Recent J/psi decay results from KEDR

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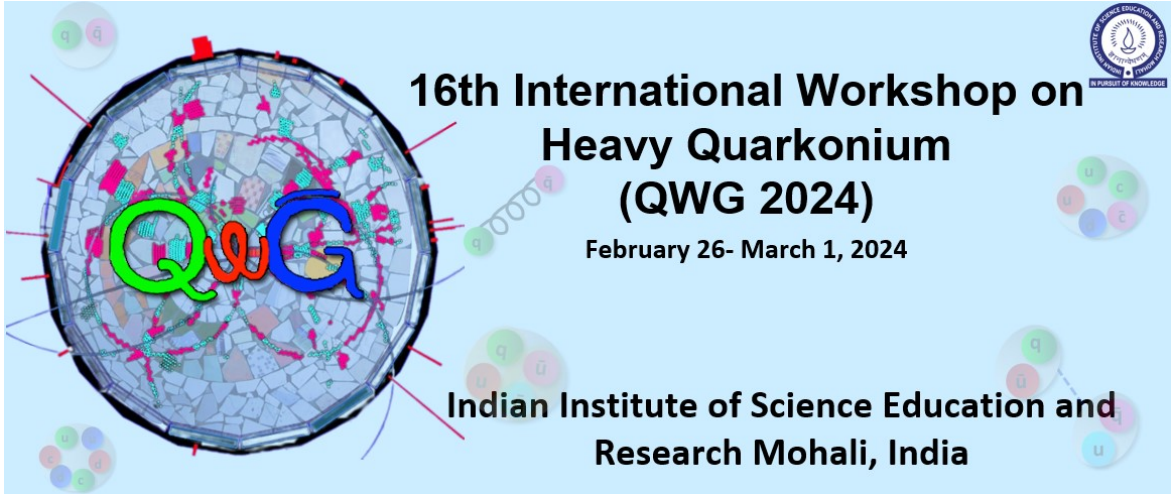
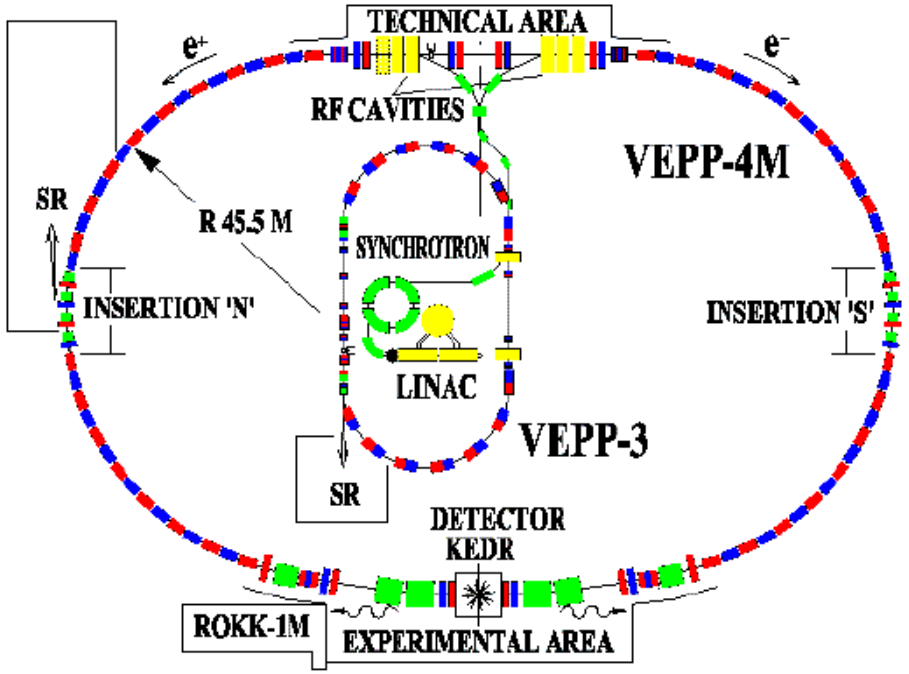
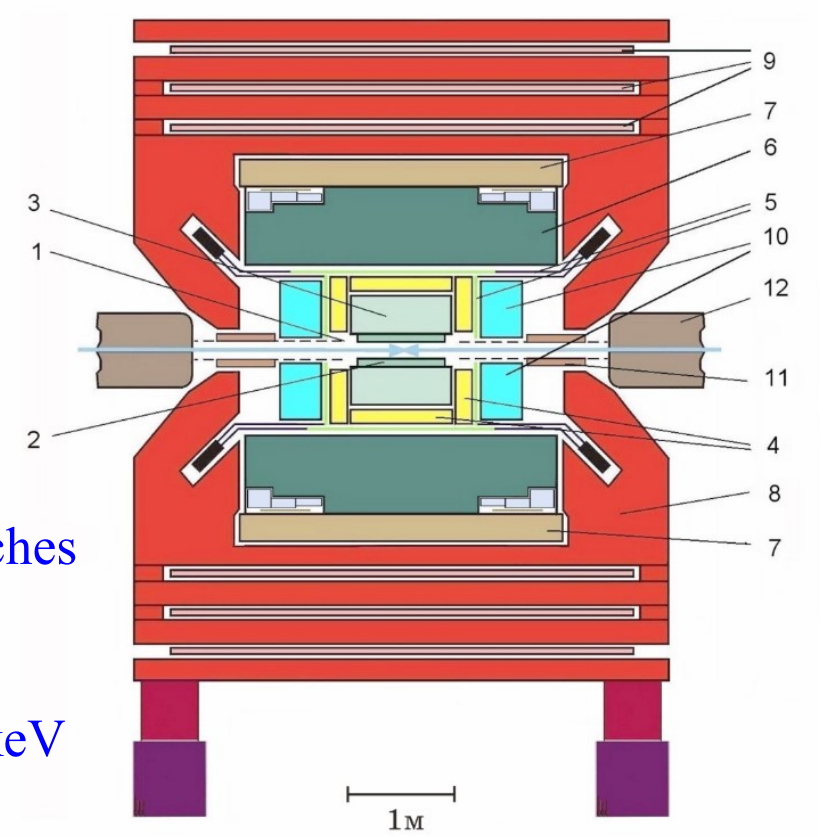


- $J/\Psi \to \rho\pi,\ \rho'\pi$
- $J/\Psi \to 5\pi,\ 2K3\pi,\ 4\pi,\ 2K2\pi$

VEPP-4M e^+e^- collider and KEDR detector





1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Threshold aerogel counters
5. ToF-counters
6. Liquid krypton calorimeter
7. Superconducting coil (0.6 T)
8. Magnet yoke
9. Muon tubes
10. CsI-calorimeter
11. Compensation solenoid
12. VEPP-4M quadrupole

- Wide energy range E_{beam}=1÷6 GeV, 2x2 bunches
- Peak luminosity 1.5×10^{30} $cm^{-2}s^{-1}$ at J/ψ
- Precise beam energy determination :
  - Resonant Depolarization Method, $\sigma_E \approx 1.5$ keV
  - Interpolation for DAQ runs $\sigma_E \approx 8\div30$ keV
  - IR-light Compton BackScattering, $\sigma_E < 100$ keV
- Scattering electron tagging system for two-photon studies

