National Nuclear Physics Summer School 2007

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Opava, Czech Republic

Opava, Czech Republic

Opava

- estab. in 1224
- popul. 62 468

Silesian University in Opava

- founded: 9. 7. 1991
- students: ~ 5 000
- wide range of fields of study
- three educational units

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- IP: ~ 20 staff, ~ 60 students

Faculty of Philosophy and Science

School of Business Administration

Mathematical Institute

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- theory, no experiment

- Ph.D. thesis:
- Some aspects of behaviour of vector mesons in hadronic medium

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- Ph.D. thesis:
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- Main fields of my interest:
- many-body decays of vector mesons
- form of Lagrangian of the $a_1\rho\pi$ interaction
- collisions with three particles in initial state

My current work

Electron-positron annihilation into four charged pions and the $a_1\rho\pi$ Lagrangian

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Institute of Physics
Silesian University in Opava, Czech Republic
and
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Czech Technical University, Prague

Motivation

- interest in elmag. probes in RHICs
- the production of prompt dileptons and photons
- two sources: (i) quark-gluon plasma, (ii) hadron gas
- DL and photon yield from (ii), not uniquely known $a_1\rho\pi$ Lagrangian

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- how to reliave this problem
- investigation of the role of the axial-vector $a_1(1260)$ resonance

  in the processes $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ and $\rho(770) \to \pi^+\pi^-\pi^+\pi^-$
- controversial situation (ignored or neglected vs. dominant)

Basic idea

- The excitation curves of e+e- annihilation into 4 charged pions
- Using three existing models with ρ`s and π`s in interm. states
- Addition of Feynman diagrams with the $a_1(1260)\pi$ intermediate states

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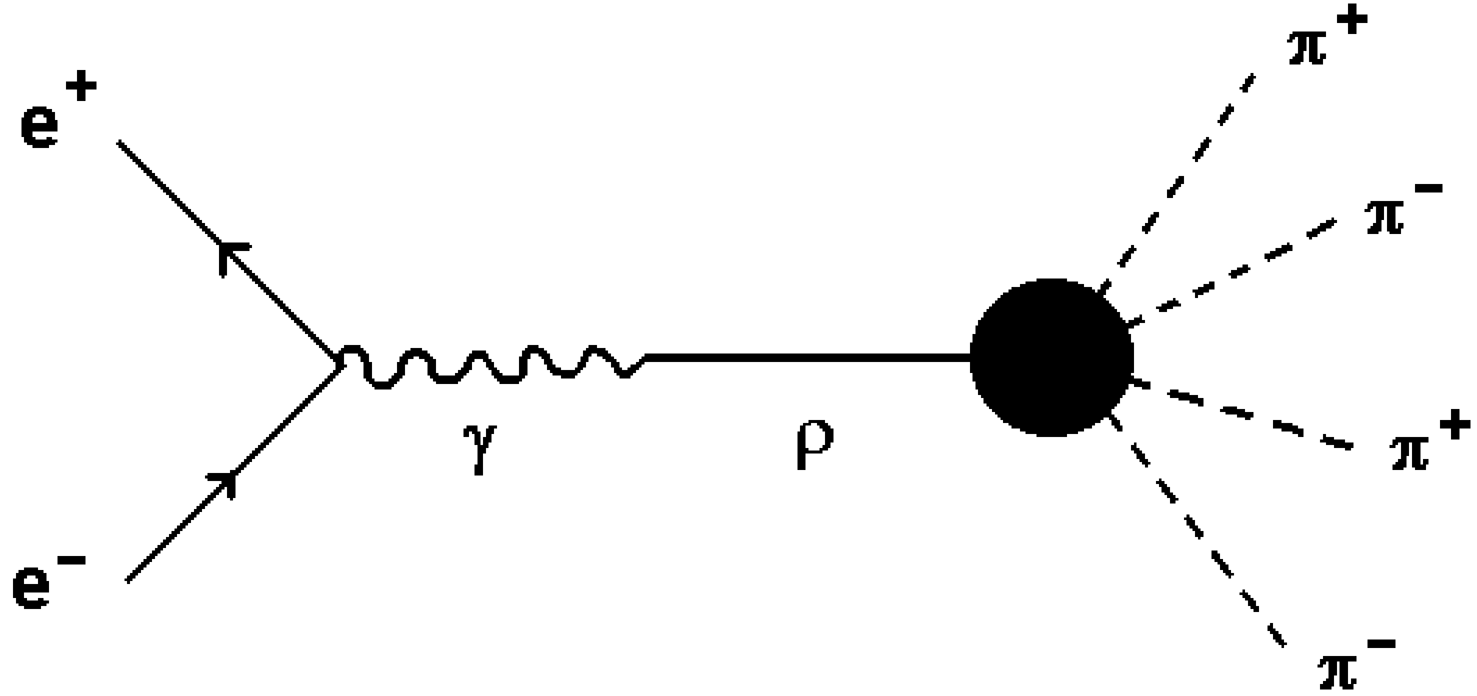
- Using three existing models with ρ`s and π`s in interm. states
- Addition of Feynman diagrams with the $a_1(1260)\pi$ intermediate states
- A two-term phenomenological $a_1\rho\pi$ Lagrangian with two free parameters
- its determination by requiring:

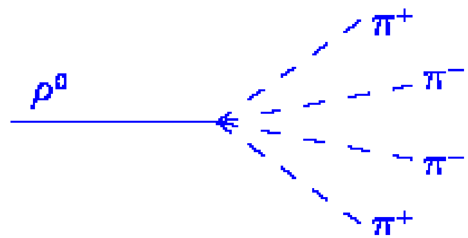
· (i) the decay width of $a_1(1260)$ be reproduced

· (ii) the best possible fitting the e+e- --> π+π-π+π- cross section

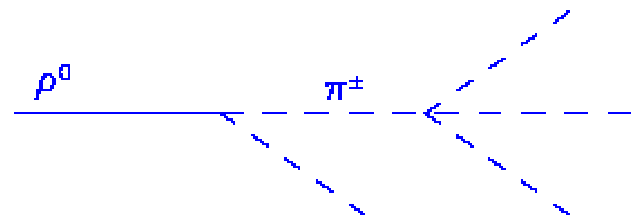
Feynman diagrams



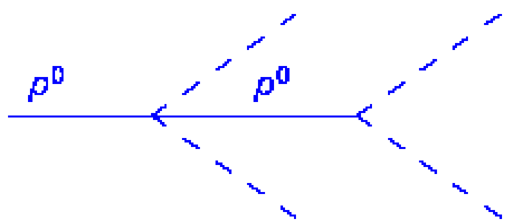
$\rho^0 \rightarrow \pi^+ \ \pi^- \ \pi^+ \ \pi^-$



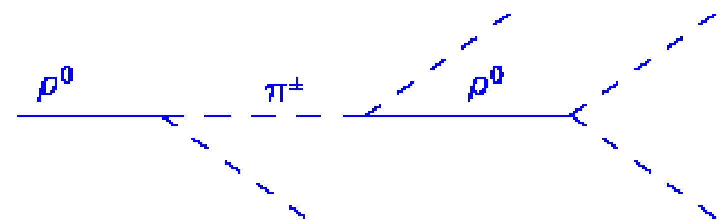
(a1), 1 diagram



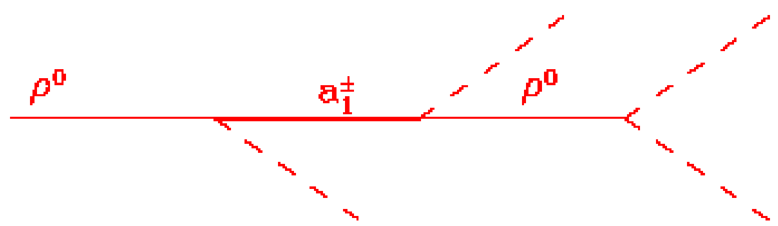
(a2), 4 diagrams



(b1), 4 diagrams



(b2), 8 diagrams



(d), 8 diagrams

Technicalities

$$\mathcal{L} = g_{a_1\rho\pi}\left(\cos\theta\mathcal{L}_1 + \sin\theta\mathcal{L}_2\right), \tag{1}$$

where $g_{a_1\rho\pi}$ and θ are yet undetermined parameters,

$$\mathcal{L}_1 = \mathbf{A}^{\mu}\cdot\left(\mathbf{V}_{\mu\nu}\times\partial^{\nu}\phi\right), \tag{2}$$

$$\mathcal{L}_2 = \mathbf{V}_{\mu\nu}\cdot\left(\partial^{\mu}\mathbf{A}^{\nu}\times\phi\right), \tag{3}$$

and $\mathbf{V}_{\mu\nu} = \partial_\mu\mathbf{V}_\nu - \partial_\nu\mathbf{V}_\mu$.

