Results of the first experiments with the ACCULINNA-2 fragment separator: ^{7}H case

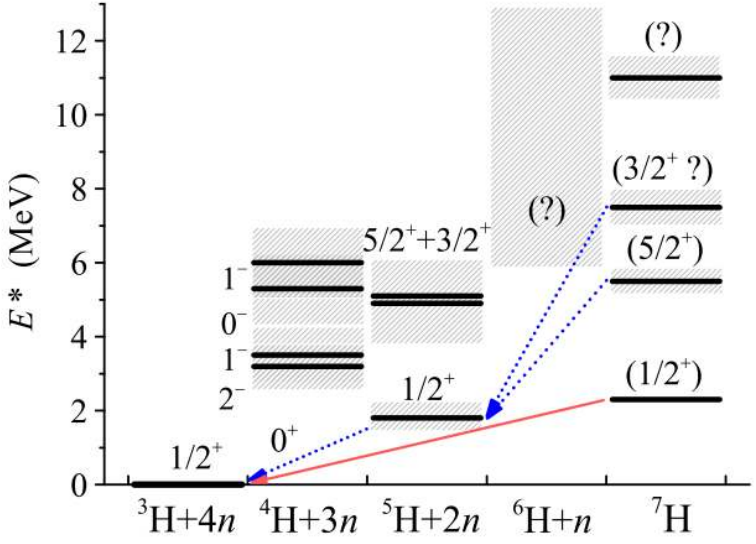
Vratislav Chudoba for

ACCULINNA-2 collaboration

as the first results of series on ^{7}H, ^{6}H, ^{7}He, ^{9}He and ^{10}Li

object of interest: ^{7}H

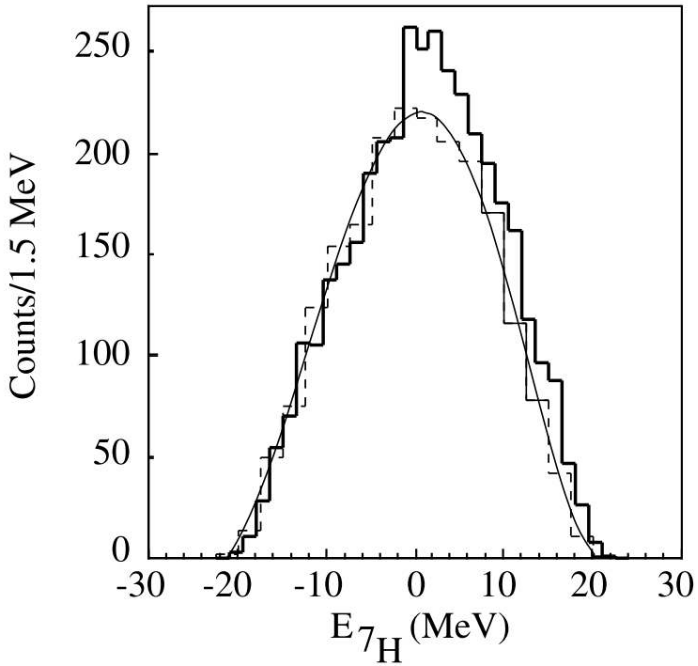
- the heaviest conceivable hydrogen isotope
- the largest A/Z = 7 ratio
- special stability of ^{7}H due to the closed $p_{3/2}$ neutron subshell
- “true” five-body core+4n decay channel of the g.s.
- extremely long-living g.s. of ^{7}H expected
  - candidate for 4n radioactivity if E_T < 100-300 keV
  - small width of g.s. (0.1-10 keV) expected even for E_T = 2 MeV
- anticipated specific correlations of fragments for core+4n decay

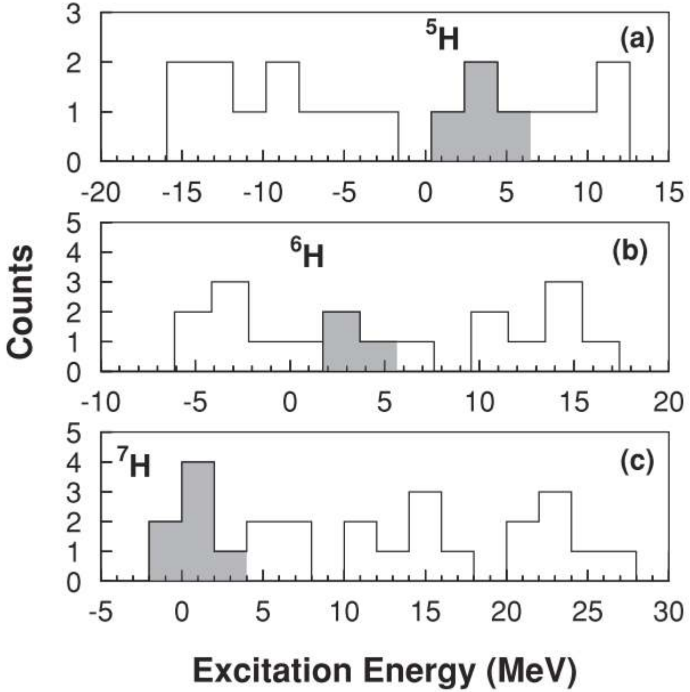


50-year-long quest

- predicted in 1972
  - A. I. Baz' et al., "Light and intermediate nuclei near the border of nuclear stability" (Nauka, Moscow, 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)**;
- $d(^{8}He,^{7}H)$
  - M. S. Golovkov et al., Phys. Lett. B 588, 163 **(2004)**;
- $^{11}B(\pi^{-},p\ ^{3}He)$
  - Y. Gurov et al., The EPJ A 32, 261 **(2007)**;
  - Y. Gurov et al., PPN 40, 558 **(2009)**;

50-year-long quest: recent data





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

A. A. Korsheninnikov, PRL 90, 082501 (2003)

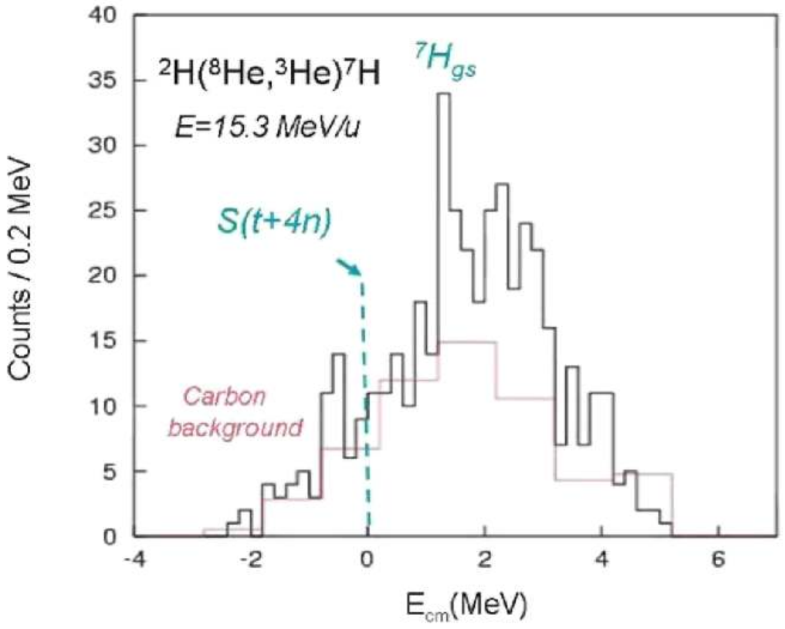
- missing mass only → 90% of background
- many events with negative MM energy
- 1.9 MeV MM resolution

