8Be nuclear theory predictions

Xilin Zhang
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X.Z. and G. Miller, arXiv:1703.04588

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Outline

- The experiment and anomaly
- Kinematics and electromagnetic transitions
- Model inspired by effective field theory (EFT) and benchmarks against on-shell photon production
- e^+e^- pair emission anisotropy
- Possible form factors in the e^+e^- production
- Comments
- Summary

Introduction

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár, T. G. Tornyi, and Zs. Vajta
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(Received 7 April 2015; published 26 January 2016)

Electron-positron angular correlations were measured for the isovector magnetic dipole 17.6 MeV ($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T = 0$) and the isoscalar magnetic dipole 18.15 MeV ($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}Be. Significant enhancement relative to the internal pair creation was observed at large angles in the angular correlation for the isoscalar transition with a confidence level of $> 5\sigma$. This observation could possibly be due to nuclear reaction interference effects or might indicate that, in an intermediate step, a neutral isoscalar particle with a mass of $16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV/c^2 and $J^\pi = 1^+$ was created.

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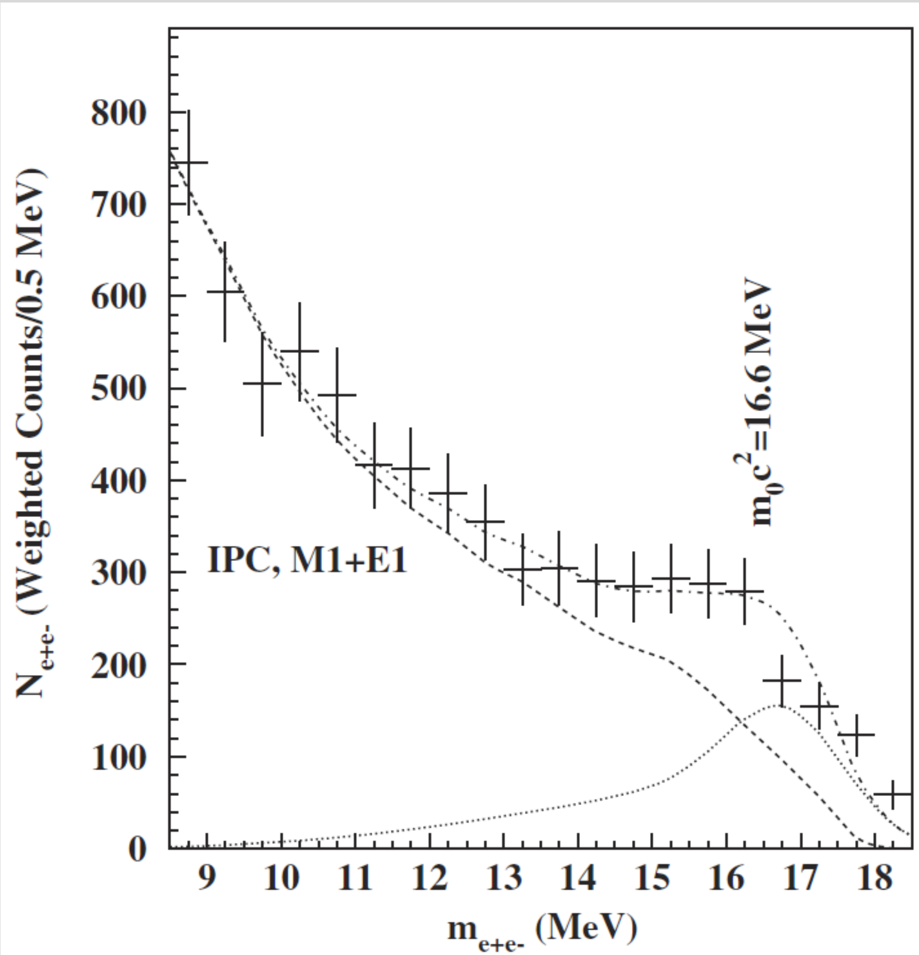

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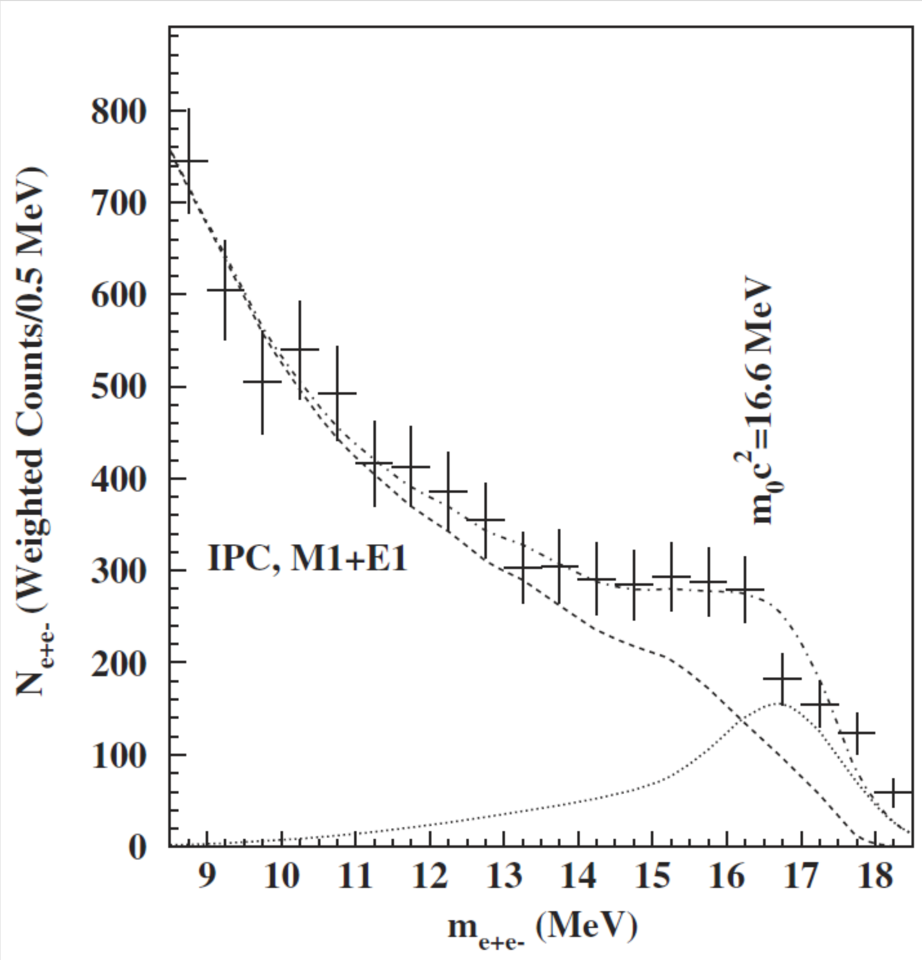

