Modern concepts for nuclear force

Dressed dibaryon as carrier of short-range NN and 3N interactions

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and P. Grabmayer

CONTENT

1. Inconsistencies in Yukawa model for NN interaction at intermediate and short ranges.

2. Why dibaryon? (Motivation for the dibaryon model of basic nuclear force.)

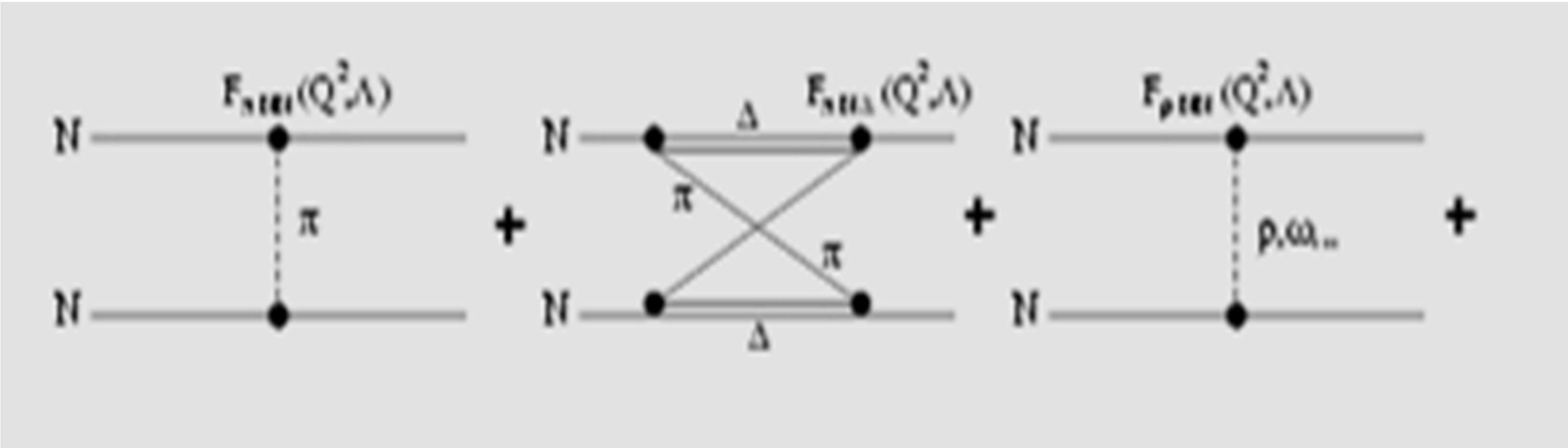
3. Intermediate dressed dibaryon as carrier for basic nuclear force (Roper resonance vs. dressed dibaryon).

4. The experimental evidence for intermediate dibaryon dressed with σ-field.

5. Conclusion.

Yukawa's conception for the nuclear force

Nowadays the traditional model for the NN-interaction and basic nuclear force, which has been based on the Yukawa's idea on the meson-exchange in *t*-channel, works very well at large distances $r_{NN} > \lambda_{\pi} \sim 1.4$ fm but there are some serious problems and fundamental difficulties at intermediate ($r_{NN} \sim 1$ fm) and especially at short ranges ($r_{NN} \sim 0.4 - 0.8$ fm).

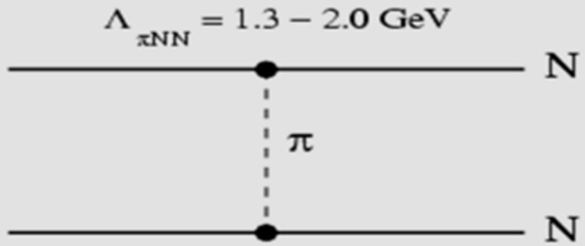


The intermediate- and short-range nuclear force should be revised somehow.

The most appropriate, consistent and related to fundamental QCD-picture way to make the revision is an introduction of the dibaryon degree of freedom in hadronic physics, NN interaction and generally in nuclear physics.

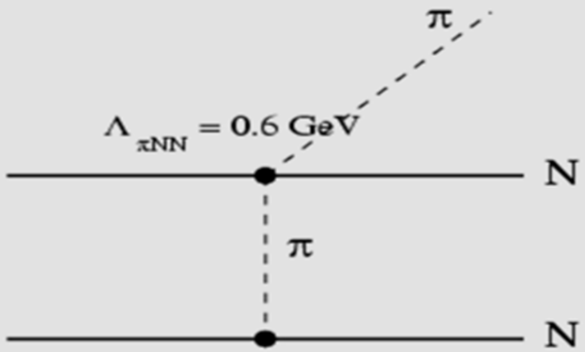
The problems in OBE-description of intermediate range interaction:

1. $\Lambda_{\pi NN}$ (in all OBE-models)$\simeq 1.3 \div 2.0$ GeV is very high and in strong disagreement with all microscopic theoretical estimates and experimental fits ($\Lambda_{\pi NN}|_{\mathrm{exp}} \sim 0.5 \div 0.8$ GeV). Moreover, the cut-off parameters $\Lambda_{\pi NN}$ and $\Lambda_{\rho NN}$, which fit the inelastic NN-data on π-meson production, like $pp \to pp\pi^0$ or $pn\pi^+$, are in good agreement just with the soft values of $\Lambda_{\pi NN} \simeq 0.5 \div 0.6$ GeV!

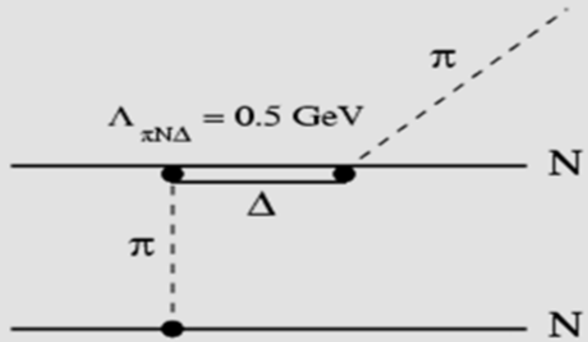


elastic channel

but

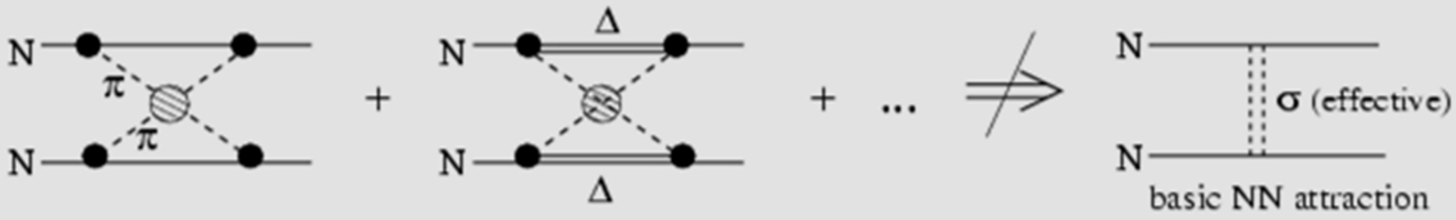


inelastic channel

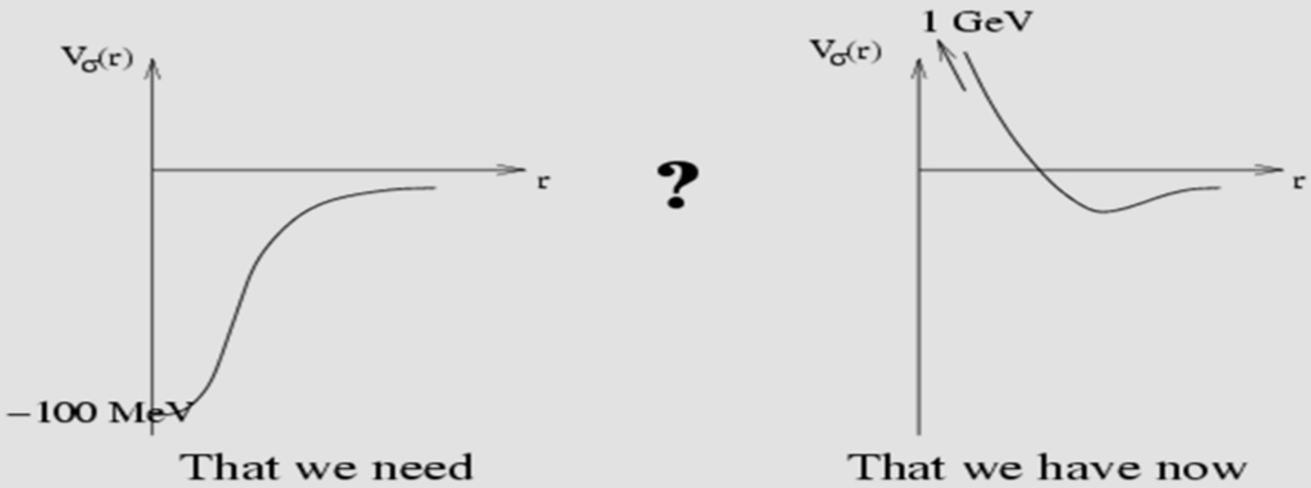


inelastic channel

Puzzle with scalar meson exchange



Contrary to the conventional view, the three independent groups have found that 2π-exchange with intermediate $\pi - \pi$ s-wave interaction leads to strong short- and intermediate-range repulsion and only very moderate peripheral attraction.



As a result, we have now NO MECHANISM FOR PROVIDING BASIC INTERNUCLEON ATTRACTION. In this point the intermediate dressed dibaryons appear!

The puzzles of OBE-models at short ranges

2. The long standing problem with short-range tensor force in ${}^3S_1 - {}^3D_1$ channel. The current NN-models of second generation lead to too low value of deuteron quadrupole moment:

$$Q_d^{\text{theor}} \simeq 0.270\,\text{fm}^2 \text{ vs. } Q_d^{\text{exp}} \simeq 0.286\,\text{fm}^2,$$

so that $\frac{\Delta Q}{Q} > 5\%$! it is too high for isoscalar MEC contribution!

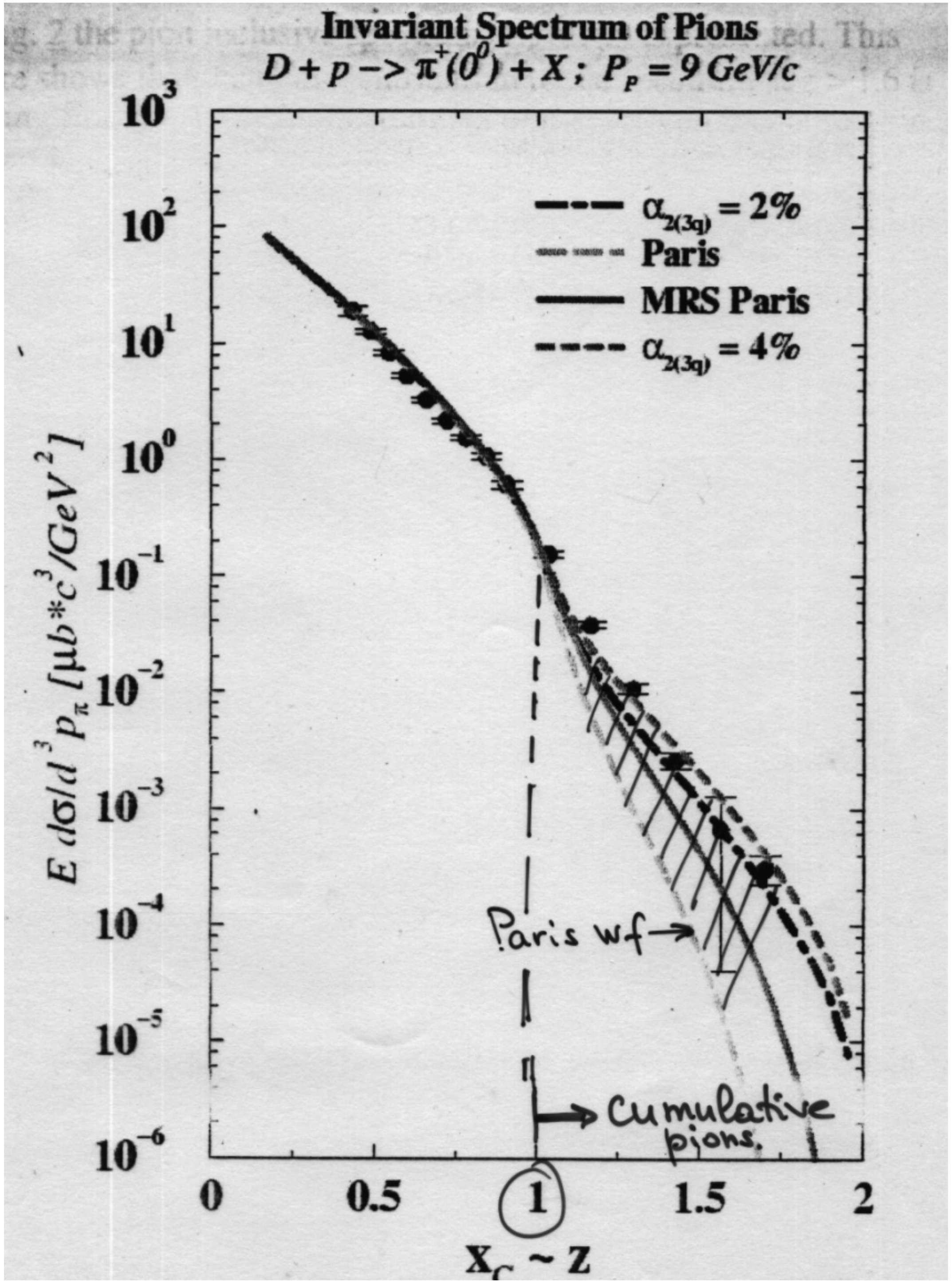
3. At short ranges

$$\frac{g^2_{\omega NN}}{4\pi}\Big|_{\substack{\text{NN fit}\\ \text{with OBE}}} \simeq 13.6 \div 15 \qquad \text{vs.} \qquad \frac{g^2_{\omega NN}}{4\pi}\Big|_{SU_6} \simeq 5$$

i.e. the OBE-value for $g_{\omega NN}$ is in few times as large as the SU_6-value, while all other coupling constants are in good agreement with SU_6-values.

4. The problem with the tensor-to-vector ρNN-coupling:
fit to NN data: $\varkappa_{\rho NN} \simeq 6 - 7$,
from πN scattering: $\varkappa_{\rho NN} \simeq 1 - 3$

The zero-angle π^+ production in D+p high-energy collisions (JINR) at P_D=9 GeV/c



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2 April 1998

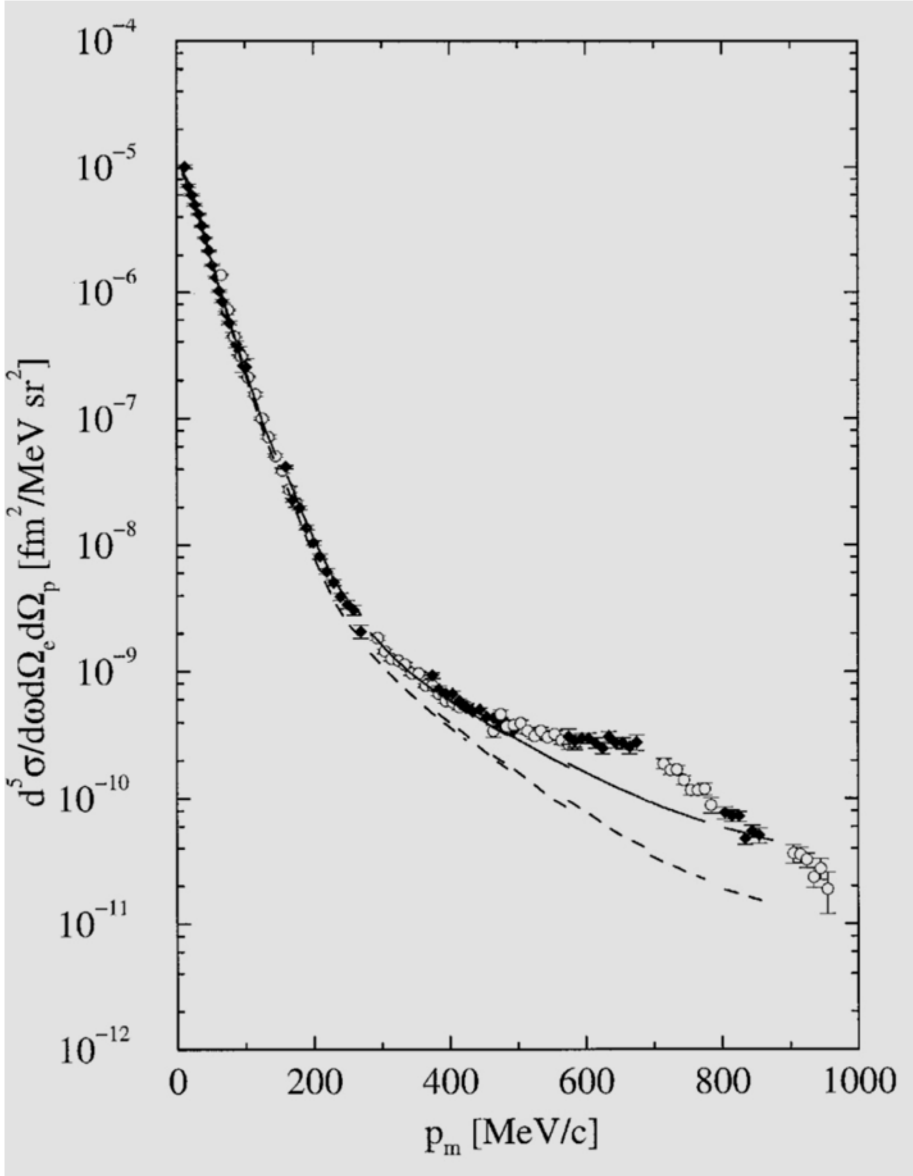
PHYSICS LETTERS B

Physics Letters B 424 (1998) 33–38

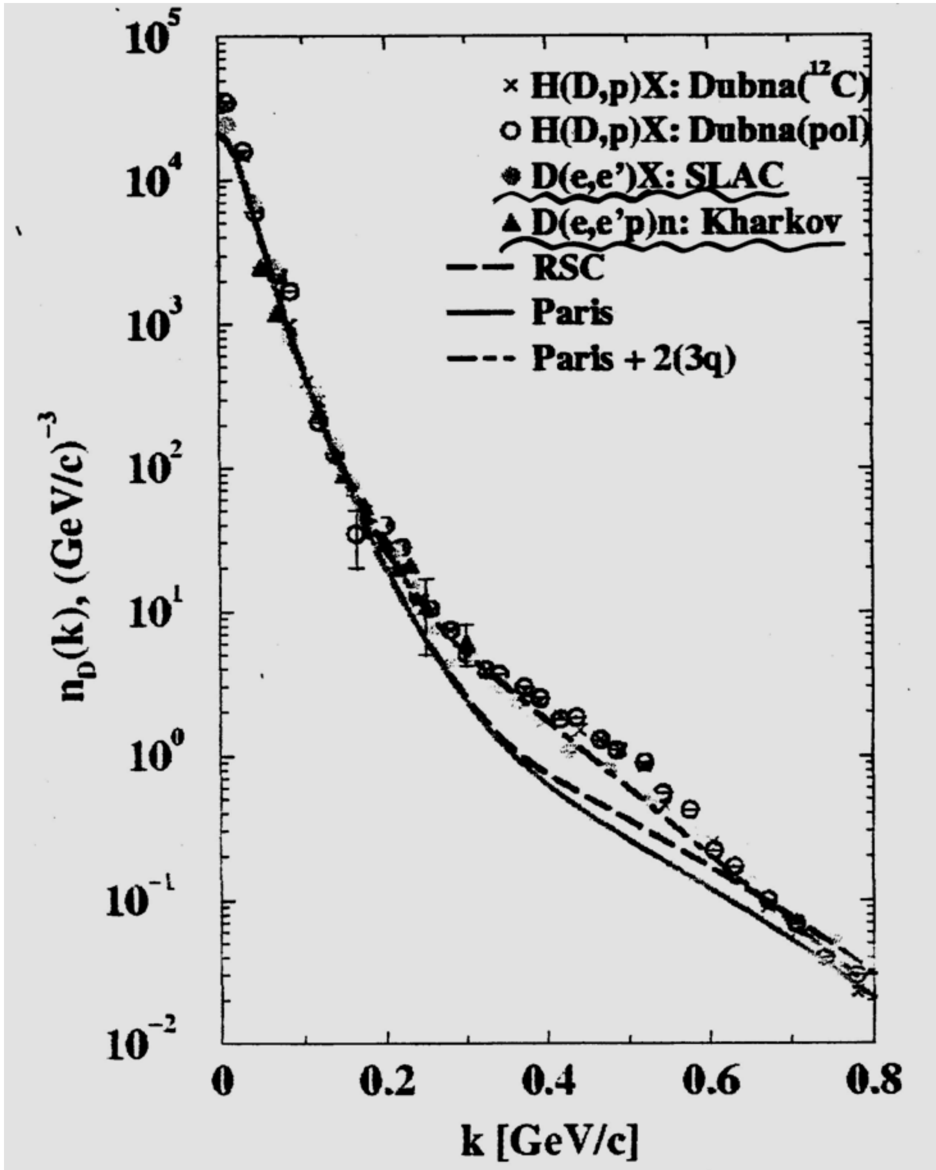
Large recoil momenta in the D(e,e′p)n reaction [1]

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]

[a] *Institut für Kernphysik, Johannes Gutenberg-Universität, J.J.-Becher-Weg 45, D-55099 Mainz, Germany*
[b] *Institut für Kernphysik, TH Darmstadt, D-64289 Darmstadt, Germany*
[c] *Institute Jožef Stefan, University of Ljubljana, SI-61111 Ljubljana, Slovenia*
[d] *Dept. für Physik und Astronomie, Universität Basel, Basel, Switzerland*

