INVESTIGATION OF THE ^{7,6}H STATES IN ^{8}He+^{2}H INTERACTION

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for ACCULINNA-2 collaboration

Light exotic nuclei

Superheavy hydrogen isotopes **– key elements!**

- The biggest A/Z ratio
- Unique many-body decay channels
- Special stability of ^{7}H: closed $p^{3/2}$ neutron subshell

- Long living ^{7}H g.s. expected candidate for 4n radioactivity

History of ^{7}H

- **Predicted in 1972**
  – A. I. Baz' et al., "Light and intermediate nuclei near the border of nuclear stability" (Nauka, Moscow, **1972**)
- **$^{7}Li(\pi-,\pi+)$**
  – K. Seth, "Pionic probes for exotic nuclei," **(1981)**
  – V. Evseev et al., Nuclear Physics A 352, 379 **(1981)**
- **^{252}Cf ternary fission**
  – D. Aleksandrov et al., Yad. Fiz. 36, 1351 **(1982)**
- **$d(^{8}He,^{7}H)^{3}He$**
  – M. S. Golovkov et al., Phys. Lett. B 588, 163 **(2004)**
- **$\pi-$ absorption : $^{11}B(\pi-,p\ ^{3}He)\ ^{7}H$; $^{9}Be(\pi-,p\ d)\ ^{7}H$**
  – Y. Gurov et al., The EPJ A 32, 261 **(2007)**
  – Y. Gurov et al., PPN 40, 558 **(2009)**

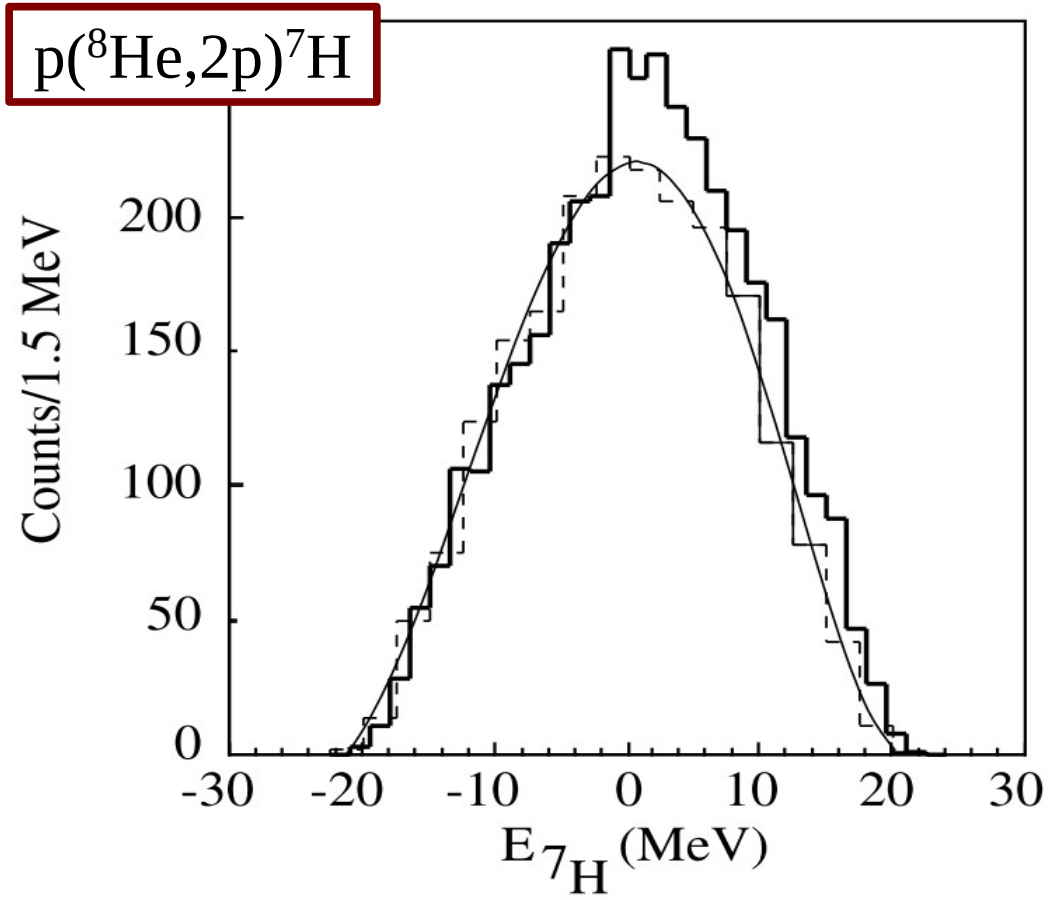
No observation of ^{7}H

History of ^{7}H

First observation

A. A. Korsheninnikov et al., PRL, 082501 (2003)

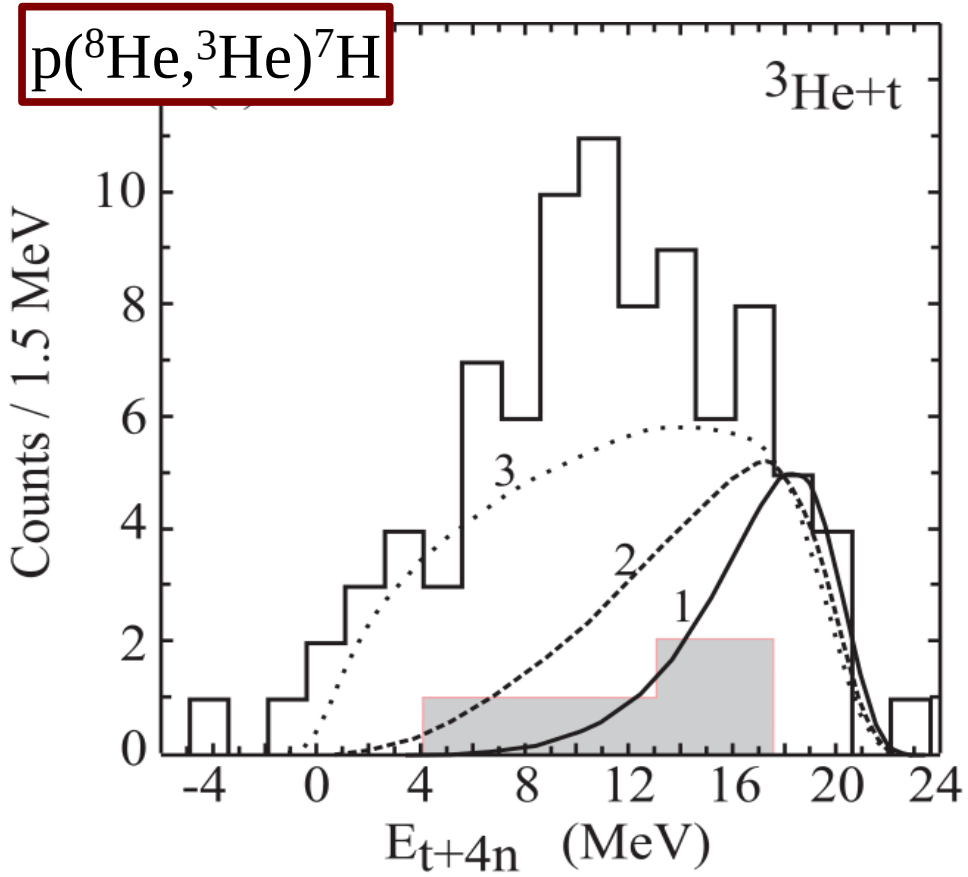
$p(^{8}He,2p)^{7}H$



- ~90% of MM -> background; negative energy events
- 1.9 MeV resolution
- **Peculiarity near the t+4n decay threshold**

E. Yu. Nikolskii et al., PRC 81, 064606 (2010)

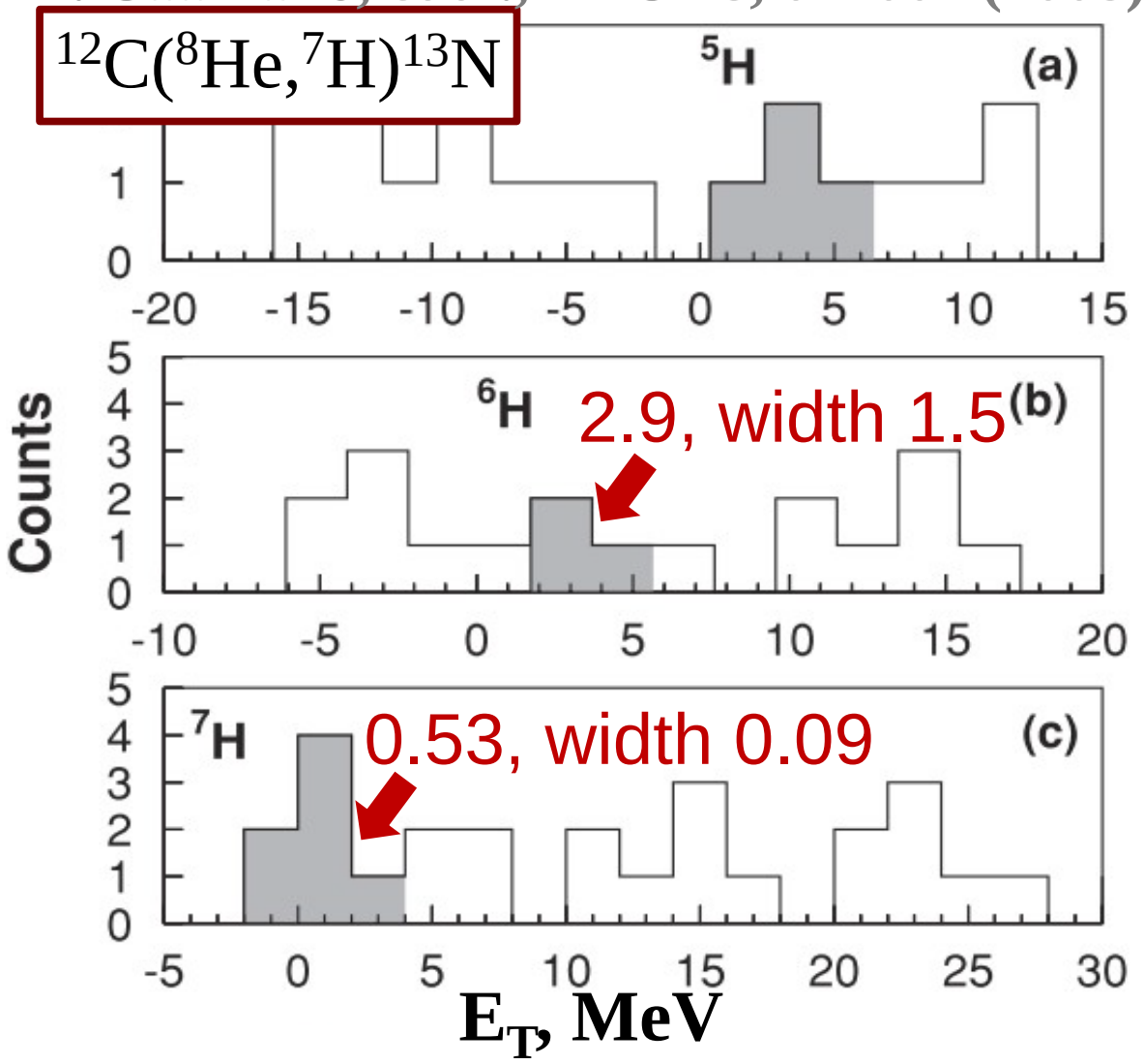
$p(^{8}He,^{3}He)^{7}H$



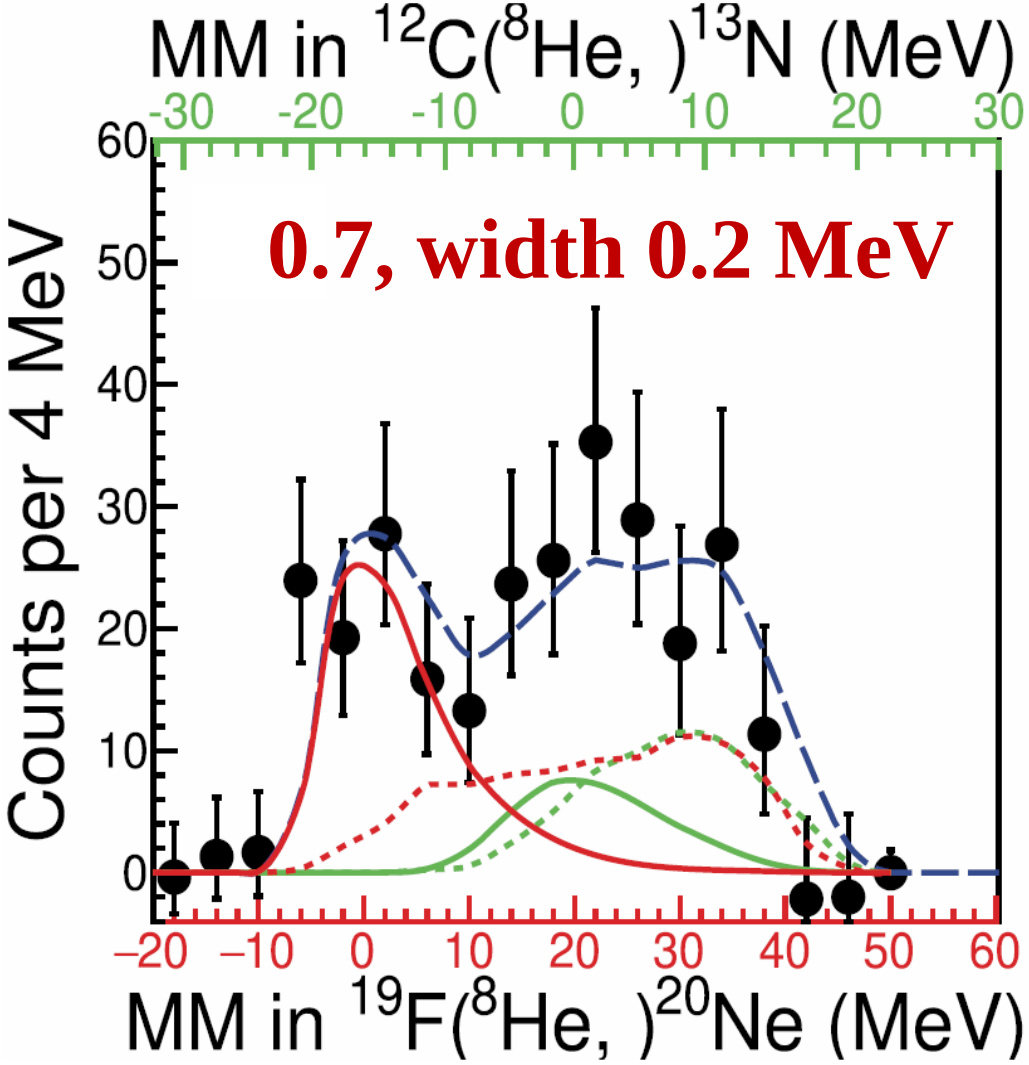
- Triton registration (without momentum)
- 1.9 MeV resolution
- **Structure could not be resolved**

History of ^{7}H

M. Caamaño, et al., PRC 78, 044001 (2008)



Caamaño et al., PLB 829, 137067 (2022)



dσ/dΩ ~ 10 mb/sr

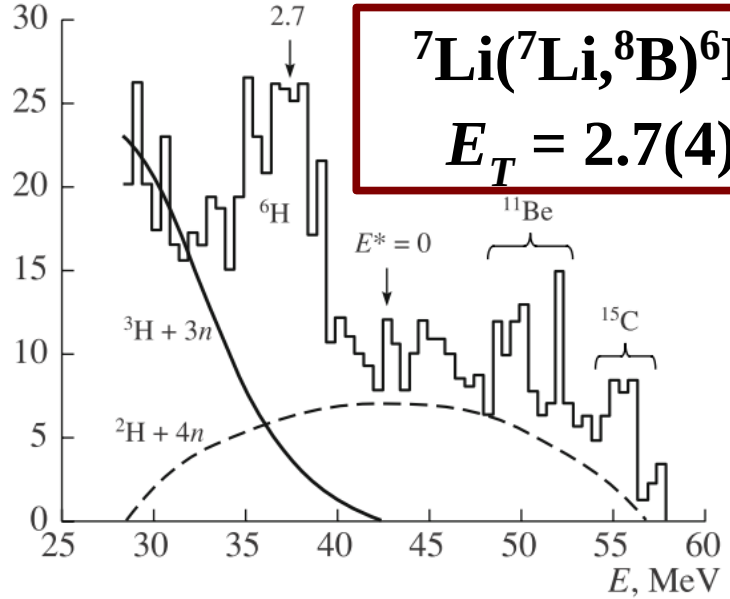
CF_4: 4x10^{19} & 10^{19} at./cm^2 (very thin target)

no background measurements;

no isotope identification -> reaction channel?

