JOHANNES GUTENBERG UNIVERSITÄT MAINZ

X17 discovery potential in $\gamma p \rightarrow e^+e^-p$ and $\gamma D \rightarrow e^+e^-pn$ with neutron tagging

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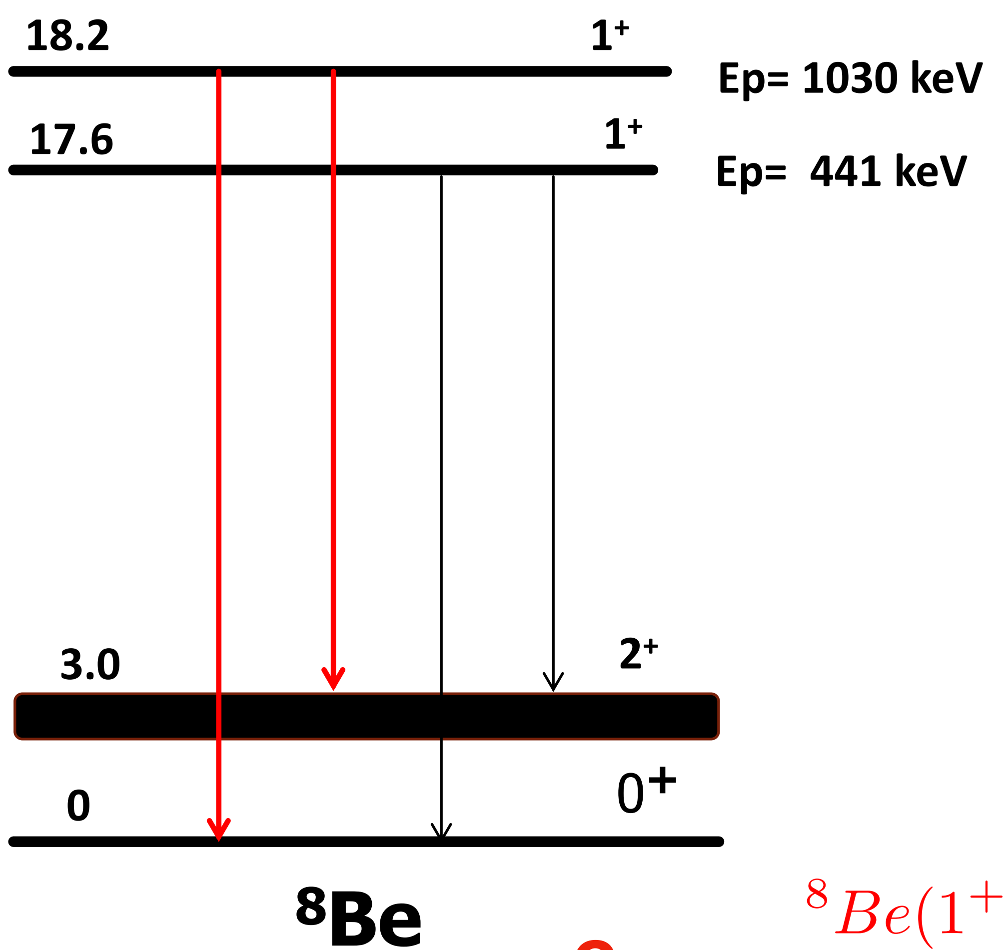
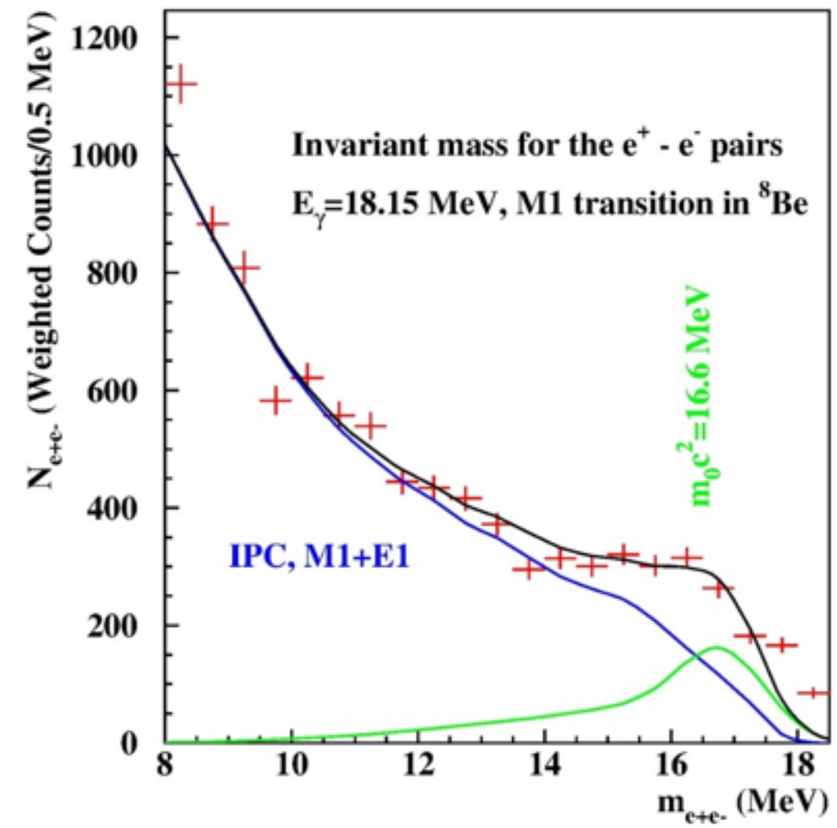
JLab PWG meeting, January 31, 2024

JGU, Mainz

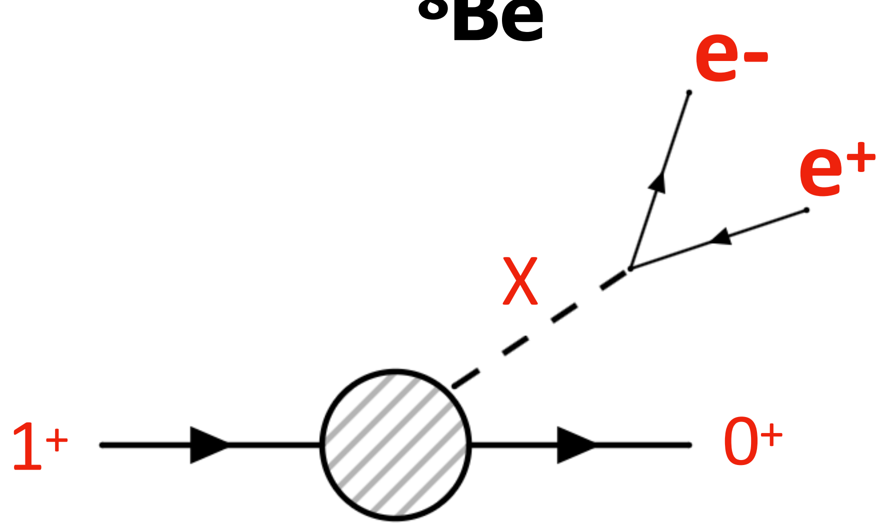
X17 in ^{8}Be (ATOMKI Coll.)

Excitation with the
$^7Li(p,\gamma)^8Be$ reaction





Krasznahorkay et al.,PRL 116,042501 (2016)



$$^8Be(1^+18.2) \rightarrow {}^8Be(0^+g.s.) + X \rightarrow {}^8Be(0^+g.s.) + e^-e^+$$

quantum numbers: **X** is either **0^-, 1^-, 1^+** state

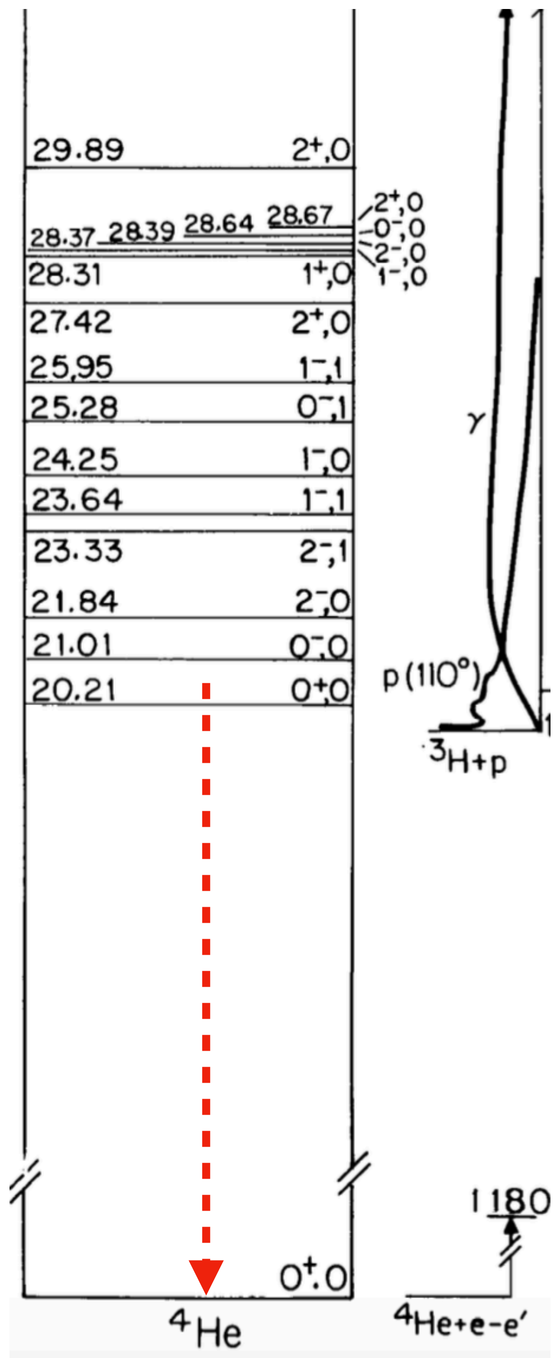
Several theoretical explanations:

- mostly as dark photon (1^-) Feng et al.(2017)
- light pseudoscalar (0^-) Ellwanger, Moretti(2016) Alves, Weiner(2018)

X17 in ^{4}He (ATOMKI Coll.)