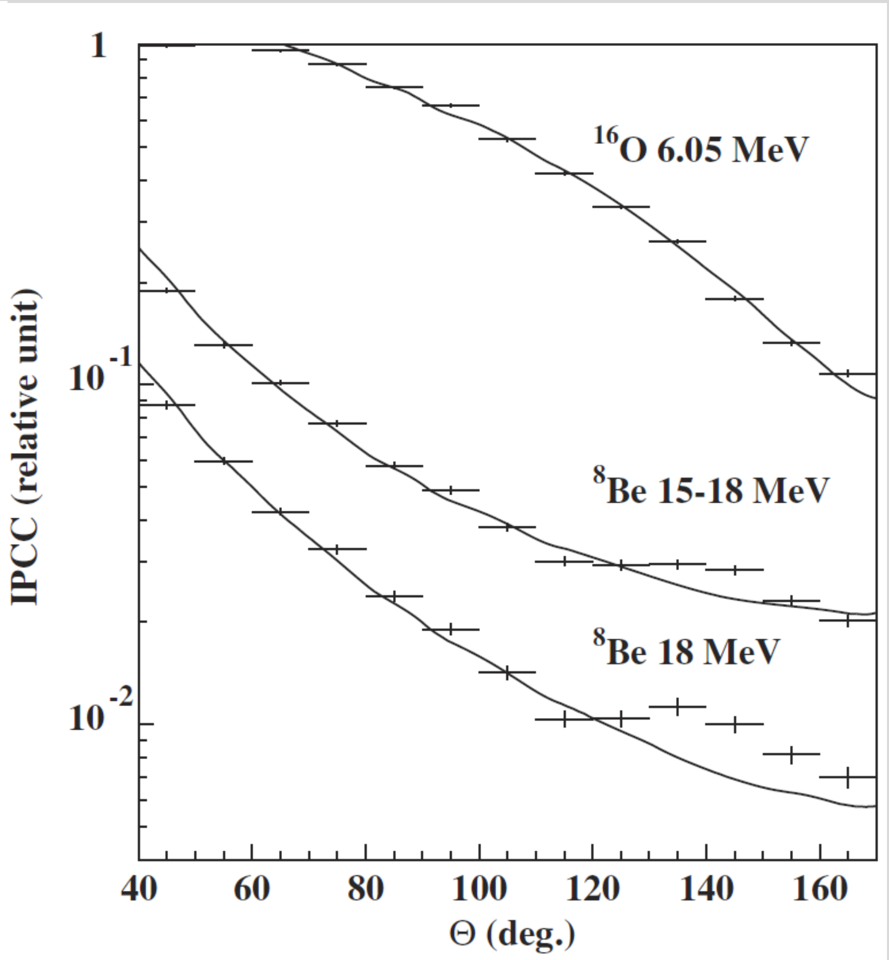

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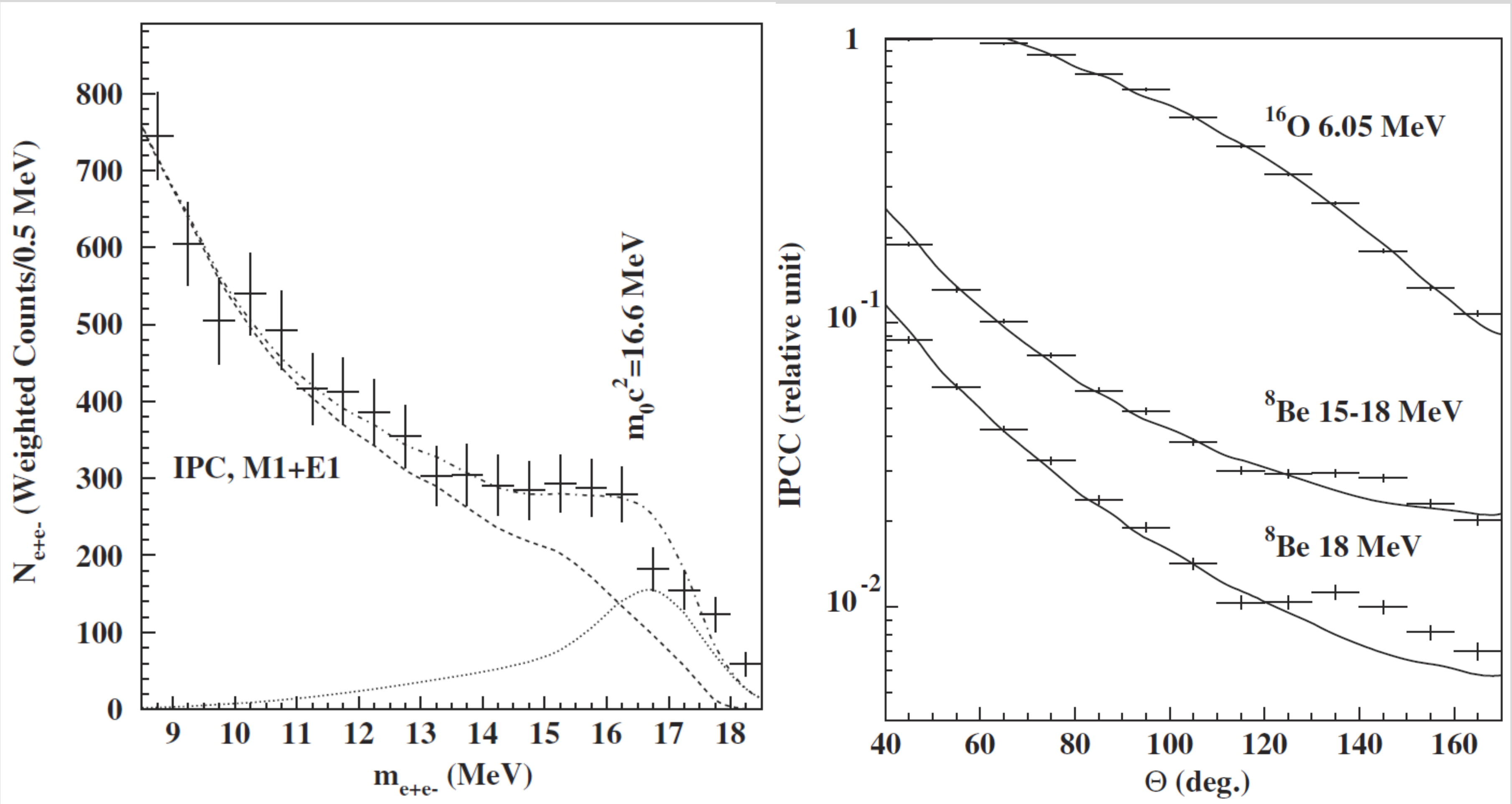
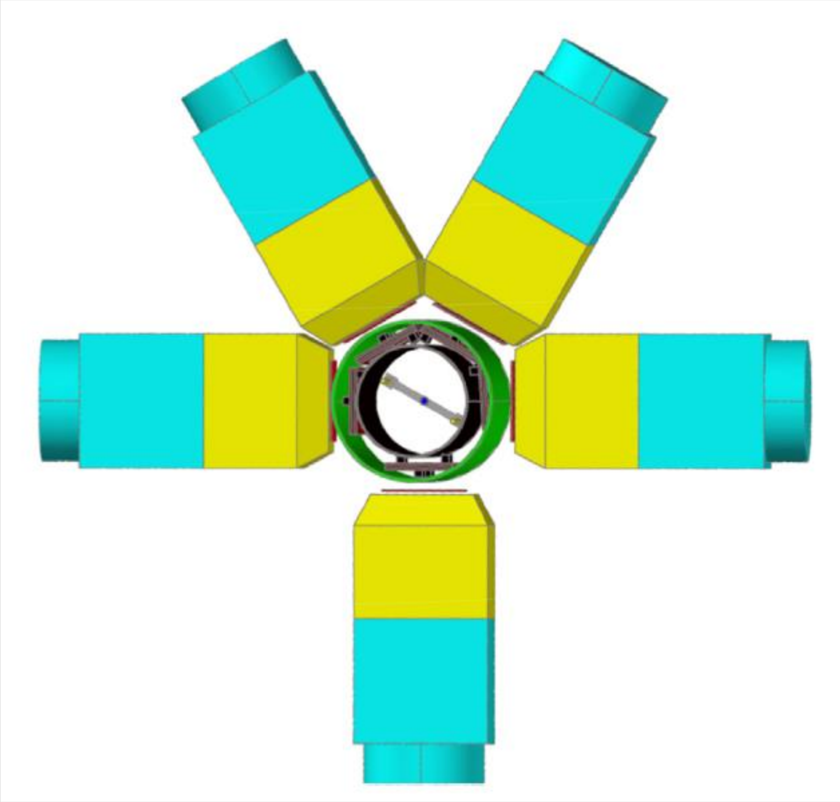
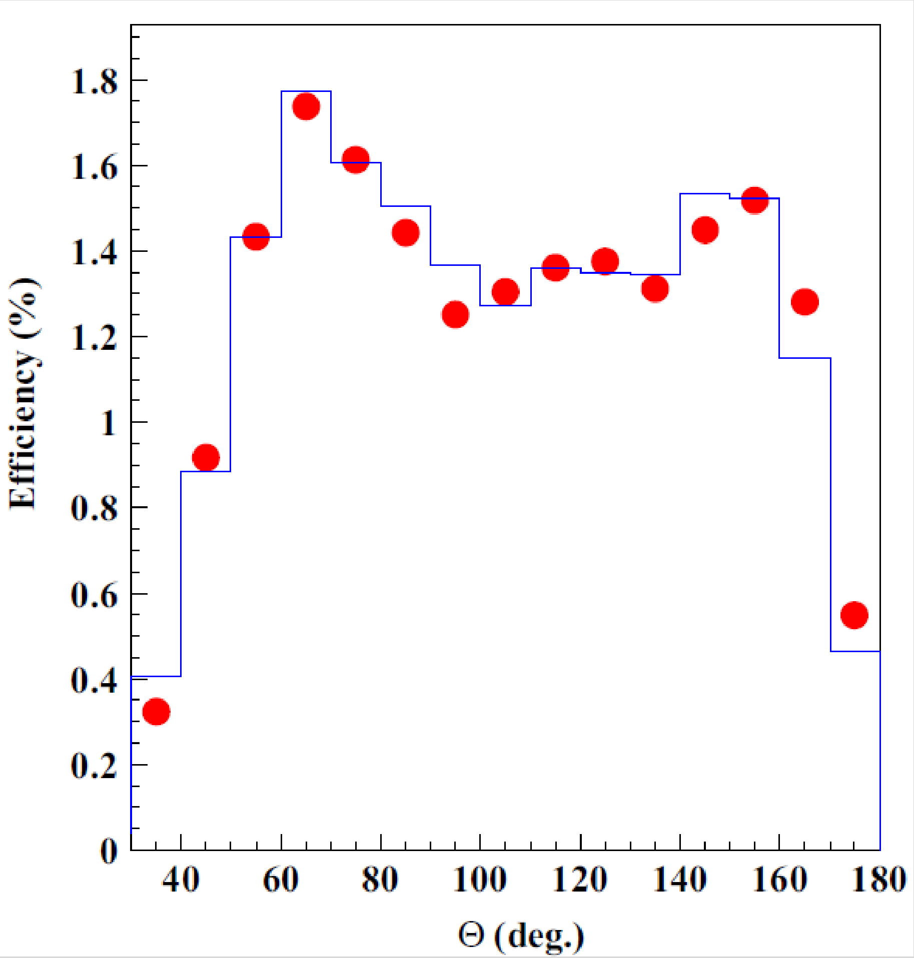


The theoretical model used is from M. E. Rose [PR 76, **678** (1949)]; No interference was studied; emission was assumed to be isotropic

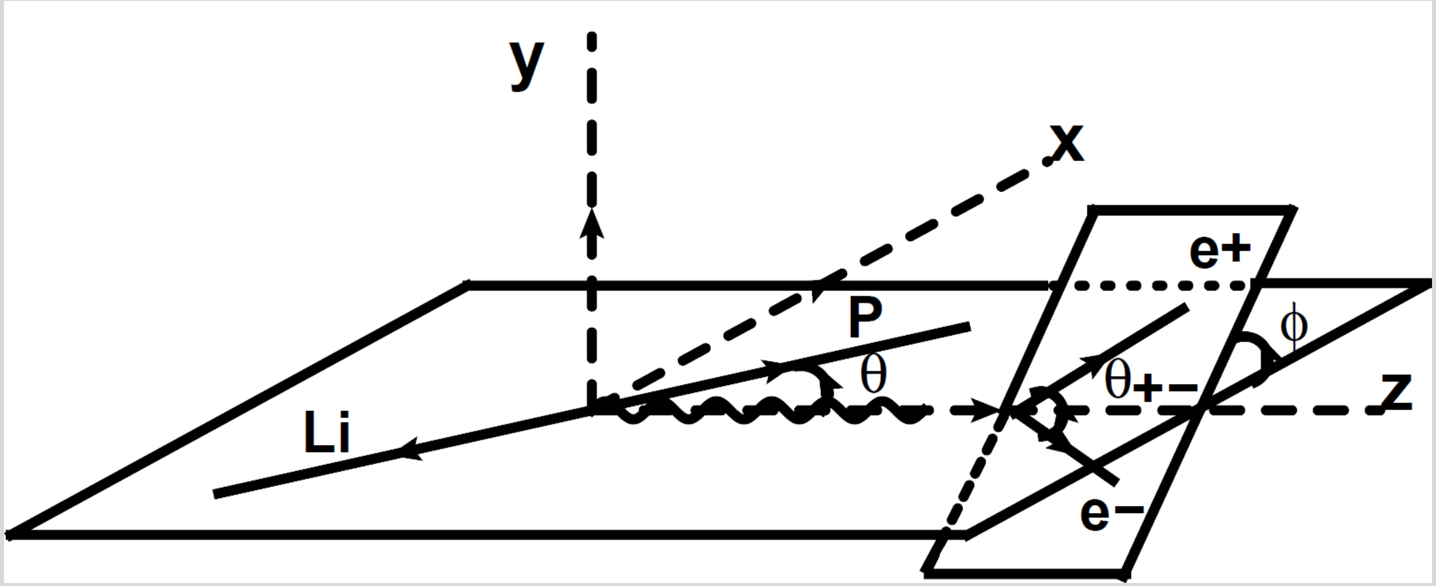
The experiment





Nuclear Instruments and Methods in Physics Research A 808, 21 (2016)

Kinematics



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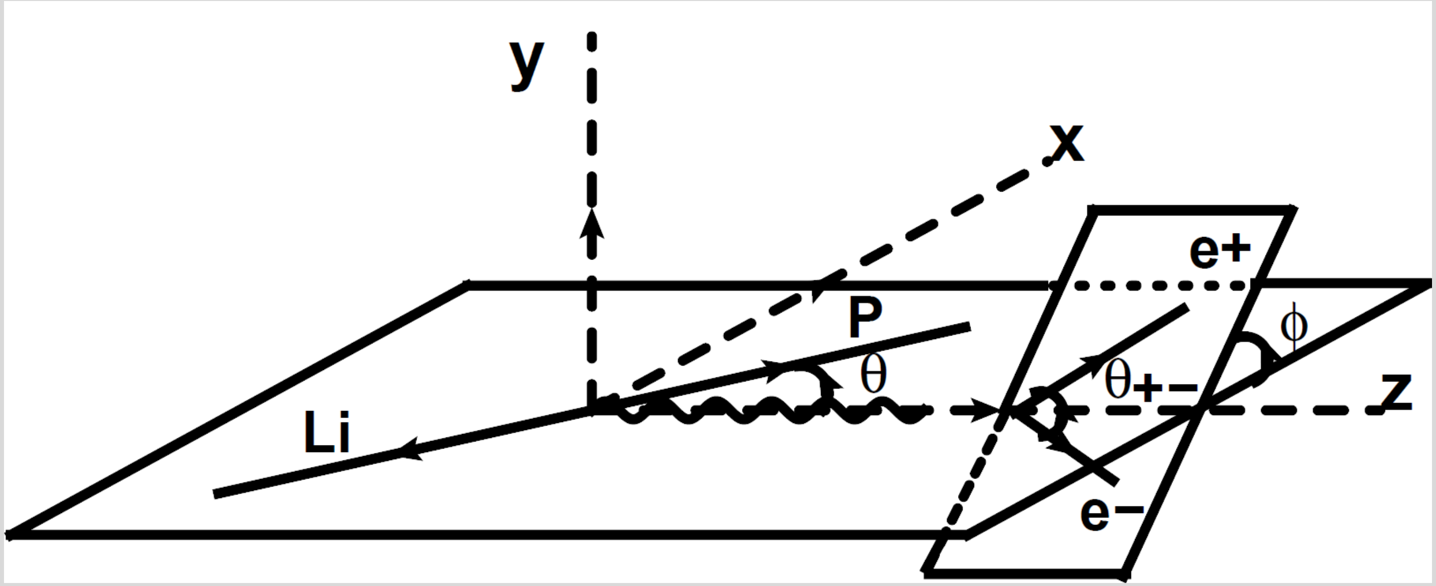
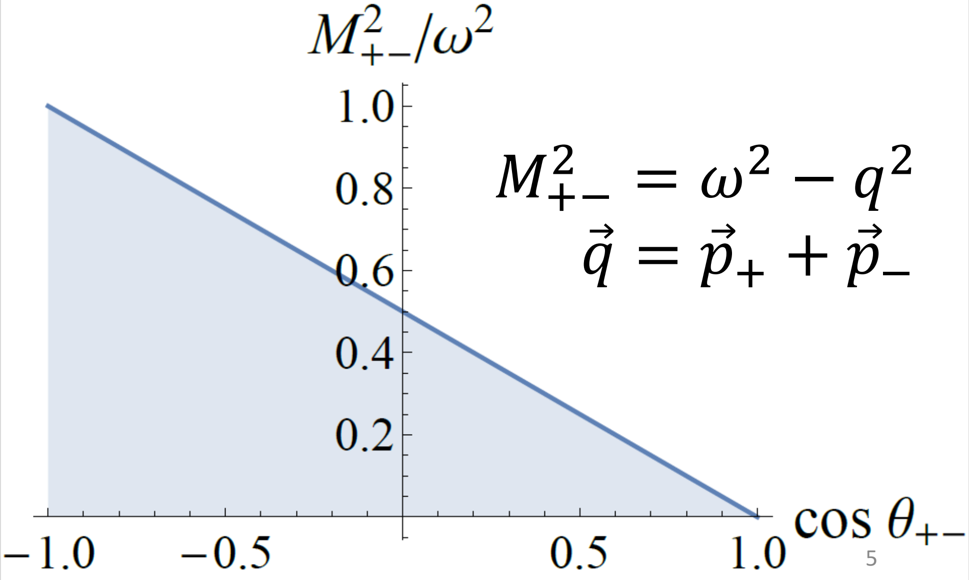


