Workshop on QFTHEP, Golitsyno, 08-15.September 2010

The problem of anomalous dilepton yield in relativistic heavy-ion collisions

A.A. Andrianov

Санкт-Петербургский государственный университет

Sankt-Petersburg State University

Institut de Ciències del Cosmos

in collaboration with V.Andrianov, D. Espriu and X.Planells

Some highlights in:

A. Andrianov, D. Espriu, P. Giacconi and R. Soldati, JHEP 09 (2009) 057

A. Andrianov, D. Espriu, F. Mescia and A. Renau, Phys.Lett. B684 (2010) 101

Tentative plan

1. Dilepton production in central collisions in experiments on PHENIX (RHIC)← NA60 (SPS) ← CERES (SPS) ← HADES (GSI)← ← DLS (Berkeley) The first clear signs of an excess of dileptons above the known decay sources at SPS energies were obtained by CERES for M<1 GeV, NA38/NA50 for M>1 GeV and by HELIOS-3 for both mass regions . Years 1994-1995.

2. Cocktail of hadron decays into dileptons at high temperatures
+ dropping mass and /or broadening of meson resonances
+ enhancement of eta meson production in proton-neutron scattering
= failure to explain abnormal dilepton yield

3. Large fluctuation of topological charge → chiral chemical potential in a fireball → "axion-like" background ~ condensate OR
Spontaneous parity breaking due to pion condensate
= time-dependent pseudoscalar background in collider kinematics

4. Parity breaking → splitting of masses for photon/vector meson polarizations → appearance of giant resonances
→ substantial enhancement of dilepton yield

Recent data from PHENIX RHIC

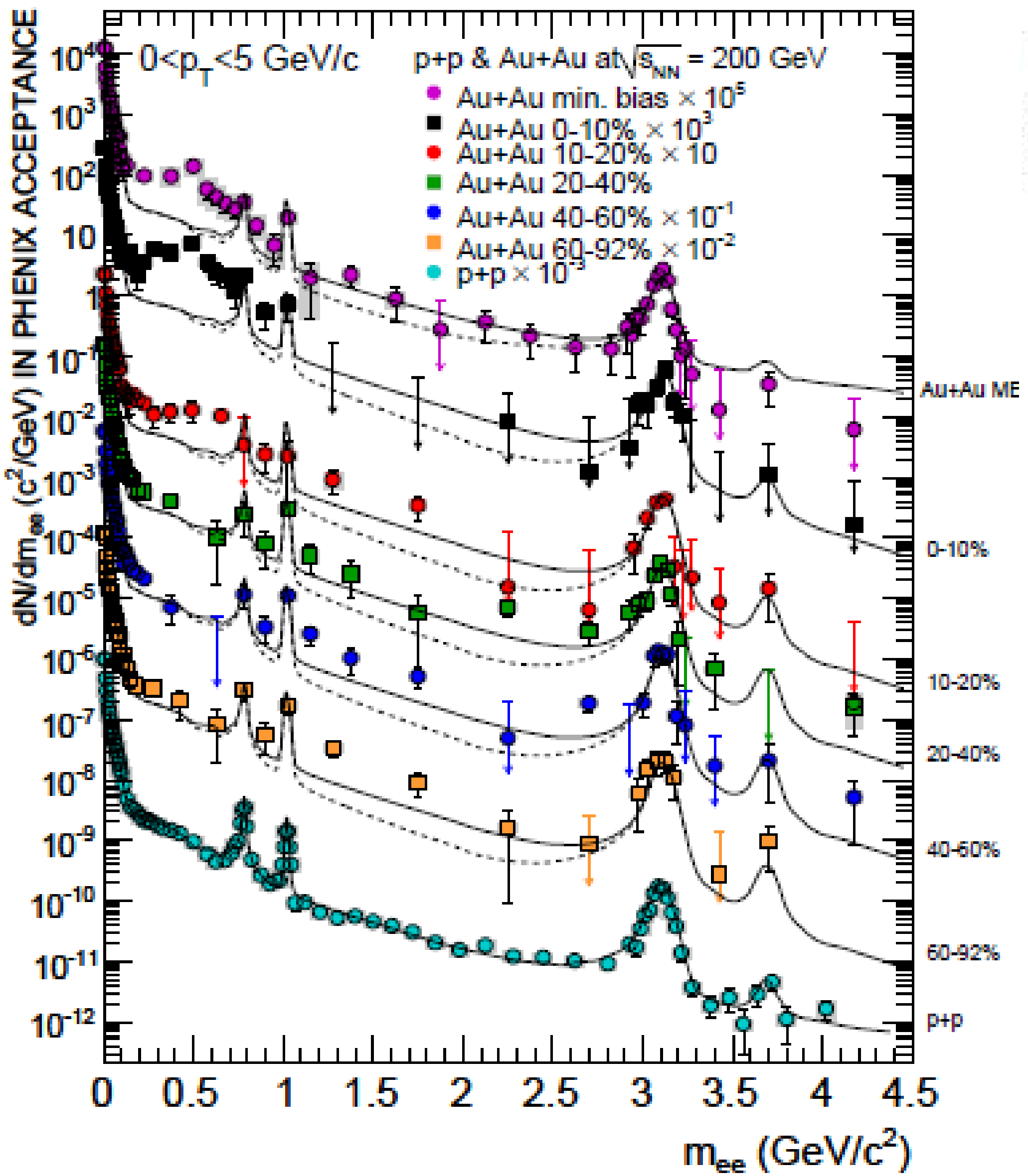


FIG. 27: (Color online) Invariant mass spectrum of e^+e^- pairs inclusive in p_T compared to expectations from the model of hadron decays for $p+p$ and for different Au + Au centrality classes.

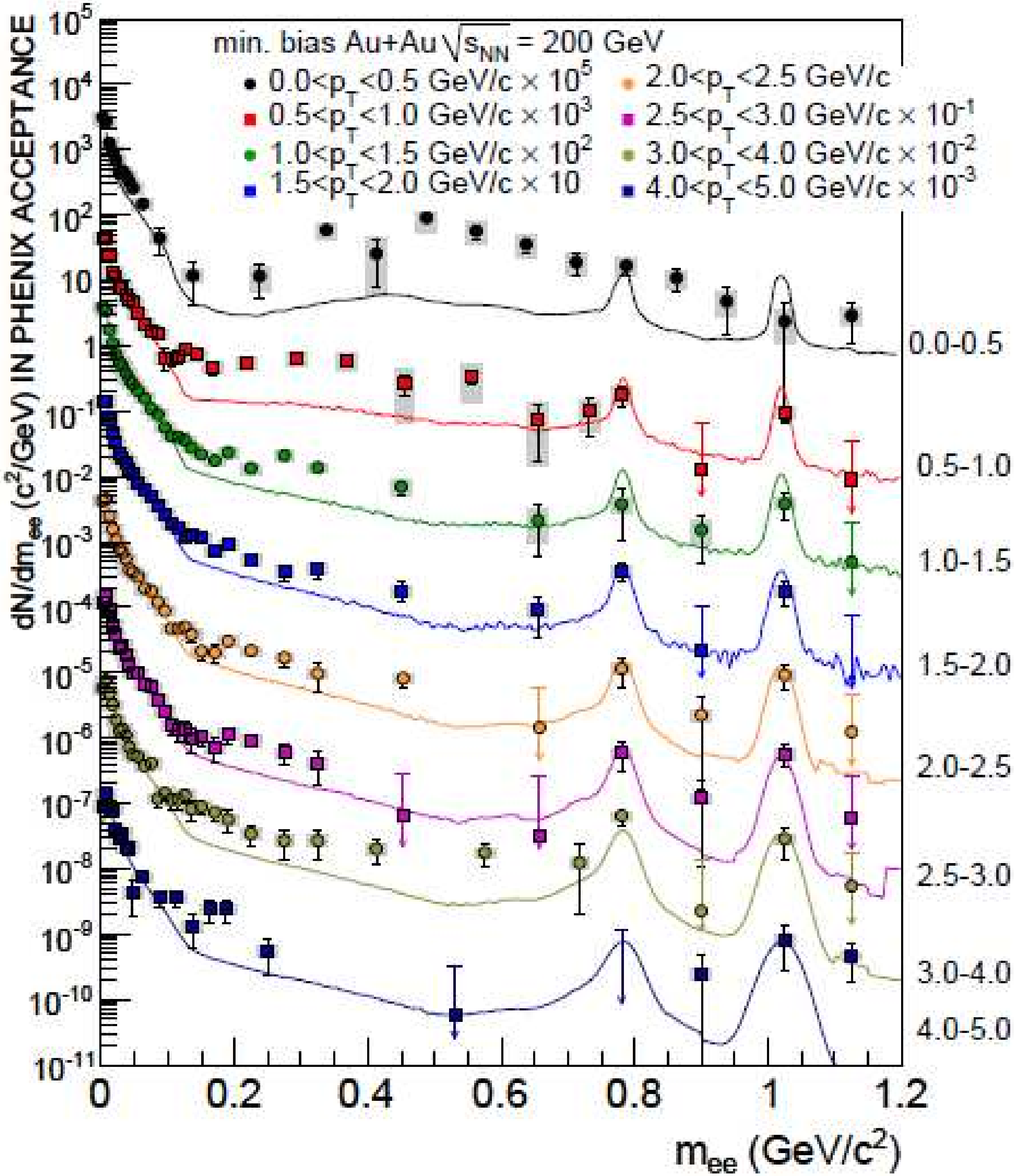
From: PHYS. REV. C **81**, 034911 (2010)
(PHENIX Collaboration)

TABLE IX: The enhancement factor, defined as the ratio between the measured yield and the expected yield for $0.15 < m_{ee} < 0.75$ GeV$/c^2$, for different centrality bins. The meaning of the errors is defined in the text.

Centrality	Enhancement (±stat ±syst ±model)
00-10 %	$7.6 \pm 0.5 \pm 1.5 \pm 1.5$
10-20 %	$3.2 \pm 0.4 \pm 0.1 \pm 0.6$
20-40 %	$1.4 \pm 1.3 \pm 0.02 \pm 0.3$
40-60 %	$0.8 \pm 0.3 \pm 0.03 \pm 0.2$
60-92 %	$1.5 \pm 0.3 \pm 0.001 \pm 0.3$
Min. Bias	$4.7 \pm 0.4 \pm 1.5 \pm 0.9$

Central collisions

Small p_T → thermal sources of dileptons



Low masses = LMR, M_ee<1 GeV

This is an old puzzle!

