Do we have sufficient data for an amplitude analysis of meson production?

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Collaboration:

M. Döring, J. Haidenbauer, C. Hanhart, S. Krewald, U.-G. Meiβner, and D. Rönchen ….. (JZ-Jülich)
F. Huang and K. Nakayama ……………………………………………….……. (UGA-Athens/GA)
H. Haberzettl ……………………………………………........................... (GWU-Washington/DC)

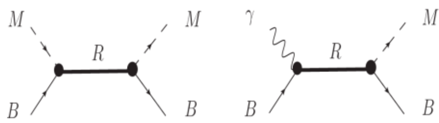
EIC Workshop: Physics with Secondary Hadron Beams in 21st Century

April 7, 2012 , GWU

Hadron Spectroscopy: to help ultimately understand the confinement property of QCD

- Baryon spectroscopy (mandatory):

  - Tools: hadro- and photo-induced reactions for studying baryon resonances



  - Relevant degrees-of-freedom: QCD → quarks and gluons
    Experiment → hadrons (baryons and mesons)

  - From experiment to QCD: reaction theory needed to extract the relevant quantities from experiment which can be connected directly to QCD and/or QCD-based models.

  - Reaction Theory: dynamical coupled-channels (DCC) approaches:
    (EBAC, JAW, DMT, Utrecht-Ohio, …)

    - analyticity → causality
    - unitarity → channel couplings
    - gauge invariance (photo-induced reactions)

    . . .

JAW = Jülich-Athens/GA-Washington/DC

Hadron Spectroscopy: to help ultimately understand the confinement property of QCD

- Data Analysis (extraction of resonances):
  - If complete and accurate experimental data were available:
    - unique partial-wave amplitude A(W) as a function of energy W.
    - analytically continue A(W) to the complex energy-plane to extract the resonance poles and residues (transition form factors).
  - But, data are not complete and have error-bars:
    - reaction models for A(W) constrained by incomplete data with finite accuracy.
    - DCC approaches to A(W) (EBAC, JAW, DMT, …):

      analytic

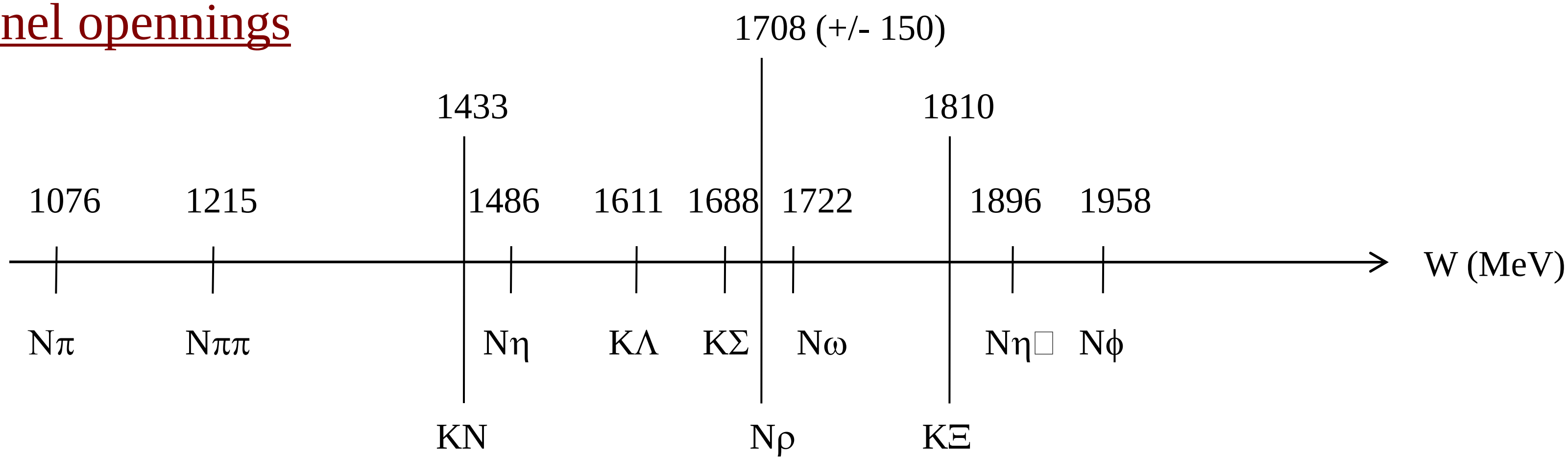
      unitary (coupled-channels: πN, ηN, $K\Lambda$, $K\Sigma$, $\pi\pi N$, σN, ρN, $\pi\Delta$, …)

      gauge invariant

      . . .
  - Necessity of new generation of data for modern coupled-channels analyses:
    - photo-induced reactions: recent, high precision, some aiming for complete experiments) (JLAB, MAMI, ELSA, Spring8, GRAAL, …)
    - hadro-induced reactions: scarce, low-precision, old (60'-80').

Channel opennings: *hadro- & photo-induced reactions*

channel opennings



one-meson productions:

$\gamma N, \pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \rho N, \omega N, \eta' N, \phi N$ … (two-body reactions)

$KN \rightarrow KN$, …

$\bar{K}N \rightarrow K\Xi, KK\Omega$ □

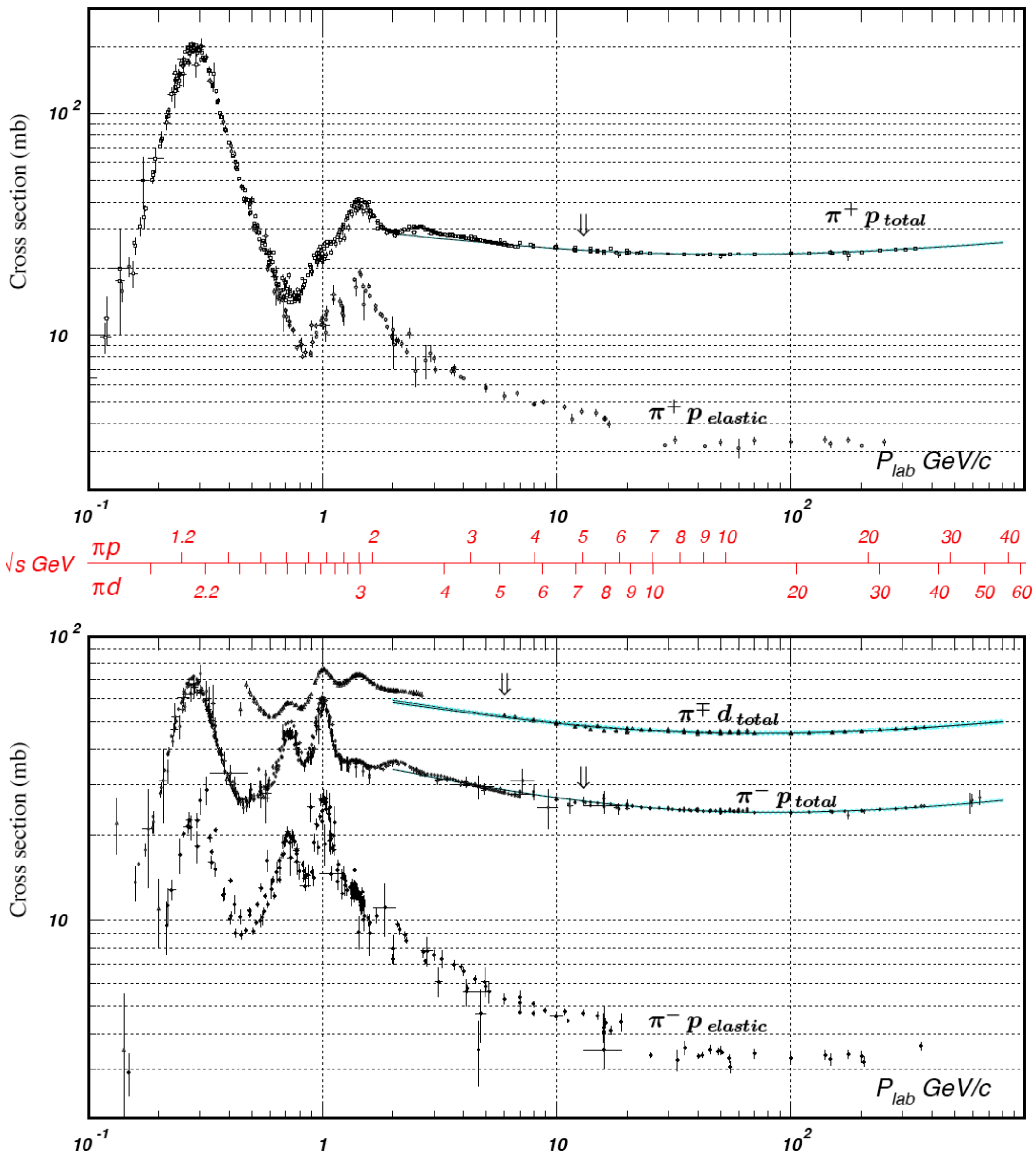
two-meson productions:

$\gamma N, \pi N \rightarrow \pi\pi N, \pi\eta N$, … (three-body reactions)

$\gamma N, \pi N \rightarrow KK\Xi, KKK\Omega$ ...

meson production data in hadronic reactions: current situation

Baryons: *resonance-energy region* $[s^{1/2} < 3\ GeV]$



Overview of the data for pion-induced reactions < 3 GeV

Reaction	Observables	Energy range	ND
$\pi^- p \to \eta n$	σ	1486 ~ 2280	230
	$d\sigma/d\Omega$	1486 ~ 2410	154
	P	1740 ~ 2230	115
$\pi^- p \to \omega n$	σ	1720 ~ 2300	34
	$d\sigma/d\Omega$	1730 ~ 2000	110
	$\rho_{\omega\omega'}$	1800 ~ 2300	90
$\pi N \to \eta' N$	σ	1930 ~ 2450	16
$\pi N \to \rho N$	σ	1630 ~ 3000	28
$\pi N \to \phi N$	σ	1960 ~ 2350	12
$\pi^- p \to \pi^+ \pi^- n$	σ	1228 ~ 2646	31
	$d^2\sigma/d\Omega_{\pi+}dT_{\pi+}$	1242 ~ 1301	40
	W	1301 ~ 1168	324
	$d\sigma/dm_{\pi\pi}^2$	1256 ~ 1315	33
	$d\sigma/dt$	1256 ~ 1315	41
$\pi^- p \to \pi^0 \pi^- p$	σ	1228 ~ 2646	17
$\pi^- p \to \pi^0 \pi^0 n$	σ	1236 ~ 1266	39
	$d\sigma/d\Omega$	1269 ~ 1525	280
$\pi^+ p \to \pi^+ \pi^+ n$	σ	1221 ~ 2574	26
	$d\sigma/dm_{\pi\pi}^2$	1256 ~ 1315	37
	$d\sigma/dt$	1256 ~ 1315	42
$\pi^+ p \to \pi^+ \pi^0 p$	σ	1228 ~ 2867	19

Reaction	Observables	Energy range	ND
$\pi^+ n \to K^+ \Lambda$	$d\sigma/d\Omega$	2143	5
	P	2143	1
$\pi^- p \to K^0 \Lambda$	σ	1631 ~ 2948	62
	$d\sigma/d\Omega$	1631 ~ 2900	854
	P	1930 ~ 2900	724
	β	1852 ~ 2262	72
$\pi^+ p \to K^+ \Sigma^+$	σ	1729 ~ 2355	34
	$d\sigma/d\Omega$	1821 ~ 2979	1041
	P	1731 ~ 2355	644
	β	2020 ~ 2106	7
$\pi^+ n \to K^0 \Sigma^+$	P	2022 ~ 2323	12
$\pi^- p \to K^0 \Sigma^0$	σ	1985 ~ 2948	31
	$d\sigma/d\Omega$	1694 ~ 2900	512
	P	1693 ~ 2883	124
$\pi^- p \to K^+ \Sigma^-$	σ	1740 ~ 2948	16
	$d\sigma/d\Omega$	1740 ~ 2900	193
	P	2733	10

<u>$\pi N \to \pi N$ (SAID PWA):</u>
S11,S31,P11,P31, …, H19,H39 (SES) [ND~1558]

Database for EBAC DCC model

(courtesy: H. Lee)

Pion-induced reactions (purely strong reactions)

	Waves	# of data	Waves	# of data
$\pi N \to \pi N$ PWA	S_{11}	56×2	D_{13}	52×2
	S_{31}	56×2	D_{15}	52×2
	P_{11}	56×2	D_{33}	50×2
	P_{13}	52×2	D_{35}	31×2
	P_{31}	52×2	F_{15}	39×2
	P_{33}	56×2	F_{17}	23×2
			F_{35}	34×2
			F_{37}	35×2
			Sum	1288

SAID

	$d\sigma/d\Omega$	P	R	a	Sum
$\pi^- p \to \eta p$	294	-	-	-	294
$\pi^- p \to K^0 \Lambda$	544	262	-	-	806
$\pi^- p \to K^0 \Sigma^0$	215	70	-	-	285
$\pi^+ p \to K^+ \Sigma^+$	552	312	-	-	864
Sum	1605	644	-	-	2249

~ 28,000 data points to fit

Photo-production reactions

	$d\sigma/d\Omega$	Σ	T	P	G	H	E	F	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	sum
$\gamma p \to \pi^0 p$	8290	1680	353	557	28	24	-	-	-	-	-	-	-	-	-	-	10860
$\gamma p \to \pi^+ n$	5384	1014	661	221	75	123	-	-	-	-	-	-	-	-	-	-	7478
$\gamma p \to \eta p$	1076	197	50	-	-	-	-	-	-	-	-	-	-	-	-	-	1323
$\gamma p \to K^+ \Lambda$	611	118	69	410	-	-	-	-	66	66	89	89	-	-	-	-	1518
$\gamma p \to K^+ \Sigma^0$	2949	116	-	320	-	-	-	-	-	-	52	52	-	-	-	-	3489
Sum	18310	3043	1133	1508	103	147	-	-	66	66	141	141	-	-	-	-	24668

