Combined analysis of η' production reactions: $\gamma N \to \eta' N$, $\pi N \to \eta' N$, and $NN \to NN\eta'$

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Motivation

Purpose of the study of η' production reactions:

$\Longrightarrow$ to extract the N^* information in the less explored high N^* mass region

Advantages of η' production reactions in N^* study:

- $m_{\eta'} = 958$ MeV $\gg$ $m_\pi = 138$ MeV

  $\Longrightarrow$ suitable for study of high mass resonances in low partial-wave states

- Pure isospin $I = 1/2$

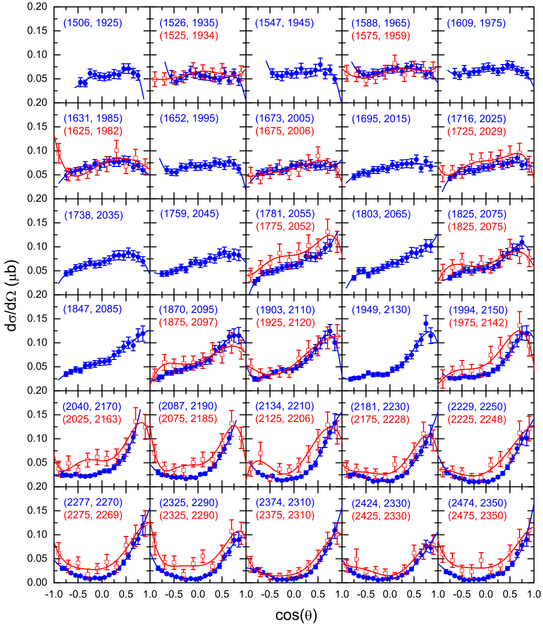
- Missing resonances?

  $\Longrightarrow$ they may couple weekly to πN but strongly to $\eta' N$ or other channels

Data overview

- $\gamma p \to \eta' p$
  - $\mathrm{d}\sigma/\mathrm{d}\Omega$: CLAS-2009 [Phys. Rev. C **80**, 045213 (2009)]
  - $\mathrm{d}\sigma/\mathrm{d}\Omega$: CBELSA/TAPS-2009 [Phys. Rev. C **80**, 055202 (2009)]
- Quasi-free $\gamma p \to \eta' p$ & $\gamma n \to \eta' n$
  - $\mathrm{d}\sigma/\mathrm{d}\Omega$: CBELSA/TAPS-2011 [Eur. Phys. J. A **47**, 11 (2011)]
- $pp \to \eta' pp$
  - $\mathrm{d}\sigma/\mathrm{d}S_{pp}$ & $\mathrm{d}\sigma/\mathrm{d}S_{p\eta'}$: COSY-2010 [Phys. Lett. B **684**, 11 (2010)]
  - σ & $\mathrm{d}\sigma/\mathrm{d}\Omega$: COSY-2004 [Eur. Phys. J. A **20**, 345 (2004)]
  - σ & $\mathrm{d}\sigma/\mathrm{d}\Omega$: DISTO-2000 [Phys. Lett. B **491**, 29 (2000)]
  - σ: COSY-2000 [Phys. Lett. B **474**, 416 (2000)]
  - σ: SPESIII-1998 [Phys. Lett. B **438**, 41 (1998)]
  - σ: COSY-1998 [Phys. Rev. Lett. **80**, 3202 (1998)]
- $pn \to \eta' pn$
  - Upper limit of σ: COSY-2010 [Phys. Rev. C **81**, 035209 (2010)]
- $\pi N \to \eta' N$
  - σ: few data from 1970's

$\gamma p \to \eta' p$: CLAS data vs CBELSA/TAPS data



- □ CBELSA/TAPS data (2009)
- ● CLAS data (2009)

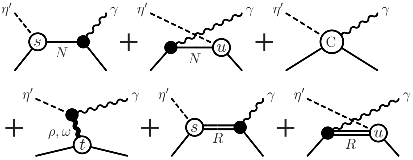
Curves: fit data with polynomials; just to guide the eye

DATA NOT CONSISTENT!

