THE CASE FOR THE DIBARYON d_1^* (1956)

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OUTLINE

- **Introduction**
- **The evidence for the d^*_1(1956) in processes with real photons.**
- **A new mechanism for dielectron production in NN collisions due to the d^*_1(1956) resonance.**
- **Contribution of the $pp \to \gamma^* d_1^* \to e^+e^- d_1^*$ mechanism to the $pp \to e^+e^- X$ *DLS* data.**
- **Contribution of the $NN \to e^+e^- d_1^*$ mechanism to the *DLS* $AA \to e^+e^- X$ data.**
- **Conclusion**

INTRODUCTION

Searches for exotic multiquark states and in particular six-quark states with the baryon number B=2 (dibaryons) has a long history.

The results of these searches are believed to be unsuccessful.

The aim of this talk to show you that in the reality this is rather not the case.
There are reasons to believe that one of the exotic states still was observed.
This is a six-quark state that we called .

FIRST EVIDENCE FOR THE $d_1^*(1956)$

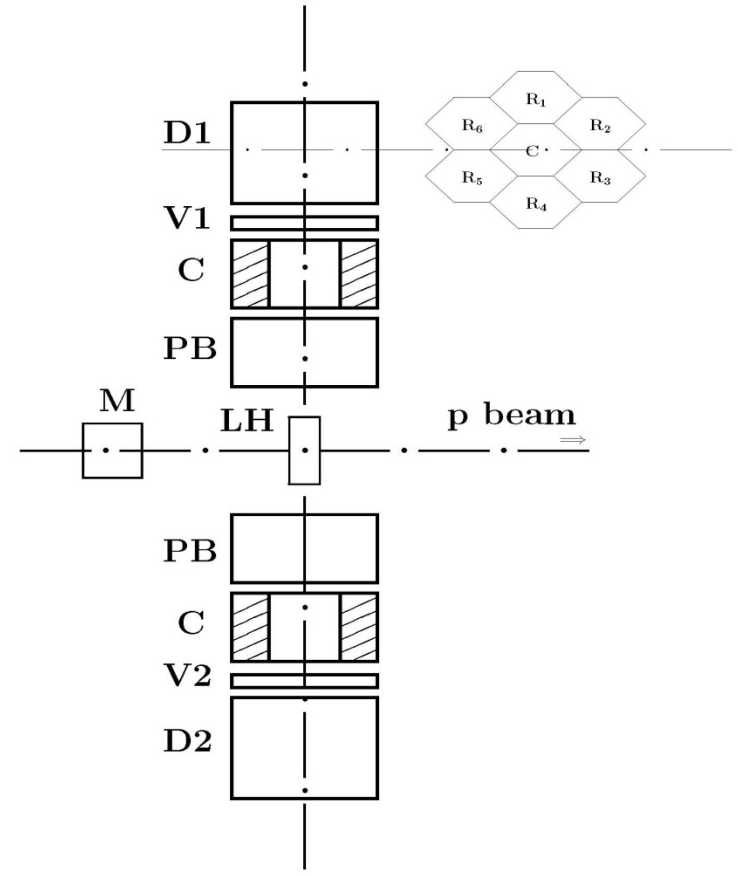
A.S. Khrykin et al., Phys.Rev. C64, 034002(2001)

Reaction : $pp \to \gamma\gamma X$

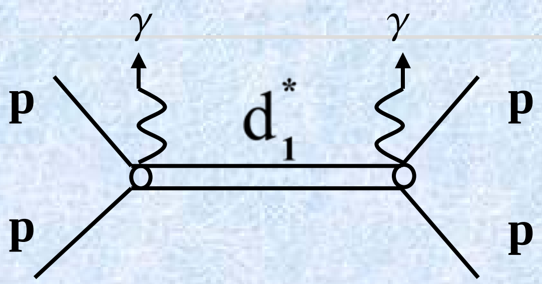
T_p=216 MeV; $\theta_\gamma = \pm 90^0$

Two photons were detected in coincidence.

Photon energy spectrum was measured.



$pp \to \gamma d_1^* \to \gamma\gamma pp$

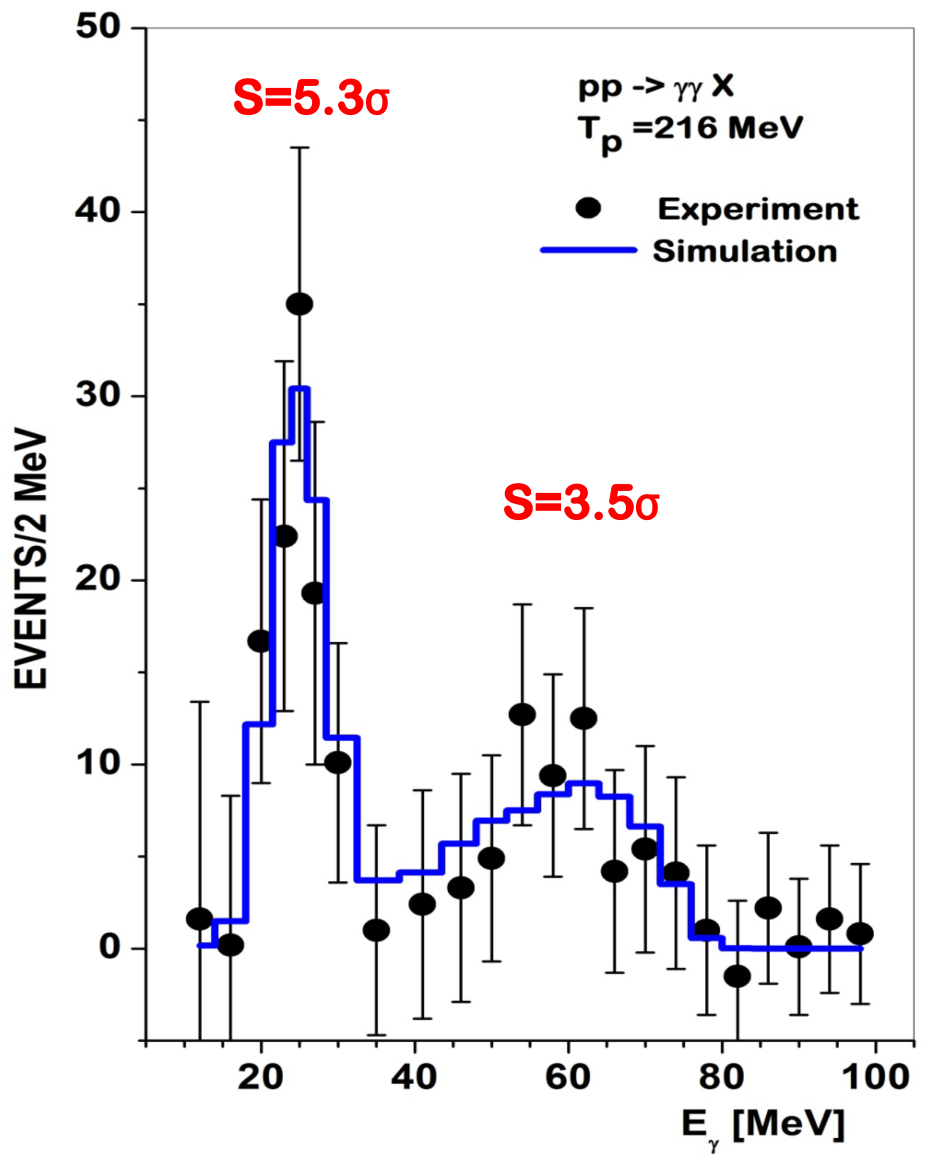


M_R~1956 MeV; ~8 MeV

Total S= 6.3 σ

$$E_\gamma^F\,(\mathrm{cms}) = \frac{S - M_R^2}{2\sqrt{S}}$$

$$E_\gamma^D(\mathrm{rf}) = \frac{M_R^2 - M_{pp}^2}{2M_R}$$



The $d_1^*(1956)$ existence implies the existence of a new mechanism of photon pair production that should be taken into account.

$$M_{\gamma\gamma}^2 = 2 * E_\gamma^F * E_\gamma^D(1 - \cos(\theta_{12}))$$

The evidence for the $d^*_1(1956)$ in the processes with real photons.