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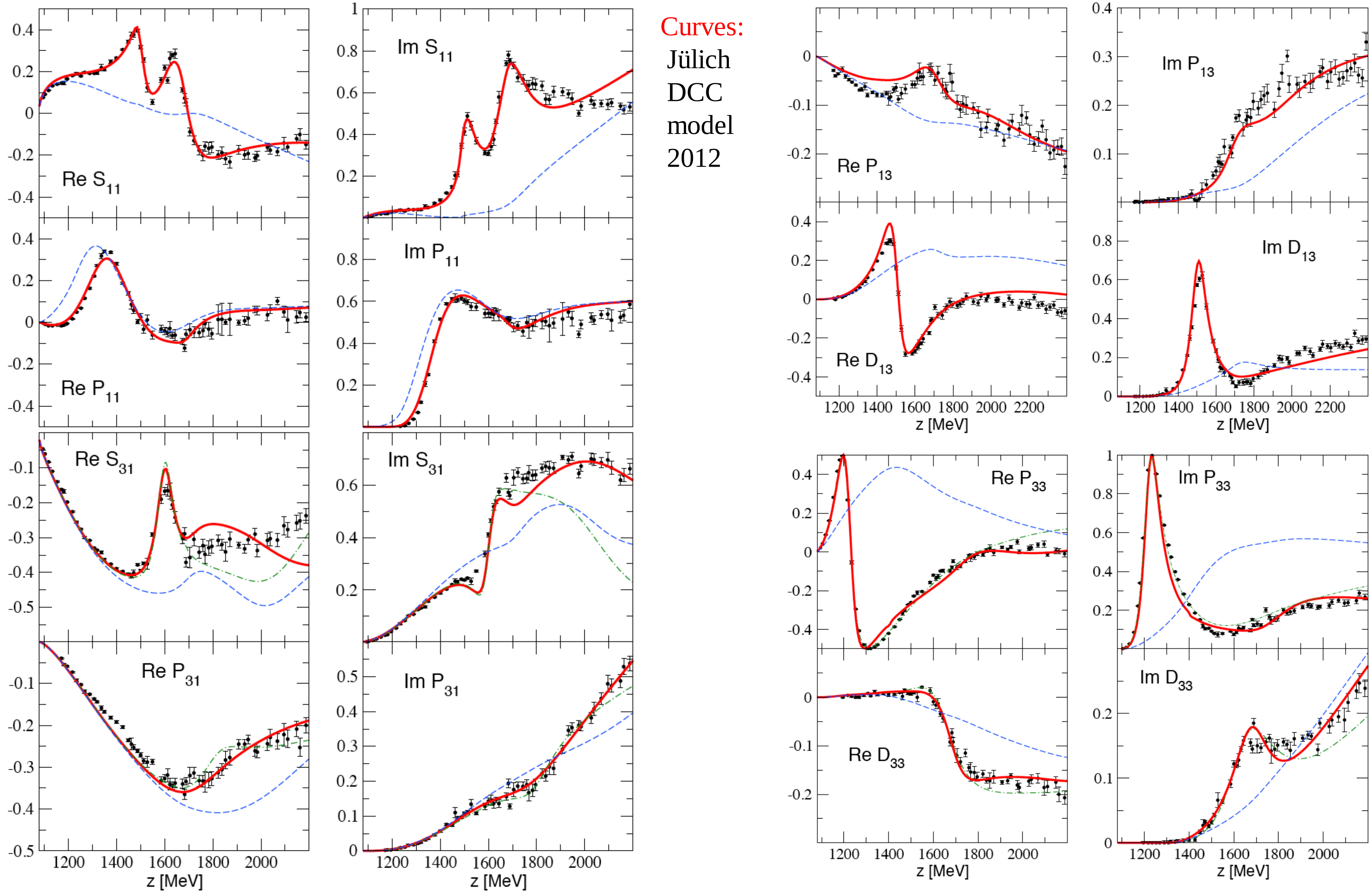
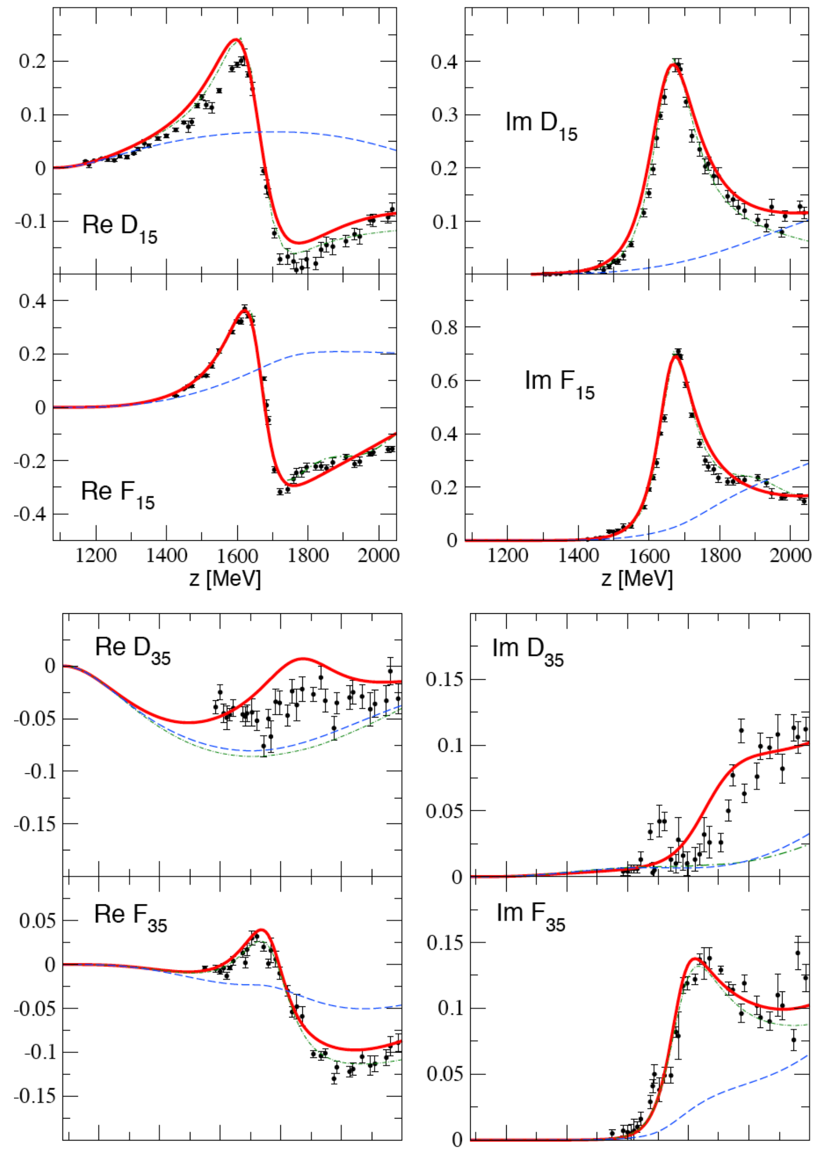
$\pi N \to \pi N$ (SAID PWA):
S11,S31,P11,P31, …, H19,H39 (SES) [ND~1558]

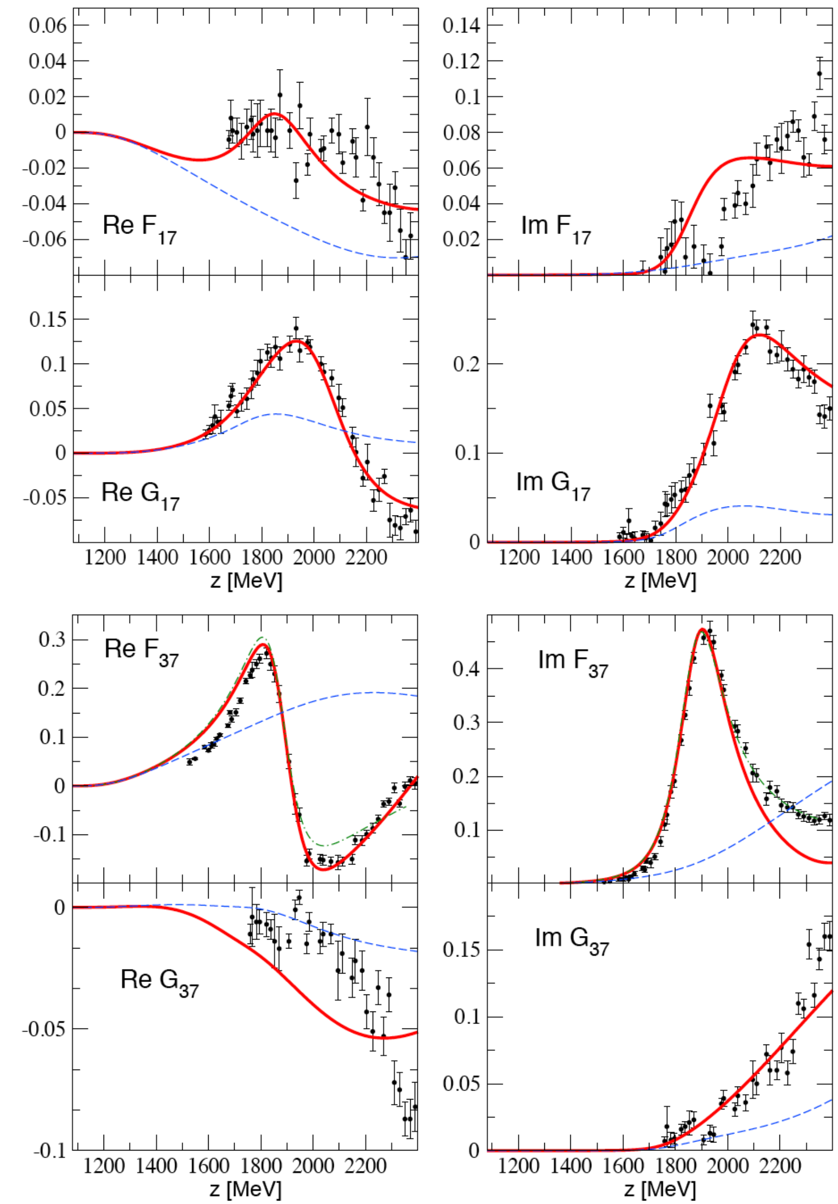
$\pi N \to \pi N$: *partial-wave amplitudes* [W < 2.6 GeV] (SAID)



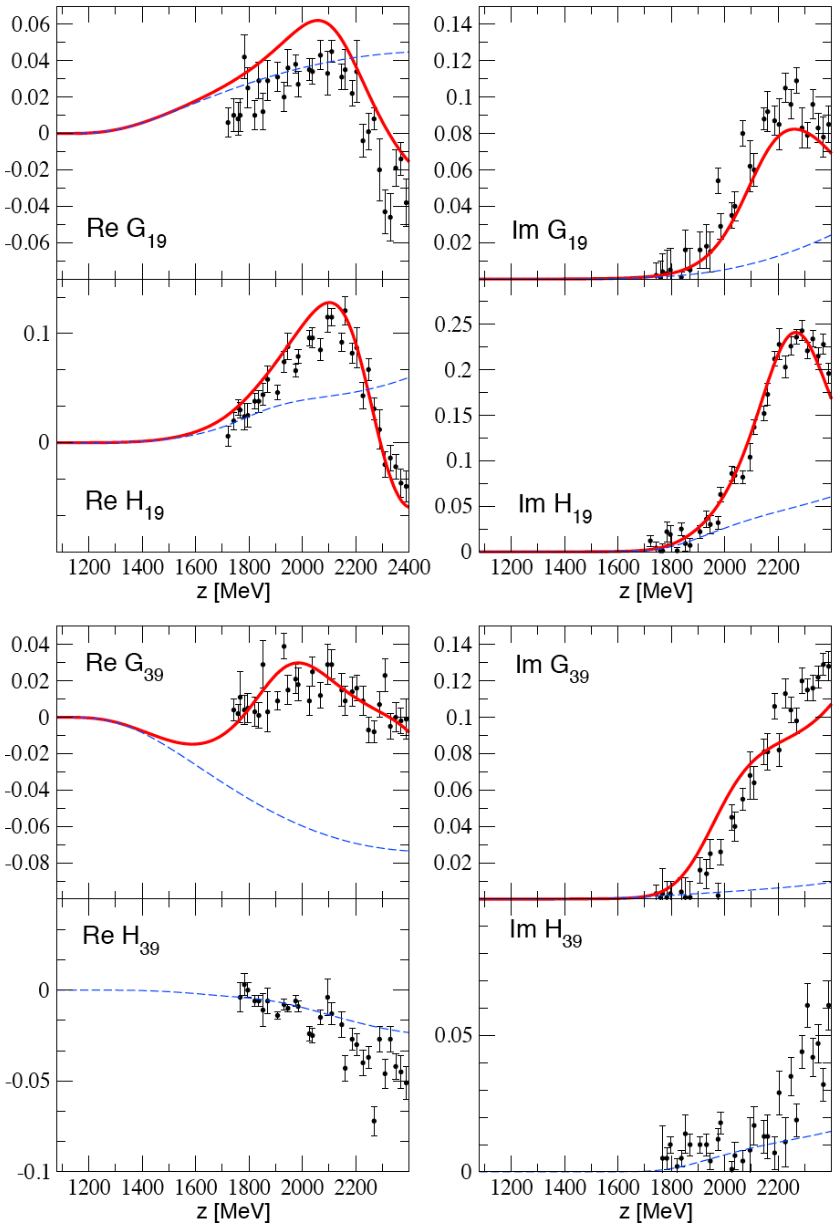
$\pi N \rightarrow \pi N$: *partial-wave amplitudes* [W < 2.6 GeV] (SAID)



Curves:
Jülich
DCC
model
2012

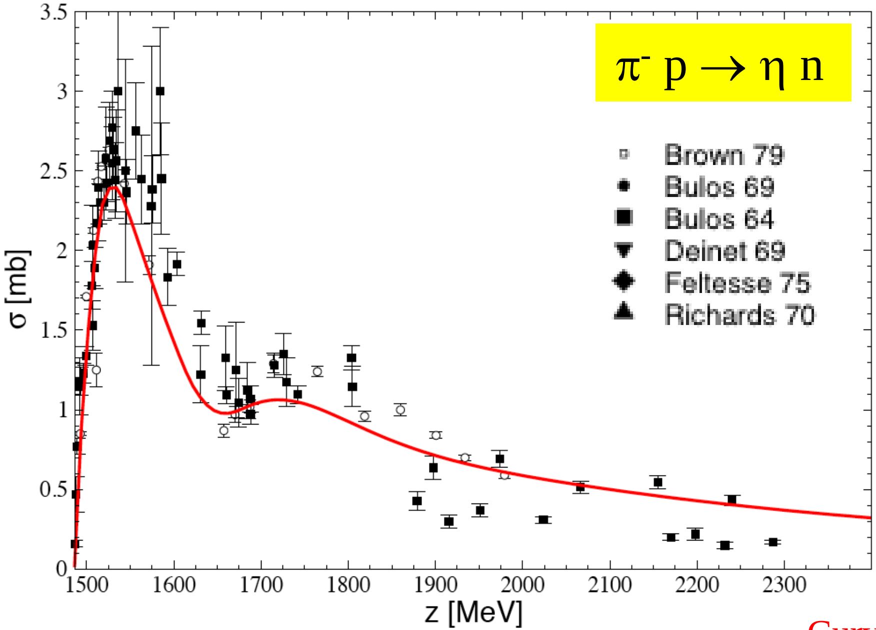


$\pi N \to \pi N$: partial-wave amplitudes [W < 2.6 GeV] (SAID)



Curves:
Jülich
DCC
model
2012

Existing data: $\pi^- p \to \eta\, n$, σ [W < 2.3 GeV]



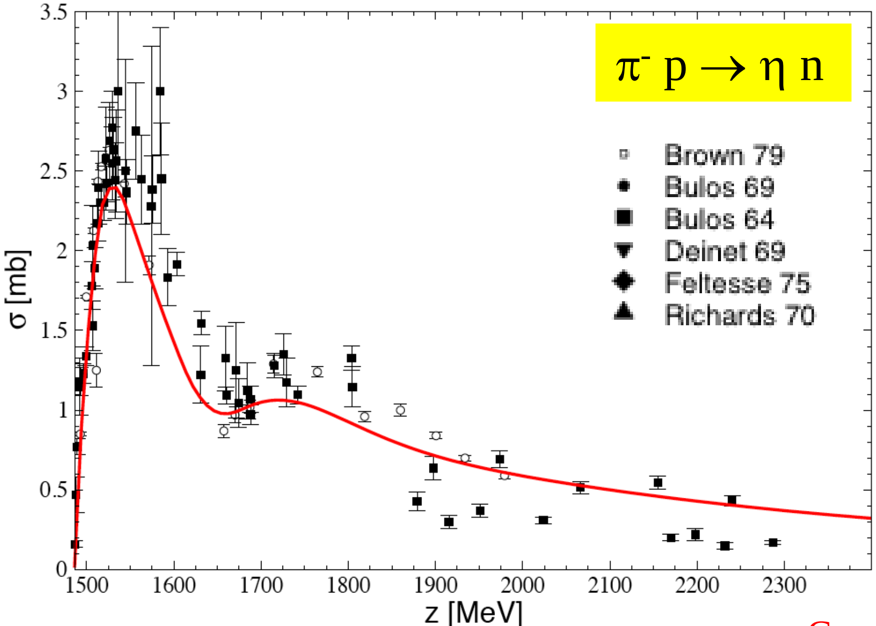
Curve:
Jülich
DCC
model
2012

various inconsistent data

<u>Detailed overview (selection & rating):</u>

Clajus & Nefkens, πN Newsletter 7, 76 (1992)

Existing data: $\pi^- p \to \eta\, n$, σ [W < 2.3 GeV]



