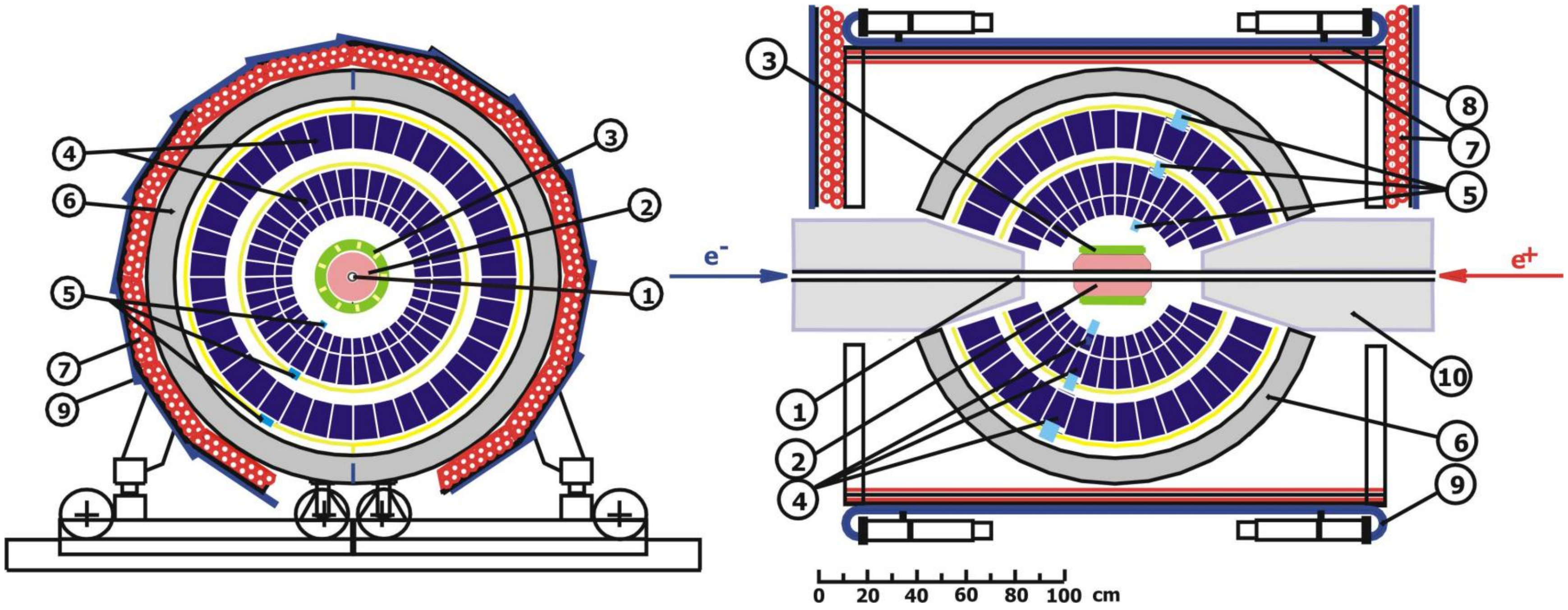
Search for the $\eta' \to e^+e^-$ decay at the SND detector

Berdyugin A.V.

SND – VEPP-2000

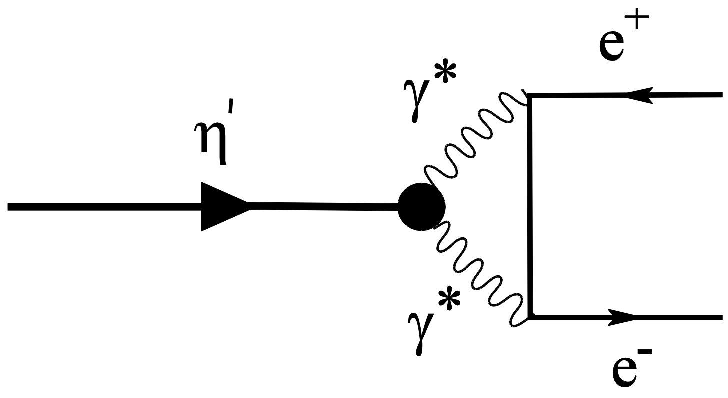
SND detector at VEPP-2000

NIM A449 (2000) 125-139



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.

