МУЛЬТИПОЛЬНЫЕ РЕЗОНАНСЫ

ФОТО- И ЭЛЕКТРОВОЗБУЖДЕНИЯ ЯДЕР

SD- ОБОЛОЧКИ

Н.Г.Гончарова

Particle Core Coupling (PCC) version of the Shell Model

$$\left|J_{i,}T_i\right\rangle = \sum_{(J'),j} C_i^{(J'),j}\left|(J'E'T')_{A-1}\times(nlj):J_i,T_i\right\rangle$$

$$C_i \approx \sqrt{\frac{S_i}{\sum S_i}}$$

$$\left|J_{f,}T_f\right\rangle = \sum_{(J'),j'} \alpha_f^{(J'),j'}\left|(J'E'T')_{A-1}\times(n'l'j'):J_f,T_f\right\rangle$$

$$\left\langle J_fT_fM_T\left\|\bar{O}^J_{TM_T}\right\|J_iT_iM_T\right\rangle = \sum_{i,j_i,j_f} \underline{<j_f\|\bar{O}^J_{TM_T}\|j_i>}\sqrt{2}\sqrt{2J_i+1}\times$$

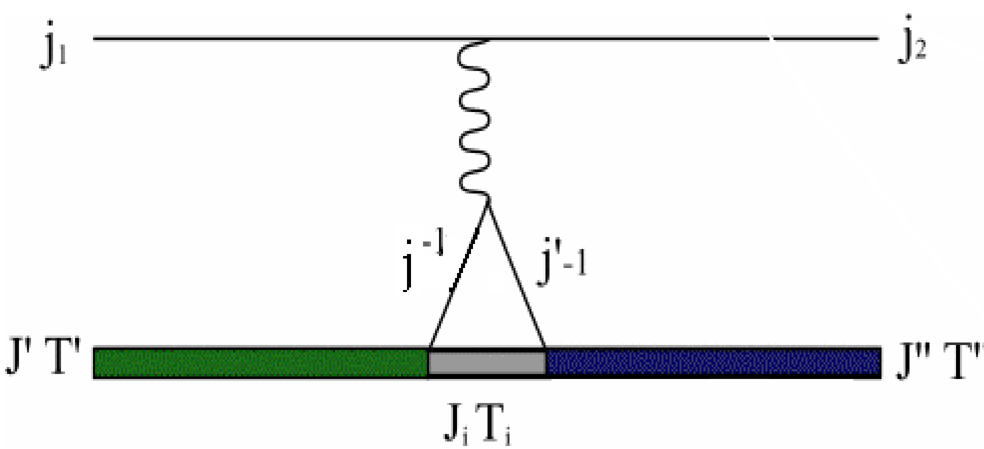
$$\sqrt{(2T+1)(2T_i+1)(2J_f+1)}\left\langle T_iM_TT0\middle|T_fM_T\right\rangle\times$$

$$\sum_{J'T'}\underline{C_i^{J'T',j_i}\alpha_f^{J'T',j_f}}(-1)^{J'-J_i+j_f-J}W(J_iJ_fj_ij_f;JJ')(-1)^{T'-T_i+1/2-T}W(T_iT_f\frac{1}{2}\frac{1}{2};TT')$$

Matrix elements of Hamiltonian

$$\hat{H}_{ij} = (E' + \varepsilon_j + E_c)\delta_{ij} + \hat{V}_{ij}$$

$$V_{ij} = J_f^{(1)} \Big(\quad \Big) J_f^{(2)}$$



Nuclear photo- and electroexcitations

$$\frac{d\sigma(e,e')}{d\Omega}=\frac{4\pi\sigma_M}{\eta_R}\left\{\left(\frac{q_\mu^4}{q^4}\right)F_L^2(q,\omega)+\left(\frac{q_\mu^2}{2q^2}+tg^2\frac{\theta}{2}\right)F_T^2(q,\omega)\right\}$$

$$F_T^2(q)=(2J_i+1)^{-1}\sum_{J=1}^{J_{max}}\left\{\left|\langle J_f\|\hat{T}_J^{el}(q)\|J_i\rangle\right|^2+\left|\langle J_f\|\hat{T}_J^{mag}(q)\|J_i\rangle\right|^2\right\}=\sum_{J=1}^{J_{max}}\left(F_{EJ}^2+F_{MJ}^2\right)$$

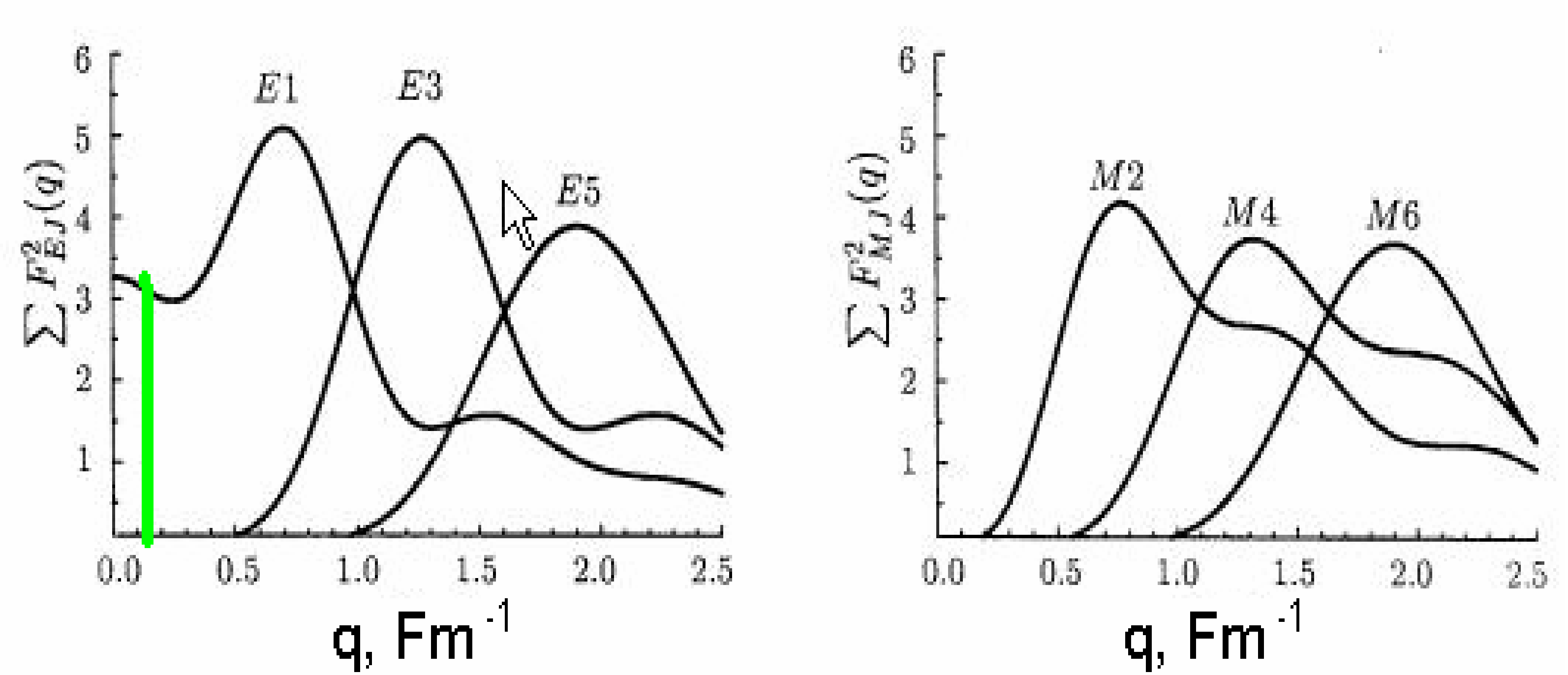
$$\hat{T}_{JM}^{el}(q)=\frac{q}{2M}\sum_{i=1}^{A}\{\hat{g}_j j_J(qr_j)\left[Y_J(\Omega_j)\times\hat{\sigma}_j\right]^{JM}+$$

$$+\frac{2\hat{e}_i}{q}\left(\sqrt{\frac{J+1}{2J+1}}j_{J-1}(qr_j)[Y_{J-1}(\Omega_j)\times\hat{\nabla}_j]^{JM}-\sqrt{\frac{J}{2J+1}}j_{J+1}(qr_j)\left[Y_{J+1}(\Omega_i)\times\hat{\nabla}_i\right]^{JM}\right)$$

$$\hat{T}_{JM}^{mag}(q)=\frac{iq}{2M}\sum_{i=1}^{A}\{\hat{g}_j\left(\sqrt{\frac{J+1}{2J+1}}j_{J-1}(qr_i)\left[Y_{J-1}(\Omega_i)\times\hat{\sigma}_j\right]^{JM}-\right.$$

$$\left.-\sqrt{\frac{J}{2J+1}}j_{J+1}(qr_j)\left[Y_{J+1}(\Omega_i)\times\hat{\sigma}_j\right]^{JM}\right)-\frac{2\hat{e}_i}{q}\left(j_J(qr_j)\left[Y_J(\Omega_i)\times\hat{\nabla}_j\right]^{JM}\right)\}.$$

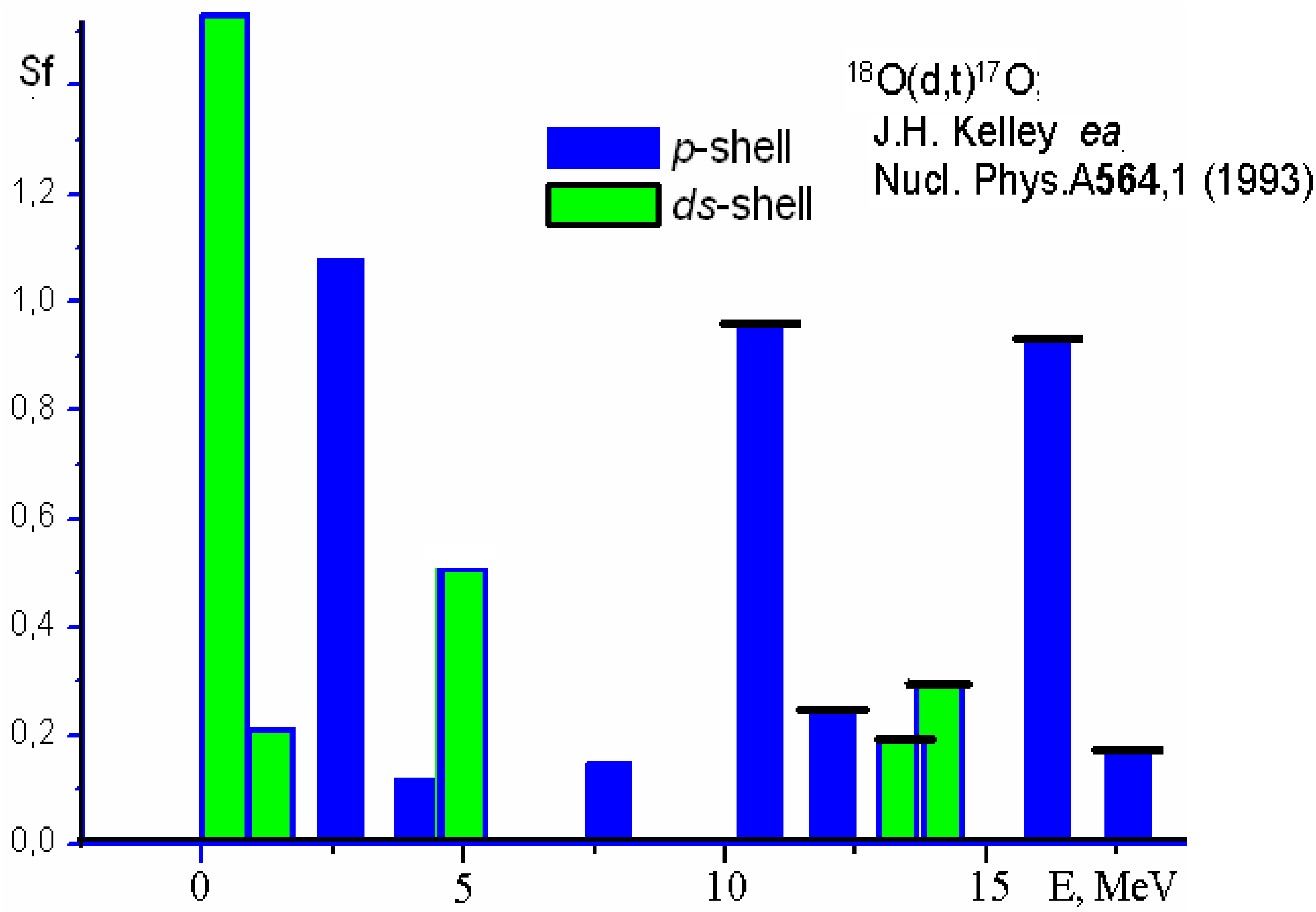
Summed squared form factors: electroexcitation of sd-shell nuclei

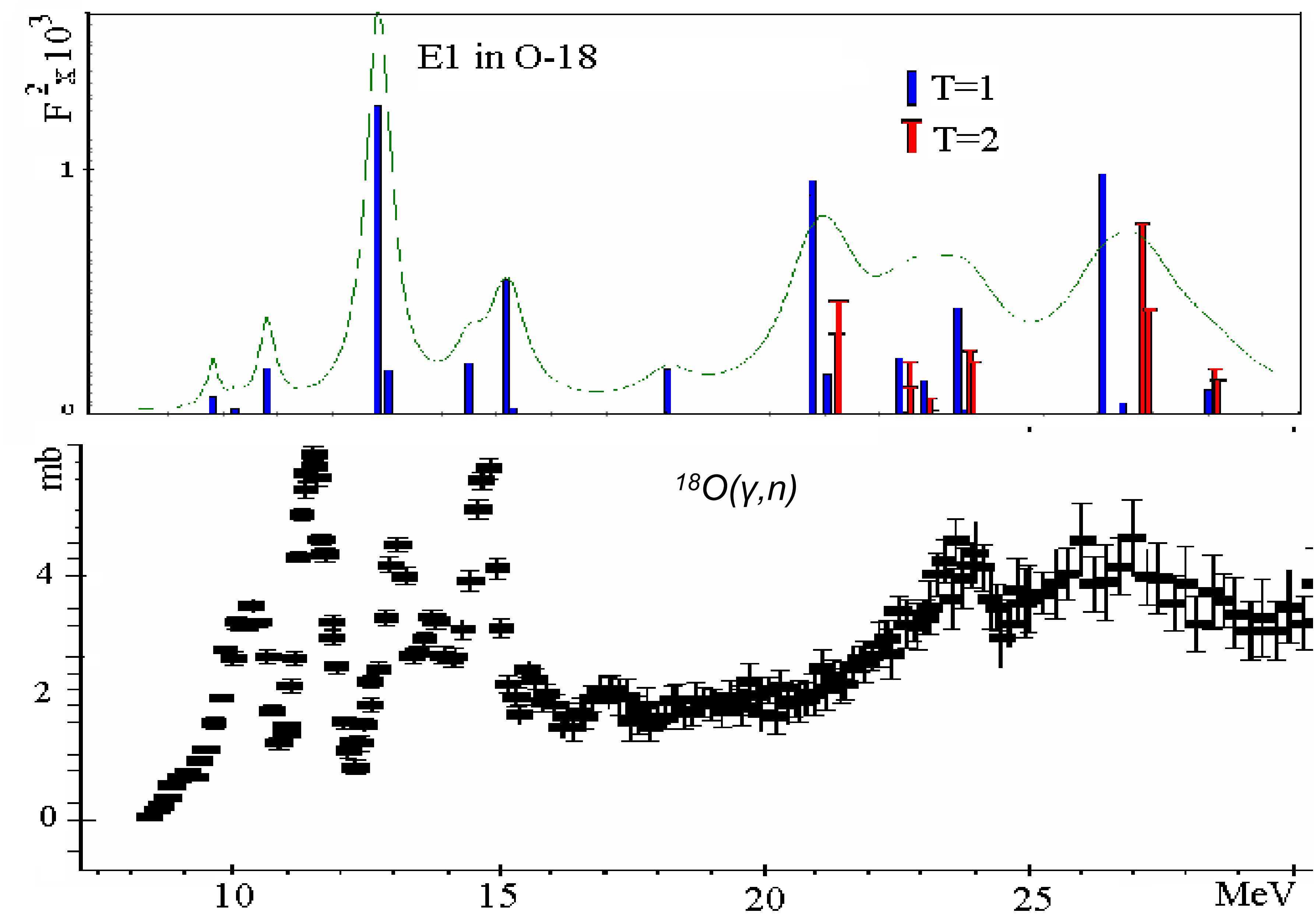


Photopoint : $$q = \omega \equiv E_{exc} \approx 0.1 \div 0.2\,\mathrm{Fm}^{-1}$$