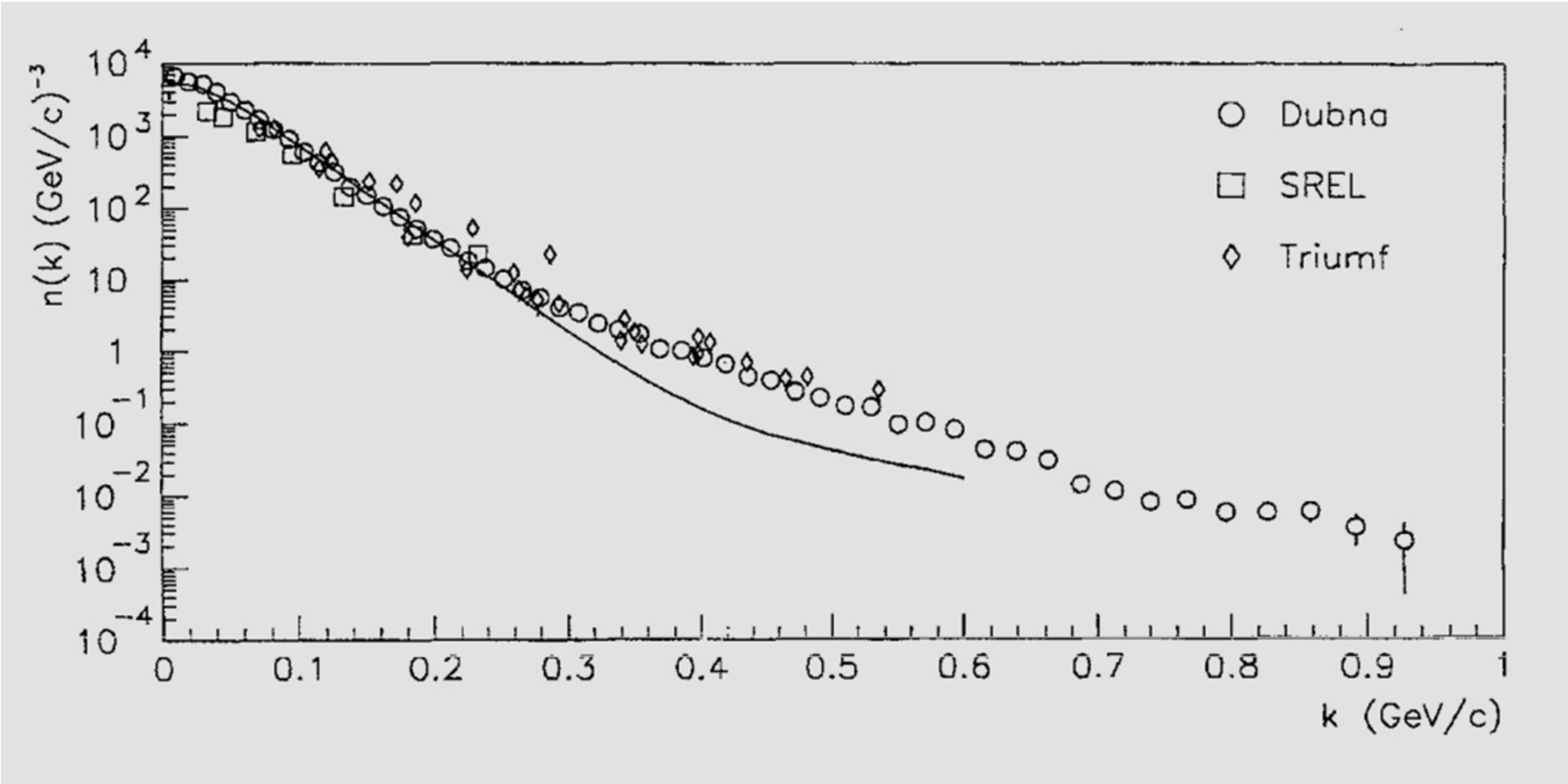


D(e,e'p) cross section

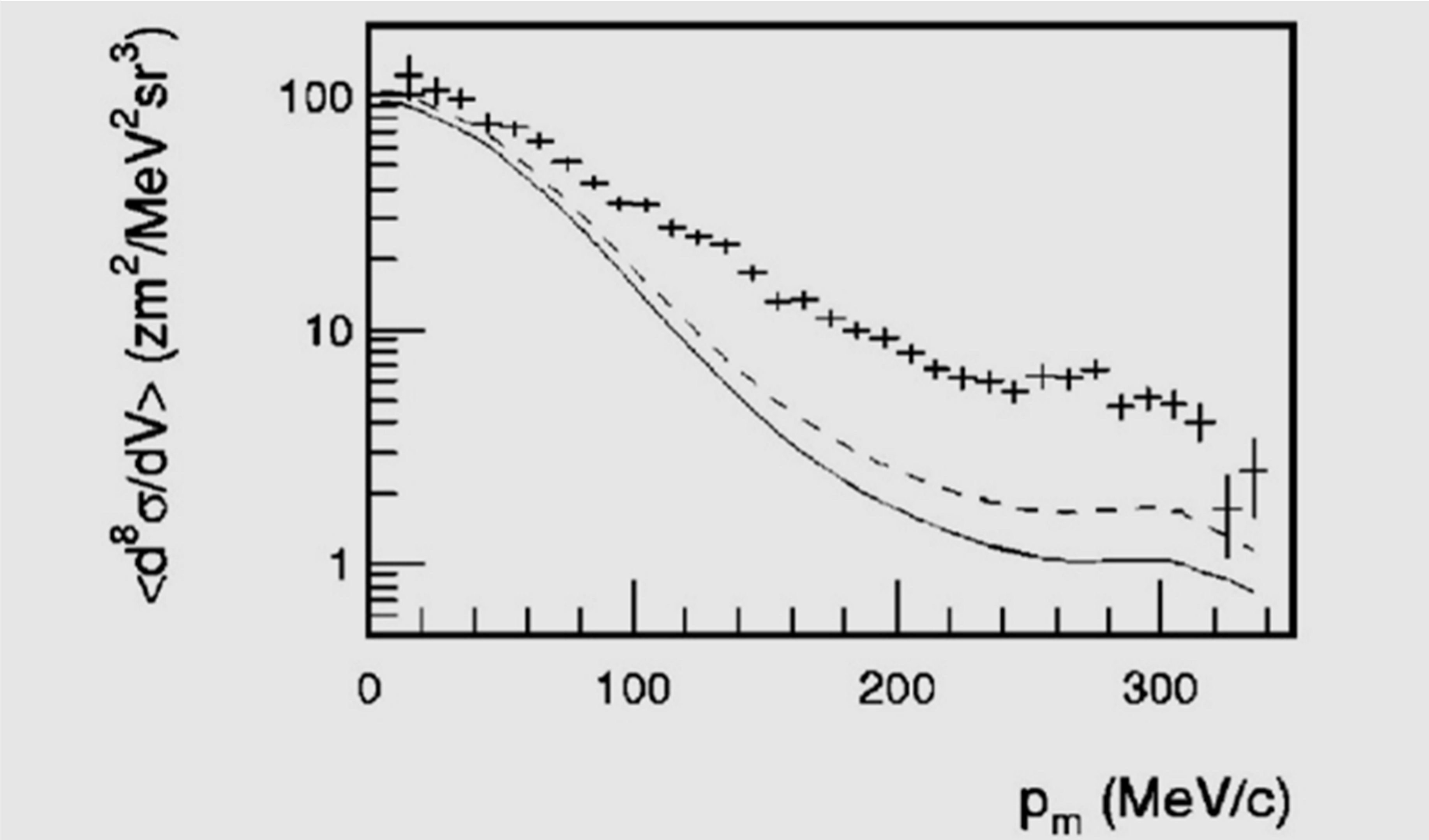


- The nucleon momentum distribution in deuteron extracted from different type experiments

The p-d momentum distribution in ^3He extracted from experimental data of Dubna, SREL and Triumf



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



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 !

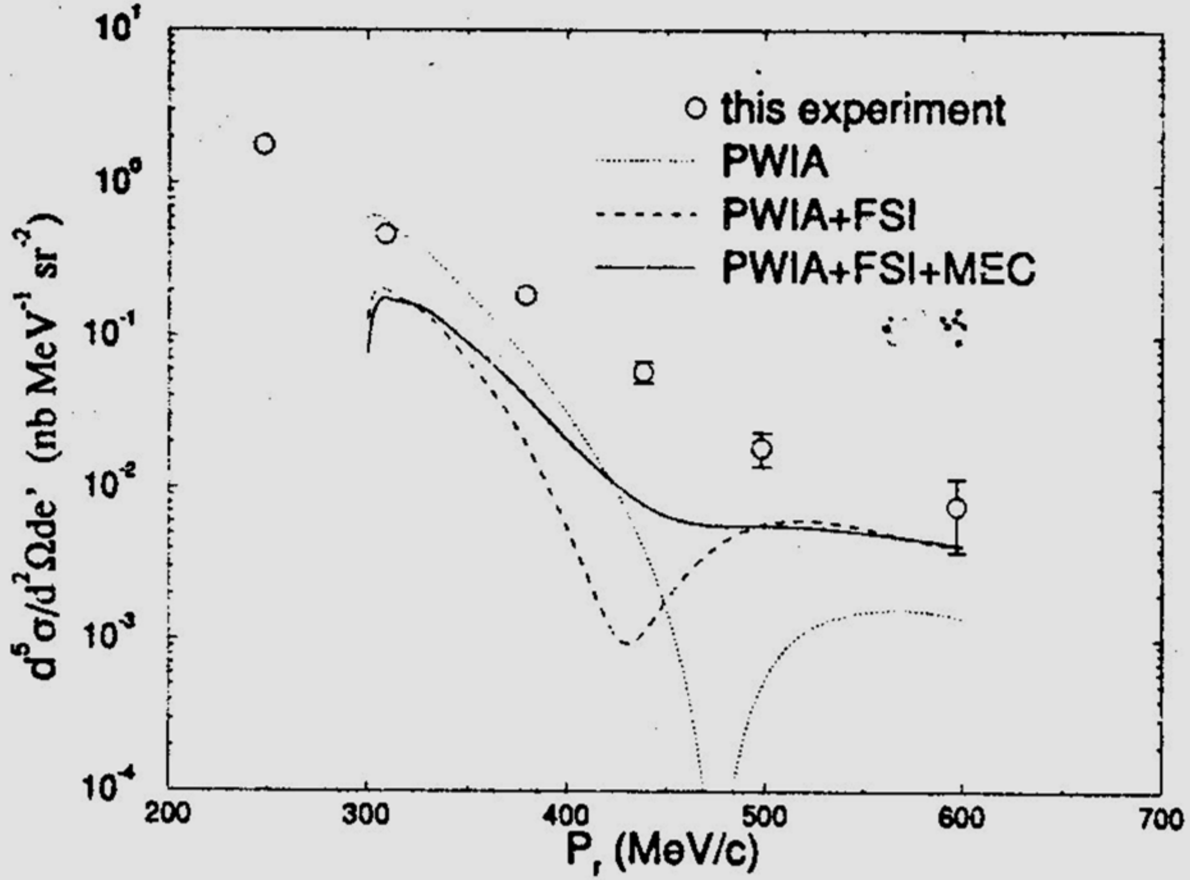
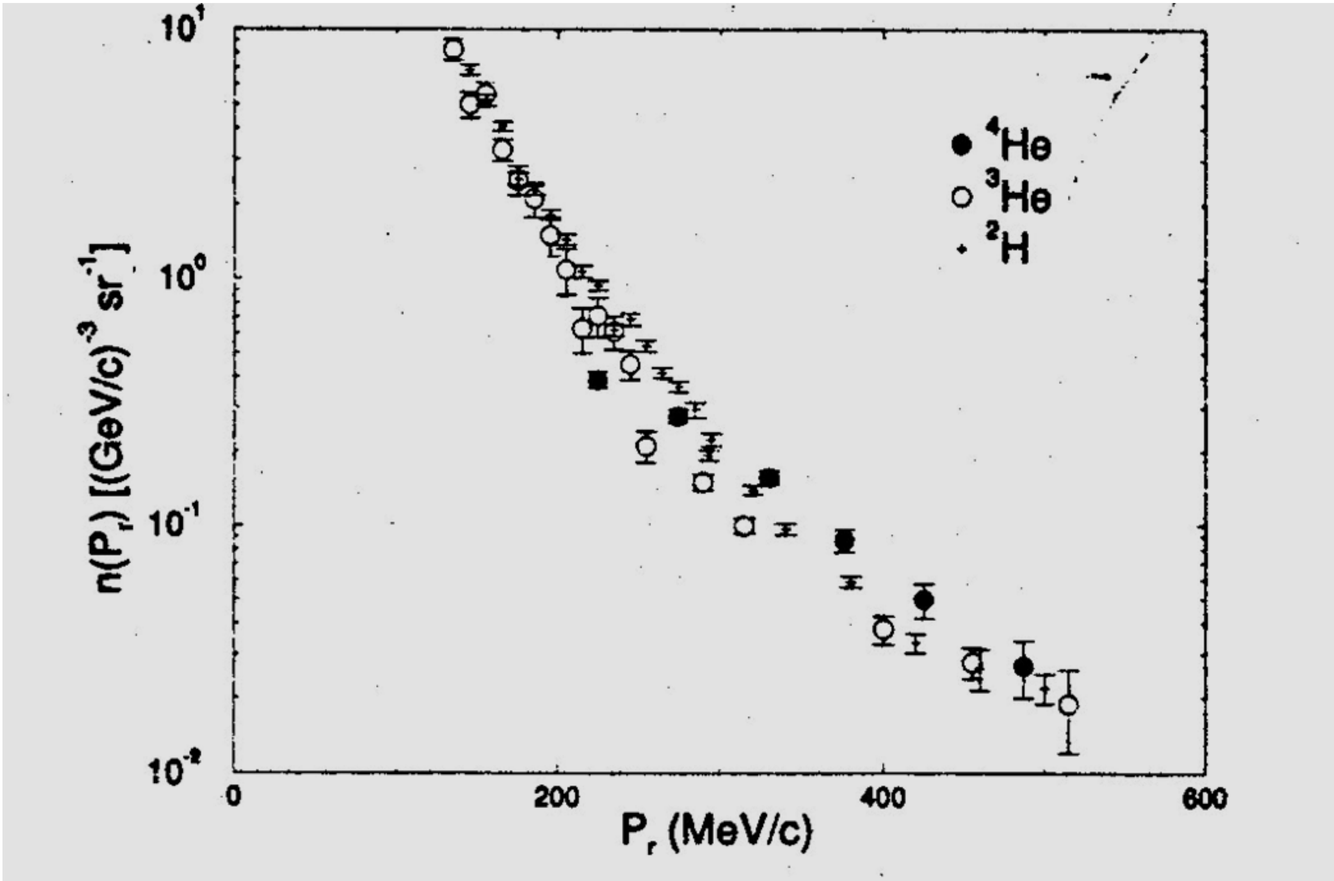


FIG. 3. Radiatively corrected cross section in the 2bbu channel. The curves are the result of a microscopic calculation based on a diagrammatic expansion of the cross section [31].

The comparison between nucleon momentum distributions in deuteron, ^{3}He and ^{4}He extracted from the e.-m. experiments like ^{4}He(e,e'p)R

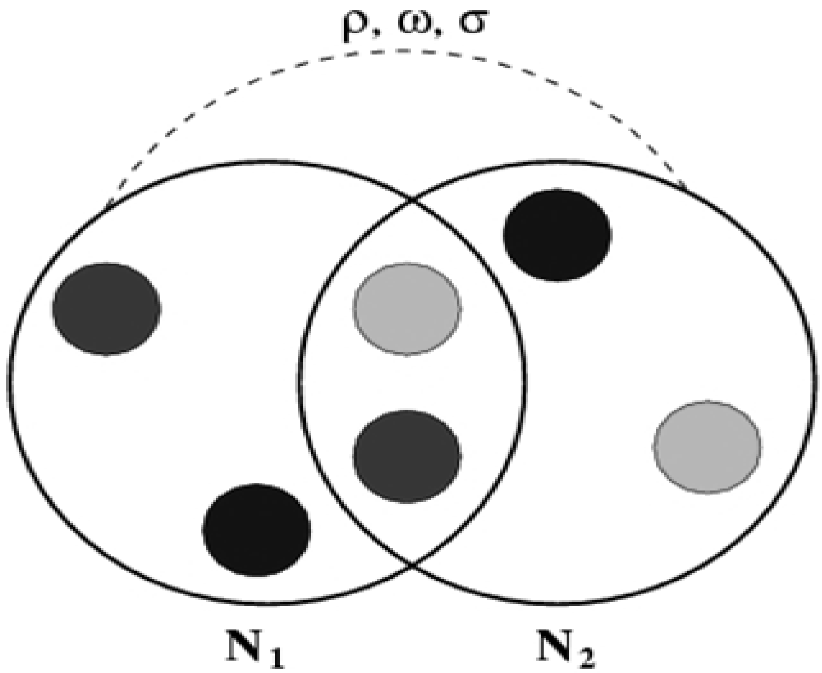


The experimental results demonstrate unambiguously the dominant contribution from direct interaction of the virtual photon with strongly overlapped two-nucleon pair in ^{4}He. In particular, it may be illustrated by the momentum distributions in ^{2}He, ^{3}He and ^{4}He extracted from different experiments.

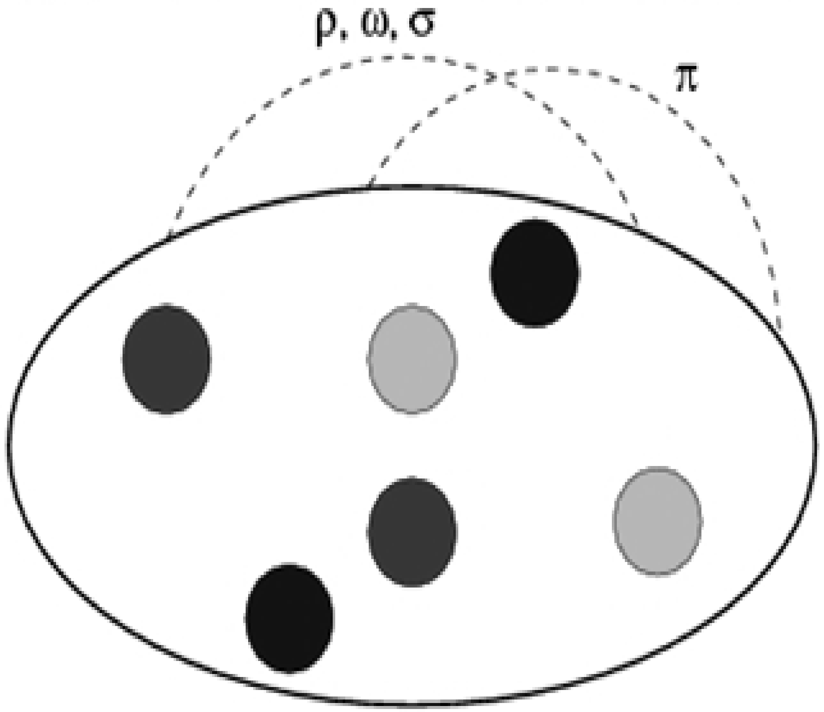
Alternative picture of nuclear force at short and intermediate distances. Why the dibaryons?

In case of heavy meson exchange with $m_\rho \cong m_\omega \cong 800$ MeV the Compton wave length $\lambda_\rho \cong \lambda_\omega \cong 0.2$ fm, so that two nucleons overlap **deeply!**

Thus, it appears, that more consistent description one can reach if to assume that the σ- ρ- or ω-meson is moving simultaneously in the field of two nucleon cores, or simply around six-quark bag, like



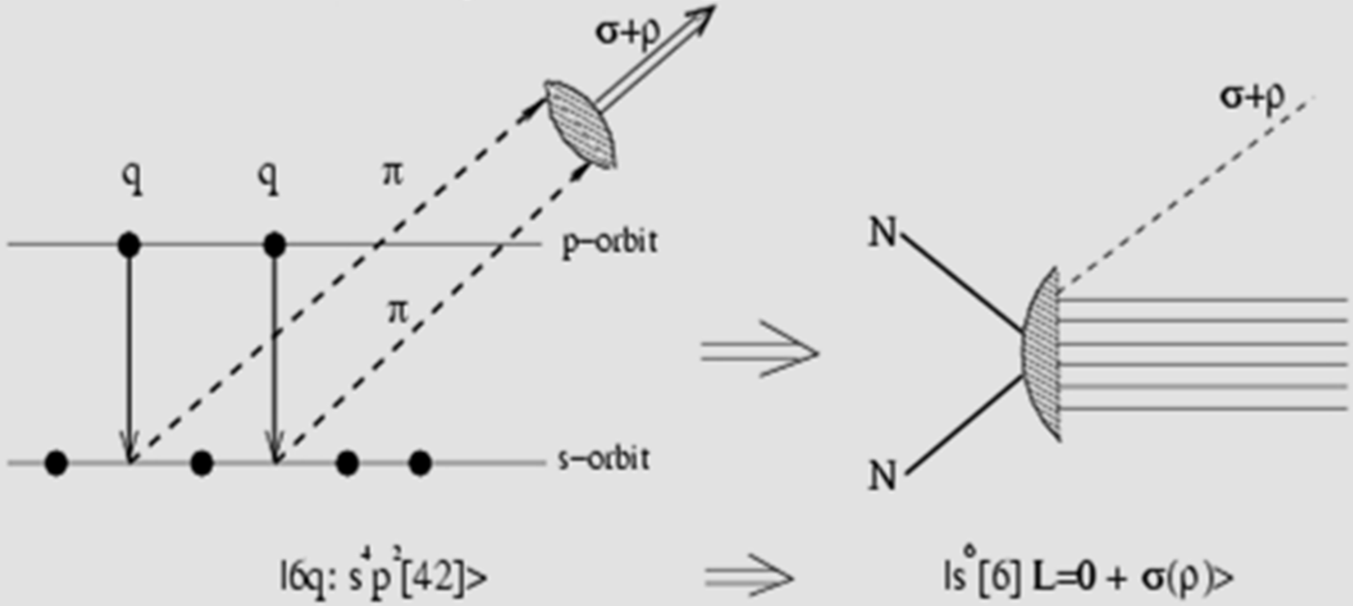
The idea of the dressed six-quark-bag



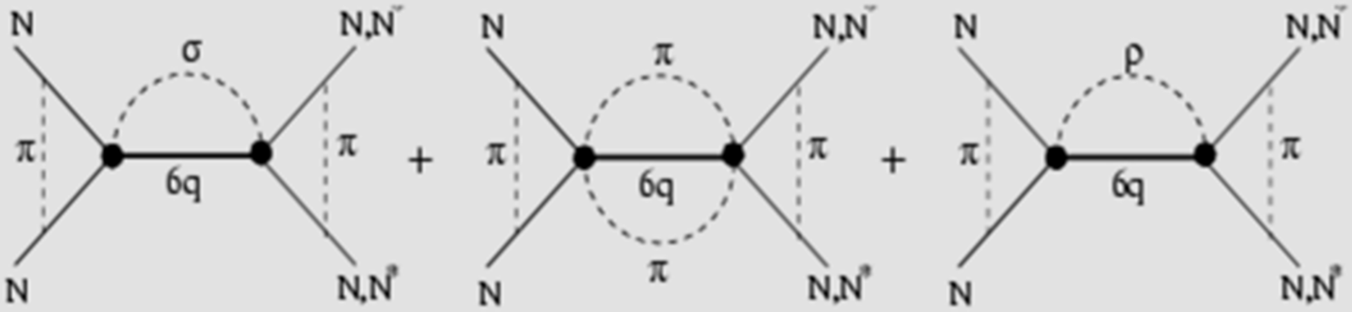
But the problem can by no means be solved by simple reformulation 2x3-clusters to common six-quark degrees of freedom and should be posed on a *different physical ground*.

We must incorporate into our consideration a few new concepts and features, e.g. restoration of (broken) chiral symmetry in multi-quark bag, non-linear mode of quark interaction with σ-field etc.

The 6q dressing mechanism.

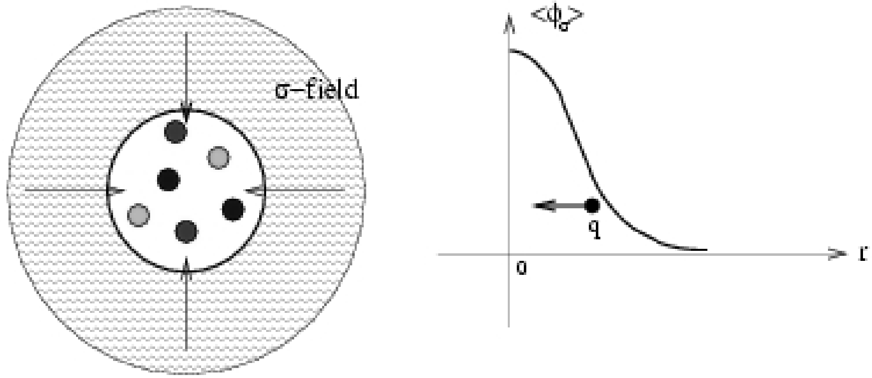


The new dressing mechanism can be presented in the form of diagrams:



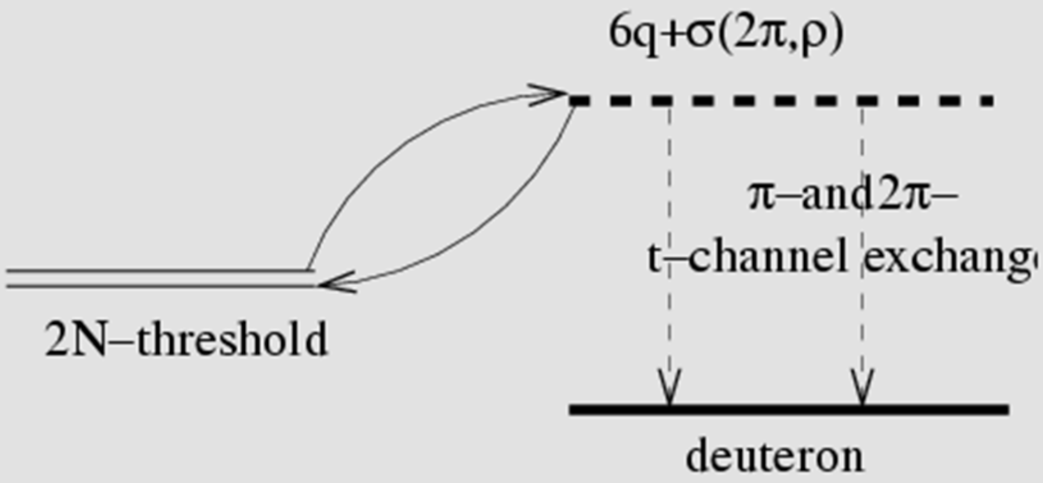
The effects of strong σ-field around six-quark bag.

