Coupled-channels approaches to meson production reactions

The way to the N*s

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ICCUB Institut de Ciències del Cosmos

CPAN ingenio 2010

EBAC

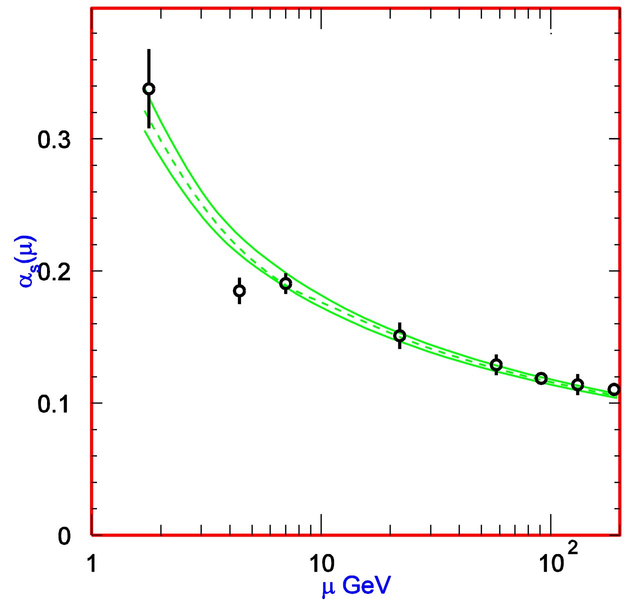
Dedicated to the memory of Dick Arndt (1933-2010)

Summary

- **N* physics**

- **Current coupled-channels efforts**

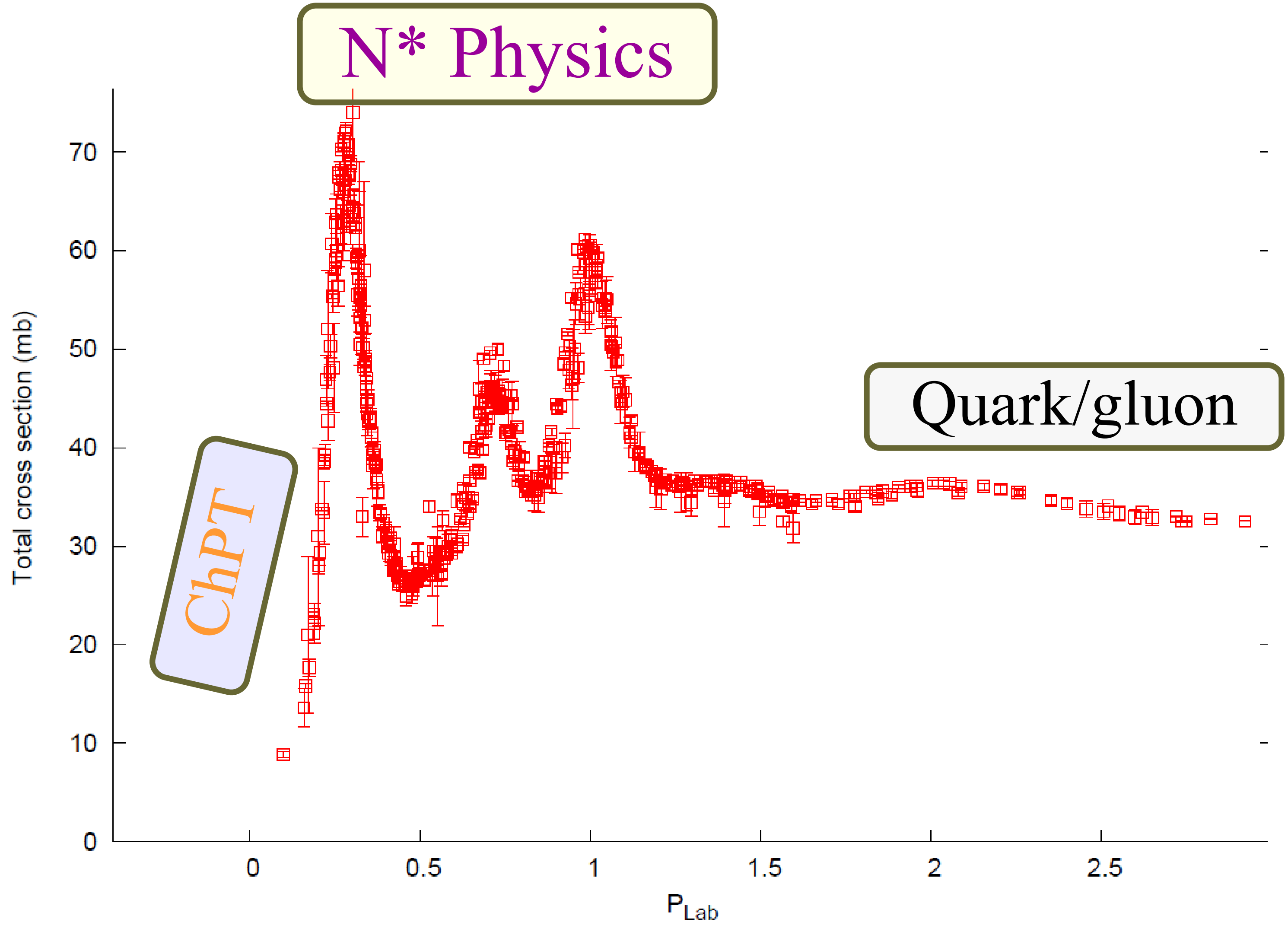
QCD



- Baryon spectrum, N* program
- Mesons, exotics, glueballs

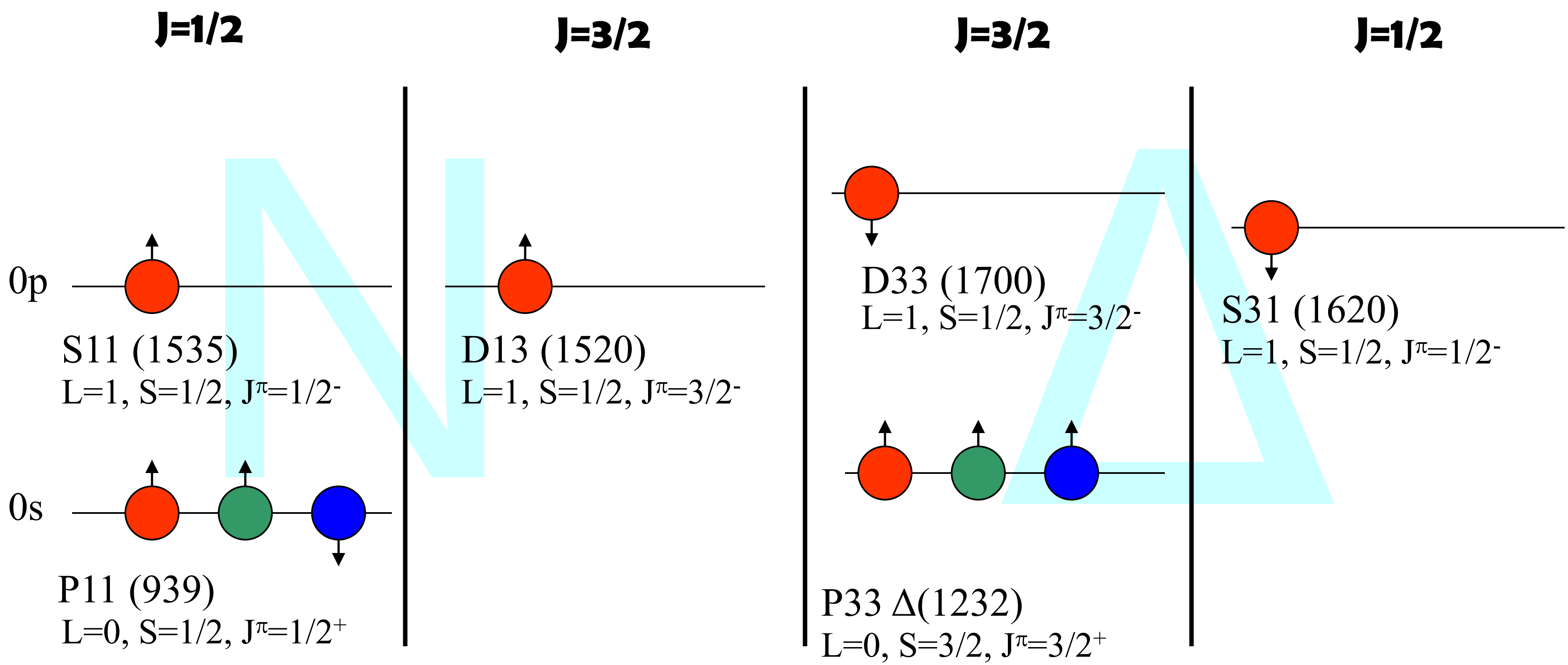
Jefferson Lab — Exploring the Nature of Matter
Mainzer Mikrotron MAMI
Crystal Barrel — universität bonn
JÜLICH FORSCHUNGSZENTRUM
FAIR — GSI Helmholtzzentrum für Schwerionenfo
GlueX — Hall D at Jefferson Lab
UNDER CONSTRUCTION

