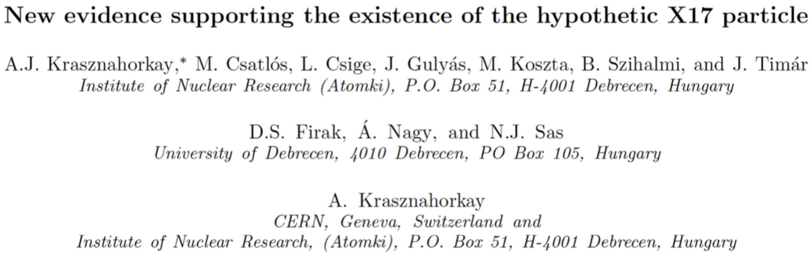
HPS Collaboration Meeting

X17 ATOMKI anomaly

Valery Kubarovsky

November 20, 2020

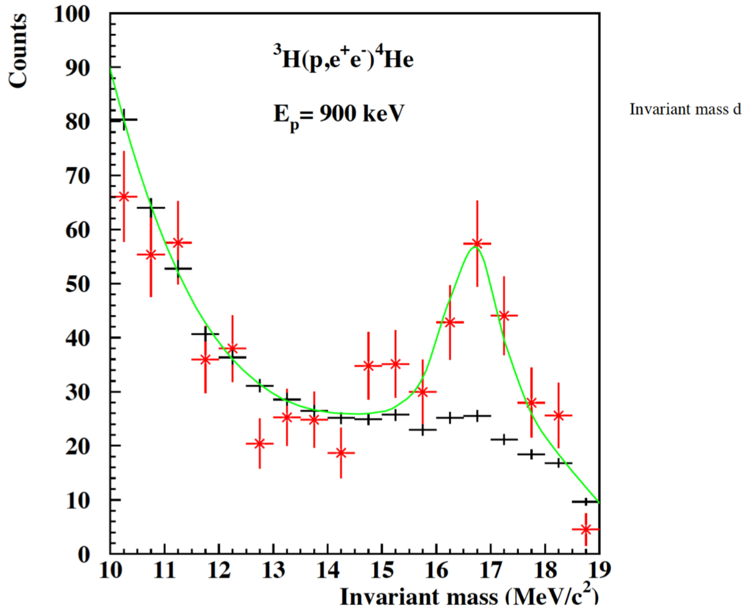


New evidence supporting the existence of the hypothetic X17 particle

A.J. Krasznahorkay,* M. Csatlós, L. Csige, J. Gulyás, M. Koszta, B. Szihalmi, and J. Timár
Institute of Nuclear Research (Atomki), P.O. Box 51, H-4001 Debrecen, Hungary

D.S. Firak, Á. Nagy, and N.J. Sas
University of Debrecen, 4010 Debrecen, PO Box 105, Hungary

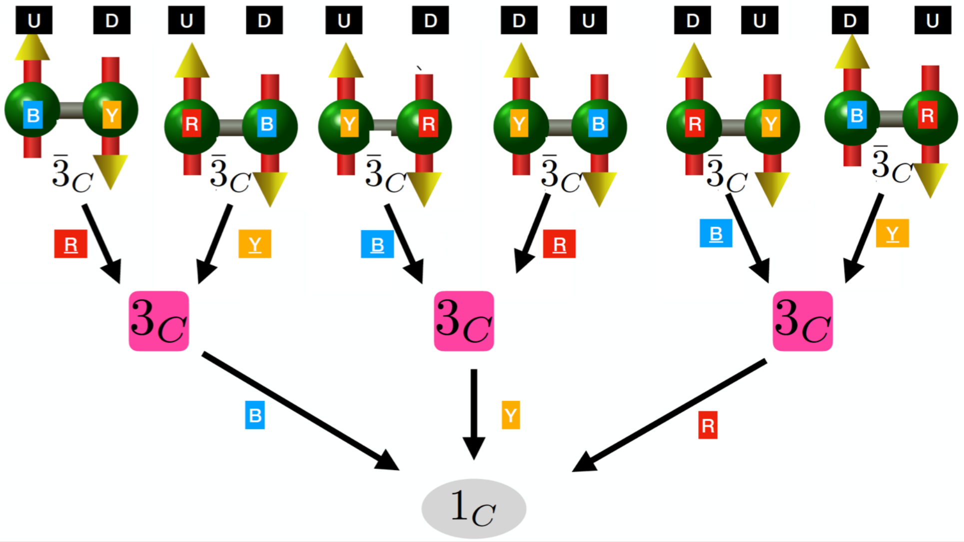
A. Krasznahorkay
CERN, Geneva, Switzerland and
Institute of Nuclear Research, (Atomki), P.O. Box 51, H-4001 Debrecen, Hungary



ATOMKI is the **Institute for Nuclear Research, Hungarian Academy of Sciences**. The institute is located in Debrecen and was established in 1954 by Sándor Szalay, the founding director.

The Hexa-Diquark and Novel QCD Effects in Nuclei

Construction of the Hexa-diQuark (HdQ)



HdQ: Jennifer Rittenhouse West, Guy de Teramond, Fred Goldhaber, and Ivan Schmidt

Other Topics: Guy de Tèramond, Hans Günter Dosch, Marina Nielsen, F. Navarra, G. Miller, Tianbo LIu, Liping Zou, S. Groote, S. Koshkarev Xing-Gang Wu, S-Q Wang, C.Lorcè, S. Sufian, A. Deur, R. Vogt, G. Lykasov, M. Karliner, S. Gardner, S. Liuti

Jefferson Lab

June 5, 2020

Stan Brodsky

SLAC NATIONAL ACCELERATOR LABORATORY

Holographic QCD and Superconformal Algebra

Baryons: quark + diquark bound states

$$|p >= |u[ud] >$$

$$|n >= |d[ud] >$$

$$|\Delta^{++} >= |u(uu) >$$

$[\mathrm{ud}]\ :\ \mathrm{S}{=}0,\ \mathrm{I}{=}\ 0,\ Q = +\frac{1}{3},\ \bar{3}_C$ *"Good" diquark*

$(\mathrm{uu})\ :\ \mathrm{S}{=}1,\ \mathrm{I}{=}\ 1,\ Q = +\frac{4}{3},\ \bar{3}_C$ *"Bad" diquark*

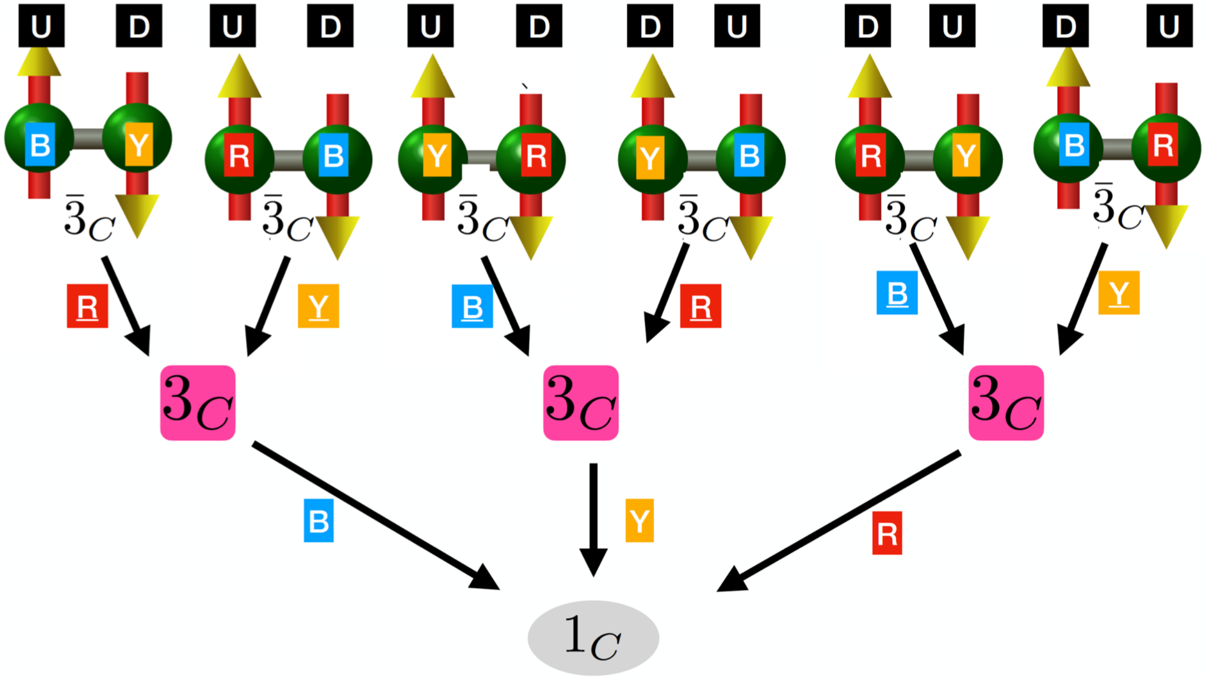
Diquarks: $3_C \times 3_C = \bar{3}_C + 6_C \to \bar{3}_C$ (attractive channel)

