DILEPTON PRODUCTION CROSS SECTION IN PP COLLISIONS AT T_{LAB} = 3.5 GeV

M. I. Krivoruchenko
ITEP, Moscow

- TÜBINGEN/ITEP MODEL - INTRODUCTION
- THRESHOLD OF PARTIAL WIDTHS IN DILEPTON CHANNELS $M\Gamma_{V\to e^+e^-}(M)$, production cross section and constraints for $1/g_V(M)$
- ETA-MESON CONTRIBUTION

Ad.Hoc Workshop on NN collisions with HADES
Darmstadt, 12 August 2011

TÜBINGEN/ITEP MODEL - INTRODUCTION

Dilepton production cross section can be calculated using the inclusive vector meson production cross sections:

$$\frac{d\sigma(s,M)^{pp\to e^+e^-X}}{dM^2} = \sum_{M} \frac{d\sigma(s,M)^{pp\to MX'}}{dM^2} B(M)^{M\to e^+eX''}.$$

where

$$B(M)^{M\to e^+eX''} = \frac{\Gamma(M)^{M\to e^+eX''}}{\Gamma_{tot}^{M}(M)}$$

In order to disentangle various contributions, we decompose the cross section into the pole and background parts:

$$d\sigma(s,M)^{pp\to MX} = d\sigma(s,M)_P^{pp\to VX} + d\sigma(s,M)_B^{pp\to M'X}$$

$$d\sigma(s,\mu)^{pp\to \mathrm{MX}} = \sigma(s)^{pp\to \mathrm{MX}} \frac{1}{\pi} \frac{\mu\Gamma_{tot}^{\mathrm{M}}(\mu) d\mu^2}{(\mu^2 - m_{\mathrm{M}}^2)^2 + (\mu\Gamma_{tot}^{\mathrm{M}}(\mu))^2}$$

$$\times \sum_{n=0}^{N_\pi} w_n C_n \Phi_{3+n}(\sqrt{s}\ldots)$$

where

\+ pions …

$$\Phi_{3+n}(\sqrt{s}\ldots) = \Phi(\sqrt{s}, m_N, m_N, \mu, \underbrace{\mu_\pi, \ldots, \mu_\pi}),$$

$$\sum_{n=0}^{N_\pi} w_n = 1,$$

$$C_n^{-1} = \int_{\mu_{TH}^2}^{(\sqrt{s}-2m_N-n\mu_\pi)^2} \frac{1}{\pi} \frac{\mu\Gamma_{tot}^{\mathrm{M}}(\mu) d\mu^2}{(\mu^2 - m_{\mathrm{M}}^2)^2 + (\mu\Gamma_{tot}^{\mathrm{M}}(\mu))^2} \Phi_{3+n}(\sqrt{s}\ldots).$$

A. Faessler et al., J. Phys. G: 29 (2003) 603

The **binomial distribution** is based on the idea of a Bernoulli trial.
Applying for pion multiplicity

$$w_n = \frac{N_\pi !}{n!(N_\pi - n)!} p^n (1-p)^{N_\pi - n}$$

The maximum number of pions

$$N_\pi = \left[(\sqrt{s} - 2m_N - m_{\mathrm{M}}) / \mu_\pi \right]$$

To fix w_n (*i*.e. parameter *p*) one has to know **two** cross sections.
Examples:

$$\sigma(s)^{pp \to NN\mathrm{M}} \quad \& \quad \sigma(s)^{pp \to NN\mathrm{M}\pi},$$

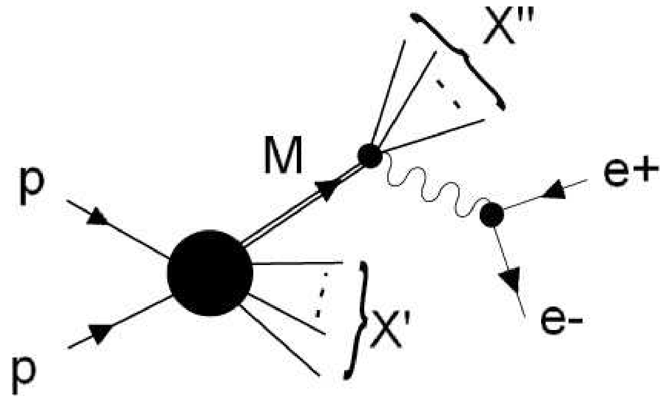
$$\sigma(s)^{pp \to \mathrm{MX}} \quad \& \quad \sigma(s)^{pp \to NN\mathrm{M}}.$$

In the last case

$$\frac{\sigma(s)^{pp \to NN\mathrm{M}}}{\sigma(s)^{pp \to NN\mathrm{MX}}} = (1-p)^{N_\pi}.$$

Phenomenology:

$$\frac{d\sigma(s,M)^{NN\to e^+e^-\mathrm{X}}}{dM^2} = \sum_M \int d\mu^2 \frac{d\sigma(s,\mu)^{NN\to \mathrm{MX'}}}{d\mu^2} \frac{dB(\mu,M)^{\mathrm{M}\to e^+e^-\mathrm{X''}}}{dM^2}$$

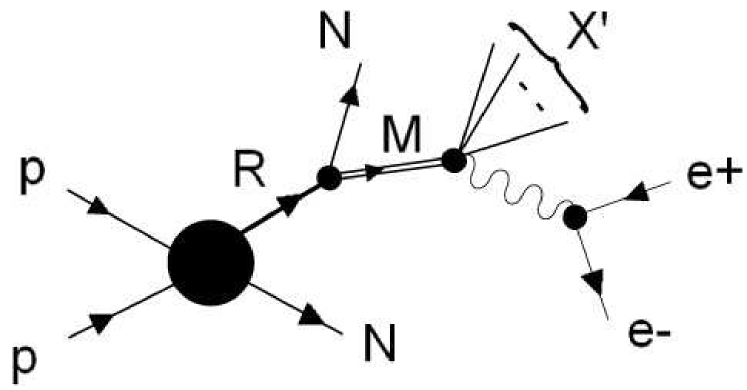


μ- invariant mass of M, M - invariant mass of e+e-,
X'' = mesons,
X' = NN + pions.

