

Study of $e^+e^- \rightarrow \omega\pi^0$ from 1.840 to 1.970 GeV at BESIII

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2025.11.12



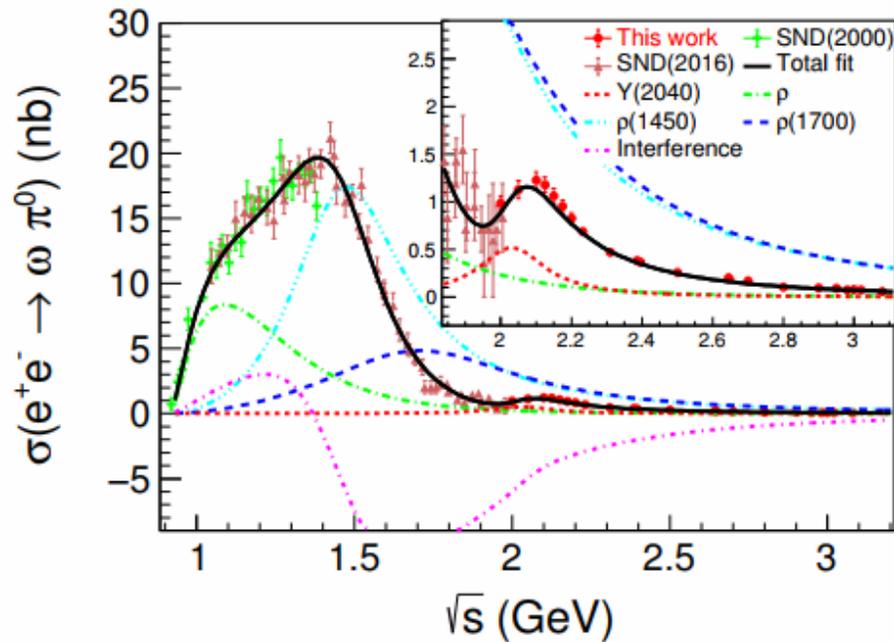


Outline

- Motivation
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- Study of $e^+e^- \rightarrow \omega\pi^0$
 - (1) Event selection
 - (2) Background study
 - (3) Signal events extraction
 - (4) Cross section measurement
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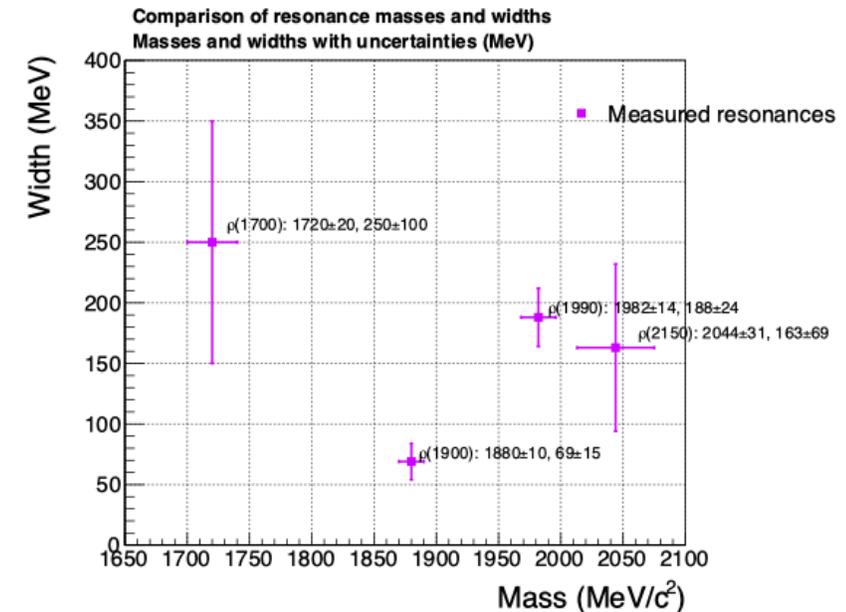
Motivation

- ✓ At low-energy e^+e^- collision experiments, if there is a **vector meson involved in the $\omega\pi^0$ process**, it is mostly likely a ρ^* resonance



[Physics Letters B 813 \(2021\) 136059](#)

- ✓ Using this batch of new data to conduct new explorations of **the cross-section of $e^+e^- \rightarrow \omega\pi^0$**





Data Sets

➤ Boss version: 7.1.3

➤ R-scan data sets:

Data sample used in this analysis.

➤ MC samples generated by ConExc

500k signal MC samples for efficiency study:

$$e^+e^- \rightarrow \omega(\pi^+\pi^-\pi^0)\pi^0(\gamma\gamma)$$

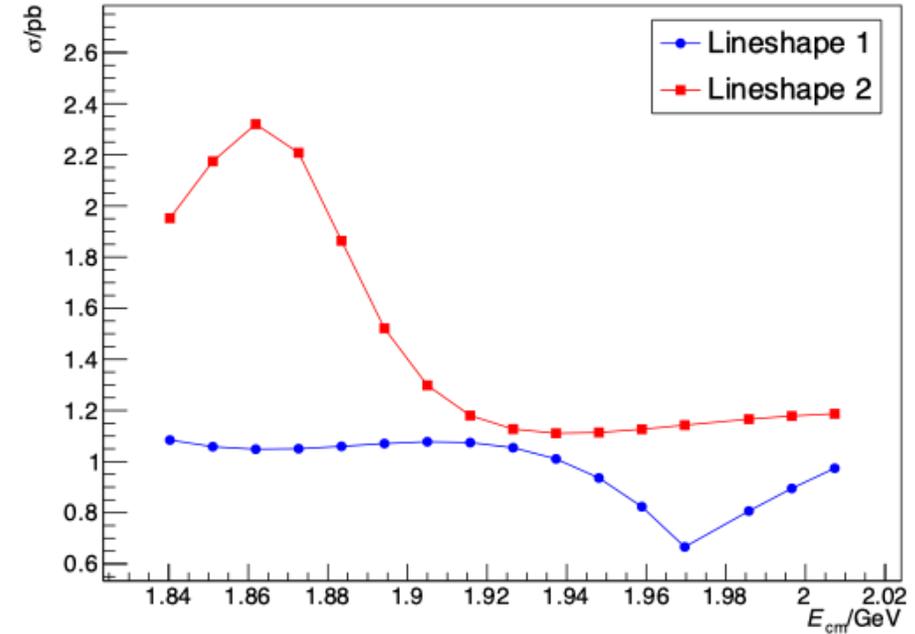
Table 1: Data samples used in this analysis.