^{4}He as Hexa-Diquark state

Construction of the Hexa-diQuark (HdQ)

$$B = 4, I = 0, Q = +2 \ J^P = 0^+$$

Same Quantum Numbers as He-4



12 quarks: 3 colors X 2 spins X 2 flavors

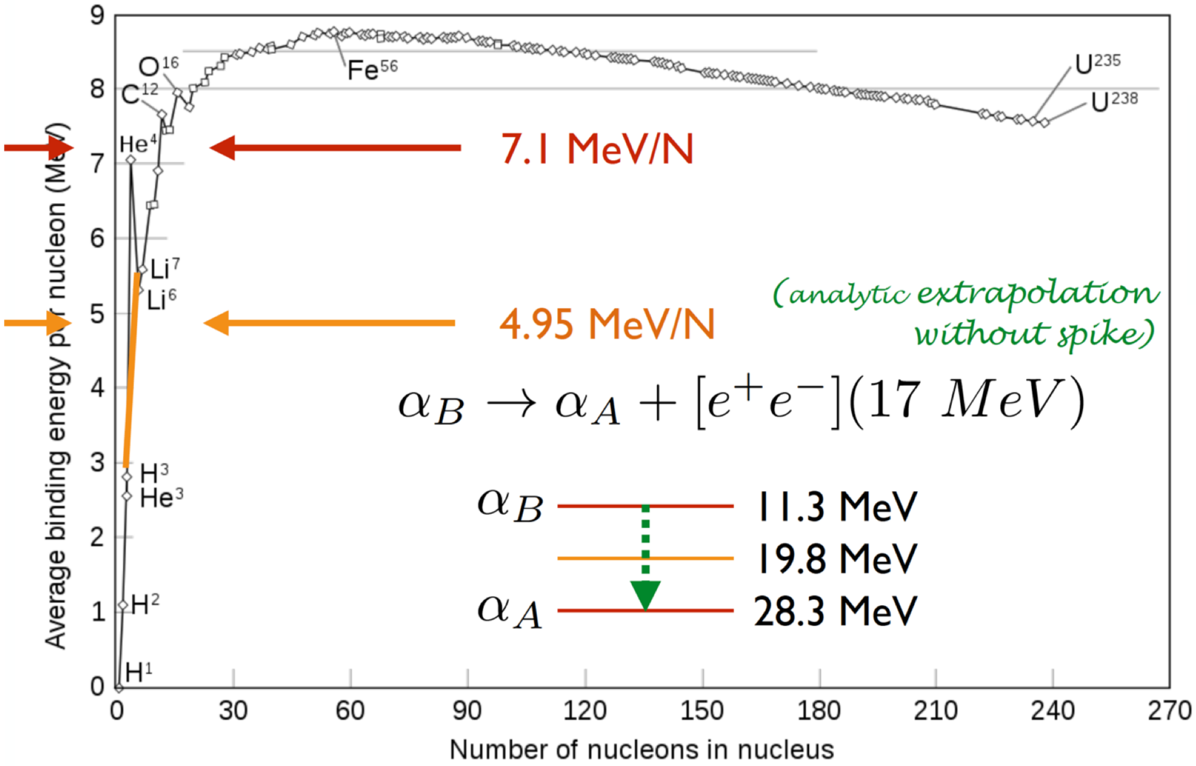
Bound by QCD strong interactions

Binding Energy per Nucleon

B.E /N of ^{4}He is significantly larger than all nearby nuclei

B.E. (He-4) = 28.3 MeV = 4 X 7.075 MeV

Remarkably strong binding



7.1 MeV/N

4.95 MeV/N

(analytic extrapolation without spike)

$$\alpha_B \rightarrow \alpha_A + [e^+e^-](17\ MeV)$$

α_B 11.3 MeV

19.8 MeV

α_A 28.3 MeV

Binding energy per nucleon of common isotopes. The binding energy per particle of helium-4 is significantly larger than all nearby nuclides.

Possible Explanation for X-17

$$|\alpha\rangle = C_{pnpn}|(u[ud])(d[ud])(u[ud])(d[ud])\rangle$$
$$+\ C_{\mathrm{HdQ}}|[ud][ud][ud][ud][ud][ud]\rangle.$$

$$\alpha_A = 4\cdot 7.08 = 28.3\ MeV$$
$$\alpha_0 = 4\cdot 4.95 = 19.3\ MeV$$
$$\alpha_B = \alpha_B - (\alpha_0 - \alpha_B) = 11.3\ Mev$$

Two-state system in Quantum Mechanics
Feynman lectures on physics

$$i\hbar\frac{dC_1}{dt} = H_{11}C_1 + H_{12}C_2$$
$$i\hbar\frac{dC_2}{dt} = H_{21}C_1 + H_{22}C_2$$

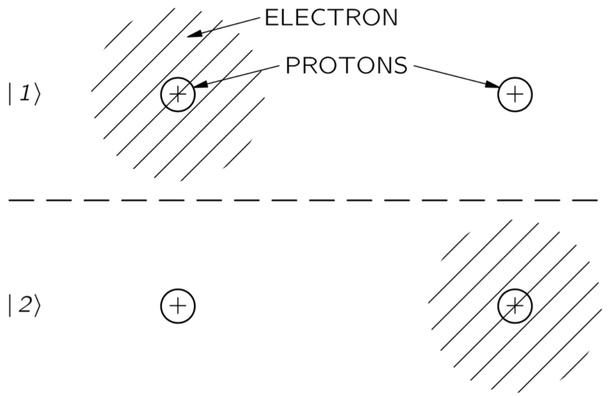


Fig. 10–1. A set of base states for two protons and an electron.

$$|I\rangle = \frac{1}{\sqrt{2}}\left[|1\rangle - |2\rangle\right]$$
$$|II\rangle = \frac{1}{\sqrt{2}}\left[|1\rangle + |2\rangle\right]$$

$$E_I = E_0 + A$$
$$E_{II} = E_0 - A$$

$$\alpha_A = 4 \cdot 7.08 = 28.3\ MeV$$
$$\alpha_0 = 4 \cdot 4.95 = 19.3\ MeV$$
$$\alpha_B = \alpha_B - (\alpha_0 - \alpha_B) = 11.3\ Mev$$

Possible Explanation for X17

Mixing of He-4 $|npnp>$ (bound by meson exchange)
with HdQ $|[ud][ud][ud][ud][ud][ud]>$ (bound by QCD strong interactions)
gives two states: $J^{PC} = 0^{++}$: α_A and α_B

Identify α_A with observed He-4 (B.E. = 28.3 MeV)

Assume excited 0^{++} state α_B $(B.E. = 11.3\ MeV)$

Electromagnetic transition: $\alpha_B \to \alpha_A + \gamma^* \to \alpha_A + [e^+e^-]$