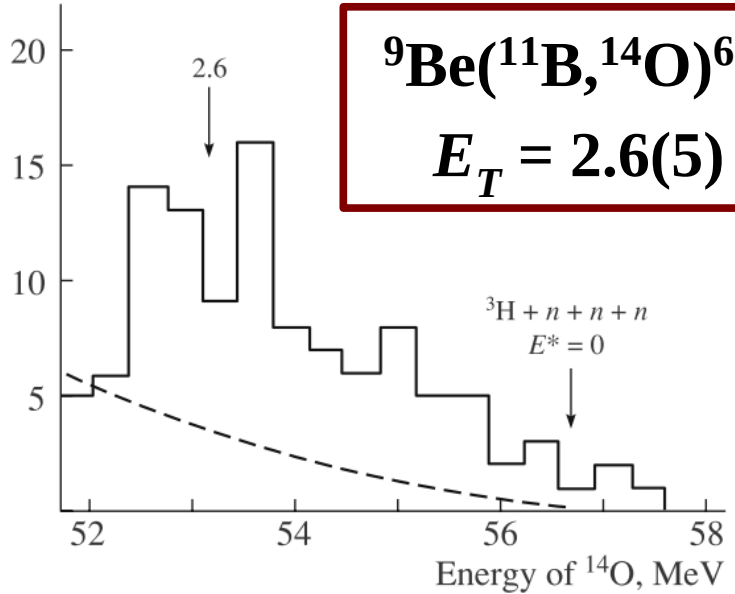
History of ^{6}H

D. Aleksandrov et al., Yad. Fiz. 39 (1984) 513



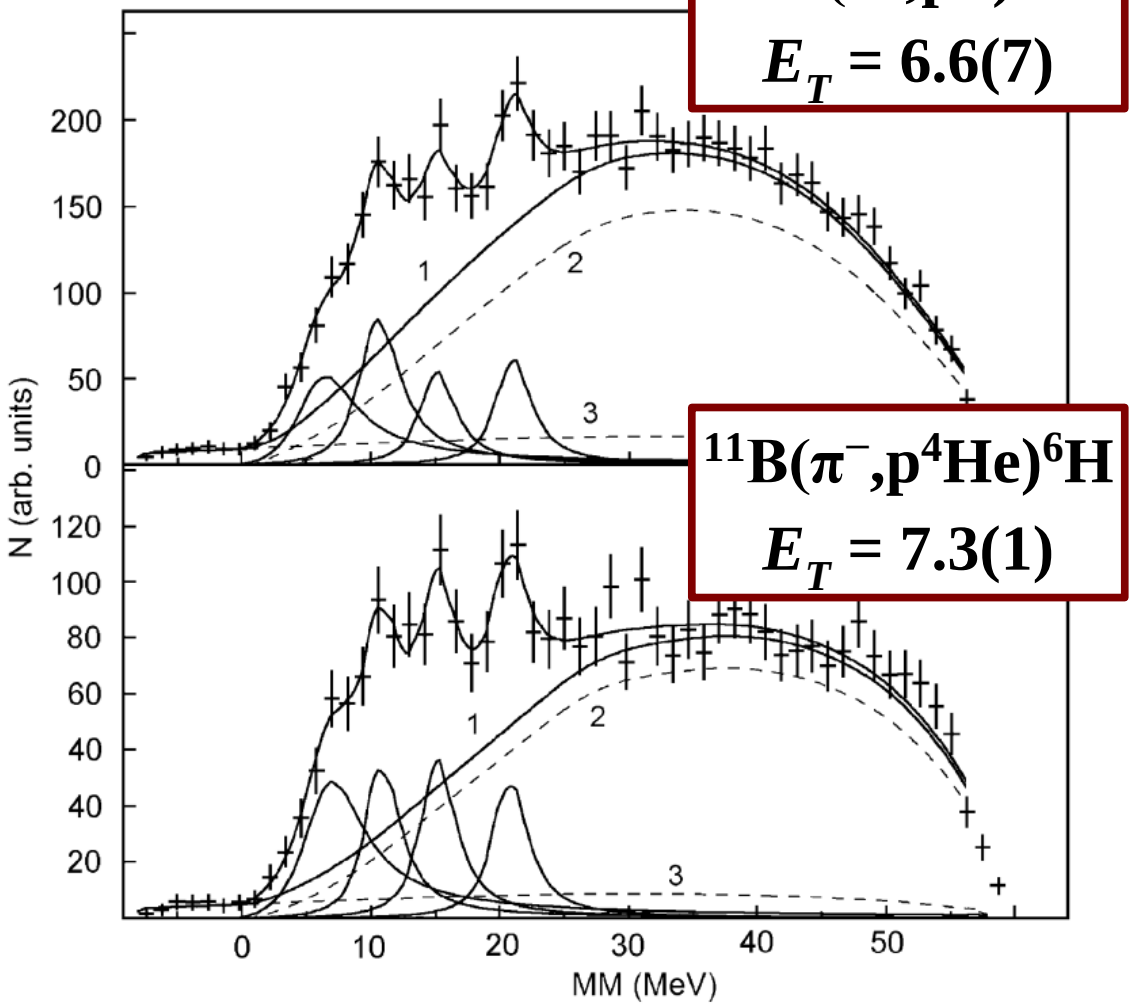
^{7}Li(^{7}Li,^{8}B)^{6}H
E_T = 2.7(4)

A. Belozyorov et al., Nucl. Phys. A 460 (1986)



^{9}Be(^{11}B,^{14}O)^{6}H
E_T = 2.6(5)

Y. Gurov, et al., EPJ A 32 (3) (2007)



^{9}Be(π^{-},pd)^{6}H
E_T = 6.6(7)

^{11}B(π^{-},p^{4}He)^{6}H
E_T = 7.3(1)

Prerequisites for successful search for ^{6,7}H

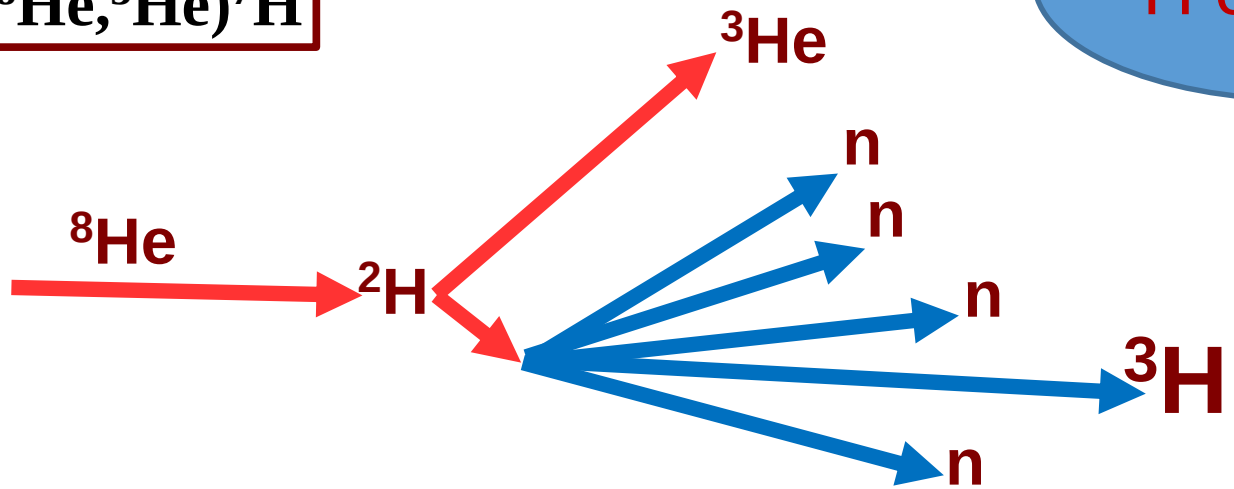
- **reliable channel identification**
- **suppression of background**
- **high energy resolution (~1 MeV)**

Experimental idea

ACCULINNA-2

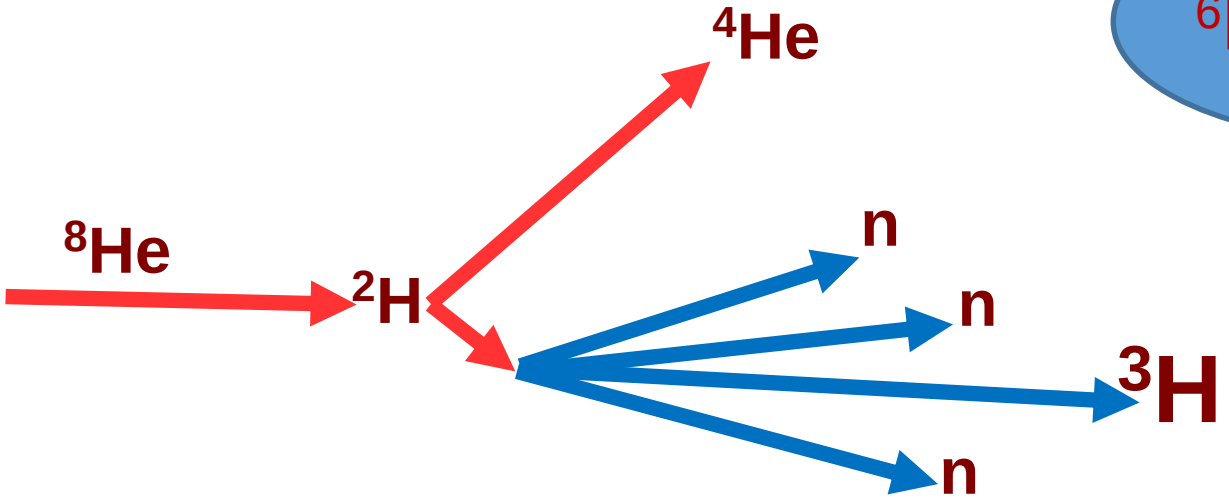
26 AMeV ^{8}He beam:
~10^{5} pps,
~90% purity

