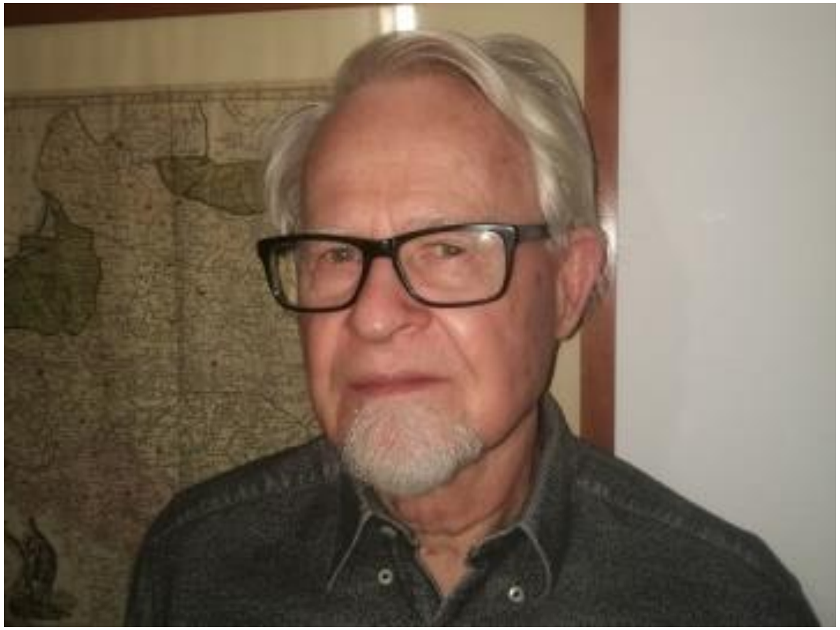
Search for Borromean objects

Dedicated to Prof. Sławomir Wycech



STRANU: Hot Topics in STRANgeness NUclear and Atomic Physics
ETC* virtual 24-28 May 2021

Paweł Moskal
Jagiellonian University, Cracow,Poland

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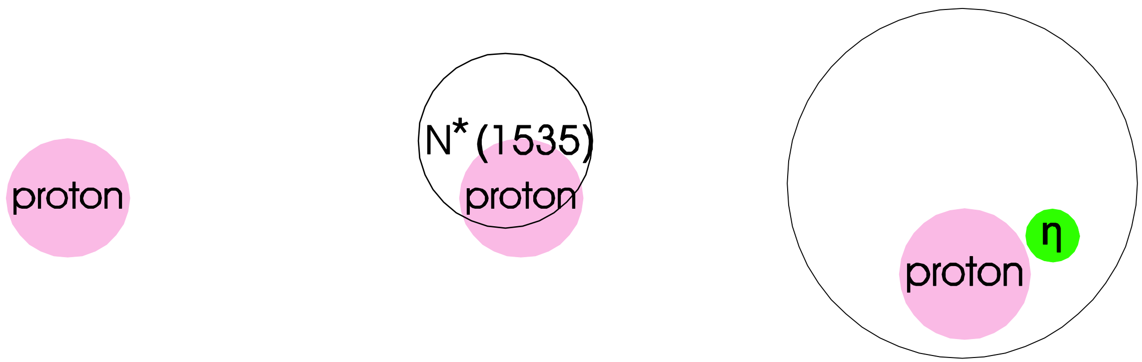
Possible $pp \rightarrow pp\eta$ reaction mechanisms:

- Resonant state:



- Simultaneous production:

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SIMPLE ANALYSIS OF THE THRESHOLD MESON PRODUCTION IN *pp* COLLISIONS *

S. Wycech

Soltan Institute for Nuclear Studies
Hoża 69, 00-681 Warsaw, Poland

(Received October 9, 1996)

A phenomenological model is used to analyze the π and η meson formation in pp collisions. The aim is to describe final state interactions. Strong ηpp correlations are found at very low energies.

Assume that the meson production is described by an operator $T(r)$ where r is the relative proton-proton coordinate. The amplitude A is then given by an integral

$$A(P,p) = \int d^3r j_o(qr/2)\psi_{pp}^-(r,p)^*T(r)\phi_{pp}(r,P) \tag{1}$$

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* Presented at the "Meson 96" Workshop, Cracow, Poland, May 10–14, 1996.

tial and final pp pairs and noninteracting final mesons. A simple form $T(r) = const * exp(-\mu r)/r(1/r + d/dr) * const$ motivated by the meson exchange models ([2]) is tried. Next, the production X-section $\sigma_o(Q)$ is calculated and used to scale the experimental one. The ratio $\sigma_{\mathrm{exp}}(Q)/\sigma_o(Q)$ for pions is shown in Fig. 1. Essentially it is a constant which we find well-independent on the parameter μ and the detailed form of $T(r)$. The actual value of this constant is a well known problem of the theory [2]. The picture changes dramatically if one turns to η production, as shown in Fig. 2. The enhancement close to threshold is due to the strong attraction in the final state. It may be described by an amplitude of the type (1) with the pp pair produced from an object of a 4 fm radius. The question arises, is that **a Borromean ηpp state?** To answer it, we have summed the final state interactions with a method used previously in the η-helium and η-deuteron interactions [4]. In order to reproduce the enhancement one needs the $\eta - p$ scattering length Re $a \geq .7$ fm, *i.e.*larger than the standard $(.3 - .5\ \mathrm{fm})$, but allowed by some analyses. The same calculation produces an η-deuteron quasibound state for Re $a \geq .8$ fm. With the uncertainties in Fig. 2 one cannot tell is the enhancement due to a Borromean system (quasi-bound state with singularity on the physical energy sheet) or a 3-body resonance tial and final pp pairs and noninteracting final mesons. A simple form $T(r) = const * exp(-\mu r)/r(1/r + d/dr) * const$ motivated by the meson exchange models ([2]) is tried. Next, the production X-section $\sigma_o(Q)$ is calculated and used to scale the experimental one. The ratio $\sigma_{\mathbf{exp}}(Q)/\sigma_o(Q)$ for pions is shown in Fig. 1. Essentially it is a constant which we find well-independent on the parameter μ and the detailed form of $T(r)$. The actual value of this constant is a well known problem of the theory [2]. The picture changes dramatically if one turns to η production, as shown in Fig. 2. The enhancement close to threshold is due to the strong attraction in the final state. It may be described by an amplitude of the type (1) with the pp pair produced from an object of a 4 fm radius. The question arises, is that **a Borromean ηpp state?** To answer it, we have summed the final state interactions with a method used previously in the η-helium and η-deuteron interactions [4]. In order to reproduce the enhancement one needs the $\eta - p$ scattering length Re $a \geq .7$ fm, *i.e.*larger than the standard ($.3 - .5$ fm), but allowed by some analyses. The same calculation produces an η-deuteron quasibound state for Re $a \geq .8$ fm. With the uncertainties in Fig. 2 one cannot tell is the enhancement due to a Borromean system (quasi-bound state with singularity on the physical energy sheet) or a 3-body resonance

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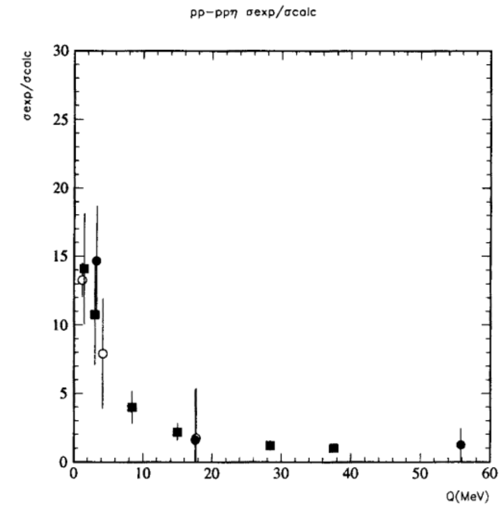

Fig. 2. The experimental [3] eta production cross section scaled by the calculated σ_o, plotted against the excess energy.

