МОДИФИКАЦИЯ СВОЙСТВ АДРОНОВ В ЯДЕРНОЙ МАТЕРИИ

М. И. Кривоученко

ИТЭФ, МФТИ, БЛТФ ОИЯИ

Семинар ИФВЭ
Протвино, 20 октября 2015

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Z. Phys. A	**1**
PRD	**1**

$SU(2)$ цветовая сверхпроводимость

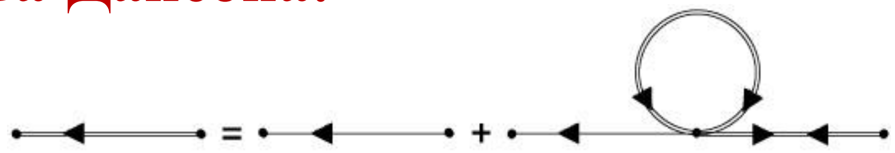
- L. A. Kondratyuk, M. M. Giannini, M. I. K.,
  Phys. Lett. B 269, 139 (1991);
- L. A. Kondratyuk and M. I. K., Z. Phys. A 344, 99 (1992).

Эфф. лагранжиан в среде (версия модели НИЛ):

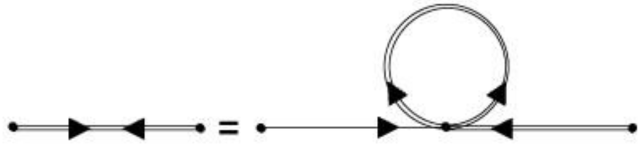
$$L_{eff} = \bar{\psi}(i\hat{\nabla} + \hat{\mu} - m)\psi - \frac{1}{2} g^2 (\bar{\psi}\gamma_\sigma t^a \psi)(\bar{\psi}\gamma^\sigma t^a \psi),$$

Система уравнений Горькова-Дайсона:

Функция Грина:



Аномальная функция Грина:



Аномальная функция Грина:

$$iF(1,2) = < N \,|\, T(\psi(1)\psi(2)) \,|\, N+2 >,$$

$$i\overleftarrow{F}(1,2) = < N+2 \,|\, T(\overleftarrow{\psi}(1)\overleftarrow{\psi}(2)) \,|\, N >,$$

$$N_f = 1 \Rightarrow J = 1$$

$\forall \alpha,\beta,\gamma \ \langle 11 | D^1_{1m}(\alpha,\beta,\gamma) \neq \delta_{m0} \langle 10 |$ $\longrightarrow$ **2 решения:**

1. Спаривание в канале $J_3 = 0$

2. Спаривание в канале $J_3 = \pm 1$

Найдены:

1. функции Грина (нормальная и аномальная)

2. щель в спектре возбуждений, закон дисперсии

3. распределение кварков по импульсам

4. спиновая плотность

5. температура фазового перехода

Щель в спектре возбуждений в канале $J_3 = 0$

$$\Delta^2 = g^4\left((\boldsymbol{a}^*\boldsymbol{a}) - (\boldsymbol{a}^*\boldsymbol{n})(\boldsymbol{a}\boldsymbol{n})\frac{-m^2+\mu^2+g^4(\boldsymbol{a}^*\boldsymbol{n})(\boldsymbol{a}\boldsymbol{n})}{\mu^2+g^4(\boldsymbol{a}^*\boldsymbol{n})(\boldsymbol{a}\boldsymbol{n})}\right) \geq 0,$$

$$\Delta = \Delta(\mathbf{p}) \geq 0$$

$\Delta = 0$ при $m = 0$, когда $\mathbf{n} \parallel \mathbf{a}$

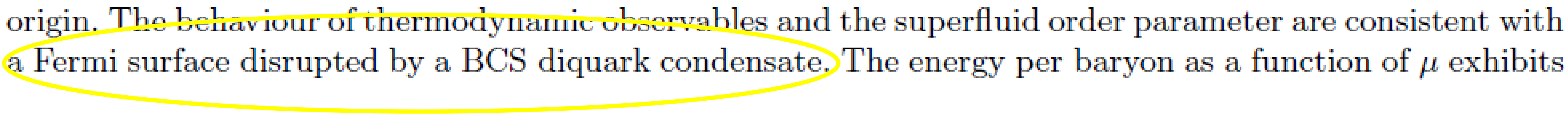
n = p/|p|

Уравнение щели:

$$\bar{F}(0) = \int \frac{d^4p}{(2\pi)^4}\bar{F}(p), \qquad \Rightarrow \qquad g^4(\boldsymbol{a}^*\boldsymbol{a}) \propto \exp\left(-\frac{8\pi^2}{(6g^2)\mu^2 v_F(1-v_F{}^2/3)}\right),$$

SU(2) цветовая сверхпроводимость на решетках:

S. Hands, S. Kim, J.-I. Skullerud, Eur. Phys. J. C 48, 193 (2006).



origin. The behaviour of thermodynamic observables and the superfluid order parameter are consistent with a Fermi surface disrupted by a BCS diquark condensate. The energy per baryon as a function of μ exhibits

SU(2) цветовая кварковая материя в модели ПНИЛ:

PHYSICAL REVIEW D **80**, 074035 (2009)

Two-color quark matter: $\mathrm{U}(1)_\mathrm{A}$ restoration, superfluidity, and quarkyonic phase

Tomáš Brauner,[1,*,†] Kenji Fukushima,[2] and Yoshimasa Hidaka[3]
[1] *Institut für Theoretische Physik, Goethe-Universität, Max-von-Laue-Straße 1, D-60438 Frankfurt am Main, Germany*
[2] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*
[3] *Department of Physics, Kyoto University, Kyoto 606-8502, Japan*

(Received 4 August 2009; published 29 October 2009)

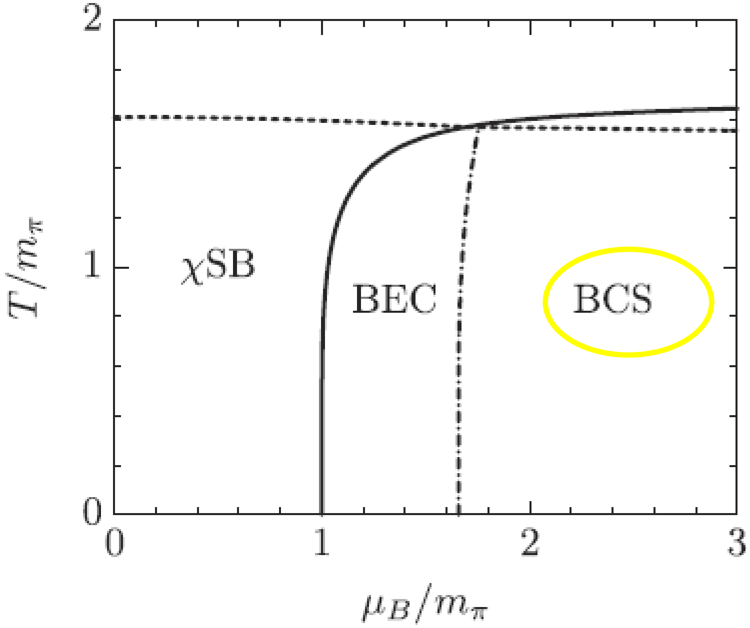
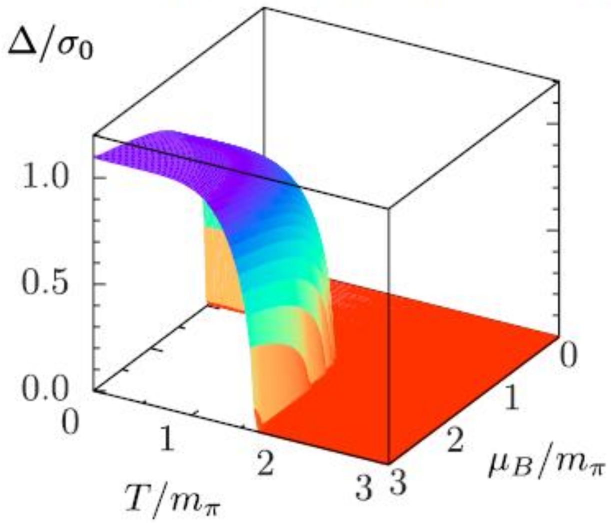
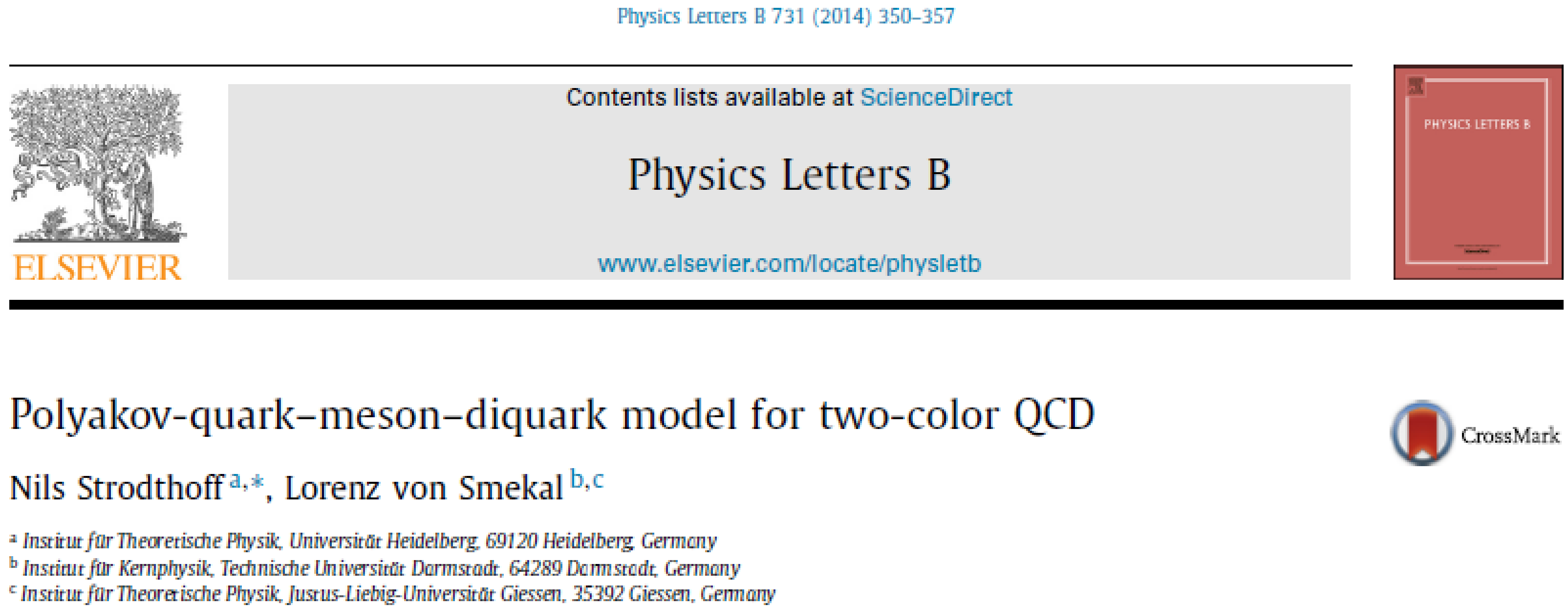


FIG. 4. Conventional presentation of the phase diagram of two-color QCD from the PNJL model in the $\mu_B - T$ plane.



Polyakov-quark–meson–diquark (PQMD) model



Physics Letters B 731 (2014) 350–357

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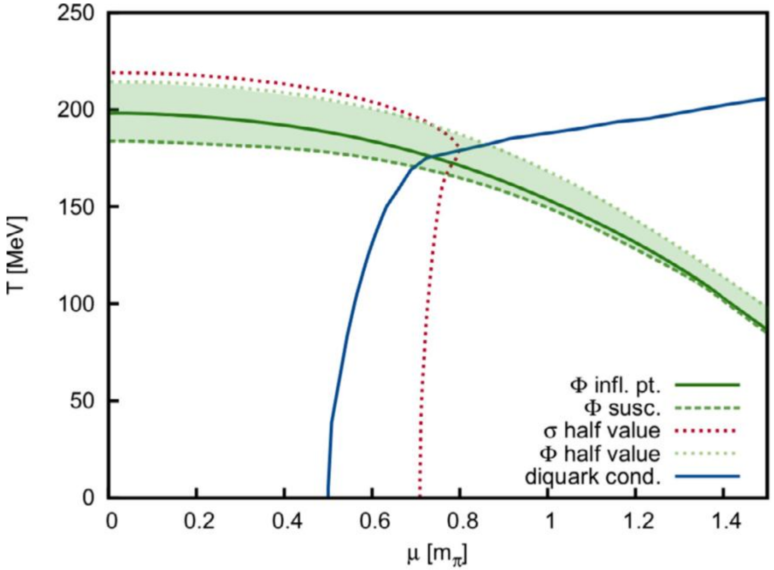
Polyakov-quark–meson–diquark model for two-color QCD

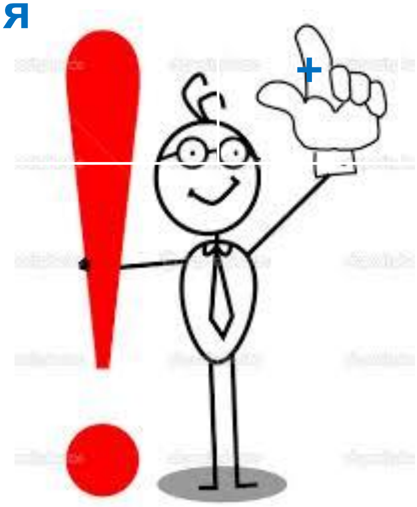
Nils Strodthoff [a,*], Lorenz von Smekal [b,c]

[a] Institut für Theoretische Physik, Universität Heidelberg, 69120 Heidelberg, Germany
[b] Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany
[c] Institut für Theoretische Physik, Justus-Liebig-Universität Giessen, 35392 Giessen, Germany



СВОЙСТВА SU(2)$_C$ КВАРКОВОЙ МАТЕРИИ ПРИ Т = 0 - ФАЗА БКШ

	НИЛ (1991)	Решетки (2006)	ПНИЛ (2009)	PQMD (2014)
Ферми-сфера кварков определяет EoS: энергию и давление *vs*. плотность барионного числа	+	+	+	
Спаривание, щель в спектре, сверхпроводимость	+	+	+	+
Бесцветные элементарные возбуждения над ферми-сферой - фаза конфайнмента		+	+	+
Цветные элементарные возбуждения над ферми-сферой - фаза деконфайнмента	+			+



Проекционная теория БКШ

Projected BCS for **U(1)**: B. F. Bayman, Nucl. Phys. 15, 33 (1960).

Projected BCS for **SU(2)**: A. A. Raduta and E. Moya de Guerra, Ann. Phys. (NY) 284, 134 (2000).

Projected BCS for **SU(3)**$_c$: P. Amore et al., Phys. Rev. D 65, 074005 (2002).

EXACT RESULTS IN THEORY OF SUPERCONDUCTIVITY OF FINITE FERMI-SYSTEMS

- A. A. Raduta, M.I.K., Amand Faessler, PRC85, 054314 (2012)

PARTICLE NUMBER PROJECTION: BCS -> PBCS/FBCS

Particle number projection operator $P_N^2 = P_N$

$$P_N = \int_0^{2\pi} \frac{d\varphi}{2\pi} e^{i(\hat{N}-N)\varphi}$$

Projected BCS wave function:

$$|BCS, N\rangle \equiv C_N P_N |BCS\rangle$$

We define $$Q(N) = C_N^{-2}$$

and get recursion:

$$Q(N) = \sum_{\beta} Q^{\beta}(N),$$

$$Q^{\beta}(N) = \frac{\Omega_{\beta}}{N} \sum_{n=1}^{N/2} (-)^{n+1} \tan^{2n}(\rho_{\beta}/2) Q(N-2n).$$

with the initial value

$$Q(0) = \prod_{\alpha} [\cos^2(\rho_{\alpha}/2)]^{2j_{\alpha}+1}.$$

- Matrix elements in PBCS/FBCS can be calculated analytically in terms of single function Q(N)
- The one-dimensional recursion for Q(N) was presented

Direct applications: Nuclear structure calculations

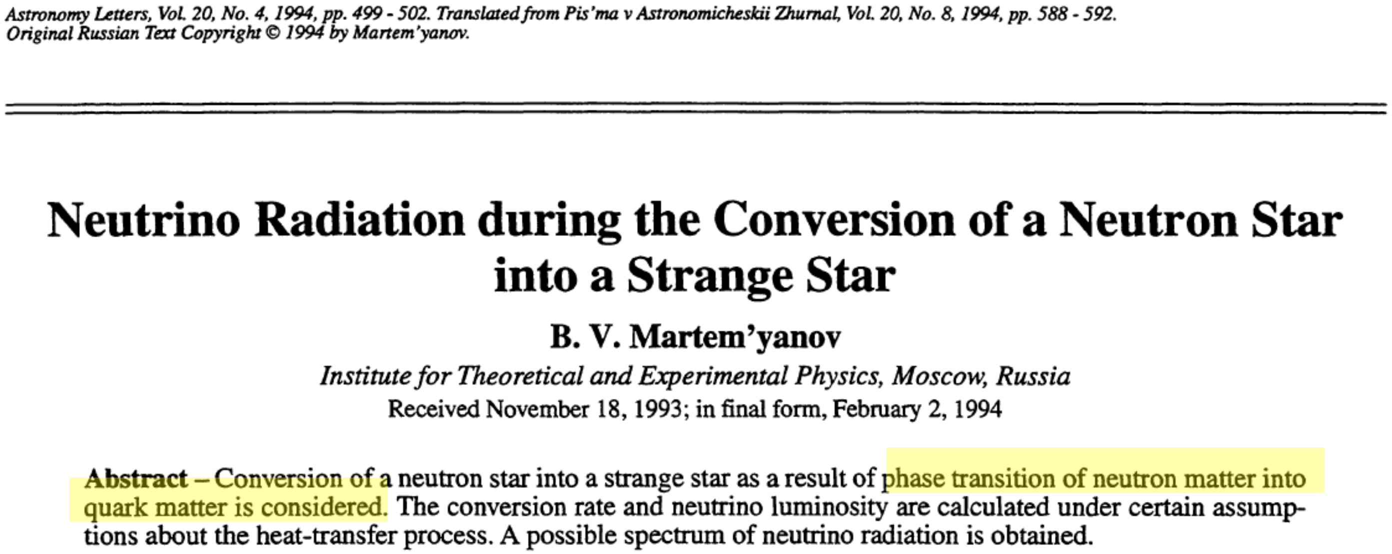
Possible applications:

Extending to non-abelian-symmetry projected BCS

Discovery potential of cold quark matter:

neutrino bursts from formation of quark stars

Длинная мягкая нейтринная вспышка



Astronomy Letters, Vol. 20, No. 4, 1994, pp. 499 - 502. Translated from Pis'ma v Astronomicheskii Zhurnal, Vol. 20, No. 8, 1994, pp. 588 - 592.
Original Russian Text Copyright © 1994 by Martem'yanov.

Neutrino Radiation during the Conversion of a Neutron Star into a Strange Star

B. V. Martem'yanov
Institute for Theoretical and Experimental Physics, Moscow, Russia

Received November 18, 1993; in final form, February 2, 1994

Abstract – Conversion of a neutron star into a strange star as a result of phase transition of neutron matter into quark matter is considered. The conversion rate and neutrino luminosity are calculated under certain assumptions about the heat-transfer process. A possible spectrum of neutrino radiation is obtained.

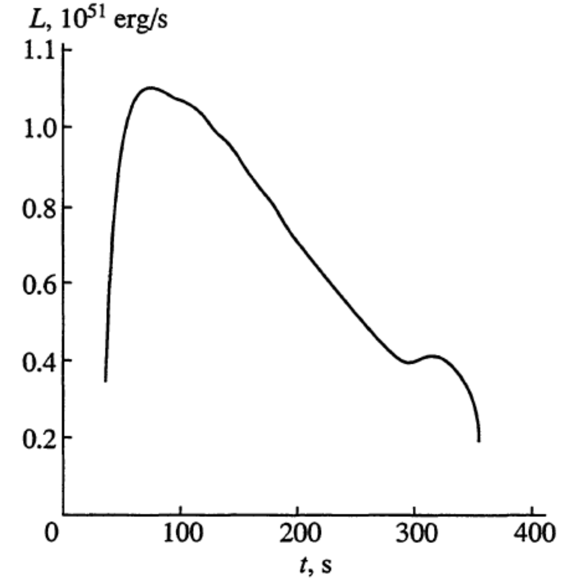
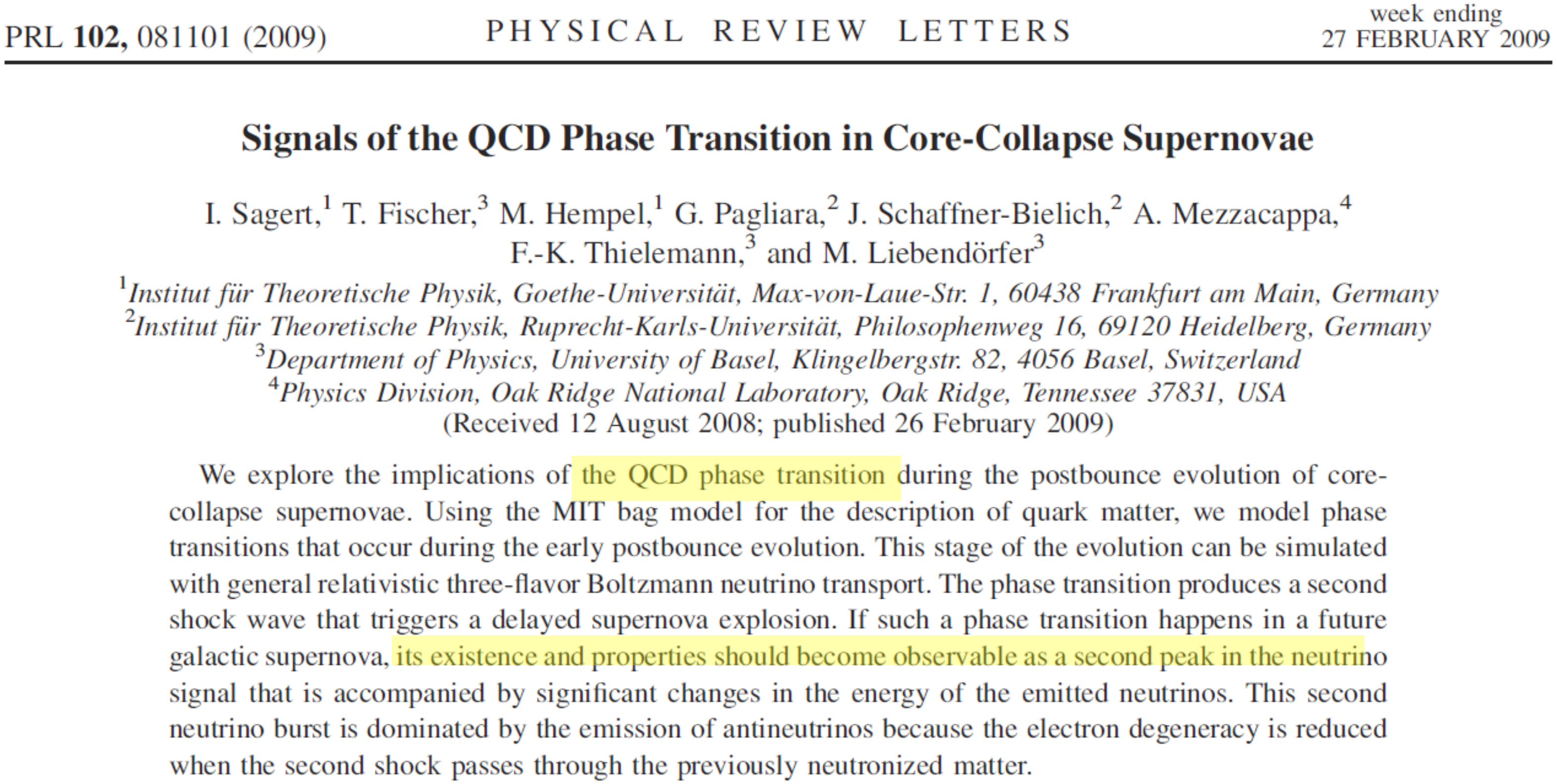


Fig. 7. Neutrino luminosity as a function of time (by the clock of a remote observer).

Длительность вспышки - минуты
vs. 10 секунд у сверхновой
Средняя энергия нейтрино 3-5 МэВ
vs. 20 МэВ у сверхновой
Полная энергия –
сравнима со сверхновой

Узкий второй пик в нейтринной вспышке от сверхновой



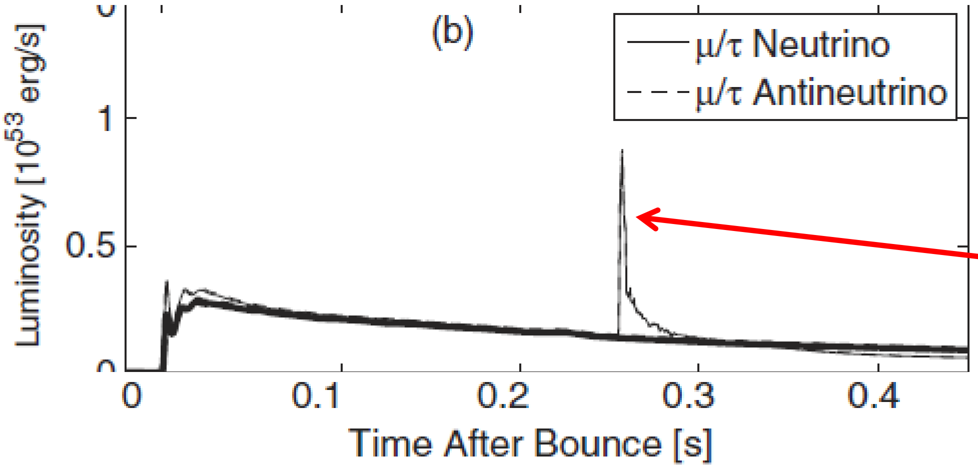
PRL **102,** 081101 (2009) PHYSICAL REVIEW LETTERS week ending 27 FEBRUARY 2009

Signals of the QCD Phase Transition in Core-Collapse Supernovae

I. Sagert,[1] T. Fischer,[3] M. Hempel,[1] G. Pagliara,[2] J. Schaffner-Bielich,[2] A. Mezzacappa,[4]
F.-K. Thielemann,[3] and M. Liebendörfer[3]
[1]*Institut für Theoretische Physik, Goethe-Universität, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany*
[2]*Institut für Theoretische Physik, Ruprecht-Karls-Universität, Philosophenweg 16, 69120 Heidelberg, Germany*
[3]*Department of Physics, University of Basel, Klingelbergstr. 82, 4056 Basel, Switzerland*
[4]*Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

(Received 12 August 2008; published 26 February 2009)

We explore the implications of the QCD phase transition during the postbounce evolution of core-collapse supernovae. Using the MIT bag model for the description of quark matter, we model phase transitions that occur during the early postbounce evolution. This stage of the evolution can be simulated with general relativistic three-flavor Boltzmann neutrino transport. The phase transition produces a second shock wave that triggers a delayed supernova explosion. If such a phase transition happens in a future galactic supernova, its existence and properties should become observable as a second peak in the neutrino signal that is accompanied by significant changes in the energy of the emitted neutrinos. This second neutrino burst is dominated by the emission of antineutrinos because the electron degeneracy is reduced when the second shock passes through the previously neutronized matter.



Δt ~ 10 миллисекунд

Бозе конденсация дибарионов в ядерной материи

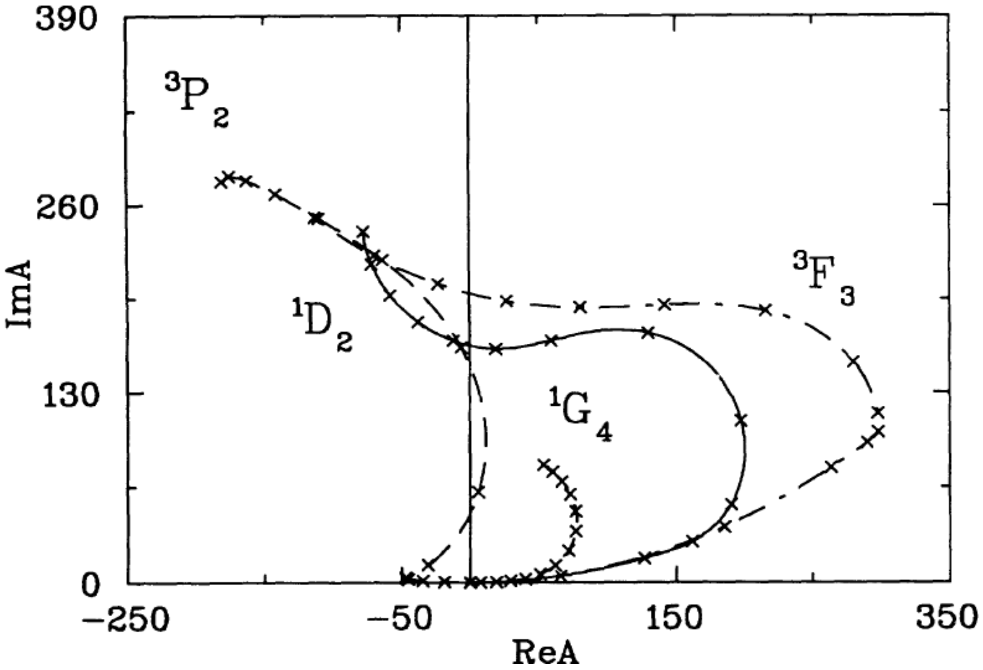
- M.I.K., Phys. Rev. C 82, 018201 (2010);
- A. Faessler, A. J. Buchmann, M.I.K., B. V. Martemyanov, J. Phys. G 24, 791 (1998);
- A. Faessler, A. J. Buchmann and M.I.K., Phys. Rev. C 57, 1458 (1998);
- A. Faessler, A. J. Buchmann and M.I.K., Phys. Rev. C 56, 1576 (1997);
- A. J. Buchmann, A. Faessler and M.I.K., Annals Phys. 254, 109 (1997);
- A. Faessler, A. J. Buchmann, M.I.K., B. V. Martemyanov Phys. Lett. B 391, 255 (1997).

Экспериментальный статус дибарионов

1 . R. L. Jaffe, PRL 38, 195 (1977). H-dibaryon
(экспериментально не подтвержден)

2. С конца 1980-х PDG перестает публиковать обзоры по дибарионам

3. R. A. Arndt et al., PRD 45, 3995 (1992);
R. A. Arndt et al., PRD 50, 2731 (1994).



PWA:
упругое NN рассеяние

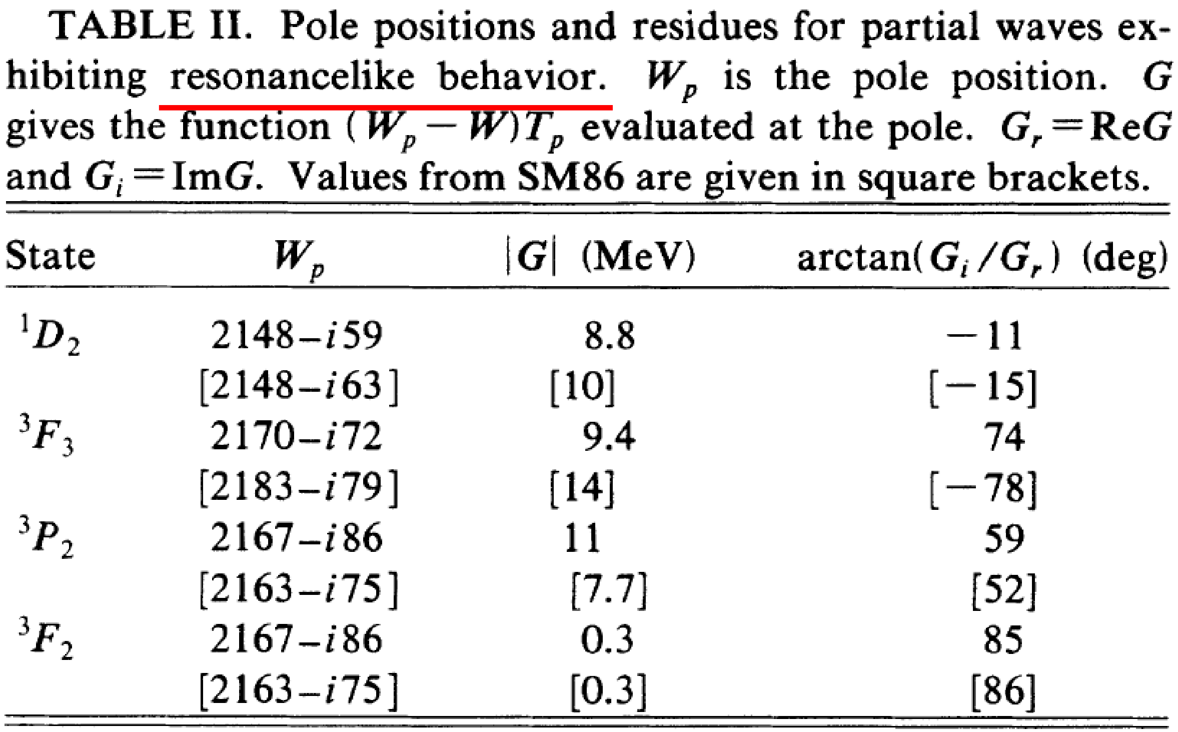


TABLE II. Pole positions and residues for partial waves exhibiting resonancelike behavior. W_p is the pole position. G gives the function $(W_p - W)T_p$ evaluated at the pole. $G_r = \mathrm{Re}G$ and $G_i = \mathrm{Im}G$. Values from SM86 are given in square brackets.