1$\hbar\omega$ resonances in *sd*-shell nuclei: <u>*E*1, *M*2</u>, *E*3, *M*4, *E*5, <u>*M*6</u>

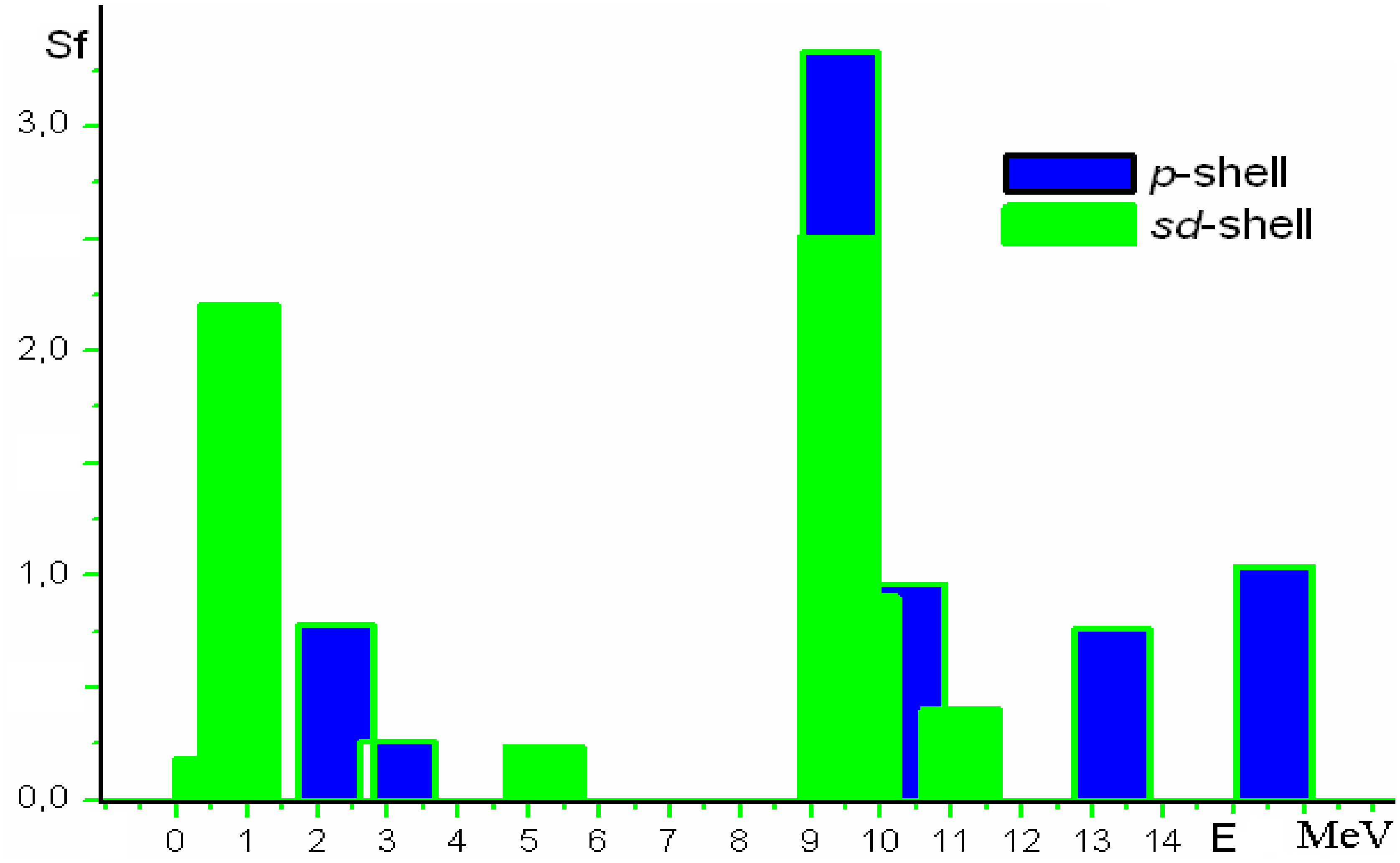
Spectroscopy of pickup reactions on ^{18}O



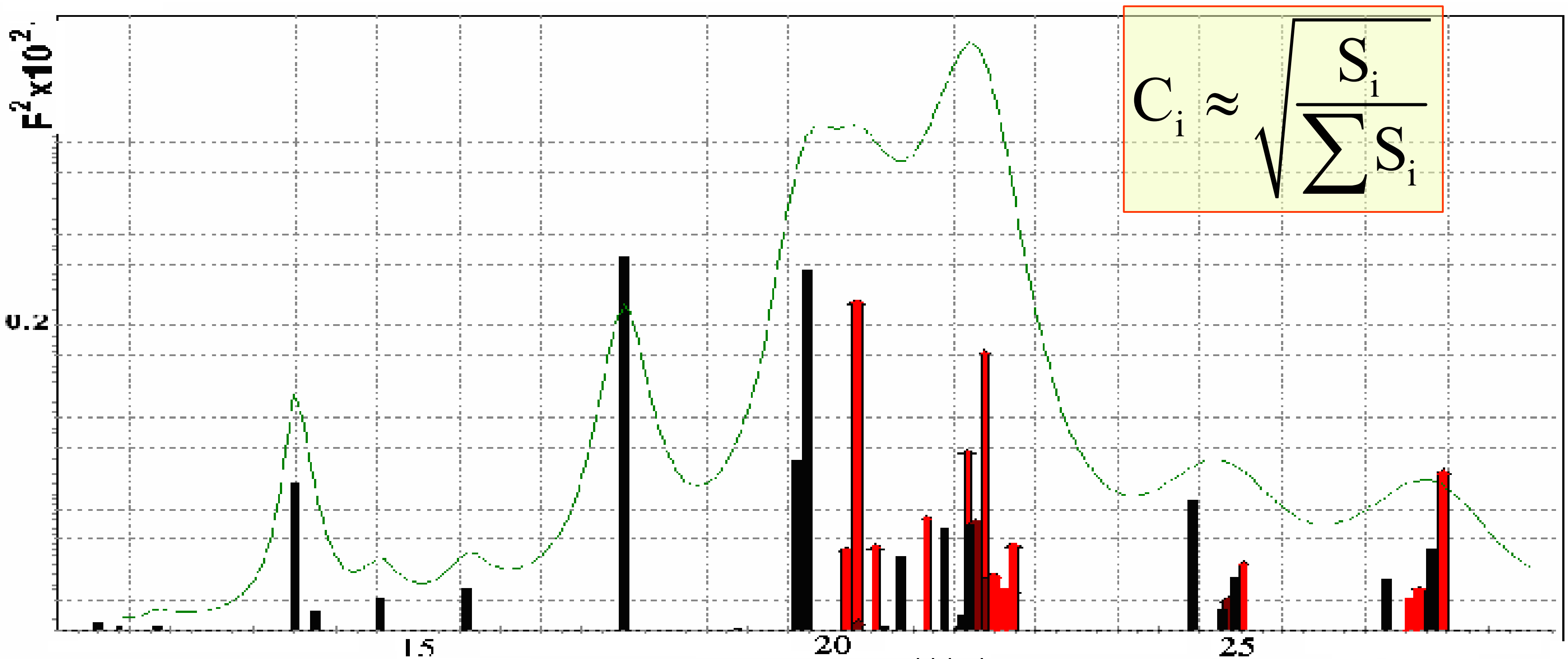


U.Kneissl *ea* // Nucl.Phys.A**272**,125 (1976)

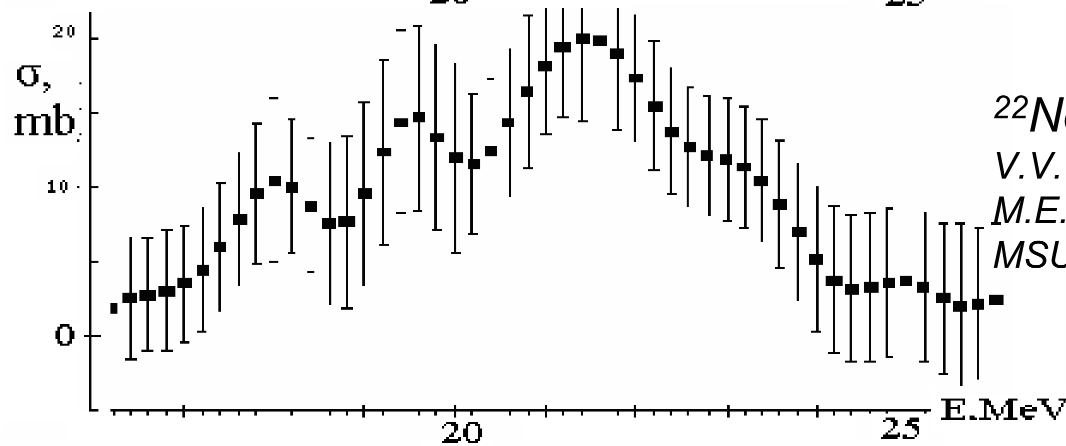
Spectroscopy of pickup reactions on ^{22}Ne



E1 in ^{22}Ne at photopoint

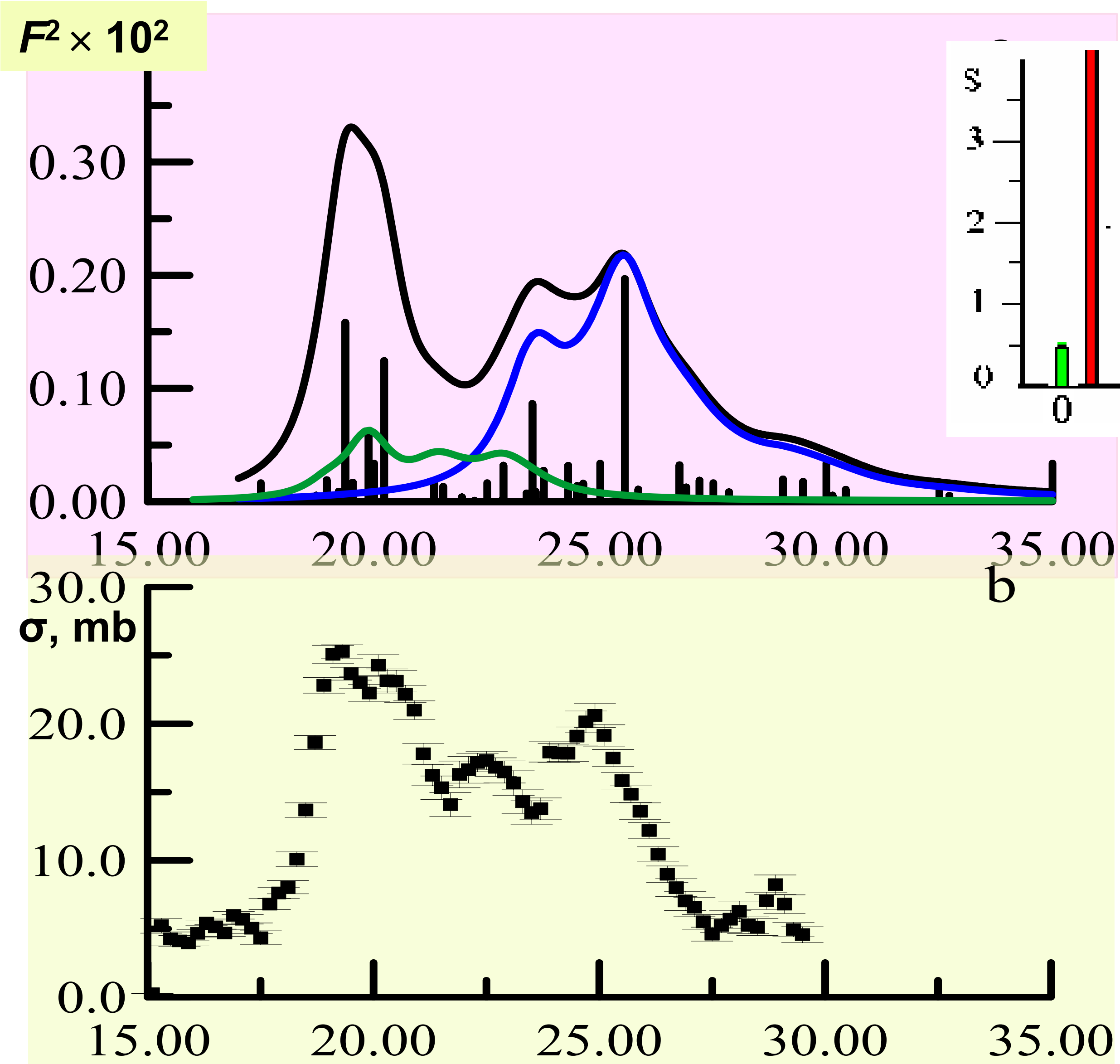


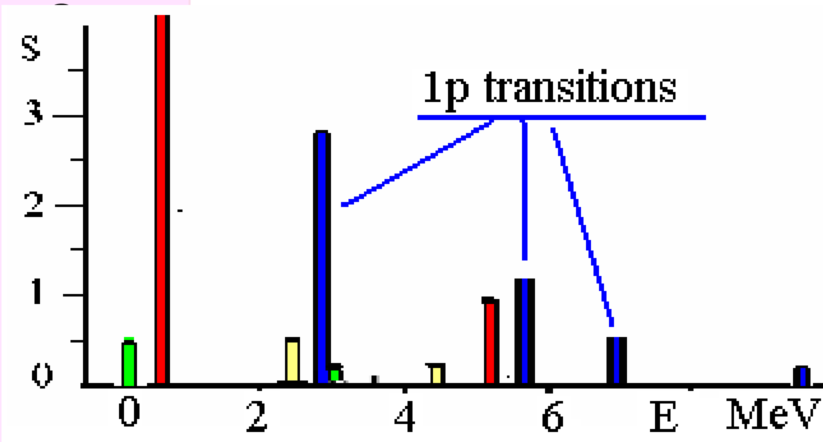
$$C_i \approx \sqrt{\frac{S_i}{\sum S_i}}$$