^{2}H(^{8}He,^{3}He)^{7}H



^{7}H channel

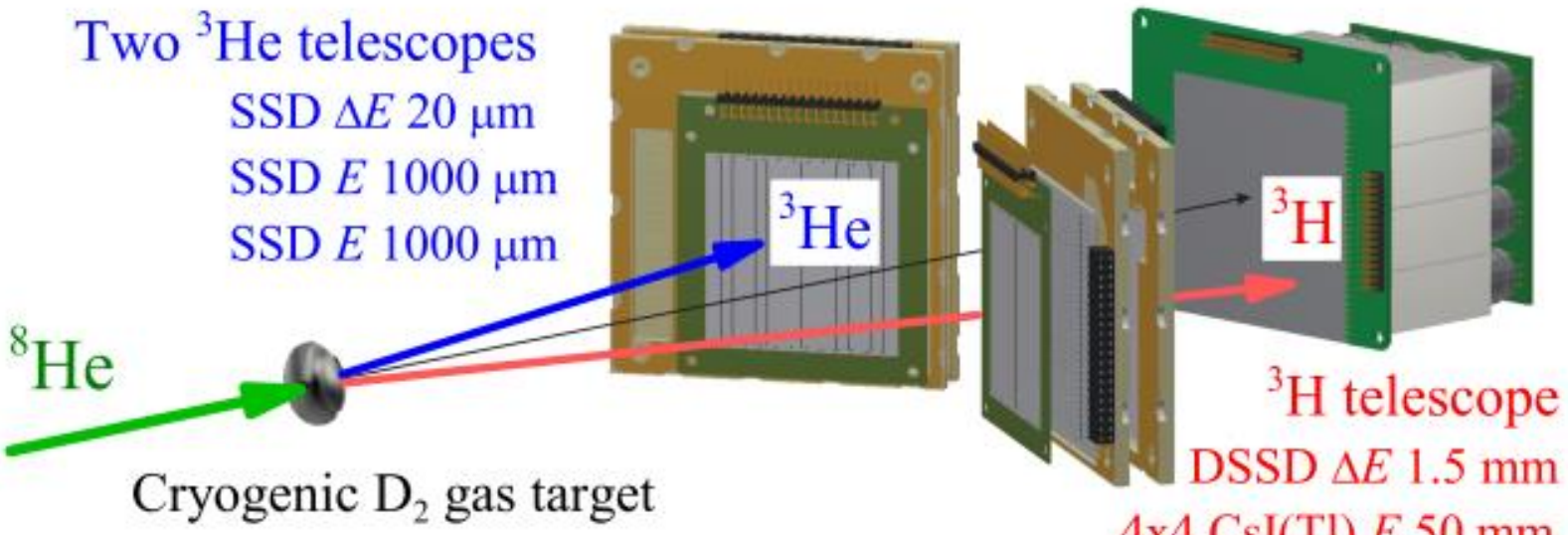
^{2}H(^{8}He,^{4}He)^{6}H



^{6}H channel

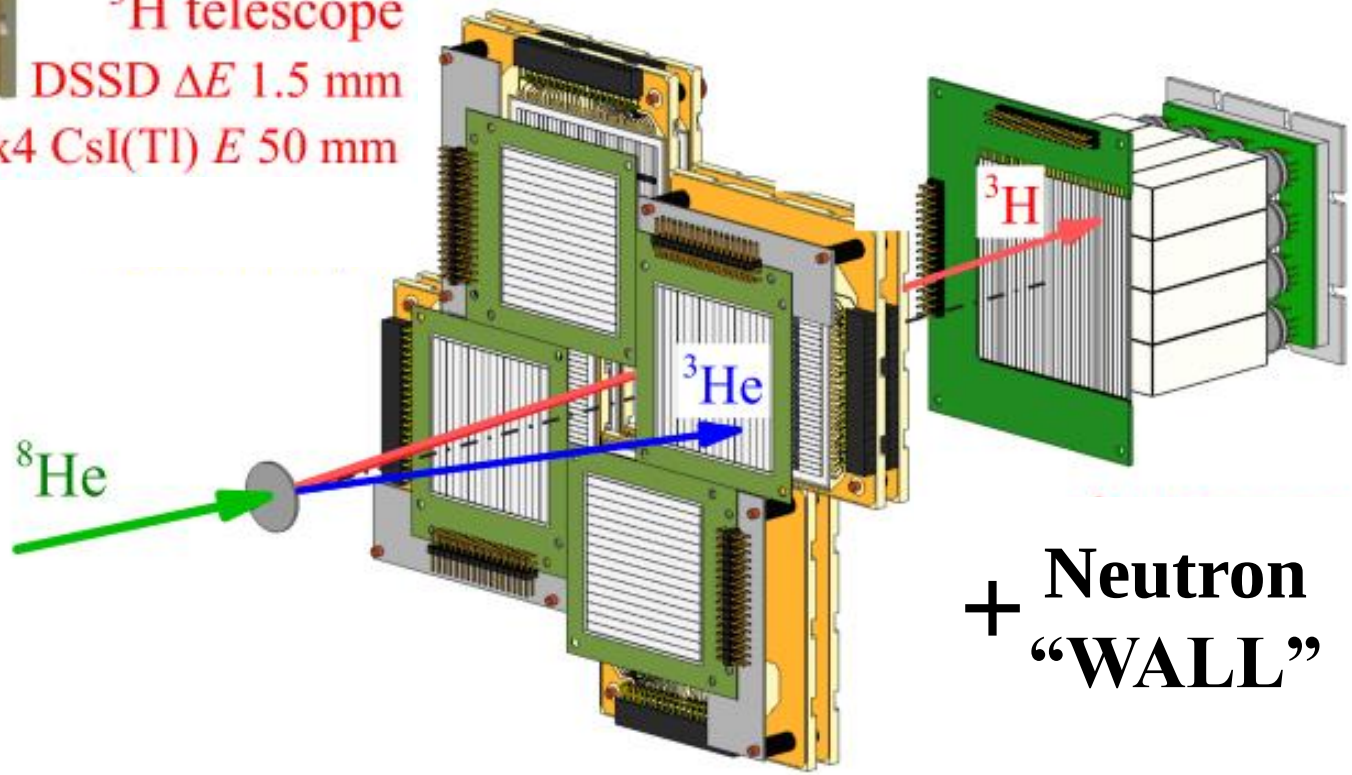
Setup

Run 1
2 weeks
119 ^{3}He-^{3}H coincidences



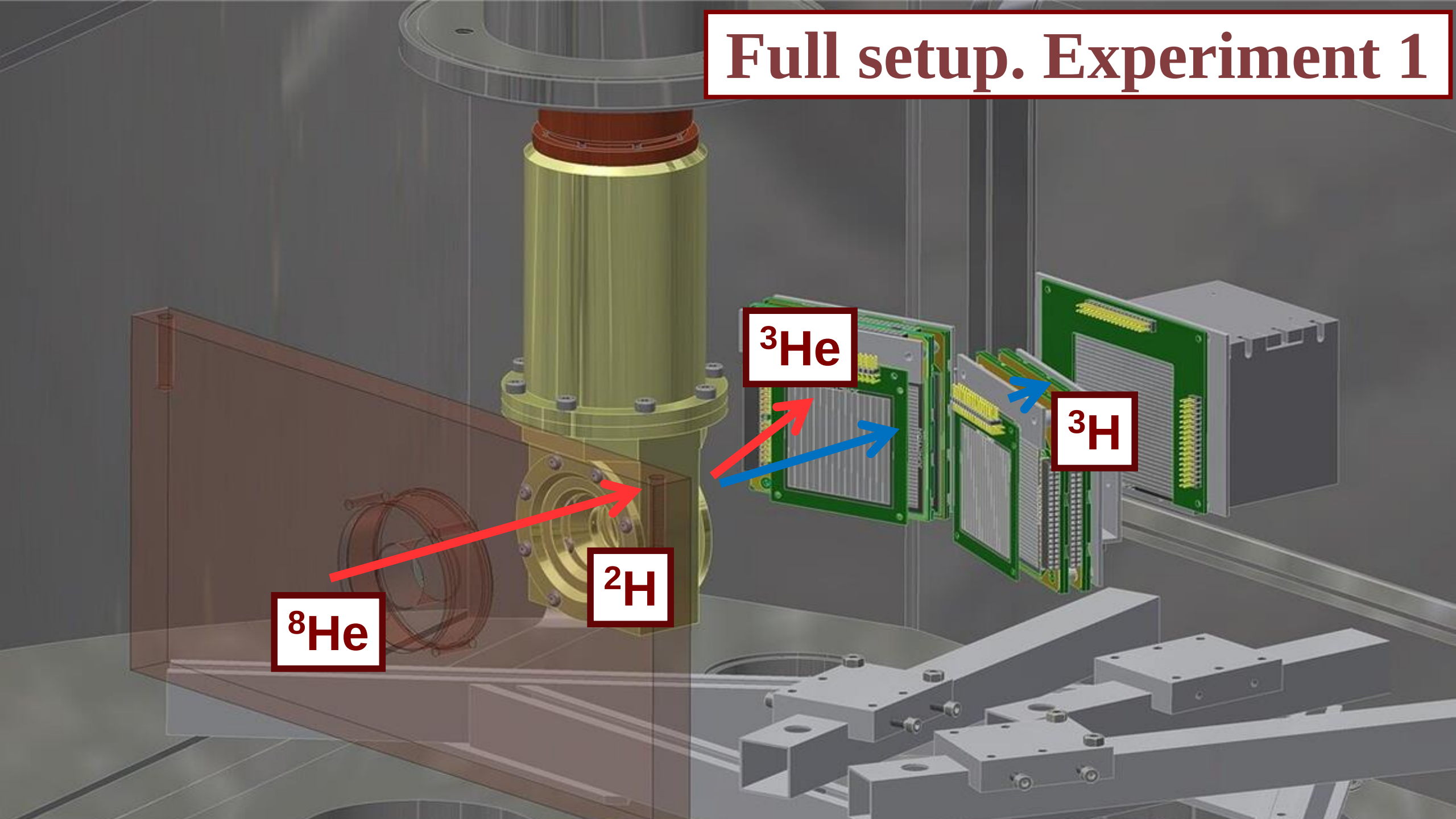
- MM resolution:
  ^{7}H - 1.1 MeV, ^{6}H - 1.5 MeV,
- Efficiency of ^{3,4}He-^{3}H registration~80%
- ^{3}H detection angular/energy resolution~ 0.5 deg / 2%

Run 2
3 weeks,
enhanced angular range and efficiency
378 ^{3}He-^{3}H coincidences

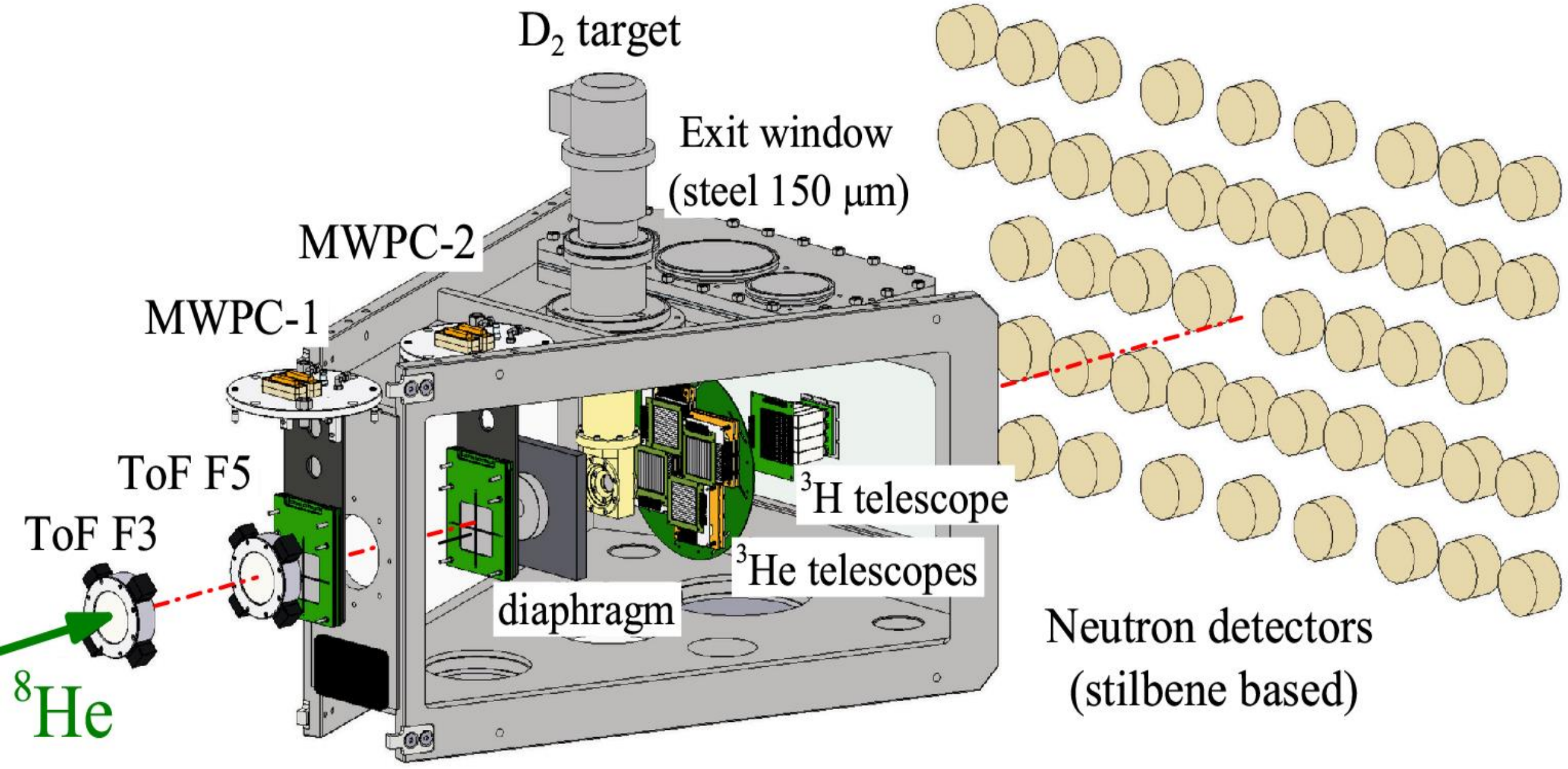


+ Neutron "WALL"

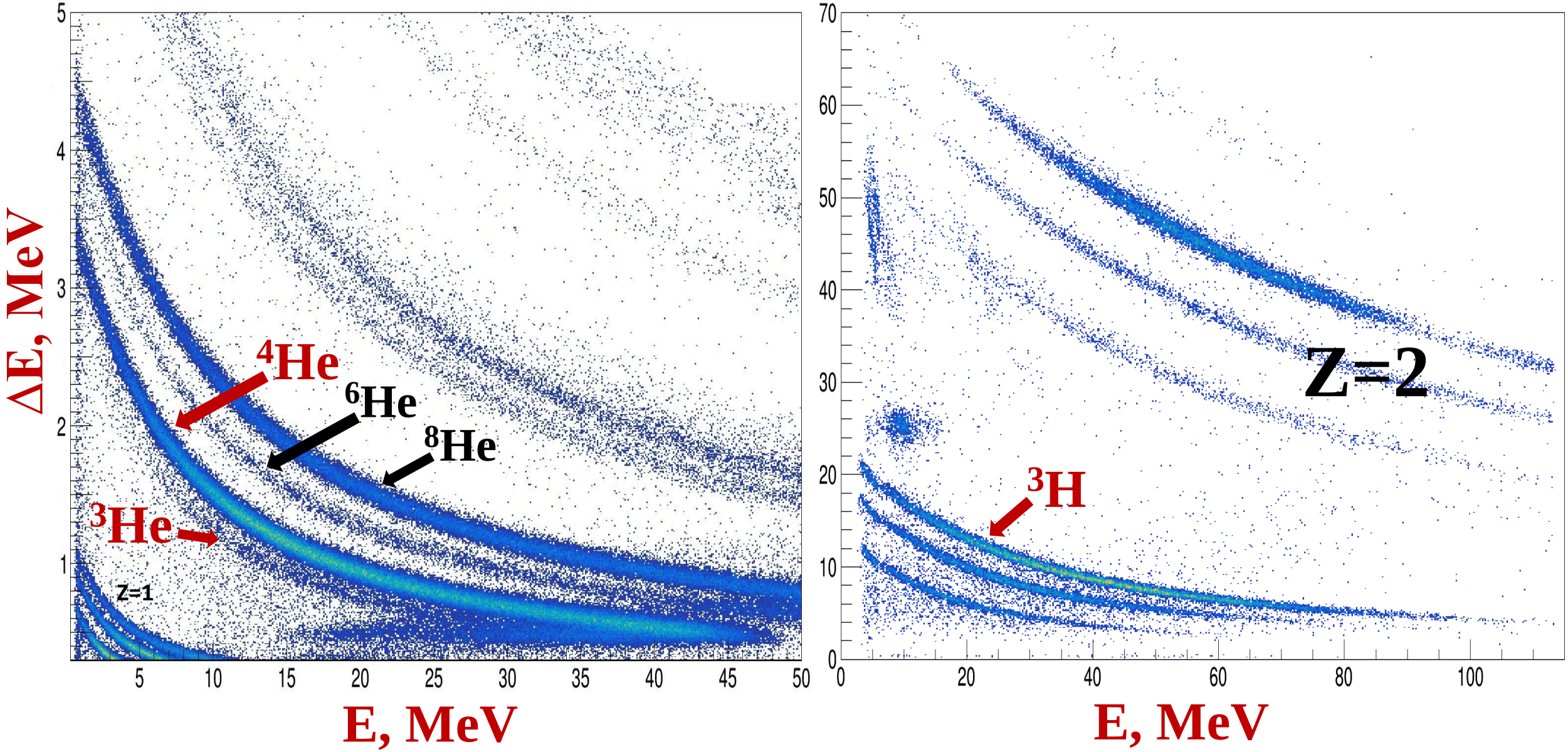
Full setup. Experiment 1



Full setup. Experiment 2



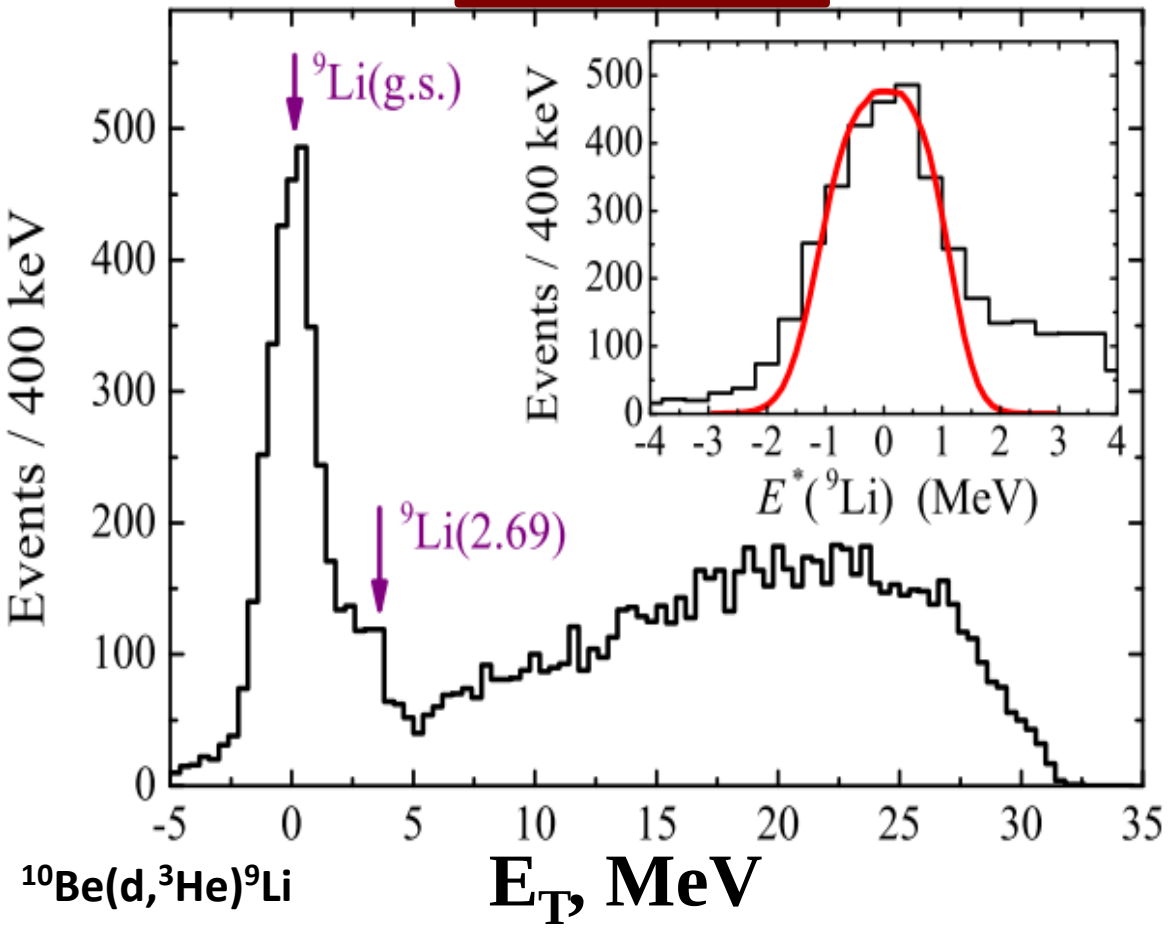
Particle identification



Reference run

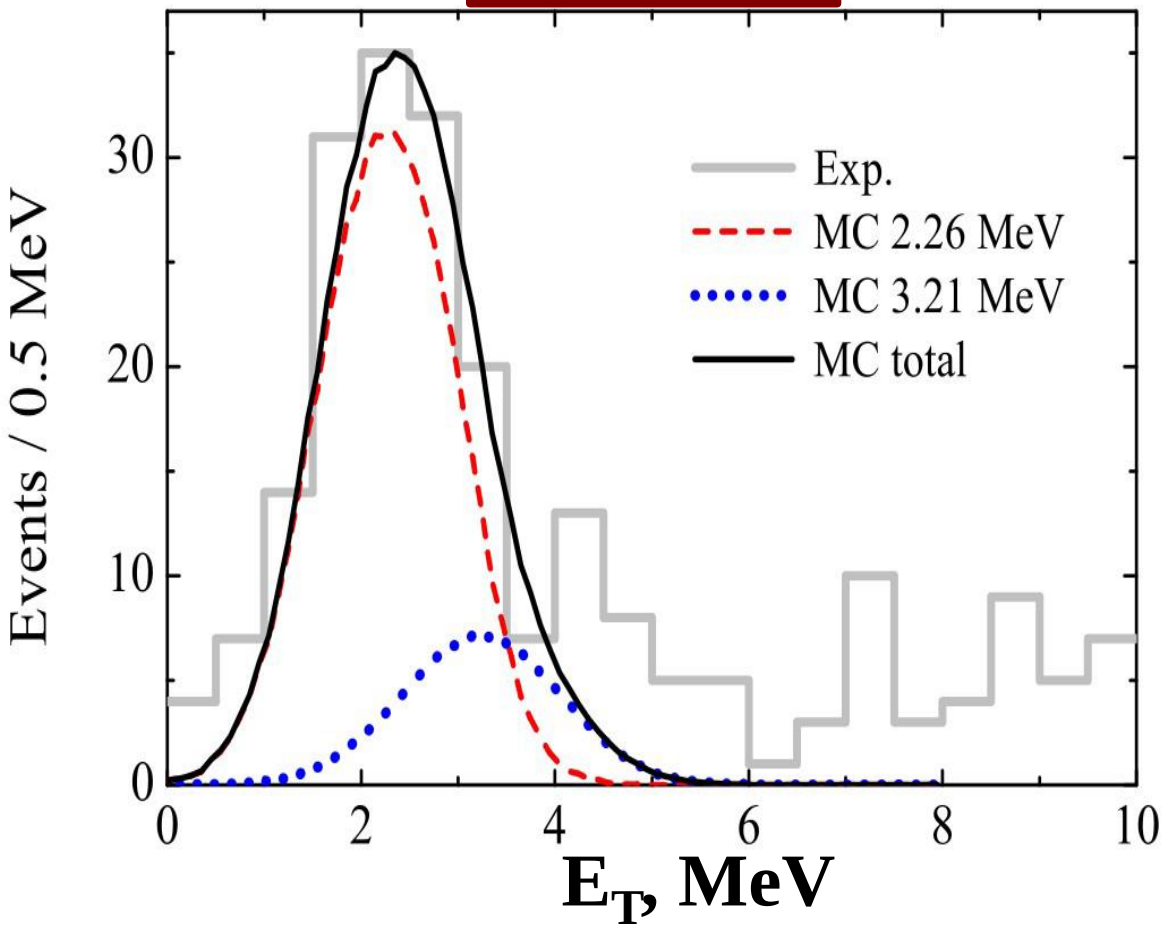
Independent **MM calibration** with 42 AMeV ^{10}Be beam

