Recent experimental results on charge exchange reactions with VES setup at U-70

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Outline

- Introductory remarks
- VES experiment: scope, methods, setup
- The glueball candidate $f_0(1710)$ in the $\omega\varphi$ system
- The first study of the $\eta'\pi^+\pi^-$ system in charge-exchange reaction
- Conclusion

Intro

- Pomeron exchange dominates at high energy hadron scattering
- Yet other Regge trajectories contribute at U-70 energy range
- Different t-channel exchanges are similar in peripheral character =>

  common experimental approaches/apparatus
- BUT: different objects accessible

➢ Experimental studies with these two are complementary

Scope of the VES experiment

Light mesons spectroscopy

- **New resonances incl. Exotics**
- **New decay channels**
- **Production mechanism studies**
- **Form-factors**

Method

- **(Quasy)Exclusive production of systems of mesons with nuclear target**
- **(Kind of) Partial Wave Analyses (PWA) for quantum numbers of structures**
- **Cross-section measurements (recently started)**

For a system X on a thin target

$$\sigma_X = \frac{N_X^{obs}}{\varepsilon_X\, N_{beam}\, nL}$$

N_X^{obs} – number of registered events of the system under study

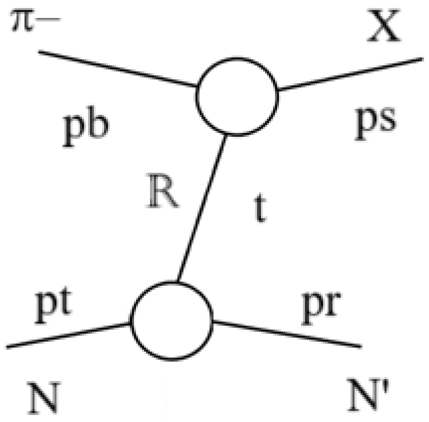
ε – overall efficiency (from modelling)

N_{beam} – number of beam particles through the target with **nuclei** concentration n and of length L

A.A.Shumakov. The Methods of Measuring the Cross Sections of the Reactions in the VES Experiment.

Physics of Particles and Nuclei 56 (2025) 3, pp. 662–667

Scketch of a reaction under study



$$mm^2 = (p_{beam} + p_{target} - p_{system})^2$$
$$t = (p_{beam} - p_{system})^2 = (p_{recoil} - p_{target})^2$$
$$t' = |t| - |t|_{min}$$

X = dedicated system of mesons

(ωφ , $\eta'\pi^+\pi^-$ -- cases of this report)

Target = A, N

Recoil = A´, N, N*, Δ not detected directly

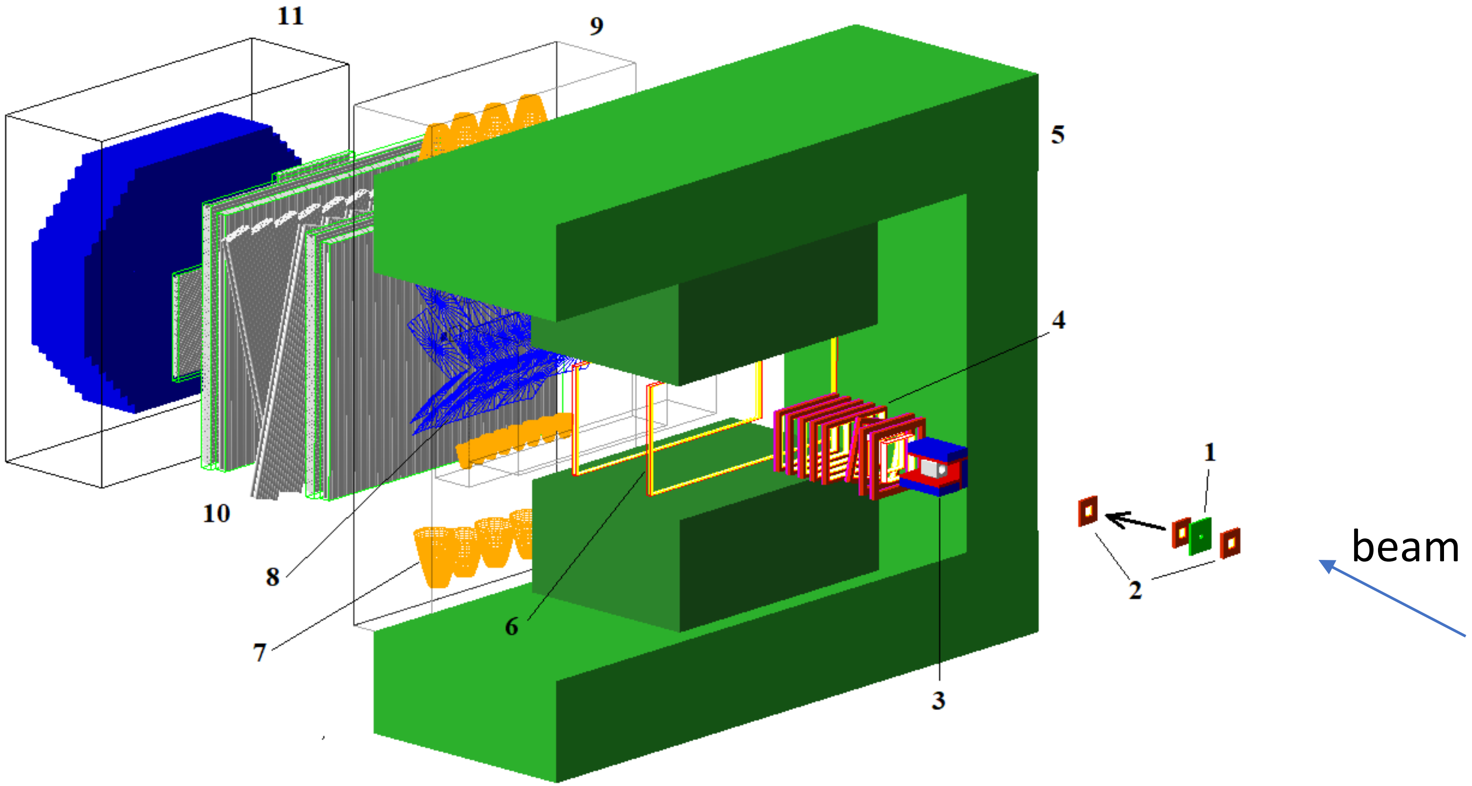
Target fragmentation suppressed with VETO

Missing mass squared *mm2* related to recoil

Momentum transferred squared *t* related to t-channel exchange

ℝ = ℙ or other Reggeon, mostly OPE

Updated VES setup



1 - last beam counter; 2- beam proportional chambers; 3 – target veto; 4 – proportional chambers; 5- main magnet; 6 - drift chambers; 7 - light collectors, 8 - mirrors, and 9 - body of the Cherenkov counter; 10 – drift tubes; 11 - electromagnetic calorimeter.

Trigger components:

Beam particle to target

$$BEAM = S1 \cdot S2 \cdot S3 \cdot \overline{(A10 + A11)}$$

Beam particle disappearance after target
== beam fragmentation

$$MWG = BEAM \cdot \overline{(BK1 + BK2)}$$

No target veto response
== interaction w/o target fragmentation

$$MAIN = MWG \cdot \overline{(VETO)}$$

Major characteristics of the setup

- Secondary beam ~2*10^6/s; p=29 GeV, dp ~ +-1%; 98% π^-, 1.6% K^-, 0.2% $\bar{p}$
- Beam spectrometer with 0.7% accuracy
- Target: ^{9}Be D=45 mm, L=40 mm
- Target Veto with crude segmentation for charged and neutral particles
- Main magnet: H x V~ 2 x 1 m^2 , $\int$B dL ~ 1.5 T*m
- Tracking Spectrometer: 0.5% (1.2%) @3 GeV (@25 GeV)
- Good transparency for γ: < 15% X_0 before the EM-calorimeter
- EMC: resolution @5 ГэВ 4% (E) and 3.2 mm (X)

Typical events selection

- Trigger by choice
- Good status of reconstruction
- Beam through target and with momentum measured (ID optional)
- Final state topology according to system under study (PID optional) w/o debris of tracks and/or gammas
- Primary vertex within target (secondary optional)
- Total momentum of reconstructed particles close to beam momentum
- Narrow signal(s) in inv. masses of subsystem(s) if applicable (π^0, η, η', ω, φ, K_s …)

Study of a scalar resonance in the ωφ system in pion-Be interaction at momentum 29 GeV

Eur.Phys.J.A 60 (2024) 5, 105

Scalar mesons $J^{PC} = 0^{++}$

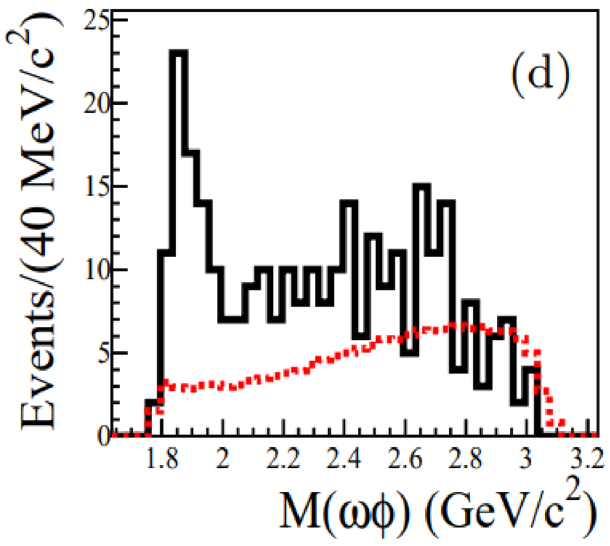
- Light scalars: uncertainty and redundancy in the $SU(3)_{flavor}$ multiplet filling
  (M= 500; 980; 1500; 1710; … MeV)
- Diversity of theoretical models (molecule, 4 - quark, glueball…)

Mass range of 1700 – 1800 MeV:

- $I^G J^{PC} = 0^+ 0^{++}$ signals in various reactions
- One of major sources: $J/\psi \to \gamma f_0$
- PDG: $f_0(1710)$ $M=1733^{+8}_{-7}$ MeV, $\Gamma=150 \pm 12$ MeV
- $Br(J/\psi \to \gamma f_0(1710))$ > than for others f_0
  ↳ (4π, K K, $\pi\pi$, **$\omega\phi$**, $\omega\omega$)

Channel ω(783) ϕ(1020)

BES: e+e- → J/ψ → γ ω(783) φ(1020)
Ablikim, M., et al. . Phys. Rev. Lett. 96, 162002 (**2006**)
https://arxiv.org/abs/hep-ex/0602031.



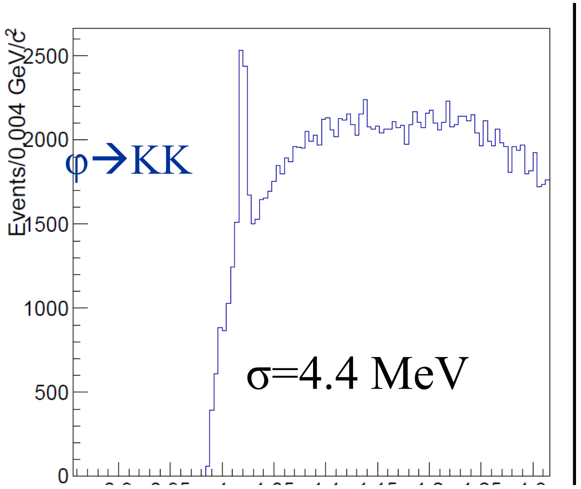
This work by VES:

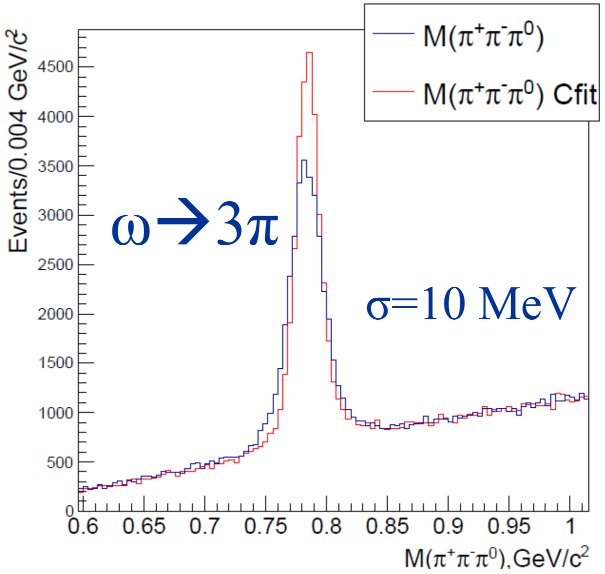
π^- Be → A' $\omega(\pi^+ \pi^- \pi^0)$ $\varphi(K^+K^-)$

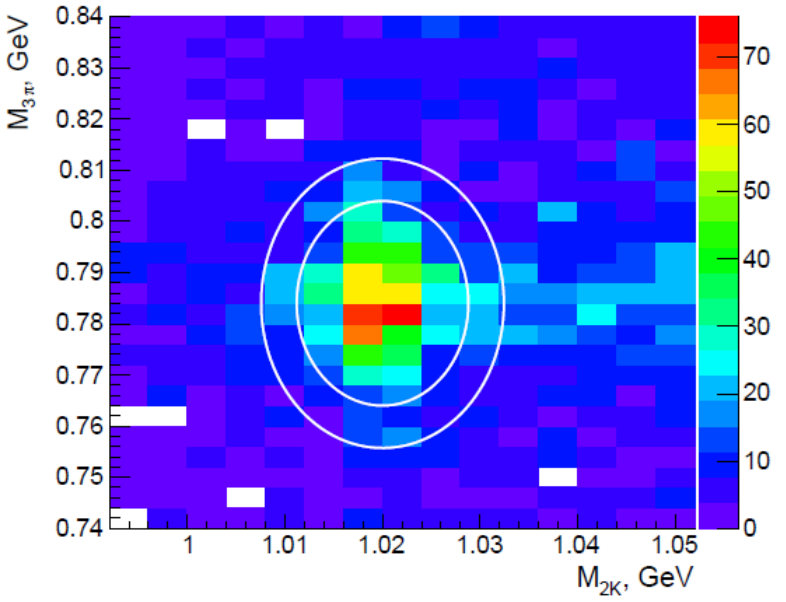
(A' – nucleus and neutron)

at p= 29 GeV

Some features of ωφ system

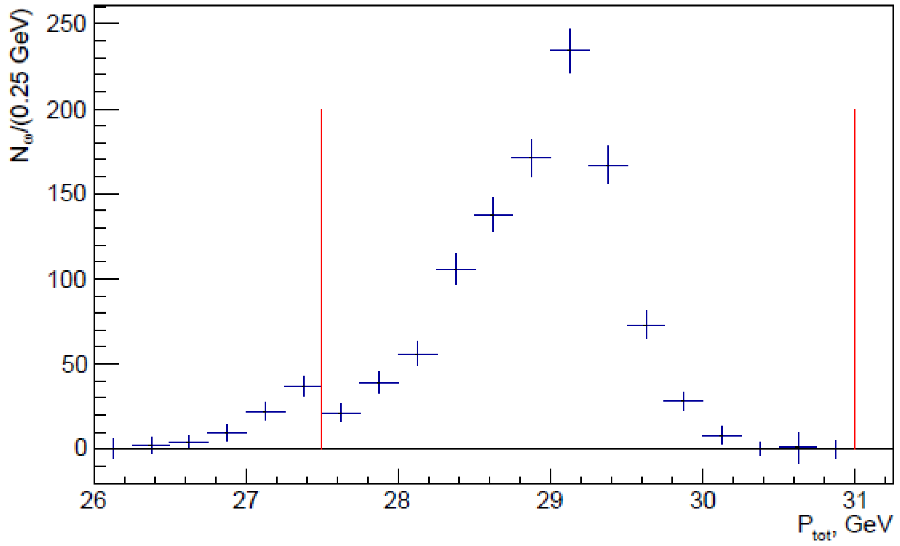




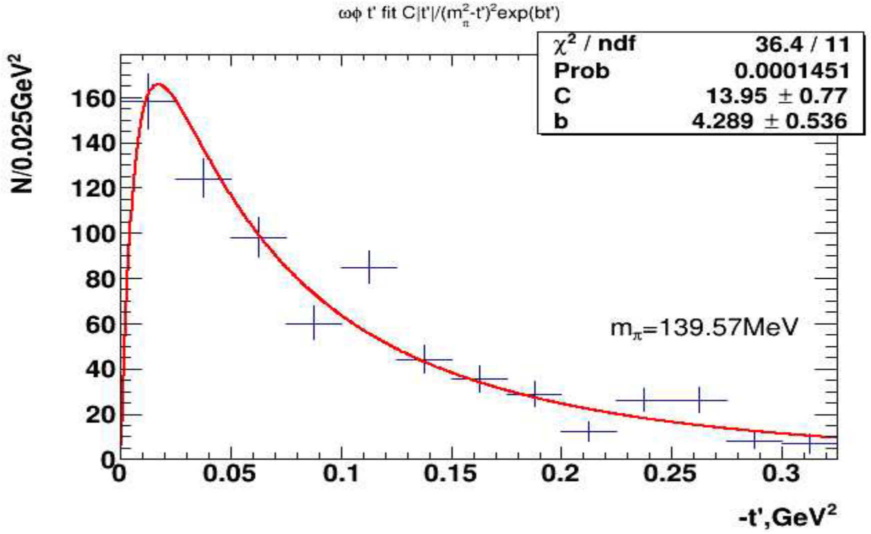


$$r_{2M}^2 = (M_{3\pi} - M_\omega)^2/(2\sigma_\omega)^2 + (M_{2K} - M_\phi)^2/(2\sigma_\phi)^2 \leq 1$$

