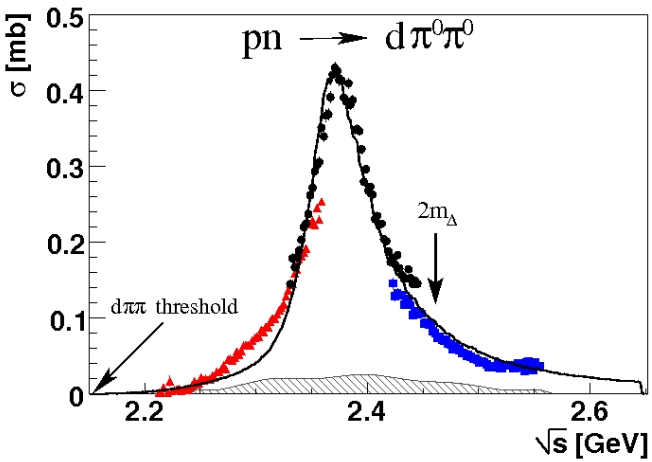
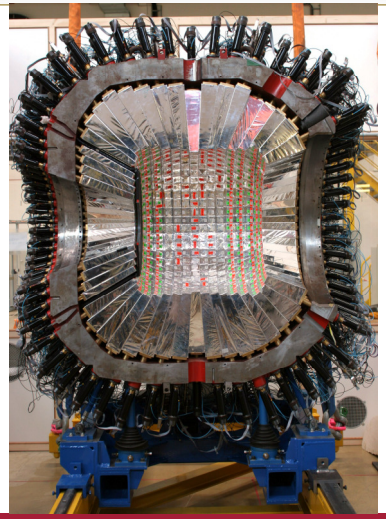
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Kepler Center for Astro and Particle Physics

Fachbereich Physik





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DFG Deutsche Forschungsgemeinschaft

From CELSIUS to COSY: On the Observation of a Dibaryon Resonance

Svenskt Kärnfysikermöte 2014
Uppsala, Nov. 11, 2014

Heinz Clement

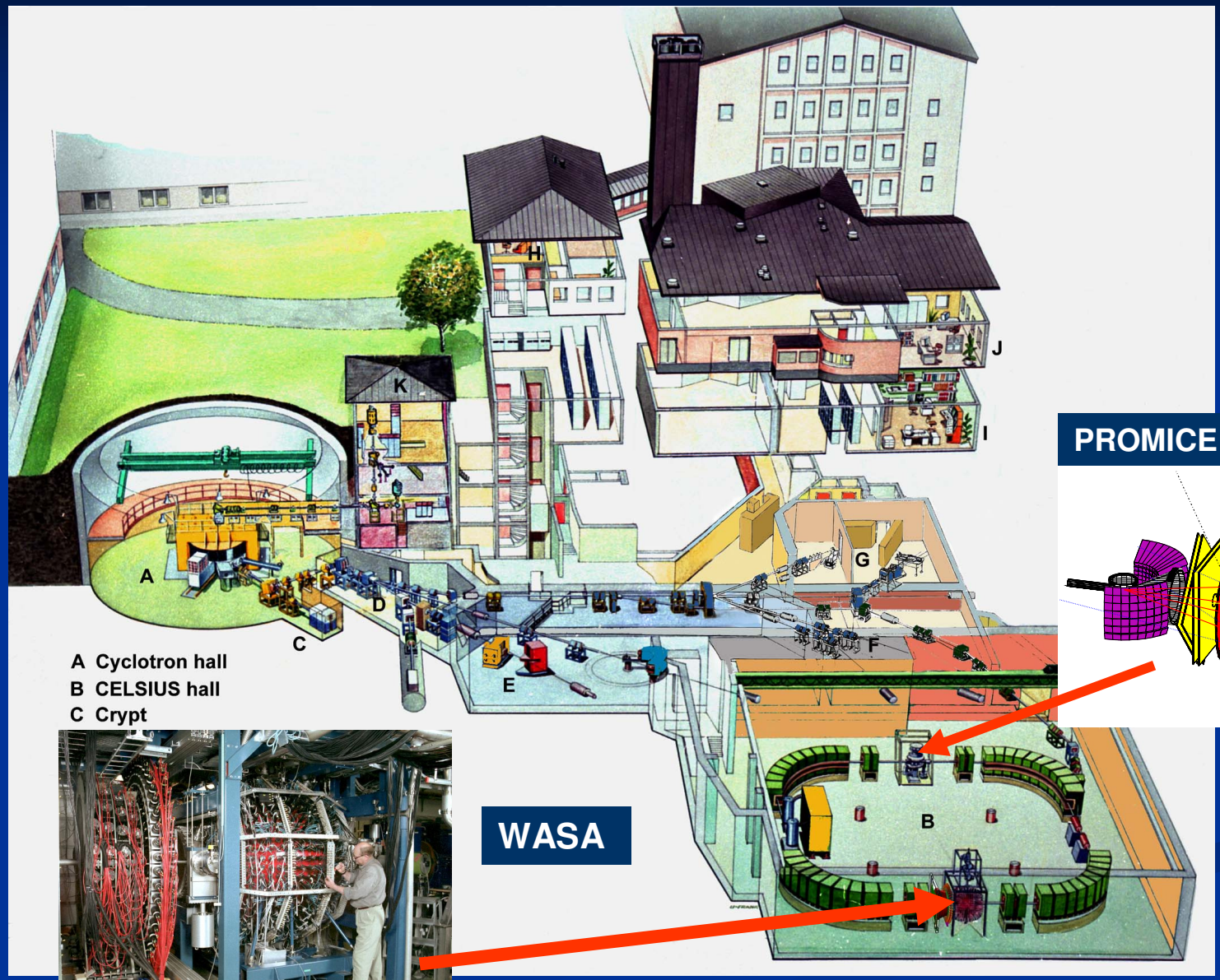
How to find a Dibaryon?

- Our approach:
  - Two-pion production with best suited equipment
    - 4π detector: WASA
    - pellet target: p and d
    - storage ring: CELSIUS $\rightarrow$ COSY
  - The learning phase:
    - pp induced two-pion production
  - Following a trace:
    - the ABC effect in double-pionic fusion
  - The surprise:
    - a narrow resonance in pn induced two-pion production

