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on High Energy Physics Problems
"Relativistic Nuclear Physics and Quantum Chromodynamics"
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# Non-nucleonic degrees of freedom and formation of mixed phase embryos in cold nuclei

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1. Experimental evidence for non-nucleonic (quark-meson) degrees of freedom in nuclei.
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3. Properties of dibaryons in cold nuclei.
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5. Di- and multi-baryons as mixed phase precursors. Chiral symmetry restoration.

2 April 1998

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 424 (1998) 33–38

# Large recoil momenta in the D(e,e′p)n reaction [1]

K.I. Blomqvist [a,2], W.U. Boeglin [a,4], R. Böhm [a], M. Distler [a,5], R. Edelhoff [a], I. Ewald [a], R. Florizone [a,5], J. Friedrich [a], R. Geiges [a], J. Jourdan [d], M. Kahrau [a], M. Korn [a], H. Kramer [a,6], K.W. Krygier [a], V. Kunde [a,7], M. Kuss [b,8], A. Liesenfeld [a], K. Merle [a], R. Neuhausen [a], E.A.J.M. Offermann [a,9], Th. Pospischil [a], M. Potokar [c], A.W. Richter [a,6], A. Rokavec [c], G. Rosner [a], P. Sauer [a,6], S. Schardt [a], A. Serdarevic [a,10], B. Vodenik [c], I. Sick [d], S. Sirca [c], A. Wagner [a], Th. Walcher [a], S. Wolf [a]

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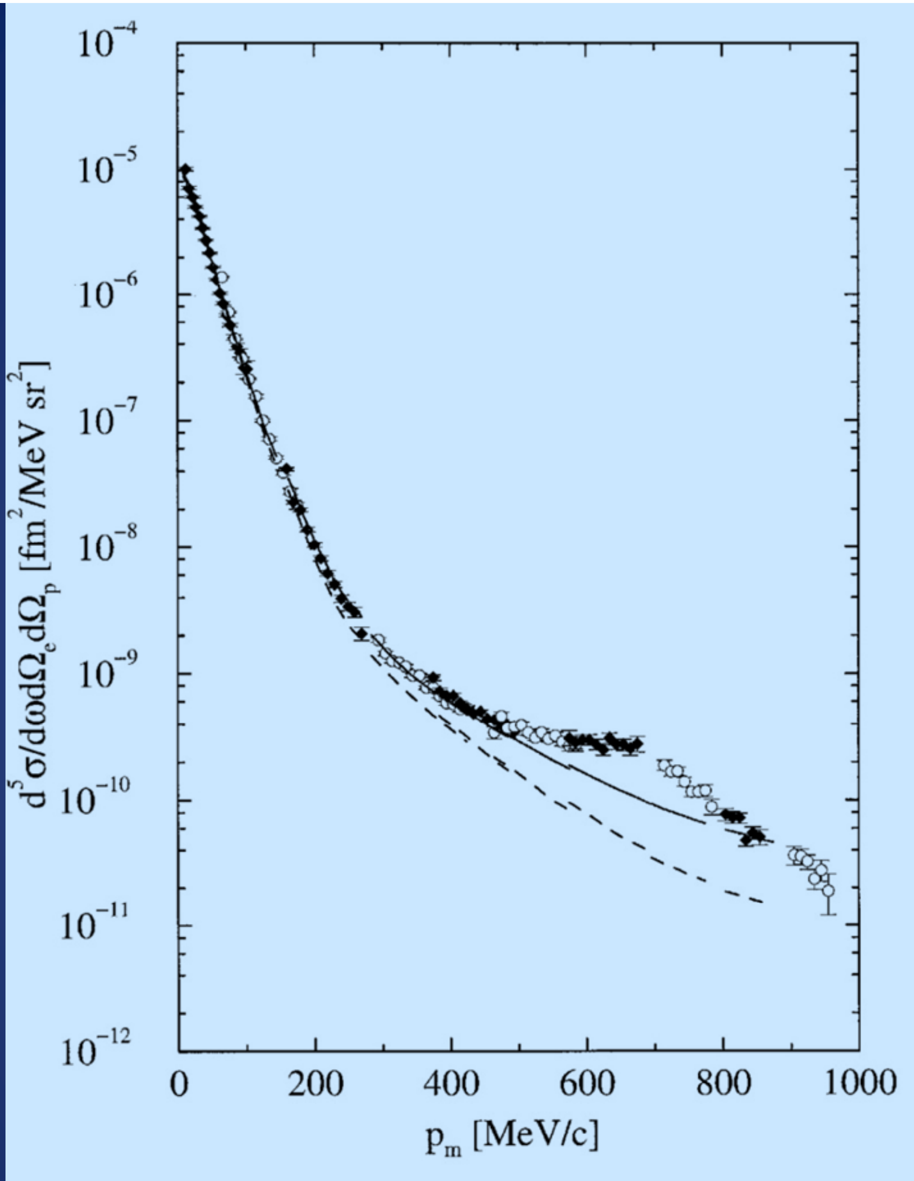
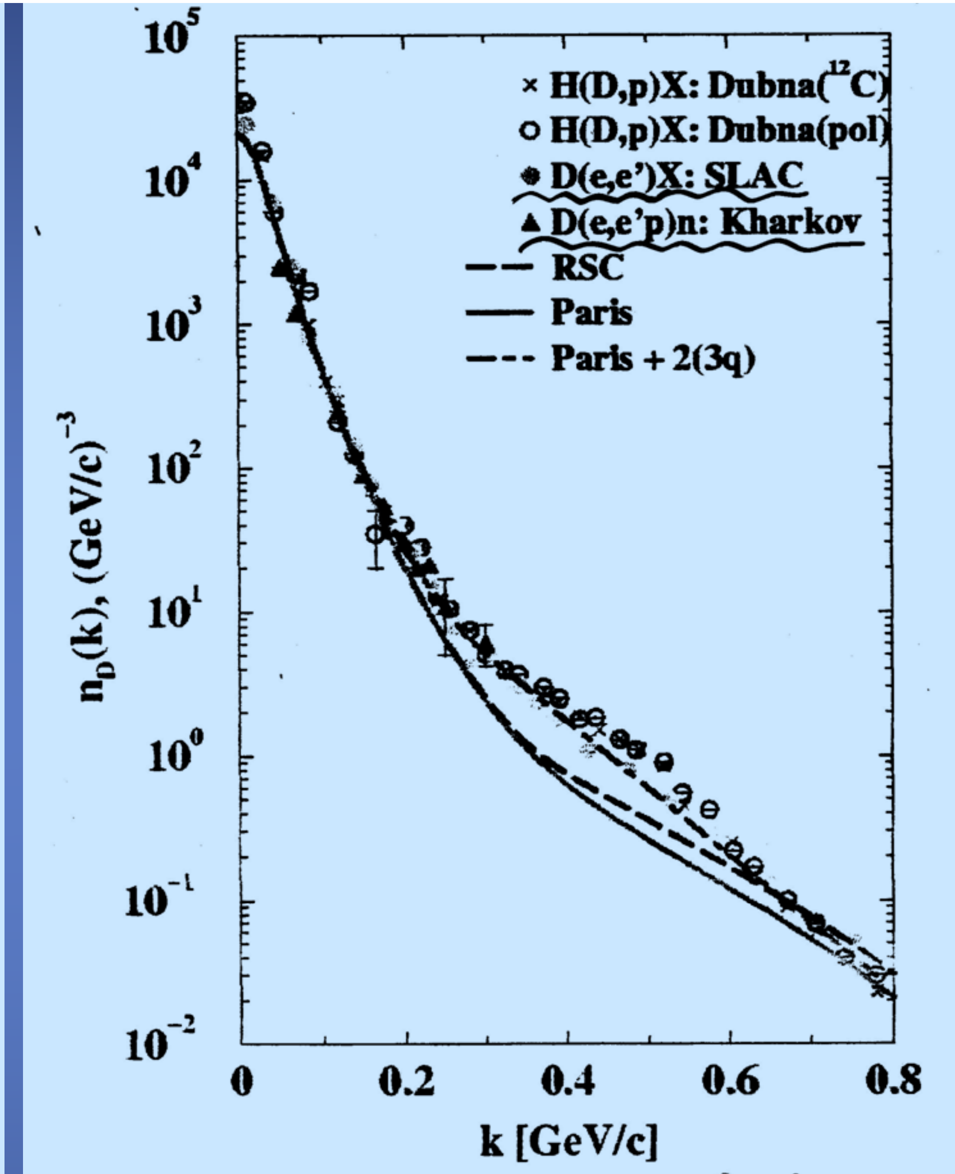
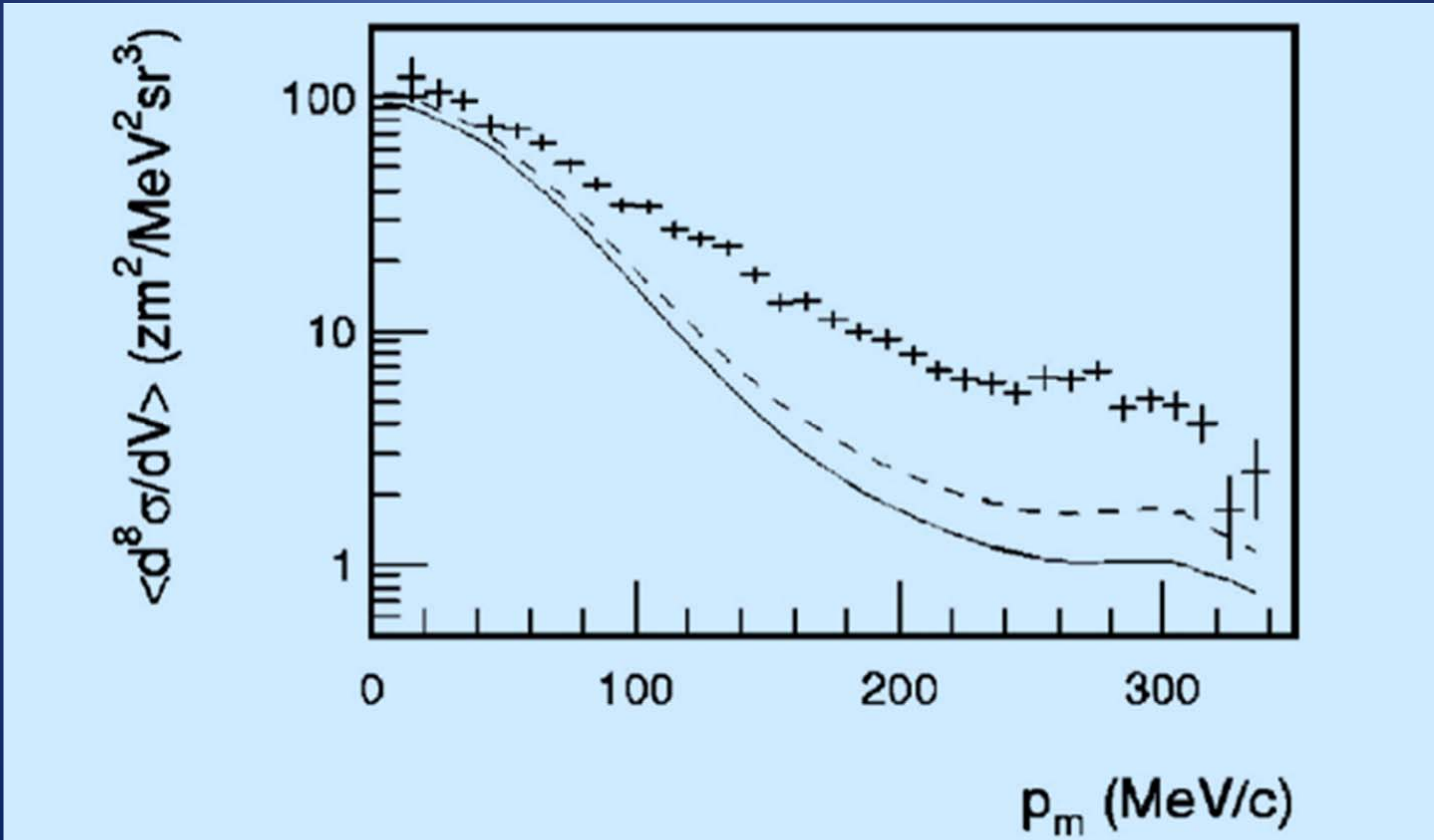



D(e,e'p) cross section




- The nucleon momentum distribution in deuteron extracted from different type experiments

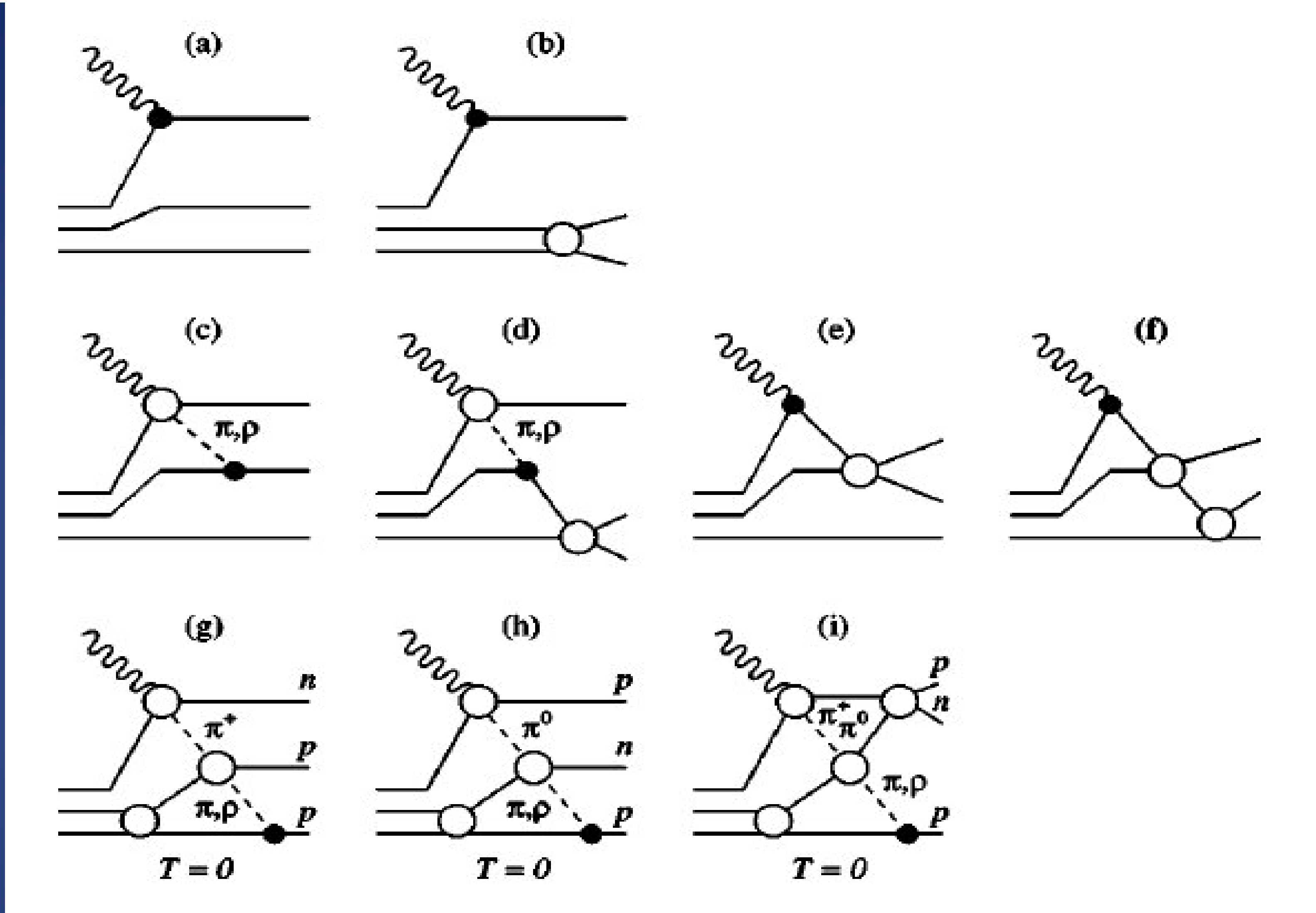
The average $^{3}He(e,e'pp)$ cross section as a function of missing momentum $p_m$ at $E_e$ = 750 MeV (the data of NIKHEF). The theoretical predictions without (solid line) and with (dashed line) pair 2N currents are based on full Faddeev 3N calculations with three-nucleon force included