Some features of ωφ system (2)

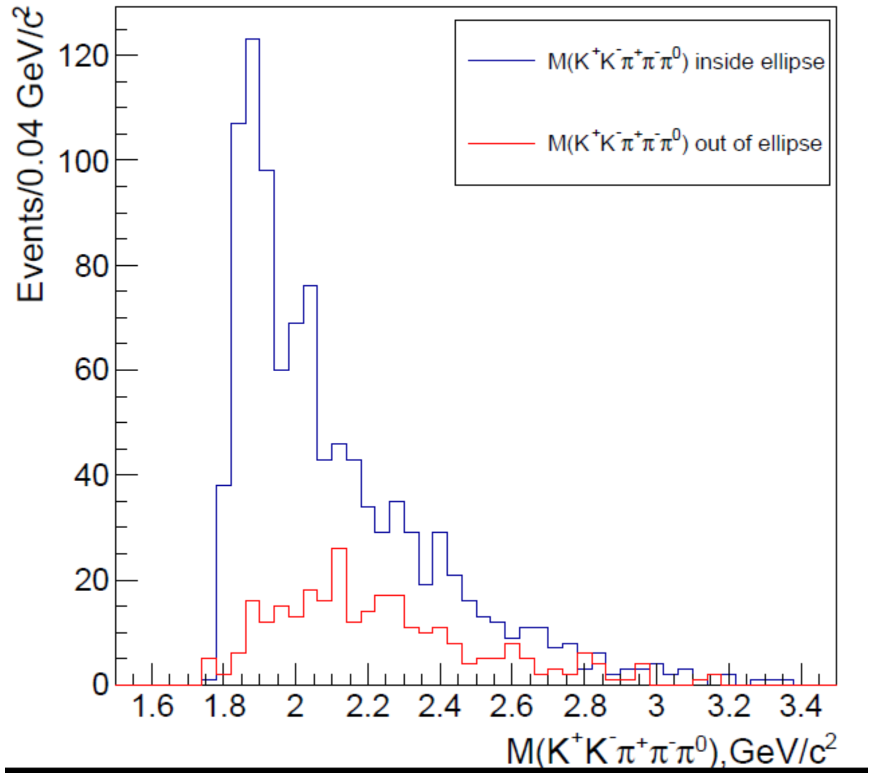


P_{tot}: "exclusivity" cut



t – distribution and OPE fit

Invariant mass spectra in signal and background regions

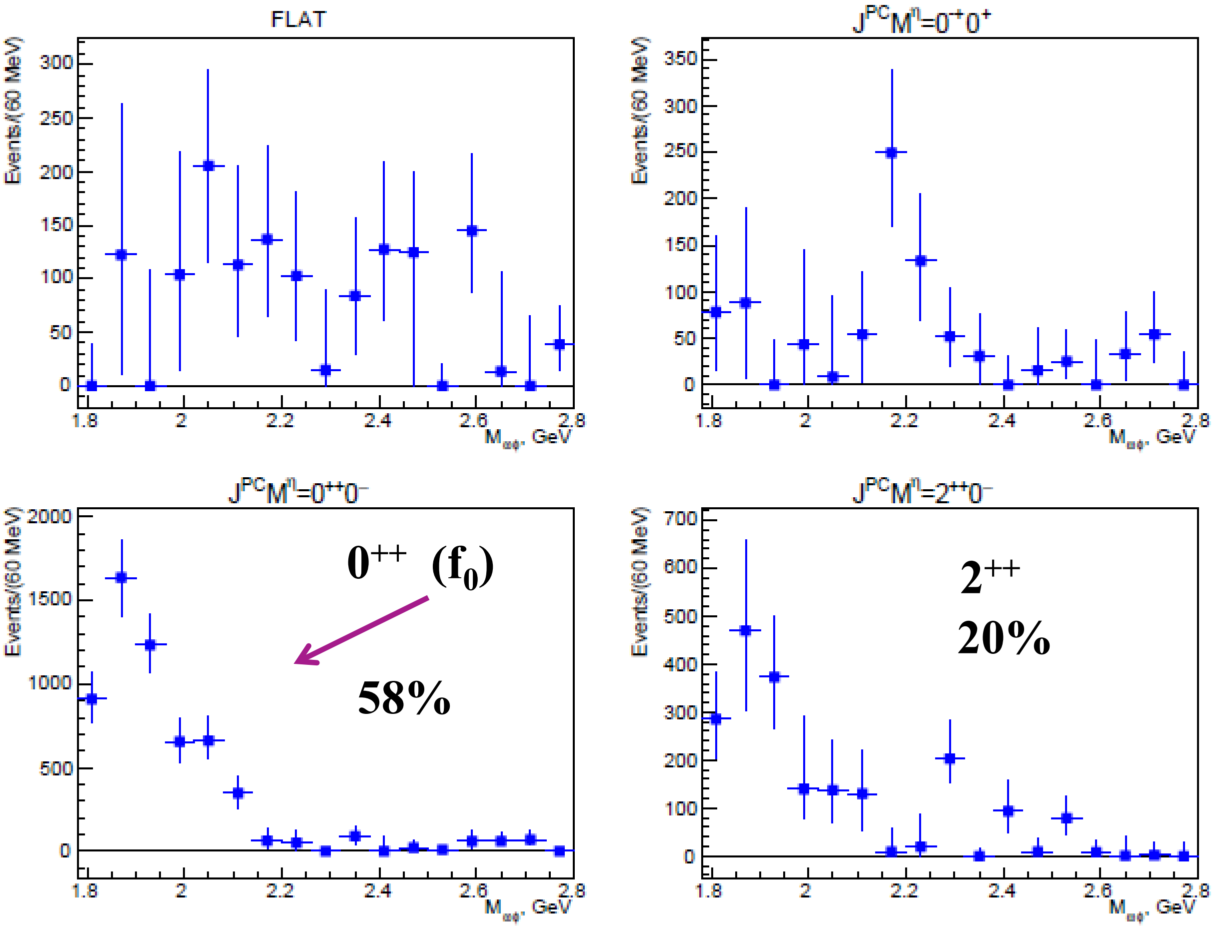


Partial Wave Analysis of $\omega\phi$

- Mass-independent PWA in 60-MeV bins, no t - binning
- Approximation of narrow ω, ϕ (quasi-2-particle PWA)
- Production matrix r=1 in Gottfried-Jackson system =>
  compex elements = fit parameters
- «reflectivity» basis: $\eta=\pm 1$ correspond to NPE, UPE
- Decay amplitudes in Zemach tensor formalism; s1+s2 → S, S+L → J
- Event-by-event extended Likelihood method
- Acceptance (efficiency) integrals with Monte-Carlo

Major PWA fit

(t<0.15 GeV^2 , 580 events)



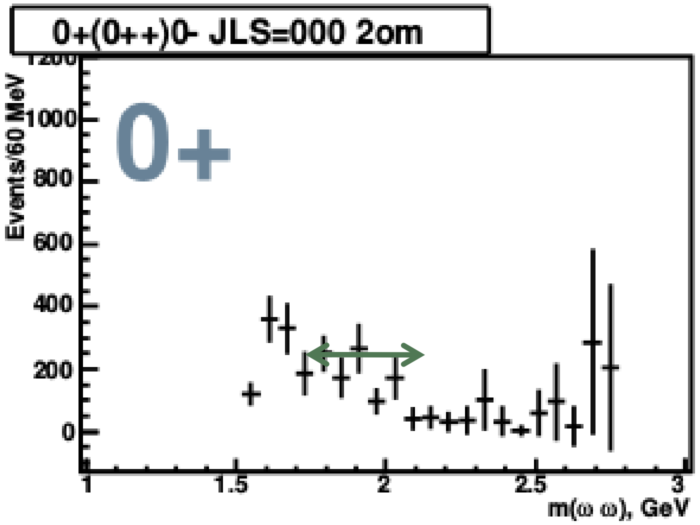
UPE waves dominate supporting OPE

Comparison of ω φ and ω ω channels

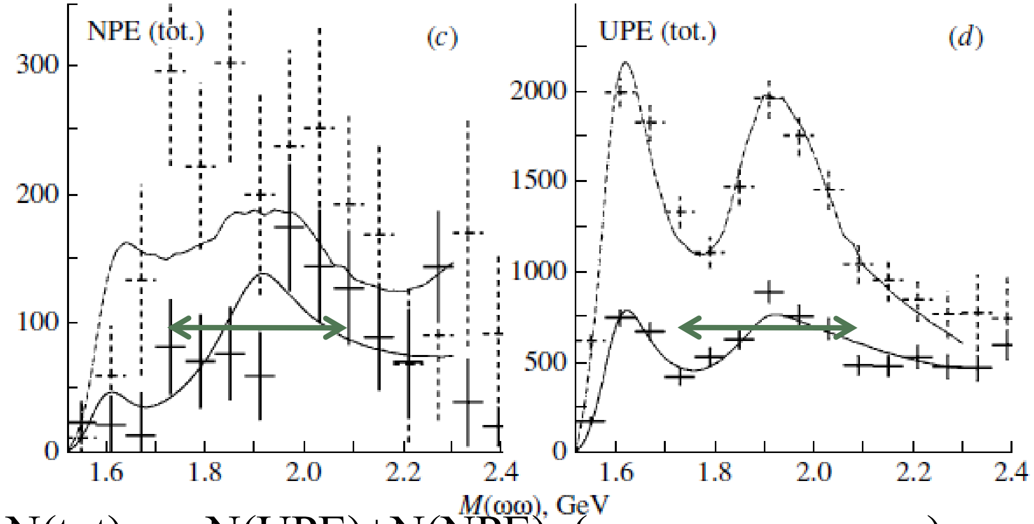
- OZI rule: in various hadron reactions w. light quarks yields ratio
  $R(\varphi/\omega) \sim \tan^2\theta = 4.2 \cdot 10^{-3}$ $(\theta = 3.7^{o}, \ \phi = s\bar{s}\cos\theta + n\bar{n}\sin\theta)$
- Nomokonov, V.P., Sapozhnikov, M.G.: Experimental tests of the Okubo-Zweig-Iizuka rule in hadron interactions. Phys.Part.Nucl. 34, 94–123 (2003)
- **Use older VES results on ωω @28 GeV for comparison with ωφ @29 GeV**

Amelin D.V, et al.. PAN 69, 690-698 (2006); Ivashin, A., et al.: AIP Conf. Proc. 1257(1), 262–266 (**2010**).

⟷ Region of Interest for ωϕ



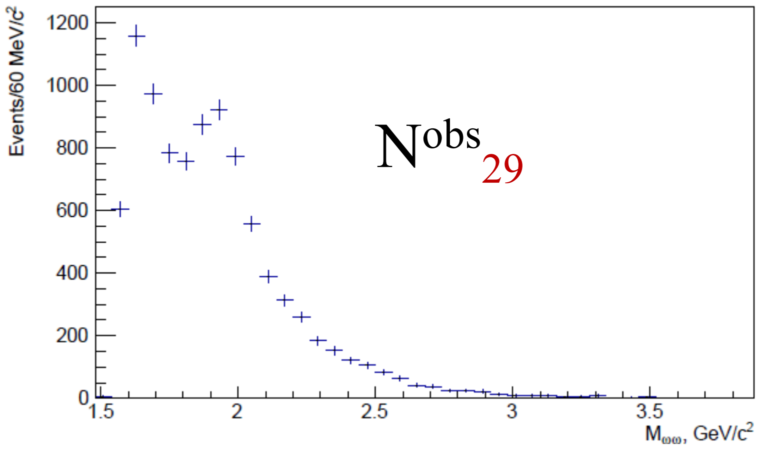
$N(0^{++})_{28}$



$N(tot)_{28}$ = N(UPE)+N(NPE) (штриховые гист.)

