

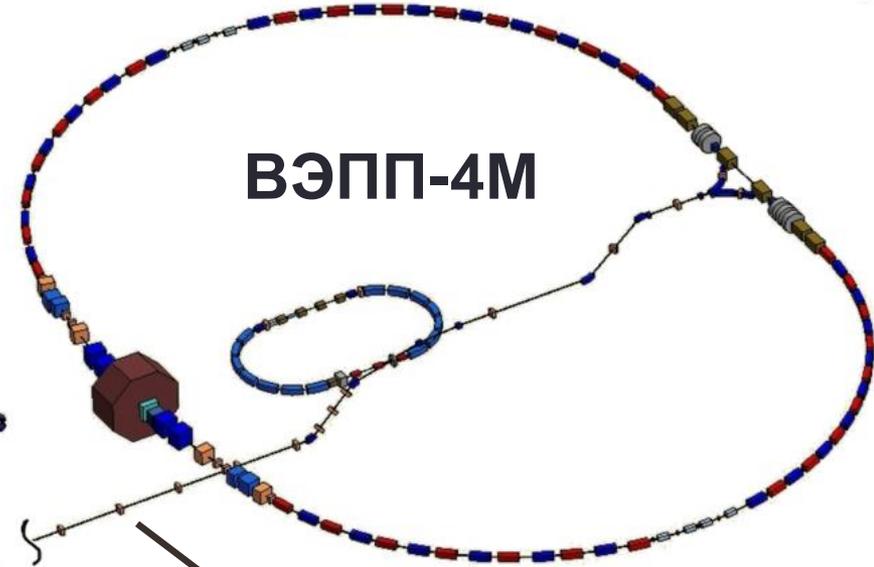
# ИЗМЕРЕНИЕ АДРОННЫХ СЕЧЕНИЙ В ЭКСПЕРИМЕНТАХ КЕДР, СНД И КМД-3

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Иван Логашенко

ИЯФ СО РАН

# Ускорительный комплекс ИЯФ СО РАН



**ВЭПП-2000**

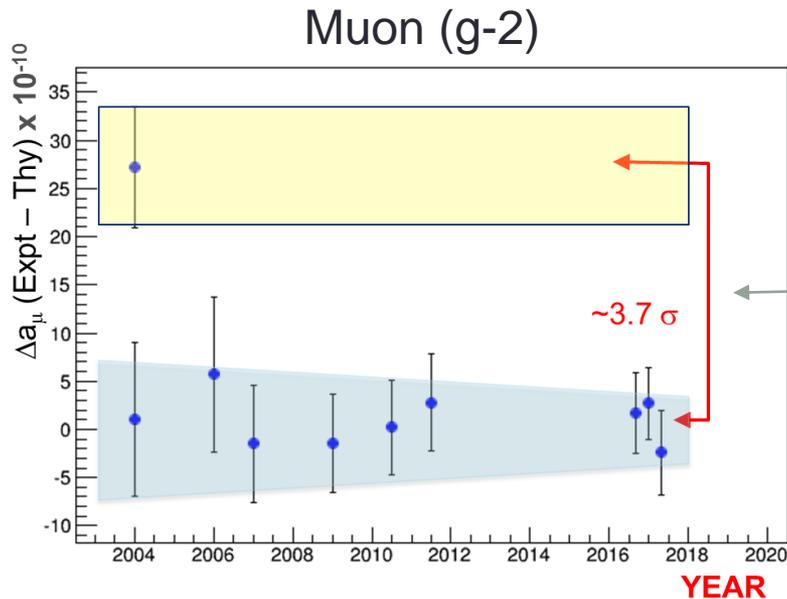
**Инжекционный  
комплекс**



$$\sqrt{s} = 0.32 \div 10 \text{ ГэВ}$$

# Аномальный магнитный момент мюона

Измеренное значение отличается на  $\sim 3.7\sigma$  от предсказания Стандартной Модели



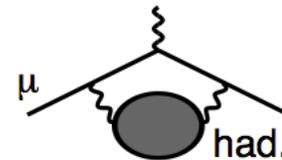
BNL E821 Experiment

Идет новый эксперимент в Фермилаб (E989)

4% адронного вклада

SM Theory Evaluations

Адронный вклад в (g-2):

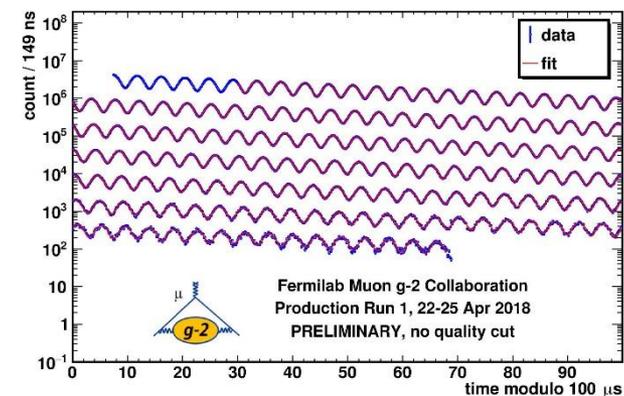
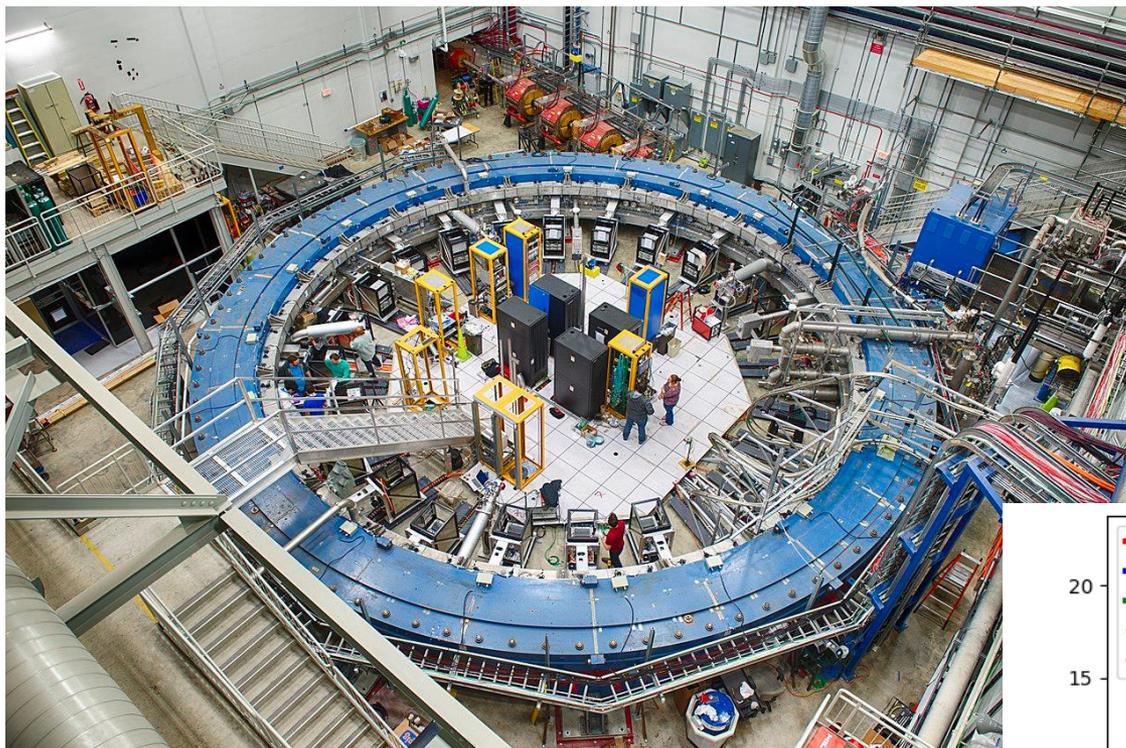


$$R = \frac{\sigma(e^-e^+ \rightarrow \text{hadrons})}{\sigma(e^-e^+ \rightarrow \mu^-\mu^+)} \approx \frac{\text{[Diagram: } e^-e^+ \rightarrow q\bar{q} \text{ via } \gamma^* \text{]} }{\text{[Diagram: } e^-e^+ \rightarrow \mu^-\mu^+ \text{ via } \gamma^* \text{]}}$$

$$a_{\mu}^{\text{had,LO}} = \frac{m_{\mu}^2}{12\pi^3} \int_{s_{\text{th}}}^{\infty} ds \frac{1}{s} \hat{K}(s) \sigma_{\text{had}}(s)$$

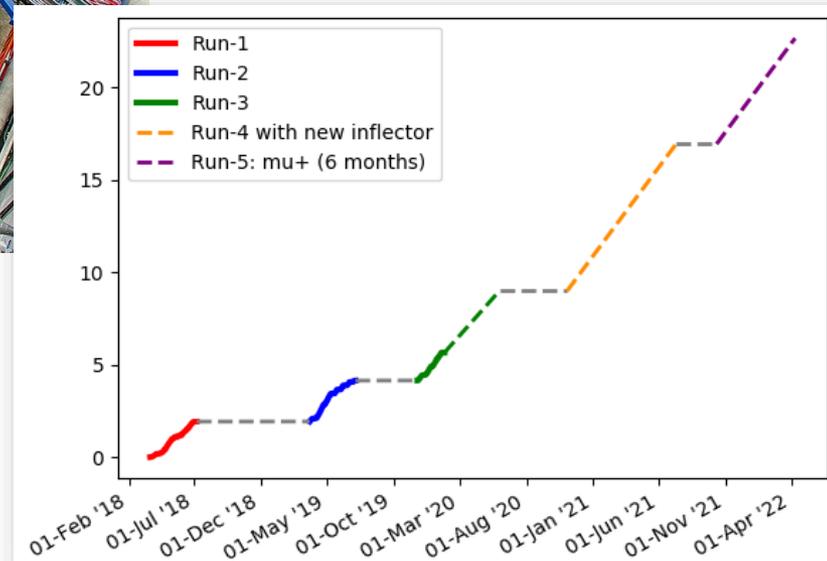
а также  $\alpha(M_Z^2), \alpha_S(s), m_q$

# Experiment E989 at Fermilab

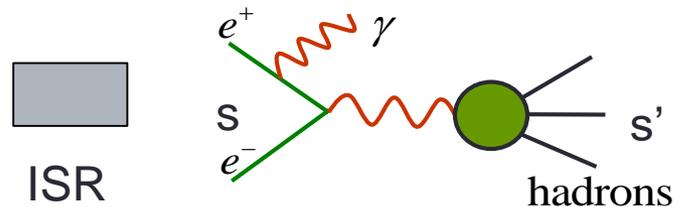
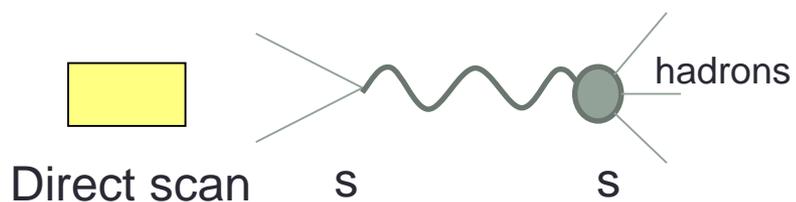
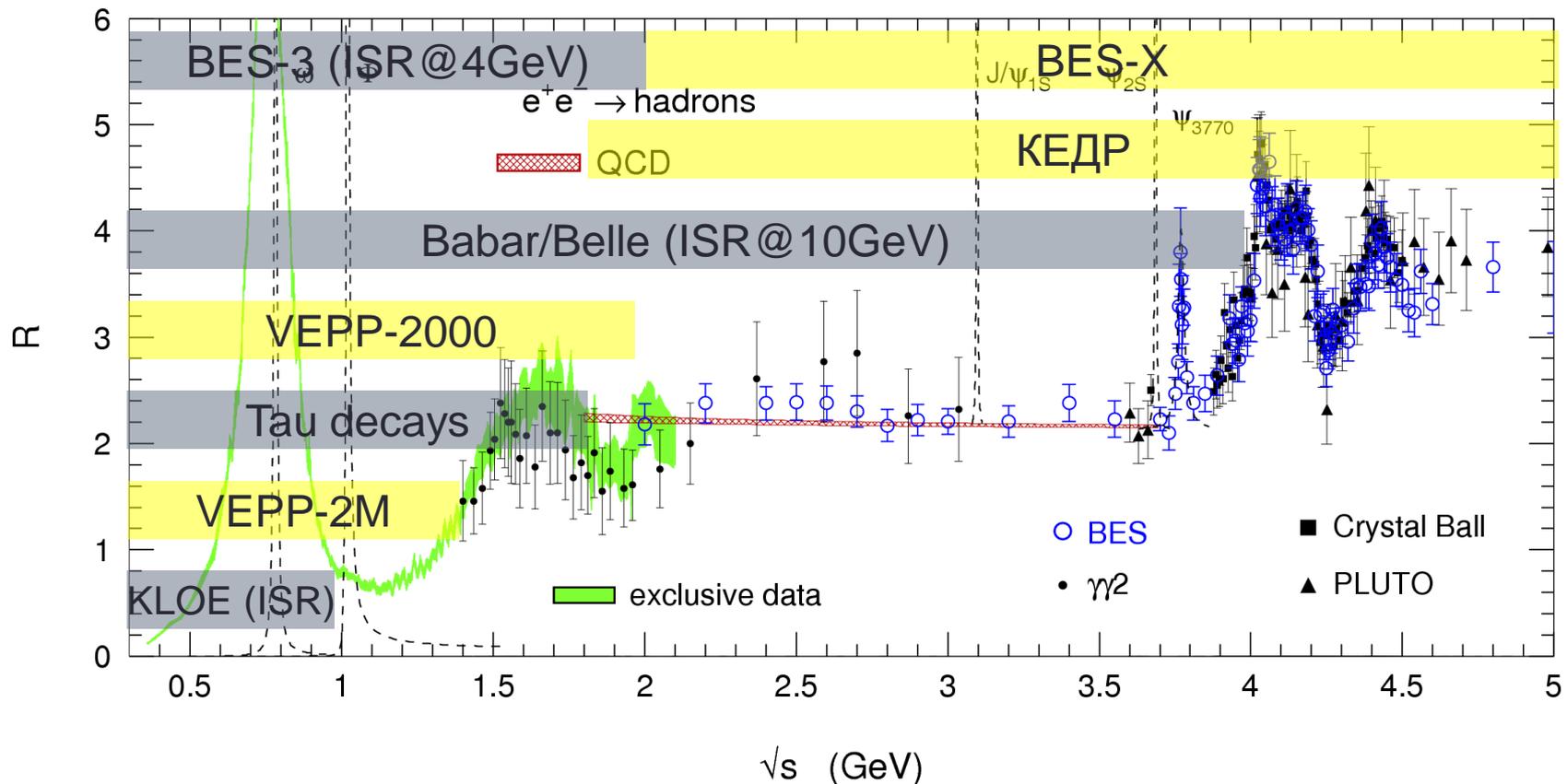


- x20 more data
- x3 smaller systematics

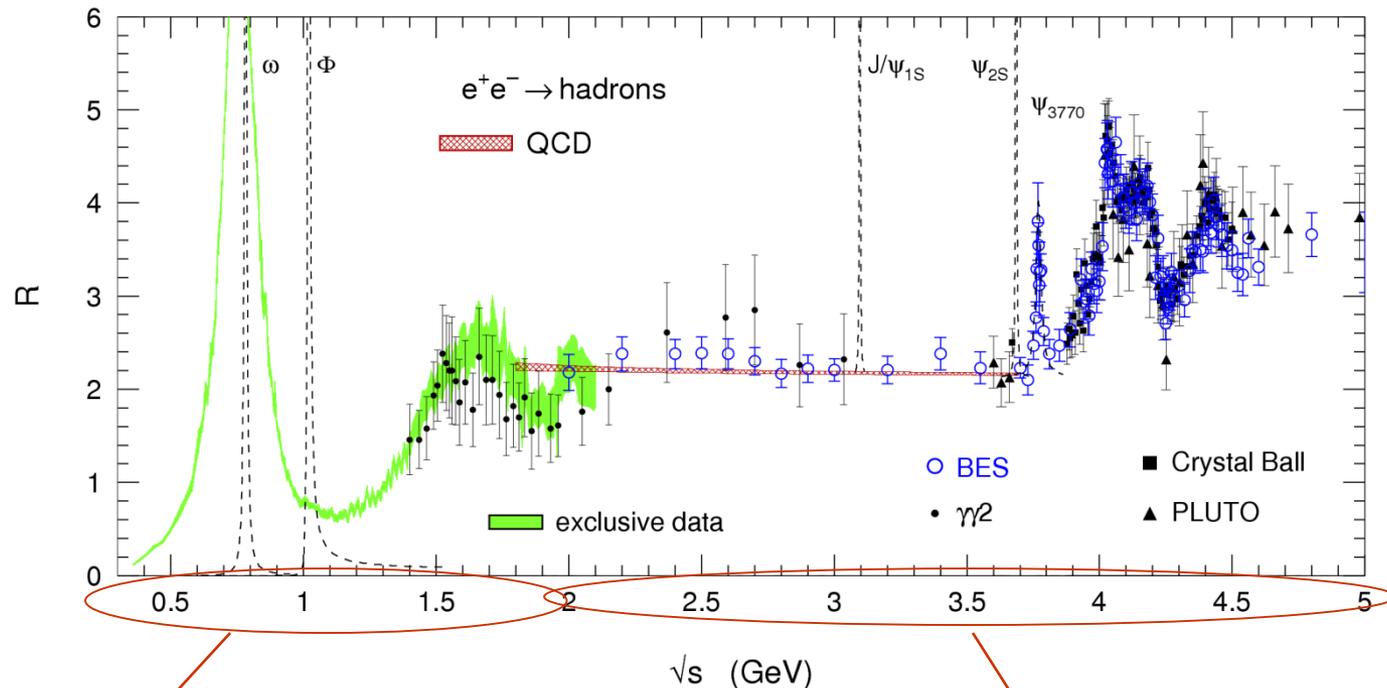
Already collected ~x6 BNL data  
First result expected in 2020



# Где измеряется R



# Inclusive vs exclusive $R(s)$ measurements



## Exclusive approach:

- measure each final state separately and calculate the sum

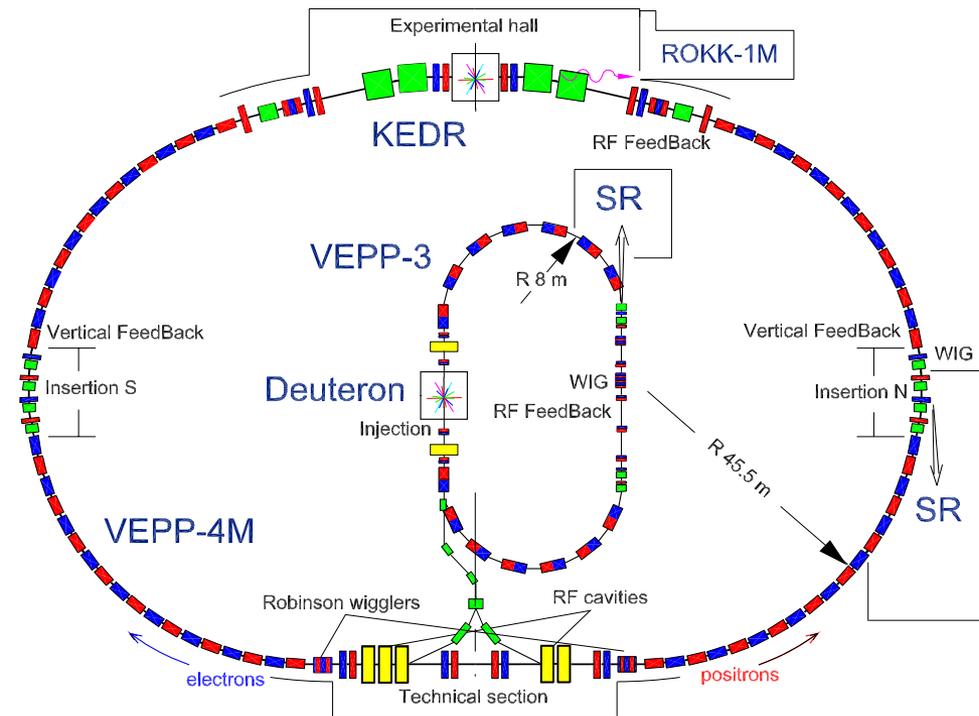
VEPP-2M, VEPP-2000, Babar, KLOE

## Inclusive approach:

- select events with any hadron(s) in the final state

BES-X, KEDR

# ВЭПП-4М



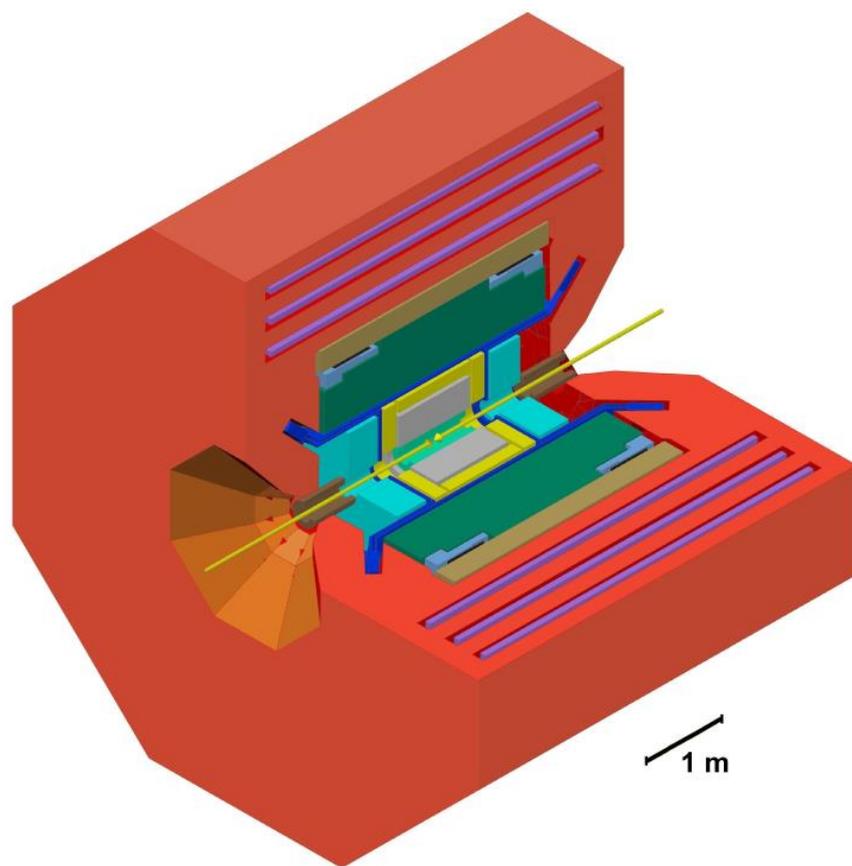
## Experimental program:

- $e^+e^-$  HEP at VEPP-4M with KEDR detector
- SR at VEPP-3 (2 GeV) and VEPP-4M (2÷4 GeV)
- Nuclear physics at VEPP-3 with Deuteron facility
- Test Beam Facility at VEPP-4M

Energy	0.925 ÷ 4.75 (5.3)				GeV
Circumference	366				m
N of bunches	$2e^+ \times 2e^-$ (16 $e^-$ )				
Harmonic number	222				
Betatron tunes, h/v	8.54/7.57				
Coupling	0.05%				
Bunch length	5				cm
Beam Energy	1.5	1.9	4.7	5.2	GeV
Emittance	16	25	167	200	nm·rad
Energy Spread	2.5	3.0	7.8	8.5	$\cdot 10^{-4}$
Bunch Current	1.6	3.5	25	25	mA
Luminosity	0.9	3.3	44	25	$10^{30} \text{ cm}^{-2} \cdot \text{s}^{-1}$

- ★ Universal magnetic detector KEDR
- ★ Electron-positron tagging system
- ★ Wide energy range 0.9÷6 GeV
- ★ Energy spread control
- ★ Precision beam energy calibration by resonance depolarization ( $10^{-6}$  accuracy!)
- ★ The first collider with beam energy monitoring by Compton backscattering

# Детектор КЕДР



- Vertex detector
- Drift chamber
- Aerogel threshold counters
- ToF counters
- Lkr calorimeter
- Superconducting coil
- Yoke
- Muon chambers
- CsI calorimeter
- Compensating solenoid

## 2001-2017 low energy luminosity run 2x(0.9÷1.9) GeV

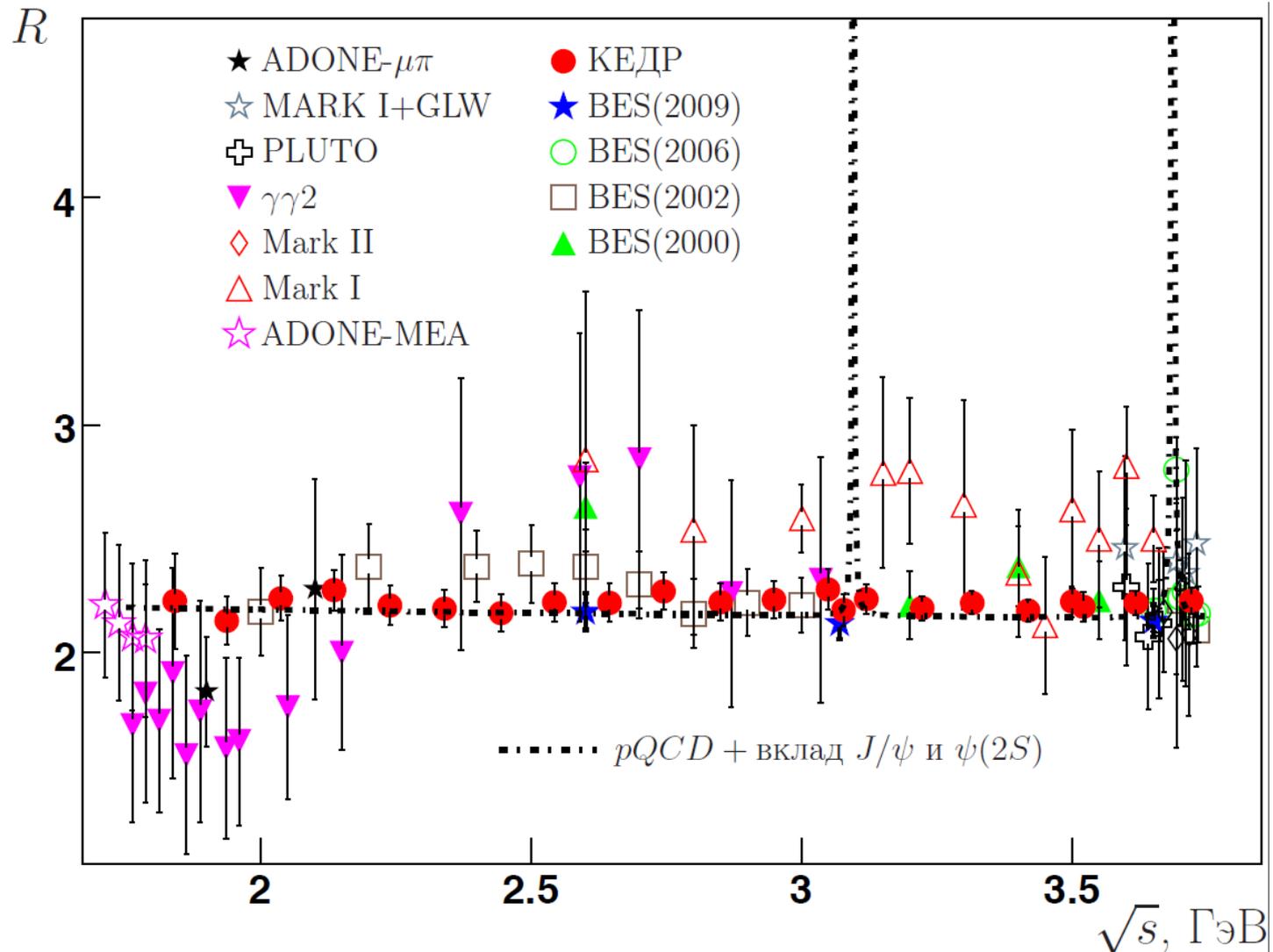
- ✓  $J/\psi$ ,  $\psi'$ ,  $\psi''$ ,  $\psi(3770)$  meson masses
- ✓  $\tau$  lepton mass
- ✓  $D^0$  mesons masses
- ✓  $D^\pm$  mesons masses
- ✓ Search for narrow resonances 1.85÷3.1 GeV
- ✓ R-scan 1.85÷3.1 GeV
- ✓  $R_{uds^-}$  and R- scan 3.12÷3.72 GeV
- ✓  $J/\psi \rightarrow \gamma \eta_c$
- ✓  $\psi$ -mesons,  $\eta_c$ , ... parameters

## High energy luminosity run 2x(1.9÷Max energy) GeV

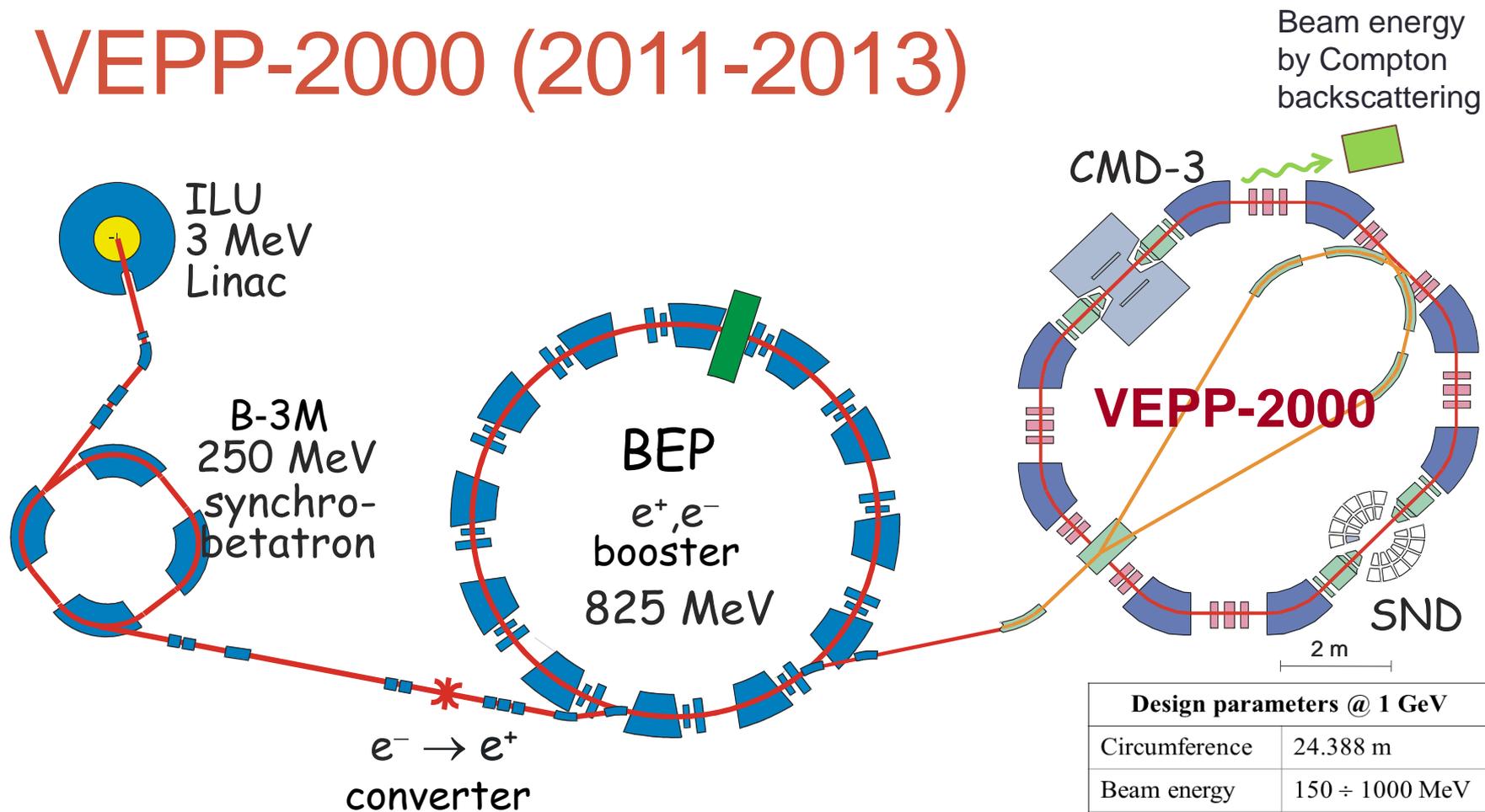
- ✓ R scan 2x(2.3÷3.5) GeV ( $\sim 10 \text{ pb}^{-1}$ )
- ✓  $Y$ -mesons study ( $\sim 50 \text{ pb}^{-1}$ )
- ✓ gamma-gamma physics ( $\sim 200 \text{ pb}^{-1}$ )

# Измерение $R(s)$ на ВЭПП-4М

Наиболее  
точное  
измерение!



# VEPP-2000 (2011-2013)



C.m. energy range is 0.32-2.0 GeV

Unique optics – “round beams”

Experiments CMD-3 and SND started by the end of 2010

Design parameters @ 1 GeV	
Circumference	24.388 m
Beam energy	150 ÷ 1000 MeV
N of bunches	1×1
N of particles	1×10 <sup>11</sup>
Betatron tunes	4.14 / 2.14
Beta*	8.5 cm
BB parameter	0.1
Luminosity	1×10 <sup>32</sup> cm <sup>-2</sup> s <sup>-1</sup>

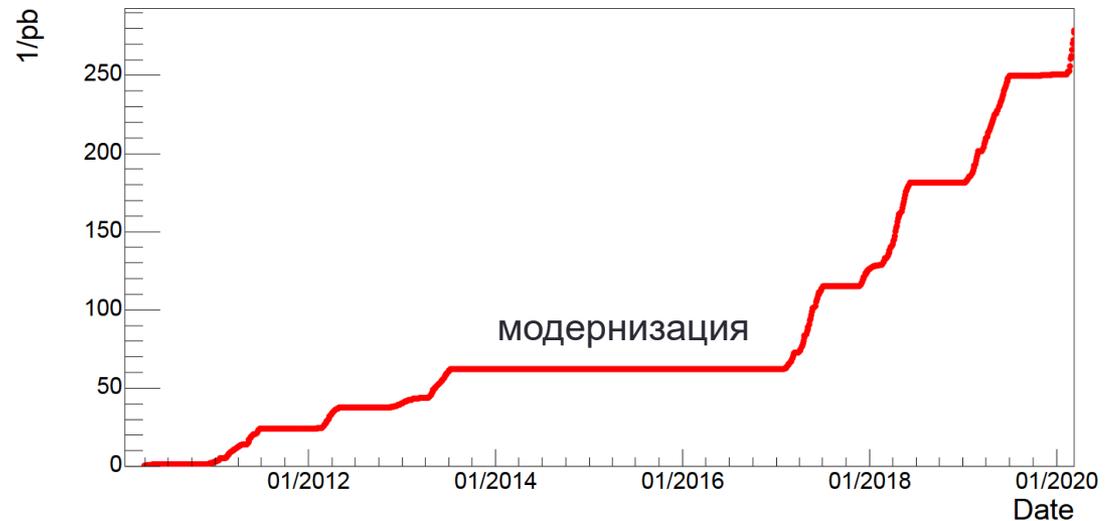
# VEPP-2000 upgrade (2013-2016)



Collider upgrades:

- x10 more intense positron source
- booster up to 1 GeV (match VEPP-2000)

История набора интеграла светимости

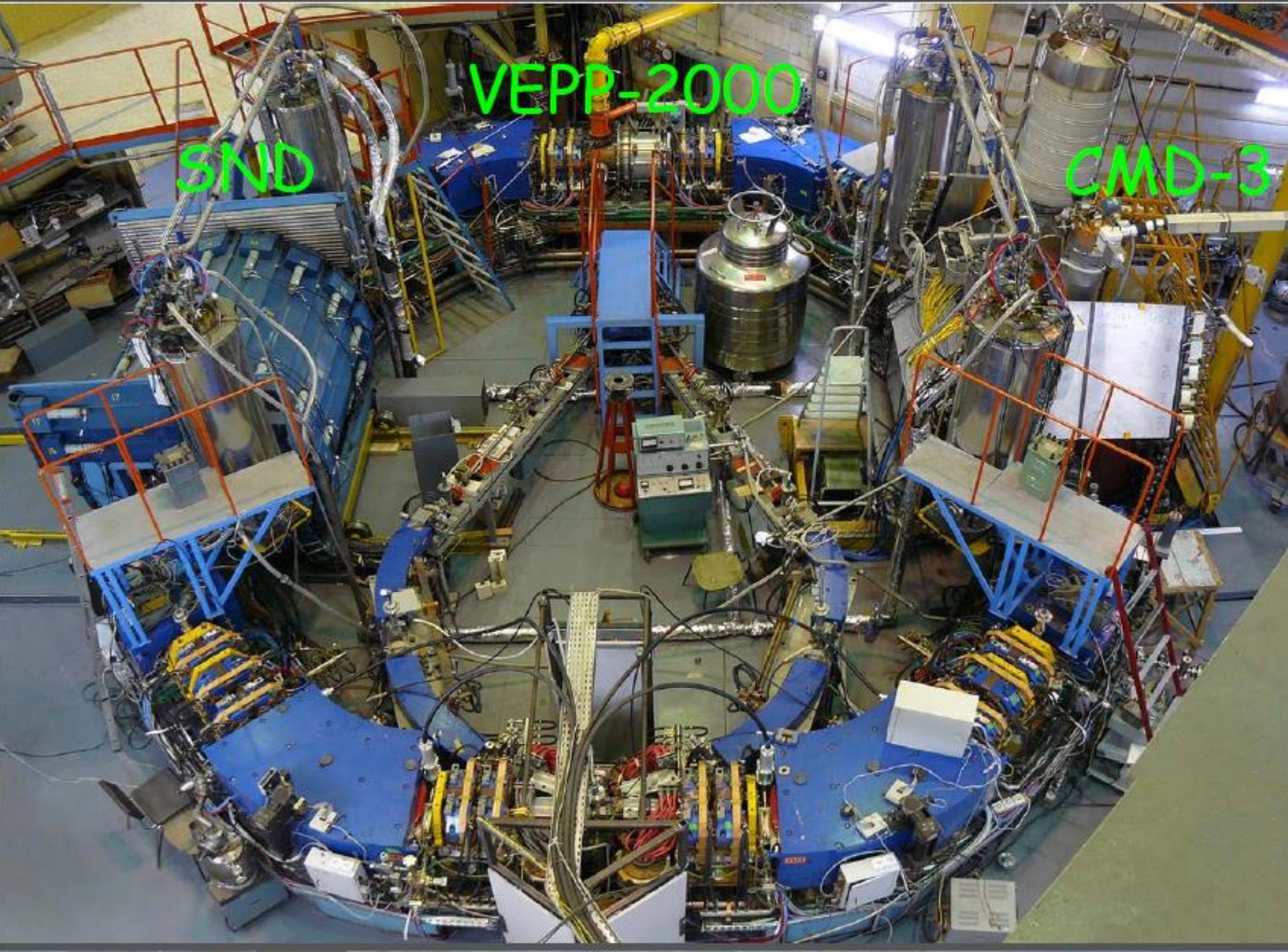


Detectors resumed data taking by the end of 2016

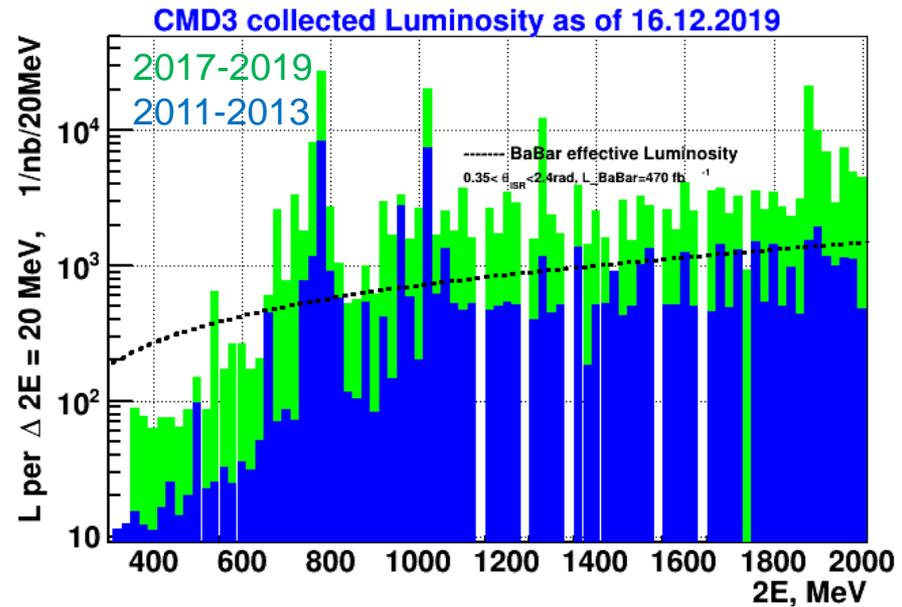
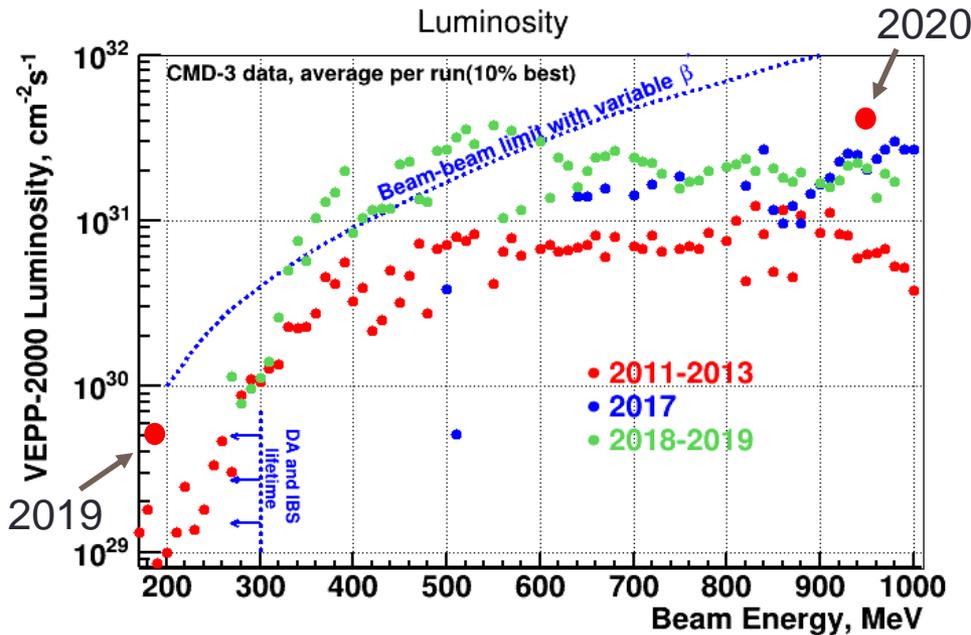
VEPP-2000

SND

CMD-3



# Collected luminosity



2017-2019: big improvement in luminosity, still way to go

Below 1 GeV:  $\sim 60 \text{ pb}^{-1}$  collected and counting

0.32 – 1.00 GeV	63 $1/pb$
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Above 1 GeV:  $\sim 180 \text{ pb}^{-1}$  collected

2.007 GeV ( $e^+e^- \rightarrow D^{0*}$ )	4 $1/pb$
$p\bar{p}$ and $n\bar{n}$ threshold	14 $1/pb$
Overall:	
1.00 – 2.007 GeV	180 $1/pb$

# Физическая программа ВЭПП-2000

1. Прецизионное измерение  $R(s)$   

$$R(s) = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$$

$< 1\%$  для основных каналов
2. Изучение адронных каналов:  
 $e^+e^- \rightarrow 2h, 3h, 4h \dots, h = \pi, K, \eta$
3. Изучение возбуждений векторных мезонов:  $\rho', \rho'', \omega', \phi', \dots$
4. Проверка CVC: сравнение сечений  $e^+e^- \rightarrow \text{hadr. (T=1)}$  со спектрами распадов  $\tau$
5. Изучение парного рождения нуклон-antinуклона – электромагнитные формфакторы нуклона, ...
6. Двухфотонная физика

## Изучение рождения адронов в аннигиляции $e^+e^-$ :

- Что рождается?
- Сколько рождается?
- Как рождается?