Data set	E^{nom} (MeV)	E^{cor} (MeV)	Luminosity(nb^{-1})	Run Number
1	1840	1844.138±0.083	1501.169	81849-81970
2	1870	1874.137±0.084	2002.611	81971-82104
3	1872	1876.035±0.079	2014.243	82543-82656
4	1874	1878.002±0.084	2018.925	82657-82783
5	1875	1879.139±0.099	1485.364	82835-82909
6	1876	1880.073±0.080	2032.830	82105-82203
7	1877	1880.925±0.101	1340.884	82784-82834
8	1878	1882.185±0.089	2020.956	82204-82261
9	1882	1886.032±0.081	2032.727	82262-82310
10	1886	1890.160±0.083	2031.153	82311-82358
11	1900	1903.824±0.080	2022.166	82359-82404
12	1940	1943.686±0.088	2036.759	82405-82462
13	1970	1973.483±0.092	2229.098	82463-82530

Decay Card

```

Particle vpho 1874.137 0.0
Decay vpho
1 ConExc -100 52;
Enddecay
Decay omega
0.9081 pi- pi+ pi0 OMEGA_DALITZ;
Enddecay
Decay pi0
0.9880 gamma gamma PHSP;
Enddecay
End
  
```



Input lineshapes for ConExc



Pre-selection

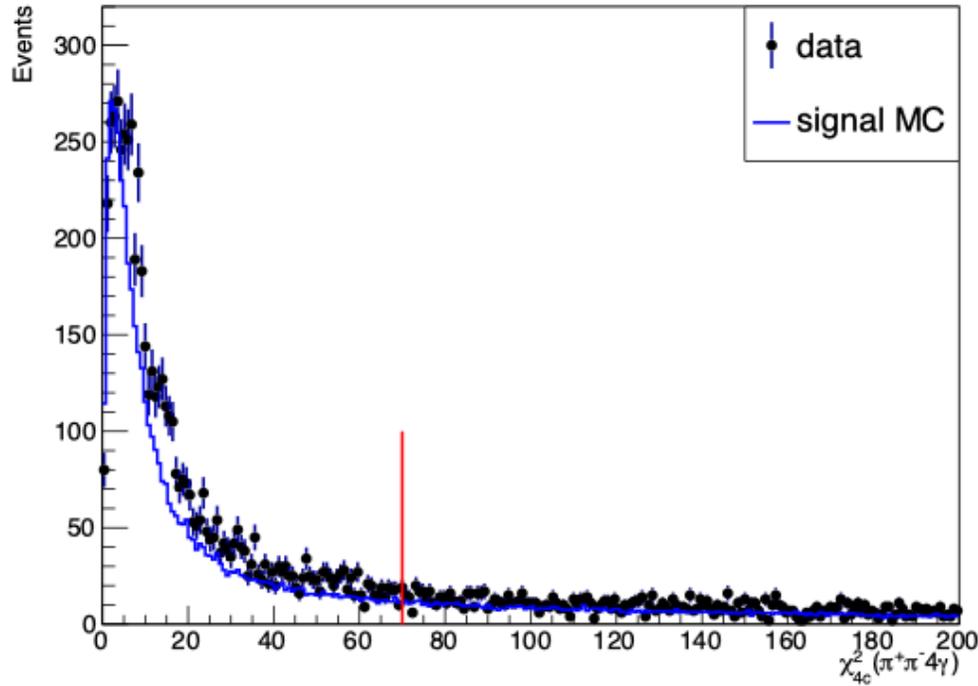
- ✓ Good charged track: $V_r < 1 \text{ cm}$, $|V_z| < 10 \text{ cm}$, $|\cos\theta| < 0.93$, $N_{good} \geq 2$
- ✓ Neutral track: $E_{barrel} > 25 \text{ MeV}$ & $|\cos\theta| < 0.80$; $E_{endcap} > 50 \text{ MeV}$ & $0.86 < |\cos\theta| < 0.93$
 $0 \leq TDC \leq 700 \text{ ns}$, $N_{gam} \geq 4$
- ✓ PID: For π : $Prob(\pi) > Prob(K)$ && $Prob(\pi) > Prob(p)$; $N(\pi^+) = N(\pi^-) = 1$
- ✓ Vertex fit ($\pi^+\pi^-$): The two charged pions are used to reconstruct primary vertex
- ✓ Kinematic fit ($\pi^+\pi^-4\gamma$): Select the four photons with the smallest χ^2 values from all photon combination

For six pairs of 4γ combination, two π^0 candidates are chosen with the minimum $\chi^2_{\pi^0\pi^0}$

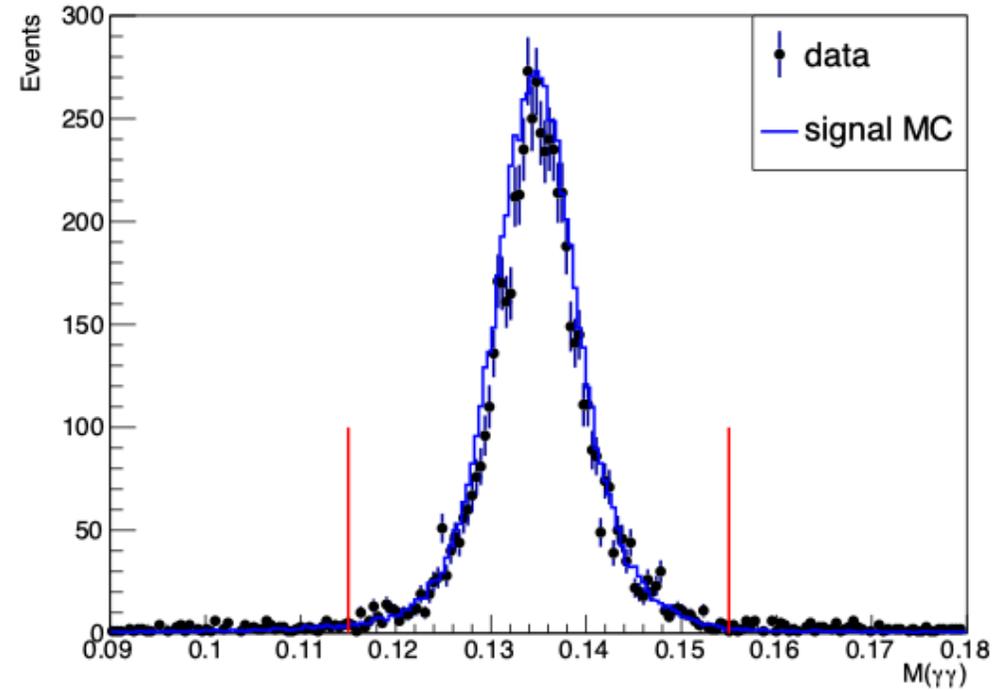
$$\chi^2(\pi^0\pi^0) = \frac{(M(\gamma_1\gamma_2) - M_{\pi^0}^{PDG})^2}{\sigma_{\pi^0}^2} + \frac{(M(\gamma_3\gamma_4) - M_{\pi^0}^{PDG})^2}{\sigma_{\pi^0}^2}$$

$$\chi^2(\pi^0\pi^0) < \chi^2(\pi^0\eta) \quad \&\& \quad \chi^2(\pi^0\pi^0) < \chi^2(\eta\eta)$$

