X17 discovery potential from $\gamma d \to e^+ e^- p n$ with neutron tagging

Cornelis J.G. Mommers & Marc Vanderhaeghen
Johannes Gutenberg-Universität Mainz

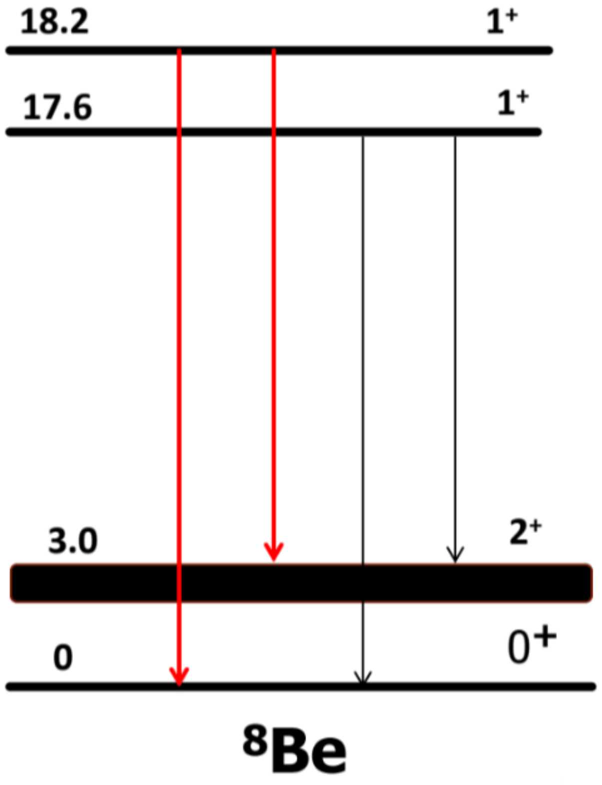
arXiv:2307.02181 [hep-ph]

Outline

1. What is X17?
2. Neutron tagging at MESA
3. X17 signal and QED background
4. Outlook
5. Questions

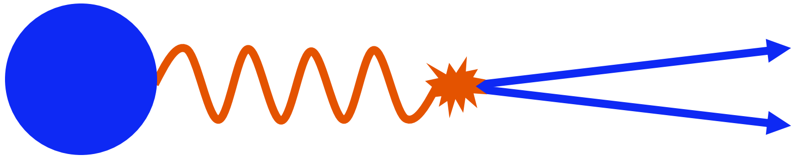
What is X17?

- New particle conjectured to explain ATOMKI anomaly in $^7Li(p,\gamma)^8Be$ with 1^+ state of $^8Be(18.15)$



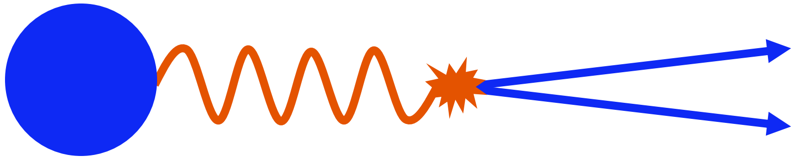
What is X17?

- New particle conjectured to explain ATOMKI anomaly in ^{7}Li(p,γ)^{8}Be with 1^{+} state of ^{8}Be(18.15)

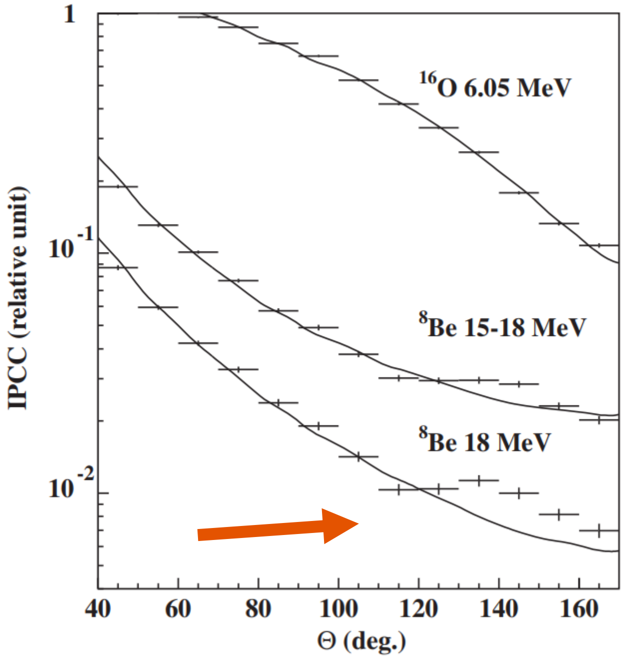


What is X17?

- New particle conjectured to explain ATOMKI anomaly in ^{7}Li(p,γ)^{8}Be with 1^+ state of ^{8}Be(18.15)

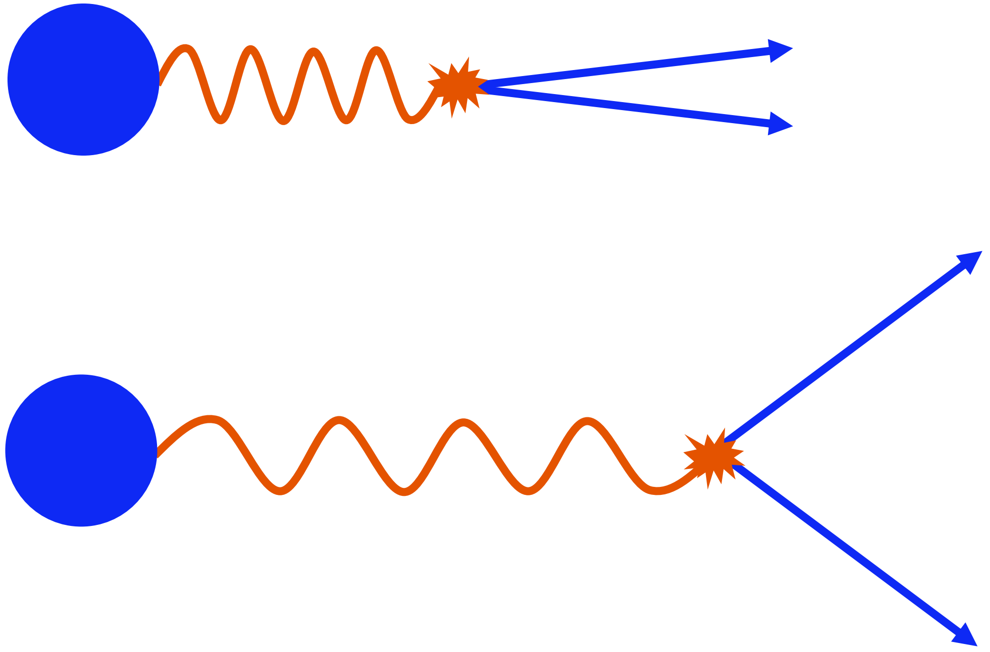


Phys. Rev. Lett. 116, 042501 (2016)

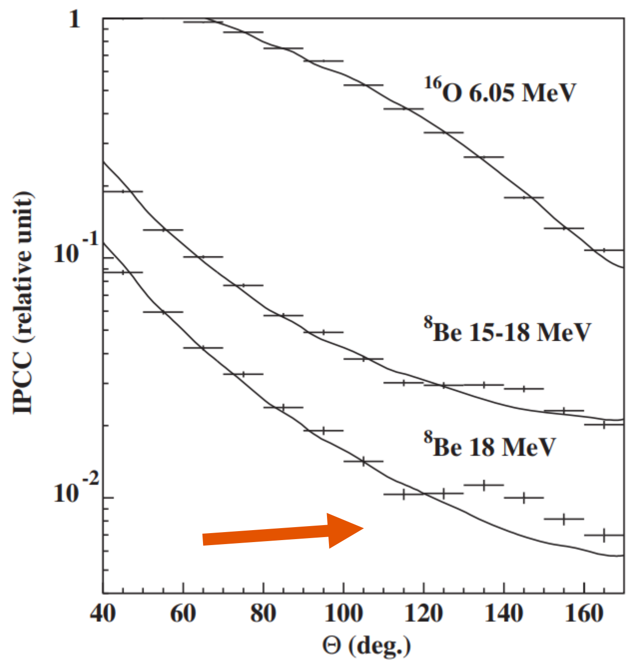


What is X17?

- New particle conjectured to explain ATOMKI anomaly in $^7Li(p,\gamma)^8Be$ with 1^+ state of $^8Be(18.15)$



Phys. Rev. Lett. 116, 042501 (2016)



Continued interest...

PRL **116,** 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

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

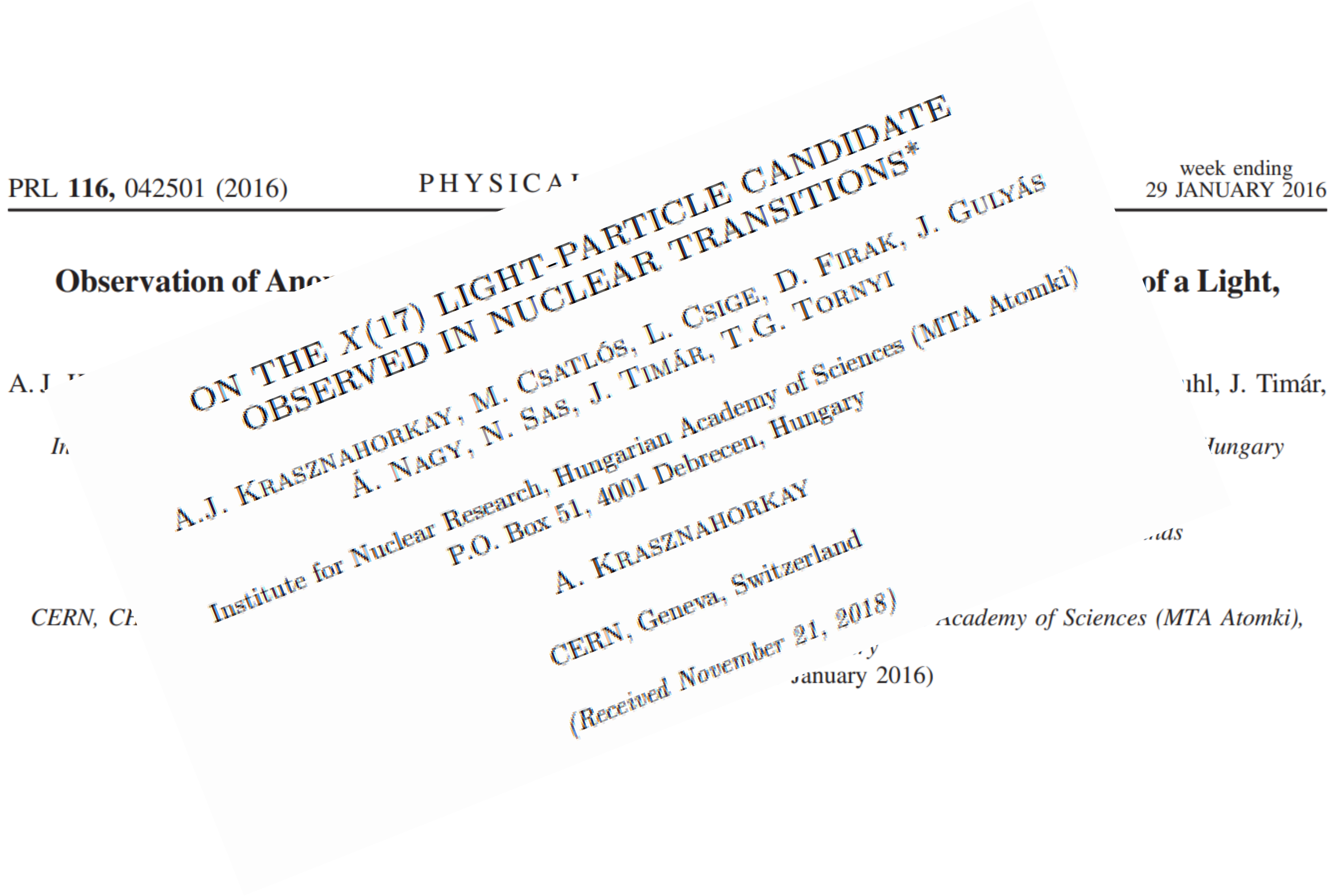
A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár, T. G. Tornyi, and Zs. Vajta
Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki), P.O. Box 51, H-4001 Debrecen, Hungary

T. J. Ketel
Nikhef National Institute for Subatomic Physics, Science Park 105, 1098 XG Amsterdam, Netherlands

A. Krasznahorkay
CERN, CH-1211 Geneva 23, Switzerland and Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki), P.O. Box 51, H-4001 Debrecen, Hungary

(Received 7 April 2015; published 26 January 2016)

Continued interest...


PRL 116, 042501 (2016) PHYSICA

week ending
29 JANUARY 2016

Observation of Ano ... of a Light,

A. J ... uhl, J. Timár,

In ... Iungary

... nds

CERN, Ch ... Academy of Sciences (MTA Atomki),

... y

January 2016)

ON THE X(17) LIGHT-PARTICLE CANDIDATE OBSERVED IN NUCLEAR TRANSITIONS*

A.J. KRASZNAHORKAY, M. CSATLÓS, L. CSIGE, D. FIRAK, J. GULYÁS
Á. NAGY, N. SAS, J. TIMÁR, T.G. TORNYI

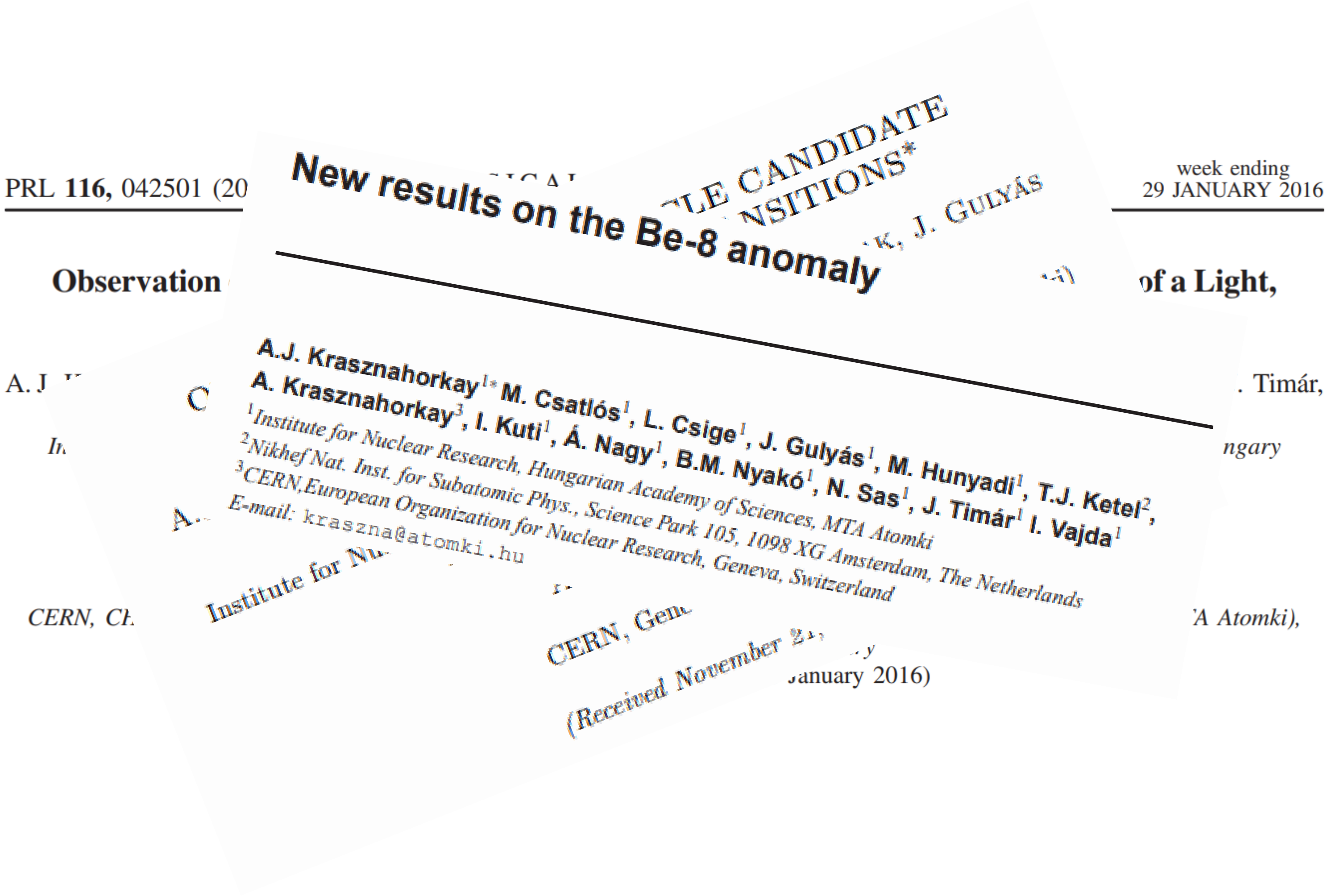
Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki)
P.O. Box 51, 4001 Debrecen, Hungary

