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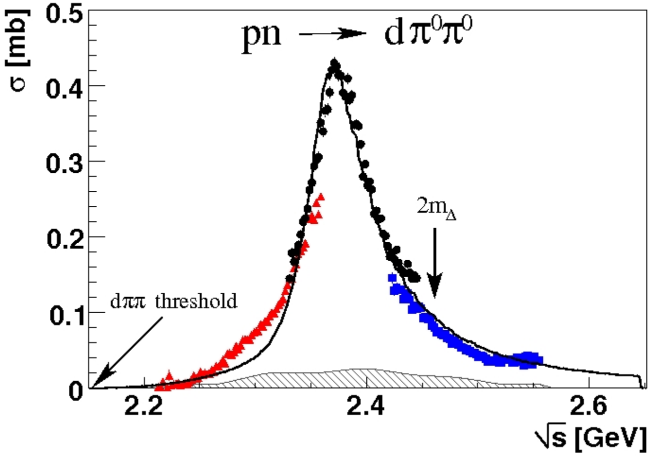

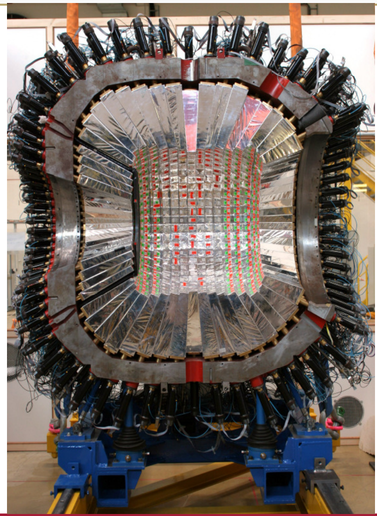

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Encounters with Di-Baryons --- Have They Finally Become True?

MESON 2014

Cracow, May 29 – June 3, 2014

Heinz Clement

Two-Baryon Scenario

- Known knowns:
  - $^3S_1$ deuteron groundstate: **$I(J^P) = 0\ (1^+)$**
  - $^1S_0$ virtual state (NN FSI): **$I(J^P) = 1\ (0^+)$**
- Known unknowns:
  - Are there six-quark bags (genuine dibaryons)?
  - Are there in general resonant states (molecular, dynamic) at all?
- Early days of dibaryon searches
  - The dibaryon rush era
- Recent experimental findings:
  - $^1D_2$ resonance near the ΔN threshold: **$I(J^P) = 1\ (2^+)$**
  - $^3D_3$ resonance much below the $\Delta\Delta$ threshold: **$I(J^P) = 0\ (3^+)$**
- Are there more states?
  - Model predictions
  - Dyson‘s multiplet

Early Predictions on Dibaryons

- 1964 Dyson & Xoung: 6 non-strange states
- 1975 Jaffe: H-dibaryon (uuddss: ΛΛ)
- Thereafter:
- multitude of predictions of a vast number of dibaryon states (Nijmegen group, ...)
- ⋮
-
    - LANL theory group (T. Goldman et al.):
        - The „inevitable dibaryon“: ΔΔ $I(J^P) = 0(3^+)$

Dyson's Multiplet Prediction

VOLUME 13, NUMBER 26 PHYSICAL REVIEW LETTERS 28 DECEMBER 1964

$Y = 2$ STATES IN SU(6) THEORY*

Freeman J. Dyson† and Nguyen-Huu Xuong
Department of Physics, University of California, San Diego, La Jolla, California
(Received 30 November 1964)

Two-baryon states.—The SU(6) theory of strongly interacting particles[1,2] predicts a classification of two-baryon states into multiplets according to the scheme

$$\underline{56} \otimes \underline{56} = \underline{462} \oplus \underline{1050} \oplus \underline{1134} \oplus \underline{490}. \qquad (1)$$

We now propose the hypothesis that all low-lying resonant states of the two-baryon system belong to the 490 multiplet.[3] This means that six zero-strangeness states shown in Table I should be observed. In all these states odd T goes with even J and vice versa.

Table I. $Y = 2$ states with zero strangeness predicted by the 490 multiplet.

Particle	T	J	SU(3) multiplet	Comment	Predicted mass
D_{01}	0	1	10*	Deuteron	A
D_{10}	1	0	27	Deuteron singlet state	A
D_{12}	1	2	27	S-wave N-N^* resonance	$A+6B$
D_{21}	2	1	35	Charge-3 resonance	$A+6B$
D_{03}	0	3	10*	S-wave N^*-N^* resonance	$A+10B$
D_{30}	3	0	28	Charge-4 resonance	$A+10B$

Dyson's Prediction

State	I	J	Asymptotic Configuration	m_{theor} [MeV]	m_{exp} [MeV]	Γ_{exp} [MeV]
D_{01}	0	1	Deuteron	1876	√ 1876	
D_{10}	1	0	virtual $^1S_0$	1876	√ 1878	
D_{12}	1	2	$NN(^1D_2) \leftrightarrow \Delta N \leftrightarrow NN\pi$	2160	(√) ΔN threshold	
D_{21}	2	1	$\Delta N \leftrightarrow NN\pi$	2160	?	
D_{03}	0	3	$NN(^3D_3) \leftrightarrow \Delta\Delta \leftrightarrow NN\pi\pi$	2350	?	
D_{30}	3	0	$\Delta\Delta \leftrightarrow NN\pi\pi$	2350	?	

… inevitable dibaryon: unique symmetry!

PHYSICAL REVIEW C VOLUME 39, NUMBER 5 MAY 1989

"Inevitable" nonstrange dibaryon

T. Goldman and K. Maltman*
Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545

G. J. Stephenson, Jr.
Physics Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545

K. E. Schmidt
Courant Institute and Department of Chemistry, New York University, New York, New York 10012

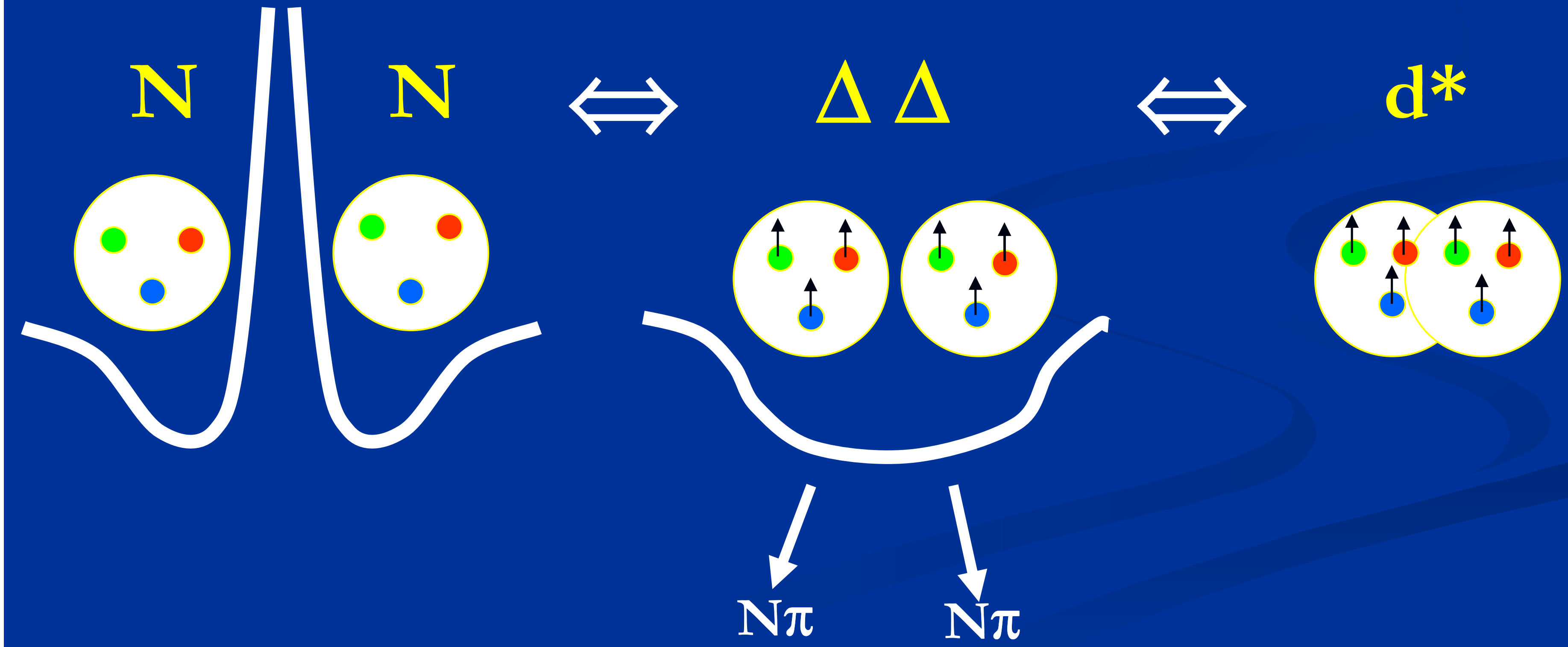
Fan Wang†
Department of Physics, University of California, Los Angeles, California 90024
(Received 13 December 1988)

Certain basic features, common to all phenomenological models of hadron structure based on the picture of confinement at large distances and effective one-gluon exchange within the confinement region, necessarily lead to the prediction of the existence of a nonstrange dibaryon resonance with quantum numbers $IJ^P=03^+$, the d^*, independent of more detailed features of the dynamics of any of the models. We discuss the qualitative physics underlying this claim, comment on the probable mass and decay properties of the resulting state, and provide estimates of the expected production cross sections in $np \to d^*$ and $\pi^\pm d \to \pi^\pm d^*$.