Further Event Selection(1.870 GeV)

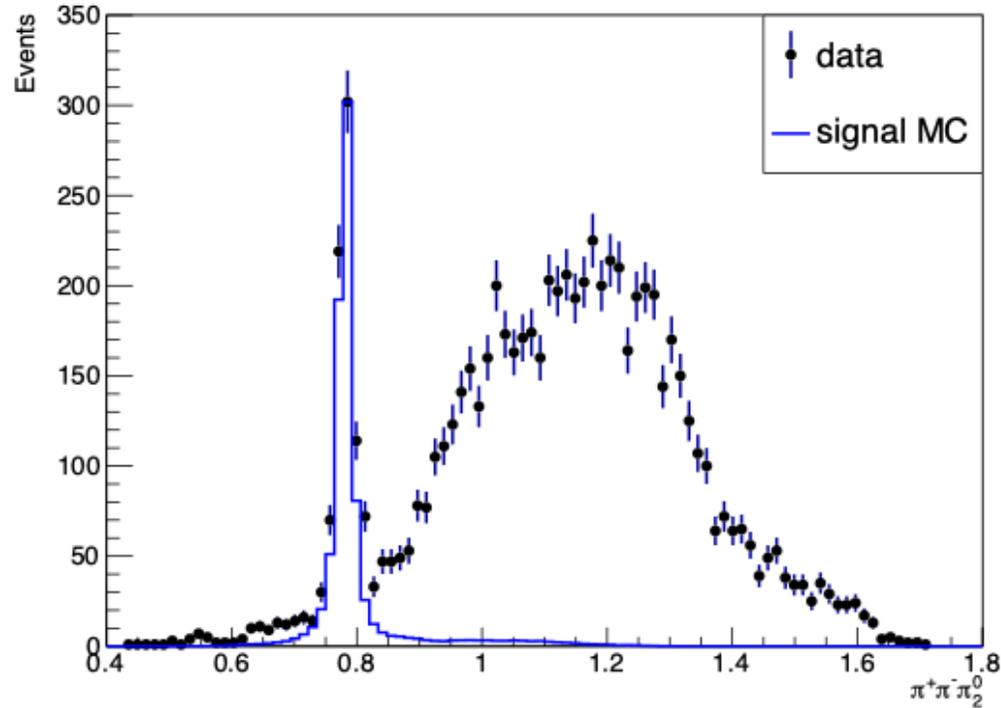


Cut 1 : $\chi_{4c}^2(\pi^+\pi^-4\gamma) < 70$



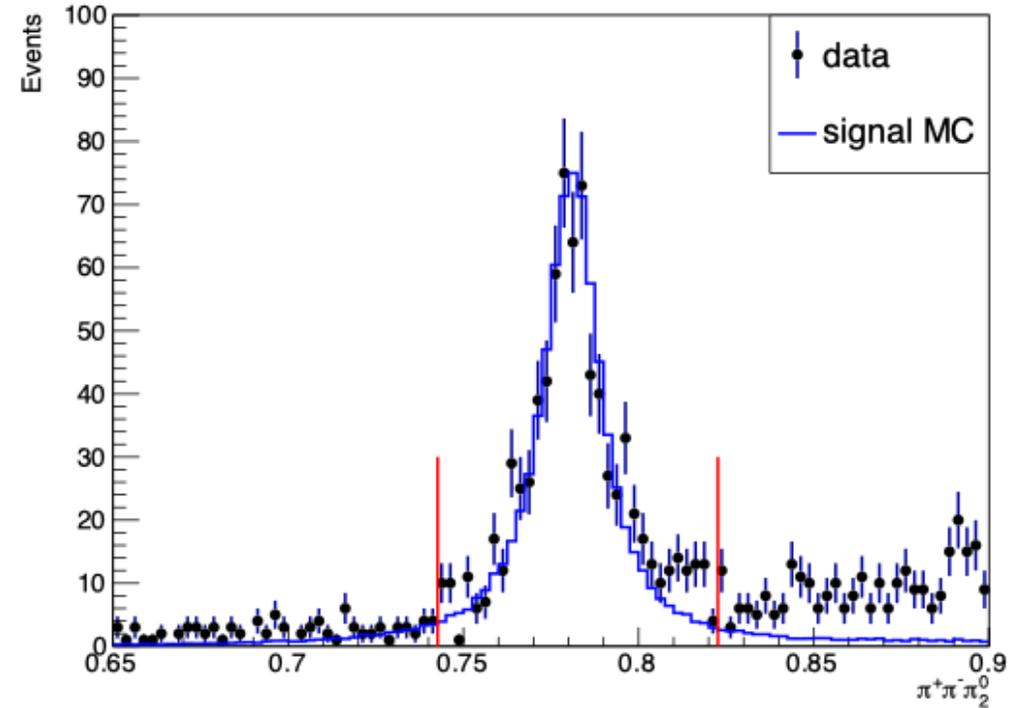
Cut 2 : $|M(\gamma\gamma) - M(\pi^0)^{PDG}| < 20MeV$

Further Event Selection (1.870 GeV)