d-^{3}He



^{10}Be(d,^{3}He)^{9}Li

d-^{4}He

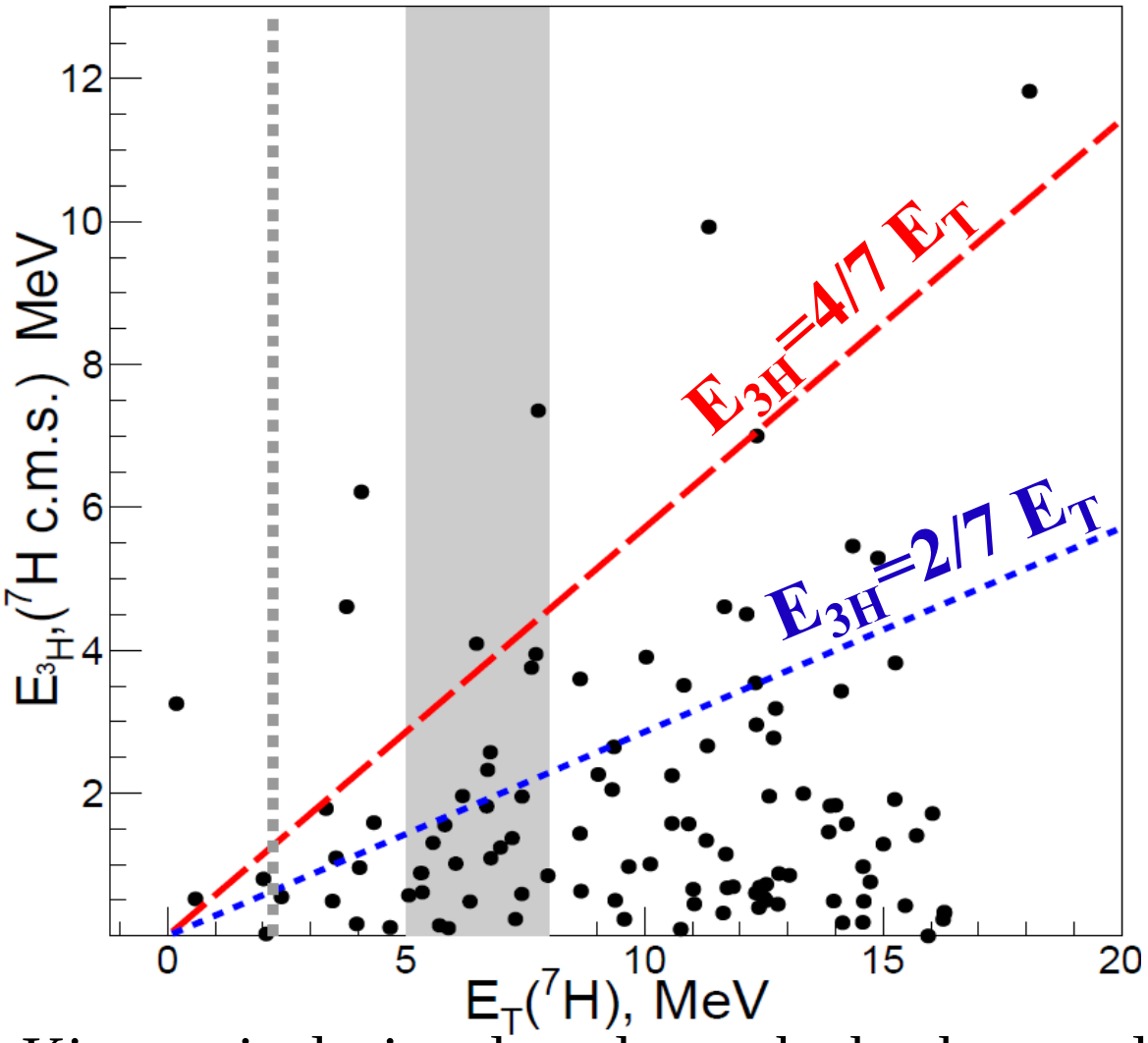


Full agreement of MC simulations with experimental data

$^{7}\mathrm{H}$

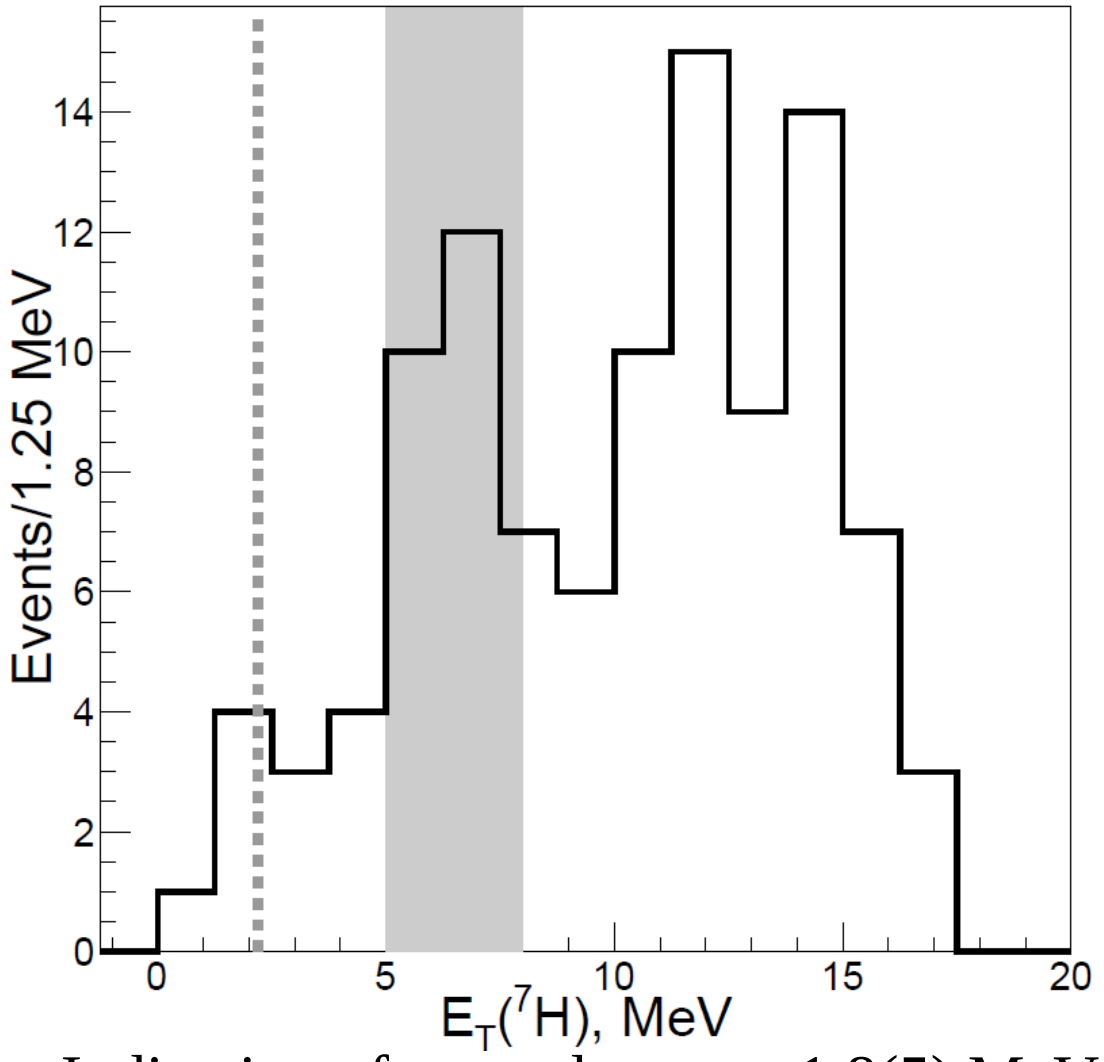
Run 1 results

Bezbakh et al., Phys.Rev.Lett. 124, 022502 (2020)



Kinematical triangle reduces the background

Excited state(s) at 6.5(5) MeV



Indication of ground state at 1.8(5) MeV

Indication of state at 11 MeV

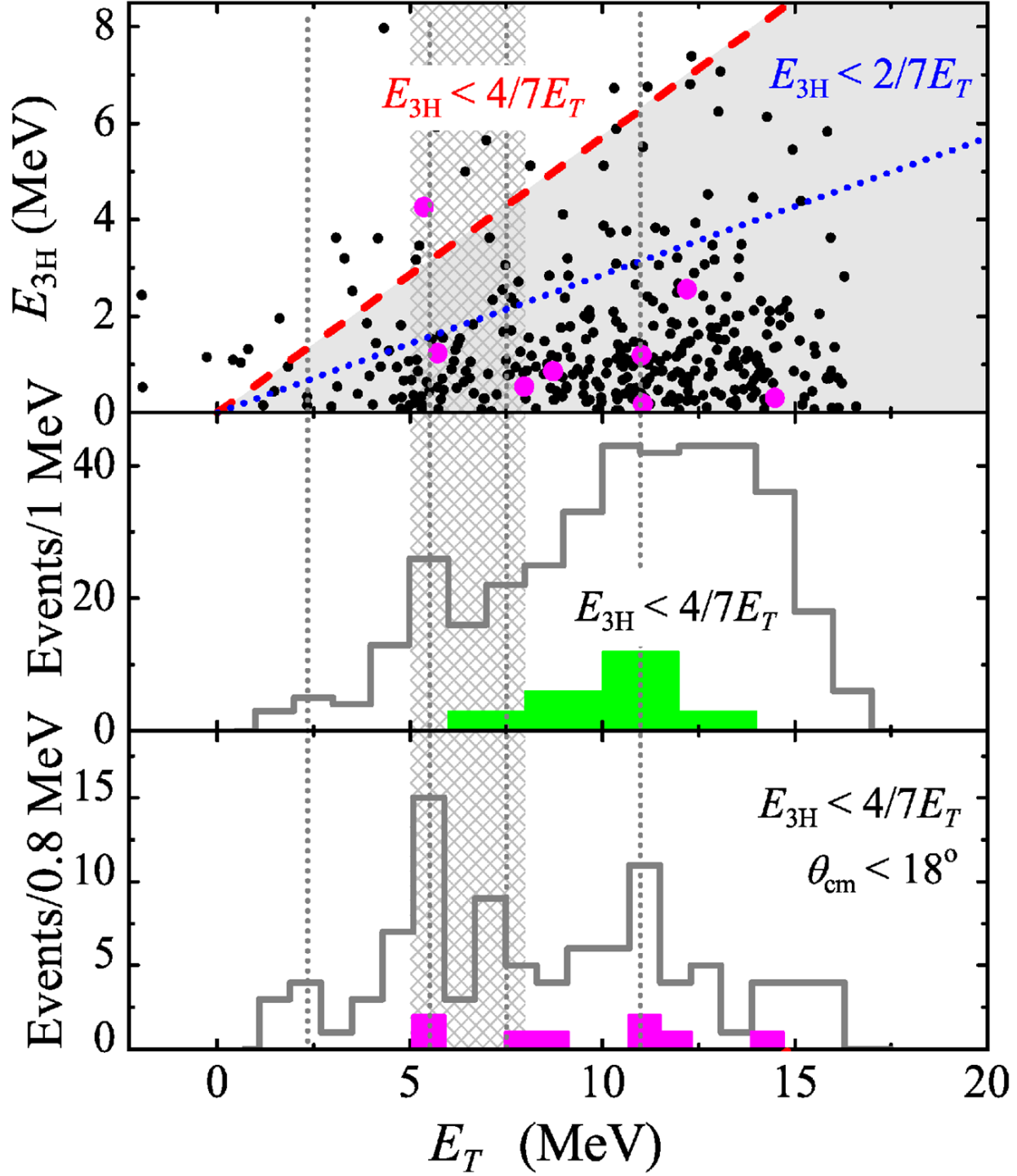
Run 2 results

I. Muzalevskii et al., Phys. Rev. C 103, 044313 (2021)

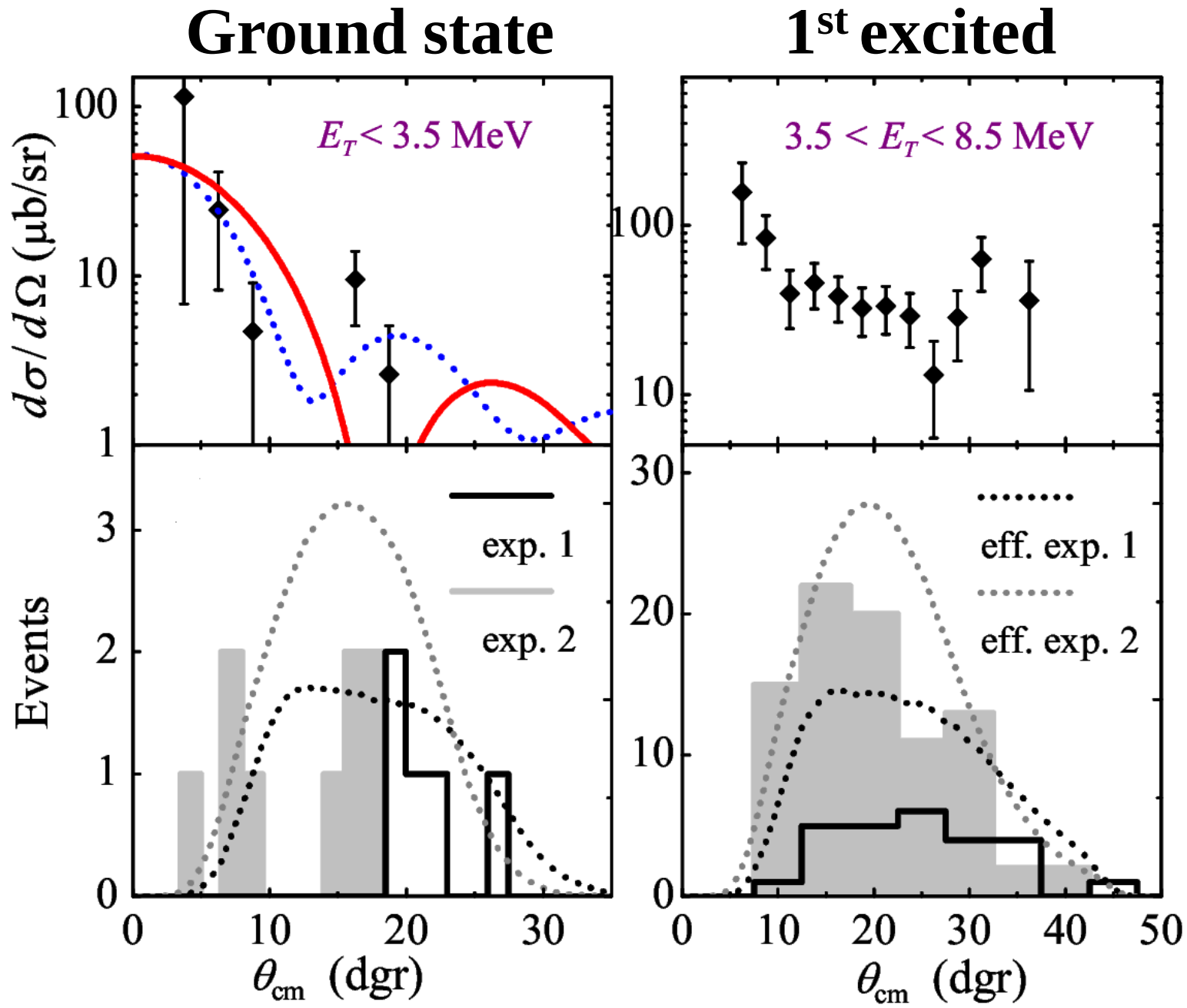
^{7}H ground state at 2.2(5) MeV

^{7}H excited state at 5.5(3) MeV (possibly doublet at 5.5-7.5 MeV)