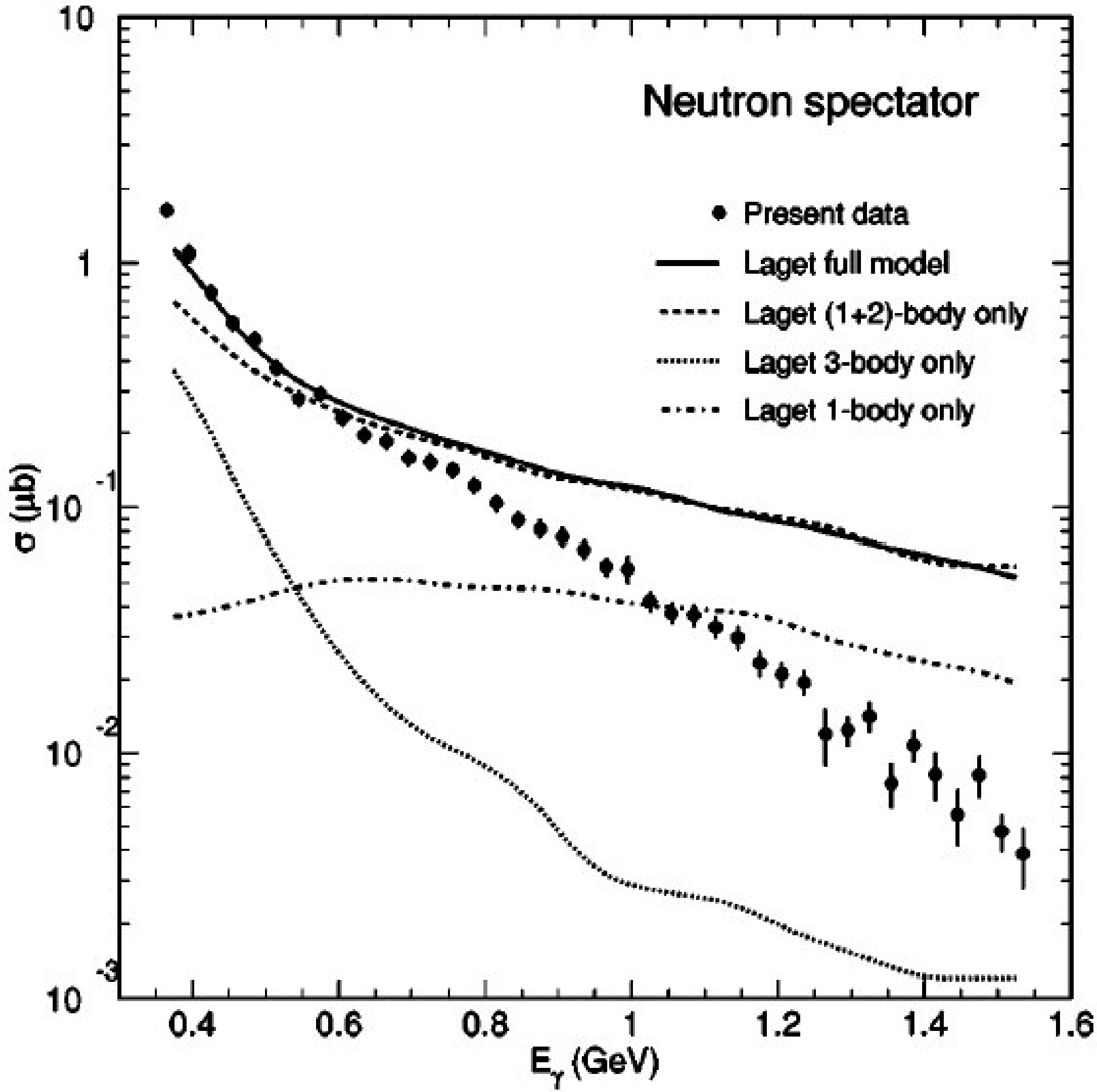
PHYSICAL REVIEW C 70, 064003 (2004)

# Complete measurement of three-body photodisintegration of $^3He$ for photon energies between 0.35 and 1.55 GeV

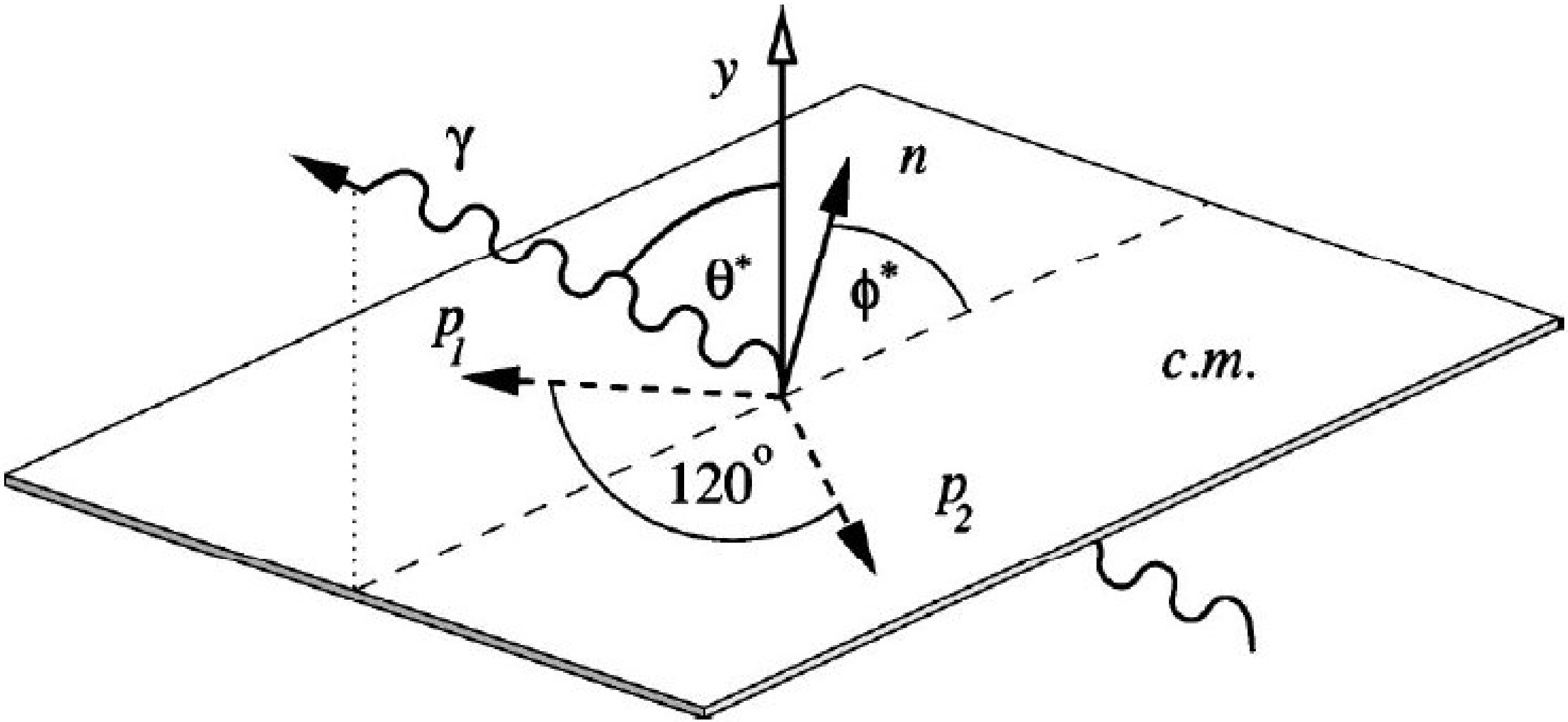
S. Niccolai,[2,11,*] G. Audit,[2] B. L. Berman,[11] J. M. Laget,[2] S. Strauch,[11] G. Adams,[28] A. Afanasev,[38] P. Ambrozewicz,[9] M. Anghinolfi,[15] J. R. M. Annand,[12] C. Armstrong,[33] B. Asavapibhop,[21] H. Avakian,[33] H. Bagdasaryan,[25] J. P. Ball,[1] S. Barrow,[10] M. Battaglieri,[15] K. Beard,[18] M. Bektasoglu,[25] M. Bellis,[4] N. Benmouna,[11] N. Bianchi,[14] A. S. Biselli,[4] S. Boiarinov,[33] B. E. Bonner,[29] S. Bouchigny,[16] R. Bradford,[4] D. Branford,[8] W. J. Briscoe,[11] W. K. Brooks,[33] V. D. Burkert,[33] C. Butuceanu,[37] J. R. Calarco,[22] D. S. Carman,[24] B. Carnahan,[5] S. Chen,[10] P. L. Cole,[13] A. Coleman,[37,†] D. Cords,[33,‡] P. Corvisiero,[15] D. Crabb,[36] H. Crannell,[5] J. P. Cummings,[28] E. De Sanctis,[14] R. DeVita,[15] P. V. Degtyarenko,[33] H. Denizli,[27] L. Dennis,[10] K. V. Dharmawardane,[25] K. S. Dhuga,[11] C. Djalali,[31] G. E. Dodge,[25] D. Doughty,[6] P. Dragovitsch,[10] M. Dugger,[1] S. Dytman,[27] O. P. Dzyubak,[31] H. Egiyan,[33] K. S. Egiyan,[38] L. Elouadrhiri,[33] A. Empl,[28] R. Ent,[33] P. Eugenio,[10] R. Fatemi,[36] G. Fedotov,[39] G. Feldman,[11] R. J. Feuerbach,[33] J. Ficenec,[35] T. A. Forest,[25] H. Funsten,[37] G. Gavalian,[25] G. P. Gilfoyle,[30] K. L. Giovanetti,[18] E. Golovatch,[39,15] C. I. O. Gordon,[12] R. W. Gothe,[31] K. Griffioen,[37] M. Guidal,[16] M. Guillo,[31] N. Guler,[25] L. Guo,[33] V. Gyurjyan,[33] C. Hadjidakis,[16] R. S. Hakobyan,[5] J. Hardie,[6,33] D. Heddle,[33] P. Heimberg,[11] F. W. Hersman,[22] K. Hicks,[24] K. Hleiqawi,[24] M. Holtrop,[22] J. Hu,[28] M. Huertas,[31] C. E. Hyde-Wright,[25] Y. Y. Ilieva,[11] D. Ireland,[12] M. M. Ito,[33] D. Jenkins,[35] H. S. Jo,[16] K. Joo,[7] H. G. Juengst,[11] J. Kellie,[12] M. Khandaker,[23] K. Y. Kim,[27] K. Kim,[19] W. Kim,[19] A. Klein,[25] F. J. Klein,[5] A. V. Klimenko,[25] M. Klusman,[28] M. Kossov,[17] L. H. Kramer,[9,33] Y. Kuang,[37] S. E. Kuhn,[25] J. Kuhn,[4] J. Lachniet,[4] J. Langheinrich,[31] D. Lawrence,[21] Ji Li,[28] A. C. S. Lima,[11] K. Livingston,[12] K. Lukashin,[5] J. J. Manak,[33] C. Marchand,[2] S. McAleer,[10] J. W. C. McNabb,[26] B. A. Mecking,[33] J. J. Melone,[12] M. D. Mestayer,[33] C. A. Meyer,[4] K. Mikhailov,[17] R. Minehart,[36] M. Mirazita,[14] R. Miskimen,[21] L. Morand,[2] S. A. Morrow,[2] V. Muccifora,[14] J. Mueller,[27] L. Y. Murphy,[11] G. S. Mutchler,[29] J. Napolitano,[28] R. Naseripour,[9] G. Niculescu,[18] I. Niculescu,[18] B. B. Niczyporuk,[33] R. A. Niyazov,[33] M. Nozar,[33] J. T. O'Brien,[5] G. V. O'Rielly,[11] M. Osipenko,[39,15] A. Ostrovidov,[10] K. Park,[19] E. Pasyuk,[1] S. A. Philips,[11] N. Pivnyuk,[17] D. Pocanic,[36] O. Pogorelko,[17] E. Polli,[14] I. Popa,[11] S. Pozdniakov,[17] B. M. Preedom,[31] J. W. Price,[3] Y. Prok,[36] D. Protopopescu,[12] L. M. Qin,[25] B. A. Raue,[9,33] G. Riccardi,[10] G. Ricco,[15] M. Ripani,[15] B. G. Ritchie,[1] F. Ronchetti,[14] G. Rosner,[12] P. Rossi,[14] D. Rowntree,[20] P. D. Rubin,[30] F. Sabatié,[2] C. Salgado,[23] J. P. Santoro,[35,33] V. Sapunenko,[15] R. A. Schumacher,[4] V. S. Serov,[17] A. Shafi,[11] Y. G. Sharabian,[33] J. Shaw,[21] A. V. Skabelin,[20] E. S. Smith,[33] L. C. Smith,[36] D. I. Sober,[5] A. Stavinsky,[17] S. Stepanyan,[25,38] P. Stoler,[28] I. I. Strakovsky,[11] R. Suleiman,[20] M. Taiuti,[15] S. Taylor,[29] D. J. Tedeschi,[31] U. Thoma,[33,§] R. Thompson,[27] R. Tkabladze,[24] L. Todor,[30] C. Tur,[31] M. Ungaro,[28] M. F. Vineyard,[34] A. V. Vlassov,[17] K. Wang,[36] L. B. Weinstein,[25] D. P. Weygand,[33] C. S. Whisnant,[18,31] M. Williams,[4] E. Wolin,[33] M. H. Wood,[31] A. Yegneswaran,[33] J. Yun,[25] and L. Zana[22]
(The CLAS Collaboration)




Diagrams used in Laget's model in the calculation of the $^3He(\gamma,pp)n$ cross sections.