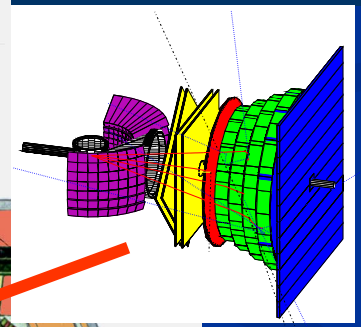
The Svedberg Laboratory

CELSIUS

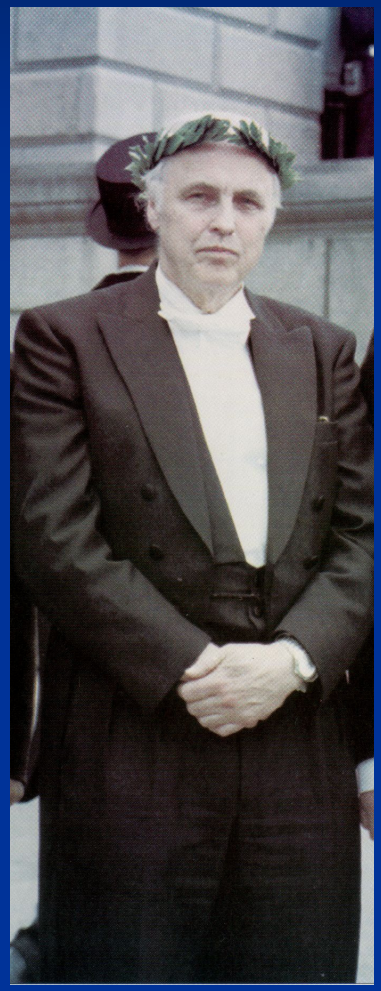
Uppsala / Sweden



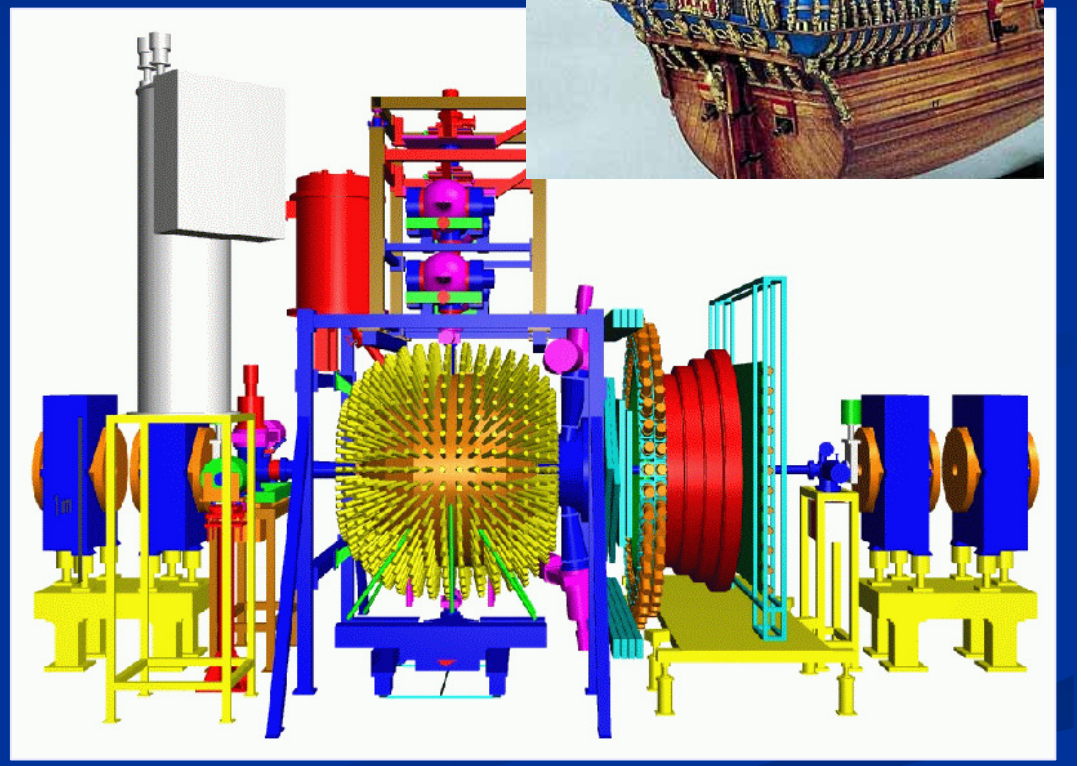
PROMICE / WASA



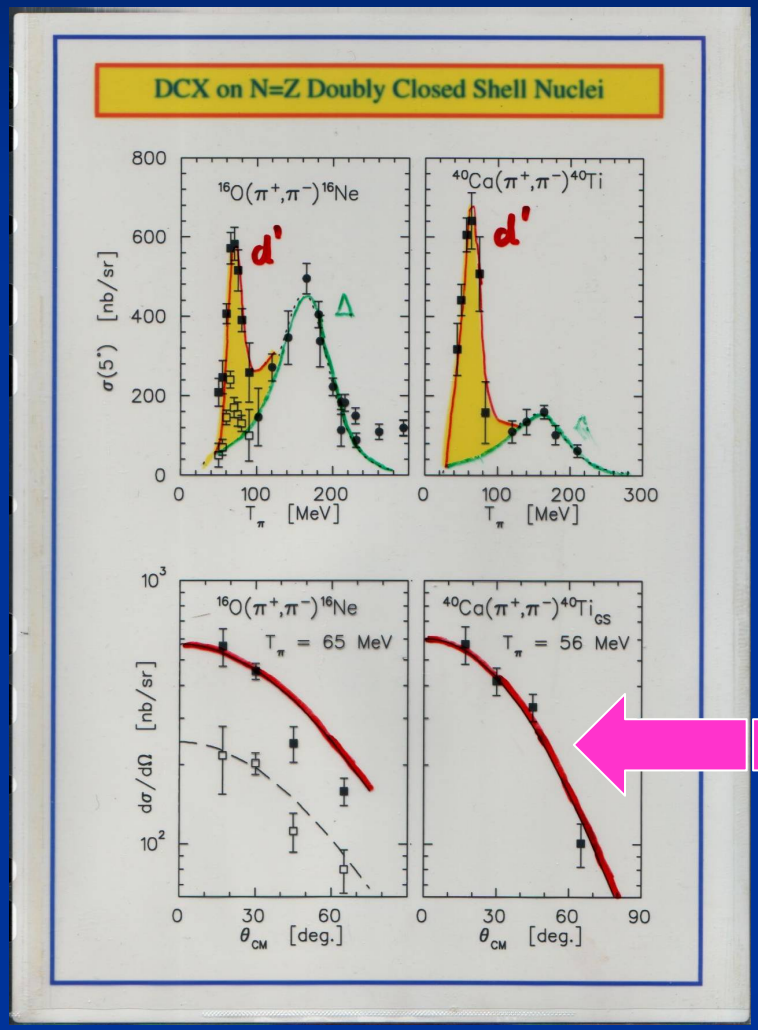
… Father of WASA



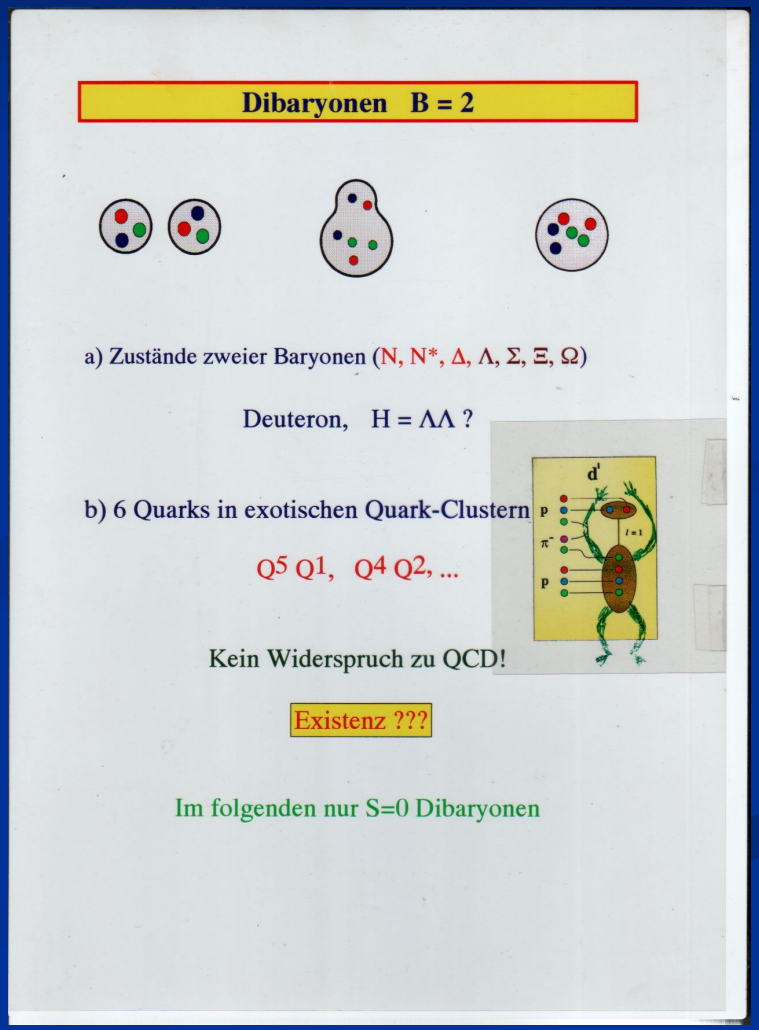
Sven Kullander



Learning by Doing ... Mistakes

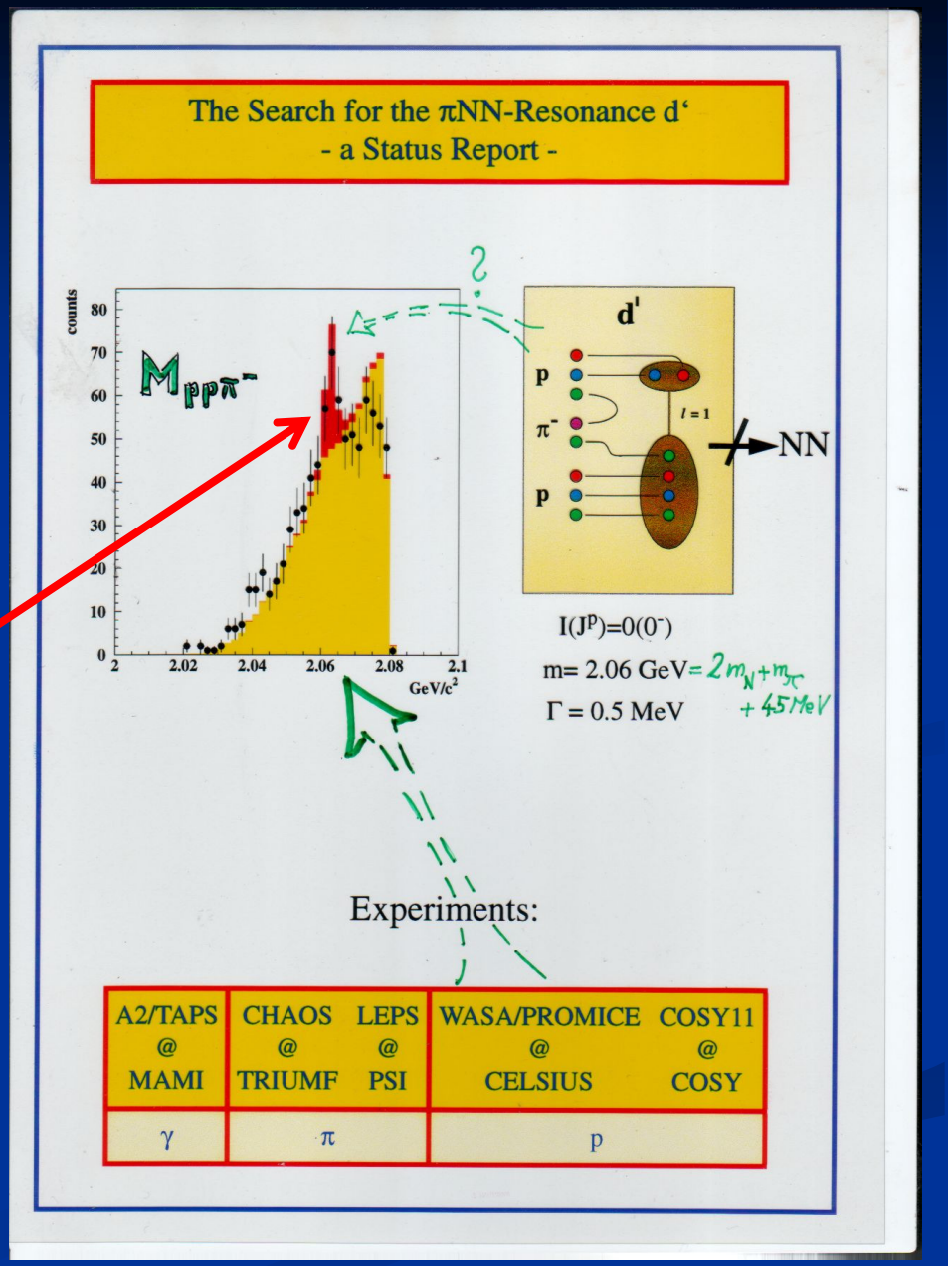


$J^P = 2^-$

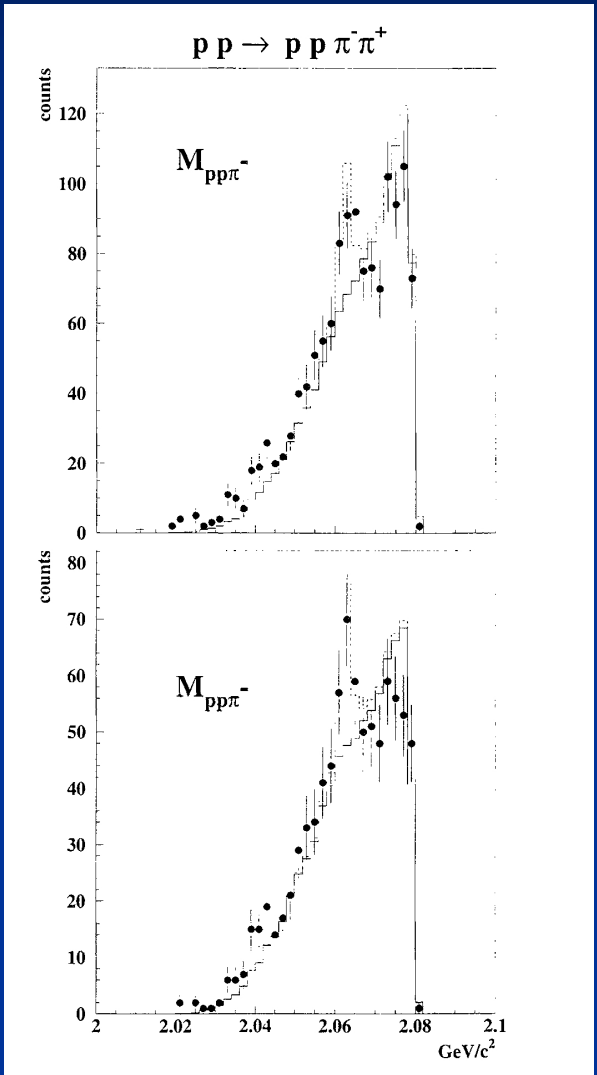


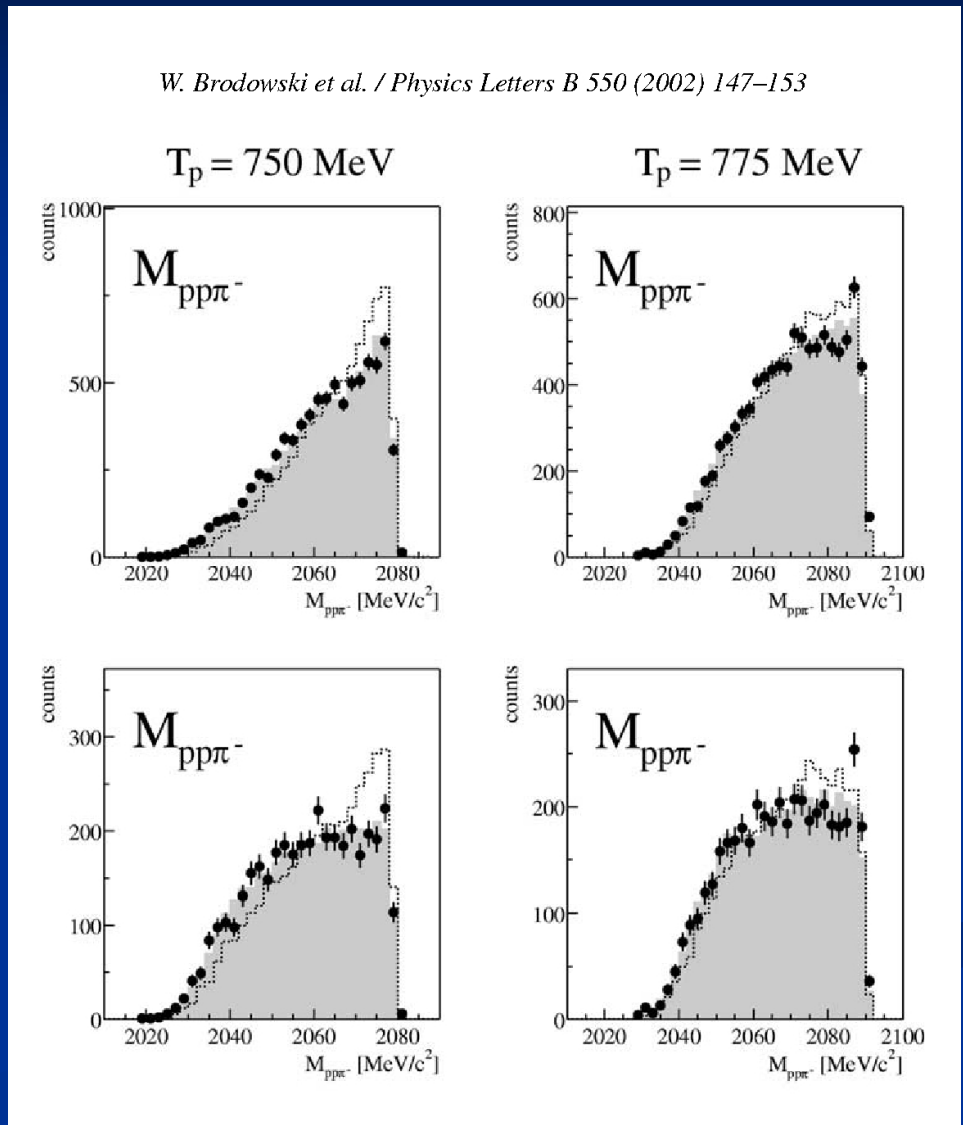
