A2: partial wave analysis

A. Anisovich, V. Nikonov, A. Sarantsev, Bonn and Gatchina
E. Klempt, U. Thoma , Bonn

Topics:
A2 and TR-16
A2 results
π induced N*

Bommerholz, 2006 Nov 27

A2 and TR-16:
Questions of spokesperson:

- **Einordnung der Fragestellung innerhalb des SFB:**
- **The extraction of baryon resonances and their properties is a central topic of TR-16. Partial wave analysis is the method to achieve this goal.**
- **Fortschritt seit Beginn der Laufzeit des SFB sowie des letzten Berichtes**
- **Publication list:**

A2 Publications

[1] A. Anisovich, E. Klempt, A. Sarantsev and U. Thoma,
"Partial wave decomposition of pion and photoproduction amplitudes,"
Eur. Phys. J. A **24** (2005) 111 [arXiv:hep-ph/0407211].

[2] A. V. Anisovich, A. Sarantsev, O. Bartholomy, E. Klempt, V. A. Nikonov and U. Thoma,
"Photoproduction of baryons decaying into $N\pi$ and $N\eta$,"
Eur. Phys. J. A **25** (2005) 427 [arXiv:hep-ex/0506010].

[3] A. V. Sarantsev, V. A. Nikonov, A. V. Anisovich, E. Klempt and U. Thoma,
"Decays of baryon resonances into $\Lambda K^+, \Sigma^0 K^+$ and $\Sigma^+ K^0$,"
Eur. Phys. J. A **25** (2005) 441 [arXiv:hep-ex/0506011].

[4] E. Klempt, A. V. Anisovich, V. A. Nikonov, A. V. Sarantsev, and U. Thoma,
"Phase motion of baryon resonances,"
Eur. Phys. J. A **29** (2006) 313.

[5] A. V. Anisovich and A. V. Sarantsev,
"Partial decay widths of baryons in the spin-momentum operator expansion method,"
accepted for publication in Eur. Phys. J. A, arXiv:hep-ph/0605135.

In Preparation

[6] A.V. Sarantsev *et al.*,
"Sensitivity of photoproduction to polarization variables,"
in preparation, to be submitted to Eur. Phys. J. A.

[7] A.V. Anisovich *et al.*,
"Proton-proton interaction in the framework of spin-orbital operator expantion method,"
in preparation, to be submitted to Eur. Phys. J. A.

A2 Publications jointly with A1

[8] O. Bartholomy *et al.*, "Neutral pion photoproduction off protons in the energy range 0.3-GeV ¡ Phys. Rev. Lett. 94 (2005) 012003.

[9] V. Crede *et al.*, "Photoproduction of η mesons off protons for 0.75-GeV< E_γ < 3-GeV," Phys. Rev. Lett. 94 (2005) 012004.

[10] H. van Pee *et al.*,
"Photoproduction of π^0 mesons off protons from the $\Delta(1232)$ region to $E_\gamma = 3$-GeV,"
submitted to Eur. Phys. J. A.

In Preparation

[11] R. Castelijns *et al.*,
"Nucleon resonance decay by the $K^0\Sigma^+$ channel,"
in preparation, to be submitted to Physics Letters.

[12] J. Junkersfeld *et al.*,
"Photoproduction of $\pi^0\omega$ off protons for $E_\gamma \leq 3\,\mathrm{GeV}$,"
in preparation, to be submitted to Eur. Phys. J. A.

[13] O. Bartholomy *et al.*,
"Photoproduction of η mesons off protons,"
in preparation, to be submitted to Eur. Phys. J. A.

[14] U. Thoma *et al.*,
"N^* and Δ^* decays into $N\pi^0\pi^0$,"
in preparation, to be submitted to Phys. Rev. Lett.

[15] A.V. Sarantsev *et al.*,
"Study of the Roper resonance and of the P_{11} partial wave,"
in preparation, to be submitted to Phys. Rev. Lett.

- nähere Bezeichnung der für den Arbeits- und Ergebnisbericht eingeplanten Resultate und neuen Erkenntnisse

  - Understanding of first, second and third baryon resonance region

- Darlegung des bisherigen Mitteleinsatzes und des Mittelbedarfs für 2007

  - One position BATIIa/Ib for

    Dr. habil. A.V. Sarantsev (50%)

    Dr. A.A. Anisovich (50%)

-Skizzierung der Absichten zum Fortsetzungsantrag

Fortsetzung: yes

Änderungen gegenüber dem ersten Antrag:

next transparencies

Physikal. und/oder personelle Umstrukturierung:

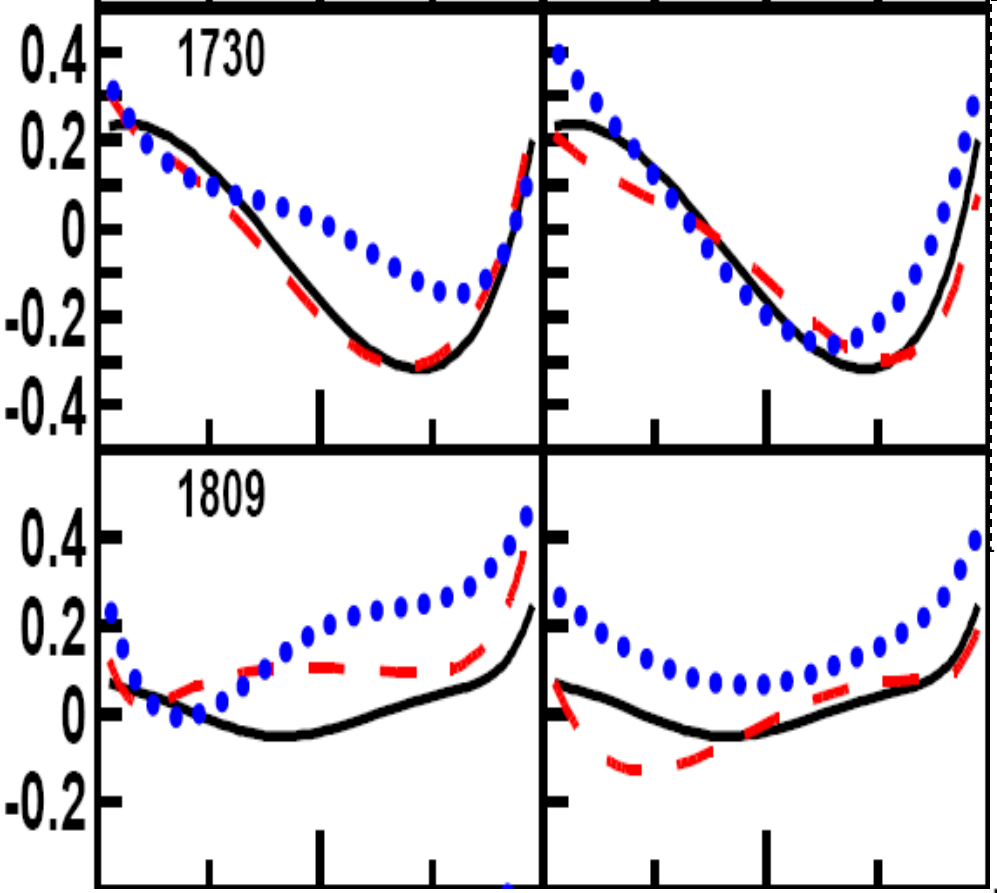
Project leader:
E. Klempt and U. Thoma

Zusammenschluss mit anderen Teilprojekten,

No plans

Stellung innerhalb des SFB:

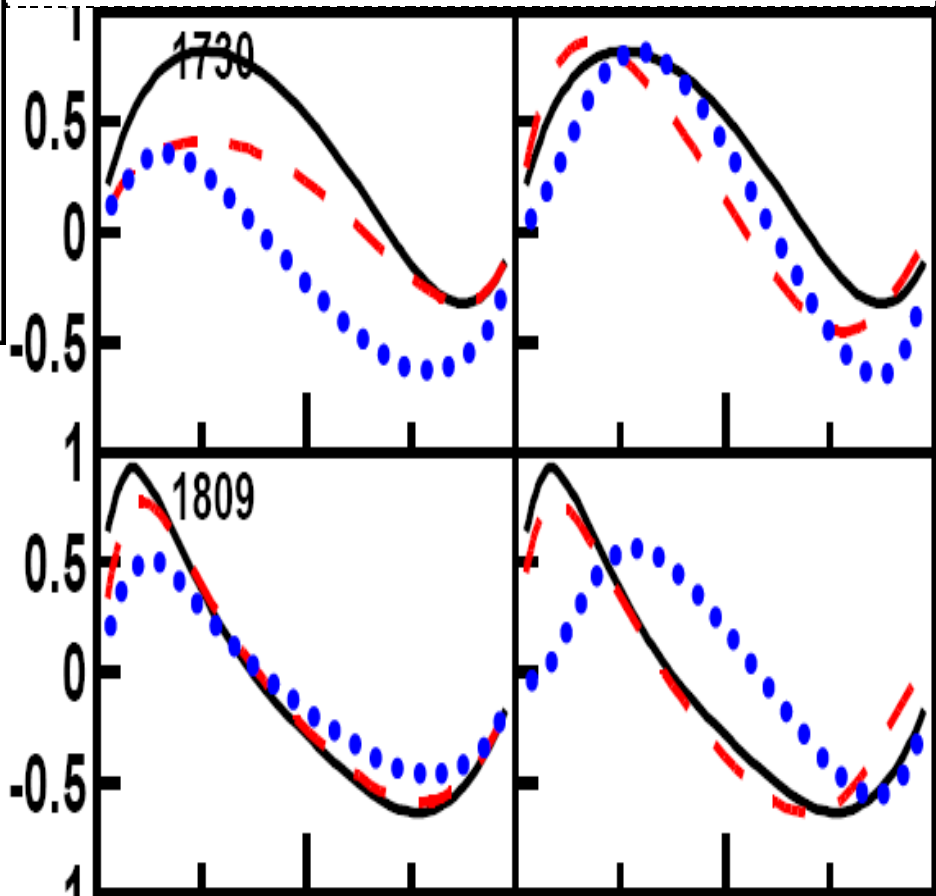
Central topic for resonance physics

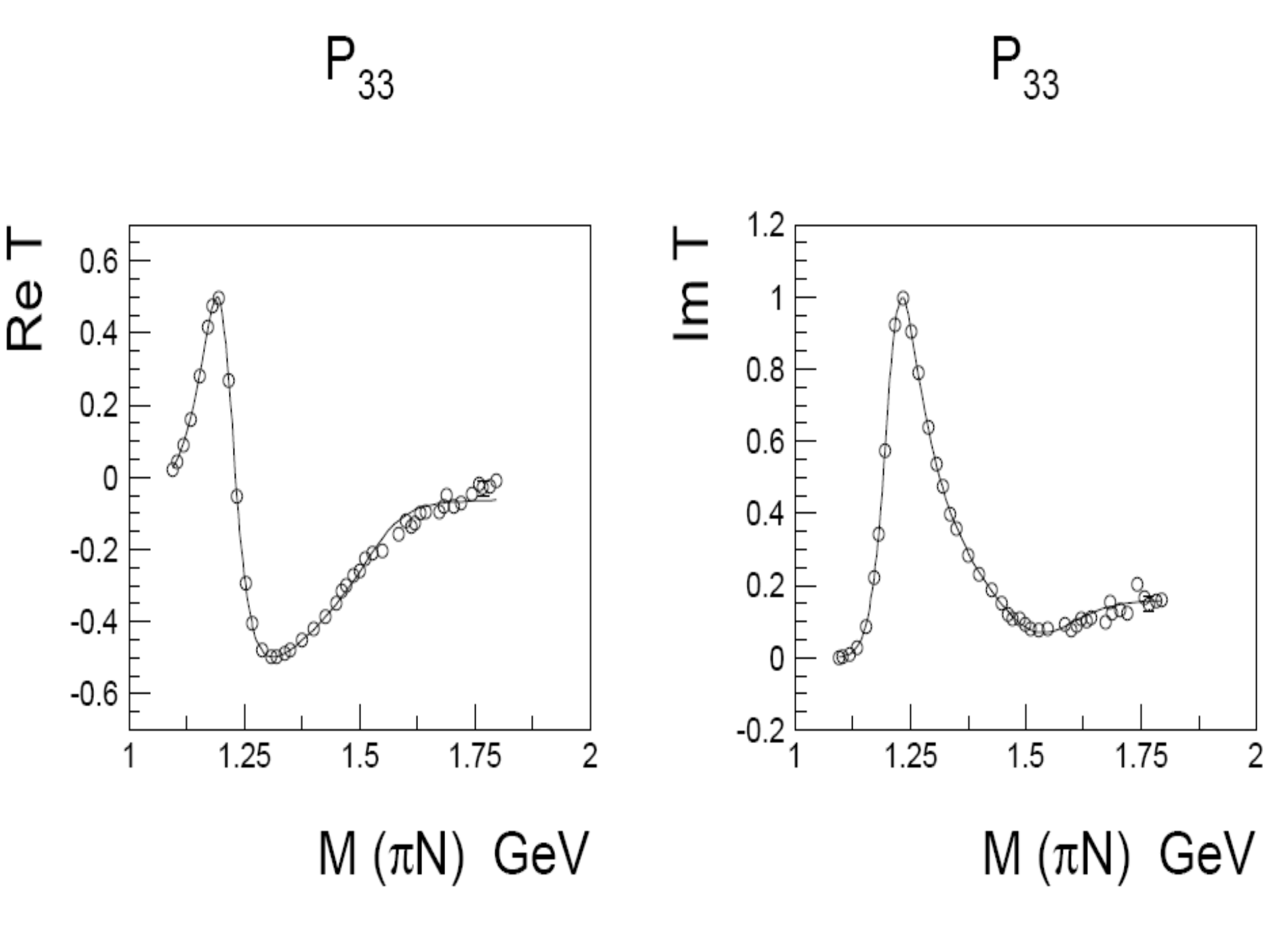


E

D15(2070) J=1/2
D15(2070) J=3/2

G

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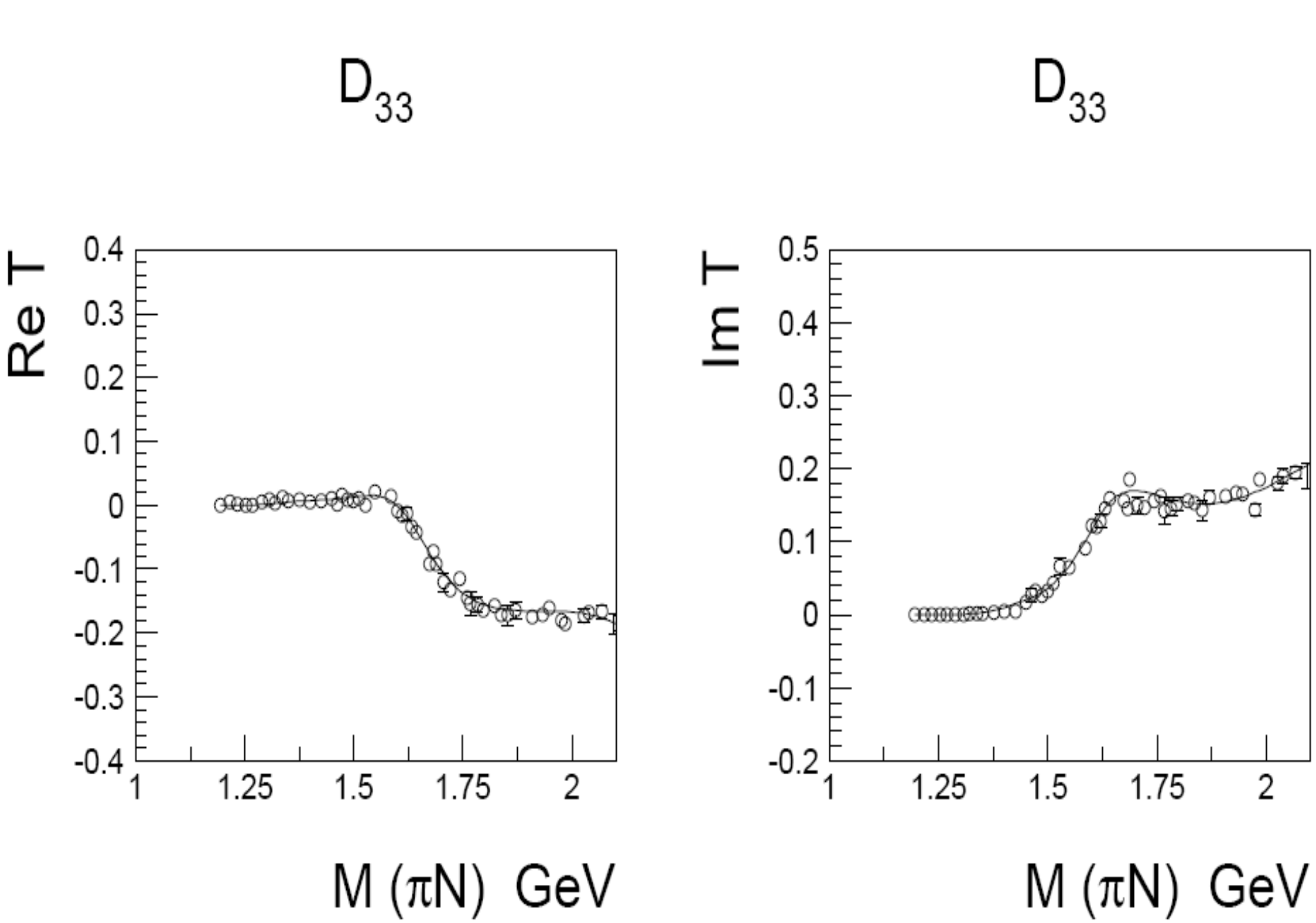
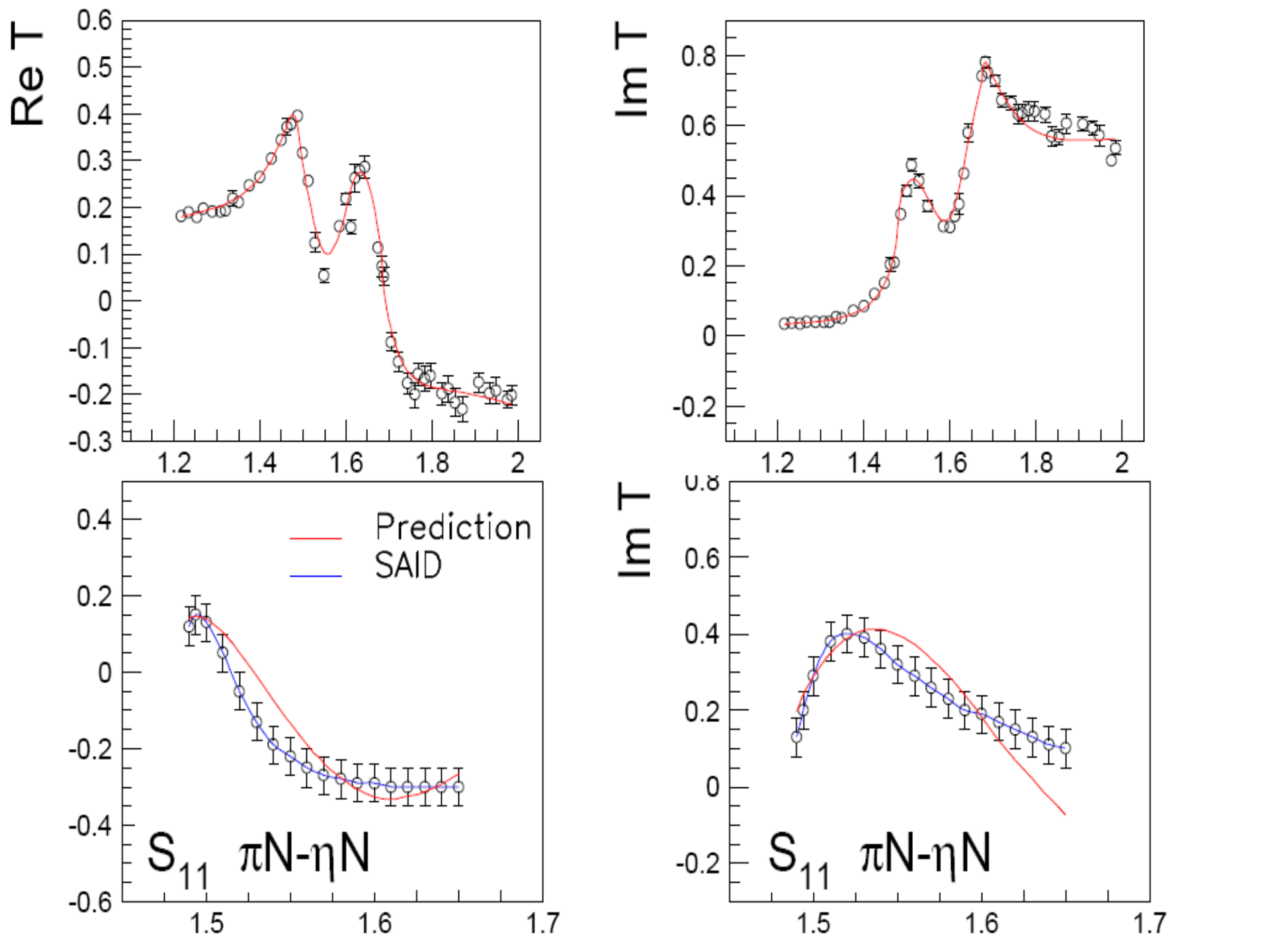
Re T
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1
1.25
1.5
1.75
2
M (πN) GeV
P33
Im T
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1
1.25
1.5
1.75
2
M (πN) GeV


D_{33}
Re T
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1
1.25
1.5
1.75
2
M (πN) GeV
D_{33}
Im T
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1
1.25
1.5
1.75
2
M (πN) GeV