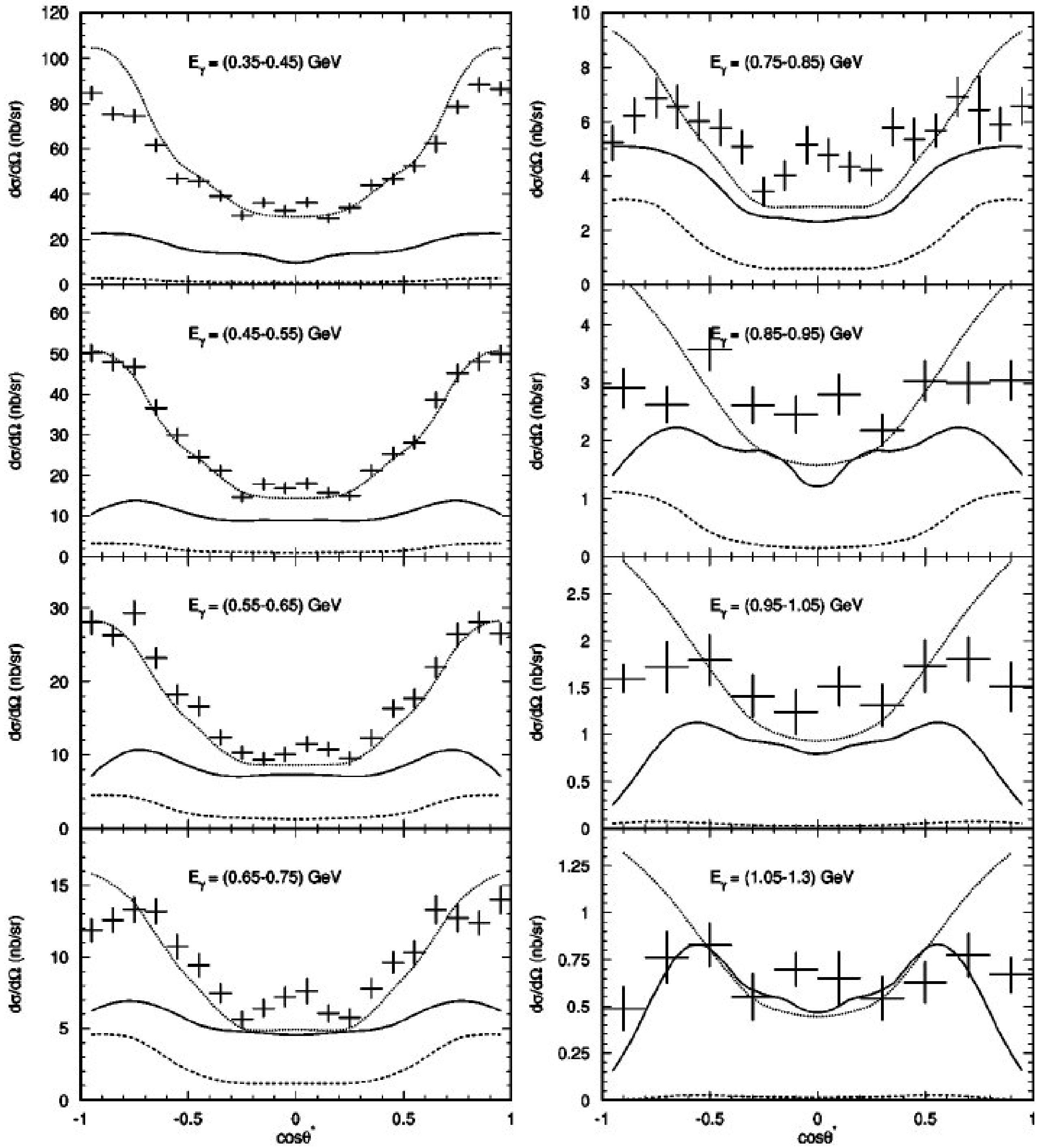


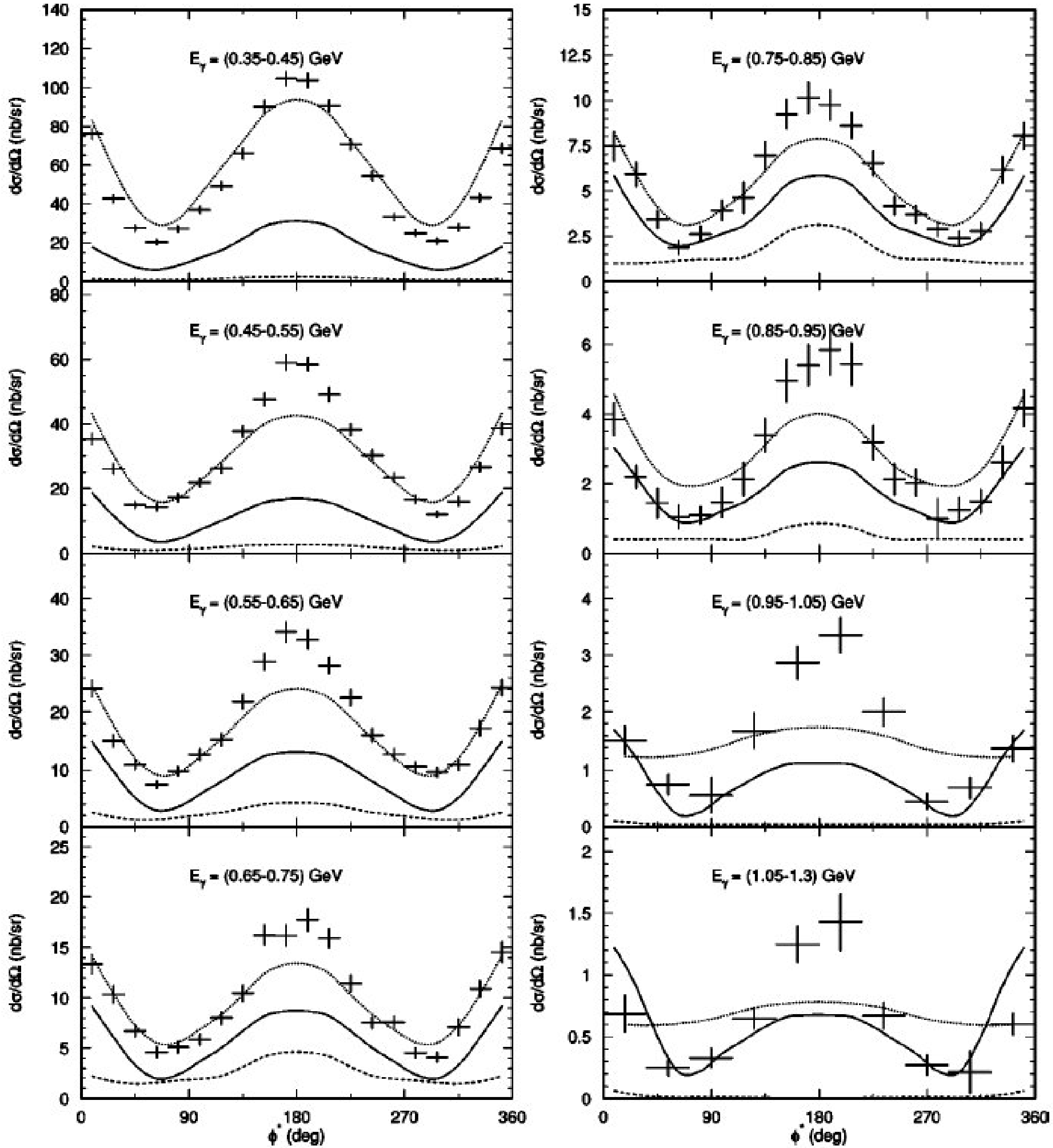

Cross sections integrated over the CLAS for the neutron-spectator kinematics plotted as a function of proton energy.



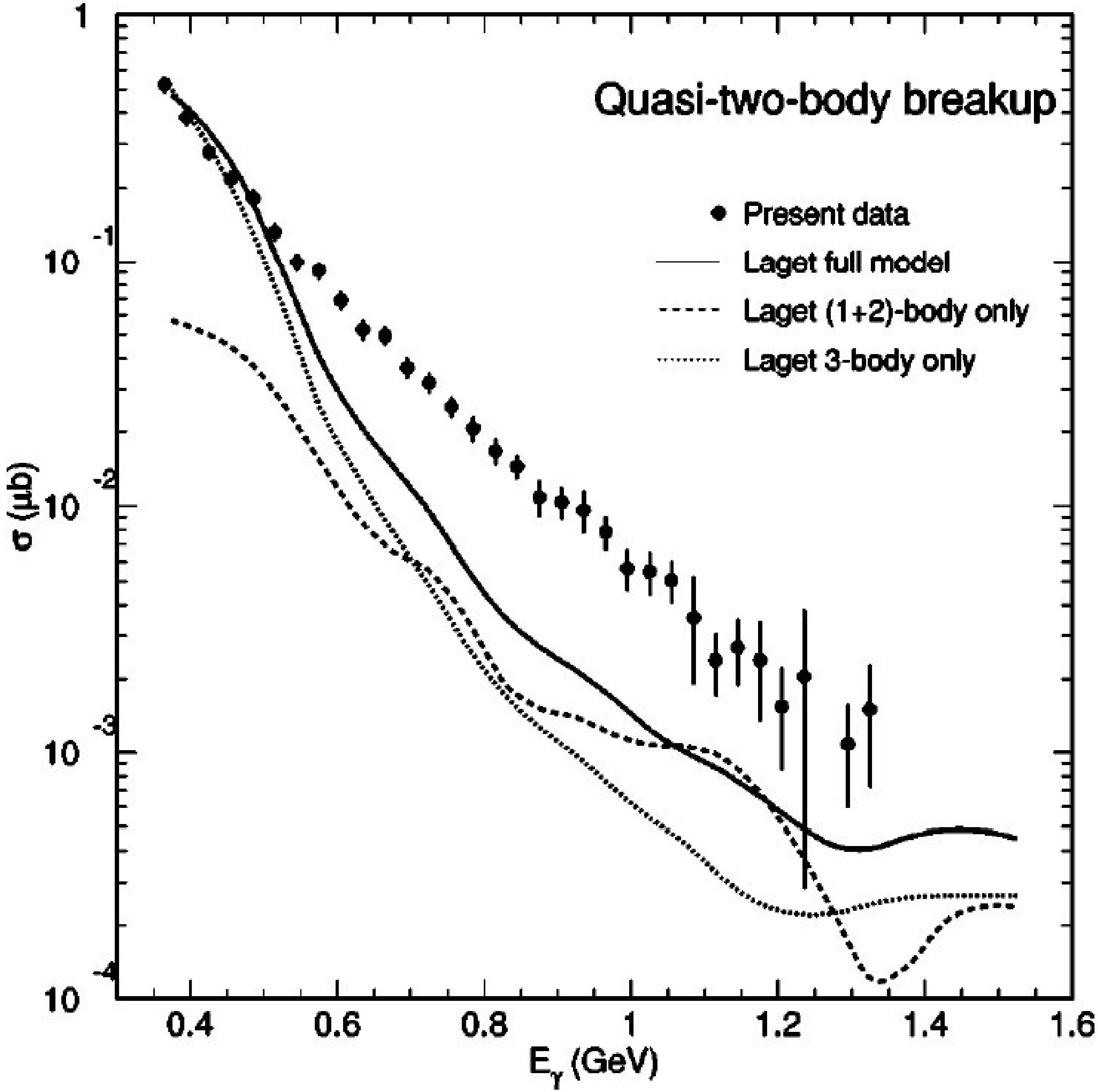

Kinematics of the star configuration in the *ppn* center-of-mass frame. The angles θ*, between the normal vector to the star plane and the photon-beam direction, and Φ*, the neutron azimuthal angle in the star plane, define the reaction.

CLAS-integrated differential cross sections with respect to θ* for the star confguration. The data, for photon energies between 0.35 and 1.30 GeV, are compared with the full-model results (solid curves) and the one-plus two-body-only part (dashed curves). The dotted curves are the phase-space distributions multiplied, for each photon-energy bin, by the constants used to normalize the full-Dalitz cross sections.

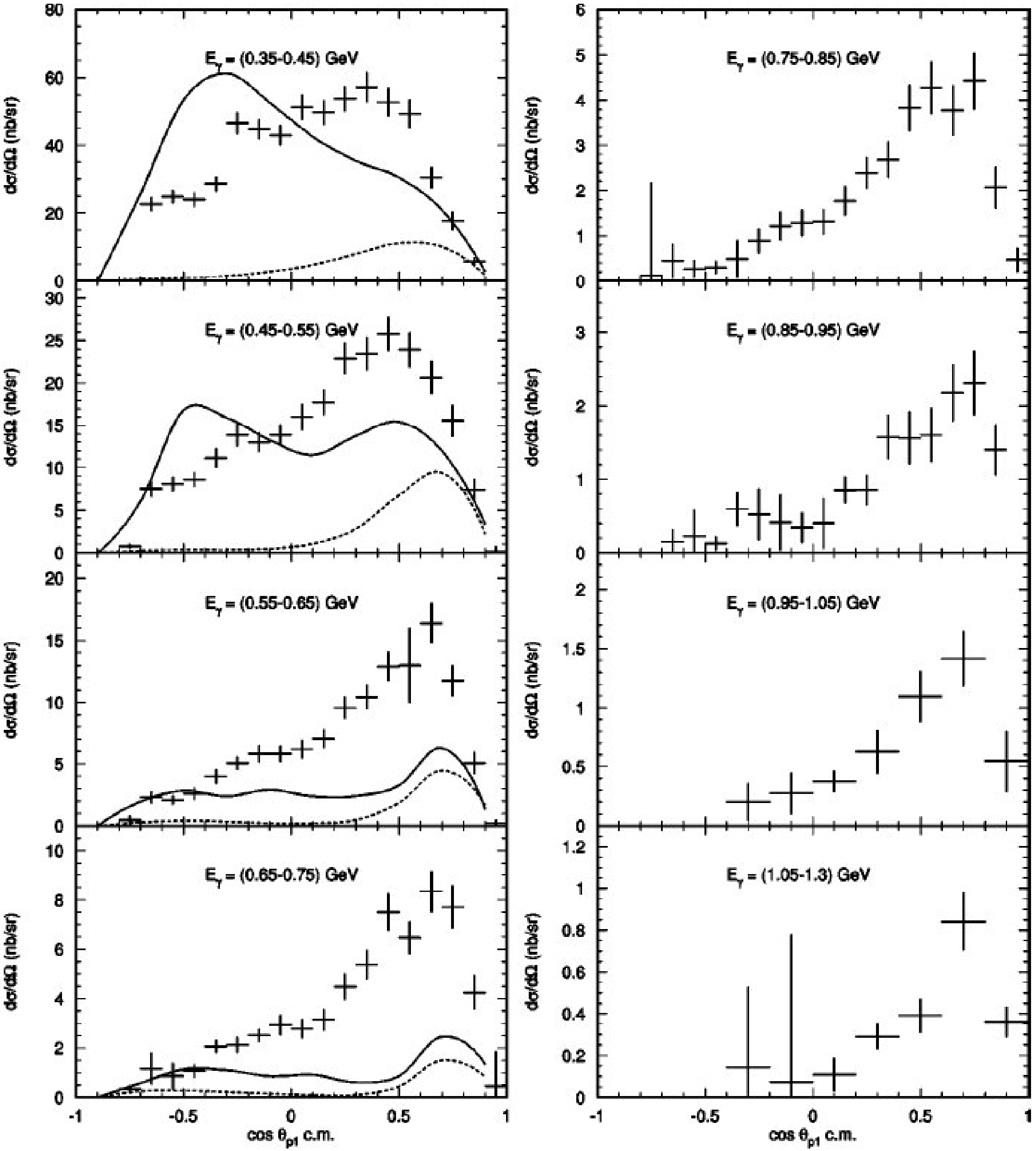





CLAS-integrated differential cross sections with respect to $\phi^*$ for the star confguration. The data, for photon energies between 0.35 and 1.30 GeV, are compared with the full-model results (solid curves) and the one-plus two-body-only part (dashed curves). The dotted curves are the phase-space distributions multiplied, for each photon-energy bin, by the constants used to normalize the full-Dalitz cross sections.




Cross sections integrated over the CLAS for the quasi-two-body breakup plotted as a function of photon energy. The data are compared with the results of the full model (solid curves) and of the (1+2)-body-only model (dashed curves). The full-model calculation agrees quantitatively with our experimental results only up to about 0.55 GeV




Differential cross sections integrated over the CLAS for the quasi-two-body breakup with respect to cos θ of the high-energy proton in the center-of-mass frame for photon energies between 0.35 and 1.30 GeV. Our data, for $0.35 < E_\gamma < 0.75$ GeV, are compared with the results of the full model (solid curves) and of the (1+2)-body-only model (dashed curves).

The comparison for the $^{4}He(e,e'p)^{3}H$ cross section between experimental data and Laget calculations with PWIA, PWIA+FSI PWIA+FSI+MEC. Disagreement is large !