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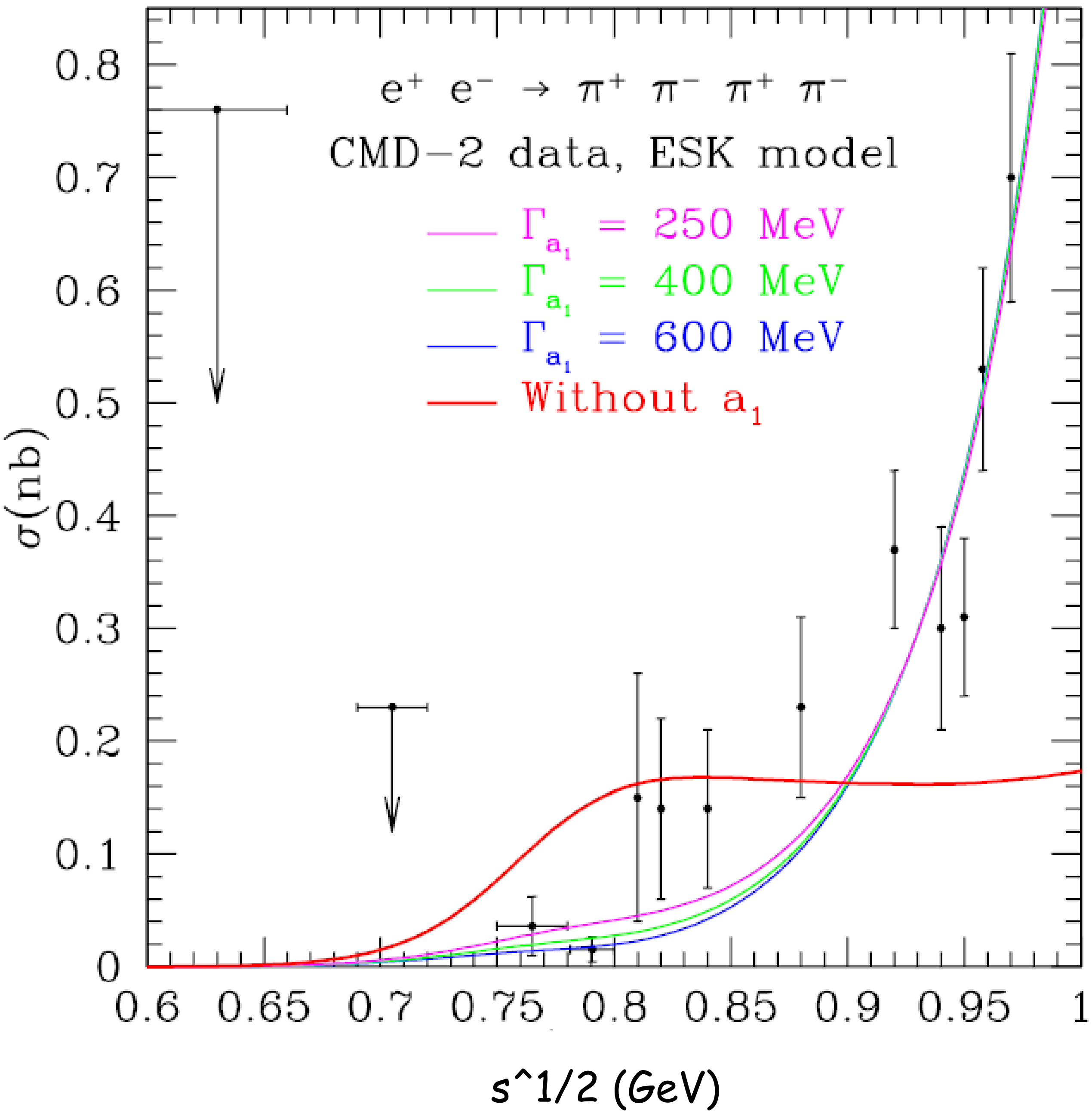
- fixing decay width of $a_1(1260)$: 250, 400, and 600 MeV ($g_{a1\rho\pi}$)
- calculation of decay width of rho(770) into 4 charged pions
- converting decay width to electron–positron cross section
- optimalization of sin(θ) by Minuit; GL quadratures; check by MC
- data: CMD–2, BaBar, D/S ratio; low and high energy region

