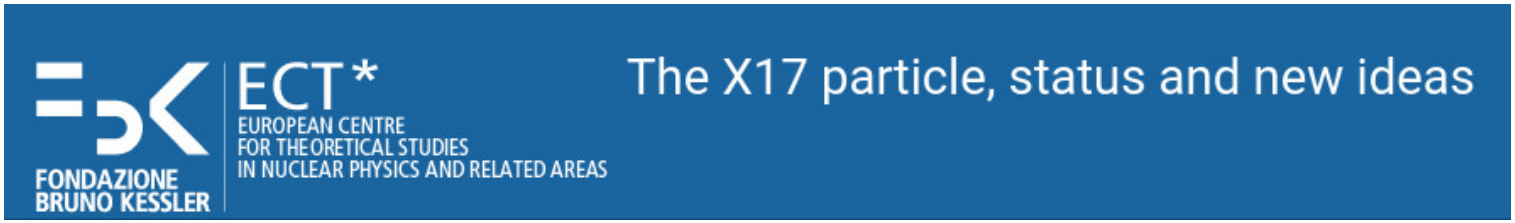
Ab-initio studies of $A = 3, 4$ processes and the "X17 anomaly"

UNIVERSITÀ DI PISA

Laura E. Marcucci
University of Pisa
INFN-Pisa



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Outline

- Introduction (from the point of view of a nuclear theorist)
- Ingredients for an *ab-initio* study:
  - Chiral effective field theory (ChEFT) framework
    - Nuclear interactions
    - Electromagnetic and X17 nuclear currents
  - *Ab-initio* method for $A = 3, 4$ bound and scattering states
- Results
  - $A = 4 \rightarrow {}^3\mathrm{H}(p, e^+e^-){}^4\mathrm{He}$ and ${}^3\mathrm{He}(n, e^+e^-){}^4\mathrm{He}$

    M. Viviani *et al.*, Phys. Rev. C **105**, 014001 (2022)
  - $A = 3 \rightarrow {}^2\mathrm{H}(p, e^+e^-){}^3\mathrm{He}$ and ${}^2\mathrm{H}(n, e^+e^-){}^3\mathrm{H}$

    M. Viviani *et al.*, Phys. Rev. C **111**, 034002 (2025)
- Conclusions, outlook and **suggestions**

Introduction: the "ATOMKI X17 anomaly"

A.J. Krasznahorkay *et al.*, Phys. Rev. Lett. **116**, 042501 (2016): X17 in $^{7}\mathrm{Li}(p, e^{+}e^{-})^{8}\mathrm{Be}$, but ... $A = 8$!!!

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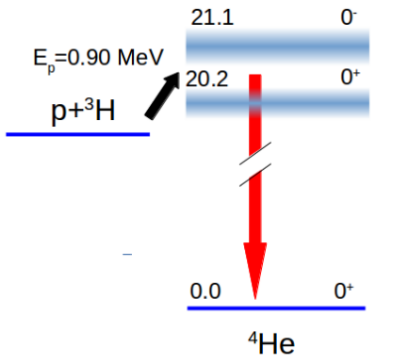

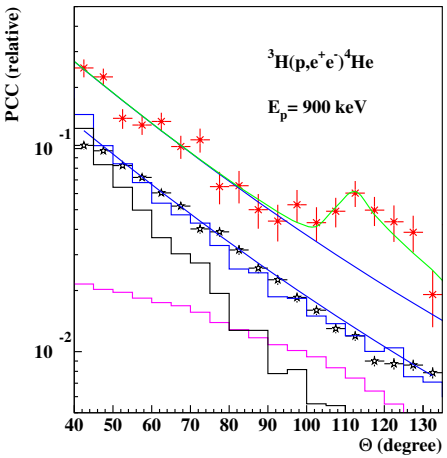

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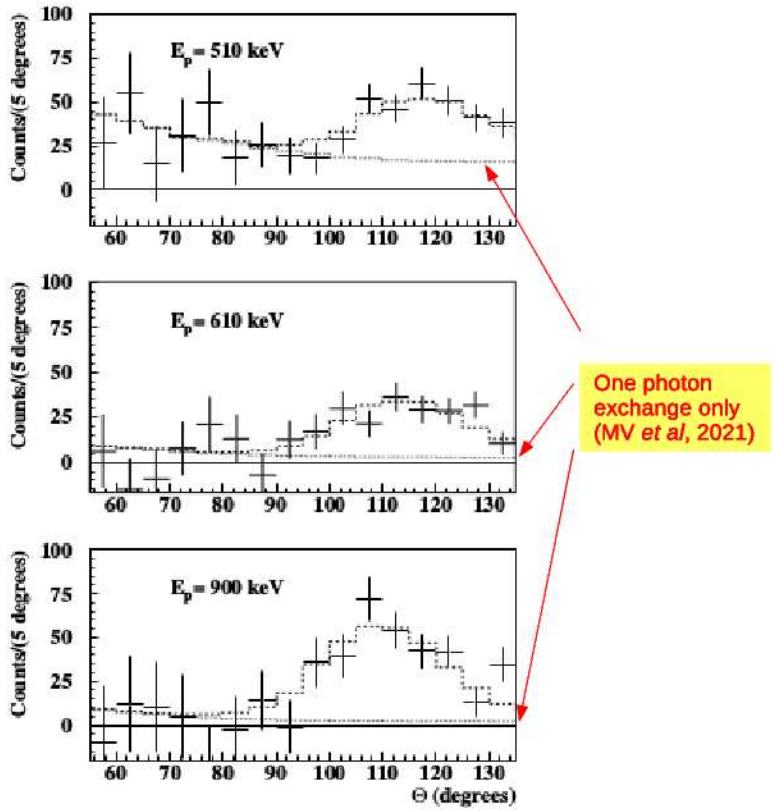

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Reaction	m_X [MeV]	Δm_X (stat) [MeV]	Δm_X (syst) [MeV]	τ [sec]	Evidence
$^7\mathrm{Li}(p, e^+e^-)^8\mathrm{Be}$	16.70	0.35	0.50	10^{-14}	$> 5\sigma$
$^3\mathrm{H}(p, e^+e^-)^4\mathrm{He}$ (2019)	16.84	0.16	0.20		$> 7.2\sigma$
$^3\mathrm{H}(p, e^+e^-)^4\mathrm{He}$ (2021)	16.94	0.12	0.21		$> 8.9\sigma$

The ATOMKI anomaly got my attention ...

Simplified theoretical studies

"Resonance saturation"

- Internal pair conversion (IPC): $p + {}^3\mathrm{H} \to ({}^4\mathrm{He})^* \to {}^4\mathrm{He} + \gamma^*$
  $\gamma^* \to e^+e^-$
- Add the X17: $p + {}^3\mathrm{H} \to ({}^4\mathrm{He})^* \to {}^4\mathrm{He} + X$
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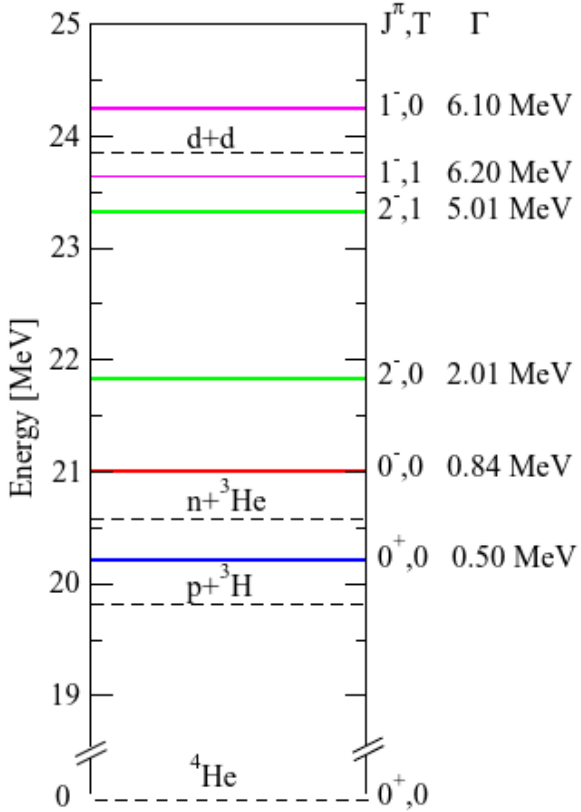

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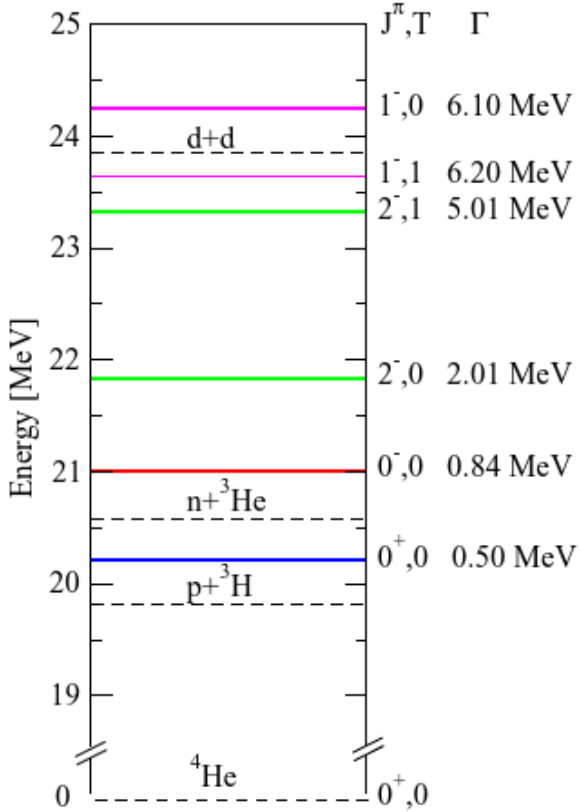
But an *ab-initio* study can be performed

- Solve "exactly" the $A = 3, 4$ nuclear dynamics
- Include all relevant partial waves in the initial scattering state
- One-photon exchange mechanism $\to$ "standard" IPC
- Treat the X17 interaction within ChPT (similar to ChEFT)



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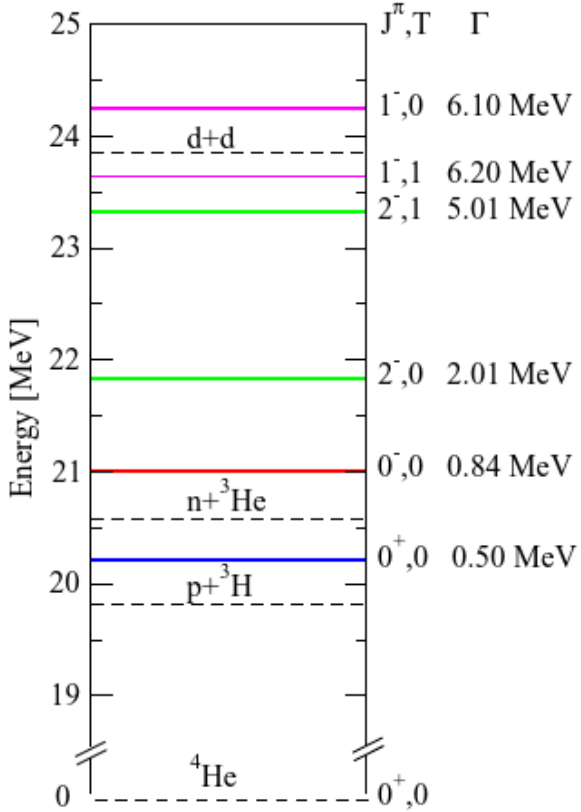
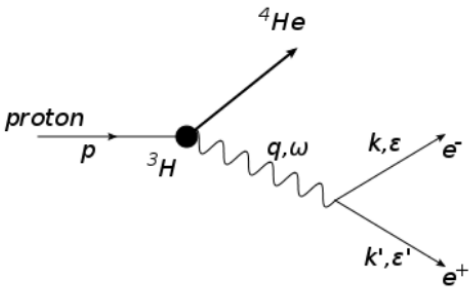


"Standard" electromagnetic processes ($p + {}^3\mathrm{H}$ as an example)



$$\frac{d^6\sigma}{d\epsilon d\hat{\boldsymbol{k}} d\epsilon' d\hat{\boldsymbol{k}}'} = \frac{\alpha^2}{8\pi^3}\frac{kk'}{Q^4 v}\delta\Big(E_0 - \epsilon - \epsilon' - \frac{(\boldsymbol{p}-\boldsymbol{q})^2}{2M_4}\Big)\sum_i v_i R_i(q,\omega)$$

$E_0 = E_p + B_4 - B_3 \approx 20$ MeV, $\boldsymbol{q} = \boldsymbol{k} + \boldsymbol{k}'$, $\omega = \epsilon + \epsilon'$, $Q^2 = \omega^2 - q^2 > 0$ "time-like"
$\cos\theta_{ee} = \hat{\boldsymbol{k}} \cdot \hat{\boldsymbol{k}}'$, $i = L, T, TT, TT', LT, LT'$

$$v_L = \frac{Q^4}{q^4}(\epsilon\epsilon' + \boldsymbol{k}\cdot\boldsymbol{k}' - m_e^2) \qquad R_L(q,\omega) = \sum_{m_1,m_3}\left|\langle\Psi_4|\rho(\boldsymbol{q})^\dagger|\Psi^{(pt)}_{m_1,m_3}\rangle\right|^2 \sim \sum_{LSJ}\left|C_J^{LSJ}\right|^2$$

$v_T, v_{TT}, \cdots =$ kinematical factors $\qquad R_T(q,\omega), R_{TT}(q,\omega), \cdots =$ other RMEs

After integrating the δ over ϵ' and numerically over ϵ [$p_r = \epsilon'(k' - p\cos\theta' + k\cos\theta_{ee})/k'$]

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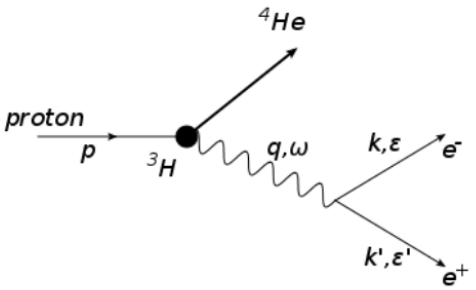
"Standard" electromagnetic processes ($p + {}^3\mathrm{H}$ as an example)



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Theoretical ingredients

- Nuclear wave functions Ψ_4 and $\Psi^{(pt)} \Rightarrow$
  - Nuclear interaction $\rightarrow$ ChEFT
  - *Ab-initio* method for bound and scattering states (the hyperspherical harmonics - **HH** - method)
- Transition operators
  - $(\rho(\boldsymbol{q}), \boldsymbol{j}(\boldsymbol{q})) \rightarrow$ "standard" nuclear electromagnetic currents

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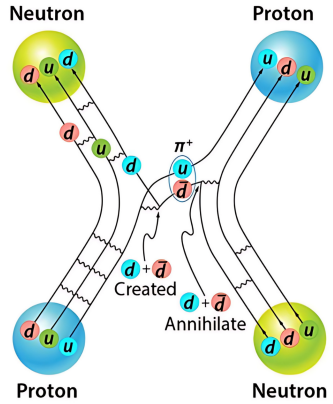
  - $(\rho(\boldsymbol{q}), \boldsymbol{j}(\boldsymbol{q})) \rightarrow$ "standard" nuclear electromagnetic currents
  - nuclear X17 currents (LO contributions)