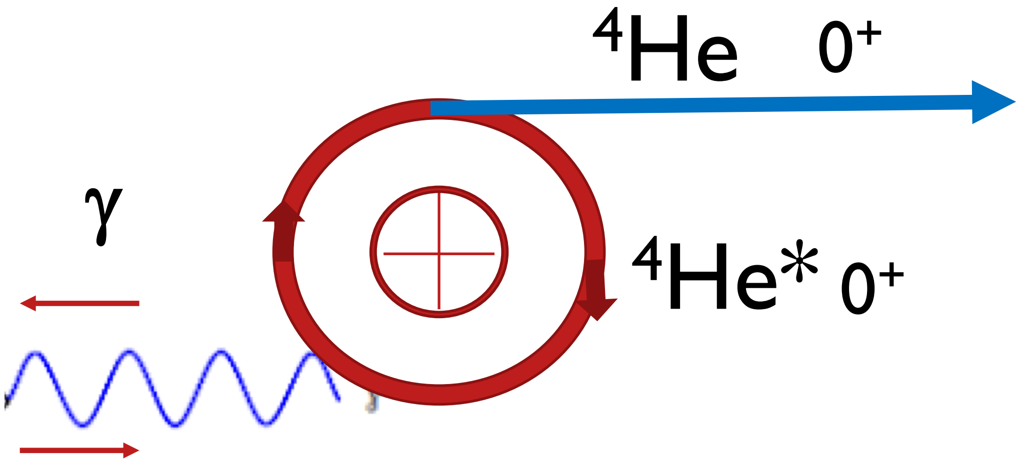
$$M([e^+e^-]) = 17\ MeV$$

Mean Value: (B.E.= 19.8 MeV) $|npnp>$ without HdQ

$$B.E./N = 4.95\ MeV$$

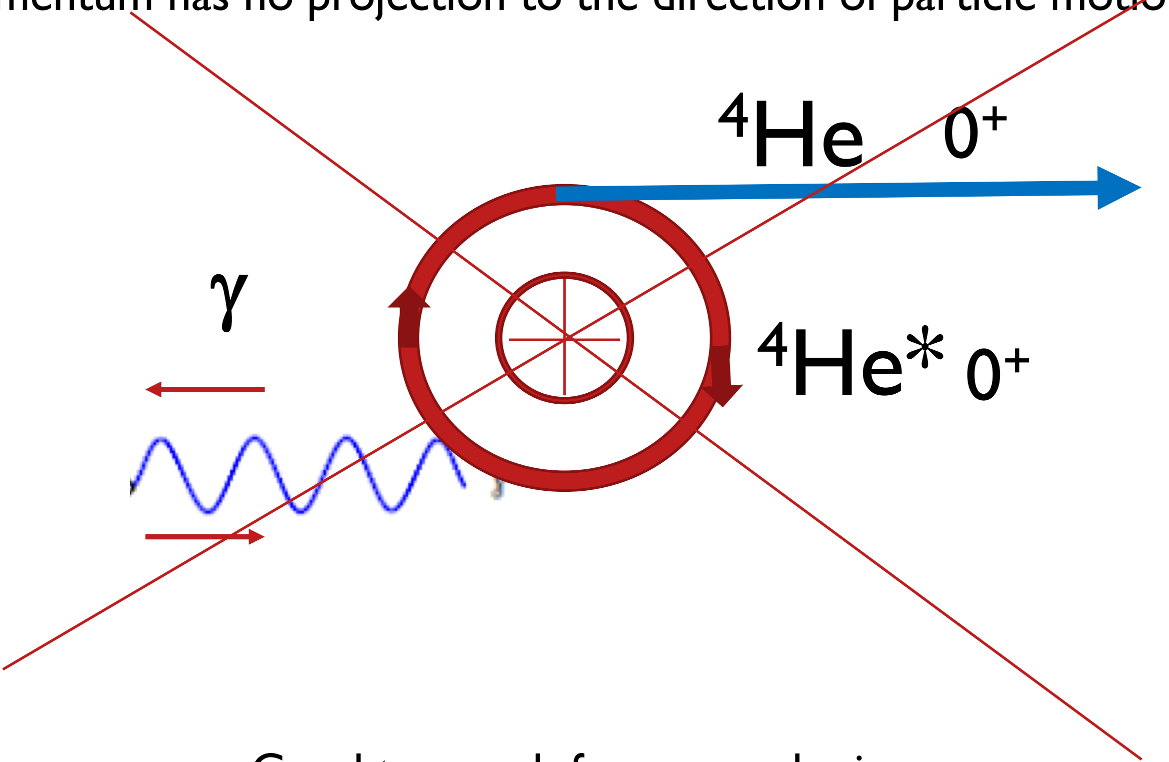
$^4He^*$->He: $0^+ \rightarrow 0^+$ EM transition

- $0^+ \rightarrow 0^+$ EM transition is forbidden with the real photons in the final state due to the conservation of the angular momentum
- Real photon has projection of the spin to the photon momentum +1 or -1.
- Orbital momentum has no projection to the direction of particle motion.



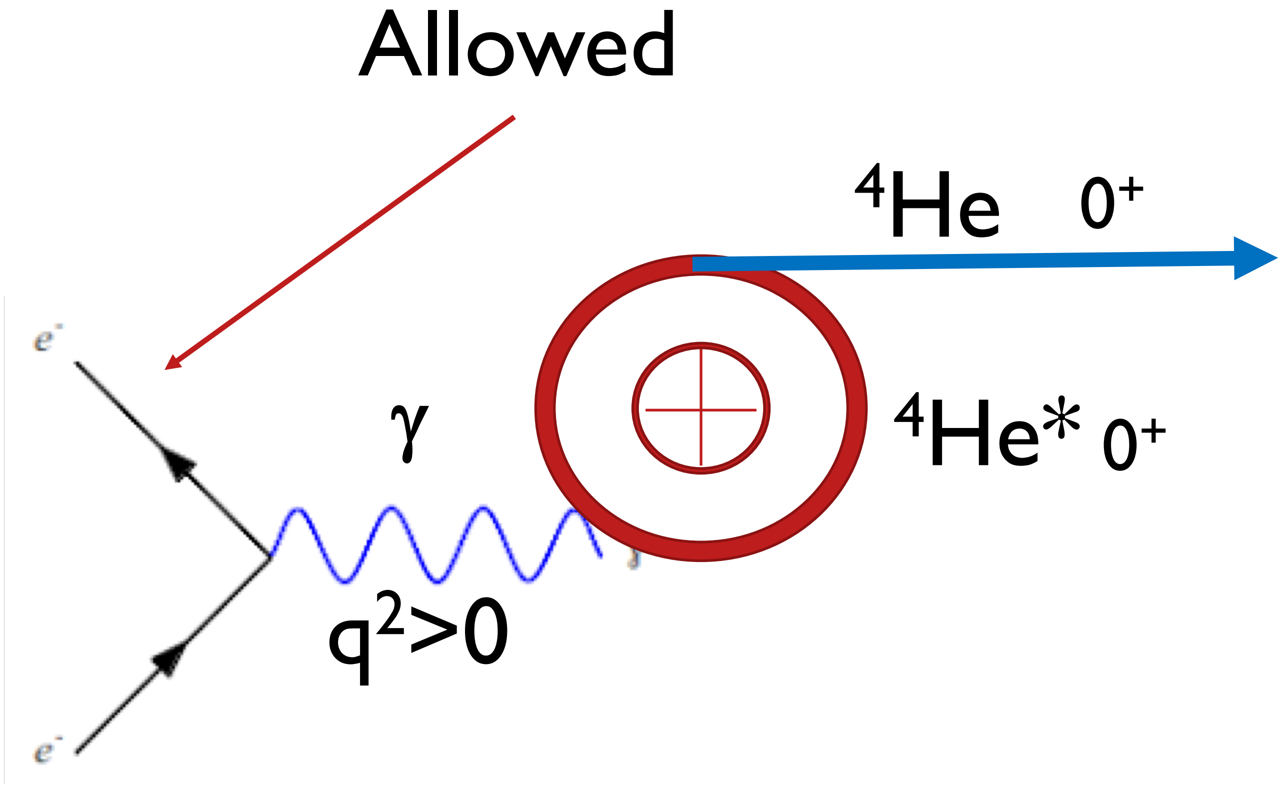
$0^+ \rightarrow 0^+$ EM transition

- $0^+ \rightarrow 0^+$ EM transition is forbidden with the real photons in the final state due to the conservation of the angular momentum
- Real photon has projection of the spin to the photon momentum +1 or -1.
- Orbital momentum has no projection to the direction of particle motion.



