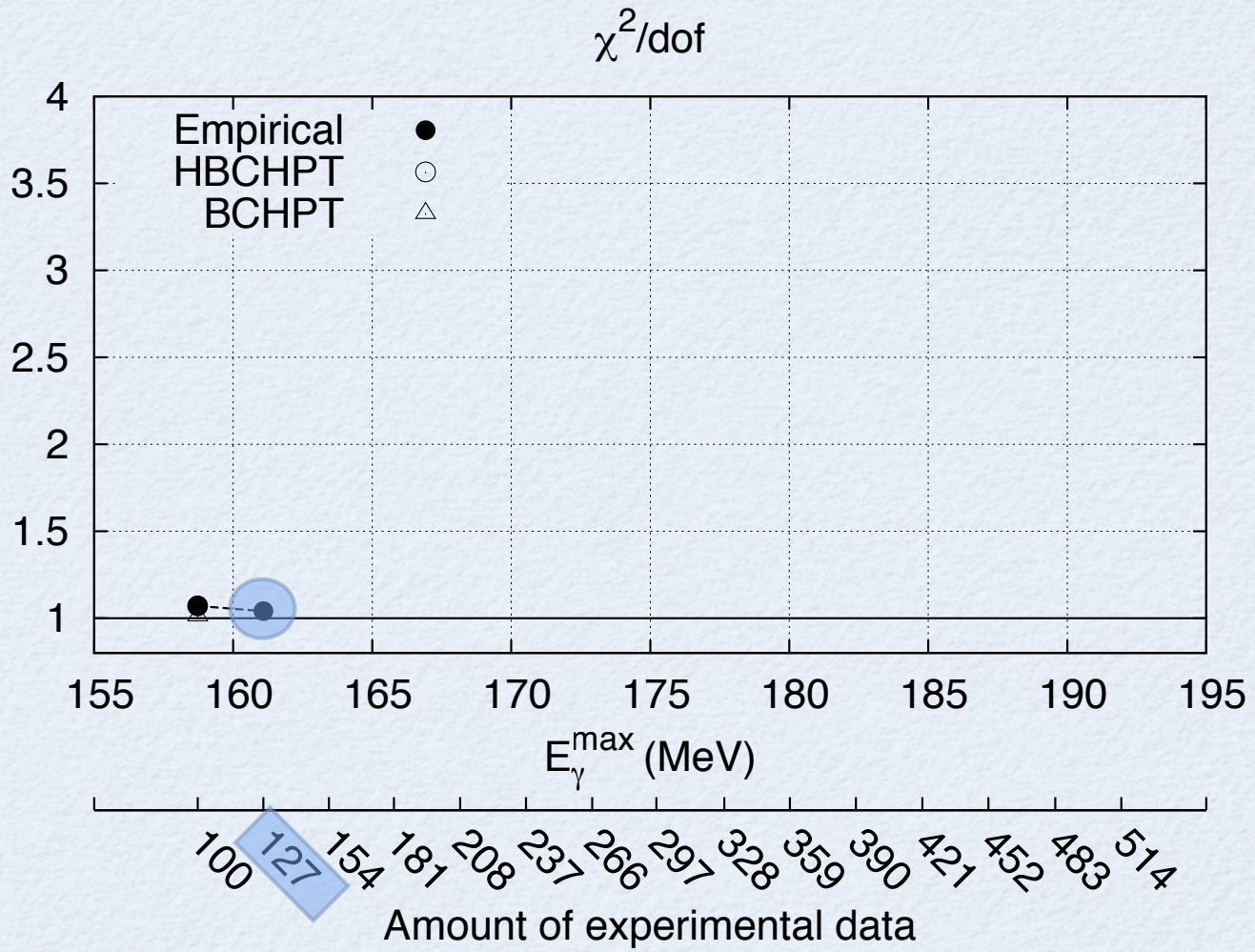

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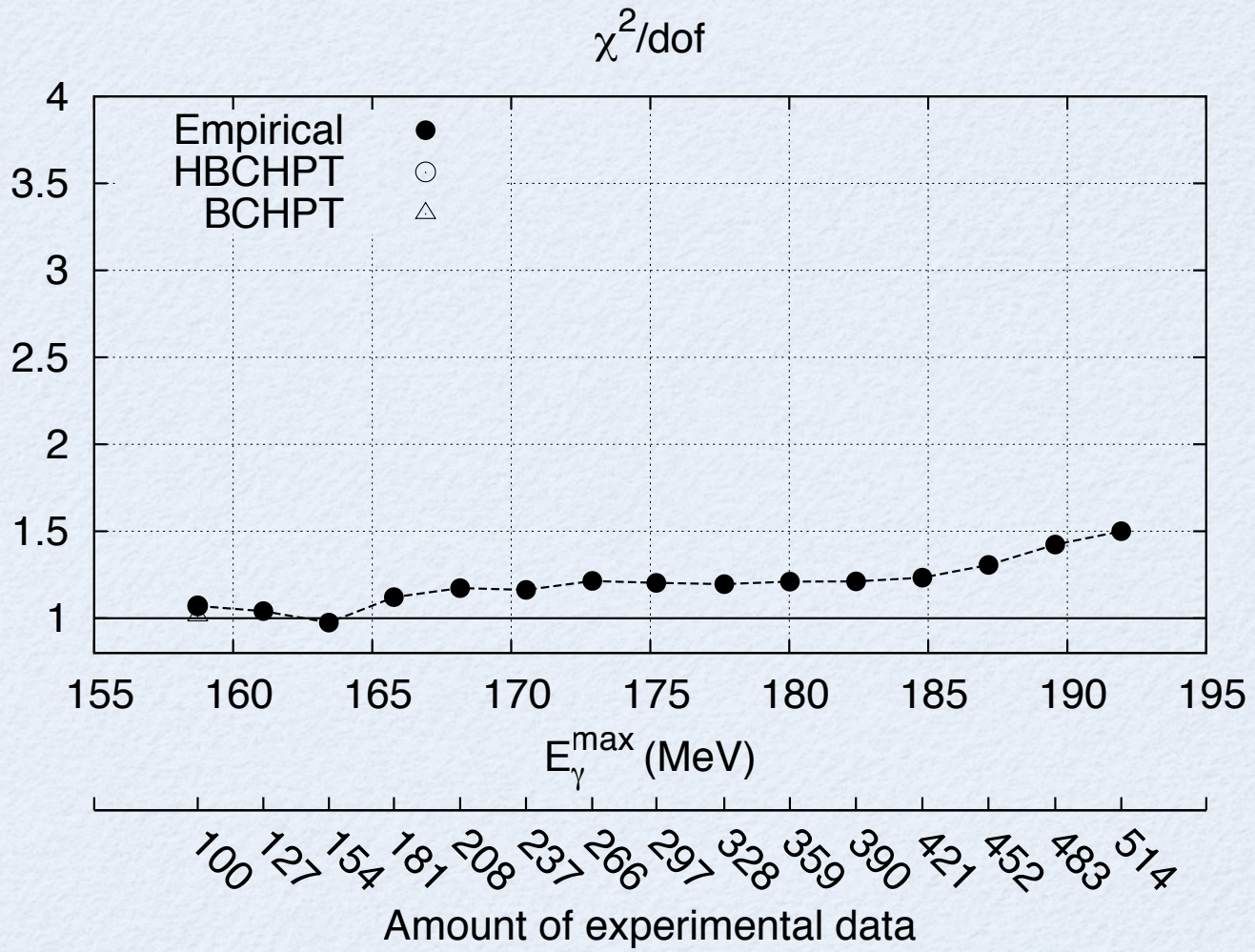

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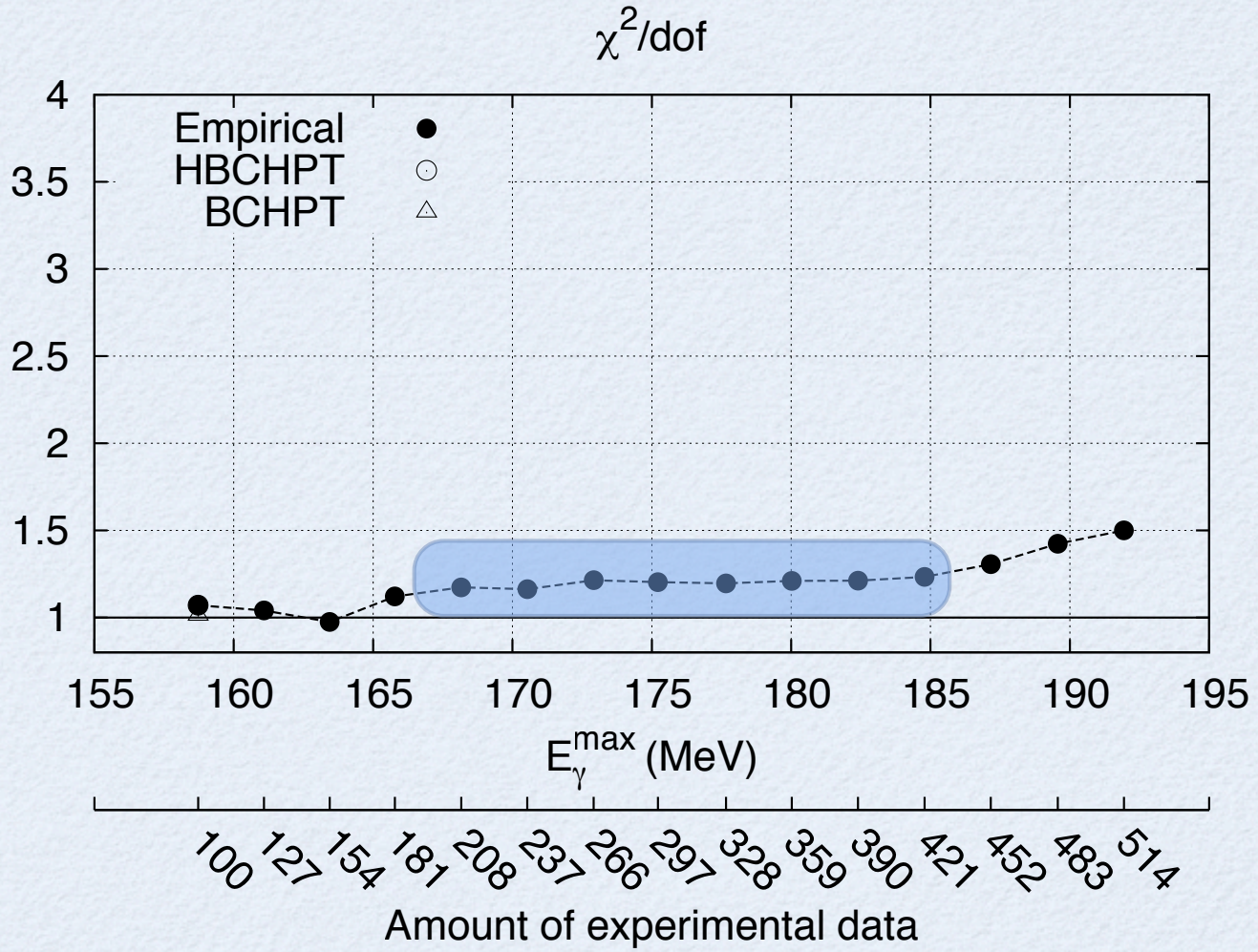

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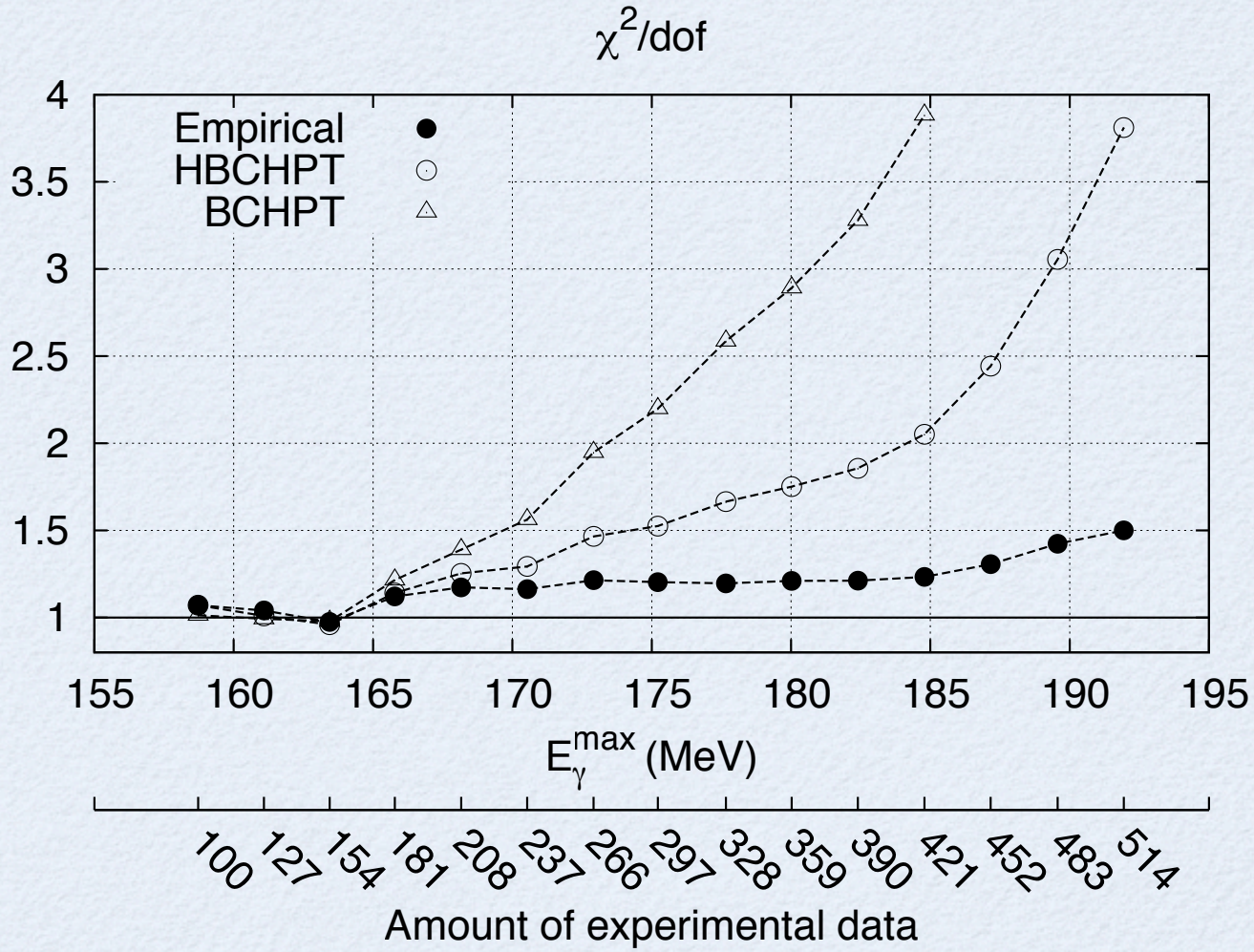

