S_{11} resonance in nuclei

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- LNS
- GeV γ experiments at LNS
  - K^0 photoproduction on nuclei
    $\pi^+\pi^-$ measurements
  - (γ, η) on nuclei
    $\gamma\gamma$ measurements

How do hadrons behave in nuclear medium?

Interactions with other baryons change their properties.

Width, lifetime, effective coupling strength, ...

Photoproduction of hadrons in nuclei

- create them softly, inside the nucleus

If the hadron decays very shortly

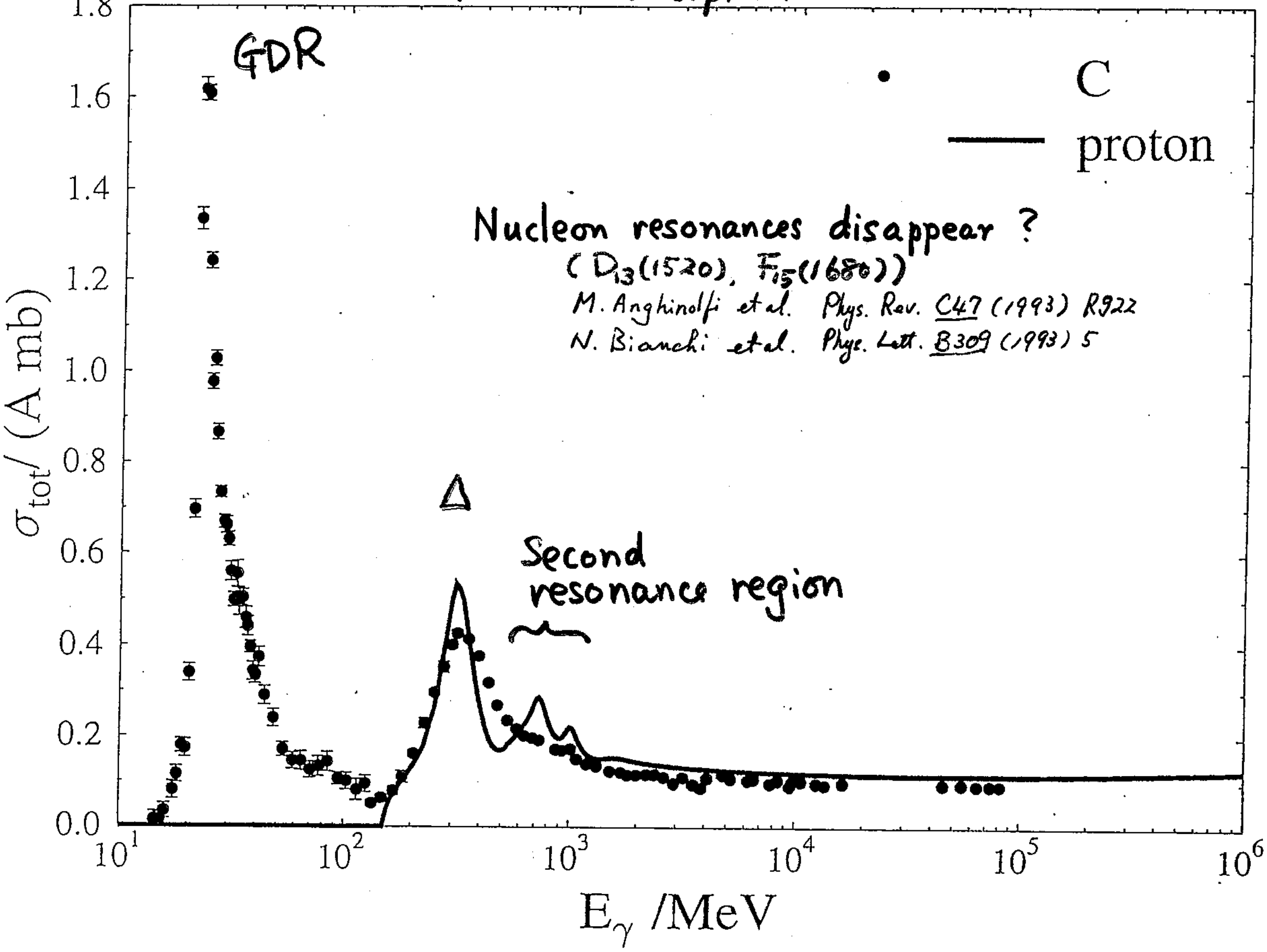
$\Rightarrow$ Information on hadrons in nuclei

Nuclei provide a different setting on QCD vacuum

$\Rightarrow$ partial restoration of chiral symmetry

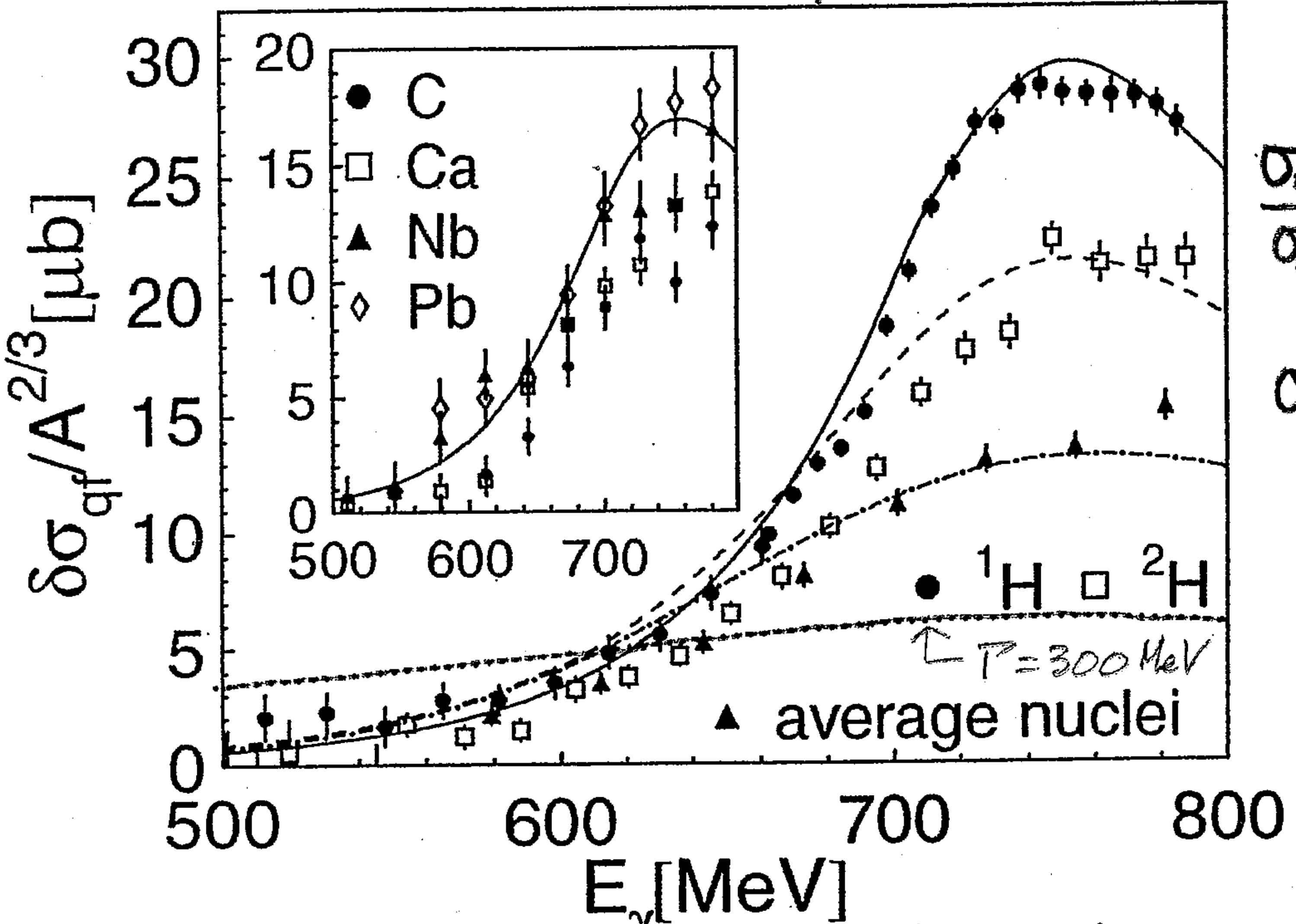
$S_{11}(1535)$ in nuclei ?

