Is New Physics Needed to Explain the "ATOMKI Anomaly" ?

CAP Congress

June 10, 2021

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Motivation: the X17 Saga

Claims of the new 17-MeV boson produced in nuclear transitions, e.g. ^{7}Li(p,e$^+$e$^-$)^{8}Be . Primary observable is e$^+$e$^-$ angular correlation

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Signature of a Light, Neutral Boson

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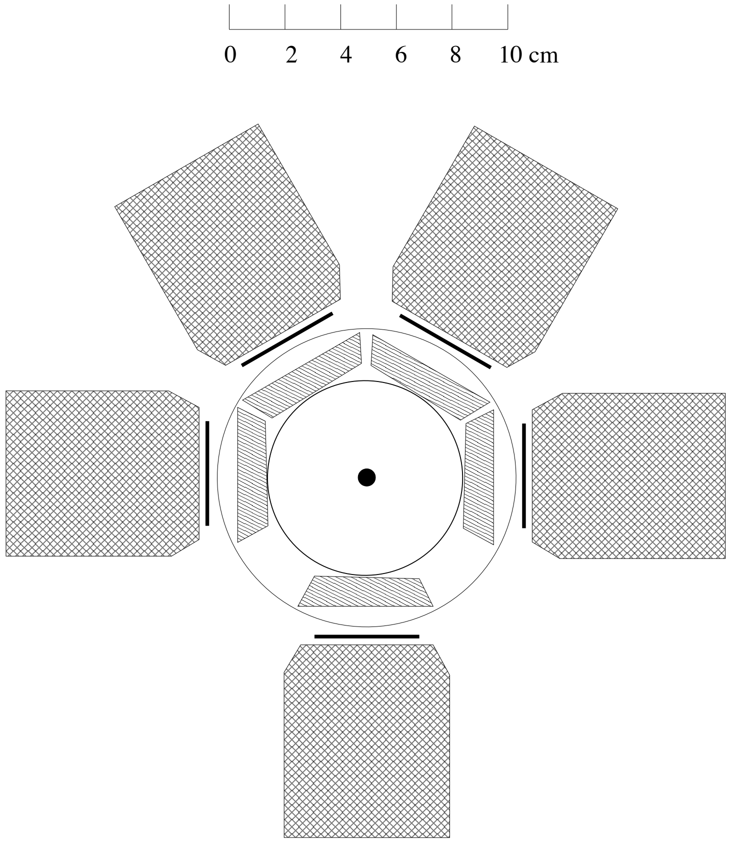
arXiv:1504.01527 [nucl-ex]
PRL 116, 042501 (2016)



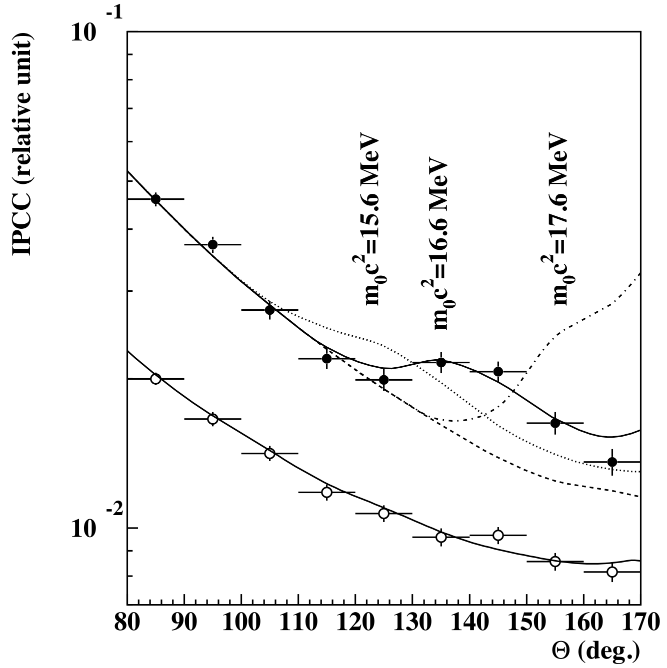


FIG. 4. *Experimental angular e^+e^- pair correlations measured in the $^7Li(p,e^+e^-)$ reaction at E_p=1.10 MeV with -0.5 ≤ y ≤ 0.5 (closed circles) and |y| ≥ 0.5 (open circles). The results of simulations of boson decay pairs added to those of IPC pairs are shown for different boson masses as described in the text.*

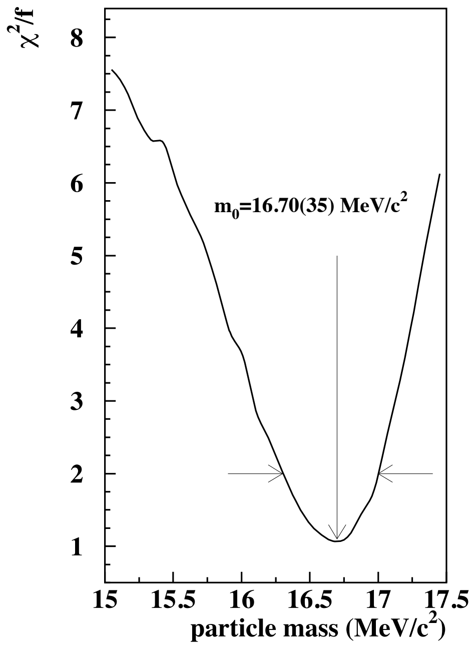
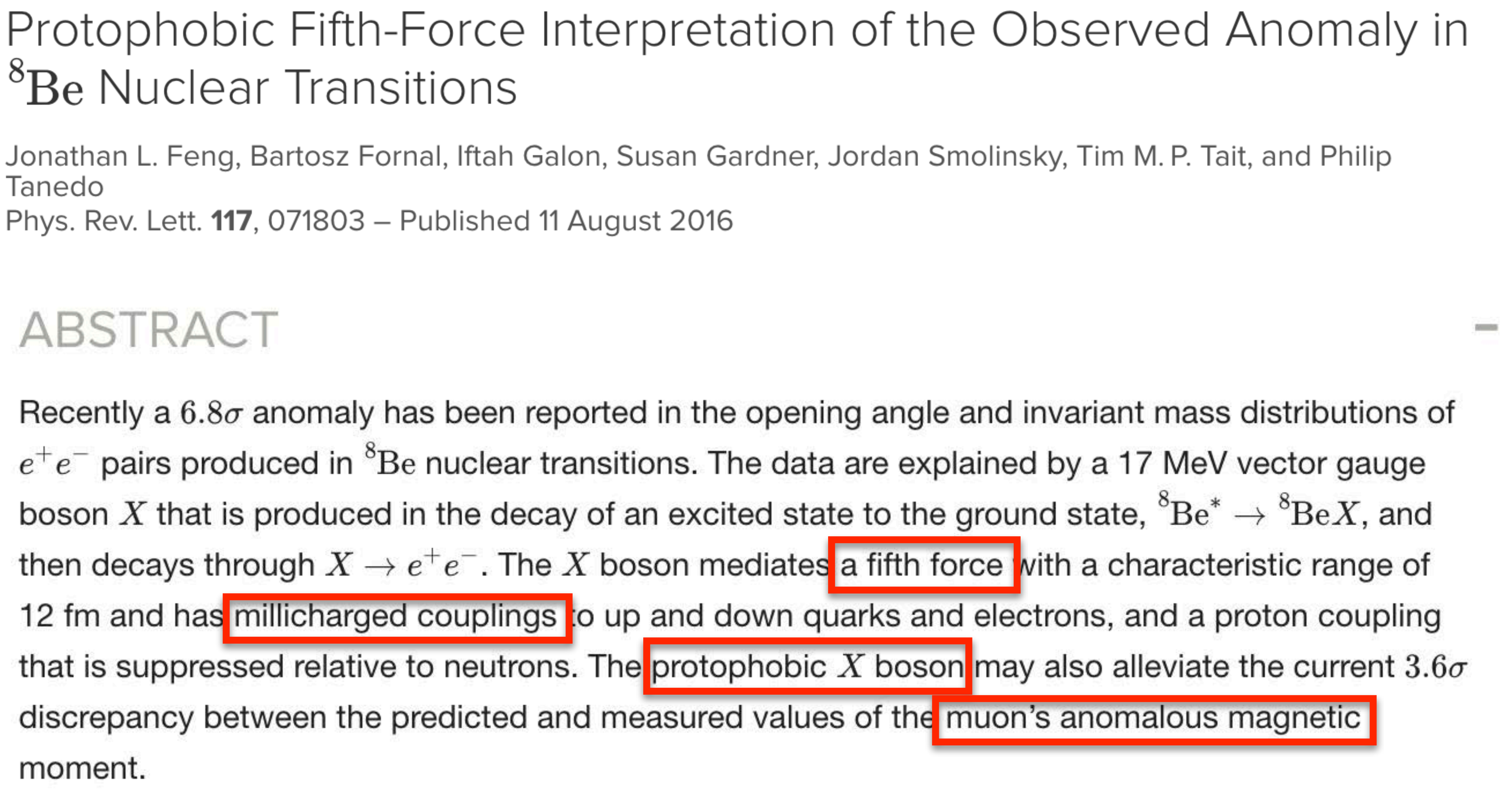


FIG. 5. *Determination of the mass of the new particle by the χ^2/f method, by comparing the experimental data with the results of the simulations obtained for different particle masses.*

As a result of the χ^2 analysis, we determined the boson mass to be m_0c^2 = 16.70±0.35 (stat) MeV. The min-

The X17 Saga

ATOMKI results received little attention until theorists invented the “fifth force” explanation.