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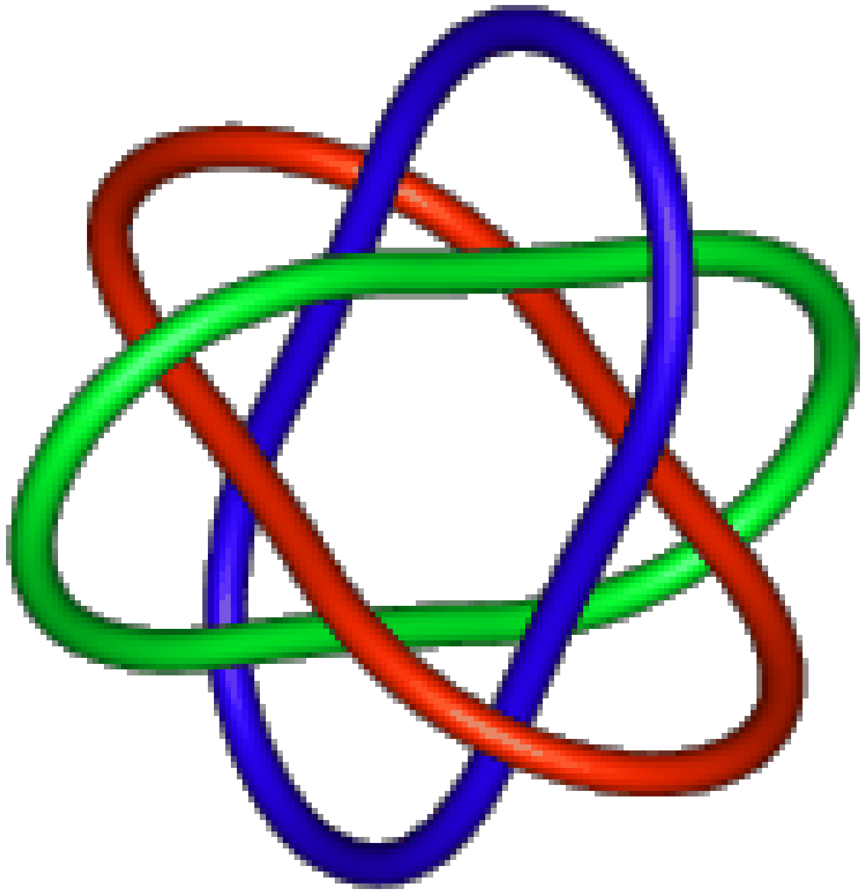
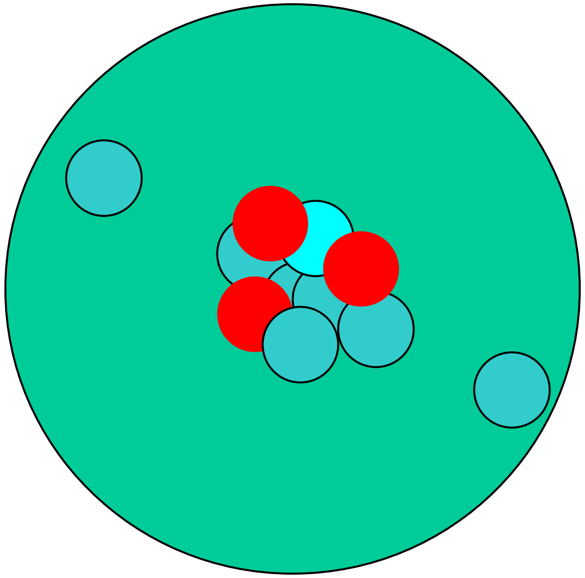
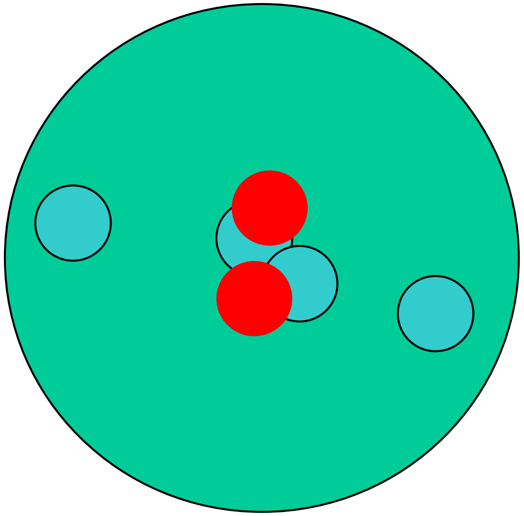


Borromean rings out of nucleons



^{11}Li



^{6}He

Correlation femtoscopy

Correlation function shape – size of the emission source

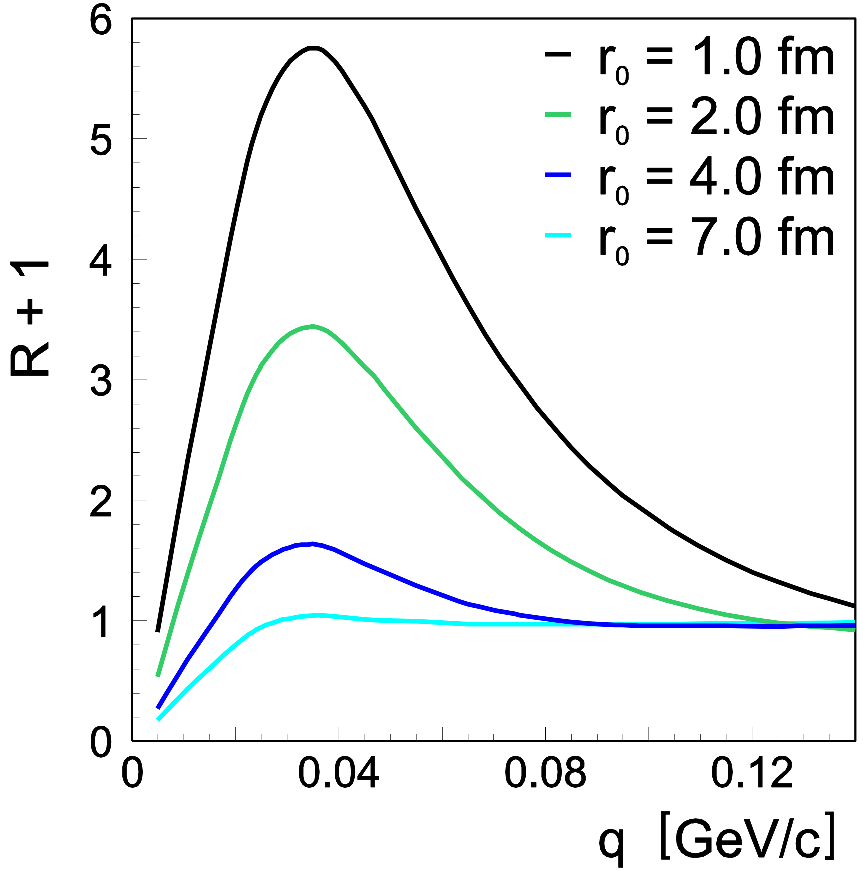
$$q = |\vec{p}_1 - \vec{p}_2|$$

Correlation function:

$$R(q) + 1 = C \cdot \frac{\sum Y_{12}(q)}{\sum Y_{12}^{\star}(q)}$$

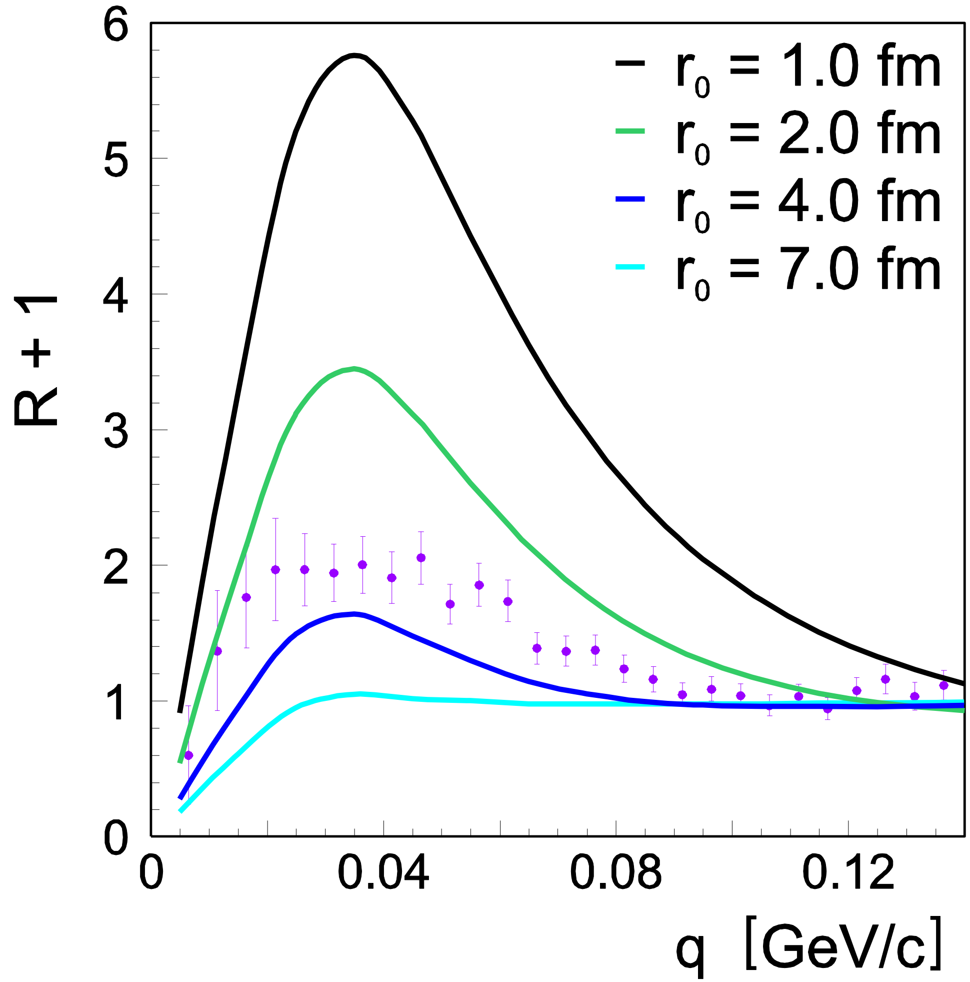
- $Y_{12}^{\star}$ - uncorrelated events
- event mixing technique

Model correlation function



- Correlation function *R(q)*
- Simultaneous production of *ppη* system
- Emission source approximated by the Gaussian distribution
- $\sigma \sim r_0$

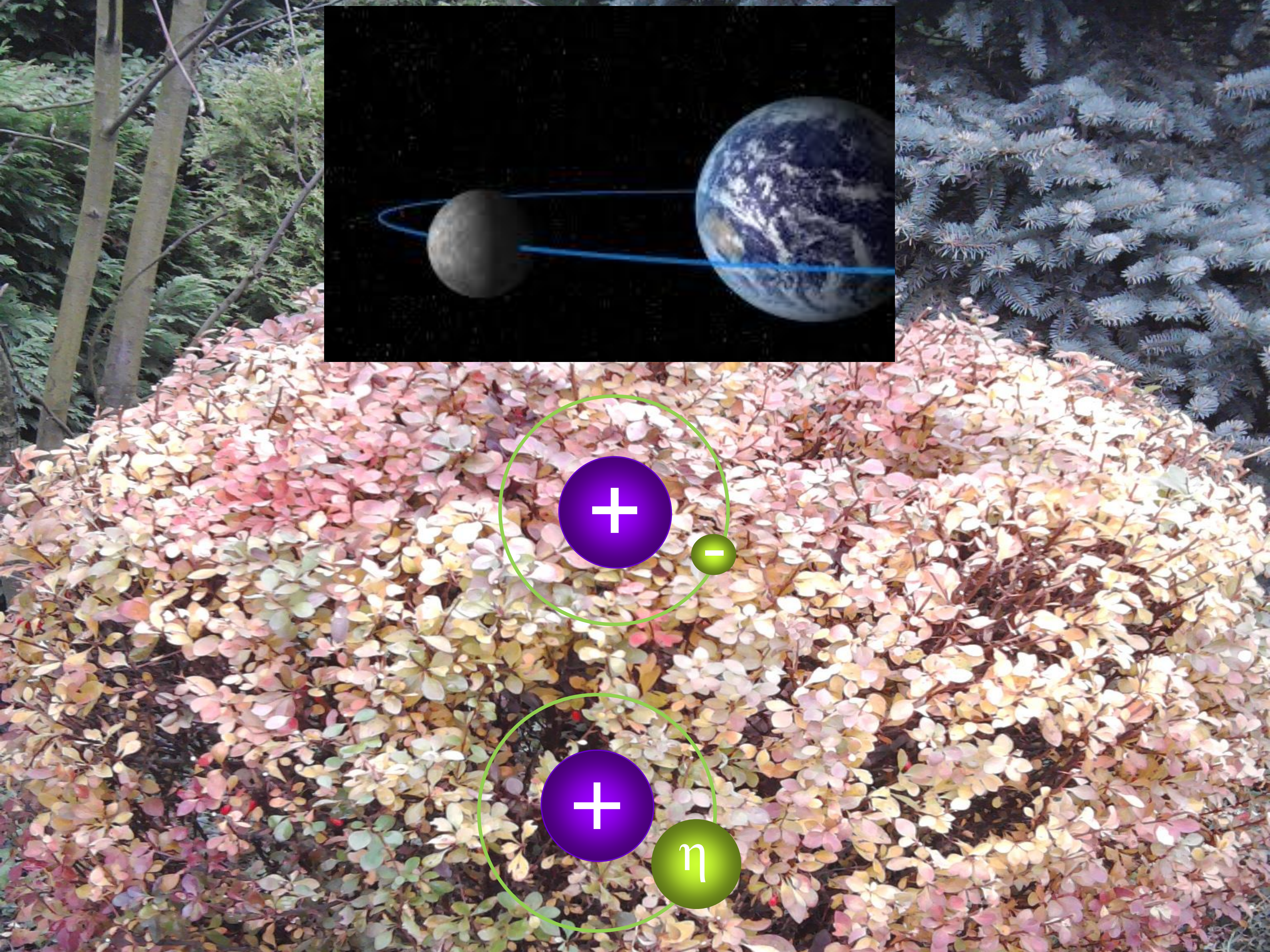
$$R-1\sim\left|\int d^3r\,\rho(\vec{r})\,e^{i(\vec{k}_1-\vec{k}_2)\cdot\vec{r}}\right|^2$$



S. Wycech, Acta Phys. Pol. **B 27** (1996) 2981.

$$r_0\approx 3.0\div 3.5\ fm$$

J. Phys. G: Nucl. Part. Phys. 37, 055003 (2010)


+
-
+
η

COoler SYnchrotron COSY

Attractive interaction between η and N

(R. Bhalerao and L. C. Liu, Phys. Lett. B54 (1985) 685)