Total Photoabsorption



$D_{13}(1520)$ in Nuclei   B. Krusche et al. Phys. Rev. Lett. 86 4764 (2001)

$A(\gamma, \pi^0)$ background subtracted



$\frac{\sigma_n(D_{13})}{\sigma_p(D_{13})} \simeq 1/3$

$\sigma / A^{2/3}$

- No anomalously large broadening
- D_{13} resonance exists in nuclei

1. Total photoabsorption cross section

$\neq$ disappearance of the D_{13} resonance in nuclei

D_{13} appears in the $A(\gamma, \pi^0)$ reactions at Mainz

2. Width of the $D_{13}(1520)$ resonance

consistent with the broadening due to Fermi motion
(needs more data for $E_\gamma > 800$ MeV)

$S_{11}(1535)$ resonance

- observed exclusively through the (γ, η) reactions
- possible candidate for a chiral partner of the nucleon
  - QCD vacuum $\leftrightarrow$ Nuclear medium
    mass shift

$SU(6) \otimes O(3)$

$S_{11}(1535)$ $^2 8$ P_M $\frac{1}{2}^-$ } mix
$S_{11}(1650)$ $^4 8$ P_M $\frac{1}{2}^-$

large $S_{11}(1535) \to N\eta$ is difficult to understand

possibility of a quasi $K\Lambda$ or $K\Sigma$ state

The 3rd S_{11} at ~ 1720

Jido, Oka, Hosaka, Prog. Theo. Phys. 106 (2001) 873

Chiral Symmetry of Baryons

Chiral Partners

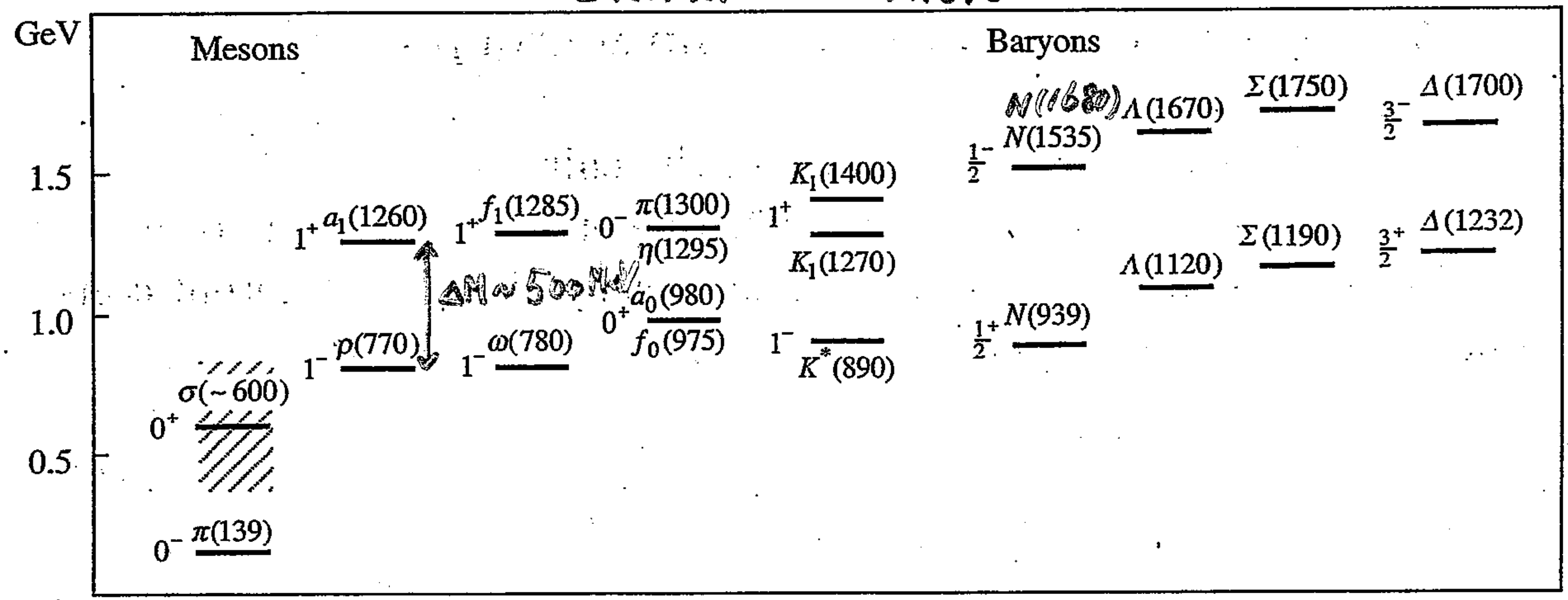
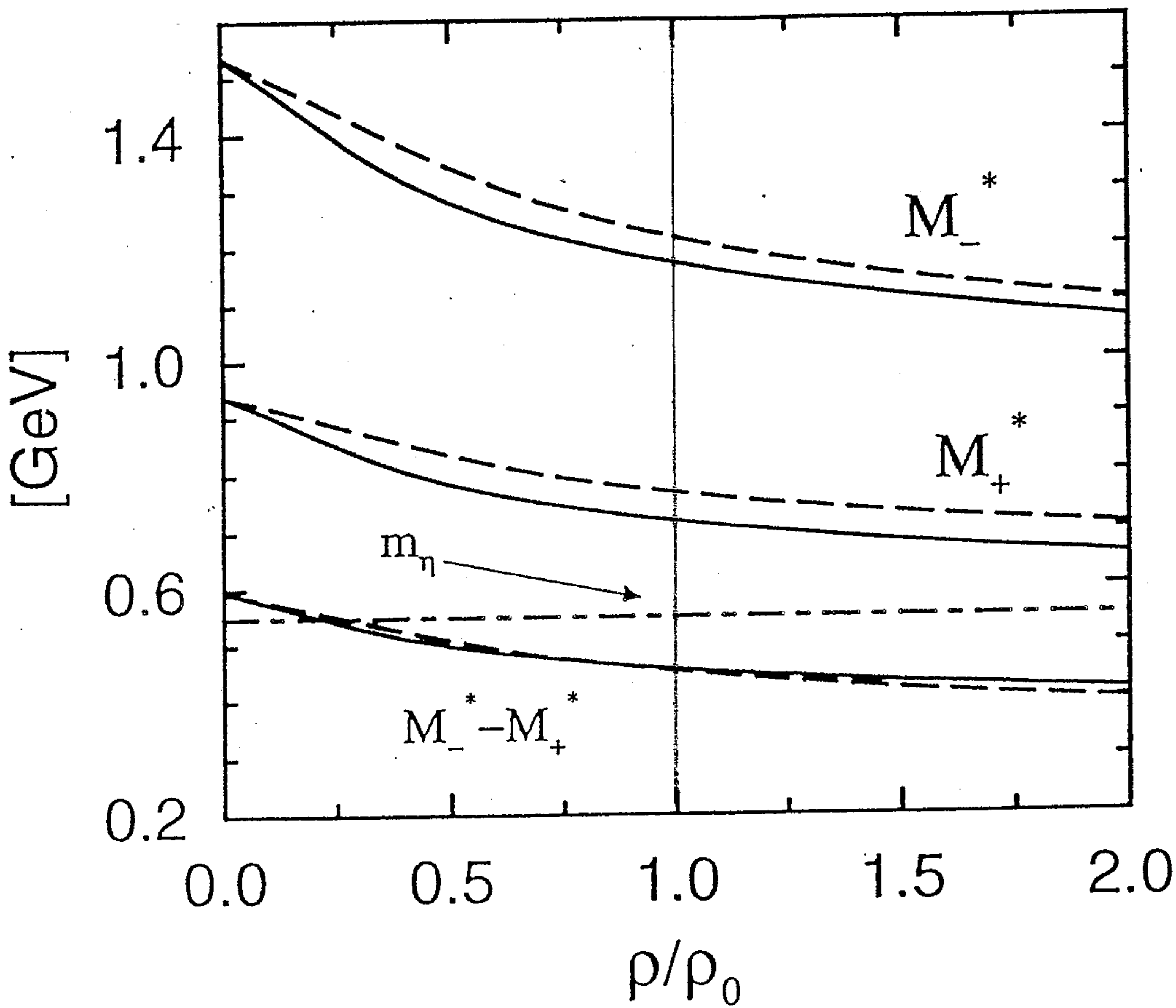


Fig. 1. Mass splittings of positive and negative parity hadrons in various channels. Data are taken from the Particle Data Booklet. [11] The uncertain mass of sigma (σ) is hatched.

Kim, Jido, Oka, Nucl. Phys. A640 (1998) 77



ΔM ≳ 100 MeV at ρ = ρ0

Phys. Lett. B476 (2000) 226

Observation of $S_{11}(1535)$ resonance in nuclear medium via the $^{12}C(\gamma,\eta)$ reaction

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Abstract

Properties of the $S_{11}(1535)$ resonance in nuclear medium were investigated through the $^{12}C(\gamma,\eta)$ reaction for photon energies between 0.68 and 1.0 GeV. A broad resonance due to the the S_{11} excitation in the carbon nucleus was clearly observed for the first time. The data were compared with calculations of the quantum molecular dynamics, and the observed shape being different from the elementary one is essentially explained by the medium effects such as the Fermi motion, the Pauli blocking and effects of $N-\eta$ and $N-N^*$ collisions.

at INS, Tokyo

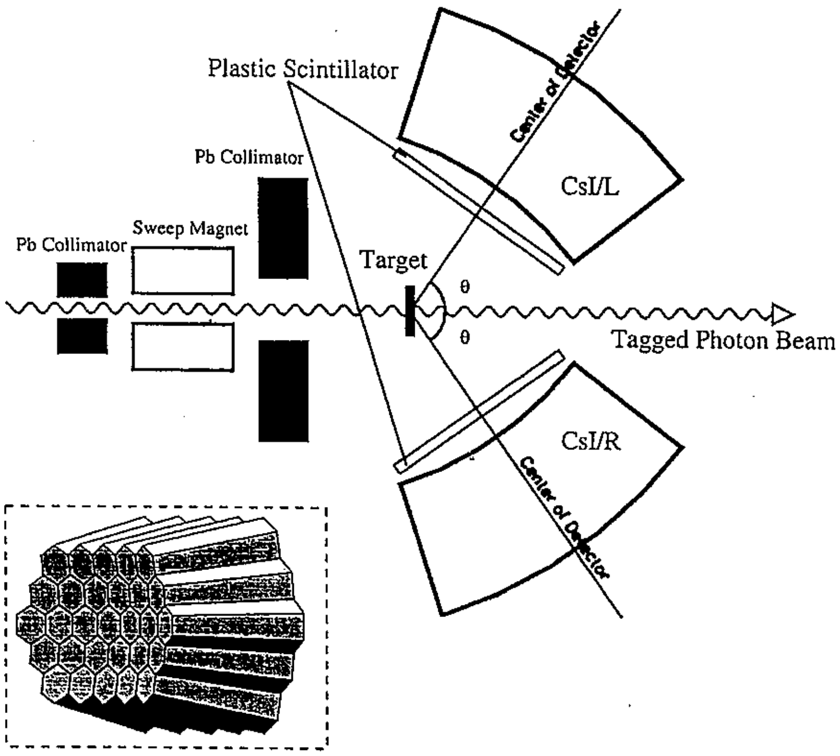


Fig. 1. Schematic drawing of the experimental setup. Two photons from the decay of an η meson are detected by two sets of the pure CsI calorimeters (CsI/L and CsI/R) with plastic scintillators for charged particle veto. The inset shows a view of the CsI calorimeter consisting of 29 CsI detectors.