A. KRASZNAHORKAY

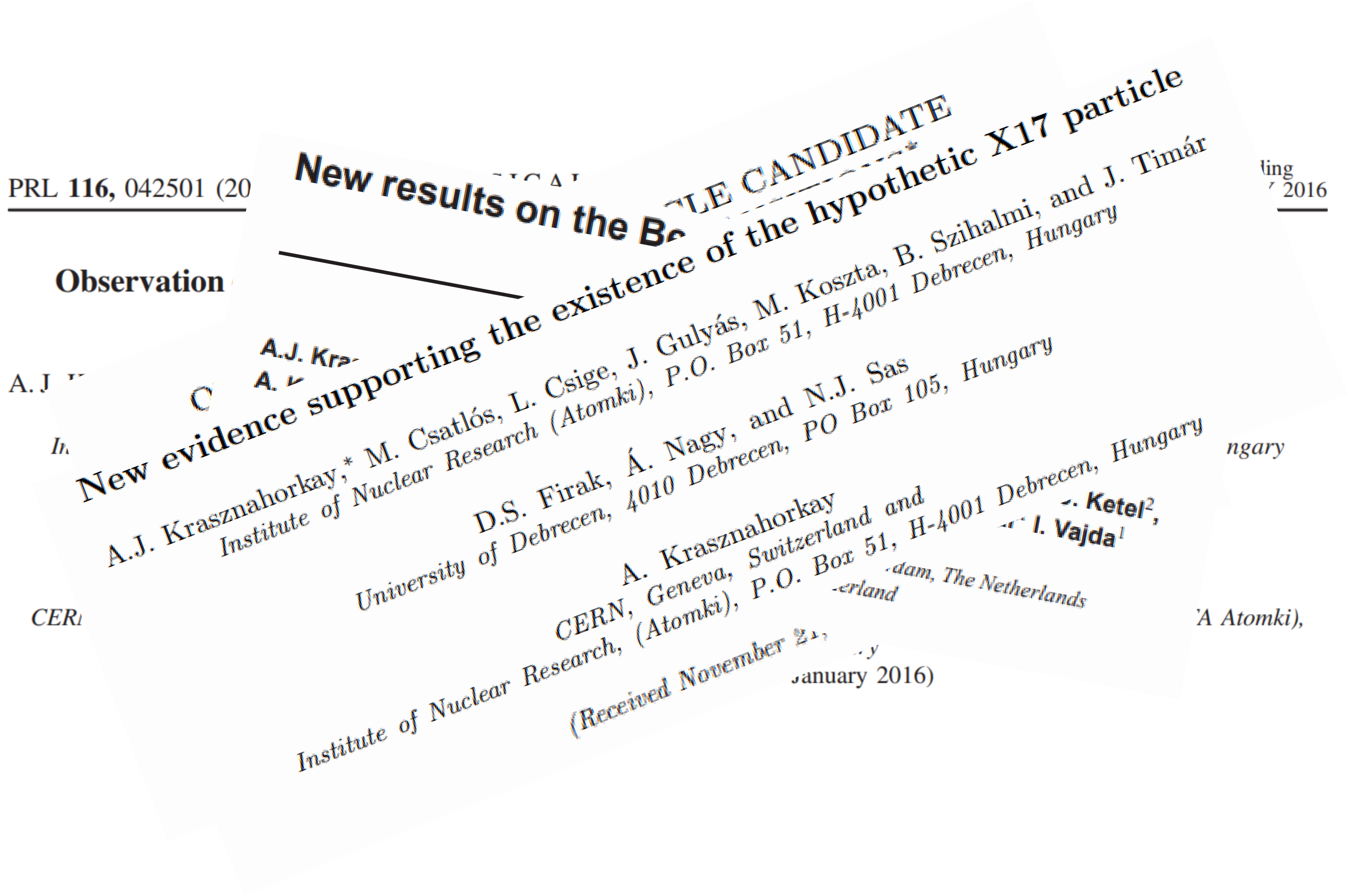
CERN, Geneva, Switzerland

(Received November 21, 2018)

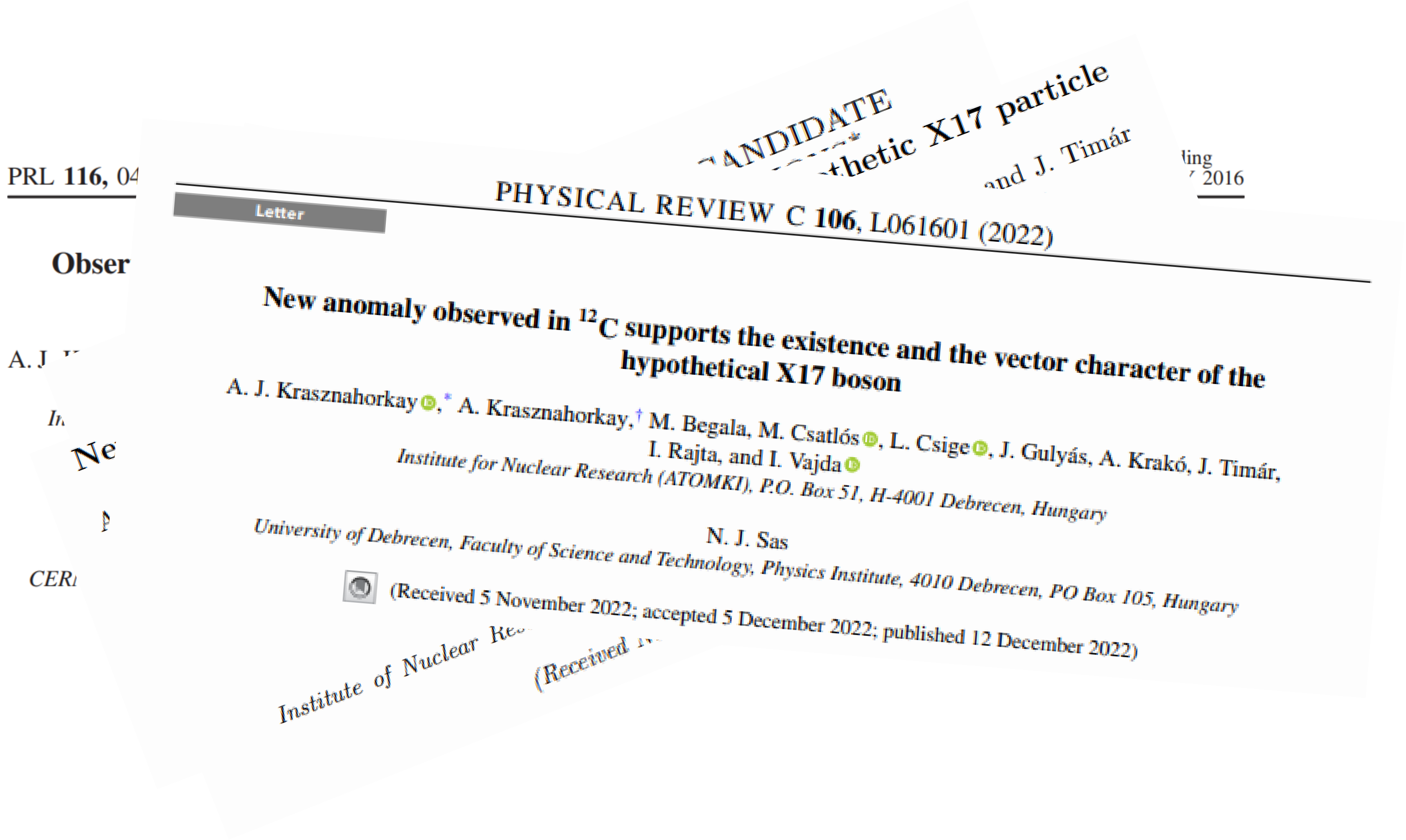
Continued interest…



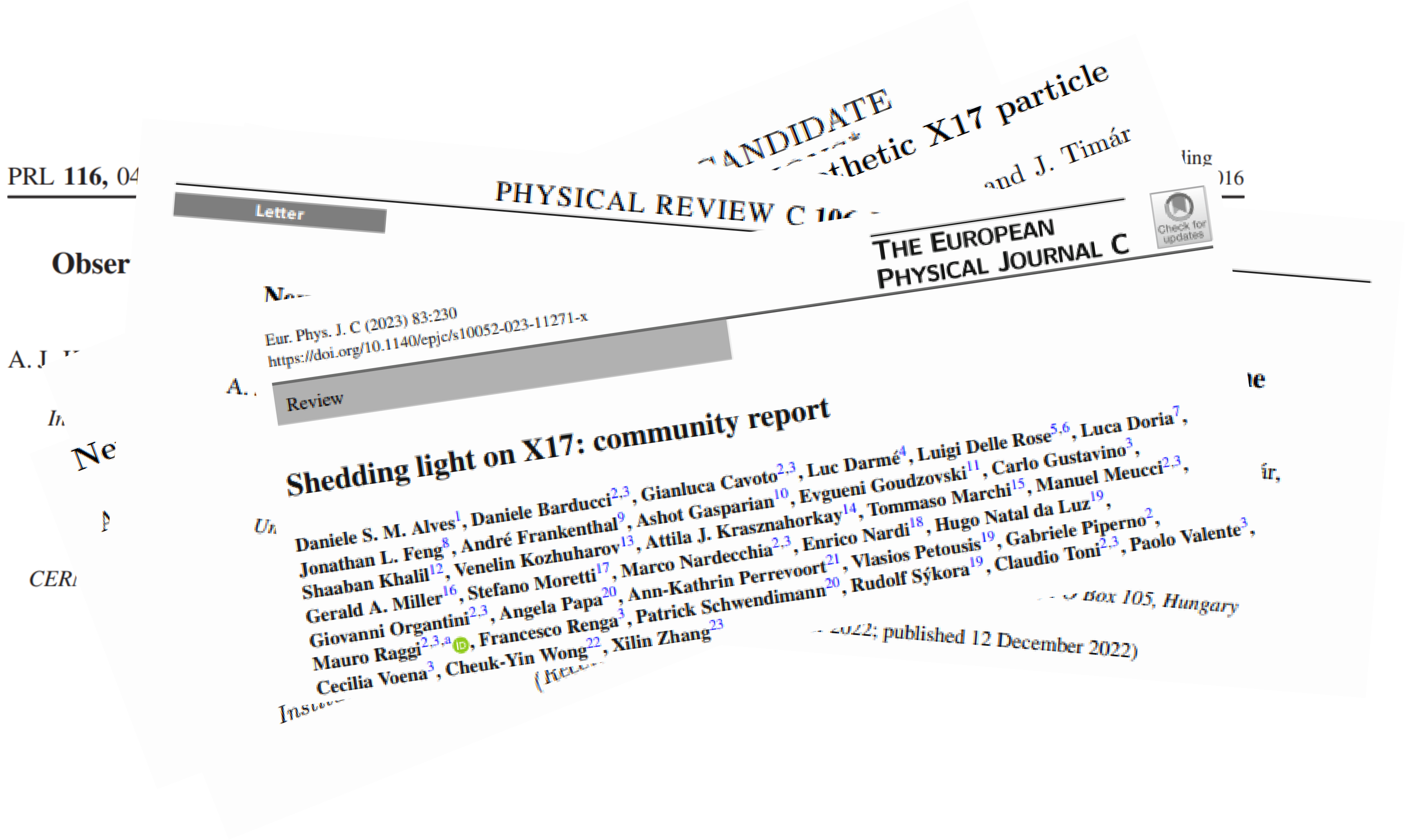
Continued interest…



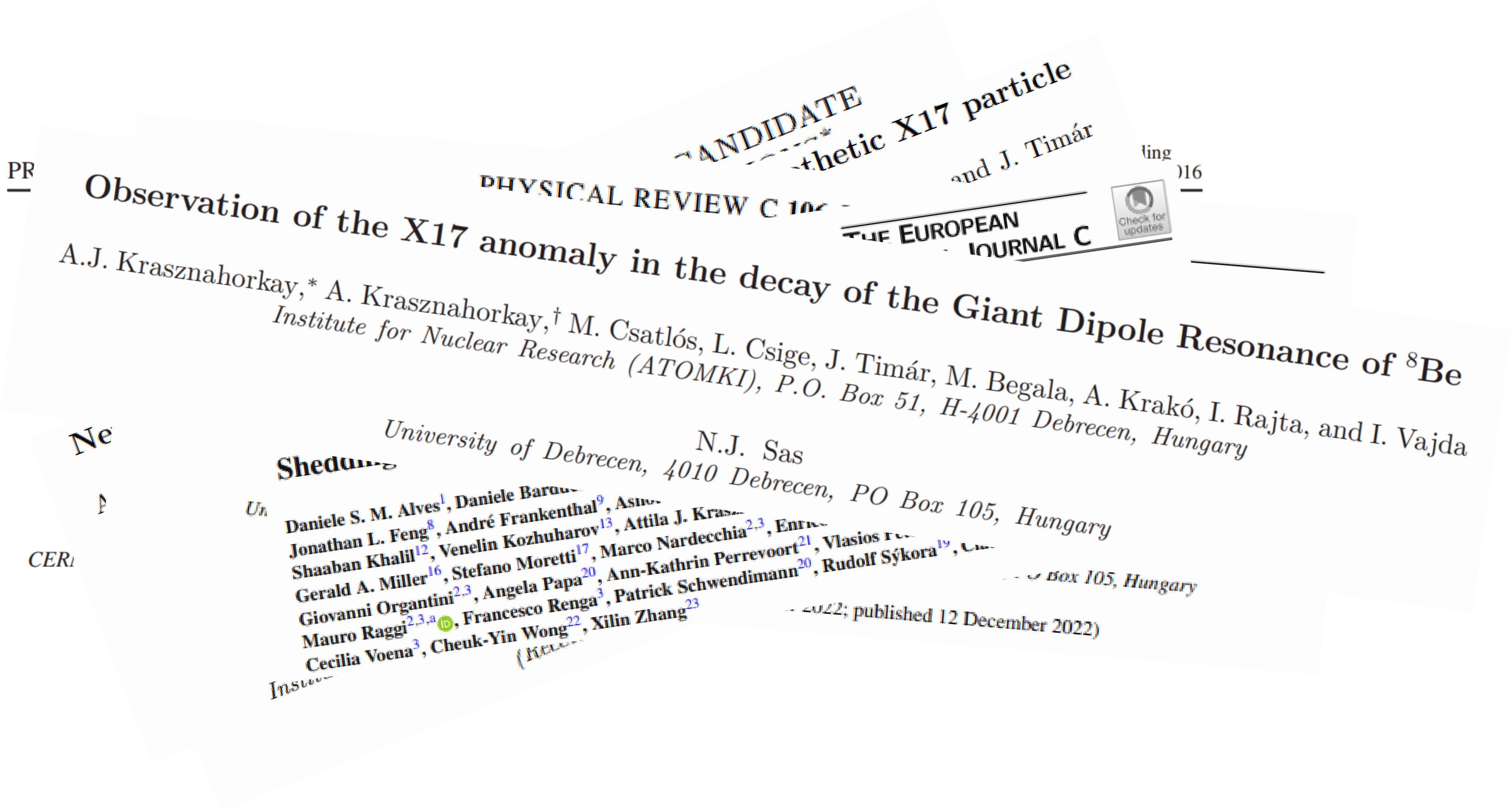
Continued interest...