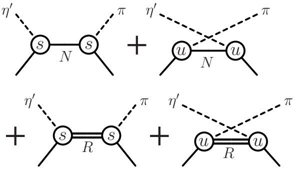
Model

$\gamma + \mathbf{N} \rightarrow \eta' + \mathbf{N}$

(CLAS, CBELSA/TAPS)

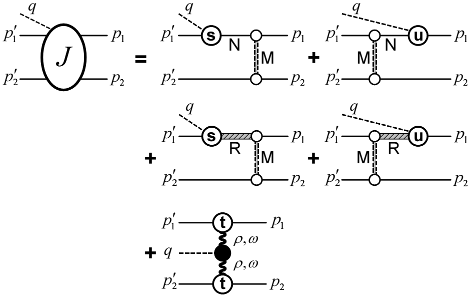


$\pi + \mathbf{N} \rightarrow \eta' + \mathbf{N}$



$\mathbf{N} + \mathbf{N} \rightarrow \eta' + \mathbf{N} + \mathbf{N}$

(COSY, DISTO, SPESIII)



DWBA:

$$A = (1 + \underbrace{T_f G_f}_{\textbf{FSI}}) J (1 + \underbrace{G_i T_i}_{\textbf{ISI}})$$

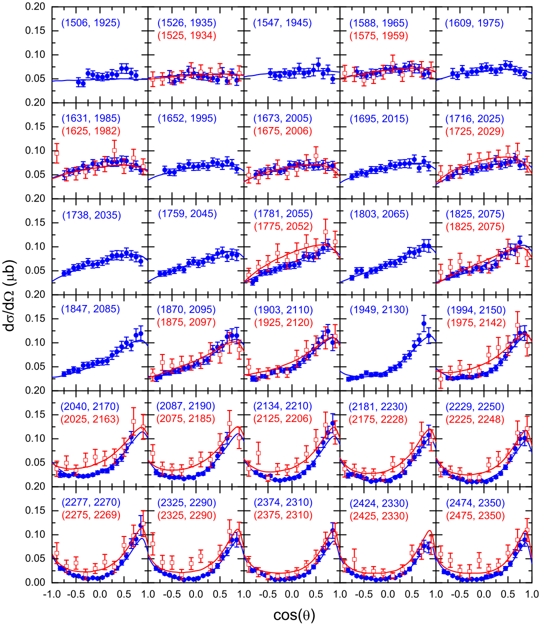
J : transition current

Combined analysis of all reactions

- A combined analysis provides a maximum of constraints for our model
- Strategy: introduce as few resonances as possible
- Good overall description of all $\gamma N \to \eta' N$, $\pi N \to \eta' N$ and $NN \to \eta' NN$ reaction processes: 4 resonances

  $S_{11}(2090)$ * $P_{11}(2100)$ * $P_{13}(1900)$ ** $P_{13}(1720)$ ****

Results: $d\sigma/d\Omega$ for $\gamma p \to \eta' p$



- □ CBELSA/TAPS data (2009)
- • CLAS data (2009)

Curves: results from our fits

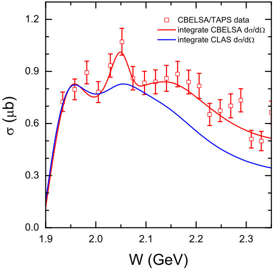
- CLAS: $\chi^2/N = 0.65$

	M	Γ	$\sqrt{\beta_{\eta'}\beta_\gamma}$
S_{11}	1924	112	1.02%
P_{11}	2129	205	0.80%
P_{13}	2050	140	0.67%
P_{13}	**1720**	**200**	—

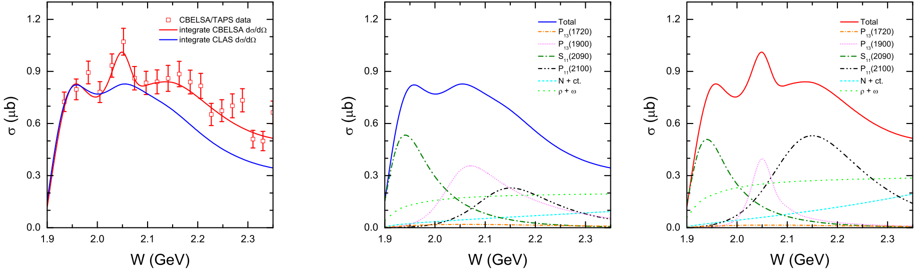
- CBELSA/TAPS: $\chi^2/N = 0.53$

	M	Γ	$\sqrt{\beta_{\eta'}\beta_\gamma}$
S_{11}	1926	99	1.02%
P_{11}	2123	246	1.21%
P_{13}	2045	52	0.72%
P_{13}	**1720**	**200**	—