… inevitable dibaryon

$I(J^P) = 0(3^+)$ **state:** totally symmetric in space, spin & color
antisymmetric in isospin

accessed via ΔΔ as doorway ?



Early Dibaryon Searches

- Before 1964 (quark model):
  - First hints for resonating $^1D_2$ partial wave from pp ↔ $d\pi^+$ (Dubna)

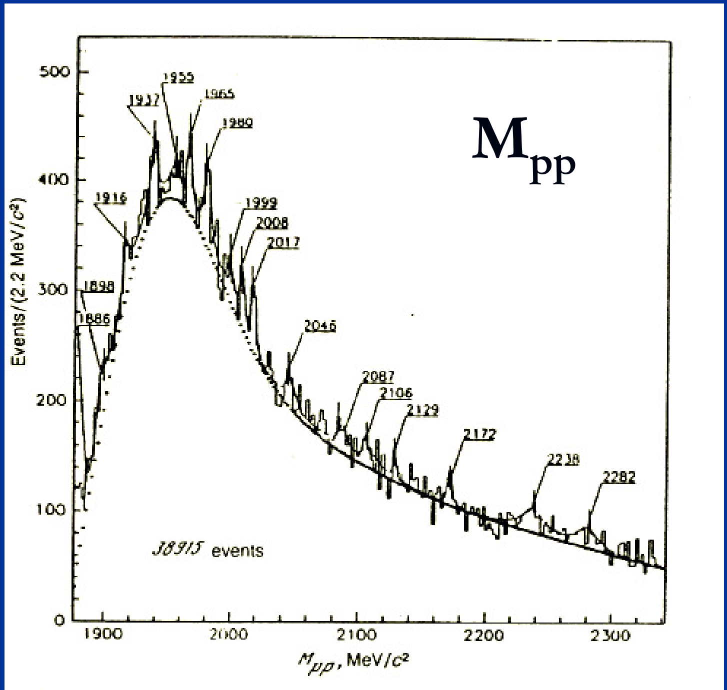
- After 1975 (Jaffe‘s H-dibaryon prediction):
  - Worldwide searches for dibaryons

In the following: only non-strange dibaryons

The Experimental Rush for Dibaryons

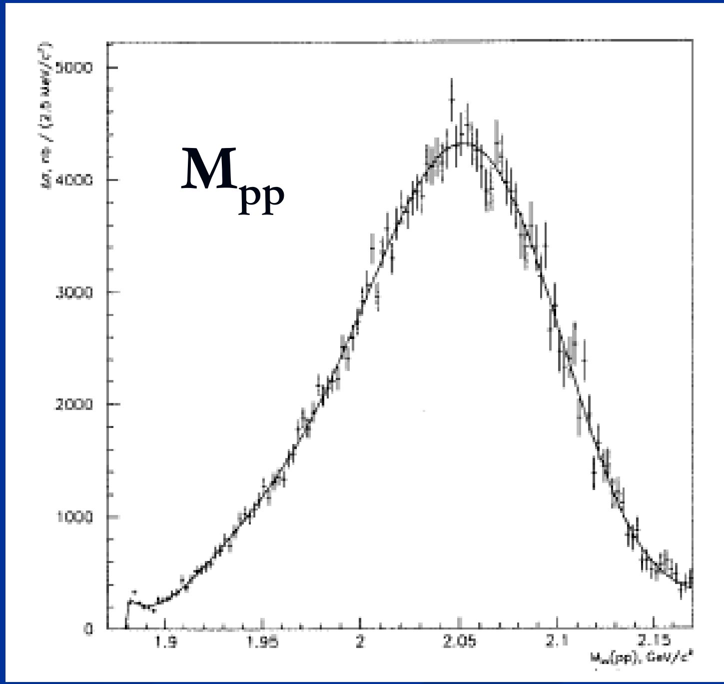
- Low statistics versus high statistics (quality):

$np \to pp\pi^- + n\pi^0$, bubble chamber



Troyan & Pechenov, Phys. At. Nucl. 56 (1993) 528

$np \to pp\pi^-$, magn. spectrometer



Abramov et al., Z. Phys. C69 (1996) 409

One of the Conclusions about this Dibaryon Rush

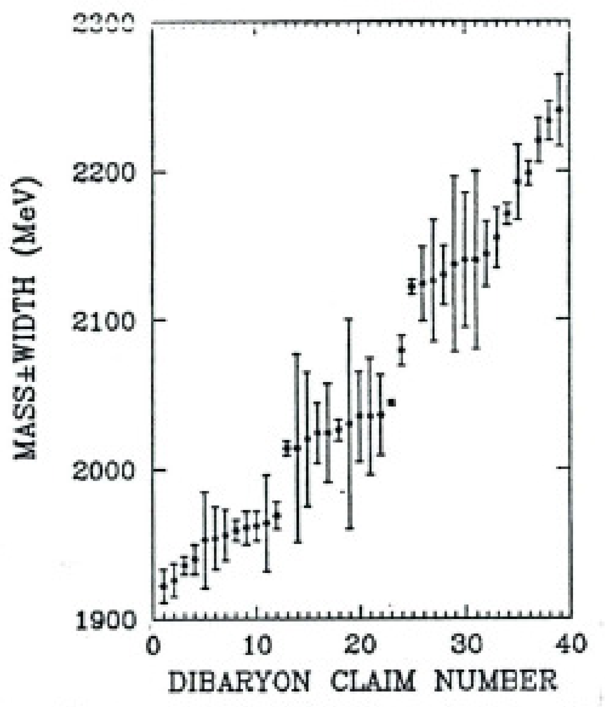


Fig. 13. Dibaryon claims of Table 3 plotted as claimed masses ± claimed widths. It is clear that claims exist at all energies between 1920 and 2250 MeV.

Kamal Seth (1988)
in
„Dibaryons in Theory and Practice"

1) **„Nobody has seen a genuine, gold- (silver-, ... or even un-) plated dibaryon, yet."**

2) **„ The days of Q & D ... are over... We must do honest hard work, or quit... We should do exclusive experiments."**

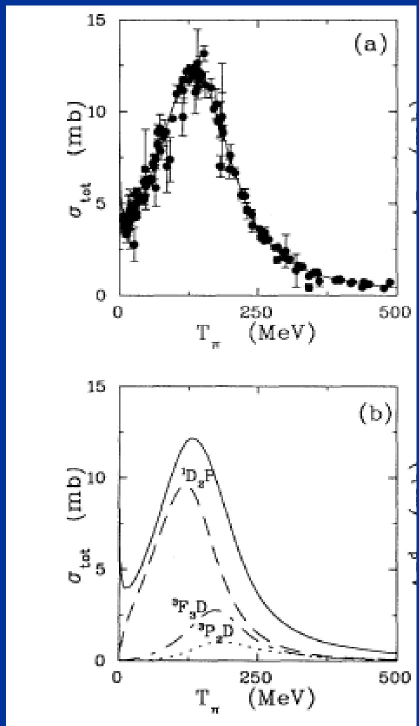
More Recent Searches

- What survived the Dibaryon Rush Era:
- $^1D_2$ in pp system
- What happened since the New Millenium:
- A new resonance: $^3D_3$ in np system

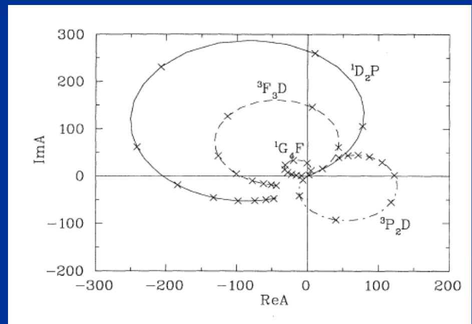
The $^1D_2$ Resonance

- Best seen in $pp \leftrightarrow d\pi^+$,
  - but also in $pp \rightarrow pn\pi^+$ as well as pp and π^+d scattering (phaseshift analyses)

σ_{tot} ($\pi^+d \rightarrow pp$)