Continued interest…



Continued interest...



Theory analysis

- Assume definite parity (J^P)

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

$$\mathbf{J}_A = \mathbf{S}_X + \mathbf{S}_B + \mathbf{L} \qquad P_A = P_X \times P_B \times (-1)^L$$

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

$$\mathbf{J}_A = \mathbf{S}_X + \mathbf{S}_B + \mathbf{L} \qquad P_A = P_X \times P_B \times (-1)^L$$

$$\mathbf{1} = \mathbf{S}_X + \mathbf{0} + \mathbf{L} \qquad +1 = P_X \times (+1) \times (-1)^L$$

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

$$\mathbf{J}_A = \mathbf{S}_X + \mathbf{S}_B + \mathbf{L} \qquad P_A = P_X \times P_B \times (-1)^L$$

$$\mathbf{1} = \mathbf{S}_X + \mathbf{0} + \mathbf{L} \qquad +1 = P_X \times (+1) \times (-1)^L$$

$$\mathbf{S}_X = \mathbf{0} \implies |L-1| \leq 0 \leq L+1 \implies L = 1$$

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

$$\mathbf{J}_A = \mathbf{S}_X + \mathbf{S}_B + \mathbf{L} \qquad P_A = P_X \times P_B \times (-1)^L$$

$$\mathbf{1} = \mathbf{S}_X + \mathbf{0} + \mathbf{L} \qquad +1 = P_X \times (+1) \times (-1)^L$$

$$\mathbf{S}_X = \mathbf{0} \implies |L-1| \leq 0 \leq L+1 \implies L = 1$$
$$\mathbf{S}_X = \mathbf{1} \implies |L-1| \leq 1 \leq L+1 \implies L = 0, 1, 2$$

Theory analysis

- Assume definite parity (J^P)
- Example: ^{8}Be(18.15), 1^+
- $A \to XB$

$$\mathbf{J}_A = \mathbf{S}_X + \mathbf{S}_B + \mathbf{L} \qquad P_A = P_X \times P_B \times (-1)^L$$

$$\mathbf{1} = \mathbf{S}_X + \mathbf{0} + \mathbf{L} \qquad +1 = P_X \times (+1) \times (-1)^L$$

$$\mathbf{S}_X = \mathbf{0} \implies |L-1| \leq 0 \leq L+1 \implies L = 1$$
$$\mathbf{S}_X = \mathbf{1} \implies |L-1| \leq 1 \leq L+1 \implies L = 0, 1, 2$$

$$J^P = 0^-, 1^+, 1^-$$

Theory analysis

- Assume definite parity (J^P)

State (MeV)	Scalar (0^+)	Pseudoscalar (0^-)	Vector (1^-)	Axial vector (1^+)
^{8}Be(18.15), 1^+				
^{8}Be(17.64), 1^+				
^{4}He(21.01), 0^-				
^{4}He(20.21), 0^+				
^{12}C(17.23), 1^-				

Theory analysis

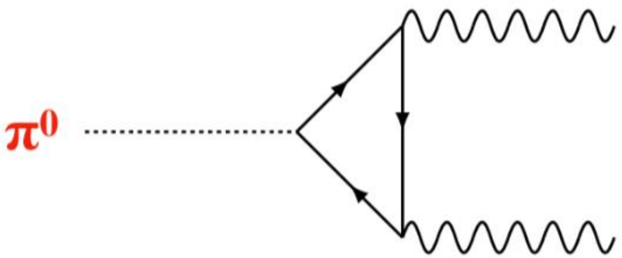
- Assume definite parity (J^P)

State (MeV)	Scalar (0^+)	Pseudoscalar (0^-)	Vector (1^-)	Axial vector (1^+)
$^{8}Be(18.15), 1^+$		✓	✓	✓
$^{8}Be(17.64), 1^+$		✓	✓	✓
$^{4}He(21.01), 0^-$		✓		✓
$^{4}He(20.21), 0^+$	✓		✓	
$^{12}C(17.23), 1^-$	✓		✓	✓

Theory analysis

- Proton coupling bounded by SINDRUM, NA48/2 (protophobic), derive limits on neutron coupling

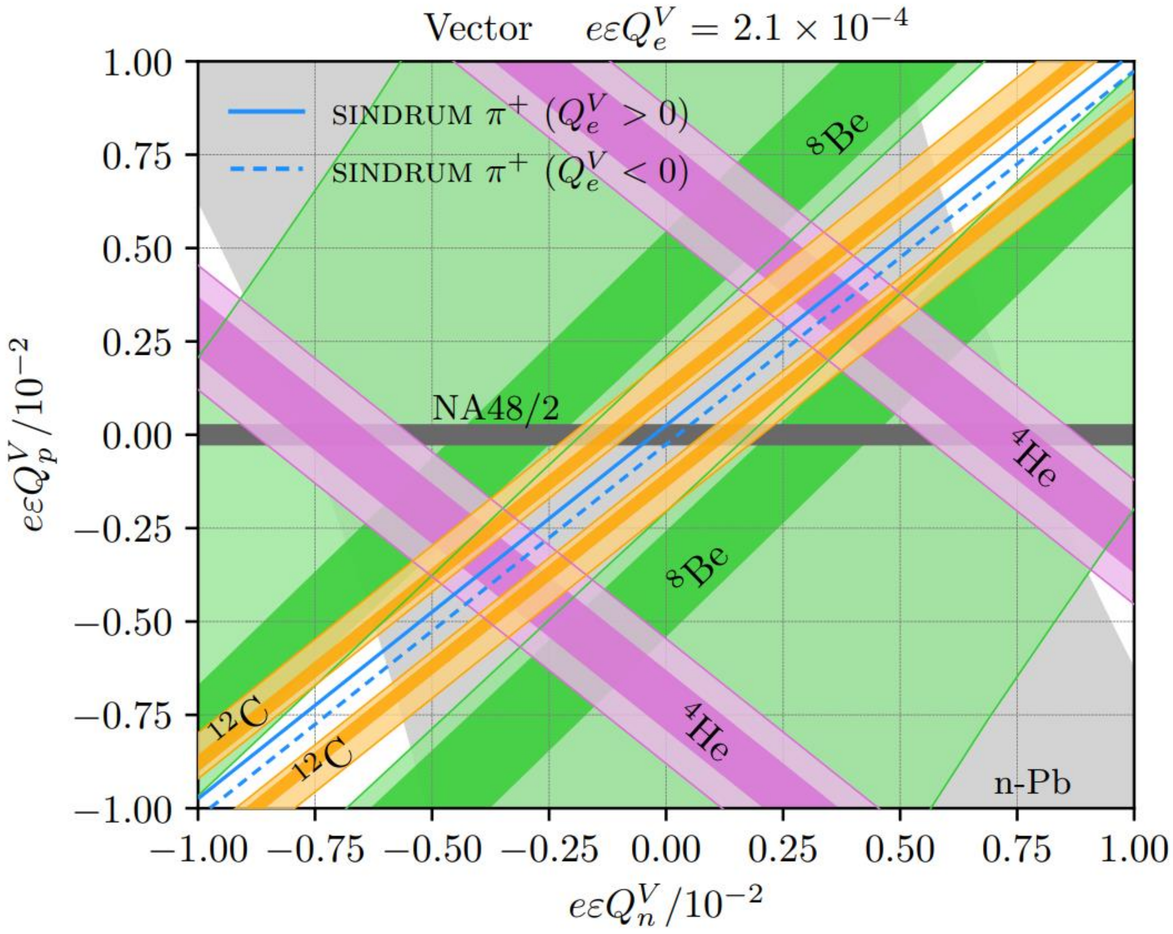
$$\pi^0 \to \gamma(X \to e^+e^-)$$



$$\propto |2\varepsilon_u + \varepsilon_d| = |\varepsilon_p|$$

Many open questions

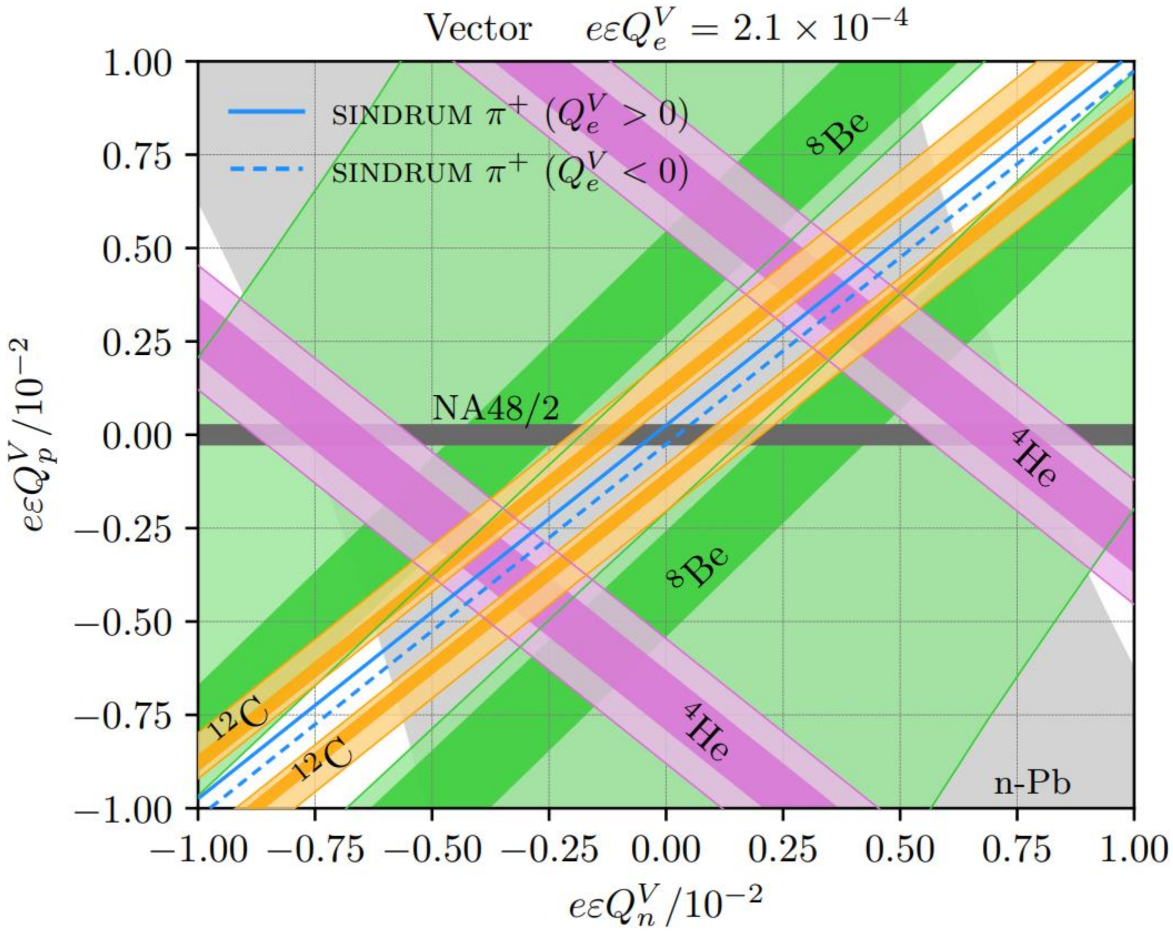
arXiv:2306.15077 [hep-ph]



- Parity etc. still unclear

Many open questions

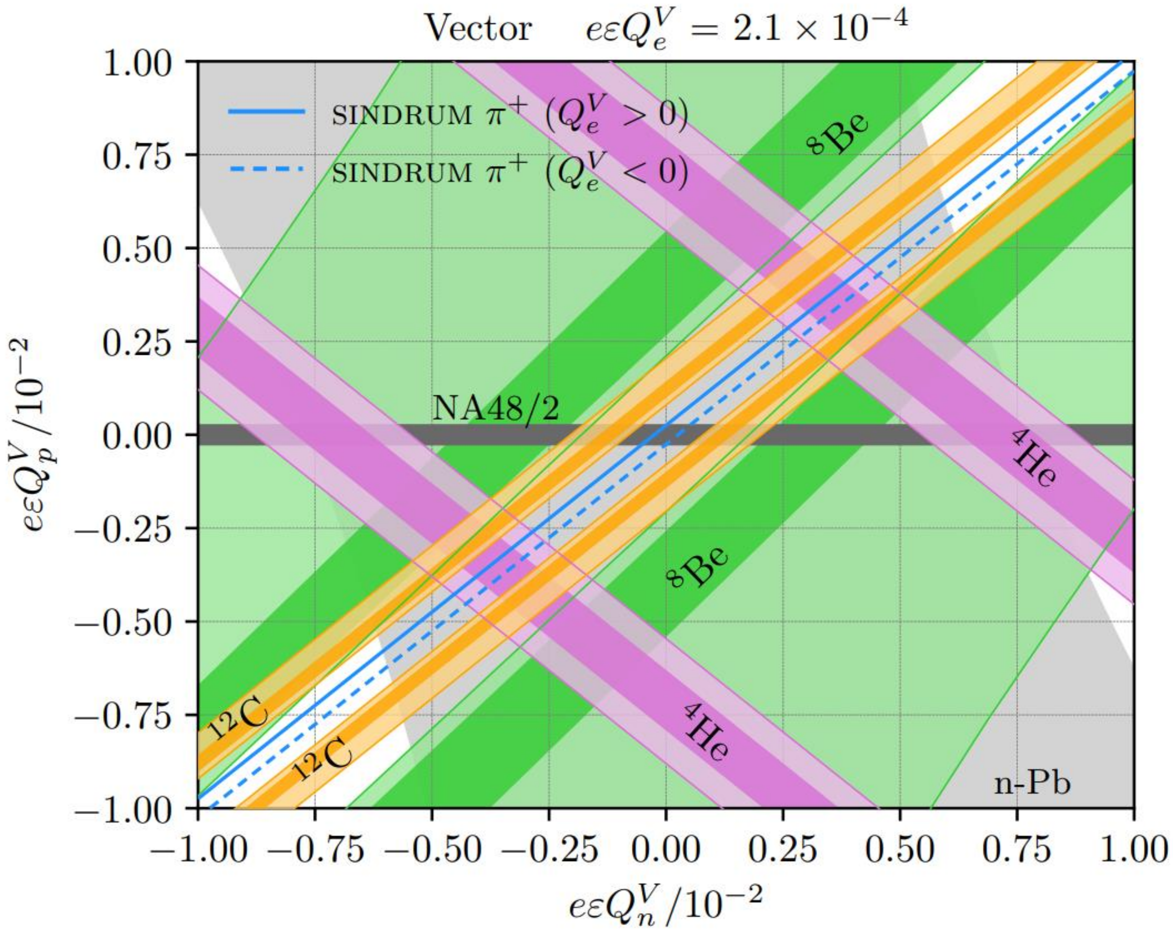
arXiv:2306.15077 [hep-ph]



- Parity etc. still unclear
- Need independent verification!