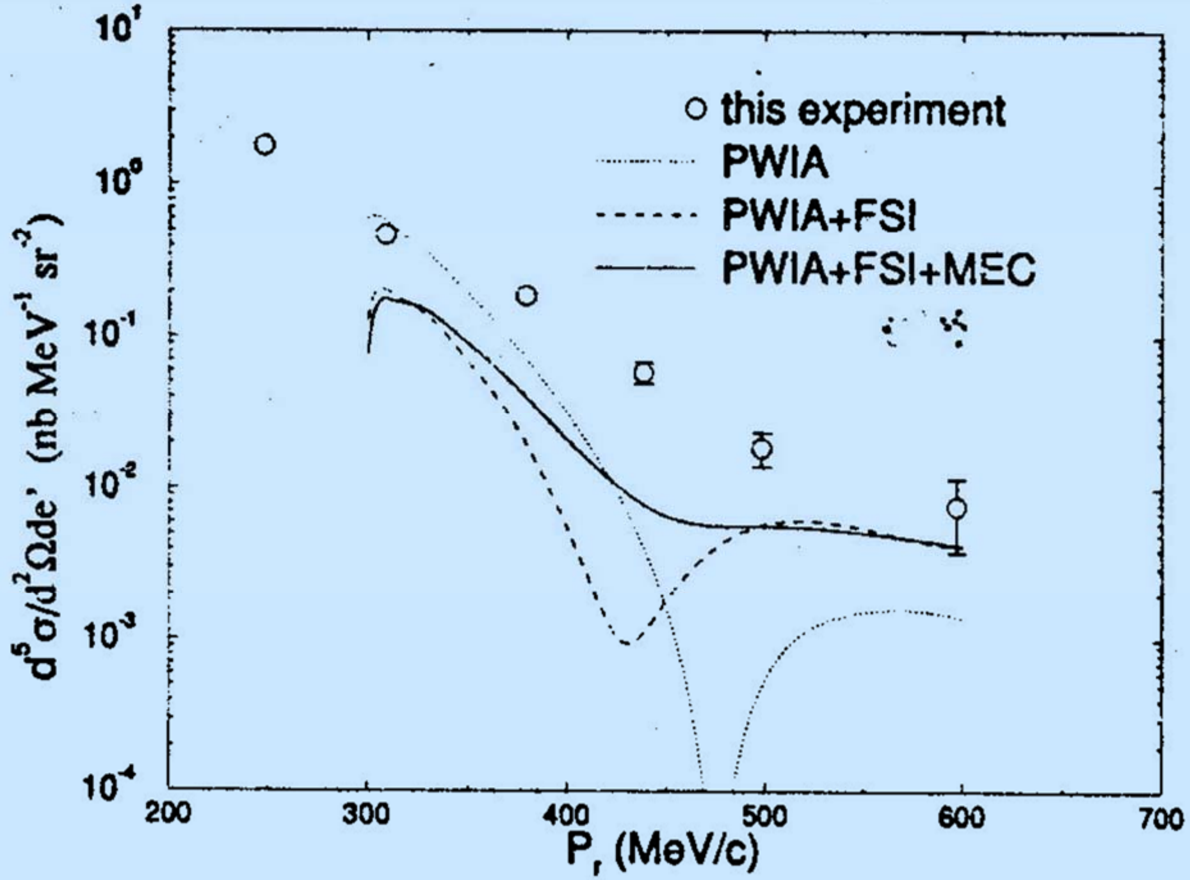
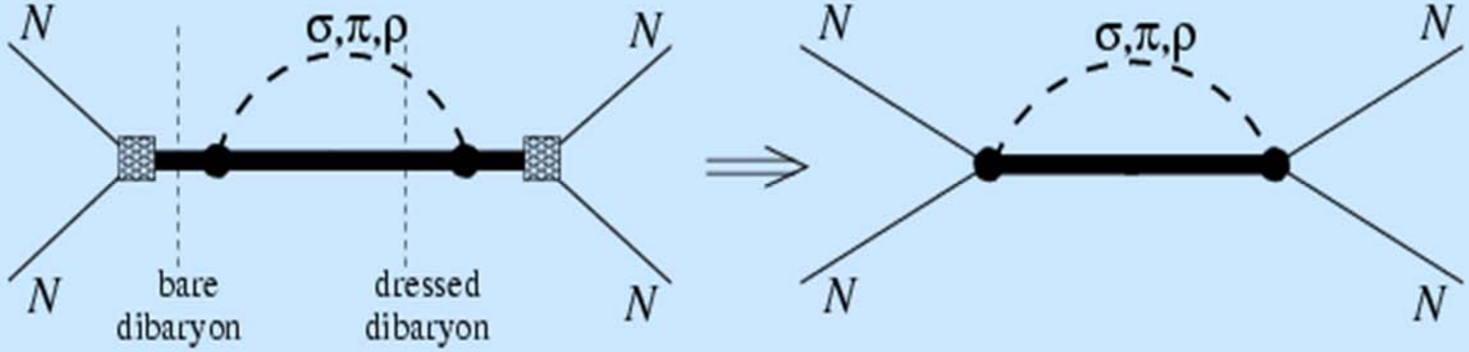



FIG. 3. Radiatively corrected cross section in the 2bbu channel. The curves are the result of a microscopic calculation based on a diagrammatic expansion of the cross section [31].

## II. The concept of NN interaction based on intermediate dressed dibarion production




The $\sigma$-dressing of intermediate dibaryon shifts its mass downward noticeably ($\Delta \sim 0.5 - 0.7$ GeV).

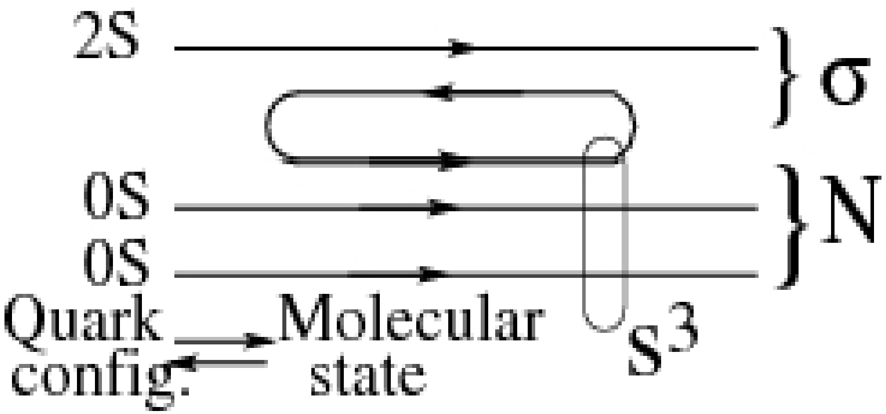
The similar $\sigma$-dressing of the Roper resonance:

$$|s^2(2s)[3]\rangle \Rightarrow |s^3[3] + \sigma\rangle$$

reduces its mass about 0.5 GeV!

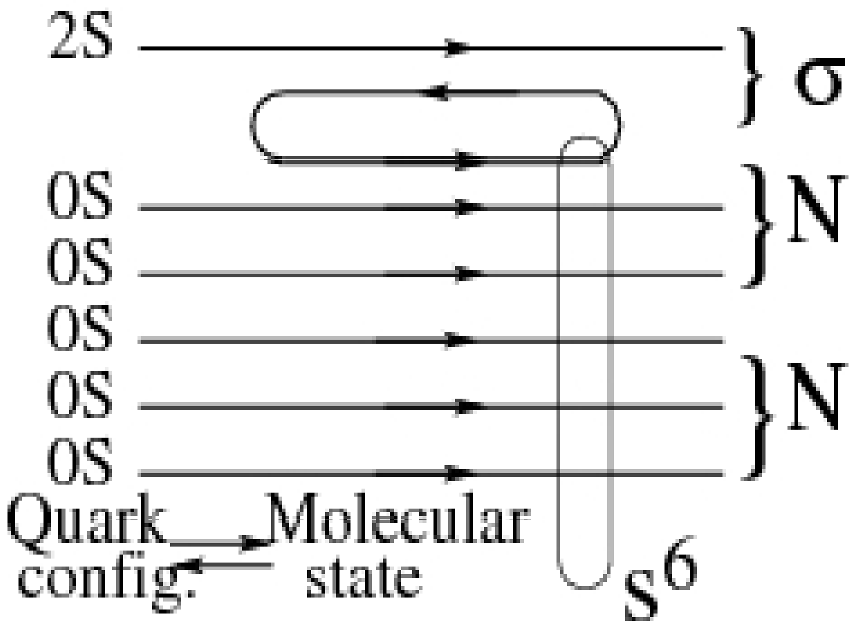
Roper

$$sp^2 \rightleftarrows s^3 + \sigma$$



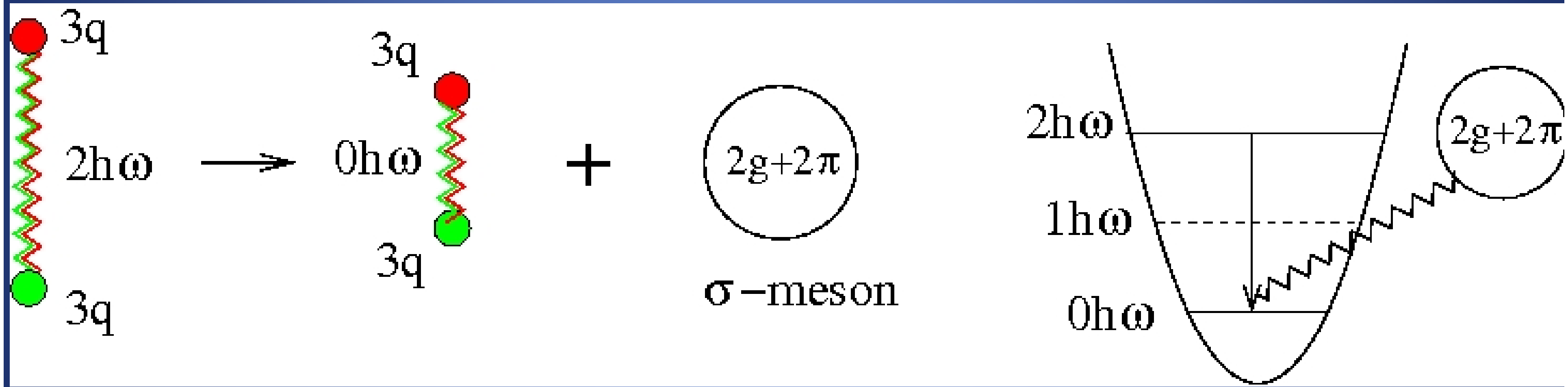

Dibaryon

$$s^4p^2 \rightleftarrows s^6 + \sigma$$



# Interpretation in terms of the $2\hbar\omega$-excited string.

See A. Faessler, V.I. Kukulin and M.A.Shikhalev, Ann. Phys. **320** (2005) 71.



## The QCD sum rules consideration for hybrid current in nucleon and Roper resonance has demonstrated that:

- The nucleon has a very small hybrid component, while for the Roper the purely hybrid current give a noticeable contribution (see e.g . L.S. Kisslinger and Z. Li, Phys.Lett. B **445** (1999) 271). So, they predicted a dominating σ+N decay mode for the Roper.

- The direct experimental data (of H. Clement et al. and many others) suggest that the width of Roper resonance decaying into sigma+N final states is generally an oder of magnitude larger than those of other resonances.

The effective potential $V_{NqN}$ induced by coupling the $NN$-channel to the intermediate-dibaryon channel in form of a sum over simple separable terms for each partial wave:

$$V_{NqN} = \sum_{S,J,L,L'} V^{SJ}_{LL'}(\mathrm{r}, \mathrm{r}'), \tag{15}$$

with

$$V^{SJ}_{LL'}(\mathrm{r}, \mathrm{r}') = \sum_{M} Z^{JM}_{LS}(\mathrm{r})\, \lambda^{J}_{SLL'}(E)\, Z^{JM^*}_{L'S}(\mathrm{r}'), \tag{16}$$

where $Z^{JM}_{LS}(\mathrm{r})$ are the potential form factors (vertex)

$$Z^{JM}_{LS}(\mathrm{r}) = \zeta^{J}_{LS}(r)\, \mathcal{Y}^{JM}_{LS}(\hat{\mathrm{r}}) \tag{17}$$

and the energy-dependent coupling constants $\lambda^{J}_{SLL'}(E)$ are expressed by integration of the product of two transition vertices $B$ and convolution of the product of meson and quark-bag propagators over the momentum $k$:

$$\lambda^{J}_{SLL'}(E) = \sum_{L_\sigma} \int_0^\infty k^2\, dk \frac{B^{J}_{L_\sigma LS}(k, E)\, {B^{J}_{L_\sigma L'S}}^*(k, E)}{E - m_{d_0} - \frac{k^2}{2m_{d_0}} - \omega_\sigma(k)}. \tag{18}$$

Table 1. Deuteron properties in the dressed bag model.

| Model | $E_d$(MeV) | $P_D$(%) | $r_m$(fm) | $Q_d$(fm$^2$) | $\mu_d\,(\mu_N)$ | $A_S$(fm$^{-1/2}$) | $\eta(D/S)$ |
|---|---|---|---|---|---|---|---|
| RSC | 2.22461 | 6.47 | 1.957 | 0.2796 | 0.8429 | 0.8776 | 0.0262 |
| Moscow 99 | 2.22452 | 5.52 | 1.966 | 0.2722 | 0.8483 | 0.8844 | 0.0255 |
| Bonn 2001 | 2.224575 | 4.85 | 1.966 | 0.270 | 0.8521 | 0.8846 | 0.0256 |
| DBM (1) $P_{in} = 3.66\%$ | 2.22454 | 5.22 | 1.9715 | 0.2754 | 0.8548 | 0.8864 | 0.0259 |
| DBM (2) $P_{in} = 2.5\%$ | 2.22459 | 5.31 | 1.970 | 0.2768 | 0.8538 | 0.8866 | 0.0263 |
| experiment | 2.224575 | | 1.971 | 0.2859 | 0.8574 | 0.8846 | 0.0263 |

# Properties of dibaryons in cold nuclei

# Three-nucleon system within dibaryon model

A $3N$ state $\Psi_3$ in the full three-body Hilbert space $\mathcal{H}_3 = \mathcal{H}_3^{\rm ex} \oplus \Sigma_i \mathcal{H}_i^{\rm in}$ is a four-component column and the total Hamiltonian of the three-body system acting in $\mathcal{H}_3$ can be written as $(4 \times 4)$ matrix:

$$\Psi_3 = \begin{pmatrix} \Psi^{\rm NN} \\ \Psi_1^{\rm DN} \\ \Psi_2^{\rm DN} \\ \Psi_3^{\rm DN} \end{pmatrix}, \qquad H_3 = \begin{pmatrix} H^{NN} & H_1^{NN\to DN} & H_2^{NN\to DN} & H_3^{NN\to DN} \\ H_1^{DN\to NN} & H_1^{DN} & 0 & 0 \\ H_2^{DN\to NN} & 0 & H_2^{DN} & 0 \\ H_3^{DN\to NN} & 0 & 0 & H_3^{DN} \end{pmatrix}.$$

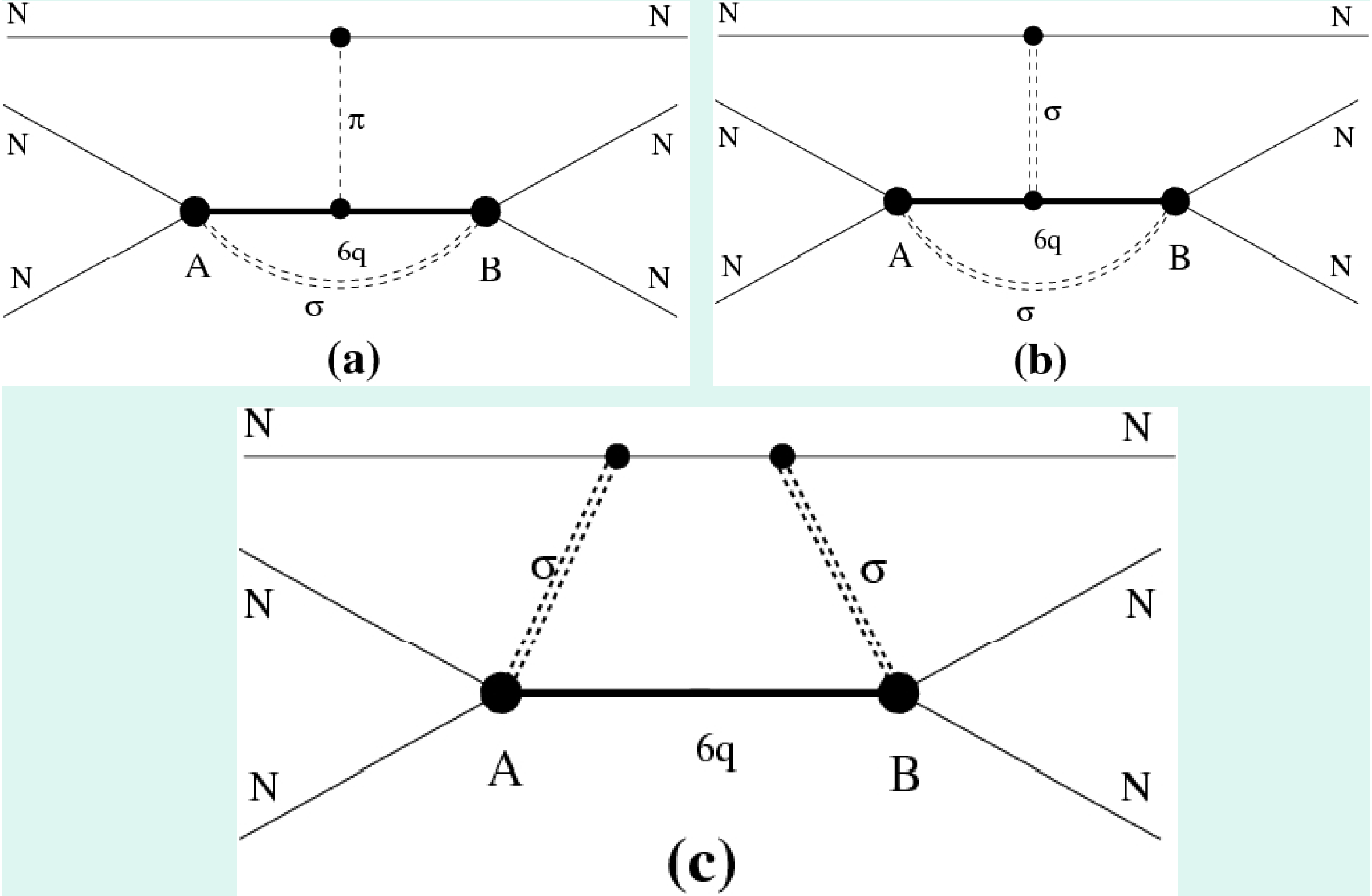
The $NN$ three-body Hamiltonian acts in the external $NN$ space $\mathcal{H}_3^{\rm ex}$ and includes the total kinetic energy $T$ and the sum of external two-body interactions (OPE + TPE): $H_3^{NN} = T + \Sigma_{i<j}\, v_{ij}^{\rm OPE+TPE}$.