Curve: Jülich DCC model 2012

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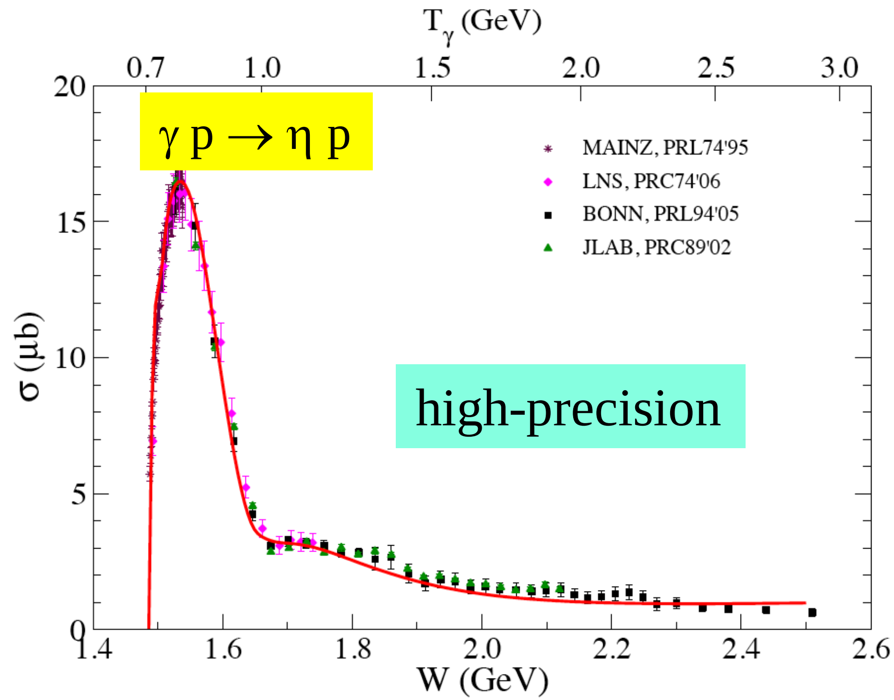
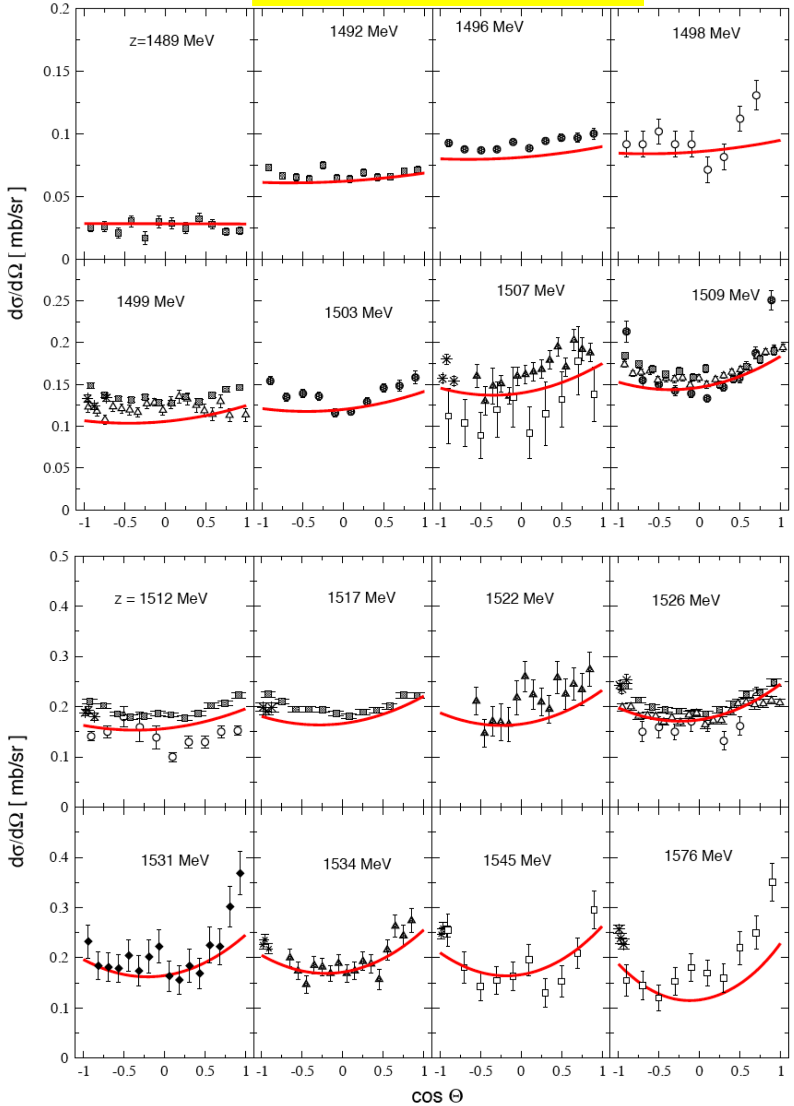


Existing data: $\pi^- p \rightarrow \eta\, n$, $d\sigma/d\Omega$ [W < 2.4 GeV]

1.49 < W<1.58 GeV



Curves:
Jülich
DCC
model
2012

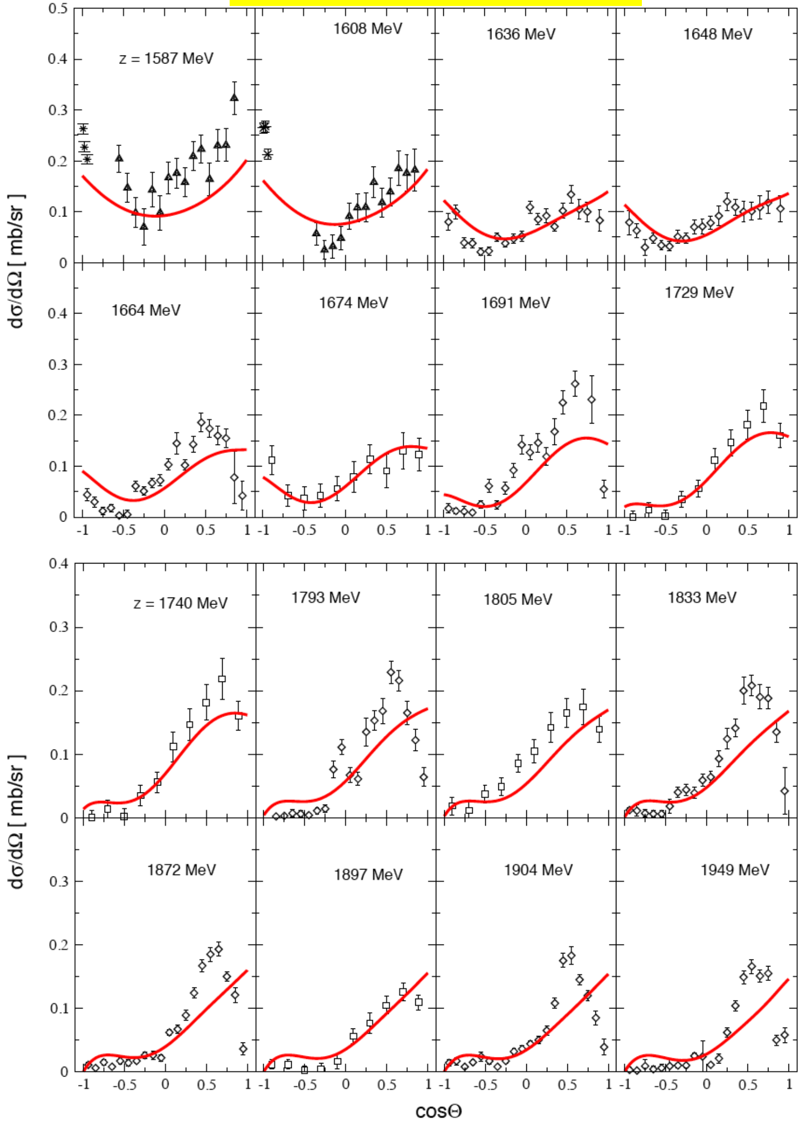
- ■ Prakhov 05
- ● Bayadilov 08
- ○ Morrison 00
- △ Kozlenko 03
- ∗ Debenham 75
- ▲ Deinet 69 (***)
- □ Richards 70
- ◆ Feltesse 75

various inconsistent data

Detailed overview (selection & rating):
Clajus & Nefkens, πN Newsletter 7, 76 (1992)

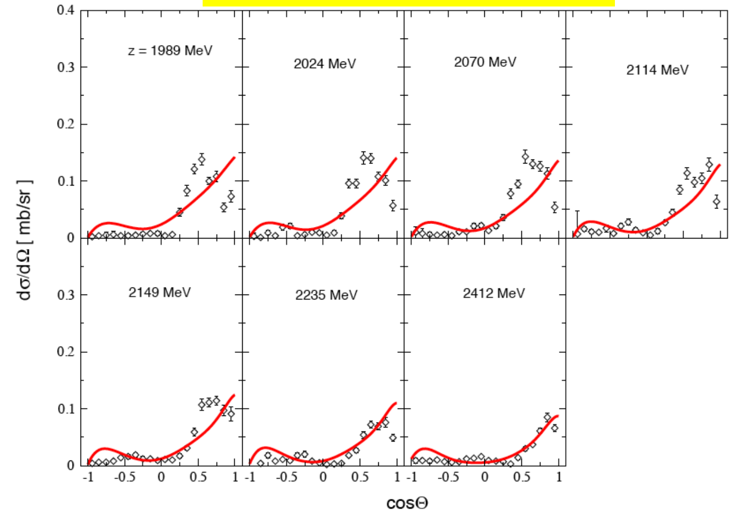
Existing data: $\pi^- p \to \eta\, n$, $d\sigma/d\Omega$ [W < 2.4 GeV]

1.59 < W < 1.95 GeV



Curves:
Jülich
DCC
model
2012

1.99 < W < 2.41 GeV



∗ Debenham 75
▲ Deinet 69 (***)
□ Richards 70
◇ Brown 79 (suggested to be eliminated from the data base)

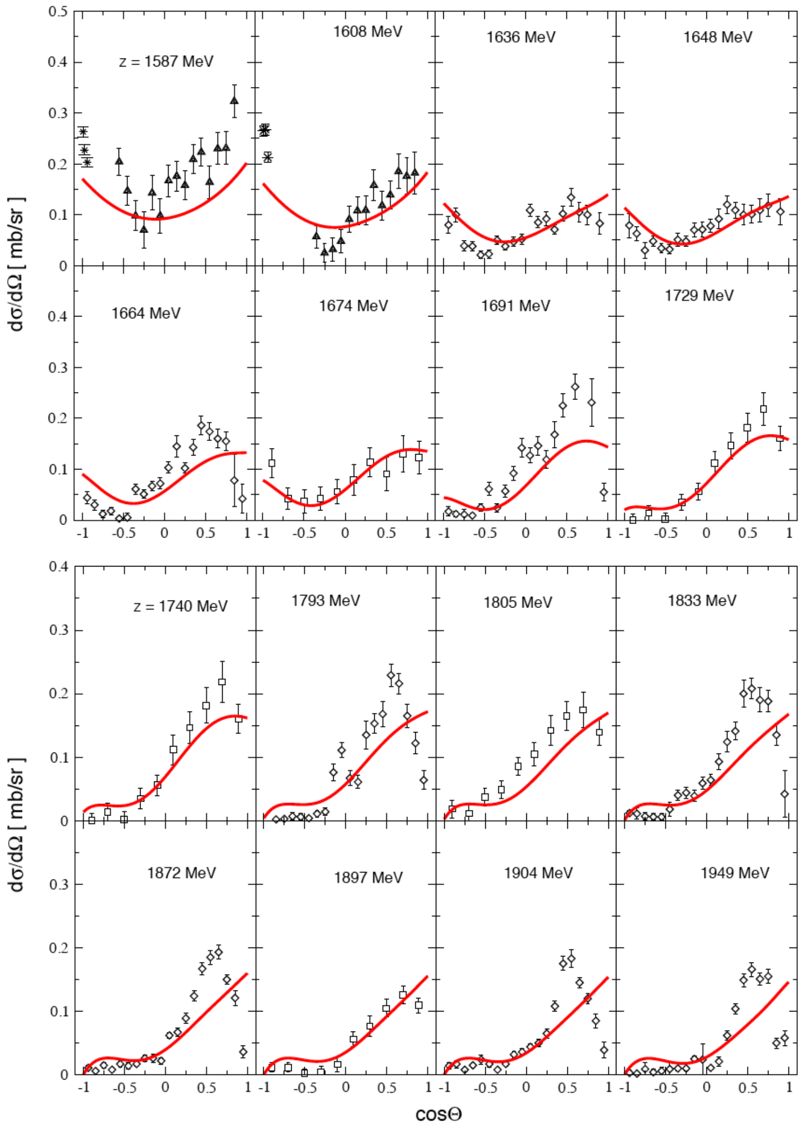
various inconsistent data

<u>Detailed overview (selection & rating):</u>

Clajus & Nefkens, πN Newsletter 7, 76 (1992)

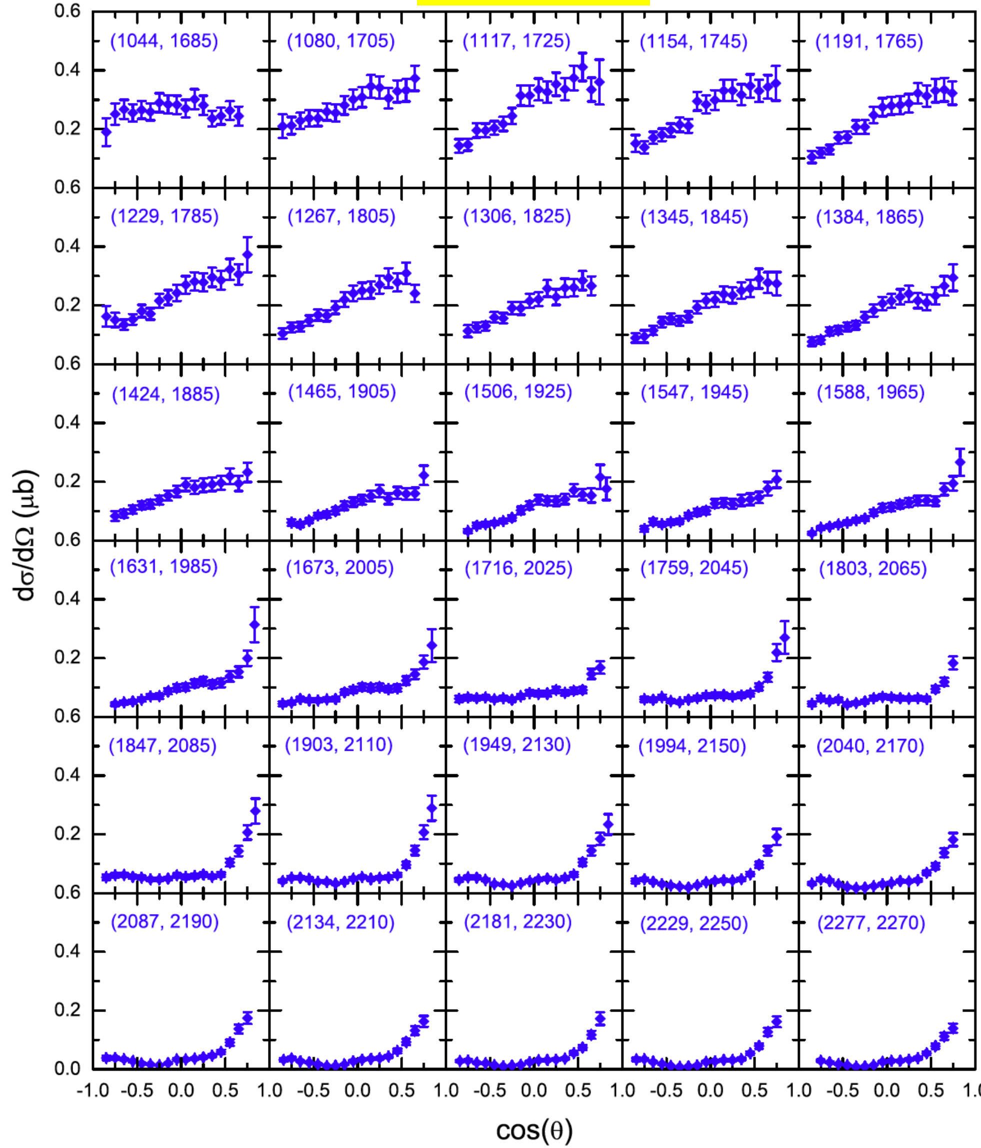
Existing data: $\pi^- p \to \eta\, n$, hadro- vrs photo-reaction

$\pi^- p \to \eta\, n$



$\gamma\, p \to \eta\, p$

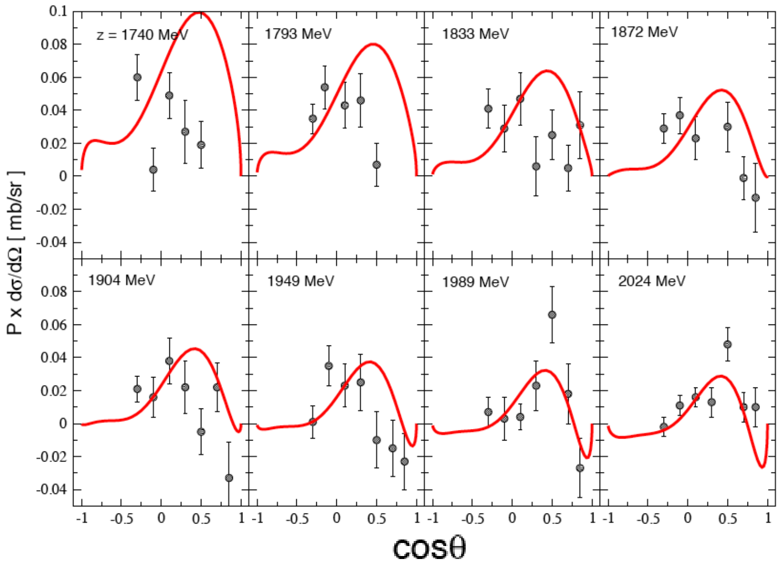
CLAS'09



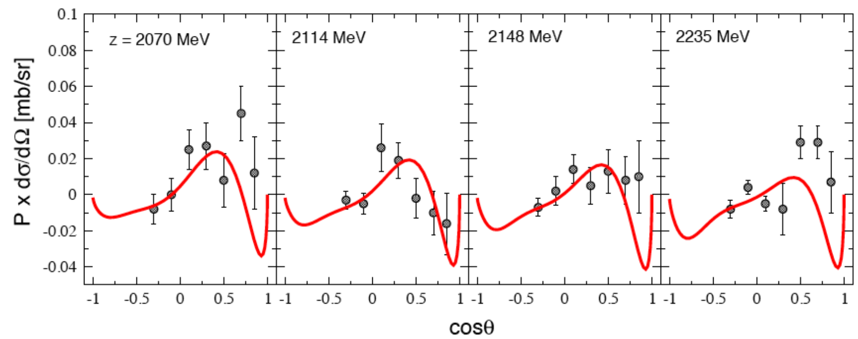
Existing data: $\pi^- p \rightarrow \eta n$, *polarization*