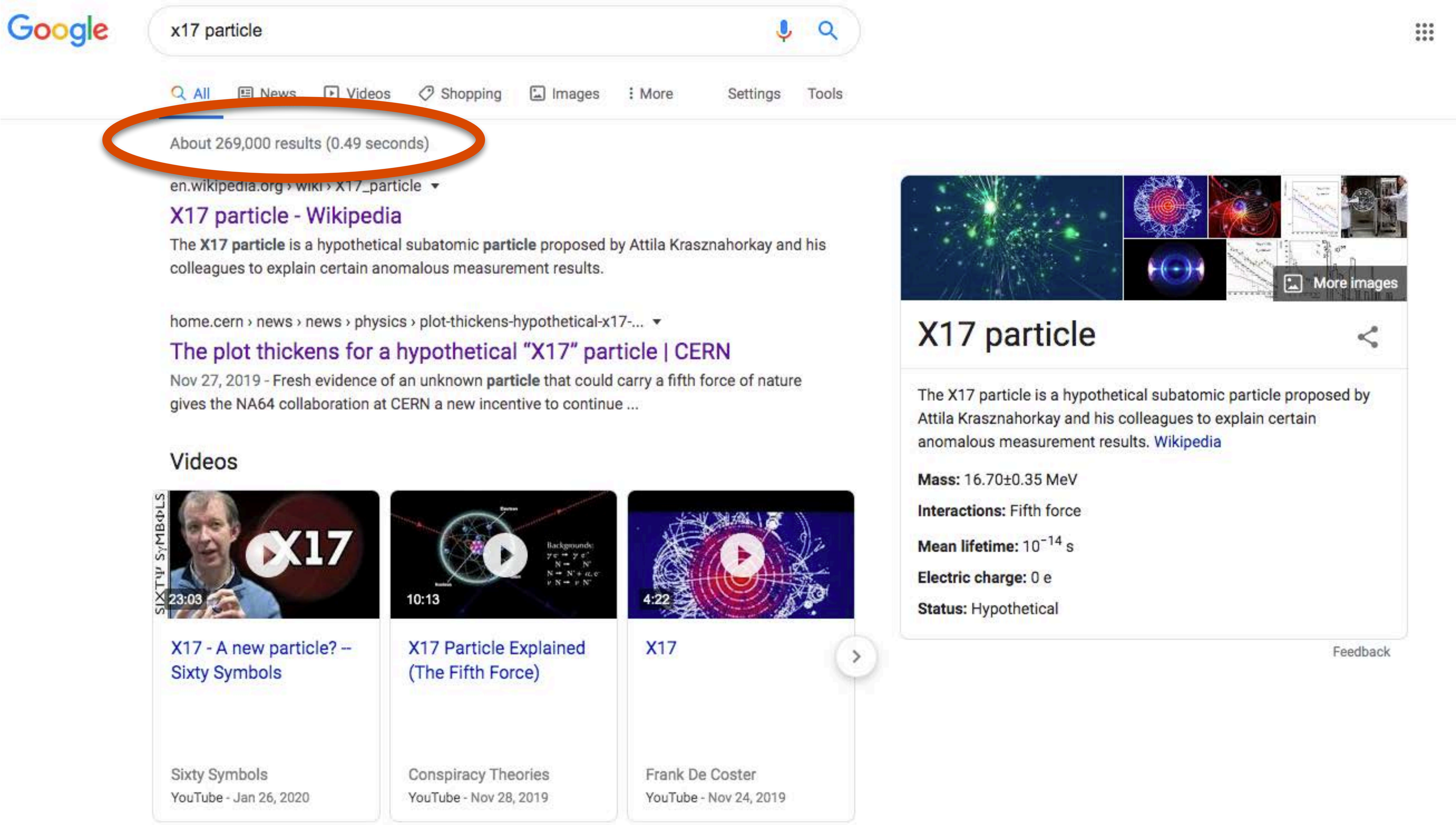
Protophobic Fifth-Force Interpretation of the Observed Anomaly in $^8\mathrm{Be}$ Nuclear Transitions

Jonathan L. Feng, Bartosz Fornal, Iftah Galon, Susan Gardner, Jordan Smolinsky, Tim M. P. Tait, and Philip Tanedo
Phys. Rev. Lett. **117**, 071803 – Published 11 August 2016

ABSTRACT

Recently a 6.8σ anomaly has been reported in the opening angle and invariant mass distributions of e^+e^- pairs produced in $^8\mathrm{Be}$ nuclear transitions. The data are explained by a 17 MeV vector gauge boson X that is produced in the decay of an excited state to the ground state, $^8\mathrm{Be}^* \to {}^8\mathrm{Be}X$, and then decays through $X \to e^+e^-$. The X boson mediates a fifth force with a characteristic range of 12 fm and has millicharged couplings to up and down quarks and electrons, and a proton coupling that is suppressed relative to neutrons. The protophobic X boson may also alleviate the current 3.6σ discrepancy between the predicted and measured values of the muon’s anomalous magnetic moment.

Publicity



x17 particle

About 269,000 results (0.49 seconds)

en.wikipedia.org › wiki › X17_particle

X17 particle - Wikipedia

The **X17 particle** is a hypothetical subatomic **particle** proposed by Attila Krasznahorkay and his colleagues to explain certain anomalous measurement results.

home.cern › news › news › physics › plot-thickens-hypothetical-x17-...

The plot thickens for a hypothetical “X17” particle | CERN

Nov 27, 2019 - Fresh evidence of an unknown **particle** that could carry a fifth force of nature gives the NA64 collaboration at CERN a new incentive to continue ...

Videos

X17 - A new particle? - Sixty Symbols
Sixty Symbols
YouTube - Jan 26, 2020

X17 Particle Explained (The Fifth Force)
Conspiracy Theories
YouTube - Nov 28, 2019

X17
Frank De Coster
YouTube - Nov 24, 2019

X17 particle

The X17 particle is a hypothetical subatomic particle proposed by Attila Krasznahorkay and his colleagues to explain certain anomalous measurement results. Wikipedia

Mass: 16.70±0.35 MeV

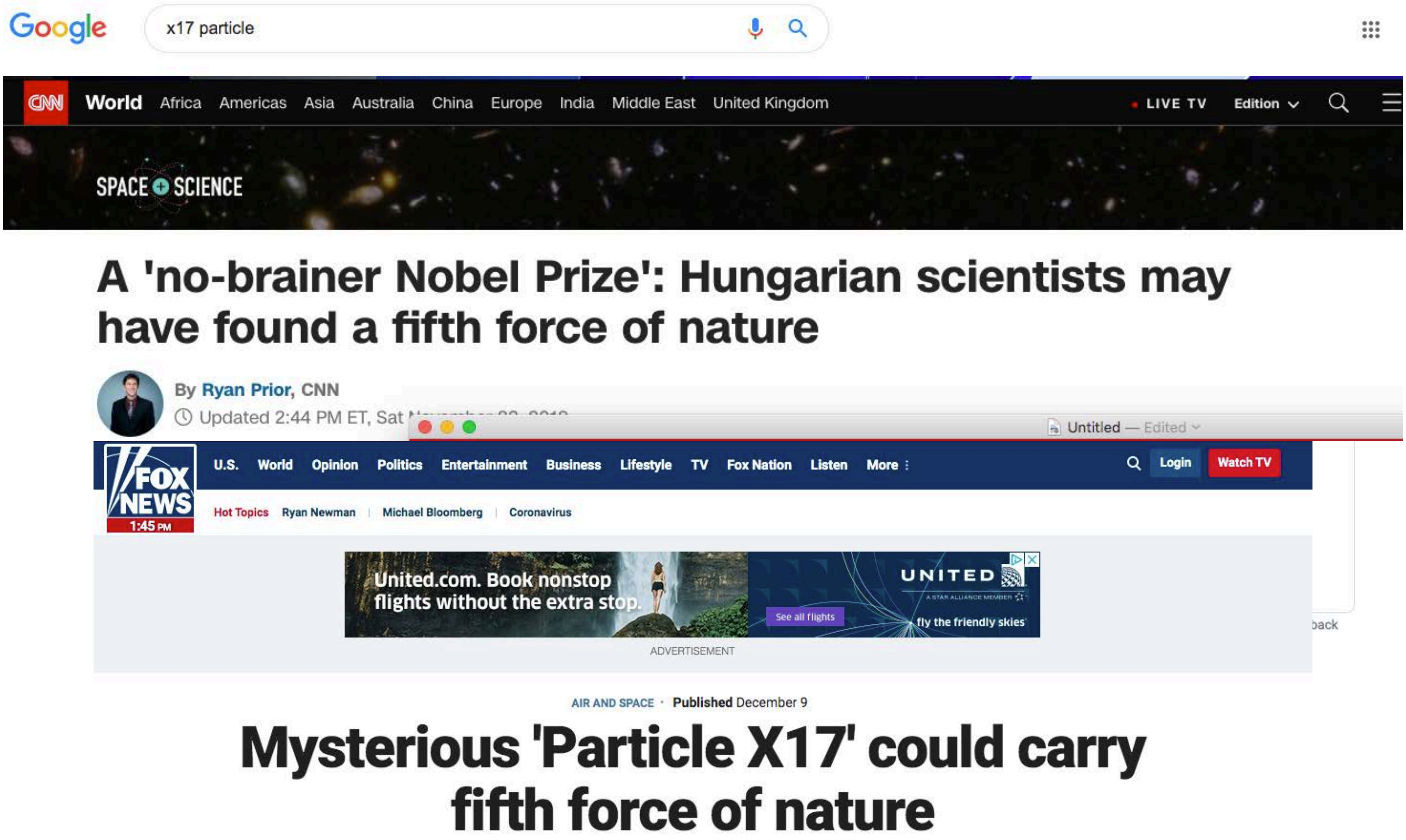
Interactions: Fifth force

Mean lifetime: 10^{-14} s

Electric charge: 0 e

Status: Hypothetical

Publicity



x17 particle

A 'no-brainer Nobel Prize': Hungarian scientists may have found a fifth force of nature