Good to search for a new physics

$0^+ \rightarrow 0^+$ EM transition



Allowed

^{4}He 0^+

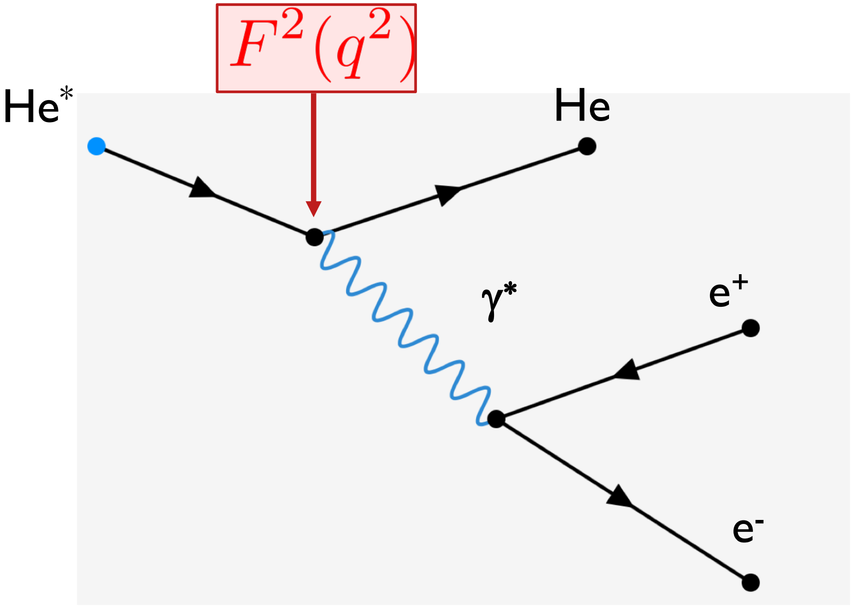
γ

^{4}He* 0^+

$q^2>0$

Good to search for a new physics

Matrix Element $^4\text{He}^* \rightarrow {}^4\text{He} + (e^+e^-)$

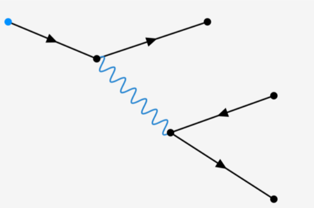


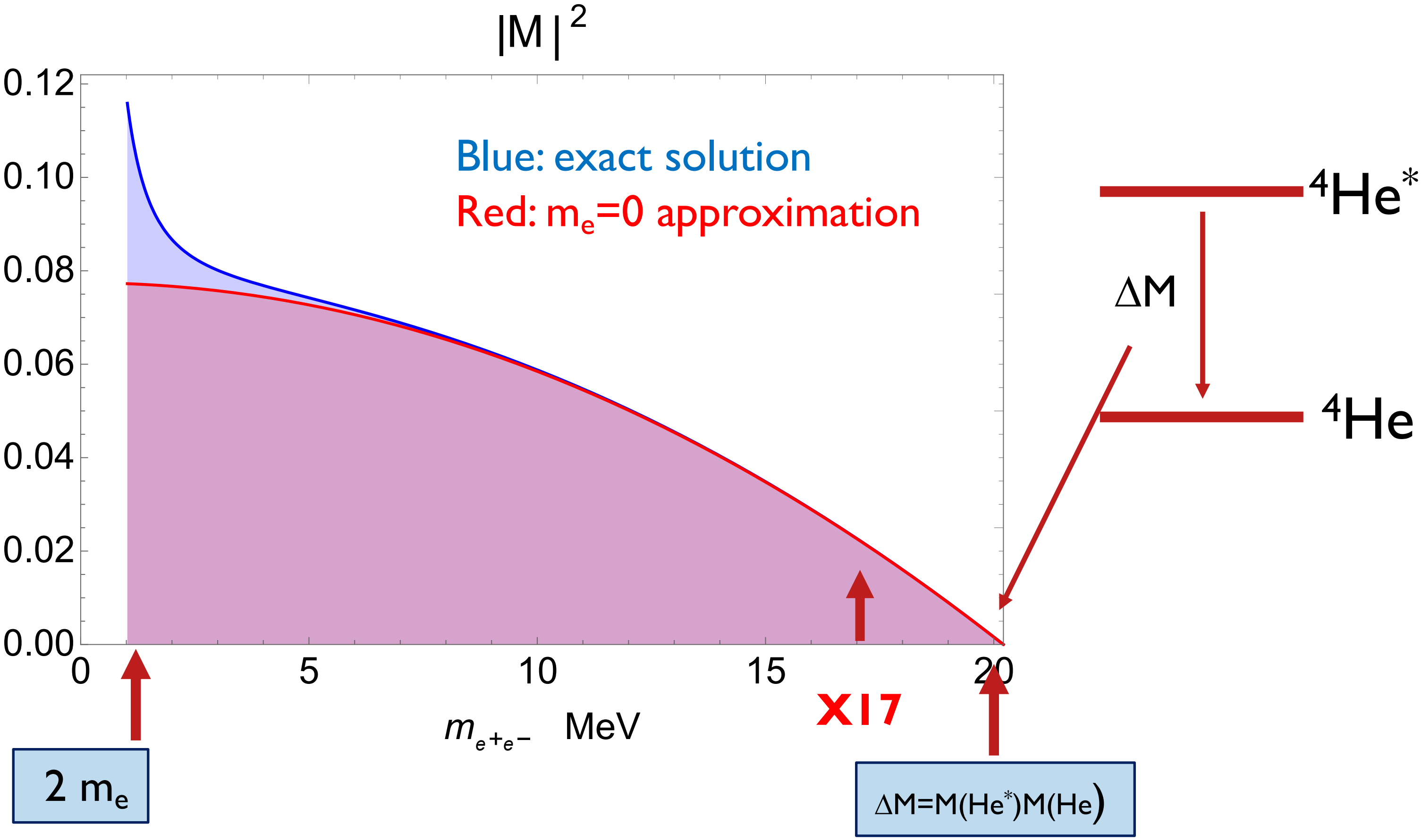
Matrix element of the EM decay $^4\text{He}^* \rightarrow {}^4\text{He} + (e^+e^-)$ was calculated in the "Dynamic evidence for the fifth force explanation of the ATOMKI nuclear anomalies", paper 2006.01151, June 2020

$$|M|^2 \sim \left[2(p_+ \cdot p_0)(p_- \cdot p_0) - m_{N_0}^2 \left((p_+ \cdot p_-) + m_e^2\right)\right] F^2(q^2)$$

The authors used $F(q^2)=1$. They did not calculate e^+e^- invariant mass distribution.