Argand plot

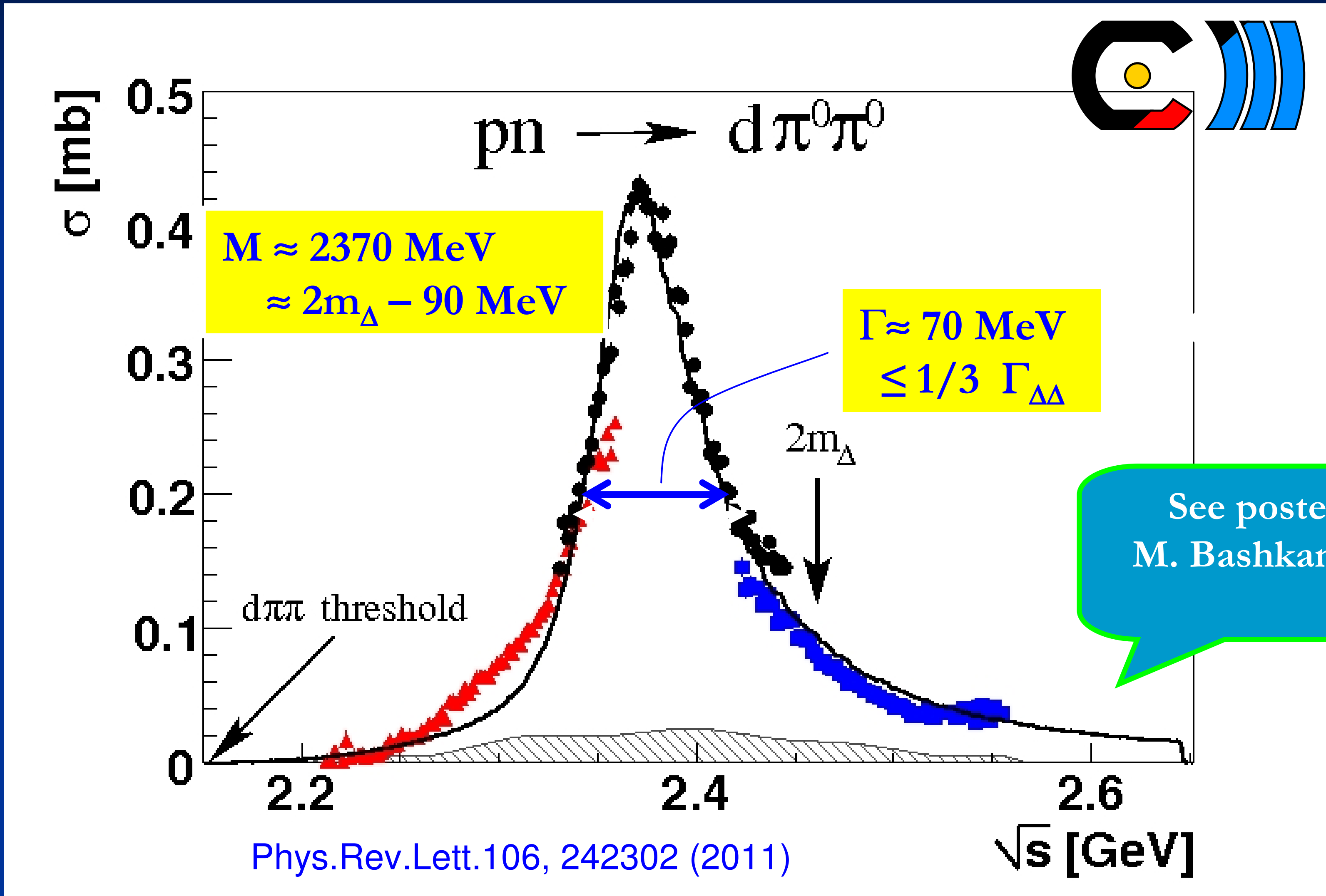


R.A. Arndt et al., PRC 48 (1993) 1926
50 (1994) 1796
56 (1997) 635
N. Hoshizaki, PRC 45 (1992) R1424
Prog. Theor. Phys. 89 (1993) 245
251
563
569

$I (J^P) = 1 (2^+)$
$M = 2144$ MeV $= m_\Delta + m_N - 26$ MeV
$\Gamma = 110$ MeV $\approx \Gamma_\Delta$

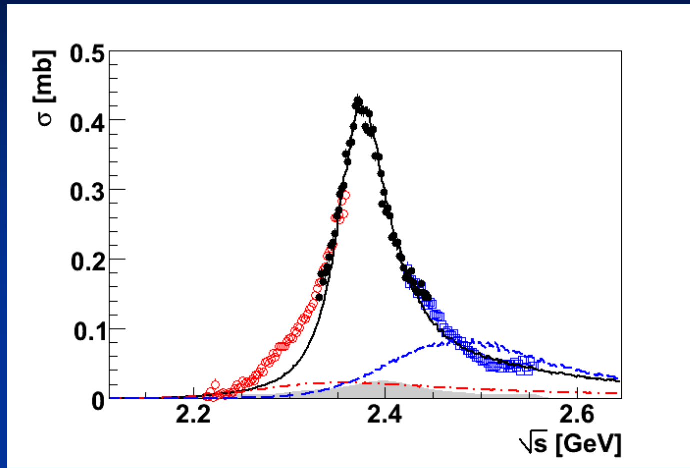
Alternative **dynamic** description: Diss. C.A. Mosbacher, Bonn 1998

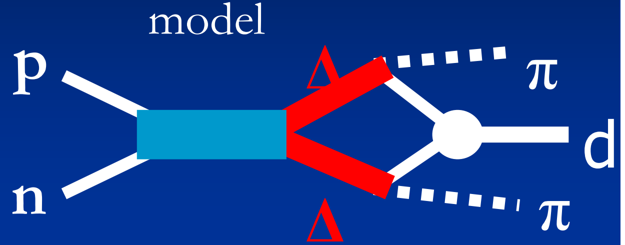
The d* Resonance $I(J^P) = 0(3^+)$



See poster
M. Bashkanov

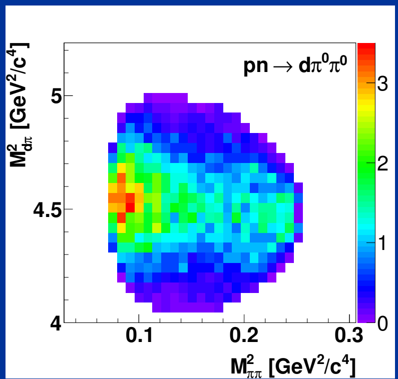
$pn \rightarrow d^* \rightarrow \Delta\Delta \rightarrow d\pi^0\pi^0$