Рождение пар  $p\bar{p}, n\bar{n}$   
 Поведение адронных сечений на пороге

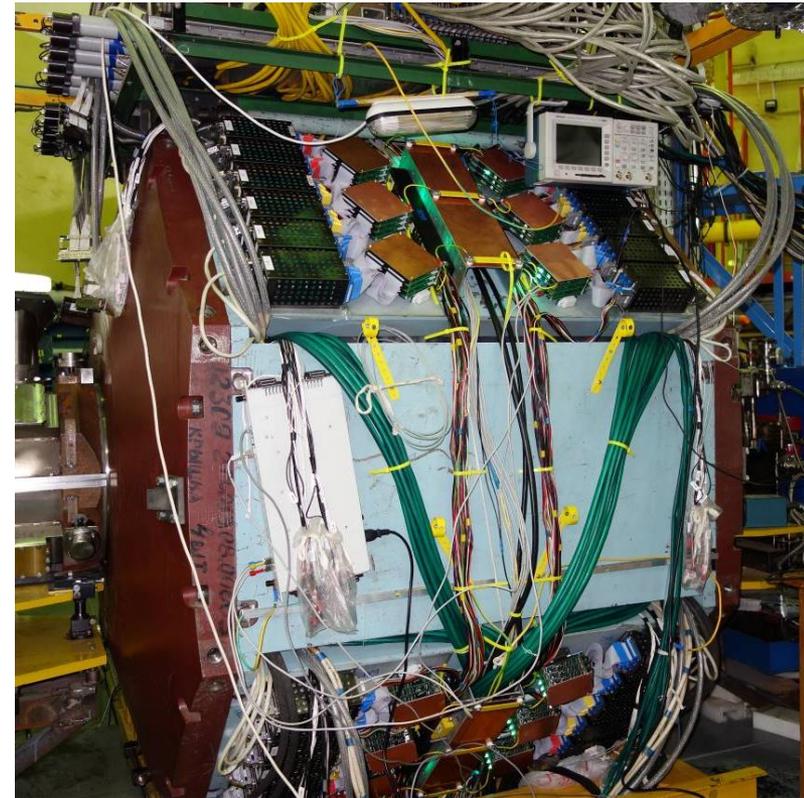
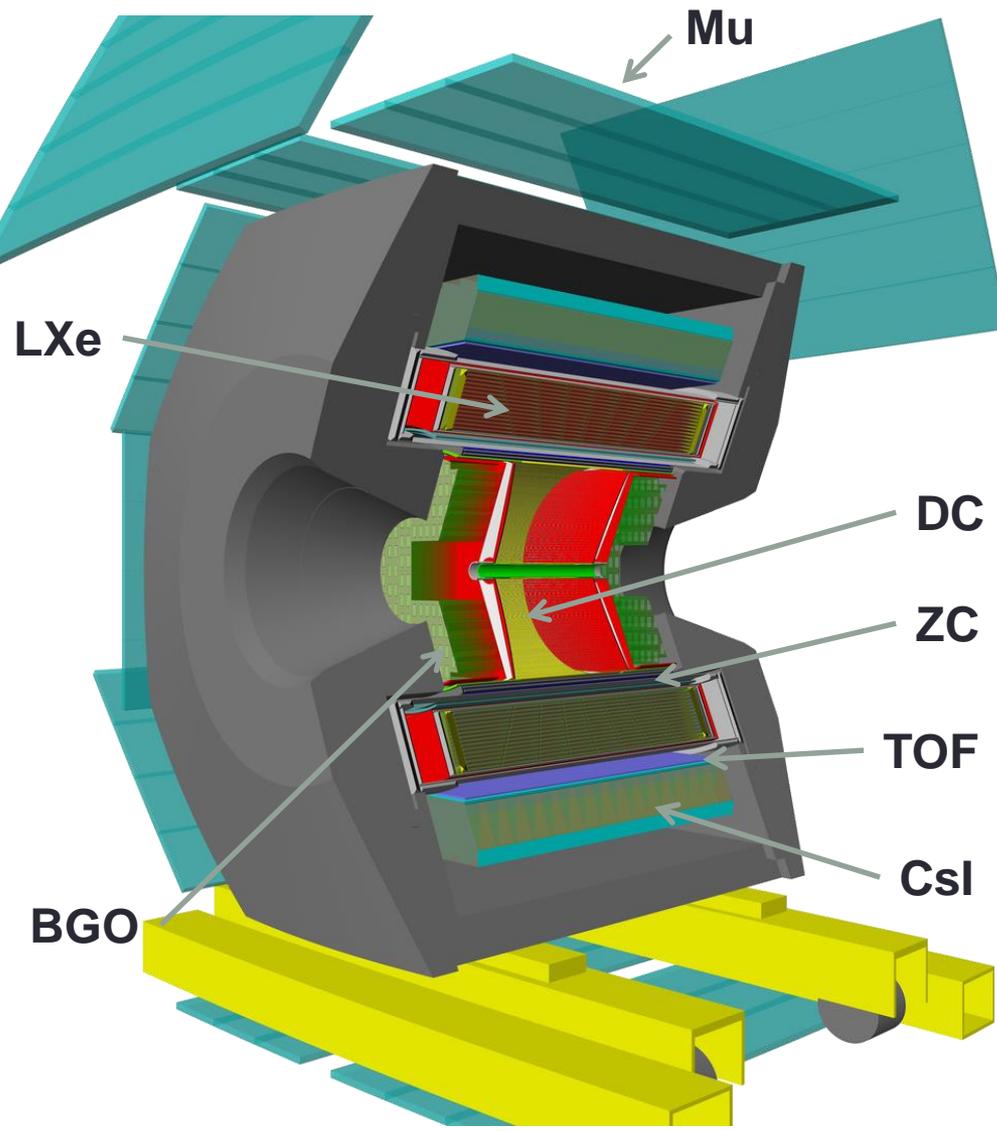
Отдельные задачи:

$$e^+e^- \rightarrow \eta, \eta', f_1$$

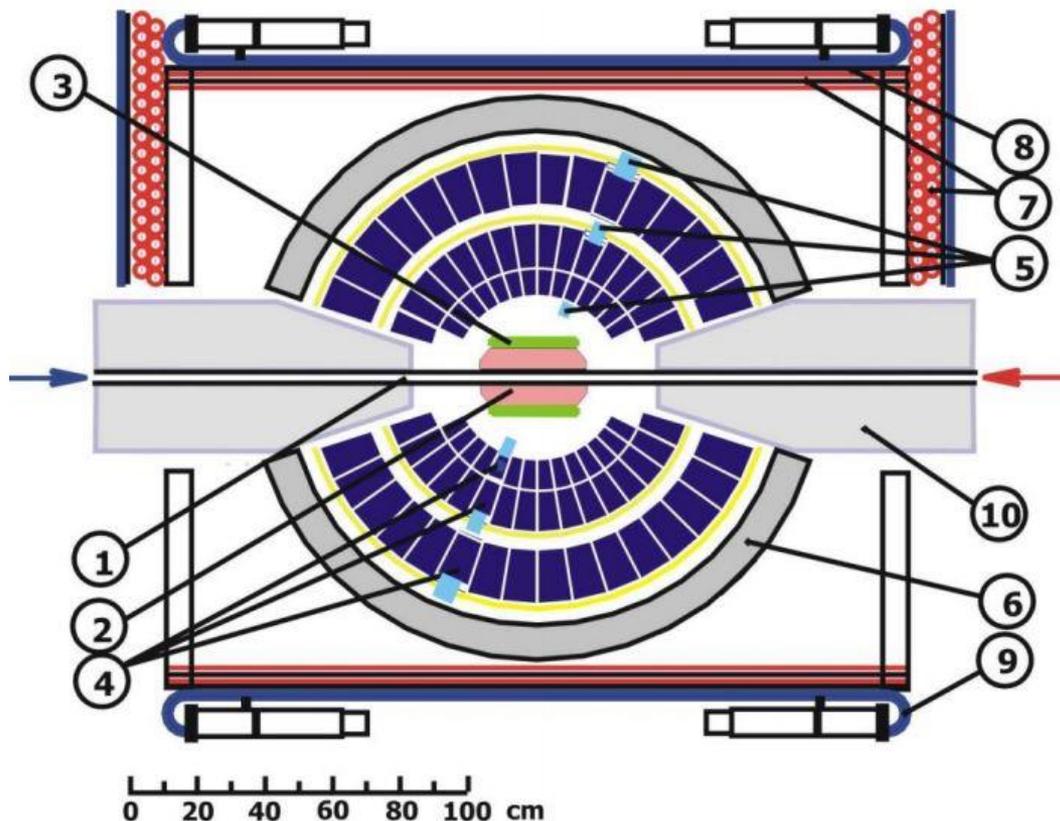
$$e^+e^- \rightarrow \pi^0 e^+e^-$$

$$e^+e^- \rightarrow D^{0*}$$

# Detector CMD-3

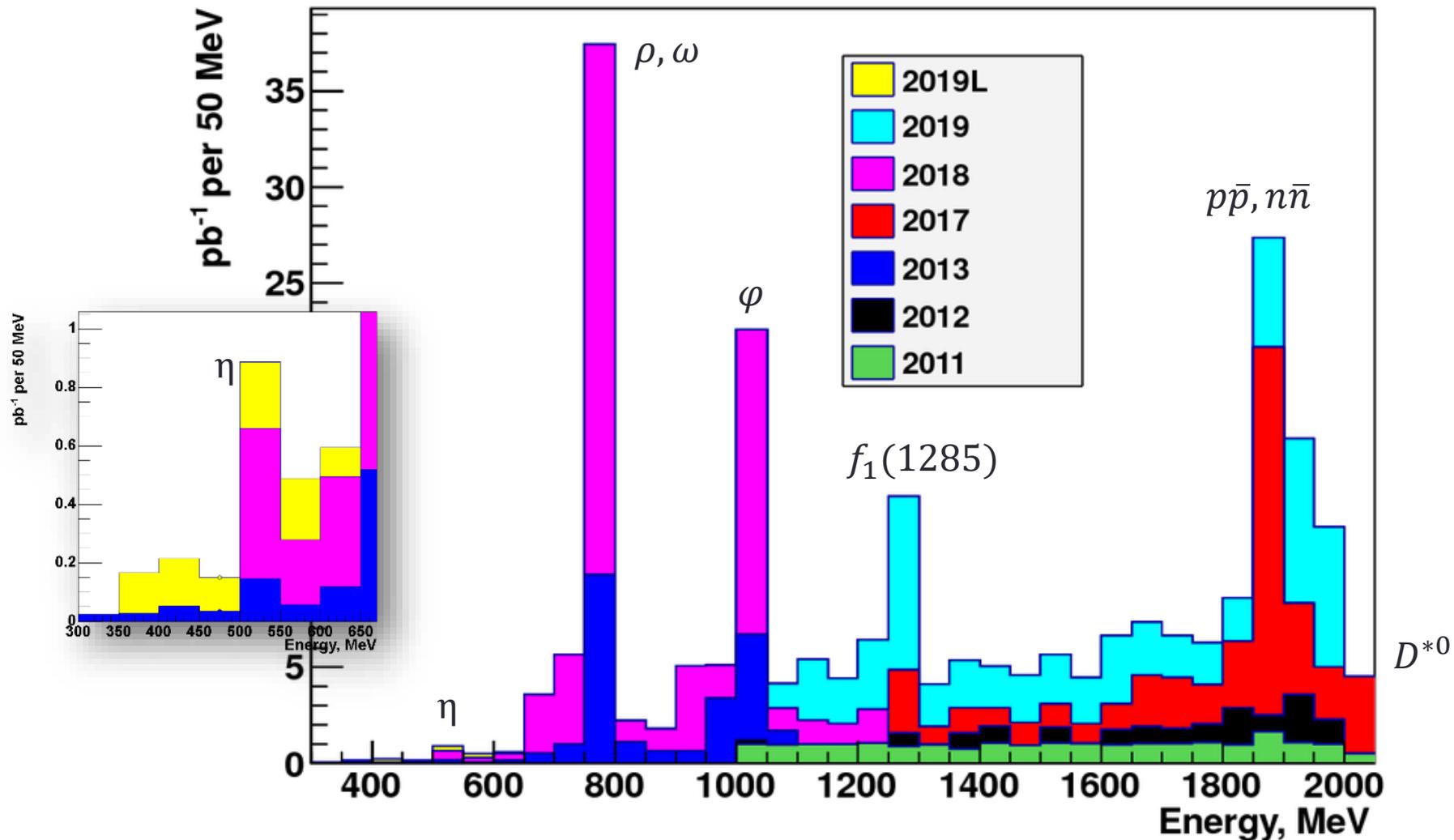


# Detector SND

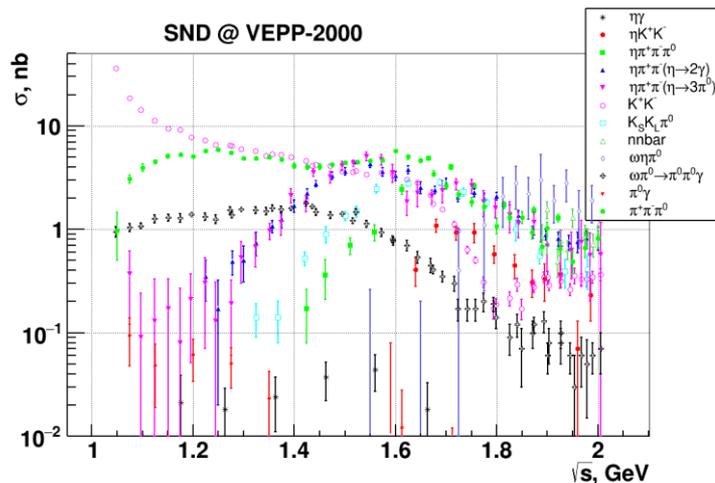
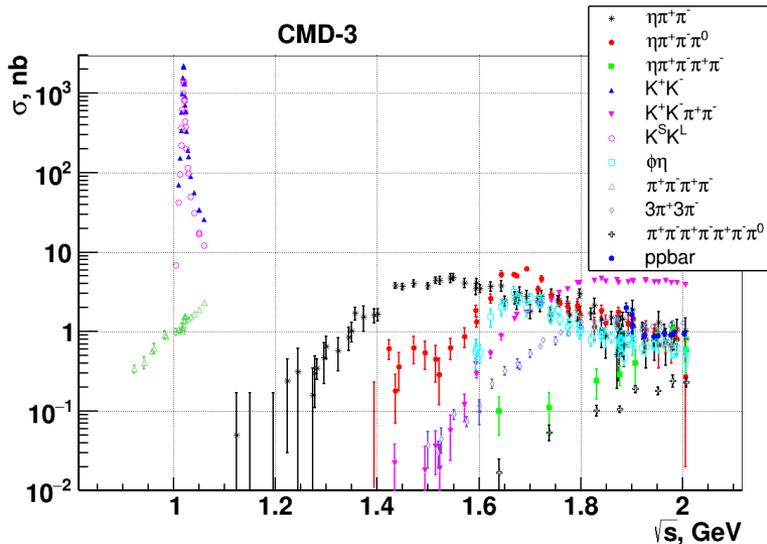


1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counters , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.

# Распределение набранного интеграла по энергии



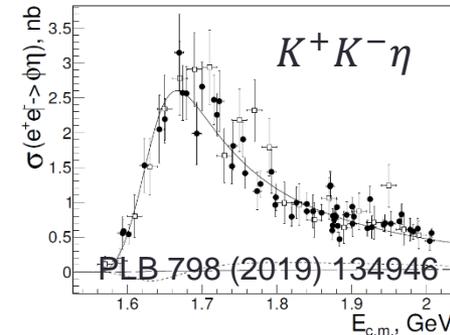
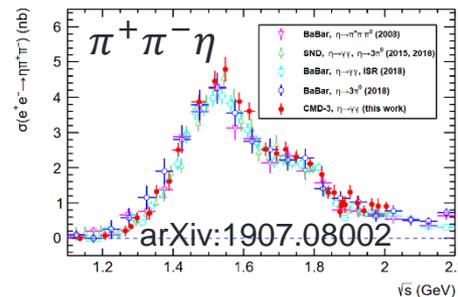
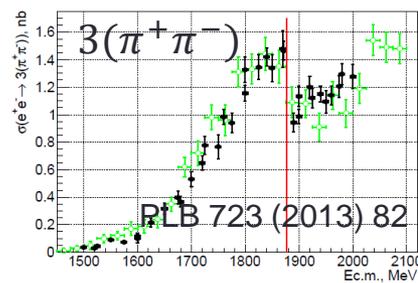
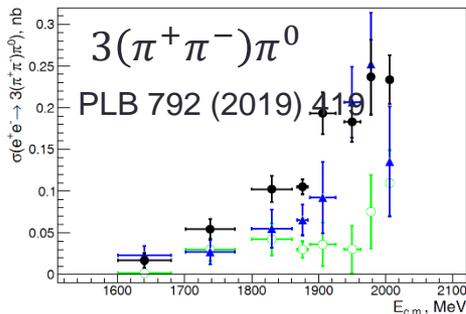
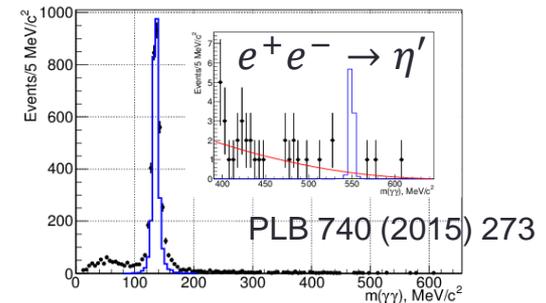
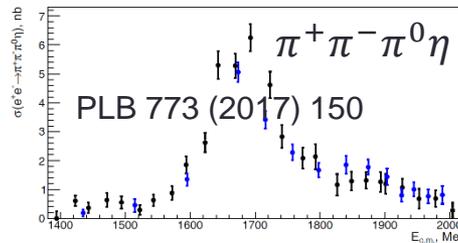
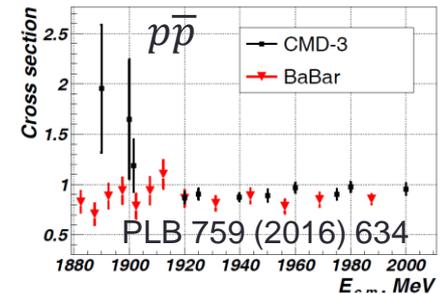
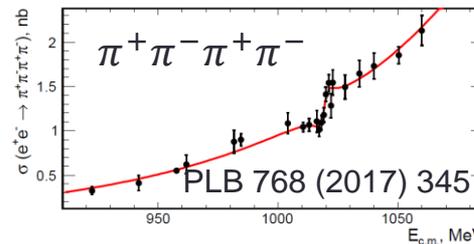
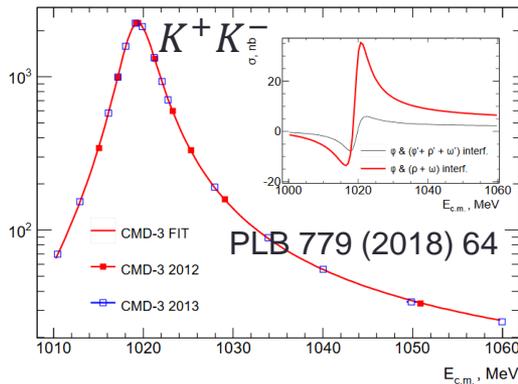
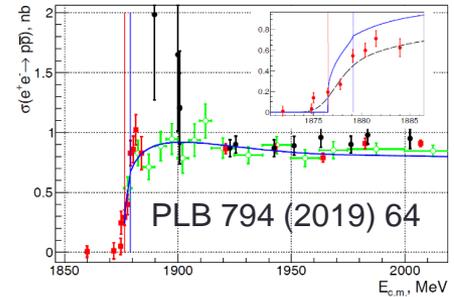
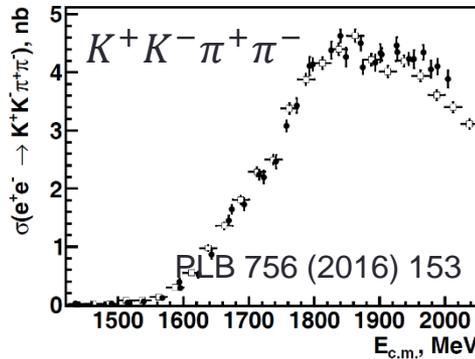
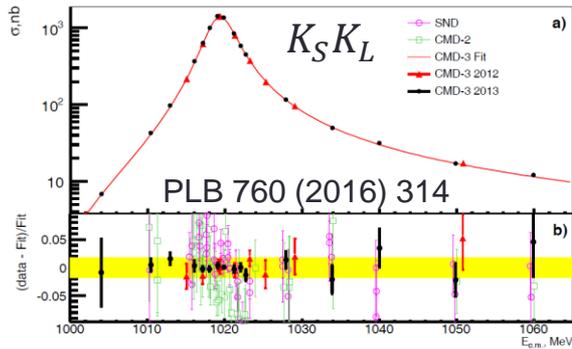
# Exclusive channels $e^+e^- \rightarrow hadrons$