Many open questions

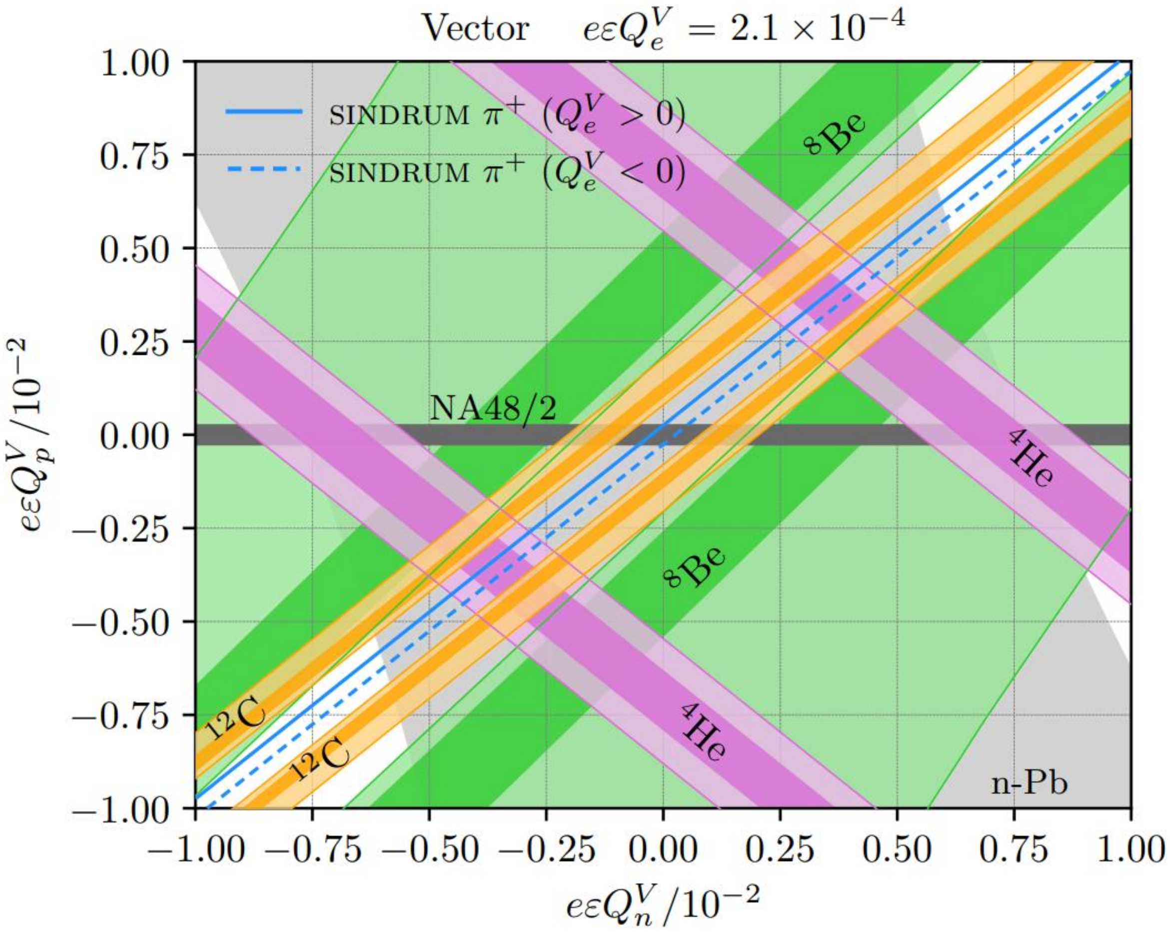
arXiv:2306.15077 [hep-ph]



- Parity etc. still unclear
- Need independent verification!
- Ongoing/planned experiments at MEG II (PSI), CCPAC (Montreal) and others (see Eur.Phys.J.C 83 (2023) 3, 230)

Many open questions

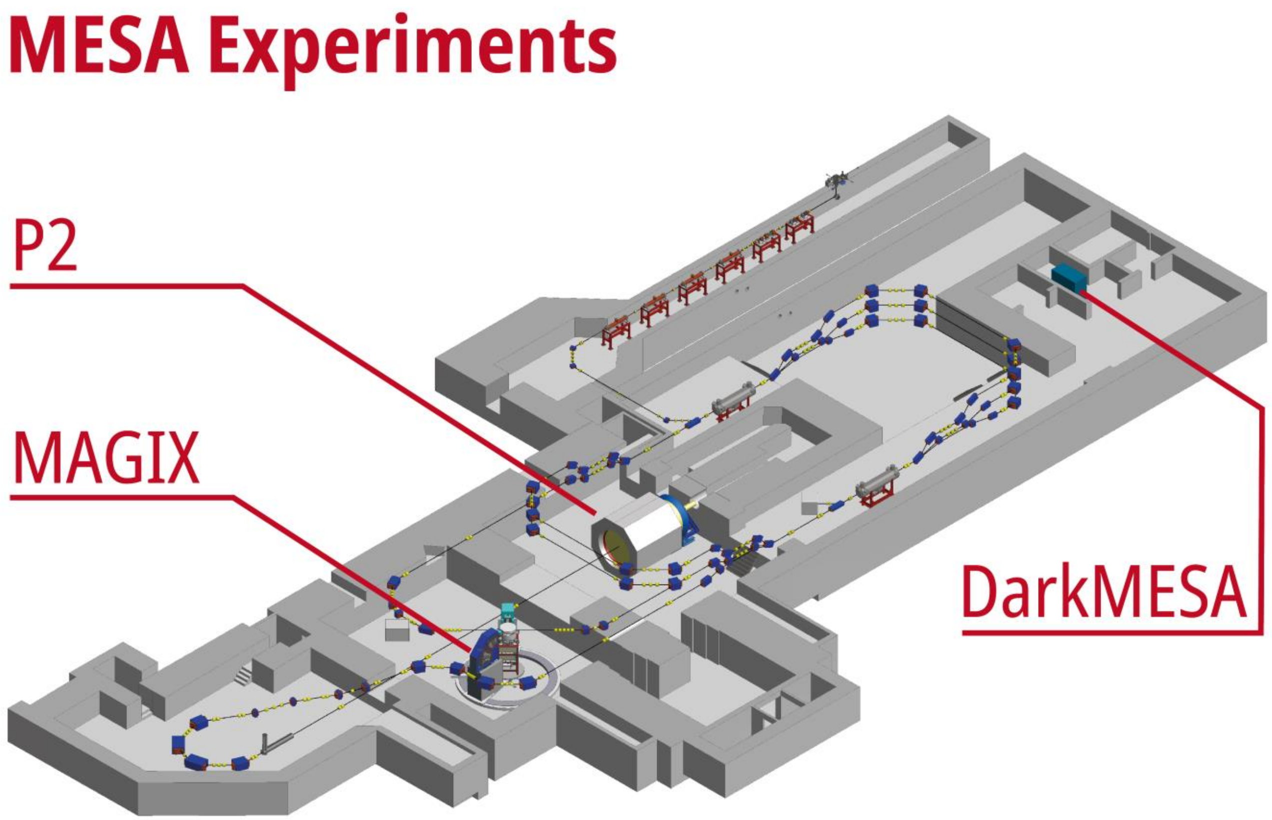
arXiv:2306.15077 [hep-ph]



- Parity etc. still unclear
- Need independent verification!
- Ongoing/planned experiments at MEG II (PSI), CCPAC (Montreal) and others (see Eur.Phys.J.C 83 (2023) 3, 230)
- We propose a direct search at MAGIX experiment at MESA

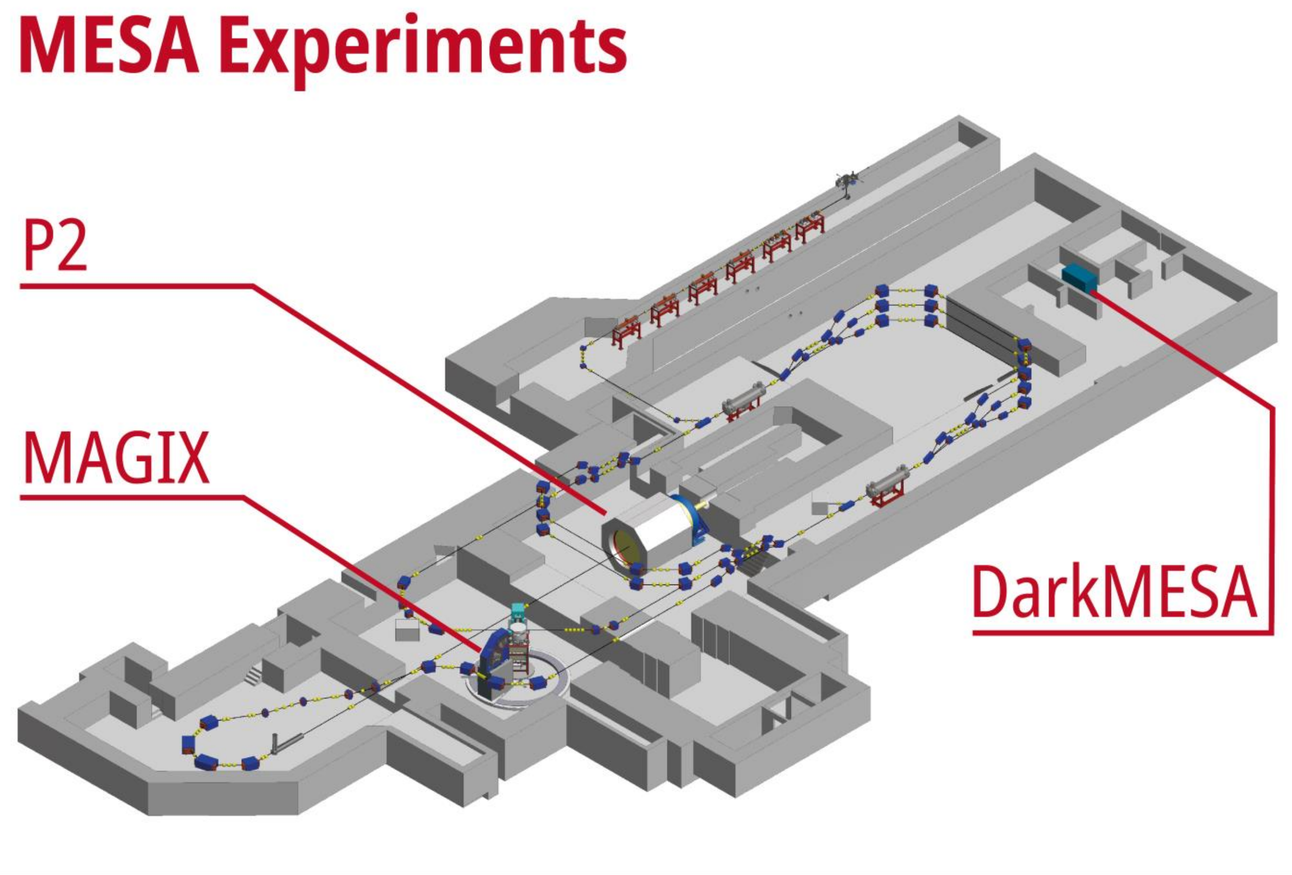
MAGIX@MESA

- MESA is a linear accelerator under construction in Mainz



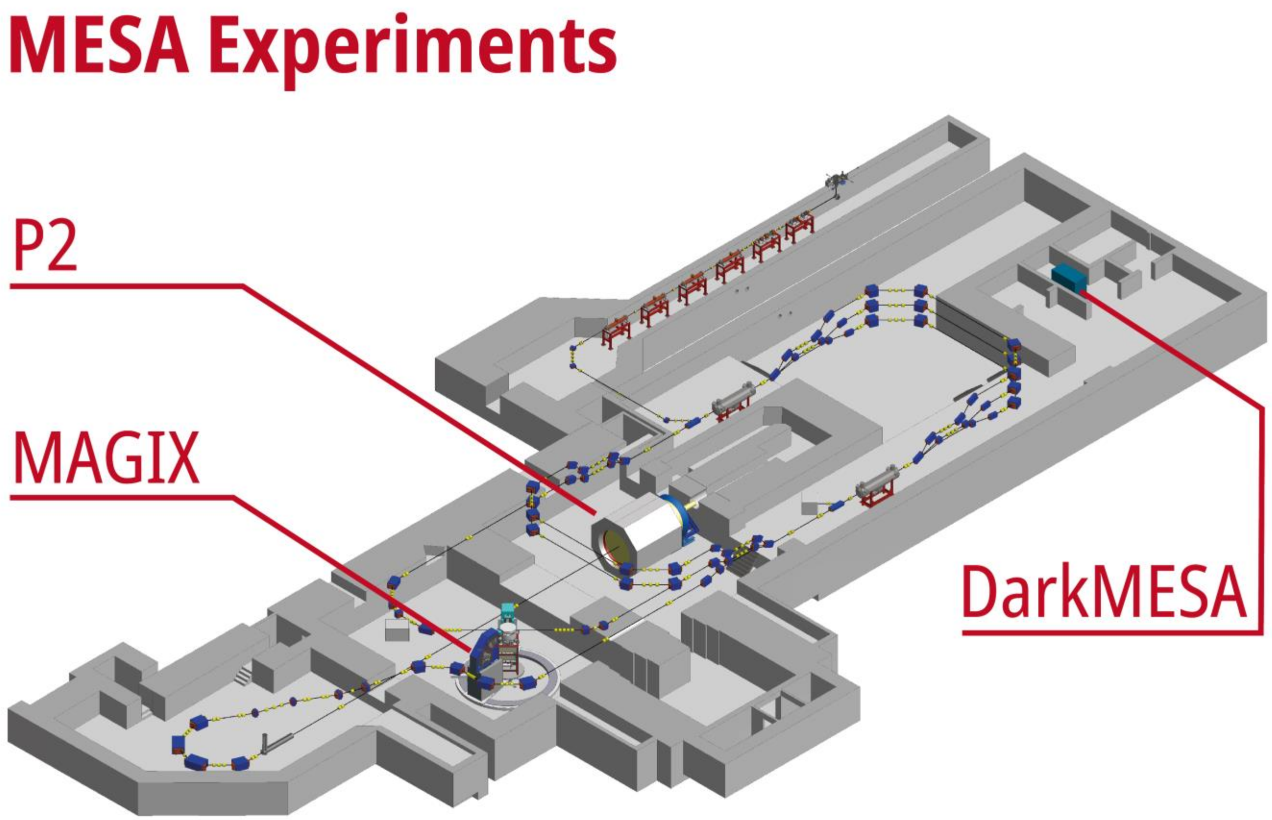
MAGIX@MESA

- MESA is a linear accelerator under construction in Mainz
- Low energy, high intensity electron beam ~105 MeV