The nuclear interaction → ChEFT

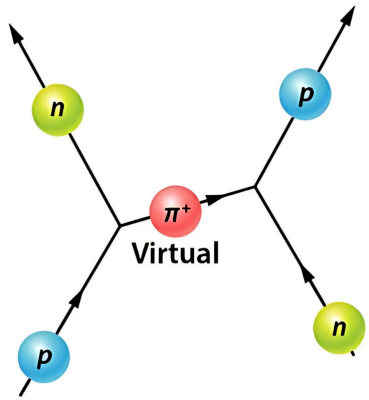
Nuclear physics

- Low-energy realization of QCD (non-Abelian theory ⇒ **non-perturbative** at low energy)
- Nuclear force = **residual** color force



QCD

$\gtrsim 1$ GeV



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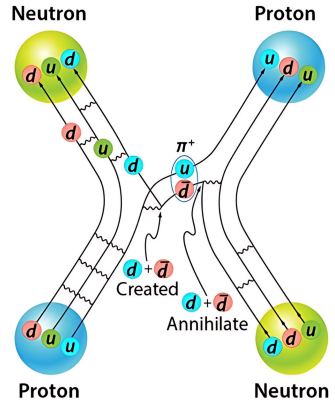

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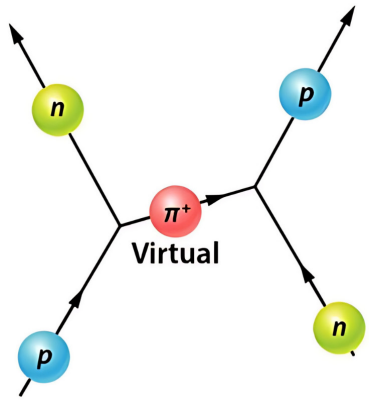

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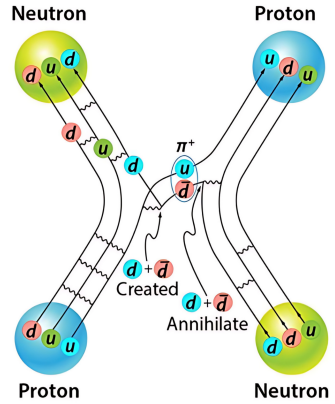

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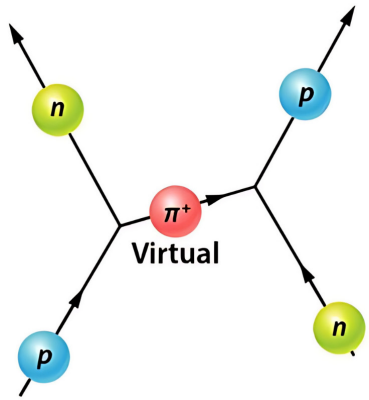

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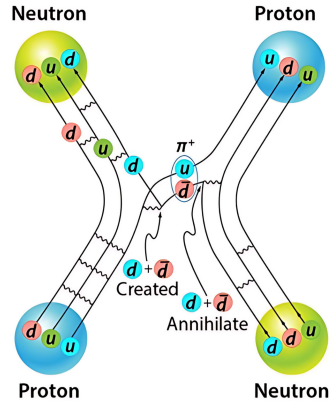

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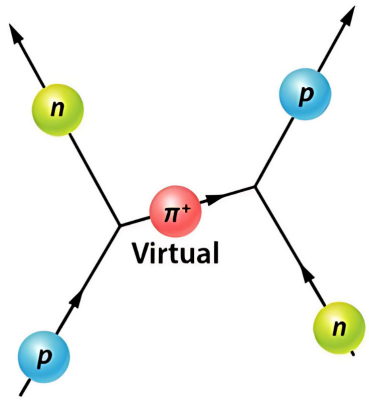

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⇒ Relevant **(broken) symmetries**

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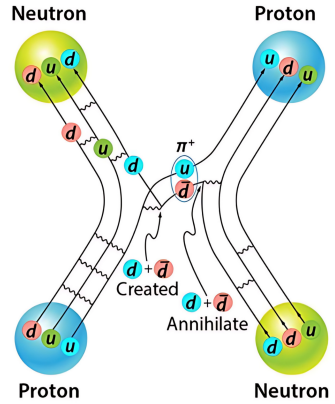

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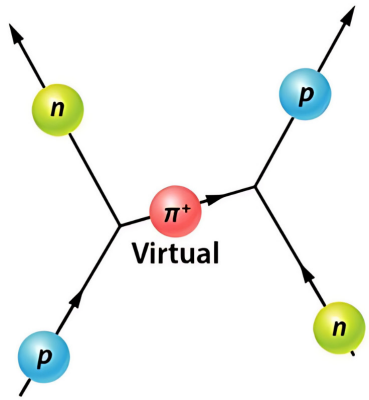

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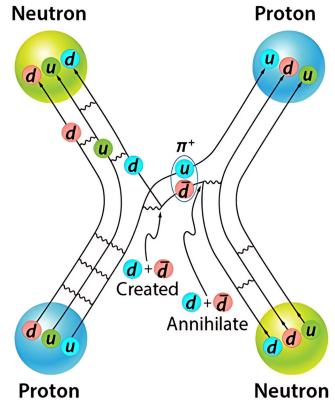

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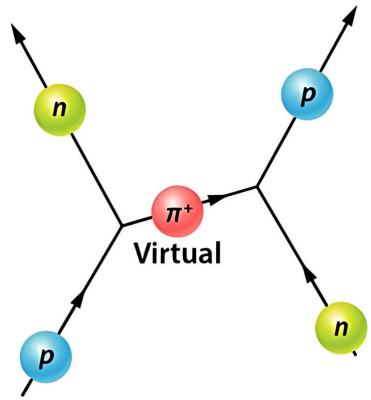

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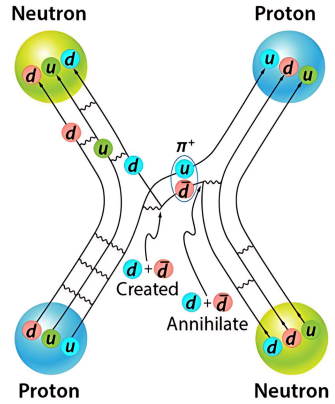

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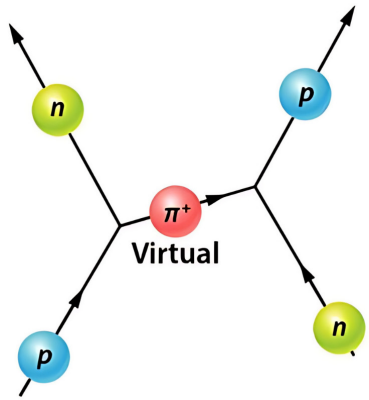

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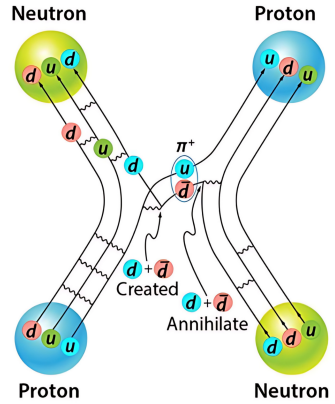

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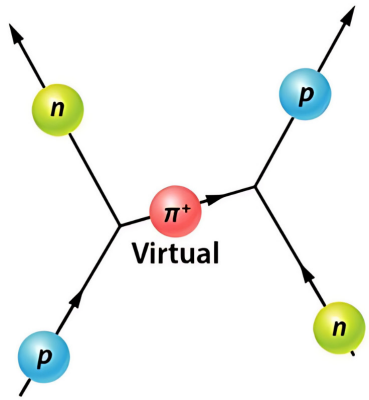

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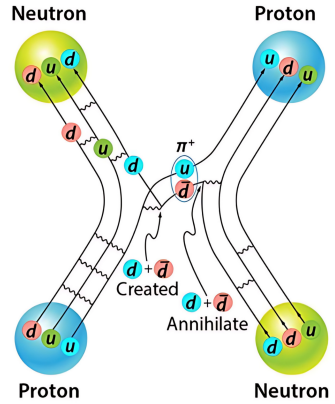

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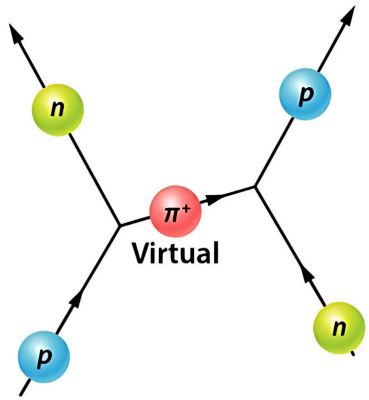

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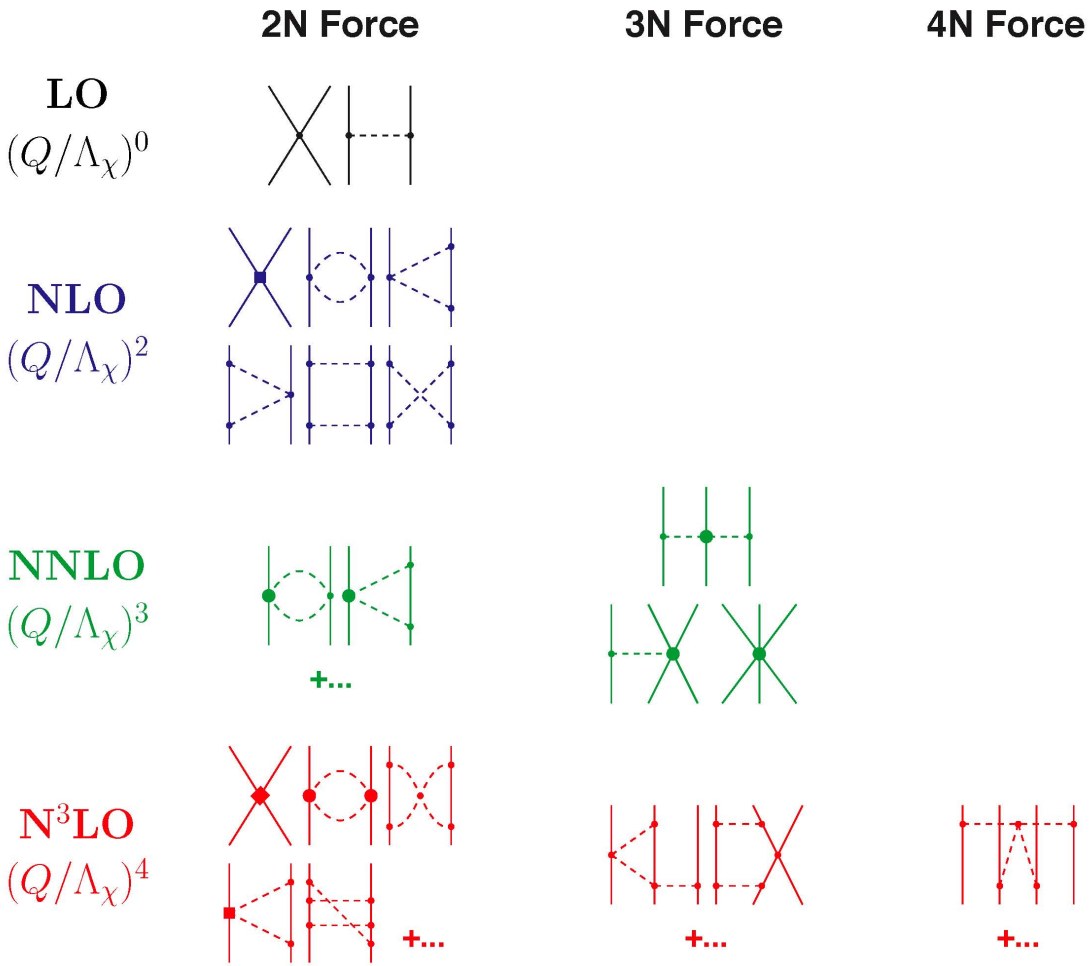
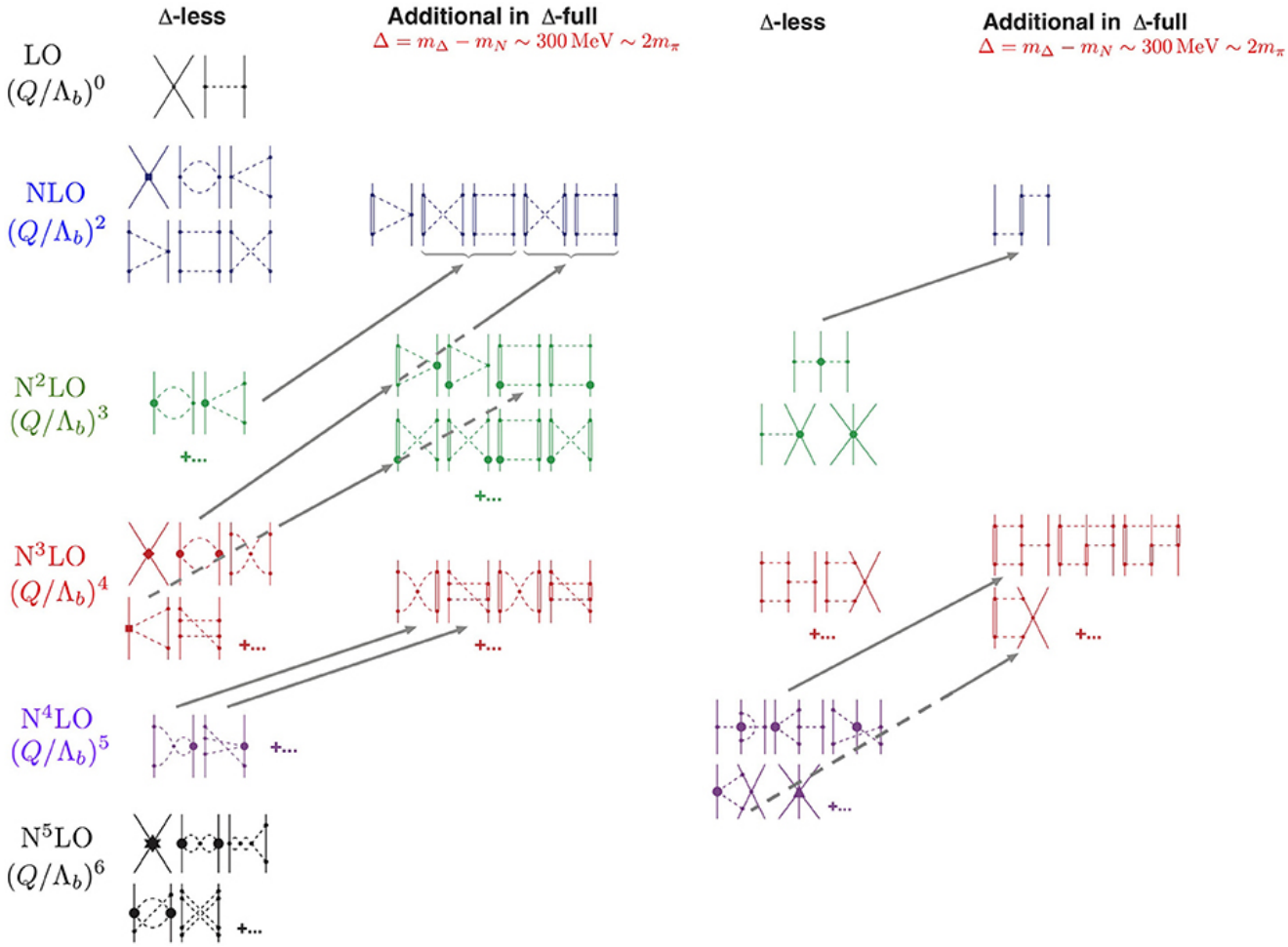
- ⇒ **Feynman diagrams** up to the desired accuracy
- ⇒ **Power counting**: terms expressed as powers of $(Q/\Lambda_\chi)^\nu$