… it should show up in the $M_{pp\pi^-}$ spectrum of the $pp \rightarrow pp\pi^+\pi^-$ reaction …

… and indeed …



… however, better statistics sometimes helps!

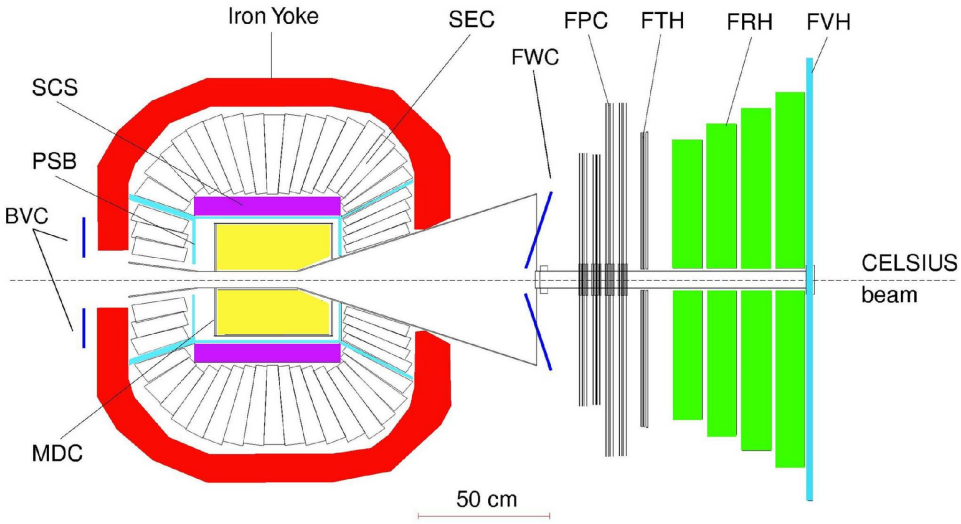




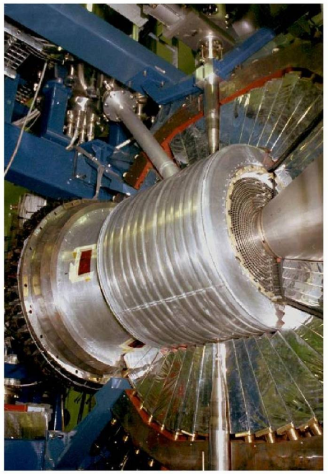
The New Millenium

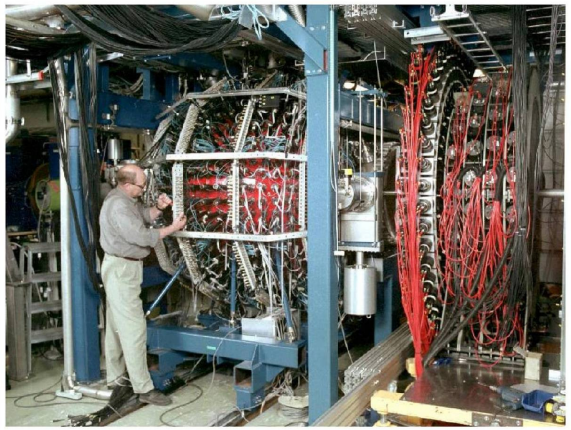
- 4π - WASA detector

WASA 4π Detector



Central Detector Forward Detector





P

p

π

γ

π

n

Θ resolution

2 deg.

2 deg.

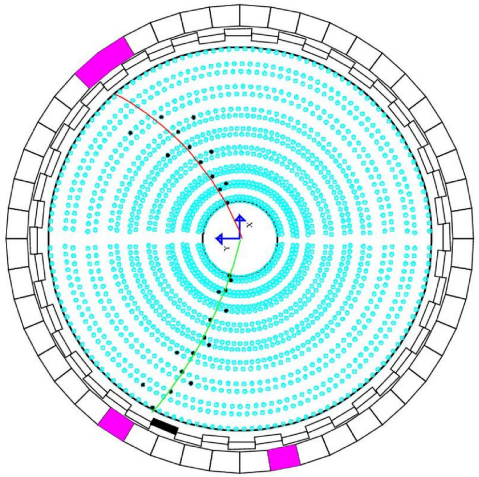
deg.

deg.