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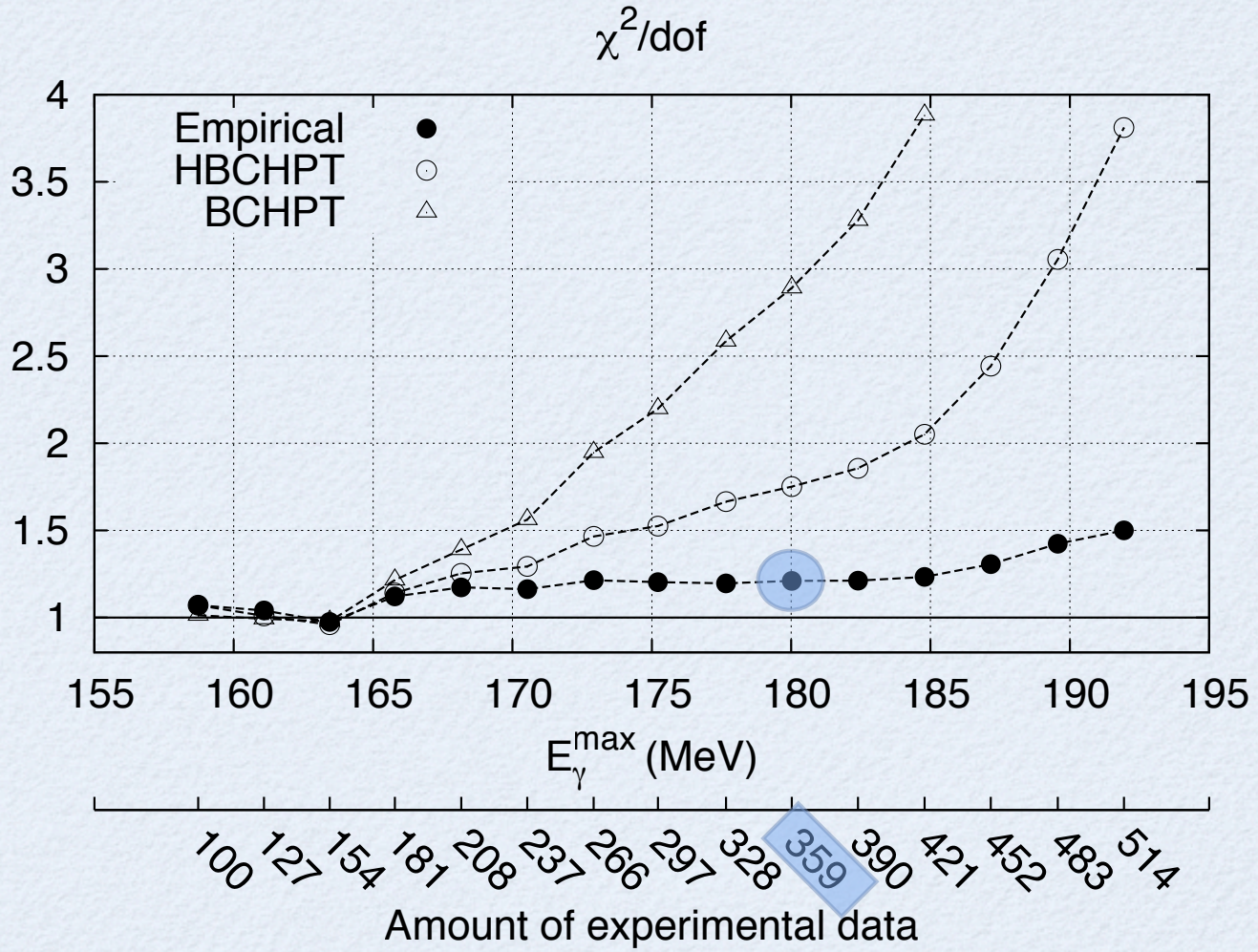

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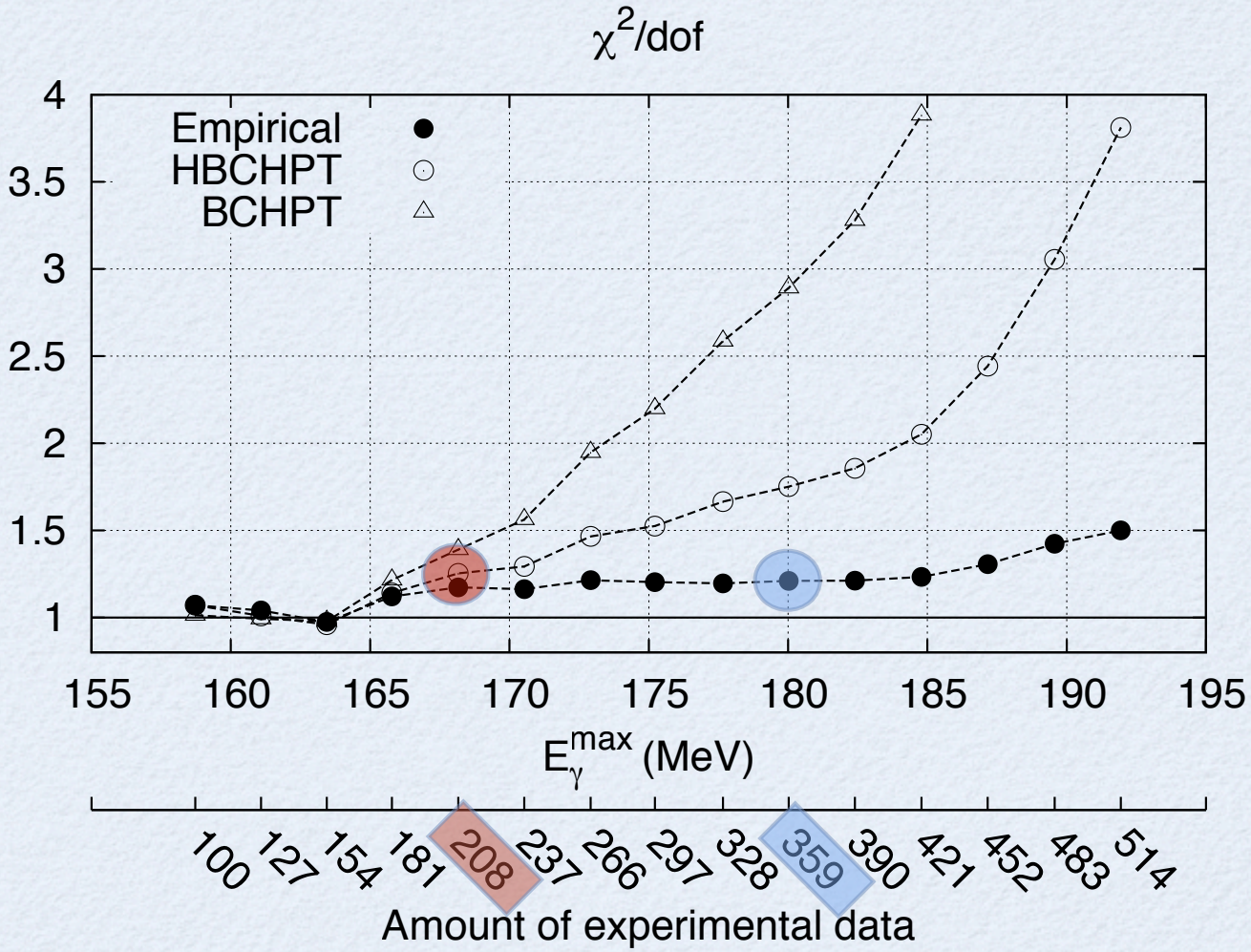

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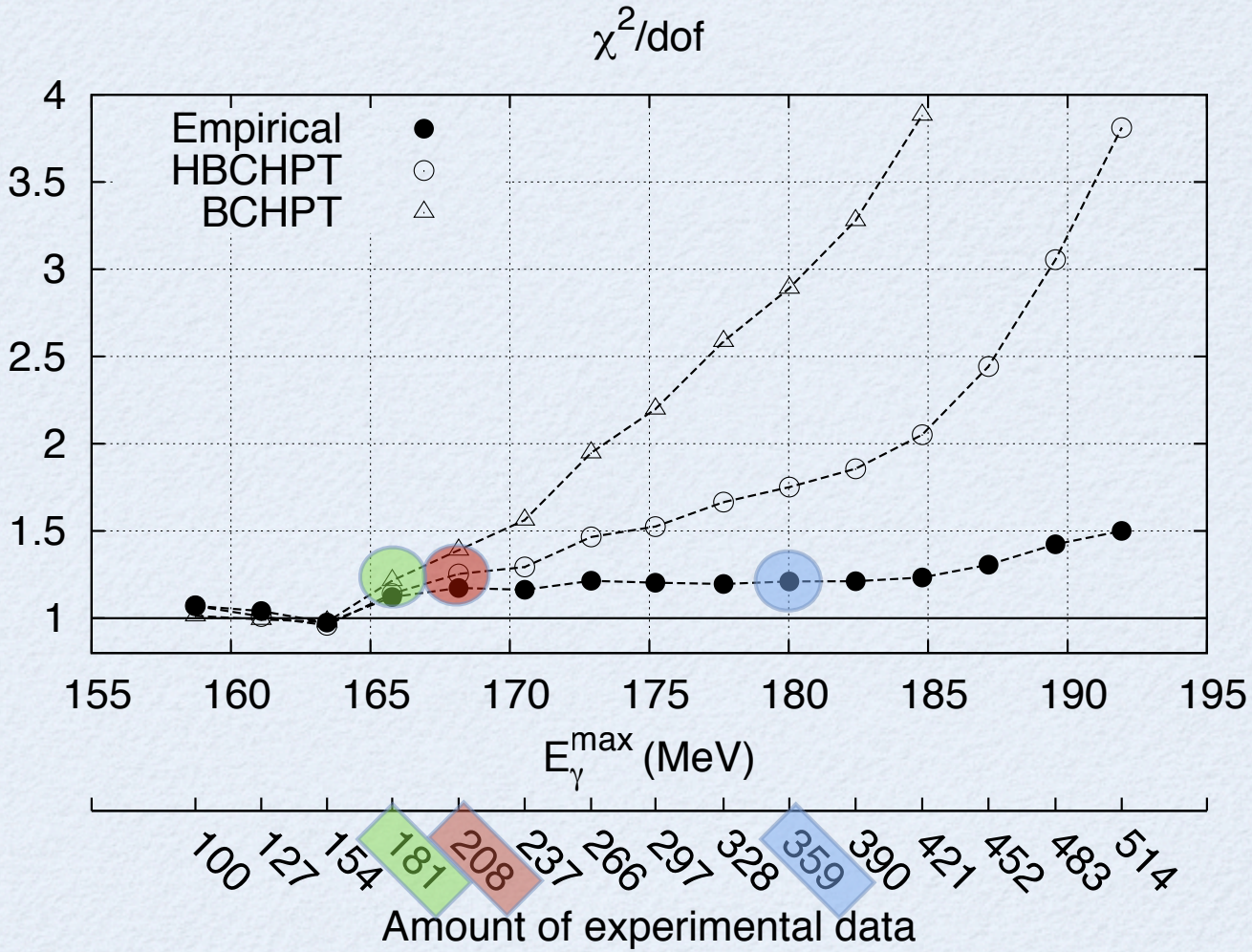
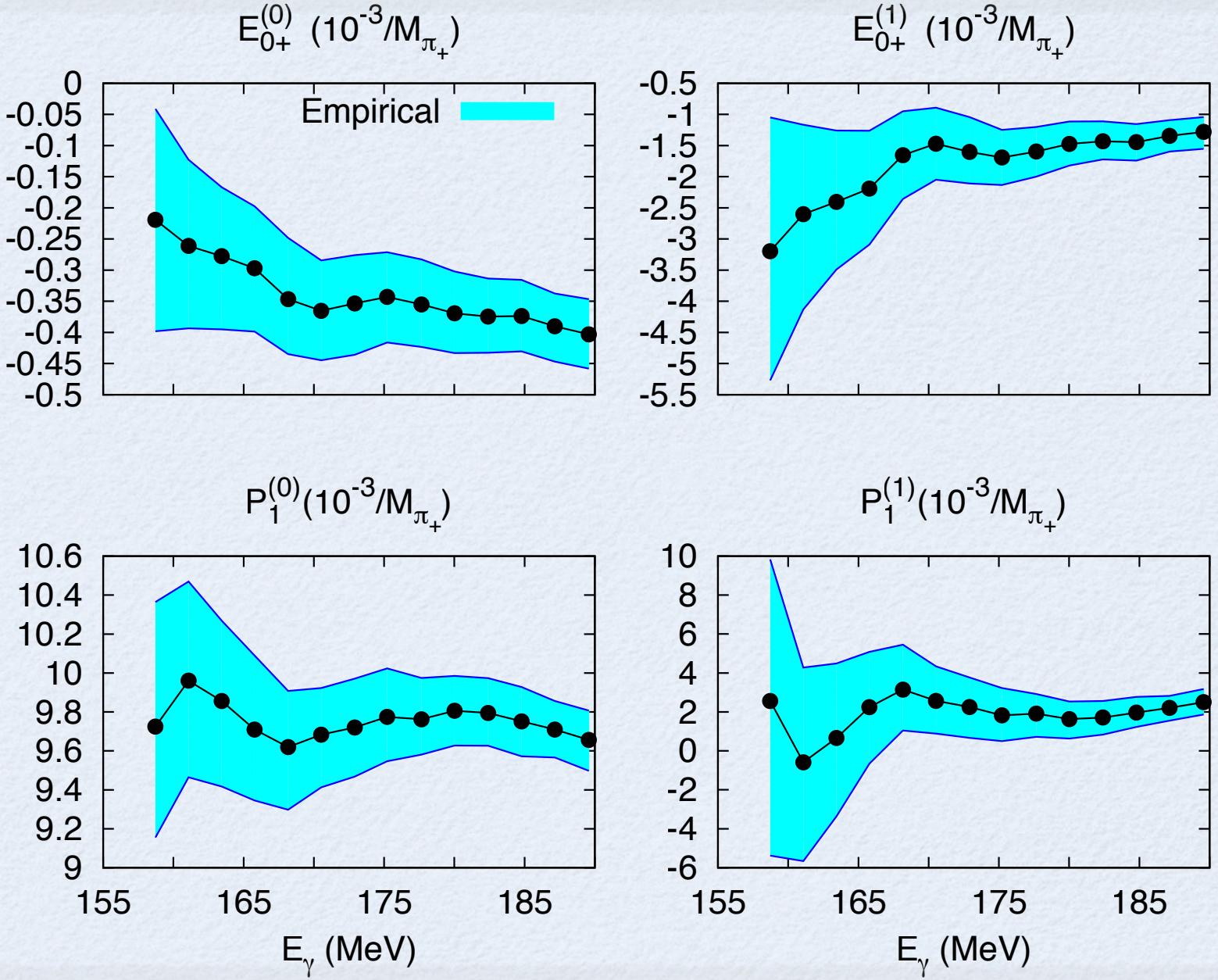


PARAMETERS (EMPIRICAL)