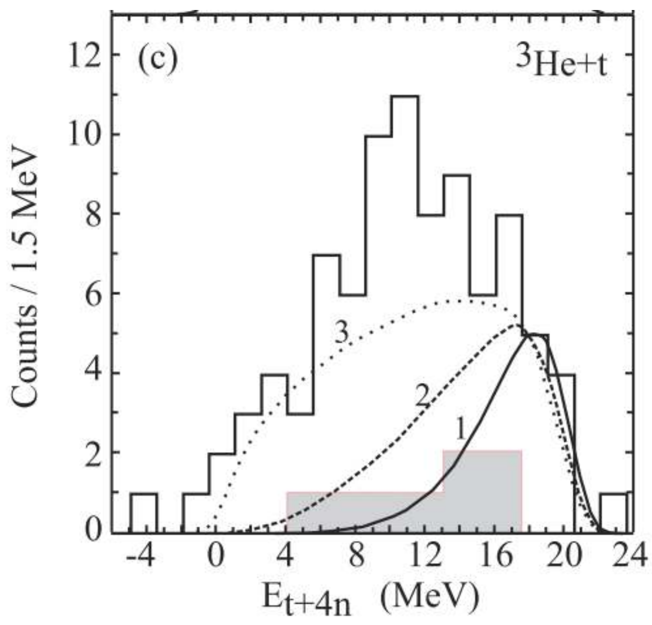
^{12}C(^{8}He,^{13}N)^{7}H

M. Caamano et al., PRL 99, 062502 (2007); PRC 78, 044001 (2008)

- mixed material active target
- missing mass with ^{3}H coincidences
- no channel identification: ^{5}H, ^{6}H, or ^{7}H

50-year-long quest: recent data





$^2H(^8He,^3He)^7H$

S. Fortier et al., AIP CP 912, 3 (2007)

- missing mass only → 70% of background
- many events with negative MM energy
- low energy cutoff (E_T < 5 MeV)