Hierarchy of nuclear force



R. Machleidt and D.R. Entem, Phys. Rep. **503**, 1 (2011)

Hierarchy of nuclear force with Δ-isobar DOF



NN *3N*

M. Piarulli and I. Tews, Front. Phys. **7**, 245 (2019)

Regularization scheme and cutoff function

$\mathcal{L}_{\text{eff}} \implies V \longrightarrow$ **Divergent terms** for short distances (or high momentum)

Regularization of $V \longrightarrow$ **cutoff functions**

- $f(p', p; \Lambda)$ or $f(r', r; R) \implies$ **non-local** $V \rightarrow p$-space
- $f(p' - p; \Lambda)$ or $f(r; R) \implies$ **local** $V \rightarrow r$-space [better with Coulomb]
- $f(p' - p; \Lambda)$ for π-exchange and $f(p', p; \Lambda)$ for contact terms $\implies$ **semi-local** $V \rightarrow p$-space

Results should be independent of Λ or R

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Results should be independent of Λ or R

Summary of the adopted ChEFT potentials

Name	DOF	O_χ	(R_S, R_L) or Λ	E range	Locality
NVIa	π, N, Δ	N^{3}LO	(0.8, 1.2) fm	0–125 MeV	local
N3LO500	π, N	N^{3}LO	500 MeV	0–300 MeV	non-local

$3N$ interaction (N^{2}LO): LECs c_D and c_E fitted to triton binding energy and β-decay rate

The Hyperspherical Harmonics (HH) method

Bound states

$$\Psi^{JJ_z} = \sum_\mu c_\mu \Psi_\mu$$

- $\Psi_\mu \rightarrow$ known functions (spin-isospin HH functions)
- Rayleigh-Ritz var. principle:
  $\delta_c \langle \Psi^{JJ_z} | H - E | \Psi^{JJ_z} \rangle = 0$
  $\Rightarrow$ Solve for E and $c_\mu \rightarrow$ get Ψ^{JJ_z}

Scattering states

$$\Psi^\gamma_{LSJ} = \Psi^{LSJ,\gamma}_{core} + \Psi^{LSJ,\gamma}_{asym} \quad \gamma = 1\,(pt), 2\,(nh)$$

- $\Psi^{LSJ,\gamma}_{core} = \sum_\mu c_\mu \Psi_\mu$
- $\Psi^{LSJ}_{asym} \propto \Omega^R_{LSJ,\gamma}$
  $+ \sum_{L'S'\gamma} T_{\gamma LS,\gamma' L'S'} (\Omega^R_{L'S'J,\gamma'} + i\Omega^I_{L'S'J,\gamma'})$
- Kohn var. principle:
  $[T_{\gamma LS,\gamma' L'S'}] = T_{\gamma LS,\gamma' L'S'} - \langle \Psi^{\gamma'}_{L'S'J} | H - E | \Psi^\gamma_{LSJ} \rangle$
  $\Rightarrow$ Solve for c_μ and $T_{\gamma LS,\gamma' L'S'} \rightarrow$ get Ψ^γ_{LSJ}

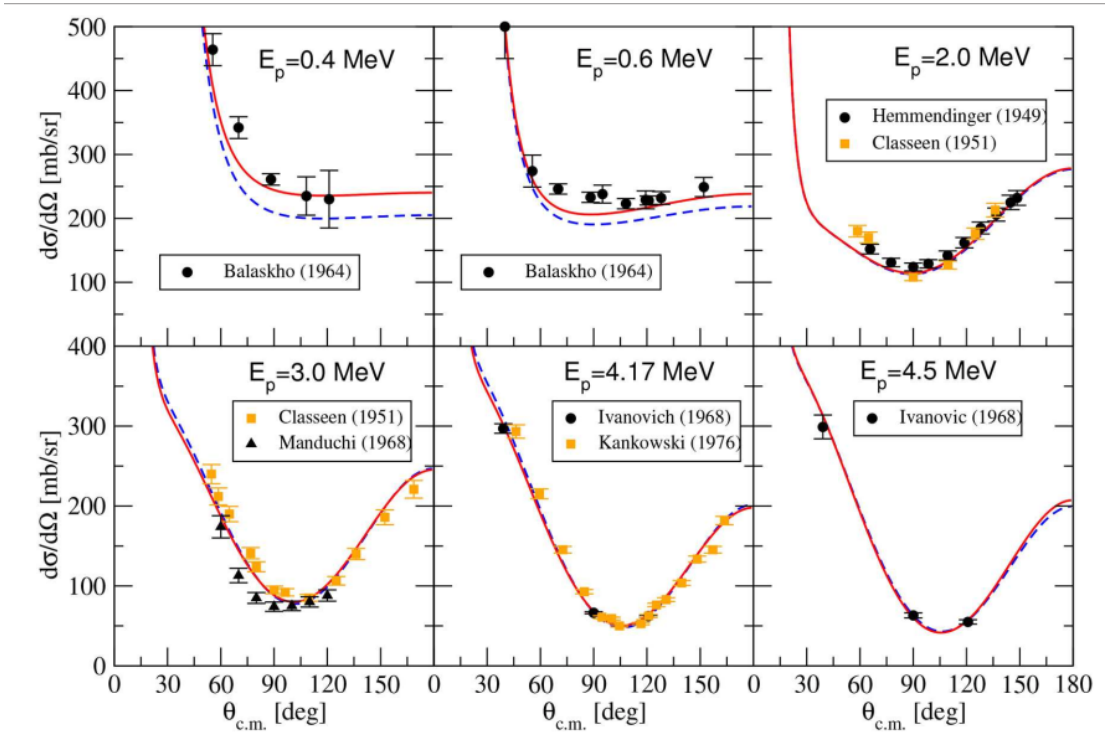
Strength and weakness

- very accurate
- both r- and p-space
- both bound and scattering states
- at present limited to $A = 6$
- in prospective $A = 8$
- not much more ...

$A = 3, 4$ HH results

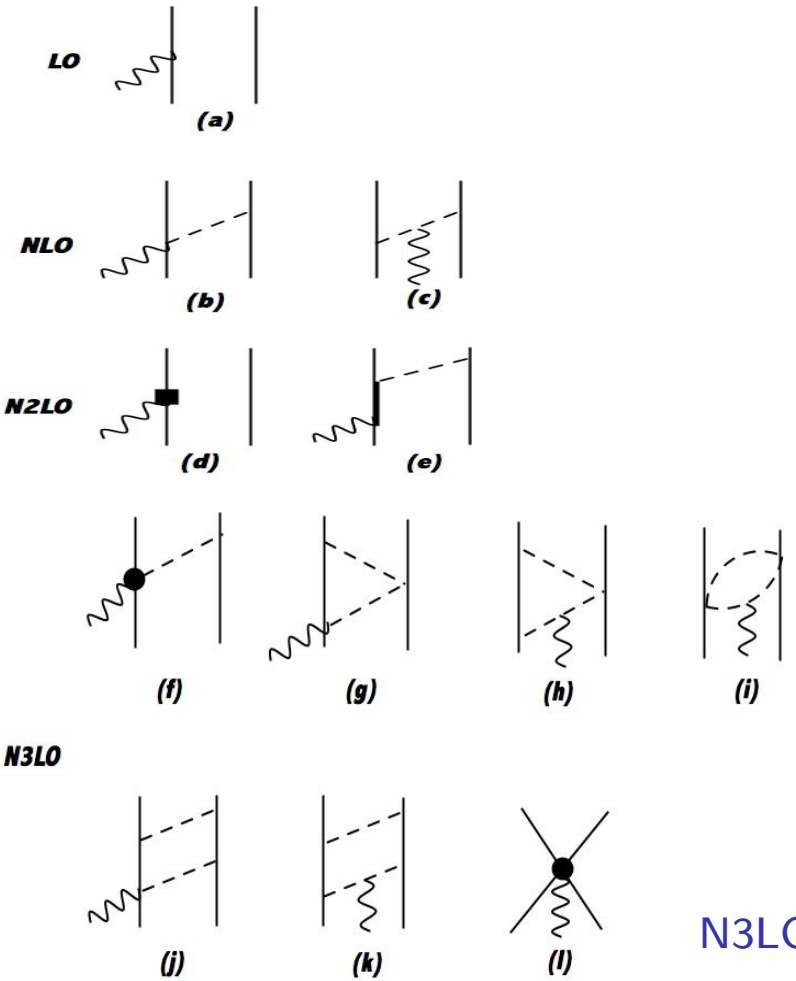
Model	B(^{3}H)	B(^{3}He)	B(^{4}He)	a^2_{nd}	a^4_{nd}	a^2_{pd}	a^4_{pd}
N3LO500	7.854	7.128	25.38	1.099	6.342	0.876	13.646
NVIa	8.718	7.090	25.15	1.119	6.326	0.959	13.596
N3LO/N2LO500	8.474	7.733	28.36	0.675	6.342	0.072	13.647
NV2+3/Ia	8.477	7.727	28.30	0.638	6.326	0.070	13.596
Exp.	8.475	7.725	28.30	0.645(10)	6.35(2)	–0.13(4)	14.7(2.3)

$p + {}^3\mathrm{H}$ elastic scattering



L.E. Marcucci *et al.*, Front. Phys. **8**, 69 (2020)

Electromagnetic current in ChEFT



Add the γ as addition DOF and proceed as before

- $\mathbf{j}^{\mathrm{N^2LO}}_{\Delta}(\mathbf{q})$ in panel (e) absent in $\not\Delta$-EFT
- not included the Δ intermediate states at N^{3}LO
- $\mathbf{j}^{\mathrm{N^3LO}}_{\mathrm{OPE}}(\mathbf{q}) \rightarrow d_2^S, d_2^V; d_3^V$
- $\mathbf{j}^{\mathrm{N^3LO}}_{\mathrm{MIN}}(\mathbf{q}) \rightarrow$ from πN scattering
- $\mathbf{j}^{\mathrm{N^3LO}}_{\mathrm{NM}}(\mathbf{q}) \rightarrow d_1^S; d_1^V$

To be noticed:

$$\mathbf{j}^{\mathrm{N3LO}}_{\mathrm{OPE}}(\mathbf{q}) \propto \frac{\boldsymbol{\sigma}_j \cdot \mathbf{k}_j}{(m_\pi^2 + \mathbf{k}_j^2)} \mathbf{q} \times [(d_2^S \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j + d_2^V \tau_j^z)\mathbf{k}_j + d_3^V (\boldsymbol{\tau}_i \times \boldsymbol{\tau}_j)^z \boldsymbol{\sigma}_i \times \mathbf{k}_j]$$

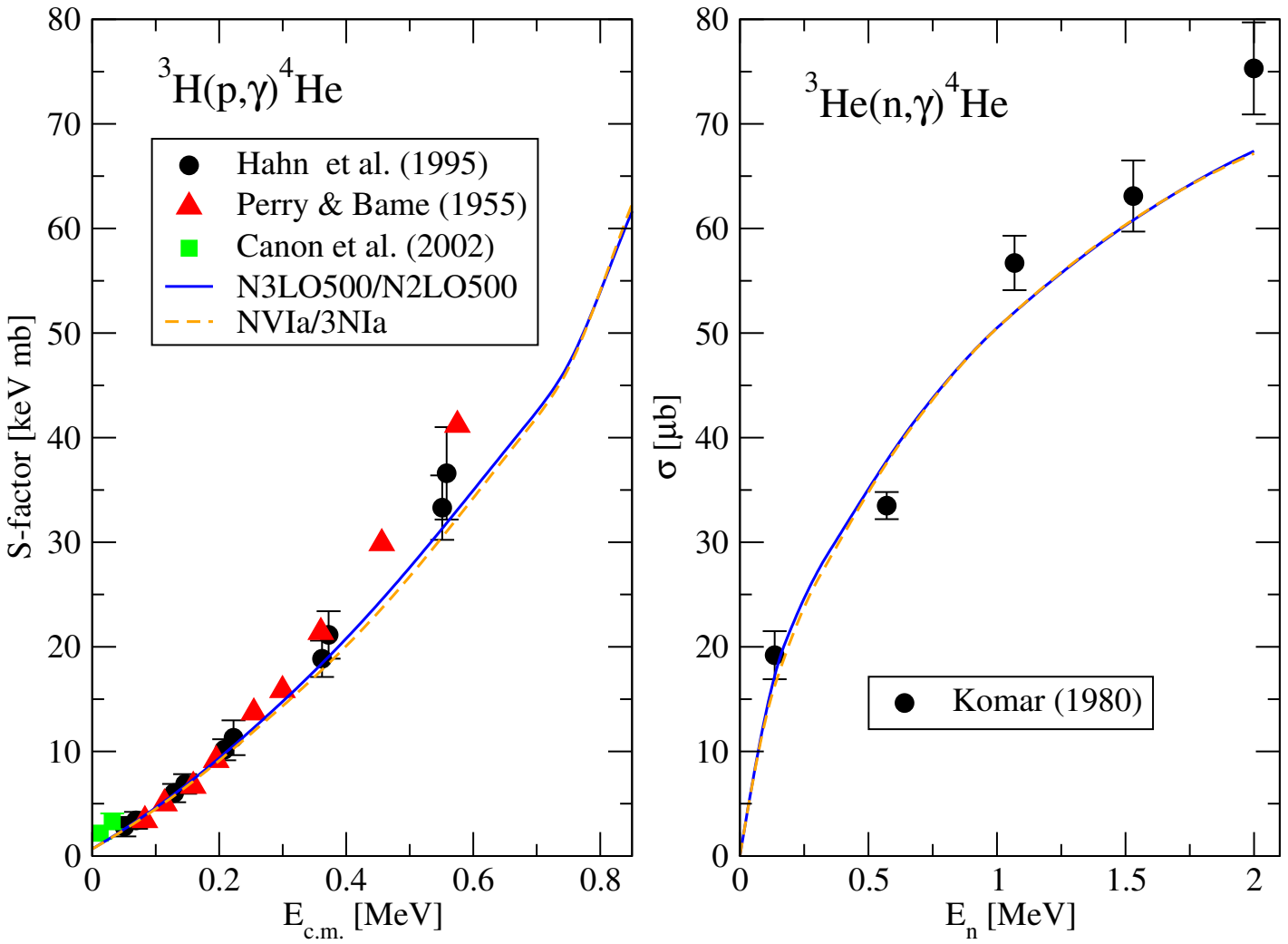
N3LO500 $d_2^V; d_3^V \rightarrow$ saturated with Δ-current of panel (e); d_1^S, d_2^S, d_1^V fitted to $A = 2, 3$ magnetic moments

NVIa all 5 LECs fitted to $A = 2, 3$ magnetic moments and $d(e, e')pn$ at threshold

N3LO500: R. Schiavilla *et al.*, Phys. Rev. C **99**, 034005 (2019)

NVIa: A. Gnech and R. Schiavilla, Phys. Rev. C **106**, 044001 (2022)