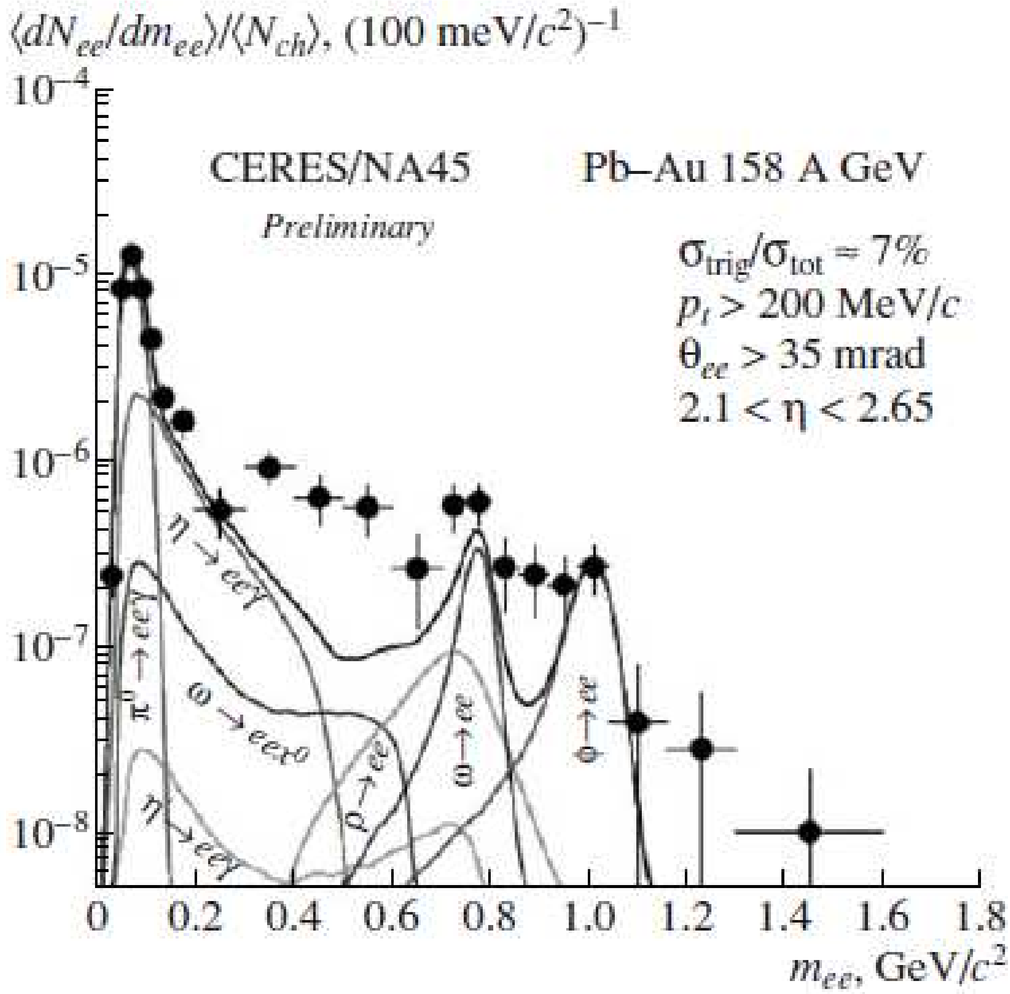
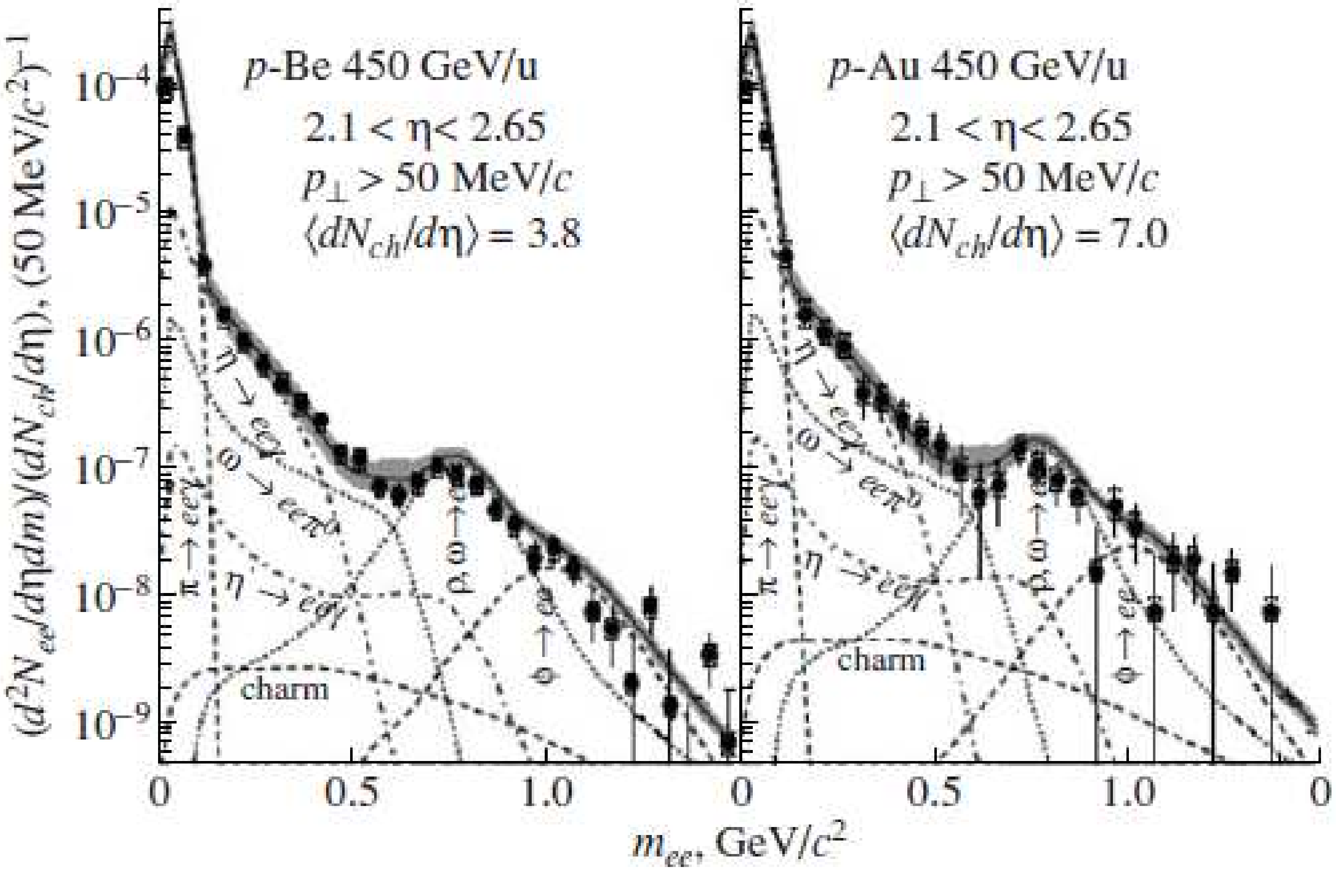


Fig. 2. CERES experiment data collected in 2000 [17].

D. Miskowiec, Nucl. Phys. A 774, 43 (2006).



CERES-experiment data for proton–nucleus collisions [16]. The solid line shows "hadronic cocktail."

G. Agakichiev et al., Eur. Phys. J. C 41, 475 (2005).

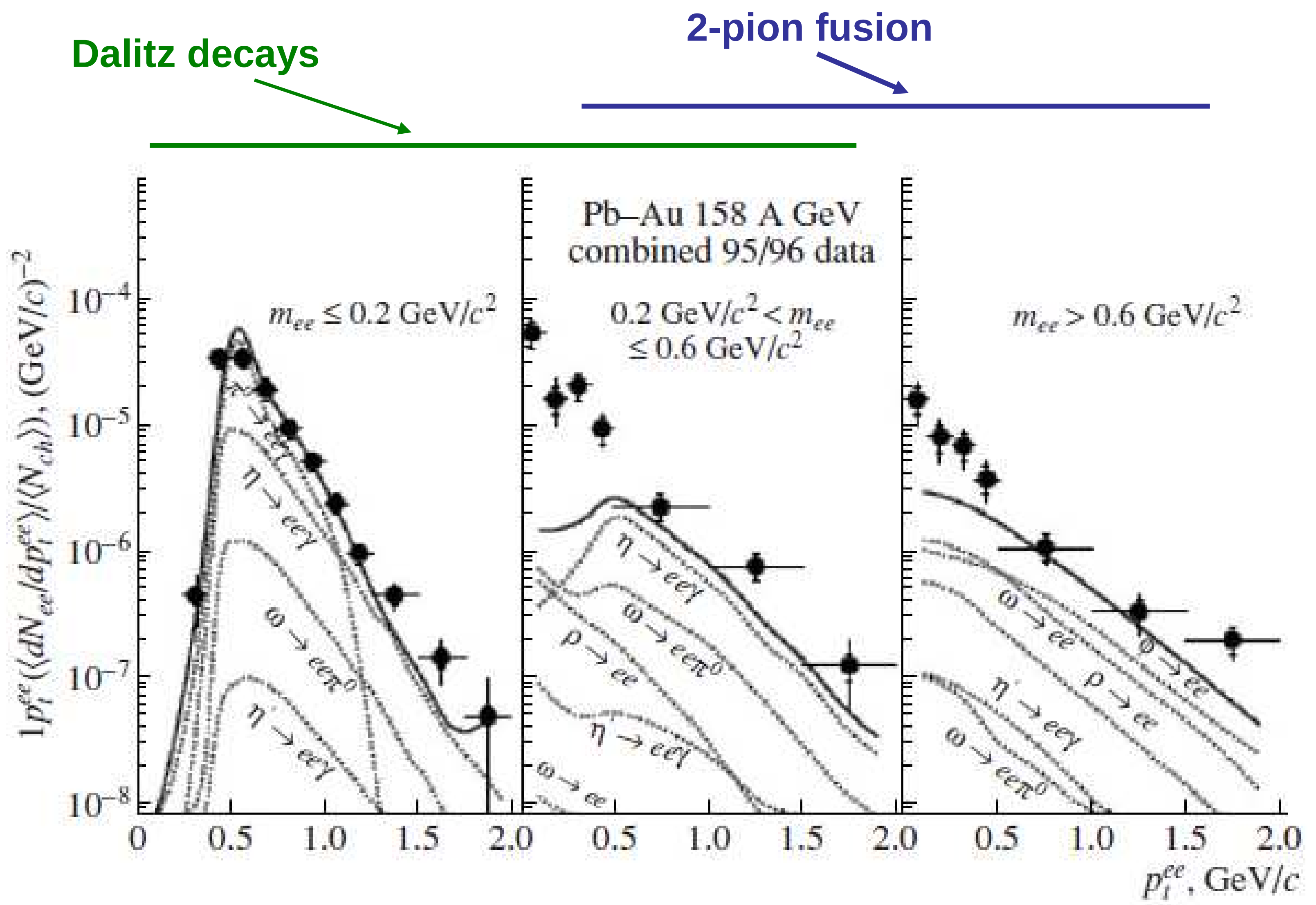


Fig. 4. Distribution of pairs as a function of the transverse momentum in three ranges of masses [16].