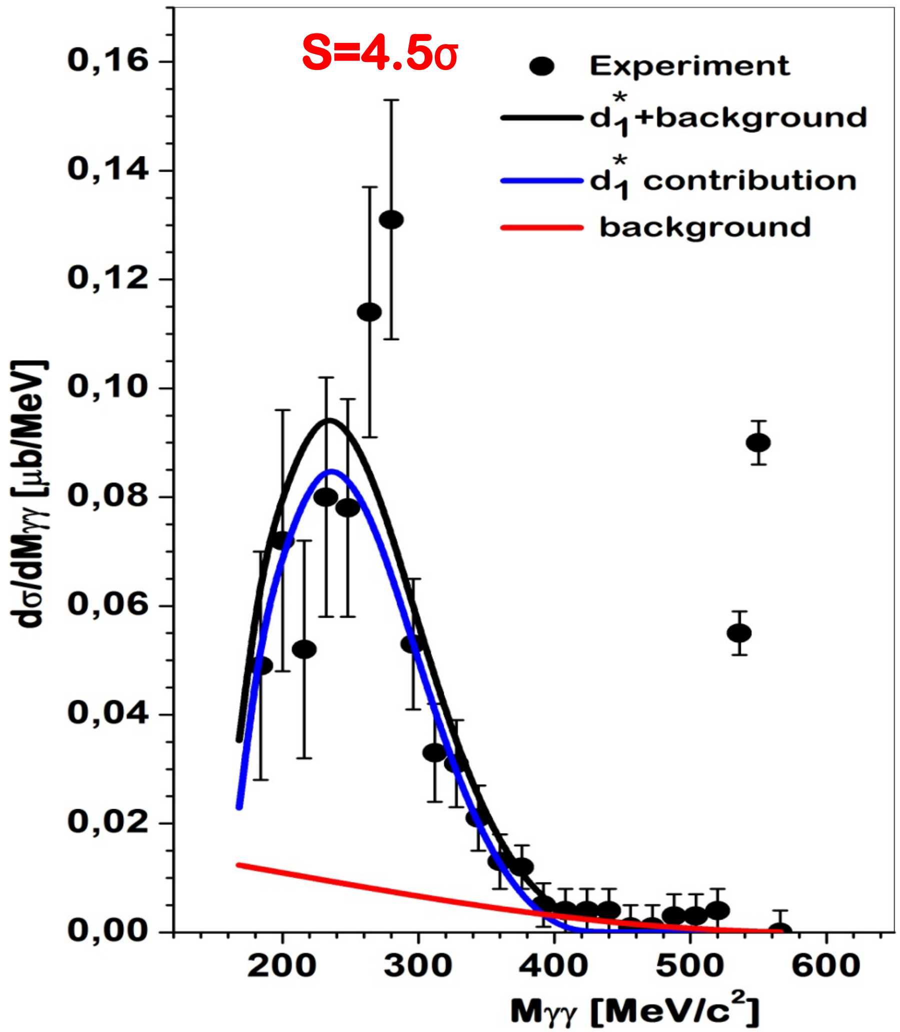
Exclusive pp→pp$\gamma\gamma$ reaction

A.S.Khrykin and S.B.Gerasimov, in : *Proc. of the MENU2007,* IKP, Forschungentrum Juelich, Germany, September 10-14, 2007, edited by H. Machner and S. Krewald, eConf C070910(2008),250.

<u>Experiment</u>
CELSIUS-WASA C*ollaboration*
Bashkanov et al. Int. Jour. of Mod. Phys. A20,554(2005); hep-ex/0406081

pp→pp$\gamma\gamma$

The two-photon invariant mass spectra of the reaction were measured at two energies:
T_p=1.36 GeV and T_p=1.2 GeV
St.sign.= $N_S/(N_S+2N_B)^{1/2}$: 4.5σ & 3.5σ



Calculations: $|M(NN\to \gamma d_1^* \to pp\ \gamma\gamma|^2$
⟹ $d^*_1(1956)\to(N\Delta)_{bound}$
$M^2_{\gamma\gamma}=(k_1+k_2)^2=2E_{\gamma 1}*E_{\gamma 2}*(1-\cos\theta_{12})$

χ^2=1.1/dof

Why the Celsius-Wasa Collaboration did not find the dibaryon signal in their pp $\rightarrow pp\gamma\gamma$ data at 310 MeV?

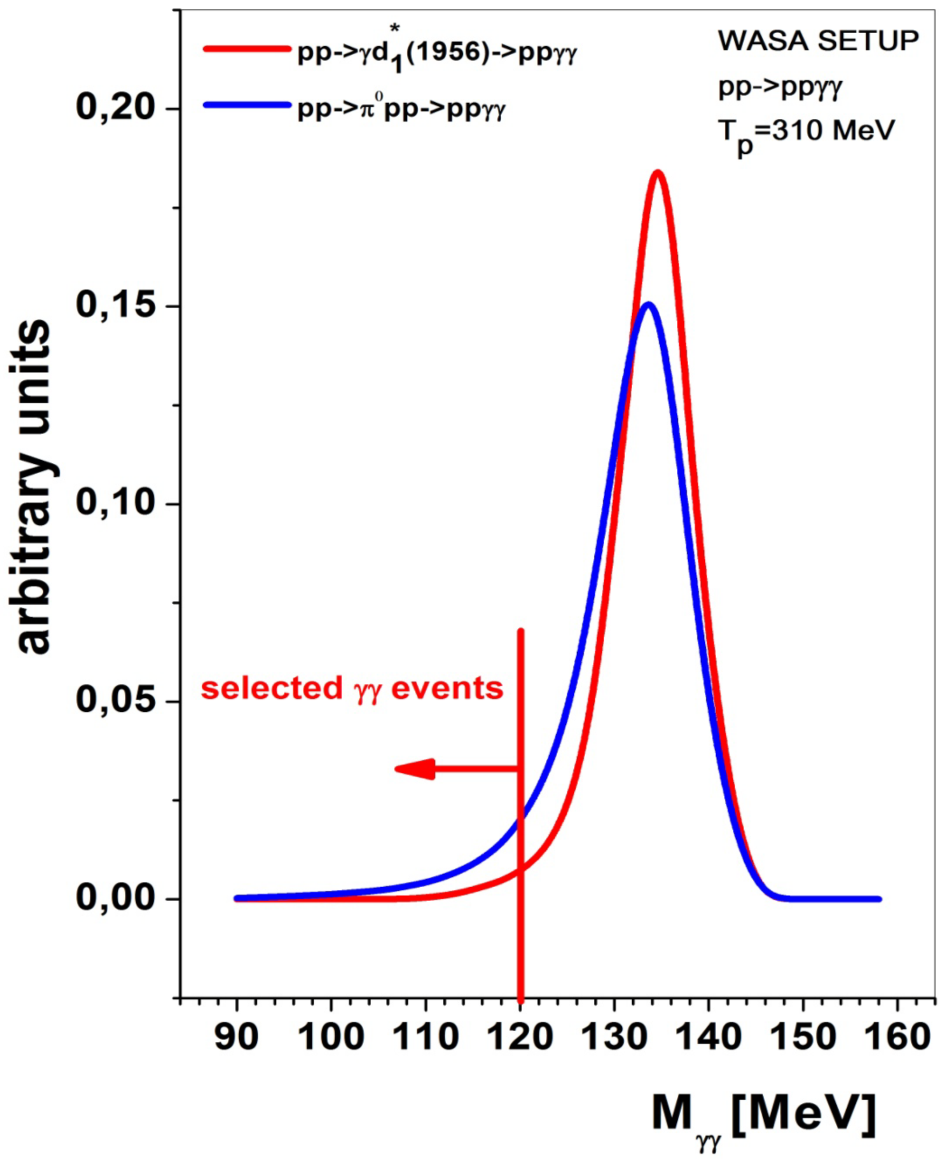
pp$\rightarrow\gamma$pp at T_k=310 MeV

H.Calen et al., Phys. Lett. B427, 248(1998).

To remove the γ-background due to the pp$\rightarrow\pi^0$pp $\rightarrow\gamma\gamma$pp process $\gamma\gamma$events also were collected. From these events were removed those connected with the π^0 – decay to search for the d^*_1

Two-photon inv. mass spectra were calculated for the **pp$\rightarrow\gamma d^*_1$(1956) $\rightarrow pp\gamma\gamma$** and **pp$\rightarrow pp\pi^0\rightarrow pp\gamma\gamma$** channels of the reaction **pp$\rightarrow$ pp$\gamma\gamma$** for the geometry and kinematic of the experiment PLB427,248 (1998).

So,all events (at least most of them) associated with the d^*_1(1956) were removed!