Peak at 11(3) MeV



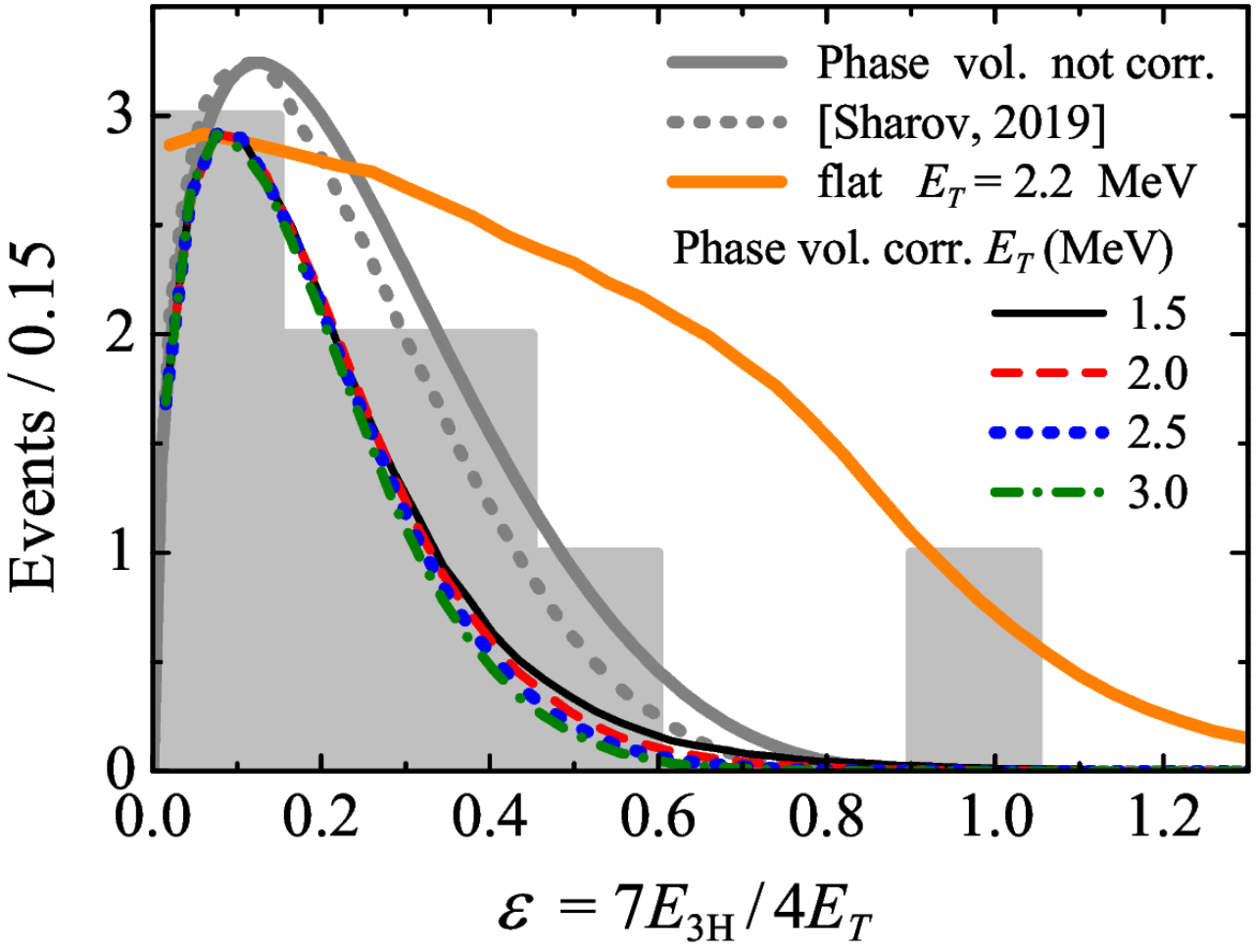
Additional evidence: angular distribution

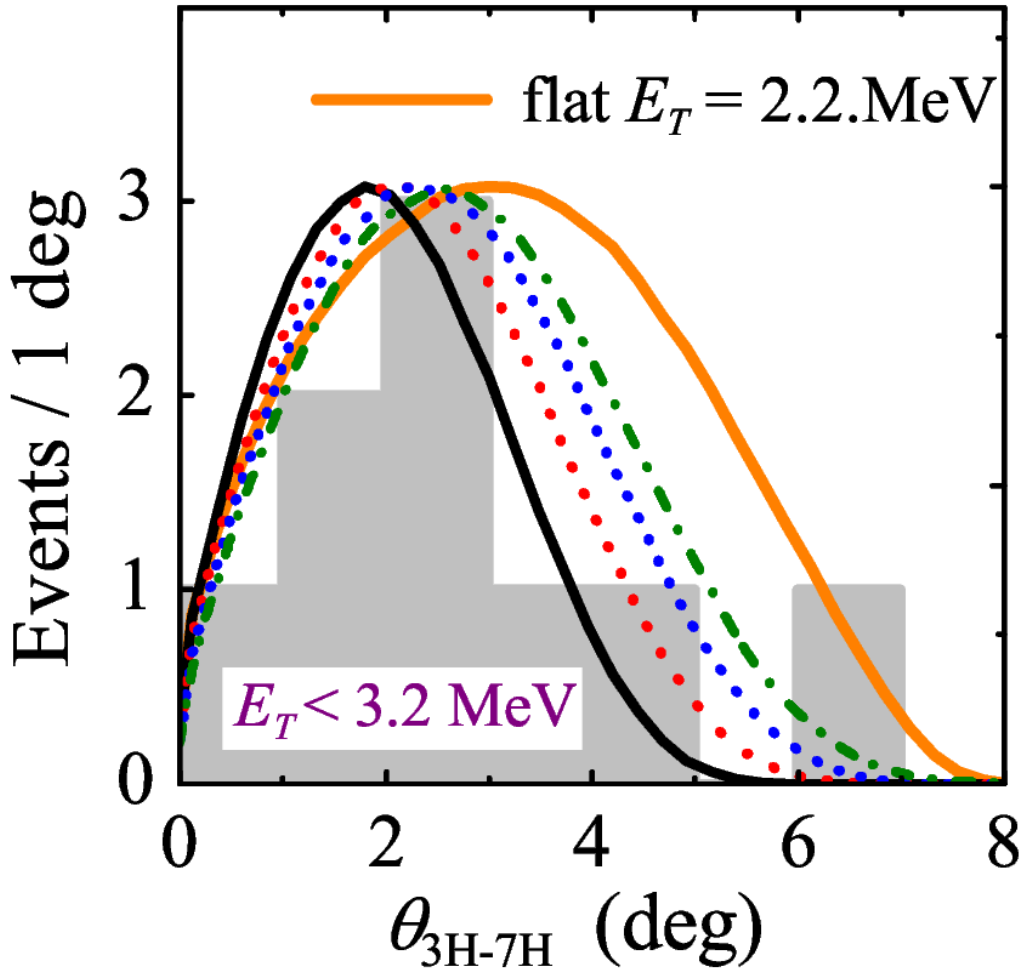


- All events of the Exp1 are in the second diff. maximum. Idea of Exp2 to populate the forward.
- **Diff. behavior of the g.s. events is clearly observed.**
- The first minimum is shifted at lower angles, 9-14^o; peripheral g.s. population.
- First excited state is well populated at 9-14^o, corresponded to efficiency.

Additional evidence: triton distributions

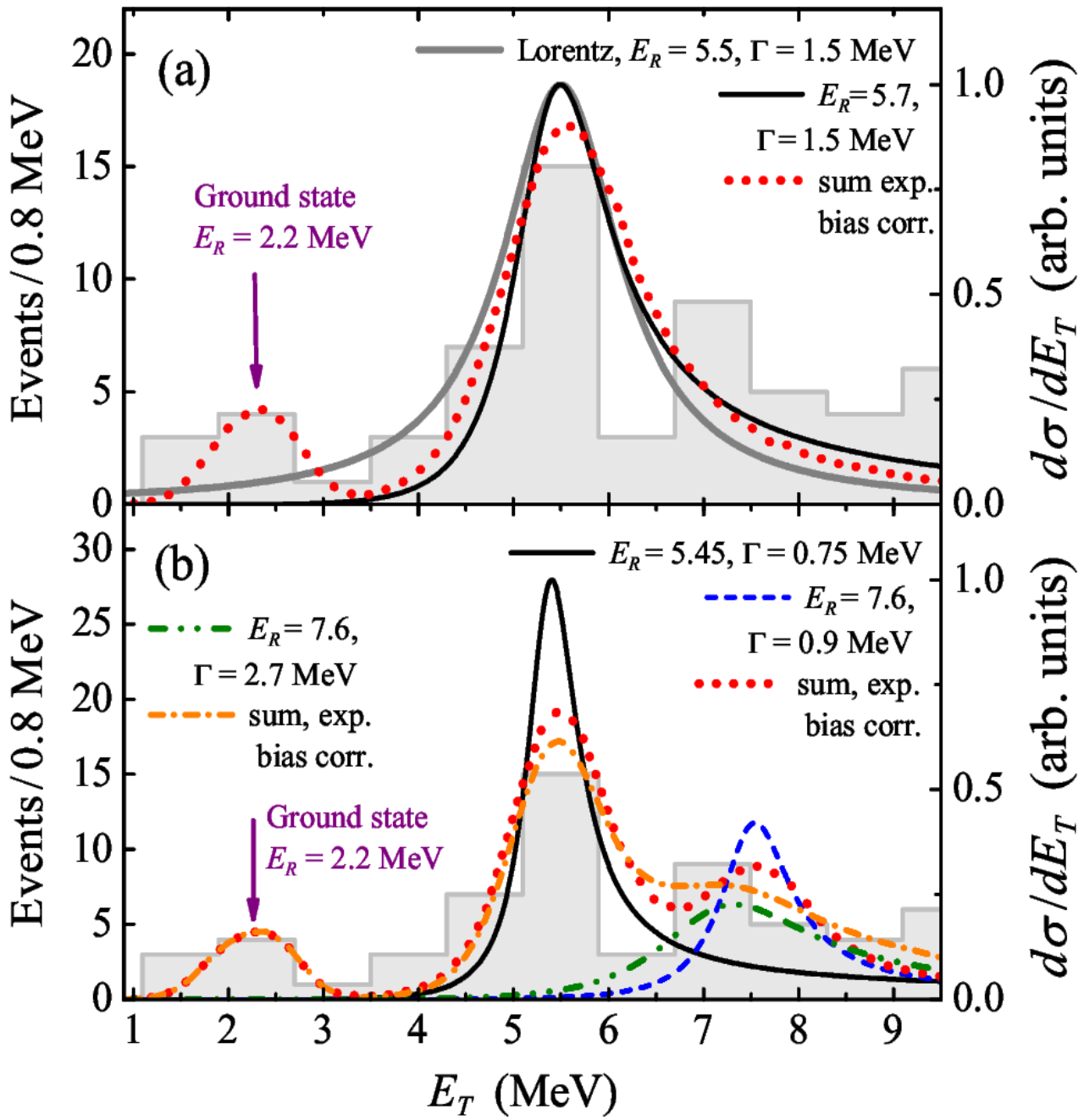
P.G. Sharov et al., JETPh Lett., 110:514, 2019





Two independent tests are consistent with **true 5-body** decay

^{7}H results



- **Ground state at 2.2 MeV**
  Cross section 24 μb/sr
- **Resonance at 5.5 MeV**
  Cross section 30 μb/sr
- **Indications for states at 7.5, 11 MeV**
- **In agreement with *[E. Yu. Nikolskii et al., PRC 81, 064606 (2010)]***

$^{6}\mathrm{H}$

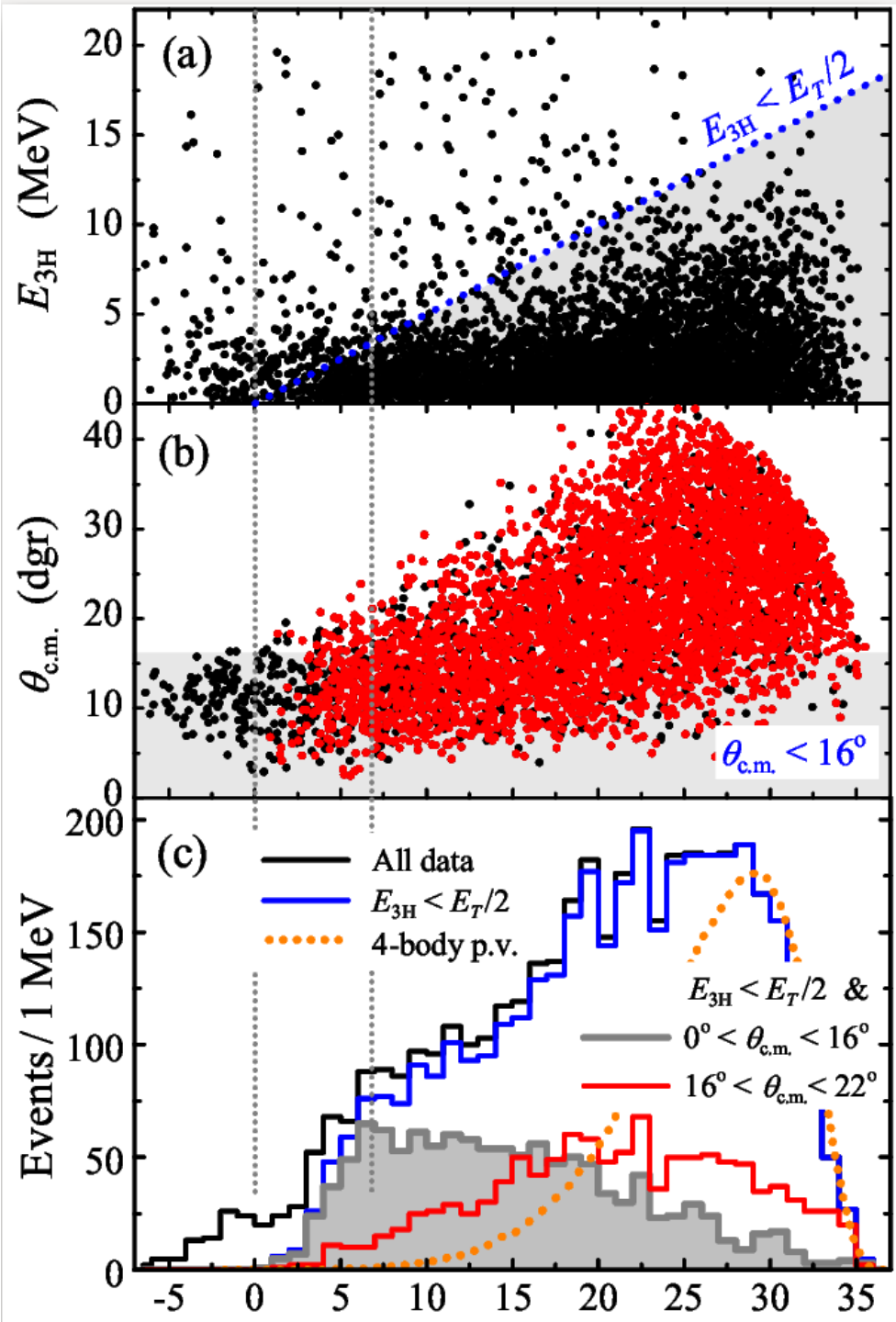
^{6}H results

4058 ^{4}He-^{3}H coincidences
131 ^{4}He-^{3}H-neutron coincidences

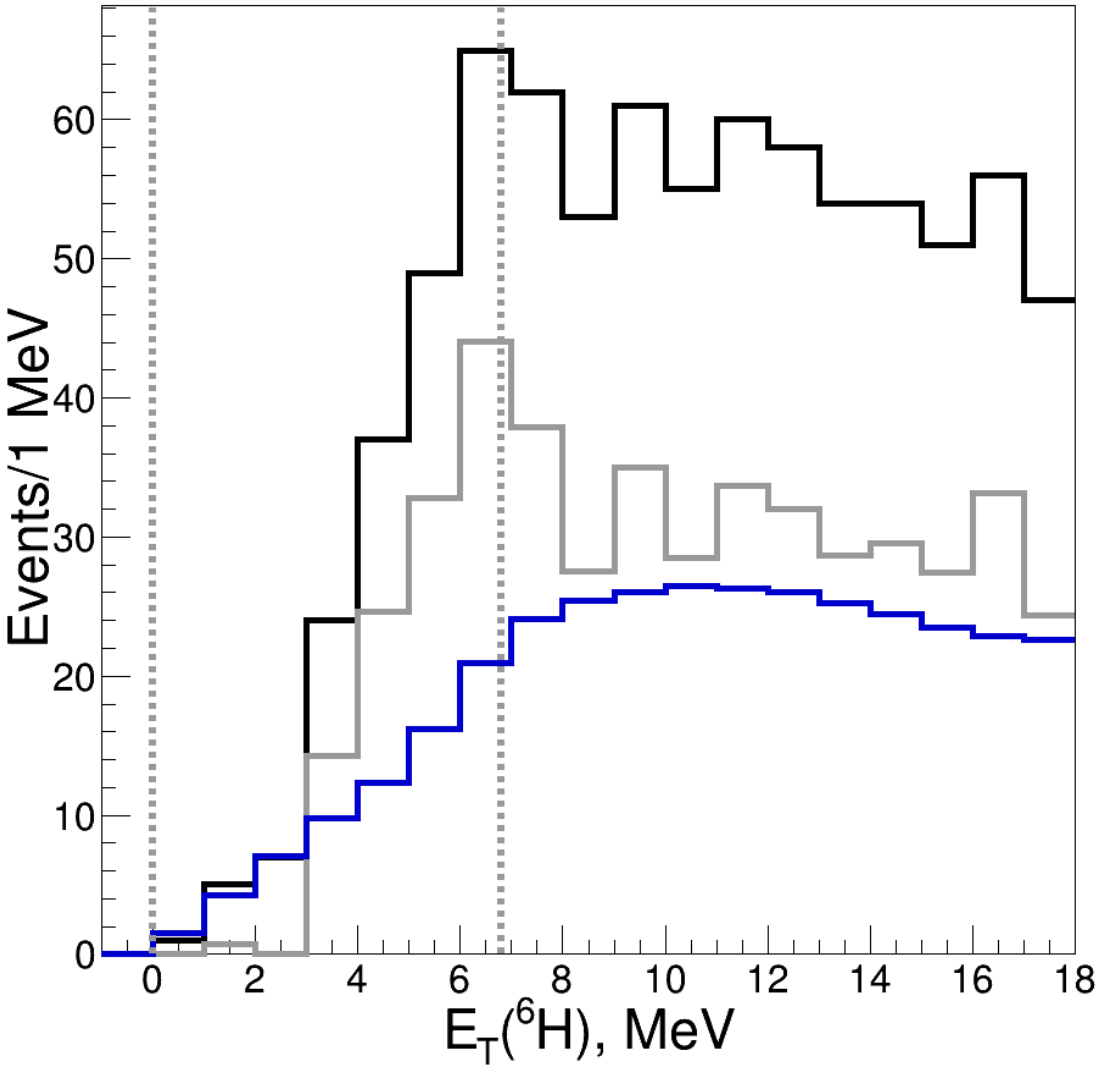
Can not be described as 4-body phase vol.

