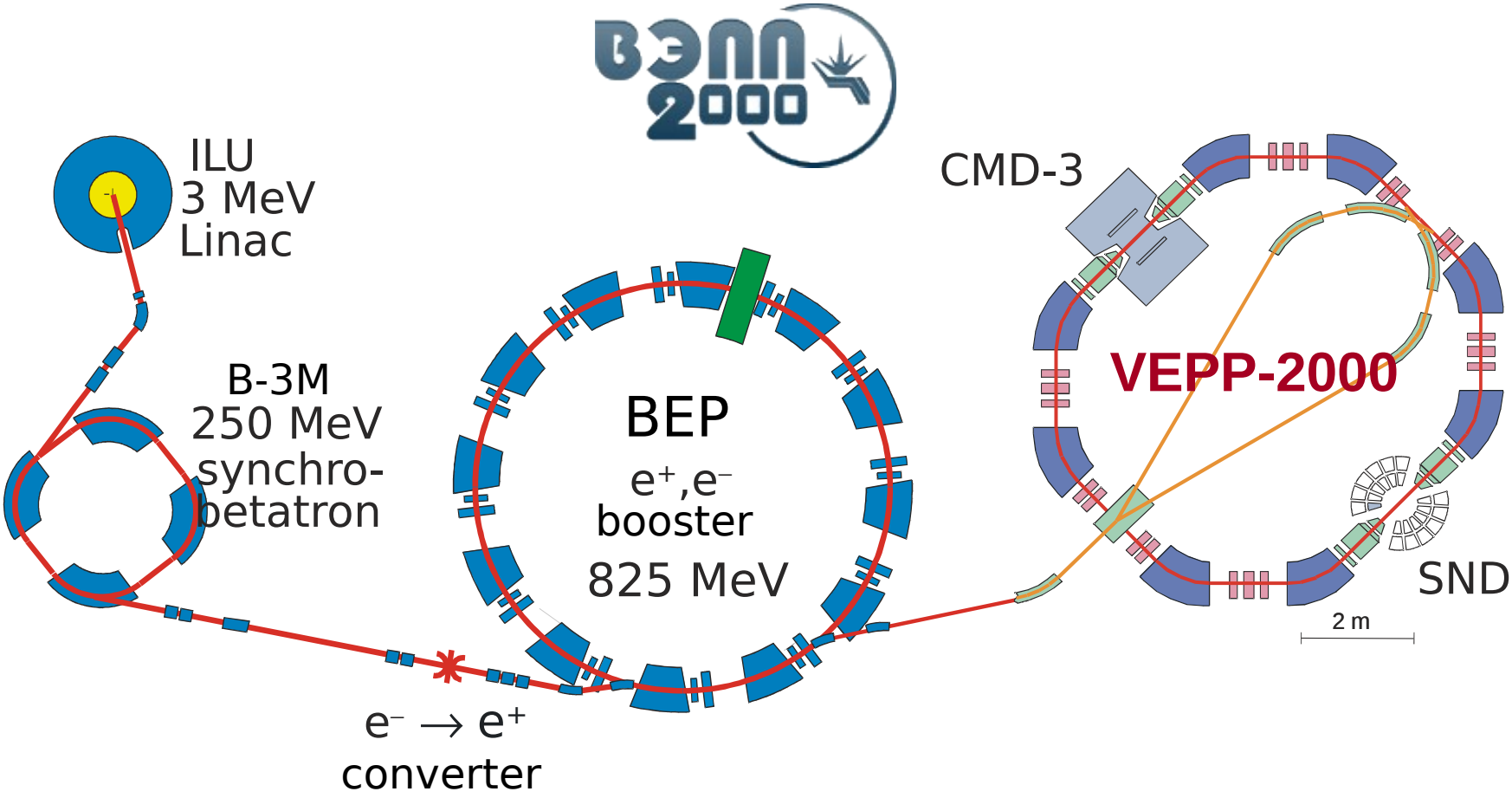
Recent results from VEPP-2000

KAZANIN VASSILI

On behalf of CMD-3 and SND collaborations
Budker Institute of Nuclear Physics
Novosibirsk State University

PHOTON**2015** conference

VEPP-2000 collider (2010-2013)



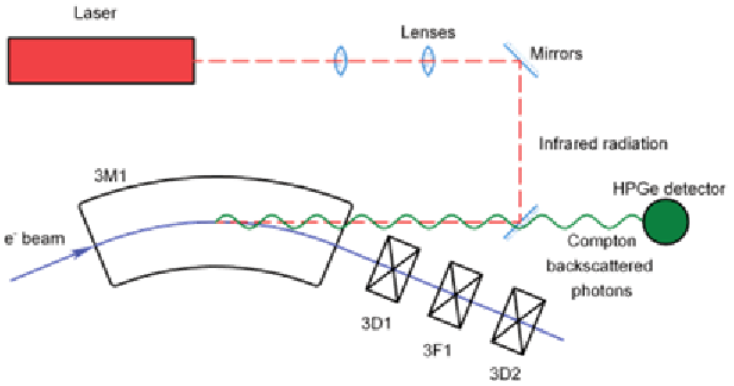
Maximum c.m. energy is 2 GeV, project luminosity is L = 10^{32} 1/cm^{2}s at $\sqrt{s}$ = 2 GeV

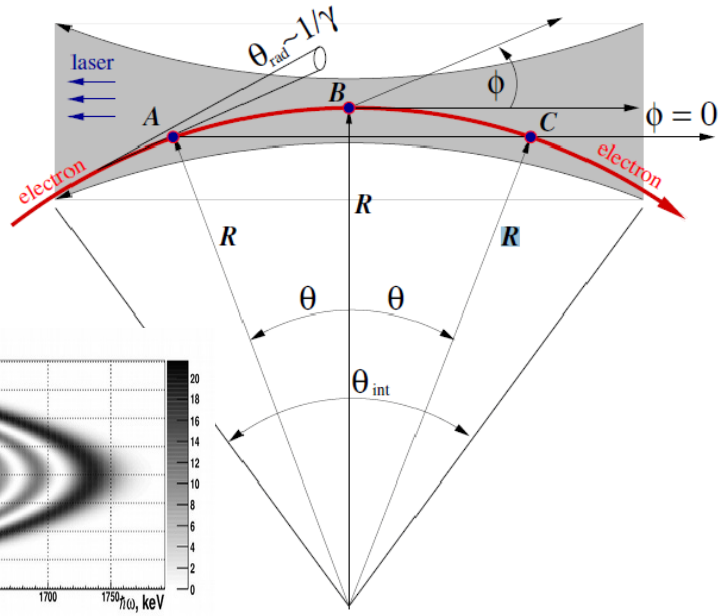
Unique optics, “round beams”, allows to reach higher luminosity

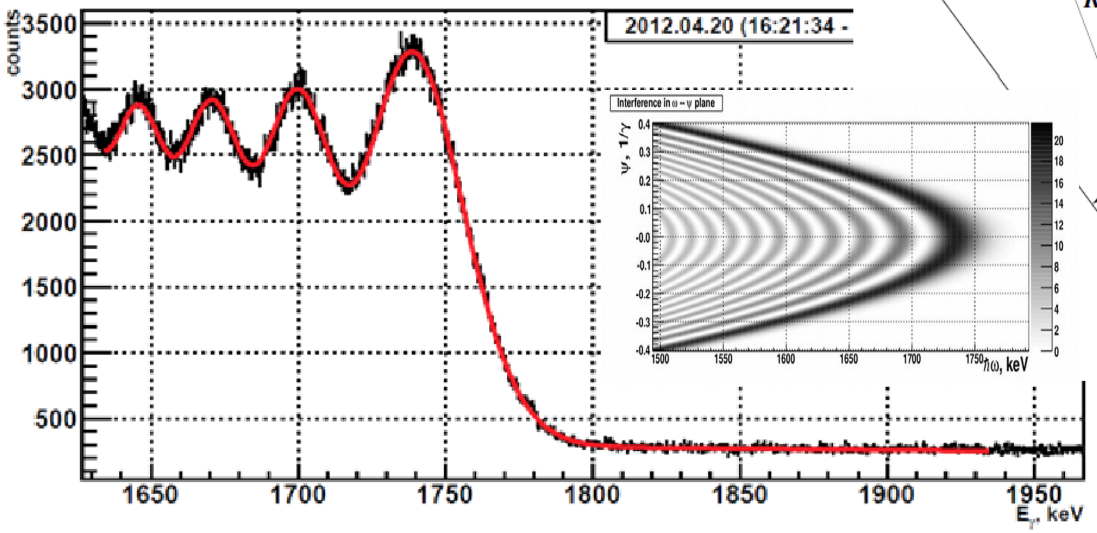
Experiments with two detectors, CMD-3 and SND, started by the end of 2010

Energy measurement

Starting from 2012, energy is monitored continuously using compton backscattering



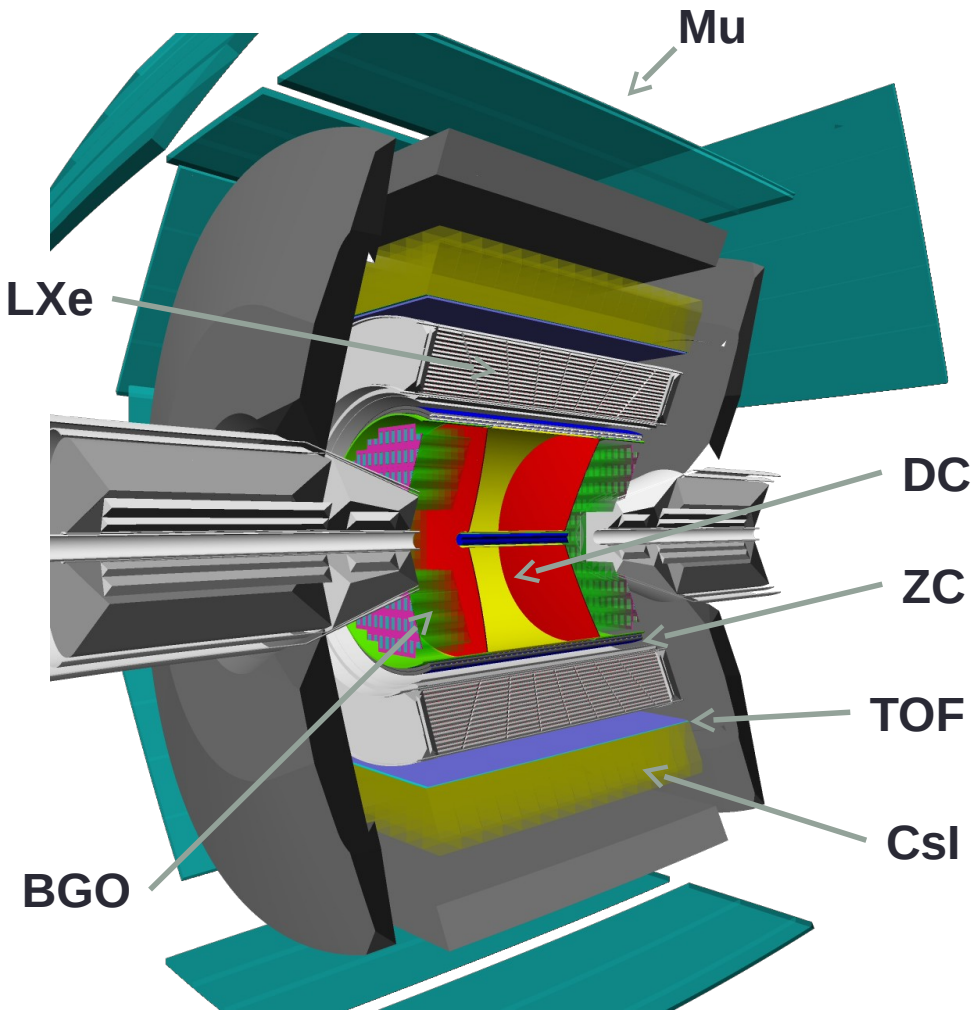




E = 993.662 ± 0.016 МэВ

E.V. Abakumova et al., Phys. Rev. Lett. 110 (2013) 14, 140402,
E.V. Abakumova et al.,Nucl.Instrum.Meth. A744 (2014) 35-40