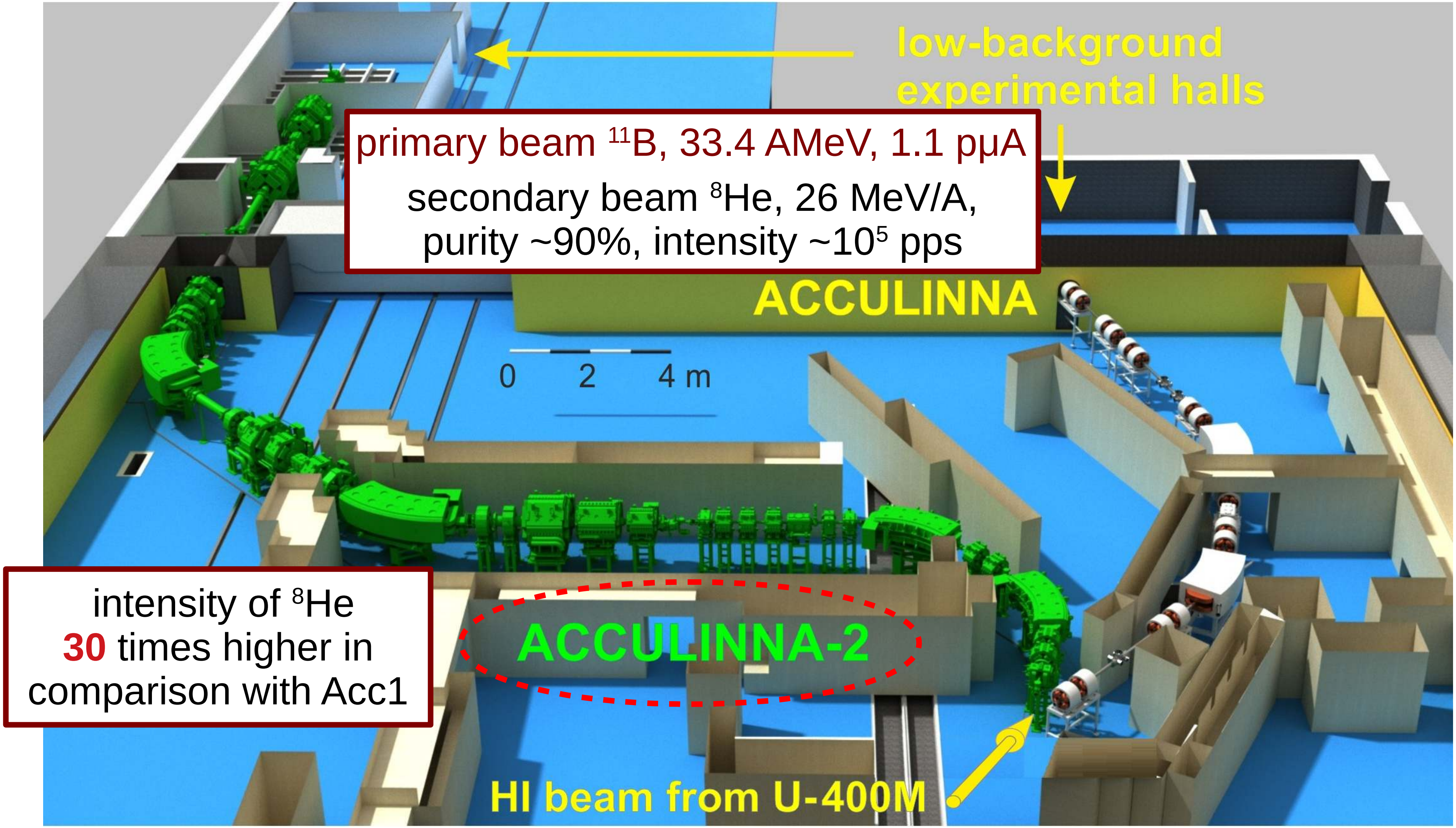
$^2H(^8He,^3He)^7H$

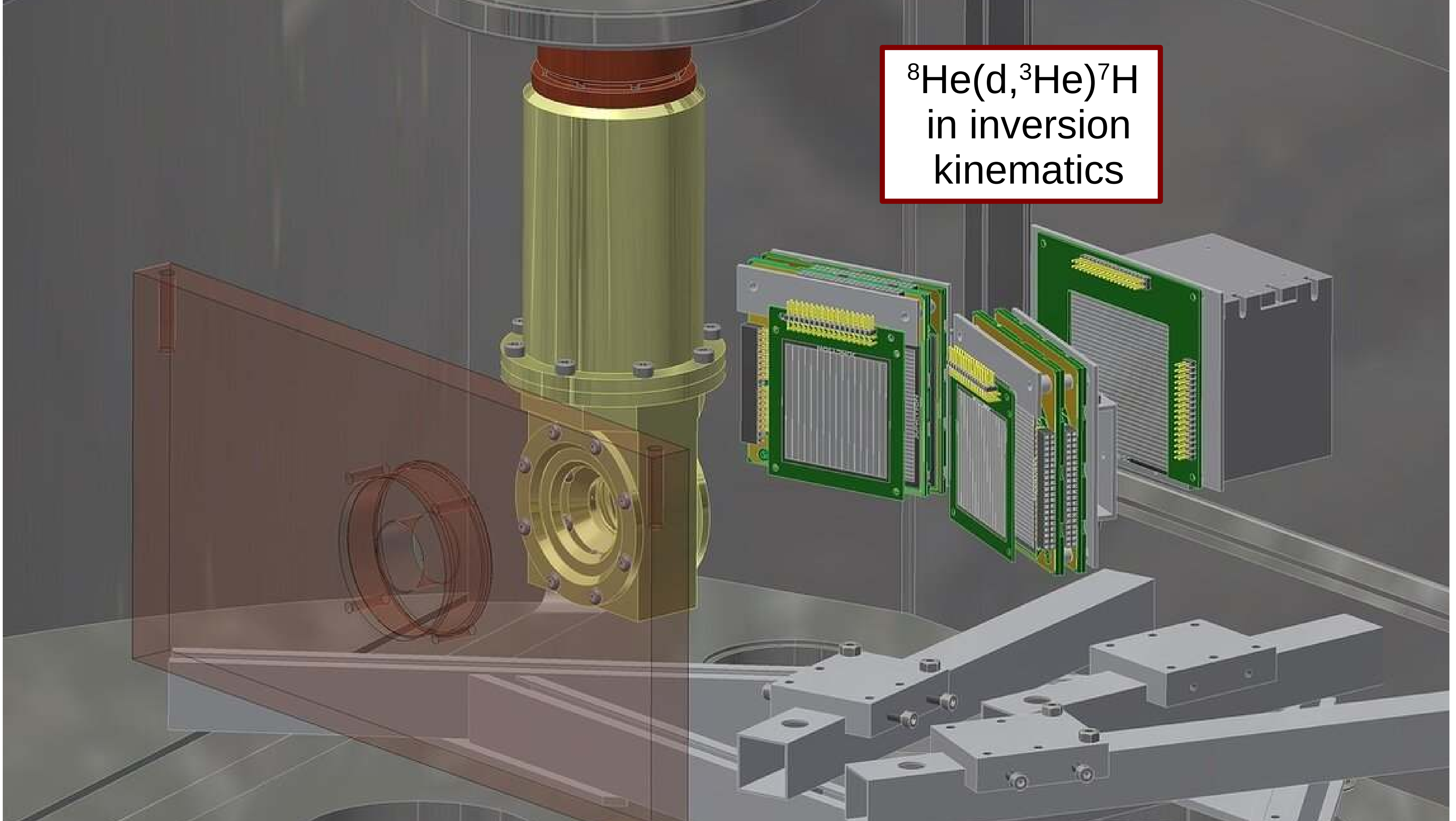
E.Yu. Nikolskii et al., Phys. Rev. C 81, 064606 (2010)

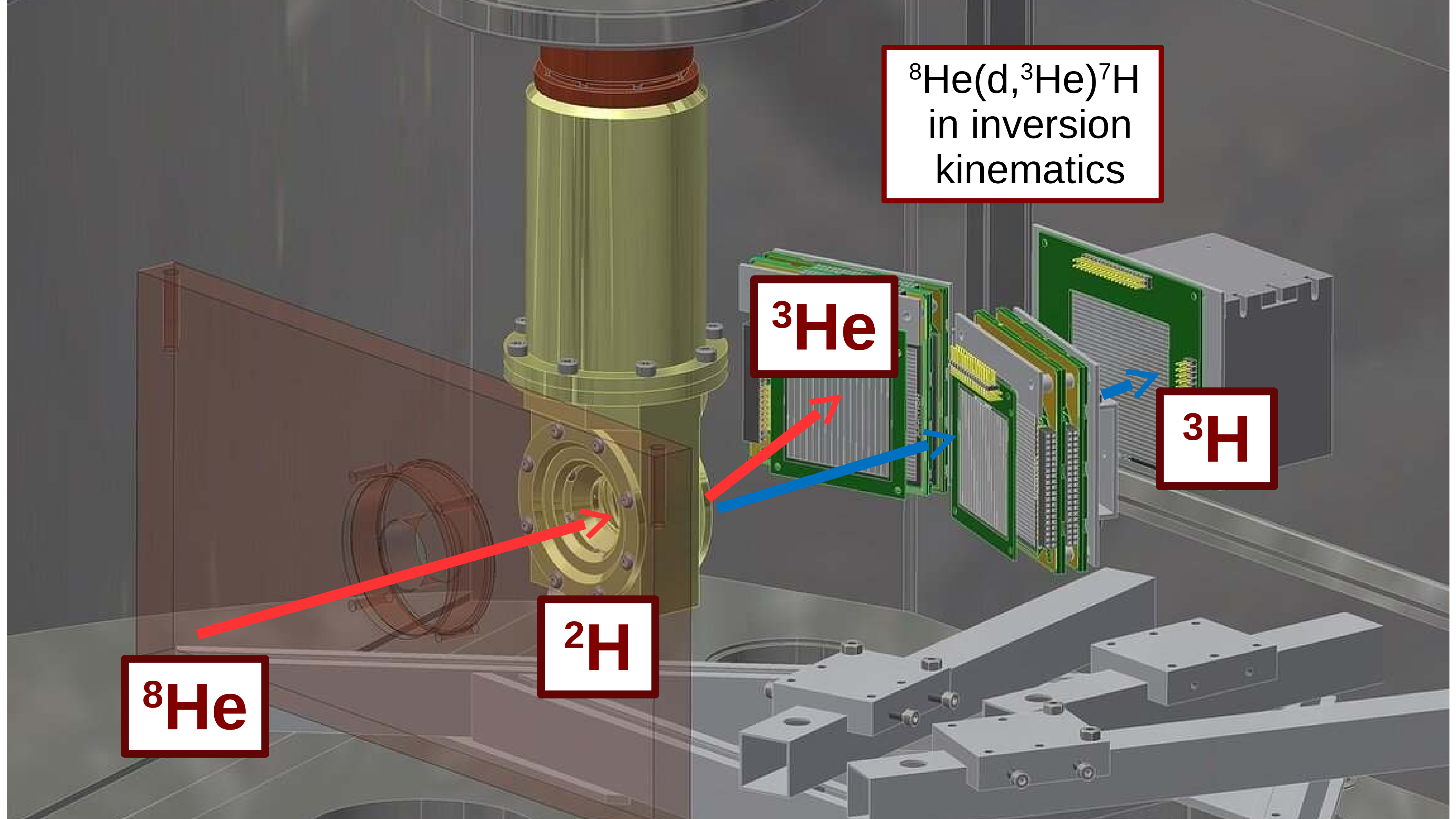
- missing mass with ^3H coincidences
- some events with negative MM energy
- 1.9 MeV MM resolution