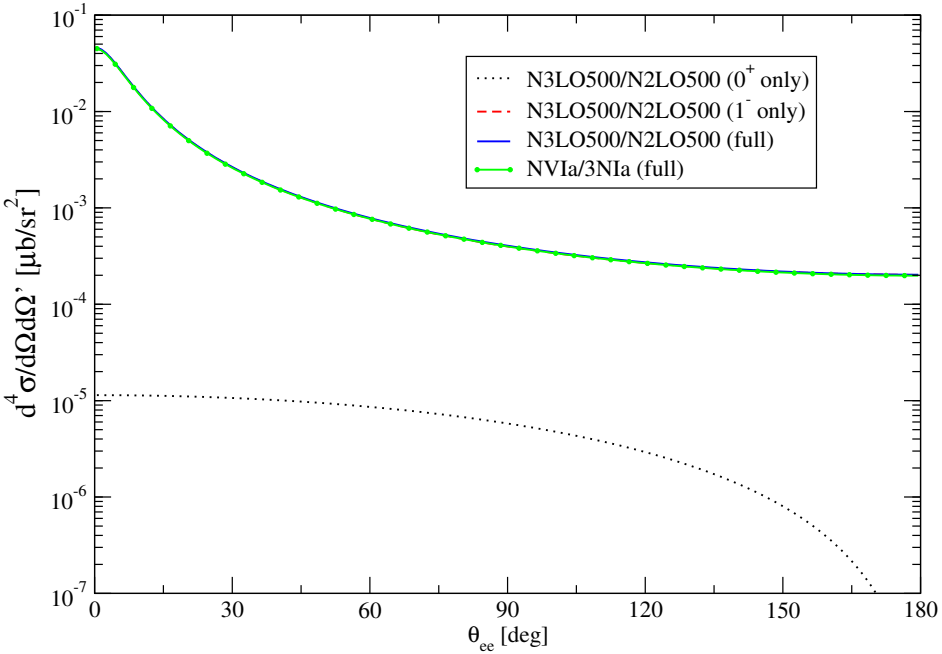
$^3H(p,\gamma)^4He$ and $^3He(n,\gamma)^4He$ as a test



$^3H(p, e^+e^-)^4He$ in the one-photon exchange approx.

state	$^{2S+1}L_J$	charge multipoles	current multipoles
0^+	$^1S_0$	C_0^{000}	–
0^-	$^3P_0$	–	–
1^+	$^3S_1, ^3D_1$	–	M_1^{L11}
1^-	$^1P_1, ^3P_1$	C_1^{1S1}	E_1^{1S1}
2^+	$^1D_2, ^3D_2$	C_2^{2S2}	E_2^{2S2}
2^-	$^3P_2, ^3F_2$	–	M_2^{L12}

Calculation performed using
N3LO/N2LO500 + consistent current
and
NV2+3/Ia + consistent current



No explanation for any large-angle bump

$\Rightarrow$ Incorporate the X17 $\Rightarrow$ X17 nuclear currents

The X17 induced amplitude emission

$$T_{fi} = T_{fi}^{EM} + T_{fi}^{cX}$$
$$\Rightarrow d\sigma \propto |T_{fi}|^2$$

$$T_{fi}^{EM} = 4\pi\alpha \frac{(\bar{u}\gamma_\mu v)\boldsymbol{j}_{fi}^{\mu}}{Q^2}$$
$$T_{fi}^{cX} = 4\pi\alpha \frac{(\varepsilon_e \bar{u}\Gamma_c v)\boldsymbol{j}_{fi}^{cX}}{Q^2 - M_X^2}$$

Note that:

- $\Gamma^{c=S,P,V,A} = 1, i\gamma^5, \gamma^\mu, \gamma^\mu\gamma^5$
- $Q^2 - M_X^2 \to Q^2 - M_X^2 + iM_X\Gamma_X \equiv D_X \qquad (\Gamma_X \ll M_X)$

EFT approach for the X17 nuclear currents $\boldsymbol{j}_{fi}^{cX}$

1. Generic interaction Lagrangian for X17 with u, d
2. Corresponding interaction Lagrangian at hadronic level (with N, π) $\to$ ChEFT $\Rightarrow$ LECs $\to \varepsilon_u, \varepsilon_d$
3. Nuclear matrix elements of the generated operators
4. Unknown quantities left: M_X, ε_u, ε_d

Details: X17 Interaction – Quark and Nucleon Lagrangians

$$\varepsilon_0 = (\varepsilon_u + \varepsilon_d)/2 \qquad \varepsilon_z = (\varepsilon_u - \varepsilon_d)/2$$

Details: X17 Interaction – Quark and Nucleon Lagrangians

$$\varepsilon_0 = (\varepsilon_u + \varepsilon_d)/2 \qquad \varepsilon_z = (\varepsilon_u - \varepsilon_d)/2$$

Scalar (S)

$$\mathcal{L}_S^q = e\,\frac{m_q}{\Lambda_S}\,\bar{q}\,(\varepsilon_0 + \varepsilon_z \tau_3)\,q\,X$$

$$\mathcal{L}_S^N = \eta_0^S\,\bar{N}NX + \eta_z^S\,\bar{N}\tau_3 NX$$

$$\eta_0^S = \varepsilon_0\left(-\frac{4c_1 m_\pi^2}{\Lambda_S}\right), \quad \eta_z^S = \varepsilon_z\left(-\frac{2c_5 m_\pi^2}{\Lambda_S}\right)$$

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Pseudoscalar (P)

$$\mathcal{L}_P^q = e\,\frac{m_q}{\Lambda_S}\,\bar{q}\,(\varepsilon_0 + \varepsilon_z\tau_3)\,i\gamma_5\,q\,X$$

$$\mathcal{L}_P^N = \eta_0^P\,\bar{N}i\gamma_5 NX + \eta_z^P\,\bar{N}i\gamma_5\tau_3 NX + 2\eta_z^P B_c m_\pi^2\,\bar{N}i\gamma_5\tau_3 N\,X$$

$$\eta_0^P = \varepsilon_0\,\frac{2m_\pi^2}{m_N}\,(d_{18} + 2d_{19})\,\frac{1}{\Lambda_S}, \quad \eta_z^P = \varepsilon_z\,\frac{f_\pi m_\pi^2}{\Lambda_S}$$

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Vector (V)

$$\mathcal{L}_V^q = e\,\bar{q}\,(\varepsilon_0 + \varepsilon_z\tau_3)\gamma_\mu q\,X^\mu$$

$$\mathcal{L}_V^N = \eta_0^V\,\bar{N}\gamma_\mu NX^\mu + \eta_z^V\,\bar{N}\gamma_\mu\tau_3 NX^\mu + \frac{1}{4m_N}\bar{N}[\kappa_0\eta_0^V + \kappa_z\eta_z^V]\sigma^{\mu\nu}N\,F^X_{\mu\nu}$$

$$\eta_0^V = 3\varepsilon_0, \quad \eta_z^V = \varepsilon_z$$

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Axial (A)

$$\mathcal{L}_A^q = e\,\bar{q}\,(\varepsilon_0 + \varepsilon_z\tau_3)\gamma_\mu\gamma_5 q\,X^\mu$$

$$\mathcal{L}_A^N = \eta_0^A\,\bar{N}\gamma_\mu\gamma_5 NX^\mu + \eta_z^A\,\bar{N}\gamma_\mu\gamma_5\tau_3 NX^\mu$$

$$\eta_0^A = (3F - D)\varepsilon_0, \quad \eta_z^A = (F + D)\varepsilon_z$$

Details: X17 Interaction – Quark and Nucleon Lagrangians

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$$\eta_0^A = (3F - D)\varepsilon_0, \quad \eta_z^A = (F + D)\varepsilon_z$$

$$\mathcal{L}_c^q(\varepsilon_{0,z}) \to \mathcal{L}_c^N(\eta_{0,z}^c) \xrightarrow{\text{TOPT}} j_c^{LO}(\eta_{0,z}^c) \quad c = S, P, V, A$$

Total cross section: kinematics matters!

$$\frac{d^5\sigma}{d\epsilon\, d\hat{\boldsymbol{k}}\, d\hat{\boldsymbol{k}}'} = \sigma_{EM}(\epsilon) + \frac{\varepsilon_e \left[R_X(\epsilon)\, D_X^* + \text{c.c.}\right]}{Q^2|D_X|^2} + \frac{\varepsilon_e^2\, R_{XX}(\epsilon)}{|D_X|^2}$$

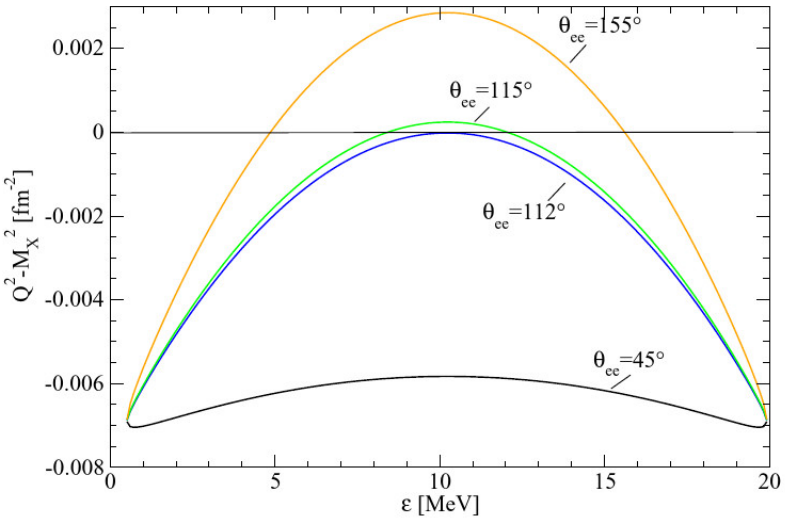
Pure EM | Interference term | Pure X17

$D_X = Q^2 - M_X^2 + iM_X\Gamma_X$

- $Q^2 - M_X^2 = 0$ verified for $\epsilon = \epsilon_{1,2}$

$\Rightarrow$ $1/|D_X|^2 \sim \sum_{i=1,2} \frac{\gamma_i}{\varepsilon_e^2}\delta(\epsilon - \epsilon_i)$

$\Rightarrow$ $D_X \sim M_X\Gamma_X \sim \alpha\varepsilon_e^2 M_X^2$ (using $\Gamma_X \simeq \alpha\varepsilon_e^2 M_X$)



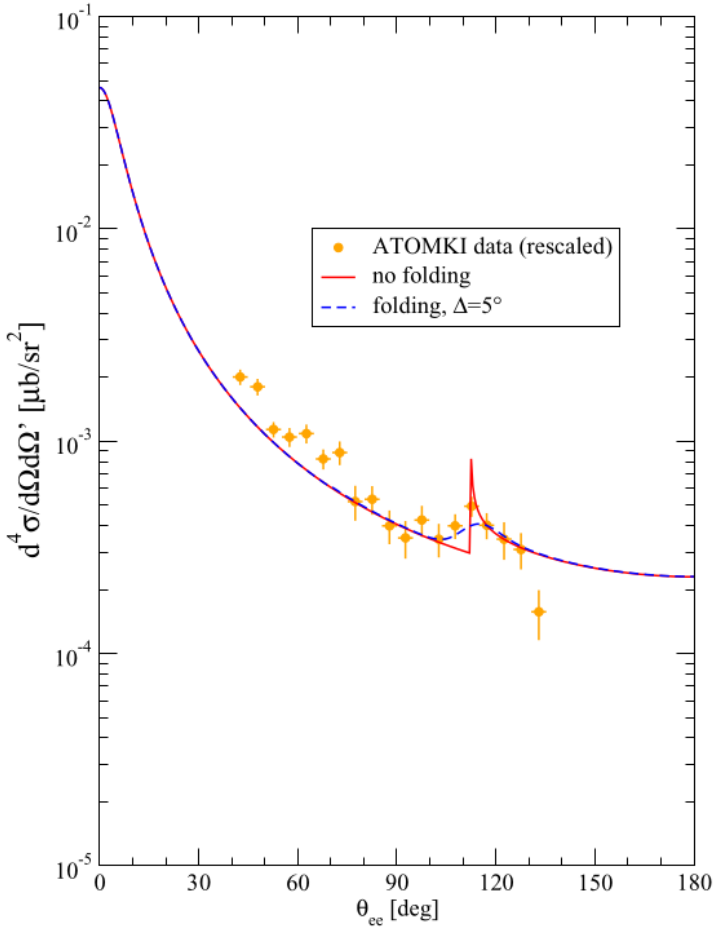
$$\frac{d^4\sigma}{d\hat{\boldsymbol{k}}\, d\hat{\boldsymbol{k}}'} = \int_{m_e}^{E_{max}} d\epsilon\, \sigma_{EM}(\epsilon) + \sum_i \left[2\varepsilon_e\alpha\Im\Big(R_X(\epsilon_i)\Big) + R_{XX}(\epsilon_i)\right]\gamma_i\delta(\epsilon - \epsilon_i)$$

- **No sensitivity to the interference term** ($2\varepsilon_e\alpha \sim 10^{-5}$)
- **Lost sensitivity to** ε_e