$$\frac{d\sigma}{d\cos\theta\, d\phi\, d\cos\theta_{+-} dE_{+}}$$

$$\frac{d\sigma}{d\cos\theta\, d\phi\, d\cos\theta_{+-} dM_{+}}$$



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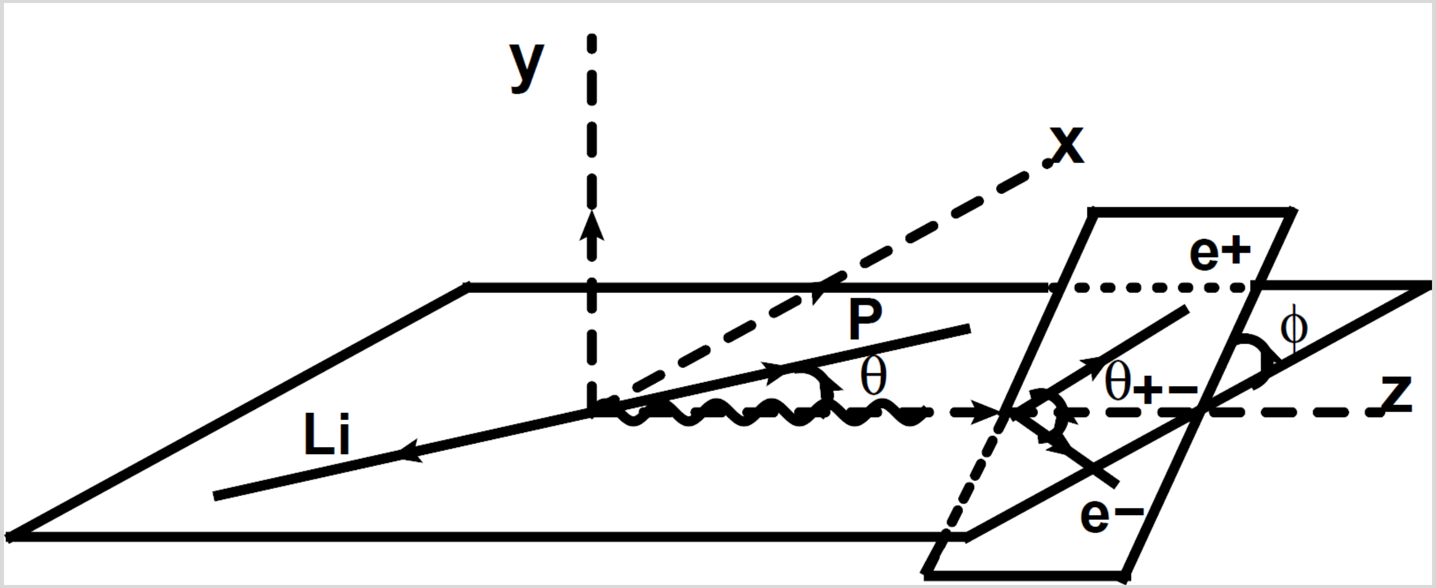

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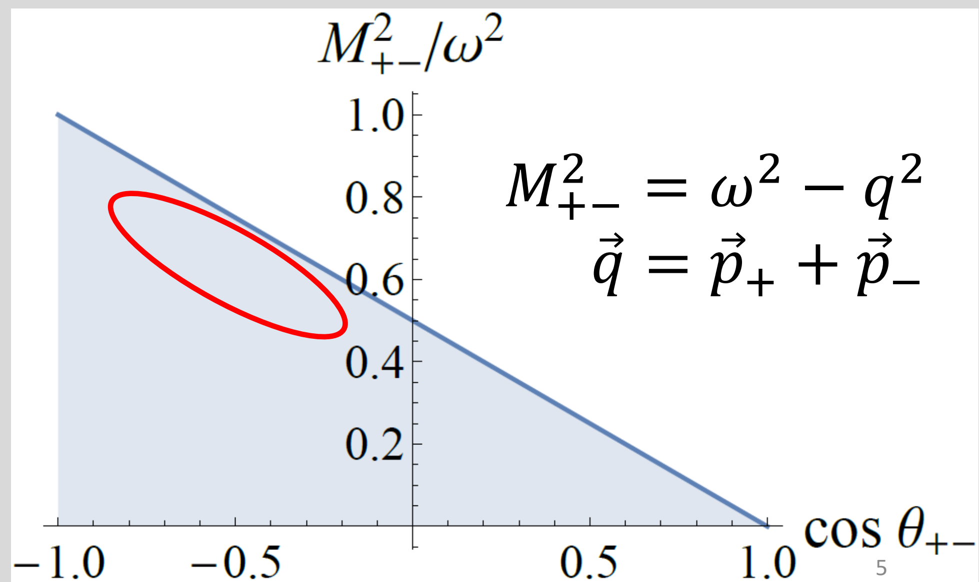
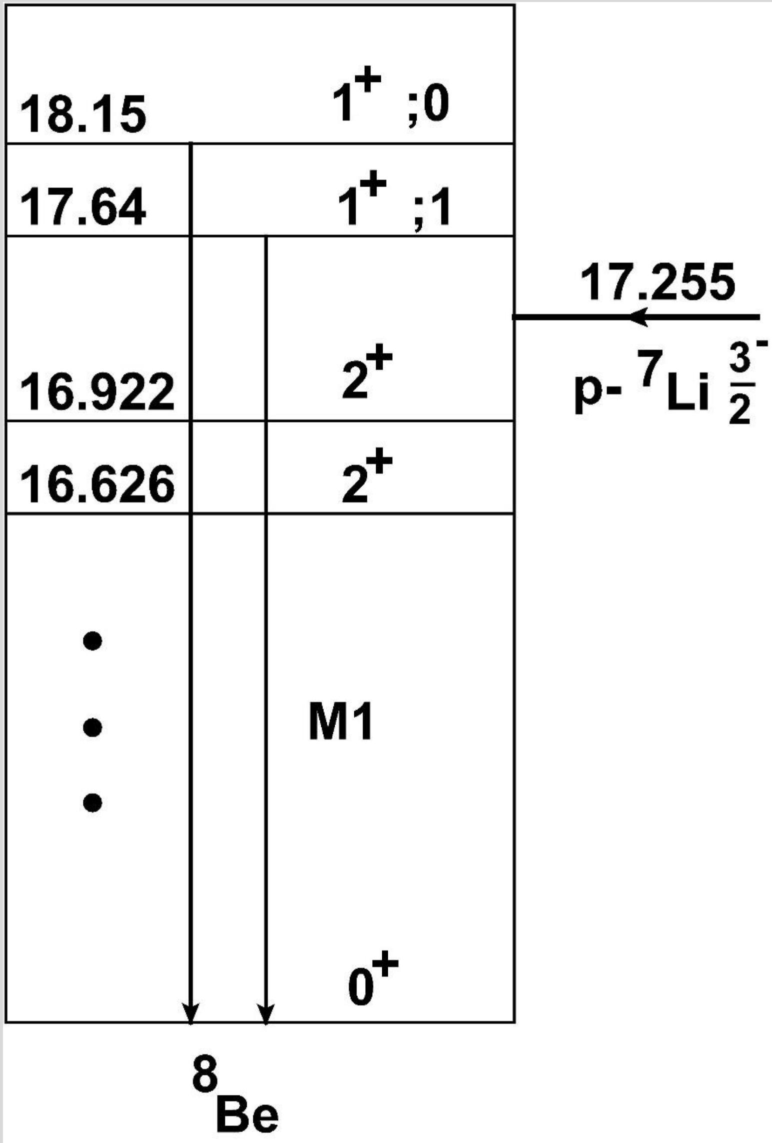


EM transitions



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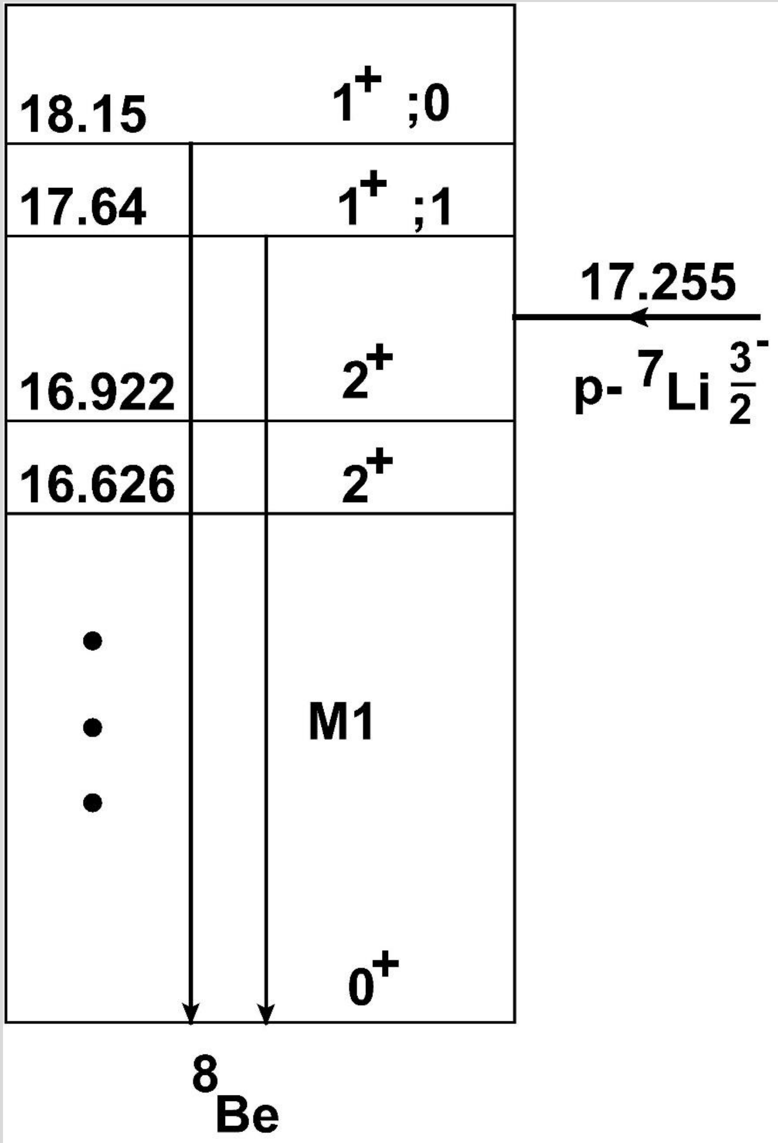
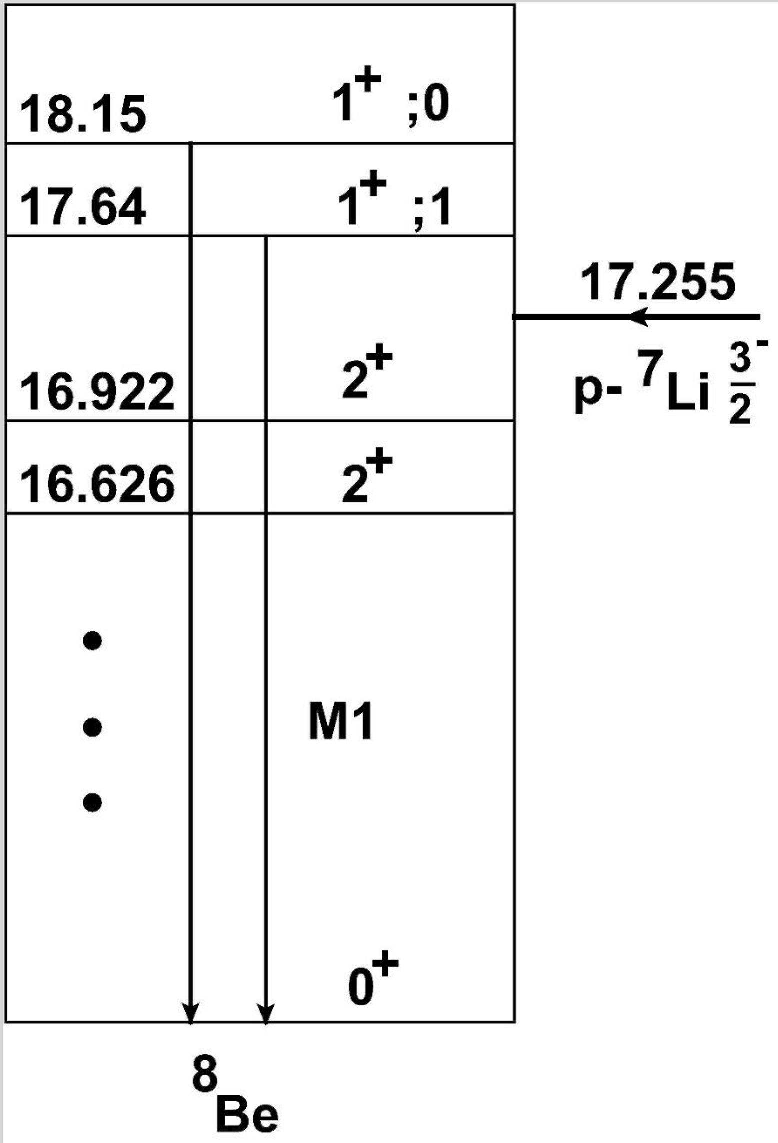