Re T
Im T
Im T
Prediction
SAID
S_{11} πN-ηN
S_{11} πN-ηN

Future programme

- **Isobar fit to all forthcoming photo-production data from Elsa, Jlab, Graal, …**
- **Implementation of methods to reconstruct energy-independent partial wave amplitudes**
- **Inclusion of decays into baryons with J>3/2**
- Implementation of amplitudes to describe pion-

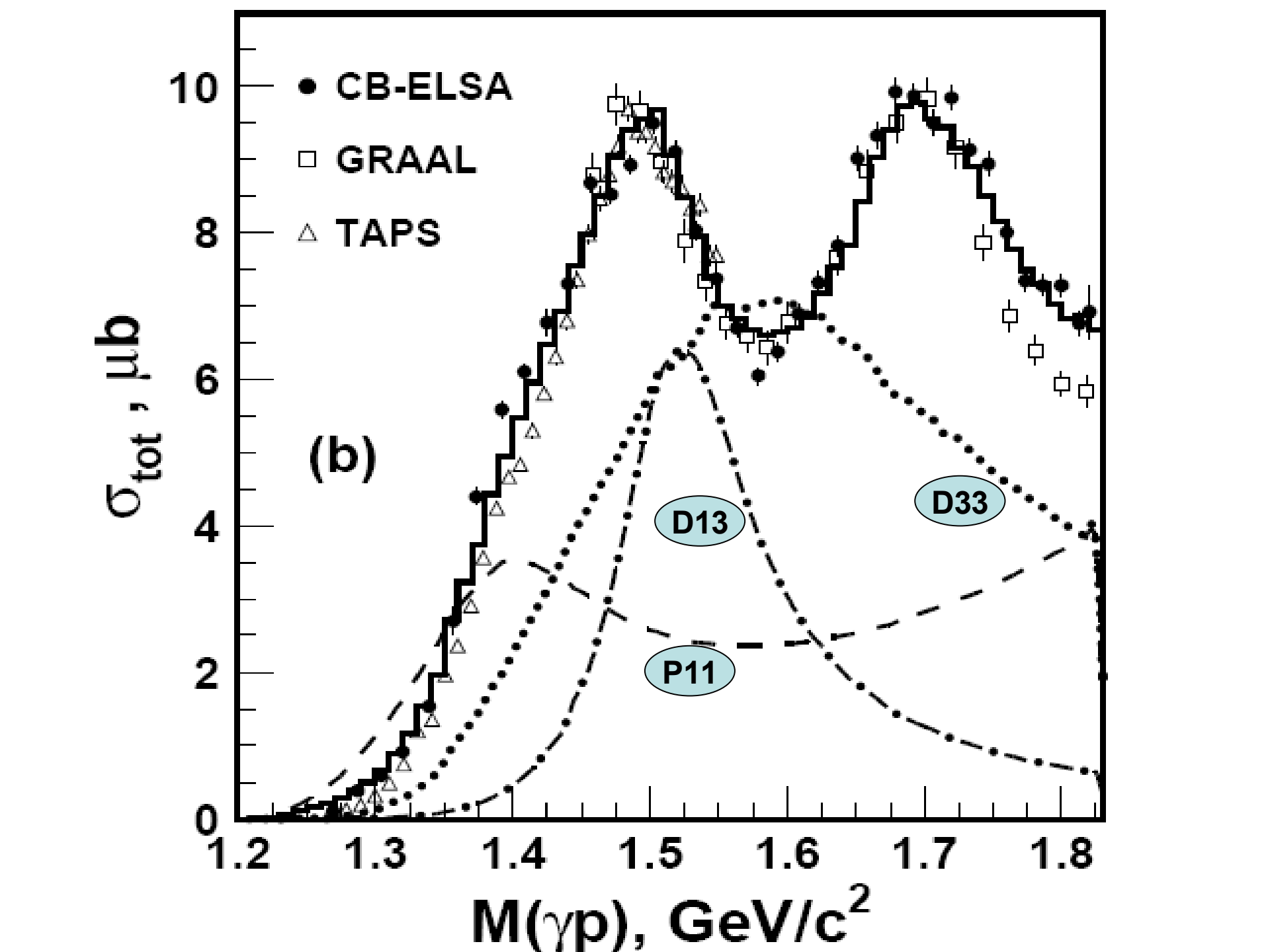
A2 Results:

from $\gamma p \rightarrow p \pi^0\pi^0$ (and other data)

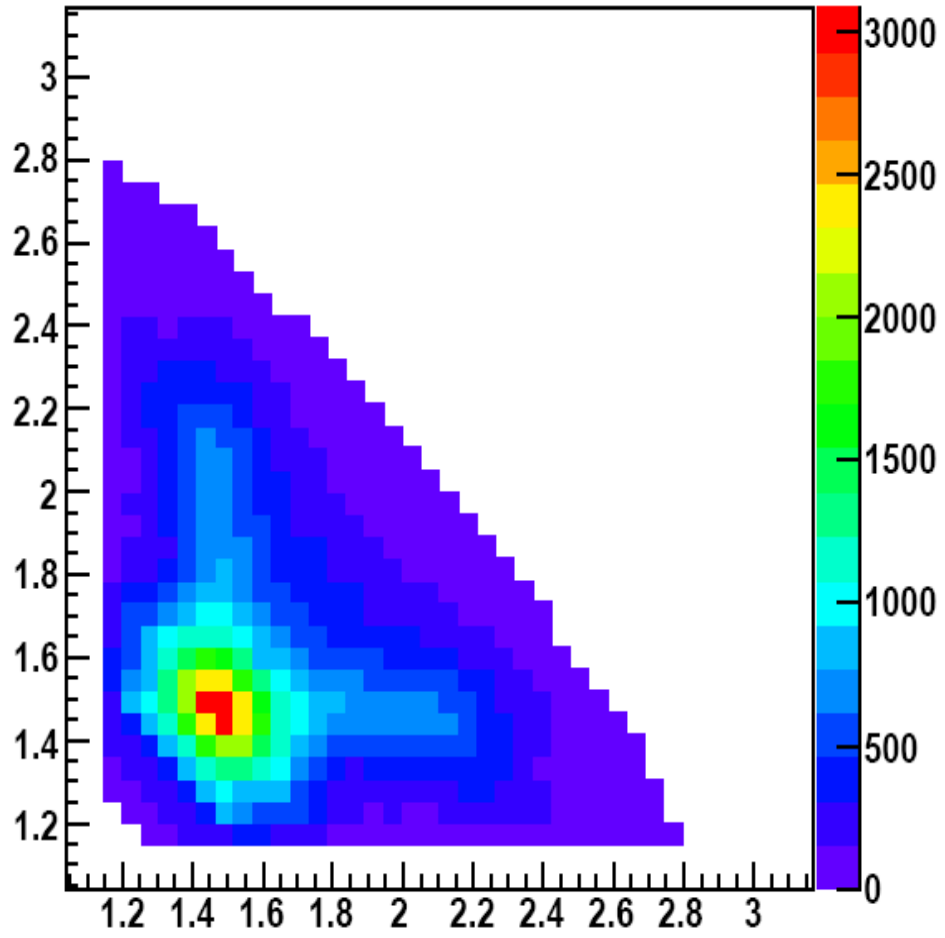
Properties of Roper resonance

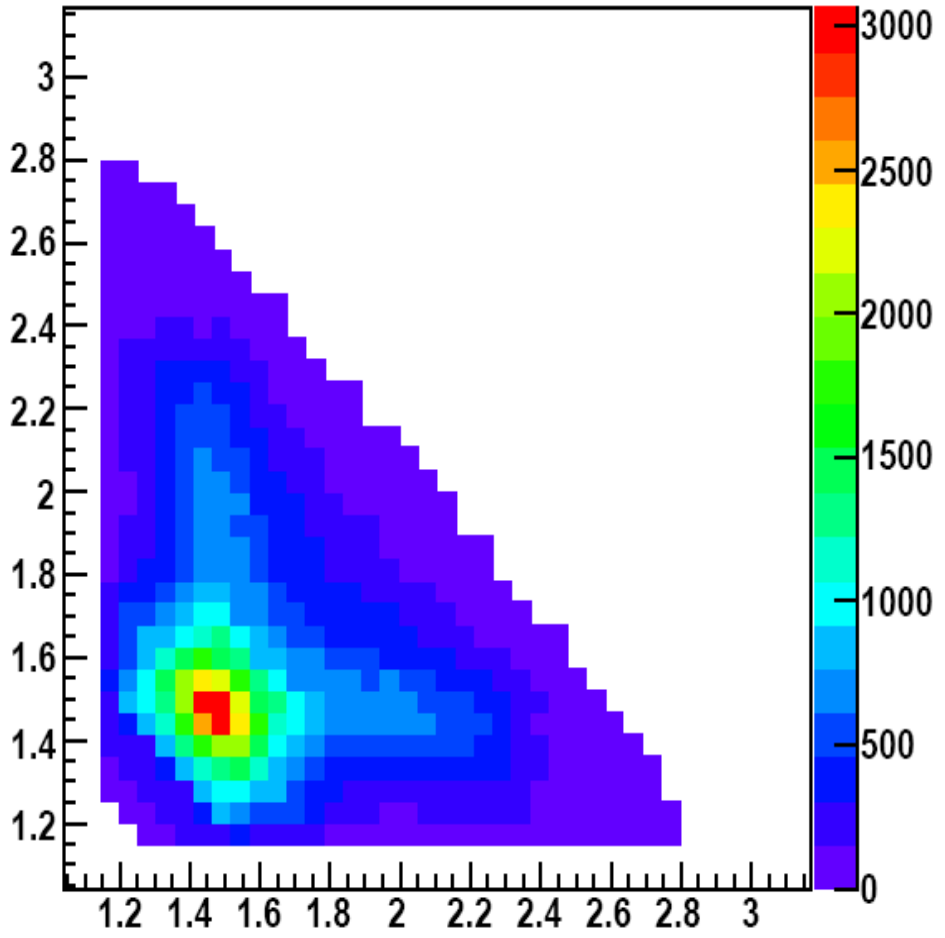
- Interest:
- Low mass, incompatible with quark models
  incompatible with LQCD
- Member of decuplet?
- Two Roper resonances?