^{22}Ne(γ,n)
V.V.Varlamov,
M.E.Stepanov
MSU-INP,1999

$E1$ in ^{24}Mg at photopoint

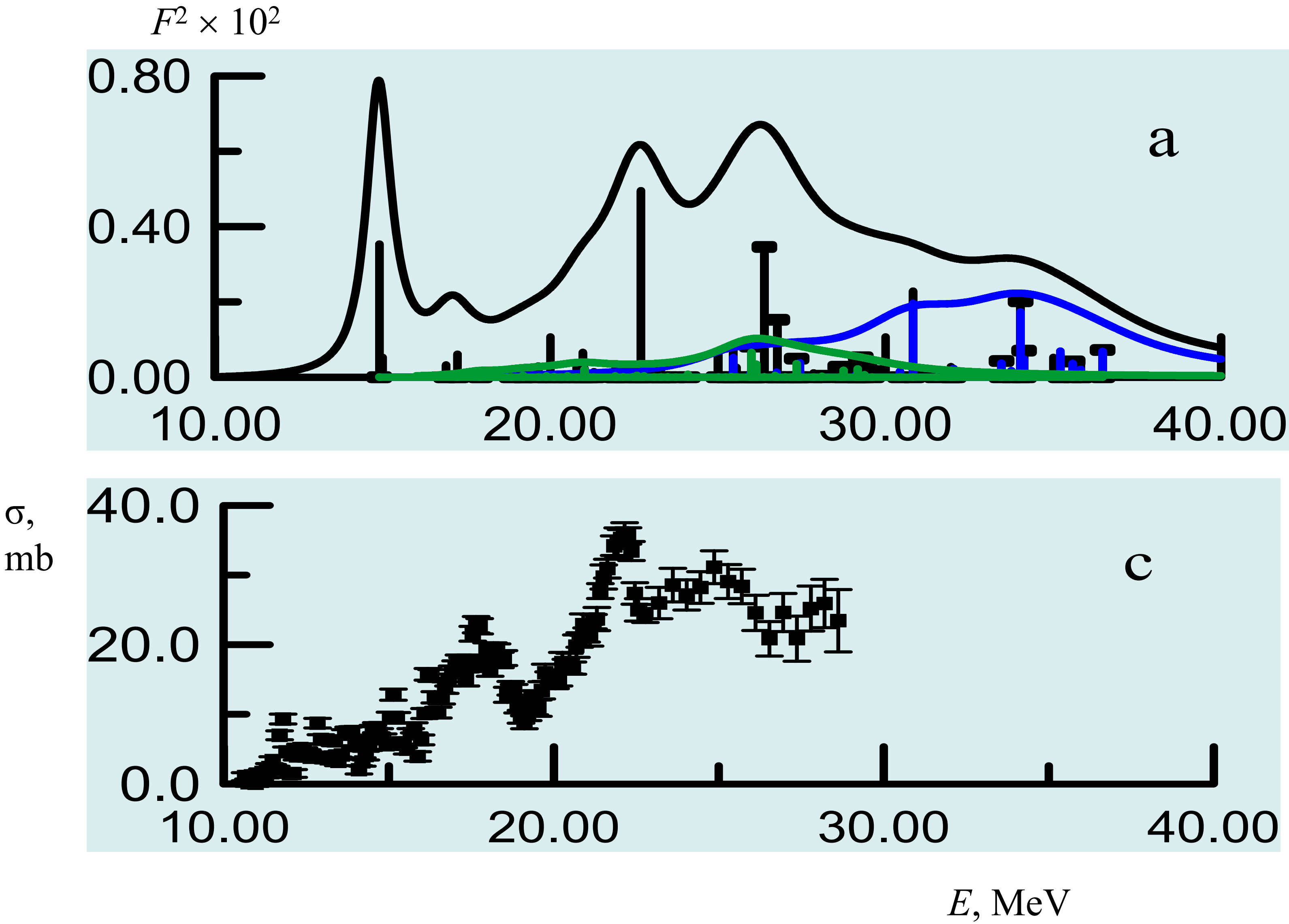




P.M. Endt, Nucl.Phys.A521(1990)1

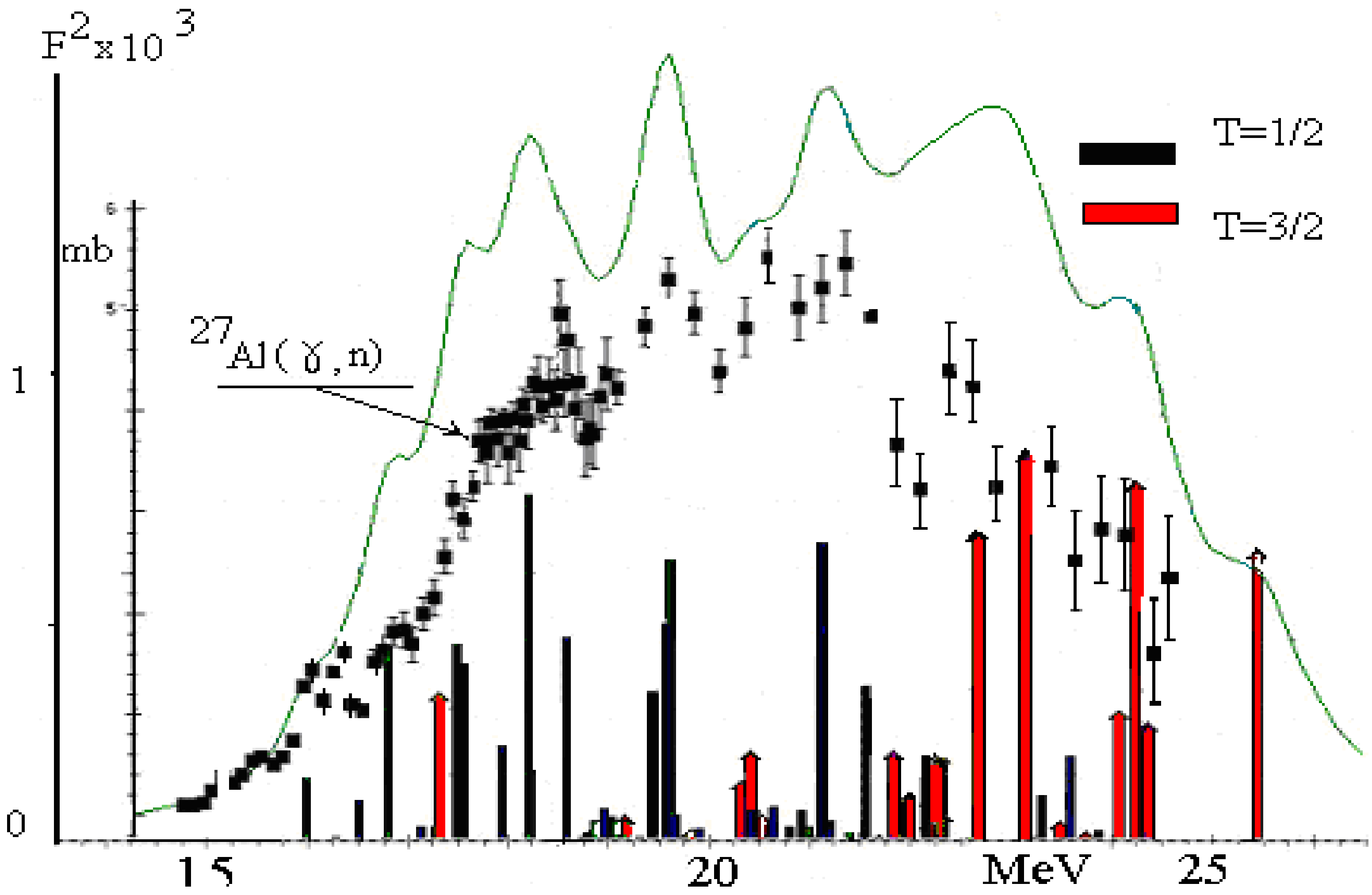
Exp: Ishkhanov B.S. *ea*., Nucl. Phys.**A186** (1972) 438

$E1$ in ^{26}Mg at photopoint



Exp (**c**): (γ, n)+(γ, n+p)+(γ, 2n) Fultz S.C. et al., Phys. Rev. C4 (1971) 149

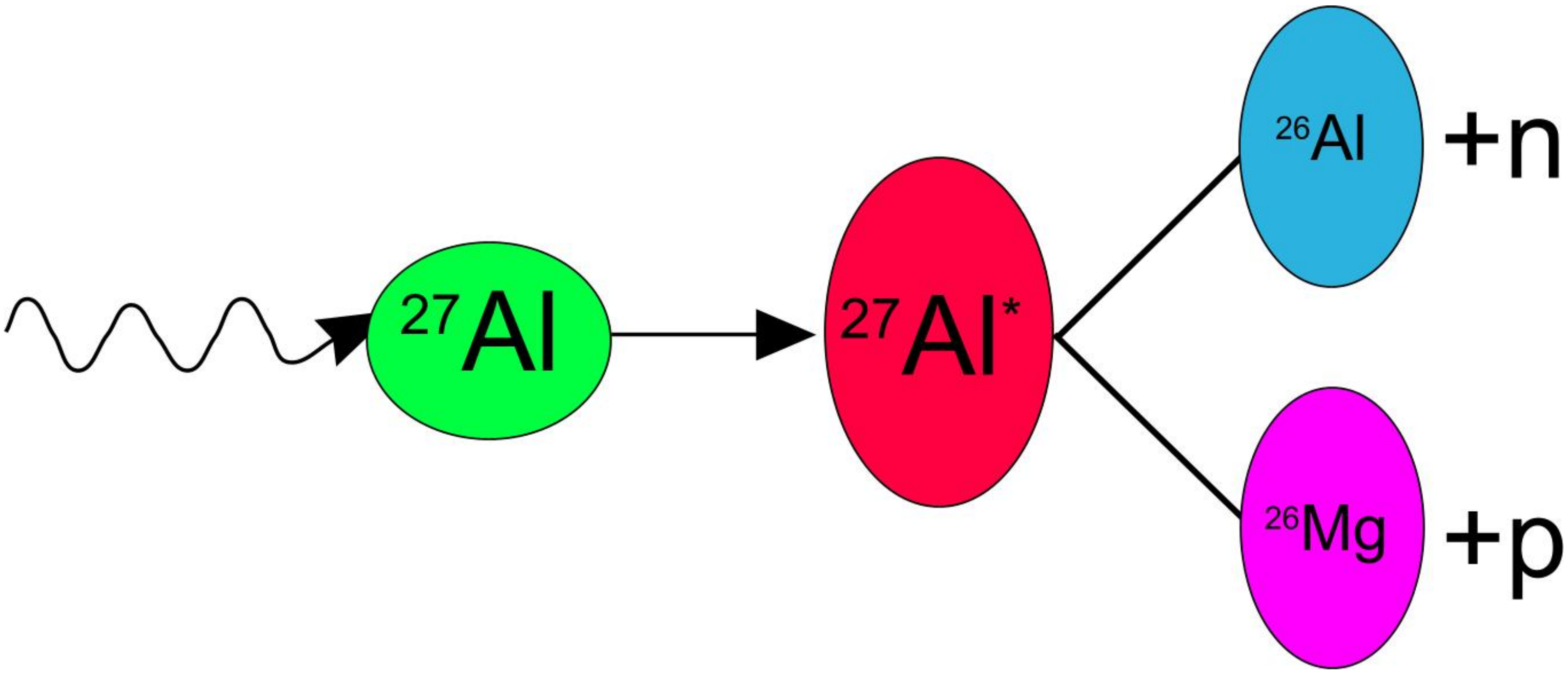
$^{27}Al+\gamma \rightarrow {}^{26}Al+n$



Exp: M.N.Thompson *et al* // Nucl. Phys. 64 (1965)486

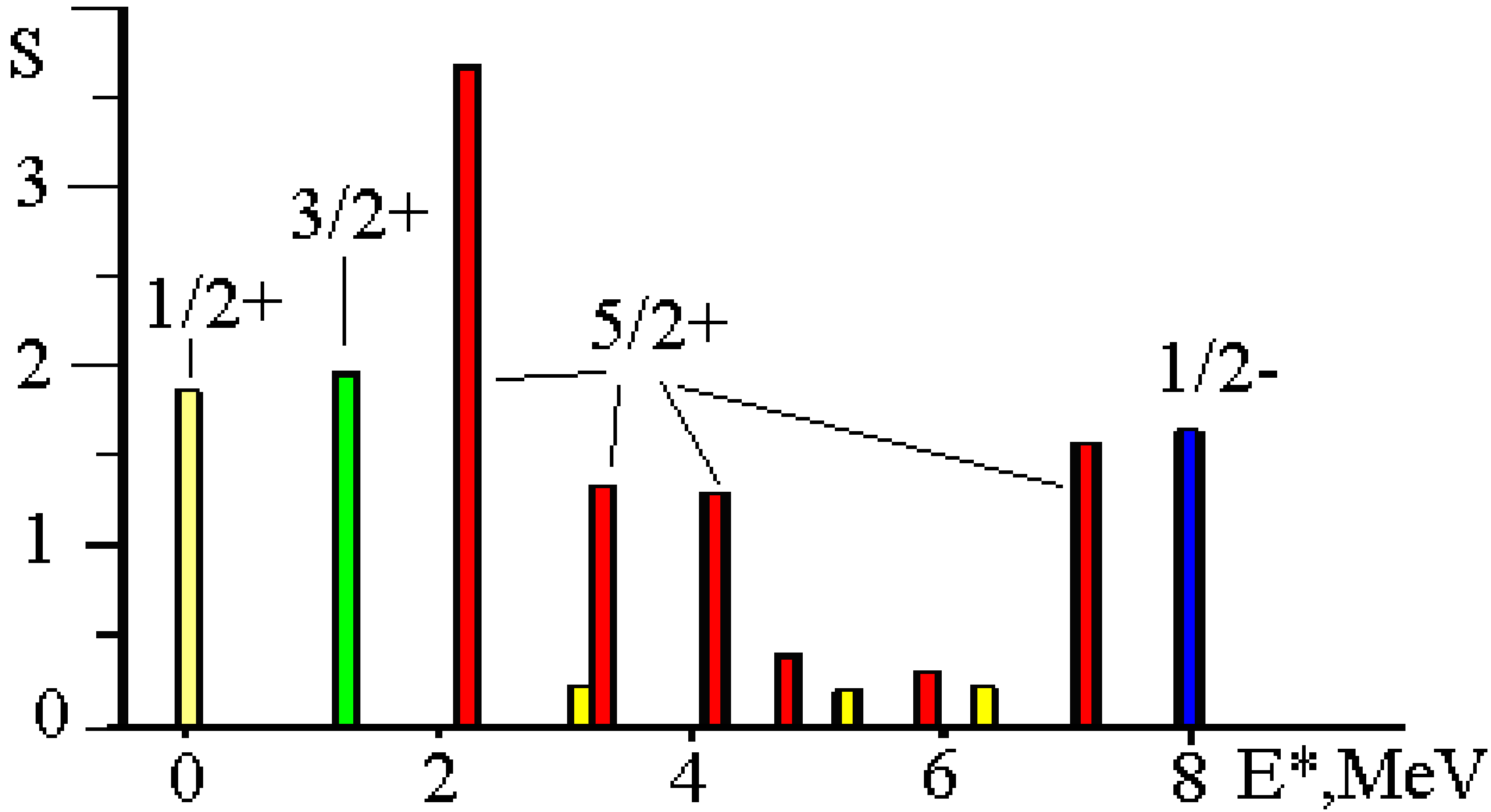
Динамические деформации при фоторасщеплении ^{27}Al

- $^{27}\text{Al}+\gamma \rightarrow {}^{26}\text{Al}+n$ $\qquad$ $^{27}\text{Al}+\gamma \rightarrow {}^{26}\text{Mg}+p$



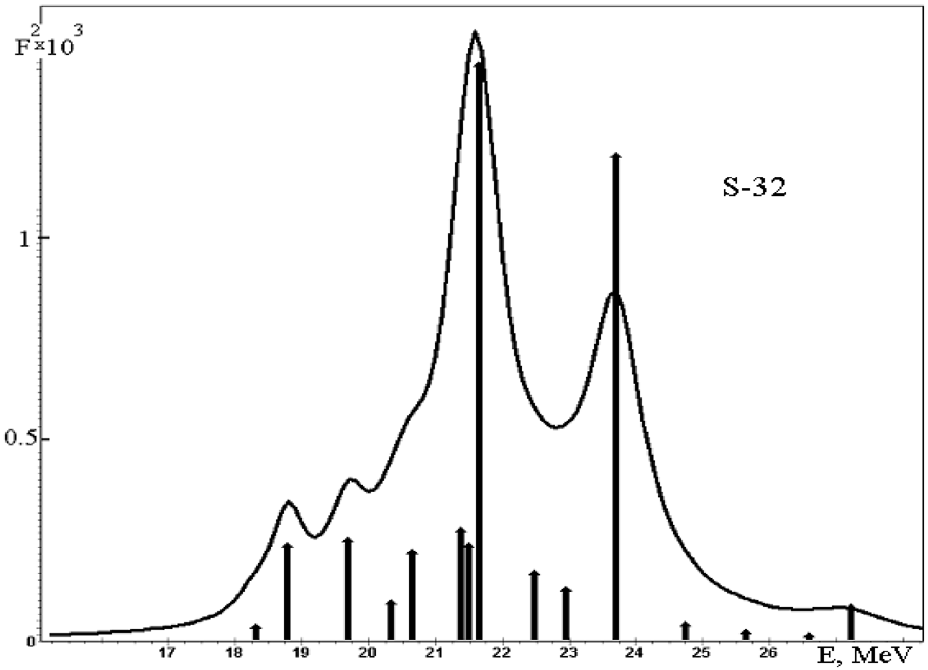
H. Röpke, P.M.Endt // Nucl. Phys. A632(1998)173.