S_{11} in nucleus essentially explained as a single nucleon excitation modified in the nuclear medium.

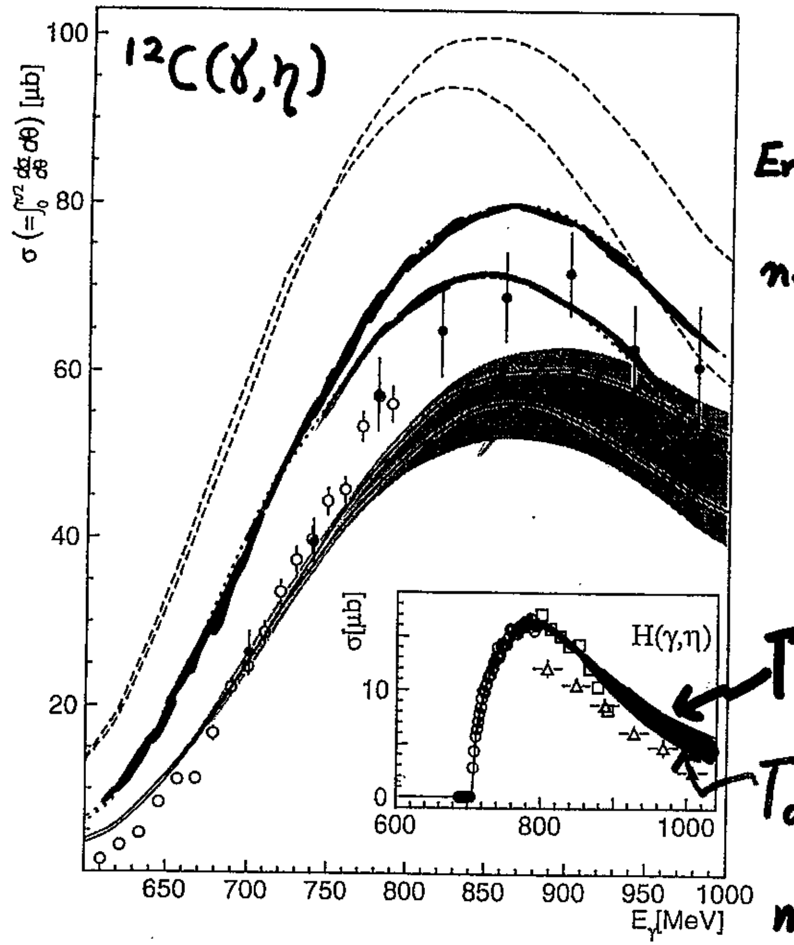


Fig. 4. Cross section of the $^{12}C(\gamma,\eta)$ reaction. The closed circles are present results integrated for $0° \leq \theta_\eta \leq 90°$. The total cross section reported in Ref. [13] is plotted with the open circle. The results of the QMD calculations for the S_{11} resonance in the carbon nucleus are also shown with various curves: the dashed curves including the effects of the Fermi motion and the Pauli blocking, the dotted curves the η absorption switched on, and the solid curves further including the collision broadening. The inset shows the cross section of the $H(\gamma,\eta)$ reaction reported in Ref. [16] (circles), in Ref. [17] (squares) and in Ref. [19] (triangles), together with the results of the parameterization reported in Ref. [15] (solid line) and in Ref. [18] (dotted line).

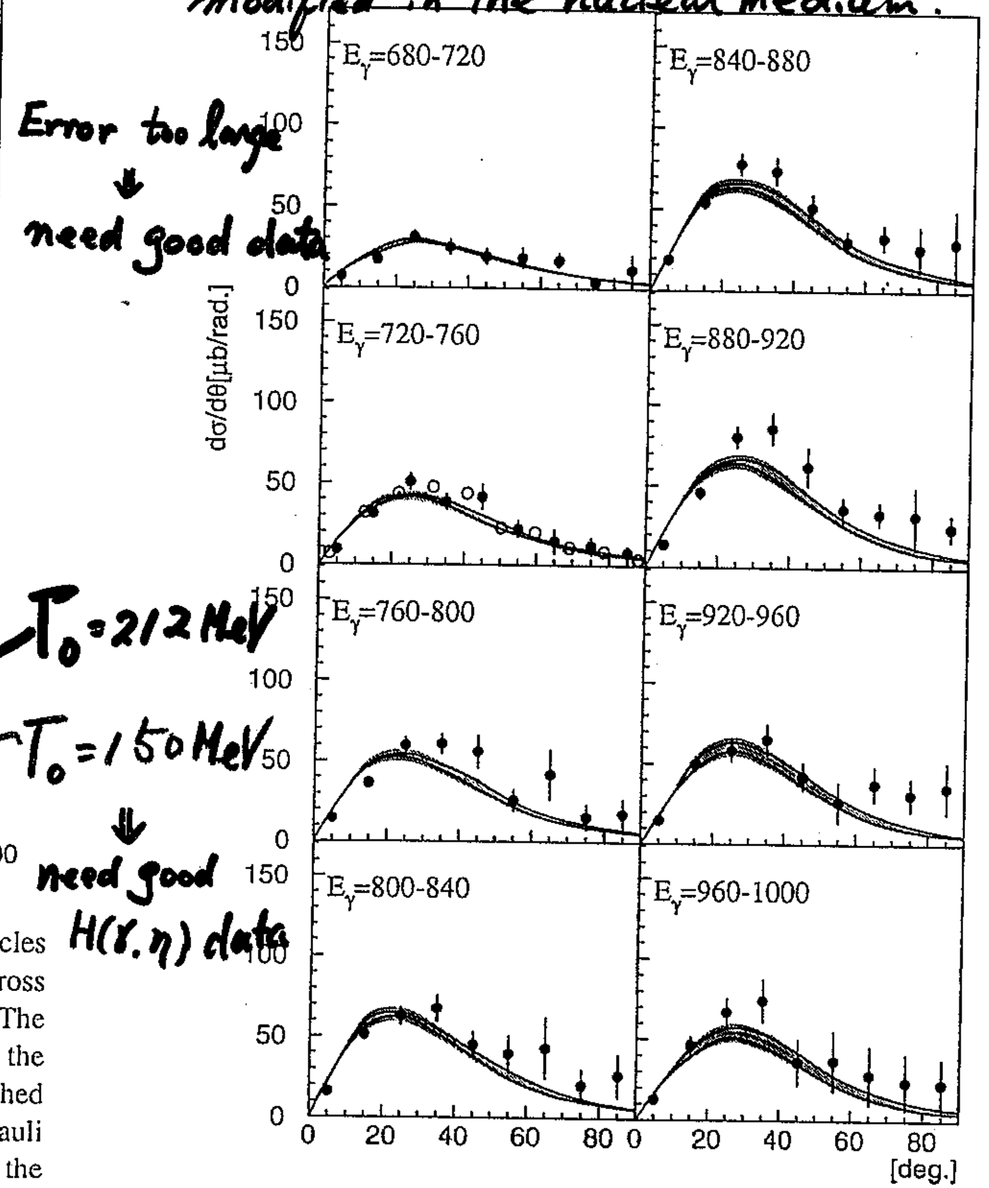
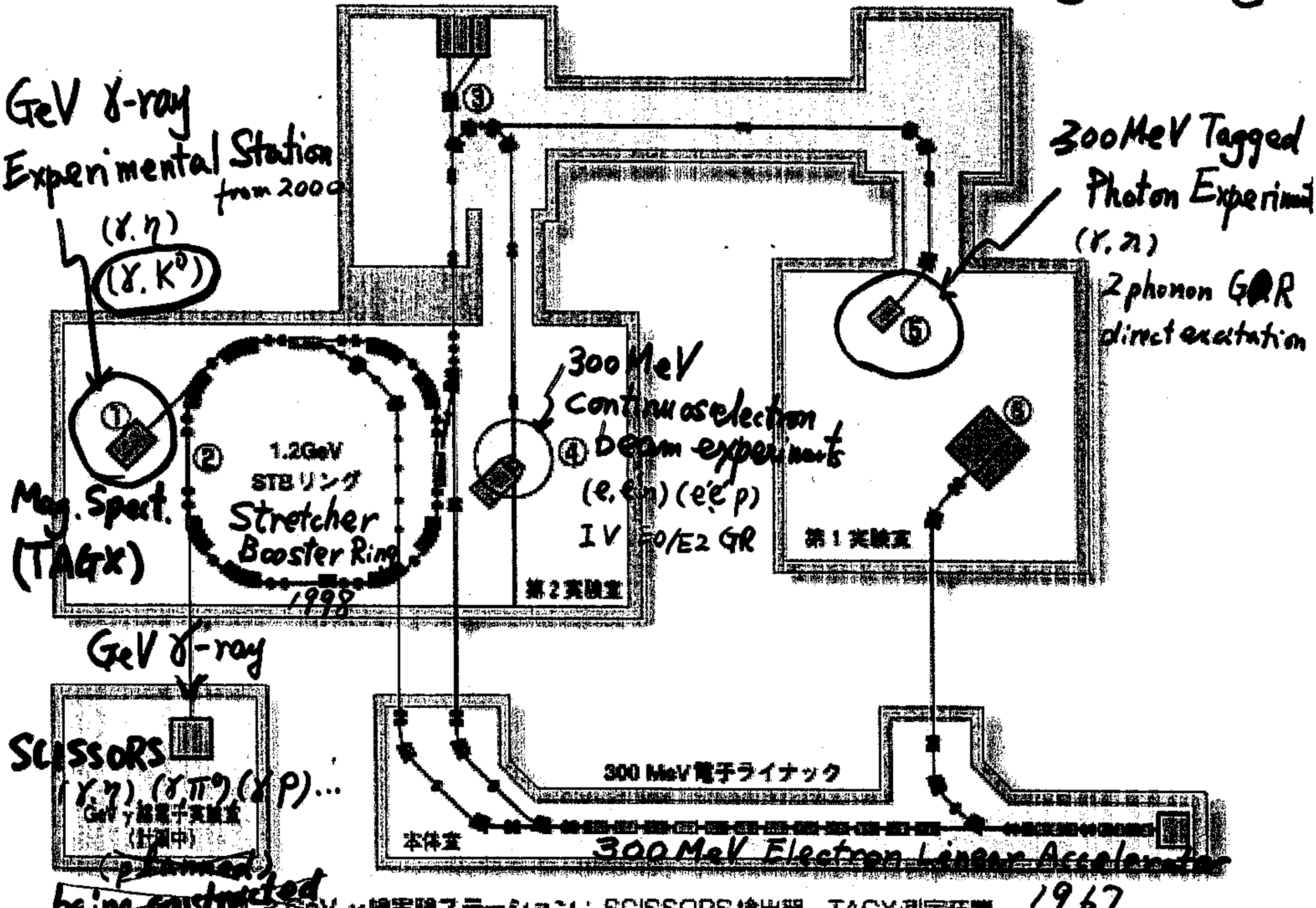