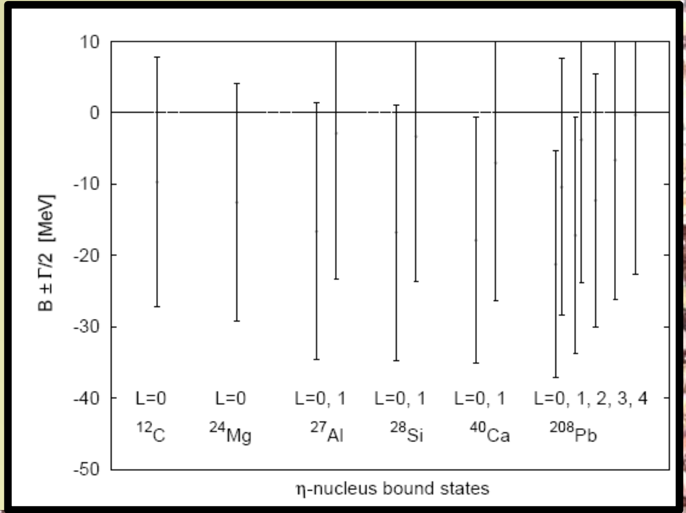
↓

possible existence of bound states of the η meson with nuclei for A>10

(Q. Haider and L. C. Liu, Phys. Lett. B172 (1986) 257)

↓

(C.Garcia-Recio, T. Inoue, J.Nieves, E. Oset, Phys. Lett. B550 (2002) 47).



η bound state possible with the light nuclei

^{3}He-η ^{3}H-η ^{4}He-η

(*C. Wilkin, Phys. Rev., C47 (1993)*)

Supported by model calculations of:

- S. Wycech et al., Phys. Rev. C52(1995)544

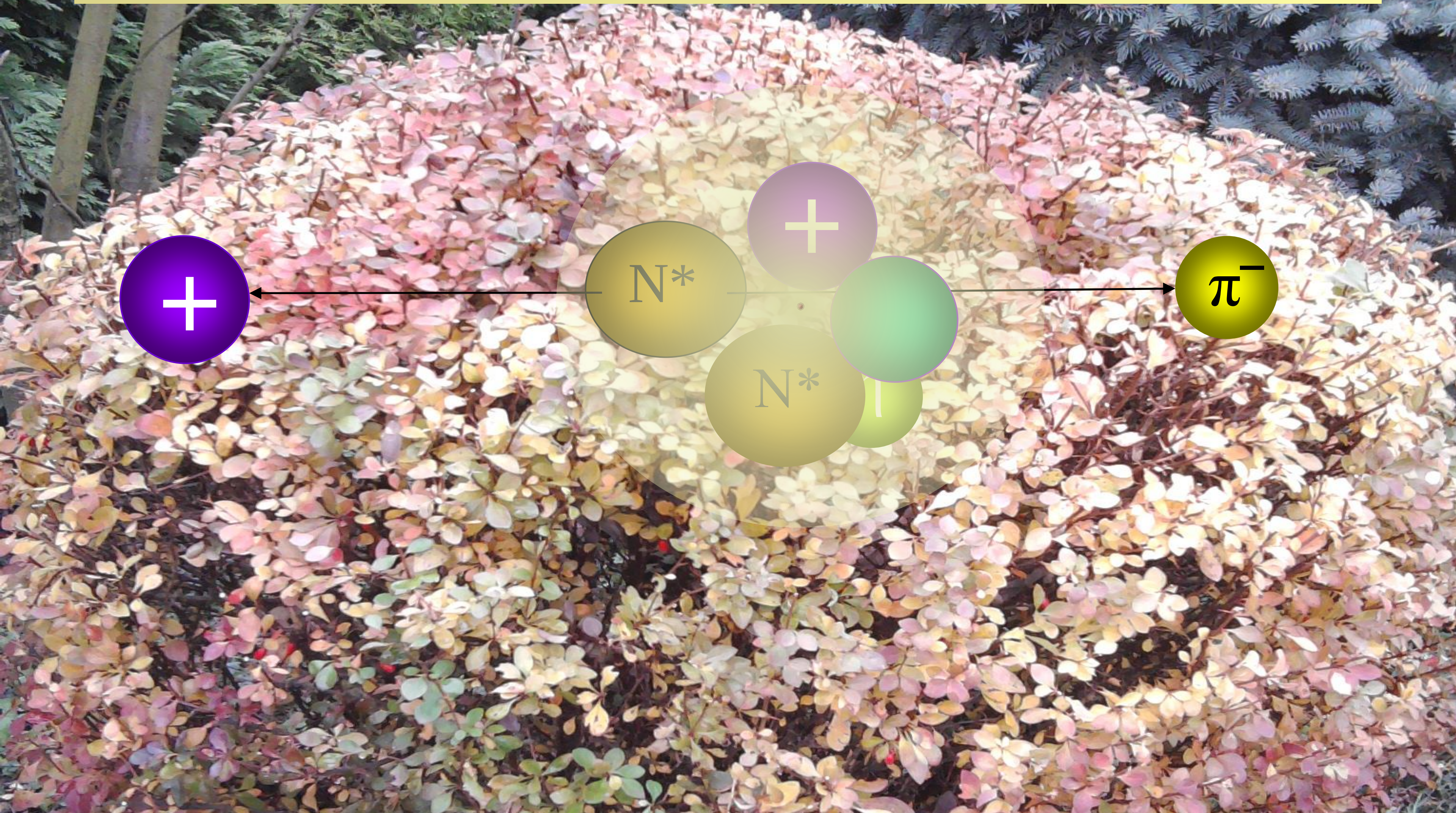
(the multiple scattering theory)

and by observations of:

- near threshold enhancements of the amplitudes for the $dd \rightarrow {}^4\text{He}\,\eta$ and $pd \rightarrow {}^3\text{He}\,\eta$ reactions

THE ETA-MESIC NUCLEUS

η meson bound with nucleus via STRONG INTERACTION



WASA-at-COSY

$$d+d \rightarrow ({}^{4}He\text{-}n)_{bound} \rightarrow {}^{3}He + p + \pi^{-}$$