Comparison of ωϕ and ωω channels (2)

- Newly measured spectrum M(ωω)
- GEANT-model efficiency
  $<\varepsilon_{29}> = 0.06 \pm \mathbf{0.003}$



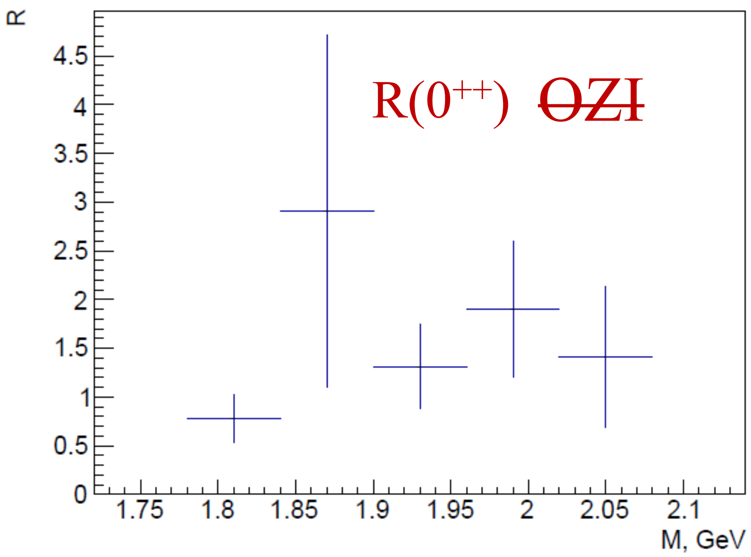
$$N^{0^+}_{\omega\omega,29}(M_{\omega\omega}) = \frac{N^{obs}_{\omega\omega,29}}{\epsilon_{29}} \cdot \frac{N^{0^+}_{\omega\omega,28}}{N_{\omega\omega,28}}$$

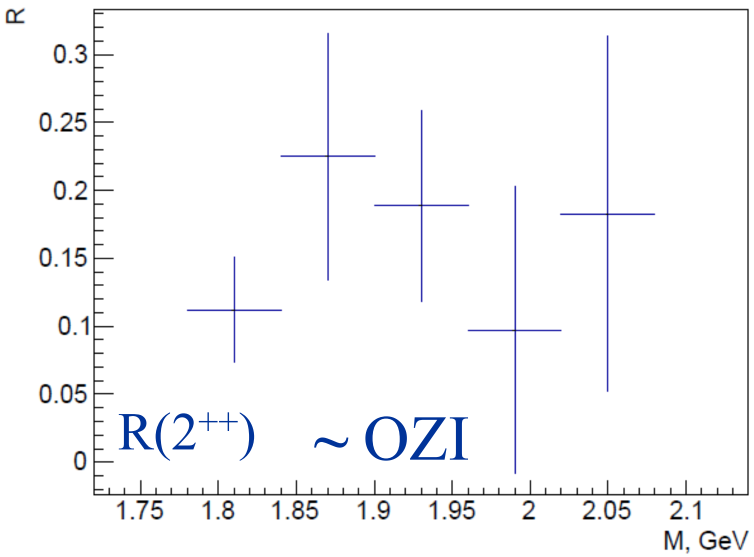
↓

$$R = \frac{N^{0^+}_{\omega\phi,29}}{N^{0^+}_{\omega\omega,29}} \cdot \frac{Br(\omega \to \pi^+\pi^-\pi^0)}{Br(\phi \to K^+K-)}$$

Ratio of 0^{++} intensities in ωφ and ωω

Comparison of $\omega\phi$ and $\omega\omega$ channels (3)





Maximal OZI – rule violation

$R_A = R\ q_{\omega\omega}/q_{\omega\varphi}$ (q – decay momenta) -- to account for phase space differense

M=[1.84…2.08]

$\langle R_A \rangle\ (0^{++}) = 2.4 \pm 0.5$ (!) $\langle R_A \rangle\ (2^{++}) = 0.30 \pm 0.08$

✓Large mixing of scalars (but not tensors) w. different quark content ?

Isgur, N., Thacker, H.B.: On the origin of the OZI rule in QCD. Phys.Rev. D 64, 094507 (2001)

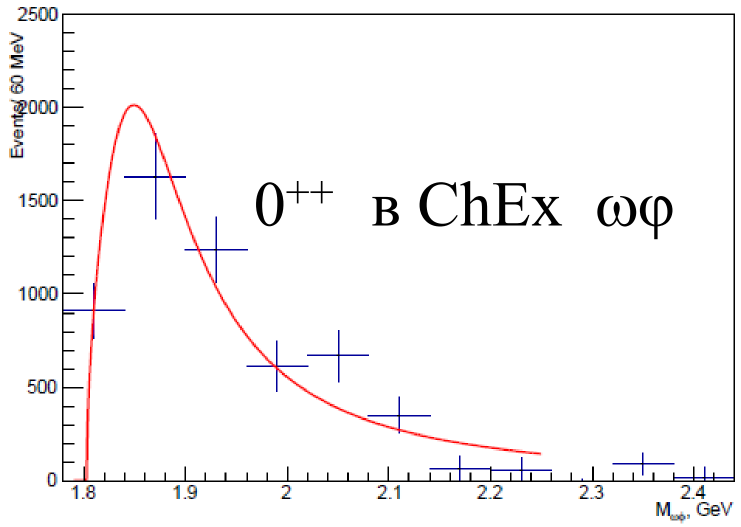
Comparison of 0^{++} in two production processes

❖ π^- Be → A' f_0 vs J/ψ → γ f_0 (1710)

|→ (ωφ, ωω) |→ (ωφ, ωω)

R(ChEx) = 0.7 ± 0.15 R(Rad.dec.) = 0.8 ± 0.4 $(M>M_{\omega\omega})$

❖ $$\frac{dN}{dM} = \frac{CM_R^2\Gamma_0 g q_{\omega\phi}}{(M_R^2 - M^2)^2 + M_R^2(\Gamma_0 + g q_{\omega\phi})^2} \quad (M > M_\omega + M_\phi)$$



M_R = 1834 ± 14 (stat.) $^{+2}_{-10}$ (syst.) MeV

Γ_0 = 114 ± 15 (stat.) $^{+5}_{-15}$ (syst.) MeV

Br(R→ ωφ) ≈ g = 0.1

N.B. Rad.dec.:

M_R = 1795 ± 7 $^{+23}_{-20}$ MeV

Γ_0 = 95 ± 10 $^{+78}_{-82}$ MeV

✓ Conclusion: the same object observed

(?) f_0(1710) according to PDG: $M=1733^{+8}_{-7}$ MeV, $\Gamma = 150^{+12}_{-10}$ MeV

ChEx cross-section for $f_0(1710)$

❖ The key element in the analysis

$\sigma(\pi^- Be \rightarrow A\ \omega\varphi)$ ($J^{PC}=0^{++}$, $M_{\omega\varphi} < 2.14$ GeV, $|t| < 0.15$ GeV^2) =

$98 \pm 7(stat.) \pm 7(syst.)$ nBn

❖ChEx on light nuclei*: $\sigma \propto Z^{0.73 \pm 0.03}$

❖ σ ($\pi^- p \rightarrow n\ \omega\varphi$) ($J^{PC}=0^{++}$, $M_{\omega\varphi} < 2.14$ GeV, $|t| < 0.15$ GeV^2) =

36 ± 5 nBn

[12] Kolbig, K.S., Margolis, B.: Particle production in nuclei and unstable particle cross-sections. Nucl. Phys. B **6**, 85–101 (1968). https://doi.org/10.1016/0550-3213(68)90271-X

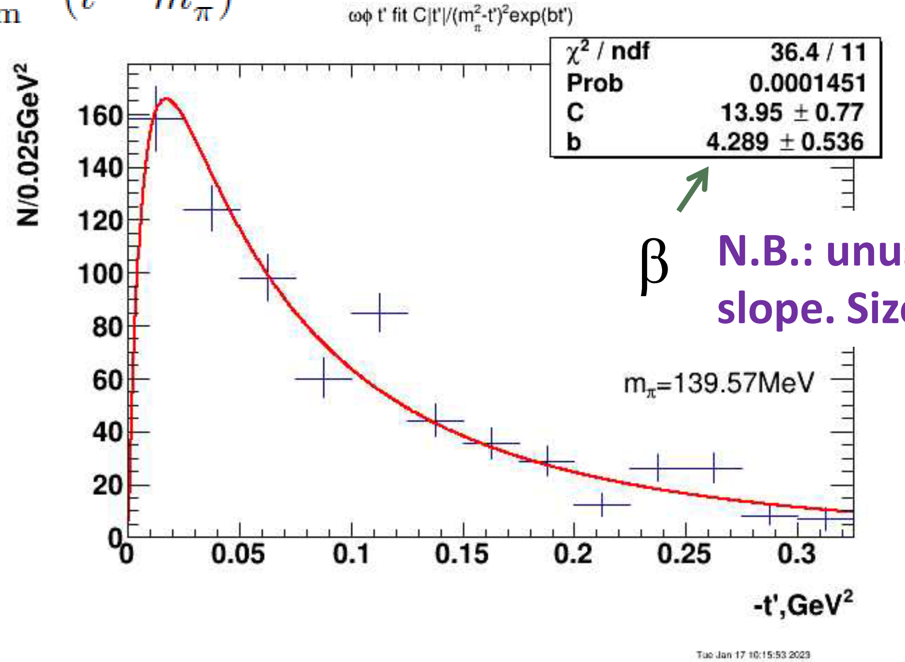
[13] Guisan, O., Bonamy, P., Le Du, P., Paul, L.: Study of pi- p —> pi0 n and pi- p —> eta n reactions in nuclei at 7.82 gev/c. Nucl. Phys. B **32**, 681–690 (1971). https://doi.org/10.1016/0550-3213(71)90500-1

* [14] Apokin, V.D., *et al.*: DETERMINATION OF THE CROSS-SECTION OF THE PROCESS pi+ pi- —> pi0 pi0 IN THE DIPION MASS RANGE 0.55-GeV < M < 2-GeV FROM THE REACTION pi- p —> pi0 pi0 n AT 39.1-GeV/c. Sov. J. Nucl. Phys. **49**, 278 (1989)

From OPE X-section to Br($f_0 \to 2\pi$)

$$\frac{d\sigma(\pi^- p \to nX) Br(X \to \text{channel})}{d|t|} =$$

$$26.9\,\text{mb}\, Br(X \to \pi\pi) Br(X \to \text{channel}) \frac{M_X \Gamma_X}{P^2_{\text{beam}}} \frac{|t|\, e^{\beta(t-m^2_\pi)}}{(t-m^2_\pi)^2}$$



β N.B.: unusually small slope. Size of f_0 ?

[16] Chew, G.F., Low, F.E.: Unstable particles as targets in scattering experiments. Phys. Rev. **113**, 1640–1648 (1959). https://doi.org/10.1103/PhysRev.113.1640

[17] Williams, P.K.: Extrapolation model for pi pi scattering. Phys. Rev. D 1, 1312–1318 (1970). https://doi.org/10.1103/PhysRevD.1.1312

[18] Hyams, B., *et al.*: t Dependence and Production Mechanisms of the rho, f and g Resonances from pi- p –> pi- pi+ n at 17.2-GeV. Phys. Lett. B **51**, 272–278 (1974). https://doi.org/10.1016/0370-2693(74)90290-1

Combining probabilities from ChEx and RadDecay data:

- $Br(f_0 \to \pi\pi) \cdot Br(f_0 \to \omega\varphi) = (4.8 \pm 1.2) \cdot 10^{-3}$ (this work) &
- $Br(J/\psi \to \gamma\, f_0(\to \pi\pi)) \cdot Br(J/\psi \to \gamma\, f_0(\to \omega\varphi)) = (9.5 \pm 2.6) \cdot 10^{-8}$ (PDG)

⬇

✓ $Br\,(J/\psi \to \gamma\, f_0(1710)) = \mathbf{(4.5 \pm 0.8) \cdot 10^{-3}}$

- Lattice calculations for a scalar glueball:

  $Br(J/\psi \to \gamma\ 0^{+}gg) = \mathbf{(3.8 \pm 0.9) \cdot 10^{-3}}$

[19] Gui, L.-C., Chen, Y., Li, G., Liu, C., Liu, Y.-B., Ma, J.-P., Yang, Y.-B., Zhang, J.-B.: Scalar Glueball in Radiative J/ψ Decay on the Lattice. Phys. Rev. Lett. **110**(2), 021601 (2013) https://arxiv.org/abs/1206.0125 [hep-lat]. https://doi.org/10.1103/PhysRevLett.110.021601

✓ Large (dominant ?) glueball component in $f_0(1710)$

More about glueball

❖ A model for Rad.Dec. of heavy vector quarkonium

Close, F.E., Farrar, G.R., Li, Z.-p.: Determining the gluonic content of isoscalar mesons. Phys. Rev. D 55, 5749–5766 (1997):

$$\Gamma\ [(1^{-}\ Q\ \bar{Q}\,) \rightarrow \gamma\, R_J\,] \ \propto\ \Gamma\,[R_J \rightarrow\ gg]$$

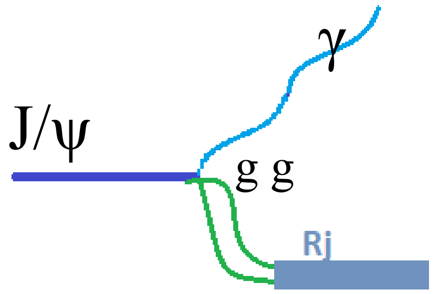
The coefficient of proportionality is calculated

Using our finding

$Br\ (J/\psi \rightarrow \gamma\ f_0(1710)\ ) = (4.5 \pm\ 0.8) \cdot 10^{-3}$

one gets

$Br(f0(1710) \rightarrow gg) = 1.7 \pm 0.4$



Alternative for $f_0(1710)$ «from PDG»

- **2** scalars are discussed in $1.7 < M < 1.8$ GeV range
- A comprehensive analisis :

[12] Sarantsev, A.V., Denisenko, I., Thoma, U., Klempt, E.: Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays. Phys. Lett. B **816**, 136227 (2021) https://arxiv.org/abs/2103.09680 [hep-ph]. https://doi.org/10.1016/j.physletb.2021.136227

$BR_{J/\psi\to\gamma f_0\to}$	$\gamma\pi\pi$	$\gamma K\bar{K}$	$\gamma\eta\eta$	$\gamma\eta\eta'$	$\gamma\omega\phi$	Missing		Total	Unit
						$\gamma 4\pi$	$\gamma\omega\omega$		
$f_0(1710)$	6±2	23±8	12±4	6.5±2.5	1±1	7±3		56±10	$\cdot 10^{-5}$
$f_0(1770)$	24±8	60±20	7±1	2.5±1.1	22±4	65±15		181±26	
$f_0(1750)$	38±5	99^{+10}_{-6}	24^{+12}_{-7}		25±6	97±18	31±10		

✓ Splitting of $f_0(1710)$ to **another $f_0(1710)$** and $f_0(1770)$

✓ **Only $f_0(1770)$** contributes to $\omega\phi$ ➔ is observed in VES

✓ Using parameters for $f_0(1770)$ and our data on X-section in $\omega\phi$ → small change of quantitative results:

$$Br(f_0(1770) \to \pi\pi)\, Br(f_0(1770) \to \omega\varphi) = (3.9 \pm 1.0) \cdot 10^{-3}$$

$$Br(J/\psi \to \gamma f_0(1770)) = (3.7 \pm 0.8) \cdot 10^{-3}$$

$$Br(f_0(1770) \to gg) = 1.12 \pm 0.32$$

Conclusion

- VES experiment measures

$\sigma(\pi^- Be \to A\, f_0\, (|t|<0.15\ GeV^2)) \cdot Br(f_0 \to \omega\varphi) = 98 \pm 7(stat.) \pm 7\ (syst.)$ nBn

- With OPE approximation , identifying the f_0 either as $f_0(1710)$ or $f_0(1770)$

and together with J/ψ Rad.Dec. data:

$$Br\ (J/\psi \to \gamma\, f_0(1710)) = (4.5 \pm 0.8) \cdot 10^{-3}$$

or Br $(J/\psi \to \gamma\, f_0(1770)) = (3.7 \pm 0.8) \cdot 10^{-3}$

According to models this points to large glueball component in this meson.