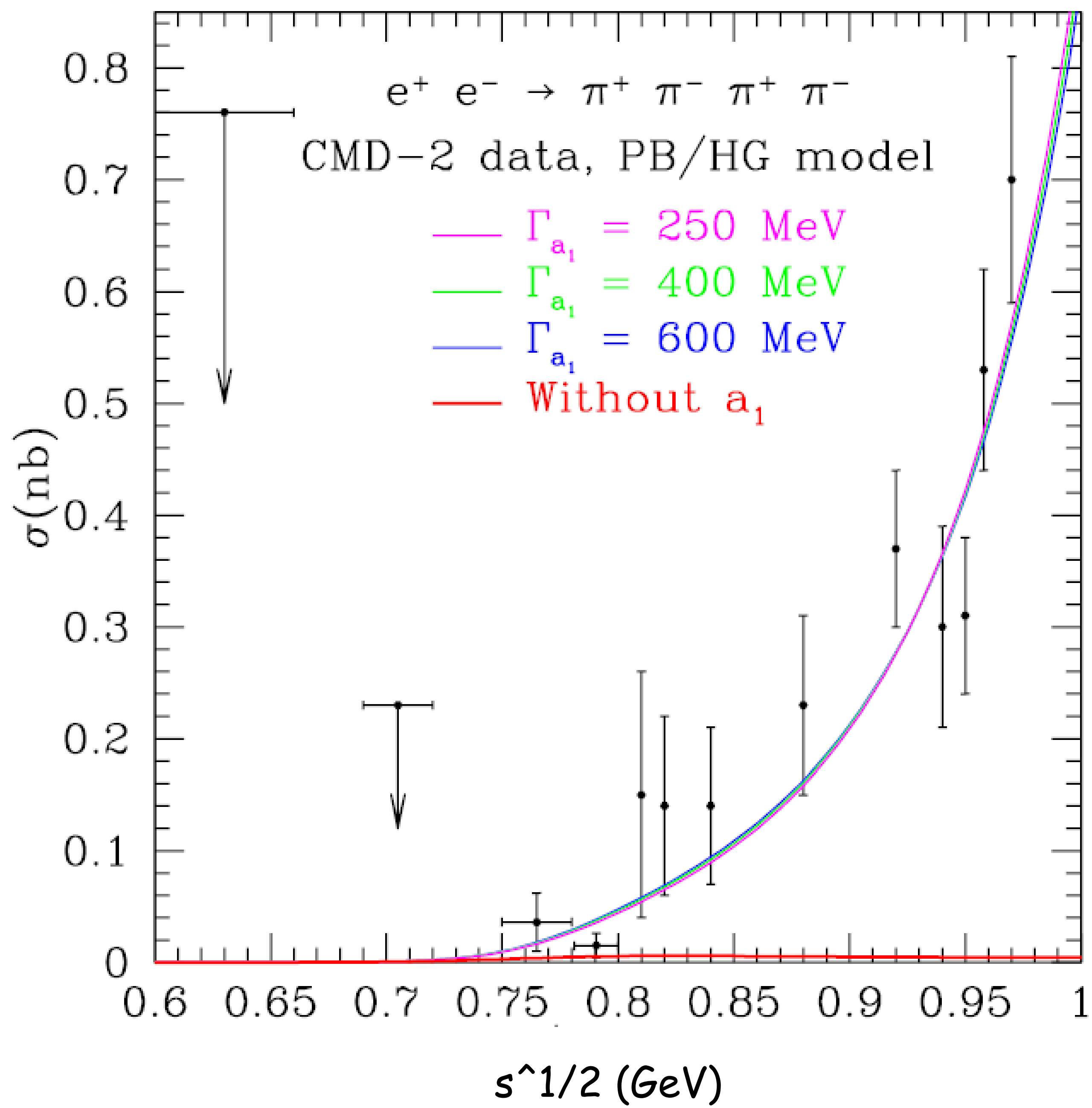
Low - energy results

TABLE I: χ^2/NDF of the fits to the CMD-2 cross section data (11 data points)

Γ_{a_1}(MeV)	ESK	PB/HG	AK	only a_1
250	1.60	1.34	1.28	1.68
400	1.53	1.37	1.30	1.82
600	1.61	1.41	1.31	1.94
Only ρ, π	17.6	15.0	14.8	/