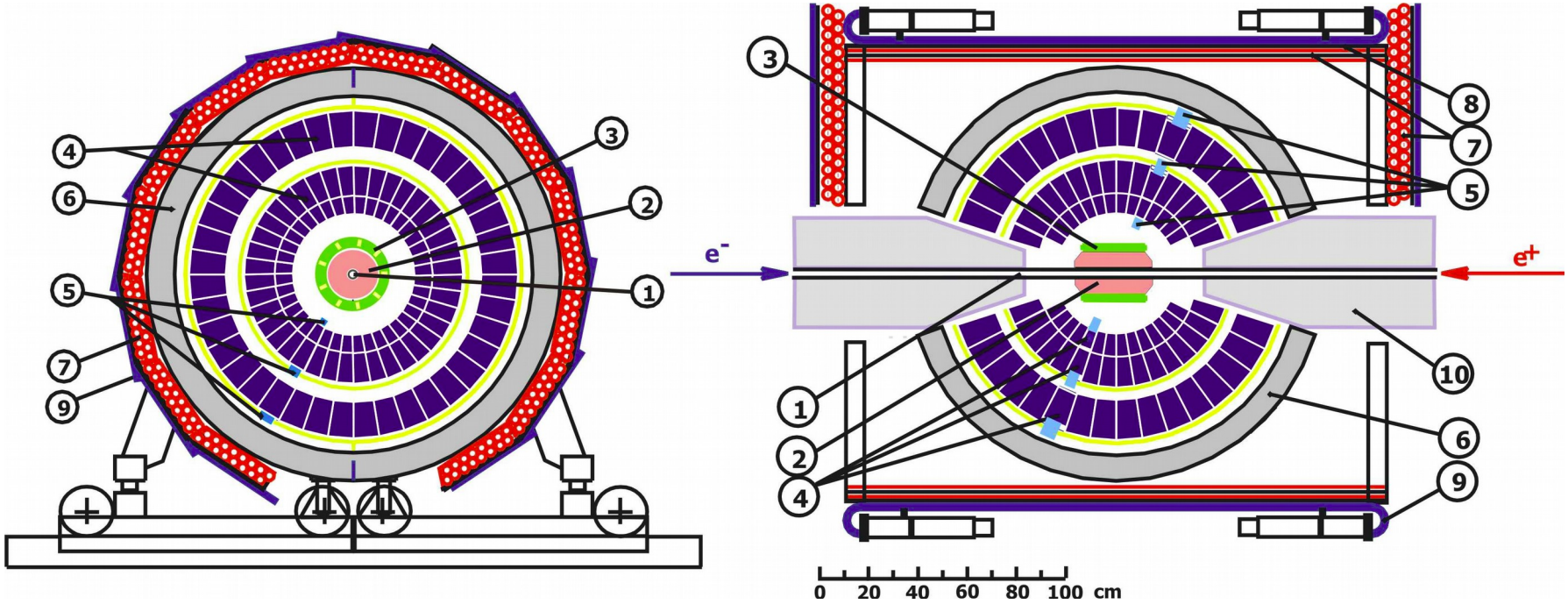
CMD-3 detector



Advantages compared to CMD-2:

- new drift chamber with two times better resolution, higher B field
  - better tracking
  - better momentum resolution
- thicker barrel calorimeter (8.3 X_0 → 13.4 X_0)
  - better particle separation
- LXe calorimeter
  - measurement of conversion point for γ's
  - measurement of shower profile
- TOF system
  - particle id (mainly p, n)

SND detector

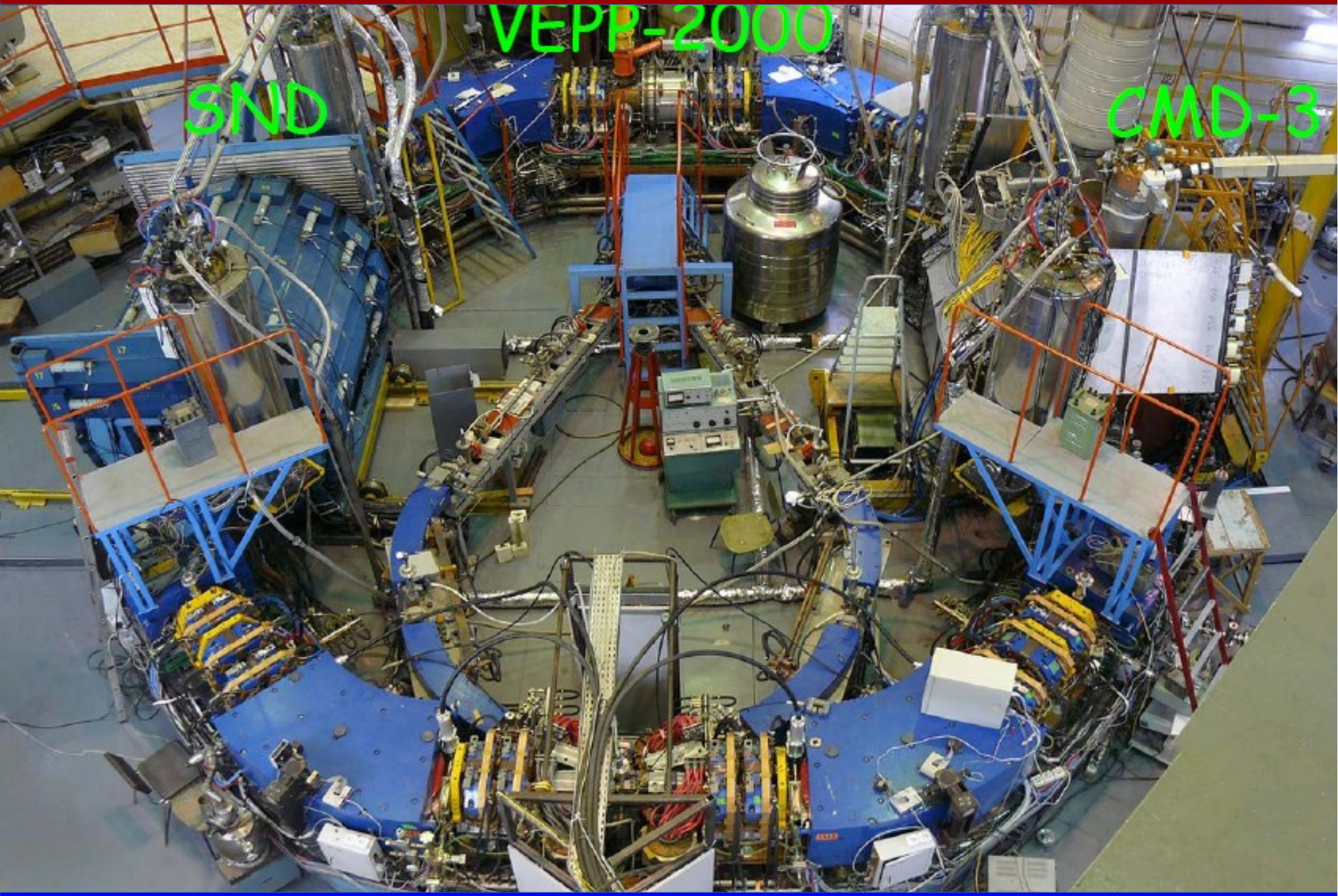


1 – beam pipe
2 – tracking system
3 – aerogel
4 – NaI(Tl) crystals
5 – phototriodes
6 – muon absorber
7–9 – muon detector
10 – focusing solenoid

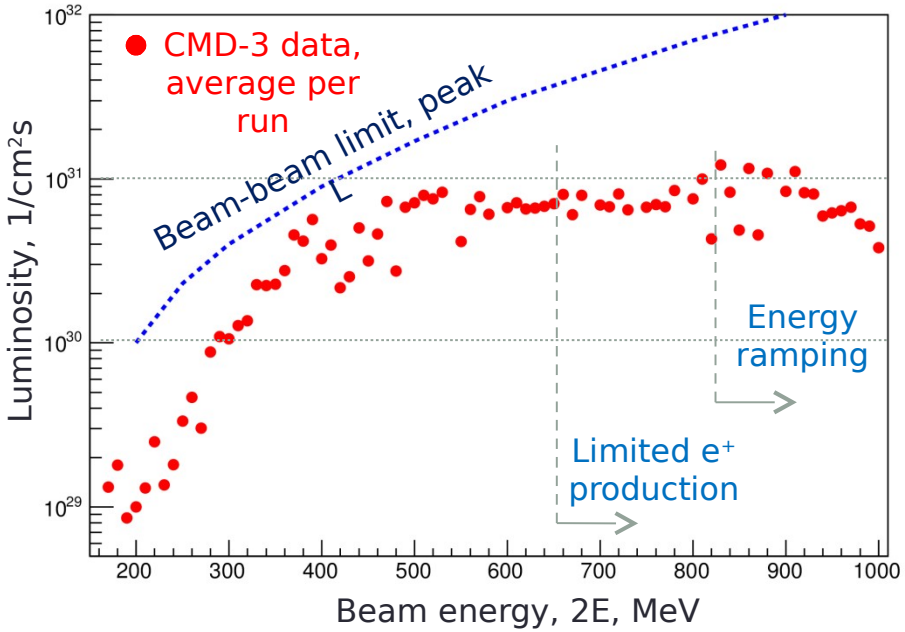
Advantages compared to previous SND:

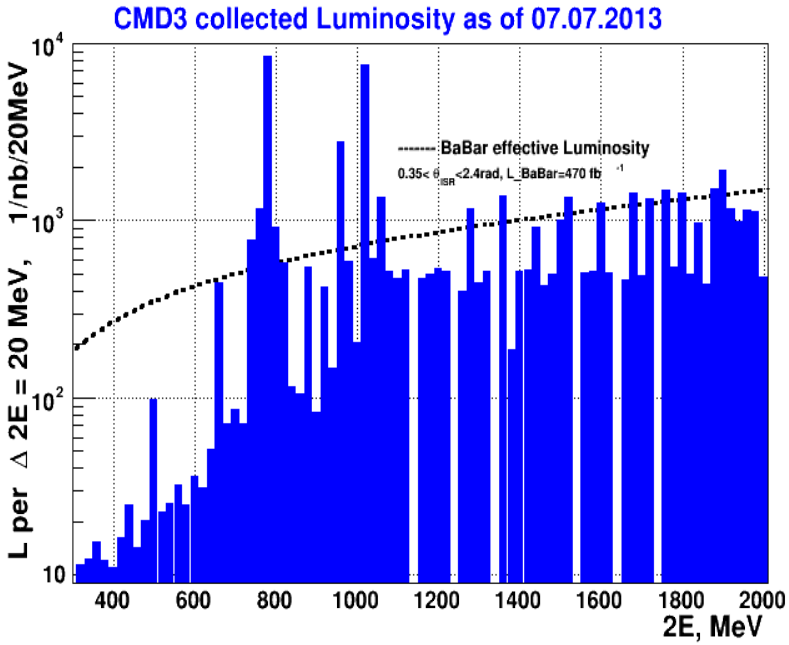
- new system - Cherenkov counter (n=1.05, 1.13)
  - e/π separation E<450 MeV
  - π/K separation E<1 GeV
- new drift chamber
  - better tracking
  - better determination of solid angle

VEPP-2000 experimental area



Collected luminosity





Currently the luminosity is limited by a deficit of positrons (650+ MeV) and limited energy of the booster (from 825 MeV).

After upgrade (ongoing) we expect luminosity increase by up to factor 10 at maximum energy.