Where are the N*?



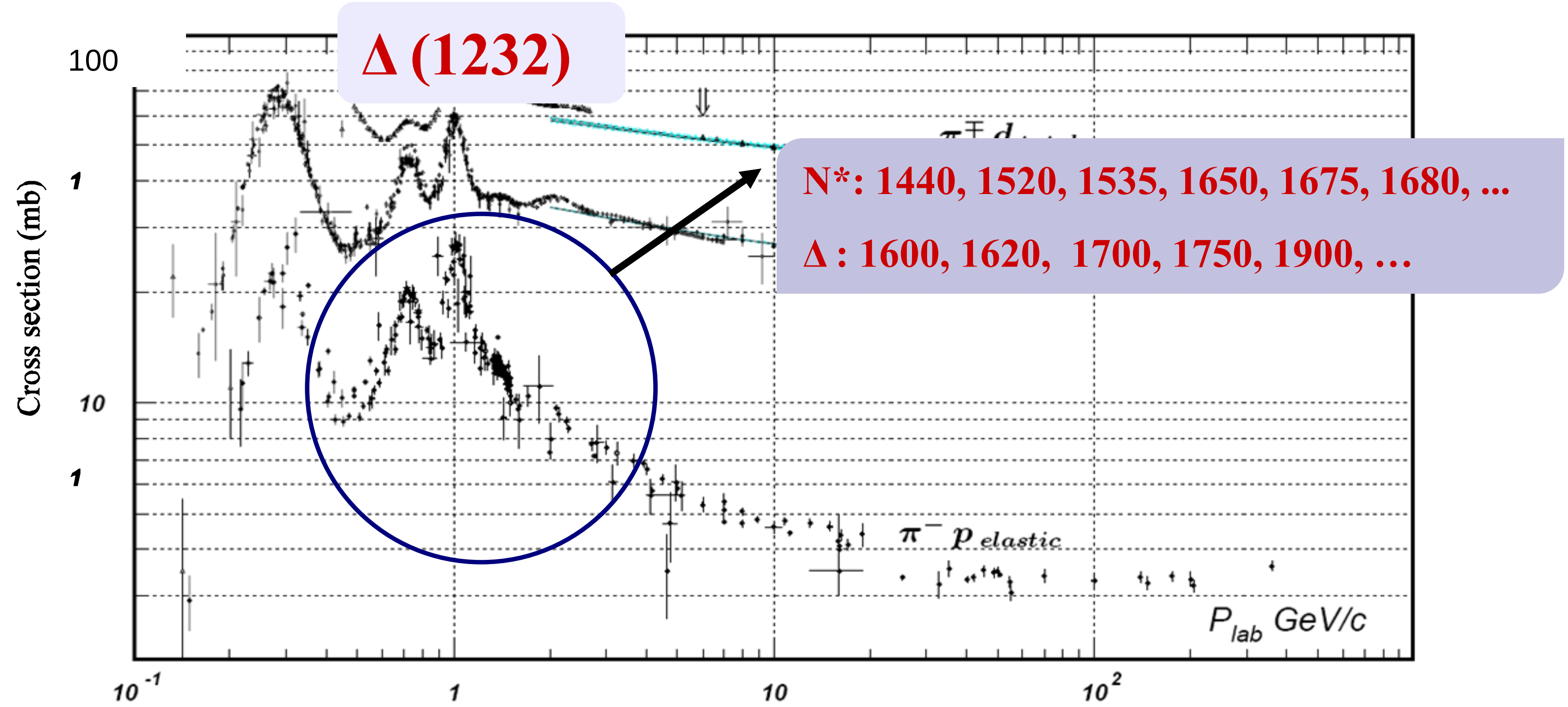
Baryon Resonances

Exciting the substructure we **learn about the forces which keep the quarks together**. E.g. the naïve **quark model picture predicts** states are:



The Δ (1232) and others

πN → X, πN



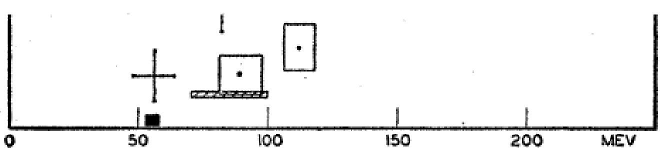
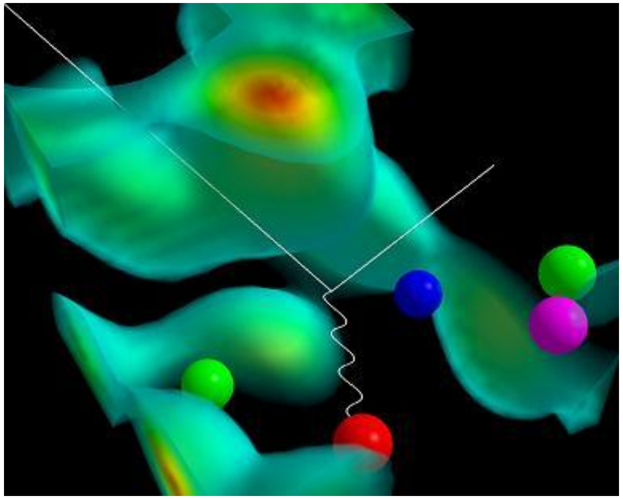


FIG. 1. Total cross sections of negative pions in hydrogen (sides of the rectangle represent the error) and positive pions in hydrogen (arms of the cross represent the error). The cross-hatched rectangle is the Columbia result. The black square is the Brookhaven result and does not include the charge exchange contribution.