Selection criteria

$J/\Psi \to \rho\pi$,

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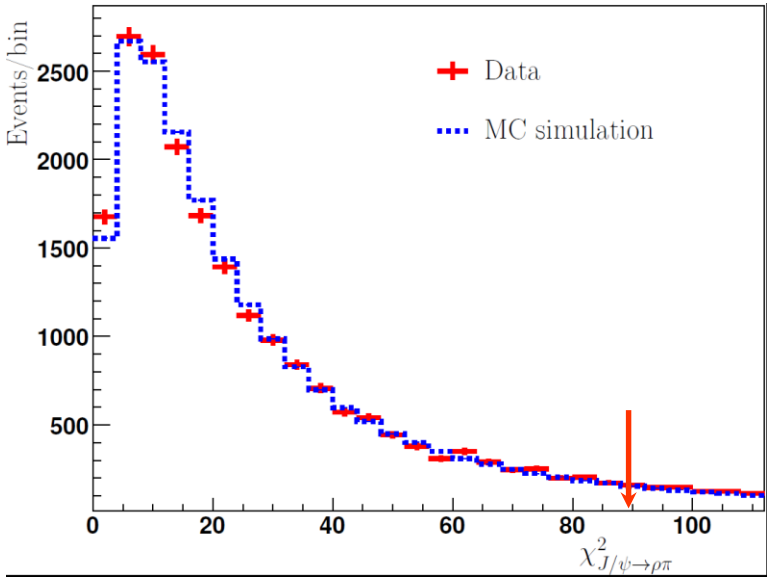
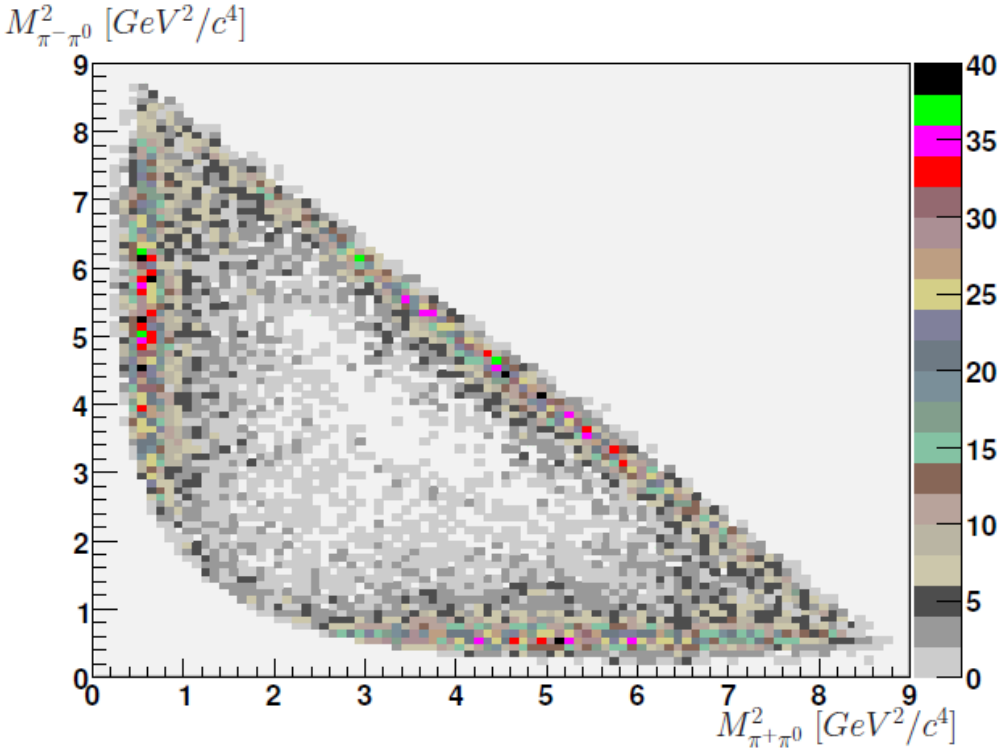
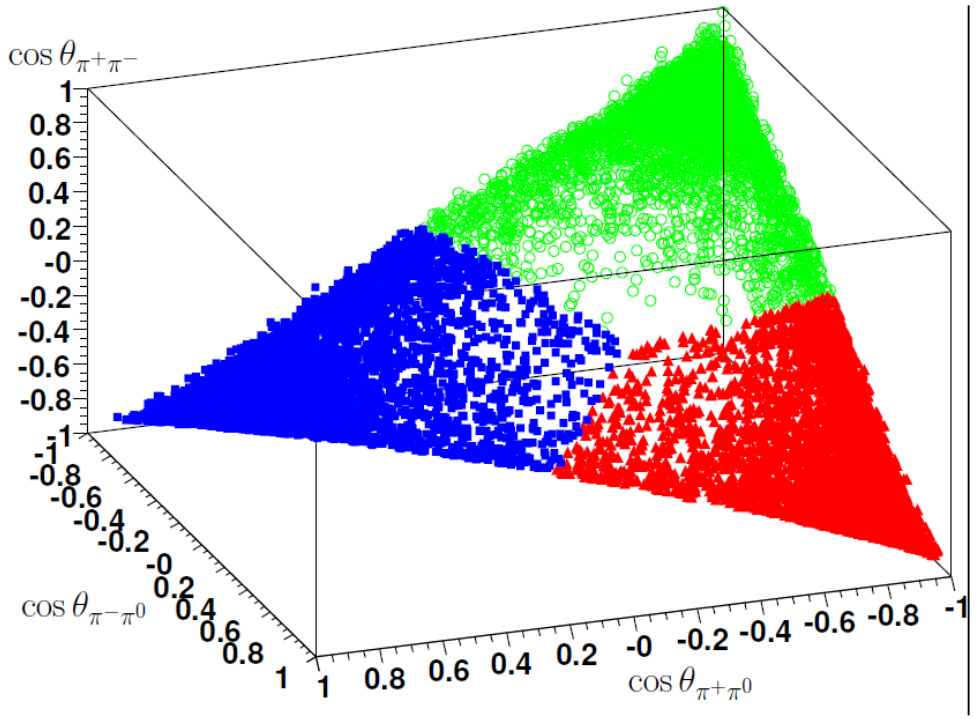
- Two reconstructed tracks are required to have d < 3 cm and $|z_0|$ < 17 cm, where d is the track impact parameter relative to the beam axis and z_0 is the coordinate of the closest approach point.
- At least one track from interaction region (d < 0.75 cm, $|z_0|$ < 13 cm) or two tracks with d < 0.75 cm were accepted.
- Two clusters in the calorimeter not associated to tracks ("neutral clusters") with energies exceeding E_1 = 50 MeV or one cluster with an energy greater than E_2 = 150 MeV.
- χ^2 ($\pi^+\pi^-\pi^0$) from a kinematic fit must be less than 90 and also satisfy the condition $\chi^2(\pi^+\pi^-\pi^0) < \chi^2(K^+K^-\pi^0)$.
- For the suppression of the background induced by the processes $e^+e^-(\gamma)$, $\mu^+\mu^-(\gamma)$ for events with "merged- π^0 we used the additional criteria. The ratio of Fox-Wolfram moments H_2/H_0 was required to be less than 0.8.
- The ratio of the energy deposited in the calorimeter to the measured momentum of the charged particle E/p must be less than 0.75.
- The sum cos $\theta(\pi^+\pi^-)$ + cos $\theta(\pi^+\pi^0)$ + cos $\theta(\pi^-\pi^0)$ was required to be less than −1.075, this distribution lies in the range of [−1.5, −1.].



J/Ψ→ρπ, ρ′π

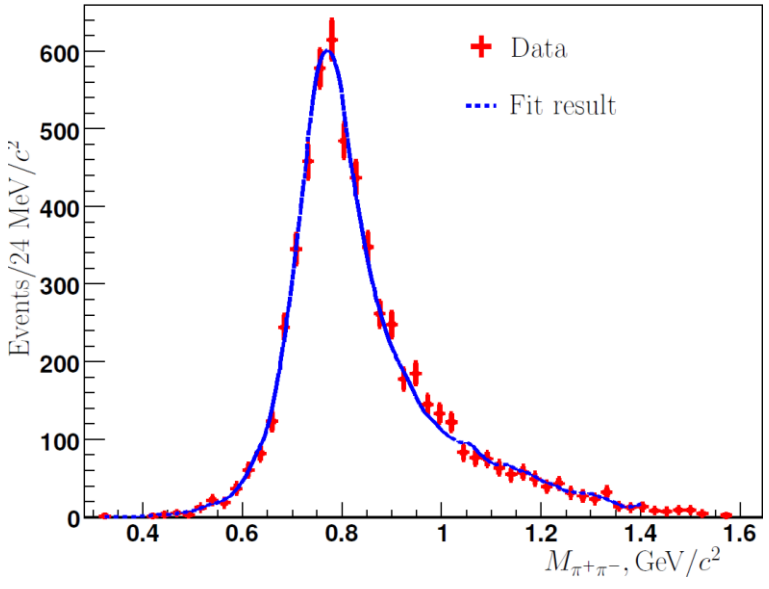


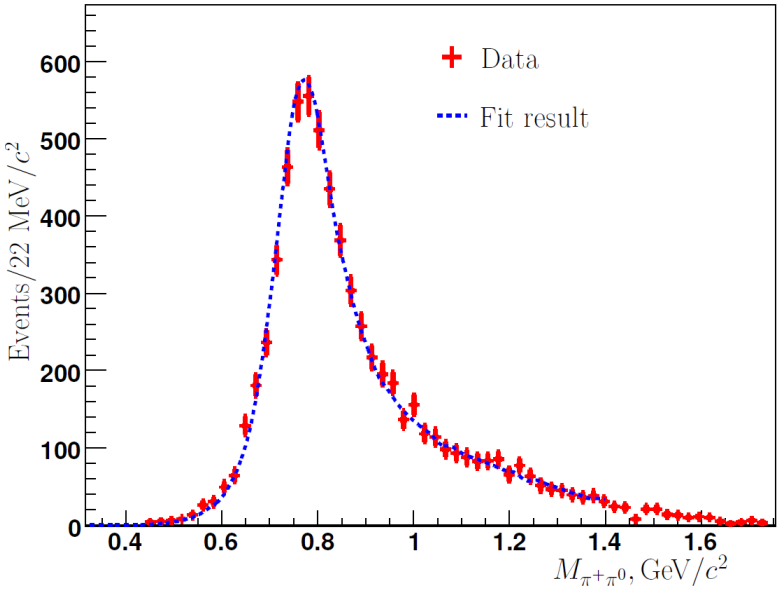
The experimental J/$\psi \rightarrow 3\pi$ Dalitz plot.