State	W_p	$\lvert G\rvert$ (MeV)	$\arctan(G_i/G_r)$ (deg)
$^1D_2$	$2148-i59$	8.8	-11
	$[2148-i63]$	[10]	$[-15]$
$^3F_3$	$2170-i72$	9.4	74
	$[2183-i79]$	[14]	$[-78]$
$^3P_2$	$2167-i86$	11	59
	$[2163-i75]$	[7.7]	[52]
$^3F_2$	$2167-i86$	0.3	85
	$[2163-i75]$	[0.3]	[86]

$^1D_2$ also is seen in

$pp(^1D_2) \leftrightarrow \pi^+ d(^3P_2)$

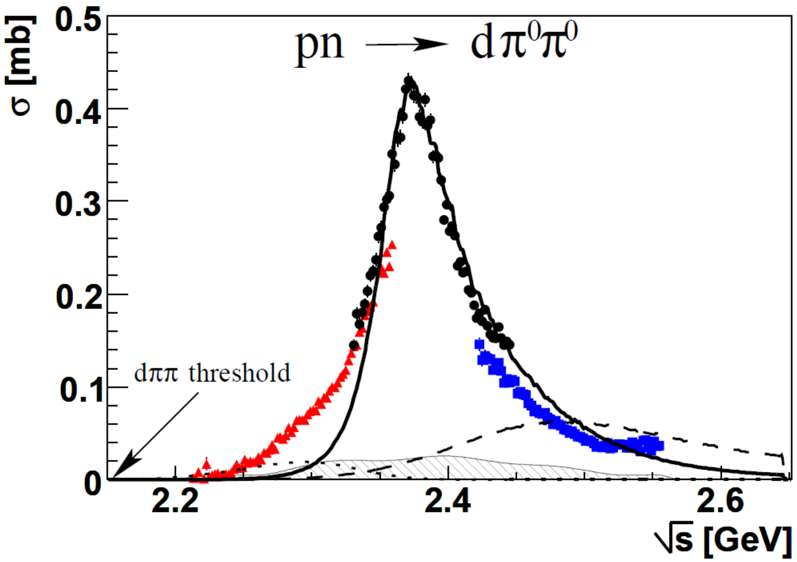
(NΔ)

4. Б. В. Мартемьянов и М. Г. Щепкин, Письма в ЖЭТФ 53, 132 (1991);
R. Bilger, H. A. Clement, M. G. Schepkin, PRL 71, 42 (1993);

d’(2063) $IJ^P = 00^-$ (экспериментально не подтвержден)

5. P. Adlarson et al. (WASA@COSY), PRL 106, 242302 (2011).

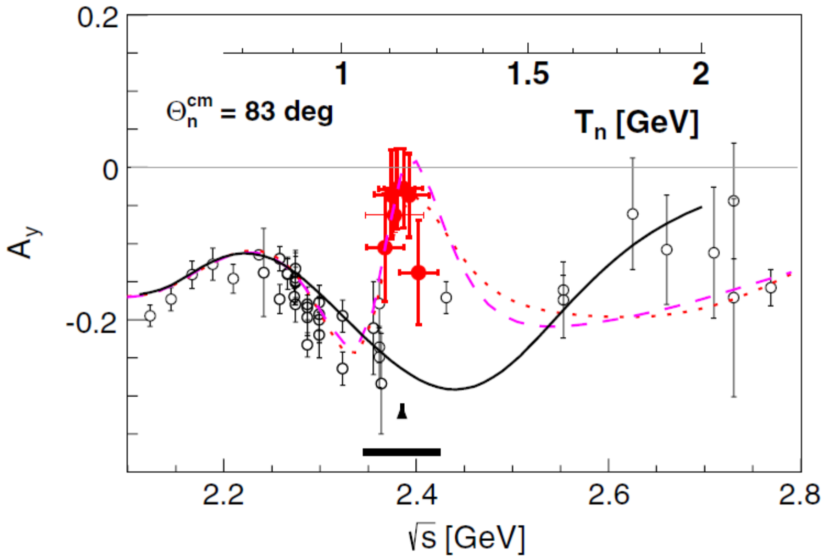
$pd \to d\pi^0\pi^0 + p_s$ ➡ $d^*(2370)\ \Gamma = 70$ MeV, $IJ^P = 03^+$ $(\Delta\Delta)$



Also seen in: $d\vec{p} \to pn + p_s$

P. Adlarson et al.,
PRL 112, 202301 (2014)

Also seen in: $pd \to d\pi^+\pi^- + p_s$



ДИБАРИОНЫ КАК РЕЗОНАНСЫ И КАК ПРИМИТИВЫ

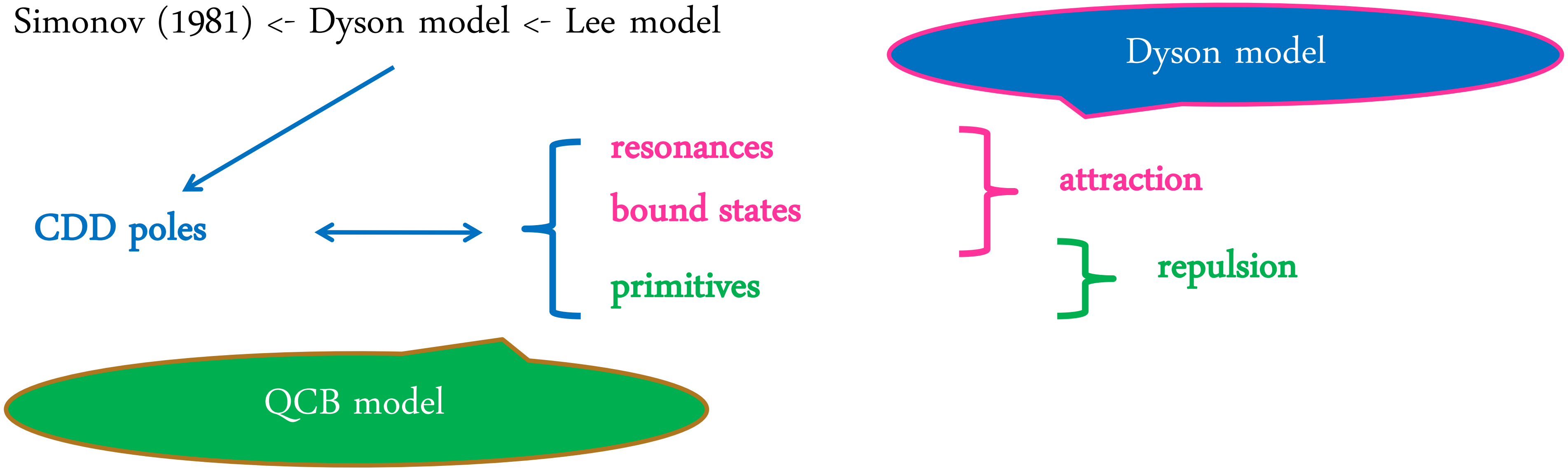
P matrix method for identifying exotic multiquark states with primitives that appear as poles of the P matrix rather than the S matrix:

Jaffe and Low (1979)

A dynamical QCB model of the P matrix was developed and applied to the description of nucleon-nucleon scattering

Im D(s) > 0

Simonov (1981) <- Dyson model <- Lee model



Dyson model

CDD poles ⟷

resonances

bound states

primitives

attraction

repulsion

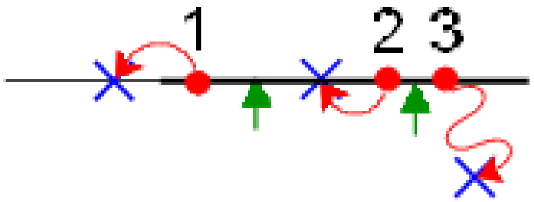
QCB model

Im D(s) ≥ 0

CDD poles correspond to **resonances, bound states**, **and primitives**

Связь полюсов P матрицы с полюсами Кастильехо-Далица-Дайсона

D-FUNCTION ZEROS IN THE COMPLEX *s*-PLANE

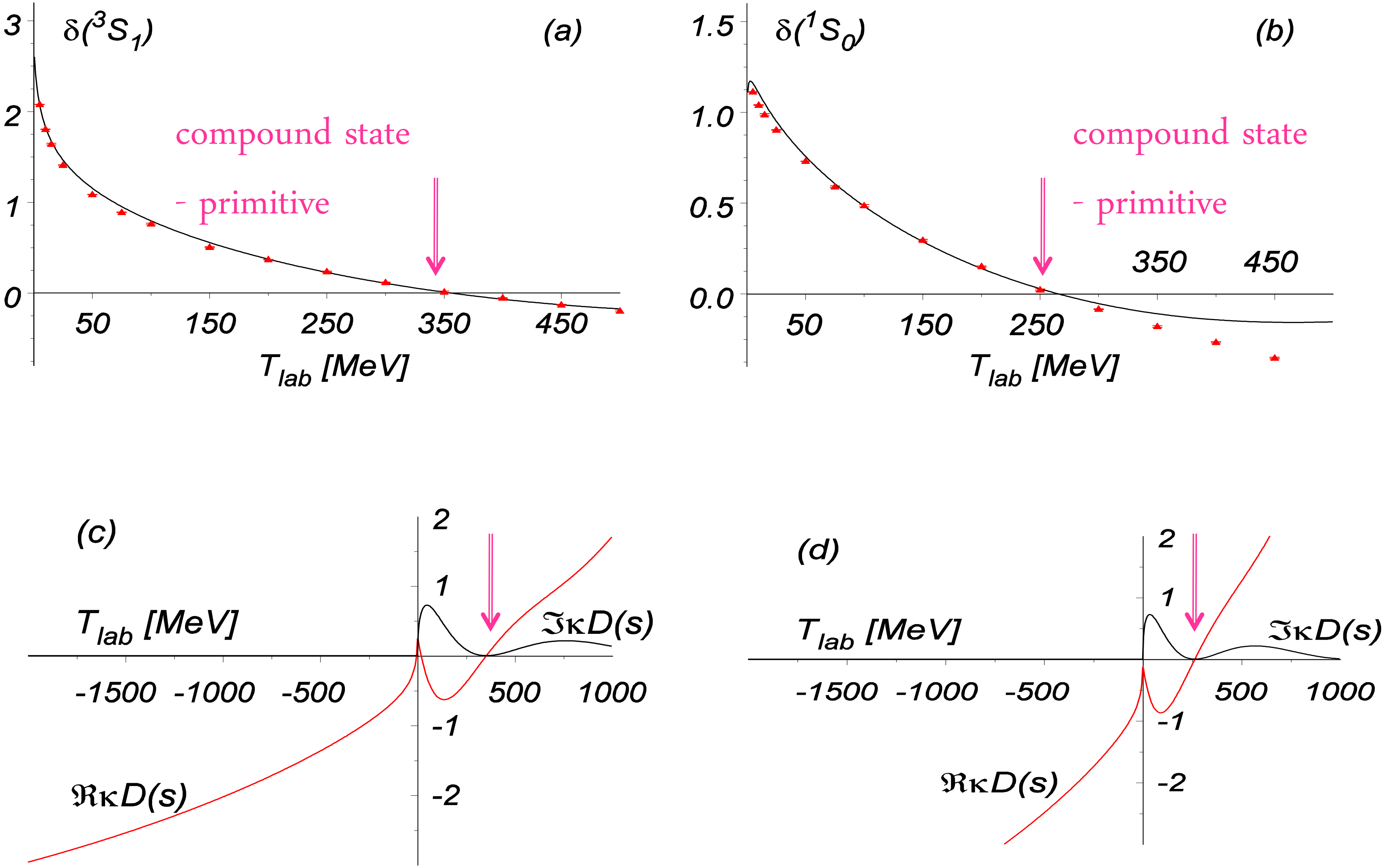


Compound states 1, 2, and 3 move to new positions:

1-bound state, 2-primitive, and 3- resonance.

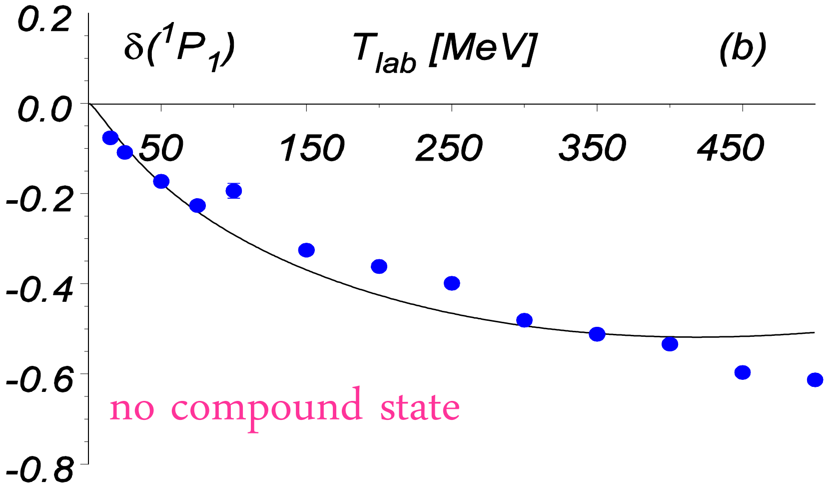
A pair of the CDD poles that squeezes compound state #2 of the primitive type is shown by arrows.

NN scattering S-wave phase shifts and the D functions vs. the proton kinetic energy

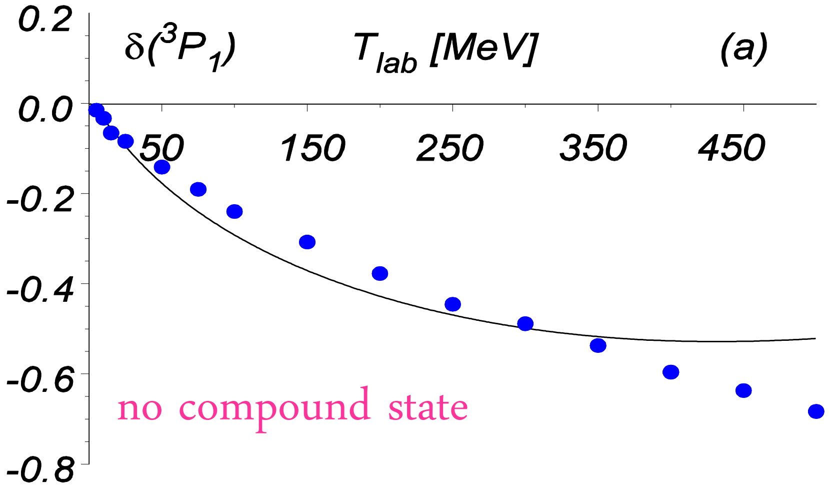


M.I.K. PRC 82, 018201 (2010)

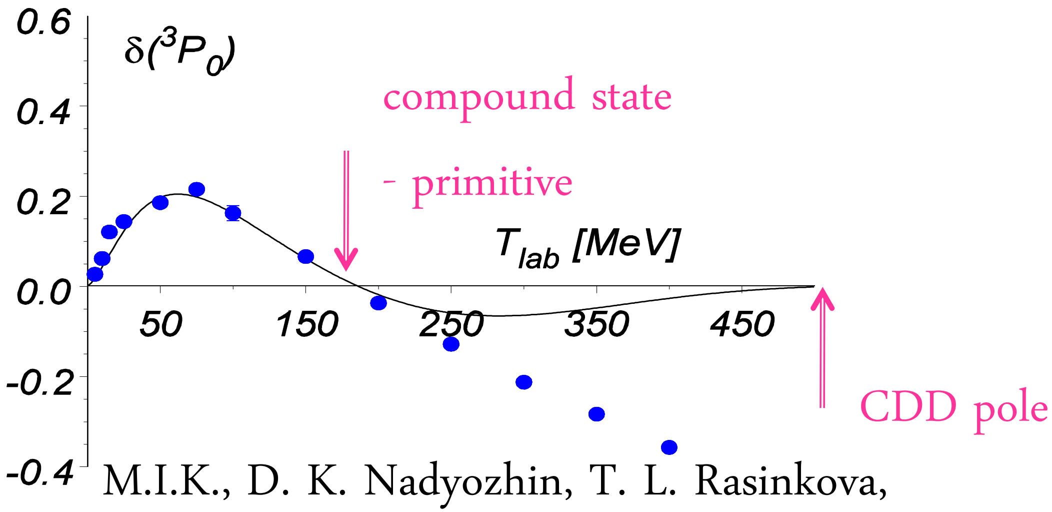
NN scattering P-wave phase shifts
vs. the proton kinetic energy



no compound state



no compound state



compound state

- primitive

CDD pole

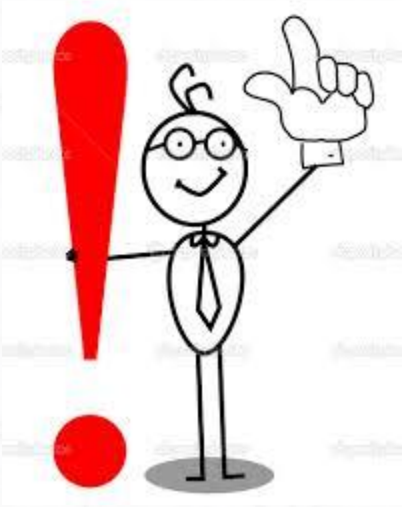
M.I.K., D. K. Nadyozhin, T. L. Rasinkova,

Yu. A. Simonov, M. A. Trusov, A. V. Yudin, PAN 74, 371 (2011)

CDD poles are related to:

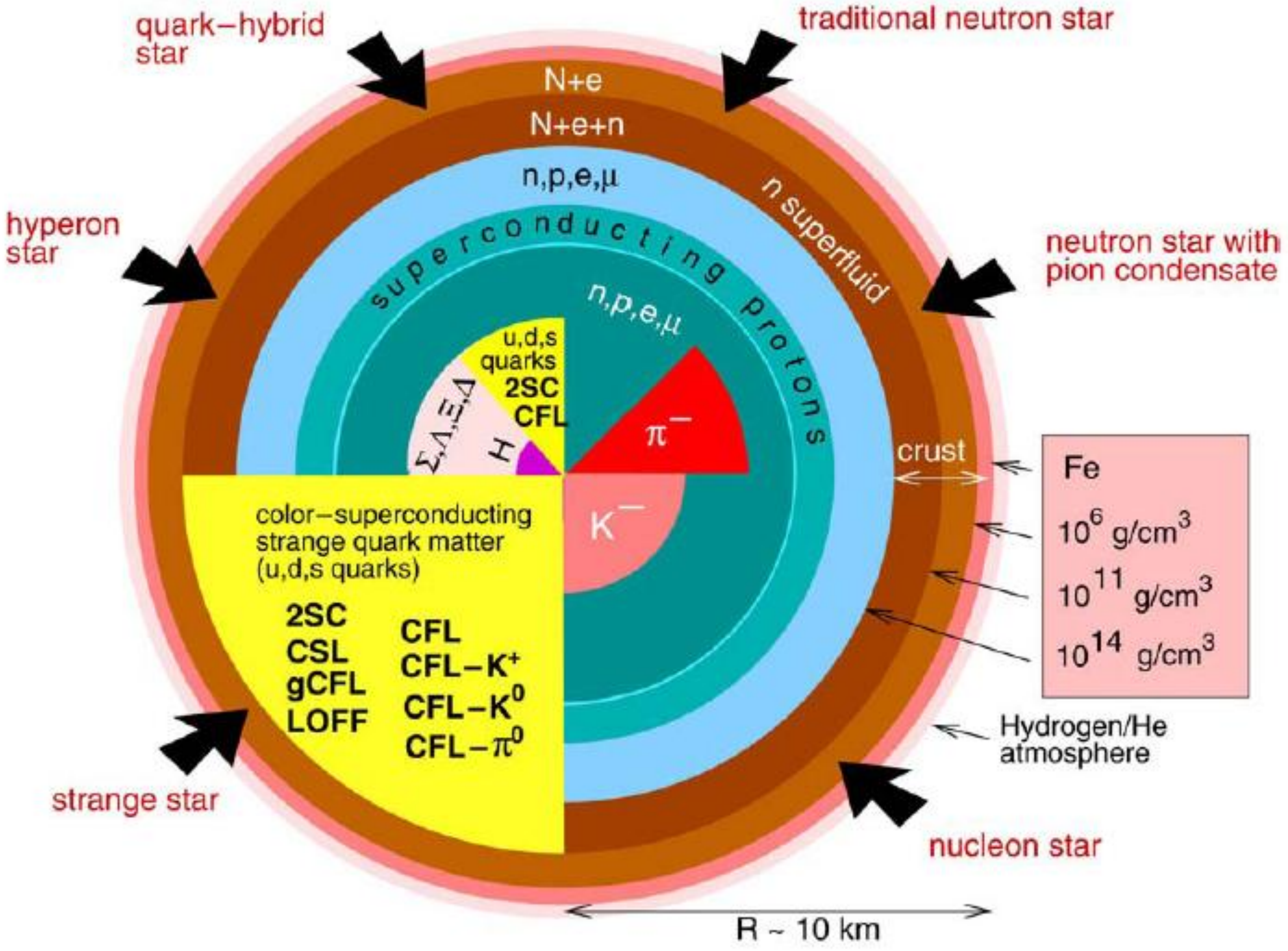
DYSON ⟹ **bound states, resonances**

+ primitives. ⟸ M.I.K. (2010)



Possible global structures of neutron stars:

196 *F. Weber / Progress in Particle and Nuclear Physics 54 (2005) 193–288*

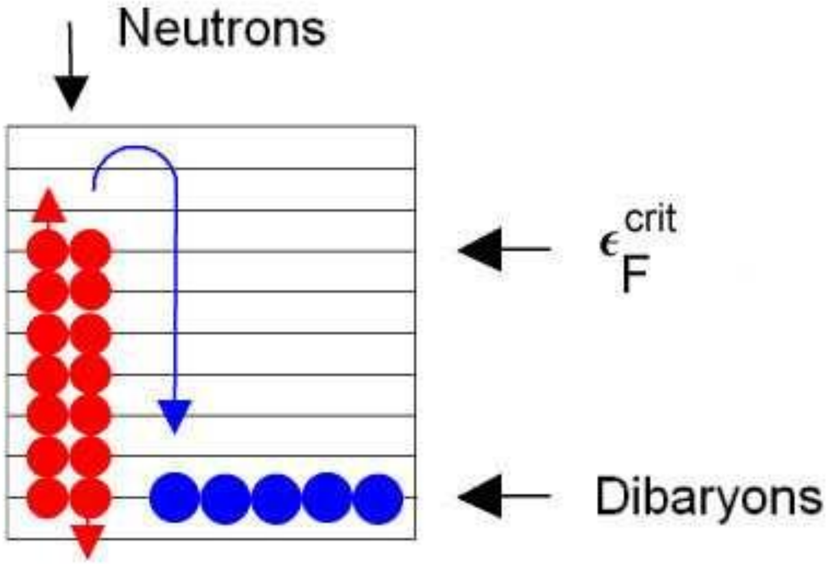


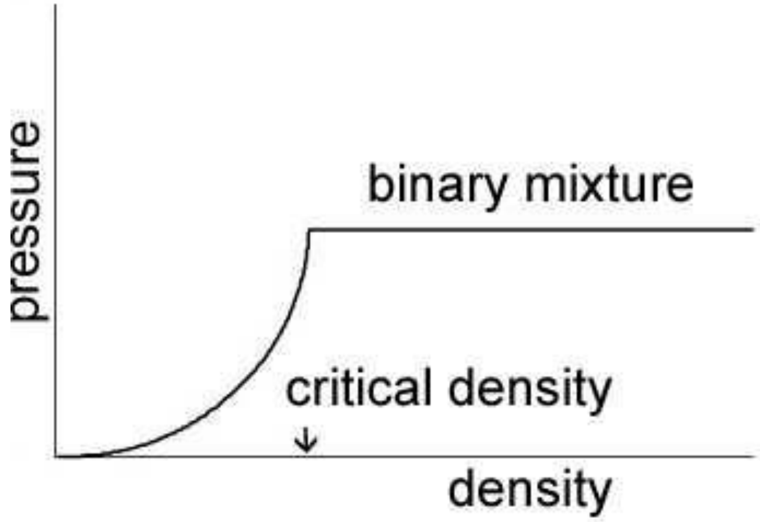
Current models for EoS & neutron stars:

like in the particle physics in 1960's:

a lot of data & THERE IS NO "standard model"

Бозе конденсация дибарионов





Бозе конденсация дибарионов в ядерной материи
А. М. Балдин и др., Докл. Акад. Наук СССР 279, 602 (1984).

Схематический вид уравнения состояния ядерной материи с примесью дибарионов в приближении идеального газа М.И.К., Письма в ЖЭТФ 46, 5 (1987)

Точно решаемая 1D модель Бозе конденсации двухфермионных резонансов в ферми-жидкости

$$\left(\sum_i \frac{\hat{p}_i^2}{2m} + \sum_{i<j} V(x_i - x_j)\right)\Psi(x_1,\dots,x_N) = E\Psi(x_1,\dots,x_N)$$

$V(x) \to \infty$ при $|x| < a$ & $a \to 0$, периодические граничные условия

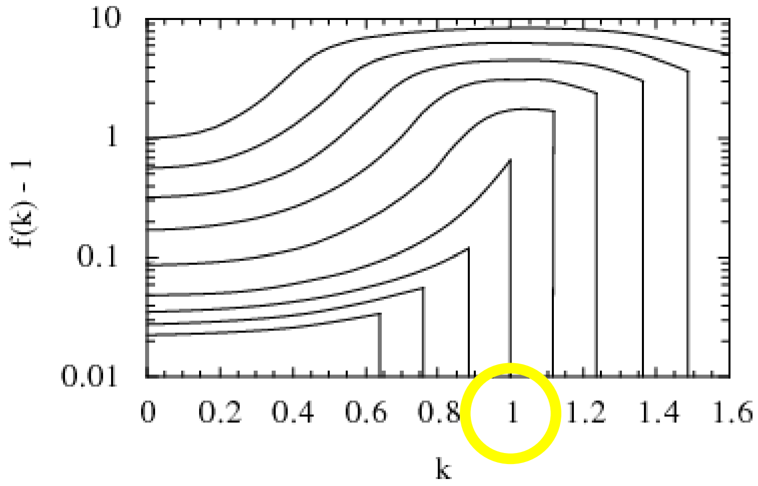
фаза рассеяния $\delta_+(k)$: $\exp(2i\delta_+(k)) = \dfrac{(k+k_0)(k-k_0^*)}{(k+k_0^*)(k-k_0)}$,

БЕТЕ АНЗАТЦ ⇒ правило квантования Бора-Зоммерфельда:

$$k_j L + \sum_{l=1}^{N} 2\delta_-\left(\frac{k_j - k_l}{2}\right) = 2\pi n_j.$$

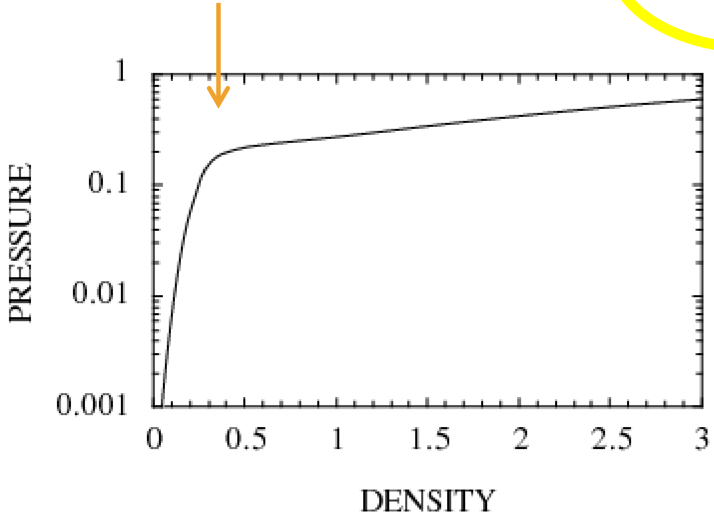
Термодинамический предел: $\sum \to \int \dfrac{L\,dk}{2\pi} f(k)$, $f(k) = 2\pi L^{-1} dn/dk$

$$f(k) = 1 + \int_{-p_F}^{p_F} \frac{dk'}{2\pi} f(k')\delta_+'\left(\frac{k-k'}{2}\right)$$



Функция распределения фермионов по импульсам $f(k)$ для отдельных значений ферми-импульса k (= k_F).

критическая плотность n = 0.36



Давление как функция плотности.

В КАЧЕСТВЕННОМ СОГЛАСИИ С МОДЕЛЬЮ ИДЕАЛЬНОГО ГАЗА

резонанс при импульсе **$k_1 = 1$, ширина $k_2 = 0.05$.**

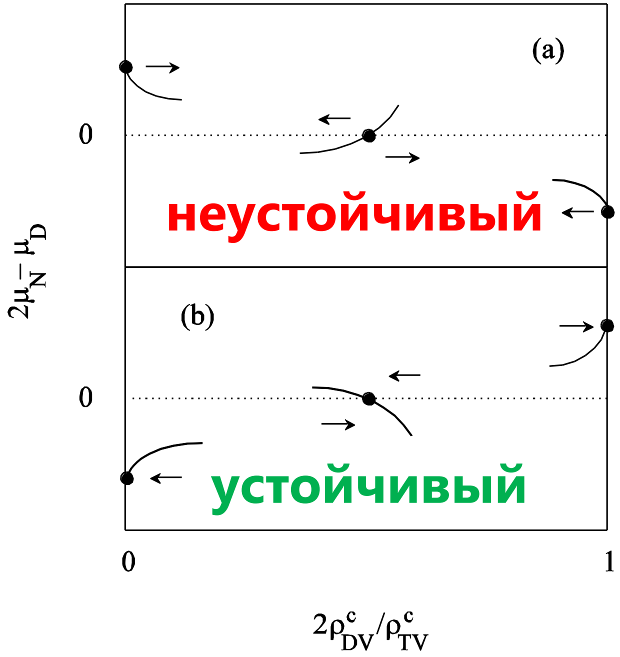
ДИБАРИОНЫ В ЯДЕРНОЙ МАТЕРИИ В МОДЕЛИ СРЕДНЕГО ПОЛЯ

Модель Валечки со скалярными дибарионами:

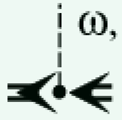
$$L = \bar{\Psi}(i\partial_\mu\gamma_\mu - m_N - g_\sigma\sigma - g_\omega\omega_\mu\gamma_\mu)\Psi$$
$$+\frac{1}{2}(\partial_\mu\sigma)^2 - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{4}F_{\mu\nu}^2 + \frac{1}{2}m_\omega^2\omega_\mu^2 - \frac{1}{2}\lambda(\partial_\mu\omega_\mu)^2$$
$$+(\partial_\mu - ih_\omega\omega_\mu)\varphi^*(\partial_\mu + ih_\omega\omega_\mu)\varphi - (m_D + h_\sigma\sigma)^2\varphi^*\varphi.$$

Конденсат:

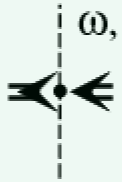
$$\varphi_c(t) = e^{-i\mu_D t}\sqrt{\rho_{DS}^c}.$$



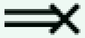
Вершины дибарионов:



$$= \begin{cases} -ih_{\omega}(2\mu_D + k' + k)_{\mu} \\ -ih_{\sigma}2m_D \end{cases}$$



$$= \begin{cases} ih_{\omega}^2 g_{\mu\nu} \\ -ih_{\sigma}^2 \end{cases}$$

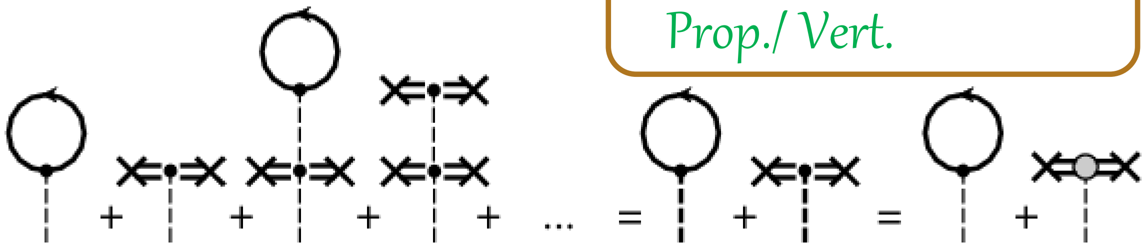


$$= \sqrt{\rho_{DS}^c}$$

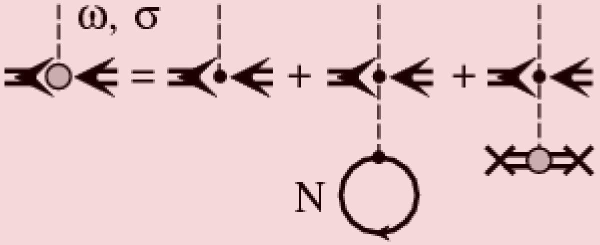
Renorm.:

Prop./ Vert.