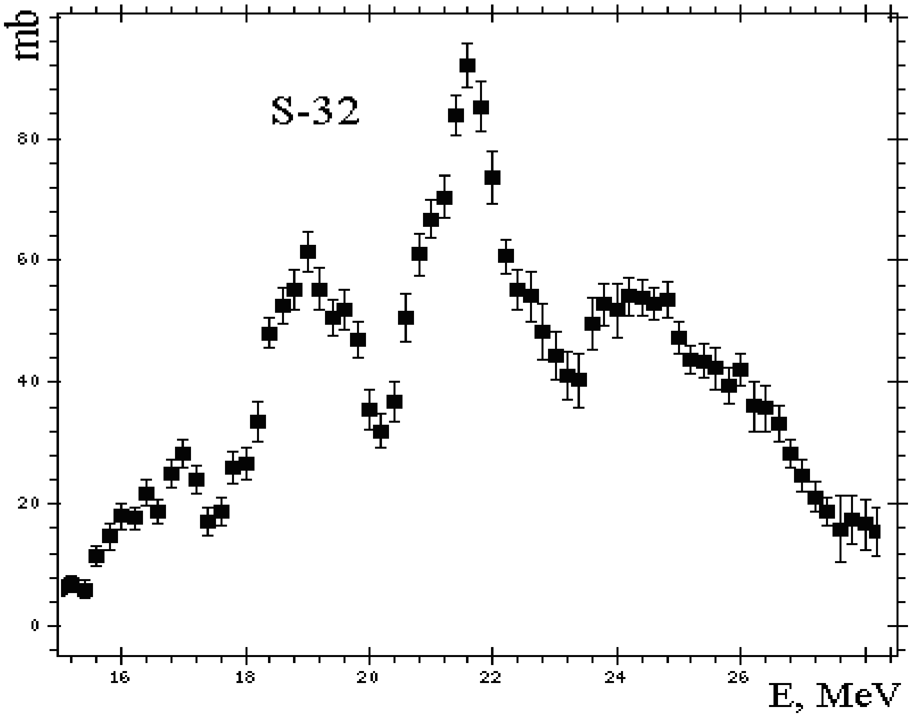
Спектроскопия реакции подхвата $^{32}S(d,^{3}He)^{31}P$



Спектроскопия реакции $^{32}S(d,^{3}He)^{31}P$;
E*- энергии возбуждения ядра ^{31}P
J.Vernotte *et al*,Nucl.Phys.**A655**(1999)415

E1 excitations ^{32}S

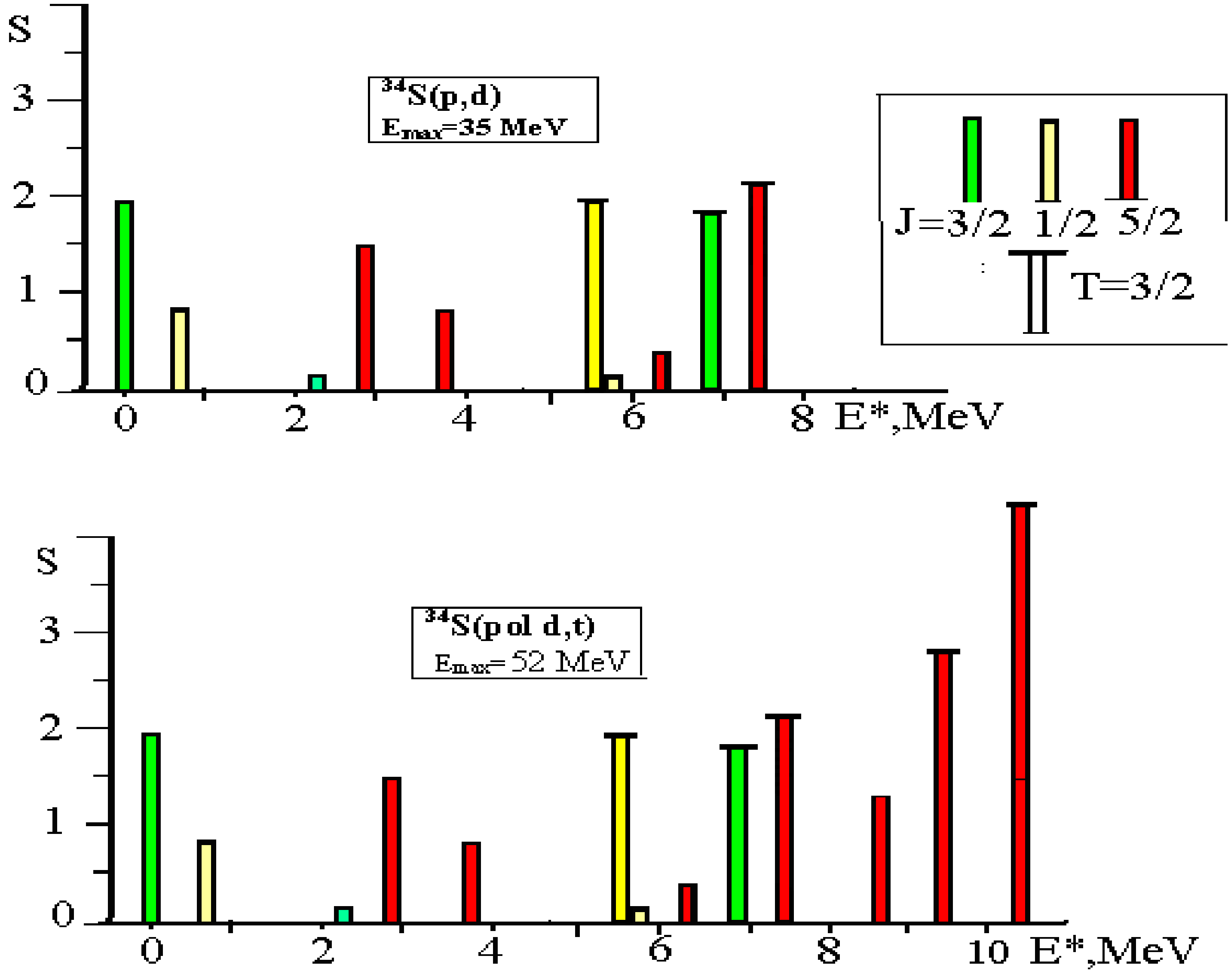




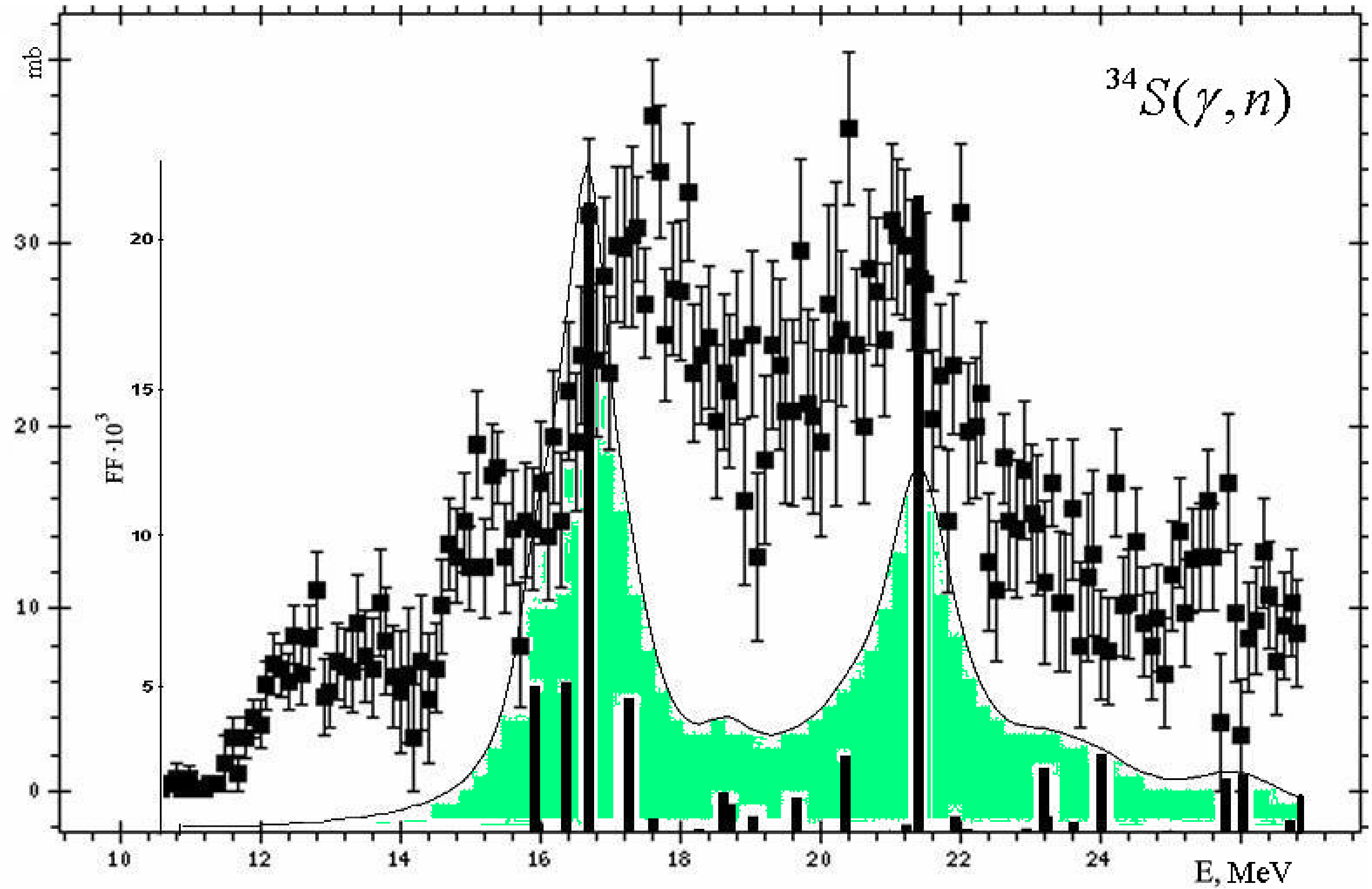
PCC version of SM

Exp: B.S.ISHKHANOV *et al,2002*.

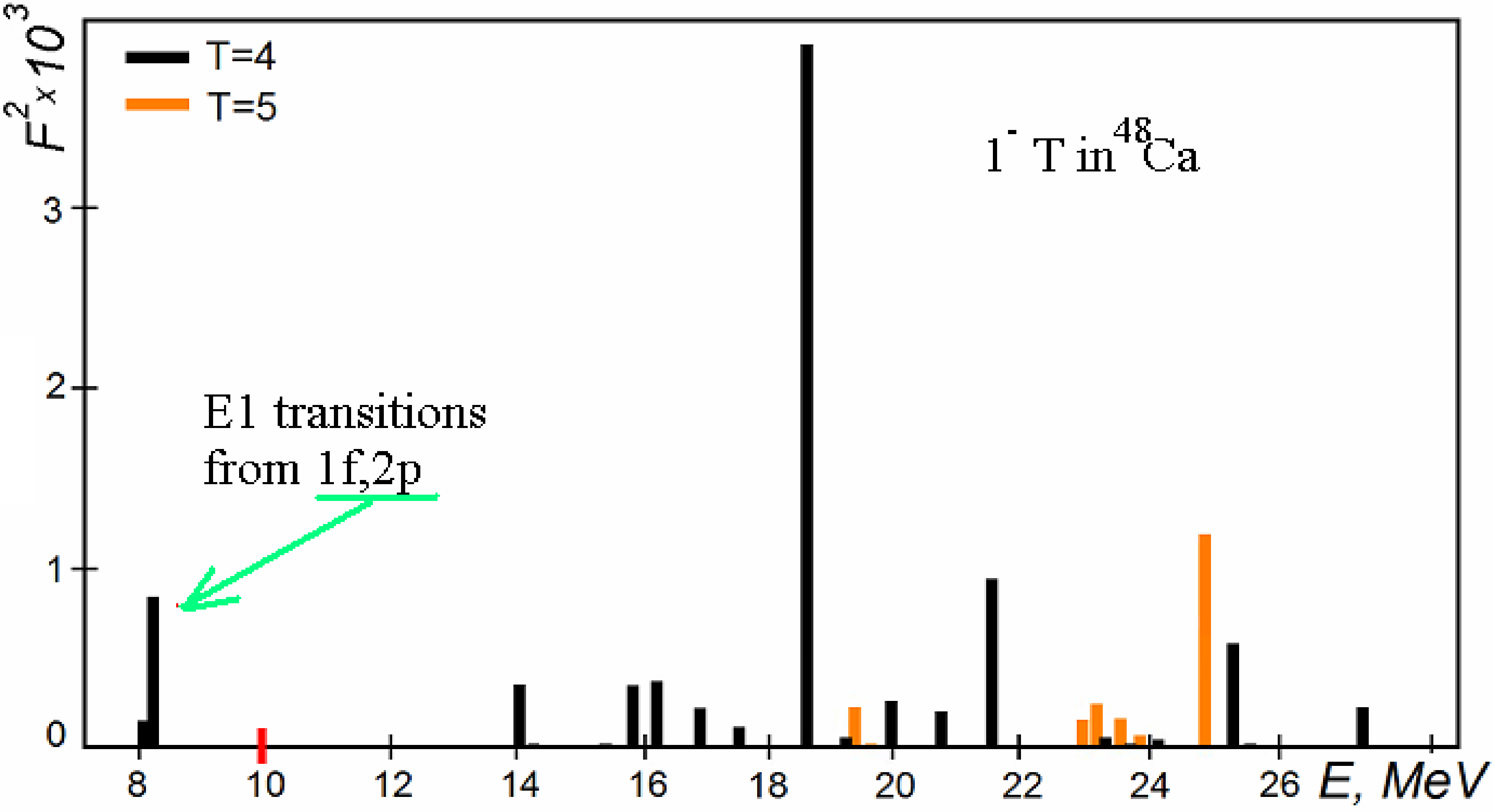
Спектроскопия реакции подхвата $^{34}S(p,d)^{33}S$