TWO PHOTON INVARIANT MASS SPECTRUM

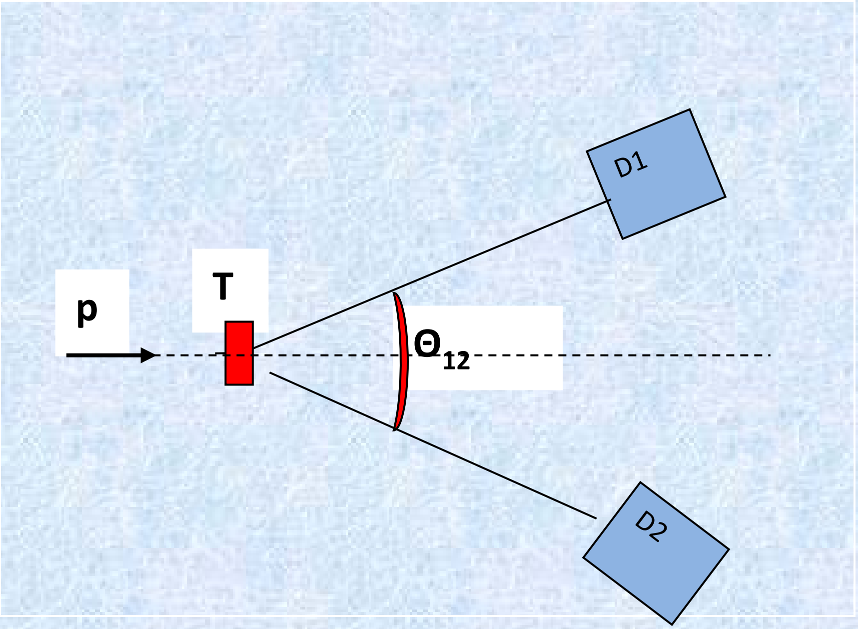
Experiment

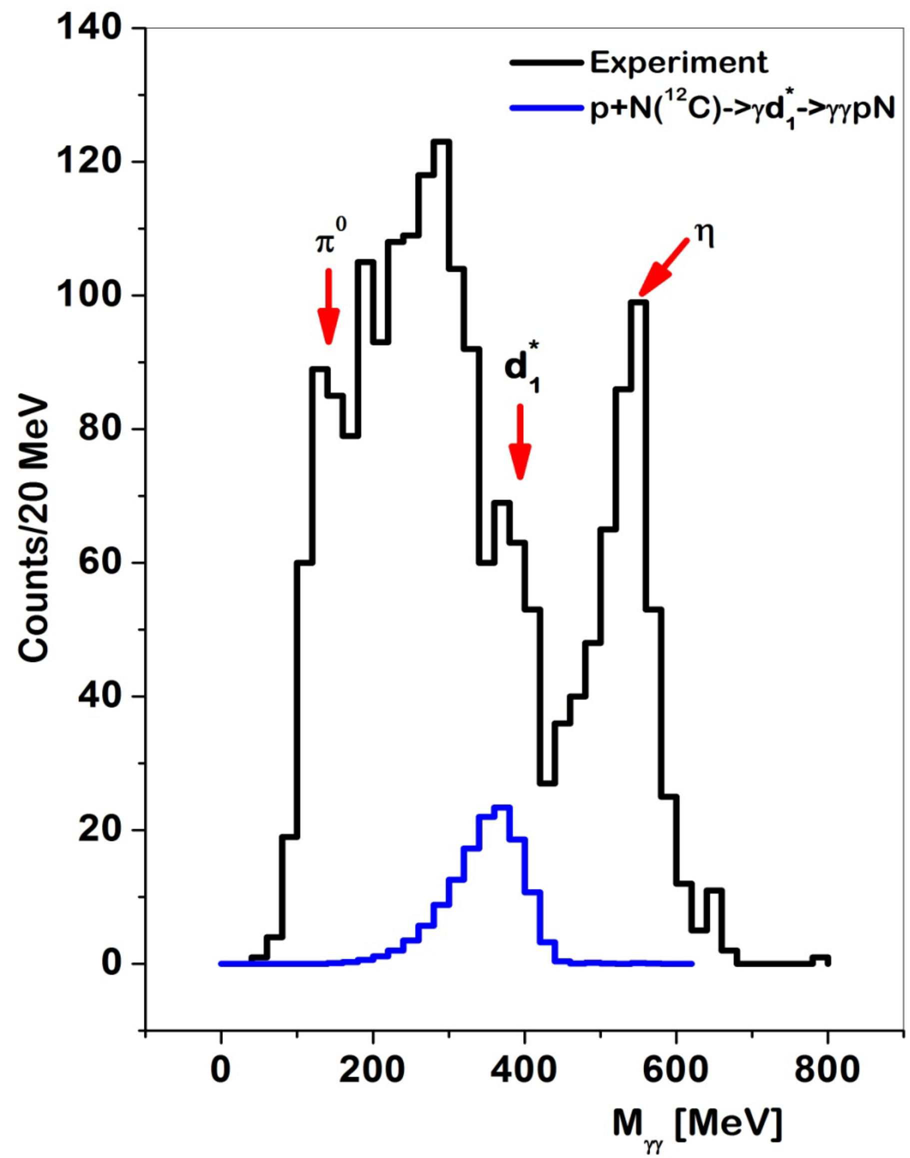
Reaction: $p + {}^{12}C \rightarrow \gamma X$

T_p=1300 MeV

PINOT Spectrometer $\Theta_{12} = 55^0$

Exp. Data: C.De Olivera Martins et al. Braz. Jour. Of Phys. V.31, n.31,p. 533(2001)





TWO PHOTON INVARIANT MASS SPECTRUM

Experiment

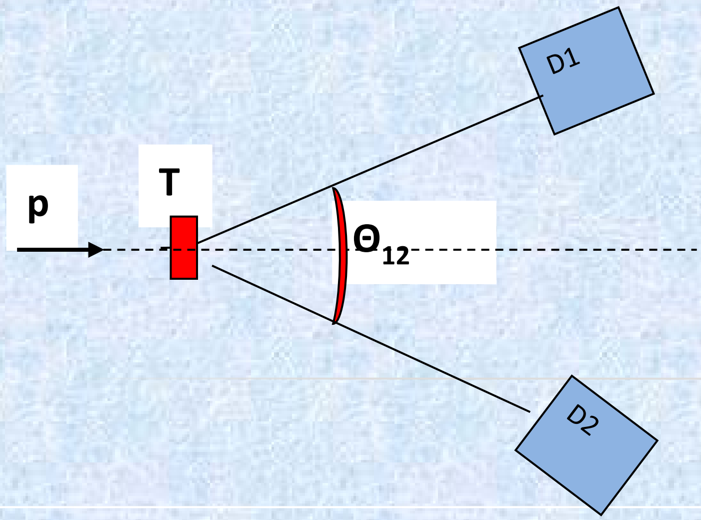
Experiment

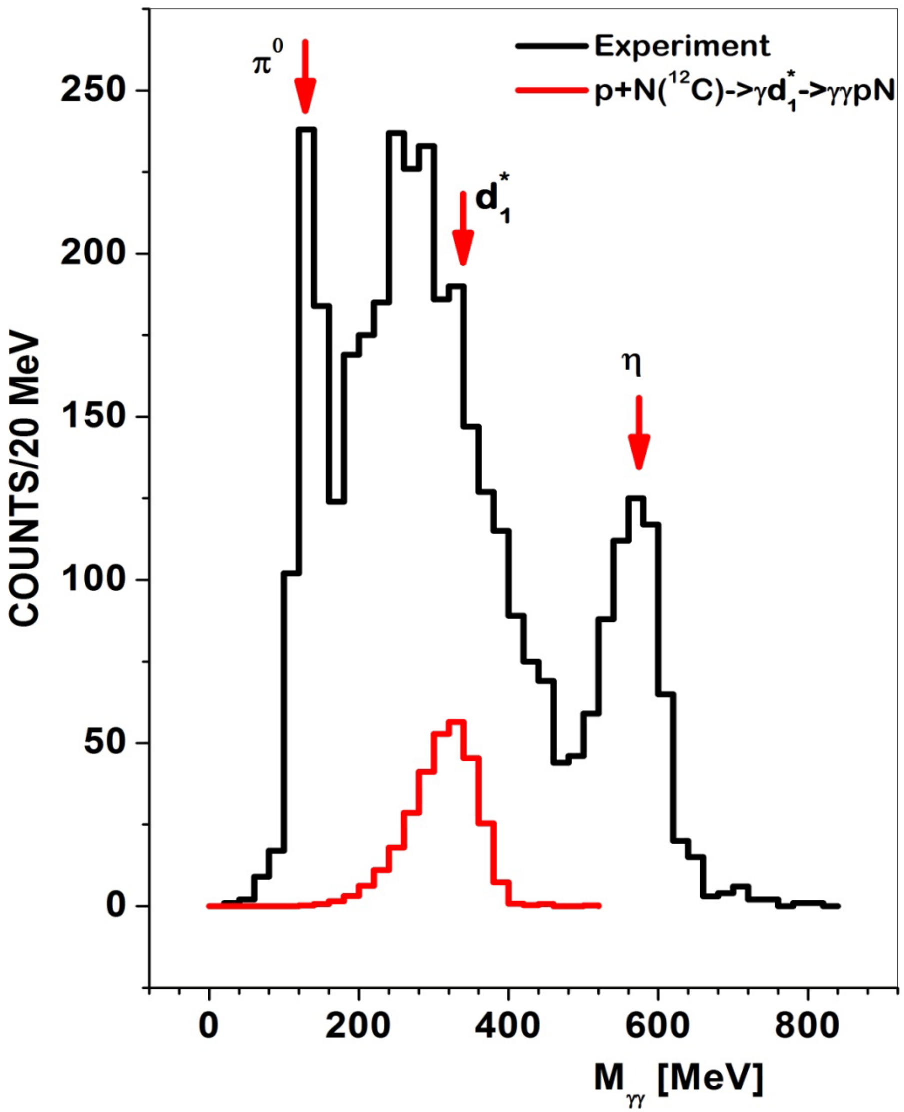
Reaction: $p + {}^{12}C \rightarrow \gamma X$

T_p=1150 MeV

PINOT Spectrometer $\Theta_{12} = 66^0$

Exp. Data: E.Chiavassa et al.,Europhys. Lett. V.41, p. 365(1998)





Inclusive photon energy spectrum for the pd→γX reaction.