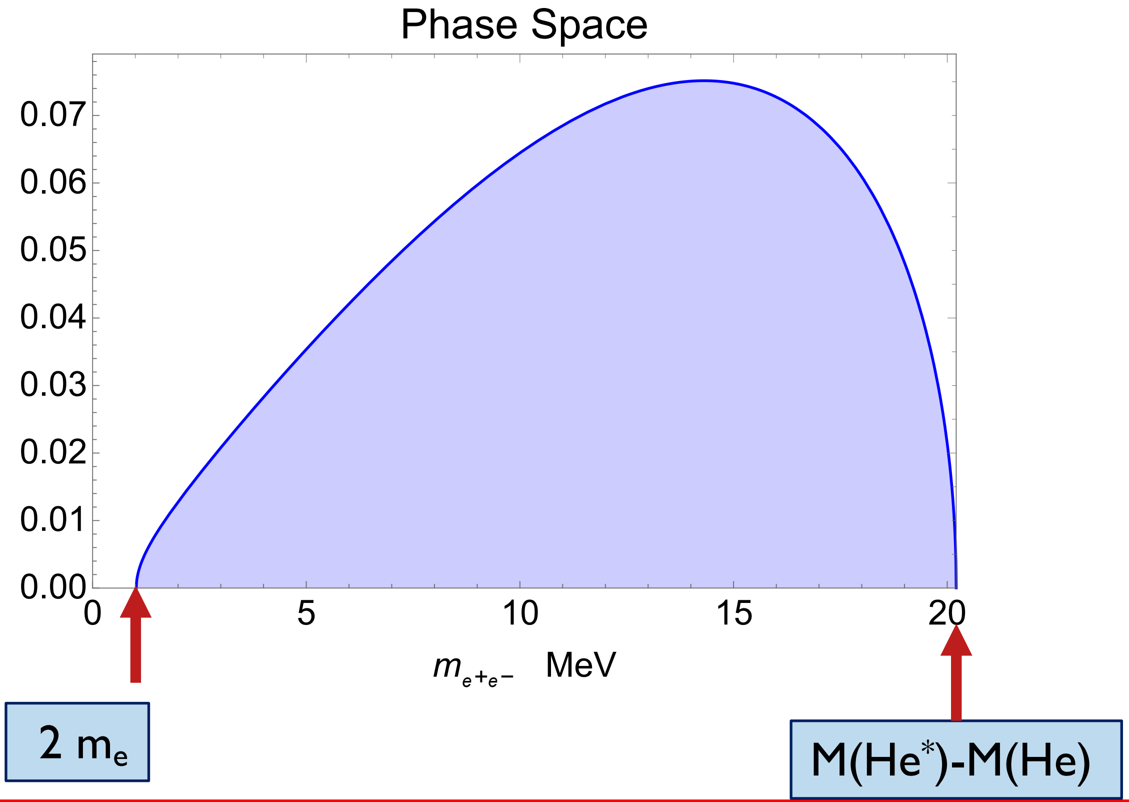
Matrix Element $^4He^* \rightarrow {}^4He + (e^+e^-)$





$$|M(q^2, \cos\theta^*)|^2 \sim \frac{\left[q^2 - \cos^2\theta^*(q^2 - 4m_e^2)\right]\left[m_*^4 + (m_0^2 - q^2)^2 - 2m(m_0^2 + q^2)\right]}{8q^2}$$

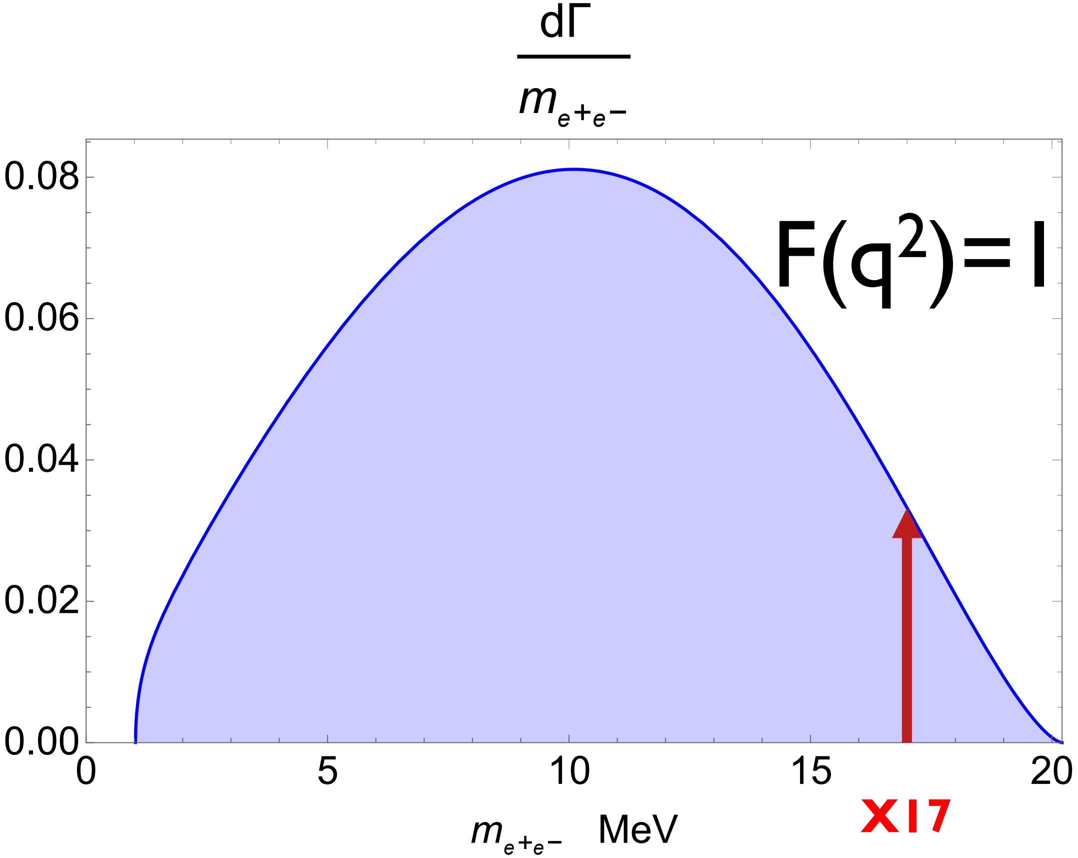
^{4}He* → ^{4}He + (e+e-) Phase space

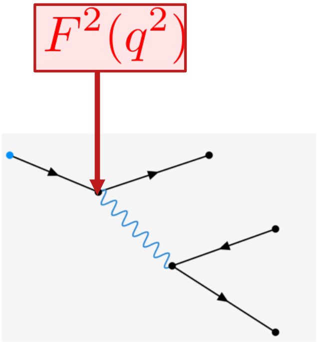


$$d\Gamma = \frac{1}{(2\pi)^5}\frac{1}{16m^2}|M|^2|p_e^*||p_0|\,dm_{e^+e^-}\,d\Omega_e^*\,d\Omega_{He}$$

$$\Phi(q^2) = |p_e^*||p_{He}| = \sqrt{\frac{q^2}{4} - m_e^2}\,\frac{\sqrt{(m^2-(m_0-q)^2)\,(m^2-(m_0+q)^2)}}{2m}$$

Differential Width $^4He^* \to {}^4He + e^+e^-$





No enchantment in the region of X17!

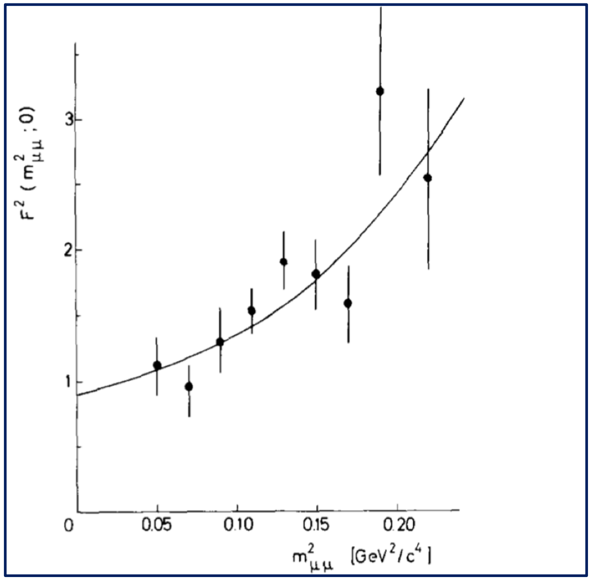
$$\frac{d\Gamma}{dq} \sim q\left(\Delta m^2 - q^2\right)^{\frac{3}{2}} F^2(q^2)$$