0$^-$: Γ = 0.84 MeV

0$^+$: Γ = 0.50 MeV



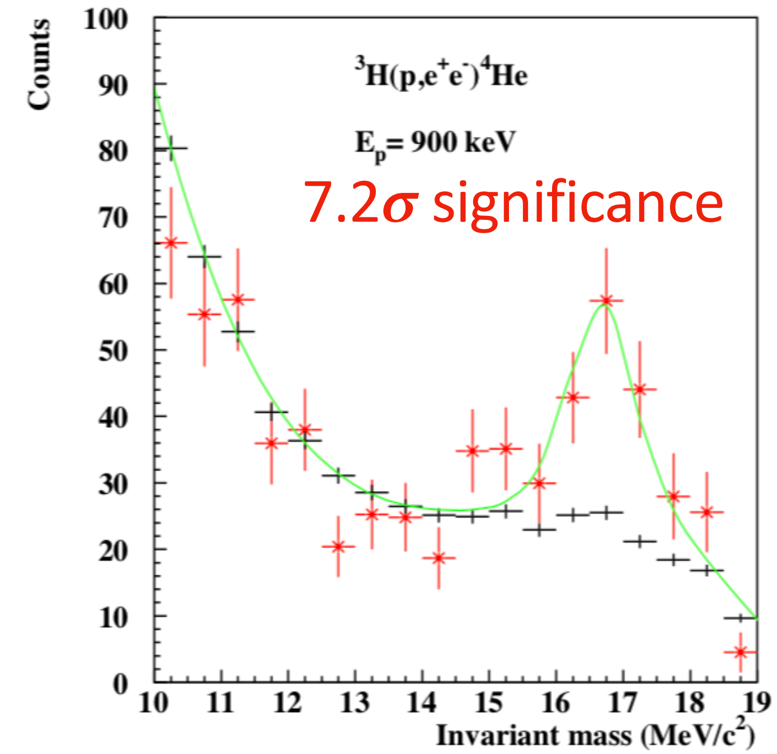


FIG. 3. *Invariant mass distribution derived for the 20.49 MeV transition in* ^{4}*He.*

$$^4\mathrm{He}(0^-, 21.01) \rightarrow ^4\mathrm{He}(0^+, g.s.) + X \rightarrow ^4\mathrm{He}(0^+, g.s.) + e^- e^+$$

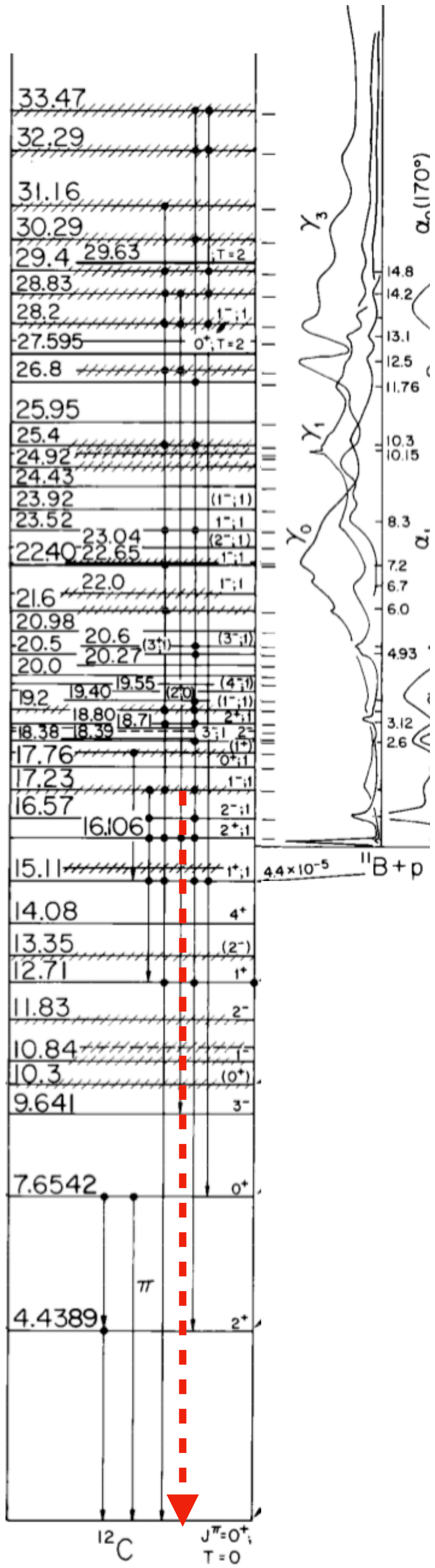
quantum numbers: **X** is either **0$^-$** or **1$^+$** state

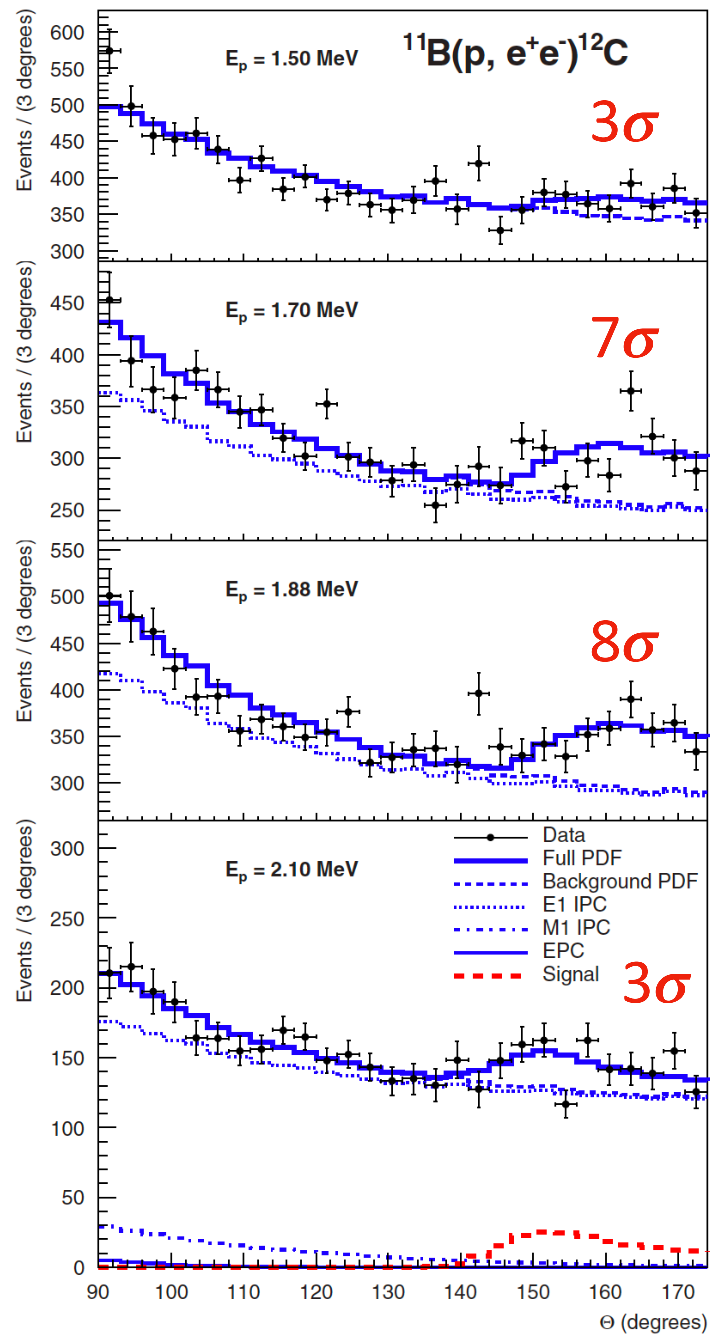
$$^4\mathrm{He}(0^+, 20.21) \rightarrow ^4\mathrm{He}(0^+, g.s.) + X \rightarrow ^4\mathrm{He}(0^+, g.s.) + e^- e^+$$

quantum numbers: **X** is either **0$^+$** or **1$^-$** state

Krasznahorkay et al.,PRC 104,044003 (2021)

X17 in ^{12}C (ATOMKI Coll.)





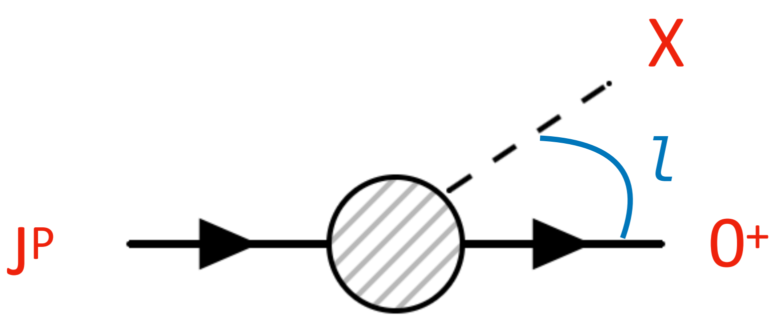
$$m_X = 17.03 \pm 0.11 \text{ (stat.)} \pm 0.20 \text{ (syst.) MeV}$$

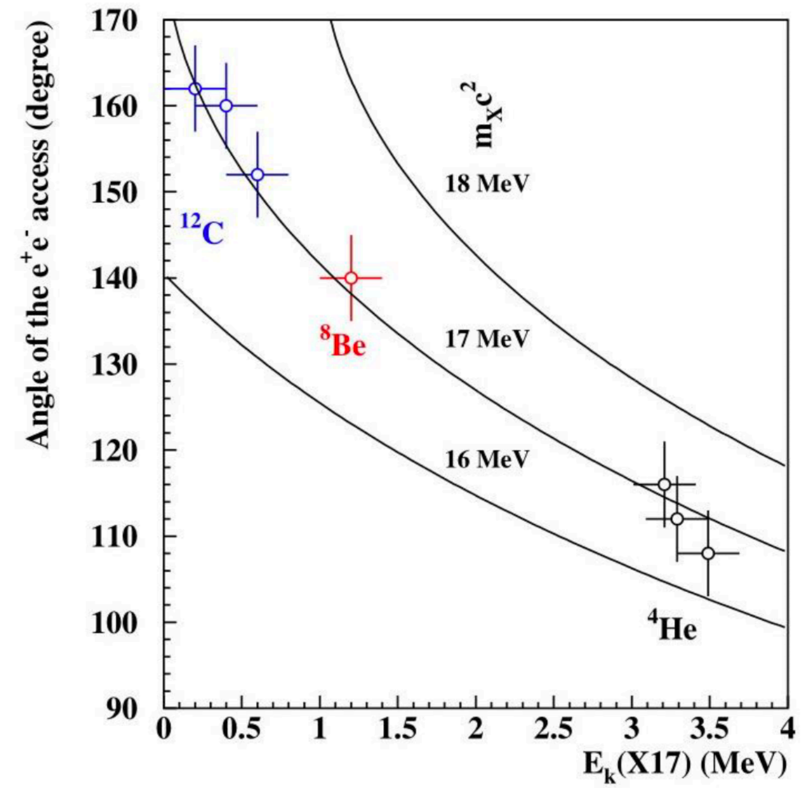
Krasznahorkay et al., PRC 106,L061601(2022)

$$^{12}\mathrm{C}(1^-, 17.23) \rightarrow ^{12}\mathrm{C}(0^+, g.s.) + X \rightarrow ^{12}\mathrm{C}(0^+, g.s.) + e^- e^+$$

quantum numbers: **X** is either **0⁺**, **1⁺** or **1⁻** state

Summary of ATOMKI X17 observations





Transition			Signal	Scalar	Pseudoscalar	Vector	Axial-vector
^{8}Be	$1^+(18.15) \to 0^+$	(M1, IS)	YES		$l=1$	$l=1$	$l=0,2$
^{8}Be	$1^+(17.64) \to 0^+$	(M1, IV)	NO		$l=1$	$l=1$	$l=0,2$
^{4}He	$0^-(21.01) \to 0^+$	(M0)	YES/NO		$l=0$		$l=1$
^{4}He	$0^+(20.21) \to 0^+$	(E0)	YES/NO	$l=0$		$l=1$	
^{12}C	$1^-(17.23) \to 0^+$	(E1, IV)	YES	$l=1$		$l=0,2$	$l=1$