$U_{\lambda SL}$	λ	S	L
E1	1	1	0
M1	1	1, 2	1
E2	2	1, 2	1

EM transitions



Operator rank

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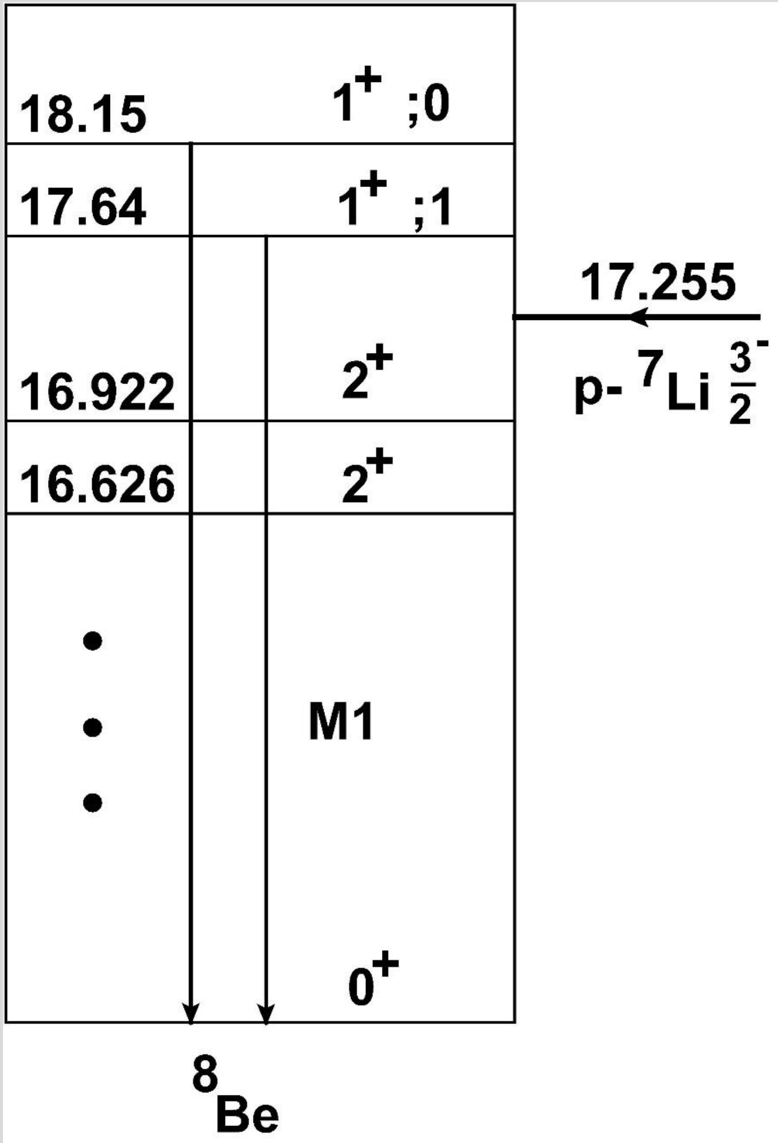

Operator rank → λ

Initial state total spin → S

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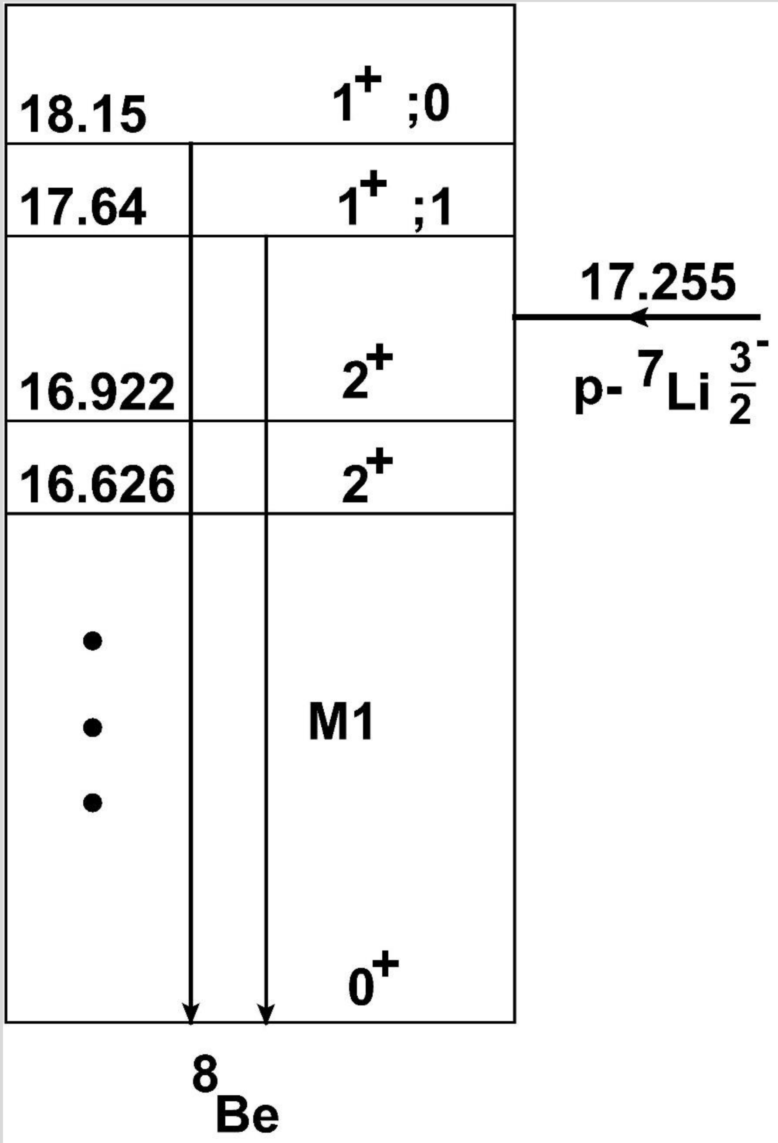

EM transitions

Operator rank → λ

Initial state total spin → S

Initial state angular momentum → L

$U_{\lambda SL}$	λ	S	L
E1	1	1	0
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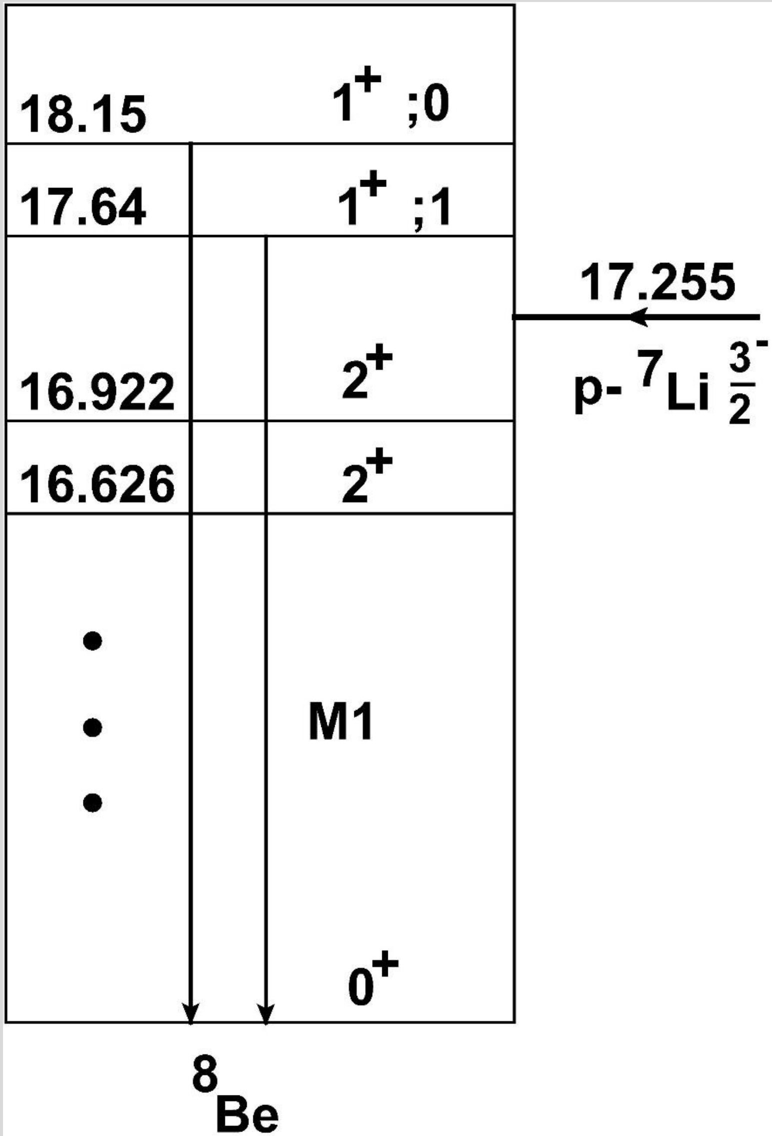

EM transitions

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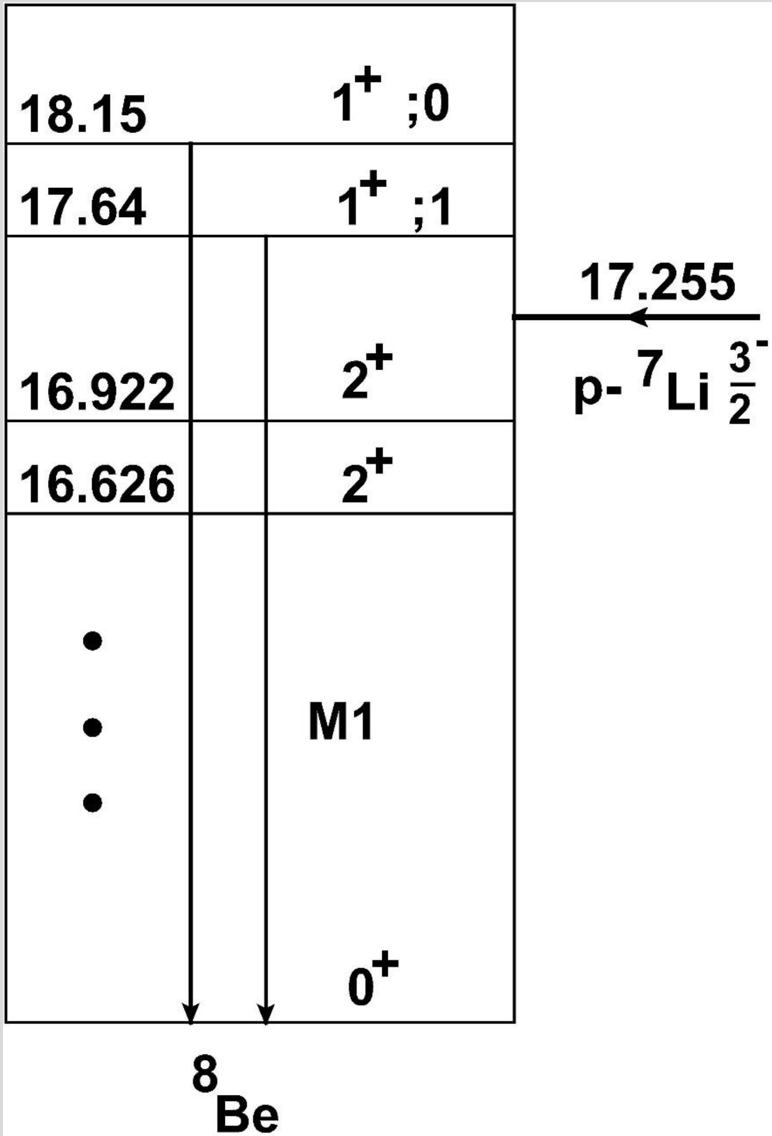
They interfere!

EM transitions



Operator rank	Initial state total spin	Initial state angular momentum

$U_{\lambda SL}$	λ	S	L
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M1	1	1, 2	1
E2	2	1, 2	1

They interfere!