2 π decays of baryon resonances

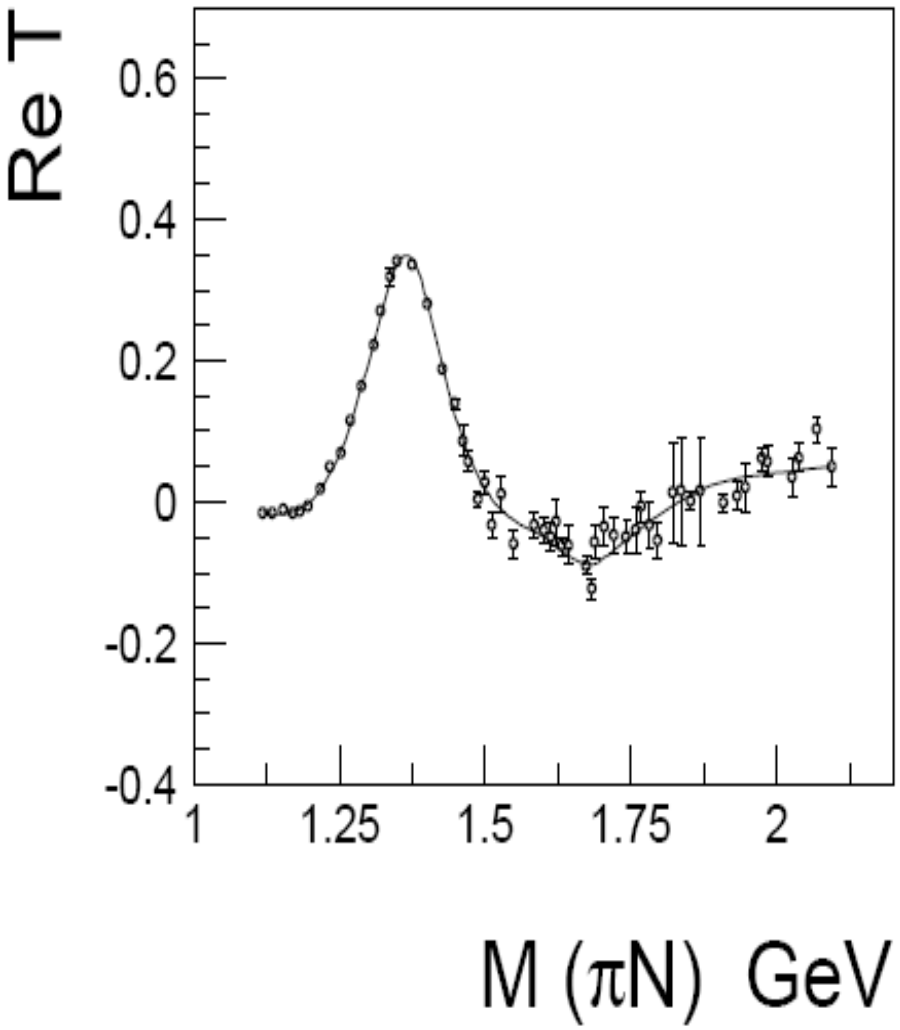

CB-ELSA
GRAAL
TAPS
(b)
D13
D33
P11
σ_{tot} , μb
M(γp), GeV/c^2
0
2
4
6
8
10
1.2
1.3
1.4
1.5
1.6
1.7
1.8

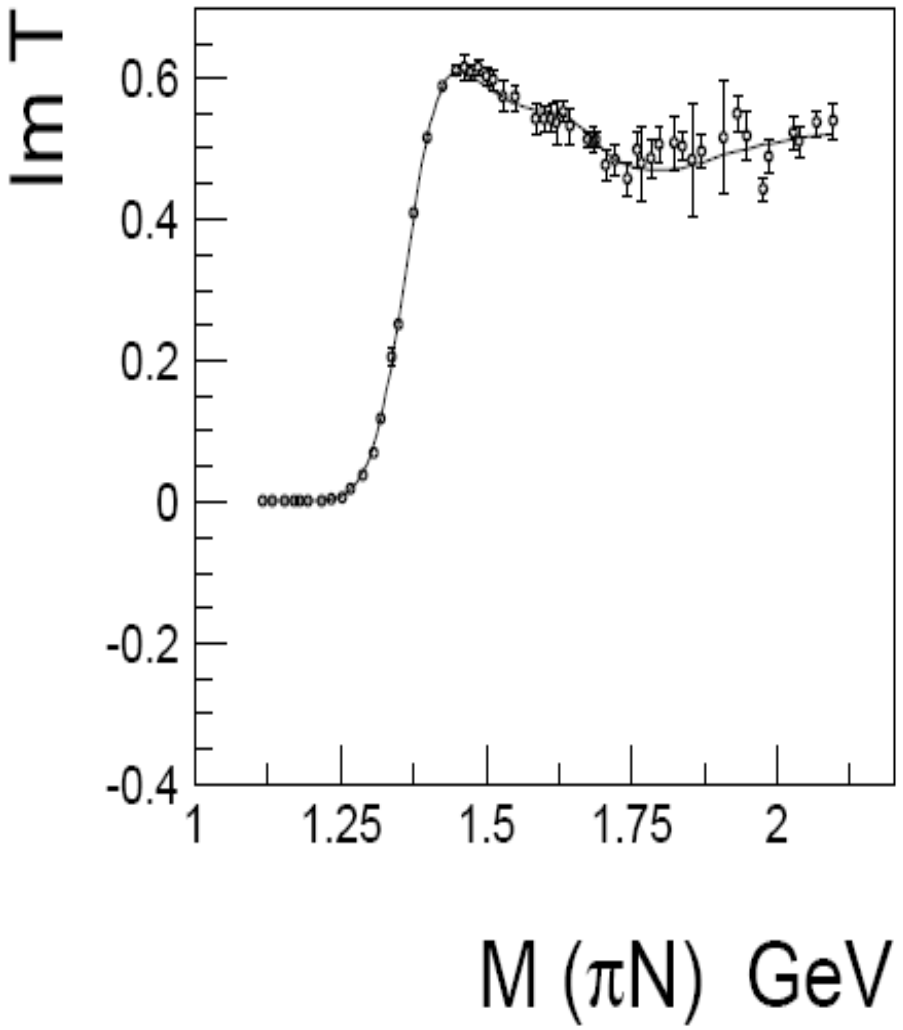
p π^0 π^0 Dalitz plot (CB)

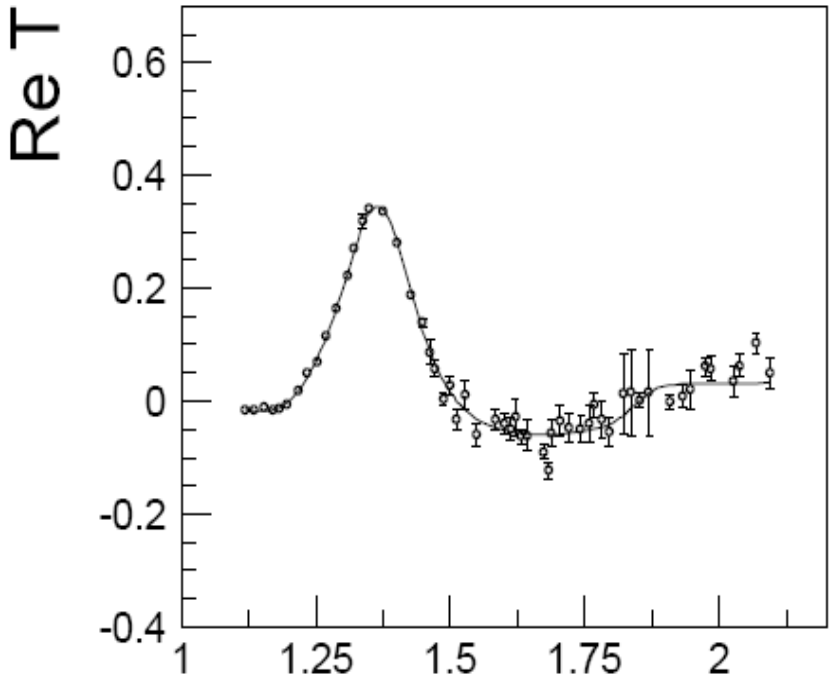




P11 elastic scattering



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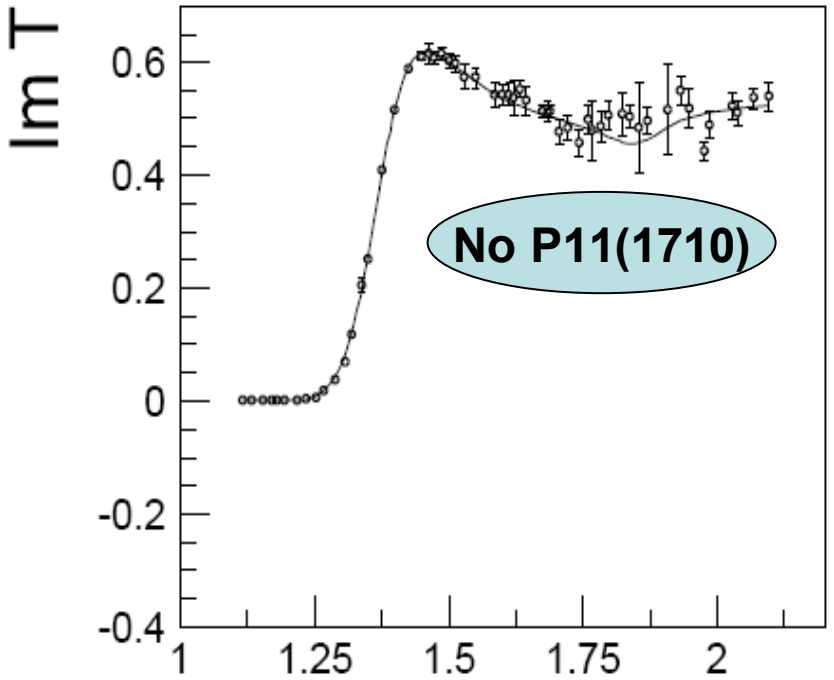
0.4
0.2
0
-0.2
-0.4
1
1.25
1.5
1.75
2


Im T
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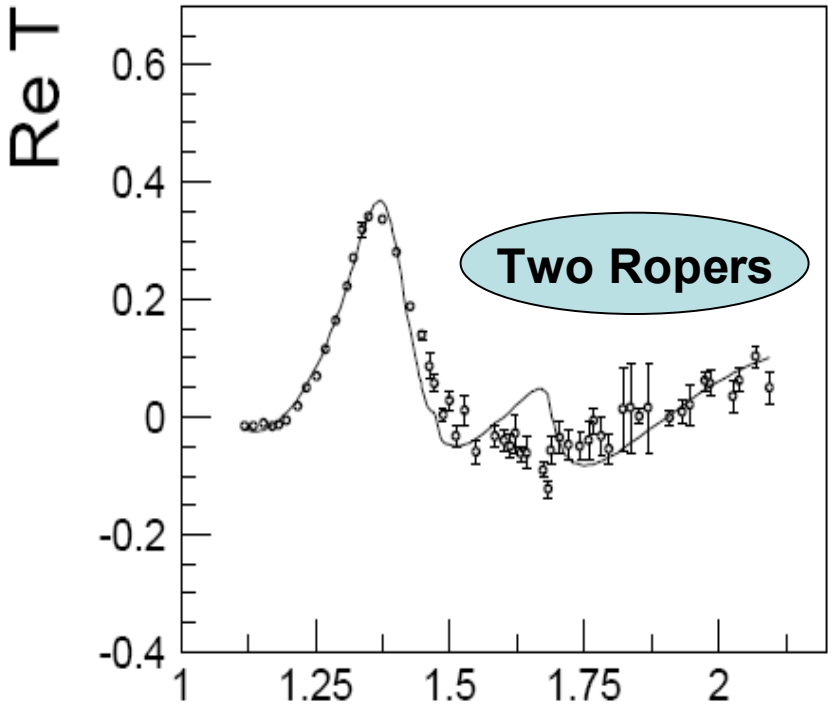
0.2
0
-0.2
-0.4
1
1.25
1.5
1.75
2
No P11(1710)