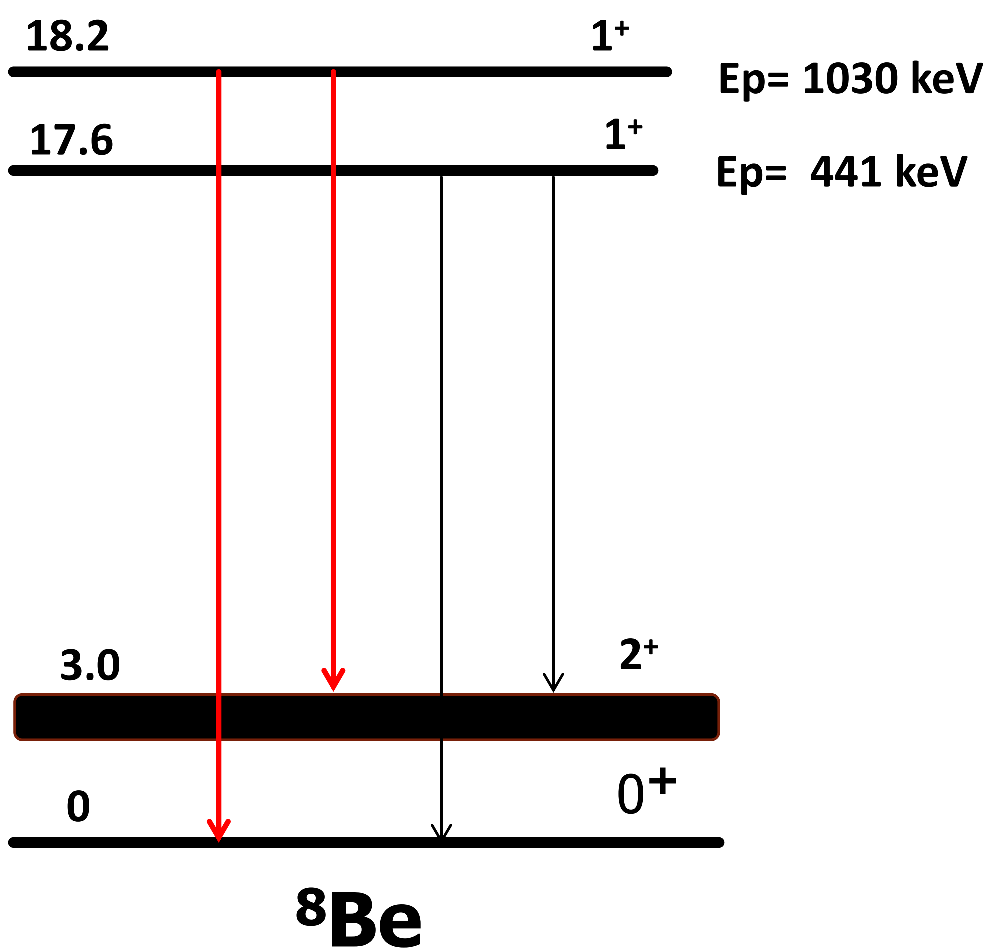
Feng, Tait, Verhaaren, PRD 102,036016(2020)

The reported 7σ anomalies reported in ^{8}Be and ^{4}He nuclear decays are both kinematically and dynamically consistent with the production of a 17 MeV protophobic gauge boson

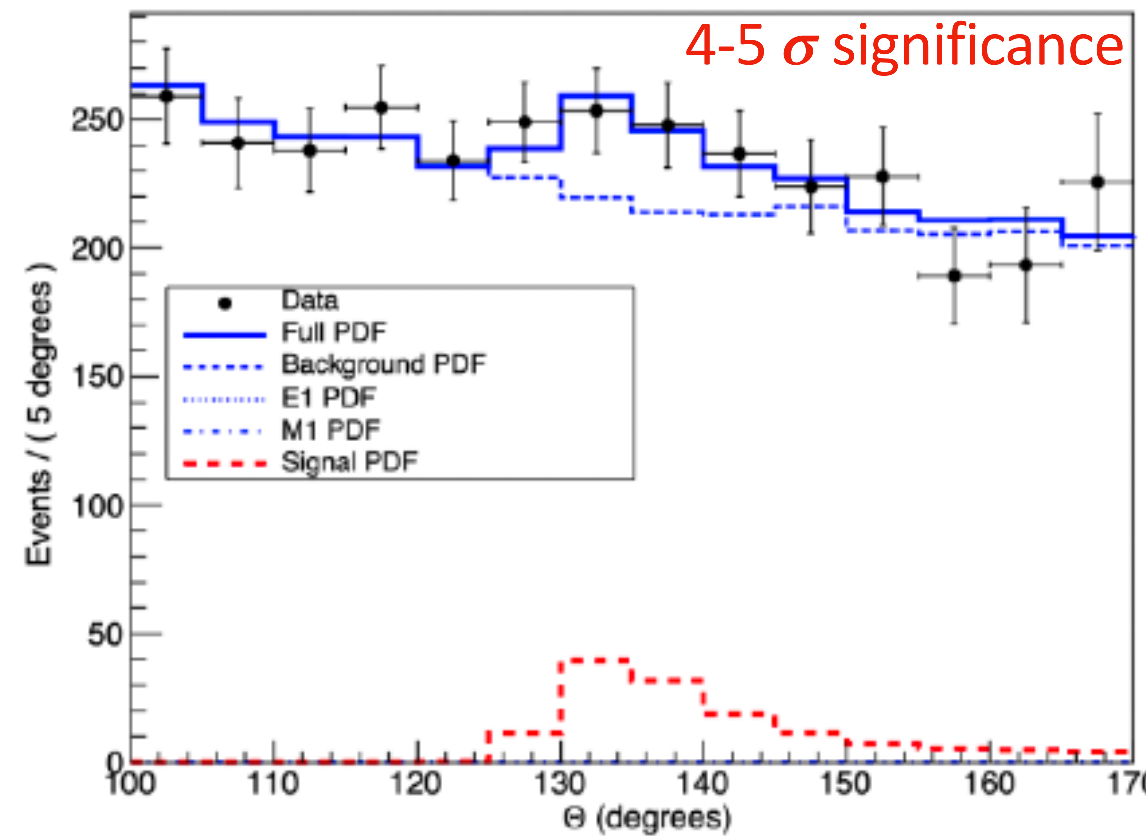
bound from NA48/2: $|\varepsilon_p| < 1.2 \times 10^{-3}$

X17 in ^{8}Be: VNU Experiment

Excitation with the $^{7}Li(p,\gamma)^{8}Be$ reaction



$$^{8}Be(1^{+}18.2) \rightarrow {}^{8}Be(0^{+}g.s.) + X \rightarrow {}^{8}Be(0^{+}g.s.) + e^{-}e^{+}$$

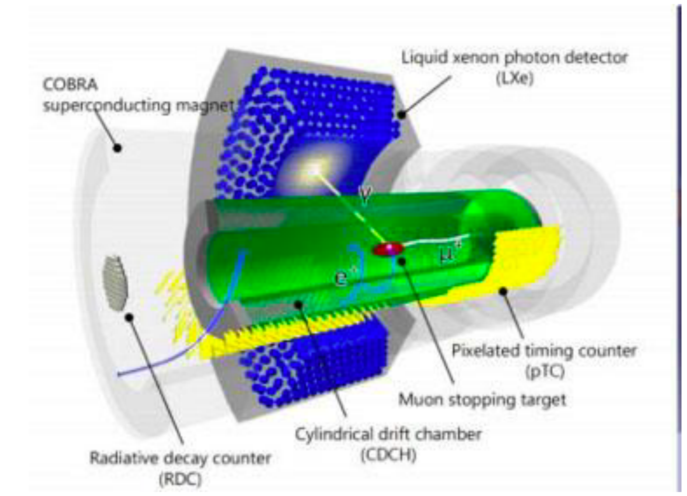


$$m_X = 16.7 \pm 0.47(\text{stat.}) \pm 0.35(\text{syst.}) \quad \text{MeV}$$

Tran The Anh et al.,arXiv:2401.11676 [nucl-ex]

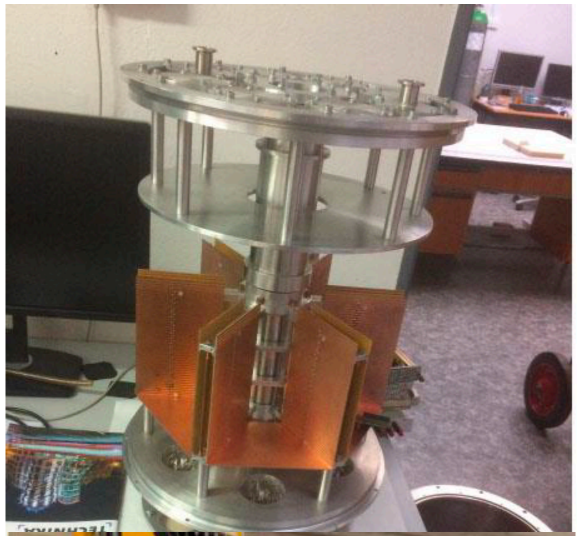
VNU experiment confirms X17 observation (with 4-5 σ significance) in ^{8}Be decay from 18.2 MeV state and its absence in decay of 17.6 MeV state

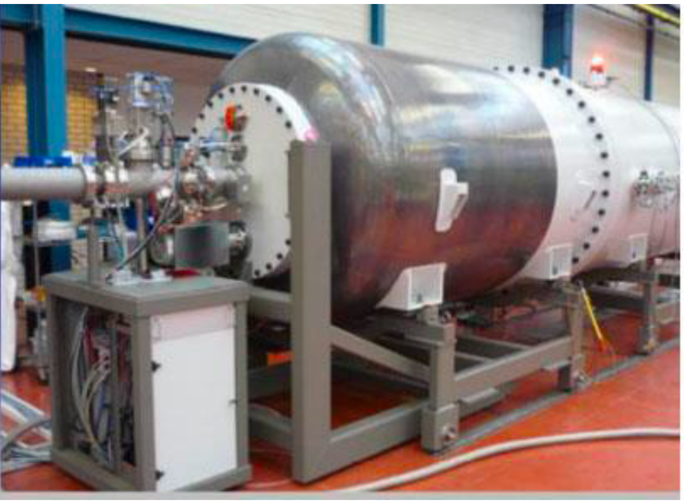
Ongoing nuclear physics efforts



MEGII @PSI
$^{7}Li(p,X17)\ ^{8}Be$
MeV Cockroft Walton
Tracking DCH, LXe
Taking data