MAGIX@MESA

- MESA is a linear accelerator under construction in Mainz
- Low energy, high intensity electron beam ~105 MeV
- MAGIX is a pair of multipurpose spectrometers, can measure m_{ee} with precision of 0.1 MeV



Deuteron with neutron tagging

- Direct search using $\gamma N \to N e^+ e^-$

Deuteron with neutron tagging

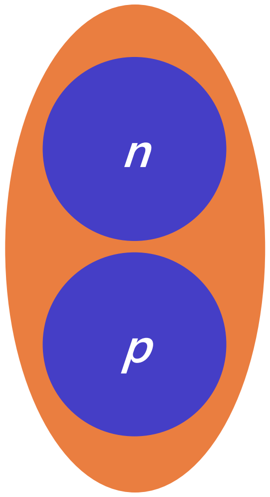
- Direct search using $\gamma N \rightarrow N e^+ e^-$
- Stronger signal with neutrons, QED background suppressed

Deuteron with neutron tagging

- Direct search using $\gamma N \rightarrow N e^+ e^-$
- Stronger signal with neutrons, QED background suppressed
- No free neutron target!

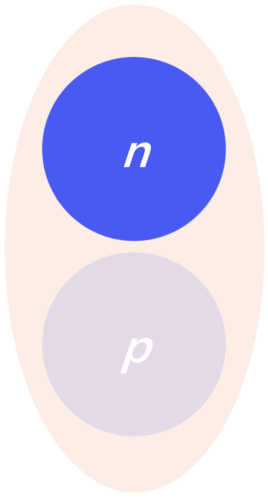
Deuteron with neutron tagging

- Direct search using $\gamma N \to N e^+ e^-$
- Stronger signal with neutrons, QED background suppressed
- No free neutron target!
- Consider neutron bound in deuteron, $\gamma d \to e^+ e^- p n$



Deuteron with neutron tagging

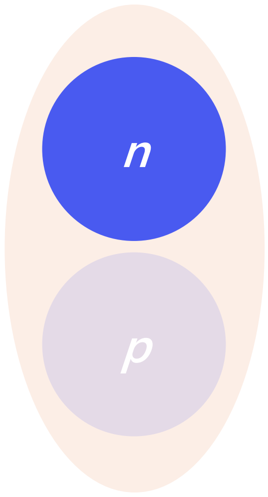
- Direct search using $\gamma N \to N e^+ e^-$
- Stronger signal with neutrons, QED background suppressed
- No free neutron target!
- Consider neutron bound in deuteron, $\gamma d \to e^+ e^- p n$
- Pick kinematics where neutron is "quasi-free"



Deuteron with neutron tagging

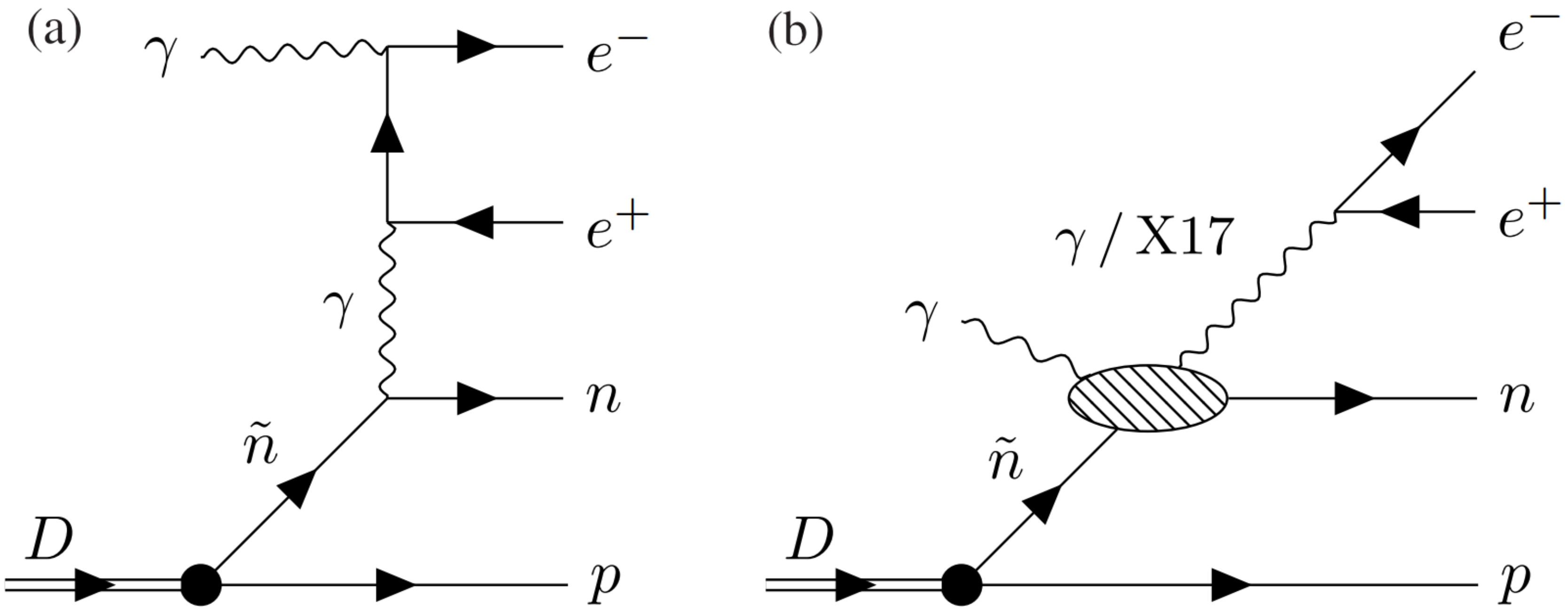
- Direct search using $\gamma N \to N e^+ e^-$
- Stronger signal with neutrons, QED background suppressed
- No free neutron target!
- Consider neutron bound in deuteron, $\gamma d \to e^+ e^- pn$
- Pick kinematics where neutron is "quasi-free"
- Work within plane-wave impulse approximation:

$$\mathcal{M}(\gamma D \to e^+e^-pn) \propto \psi_D \times \mathcal{M}(\gamma n \to e^+e^-n) + \psi_D \times \mathcal{M}(\gamma p \to e^+e^-p)$$

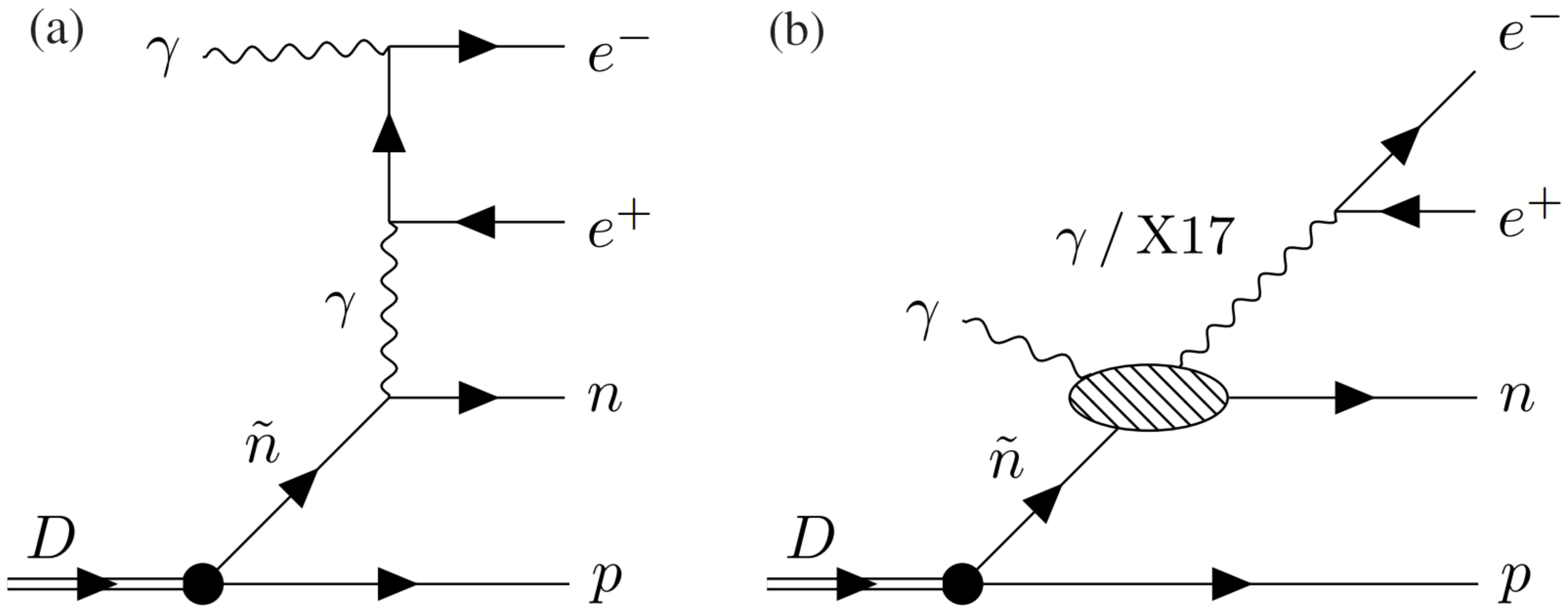


X17 discovery potential from $\gamma d \to e^+ e^- pn$, Cornelis J.G. Mommers & Marc Vanderhaeghen, arXiv:2307.02181 [hep-ph]

Relevant diagrams

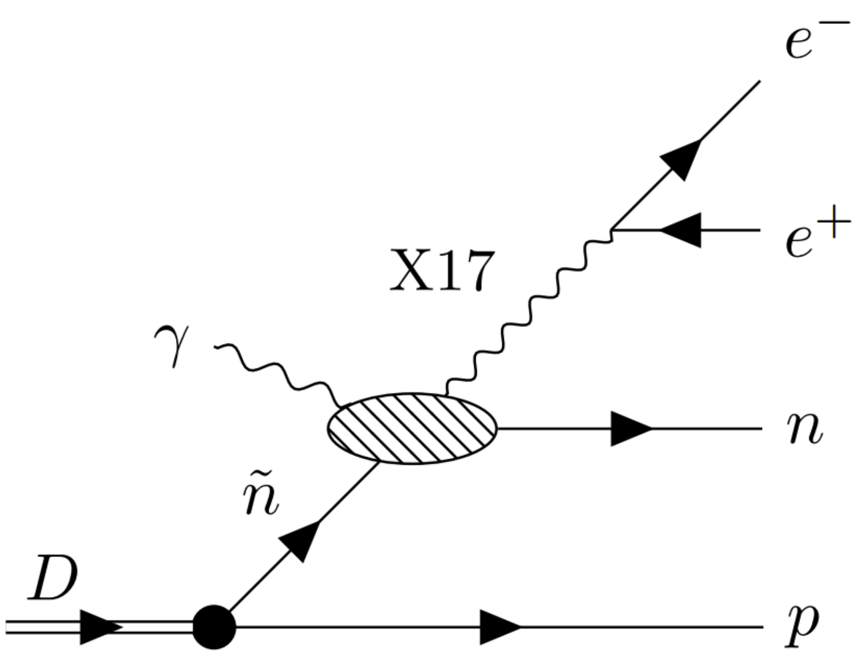


Relevant diagrams



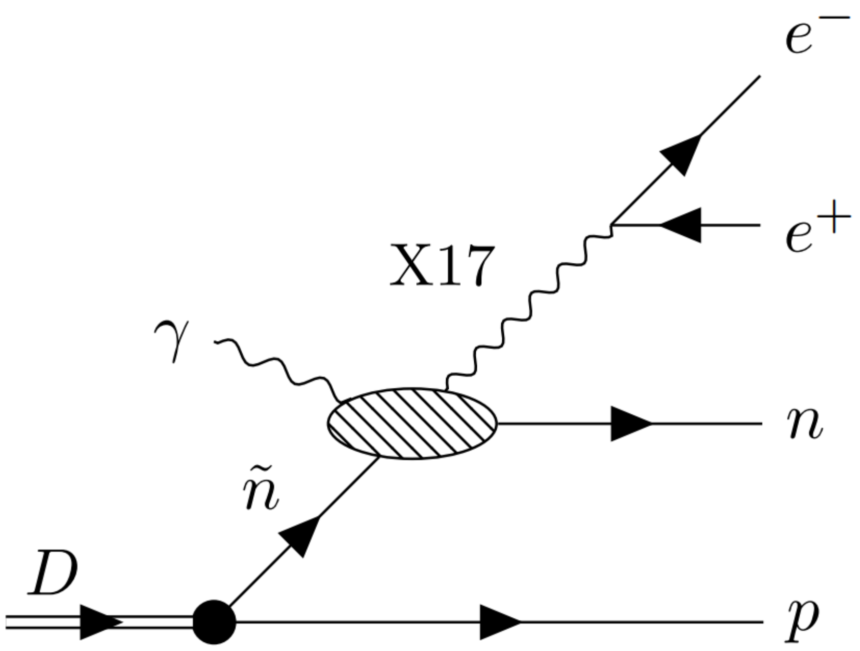
- Higher-order corrections ~25%, tree level sufficient for this work

Signal optimization

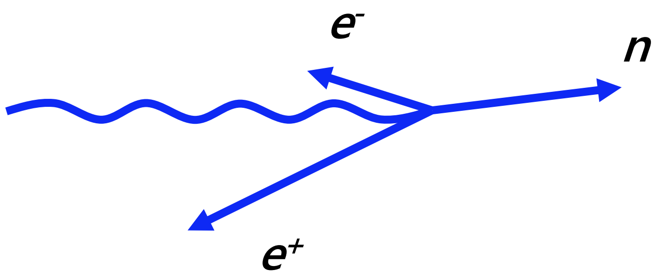


- Optimize kinematics such that X17 signal is visible over QED background, subject to constraints