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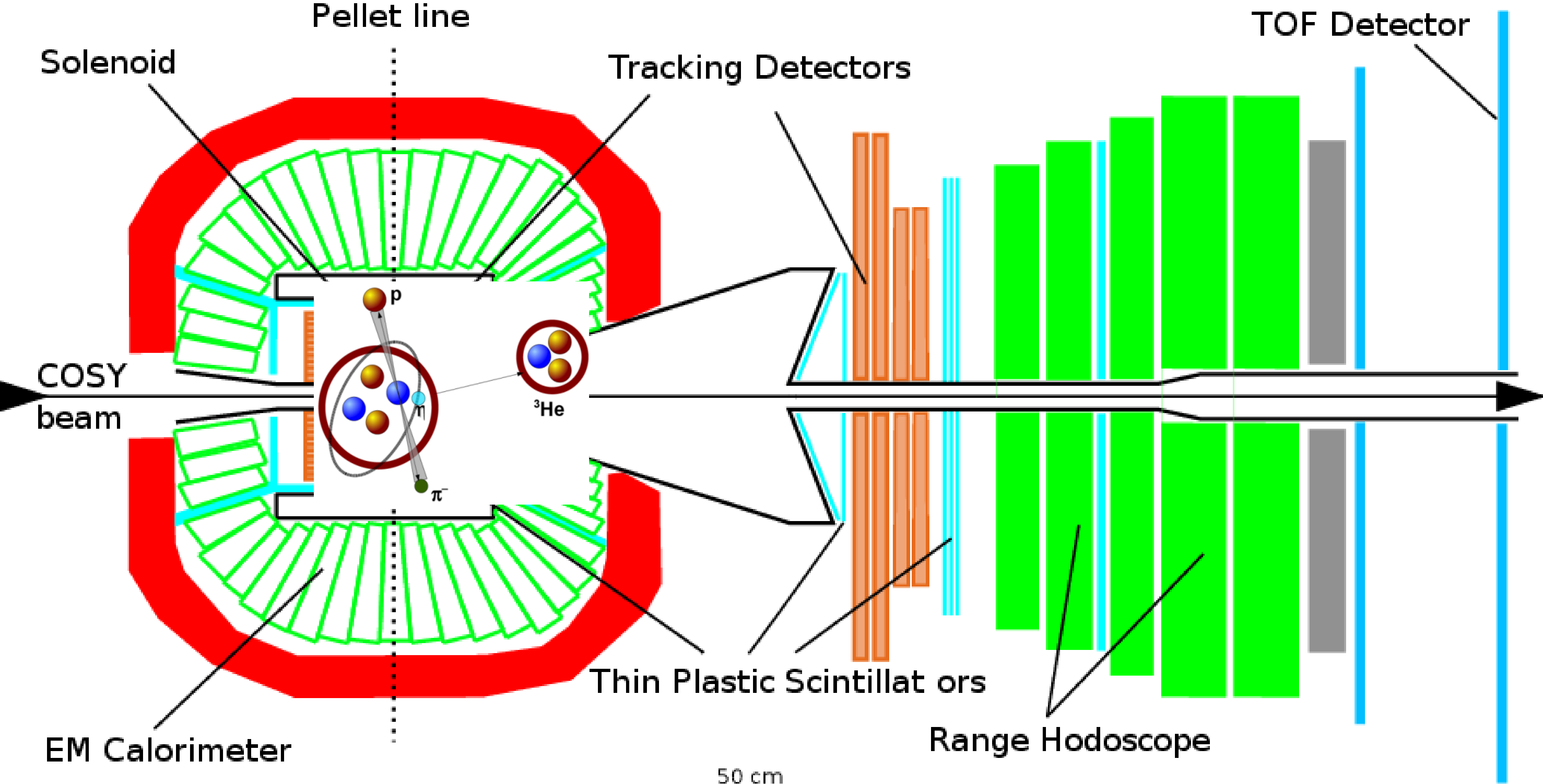

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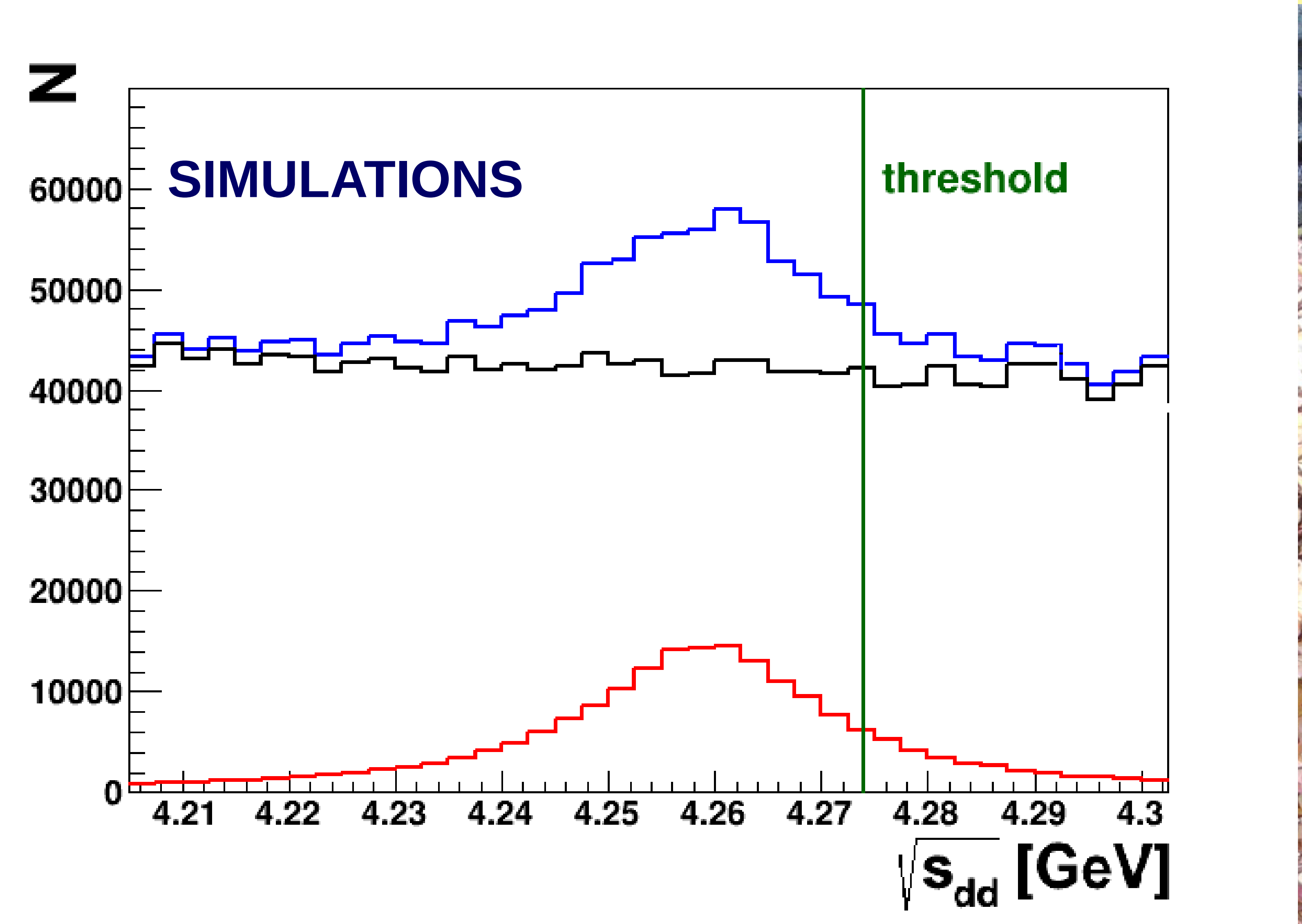
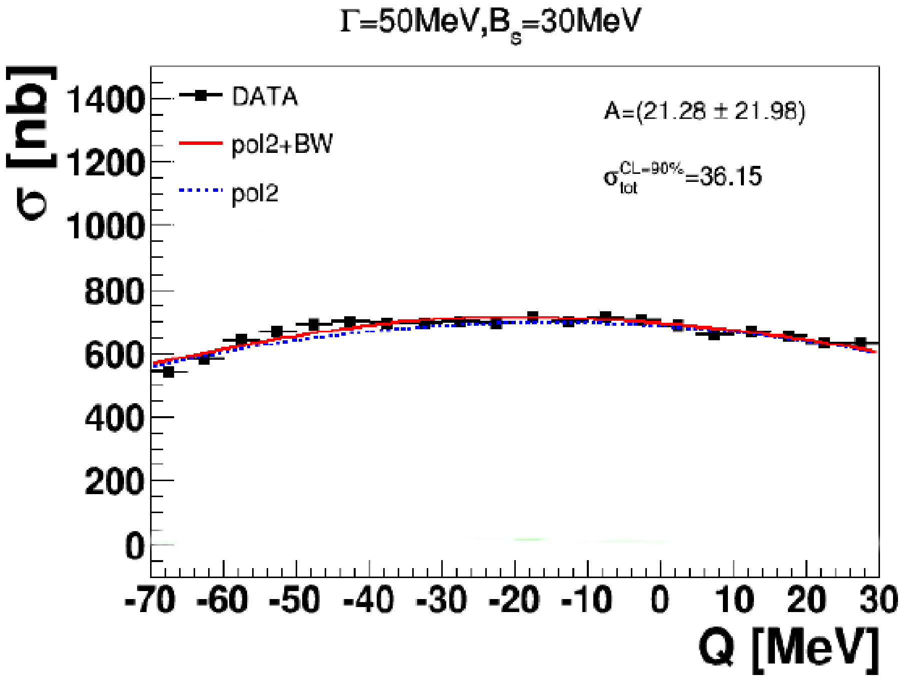
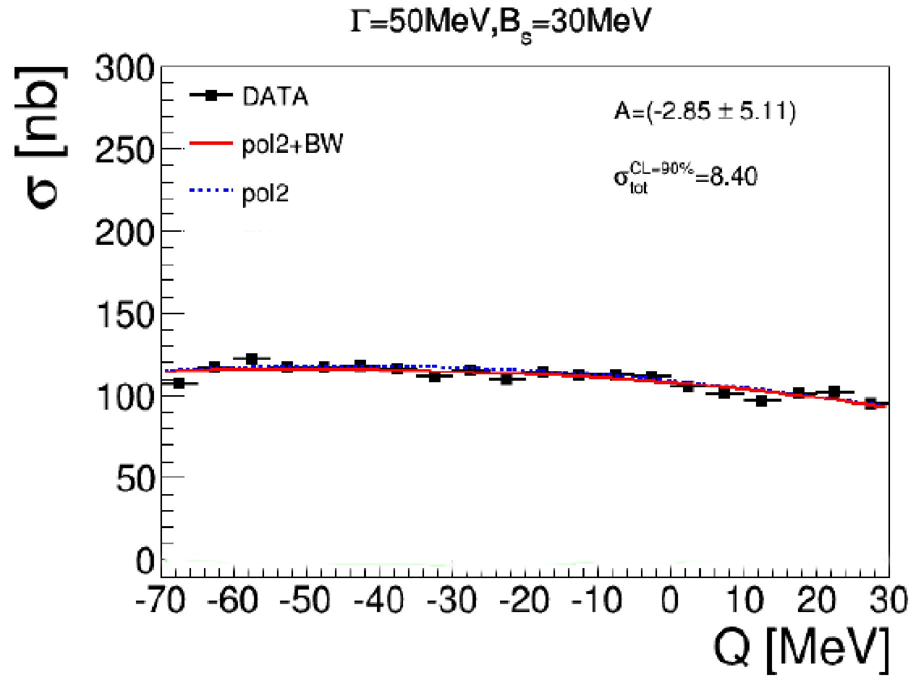