	$E_{(i)}$ (MeV)	$\Gamma_{\gamma(i)}$ (eV)	$\Gamma_{(i)}$ (keV)
$i = 0$	0.895	1.9(±0.4)	138(±6)
$i = 1$	0.385	15.8(±1.8)	10.7(±0.6)

EFT-based model for $J \equiv \langle \mathrm{Be} | \hat{J} | \mathrm{Li} + \mathrm{p} \rangle$

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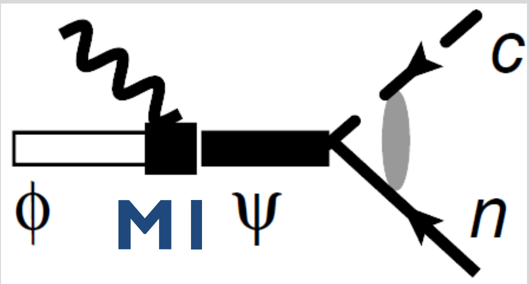

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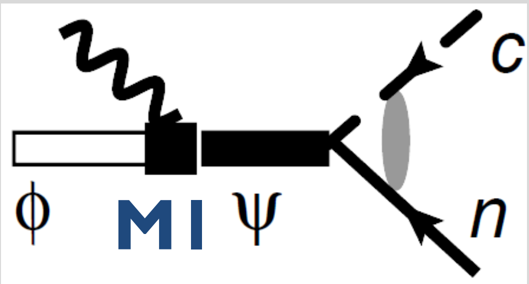

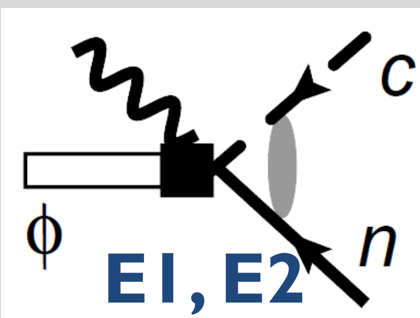

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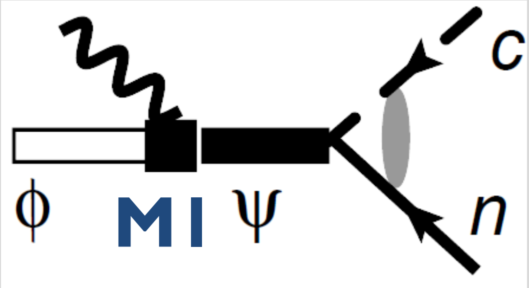
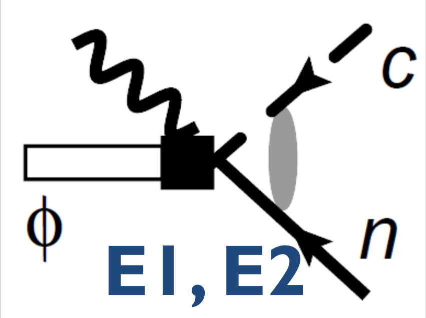


$$J^0 = (CG)\, q\, U_{E1} + q^2 \frac{p}{M} \left[(CG)\, U_{E2,1} + (CG)\, U_{E2,2} \right]$$

$$J^i = (CG)\, \omega\, U_{E1} + q \frac{p}{M} \left[\begin{array}{l} (CG)\, U_{M1,1} + (CG)\, U_{M1,2} \\ + (CG)\, \omega\, U_{E2,1} + (CG)\, \omega\, U_{E2,2} \end{array} \right]$$



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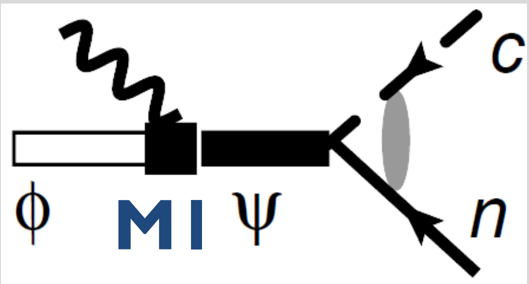

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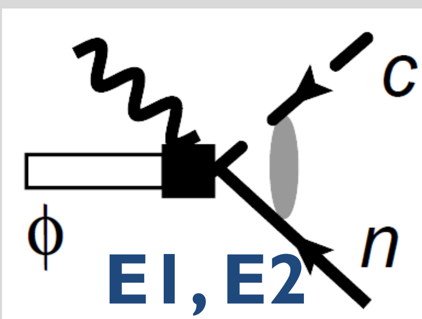
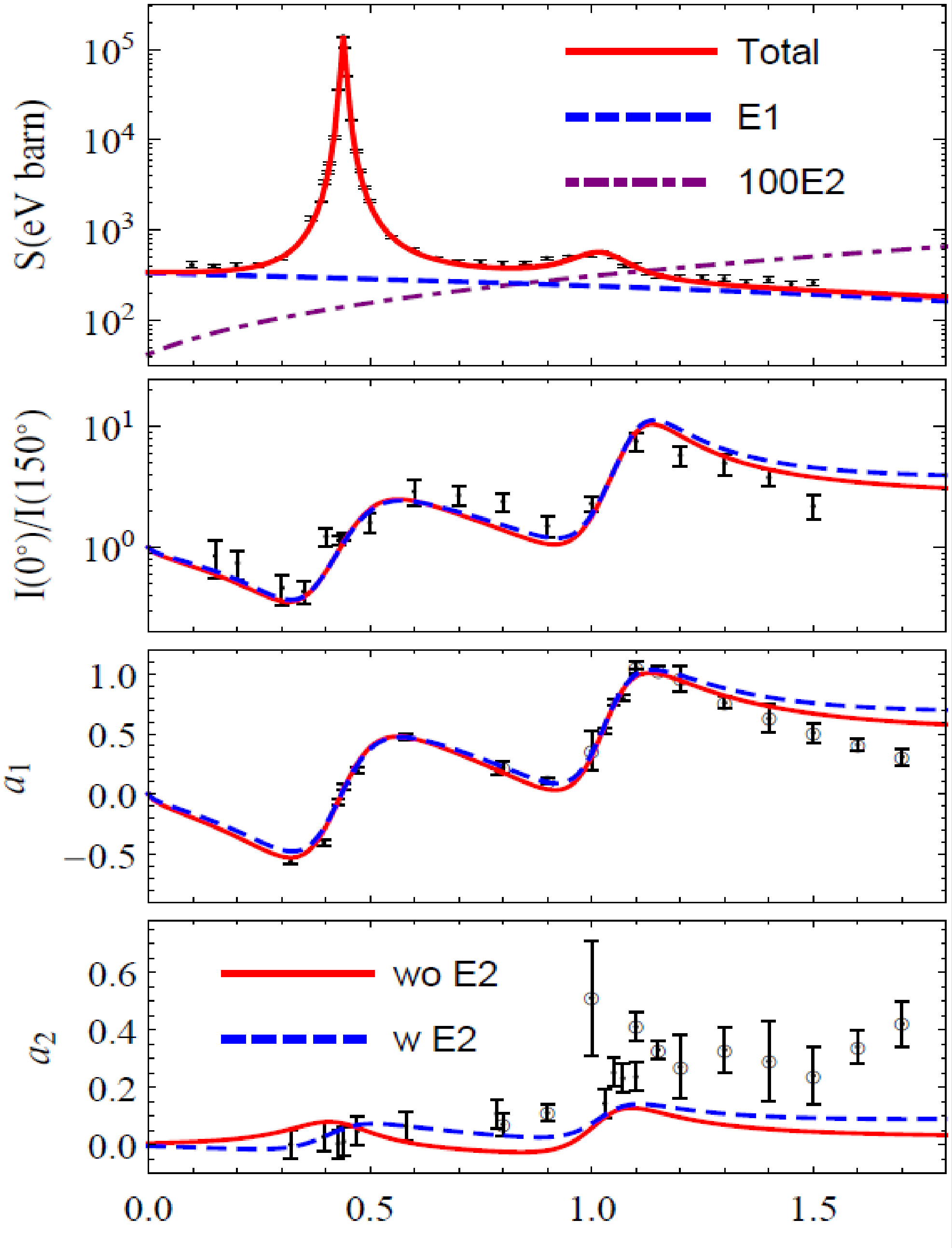


$$U_{M1,1} \sim -\frac{\sqrt{\Gamma_{\gamma(0)} \Gamma_{(0)} X_{(0)}}}{E - E_{(0)} + i \frac{\Gamma_{(0)}}{2}} + \frac{\sqrt{\Gamma_{\gamma(1)} \Gamma_{(1)} X_{(1)}}}{E - E_{(1)} + i \frac{\Gamma_{(1)}}{2}}$$

$$U_{M1,2} \sim \frac{\sqrt{\Gamma_{\gamma(0)} \Gamma_{(0)} (1 - X_{(0)})}}{E - E_{(0)} + i \frac{\Gamma_{(0)}}{2}} + \frac{\sqrt{\Gamma_{\gamma(1)} \Gamma_{(1)} (1 - X_{(1)})}}{E - E_{(1)} + i \frac{\Gamma_{(1)}}{2}}$$

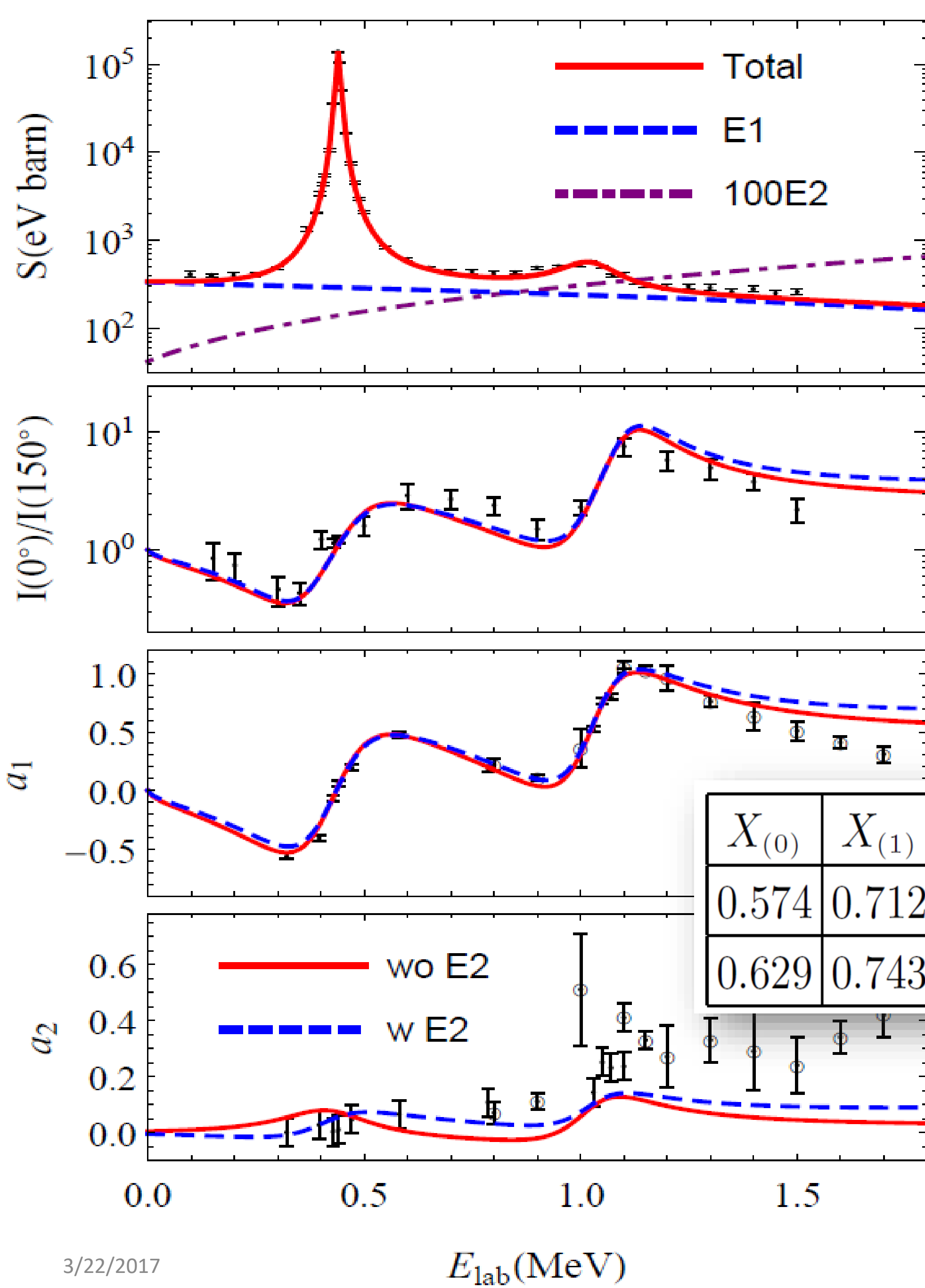
$$U_{E1} \sim d_{E1} (1 - d'_{E1} \frac{p^2}{\Lambda^2}); \quad U_{E2,1} \sim d_{E2,1}; \quad U_{E2,2} \sim d_{E2,2}$$



On-shell photon production

$$\sum |\mathrm{M}|^2 \equiv T_0 \times$$
$$\left[1 + a_1 P_1(\cos\theta) + a_2 P_2(\cos\theta)\right]$$

D. Zahnow et.al., *Z. Phys. A* **351**, 229 (1995);
B. MainsBridge, *Nucl.Phys.* **21**, 1(1960);
D.J. Schlueter, et.al., *Nucl.Phys.* **58**, 254 (1964)



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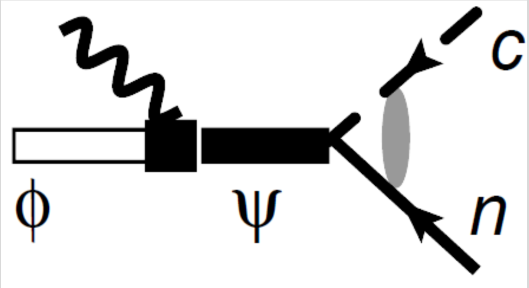
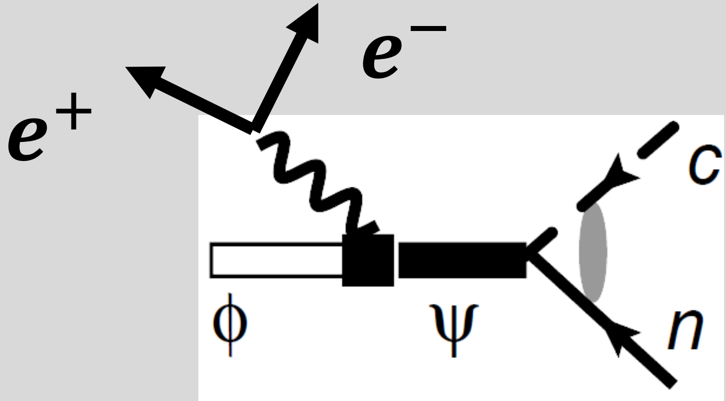
$X_{(0)}$	$X_{(1)}$	d_{E1} $(\Lambda^{-\frac{5}{2}})$	d'_{E1}	$d_{E2,1}$ $(\Lambda^{-\frac{7}{2}})$	$d_{E2,2}$ $(\Lambda^{-\frac{7}{2}})$
0.574	0.712	0.866	1.64	0	0
0.629	0.743	0.860	1.61	8.27	–18.0