Study of the $\eta'\pi^+\pi^-$ system

in charge-exchange reaction of pions with Be at 29 GeV

Motivation

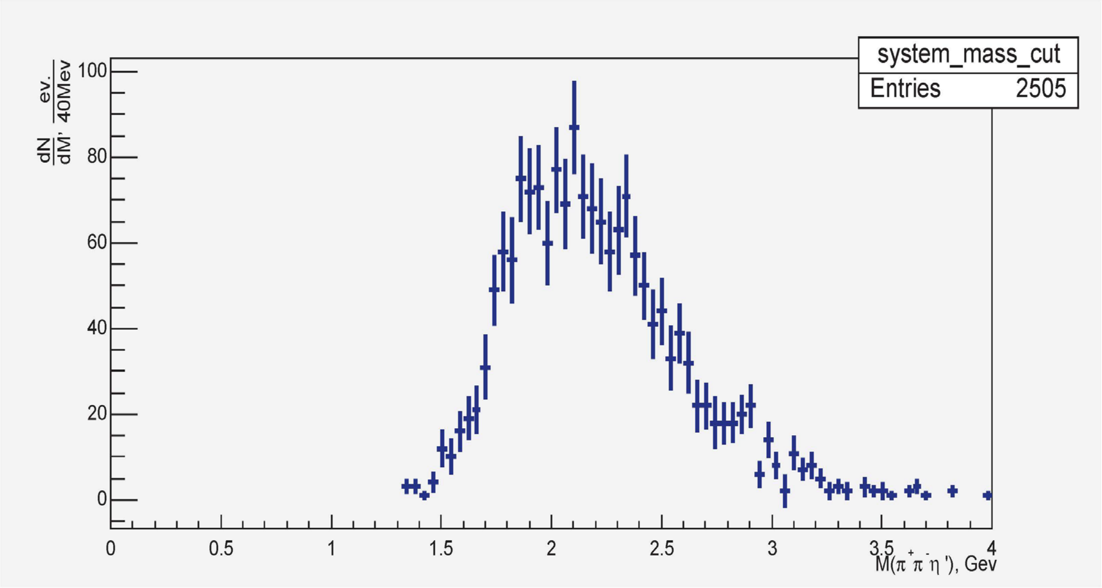
- A special role of the η´ in $J^P = 0^-$ (ℙ) nonet. Large mass due to ► - anomaly
- What are its radial excitations ? In particular in the $\eta'\pi^+\pi^-$ channel
- ℙ – glueball also coupled to $\eta'\pi^+\pi^-$
- Wide set of quantum numbers possible. Comparison of structures in η´ππ and ηππ from point for a search for hybrids.
- Possible qq –exotic $J^{PC} = 1^{-+}$ wave in the subsystem η´π
- Experimental data on η´ππ are scarce: some form pp, majority form e^+e^- , including rad.decays of J/ψ. In particular X(2600) with $I^G J^{PC} = 0^+0^{-+}$ or 0^+2^{-+}.
- **No data** in ChEx. Another mechanism → possible access to different set of states

Characteristics of the selected sample

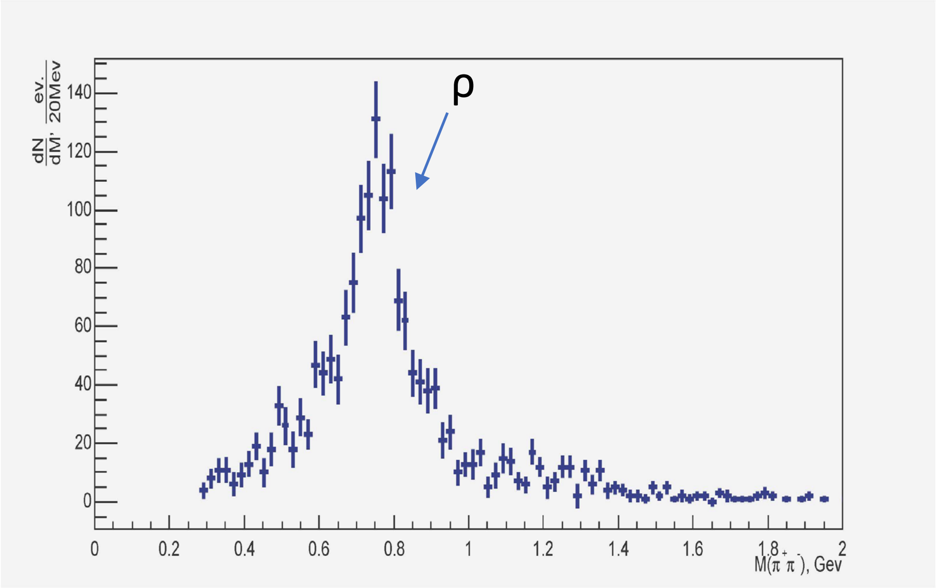
$\eta'\pi^+\pi^-$ $\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^- 2\gamma$ Br = 16.75%

- Data of 7 runs y. 2013 - 2024 ; ~$2.8 * 10^{11}$ beam particles during live-time

$\pi\pi\eta'$ invariant mass spectrum



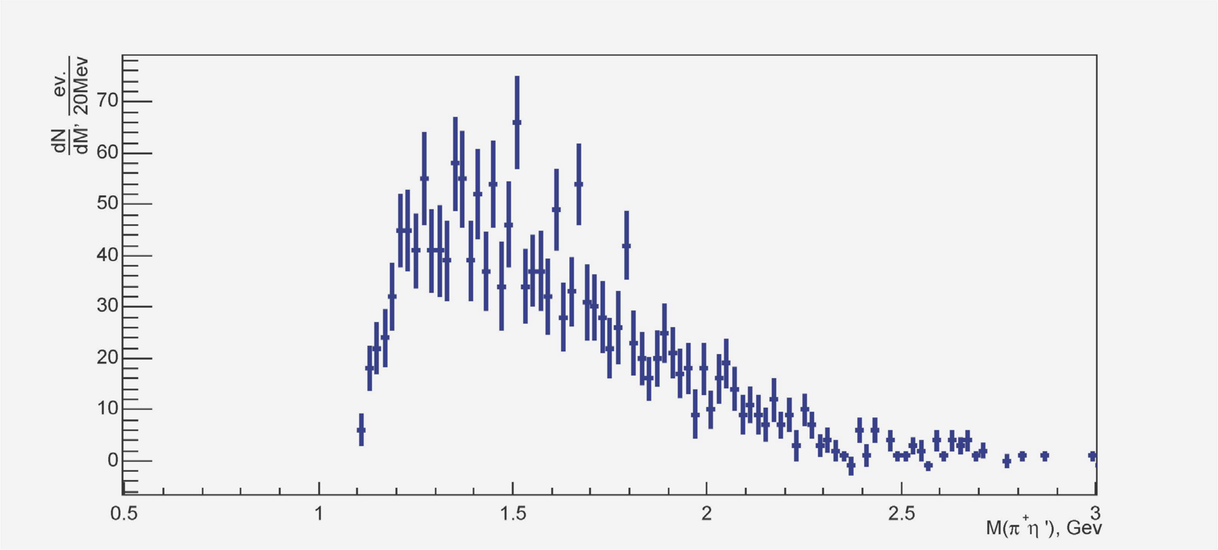
$\pi^+\pi^-$ mass spectrum



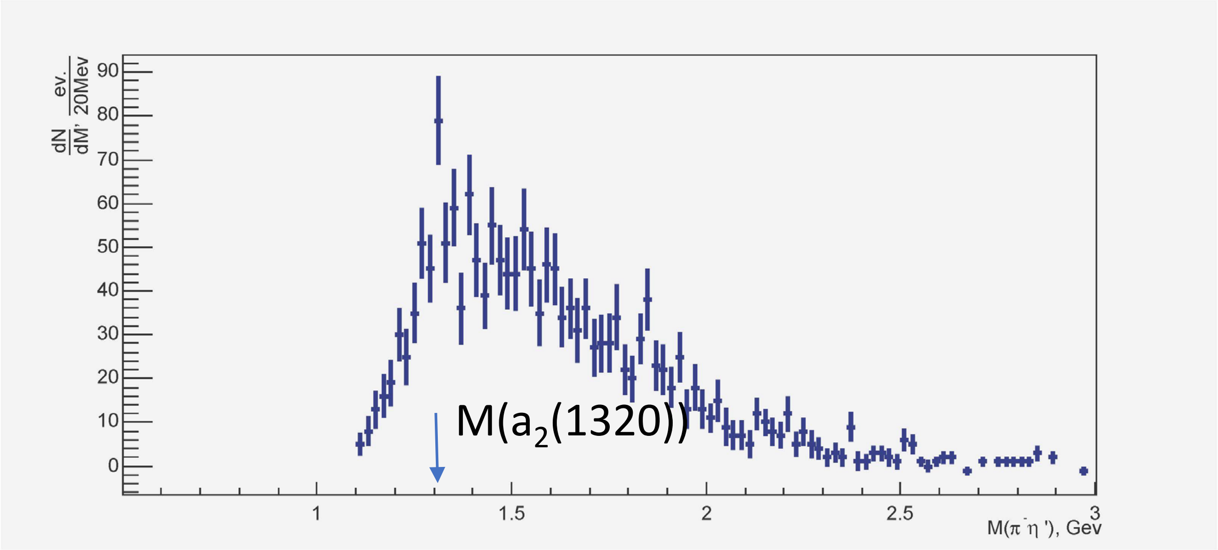
- **I=1 states ρη´ dominate in the ππη´**

Characteristics of the selected sample (2)

$\pi^+ \eta'$ mass spectrum



$\pi^- \eta'$ mass spectrum

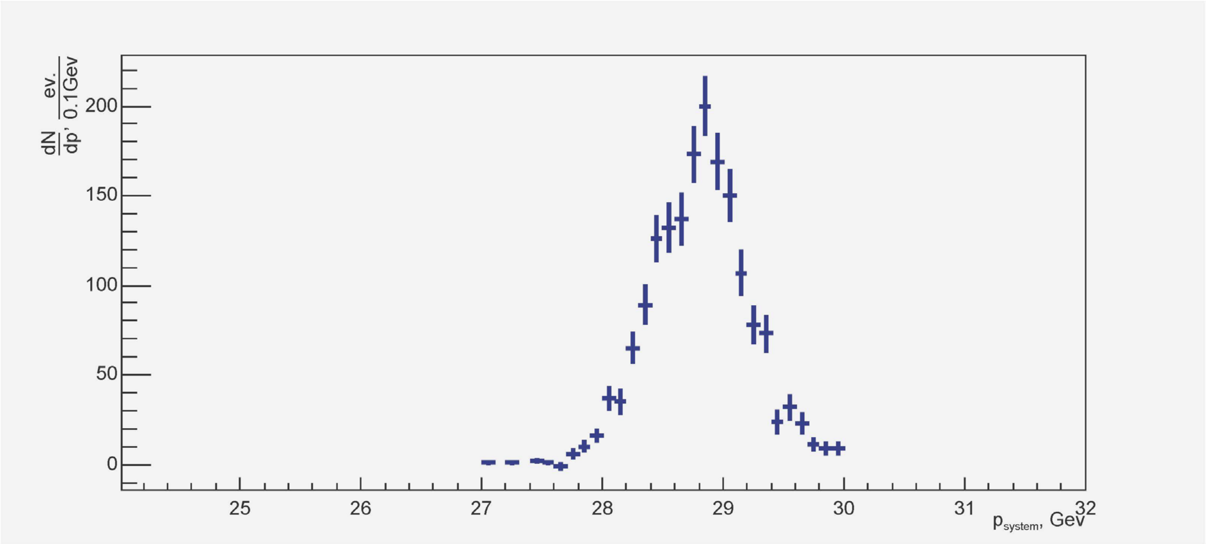


No evident structures

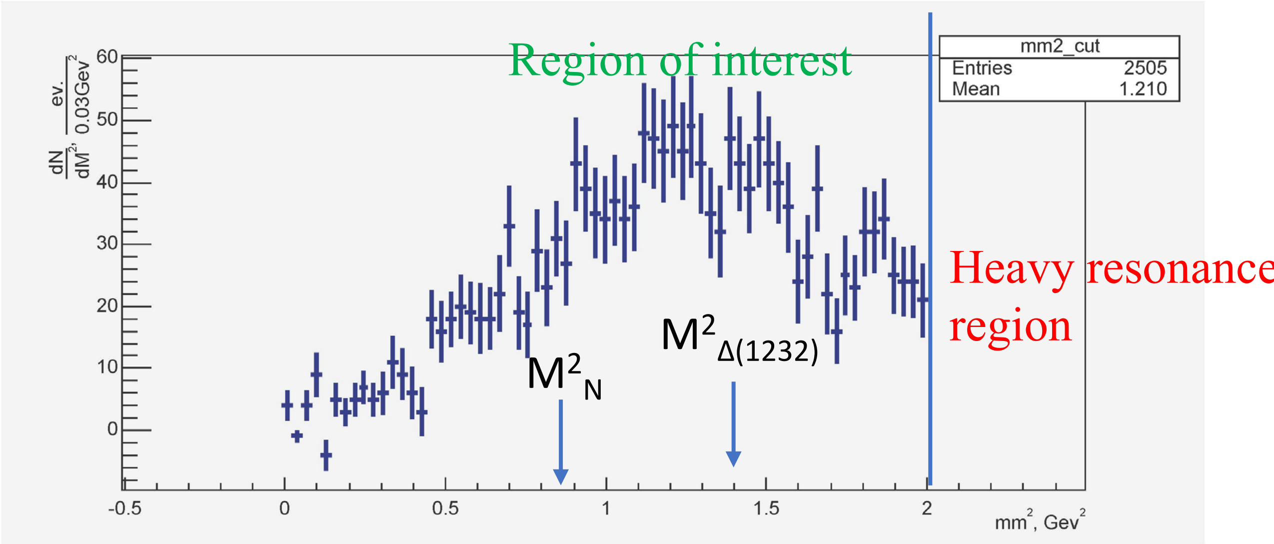
$a_2(1320)$?

Characteristics of the selected sample (3)

Momentum spectrum of the system



Missing mass squared distribution



Exclusivity:

- **no missed "fast" particles from beam fragmentation.**
- **target fragmentation dominates over nucleon recoil**

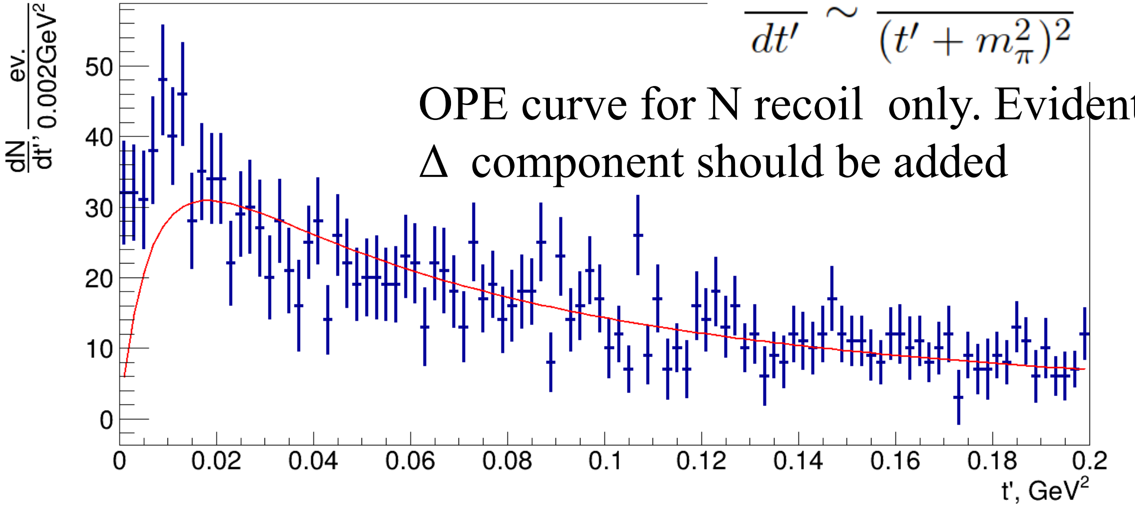
Characteristics of the selected sample $\eta'\pi^+\pi^-$ (4)