Selection of triton energies and reaction angle allowed to highlight the broad peak at 4-8 MeV

Special background analysis methods should be applied



Background subtraction



small reaction angle spectrum, $\theta_{CM}<16^o$

empty target spectrum

background subtraction result

The MC procedure of background subtraction emphasizes the **resonance presence at 6.8 MeV**

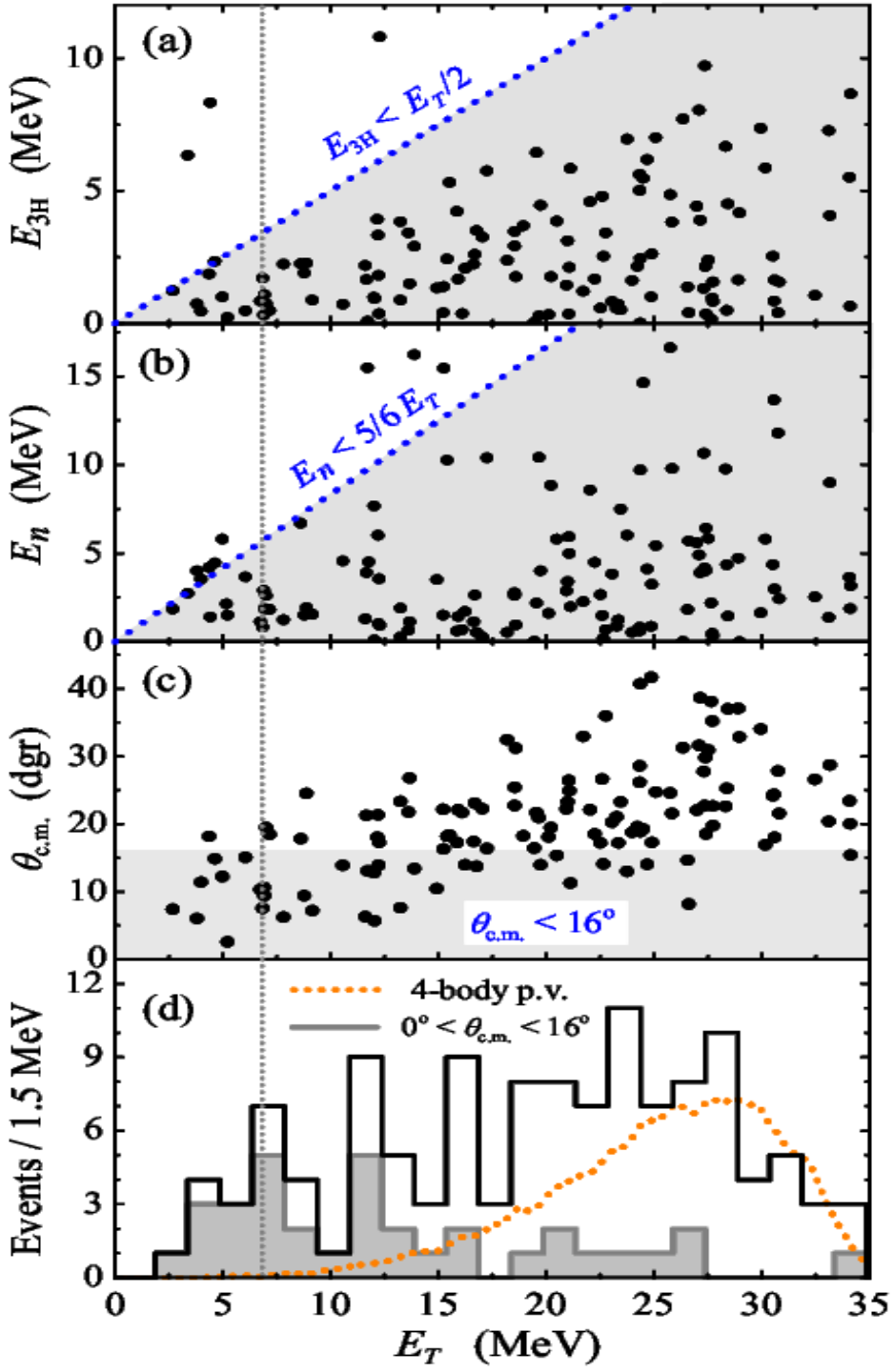
Neutron coincidence

131 ^{4}He-^{3}H-neutron coincidences

Background free

No resonance states lower 3.5 MeV

Peak at 6.8 MeV

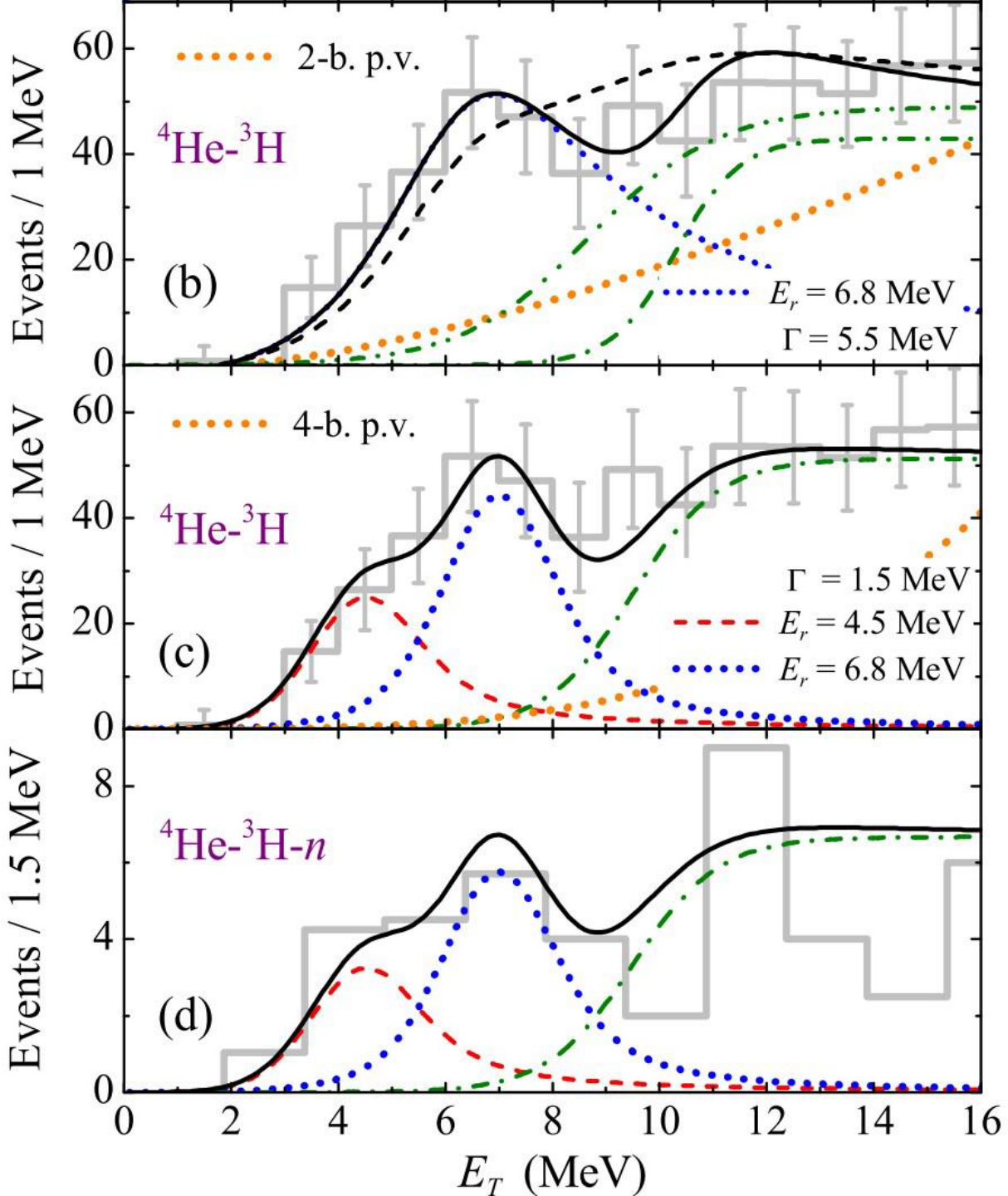


^{6}H results

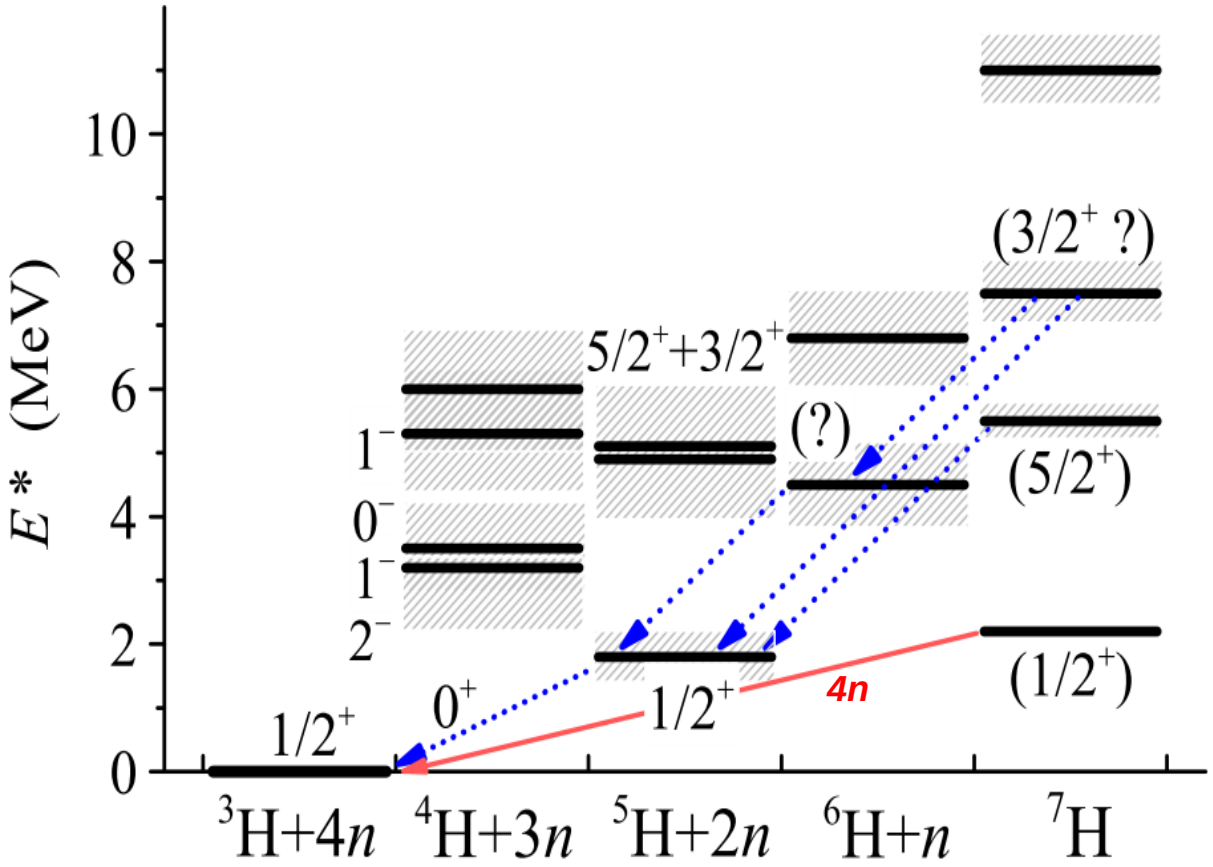
NO states below 3.5 MeV
($d\sigma/d\Omega < 5$ μb/sr)

Peak at 4-8 MeV (~190 μb/sr):

- 4.5 MeV ground state
- 6.8 MeV excited state



Light exotic nuclei today



New level schemes for all isotopes ^{3}H-^{7}H

^{6}H as the evidence of 5-body decay of ^{7}H

The unique true 4n-decay mechanism is proved to be realized for ^{7}H.

This is the first such case found in the nuclide map.

Summary

The ^{7}H g.s. was observed at 2.2 MeV ($d\sigma/d\Omega$ ~ 25 μb/sr)

The ^{7}H excited state at 5.5 MeV ($d\sigma/d\Omega$ ~ 30 μb/sr)

Possible +5/2-3/2 doublet with 7.5 MeV

Indication of state at 11 MeV

Thanks for attention

No ^{6}H states at energy less than 3.5 MeV for $d\sigma/d\Omega$<5 μb/sr limit

^{6}H resonance presence at 4-8 MeV ($d\sigma/d\Omega$ ~ 190 μb/sr).

^{6}H g.s. at 4.5 MeV, ^{6}H* at 6.8 MeV

- confirms the ^{7}H g.s. five-body decay channel
- decay of ^{6}H through ^{5}H g.s.

The obtained results represent an important step towards resolving the ^{6,7}H problem

PHYSICAL REVIEW LETTERS **124,** 022502 (2020)

Evidence for the First Excited State of ^{7}H

A. A. Bezbakh,[1,2] V. Chudoba,[1,2,*] S. A. Krupko,[1,3] S. G. Belogurov,[1,4] D. Biare,[1] A. S. Fomichev,[1,5] E. M. Gazeeva,[1] A. V. Gorshkov,[1] L. V. Grigorenko,[1,4,6] G. Kaminski,[1,7] O. A. Kiselev,[8] D. A. Kostyleva,[8,9] M. Yu. Kozlov,[10] B. Mauyey,[1,11] I. Mukha,[8] I. A. Muzalevskii,[1,2] E. Yu. Nikolskii,[6,1] Yu. L. Parfenova,[1] W. Piatek,[1,7] A. M. Quynh,[1,12] V. N. Schetinin,[10] A. Serikov,[1] S. I. Sidorchuk,[1] P. G. Sharov,[1,2] R. S. Slepnev,[1] S. V. Stepantsov,[1] A. Swiercz,[1,13] P. Szymkiewicz,[1,13] G. M. Ter-Akopian,[1,5] R. Wolski,[1,14] B. Zalewski,[1,7] and M. V. Zhukov[15]

PHYSICAL REVIEW C **103**, 044313 (2021)

Resonant states in ^{7}H: Experimental studies of the ^{2}H(^{8}He, ^{3}He) reaction

I. A. Muzalevskii,[1,2,*] A. A. Bezbakh,[1,2] E. Yu. Nikolskii,[3,1] V. Chudoba,[1,2] S. A. Krupko,[1] S. G. Belogurov,[1,4] D. Biare,[1] A. S. Fomichev,[1,5] E. M. Gazeeva,[1] A. V. Gorshkov,[1] L. V. Grigorenko,[1,4,3] G. Kaminski,[1,6] O. Kiselev,[7] D. A. Kostyleva,[7,8] M. Yu. Kozlov,[9] B. Mauyey,[1,10] I. Mukha,[7] Yu. L. Parfenova,[1] W. Piatek,[1,6] A. M. Quynh,[1,11] V. N. Schetinin,[9] A. Serikov,[1] S. I. Sidorchuk,[1] P. G. Sharov,[1,2] N. B. Shulgina,[3,12] R. S. Slepnev,[1] S. V. Stepantsov,[1] A. Swiercz,[1,13] P. Szymkiewicz,[1,13] G. M. Ter-Akopian,[1,5] R. Wolski,[1,14] B. Zalewski,[1,6] and M. V. Zhukov[15]

