Recent results from the SND detector

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SND detector

SND collected data at the VEPP-2M (1996-2000) and VEPP-2000 (2010-2013, 2016-…)

Main physics task of SND is study of all possible processes of $e^+e^-$ annihilation into hadrons below 2 GeV.

✓ The total hadronic cross section, which is calculated as a sum of exclusive cross sections.

✓ Study of hadronization (dynamics of exclusive processes).

- Properties of excited vector mesons of the $\rho$, $\omega$, $\phi$ families
- Development of MC event generator for $e^+e^- \rightarrow$ hadrons below 2 GeV.

1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counter, 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.
**VEPP-2000 e^+e^- collider**

**VEPP-2000 parameters:**
- c.m. energy $E=0.3$-$2.0$ GeV
- circumference – 24.4 m
- round beam optics
- Luminosity at $E=1.8$ GeV
  - $1 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ (project)
  - $4 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ (achieved)

During 2010-2013 the luminosity was limited by the deficit of positrons

✓ x10 more intense positron source
✓ Experiments at upgraded VEPP-2000 was restarted by the end of 2016.
✓ About 50 pb$^{-1}$ of integrated luminosity has been already collected during the 2017 run
SND data

VEPP-2M

<table>
<thead>
<tr>
<th></th>
<th>Below $\phi$</th>
<th>Near $\phi$</th>
<th>Above $\phi$</th>
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</thead>
<tbody>
<tr>
<td>IL, pb$^{-1}$</td>
<td>9.1</td>
<td>13.2</td>
<td>8.8</td>
</tr>
<tr>
<td>$E_{cm}$, GeV</td>
<td>0.36-0.97</td>
<td>0.98-1.06</td>
<td>1.06-1.38</td>
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VEPP-2000

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</thead>
<tbody>
<tr>
<td>IL, pb$^{-1}$</td>
<td>15.4</td>
<td>6.9</td>
<td>100.0</td>
</tr>
<tr>
<td>$E_{cm}$, GeV</td>
<td>0.30-0.97</td>
<td>0.98-1.05</td>
<td>1.05-2.00</td>
</tr>
</tbody>
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Precision measurements:

➢ $e^+e^- \rightarrow \pi^0\gamma$ (VEPP-2M data)
➢ $e^+e^- \rightarrow K^+K^-$

First measurements

➢ $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$
➢ $e^+e^- \rightarrow \omega\pi^0\eta$

~15 hadronic processes are currently under analysis
$e^+e^\rightarrow \pi^0\gamma$ (VEPP-2M data)

- Third largest cross section (after 2$\pi$ and 3$\pi$) below 1 GeV
- Measurement of the $\pi^0\gamma^*\gamma$ transition form factor
- Measurement of the radiative decays $V\rightarrow\pi^0\gamma$, $V=\rho$, $\omega$, $\phi$ ...
- There is a tension between the KLOE measurement of the ratio $\Gamma(\omega\rightarrow\pi^0\gamma)/\Gamma(\omega\rightarrow\pi^+\pi^-\pi^0)$ and other measurements of $\omega$-meson parameters.

KLOE studies the $e^+e^\rightarrow\omega\pi^0$ process near the $\phi$-meson resonance in two $\omega$ decay modes.

The KLOE measurement led to a large shifts of the previously measured $\omega$-meson parameters, especially for $\omega\rightarrow\pi^0\gamma$. 
The process $e^+e^- \rightarrow \gamma\gamma$ is used for normalization. Many selection criteria are common for $2\gamma$ and $3\gamma$.

- trigger, absence of charged tracks, cuts on the total energy deposition and event momentum, muon system veto.

Final selection is based on 4C kinematic fit ($\chi^2_{3\gamma} < 30$, $36^\circ < \theta_\gamma < 144^\circ$, $80 < M_{\text{rec}} < 190$ MeV, where $M_{\text{rec}}$ is the mass recoiling against largest energy photon).