Fig. 3. Angular distribution of differential cross section, $d\sigma/d\theta$ of the $^{12}C(\gamma,\eta)$ reaction for incident photon energies between 0.68 and 1.0 GeV. The present results are plotted with closed circles, while open circles for E_γ = 720–760 are the data from Mainz for E_γ = 735–765 MeV. [13]. The solid lines are results of the QMD calculation including nuclear medium effects.

実験室レイアウト

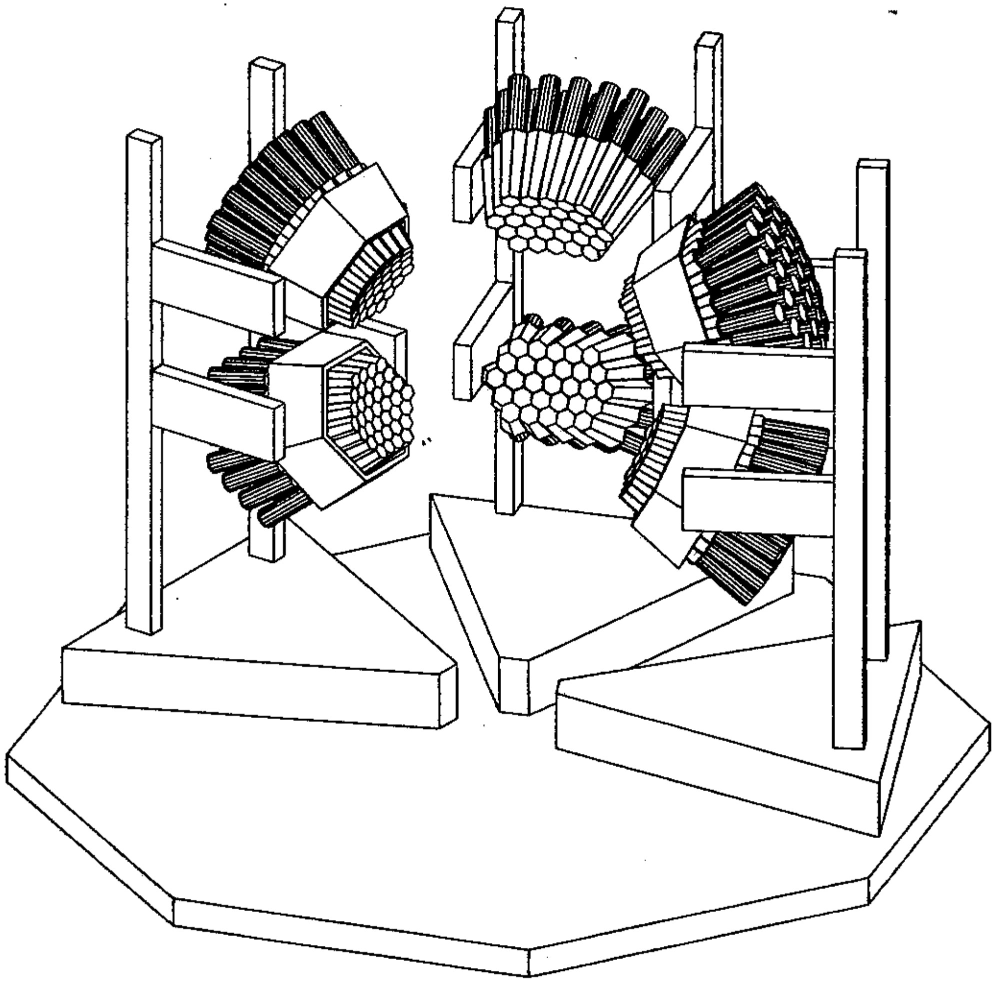
STB ring •Stretcher mode : 300 MeV continuous electron beam
•Booster mode : 1.2 GeV electron circulating in the ring

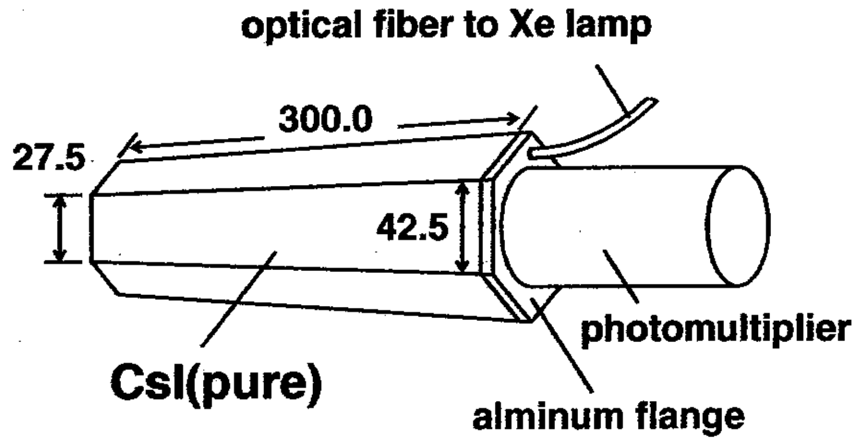


①1.2 GeV γ線実験ステーション：SCISSORS検出器、TAGX測定装置
②1.2 GeV 電子線実験ステーション：内部標的実験装置（計画中）
③300 MeV パルスビーム実験ステーション：コヒーレント放射測定装置
④300 MeV 連続電子線実験ステーション：大型磁気分析装置
⑤300 MeV γ線実験ステーション：標識化γ線発生装置
⑥60 MeV パルス電子ビーム実験ステーション：大強度電子線照射装置

300MeV 電子ライナック：
電子を最高300MeVまで加速します。2マイクロ秒の時間巾のパルス（束）状電子ビームが1秒間に最高300パルスの割合で取り出されます。

SCISSORS
(Sendai CsI Scintillator System On Radiation Search)

