ON A MISSED MECHANISM OF DIELECTRON PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS.

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OUTLINE

- Introduction
- The case for the $d^*_1(1956)$ in processes with real photons.
- Dibaryon mechanism for dielectron production in NN collisions.
- 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

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^- pairs in the mass region $0.15 < M_{ee} < 0.6$ GeV

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

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

To understand the origin of this excess (the DLS puzzle) the DLS has measured the spectra for the $pp \rightarrow e^+e^-X$ **and** $pd \rightarrow e^+e^-X$ **reactions at** T_p **= 1-5 GeV**
Excees of the e^+e^- **pairs in the same mass region as in the AA collisions**

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

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

Excess origin $\Longrightarrow$ a new source of dielectron production ?

The aim of this talk: to explore whether the experimental e^+e^- pair surplus is due to a new source $NN \rightarrow \gamma^* d^*_1(1956) \rightarrow e^+e^- d^*_1$ **?**

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

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

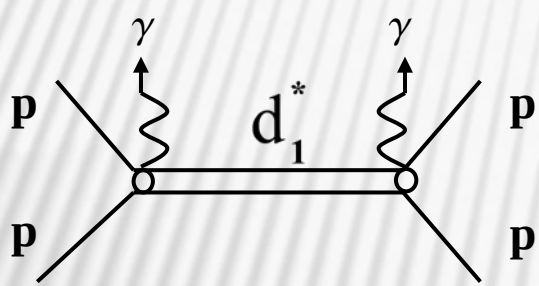
A.S. Khrykin et al., Phys.Rev. C64, 034002(2001)

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

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

S=5.3σ & 3.5σ; Total S= 6.3 σ

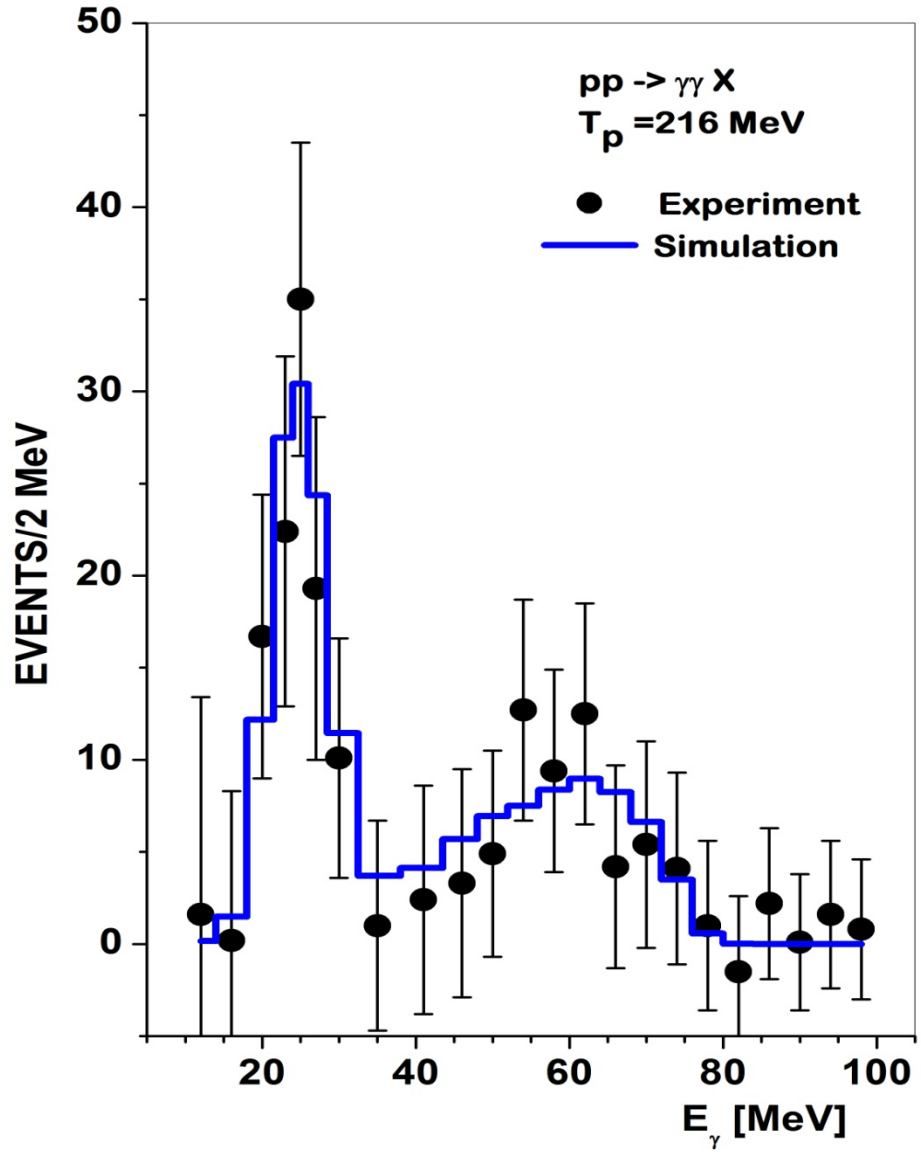
$$pp \to \gamma d_1^* \to \gamma\gamma pp$$



$$E_\gamma^F(\mathrm{cms}) = \frac{S - M_R^2}{2\sqrt{S}} \qquad E_\gamma^D(\mathrm{rf}) = \frac{M_R^2 - M_{PP}^2}{2M_R}$$

M_R~1956 MeV; □ ~8 MeV

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



FURTHER EVIDENCES FOR THE $d_1^*(1956)$

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

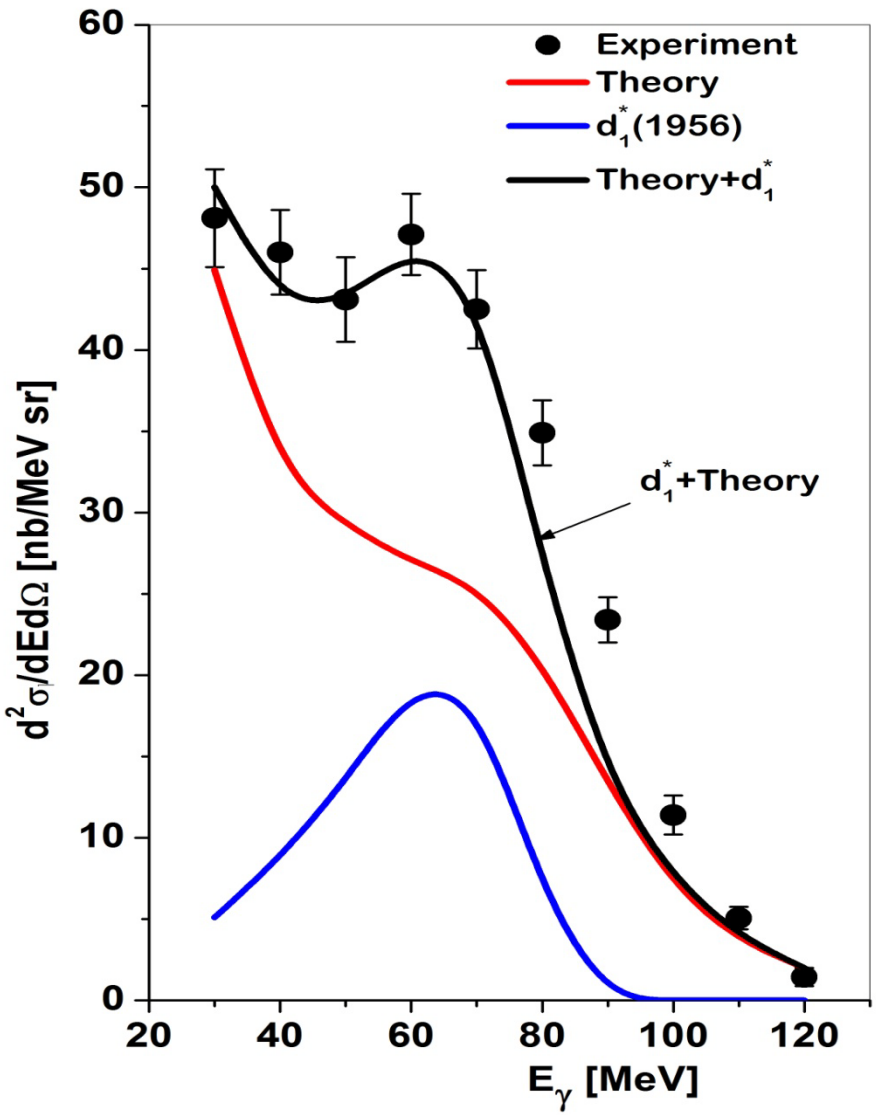
J.A. Pinston et al.,

Phys.Lett. B249, 402(1990)

Theory

K.Nakayama,

Phys.Rev. C45, 2039 (1992).