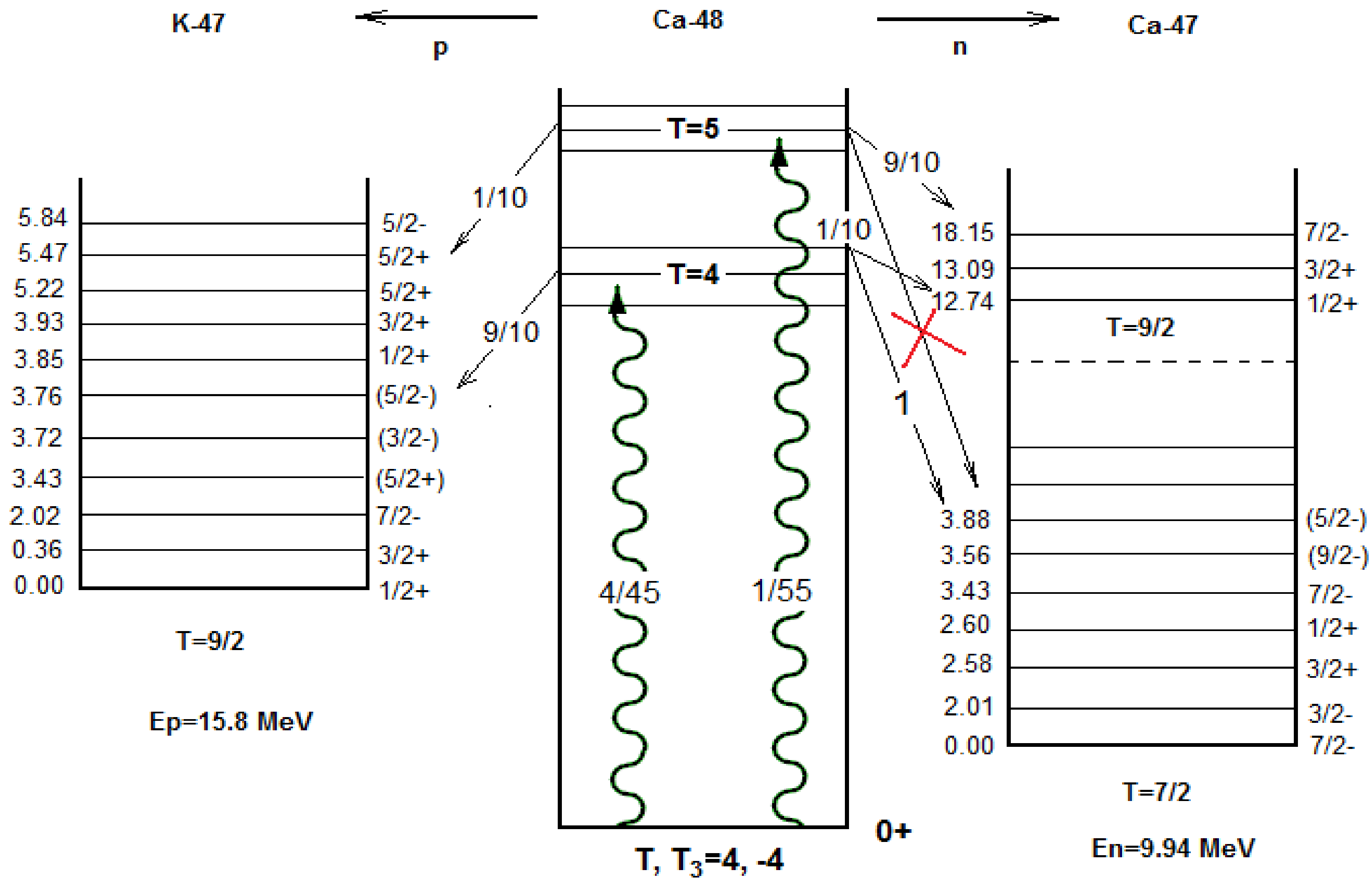
^{34}S – photoneutron reaction



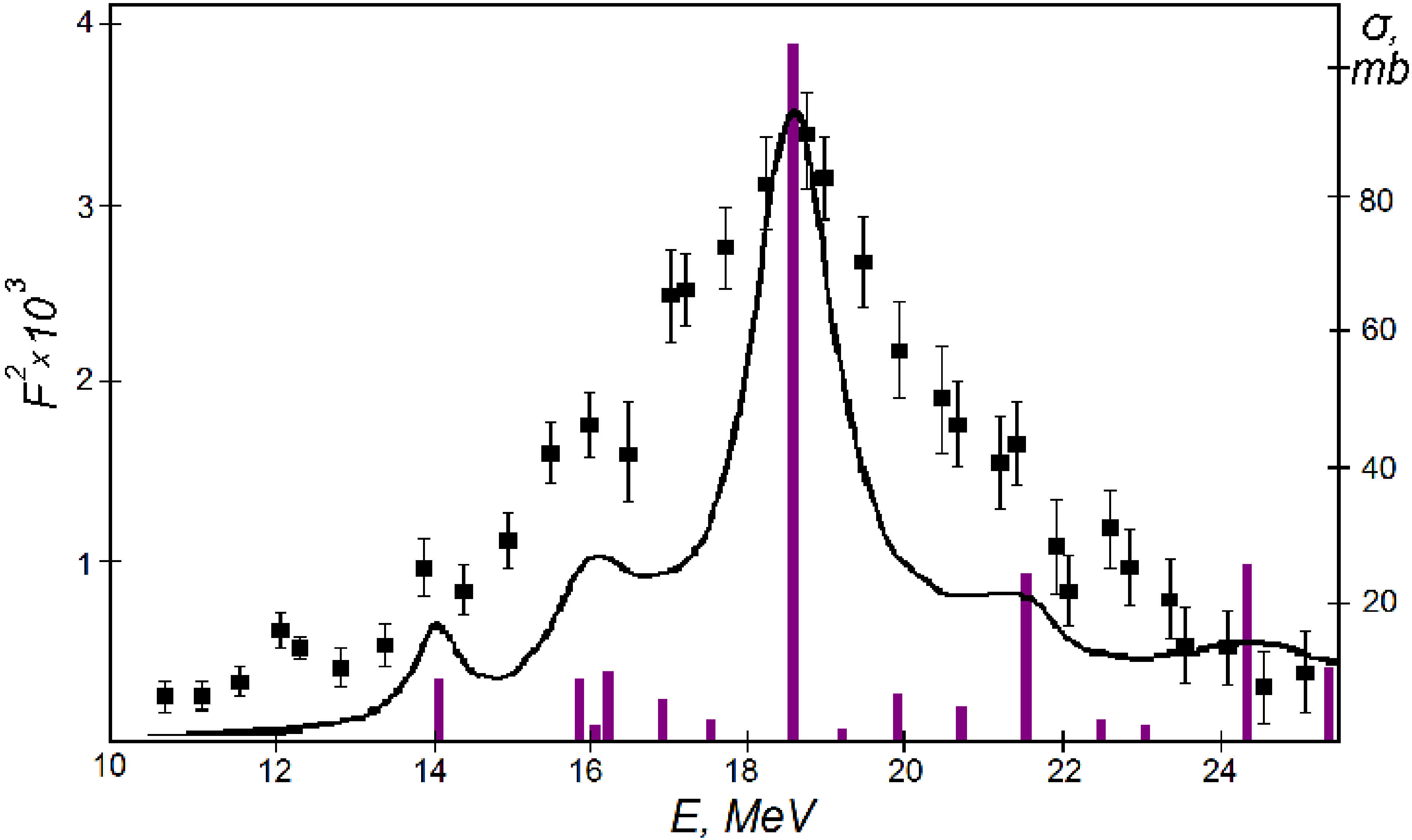
E1 excitation of ^{48}Ca



Excitation and disintegration of ^{48}Ca (isospin factors)