Results: $\sigma_{\gamma p \to \eta' p}$



Results: $\sigma_{\gamma p \to \eta' p}$



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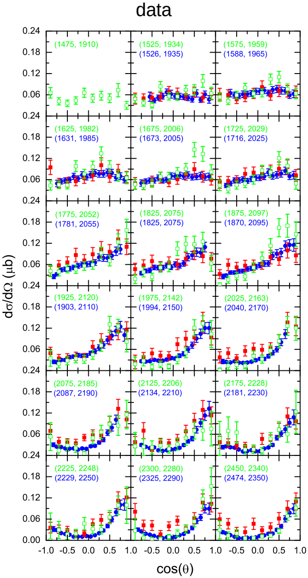
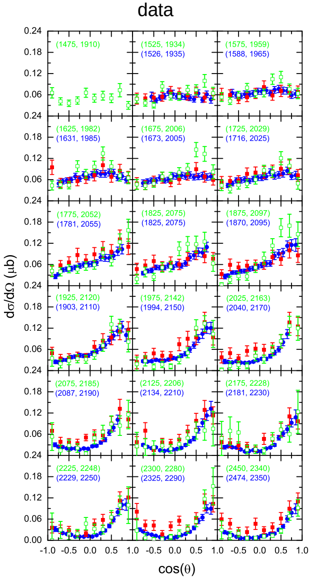
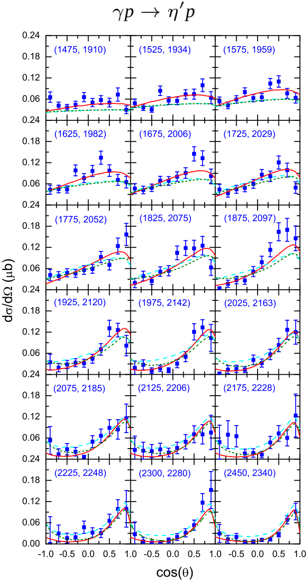
- Nucleonic & mesonic current contributions: small
- $P_{13}(1720)$ contributions: negligible
- Near-threshold cross sections dominated by S_{11} resonance
- P_{11} resonance much stronger for CBELSA/TAPS
- above-threshold P_{13} resonance much narrower for CBELSA/TAPS



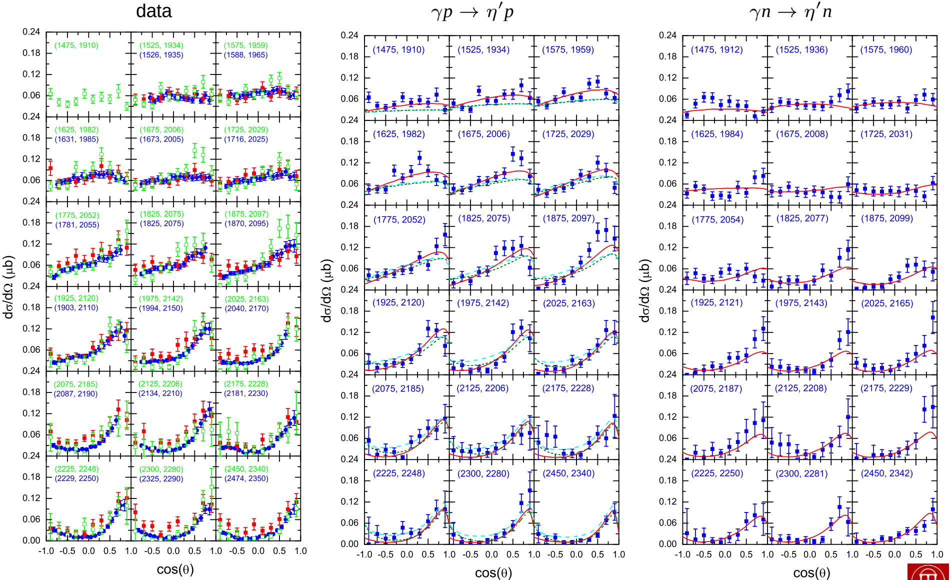
data
(1475, 1910)
(1525, 1934)
(1526, 1935)
(1575, 1959)
(1588, 1965)
(1625, 1982)
(1631, 1985)
(1675, 2006)
(1673, 2005)
(1725, 2029)
(1716, 2025)
(1775, 2052)
(1781, 2055)
(1825, 2075)
(1825, 2075)
(1875, 2097)
(1870, 2095)
(1925, 2120)
(1903, 2110)
(1975, 2142)
(1994, 2150)
(2025, 2163)
(2040, 2170)
(2075, 2185)
(2087, 2190)
(2125, 2206)
(2134, 2210)
(2175, 2228)
(2181, 2230)
(2225, 2248)
(2229, 2250)
(2300, 2280)
(2325, 2290)
(2450, 2340)
(2474, 2350)
0.24
0.18
0.12
0.06
0.00
-1.0 -0.5 0.0 0.5 1.0
dσ/dΩ (μb)
cos(θ)