Resonance model:

$$\frac{d\sigma(s,M)^{NN\to e^+e^-\mathrm{X}}}{dM^2} = \sum_{\mathrm{R}} \int_{(m_N+M)^2}^{(\sqrt{s}-m_N)^2} d\mu^2 \frac{d\sigma(s,\mu)^{NN\to N\mathrm{R}}}{d\mu^2}$$

$$\times \sum_{\mathrm{M}} \frac{dB(\mu,M)^{R\to \mathrm{M}N\to e^+e^-\mathrm{X'}N}}{dM^2}$$



μ- invariant mass of R, *M* - invariant mass of e+e-,
X' = mesons

subthreshold

$$\sigma(s)^{excl.} = \sigma(s)^{NN\to RN\to e^+e^-NX'N} = w_0\sigma(s)^{NN\to e^+e^-X},$$

$$\sigma(s)^{excl.+n\pi} = w_n\sigma(s)^{NN\to e^+e^-X},$$

$$\sigma(s)^{incl.} = \sum_{n=0}^{N_\pi} \sigma(s)^{excl.+n\pi} = \sigma(s)^{NN\to e^+e^-X}.$$

We used suppression factor $0<S_F<1$ such that

$$d\sigma(s,M)^{excl.} = S_F d\sigma(s,M)^{NN\to RN\to e^+e^-NX'N} + (1-S_F)w_0 d\sigma(s,M)^{NN\to e^+e^-X},$$

$S_F=0$ around the peak and $S_F=1$ at small invariant masses

THRESHOLD OF PARTIAL WIDTHS IN DILEPTON CHANNELS

Multichannel Breit-Wigner formula:

$$f_{ab}^{(l)} = \frac{1}{2ik_a}(e^{2i\delta_a}-1)\delta_{ab} - \frac{1}{2\sqrt{(k_a k_b)}} e^{i(\delta_a+\delta_b)} \frac{\Gamma M_{ab}}{E-E_0+\frac{1}{2}i\Gamma}$$

where

$$M_{ab} = \pm\sqrt{(\Gamma_a \Gamma_b)}/\Gamma$$

from § 145 of

QUANTUM MECHANICS

NON-RELATIVISTIC THEORY

by

L. D. LANDAU AND E. M. LIFSHITZ

INSTITUTE OF PHYSICAL PROBLEMS, U.S.S.R. ACADEMY OF SCIENCES

Volume 3 of *Course of Theoretical Physics*

Every channel has its own threshold

Every channel has its own threshold, e.g.,

$$\omega \rightarrow \pi^+\pi^-\pi^0, \qquad \sqrt{s_{TR}} = 3\mu_\pi,$$

$$\omega \rightarrow e^+e^-\pi^0, \qquad \sqrt{s_{TR}} = \mu_\pi + 2m_e,$$

$$\omega \rightarrow e^+e^-, \qquad \sqrt{s_{TR}} = 2m_e.$$

$$\frac{d\sigma(s,M)^{NN\rightarrow e^+e^-\mathrm{X}}}{dM^2} = \sum_M \int d\mu^2 \frac{d\sigma(s,\mu)^{NN\rightarrow \mathrm{MX'}}}{d\mu^2} \frac{dB(\mu,M)^{\mathrm{M}\rightarrow e^+e^-\mathrm{X''}}}{dM^2}$$

$$= \sum_M \int \sigma(s)^{NN\rightarrow \mathrm{MX'}} \frac{1}{\pi} \frac{\mu\Gamma_{tot}^{\mathrm{M}}(\mu) d\mu^2}{(\mu^2 - m_{\mathrm{M}}^2)^2 + (\mu\Gamma_{tot}^{\mathrm{M}}(\mu))^2}$$

$$\times \frac{d}{dM^2} \frac{\Gamma(\mu,M)^{\mathrm{M}\rightarrow e^+e^-\mathrm{X''}}}{\Gamma_{tot}^{\mathrm{M}}(\mu)}$$

Every channel has its own threshold, e.g.,

$$\omega \to \pi^+\pi^-\pi^0, \qquad \sqrt{s_{TR}} = 3\mu_\pi,$$

$$\omega \to e^+e^-\pi^0, \qquad \sqrt{s_{TR}} = \mu_\pi + 2m_e,$$

$$\omega \to e^+e^-, \qquad \sqrt{s_{TR}} = 2m_e.$$

$$\frac{d\sigma(s,M)^{NN\to e^+e^-\mathrm{X}}}{dM^2} = \sum_M \int d\mu^2 \frac{d\sigma(s,\mu)^{NN\to \mathrm{MX'}}}{d\mu^2} \frac{dB(\mu,M)^{\mathrm{M}\to e^+e^-\mathrm{X''}}}{dM^2}$$

$$= \sum_M \int \sigma(s)^{NN\to \mathrm{MX'}} \frac{1}{\pi} \frac{\mu\Gamma_{tot}^{\mathrm{M}}(\mu) d\mu^2}{(\mu^2 - m_{\mathrm{M}}^2)^2 + (\mu\Gamma_{tot}^{\mathrm{M}}(\mu))^2}$$

$$\times \frac{d}{dM^2} \frac{\Gamma(\mu,M)^{\mathrm{M}\to e^+e^-\mathrm{X''}}}{\Gamma_{tot}^{\mathrm{M}}(\mu)}$$