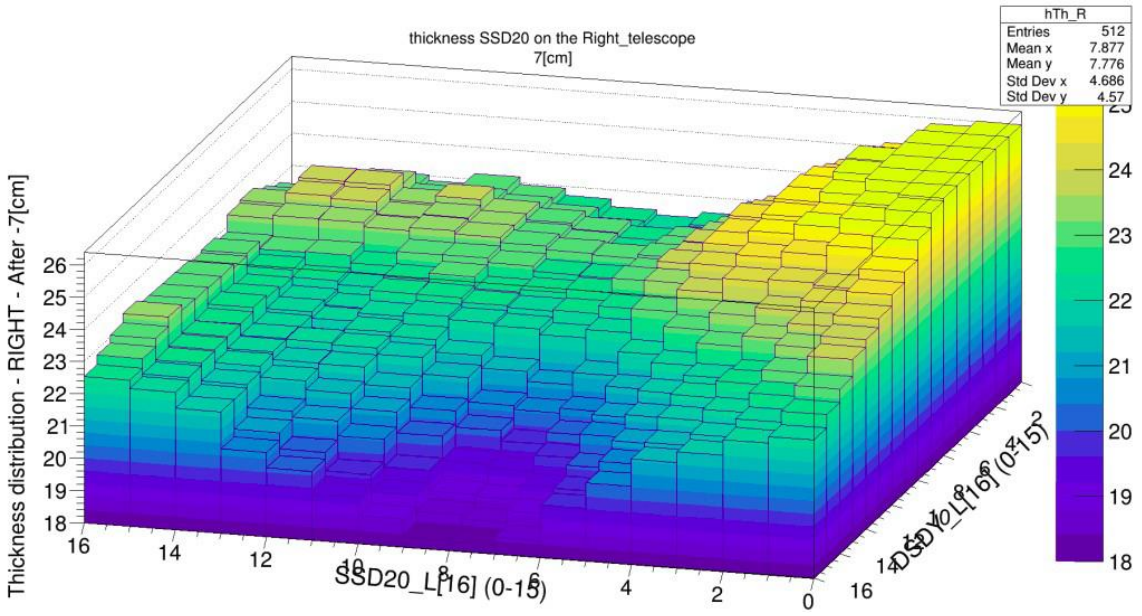
PHYSICAL REVIEW C **105**, 064605 (2022)

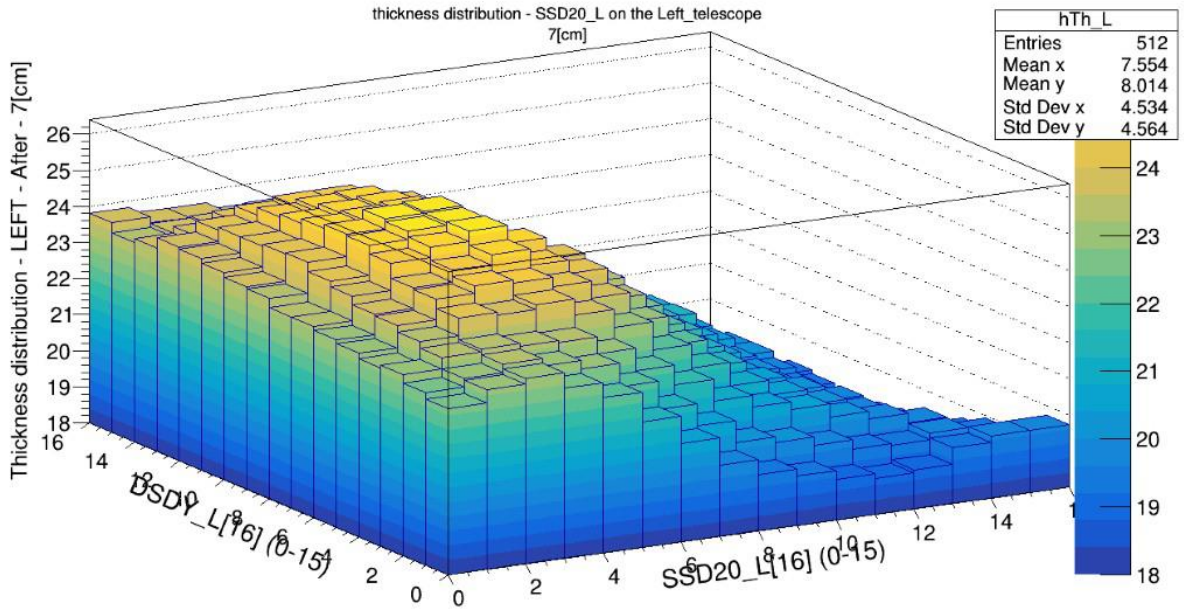
^{6}H states studied in the ^{2}H(^{8}He, ^{4}He) reaction and evidence of an extremely correlated character of the ^{5}H ground state

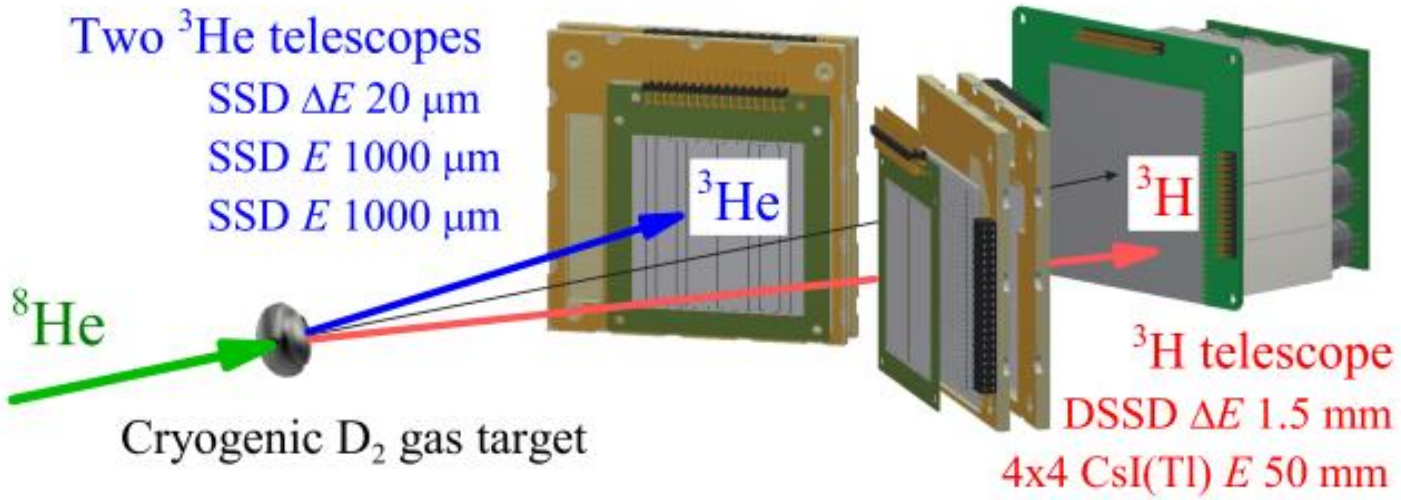
E. Yu. Nikolskii,[1,2,*] I. A. Muzalevskii,[2,3] A. A. Bezbakh,[2,3] V. Chudoba,[2,3] S. A. Krupko,[2] S. G. Belogurov,[2,4] D. Biare,[2] A. S. Fomichev,[2,5] E. M. Gazeeva,[2] A. V. Gorshkov,[2] L. V. Grigorenko,[2,4,1] G. Kaminski,[2,6] M. Khirk,[7,2] O. Kiselev,[8] D. A. Kostyleva,[8,9] M. Yu. Kozlov,[10] B. Mauyey,[2,11] I. Mukha,[8] Yu. L. Parfenova,[2] W. Piatek,[2,6] A. M. Quynh,[2,12] V. N. Schetinin,[10] A. Serikov,[2] S. I. Sidorchuk,[2] P. G. Sharov,[2,3] N. B. Shulgina,[1,13] R. S. Slepnev,[2] S. V. Stepantsov,[2] A. Swiercz,[2,14] P. Szymkiewicz,[2,14] G. M. Ter-Akopian,[2,5] R. Wolski,[2,15] B. Zalewski,[2,6] and M. V. Zhukov[16]

^{3}He identificatioin

I. Muzalevski et al., Bull.Rus.Acad.Sci.: Phys., 84, 500 (2020)



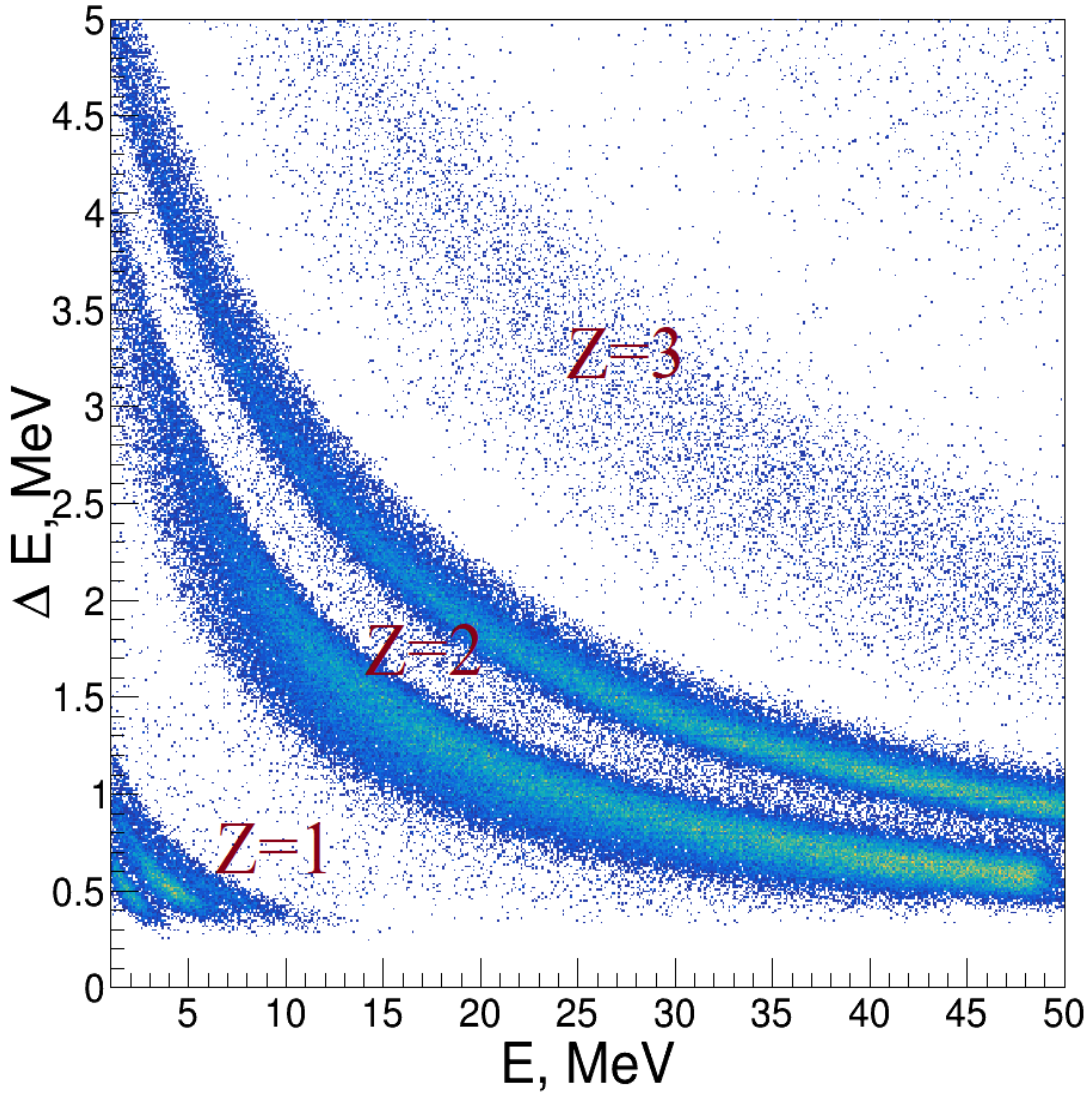


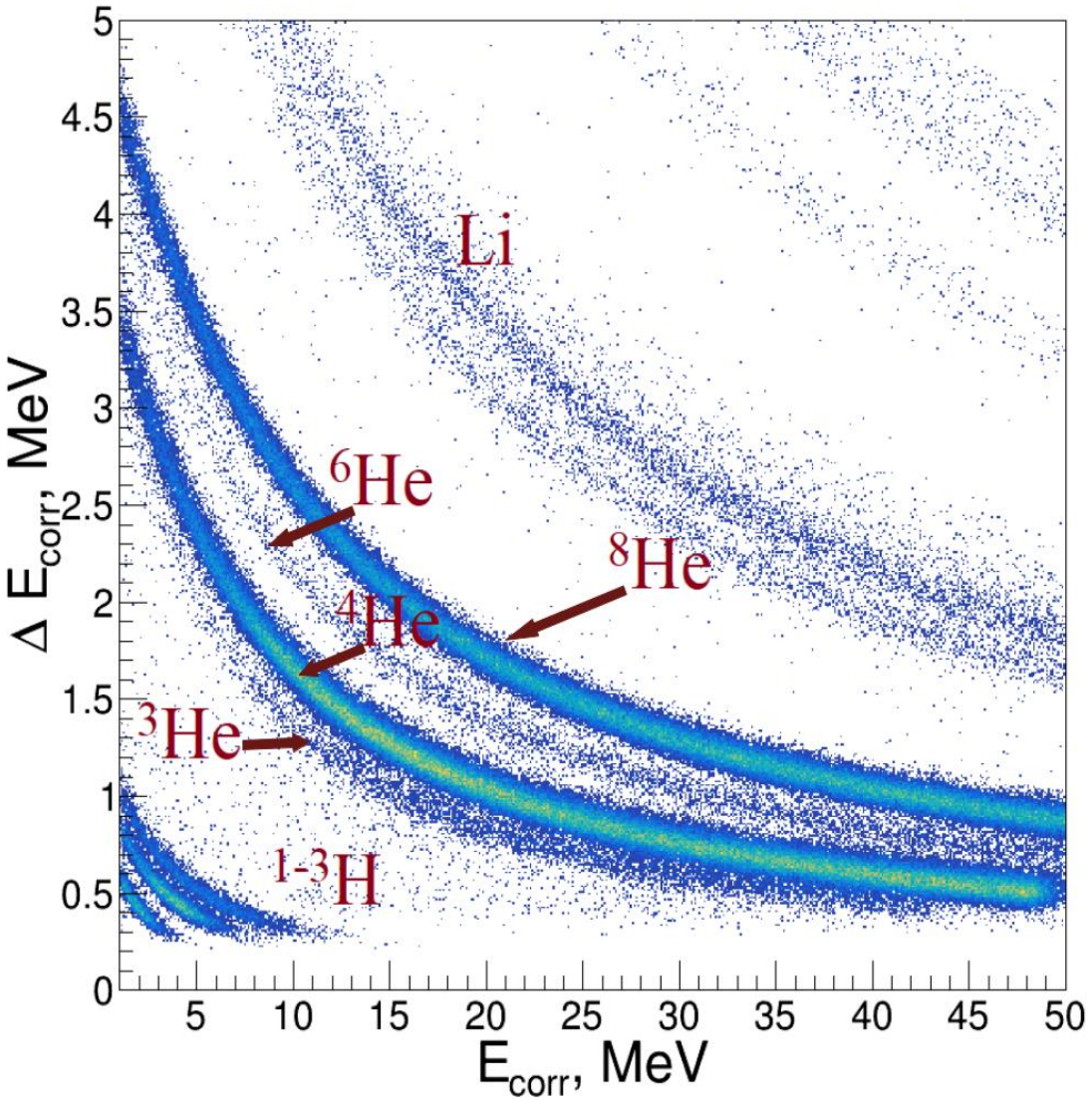


ΔThickness up to 8 μm (30%)!
Should be taken into account!