Search for the $\eta' \to e^+e^-$ decay



$$\sigma_0 = \frac{4\pi}{m_{\eta'}^2} B(\eta' \to e^+e^-), at\ E_{cm} = m_{\eta'}c^2$$

The current upper limit (CMD-3):

$B(\eta' \to e^+e^-) < 1.2 \cdot 10^{-8}$

Unitary limit obtained from $B(\eta' \to \gamma\gamma)$:

$B(\eta' \to e^+e^-) > 3.8 \cdot 10^{-11}$

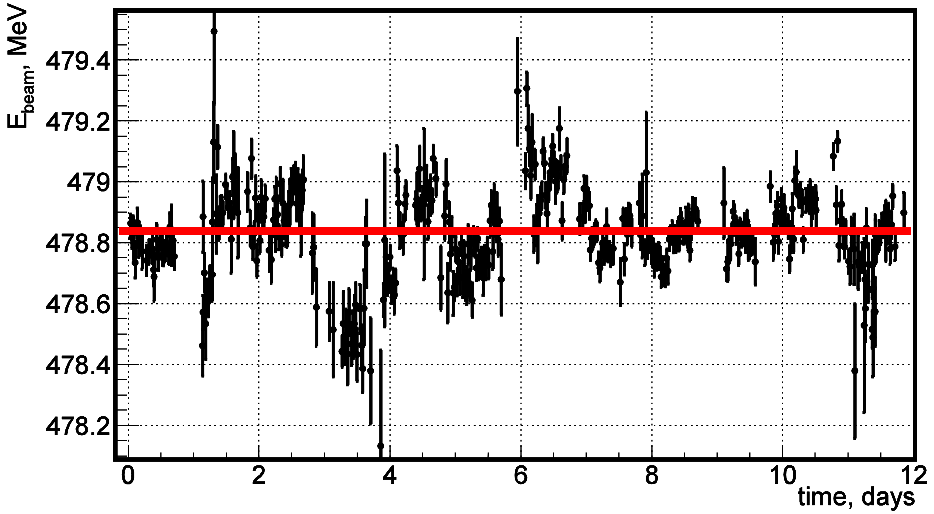
The real part of the decay amplitude depending on the $\eta' \to \gamma^*\gamma^*$ transition form factor may increase the branching fraction by a factor of 3-5.

The decay may be sensitive to a new-physics contributions.

Experimental conditions

Diagrams and calculations taken from CMD-3

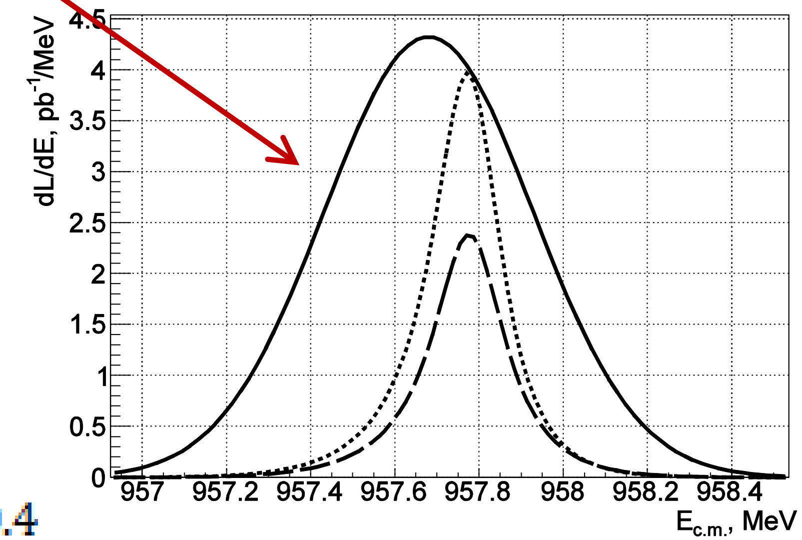
Beam energy measurements during data taking