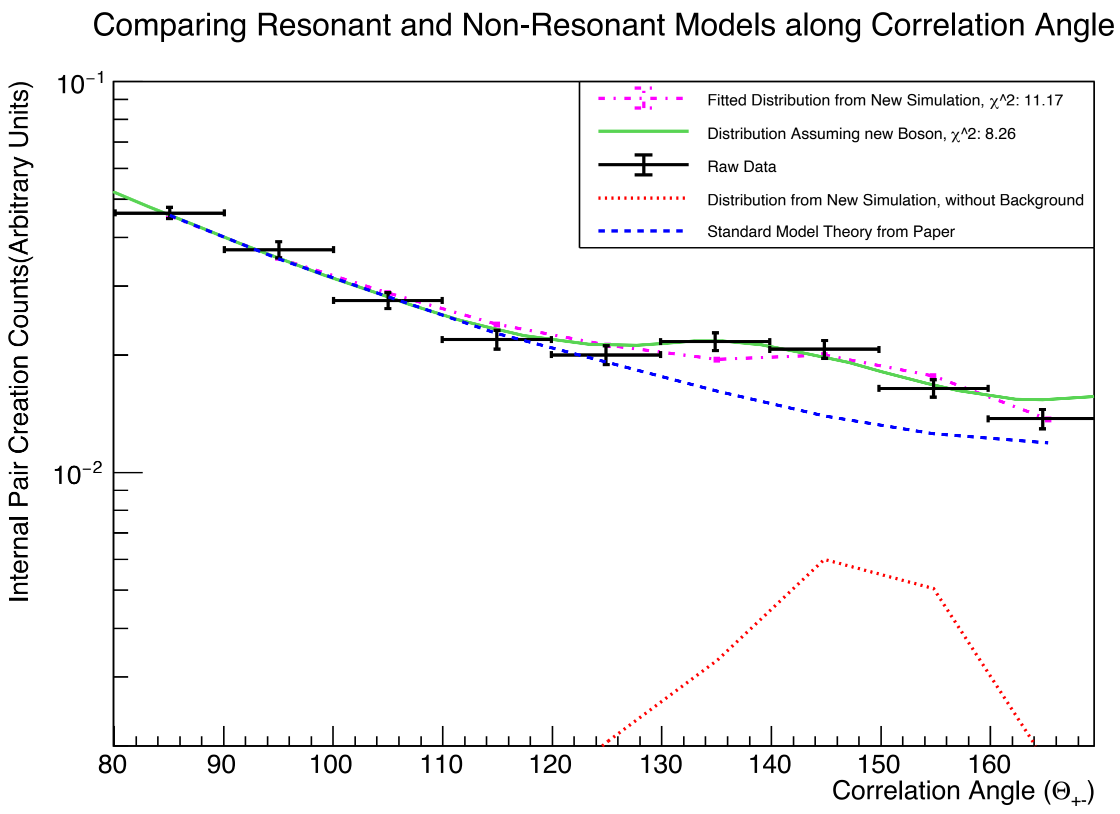
By Ryan Prior, CNN

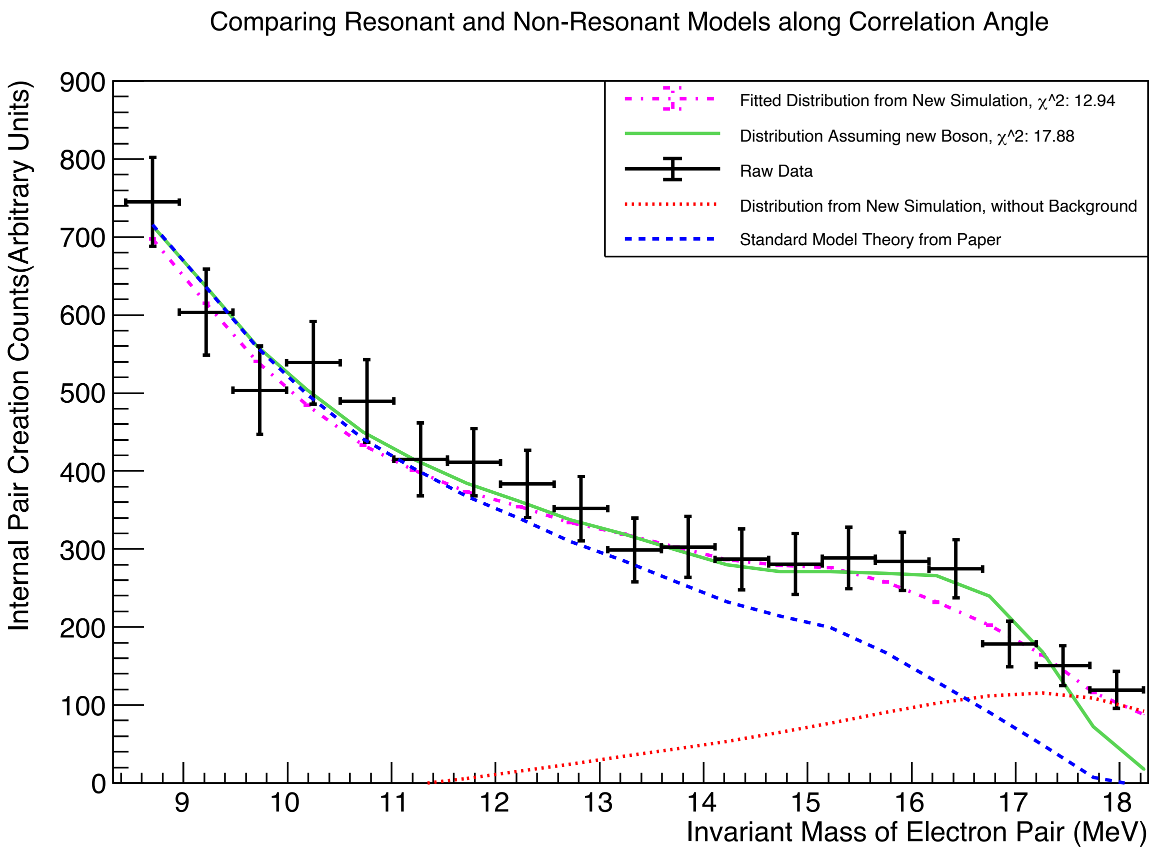
Updated 2:44 PM ET, Sat

AIR AND SPACE · **Published** December 9

Mysterious 'Particle X17' could carry fifth force of nature

First Attempt at a Mundane Explanation



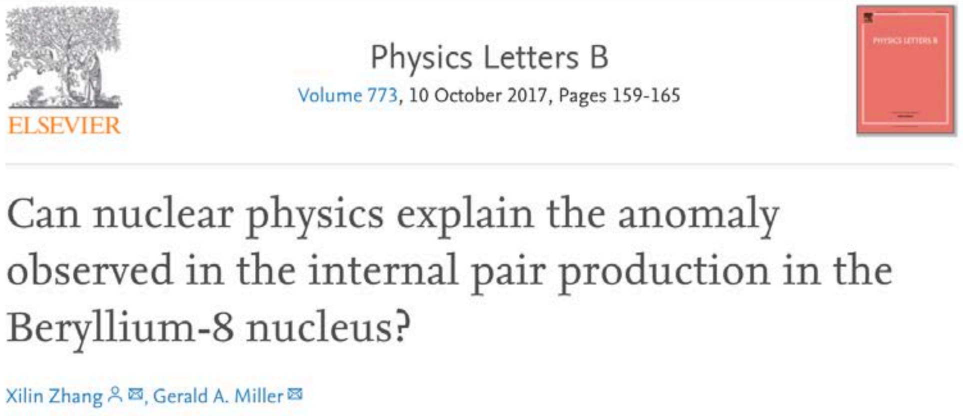


Proof of concept: interference effects could produce a shoulder in the angular distribution; non-uniform detector acceptance and energy asymmetry cut could turn a broad shoulder into a peak.

At the time, had a vague idea of what the “second amplitude” may be.

Considered non-resonant decay ^{8}Be*⟶ ^{4}He ^{4}He e^{+}e^{-} , or two-photon exchange in ^{8}Be*⟶ ^{8}Be e^{+}e^{-}.

Other Efforts to Explain ATOMKI within SM



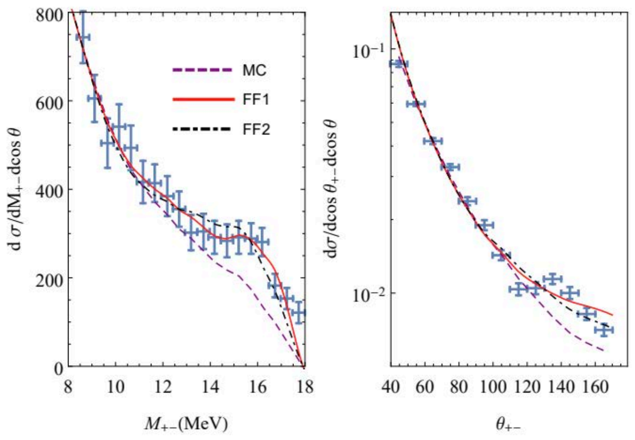
Physics Letters B

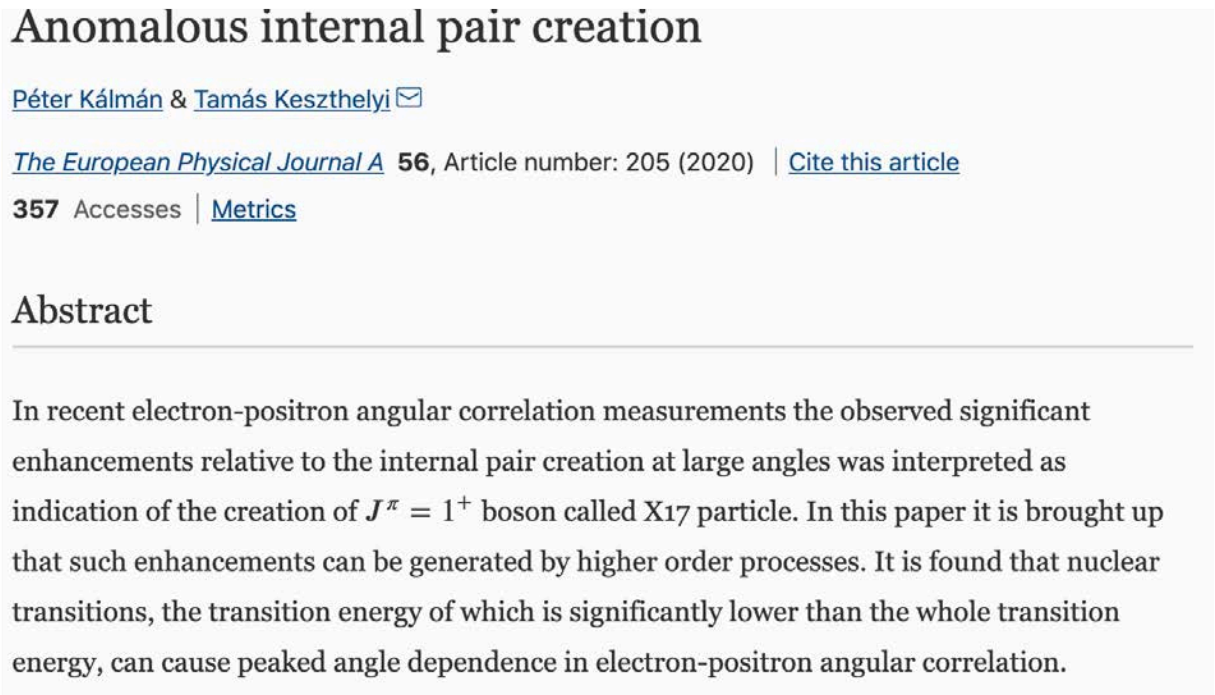
Volume 773, 10 October 2017, Pages 159-165