Results: $^3H(p, e^+e^-)^4He$ and $^3He(n, e^+e^-)^4He$

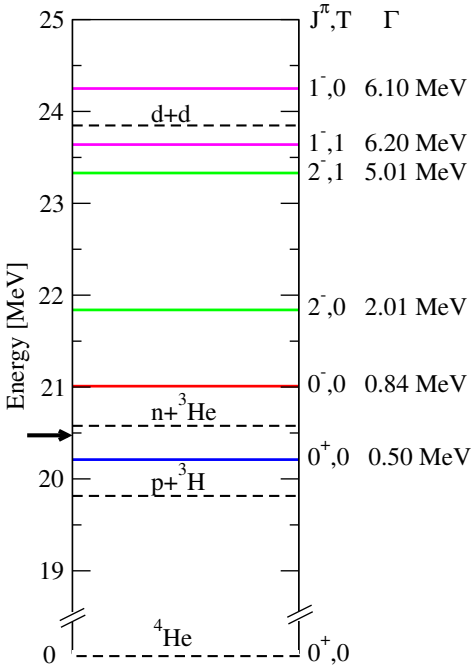
Fit to the 2019 ATOMKI data

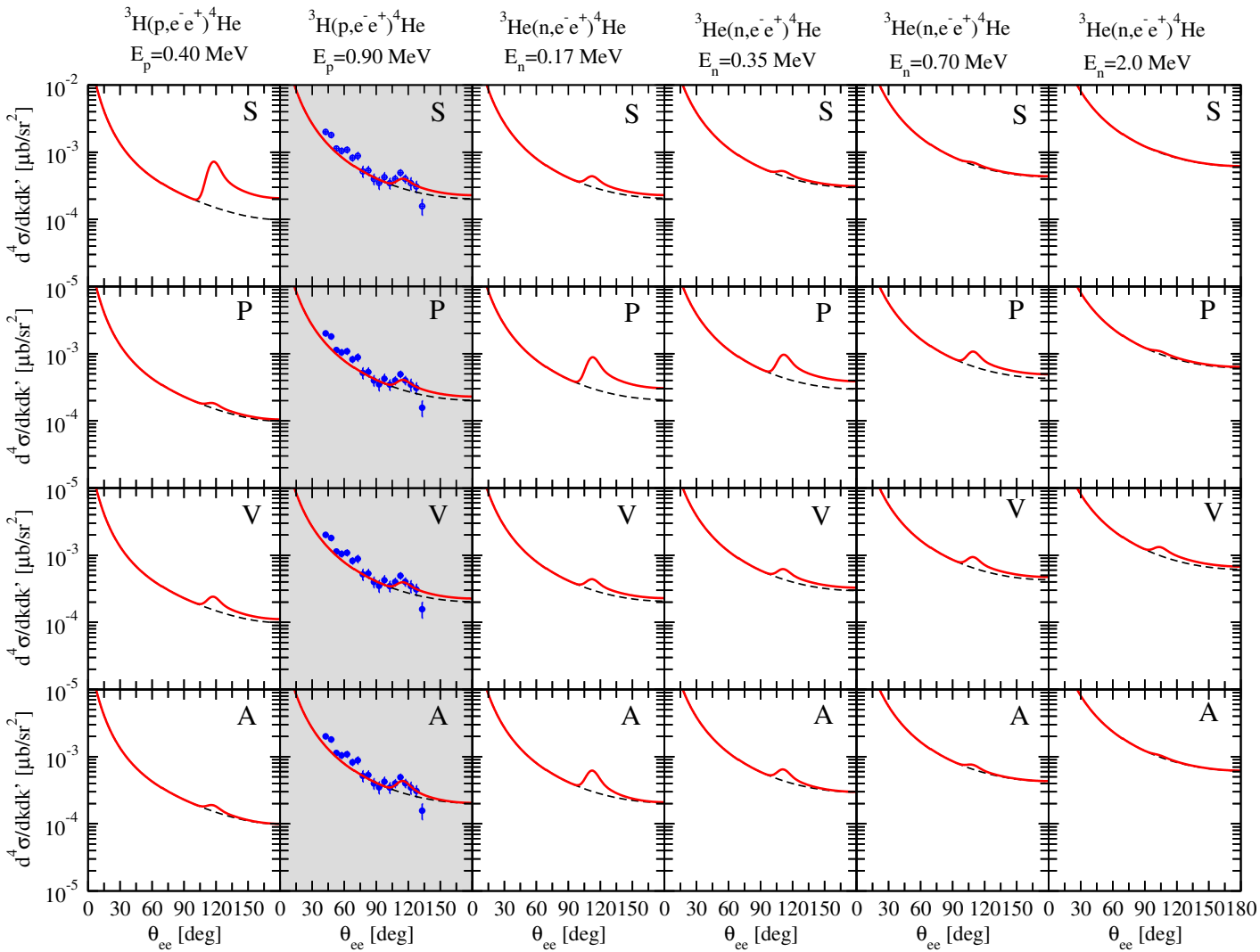
- In the perpendicular plane, the X17 signal appears for $\theta_{ee} > 110^\circ$
- No experimental details on the flux/target/efficiencies
- Procedure:
  - Rescale the ATOMKI rate by a factor to reproduce $\frac{d^4\sigma}{d\hat{\mathbf{k}}d\hat{\mathbf{k}}'}$ for $\theta_{ee} < 110^\circ$
  - For $\theta_{ee} < 110^\circ$: "standard" electromagnetic process $\Rightarrow$ no unknown parameter
  - Account for the finite angular detector resolution with a normalized Gaussian of width Δ
  - **Fix M_X, ε_u, ε_d to reproduce the "bump"**



Comparison with the 2019 ATOMKI data

e^+e^- emission in the perpendicular plane – peak fitted at 0.90 MeV





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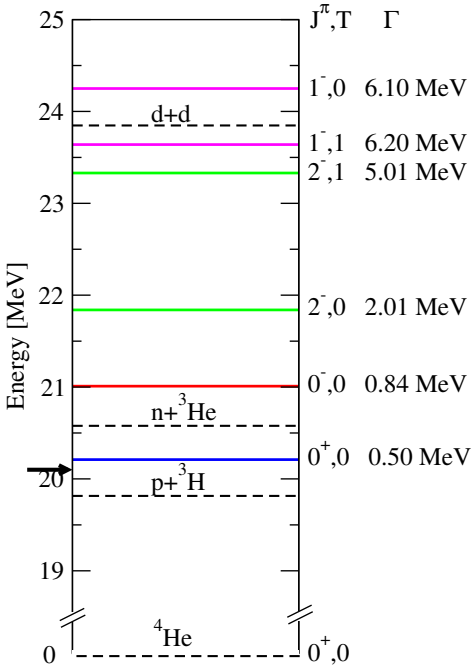

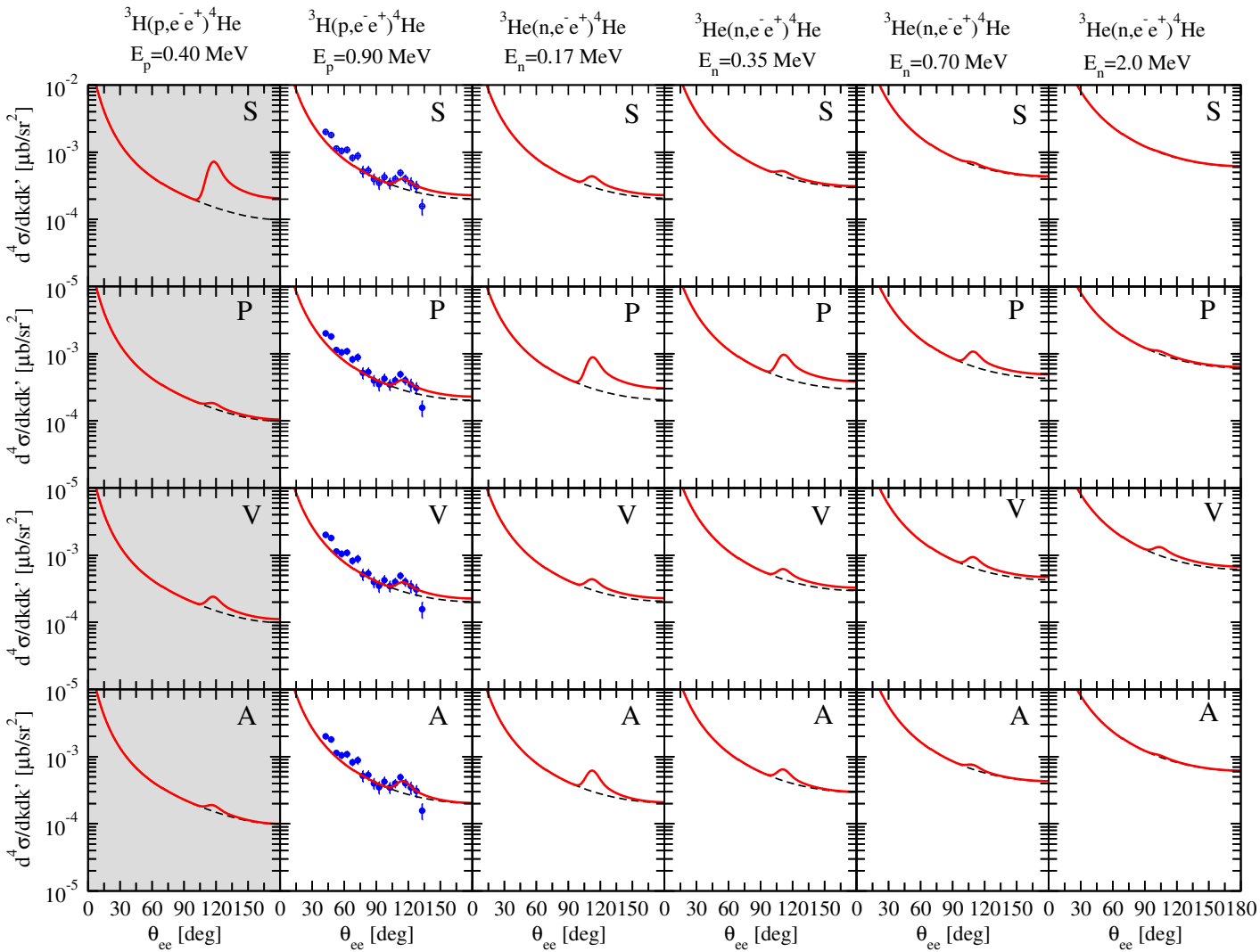

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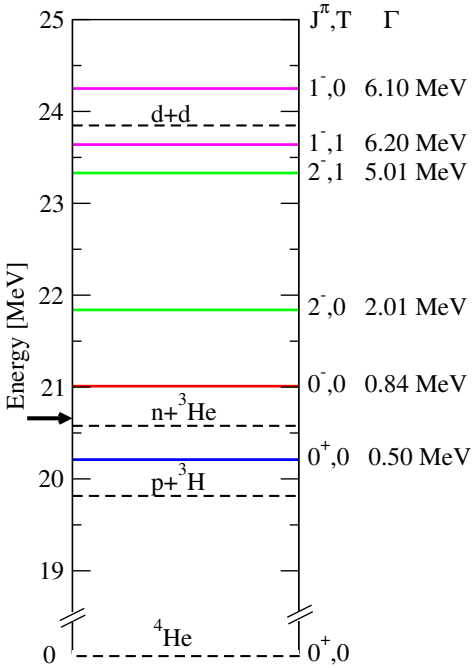

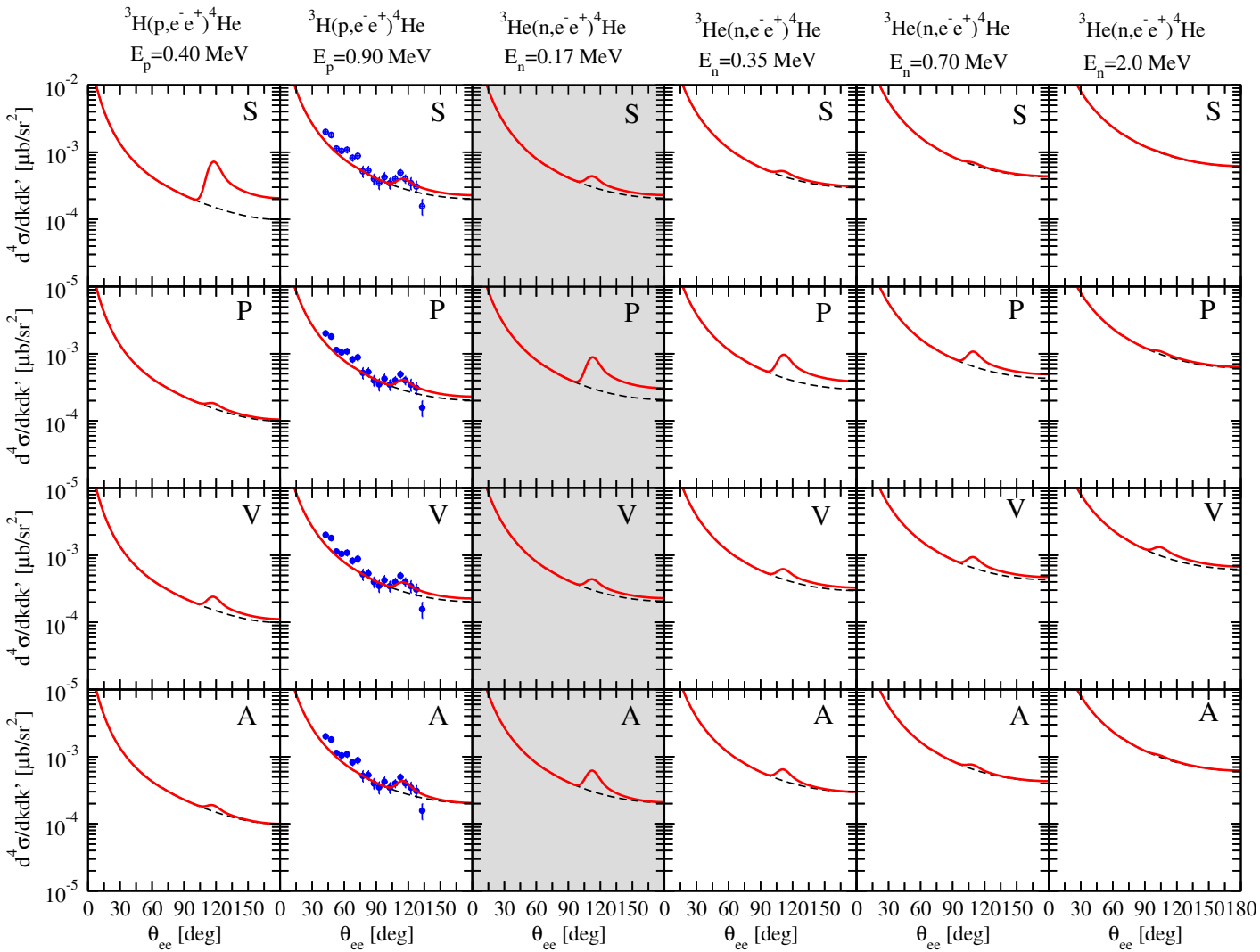

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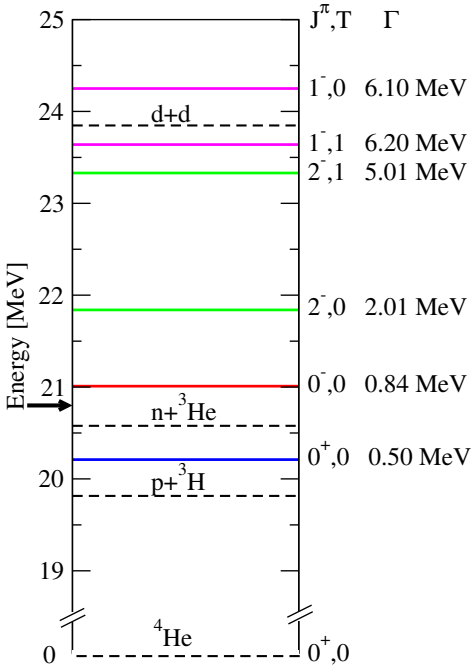