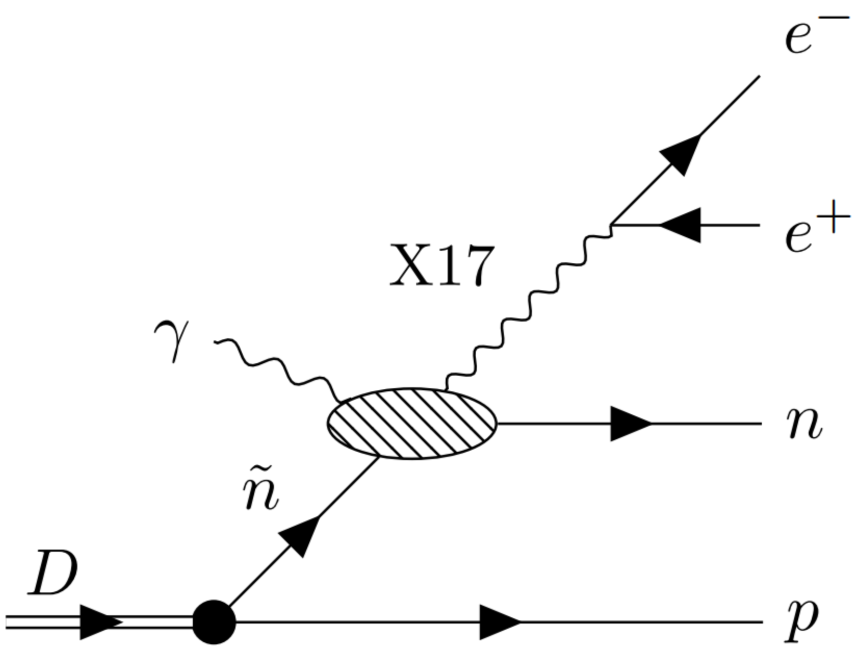
Signal optimization



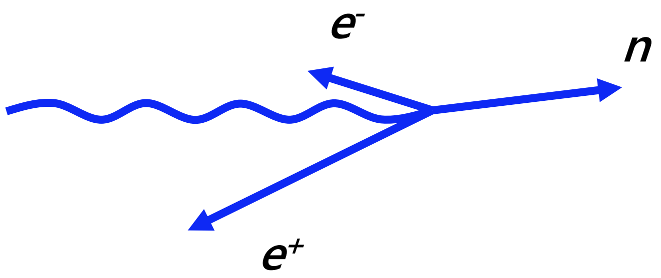
- Optimize kinematics such that X17 signal is visible over QED background, subject to constraints



Signal optimization

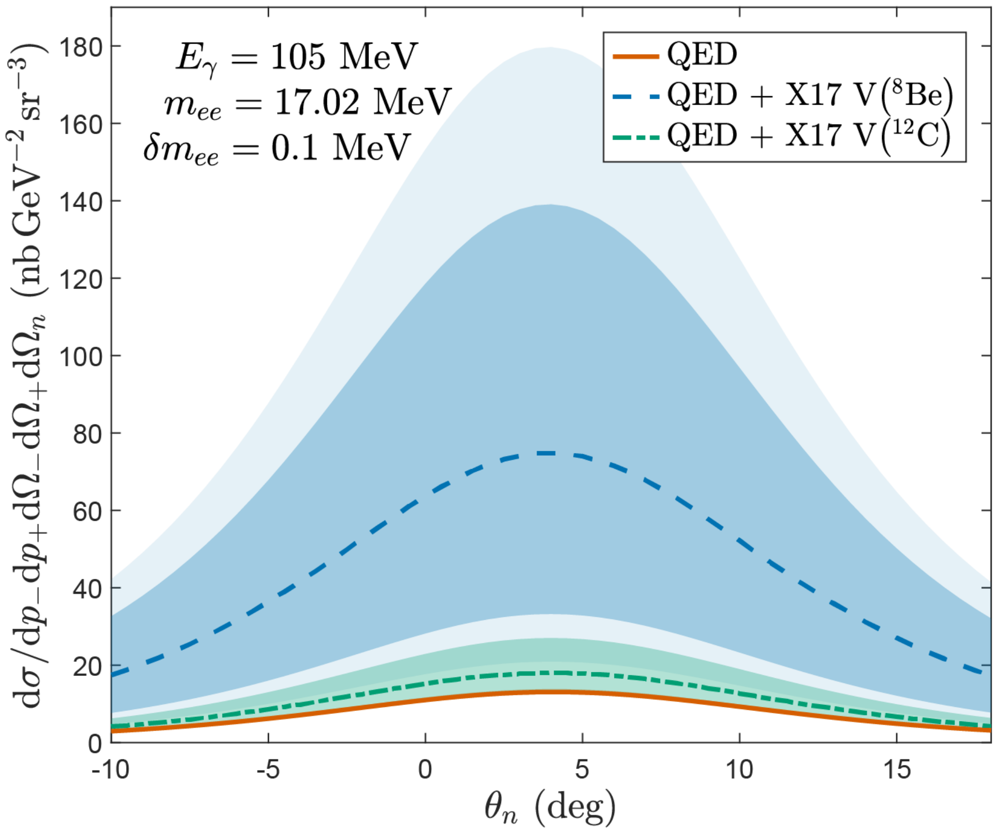


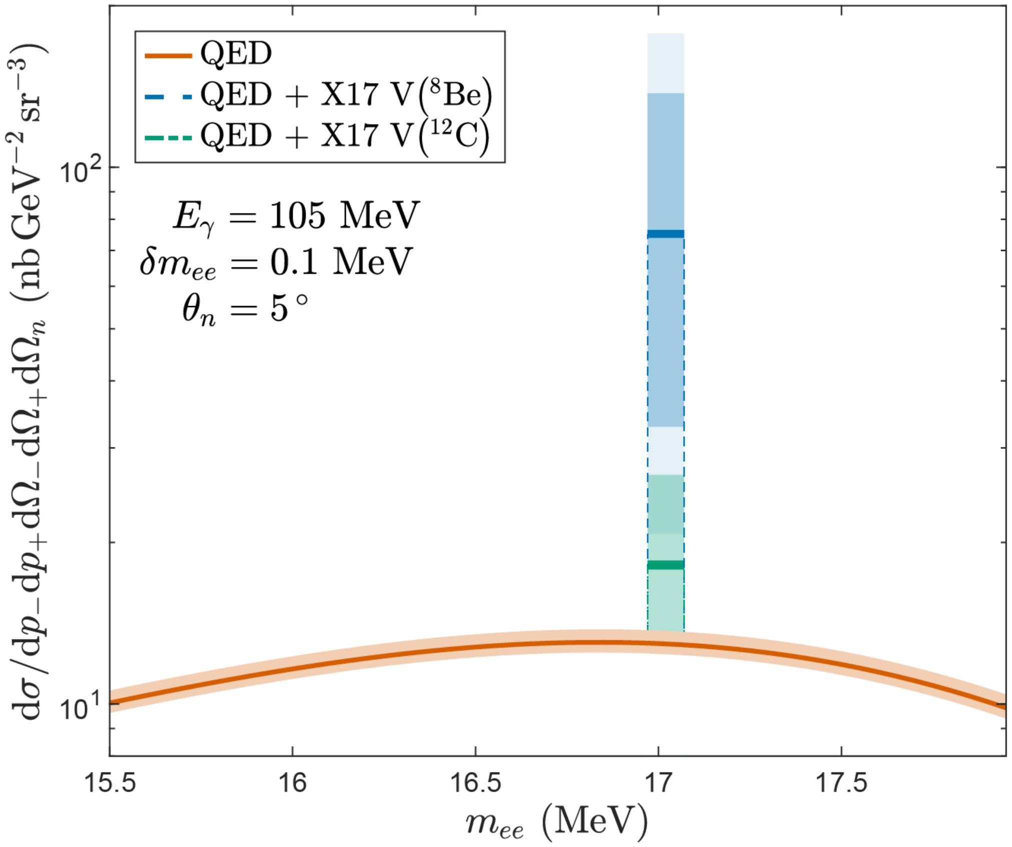
- Optimize kinematics such that X17 signal is visible over QED background, subject to constraints



- Sensitivity MESA: δm_{ee} = 0.1 MeV

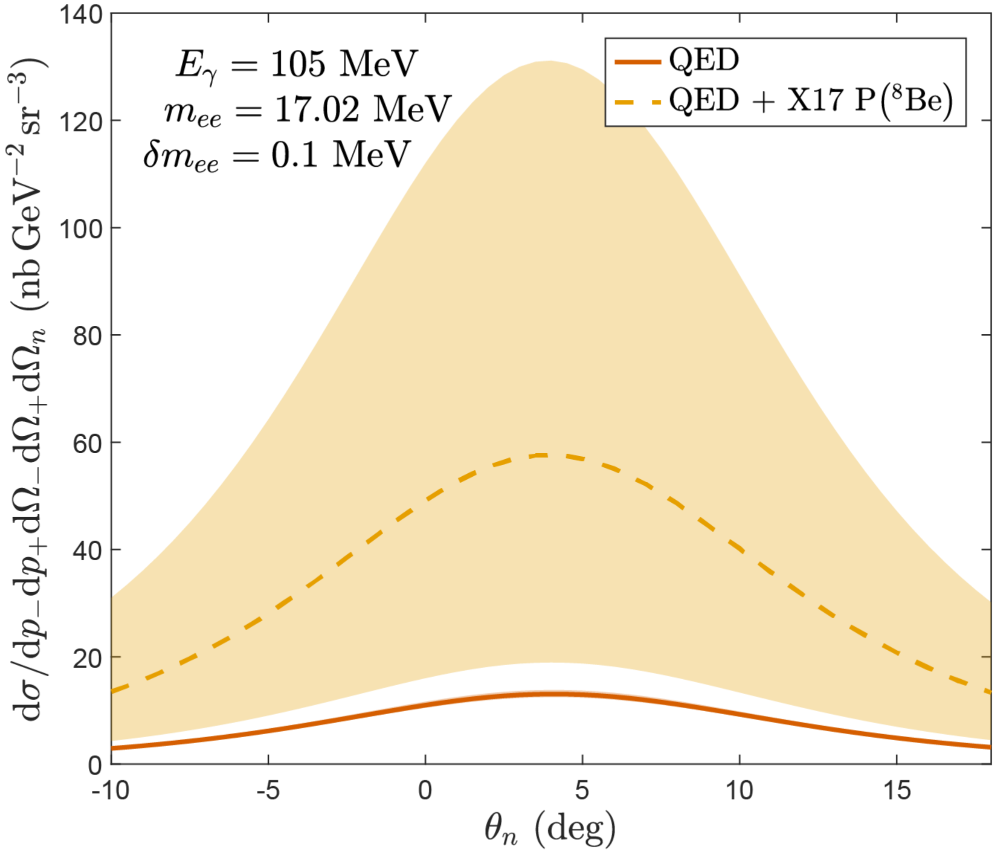
Results (I)

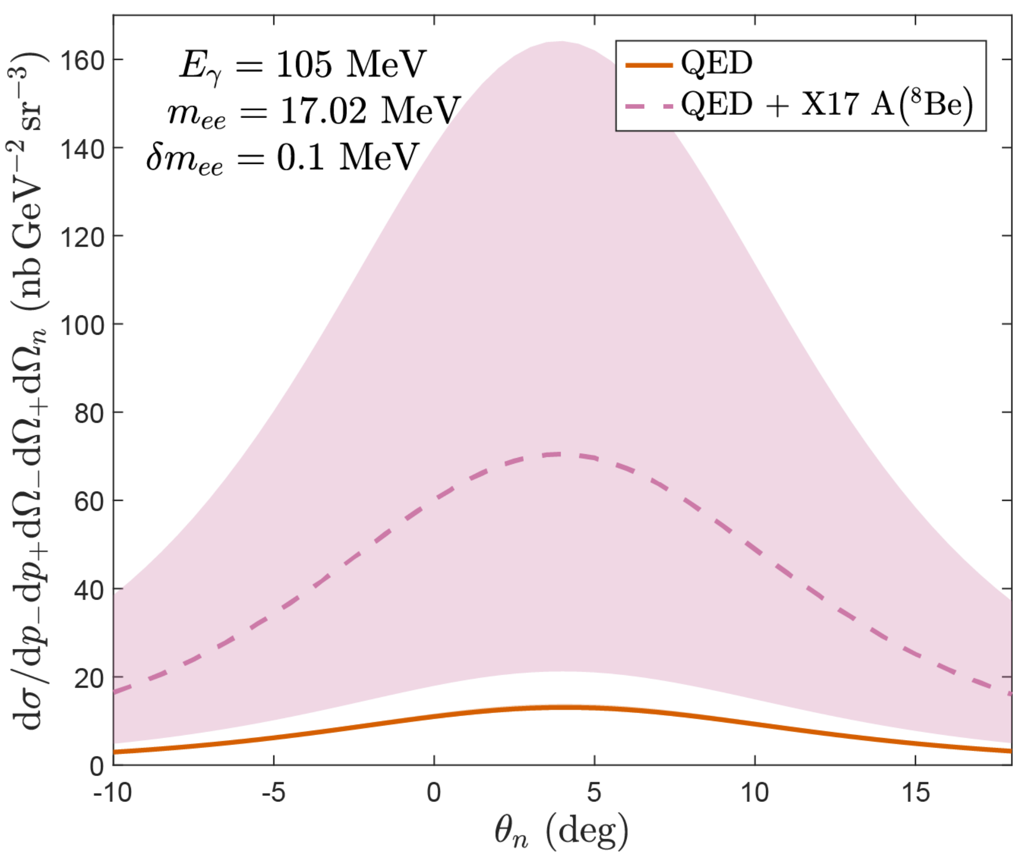




X17 discovery potential from $\gamma d \to e^+ e^- pn$, Cornelis J.G. Mommers & Marc Vanderhaeghen, arXiv:2307.02181 [hep-ph]

Results (II)





X17 discovery potential from $\gamma d \to e^+ e^- pn$, Cornelis J.G. Mommers & Marc Vanderhaeghen, arXiv:2307.02181 [hep-ph]

Outlook

- Not limited to X17 – can draw exclusion limits

Outlook

- Not limited to X17 – can draw exclusion limits
- Use same measurement data to get neutron polarizabilities

Photon Scattering on Quasi-Free Neutrons in the Reaction $\gamma d \to \gamma' np$ and Neutron Polarizabilities

M. I. Levchuk[1], A. I. L'vov[2], and V. A. Petrun'kin[2]

[1] B. I. Stepanov Institute of Physics, Belorussian Academy of Sciences, F. Scarina Prospect 70, 220602 Minsk, Belarus

[2] P. N. Lebedev Physical Institute, Russian Academy of Sciences, Leninsky Prospect 53, Moscow 117924, Russia