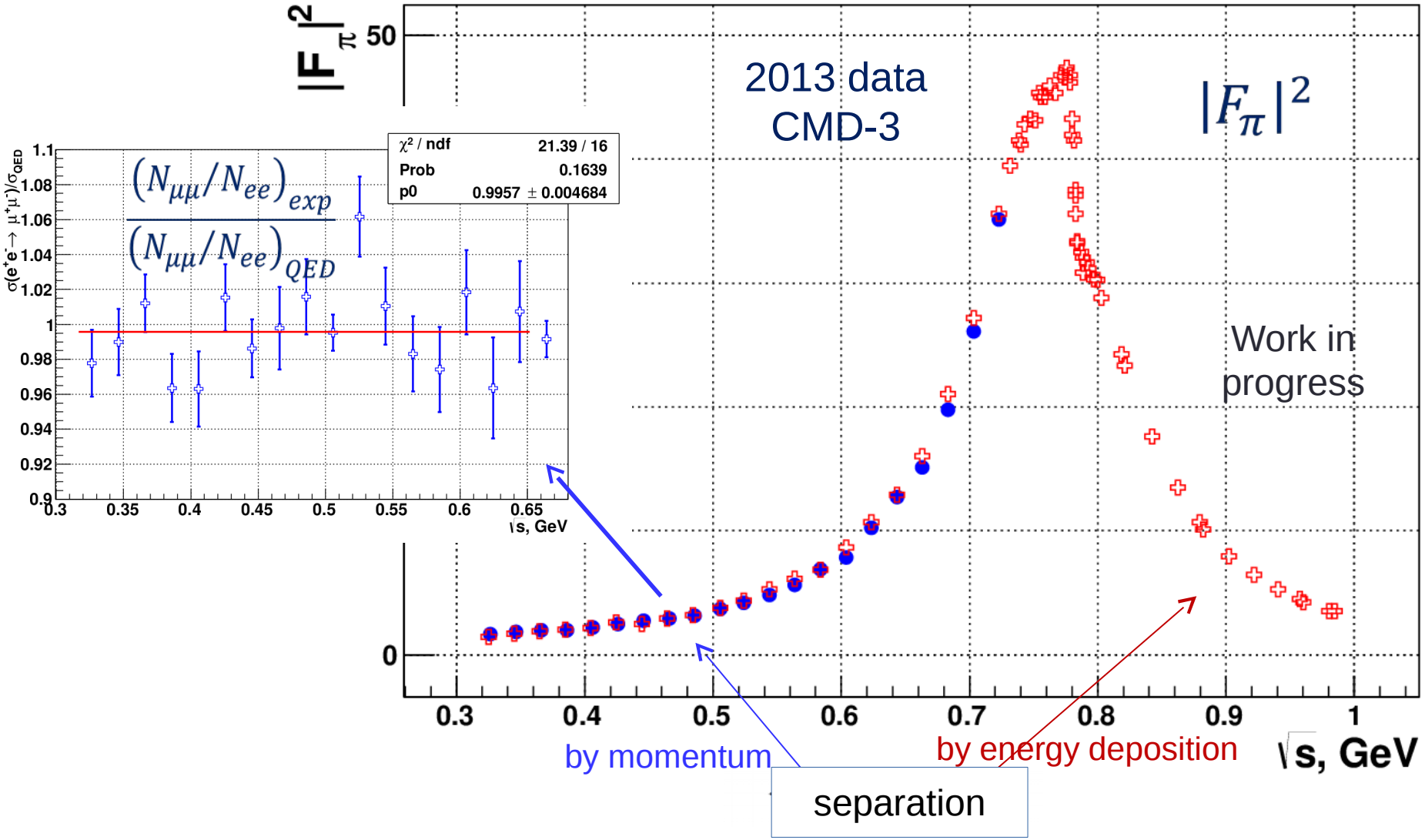
Collected L ~ 60 pb^{-1} per detector	
8.3 pb^{-1}	ω-region
9.4 pb^{-1}	region below 1 GeV (except ω)
8.4 pb^{-1}	φ-region
34.5 pb^{-1}	region higher than φ

Physics program

1. Precision measurement of R = $\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$
   exclusive approach, up to 1% for major modes;
2. Study of hadronic final states:
   $e^+e^- \to 2h, 3h, 4h, \ldots$ where $h = \pi, K, \eta$;
3. Study of vector mesons and their excitations:
   $\rho', \rho'', \omega', \varphi', \ldots$;
4. Comparison of cross-sections $e^+e^- \to$ hadrons ($I = 1$) with spectral functions of τ-decays;
5. Study of nucleon electromagnetic formfactors at threshold
   $e^+e^- \to p\bar{p}, n\bar{n}$;
6. Measurement of the cross-sections using ISR;
7. Study of higher order QED processes.

Overall, we plan to collect $0.5 \div 1$ fb^{-1}

$e^+e^- \to \pi^+\pi^-$ very preliminary @ CMD-3



$e^+e^- \to \pi^+\pi^-$ statistics and systematics @ CMD-3

Main sources of systematics:

separation – 0.2%

multiple ways to get detector response from data itself

fiducial volume – 0.1%

2 independent systems, which can be used to determine fiducial volume

beam energy – 0.1%

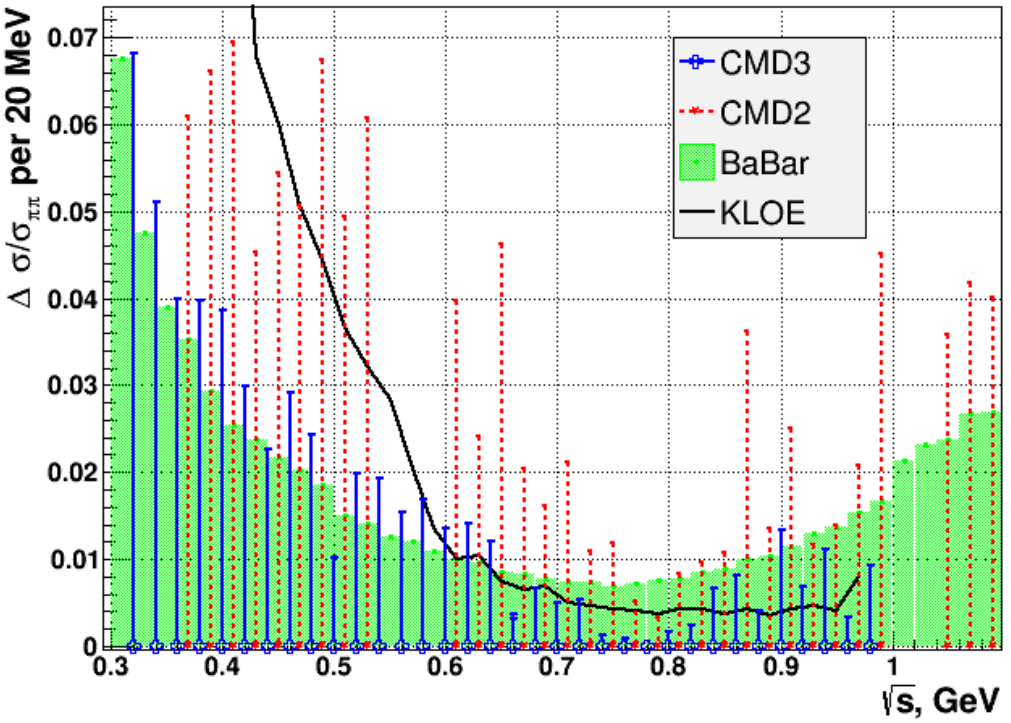
constant monitoring with Compton backscattering

radiative corrections – 0.1%

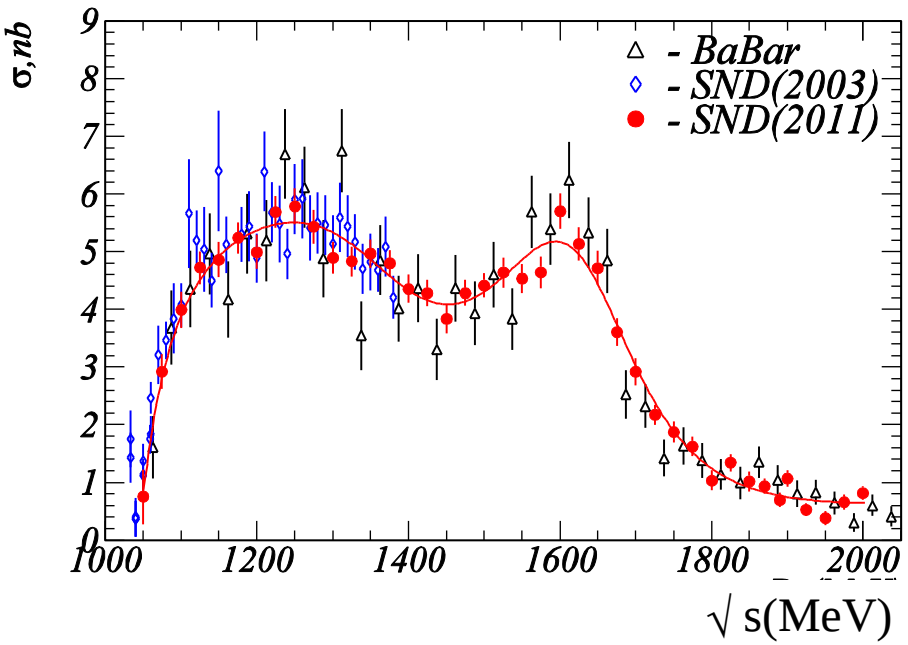
proof from data

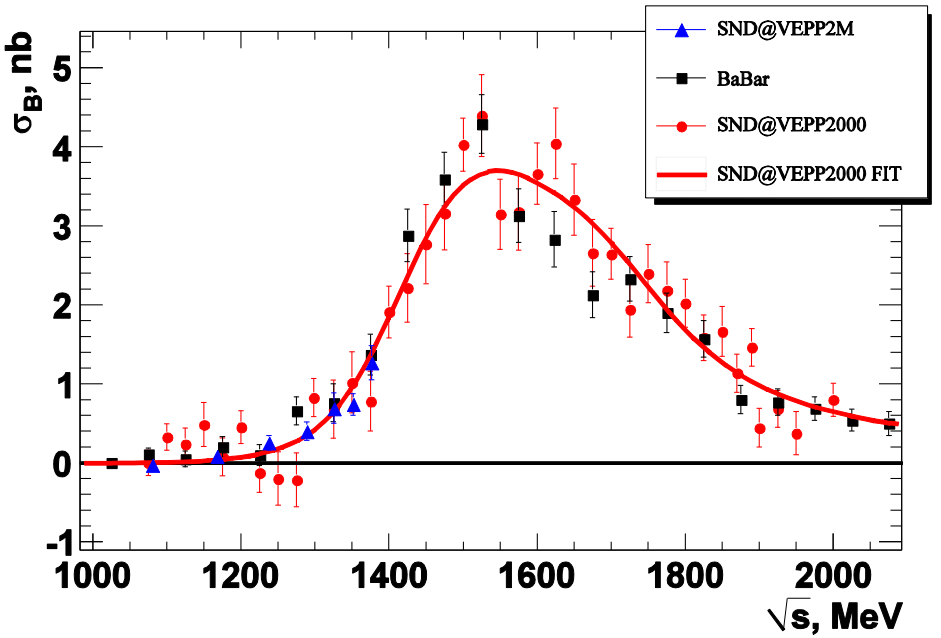
Many systematic studies rely on high statistics