Re T
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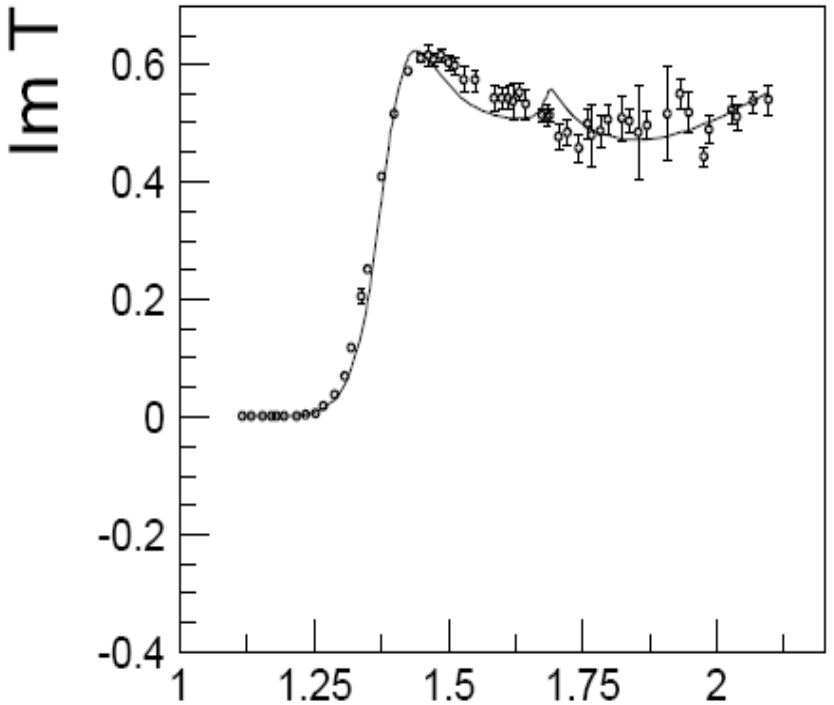
0.4
0.2
0
-0.2
-0.4
1
1.25
1.5
1.75
2
Two Ropers


Im T
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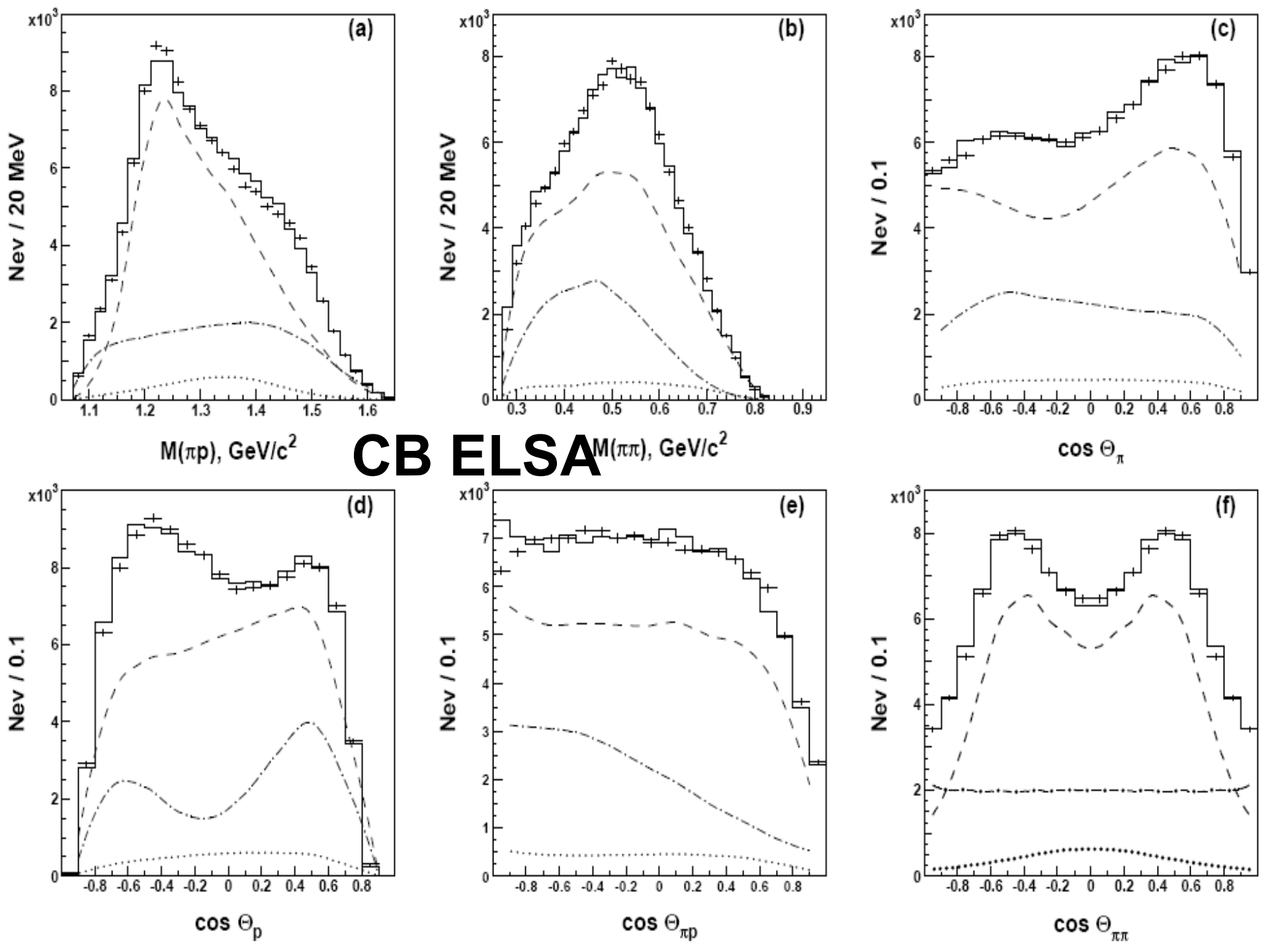
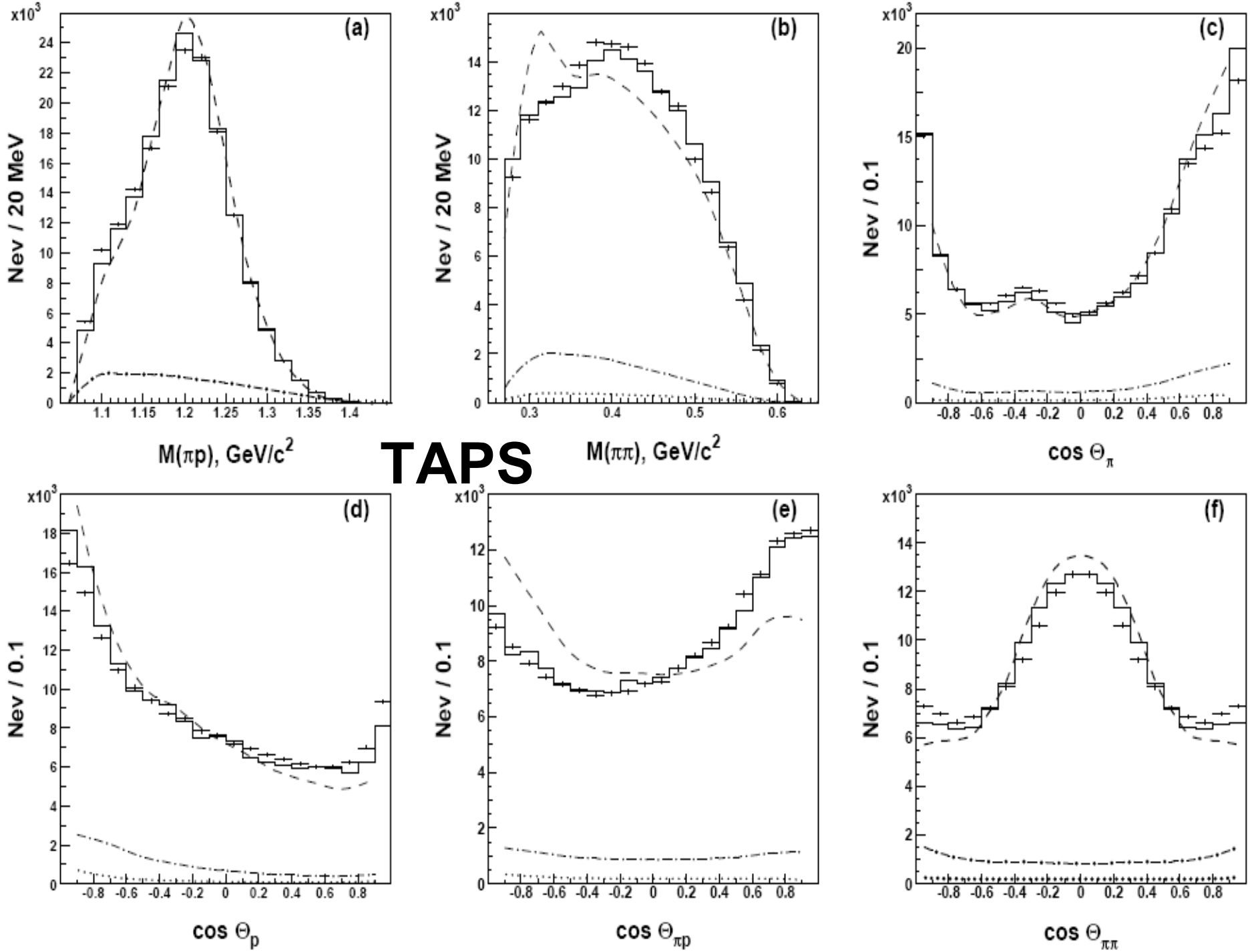
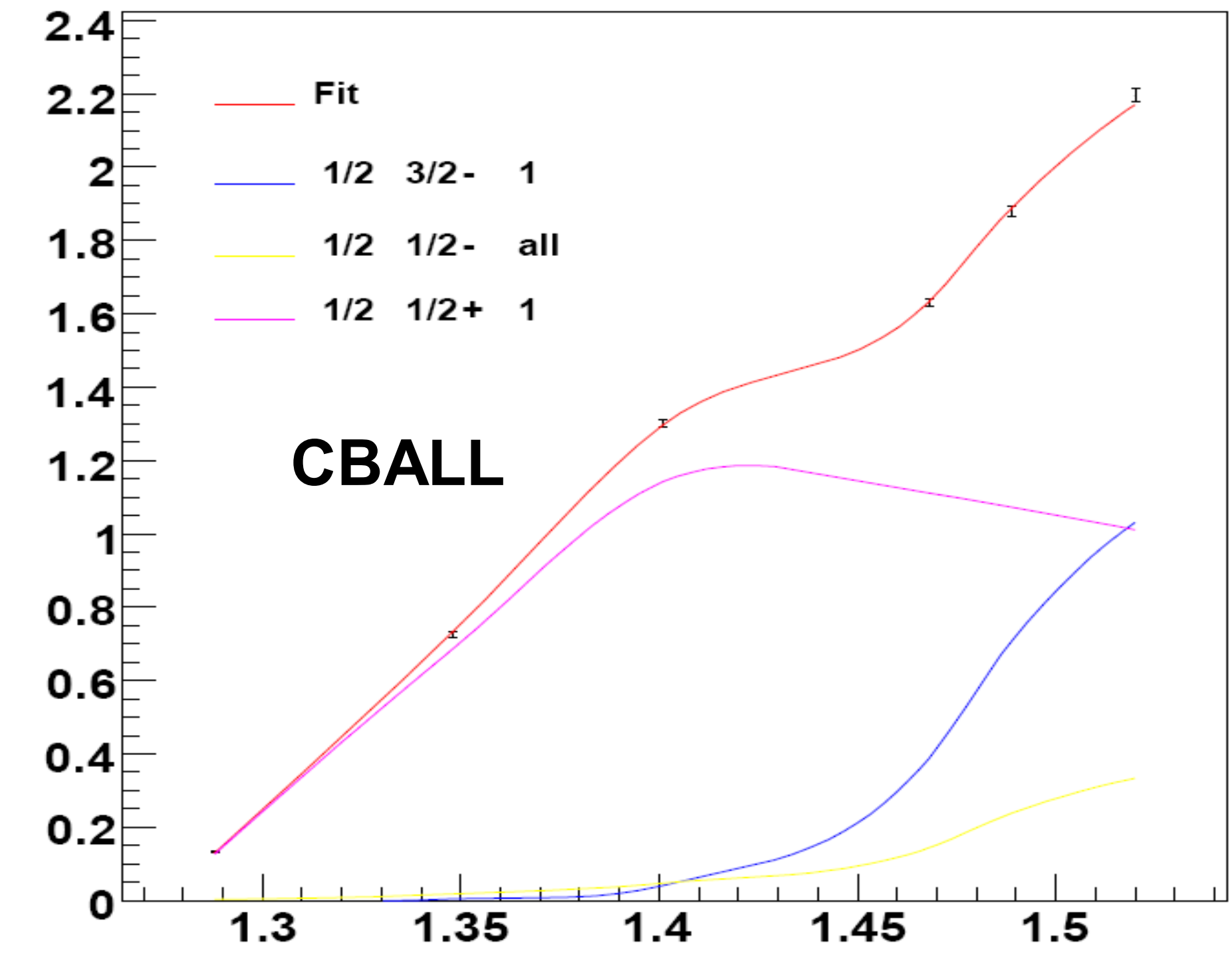
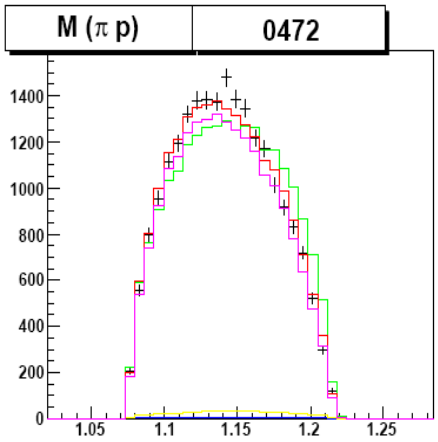
0.4
0.2
0
-0.2
-0.4
1
1.25
1.5
1.75
2