E_{cm} = 957.68 ± 0.060 MeV
$\sigma(E_{cm})$ = 0.246 ± 0.030 MeV

The energy spread is significantly larger than the η′ width:
FWHM=0.590 MeV > $\Gamma_{\eta'}$ (0.198 MeV)

The luminosity as a function of the c.m. energy



Rad. correction $\delta = -0.4$

$\sigma_{vis}(\text{nb}) = (6.38 \pm 0.23)\Gamma_{\eta' \to e^+e^-}$

$\sigma_{vis} = 0.0454$ pb (unitary limit)

η' decay modes

1. $\eta' \rightarrow \eta\pi^+\pi^-$

   $\eta \rightarrow \gamma\ \gamma$ - 2 charged particles and 2 photons (0.17)

   $\eta \rightarrow \pi^0\pi^0\pi^0$ - 2 charged particles and 6 photons (0.14)

2. $\eta' \rightarrow \eta\pi^0\pi^0$

   $\eta \rightarrow \pi^+\pi^-\pi^0$ - 2 charged particles and 6 photons (0.049)

   $\eta \rightarrow \gamma\ \gamma$ - 6 photons (0.085)

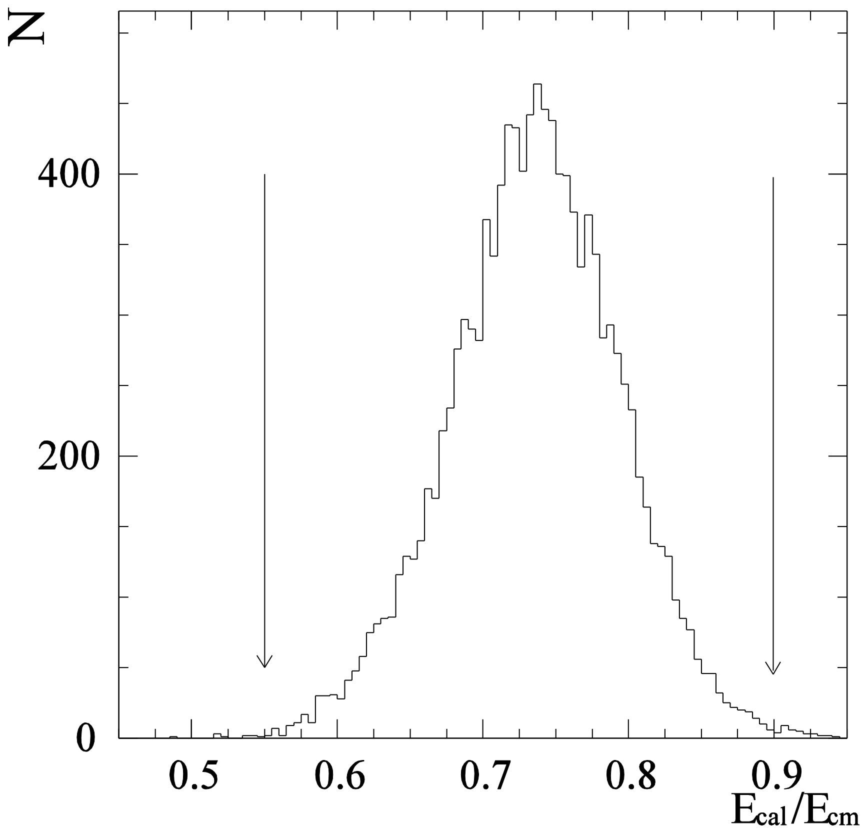
   $\eta \rightarrow \pi^0\pi^0\pi^0$ - 10 photons (0.07)

Σ probability: ~ 51.5%

Event selection for decay channel $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$ (1)

Preliminary selection:

- 2 charged particles, 2 photons
- Veto from the muon detector
- Minimal angle between π and γ >20°
- Minimal angle between pions >20°
- $40° < \theta$ pions $< 140°$
- $d\varphi = |180 - |\varphi_1 - \varphi_2|| > 10°$ (for pions)
- $0.55 < E_{cal}/E_{c.m.} < 0.9$