Inclusive photon spectrum for the np→γX reaction

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

Reaction: **n+p→γX**

Experiment

At the Saturne National Laboratory in Saclay.

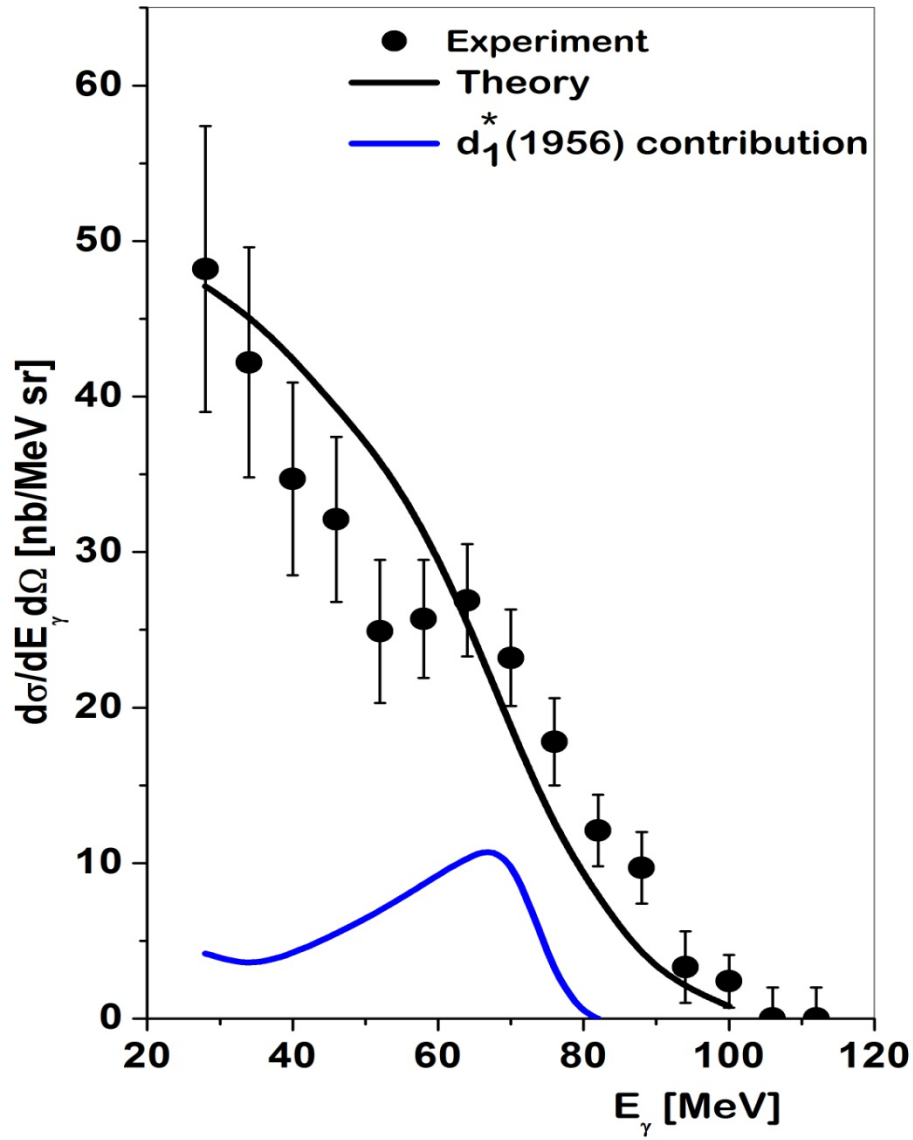
T_n=170±35 MeV ; θ_γ=90^0

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 → γX reaction

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

Reaction: p+ ^{12}C →γX

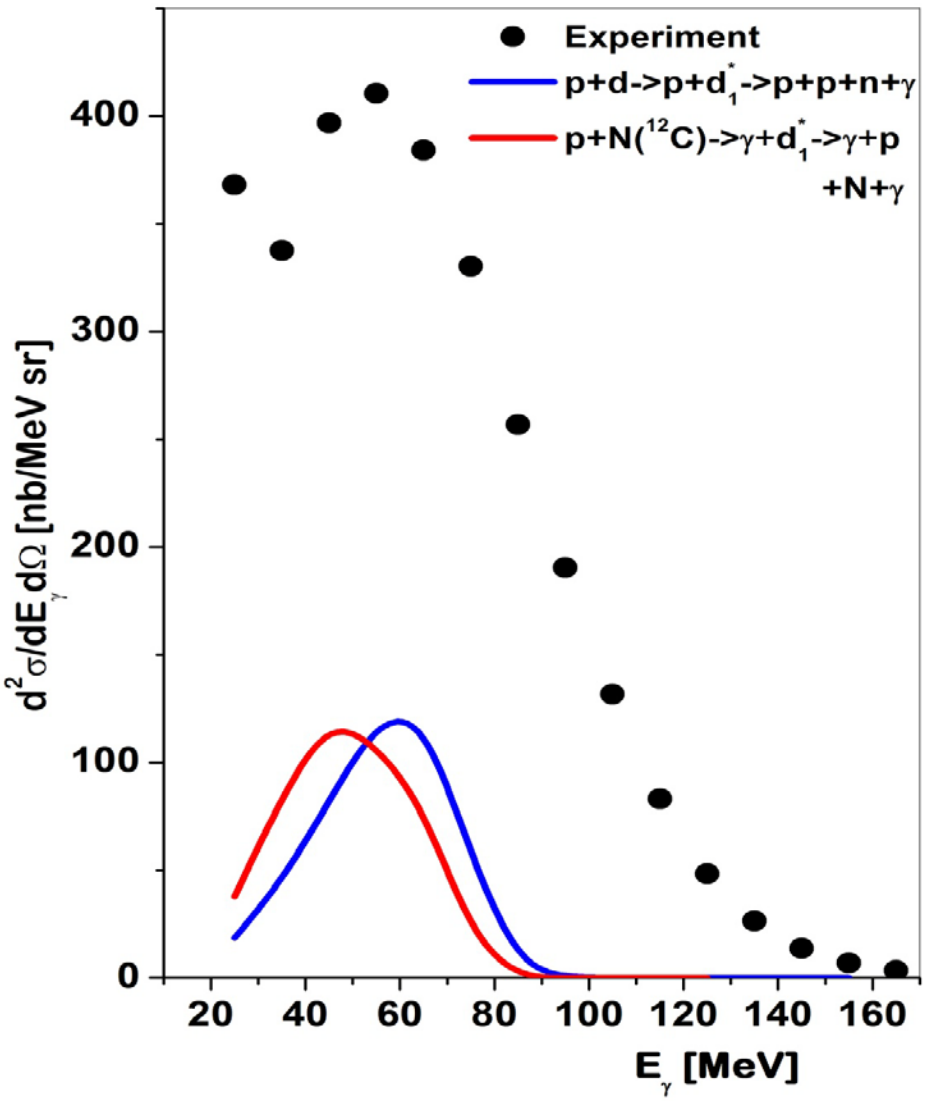