$q=m_{e+e-}$

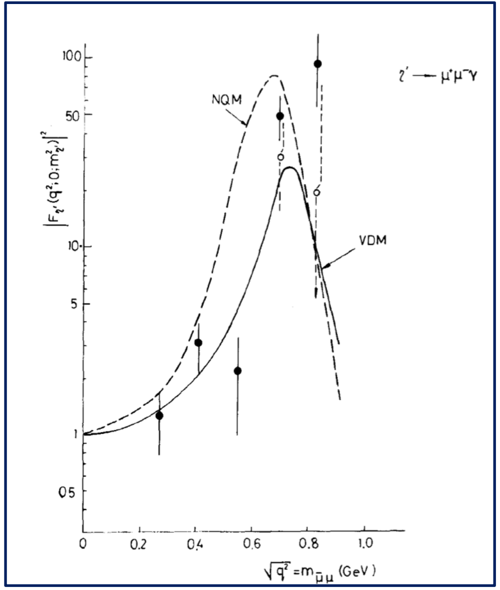
$m_e=0$ approximation

Transition Formfactors in Time-Like region

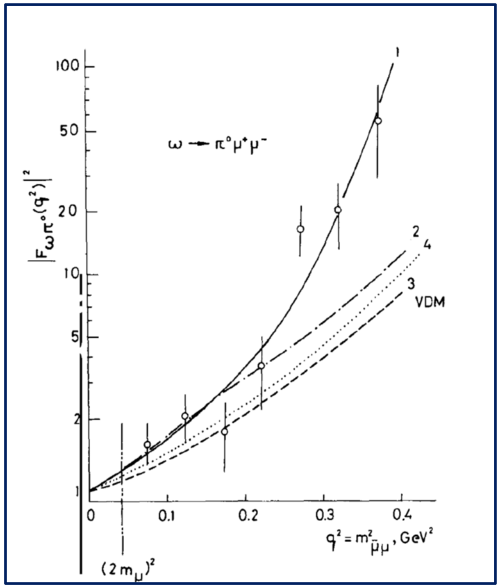
$\eta \to \mu^+\mu^-\gamma$



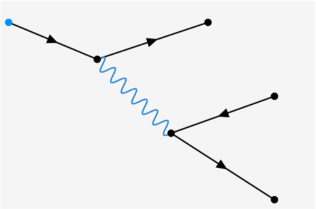
$\eta' \to \mu^+\mu^-\gamma$



$\omega \to \pi^0\mu^+\mu^-$

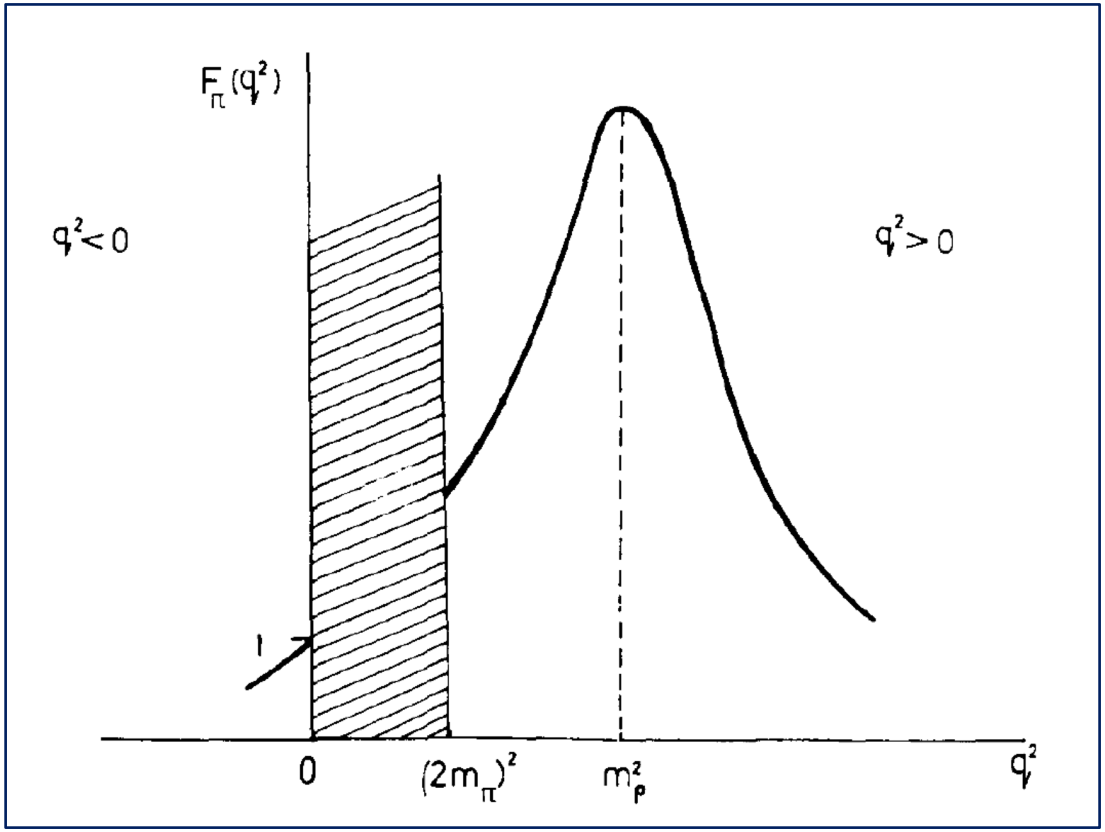


Experiments from LEPTON setup, IHEP, Protvino, Russia
1979-1981

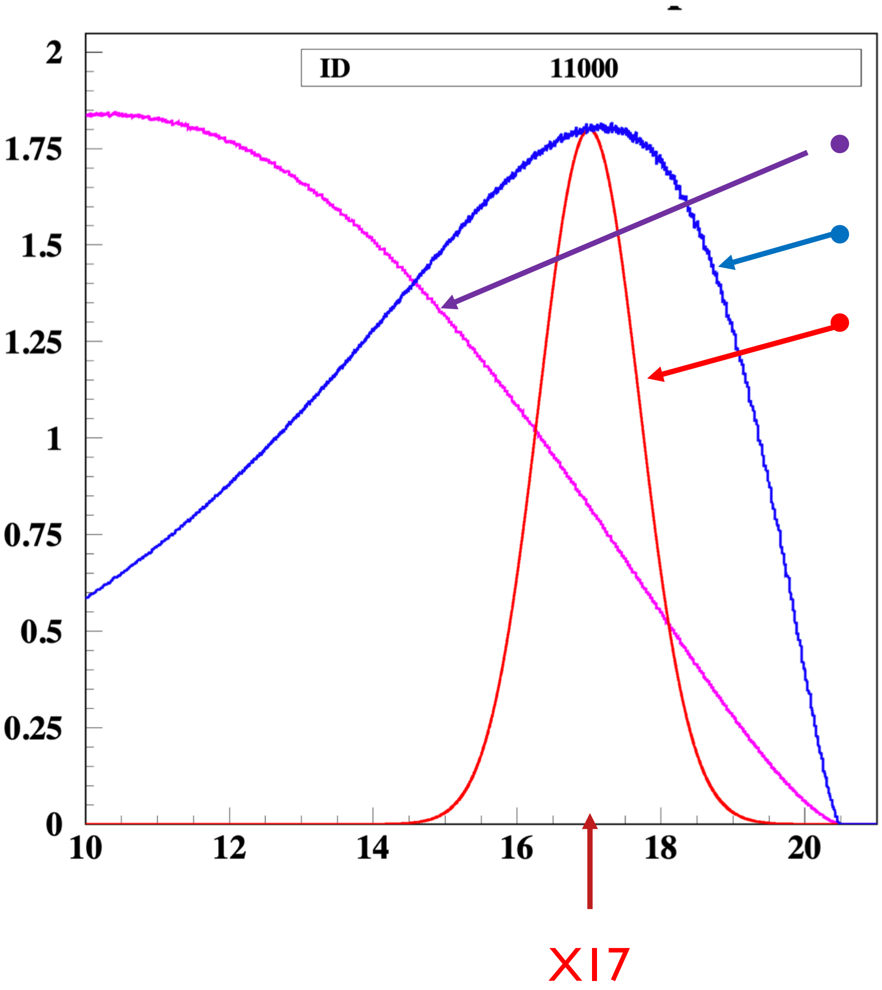


Transition Formfactors in Time-Like region

Vector dominance model gives an idea how time-like and space-like form factors look like