[1.74 < W<2.23 GeV]

1.74 < W < 2.02 GeV

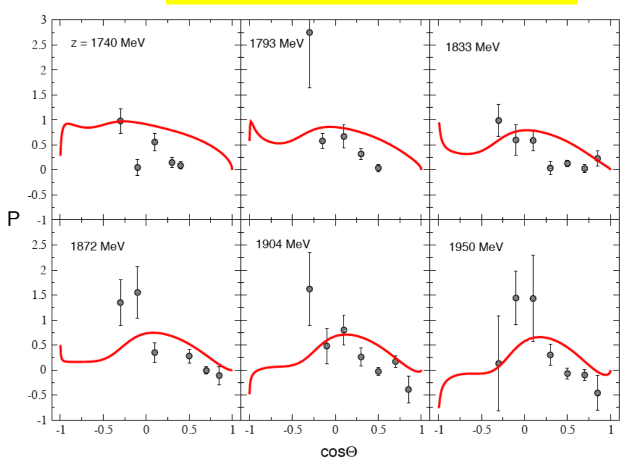


2.07 < W < 2.23 GeV



Curves:
Jülich DCC model 2012

1.74 < W < 1.95 GeV

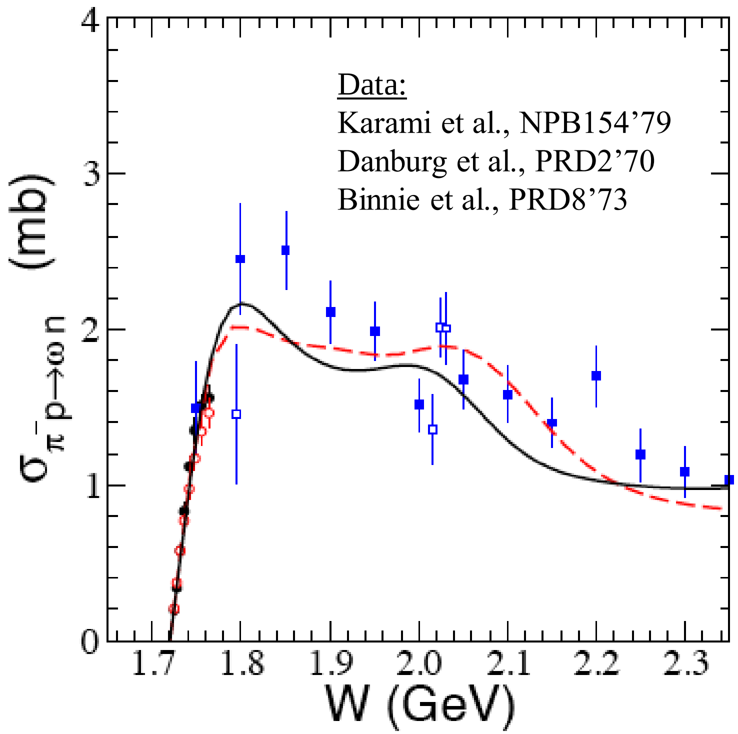


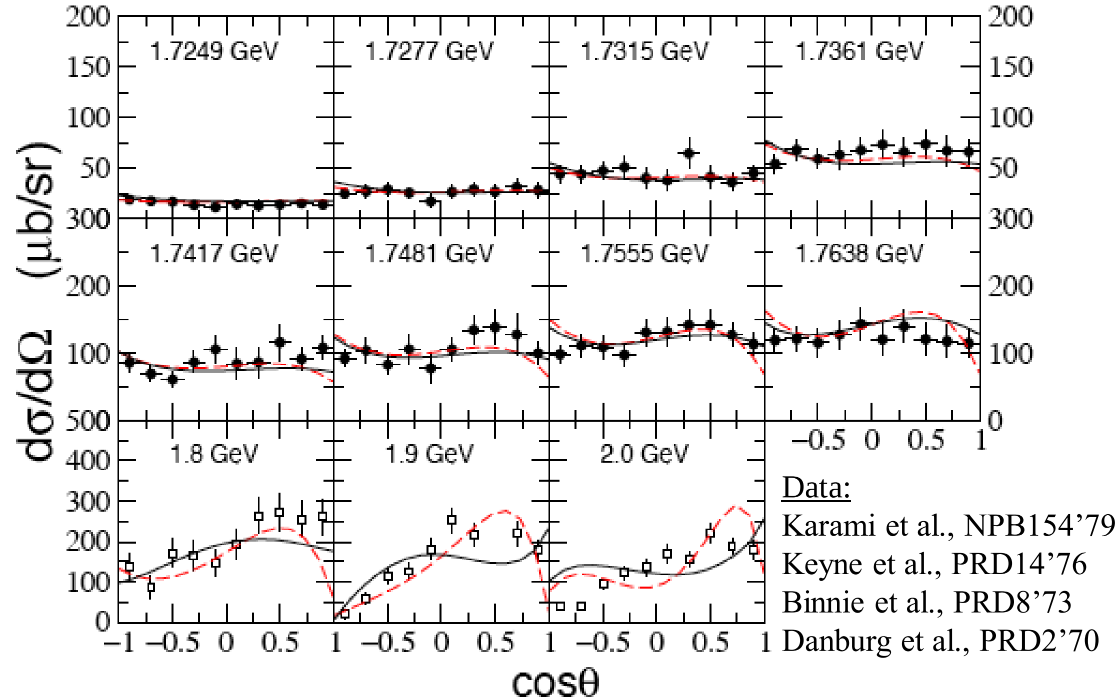
Data: Baker et al., NPB156'79
(suggested to be eliminated from the data base)

some data points > 1

<u>Detailed overview (selection & rating):</u>
Clajus & Nefkens, πN Newsletter 7, 76 (1992)

Existing data: $\pi^- p \to \omega n$, $\sigma_{[W<2.3]}$ & $d\sigma/d\Omega_{[W < 2\ GeV]}$





Controversy? :

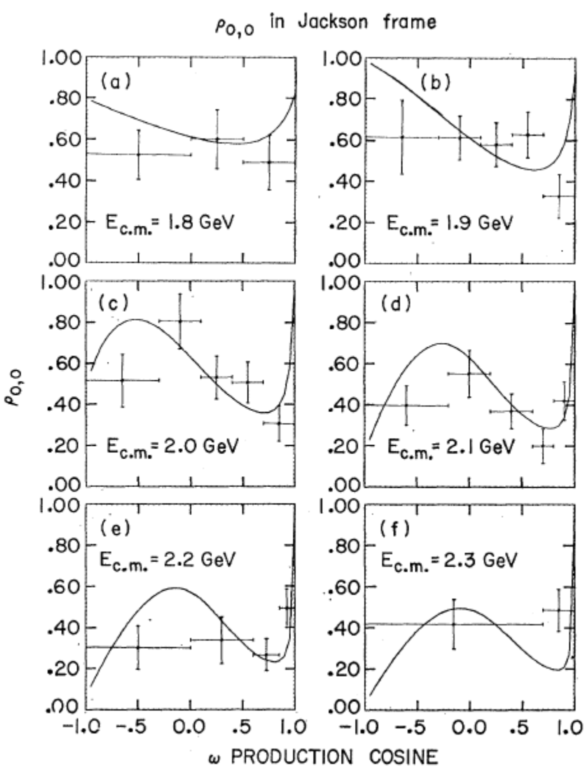
Sibirtsev & Cassing, EPJA7’00
Titov et al., arXiv:nucl-th/0102032
Hanhart et al., arXiv:hep-ph/0107245
Penner & Mosel, arXiv:nucl-th/0111024

needs to be re-measured (HADES at GSI)

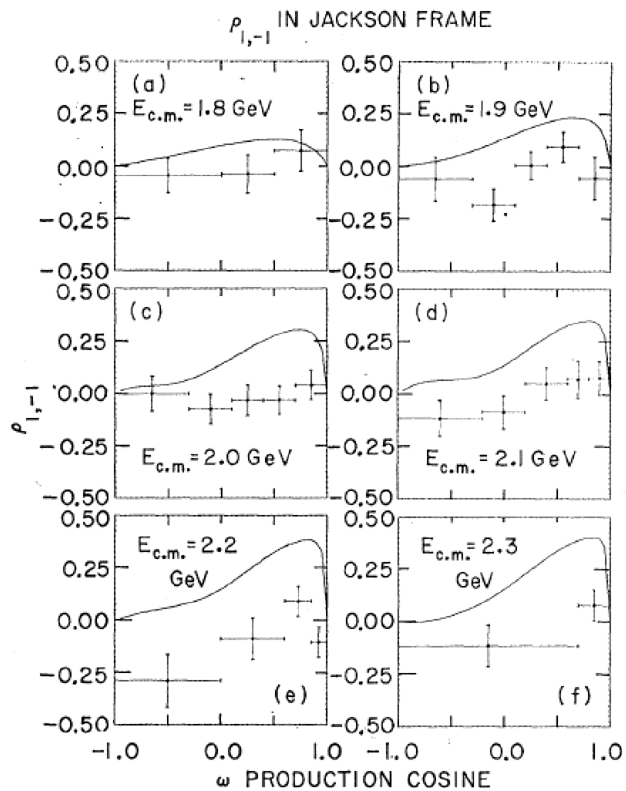
Existing data: $\pi^+ n \rightarrow \omega\, p$, spin density matrices

[$1.8 < W < 2.3$ GeV]

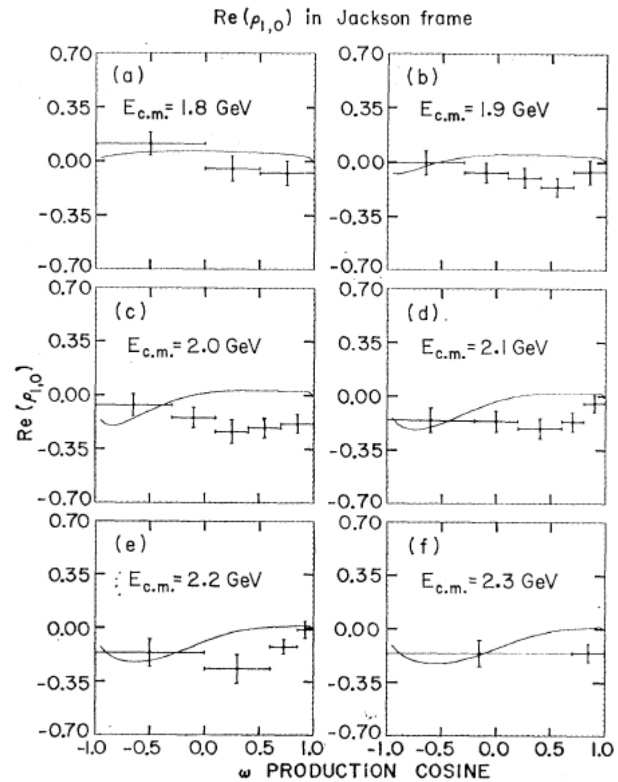
ρ_{00}



$\rho_{1,-1}$



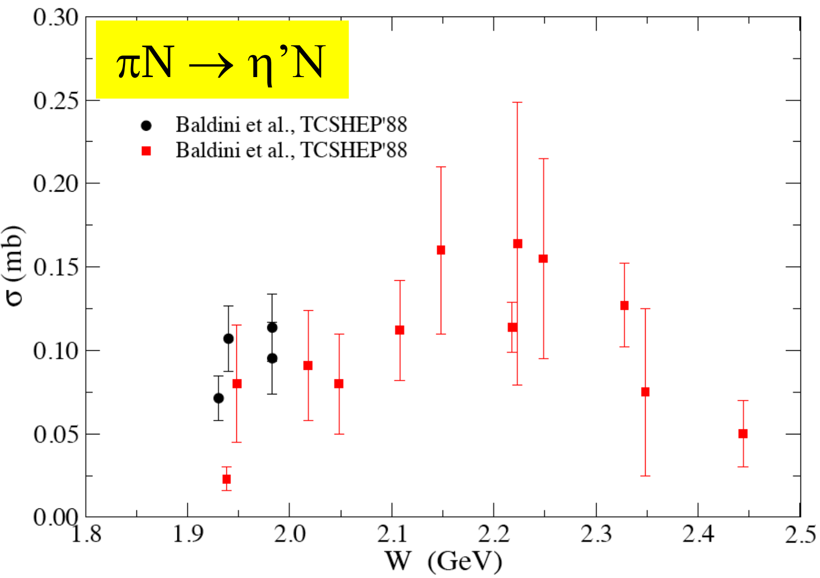
$\mathrm{Re}[\rho_{10}]$



$\rho_{1,-1}$: natural x unnatural parity t-channel exchange

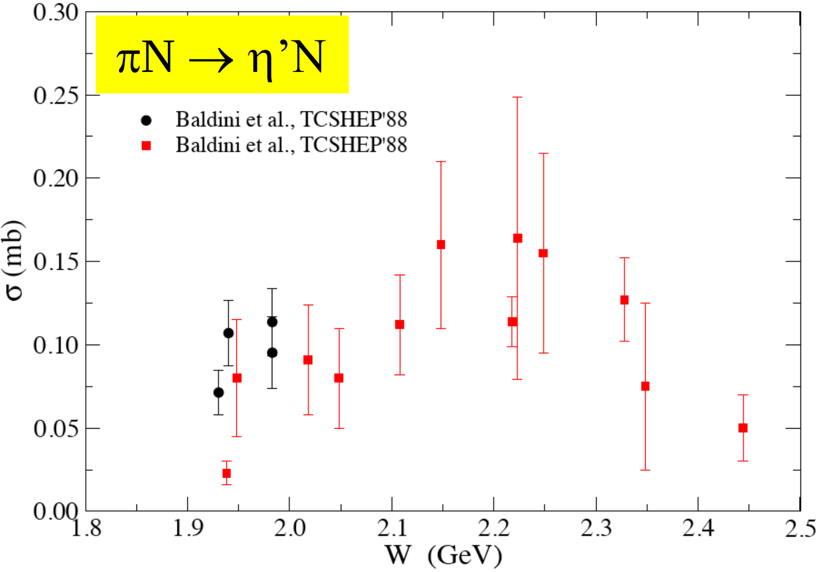
Data:
Danburg et al., PRD2'70

Existing data: $\pi N \to \eta' N$, σ [W < 2.3 GeV]