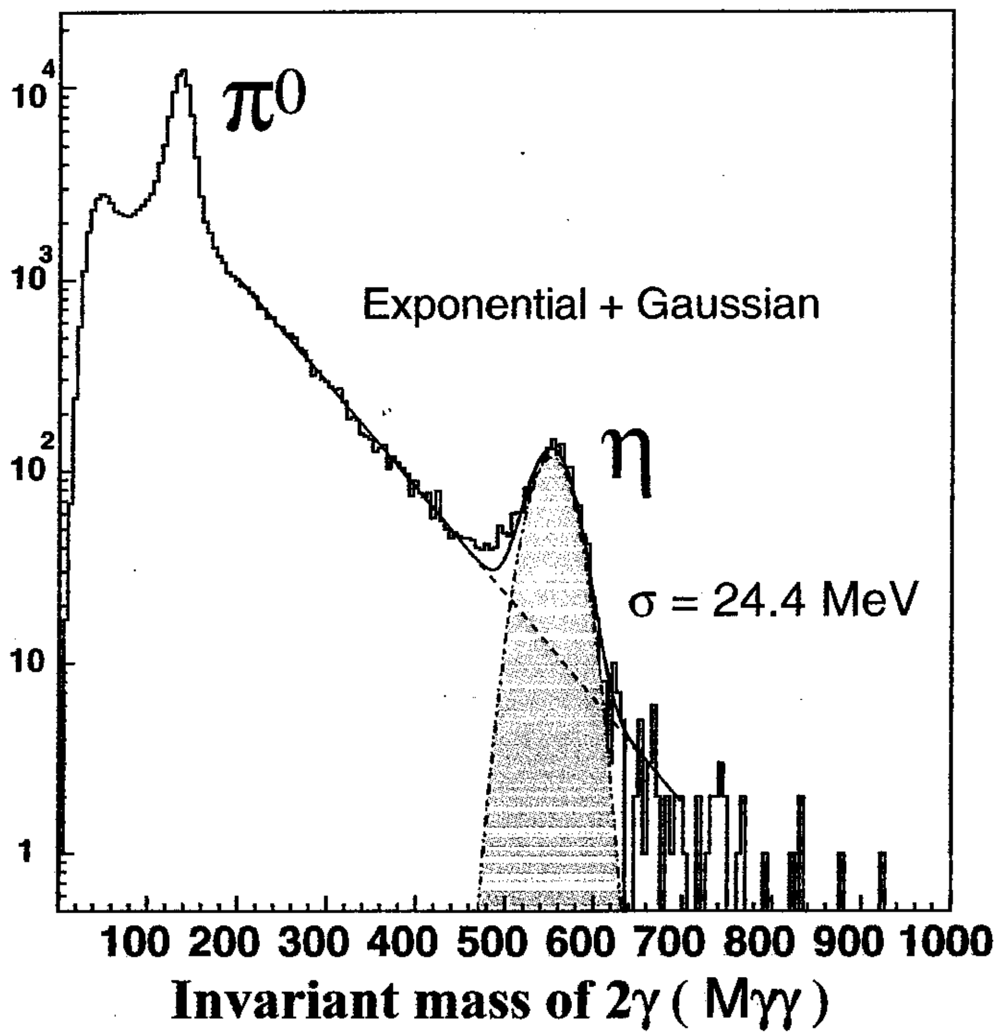




206 ch pure CsI crystal array
(about 1 sr.)
Energy resolution ~ 2% at 1 GeV
Position resolution ~ 3 cm
(Energy weighted average)

Invariant mass of 2γ events

$$M_{\gamma\gamma} = \sqrt{(E_{\gamma_1} + E_{\gamma_2})^2 - (p_{\gamma_1} + p_{\gamma_2})^2}$$



$M\gamma\gamma$ ~ 140 MeV/c^2 π^0
550 MeV/c^2 η

ΔM(η) ~ 22.4 MeV/c^2
(~ 4 %)

Subtracting the background
as the exponential function

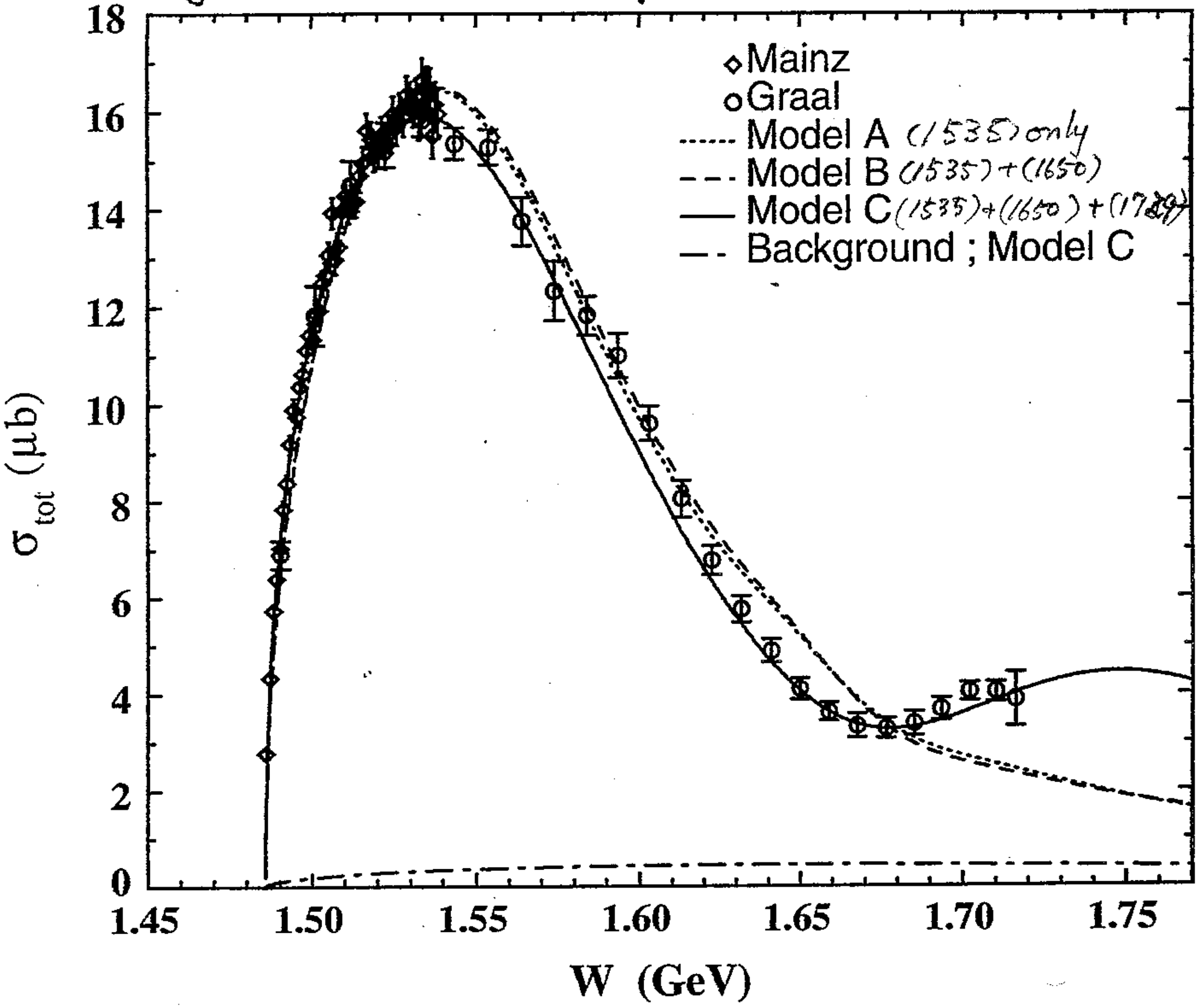
↓

Yield of η meson

↓

Total cross section on C

Saghai and Li : Eur. Phys. J. A11 (2001) 217 Quark model analysis



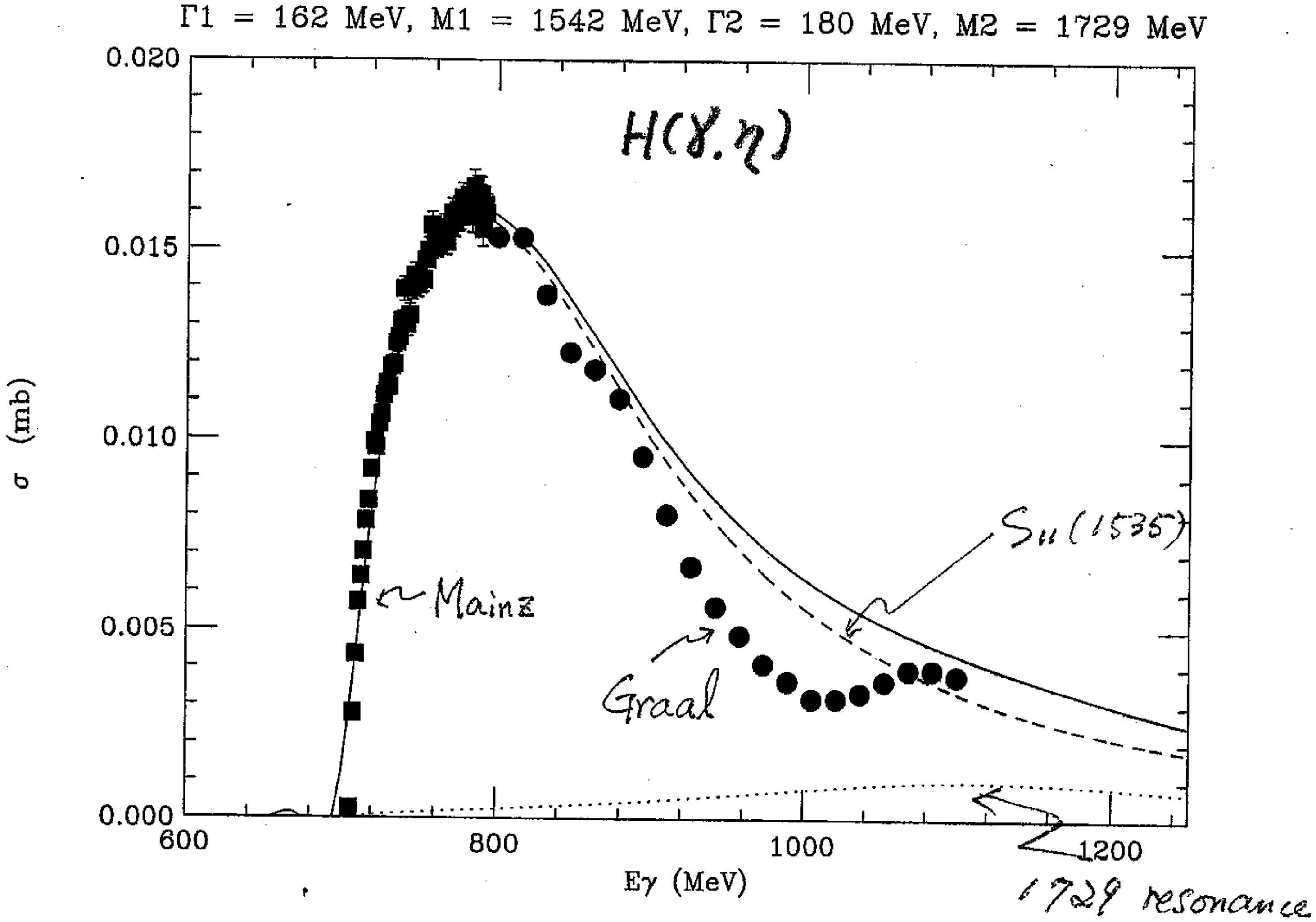
	(SU(6)⊗O(3))	Mass	Width
$S_{11}(1535)$	$(^2 8\ L=1^-)$ } mixed	1.542	0.162
$S_{11}(1650)$	$(^4 8\ L=1^-)$	1.650	0.150
the 3rd S_{11}		1.739	0.183