Every channel has its own threshold, e.g.,

$$\omega \to \pi^+\pi^-\pi^0, \qquad \sqrt{s_{TR}} = 3\mu_\pi,$$

$$\omega \to e^+e^-\pi^0, \qquad \sqrt{s_{TR}} = \mu_\pi + 2m_e,$$

$$\omega \to e^+e^-, \qquad \sqrt{s_{TR}} = 2m_e.$$

$$\frac{d\sigma(s,M)^{NN\to e^+e^-\mathrm{X}}}{dM^2} = \sum_M \int d\mu^2 \frac{d\sigma(s,\mu)^{NN\to \mathrm{MX'}}}{d\mu^2} \frac{dB(\mu,M)^{\mathrm{M}\to e^+e^-\mathrm{X''}}}{dM^2}$$

$$= \sum_M \int \sigma(s)^{NN\to \mathrm{MX'}} \frac{1}{\pi} \frac{\mu\Gamma^{\mathrm{M}}_{tot}(\mu)d\mu^2}{(\mu^2 - m^2_{\mathrm{M}})^2 + (\mu\Gamma^{\mathrm{M}}_{tot}(\mu))^2}$$

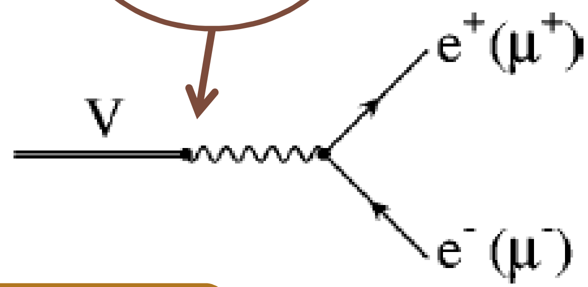
in various event generators

$$\times \frac{d}{dM^2} \frac{\Gamma(\mu,M)^{\mathrm{M}\to e^+e^-\mathrm{X''}}}{\Gamma^{\mathrm{M}}_{tot}(m_{\mathrm{M}})}$$

??

Direct decay modes

$$\frac{1}{g_V(m_V)}$$



$$M\Gamma_{V\to e^+e^-}(M) \equiv \Im\Sigma_V(M^2)$$

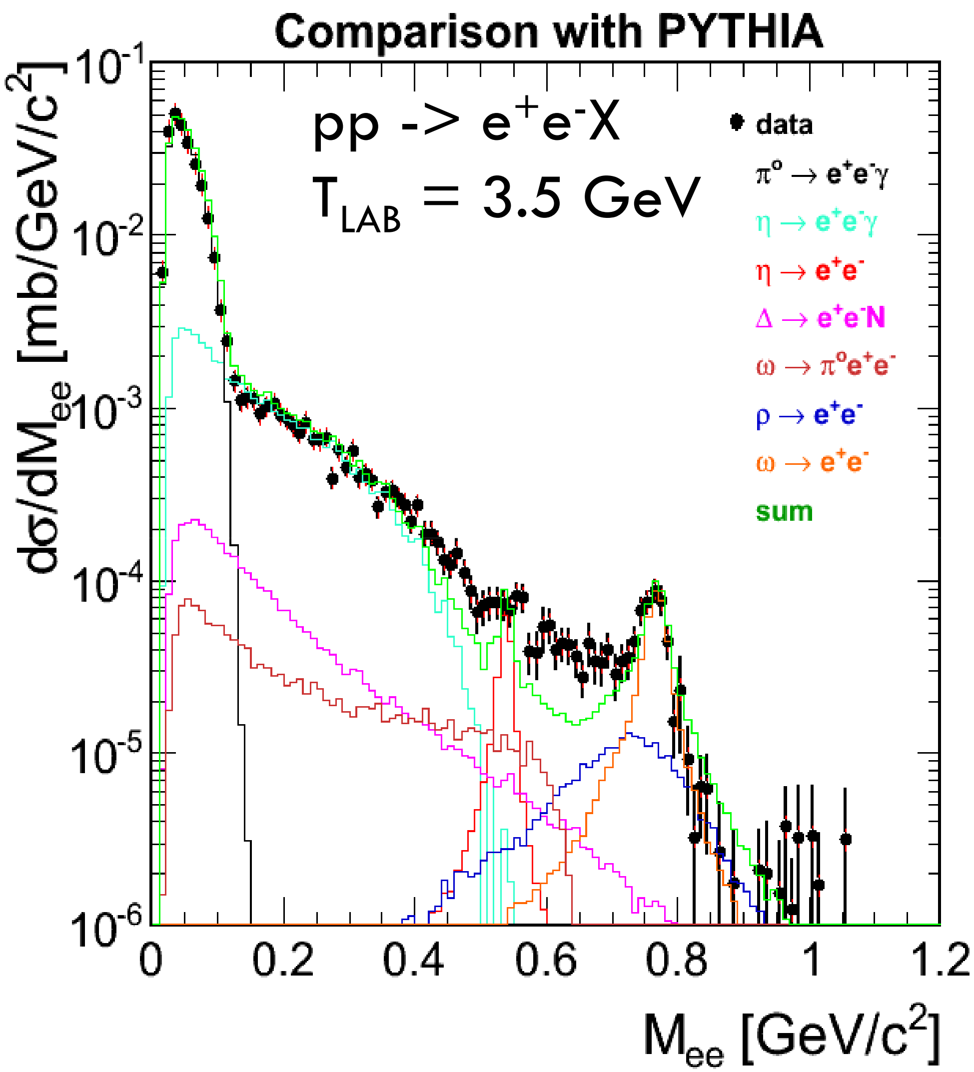
Self energy

$$= m_V \Gamma_{V\to e^+e^+}(m_V)$$

$$\times \frac{M^2+2m_e^2}{m_V^2+2m_e^2}\left(\frac{m_V}{M}\right)^4 \frac{\Phi_2(M,m_e,m_e)}{\Phi_2(m_V,m_e,m_e)}$$