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

Xilin Zhang, Gerald A. Miller

- Considered interference between multipole amplitudes (not enough to explain data)
- Considered (somewhat extreme) form-factors for the nuclear vertex (success)





Anomalous internal pair creation

Péter Kálmán & Tamás Keszthelyi

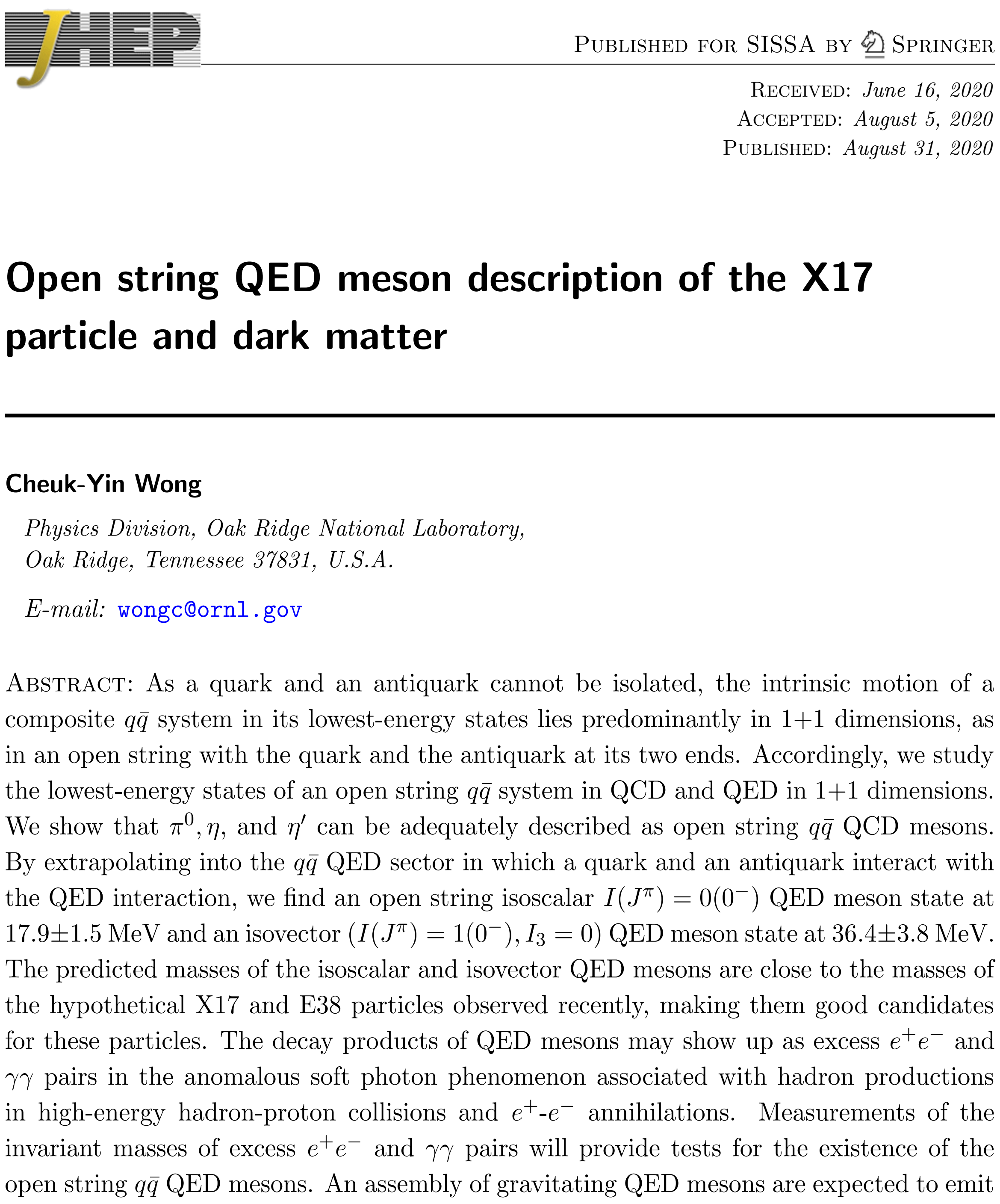
The European Physical Journal A **56**, Article number: 205 (2020) | Cite this article

357 Accesses | Metrics

Abstract

In recent electron-positron angular correlation measurements the observed significant enhancements relative to the internal pair creation at large angles was interpreted as indication of the creation of $J^\pi = 1^+$ boson called X17 particle. In this paper it is brought up that such enhancements can be generated by higher order processes. It is found that nuclear transitions, the transition energy of which is significantly lower than the whole transition energy, can cause peaked angle dependence in electron-positron angular correlation.

Argue that the ATOMKI data could be explained by interference effects in the initial-state



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Open string QED meson description of the X17 particle and dark matter

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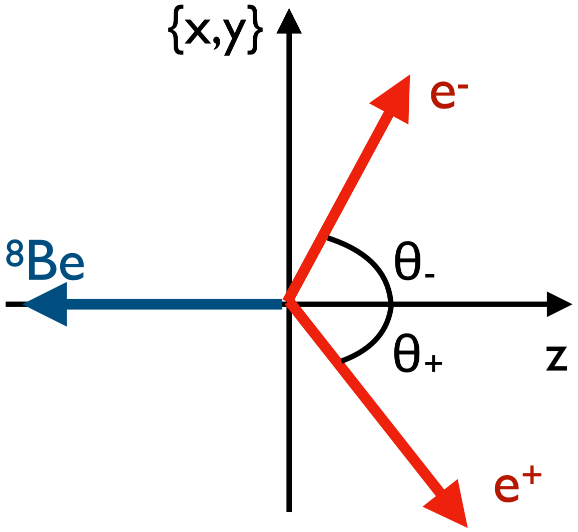
Abstract: As a quark and an antiquark cannot be isolated, the intrinsic motion of a composite $q\bar q$ system in its lowest-energy states lies predominantly in 1+1 dimensions, as in an open string with the quark and the antiquark at its two ends. Accordingly, we study the lowest-energy states of an open string $q\bar q$ system in QCD and QED in 1+1 dimensions. We show that π^0, η, and η' can be adequately described as open string $q\bar q$ QCD mesons. By extrapolating into the $q\bar q$ QED sector in which a quark and an antiquark interact with the QED interaction, we find an open string isoscalar $I(J^\pi) = 0(0^-)$ QED meson state at 17.9±1.5 MeV and an isovector $(I(J^\pi) = 1(0^-), I_3 = 0)$ QED meson state at 36.4±3.8 MeV. The predicted masses of the isoscalar and isovector QED mesons are close to the masses of the hypothetical X17 and E38 particles observed recently, making them good candidates for these particles. The decay products of QED mesons may show up as excess e^+e^- and $\gamma\gamma$ pairs in the anomalous soft photon phenomenon associated with hadron productions in high-energy hadron-proton collisions and e^+-e^- annihilations. Measurements of the invariant masses of excess e^+e^- and $\gamma\gamma$ pairs will provide tests for the existence of the open string $q\bar q$ QED mesons. An assembly of gravitating QED mesons are expected to emit

Postulate that X17 is a QED "bound state" of a $q\bar q$ pair

Next-to-the-Leading-Order (NLO) QED corrections in ^{8}Be(18.15) $\longrightarrow$ ^{8}Be $e^{+}e^{-}$ decay

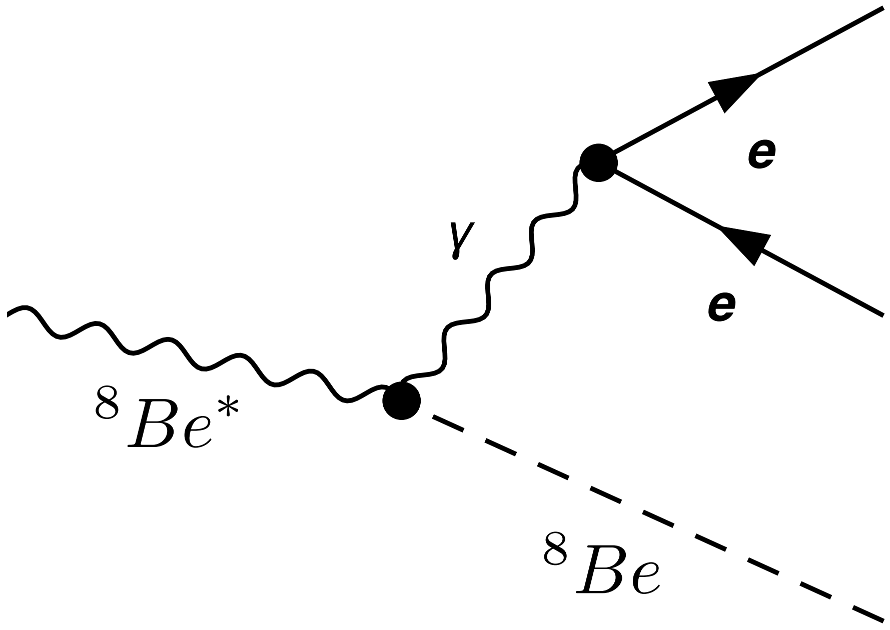
- Consider doubly differential decay rate in the rest frame of ^{8}Be(18.15) ≡ ^{8}Be*:

$$\frac{d^2\Gamma}{d\theta_+ d\theta_-} \to \left(\underbrace{|M_{LO}|^2}_{\text{Leading-Order}} + \underbrace{2\Re\left[M_{LO} M^*_{NLO}\right]}_{\text{Interference term between LO and NLO orders}} \right) \Phi$$



- Φ is phase space for the case of three body decay.