Prerequisites for successful search of ^7H

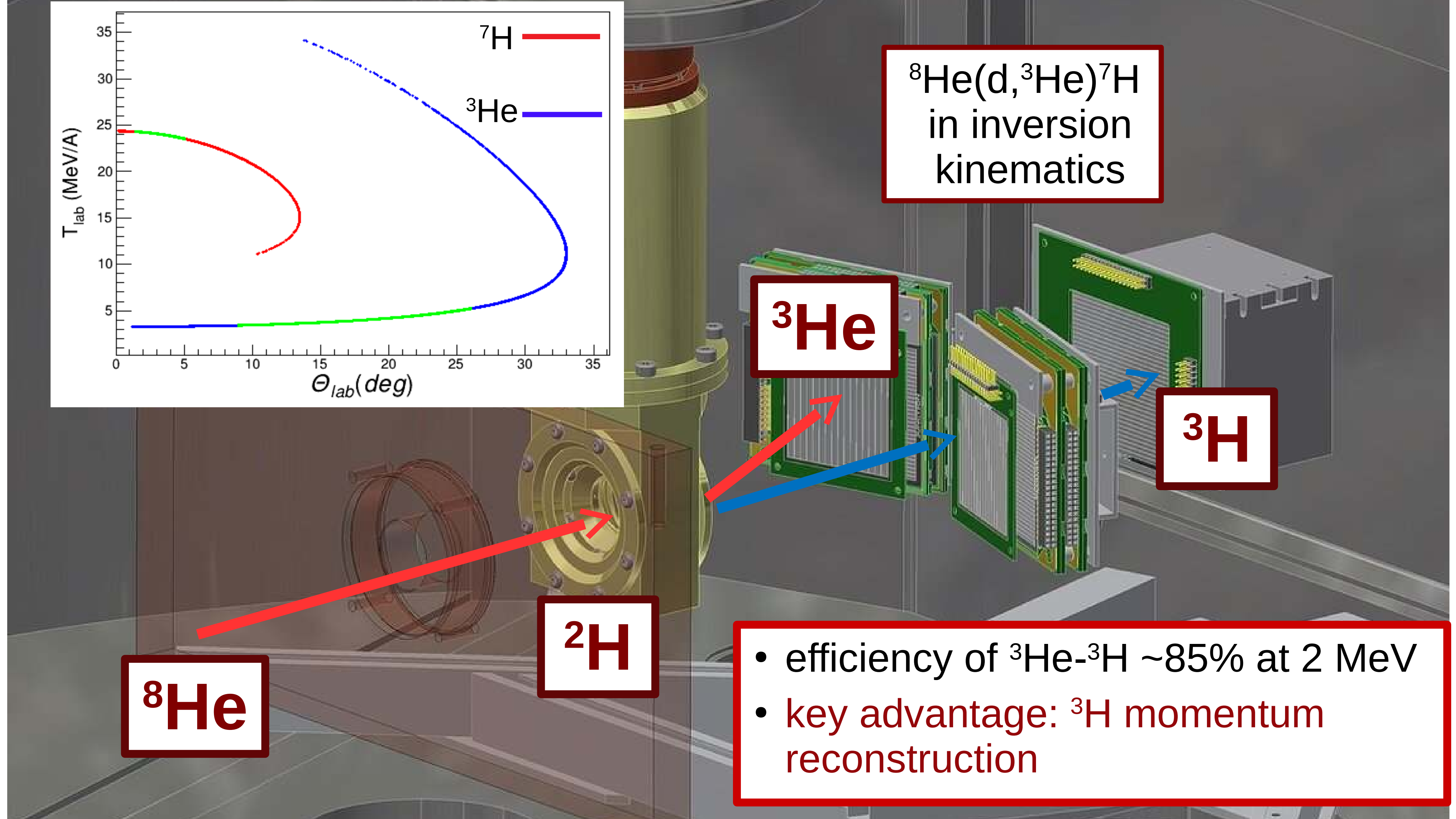
- **reliable channel identification**
- **suppression of background**
- **high energy resolution**


low-background
experimental halls
primary beam ^{11}B, 33.4 AMeV, 1.1 pμA
secondary beam ^{8}He, 26 MeV/A,
purity ~90%, intensity ~10^5 pps
ACCULINNA
0 2 4 m
intensity of ^{8}He
30 times higher in
comparison with Acc1
ACCULINNA-2
HI beam from U-400M


$^{8}He(d,^{3}He)^{7}H$
in inversion
kinematics

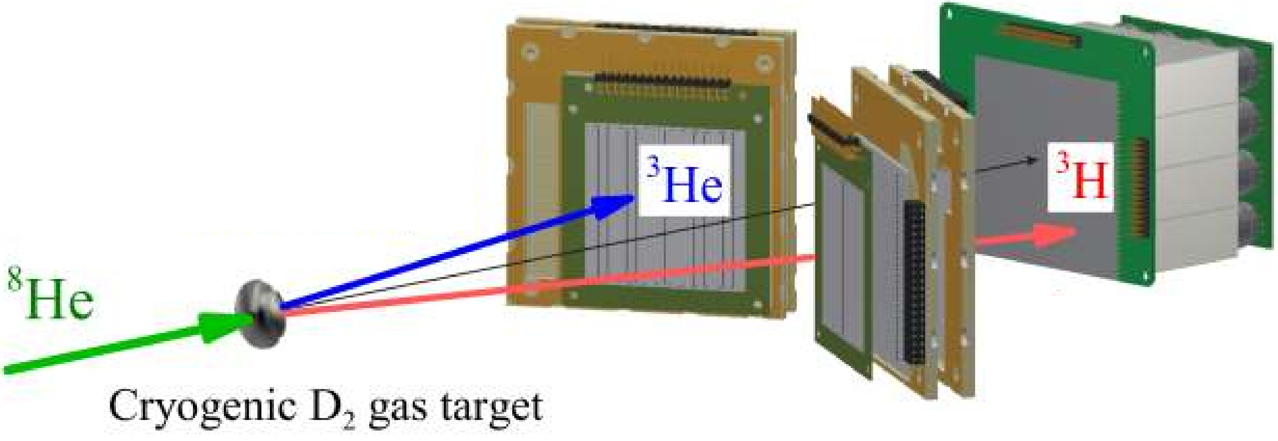


$^8He(d,^3He)^7H$
in inversion
kinematics
^3He
^3H
^2H
^8He

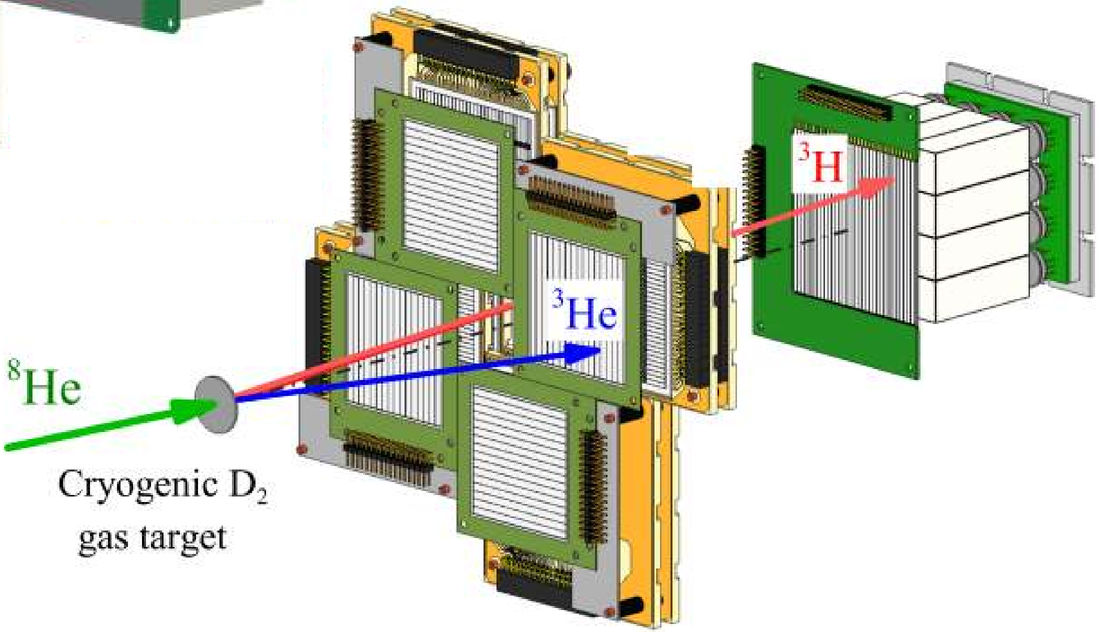


^{8}He(d,^{3}He)^{7}H
in inversion
kinematics
^{7}H
^{3}He
T_{lab} (MeV/A)
$\Theta_{lab}(deg)$
0 5 10 15 20 25 30 35
5 10 15 20 25 30 35
^{3}He
^{3}H
^{2}H
^{8}He
• efficiency of ^{3}He-^{3}H ~85% at 2 MeV
• key advantage: ^{3}H momentum reconstruction