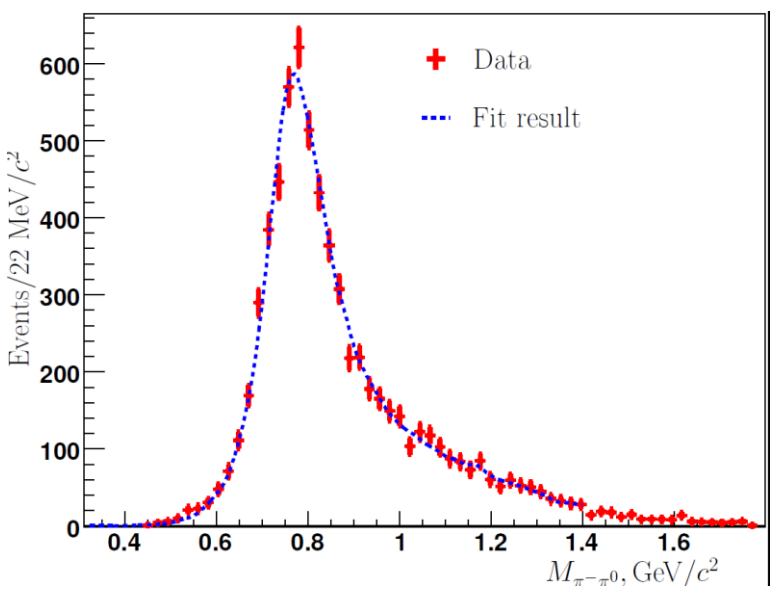


The experimental distribution of events over the cosines cos $\theta(\pi^+\pi^0)$, cos $\theta(\pi^-\pi^0)$, cos $\theta(\pi^+\pi^-)$.

M(3π) distributions analysis







In our analysis, we perform a binned simultaneous fit of the $\pi^+\pi^-$, $\pi^0\pi^+$ and $\pi^0\pi^-$ invariant mass distributions $\rho(750)$ and $\rho'(1450)$ are included to the fit

The systematic uncertainty connected to the fit model were checked by inclusion of $\rho'(1700)\pi$ and $\omega\pi$ states to the fit

J/Ψ→ρπ, ρ′π, - Results

$\mathcal{B}(J/\psi \to \rho\pi) = (2.072 \pm 0.017 \pm 0.062) \times 10^{-2}$

$\mathcal{B}(J/\psi \to \rho'(1450)\pi) \times \mathcal{B}(\rho'(1450) \to \pi\pi) = (2.2 \pm 0.2 \pm 1.1) \times 10^{-4}$

$\mathcal{B}(J/\psi \to \pi^+\pi^-\pi^0) = (1.878 \pm 0.013 \pm 0.051) \times 10^{-2}$

Dominant systematic uncertainties in the $\mathcal{B}(J/\psi \to \rho\pi)$.

Source	Uncertainty, %
Fitting model	1.5
Fitting procedure	1.2
Number of J/ψ decays	1.1
Detector response	0.8
Background	0.2
Selected criteria	1.8
Sum in quadrature	3.0

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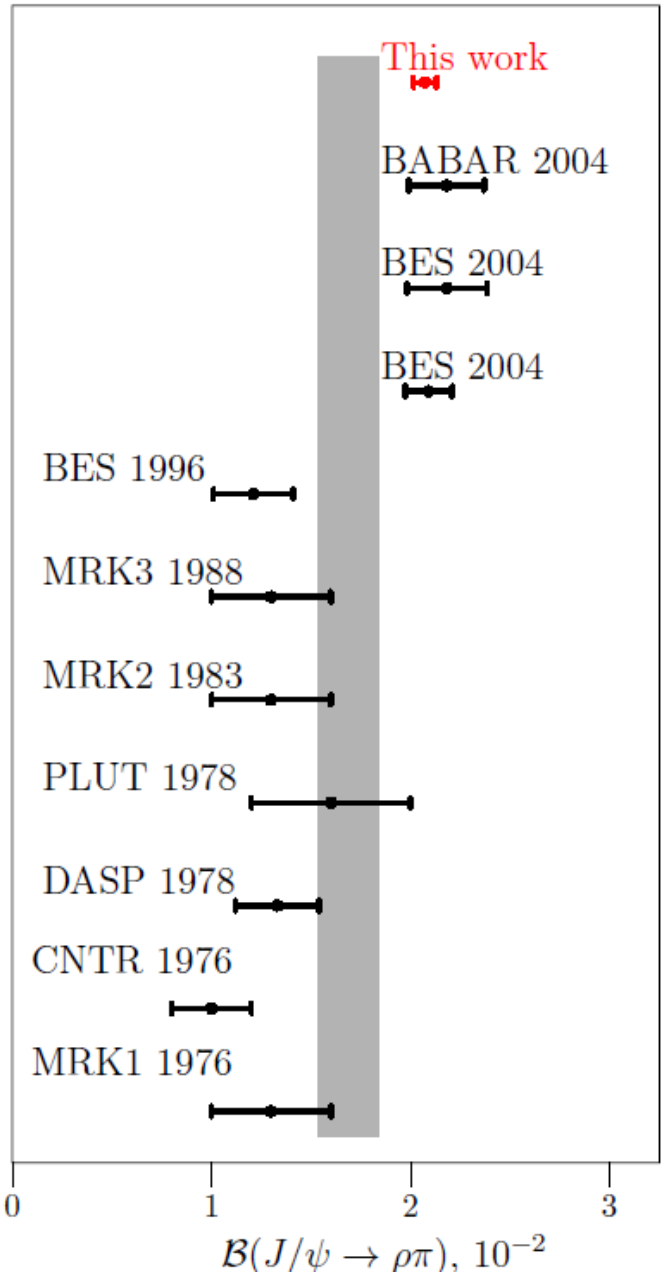
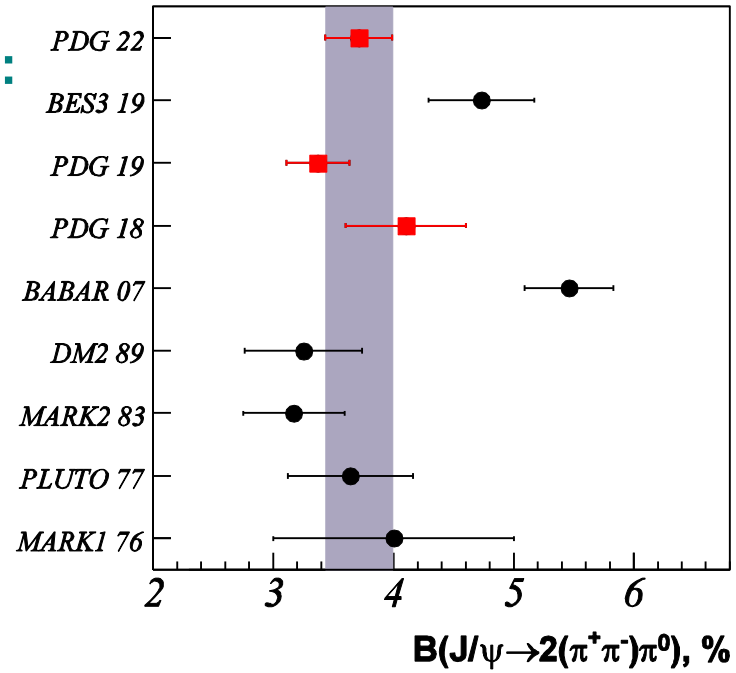


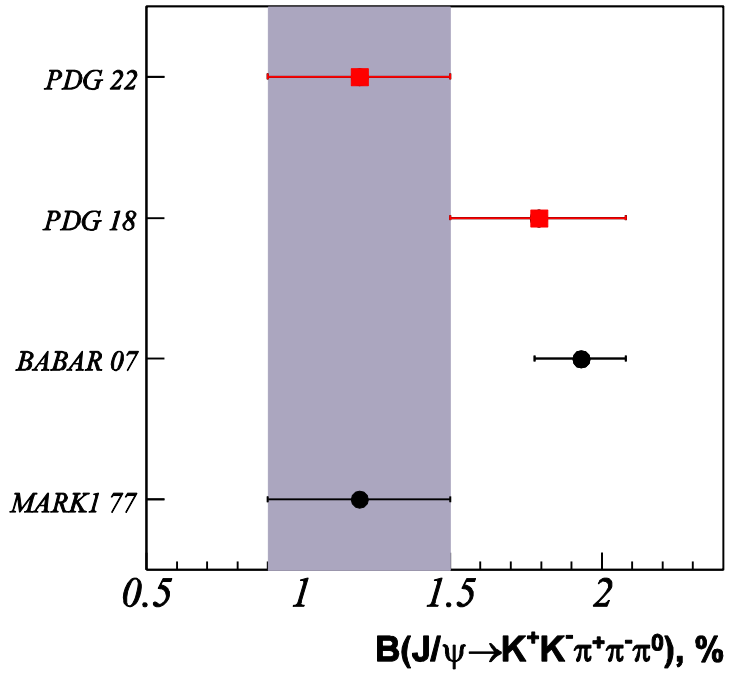
$J/\psi \to 2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$ - decays