WASA-at-COSY:
P. Adlarson et al., Nucl. Phys. A 959 (2017) 102

$dd \to {}^3\mathrm{He}n\pi^0$ $\qquad$ $dd \to {}^3\mathrm{He}p\pi^-$





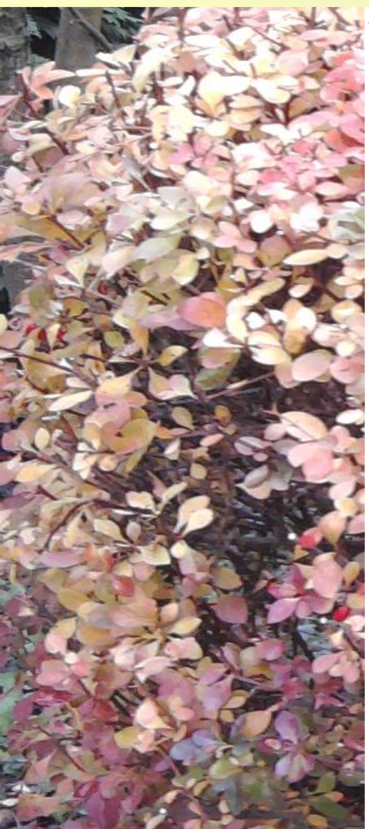
$$\sigma(Q,\Gamma,B_s,A) = \frac{A\cdot\Gamma^2/4}{(Q-B_s)^2+\Gamma^2/4}$$

η - ^{4}He

~ 6 nb -- Present preliminary experimental upper limit

~ 4 nb -- Theoretical estimation

S. Wycech, W. Krzemien , Acta. Phys. Pol. B45 (2014) 745



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STUDIES OF MESIC NUCLEI VIA DECAY REACTIONS*

Sławomir Wycech

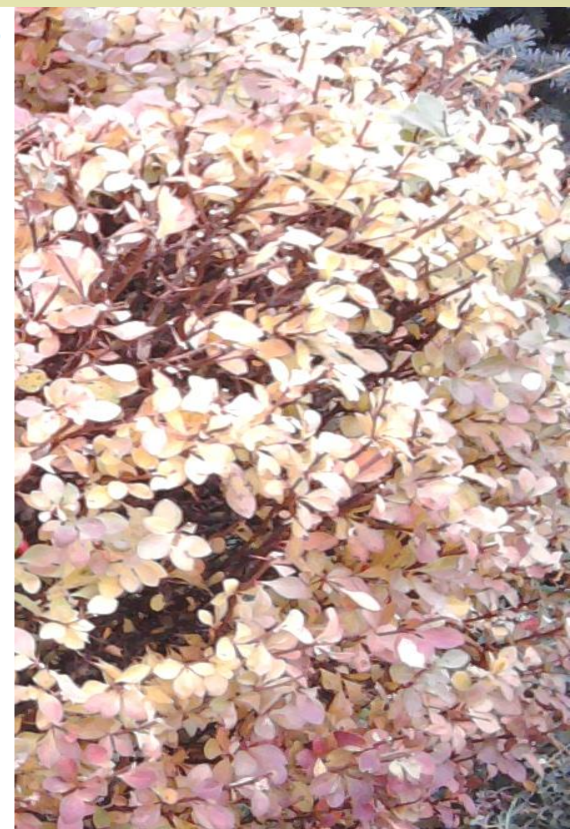
National Centre for Nuclear Studies, Hoża 69, 00-681 Warszawa, Poland

Wojciech Krzemień

The Marian Smoluchowski Institute of Physics, Jagiellonian University
Reymonta 4, 30-059 Kraków, Poland

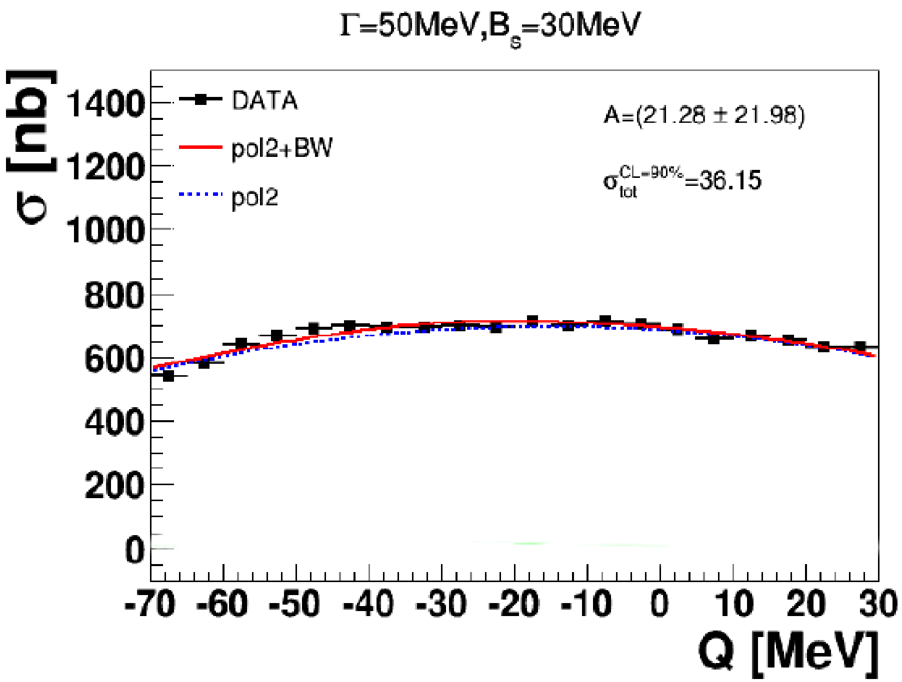
(Received January 7, 2014)