- The Delta [illegible] peak
- The region 1.4 GeV – 2 GeV hosts ~ 20 resonances

Electromagnetic probes

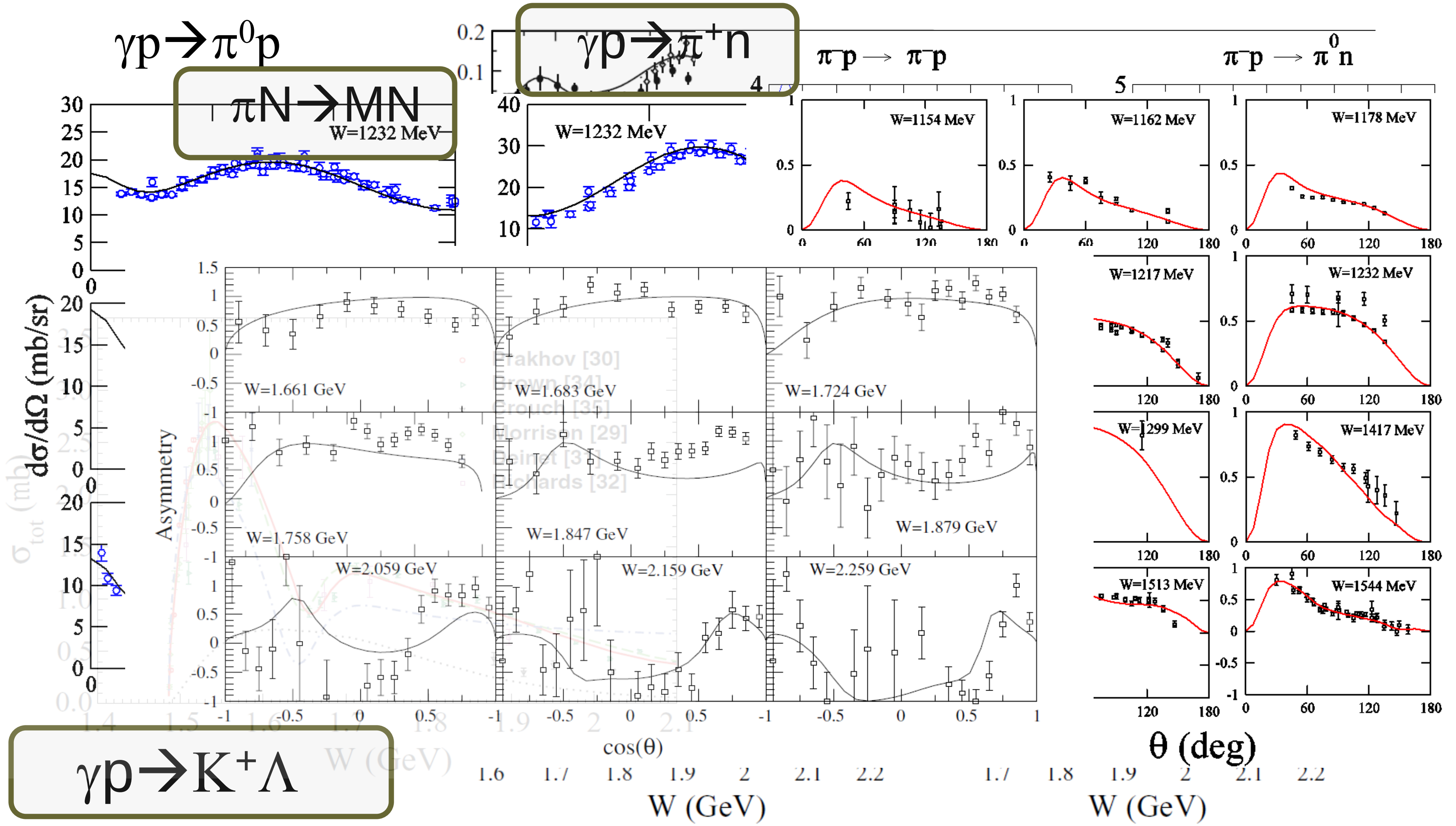


Courtesy of D. Leinweber

- Jefferson LAB (USA)
- GRAAL (Grenoble)
- MAMI (Mainz)
- BATES (MIT)
- ELSA (Bonn)
- SPring 8 (Japan)

Originaly, the hope was that probing the structure with electrons would minimize the “hadronic” debris, providing a cleaner access to the properties of nucleons and resonances

High precision (new&old) data



PDG *s and N*'s origin

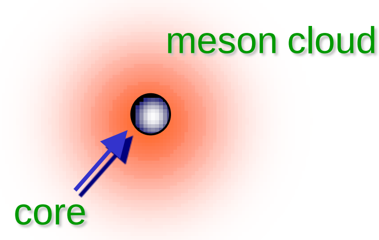
Particle	$L_{2I.2J}$	status	$N\pi$	$N\eta$	ΛK				
$N(939)$	P_{11}	****							
$N(1440)$	P_{11}	****	****	*					
$N(1520)$	D_{13}	****	****	***					
$N(1535)$	S_{11}	****	****	****					
$N(1650)$	S_{11}	****	****	*	***				
$N(1675)$	D_{15}	****	****	*	*				
$N(1680)$	F_{15}	****	****	*			****	***	
$N(1700)$	D_{13}	***	***	*	**	*	**		
$N(1710)$	P_{11}	***	***	**	**	*	**	*	***
$N(1720)$	P_{13}	****	****	*	**	*	*	**	**
$N(1900)$	P_{13}	**	**					*	
$N(1990)$	F_{17}	**	**	*	*	*			*
$\Delta(1232)$	P_{33}	****	****	F					****
$\Delta(1600)$	P_{33}	***	***	o			***	*	**
$\Delta(1620)$	S_{31}	****	****	r			****	****	***
$\Delta(1700)$	D_{33}	****	****	b		*	***	**	***
$\Delta(1750)$	P_{31}	*	*						
$\Delta(1900)$	S_{31}	**	**	d		*	*	**	*
$\Delta(1905)$	F_{35}	****	****	d		*	**	**	***
$\Delta(1910)$	P_{31}	****	****	e		*	*	*	*
$\Delta(1920)$	P_{33}	***	***	n		*	**		*
$\Delta(1930)$	D_{35}	***	***			*			**
$\Delta(1940)$	D_{33}	*	*	F					
$\Delta(1950)$	F_{37}	****	****	o		*	****	*	****

All of these studies essentially agree on the existence and (most) properties of the 4-star states. For the 3-star and lower states, however, even a statement of existence is problematic.

GWU , PRC 74 045205 (2006)

Are they all genuine quark/gluon excitations (with meson cloud) ?

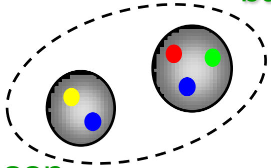
$$|N^*\rangle = |qqq\rangle + |\text{m.c.}\rangle$$