5deg

MDC event

$pp \rightarrow pp\pi^+\pi^-$



– reconstruction of all particles ⇒ overdetermin

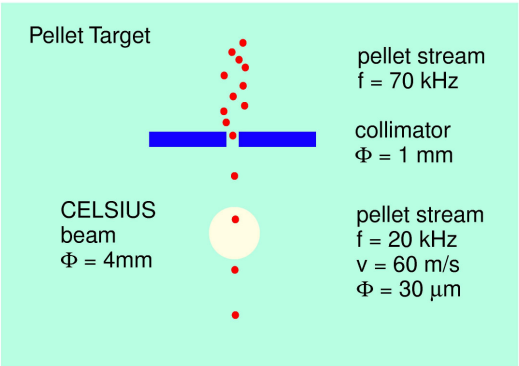
– magnetic fiel

η

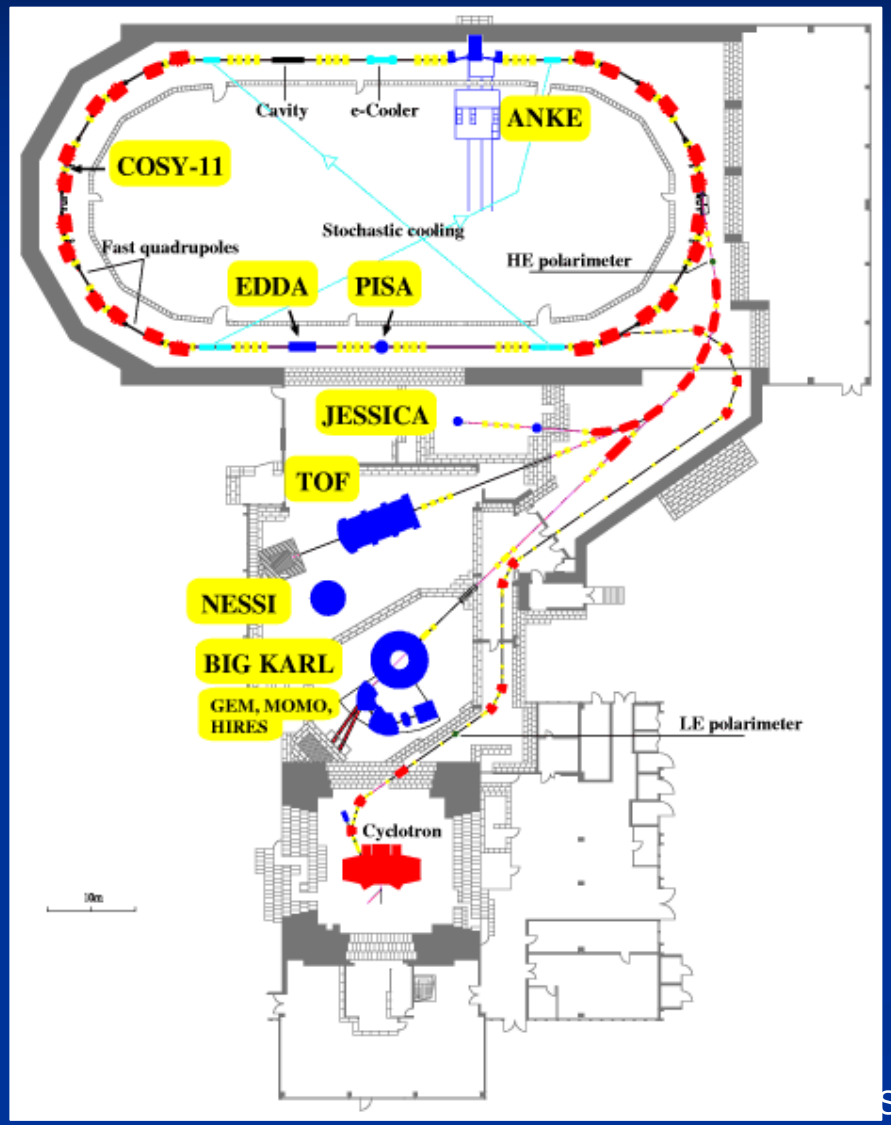
ω

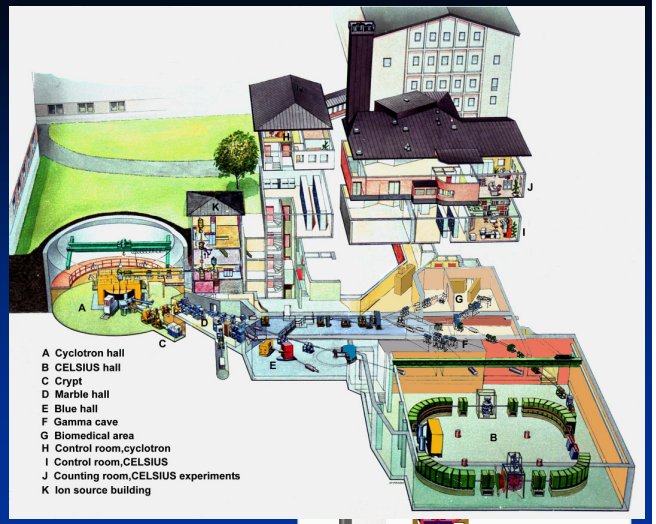
SY: Dibaryon

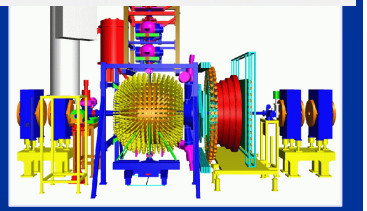
Pellet Target



WASA at COSY



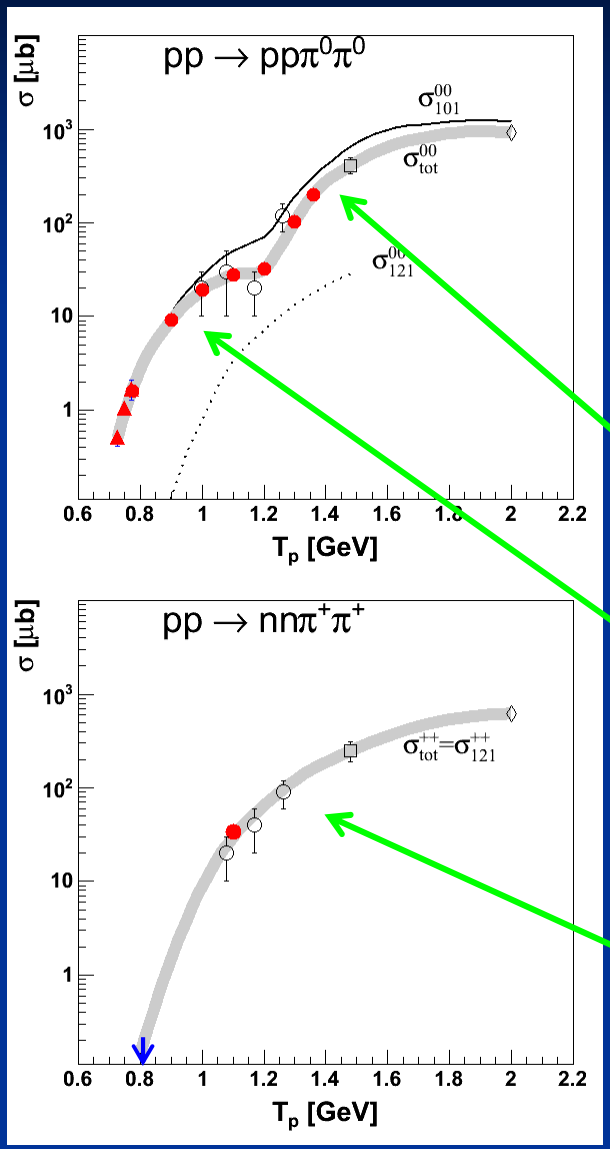




2005 - 2006

CELSIUS/WASA

Isovector : Total Cross Sections



isospin decomposition

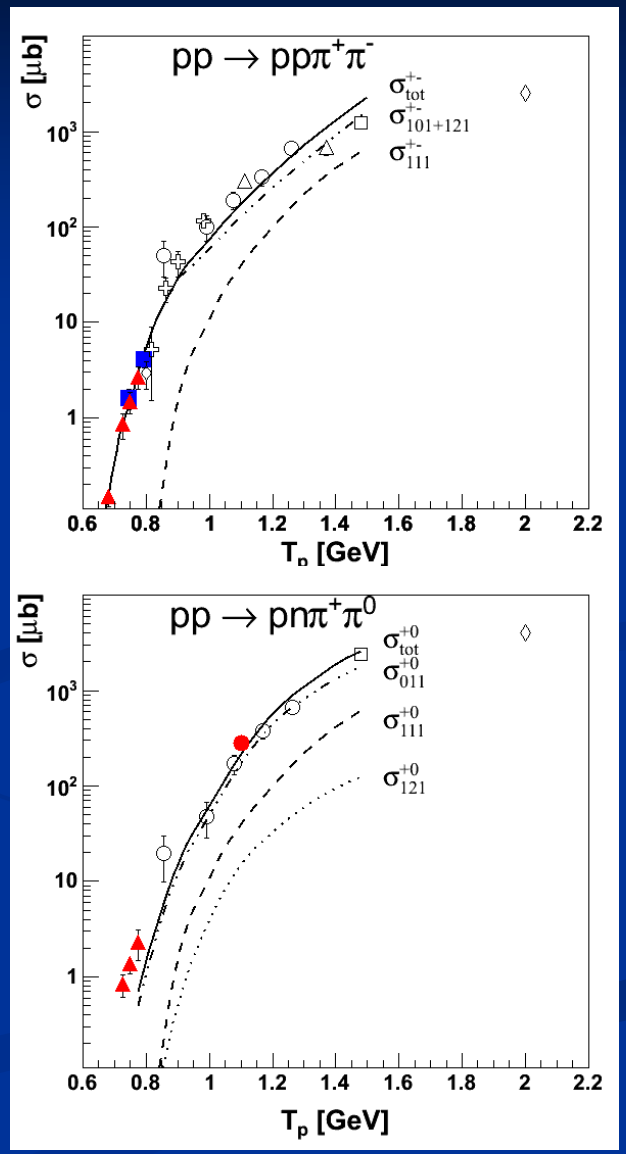
⇒

ΔΔ

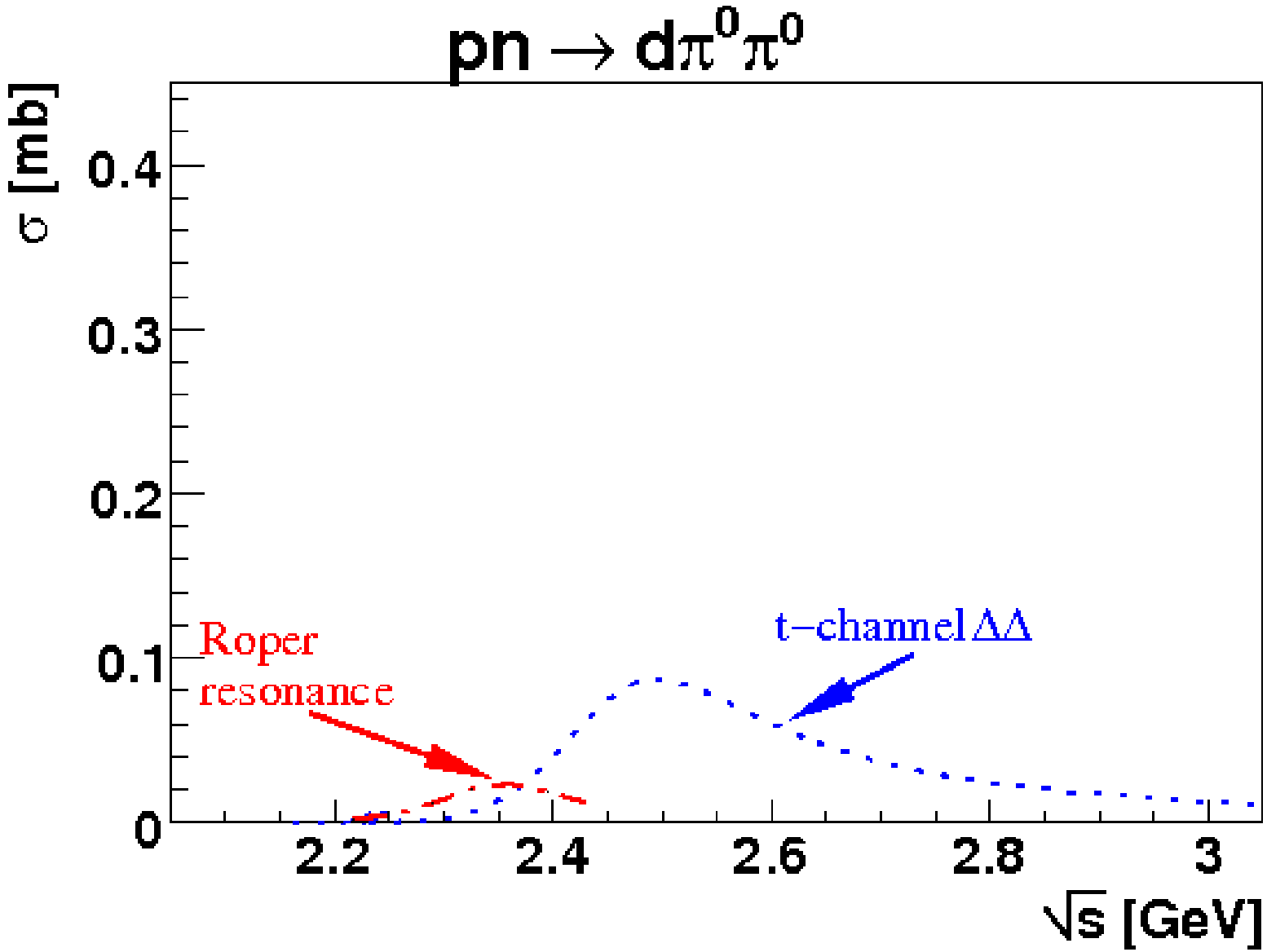
N*(1440)

Δ(1600) (?)