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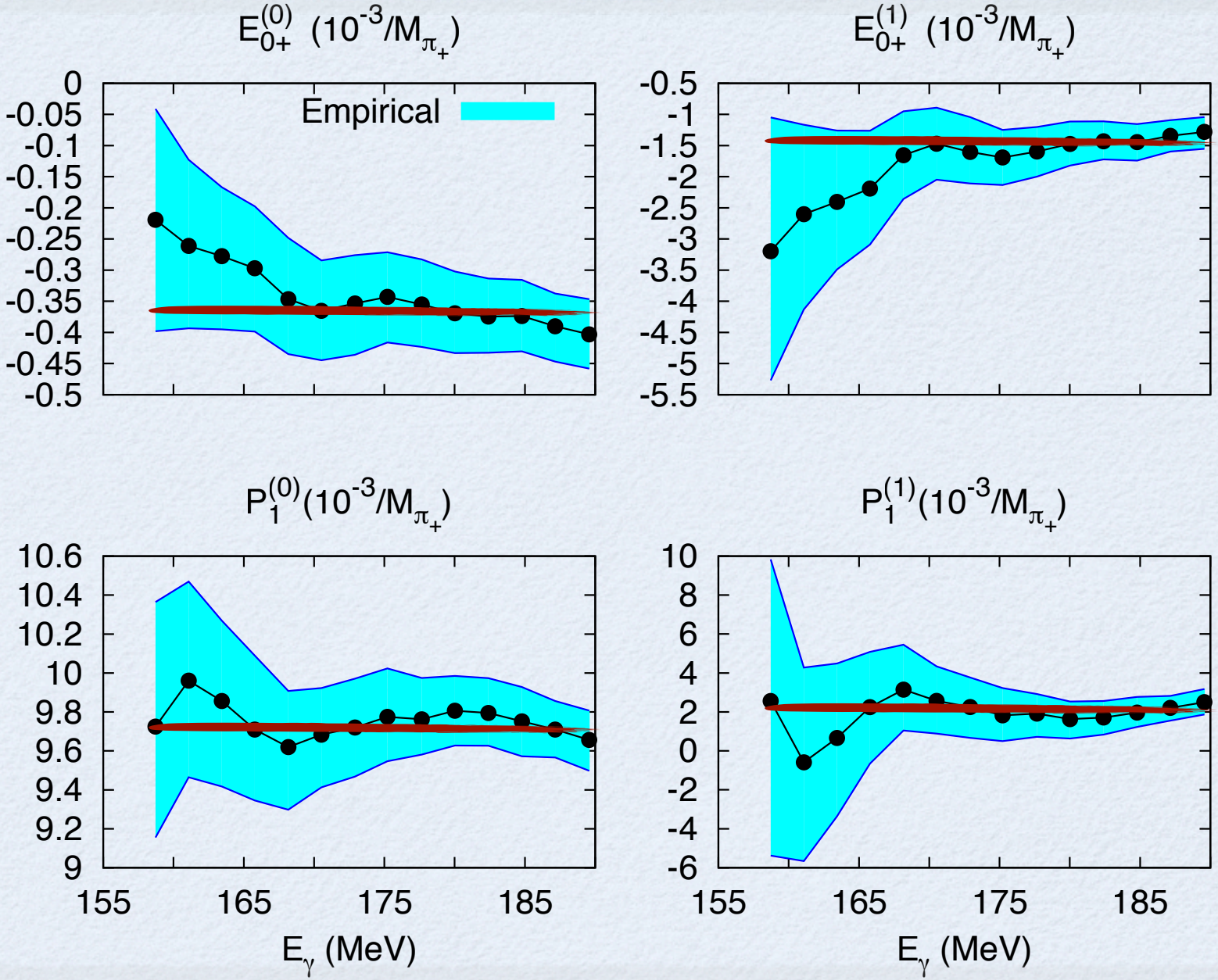

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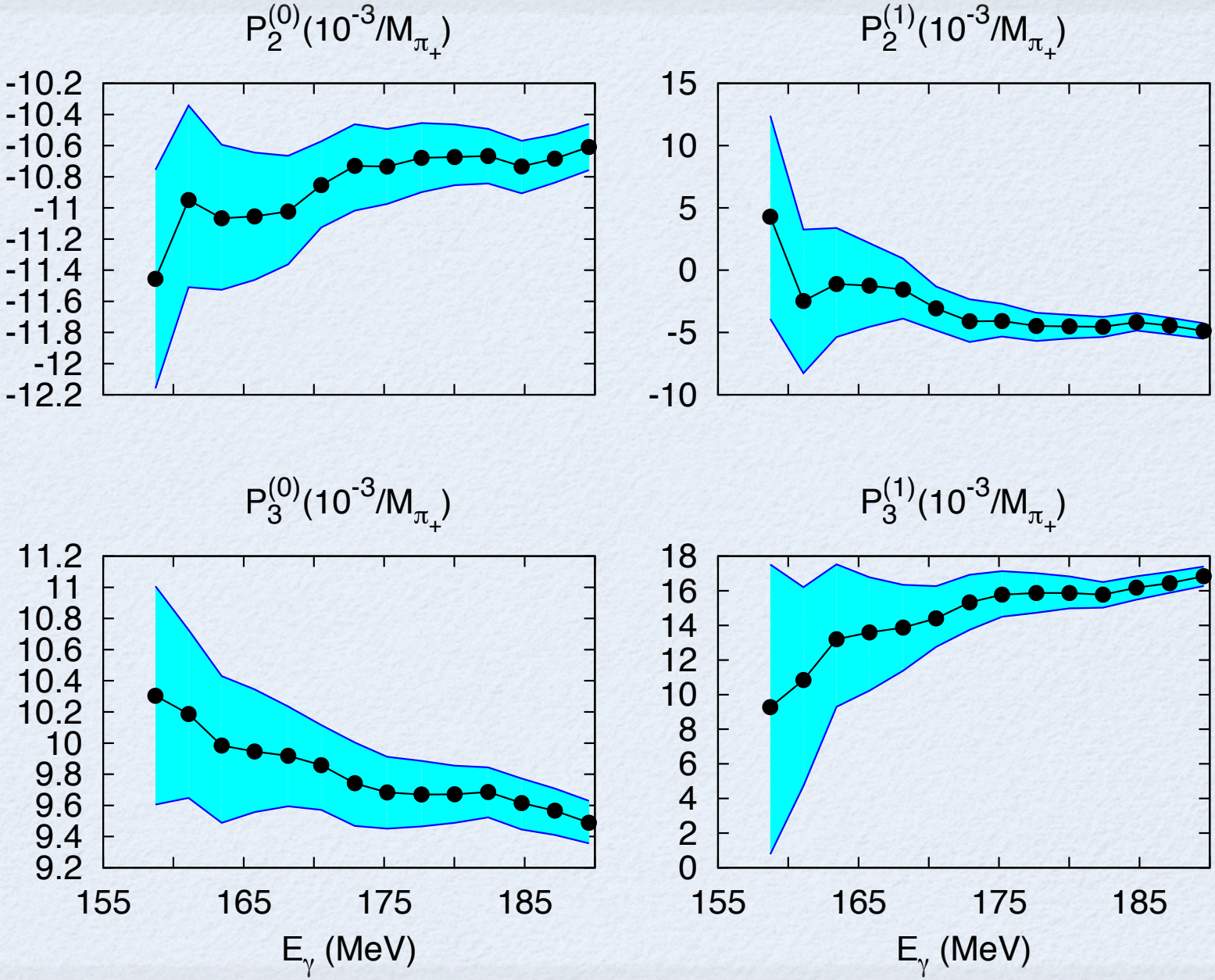

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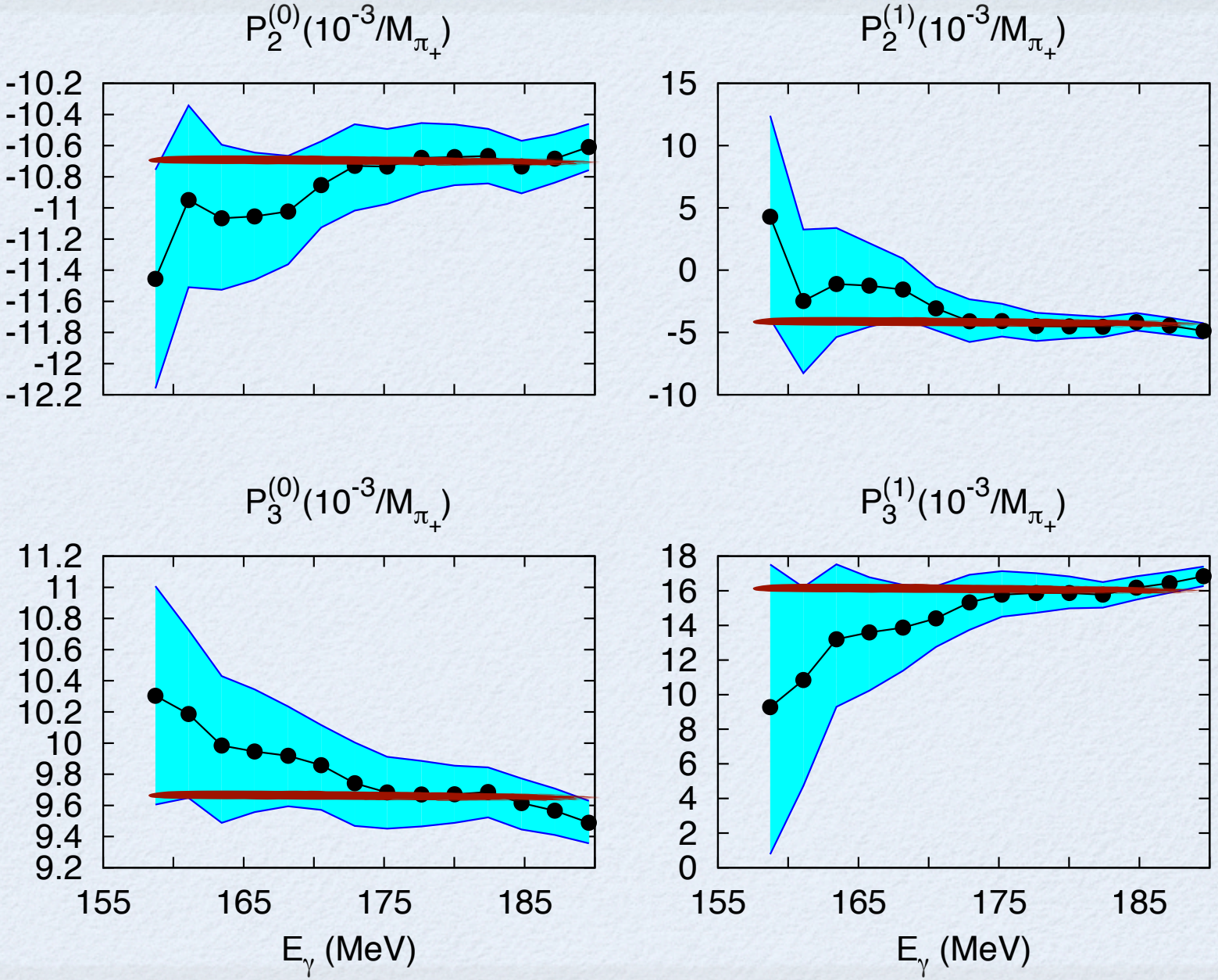
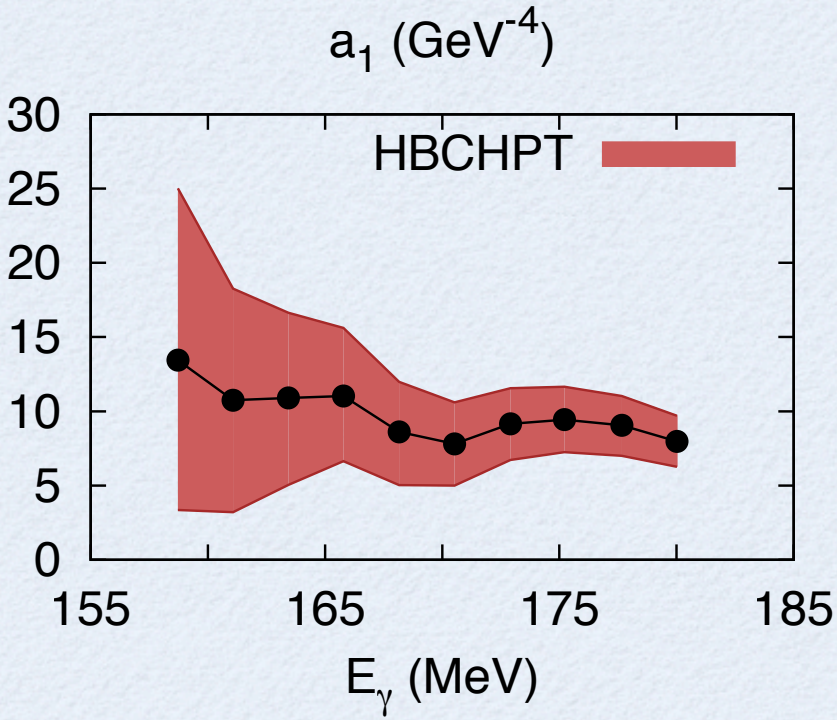
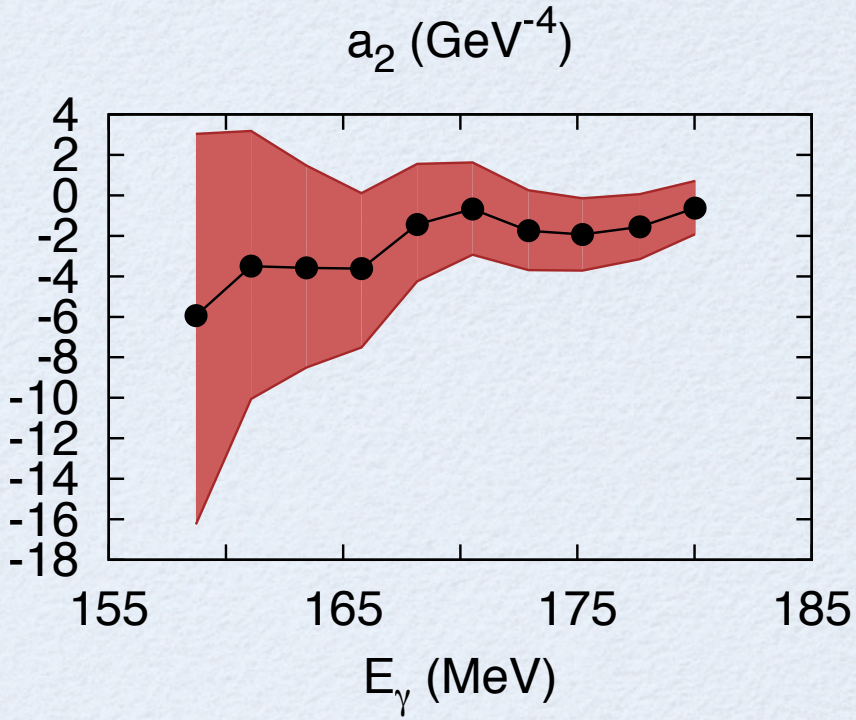