Experiment 1, 2018
2 weeks

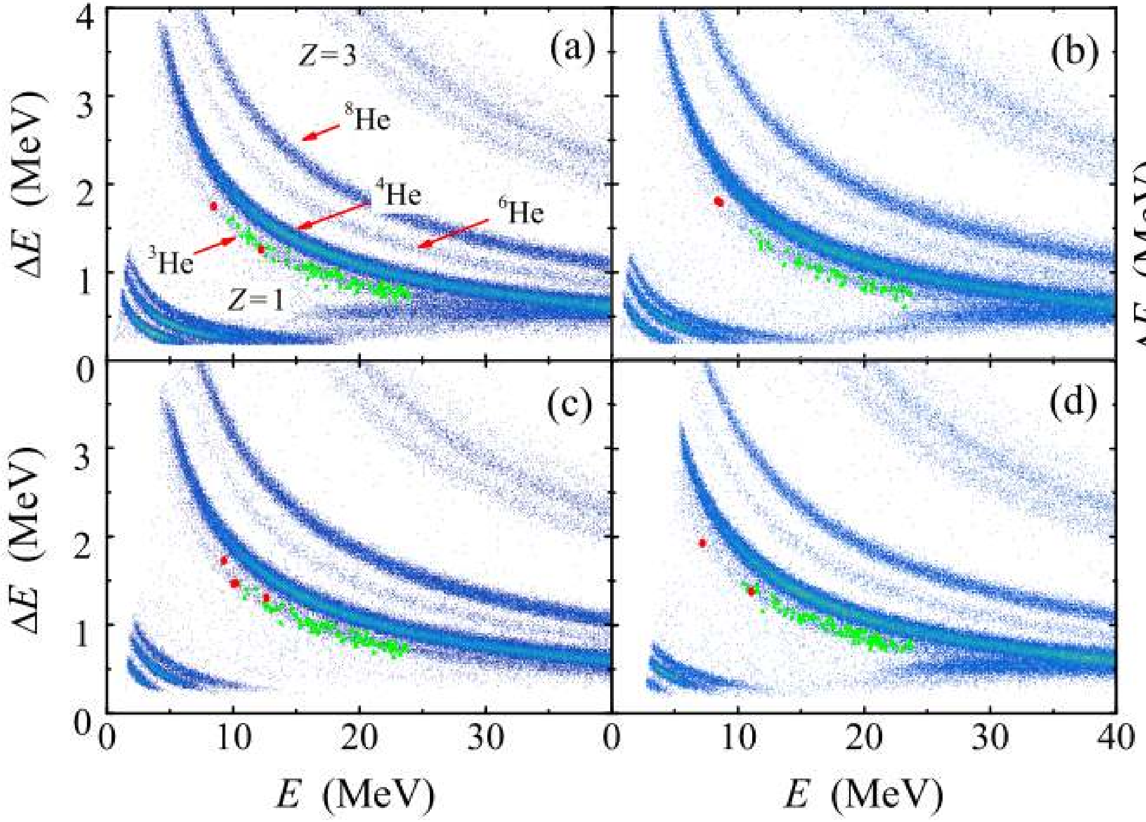


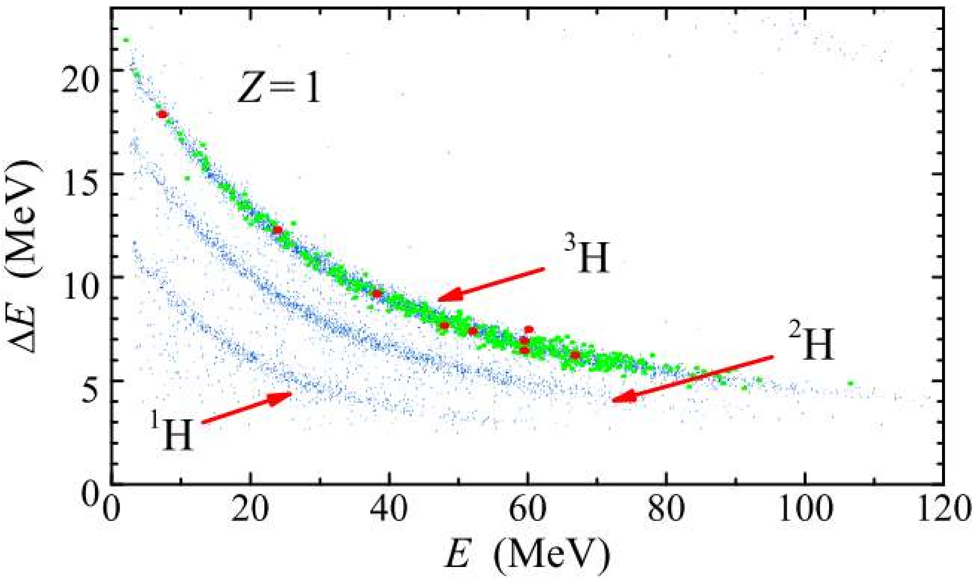
Experiment 2, 2019
3 weeks



- energy resolution for the ^{7}H missing mass ~(0.6 - 1.1) MeV
- 2018 – **119** ^{3}He-^{3}H coincidences
- 2019 – **378** ^{3}He-^{3}H coincidences
- background ~10% of events