***J/ψ*(1*S*) decay modes (PDG 2022) :**

Decays into stable hadrons

$2(\pi^+\pi^-)\pi^0$	(3.71±0.28)%
$3(\pi^+\pi^-)\pi^0$	(2.9±0.6)%
$\pi^+\pi^-3\pi^0$	(1.9±0.9)%
$\pi^+\pi^-\pi^0$	(2.10±0.08)%
$\pi^+\pi^-\pi^0K^+K^-$	(1.20±0.30)%
$2(\pi^+\pi^-)3\pi^0$	(6.2±0.9)%





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KEDR data and selections

- **Integrated luminosity at E_{beam}=1561.4 MeV (J/ψ peak) L = 1.32 ± 0.07 pb^{-1} and at E_{beam}=1550.5 MeV (continuum) L = 82.3 ± 4.1 nb^{-1} is collected**
- **Measured beam energy spread was used for calculation of the number of J/ψ produced : N_ψ = 5.1 ± 0.3 M**

- **For selection of the $J/\psi \to 2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$ or $K^+K^-\pi^+\pi^-$ final states corresponding number of $\pi^\pm$ and $K^\pm$ originated from IP as well as π^0 should be reconstructed. Any number of additional photons were allowed.**
  - **The $\pi^\pm$ and $K^\pm$ identification for the track momentum of P<0.6 GeV was performed by the barrel part of the time-of-flight system of scintillation counters (ToF) while at P>0.6 GeV a system of threshold Cherenkov counters (ATC) was used.**
  - **A cluster in liquid krypton (LKr) or CsI calorimeter with energy Ecl>50 MeV was considered a photon if it was not associated with reconstructed tracks in drift chamber.**
  - **A combination of two photons with a mass closer to the mass of π^0 or η than double the mass resolution was considered as a π^0 or η candidate.**
- **Kinematic fit:**
  - **$(4+n_1\pi^0+n_2\eta)$C – fit : constrains on E, P, M(π^0), M(η)**
  - **For signal events the condition $\chi^2 < 50$ for 5π, $2K3\pi$ and $\chi^2 < 40$ for 4π, $2K2\pi$ were applied**

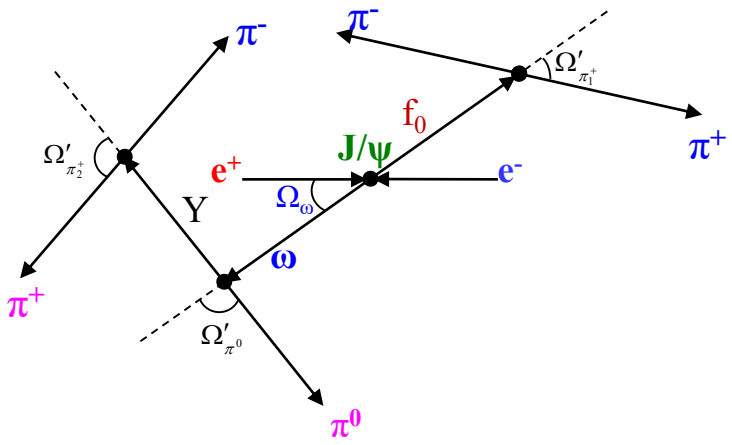
	$2(\pi^+\pi^-)\pi^0$	$K^+K^-\pi^+\pi^-\pi^0$	$2(\pi^+\pi^-)$	$K^+K^-\pi^+\pi^-$
Selection efficiencies (MC), %:	8.47±0.13	2.88±0.05	17.7±0.20	7.18±0.15
Number of signal events selected:	22995	2616	2654	2671

Measurement of $J/\psi \to 5\pi$, $2K3\pi$, 4π, $2K2\pi$

$$B_i / B_{mh} = \frac{N_i^{peak} - N_i^{cont} \cdot L/L_{cont}}{N_{mh}^{peak} - N_{mh}^{cont} \cdot L/L_{cont}} \frac{\varepsilon_{mh}^{MC}}{\varepsilon_i^{MC}} \frac{R_i^{MC}}{R_i^{exp}}$$

B_i – branching fraction of $J/\psi \to X_i$ decay,
B_{mh}=(87.7 ± 0.5)% – branching fraction of J/ψ multihadron decays (PDG),
N_i^{peak} – number of selected signal events in $J/\psi \to X_i$ channel

N_i^{cont} – number of selected signal events in continuum
N_{mh}^{peak}=4618k – number of selected multihadron events at the J/ψ peak,
N_{mh}^{cont}=32.3k – number of selected multihadron events in the continuum,
L=1.315 pb^{-1} – integrated luminosity at the J/ψ peak,
L^{cont}=82.3 nb^{-1} – integrated luminosity in the continuum,
ε_{mh}^{MC}=0.938 – selection efficiency of J/ψ multihadron decays (MC),
ε_i^{MC} – selection efficiency of $J/\psi \to X_i$ decays (MC),
R_i^{exp} – fractions of signal events in candidate events for $J/\psi \to X_i$ decays,
R_i^{MC} – fractions of signal events in candidate events for $J/\psi \to X_i$ decays(MC).



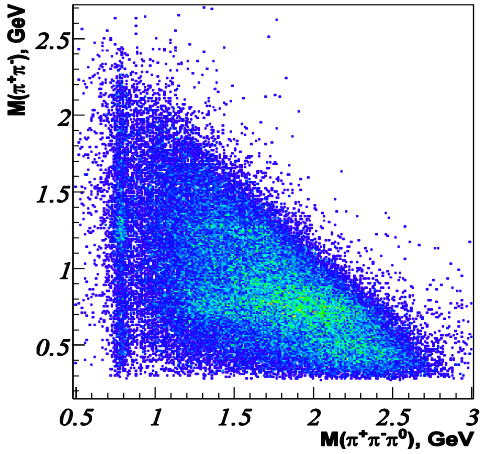
example:
$J/\psi \to \omega f_0 \to 2(\pi^+\pi^-)\pi^0$ decay

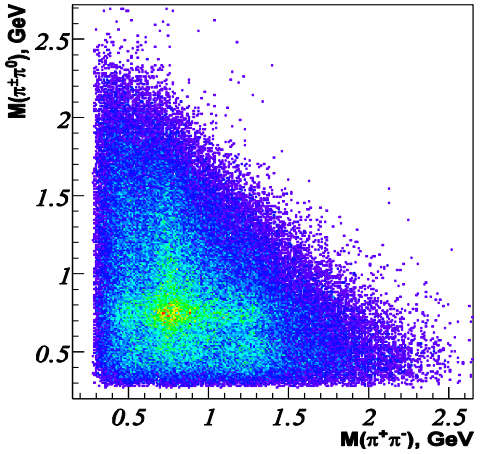
Angular and momentum distributions in J/ψ decays:

- **LundCharm** generator (based on Jetset 7.4), J.C. Chen et al., PRD V62, 034003
- **KsGenHAmp** generator (helicity formalism), J.D. Richman, CALT-68-1148

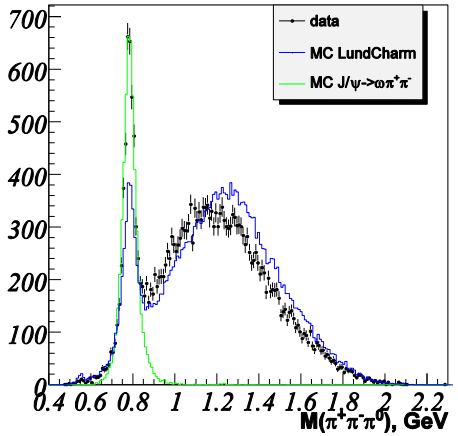
$$d\Gamma = \frac{(2\pi)^4}{2M_\psi} \frac{1}{2} \sum_{\lambda=\pm 1} \left| M_{fi}^{\lambda} \right|^2 d\Phi \qquad d\Phi \propto \prod_i p_i' d\Omega_i' \prod_k dm_k \qquad M_{fi}^{\lambda} = \sum_{\lambda_k} \prod_i \left(\frac{2J_i+1}{4\pi} \right)^{1/2} D^{J_i *}_{\lambda_i, \lambda_{i1} - \lambda_{i2}} (\Omega_i') A^i_{\lambda_{i1} \lambda_{i2}} \qquad A_{\lambda_1, \lambda_2} = \eta_0 \eta_1 \eta_2 (-1)^{J - S_1 - S_2} A_{-\lambda_1, -\lambda_2}$$