Quasi-free $\gamma p \to \eta' p$ & $\gamma n \to \eta' n$

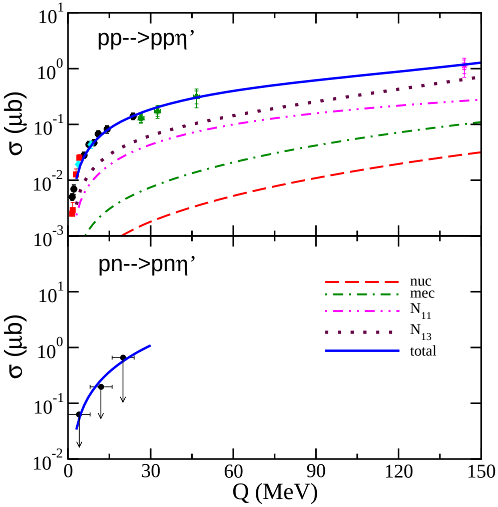




Quasi-free $\gamma p \to \eta' p$ & $\gamma n \to \eta' n$

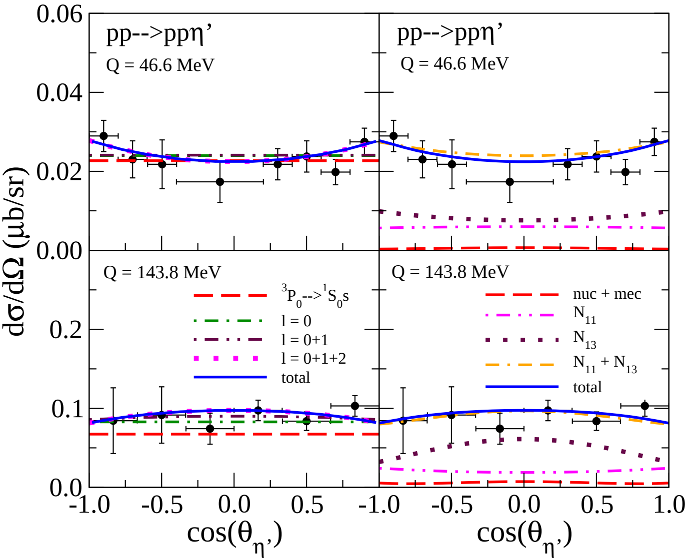


Results: $\sigma_{pp\to pp\eta'}$ & $\sigma_{pn\to pn\eta'}$

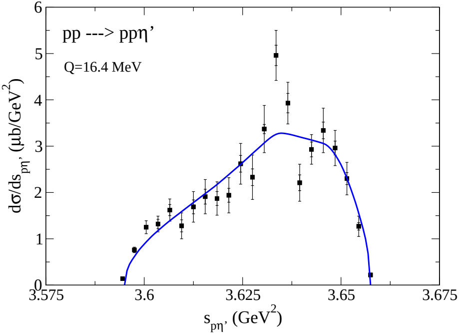


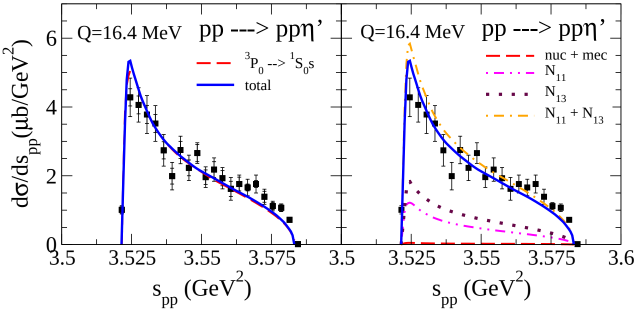
- Nucleonic and mesonic currents are small
- In low Q region, spin-1/2 resonance contribution is slightly smaller than spin-3/2
- In high Q region, spin-3/2 resonance dominates
- More $pn \to pn\eta'$ data needed to constrain the iso-scalar and iso-vector meson couplings to resonances

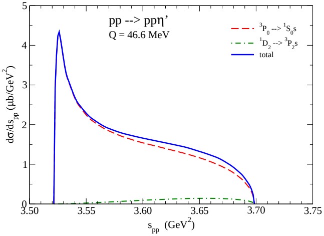
Results: $d\sigma/d\Omega$ for $pp \to pp\eta'$



Results: $d\sigma/ds_{p\eta'}$ for $pp \to pp\eta'$







- Enhancement in $pp \to pp\eta$:

  strong ηp FSI;
  high partial waves;
  production mechanism;
  ......

- Enhancement in $pp \to pp\eta'$:

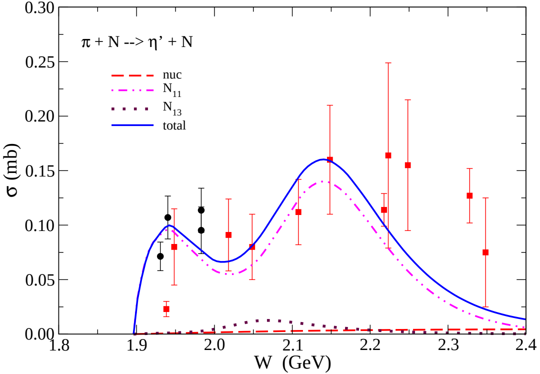
  $^3P_0 \to {}^1S_0\, s$

- Constructive interference between spin-1/2 & spin-3/2 resonances

- $^1D_2 \to {}^3P_2\, s$ enters at high Q & high s_{pp}

- P-wave contribution in $pp \to pp\eta'$ much smaller than in $pp \to pp\eta$