G. Agakichiev et al., Eur. Phys. J. C 41, 475 (2005).

The oldest evidence of dilepton excess

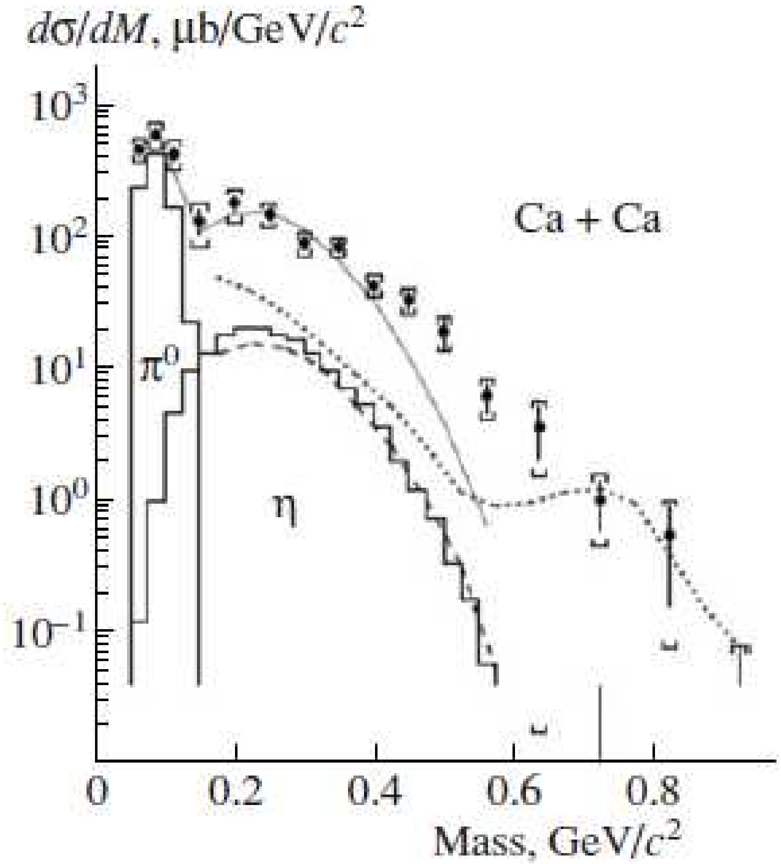
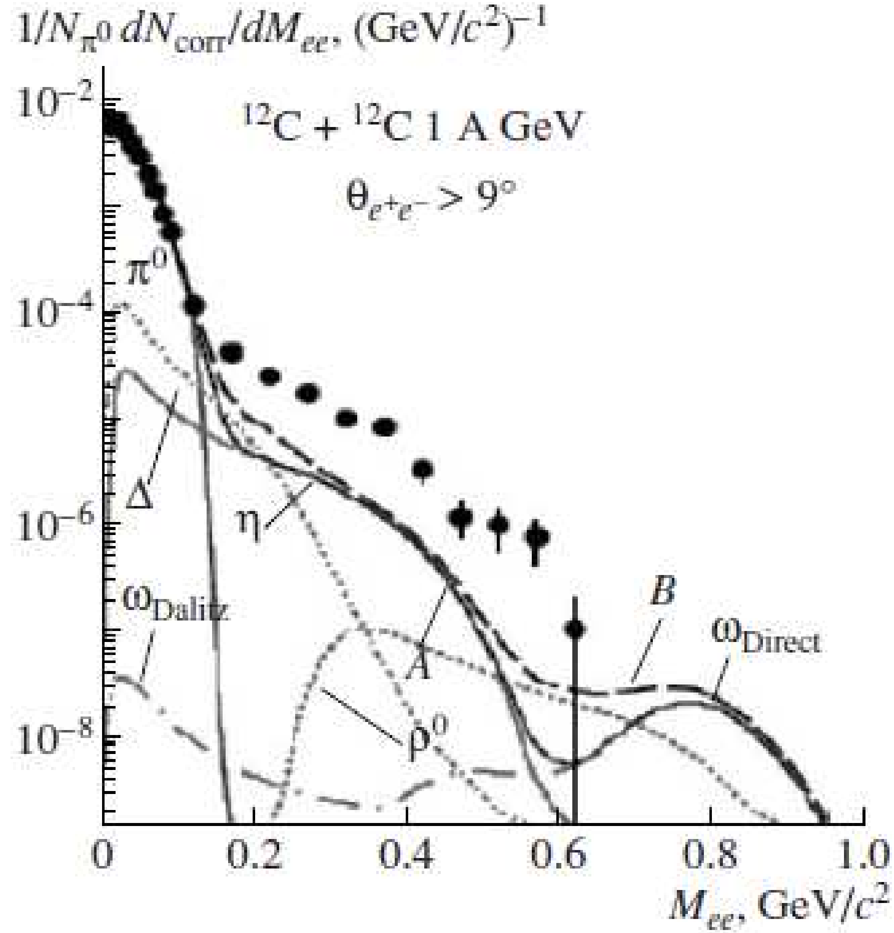


Fig. 1. DLS-experiment data [15].

were obtained at the DLS setup (DiLepton Spectrometer) in the late 1980s. The setup was mounted at the accelerator Bevalac (Berkeley National Laboratory, USA). In the collisions between the ^{40}Ca + ^{40}Ca nuclei at E_{lab} = 1.04 GeV/nucleon

R. J. Porter et al., Phys. Rev. Lett. **79**, 1229 (1997



HADES-experiment data on the dilepton yield

Proton-neutron enhancement

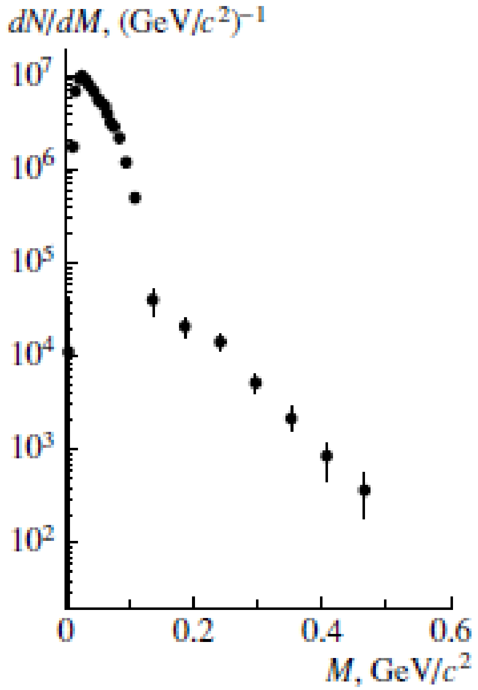


Fig. 1. Invariant-mass spectrum of dielectrons detected in the (p, p) reaction.

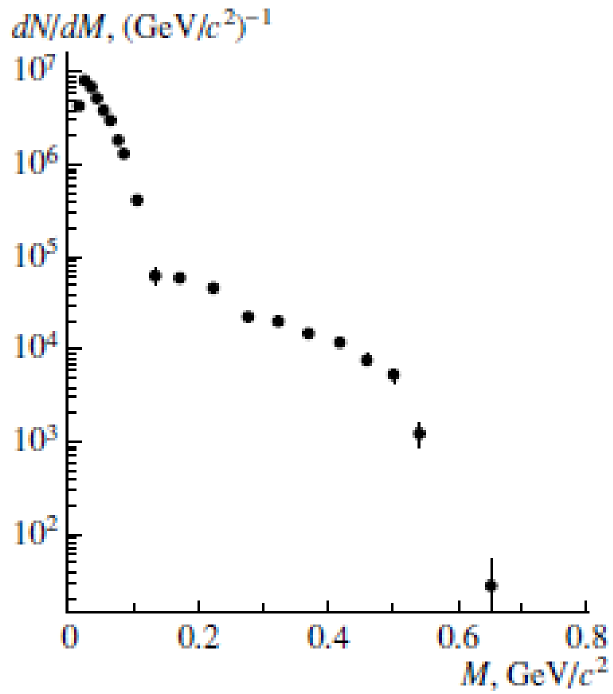


Fig. 2. As in Fig. 1, but for the (d, p) reaction in the case where the quasifree neutron–proton channel is selected.

K. O. Lapidus Physics of Atomic Nuclei, 2010, Vol. 73, No. 6, pp. 985–987.

Not sufficient to saturate anomalous e+e- yield !