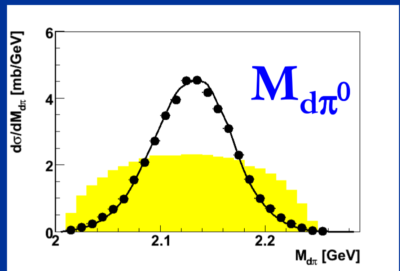




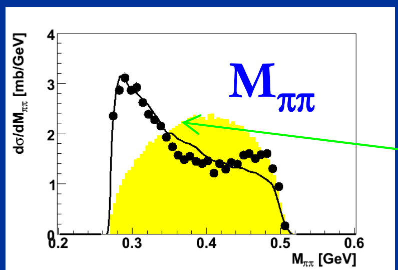
$I\,(J^P) = 0\,(3^+)$

$M, \Gamma, \Gamma_i * \Gamma_f, F(q_{\Delta\Delta})$

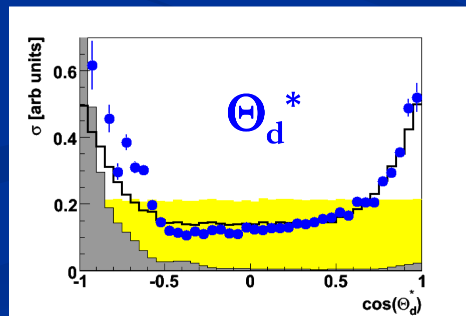




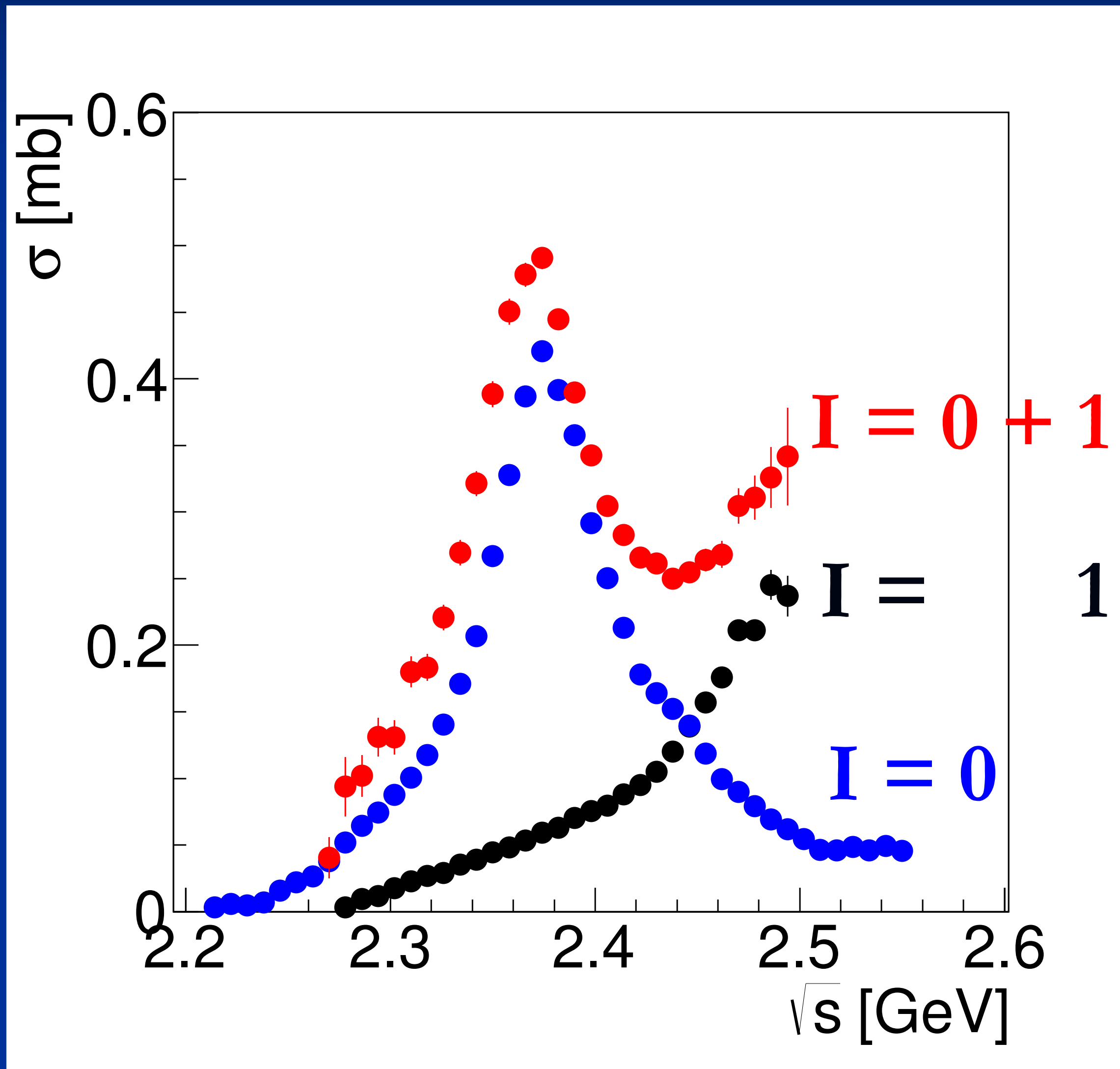
Phys.Rev.Lett.106, 242302 (2011)



ABC effect



$\sigma(pN \rightarrow d\,\pi\,\pi)$



$\sigma(pn \rightarrow d\,\pi^+\pi^-)$

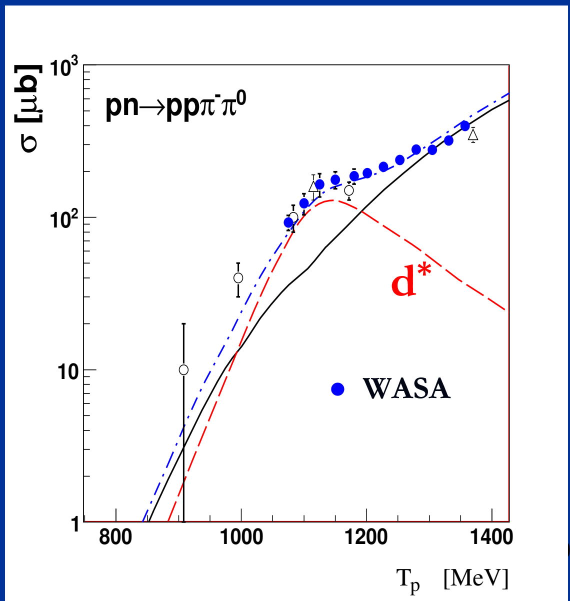
$\frac{1}{2}\;\sigma(pp \rightarrow d\,\pi^+\pi^0)$

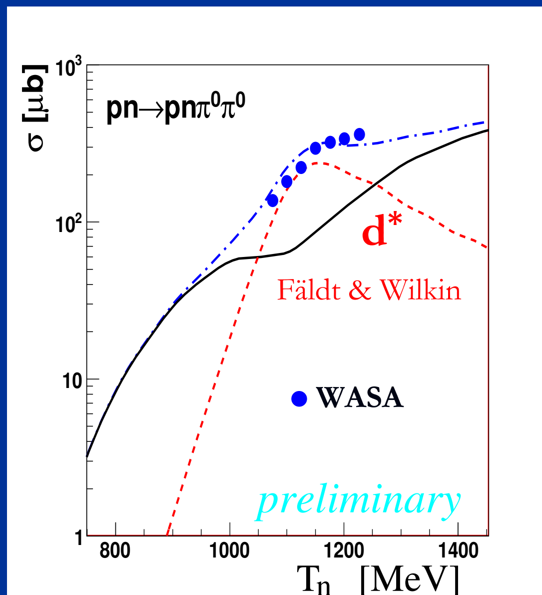
$2\;\sigma(pn \rightarrow d\,\pi^0\pi^0)$

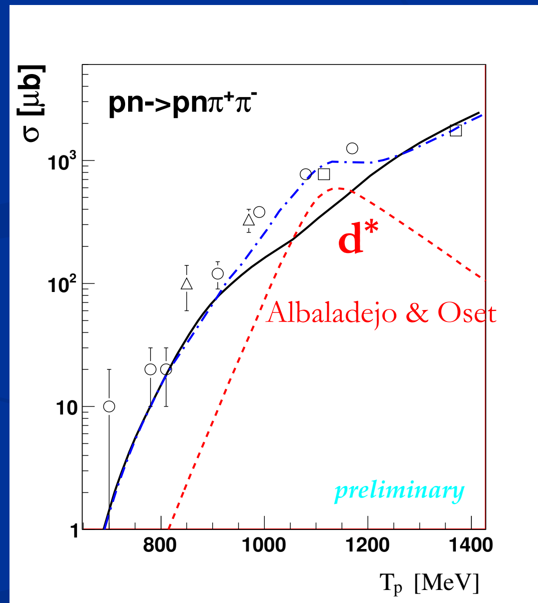
COSY Annual Report 2012
Phys. Lett. B721 (2013) 229