$J/\psi \to 2(\pi^+\pi^-)\pi^0$ decay

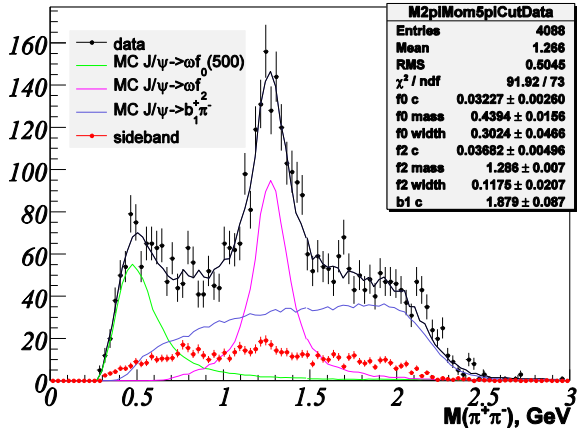




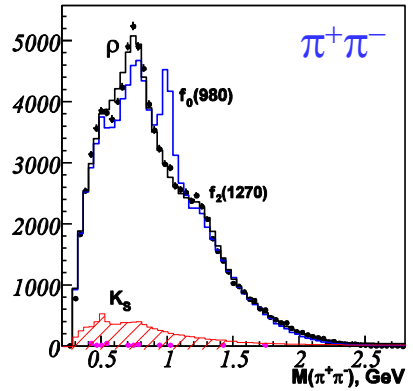
Experimental mass distributions for selected $J/\psi \to 2(\pi^+\pi^-)\pi^0$ events

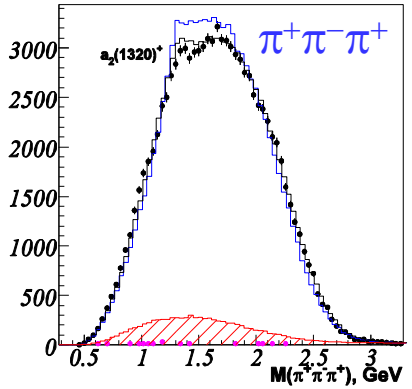


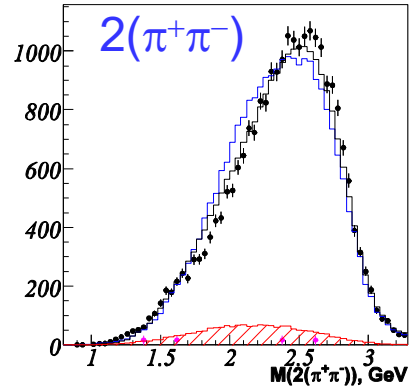
$M(\pi^+\pi^-\pi^0)$ distribution for selected $J/\psi \to 2(\pi^+\pi^-)\pi^0$ events (combination with mass closest to ω mass)

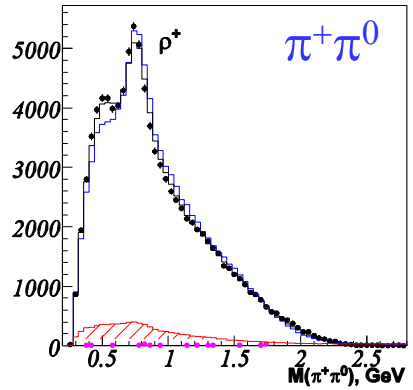


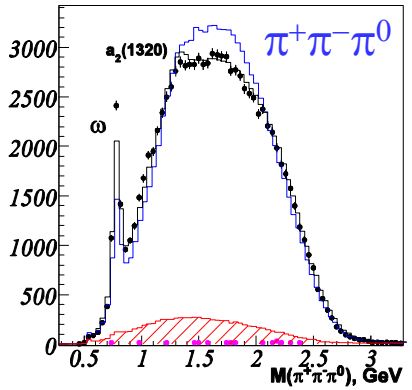
$M(\pi^+\pi^-)$ distribution for selected $J/\psi \to \omega\pi^+\pi^- \to 2(\pi^+\pi^-)\pi^0$ events