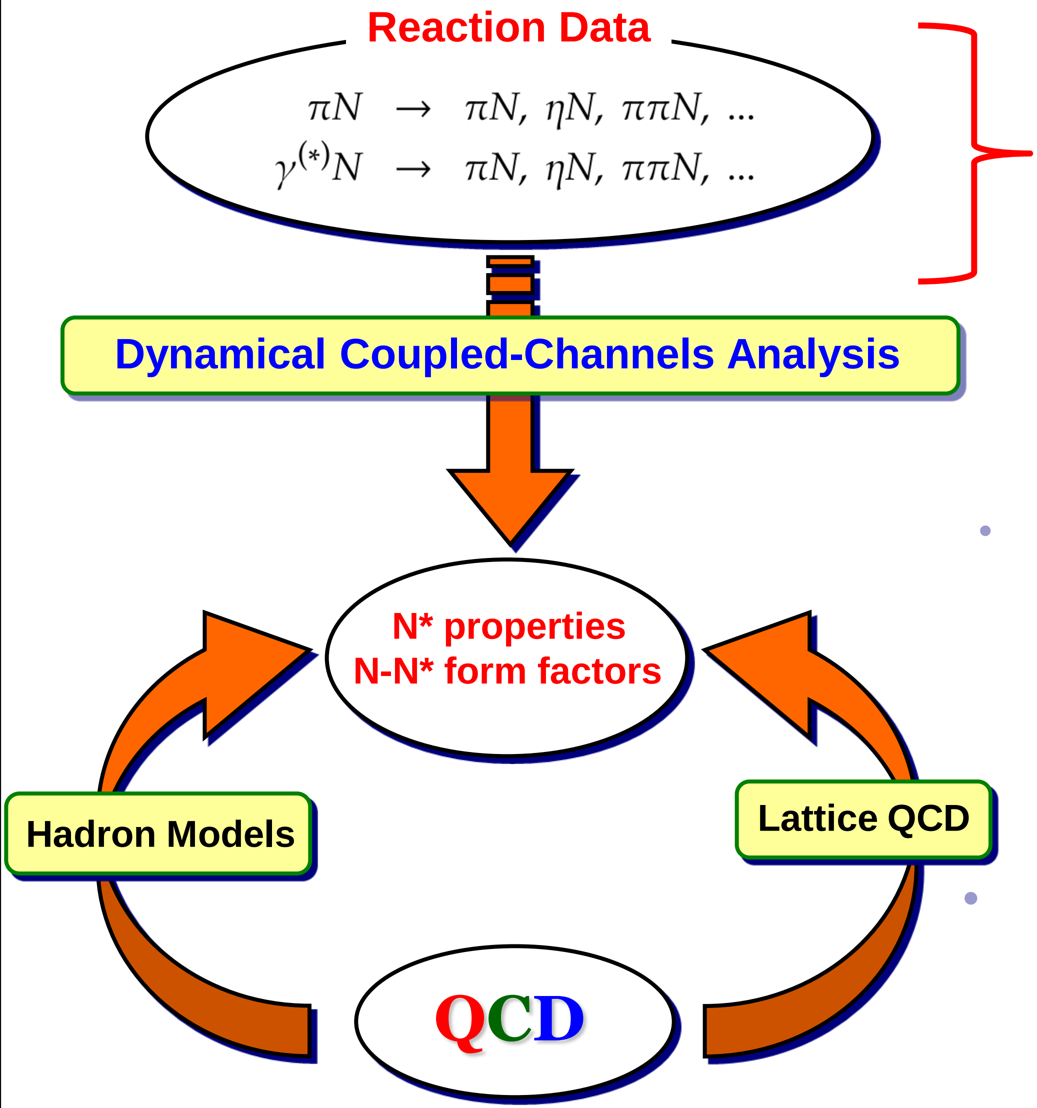
✓ **Is their origin dynamical ?**

→ **some could be understood as arising from meson-baryon dynamics**

$$|N^*\rangle = |MB\rangle$$



Basic Goal



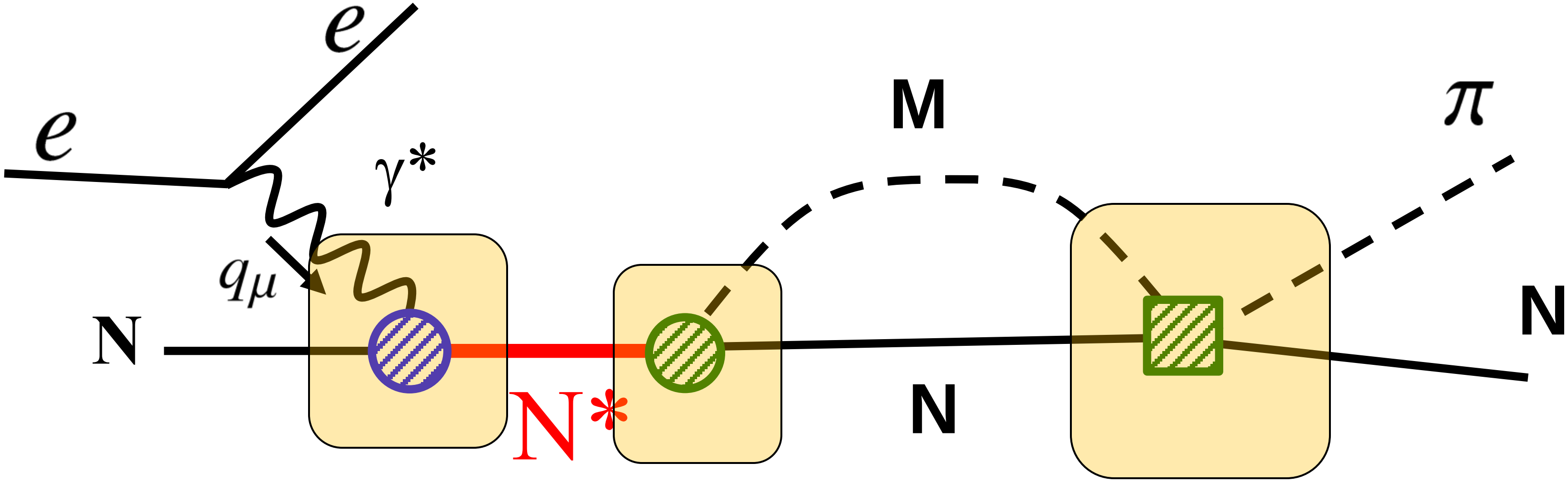
Resonances can be regarded as correlations among all the data:

- A combined study is essential

  Recent example: Zagreb group's analysis of $P_{11}(1710)$. Emphasizing the capital importance of including $\pi N \rightarrow \eta N$. Ceci, Svarc, Zauner, PRL (2006)

- Models should be built in a flexible way allowing N* to show up in any channel

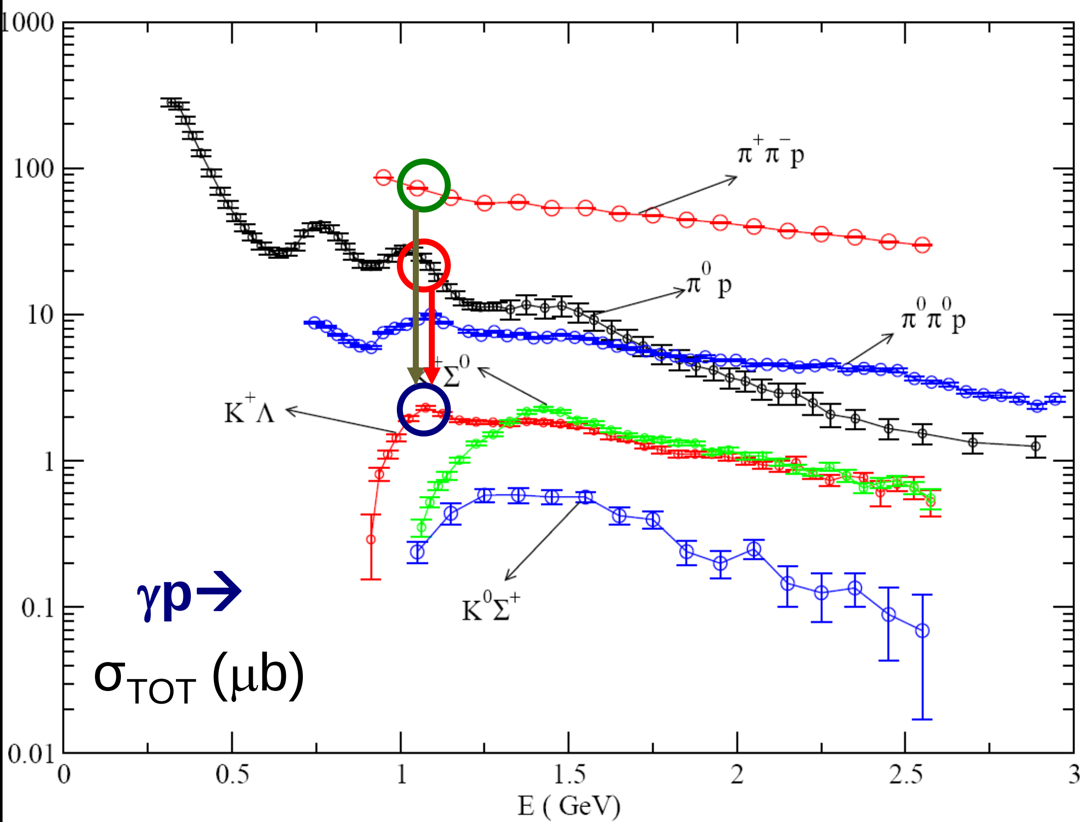
Production of mesons



Main elements:

1. Strong-strong interactions
2. Hadronic structure of Resonances
3. Electromagnetic structure of Resonances

Multi step (unitarity)