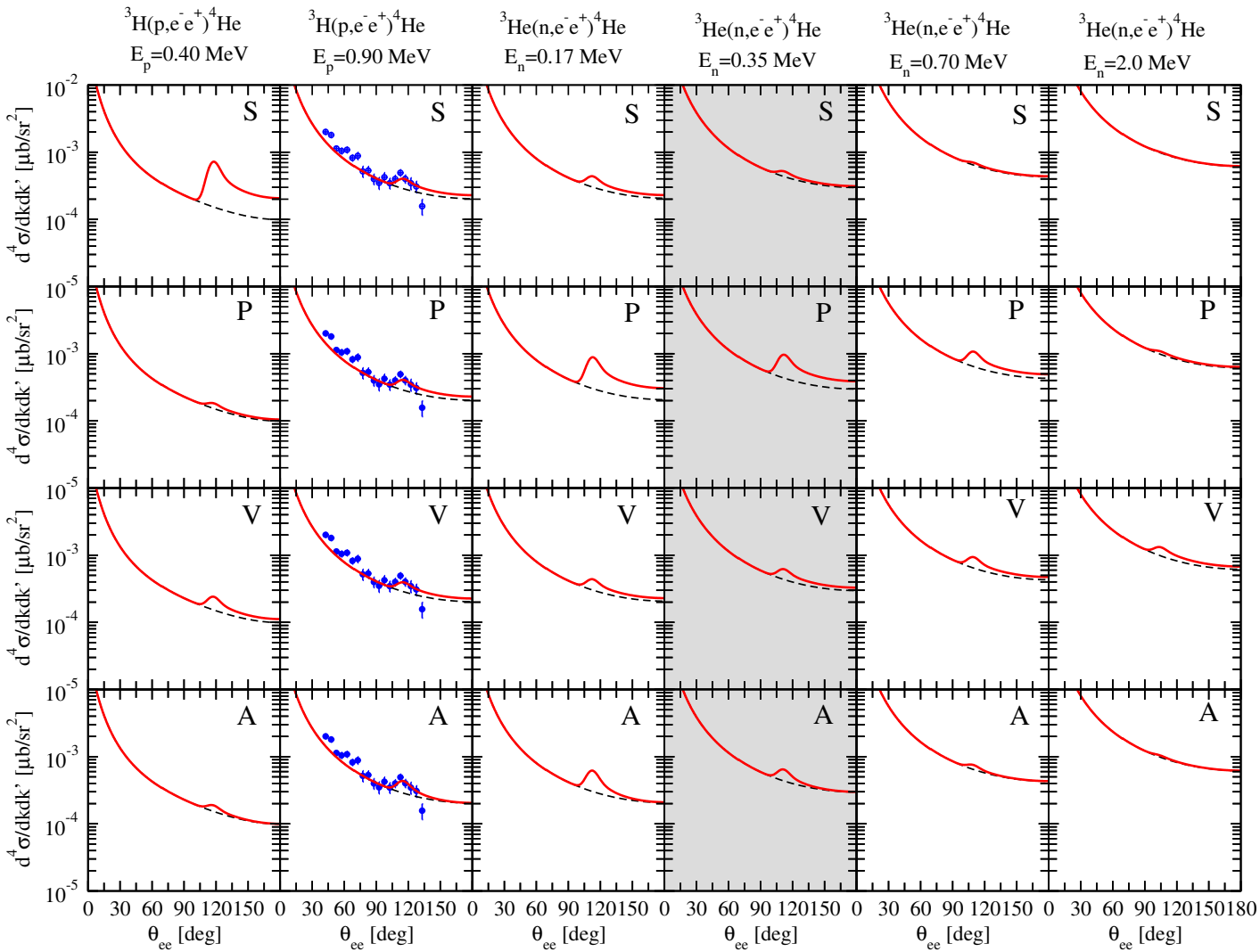

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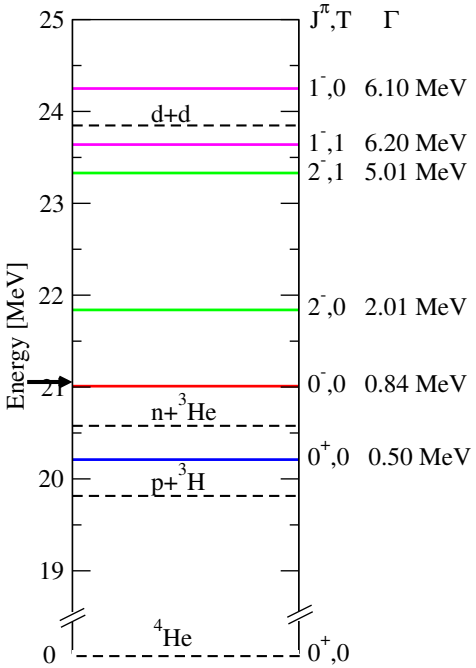

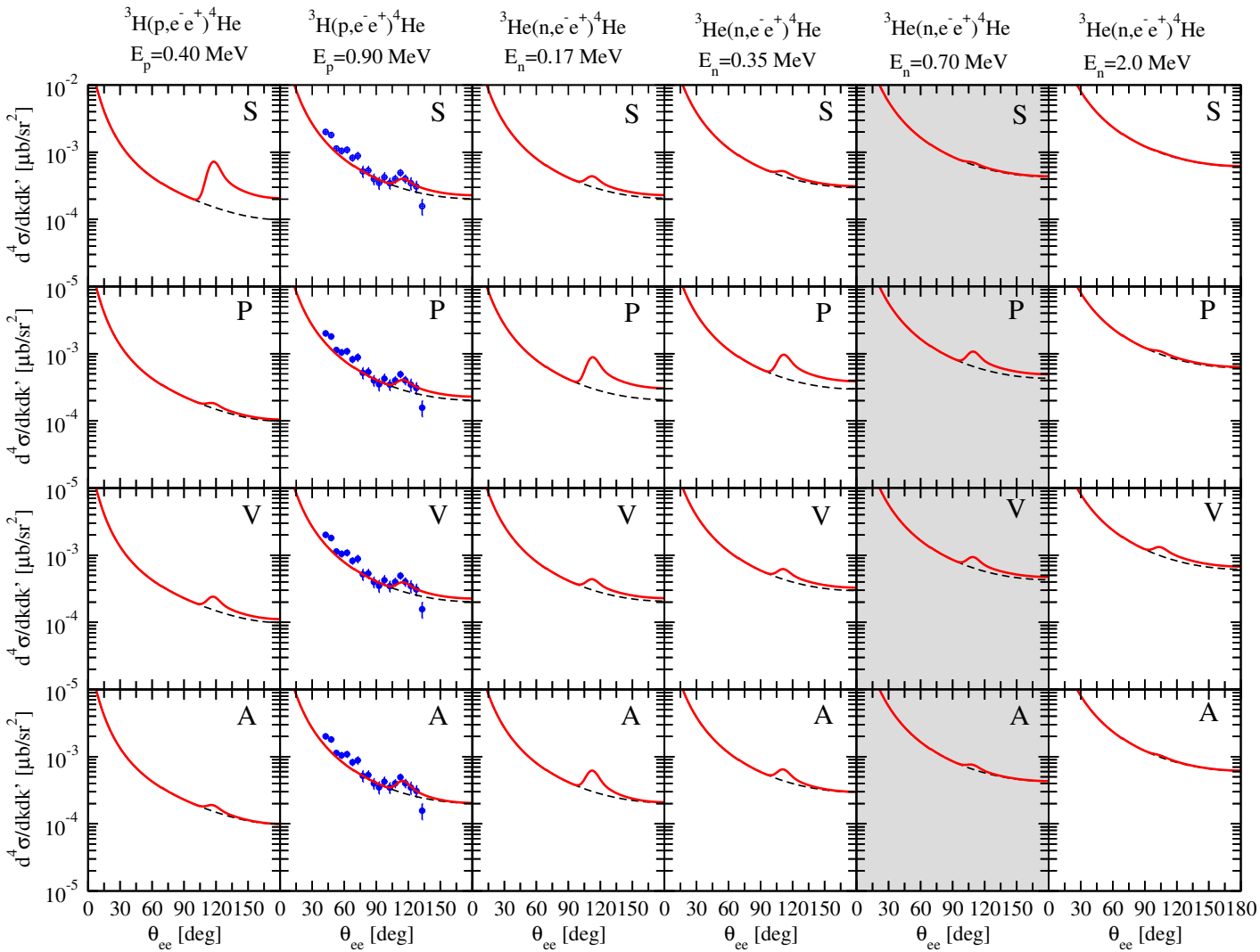

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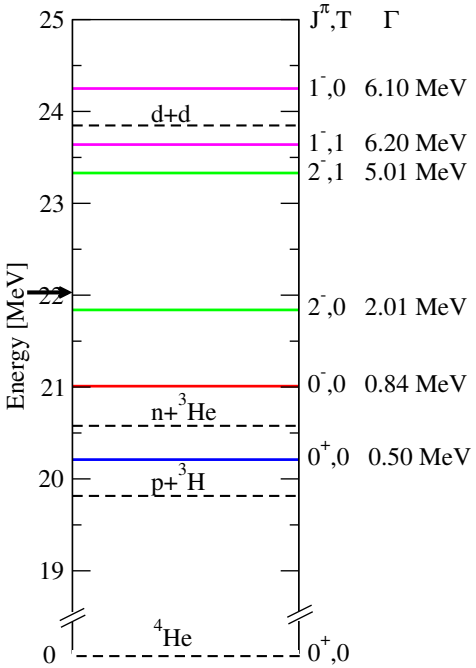

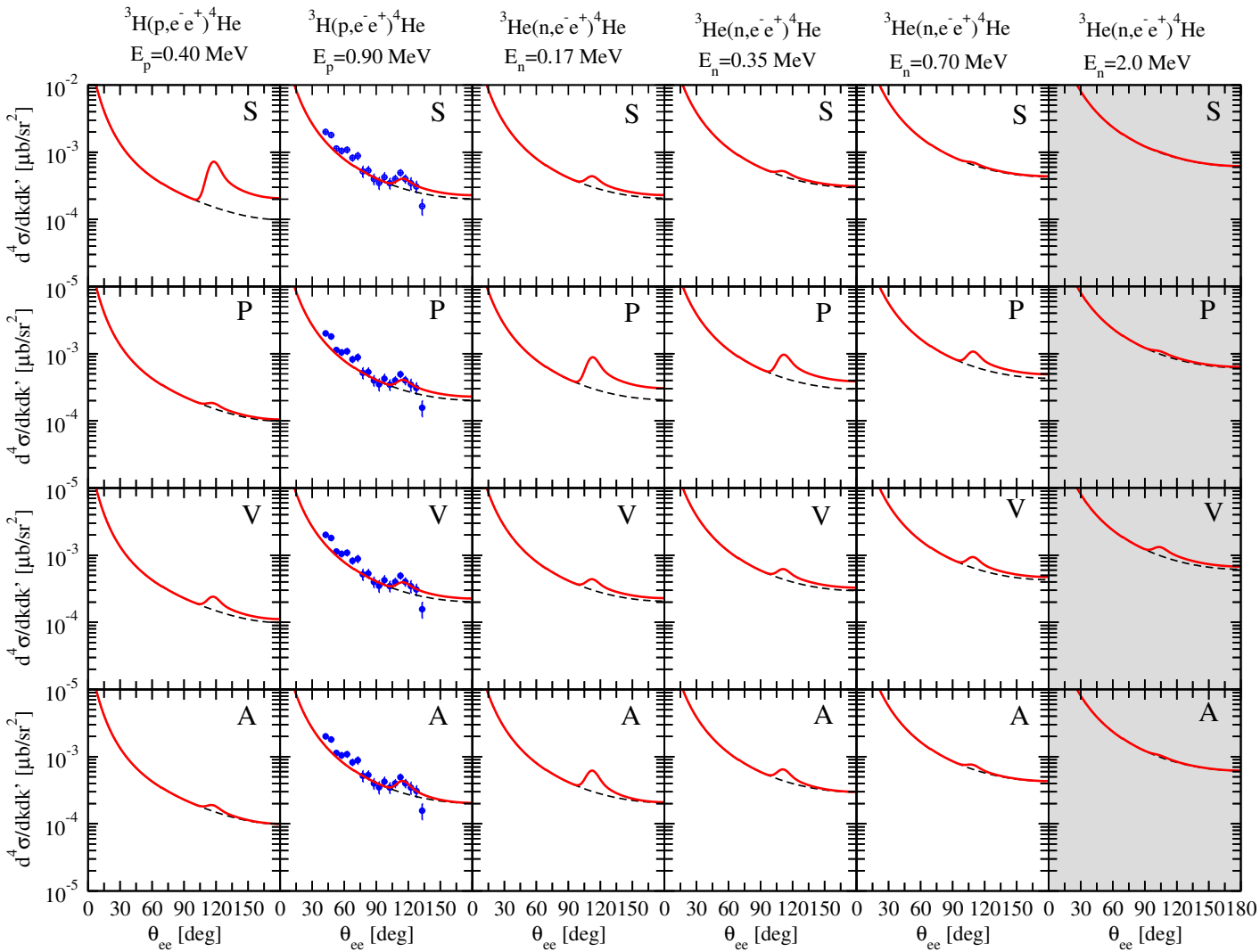

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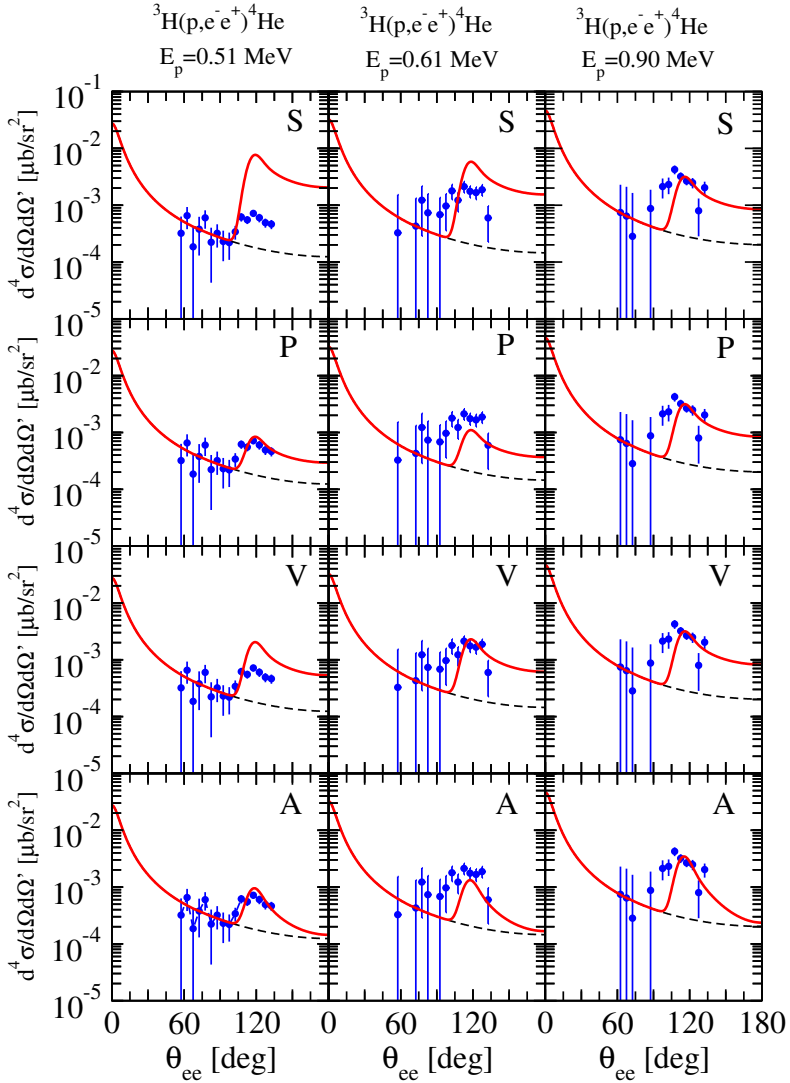
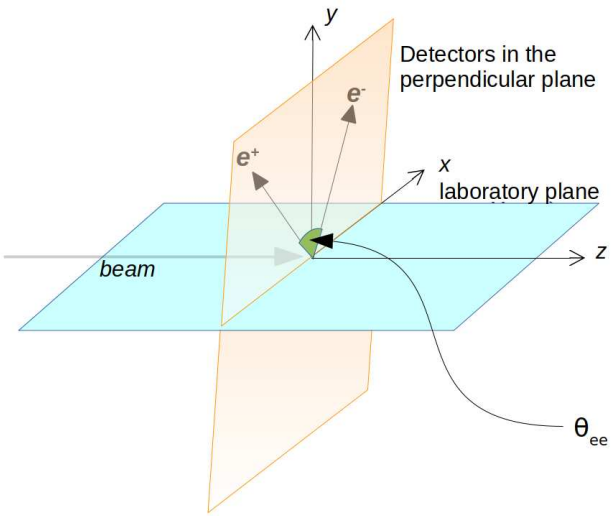
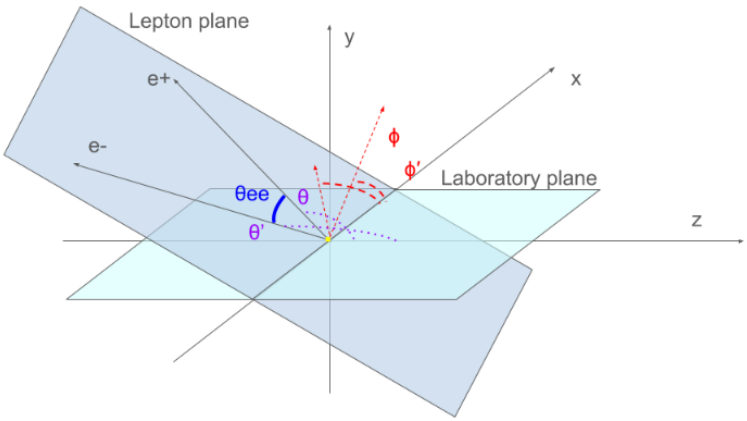