Summary

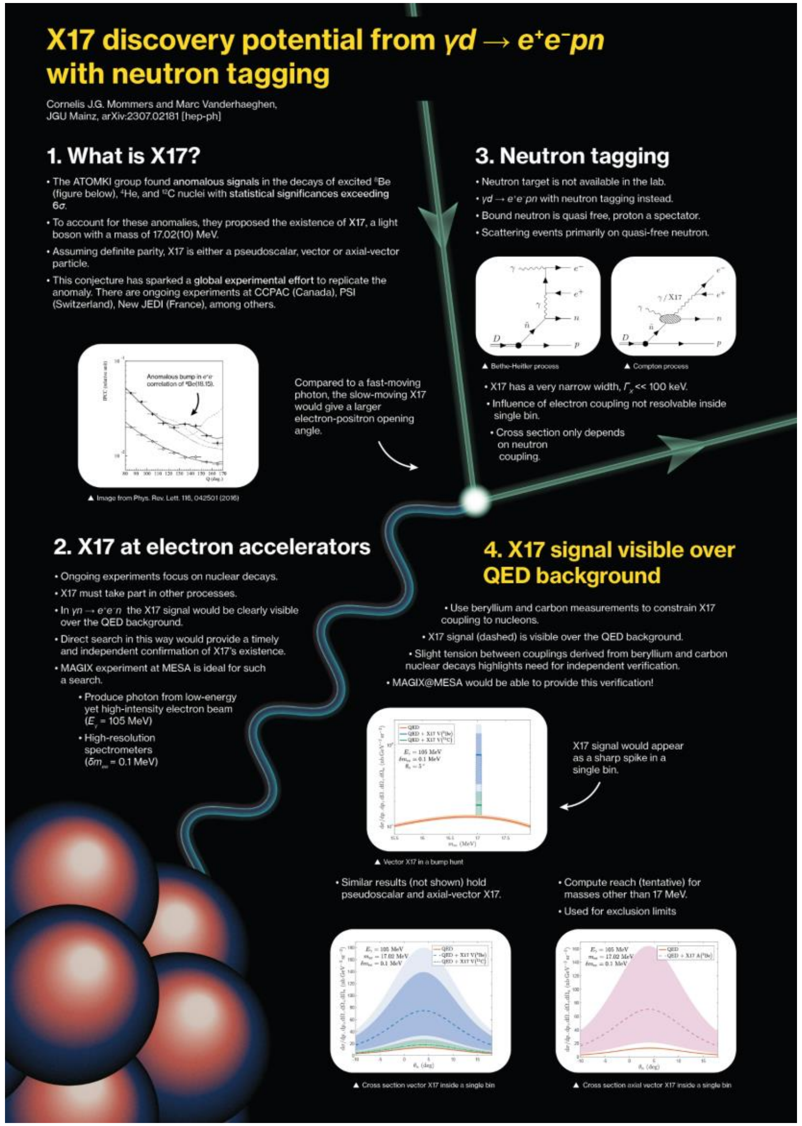
- ATOMKI anomaly is a smoking gun
- Much is still unclear, clear need for independent experiments
- MAGIX experiment at MESA is uniquely suited for a direct search using neutron tagging
- Calculation may be extended for exclusion plots

X17 discovery potential from $\gamma d \to e^+e^-pn$ with neutron tagging

Cornelis J.G. Mommers & Marc Vanderhaeghen

Johannes Gutenberg-Universität Mainz

arXiv:2307.02181 [hep-ph]



Bonus slides

Table ATOMKI decays

Ref.	State (MeV)	Transition (J^P)	
[2]–[4], [6]	^{8}Be(18.15)	$1^+ \to 0^+$	(M1, isoscalar)
[2]–[4], [6]	^{8}Be(17.64)	$1^+ \to 0^+$	(M1, isovector)
[5], [7]–[9]	^{4}He(21.01)	$0^- \to 0^+$	(M0)
[5], [7]–[9]	^{4}He(20.21)	$0^+ \to 0^+$	(E0)
[10]	^{12}C(17.23)	$1^- \to 0^+$	(E1, isovector)

States (MeV)	m_X (MeV)	Γ_X (eV)	$\mathcal{B}$
^{8}Be(18.15)	$16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$	$1.1(2) \times 10^{-5}$	5.8×10^{-6}
^{8}Be(18.15), ^{8}Be(17.64)	17.01(16)	$1.2(2) \times 10^{-5}$	$6(1) \times 10^{-6}$
^{4}He(21.01), ^{4}He(20.21)	$16.94 \pm 0.12(\text{stat}) \pm 0.21(\text{syst})$		
^{4}He(21.01), ^{4}He(20.21)	$16.84 \pm 0.16(\text{stat}) \pm 0.20(\text{syst})$	3.9×10^{-5}	$1.2(4) \times 10^{-1}$
^{12}C(17.23)	$17.03 \pm 0.11(\text{stat}) \pm 0.20(\text{syst})$	$1.6(1) \times 10^{-4}$	$3.6(3) \times 10^{-6}$

Deriving limits on couplings (P)

$$\mathcal{L}_{0^-} = i\bar{N}\gamma_5 \left(g^{(0)}_{XNN} + g^{(1)}_{XNN}\tau^3\right) NX$$

- SINDRUM: $|g^{(1)}_{XNN}| \lesssim 0.6 \times 10^{-3}$ (Phys. Lett. B 175, 101 (1986))
- Multipole: $\frac{\Gamma_X^{^8\mathrm{Be}}}{\Gamma_\gamma^{\mathrm{M1}}} = \frac{1}{2\pi\alpha}\left(\frac{g^{(0)}_{XNN}\cos\theta_{1+} - g^{(1)}_{XNN}\sin\theta_{1+}}{[\mu^{(0)} - \eta^{(0)}]\cos\theta_{1+} - [\mu^{(1)} - \eta^{(1)}]\sin\theta_{1+}}\right)^2 \left(\frac{k_X}{k_\gamma}\right)^3$

Deriving limits on couplings (V)

$$\mathcal{L}_{\mathrm{V}} = -eX_\mu \sum_{N=p,n} \varepsilon_N \bar{N}\gamma^\mu N$$

- NA48/2: $|\varepsilon_p| \lesssim \frac{(0.8-1.2)\times 10^{-3}}{\sqrt{\mathcal{B}(X\to e^+e^-)}}$ (Phys. Lett. B 746, 178 (2015))
- Multipole: $\frac{\Gamma_X^{^8\mathrm{Be}}}{\Gamma_\gamma^{\mathrm{M1}}} = \frac{|(\varepsilon_p+\varepsilon_n)\cos\theta_{1^+}M1_{1,T=0} + (\varepsilon_p-\varepsilon_n)(-\sin\theta_{1^+}M1_{1,T=1} + \cos\theta_{1^+}\kappa M1_{1,T=1})|^2}{|\cos\theta_{1^+}M1_{1,T=0} - \sin\theta_{1^+}M1_{1,T=1} + \cos\theta_{1^+}\kappa M1_{1,T=1}|^2}\left(\frac{k_X}{k_\gamma}\right)^3$

$$\frac{\Gamma_{X,V}^{^{12}\mathrm{C}(17.23)}}{\Gamma_\gamma^{\mathrm{E1}}} = \frac{k}{\Delta E}\left(1+\frac{m_X^2}{2\Delta E^2}\right)|\varepsilon_p-\varepsilon_n|^2$$

Deriving limits on couplings (A)

$$\mathcal{L}_{\mathrm{A}} = -X_\mu \sum_{N=p,n} a_N \bar{N} \gamma^\mu \gamma_5 N$$

- Matrix elements from Phys. Rev. D 95, 115024
- Multipole: $\dfrac{\Gamma_{X,A}^{^8\mathrm{Be}(18.15)}}{\Gamma_\gamma^{\mathrm{M1}}} = \dfrac{1}{\Gamma_\gamma(^8\mathrm{Be}(18.15))} \dfrac{k_X}{18\pi} \left[2 + \left(\dfrac{\Delta E}{m_X}\right)^2\right] |\langle f || a_p \hat{\sigma}_M^{(p)} + a_n \hat{\sigma}_M^{(n)} || i_* \rangle|^2$

Diagrams in detail (QED)

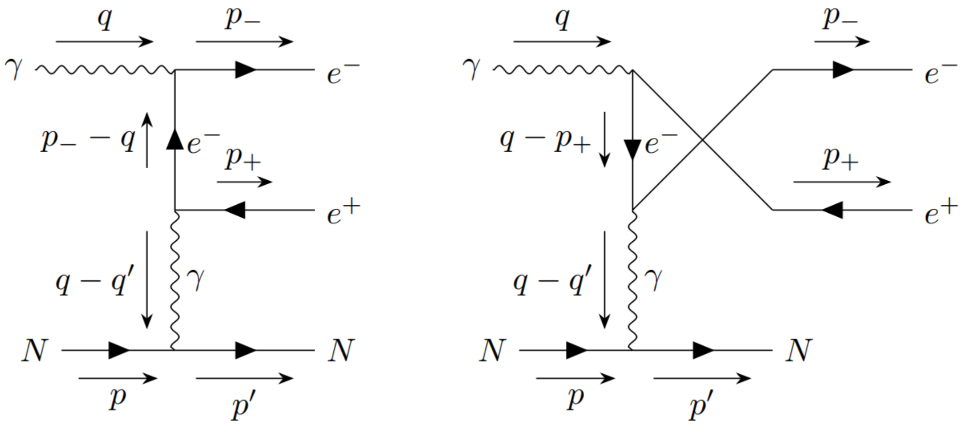


Figure 2: The direct and crossed diagram for the BH process.

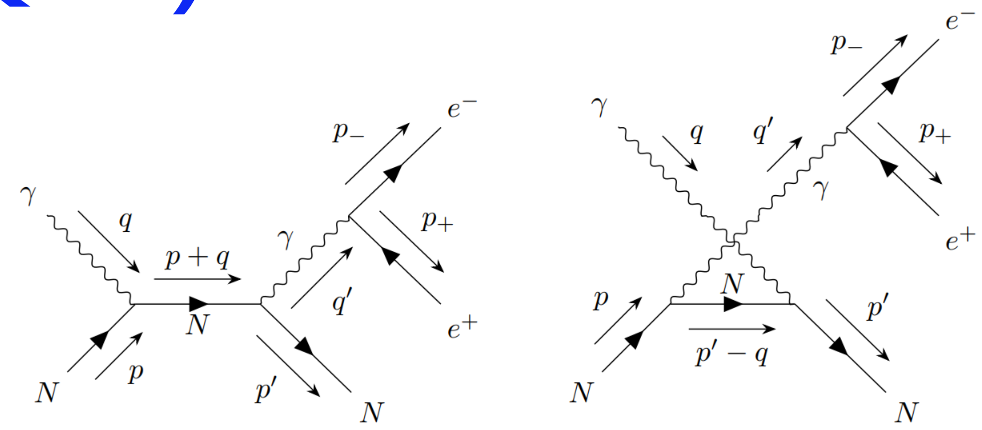


Figure 1: The direct and crossed diagram for the Born process.

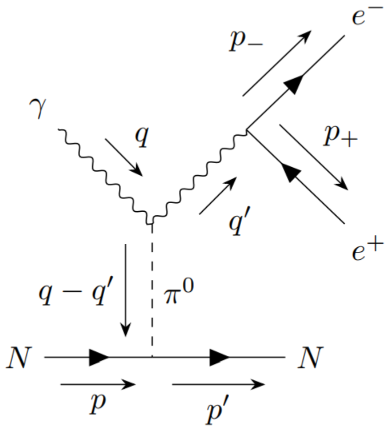
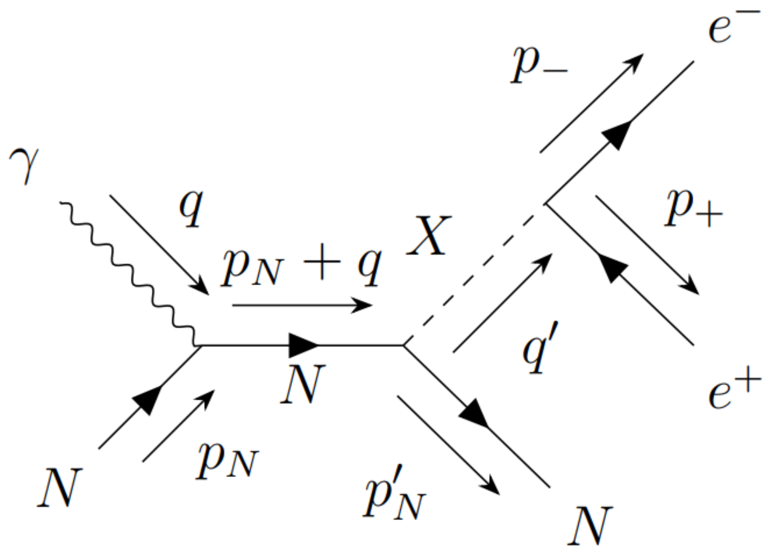
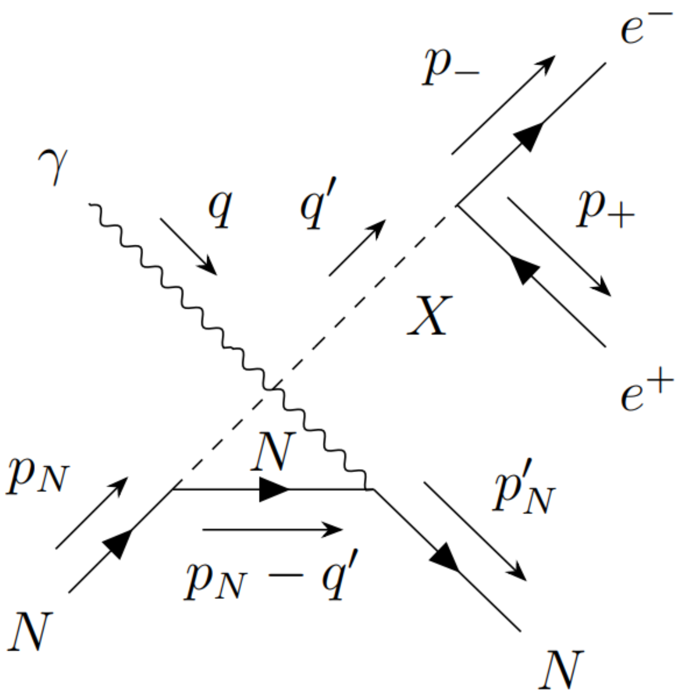


Figure 3: The diagram for the pion-pole amplitude.