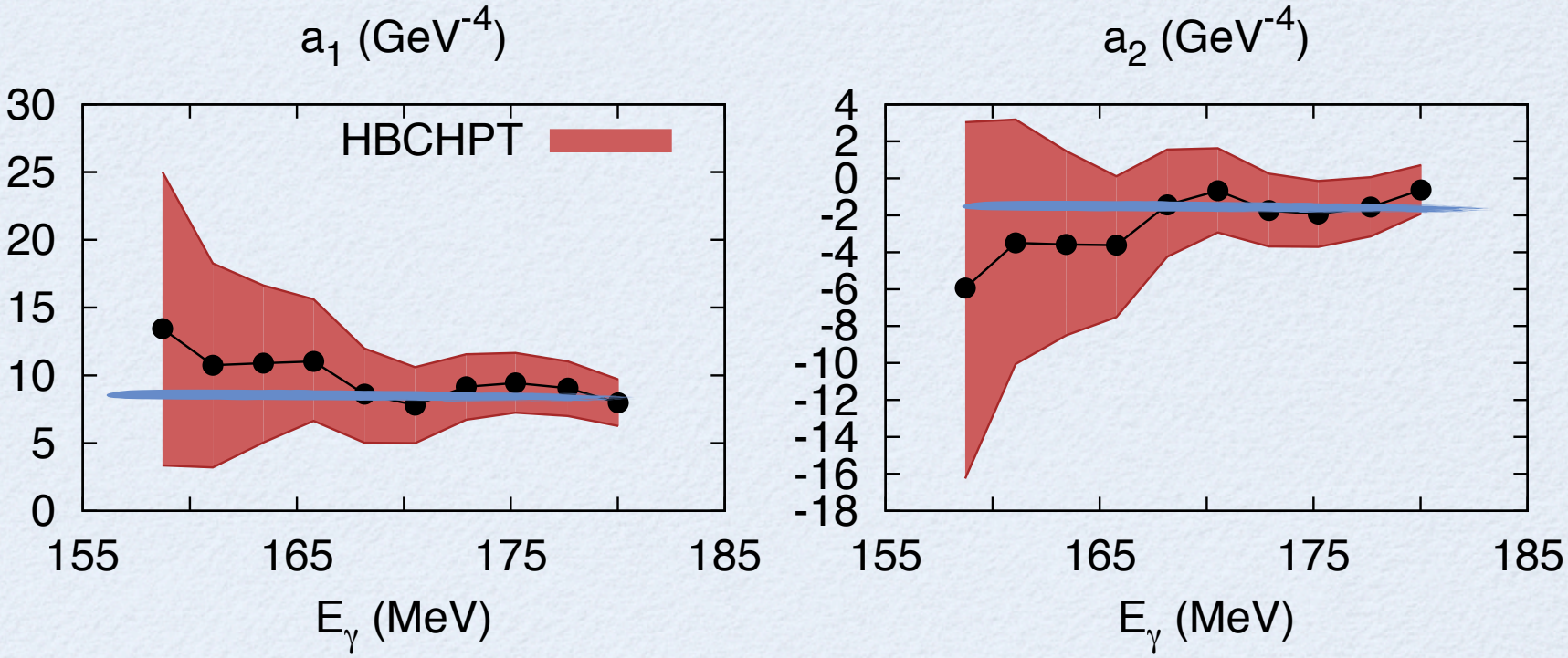
LECS (HBCHPT, S-WAVE)





$$E_{0+}^{ct} = e a_1 \omega M_\pi^2 + e a_2 \omega^3$$

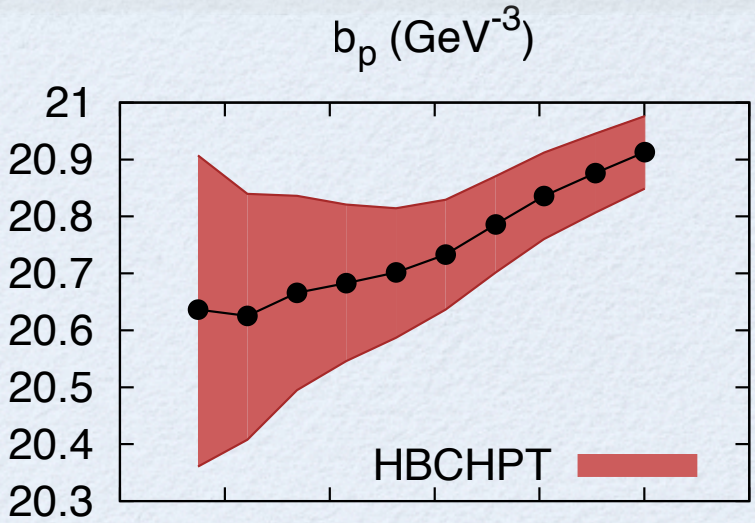
LECS (HBCHPT, S-WAVE)

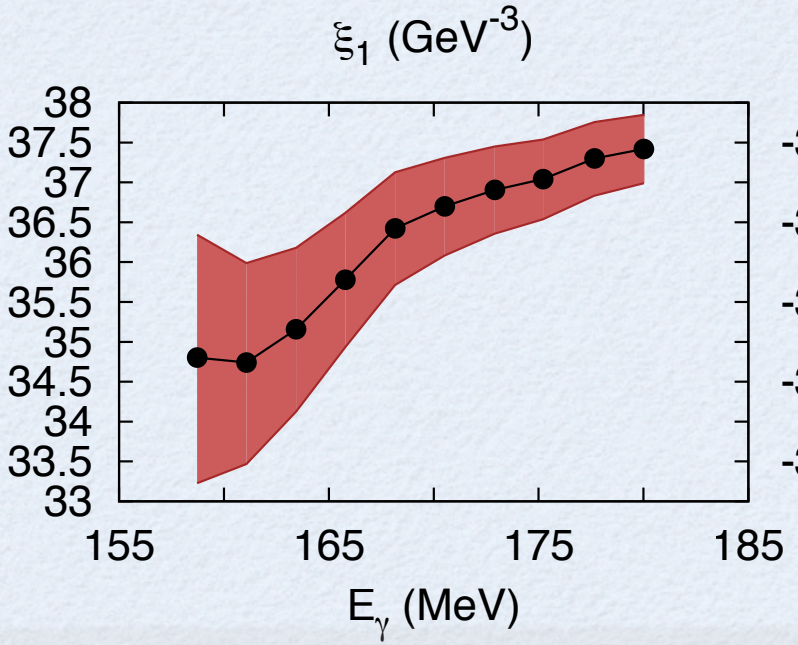


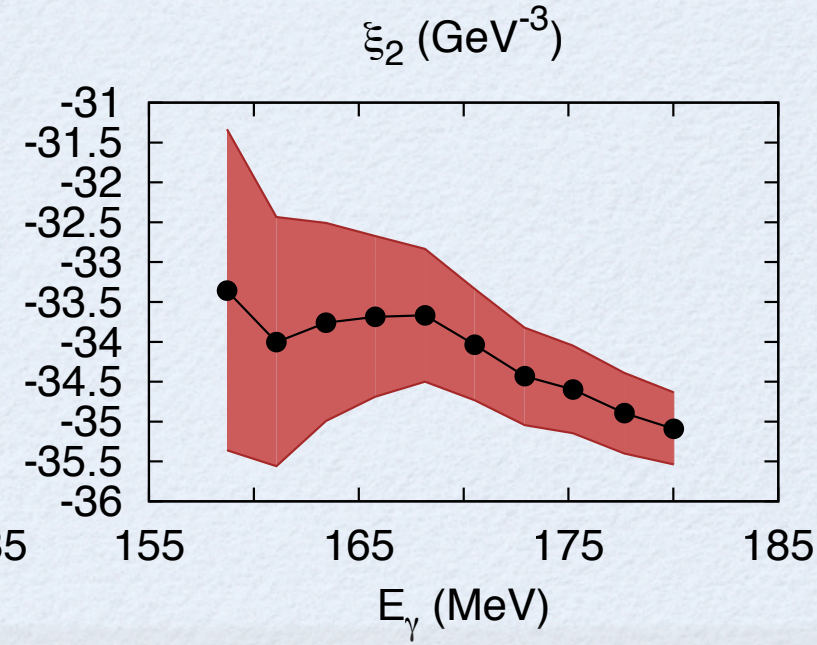
$$E_{0+}^{ct} = e a_1 \omega M_\pi^2 + e a_2 \omega^3$$

LECS (HBCHPT, P-WAVES)

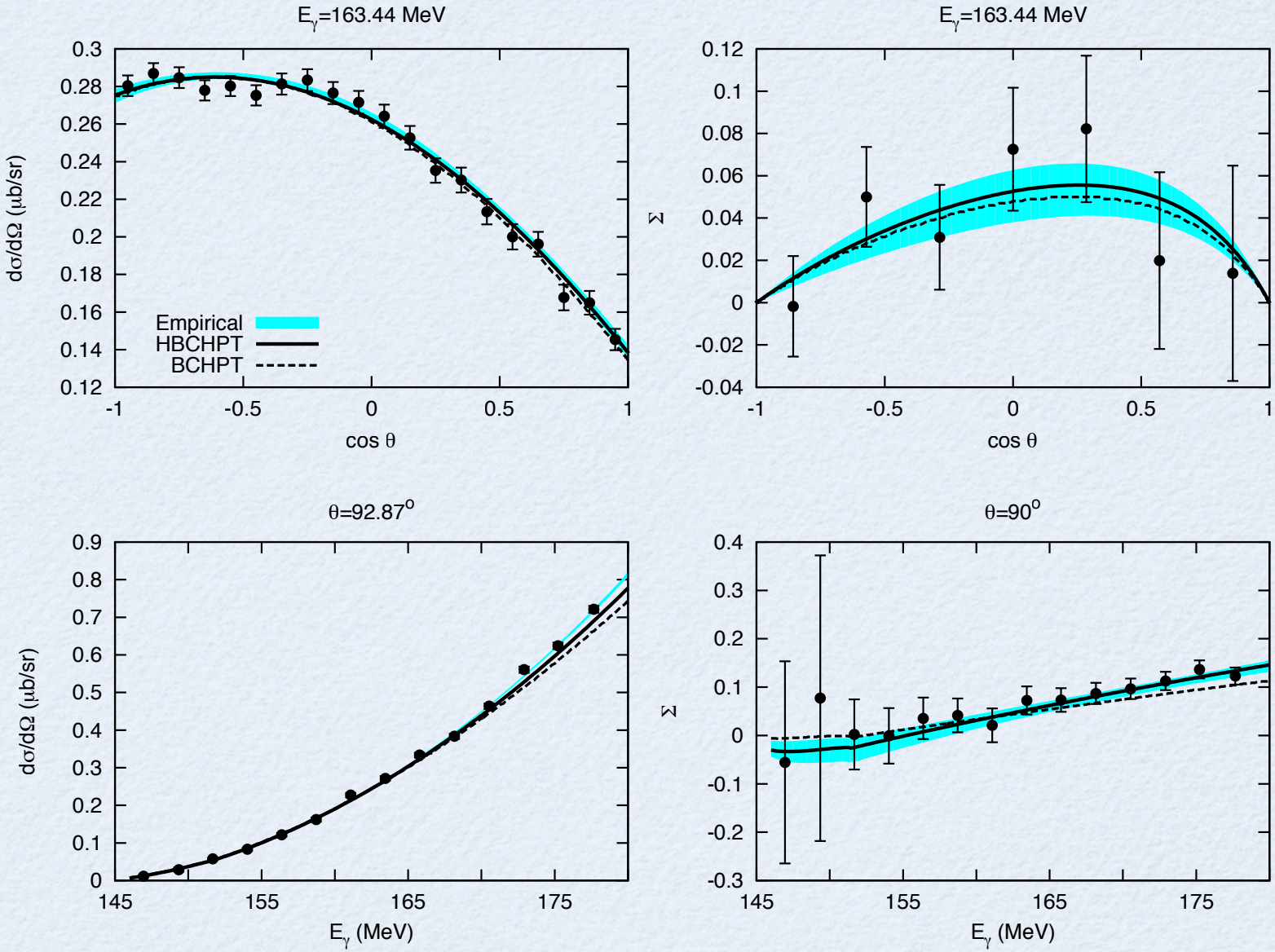
Don't forget: Convergence problem







OBSERVABLES



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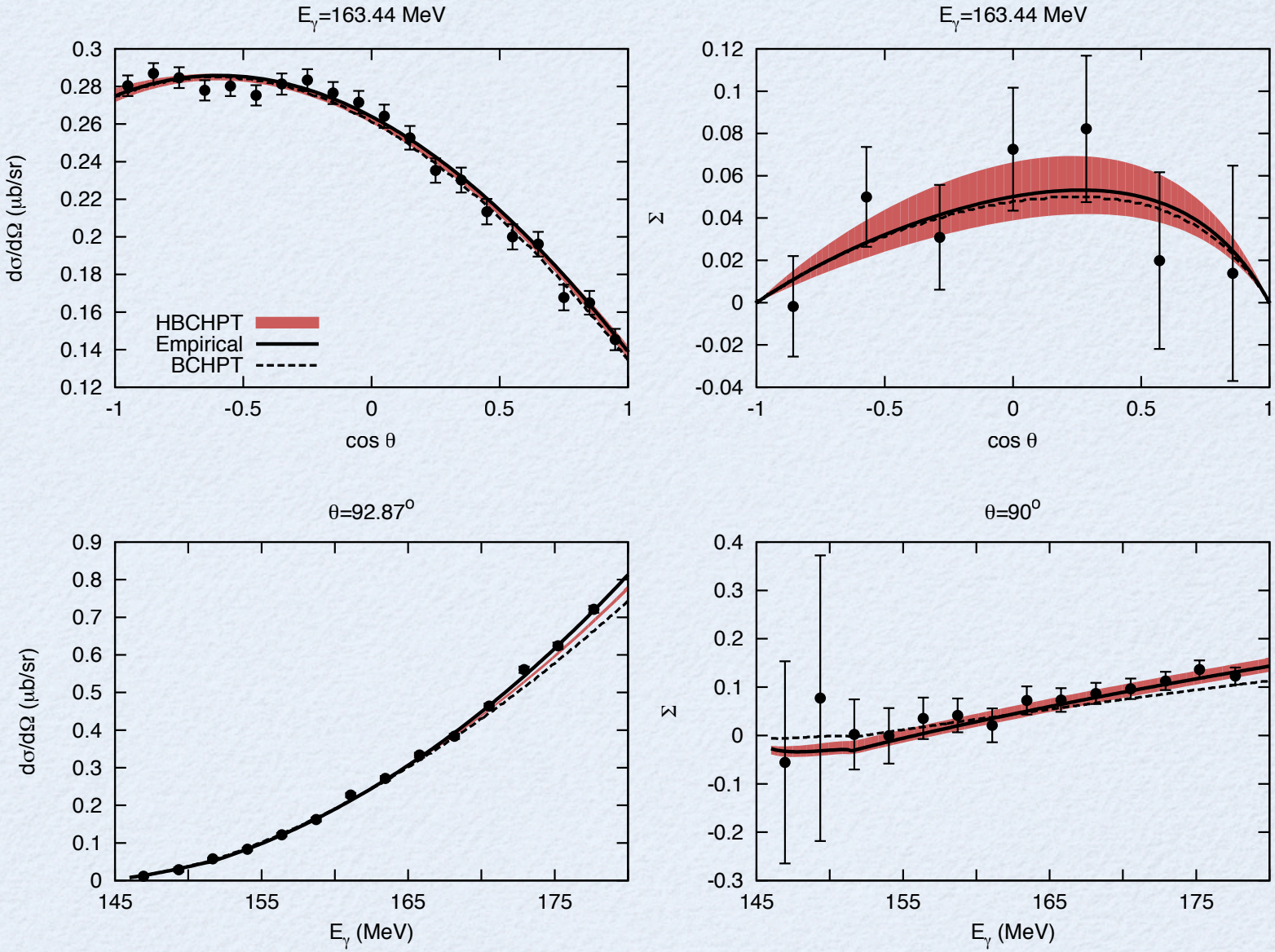