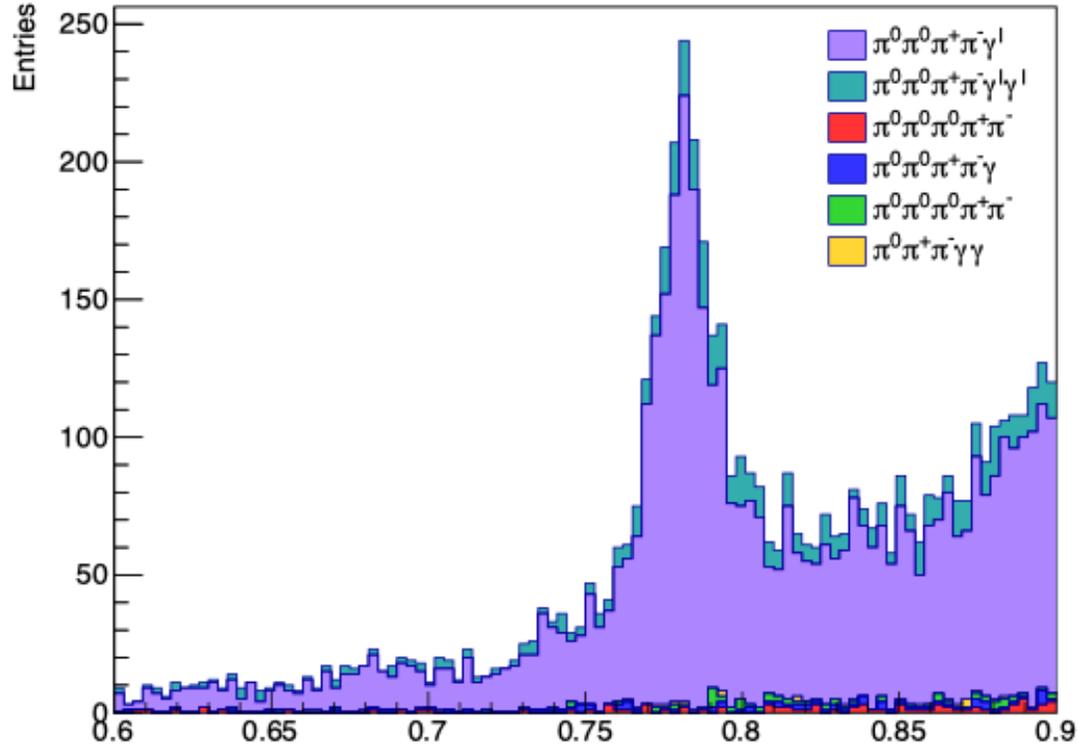
The bachelor π^0 is tagged as π_1^0 and the π^0 from decay is tagged as π_2^0 .

The π^0 , combined with $\pi^+\pi^-$ more close to ω^{PDG} mass, is considered as the π_2^0 , and the other π^0 is π_1^0 .



the $M(\pi^+\pi^-\pi_2^0)$ invariant mass distribution within [0.65, 0.9] GeV.

Background study (1.870 GeV)



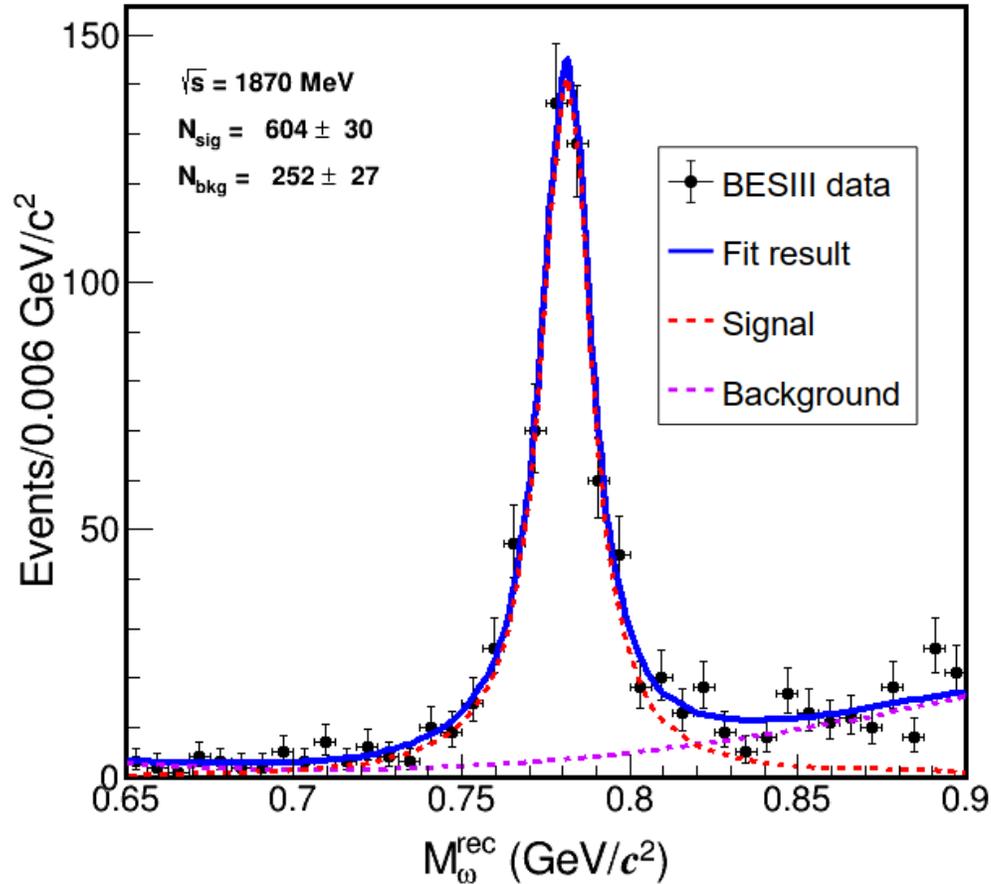
Topology before cut in ω signal mass region

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$e^+e^- \rightarrow \pi^0\pi^0\pi^+\pi^-\gamma^I$	$\pi^0\pi^0\pi^+\pi^-\gamma^I$	0	3506	3506
2	$e^+e^- \rightarrow \pi^0\pi^0\pi^+\pi^-\gamma^I\gamma^I$	$\pi^0\pi^0\pi^+\pi^-\gamma^I\gamma^I$	1	325	3831
3	$e^+e^- \rightarrow \pi^0\pi^0\pi^+\pi^-\gamma^I, \pi^0 \rightarrow e^+e^-\gamma^F$	$e^+e^-\pi^0\pi^+\pi^-\gamma^I\gamma^F$	3	2	3833
4	$e^+e^- \rightarrow vgam\gamma^I, vgam \rightarrow \pi^0\pi^+\pi^-\omega, \omega \rightarrow \pi^0\gamma$	$\pi^0\pi^0\pi^+\pi^-\gamma^I\gamma$	2	1	3834
5	$e^+e^- \rightarrow \pi^0\pi^+\pi^-\omega, \omega \rightarrow \pi^0\gamma$	$\pi^0\pi^0\pi^+\pi^-\gamma$	4	1	3835

Table 2: Topology after above cuts in ω signal mass region

- Background is very low compared to the number of signal events
- No peaking background, the background can be described using the polynomial function.