Среднее поле:

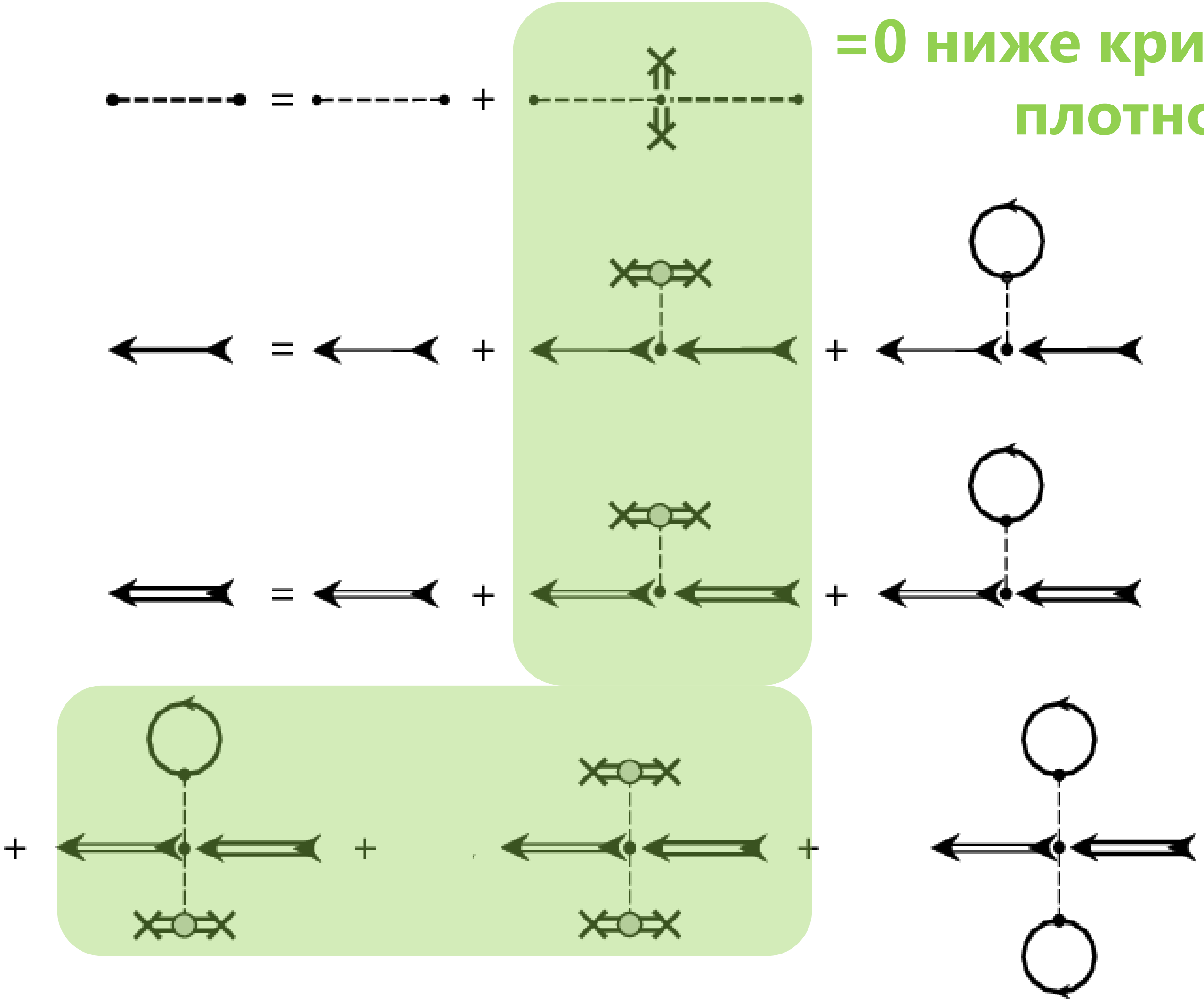


Полные вершины в MFT :



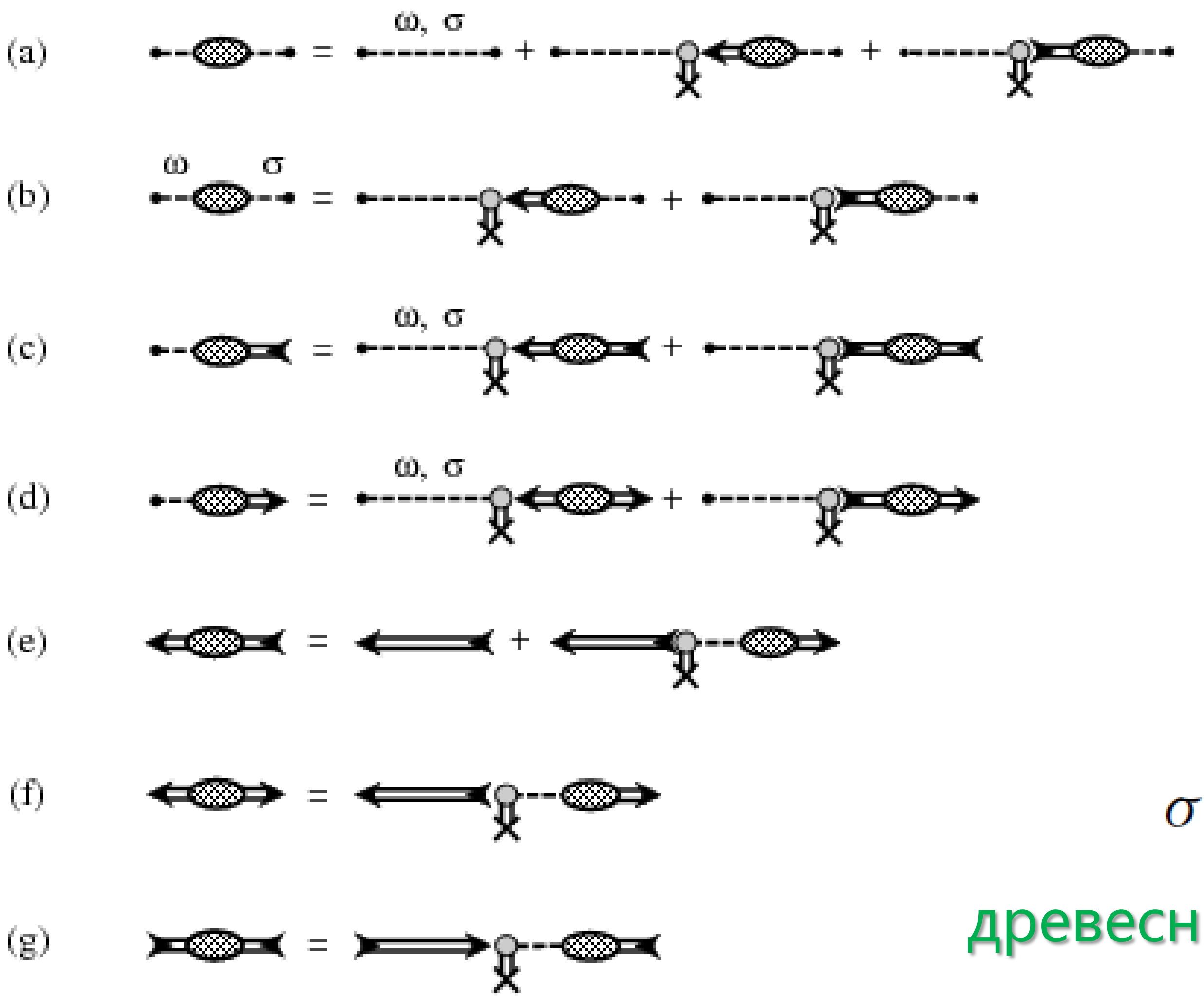
$$= \begin{cases} -ih_{\omega}(2\mu_D^* + k' + k)_{\mu} \\ -ih_{\sigma}2m_N^* \end{cases}$$

Уравнения Дайсона в MFT :



=0 ниже критической плотности

Уравнения Беляева-Дайсона в MFT :

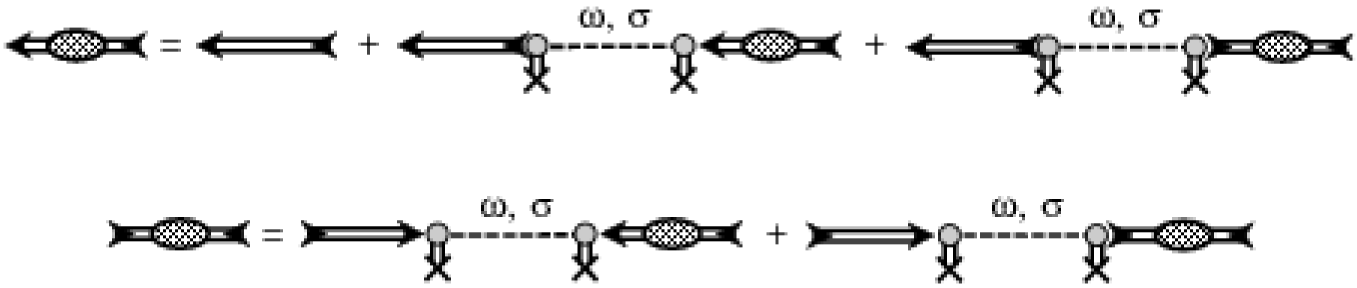


$\sigma\text{–}\omega\text{–}\varphi\text{–}\varphi^{*}$ mixing

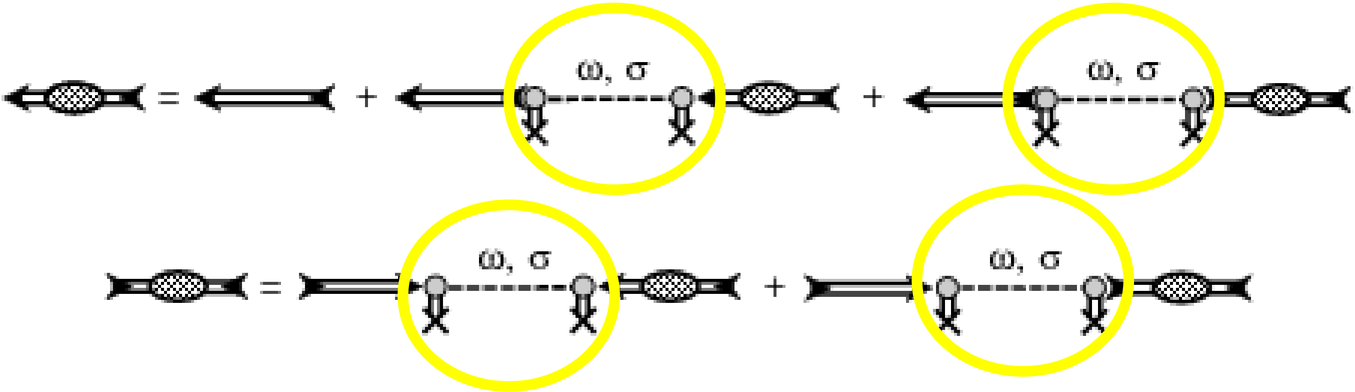
древесное приближение

b,c,d,f,g - АНОМАЛЬНЫЕ ФУНКЦИИ ГРИНА

Замкнутая система 2-х уравнений для функций Грина дибариона :



Замкнутая система 2-х уравнений для функций Грина дибариона :



Аналог уравнений Горькова в теории сверхпроводимости

$$\boxed{\mu_{\mathrm{D}}^{*2} - m_{\mathrm{D}}^{*2} = \Sigma^{\varphi\varphi^*}(0) - \Sigma^{\varphi\varphi}(0)}$$

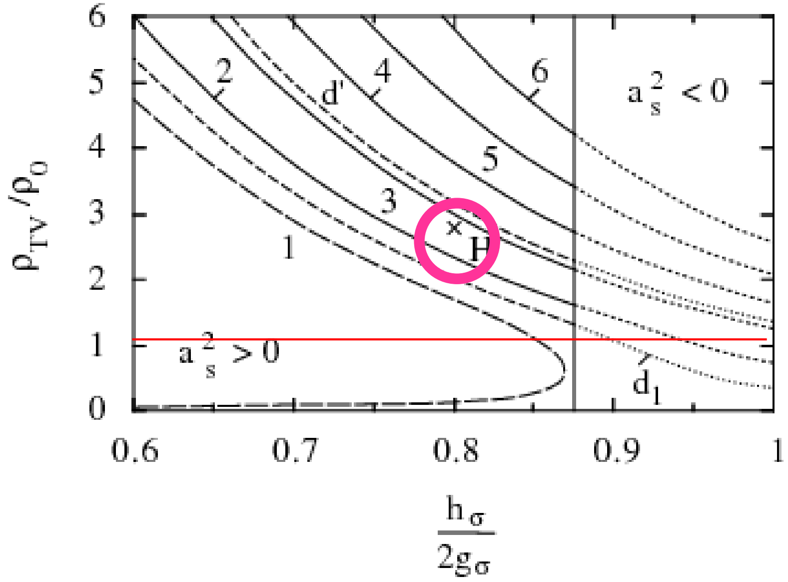
➡ $\mu_{\mathrm{D}}^{*} = m_{\mathrm{D}}^{*}$ --> like in the ideal gas & MF

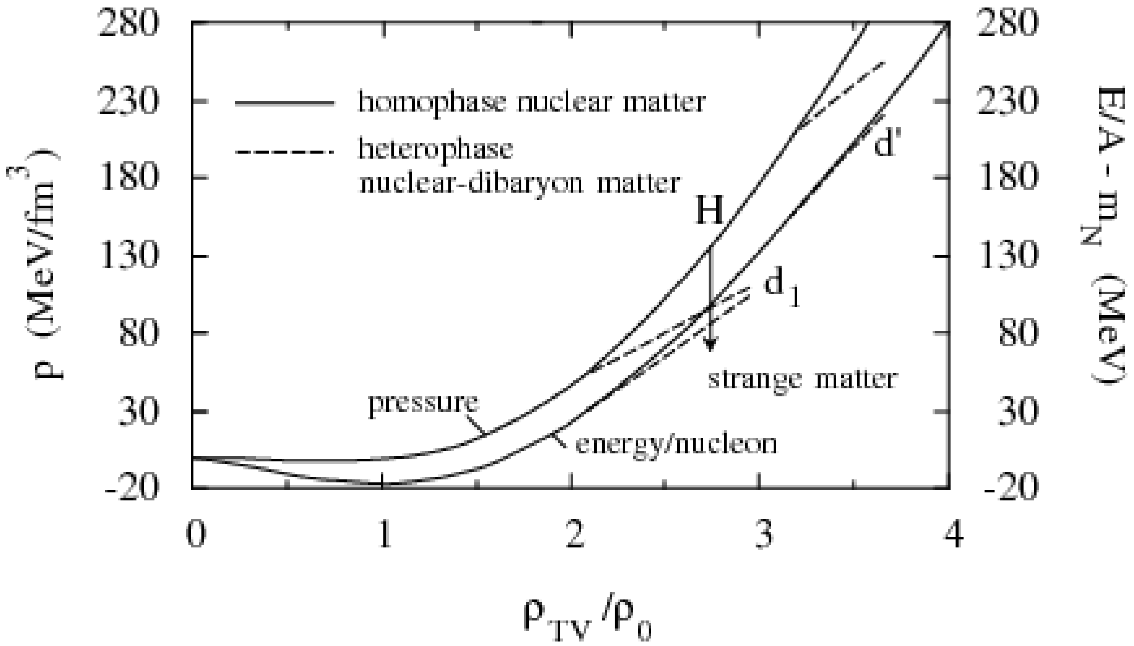
звук

$$a_s^2 = \left(\frac{\partial\omega_s(\boldsymbol{k})}{\partial\boldsymbol{k}}\right)\Bigg|_{k=0}^2 = \frac{\alpha}{1+\alpha}$$

$$\alpha = 2\rho_{\mathrm{DS}}^c \frac{m_\sigma^2}{\tilde{m}_\sigma^2}\left(\frac{h_\omega^2}{m_\omega^2} - \frac{h_\sigma^2}{m_\sigma^2}\right) > 0$$

Уравнение состояния ядерной материи с дибарионами (MFT)





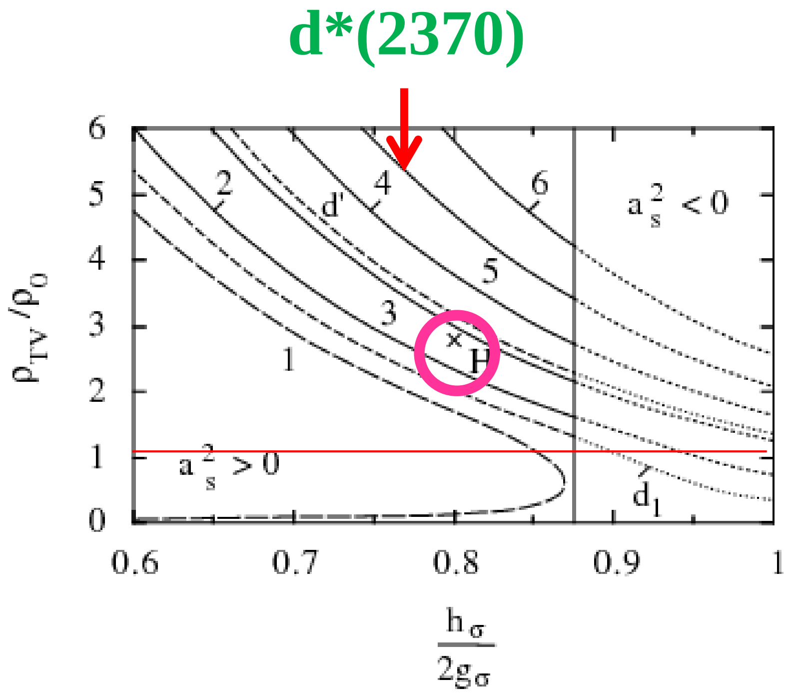
Критическая плотность образования H(2220), d'(2060), d_1(1920)

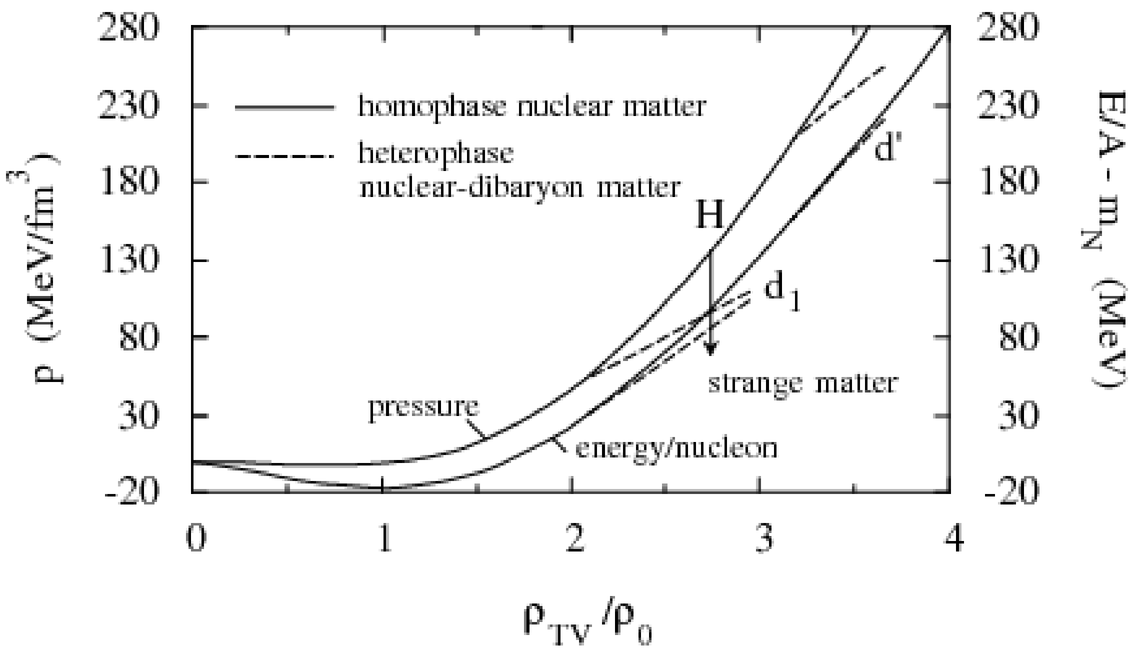
$$h_\omega = 2g_\omega$$

$$h_\sigma / (2g_\sigma) = 0.8$$

$$\rho_{TV} = \rho_{NV} + 2\rho_{DV}^c$$

Уравнение состояния ядерной материи с дибарионами (MFT)





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ДИБАРИОНЫ В ЯДЕРНОЙ МАТЕРИИ В RHA (= MFT + CASIMIR EFF.)

$$\rho_{NS}=\langle\overline{\Psi}(0)\Psi(0)\rangle=\gamma\int\frac{d\mathbf{p}}{(2\pi)^3}\frac{m_N^*}{E^*(\mathbf{p})}\theta(p_F-|\mathbf{p}|)$$

$$-4m_N^3\zeta(m_N^*/m_N),$$

← *Casimir effect*

$$2m_D^*\rho_{DS}=2m_D^*\langle\varphi(0)^*\varphi(0)\rangle=m_D^3\zeta(m_D^*/m_D)$$

$$\langle T^N_{\mu\nu}(0)\rangle_{\text{vac}}=-4g_{\mu\nu}m_N^4\eta(m_N^*/m_N)$$

$$\langle T^D_{\mu\nu}(0)\rangle_{\text{vac}}=g_{\mu\nu}m_D^4\eta(m_D^*/m_D)$$

$$\left\{\begin{aligned}4\pi^2\zeta(x)&=x^3\ln x+1-x-\tfrac{5}{2}(1-x)^2+\tfrac{11}{2}(1-x)^3\\16\pi^2\eta(x)&=x^4\ln x+1-x-\tfrac{7}{2}(1-x)^2+\tfrac{13}{3}(1-x)^3-\tfrac{25}{12}(1-x)^4\end{aligned}\right.$$

RHA

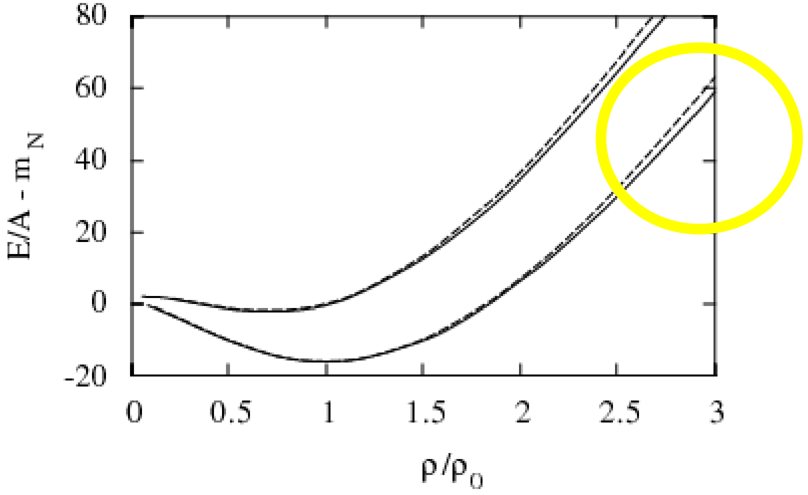
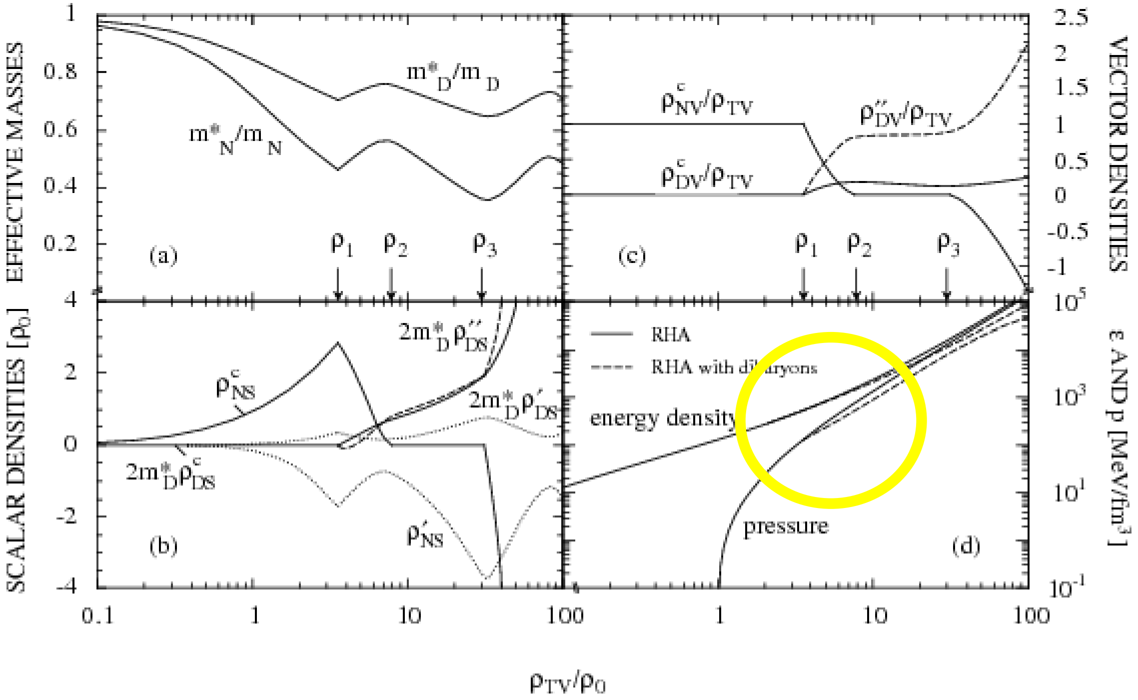


FIG. 2. Saturation curve for nuclear matter in the RHA: without dibaryons (solid line) and with the inclusion of H dibaryons (dashed line) for $h_\sigma/(2g_\sigma)=0.6$.

RHA



a) m^*_N & m^*_D vs ρ_{TV}

b) scalar density of nucleons

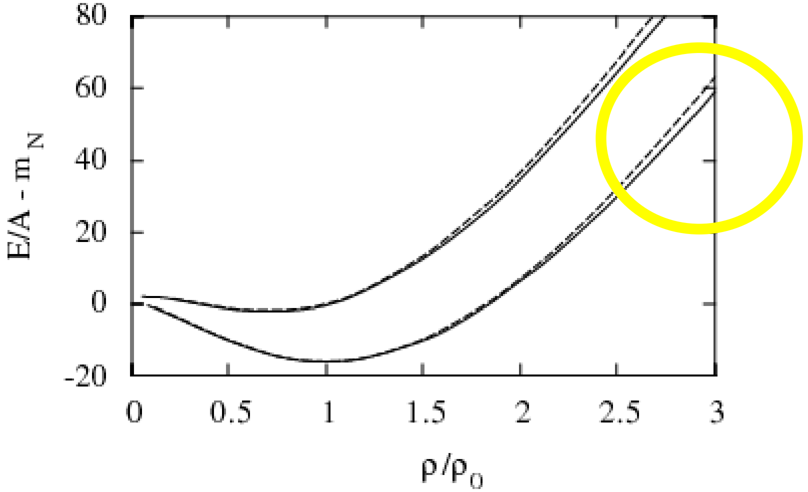
c) fraction of nucleons and dibaryons

d) energy density and pressure

$m_D = 2060$ MeV

Я. Б. Зельдович, ЖЭТФ 41, 1809 (1961).

RHA



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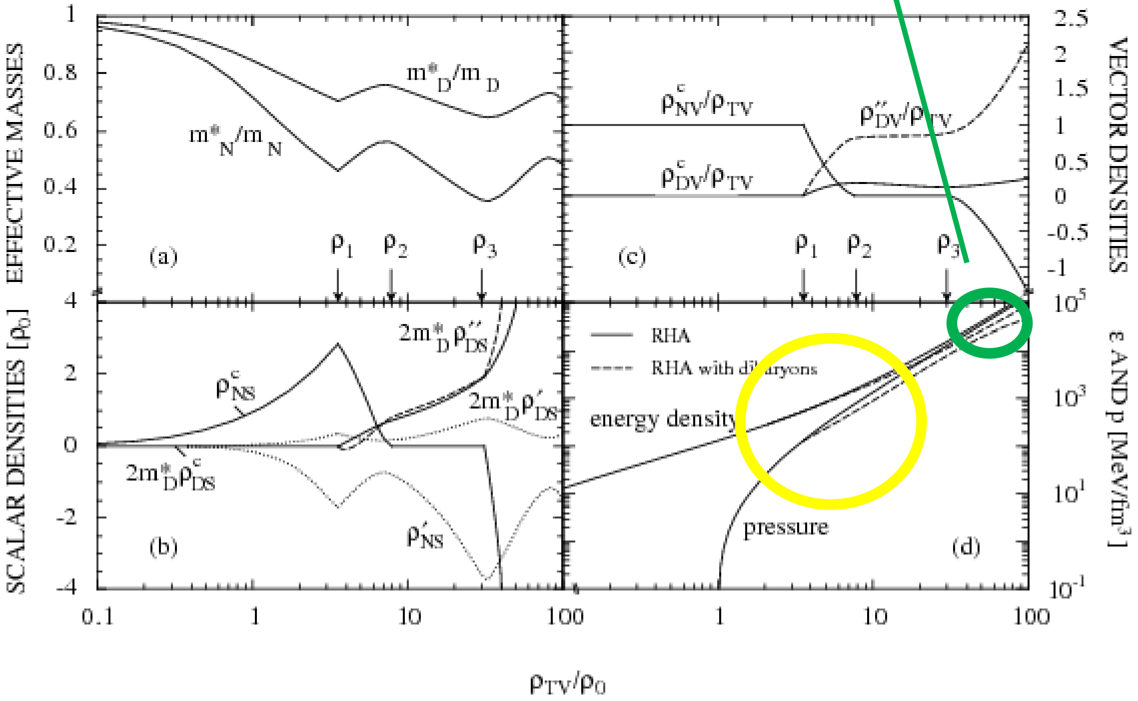
RHA



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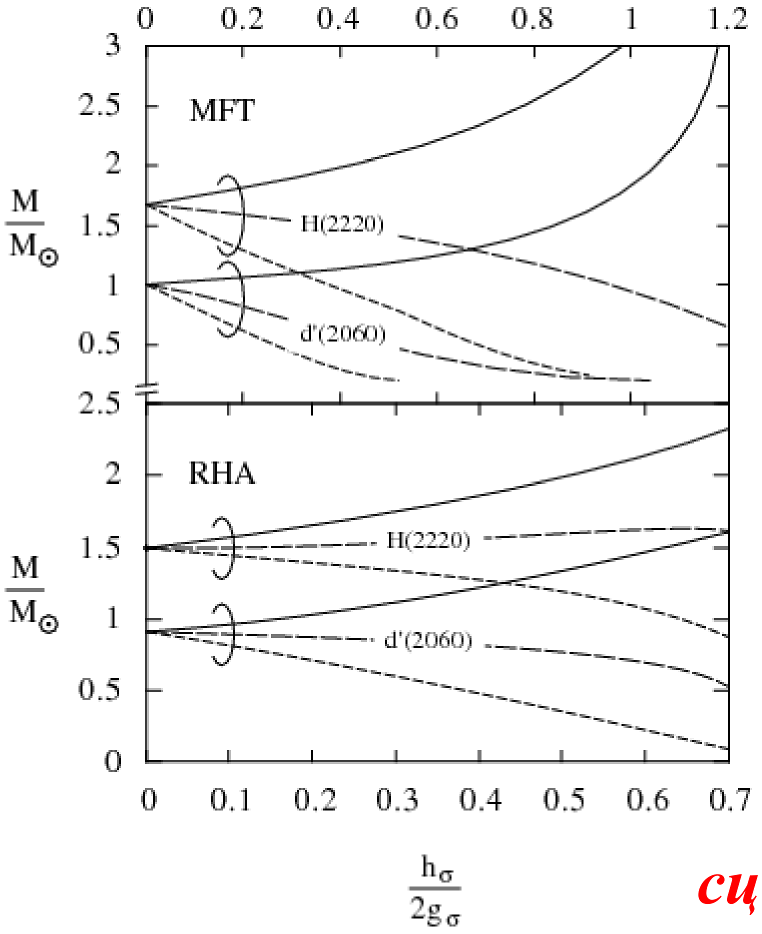
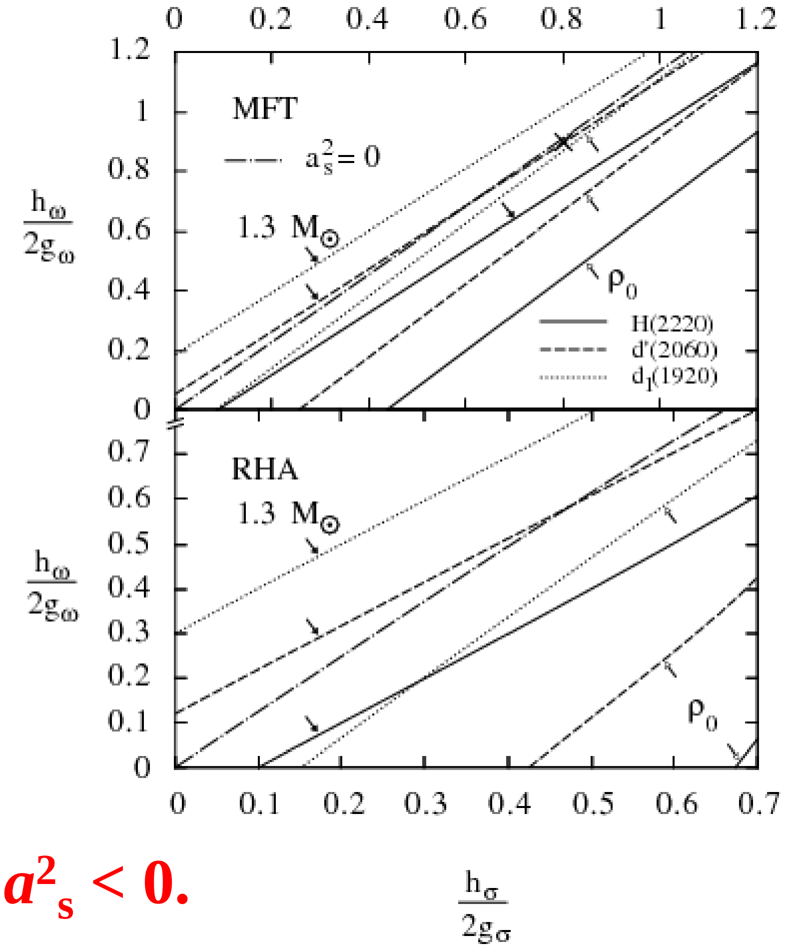




сценарий $a^2_s < 0$.

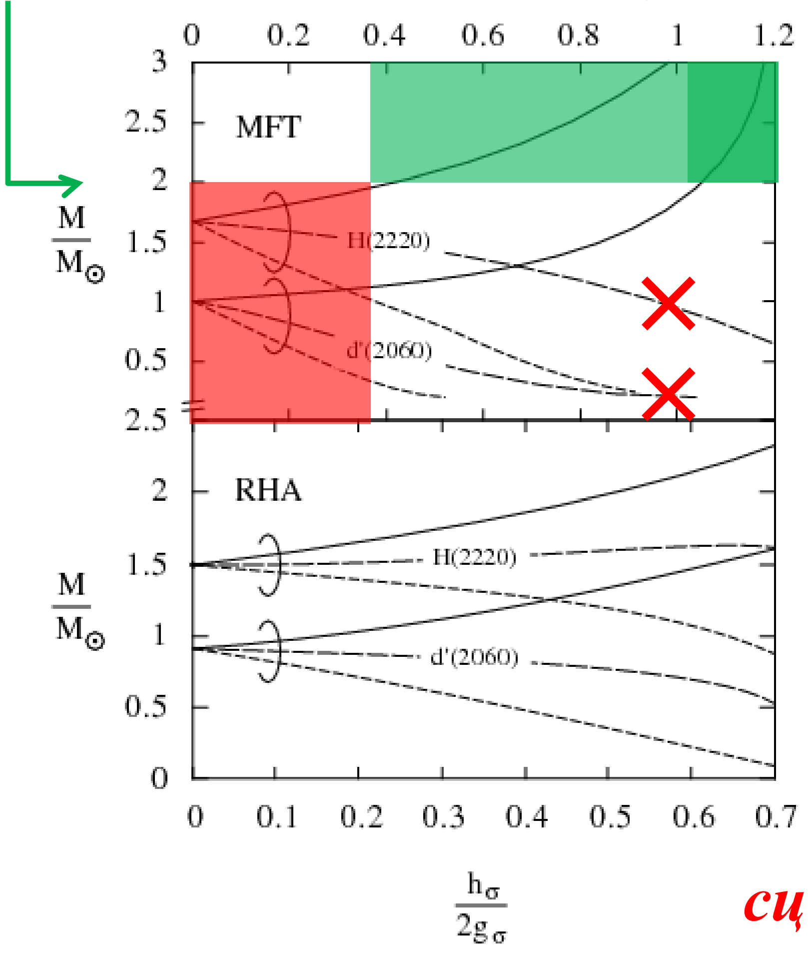
Lowest neutron star masses, for which dibaryon formation becomes energetically favorable for $h_\omega/h^{max}_\omega = 1, 0.8, 0.6$;

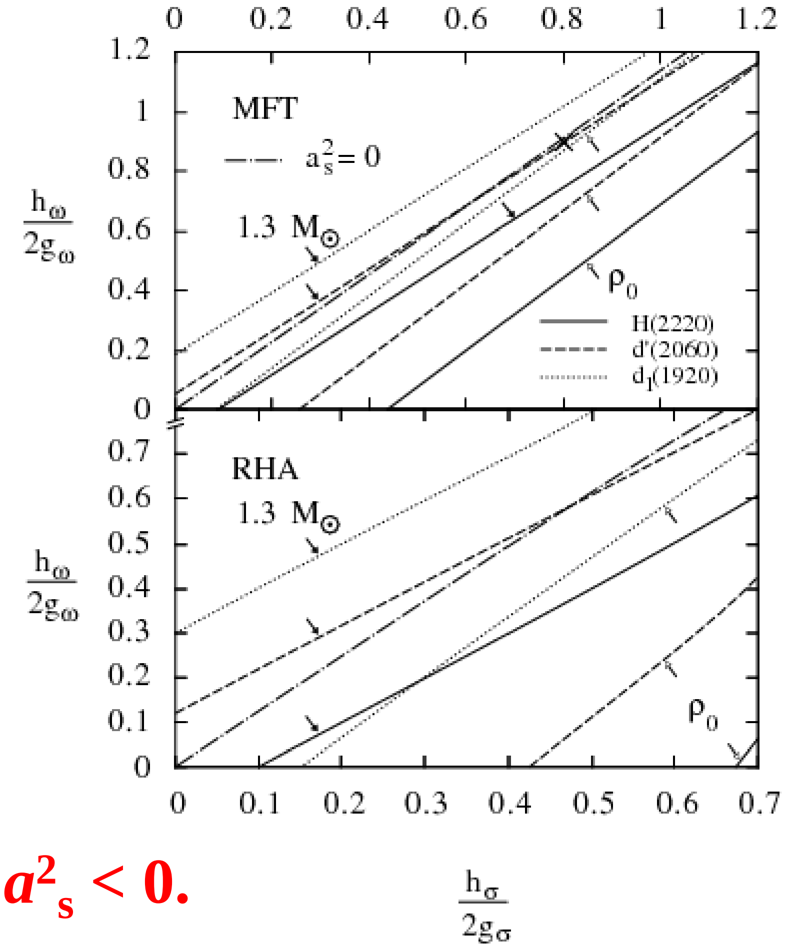
Parameter space for the dibaryon coupling constants in MFT and RHA.

