# Dilepton production in HADES pp and np reactions at 1.25 GeV

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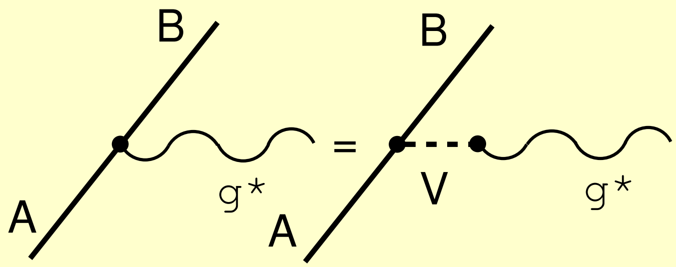
## Motivations




$$\mathbf{F(q^2) = F(0)\frac{m_V^2}{m_V^2 - q^2}}$$

Experiment: $\mathbf{F_{\omega\pi\gamma^*}(q^2) \sim 1/q^4}$, $\mathbf{F_1^N(Q^2) \sim 1/Q^4}$, $\mathbf{F_2^N(Q^2) \sim 1/Q^6}$

Quark counting rules: $\mathbf{F(Q^2) \sim 1/Q^{2n}}$, $\mathbf{Q^2 \to \infty}$, $\mathbf{n = 1, 2, ...}$ depending on the process.

Radiative versus vector meson decays of baryonic resonances: $\mathbf{\Gamma(R \to N\gamma)}$ is too large when calculated from $\mathbf{\Gamma(R \to NV)}$ using VDM.

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Extended VMD model and $\triangle$ Dalitz decay (page 2)
*Annals of Phys.*, **296**, 299 − 346 (2002)
*Phys. Rev.* **D65**, 017502 (2002)

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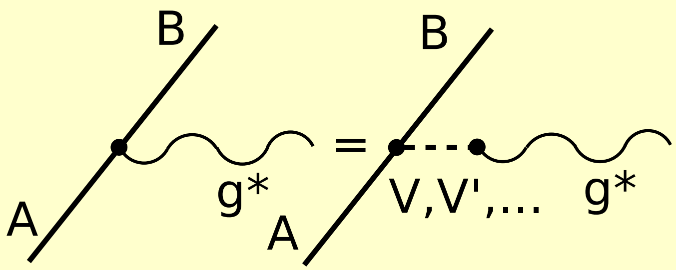
## Extension




$$\mathbf{F(q^2) = F(0)\frac{m_V^2 m_{V'}^2}{m_{V'}^2 - m_V^2}\left(\frac{1}{m_V^2 - q^2} - \frac{1}{m_{V'}^2 - q^2}\right) = F(0)\frac{m_V^2 m_{V'}^2}{(m_V^2 - q^2)(m_{V'}^2 - q^2)}}$$

The destructive interference of $\mathbf{V, V', ...}$ vector mesons can reduce $\mathbf{\Gamma(R \to N\gamma)}$ radiation width in comparison to contribution of only ground state vector meson $\mathbf{V}$.

Quark counting rules give constraints on the unknown couplings of excited vector mesons $\mathbf{V', ...}$ to baryons and photon.



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## Helicity amplitudes

The process of decay $R \to N\gamma^*$ of baryonic resonance with spin $J = l + 1/2$ to nucleon and virtual photon is described by helicity amplitudes

$$< \lambda\lambda_{\gamma^*}|\mathbf{S}|\mathbf{J}\lambda_* >; \quad \lambda_* = \lambda_{\gamma^*} - \lambda; \quad \lambda_{\gamma^*} = \mathbf{0}, \pm\mathbf{1}; \quad \lambda = \pm\frac{\mathbf{1}}{\mathbf{2}}$$