Results: $\sigma_{\pi N \to \eta' N}$



- Data offer litter constraints on model parameters
- Bump structure caused by $S_{11}(2090)$ [$M = 1924$ MeV] & $P_{11}(2100)$ [$M = 2129$ MeV]
- X. Cao and X.G. Lee, Phys. Rev. C **78**, 035207 (2008):

  Assumption of sub-threshold $S_{11}(1535)$ resonance dominance
- More accurate data needed

Summary

- A unified description of all available data for $\gamma N \to \eta' N$, $\pi N \to \eta' N$ and $NN \to \eta' NN$ is obtained by introducing 3 above-threshold resonances and 1 sub-threshold resonance (the latter is negligible for $\gamma N \to \eta' N$ but important for $NN \to \eta' NN$):

  $S_{11}(2090)$ * $P_{11}(2100)$ * $P_{13}(1900)$ ** $P_{13}(1720)$ ****

- $\gamma p \to \eta' p$: the most recent CLAS data and CBELSA/TAPS data are not consistent

- Enhancement of pp invariant mass distributions at larger pp invariant mass in $pp \to \eta' pp$ may be explained as due to constructive interference between spin-1/2 and spin-3/2 resonances

- Discrepancy of CLAS data and CBELSA/TAPS data on $\gamma p \to \eta' p$ needs to be resolved and more accurate data for $\pi N \to \eta' N$ and $NN \to \eta' NN$ are needed to further constrain the model