Add formfactor: $F(q^2) = e^{(q/\lambda)^2}$



- $F(q^2)=1$
- $F(q^2)=e^{(q/\lambda)2}$ $,\lambda=14$ MeV
- X17 signal

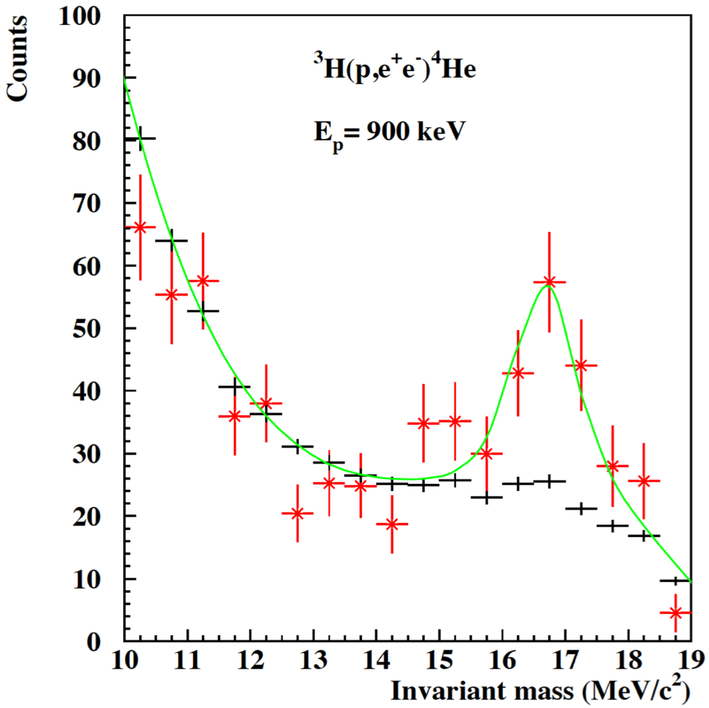
Form factor may create peak at 17 MeV but it is too wide in comparison with ATOMKI signal

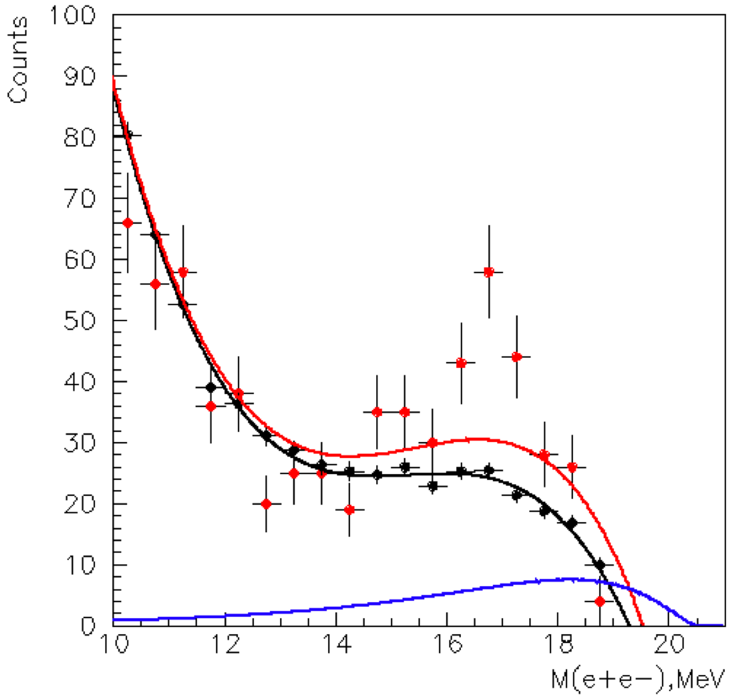
Add formfactor: $F(q^2) = e^{(q/\lambda)^2}$

ATOMKI signal M=17 MeV σ= 0.7 MeV
1. Narrow
2. Far away from the kinematical limit 20.5 MeV

- Fit gives λ=11 MeV
- No peak appears
- Form factor did not help!

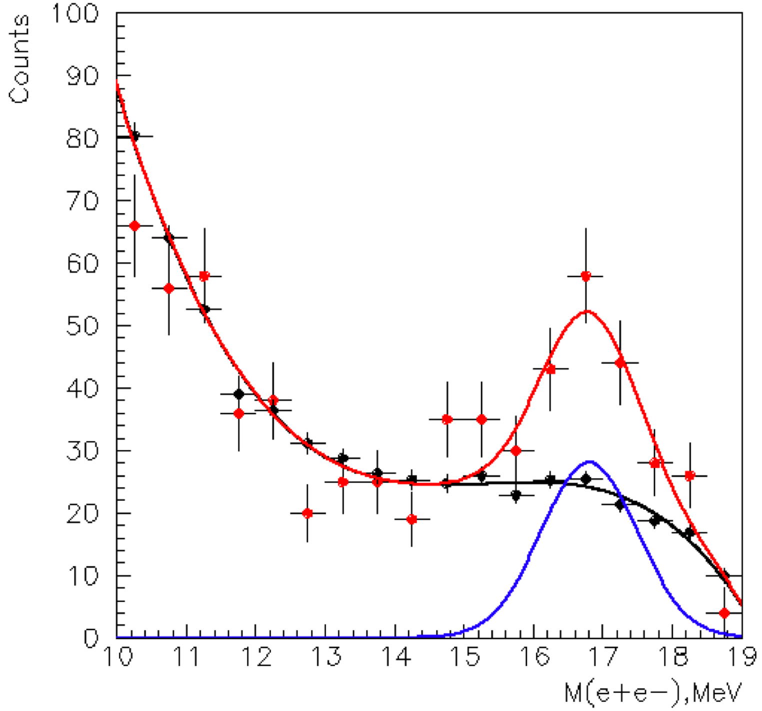
There is no way to describe this signal by any reasonable matrix element with FF



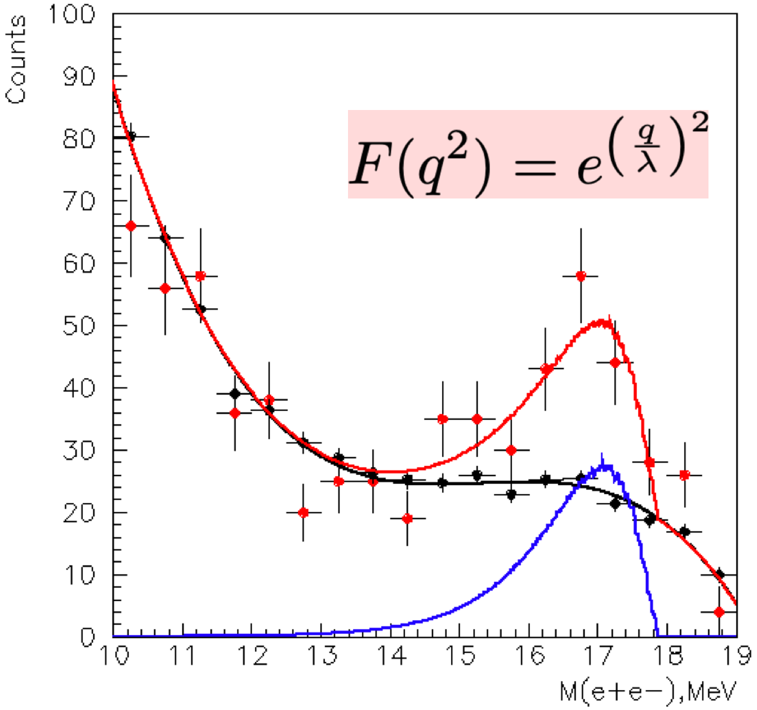


What if ΔM=17.9 instead of 20.5 MeV?