Experiment

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

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

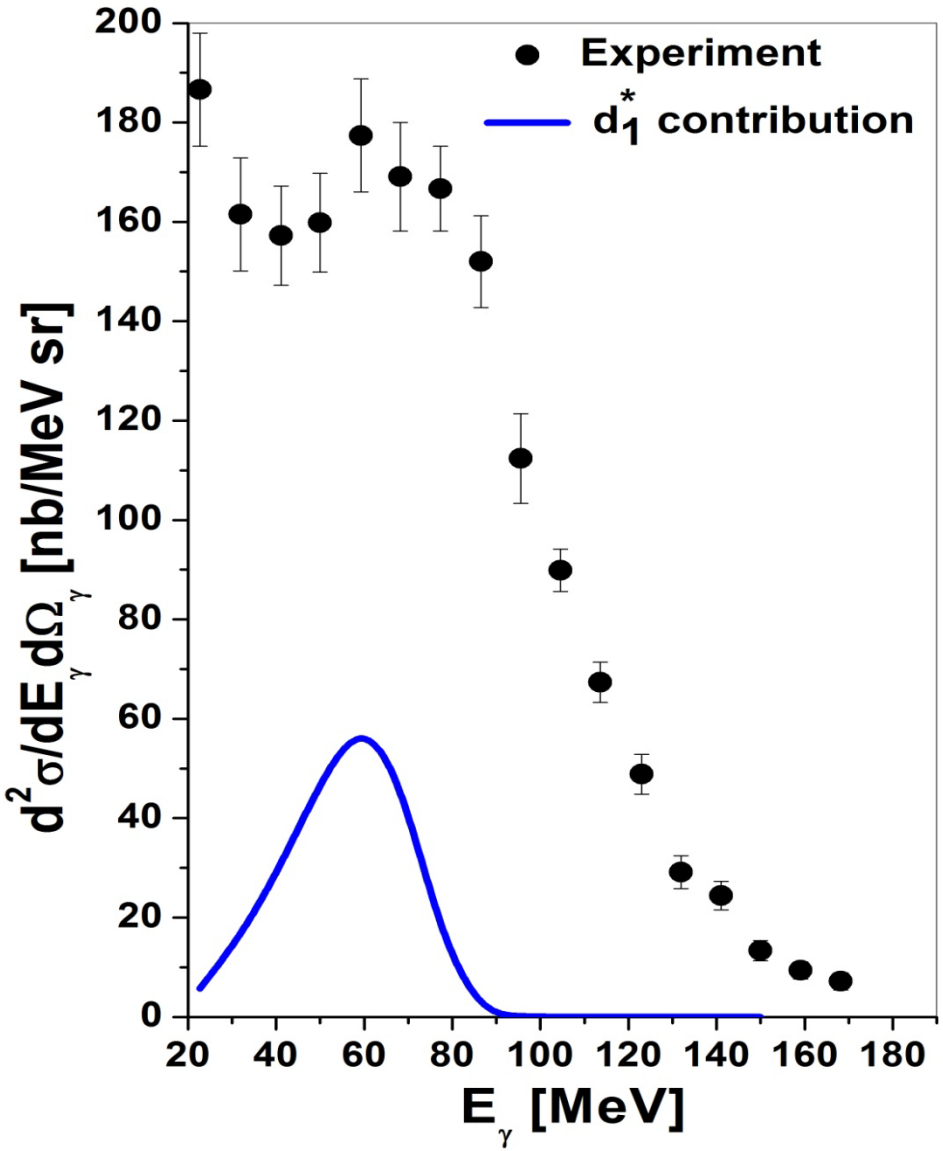
Experiment

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).



TWO PHOTON INVARIANT MASS SPECTRUM

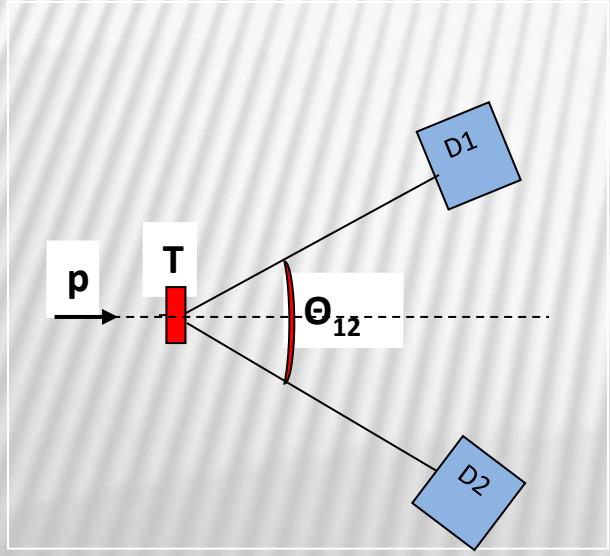
Experiment

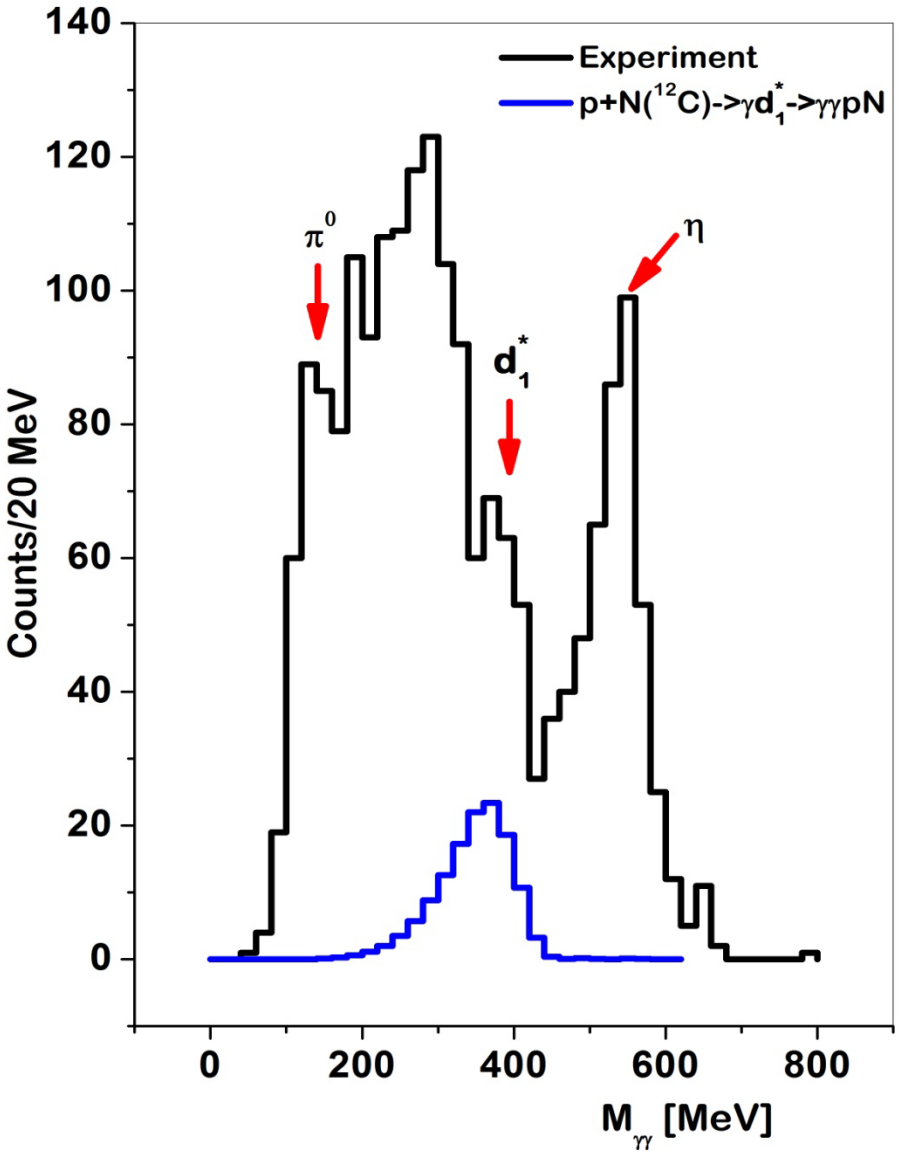
Reaction: $p + {}^{12}C \rightarrow \gamma X$