Expected statistical error for 2013 data



$e^+e^- \to \pi^+\pi^-\gamma\gamma$ @ SND



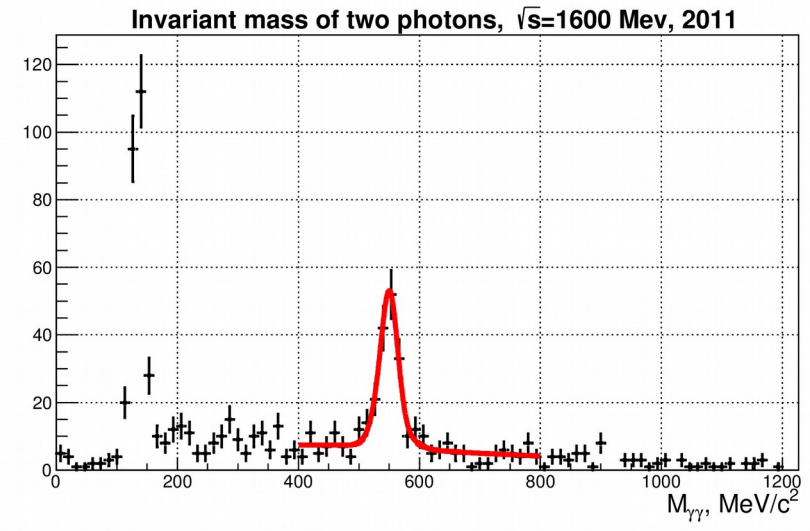


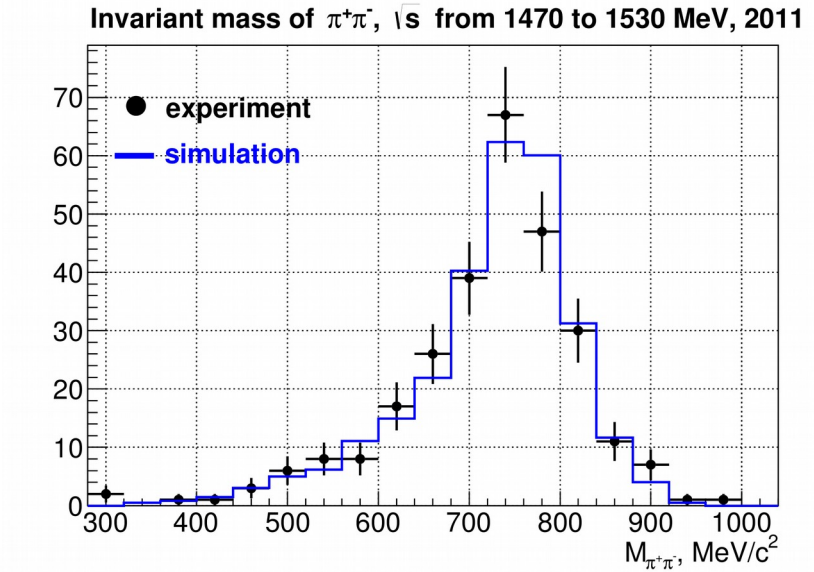
$e^+e^- \to \pi^+\pi^-\pi^0$ $e^+e^- \to \pi^+\pi^-\eta$

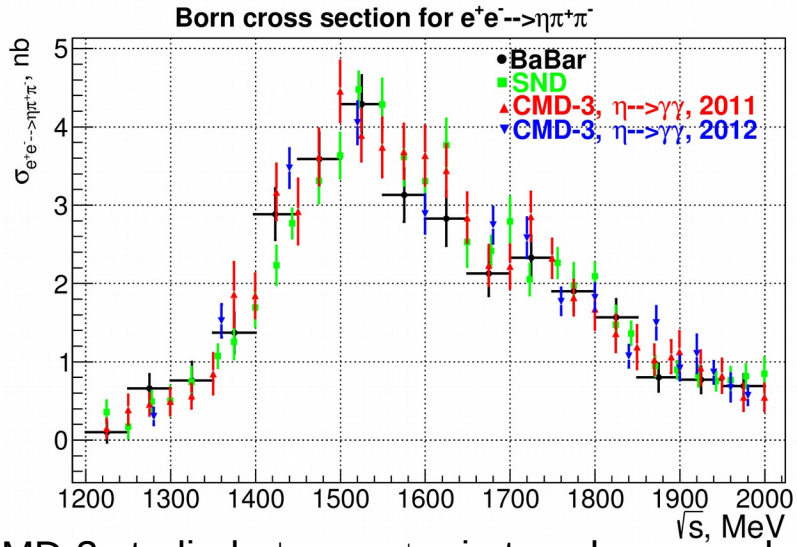
- $\pi^+\pi^-\pi^0$ mode: It's interesting to disentangle the $\rho(')\pi$ and direct 3π modes, currently the $\rho\pi$ mechanism only is assumed; fit is made with $\omega(783)$, $\omega'(1420)$, $\omega''(1650)$ contributions. To be published;
- $\pi^+\pi^-\eta$ mode: fit is made with $\rho(770)$, $\rho'(1450)$, $\rho''(1700)$ contributions, Phys.Rev D91 052013 (2015);
- Systematic error is about 5% for both processes

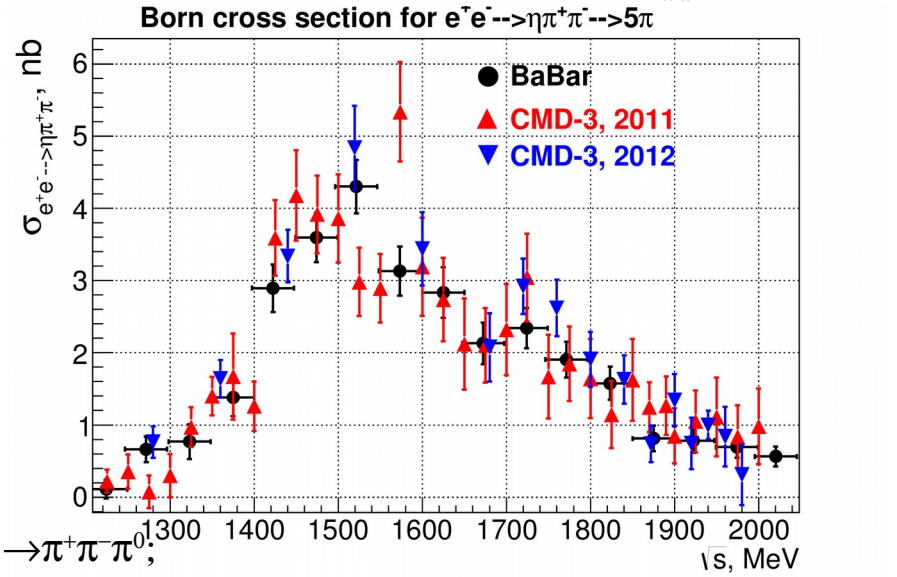
CVC test:
SND $Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau)=(0.188+0.058-0.057)\%$;
PDG $Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.139\pm0.01)\%$

$e^+e^- \to \pi^+\pi^-\eta$ @ CMD-3



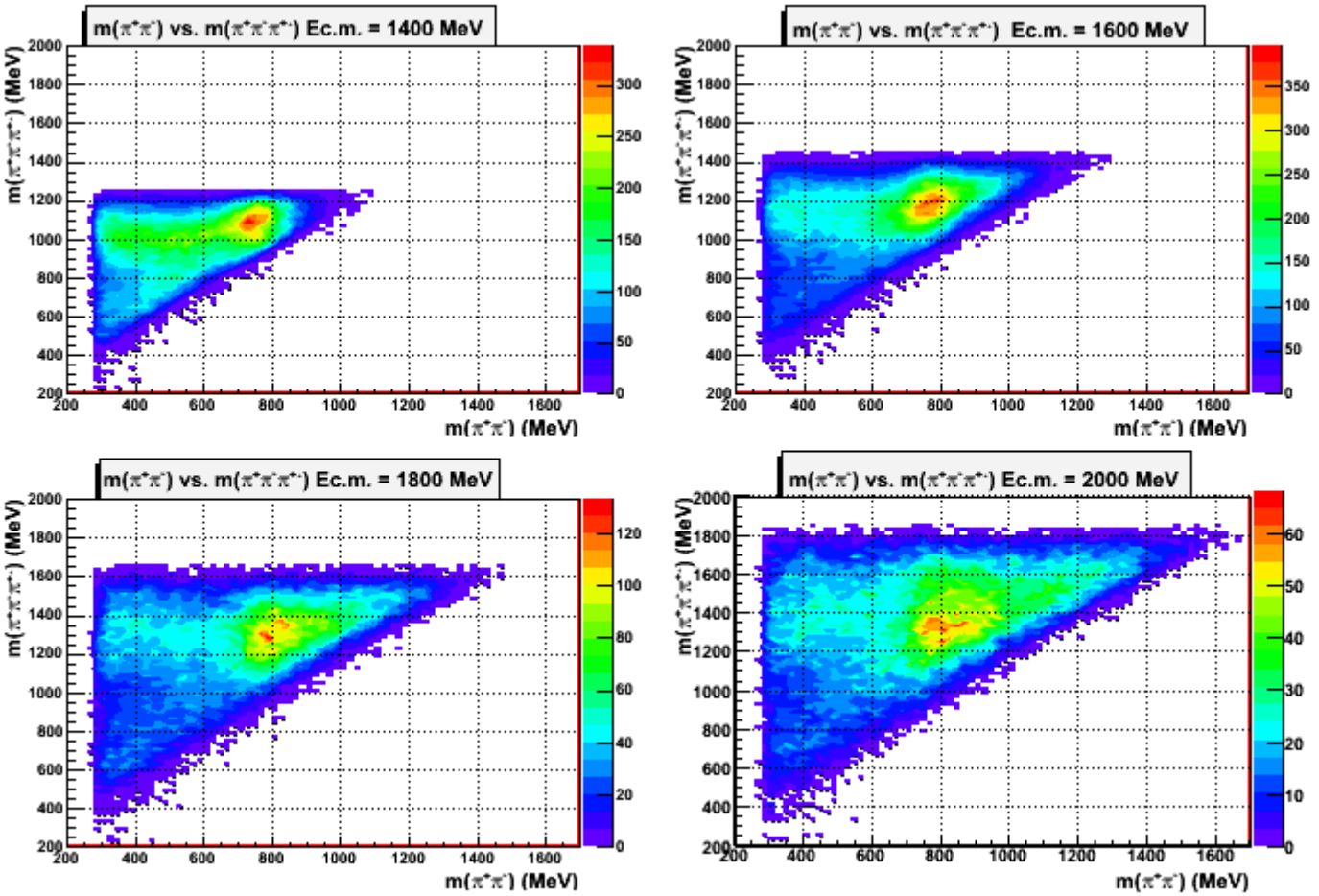






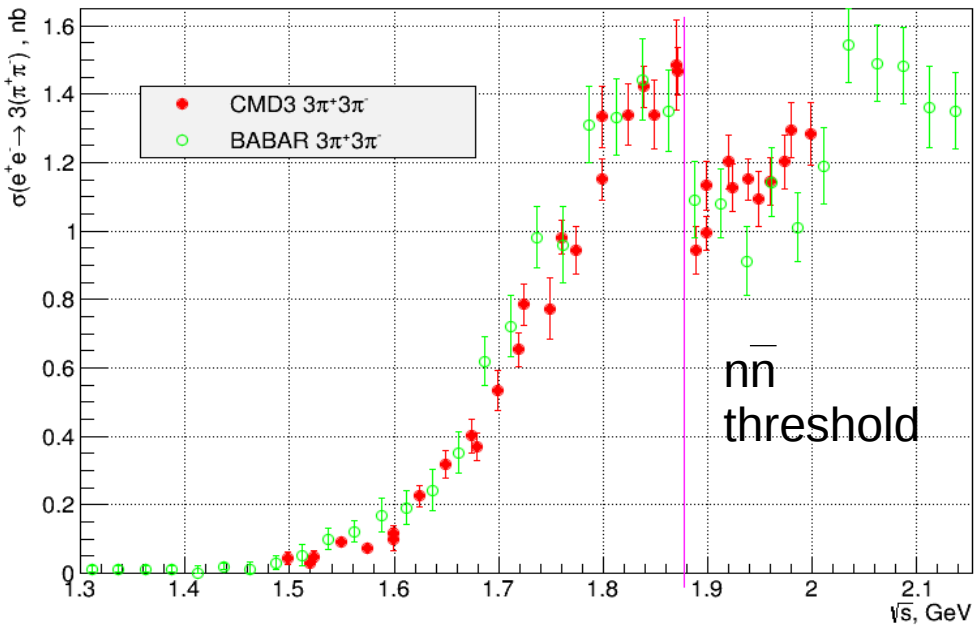
- CMD-3 studied $e^+e^- \to \eta\pi^+\pi^-$ in two decay modes: $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$;
- The $\pi^+\pi^-$ mass spectrum agrees with ρ, but a search fot a non-ηρ contribution is in order;
- A CVC test by comparing the $\eta\pi^-\pi^0$ mass spectrum in τ^- decays with the energy dependence of $\sigma(e^+e^- \to \eta\pi^+\pi^-)$ needed;
- A fit of the energy dependence of $\sigma(e^+e^- \to \eta\pi^+\pi^-)$ will determine the parameters of the ρ(1450), ρ(1700) and their interference