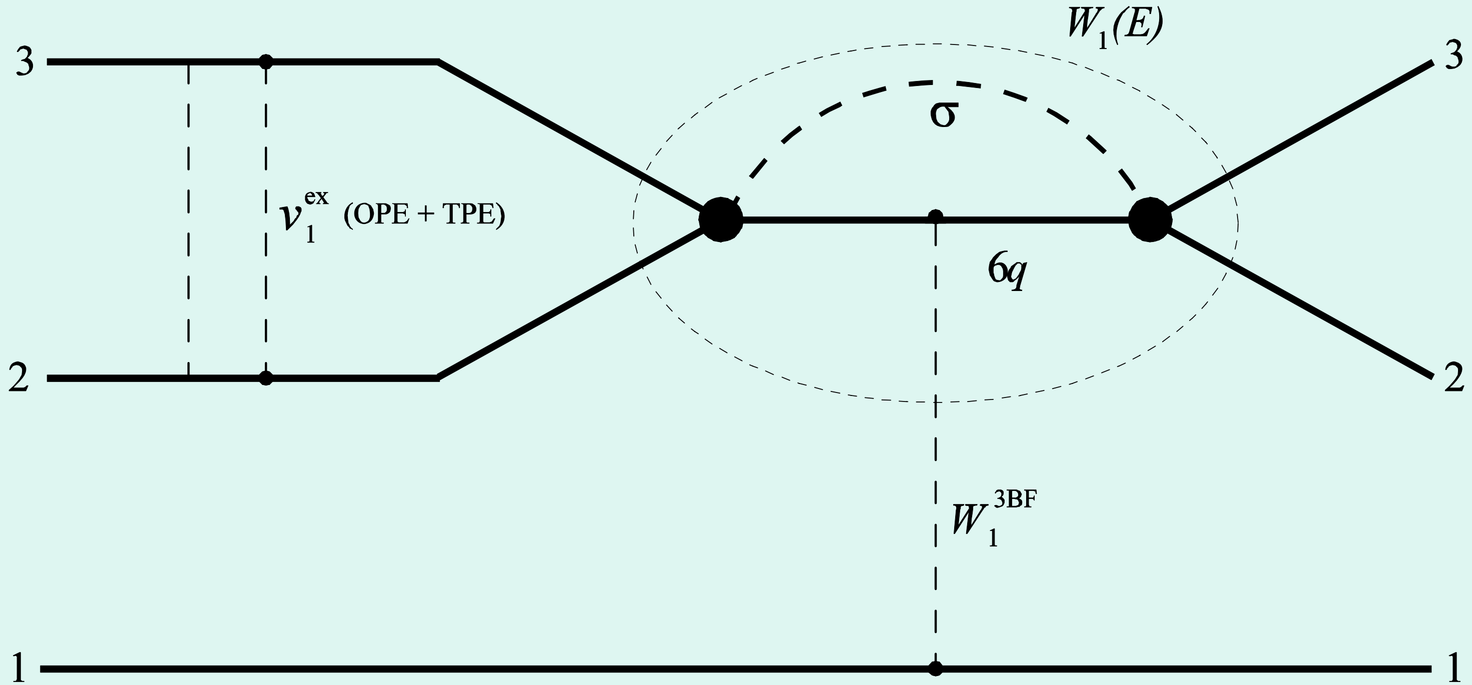
Writing the four-component Schrödinger equation with Hamiltonian $H_3$: and excluding three dibaryon components, one obtains an effective Schrödinger equation for the $NN$ component of three-body wavefunction $\Psi^{\rm NN}$ with the effective Hamiltonian $H^{\rm eff}(E)$, which in the dibaryon model has a form:

$$H^{\rm eff} = T + \sum_{\alpha}\{V_\alpha^{\rm OPE} + \lambda(E - q^2/(2m))\,|\varphi_\alpha\rangle\langle\varphi_\alpha|\}.$$

But this model leads to appearance of **a new three-body force** in the $3N$ system due to interaction between the dressed bag and third nucleon.

# New dibaryon induced 3N force






These three-body forces are expressed (in momentum representation) by integral operators with factorized kernel like:

$$W_\alpha^{3BF}(\mathbf{p}_\alpha, \mathbf{p'}_\alpha, \mathbf{q}_\alpha, \mathbf{q}'_\alpha; E) = \varphi(\mathbf{p}_\alpha)\, w^{3BF}(\mathbf{q}_\alpha, \mathbf{q}'_\alpha; E)\, \varphi(\mathbf{p}'_\alpha),$$

where $\mathbf{p}_\alpha$ is the relative momentum of pair nucleons $(\beta\gamma)$, $\mathbf{q}_\alpha$ is momentum of third nucleon in respect to the pair center of mass, and $E$ is the total three-nucleon energy.

Adding these three-body forces to $H^{\rm eff}$ , we get the total effective Hamiltonian in the $NN$ channel:

$$H^{\rm tot}(E) = H^{\rm eff}(E) + \sum_\alpha W_\alpha^{3BF}(E)$$

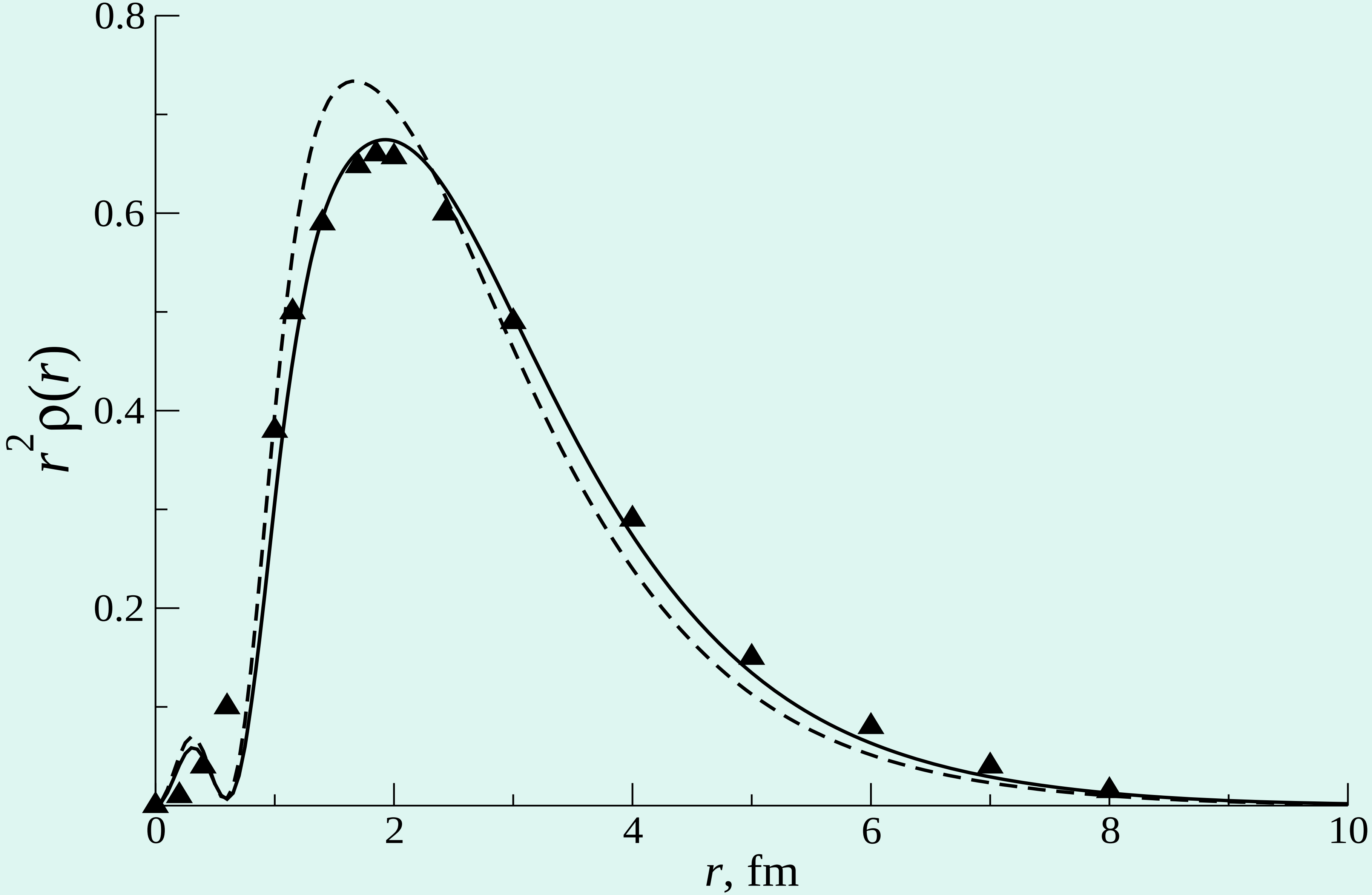
**Table 2.** Results of the $3N$ calculations with two- and three-body forces for two variants of the dibaryon model

| Model | $E$, MeV | $P_D$,% | $P_{S'}$,% | $P_{6qN}$,% | Contributions to $H$, MeV | | |
|---|---|---|---|---|---|---|---|
| | | | | | $T$ | $T+V^{(2N)}$ | $V^{(3N)}$ |
| $^3$H | | | | | | | |
| DBM(I) $g=9.577^{(a)}$ | −8.482 | 6.87 | 0.67 | 10.99 | 112.8 | −1.33 | −7.15 |
| DBM(II) $g=8.673^{(a)}$ | −8.481 | 7.08 | 0.68 | 7.39 | 112.4 | −3.79 | −4.69 |
| AV18 + UIX | −8.48 | 9.3 | 1.05 | − | 51.4 | −7.27 | −1.19 |
| $^3$He | | | | | | | |
| DBM(I) | −7.772 | 6.85 | 0.74 | 10.80 | 110.2 | −0.90 | −6.88 |
| DBM(II) | −7.789 | 7.06 | 0.75 | 7.26 | 109.9 | −3.28 | −4.51 |
| AV18 + UIX | −7.76 | 9.25 | 1.24 | − | 50.6 | −6.54 | −1.17 |

[a] These values of $\sigma NN$ coupling constant in $^3$H calculations have been chosen to reproduce the exact binding energy of $^3$H nucleus. The calculations for $^3$He have been carried out without any free parameters.

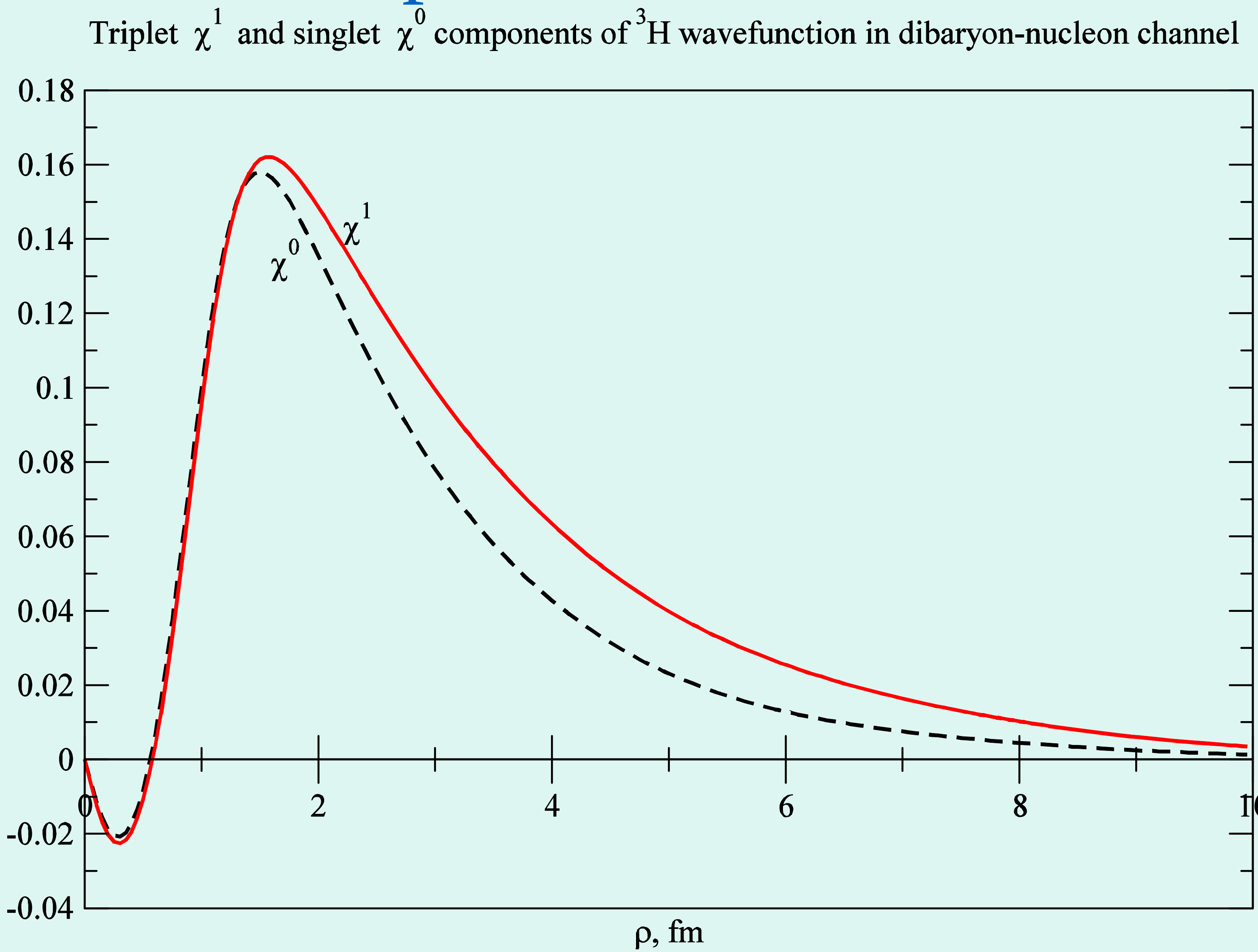
$$\Delta E_{\text{Coul}}^{\text{theor}} = 754 \text{ keV} \text{ (with no one adjustable parameter)}$$

$$\Delta E_{\text{Coul}}^{\text{exp}} = 764 \text{ keV } !$$

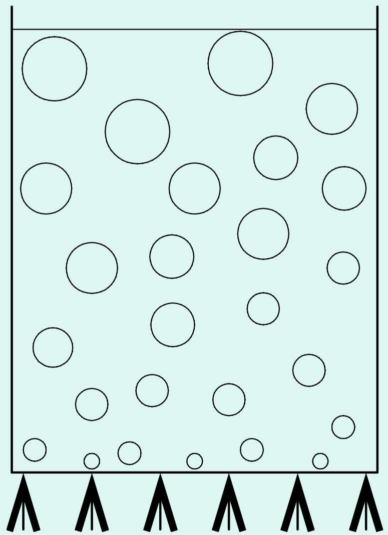



Two-proton density in 3He (solid line) and two-neutron density in 3H for dibaryon model vs  two-proton density in 3He  for Bonn NN potential (triangles).