Hadron cocktail

Dilepton masses **< 140 MeV, < 550 MeV**

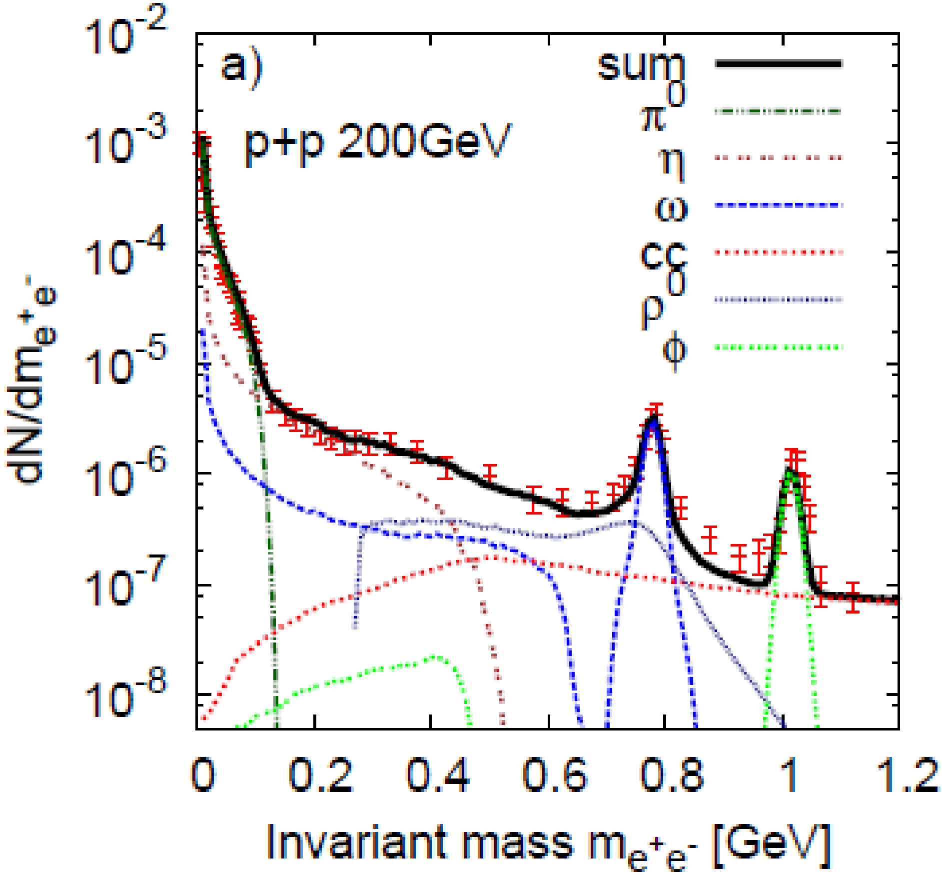
Dominant Dalitz decays $\pi_0 \rightarrow \gamma e^+ e^-, \eta \rightarrow \gamma e^+ e^-$

Dilepton masses **300 MeV < M_ee < 900 MeV**

Dominant 2-pion fusion $\pi\pi \rightarrow \rho, \omega \rightarrow \gamma^* \rightarrow e^+ e^-$

Hadron	direct	Dalitz	other
π^0	-	$\pi^0 \rightarrow \gamma\, e^+ e^-$	-
η^0	-	$\eta^0 \rightarrow \gamma\, e^+ e^-$	$\eta^0 \rightarrow \pi^+ \pi^- e^+ e^-$
η'	-	$\eta' \rightarrow \gamma\, e^+ e^-$	$\eta' \rightarrow \pi^+ \pi^- e^+ e^-$
ρ^0	$\rho^0 \rightarrow e^+ e^-$	-	-
ω^0	$\omega^0 \rightarrow e^+ e^-$	-	$\omega^0 \rightarrow \pi^0\, e^+ e^-$
ϕ^0	$\phi^0 \rightarrow e^+ e^-$	-	$\phi^0 \rightarrow \eta\, e^+ e^-$
J/ψ	$J/\psi \rightarrow e^+ e^-$	$J/\psi \rightarrow \gamma\, e^+ e^-$	
ψ'	$\psi' \rightarrow e^+ e^-$	$\psi' \rightarrow \gamma\, e^+ e^-$	-
D mesons	-	-	$D^\pm \rightarrow e^\pm \nu_e + X$

TABLE I: List of decay channels relevant for dielectron production in $p+p$ collisions at $\sqrt{s}$=200 GeV. For $D^\pm$ mesons,



a)
p+p 200GeV
sum
π0
η
ω
cc
ρ0
φ
dN/dm$_{e^+e^-}$
Invariant mass m$_{e^+e^-}$ [GeV]

PHENIX: LMR anomaly

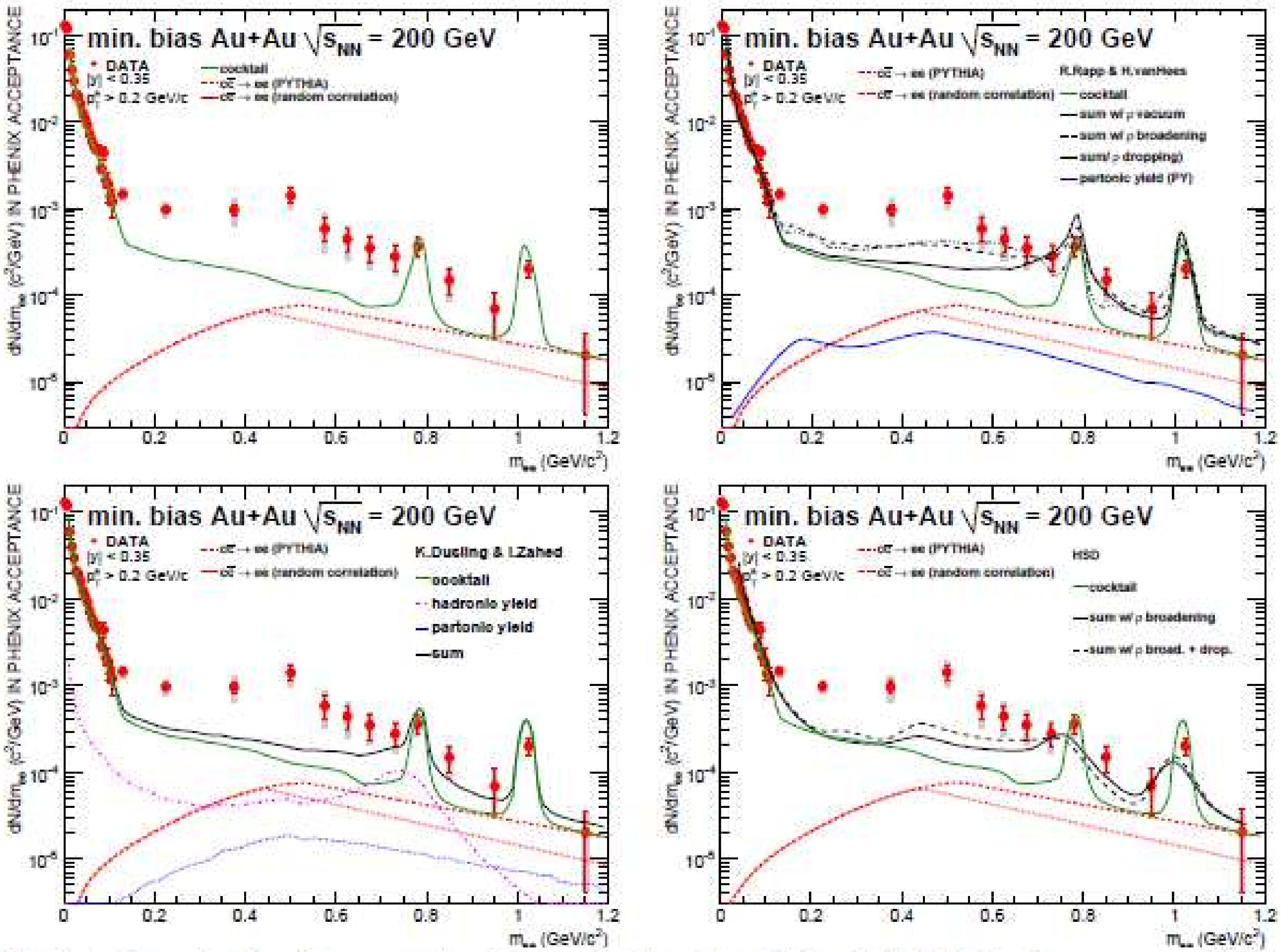
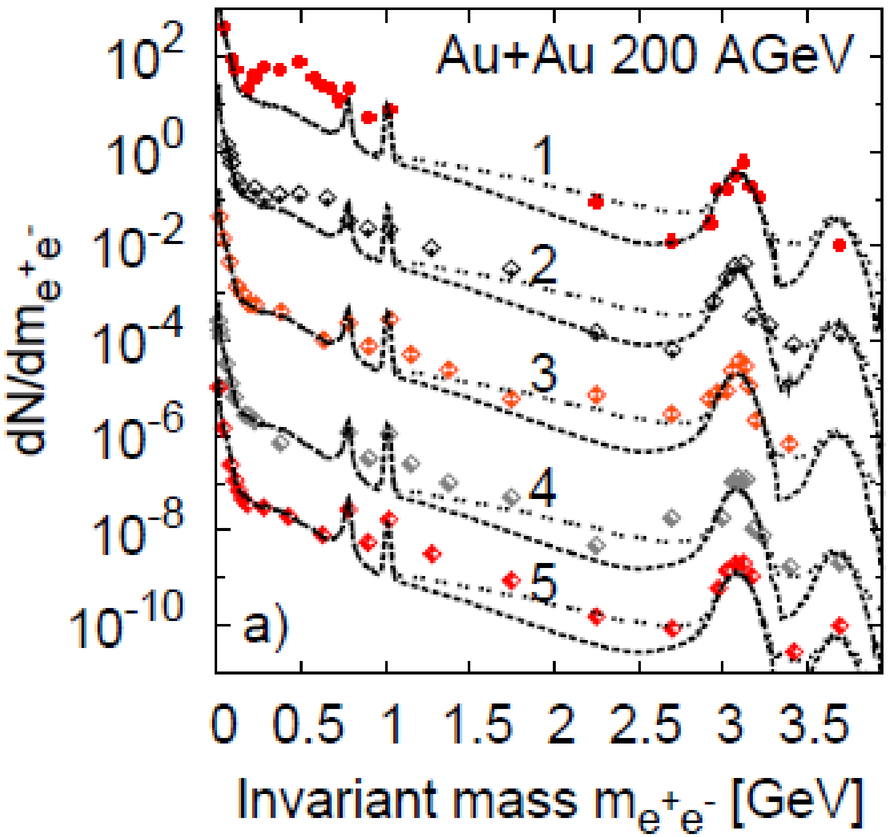
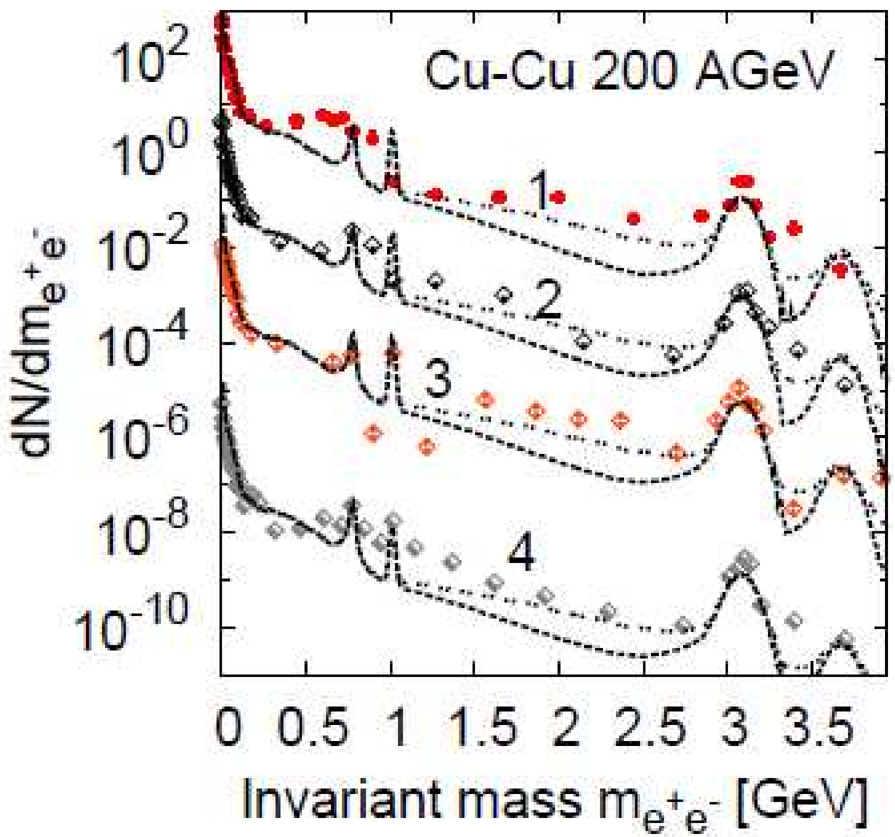