A.S. Khrykin, Nucl. Phys. A721, 625c (2003)

Reaction : **p+d→γX**

Experiment

T_p=195 MeV; θ_γ=90^0

Michigan State group

J. Clayton et al., Phys. Rev. C45, 1810 (1992).

T_p=200 MeV; θ_γ=90^0

Grenoble group

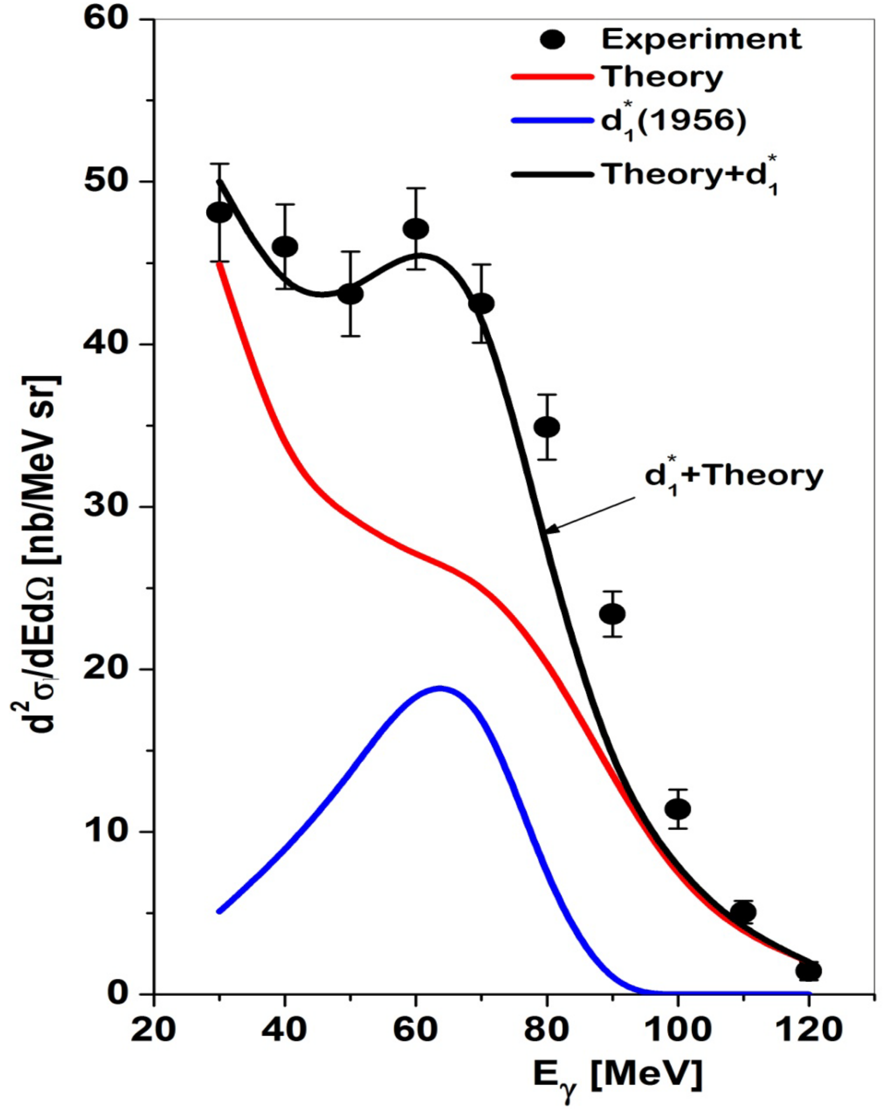
J.A. Pinston et al.,

Phys.Lett. B249, 402(1990)

Theory

K.Nakayama,

Phys.Rev. C45, 2039 (1992).



Inclusive photon energy spectrum for the $np \to \gamma X$ reaction

A.S. Khrykin, Nucl. Phys. A721, 625c (2003)

Reaction: $n+p \to \gamma X$

Experiment

At the Saturne National Laboratory in Saclay.

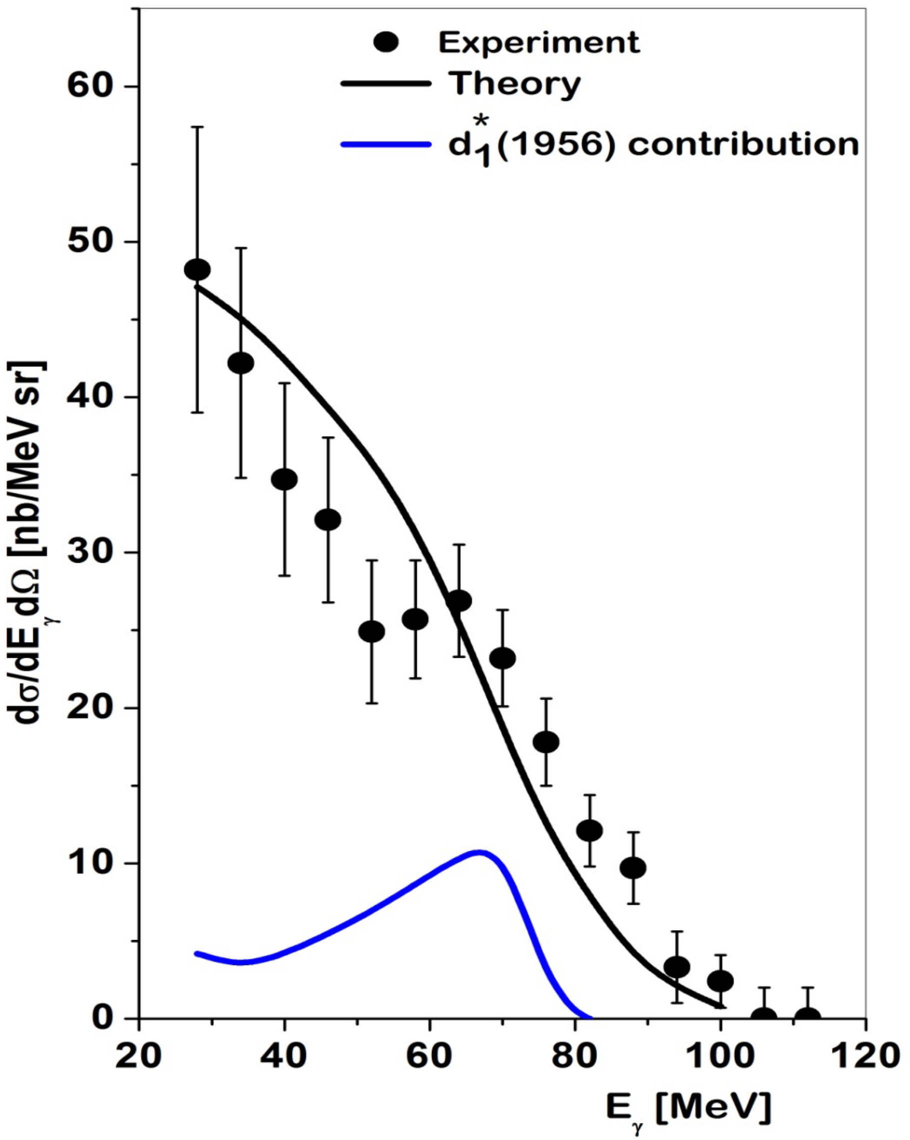
T_n=170±35 MeV ; $\theta_\gamma = 90^0$

F.Malek et al., Phys.Lett. B266, 255(1991).

Theory

M.Schafer et al.