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

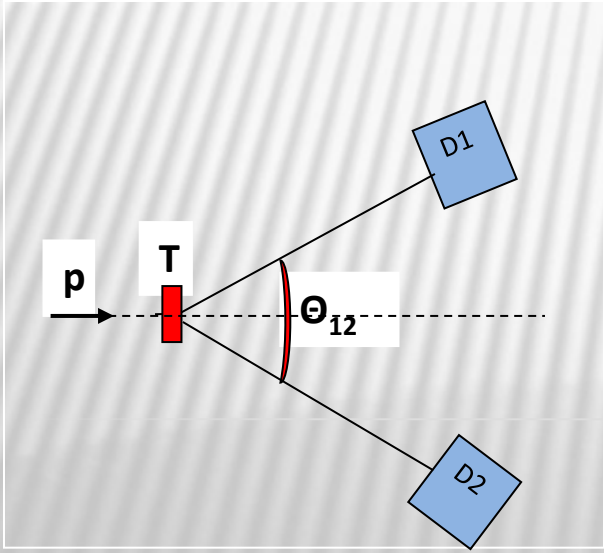
Experiment

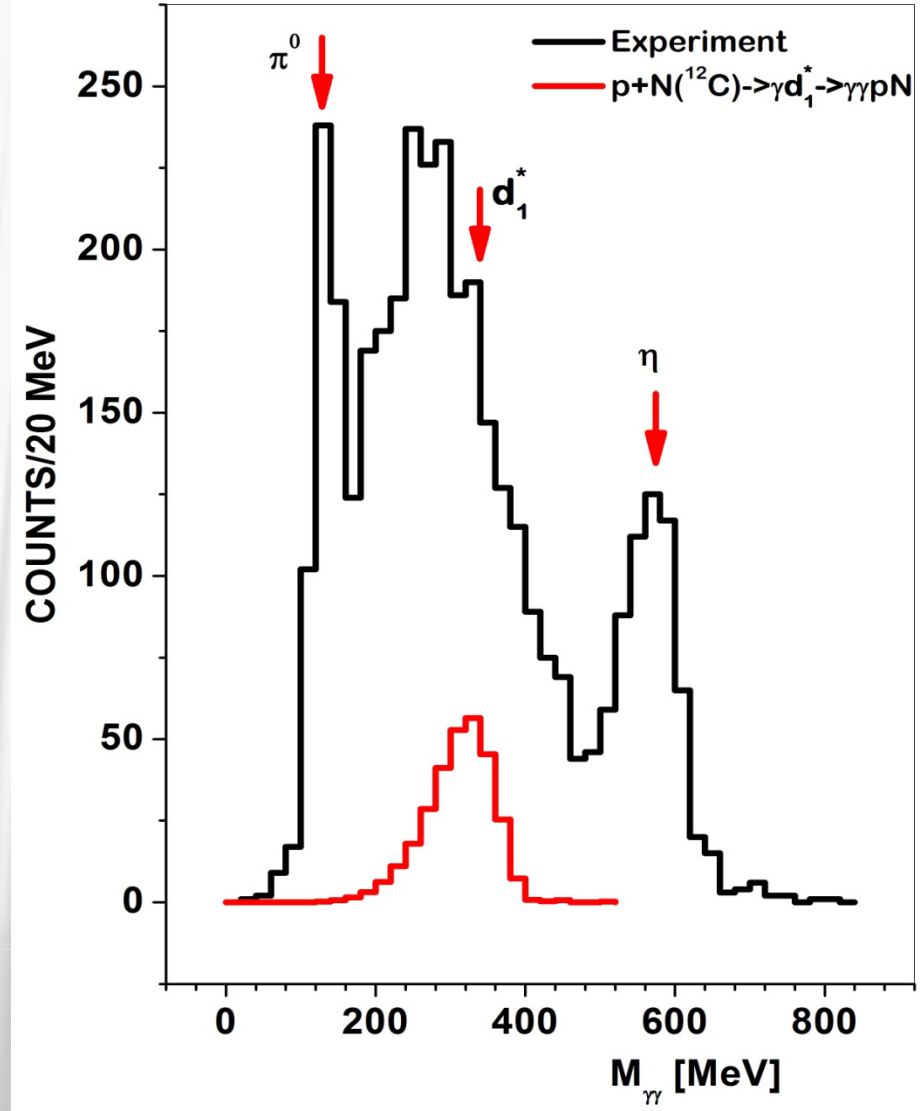
Reaction: $p + {}^{12}C \rightarrow \gamma X$

T_p=1150 MeV

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

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





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.

Experiment

CELSIUS-WASA *Collaboration*

Bashkanov et al. Int. Jour. of Mod. Phys. A20,554(2005); hep-ex/0406081

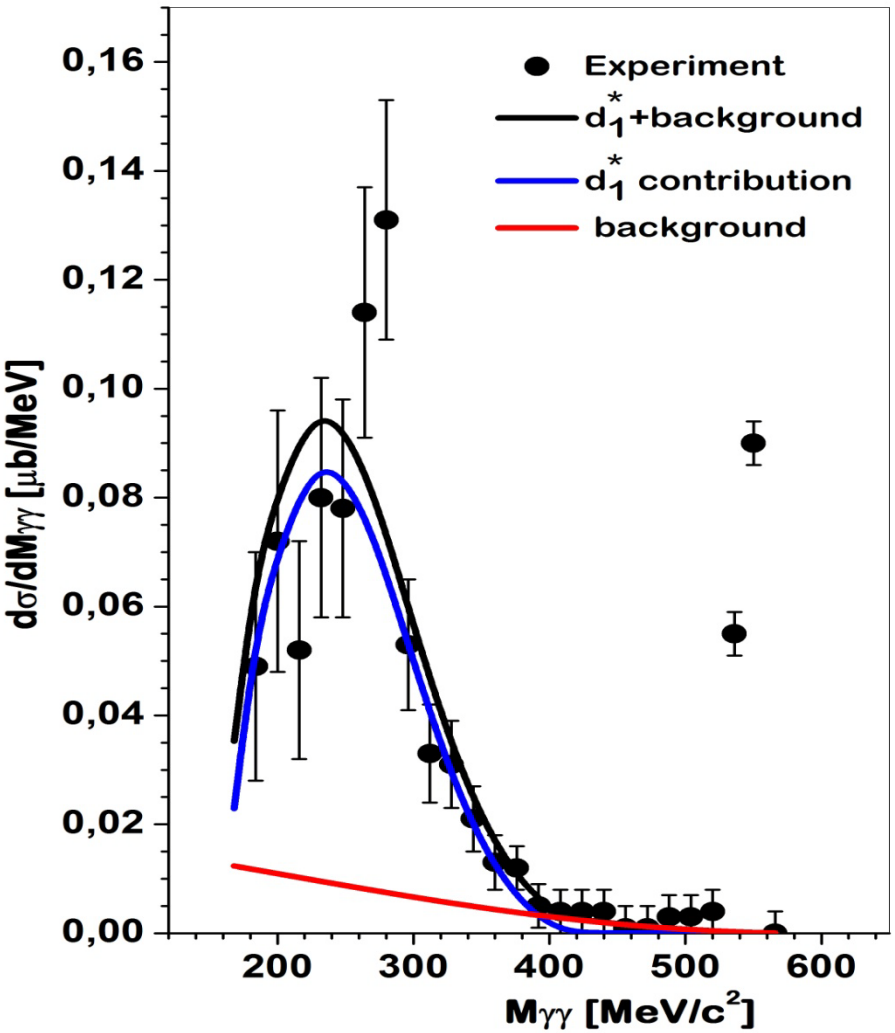
$M^2_{\gamma\gamma}=(k_1+k_2)^2=2E_{\gamma 1}*E_{\gamma 2}*(1-\cos\theta_{12})$