FIG. 42: (Color online) Invariant mass spectra of e^+e^- pairs in Au + Au collisions in the LMR. The data are compared to the sum of cocktail+charm (top left). The data are also compared to the sum of cocktail+charm and hadronic+partonic contributions from different models. The calculations are from The calculations are from (top right) Rapp and van Hees [15, 18, 83], (bottom right) Dusling and Zahed [19, 84, 85], and Cassing and Bratkowskaya [20, 27, 86, 87].

PHENIX: intermediate masses = IMR, 1<M<2.5 GeV





J.Manninen et al
arXiv:1005.0500

FIG. 7: (Color online) Invariant mass spectrum of pairs of electrons and positrons in $Au + Au$ (top) [2] and $Cu + Cu$ (bottom) [54] collisions at $\sqrt{s}_{\rm NN}$=200 GeV in different centrality classes compared with model calculations. The centrality bins are labelled from central to peripheral as 1 (0-10%), 2 (10-20%), 3 (20-40%). Centrality bin 4 consist on (40-94%) and (40-60%) most central events in $Cu + Cu$ and $Au + Au$ collisions, respectively, while the centrality bin 5 includes (60-92%) most central collisions. Both the data and

NA60 results on thermal dimuons

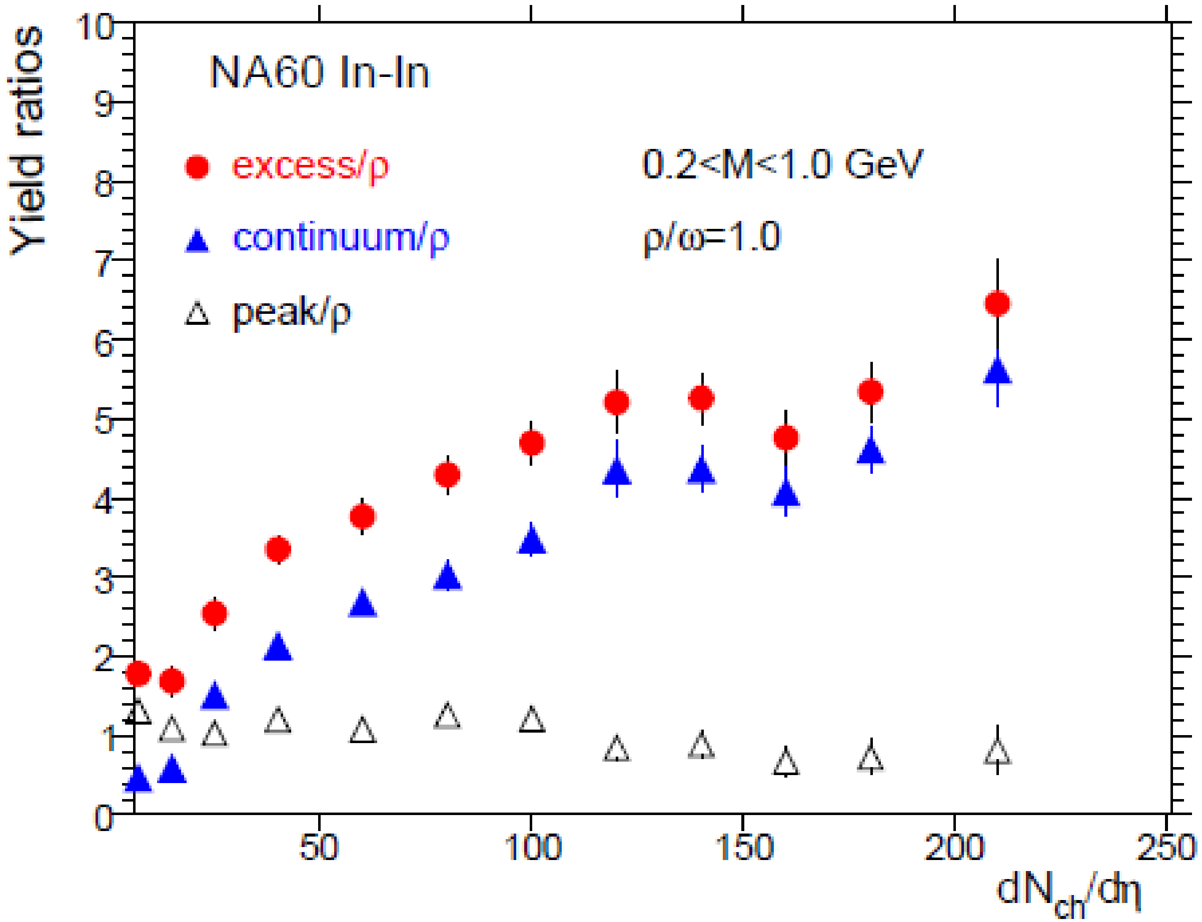


Fig. 9. Excess yield ratios for peak, continuum and total vs. centrality for the mass window $0.2 < M < 1$ GeV. Open charm is subtracted throughout. No acceptance correction applied.

Photon(vector mesons) instability in pseudoscalar background

For slowly growing/decreasing neutral pion (isovector) condensate

$$\zeta \sim \alpha \langle \dot{\pi}_0 \rangle / \pi f_\pi$$

or large-scale isoscalar axion-like field $\zeta_\mu \simeq \delta_{\mu 0}\, \alpha\, \langle \dot{\theta}(t) \rangle / \pi f_\pi \simeq const$

$\mu_5 = \partial_0 \theta / (2N_f)$ ← **axial chemical potential**

(in central heavy ion collisions)

Induced C-S term

$$\boxed{\frac{1}{2} \varepsilon^{\mu\nu\rho\sigma}\, \zeta_\mu\, A_\nu(x)\, \partial_\rho A_\sigma(x)}$$

Adiabatic approximation: in units $1/fm \sim f_\pi$

time derivative of CS vector << photon frequency/vector meson energy

P-and CP-odd condensates

Isoscalar condensate → theta vacuum bubbles

D. Kharzeev, R. D. Pisarski and M. H. G. Tytgat, Phys. Rev. Lett. 81, 512 (1998)

K. Buckley, T. Fugleberg, and A. Zhitnitsky, Phys. Rev. Lett. 84 (2000) 4814

D. E. Kharzeev, L. D. McLerran and H. J. Warringa, Nucl. Phys. A 803, 227 (2008)

Isotriplet neutral condensate =“pion” condensate

A.A.Andrianov and D.Espriu, Phys.Lett. B 663 (2008) 450 (*and refs..therein)*

A.A.Andrianov, V.A.Andrianov and D.Espriu, Phys.Lett. B 678 (2009) 416

(the talk by Vladimir Andrianov)

Start with

photons of different circular polarizations. They have different dispersion relation between their frequencies and wave vectors

Polarizations $A = T, L, +, -$

$$\varepsilon_L^\mu = \frac{\zeta^\mu k^2 - k^\mu(\zeta\cdot k)}{\sqrt{k^2\left((\zeta\cdot k)^2 - \zeta^2 k^2\right)}}; \quad \varepsilon_{\mu,L}\varepsilon_L^\mu = -1,$$

Mass-shell $k^2 =$ **0**

(Almost) circular polarizations of distorted photons

$$\varepsilon_\pm^\mu(k) \equiv \left[\frac{\mathbf{k}^2 - (\epsilon\cdot k)^2}{2\mathbf{k}^2}\right]^{-1/2} P_\pm^{\mu\nu}\,\epsilon_\nu$$

$$\hat{K}_\nu^\mu \varepsilon_\pm^\nu = \left(k^2 \pm \sqrt{(\zeta\cdot k)^2 - \zeta^2 k^2}\,\right)\varepsilon_\pm^\mu$$

Polarized decay !!