(a)
(b)
(c)
(d)
(e)
(f)
x10^3
Nev / 20 MeV
Nev / 0.1
M(πp), GeV/c^2
M(ππ), GeV/c^2
cos Θ_π
cos Θ_p
cos Θ_πp
cos Θ_ππ
CB ELSA


TAPS
(a)
(b)
(c)
(d)
(e)
(f)
x10^3
Nev / 20 MeV
Nev / 0.1
M(πp), GeV/c^2
M(ππ), GeV/c^2
cos Θ_π
cos Θ_p
cos Θ_πp
cos Θ_ππ


Fit
1/2 3/2- 1
1/2 1/2- all
1/2 1/2+ 1
CBALL
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.3
1.35
1.4
1.45
1.5


M (π p)
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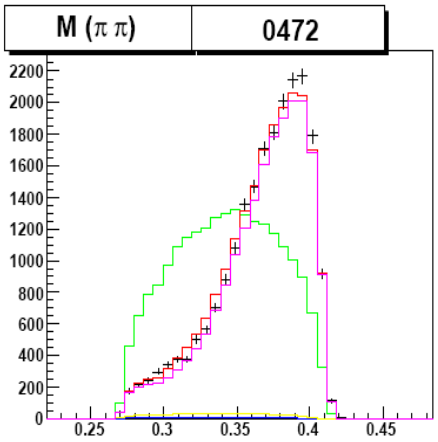
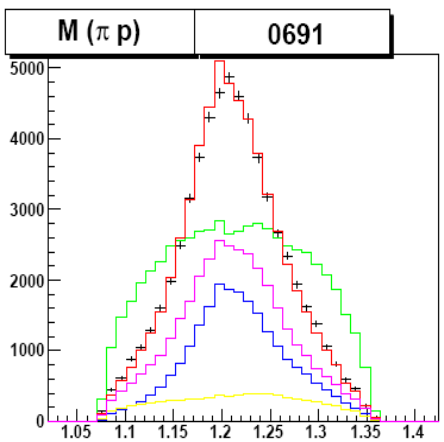
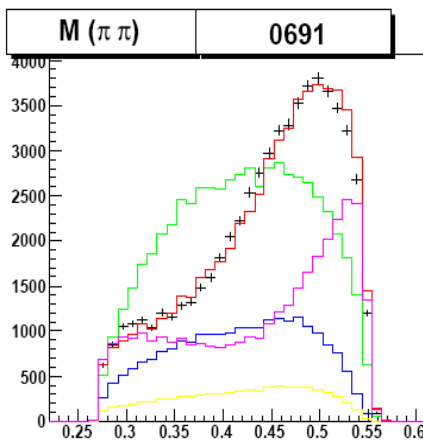
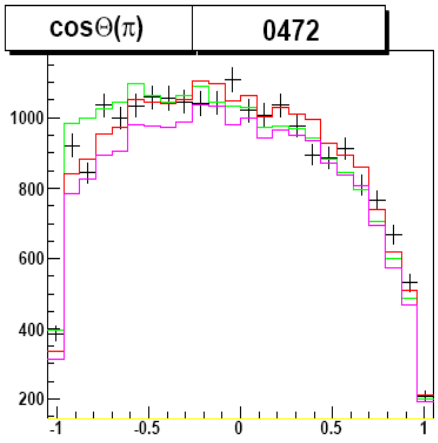

M (π π)
0472


M (π p)
0691


M (π π)
0691


cosΘ(π)
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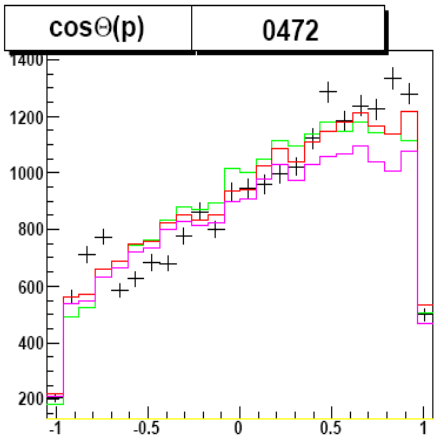
cosΘ(p)
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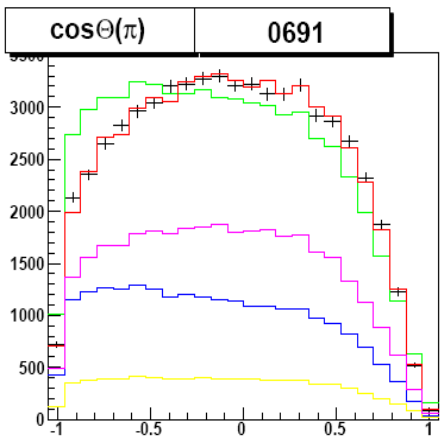
cosΘ(π)
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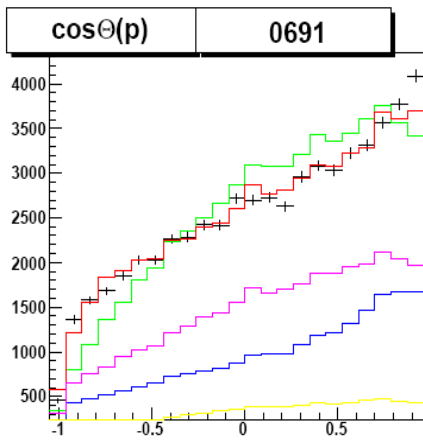
cosΘ(p)
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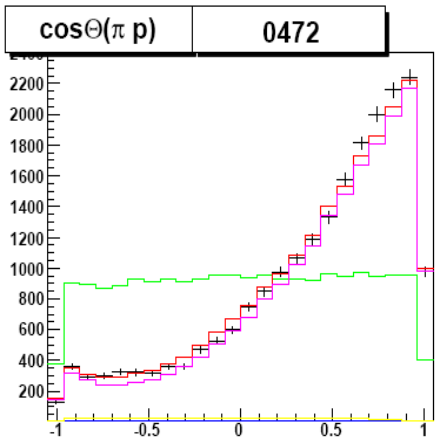
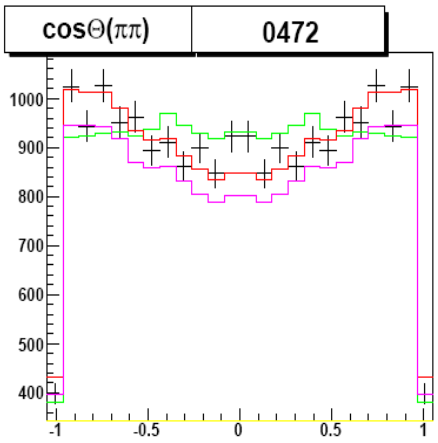

cosΘ(π p)
0472


cosΘ(ππ)
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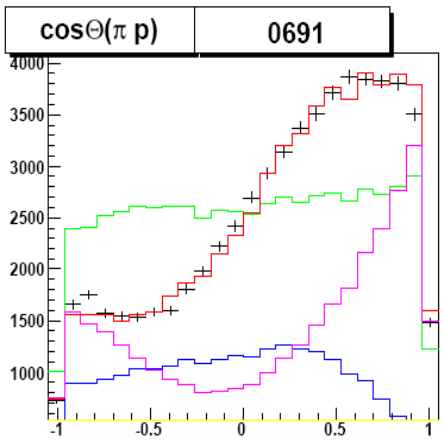
cosΘ(π p)
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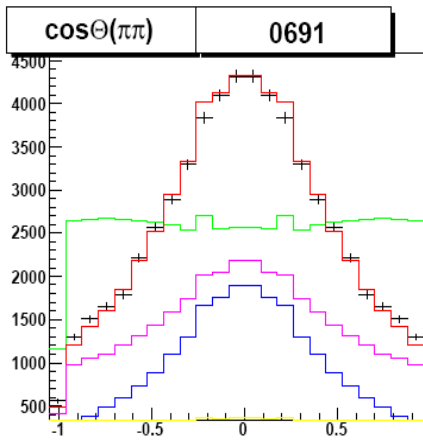
cosΘ(ππ)
0691

First fits where resonances are overconstrained:

- $\pi N \rightarrow N\pi$ **elastic scattering**

  $\pi^- p \rightarrow n\pi^0\pi^0$ **inelastic scattering**

  $\gamma p \rightarrow N\pi$ **photoproduction**

  $\gamma p \rightarrow p\pi^0\pi^0$ **photoproduction**

First event based likelihood fits In baryon spectroscopy

Results:

TABLE I: Properties of N(1440)P_{11}. The left column lists mass, width, partial widths of the Breit-Wigner resonance; the right column pole position and squared couplings to the final state at the pole position.