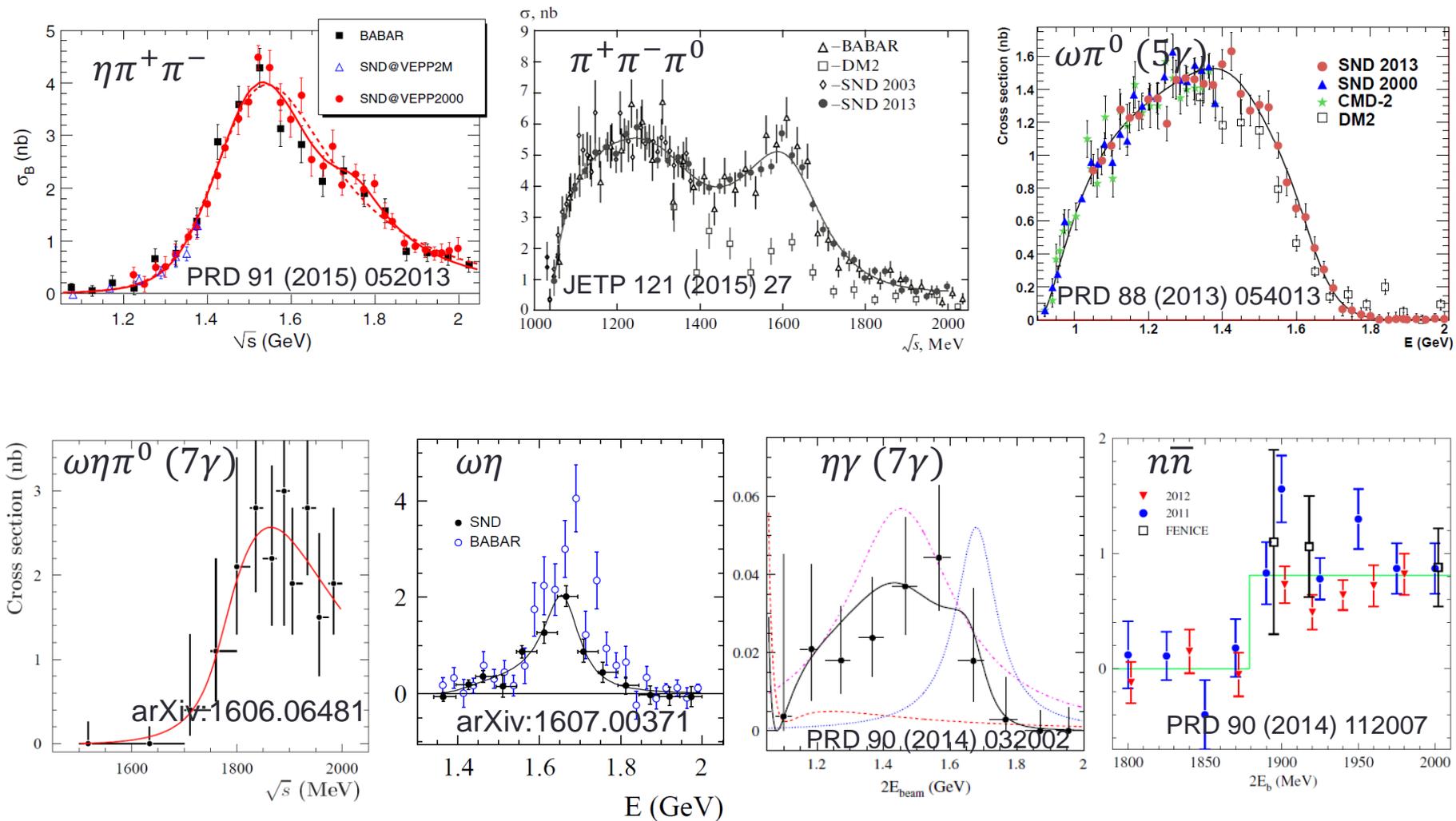
## Final states under analysis at CMD-3

Signature	Final states (preliminary, published)
2 charged	$\pi^+\pi^-$ , $K^+K^-$ , $K_S K_L$ , $p\bar{p}$
2 charged + $\gamma$ 's	$\pi^+\pi^-\gamma$ , $\pi^+\pi^-\pi^0$ , $\pi^+\pi^-2\pi^0$ , $\pi^+\pi^-3\pi^0$ , $\pi^+\pi^-4\pi^0$ , $\pi^+\pi^-\eta$ , $\pi^+\pi^-\pi^0\eta$ , $\pi^+\pi^-2\pi^0\eta$ , $K^+K^-\pi^0$ , $K^+K^-2\pi^0$ , $K^+K^-\eta$ , $K_S K_L\pi^0$ , $K_S K_L\eta$
4 charged	$2(\pi^+\pi^-)$ , $K^+K^-\pi^+\pi^-$ , $K_S K^\pm\pi^\mp$
4 charged + $\gamma$ 's	$2(\pi^+\pi^-)\pi^0$ , $2\pi^+2\pi^-2\pi^0$ , $\pi^+\pi^-\eta$ , $\pi^+\pi^-\omega$ , $2\pi^+2\pi^-\eta$ , $K^+K^-\omega$ , $K_S K^\pm\pi^\mp\pi^0$
6 charged	$3(\pi^+\pi^-)$ , $K_S K_S\pi^+\pi^-$
6 charged + $\gamma$ 's	$3(\pi^+\pi^-)\pi^0$
Neutral	$\pi^0\gamma$ , $2\pi^0\gamma$ , $3\pi^0\gamma$ , $\eta\gamma$ , $\pi^0\eta\gamma$ , $2\pi^0\eta\gamma$
Other	$n\bar{n}$ , $\pi^0e^+e^-$ , $\eta e^+e^-$
Rare decays	$\eta'$ , $D^*(2007)^0$

# CMD-3 published results

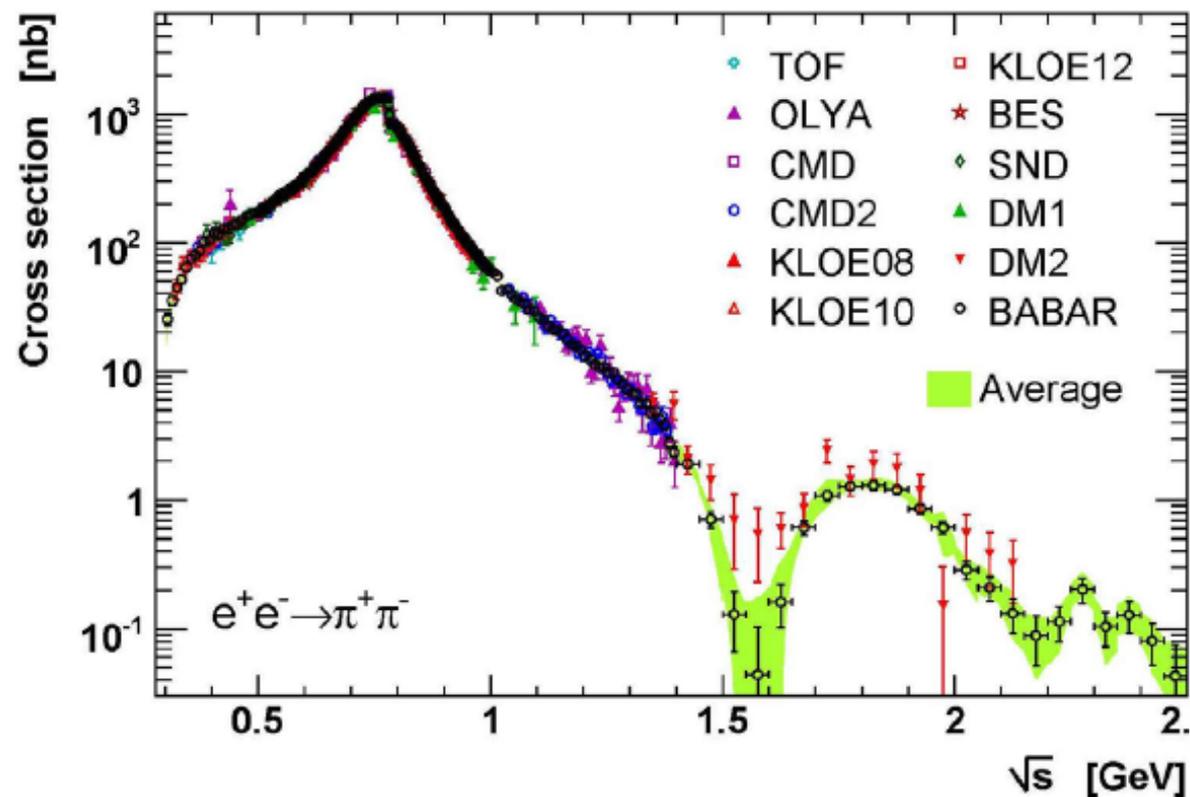


# Published results from 2011-2013: SND



$$e^+e^- \rightarrow \pi^+\pi^-$$

Gives 75% of hadronic contribution to muon (g-2), mostly at  $\rho(770)$ .  
Needs to be measured with sub-% precision.



Before VEPP-2000:

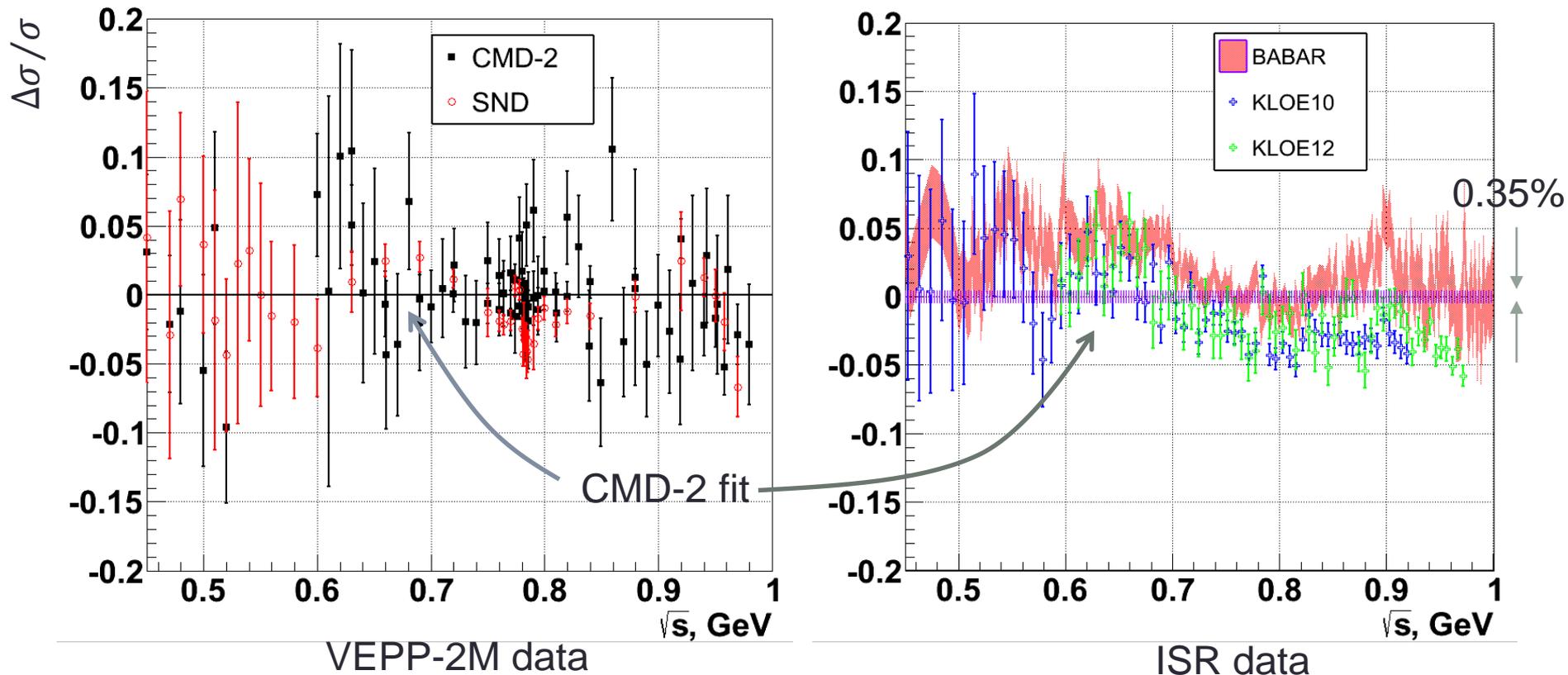
1) Energy scan:

CMD(2)	( $\delta_{sy}$ : 0.8%)	2003
SND	( $\delta_{sy}$ : 1.5%)	2003
DM1, OLYA, TOF, DM2		

2) ISR based experiments:

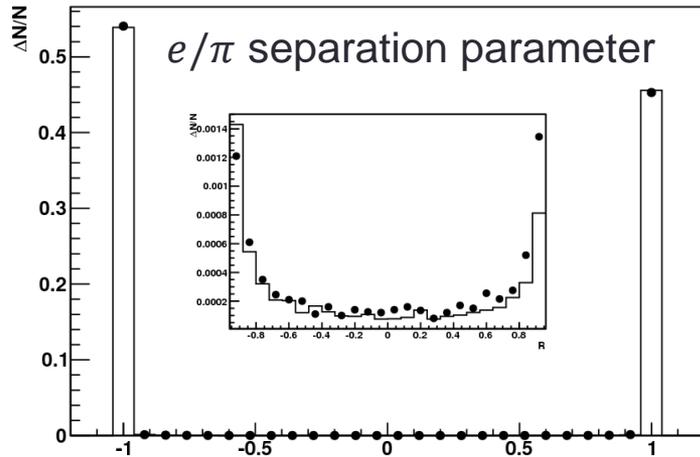
BABAR	( $\delta_{sy}$ : 0.5%)	2010
BESIII	( $\delta_{sy}$ : 0.9%)	2015
KLOE	( $\delta_{sy}$ : 0.8%)	2008
	( $\delta_{sy}$ : 1.4%)	2010
	( $\delta_{sy}$ : 0.8%)	2012
		correlated/2008

# Согласуются ли существующие данные по $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ ?



- Интегралы, вычисленные по данным разных экспериментов, неплохо согласуются
- Локально, различия в данных в разы превышают заявленные ошибки

# $e^+e^- \rightarrow \pi^+\pi^-$ : new SND measurement

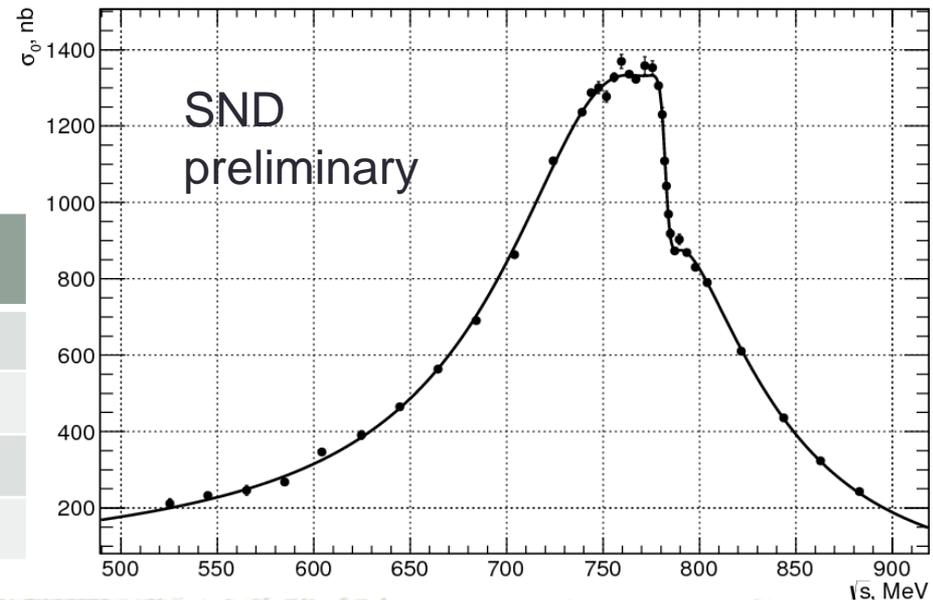


## Systematic uncertainty on the cross section (%)

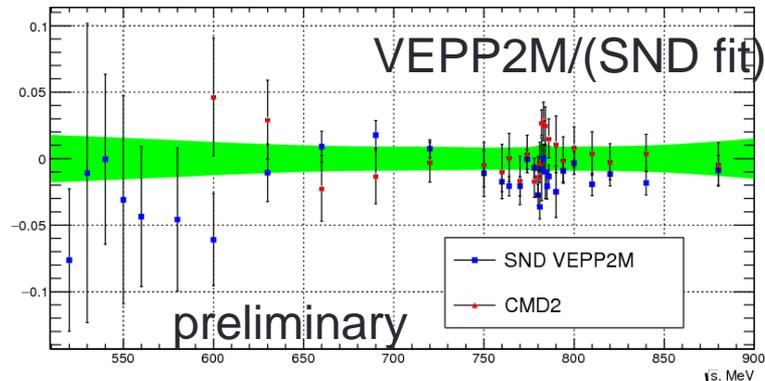
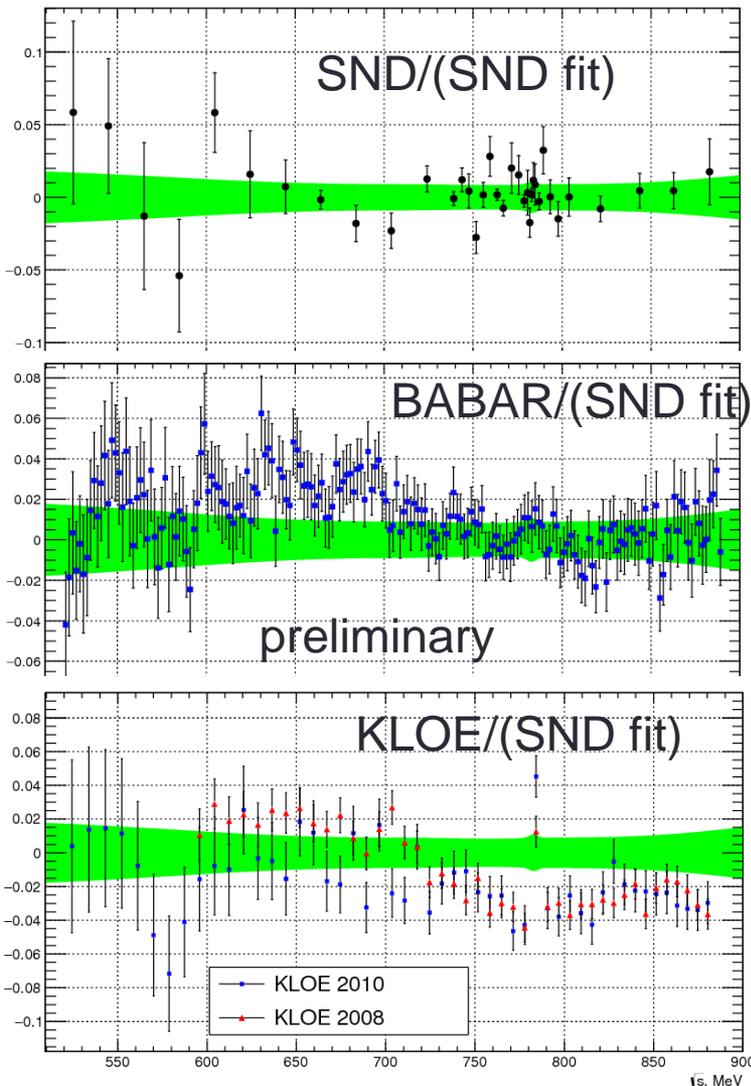
Source	< 0.6 GeV	0.6 - 0.9 GeV
Trigger	0.5	0.5
Selection criteria	0.6	0.6
$e/\pi$ separation	0.5	0.1
Nucl. interaction	0.2	0.2
Theory	0.2	0.2
<b>Total</b>	<b>0.9</b>	<b>0.8</b>

The analysis is based on  $4.7 \text{ pb}^{-1}$  data (1/10 full SND data set) recorded in 2013

	SND @ VEPP-2000	SND @ VEPP-2M	PDG
$M_\rho$ , MeV	$775.4 \pm 0.5 \pm 0.4$	$775.6 \pm 0.4 \pm 0.5$	$775.3 \pm 0.3$
$\Gamma_\rho$ , MeV	$145.7 \pm 0.7 \pm 1.0$	$146.1 \pm 0.8 \pm 1.5$	$147.8 \pm 0.9$
$B_{\rho ee} \times 10^5$	$4.89 \pm 0.2 \pm 0.4$	$4.88 \pm 0.2 \pm 0.6$	$4.72 \pm 0.5$
$B_{\omega \text{ППП}}$ , %	$1.77 \pm 0.08 \pm 0.02$	$1.66 \pm 0.08 \pm 0.05$	$1.53 \pm 0.06$