This strong σ-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 σ-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.

(iii) In six-quark system with two p-shell excited quarks the energy gain should be even higher, e.g. $\Delta E_{\sigma-6q} \simeq 600 \div 700$ MeV! As a result, the mass of the dressed six-quark bag occurs ca. 2.1 GeV, i.e. near the 2N-threshold.



So that, if to incorporate additional (to the DBS) t-channel π and 2π-exchanges they will induce an additional moderate attraction in 2N-system which leads eventually to the bound deuteron state in $^3S_1 - {}^3D_1$ channel and $^1S_0$-virtual state in $^1S_0$-channel.

Thus, from this point of view, the inner part of the deuteron state consists mainly from *the dressed dibaryon!* Our microscopic calculations confirm this: the weight of the DBS state in deuteron happened around 3.5%!

Estimates of the respective energy gains in various systems due to coupling to σ-field.

(i) Energy effects of coupling the σ- and ω-fields with nucleon (3q) core within QBM have been studied recently by B. Jennings et al. They found, in particular $\Delta E_{N\sigma}(\text{in } N_{gr.st.}) \simeq 120$ MeV.

(ii) The above mechanism of enhanced σ field (and scalar $\pi\pi$ correlation) $2q\,(p\text{-wave}) \to 2q\,(s\text{-wave}) + \sigma$ can be predicted also for the Roper resonance:

$$|s^3\rangle_N \Rightarrow |sp^2\rangle_{N^*(0^*)} \overset{2\pi}{\Rightarrow} |s^3 + \sigma\rangle|_{L_\sigma} \to E^*(1440).$$

Non-shifted mass of the Roper resonance should be $\sim 2\hbar\omega \simeq 2$ GeV vs. $m(R) = 1440$ MeV, i.e. $\Delta E_{\sigma-6q} \simeq 500$ MeV!

Thus we have a hierarchy of energy gains in various hadrons due to strong coupling to σ-field:

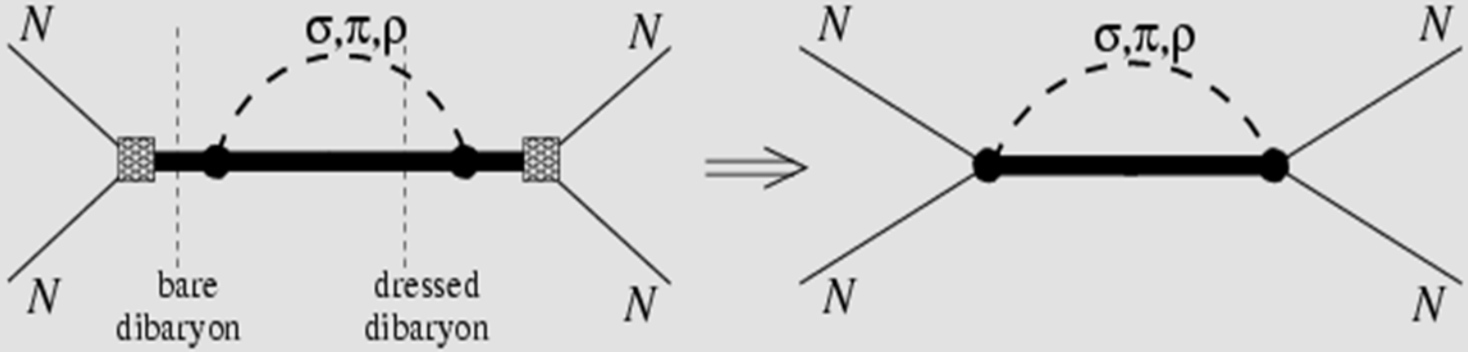
$$N_{gr.st.} \Rightarrow \Delta E_\sigma \simeq 120\,\text{MeV};$$

$$N^*(1440) \Rightarrow \Delta E_\sigma \simeq 500\,\text{MeV};$$

$$\text{DBS}(6q + \sigma) \Rightarrow \Delta E_\sigma \simeq 600 \div 700\,\text{MeV};$$

This additional enhancement of the σ-field effects in symmetric six-quark bag (in DBS) comes from partial restoration of chiral symmetry in multi-quark system with high density. (In fact, the fully symmetric six-quark bag has a highest possible density!) This chiral restoration is in a nice agreement with recent findings of Hatsuda and Kunihiro and Glozman and Cohen who suggested a chiral restoration at high excitation in baryons (as demonstrated e.g. by appearance of close parity doublets high in the spectra). In fact, $|s^4p^2[42]\rangle$ is $2\hbar\omega$ excited configuration in 6q-channel!

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



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

The similar σ-dressing of the Roper resonance:

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

reduces its mass about 0.5 GeV!

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:

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

with

$$V_{LL'}^{SJ}(\mathrm{r}, \mathrm{r}') = \sum_{M} Z_{LS}^{JM}(\mathrm{r})\, \lambda_{SLL'}^{J}(E)\, Z_{L'S}^{JM^*}(\mathrm{r}'), \tag{16}$$

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

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

and the energy-dependent coupling constants $\lambda_{SLL'}^{J}(E)$ 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:

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

The phase shifts of NN scattering in low partial waves

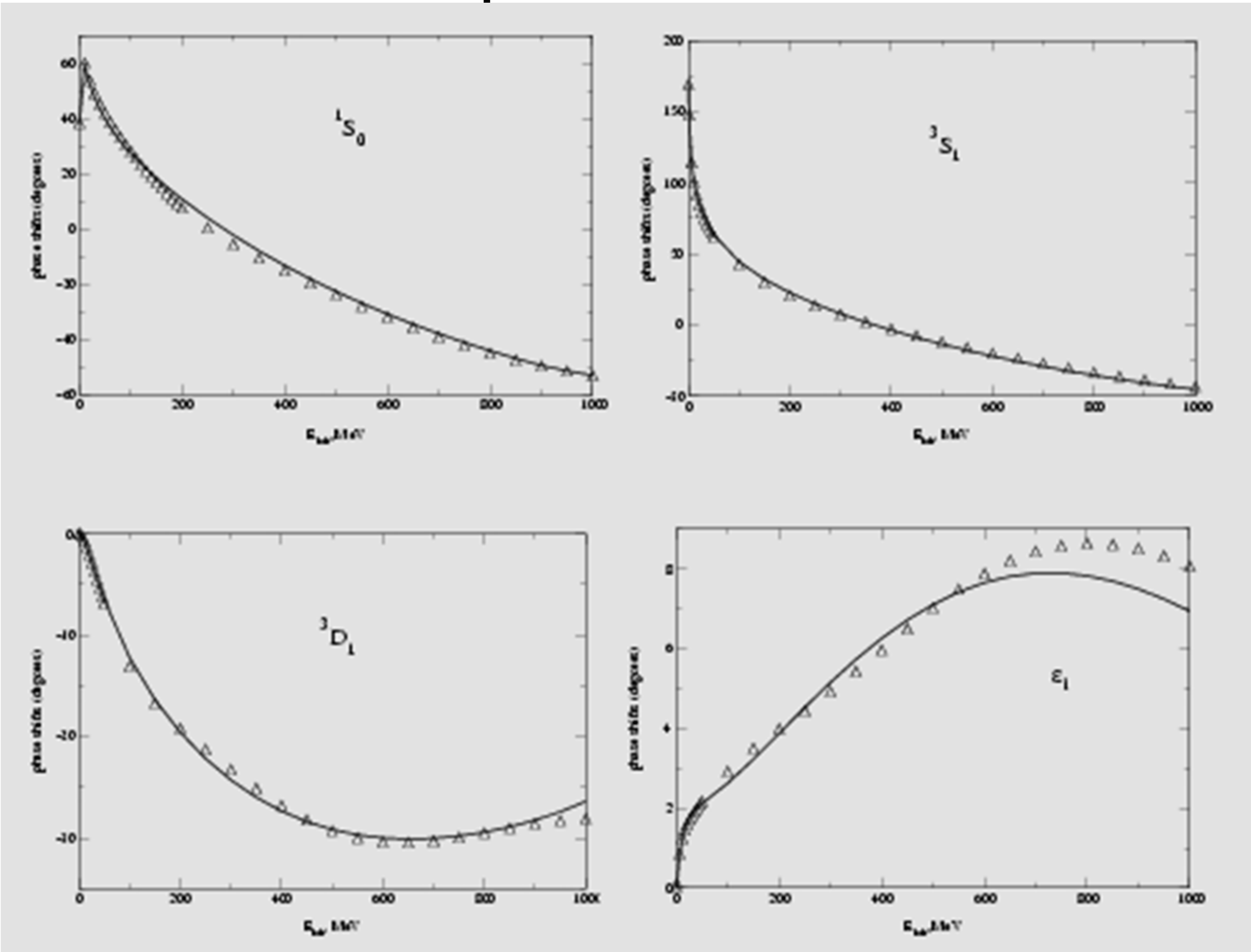
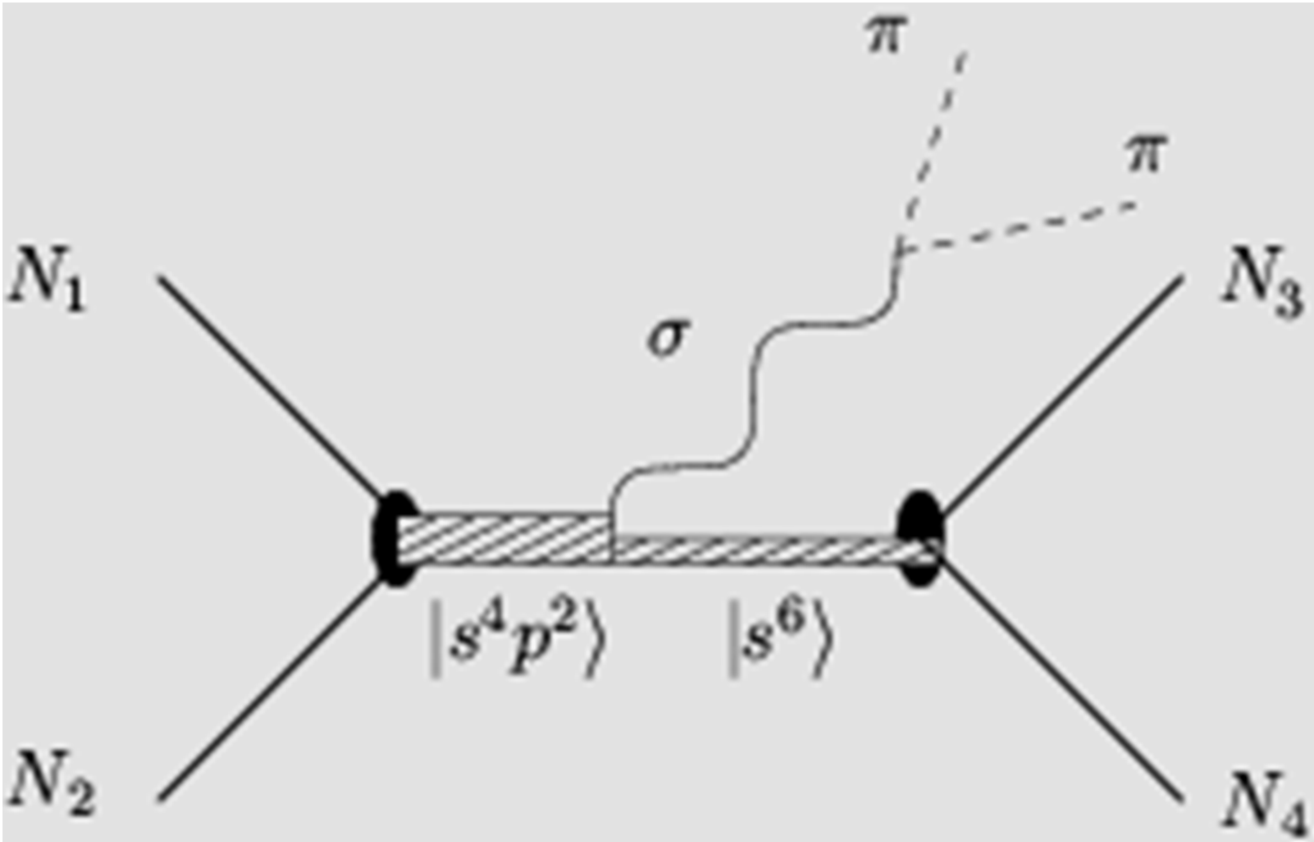


Table 1. Deuteron properties in the dressed bag model.

Model	E_d(MeV)	P_D(%)	r_m(fm)	Q_d(fm^2)	μ_d (μ_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) $P_{\text{in}} = 3.66\%$	2.22454	5.22	1.9715	0.2754	0.8548	0.8864	0.0259
DBM (2) $P_{\text{in}} = 2.5\%$	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

The dibaryon model prediction for the two-pion production via σ-meson at p+n or p+p collisions



γN, πN, … $\Leftrightarrow$ NN collisions

- **Nucleon Resonances**
  - s-channel production $\leftrightarrow$ associate production

    (if 2-body decay)
  - excitation by γ, π, ... $\leftrightarrow$ virtual π, σ, ...

- **NN system**
  - only measurements on d $\leftrightarrow$ NN and Nd collisions

π and $\pi\pi$ Production @ CELSIUS and COSY

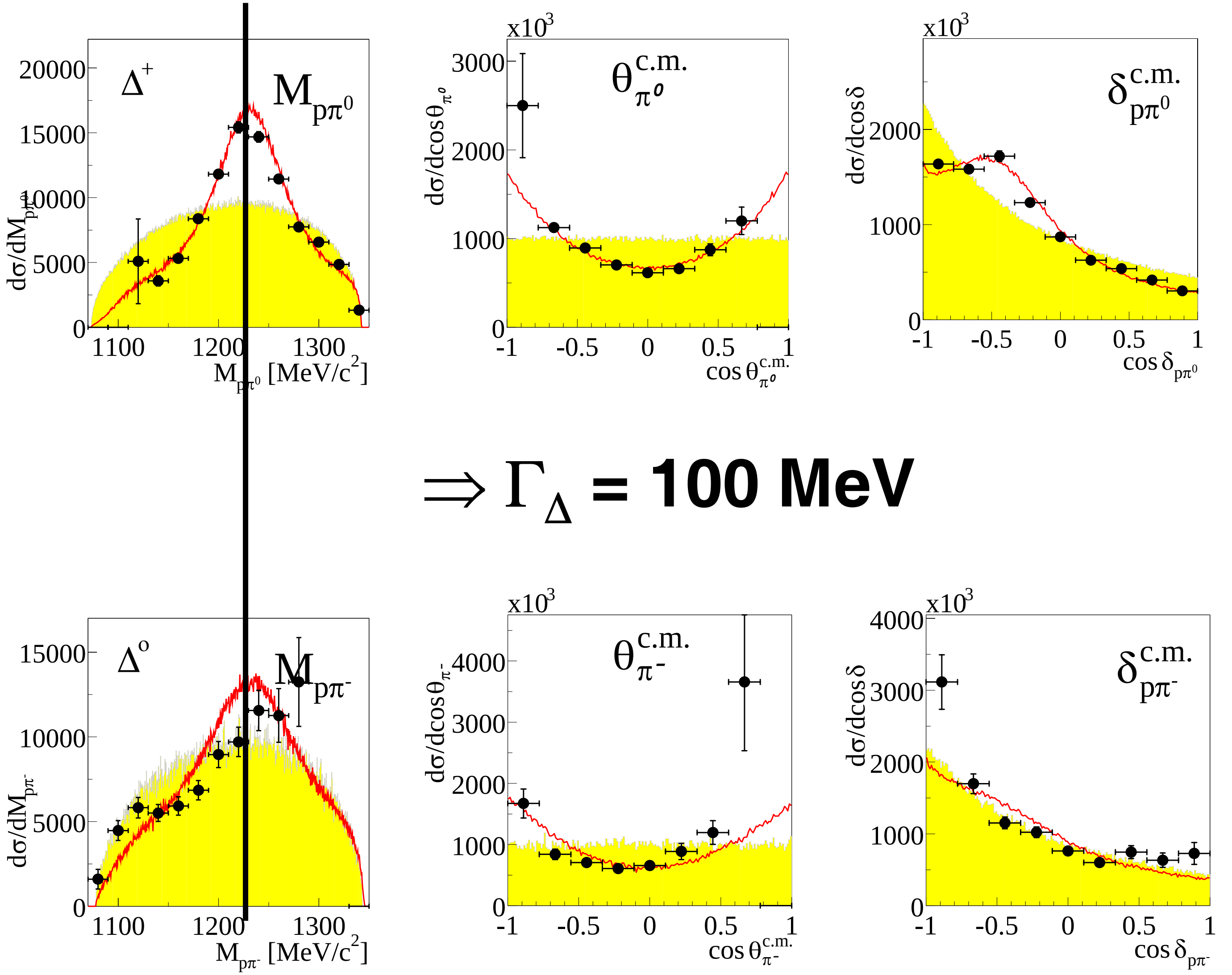
- Δ — **N^*(1440)**

  test case — *investigate by σ excitation*

- excitations in the **NN** system

- **NN** excitations in Nuclei

Δ excitation in $pN \rightarrow NN\pi$



$pp \rightarrow pp\pi^0$

@ 893 MeV

$\Rightarrow \Gamma_\Delta$ = 100 MeV

$pn \rightarrow pp\pi^-$

@ 893 MeV

Roper Resonance
$N^*(1440)$

- **πN and γN:**
  - Roper´s resonance
  - a resonance without seeing it
- **New generation of measurements:**
  - the „narrow“ Roper

How to excite the Roper?

- N $\rightarrow$ N^{*} (1440)

I(J^p): ½(½ $)^+$ $\rightarrow$ ½(½ $)^+$

$\Rightarrow$

- **scalar-isoscalar excitation:** σ

  or

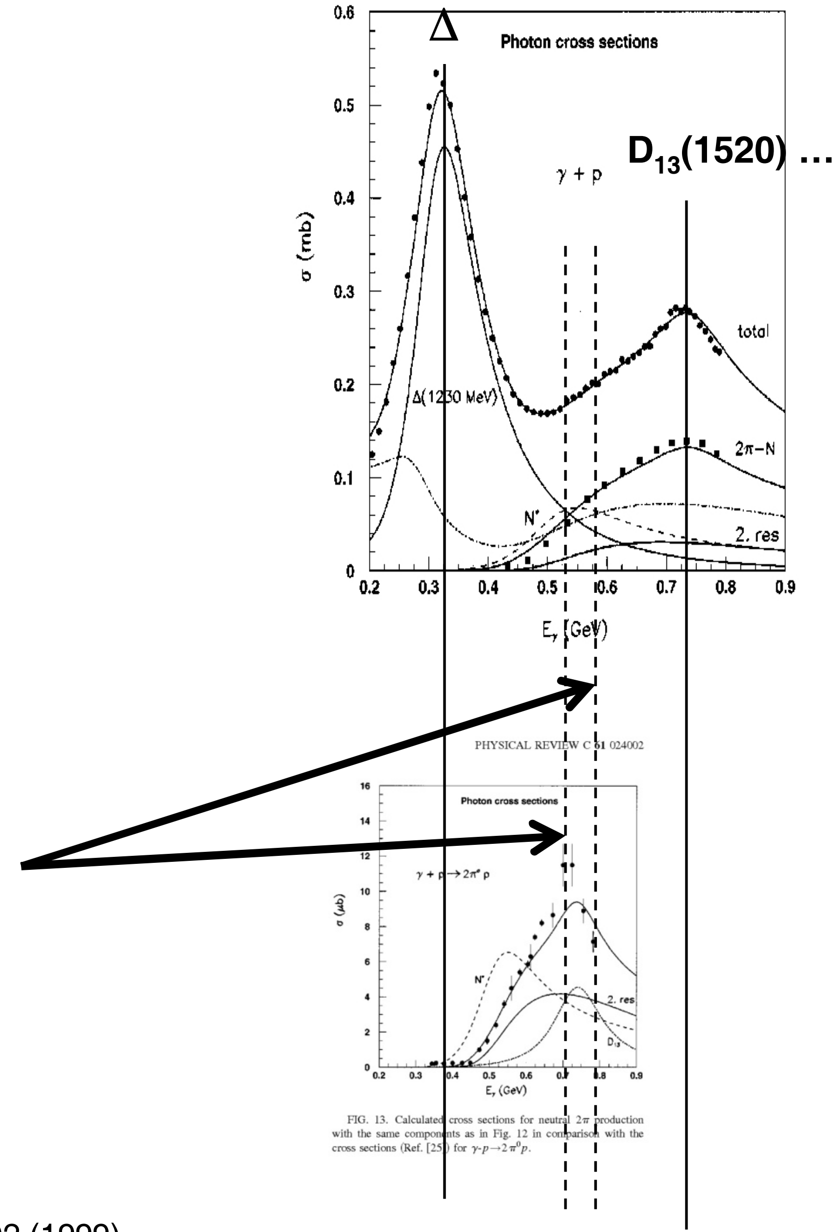
- **isovector excitation:** π**,** γ **(M1), …**

  with spinflip preferred

Where to see?