M	$= 1429 \pm 14\,\mathrm{MeV}$	M_{pole}	$= 1371 \pm 10\,\mathrm{MeV}$
Γ	$= 182 \pm 16\,\mathrm{MeV}$	Γ_{pole}	$= 320 \pm 60\,\mathrm{MeV}$
$\Gamma_{\pi\mathrm{N}}$	$= 112 \pm 11\,\mathrm{MeV}$	$g_{\pi\mathrm{N}}$	$= (0.49 \pm 0.05) \cdot e^{-i\pi \frac{(40\pm5)}{180}}$
$\Gamma_{\sigma\mathrm{N}}$	$= 39 \pm 7\,\mathrm{MeV}$	$g_{\sigma\mathrm{N}}$	$= (0.89 \pm 0.13) \cdot e^{-i\pi \frac{(30\pm11)}{180}}$
$\Gamma_{\pi\Delta}$	$= 27 \pm 4\,\mathrm{MeV}$	$g_{\pi\Delta}$	$= (-0.58 \pm 0.08) \cdot e^{i\pi \frac{(35\pm20)}{180}}$

$$A_{1/2} = -0.065 \pm 0.015\,\mathrm{GeV}$$

	$N(1535)S_{11}$	$N(1650)S_{11}$	$N(1720)P_{13}$	$N(1520)D_{13}$	$N(1700)D_{13}$	$N(1675)D_{15}$	$N(1680)F_{15}$	$\Delta(1620)S_{31}$	$\Delta(1700)D_{33}$
Mass	1508^{+10}_{-30}	1639±15	1640±55	1509±7	1730±15	1639±10	1674±5	1615±25	1615±50
PDG	1495–1515	1640–1680	1650–1750	1505–1515	1630–1730	1655–1665	1665–1675	1580–1620	1620–1700
$\Gamma_{\rm tot}$	165±15	187±20	418±20	116±11	133±18	155±20	95±10	200±30	300±60
PDG	90–250	150–170	110–390	110–120	50–150	125–155	105–135	100–130	150–250
M_{BW}	1543±10	1648±15	1745±25	1529±7	1750±18	1672±12	1684±8	1660±25	1770±60
PDG	1520–1555	1640–1680	1650–1750	1515–1530	1650–1750	1670–1685	1675–1690	1615–1675	1670–1770
Γ^{BW}_{tot}	150±15	180±20	481±65	133±12	145±20	210±25	98±10	250±60	600±120
PDG	100–200	145–190	100–200	110–135	50–150	140–180	120–140	120–180	200–400
$A_{1/2}$	-0.086±0.035	-0.095±0.035	-0.102±0.023	0.007±0.015	0.026±0.012	-0.025±0.010	-0.012±0.008	-0.12±0.04	0.145±0.035
phase	$(35 \pm 25)^\circ$	$(25 \pm 30)^\circ$	$-(10 \pm 5)^\circ$	–	$-(4 \pm 5)^\circ$	$-(7 \pm 5)^\circ$	$-(40 \pm 15)^\circ$	$-(8 \pm 5)^\circ$	$-(15 \pm 10)^\circ$
PDG	(0.090 ± 0.030)	(0.053 ± 0.016)	$+(0.018 \pm 0.030)$	$-(0.024 \pm 0.009)$	$-(0.018 \pm 0.013)$	0.019±0.008	$-(0.015 \pm 0.006)$	0.027 ± 0.011	(0.104 ± 0.015)
$A_{3/2}$			-0.1±0.02	0.137±0.012	0.075±0.030	-(0.044±0.012)	0.105±0.015		0.220±0.100
phase			$-(10 \pm 5)^\circ$	$-(5 \pm 5)^\circ$	$-(6 \pm 8)^\circ$	$-(7 \pm 5)^\circ$	$-(5 \pm 5)^\circ$		$-(15 \pm 10)^\circ$
PDG			$-(0.019 \pm 0.020)$	0.166 ± 0.005	$-(0.002 \pm 0.024)$	0.015±0.009	0.133±0.012		0.085±0.022
$\Gamma_{\rm miss}$	-	-	6±1 %	13±5 %	6±5 %	20±8 %	2±2 %	20±5 %	5±5 %
PDG($N\rho$)	< 4 %	4–12 %	70–95 %	15–25 %	< 35 %	< 1 – −3 %	3–15 %	7–25 %	30–55
$\Gamma_{\pi N}$	37±9 %	76±10 %	22.6±3 %	56±8 %	8^{+8}_{-4} %	33±8 %	72±15 %	25±8 %	15±8 %
PDG	35–55 %	55–90 %	10–20 %	50–60 %	5–15 %	40–50 %	60–70 %	10–30 %	10–20
$\Gamma_{\eta N}$	40±10 %	9±4 %	16±8 %	0.2±0.1 %	7±4 %	1±5 %	0±3 %	-	-
PDG	30–55 %	3–10 %	(4±1)%	0.23±0.04 %	0±1 %	0±1 %	0±1 %		
$N\sigma$	-	-	4±3 %	< 4 %	24±12 %	10±5	15±4 %	-	
PDG		< 4 %		< 8 %			5–20 %		
$\Gamma_{\Delta\pi({\rm L<J})}$			40±11 %	12±4 %	9±5 %	24±8 %	8±3 %		
L<J PDG				5–12 %			6–14 %		80±15 %
$\Gamma_{\Delta\pi({\rm L>J})}$	20±8 %	12±4 %	0.2±0.2 %	16±5 %	30±15 %	< 3 %	3±3 %	33±20 %	30–60 %
L>J PDG	<1 %			10-14 %			< 2 %	30–60 %	
$\Gamma_{P_{11}\pi}$				2±2 %	14±8 %	< 3 %	-	21±15 %	< 5 %
$\Gamma_{D_{13}\pi}$				-	-	10±6 %	-	-	-

	$N(1650)S_{11}$	$N(1720)P_{13}$	$N(1520)D_{13}$	$N(1700)D_{13}$	$\Delta(1700)D_{33}$
$\Gamma_{\Delta\pi(L<J)}$	$40\pm11\,\%$	$12\pm4\,\%$	$9\pm5\,\%$	$24\pm8\,\%$	
L<J PDG		5–12 %			$80\pm15\,\%$
$\Gamma_{\Delta\pi(L>J)}$	$0.2\pm0.2\,\%$	$16\pm5\,\%$	$30\pm15\,\%$	$< 3\,\%$	30–60 %
L>J PDG		10-14 %			

Strange pattern in $\Delta\pi$ decays, not predicted by any model

Analysis techniques:

- **Scattering theory** $S=I+iT,$ $(T^{-1}+i\,I)^{+} = T^{-1}+iI = K$
- **Elastic scattering** $T = K\,(I - iK)^{-1}$
- **Weak couplings (D-vector)** $A = K\,(I - iK)^{-1}\,D$
- **Production (P-vector)** $F = P\,(I - iK)^{-1}$
- **Production and weak decay**

Plus non-resonant contributions

Baryons from Protvino

- Use existing equipment to get more data on baryon resonances
- Study pion induced reactions
- No additional manpower

- Constraints from Protvino data will yield more and better results which will be assigned (in Germany) to TR-16

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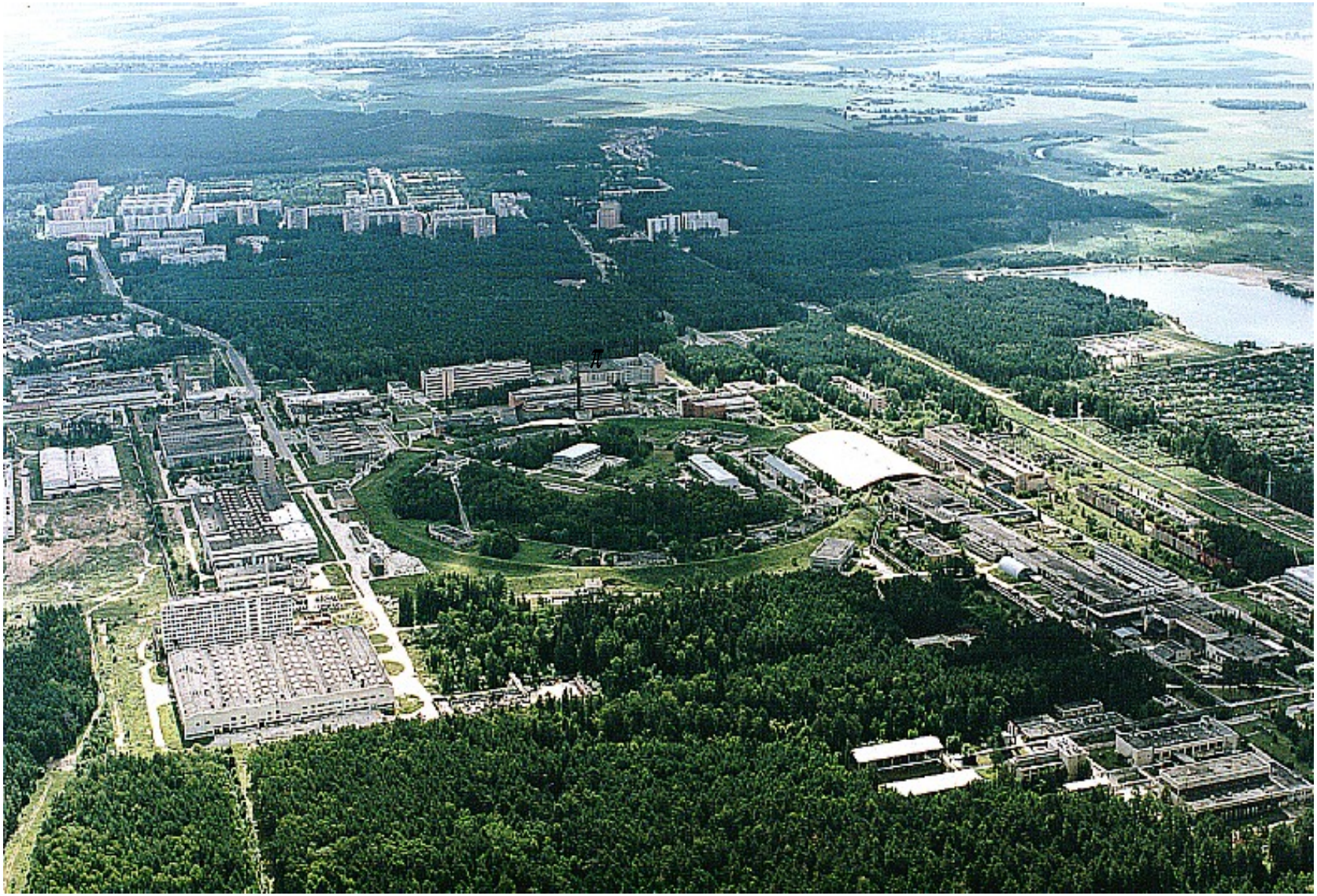

