Status of $e^+e^- \to \pi^+\pi^-$ analysis with SND at VEPP-2000

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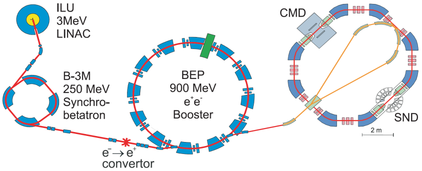
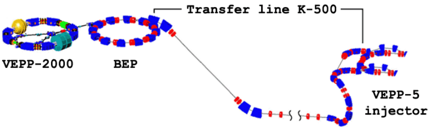
on behalf of SND collaboration

Muon g-2 Theory Initiative workshop
September 9 – 13, 2024

VEPP-2000 e^+e^- collider



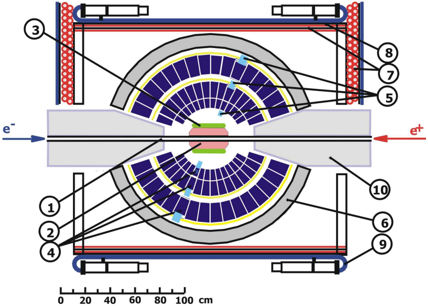


VEPP-2000 parameters

- c.m. energy E=0.3-2.0 GeV
- Luminosity at E=1.8 GeV
  $10^{32} cm^{-2} sec^{-1}$ (project)
  $6x10^{31} cm^{-2} sec^{-1}$ (achieved)
- Beam energy spread - 0.6 MeV at E=1.8 GeV

- 10 times more intense positron source
- Experiments at upgraded VEPP-2000 were continued in the late 2016

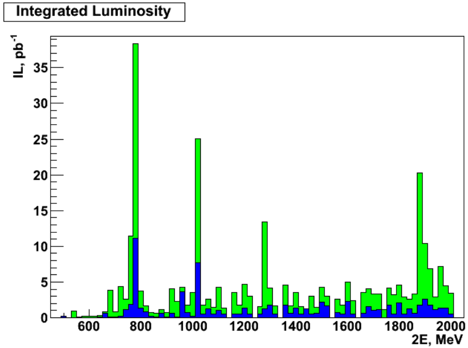
SND detector



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.

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)
- Study of the light vector mesons
- Production of the C-even resonances



Current $e^+e^- \to \pi^+\pi^-$ analysis is based on the statistics, collected in 2017 – 2018 in 100 energy points $\sqrt{s} < 1$ GeV. This year 90 pb^{-1} of data has been collected in the low energy region ($\sqrt{s} \approx M_\varphi$ and $M_\omega < \sqrt{s} < M_\varphi$). With 2.4 and 3.5 times greater statistics comparing to data, collected in the same energy points for the RHO 2018.

Timeline

- MHAD2012 – 48 pb^{-1}
- RHO 2013 – 32 pb^{-1}
- MHAD2017 – 50 pb^{-1}
- RHO 2018 – 90 pb^{-1}
- MHAD2019 – 65 pb^{-1}
- RHO 2019 – 1 pb^{-1}
- MHAD2020 – 45 pb^{-1}
- MHAD2021 – 57 pb^{-1}
- MHAD2022 – 360 pb^{-1}
- MHAD2023 – 223 pb^{-1}
- MHAD2024 – 114 pb^{-1}
- PHI 2024 – 57 pb^{-1}
- RHO 2024 – 33 pb^{-1}

Event selection

1. $N_{ch} \geq 2$ – two or more charged particles are allowed
2. $|\Delta\theta| = |180^\circ - (\theta_1 + \theta_2)| < 14^\circ$ и $|\Delta\varphi| = |180^\circ - |\varphi_1 - \varphi_2|| < 6^\circ$
3. $E_{1,2} > 40$ MeV, here E_i – energy deposition for the i–th particle
4. $60^\circ < \theta_0 = (\theta_1 - \theta_2 + 180^\circ) \times 0.5 < 120^\circ$
5. $|r_1| < 1$ cm , $|r_2| < 1$ cm, here r_i – distance between a track of i–th particle and the beam axis
6. $|z0_1| < 8$ cm , $|z0_2| < 8$ cm, here z_i – longitudinal coordinate of the vertex
7. Cosmic veto: $veto = 0$ ($\sqrt{s} < 900$ MэВ)

With $e^+e^- \to \pi^+\pi^-$, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to e^+e^-$ and residual cosmic background events passing these cuts. Contributions from $e^+e^- \to e^+e^-e^+e^-$ (0.1 – 2 %) and $e^+e^- \to \pi^+\pi^-\pi^0$ (0.01 – 0.4 %) to $e^+e^- \to \pi^+\pi^-$ were estimated from MC. Efficiencies for major processes are calculated via MC simulation with MCGPJ used for primary particles generation.

e/π separation

In order to separate events with e^+e^- and $\pi^+\pi^-$ in the final state machine learning methods (based on BDTG) were developed, with input parameters:

- $^{0}\mathbf{e_j}$ – energy deposition for the $j-$th layer in the central tower
- $^{1}\mathbf{e_j}$ – energy deposition for the $j-$th layer in the towers, next to the central one
- $^{2}\mathbf{e_j}$ – energy deposition for the $j-$th layer outside
- $\mathbf{E_j}$ – full energy deposition for $j-$th layer
- $\mathbf{E}$ – total energy deposition
- $<$ **dEdx** $>$ – dE/dx of a particle in the DC, averaged over layers

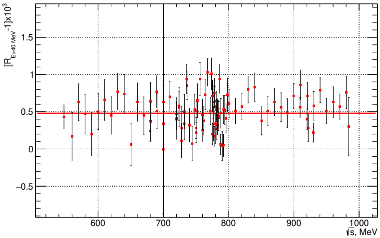
Overall $(4 \times 3 + 2) \times 2 =$ **28** parameters for the main discriminator.
There is a vertion of discriminator for separate particles.
And one for μ/π separation

Changes in the reconstruction algorithm

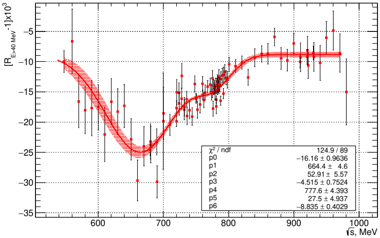
- Reduced number of shifted tracks by altering reconstruction algorithm (RA): common z-vertex for bouth tracks, more robust filter for the false strip clusters and wire hits
- There was a bug in parts of code, related to calculation of the track parameters in the transversal plane (small affect on track parameters)
- It was discovered, that erros for the cathode strips strongly depend on polar angle of track bouth in Data and MC, and it wasn't taken in to account in the RA

Efficiency of the $E_i > 40$ MeV cut

Using ee и 2π events (with some additional cuts*) to calculate efficiency corrections



$e^+e^- \to e^+e^-$ events



$e^+e^- \to \pi^+\pi^-$ events

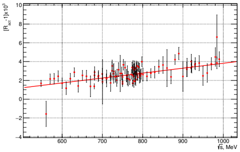
The largest correction comes from $E_i > 40$ MeV cut. It's possible to calculate cross section with different cut

($\max(E_1, E_2) > 80$ MeV or $\min(E_1, E_2) > 40$ MeV)

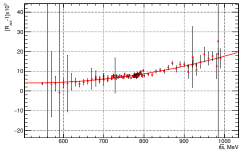
* ACC (not)firing, muon suppression

Issues with a cosmic veto efficiency

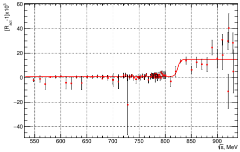
Using e^+e^-, $\mu^+\mu^-$ and 2π events (with some additional cuts* and cosmic background subtraction via fit of the vertex z-coordinate distribution) to calculate efficiency correction



$e^+e^- \to e^+e^-$ events



$e^+e^- \to \pi^+\pi^-$ events



$e^+e^- \to \mu^+\mu^-$ events

Probability of the muon system firing in case of $e^+e^- \to \pi^+\pi^-$ is higher for MC due to the elastic scattering of the neutrons in a plastic scintilator, resulting in production of low energy protons and nuclei. Because of the high dE/dx their dL/dE is very small, comparing to relativistic paricles. This effect wasn't taken in to account in MC (now it has Q=1/(1+k*dE/Ex) factor).

* $|\sin(\varphi)|<0.5$, ACC (not)firing, muon (pion) suppression

Systematics (best case scenario)

Source	$\sqrt{s} < 700$ MeV, %	$\sqrt{s} > 700$ MeV, %
e/π	$0.3 \to 0.1$	0.1
$E_i > 40$ MeV	$0.4 \to 0.2$	$0.4 \to 0.1$
rad	0.2	
nc2	0.1	
col	0.2	
θ_0	$0.5 \to 0.4$	
nucl	0.2	
total	$0.8 \to 0.6$	$0.7 \to 0.6$

Current status and plans for nearest (< 6 month) future

- Due to technical issues (related to software updates) we couldn't process data with improved reconstruction algorithm and produce new MC samples at scale
- We expect better agreement between MC and Data regarding $\Delta\theta$, θ_0 distributions and cosmic veto efficiency
- New version of the Geant4 (11.2.1) has better descriptions of the nuclear iteractions for the low-energy pions, resulting (possibly) in the smaller corrections for energy deposition and particle ID cuts in case of $e^+e^- \to \pi^+\pi^-$ events
- To get a final (But blinded) results for 2018 data
- Measure cross section in $520 \leq \sqrt{s} \leq 600$ MeV energy range with 2019 data using n=1.13 ACC to test $e^+e^- \to \mu^+\mu^-$ subtraction technique
- Apply current analysis techniques to the 2013 data

Plans for distant (1-2 year) future

- Publish unblinded results with 0.6–0.7 % systematics
- If current trends continue, in 1-1.5 year we'll collect 2–3 times more data (comparing to **RHO 2018** experiment) for $\sqrt{s} < M_{\varphi}$, with better tracking system performance (stable signal gain in DC, fresh ACC, faster electronics) and EMC time measurements
- Current 3π analysis will be published

Thank you for attention !