- Leading-Order (LO):



- Spin 1⟶0 transition is described by the Lagrangian:

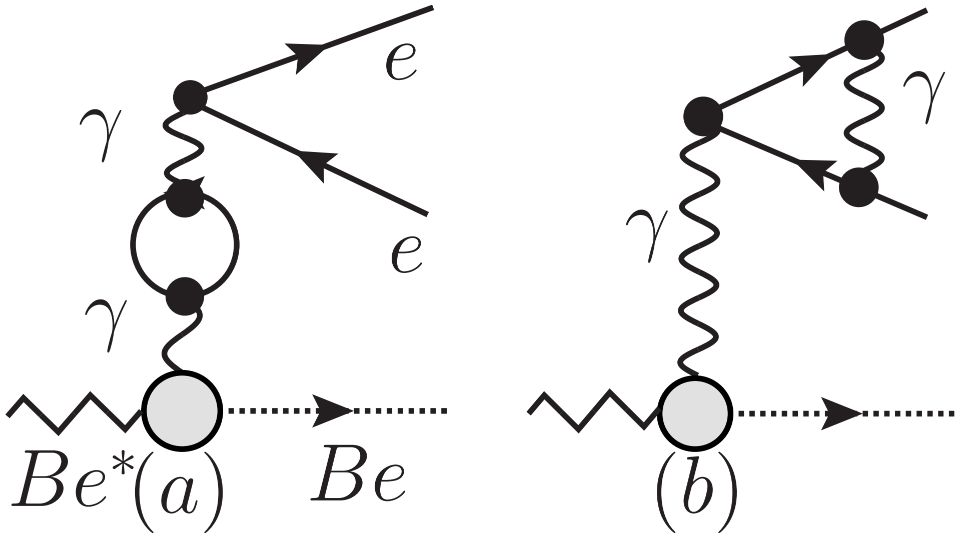
$$L^{1\to 0} = \frac{Ze}{\Lambda}\epsilon^{\mu\nu\alpha\beta} B^*_{\mu\nu} F_{\alpha\beta} B$$

$$B^*_{\mu\nu} = \partial_\mu B^*_\nu - \partial_\nu B^*_\mu$$

$$F_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$$

NLO QED Contribution: Self-Energies and Vertex Corrections

- At the NLO order, including only interaction term for spin 1⟶0 transition, we can form the following topologies:



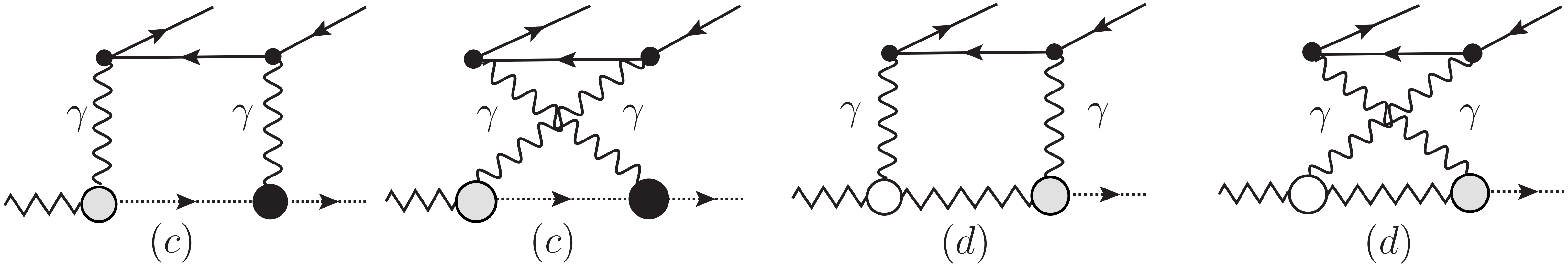
- Type (a) graphs correspond to self-energies. Hadronic vacuum polarization has been calculated with effective light quark masses to fit e^+e^- to hadrons cross section.

- Type (b) graphs correspond to electron current vertex corrections. We use soft-photon approximation to treat infrared divergencies.

- Both (a) and (b) graphs are ultraviolet divergent. We employ on-shell renormalization and observe analytical cancellation of divergent poles.

NLO QED Contribution: Boxes

- Including additional interaction terms for spin 1⟶1 and 0 ⟶ 0 transitions, we get:



$$L^{1\to 1} = -ieZ\left[B^{*\mu\nu}B^{*\dagger}_{\mu}A_{\nu} - B^{*\mu\nu\dagger}B^{*}_{\mu}A_{\nu} + B^{*}_{\mu}B^{*\dagger}_{\nu}F^{\mu\nu}\right]$$

$$L^{0\to 0} = -ieZ\left[B\partial_{\mu}B^{\dagger} - \partial_{\mu}BB^{\dagger}\right]A^{\mu}$$

- Type (c) graphs correspond to boxes and crossed boxes with ^{8}Be state in the loop.

- Type (d) graphs correspond to boxes and crossed boxes with ^{8}Be* state in the loop.

- Both (c) and (d) graphs are infrared divergent. We take into account only infrared-finite part of the NLO interference term.

Phase Space

- Reduce three-body decay phase space, we get the following:

$$\Gamma = \frac{1}{(2\pi)^3}\frac{1}{8m_{Be^*}}\int dE_+ \int dE_- \int d\theta_\pm \sin\theta_\pm \frac{p_- p_+}{E_{Be}} |M_{fi}|^2 \delta[E_{Be^*} - \sum_{i=1}^{3} E_i]$$

$$\downarrow$$

$$\theta_\pm = \theta_+ + \theta_-$$

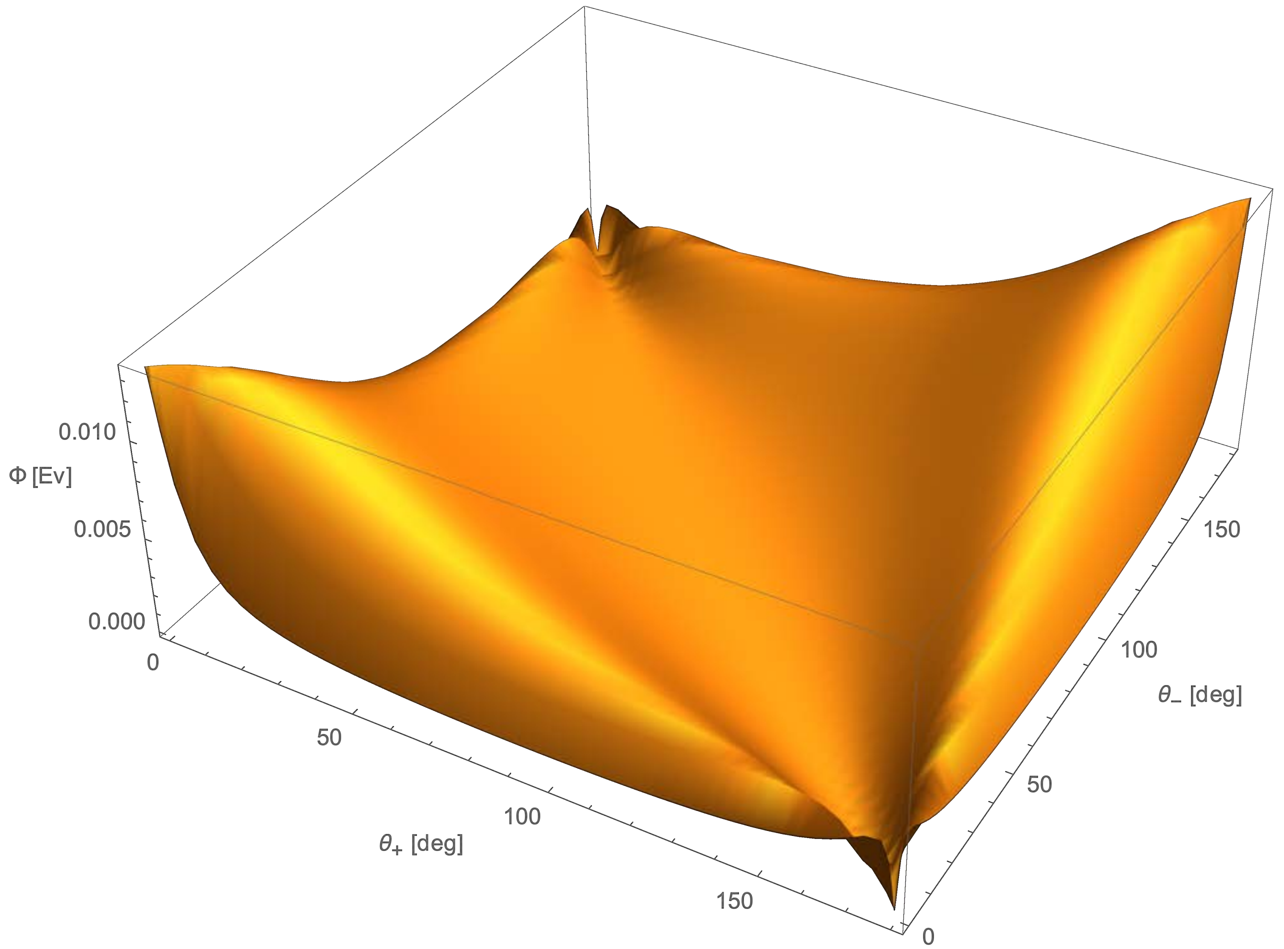
- After integration over positron’s energy:

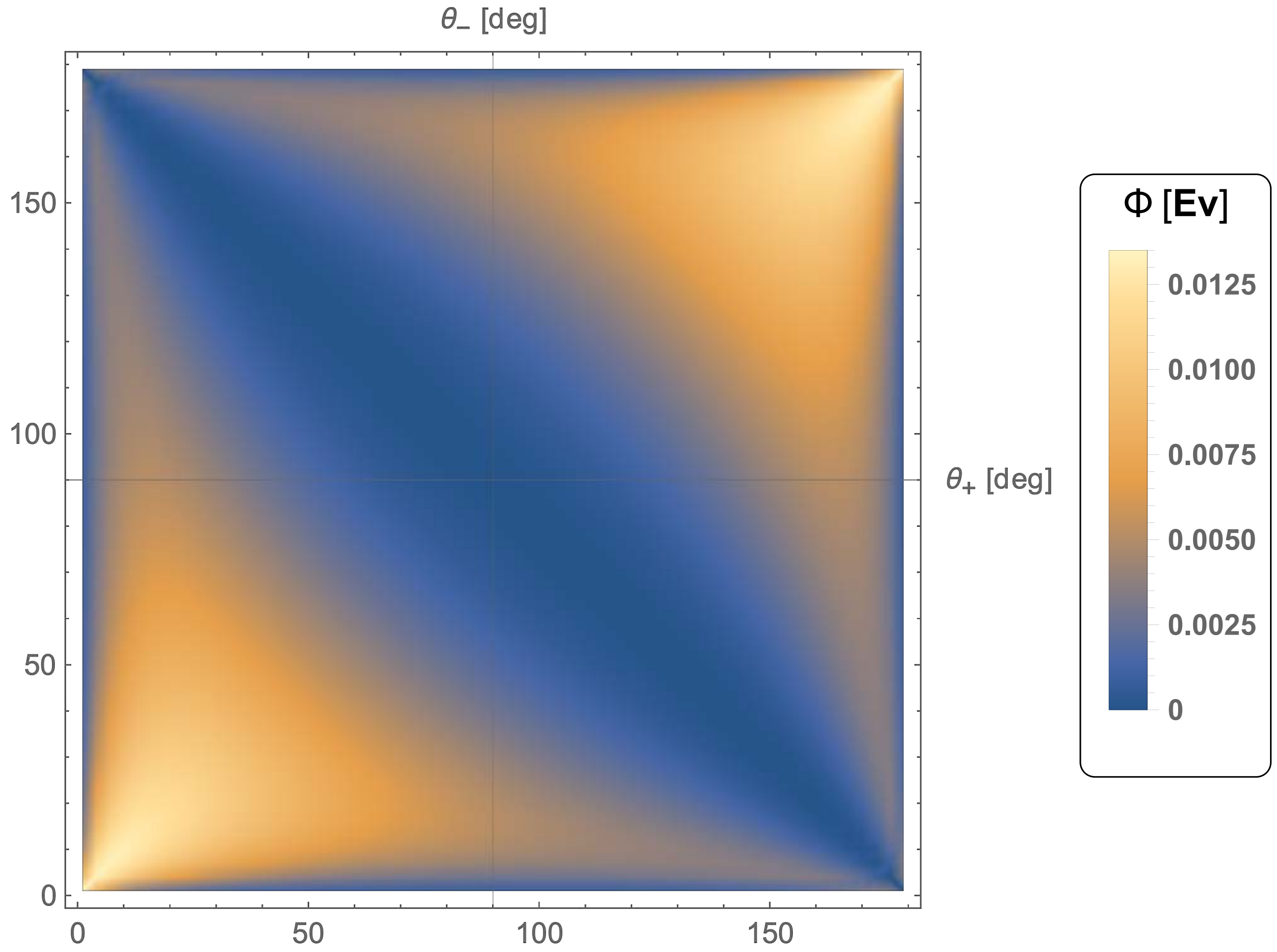
$$\Gamma = \frac{1}{(2\pi)^3}\frac{1}{8m_{Be^*}}\int dE_- \int d\theta_\pm \sin\theta_\pm \frac{E_-^2}{E_{Be}} \frac{\sin\theta_-}{\sin\theta_+} |M_{fi}|^2$$

- After transformation from $dE_- d\theta_\pm$ to $d\theta_+ d\theta_-$, we obtain:

$$\frac{d^2\Gamma}{d\theta_+ d\theta_-} = \frac{J}{(2\pi)^3}\frac{\sin\theta_\pm}{8m_{Be^*}}\frac{E_-^2}{E_{Be}}\frac{\sin\theta_-}{\sin\theta_+}|M_{fi}|^2$$

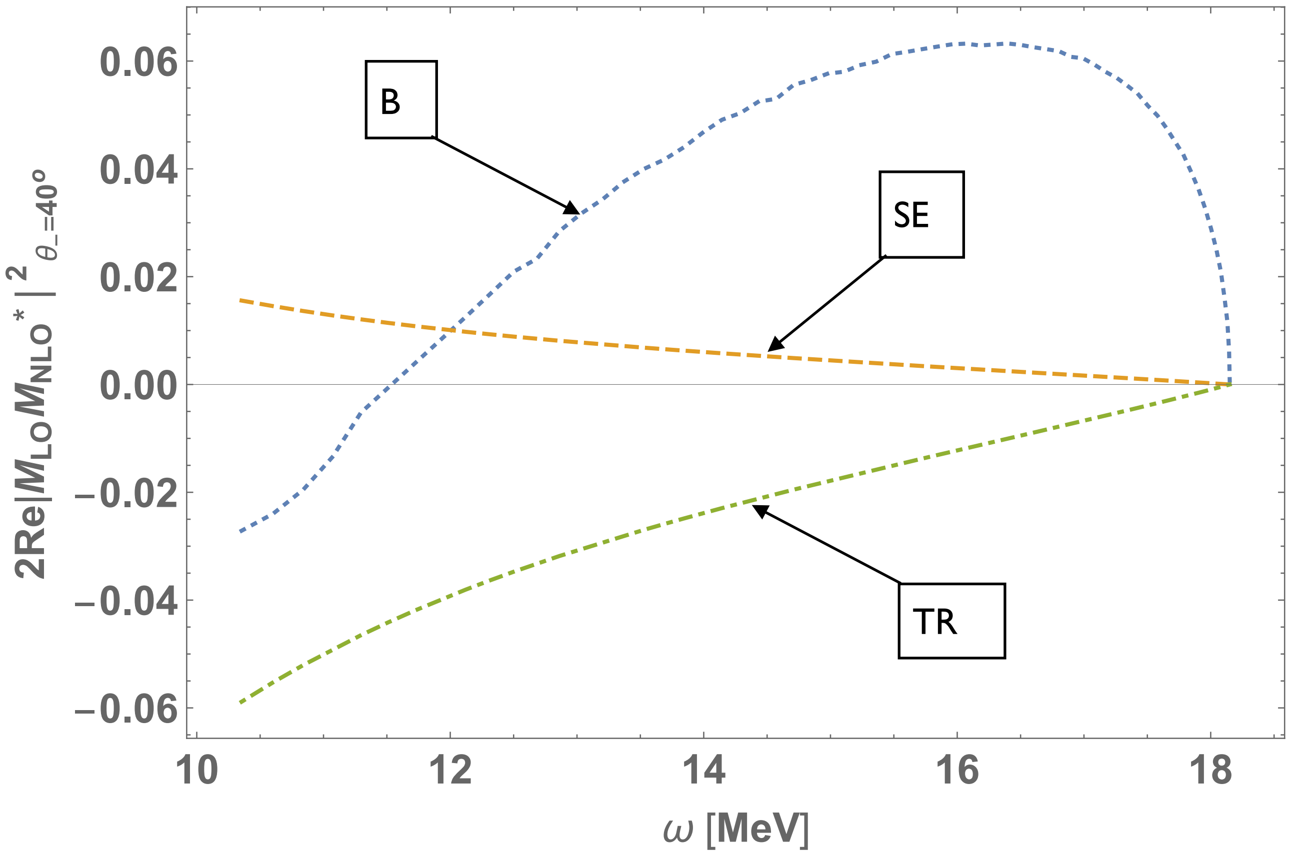
- Jacobian: $J = \frac{\partial E_-}{\partial\theta_+} - \frac{\partial E_-}{\partial\theta_-}$

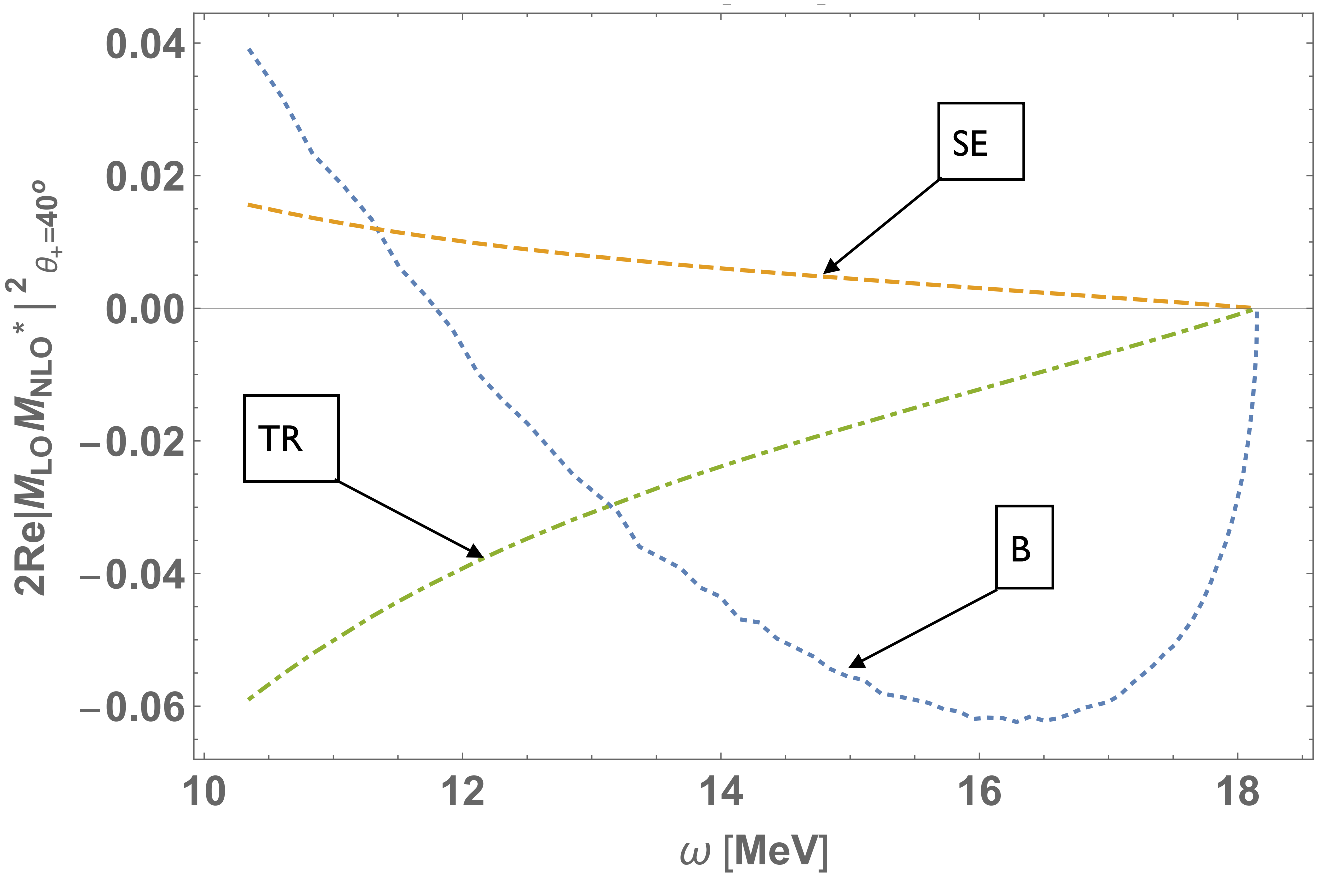




Interference Term: 2Re[$M_{LO}M_{NLO}$]