# Di- and multi-baryons as mixed phase precursors.



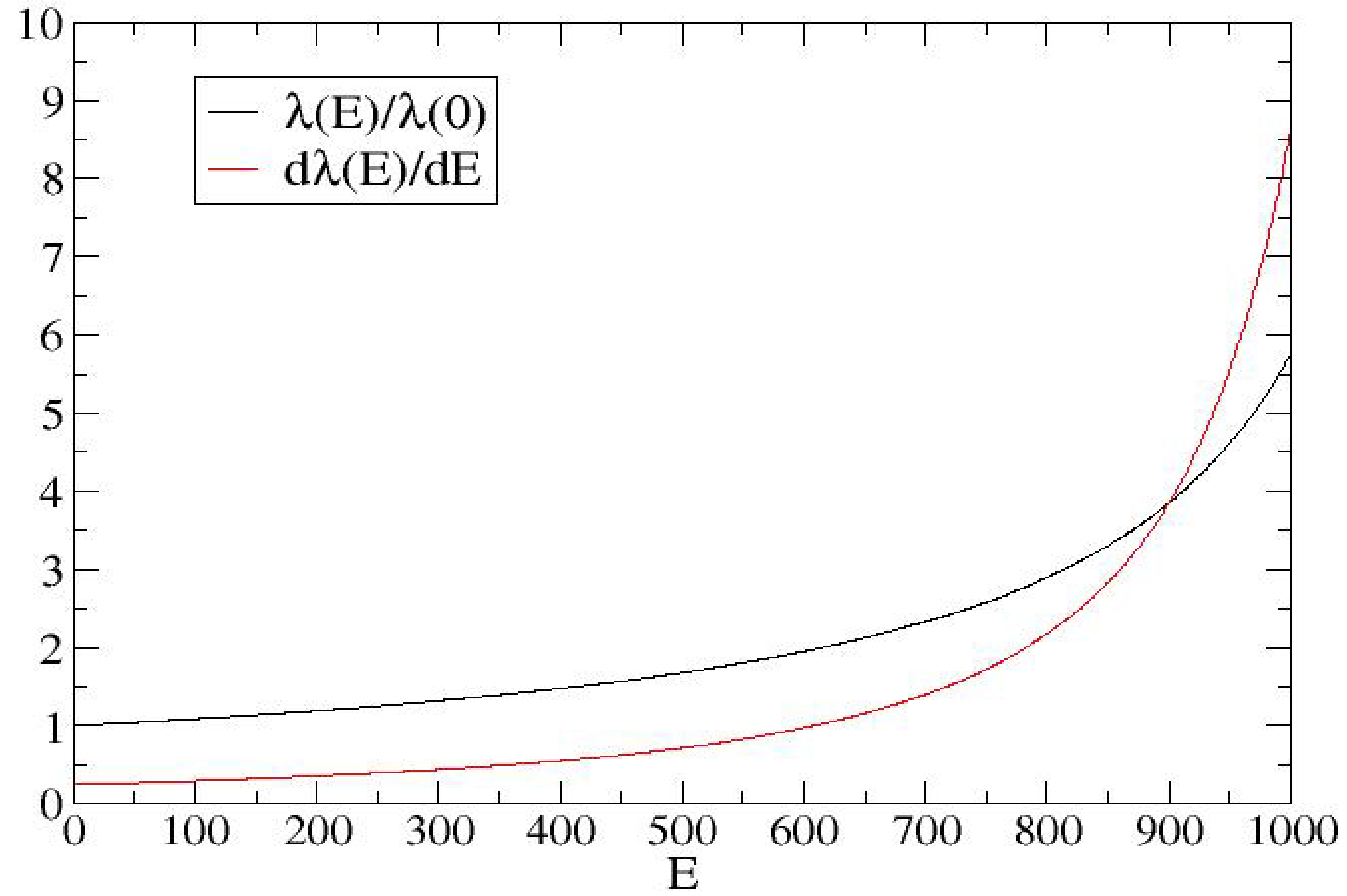
Phase transition (e.g. from a liquid to vapour) starts from formation of microbubbles:



The faster the energy application to the water the faster rising of the vapour bubbles.

The weight of dibaryon component in a nucleus as a function of excitation energy is

$$W(E) \sim -d\lambda/dE$$



## Production of σ-field in excited multiquark configurations (in the language of quark shell model):

2N: $s^4p^2 \rightarrow s^6 + \sigma$

3N: $s^5p^4 \rightarrow s^9 + 2\sigma$

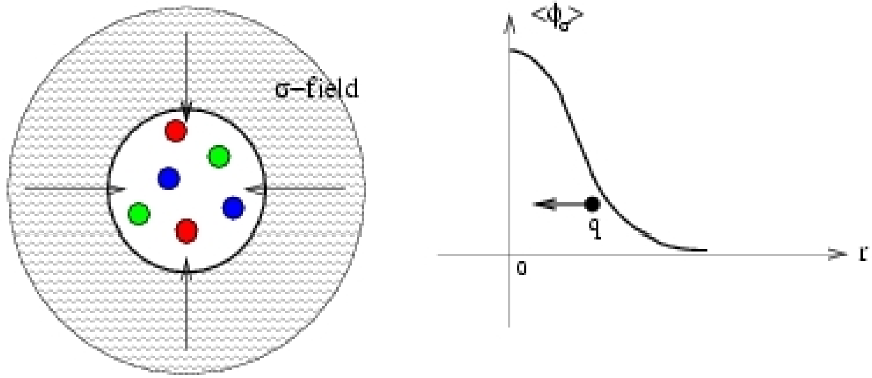
4N: $s^6p^6 \rightarrow s^{12} + 3\sigma$

The one-gluon exchange interaction gives just these multiquark configurations as leading ones.

When temperature of nuclear matter is rising the admixture of multiquark bags (dressed with meson fields) is rising as well. Eventually when the temperature becomes sufficiently high the whole nuclear matter goes to quark-meson-gluon plasma state.

## The effects of strong $\sigma$-field around six-quark bag.

This strong $\sigma$-field leads to highly non-linear effects:
— *(partial) restoration of chiral symmetry in the dressed bag;*
— *shrinking the multi-quark bag due to strong 'pressure' of scalar field;*
— *enhancement of scalar diquark correlations in the bag.*




The $\sigma$-field has mainly spherical symmetry due to $L_\sigma = 0$ and high space symmetry ($s^6[6]L_q = 0$) of the bag, and thus the field pulls quarks to the center of the bag and results in effective strong attraction among all the six quarks in the bag in this dressed bag state (DBS). As a net result of this inter-quark effective attraction there arises a strong attraction between two nucleons in NN-channel.

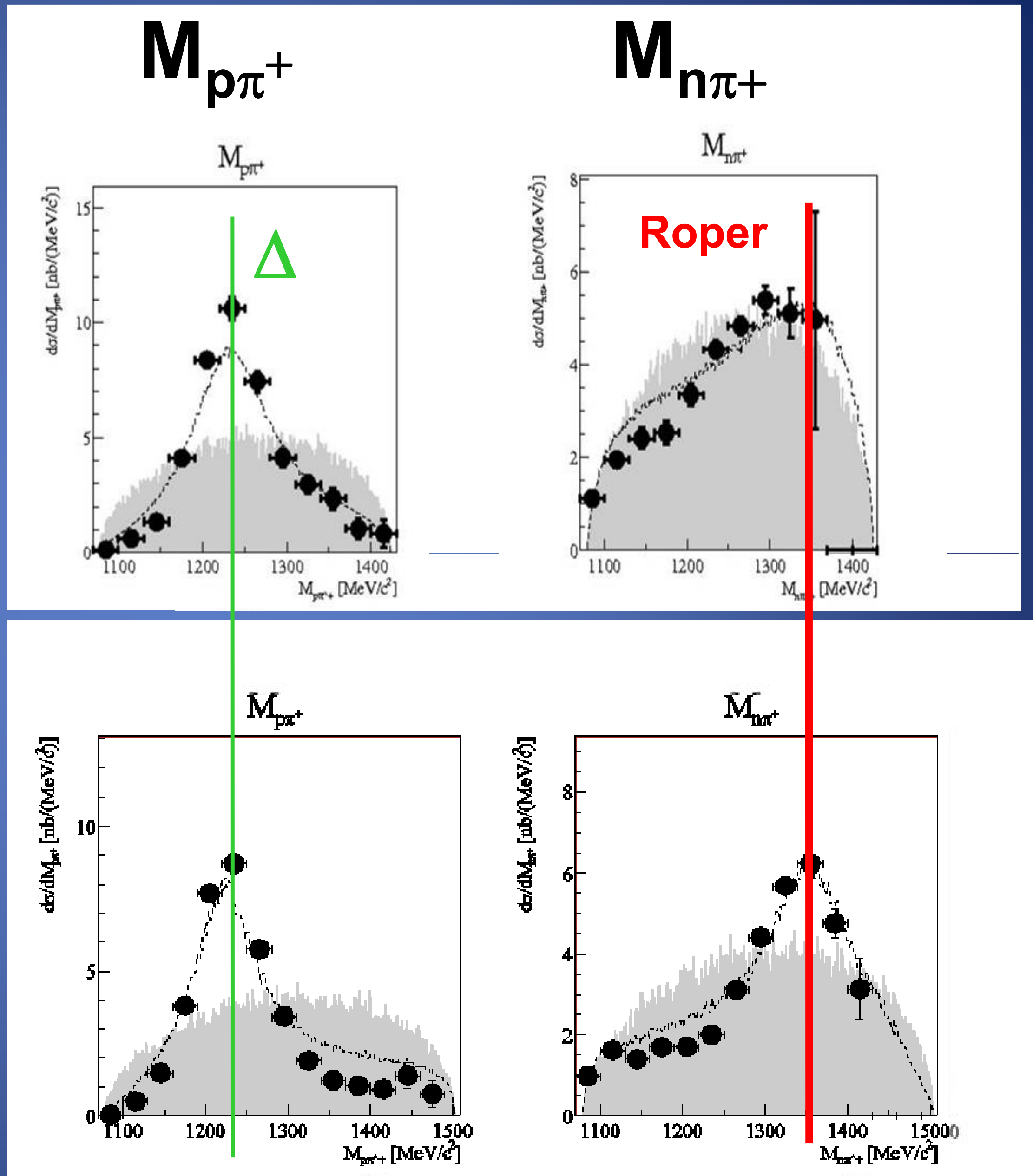
# Direct experimental evidence for σ-dressed dibaryon production in hadronic collisions

# $pp \rightarrow np\pi^+$

(WASA)

- $T_p$ = 1.1 GeV

- $T_p$ = 1.3 GeV




**Data prefer Roper values:**
**M ≈ 1355 MeV**
**Γ≈ 140 MeV**
(nucl-ex/0612015)

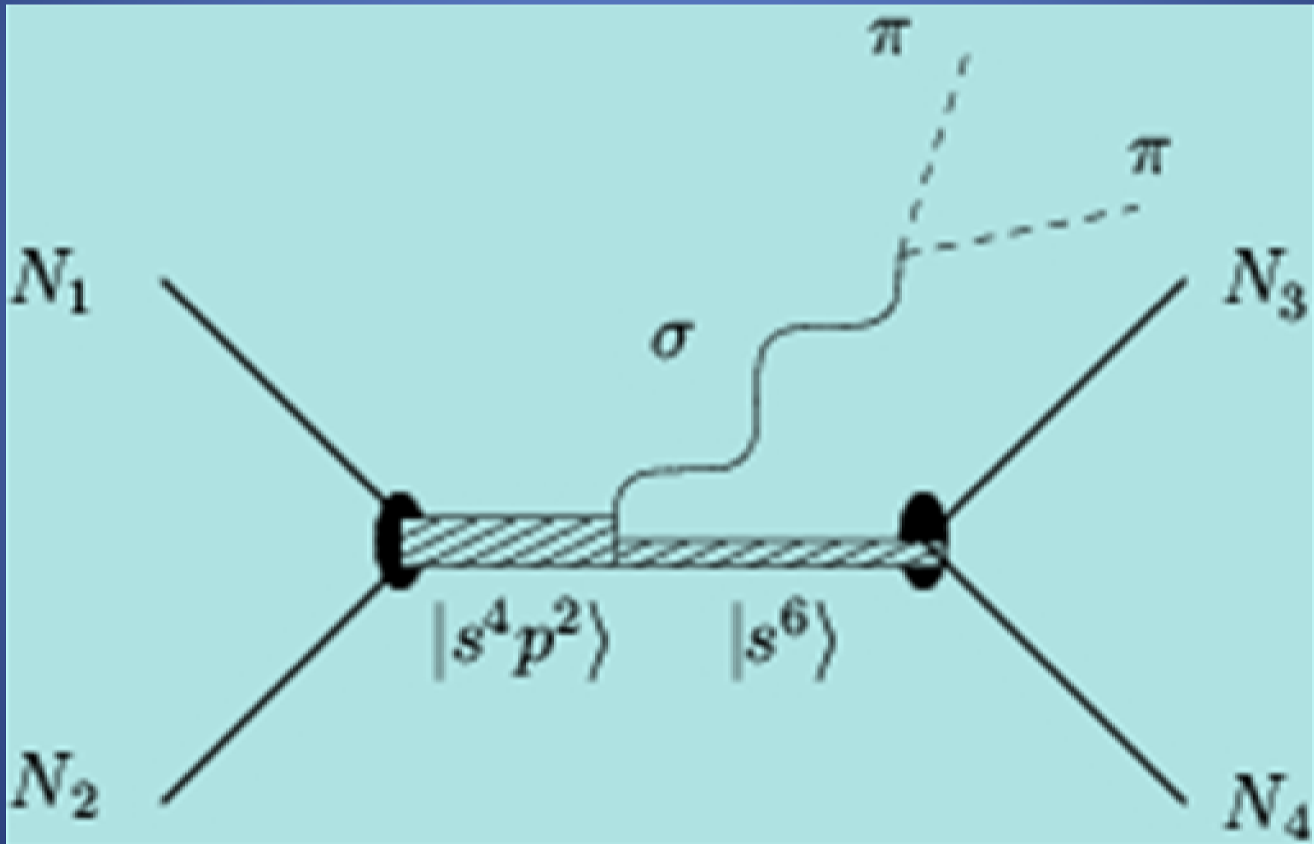
# $\pi\pi$ Production in Nuclei

- medium effects of the $\pi\pi$ system
- nuclei as isospin filter:

| | $\pi^0\pi^0$ – system |
|---|---|
| – $pp \rightarrow pp\ \pi\pi$ | I = 0, ~~1~~, 2 |
| – $pn \rightarrow d\ \pi\pi$ | 0, ~~1~~ |
| – $pd \rightarrow {}^3He\ \pi\pi$: | 0, ~~1~~ |
| – $dd \rightarrow {}^4He\ \pi\pi$: | 0 |

} **ABC effect**

# The dibaryon model mechanism for the two-pion production via σ-meson in p+n or p+p collisions



# ABC effect

(**A**bashian, **B**oth, **C**rowe )