$e^+ e^- \to \pi^+ \pi^- \pi^+ \pi^-$
CMD−2 data, ESK model
Γ_{a_1} = 250 MeV
Γ_{a_1} = 400 MeV
Γ_{a_1} = 600 MeV
Without a_1
σ(nb)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
s^1/2 (GeV)



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Γ_{a_1} = 250 MeV
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Without a_1
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0
0.1
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0.6
0.7
0.8
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
s^1/2 (GeV)

TABLE XI: Decay width $\Gamma(\rho^0 \to \pi^+\pi^-\pi^+\pi^-)$ (keV) calculated in various models using $\sin\theta$ from the fits to the combined CMD-2 & BaBar data. Experimental value is $(2.8 \pm 1.4 \pm 0.5)$ keV.

Γ_{a_1}(MeV)	ESK	PB/HG	AK	only a_1
250	4.35	3.41	2.94	4.79
400	2.80	3.62	3.10	5.15
600	1.94	3.79	3.24	5.42
Only ρ, π	16.2	0.59	0.89	/

TABLE VIII: Values of $\sin\theta$ from the fit to the CMD-2 & BaBar data + D/S ratio.

Γ_{a_1} (MeV)	ESK	PB/HG	AK	only a_1
250	0.4092(33)	0.4278(32)	0.4267(32)	0.4312(35)
400	0.4352(24)	0.4624(34)	0.4608(32)	0.4679(39)
600	0.4659(27)	0.5046(44)	0.5022(41)	0.5132(55)

The optimized values of sin (θ) squeeze into interval (0.40,0.51).