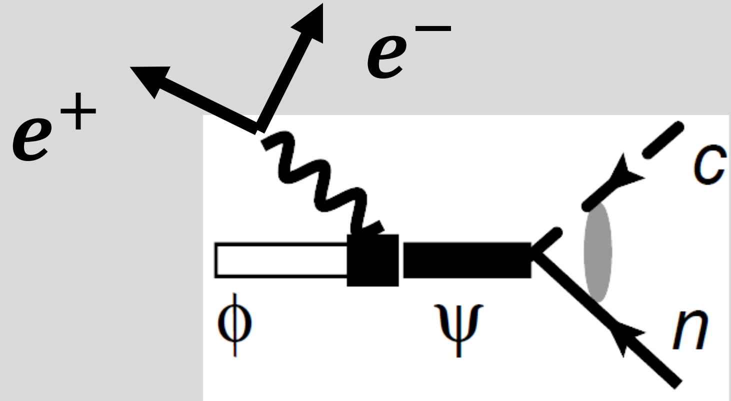
e^+e^- production



$e^{+}e^{-}$ production

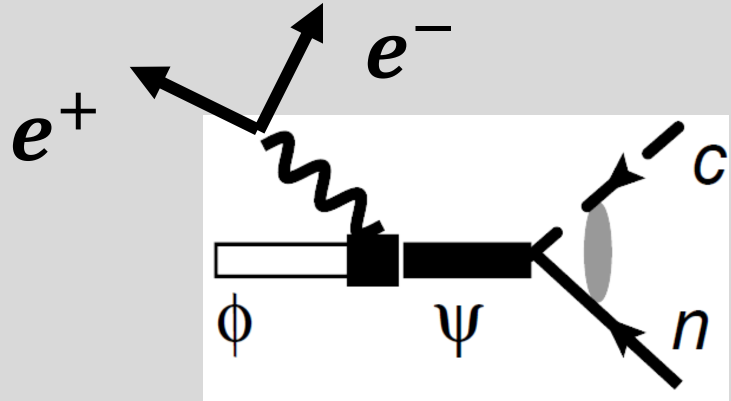


$e^{+}e^{-}$ production



e^+e^- production

$$\frac{M_{+-}^{4}}{2}\sum\left|\mathsf{M}\right|^{2} \equiv T_{0,0} + T_{0,2}\cos 2\phi + T_{1,0}P_1(\cos\theta) + T_{2,0}P_2(\cos\theta) + T_{2,2}P_2(\cos\theta)\cos 2\phi + T_{3,1}\sin\theta\cos\phi + T_{4,1}\sin 2\theta\cos\phi$$



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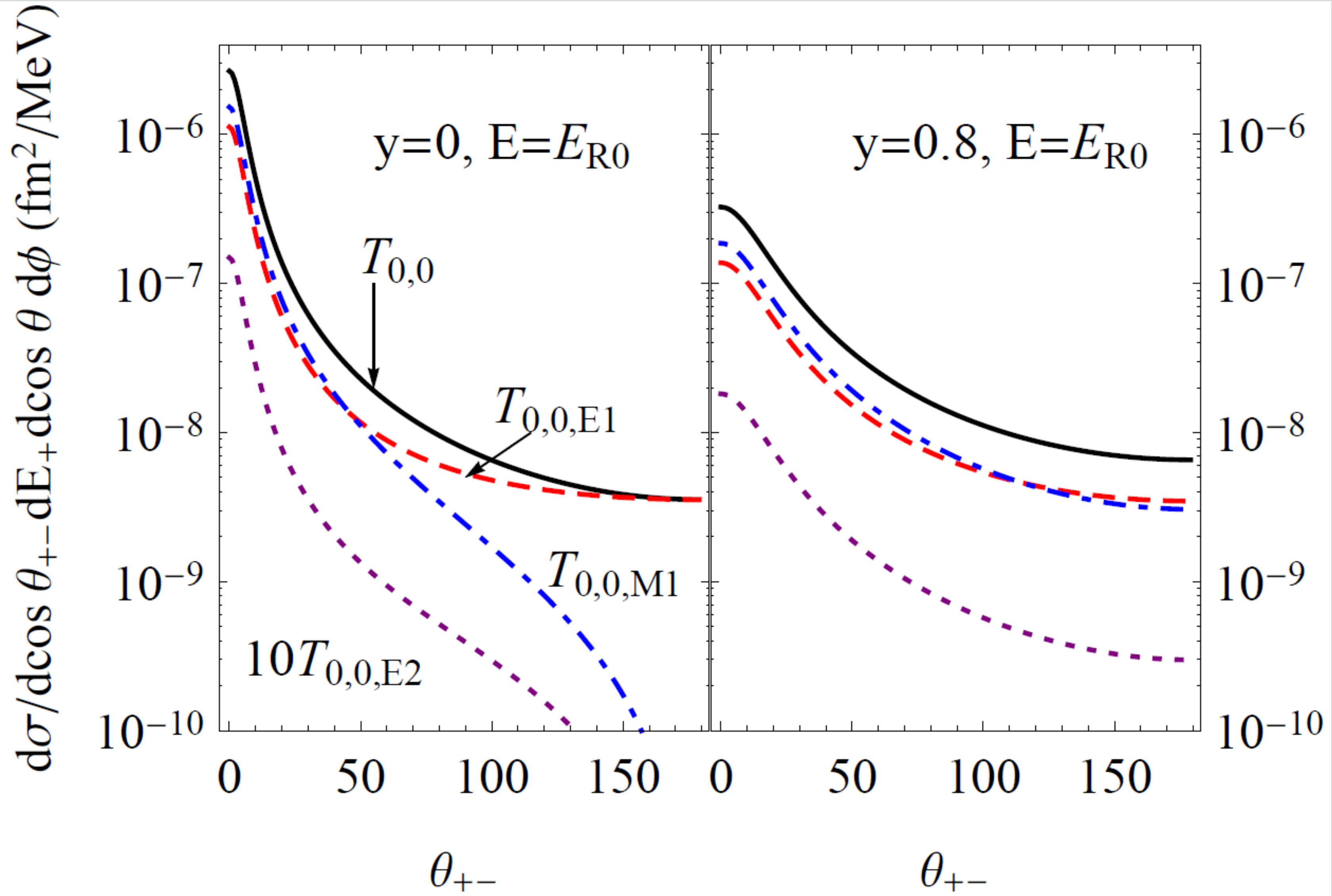
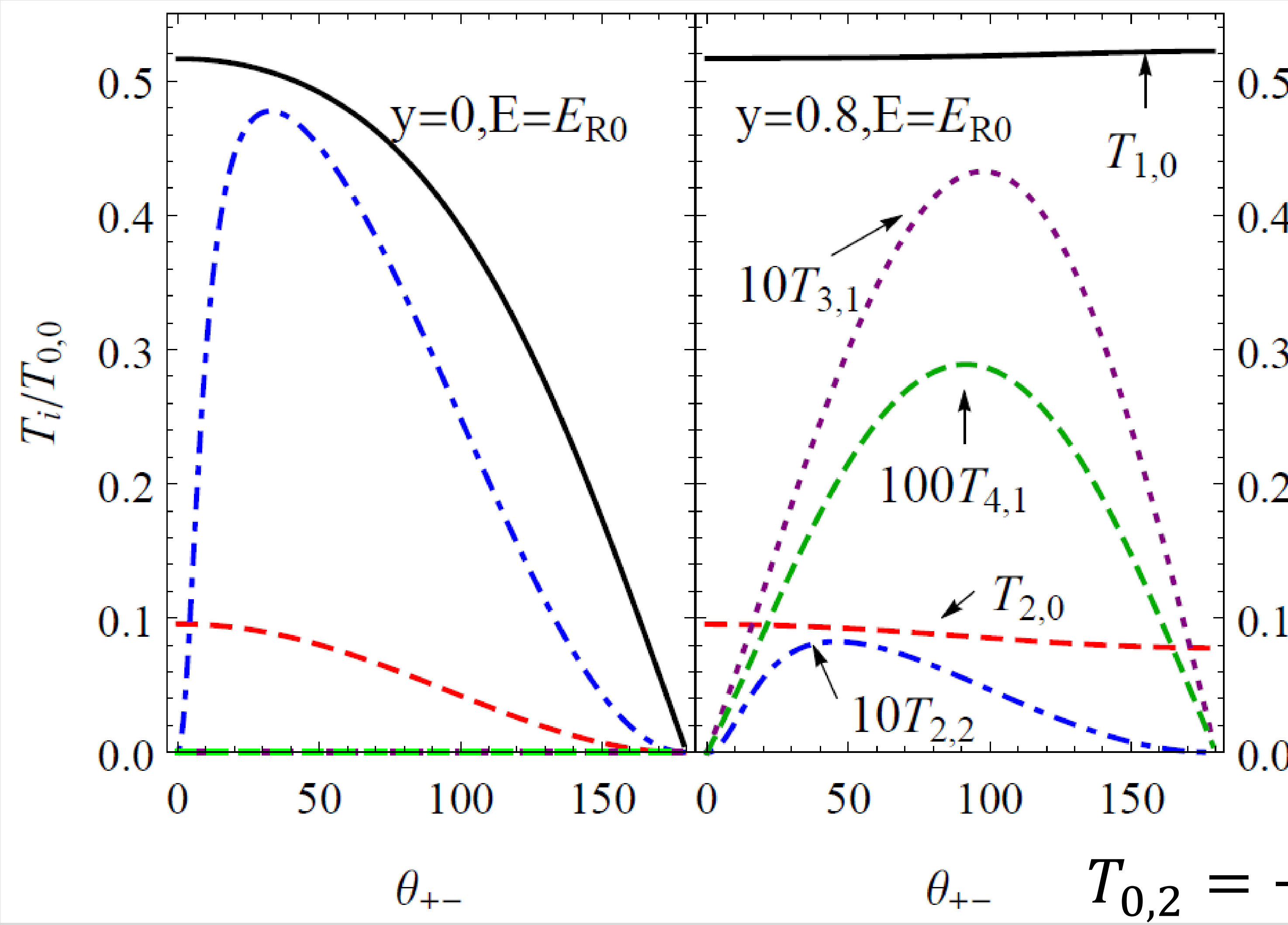
$$+ T_{2,2}P_2(\cos\theta)\cos 2\phi + T_{3,1}\sin\theta\cos\phi + T_{4,1}\sin 2\theta\cos\phi$$

- Cross section depends on θ and ϕ
- Interferences exist between different multipoles
- Experimental simulation needs to be improved

$$\frac{d\sigma}{d\cos\Theta_{+-}\, dE_{+} d\cos\Theta\, d\phi} \qquad y \equiv \frac{E_{+} - E_{-}}{E_{+} + E_{-}}$$