PSR J1614-2230 $M = 1.97 \pm 0.04 \ M_{\odot}$

P. B. Demorest et al., Nature 467 (2010) 1081.

provided just neutron star





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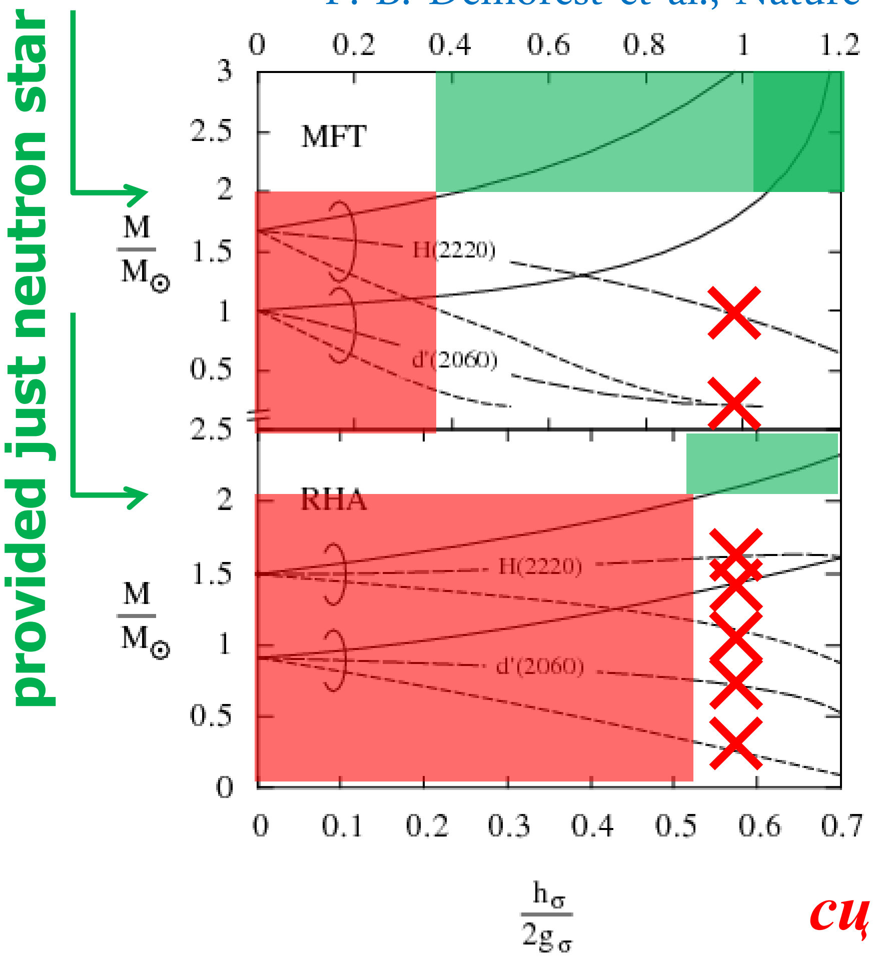

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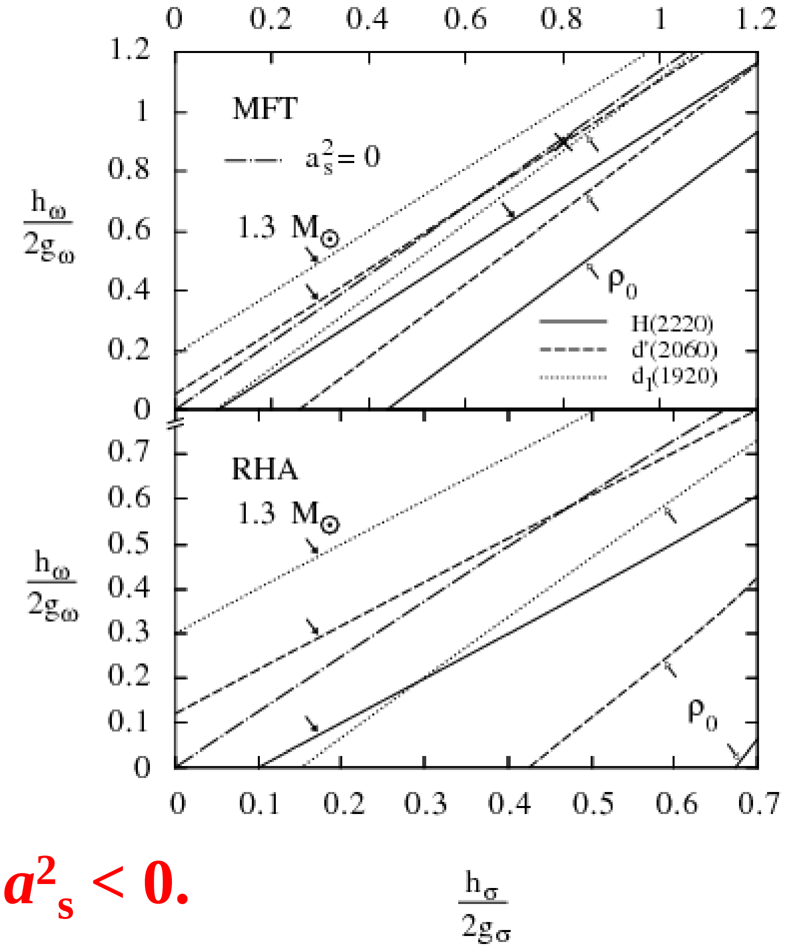

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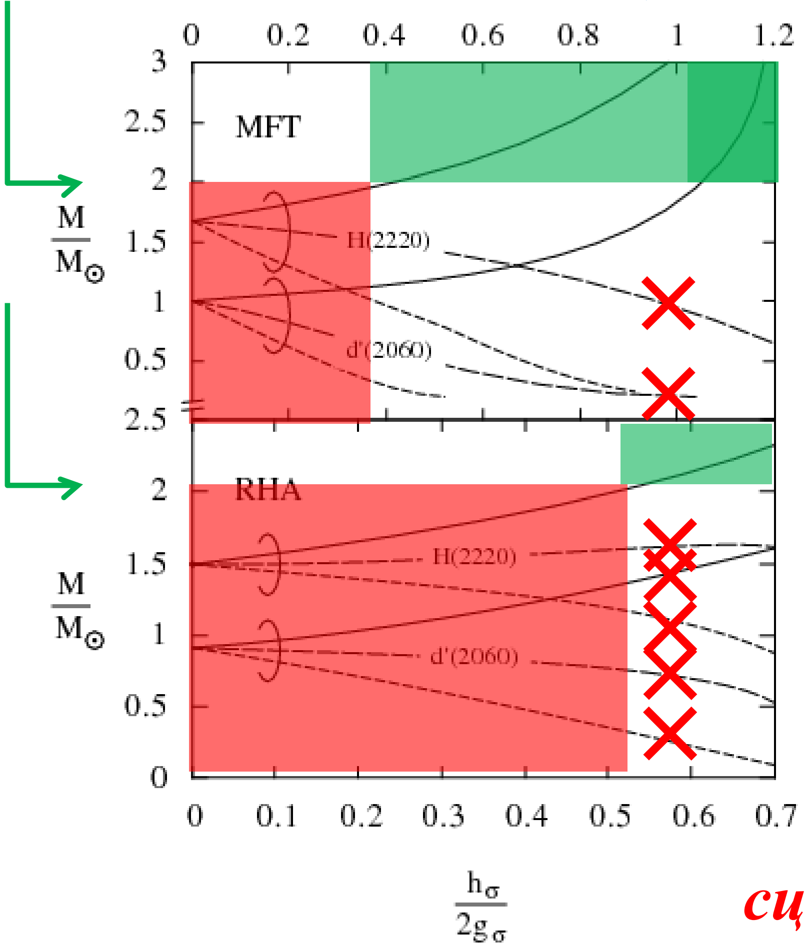

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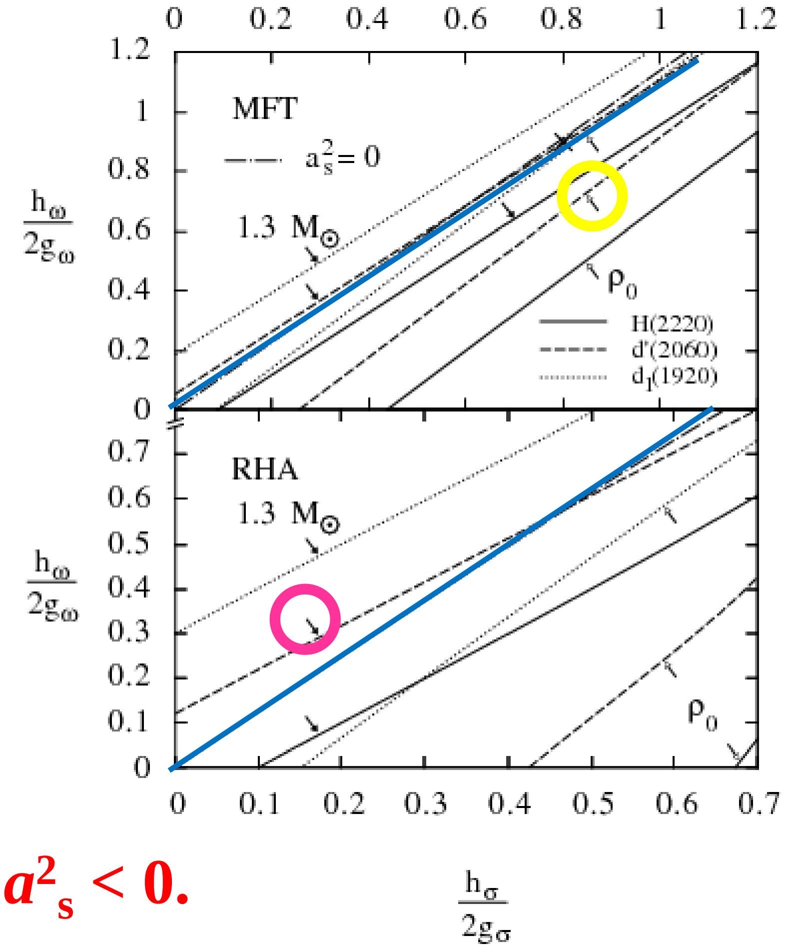

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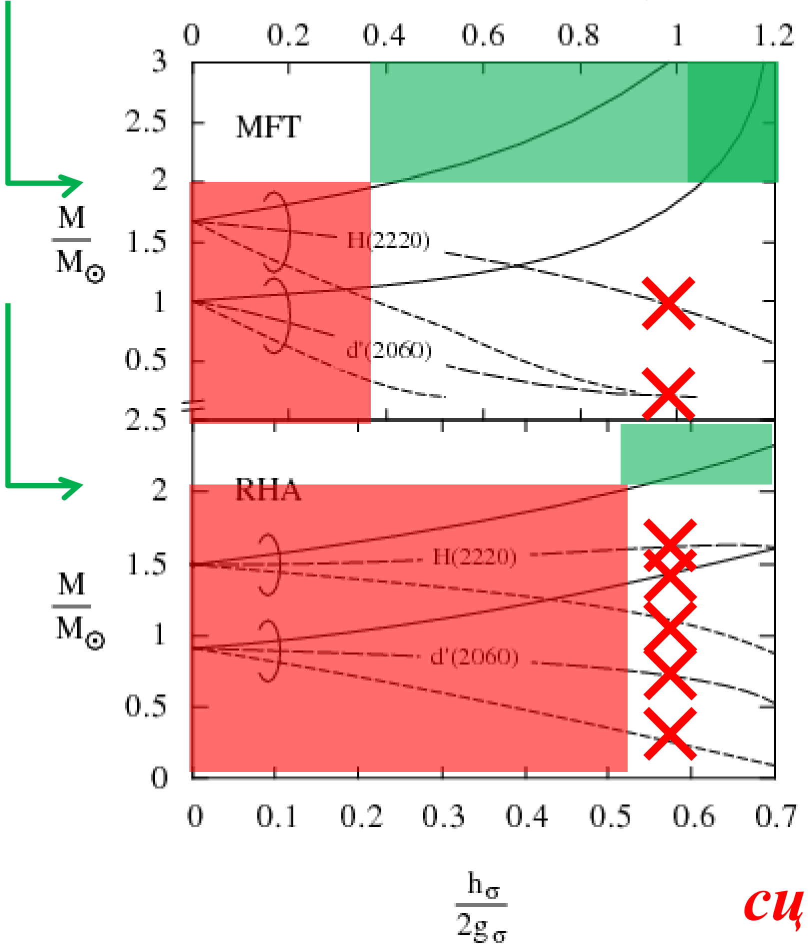

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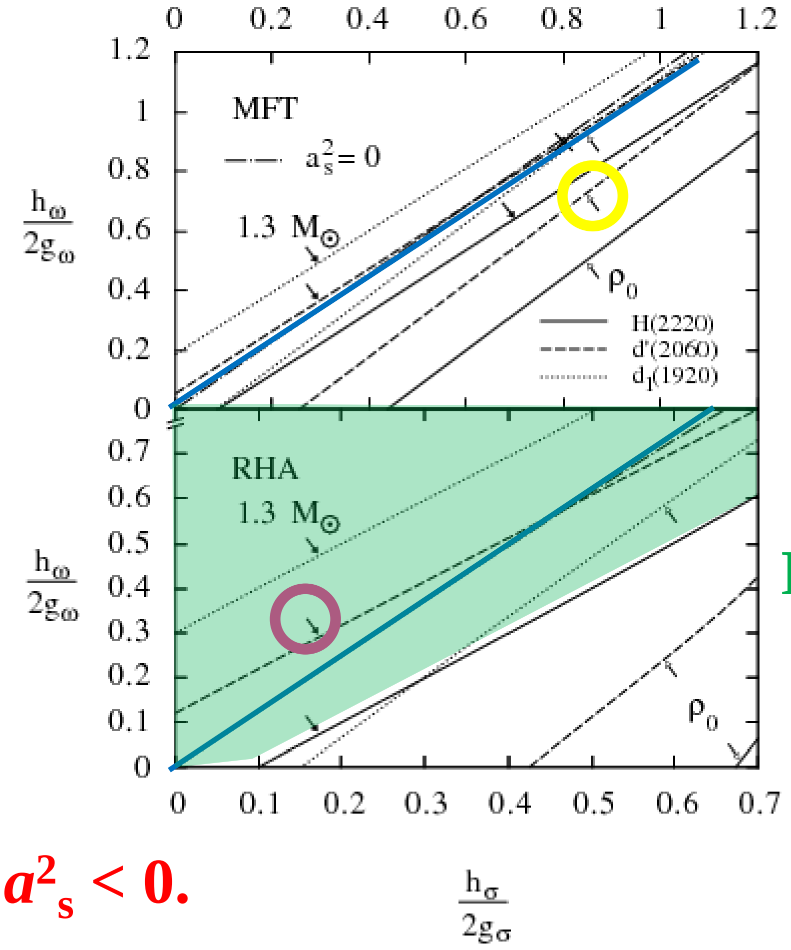

H(2220)

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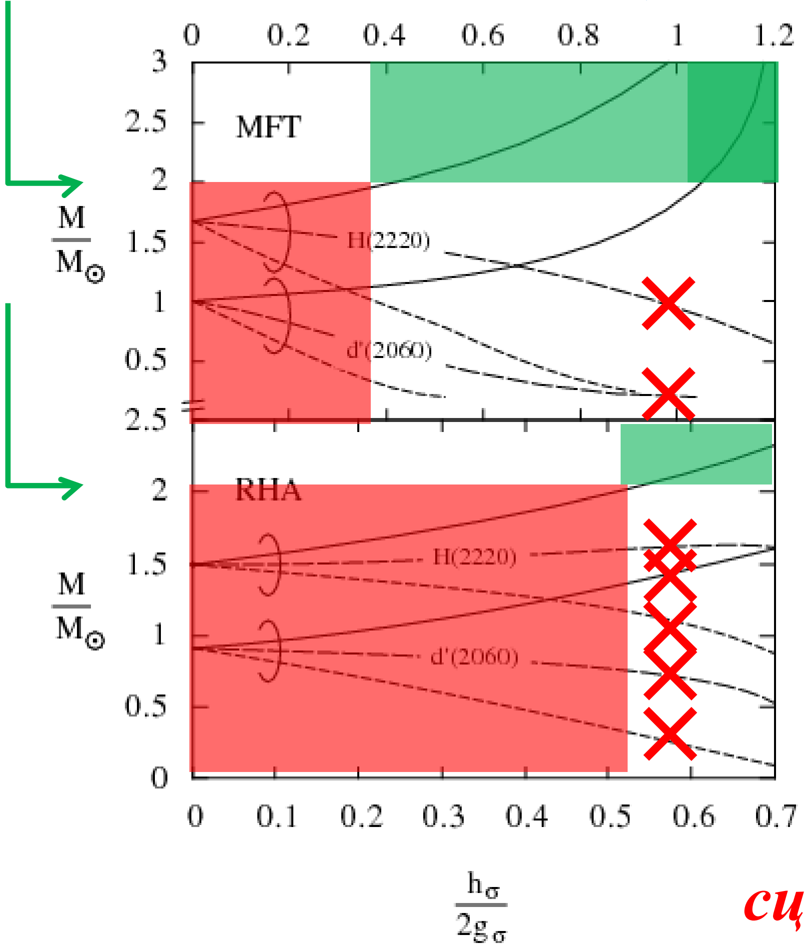

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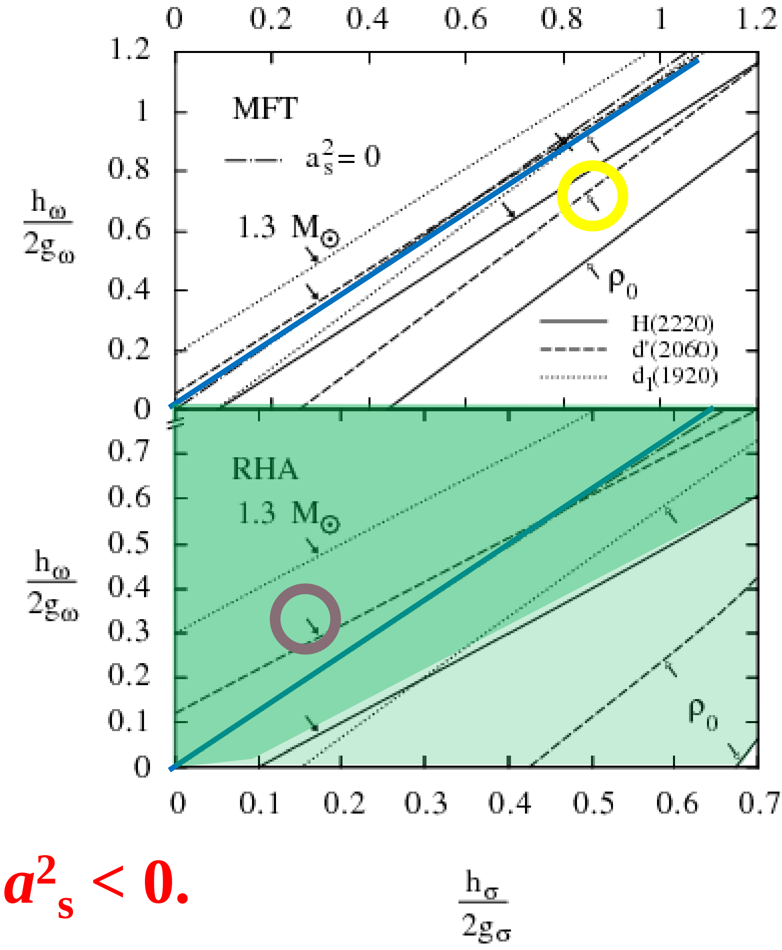

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Parameter space for the dibaryon coupling constants in MFT and RHA.

1. Существует новый тип КДД полюсов, связанный с примитивами

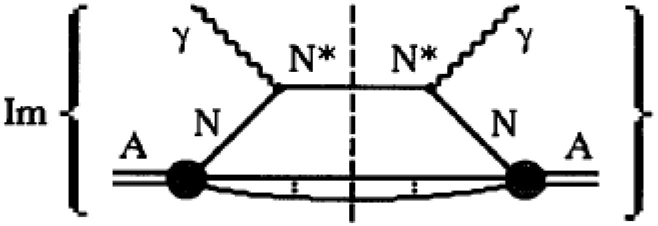
2. Исследовано уравнение состояния ядерной материи с учетом Бозе конденсации дибарионов в MFT & RHA

3. Получены ограничения на массы и константы связи дибарионов из существования массивных нейтронных звезд
4. Бинарная смесь нуклонов и легких дибарионов устойчива ($a^2_s > 0$).

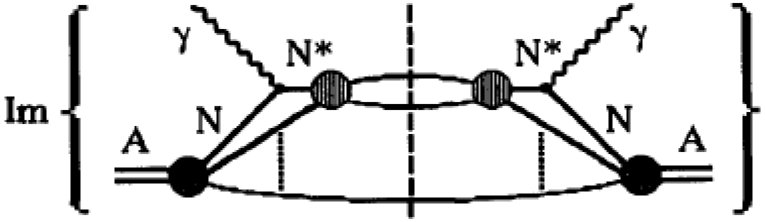
Рождение резонансов в ядрах

- L. A. Kondratyuk, M. I. K., N. Bianchi, E. De Sanctis and V. Muccifora, Nucl. Phys. A 579, 453 (1994);
- K. G. Boreskov, L. A. Kondratyuk, M. I. K. and J. H. Koch Nucl. Phys. A 619, 295 (1997).

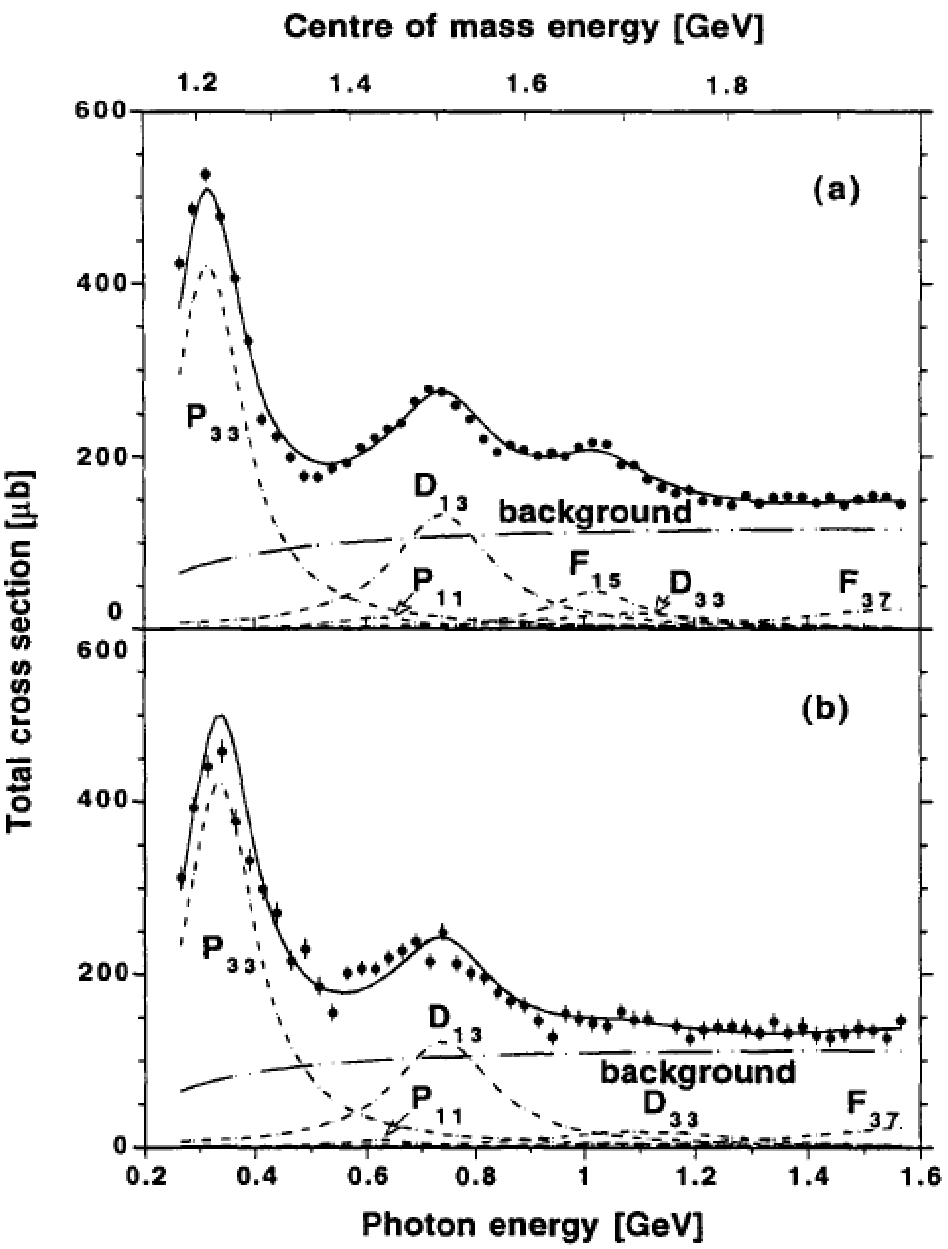
Фраскати (1992) и Майнц (1994) измерили полные сечения фотопоглощения на некоторых ядрах для изучения поведения барионных резонансов в ядерной среде.



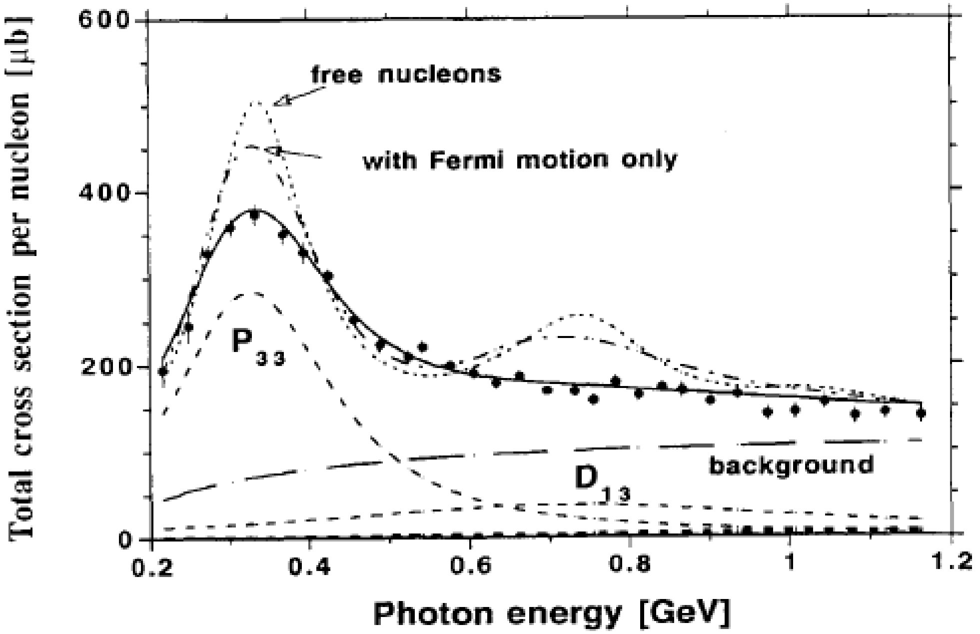
свободные нуклоны



с учетом перерассеяния



фотопоглощение на нуклонах



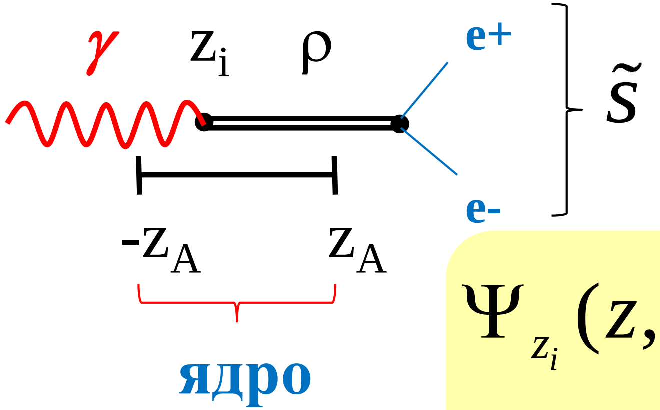
$$\delta M = -\frac{2\pi}{M}\Re f_{NN^*}(\theta=0)\rho_0,$$

$$\Gamma^* = \frac{4\pi}{M}\Im f_{NN^*}(\theta=0)\rho_0.$$

$$\Im f_{NN^*}(\theta=0) = \frac{k}{4\pi}\sigma^*$$

фотопоглощение на уране

Когерентное рождение резонансов: двухкомпонентная формула Брейта-Вигнера



\1D model

$$P = \sqrt{E^2 - M_R^2 + iM_R\Gamma} \equiv p - Q_R,$$

$$P^* = \sqrt{E^2 - M_R^2 + iM_R\Gamma + 2M_R V^*} \equiv p - Q_R^*$$

$$\Psi_{z_i}(z,E) = N(z_i)\Big[\exp(iP^*(z - z_A))\theta(z_i < z < z_A) + \exp(iP(z - z_A))\theta(z_A < z)\Big].$$

$$T(p,p') = \int_{-z_A}^{z_A} dz_i \int_{z_i}^{+\infty} dz_f e^{-ip'z_f} \Psi_{z_i}(z_f,E)$$

← **амплитуда**

$$\propto \int_{-z_A}^{z_A} dz_i N(z_i)\left[\frac{1 - \exp(iD^*(z_A - z_i)/2p)}{D^*} + \frac{\exp(iD(z_A - z_i)/2p)}{D}\right].$$

широкая компонента

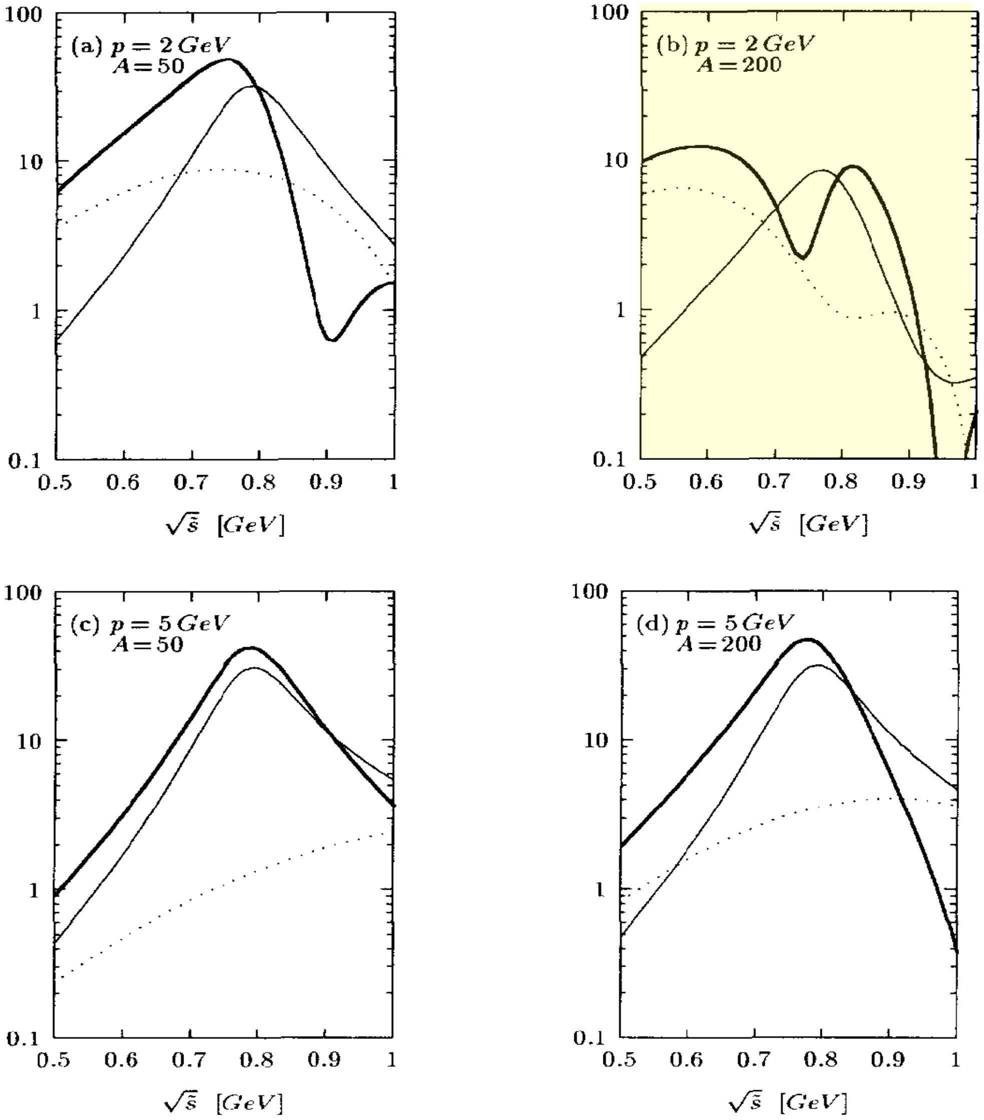
узкая компонента

$$D \simeq \tilde{s} - M_R^2 + iM_R\Gamma_R\,,$$

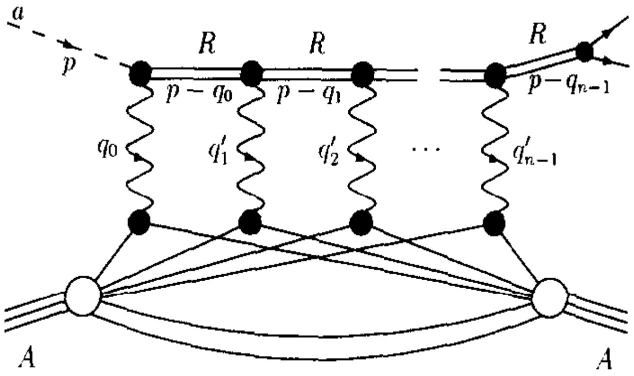
$$D^* \simeq \tilde{s} - M_R^{*2} + iM_R^*\Gamma_R^*\,.$$

← **знаменатели**

1D model ⇐ 3D model ⇒ diagrams for high energy



$$\gamma A \to \rho A \to (e^{+}e^{-})A$$



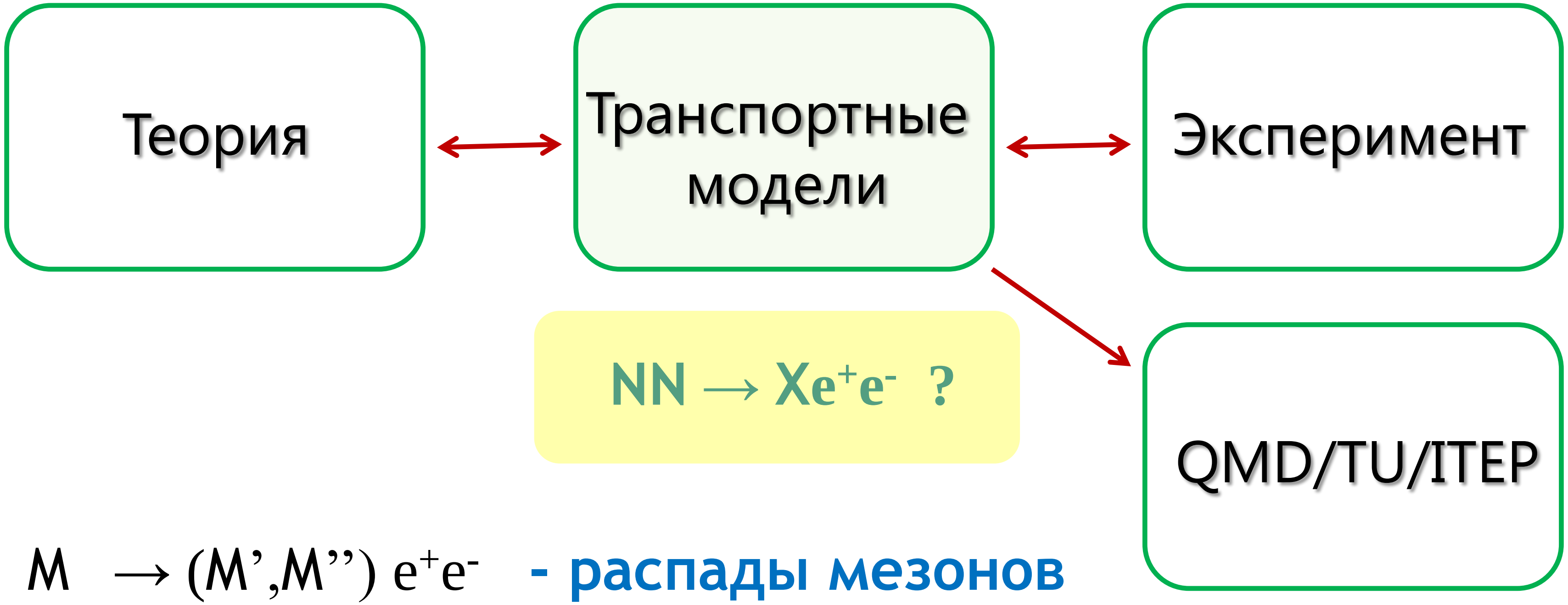
спектр $e^{+}e^{-}$ пары
в распаде ρ-мезона

1. Столкновительная ширина, описание данных Фраскати по фотопоглощению на ядрах

2. Двухкомпонентная формула Брейта-Вигнера

Рождение e+e- пар в столкновениях тяжелых ионов

- A. Faessler, C. Fuchs and M. I. K., Phys. Rev. C 61, 035206 (2000);
- M. I. K. and A. Faessler, Phys. Rev. D 65, 017502 (2002);
- M. I. K., B. V. Martemyanov, A. Faessler and C. Fuchs, Annals Phys. 296, 299 (2002);
- A. Faessler, C. Fuchs, M. I. K. and B. V. Martemyanov, J. Phys. G 29, 603 (2003);
- C. Fuchs, M. I. K., H. L. Yadav, A. Faessler, B. V. Martemyanov and K. Shekhter, Phys. Rev. C 67, 025202 (2003);
- K. Shekhter, C. Fuchs, A. Faessler, M. I. K., B. Martemyanov, Phys. Rev. C 68, 014904 (2003);
- E. Santini, M. D. Cozma, A. Faessler, C. Fuchs, M. I. K., B. Martemyanov, Phys. Rev. C 78, 034910 (2008).