$M_{if} = M_s + M_u$

s-channel

$$M_{N^*} = \frac{2 M_{N^*}}{s - M_{N^*}(M_{N^*} - i\Gamma(q))} e^{-\frac{k^2 q^2}{6\alpha_{ho}^2}} A_{N^*}$$

Fig. 3. Total cross-section for the reaction $\gamma p \to \eta p$ as a function of total center-of-mass energy. The dot-dashed curve comes from the background terms in model C, other curves and data are as in fig. 1.



QMD input

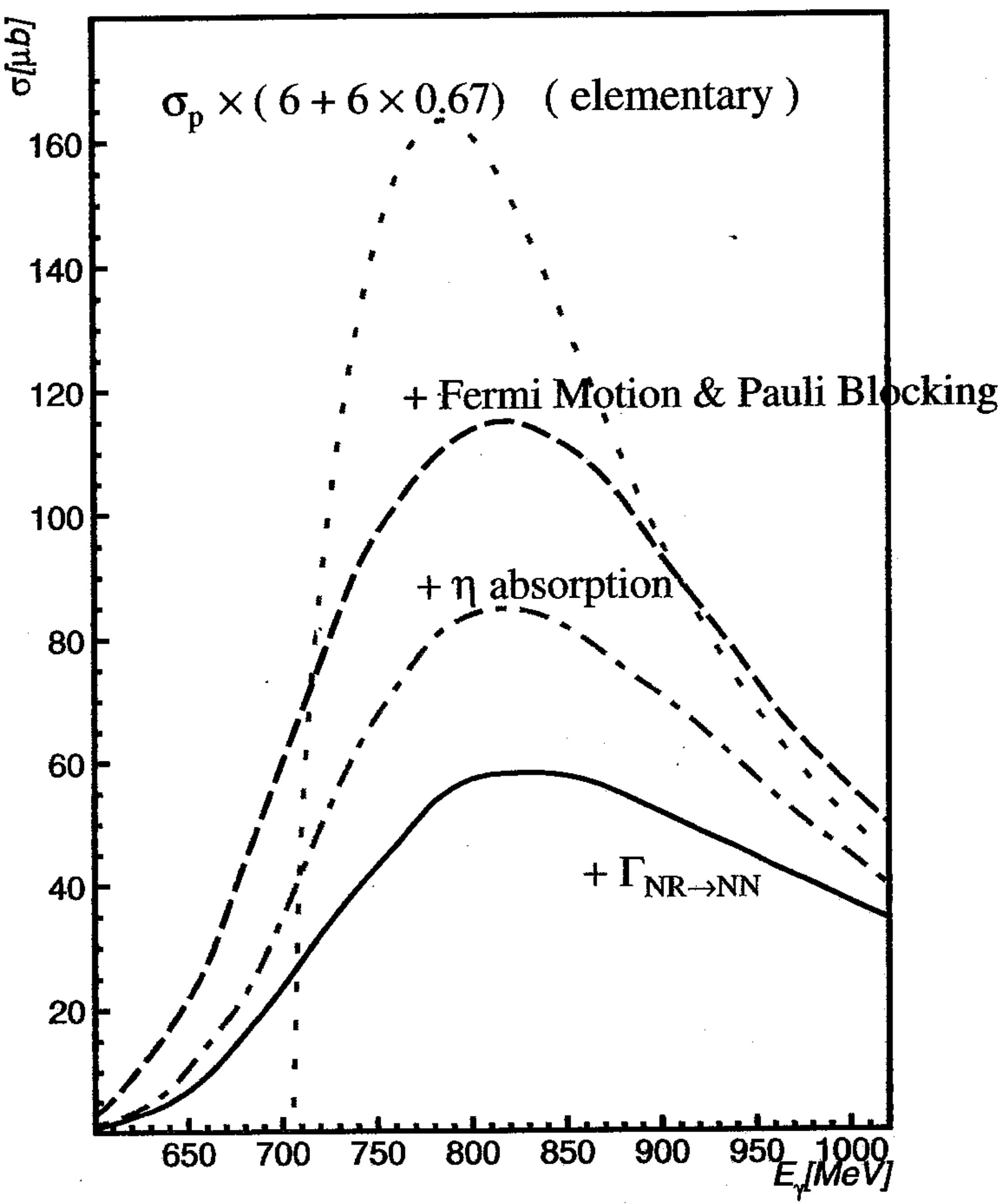
$S_{11}(1535)$ $M = 1.542$ GeV $\Gamma_0 = 0.162$ GeV

The 3rd S_{11} $M = 1.729$ $\Gamma = 0.180$ GeV

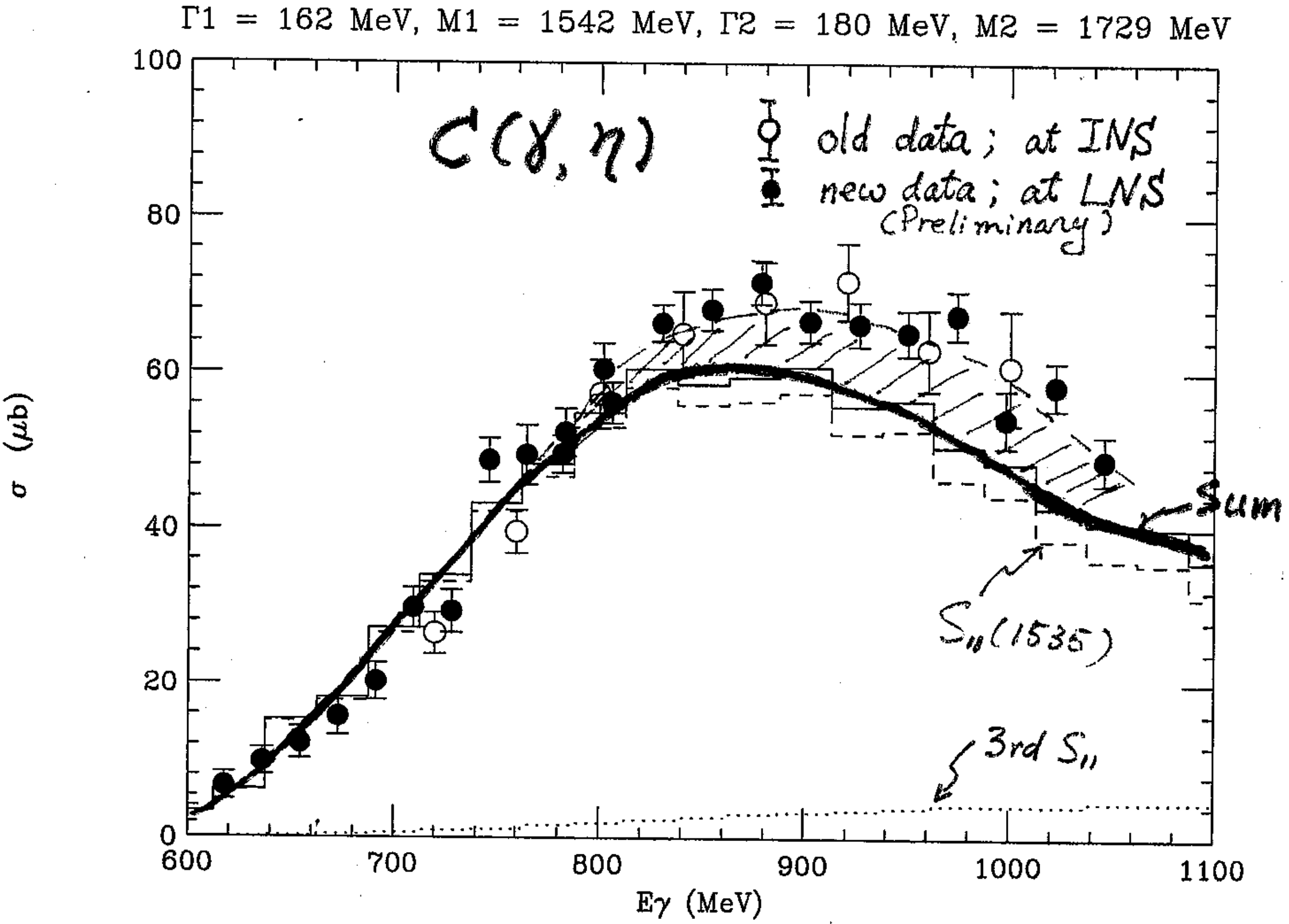
$$\sigma_{\gamma p \to \eta p} = A\left(\frac{k_0}{k}\right)^2 \frac{s\Gamma_\gamma \Gamma_\eta}{(s-M^2)^2 + s\Gamma_{tot}}$$