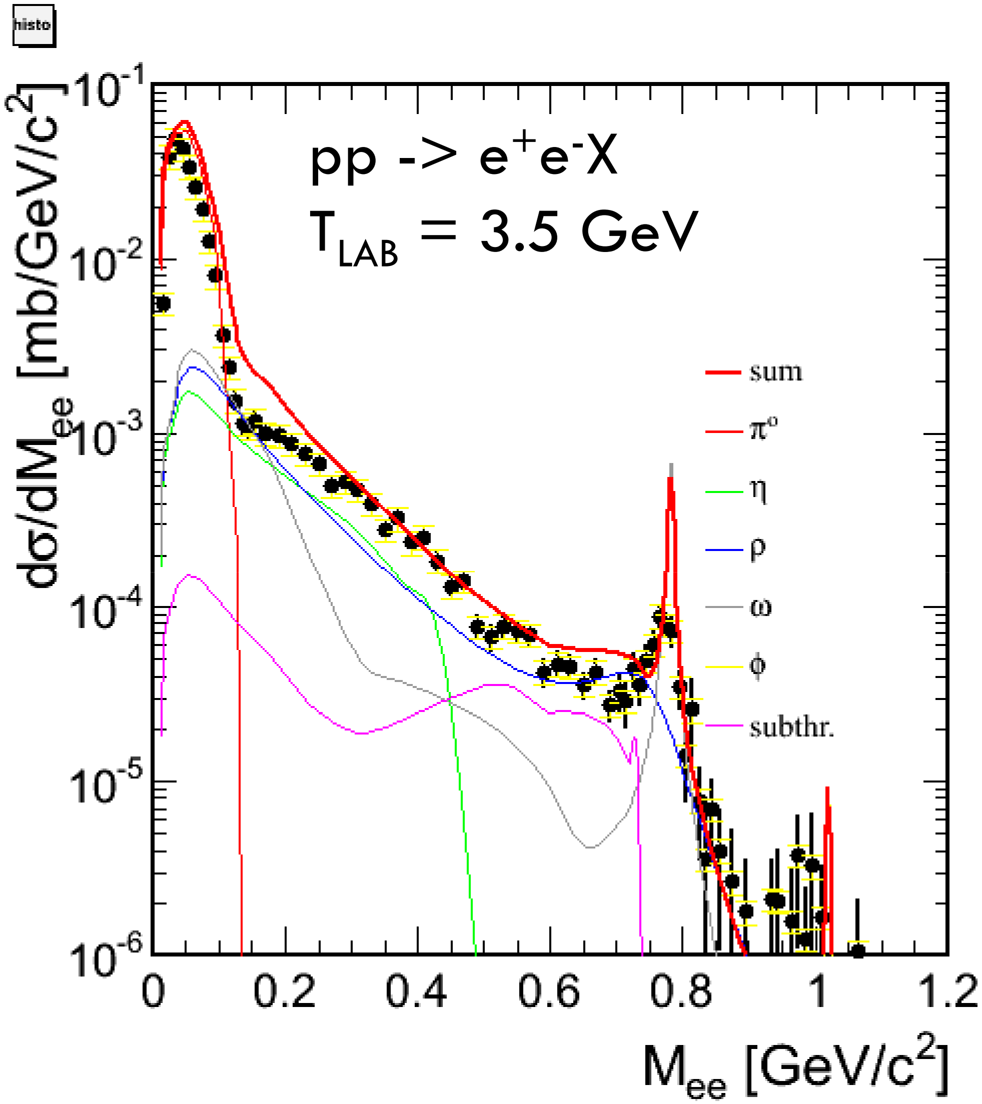
The width grows as $1/M^3$ at small invariant masses

$$m_V\Gamma_{V\to e^+e^+}(m_V) \sim \frac{1}{g_V^2(m_V)} \to \frac{1}{g_V^2(M)} = \textit{but assumed constant}$$



A. Rustamov, GSI, Darmstadt, April 18, 2011

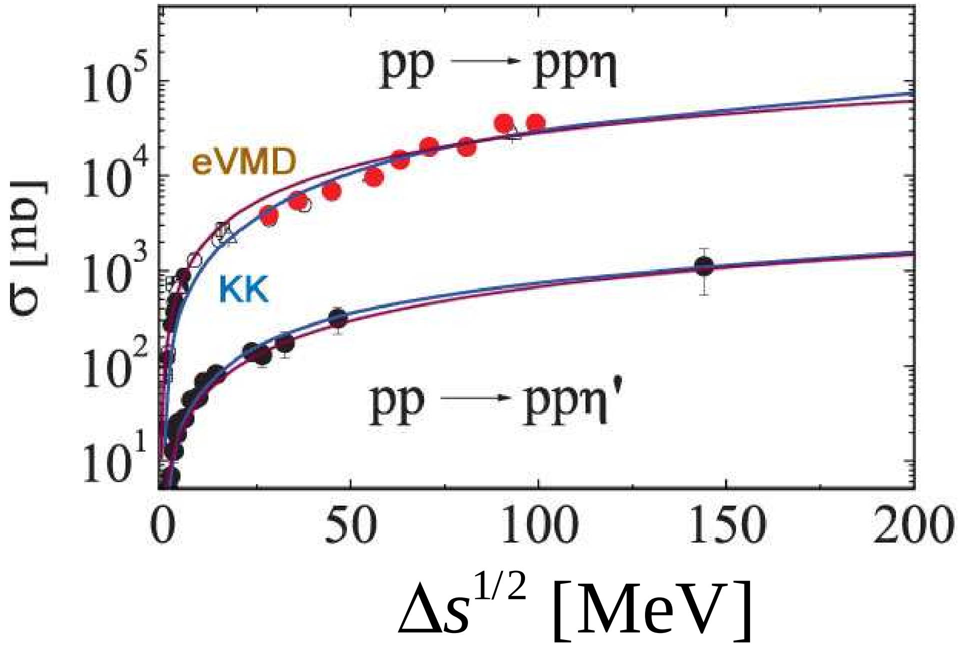
Comparison with Tübingen/ITEP model



MIK, June 2011

[without smearing]