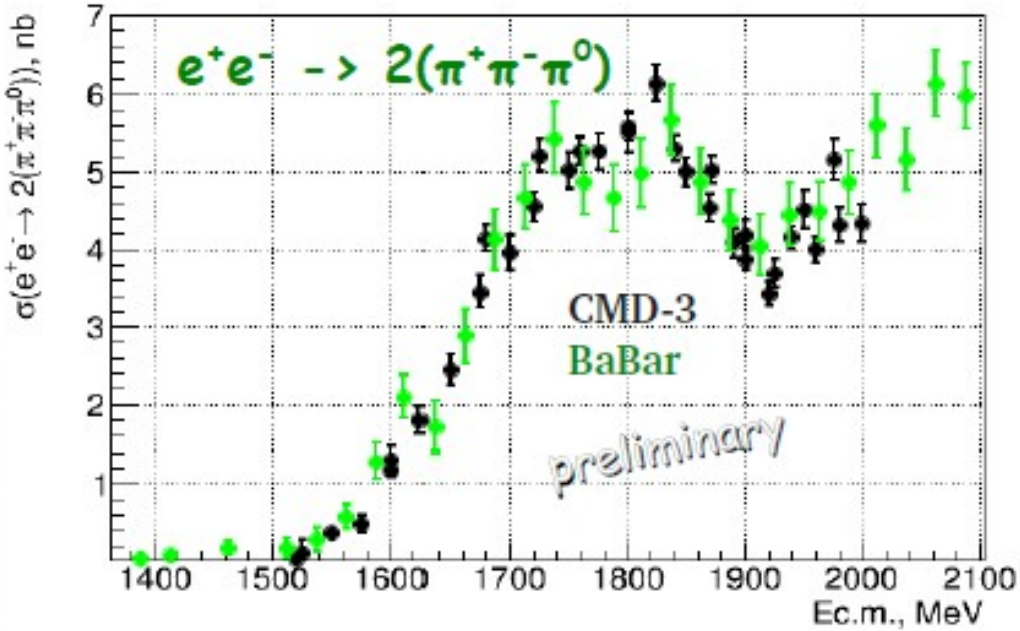
Dynamics of $e^+e^- \to 2\pi^+2\pi^-$ @ CMD-3



A ρ^0 is always present, $a_1(1260)\pi$ ($a_2(1320)\pi$) significant, at higher energies other mechanisms like $\rho^0 f_0$, $\rho^0 f_2(1270)$ appear.

$e^+e^- \to 6\pi$ @ CMD-3





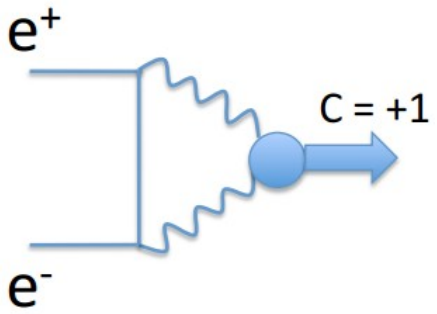
Systematic error is 6%, main source is model dependence. High statistics will help to reduce this error.

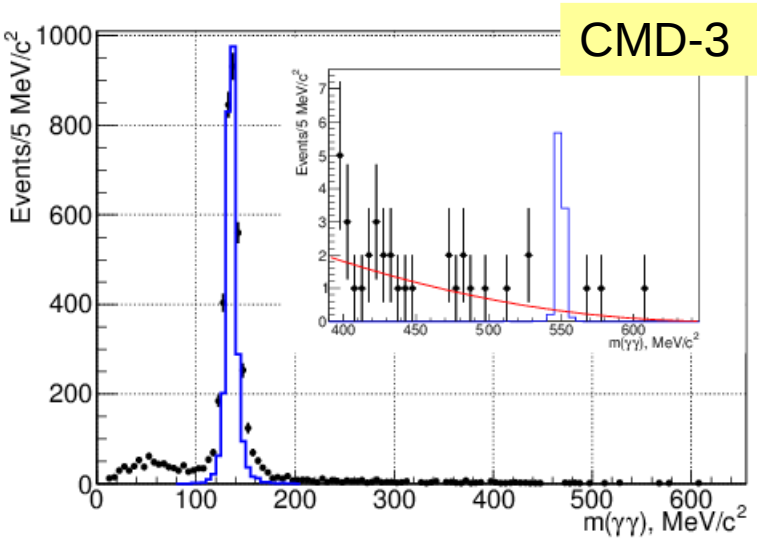
Preliminary studies of dynamics:

- Main production mode: (phase space or $f_0(1370)$);
- Hint of energy dependent dynamics in 1.7-1.9 GeV energy range;
- $3\pi^+3\pi^-$: The dip structure near $n\bar{n}$ threshold is confirmed;
- Phys. Lett. B 723 (2013) 82.

Search for $e^+e^- \to \eta'(958)$ @ VEPP-2000

C-even resonances can be produced via

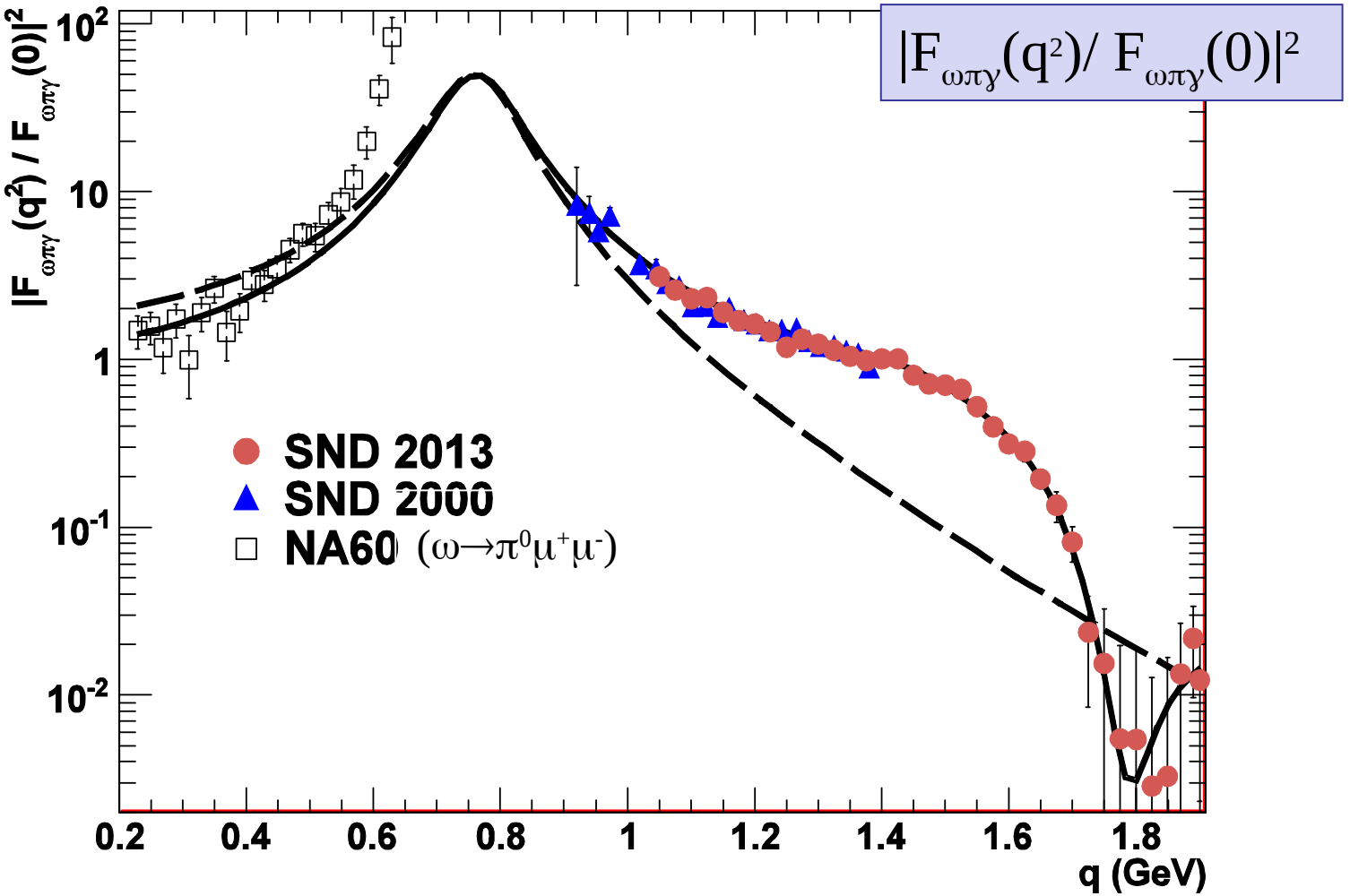




Theory: assuming real γ, $B(\eta \to e^+e^-) = 3{,}7 \times 10^{-11}$.
Virtuality and transition form factor can enhance it.

- CMD-3 uses 2.69 pb^{-1} at $\sqrt{s} \sim M_{\eta'}$ to look for $e^+e^- \to \eta'(958)$, $\eta' \to \eta\pi^+\pi^-$, $\eta \to 2\gamma$.
  $\Gamma(\eta \to e^+e^-) < 0.0024$ eV at 90%CL, Phys. Lett. B740 (2015) 273;
- SND uses 2.9 pb^{-1} at $\sqrt{s} \sim M_{\eta'}$ to look for $e^+e^- \to \eta'(958)$:
  $\eta' \to \eta\pi^+\pi^-$, $\eta \to 2\gamma$, $3\pi^0$,
  $\eta' \to \eta\pi^0\pi^0$, $\eta \to 2\gamma$, $3\pi^0$, $\pi^+\pi^-\pi^0$,
- $\Gamma(\eta' \to e^+e^-) < 0.0020$ eV at 90%CL, Phys. Rev. D 91, 092010;
- Combine SND data with CMD-3:
  $\Gamma(\eta' \to e^+e^-) < 0.0011$ eV at 90%CL,
  $B(\eta' \to e^+e^-) < 5.6 \times 10^{-9}$ at 90%CL.