Due to P-invariance only 3 of them with $\lambda_* > \mathbf{0}$

$$\mathbf{A}_{\frac{3}{2}} \equiv < -\frac{\mathbf{1}}{\mathbf{2}}\mathbf{1}|\mathbf{S}|\frac{\mathbf{3}}{\mathbf{2}} >, \quad \mathbf{A}_{\frac{1}{2}} \equiv < \frac{\mathbf{1}}{\mathbf{2}}\mathbf{1}|\mathbf{S}|\frac{\mathbf{1}}{\mathbf{2}} >, \quad \mathbf{S}_{\frac{1}{2}} \equiv < -\frac{\mathbf{1}}{\mathbf{2}}\mathbf{0}|\mathbf{S}|\frac{\mathbf{1}}{\mathbf{2}} >$$

are independent and it means that there are 3 ($\mathbf{F_{1,2,3}(q^2)}$) independent invariant form factors

$$\langle \lambda\lambda_{\gamma^*}|\mathbf{S}|\mathbf{J}\lambda_* \rangle = \mathbf{e\overline{u}(p,\lambda)} \left\{ \mathbf{q}_{\beta_1} ... \mathbf{q}_{\beta_{l-1}} \sum_{\mathbf{k=1}}^{\mathbf{3}} \mathbf{\Gamma}^{\mathbf{k}}_{\beta_l\mu} \mathbf{F_k(q^2)} \right\} \mathbf{u}_{\beta_1...\beta_l}(\mathbf{p}_*, \lambda_*) \epsilon_\mu^{*(\lambda_{\gamma^*})}(\mathbf{q})$$

$$\mathbf{\Gamma}^{\mathbf{1}}_{\beta\mu} = \mathbf{m}_*(\mathbf{q}_\beta\gamma_\mu - \hat{\mathbf{q}}\mathbf{g}_{\beta\mu})\gamma_\mathbf{5}, \quad \mathbf{\Gamma}^{\mathbf{2}}_{\beta\mu} = (\mathbf{q}_\beta\mathbf{P}_\mu - \mathbf{q}\cdot\mathbf{P}\mathbf{g}_{\beta\mu})\gamma_\mathbf{5}, \quad \mathbf{\Gamma}^{\mathbf{3}}_{\beta\mu} = (\mathbf{q}_\beta\mathbf{q}_\mu - \mathbf{q^2}\mathbf{g}_{\beta\mu})\gamma_\mathbf{5}$$



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## Quark counting rules

Electroproduction of baryonic resonances in deep inelastic region $\mathbf{q^2 = -Q^2}, \quad \mathbf{Q^2 \to \infty}$ is described by quark model that gives in asymptotics

$$\mathbf{A_{\frac{3}{2}} \sim \frac{1}{(Q^2)^{\frac{5}{2}}}}, \quad \mathbf{A_{\frac{1}{2}} \sim \frac{1}{(Q^2)^{\frac{3}{2}}}}, \quad \mathbf{S_{\frac{1}{2}} \sim \frac{1}{(Q^2)^2}}$$

This requires the following behaviour of invariant form factors

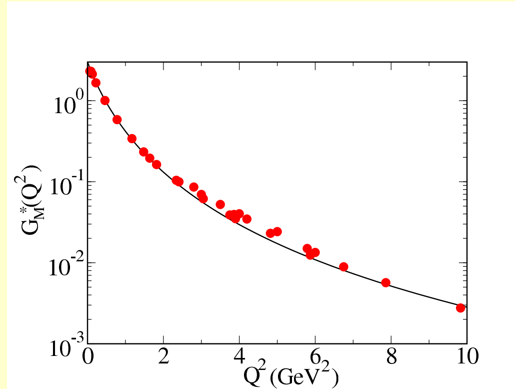
$$\mathbf{F_1(Q^2) \sim \frac{1}{(Q^2)^{\mathit{l}+2}}}, \quad \mathbf{F_2(Q^2) \sim \frac{1}{(Q^2)^{\mathit{l}+3}}}, \quad \mathbf{F_3(Q^2) \sim \frac{1}{(Q^2)^{\mathit{l}+3}}} \ .$$

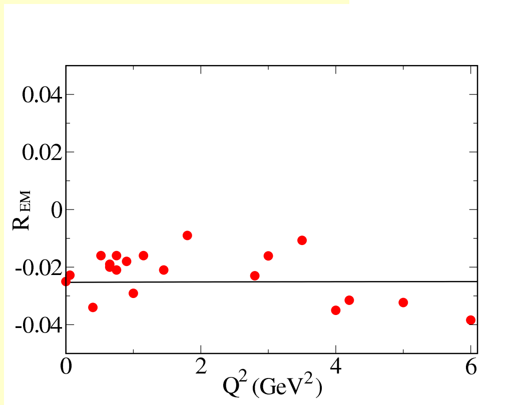
In extended VMD model it can be produced by destructive interference of the ground vector meson and $\mathbf{\mathit{l}+2}$ its radial excitations