Out of the perpendicular plane

$\Delta\phi = \phi - \phi' =$ azimuthal angles of $\boldsymbol{k}, \boldsymbol{k}'$





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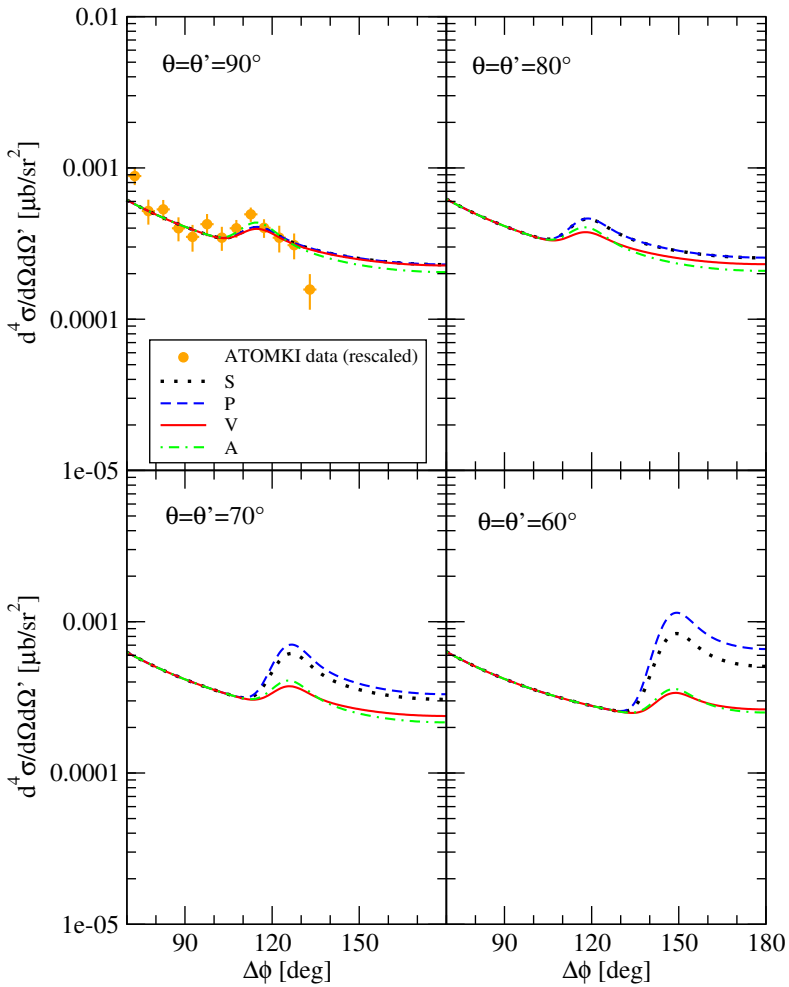

Extracted coupling constants

$$\varepsilon_0 = \frac{\varepsilon_u + \varepsilon_d}{2}$$

$$\varepsilon_z = \frac{\varepsilon_u - \varepsilon_d}{2}$$

	N3LO500/N2LO500		NVIa/3NIa	
Case	ε_0	ε_z	ε_0	ε_z
S	0.86	**0**	0.75	**0**
$P\not{}$	25.5	**0**	27.2	**0**
P	**0**	5.06	**0**	4.82
$V\not{p}$	2.56×10^{-3}	$-\mathbf{3}\,\varepsilon_0$	2.66×10^{-3}	$-\mathbf{3}\,\varepsilon_0$
A	2.58×10^{-3}	**0**	2.89×10^{-3}	**0**

- **Nice model-independence of our predictions**
- S-exchange: isovector m.e. small & $\eta_z^S \sim c_5 \Rightarrow \varepsilon_z = 0$
  - S-exchange **excluded** by earlier studies
- P-exchange $\not{}$: piophobic hypothesis $\Rightarrow \varepsilon_z = 0$
  - Delle Rose *et al.*, Front. Phys. **7**, 73 (2019) & Alves, Phys. Rev. D **103**, 055018 (2021) $\rightarrow |\varepsilon_{u,d}| \sim 1$

  $\Rightarrow$ **inconsistent**
- V-exchange $\not{p}$: protophobic hypothesis $\Rightarrow 2\varepsilon_u + \varepsilon_d = 0 \Rightarrow 3\varepsilon_0 + \varepsilon_z = 0$
  - Feng *et al.*, Phys. Rev. Lett. **117**, 071803 (2016) $\rightarrow |\varepsilon_{u,d}| \sim 10^{-3}$

  $\Rightarrow$ **consistent**
- A-exchange: isoscalar m.e. much larger than isovector
  - Kozaczuk *et al.*, Phys. Rev. D **95**, 115024 (2017) $\rightarrow |\varepsilon_{u,d}| \sim 10^{-3} - 10^{-4}$

  $\Rightarrow$ **inconsistent** (but it can be explained by suppression effects in ^{4}He nuclear transition m.e.)

$A = 3$ processes: $^2\mathrm{H}(p, e^+e^-)^3\mathrm{He}$ and $^2\mathrm{H}(n, e^+e^-)^3\mathrm{H}$

Question: is it possible to see X17 in simpler systems? $\Rightarrow \boldsymbol{A} = 3$. Same ingredients:

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$\frac{1}{2}^+$	$^2S_{\frac{1}{2}}, {}^4D_{\frac{1}{2}}$	$C_0^{LS\frac{1}{2}}$		$M_1^{LS\frac{1}{2}}$	$L_0^{LS\frac{1}{2}}$
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$\frac{3}{2}^-$	$^2P_{\frac{3}{2}}, {}^4P_{\frac{3}{2}}, {}^4F_{\frac{3}{2}}$	$C_1^{LS\frac{3}{2}}$	$M_2^{LS\frac{3}{2}}$	$E_1^{LS\frac{3}{2}}$	$L_1^{LS\frac{3}{2}}$
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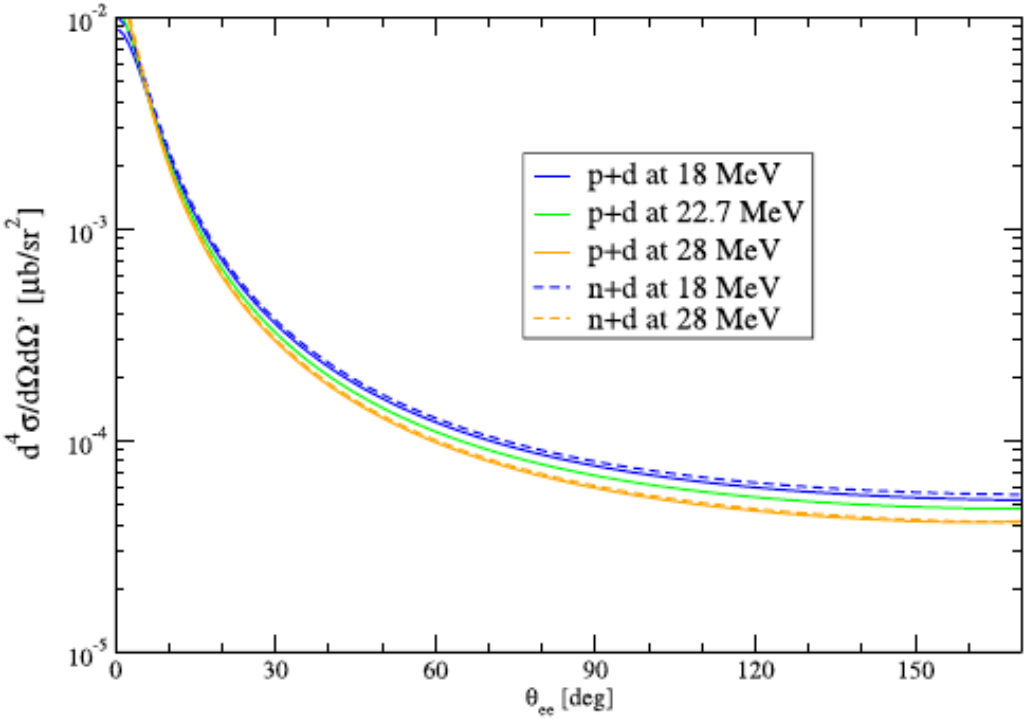

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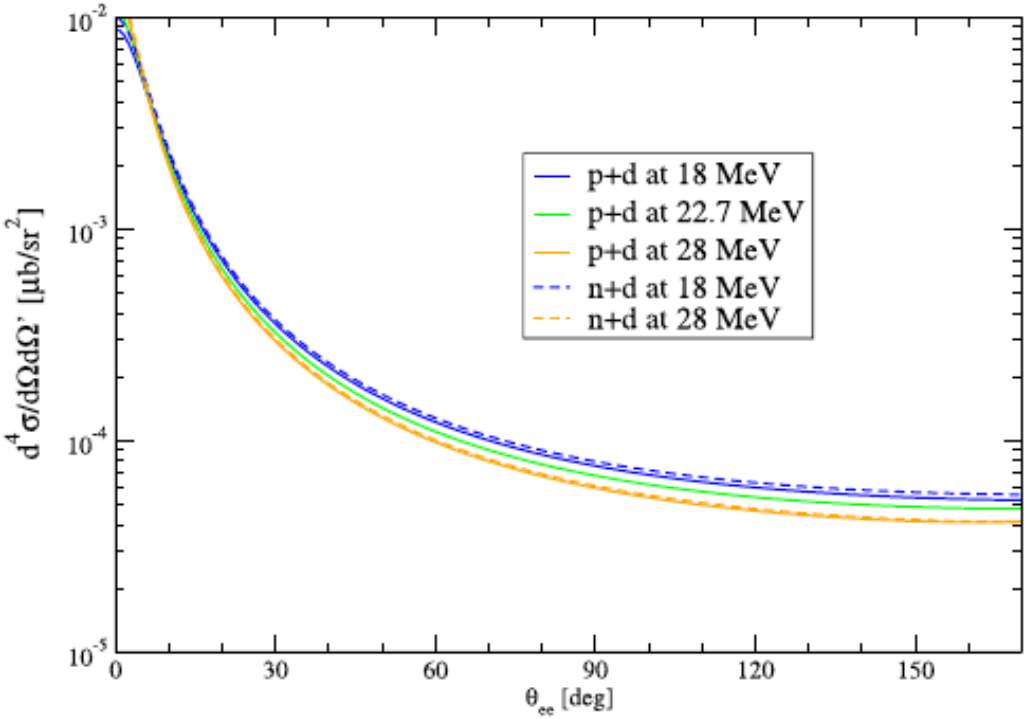
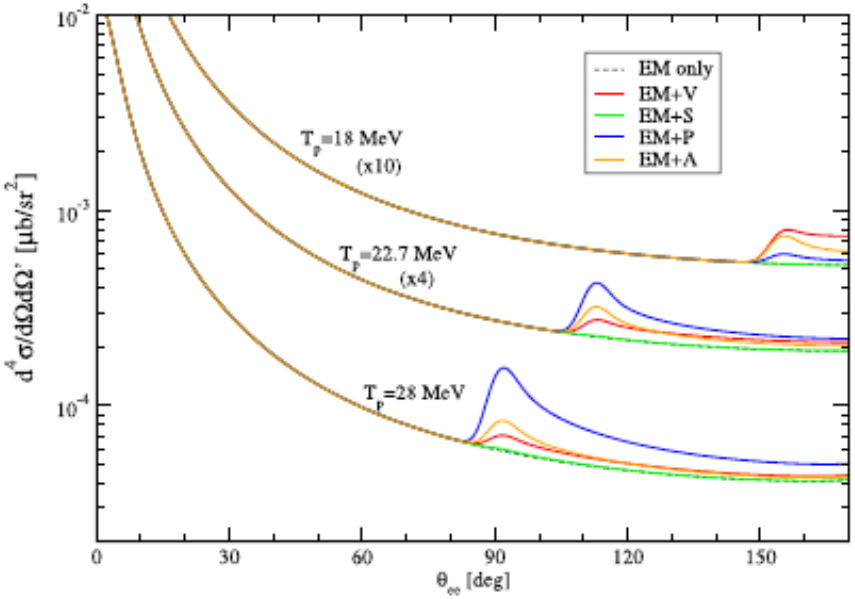


- **Include X17: same approach as for $A = 4$**

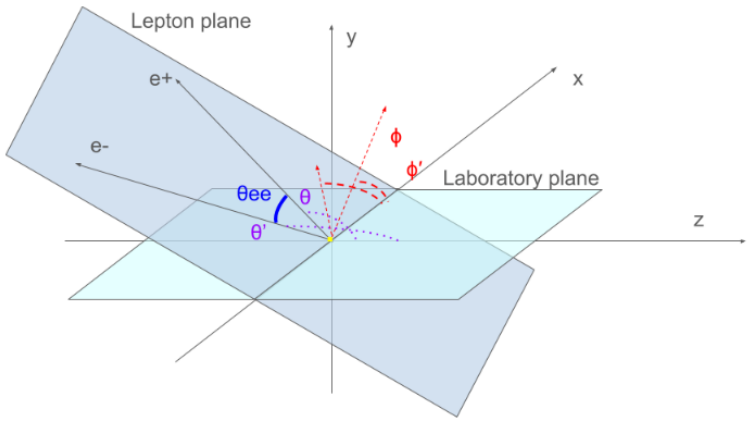
Results: $^2\mathrm{H}(p, e^+e^-)^3\mathrm{He}$ (I)