Теория

Транспортные модели

Эксперимент

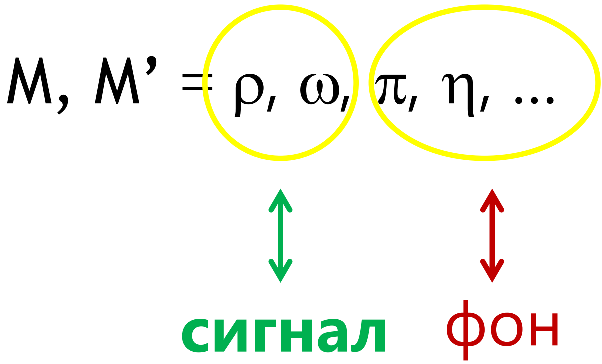
$NN \rightarrow Xe^+e^-$?

QMD/TU/ITEP

$M \rightarrow (M',M'')\, e^+e^-$ **- распады мезонов**

$R \rightarrow Ne^+e^-$ **- распады нуклонных резонансов**

$NN \rightarrow NR,\ R \rightarrow N(M, e^+e^-)$ **- резонансная модель NRD**



$M,\ M' = \rho,\ \omega,\ \pi,\ \eta,\ \ldots$

сигнал фон

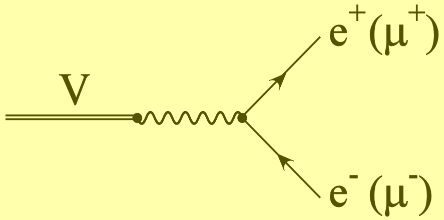
Дилептонные распады легких нестранных мезонов

$$M \;\; \rightarrow (M',M'')\, e^+e^-$$

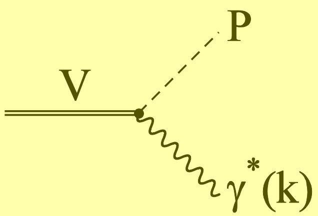
Вычислены γ и e^+e^- ширины всех легких нестранных мезонов с массой ниже $\phi(1020)$.

Некоторые примеры:

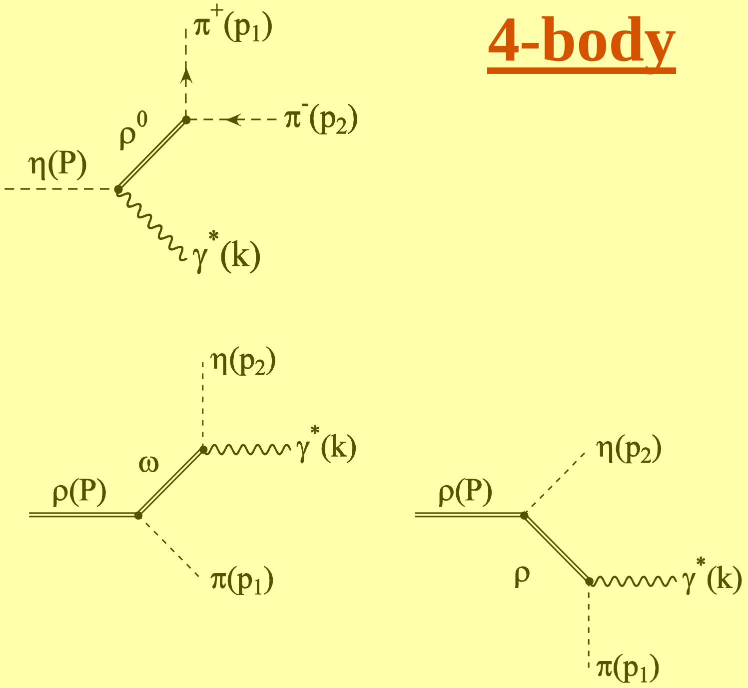
2-body



3-body



4-body



$M \;\; \rightarrow (M',M'')\, e^+e^-$

Ширины e^+e^- распадов

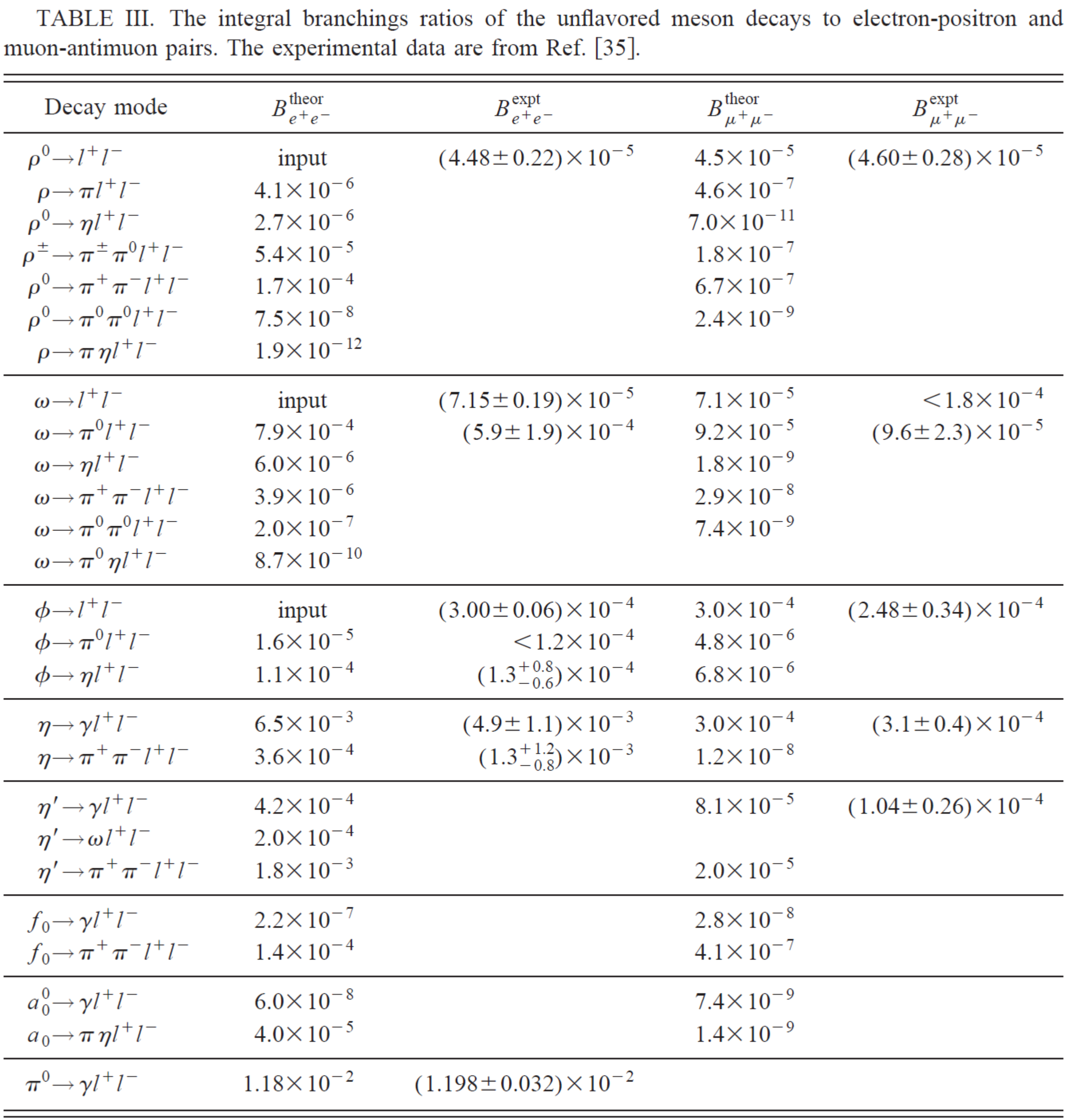
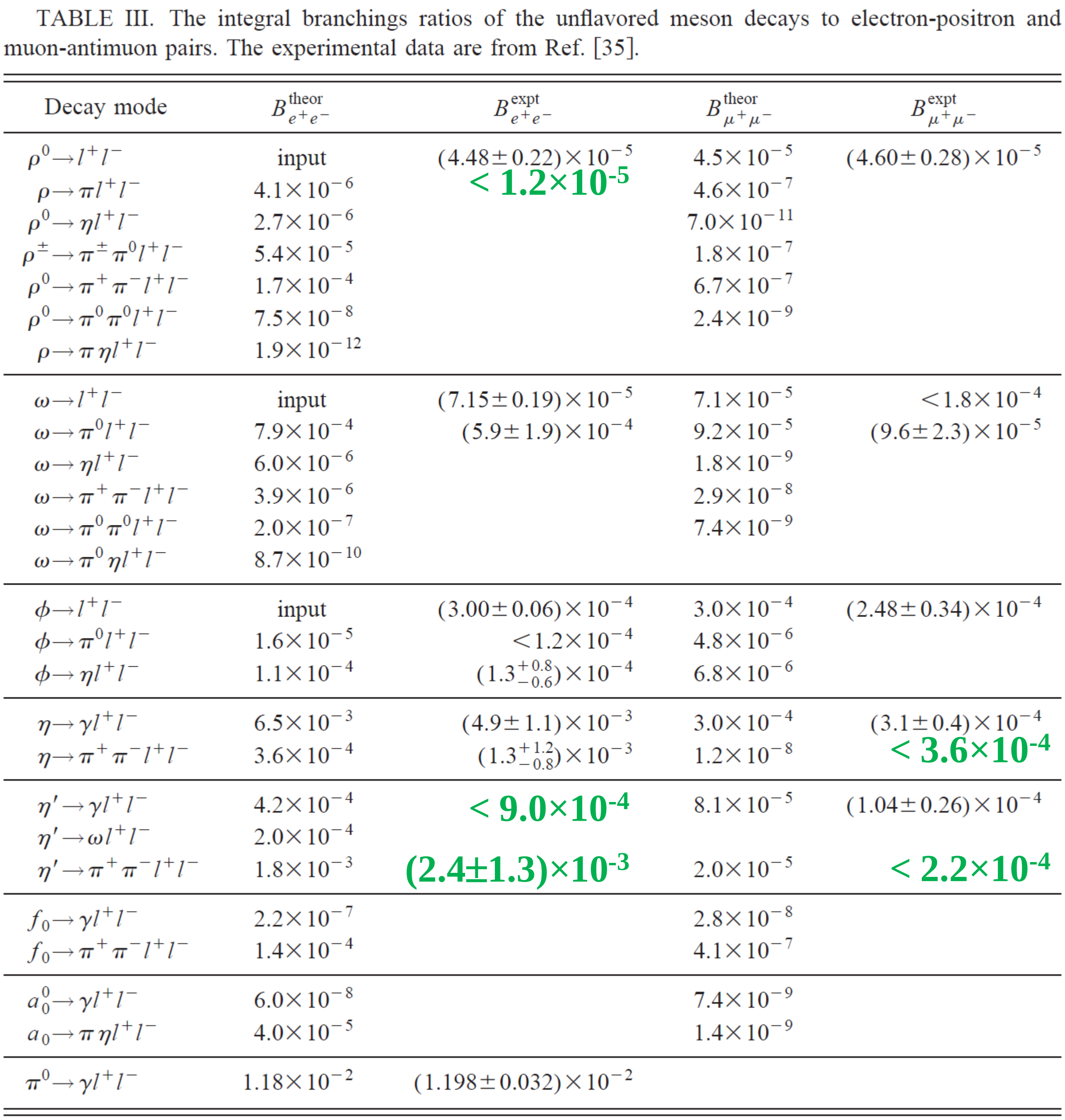


TABLE III. The integral branchings ratios of the unflavored meson decays to electron-positron and muon-antimuon pairs. The experimental data are from Ref. [35].

Decay mode	$B^{\text{theor}}_{e^+e^-}$	$B^{\text{expt}}_{e^+e^-}$	$B^{\text{theor}}_{\mu^+\mu^-}$	$B^{\text{expt}}_{\mu^+\mu^-}$
$\rho^0 \to l^+l^-$	input	$(4.48 \pm 0.22) \times 10^{-5}$	4.5×10^{-5}	$(4.60 \pm 0.28) \times 10^{-5}$
$\rho \to \pi l^+l^-$	4.1×10^{-6}		4.6×10^{-7}	
$\rho^0 \to \eta l^+l^-$	2.7×10^{-6}		7.0×10^{-11}	
$\rho^\pm \to \pi^\pm \pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0 \to \pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0 \to \pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho \to \pi \eta l^+l^-$	1.9×10^{-12}			
$\omega \to l^+l^-$	input	$(7.15 \pm 0.19) \times 10^{-5}$	7.1×10^{-5}	$< 1.8 \times 10^{-4}$
$\omega \to \pi^0 l^+l^-$	7.9×10^{-4}	$(5.9 \pm 1.9) \times 10^{-4}$	9.2×10^{-5}	$(9.6 \pm 2.3) \times 10^{-5}$
$\omega \to \eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega \to \pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
$\omega \to \pi^0\pi^0 l^+l^-$	2.0×10^{-7}		7.4×10^{-9}	
$\omega \to \pi^0 \eta l^+l^-$	8.7×10^{-10}			
$\phi \to l^+l^-$	input	$(3.00 \pm 0.06) \times 10^{-4}$	3.0×10^{-4}	$(2.48 \pm 0.34) \times 10^{-4}$
$\phi \to \pi^0 l^+l^-$	1.6×10^{-5}	$< 1.2 \times 10^{-4}$	4.8×10^{-6}	
$\phi \to \eta l^+l^-$	1.1×10^{-4}	$(1.3^{+0.8}_{-0.6}) \times 10^{-4}$	6.8×10^{-6}	
$\eta \to \gamma l^+l^-$	6.5×10^{-3}	$(4.9 \pm 1.1) \times 10^{-3}$	3.0×10^{-4}	$(3.1 \pm 0.4) \times 10^{-4}$
$\eta \to \pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(1.3^{+1.2}_{-0.8}) \times 10^{-3}$	1.2×10^{-8}	
$\eta' \to \gamma l^+l^-$	4.2×10^{-4}		8.1×10^{-5}	$(1.04 \pm 0.26) \times 10^{-4}$
$\eta' \to \omega l^+l^-$	2.0×10^{-4}			
$\eta' \to \pi^+\pi^- l^+l^-$	1.8×10^{-3}		2.0×10^{-5}	
$f_0 \to \gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0 \to \pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0 \to \gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0 \to \pi \eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
$\pi^0 \to \gamma l^+l^-$	1.18×10^{-2}	$(1.198 \pm 0.032) \times 10^{-2}$		

PDG/1998 - PDG/2013

Ширины e^+e^- распадов



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Decay mode	$B^{\rm theor}_{e^+e^-}$	$B^{\rm expt}_{e^+e^-}$	$B^{\rm theor}_{\mu^+\mu^-}$	$B^{\rm expt}_{\mu^+\mu^-}$
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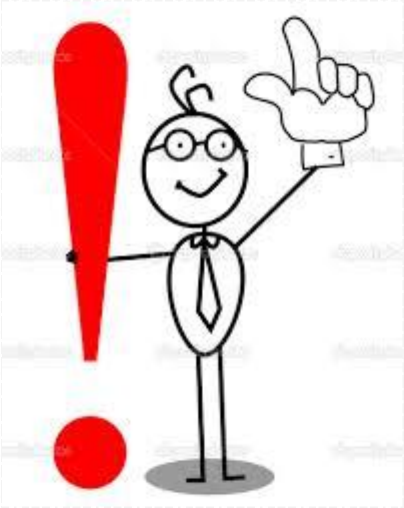
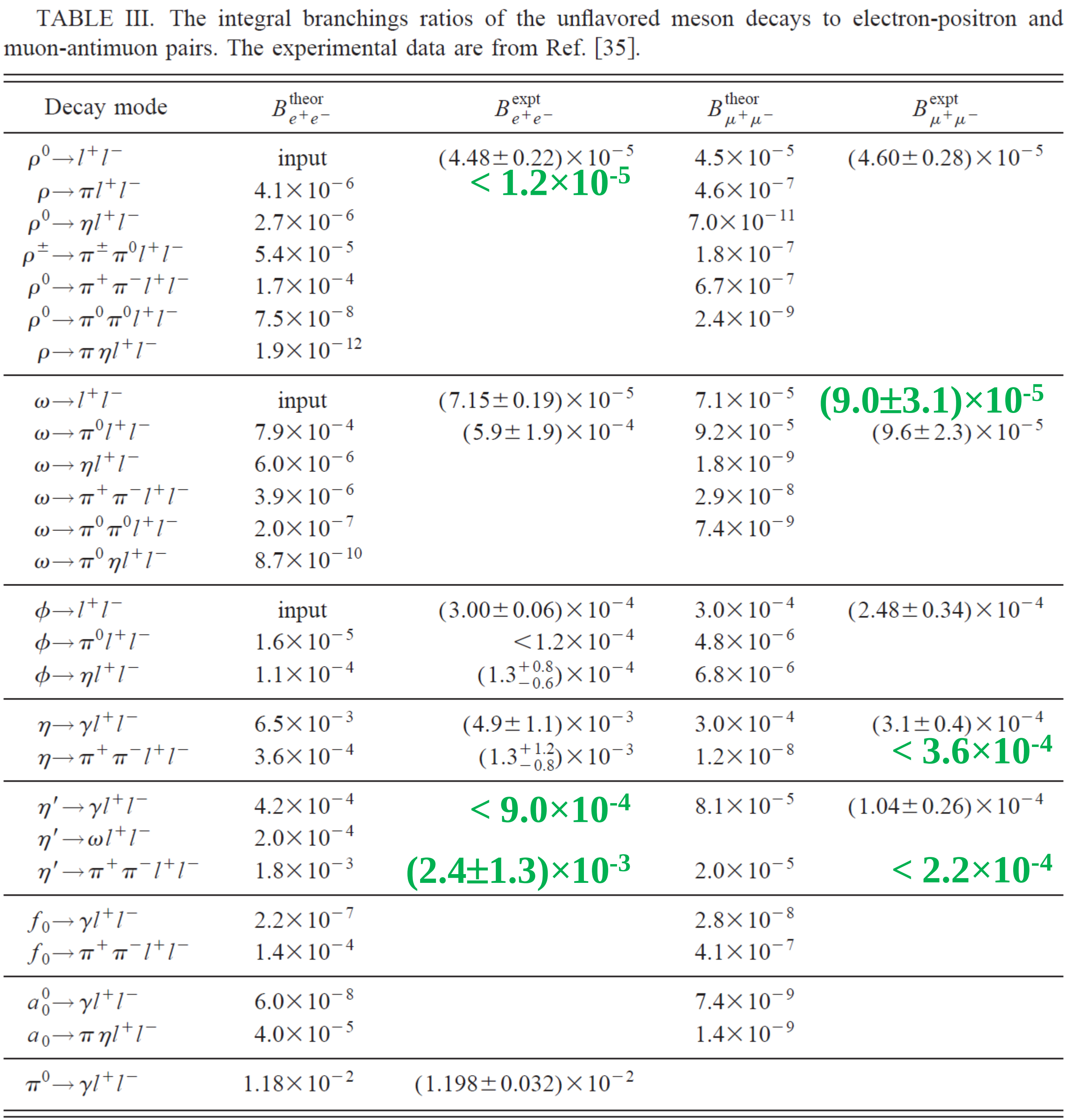
$\rho^0\to\eta l^+l^-$	2.7×10^{-6}		7.0×10^{-11}	
$\rho^\pm\to\pi^\pm\pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0\to\pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0\to\pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho\to\pi\eta l^+l^-$	1.9×10^{-12}			
$\omega\to l^+l^-$	input	$(7.15\pm0.19)\times10^{-5}$	7.1×10^{-5}	$<1.8\times10^{-4}$
$\omega\to\pi^0 l^+l^-$	7.9×10^{-4}	$(5.9\pm1.9)\times10^{-4}$	9.2×10^{-5}	$(9.6\pm2.3)\times10^{-5}$
$\omega\to\eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega\to\pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
$\omega\to\pi^0\pi^0 l^+l^-$	2.0×10^{-7}		7.4×10^{-9}	
$\omega\to\pi^0\eta l^+l^-$	8.7×10^{-10}			
$\phi\to l^+l^-$	input	$(3.00\pm0.06)\times10^{-4}$	3.0×10^{-4}	$(2.48\pm0.34)\times10^{-4}$
$\phi\to\pi^0 l^+l^-$	1.6×10^{-5}	$<1.2\times10^{-4}$	4.8×10^{-6}	
$\phi\to\eta l^+l^-$	1.1×10^{-4}	$(1.3^{+0.8}_{-0.6})\times10^{-4}$	6.8×10^{-6}	
$\eta\to\gamma l^+l^-$	6.5×10^{-3}	$(4.9\pm1.1)\times10^{-3}$	3.0×10^{-4}	$(3.1\pm0.4)\times10^{-4}$
$\eta\to\pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(1.3^{+1.2}_{-0.8})\times10^{-3}$	1.2×10^{-8}	$< 3.6\times10^{-4}$
$\eta'\to\gamma l^+l^-$	4.2×10^{-4}	$< 9.0\times10^{-4}$	8.1×10^{-5}	$(1.04\pm0.26)\times10^{-4}$
$\eta'\to\omega l^+l^-$	2.0×10^{-4}			
$\eta'\to\pi^+\pi^- l^+l^-$	1.8×10^{-3}	$(2.4\pm1.3)\times10^{-3}$	2.0×10^{-5}	$< 2.2\times10^{-4}$
$f_0\to\gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0\to\pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0\to\gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0\to\pi\eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
$\pi^0\to\gamma l^+l^-$	1.18×10^{-2}	$(1.198\pm0.032)\times10^{-2}$		



PDG/1998 - PDG/2013

Ширины e^+e^- распадов



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Decay mode	$B^{\text{theor}}_{e^+e^-}$	$B^{\text{expt}}_{e^+e^-}$	$B^{\text{theor}}_{\mu^+\mu^-}$	$B^{\text{expt}}_{\mu^+\mu^-}$
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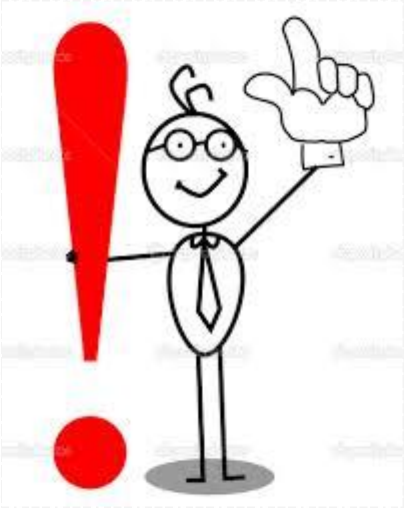
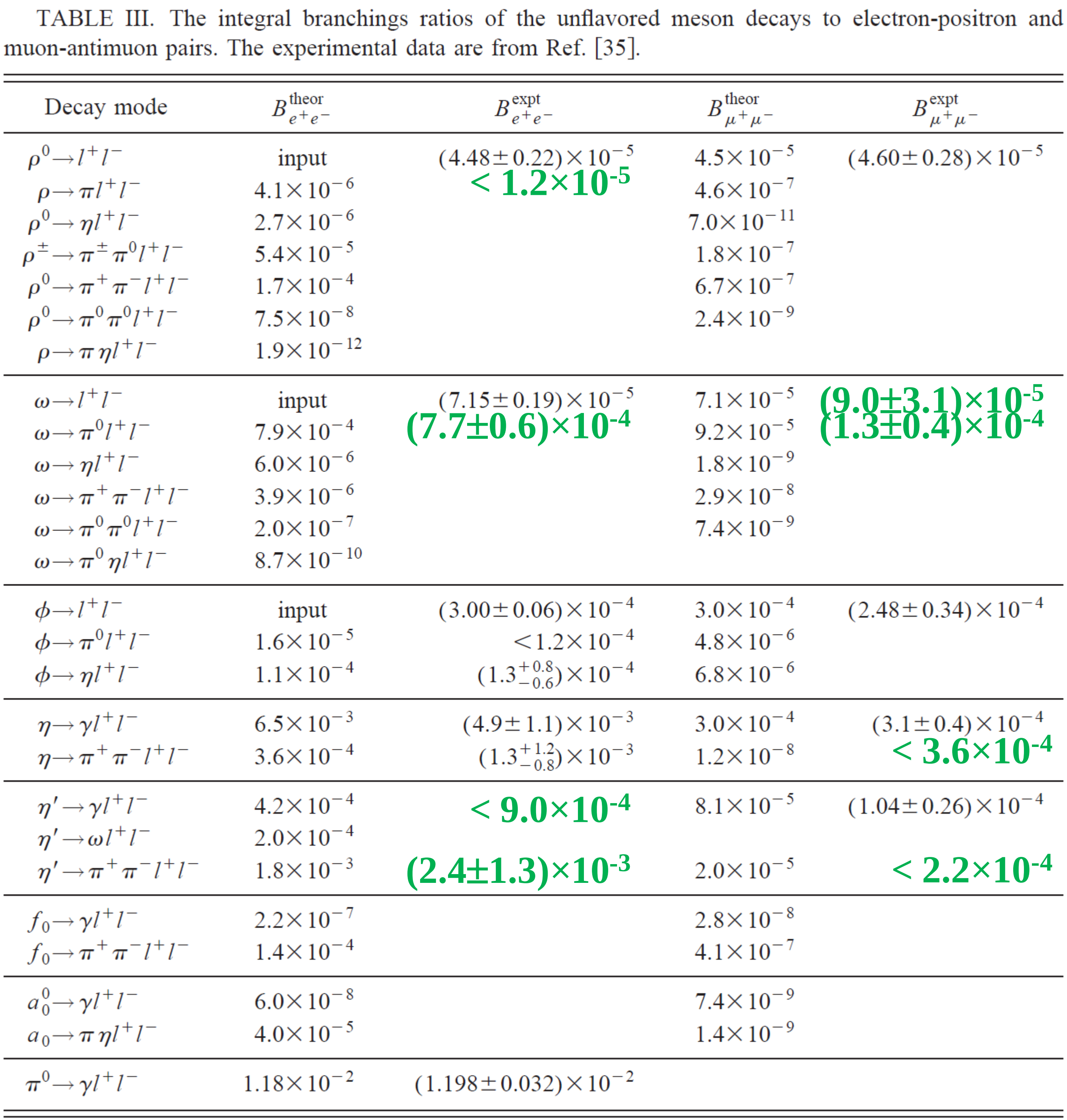
$\rho \to \pi l^+l^-$	4.1×10^{-6}	$< 1.2\times10^{-5}$	4.6×10^{-7}	
$\rho^0 \to \eta l^+l^-$	2.7×10^{-6}		7.0×10^{-11}	
$\rho^\pm \to \pi^\pm \pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0 \to \pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0 \to \pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho \to \pi \eta l^+l^-$	1.9×10^{-12}			
$\omega \to l^+l^-$	input	$(7.15 \pm 0.19) \times 10^{-5}$	7.1×10^{-5}	$(9.0\pm3.1)\times10^{-5}$
$\omega \to \pi^0 l^+l^-$	7.9×10^{-4}	$(5.9 \pm 1.9) \times 10^{-4}$	9.2×10^{-5}	$(9.6 \pm 2.3) \times 10^{-5}$
$\omega \to \eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega \to \pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
$\omega \to \pi^0\pi^0 l^+l^-$	2.0×10^{-7}		7.4×10^{-9}	
$\omega \to \pi^0 \eta l^+l^-$	8.7×10^{-10}			
$\phi \to l^+l^-$	input	$(3.00 \pm 0.06) \times 10^{-4}$	3.0×10^{-4}	$(2.48 \pm 0.34) \times 10^{-4}$
$\phi \to \pi^0 l^+l^-$	1.6×10^{-5}	$< 1.2 \times 10^{-4}$	4.8×10^{-6}	
$\phi \to \eta l^+l^-$	1.1×10^{-4}	$(1.3^{+0.8}_{-0.6}) \times 10^{-4}$	6.8×10^{-6}	
$\eta \to \gamma l^+l^-$	6.5×10^{-3}	$(4.9 \pm 1.1) \times 10^{-3}$	3.0×10^{-4}	$(3.1 \pm 0.4) \times 10^{-4}$
$\eta \to \pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(1.3^{+1.2}_{-0.8}) \times 10^{-3}$	1.2×10^{-8}	$< 3.6\times10^{-4}$
$\eta' \to \gamma l^+l^-$	4.2×10^{-4}	$< 9.0\times10^{-4}$	8.1×10^{-5}	$(1.04 \pm 0.26) \times 10^{-4}$
$\eta' \to \omega l^+l^-$	2.0×10^{-4}			
$\eta' \to \pi^+\pi^- l^+l^-$	1.8×10^{-3}	$(2.4\pm1.3)\times10^{-3}$	2.0×10^{-5}	$< 2.2\times10^{-4}$
$f_0 \to \gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0 \to \pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0 \to \gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0 \to \pi \eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
$\pi^0 \to \gamma l^+l^-$	1.18×10^{-2}	$(1.198 \pm 0.032) \times 10^{-2}$		