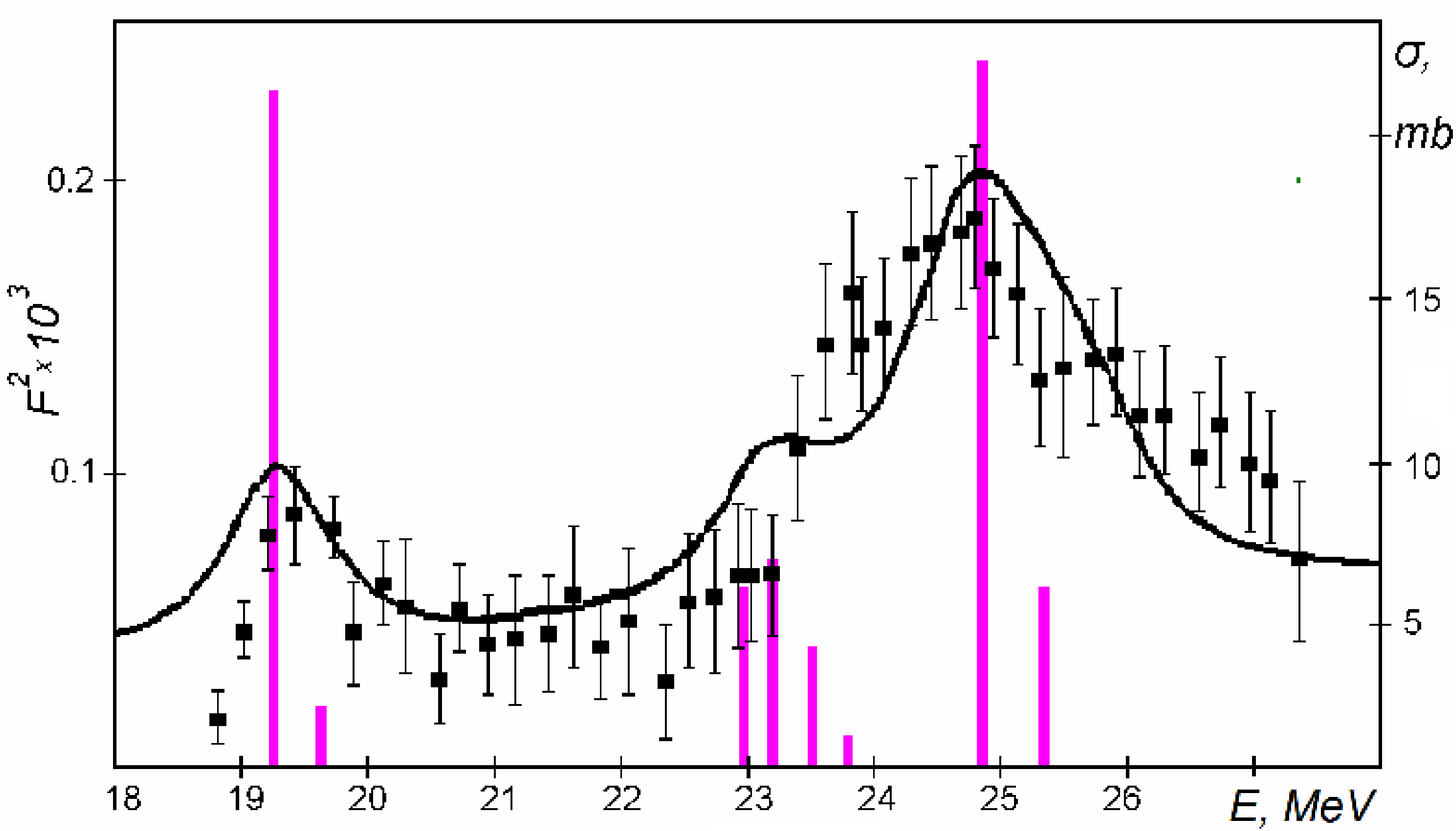


$^{48}Ca(\gamma, n)$



O'Keefe G.J. , Thompson M.N. *et al* // Nucl.Phys.**A469**(1987) 239

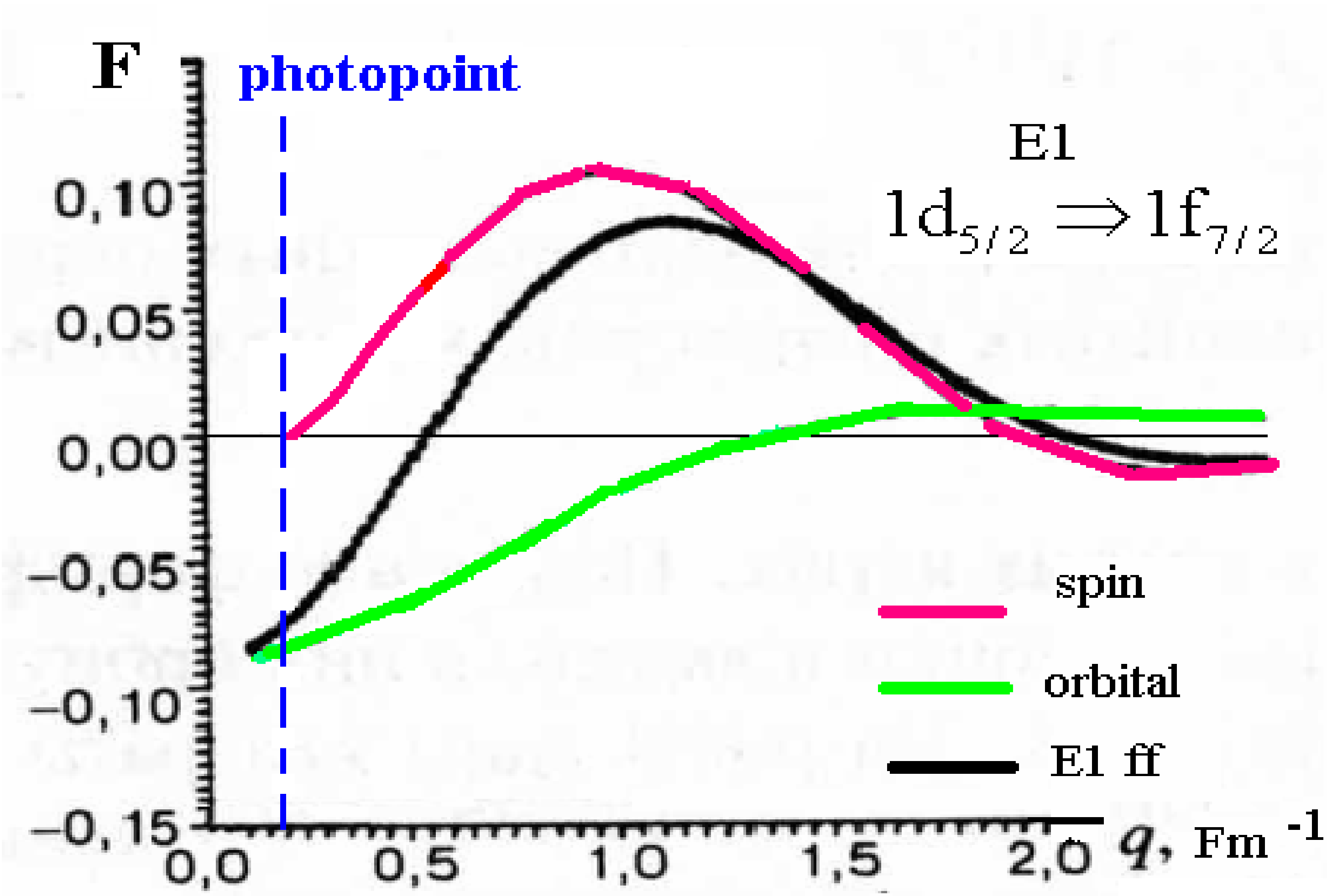
$^{48}Ca(\gamma, p)$



O'Keefe G.J. , Thompson M.N. *et al* // Nucl.Phys.**A**469(1987) 239

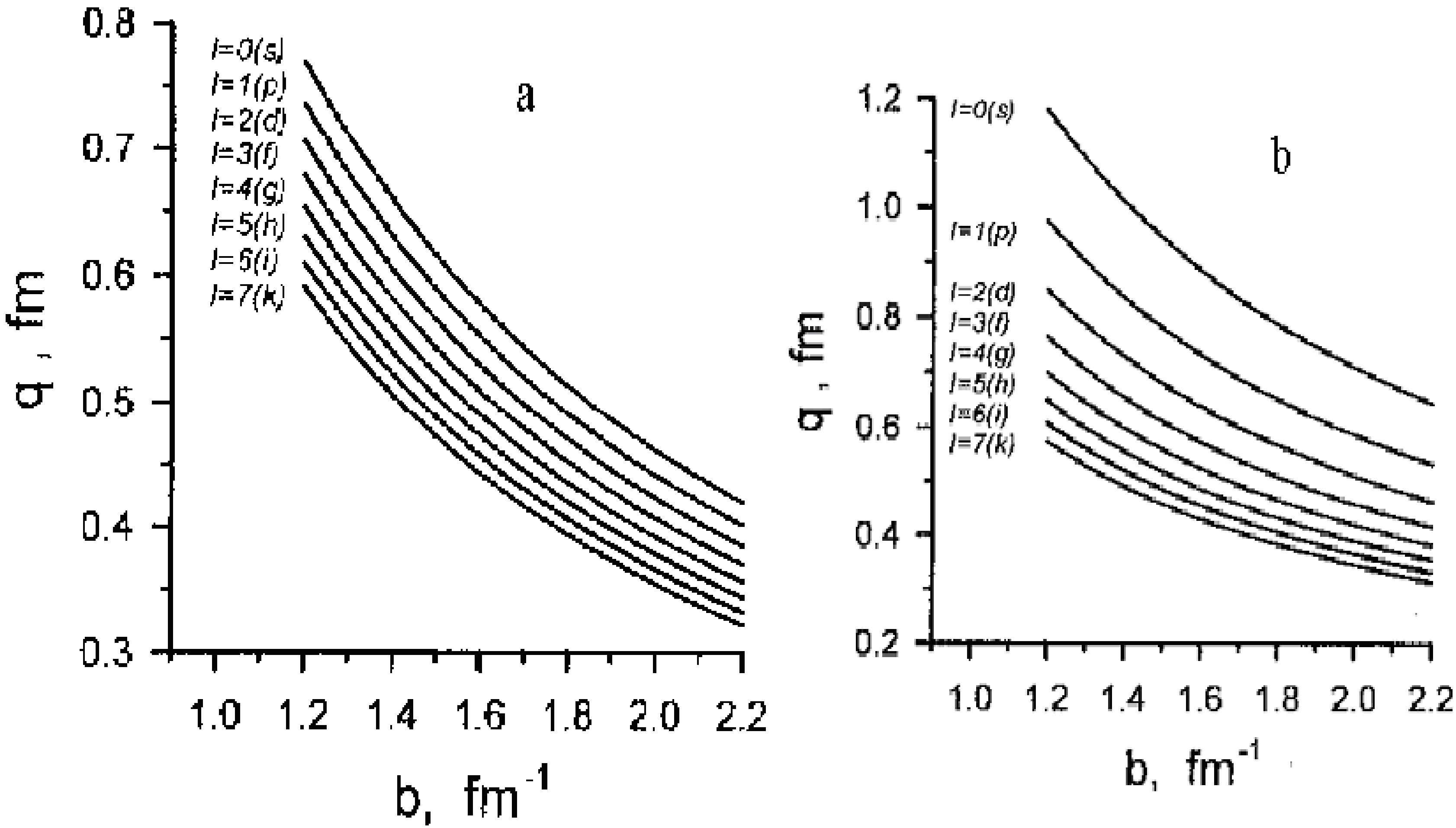
E1 resonances in (e.e')

Spin- and orbital currents interference in E1 sd-shell form factors

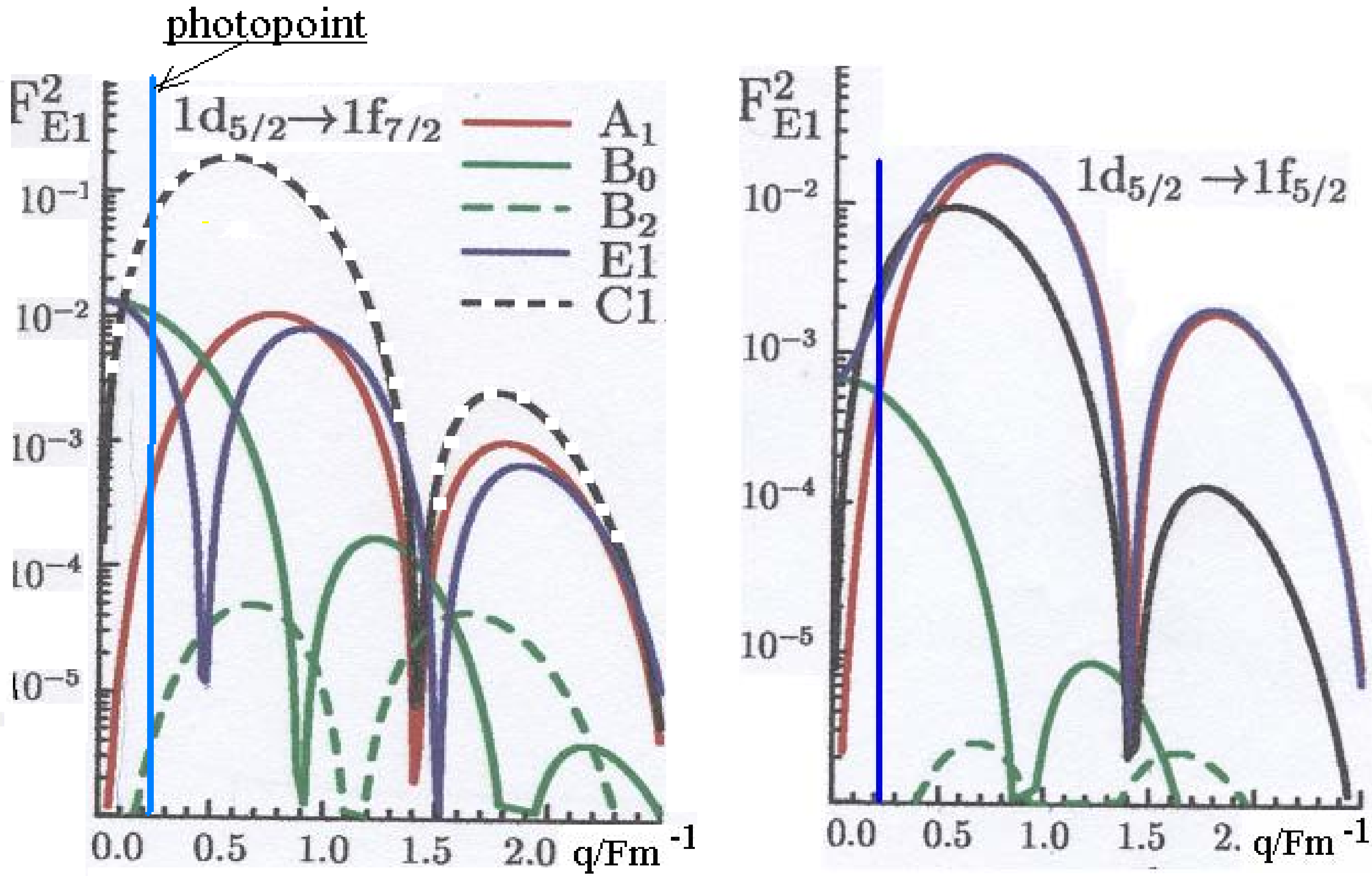


For E1 transitions $1L_{j=L+1/2} \Rightarrow 1(L+1)_{j=L+3/2}$

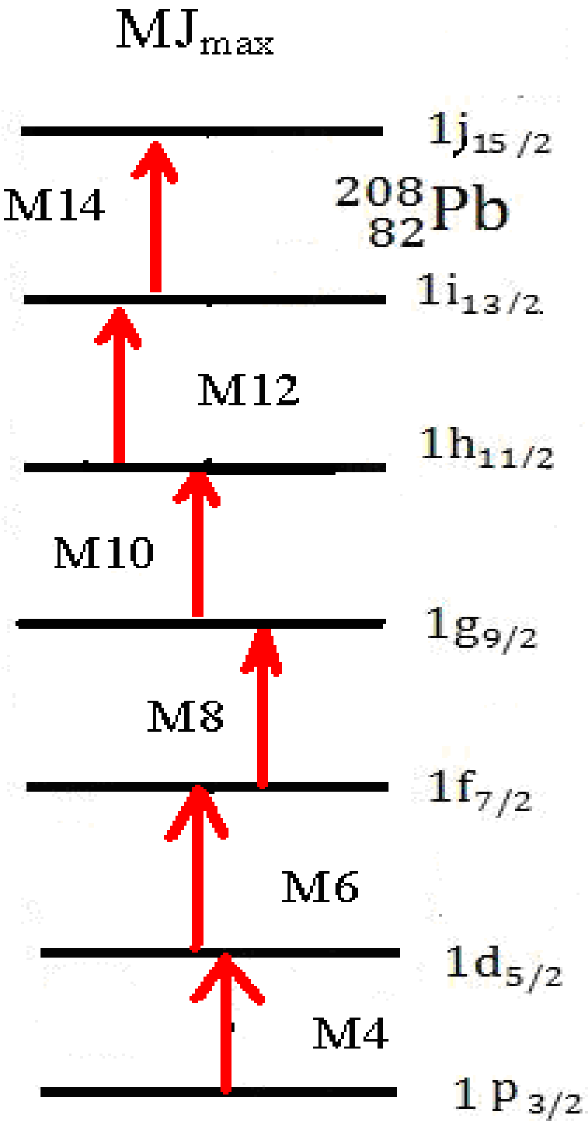
maxima **of C1 form factors (a) are near** ***minima*** **of E1 form factors(**b**)**



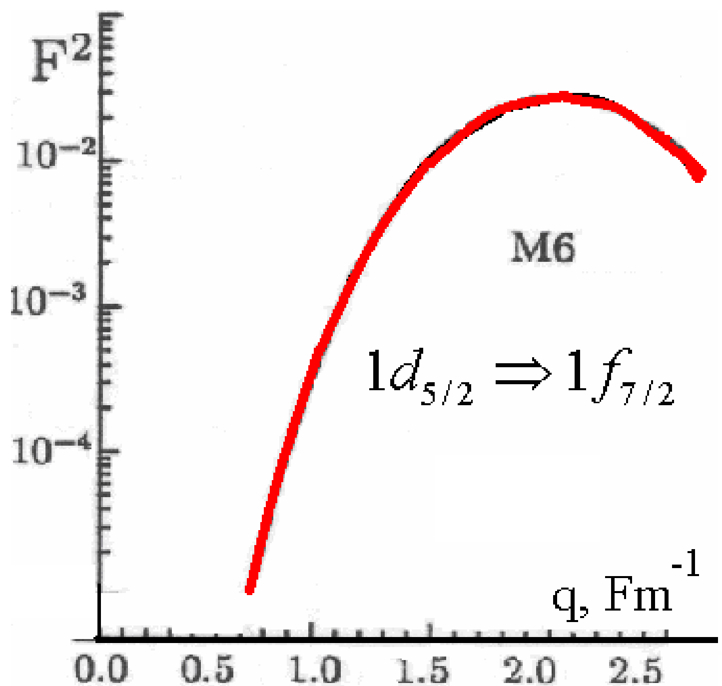
$F^2(q)$ for E1 transitions



$1\hbar\omega$ MJ_{max} excitations



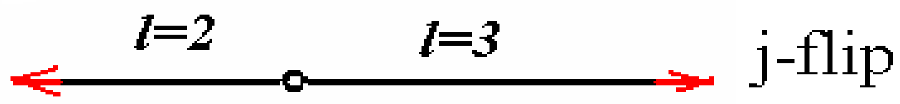
$$F^2_{MJ_{max}} \sim \langle J_f \| \hat{O}_J(q) \| J_i \rangle^2 = C \times q^{2J} \exp(-\frac{b^2 q^2}{2})$$



$$q_{max} = \frac{\sqrt{2J}}{b}$$

MJ_{max} (stretched states)

M6 → $1d_{5/2} \Rightarrow 1f_{7/2}$



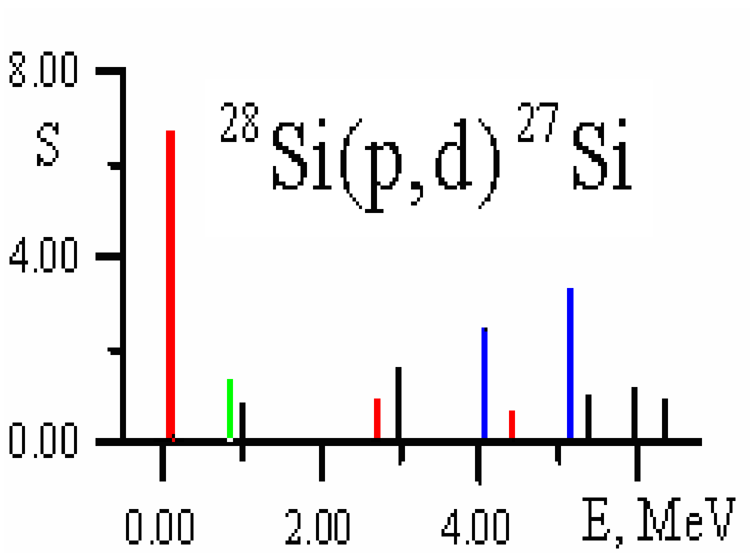
Spin current contributions only

$$\hat{T}^{mag}_{JM} \sim \mathbf{A}_{J-1} + \mathbf{A}_{J+1} + \mathbf{B}_J . \Rightarrow$$

$$\Rightarrow \hat{T}^{mag}_{JM}(M6) = \underline{\mathbf{A}_5} =$$

$$= \frac{iq}{2M} \sum_{i=1}^{A} \hat{\mu}_j \sqrt{\frac{J+1}{2J+1}} j_5(qr_i) \underline{\left[Y_5(\Omega_i) \times \hat{\sigma}_j \right]^{JM}}$$