Event selection for decay channel $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$ (2)

Final selection:

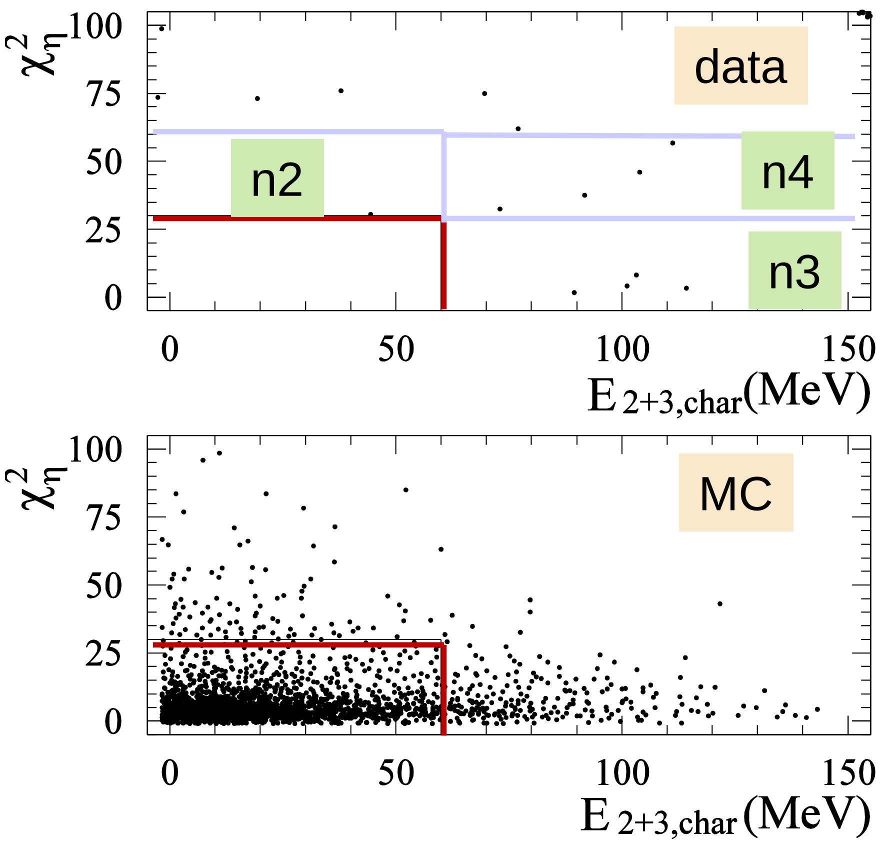
- Kinematic fit: $\chi^2_\eta < 30$
- Σ(energy deposition in 2 and 3 calorimeter layers for charged particles) < 60 MeV

Background:

$e^+e^- \to \eta\gamma$, $\eta \to \pi^+\pi^-\pi^0$ – 0.7 ± 0.1

$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ – 0.10 ± 0.05

calculated from data (n2·n3/n4) – 1 ± 1

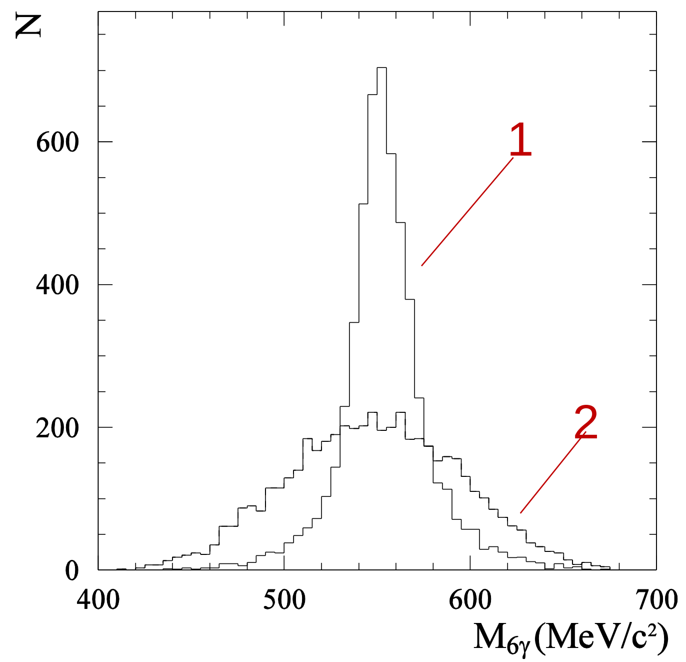


Event selection for decay channel $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^0\pi^0\pi^0$ (1)