PDG/1998 - PDG/2013

Ширины e^+e^- распадов



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$\rho \to \pi l^+l^-$	4.1×10^{-6}	$< 1.2\times10^{-5}$	4.6×10^{-7}	
$\rho^0 \to \eta l^+l^-$	2.7×10^{-6}		7.0×10^{-11}	
$\rho^\pm \to \pi^\pm \pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0 \to \pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0 \to \pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho \to \pi \eta l^+l^-$	1.9×10^{-12}			
$\omega \to l^+l^-$	input	$(7.15 \pm 0.19)\times 10^{-5}$	7.1×10^{-5}	$(9.0\pm3.1)\times10^{-5}$
$\omega \to \pi^0 l^+l^-$	7.9×10^{-4}	$(7.7\pm0.6)\times10^{-4}$	9.2×10^{-5}	$(1.3\pm0.4)\times10^{-4}$
$\omega \to \eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega \to \pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
$\omega \to \pi^0\pi^0 l^+l^-$	2.0×10^{-7}		7.4×10^{-9}	
$\omega \to \pi^0 \eta l^+l^-$	8.7×10^{-10}			
$\phi \to l^+l^-$	input	$(3.00 \pm 0.06)\times 10^{-4}$	3.0×10^{-4}	$(2.48 \pm 0.34)\times 10^{-4}$
$\phi \to \pi^0 l^+l^-$	1.6×10^{-5}	$<1.2\times 10^{-4}$	4.8×10^{-6}	
$\phi \to \eta l^+l^-$	1.1×10^{-4}	$(1.3^{+0.8}_{-0.6})\times 10^{-4}$	6.8×10^{-6}	
$\eta \to \gamma l^+l^-$	6.5×10^{-3}	$(4.9 \pm 1.1)\times 10^{-3}$	3.0×10^{-4}	$(3.1 \pm 0.4)\times 10^{-4}$
$\eta \to \pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(1.3^{+1.2}_{-0.8})\times 10^{-3}$	1.2×10^{-8}	$< 3.6\times10^{-4}$
$\eta' \to \gamma l^+l^-$	4.2×10^{-4}	$< 9.0\times10^{-4}$	8.1×10^{-5}	$(1.04 \pm 0.26)\times 10^{-4}$
$\eta' \to \omega l^+l^-$	2.0×10^{-4}			
$\eta' \to \pi^+\pi^- l^+l^-$	1.8×10^{-3}	$(2.4\pm1.3)\times10^{-3}$	2.0×10^{-5}	$< 2.2\times10^{-4}$
$f_0 \to \gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0 \to \pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0 \to \gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0 \to \pi \eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
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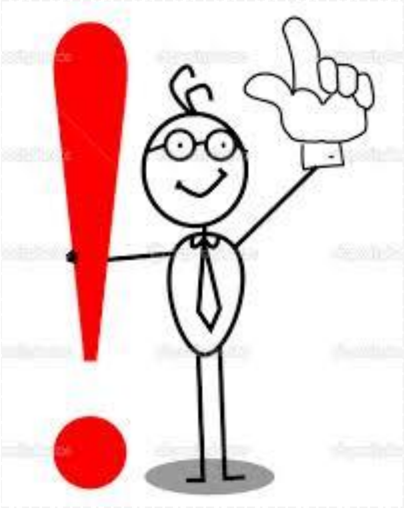
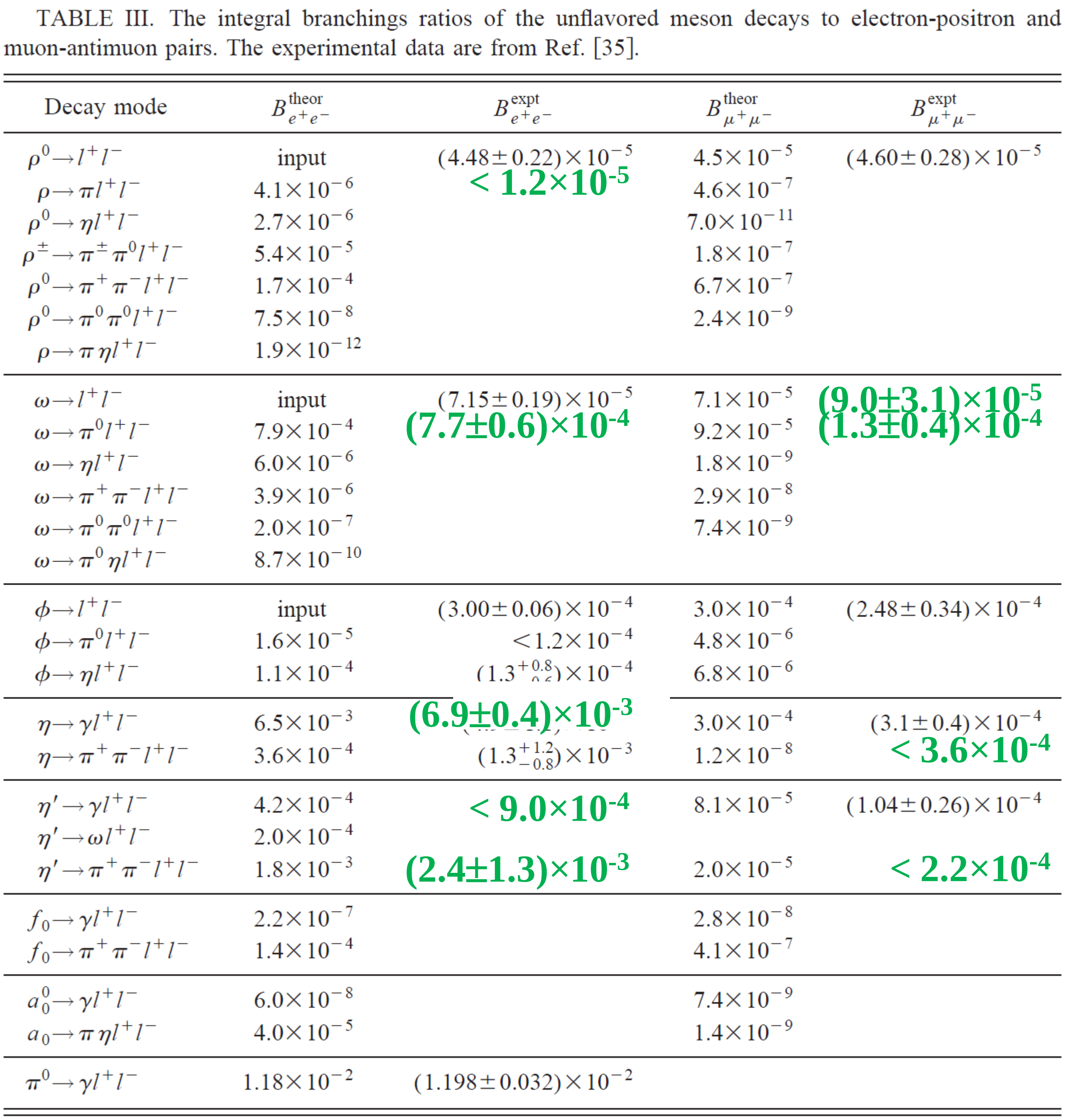


PDG/1998 - PDG/2013

Ширины e^+e^- распадов



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$\rho^\pm \to \pi^\pm\pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0 \to \pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0 \to \pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho \to \pi\eta l^+l^-$	1.9×10^{-12}			
$\omega \to l^+l^-$	input	$(7.15 \pm 0.19)\times 10^{-5}$	7.1×10^{-5}	$(9.0\pm3.1)\times10^{-5}$
$\omega \to \pi^0 l^+l^-$	7.9×10^{-4}	$(7.7\pm0.6)\times10^{-4}$	9.2×10^{-5}	$(1.3\pm0.4)\times10^{-4}$
$\omega \to \eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega \to \pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
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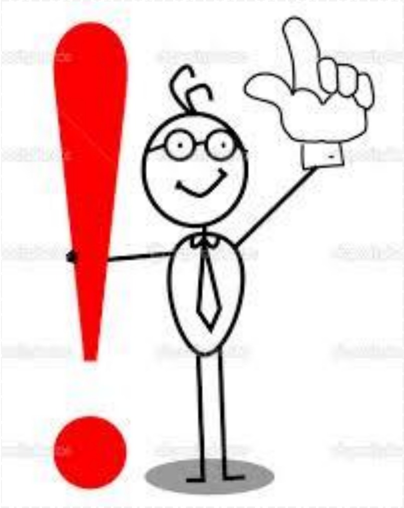
$\eta \to \gamma l^+l^-$	6.5×10^{-3}	$(6.9\pm0.4)\times10^{-3}$	3.0×10^{-4}	$(3.1 \pm 0.4)\times 10^{-4}$
$\eta \to \pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(1.3^{+1.2}_{-0.8})\times 10^{-3}$	1.2×10^{-8}	$< 3.6\times10^{-4}$
$\eta' \to \gamma l^+l^-$	4.2×10^{-4}	$< 9.0\times10^{-4}$	8.1×10^{-5}	$(1.04 \pm 0.26)\times 10^{-4}$
$\eta' \to \omega l^+l^-$	2.0×10^{-4}			
$\eta' \to \pi^+\pi^- l^+l^-$	1.8×10^{-3}	$(2.4\pm1.3)\times10^{-3}$	2.0×10^{-5}	$< 2.2\times10^{-4}$
$f_0 \to \gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0 \to \pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0 \to \gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0 \to \pi\eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
$\pi^0 \to \gamma l^+l^-$	1.18×10^{-2}	$(1.198 \pm 0.032)\times 10^{-2}$		

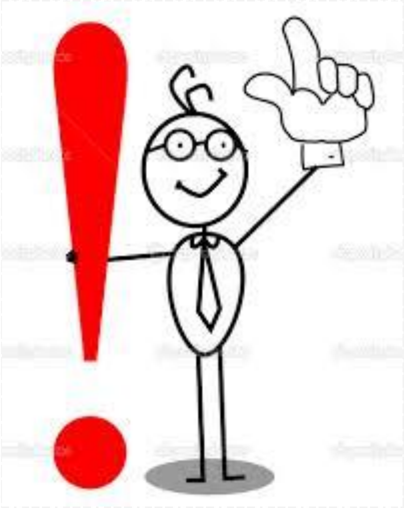


PDG/1998 - PDG/2013

Ширины e^+e^- распадов

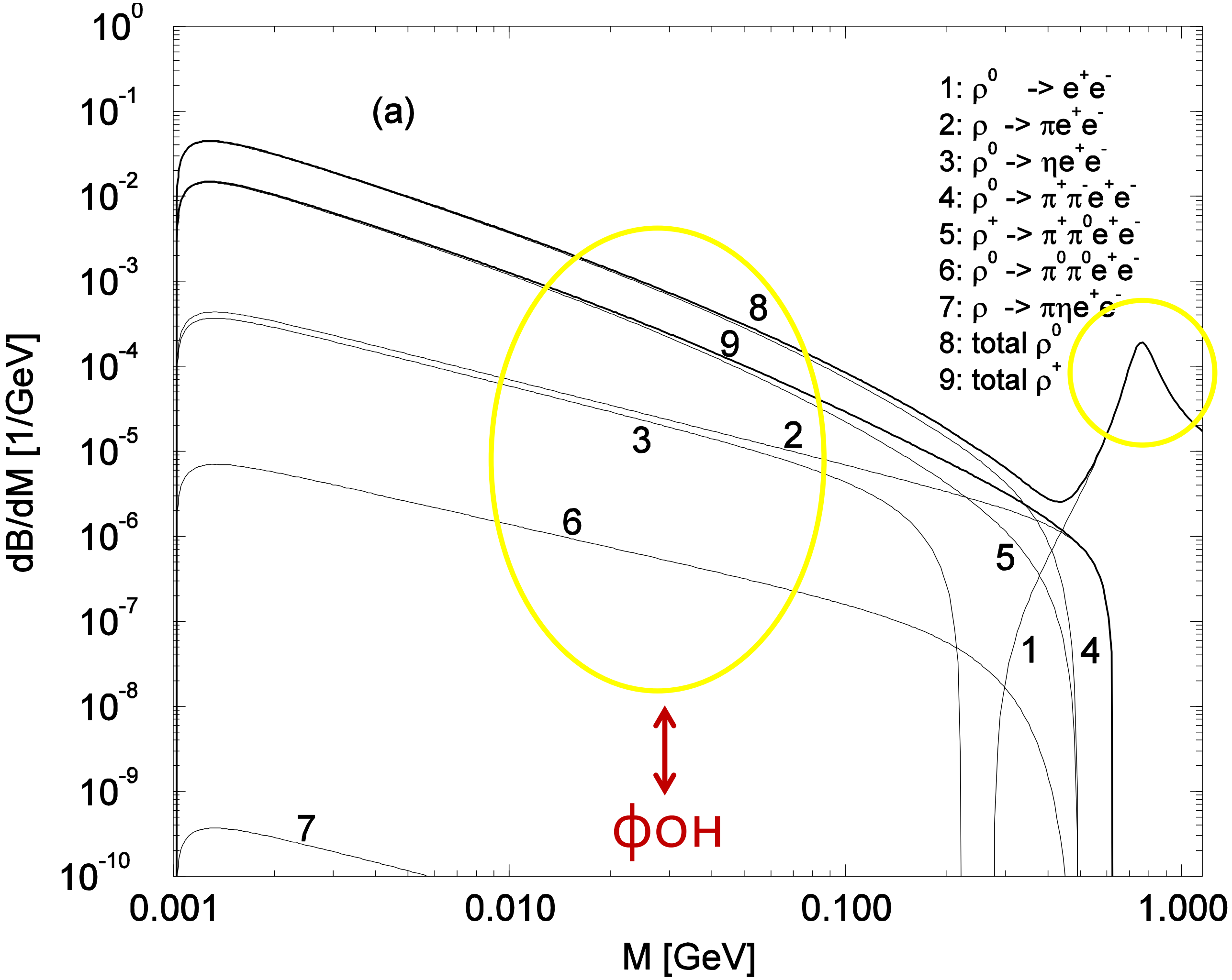
TABLE III. The integral branchings ratios of the unflavored meson decays to electron-positron and muon-antimuon pairs. The experimental data are from Ref. [35].

Decay mode	$B^{\rm theor}_{e^+e^-}$	$B^{\rm expt}_{e^+e^-}$	$B^{\rm theor}_{\mu^+\mu^-}$	$B^{\rm expt}_{\mu^+\mu^-}$
$\rho^0\to l^+l^-$	input	$(4.48\pm0.22)\times10^{-5}$	4.5×10^{-5}	$(4.60\pm0.28)\times10^{-5}$
$\rho\to\pi l^+l^-$	4.1×10^{-6}	$< 1.2\times10^{-5}$	4.6×10^{-7}	
$\rho^0\to\eta l^+l^-$	2.7×10^{-6}		7.0×10^{-11}	
$\rho^\pm\to\pi^\pm\pi^0 l^+l^-$	5.4×10^{-5}		1.8×10^{-7}	
$\rho^0\to\pi^+\pi^- l^+l^-$	1.7×10^{-4}		6.7×10^{-7}	
$\rho^0\to\pi^0\pi^0 l^+l^-$	7.5×10^{-8}		2.4×10^{-9}	
$\rho\to\pi\eta l^+l^-$	1.9×10^{-12}			
$\omega\to l^+l^-$	input	$(7.15\pm0.19)\times10^{-5}$	7.1×10^{-5}	$(9.0\pm3.1)\times10^{-5}$
$\omega\to\pi^0 l^+l^-$	7.9×10^{-4}	$(7.7\pm0.6)\times10^{-4}$	9.2×10^{-5}	$(1.3\pm0.4)\times10^{-4}$
$\omega\to\eta l^+l^-$	6.0×10^{-6}		1.8×10^{-9}	
$\omega\to\pi^+\pi^- l^+l^-$	3.9×10^{-6}		2.9×10^{-8}	
$\omega\to\pi^0\pi^0 l^+l^-$	2.0×10^{-7}		7.4×10^{-9}	
$\omega\to\pi^0\eta l^+l^-$	8.7×10^{-10}			
$\phi\to l^+l^-$	input	$(3.00\pm0.06)\times10^{-4}$	3.0×10^{-4}	$(2.48\pm0.34)\times10^{-4}$
$\phi\to\pi^0 l^+l^-$	1.6×10^{-5}	$<1.2\times10^{-4}$	4.8×10^{-6}	
$\phi\to\eta l^+l^-$	1.1×10^{-4}	$(1.3^{+0.8}_{-0.6})\times10^{-4}$	6.8×10^{-6}	
$\eta\to\gamma l^+l^-$	6.5×10^{-3}	$(6.9\pm0.4)\times10^{-3}$	3.0×10^{-4}	$(3.1\pm0.4)\times10^{-4}$
$\eta\to\pi^+\pi^- l^+l^-$	3.6×10^{-4}	$(2.68\pm0.11)\times10^{-4}$	1.2×10^{-8}	$< 3.6\times10^{-4}$
$\eta'\to\gamma l^+l^-$	4.2×10^{-4}	$< 9.0\times10^{-4}$	8.1×10^{-5}	$(1.04\pm0.26)\times10^{-4}$
$\eta'\to\omega l^+l^-$	2.0×10^{-4}			
$\eta'\to\pi^+\pi^- l^+l^-$	1.8×10^{-3}	$(2.4\pm1.3)\times10^{-3}$	2.0×10^{-5}	$< 2.2\times10^{-4}$
$f_0\to\gamma l^+l^-$	2.2×10^{-7}		2.8×10^{-8}	
$f_0\to\pi^+\pi^- l^+l^-$	1.4×10^{-4}		4.1×10^{-7}	
$a_0^0\to\gamma l^+l^-$	6.0×10^{-8}		7.4×10^{-9}	
$a_0\to\pi\eta l^+l^-$	4.0×10^{-5}		1.4×10^{-9}	
$\pi^0\to\gamma l^+l^-$	1.18×10^{-2}	$(1.198\pm0.032)\times10^{-2}$		



PDG/1998 - PDG/2013

Спектр дилептонов (ρ-мезон)

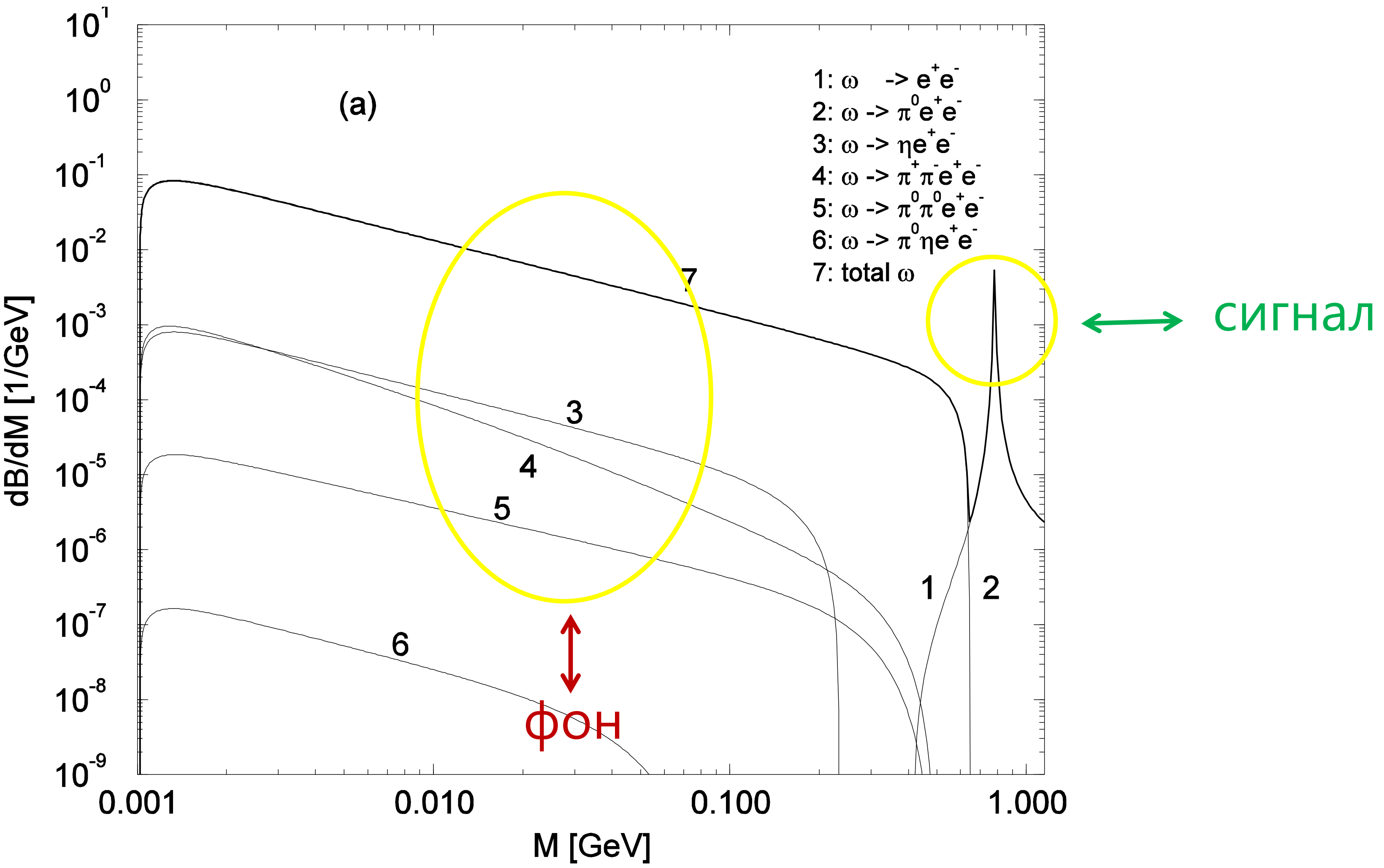


сигнал

фон

$M \rightarrow (M', M'')\, e^+e^-$

Спектр дилептонов (ω-мезон)



сигнал

фон

$M \longrightarrow (M', M'')\, e^+e^-$

Дилептонные распады нуклонных резонансов
$N^* \to N\, e^+e^-$

Распады $R \to N\, e^+e^-$, $R = N^*, \Delta^*$, произвольная спин-четность ($J = l+1/2$):

$$\Gamma(N^*_{(\pm)} \to N\gamma^*) = \frac{9\alpha}{16}\frac{(l!)^2}{2^l(2l+1)!}\frac{m_\pm^2(m_\mp^2 - M^2)^{l+1/2}(m_\pm^2 - M^2)^{l-1/2}}{m_*^{2l+1}m^2}$$

$$\left(\frac{l+1}{l}\left|G^{(\pm)}_{M/E}\right|^2 + (l+1)(l+2)\left|G^{(\pm)}_{E/M}\right|^2 + \frac{M^2}{m_*^2}\left|G^{(\pm)}_C\right|^2\right).$$

$$d\Gamma(N^* \to Ne^+e^-) = \Gamma(N^* \to N\gamma^*)M\Gamma(\gamma^* \to e^+e^-)\frac{dM^2}{\pi M^4},$$

$$M\Gamma(\gamma^* \to e^+e^-) = \frac{\alpha}{3}(M^2 + 2m_e^2)\sqrt{1 - \frac{4m_e^2}{M^2}}$$

$R \to Ne^+e^-$

eVMD модель

Правила кваркового счета:

$$F_1^{(\pm)}(M^2) = O(\frac{1}{(-M^2)^{l+2}}),$$

$$F_2^{(\pm)}(M^2) = O(\frac{1}{(-M^2)^{l+3}}),$$

$$F_3^{(\pm)}(M^2) = O(\frac{1}{(-M^2)^{l+3}}).$$

Форм-факторы в eVMD

$$F_1^{(\pm)}(M^2) = \frac{\sum_{j=0}^{n+1} C_{1j}^{(\pm)} M^{2j}}{\prod_{i=1}^{l+3+n} (1 - M^2/m_i^2)},$$

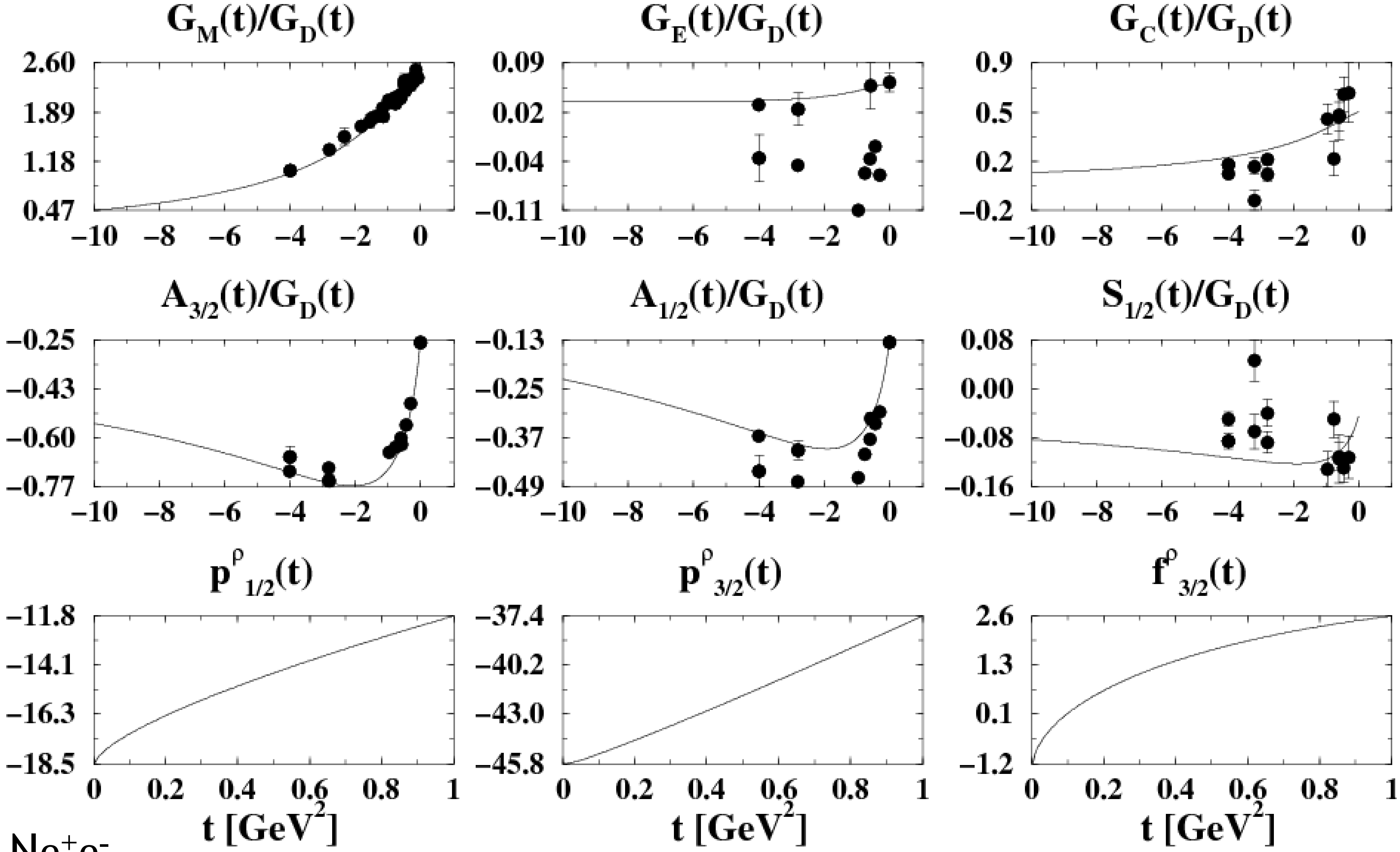
$$F_2^{(\pm)}(M^2) = \frac{\sum_{j=0}^{n} C_{2j}^{(\pm)} M^{2j}}{\prod_{i=1}^{l+3+n} (1 - M^2/m_i^2)},$$

$$F_3^{(\pm)}(M^2) = \frac{\sum_{j=0}^{n} C_{3j}^{(\pm)} M^{2j}}{\prod_{i=1}^{l+3+n} (1 - M^2/m_i^2)}.$$

$R \longrightarrow Ne^+e^-$

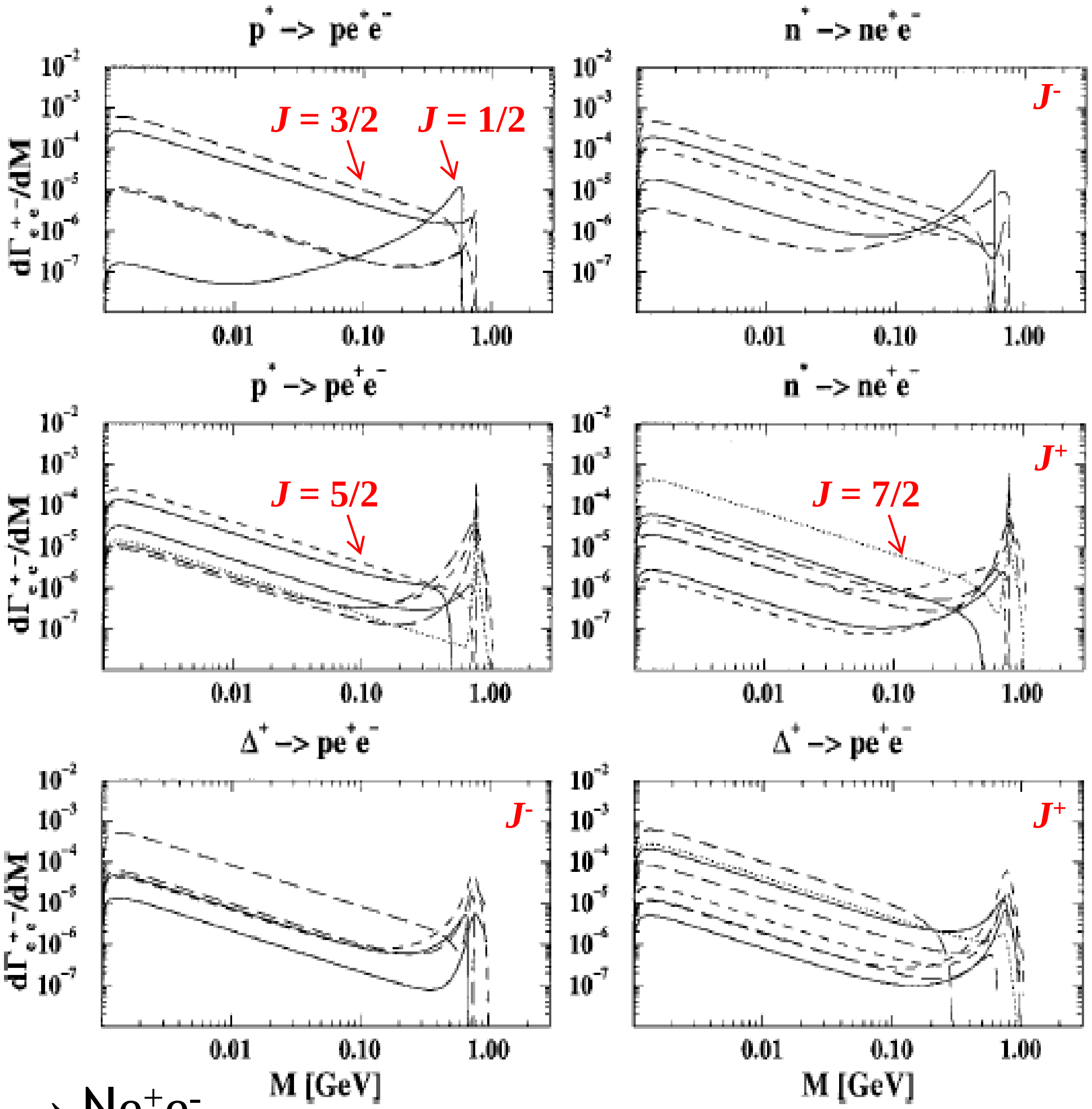
$G_D(t) = (1 - t/0.81)^{-2}.$

eVMD модель для Δ(1232)



$R \rightarrow Ne^+e^-$

e^+e^- спектры R → N e^+e^-
R с массой < 2 ГэВ



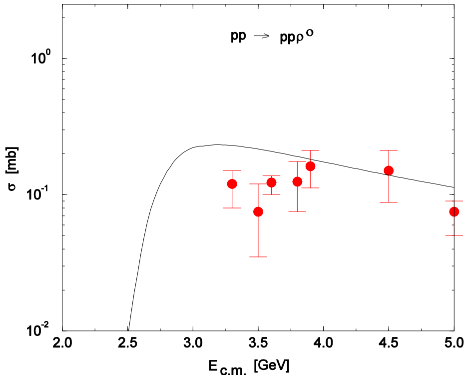
R → Ne^+e^-

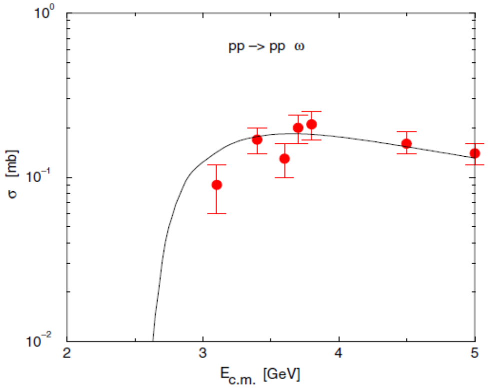
Рождение e^+e^- в pp соударениях. NRD model.
Сравнение с данными DLS (Bevalac)

Прямой канал $V = \rho^0, \omega, \phi$

$$\frac{d\sigma(s,M)^{pp\to e^+e^-X}}{dM^2} = \sum_V (\frac{d\sigma(s,M)^{pp\to VX}}{dM^2} B(M)^{V\to e^+e^-}.$$

Нормировка на эксклюзивные сечения ρ и ω (pp →pN*, N* → NV)





Фон:

$$\frac{d\sigma(s,M)_B^{e^+e^-X}}{dM^2}\Big|_{X\neq NN} = \sum_{\mathrm{M}}\int d\mu^2 \frac{d\sigma(s,\mu)^{\mathrm{MX}'}}{d\mu^2}\frac{dB(\mu,M)^{\mathrm{M}\to e^+e^-X''}}{dM^2}..$$

NN → NR, R → N(M,e^+e^-)

Сумма берется по мезонам $\mathrm{M} = \pi, \eta, \rho, \omega, \phi$

Константы связи RNρ из R → Nρ & R → Nγ в VMD

R	$N1440$	$N1520$	$N1535$	$N1650$	$N1680$	$N1720$	$\Delta1232$	$\Delta1620$	$\Delta1700$	$\Delta1905$
J^P	$\frac{1^+}{2}$	$\frac{3^-}{2}$	$\frac{1^-}{2}$	$\frac{1^-}{2}$	$\frac{5^+}{2}$	$\frac{3^+}{2}$	$\frac{3^+}{2}$	$\frac{1^-}{2}$	$\frac{3^-}{2}$	$\frac{5^+}{2}$
$f_{RN\rho}$	<26	7.0	<2.0	0.9	6.3	7.8	15.3	2.5	5.0	12.2
$f^{\gamma}_{RN\rho}$	1.3	3.8	1.8	<0.8	3.9	2.2	10.8	0.7	2.7	2.1

eVMD форм-фактор & правила кваркового счета

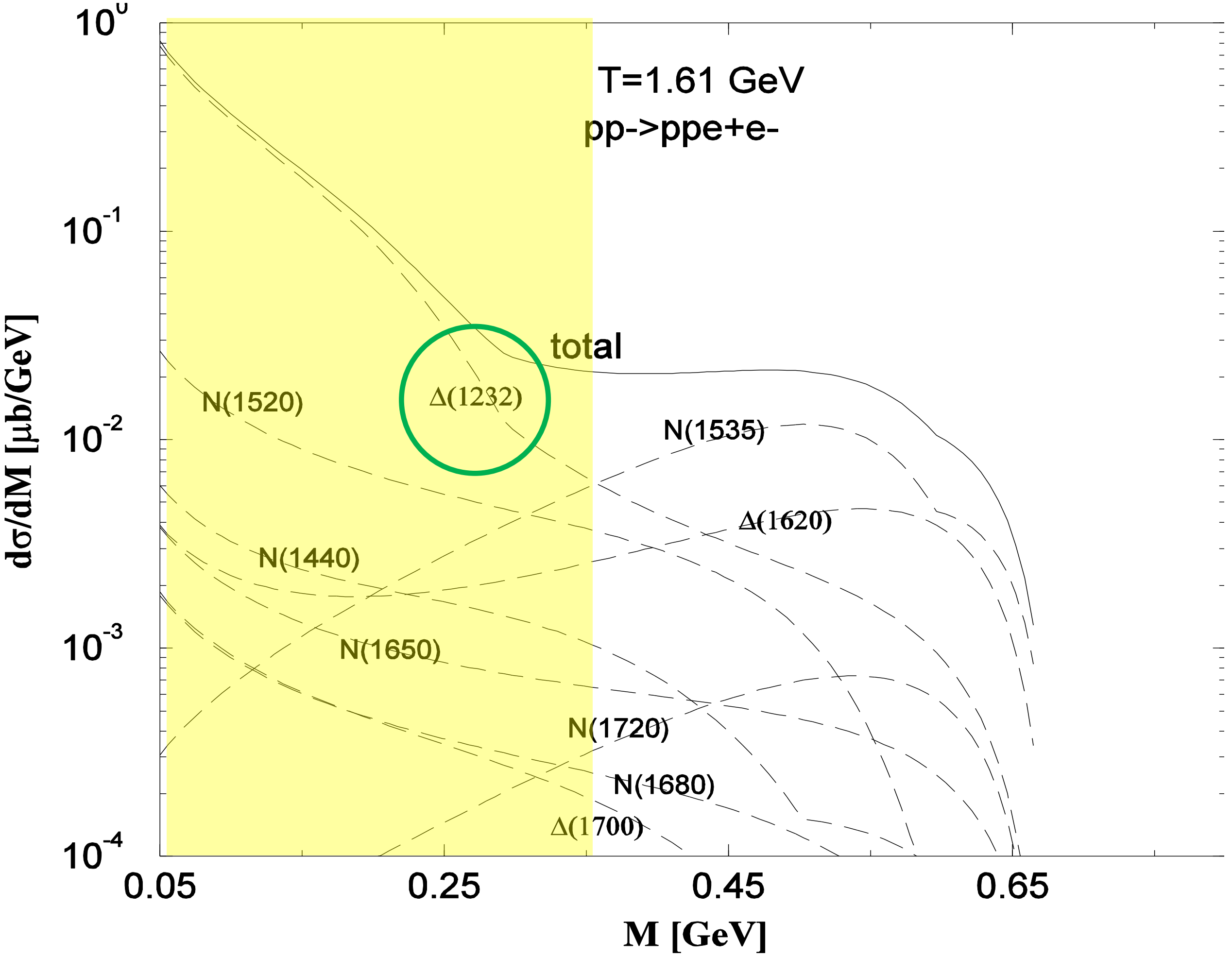
$$\mathrm{M}(M^2) = \frac{f_{RN\rho}}{m_\rho}\frac{m_\rho^2}{g_\rho}\frac{1}{\tilde{m}_\rho^2 - M^2}\left(\frac{\tilde{m}_{\rho'}^2 - \tilde{m}_\rho^2}{\tilde{m}_{\rho'}^2 - M^2}\right)\left(\frac{\tilde{m}_{\rho''}^2 - \tilde{m}_\rho^2}{\tilde{m}_{\rho''}^2 - M^2}\right).$$

Поправочный фактор:

$$F_\rho(M^2) = \left|\left(\frac{\tilde{m}_{\rho'}^2 - \tilde{m}_\rho^2}{\tilde{m}_{\rho'}^2 - M^2}\right)\left(\frac{\tilde{m}_{\rho''}^2 - \tilde{m}_\rho^2}{\tilde{m}_{\rho''}^2 - M^2}\right)\right|^2.$$

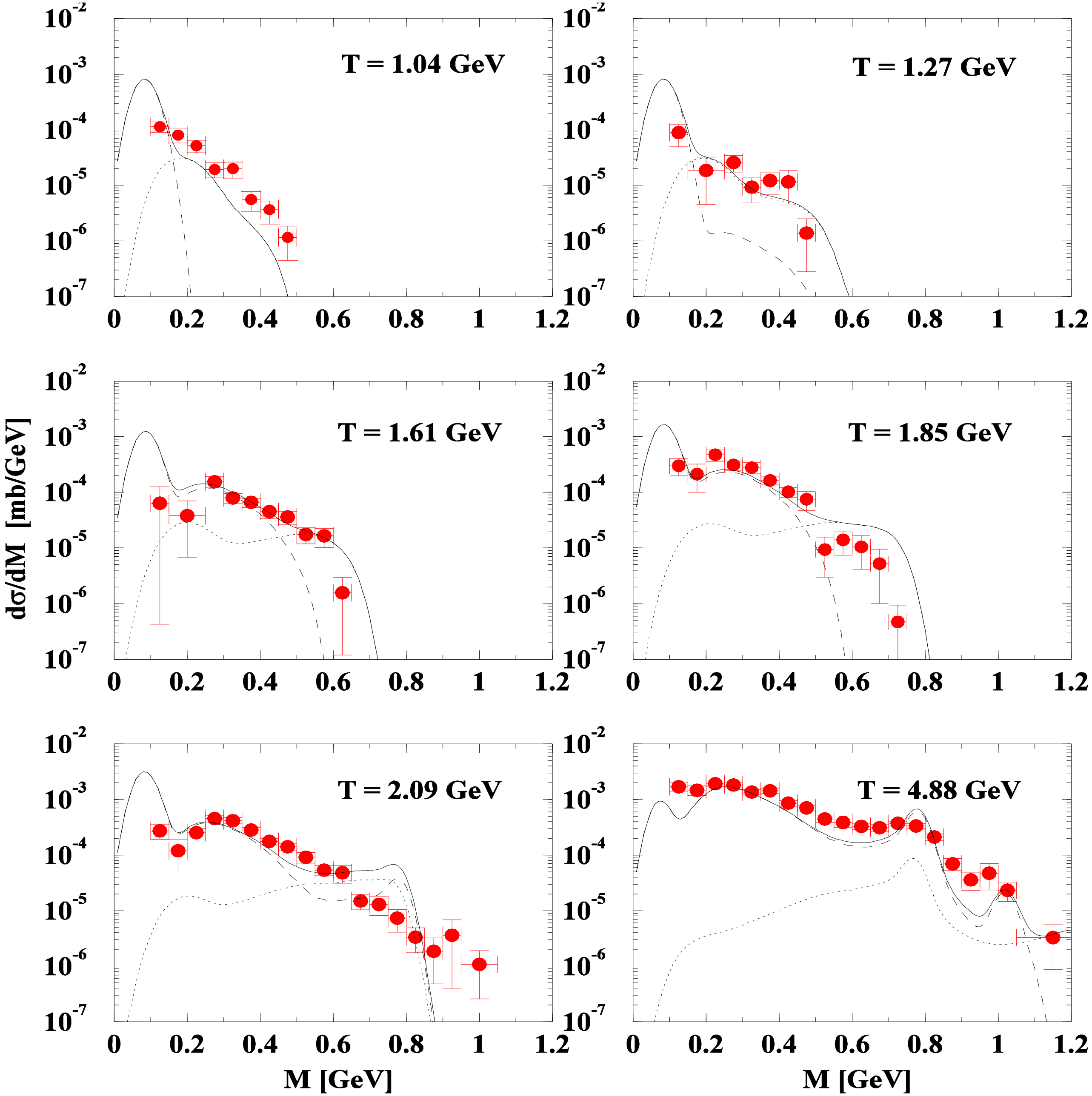
$$\boxed{F_\rho(M^2 = m^2_\rho) = 1 \;\; \& \;\; F_\rho(M^2 = 0) = 0.56}$$

NN → NR, R → N(M,e^+e^-)



Сечение рождения дилептонов в реакции *$pp \to e^+e^-pp$* в схеме *$pp \to Rp$, $R \to e^+e^-p$* при *T* = 1.61 ГэВ. Показаны вклады 10-и нуклонных резонансов.