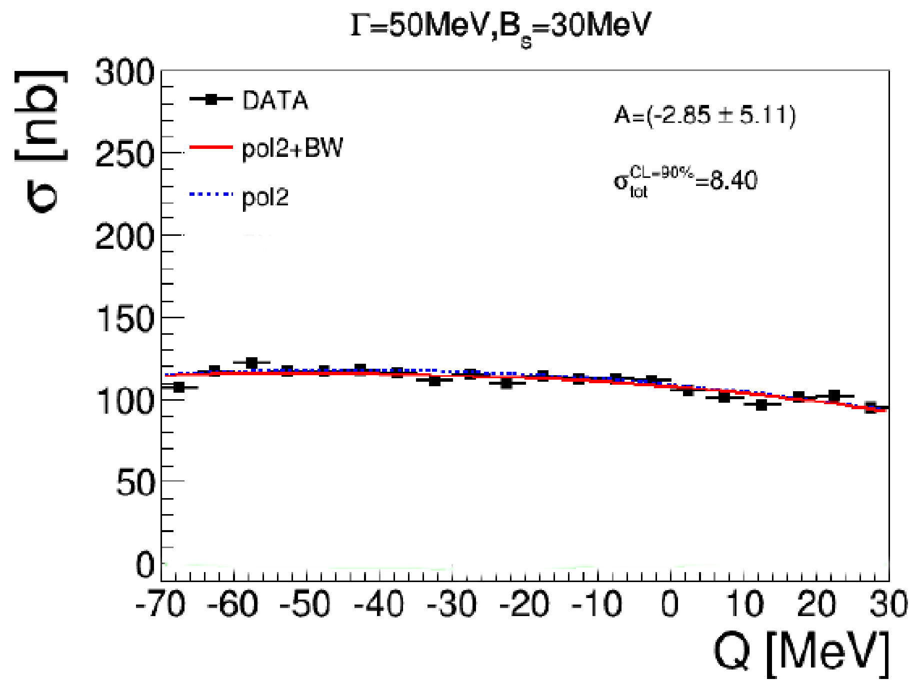
Collisions in a system of two particles at energies close to a bound state in different channels are discussed. Next, the bound state decays into a third coupled channel. A phenomenological approach to $dd \to \pi^- p\ ^3$He reaction is presented.



WASA-at-COSY:
P. Adlarson et al., Nucl. Phys. A 959 (2017) 102

$dd \to {}^3\mathrm{He}n\pi^0$ $dd \to {}^3\mathrm{He}p\pi^-$





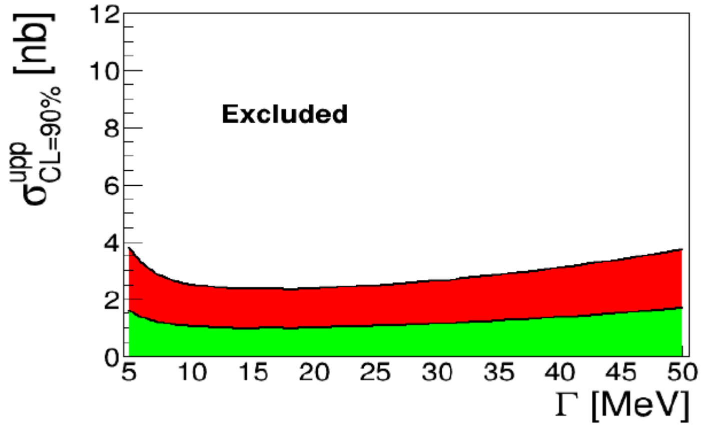
$$\sigma(Q,\Gamma,B_s,A) = \frac{A\cdot\Gamma^2/4}{(Q-B_s)^2+\Gamma^2/4}$$

WASA-at-COSY:
P. Adlarson et al., Nucl. Phys. A 959 (2017) 102

$\sigma^{upp}_{CL=90\%}$ for

$$dd \rightarrow (^4\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}n\pi^0$$

$\Downarrow$



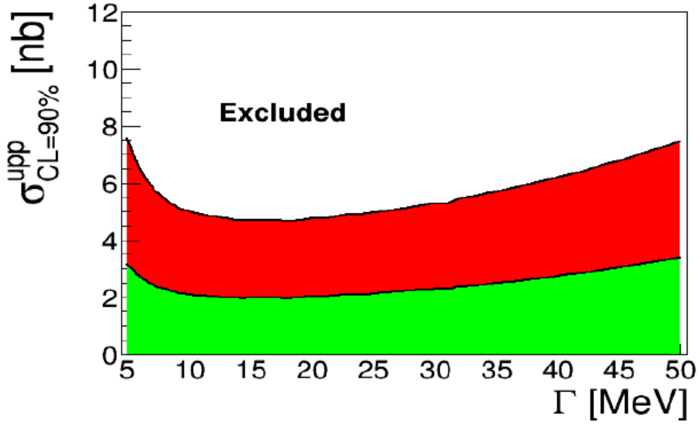
RESULT:

$$\sigma_{dd \rightarrow (^4He-\eta)_{bound} \rightarrow {}^3Hen\pi^0} < 3.5\ nb$$

$\sigma^{upp}_{CL=90\%}$ for

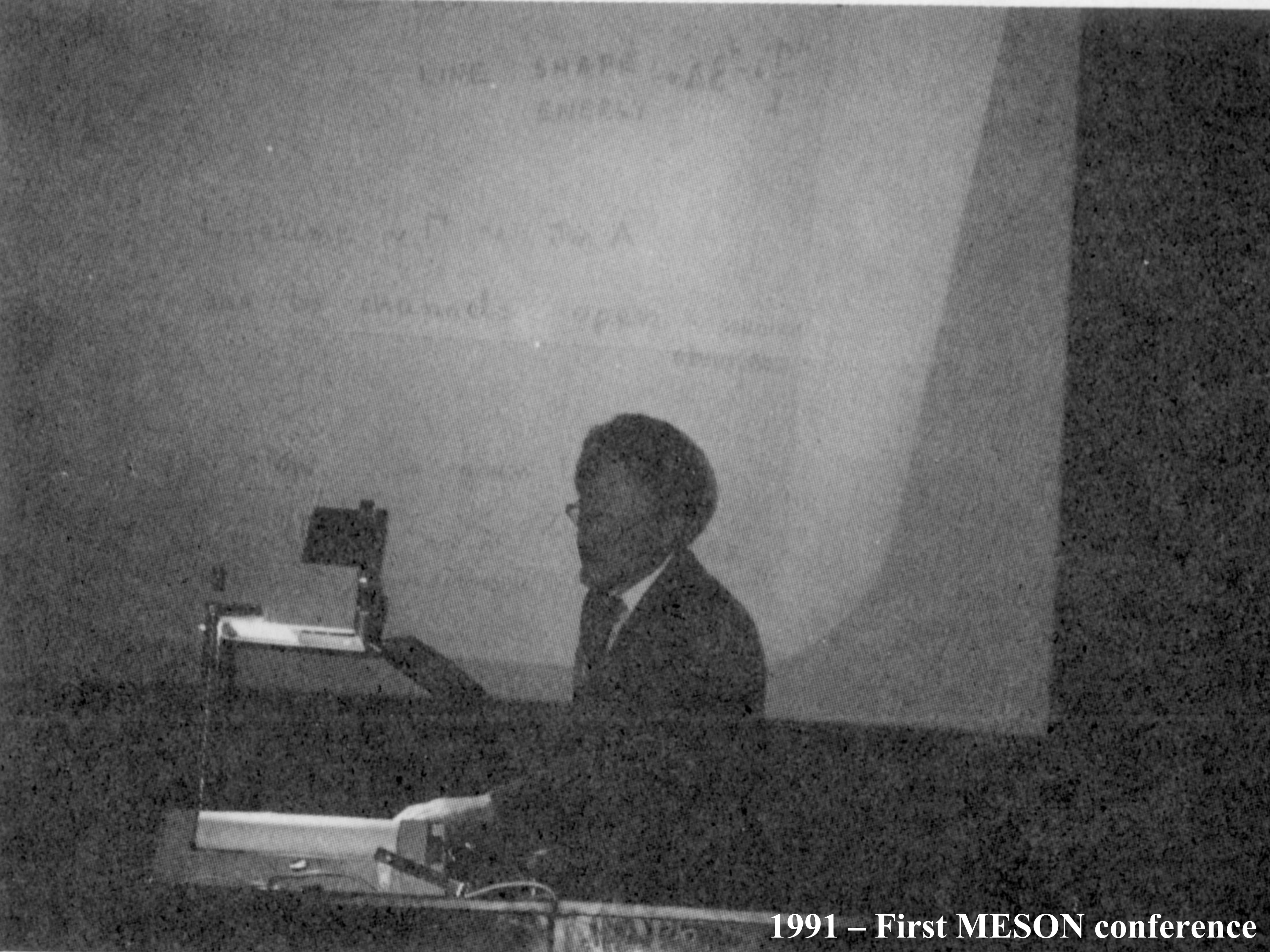
$$dd \rightarrow (^4\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}p\pi^-$$