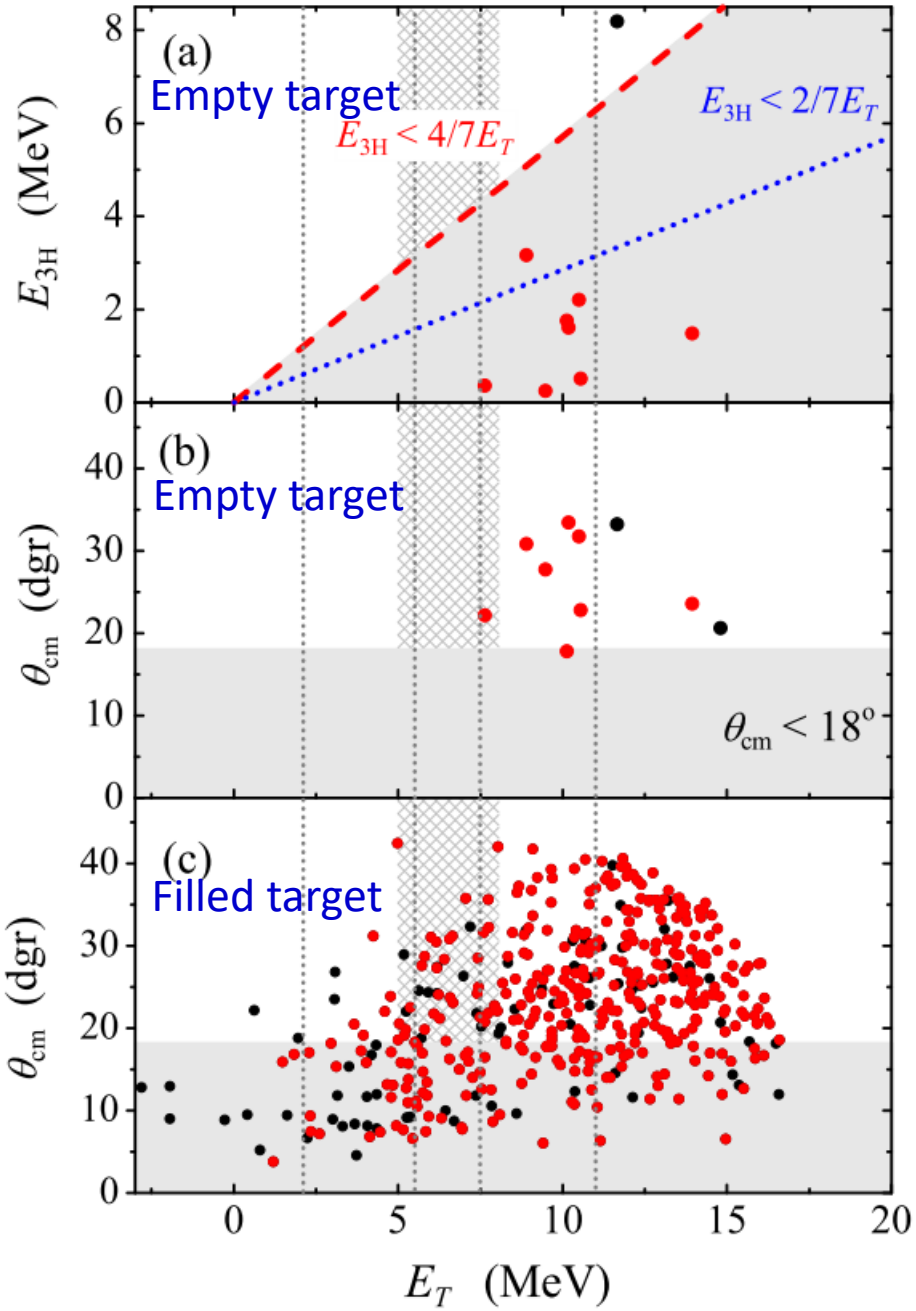
^{3}He identificatioin

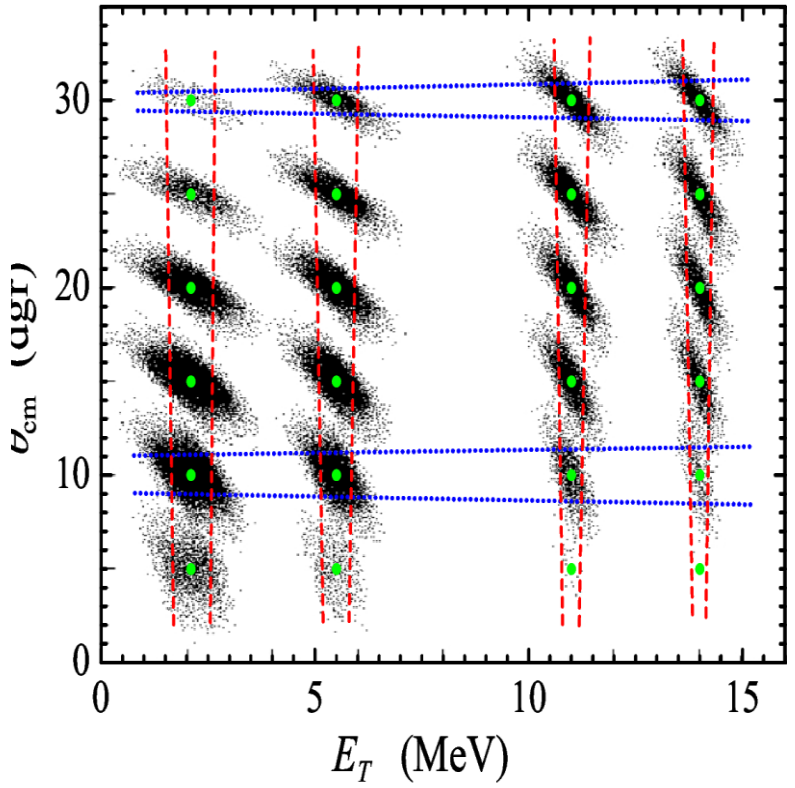
I. Muzalevski et al., Bull.Rus.Acad.Sci.: Phys., 84, 500 (2020)

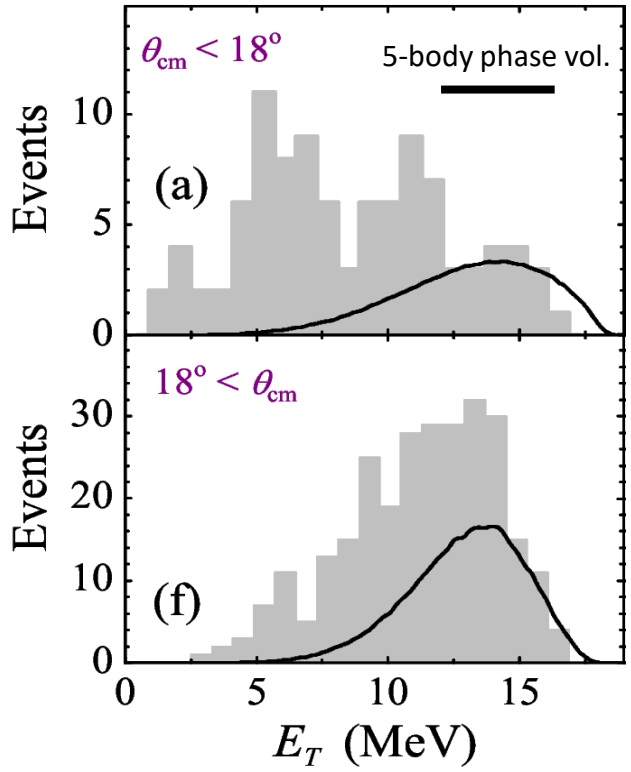




Reaction angle selection



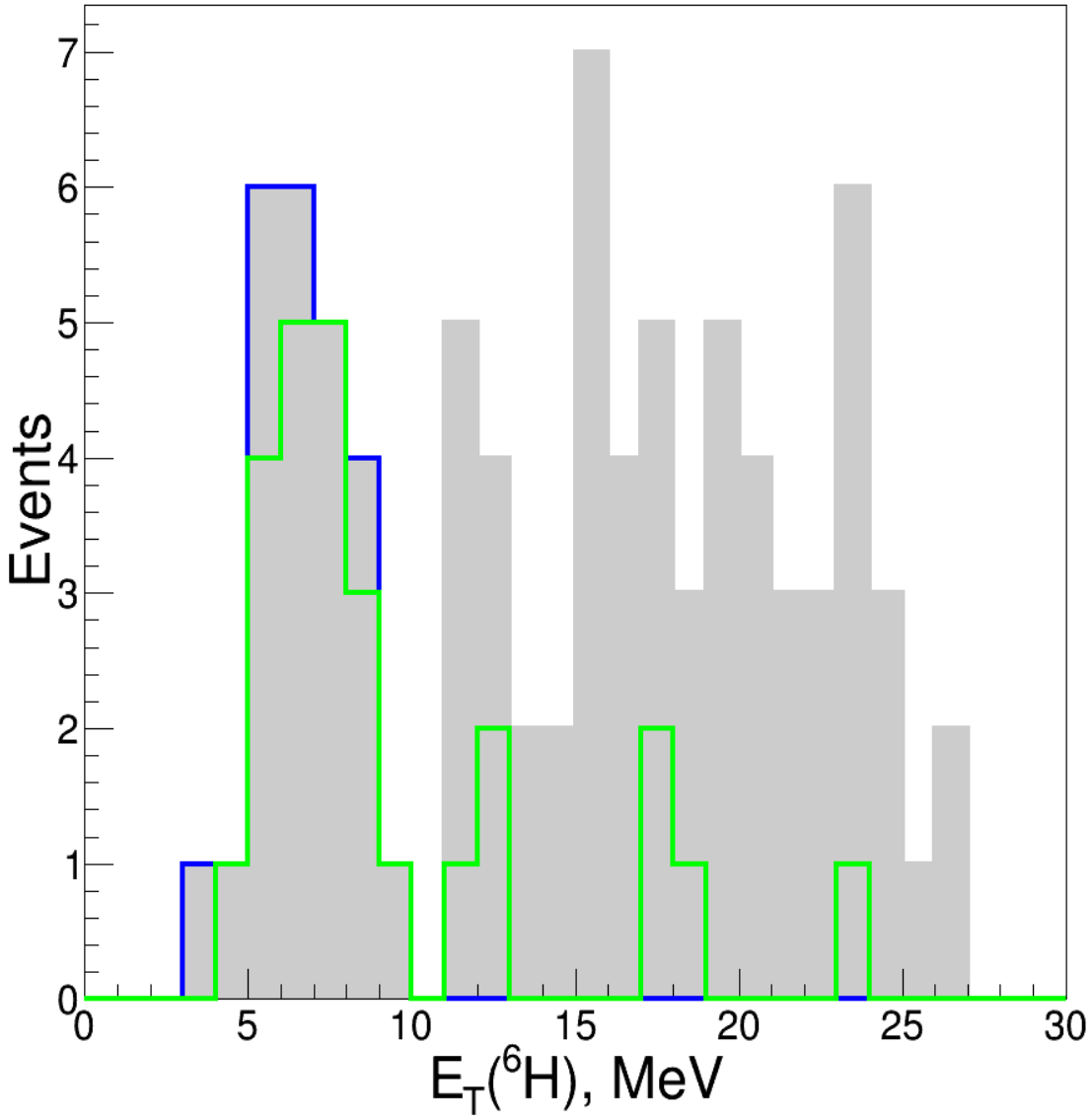


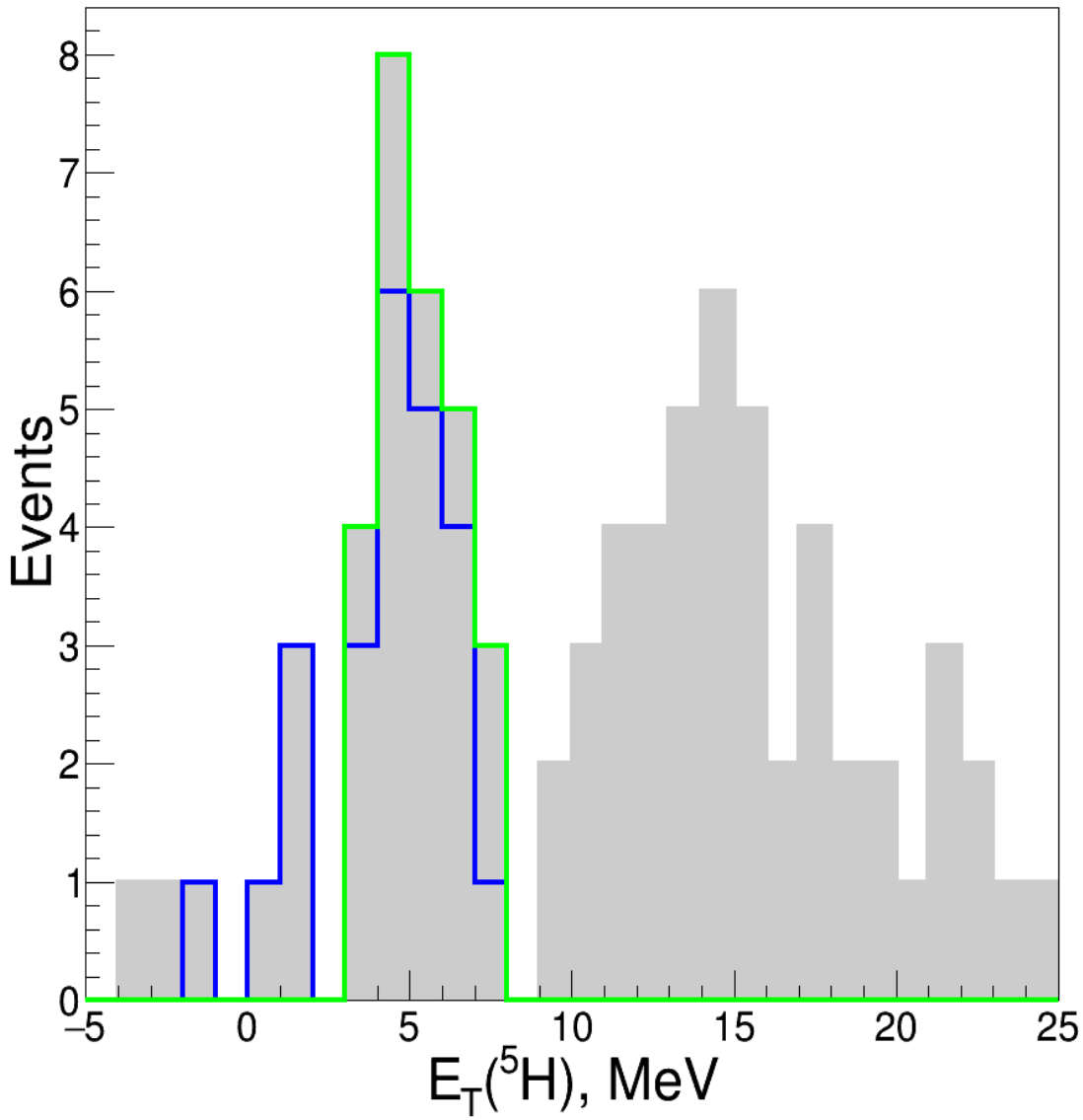


Data for $\theta_{CM} > 18°$ suffered from

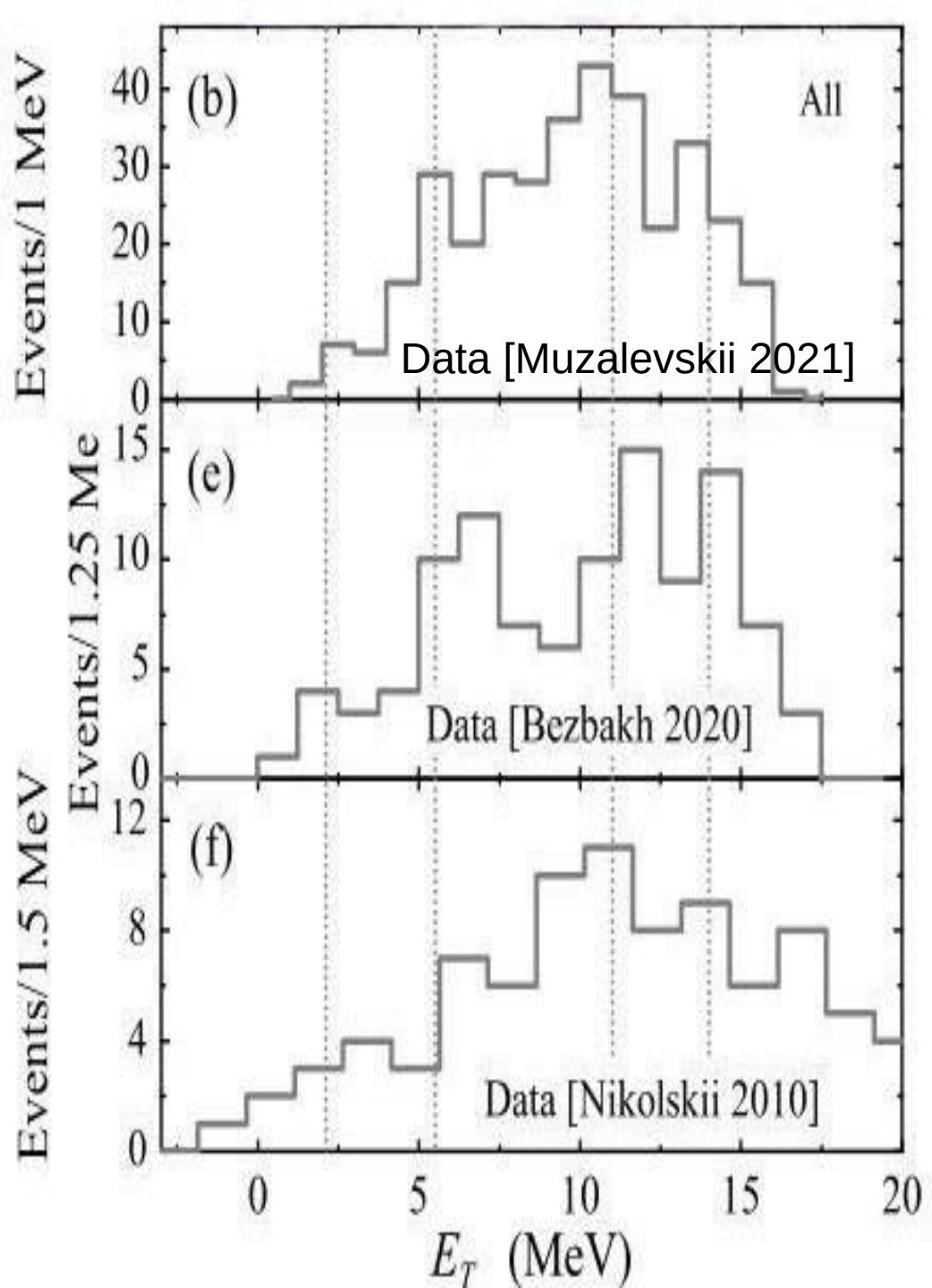
- **low energy resolution**
- **complex background conditions**

^{6}H-^{5}H correlation





Strong low-energy spectra correlation. Sequential decay.



^{7}H results agreement with E. Yu. Nikolskii et al., PRC 81, 064606 (2010)