- γ**N**
  - **photo absorption**
  - γ**p** $\rightarrow$ **p** $\pi^0\pi^0$

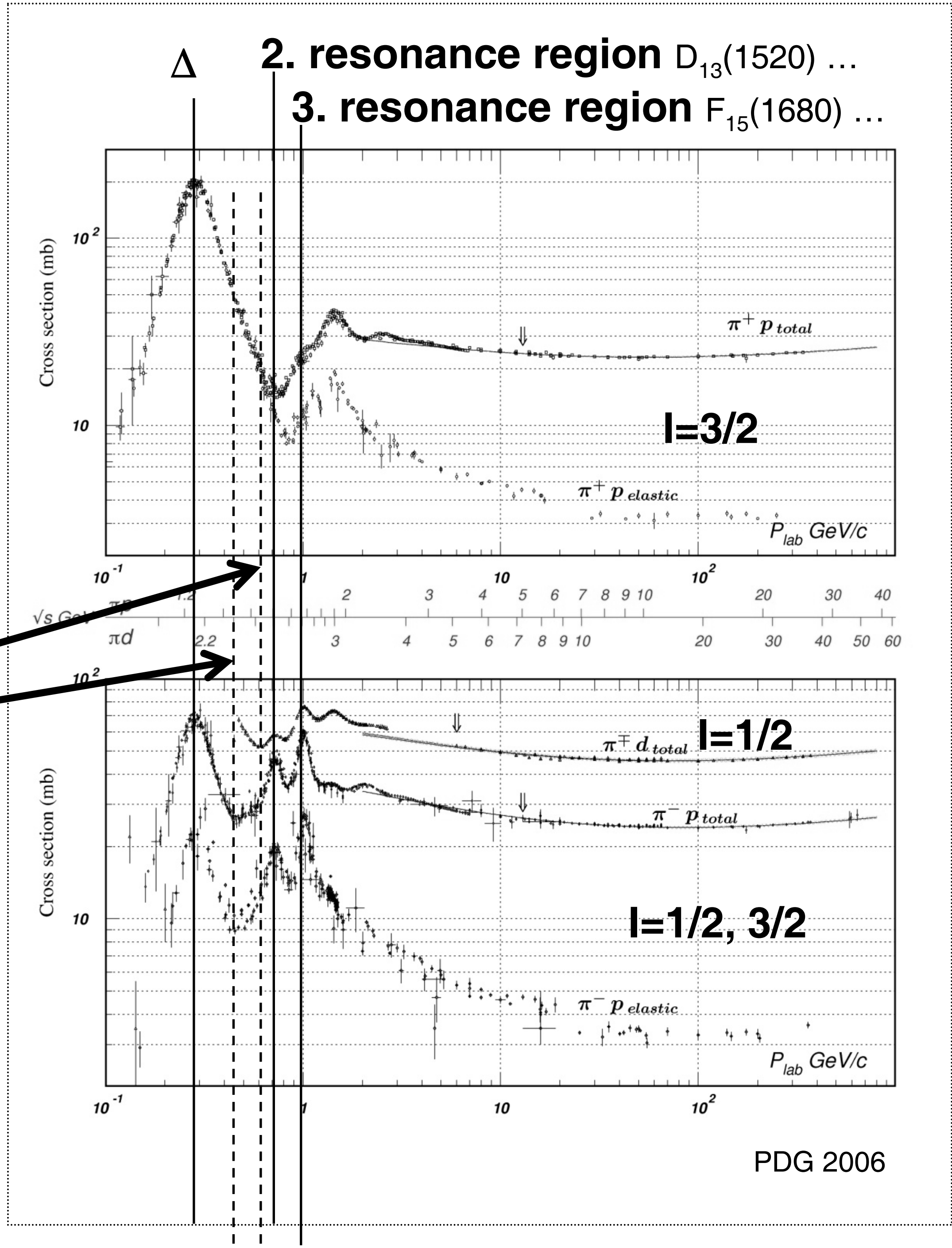
- **Where is the Roper?**



Morsch and Zupranski, PRC 61, 024002 (1999)

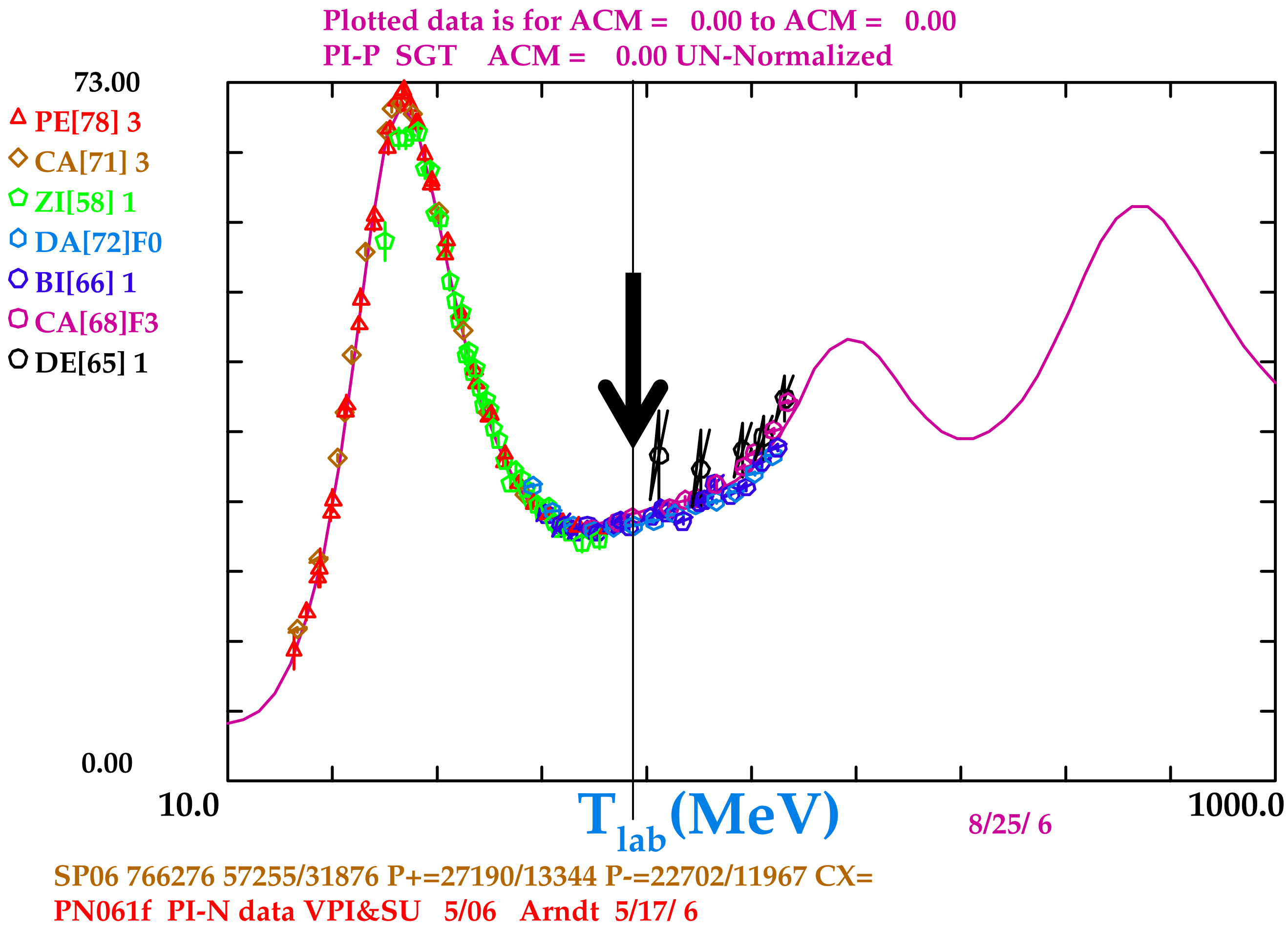
Where to see?

- **πN scattering:**
- **Where is the Roper?**



π^- p total cross section

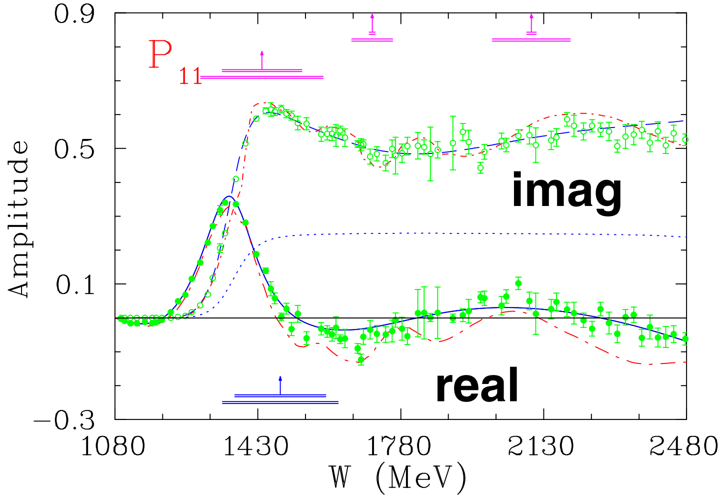
Where is the Roper?

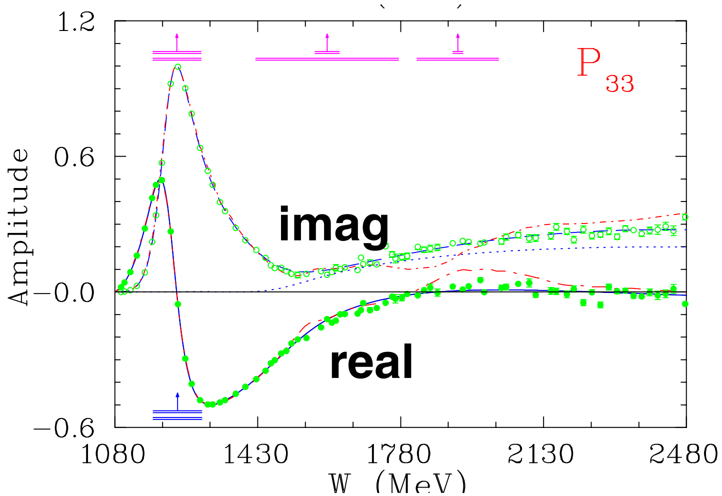


SAID data base

πN partial wave analysis

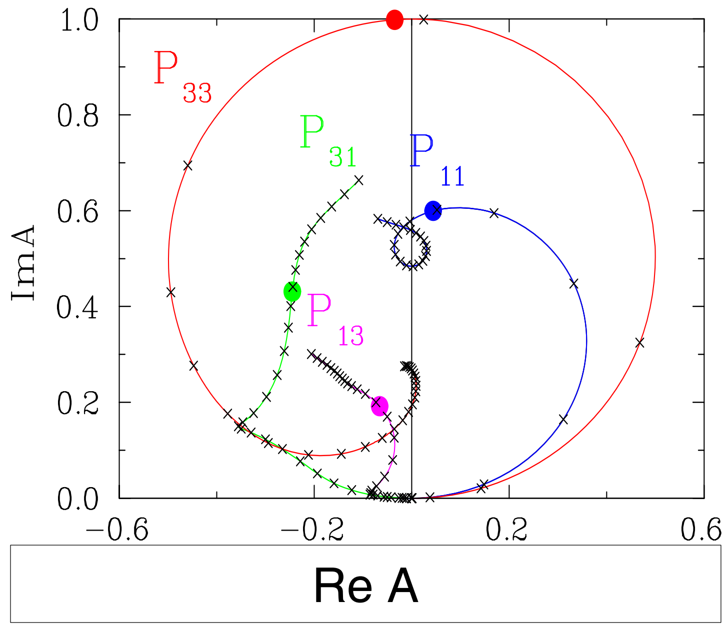
- **Partial wave amplitudes**





- **Argand plot**

SAID nucl-th/0605082



here is theRoper :

SAID: $\mathbf{M_{pole} = 1357}$ **MeV**

$\mathbf{\Gamma_{pole} = 160}$ **MeV**

Bonn *(Sarantsev et al.)*: **1371 (2)**

πN + γN **184 (20)**

What does the „Bible“ tell us today?

PDG 2006:

$N(1440)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

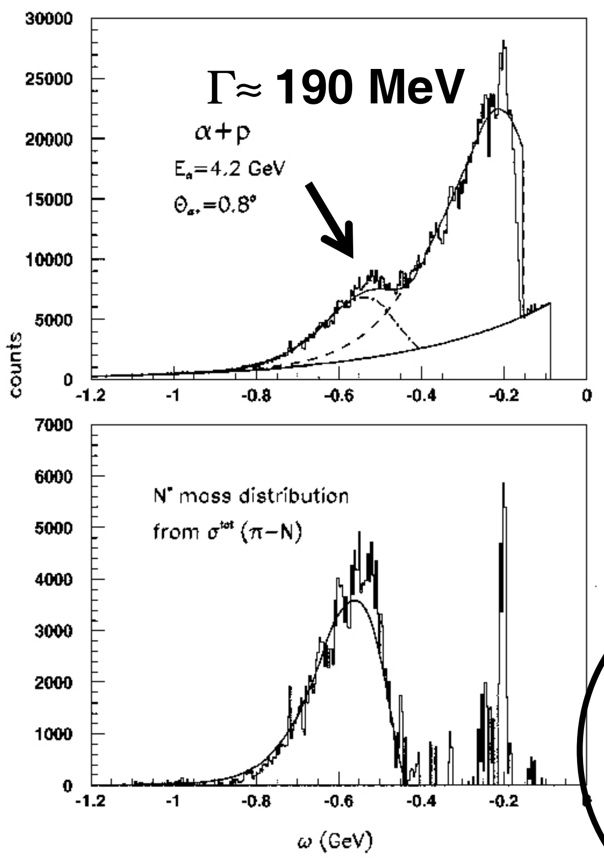
Breit-Wigner mass = 1420 to 1470 (≈ 1440) MeV
Breit-Wigner full width = 200 to 450 (≈ 300) MeV
$p_{beam} = 0.61$ GeV/c $\quad 4\pi\bar{\lambda}^2 = 31.0$ mb
Re(pole position) = 1350 to 1380 (≈ 1365) MeV
−2Im(pole position) = 160 to 220 (≈ 190) MeV

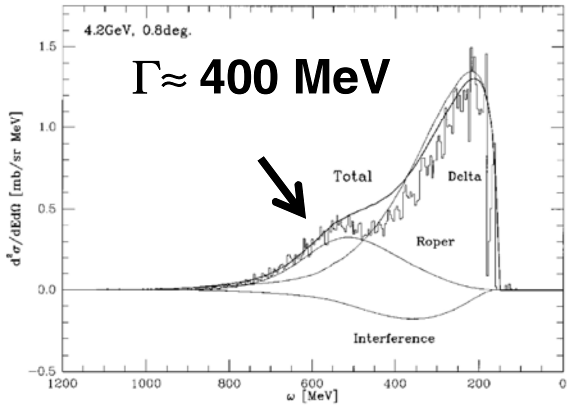
$N(1440)$ DECAY MODES	Fraction (Γ_i/Γ)
$N\pi$	0.55 to 0.75
$N\pi\pi$	30–40 %
$\Delta\pi$	20–30 %
$N\rho$	<8 %
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	5–10 %
$p\gamma$	0.035–0.048 %
$p\gamma$, helicity=1/2	0.035–0.048 %
$n\gamma$	0.009–0.032 %
$n\gamma$, helicity=1/2	0.009–0.032 %

New Generation of Experiments visualizing a „narrow“ Roper (?)

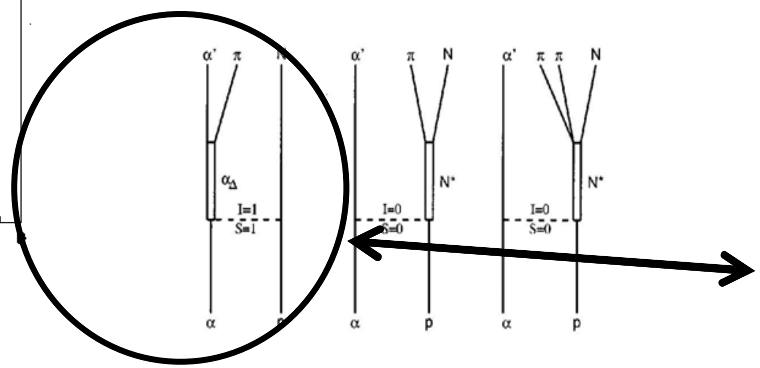
- **α p $\rightarrow$ α X @ 4.2 GeV (Saturne)**
- **$J/\psi \rightarrow \bar{N} N^*$ and $N \bar{N}^*$ (BES)**
- **$pp \rightarrow np\pi^+$ @ 1.1 and 1.3 GeV (WASA)**

New Generation of Experiments:
1. $\alpha\, p \rightarrow \alpha\, X$ (Saclay)





Hirenzaki et al., PRC 53, 277 (1996)



- **scalar-isoscalar probe α**

  however:

- **interfering background from projectile excitation**

Morsch et al., PRL 69, 1336 (1992) and PRC 61, 024002 (1999)

New Generation of Experiments: 3. pp $\rightarrow$ npπ^+ @ 1.1 and 1.3 GeV

(WASA)

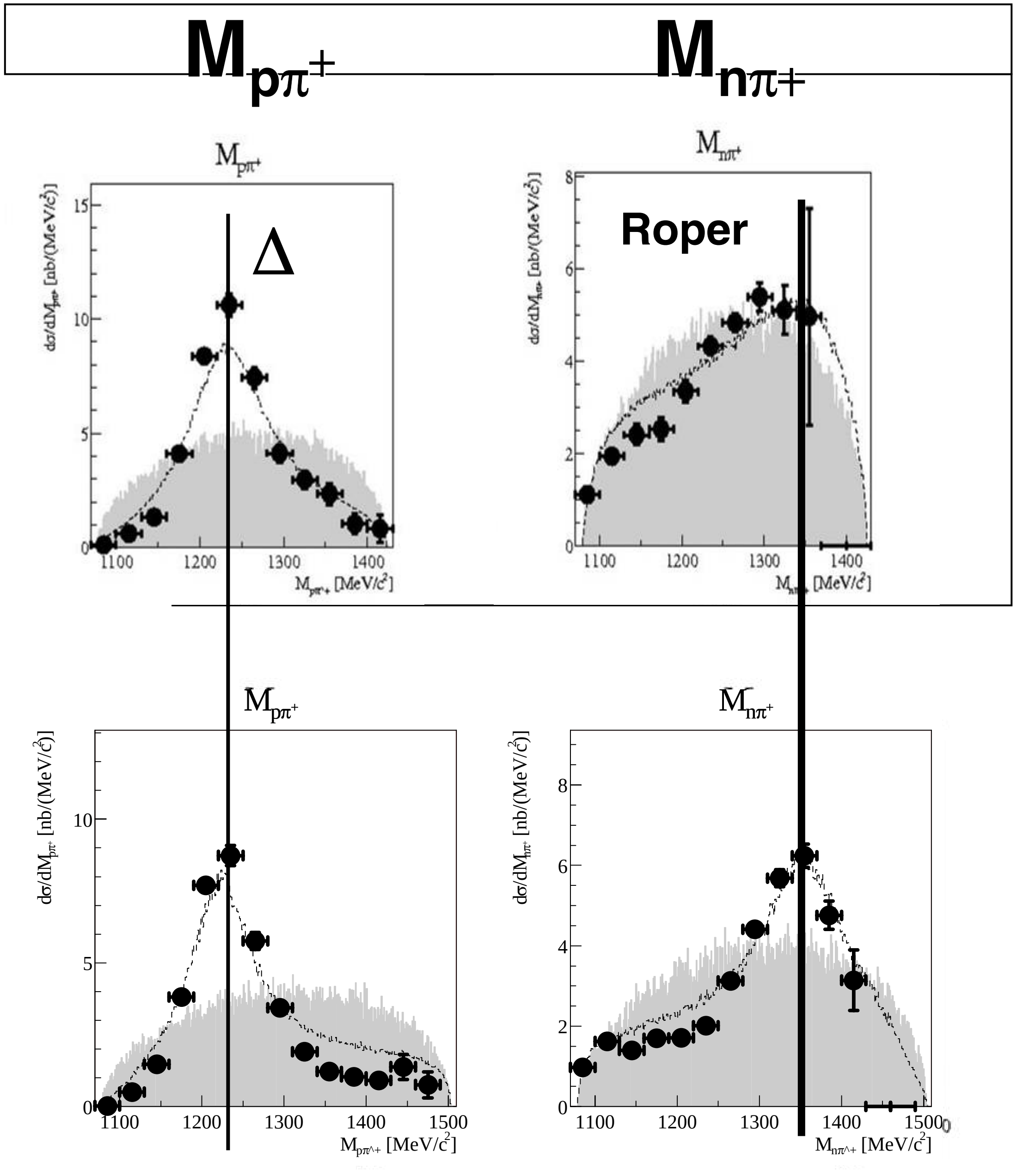
- **beam energy allows only Δ and Roper excitations** $\Rightarrow$
  - no kinematic reflections
  - clean and simple situation
- **scalar-isoscalar (σ) excitation of Roper possible**
- **pπ^+ invariant mass: I=3/2** $\Rightarrow$ **only Δ^{++}**
- **nπ^+ : I=1/2, 3/2** $\Rightarrow$ **Roper** (Δ^+ very weak)

3. $pp \rightarrow np\pi^+$

(WASA)

- **T_p = 1.1 GeV**

- **T_p = 1.3 GeV**

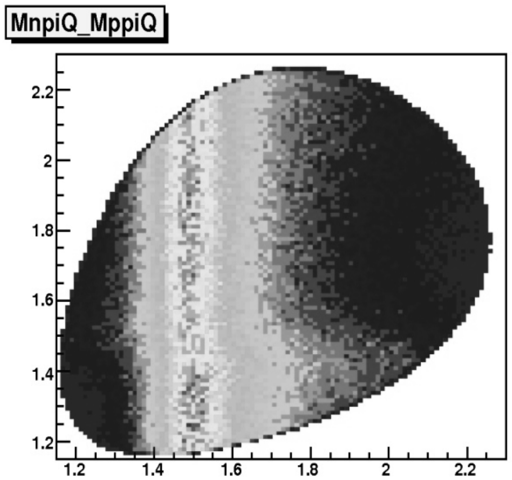


Data prefer Roper values:
M ≈ 1355 MeV
Γ ≈ 140 MeV
(nucl-ex/0612015)

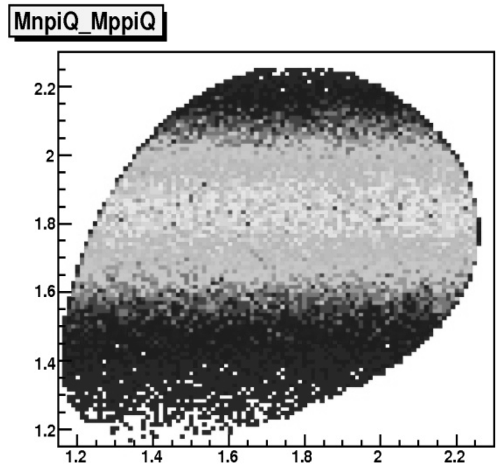
Dalitz plots MC

$pp \rightarrow np\pi^{+}$ @ 1.3 GeV

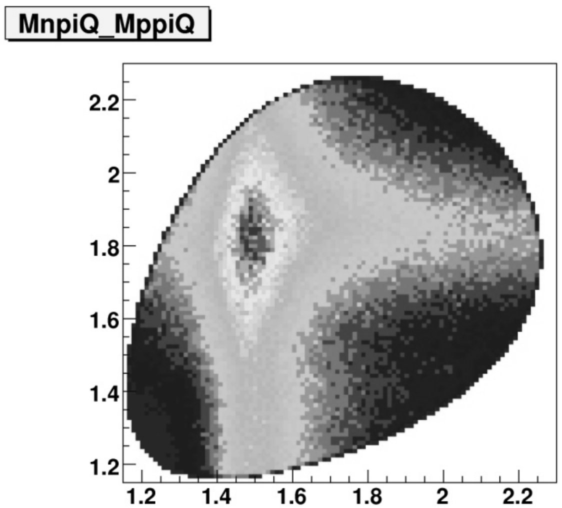
- Δ^{++} and Δ^{+}

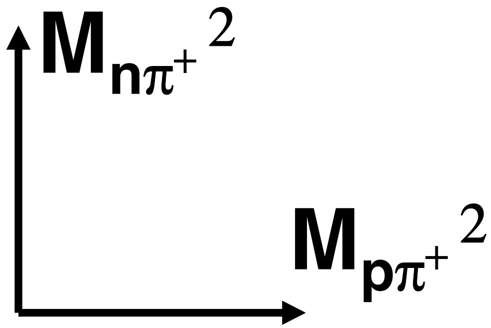


- **only Roper**



- Δ^{++}, Δ^{+}, **Roper**





Decay of Roper

- **decay channels:** **BR(1440)** **BR(1371)**

	PDG 2006	Bonn 2007
(Sarantsev et al.)		
– $N^* \to N\pi$ (2)	0.55 – 0.75	0.61
– $N^* \to N\pi\pi$ (5)	0.30 – 0.40	0.39
– $\to \Delta\pi \to N\pi\pi$	0.20 – 0.30	0.18 (2)
– $\to N\rho \to N(\pi\pi)_{I=L=1}$	< 0.08	
– $\to N\sigma \to N(\pi\pi)_{I=L=0}$	0.05 – 0.10	0.21 (3)
– **$N^* \to \Delta\pi$ / $N^* \to N\sigma$:**	**2 – 6**	**0.9 (2)**