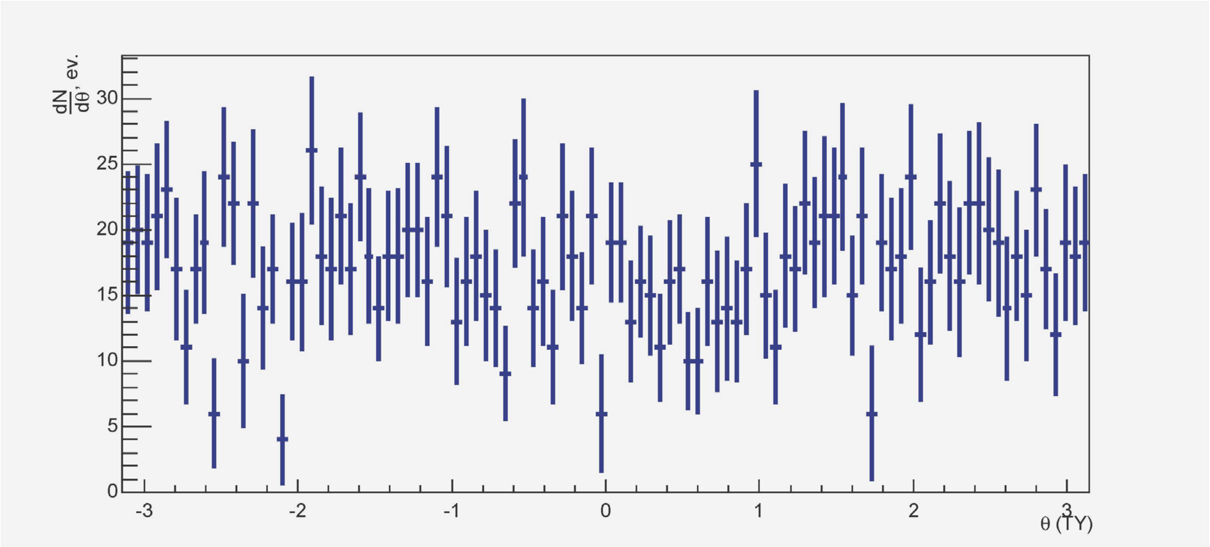
t' distribution

Treiman – Yang angle spectrum for η´

$$\frac{dN}{dt'} \sim \frac{t' e^{-at'}}{(t'+m_\pi^2)^2}$$

OPE curve for N recoil only. Evidently Δ component should be added





Narrow t' – distribution and uniformity over φ_{TY} are in accordance with OPE hypothesis

A «standard» region $t'<0.2$ GeV^2 is further analysed

X-section. Model for efficiency

- Detailed setup model
- Detailed model (generators) for particles passage through the matter

- Simplified model for the reaction
- realistic beam and scattering vertex
- t –spectrum – according to OPE with N (J =1/2) or Δ (J =3/2)
- System X of mass m_s decays to eta' 2pi according to phase space

$$\frac{dN}{dt'} \sim \frac{t' e^{-at'}}{(t' + m_\pi^2)^2}$$

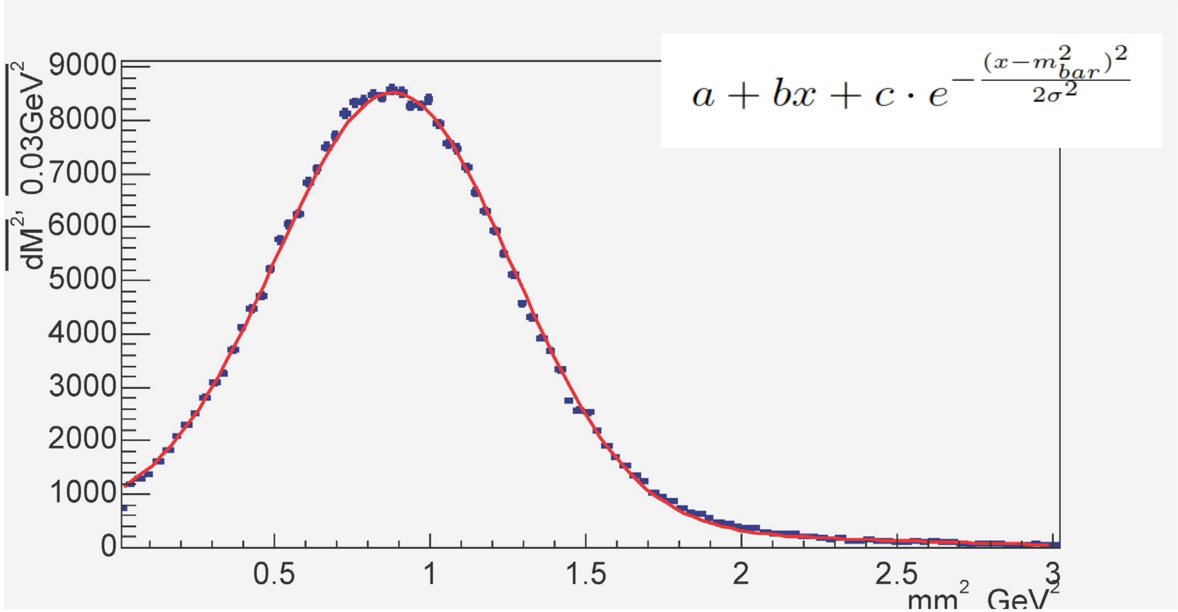
$$\frac{dN}{dt'} \sim \frac{e^{-at'}}{(t' + m_\pi^2)^2}$$

- **Recoil**: free mixture of n, Δ(1232) → N π, "Δ(1600)"→ Δ π

- Input channels according to ^{9}Be composition p:n = 4:5.
- Isotopic states and decay modes according to Clebsh coefficients

X-section. Model for efficiency (2)

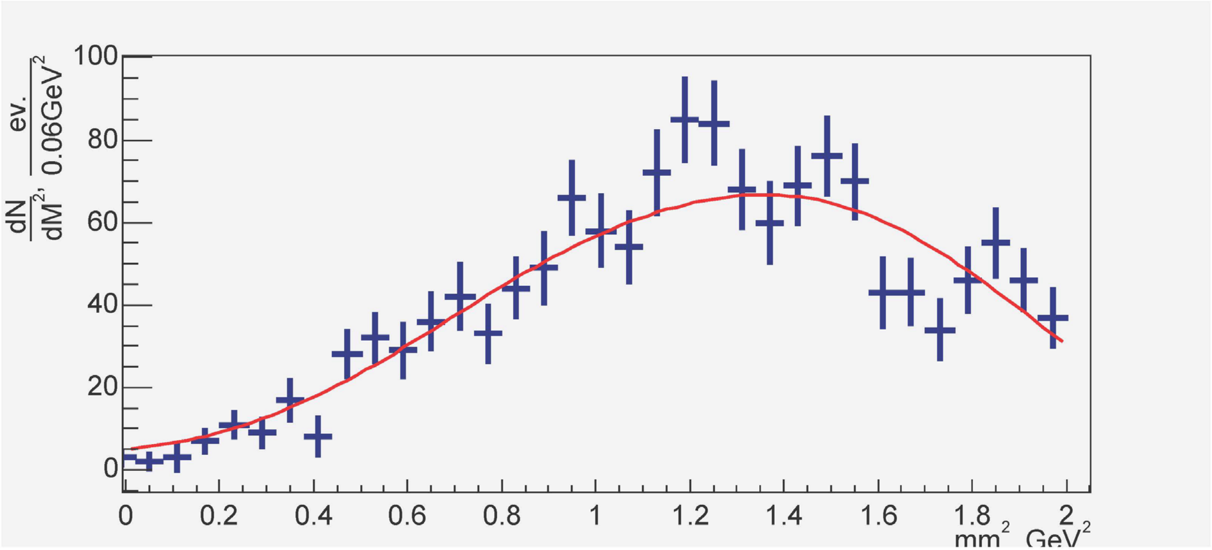
Recoil composition



Model function f_1(mm2) for neutron component

PRELIMINARY

Data fit with 3 model functions

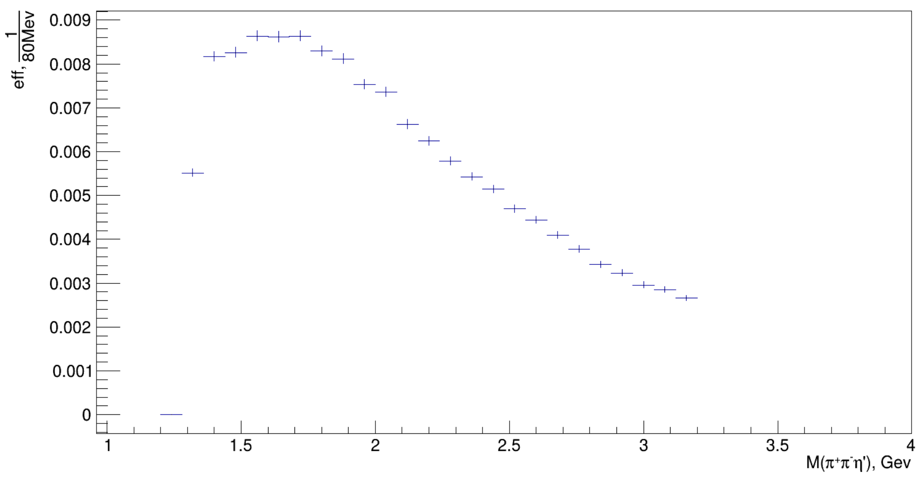


$$f(x) = n_1 f_1(x) + n_2 f_2(x) + n_3 f_3(x)$$

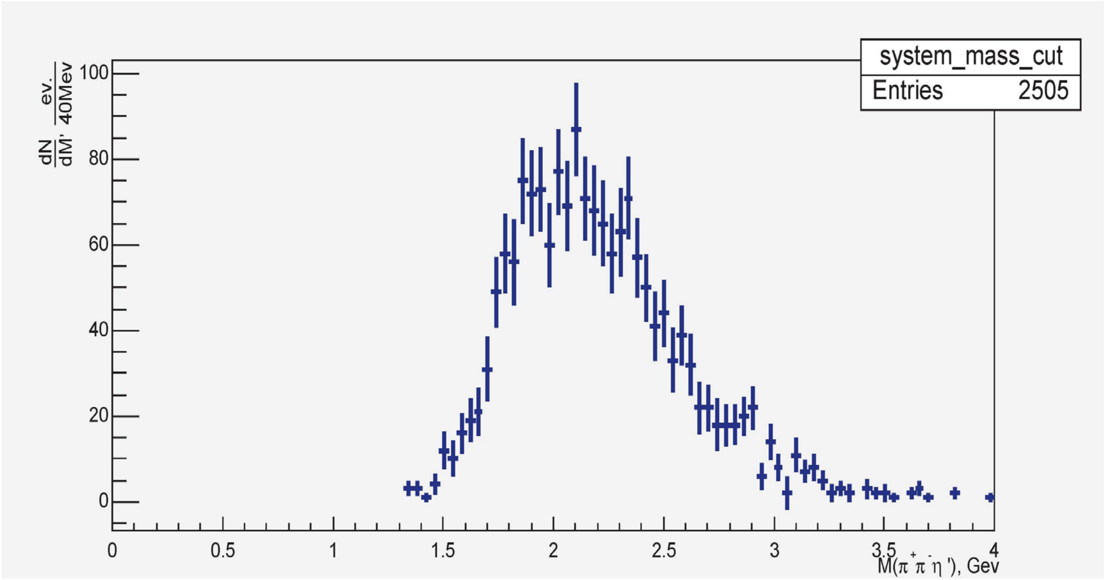
Resulting ratio of components in initial mixture
n : Δ(1232) = 0.14

Efficiency and mass spectra

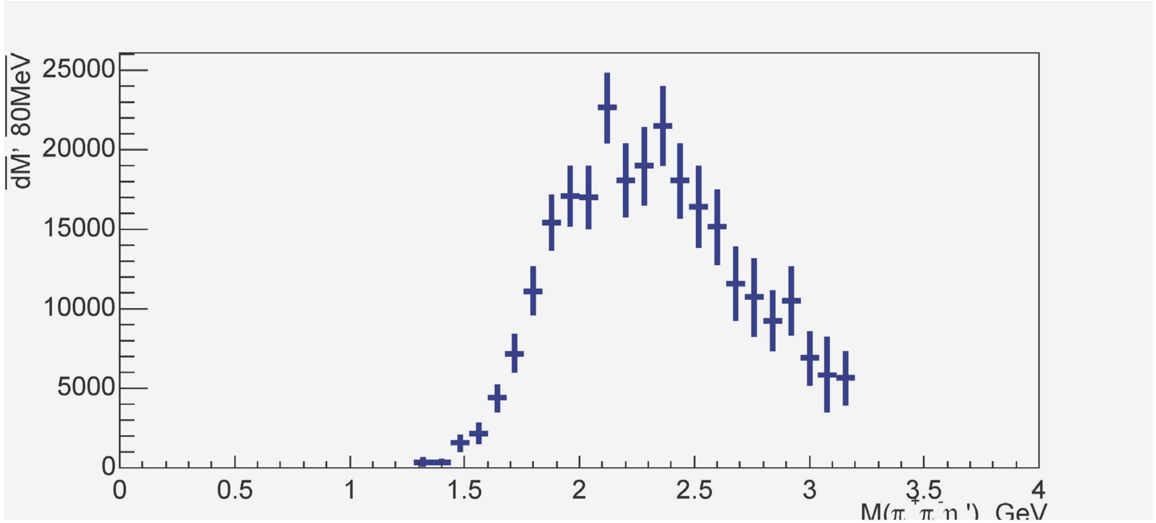
Efficiency vs $M(\eta^{\prime}\pi^{+}\pi^{-})$



Observed $M(\eta^{\prime}\pi^{+}\pi^{-})$ spectrum



$M(\eta^{\prime}\pi^{+}\pi^{-})$ spectrum corrected by efficiency



Resulting X-section on ^{9}Be

Run#	X-section, μBn
run44	1.92 ± 0.11
run45	1.80 ± 0.16
run47	1.55 ± 0.22
run48	2.29 ± 0.22
run59	1.32 ± 0.17
run60	1.96 ± 0.47
run62	1.55 ± 0.27

$\approx 2 * 10^3$ events in Trig=MAIN

Topology with Br=16.8%

PRELIMINARY

$\sigma(\pi^- p \rightarrow n\ \eta' \pi^+ \pi^-,\ t' < 0.2\ \mathrm{GeV}^2,\ P = 29\ \mathrm{GeV},\ {}^9\mathrm{Be}) = 1.78 \pm 0.07\ \mu\mathrm{Bn}$

Only Stat. uncertainty!
Syst. uncertainty is factor ~1.5 (expert guess)

Results discussion

- $\eta'\pi^+\pi^-$ Ch-Ex production with I=1 $\rho\eta'$
- compatible with **OPE**
- process with $\Delta(1232)$ dominates, with n significant.
- $\sigma(\pi^- p \rightarrow n\ \eta'\pi^+\pi^-,\ t'<0.2\ \mathrm{GeV}^2$, target = ^{9}**Be**) = 1.78 ± 0.07 (stat) μBn

➢ Let's reduce to proton target :

$$\sigma(\pi^- p \rightarrow n\,X,\ Z) = \sigma(\pi^- p \rightarrow n\,X,\ p)*Z^{2/3} \rightarrow$$