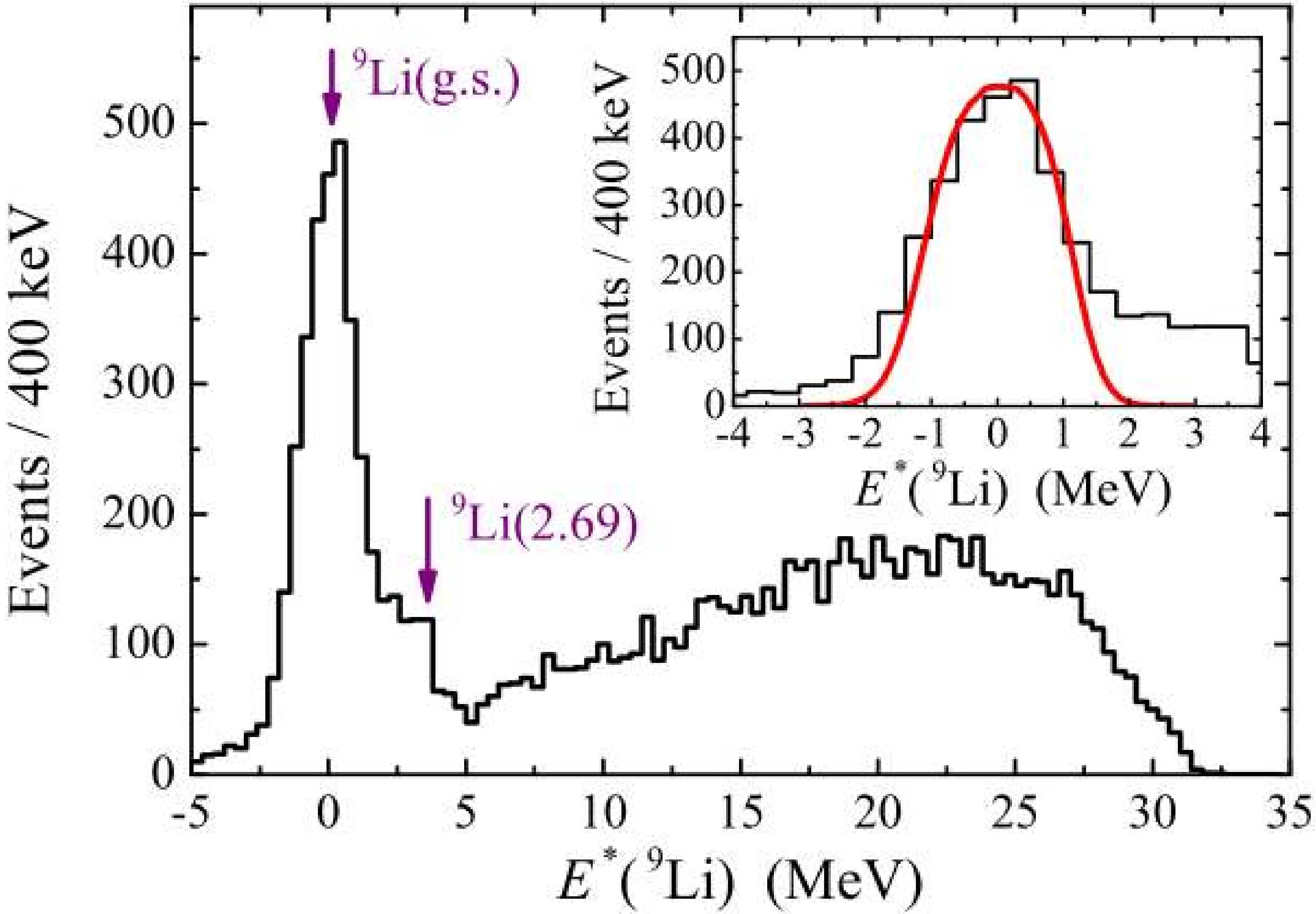
Channel identification





- reliable identification of both ^{3}He and ^{3}H
- special treatment of 20 μm Si detectors

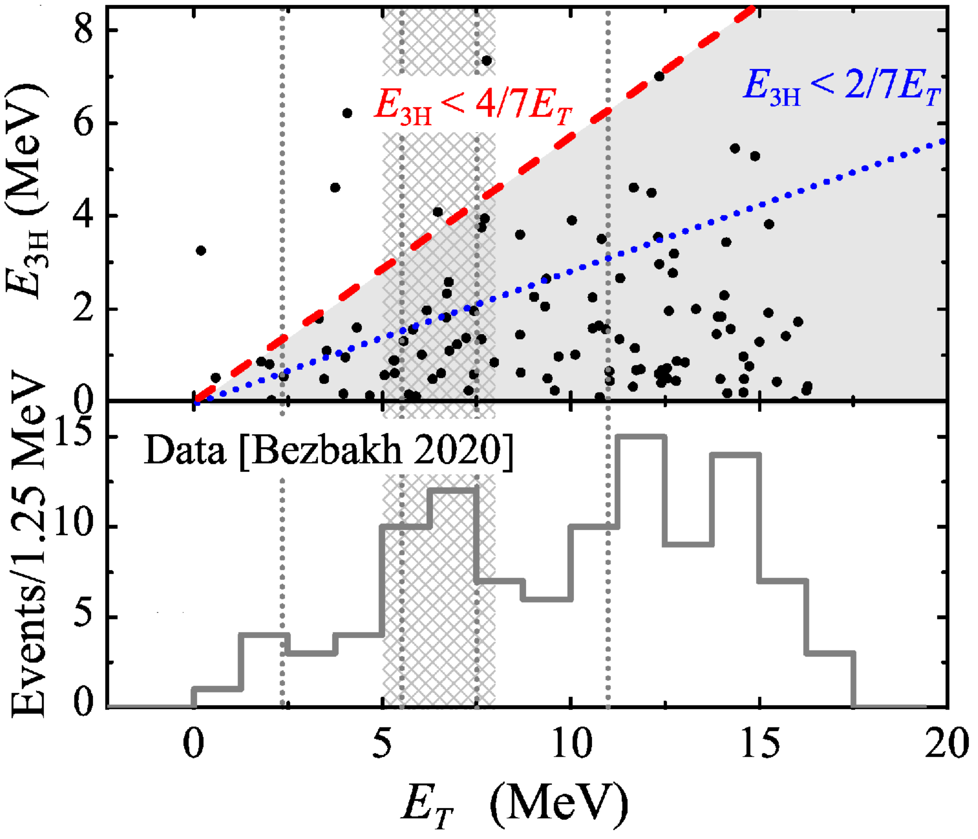
Calibration reaction



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

- ^{10}Be at 42 AMeV
- Independent MM calibration with ^{10}Be beam
- MC simulations validated by the comparison ^{9}Li data