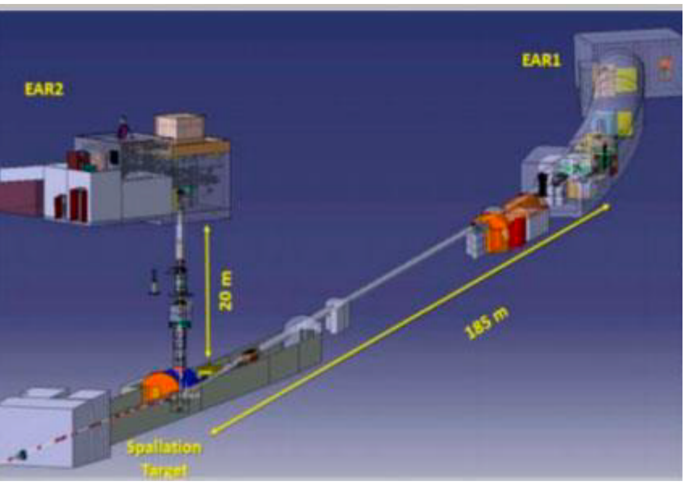
COPE @ IEAP – CTU Prague
$^{7}Li(p,X17)\ ^{8}Be$
2.5 MeV Van de Graaff
Mag. spectrometer ATOMKI → IEAP
Vertexing with Timepix 3





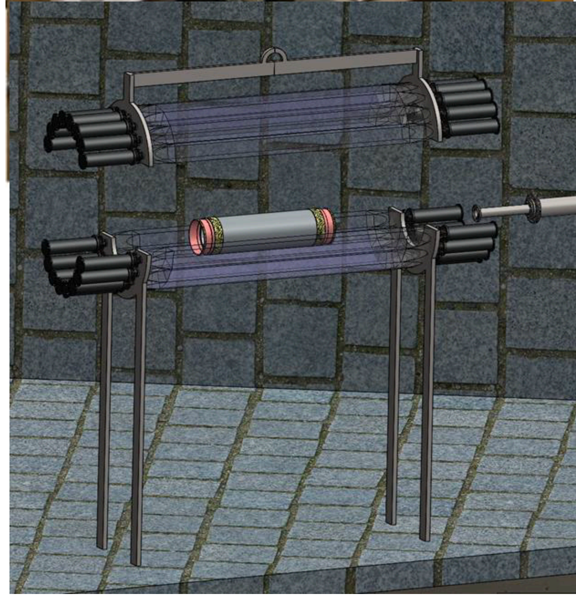
NUCLEX @ LNGS
$^{3}H(p,X17)\ ^{4}He$
I_p = 100 μA
Dedicated detector
LoI 2022

NewJedi @ IJCLab, GANIL, Ithemba
$^{7}Li(p,X17)\ ^{8}Be;\ \ ^{3}H(p,X17)\ ^{4}He$
Vertexing w. DSSSDs;
E- plastic scints.
Ongoing



N_Tof @ CERN
$^{3}He(n,X17)\ ^{4}He$
Pulsed n- beam
Dedicated detector
LoI 2022

Project X17 @ U. Montreal
$^{7}Li(p,X17)\ ^{8}Be;$
$^{7}Li(\ ^{3}He,X17)^{10}B$
DAPHNE vertex chamber;
E- plastic scints 0.95 4π
Ongoing

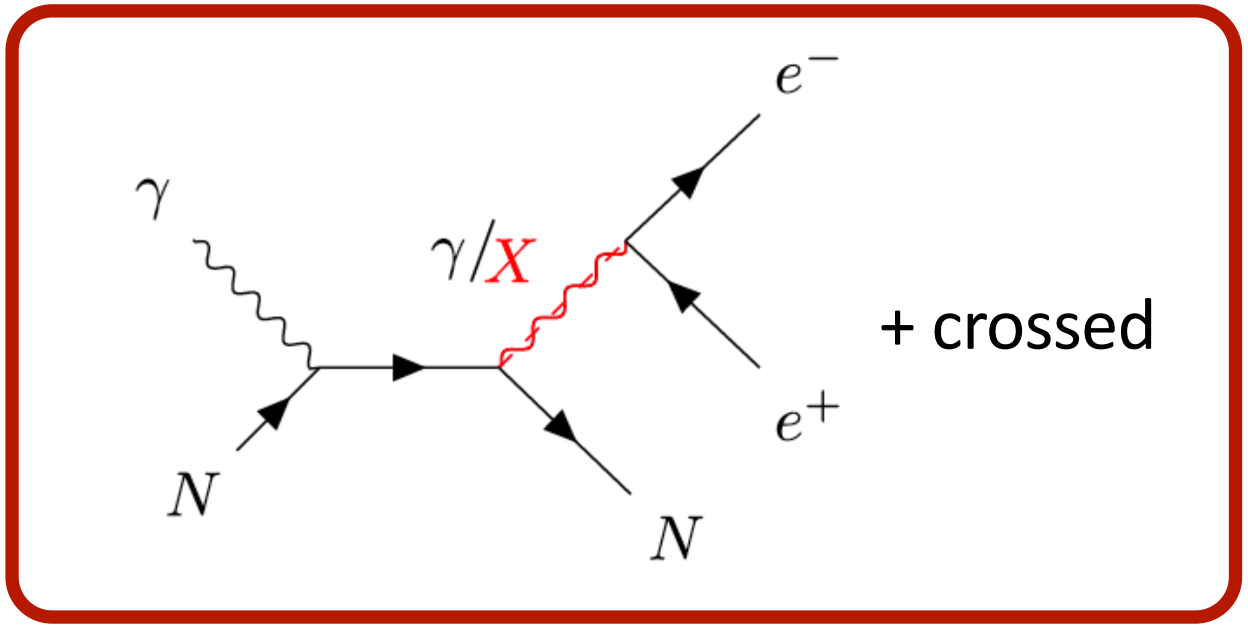


Ongoing efforts at accelerators

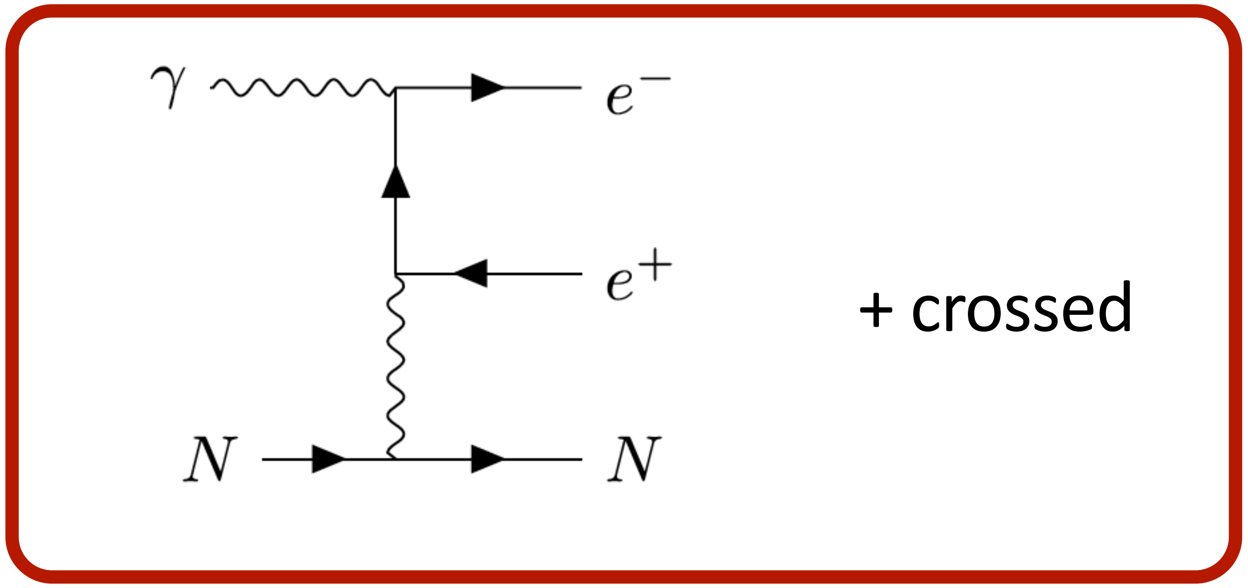
- Darklight @ ARIEL (TRIUMF)
- PADME@Frascati
- NA64@CERN/SPS
- JLab
- MAMI, MAGIX@MESA
- …

X17 production in $\gamma N \rightarrow e^+e^- N$

➡ Signal process: X17 production



➡ Background process:
Bethe-Heitler
+ Compton: (X replaced by γ in above graph)



Background process suppressed at small -t on neutron

X17 production in $\gamma N \rightarrow e^+e^- N$

- For X17 signal process: 3 scenarios were studied, **0^-, 1^-, 1^+** assuming a $BR(X \rightarrow e^-e^+) = 1$

- Coupling to nucleons:

$J^P = 0^-$ $$\mathcal{L}_{PS} = i\bar{N}\gamma_5 \left(g^{(0)}_{XNN} + g^{(1)}_{XNN}\tau_3 \right) NX$$

$J^P = 1^-$ $$\mathcal{L}_V = -eX_\mu \sum_q \varepsilon_q \bar{q}\gamma^\mu q$$

proton, neutron couplings: $$\varepsilon_p = 2\varepsilon_u + \varepsilon_d$$ $$\varepsilon_n = \varepsilon_u + 2\varepsilon_d$$

$J^P = 1^+$ $$\mathcal{L}_A = -X_\mu \sum_q g_q \bar{q}\gamma^\mu \gamma_5 q$$

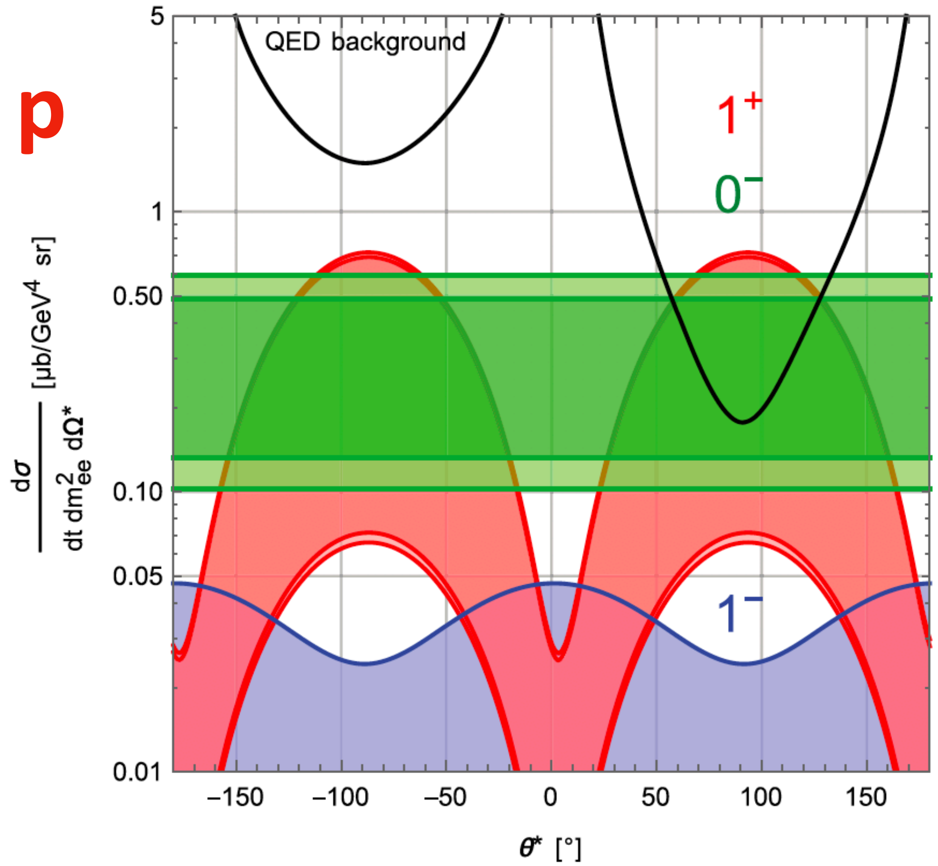
- Constraints on couplings from existing exclusions + ATOMKI ^{8}Be