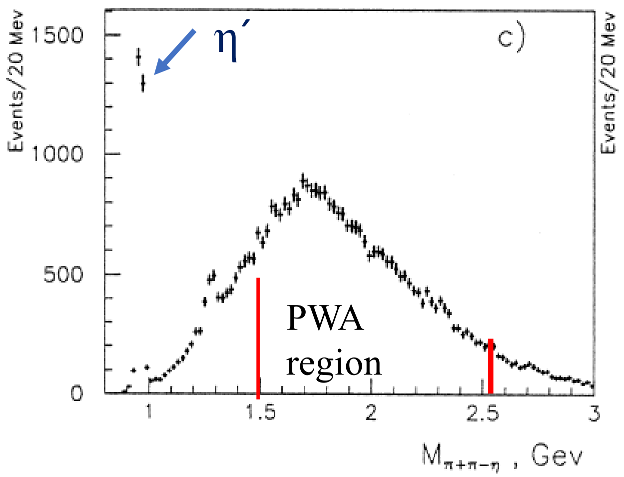
$\sigma(\pi^- p \rightarrow n\ \eta'\pi^+\pi^-,\ t'<0.2\ \mathrm{GeV}^2,\ P=29\ \mathrm{GeV},\ \mathrm{target} = p) \approx 0.7\ \mu\mathrm{Bn}$ (VES, 2025)

Results discussion (2)

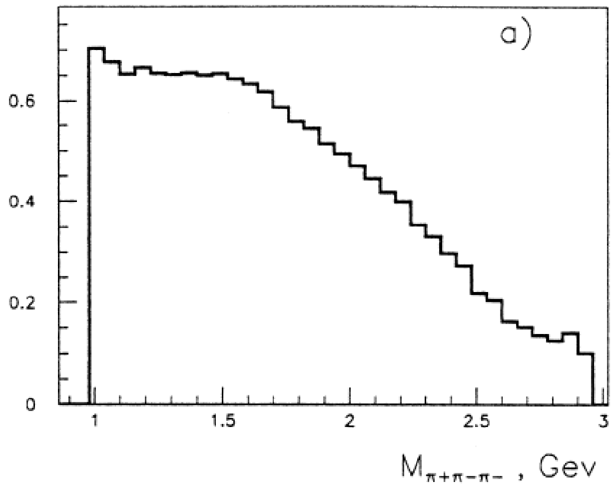
What object(s) could be here ? **Natural** hypothesis for $\pi\pi \rightarrow R$ with I=1: $\mathbf{J^{PC} = 1^{--}, 3^{--}}$, …

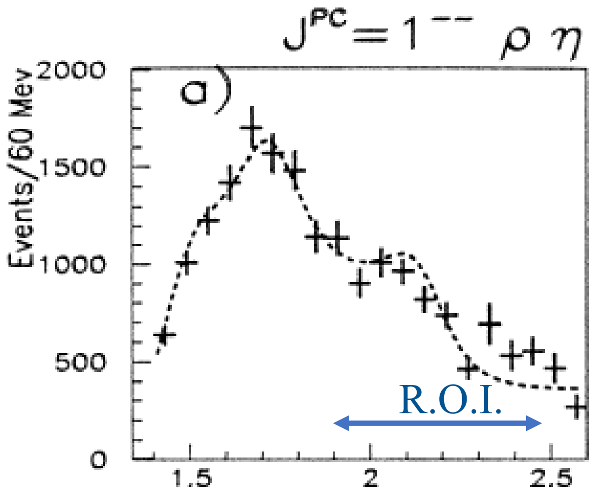
PWA of similar system **$\eta\, \pi^+\pi^-$** (VES, Nuclear Physics A 668 (2000) 83-96): **major waves intensities**

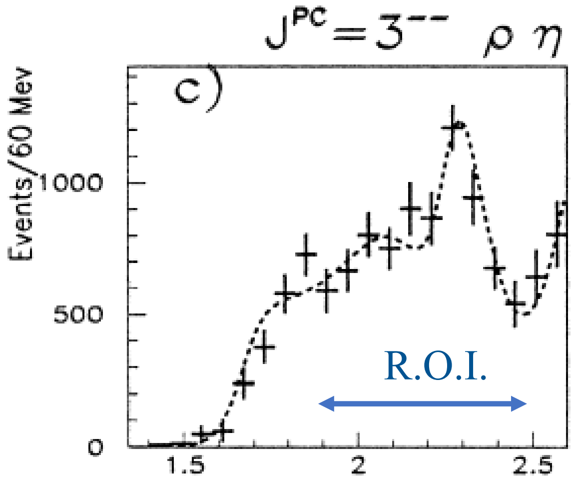
M($\eta\pi^+\pi^-$) specrum



Efficiency over M ($\eta\pi^+\pi^-$)







No X-section in VES-2000. Estimation with:

- normalization to $\eta' \rightarrow \eta\pi^+\pi^-$
- known σ ($\pi^- p \rightarrow \eta'_{(\rightarrow 2\gamma)}$ n, |t|<1.5 GeV^2, P=15 – 40 GeV) Phys.Let. 83B (1979) 1
- given intensities for 1^{--}, 3^{--}
- given efficiency
- reduction of X-sec to unified P beam and t range

Results discussion (3)

- Estimate result:

$\sigma(\pi^- p \rightarrow \rho\eta\ \ 1^{--}$; 1.9--2.3 GeV; $|t|<0.2$ GeV^2; P=27 GeV; target = p) $\approx 0.6\ \mu$Bn

$\sigma(\pi^- p \rightarrow \rho\eta\ \{1^{--} + 3^{--}\}$; 1.9--2.5 GeV) $\approx 1.8\ \mu$Bn

- New measurement VES-2025 for **ρη´** **is in this range**
- is compatible with both **ρη** values within large uncertainty

➢ **A good object to consider: ρ(2150)**

Results discussion (4)

ρ(2150) observations: e+e- π-p $p\bar{p}$

ρ(2150)

$I^G(J^{PC}) = 1^+(1^{--})$

OMITTED FROM SUMMARY TABLE

This entry was previously called $T_1(2190)$. See the review on "Spectroscopy of Light Meson Resonances."

ρ(2150) MASS

e^+e^- PRODUCED

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2034 ±13 ± 9		[1] ABLIKIM	21A	BES3	$e^+e^- \to \omega\pi^0$
2111 ±43 ±25		[2] ABLIKIM	21X	BES3	$e^+e^- \to \eta'\pi^+\pi^-$
2255 $^{+17}_{-18}$ $^{+50}_{-41}$	1.8k	[3] ABLIKIM	20F	BES3	$\psi(2S) \to K^+K^-\eta$
2201 ±19		[4] LEES	20	BABR	$e^+e^- \to K^+K^-\gamma$
2227 ± 9 ± 9		[5] LEES	20	RVUE	$e^+e^- \to K^+K^-$
2039 ± 8 $^{+36}_{-18}$		[6] ABLIKIM	19AQ	BES	$J/\psi \to K^+K^-\pi^0$
2239.2± 7.1 ±11.3		[7] ABLIKIM	19L	BES3	$e^+e^- \to K^+K^-$
2254 ±22		[8] LEES	12G	BABR	$e^+e^- \to \pi^+\pi^-\gamma$
2150 ±40 ±50		AUBERT	07AU	BABR	10.6 $e^+e^- \to f_1(1285)\pi^+\pi^-\gamma$
1990 ±80		AUBERT	07AU	BABR	10.6 $e^+e^- \to \eta'\pi^+\pi^-\gamma$
2153 ±37		BIAGINI	91	RVUE	$e^+e^- \to \pi^+\pi^-$, K^+K^-
2110 ±50		[9] CLEGG	90	RVUE	$e^+e^- \to 3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$

ρ(2150) DECAY MODES

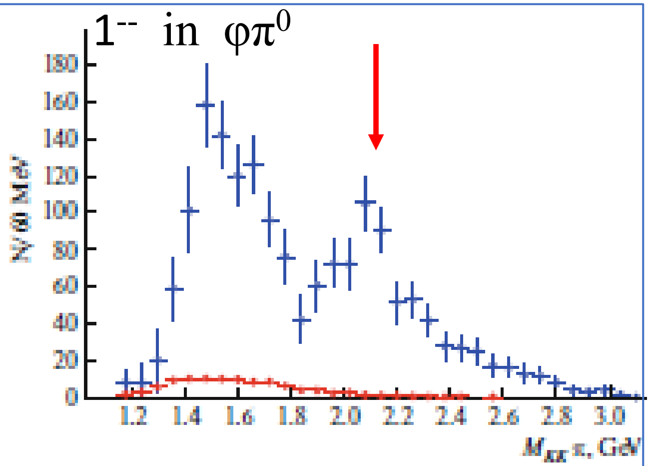
	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	
Γ_2	$\pi^+\pi^-$	seen
Γ_3	K^+K^-	seen
Γ_4	$3(\pi^+\pi^-)$	seen
Γ_5	$2(\pi^+\pi^-\pi^0)$	seen
Γ_6	$\eta'\pi^+\pi^-$	seen
Γ_7	$f_1(1285)\pi^+\pi^-$	seen
Γ_8	$\omega\pi^0$	seen
Γ_9	$\omega\pi^0\eta$	seen
Γ_{10}	$p\bar{p}$	

also in ηϱ (VES, 2000)

possibly in

η'ϱ (VES, 2025)

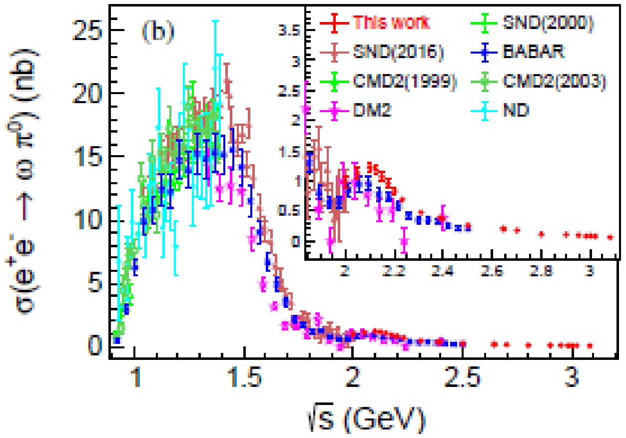
and in $\varphi\pi^0$ (VES, 2024)

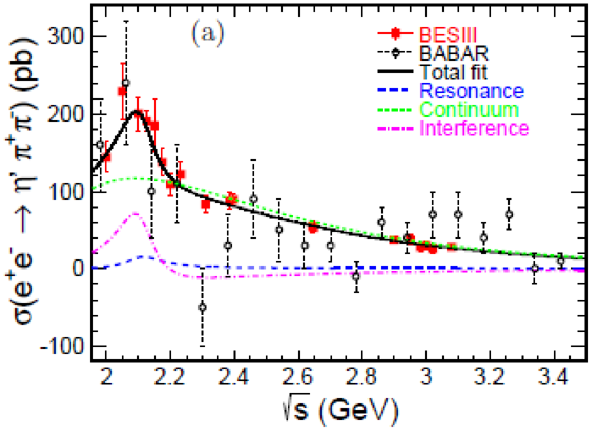


Physics of Particles and Nuclei Letters v.22 (2025) 1, p.131–136

Results discussion (5)

Comparison of branchings for ρ/X(2150)

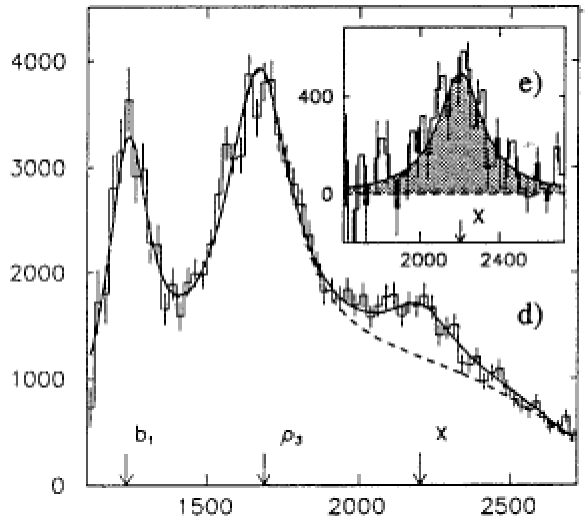




a) e^+e^- (BESIII): two fit models

$R_1=\Gamma(\rho\eta'):\Gamma(\omega\pi) = 0.69 \pm 0.4$

$R_2=\Gamma(\rho\eta'):\Gamma(\omega\pi) = 0.019 \pm 0.020$



b) $\pi^- p$

$\sigma(X, P=27\ \text{GeV})\cdot BR(\omega\pi) \approx 0.24$ uBn

(GAMS – IHEP and GAMS – CERN)

$$\sigma(\pi^- p \to Xn)\cdot BR(X \to \omega\pi^0) = \begin{cases} 120 \pm 25\ \text{nb} & \text{at } 38\ \text{GeV/c} \\ 20 \pm 6\ \text{nb} & \text{at } 100\ \text{GeV/c} \end{cases}$$

$\sigma(X)\cdot BR(\rho\eta') \approx$ { 0.7 μBn (if 1^- dominates) ; 0.3 μBn (if 1^- и 3^- are comparable) }

(VES, 2025)

$R=Br(\rho\eta'):Br(\omega\pi) \approx$ 1. -- 2.9

Conclusion

- ✓ VES (U-70): first observation of $\eta'\pi\pi$ in ChEx
- ✓ Compatible with OPE
- ✓ $\sigma(\pi^- p \to n\ \eta'\pi^+\pi^-$, $t'<0.2$ GeV^2, P=29 GeV, target = ^{9}Be) = 1.78 ± 0.07 (стат.) μBn
- ✓ Mass spectrum with maximum @2.2 GeV and dominance of $\rho\eta'$
- ✓ Assuming $\rho(2150) \to \rho\eta'$ and using data available:

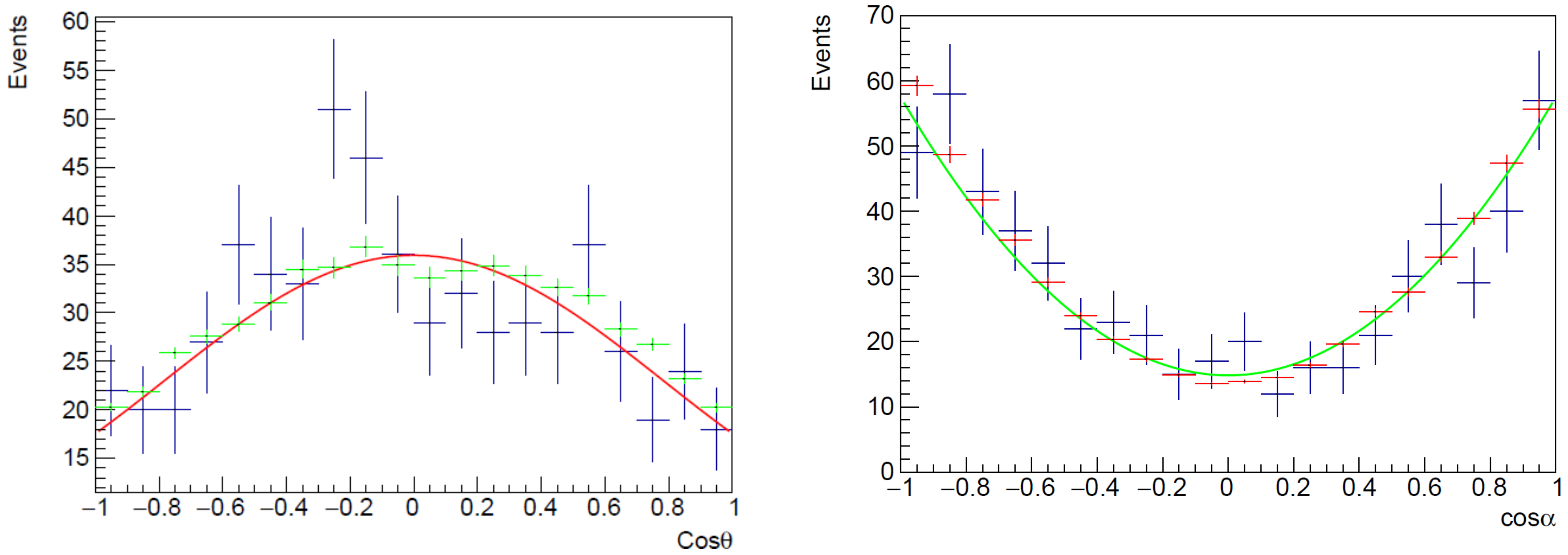
  $R = Br(\rho(2150) \to \rho\eta') : Br(\rho(2150) \to \omega\pi) \approx$ 1. -- 2.9

  not far from BESIII in one model and excludes another one
- ✓ PWA of $\eta'\pi\pi$ could confirm $\rho(2150)$ and looks feasible.