# $e^+e^- \rightarrow \pi^+\pi^-$ : new SND vs others

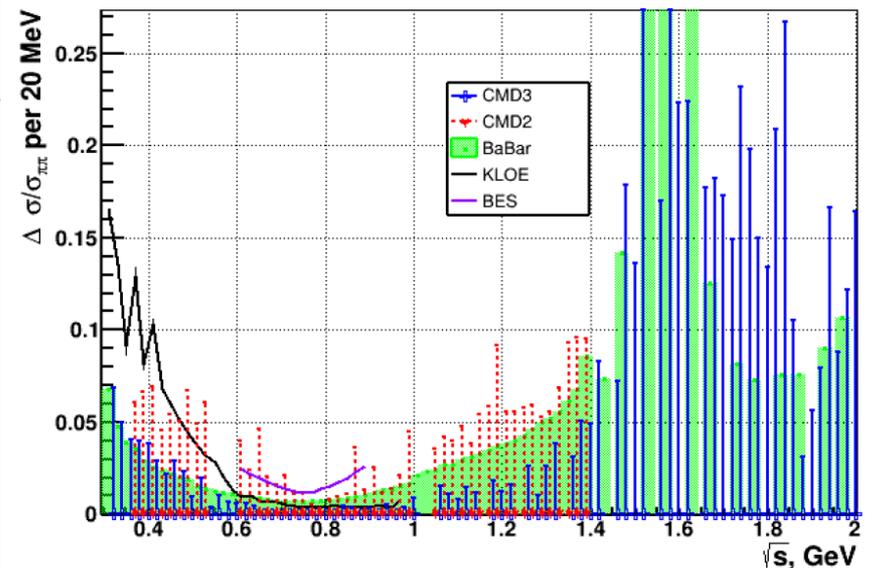
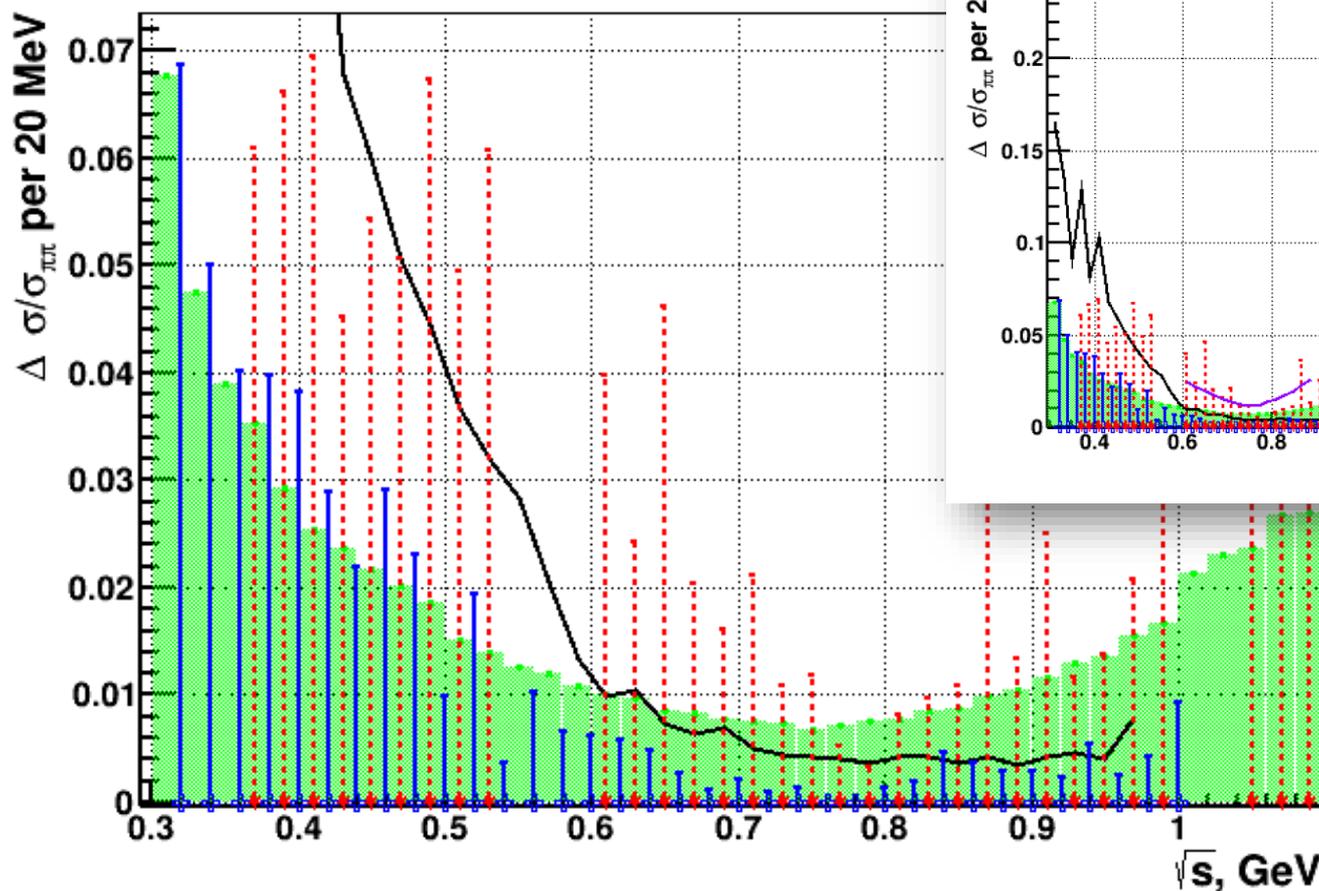


$$0.53 < \sqrt{s} < 0.88 \text{ GeV}$$

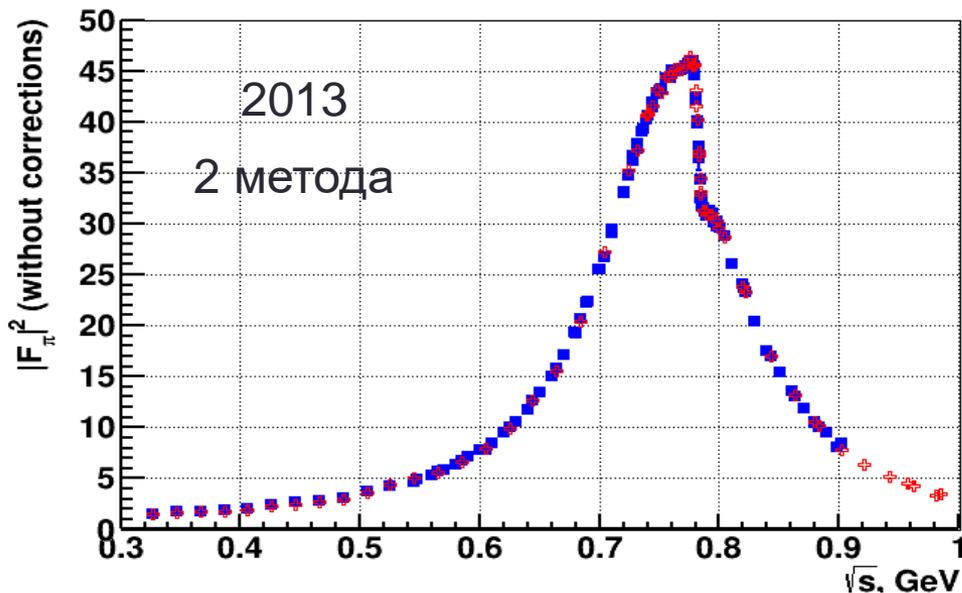
	$a_\mu(\pi^+\pi^-) \times 10^{10}$
SND & VEPP-2000	$411.8 \pm 1.0 \pm 3.7$
SND & VEPP-2M	$408.9 \pm 1.3 \pm 5.3$
BABAR	$414.9 \pm 0.3 \pm 2.1$

# $e^+e^- \rightarrow \pi^+\pi^-$ : статистика КМД-3 2013+2018+2017+2019

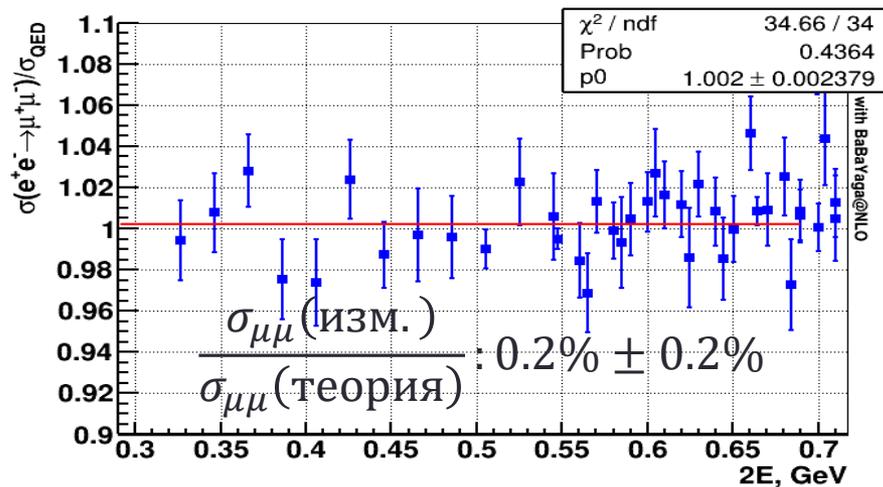
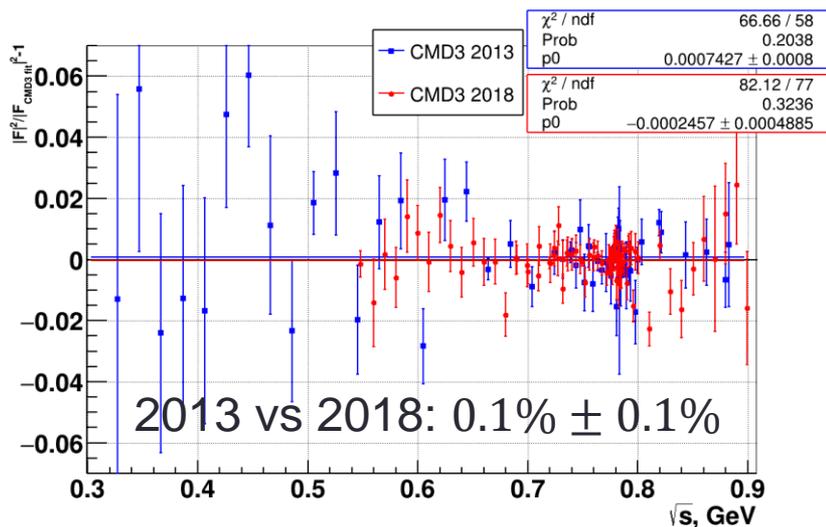
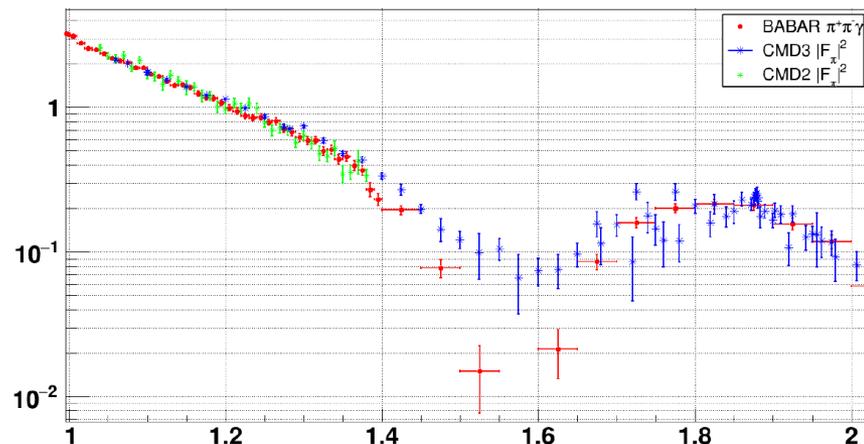
Стат.ошибка  $\Delta\sigma/\sigma$  в 20 MeV бинах



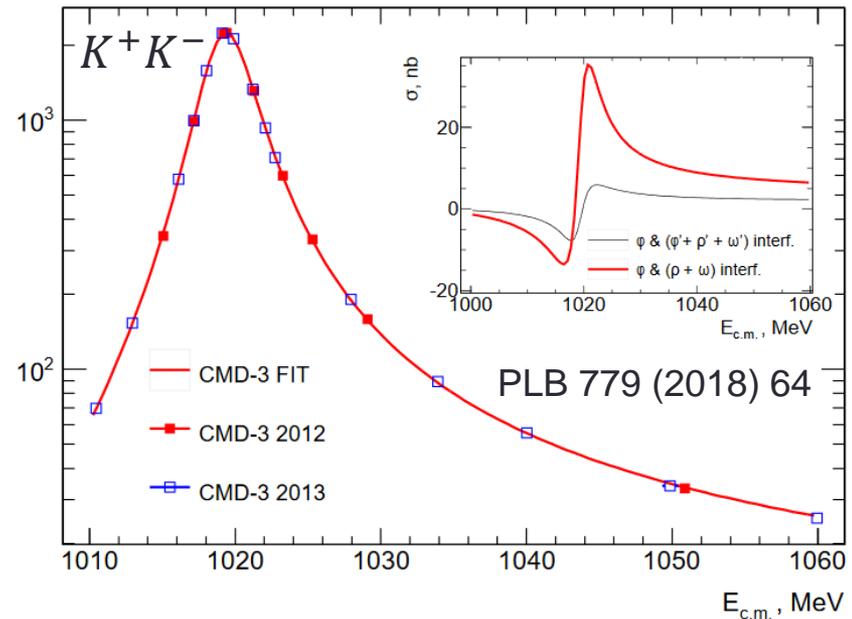
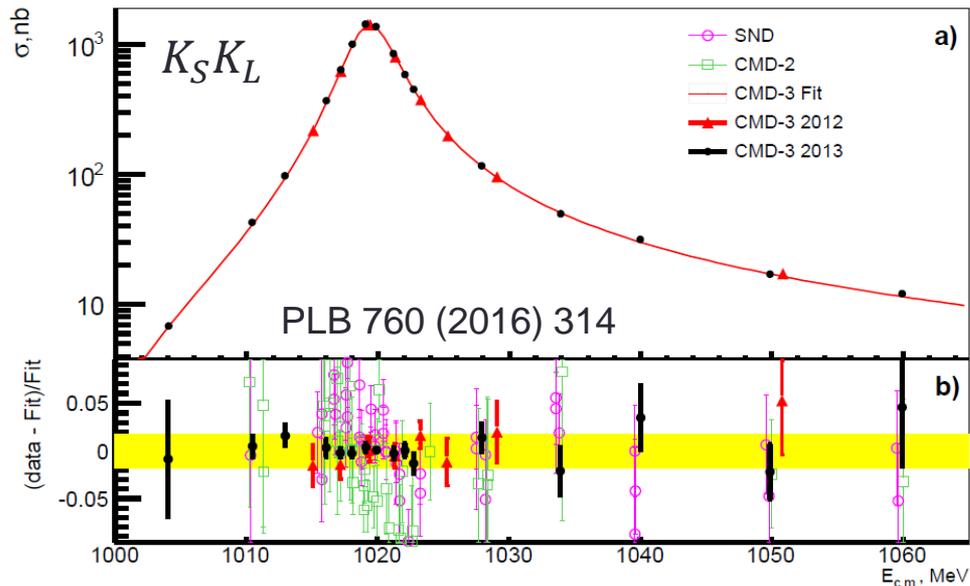
# $e^+e^- \rightarrow \pi^+\pi^-$ : предварительные результаты КМД-3



Первый результат выше 1 ГэВ  
Данные 2017 и 2019



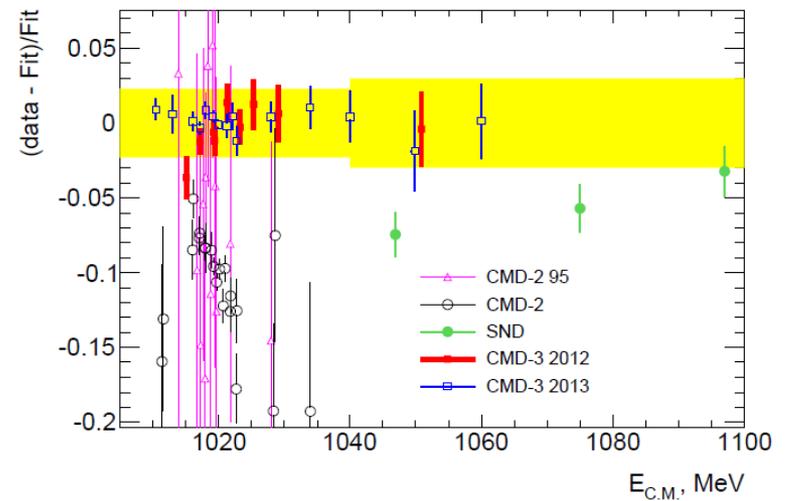
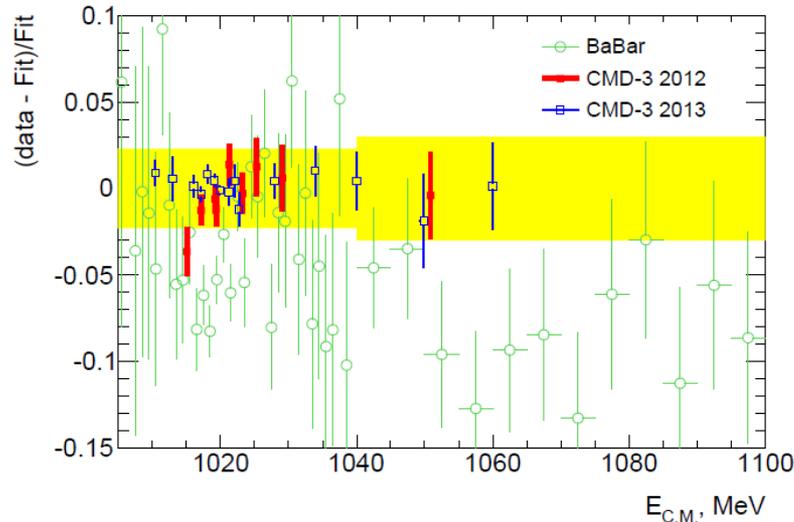
# $K_S K_L$ and $K^+ K^-$ @ $\varphi(1020)$



Recent result from CMD-3:

- $K_S K_L$  at  $\varphi$ , systematic precision 1.8%
- $K^+ K^-$  at  $\varphi$ , systematic precision 2.0% (2.8%)

# $K^+K^-$ : comparison with other measurements



$K_S K_L$  at  $\varphi$  is consistent between different experiments, but there is discrepancy in  $K^+ K^-$  channel.

New CMD-3  $K^+ K^-$  cross-section is above CMD-2 and BaBar, but is consistent with isospin symmetry:

$$R = \frac{g_{\varphi K^+ K^-}}{g_{\varphi K_S K_L} \sqrt{Z(m_\varphi)}} = 0.990 \pm 0.017$$

- $R_{SND} = 0.92 \pm 0.03 (2.6\sigma)$
- $R_{CMD-2} = 0.943 \pm 0.013 (4.4\sigma)$
- $R_{BaBar} = 0.972 \pm 0.017 (1.5\sigma)$

# $K_S K_L$ and $K^+ K^-$ : $\rho - \varphi$ interference

$\rho - \varphi$  interference can be directly observed:

$$R_{c/n} = \sigma(e^+e^- \rightarrow K^+K^-) \times \frac{p_{K^0}^3(s)}{p_{K^\pm}^3(s)} \times \frac{1}{Z(s)} - \delta \times \sigma(e^+e^- \rightarrow K_S K_L)$$