$\sigma_{sum} = \sigma_1 + \sigma_3$ incoherent sum

Nuclear medium effects in QMD



M_R = 1544 MeV
Γ_R = 150 MeV



elementary cross section : σ_p , $\frac{2}{3}\sigma_p$ for σ_n

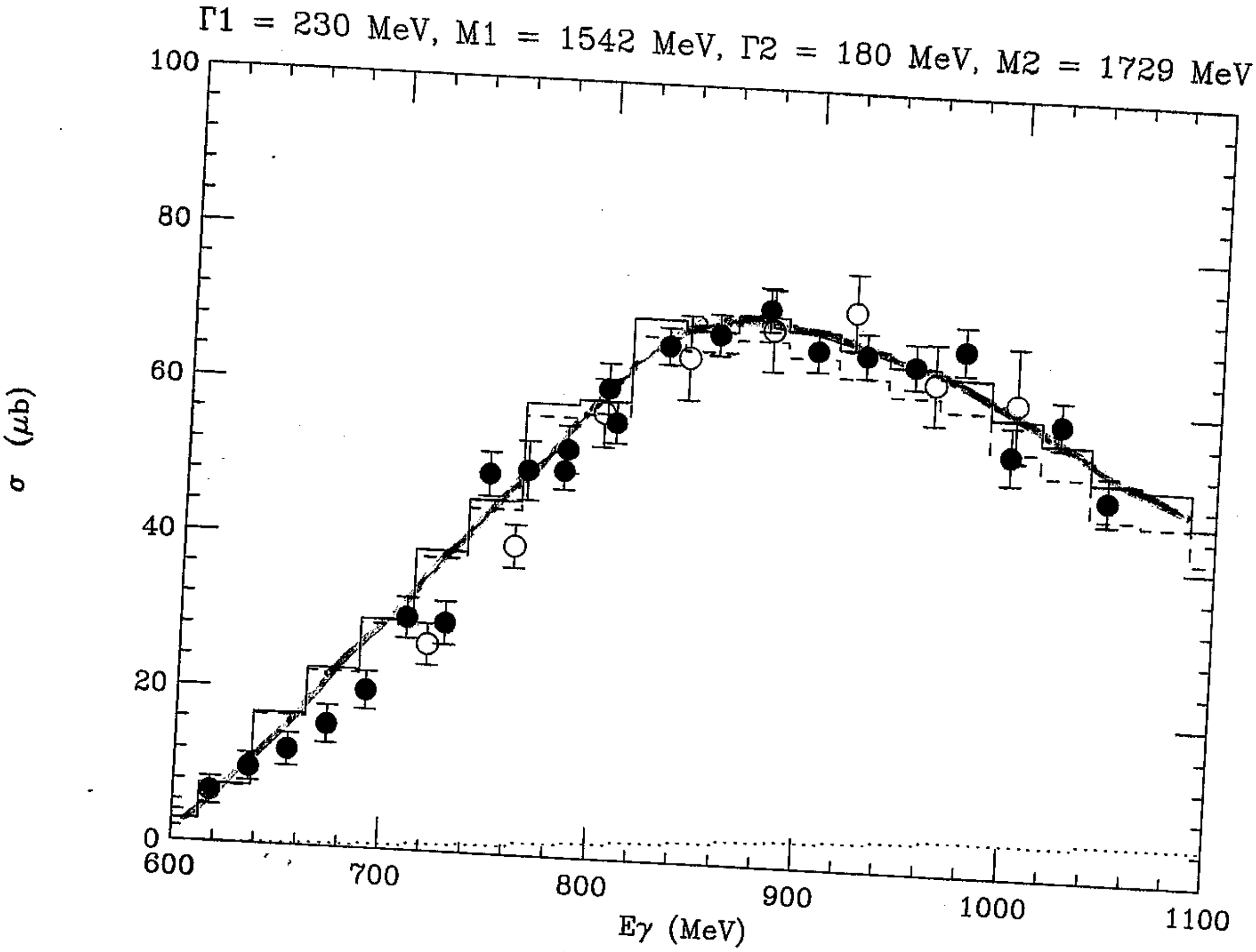
Fermi motion

Pauli blocking

η absorption : estimated from $\pi^- p \to \eta n$

collision broadening : $\Gamma_{NR\to NN}$

$$\propto \int_0^{P_F} d^3P_N \int d\Omega \frac{d\sigma_{NR\to NN}}{d\Omega} P_N P_R$$



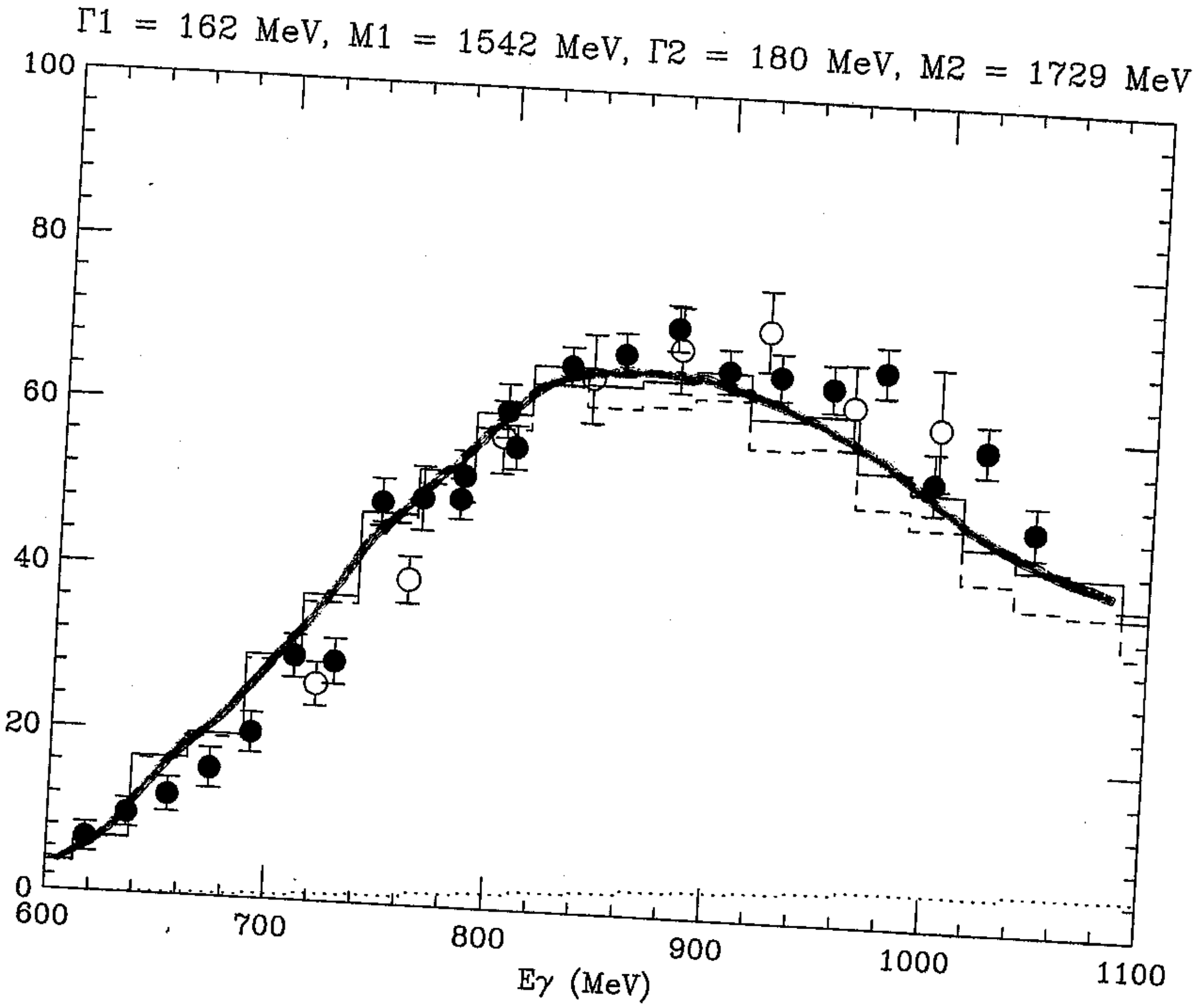
$S_{11}(1535)$ $\quad \Gamma \to 230$ MeV