- Contributions coming from self-energies (SE), vertex corrections (VC) and boxes (B):



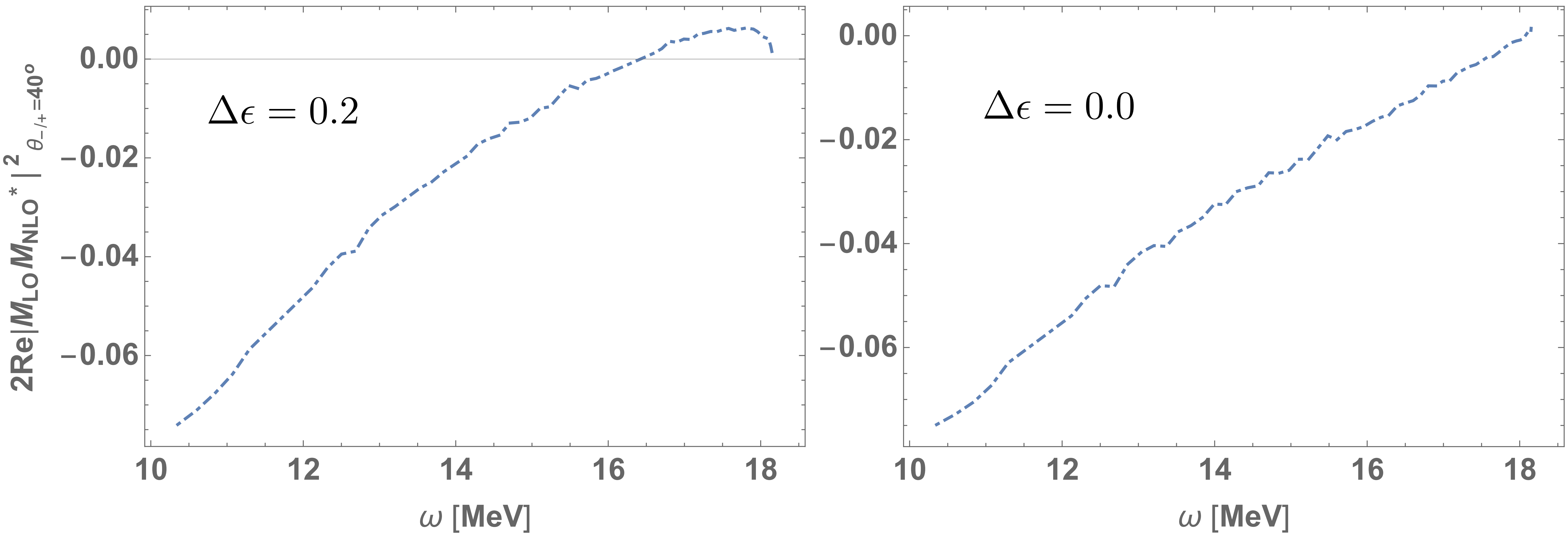


- Self-energies and vertex corrections are completely symmetrical under e^-/e^+ flip.

- Contribution from boxes cancels out at large extend when both electron and positron events are combined, but does not go to zero.

Interference Term: 2Re[$M_{LO}M_{NLO}$]

- If we assume difference in efficiency between e^- and e^+ signal, for example at 20%, the summed correction shows bump-like behaviour (left plot). Right plot shows no difference in efficiency.



- Here, for example, we fix either electron or positron angle to 40^0. All the possible angular combinations are included in the final simulation.

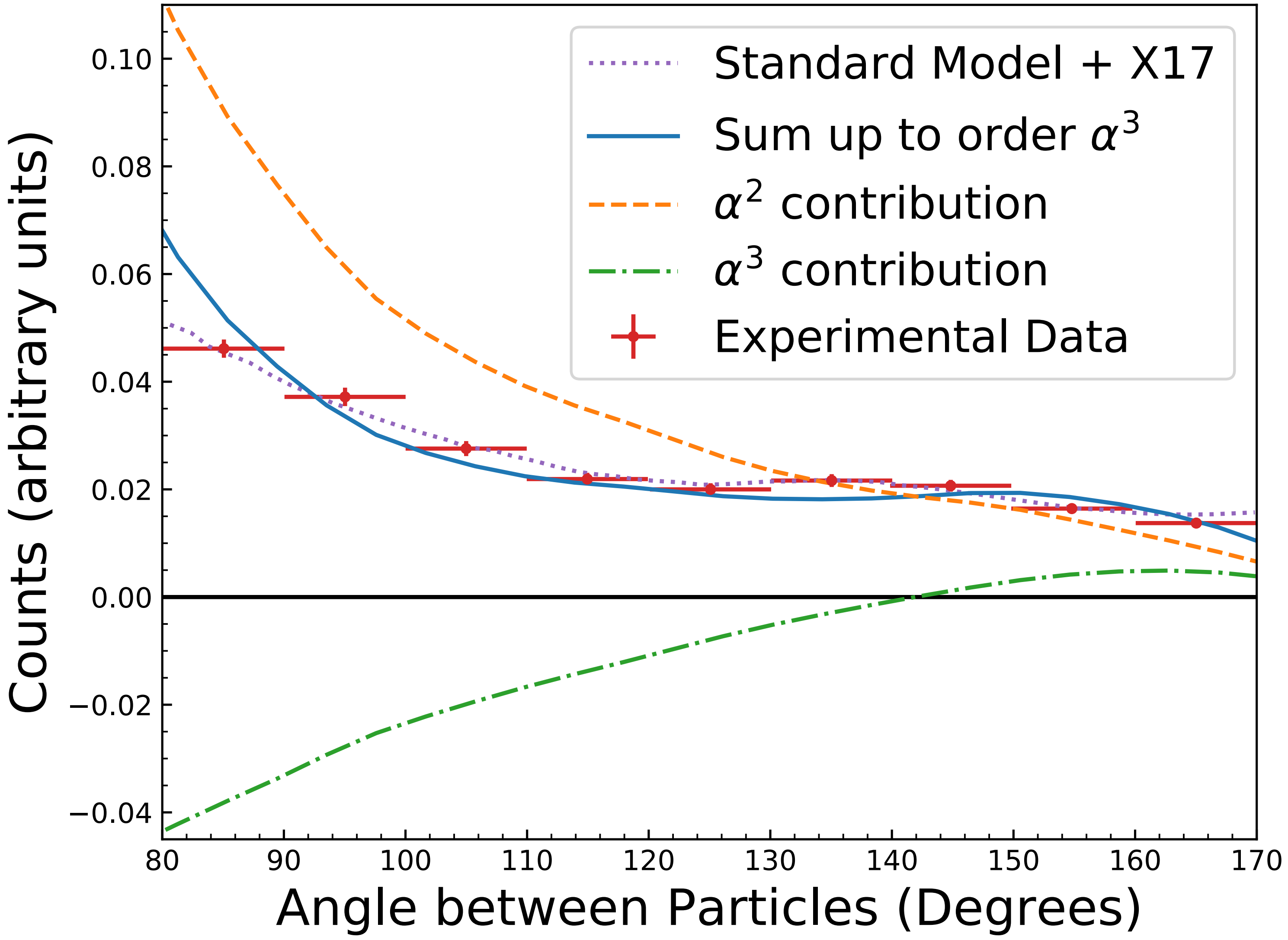
- For the MC simulations, look-up tables are compiled including tree level, interference term and phase space for three body decay.

Simulation Results: Angular Distribution

$$f\,(\text{Angle}) = \mathcal{N}\left(\Gamma\,(\text{tree}) + \epsilon\Gamma\left(\alpha^3\ \text{term}\right)\right)$$

Final result fits qualitatively well.

- $\chi^2 = 38$
- Removing lowest e^+e^- separation bin, we have $\chi^2 = 11$
- Fit from ATOMKI paper has $\chi^2 = 9.6$