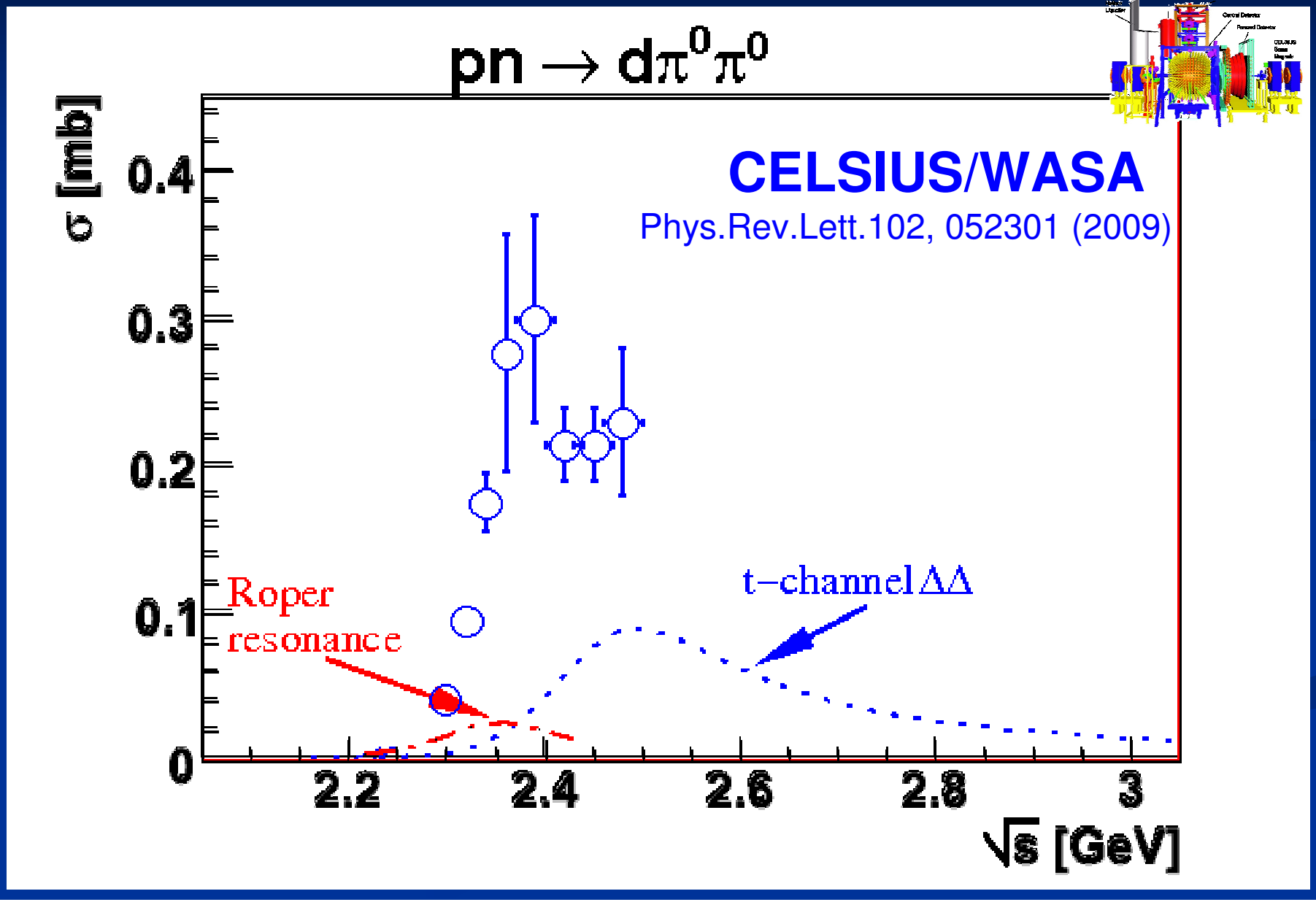
Phys. Lett. B 679 (2009) 30



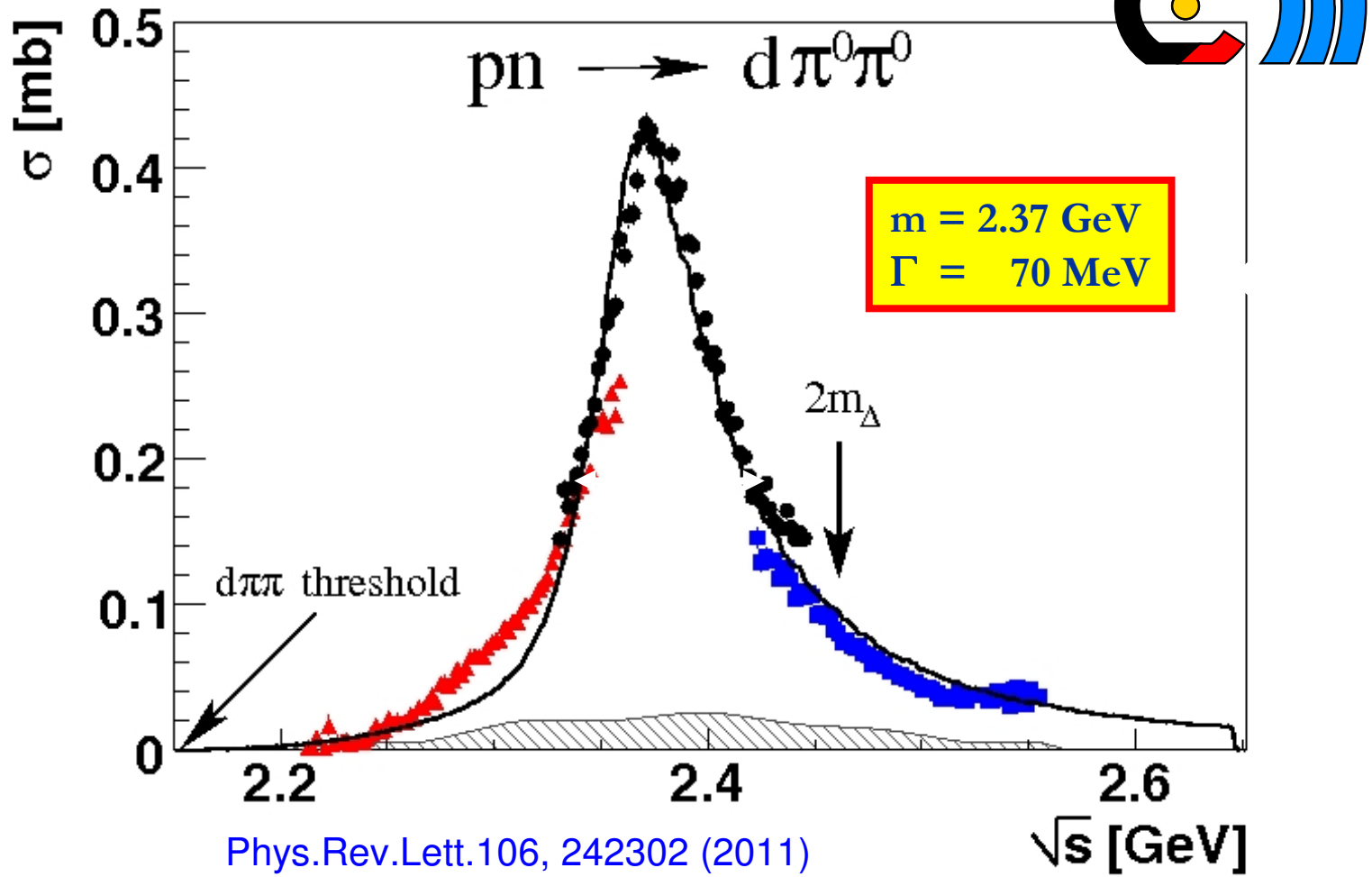
Isoscalar : … this is what we expected!



Isoscalar : … and this is what we found!

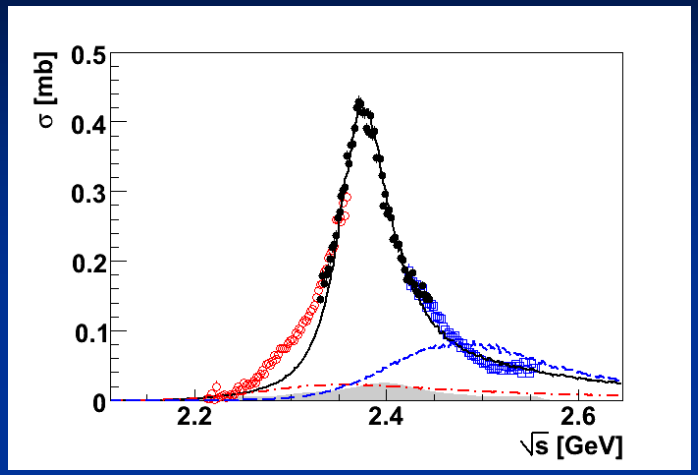


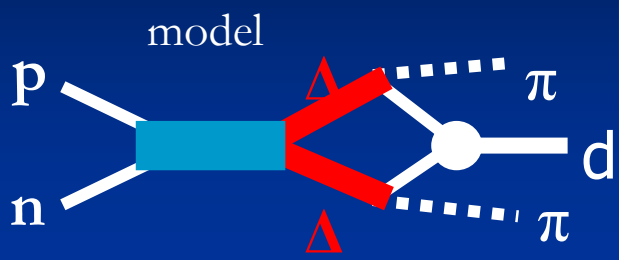
Isoscalar : Results from WASA at COSY



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

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

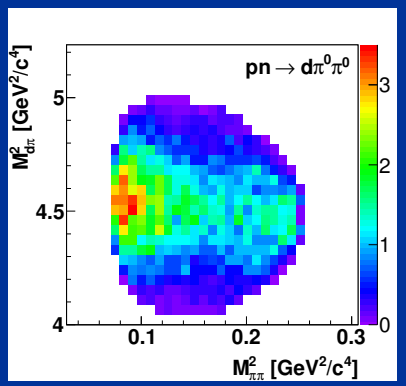


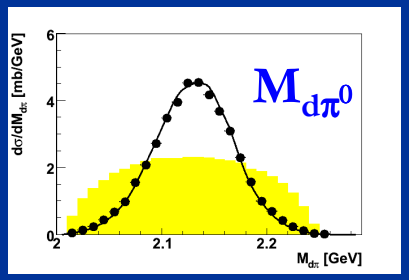


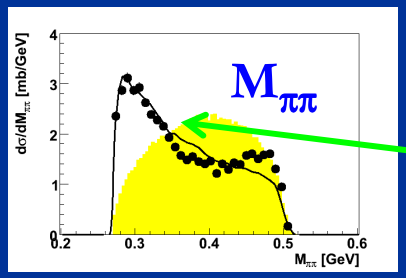