Z. Phys. A 339, 391 (1991).



Inclusive photon spectrum for the $p + {}^{12}C \to \gamma X$ *reaction*

A.S. Khrykin, Nucl. Phys. A721, 625c (2003)

<u>**Reaction:**</u> $p + {}^{12}C \to \gamma X$

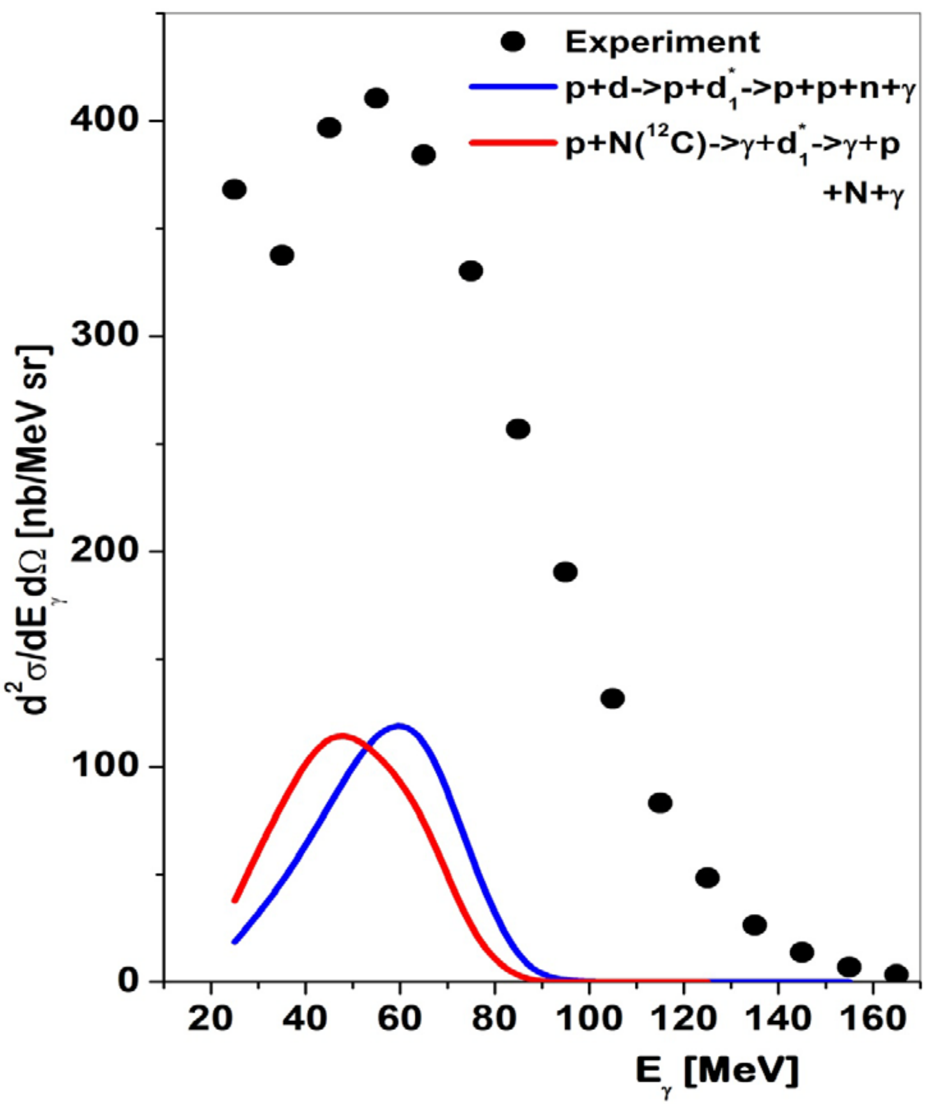
<u>**Experiment**</u>

At the Orsay synchrocyclotron.

T_p =200 MeV ; θ_γ=90^0

J.A.Pinston et al., Phys.Lett. B249, 402(1990).

CNWF:O.Benhar et al., Phys. Lett. **B177**,135(1986)



Inclusive photon spectrum for the p +^{12}C → γX reaction

<u>Reaction:</u> p+ ^{12}C →γX

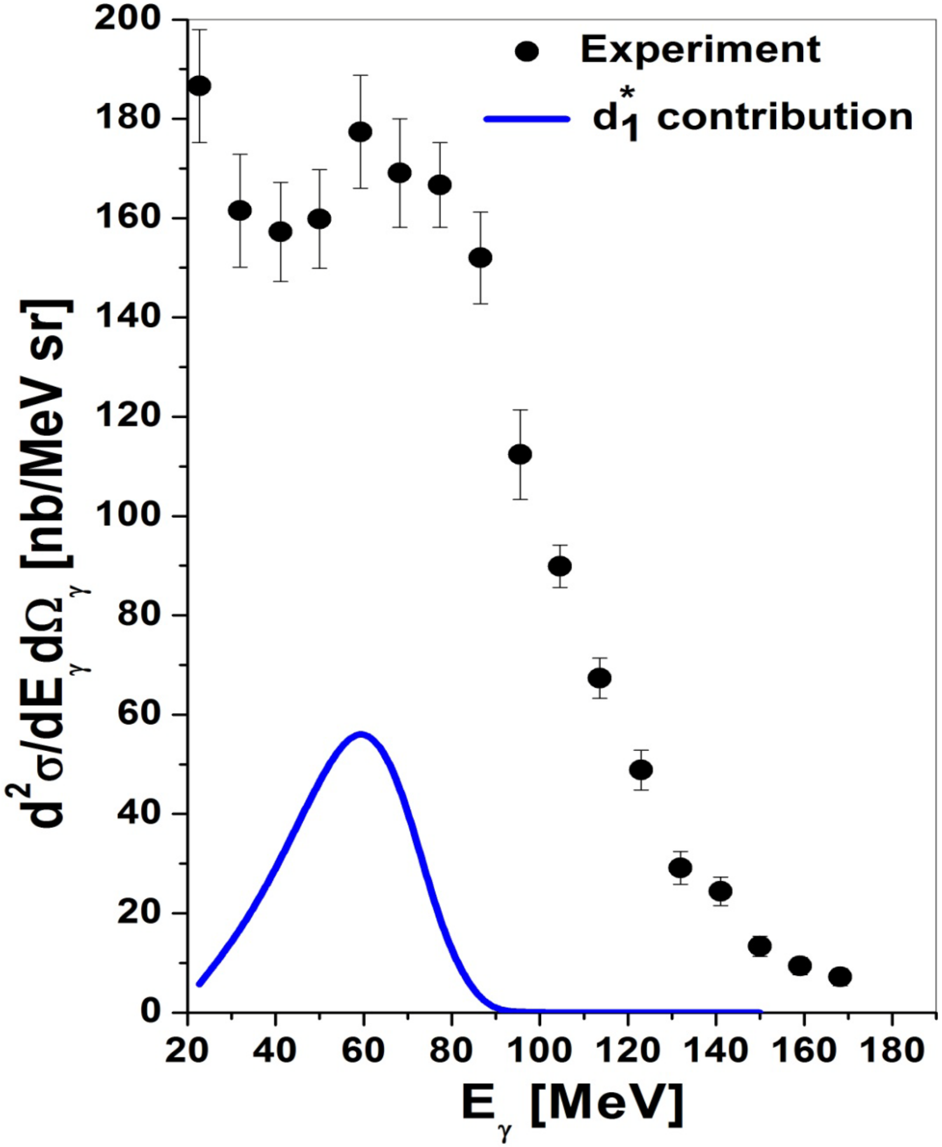
<u>Experiment</u>

At the AGOR facility of the KVI Groningen.

Photon Spectrometer TAPS

T_p =190 MeV ; θ_γ=75^0

M.J. van Goethem et al., Phys.Rev. Lett 88,122302(2002).



A new mechanism for dielectron production in NN collisions.

A. S. Khrykin, in Proceedings of the 12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon,College of William and Mary, Williamsburg, Virginia USA, May 31-June 4, 2010,will be published by the AIP.

DLS Measurements: $A+A \rightarrow e^+e^-X$ for C+C and Ca+Ca at 1.04 A GeV $\Longrightarrow$
Substantial Excess of the e^+e^- pair yield in the mass region $0.2 < M_{ee} < 0.6$ GeV

HADES Measurements: $A+A \rightarrow e^+e^-X$ spectra for C+C collisions at 1A and 2A GeV. The DLS finding was confirmed.

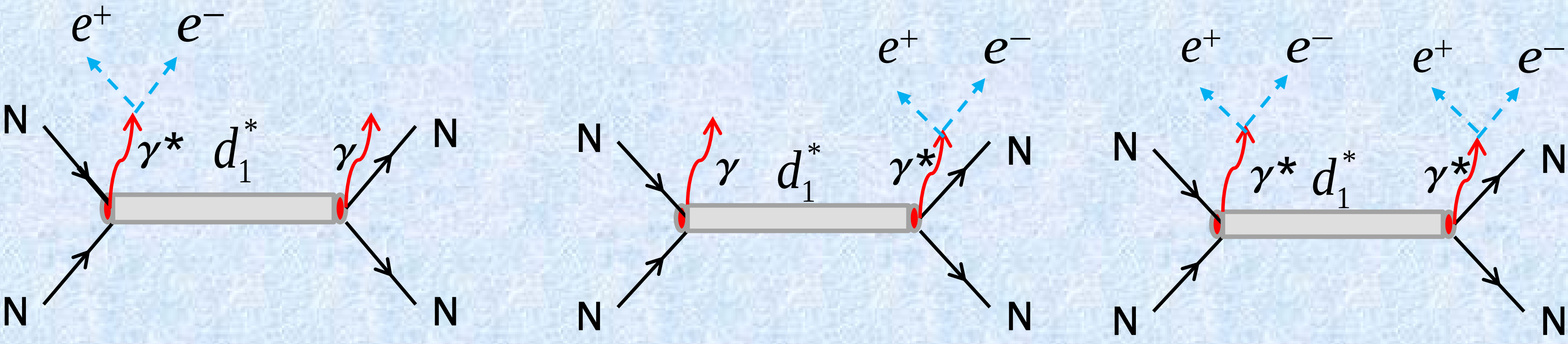
Conventional mechanisms of dielectron production at 1-2 GeV per nucleon:

- **Dalitz decay of the π^0-, η-, and ω mesons and baryon resonances Δ(1232), N*(1520),...**
- **Direct decay of the π^0-, ρ-, and ω- mesons**
- **Bremsstrahlung in NN and $\pi\pi$ collisions**
- **Pion annihilation**

Up to now there is no clear conception of the origin of such an excees.