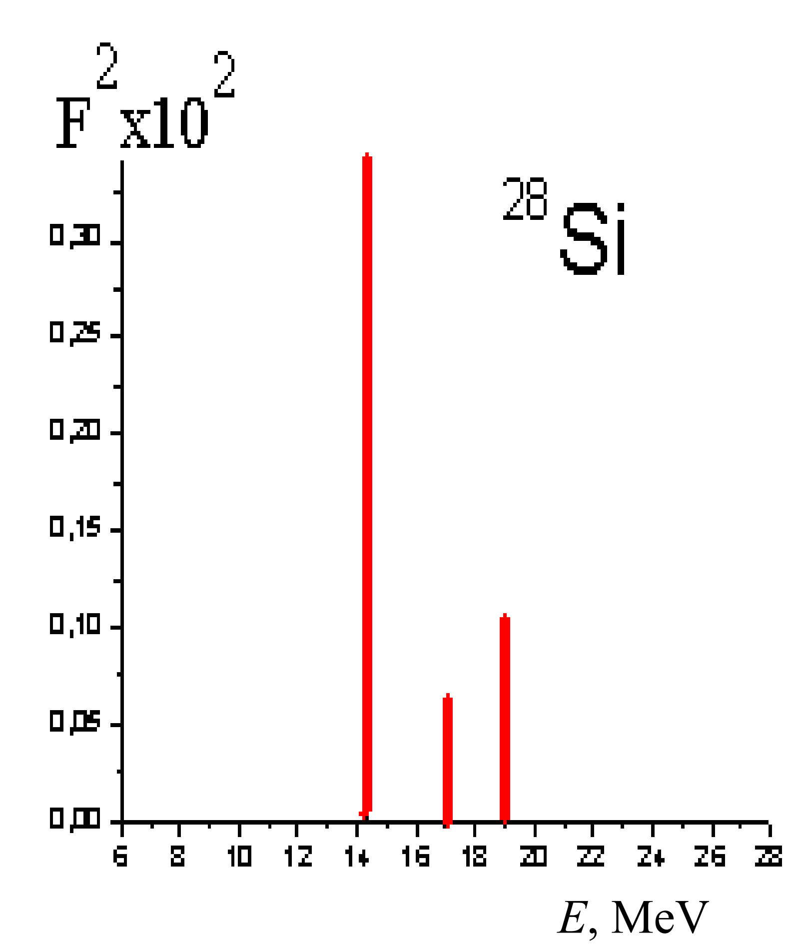
*M*6 in sd-shell nuclei : ^{28}Si



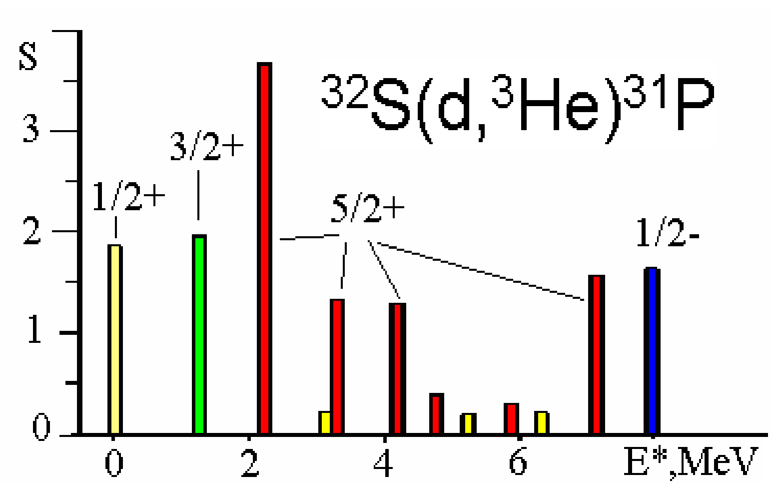
Endt P.M. Nucl. Phys. A 310 (1978)

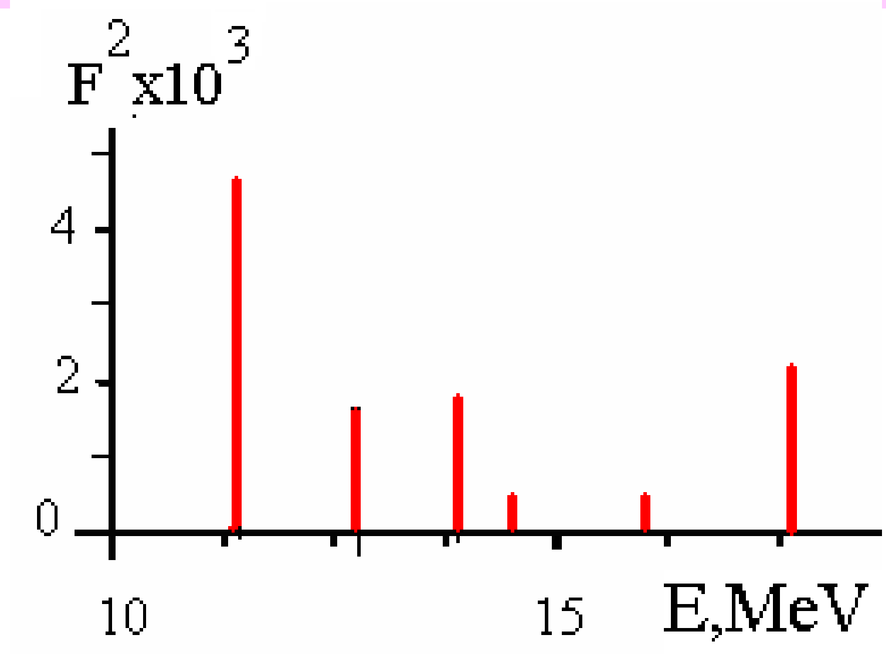
S.Yen,*ea*,Phys.Lett.B**289,** 22(1992):
6^- T=1 at 14.32 MeV

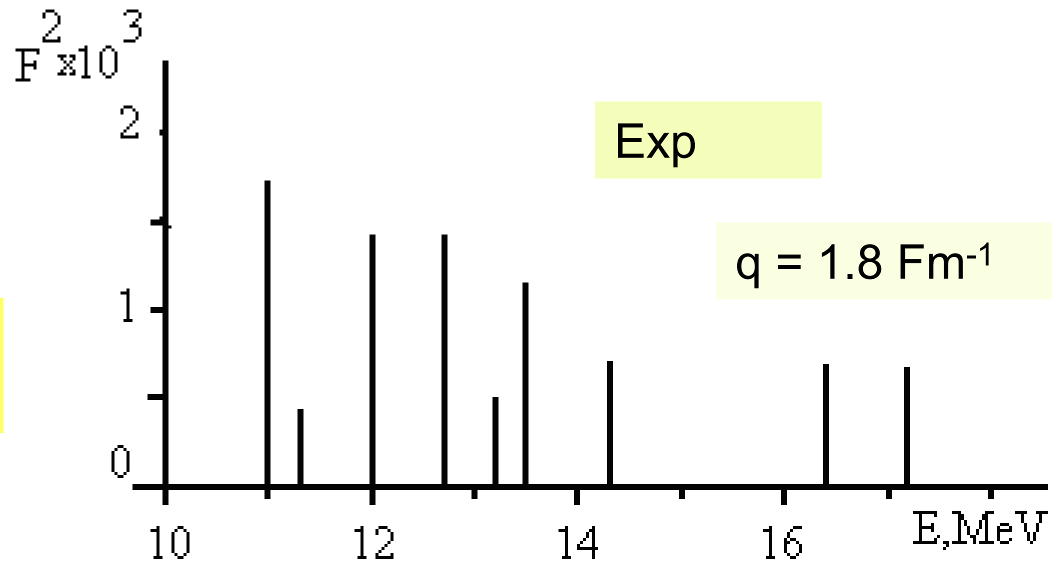
q = 1.8 Fm^{-1}



$M6$ in sd-shell nuclei : ^{32}S

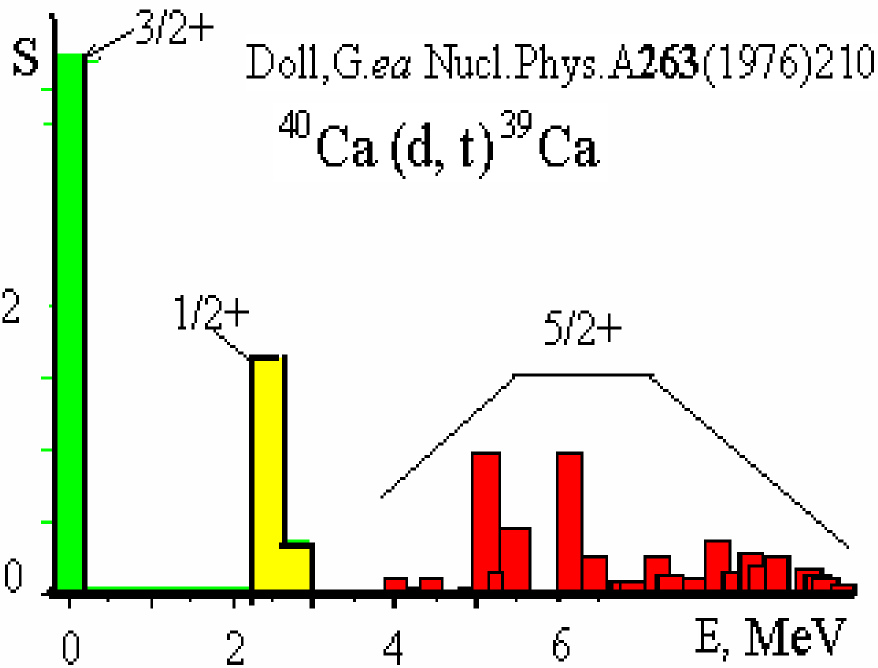




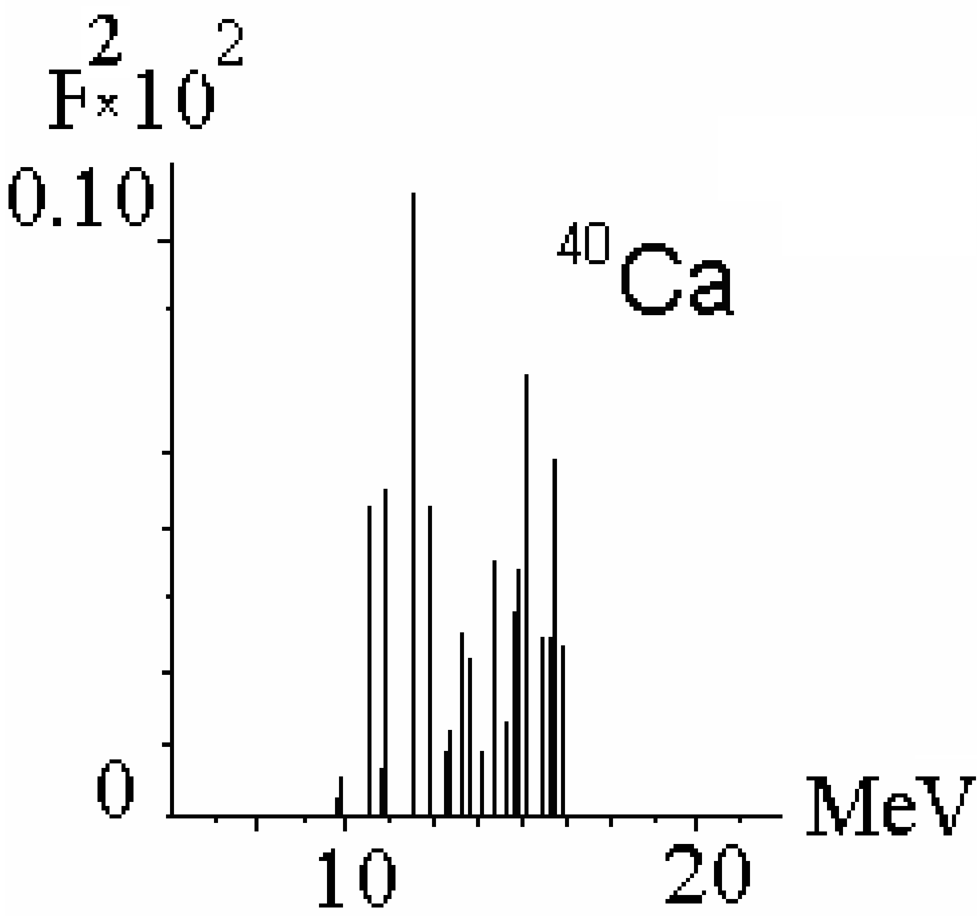


Exp.: Clausen B.L *et al* ,
Phys.Rev.**C48,** 1632(1993).

M6 in Ca-40



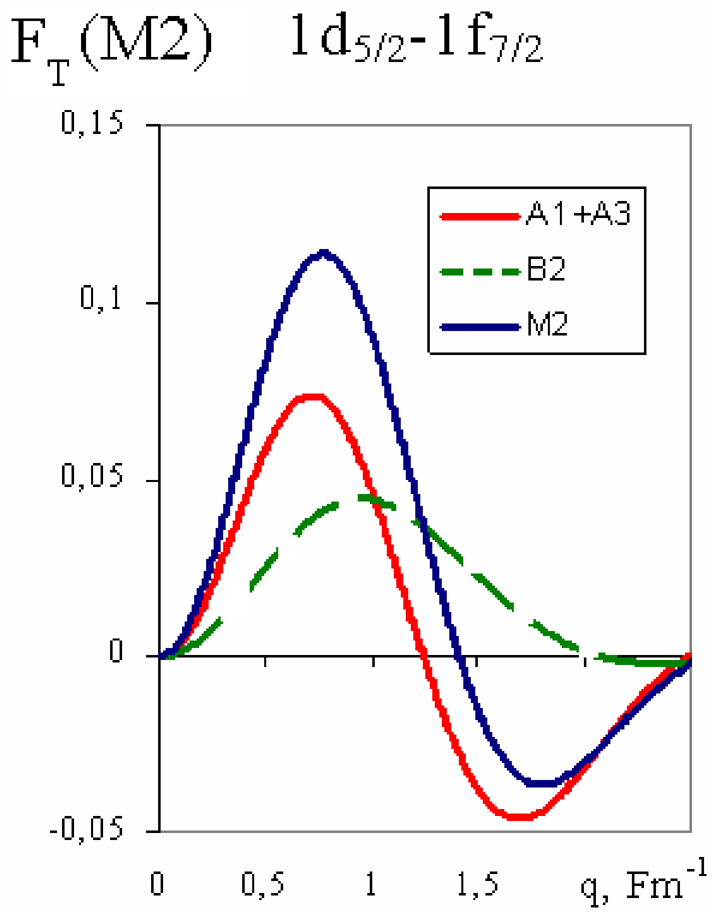
S
3/2+
Doll,G.ea Nucl.Phys.A263(1976)210
40Ca (d, t) 39Ca
1/2+
5/2+
2
0
0
2
4
6
E, MeV

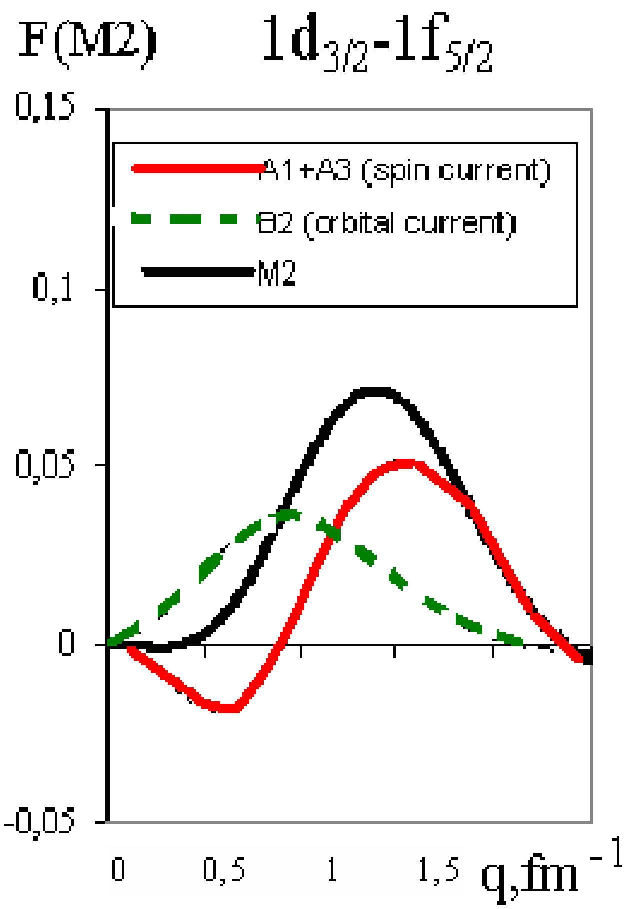


F2 × 102
0.10
40Ca
0
MeV
10
20

M2 resonances

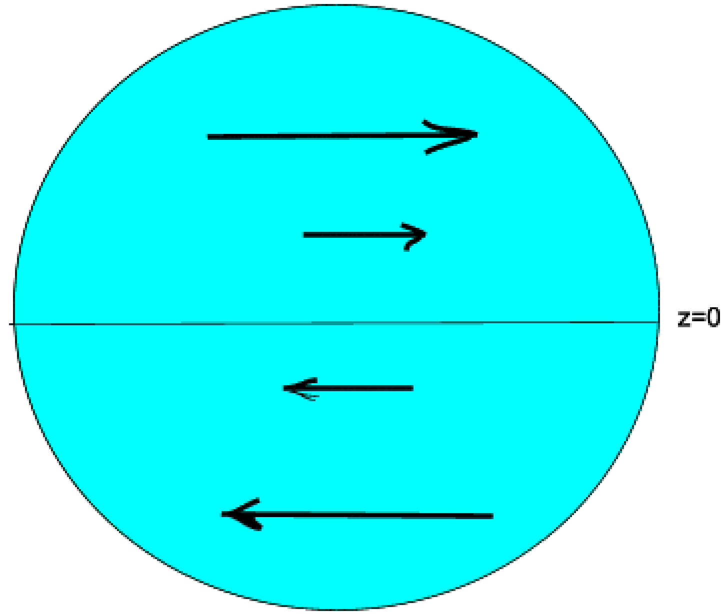
Spin- an orbital currents in M2 excitations