Preliminary selection:

- 2 charged particles, 6 photons
- Veto from the muon detector
- Minimal angle between pions and π and $\gamma > 20^\circ$
- $d\varphi = |180 - |\varphi_1 - \varphi_2|| > 10^\circ$ (for charged pions)
- $0.5 < E_{cal}/E_{c.m.} < 0.9$
- Σ(energy deposition in 2 and 3 calorimeter layers for charged particles) < 60 MeV

1 – $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^0\pi^0\pi^0$
2 – $\eta' \to \eta\pi^0\pi^0$, $\eta \to \pi^+\pi^-\pi^0$



Event selection for decay channel $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^0\pi^0\pi^0$ (2)

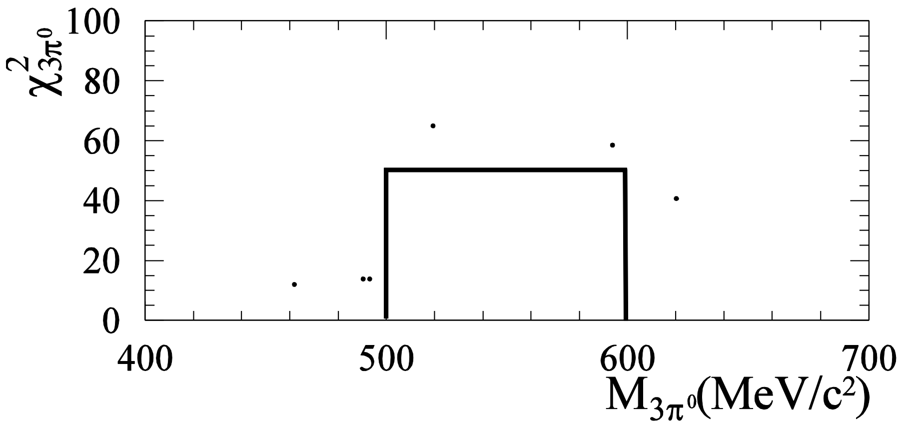
Kinematic fit:

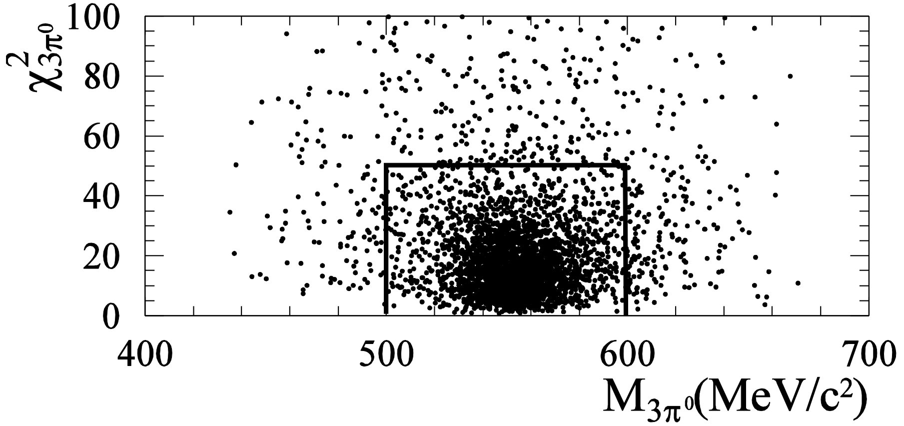
- $\chi^2_{3\pi 0} < 50$
- $500 < M_{3\pi 0} < 600$ MeV

Background:

$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ – 2.7 ± 0.5

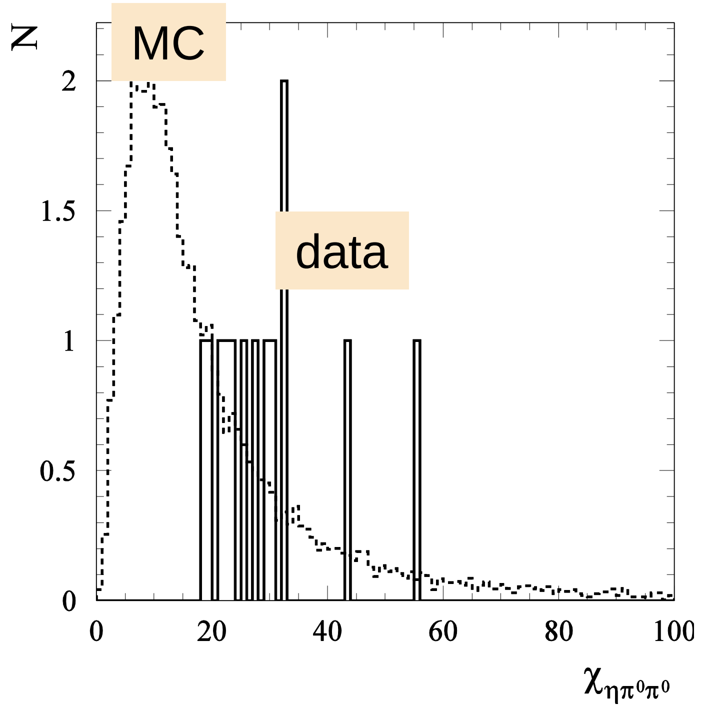
calculated from data – 2 ± 1





Event selection for decay channel $\eta' \to \eta\pi^0\pi^0$, $\eta \to \gamma\gamma$

- No charged particles, 6 photons
- Veto from the muon detector
- The photon transverse energy distribution in the calorimeter is consistent with the distribution for an electromagnetic shower
- $0.7 < E_{tot}/E_{cm} < 1.2$; $P_{cal}/E_{cm} < 0.3$;
- $E_{tot}/E_{cm} - P_{cal}/E_{cm} > 0.7$
- Kinematic fit: $\chi^2_{\eta\pi0\pi0} < 15$



Background:

$e^+e^- \to \eta\gamma$, $\eta \to \pi^0\pi^0\pi^0$ – 1.3 ± 0.3; $e^+e^- \to \pi^0\pi^0\gamma$ – 0.4 ±0.1

$\chi^2_{\eta\pi0\pi0} < 100$: experiment - 13, MC - 12 ± 2 / 3 ± 1

Event selection for decay channel $\eta' \to \eta\pi^0\pi^0$, $\eta \to \pi^0\pi^0\pi^0$

Selection:

- No charged particles, 10 photons
- Veto from the muon detector
- The photon transverse energy distribution in the calorimeter is consistent with the distribution for an electromagnetic shower
- $0.7 < E_{tot}/E_{cm} < 1.2$; $P_{cal}/E_{cm} < 0.3$;
- $E_{tot}/E_{cm} - P_{cal}/E_{cm} > 0.7$

This channel does not have hadron background. Only background source is cosmic-ray showers!

Efficiency

1. $\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$ — $(12.2 \pm 1.2)\%$
2. $\eta' \to \eta\pi^+\pi^-$, $\eta \to \pi^0\pi^0\pi^0$ — $(7.5 \pm 0.8)\%$

   $\eta' \to \eta\pi^0\pi^0$, $\eta \to \pi^+\pi^-\pi^0$ — $(4.9 \pm 0.5)\%$
3. $\eta' \to \eta\pi^0\pi^0$, $\eta \to \gamma\gamma$ — $(14.6 \pm 0.7)\%$
4. $\eta' \to \eta\pi^0\pi^0$, $\eta \to \pi^0\pi^0\pi^0$ — $(22.6 \pm 1.1)\%$

Luminosity:

$L_{ee} = 2.91\ \mathrm{pb}^{-1}$

$L_{\gamma\gamma} = 2.82\ \mathrm{pb}^{-1}$

(difference ~3%)