$\Downarrow$



RESULT:

$$\sigma_{dd \rightarrow (^4He-\eta)_{bound} \rightarrow {}^3Hep\pi^-} < 7\ nb$$



1991 – First MESON conference

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1 – First MESON conference

1992 – MESON conference in Cracow

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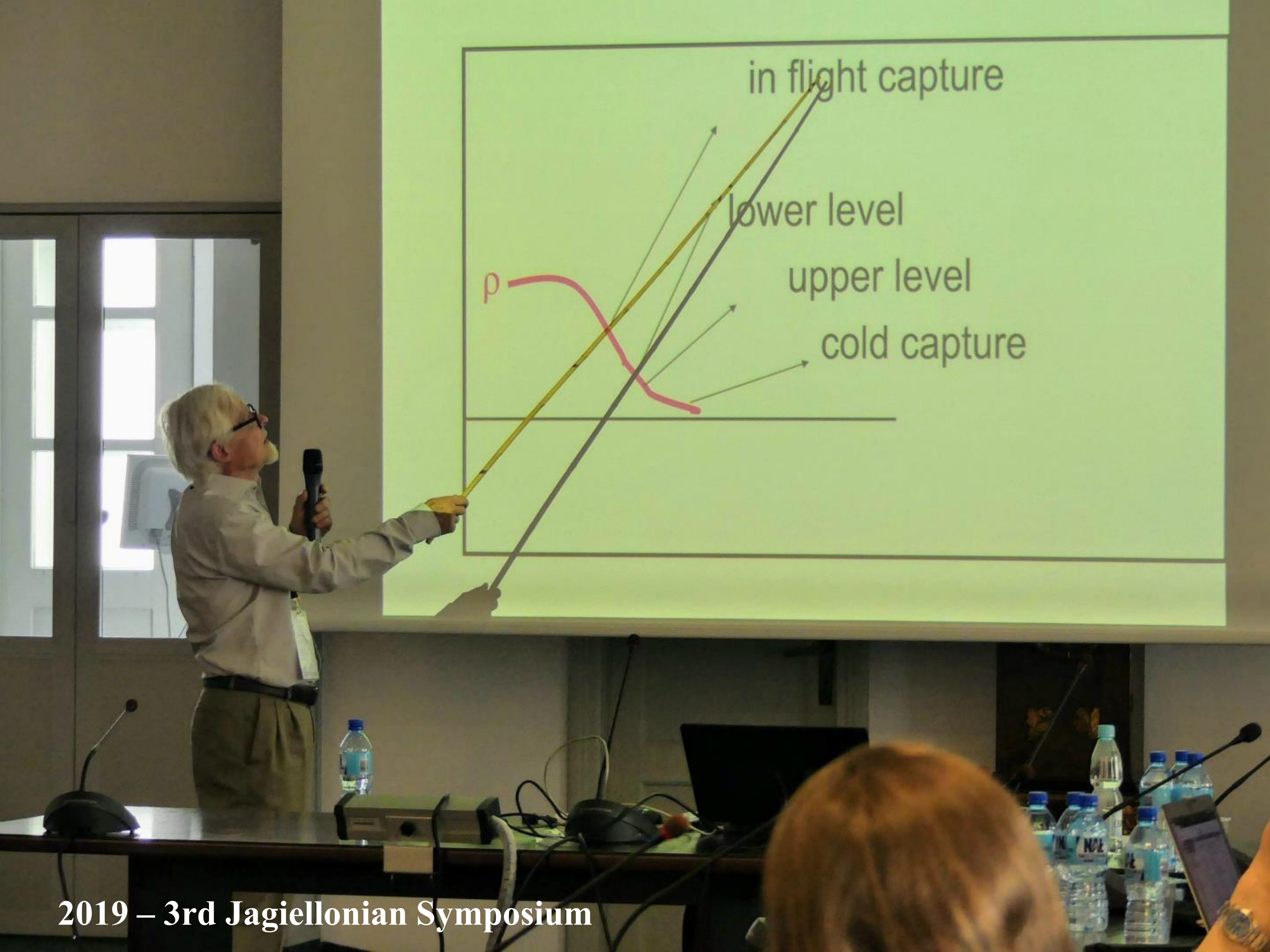
2010 – Symposium on Mesic Nuclei

2010 – Symposium on Mesic Nuclei

2016 – MESON conference



2019 – 3rd Jagiellonian Symposium

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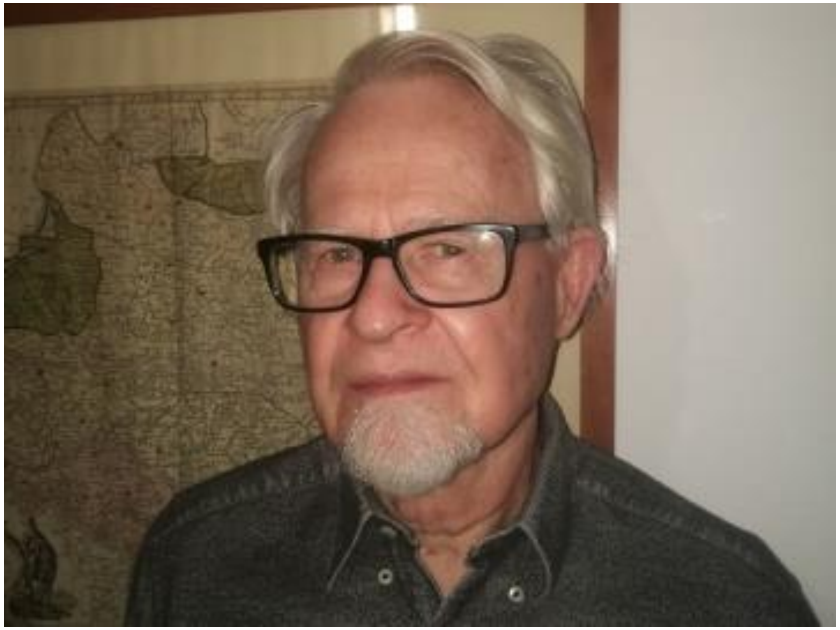
Search for Borromean objects

Thank you dear Prof. Sławomir Wycech for your scientific guidance and support



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