J^P_X	$m_X = 17.01$ MeV	1σ uncertainty in m_X
0^-	$\lvert g^{(1)}_{XNN}\rvert = (0-0.6) \times 10^{-3}$	
	$g^{(0)}_{XNN} = (3.0-4.0) \times 10^{-3}$	$g^{(0)}_{XNN} = (2.7-4.4) \times 10^{-3}$
1^-	$\lvert\varepsilon_p\rvert = (0-0.12) \times 10^{-2}$	
	$\lvert\varepsilon_n\rvert = (1.2-1.7) \times 10^{-2}$	$\lvert\varepsilon_n\rvert = (1.1-1.9) \times 10^{-2}$
1^+	$a_{p,n} = (1.9-5.9) \times 10^{-5}$	$a_{p,n} = (1.8-6.1) \times 10^{-5}$

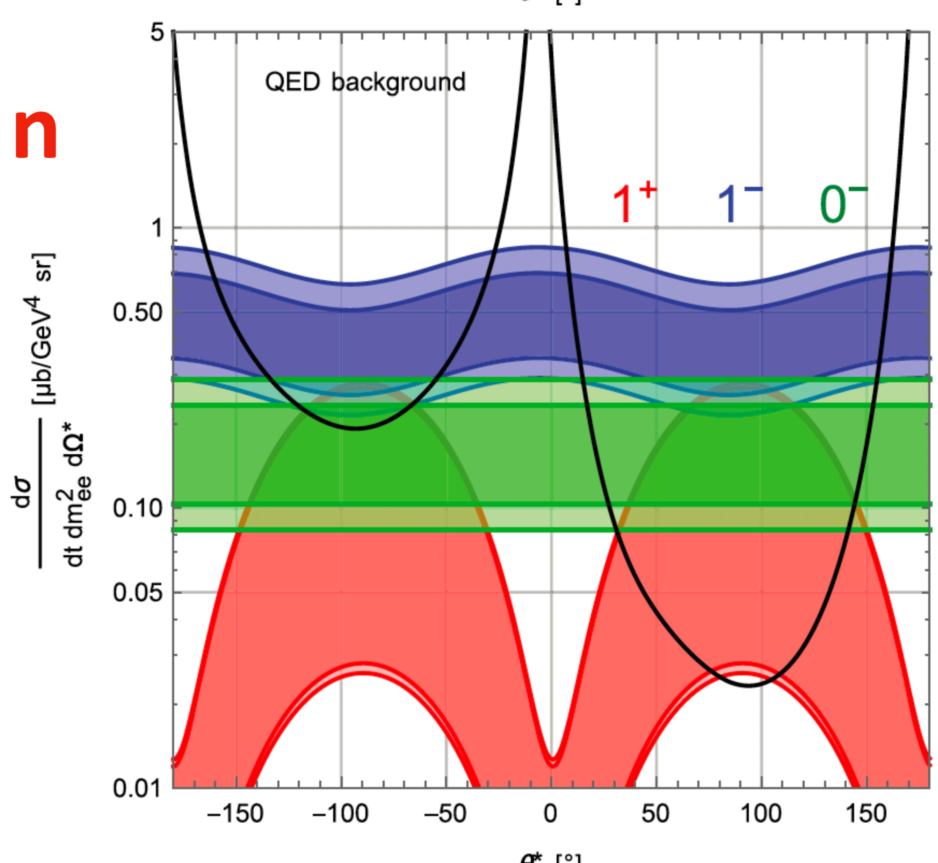
Backens, Vdh,
PRL 128,091802 (2022)

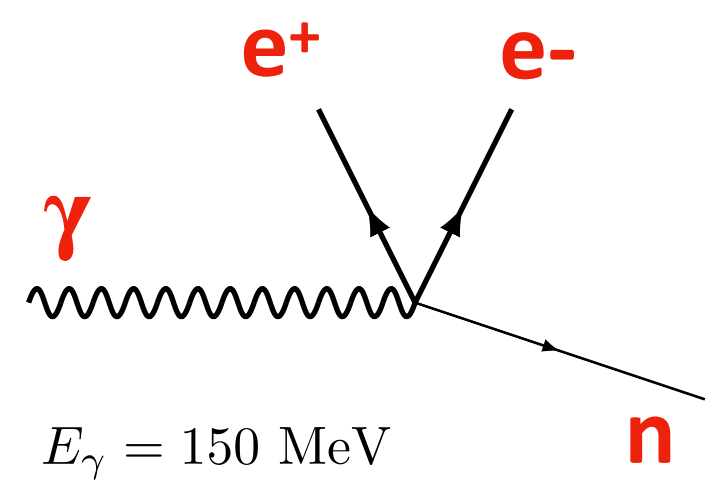
X17 production in $\gamma N \rightarrow e^+e^- N$

$\gamma p \rightarrow e^+e^- p$



$\gamma n \rightarrow e^+e^- n$





$E_\gamma = 150$ MeV

$e^+ : \quad p = 63.2$ MeV/c, $\quad \theta = 100^o$

$e^- : \quad p = 65.5$ MeV/c, $\quad \theta = 85.2^o$

$n : \quad p = 201$ MeV/c, $\quad \theta = 39.3^o$

QED background: BH + Born

Signal curves: X17-NN couplings range from ATOMKI expt.

Signal X17: 0^-

Signal X17: 1-

Signal X17: 1^+

$\delta m_{e^-e^+} = 0.2$ MeV

Backens, Vdh, PRL 128,091802 (2022)

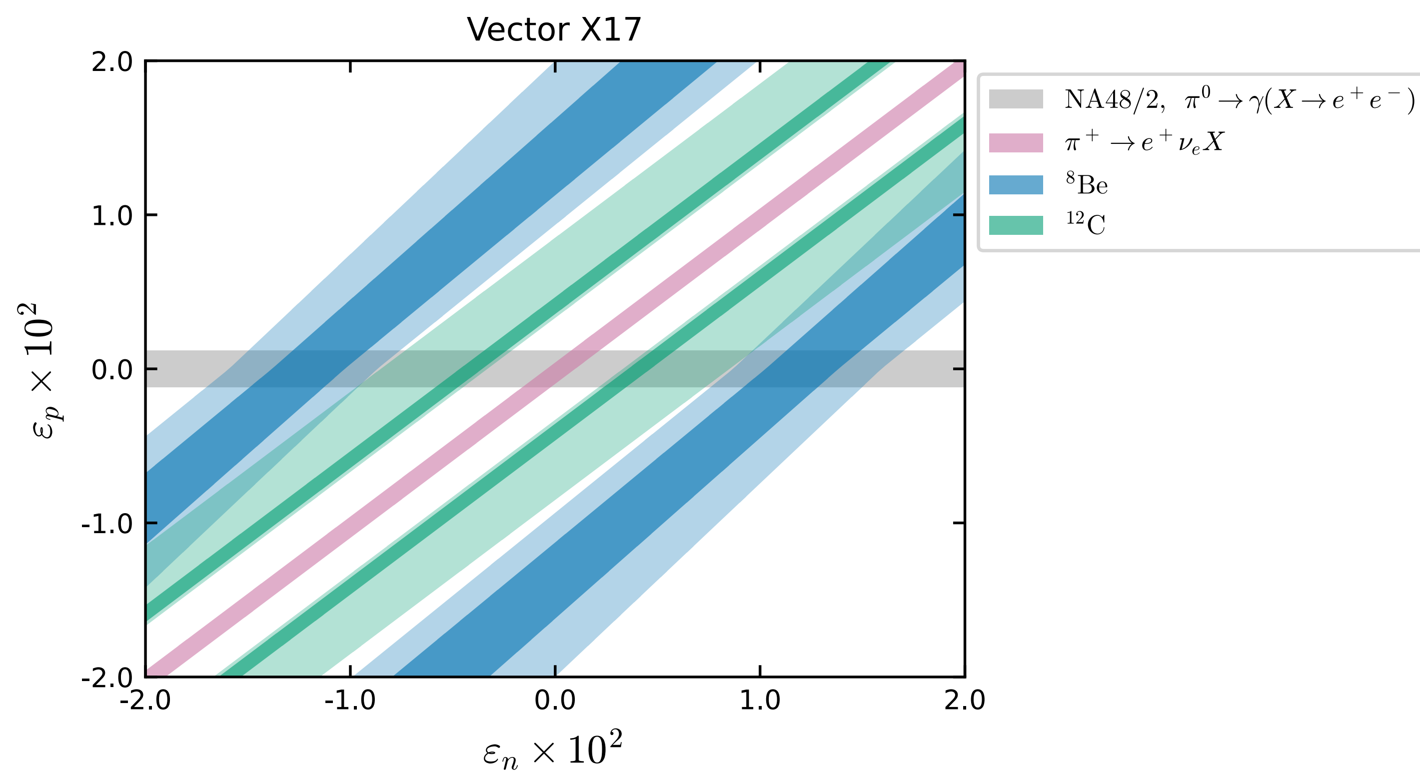
Limits on X17 to proton and neutron couplings