Appendix: Model parameters (1)

	free p			quasi-free p
	CLAS	CBELSA		CBELSA
		fit 1	fit 2	
χ^2/N	0.65	0.53	0.55	1.12
$g_{NN\eta'}$	1.00 ± 0.06	1.17 ± 0.31	1.32 ± 0.48	0.41 ± 0.09
$\lambda_{NN\eta'}$	0.53 ± 0.06	0.44 ± 0.22	0.18 ± 0.29	$0.00 {+0.20 \atop -0.00}$
Λ_v	1183 ± 5.50	1244 ± 34.6	1233 ± 47.1	1253 ± 1.43
$\hat{h}$	3.89 ± 0.18	5.37 ± 1.57	4.18 ± 1.82	6.00 ± 5.83
P_{13}				
M_R	**1720**	**1720**	**1720**	**1720**
Γ_R	**200**	**200**	**200**	**200**
$\sqrt{\beta_{N\eta'}}A_{1/2}$	0.09	0.09	0.11	-0.66
$\sqrt{\beta_{N\eta'}}A_{3/2}$	-0.16	-0.13	-0.01	1.36
P_{13}				
M_R	2050 ± 3.68	2045 ± 6.76	2049 ± 16.0	1961 ± 24.1
Γ_R	140 ± 10.3	$52 \pm 184.$	**140**	176 ± 52.3
$\sqrt{\beta_{N\eta'}}A_{1/2}$	-5.71	-2.02	-4.33	-3.33
$\sqrt{\beta_{N\eta'}}A_{3/2}$	9.89	7.31	10.11	8.98
S_{11}				
M_R	1924 ± 3.67	1926 ± 10.1	1910 ± 23.4	1896 ± 0.01
Γ_R	112 ± 7.03	99 ± 22.8	121 ± 34.9	228 ± 42.7
λ	$1.00 {+0.00 \atop -0.06}$	$1.00 {+0.00 \atop -0.98}$	$1.00 {+0.00 \atop -0.99}$	$1.00 {+0.00 \atop -0.67}$
$\sqrt{\beta_{N\eta'}}A_{1/2}$	-11.84	-11.07	-10.19	-3.59
P_{11}				
M_R	2129 ± 4.82	2123 ± 22.5	2150 ± 20.9	2096 ± 9.65
Γ_R	205 ± 11.6	246 ± 54.4	260 ± 69.6	74 ± 35.8
λ	$1.00 {+0.00 \atop -0.04}$	$1.00 {+0.00 \atop -0.61}$	$1.00 {+0.00 \atop -0.99}$	$0.00 {+0.70 \atop -0.00}$
$\sqrt{\beta_{N\eta'}}A_{1/2}$	-11.34	-18.80	-16.76	-8.87

Appendix: Model parameters (2)

	$P_{13}(1720)$	$P_{13}(2050)$	$S_{11}(1924)$	$P_{11}(2129)$
$\sqrt{\beta_{N\eta'}}A_{1/2}$	0.32	−3.48	0.00	−2.33
$\sqrt{\beta_{N\eta'}}A_{3/2}$	2.06	8.16	—	—
$\beta_{n\gamma}/\beta_{p\gamma}$	1.90	0.86	0.00	0.07

parameters	S_{11}	P_{11}	P_{13}	P_{13}
M_R (MeV)	1924	2129	**1720**	2050
Γ_R (MeV)	112	205	**200**	140
$\beta_{N\eta'}$ (%)	4	2	0.006	2
$\beta_{N\pi}$ (%)	20	1	[10-20] 7	9
$\beta_{N\eta}$ (%)	25	[61 ± 60] 11	[4.0 ± 1.0] 11	2
$\beta_{N\rho}$ (%)	33	56	[70-85] 64	56
$\beta_{N\omega}$ (%)	17	28	2	30
$(g_{RN\eta'}, \lambda)$	(0.68, 1.00)	(1.77, 1.00)	(1.20, —)	(1.38, —)
$(g_{RN\pi}, \lambda)$	(-0.34, 0.96)	(0.20, 0.22)	(-0.12, —)	(-0.07, —)
$(g_{RN\eta}, \lambda)$	(-0.74, 0.85)	(-1.77, 0.22)	(-1.67, —)	(0.29, —)
$(g^{(1)}_{RN\rho}, g^{(2)}_{RN\rho}, g^{(3)}_{RN\rho})$	(-2.49, -0.08, —)	(2.32 -0.22, —)	(-14.58, 45.79, 24.32)	(1.72, 8.45, 32.38)
$(g^{(1)}_{RN\omega}, g^{(2)}_{RN\omega}, g^{(3)}_{RN\omega})$	(1.45, -1.22, —)	(3.46, 1.32, —)	(-6.55, 0.18, -32.30)	(-1.05, -18.04, -22.61)