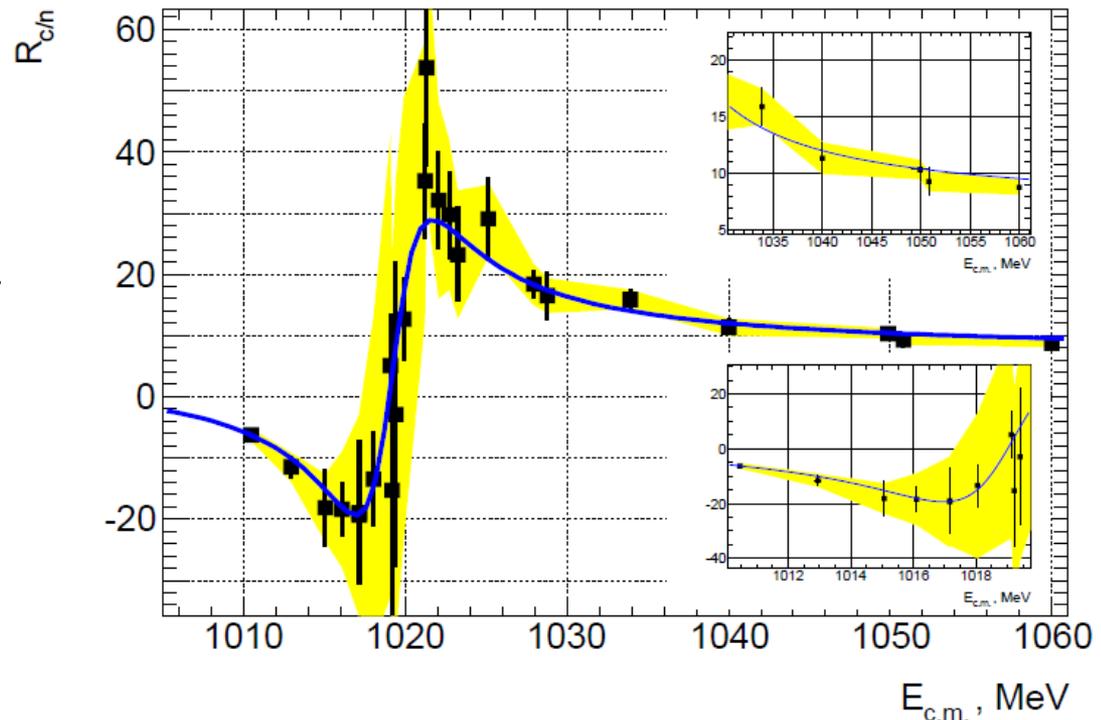
- $r_{\rho,\omega} = 0.91 \pm 0.04$

deviation of SU(3) relations

$$g_{\omega K^+ K^-} = g_{\rho K^+ K^-} = -g_{\varphi K^+ K^-} / \sqrt{2}$$

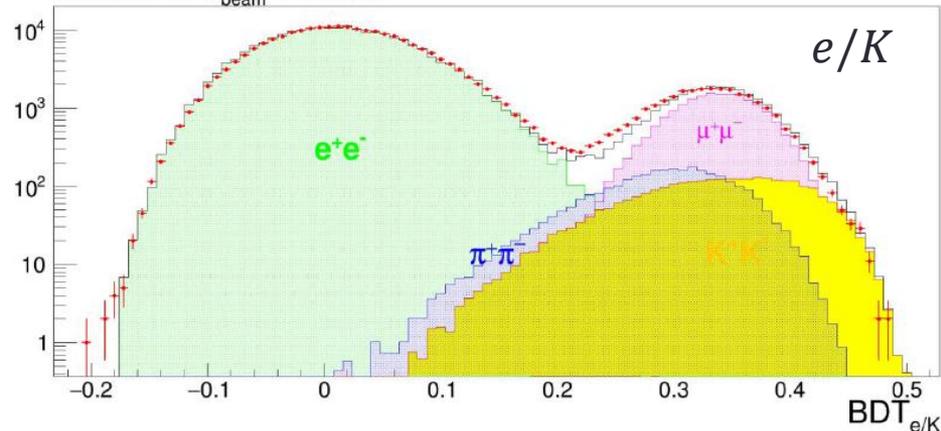
- $\delta = 0.989 \pm 0.003$

test of systematic errors

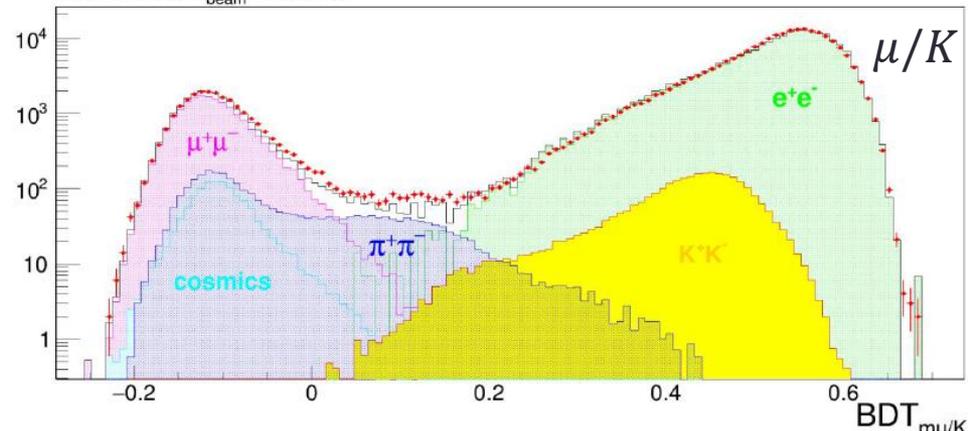


# Идентификация частиц в LХе (КМД-3)

HIGH 2019,  $E_{\text{beam}} = 750 \text{ MeV}$



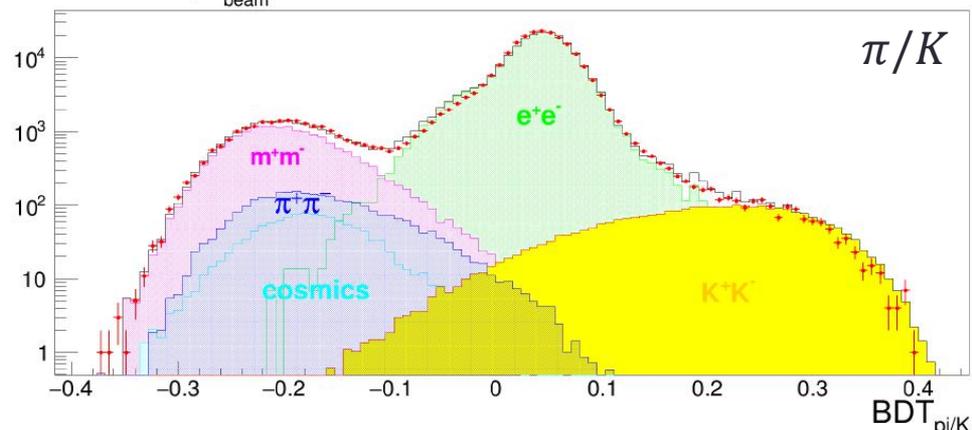
HIGH 2019,  $E_{\text{beam}} = 750 \text{ MeV}$

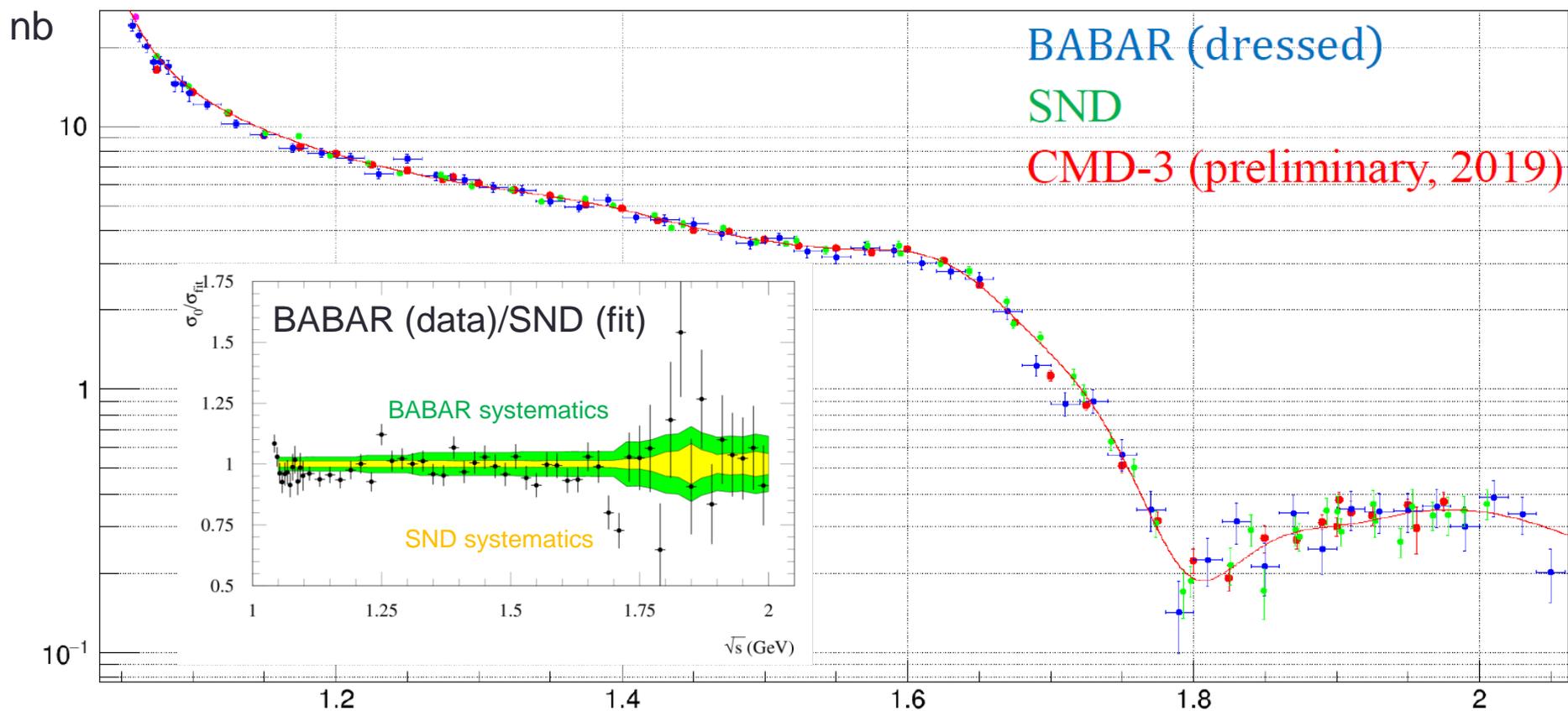


LХе калориметр измеряет профиль энергосвыделения, который можно использовать для идентификации частиц.

В 2019 году завершена работа по созданию классификаторов (потребовала улучшения моделирования, расчета полей в калориметре и т.п.)

HIGH 2019,  $E_{\text{beam}} = 750 \text{ MeV}$

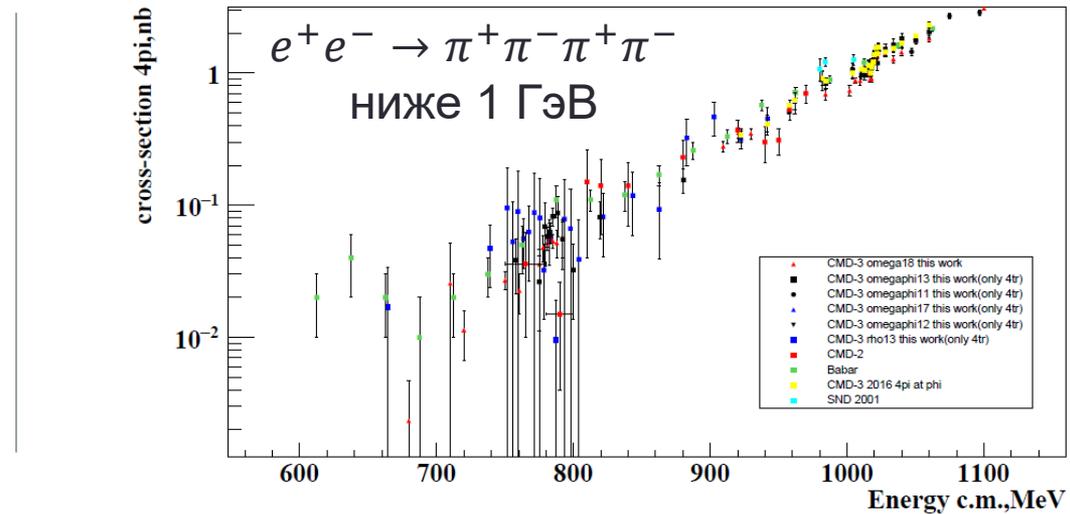


$e^+e^- \rightarrow K^+K^-$  @SND and @CMD-3

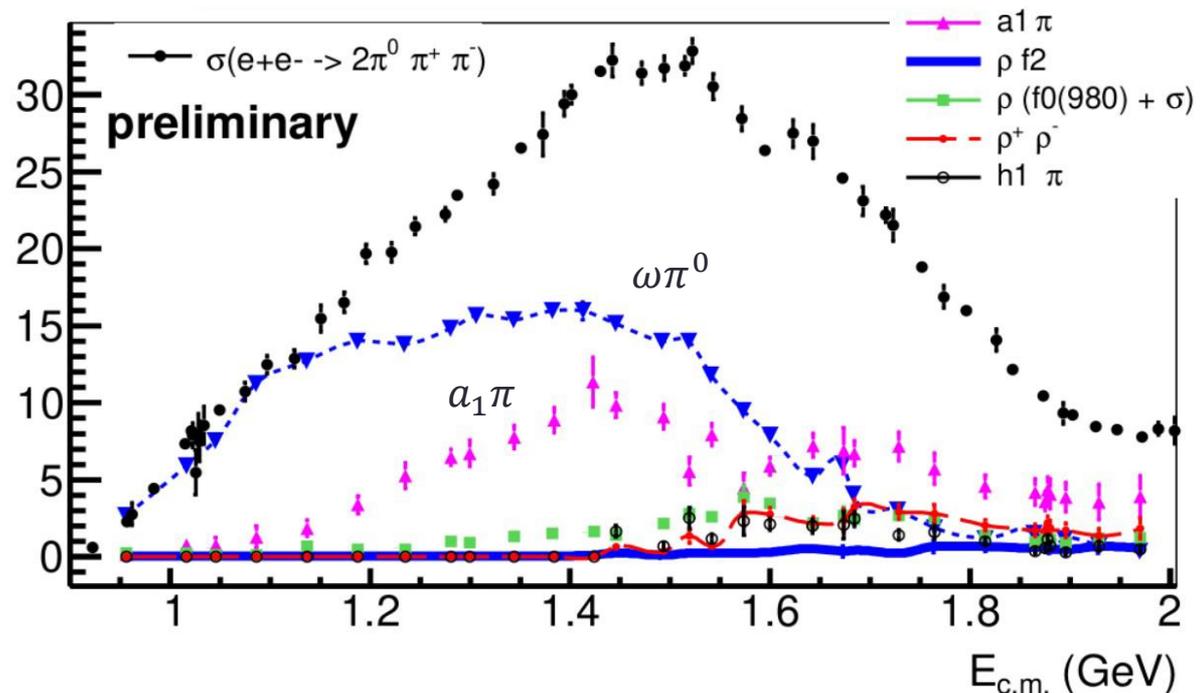
$$e^+e^- \rightarrow 4\pi$$

Изучение динамики  
 $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$  и  
 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$

- $\omega[1^{--}]\pi^0[0^{-+}]$
- $a_1(1200)[1^+]\pi[0^-]$
- $\rho[1^{--}]f_0/\sigma[0^{++}]$
- $\rho f_2(1270)[2^{++}]$
- $\rho^+\rho^-$
- $a_2(1320)[2^{++}]\pi$
- $h_1(1170)[1^{+-}]\pi^0$
- $\pi'(1300)(0^{-+})\pi$

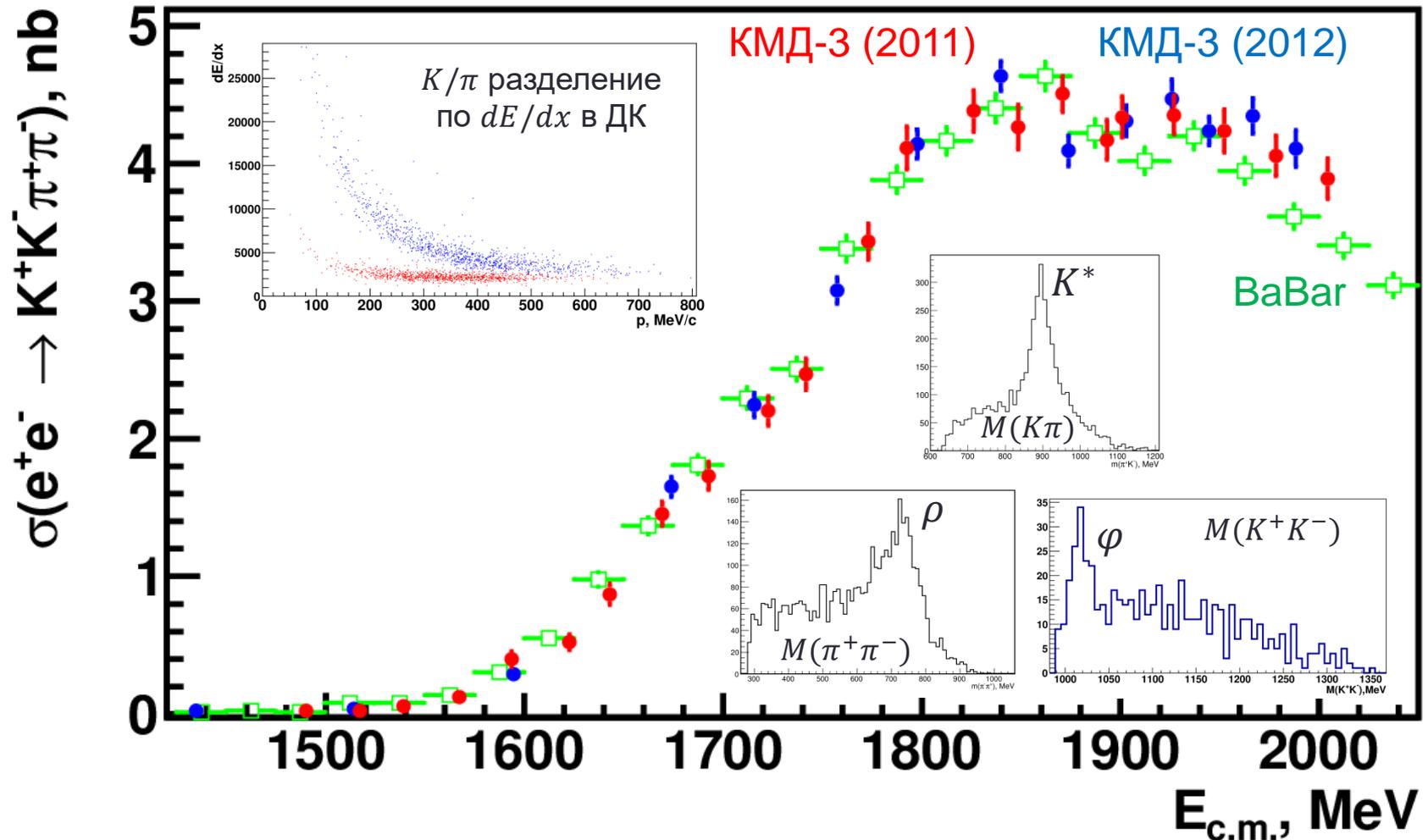


cross section (nb)



# $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$ @CMD-3

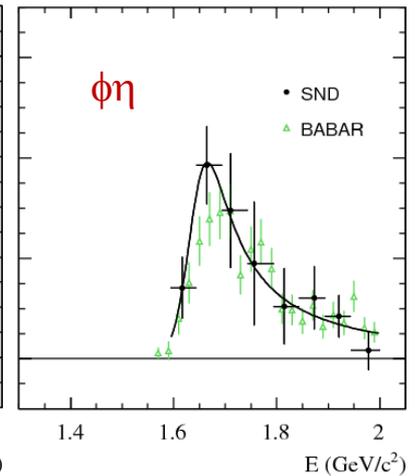
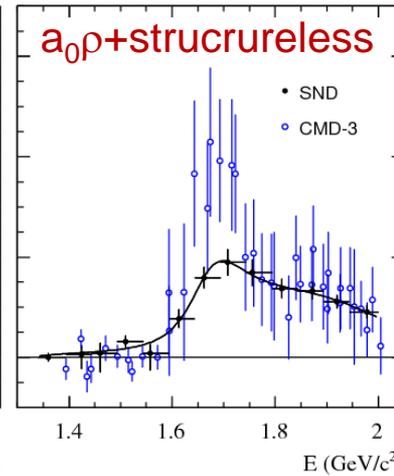
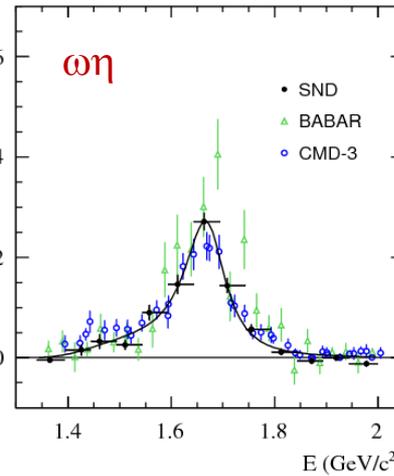
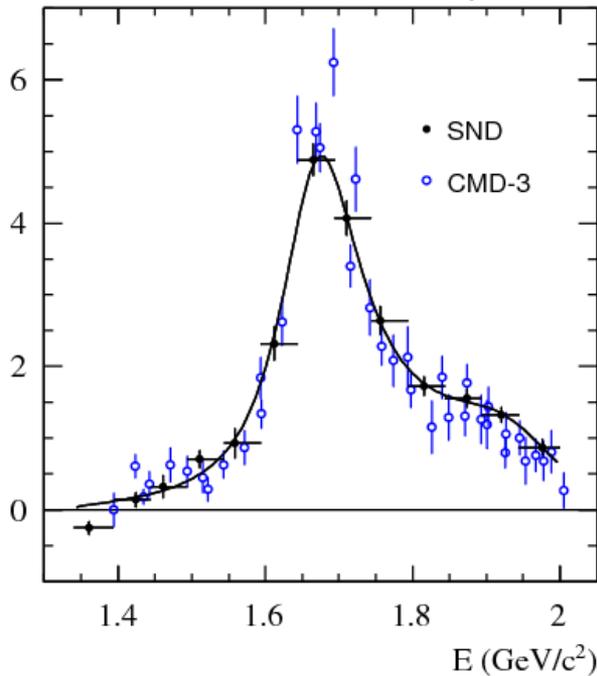
PLB 756 (2016) 153



# $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$ @SND and @CMD-3

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

Cross sections in nb



The total  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$  cross section measured by SND is, in general, consistent with the CMD-3 result. The  $\sim 15\%$  difference in the cross section maximum is

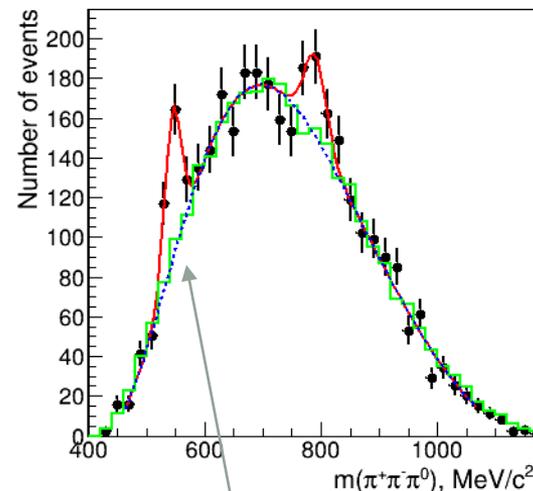
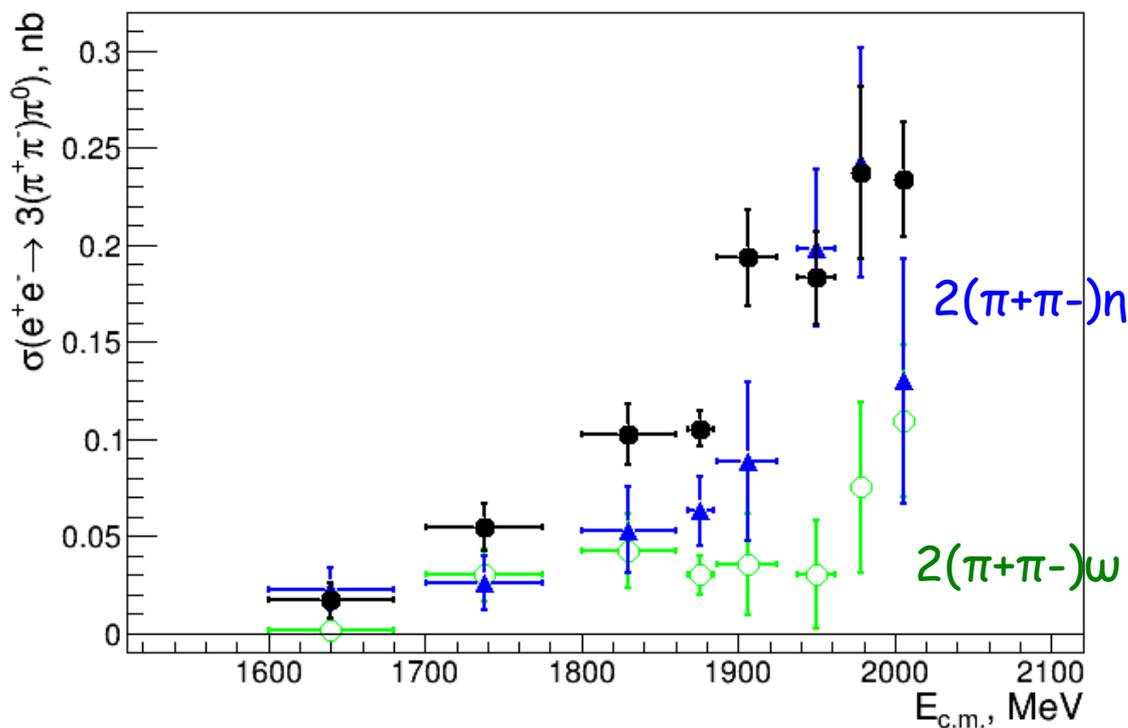
within the systematic uncertainties, which are 7% for SND and 11% for CMD-3.