Limit

$$\sigma_{vis}^{exp} = \frac{N_s}{\sum L_i \epsilon_i}$$

$\epsilon_s = 6.2 \pm 0.4\ \%$

$N_s < 2.32$ (90% CL)

(following the implementation of Barlow)

$\sigma_{vis}^{exp} < 12.7$ pb (90% CL)

$\Gamma_{\eta' \to e^+e^-} < 0.0020$ eV (90%CL)

Combined SND-CMD-3 limit

SND:

$N_{event} = 0$, $L_{ee} = 2.91\ pb^{-1}$, $\epsilon = (6.2 \pm 0.4)\%$

CMD-3:

$N_{event} = 0$, $L_{ee} = 2.69\ pb^{-1}$, $\epsilon = (5.3 \pm 0.3)\%$

$\boldsymbol{\Gamma_{\eta' \to e+e-} < 0.0011\,\mathrm{eV}\ (90\%\mathrm{CL})}$

$\boldsymbol{B(\eta' \to e+e) < 5.6 \cdot 10^{-9}\ (90\%\mathrm{CL})}$

Unitary limit:

$B(\eta' \to e^+e^-) > 3.8 \cdot 10^{-11}$

Proposal for search for the $\eta \to e^+e^-$

- Inversed reaction $e^+e^- \to \eta$ is used
- VEPP-2000 parameters at $m_\eta c^2$
  - ✓ $L = 0.35 \times 10^{30}$ cm^{-2}sec^{-1}
  - ✓ $\sigma_{Ecm} = 150$ keV ; $\Gamma_\eta = 1.3$ keV
  - ✓ E_{cm} setting accuracy - 60 keV
- For unitary bound $B(\eta \to e^+e^-) = 1.78 \times 10^{-9}$
  - $\sigma_{Born} = (4\pi/m_\eta^2)\, B(\eta \to e^+e^-) \approx 30$ pb
  - + rad. corr. ≈ 15 pb
  - + energy spread = $\approx 0.11 \pm 0.01$ pb

1/140 of collected luminosity may be effectively used

- The most suitable decay mode $\eta \to \pi^0\pi^0\pi^0$
  - Visible cross section of background processes $e^+e^- \to \pi^0\pi^0\gamma$, 5γ, 6γ, about 0.04 pb, corresponds to $B(\eta \to e^+e^-) \sim 3$ UB
- Data from the energy region 520–580 MeV have been used to determine background level in real experiment.
  - For $L \approx 100$ nb^{-1} zero data events have been selected in the decay mode $\eta \to \pi^0\pi^0\pi^0$
- In absence of background a sensitivity to $B(\eta \to e^+e^-)$ of 10^{-6} can be reached during two weeks of VEPP-2000 operation (324 nb^{-1}), which is better then the current upper limit by a factor of 2.3.

Conclusion

- In the experiment with SND detector the upper limit $B(\eta'\to e+e) < 1.0\cdot10^{-8}$ has been obtained at 90%CL. The combined SND-CMD-3 upper limit is $5.6\cdot10^{-9}$ (90% CL) (unitary bound $B(\eta'\to e^+e^-) > 3.8\cdot10^{-11}$, 150 times smaller)
- Our next step is to increase statistics for the $\eta'\to e^+e^-$ decay by a factor of ten.
- A search for the $\eta\to e^+e^-$ decay will be performed with a sensitivity to $B(\eta \to e^+e^-)$ of 10^{-6}

As a test, we perform measurements of the cross section for the process:

- $\sigma(e^+e^- \to \pi^+ \pi^- \pi^0) = 11.7 \pm 0.2$ nb ($\sigma(e^+e^- \to \pi^+ \pi^- \pi^0) = 11.33 \pm 0.64$ nb)
- $\sigma(e^+e^- \to \pi^0 \pi^0 \gamma) = 285 \pm 21$ pb ($\sigma(e^+e^- \to \pi^0 \pi^0 \gamma) = 242 \pm 89$ pb)
- $\sigma(e^+e^- \to \eta\gamma) = 244 \pm 30$ pb ($\sigma(e^+e^- \to \eta\gamma) = 300 \pm 110$ pb)