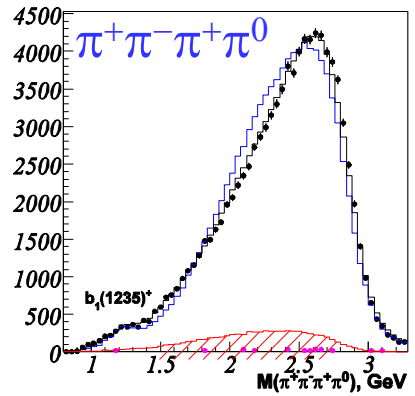






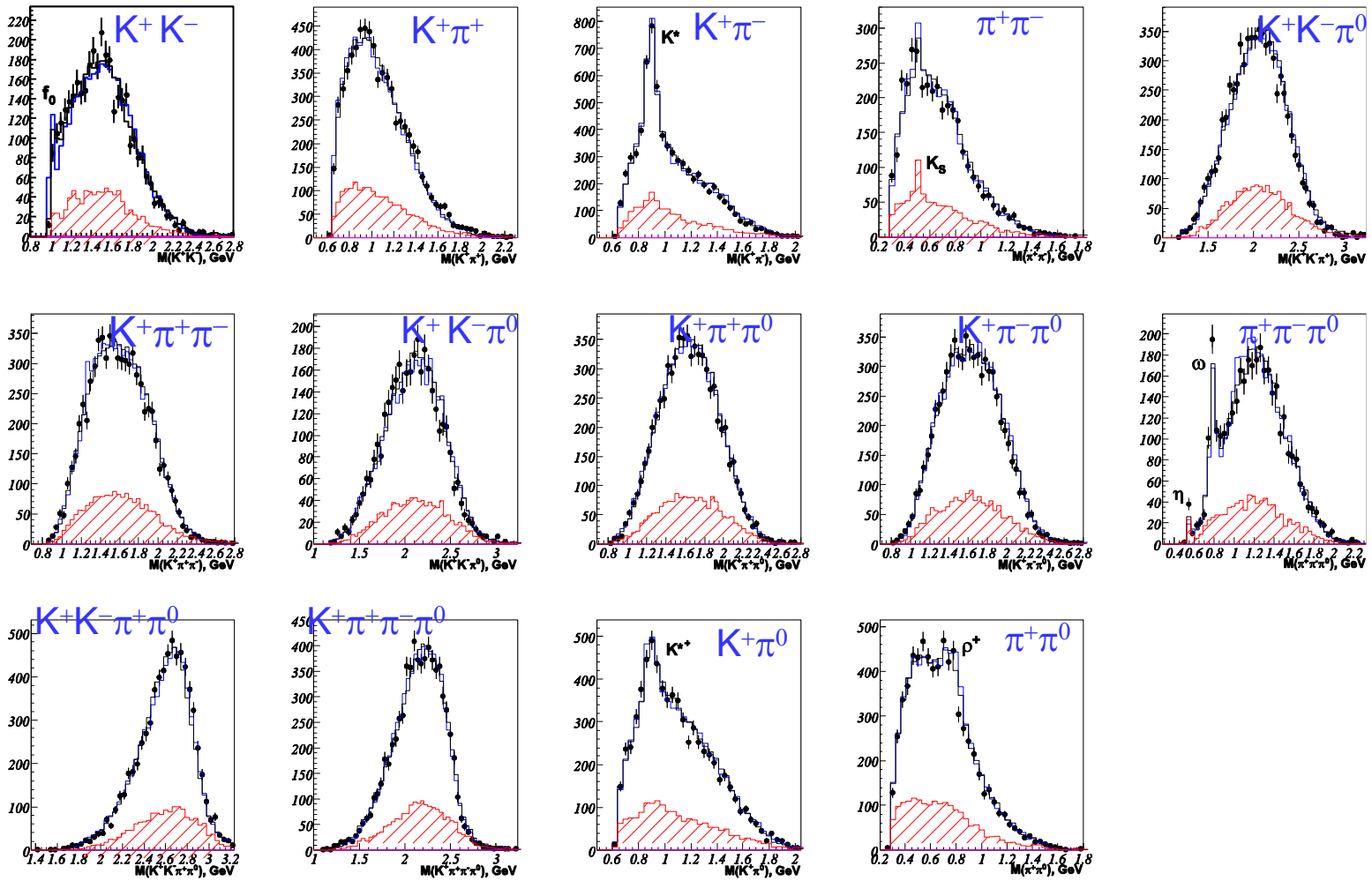


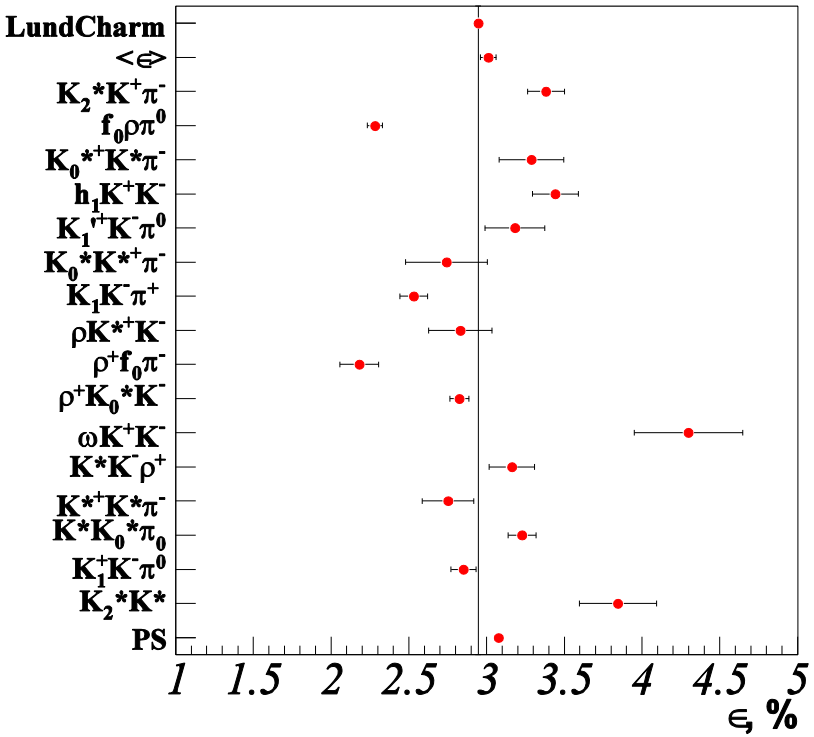




Mass distributions for $2(\pi^+\pi^-)\pi^0$ selected signal events: ┼ data, – MC with LundCharm generator, ─ MC with KsGenHAmp generator, – background (non-$J/\psi \to 5\pi$ decays, LundCharm generator), ┼ continuum events

$J/\psi \to K^+K^-\pi^+\pi^-\pi^0$ decay

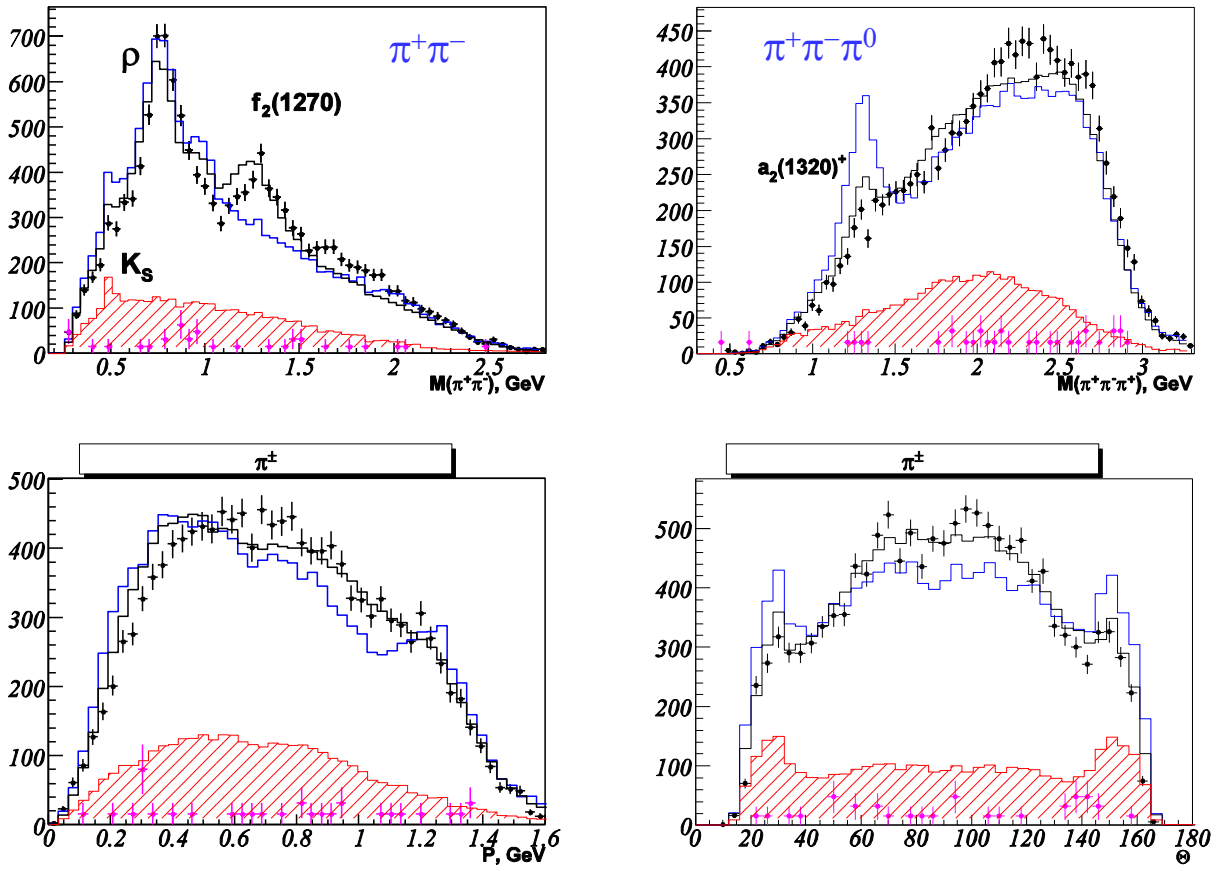


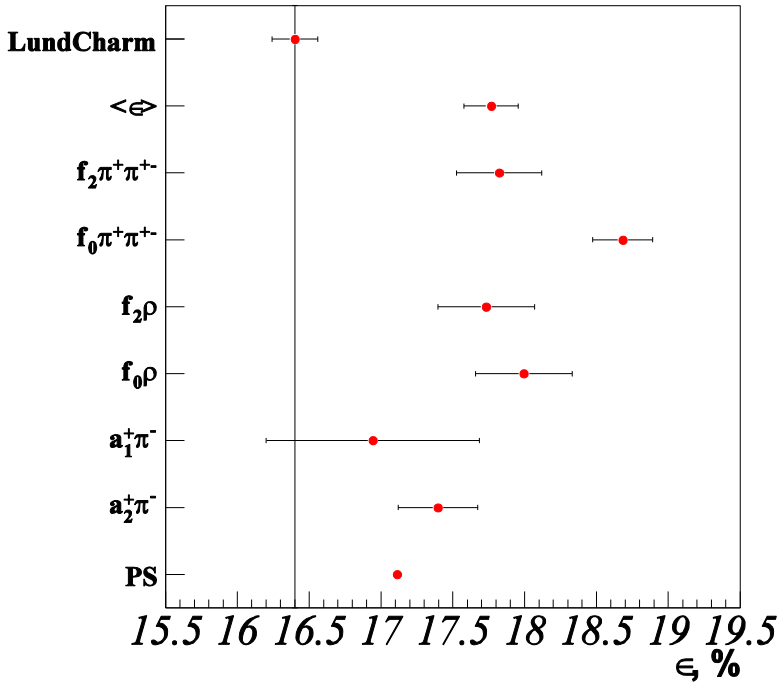


Selection efficiencies for $J/\psi \to K^+K^-\pi^+\pi^-\pi^0$ decays, MC with LundCharm and KsGenHAmp generators

Mass distributions for $K^+K^-\pi^+\pi^-\pi^0$ selected signal events: ┼ data, – MC with LundCharm generator, – MC with KsGenHAmp generator, – background (non-$J/\psi \to 2K3\pi$ decays, LundCharm generator), ┼ continuum events