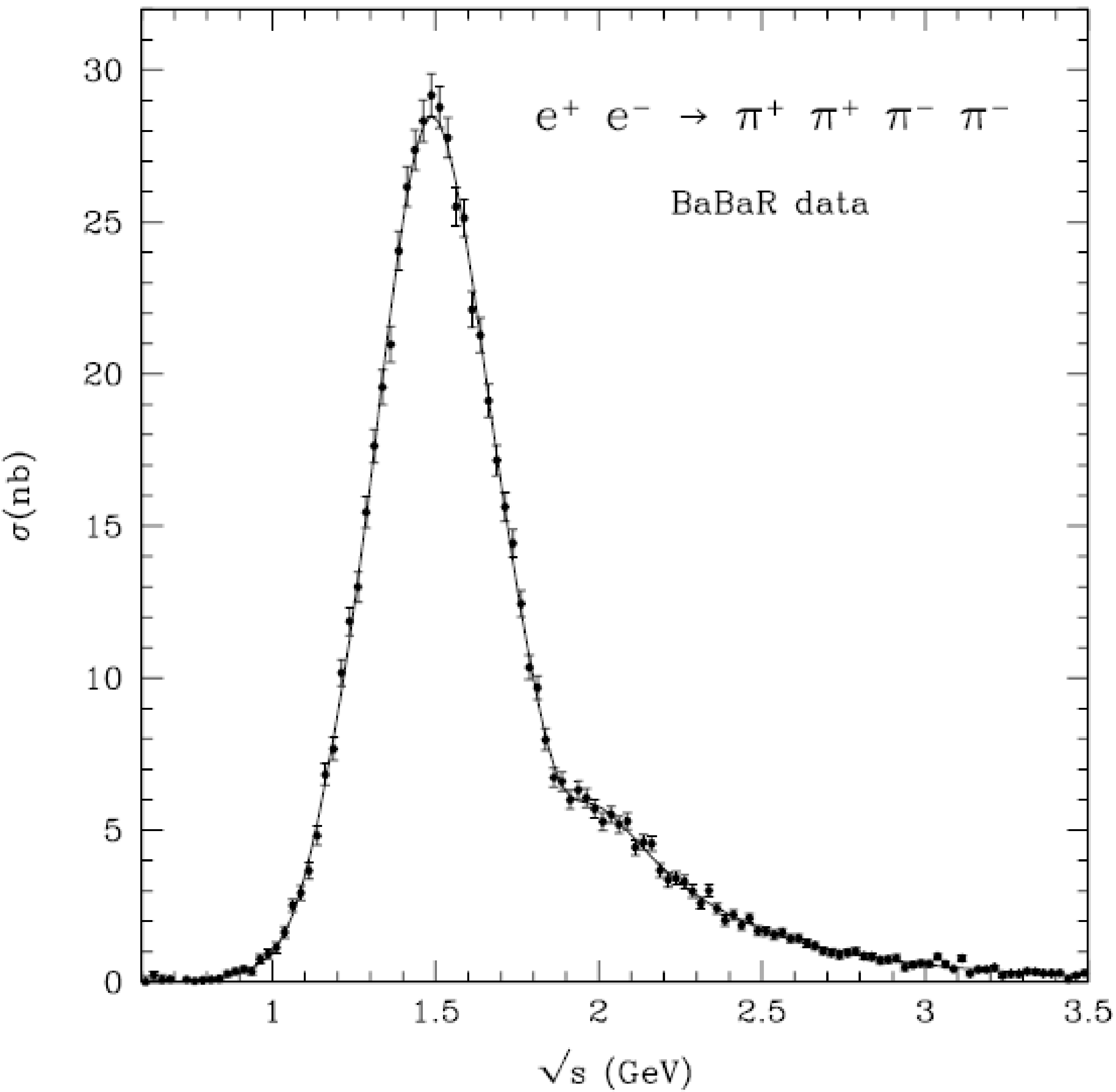
High - energy results

- fit to BaBar cross section data (up to 4.5 GeV, 144 data points)

  + D/S ratio
- contribution from higher ρ-resonances: $\rho' = \rho(1450)$, $\rho'' = \rho(1700)$
- assumption: decay of higher resonances is governed by the same Feynman diagrams
- 10 real parameters to be determined by fitting
- in the following for Γ_{a1}= 600 MeV (best results at energies below 1 GeV)

TABLE VII: Results of the fit to the BaBaR cross section data and D/S ratio (145 data points) for $\Gamma_{a_1} = 600$ MeV.

Model	ESK	PB/HG	AK	only $a_1\pi$
χ^2/NDF	1.21	1.12	1.12	1.12
$\sin\theta$	0.4474(22)	0.4592(28)	0.4588(27)	0.4603(28)
β (GeV)	0.3505(89)	0.3665(97)	0.3657(97)	0.3695(98)
$m_{\rho'}$ (GeV)	1.419(12)	1.439(13)	1.438(13)	1.442(13)
$\Gamma_{\rho'}$ (GeV)	0.564(20)	0.568(21)	0.568(21)	0.566(21)
$m_{\rho''}$ (GeV)	1.903(21)	1.923(24)	1.922(24)	1.926(24)
$\Gamma_{\rho''}$ (GeV)	0.247(38)	0.284(44)	0.283(44)	0.290(45)



$e^+ e^- \to \pi^+ \pi^+ \pi^- \pi^-$
BaBaR data
σ(nb)
0
5
10
15
20
25
30
1
1.5
2
2.5
3
3.5
$\sqrt{s}$ (GeV)

Conclusions and comments

- the inclusion of the $a_1\pi$ intermediate states is of vital importance for obtaining a good agreement with the experimental data on the cross section (LE and also HE fits, the same CL)
- also pure a_1-model is good (especially in HE fits)
- adding the diagrams from PB/HG, AK improves fit (no ESK)

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- D/S ratio can discriminate among various models

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- also pure a_1-model is good (especially in HE fits)
- adding the diagrams from PB/HG, AK improves fit (no ESK)

- D/S ratio strongly prefers larger value of a_1 decay width
- D/S ratio can discriminate among various models

- also the partial decay width of $\rho(770) \to \pi^+\pi^-\pi^+\pi^-$ is better with inclusion of $a_1\pi$ intermediate states
- all values of decay width are brought into interval given by experimental value and its errors

- with respect to the $a_1\rho\pi$ Lagrangian, no clear picture can be inferred from our results yet

No.	$\sin\theta$	Reference
1	0	[35, 36]
2	0.2169	[21, 22, 50]
3	0.5582	[55]
4	0.6308	[21, 22, 56]
5	1	[34]
	0.40–0.51	our low-energy fits
	0.41–0.47	our all-energy fits

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- our failure to obtain more precise value of sin(θ) suggests that it is necessary to make a simultaneous fit to data about several physical processes (e+e- anihilation into various 4π`s, τ-lepton decay into neutrino and 3 or 4π`s, ...)

Thank you for your attention.