pn →

$pp\pi^0\pi^-$ $pn\pi^0\pi^0$ $pn\pi^+\pi^-$





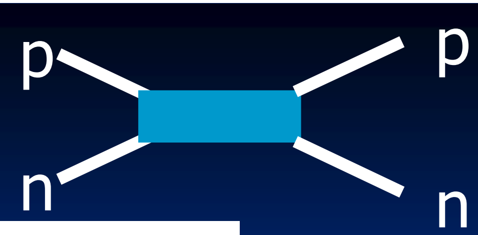


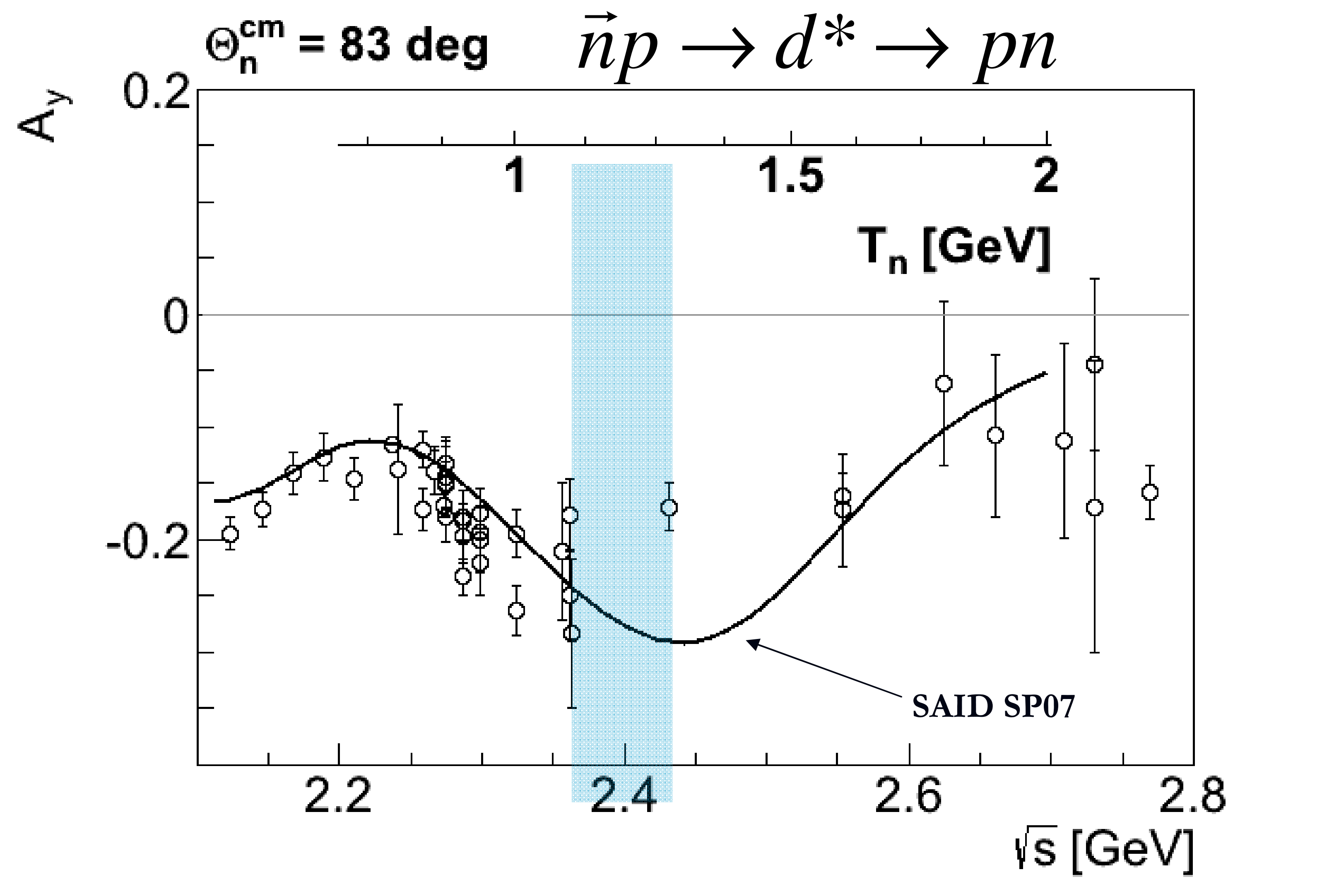
PRC 88 (2013) 055208

Experimentum Crucis for d^*

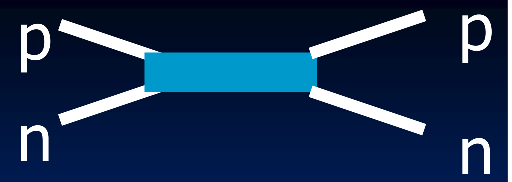
- If d^* a true s-channel resonance
- $\Leftrightarrow$
- then also a resonance in the np system
- $\Leftrightarrow$
- to be sensed in np scattering
- $\Leftrightarrow$
- in particular in the analyzing power
- $\Leftrightarrow$
- resonance effect $\sim$ $P^1_3(\Theta)$
- i.e. maximal at $\Theta = 90^0$