Production of meson-baryon final states

- Directly
- Through MB states
- Through MMB states

→ Multi-step processes should be taken into account: **Coupled-channels**

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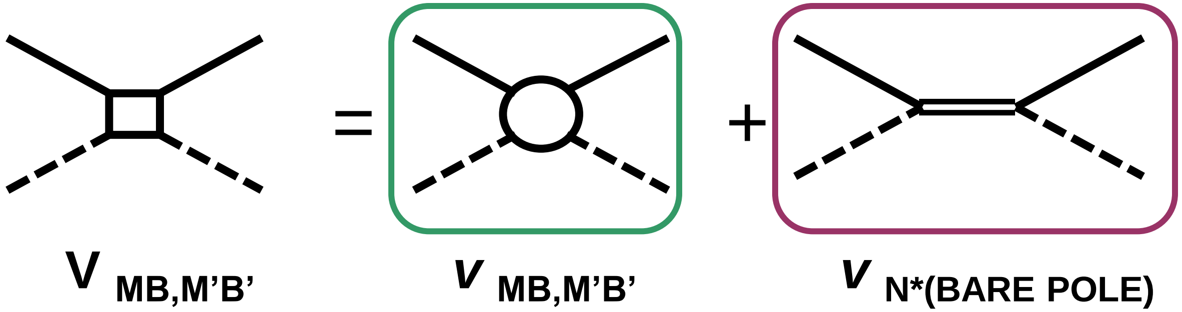
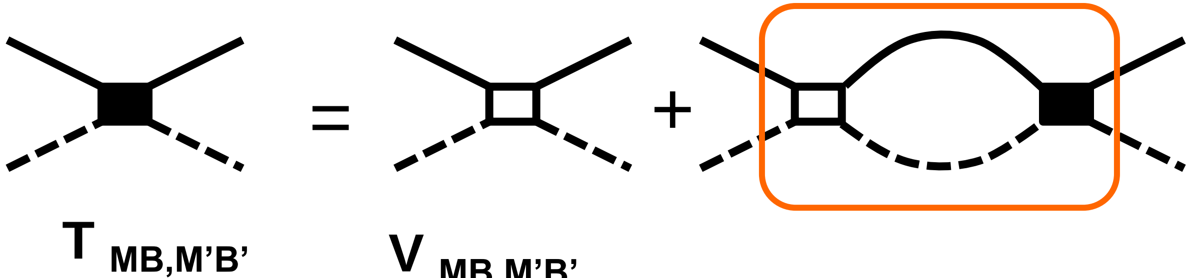
Reaction theory ingredients

Full integration? K matrix?

Effective lagrangians, quark models, …?



How many channels ?



E.m and hadronic simultaneously?

Bare N* seeds in the model?

Skecth of coupled channels models

- K matrix and related models:
  - *Phenomenological*
    - ✓ SAID, Bonn-Gatchina, MAID
  - *Unitarized chiral models*
    - ✓ Valencia, GSI, …
  - *Effective lagrangians*
    - ✓ Giessen, KVI

A. Sarantsev (5B)

M. Paris (5B)

L. Tiator (3A)

J. Garzon (6B)

A. Gasparyan (4D)

- Dynamical Coupled-Channels
  - ✓ EBAC@JLAB, Juelich, Mainz&Taipei, …

H. Kamano (5B)
S. Nakamura (5B)

M. Doring (4D), F. Huang (4B)
S. Krewald (5B)

	Unitarized Chiral	Dynamical CC	K MATRIX
Example	*e.g. Valencia*	*e.g EBAC*	*e.g. GWU/SAID*
Channels	πN, ηN, KY	πN, ηN, σN, ρN, $\pi\Delta$,KY	πN, ηN
Dynamics	K matrix	T matrix	K matrix +DR
Kernel	Weinberg-Tomozawa	Meson Exchange	Polynomia
Bare N* seeds	NO	Minimal number	NO

Example: MSL (used at EBAC)

- ✓ Partial wave amplitude of a → b reaction:

$$T_{a,b}(p_a, p_b; E) \;=\; V_{a,b}(p_a, p_b; E) + \sum_c \int_0^\infty q^2 dq V_{a,c}(p_a, q; E)\, G_c(q; E)\, T_{c,b}(q, p_b; E)$$

- ✓ Reaction channels:

- ✓ Potential:

2-body v potential (no ππN cut)

2-body Z potential (with ππN cut)

bare N* state

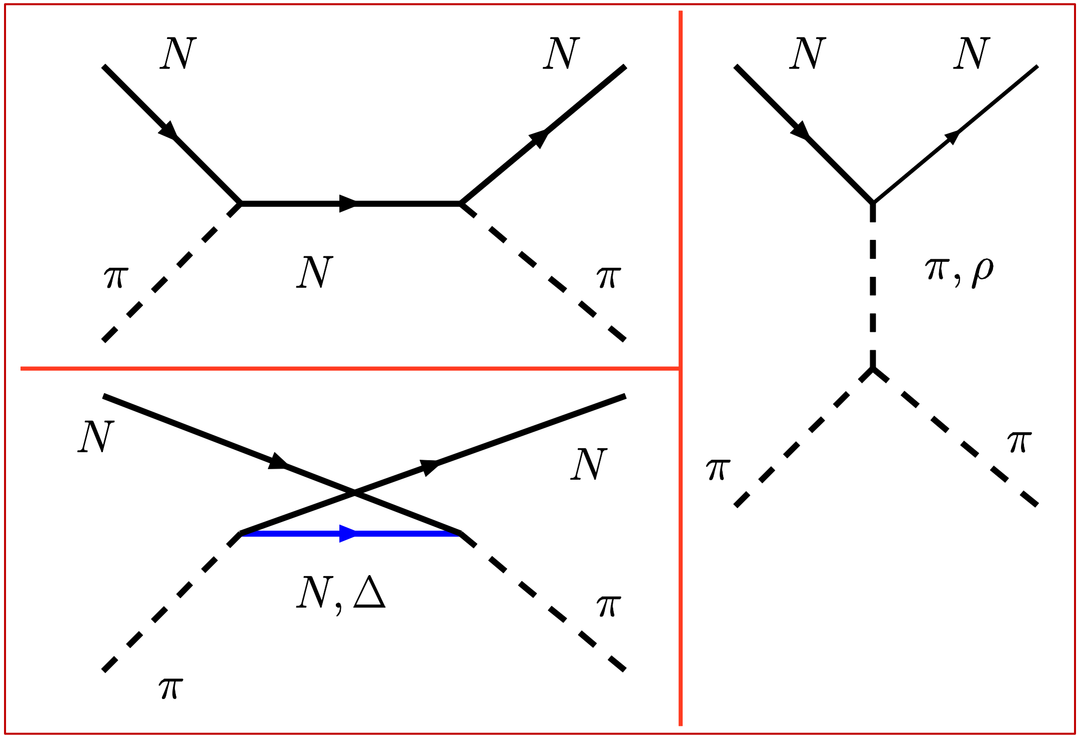
A. Matsuyama, T. Sato, T.-S.H. Lee, Phys. Rep. 2007

Two body v's (strong)

$\pi N \rightarrow \pi N$

5 diagrams

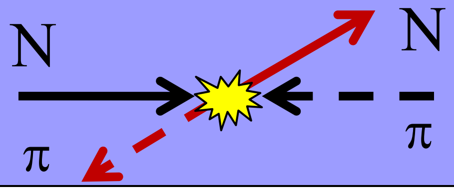
- **s-ch N**
- **u-ch N**
- **u-ch Δ**
- **t-ch ρ**
- **t-ch σ**



Two body υ's (e.m.)