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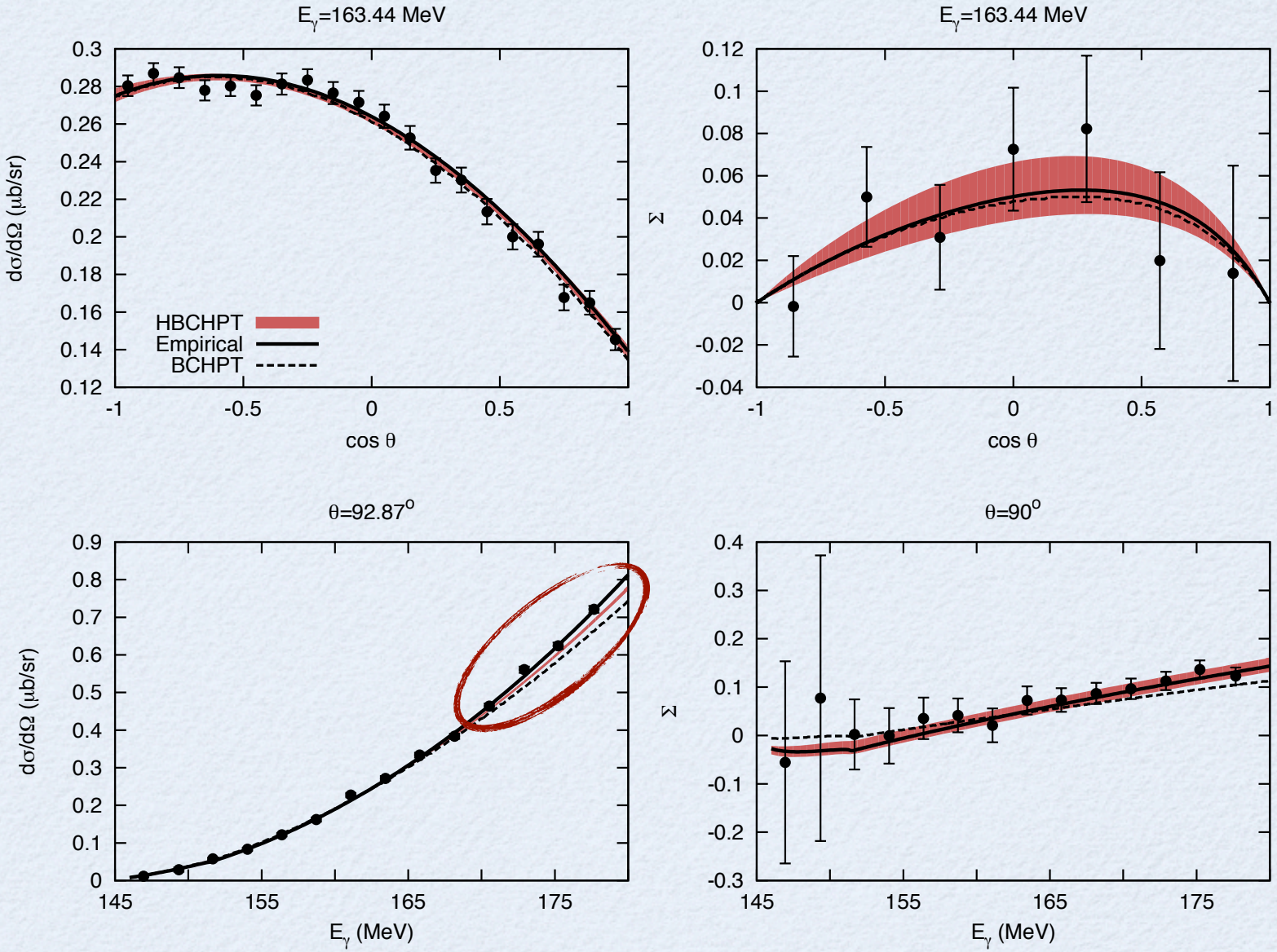
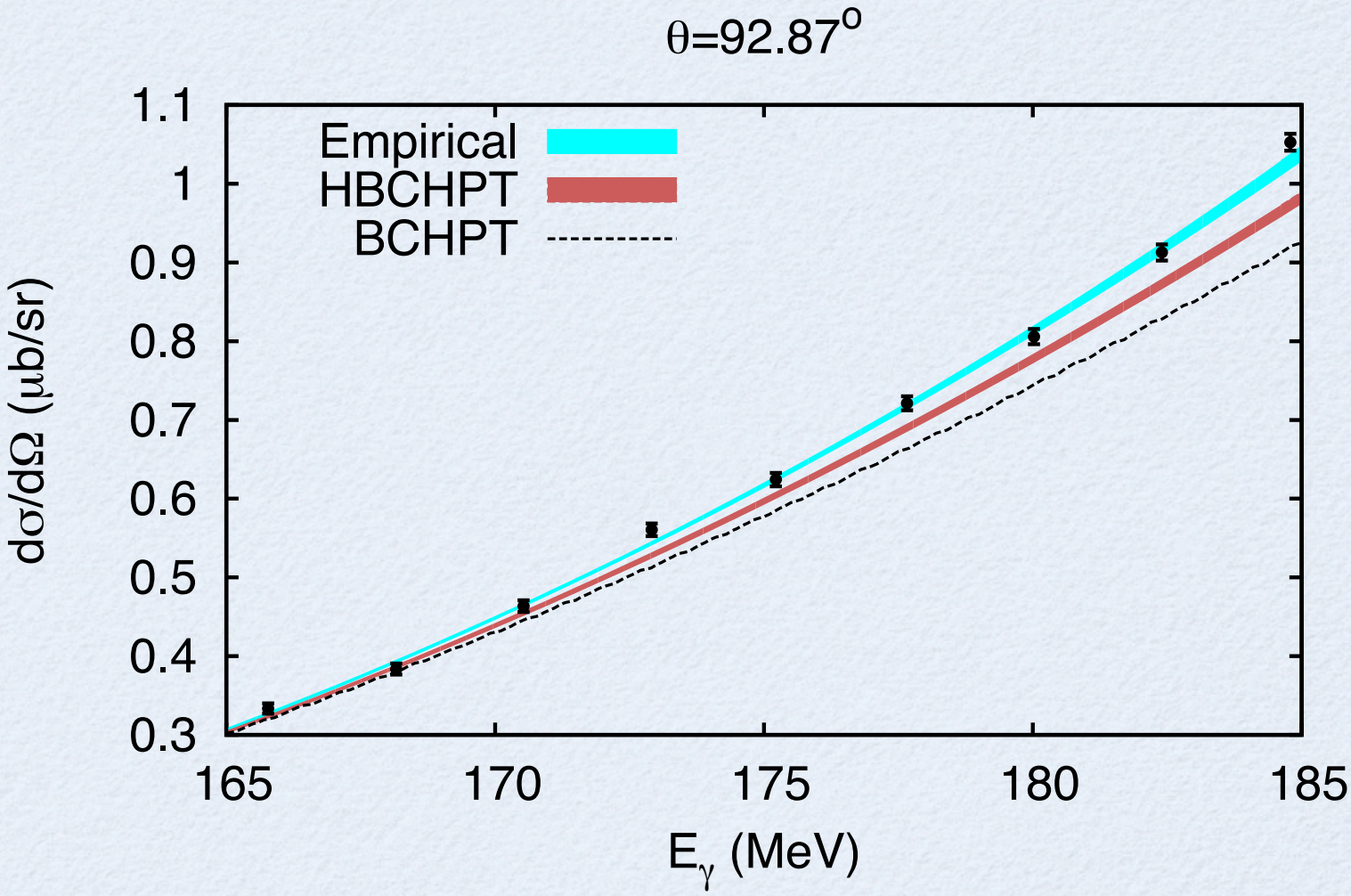


CROSS SECTION AT 92.87°



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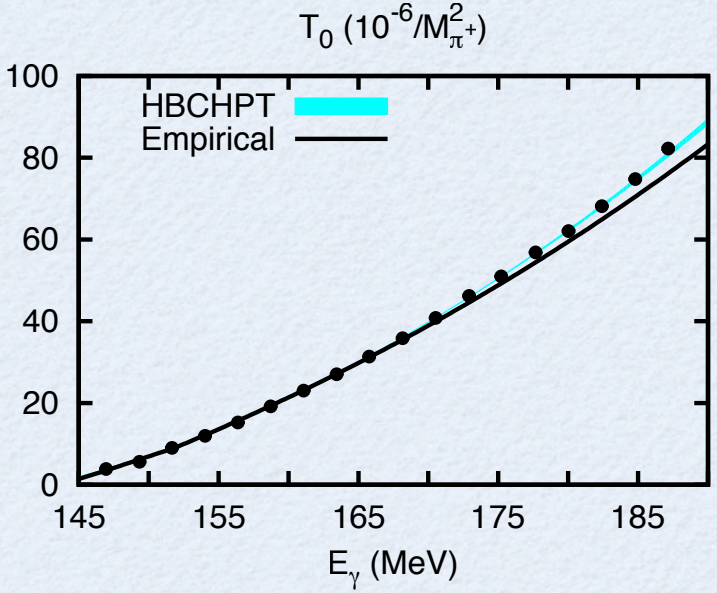
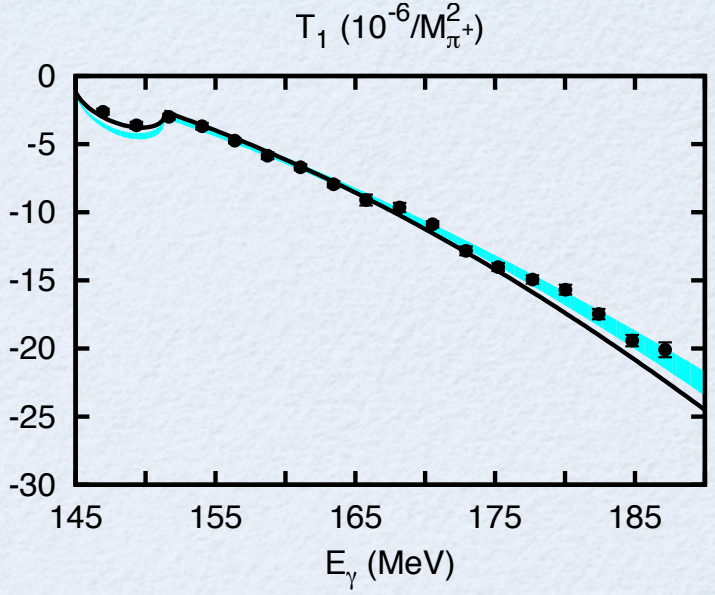
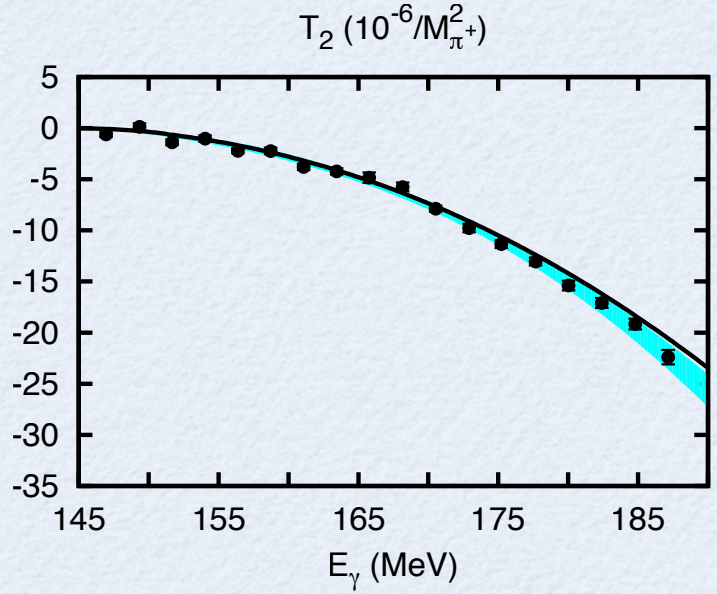
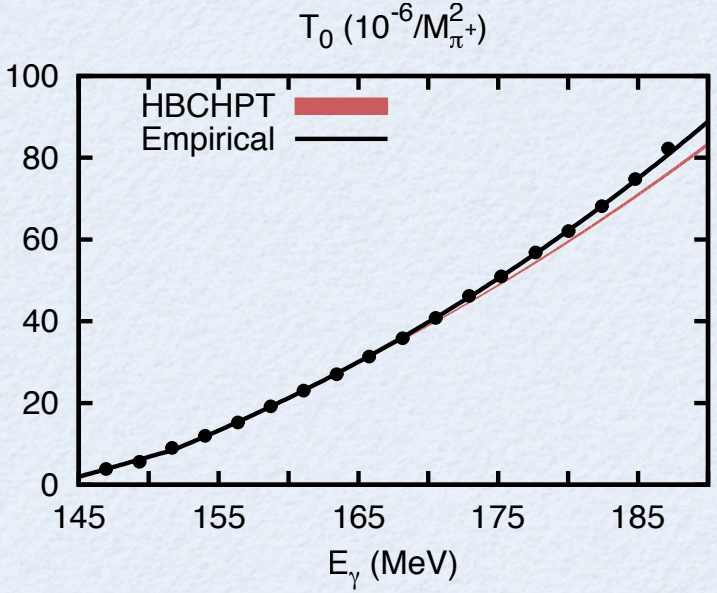


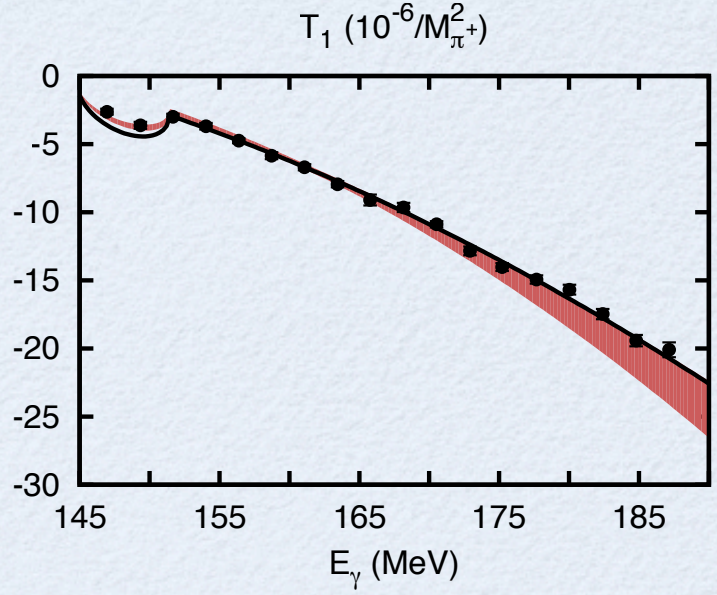


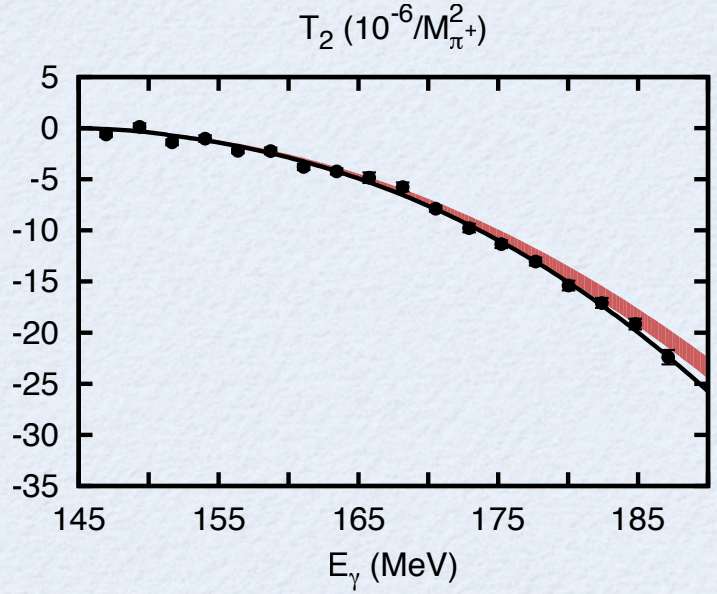


$$\sigma_T(W,\theta) = \frac{q_\pi}{k_\gamma}\left[T_0(W) + T_1(W)\,\mathcal{P}_1(\theta) + T_2(W)\,\mathcal{P}_2(\theta)\right]$$