$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ @ SND

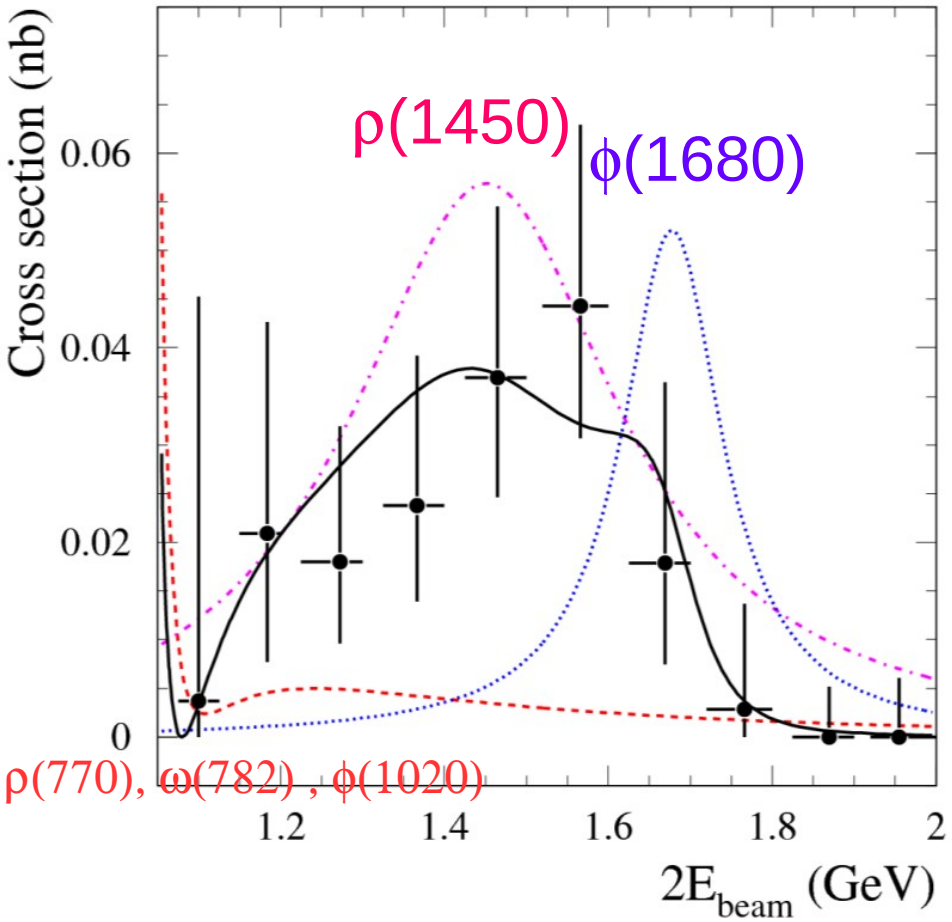


- Transition formfactor $\gamma^* \to \omega\pi_0$, $F_{\omega\pi\gamma}$, cross section of $e^+e^- \to \omega\pi^0$

$$\sigma_{\omega\pi^\circ} = \frac{4\pi\alpha^2}{E^3}\left|F_{\omega\pi\gamma}(E^2)\right|^2 P_f(E),\ P_f(E) - \text{phase space factor}$$

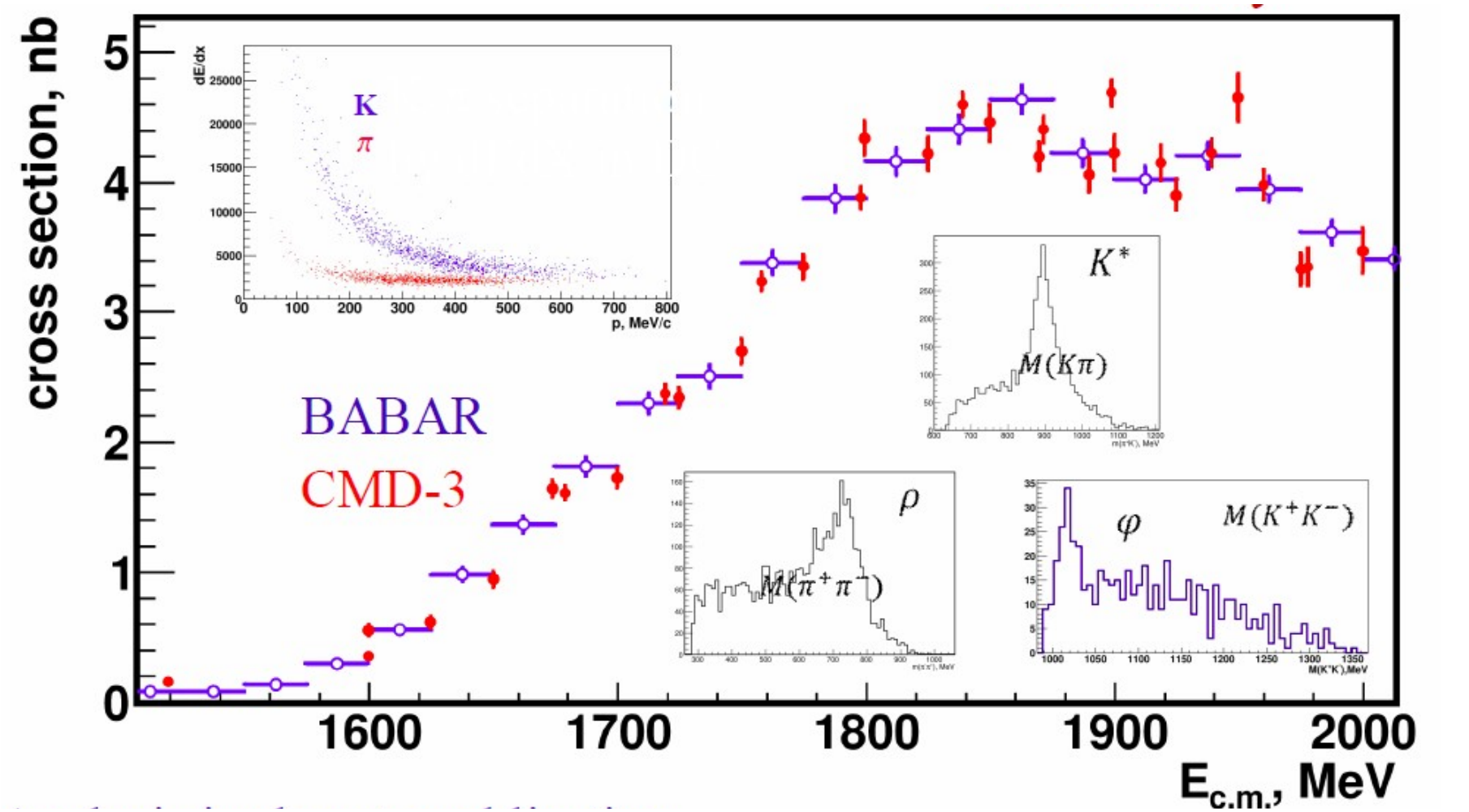
- Solid line - fit with $\rho(770)$, $\rho'(1450)$, $\rho''(1700)$, dashed line – only $\rho(770)$;
- Phys. Rev. D 88 (2013) 054013

$e^+e^- \to \eta\gamma$ @ SND



- Analysis uses statistics 32 pb^{-1};
- First measurement above 1,4 GeV;
- Fit contains sum of ρ(770), ω(782) , ϕ(1020) and ρ(1450), ϕ(1680) with interference;
- It is first observation of radiative decays of ρ(1450), ϕ(1680) mesons;
- Phys. Rev. D 88 (2013) 054013

$e^+e^- \to K^+K^-\pi^+\pi^-$ @ CMD-3



CMD-3 studies uses 22 pb^{-1} between 1.5 and 2 GeV, more than 10000 events with 3 and 4 tracks observed;

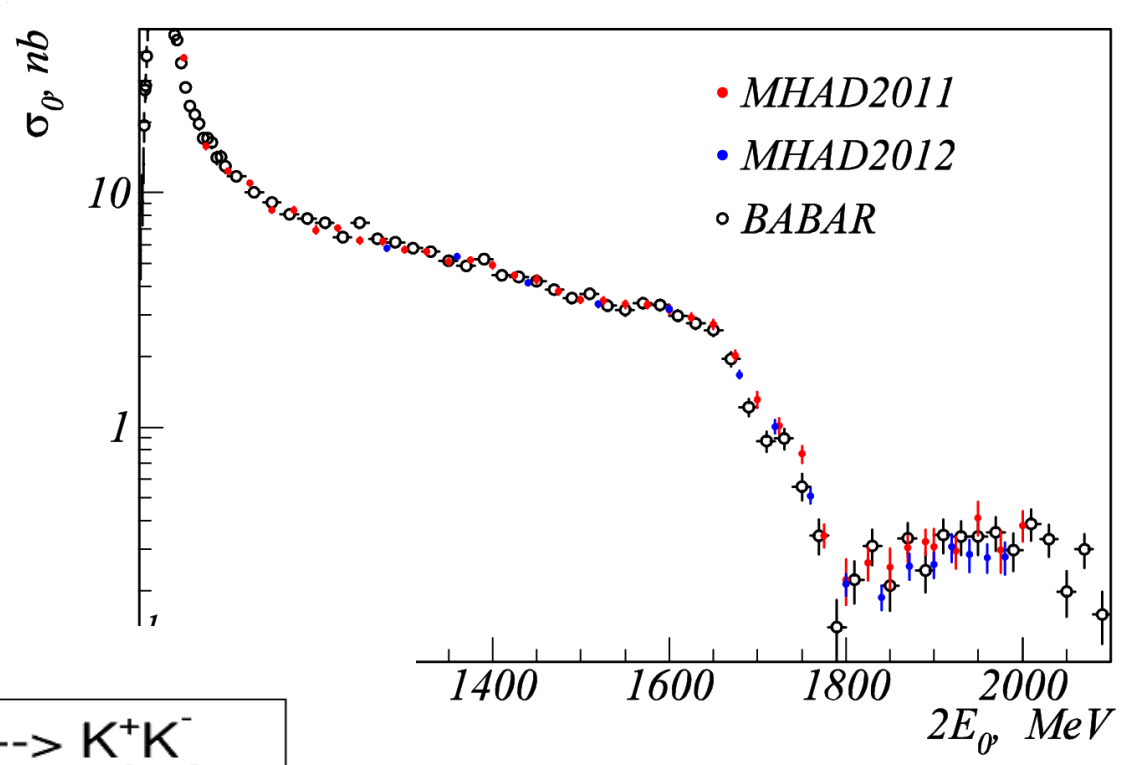
Ionisation losses in DC dE/dx provide good K/π separation;

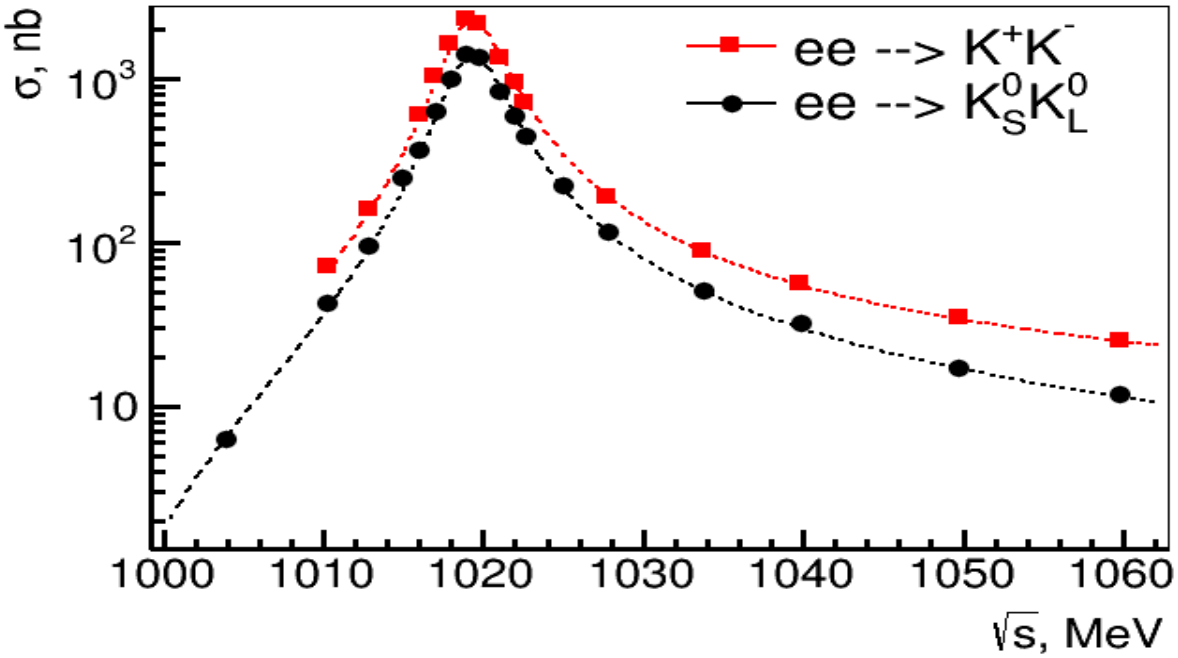
Analysis of $\pi^+\pi^-$, $K^\pm\pi^\mp$, KK invariant masses shows clear signals from ρ^0, $K^{*0}(892)$, ϕ^0;

Many different mechanisms seen: $K_1(1270)\overline{K} \to K\overline{K}\rho$, $K^*(892)\overline{K}\pi$, $K_1(1400)\overline{K} \to K^*(892)\overline{K}\pi$, $\phi\pi^+\pi^-$.