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

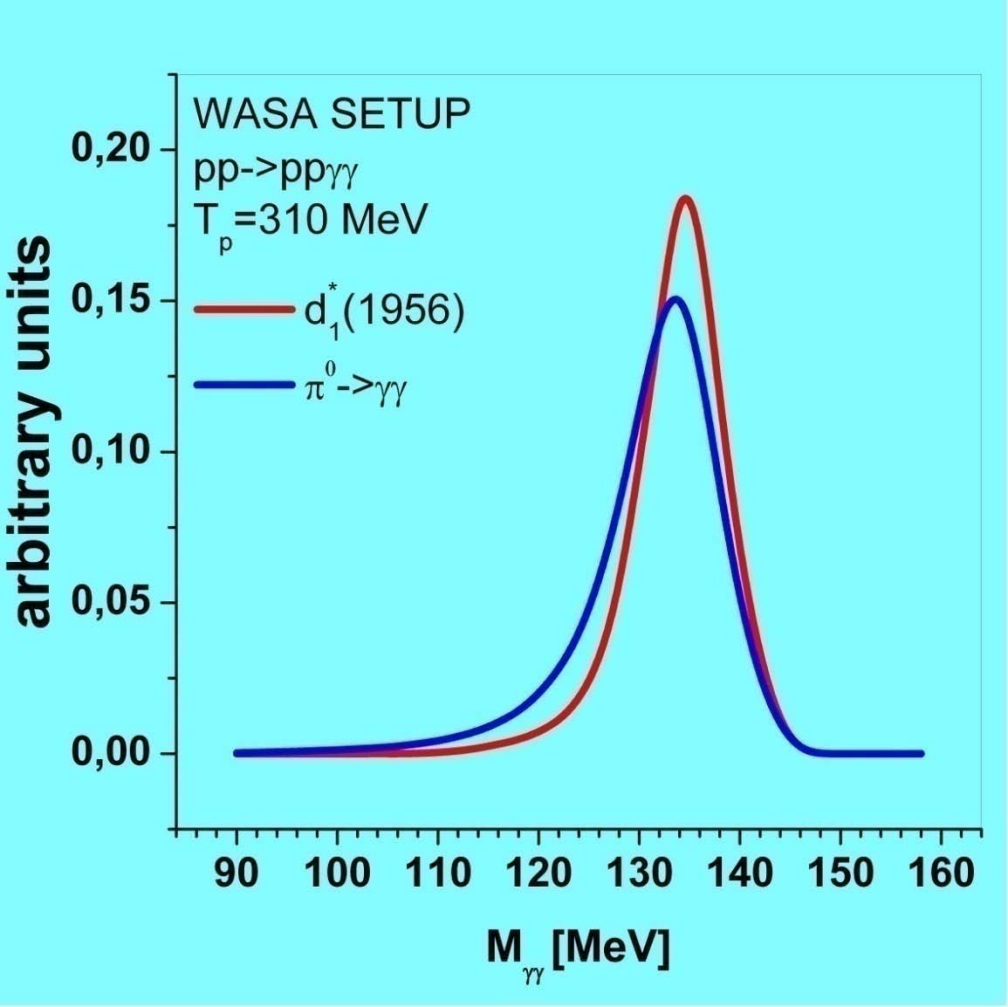
Calculations: $|M(NN\to \gamma d_1^*)|^2 \Longrightarrow$ $d^*_1(1956)\to(N\Delta)_{bound}$

χ^2=1.1/dof



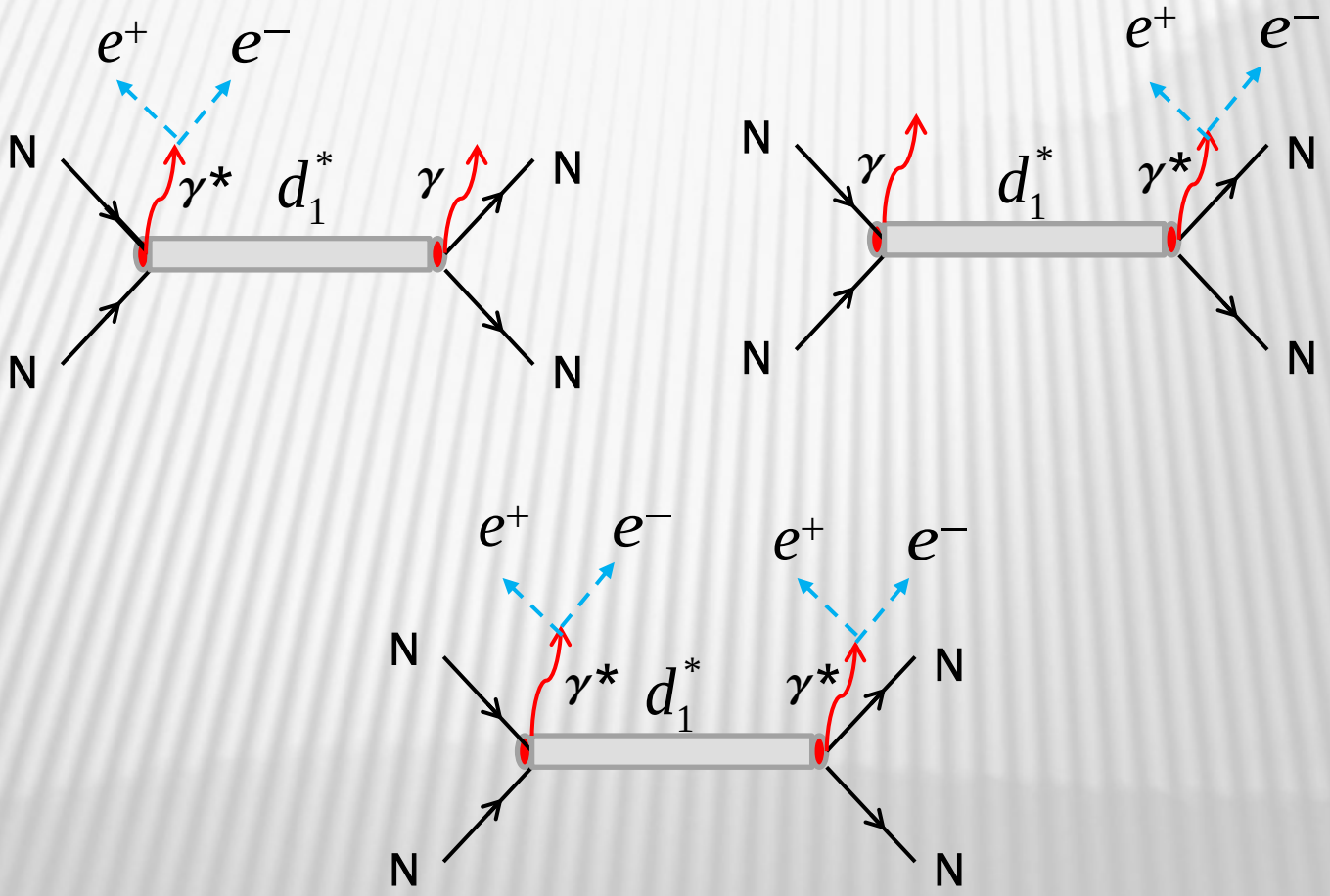
Why the Celsius-Wasa Collaboration did not find the dibaryon signal in their pp →ppγ data?

Two-photon inv. mass spectra were calculated for the pp→γd$^*_1$(1956) →pp$\gamma\gamma$ and pp→ppπ^0 →pp$\gamma\gamma$ channels of the reaction **pp→ pp$\gamma\gamma$** for the geometry and kinematic of the experiment PL**B427**,248 (1998). So,all events (at least most of them) associated with the resonance d$^*_1$(1956) were removed!