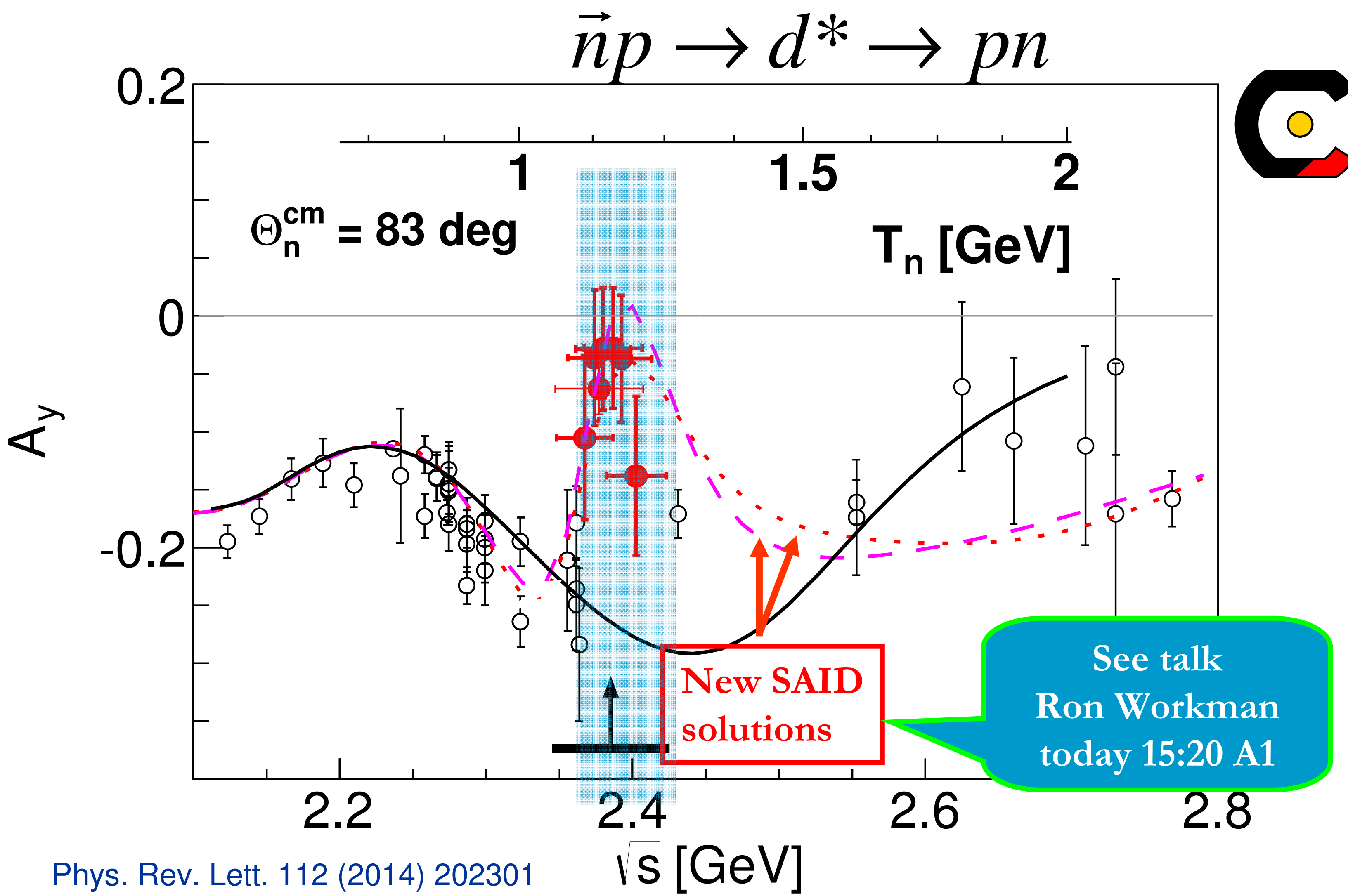
Energy Dependence



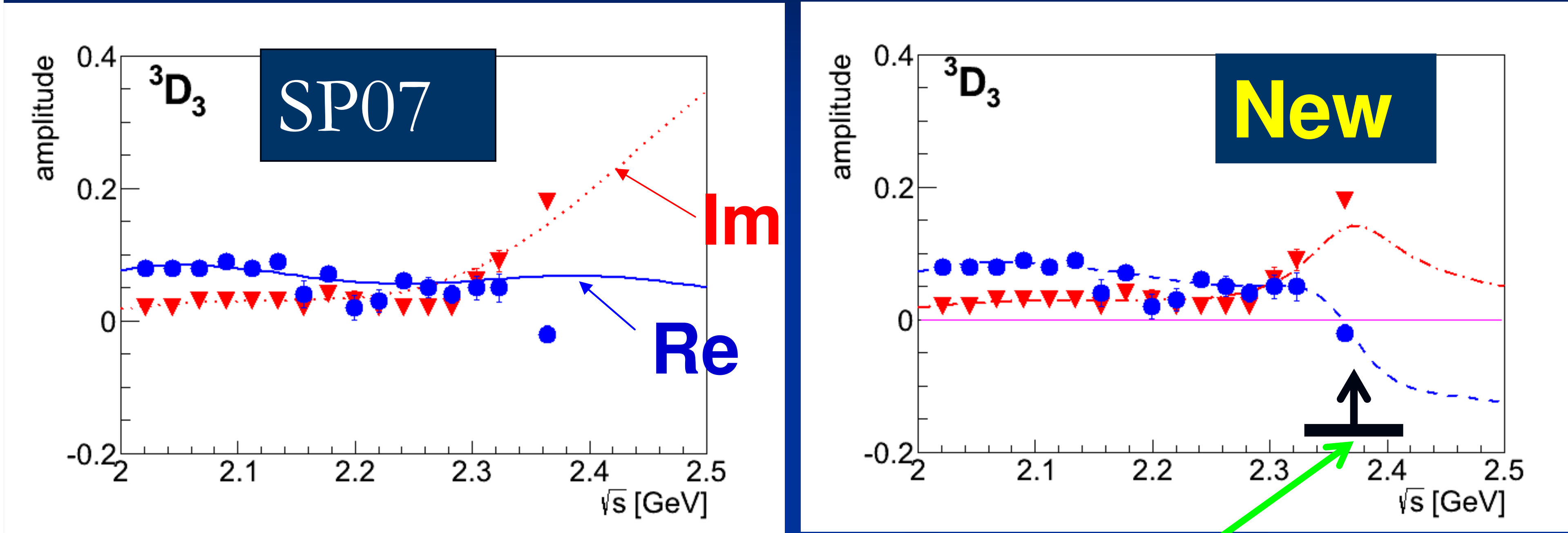


Energy Dependence





$^3D_3$ Partial Wave

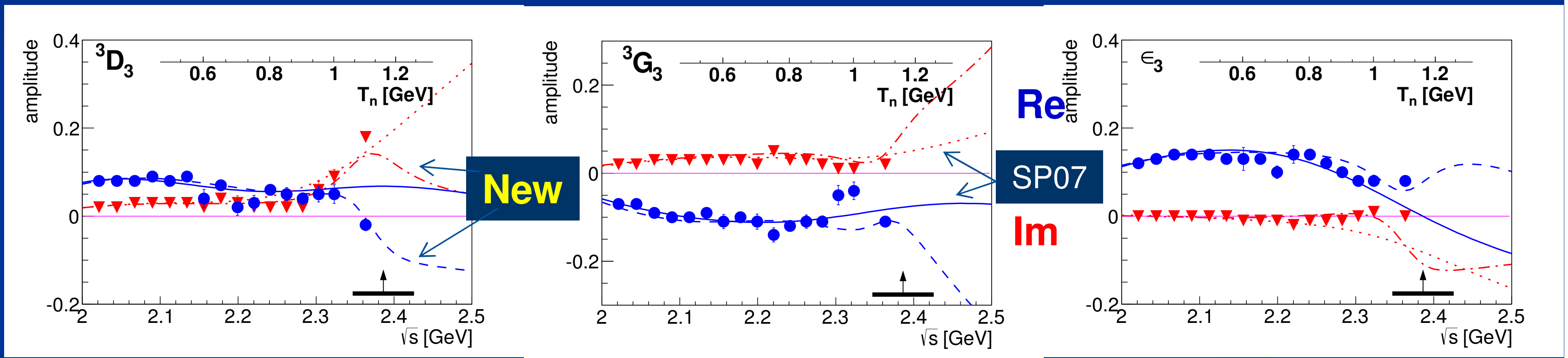


Pole at (2380 ± 10) – i (40 ± 5) MeV

Phys. Rev. Lett. 112 (2014) 202301

See talk
Ron Workman
today 15:20 A1

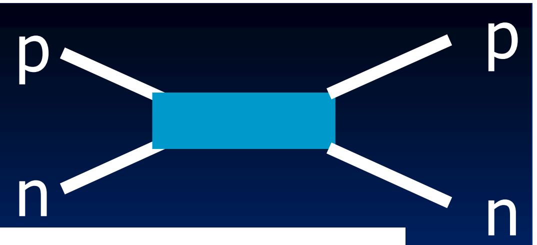
$^{3}D_{3}$ – $^{3}G_{3}$ Coupled Partial Waves