If the resonance d^*_1 (1956) really exists then together with its formation (decay) channel with a real photon the same channels with a virtual, massive photon should also take place. Conversion of such photons into e^+e^- pairs would give rise to a new source of dielectrons.

Dibaryon mechanism for dielectron production in NN Collisions



The kinematical region for a photon mass overlaps with that where the shortage of dielectrons of interest was observed.

We decided to examine whether a new source NN→ $\gamma^* d^*_1$(1956)→ $e^+e^- d^*_1$ can supply the observed shortages of e^+ e^- pairs in the DLS data in the mass region 0.2< M_{ee} < 0.6 GeV.

$$NN \Longrightarrow \gamma^* \boldsymbol{d}_1^*(1956) \longrightarrow e^+e^- \boldsymbol{d}_1^*(1956)$$

$$p_a+p_b=p_1+p_2+p_3$$

$p=p_a+p_b$, p_a- and p_b- the four momenta of colliding nucleons,
$p^2=s$ – the total energy of the colliding nuclens inc.m.s.

$p_1(E_1,\vec{p}_1), p_2(E_2,\vec{p}_2)$ **and** $p_3(E_3,\vec{p}_3)$ **-the four momenta of dielectrons and resonance.**

$$\frac{d\sigma}{dM} = \frac{(2\pi)^4}{f} \int \prod_{i=1}^{3} \frac{d^3\,\vec{p}_i}{2E_i(2\pi)^3} |\mathcal{M}|^2 \delta(p - \sum_{i=1}^{3} p_i) \bullet \delta(M - M(\vec{p}_1,\vec{p}_2))$$

$$f = 4\sqrt{(p_a p_b)^2 - m_a^2 m_b^2}$$

M- ***the invariant mass of the*** **e^+e^- - pair**

$|\mathcal{M}|^2$ – ***the matrix element for the transition NN*** $\rightarrow e^+e^-d_1^*$

$$\mathcal{M} = \frac{e^2}{k^2} j^\mu J_\mu, \quad j_\mu = < e^+ e^- \frac{1}{\ } \left| \hat{j} \right| \mathbf{0} >, \quad J_\mu = (J_0, \vec{J}) = < d_1^* \left| \hat{J}_\mu \right| NN >$$

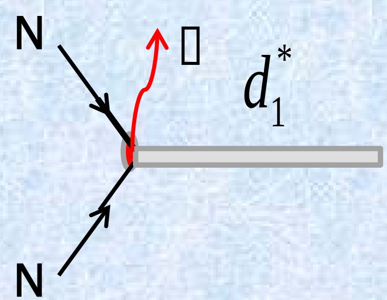
$$\vec{J} = \vec{J}_T + \vec{J}_L$$

$$|\mathcal{M}|^2 = \frac{1}{4} \frac{e^4}{M^4} \frac{1}{2m_e^2} \{ M^2 |\vec{J}_T|^2 - |\vec{J}_T \vec{q}_T|^2 + \frac{M^2}{k_0^2} (1 - \frac{M^2}{k_0^2} |\vec{J}_L \vec{q}_L|^2)$$

$$- 2 |\vec{J}_L \vec{q}_L| |\vec{J}_T \vec{q}_T| \}, \quad k = (k_0, \vec{k}) = p_1 + p_2, \quad q = (q_0, \vec{q}) = p_1 - p_2$$

O. Scholton et al. PRC71,034005(2005)

$J^P(d_1^*) = 0^-$ **the vertex**



is magnetic in structure $\quad 1^- \xrightarrow{M1} 0^-$

$$|\mathcal{M}_E|^2 = e^2 |\vec{J}_T|^2 = C \cdot (p_a \cdot k)(p_b \cdot k)$$

Hadronic current for the magnetic transition is transverse, $\vec{J}_L = 0$

$$|\mathcal{M}|^2 = \frac{1}{4}\frac{e^4}{M^2}\frac{1}{2m_e^2}\left(|\vec{J}_T|^2 - \frac{1}{M^2}|\vec{J}_T\vec{q}_T|^2\right) \cong \frac{1}{4}\frac{e^4}{M^2}\frac{1}{2m_e^2}|\vec{J}_T|^2$$

$$|\mathcal{M}_{NN\to e^+e^-d_1^*}|^2 = \frac{N}{M^2}|\mathcal{M}_E|^2|F(M^2)|^2$$

$$|F(M^2)|^2 = \frac{m_\rho^4 - m_\rho^2\Gamma_\rho^2}{(m_\rho^2 - M^2)^2 + m_\rho^2\Gamma_\rho^2}$$

N-is the normalization constant

The calculations $\Longrightarrow$ Monte Carlo method. Event generator $\Longrightarrow$ GENBOD. It used to randomly generate four momenta of the outgoing particles of the explored reaction. The probabilty of any event has been given its weight:

$$WT = |\mathcal{M}_{NN\to e^+e^-d_1^*}|^2$$

Energy resolution: by procedure of a spectrum smearing with a Gaussian distribution with the corresponding σ.

$$\frac{\sigma_{tot}^{ee}}{\sigma_{tot}^{\gamma}} = \frac{\alpha}{\pi}\left[\frac{2}{3}\ln\left(\frac{\Delta M}{m_e}\right) - \frac{5}{9} + \frac{1}{3}I_1 + O\left(\left(\frac{m_e}{\Delta M}\right)^2\right)\right], \quad I_1 \approx 1$$

B.E.Lautrup and J.Smith, PRD3,1122(1971)

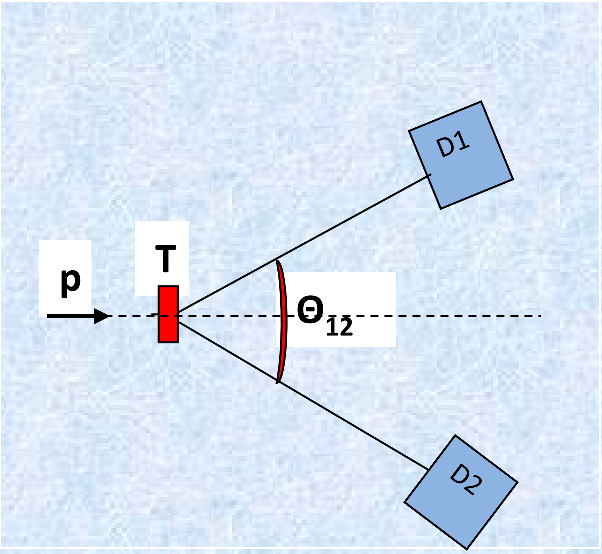
Contribution of the $pp \rightarrow e^+e^-d_1^*$ ***mechanism to the DLS*** $pp \rightarrow e^+e^-X$ ***data***

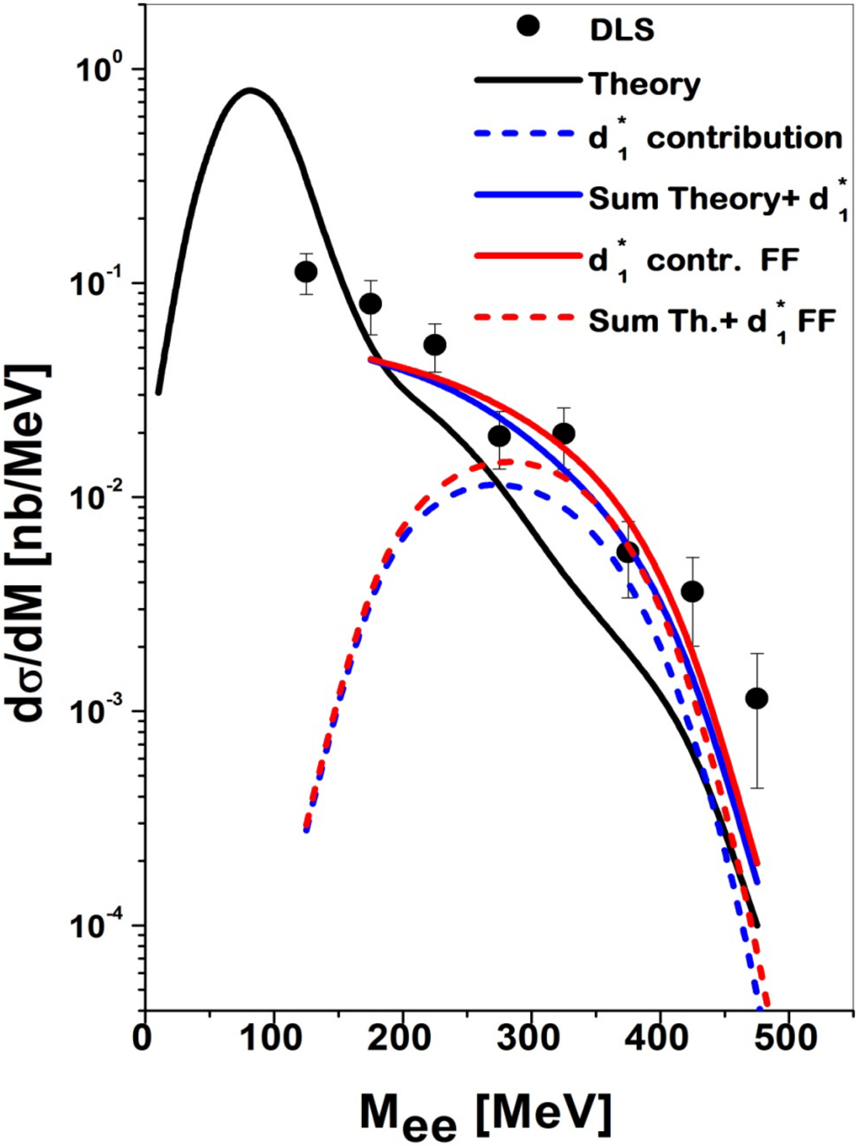
DLS data:W.K.Wilson et al.,Phys.Rev. C **57**, 1865(1998)
Theoretical data:Amand Faessler et al.,J.Phys. G **29**, 603(2003)