Signal events extraction (1.870 GeV)



Consist with PDG Value:

$$\text{Mass}(\omega) = 782.66 \pm 0.13 \text{ MeV}$$

$$\text{Width} = 8.68 \pm 0.13 \text{ MeV}$$

Fitting function:

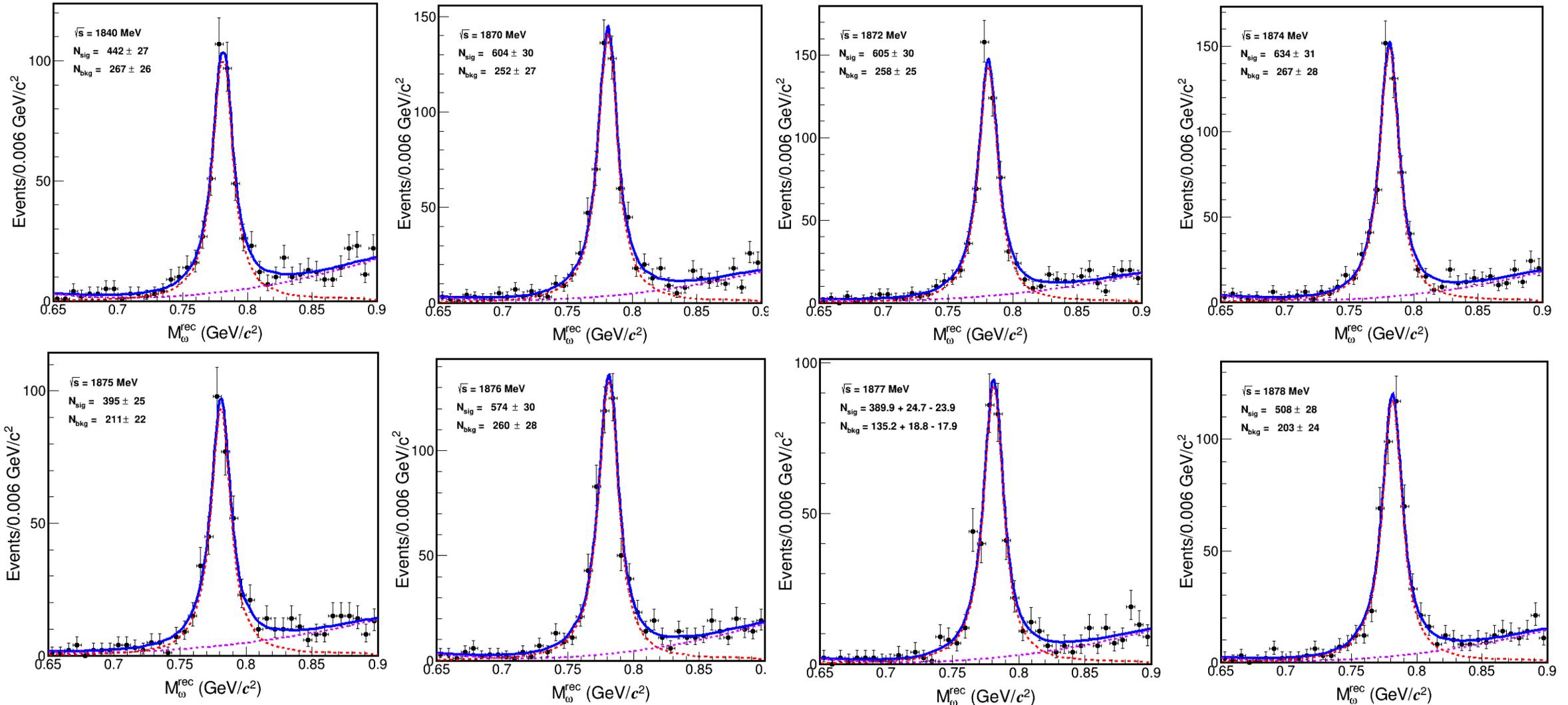
For data: Breit-Wigner \otimes Gaussian + the second-order Chebyshev

$$\sigma = \frac{N_{\text{signal}}}{L * \epsilon * Br^2(\pi^0 \rightarrow \gamma\gamma) * Br(\omega \rightarrow \pi^+\pi^-\pi^0) * (1 + \delta)}$$