CROSS SECTION







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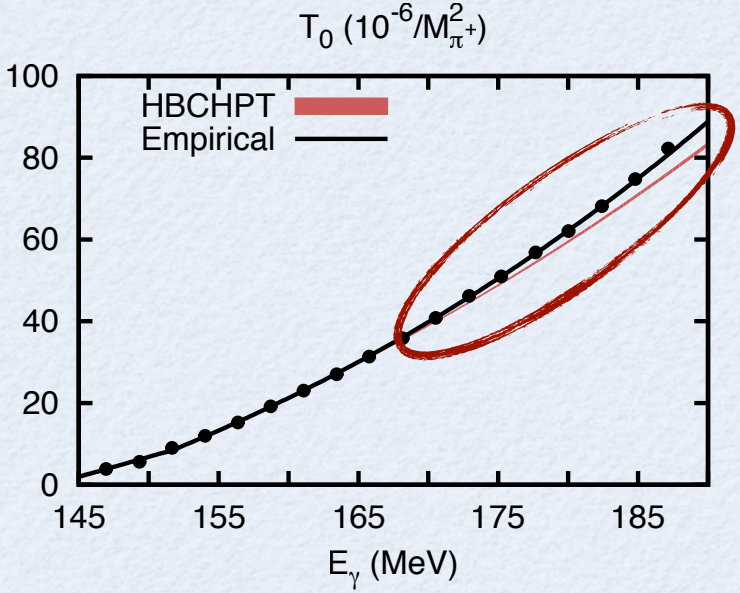
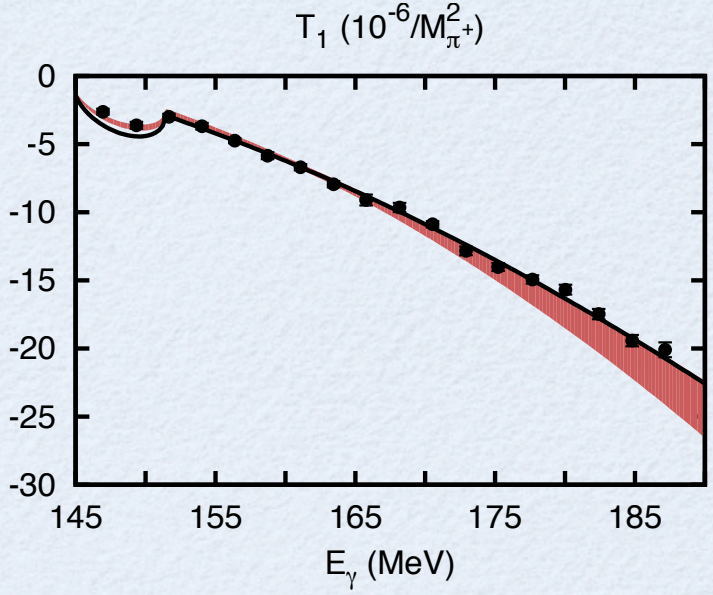
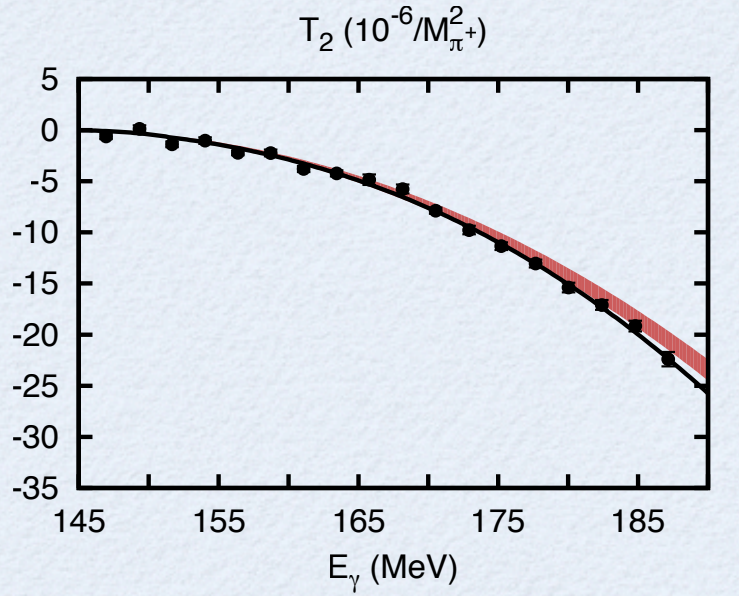
CROSS SECTION

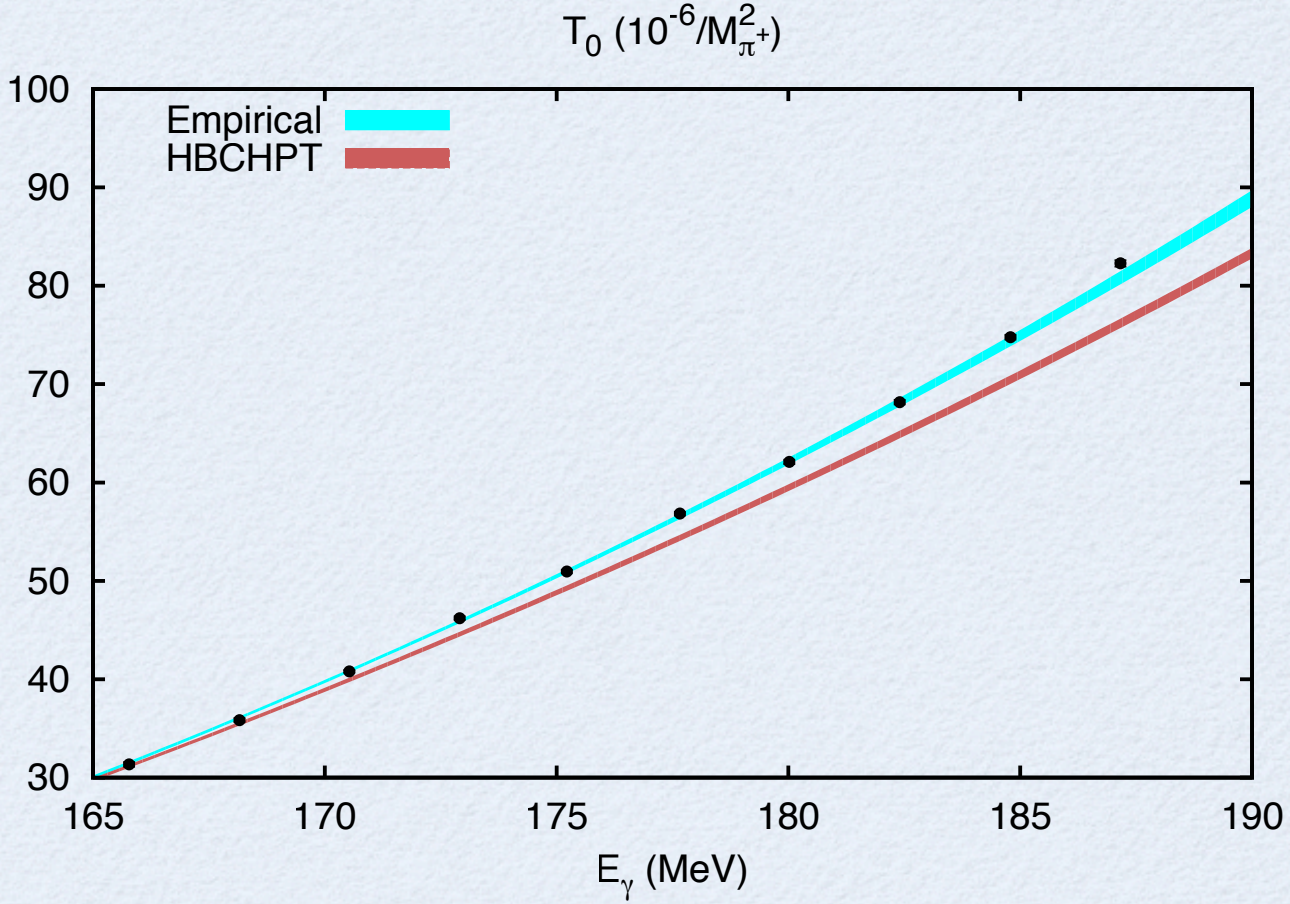






$$\sigma_T(W,\theta) = \frac{q_\pi}{k_\gamma}\left[T_0(W) + T_1(W)\,\mathcal{P}_1(\theta) + T_2(W)\,\mathcal{P}_2(\theta)\right]$$

T_0 (total cross section)

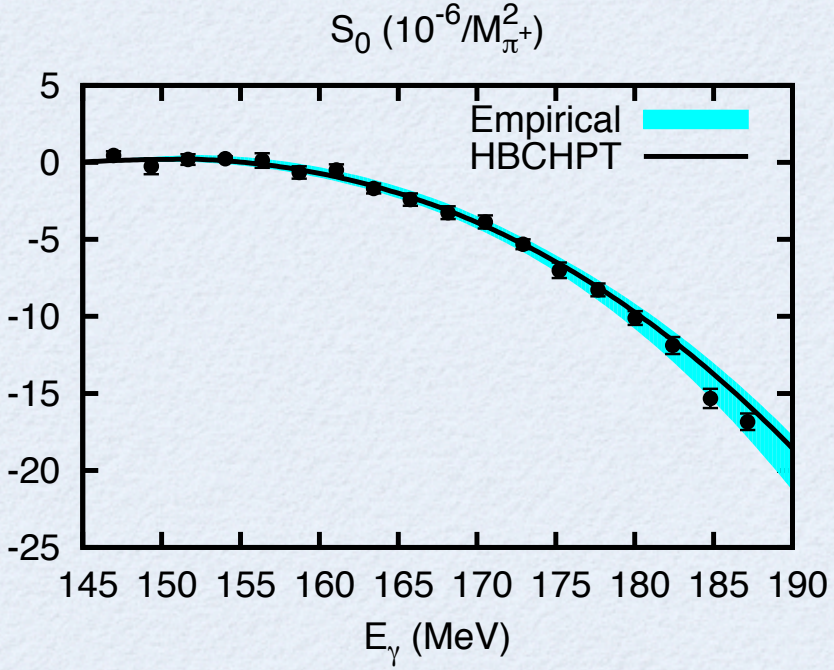


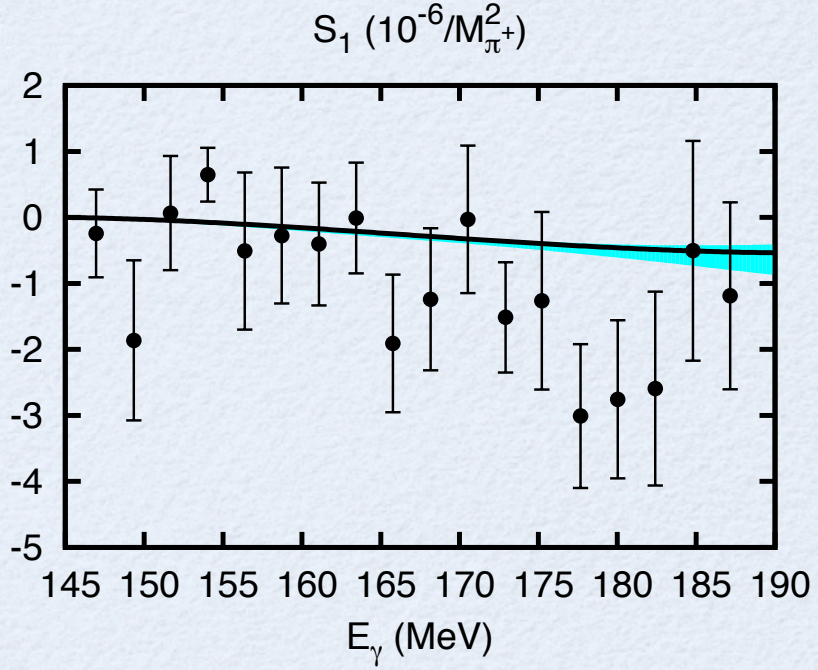
Deviation due to P waves ➢ $\Delta(1232)$