Thank You for Attention

Extra materials

Some features of $\omega\ \omega$ events (4)



$\theta = \angle\,(\mathbf{p}(\phi)\,,\,\mathbf{p}(K))$
(spin alignment of ϕ)

$\alpha = \angle\,(\mathbf{n}(\omega)\,,\,\mathbf{p}(K))$
n – normal to decay plane
(significant contribution of LS=00)

large errors: data
small errors: PWA model
line: $p_1+p_2\cos^2\theta$ function

PWA model for ωφ

$$ln\mathcal{L} = \sum_k ln \sum_{\eta=\pm1} \left| \sum_i T_i^\eta A_i^\eta(\tau_k) \right|^2 - \sum_{\eta=\pm1} \sum_{i,j} T_i^\eta T_j^{\eta*} \int A_i^\eta(\tau) A_j^{\eta*}(\tau)\zeta(\tau)d\tau$$

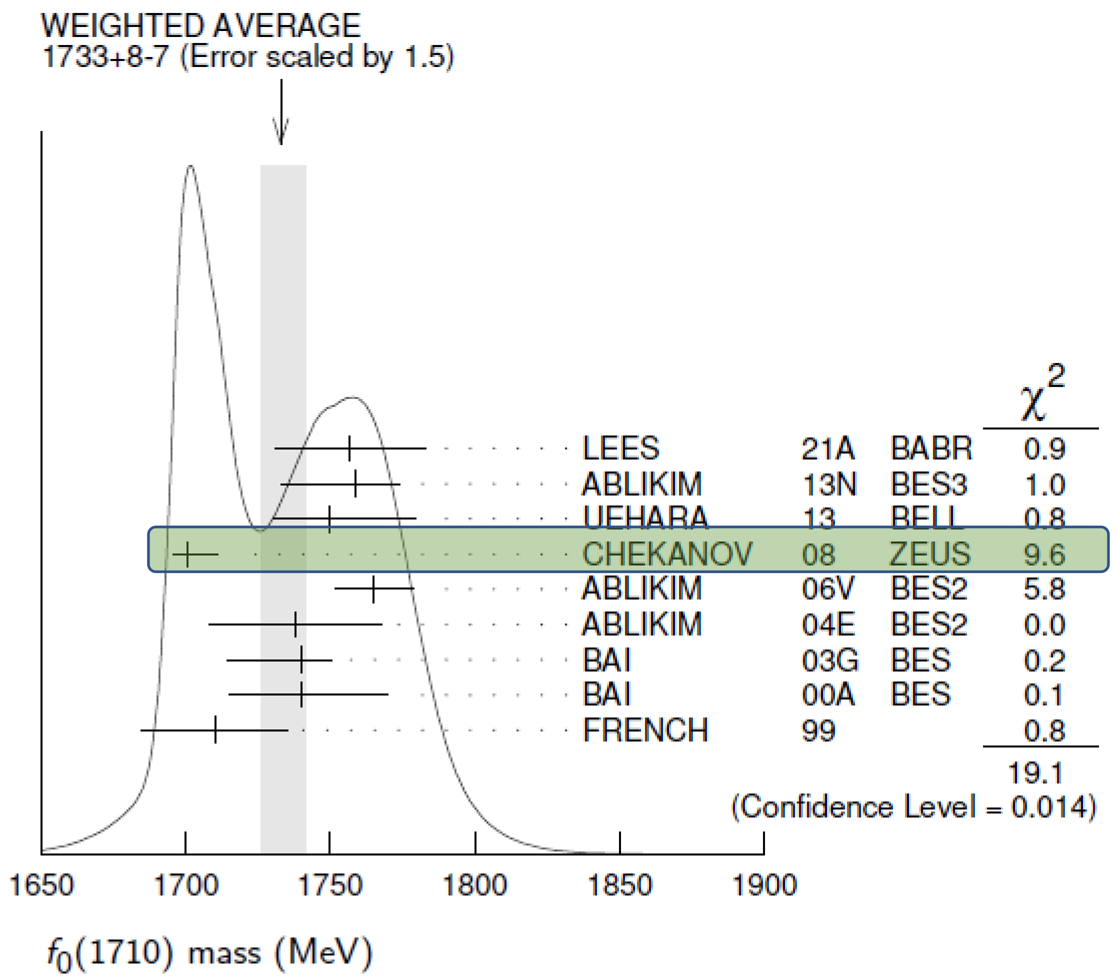
ev.   ph. sp.   prod. ampl.   dec. ampl.   acc. fun.

- Results: waves intensities (in number of produced events) and phases
- Set of significant waves $J^{PC}M^{\eta}LS$:

  $0^{++}0^{-}00$, $2^{++}0^{-}02$, $0^{-+}0^{+}00$, Flat (pseudo wave with uniform population of 5-particle phase space)
- Efficiency (M) is a weak function, 5.1 – 6.7% including ε(PID) ≈0.3

Mass of $f_0(1710)$ in PDG

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

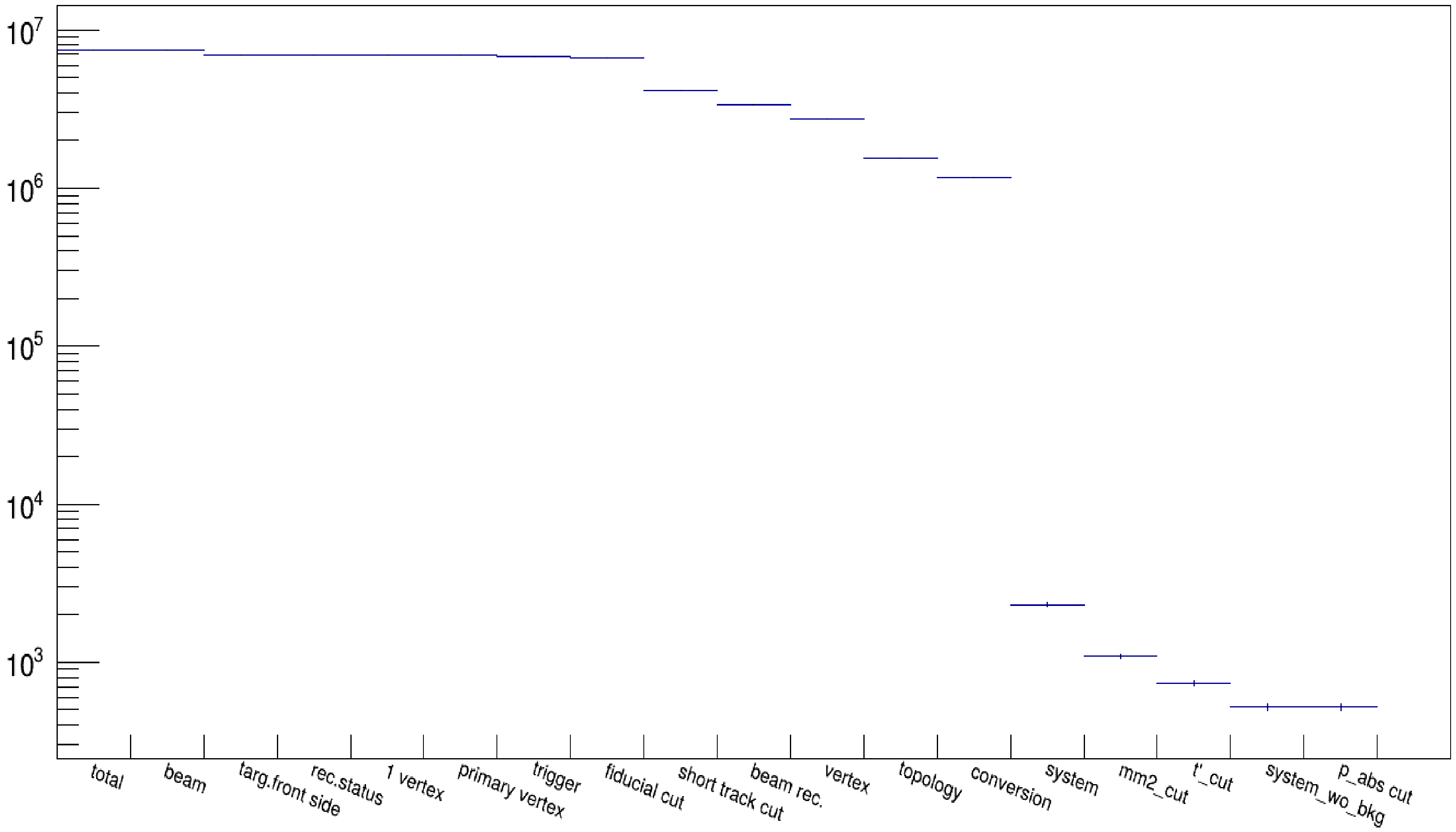


Mass of gg 0^{++} in Lattice

TABLE I: Scalar glueball masses (in units of MeV) in quenched (top) and unquenched (bottom) lattice QCD.

Bali *et al.* (1993) [34]	1550 ± 50
H. Chen *et al.* (1994) [37]	1740 ± 71
Morningstar, Peardon (1999) [38]	$1730 \pm 50 \pm 80$
Vaccarino, Weingarten (1999) [39]	1648 ± 58
Loan *et al.* (2005) [40]	1654 ± 83
Y. Chen *et al.* (2006) [33]	$1710 \pm 50 \pm 80$
Gregory *et al.* (2012) [41]	1795 ± 60