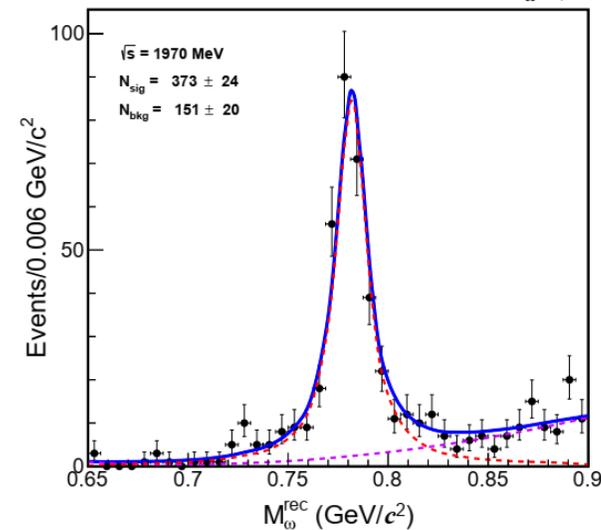
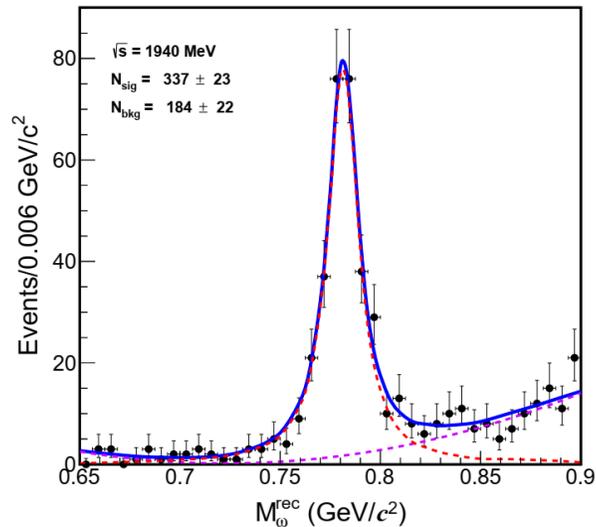
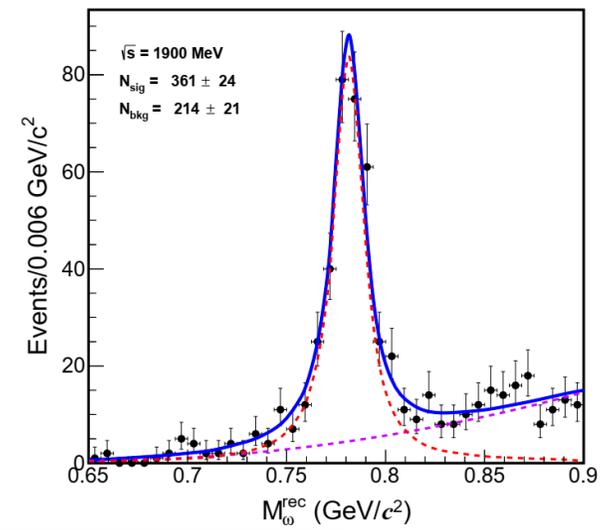
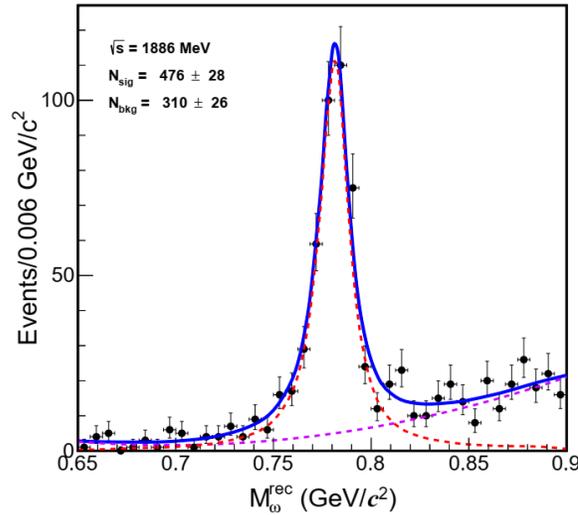
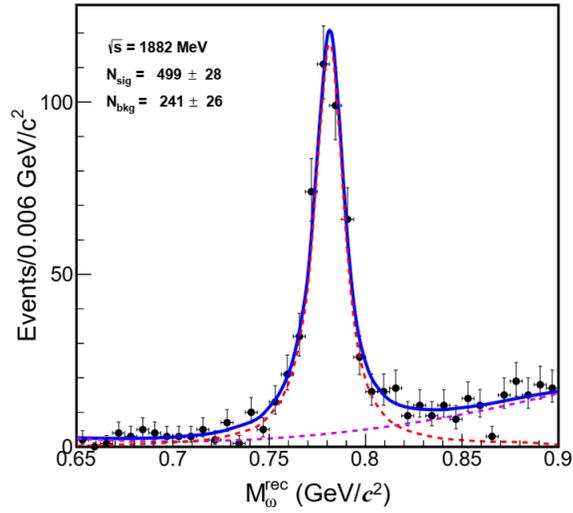
- $1 + \delta : f(\text{ISR}) * f(\text{VP})$



Signal events extraction



Signal events extraction



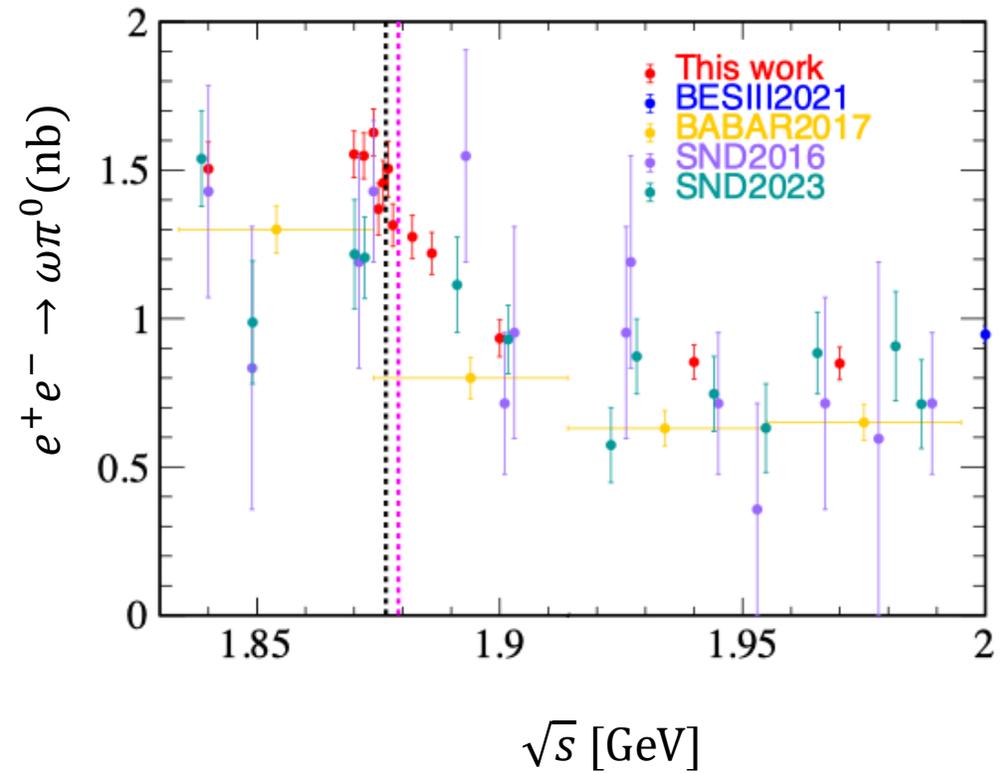
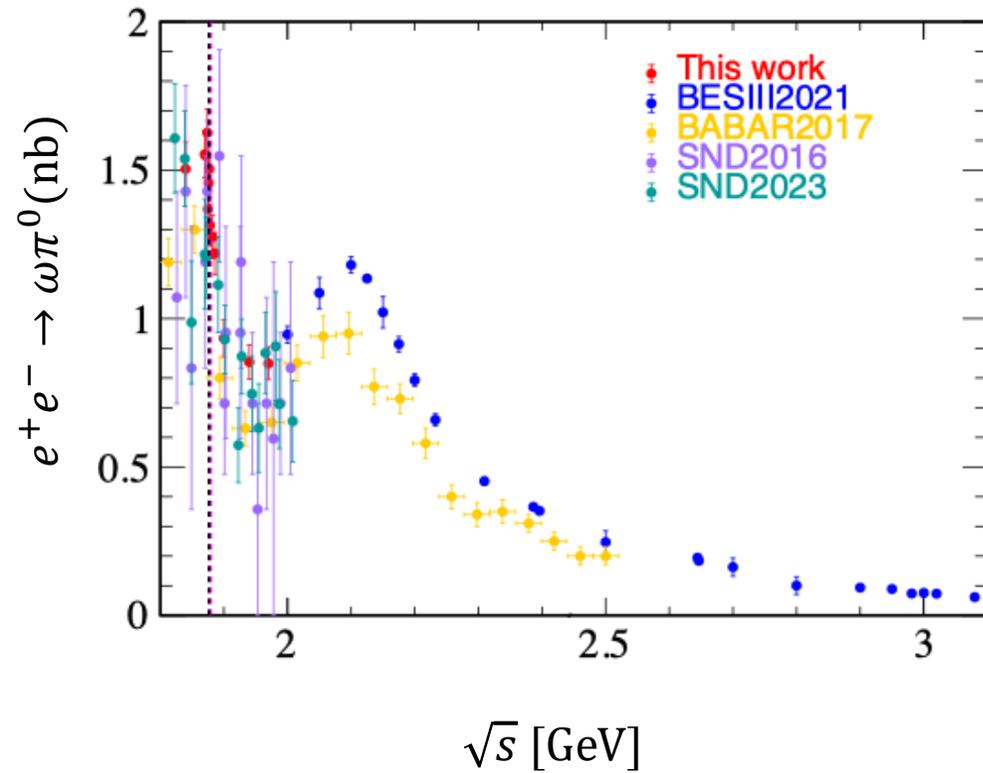