MM spectrum: Exp1

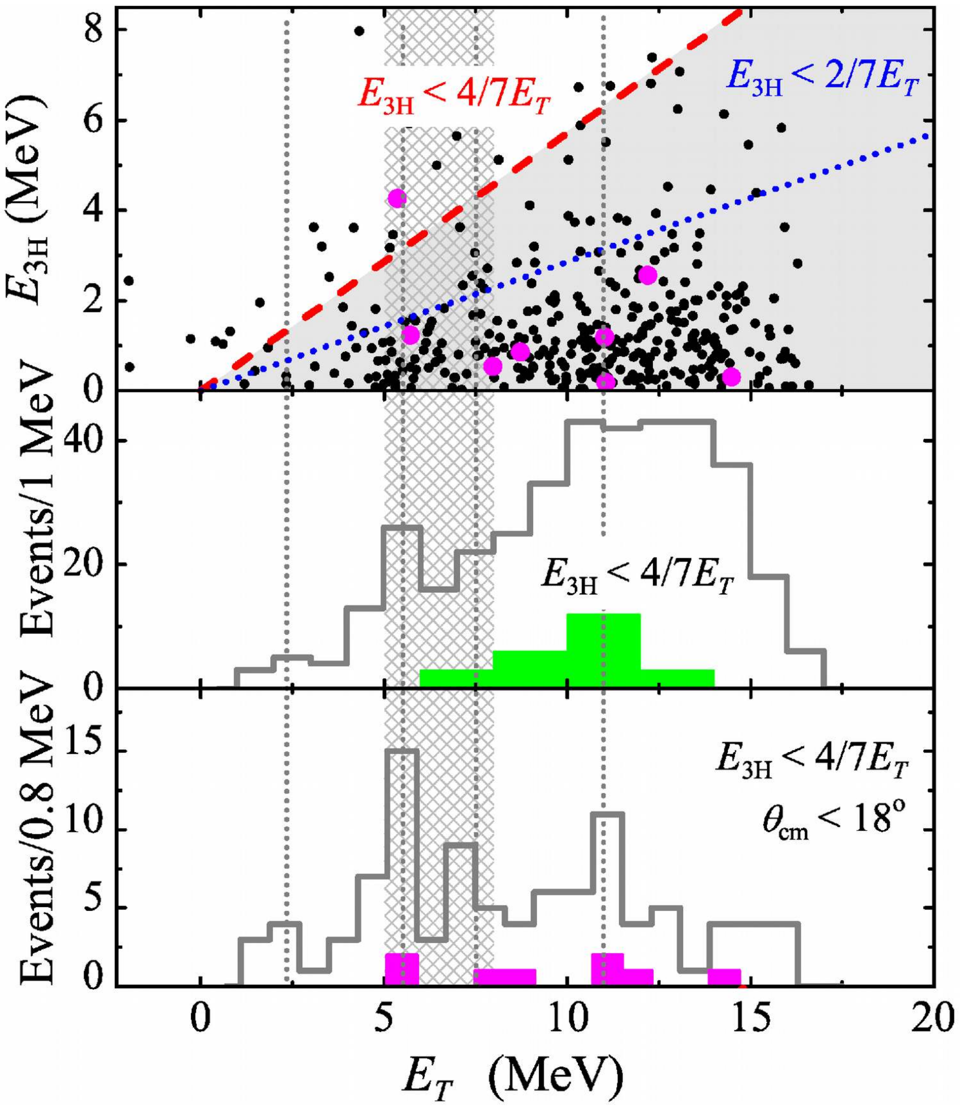


- kinematical “triangle” cuts reduce the backgrounds
- ground state at 1.8(5) MeV
- excited state at 6.5(5) MeV
  - possibly 5.5-7.5 MeV doublet
- some evidence for ^{7}H excited state at 11 MeV

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

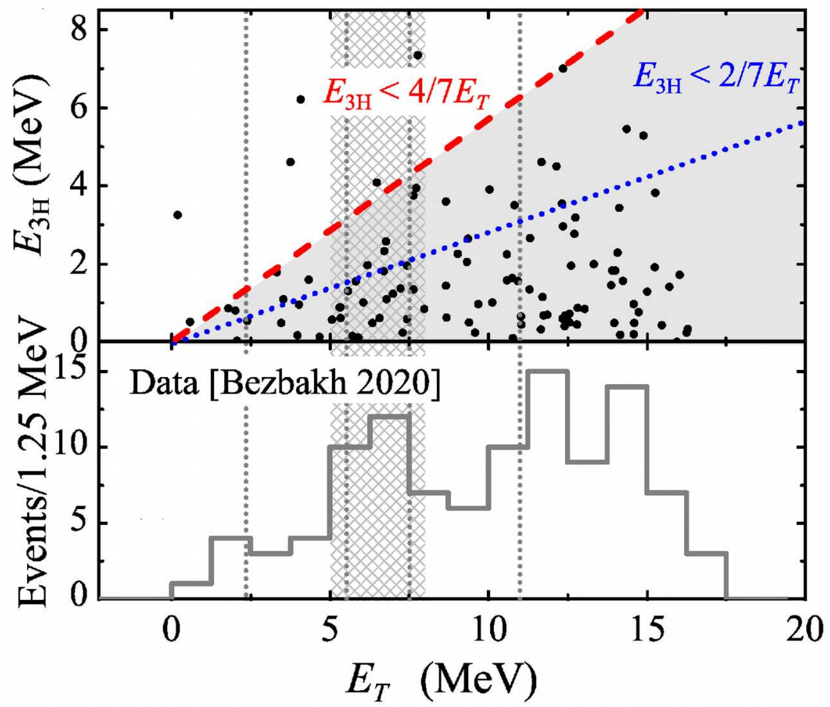
MM spectrum: Exp2

- ^{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
- reaction c.m. angle cutoff θ_{cm}<18° provides especially safe result for the ^{7}H g.s.

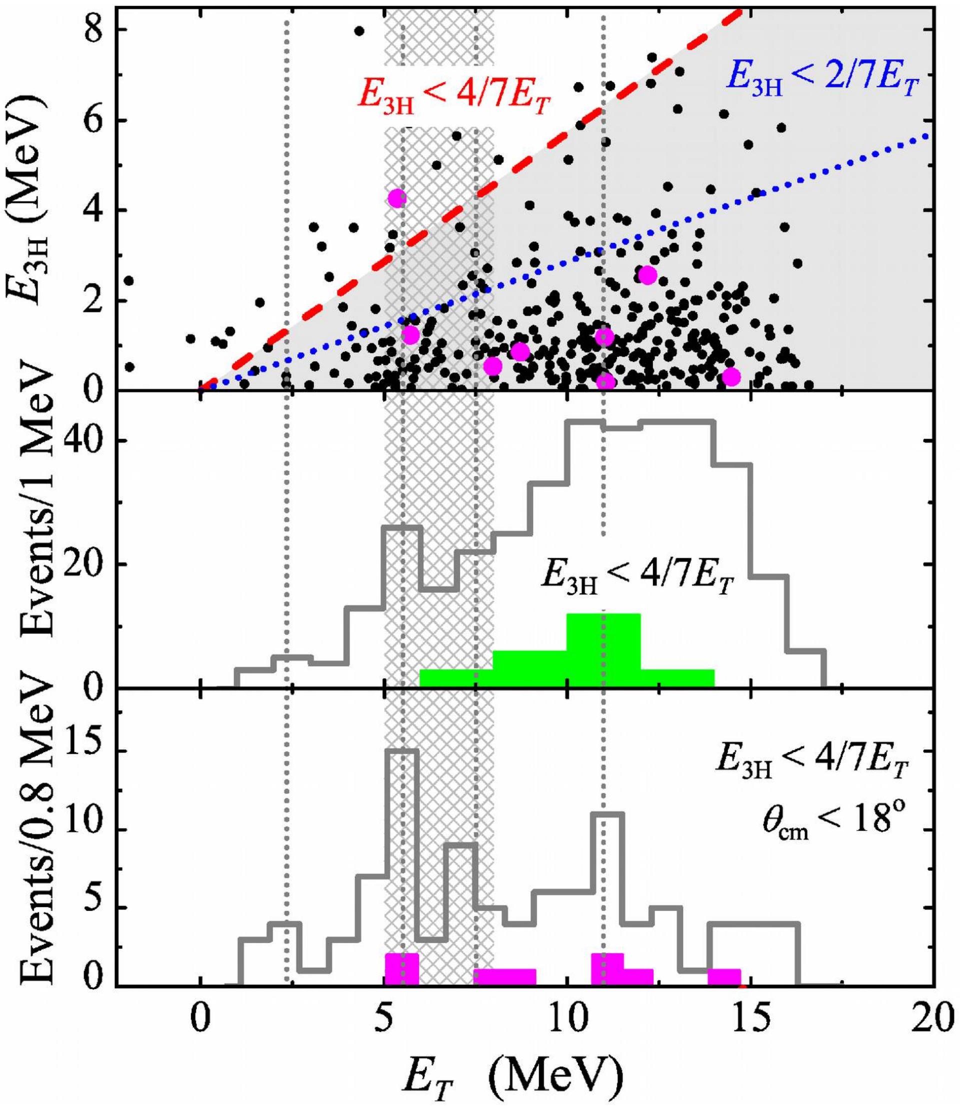


Muzalevskii et al., https://arxiv.org/abs/2010.09655, submitted to **Physical Review C**