$\gamma N \rightarrow \pi N$	$\gamma N \rightarrow \eta N$	$\gamma N \rightarrow \pi\Delta$	$\gamma N \rightarrow \sigma N$	$\gamma N \rightarrow \rho N$
7 diagrams	2 diagrams	5 diagrams	2 diagrams	4 diagrams
s-ch N	s-ch N	s-ch N	s-ch N	s-ch N
u-ch N	u-ch N	u-ch N	u-ch N	u-ch N
u-ch Δ		u-ch Δ		t-ch ρ
t-ch π		t-ch π		contact
t-ch ρ		contact		
t-ch σ				
contact				

Total 20 diagrams

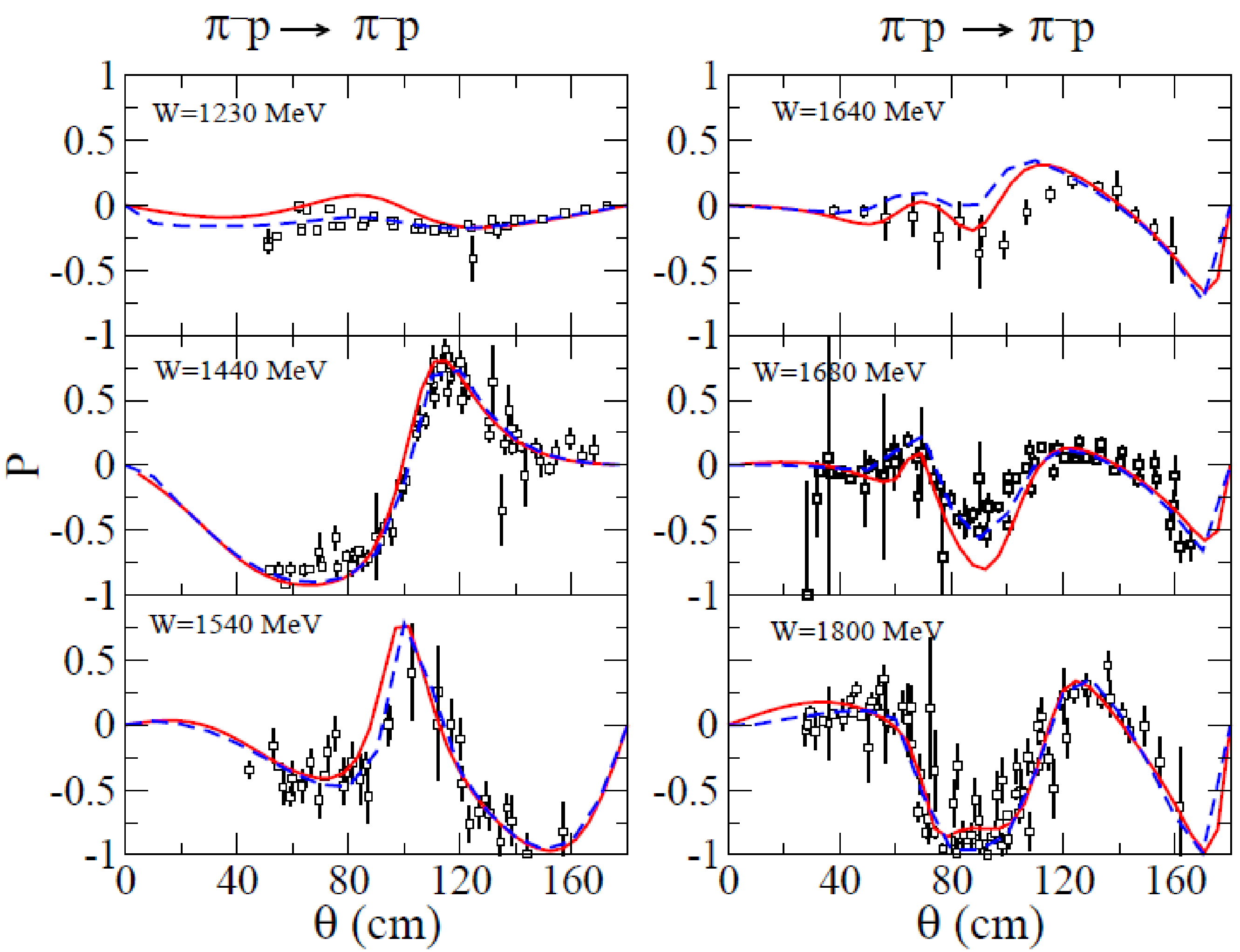


EBAC
JLMS(07)

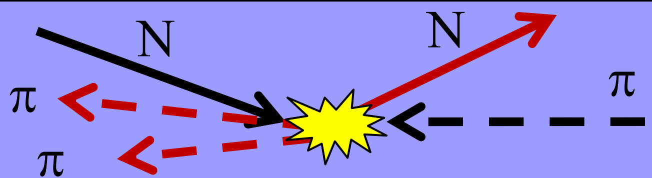
SAID06

Differential Cross sections, dσ/dΩ

Target Polarization Asymmetry, P
(very sensitive to the specific N* content)



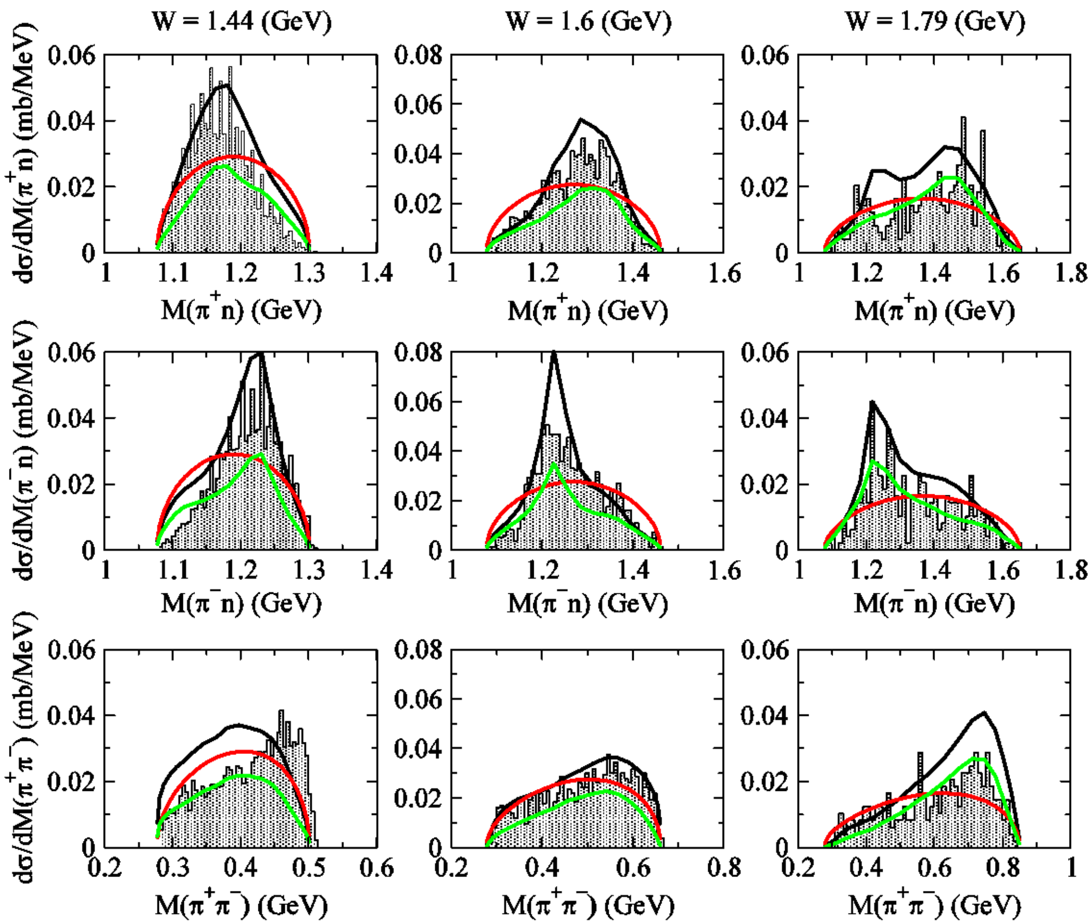
BJ-D, Lee, Matsuyama, Sato, Phys. Rev C (2007)