$\Delta\Gamma \simeq 70$ MeV

$$\sigma_{\gamma p\to\gamma\eta} = A\left(\frac{k_0}{k}\right)^2 \frac{s\,\Gamma_\gamma \Gamma_\eta}{(s - M_{N^*}^2)^2 + s\,\Gamma_{tot}^2}$$

$$\underline{\Gamma_\gamma} = b_\gamma \left(\frac{k}{k_0}\right) \underline{\Gamma}, \quad \Gamma_\pi = b_\pi X_\pi \Gamma, \quad \underline{\Gamma_\eta} = b_\eta X_\eta \underline{\Gamma}$$

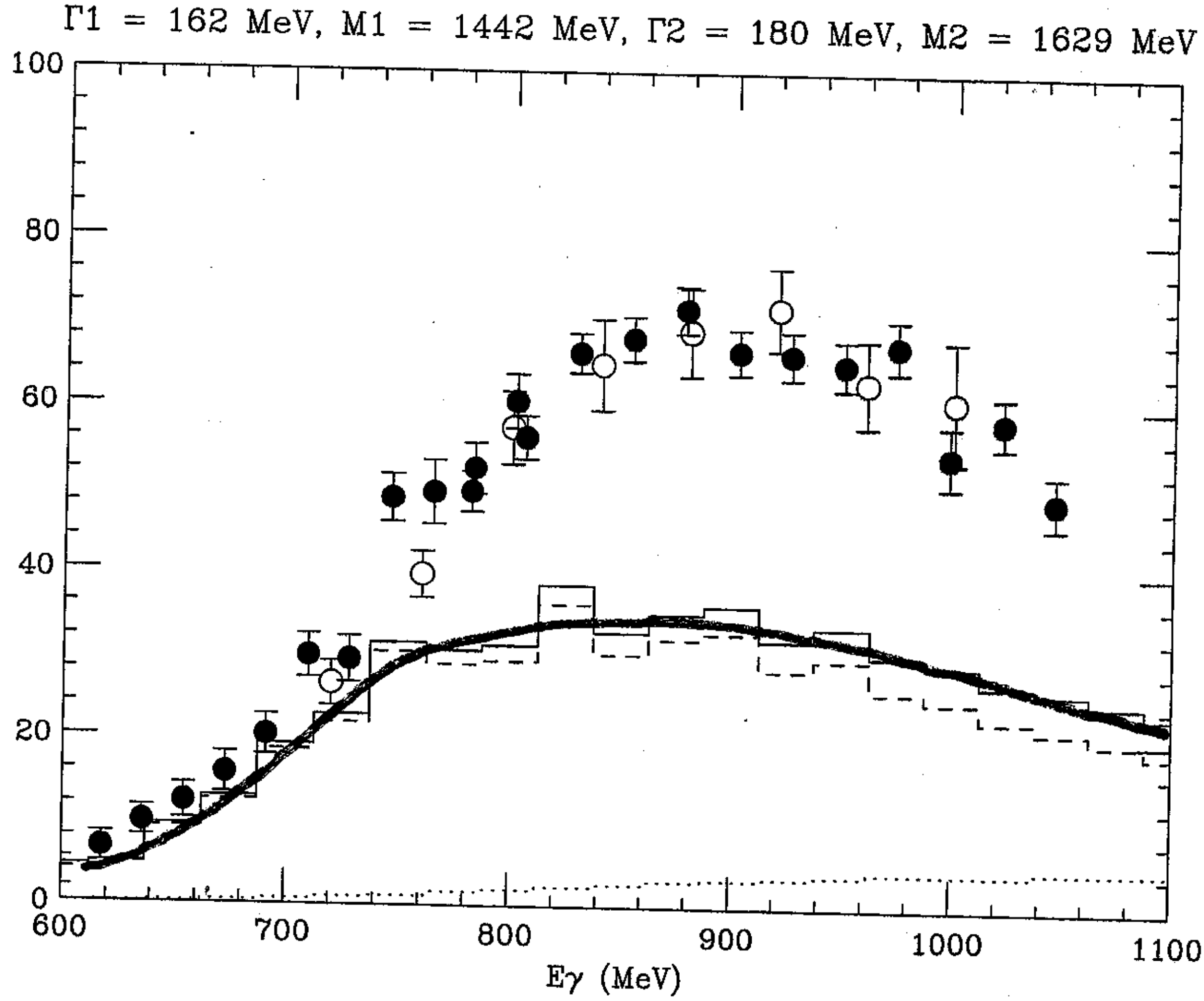
$$\underline{\Gamma_{tot}} = \Gamma_\pi + \Gamma_\eta = (b_\pi X_\pi + b_\eta X_\eta)\,\underline{\Gamma}$$



elementary cross section ×1.1

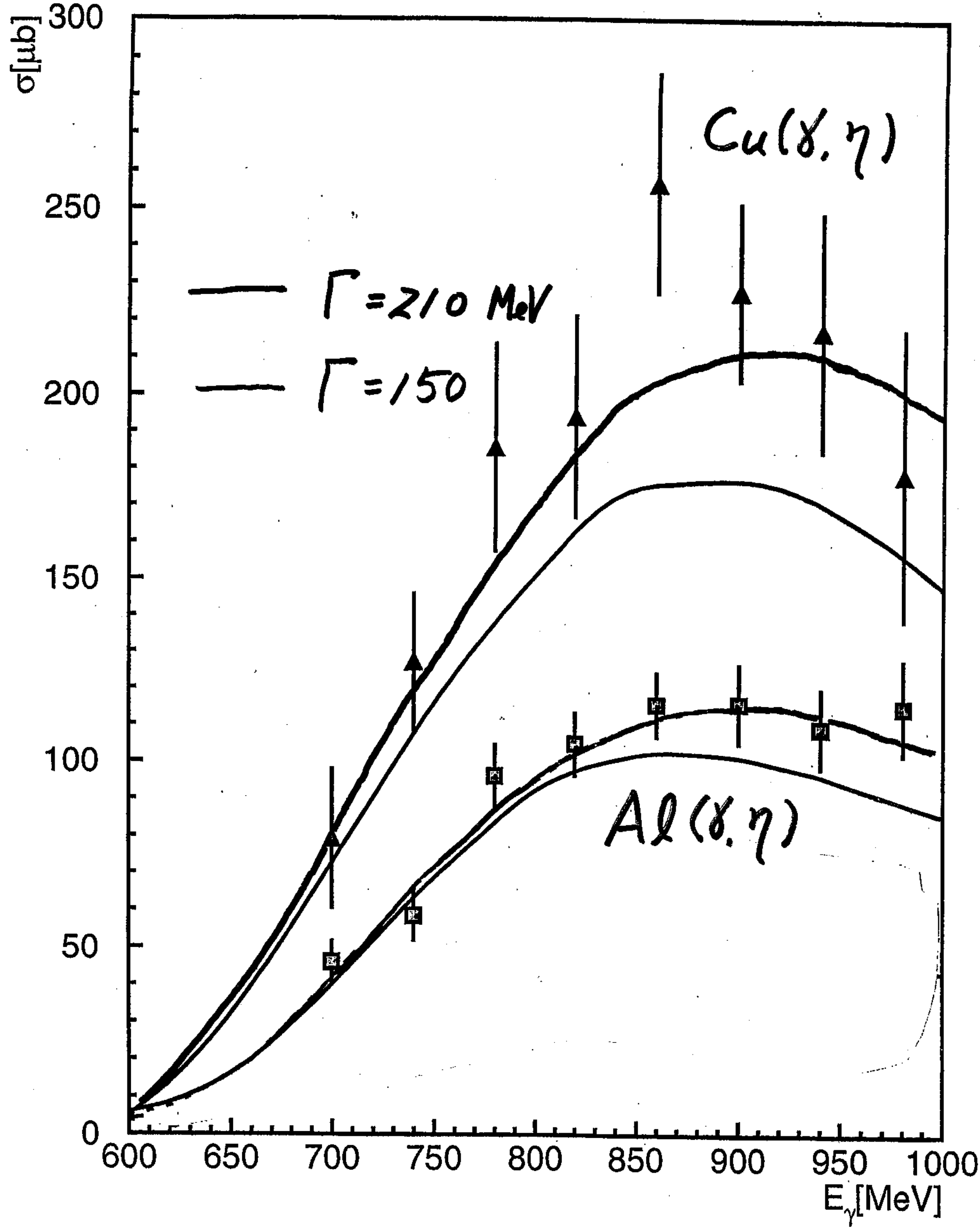
or

$A^p_{1/2} \rightarrow 1.06\, A^p_{1/2}$



$S_{11}(1535)$: $M \Rightarrow 1442$ MeV

$\Delta M \simeq 100$ MeV


σ[μb]
300
250
200
150
100
50
0
600
650
700
750
800
850
900
950
1000
E_γ[MeV]
Cu(γ, η)
Γ=210 MeV
Γ=150
Al(γ, η)

S_{11} (1535) resonance in nuclei

1. The resonance shape cannot be explained with the cross section of the $H(\gamma,\eta)$ reaction

   $\Gamma \simeq 230$ MeV (160 MeV)
   or
   $\sigma_{\gamma N \to \gamma\eta}$ increased ~10%

2. The resonance energy ?

   not changed
   S_{11}(1535) is not the chiral partner of nucleon.
   or
   Similar amounts of the mass shift for both $1/2^+$ and $1/2^-$

3. More systematic data

   $D(\gamma,\eta)$
   $^4He(\gamma,\eta)$
   $Li(\gamma,\eta)$
   } being prepared at the new experimental hall

   Large Solid Hydrogen target