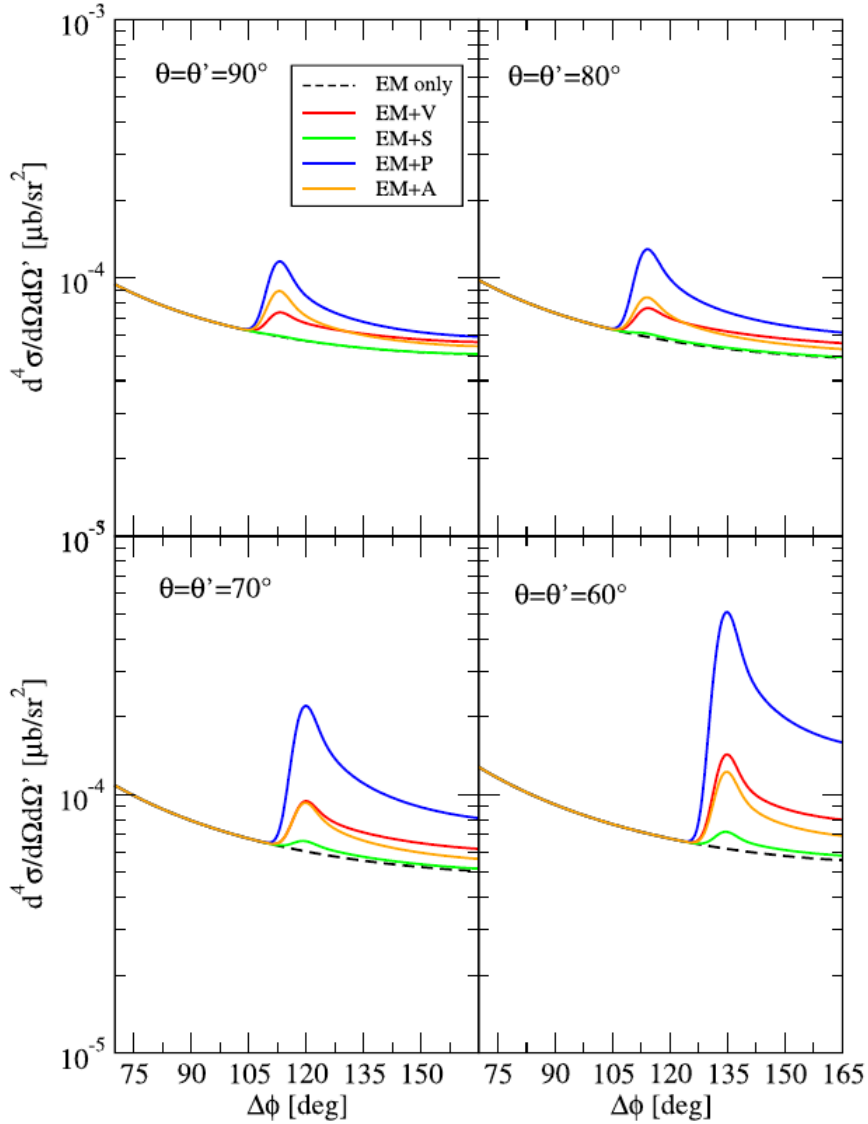
- Kinematics constraints $\Rightarrow$ $T_p > 17.3$ MeV ($T_n > 16.1$ MeV) for X17
- X17 peak to lower values of θ_{ee} as energy increases
- S-exchange: **tiny** effect
- P-exchange $\not{\pi}$: peak **increases** as T_p increases
- V-exchange $\not{\phi}$: peak **T_p-independent**
- A-exchange (IS): peak **slightly decreases** as T_p increases



Results: ^{2}H(p, e^+e^-)^{3}He (II)

The "out of the perpendicular plane" opportunity

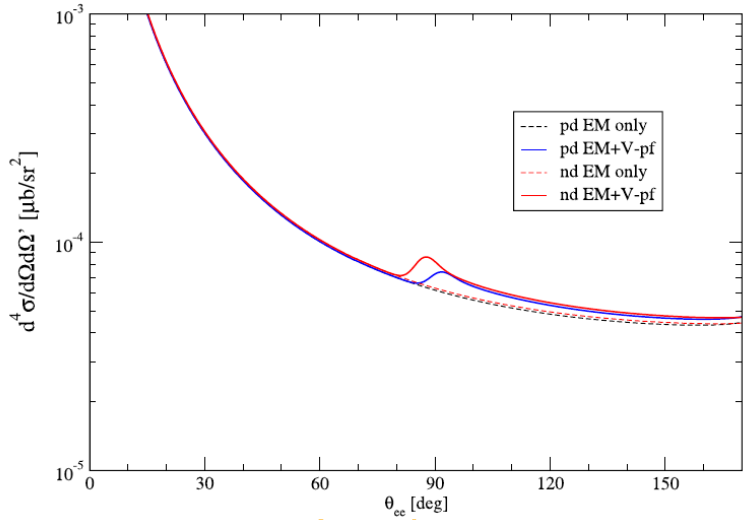




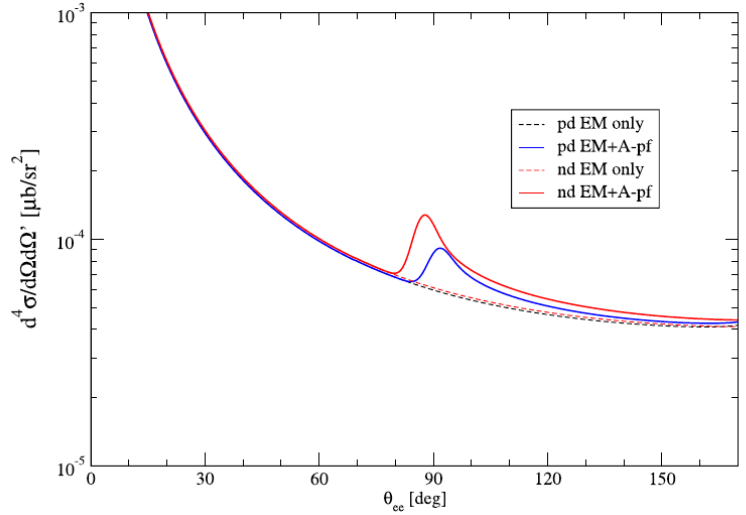
Results: $^2H(p, e^+e^-)^3He$ vs. $^2H(n, e^+e^-)^3H$

$T_{p/n} = 28$ MeV, NVIa/3NIa and $\theta = \theta' = 90^0$

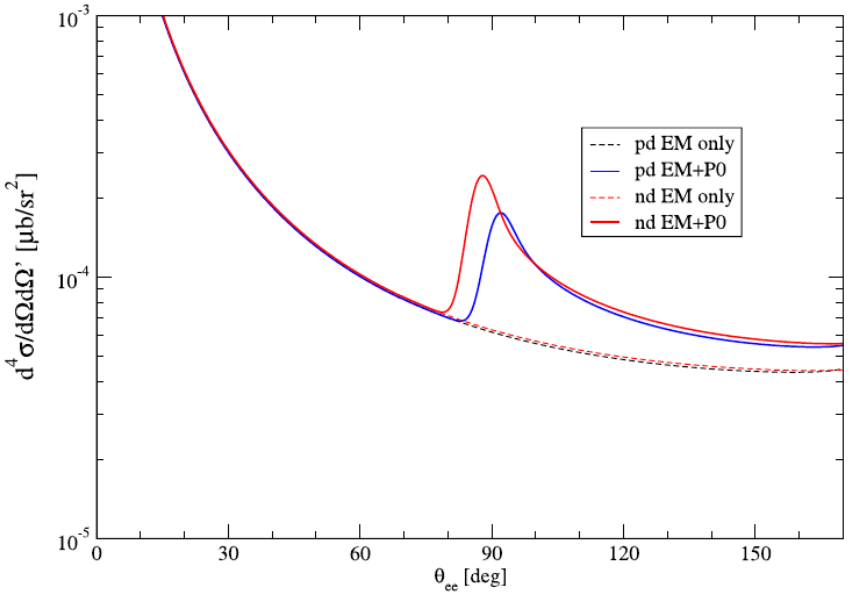
V-exchange $\not{p}$



A-exchange $\not{p}$



Isoscalar P-exchange



Conclusions, outlook and suggestions

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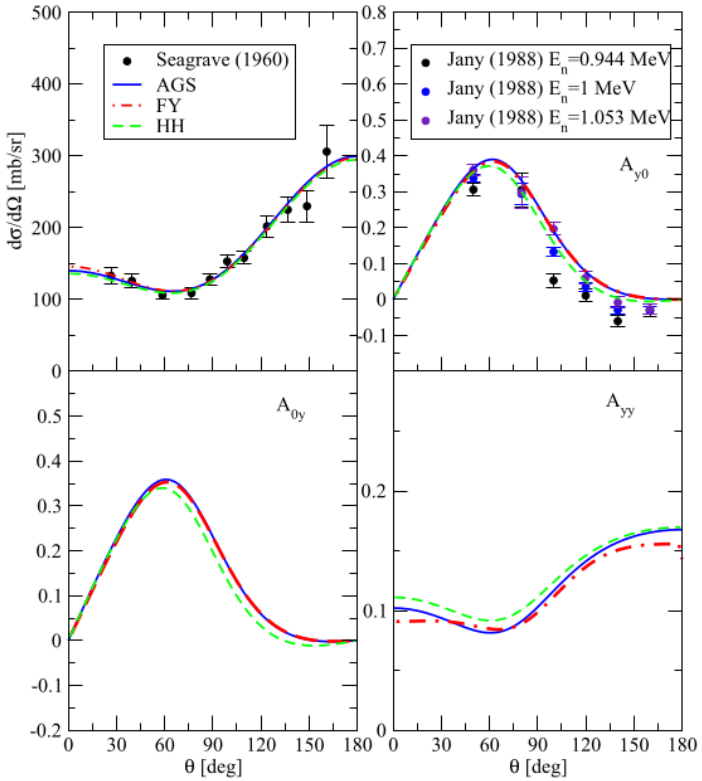
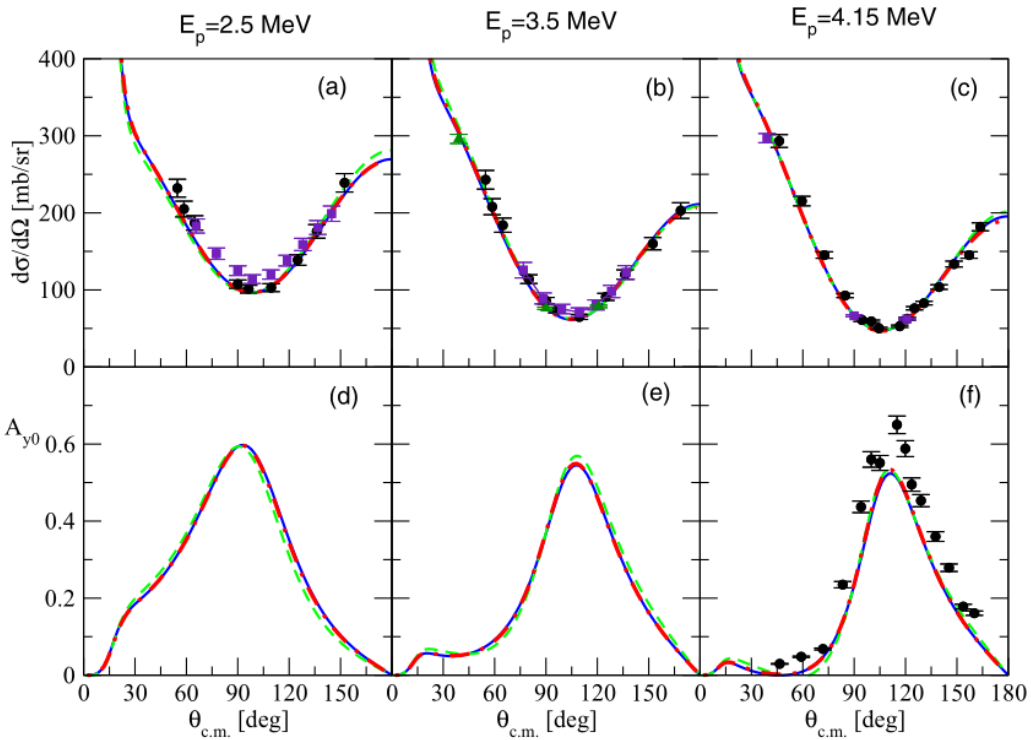
Suggestions: looking for **benchmarks**

Benchmark calculation of $p-{}^3$H and $n-{}^3$He scattering

$n+{}^3$He elastic scattering

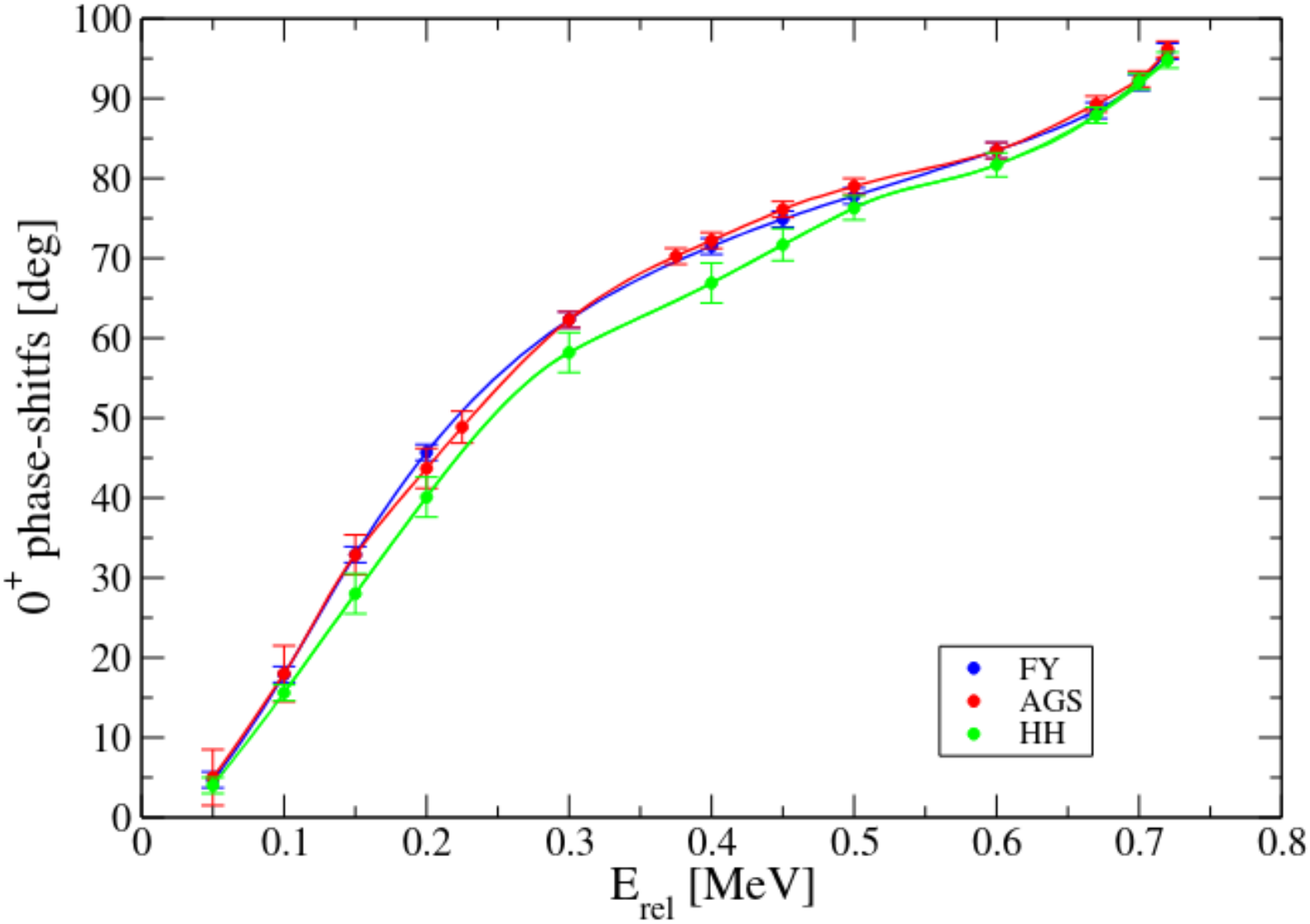


$p+{}^3$H elastic scattering



M. Viviani *et al.*, Phys. Rev. C **95**, 034003 (2017)

The excited state of the α-particle: a **benchmark** study (N3LO500)



P.-Y. Duerinck *et al.*, Phys. Rev. C **112**, 044001 (2025)

Conclusions, outlook and suggestions

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  - can handle the X17 hypothesis with **little theoretical uncertainty**
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- Current predictions can serve as the basis for future experimental efforts

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- Improve the X17–nucleon interaction: **extend beyond LO in ChEFT**
- Improve the IPC calculation: **go beyond the one-photon exchange approximation**

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In collaboration with

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- **E. Filandri** (ECT* and FBK - Trento)
- L. Girlanda (Univ. del Salento)
- C. Gustavino (INFN-Roma 1)
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Thank you for your attention!