$NN \to NR,\ R \to N(M, e^+e^-)$



Сечение

$pp \rightarrow e^+e^-X$ vs. M_{e+e-}

в сравнении с данными DLS

$NN \rightarrow NR,\ R \rightarrow N(M, e^+e^-)$

Рождение ω–мезона в NN столкновениях вблизи порога

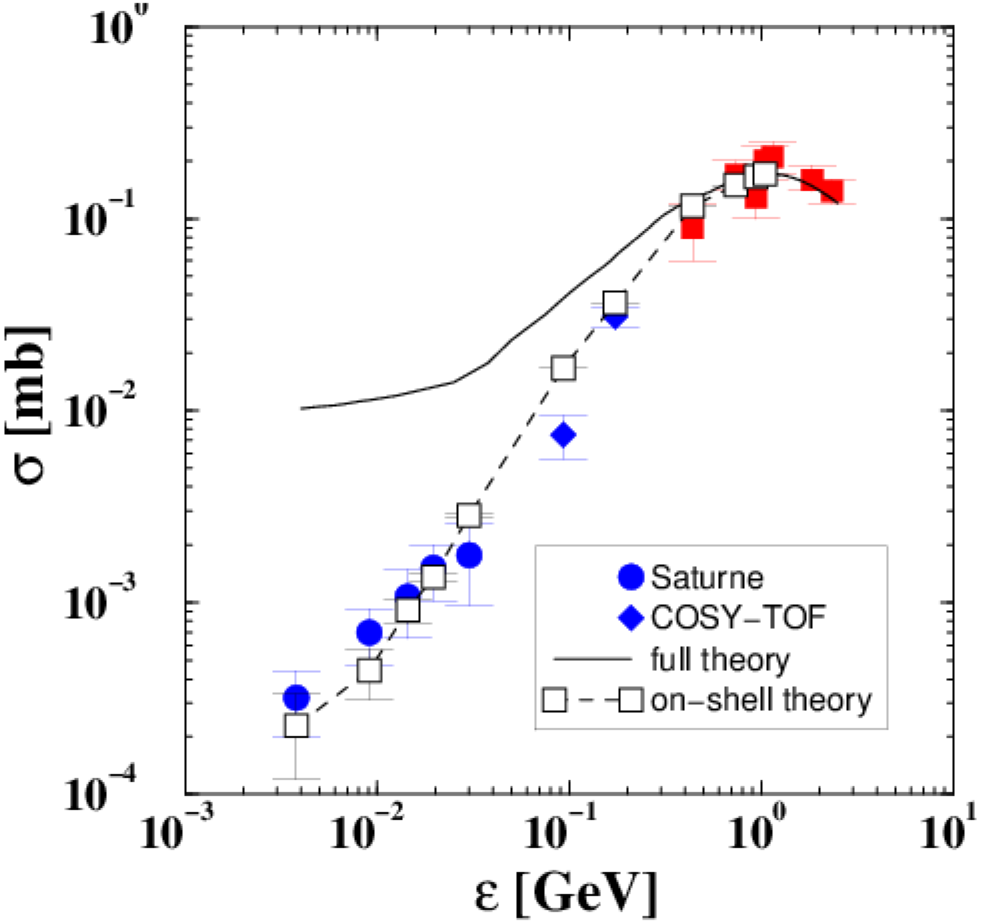
сравнение с данными Saturne & COSY-TOF

$$\frac{d\sigma(s,M)^{pp\to pp\omega}}{dM^2} = \sum_R \int_{(m_p+M)^2}^{(\sqrt{s}-m_p)^2} d\mu^2 \frac{d\sigma(s,\mu)^{pp\to pR}}{d\mu^2} \frac{dB(\mu,M)^{R\to p\omega}}{dM^2}.$$

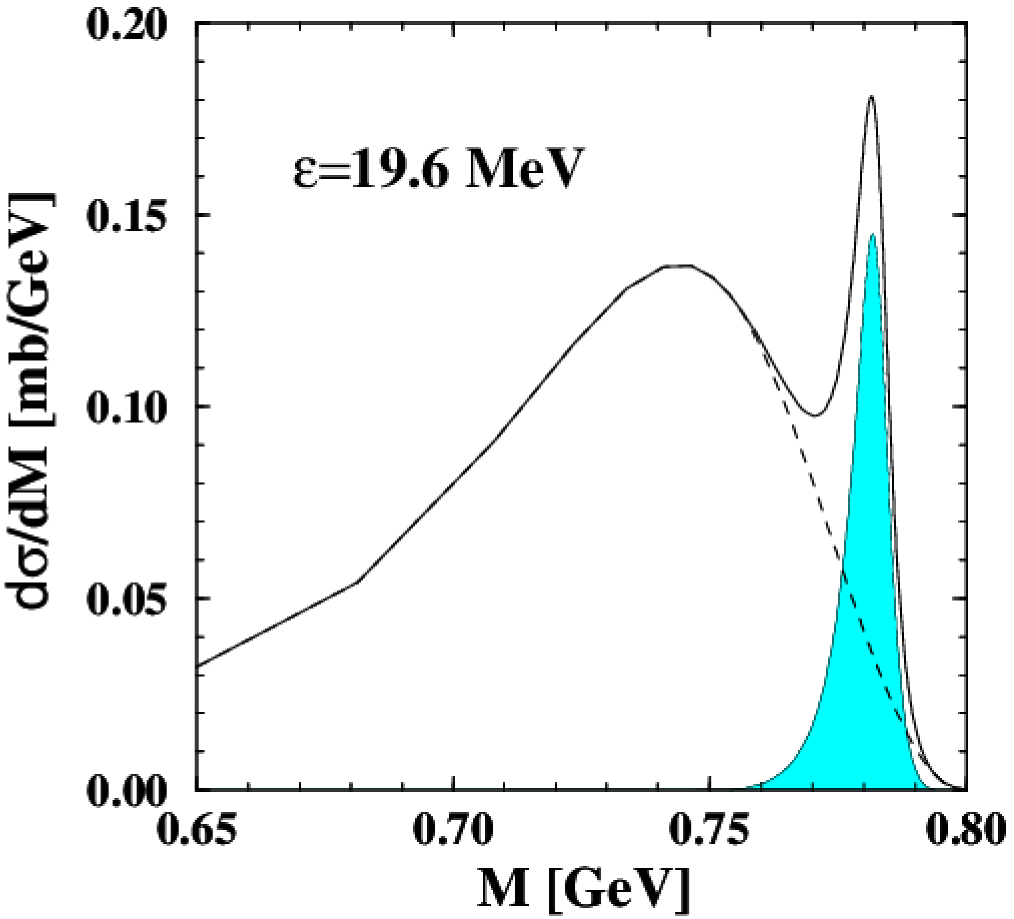
$$d\sigma(s,\mu)^{pp\to pR} = \frac{|M_R|^2}{16 p_i \sqrt{s}\pi^2} \Phi_2(\sqrt{s},\mu,m_p) dW_R(\mu)$$

$$dW_R(\mu) = \frac{1}{\pi} \frac{\mu\Gamma_R(\mu) d\mu^2}{(\mu^2 - m_R^2)^2 + (\mu\Gamma_R(\mu))^2}.$$

NN → NR, R → N(M,e^+e^-)



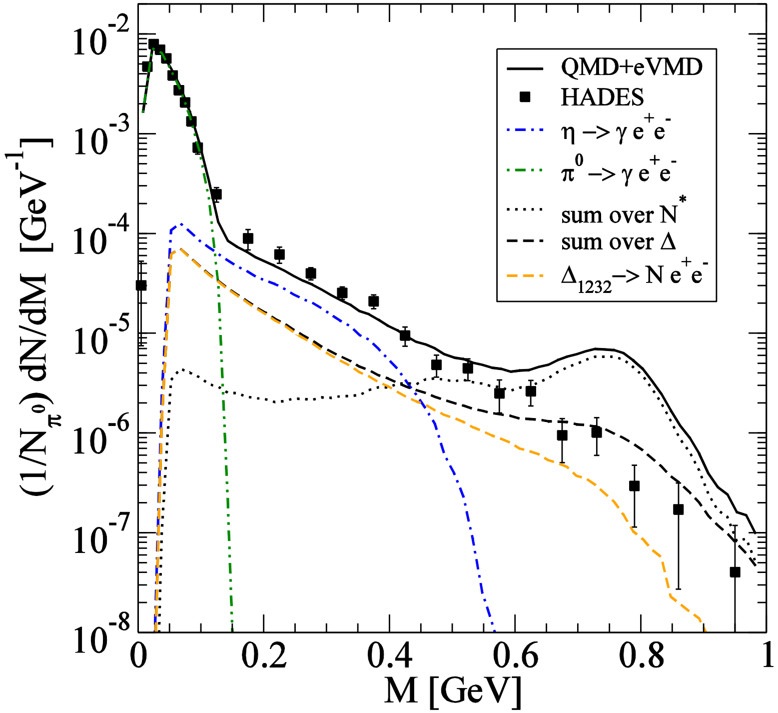
Эксклюзивное сечение в резонансной модели vs. эксперимент; ε –энергия над порогом.



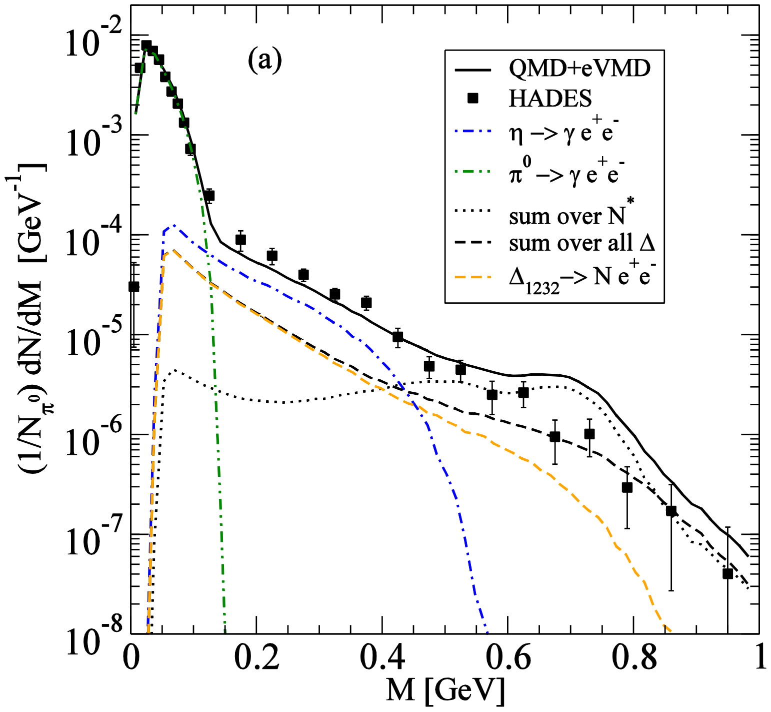
Теоретический фон, обусловленный подпороговым рождением ω-мезона, вычитается из полного сечения.

$NN \rightarrow NR$, $R \rightarrow N(M, e^{+}e^{-})$

Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.



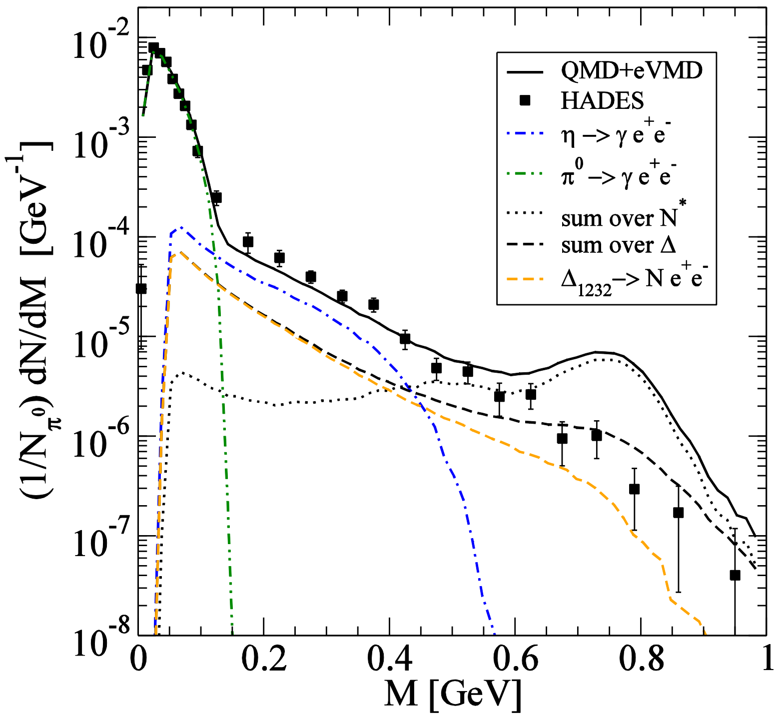
вакуумная версия NRD + eVMD



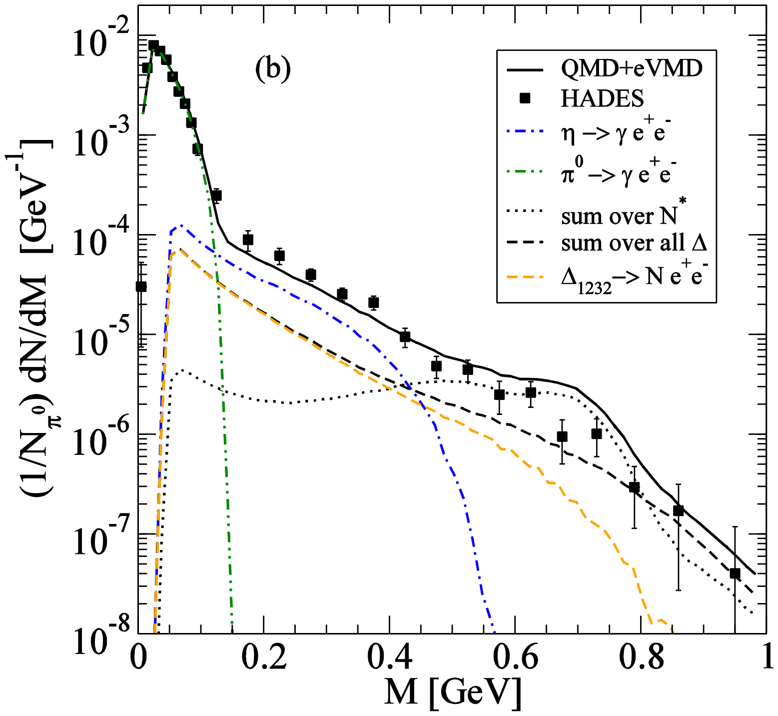
модифицированные ширины ρ и ω

(a) 200 и 60 МэВ

Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.



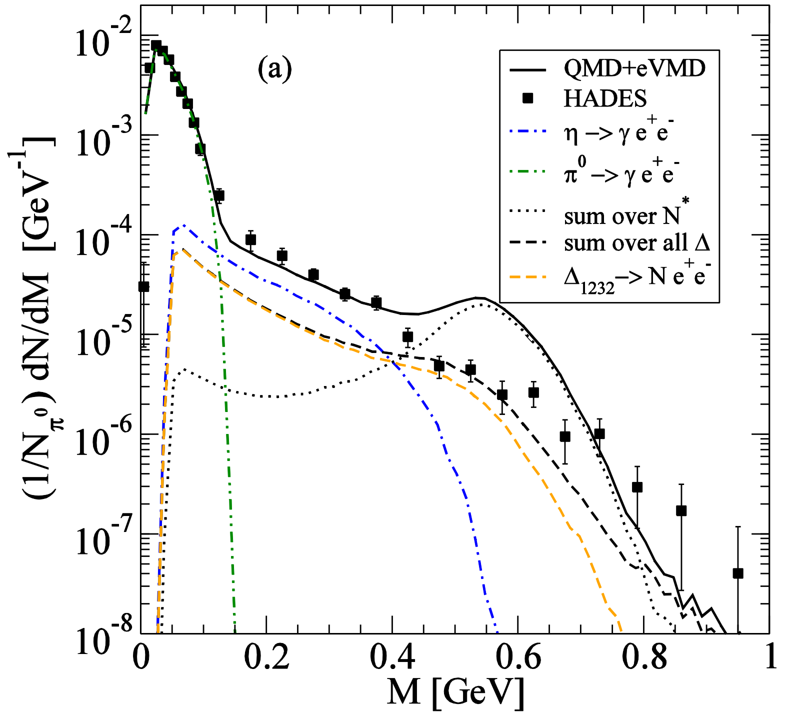
вакуумная версия NRD + eVMD



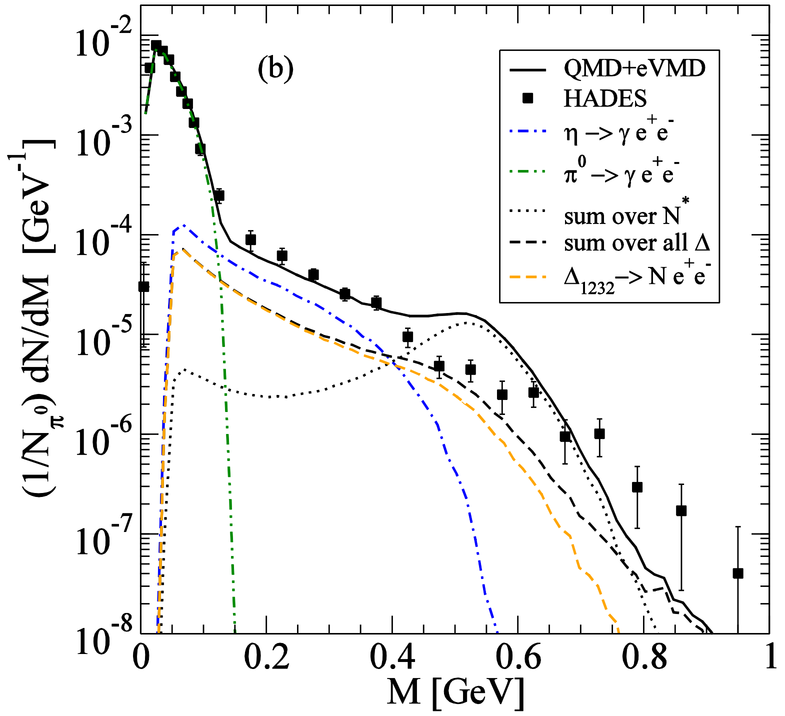
модифицированные ширины ρ и ω

(b) 250 и 120 МэВ

Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.



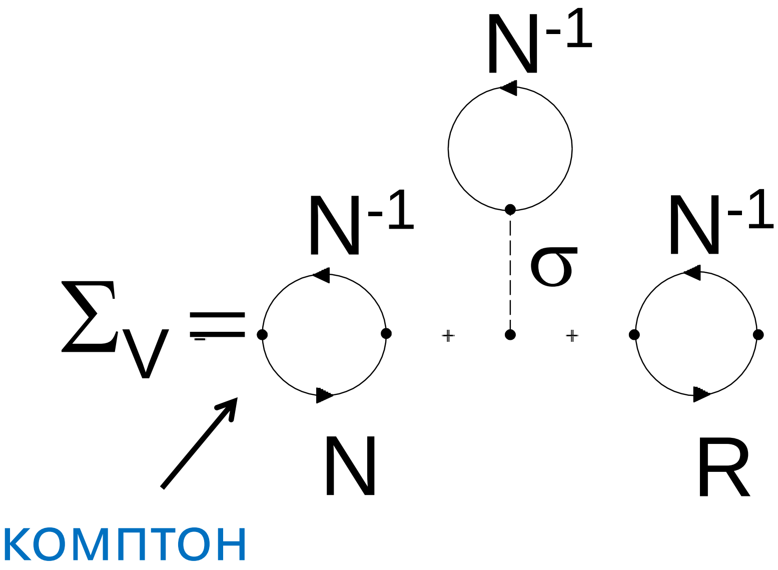
«Скейлинг Брауна-Ро»
ширины ρ и ω **= 200 и 60 МэВ**



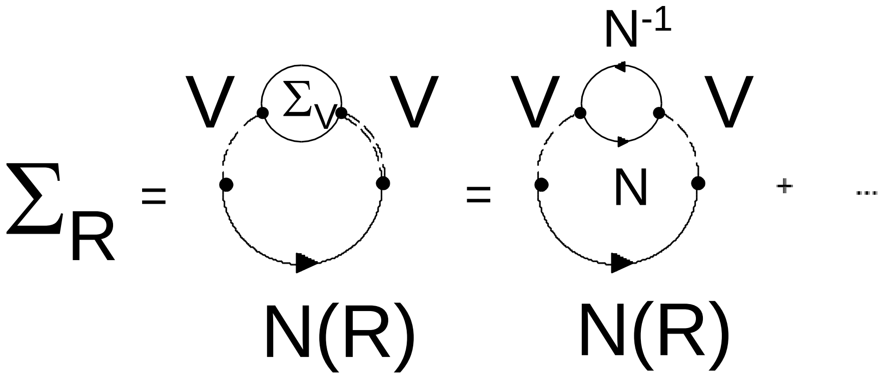
«Скейлинг Брауна-Ро»
ширины ρ и ω **= 250 и 120 МэВ**

скейлинг Brown-Rho-Hatsuda-Lee

Массовые операторы V = ρ, ω и R в ядерной среде

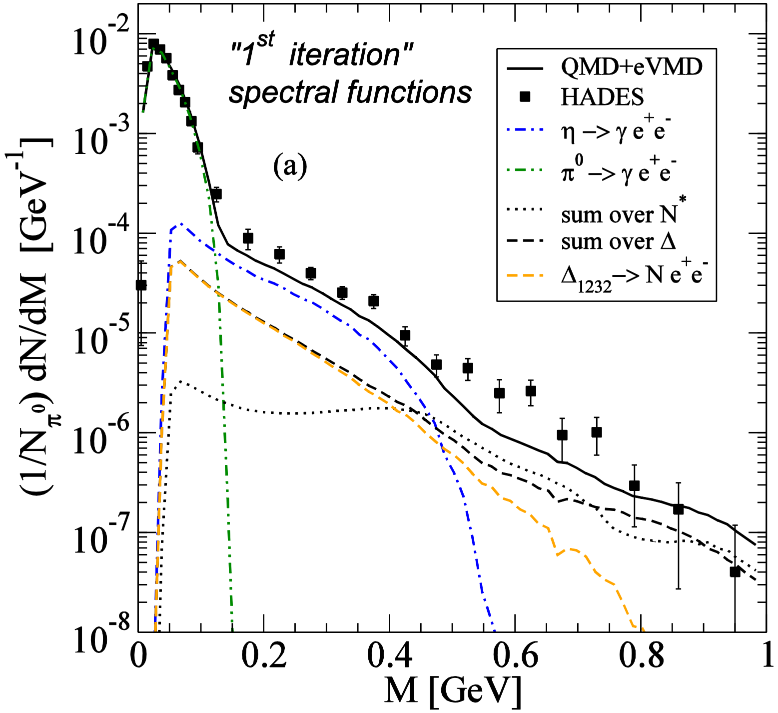


$$\mathbf{R} = \left\{ \begin{array}{l} N^*(1535)\frac{1}{2}^-, N^*(1650)\frac{1}{2}^-, N^*(1520)\frac{3}{2}^-, \\ N^*(1440)\frac{1}{2}^+, N^*(1720)\frac{3}{2}^+, N^*(1680)\frac{5}{2}^+ \\ \Delta(1620)\frac{1}{2}^-, \Delta(1700)\frac{3}{2}^-, \Delta(1232)\frac{3}{2}^+, \Delta(1905)\frac{5}{2}^+, \Delta(1950)\frac{7}{2}^+ \end{array} \right.$$



$\mathrm{Im}\{\Sigma_{V,R}\}$ ~ столкновительная ширина

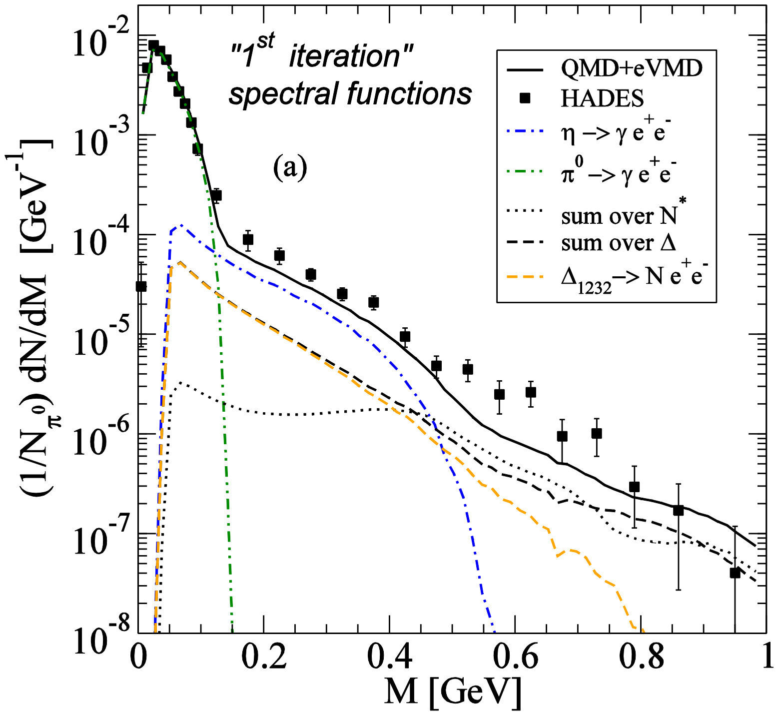
Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.

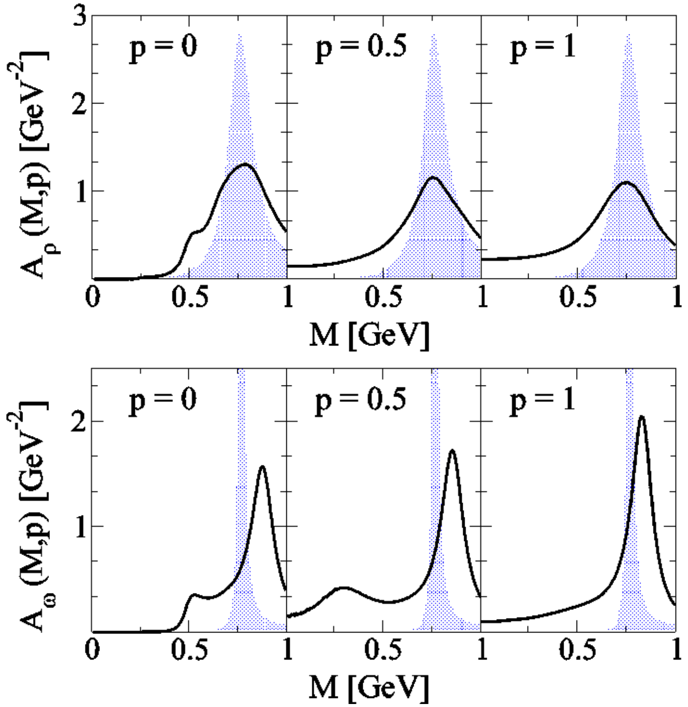


$\mathrm{Im}\{\Sigma^*_R\} = 0$

$\mathrm{Im}\{\Sigma_R\} \sim$ selfconsistent

Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.

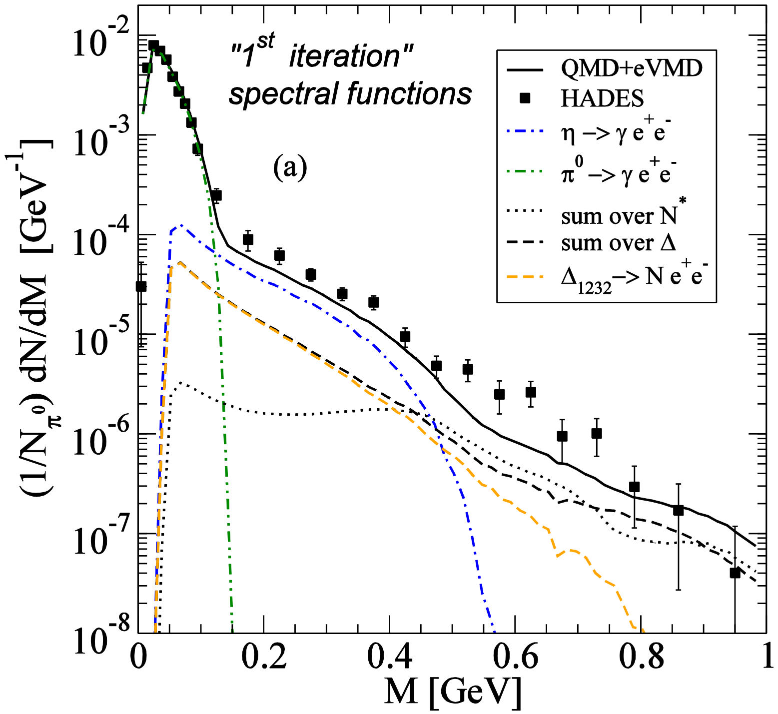




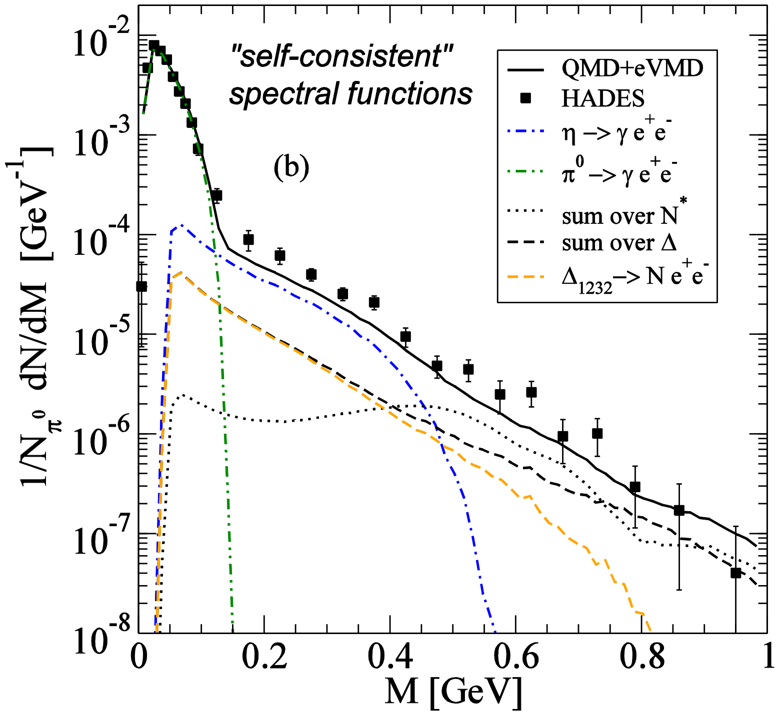
$\mathrm{Im}\{\Sigma^*_R\} = 0$

$\mathrm{Im}\{\Sigma_R\}$ ~ selfconsistent

Дилептонный спектр в реакции C + C при энергии 2 АГэВ в сравнении с данными HADES.