Time-like CS vector $(\zeta_\mu) = (\zeta, 0, 0, 0)$

Mass-shell $k^2 = \pm\zeta|\vec{k}|$ $\longrightarrow$ $w_\pm(\vec{k}) = \sqrt{\vec{k}^2 \pm \zeta|\vec{k}|}$

Photon "-" is a tachyon

Photon "+"decays

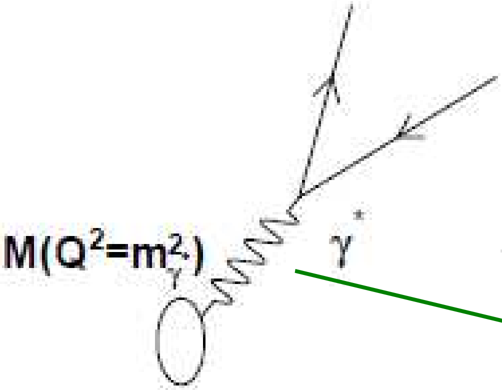
$\gamma \to l^+ l^-$ **with threshold** $\boxed{|\vec{k}| > 4m_e^2/\zeta}$

Decay width is small $\boxed{\Gamma_\gamma \simeq \alpha\zeta/3}$

But the distorted photon is not a proper *Breit-Wigner* resonance as its position (effective mass) moves with momentum!

Threshold hierarchy!
If for electrons/positrons the threshold is of order 1 MeV then for muons it is four orders of magnitude higher , i.e. 10 GeV !
No muon pairs excess in the PHENIX data!? There is an excess in NA60!

Dilepton pair creation



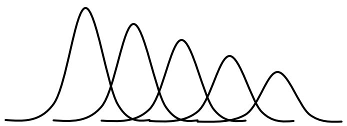
QED

$$\frac{d^2N_{ee}}{dM^2} = \frac{2\alpha}{3}\frac{M^2}{(M^2-m_\gamma^2)^2}\Phi(M)dN_{\gamma_*}$$

$$M \equiv m_{ee} \equiv m_{\gamma^*} \qquad \Phi(M) = \sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)$$

"Giant" resonance
with variable position

$$\frac{1}{3}\Theta\left(|\vec{k}| - \frac{4m_e^2-m_\gamma^2}{\zeta}\right)\frac{\Gamma_+\omega_+(|\vec{k}|)}{(M^2-m_\gamma^2-\zeta|\vec{k}|)^2+\Gamma_+^2\omega_+^2(|\vec{k}|)}$$



$|\vec{k}|$

"On-shell" enhancement in a range of | k | !

$$\sim \frac{1}{\Gamma_+\omega_+(|\vec{k}|)} \sim \frac{3}{\alpha M^2} \qquad |\vec{k}| \gg \frac{4m_e^2-m_\gamma^2}{\zeta}, \zeta, m_\gamma$$

$$\boxed{R_{enh}\Big|_{M\gg m_\gamma} = 3/\alpha^2 \sim 10^5}$$

Taking into account thermal distribution

Boltzmann $$f^B(k^0,T) = \frac{1}{e^{k^0/T}-1}$$

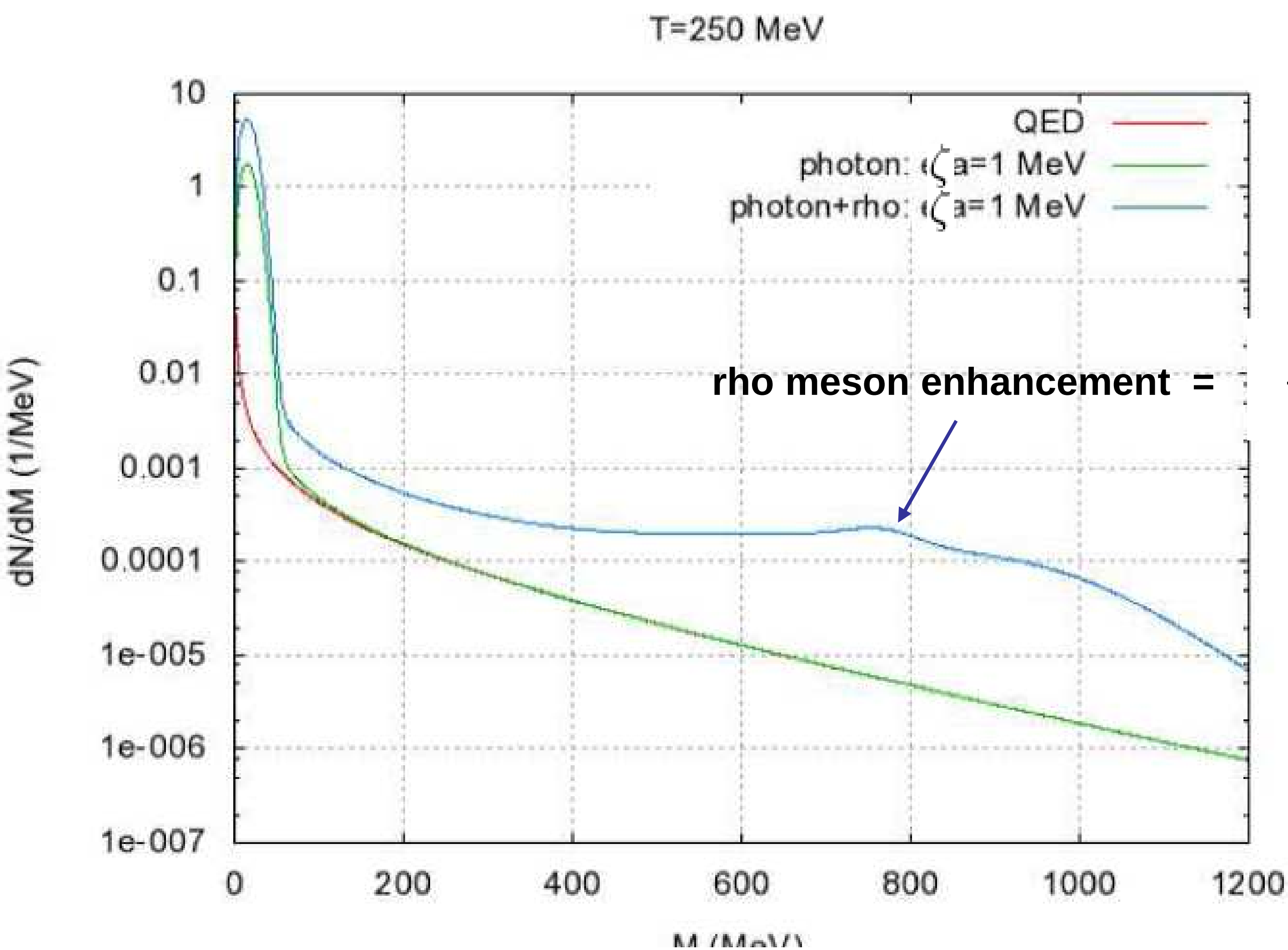
For transversal polarizations

$$\frac{dN_{ee}}{dM} = M^3 \frac{\alpha^2}{9\pi^2}\int \frac{1}{[M^2 - m_{\rm eff}^2(|\vec{k}|)]^2 + \Gamma_\pm^2 w_\pm^2(|\vec{k}|)} \frac{\sqrt{(k^0)^2 - M^2}}{e^{k^0/T}-1} dk^0 \qquad |\vec{k}| = \sqrt{(k^0)^2 - M^2}$$

Production rate is sensitive to temperatures via photon effective mass and width

RHIC temperatures T = 150 – 250 MeV

Photon thermal distribution makes resonances broader



rho meson enhancement = $\frac{1}{3}\frac{m_\rho^2+\Gamma_\rho^2}{\Gamma_\rho^2} \simeq 9$

Does it provide the abnormal ee excess in the range 100 – 700 MeV?

Only partially! **Zeta scale is plausibly of order of few MeV's,** $\zeta \sim \alpha f_\pi \sim 1 \text{ MeV}$

ρ, ω **mesons must enter the game.**

Finite-volume suppression (qualitatively)

A typical size of nuclear fireball $L \sim 5 \div 10$ fm.

Time spent by photons in nuclear medium $\tau_\eta \simeq L$

Resonance wave function and amplitude

$$\psi[\tau] = \exp\left((-i\omega - \frac{1}{2}\Gamma)\tau\right) \Longrightarrow D[E] = i\int_0^{\tau_\eta} d\tau \exp\left((i\Delta E - \frac{1}{2}\Gamma)\tau\right) = \frac{\exp\left((i\Delta E - \frac{1}{2}\Gamma)\tau_\eta\right) - 1}{\Delta E + \frac{1}{2}i\Gamma},$$

$$\Delta E = E - \omega$$

Breit-Wigner

In the peak for $\Delta E = 0$ $\Gamma\tau_\eta \ll 1$ $D_\eta(0)/D(0) \simeq \Gamma\tau_\eta/2 \ll 1$

Absolute enhancement $\sim \frac{\Gamma_+\tau_\eta}{2}\frac{2}{3\Gamma_+\omega_+(|\vec{k}|)} \sim \frac{\tau_\eta}{3|\vec{k}|} \sim \frac{\tau_\eta\eta}{3M^2};$ $|\vec{k}| \gg \eta, m_\gamma$

Relative enhancement $R_{enh,fin}\Big|_{M\gg m_\gamma} \sim \frac{\tau_\eta\eta}{2\alpha}$

For $\tau_\eta \sim 5$ fm $\sim 1/40MeV^{-1}$ **rather large**

Mixing with vector mesons

$$\mathcal{L}_{int} = \bar{q}\gamma_\mu \hat{V}^\mu q; \quad \hat{V}_\mu \equiv -eA_\mu Q + \frac{1}{2} g_\omega \omega_\mu \mathbf{I} + g_\rho \rho_\mu \frac{\tau_3}{2},$$

$$(V_{\mu,a}) \equiv (A_\mu,\, \omega_\mu,\, \rho_\mu \equiv (\rho_0)_\mu),$$

$$Q = \frac{\tau_3}{2} + \frac{1}{6}; \qquad g_\omega \simeq g_\rho \equiv g \simeq 6$$

$$\mathcal{L}_{kin} = -\frac{1}{4}\left(F_{\mu\nu}F^{\mu\nu} + \omega_{\mu\nu}\omega^{\mu\nu} + \rho_{\mu\nu}\rho^{\mu\nu}\right) \qquad + \frac{1}{2} V_{\mu,a} (\hat{m}^2)_{a,b} V_b^\mu;$$

$$(\hat{m}^2)_{a,b} = m_V^2 \begin{pmatrix} \frac{10e^2}{9g^2} & -\frac{e}{3g} & -\frac{e}{g} \\ -\frac{e}{3g} & 1 & 0 \\ -\frac{e}{g} & 0 & 1 \end{pmatrix}, \ \det(\hat{m}^2) = 0,$$

$$m_V^2 = m_\rho^2 = 2g_\rho^2 f_\pi^2 \simeq m_\omega^2$$

Chern-Simons “mass”

$$\mathcal{L}_{mixing}(k) \propto -\frac{1}{4}\varepsilon^{\mu\nu\rho\sigma}\,\mathrm{tr}\,\hat{\zeta}_\mu\,\hat{V}_\nu(x)\,\hat{V}_{\rho\sigma}(x)$$

$$= \frac{1}{2}\mathrm{tr}\,\hat{\zeta}\,\epsilon_{jkl}\,\hat{V}_j\,\partial_k\hat{V}_l = \frac{1}{2}\,\zeta\,\epsilon_{jkl}\,V_{j,a}\,N_{ab}\,\partial_k V_{l,b},$$