Dibaryon mechanism for dielectron production in NN Collisions

$$NN \Rightarrow \gamma^* d_1^* \Rightarrow e^+ e^- d_1^*$$



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

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

***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.**

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

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

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

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

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

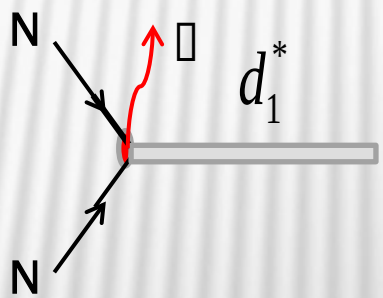
$$\vec{J} = \vec{J}_T + \vec{J}_L$$

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

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

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

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



$1^- \xrightarrow{M1} 0^-$

is magnetic in structure

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

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

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

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

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

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:

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

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)

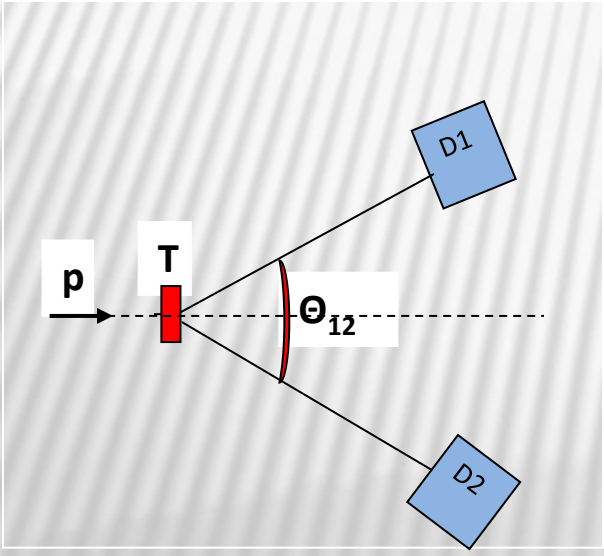
Contribution of the $pp \to e^+e^-d_1^*$ *mechanism to the DLS* $pp \to e^+e^-X$ *data*

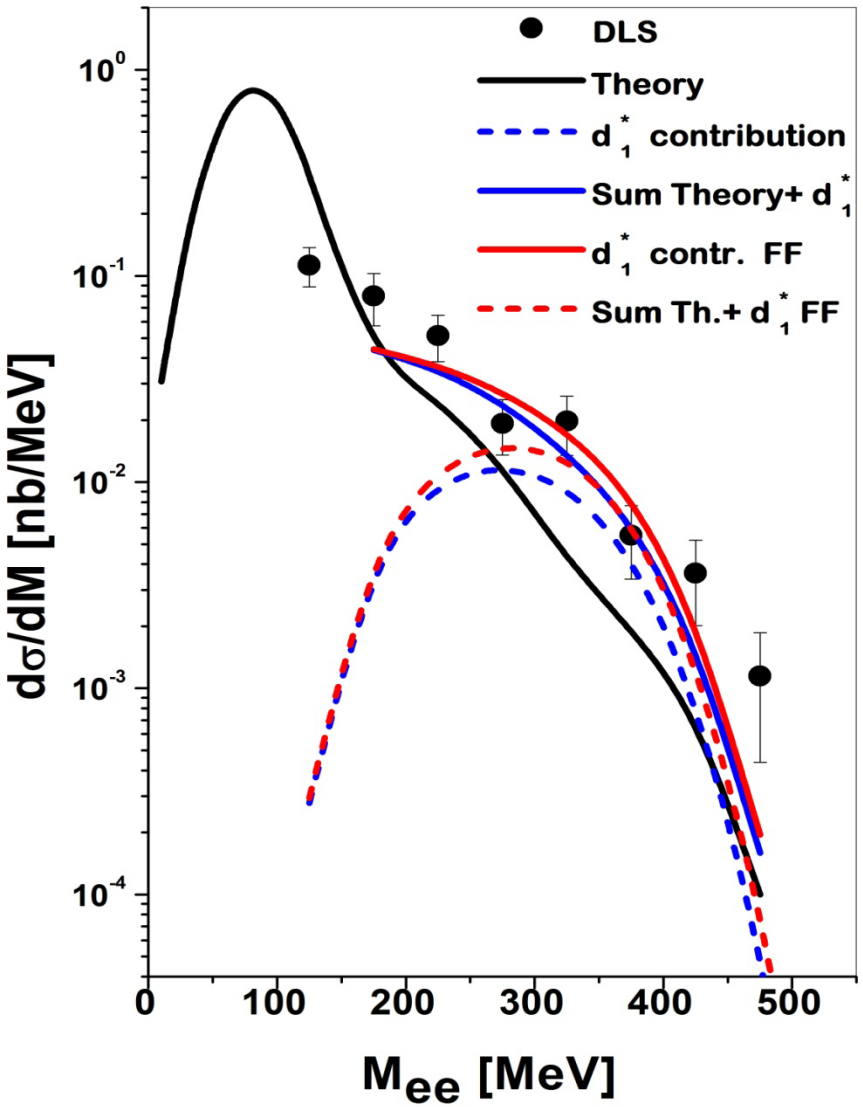
DLS data:W.K.Wilson et al.,Phys.Rev. C **57**, 1865(1998)
Theoretical data:Amand Faessler et al.,J.Phys. G **29**, 603(2003)