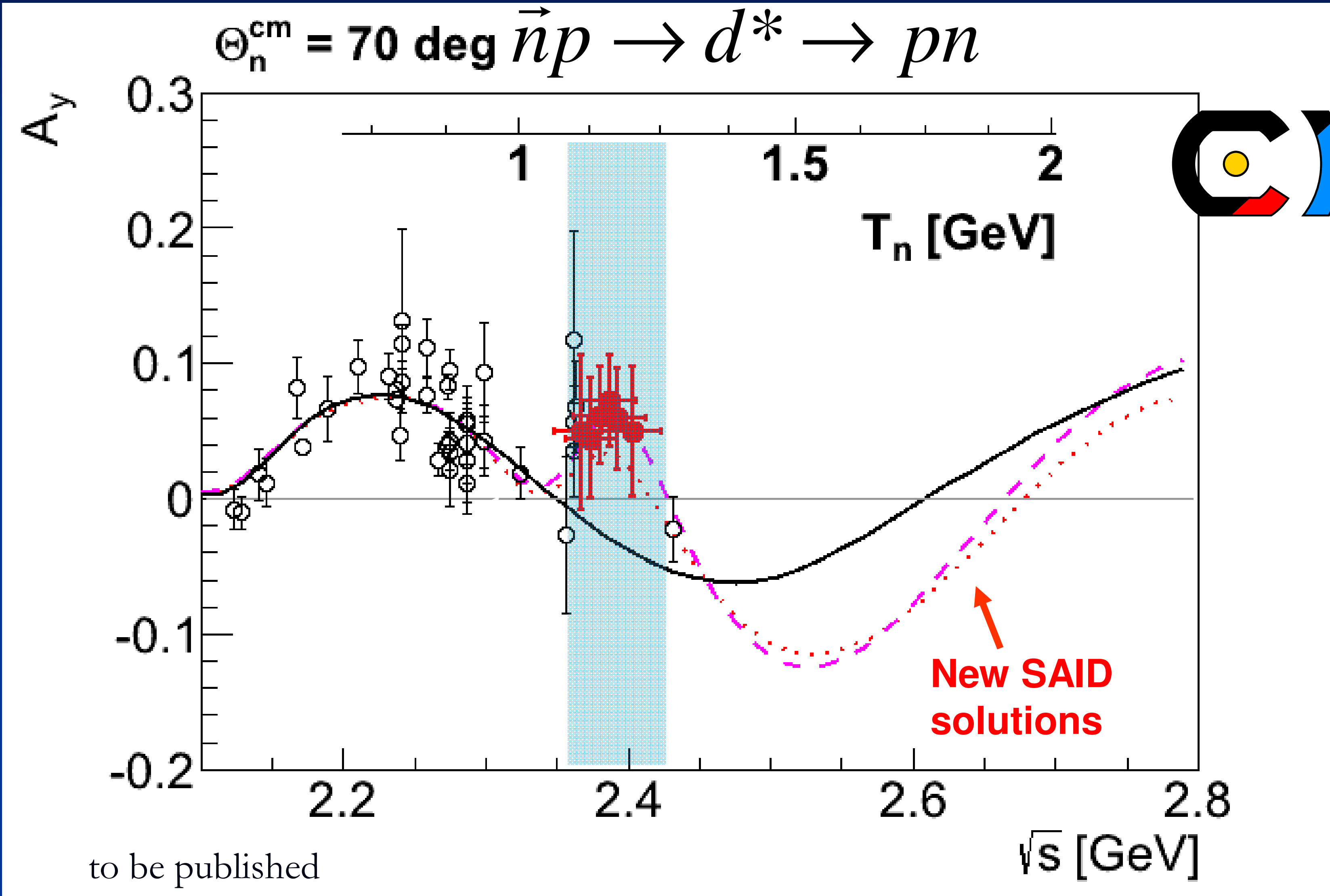


Phys. Rev. Letters 112 (2014) 202301

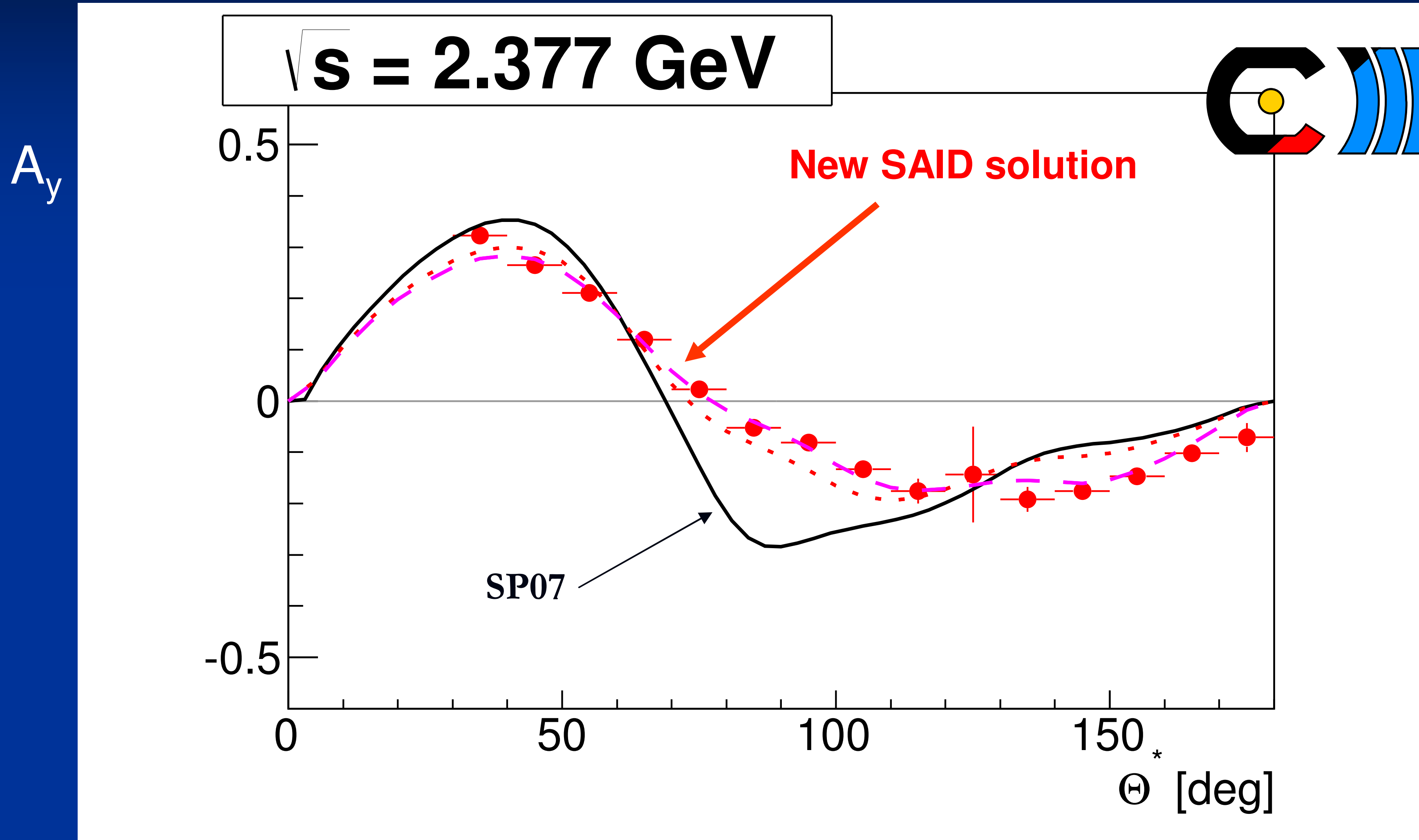
See talk
Ron Workman
today 15:20 A1

A_y Energy Dependence



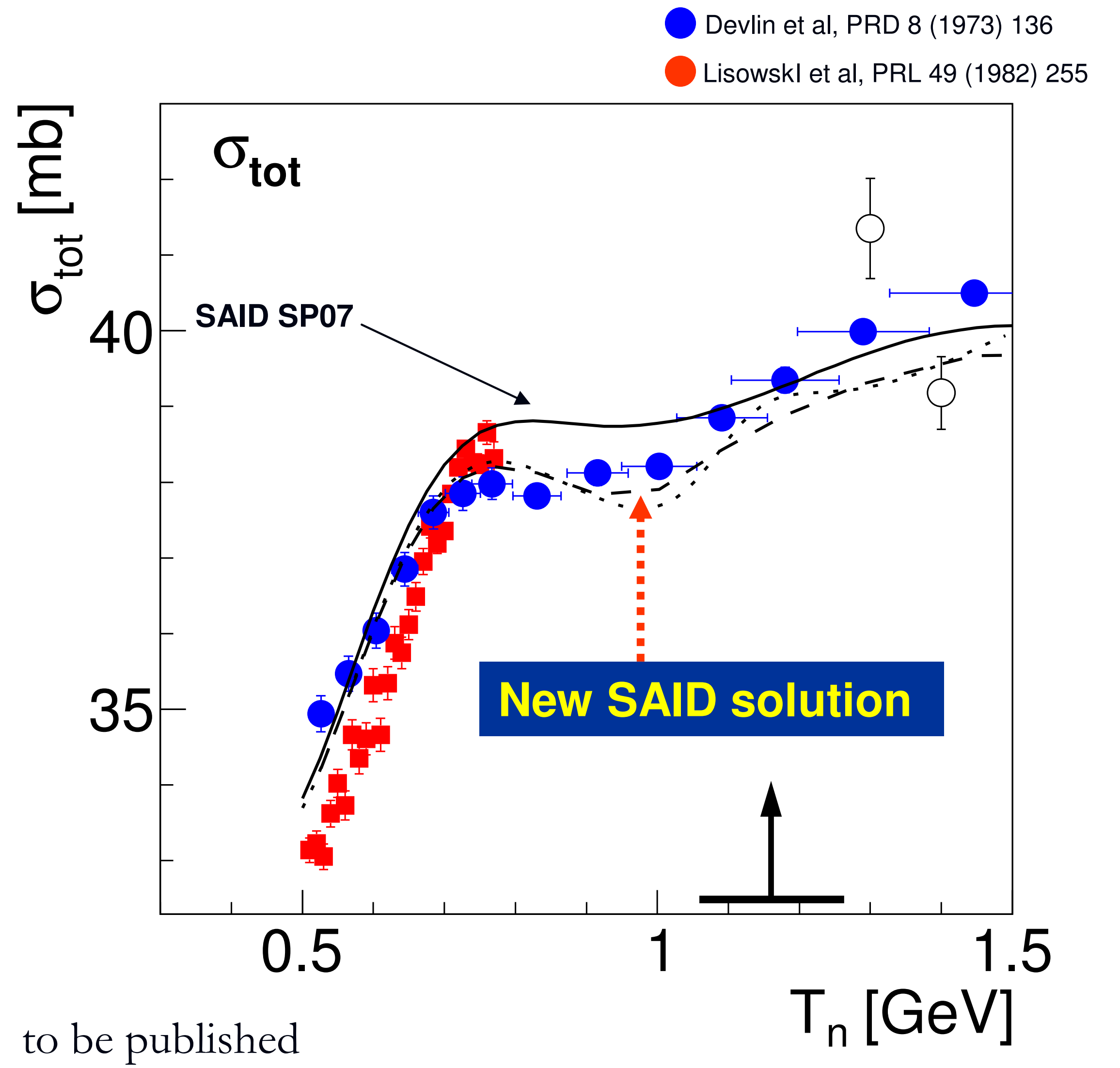


A_y Angular Distribution at Resonance



Phys. Rev. Lett. 112 (2014) 202301

pn Total Cross Section



to be published

Status of the d* Resonance

- hadronic decays

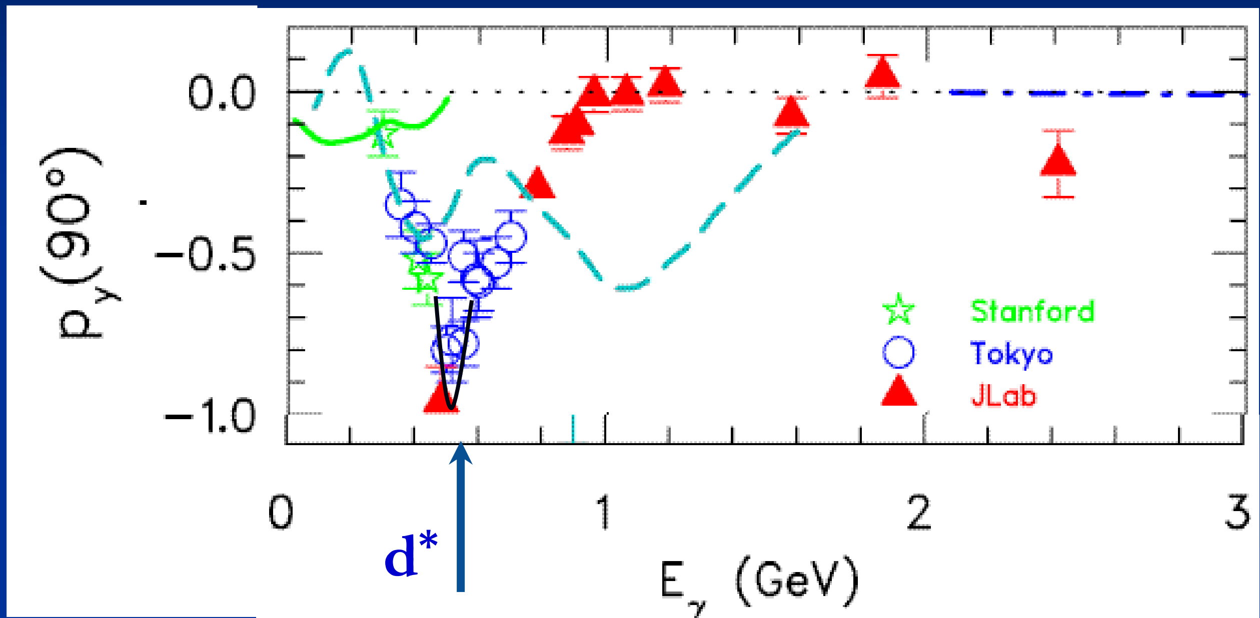
arXiv:1310.5532

decay channel	branching	status
d $\pi^0\pi^0$	14 %	observed
d $\pi^+\pi^-$	23 %	observed
pp$\pi^0\pi^-$	6 %	observed
nn$\pi^+\pi^0$	6 %	isospin mirrored
np$\pi^0\pi^0$	(12 %, predicted[+*])	observed
np$\pi^+\pi^-$	(30 %, predicted[*])	data analysis, HADES
np	(10 %, predicted)	observed