Diagrams in detail (signal)

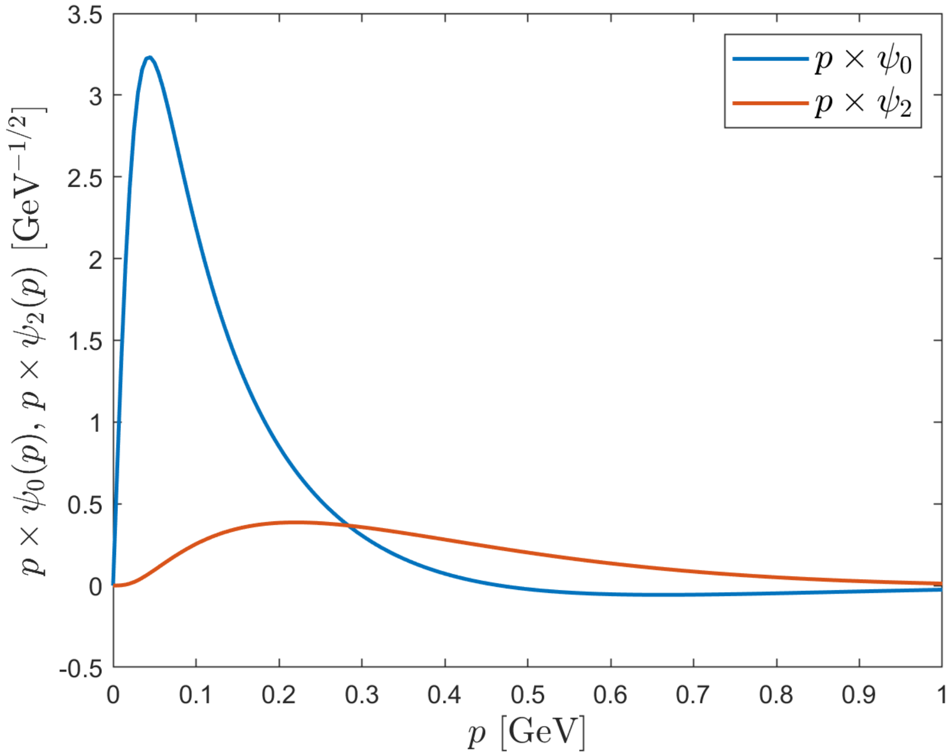




Deuteron wave function

- Use CD-Bonn wave function in momentum space (DOI: 10.1103/PhysRevC.63.024001)

$$\tilde{\Psi}_d^{M_d}(\boldsymbol{p}) = \frac{(2\pi)^{3/2}}{\sqrt{4\pi}} \left[\psi_0(p) - \frac{1}{\sqrt{8}} \psi_2(p) S_{12}(\hat{\boldsymbol{p}}) \right] \chi_1^{M_d}$$



PWIA

$$
\begin{aligned}
\mathcal{M}_{\mathrm{IA}}^{\mathrm{lab}}(d\gamma \to e^+e^-pn) = \frac{(2\pi)^{3/2}(2m_d)^{1/2}}{\sqrt{2}} \\
\times \Bigg\{ \left(\frac{E^{(n)}_{p_n}}{E^{(p)}_{p_n}}\right)^{1/2} \Bigg[\mathcal{M}\left(\gamma(\boldsymbol{q},\lambda)\, p(-\boldsymbol{p}_n, m_d - s_n) \to e^-(\boldsymbol{p}_-, s_-)\, e^+(\boldsymbol{p}_+, s_+)\, p(\boldsymbol{p}_p, s_p)\right) \\
\times \frac{1}{\sqrt{4\pi}} \psi_0(p_n) \left\langle \tfrac{1}{2}\, \tfrac{1}{2}\, ;\, m_d - s_n\, s_n \,\middle|\, 1 m_d \right\rangle \\
- \sum_{m_s=-1}^{+1} \mathcal{M}\left(\gamma(\boldsymbol{q},\lambda)\, p(-\boldsymbol{p}_n, m_s - s_n) \to e^-(\boldsymbol{p}_-, s_-)\, e^+(\boldsymbol{p}_+, s_+)\, p(\boldsymbol{p}_p, s_p)\right) \\
\times Y_2^{m_d - m_s}(-\hat{\boldsymbol{p}}_n)\psi_2(p_n) \left\langle 2\, 1\, ;\, m_d - m_s\, m_s \,\middle|\, 1\, m_d \right\rangle \left\langle \tfrac{1}{2}\, \tfrac{1}{2}\, ;\, m_s - s_n\, s_n \,\middle|\, 1\, m_s \right\rangle \Bigg] \\
+ \left(\frac{E^{(p)}_{p_p}}{E^{(n)}_{p_p}}\right)^{1/2} \Bigg[\mathcal{M}\left(\gamma(\boldsymbol{q},\lambda)\, n(-\boldsymbol{p}_p, m_d - s_p) \to e^-(\boldsymbol{p}_-, s_-)\, e^+(\boldsymbol{p}_+, s_+)\, n(\boldsymbol{p}_n, s_n)\right) \\
\times \frac{1}{\sqrt{4\pi}} \psi_0(p_p) \left\langle \tfrac{1}{2}\, \tfrac{1}{2}\, ;\, s_p\, m_d - s_p \,\middle|\, 1 m_d \right\rangle \\
- \sum_{m_s=-1}^{+1} \mathcal{M}\left(\gamma(\boldsymbol{q},\lambda)\, n(-\boldsymbol{p}_p, m_s - s_p) \to e^-(\boldsymbol{p}_-, s_-)\, e^+(\boldsymbol{p}_+, s_+)\, n(\boldsymbol{p}_n, s_n)\right) \\
\times Y_2^{m_d - m_s}(\hat{\boldsymbol{p}}_p)\psi_2(p_p) \left\langle 2\, 1\, ;\, m_d - m_s\, m_s \,\middle|\, 1\, m_d \right\rangle \left\langle \tfrac{1}{2}\, \tfrac{1}{2}\, ;\, s_p\, m_s - s_p \,\middle|\, 1\, m_s \right\rangle \Bigg] \Bigg\}.
\end{aligned}
$$

Averaging the signal

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|\boldsymbol{p}_+|\,\mathrm{d}|\boldsymbol{p}_-|\,\mathrm{d}\Omega_n\,\mathrm{d}\Omega_-\,\mathrm{d}\Omega_+} = \frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

We have

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right|_{\text{measured}} = \frac{1}{\delta m_X}\int_{m_X-\delta m_X/2}^{m_X+\delta m_X/2} \mathrm{d}\sqrt{q'^2}\,\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

Averaging the signal

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|\boldsymbol{p}_+|\,\mathrm{d}|\boldsymbol{p}_-|\,\mathrm{d}\Omega_n\,\mathrm{d}\Omega_-\,\mathrm{d}\Omega_+} = \frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

We have

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right|_{\text{measured}} = \frac{1}{\delta m_X}\int_{m_X-\delta m_X/2}^{m_X+\delta m_X/2} \mathrm{d}\sqrt{q'^2}\,\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

$$\frac{1}{q'^2}\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right)\frac{\left[\left(q'^2-m_X^2\right)^2+\left(m_X\Gamma_X\right)^2\right]}{g_{Xee}^2} \approx \text{constant between } \left[m_X-\frac{\delta m_X}{2}, m_X+\frac{\delta m_X}{2}\right]$$

Averaging the signal

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|\boldsymbol{p}_+|\,\mathrm{d}|\boldsymbol{p}_-|\,\mathrm{d}\Omega_n\,\mathrm{d}\Omega_-\,\mathrm{d}\Omega_+} = \frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

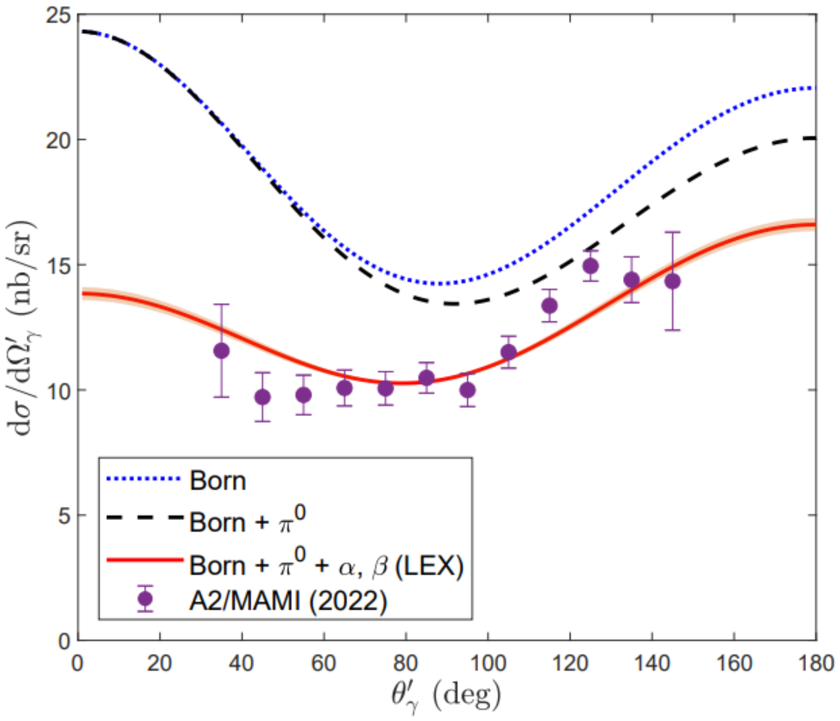
We have

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right|_{\text{measured}} = \frac{1}{\delta m_X}\int_{m_X-\delta m_X/2}^{m_X+\delta m_X/2} \mathrm{d}\sqrt{q'^2}\,\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}.$$

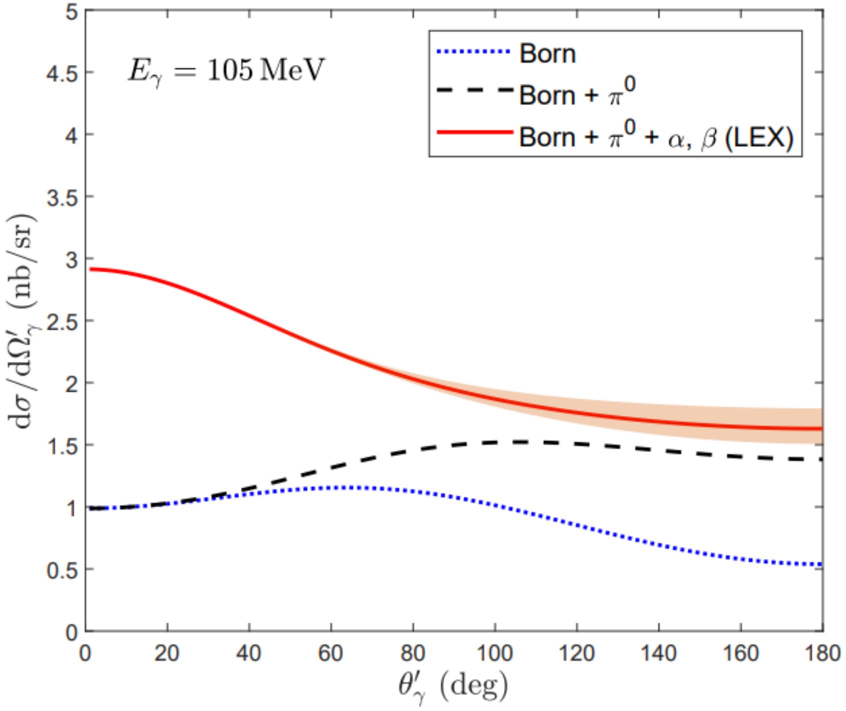
$$\frac{1}{q'^2}\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right)\frac{\left[(q'^2-m_X^2)^2+(m_X\Gamma_X)^2\right]}{g_{Xee}^2} \approx \text{constant between } \left[m_X-\frac{\delta m_X}{2}, m_X+\frac{\delta m_X}{2}\right]$$

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right|_{\text{measured}} \approx \left.\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Pi}\right)\right|_{q'^2=m_X^2,\,\varepsilon_e^2=1,\,\Gamma_X=1} \frac{1}{\delta m_X}\frac{6\pi^2}{e^2 m_X}\left(1+\frac{2m_e^2}{m_X^2}\right)^{-1}\left(1-\frac{4m_e^2}{m_X^2}\right)^{-1/2}\mathcal{B}(a\to e^+e^-),$$

Verifying the QED background (I)



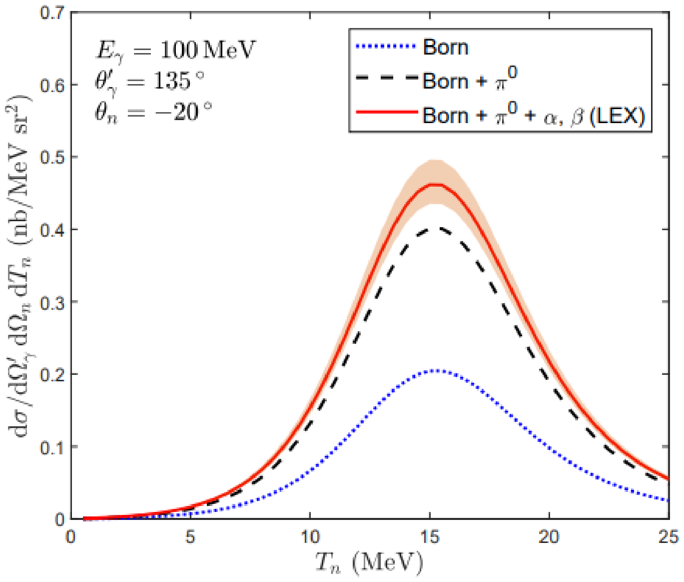
(a) $\gamma p \to \gamma p$



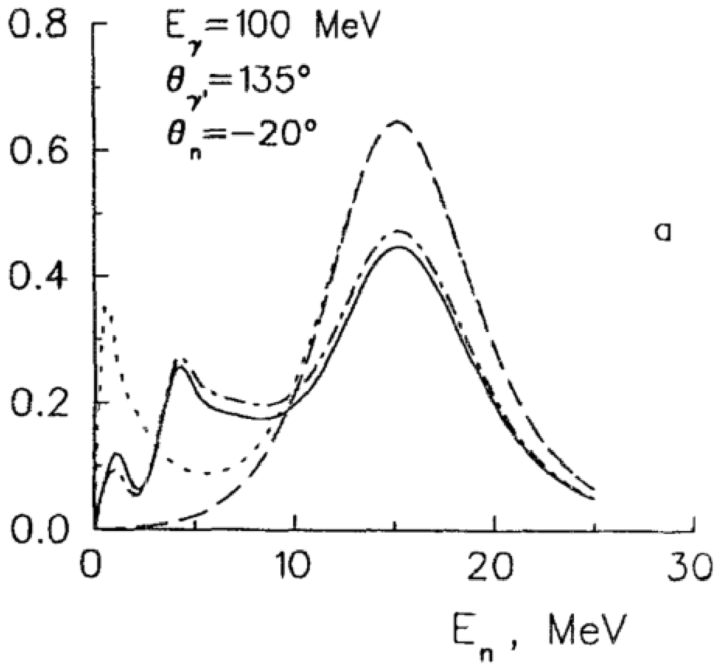
(b) $\gamma n \to \gamma n$

Verifying the QED background (II)

Few Body Syst. 16 (1994) 101-125
DOI: 10.1007/BF01355284



(a) $\gamma D \to \gamma p n$ (mine, PWIA)



(b) $\gamma D \to \gamma p n$ (Levchuk, PWIA [dashed], DWIA [dash-dot], DWIA + MEC [full])

Optimizing kinematics

1. $|\boldsymbol{p}_p| < (m_N\,\Delta)^{1/2} \sim 45.7$ MeV/c
2. $15\,° < |\theta_i| < 165\,°$, i = +, -
3. $5\,° < |\theta_n| < 165\,°$,
4. $|\boldsymbol{p}_\pm| > 20$ MeV/c

- Scan parameter range
- Find maximum
- Fine tune parameters