DLS Experiment

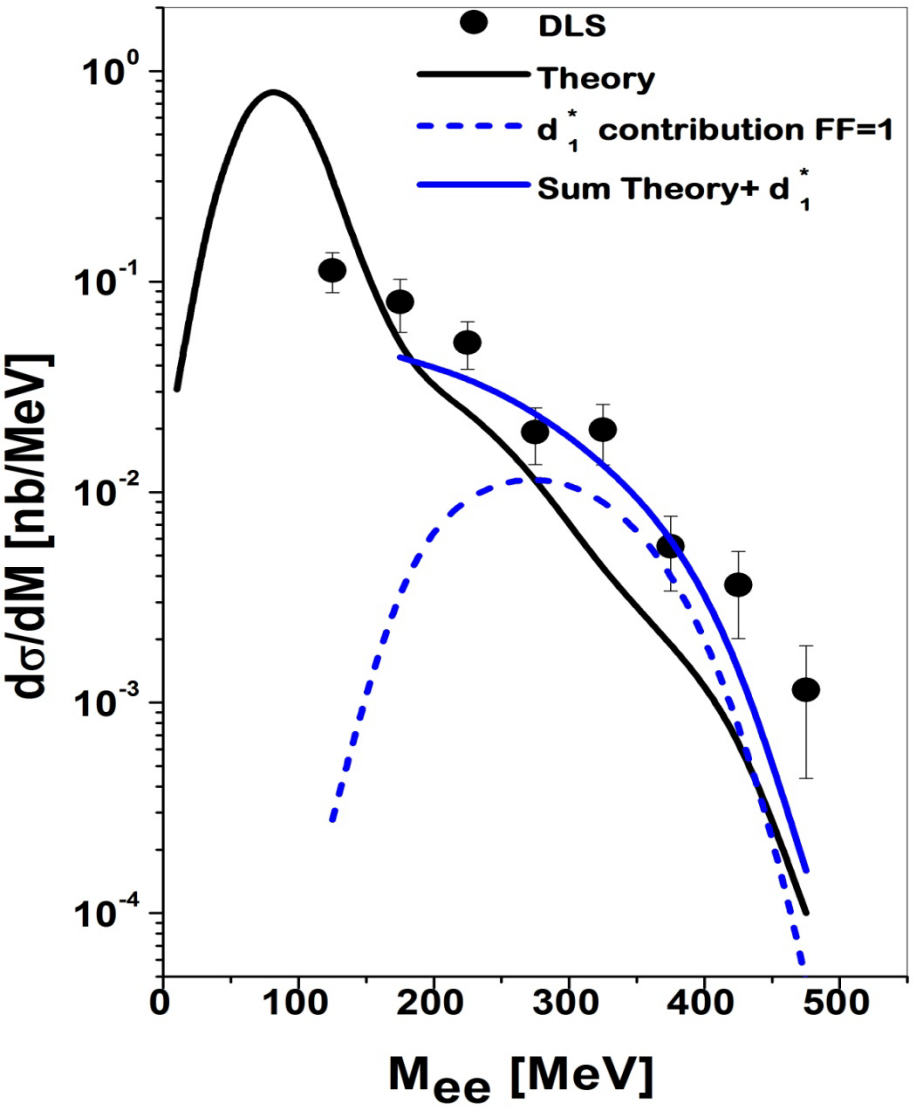
Reaction: $p + p \rightarrow e^+ e^- X$

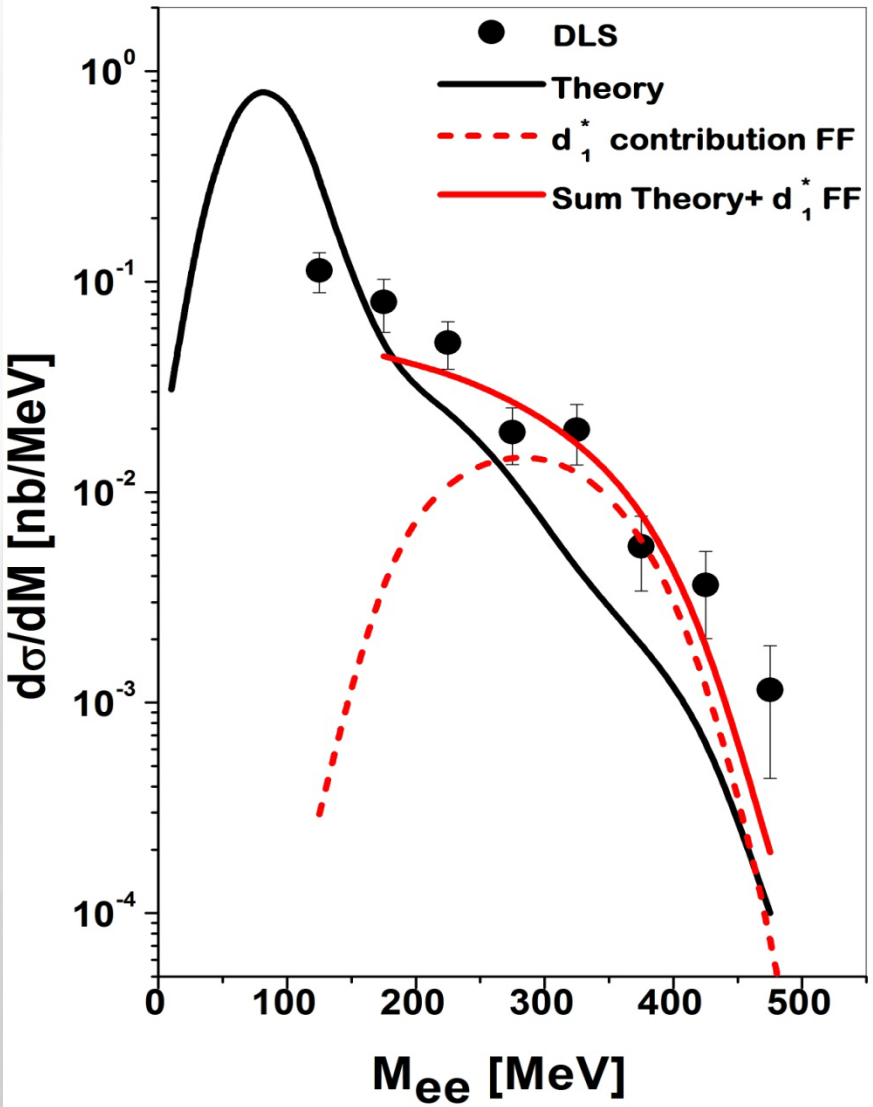
T=1.04 GeV





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)





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)

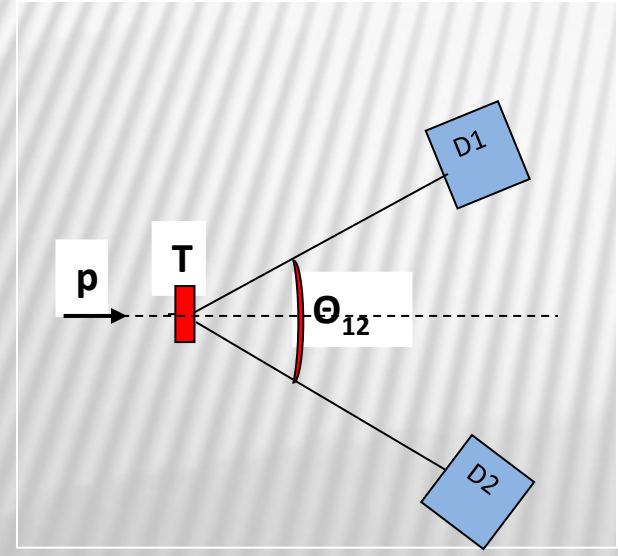
DLS Experiment

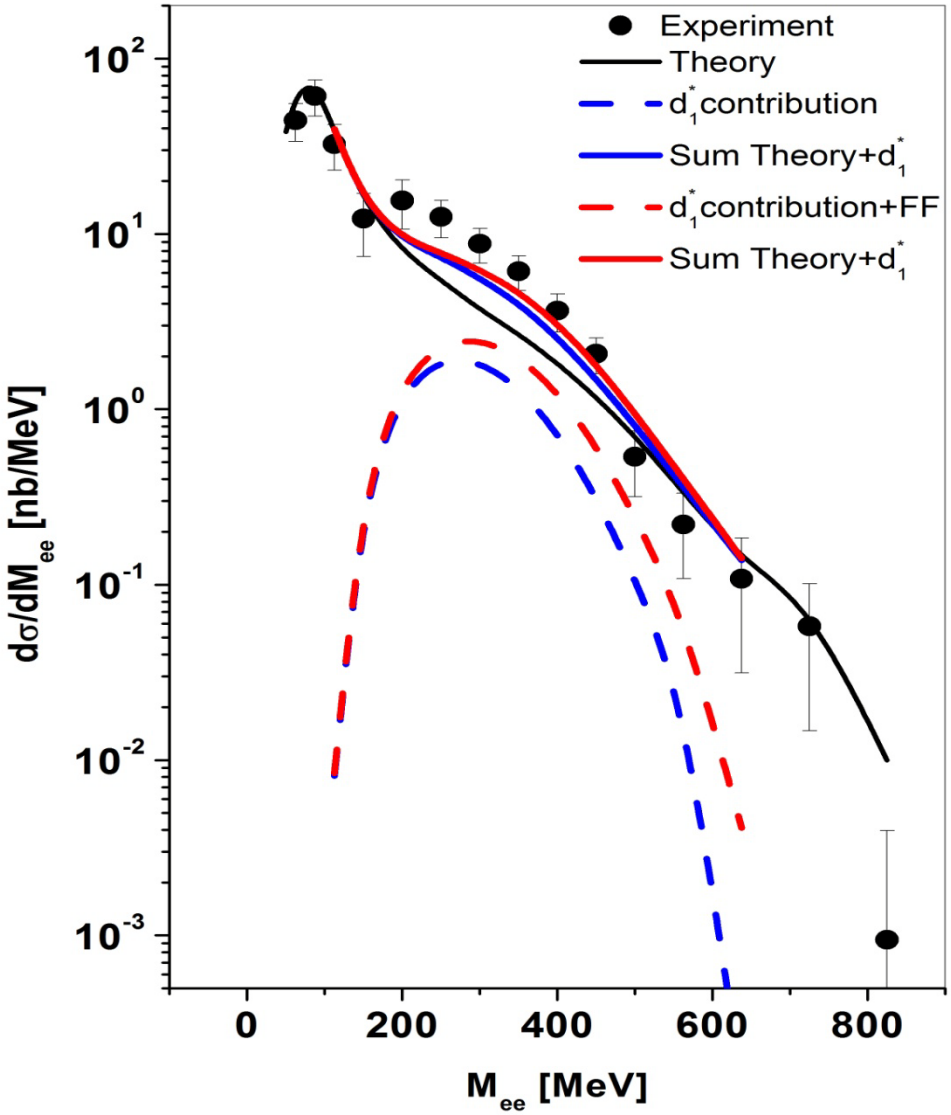
Reaction: $^{12}C + ^{12}C \rightarrow e^+ e^- X$