Gaussian Fit



ΔM=17.9 +/-0.8MeV
FF with λ=6.2 +/-0.2 MeV



$$F(q^2) = e^{\left(\frac{q}{\lambda}\right)^2}$$

- Very good fit, even better than with Gaussian function
- Predicted the new ^{4}He* excited state with ΔM=17.9 MeV above the He ground state

- Form factor has unrealistic λ=6.2 MeV (~30 fm)
- Expected λ around 150 MeV (~1 fm)
- Contradicts the ATOMKI event selection cuts $E(e^+e^-)$=20.5+/- 1 MeV

^{8}Be*(18.15) → ^{8}Be+(e$^+$e$^-$)

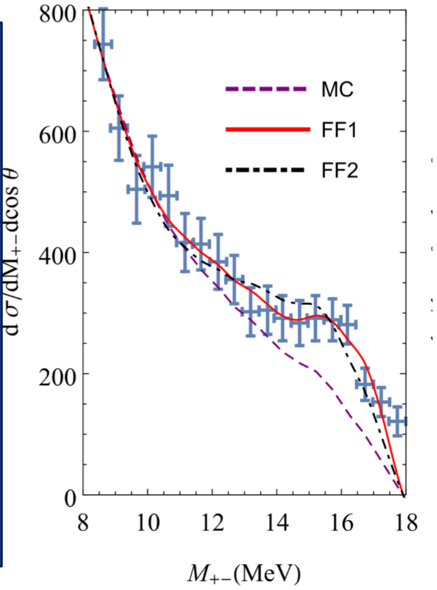
Xilin Zhang, Gerald A. Miller (Univ of Washington)

Can nuclear physics explain the anomaly observed in the internal pair production in the Beryllium-8 nucleus?

Physics Letters B 773 (2017)

- The nuclear physics modeling of the reaction can not explain the anomaly
- Explore the nuclear transition form factor as a possible origin of the anomaly and find the required form factor to be unrealistic for the ^{8}Be nucleus (λ=20 MeV)

FF with λ=20 MeV



ATOMKI anomaly 2016

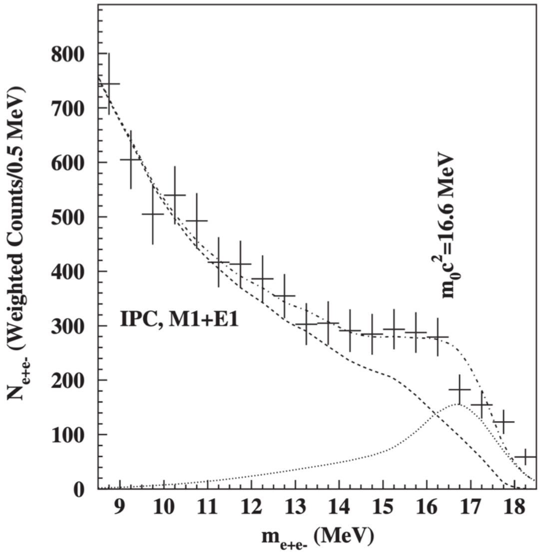


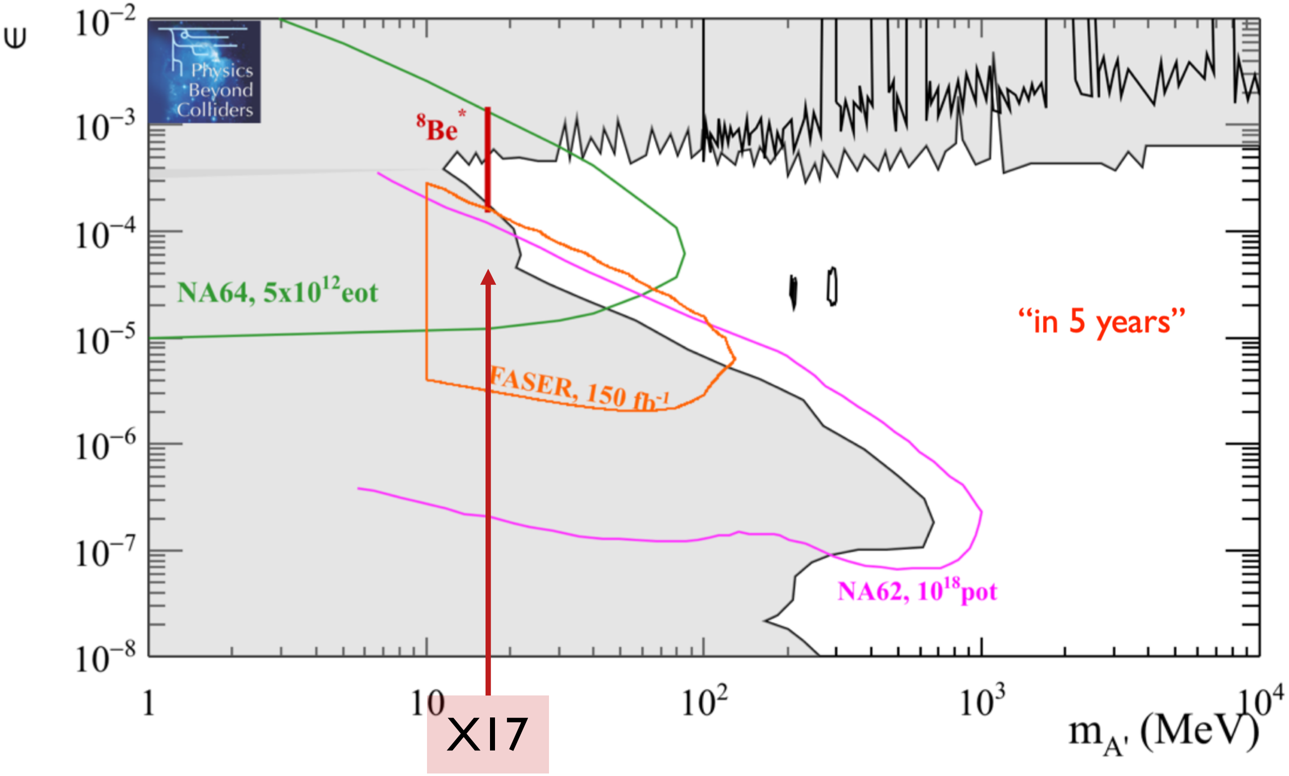
FIG. 5. Invariant mass distribution derived for the 18.15 MeV transition in ^{8}Be.

Nuclear Physics and X17 anomaly

- Nuclear physics conventual electromagnetic transitions cannot explain the X17 ATOMKI anomaly for both ^{8}Be or ^{4}He
- Adding form factor helps but the required parameters are unrealistic for the nuclear transition of these nuclei
- It makes interpretation of the X17 as an exotic particle more robust

X17 anomaly

https://arxiv.org/abs/1901.09966



It is still not late for HPS to make a contribution in resolving the X17 anomaly mystery

Summary

- I examine the possible explanation of the ATOMKI anomaly in the framework of the effective field theory of the electromagnetic transition ^{4}He*(20.5)→^{4}He+(e^+e^-).
- This theory cannot explain the anomaly
- The nuclear transition form factor may help to simulate peak in the e^+e^- invariant mass spectrum but doesn't describe the experimental signal with any reasonable FF parameters
- The ATOMKI signal looks like a transition from the new excited ^{4}He(17.9) state but the required FF parameter is unrealistic for the ^{4}He nucleus (λ=6.2 MeV)
- This hypothesis contradicts also the experimental event selection cuts
- All these arguments make the interpretation of the X17 anomaly as production of the new exotic particle more solid.
- It may affect in my view the future HPS program