$e^+e^- \to K^+K^-$ @ VEPP-2000

CMD-3, @ $\phi(1020)$
Cross-section of K^+K^- production is shown together with K_SK_L

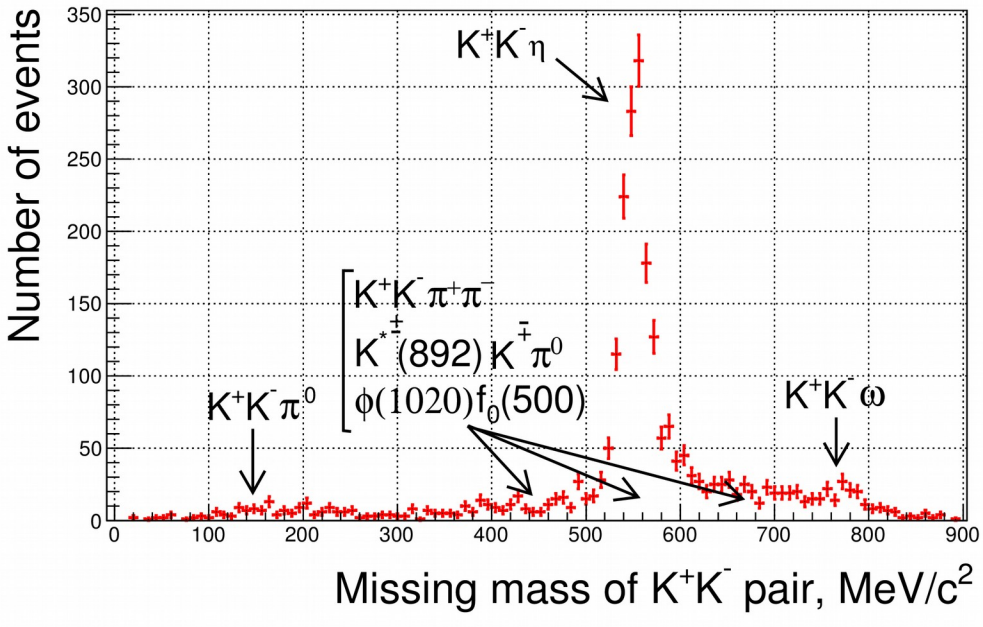


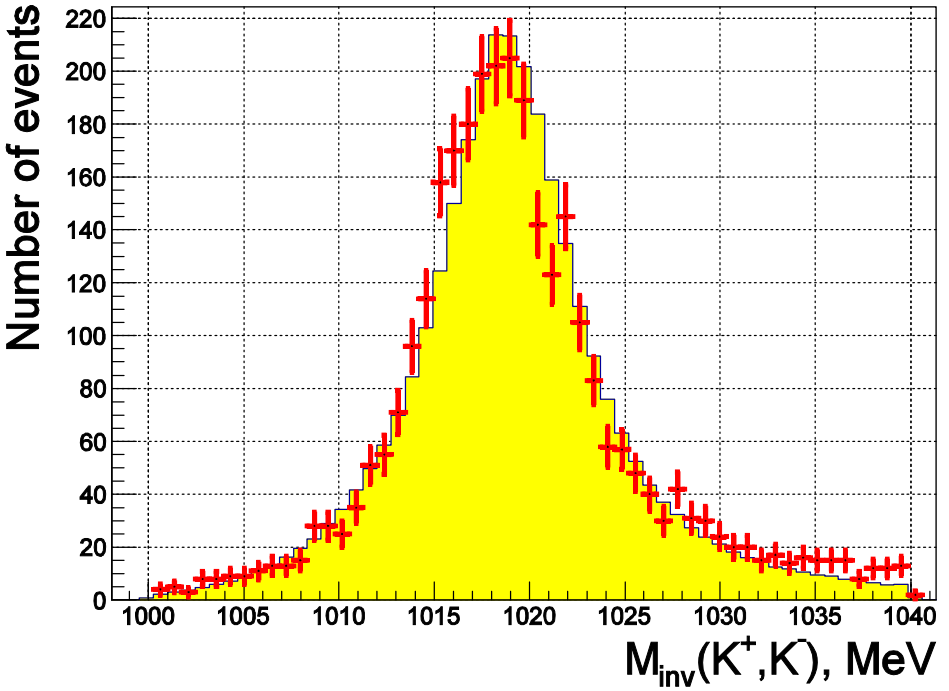


SND, above $\phi(1020)$

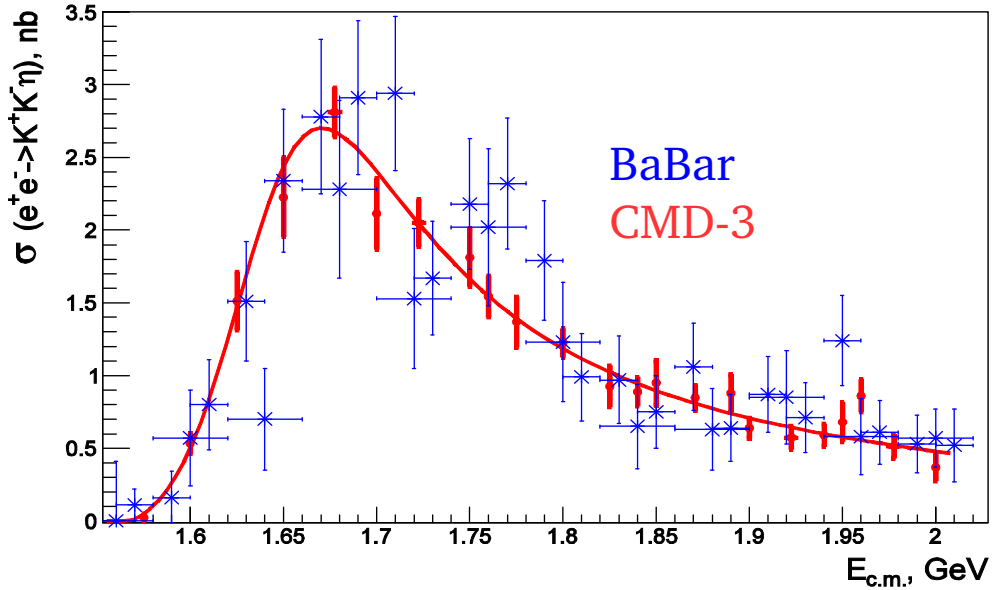
Complicated σ(s) due to interference of excited vector resonances
Aerogel Cherenkov counters provide kaon PID

$e^+e^- \to K^+K^-\eta$ @ CMD-3



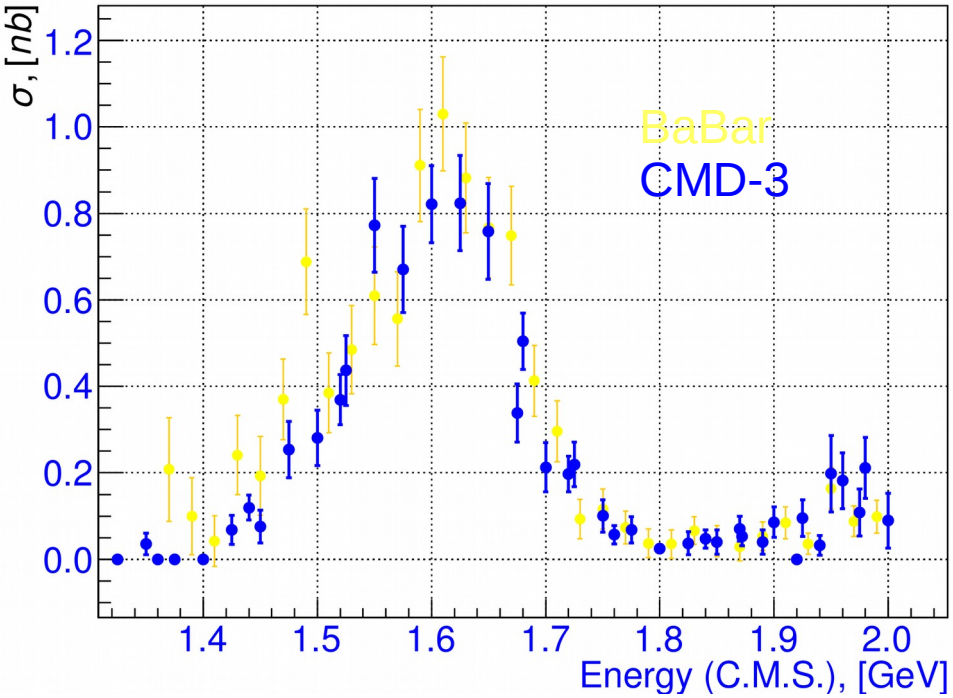


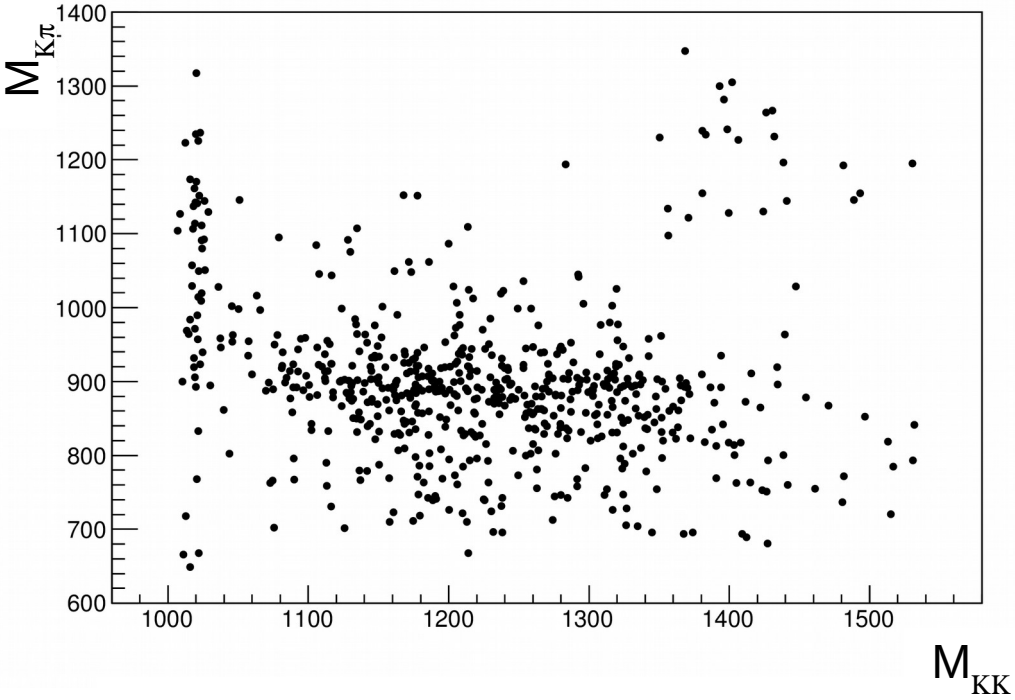
- A data sample of 22 pb^{-1} collected in 2011-2012 is used to study $e^+e^- \to K^+K^-\eta$;
- 23 c.m. energy points between 1.57 and 2.0 GeV;
- Analysis method empasizes the dominant $\phi\eta$ signal, studies of non-resonant $K^+K^-\eta$ needed;
- Rich background with numerous components seen;
- The data sample includes 1600 events of the signal and about 600 background events;