$I\ (J^P) = 0\ (3^+)$

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

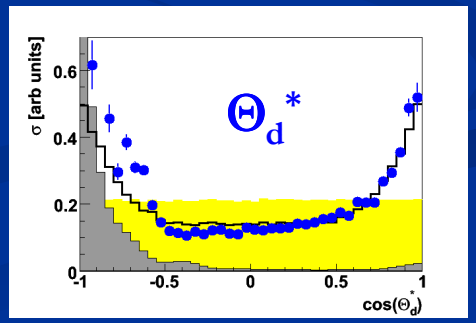
Phys.Rev.Lett.106, 242302 (2011)





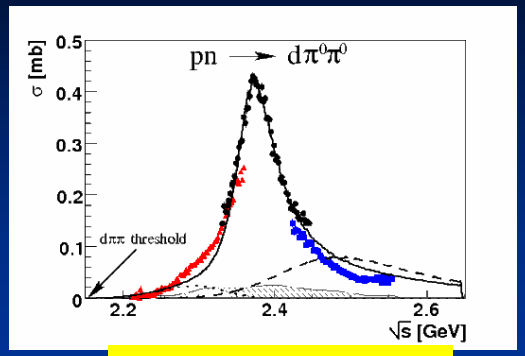


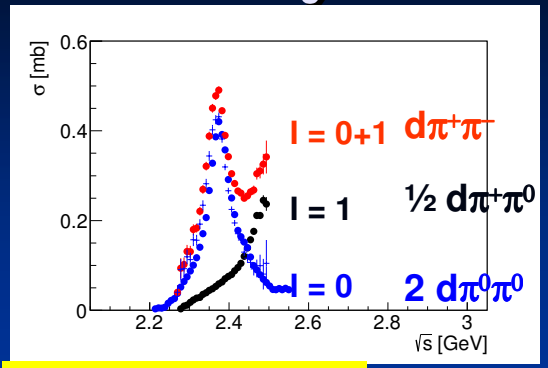
ABC effect



hadronic decays

PRL 106 (2011) 242302





PLB 721 (2013) 229

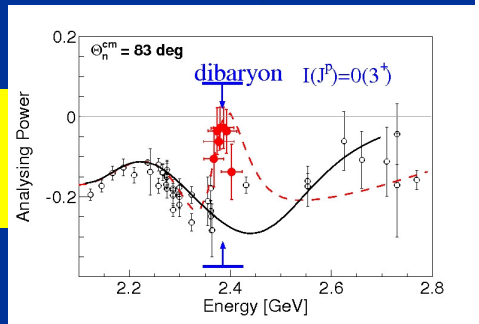
○ ● ● WASA data

$d\pi^0\pi^0$

$d\pi^+\pi^-$

pn → d*(2380)

pn

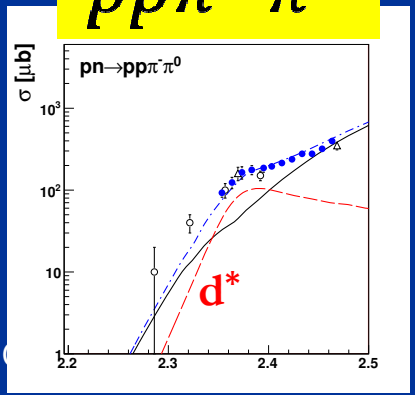


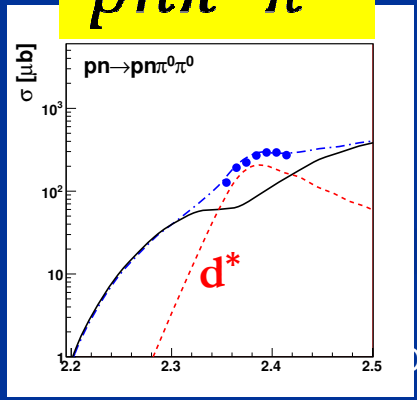
PRL 112 (2014) 202301
PRC 90 (2014) 035204