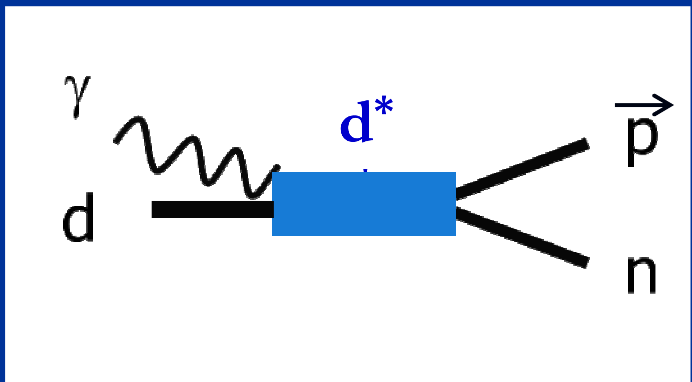
+ Fäldt & Wilkin, PLB 701 (2011) 619

* Albaladejo & Oset, PRC 88 (2013) 014006

Further hints: $\gamma d \rightarrow \vec{p} n$



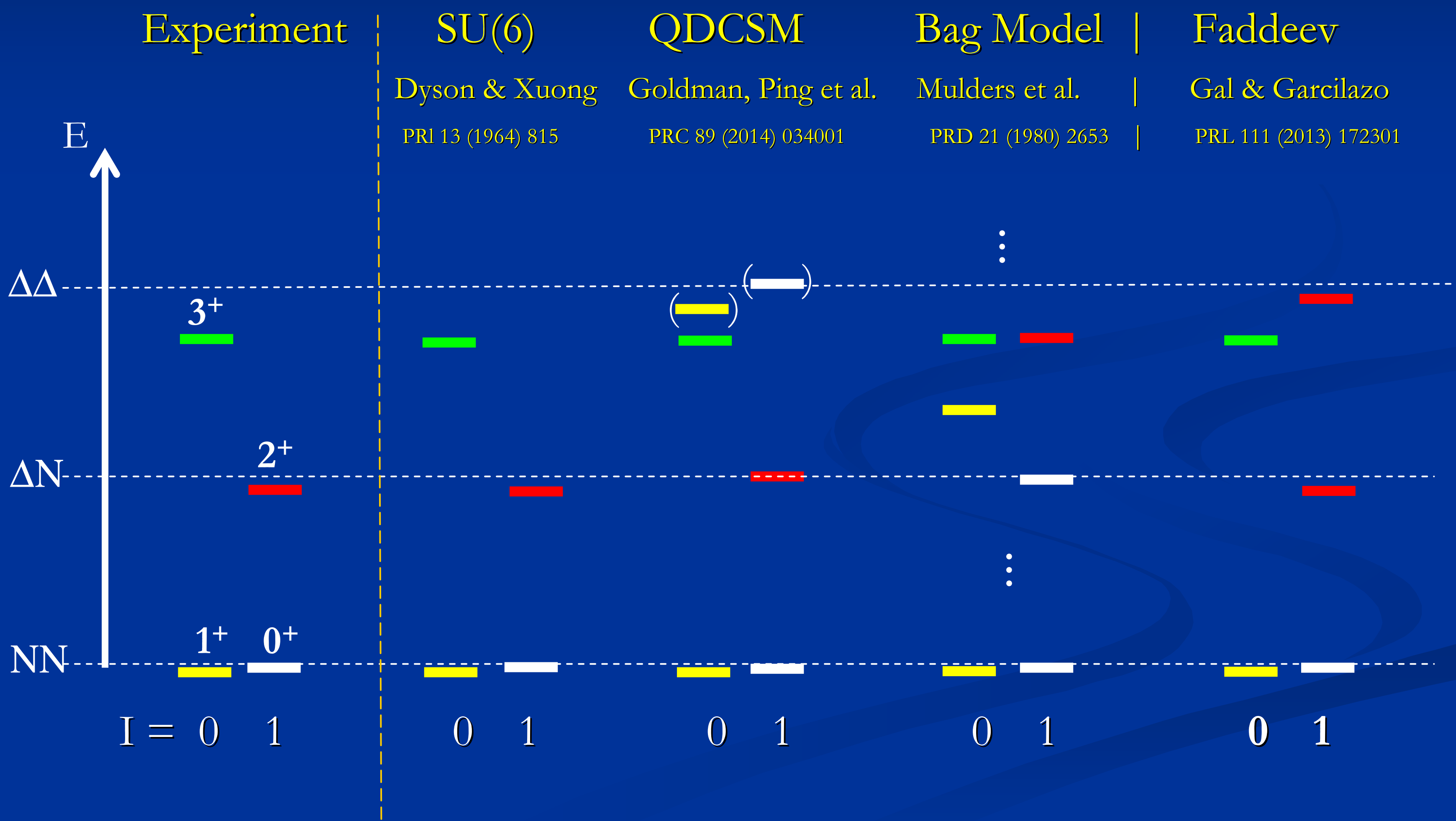
R. Gilman and F. Gross AIP Conf. Proc. 603 (2001) 55



T. Kamae, T. Fujita Phys. Rev. Lett. 38 (1977) 471

H. Ikeda et al., Phys. Rev. Lett. 42 (1979) 1321

Comparison to predictions from Quark and Hadron Models



Width of d*

- Experiment: $\Gamma \approx 70$ MeV
    - (t-channel ΔΔ: ≈ 250 MeV)
- QDCSM: 110 MeV
- Faddeev: 65 MeV x 3/2 (?)
    - Hidden Color ?

Dyson's Prediction

State	I	J	Asymptotic Configuration	m_{theor} [MeV]		m_{exp} [MeV]	Γ_{exp} [MeV]
D_{01}	0	1	Deuteron	1876	√	1876	
D_{10}	1	0	virtual $^1S_0$	1876	√	1878	
D_{12}	1	2	$NN(^1D_2) \leftrightarrow \Delta N \leftrightarrow NN\pi$	2160	√	2144	110
D_{21}	2	1	$\Delta N \leftrightarrow NN\pi$	2160			
D_{03}	0	3	$NN(^3D_3) \leftrightarrow \Delta\Delta \leftrightarrow NN\pi\pi$	2350	√	2380	70
D_{30}	3	0	$\Delta\Delta \leftrightarrow NN\pi\pi$	2350			

Dyson‘s Prediction

State	I	J	Asymptotic Configuration	m_{theor} [MeV]		m_{exp} [MeV]	Γ_{exp} [MeV]
D_{01}	0	1	Deuteron	1876	√	1876	
D_{10}	1	0	virtual $^1S_0$	1876	√	1878	
D_{12}	1	2	$NN(^1D_2) \leftrightarrow \Delta N \leftrightarrow NN\pi$	2160	√	2144	110
D_{21}	2	1	$\Delta N \leftrightarrow NN\pi$	2160		?	?
D_{03}	0	3	$NN(^3D_3) \leftrightarrow \Delta\Delta \leftrightarrow NN\pi\pi$	2350	√	2370	70
D_{30}	3	0	$\Delta\Delta \leftrightarrow NN\pi\pi$	2350		?	?

A hint for D_{21} $I(J^P) = 2(1^+)$?

- Pionic Double Charge Exchange in Nuclei:
- non-analog transitions:

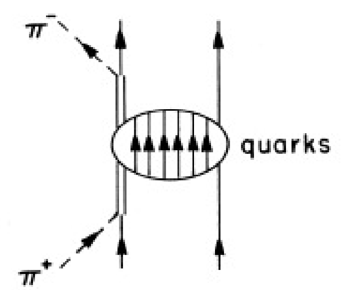


FIG. 3. The short-range part of the Δ-nucleon interaction, involving direct participation of the quark-gluon degrees of freedom.

intermediate system:

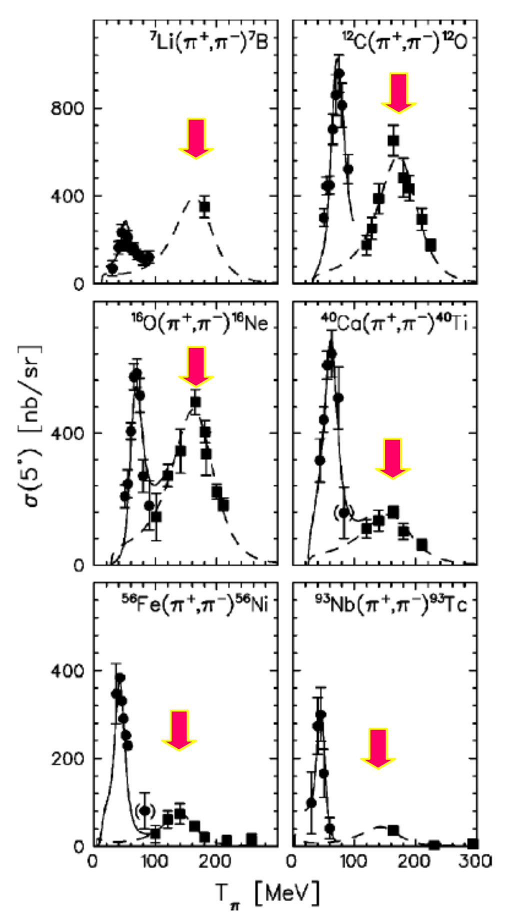
$(\Delta N)_{I=2,\, J^P=1^+}$

M ≈ 2150 MeV

Γ ≈ 90 MeV

A. Wirzba et al., PRC 40 (1989) 2745
M.B. Johnson, L.S. Kisslinger, PLB 168 (1986) 26

Prediction Gal & Garcilazo: M ≈ 2165 MeV, Γ ≈ 130 MeV



J. Draeger et al., PRC 62 (2000) 064615

Conclusions

- Non-Strange Two-Baryon Spectrum
  - 3 established states: $^3S_1$ deuteron groundstate
    $^1S_0$ virtual state
    $^1D_2$ resonance (ΔN)
  - 1 new - presumably exotic - candidate:
    d^* resonance (ΔΔ)
  - Are there more states?
    - NN-decoupled states with I = 2, 3?
    - Search in pp → $pp\pi^+\ \pi^-$
      and in pp → $pp\pi^+\pi^+\ \pi^-\pi^-$
- Strange, charmed ... Di-Baryons?

See poster M. Bashkanov