PRC 67 (2003) 052202

pp $\rightarrow$ NN$\pi\pi$

- Subsystems :

- NN *FSI*
- $\pi\pi$ σ *and* ρ ⇦
- Nπ Δ *(1232)*
- N$\pi\pi$ *N^* (1440), N^* (1520)* ⬅
- NNπ(π) *dibaryonic systems (ΔN, $\Delta\Delta$, ...)* ⇦

Status on pp $\rightarrow$ NN$\pi\pi$

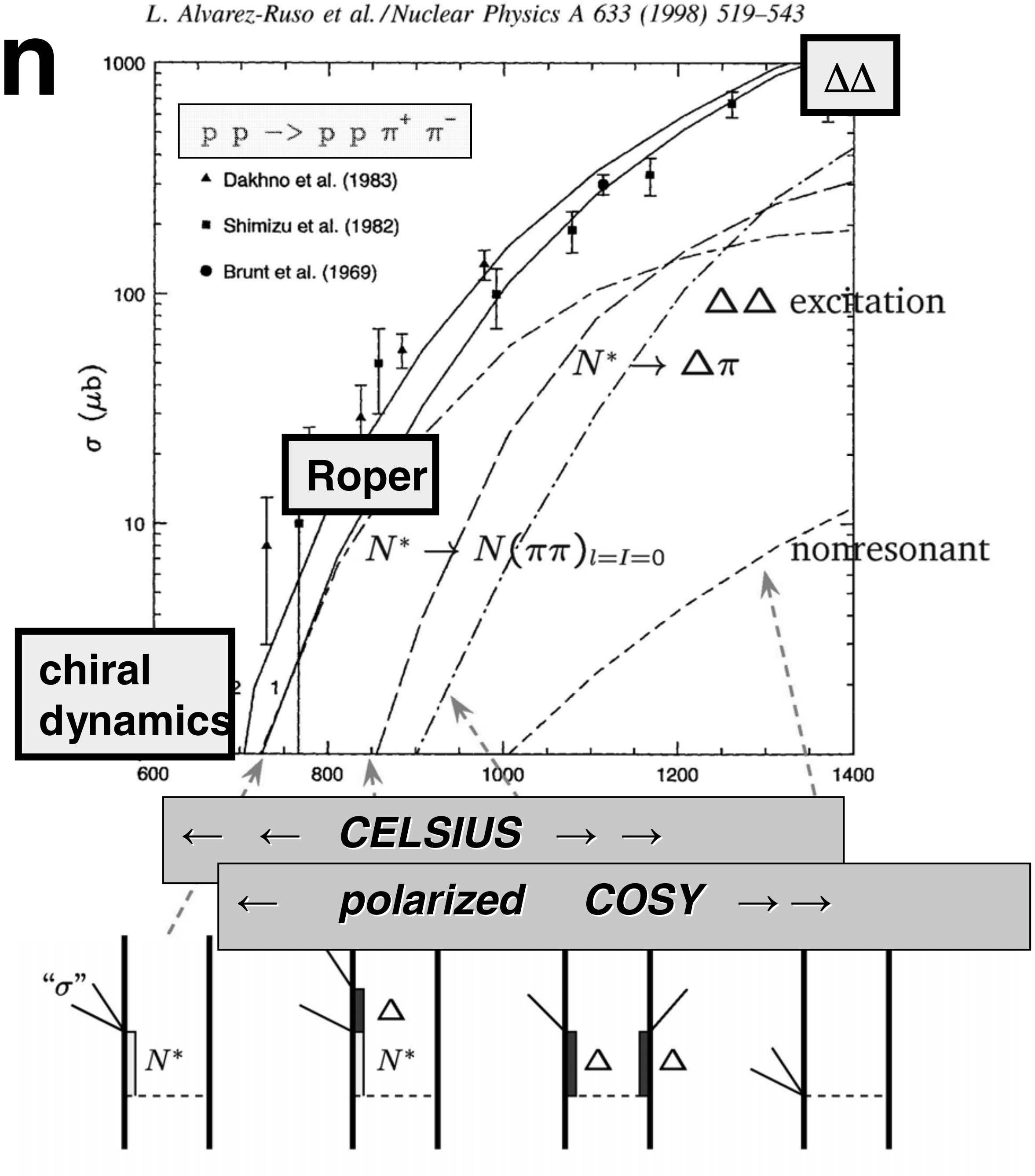
- exit channels :
- exclusive measurements

exit channel	PW	COSY-TOF	CELSIUS-WASA
$pp\pi^+\pi^-$	+	+ ↑	+
$pp\pi^0\pi^0$			+
$nn\pi^+\pi^+$			+
$pn\pi^+\pi^0$			(+)
$d\,\pi^+\pi^0$			+

ππ production

Status quo ante:

experimental and theoretical situation



PROMICE / WASA

- $T_p = 650 - 775$ MeV

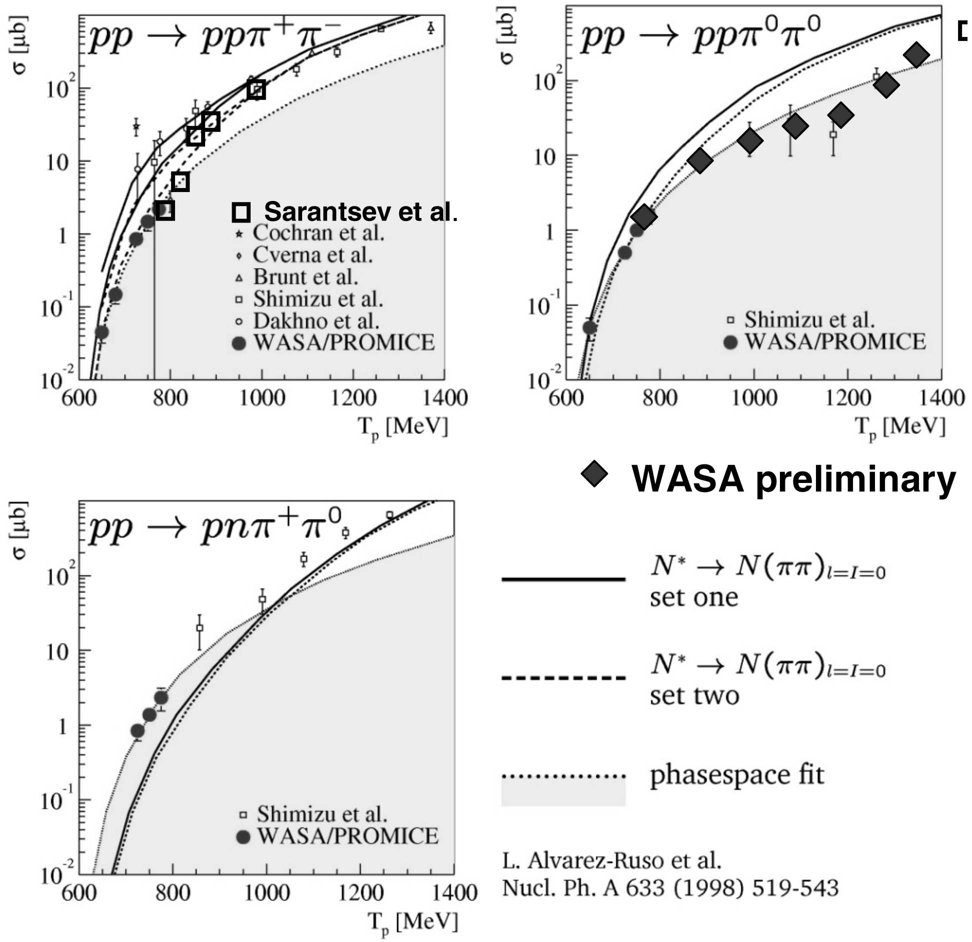
Phys. Rev. Lett. 88 (2002) 192301
Nucl. Phys. A 712 (2002) 75
Phys. Lett. B 550 (2002) 147
Phys. Rev. C 67 (2003) 052202 Rapid Comm.
many conference contributions

WASA

- $T_p = 775 - 1450$ MeV

M. Bashkanov
T. Skorodko

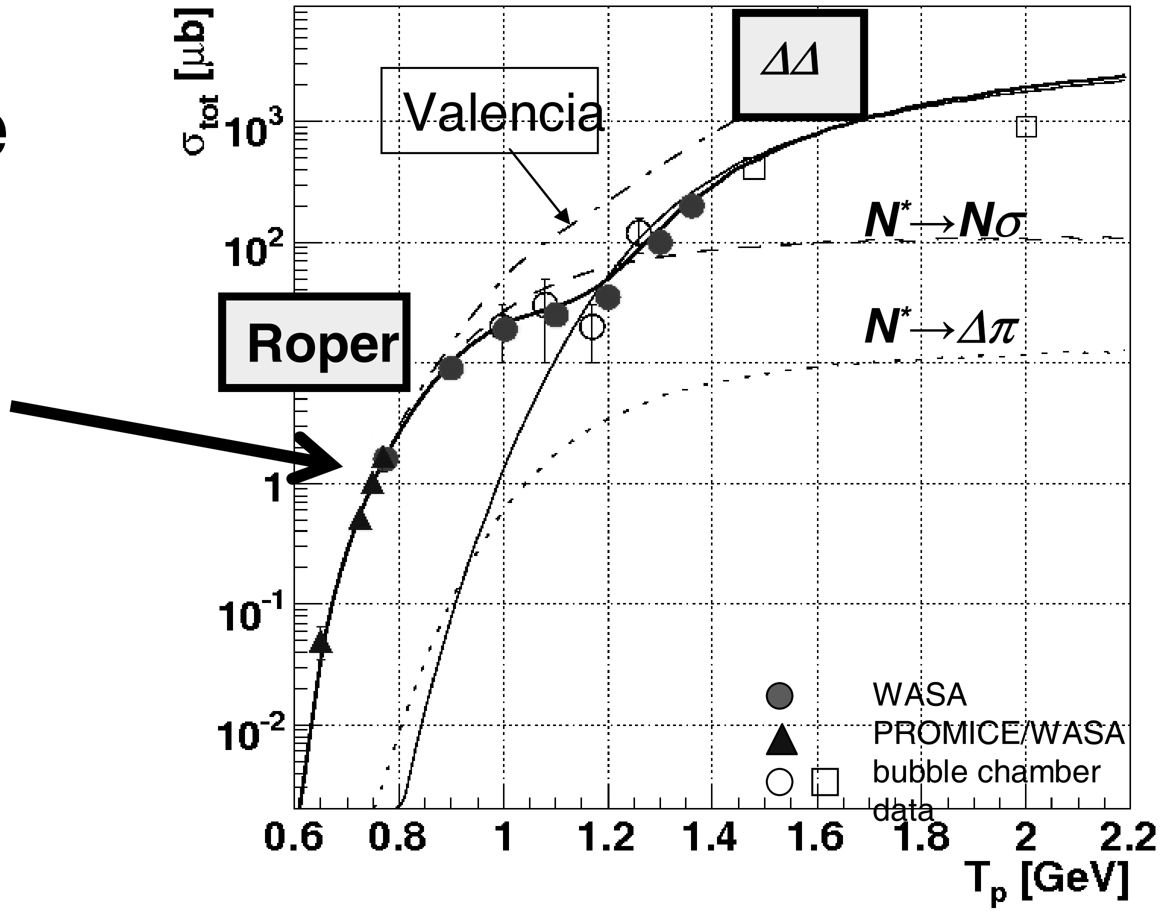
Total Cross Sections



L. Alvarez-Ruso et al.
Nucl. Ph. A 633 (1998) 519-543

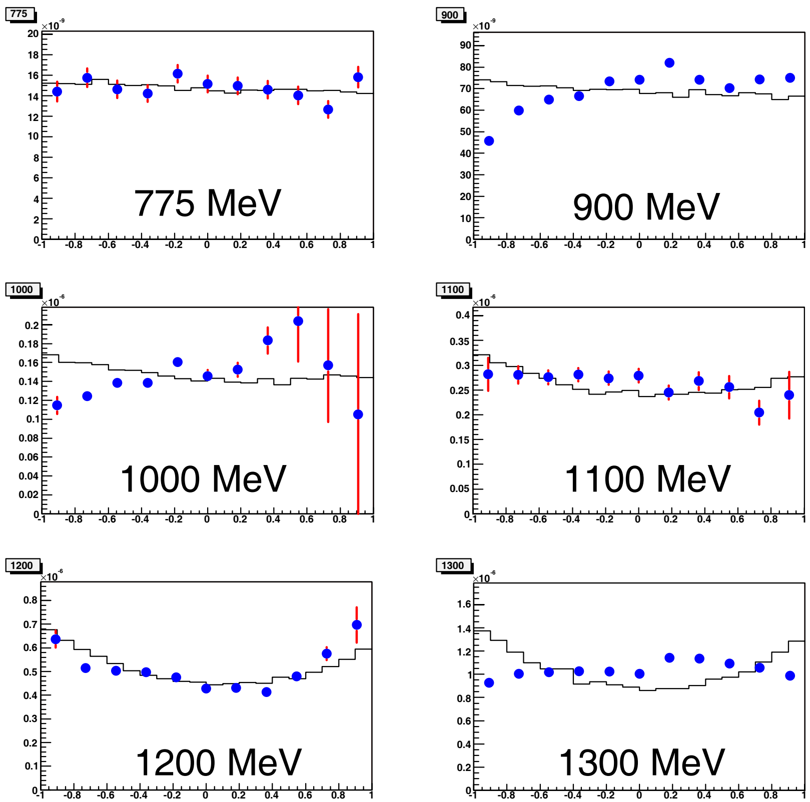
$\pi\pi$ Production: pp $\rightarrow$ pp$\pi^0\pi^0$

- Energy dependence of total cross section

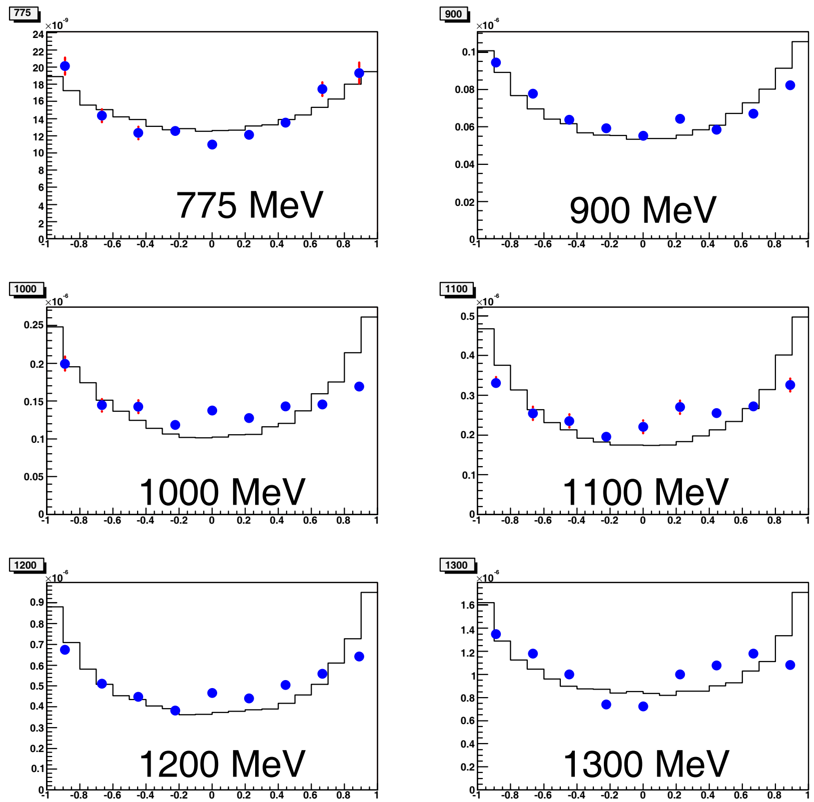


Angular distributions

$\cos \Theta_{\pi}^{cm}$

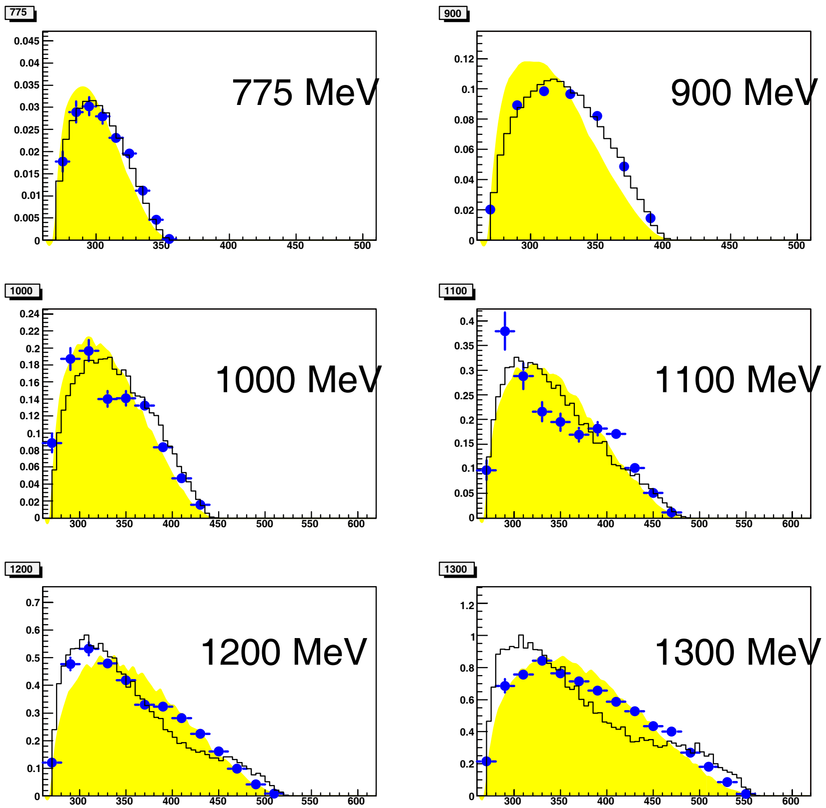


$\cos \Theta_{p}^{cm}$

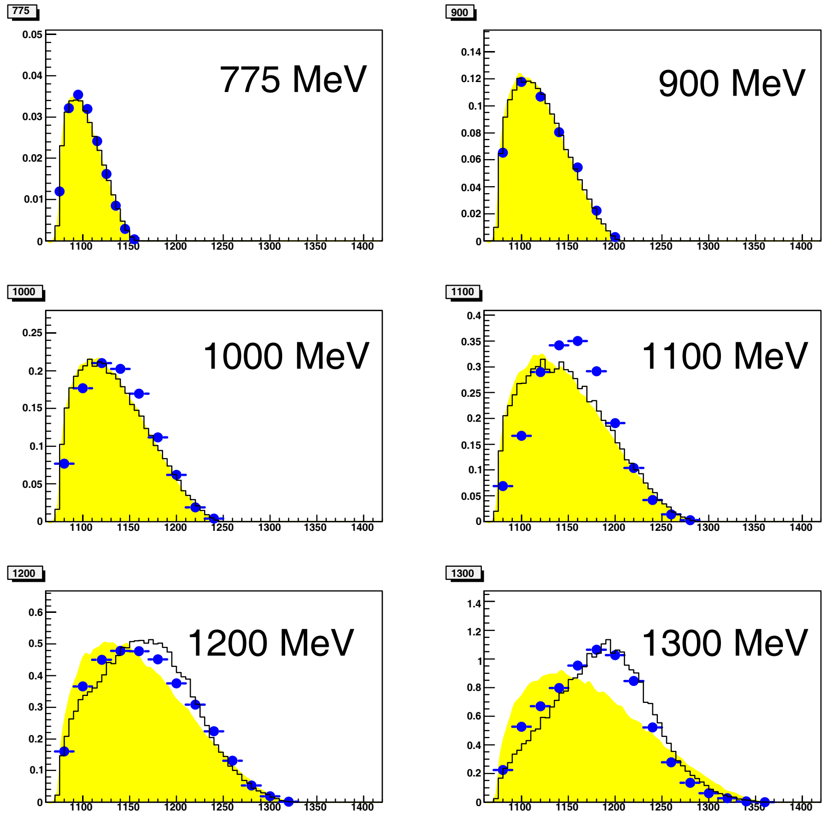


Invariant Mass distributions

$M_{\pi^0\pi^0}$



$M_{p\pi^0}$

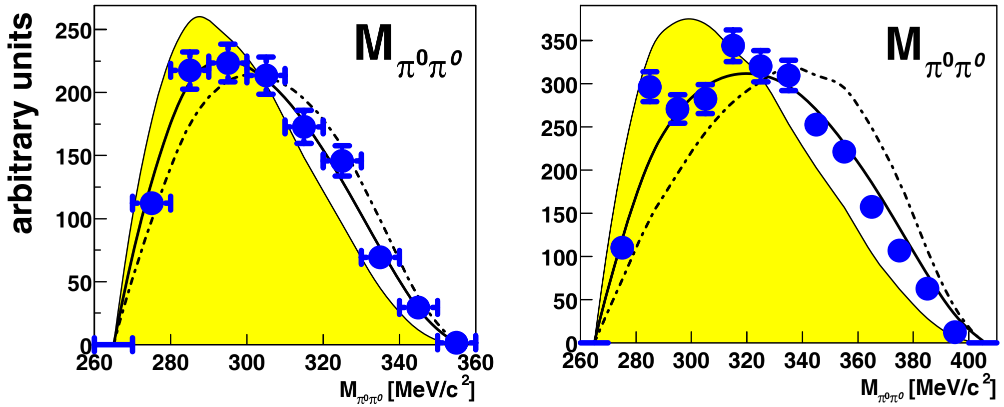


CELSIUS-WASA

$pp \to pp\pi^0\pi^0$

T_p = 775 MeV　　　T_p = 900 MeV

$I_{\pi\pi} = 0$



See talk Tatiana Skorodko

········	BR($\Delta\pi/N\sigma$) = 1 : 2	$I_{\pi\pi} = 0 + 1$
———	BR($\Delta\pi/N\sigma$) = 1 : 8	$I_{\pi\pi} = 0$

⇒ $N^* \to N\pi\pi$

dominantly $N \to N\sigma$!