ETA-MESON CONTRIBUTION



Comparison with
Kaptari and Kampfer, 2007

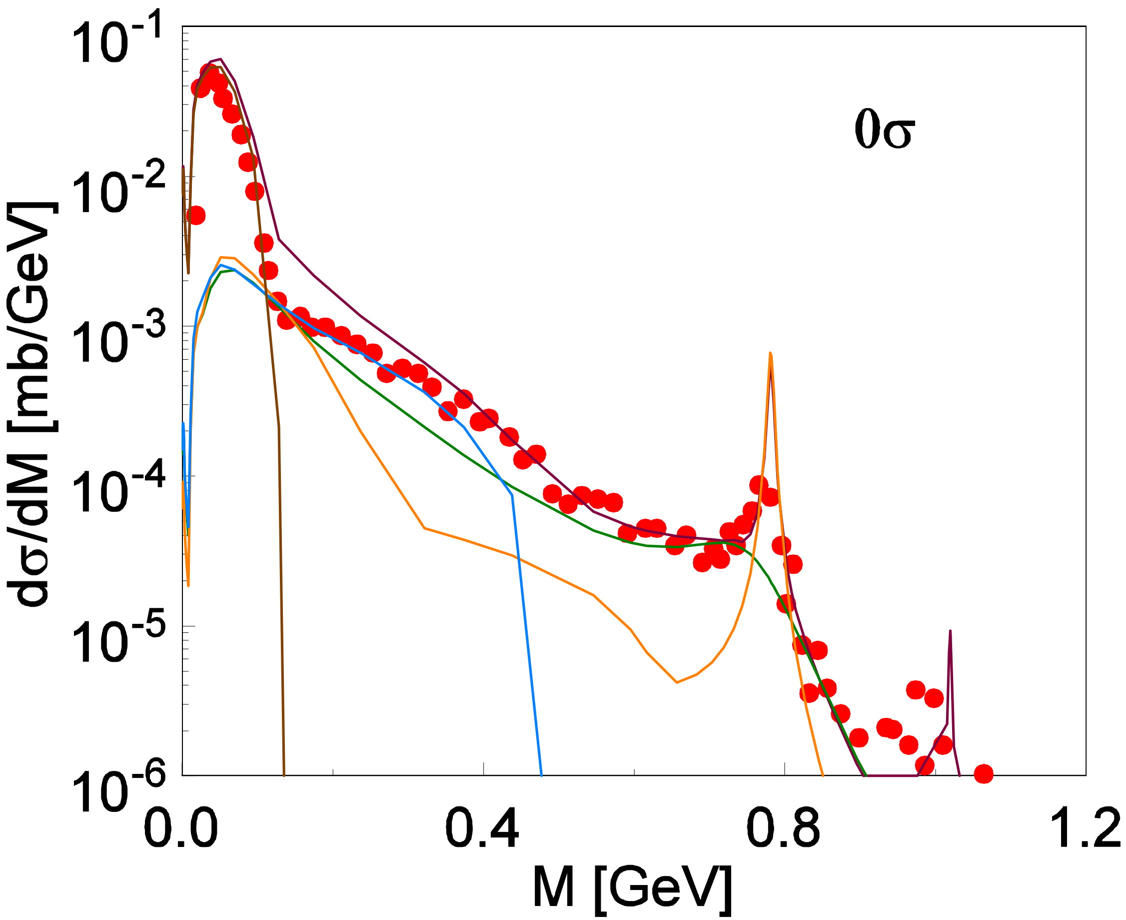
Ad.Hoc fit:

$$\xi = \frac{s}{s_0}, \quad \begin{cases} a = 0.50\text{ mb}, \\ b = 1.21, \\ c = 1.93. \end{cases}$$