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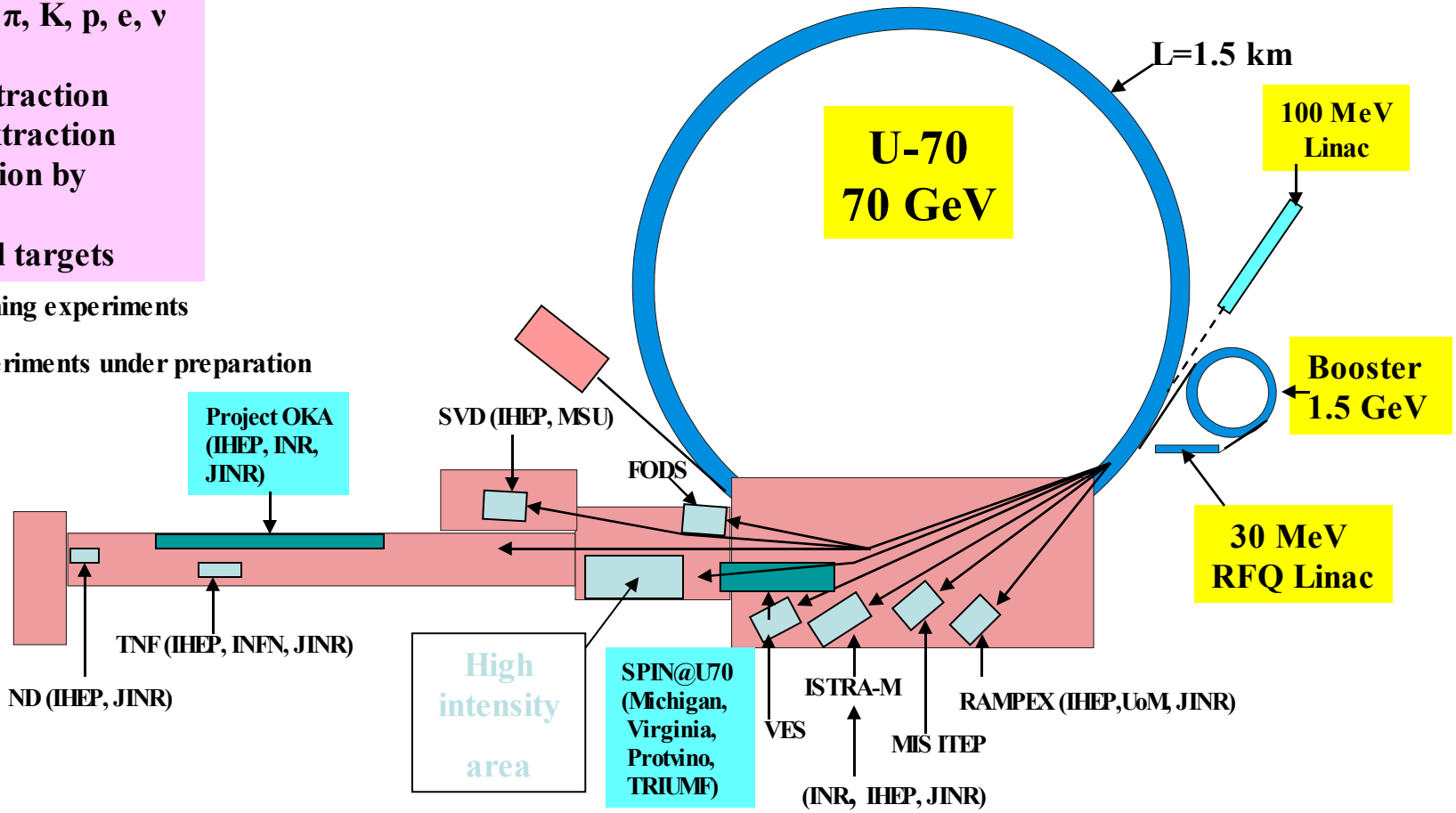
LAYOUT OF IHEP EXPERIMENTAL AREA

E=70 GeV,
I=1.7•10^{13} ppp
Beams of π, K, p, e, ν

- **Fast extraction**
- **Slow extraction**
- **Extraction by crystal**
- **Internal targets**

- **Running experiments**
- **Experiments under preparation**



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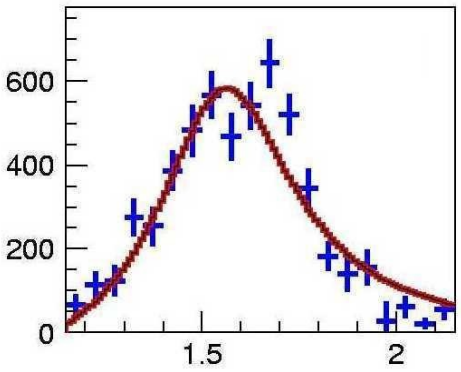
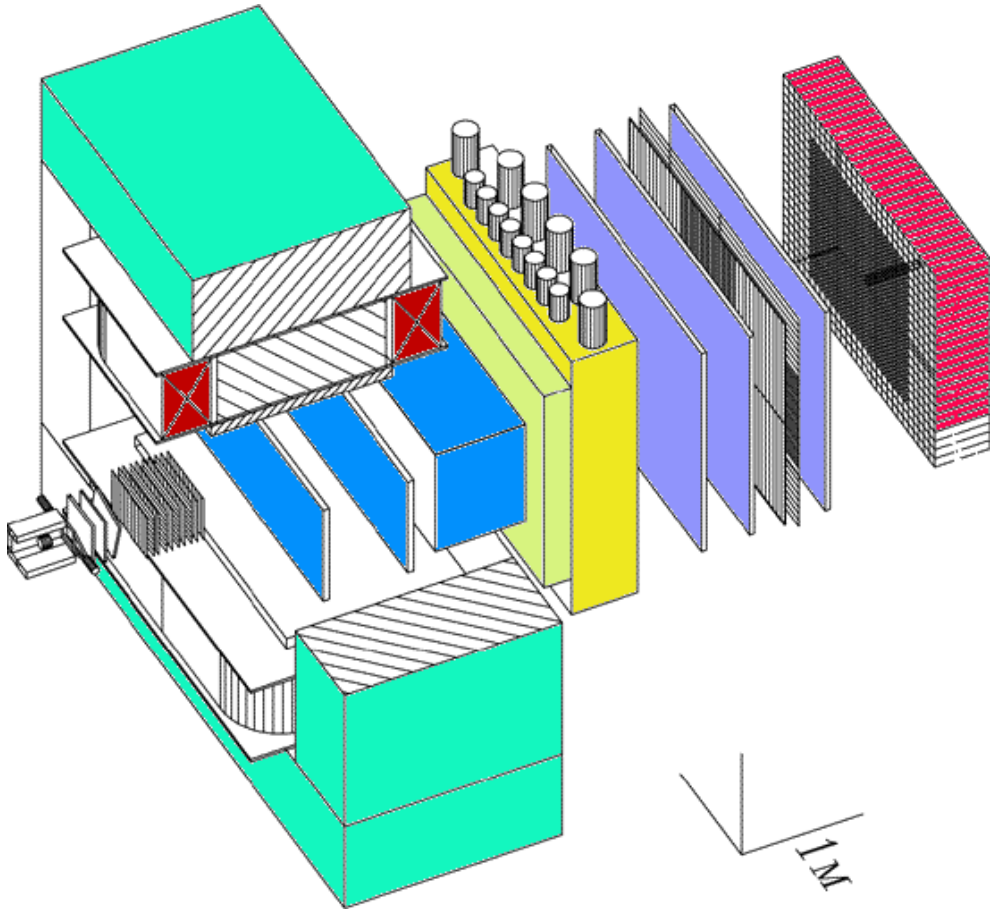
Meson spectroscopy

VES (IHEP)

- **Observation of $\pi(1800)$ unusual decay modes, which are in agreement with predictions of Flux Tube model foe hybrid mesons.**

- **Observation of $\rho(1600)$ state with exotic quantum numbers $J^{PC}=1^{-+}$ (forbidden in quark-antiquark system) for $\eta'\pi$, $b_1\pi$, $\rho\pi$ decay modes. This state is strong candidate to hybrid meson.**





VES layout

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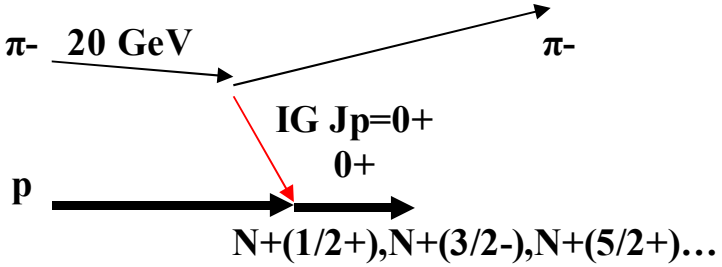
GAMS-4π

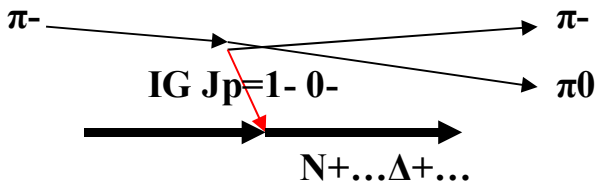
VES

Baryon production in π- p interactions at 20 Gev/c

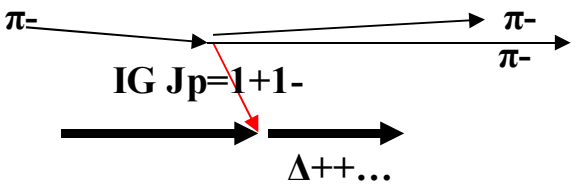
(few examples of baryon-meson correlations)



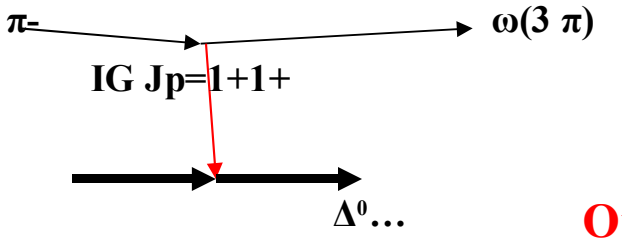
σ≈1mb -> ≈ 3*10^7 ev/day



σ≈100 μb -> ≈3* 10^6 ev/day



σ≈30 μb -> ≈ 10^6 ev/day



σ≈30 μb -> ≈ 10^6 ev/day

Optimal momentum: 15 -:- 20 Gev/c