$J/\psi \to 2(\pi^+\pi^-)$ decay

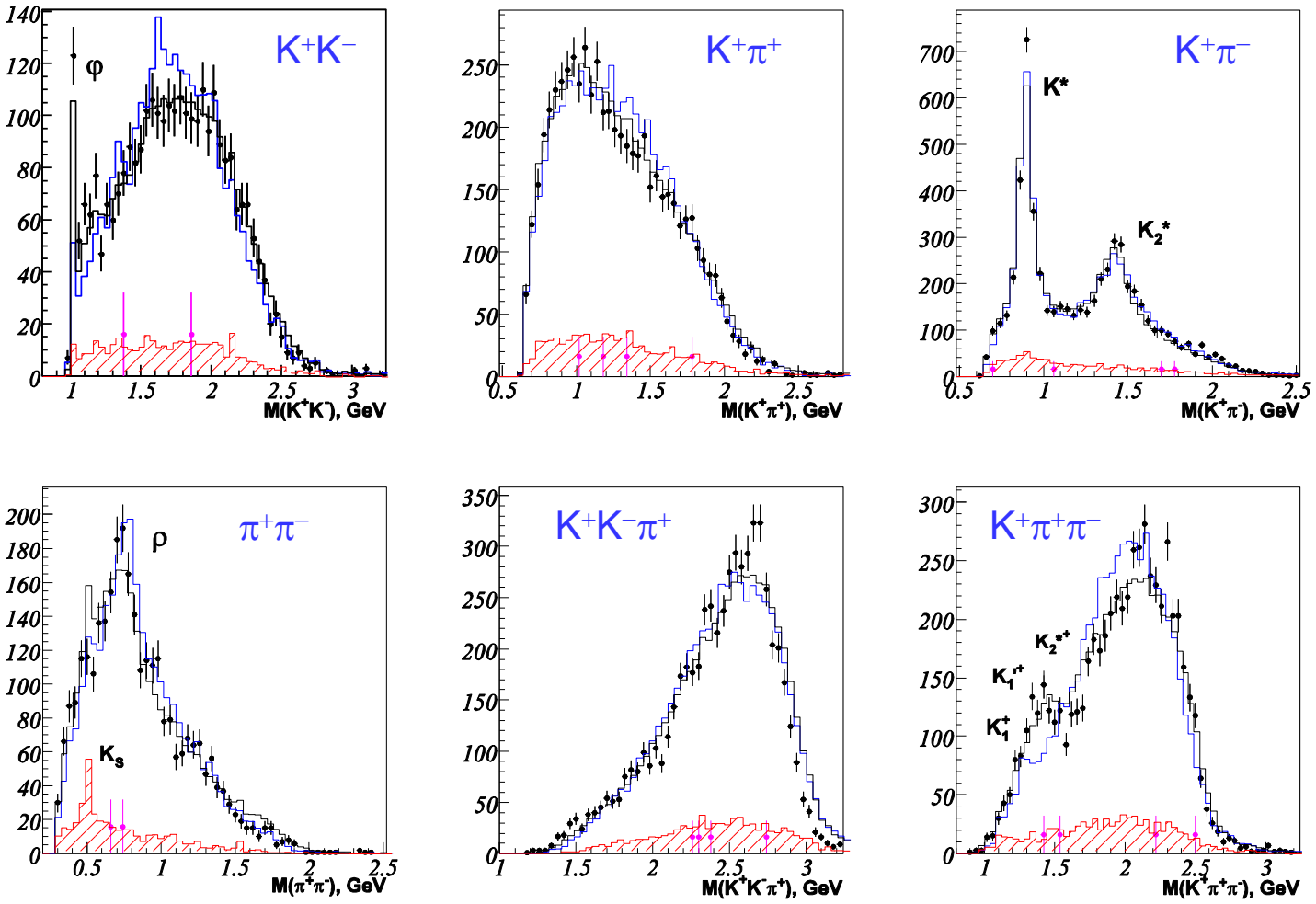




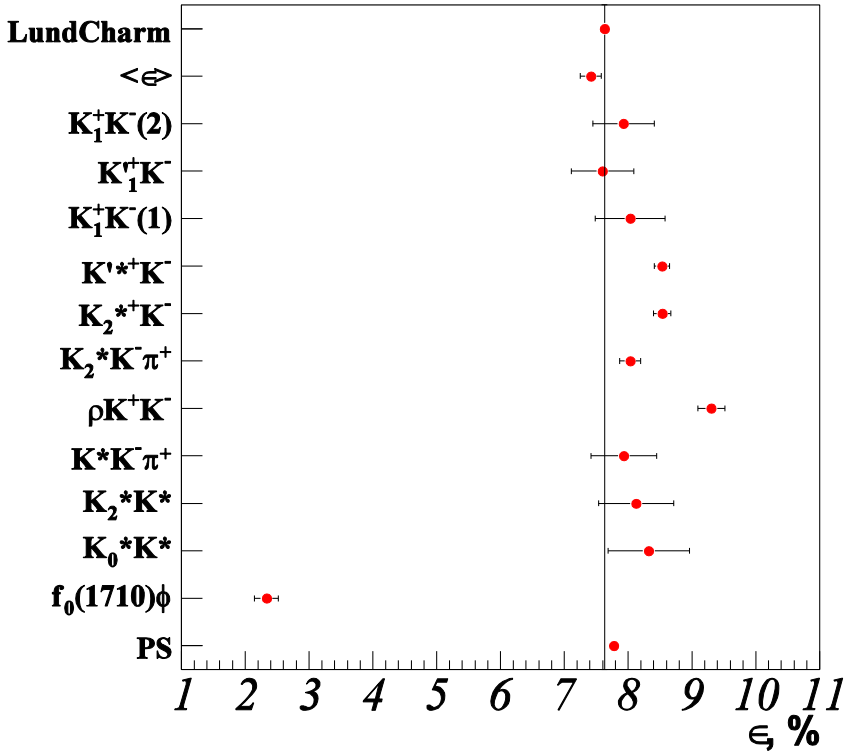
Selection efficiencies for $J/\psi \to 2(\pi^+\pi^-)$ decays, MC with LundCharm and KsGenHAmp generators

Mass, momentum and polar angle distributions for $2(\pi^+\pi^-)$ selected signal events: ┼ data, – MC with LundCharm generator, – MC with KsGenHAmp generator, – background (non-$J/\psi \to 4\pi$ decays, LundCharm generator), ┼ continuum events

$J/\psi \to K^+K^-\pi^+\pi^-$ decay



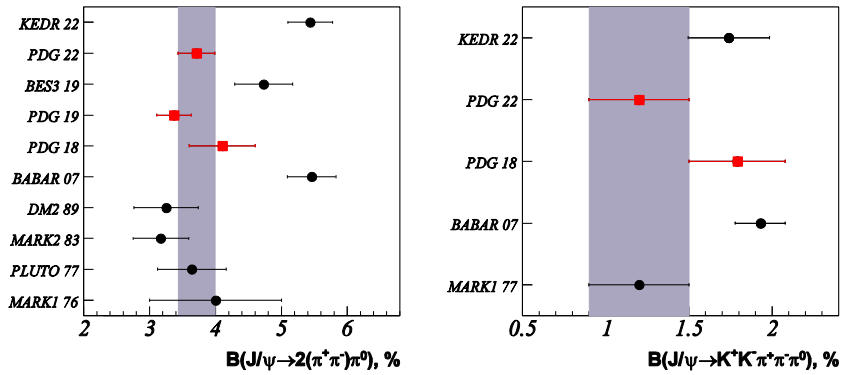
Mass distributions for $K^+K^-\pi^+\pi^-$ selected signal events: ┼ data, – MC with LundCharm generator, – MC with KsGenHAmp generator, – background (non-$J/\psi \to 2K2\pi$ decays, LundCharm generator), ┼ continuum events

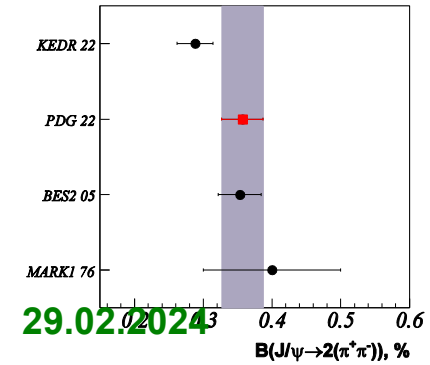


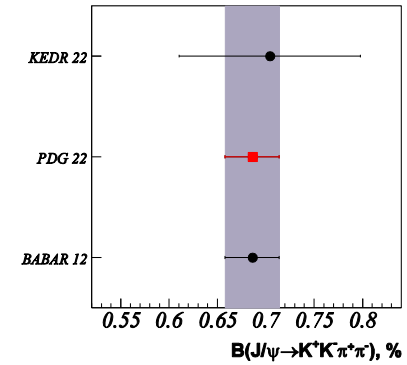
Selection efficiencies for $J/\psi \to K^+K^-\pi^+\pi^-$ decays, MC with LundCharm and KsGenHAmp generators

Systematic uncertainties and results

	N_i^{sig}	ε_i (MC KsGenHamp), %	B_i, % (this work)
$2(\pi^+\pi^-)\pi^0$	22995	8.31 ± 0.32	5.44 ± 0.07 ± 0.33
$K^+K^-\pi^+\pi^-\pi^0$	2616	3.05 ± 0.10	1.74 ± 0.08 ± 0.23
$2(\pi^+\pi^-)$	2654	17.7 ± 0.19	0.288 ± 0.014 ± 0.022
$K^+K^-\pi^+\pi^-$	2671	7.42 ± 0.40	0.704 ± 0.026 ± 0.090