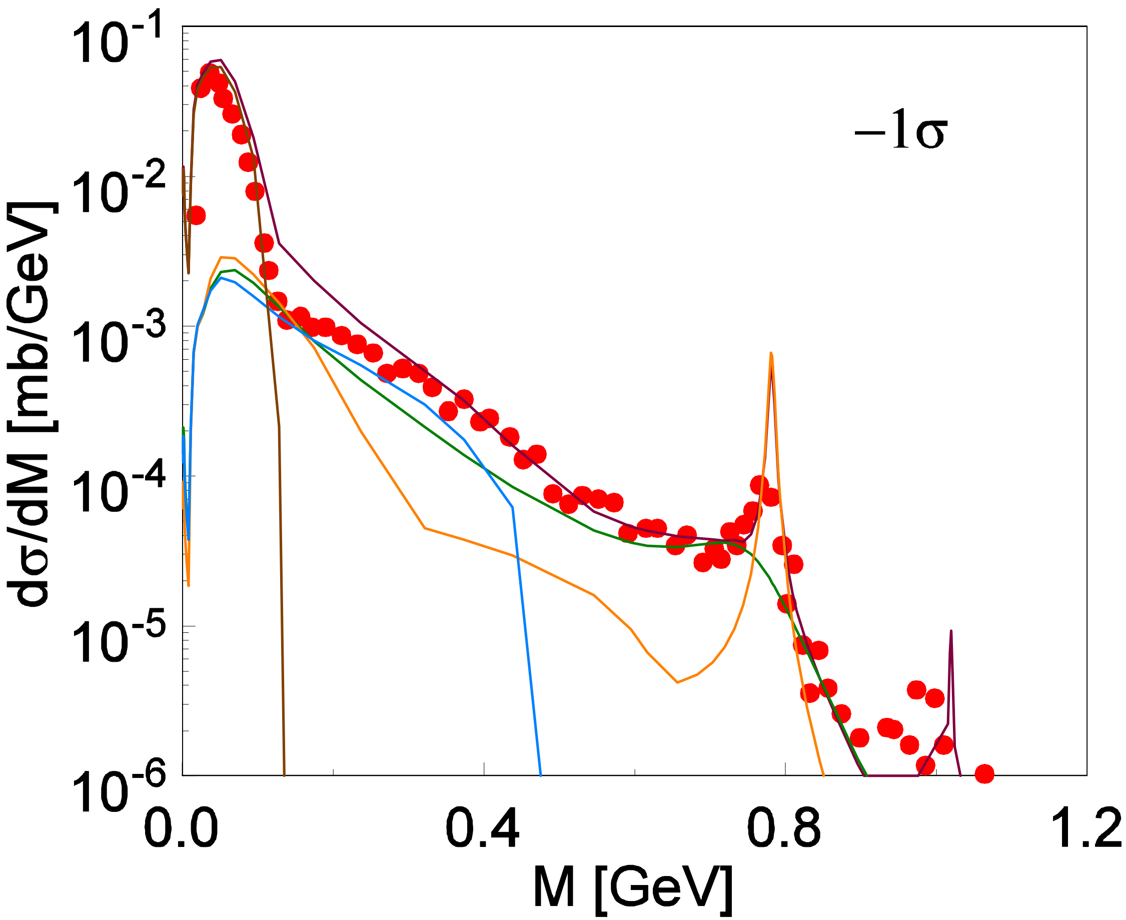
$$\boxed{\sigma_{pp\to\eta X}(T) \;=\; a(\xi - 1)^b \xi^c}$$

$$\sigma_{pp\to\eta X}(T = 3.5\,\text{GeV})$$
$$= 0.94\text{ mb } (-1\,\sigma)$$

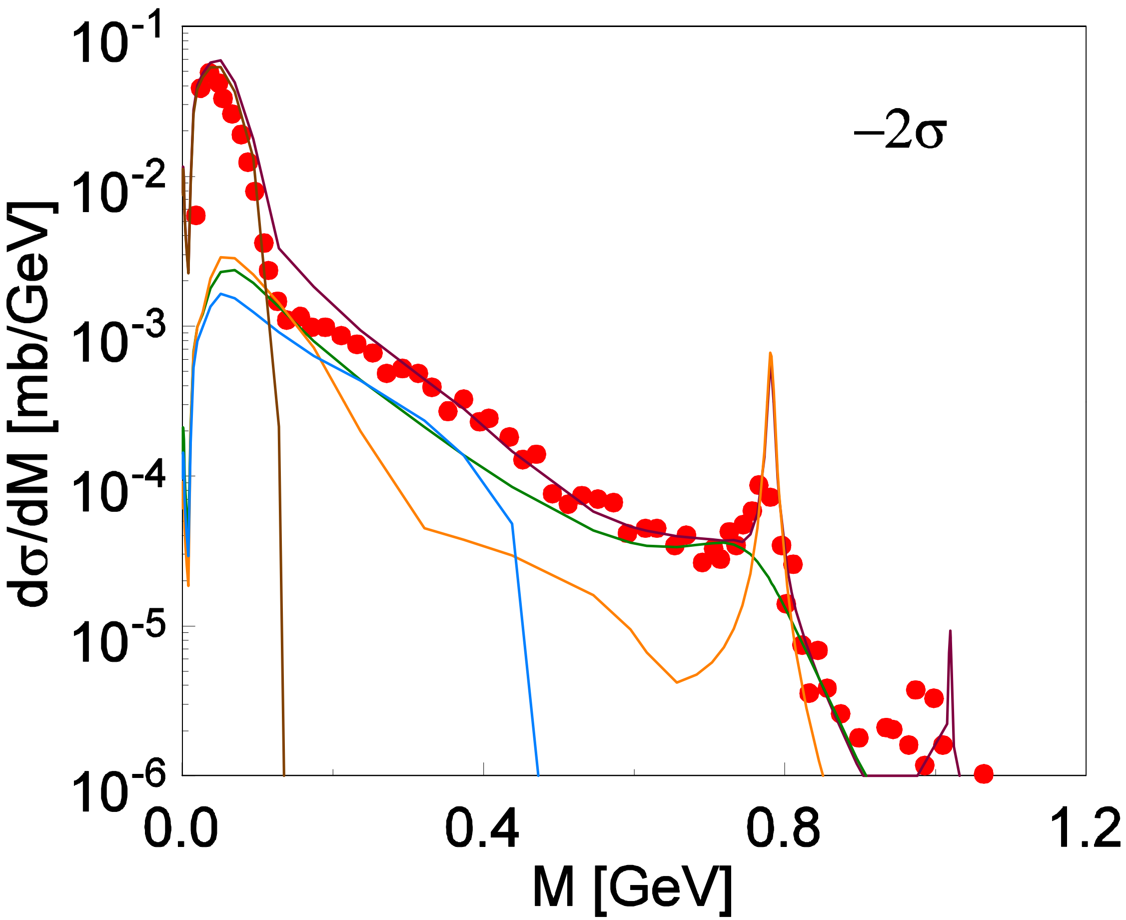
Sensitivity of the HADES data to the η-meson according to Tübingen/ITEP model