DLS Experiment

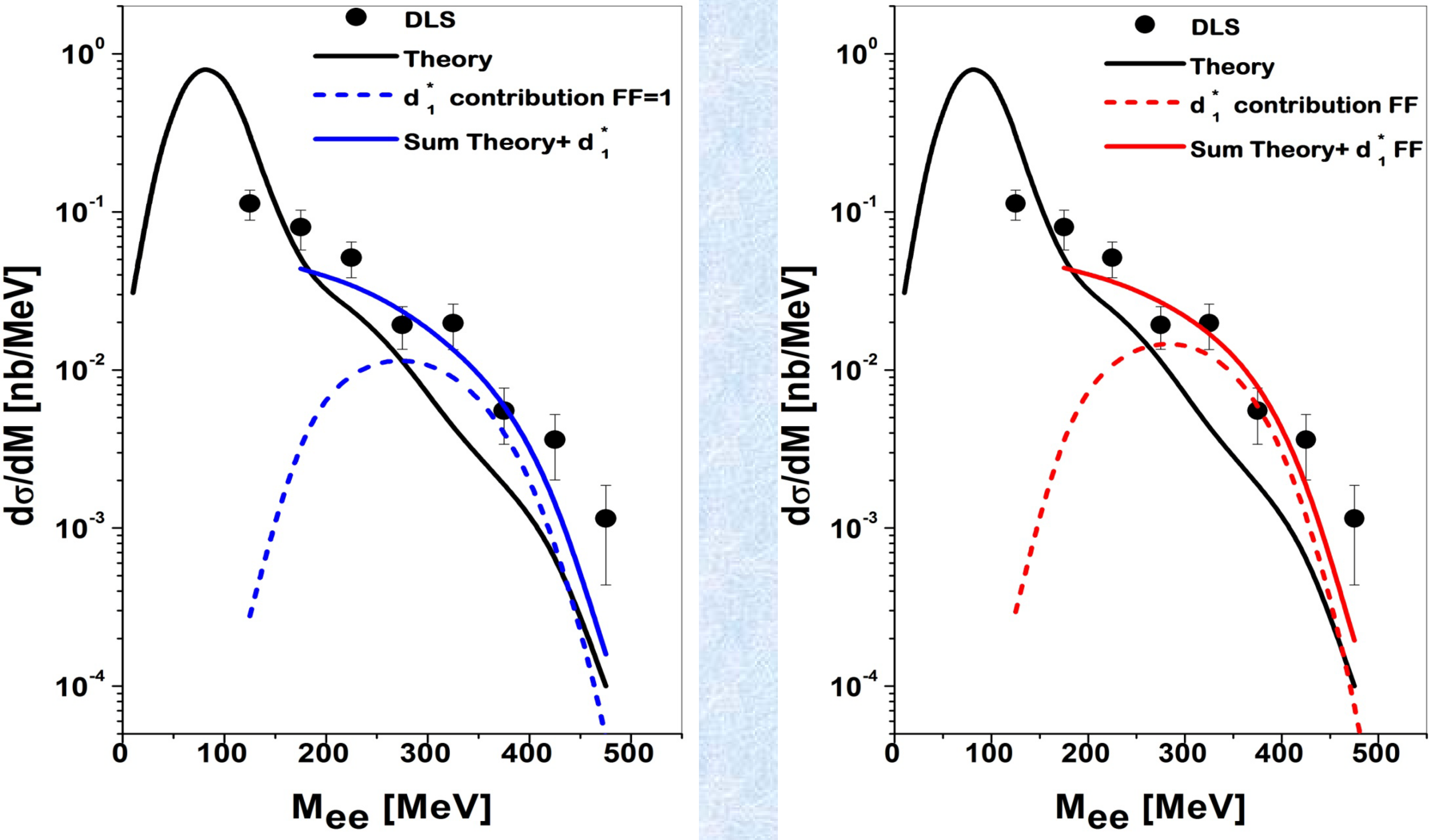
Reaction: $p + p \rightarrow e^{+} e^{-} X$

T_p=1.04 GeV





DLS data:W.K.Wilson et al.,Phys.Rev. C **57**, 1865(1998)
Theoretical data:Amand Faessler et al.,J.Phys. G **29**, 603(2003)



Contribution of the $NN \rightarrow e^+e^-d_1^*$ ***mechanism to the DLS*** $^{12}C + ^{12}C \rightarrow e^+e^-X$ ***data***

DLS data:R.J.Porter et al.,Phys.Rev.Lett. **79**, 1229(1997)
Theoretical data:E.L.Bratkovskaya et al.,Nucl.Phys. **A634**,168(1998)

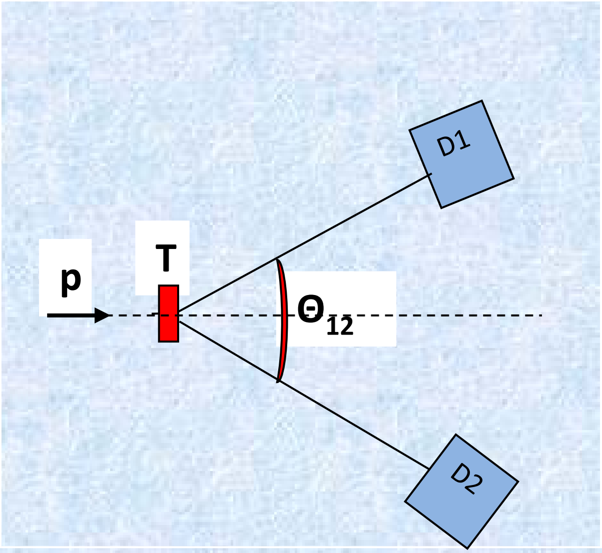
DLS Experiment

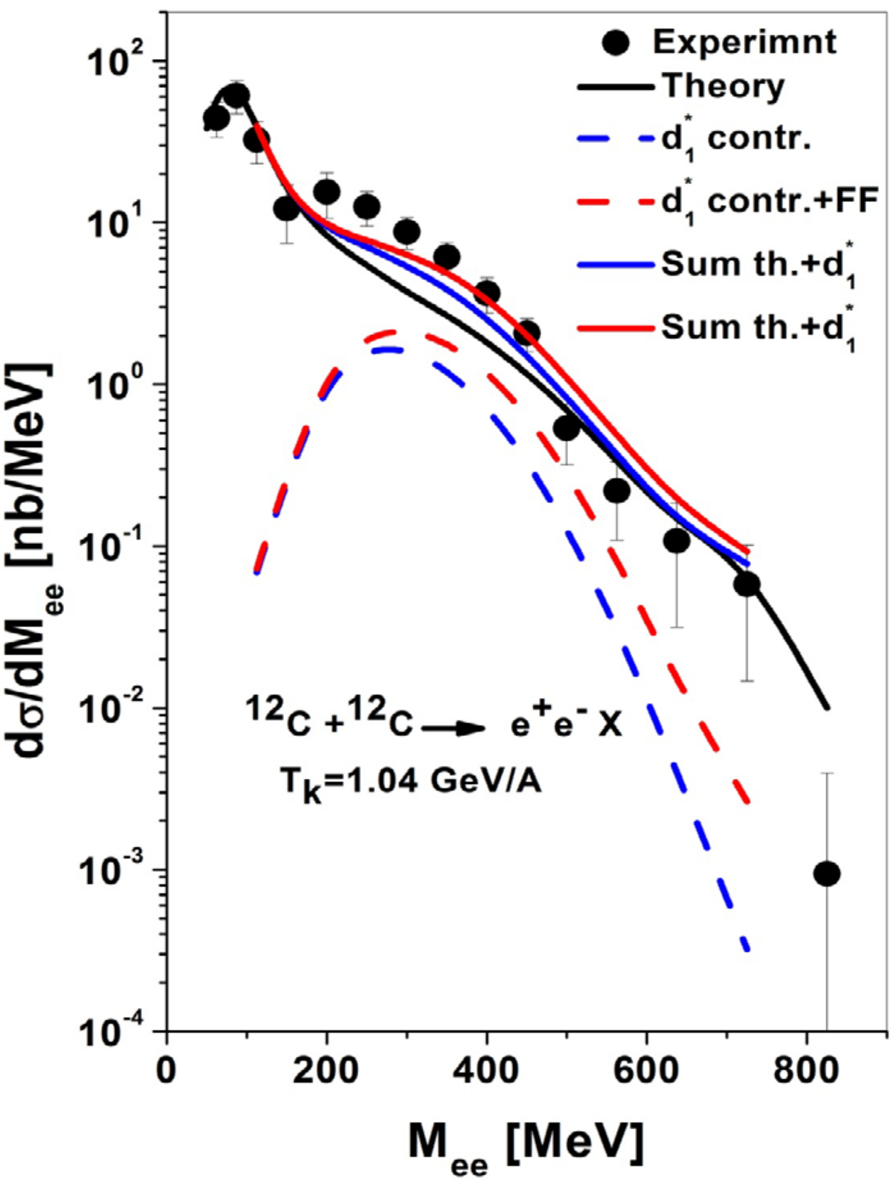
Reaction: $^{12}C + ^{12}C \rightarrow e^+ e^- X$