(nucl-ex/0612015)

Conclusions (1)

- **Roper Resonance historically:**
  - **Originally found in πN phase shifts of P_{11} partial wave**
    - Interpretation as a Breit-Wigner resonance in πN

$\Rightarrow$ **M $\approx$ 1440 MeV, $\Gamma \approx$ 400 MeV**

Conclusions (2)

- **Roper resonance now:**

	M	Γ (MeV)
– **SAID πN** partial wave analysis**:**	**1357**	**160**
– **Bonn** *(Sarantsev et al)* **πN + γN**	**1371(2)**	**184(20)**
– **Explicitly seen in:**		
– **α p $\rightarrow$ α X**	**1390**	**190 (?)**
– **J/ψ $\rightarrow$ n pπ^-**	**1358**	**160**
– **p p $\rightarrow$ p nπ^+**	**1355**	**140**

- **Roper decay N* $\rightarrow$ N $\pi\pi$**
  - **pp $\rightarrow$ NN$\pi\pi$** $\Rightarrow$ dominantly **N* $\rightarrow$ N σ**

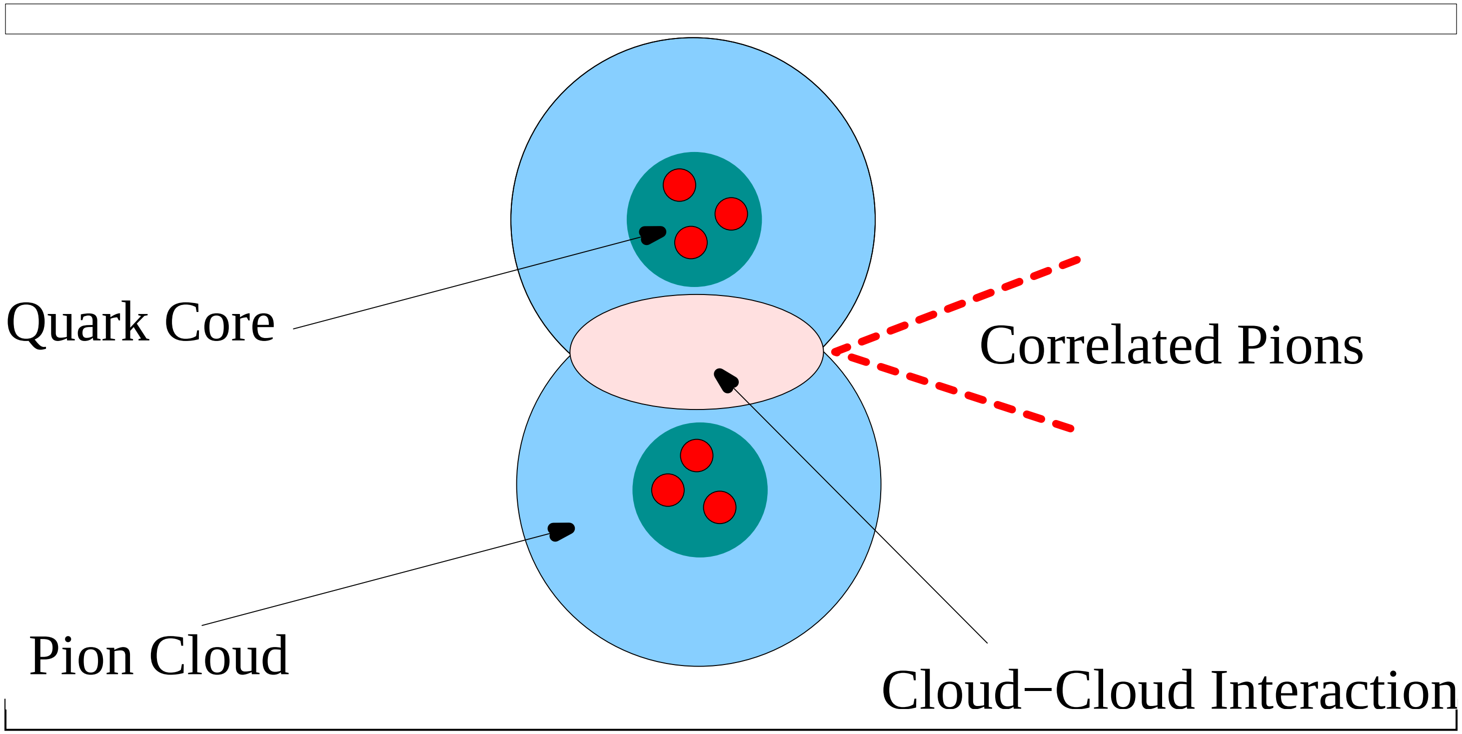
Conclusions (3)

- **Scalar-isoscalar probes (σ exchange) see „narrow“ monopole excitation at very low excitation energy :**

breathing mode @ $\omega \approx$ 400 MeV !

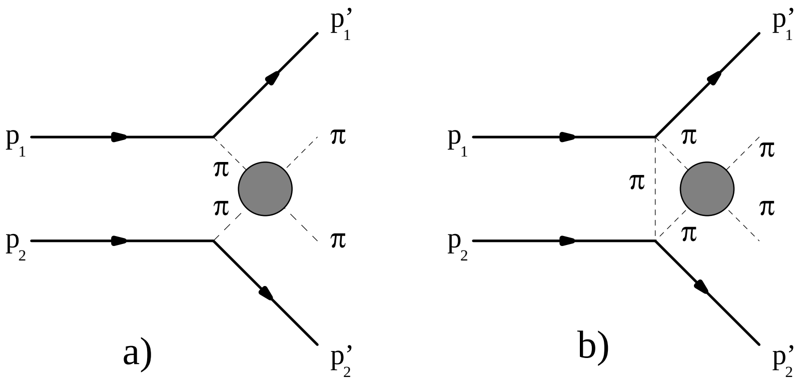
i.e. only 100 MeV above Δ, the lowest excited state

alternative approach close to threshold: inclusion of dynamic σ by ππ rescattering



M.M.Kaskulov et al., MESON2004, Int. J. Mod. Phys. A20 (2005) 674

Phys. Rev. C70 (2004) 014002 and 057001



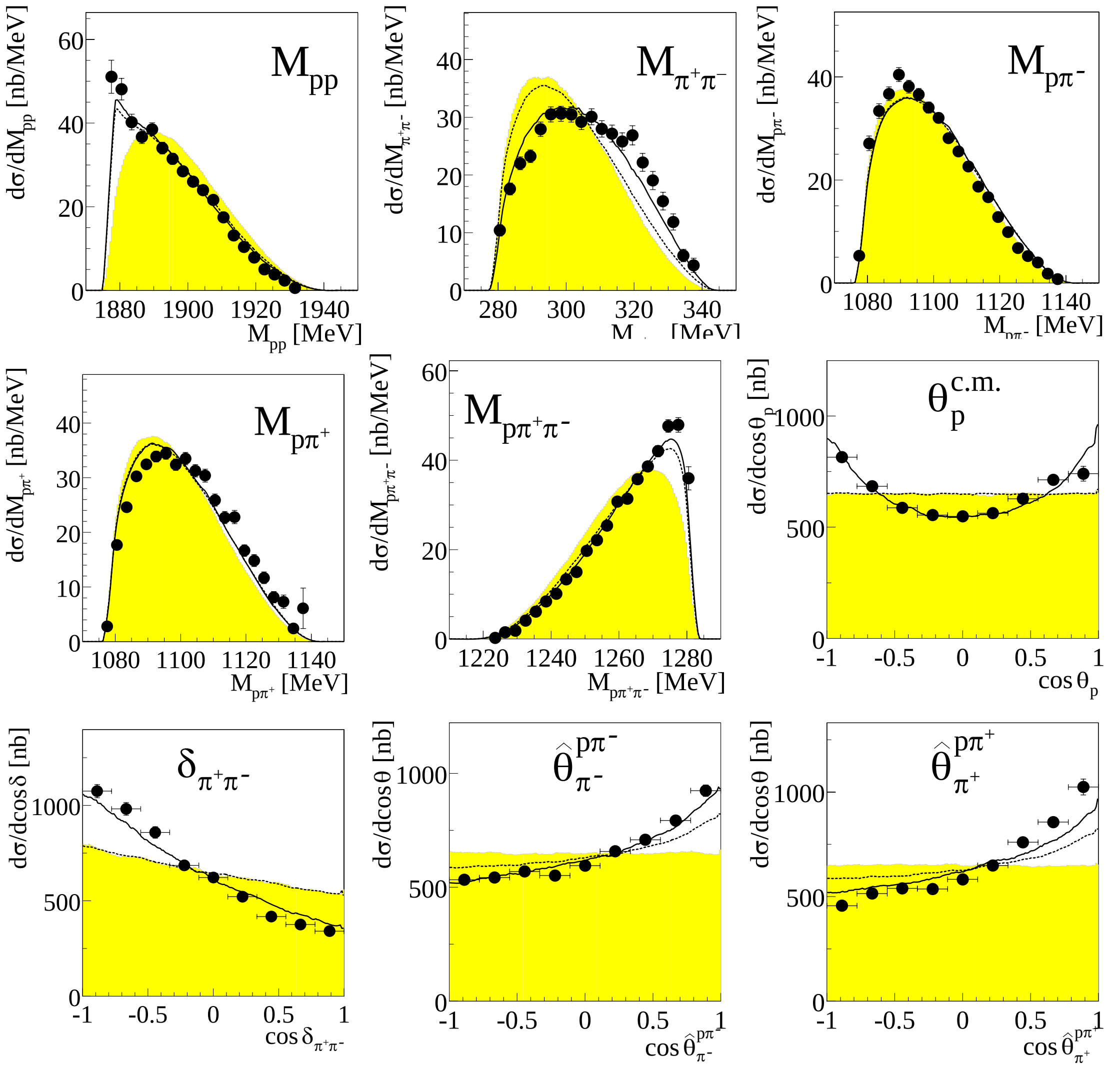
- ☺ ππ rescattering ⇔ ππ phase shifts
- ☺ no explicit Roper resonance !
- ☺ only 1 parameter ⇔ fixed by absolute scale of cross section

dynamic σ , no explicit Roper

T_p = 750 MeV

phase space

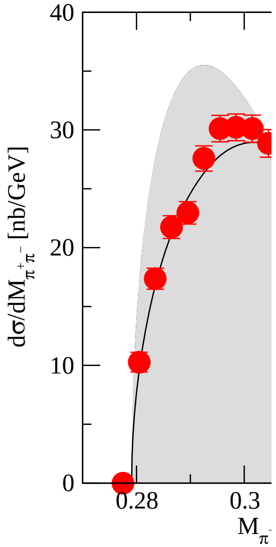
calculation without free parameter

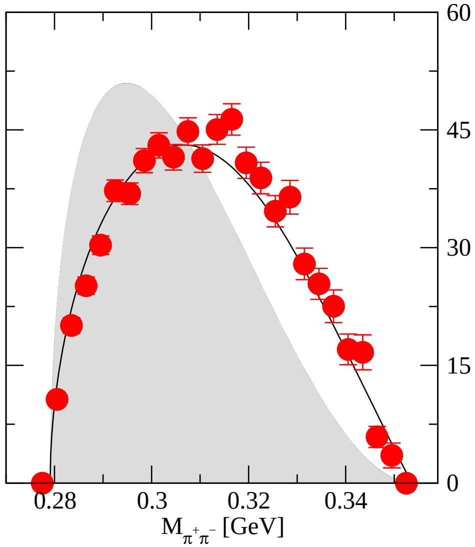


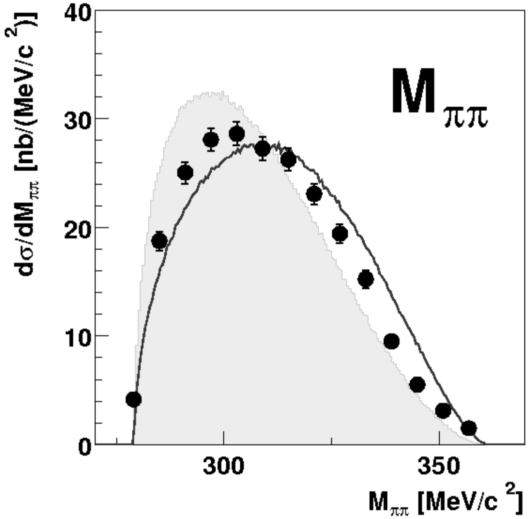
oper

800 MeV

$M_{\pi^+\pi^-}$







PROMICE/WASA

COSY-TOF

Conclusions on vacuum reaction

- **close to threshold**: $\pi^+\pi^-$ *data consistent with dynamic* σ

  ($\pi\pi$ *rescattering)* *- however, fails at higher energies (no* Δ*, no Roper)*

- **T_p < 1 GeV** : Roper excitation and decay

  resonance parameters – partly in good agreement

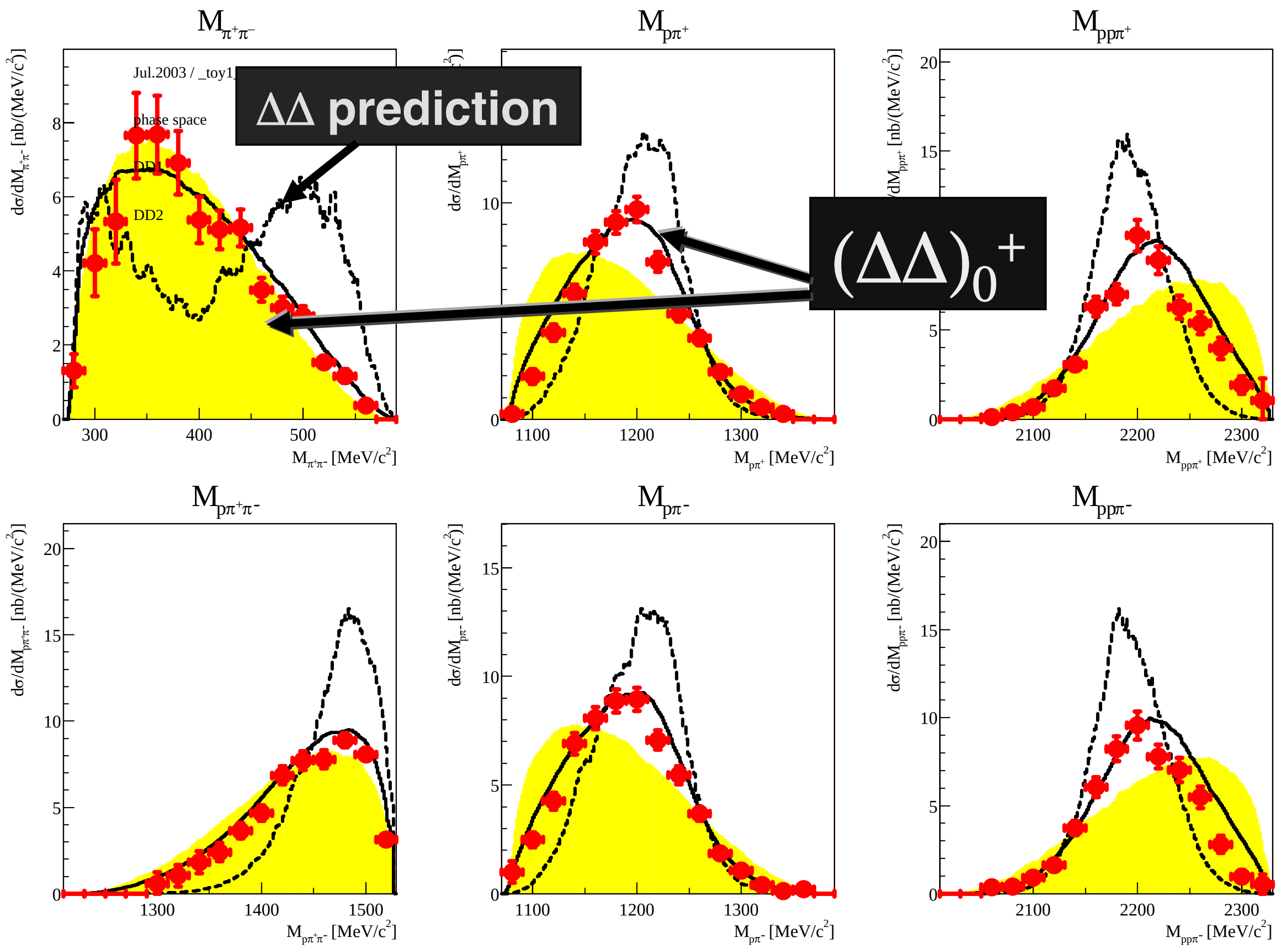
  with most recent results from other experiments

- **T_p > 1 GeV**: dominant configuration **($\Delta\Delta$)** $_{0^+}$ **?**

  present theoretical calculations do ***not***

ΔΔ region

$pp \rightarrow pp\pi^+\pi^-$ @ $T_p = 1360$ MeV



ππ Production in Nuclei

- medium effects of the ππ system

- nuclei as isospin filter:

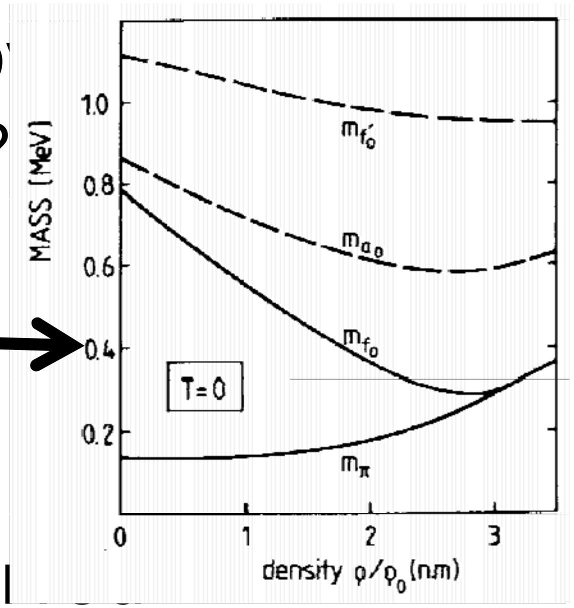
0 0

		ππ – system
– pp → pp ππ		I = ~~0~~, 1, 2
– pn → d ππ		0,/ 1
– pd → ^{3}He ππ:		/ 0, 1
– dd → ^{4}He ππ:		0

} **ABC effect**

Inclusive Measurements on Nuclei
(unresolved nuclear final states)

Lutz et al., NPA542, 521(1992)



- Medium modifications of hadrons b
  - conventional processes (e.g. Δ – h) ?
  - partial chiral restoration ?

    σ chiral partner of π ?

- Low-mass $M_{\pi\pi}$ enhancement obse
  in measurements on nuclei :
  - (π^-, $\pi^+ \pi^-$) CHAOS @ TRIUMF
  - (π^-, $\pi^0 \pi^0$) Crystal Ball @ BNL
  - (γ , $\pi^0 \pi^0$) TAPS @ MAMI

} **isoscalar effect**

Exclusive Measurements on Nuclei
(bound nuclear final states)

- **ABC – Effect:**

  low-mass enhancement in $M_{\pi\pi}$ spectra

  in scalar-isoscalar channel

  $\Leftrightarrow$

- **excitation of the $\Delta\Delta$ system**

ABC effect

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

- **Inclusive measurements:**

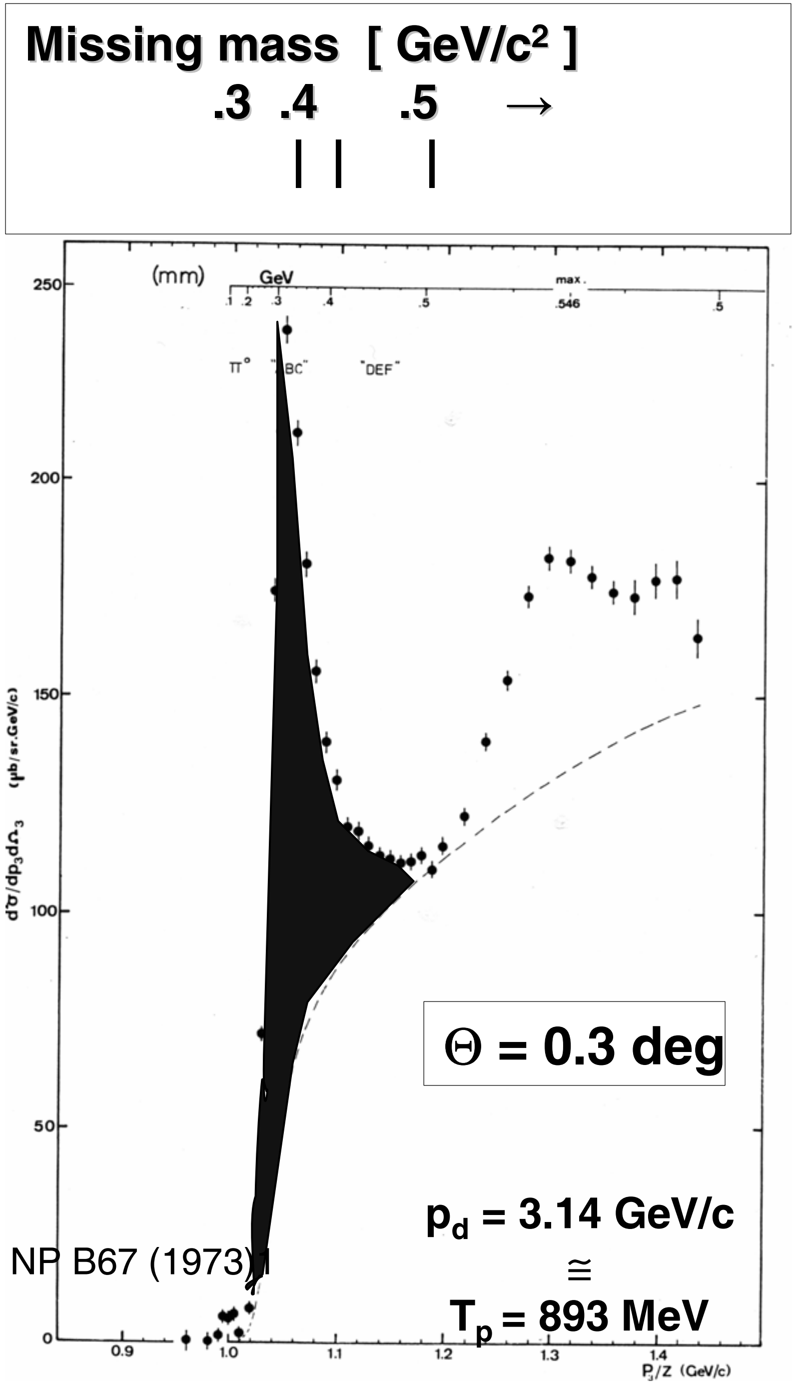
  pd → ^{3}He X

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

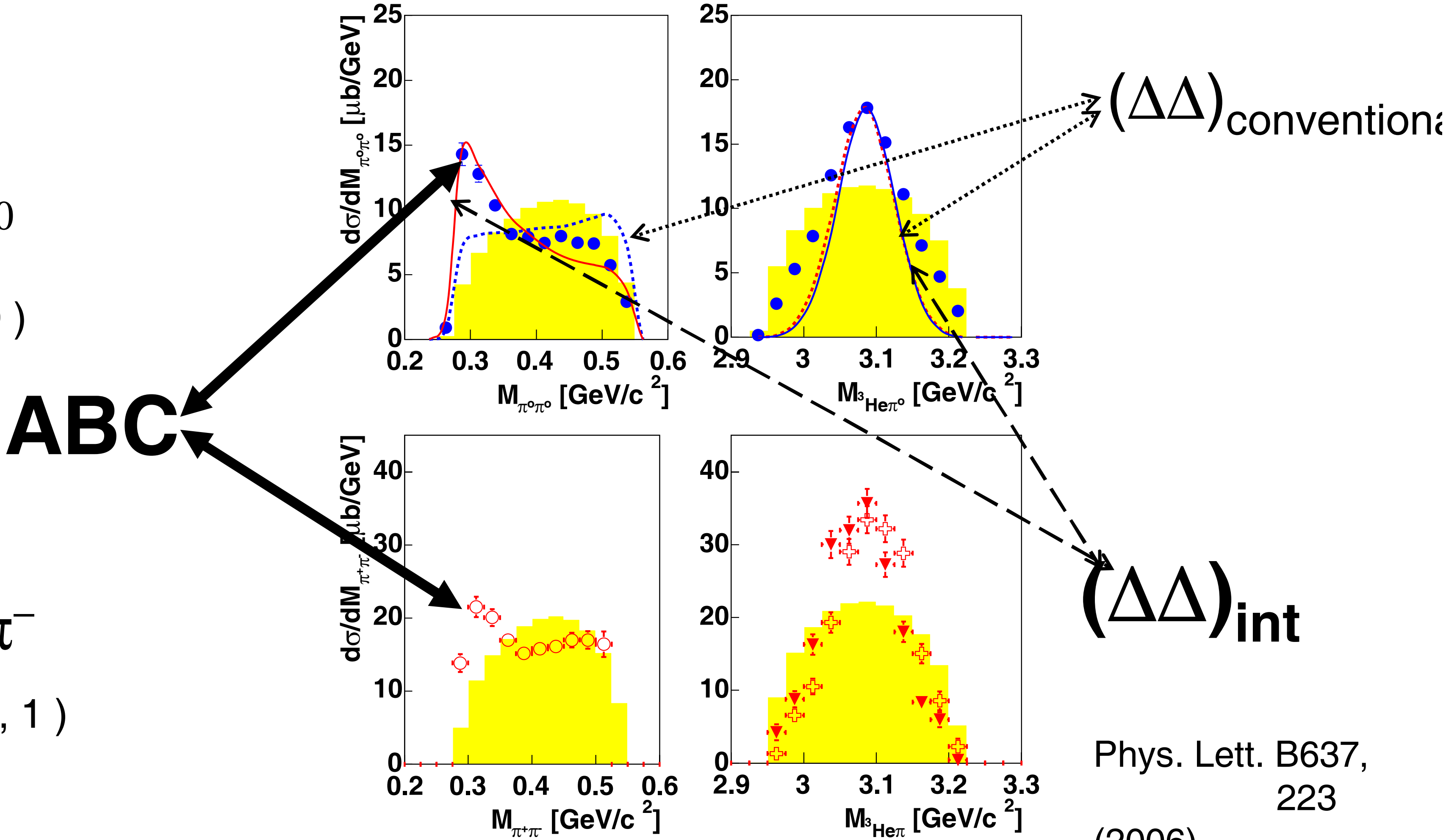
$M_{\pi\pi}$ $M_{{}^3He\,\pi}$

$\pi^0\pi^0$

(I = 0)