- large uncertainties
- no other observable exists

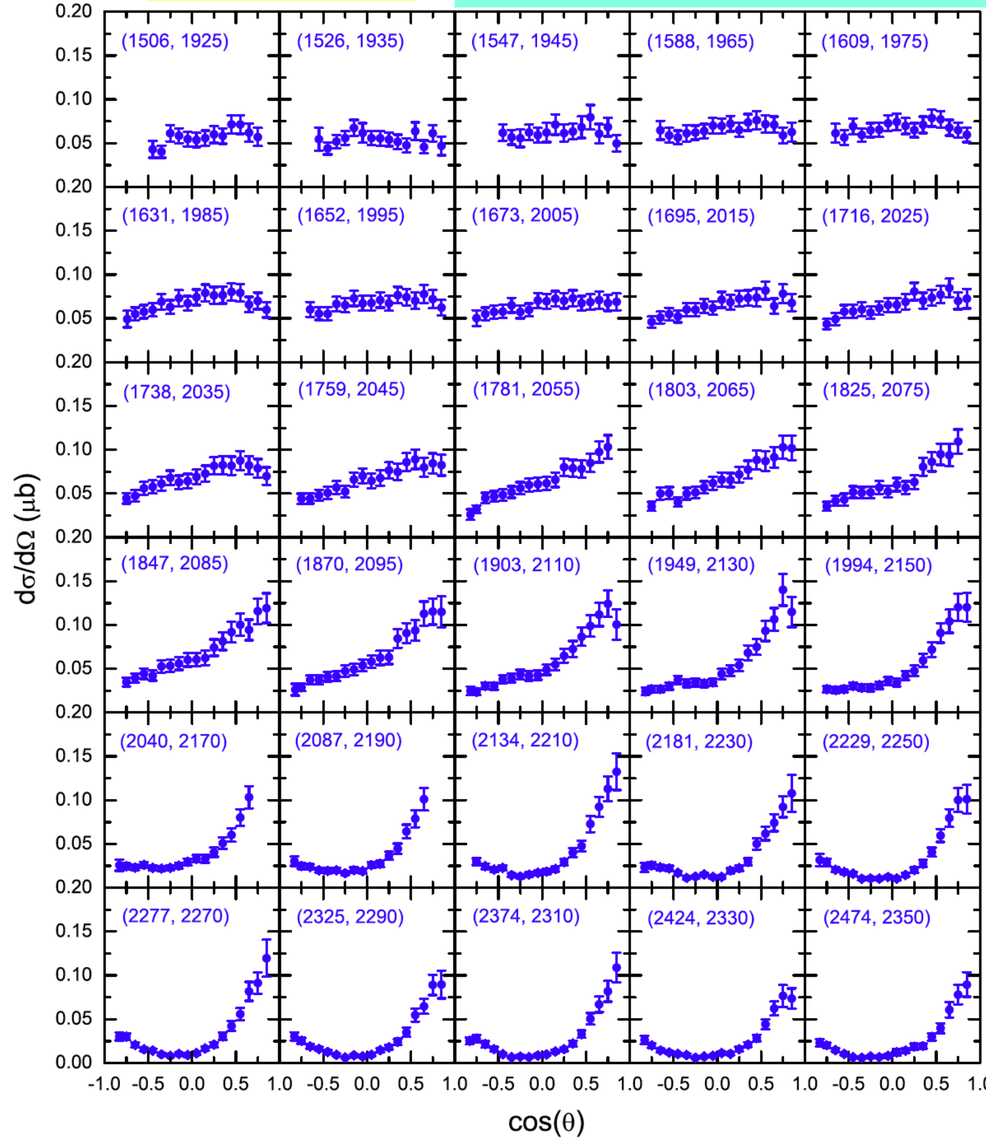
Existing data: $\pi N \to \eta$□N, σ [W < 2.3 GeV]



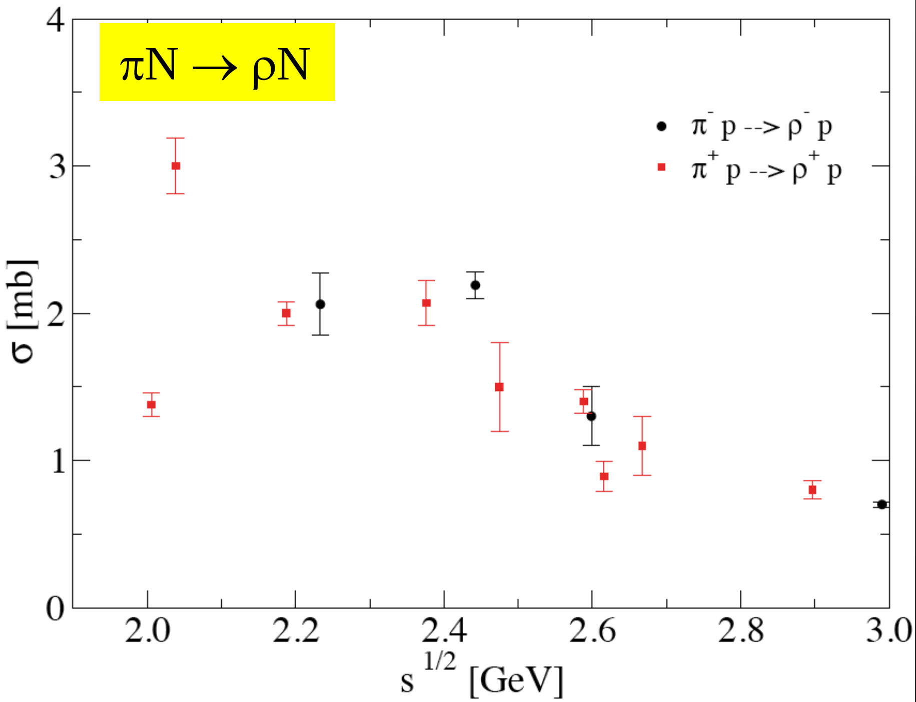
- large uncertainties
- no other observable exists

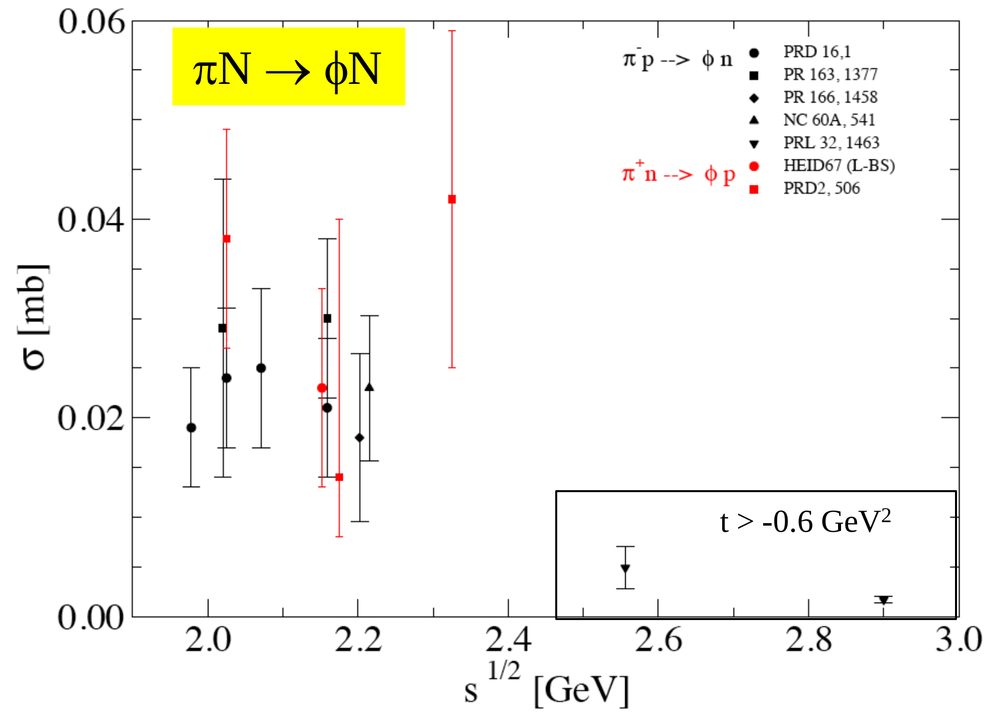
γ p → η’ p

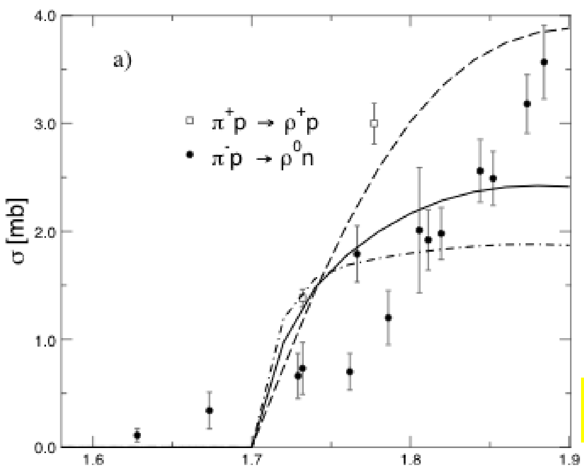
high-precision CLAS’09



Existing data: $\pi N \to \rho N, \phi N, \quad \sigma$





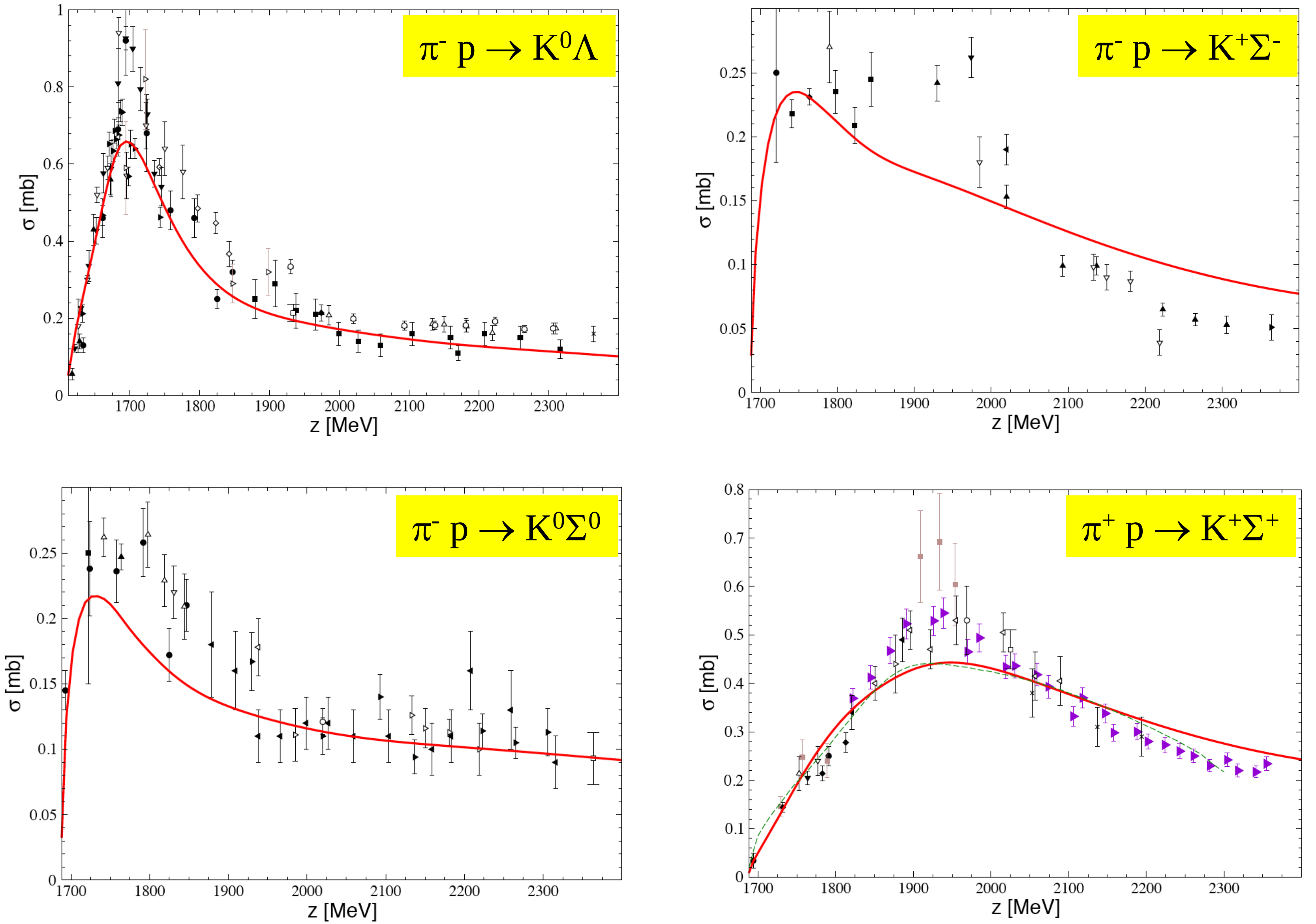


W < 1.9 GeV

- large uncertainties
- no other observable exists

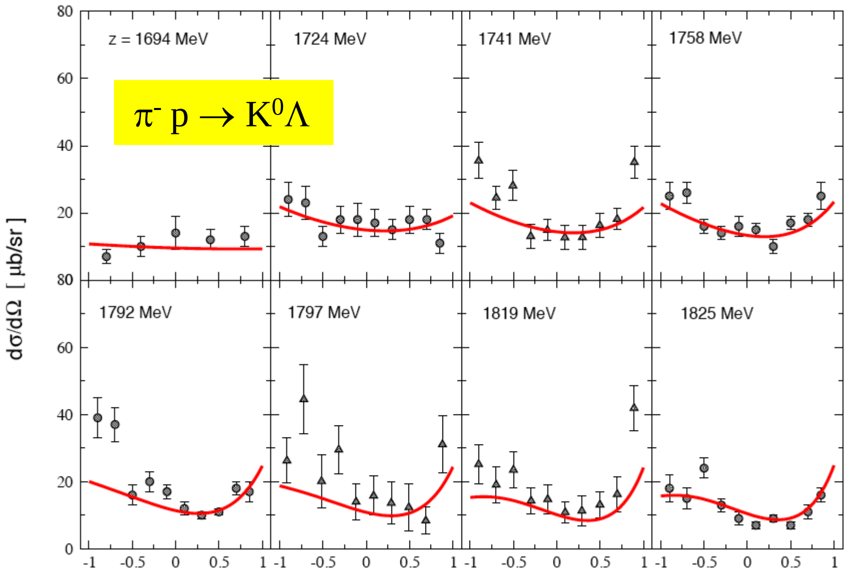
HADES at GSI: plan to measure $\pi N \to \rho N$

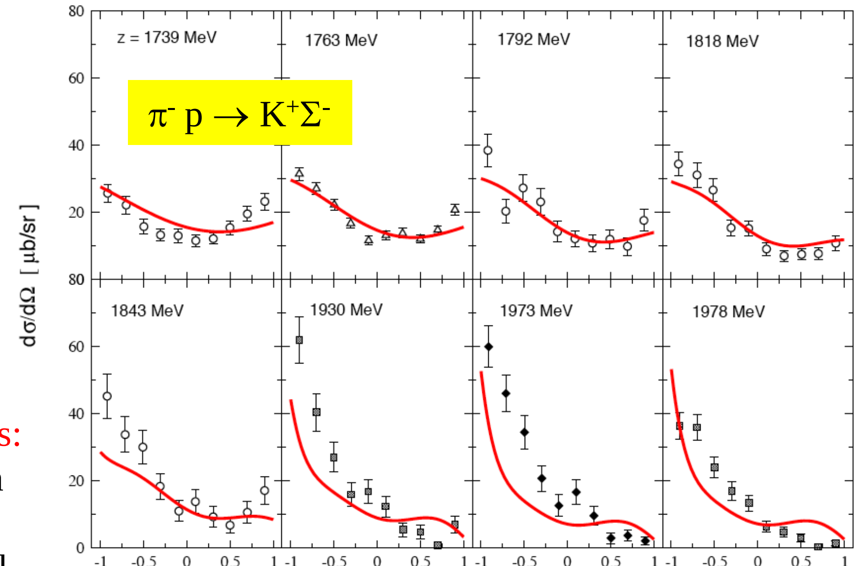
Existing data: $\pi N \to KY, \quad \sigma$