Cross section measurement

Table 3 : Summary of Born cross section for $e^+e^- \rightarrow \omega\pi^0$

\sqrt{s} (MeV)	N_{sig}	$L(pb^{-1})$	ε (%)	$1 + \delta$	σ
1840	441.67±26.67	1501.17	11.96±0.05	1.88	1503.98±90.82
1870	604.10±30.46	2002.61	12.37±0.05	1.80	1553.39±78.34
1872	605.15±30.46	2014.24	12.41±0.05	1.80	1548.43±76.92
1874	634.28±30.91	2018.93	12.40±0.05	1.79	1626.38±79.26
1875	395.39±25.07	1485.36	12.52±0.05	1.78	1368.80±86.78
1876	573.92±29.94	2032.83	12.49±0.05	1.78	1456.81±76.00
1877	389.85±24.33	1340.88	12.48±0.05	1.78	1504.51±93.89
1878	508.18±27.71	2020.96	12.38±0.05	1.77	1314.76±71.69
1882	499.34±28.15	2032.73	12.56±0.05	1.76	1275.24±71.90
1886	476.39±27.54	2031.15	12.64±0.05	1.75	1219.78±70.53
1900	361.17±23.90	2022.17	12.88±0.05	1.71	933.54±61.77
1940	337.24±22.55	2036.76	12.88±0.05	1.73	853.64±57.09
1970	372.73±24.00	2229.10	11.37±0.05	1.99	848.69±54.65

Comparison with other measurements





Lineshape fit

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$$\sigma(\sqrt{s}) = \frac{4\pi\alpha^2}{3s^{3/2}} |F_{\omega\pi\gamma}(s)|^2 P_f(\sqrt{s}) \quad P_f(\sqrt{s}) = q^3(\sqrt{s})$$

$$F_{\omega\pi\gamma}(s) = \frac{g_{\rho\omega\pi}}{f_\rho} (f_0 + A_1 e^{i\phi_1} f_1 + A_2 e^{i\phi_2} f_2 + A_3 e^{i\phi_3} f_3 + A_4 e^{i\phi_4} f_4)$$

$$f_i (i = 0, 1, 2, 3, 4) = \frac{m_{\rho_i}^2}{D_{\rho_i}} = \frac{m_{\rho(1450)}^2}{m_{\rho_i}^2 - s - i\sqrt{s}\Gamma_{\rho_i}(\sqrt{s})}$$

$q(\sqrt{s})$: ω momentum in the e^+e^- c.m.

$F_{\omega\pi\gamma}(s)$: transition form factor of $\gamma^* \rightarrow \omega\pi^0$

$g_{\rho\omega\pi}$: $\rho \rightarrow \omega\pi^0$ coupling constant

f_ρ : $\gamma^* \rightarrow \rho$ coupling constant calculated with $\rho \rightarrow e^+e^-$ decay width

f_i : BW function for $\rho(770)\rho(1450)\rho(1700)\rho(1900)\rho(2000)$

fixed parameters : $M_\rho(770)\Gamma_\rho(770)M_\rho(1450) M_\rho(1700)$.

free fit parameters : $g_{\rho\omega\pi}, A_i, \phi_i (i = 1, 2, 3, 4) M_\rho(1900) M_\rho(2000) \Gamma_\rho(1450) \Gamma_\rho(1700) \Gamma_\rho(1900) \Gamma_\rho(2000)$

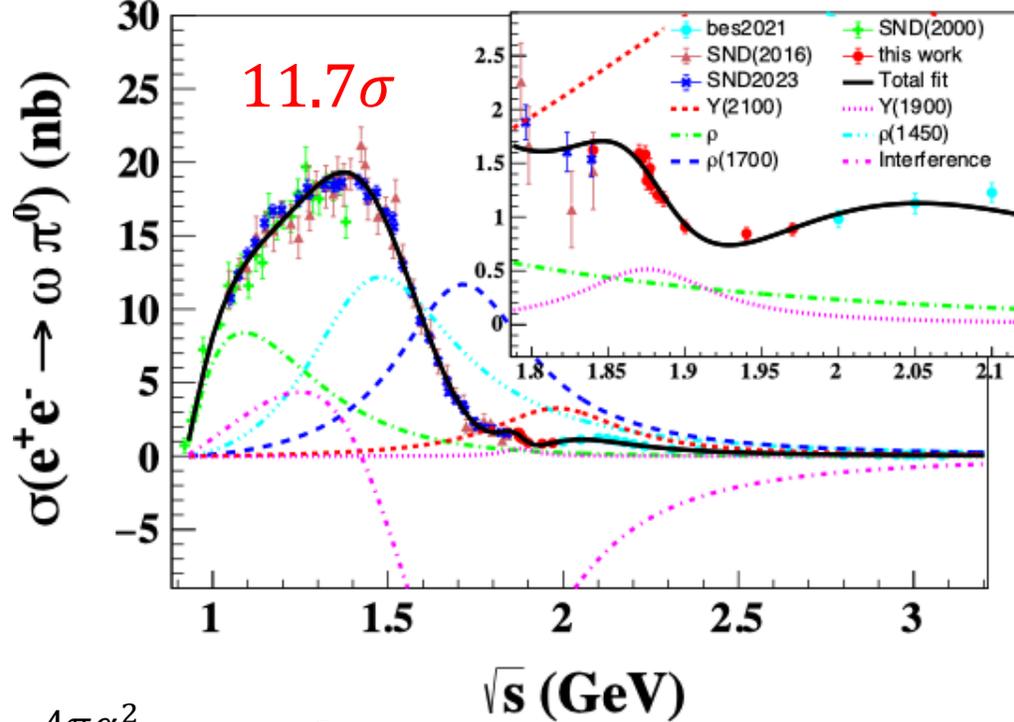
$$\sigma(e^+e^- \rightarrow \omega\pi^0) = \frac{4\pi\alpha^2}{3s^{3/2}} \left| \frac{g_{\rho\omega\pi}}{f_\rho} \left(\frac{m_\rho^2}{\Gamma_\rho} + A_1 e^{i\phi_1} \frac{m_{\rho(1450)}^2}{\Gamma_{\rho(1450)}} + A_2 e^{i\phi_2} \frac{m_{\rho(1700)}^2}{\Gamma_{\rho(1700)}} + A_3 e^{i\phi_3} \frac{m_{\rho(1900)}^2}{\Gamma_{\rho(1900)}} + A_4 e^{i\phi_4} \frac{m_{\rho(2000)}^2}{\Gamma_{\rho(2000)}} \right) \right|^2 P_f(\sqrt{s})$$