T=1.04 GeV/A

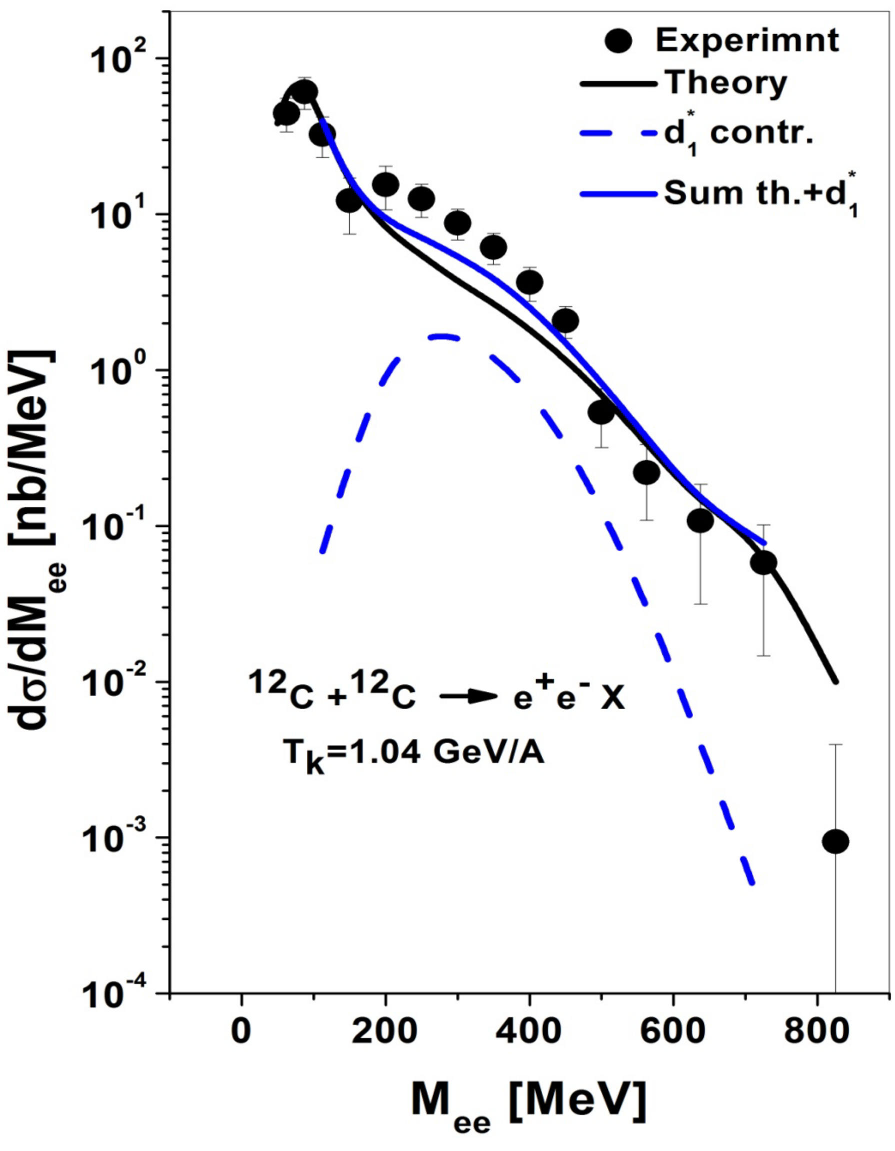
Mass resolution $\Delta M/M = 10\%$

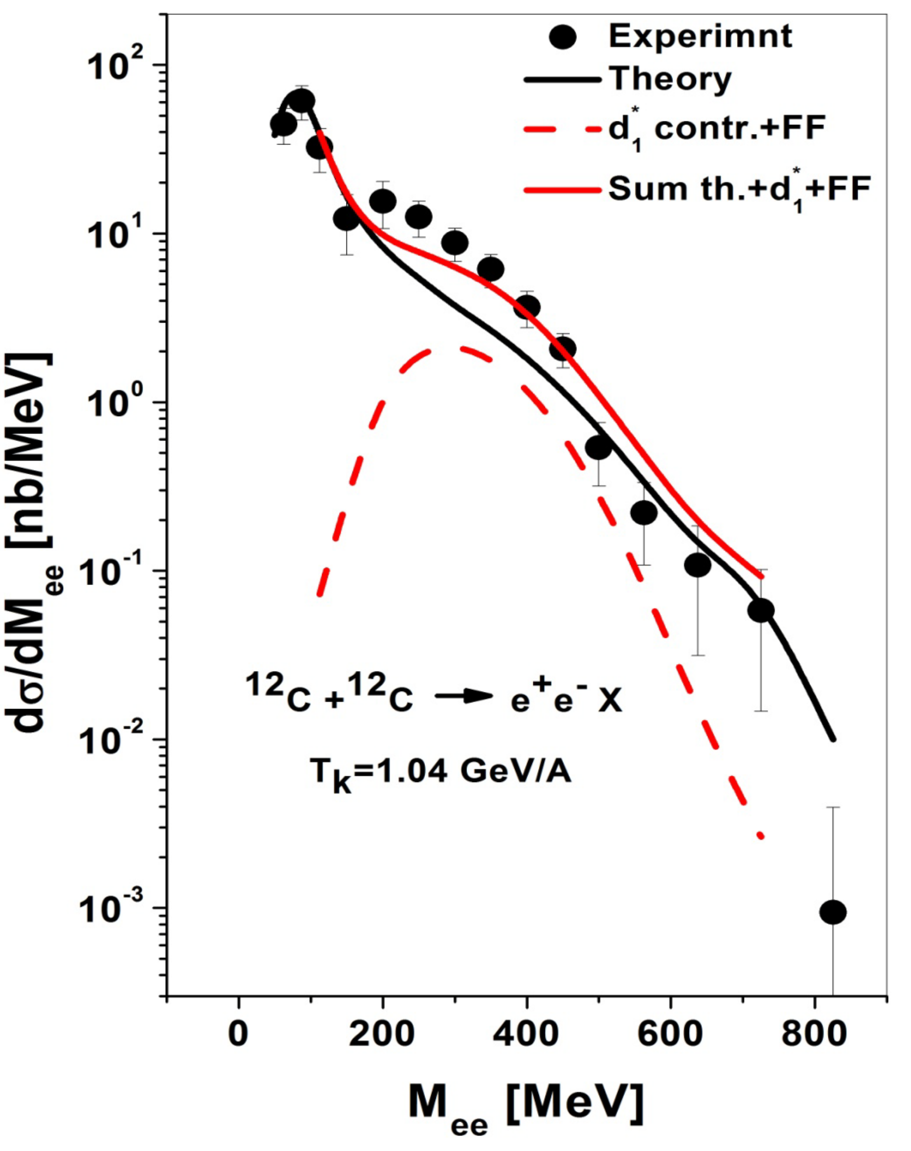
Filter v4.1p, CNWF:O.Benhar et al., Phys. Lett. **B177**,135(1986)





DLS data:R.J.Porter et al.,Phys.Rev.Lett. **79**, 1229(1997)
Theoretical data:E.L.Bratkovskaya et al.,Nucl.Phys. **A634**,168(1998)





Conclusions

- **The presented data strongly suggest the existence of the NN-decoupled dibaryon resonance $d_1^*(1956)$.**

- **The idea of the existing of this resonance can be confirmed or refuted by the direct measurement of the photon energy spectrum of the reaction *$pp \rightarrow \gamma\gamma pp$ at energy below the pion production threshold or the* missing mass spectrum of the reactions *$pp \rightarrow e^+e^-X$* .**