Curves:
Jülich
DCC
model
2012

Selected data: $\pi N \to KY$, $d\sigma/d\Omega$





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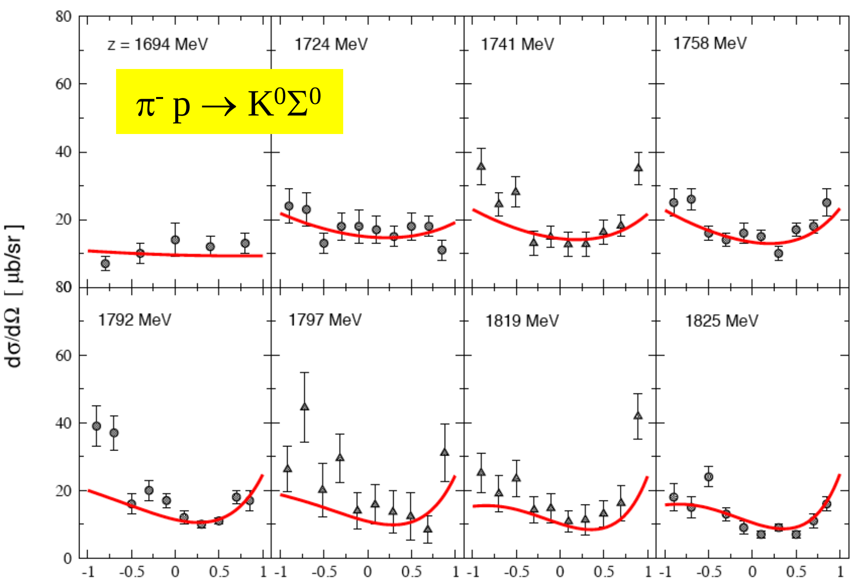
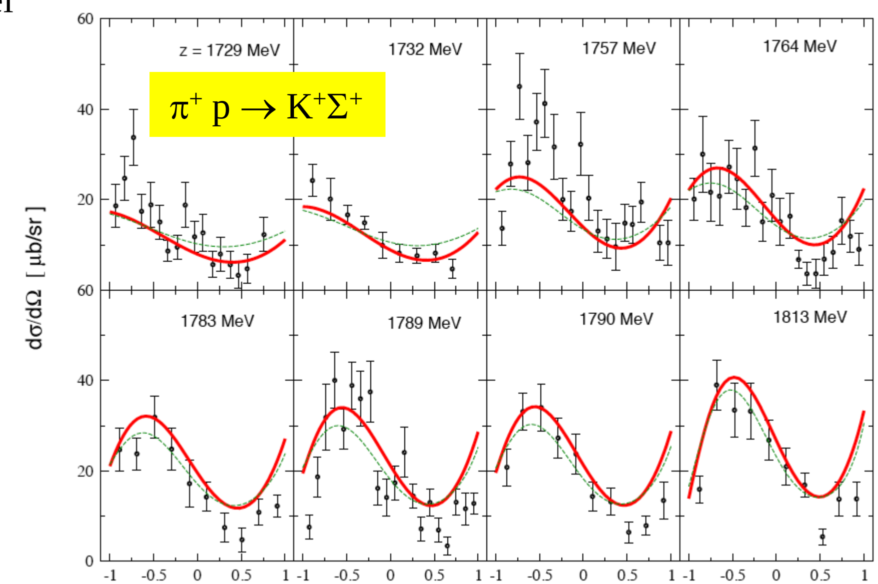
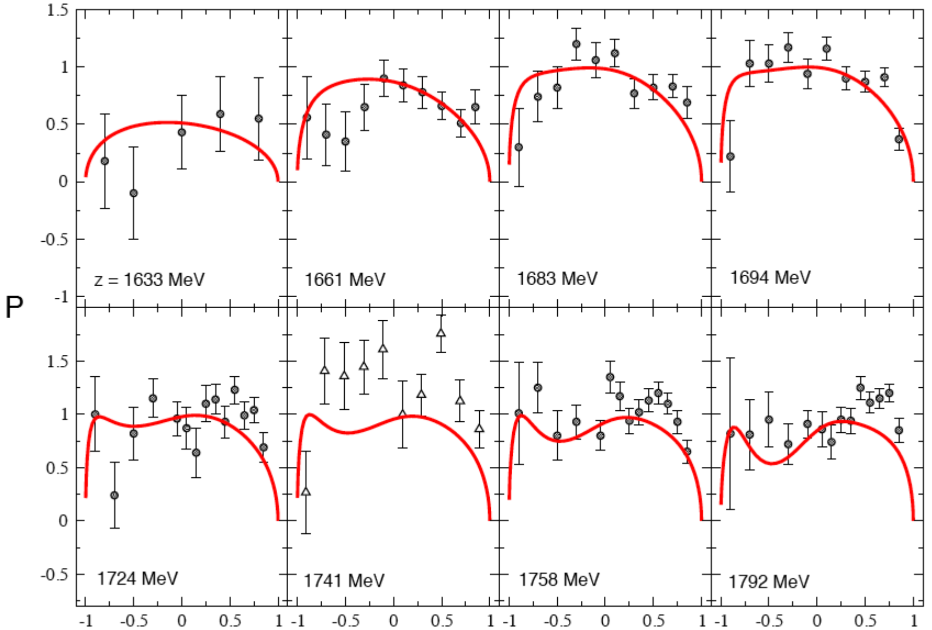


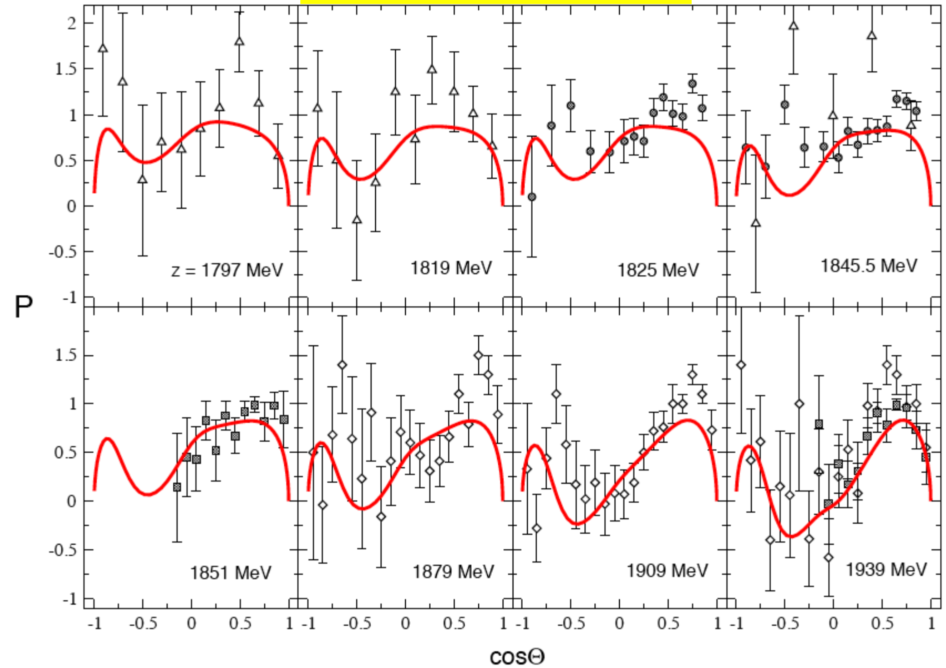


Selected data: $\pi^- p \to K^0 \Lambda$, polarization

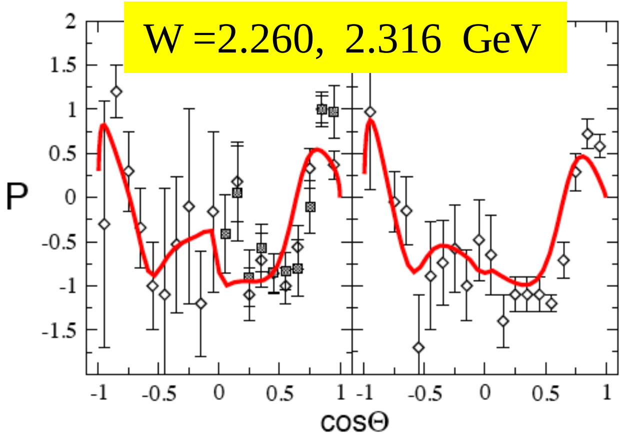
1.63 < W < 1.8 GeV



1.8 < W < 1.94 GeV



W =2.260, 2.316 GeV

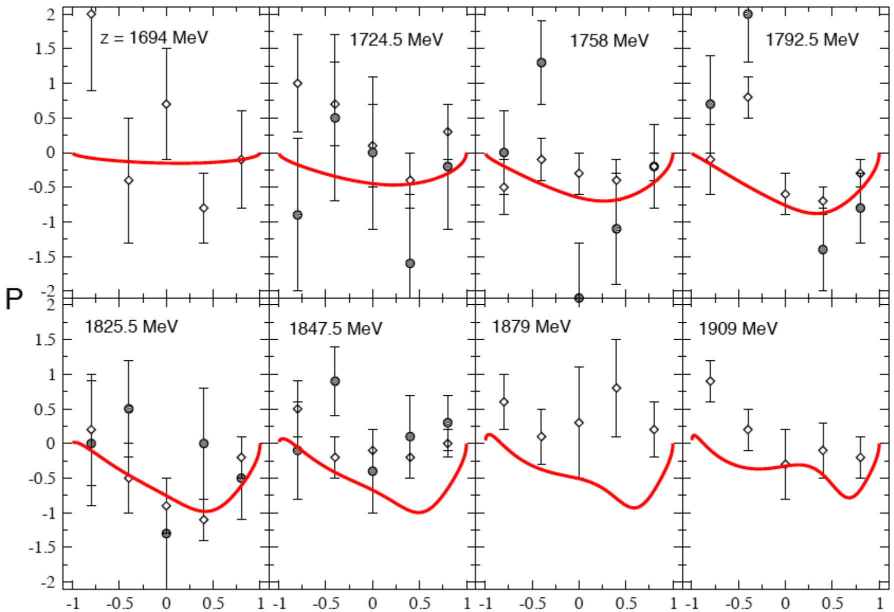


Curves:
Jülich
DCC
model
2012

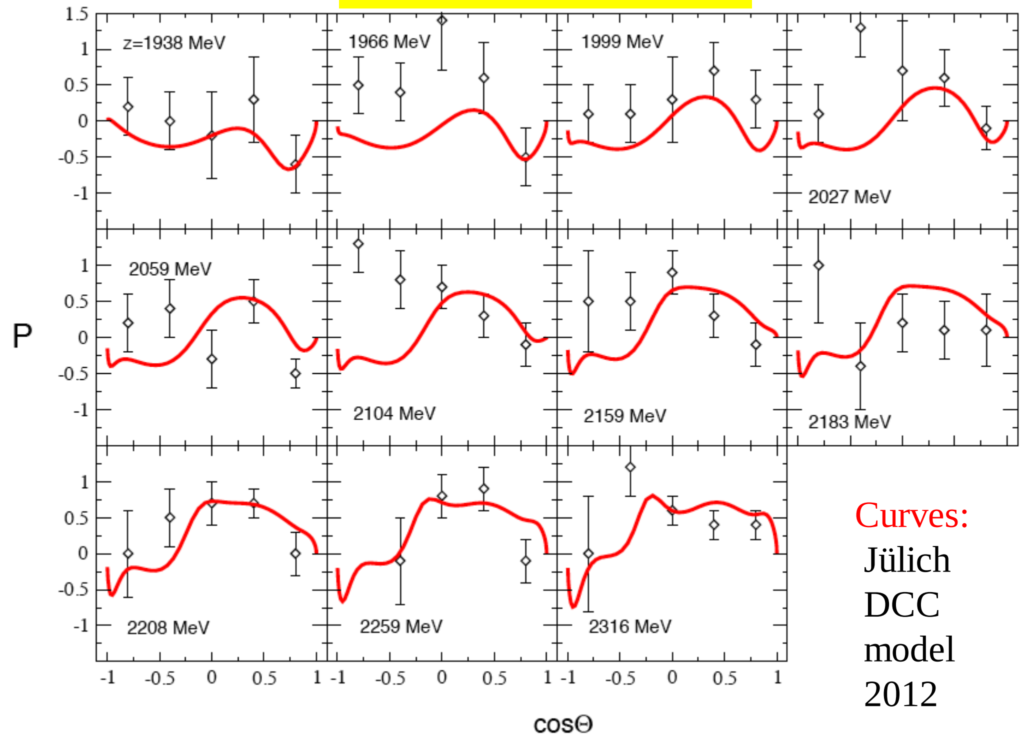
- very large uncertainties for cos(θ) < 0
- several data points > 1

Selected data: $\pi^- p \to K^0 \Sigma^0$, *polarization*

1.69 < W < 1.91 GeV



1.94 < W < 2.32 GeV



Curves:
Jülich
DCC
model
2012

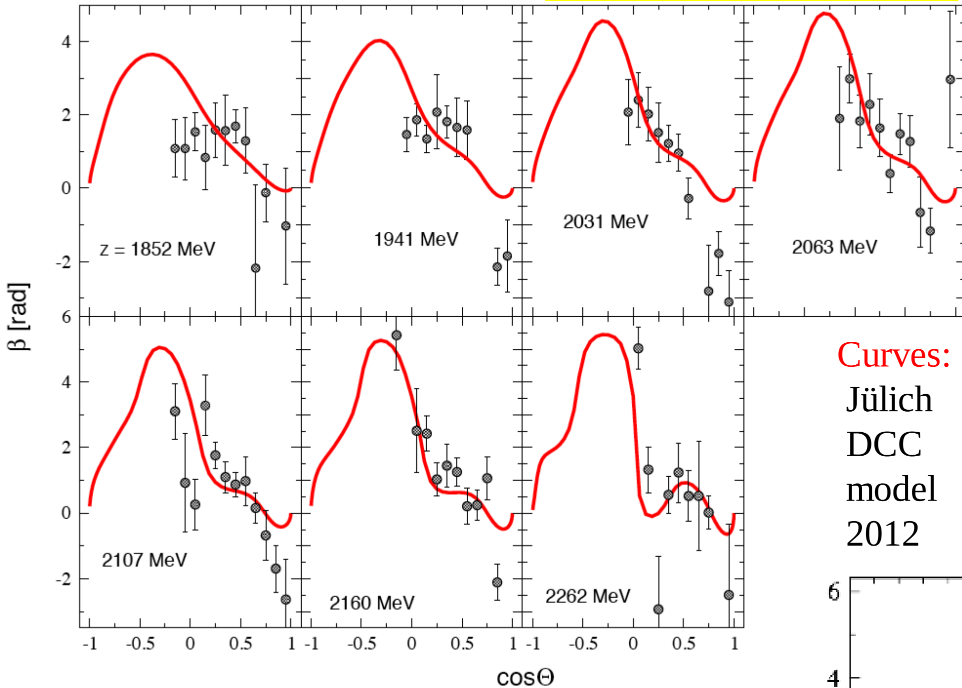
- large uncertainties
- data sets not consistent at all points
- several data points > 1

- data for the $K^+\Sigma^-$ channel are limited (no polarization data below 2.7 GeV)

Existing data: $\pi^- p \rightarrow K^0\Lambda, K^+\Sigma^+$, *spin rotation parameter*