PHOTON ASYMMETRY

D waves effect hinted in S_1 but no claim can be made so far

We need better asymmetry data





PHOTON ASYMMETRY

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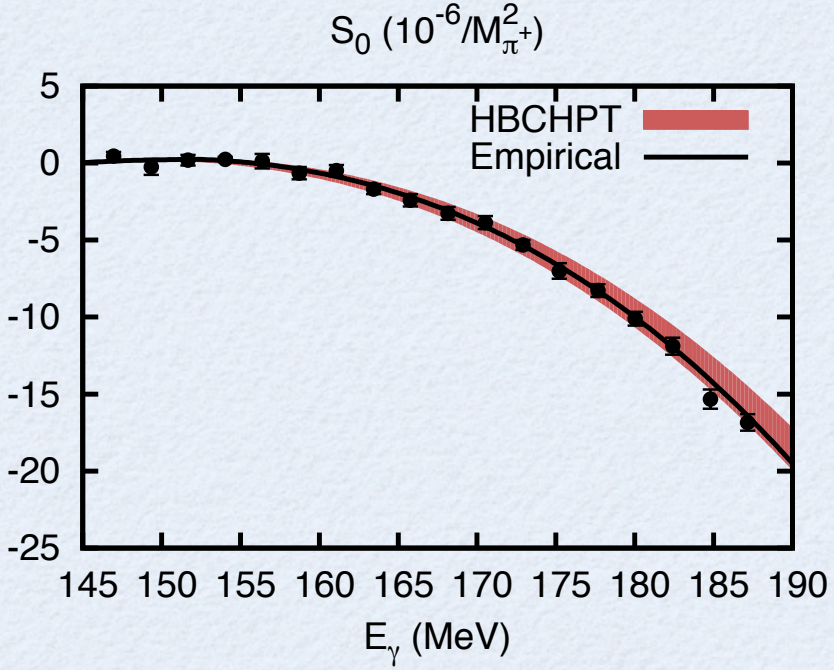
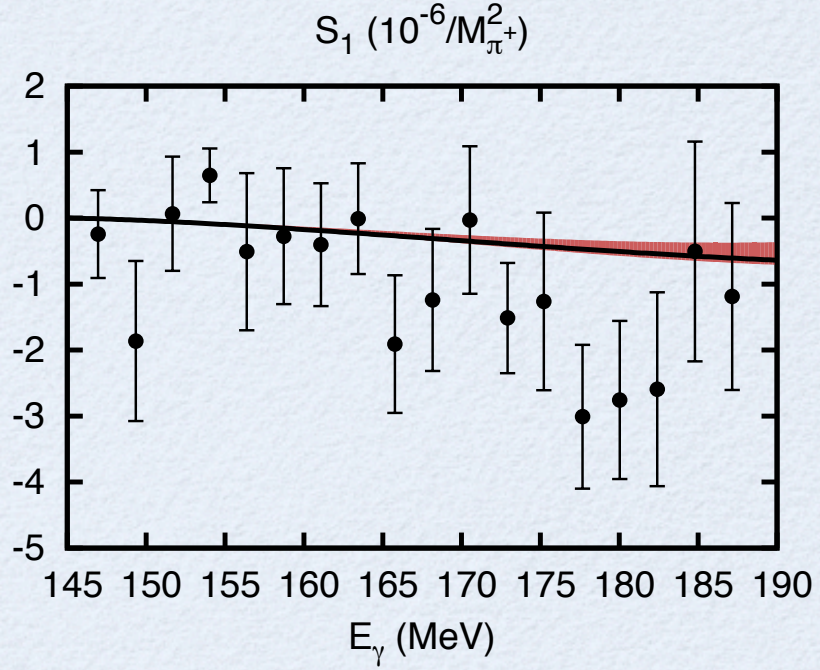
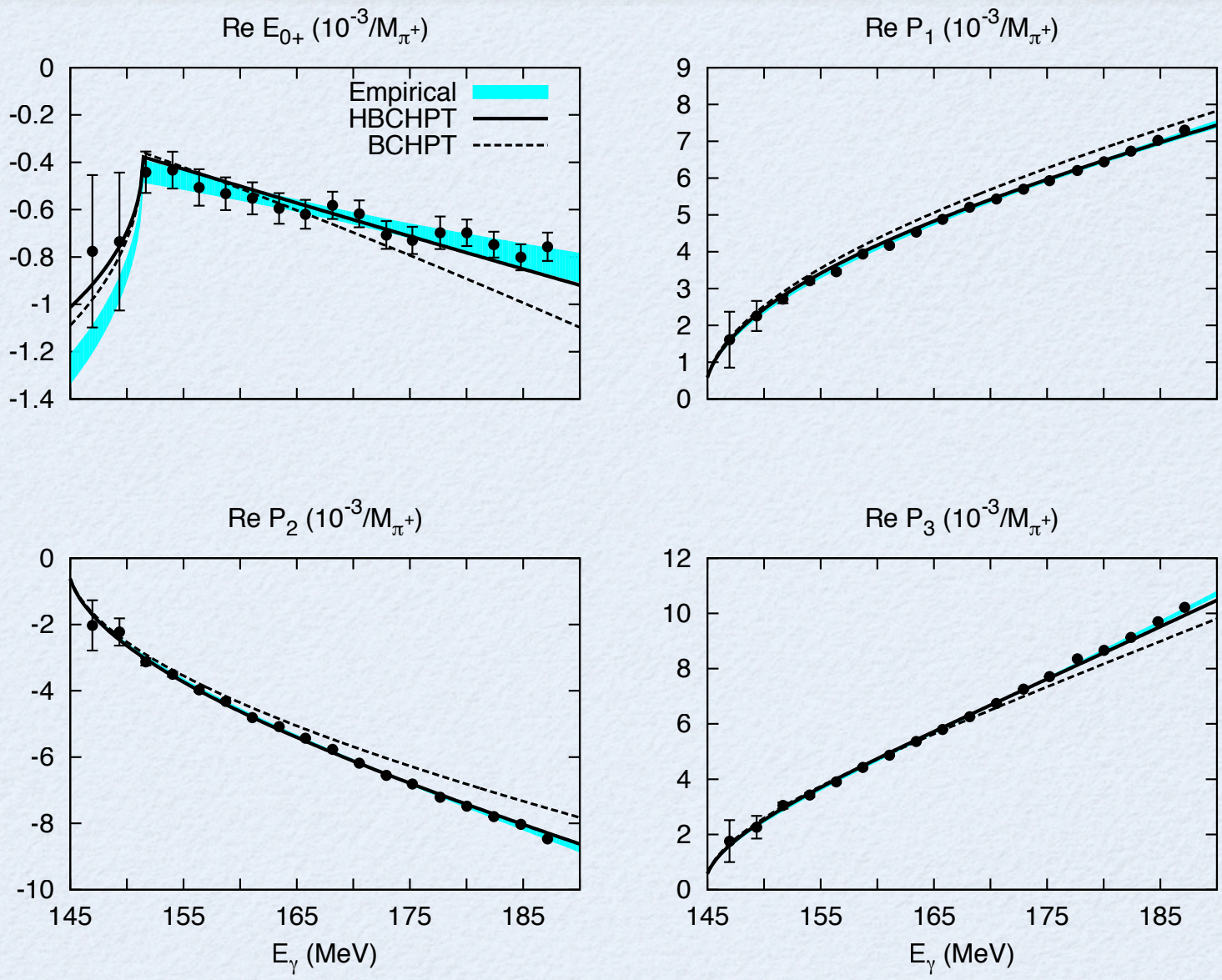
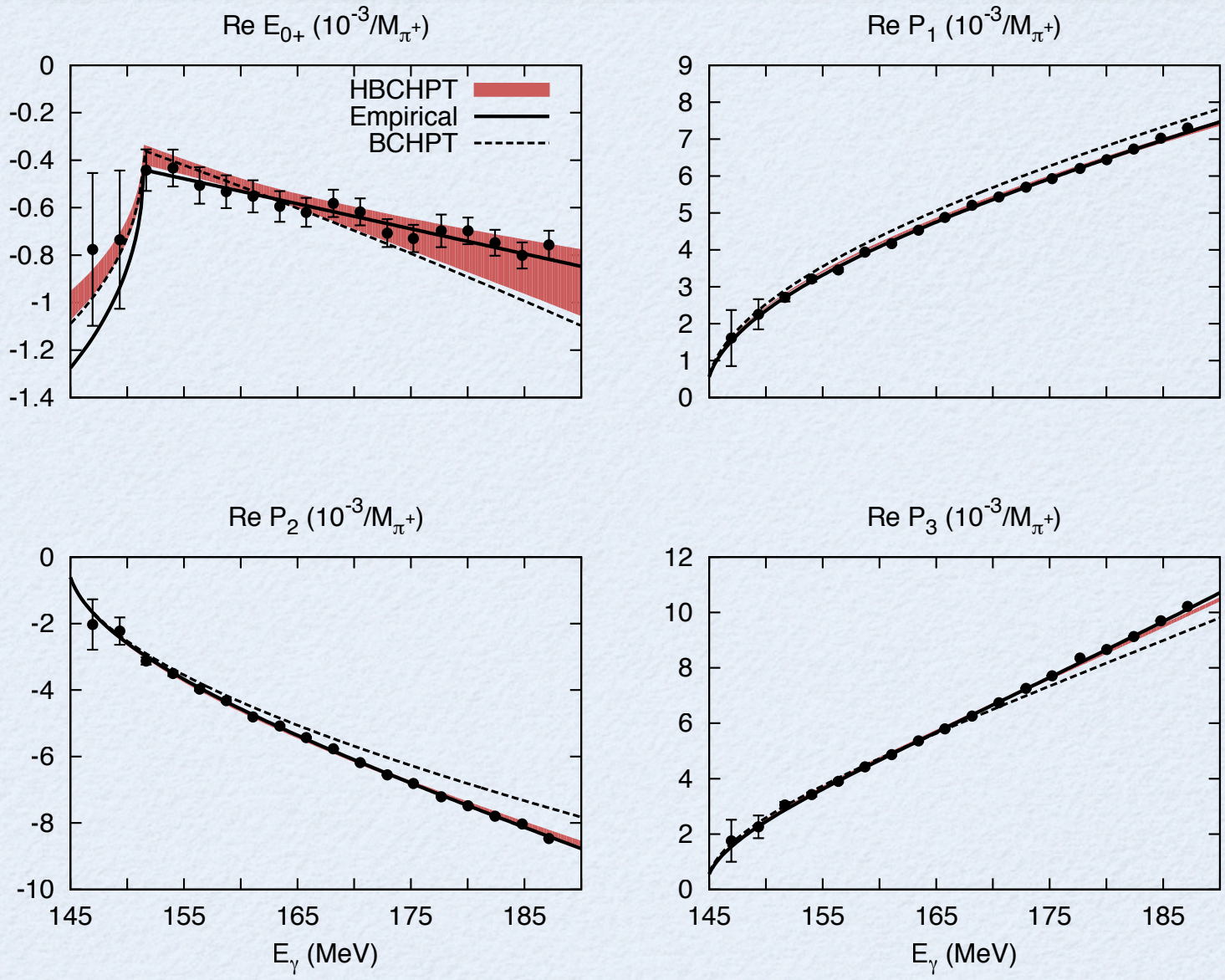




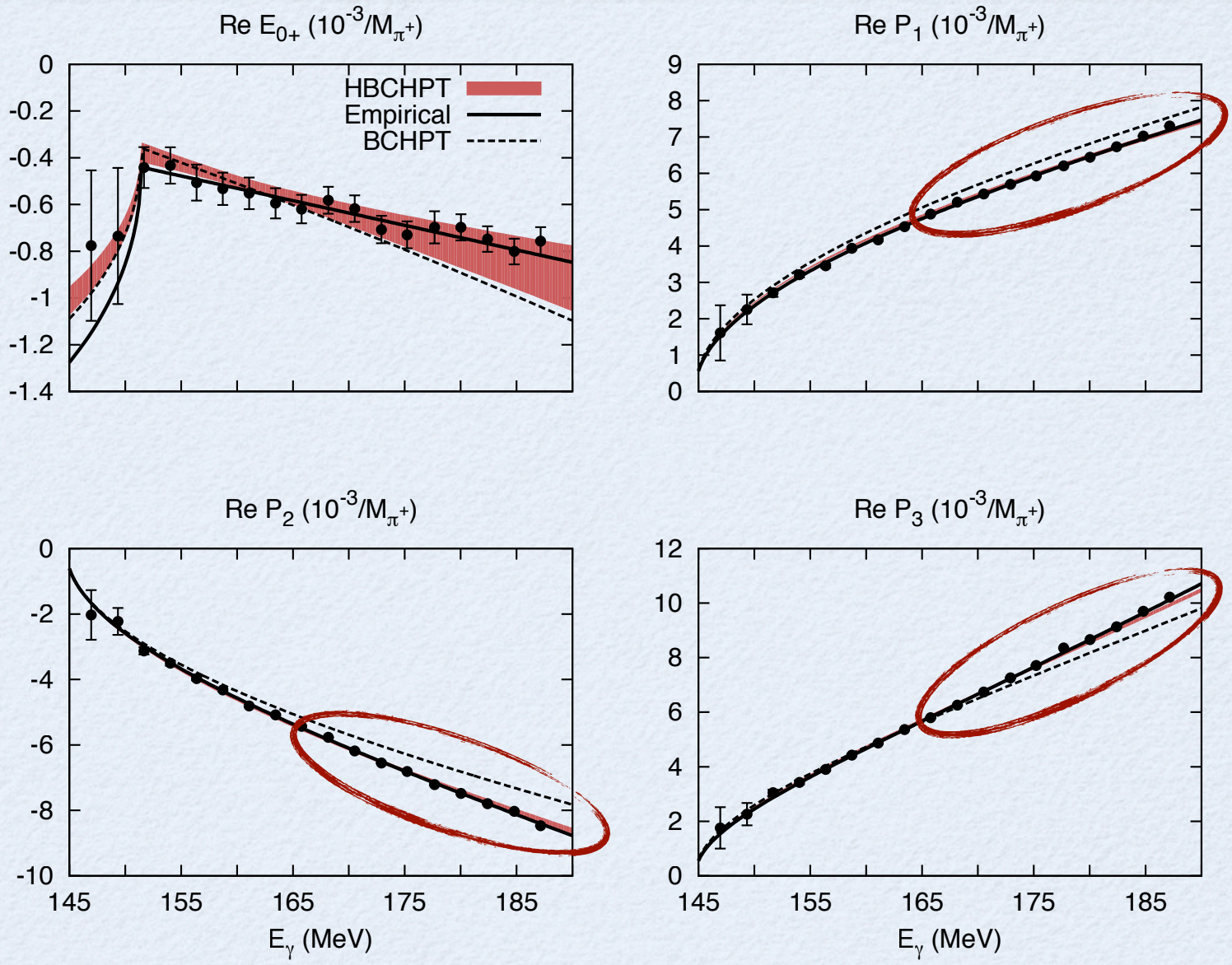
PARTIAL WAVES



PARTIAL WAVES

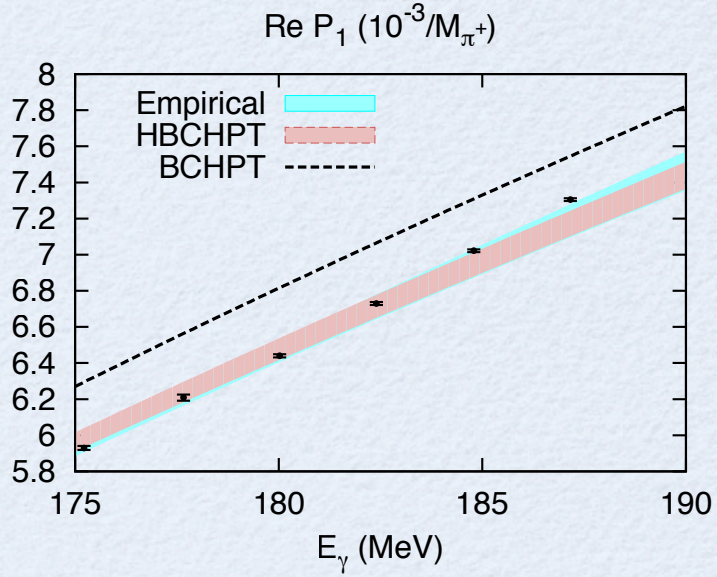


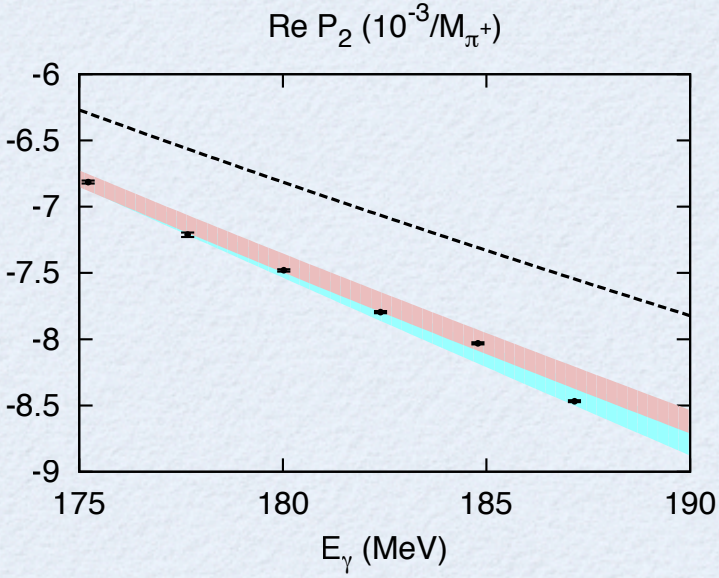
PARTIAL WAVES

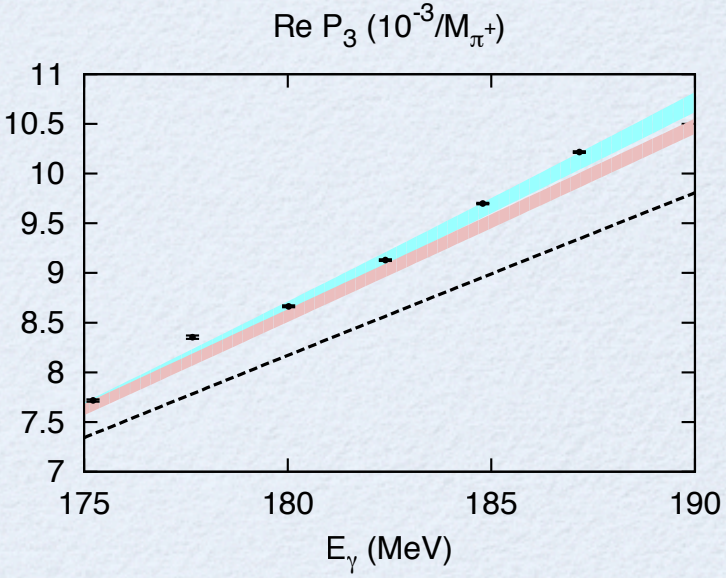


PARTIAL WAVES

P_3 is largely underestimated in CHPT







SUMMARY AND FUTURE

SUMMARY

- Very good description of data
- No D waves isolated yet
- Large errors in the determination of the S wave