Allowed couplings for **1⁻ X17** state

- Protophobic (NA48/2)
- tension between extractions

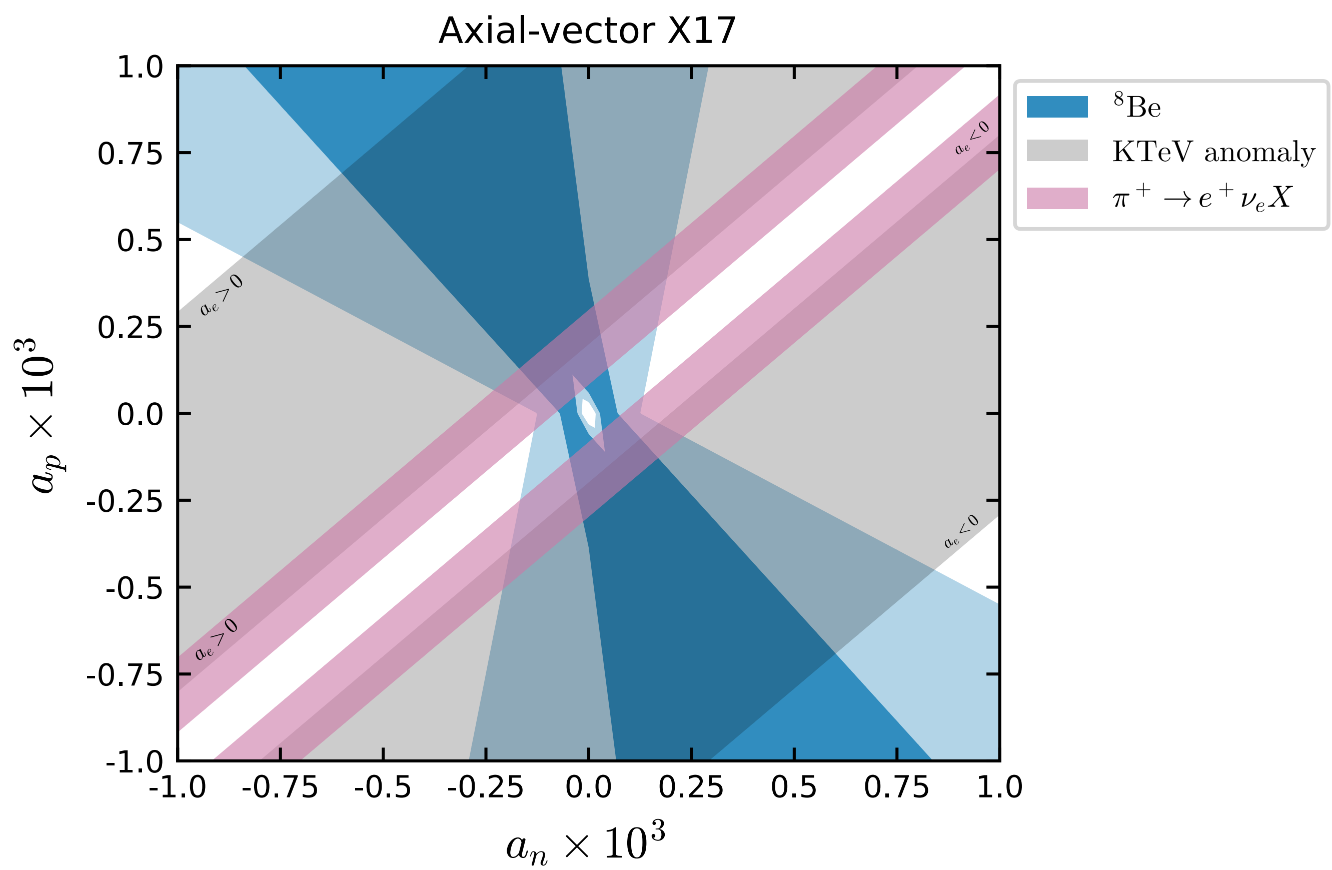
Dark bands: 1σ limits

Light bands: 2σ limits



Allowed couplings for **1⁺ X17** state

Larger uncertainty in nuclear axial-vector matrix element



Barducci,Toni: JHEP02,154 (2023)

Hostert,Pospelov: PRD108,055011 (2023)

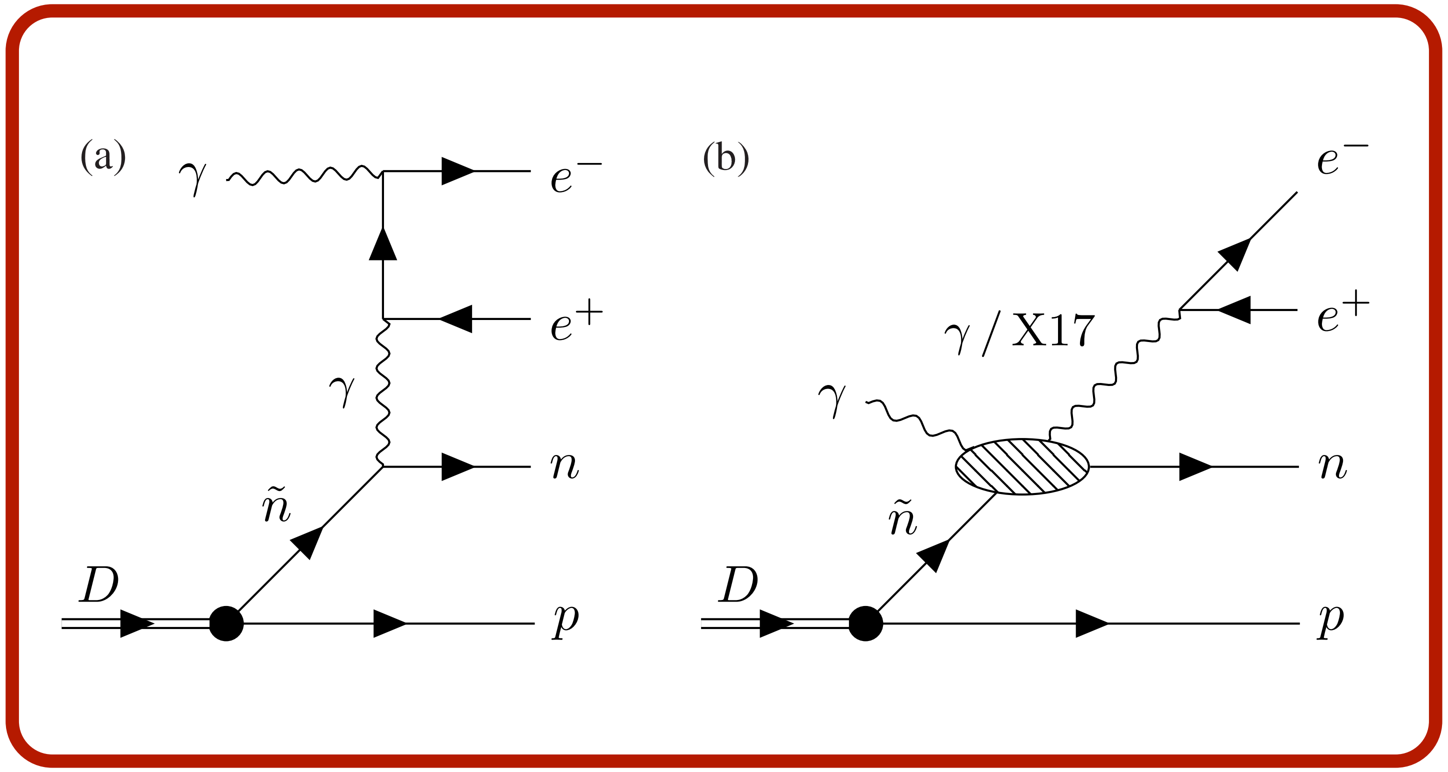
Mommers,Vdh: arXiv:2307.02181[hep-ph]

How to realise an experiment on neutron

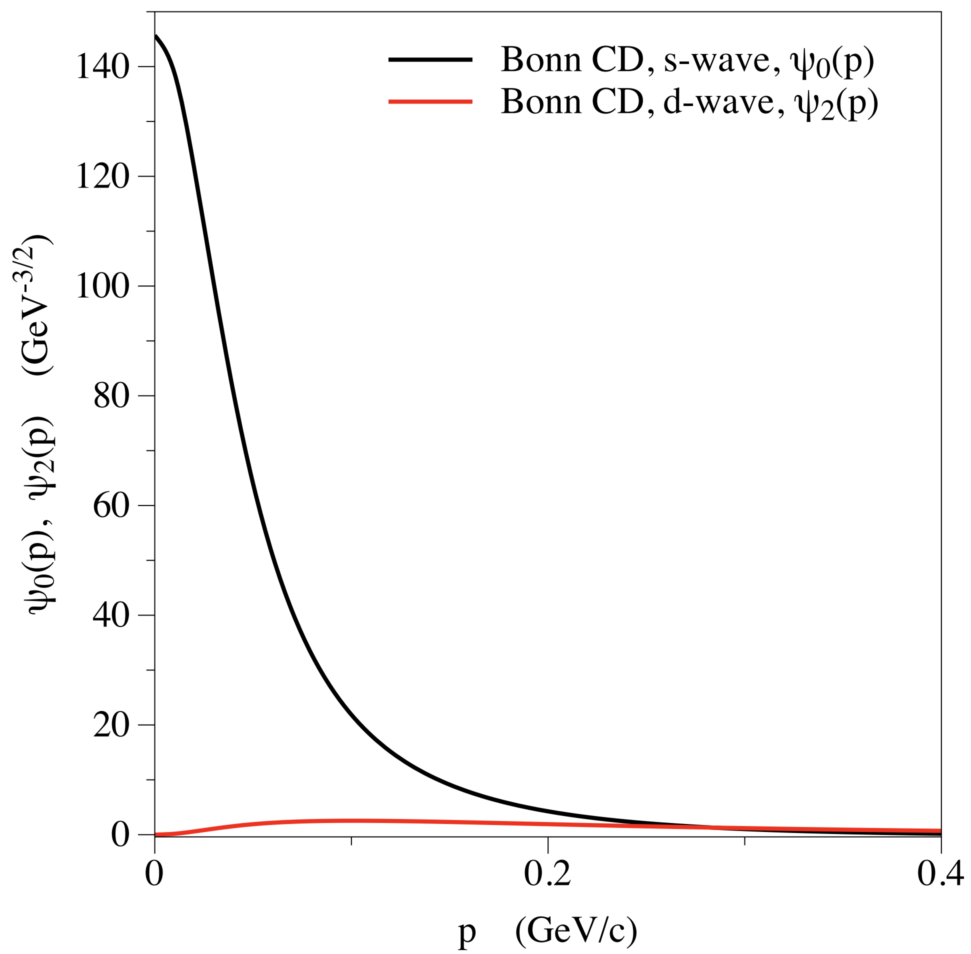
- Deuteron target and **neutron tagging:** **$\gamma D \rightarrow e^+e^- np$** process

  to select process on neutron, proton has to be spectator

  momentum neutron >> momentum proton

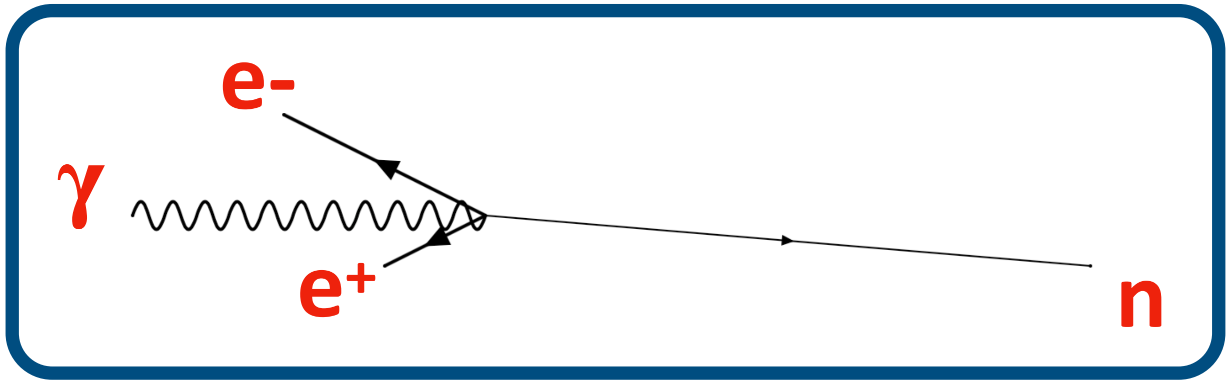


Deuteron wavefunction



Machleidt,
PRC 63,024001 (2001)