- **Inclusive measurements:**

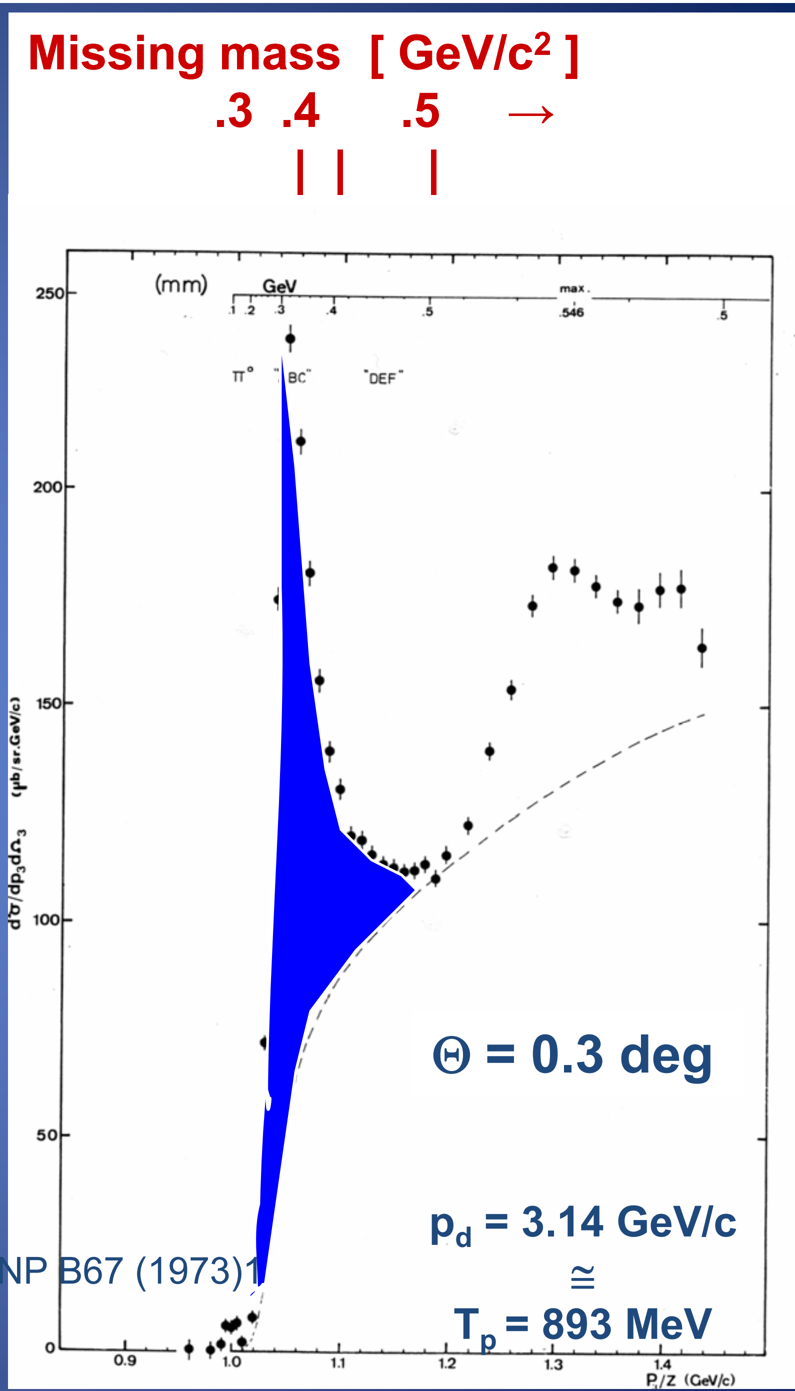
  **pd ⟶ $^3$He X**

Abashian et al. Berkeley

Banaigs et al. Saclay

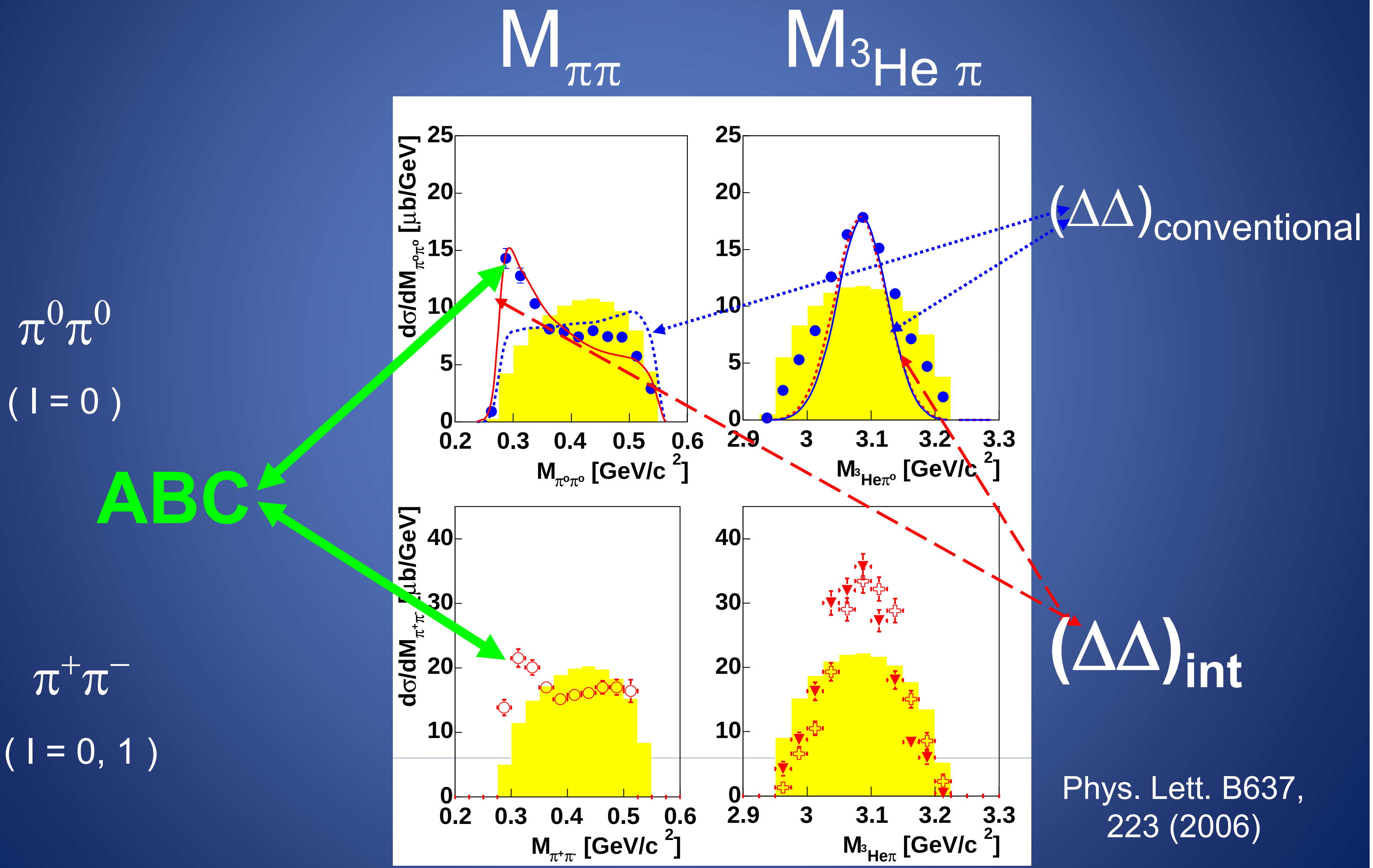
⇒

**low-mass enhancement !**



**First exclusive measurement: @ CELSIUS-WASA**

# $p\,d \rightarrow {}^3He\ \pi\pi$ @ $T_p$ = 895 MeV

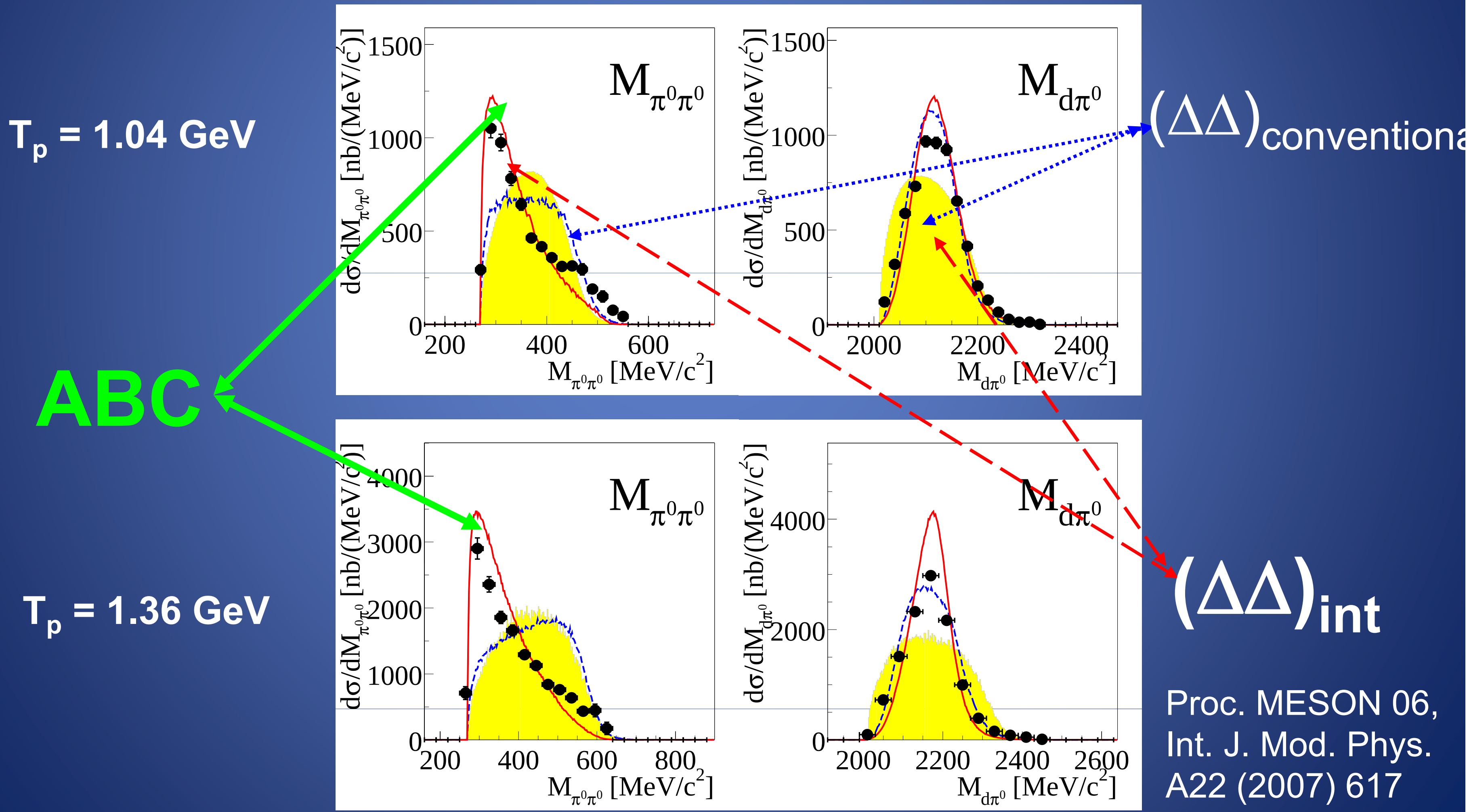



Phys. Lett. B637, 223 (2006)

First exclusive measurement: @ CELSIUS-WASA

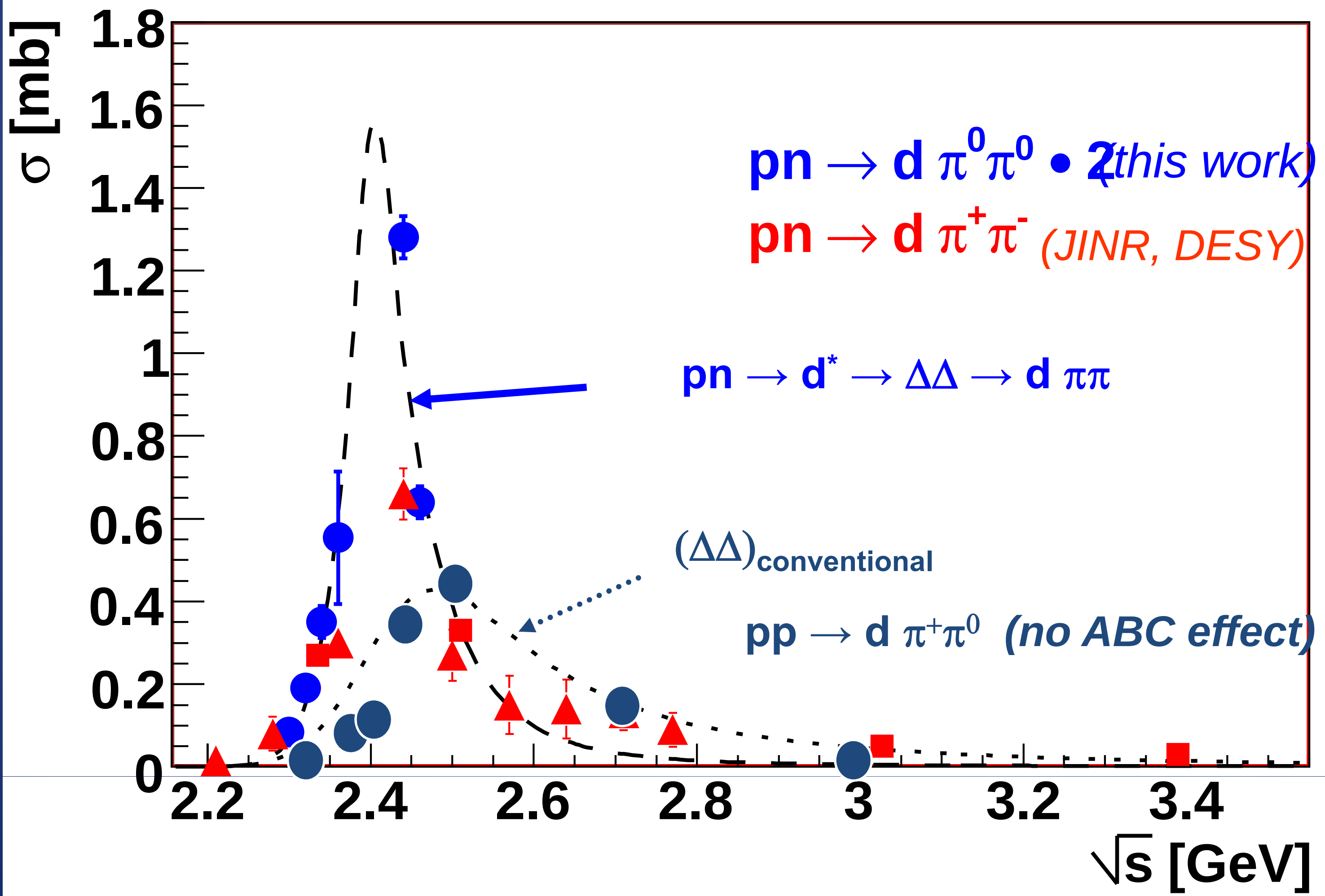
# $p\,d \rightarrow d\,\pi^0\pi^0 + p_{spectator}$

$M_{\pi\pi}$ $M_{d\pi}$




Proc. MESON 06, Int. J. Mod. Phys. A22 (2007) 617

# Energy Dependence of ABC



# Direct experimental evidence for the *s*-channel dibaryon induced σ-meson production

## Observation of a Structure in $pp \to pp\gamma\gamma$ near the $\pi\pi$ Threshold and its Possible Interpretation by $\gamma\gamma$ Radiation from Chiral Loops in the Mesonic $\sigma$ Channel


M. Bashkanov[1], D. Bogoslawsky[2], H. Calén[3], F. Cappellaro[4], H. Clement[1], L. Demiroers[5], E. Doroshkevich[1], C. Ekström[3], K. Fransson[3], J. Greiff[5], L. Gustafsson[4], B. Höistad[4], G. Ivanov[2], M. Jacewicz[4], E. Jiganov[2], T. Johansson[4], M.M. Kaskulov[1], S. Keleta[4], I. Koch[4], S. Kullander[4], A. Kupść[3], A. Kuznetsov[2], P. Marciniewski[3], R. Meier[1], B. Morosov[2], W. Oelert[8], C. Pauly[5], Y. Petukhov[2], A. Povtorejko[2], R.J.M.Y. Ruber[3], W. Scobel[5], B. Shwartz[10], T. Skorodko[1], V. Sopov[12], J. Stepaniak[7], V. Tchernyshev[12], P. Thörngren Engblom[4], V. Tikhomirov[2], A. Turowiecki[11], G.J. Wagner[1], U. Wiedner[4], M. Wolke[4], A. Yamamoto[6], J. Zabierowski[7], J. Zlomanczuk[4]

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[8] *Forschungszentrum Jülich, Germany*
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[11] *Institute of Experimental Physics, Warsaw, Poland*
[12] *Institute of Theoretical and Experimental Physics, Moscow, Russia*

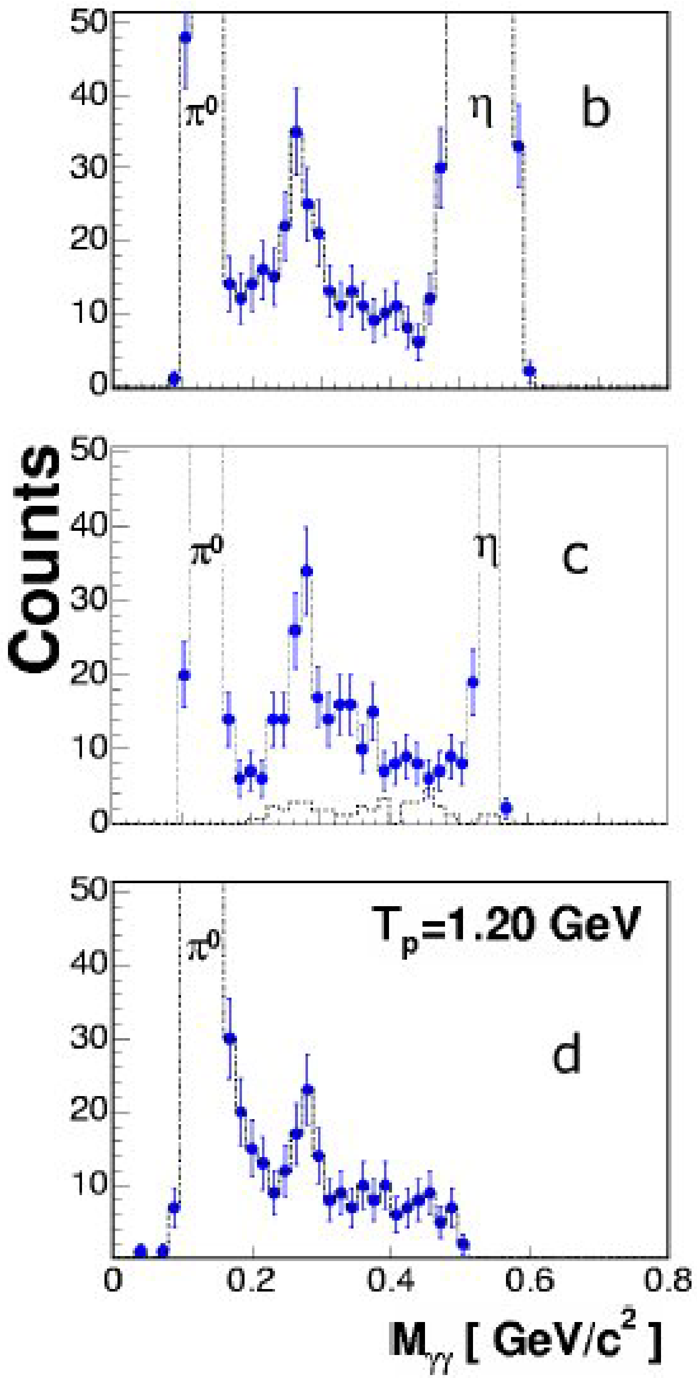
*(CELSIUS-WASA Collaboration)*



(Dated: February 7, 2008)



The $pp \to pp\gamma\gamma$ reaction has been measured at CELSIUS using the WASA $4\pi$-detector with hydrogen pellet target. At $T_p = 1.20$ and 1.36 GeV, where most of the statistics has been accumulated, the $\gamma\gamma$ invariant mass spectrum exhibits a narrow structure around the $\pi\pi$ threshold, which possibly may be associated with two-photon radiation of $\pi^+\pi^-$ loops in the mesonic $\sigma$ channel.