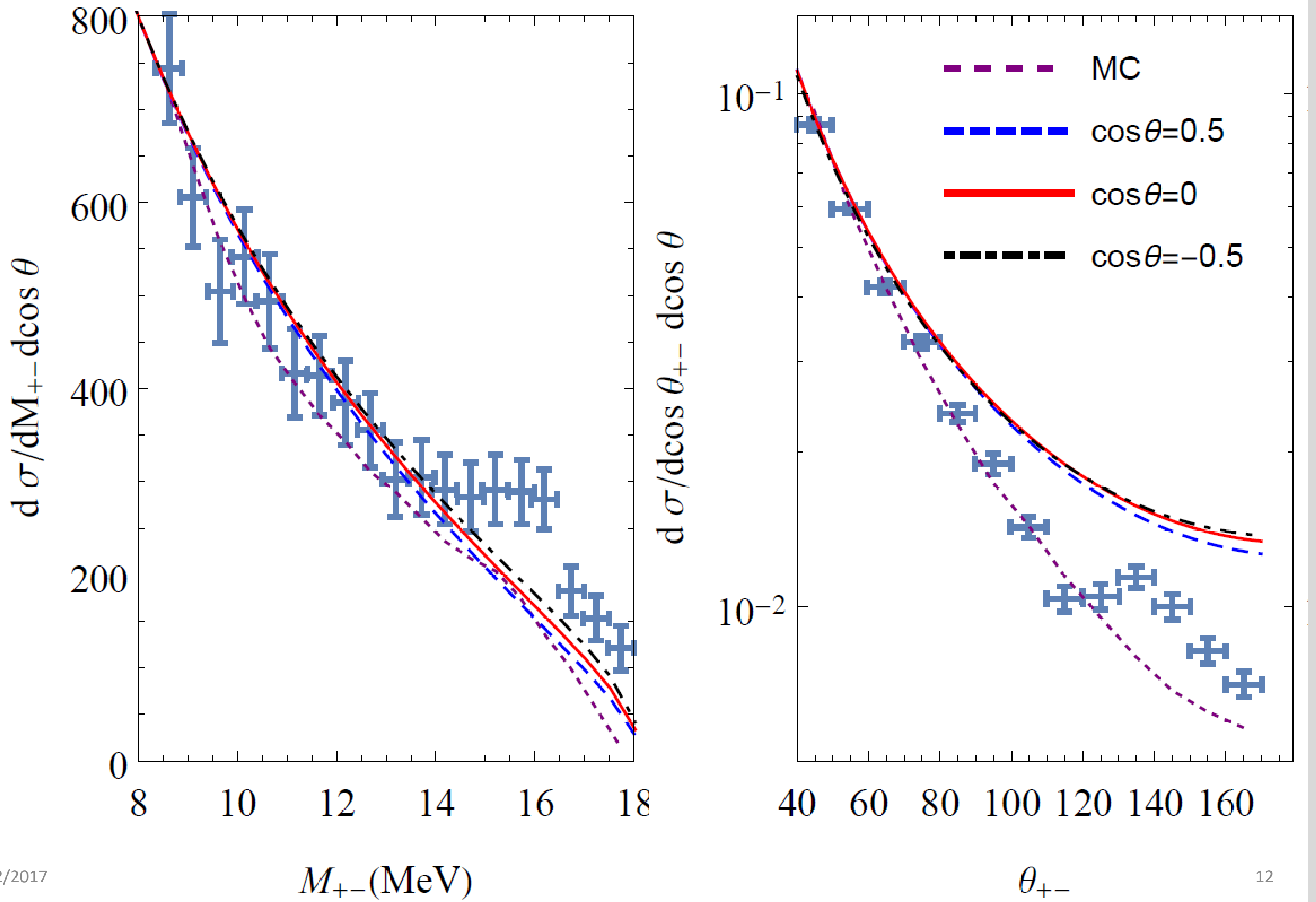
Pair emission anisotropy



$$T_{0,2} = -T_{2,2}$$

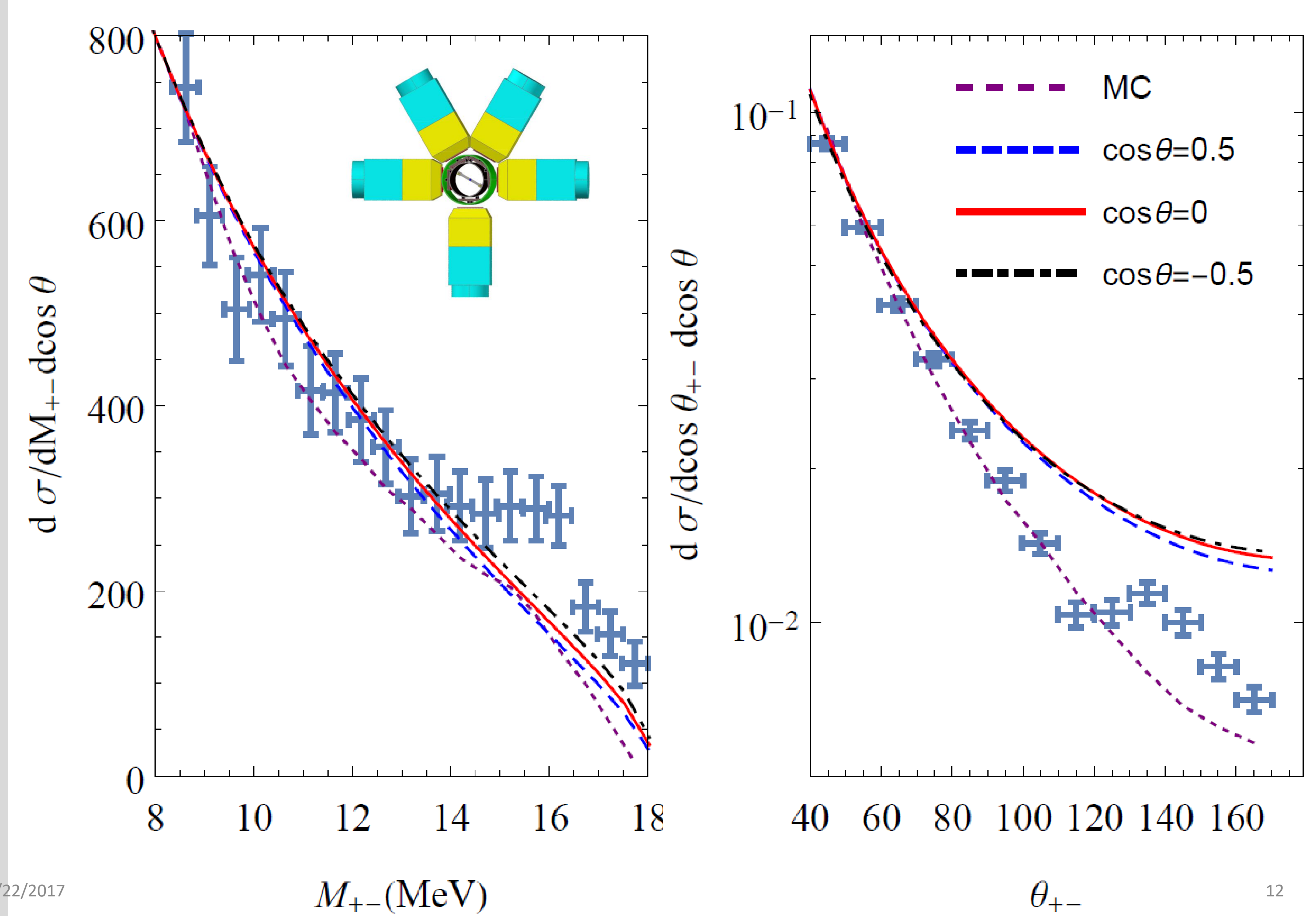
$$T_{0,0} + T_{0,2}\cos 2\phi + T_{1,0}P_1(\cos\theta) + T_{2,0}P_2(\cos\theta)$$
$$+ T_{2,2}P_2(\cos\theta)\cos 2\phi + T_{3,1}\sin\theta\cos\phi + T_{4,1}\sin 2\theta\cos\phi$$

Anomaly



800
600
400
200
0
8
10
12
14
16
18
d σ/dM+−dcos θ
M+−(MeV)
10−1
10−2
40
60
80
100
120
140
160
d σ/dcos θ+− dcos θ
θ+−
MC
cosθ=0.5
cosθ=0
cosθ=−0.5

Anomaly



800
600
400
200
0
8
10
12
14
16
18
d σ/dM+−dcos θ
M+−(MeV)
MC
cosθ=0.5
cosθ=0
cosθ=-0.5
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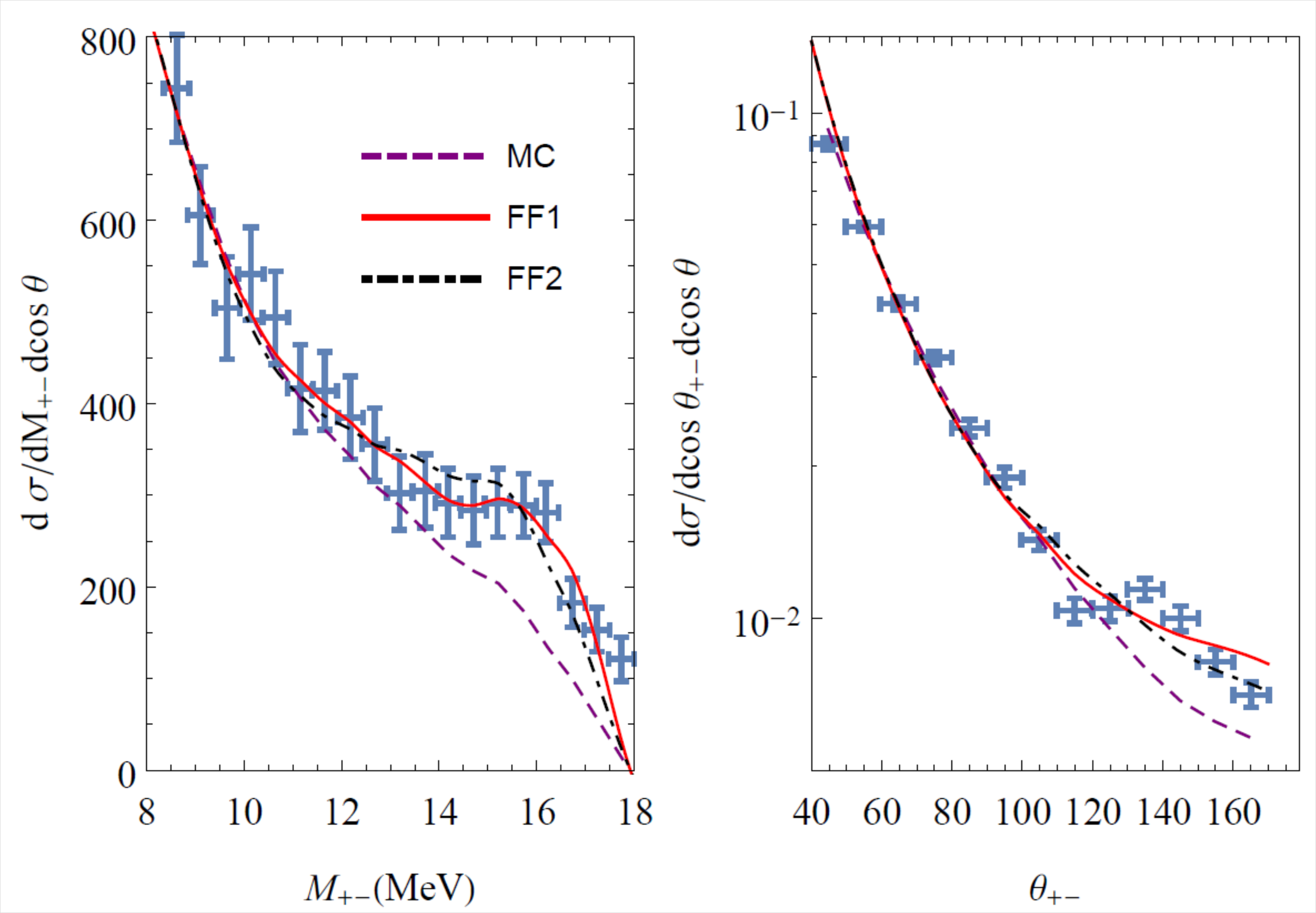
10−2
40
60
80
100
120
140
160
d σ/dcos θ+− dcos θ
θ+−

Form factor for M1?