The number of $e^+e^- \rightarrow \pi^0\gamma$ events is determined from the fit to the $M_{\text{rec}}$ spectrum.
**The most precise measurement of the cross section**

**Systematic uncertainty at the ω peak is 1.4% (1.2% from luminosity and 0.6% due to selection criteria)**
Results on radiative decays

\[ B(\omega \to \pi^0 \gamma)B(\omega \to e^+ e^-) = (6.336 \pm 0.056 \pm 0.089) \times 10^{-6} \]

Using PDG value for \( B(\omega \to \pi^+ \pi^- \pi^0) \) \( B(\omega \to e^+ e^-) \) we obtain
\[ \frac{\Gamma(\omega \to \pi^0 \gamma)}{\Gamma(\omega \to \pi^+ \pi^- \pi^0)} = 0.0992 \pm 0.0023, \]
which is higher than the KLOE value 0.0897 ± 0.0016 by 3.4σ.

\[ B(\rho \to \pi^0 \gamma) = (4.20 \pm 0.47 \pm 0.22) \times 10^{-4} \]

By 1.8 σ lower than the current PDG value (6.0 ± 0.8) × 10^{-4}, but agrees with the branching fraction for the charged mode \( B(\rho^\pm \to \pi^\pm \gamma) = (4.5 \pm 0.5) \times 10^{-4} \)

\[ B(\phi \to \pi^0 \gamma)B(\phi \to e^+ e^-) = (3.92^{+0.71}_{-0.40} \pm 0.51) \times 10^{-7} \]

The model uncertainties of the previous measurements (~8%) were underestimated. For \( \phi \) fixed at the value (163 ± 7)° obtained in the VMD fit to \( e^+ e^- \to \pi^+ \pi^- \pi^0 \) data
\[ B(\phi \to \pi^0 \gamma)B(\phi \to e^+ e^-) = (4.04 \pm 0.09 \pm 0.19) \times 10^{-7} \]
Our measurement agrees with the BABAR data and has comparable or better accuracy.

At \( E < 2 \) GeV the total cross section is calculated as a sum of exclusive channels.

The exclusive data are incomplete in the region \( 1.6 < E < 2.0 \) GeV.

There is no experimental information on the final states \( \pi^+\pi^-\pi^0\eta, \pi^+\pi^-\eta\eta, \pi^+\pi^-\pi^0\pi^0\pi^0, \pi^+\pi^-\pi^0\pi^0\eta \) ...

The important experimental task is to measure all significant exclusive channels below 2 GeV, and perform comparison with inclusive measurements and pQCD prediction.

\[
R(s) = \frac{\sigma(e^+e^- \rightarrow \gamma^* \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}
\]
$e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$

Mass recoiling against $\eta$

- $\omega\eta$ and $\phi\eta$ intermediate states are clearly seen in the spectrum of the mass recoiling against $\eta$
- $\alpha_0(980)\rho$ intermediate state is seen in the $\eta\pi$ spectrum
- Some fraction of events at $E$ below 1.8 GeV do not have any clear structure.
The process $e^+e^- \rightarrow \omega\eta$ has been measured separately.

There is a significant difference between our result and the previous BABAR measurement.

First measurement of this process
The intermediate states are $\omega\eta$, $\phi\eta$, $a_0\rho$ and structureless $\pi^+\pi^-\pi^0\eta$

The known $\omega\eta$ and $\phi\eta$ contributions explain about 50-60% of the cross section below 1.8 GeV.

Above 1.8 GeV the dominant reaction mechanism is $a_0\rho$
First measurement of the $e^+e^- \rightarrow \omega \pi^0 \eta$ cross section.

The dominant mechanism is $\omega a_0(980)$.

The cross section is about 2.5 nb, 5% of the total hadronic cross section.
The SND detector accumulated ~120 pb\(^{-1}\) of integrated luminosity at the VEPP-2000 e\(^{+}\)e\(^{-}\) collider in the c.m. energy range 0.3 – 2 GeV.

Data analysis on hadron production is in progress. The obtained results have comparable or better accuracy than previous measurements (\(\omega\pi^{0}, \pi^{+}\pi^{-}\pi^{0}, \pi^{+}\pi^{-}\eta, n\) anti-\(n\), \(\pi^{0}\gamma, K^{+}K^{-}\))

For several processes the cross sections have been measured for the first time (\(\eta\gamma, \pi^{+}\pi^{-}\pi^{0}\eta, \omega\pi^{0}\eta\))

After VEPP-2000 upgrade, data taking was resumed, with a goal of ~1 fb\(^{-1}\) of integrated luminosity.