$M_{\gamma\gamma}$ spectra for the process $pp \rightarrow pp\gamma\gamma$ at $T_p$=1.36 GeV before (b) and after (c) kinematic fit. The plot (d) is the same as (c) but for $T_p$=1.20 GeV

The spike around 2π-threshold turns out to be very stable against cuts. E.g., increase of the threshold $E_\gamma$= 50 MeV to $E_\gamma$ = 100 MeV has no significant effect on this intermediate spike.
Moreover, the model which incorporates very well the γγ events and $M_{\gamma\gamma}$ from $\pi^0$ and η production gives practically no events in the intermediate area with $M_{\gamma\gamma}$ ~300 – 400 MeV! Also from MC simulation of $\pi^+\pi^-$ production we do not get any contributions in the $M_{\gamma\gamma}$ spectrum.

**Then the experimentalists (CELSIUS-WASA) conlude:**

"Since none of these simulated processes is able to account for the structure observed near the ππ threshold and also detailed and comprehensive tests of detector performance and event structures have **not given** any hint for an artifact, we are led to consider seriously the possibility that the observed structure (at $M_{\gamma\gamma}$ ~300 – 400 MeV) is real and might be due to the process $pp \to pp\sigma \to pp\gamma\gamma$, in particular also since $pp \to pp\pi^+\pi^-$ and $pp \to pp\pi^0\pi^0$ reactions are dominated by σ production."

# The new γγ-data with large statistics

In these nice experiments done at the Dubna Nuclotron machine the authors analyzed the γγ-spectra from pC and dC collisions at 5.5 GeV/c (for protons) and 1.7-3.8 GeV/c per nucleon (for deuterons).

# Observation of a Resonance-like Structure in the Invariant Mass Spectrum of two photons from pC- and dC-Interactions

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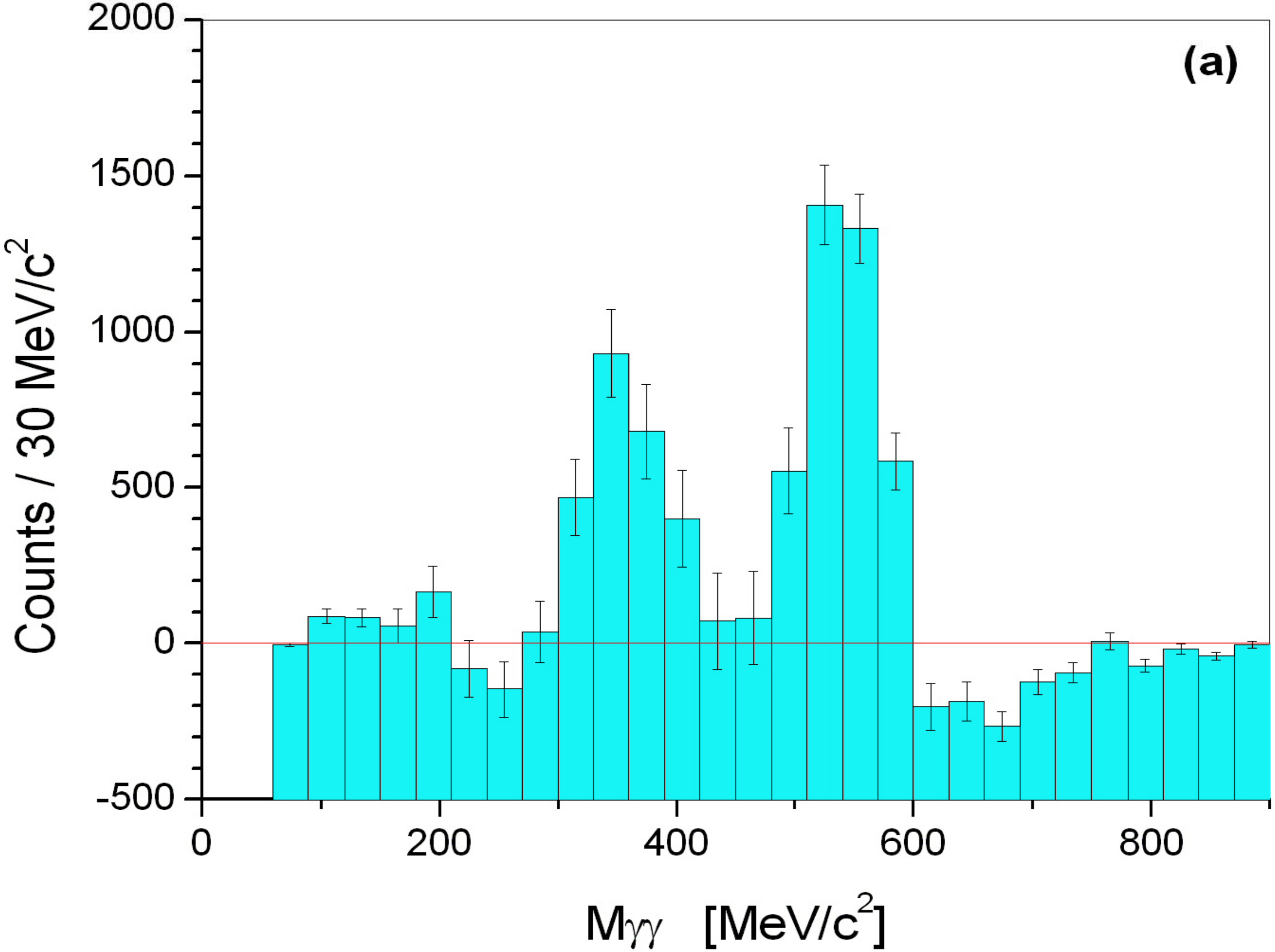
*b) Yerevan State University, Yerevan, Armeniya*
*c) Institute of Applied Physics, Kishinev, Moldova*
*d) LIT JINR, 141980 Dubna, Moscow region, Russia*
*e) Gesellschaft für Schwerionenforschung, Darmstadt, Germany*
*f) Moscow State Institute of Radioengineering, Electronics and Automation, 119454 Moscow, Russia*
*g) BLTP JINR, 141980 Dubna, Moscow region, Russia*

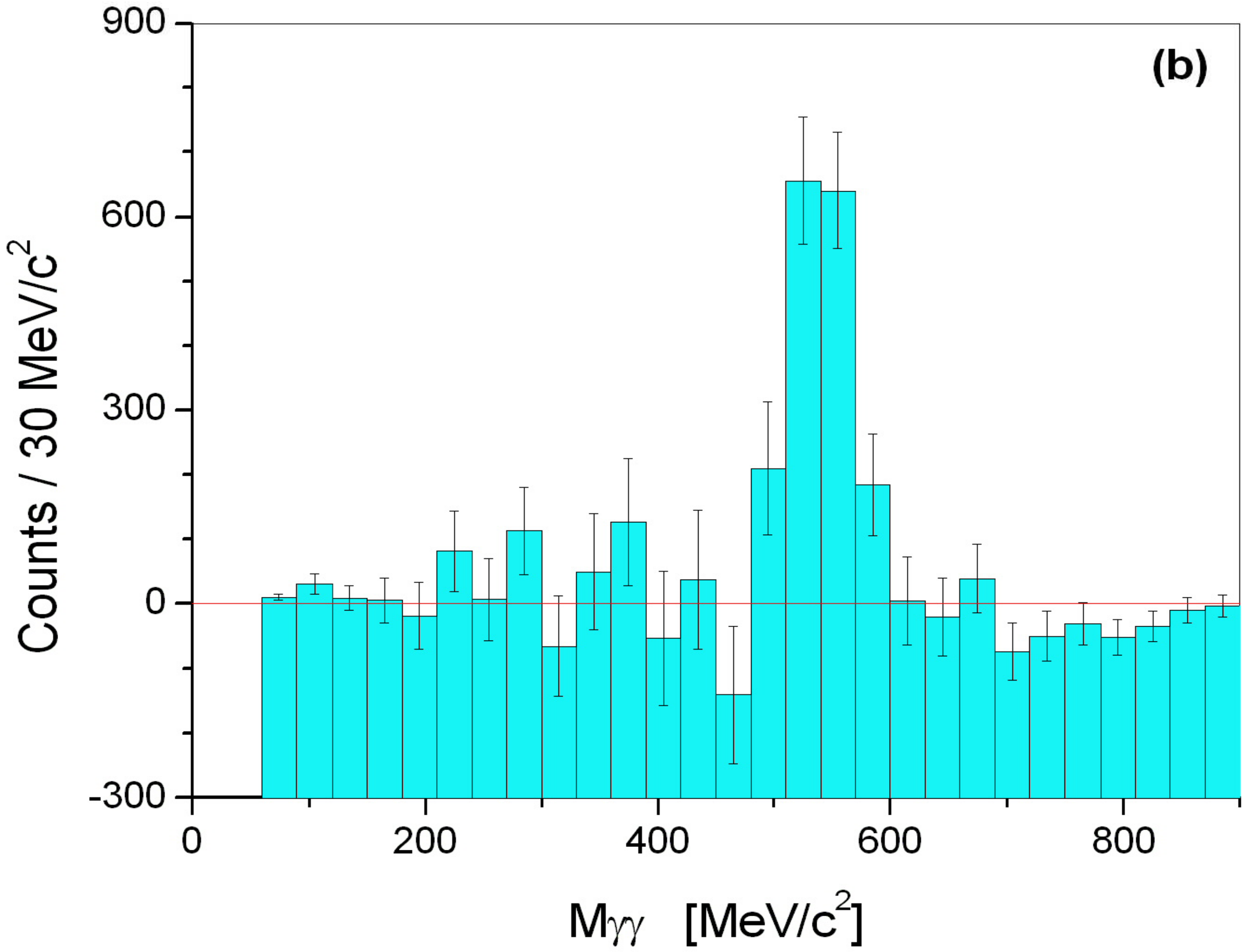
## Abstract

Along with $\pi^0$ and $\eta$ mesons, a resonance structure in the invariant mass spectrum of two $\gamma$-quanta at $M = 360 \pm 7 \pm 9$ MeV is first observed in the reaction $dC \to \gamma + \gamma + X$ at momentum 2.75 GeV/c per nucleon. Preliminary estimates of its width and cross section are $\Gamma = 49.2 \pm 18.6$ MeV and $\sigma_{\gamma\gamma} \sim 98\ \mu b$. The collected statistics is $2339 \pm 340$ events of $1.5 \cdot 10^6$ triggered interactions of a total number of $\sim 10^{12}$ dC-interactions. This structure is not observed in $pC$ collisions at the beam momentum 5.5 GeV/c. Possible mechanisms of this ABC-like effect are discussed.

# γγ-yield from dC collisions at E=2.75 GeV/cA



# γγ-yield from pC collisions at E=5.5 GeV/c



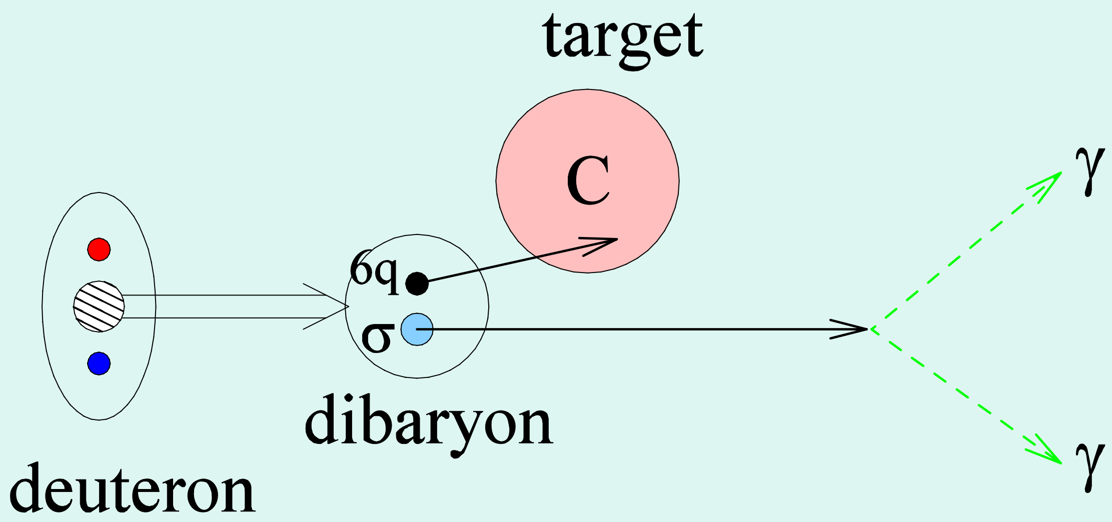
# From authors' conclusion:

Thus, based on a thorough analysis of experimental data measured at the JINR Nuclotron and record statistics of 2339 ± 340 events of $1.5 \cdot 10^6$ triggered interactions of a total number $2 \cdot 10^{12}$ of dC interactions there was observed a resonance-like enhancement at the mass $M_{\gamma\gamma} = 360 \pm 7 \pm 9$ MeV, width $\Gamma = 49 \pm 19$ MeV at momentum of incident deuterons 2.75 GeV/c per nucleon. A structure like this is not observed in the $M_{\gamma\gamma}$ spectrum from pC (5.5 GeV/c) interactions while the η meson is clearly seen in both the cases.

…This enhancement at $M_{\gamma\gamma} \sim (2-3)m_\pi$ is similar to the puzzling ABC effect observed for two-pion pairs from nucleon-nucleon and lightest nuclei collisions at the near threshold energy.

…Several dynamic mechanisms were attempted: production of the hypothetic R resonance (really it is a renormalized σ-meson) in ππ interactions during the evolution of the nuclear collision, formation of the R resonance with participation of photons from the decay, the $\pi^0\pi^0$ interaction effect in the $3\pi^0$ channel of the η decay, a particular decoupled dibaryon mechanism. Unfortunately, none of these mechanisms is able to explain the measured value of the resonance-like enhancement

# Production of two γ-quanta according to dibaryon model



## To summarize:

dibaryons and other multibaryons in cold matter can be considered as precursers of phase transition to quark-meson-gluon plasma state through the intermediate MIXED PHASE state.