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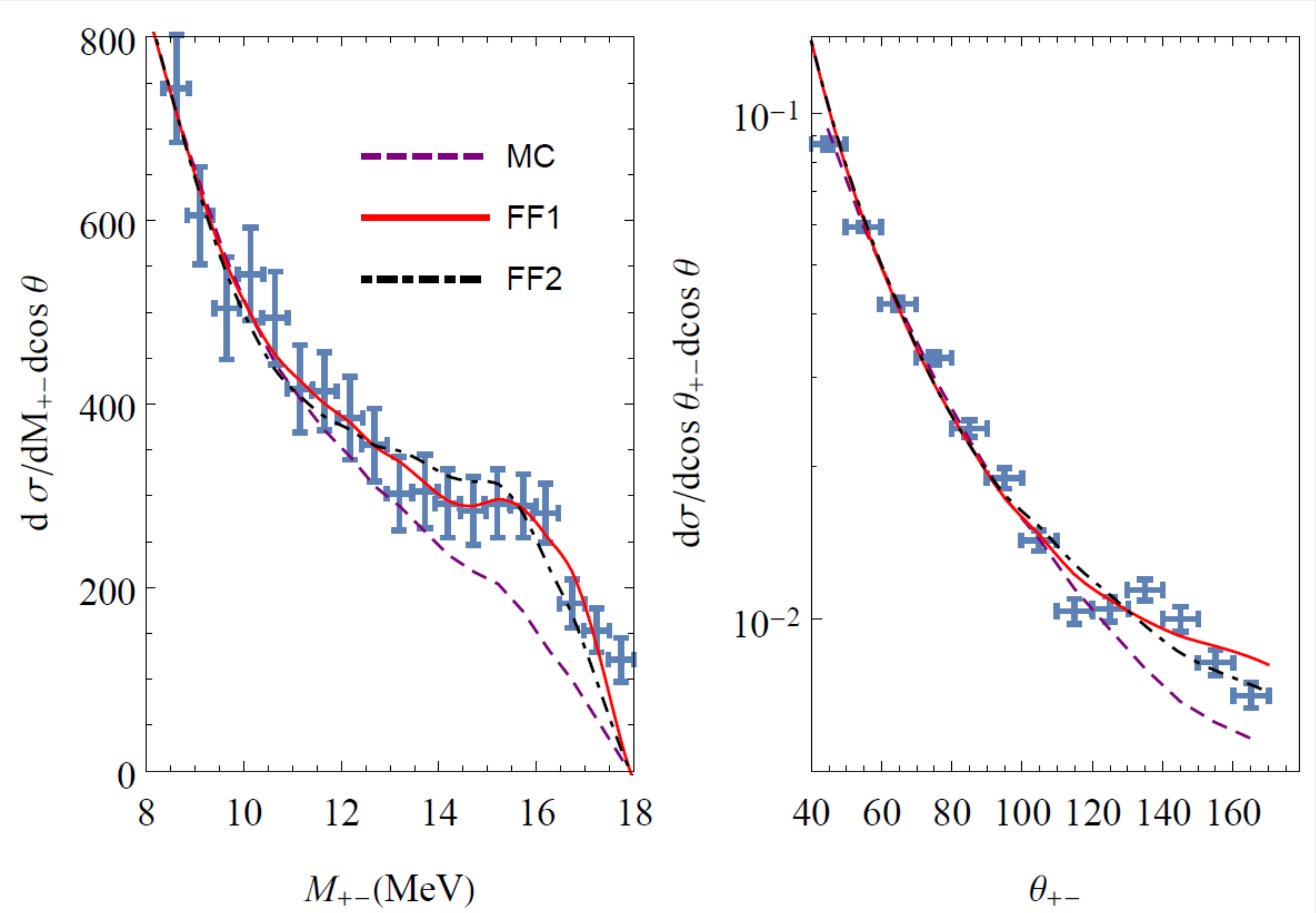
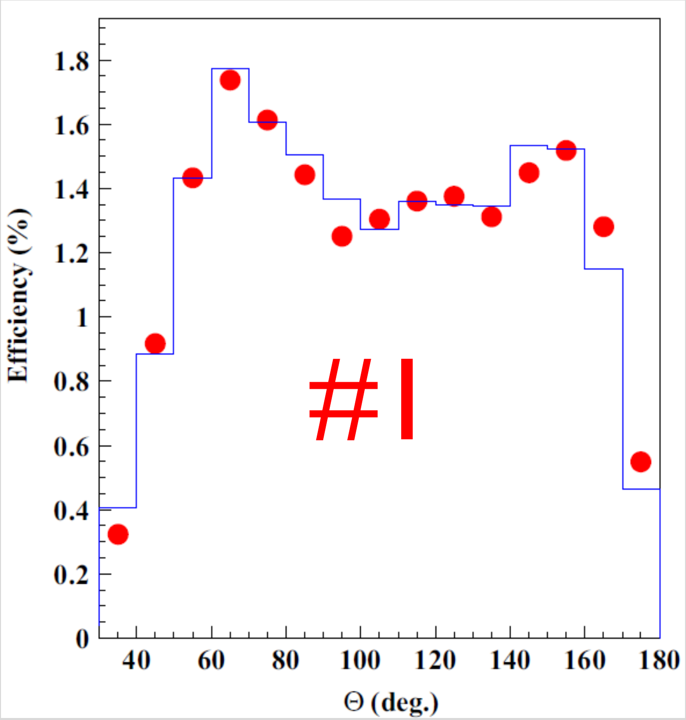


$$f\left(M_{+-}^2\right)=1+f_1\frac{M_{+-}^2}{(20\mathrm{MeV})^2}+f_2\frac{M_{+-}^4}{(20\mathrm{MeV})^4}+f_3\frac{M_{+-}^6}{(20\mathrm{MeV})^6}$$

	f_1	f_2	f_3
FF1	-3.3	-5.8	18.0
FF2	-3.3	0	0

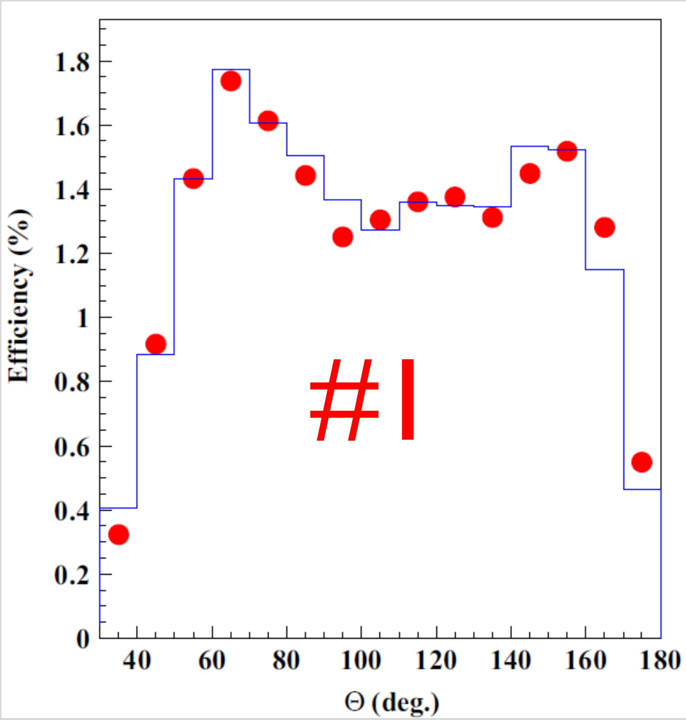
Comments

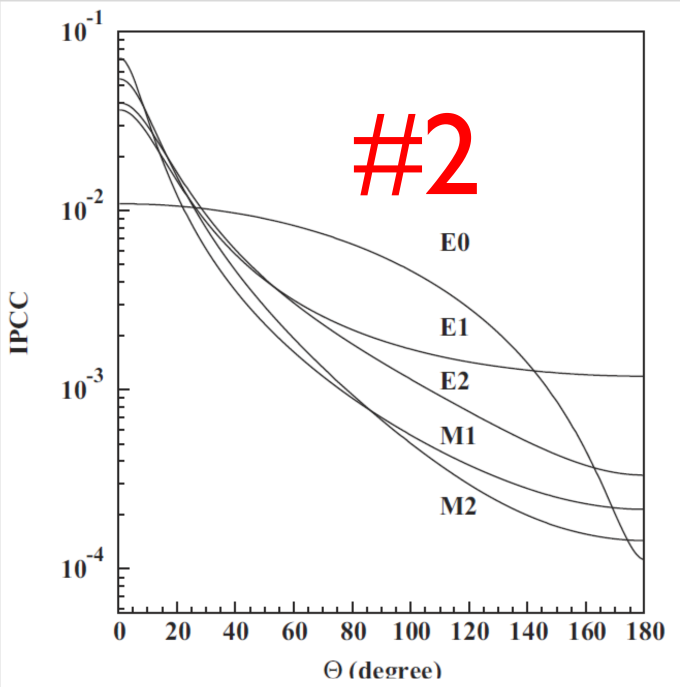
Comments

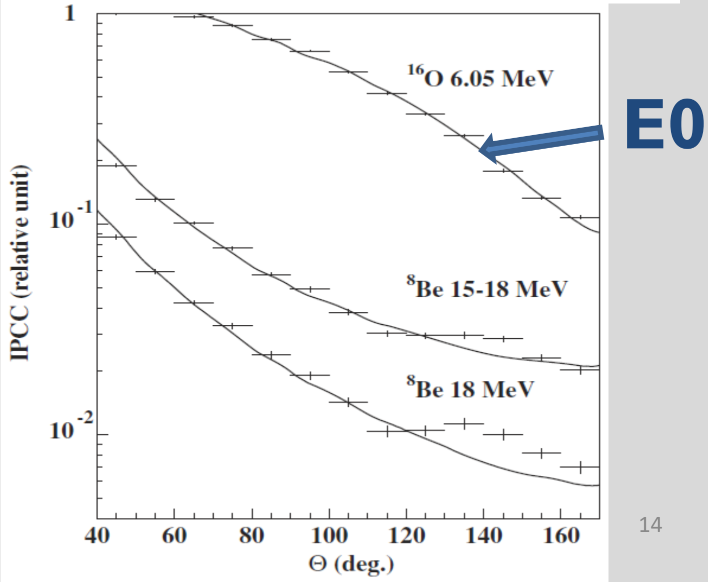


Efficiency (%)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
40
60
80
100
120
140
160
180
Θ (deg.)
#1

Comments







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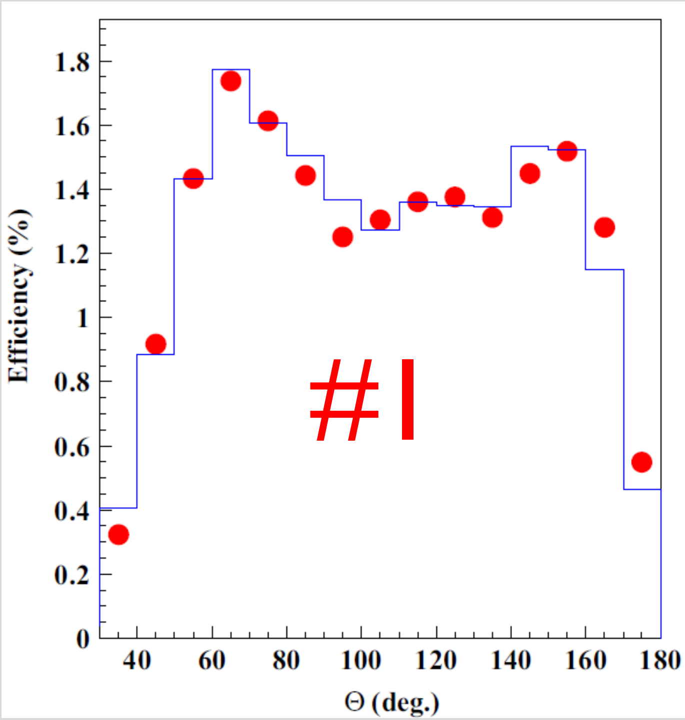
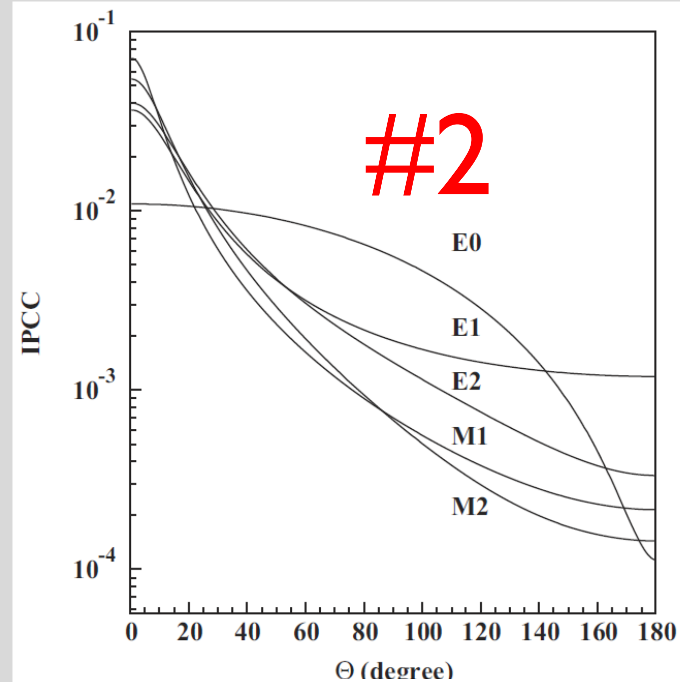
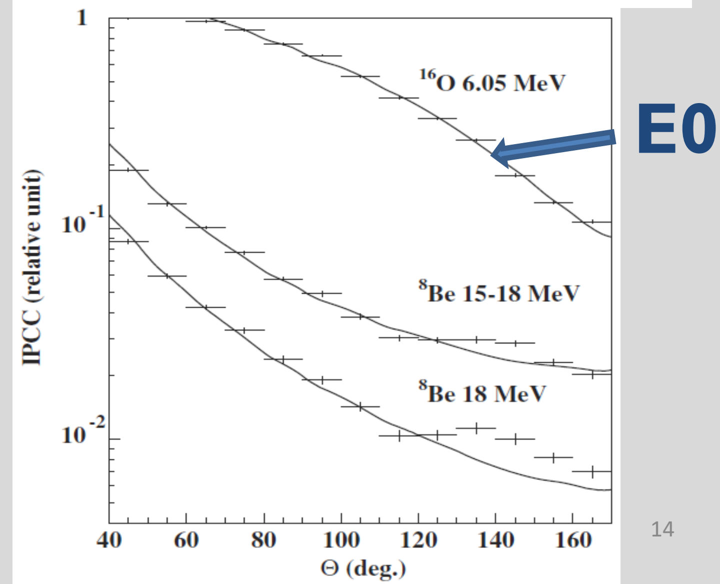
Comments





#3 Model predicts M1/E1 = 1; Expt fit requires M1/E1=3.4 from PRL **116**, 042501 (2016)



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Summary

- A model handling different EM transitions and interferences is available now
- The model is benchmarked against on-shell photon process (the photon production provides valuable constraints)
- Interferences give nontrivial angular dependences
- Form factor could reduce the significance of the anomaly, or even explain it, but requires a large length scale (unexpected)
- The model could be adapted to study the interplay between new particle decay mechanism and the virtual photon decay
- More experimental efforts are needed