- ✘ The obtained  $e^+e^- \rightarrow \omega\eta$  cross section agrees with the CMD-3 measurement. Both the SND and CMD-3 results lie below the BABAR data.
- ✘ The SND and BABAR  $\phi\eta$  measurements are in reasonable agreement.
- ✘ The significant difference between the SND and CMD-3 measurements is observed for the  $a_0\rho + \text{structureless}$  final state.

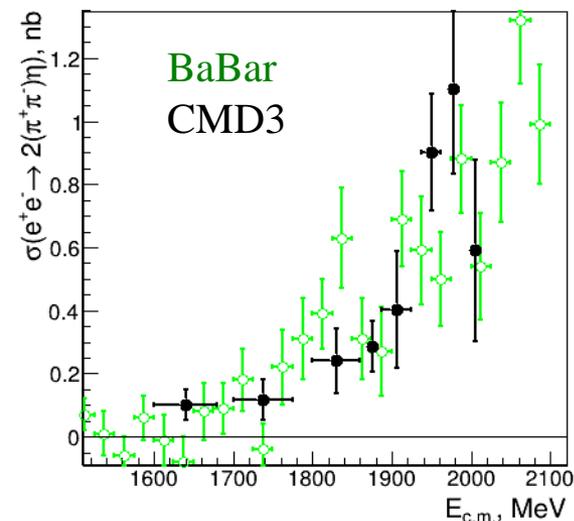
$$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^0$$

Впервые измерено полное сечение  $e^+e^- \rightarrow 3(\pi^+\pi^-)\pi^0$

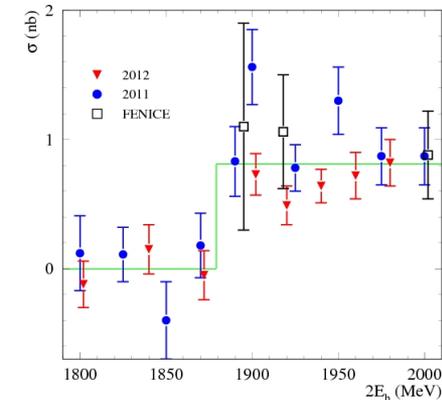
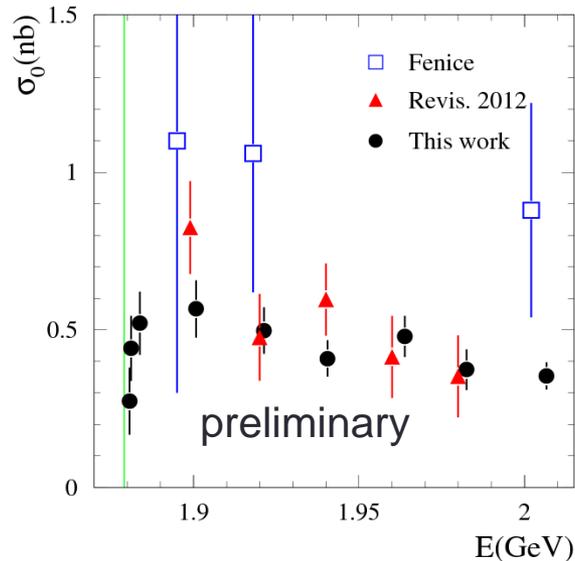
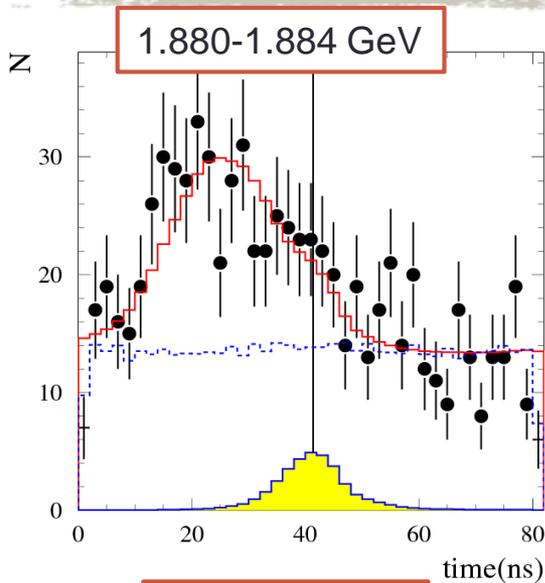
Показано, что доминируют каналы  $2(\pi^+\pi^-)\eta$  и  $2(\pi^+\pi^-)\omega$



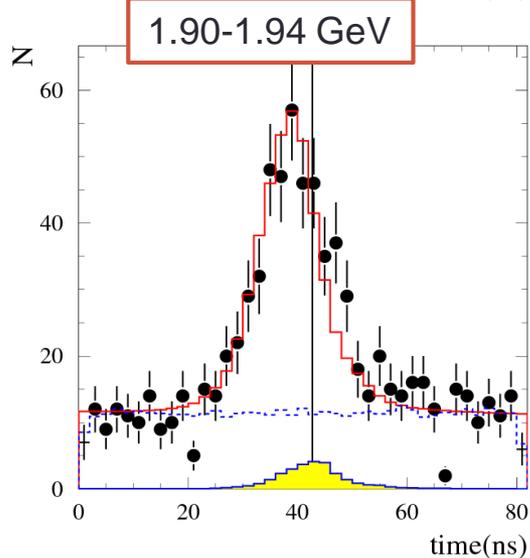
$2(\pi^+\pi^-)\eta$



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



This process was previously measured by FENICE and SND using the 2011-2012 dataset.



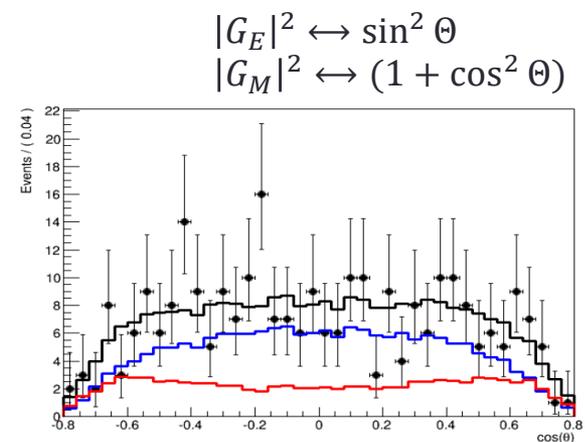
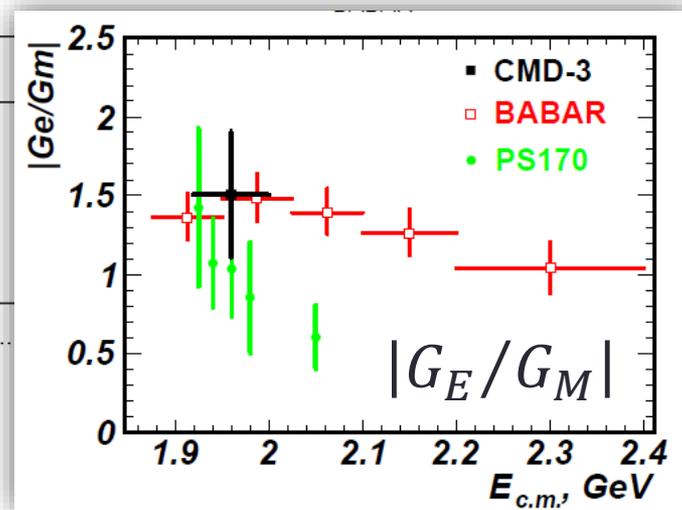
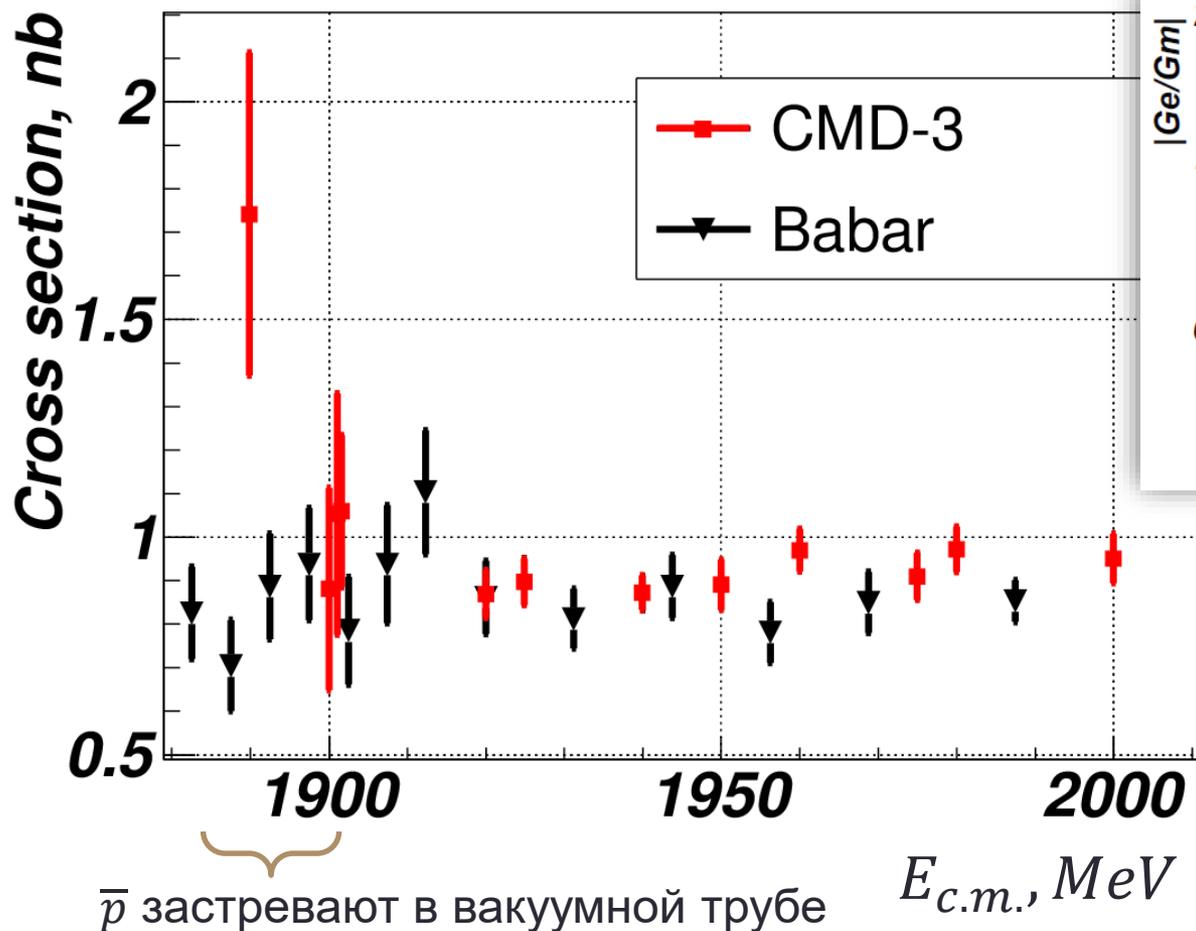
- ❑ The new measurement is based on the 2017 dataset and uses a different method. The calorimeter-trigger-time distribution is analyzed.
- ❑ The time distribution is fitted by a sum of distributions for signal, cosmic background, and beam +  $e^+e^-$  annihilation background.
- ❑ Our new result is lower than the previous SND measurement. The reasons are underestimated beam background and incorrect MC simulation.
- ❑ The systematic uncertainty on the cross section is estimated to be about 20%, mainly due to MC simulation.

Доклад С.И.Середнякова на параллельной секции

# $e^+e^- \rightarrow p\bar{p}$ @CMD-3

PLB 759 (2016) 634

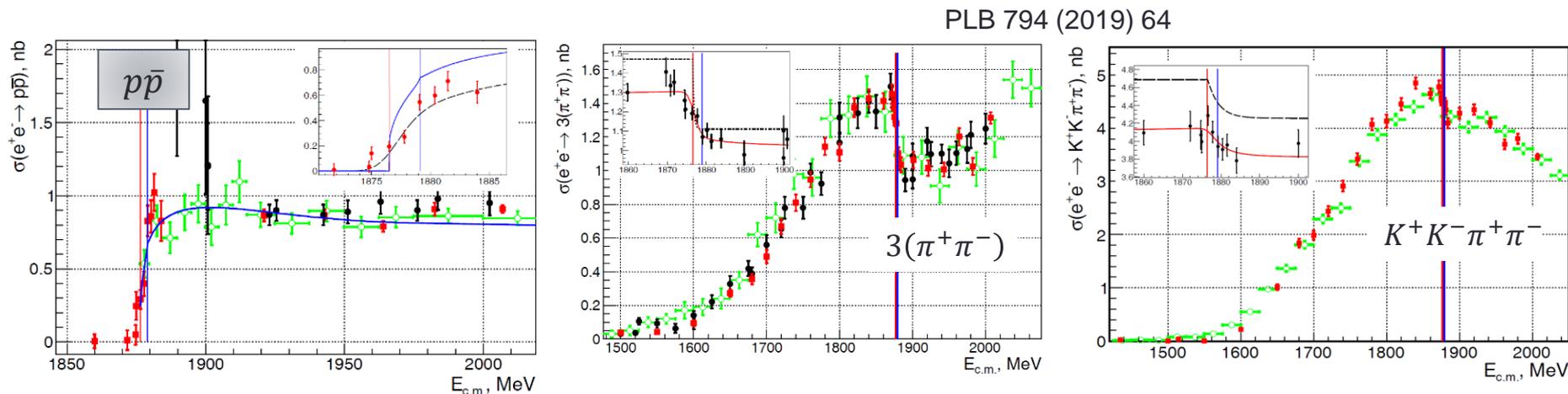
Данные 2011-2012



# $R(s)$ at $N\bar{N}$ threshold @CMD-3

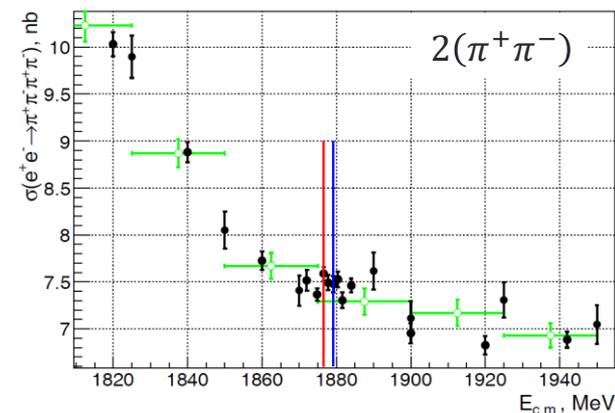
VEPP-2000: unique ability for detailed scan of  $p\bar{p}$  and  $n\bar{n}$  threshold.

2017 data



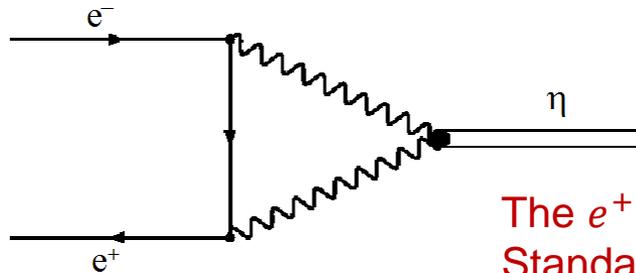
- observed the sharp change of  $e^+e^- \rightarrow p\bar{p}$ ,  $3(\pi^+\pi^-)$ ,  $K^+K^-\pi^+\pi^-$
- width is  $\sim 1$  MeV – consistent with energy resolution
- puzzle – why there is no change in  $e^+e^- \rightarrow 2(\pi^+\pi^-)$ ?

Plan to do comprehensive study of this energy range.



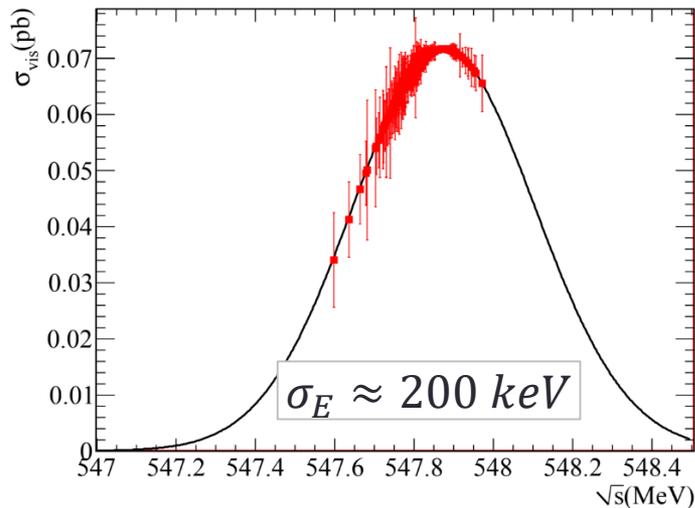
# Search for $e^+ e^- \rightarrow \eta$ @SND

Phys. Rev. D 98,  
052007 (2018)



The process of production of C-even resonance is **rare**, suppressed by  $\alpha^2$  compared with single-photon annihilation. For spin-0 resonances there is additional helicity suppression by a factor of  $(m_e/m_R)^2$ .

The  $e^+ e^- \rightarrow \eta$  cross section is proportional to  $B(\eta \rightarrow e^+ e^-)$ . The Standard Model prediction for this decay is about  $5 \times 10^{-9}$ .



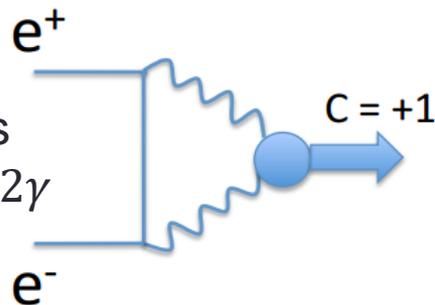
- The  $650 \text{ nb}^{-1}$  data sample was recorded in 2018 at  $\sqrt{s} = m_\eta$ .
- The visible  $\eta$  line shape is determined by the energy spread.
- The beam energy and spread were measured with a special system based on Compton backscattering of laser photons off the electron beam.
- The decay mode  $\eta \rightarrow 3\pi^0$  is used, in which the single photon annihilation background is absent.
- Zero signal events have been selected.

The upper limit  $B(\eta \rightarrow e^+ e^-) < 7 \times 10^{-7}$  at 90% CL has been set, which improves the previous limit of the HADES Collaboration by a factor of 3.