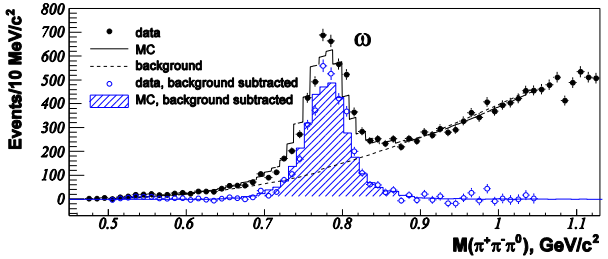


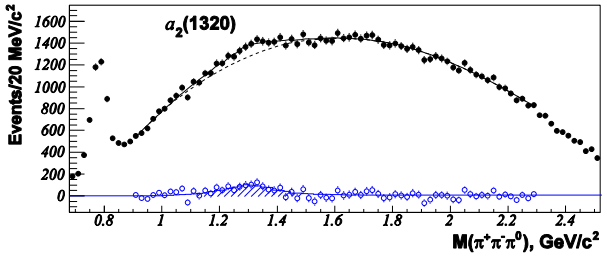


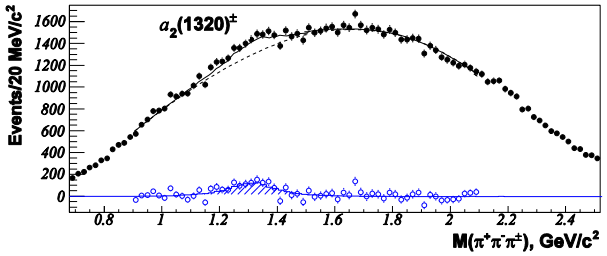
Systematic uncertainties (percent) of measured branching fraction of the $J/\psi\to X_i$ decay:

	$2(\pi^+\pi^-)\pi^0$	$K^+K^-\pi^+\pi^-\pi^0$	$2(\pi^+\pi^-)$	$K^+K^-\pi^+\pi^-$
χ^2 distributions of the kinematic fits	1.0	3.9	3.6	2.9
track registration efficiency	3.6	3.6	3.6	3.6
π^0 registration efficiency	1.5	1.5	-	-
fake π	1.9	3.5	2.8	<1
$\pi\to K$ misidentification	2.1	1.1	2.1	1.1
$K\to\pi$ misidentification	<1	11	<1	10
fitting procedure (range, bin width)	<1	2.6	4.0	2.9
threshold on χ^2 of the kinematic fit	<1	<1	<1	<1
trigger + selection cuts	<1	<1	<1	<1
nonresonant background subtraction	1.6	1.6	1.6	1.6
interference with the continuum	1.9	<1	3.3	1.5
helicity amplitudes of decay	1.6	1.9	1.1	2.2
modes branching fractions of decay modes	2.0	2.9	<1	4.9
interference between decay mode amplitudes	<1	<1	<1	<1
Total	7.4	14.5	7.5	14.7

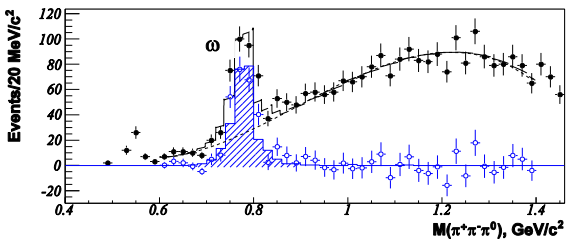
Decays of J/ψ involving intermediate resonances

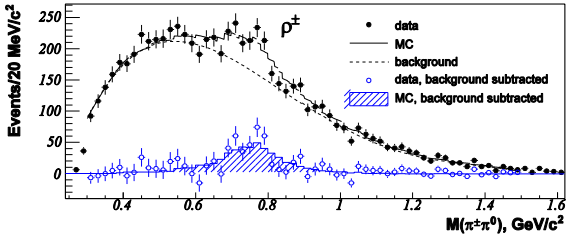




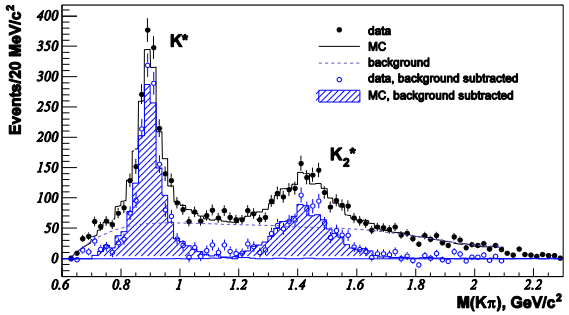


$\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^\pm$ mass distributions for $2(\pi^+\pi^-)\pi^0$ signal events (all combinations per event are shown)



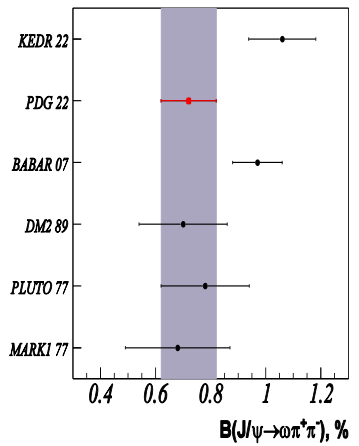


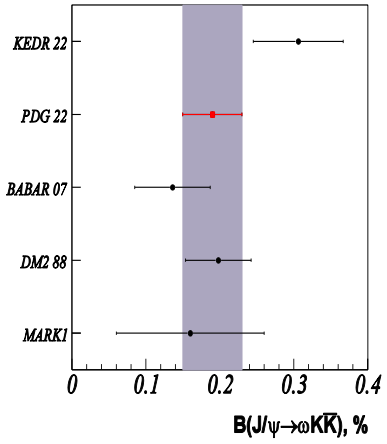
$\pi^+\pi^-\pi^0$ and $\pi^\pm\pi^0$ mass distributions for $K^+K^-\pi^+\pi^-\pi^0$ signal events

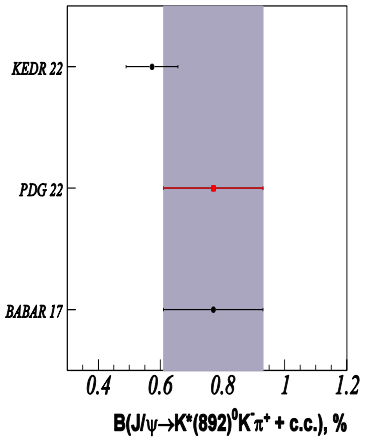


$K^+\pi^-$ and $K^-\pi^+$ mass distributions for $K^+K^-\pi^+\pi^-$ signal events

Decay	ε_R^{MC},%	N_R^{peak}	B_R, % (this work)
$J/\psi \to a_2(1320)^0\pi^+\pi^- \to 2(\pi^+\pi^-)\pi^0$	9.12 ± 0.29	1317 ± 36 ± 265	0.284 ± 0.008 ± 0.060
$J/\psi \to a_2(1320)^+\pi^-\pi^0 + \text{c.c.} \to 2(\pi^+\pi^-)\pi^0$	8.71 ± 0.56	1628 ± 40 ± 247	0.367 ± 0.009 ± 0.073
$J/\psi \to \omega\pi^+\pi^- \to 2(\pi^+\pi^-)\pi^0$	7.34 ± 0.27	3531 ± 59 ± 212	0.946 ± 0.016 ± 0.108
$J/\psi \to \omega\pi^+\pi^-$			1.06 ± 0.02 ± 0.12
$J/\psi \to \omega K^+K^- \to K^+K^-\pi^+\pi^-\pi^0$	4.11 ± 0.42	276 ± 17 ± 17	0.136 ± 0.008 ± 0.026
$J/\psi \to \omega K^+K^-$			0.153 ± 0.009± 0.029
$J/\psi \to \rho^+K^+K^-\pi^- + \text{c.c.} \to K^+K^-\pi^+\pi^-\pi^0$	2.79 ± 0.063	485 ± 22 ± 94	0.353 ± 0.016 ± 0.081
$J/\psi \to K^*(892)^0K^-\pi^+ + \text{c.c.} \to K^+K^-\pi^+\pi^-$	8.00 ± 0.39	1559 ± 39 ± 17	0.381 ± 0.010 ± 0.054
$J/\psi \to K^*(892)^0K^-\pi^+ + \text{c.c.}$			0.573 ± 0.014 ± 0.082
$J/\psi \to K_2^*(1430)^0K^-\pi^+ + \text{c.c.} \to K^+K^-\pi^+\pi^-$	8.06 ± 0.23	1094 ± 33 ± 90	0.265 ± 0.080 ± 0.044







Conclusion

Branching fractions of the $J/\Psi \to \rho\pi$, $2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$ decays were measured with high precision by the KEDR collaboration at VEPP-4M e^+e^- collider