$\pi^+\pi^-$

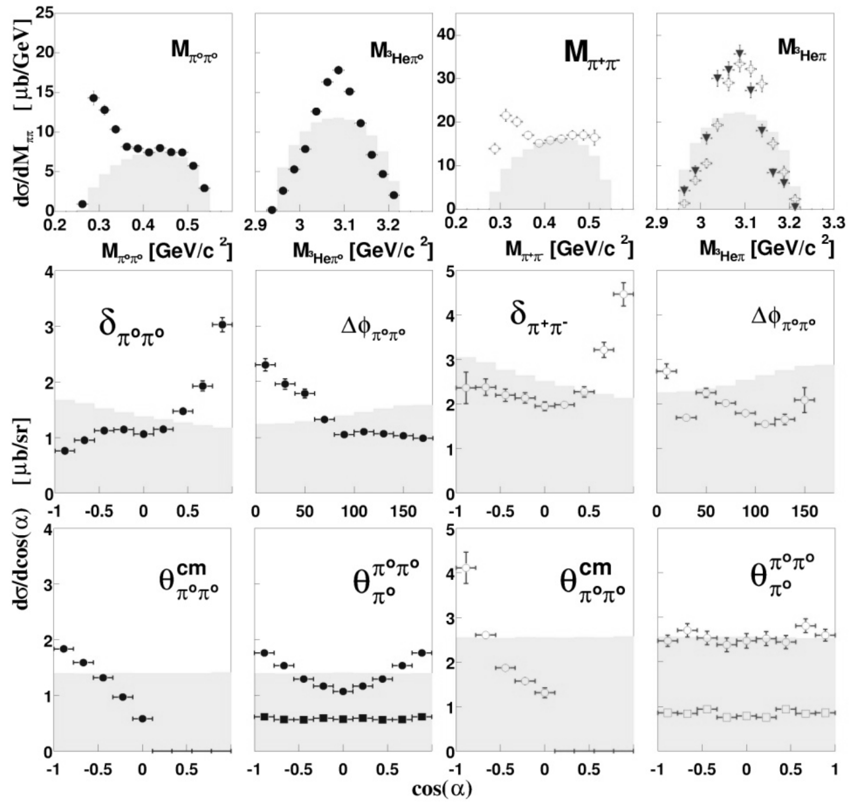
(I = 0, 1)

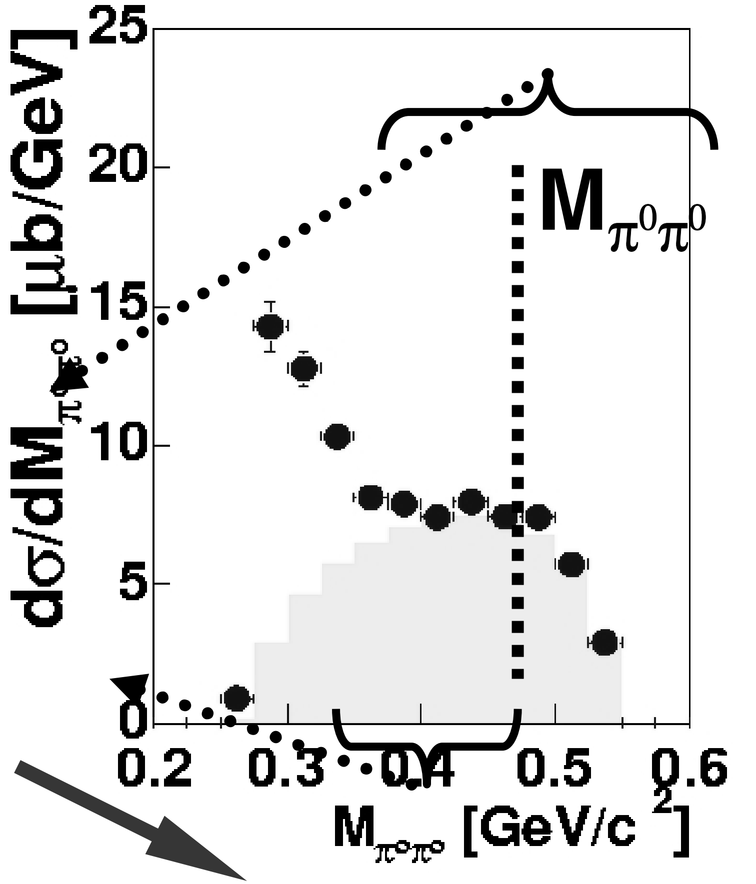


Phys. Lett. B637, 223 (2006)

Angular Distribution of Isoscalar Low-Mass Enhancement ?

Phys. Lett. B637, 223 (2006)





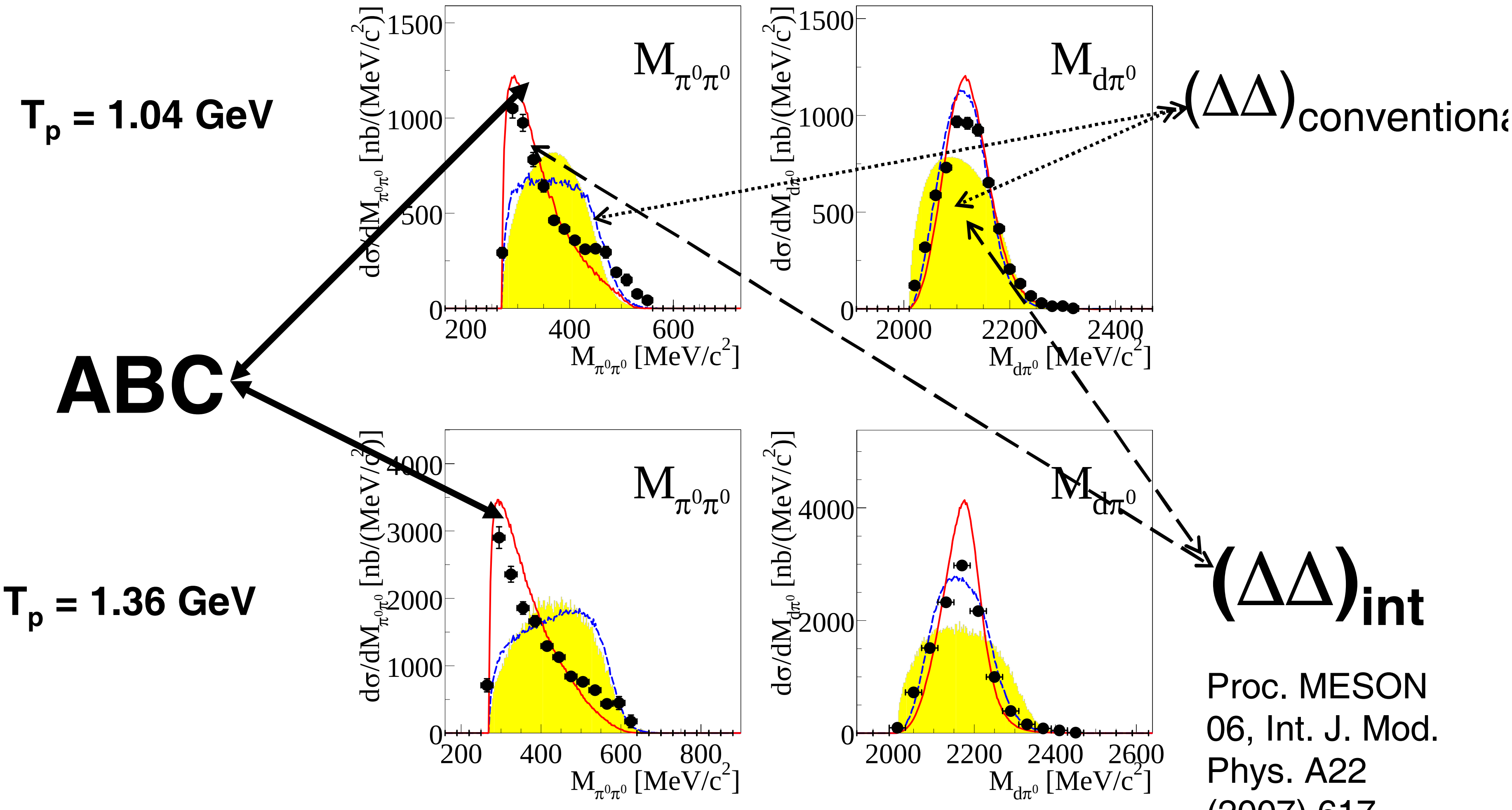
$$\cos\left(\Theta^{\pi^0\pi^0}_{\pi^0}\right)$$

scalar – isoscalar !

First exclusive measurement: @ CELSIUS-WASA

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

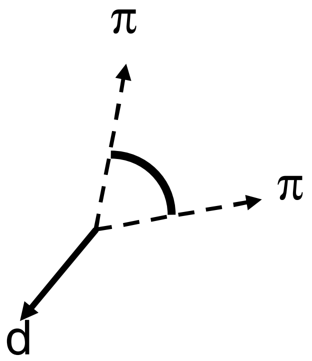
$M_{\pi\pi}$ $M_{d\pi}$

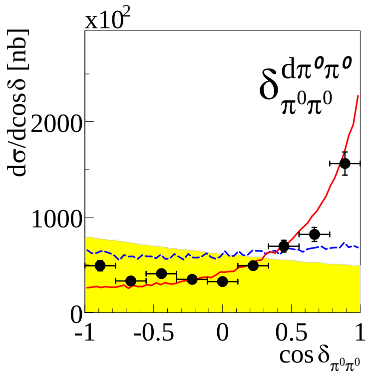


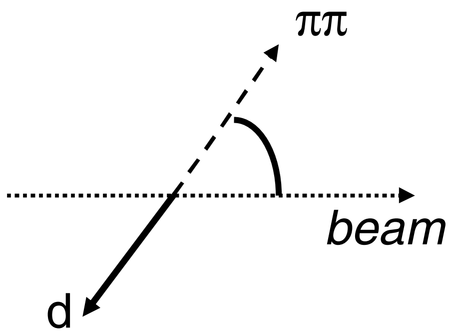
Proc. MESON 06, Int. J. Mod. Phys. A22 (2007) 617

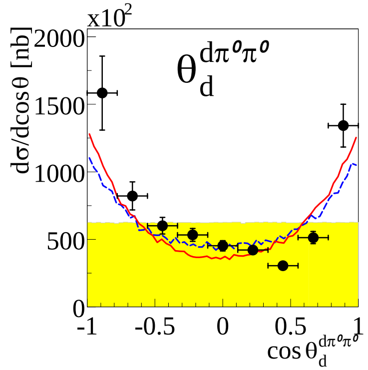
Quasifree pn → $d\pi^0\pi^0$ *(bin T_p = 1.0 – 1.04 GeV)*

- Angular distributions: <u>overall cms</u>

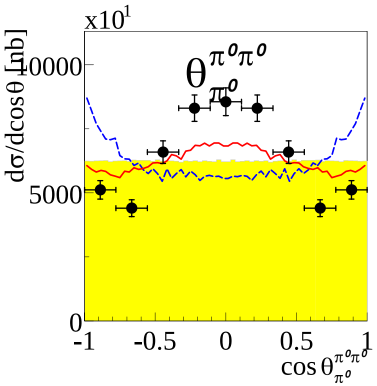


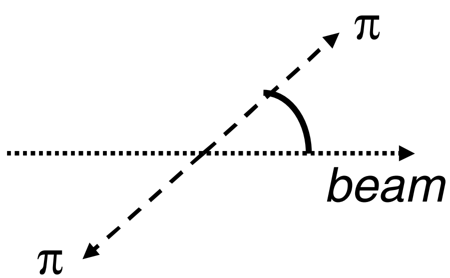


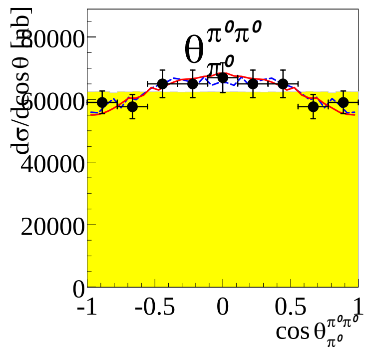




ππ subsystem (Jackson frame)

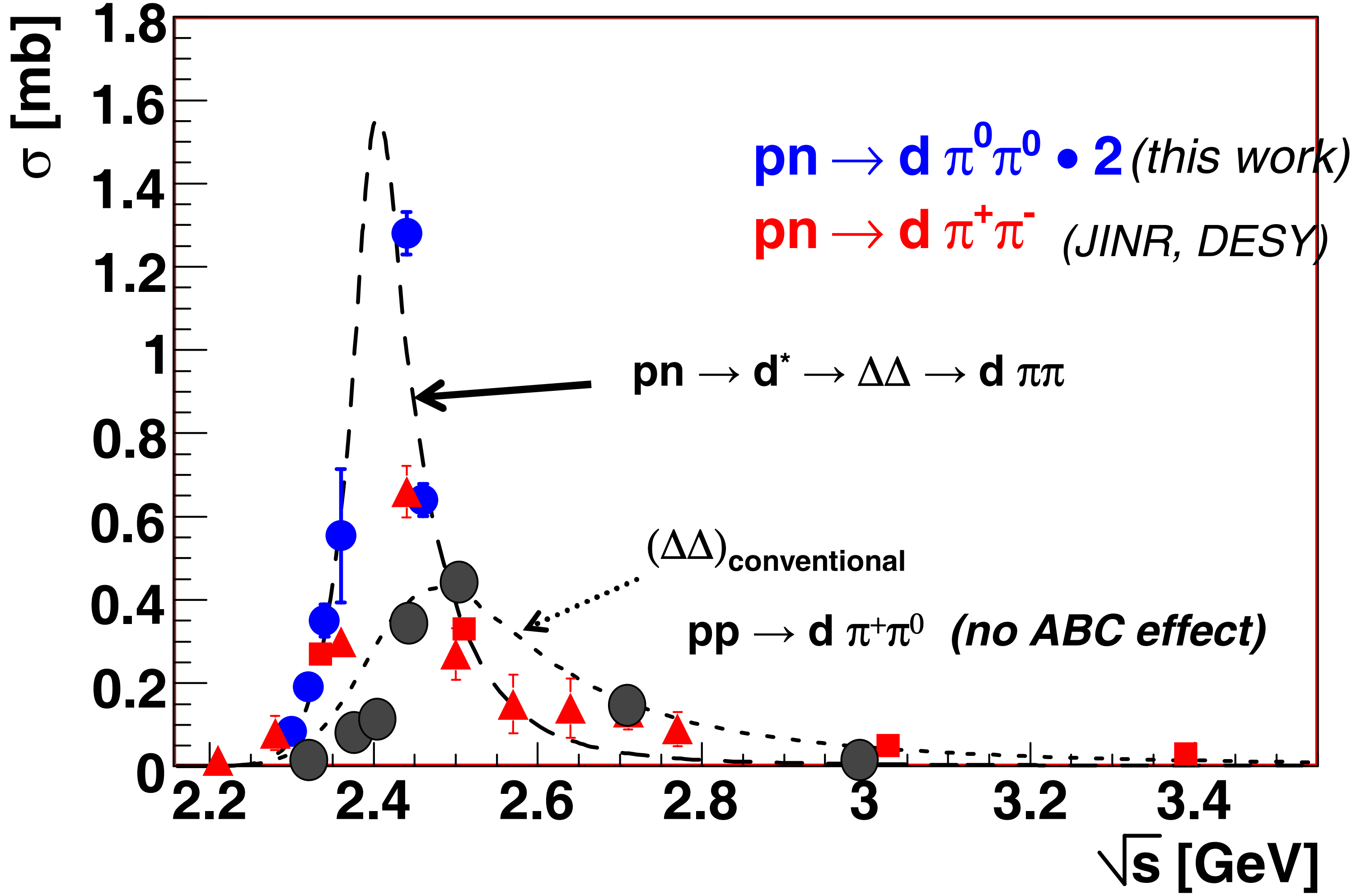






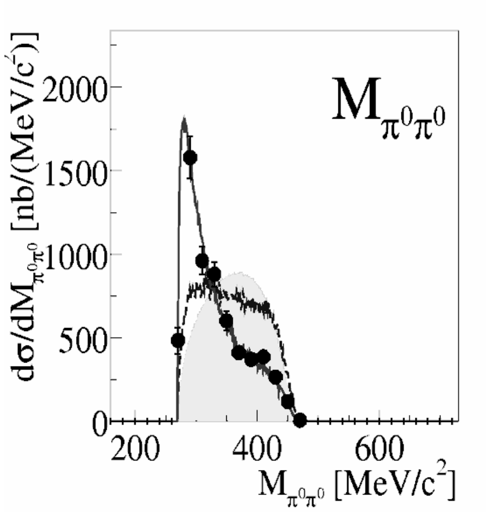
with cut on ABC peak

Energy Dependence of ABC

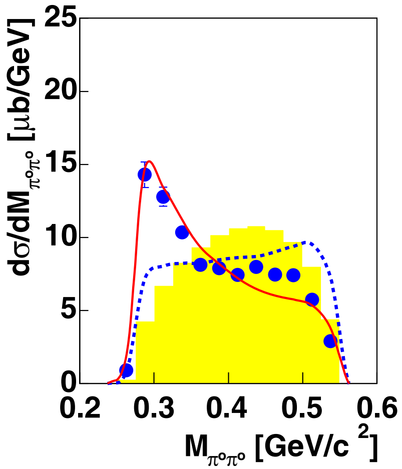


$\pi^0\pi^0$ Enhancement Gallery

pn → d $\pi^0\pi^0$
@ 1.0 GeV



pd → ^{3}He $\pi^0\pi^0$
@ 0.9 GeV



dd → ^{4}He $\pi^0\pi^0$

ABC largest
→ $\pi^0\pi^0$
enhancement
huge ?

heavier nuclei ??

CELSIUS-WASA measurements

WASA@COSY proposal: exclusive measurements

at several energies

Summary on $\pi\pi$ Production in Nuclei

- **inclusive measurements:**

  $\pi A \rightarrow X \pi\pi$ } isoscalar low-mass enhancement in $M_{\pi\pi}$

  $\gamma A \rightarrow X \pi\pi$ } increasing with increasing A

- **exclusive measurements:**

  A B → C $\pi\pi$ $\Rightarrow$ ABC effect:

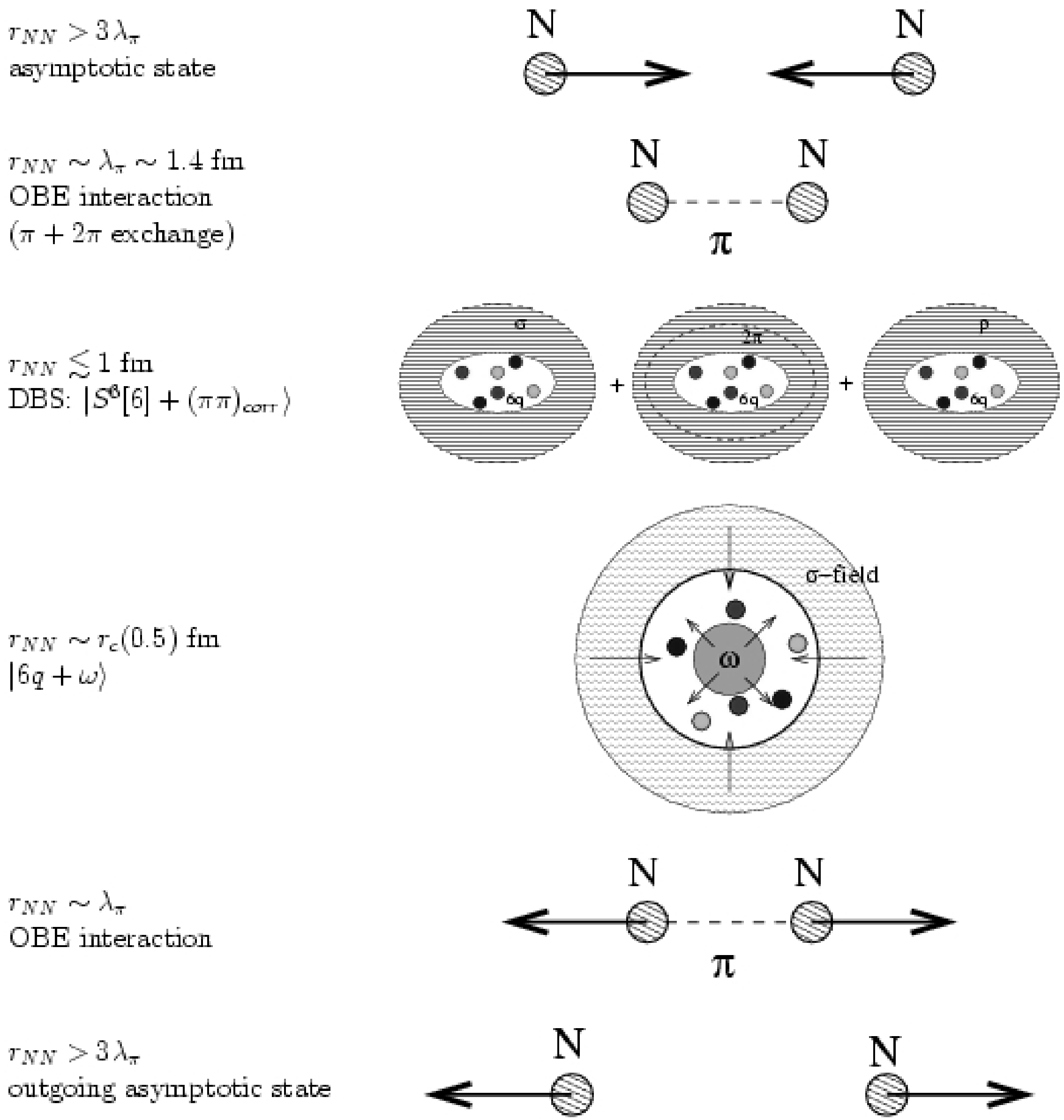
  scalar-isoscalar low-mass enhancement in $M_{\pi\pi}$

  increasing with increasing A

  - **correlated with the excitation of a $\Delta\Delta$ system !**
  - *specific configuration ($I = 0$, $J^p = 1^+$ or 3^+) in pn syste*

supported by BMBF, DFG (Europ. Graduate School), COSY-FFE and Landesforschungsschwerpunkt Baden-Württemberg

The physical picture of NN interaction at intermediate and short distances



The leading contribution of the Roper resonance excitation in pp-collisions at GeV energies