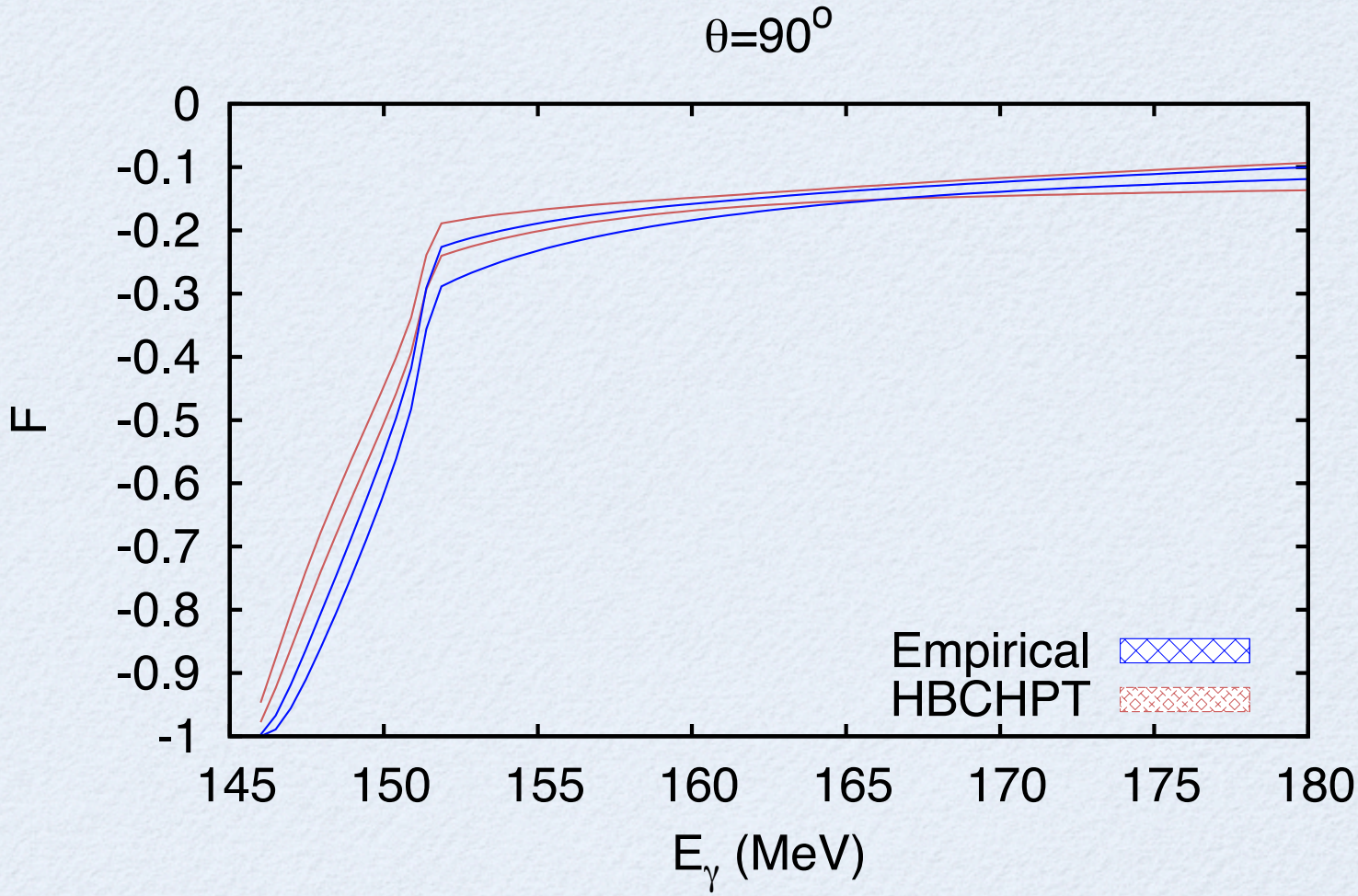
SUMMARY

- Empirical fit goes well up to 185 MeV
- HBCHPT and BCHPT fine up to 165-170 MeV
- Above 165-170 MeV: Put the $\Delta(1232)$

FUTURE

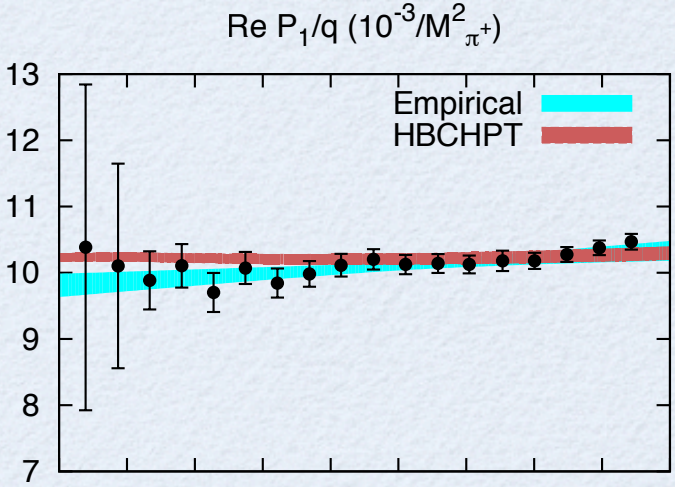
- Theory
  - BCHPT with $\Delta(1232)$
- Experiment
  - F asymmetry ➢ S wave and D waves effects
  - T asymmetry ➢Im E_{0+} ➢Unitarity

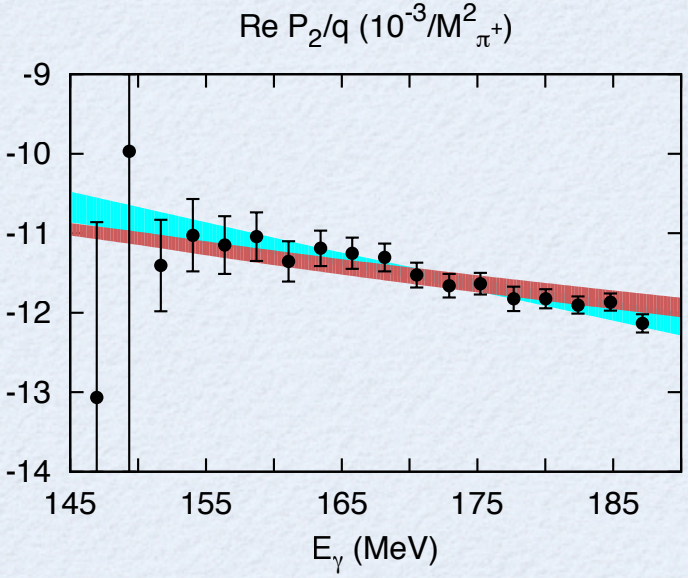
F ASYMMETRY

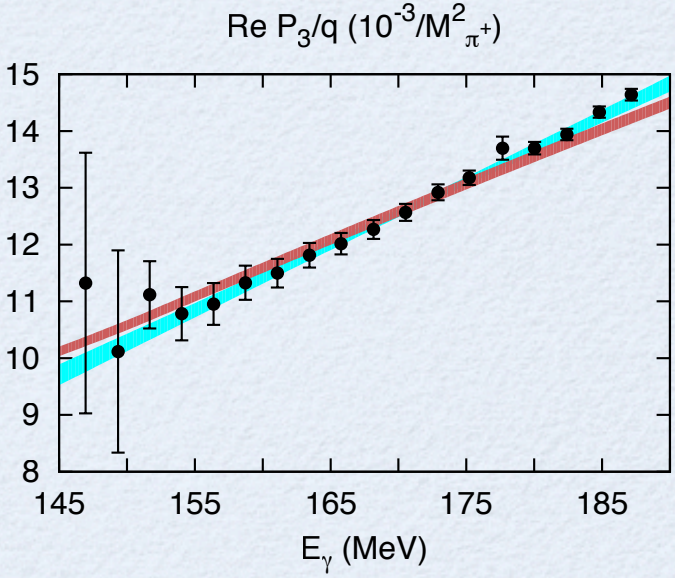

θ=90°
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
F
145
150
155
160
165
170
175
180
Eγ (MeV)
Empirical
HBCHPT

SUPPORTING MATERIAL

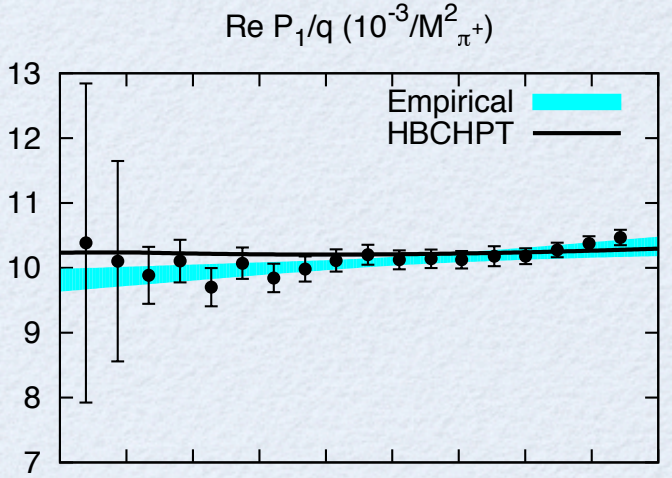
PARTIAL WAVES

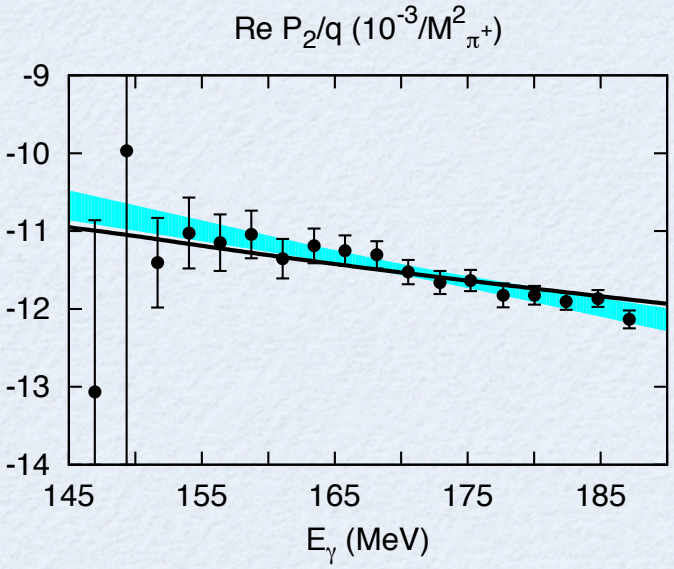


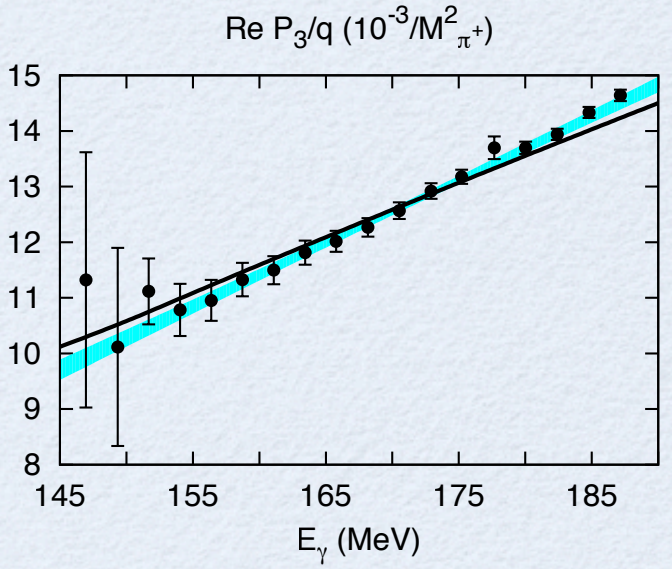




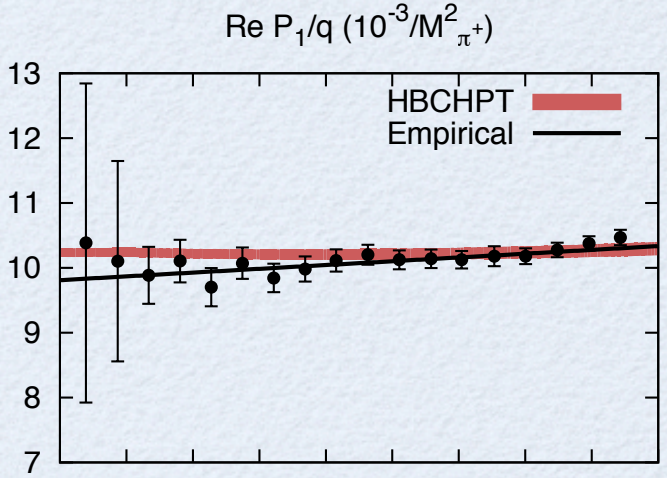
PARTIAL WAVES

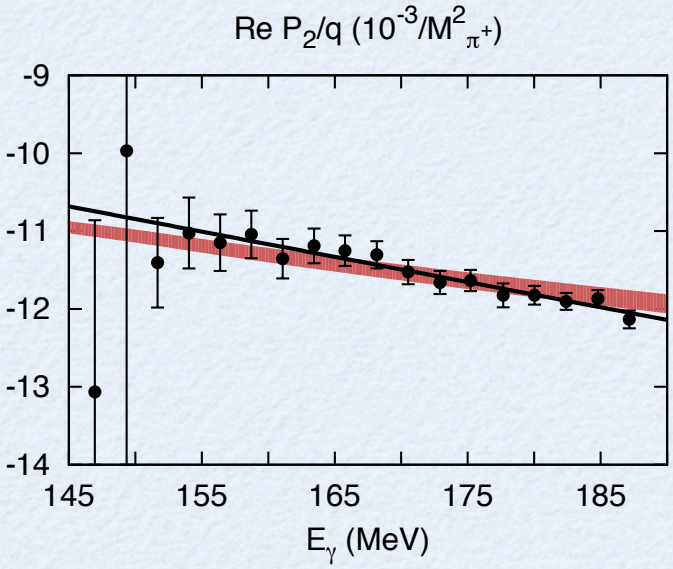


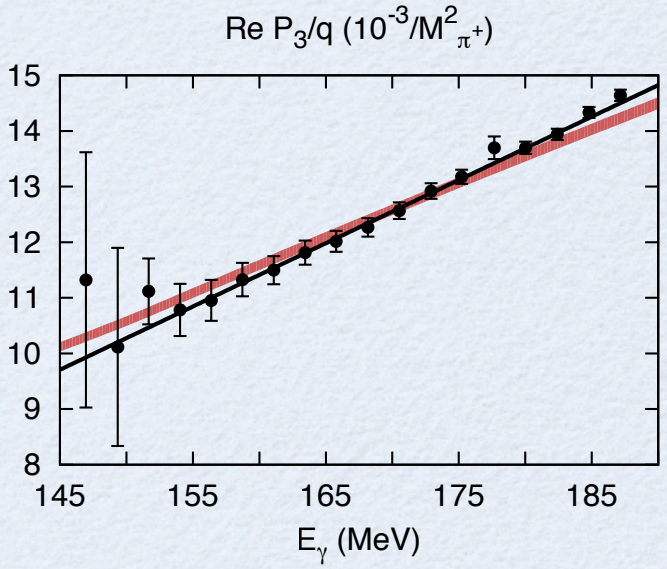




PARTIAL WAVES







LECS (HBCHPT, S-WAVE)