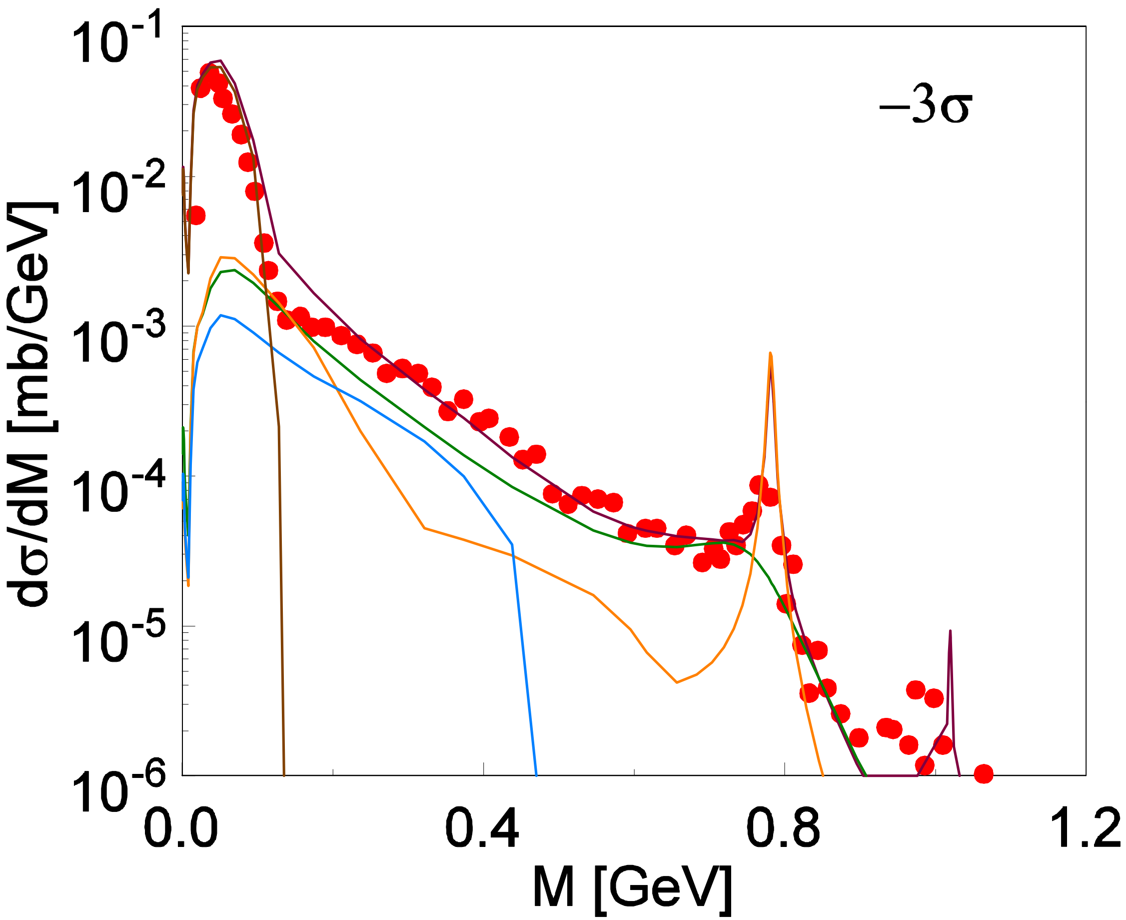
Sensitivity of the HADES data to the η-meson according to Tübingen/ITEP model



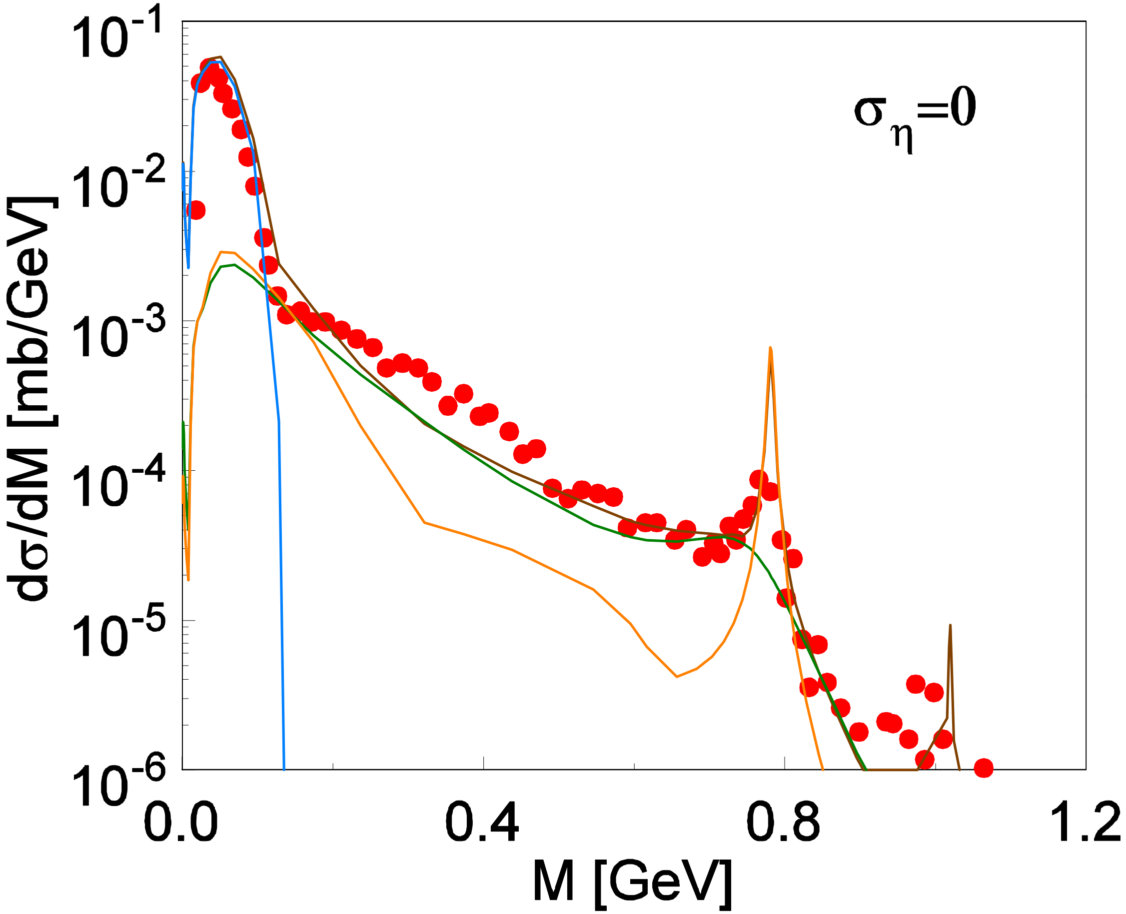
Sensitivity of the HADES data to the η-meson according to Tübingen/ITEP model