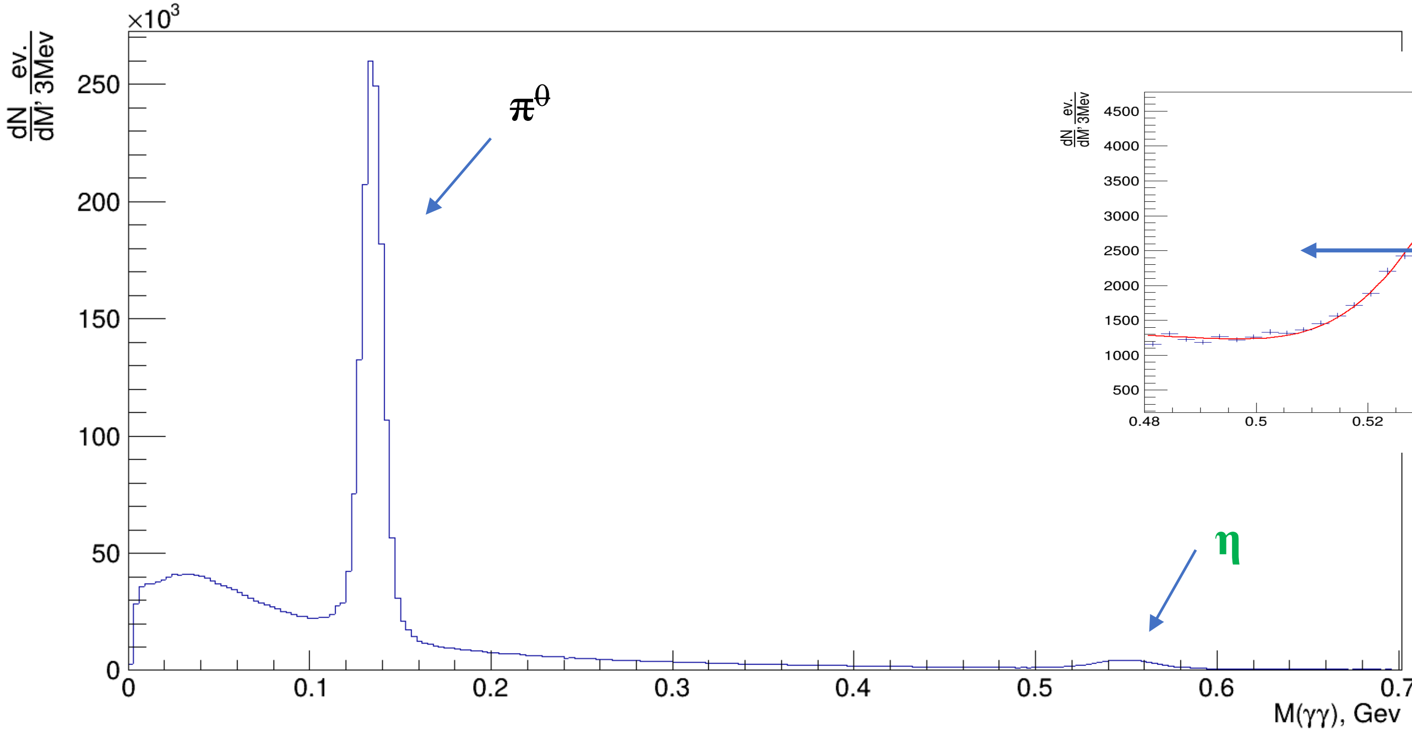
Прохождение отборов η΄π π

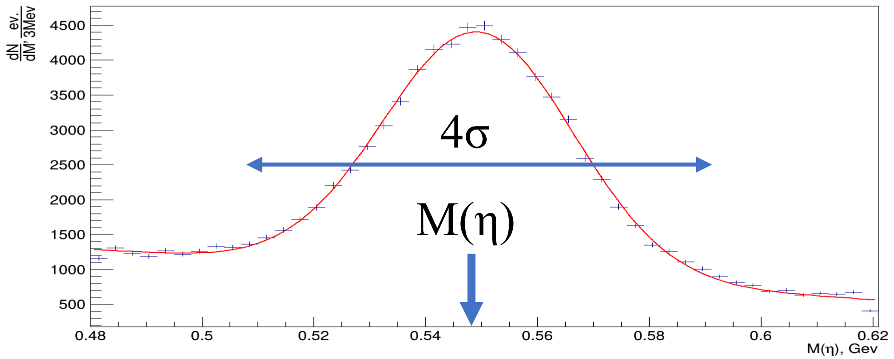


Иллюстрации к отборам

$$\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-2\gamma$$

Спектр инв. масс 2γ



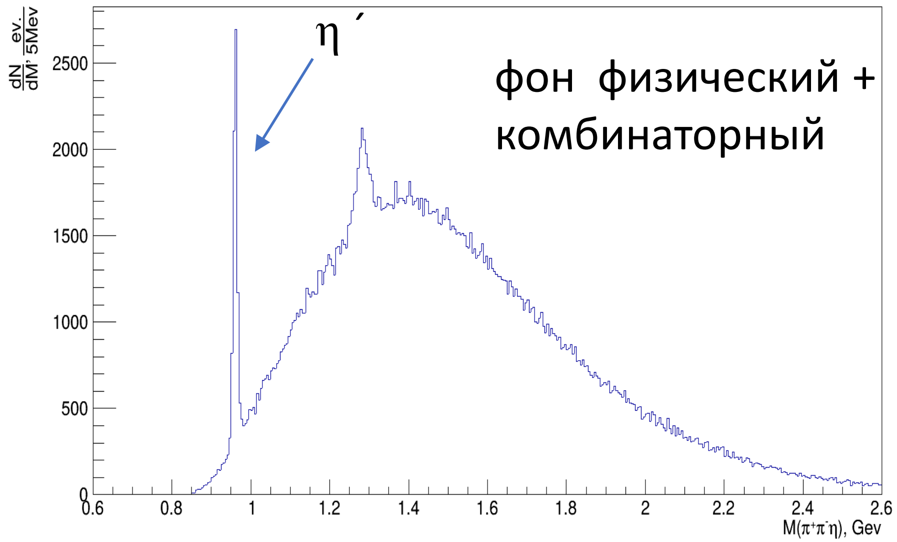


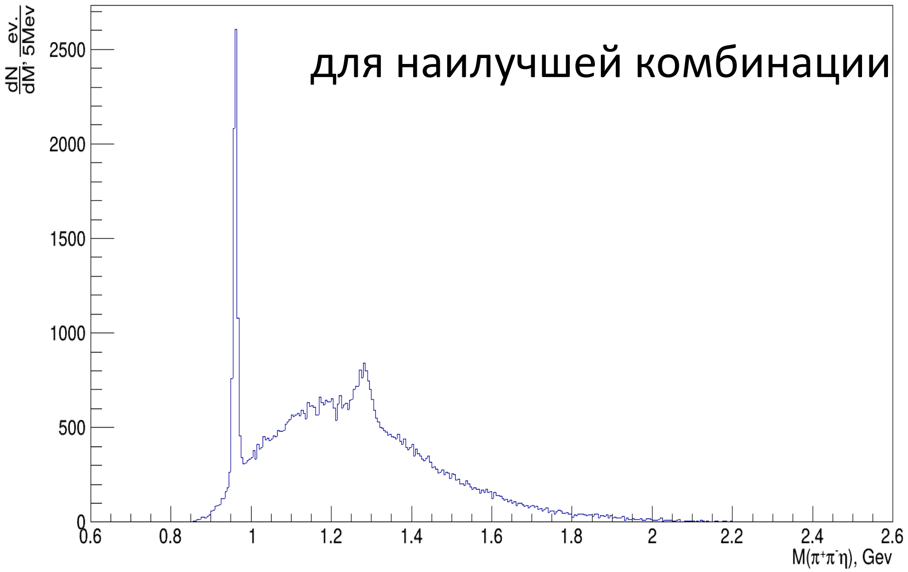
Fit :
M= 549.3 МэВ
σ = 17 МэВ

Иллюстрации к отборам (2)

$\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^- 2\gamma$ (Мода 2TPL)

Спектр инв. масс ππη

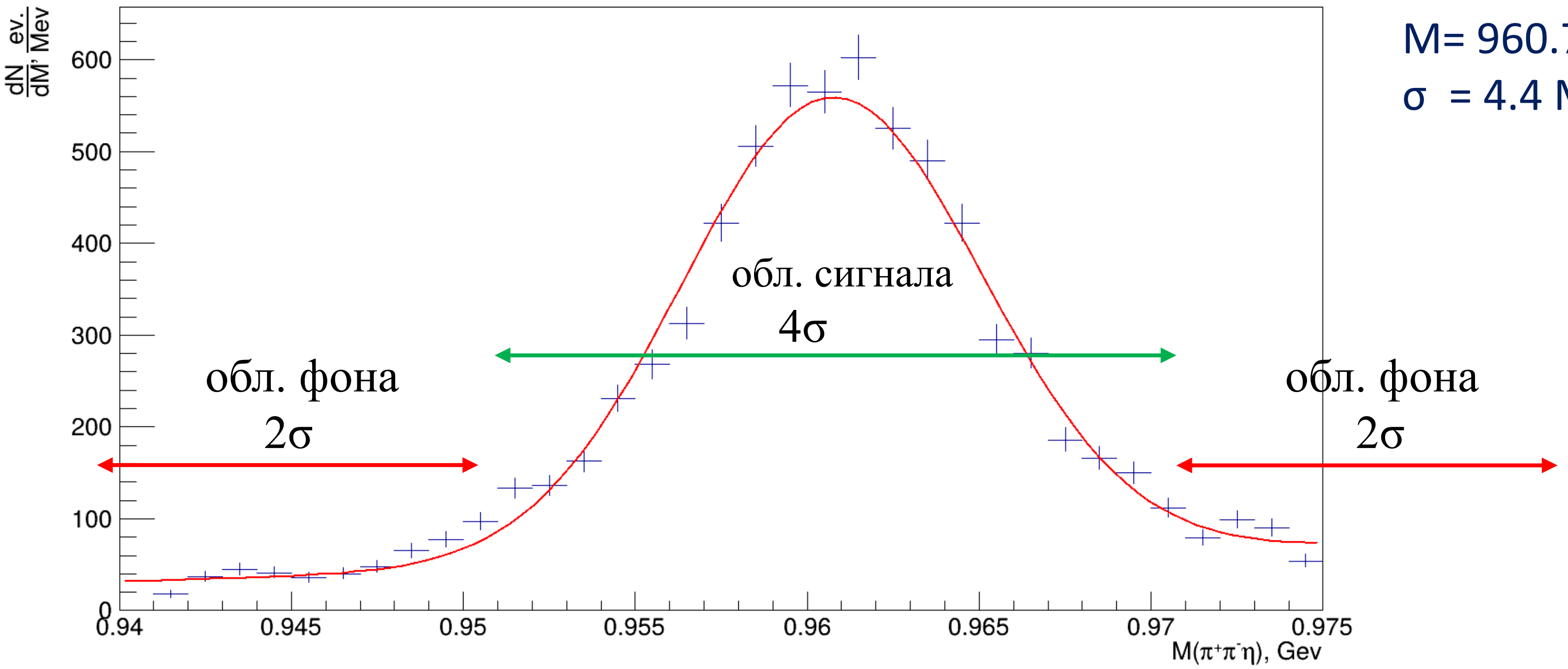




Иллюстрации к отборам (3)

$\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-2\gamma$ (Мода 2TPL)

Спектр инв. масс ππη (область η´)



Fit :
M= 960.7 МэВ
σ = 4.4 МэВ

Об эффективности

- Усредненно по всем переменным системы «верхней» вершины, кроме m_s – массы $\boldsymbol{\eta'\pi^+\pi^-}$
- Наблюдается факторизация эффективности по «верхней» и «нижней» вершинам
- Для нижней вершины аргумент mm2 включает (квадрат) массу отдачи **и характер распада**

$$\epsilon_{tot}(m_s, mm^2) = \epsilon_1(m_s) \cdot \epsilon_2(mm^2)$$

$$\epsilon_{tot}(m_s) = \int \epsilon 1(m_s) \cdot \epsilon_2(mm^2)\, d(mm^2) = \epsilon_2 \cdot \epsilon_1(m_s)$$

$$\epsilon_{tot}(m_s, n) = \epsilon_2(n) \cdot \epsilon_1(m_s)$$

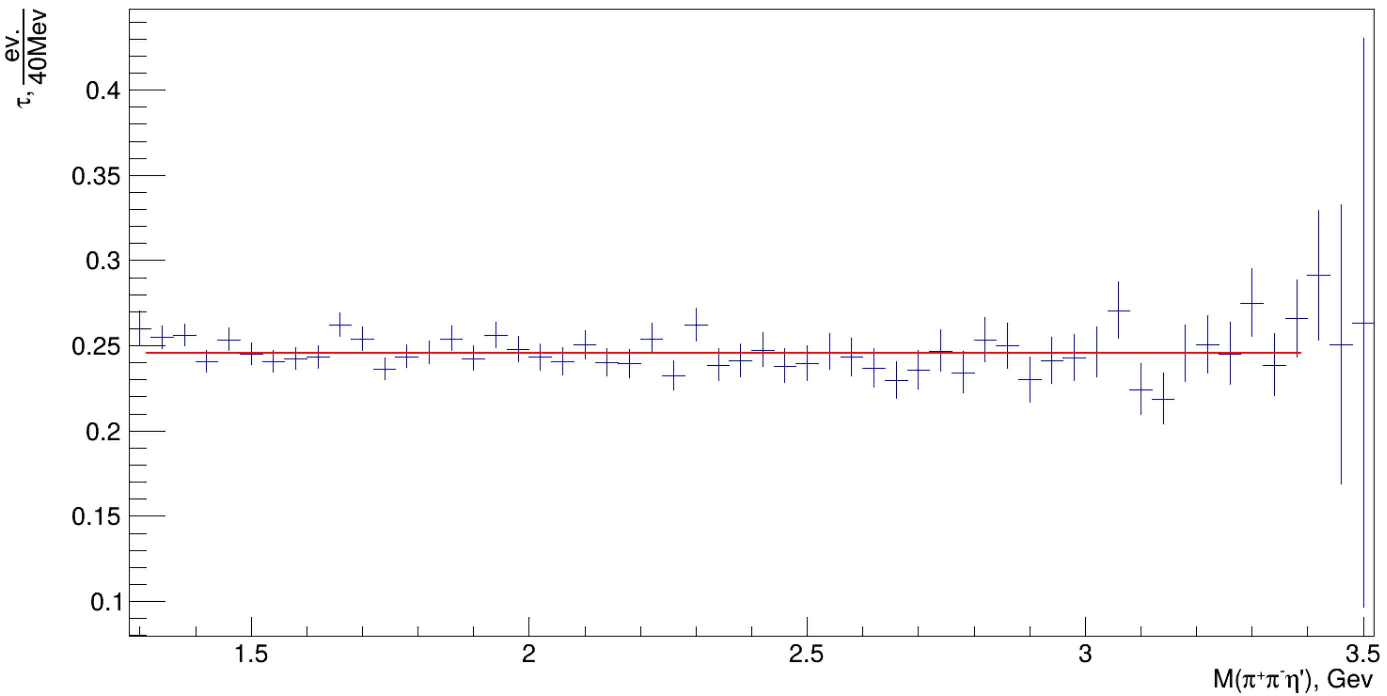
$$\epsilon_{tot}(m_s, \Delta) = \epsilon_2(\Delta) \cdot \epsilon_1(m_s)$$

$$\tau = \epsilon_{tot}(m_s, \Delta)/\epsilon_{tot}(m_s, n) = \epsilon_2(\Delta)/\epsilon_2(n)$$

Об эффективности (2)

Отношение τ эффективностей в триггере MAIN

для реакций $\pi^- p \to n\, \eta'\pi^+\pi^-$ и $\pi^- N \to \Delta\, \eta'\pi^+\pi^-$

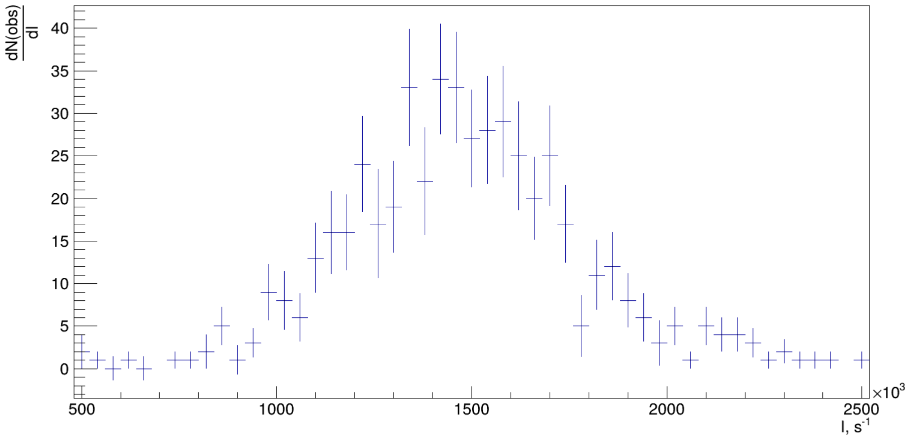


$\tau = const(m_s)$

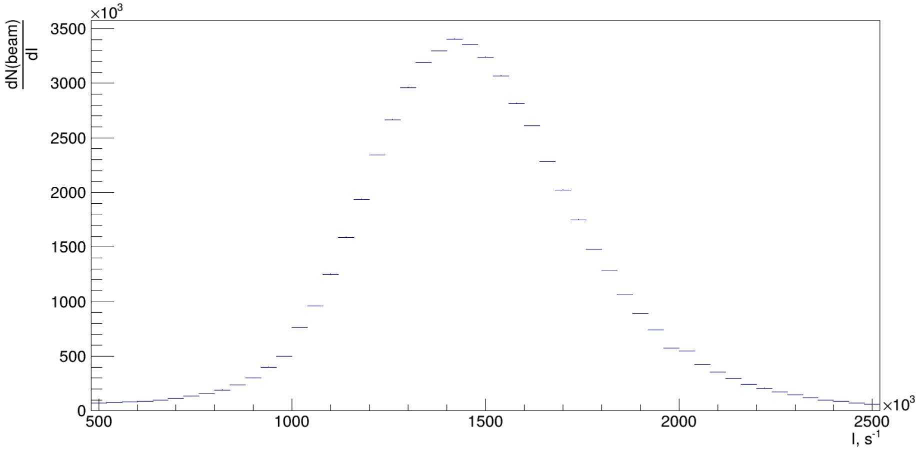
$\tau(Trig{=}MWG) \sim 0.9$

$\tau(Trig{=}MAIN) \ll 1$ из-за VETO

Об эффективности (3)



Распределение по интенсивности пучка для событий изучаемой реакции



Распределение по интенсивности пучка для пучковых событий

X-section. Recoil model

Δ(1232)

$p\pi^- \to \Delta^0 \to p\pi^-$ $4 \cdot 1 \cdot 1/3 = 4/3$

$p\pi^- \to \Delta^- \to n\pi^0$ $4 \cdot 1 \cdot 2/3 = 8/3$

$n\pi^- \to \Delta^- \to n\pi^-$ $5 \cdot 3 \cdot 1 = 15$

«Δ(1600)»
Effective description for high-end tail in mm2

$p\pi^- \to \Delta^0 \to \Delta^0\pi^0 \to p\pi^-\pi^0$ $4 \cdot 1 \cdot 1/15 \cdot 1/3 = 4/45$

$p\pi^- \to \Delta^0 \to \Delta^0\pi^0 \to n\pi^0\pi^0$ $4 \cdot 1 \cdot 1/15 \cdot 2/3 = 8/45$

$p\pi^- \to \Delta^0 \to \Delta^-\pi^+ \to n\pi^-\pi^+$ $4 \cdot 1 \cdot 2/5 \cdot 1 = 8/5$

$p\pi^- \to \Delta^0 \to \Delta^+\pi^- \to p\pi^0\pi^-$ $4 \cdot 1 \cdot 8/15 \cdot 2/3 = 64/45$

$p\pi^- \to \Delta^0 \to \Delta^+\pi^- \to n\pi^+\pi^-$ $4 \cdot 1 \cdot 8/15 \cdot 1/3 = 32/45$

$n\pi^- \to \Delta^- \to \Delta^-\pi^0 \to n\pi^-\pi^0$ $5 \cdot 3 \cdot 3/5 \cdot 1 = 9$

$n\pi^- \to \Delta^- \to \Delta^0\pi^- \to p\pi^-\pi^-$ $5 \cdot 3 \cdot 2/5 \cdot 1/3 = 2$

$n\pi^- \to \Delta^- \to \Delta^0\pi^- \to n\pi^0\pi^-$ $5 \cdot 3 \cdot 2/5 \cdot 2/3 = 4$

ρ(2150) REFERENCES

ABLIKIM 21A PL B813 136059 M. Ablikim et al. (BESIII Collab.)
ABLIKIM 21X PR D103 072007 M. Ablikim et al. (BESIII Collab.)