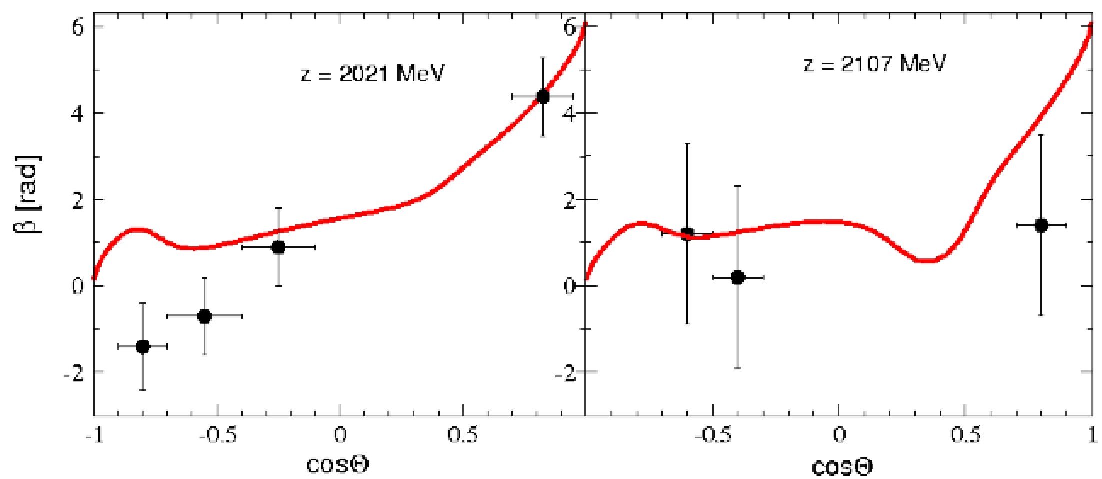
$\pi^+ p \rightarrow K^0\Lambda$

$1.85 < W < 2.26$ GeV

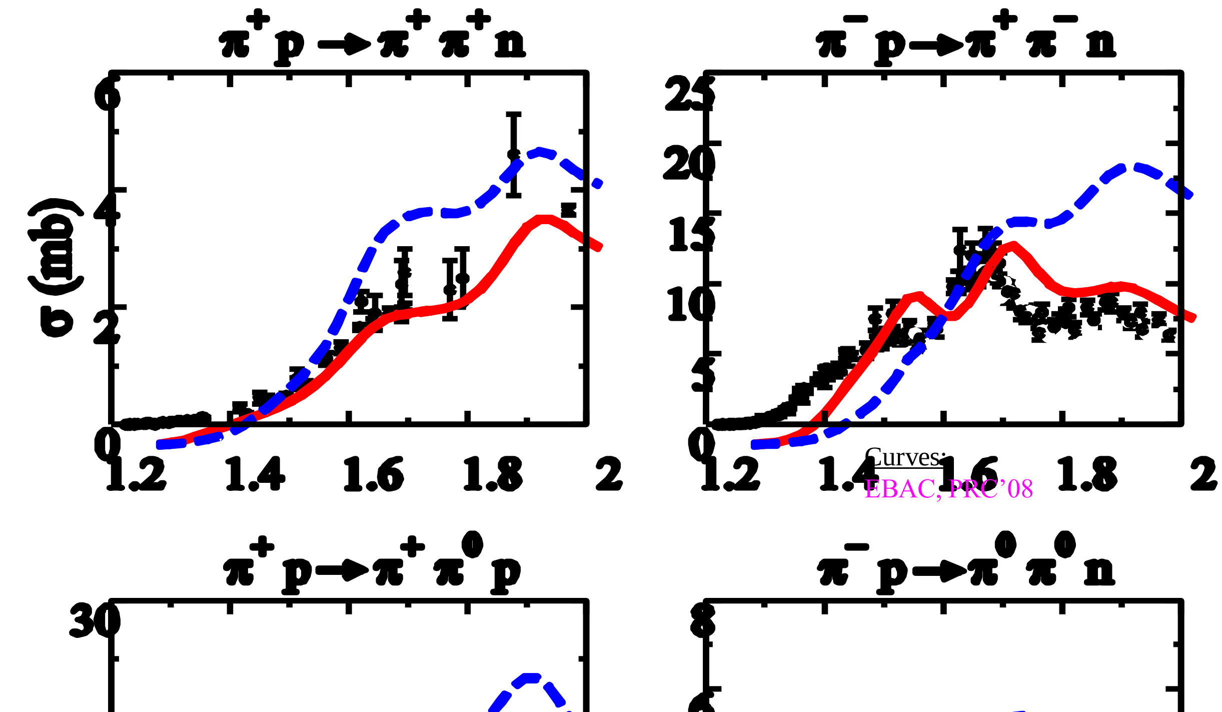


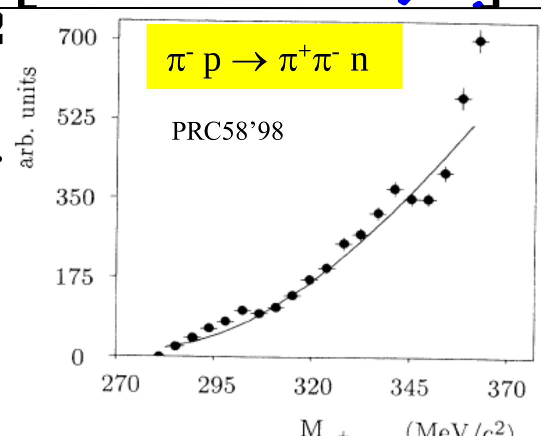
Curves:
Jülich
DCC
model
2012

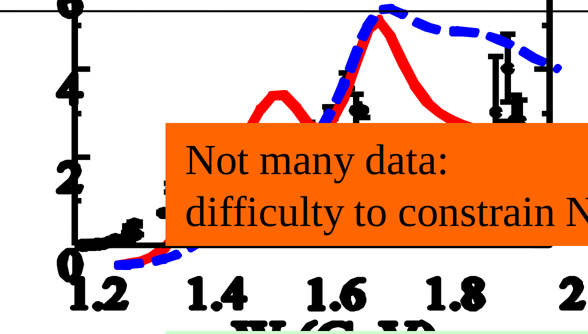
$\pi^+ p \rightarrow K^+\Sigma^+$



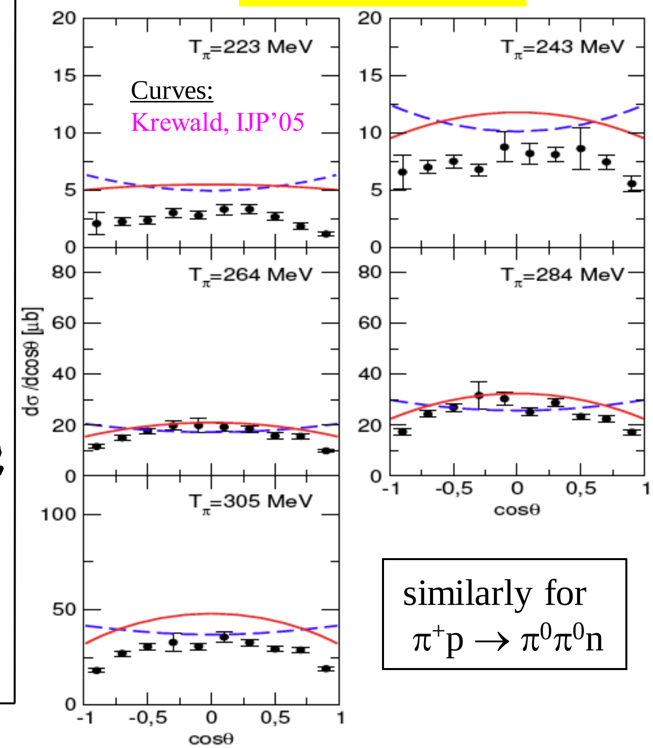
Selected data: $\pi N \to \pi\pi N$, σ & $d\sigma/d\Omega$







$\pi^+ p \to \pi^+\pi^+ n$



similarly for $\pi^+ p \to \pi^0\pi^0 n$

Not many data:
difficulty to constrain $N^* \to \sigma N, \rho N, \pi\Delta \to \pi\pi N$

(EBAC, PRC'08)

J-PARC: considering to measure $\pi N \to \pi\pi N$

some observables:
sensitivity to model details

Jülich DCC model: *D. Rönchen, M. Döring, F. Huang et al., 2012*

Jülich Hadronic Model (TOPT):

$$T_{ij} = V_{ij} + \sum_k V_{ik} G_k T_{kj}$$

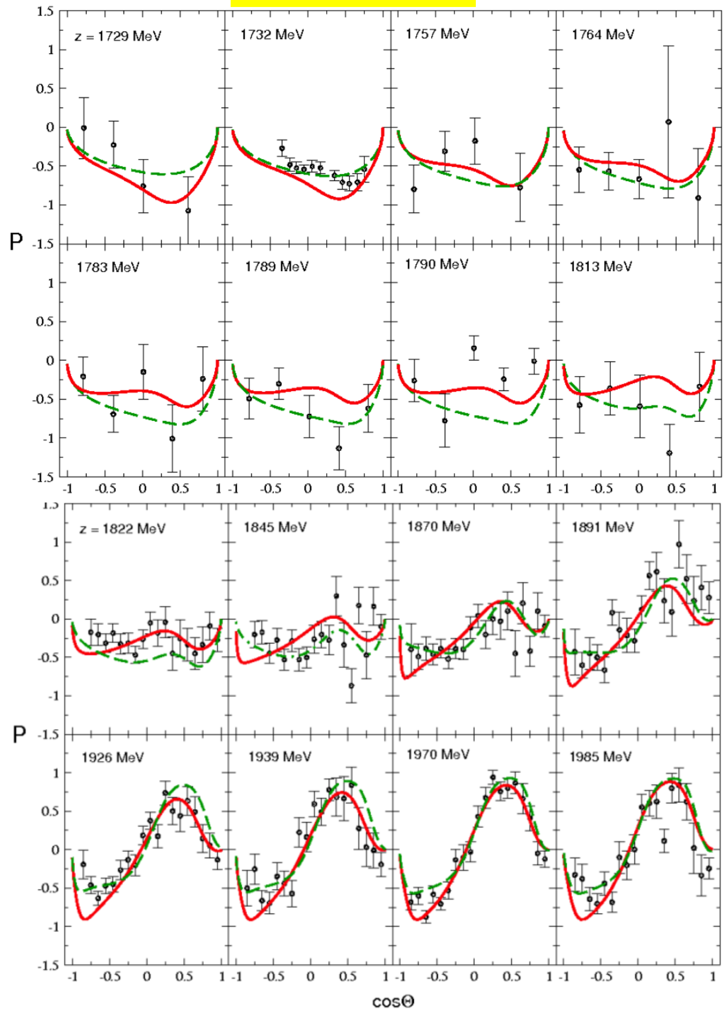
$$i, j, k = \pi N, \eta N, K\Lambda, K\Sigma, \underbrace{\sigma N, \rho N, \pi\Delta}_{\text{effective } \pi\pi N}$$

W < 2 GeV

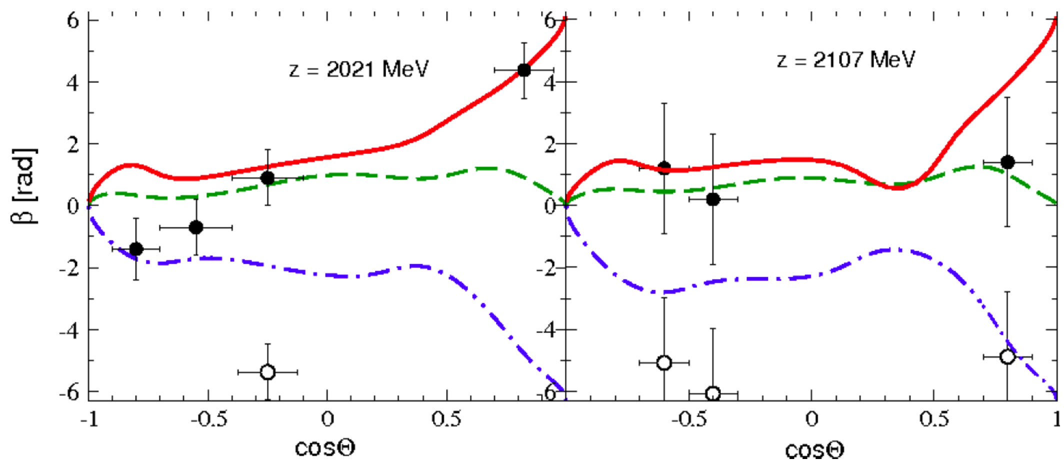
Data sensitivity: *polarization & spin rotation coefficient*

$\pi^+ p \rightarrow K^+\Sigma^+$

polarization



spin rotation parameter



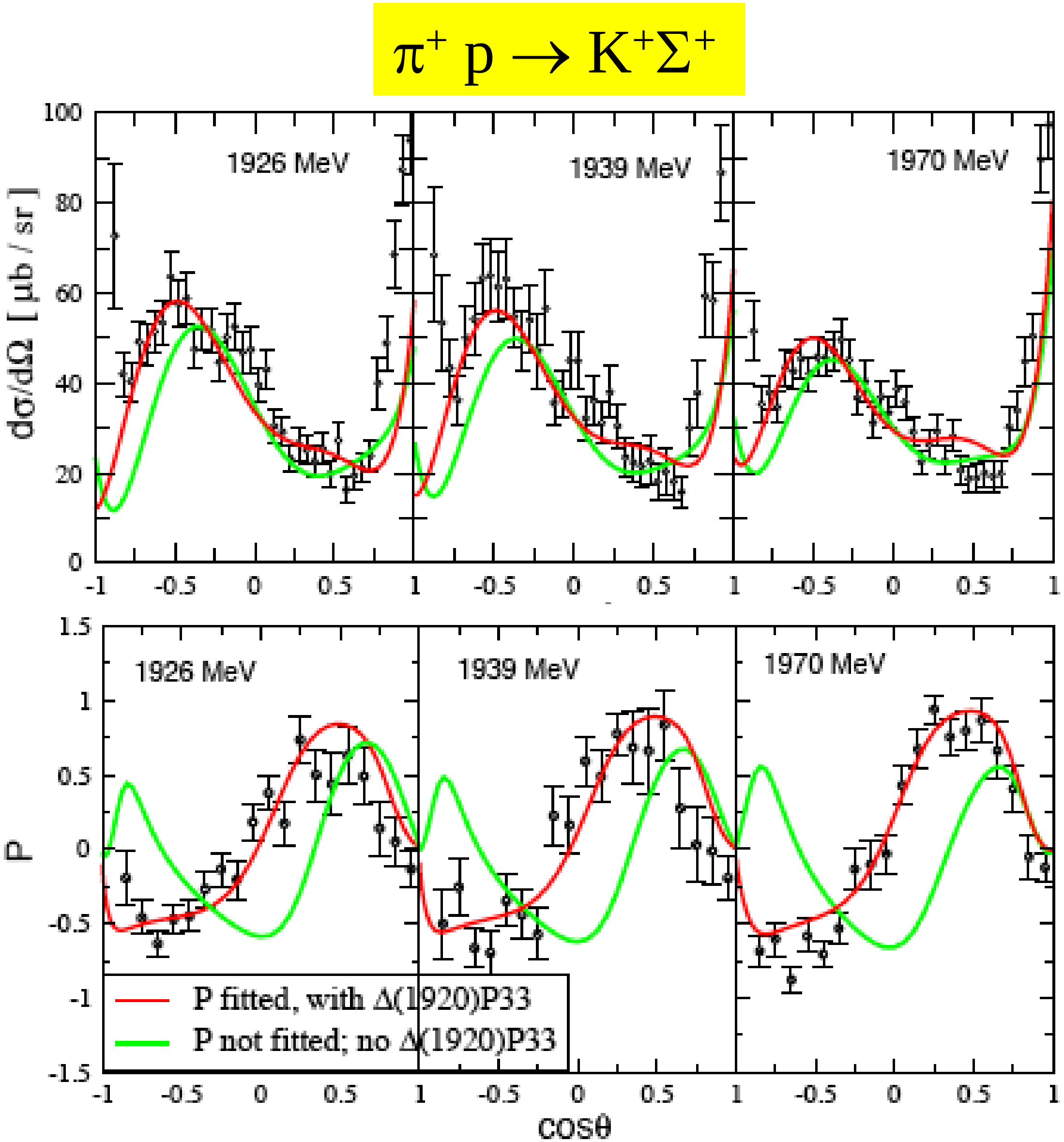
Rönchen et al., 2012 (in preparation)

Döring et al., NPA851'11

Candline et al., NPB311'89

They all fit the cross section data equally well

Data sensitivity: $\pi^- p \rightarrow K^+ \Sigma^+$, polarization

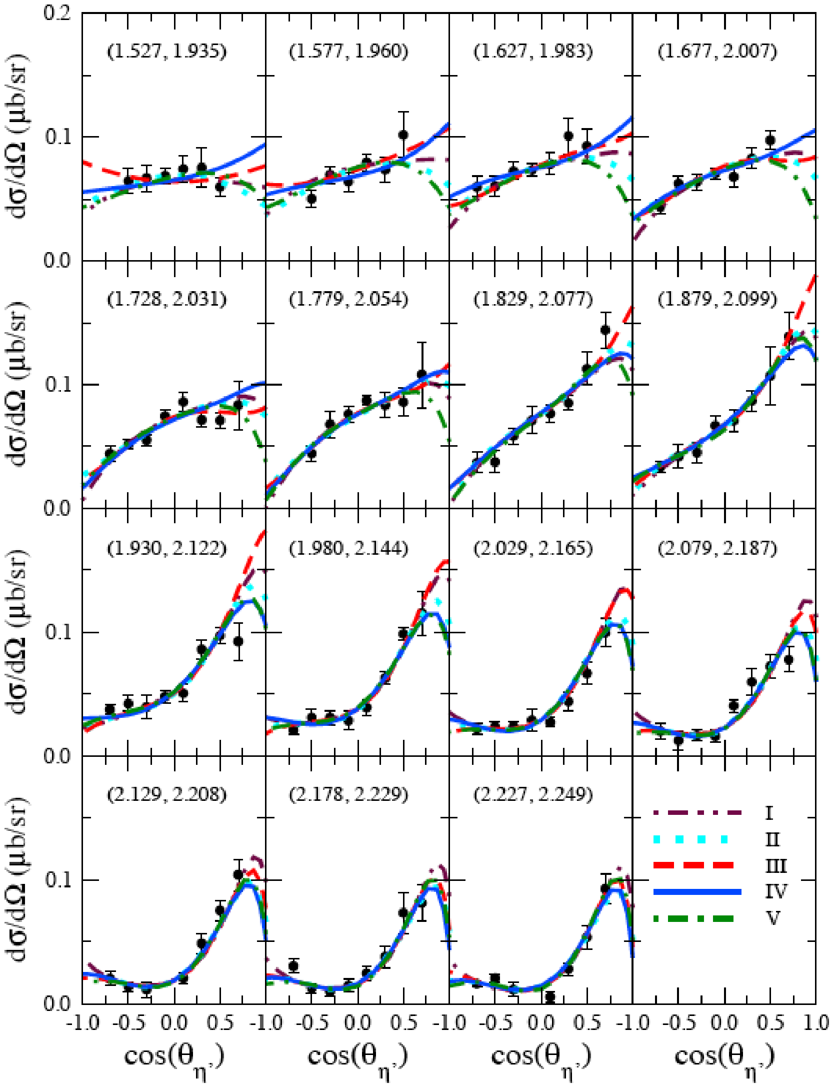


Δ(1920) P33:
most important resonance invisible in $\pi N \rightarrow \pi N$ but needed in $\pi^+ p \rightarrow K^+\Sigma^+$