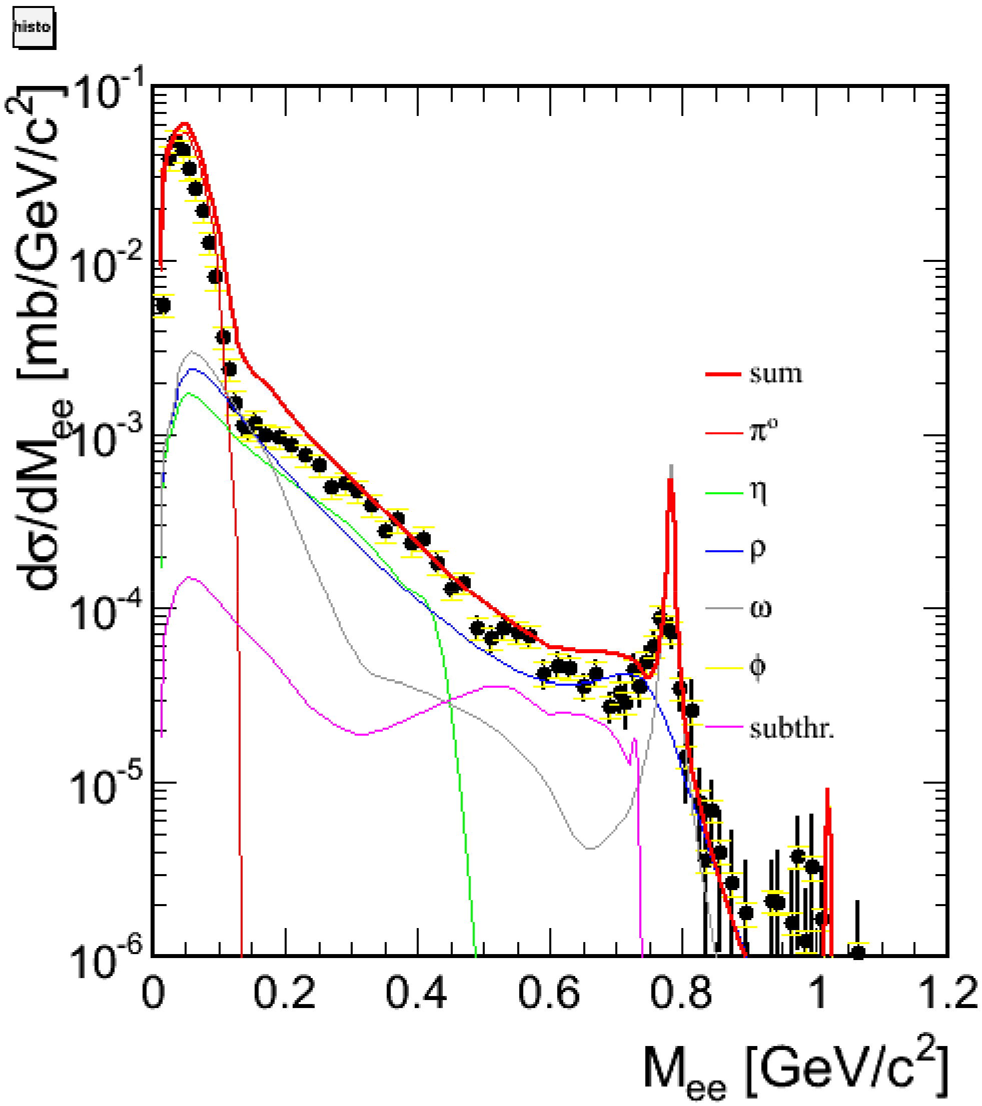


Sensitivity of the HADES data to the η-meson according to Tübingen/ITEP model



Sensitivity of the HADES data to the η-meson according to Tübingen/ITEP model





Comparison with the HADES data gives constraint:

$$\frac{1}{g_V^2(M)} = O(1) \text{ at } M \to 0.$$

Possible option:

$$\frac{1}{g_V^2(M)} \sim |\Psi_{q\bar{q}}(0)|^2 \sim M^3 \quad (?)$$

CONCLUSIONS

- TÜBINGEN/ITEP MODEL IS IN REASONABLE AGREEMENT WITH HADES DATA AT 3.5 GEV
- THRESHOLD OF PARTIAL WIDTHS IN THE DILEPTON CHANNELS IS TWICE THE ELECTRON MASS
- FROM THE LOW-M BEHAVIOR $1/g_{\mathrm{V}}(M)=O(1)$ for $M\to 0$
- THE HADES DATA ARE NOT VERY SENSITIVE TO ETA-MESON WHEN THE DILEPTON THRESHOLDS ARE SET CORRECTLY