Nuclear Orbital M2 Current

Orbital M2 TWIST Mode:
Orbital current has opposite signes in the upper and lower semispheres.
The current vanishes at
Z=0

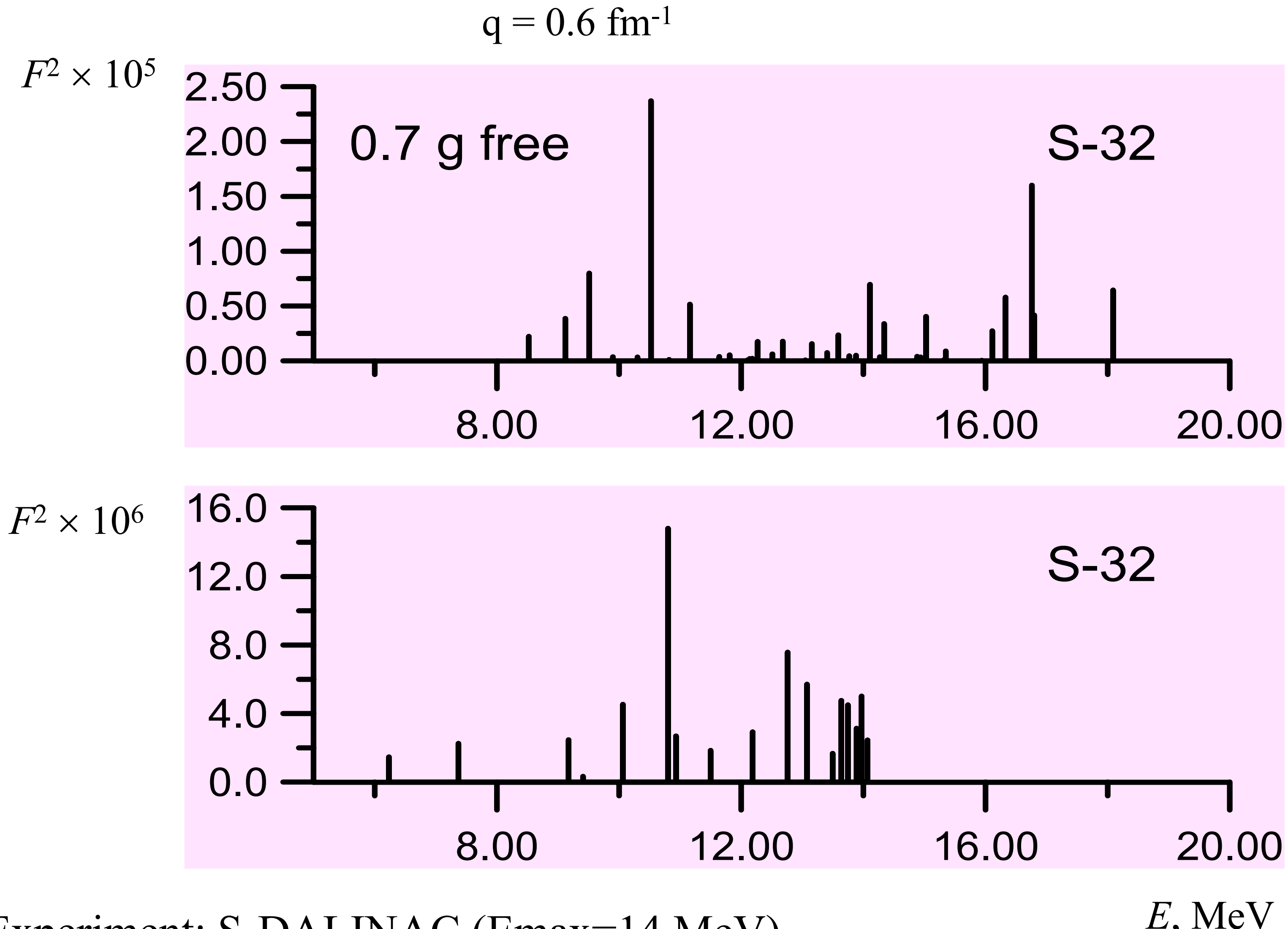


(e,e’) excitation ~Spin +orbital(twist) modes

(p,p’) excitations –SPIN part only
Comparison of (e,e’) and (p,p’) reveals
ORBITAL TWIST M2-

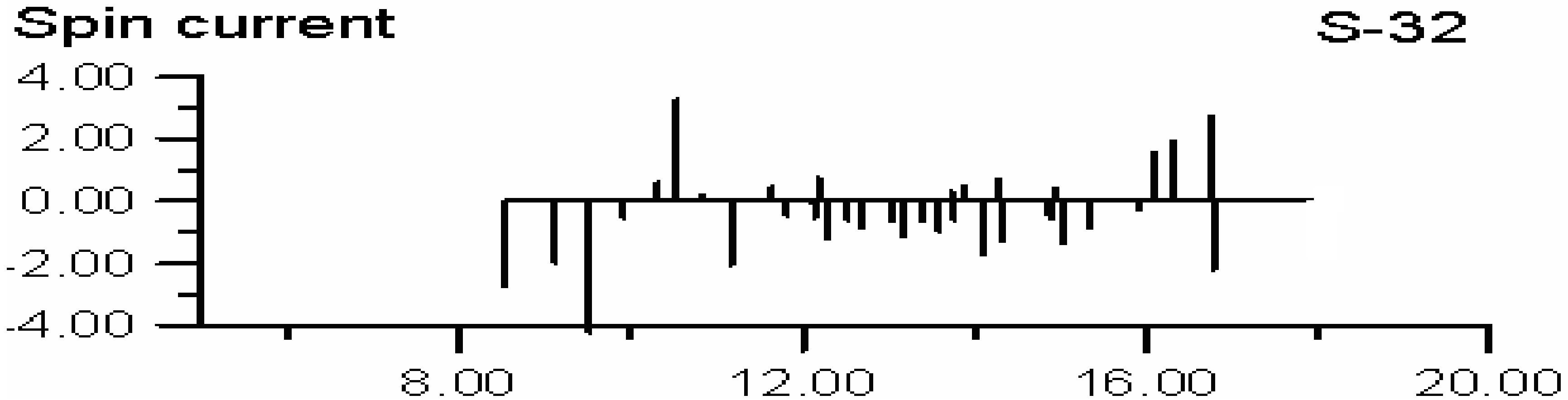
$$\hat{T}_2^{mag} \sim \frac{2\hat{e}_i}{q}\left(j_2\left(qr_j\right)\left[\mathrm{Y}_2\left(\Omega_i\right)\times\hat{\nabla}_j\right]^{J=2}\right)$$

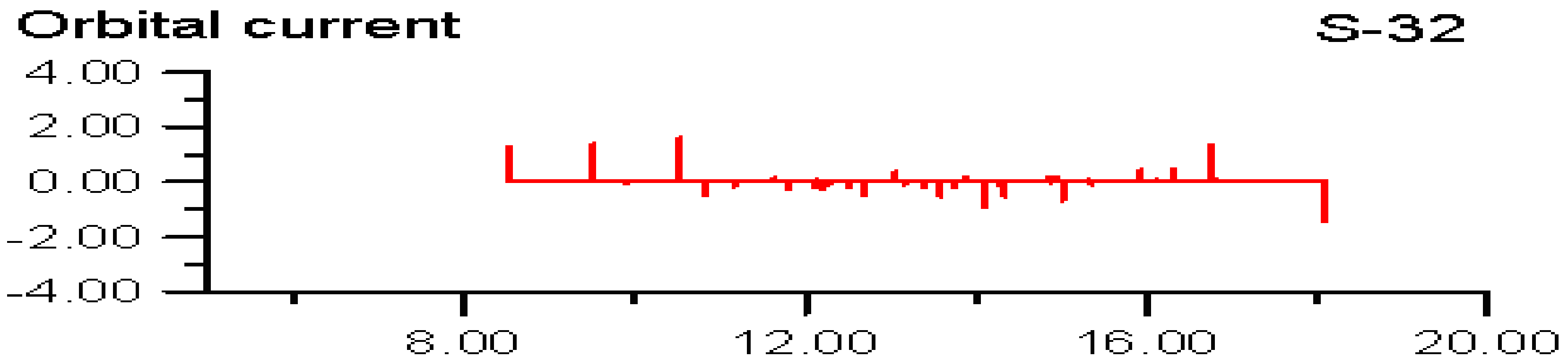
$M2$ in ^{32}S(e,e')

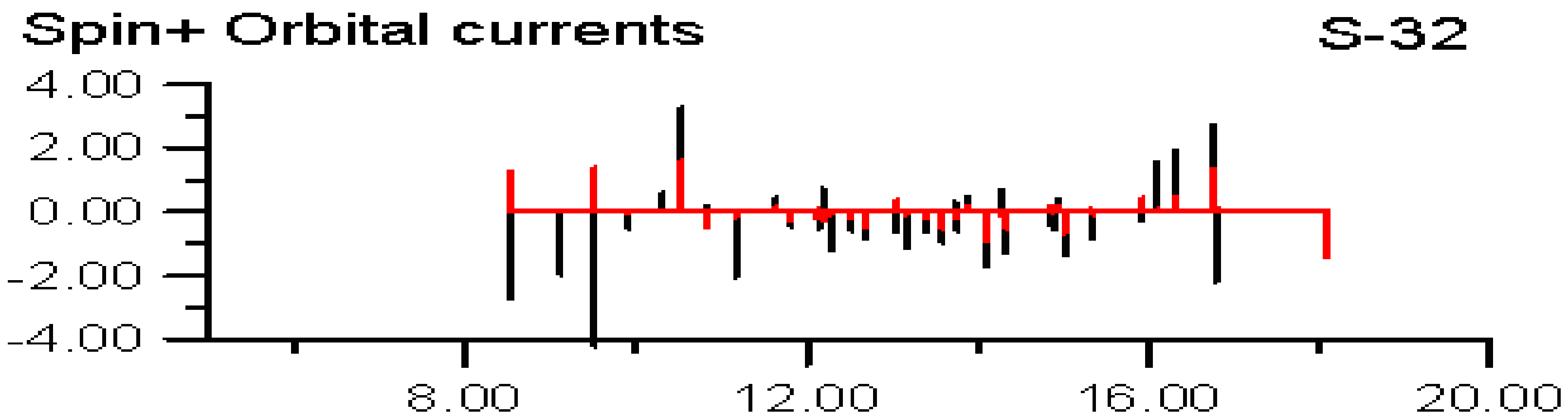


Experiment: S-DALINAC (Emax=14 MeV)

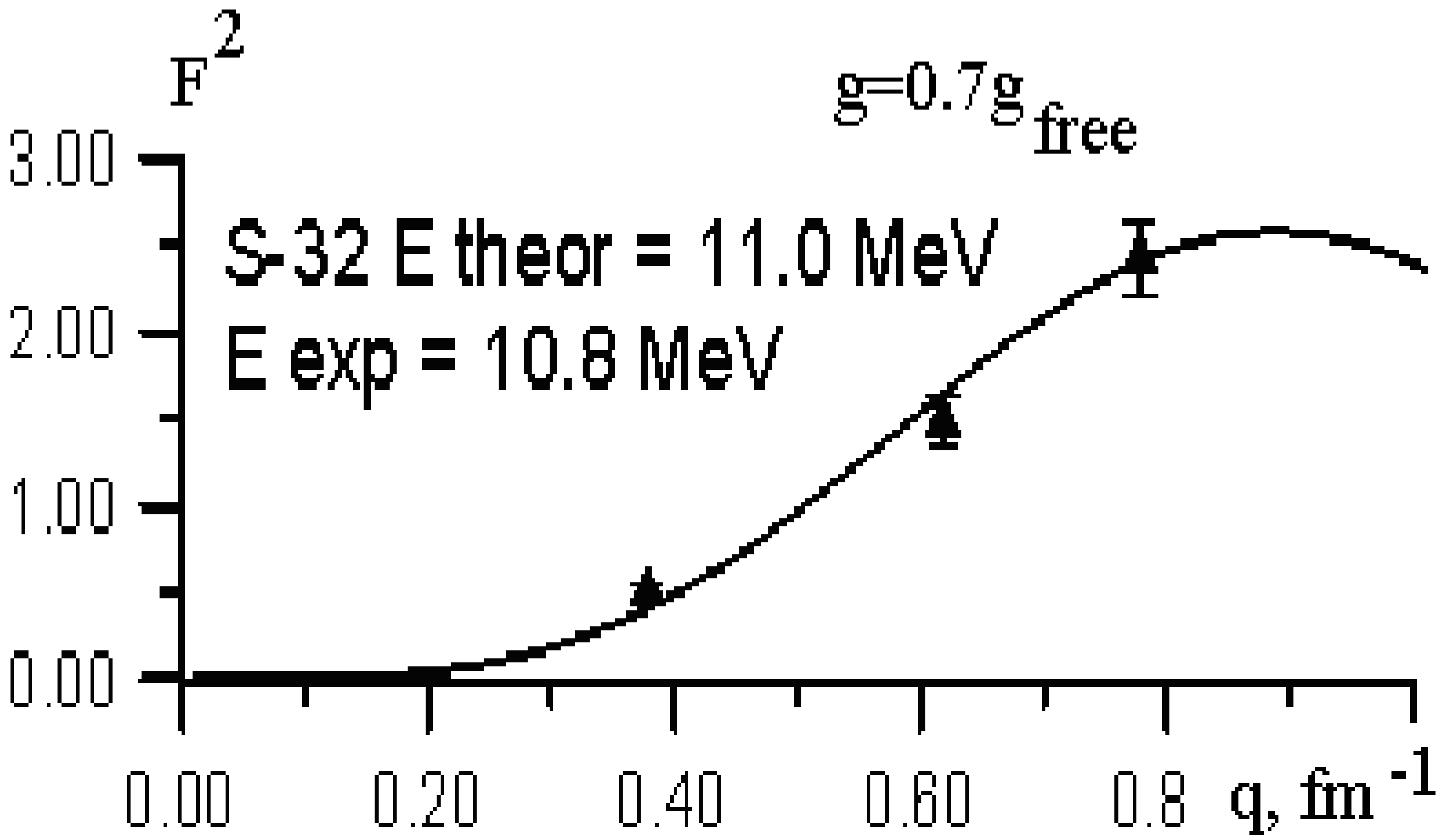
Spin and orbital currents in M2 ^{32}S







q-dependence of M2 peaks



Summary

- In the PCC version of SM distributions of the ”hole” among the (A-1) nuclei states are taken into account in microscopic description of multipole resonances in sd-shell nuclei using spectroscopy of pick-up reactions.

- The energy spread of final nuclei states is the main origin of the multipole resonances fragmentation in open shell nuclei. Comparison of PCC SM results with experimental data on MR confirms the validity of this approach for a range of momentum transfer from “photopoint” up to q≈2 Fm^{-1}.
- The assumption that some very valuable information on MR in excited deformed nucleus is embedded in direct reactions spectroscopy data proved to be right.