For isosinglet condensate $\zeta_\mu \simeq \delta_{\mu 0}\;\alpha\,\langle\dot{\theta}(t)\rangle/\pi f_\pi \simeq const$

$$(N_{ab}) \simeq \begin{pmatrix} 1 & -\frac{3g}{10e} & -\frac{9g}{10e} \\ -\frac{3g}{10e} & \frac{9g^2}{10e^2} & 0 \\ -\frac{9g}{10e} & 0 & \frac{9g^2}{10e^2} \end{pmatrix}; \quad \det(N) = 0,$$

For isotriplet condensate $\zeta \sim \alpha\langle\dot{\pi}_0\rangle/\pi f_\pi$

$$(N^\pi_{ab}) \simeq \begin{pmatrix} 1 & -\frac{3g}{2e} & -\frac{g}{2e} \\ -\frac{3g}{2e} & 0 & \frac{3g^2}{2e^2} \\ -\frac{g}{2e} & \frac{3g^2}{2e^2} & 0 \end{pmatrix}; \quad \det(N^\pi) = 0,$$

Mass splitting for transversal polarizations

Mass shell

$$K^{\mu\nu}_{ab} V_{\nu,b} = 0; \quad k^{\nu}\, V_{\nu,b} = 0;$$
$$\hat{K}^{\mu\nu} \equiv g^{\mu\nu}(k^2\mathbf{I} - \hat{m}^2) - k^{\mu}k^{\nu}\mathbf{I} - i\varepsilon^{\,\mu\nu\rho\sigma}\,\hat{\zeta}_{\rho}k^{\sigma}\hat{N},$$

for transversal polarizations $\hat{K}^{\mu}_{\nu}\varepsilon^{\nu}_{\pm} = \left(k^2\mathbf{I} - \hat{m}^2 \pm \sqrt{(\zeta\cdot k)^2 - \zeta^2 k^2}\;\hat{N}\right)\varepsilon^{\mu}_{\pm}$

$$k_0^2 - \vec{k}^2 = m_V^2 \pm \frac{9g^2}{10e^2}\zeta|\vec{k}| \simeq m_V^2 \pm 360\zeta|\vec{k}| \equiv m^2_{V,\pm}$$

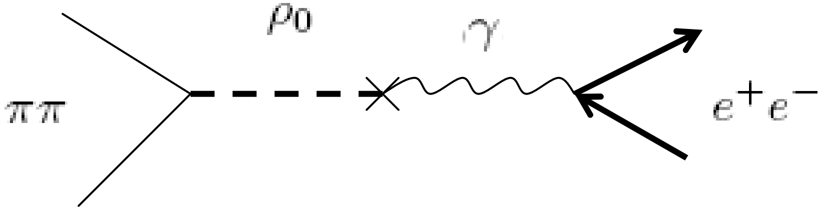
For massless photons and isoscalar condensate

$$N^{\theta} = \mathrm{diag}\left[0,\, \frac{9g^2}{10e^2},\, \frac{9g^2}{10e^2} + 1\right]; \quad \hat{m}^2 = m_V^2\,\mathrm{diag}\left[0,\, 1,\, 1 + \frac{10e^2}{9g^2}\right] \simeq \mathrm{diag}[0,\, 1,\, 1].$$

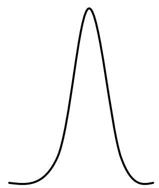
Transversal photon are not distorted and not decaying!

But for a mixture of isoscalar and isovector condensates they do decay.

$\pi\pi \to e^+e^-$ **channel and VMD**

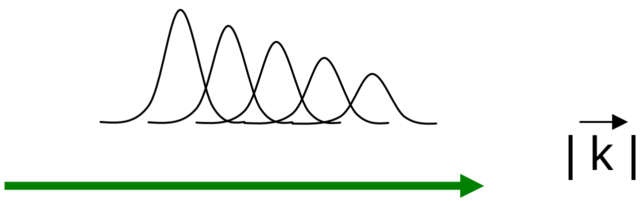


Normal rho meson resonance for longitudinal polarization



$m_\rho \simeq 770 Mev$

"Giant" resonances for transversal polarizations with variable position



e^+e^-

production rate

$n_V = 2, 3$ for ρ and ω

$$\frac{dN_{ee}}{d^4x dM} \simeq c_V \frac{\alpha^2 \Gamma_V m_V^2}{3\pi^2 g^2 M^2} \times \left(\frac{M^2 - n_V^2 m_\pi^2}{m_V^2 - n_V^2 m_\pi^2}\right)^{3/2} \Theta(M^2 - n_V^2 m_\pi^2) \times \sum_\epsilon \int_M^\infty dk_0 \frac{\sqrt{k_0^2 - M^2}}{e^{k_0/T} - 1} \frac{m_{V,\epsilon}^4 \left(1 + \frac{\Gamma_V^2}{m_V^2}\right)}{\left(M^2 - m_{V,\epsilon}^2\right)^2 + m_{V,\epsilon}^4 \frac{\Gamma_V^2}{m_V^2}},$$

Dalitz decays $\pi_0 \to \gamma e^+ e^-, \eta \to \gamma e^+ e^-$

low invariant masses $< 300 MeV$

$$\frac{d\Gamma_{\Pi \to \gamma ee}}{dM} \simeq \sum_V c_\Pi \frac{\alpha^3 m_\Pi^3}{48\pi^3 f_\Pi^2} \left(1 - \frac{M^2}{m_\Pi^2}\right)^3$$

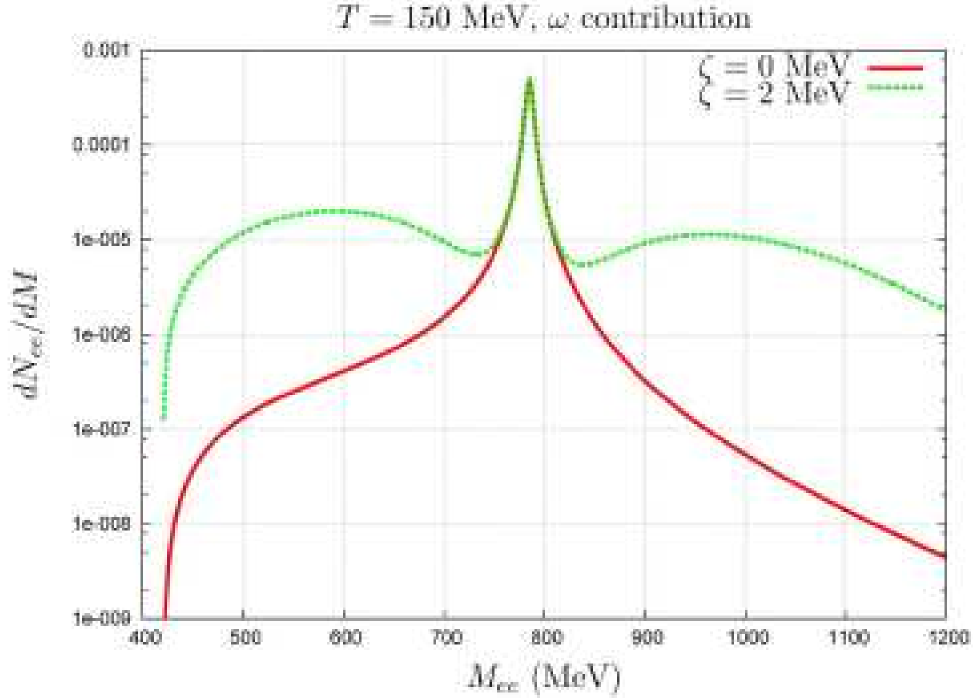
$$\times \sum_\epsilon \int_M^\infty dk_0 \frac{\sqrt{k_0^2 - M^2}}{e^{k_0/T} - 1} \left|F(M, m_{V,\epsilon})\right|^2 ;$$

$$F(M, m_{V,\epsilon}) \equiv \left[\left(1 - \frac{M^2}{m_{V,\epsilon}^2}\right)^2 - i\frac{\Gamma_{Vee}}{m_V}\right]^{-1} ,$$

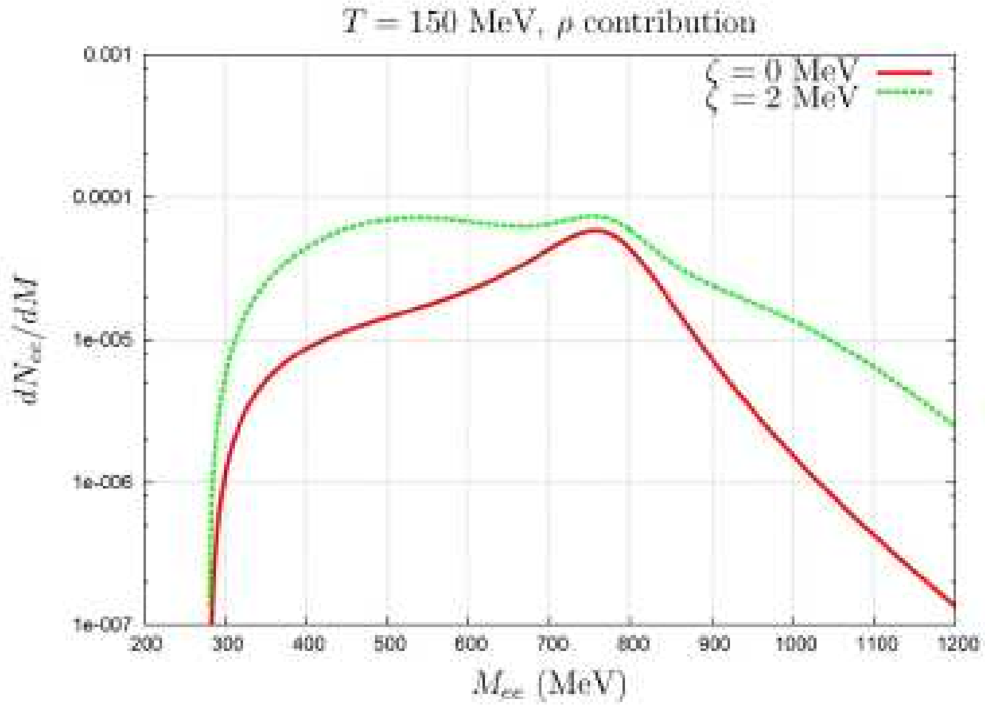
10)

$$m_{V,\epsilon}^2 \simeq M_\rho^2 + \epsilon\ 360\ \zeta|\vec{k}|;\ m_V^2 \equiv m_{V,0}^2 \simeq M_\rho^2;$$

$$\Gamma_{\rho ee}/m_\rho \simeq 10^{-5};\ \Gamma_{\omega ee}/m_\omega \simeq 0.8 \cdot 10^{-6}$$