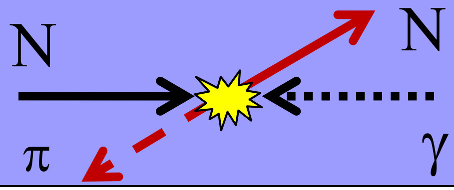
Invariant mass distributions

Full model

Phase space

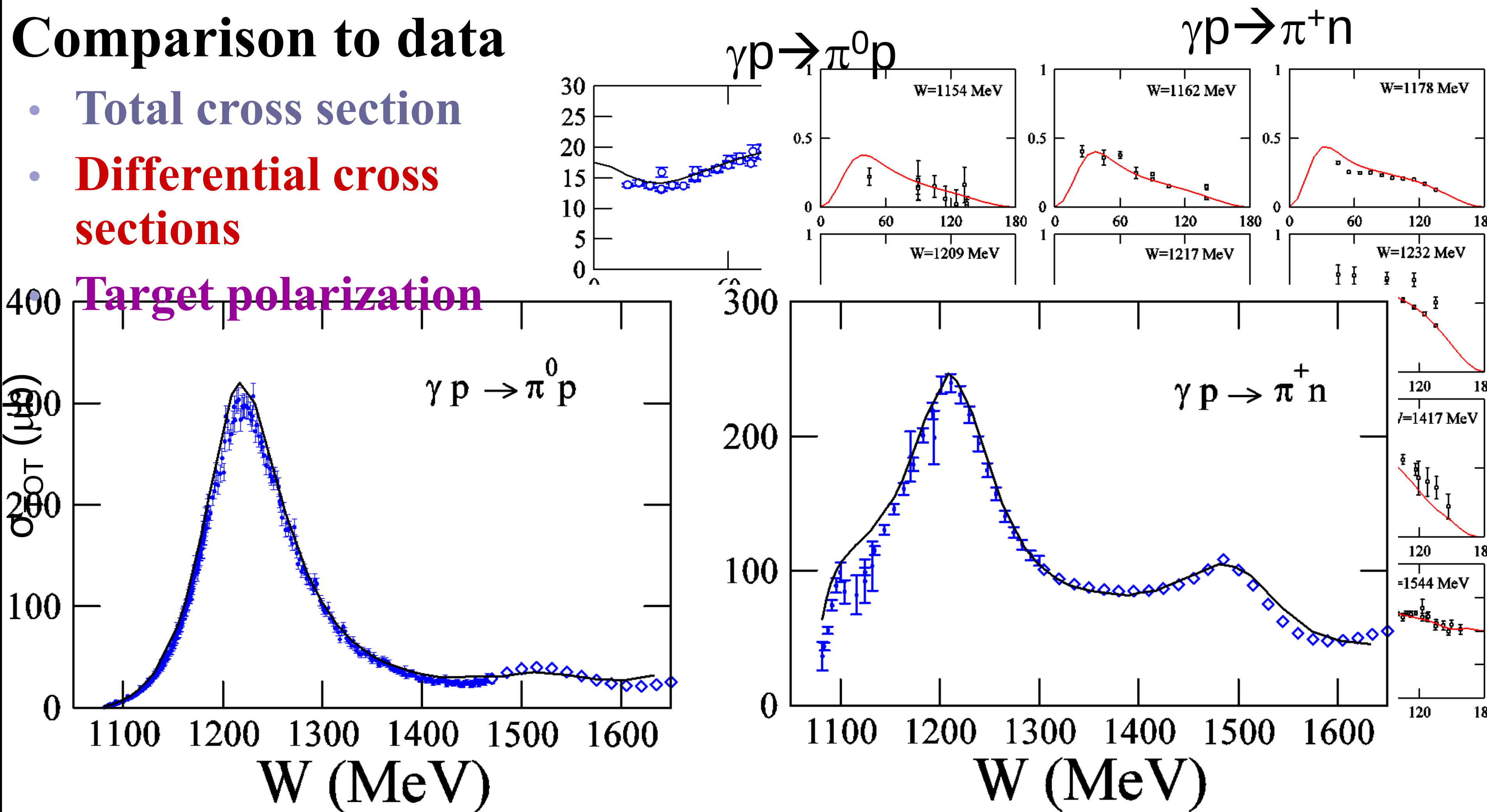


Kamano, BJ-D, Lee, Matsuyama, Sato, Phys. Rev C (2009)

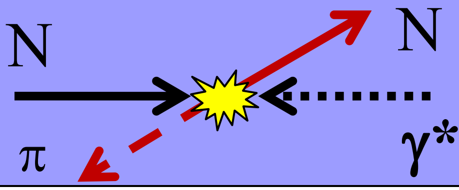


Comparison to data

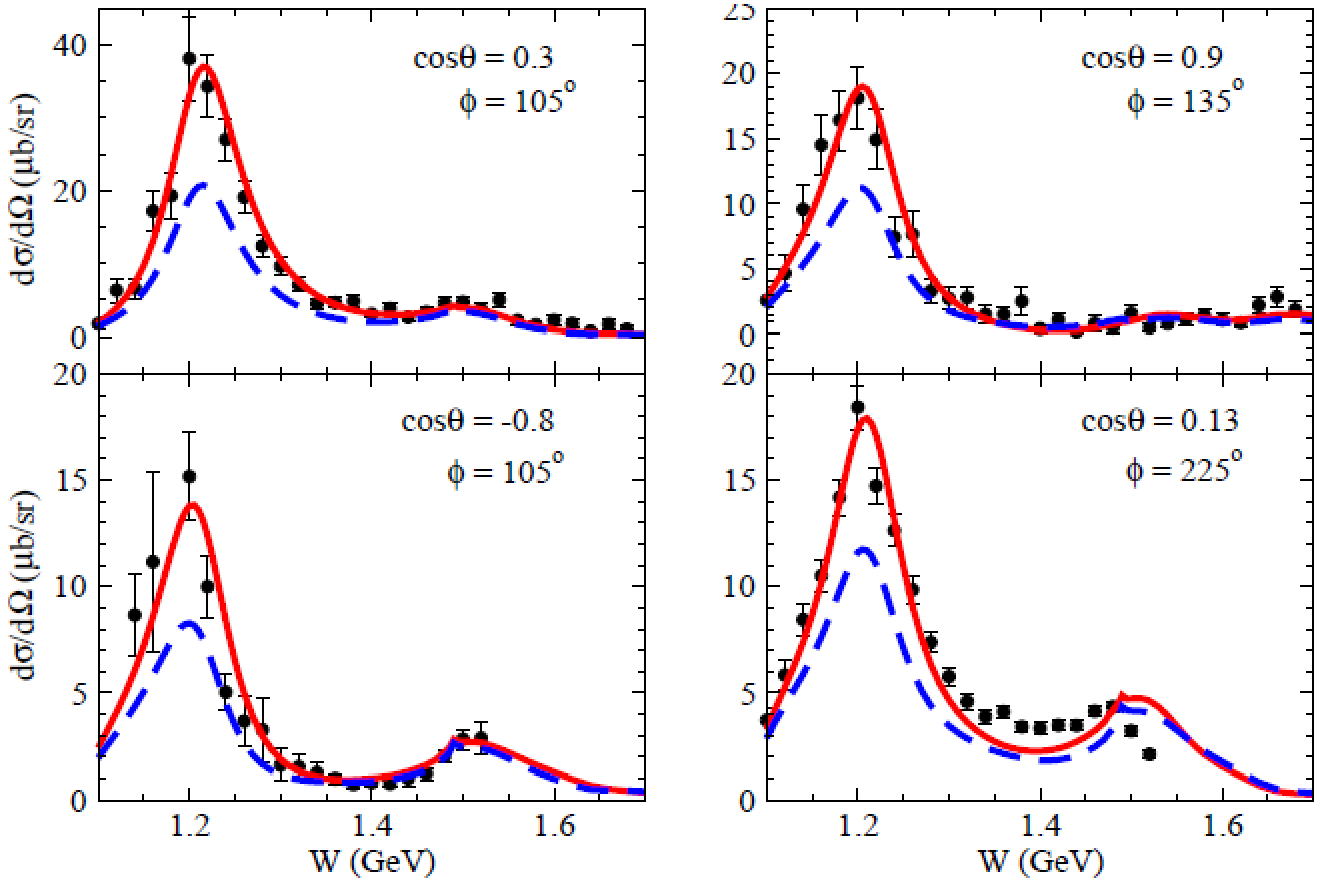
- Total cross section
- Differential cross sections
- Target polarization