Cross-section $e^+e^- \to K^+K^-\eta$

$e^+e^- \to K^+K^-\pi^0$ @ CMD-3



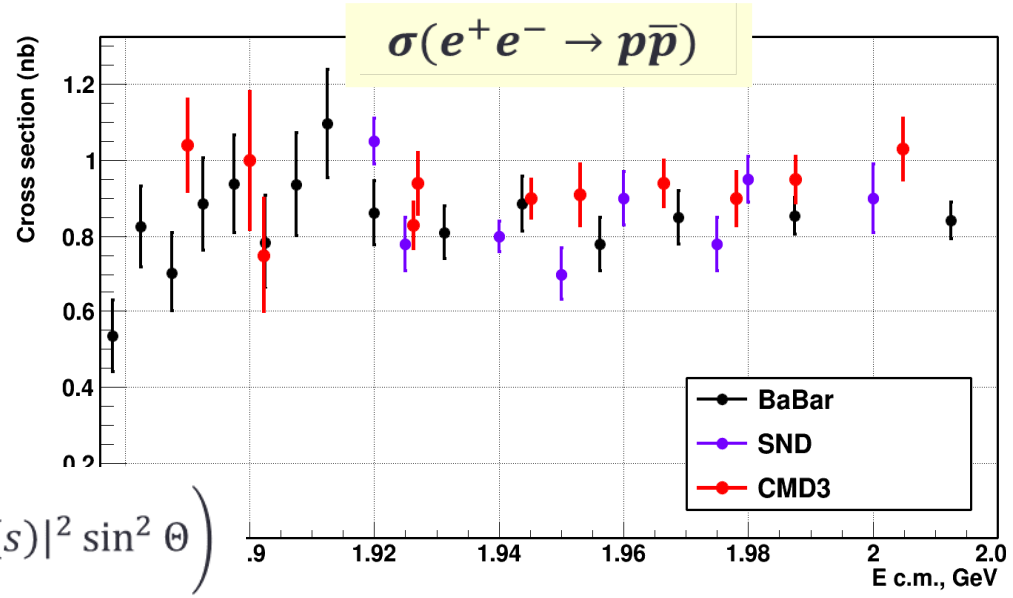


Cross section, very preliminary

- The $K\pi$ vs. K^+K^- plot clearly shows the $\phi\pi^0$ and $K^*(892)K$ mechanisms;
- Cross section is consistent with and more precise than BaBar.

$e^+e^- \to p\bar{p}$ @ VEPP-2000

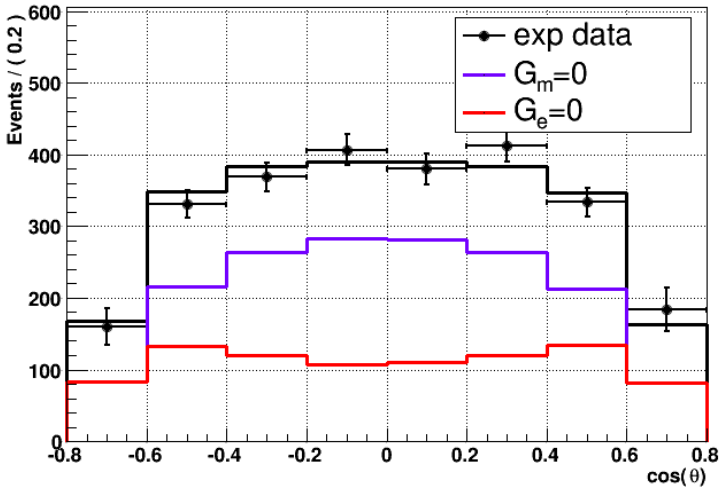
PID by dE/dx, secondaries

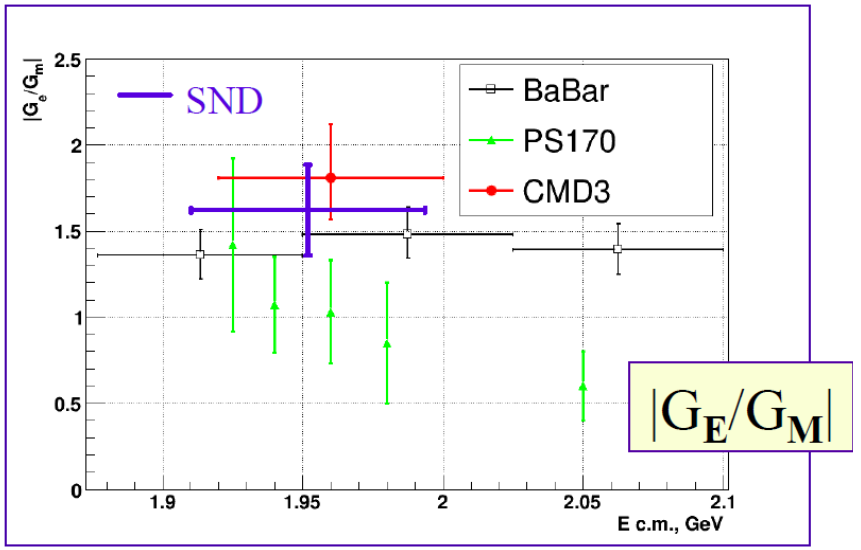


Angular distribution allows to measure

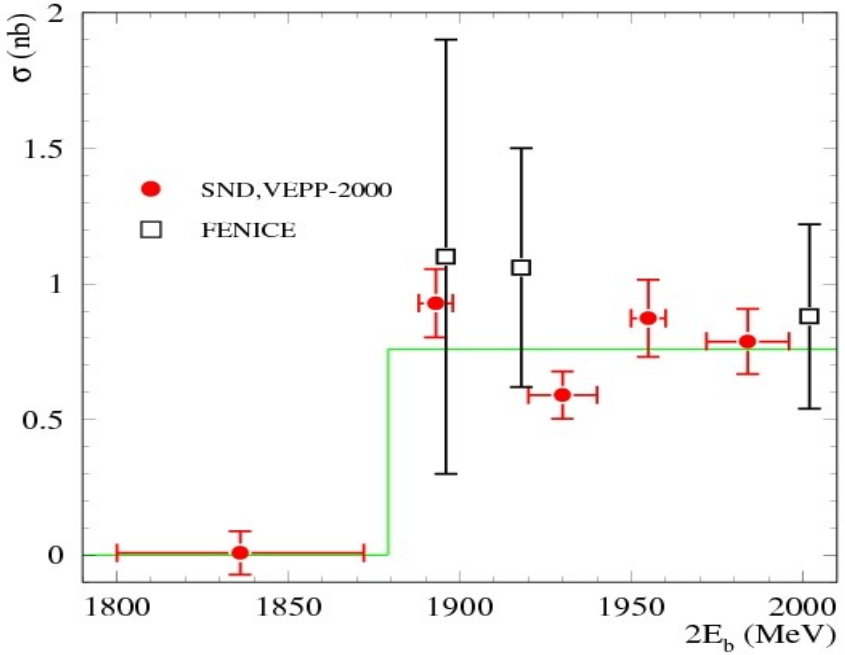
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4s}\left(|G_M(s)|^2(1+\cos^2\Theta) + \frac{4m^2}{s}|G_E(s)|^2\sin^2\Theta\right)$$

CMD3





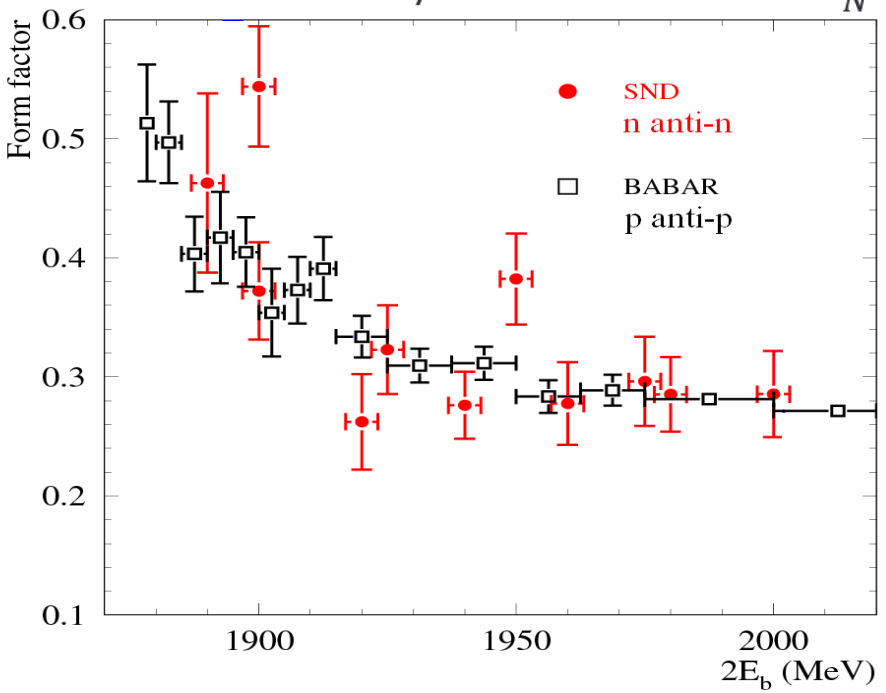
$e^+e^- \to n\bar{n}$ @ SND



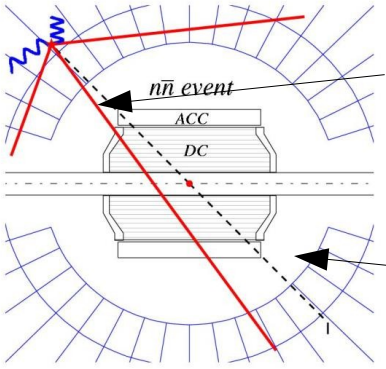
$\sigma_{aver} = 0.8 \pm 0.2$ nb

Effective formfactor

$$|F|^2 = \frac{|G_M|^2 + |G_E|^2/2\tau}{1 + 1/2\tau}, \qquad \tau = \frac{s}{4m_N^2}$$



Systematics: ~0.25 nb (~30%)



$\bar{n}$

n

Signature:
Small energy in calorimeter from n;
"star" from $\bar{n}$ annihialtion in cerenkov/calorimeter

Main features of the cross section:

- cross section has a threshold behavior;
- selected events are delayed by 5-10 nsec;
- cross section is stable under condition variations;
- Uniform φ distribution;
- First and more precise measurement after FENICE;
- **Phys. Rev. D 90, 112007 (2014)**.

Conclusions

- VEPP-2000 was running smoothly with CMD-3 and SND in 2011-2013 and collected about 60 pb^{-1} per detector;
- New channels observed: $3\pi^+3\pi^-$, $n\bar{n}$, $\eta\gamma$, ...;
- Various studies of transition form factors are in progress: $e^+e^- \to \pi^0\gamma$, $\eta\gamma$, $\pi^0e^+e^-$, ηe^+e^-, η', η, ...;
- Extensive studies of multibody dynamics demands MC generators;
- In fall 2015 experiments with an upgraded booster and new injection complex will resume to provide $L \sim 10^{32}$ $cm^{-2}s^{-1}$;
- CMD-3 and SND at VEPP-2000 will provide high accuracy, compatible or better than ISR measurements for HPV, the tentative goals are 0.35% (0.5%) for $\pi^+\pi^-$ and ~3% for multibody modes;
- We expect to produce new precise measurements of hadron production R(s), to improve the precision of the hadronic contribution to muon (g-2).