$Im\{\Sigma^*_R\} = 0$

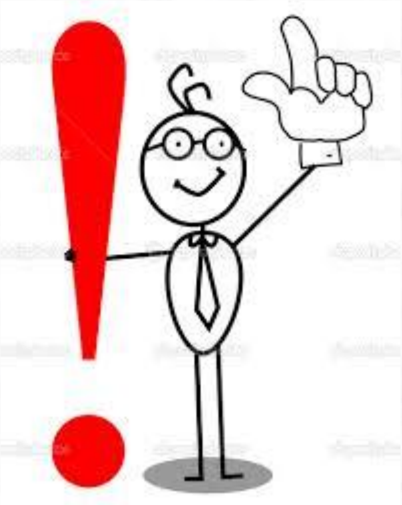


$Im\{\Sigma^*_R\}$ ~ selfconsistent

Анализ данных DLS/HADES по спектру дилептонов:

1. $\Gamma^{coll}_V \neq 0$ & $\Gamma^{coll}_R \neq 0$

2. $\Delta m_V \sim 0$, **что согласуется с теоретическими моделями:**
Бернард & Мейсснер Nucl. Phys. A **489**, 647 (1988), **$p \sim 0$**
Елецкий & Иоффе Phys. Rev. Lett. **78**, 1010 (1997), **$p \sim 2$ ГэВ**
Кондратюк и др., Phys. Rev. C **58** 1078 (1998) **$p \sim 0$**



Quantum characteristics method for many – body scattering problem

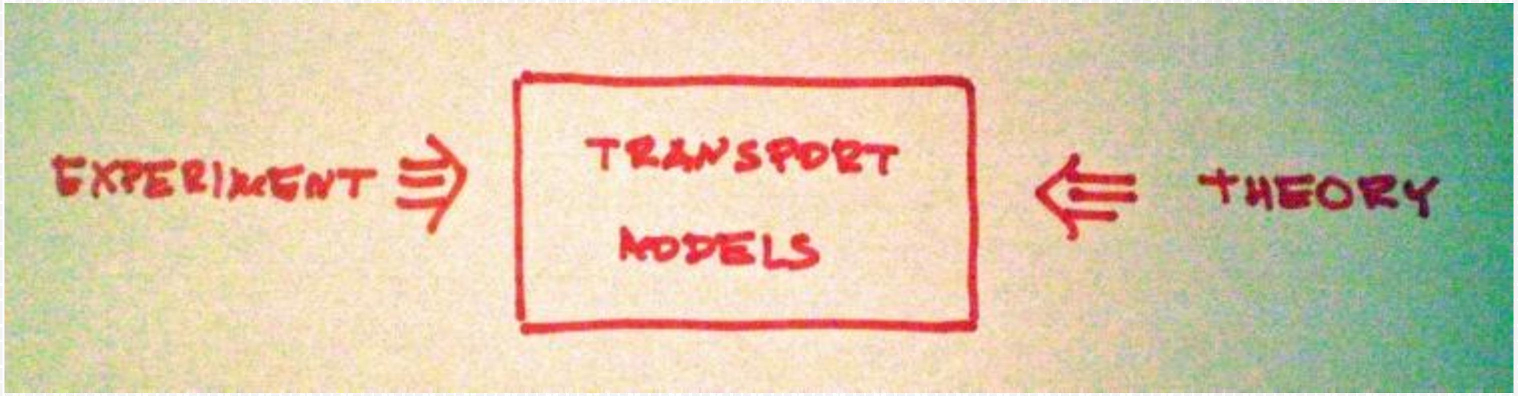
M. I. Krivoruchenko
ITEP, Moscow

October 12, 2009
Internal seminar

- Classical trajectories vs quantum transport. Why do we need trajectories?
- Weyl's correspondence & quantum characteristics.
- Quantum Liouville equation and quantum Hamilton's equations.
- Semiclassical expansion. A system of ODE for quantum transport.

- M. I. K., C. Fuchs, A. Faessler, Annalen der Physik **16**, 587-614 (2007);
- M. I. K., B. V. Martemyanov and C. Fuchs,
  Phys. Rev. C **76**, 059801 (2007).

+ M. I. Krivoruchenko, *Some Applications of Quantum Mechanics*,
  Ed. M. R. Pahlavani (InTech, Zagreb, 2012), pp. 67 – 90;
+ M. I. K. and A. Faessler, J. Math. Phys. **48**, 052107 (2007);



Trajectories is fundamental feature of transport models

CLASSICAL	QUANTUM
$\mathrm{N} < \infty$	$\mathrm{N} = \infty$
ODE	PDE

Significant reduction of complexity of the problem: By means of trajectories the field-theoretic problem reduces to statistical-mechanical problem of computing an ensemble of classical trajectories.

CAN WE GO BEYOND $\hbar^0$?

WIGNER FUNCTION & WIGNER MAP

For a pure state

$$W(p,x)=\int_{-\infty}^{+\infty}\frac{d\xi}{2\pi\hbar}e^{ip\xi/\hbar}\left\langle x-\xi/2\middle|\psi\right\rangle\left\langle\psi\middle|x+\xi/2\right\rangle$$

For a mixture

$$W(p,x)=\int_{-\infty}^{+\infty}\frac{d\xi}{2\pi\hbar}e^{ip\xi/\hbar}\left\langle x-\xi/2\middle|\hat{\rho}\middle|x+\xi/2\right\rangle$$

AND FOR ANY OPERATOR

$$\boxed{f(p,x)=\int_{-\infty}^{+\infty}\frac{d\xi}{2\pi\hbar}e^{ip\xi/\hbar}\left\langle x-\xi/2\middle|\hat{f}\middle|x+\xi/2\right\rangle}$$

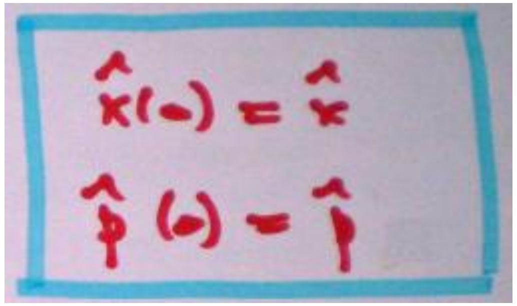
TO: functions in phase space $\xleftarrow{\quad W \quad}$ FROM: operators in Hilbert space

AND FOR ANY OPERATOR

$$\boxed{f(p,x)=\int_{-\infty}^{+\infty}\frac{d\xi}{2\pi\hbar}e^{ip\xi/\hbar}\left\langle x-\xi/2\right|\hat{f}\left|x+\xi/2\right\rangle}$$

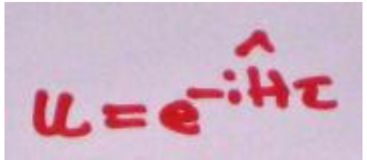
TO: functions in phase space $\xleftarrow{W}$ FROM: operators in Hilbert space

Heisenberg picture

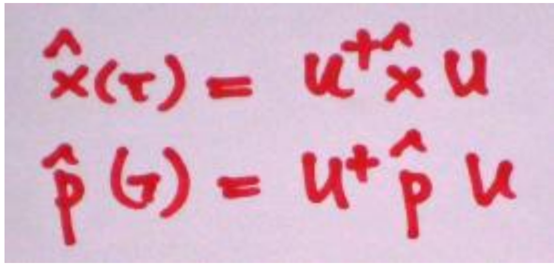


$$\boxed{\begin{aligned}\hat{x}(0)&=\hat{x}\\ \hat{p}(0)&=\hat{p}\end{aligned}}$$

evolution operator



$$U=e^{-i\hat{H}\tau}$$



$$\hat{x}(\tau)=U^{+}\hat{x}\,U$$

$$\hat{p}(\tau)=U^{+}\hat{p}\,U$$

$$\left(\hat{x},\hat{p}\right)\xrightarrow{w}\left(x,p\right)$$

$$\left(\hat{x}(\tau),\hat{p}(\tau)\right)\xrightarrow{w}\left(X(x,p,\tau),\ P(x,p,\tau)\right)$$

+ initial conditions:

$$X(x,p,0)=x\quad\&\quad P(x,p,0)=p$$

Summarizing:

WE HAVE CONSTRUCTED **PHASE SPACE TRAJECTORIES**

$$\begin{gathered}\left(\hat{x}(\tau), \hat{p}(\tau)\right) \\ \downarrow \boldsymbol{W} \\ \left(X(x,p,\tau), P(x,p,\tau)\right): \quad X(x,p,0) = x \quad \& \quad P(x,p,0) = p\end{gathered}$$

However,

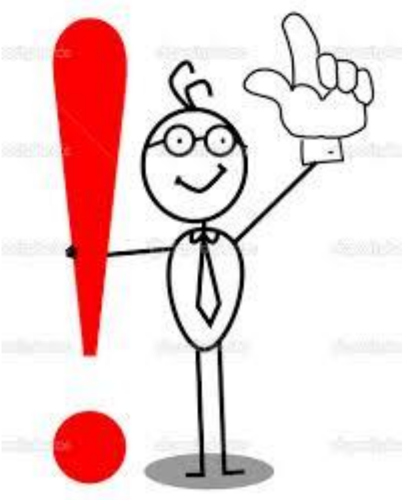
- ***do they play any role in the dynamics?***
- ***If yes, how to find them?***

Do they play any role in the dynamics?

First,

$$\forall\hat{f}\quad\exists f(p,x)\overset{w}{\leftarrow}\hat{f}:\quad f(\hat{p},\hat{x})=\hat{f}$$

I.E. THE SET $\left(\hat{p},\hat{x}\right)$ IS COMPLETE FOR THE CONSTRUCTION OF OPERATORS



Evolution:

$$\begin{aligned}\hat{f}\rightarrow\hat{f}(\tau)&=e^{iH\tau}\hat{f}e^{-iH\tau}\\&=e^{iH\tau}f(\hat{p},\hat{x})e^{-iH\tau}\\&=f(e^{iH\tau}\hat{p}e^{-iH\tau},e^{iH\tau}\hat{x}e^{-iH\tau})\\&=f(\hat{p}(\tau),\hat{x}(\tau)).\end{aligned}$$

Given $(\hat{p}(t),\hat{x}(t))$ are known

THE EVOLUTION PROBLEM IS SOLVED

Next step: Wigner transformation

If yes, how to find them?

QUANTUM version of Hamilton equations:

$$\frac{\partial}{\partial \tau} u^i(\xi,\tau) = \{\zeta^i, H(\zeta)\}|_{\zeta^i = *u^i(\xi,\tau)}$$

+ initial conditions:

$$u^i(\xi,0) = \xi^i$$

RIGHT HAND SIDE BECOMES ★-FUNCTION

T. A. Osborn and F. H. Molzahn, Ann. Phys. 241, 79 (1995),
M.I.K., A. Faessler, J. Math. Phys. 48, 052107 (2007)

Semiclassical expansion of quantum Hamilton's equations

- **4-th step: truncate the expansion and solve ODE:**

Expanded quantum Hamilton's equations

$$\begin{aligned}\frac{d}{d\tau}u^i_s(\xi,\tau) &= F^i_s(u_0(\xi,\tau),\ldots,J^i_{r,i_1\ldots i_t}(\xi,\tau),\ldots),\\ \frac{d}{d\tau}J^i_{r,i_1\ldots i_t}(\xi,\tau) &= G^i_{r,i_1\ldots i_t}(u_0(\xi,\tau),\ldots,J^i_{r,i_1\ldots i_t}(\xi,\tau),\ldots).\end{aligned}$$

with initial conditions

$$\begin{aligned}u^i_0(\xi,0) &= \xi^i, \quad J^i_{0,j}(\xi,0) = \delta^i_j\\ u^i_s(\xi,0) &= 0, \quad J^i_{s,i_1\ldots i_t}(\xi,0) = 0 \quad (s \geq 1).\end{aligned}$$

To any fixed order in the Planck's constant, quantum characteristics can be found by solving a finite system of ordinary differential equations (ODE):

The quantum evolution problem can be approached using numerically efficient ODE integrators.

Semiclassical expansion of quantum Hamilton's equations

- **1-st step: expand trajectories**

$$\mathbf{u}^{\mathbf{i}}(\xi,\tau)=\sum_{\mathbf{s}=0}^{\infty}\hbar^{\mathbf{2s}}\mathbf{u}^{\mathbf{i}}_{\mathbf{s}}(\xi,\tau),$$

where $u^i_0(\xi,\tau)$ is the classical trajectory.

- **2-nd step: define Jacobi fields**

$$\mathbf{J}^{\mathbf{i}}_{\mathbf{r},\mathbf{i}_1\ldots\mathbf{i}_t}(\xi,\tau)=\frac{\partial^{\mathbf{t}}\mathbf{u}^{\mathbf{i}}_{\mathbf{r}}(\xi,\tau)}{\partial\xi^{\mathbf{i}_1}\ldots\partial\xi^{\mathbf{i}_t}}$$

- **3-rd step: expand r.h.s. of Hamilton's equations**

$$\{\zeta^{\mathbf{i}},\mathcal{H}(\zeta)\}|_{\zeta=\star\mathbf{u}(\xi,\tau)}\equiv\mathbf{F}^{\mathbf{i}}(\star\mathbf{u}(\xi,\tau))=\sum_{\mathbf{s}=0}^{\infty}\hbar^{\mathbf{2s}}\mathbf{F}^{\mathbf{i}}_{\mathbf{s}}(\mathbf{u}_0(\xi,\tau),\ldots,\mathbf{J}^{\mathbf{i}}_{\mathbf{r},\mathbf{i}_1\ldots\mathbf{i}_t}(\xi,\tau),\ldots).$$

Semiclassical expansion of quantum Hamilton's equations

To the lowest order in $\hbar^2$,

$$\begin{aligned} F_0^i &= F^i, \\ F_1^i &= u_1^j F^i_{,j} - \frac{1}{24} J^j_{0,m} J^k_{0,n} J_0^{l,mn} F^i_{,jkl} - \frac{1}{16} J^j_{0,lm} J_0^{k,lm} F^i_{,jk}, \\ G^i_{0,k} &= F^i_{,l} J^l_{0,k}, \\ G^i_{0,kl} &= F^i_{,mn} J^m_{0,k} J^n_{0,l} + F^i_{,m} J^m_{0,kl}. \end{aligned}$$

Evolution equations:

$$\frac{d}{d\tau} u_0^i = F_0^i,$$

classical Hamilton eqs.

$$\left. \begin{aligned} \frac{d}{d\tau} u_1^i &= F_1^i, \\ \frac{d}{d\tau} J^i_{0,k} &= G^i_{0,k}, \\ \frac{d}{d\tau} J^i_{0,mn} &= G^i_{0,mn} \end{aligned} \right\}$$

1^{st} quantum correction to classical Hamilton eqs.

A closed system ..

Summary

- Quantum characteristics are existent.

✦ Quantum characteristics allow to reduce the evolution problem of complex quantum systems to a statistical mechanical problem of computing an ensemble of phase space trajectories and their Jacobi fields. The method works at any fixed order of the semiclassical expansion over the Planck's constant.

✦ Quantum characteristics allow to implement consistently quantum effects into transport models.

- In terms of **quantum characteristics** & **semiclassical expansion** the evolution problem reduces to:

solving an ODE system.

Свойства K мезонов в пионной материи

◆ B. V. Martemyanov, A. Faessler, C. Fuchs, M. I. Krivoruchenko, Phys. Rev. Lett. **93**, 052301 (2004).

Ульрарелятивистские тяжелые ионы: По множественности в рождении доминирют пионы, T ~ 200 МэВ.

PHENIX Collaboration at RHIC (2003):

$$\frac{\phi \to e^+ e^-}{\phi \to K^+ K^-}$$ **= 2-4 times of the vacuum value** **?**

Оператор собственной энергии K-мезонов определяется через πK амплитуду рассеяния вперед:

$$-\Sigma(p^2,E)=\int A^{+}(s,0,p^2)(dn_{s\pi^{+}}+dn_{s\pi^{0}}+dn_{s\pi^{-}})$$
$$+\int A^{-}(s,0,p^2)(-dn_{s\pi^{+}}+dn_{s\pi^{-}})\,.$$

πK амплитуда: $A^{1/2}=A^{+}+2A^{-},\ A^{3/2}=A^{+}-A^{-},$

$$A^{+}\propto K^{\dagger}K\vec{\pi}\vec{\pi},\ A^{-}\propto K^{\dagger}\vec{\sigma}K\vec{\pi}\times\vec{\pi},$$

T < m_π - киральная теория возмущений

$$A^{\pm}(s,t,p^2)=8\pi\sqrt{s}\left(a_0^{\pm}+p^{*2}(b_0^{\pm}+3a_1^{\pm})+\frac{3}{2}ta_1^{\pm}\right)+c^{\pm}(p^2-M_K^2)$$

длины рассеяния *a_0*, *a_1*, эффективный радиус *b_0* и *c* из киральной теории возмущений

πK амплитуда:

T > m_π - феноменология, πK→ K*→ πK

В киральной теории возмущений T < m_π:

$$\Sigma(M_K^2, M_K) = -4\pi n_v \frac{M_\pi + M_K}{M_\pi} a_0^+,$$

$$V_K = -\frac{2\pi n_v}{M_\pi + M_K}[a_0^+ + 2M_\pi M_K(b_0^+ + 3a_1^+)].$$

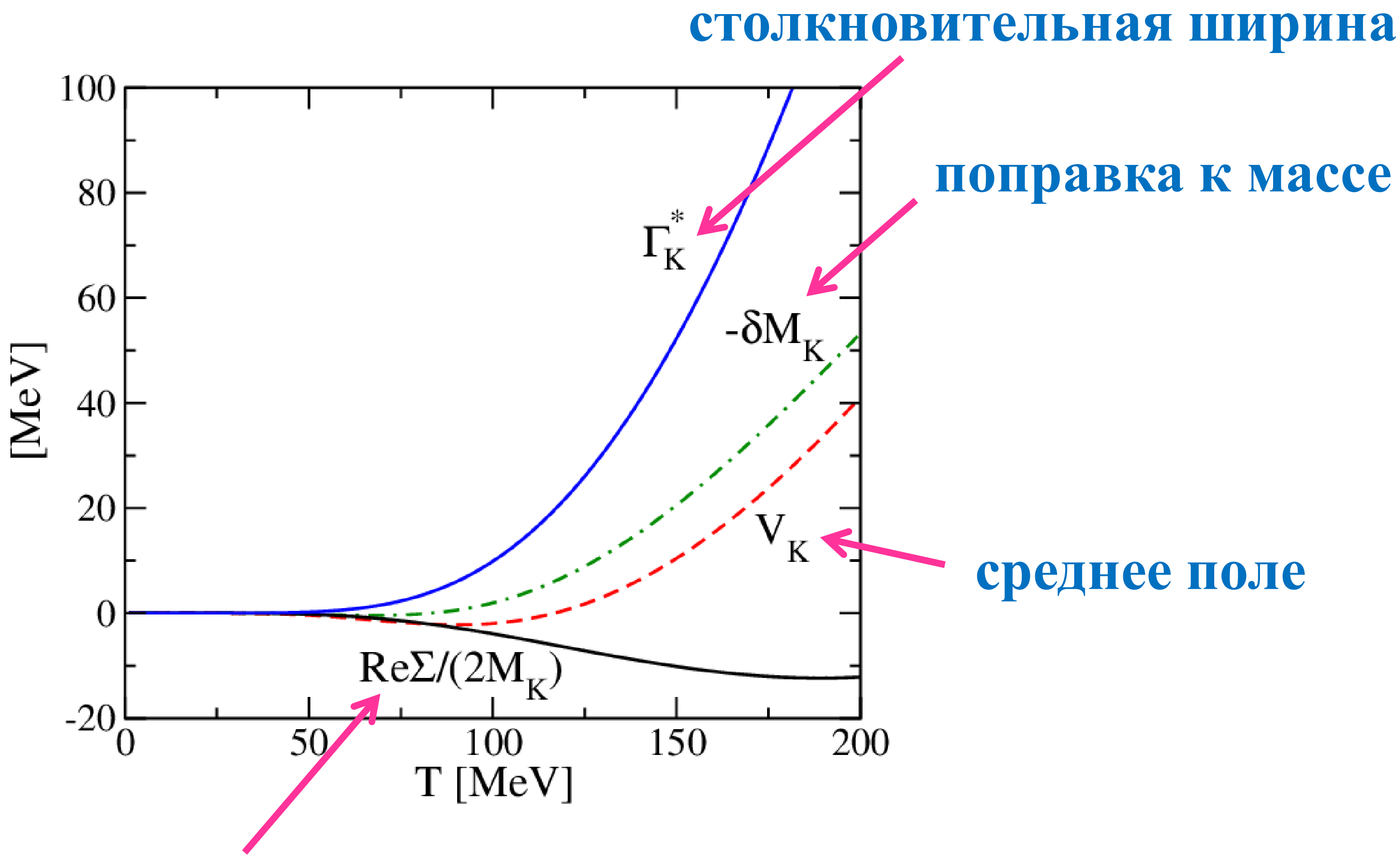
$$\delta M_K + V_K = \frac{\Sigma(M_K^2, M_K)}{2M_K}.$$

Феноменология T > m_π, с учетом πK→ K*→ πK :

$$a_0^I + b_0^I p^{*2} \longrightarrow e^{i\delta_0^I(p^*)}\sin\delta_0^I(p^*)/p^*,$$

$$a_1^{1/2} \longrightarrow a_1^{1/2} \frac{|(M_\pi + M_K)^2 - M_{K^*}^2 + iM_{K^*}\Gamma_{K^*}|}{s - M_{K^*}^2 + iM_{K^*}\Gamma_{K^*}}.$$

Модификация свойств K-мезонов в изотопически симметричной пионной материи



столкновительная ширина

поправка к массе

среднее поле

собственная энергия *K*-мезона = $\delta M_K + V_K < 0$

ϕ(1020)–мезон распадается в зоне реакции, K-мезоны выходят без перерассеяния на пионах. ВЕРОЯТНОСТЬ:

$$w \sim \int_0^\tau (e^{-\Gamma_K^*(\tau-t)})^2 e^{-\Gamma_\phi^* t}\Gamma_\phi \, dt.$$

Пары K-мезонов с инвариантной массой ϕ(1020) :

$$N_{K\bar{K}} \sim e^{-\Gamma_\phi^*\tau} + \frac{\Gamma_\phi}{2\Gamma_K^* - \Gamma_\phi^*}(e^{-\Gamma_\phi^*\tau} - e^{-2\Gamma_K^*\tau}).$$

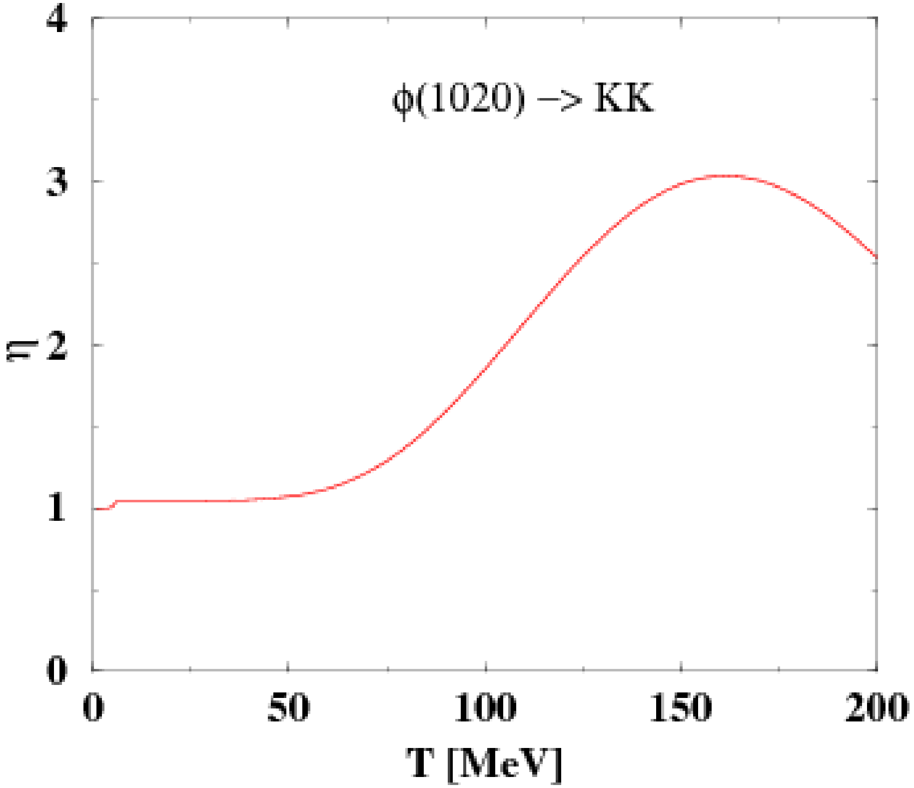
Выход e^+e^- пар:

$$N_{e^+e^-} \sim e^{-\Gamma_\phi^*\tau}B + (1 - e^{-\Gamma_\phi^*\tau})B^*,$$

Наблюдаемое отношение ширин:

$$B^{\mathrm{app}} = B\frac{1 + (e^{\Gamma_\phi^*\tau} - 1)\Gamma_\phi/\Gamma_\phi^*}{1 + \frac{\Gamma_\phi}{2\Gamma_K^* - \Gamma_\phi^*}(1 - e^{-(2\Gamma_K^* - \Gamma_\phi^*)\tau})}.$$

According to transport calculations $e^{-\tau\Gamma_\phi} \sim 1/2$ at RHIC



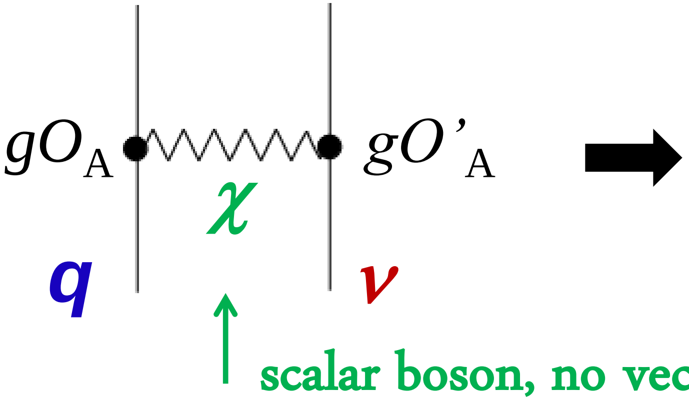
$T = 120 \div 170$ for thermal and chemical freeze-out

η = B^{app}/B ~ 2-3, in accord with the PHENIX data.

Майорановское нейтрино в ядерной материи

- S. Kovalenko, M. I. K., F. Simkovic, Phys. Rev. Lett.**112**,142503 (2014).

effective scalar 4-fermion interaction

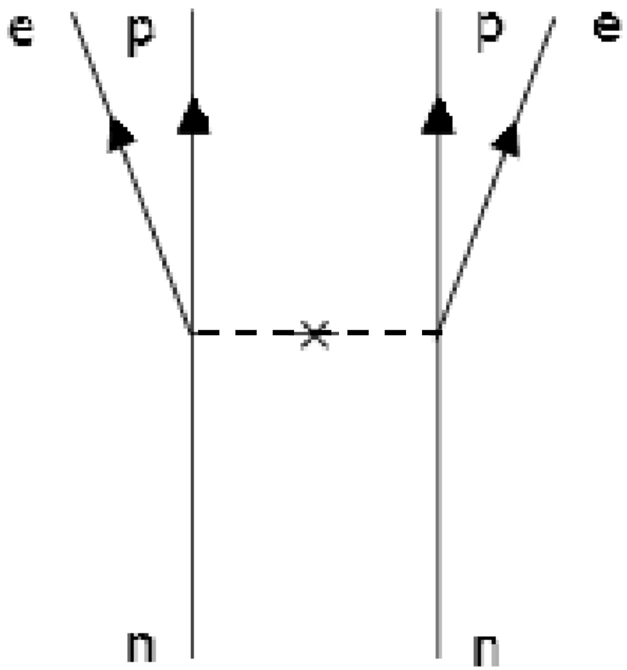


scalar boson, no vector

$$\mathcal{L}_{\text{eff}} = \frac{1}{\Lambda^2}\sum_A (\bar{q}O_A q)(\bar{\nu}^c O'_A \nu)$$

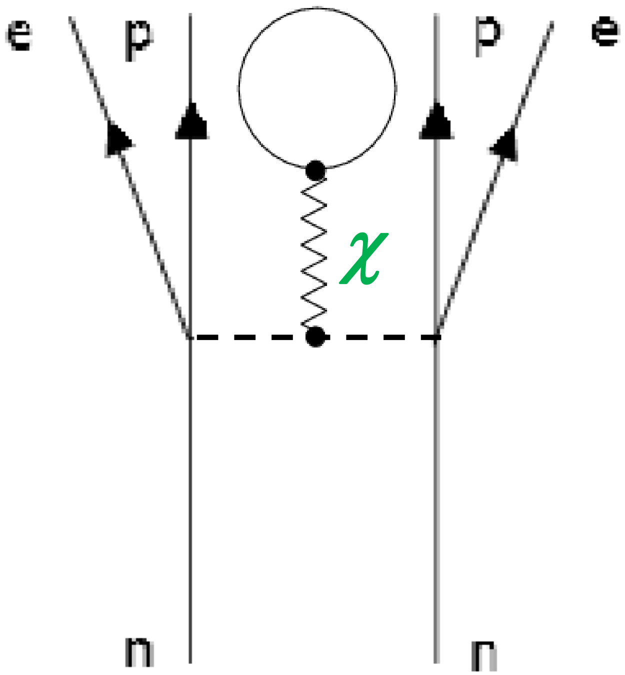
In-medium Majorana mass of neutrino

Induced 0νββ decay mechanism:



vacuum diagram

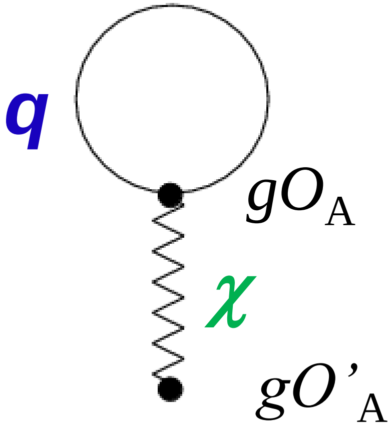
➡



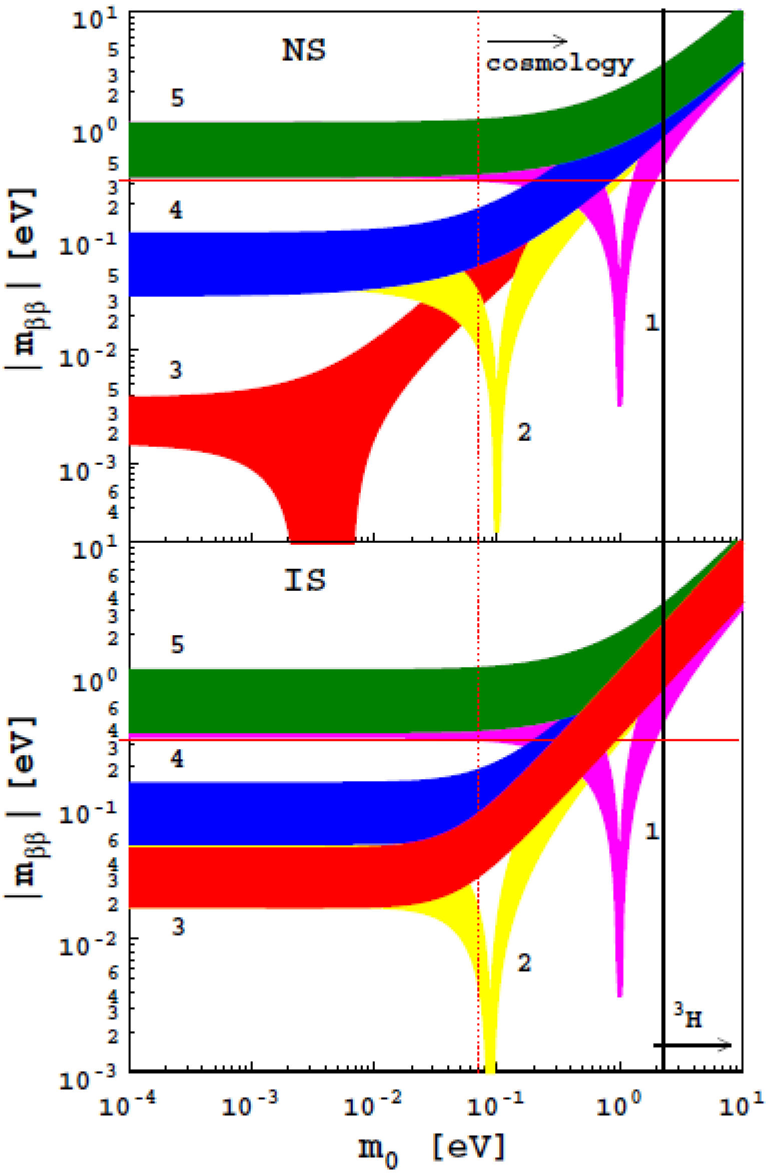
in nuclei + scalar

1. Classification of the vertices gO_A and gO'_A
2. Evaluation of the in-medium Majorana mass of neutrino:

$m_\nu^{eff} =$



3. Derive constraints for Λ_{NLV} from the 0νββ decay limits (+ космология + бета-распад трития)



Area	$\langle\chi\rangle g_1$
1	-1
2	-0.1
3	0
4	0.1
5	1

&

$g_2 = g_4 = 0$

$$m_{\beta\beta} = \sum_{i=1}^{n} U_{ei}^2 \xi_i m_i .$$

⬇

$$m_{\beta\beta} = \sum_{i=1}^{n} U_{ei}^2 \xi_i \frac{\sqrt{(m_i + \langle\chi\rangle g_1)^2 + (\langle\chi\rangle g_2)^2}}{(1 - \langle\chi\rangle g_4)^2} .$$

- Total lepton number violation can be associated with an exotic scalar-type interaction

- **The mean scalar field in nuclei generates an additional contribution to the Majorana neutrino mass, which leads to a modification of the $0\nu\beta\beta$ decay probability**

- **Observation of $0\nu\beta\beta$ decay VS. more stringent constraints on m_ν from cosmology and ^{3}H β-decay ➡ indication of an exotic interaction**

- **Constraint for the scale parameter $\Lambda_{NLV} > 2.4$ TeV derived**

Содержание:

1. Сверхпроводимость в кварковой материи и ядрах
2. Бозе конденсация дибарионов в ядерной материи
3. Рождение резонансов на ядрах
4. Рождение e^+e^- пар в столкновениях тяжелых ионов
5. Квантовый транспорт в формализме деформационного квантования
6. Свойства K мезонов в пионной материи
7. Майорановское нейтрино в ядерной материи