# Search for $e^+e^- \rightarrow \eta'(958)$ at CMD-3

Phys.Lett. B740 (2015) 273-277

C-even resonances  
can be produced via  $2\gamma$



Theory: assuming real  $\gamma$

$$B(\eta' \rightarrow e^+e^-) = 3.7 \cdot 10^{-11}$$

$\gamma$  virtuality and transition form factor can  
enhance it

New limit:

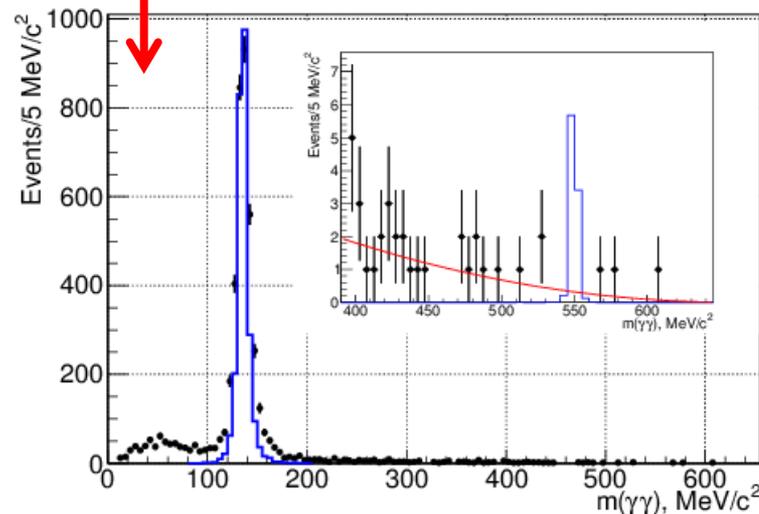
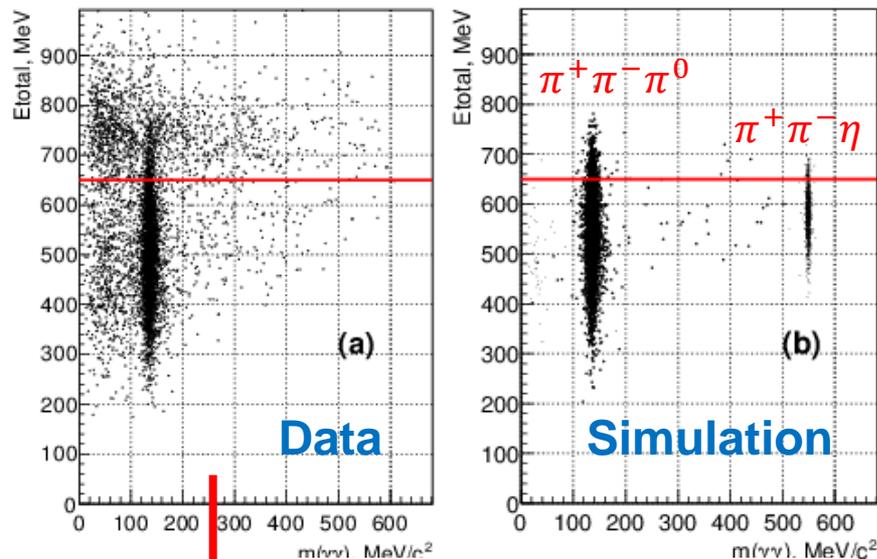
$$B(\eta' \rightarrow e^+e^-) < 5.6 \cdot 10^{-9} \text{ (90\%CL)}$$

**CMD3+SND**

Dedicated data taking at  $\sqrt{s} = M_{\eta'}$

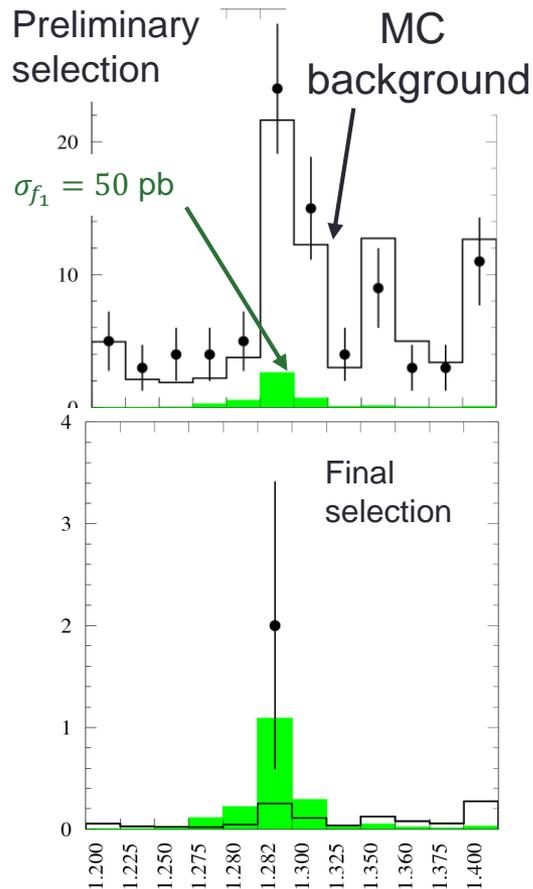
Continuous beam energy monitoring

is crucial



# Search for $e^+ e^- \rightarrow f_1(1285) @ \text{SND}$

The predicted branching fraction  $B(f_1 \rightarrow e^+ e^-) = 3-8 \times 10^{-9}$  [A. S. Rudenko, Phys. Rev. D96, 076004 (2017)] corresponds to the  $f_1$  production cross section of 30-70 pb.



- ❑ The 15 pb<sup>-1</sup> data sample recorded in the energy range  $\sqrt{s} = 1.2-1.4$  GeV is analyzed. About 4 pb<sup>-1</sup> of them were collected in the resonance maximum.
- ❑ The decay mode  $f_1 \rightarrow \eta\pi^0\pi^0 \rightarrow 6\gamma$  is used. This final state is not produced in single photon annihilation.
- ❑ The main background sources are  $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ ,  $e^+e^- \rightarrow \eta\gamma$ , and  $e^+e^- \rightarrow \omega\pi^0\pi^0$ .
- ❑ After applying the selection criteria, two events have been observed at the peak of the  $f_1(1285)$  resonance and zero events beyond the resonance.
- ❑ These two events correspond to

$$\sigma(f_1 \rightarrow e^+ e^-) = 54_{-23}^{+32} \text{ pb},$$

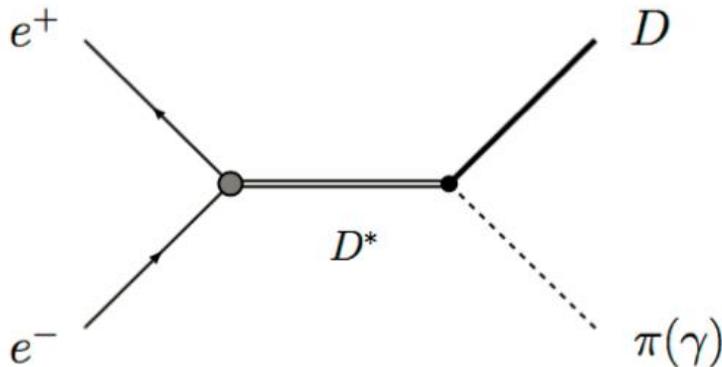
$$B(f_1 \rightarrow e^+ e^-) = 6.1_{-2.6}^{+3.6} \times 10^{-9}.$$

The significance of the  $f_1(1285)$  signal is  $2.7\sigma$ .

# Поиск редкого распада: $e^+ e^- \rightarrow D^{*0}$

Talk by Alexey Petrov (WSU) at ICHEP'16 and JHEP 1511 (2015) 142

$$\sigma(e^+e^- \rightarrow D\pi)_{\sqrt{s} \simeq m_{D^*}} \equiv \sigma_{D^*}(s) = \frac{12\pi}{m_{D^*}^2} \mathcal{B}_{D^* \rightarrow e^+e^-} \mathcal{B}_{D^* \rightarrow D\pi} \frac{m_{D^*}^2 \Gamma_0^2}{(s - m_{D^*}^2)^2 + m_{D^*}^2 \Gamma_0^2}$$



Estimated sensitivity:

$$B_{D^* \rightarrow e^+e^-} \geq \frac{4 \times 10^{-10}}{\varepsilon \int L dt [pb^{-1}]} \times \frac{\sigma_{2E}}{\Gamma_{D^*} [60 keV]}$$

Standard Model:

$$B_{D^* \rightarrow e^+e^-} \approx (0.1 \div 7) \times 10^{-19}$$

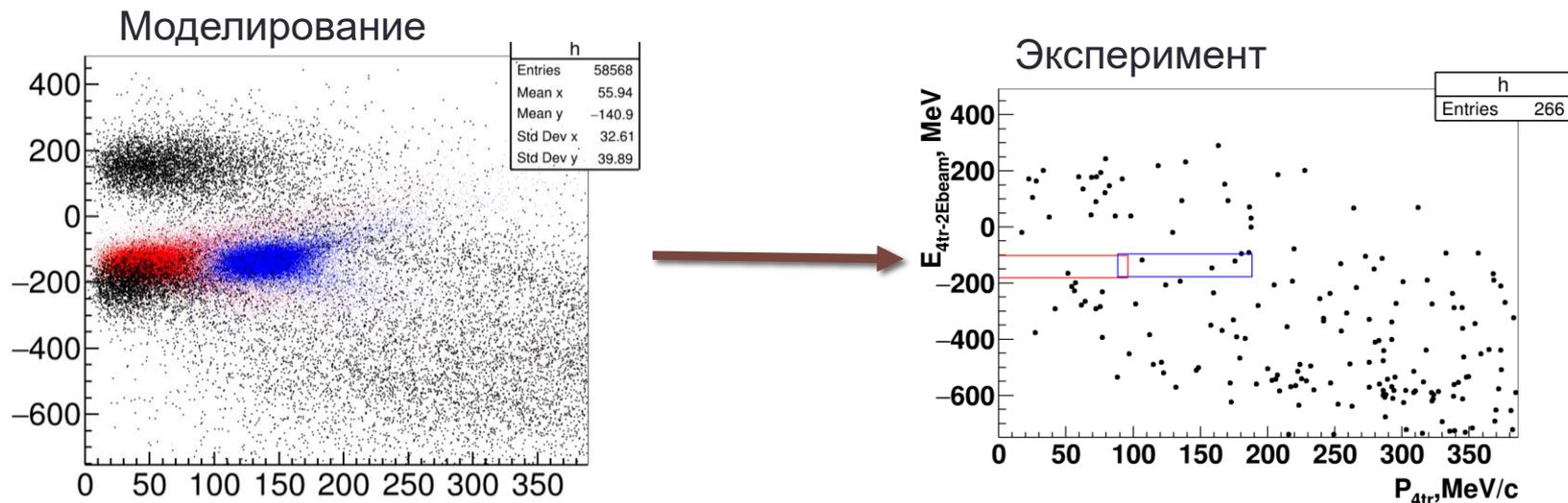
Example of New Physics contribution:

$$B_{D^* \rightarrow e^+e^-}^{Z'} < 2.5 \times 10^{-11}$$

In 2017 CMD-3 collected  $4 pb^{-1}$  at 2007 MeV with  $\sigma_{2E} \approx 2 MeV$

# Поиск редкого распада: $e^+e^- \rightarrow D^{*0}$

Поиск в канале  $e^+e^- \rightarrow D^{*0} \rightarrow D^0\pi^0(\gamma) \rightarrow K^-\pi^+\pi^-\pi^+ + \pi^0(\gamma)$  (~8%)



$$D^{*0} \rightarrow D^0\gamma: \quad B(D^{*0} \rightarrow e^+e^-) < 5.2 \cdot 10^{-6}$$

$$D^{*0} \rightarrow D^0\pi^0: \quad B(D^{*0} \rightarrow e^+e^-) < 1.7 \cdot 10^{-6}$$

Первое измерение. Важно для оценки возможности поиска этого распада на ВЕРС-2 и Супер С-тау фабрике.

Доклад Д.Н.Шемякина на параллельной секции

# Заключение

- ВЭПП-4М и детектор КЕДР продолжают детальное измерение полного сечения рождения адронов  $R(s)$  в области энергий  $\sqrt{s} > 1.8$  ГэВ.
- ВЭПП-2000 и детекторы КМД-3 и СНД продолжают набор статистики в области энергий  $0.32 \leq \sqrt{s} \leq 2.0$  ГэВ. Набрано по 280 пб-1 на детектор. Продолжается измерение эксклюзивных сечений и динамики рождения адронов.
- ВЭПП-2000 предоставляет уникальные возможности по измерению поведения адронных сечений на пороге рождения пары  $N\bar{N}$ .
- В 2020 году ожидается публикация первых результатов по измерению сечения  $e^+e^- \rightarrow \pi^+\pi^-$ , играющего ключевую роль при расчете адронного вклада в  $(g-2)$  мюона.

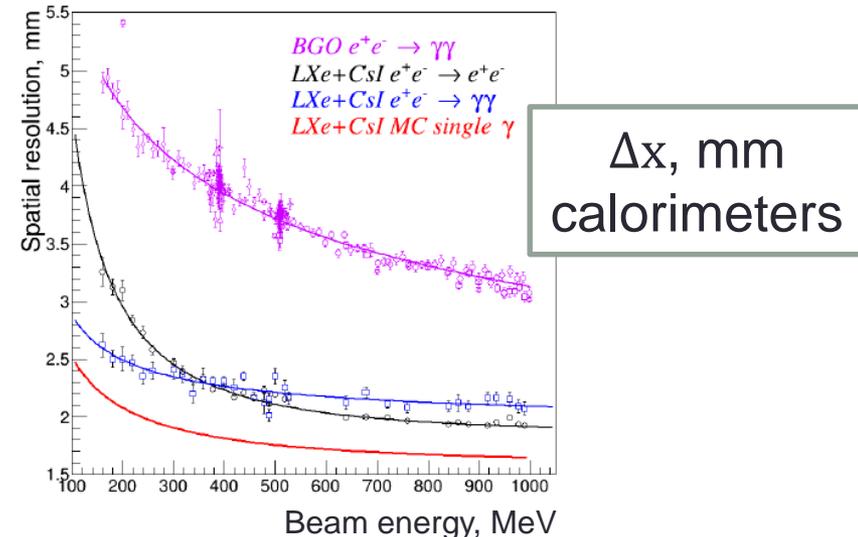
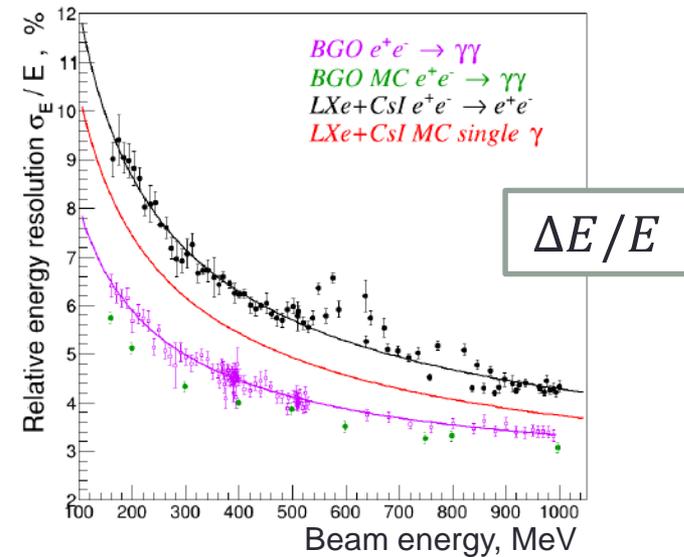
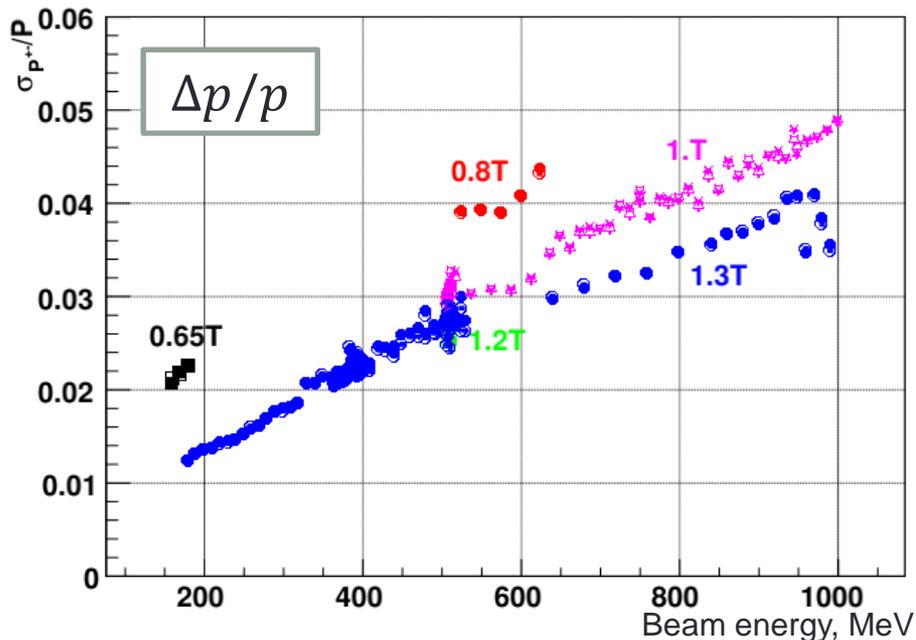
Доклады на параллельных секциях:

Т.В.Димова, В.Н.Жабин, Л.В.Кардапольцев, А.А.Усков, Е.В.Пахтусова

# Backup slides

# CMD-3 Performance

- 1.0-1.3 T magnetic field
- Tracking:  $\sigma_{R\phi} \sim 100 \mu$ ,  $\sigma_z \sim 2 - 3 \text{ mm}$
- Combined EM calorimeter (LXe, CsI, BGO),  $13.5 X_0$ 
  - $\sigma_E/E \sim 3\% - 10\%$
  - $\sigma_\Theta \sim 5 \text{ mrad}$



# Эксклюзивные каналы $e^+e^- \rightarrow$ адроны

- Необходимо измерить сечение  $e^+e^- \rightarrow$  адроны отдельно для каждого конечного состояния (эксклюзивный подход)
- Необходимо измерить не только сечение, но и динамику (понять механизм)

- 2 заряженные частицы

$$e^+e^- \rightarrow \pi^+\pi^-, K^+K^-, K_S K_L, p\bar{p}$$

- 2 заряженные частицы + фотоны

$$e^+e^- \rightarrow \pi^+\pi^-\gamma, \pi^+\pi^-\pi^0, \pi^+\pi^-\eta, K^+K^-\pi^0, K^+K^-\eta, K_S K_L \pi^0, \pi^+\pi^-\pi^0\eta, \pi^+\pi^-\pi^0\pi^0, \pi^+\pi^-\pi^0\pi^0\pi^0, \pi^+\pi^-\pi^0\pi^0\pi^0\pi^0$$

- 4 заряженные частицы

$$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-, K^+K^-\pi^+\pi^-, K_S K^*$$

- 4 заряженные частицы + фотоны

$$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0, \pi^+\pi^-\eta, \pi^+\pi^-\omega, \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0, K^+K^-\eta, K^+K^-\omega$$

- 6 заряженных частиц

$$e^+e^- \rightarrow 3(\pi^+\pi^-), K_S K_S \pi^+\pi^-, K_S K^\pm \pi^\mp \pi^-$$

- Только фотоны

$$e^+e^- \rightarrow \pi^0\gamma, \eta\gamma, \pi^0\pi^0\gamma, \pi^0\eta\gamma, \pi^0\pi^0\pi^0\gamma, \pi^0\pi^0\eta\gamma$$

- Другие конечные состояния

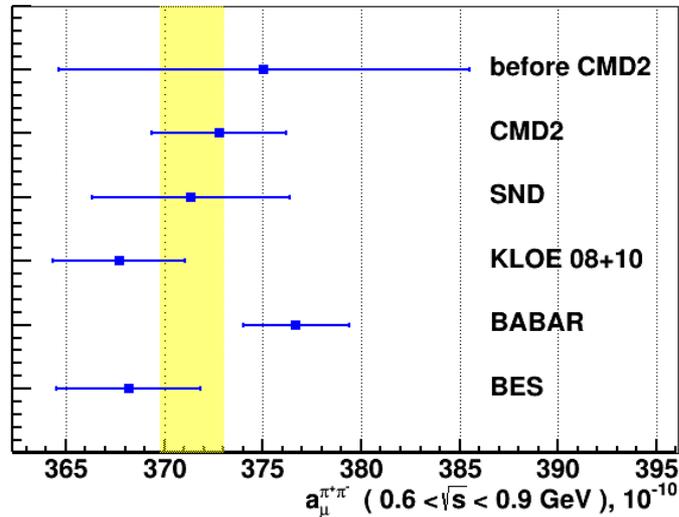
$$e^+e^- \rightarrow n\bar{n}, \pi^0 e^+ e^-, \eta e^+ e^-, 3(\pi^+\pi^-)\pi^0$$

- Редкие распады

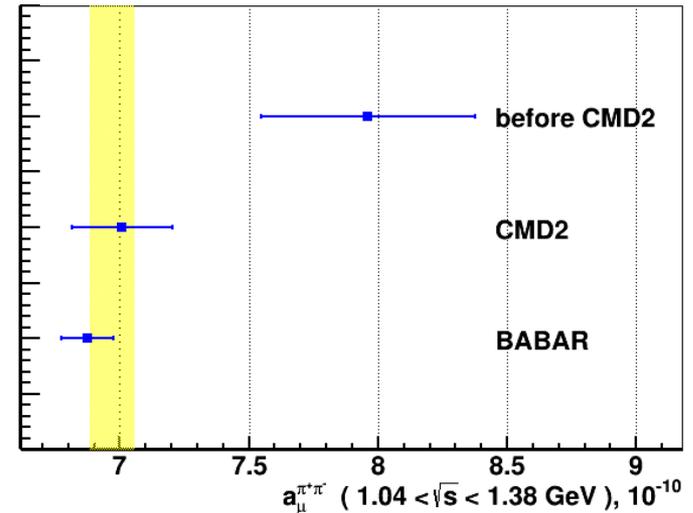
$$e^+e^- \rightarrow \eta, \eta', f_1, D^{0*}$$

# Comparison of contributions to $a_\mu(had; LO)$

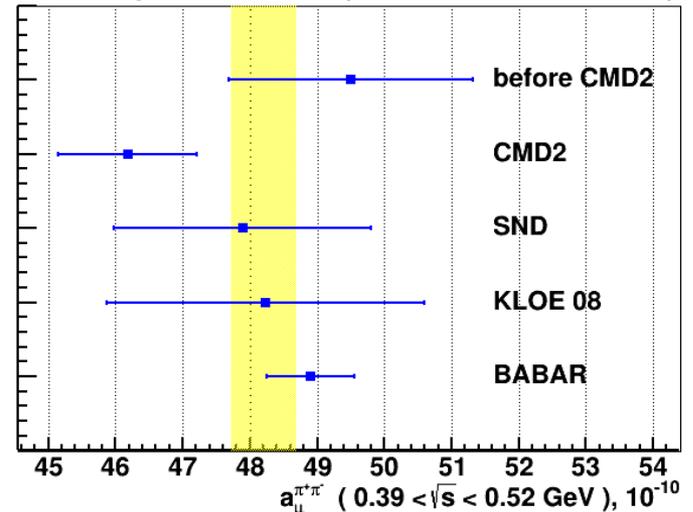
$\rho$  meson (0.6-0.9 GeV)



Above  $\phi$  meson (1.04-1.38 GeV)



Below  $\rho$  meson (0.39-0.52 GeV)



Compared are values of integral:

$$a_\mu(had; LO) = \frac{\alpha^2}{3\pi^2} \int_{E_{min}}^{E_{max}} \frac{ds}{s} \frac{\sigma^0(e^+e^- \rightarrow \pi^+\pi^-)}{4\pi\alpha^2/3s} K(s)$$

calculated in different energy ranges and with various data sets