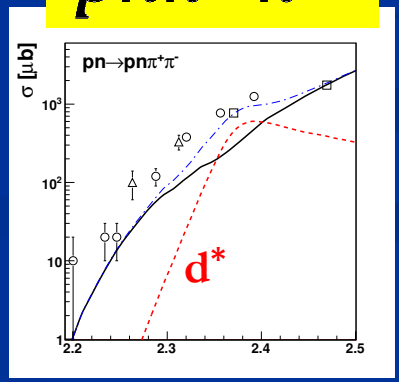
$pp\pi^-\pi^0$

$pn\pi^0\pi^0$

$pn\pi^+\pi^-$



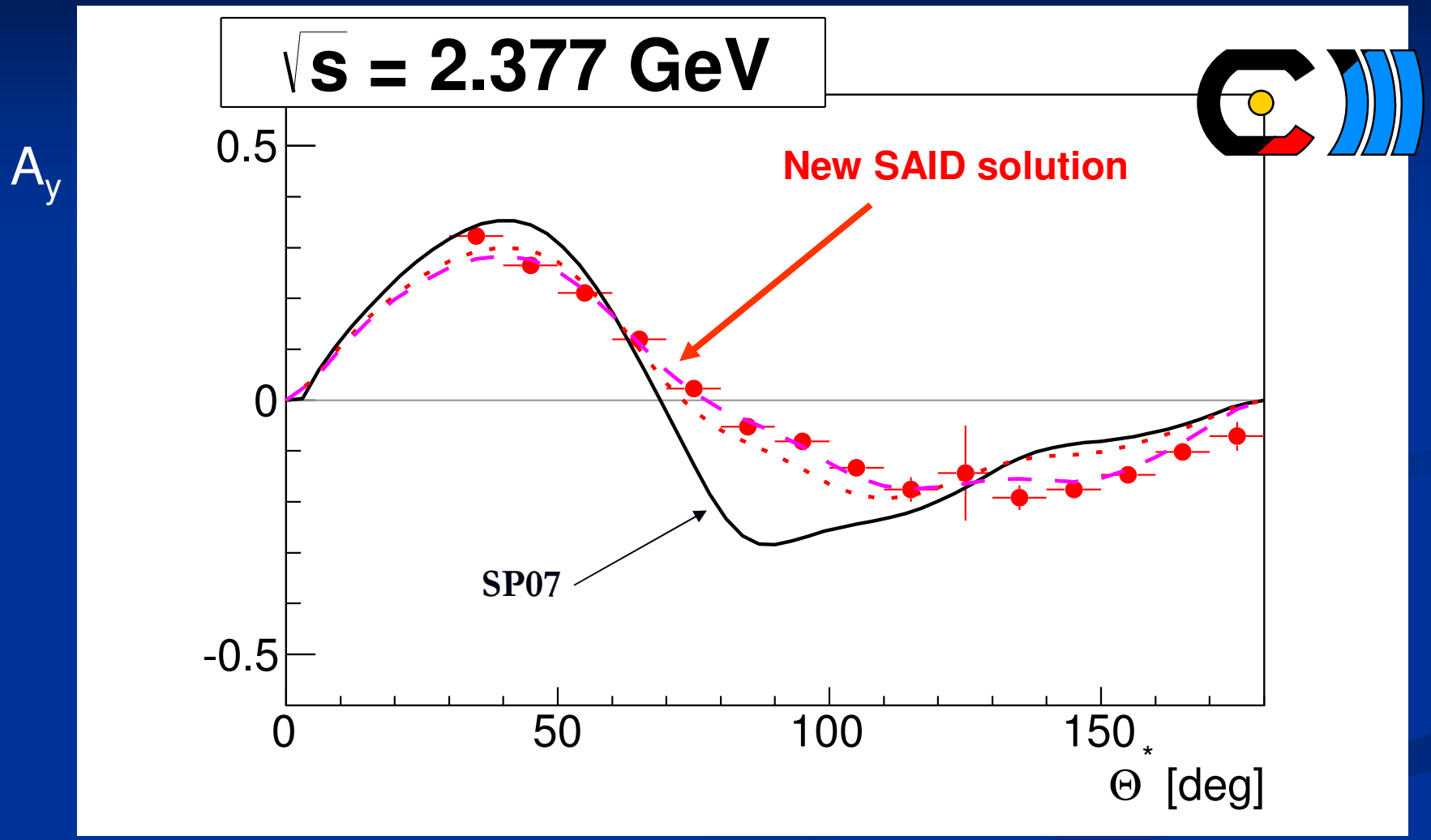




PRC 88 (2013) 055208
arXiv:1409.2659 [nucl-ex]

→ √s [GeV]

A_y Angular Distribution at Resonance

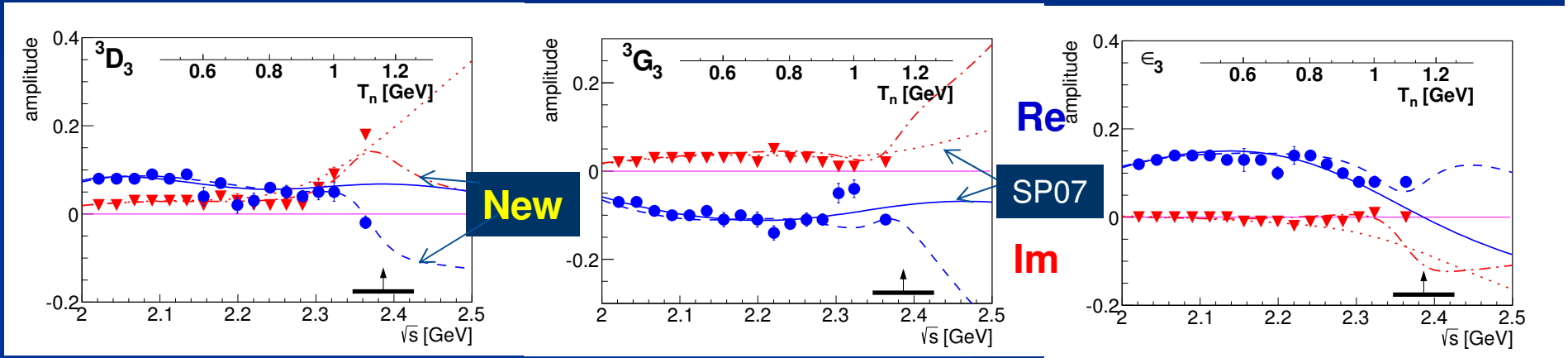


Phys. Rev. Lett. 112 (2014) 202301

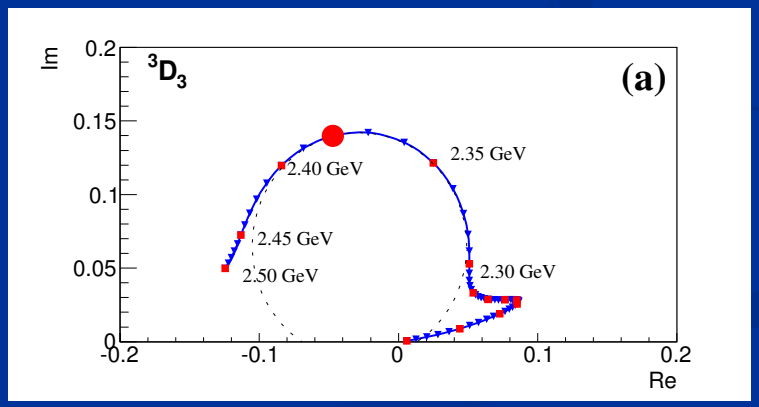
SAID Partial-Wave Analysis

$^3D_3 - {}^3G_3$ Coupled Partial Waves

Phys. Rev. Letters 112 (2014) 202301



Argand diagram:

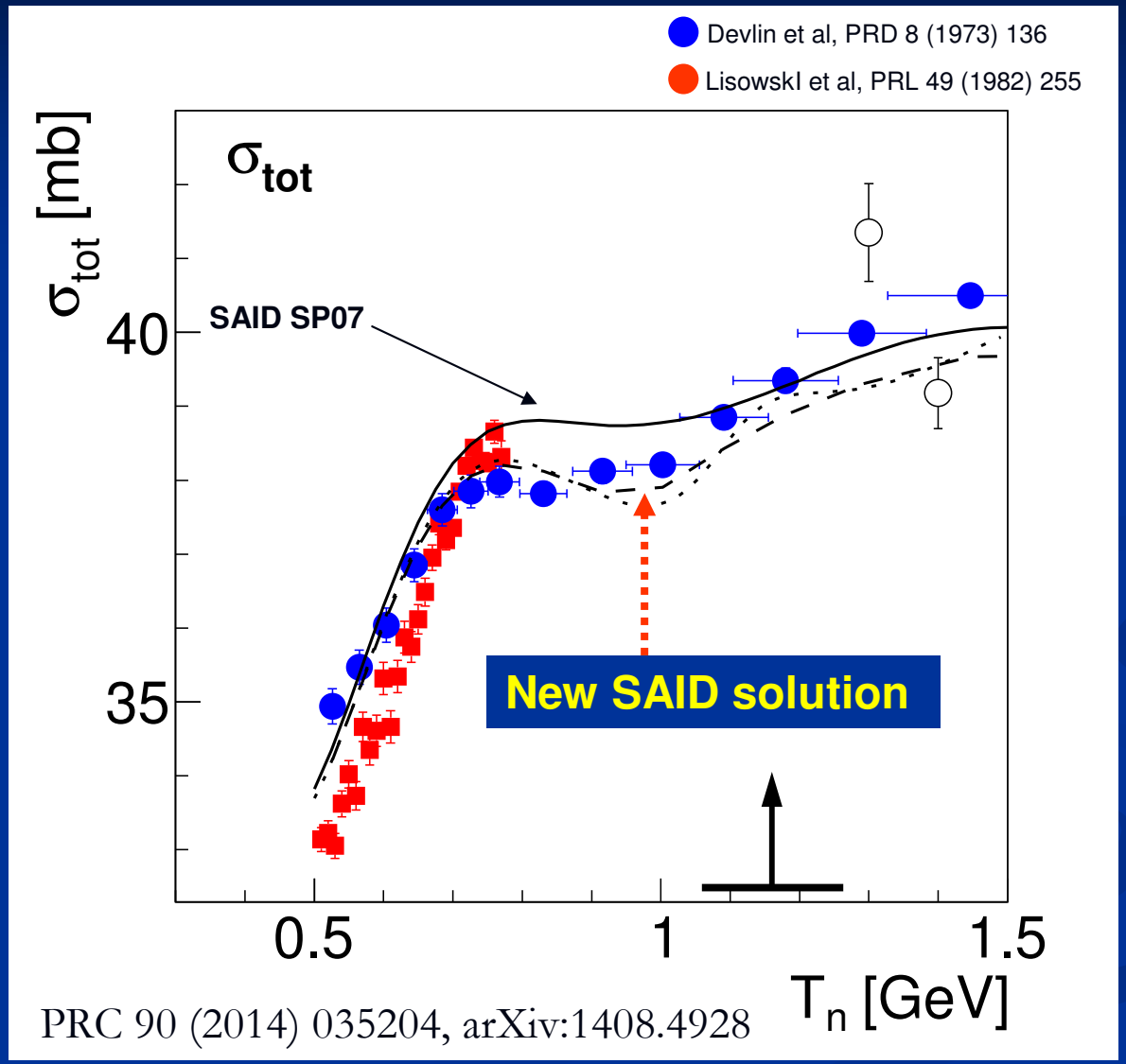


PRC 90 (2014) 035204
arXiv: 1408.4928 [nucl-ex]

Pole in $^3D_3$ at 2380±10 - i 40±5 MeV

⇔ Genuine Resonance in np System

pn Total Cross Section



PRC 90 (2014) 035204, arXiv:1408.4928

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“: $\Delta\Delta$ $I(J^P) = 0(3^+)$

… 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

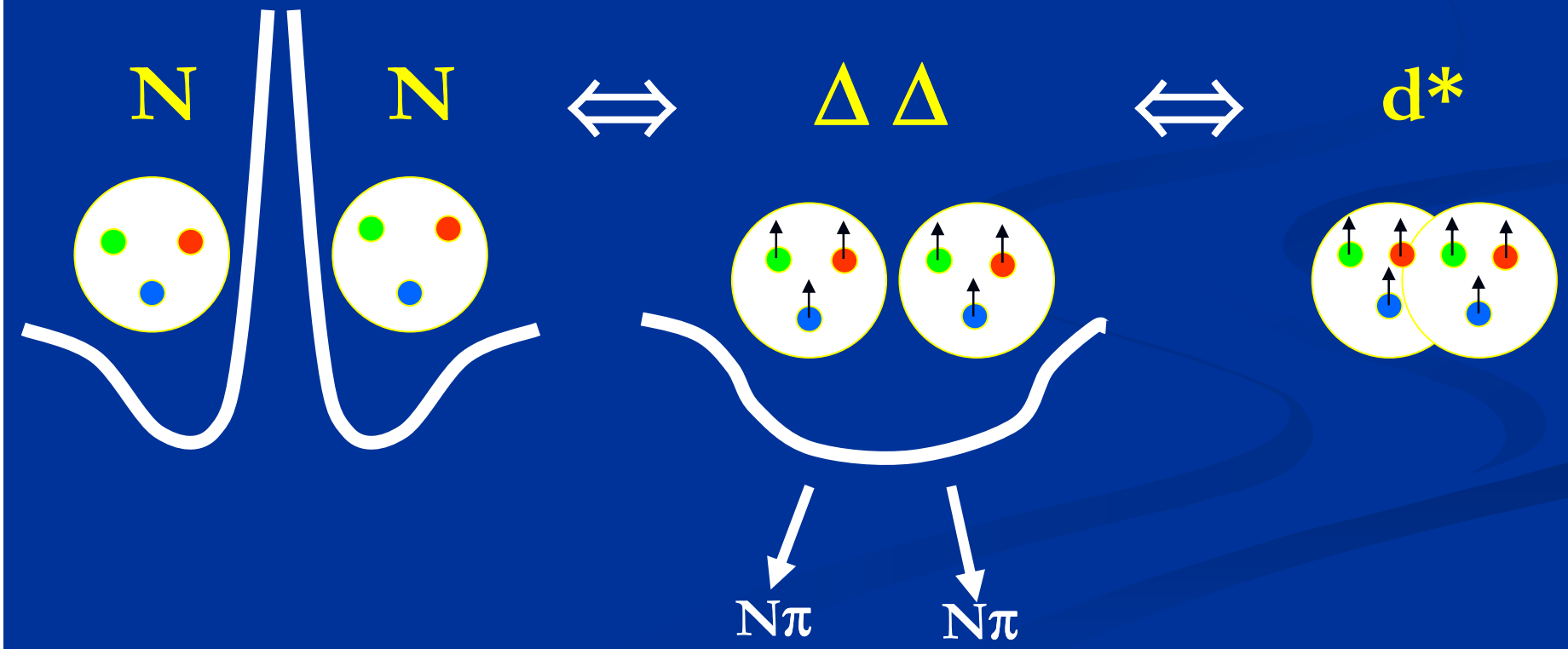
Fan Wang†
Department of Physics, University of California, Los Angeles, California 90024
(Received 13 December 1988)

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 $np \rightarrow d^*$ and $\pi^\pm d \rightarrow \pi^\pm d^*$.

… inevitable dibaryon

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

accessed via ΔΔ as doorway ?



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	$A+10B$

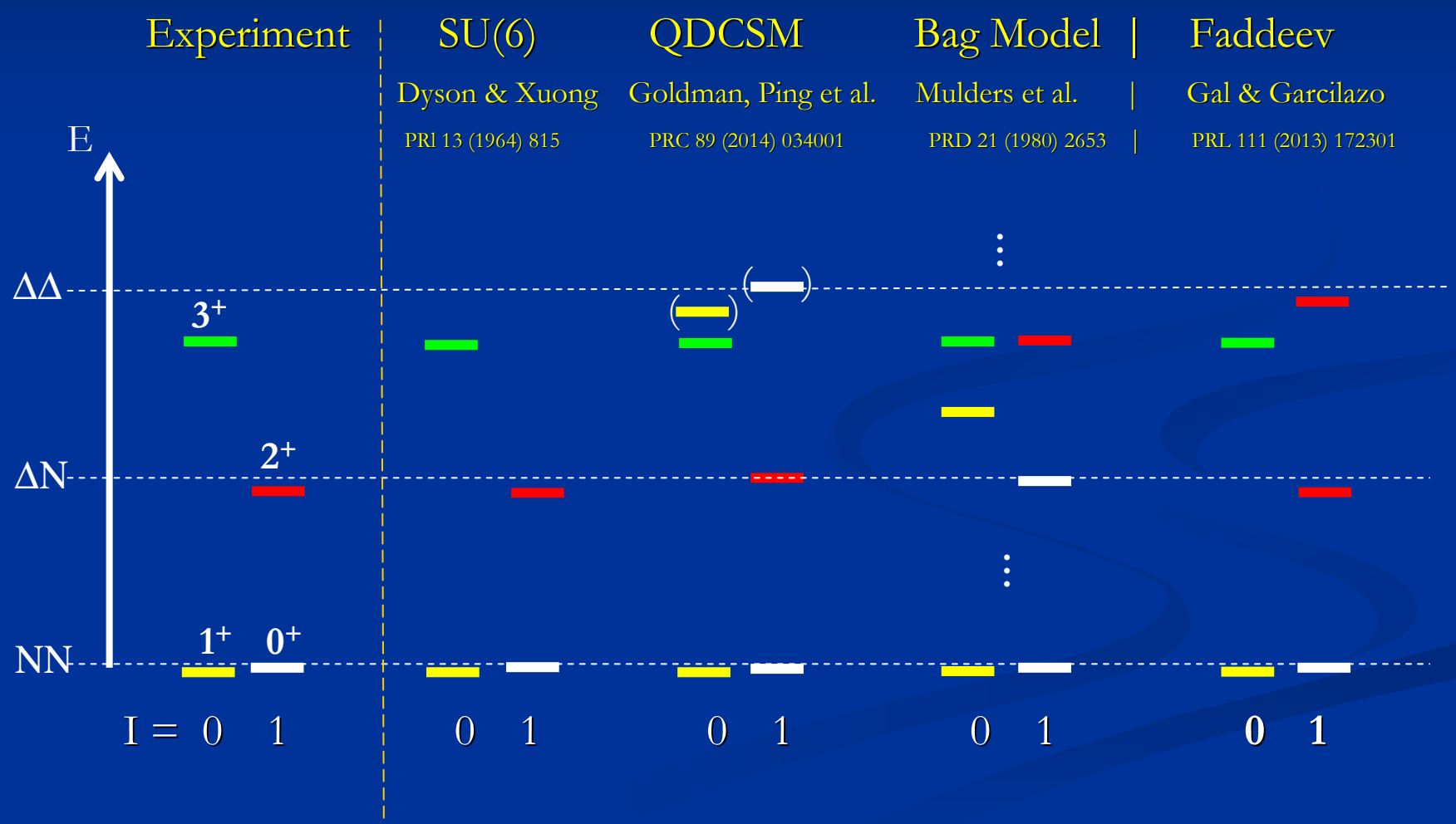
Dyson's Prediction

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	?		

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		?	?

Comparison to predictions from Quark and Hadron Models



Width of d*

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

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 ($\Delta\Delta$)
  - Are there more states?
    - NN-decoupled states with I = 2, 3?
    - Search in pp $\rightarrow$ ppπ^+ π^-
      and in pp $\rightarrow$ pp$\pi^+\pi^+$ $\pi^-\pi^-$
- Strange, charmed ... Di-Baryons?

Zhang, Shen et al.

Ping et al.

Gal & Garcilazo

Dyson's prediction