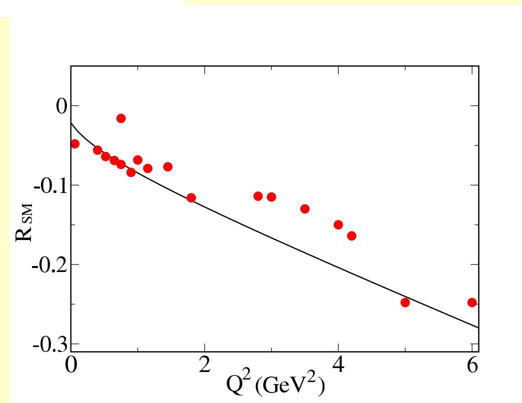
$$\mathbf{F_i(Q^2) = \frac{C_i - C'_i Q^2}{(1+\frac{Q^2}{m_V^2})(1+\frac{Q^2}{m_{V_1}^2})\ldots(1+\frac{Q^2}{m_{V_{\mathit{l}+2}}^2})}}, \quad \mathbf{C'_2 = C'_3 = 0} \ .$$

So, we have 4 fitting parameters $\mathbf{C_1, C'_1, C_2, C_3}$ for the description of $\mathbf{RN\gamma^*}$ transition.

## *Fit of* $\Delta N \gamma^*$ *data*




$$\mathbf{C_1 = 1.77,\ C_1' = 0.025,\ C_2 = -1.1,\ C_3 = -0.93}$$

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# Sources

For the dilepton production in $pN$ collision we distinguish generally between three different channels