*H.P. Morsch and P. Zupanski, Phys. Rev. C **71**, 065203 (2005)*

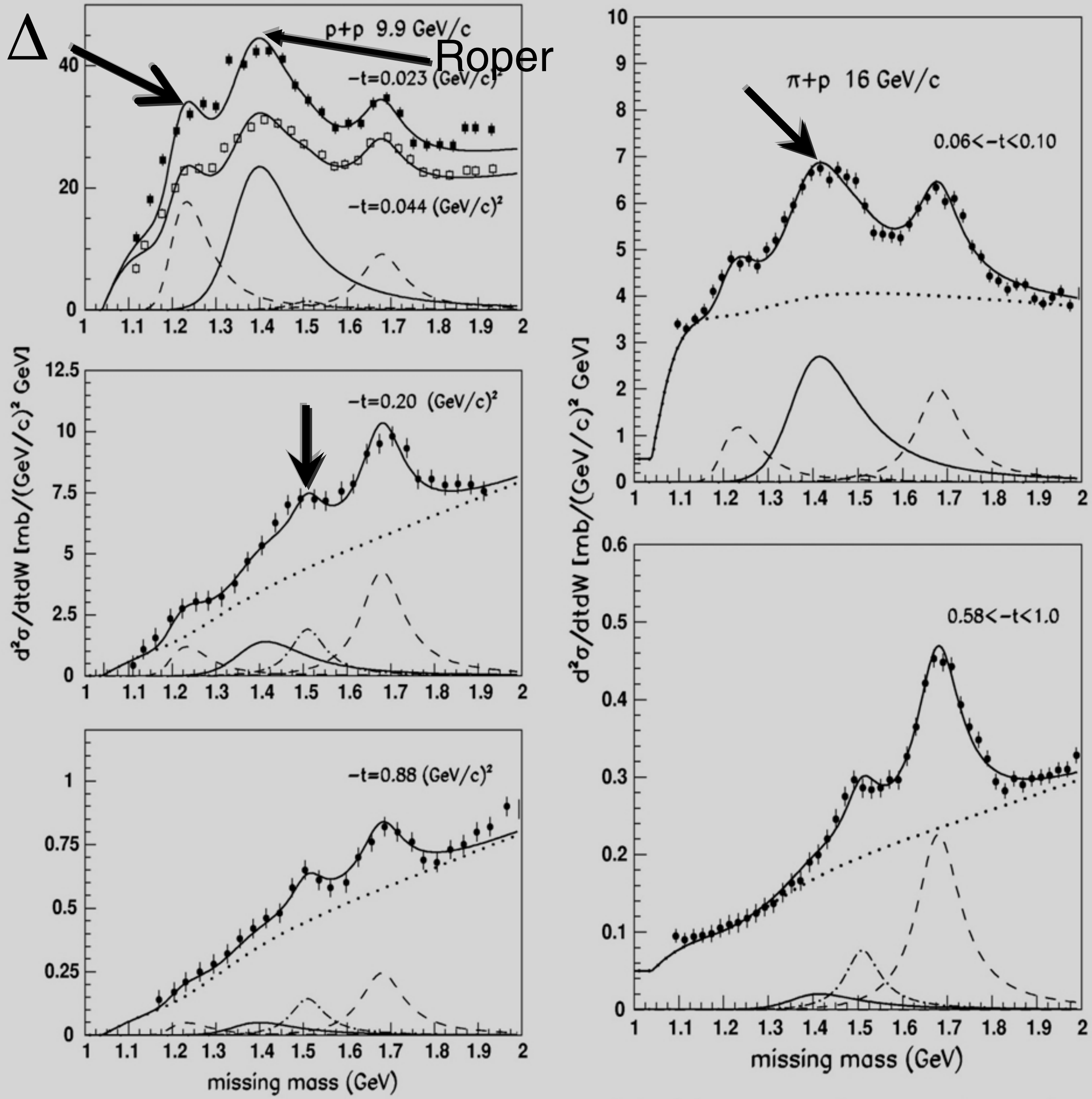


FIG. 1. Missing mass spectra for p-$p \rightarrow p' + x$ at a beam momentum of 9.9 GeV/c from Ref. [15] in comparison with resonance fits (solid lines) using a background shape (dotted lines) given by Eq. (1). The separate resonances are given; in particular, strong excitation of the P_{11} at 1400 MeV at small momentum transfer is indicated by solid lines.

FIG. 2. Missing mass spectra for $\pi - p \rightarrow \pi' + x$ at a beam momentum of 16 GeV/c from Ref. [15] in comparison with resonance and background fits similar to those in Fig. 1.

Roper resonance

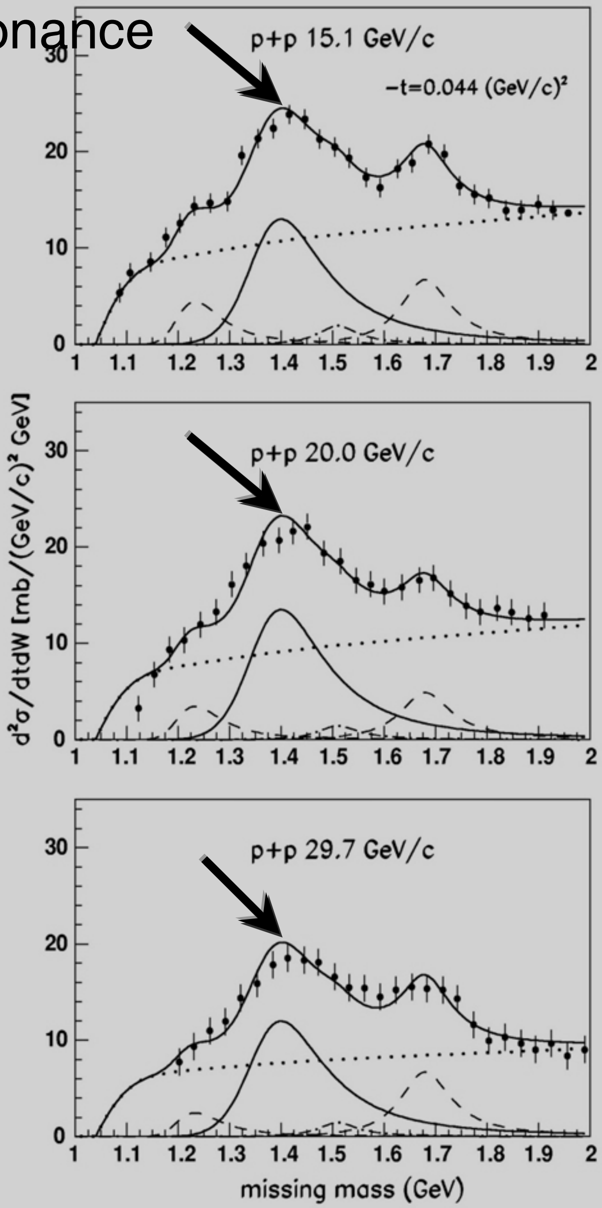


FIG. 3. Missing mass spectra for p-$p \rightarrow p' + x$ at beam momenta of 15.1, 20.0, and 29.7 GeV/c at a momentum transfer of 0.044 (GeV/c)^2 from Ref. [15] in comparison with resonance and background fits similar to those in Fig. 1.

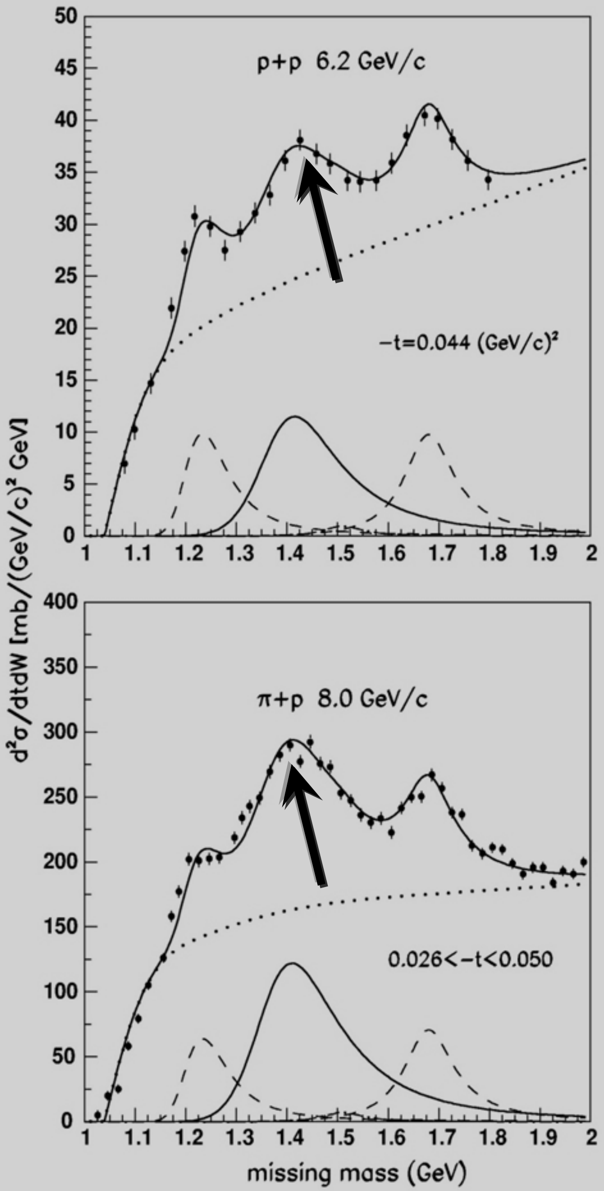


FIG. 4. Missing mass spectra for p-$p \rightarrow p' + x$ at a beam momentum of 6.2 GeV/c (upper part) and $\pi - p \rightarrow \pi' + x$ at a beam momentum of 8.0 GeV/c from Refs. [15,16] in comparison with resonance and background fits similar to those in Fig. 1.

The $(\pi^+ \pi^-)$ low-energy enhancement at E_p =5.9 GeV

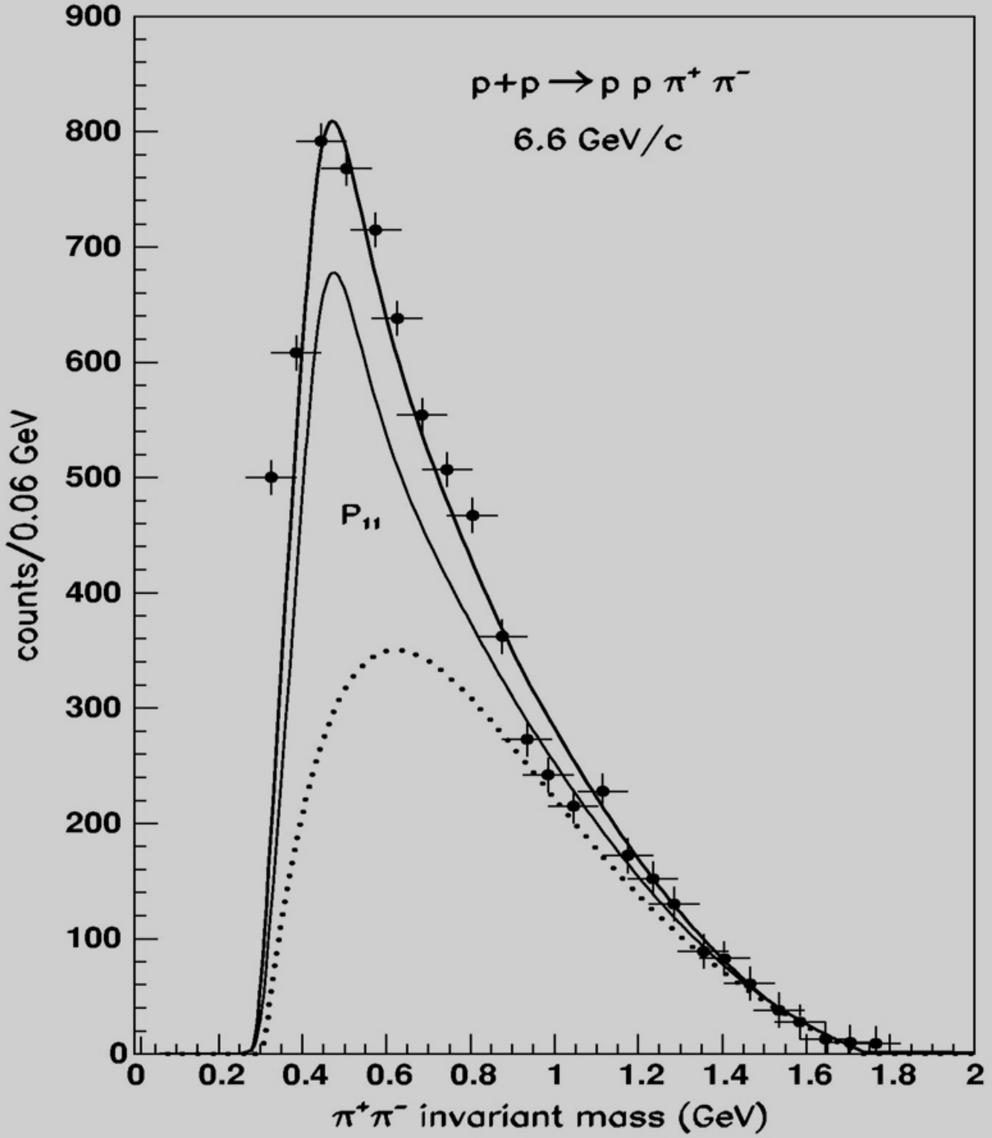
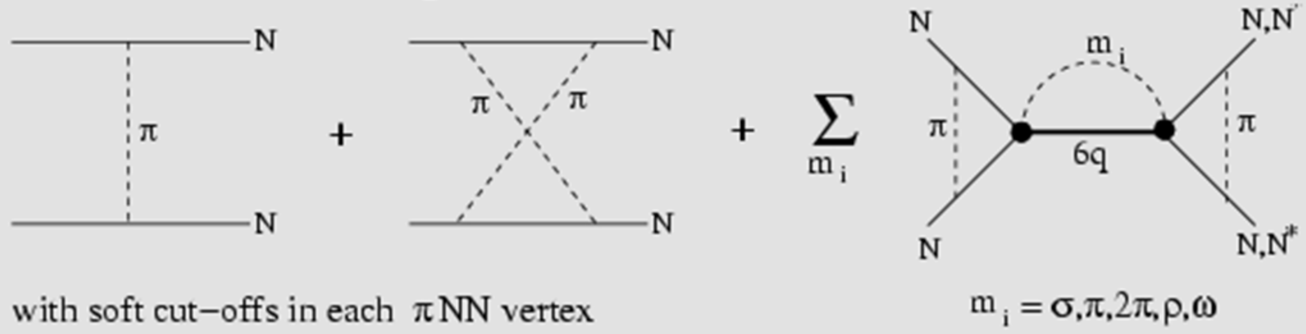


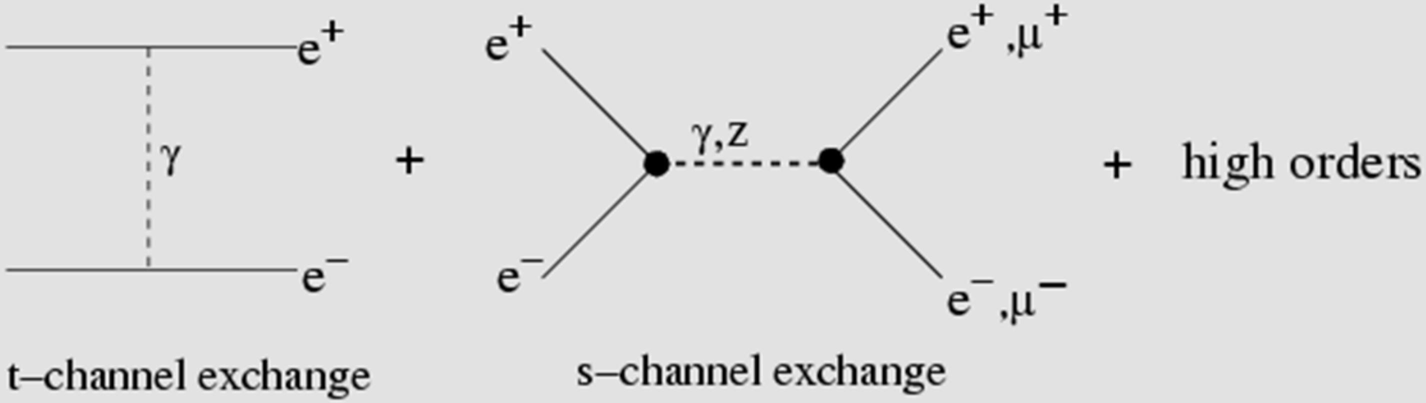
FIG. 5. Invariant $\pi^+\pi^-$ mass spectrum from the data in Ref. [19] in comparison with a resonance fit (upper solid line) consistent with Fig. 1. The 2π background without and with the contribution of the P_{11} at 1400 MeV is given by the dotted and lower solid line, respectively.

To summarize:

The basic NN-force can be represented by a sum of t-channel (i.e. Yukawa like) and s-channel exchanges:



This picture of baryon-baryon interaction is in a general agreement with the picture for e^+e^- interaction in Weinberg-Salam elecroweak theory:



B. The case of the $^3S_1 - ^3D_1$ mixed channel

According to the results for the dibaryon propagator in the mixed channel, the NN potential should be a 2×2 matrix:

$$V^{(^3SD_1)}(q',q;P) = -2[\bar{u}(-\mathbf{q}')\gamma^\mu v(\mathbf{q}')][\bar{v}(\mathbf{q})\gamma^\nu u(-\mathbf{q})]F_{\mu\nu}(q',q;P), \tag{47}$$

where the elements of the matrix tensor $F_{\mu\nu}(q',q;P)$ are

$$F^{(00)}_{\mu\nu} = \Big[\widetilde{\mathcal{G}}(P^2)\widetilde{\Phi}_{(0s)}(q',P)\widetilde{\Phi}_{(0s)}(q,P)+ \\ \left(\widetilde{\mathcal{G}}_0(P^2)\cos^2\chi + \widetilde{\mathcal{G}}_2(P^2)\sin^2\chi\right)\widetilde{\Phi}_{(2s)}(q',P)\widetilde{\Phi}_{(2s)}(q,P)\Big]\mathcal{P}^1_{\mu\nu}, \tag{48}$$

$$F^{(02)}_{\mu\nu} = \frac{3}{\sqrt{2}}\widetilde{\Phi}_{(2s)}(q',P)\widetilde{\Phi}_{(2d)\mu\nu}(q,P)\left[\widetilde{\mathcal{G}}_2(P^2) - \widetilde{\mathcal{G}}_0(P^2)\right]\sin\chi\cos\chi, \tag{49}$$

$$F^{(20)}_{\mu\nu} = \frac{3}{\sqrt{2}}\widetilde{\Phi}_{(2d)\mu\nu}(q',P)\widetilde{\Phi}_{(2s)}(q,P)\left[\widetilde{\mathcal{G}}_2(P^2) - \widetilde{\mathcal{G}}_0(P^2)\right]\sin\chi\cos\chi, \tag{50}$$

$$F^{(22)}_{\mu\nu} = \frac{9}{2}\widetilde{\Phi}_{(2d)\mu\alpha}(q',P)\widetilde{\Phi}_{(2d)\alpha\nu}(q,P)\left(\widetilde{\mathcal{G}}_0(P^2)\sin^2\chi + \widetilde{\mathcal{G}}_2(P^2)\cos^2\chi\right), \tag{51}$$

where formfactor $\widetilde{\Phi}_{(2d)\mu\nu}(q,P)$ is defined by Eq. (??) and one has in explicit form:

$$\widetilde{\Phi}_{(2d)\mu\nu}(q,P) = \frac{2\beta}{\sqrt{15}(\beta+\alpha/2)^2}q_\alpha q_\tau\left(\frac{1}{3}\mathcal{P}^1_{\mu\nu}\mathcal{P}^1_{\alpha\tau} - \mathcal{P}^1_{\mu\alpha}\mathcal{P}^1_{\tau\nu}\right)\widetilde{\Phi}_{(0s)}(q,P). \tag{52}$$

After making the respective Fierz transformations, one arrives eventually at the follows expressions for the matrix elements $V^{(ij)}$:

$$V^{(00)}(q',q,P)=(3+\sigma_1\sigma_2)W\left(1+\frac{\mathbf{q}'^2+S_{12}(\mathbf{q}')}{3(E_{q'}+m_N)^2}\right)\left(1+\frac{\mathbf{q}^2+S_{12}(\mathbf{q})}{3(E_q+m_N)^2}\right)F^{(00)}(q',q;P), \tag{53}$$

$$V^{(02)}(q',q,P)=(3+\sigma_1\sigma_2)W\left(1+\frac{\mathbf{q}'^2+S_{12}(\mathbf{q}')}{3(E_{q'}+m_N)^2}\right)\times \left(1+\frac{\mathbf{q}^2+S_{12}(\mathbf{q})}{3(E_q+m_N)^2}\right)\frac{S_{12}(\mathbf{q})}{6\mathbf{q}^2}F^{(02)}(q',q;P), \tag{54}$$

$$V^{(20)}(q',q,P)=(3+\sigma_1\sigma_2)W\frac{S_{12}(\mathbf{q}')}{6\mathbf{q}'^2}\left(1+\frac{\mathbf{q}'^2+S_{12}(\mathbf{q}')}{3(E_{q'}+m_N)^2}\right)\times \left(1+\frac{\mathbf{q}^2+S_{12}(\mathbf{q})}{3(E_q+m_N)^2}\right)F^{(20)}(q',q;P), \tag{55}$$

$$V^{(22)}(q',q,P)=(3+\sigma_1\sigma_2)W\frac{S_{12}(\mathbf{q}')}{6\mathbf{q}'^2}\left(1+\frac{\mathbf{q}'^2+S_{12}(\mathbf{q}')}{3(E_{q'}+m_N)^2}\right)\times \left(1+\frac{\mathbf{q}^2+S_{12}(\mathbf{q})}{3(E_q+m_N)^2}\right)\frac{S_{12}(\mathbf{q})}{6\mathbf{q}^2}F^{(22)}(q',q;P), \tag{56}$$

where

$$S_{12}(\mathbf{q})=3(\sigma_1\mathbf{q})(\sigma_2\mathbf{q})-\mathbf{q}^2(\sigma_1\sigma_2)$$

stands for the tensor operator and functions $F^{(ij)}(q',q;P)$ are defined as follows

$$F^{(00)}(q',q;P)=\frac{1}{3}F^{(00)}_{\mu\nu}(q',q;P)\mathcal{P}^1_{\mu\nu}, \tag{57}$$

$$F^{(02)}=\frac{3}{\sqrt{2}}\widetilde{\Psi}_{(2s)}(q',P)\widetilde{\Psi}_{(2d)}(q,P)\left[\widetilde{\mathcal{G}}_0(P^2)-\widetilde{\mathcal{G}}_2(P^2)\right]\sin\chi\cos\chi, \tag{58}$$

$$F^{(20)}=\frac{3}{\sqrt{2}}\widetilde{\Psi}_{(2d)}(q',P)\widetilde{\Psi}_{(2s)}(q,P)\left[\widetilde{\mathcal{G}}_0(P^2)-\widetilde{\mathcal{G}}_2(P^2)\right]\sin\chi\cos\chi, \tag{59}$$

$$F^{(22)}=\frac{9}{2}\widetilde{\Psi}_{(2d)}(q',P)\widetilde{\Psi}_{(2d)}(q,P)\left(\widetilde{\mathcal{G}}_0(P^2)\sin^2\chi+\widetilde{\mathcal{G}}_2(P^2)\cos^2\chi\right), \tag{60}$$

Summary

The dibaryon model for nuclear force is motivated essentially by QCD and quark dynamics. Thus, the success of the model opens the door to the modern nuclear physics based on a fundamental quantum chromodynamics!

In this report the Internet material from the talks of
H. Clement and T. Skorodko has been employed (see the site:
http://www.uni-tuebingen.de/erice/2007/sec/program2007.html).