SND's result fit

This work and BES3(2021) results fit

Lineshape fit

$$\left(\frac{\chi^2}{ndf}\right)_{this} = \frac{11.99}{9} = 1.33 \quad \left(\frac{\chi^2}{ndf}\right)_{total} = \frac{206.48}{147} = 1.40$$



$$\sigma(\sqrt{s}) = \frac{4\pi\alpha^2}{3s^{3/2}} |F_{\omega\pi\gamma}(s)|^2 P_f(\sqrt{s})$$

$$F_{\omega\pi\gamma}(s) = \frac{g_{\rho\omega\pi}}{f_\rho} (f_0 + A_1 e^{i\phi_1} f_1 + A_2 e^{i\phi_2} f_2 + A_3 e^{i\phi_3} f_3 + A_4 e^{i\phi_4} f_4)$$

Parameters	This fit	PDG's values
$g_{\rho\omega\pi}$	17.7 ± 0.3	—
A_1	0.186 ± 0.014	—
A_2	0.115 ± 0.017	—
A_3	0.0046 ± 0.0024	—
A_4	0.045 ± 0.011	—
$\Gamma_{\rho(1450)}$	0.535 ± 0.044	0.400 ± 0.060
$\Gamma_{\rho(1700)}$	0.471 ± 0.047	0.250 ± 0.100
$M_{\rho(1900)}$	1.876 ± 0.009	1.880 ± 0.010
$\Gamma_{\rho(1900)}$	0.105 ± 0.031	0.069 ± 0.015
$M_{\rho(2000)}$	1.99 ± 0.15	—
$\Gamma_{\rho(2000)}$	0.45 ± 0.06	—
ϕ_1	1.12 ± 0.17	—
ϕ_2	-1.97 ± 0.15	—
ϕ_3	3.66 ± 0.36	—
ϕ_4	2.43 ± 0.29	—



Systematic uncertainties (1.876GeV)

Source	Method	Value
Tracking efficiency	Control sample of $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$	2.0%(1.0% per π)
Particle identification	Control sample of $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$	2.0%(1.0% per π)
Photon detection efficiency	Control sample of $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$	4.0%(1.0% per γ)
Branching fraction	PDG	0.7% (PDG)
luminosity	arXiv:1705.09722v2	1.0%
$(1 + \delta)$ correction	Difference with last version	0.1%
4C kinematic fit	Pull track parameter	0.2%
π_1^0 mass window	[0.115,0.155] \rightarrow [0.112,0.158] or [0.118,0.152]	0.9%
π_2^0 mass window	[0.115,0.155] \rightarrow [0.112,0.158] or [0.118,0.152]	1.3%
Signal shape MCshape	BW \otimes Gaussian \rightarrow MC sample	0.2%
Background shape	2nd order Chebychev \rightarrow 3rd order Chebychev	0.1%
Fitting range	[0.65,0.9] \rightarrow [0.63,0.92] or [0.67,0.88]	0.9%
Total	-	5.4%



Systematic uncertainties

- Summary of systematic uncertainties(%) in the cross section measurement of $e^+e^- \rightarrow \omega\pi^0$

Energies	L	Track	Photon	PID	BR	4C fit	BKG shape	Fit range	Sig shape	π_1^0 mass	π_2^0 mass	$1 + \delta$	Total
1.840	1.0	2.0	4.0	2.0	0.7	0.3	0.5	0.9	0.2	0.7	1.1	0.1	5.5
1.870	1.0	2.0	4.0	2.0	0.7	0.2	2.0	0.8	0.1	0.8	1.3	0.1	5.6
1.872	1.0	2.0	4.0	2.0	0.7	0.3	1.3	0.6	0.2	0.9	1.0	0.2	5.7
1.874	1.0	2.0	4.0	2.0	0.7	0.2	1.1	0.7	0.1	0.7	1.0	0.3	6.1
1.875	1.0	2.0	4.0	2.0	0.7	0.2	1.7	0.7	0.1	1.0	0.9	0.1	6.4
1.876	1.0	2.0	4.0	2.0	0.7	0.2	0.1	0.9	0.2	0.9	1.3	0.1	5.4
1.877	1.0	2.0	4.0	2.0	0.7	0.3	0.9	0.2	0.1	0.8	1.1	0.1	5.0
1.878	1.0	2.0	4.0	2.0	0.7	0.2	1.1	0.8	0.2	0.6	1.4	0.2	6.6
1.882	1.0	2.0	4.0	2.0	0.7	0.3	0.5	0.7	0.2	0.6	1.1	0.1	5.0
1.886	1.0	2.0	4.0	2.0	0.7	0.2	0.3	0.8	0.1	1.0	1.2	0.1	5.1
1.900	1.0	2.0	4.0	2.0	0.7	0.3	1.1	0.7	0.1	0.9	1.4	0.2	6.4
1.940	1.0	2.0	4.0	2.0	0.7	0.2	0.6	0.8	0.1	1.0	1.3	0.1	5.9
1.970	1.0	2.0	4.0	2.0	0.7	0.3	1.0	0.7	0.2	0.7	1.1	0.3	5.4



Summary and next to do

- ✓ Measure the cross section of the processes $e^+e^- \rightarrow \omega\pi^0$
- ✓ Fit the lineshape of $e^+e^- \rightarrow \omega\pi^0$ from 1.84 — 1.97 GeV
- ✓ The measurement of systematic uncertainties has been completed
- ✓ A resonance was observed near 1.9 GeV with a significance of 11.7σ
- ◆ Preparing the memo

Thanks for your attention!