$$pN \to NR \to NN\pi^0 \; ; \; \pi^0 \to \gamma e^+ e^- \; ,$$

$$pN \to NR \to NN\eta \; ; \; \eta \to \gamma e^+ e^- \; ,$$

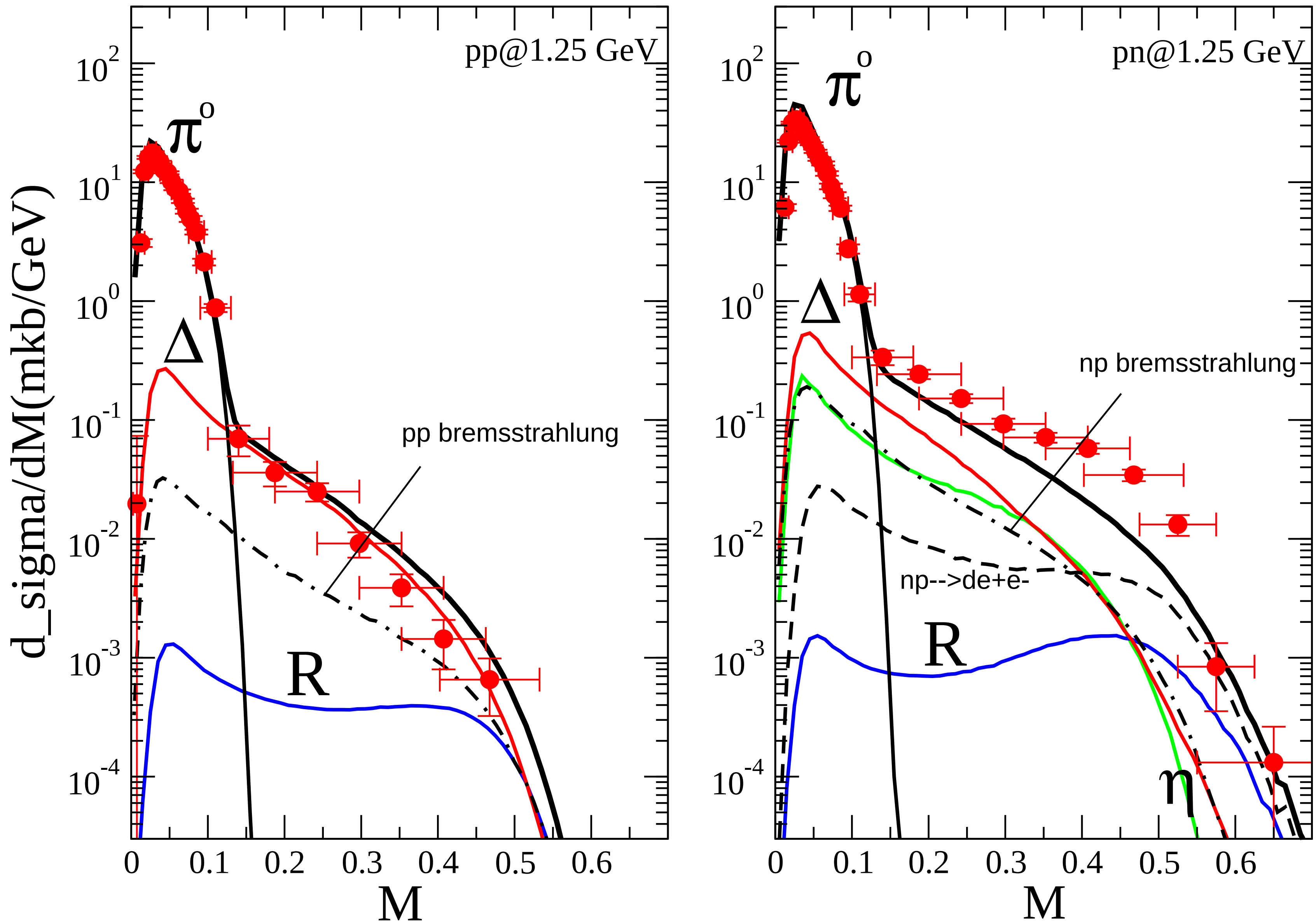
$$pN \to NR \to NN e^+ e^- \; ,$$

Also we add the reaction $pn \to d\eta$ to the $\eta$ production sources by a parameterization of the experimental cross section.

The situation with bremsstrahlung in rather undefinite. Nevertheless we will include bremsstrahlung contribution to our dilepton data. For this we will take the the results of R. Shyam, U. Mosel available also without electromagnetic form factors and scale them by VMD formfactor $1/(1 - M^2/m_\rho^2)$.

The radiative capture $np \to de^+e^-$ was never considered as a possible source of dileptons in $np$ collisions. Unexpectedly its contribution is large in the region $M > 0.4$ GeV.

The comparable size of radiative capture and $np$ - bremsstrahlung contributions could be the effect of the dibaryon resonance $I(J^P) = 0(3^+)$ with mass $m = 2.37$ GeV and width $\Gamma \approx 70$ MeV seen in pn system


pp@1.25 GeV
pn@1.25 GeV
d_sigma/dM(mkb/GeV)
$\pi^o$
$\Delta$
R
$\eta$
pp bremsstrahlung
np bremsstrahlung
np-->de+e-
M
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
0
0.1
0.2
0.3
0.4
0.5
0.6

# Conclusion

- It is found that the HADES data on the $e^+e^-$ invariant mass distribution in the $pp \to e^+e^-X$ reaction at 1.25 GeV are well reproduced by $R \to Ne^+e^-$ and $\pi^0 \to \gamma e^+e^-$ contributions.
- Moreover $R \to Ne^+e^-$ decays are dominated by the $\Delta(1232) \to Ne^+e^-$ one and neutral pions come dominantly from $\Delta(1232) \to N\pi^0$ decay.
- In the $np \to e^+e^-X$ case additional contributions from Dalitz decays of $\eta$ mesons produced in $np \to np\eta$ and $np \to d\eta$ reactions, from $np \to de^+e^-$ radiative capture and from $np \to npe^+e^-$ bremsstrahlung could give partial explanation of the huge (from 7 to 100 times in the region of invariant masses from 0.2 to 0.5 GeV) excess of dileptons in $np$ reaction compared to the case of $pp$ reaction.
- If the resonance $I(J^P) = 0(3^+)$ with mass $m = 2.37$ in pn system is relevant its contribution in the cannel $np \to dibaryon \to npe^+e^-$ could explain the huge excess of dileptons in $np$ reaction.