X17 search in $\gamma D \longrightarrow e^+e^- np$ at MAGIX@MESA



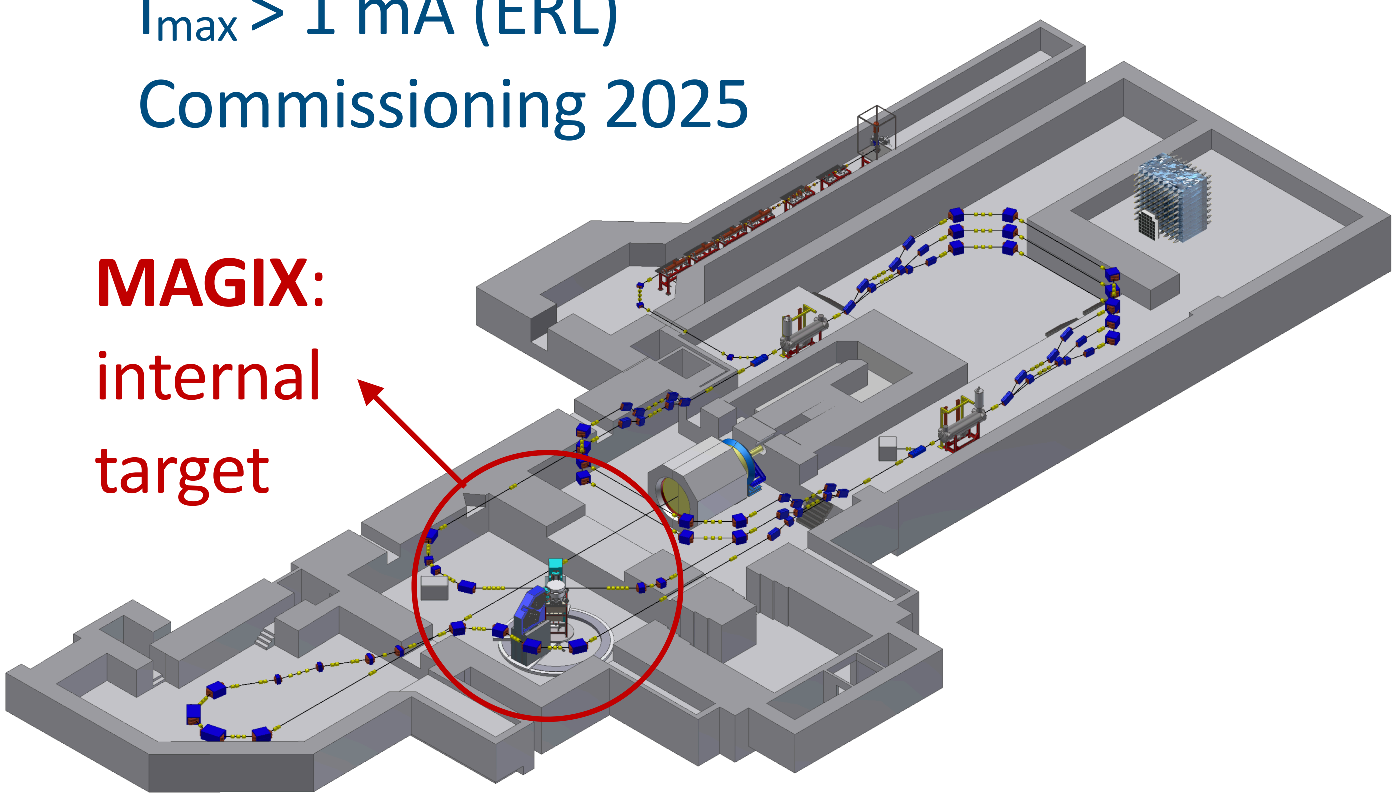
Recirculating ERL

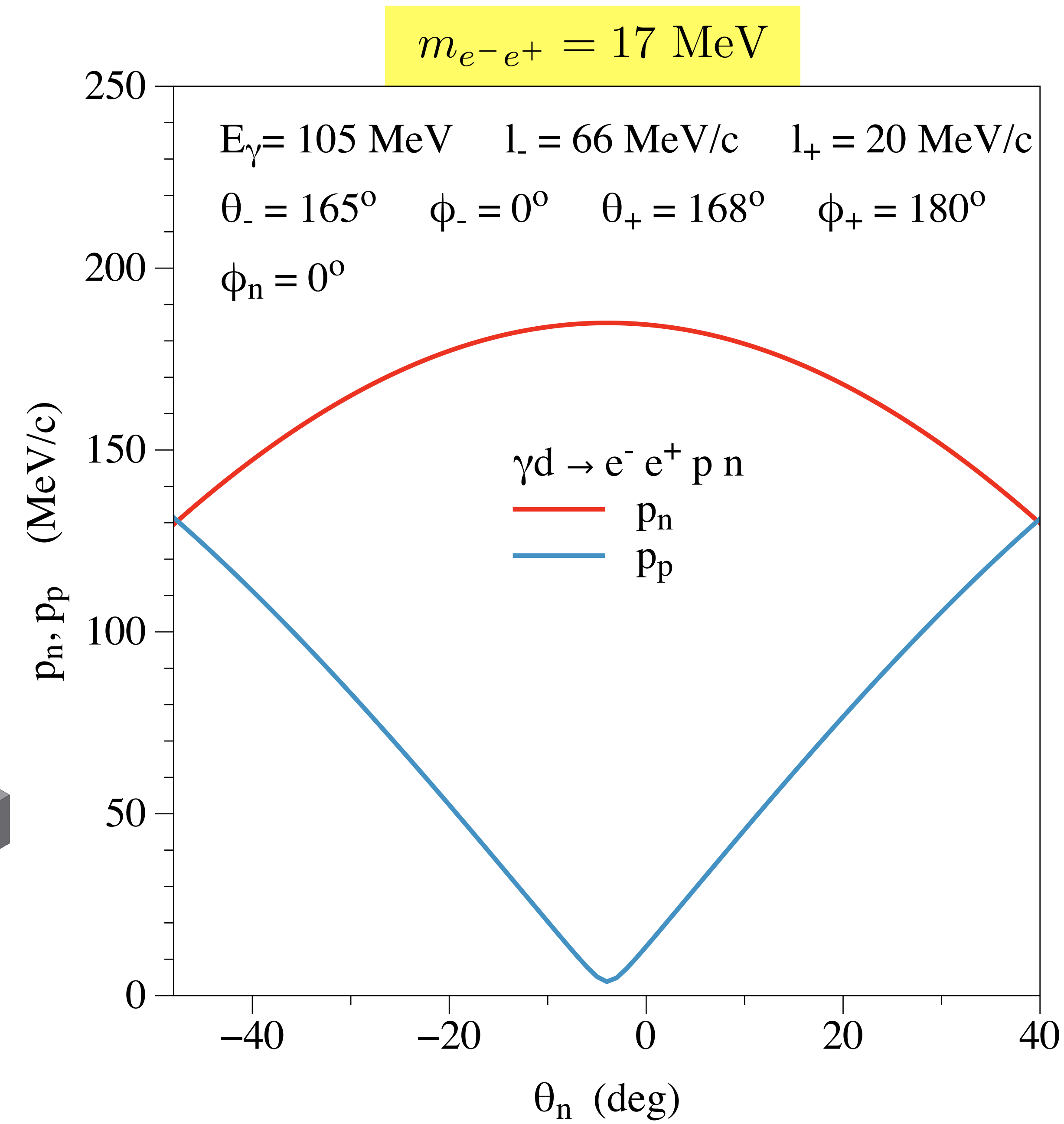
E_{max} = 105 / 155 MeV

I_{max} > 1 mA (ERL)