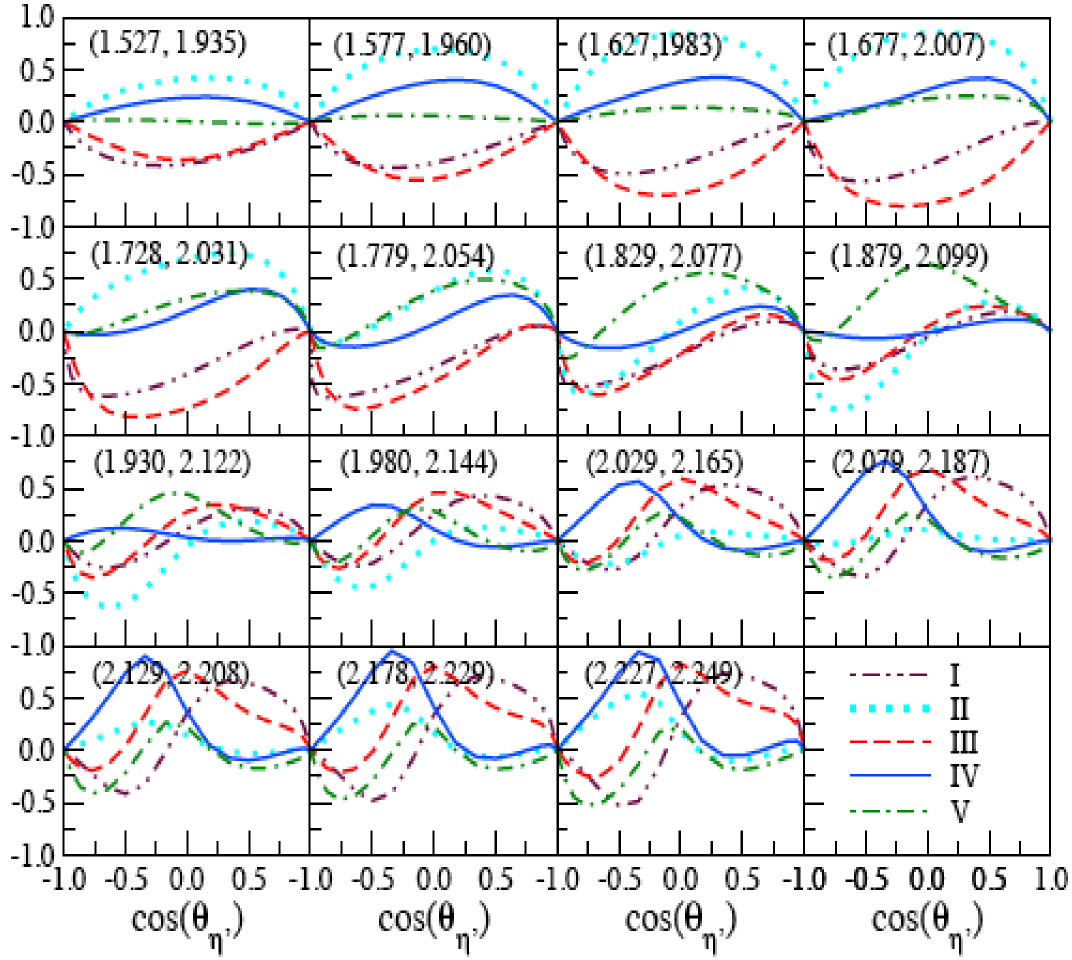
Data sensitivity: $\gamma p \rightarrow \eta' p$, *beam asymmetry*

(Nakayama & Haberzettl, PRC73'06)

dσ/dΩ

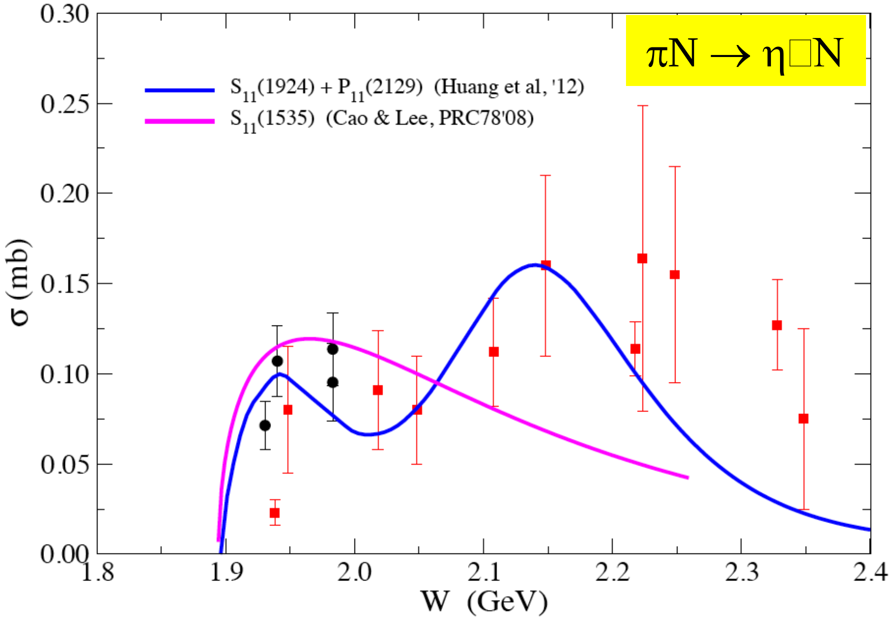


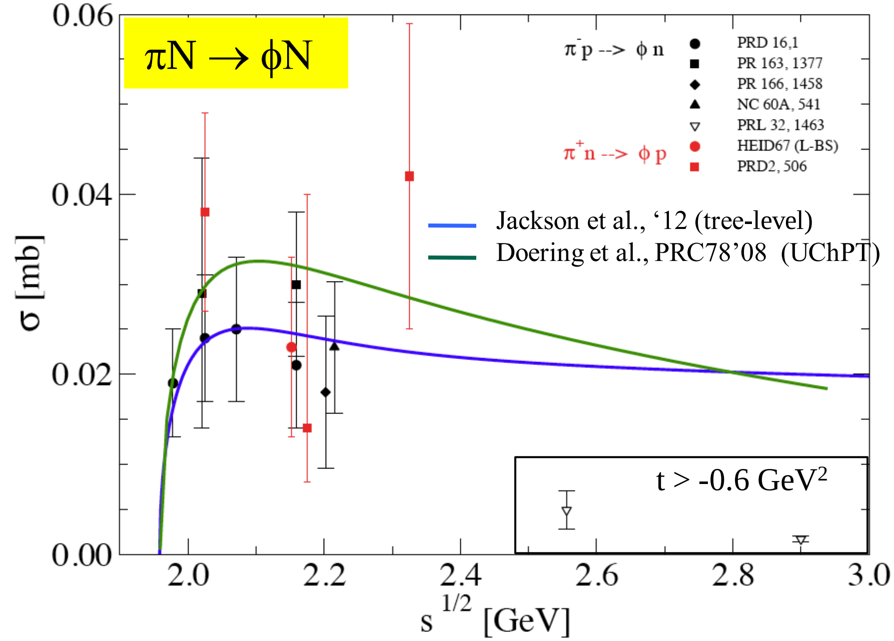
Σ



T: similar sensitivity as Σ

Model sensitivity: *cross sections*





they reproduce the $NN \to NN\eta'$ cross section data equally well

Summary: database (hadr. react.): dismal situation

- Hadro-induced meson production reaction data are badly needed for modern coupled-channels analyses in baryon spectroscopy:
    - Existing data in the non-strange sector are very scarce, especially the spin observables (no double-polarization observable), and suffer from large uncertainty problem.
    - Many data are inconsistent with each other (e.g., $\pi N \to \eta N$) and/or of dubious reliability, requiring to be re-measured.
    - Better situation in the strangeness sector ($K\Lambda$, $K\Sigma$), although many of the polarization data require to be re-measured due to large uncertainties; only handful data points for double-polarization observable.

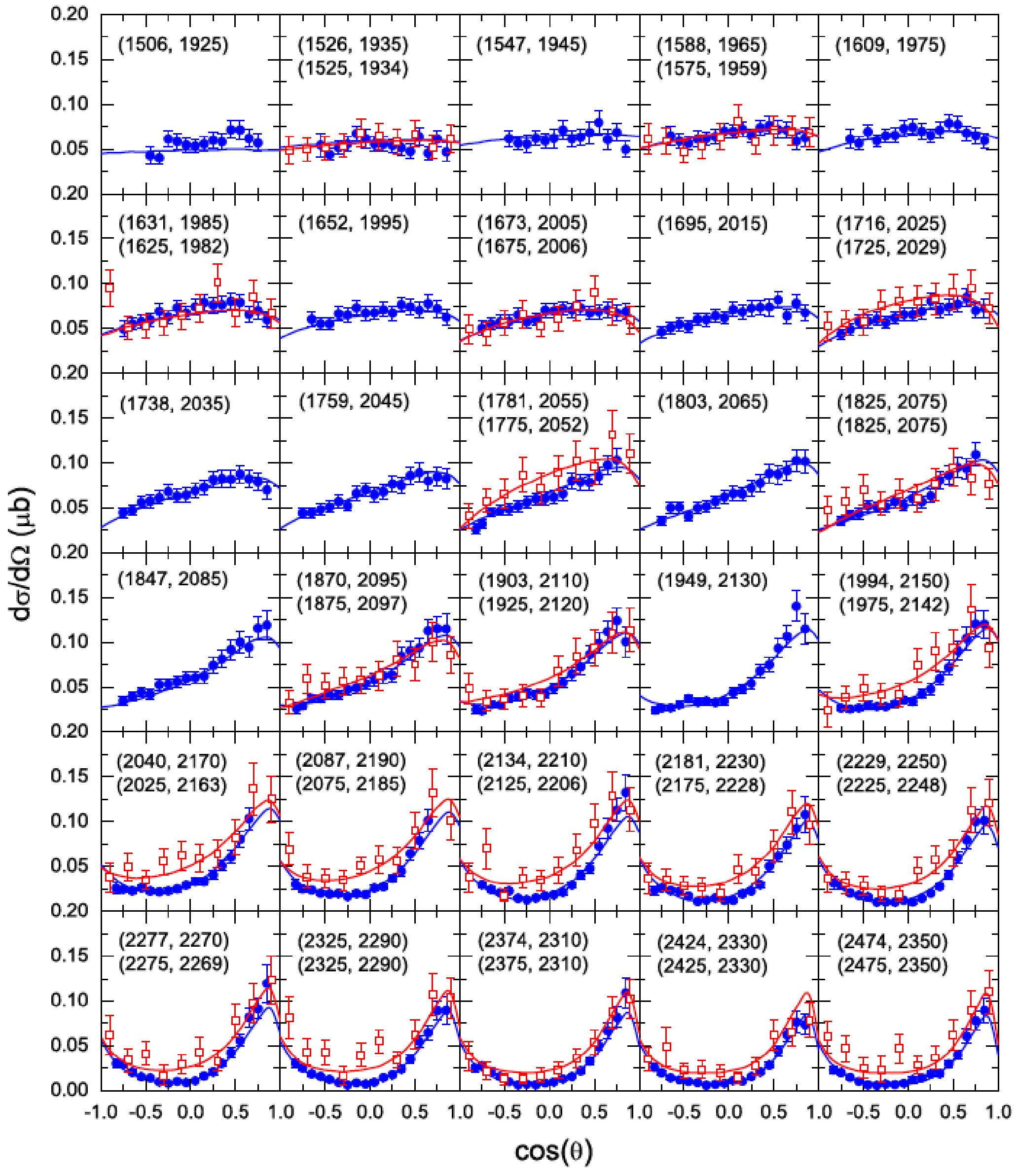
- The lack of data in hadronic reactions is one of the major limitations for developing more accurate coupled-channels models:
    - Some spin observables are quite sensitivity to the details of the model.
    - In $\pi N \to \pi\pi N$: difficulty to pin down $N^* \to \sigma N, \rho N, \pi\Delta \to \pi\pi N$

HADES at GSI: $\pi N \to \omega N$, ρN reactions ($W < 2.4$ GeV); no spin observables.

J-PARC: $\pi N \to KY$, $\pi\pi N$; $\bar{K}N \to K\Xi$, $KK\Omega$ □

The End

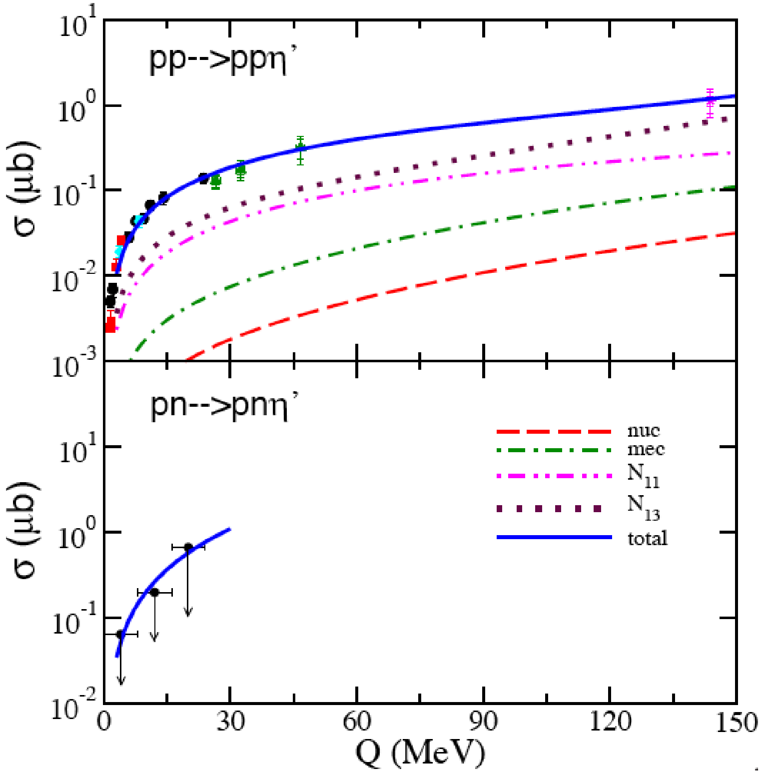
$\gamma p \to \eta' p$:

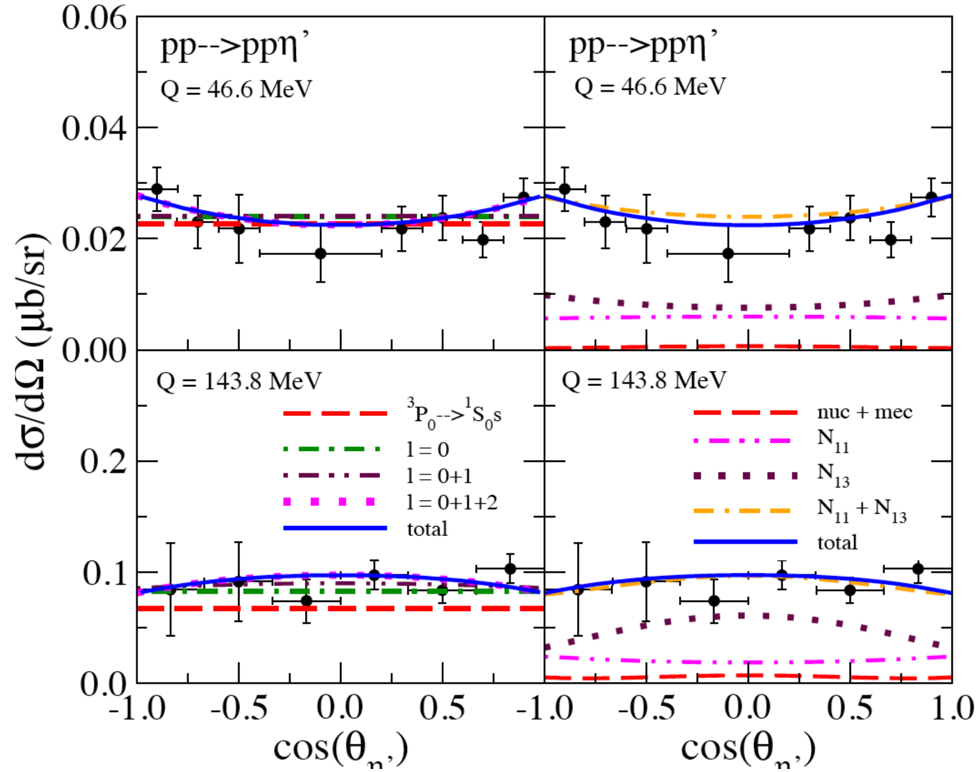


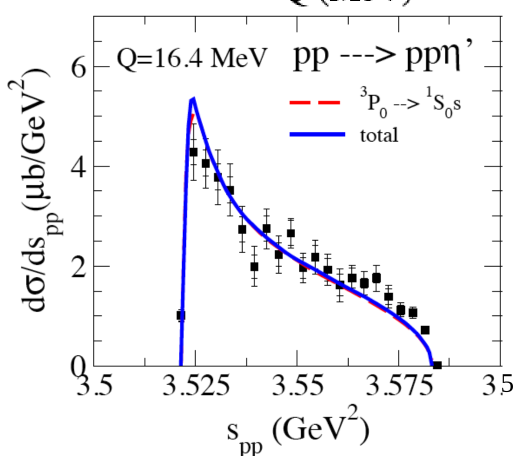
Red: CBELSA/TAPS'09
Blue: CLAS'09

curves: Huang et al. '12

$NN \rightarrow NN\eta'$:







data: COSY11'11, …

curves: Huang et al. '12