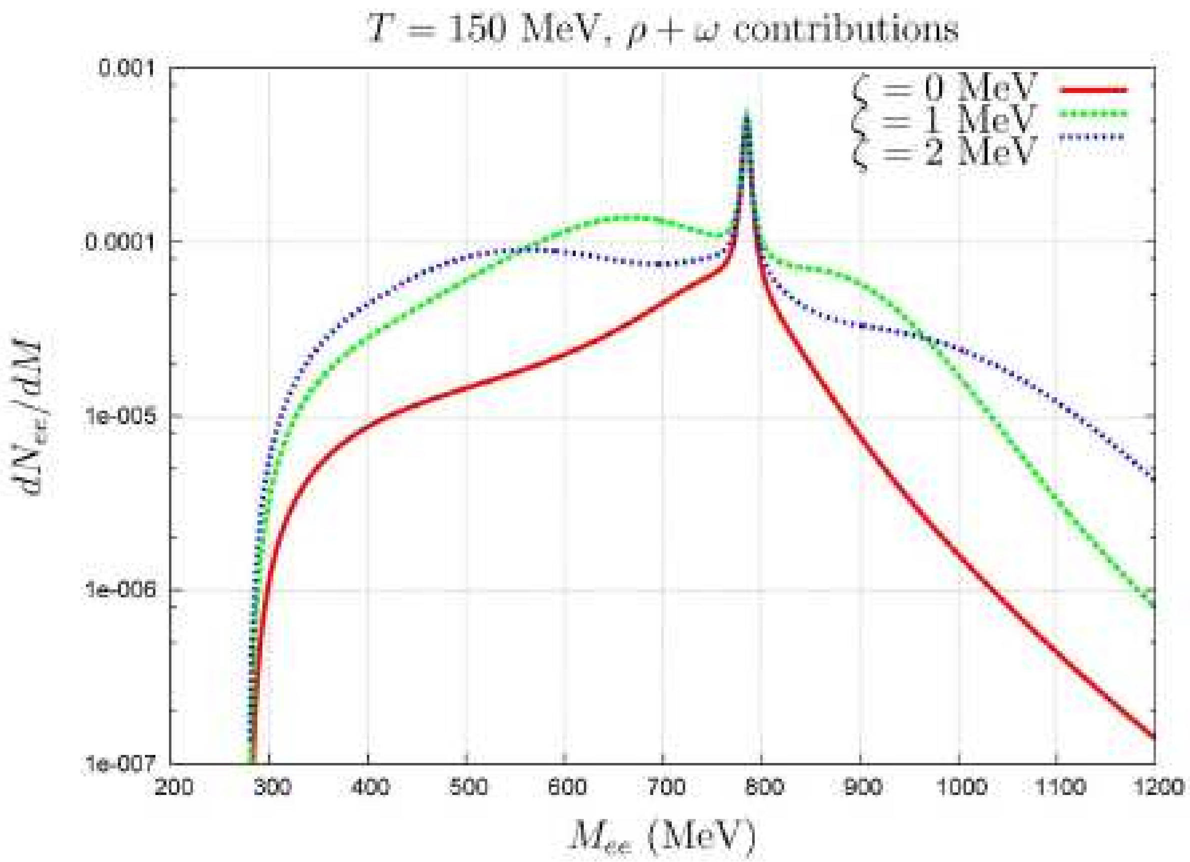


$T = 150$ MeV, ω contribution
$\zeta = 0$ MeV
$\zeta = 2$ MeV
0.001
0.0001
1e-005
1e-006
1e-007
1e-008
1e-009
dN_{ee}/dM
400
500
600
700
800
900
1000
1100
1200
M_{ee} (MeV)



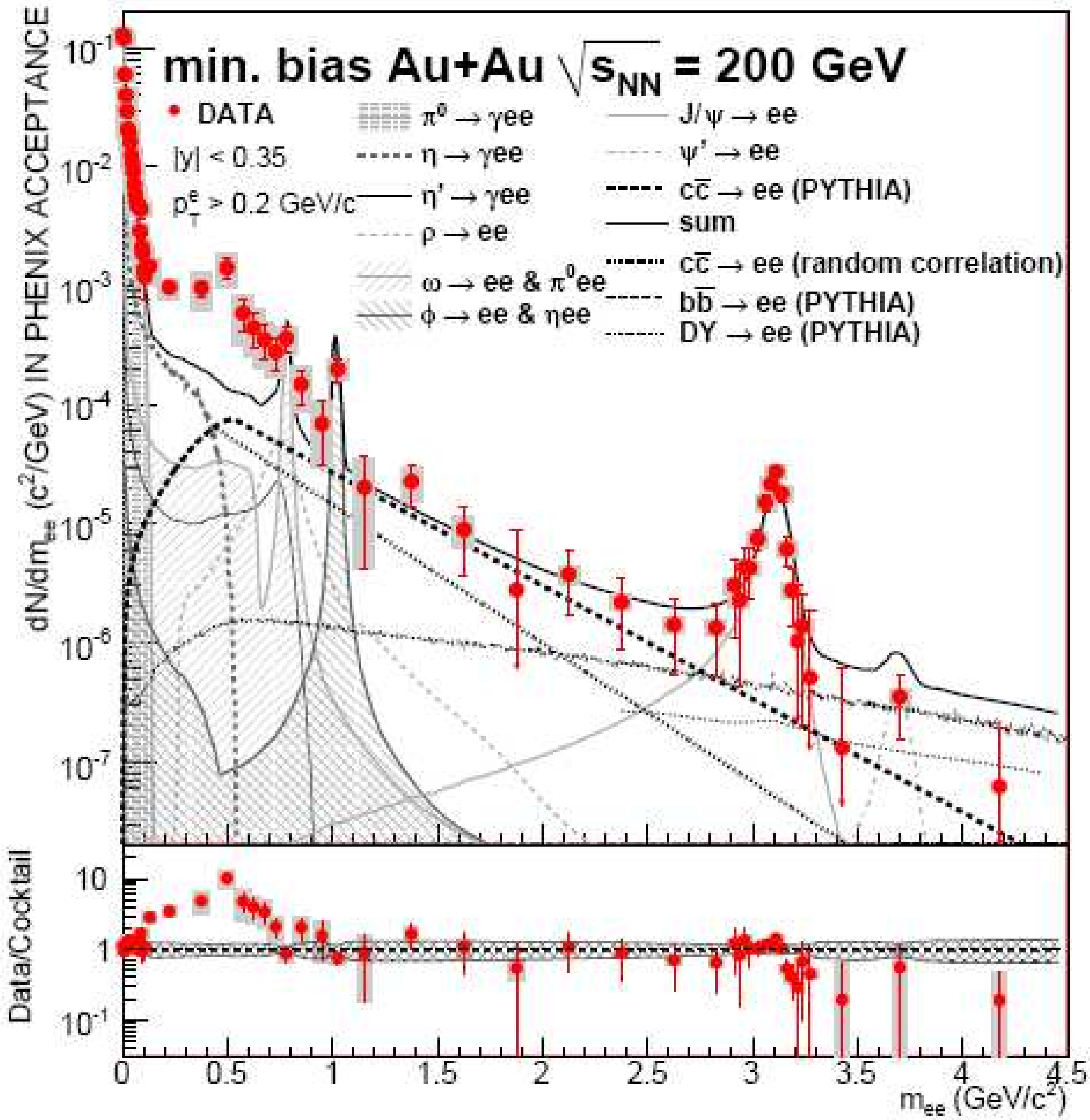
$T = 150$ MeV, ρ contribution
$\zeta = 0$ MeV
$\zeta = 2$ MeV
0.001
0.0001
1e-005
1e-006
1e-007
dN_{ee}/dM
200
300
400
500
600
700
800
900
1000
1100
1200
M_{ee} (MeV)

Abnormal enhancement of dilepton yield



The normalization of the $\rho + \omega$ peak is chosen on the PHENIX data

Compare with PHENIX



Signatures and searches of parity breaking

- Positions of resonances with two transversal polarizations depend on vector meson wave vector k and therefore convolution with thermal meson distribution makes them broader. Distorted vector meson resonances trigger considerably the yield of dileptons (see Fig. 1-3). Therefrom it follows that an empirical value of $\zeta \sim 1 - 2MeV$.
- As the amplification of dilepton yield at a given value of their invariant mass is owed to photons/vector mesons with a definite polarization one could search for polarization asymmetry in event-by-event measurements. These measurements may reveal in an unambiguous way the existence of parity violation .
- For distorted photons with "+" polarization there are different thresholds $\sim 4m_l^2/\zeta$ to start a resonant behavior for different dilepton species (five orders of magnitude between e^+e^- and $\mu^+\mu^-$). For massive vector mesons such a difference in thresholds are smeared out and one could expect also an abnormal dimuon excess for invariant masses $> 300MeV$ (presumably seen in [26]).
- Mixing with vector mesons is sensitive to isospin of pseudoscalar condensate and therefore the fraction of distorted photon decays helps to disentangle its isospin content.

<u>Program for</u> **RHIC → CBM FAIR + NICA**