Commissioning 2025

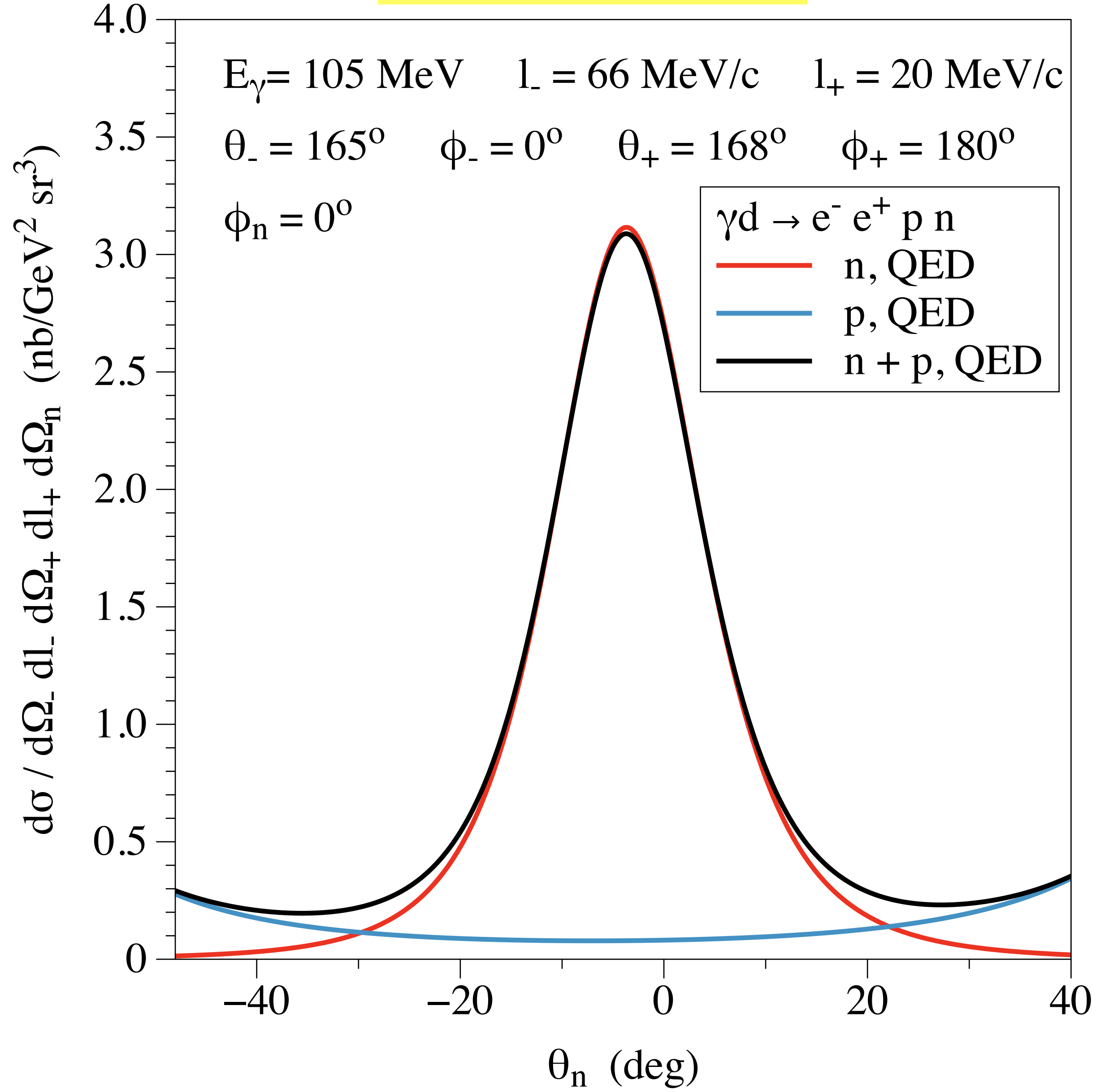
MAGIX:
internal
target





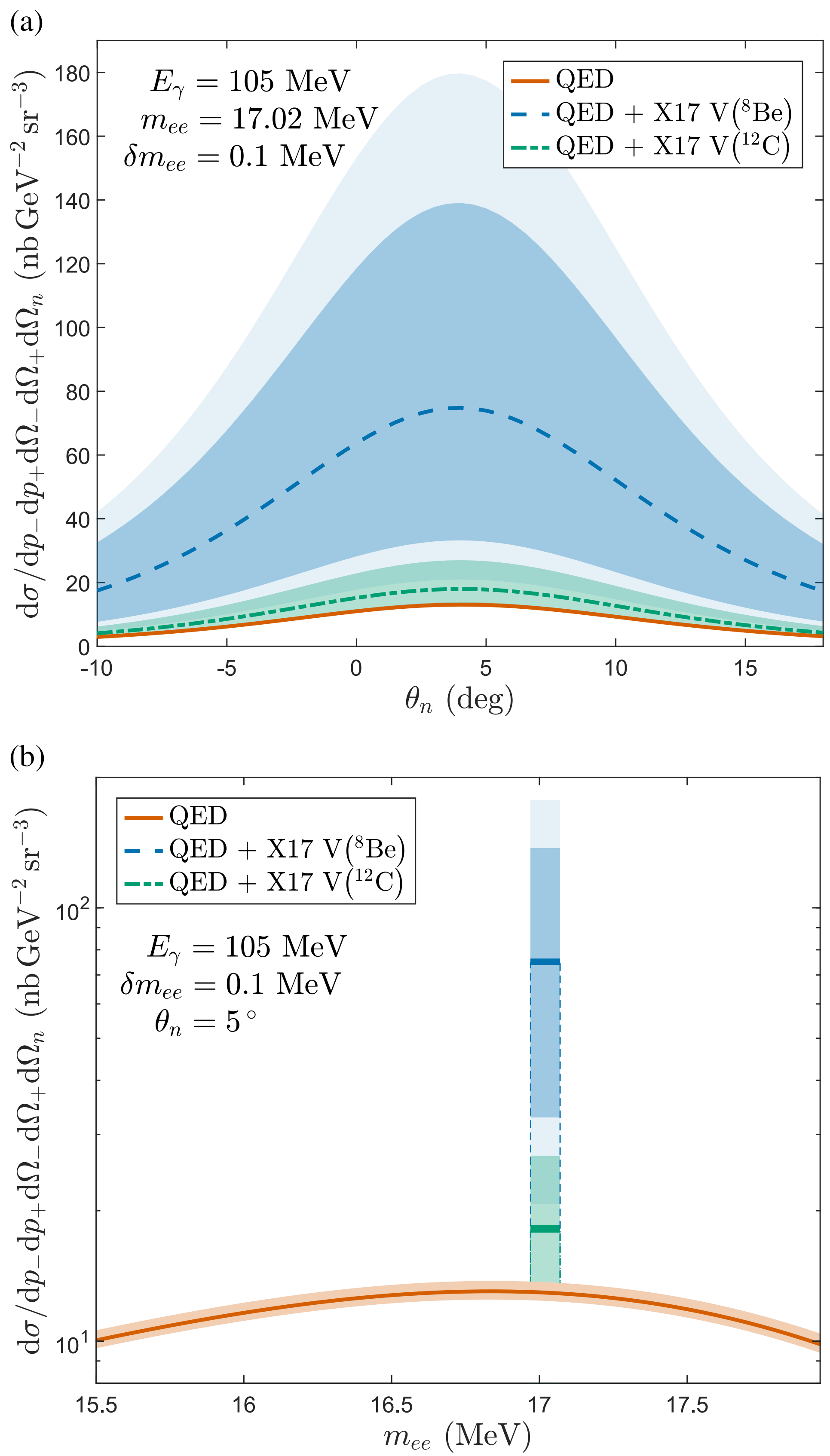
X17 search in $\gamma D \to e^+e^- np$: QED background

$m_{e^-e^+} = 17$ MeV



with **neutron tagging**: in forward neutron angular range process on neutron largerly dominates over process on proton

X17 search in $\gamma D \longrightarrow e^+e^- np$: signal vs background

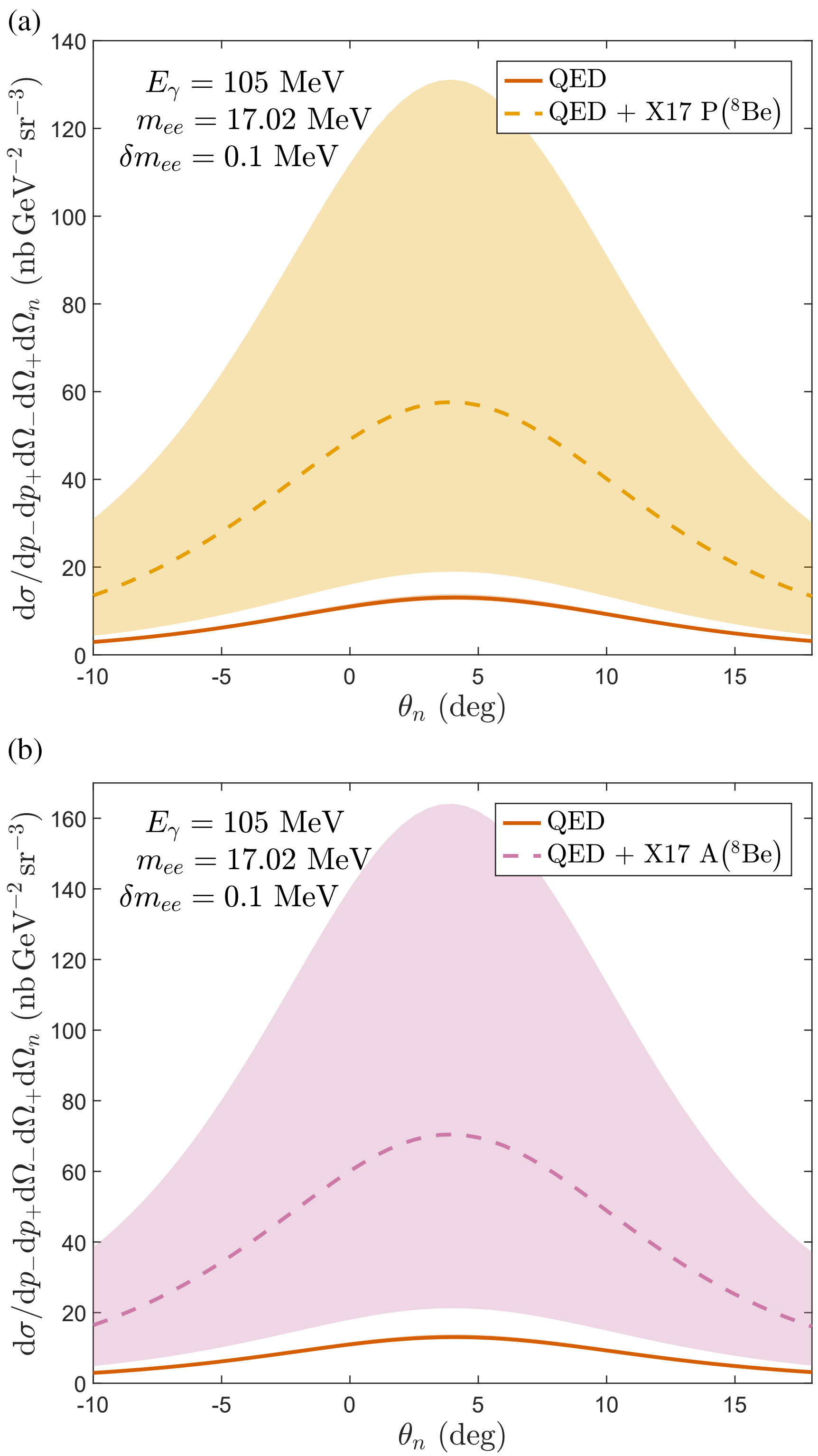


$J^P = \mathbf{1}^-$ scenario for X17

Mommers,Vdh: arXiv:2307.02181[hep-ph]

In backward kinematics for e^-e^+, forward angles for neutron:
X17 (vector) signal on neutron is up to an order of magnitude larger than QED background for $\delta m_{e\text{-}e+} = 0.1$ MeV (for ^{8}Be couplings)

X17 search in $\gamma D \rightarrow e^+e^- np$: signal vs background



$J^P = \mathbf{0}^-$ scenario for X17

$J^P = \mathbf{1}^+$ scenario for X17

Mommers,Vdh: arXiv:2307.02181[hep-ph]

Conclusions and outlook

- ATOMKI experiments: signals seen in ^{8}Be, ^{4}He, and ^{12}C were interpreted due to production of 17 MeV particle decaying into $e^- e^+$

- ^{8}Be results: confirmed by VNU, many more experiments ongoing / planned

- Theory constraints for **vector scenario**:
  Tight constraints on proton: protophobic vector particle
  Tensions between constraints on neutron

- Theory allows viable parameter range for **axial-vector scenario**

- X17 in di-lepton production experiment on nucleon: $\gamma N \longrightarrow e^+ e^- N$
  X17 signal / QED background up to factor 10 for neutron
  for $e^+ e^-$ mass resolution which has already been achieved at MAMI

- X17 production on neutron by $\gamma D \longrightarrow e^+ e^- np$ process with neutron tagging
  X17 signal / QED background found to be up to factor 10
  in MAGIX@MESA kinematics (E_e = 105 MeV) for δm_{e-e+} = 0.1 MeV