BJ-D, Matsuyama, Lee, Sato, Smith, Phys. Rev. C(2008)



$Q^2 = 0.4\ GeV^2$



1. Model
2. Dashed only πN intermediate (in e.m. piece)
3. Data from CLAS http://clasweb.jlab.org/physicsdb/

BJ-D, Kamano, Matsuyama, Lee, Matsuyama, Sato, Suzuki, Phys. Rev. C (2009)

Sample of reactions studied

πN→ / γN→	πN	ππN	ηN	KΛ / KΣ
SAID	red ● blue ●	red ●	red ● blue ●	
Bonn-Gatchina	red ● blue ●	red ● blue ●	red ● blue ●	red ● blue ●
EBAC	red ● blue ●	red ● blue ●	red ● blue ★	red ★ blue ★
Juelich-UGA	red ● blue ★	red ●	red ●	red ●

☆ In progress

From T. Sato review talk "EBAC meeting", May 2010

Timeline of DCC efforts

● = 1 Paper

YEAR: 1994 · 1998 · 2002 · 2006 · 2010

JULICH

M. Doring
J. Haidenbauer
C. Hanhart
U.-G. Meissner
S. Krewald

F. Huang
K. Nakayama
Haberzettl

1994	~1996–1998	2009–2010
πN	$\eta N, \sigma N, \rho N, \pi\Delta$	KY, γN
W<1.4 GeV	**W<2 GeV**	
	$\pi N \to \pi N$ $\pi N \to \eta N$	$\gamma N \to \pi N$ $\pi N \to KY$
S,P waves	S,P,D waves J=1/2,3/2	

Sato/Lee — EBAC

B. Julia-Diaz
H. Kamano
T.-S.H. Lee
A. Matsuyama
S. Nakamura
B. Saghai
T. Sato

~1996	~2001	2007–2010
$\pi N, \gamma N$	$\gamma^* N$	$\eta N, \sigma N, \rho N, \pi\Delta$, KY
W<1.3 GeV	**W<1.3 GeV** **Q^2<4 GeV^2**	**W< 2GeV** **Q^2<4 GeV^2**
$\pi N \to \pi N$ $\gamma N \to \pi N$	$\gamma^* N \to \pi N$	$\gamma N \to \pi\pi N$ $\gamma N \to KY$ $\pi N \to \pi\pi N$ $\pi N \to KY$
S,P waves	S,P waves	S,P,D,F,G, J=1/2,3/2,5/2,7/2

N*,Δ* (with 4* in pdg)

	Re z_0 [MeV]	-2 Im z_0 [MeV]
$N^*(1440)\ P_{11}$		
JUELICH	1387, 1387	147, 142
EBAC	1357, 1364	152, 210
ARN	1359, 1388	162, 166
HOE	1385	164
Bonn-Gatchina	1371 ± 7	192 ± 20
$N^*(1520)\ D_{13}$		
JUELICH	1505	95
EBAC	1521	116
ARN	1515	113
HOE	1510	120
Bonn-Gatchina	1509 ± 7	113 ± 12
$N^*(1535)\ S_{11}$		
JUELICH	1519	129
EBAC	1540	382
ARN	1502	95
HOE	1487	
Bonn-Gatchina	1508^{+10}_{-30}	165 ± 15
$N^*(1650)\ S_{11}$		
JUELICH	1669	136
EBAC	1642	82
ARN	1648	80
HOE	1670	163
Bonn-Gatchina	1645 ± 15	187 ± 20
$N^*(1675)\ D_{15}$		
JUELICH		NPW
EBAC	1654	154
ARN	1657	139
HOE	1656 ± 8	126
Bonn-Gatchina	1639 ± 10	180 ± 20
$N^*(1680)\ F_{15}$		
JUELICH	NPW	NPW
EBAC	1674	106
ARN	1674	139
HOE	1673	126
Bonn-Gatchina	1674 ± 5	95 ± 10
$N^*(1720)\ P_{13}$		
JUELICH	1663	212
EBAC	—	—
ARN	1666	355
HOE	1686	187
Bonn-Gatchina	1630 ± 90	460 ± 80

- <1.5%
- <5.5%
- <15%
- <50%

	Re z_0 [MeV]	-2 Im z_0 [MeV]
$\Delta(1232)\ P_{33}$		
JUELICH	1218	90
EBAC	1211	100
ARN	1211	99
HOE	1209	100
$\Delta^*(1620)\ S_{31}$		
JUELICH	1593	72
EBAC	1563	190
ARN	1595	135
HOE	1608	116
Bonn-Gatchina	1615 ± 25	180 ± 35
$\Delta^*(1700)\ D_{33}$		
JUELICH	1637	236
EBAC	1604	212
ARN	1632	253
HOE	1651	159
Bonn-Gatchina	1610 ± 35	320 ± 60
$\Delta^*(1905)\ F_{35}$		
JUELICH	NPW	NPW
EBAC	1738	220
ARN	1819	247
HOE	1829	303
$\Delta^*(1910)\ P_{31}$		
JUELICH	1840	221
EBAC	—	—
ARN	1771	479
HOE	1874	283
$\Delta^*(1950)\ F_{37}$		
JUELICH	NPW	NPW
EBAC	1858	200
ARN	1876	227
HOE	1878	230

JUELICH : Doring et al. NPA 829, 170 (2009)
EBAC : Suzuki et al., PRL 104, 042302 (2010)
ARNDT : Arndt et al., PRC 74 (2006)
HOELER : Höhler, πN Newsl. 9 (1993)
Bonn-Gatchina : Thoma et al. PLB650, 87 (2003).

Partly from Doring at "EBAC meeting", May 2010, source pdg

Concluding remarks (1)

- The spectrum of low lying N* and Δ* is an essential feature of QCD
- There is an increasingly large high-precision database
- Extracting the properties of all resonances from the data for further comparison with QCD requires an important theoretical effort

- Recent developments have boosted the state-of-the-art of dynamical coupled-channels analyses (notably the creation of the Excited Baryon Analysis Center (2006))
  - *Ambitious reaction theory*
  - *Meson-exchange kernels*
  - *Use of supercomputing resources,*

    e.g. NERSC, Barcelona, Jülich, Argonne
  - *Broad range of W and Q^2*

Concluding remarks (final)

With the help of recent dedicated workshops worldwide, the common difficulties faced by the different groups have been identified, notably:

1. The need to **consistently analyze** hadro- and electro-production reactions
2. Need of multi-channels models to ensure correlations between all extant data are taken into account.
3. Use of analytic extrapolation methods to extract properties of resonances (pole positions, residues)

With the proper support, these efforts will settle the properties of known, and still to be discovered, low lying baryon resonances or more exotic baryons

M. Doring (4D), J. Garzon (6B), A. Gasparyan (4D), F. Huang (4B), H. Kamano (5B), S. Krewald (5B), S. Nakamura (5B), M. Paris (5B), A. Sarantsev (5B), L. Tiator (3A)