T=1.04 GeV/A

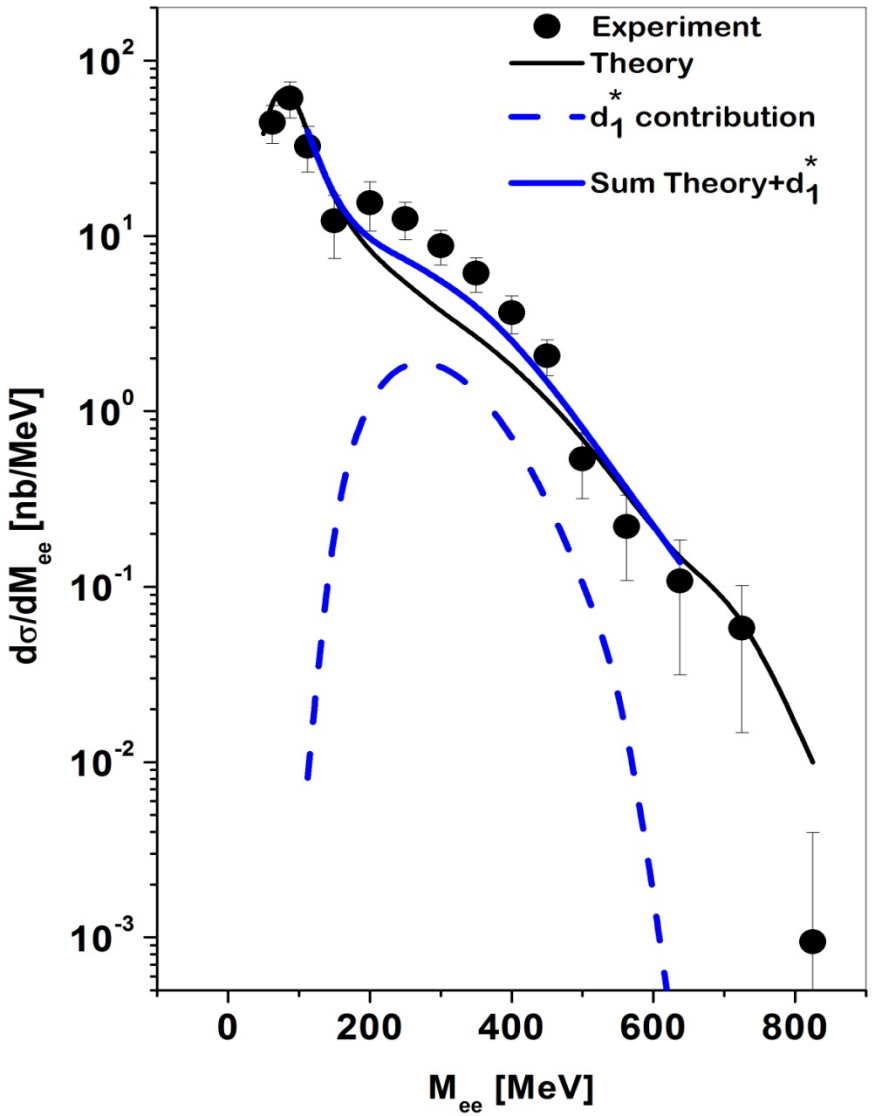
Mass resolution $\Delta M/M = 10\%$

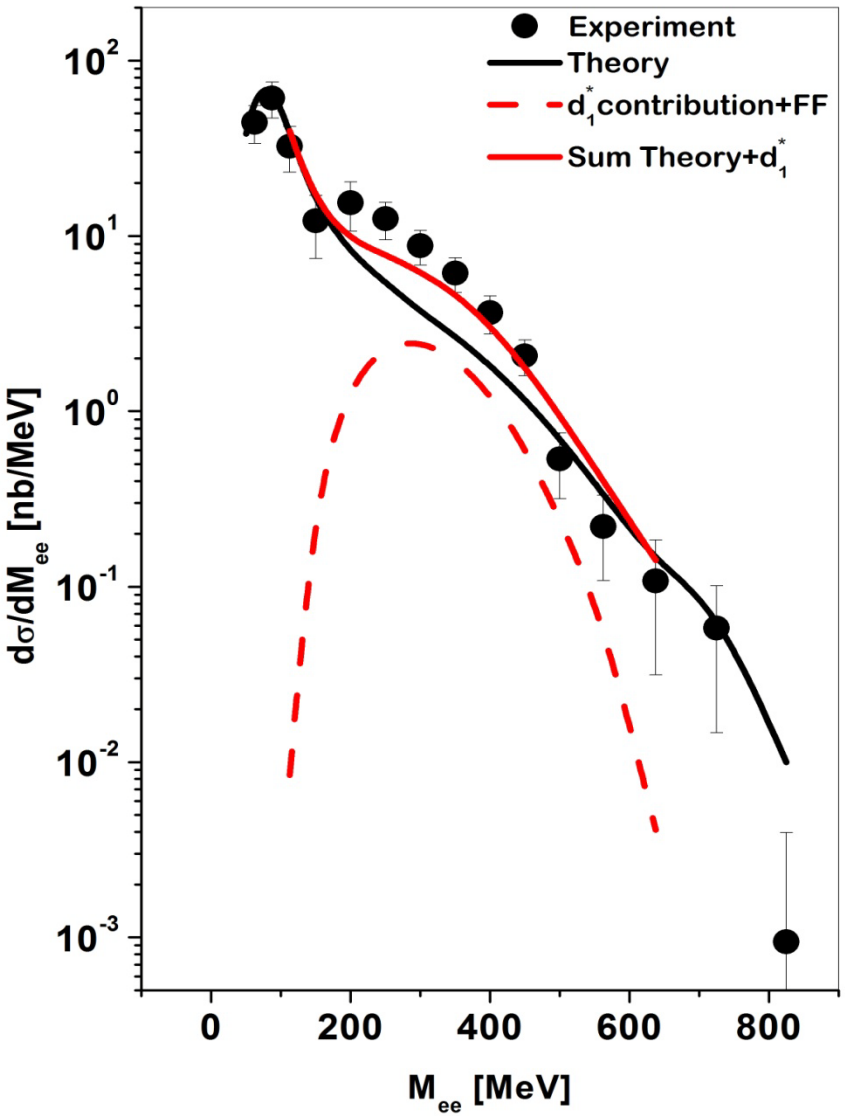
Filter v4.1p, CNWF:O.Benhar et al., Phys. Lett. B177,135(1986)





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 contributions of the dibaryon mechanism** $NN \to e^+e^-d_1^*(1956)$ **of dielectron production in NN collisions to the invariant mass spectra of the reaction** $pp \to e^+e^-X$ **were calculated for the energies and geometry of the DLS experiments.**

- **Results of the comparison of these contributions with the corresponding DLS data supports the idea that the observed excess of dielectron pairs in the mass region** $0.15 < M_{e+e-} < 0.6$ **GeV/c^2 can be attributed to their production in the process** $pp \to e^+e^-d_1^*(1956)$ **.**

- **The contributions of the** $NN \to e^+e^-d_1^*(1956)$ **mechanism to the invariant mass spectra of the reaction** $NN \to e^+e^-X$ **were calculated for the energies and geometry of the CC DLS experiments. Adding these contributions to the corresponding theoretical spectra we found that the resultant spectra reasonably well reproduce the experimentally observed ones in the mass region** $0.15 < M_{e+e-} < 0.6$ **GeV/c^2.**

- **The idea of the existing of the dibaryon mechanism of dielectron production can be confirmed or refuted by the direct measurement of the missing mass spectrum of the reaction** $pp \to e^+e^-X$ **.**