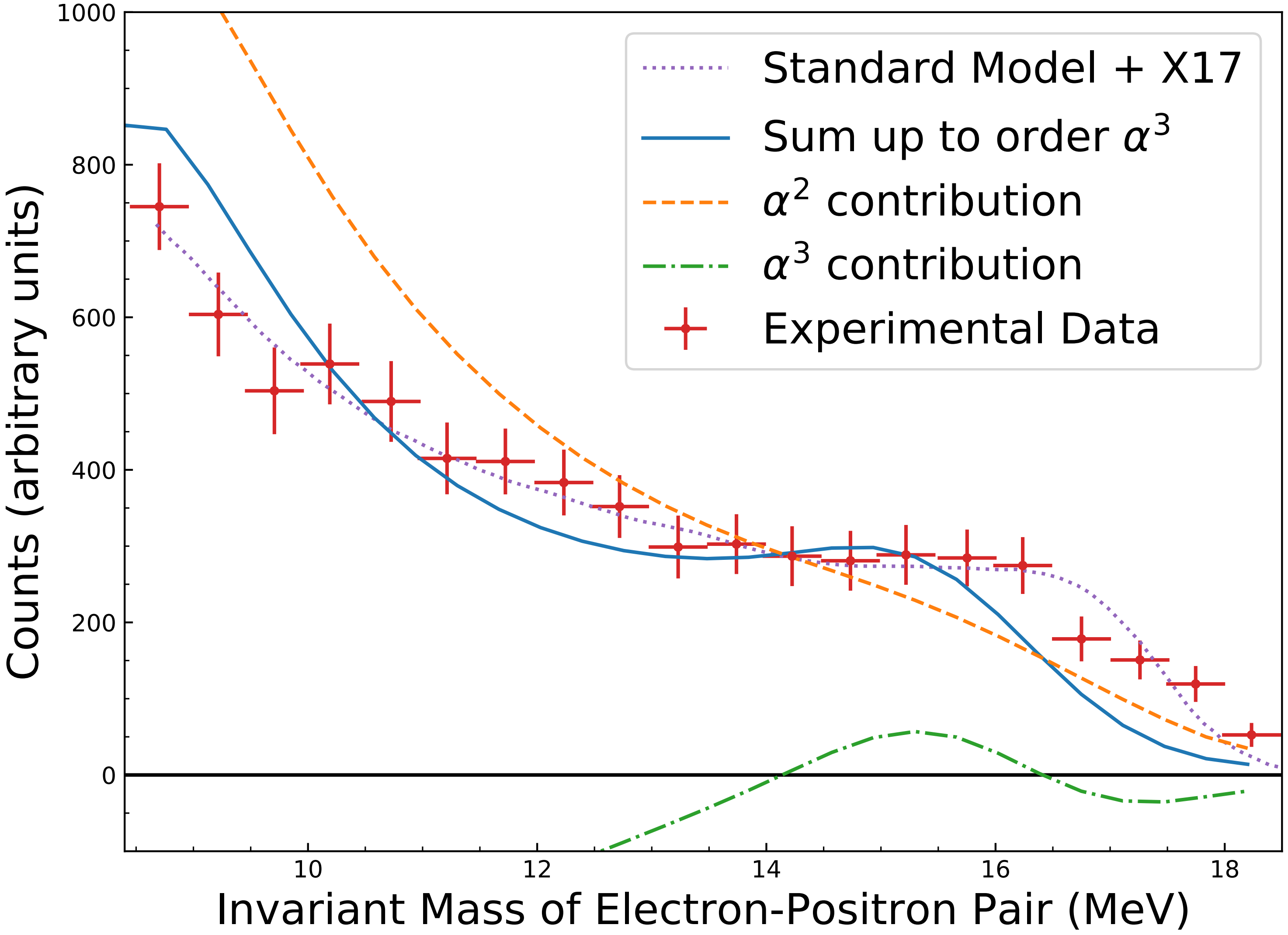


Simulation Results: Invariant Mass

$$f\,(\mathsf{Angle}) = \mathcal{N}\left(\Gamma\,(\mathsf{tree}) + \epsilon\Gamma\left(\alpha^3\ \mathsf{term}\right)\right)$$

Can reproduce a bump structure, though positioning is slightly off, skewing χ^2

- $\chi^2 = 72$
- Removing lowest 3 invariant mass bins, we have $\chi^2 = 56$
- Fit from ATOMKI paper has $\chi^2 = 20$



ATOMKI boson under fire

Particle physicists in Canada and the US have added a new twist to the tale of the ATOMKI anomaly – a reported 6.8σ excess of e^+e^- pairs created during nuclear transitions of excited ^{8}Be nuclei to their ground state spotted by a team in Hungary in 2015, and for which a new 17 MeV gauge boson ("X17") has been proposed as an explanation (*CERN Courier* January/February 2019 p7). In a preprint posted on 3 February, Aleksandrs Aleksejevs (Memorial University of Newfoundland) and co-workers pour cold water on this interpretation, arguing that the anomaly can be explained by adding the full set of second-order corrections and the interference terms to the Born-level decay amplitudes considered by the ATOMKI team (arXiv:2102.01127).

X17's proponents remain undeterred. "The authors appear to let the size of the higher-order effects be a free parameter and find that by assuming they are much larger than expected, one could produce a bump at 15 MeV, not the 17 MeV observed. So it's an interesting step, but there's still more work to be done," says Jonathan Feng of UC Irvine. Meanwhile, spokesperson for the ATOMKI experiment Attila Krasznahorkay protests that the effect has since also been seen in other nuclear species: "Our results for ^{4}He and ^{12}C would not be affected by any interference phenomenon, while we see the X17 anomaly in both of them, so we continue our experiments, with new results soon to be published."

antiprotons, Fermilab an impressive 15 ng, and 2 ng of positrons had been produced at DESY. But the total annihilation energy obtainable using this ersatz antimatter is insufficient to boil cup of tea.

Media corner

"At Brookhaven, I was always sitting on the edge of my chair [during unblinding], and I think I will be here, too."

Experimentalist **Lee Roberts** of Boston University quoted in *Science* (27 January) about the hotly anticipated muon g-2 measurement from Fermilab.

"That statement made me furious, so I started studying physics."

A 1997 quote by the late Nobel laureate **Masatoshi Koshiba**, on how a professor telling him that he cannot study physics made him take it up in the first place, has resurfaced after the 94 year-old neutrino pioneer's passing in November (American Institute of Physics).

"I could not be more excited about the new supercollider!"

Elon Musk on Twitter (2 November) interacting with Fermilab director Nigel Lockyer on the subject of a future circular collider.

"Today, Jane Street's source code is 25M lines long, about half as much as the Large Hadron Collider uses."

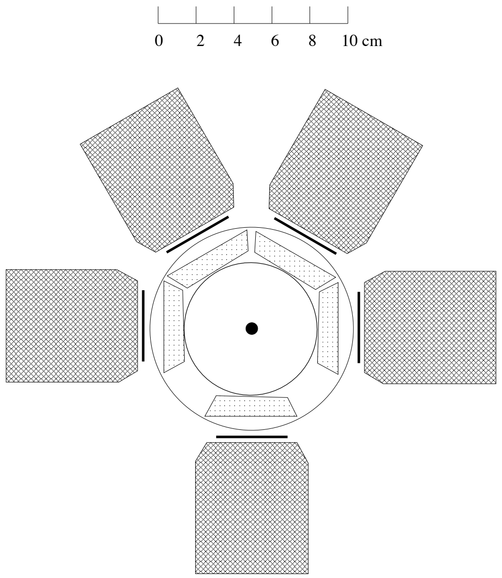
The Financial Times (28 January) channels CERN to communicate the complexity of the algorithms used by quantitative trading firm Jane Street.

Conclusions

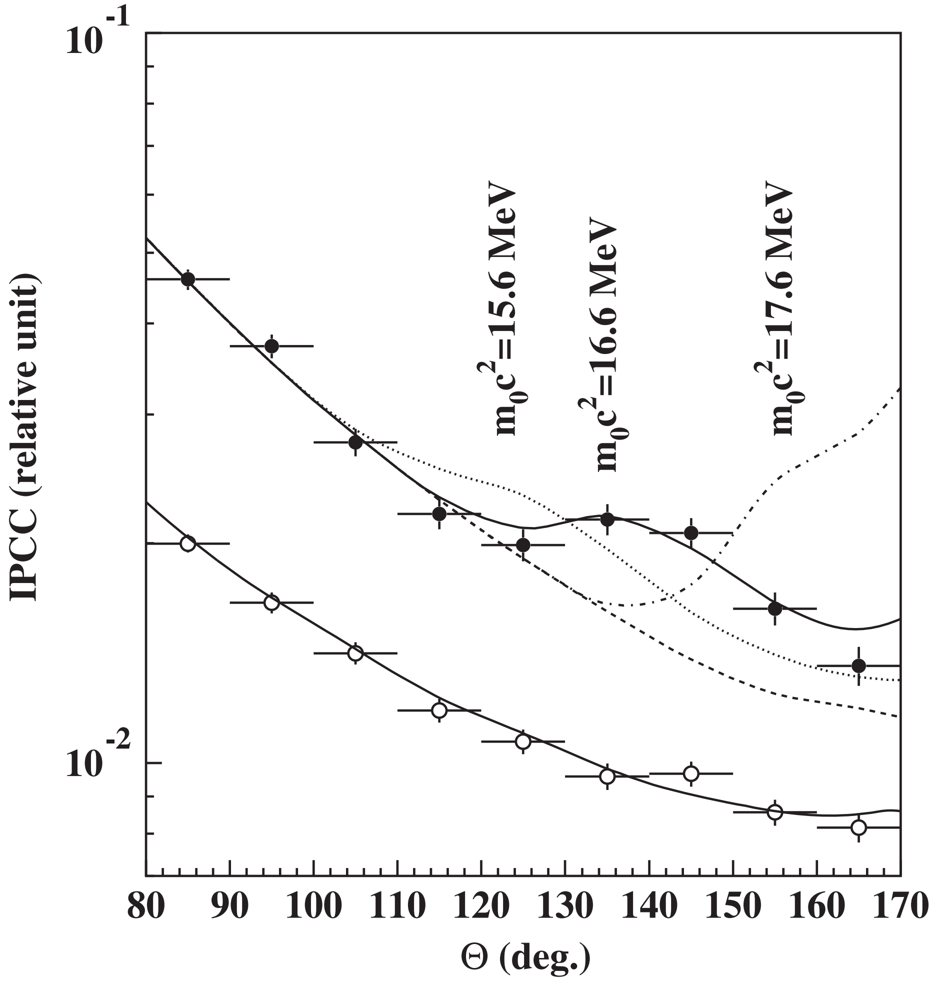
- Resonant decay processes may not be needed to resolve the anomaly
  - Loop order effects
  - Detector bias
- Interest in future experiments testing this parameter space, possibly:
  - Focus on invariant mass resolution
  - Tag initial nuclear state to catch interference
  - Show effects from different or reduced detector bias

Extra Slides

Let’s Examine the Experiment Closely



Schematic of the ATOMKI spectrometer [NIMA **808**, 21(2016) , arXiv:1504.00489]



- Reaction: ^{7}Li(p,e$^+$e$^-$)^{8}Be
- 1.03 MeV proton beam on ^{7}Li target
- Populates 18.15 MeV excited 1^+ state of ^{8}Be (selected by a coarse cut on $E_+ + E_-$)
- Followed by ^{8}Be*$\longrightarrow$ ^{8}Be e$^+$e$^-$ IPC decay
- Experiment detects e$^+$e$^-$ at ~90^o to beamline in a “pair spectrometer” consisting of MWPC planes and ΔE-E plastic scintillators
- No magnetic field, no attempt to identify e$^+$/e$^-$ event by event
- Different resolution/efficiency/calibration for e$^+$ and e$^-$ (unclear if taken into account)
- Decent angular resolution, poor energy (and invariant mass) resolution
- Primary observable: e$^+$e$^-$ opening angle