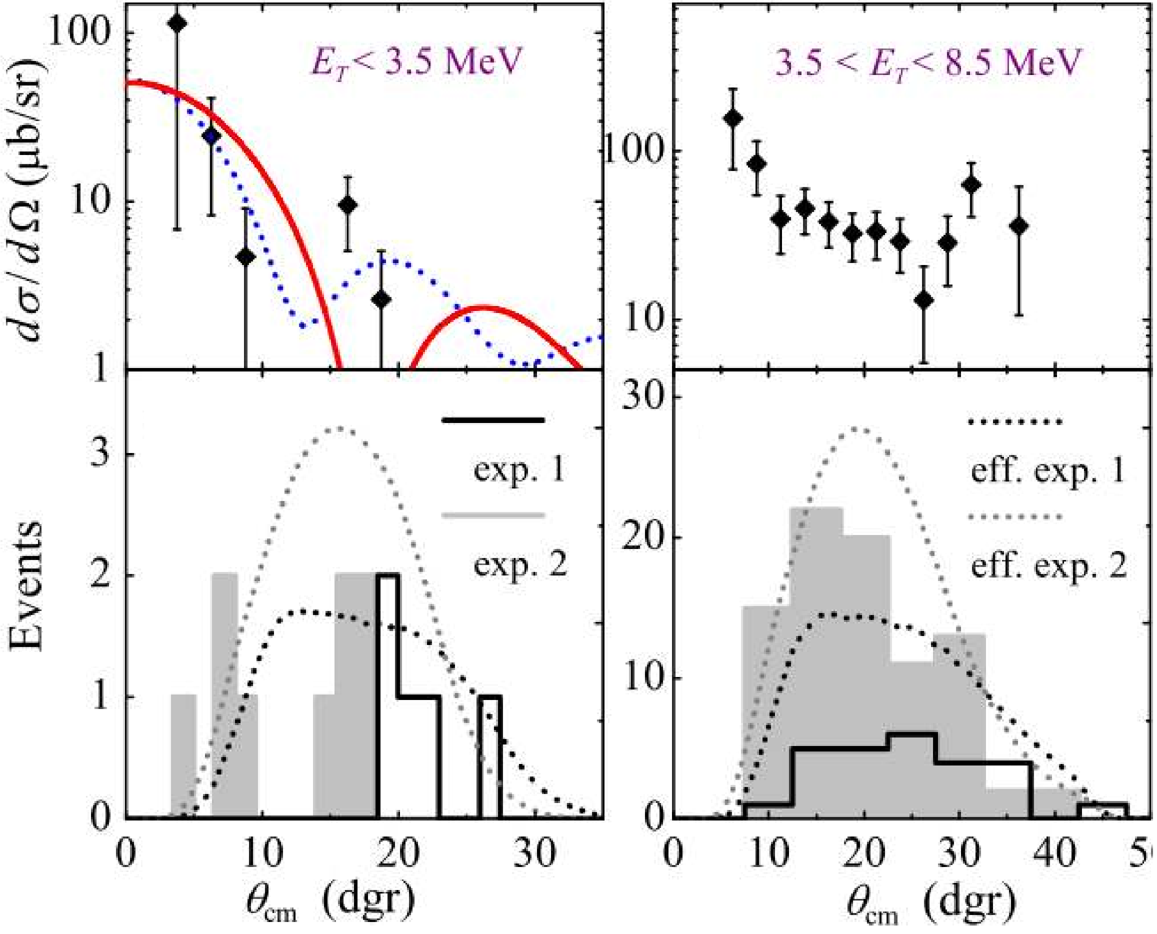
MM spectra



- consistent results in 2 independent JINR experiments
- consistent with data of Nikolskii et al.
- level- and decay-scheme for the ^7H

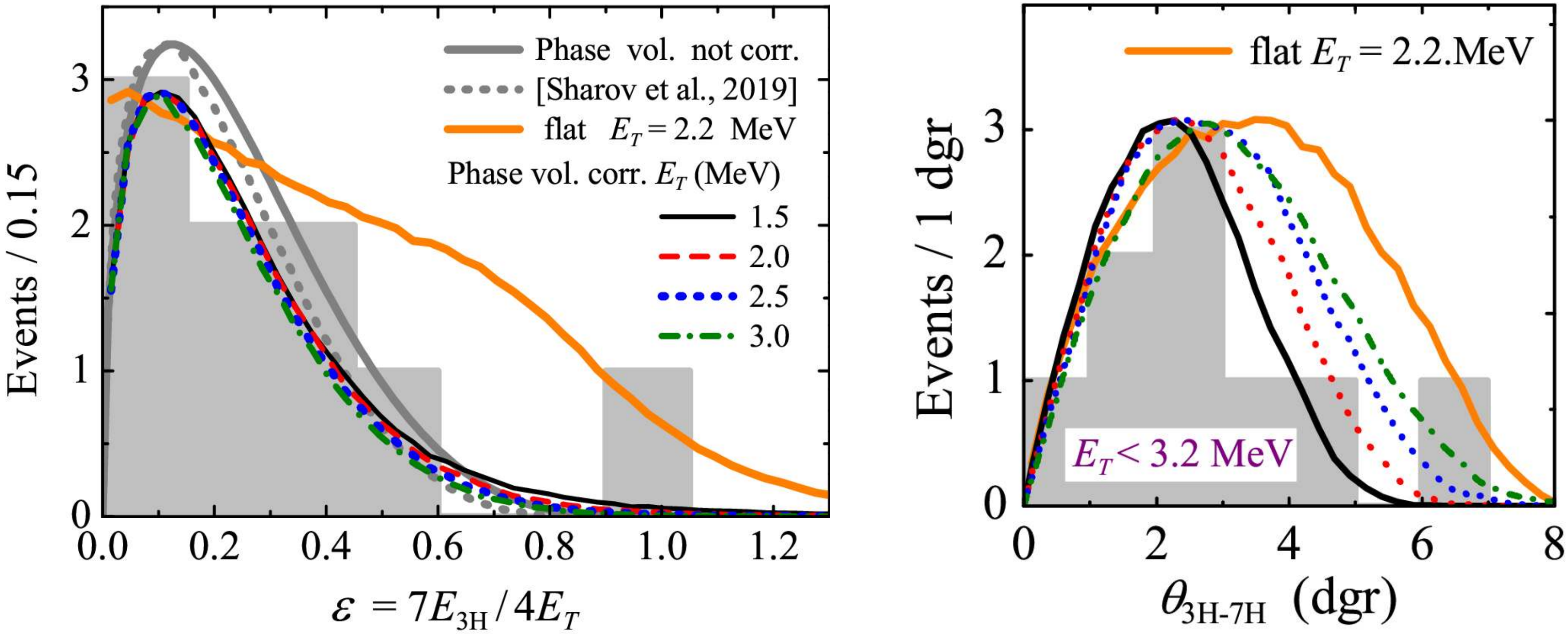


Reaction angle distributions



- Exp1 — second diffraction maximum is populated for the ^{7}H g.s.
- Exp2 planned to populate the forward peak for the ^{7}H g.s.
- gap in the data from 9 to 14 degrees observed in the second data

Energy and angular distributions of tritons



- reflection of the specific dynamics of true five-body decay
- obtained in independent way

Both patterns consistent with correlated emission of tritons expected for **true five-body** decay

Our team

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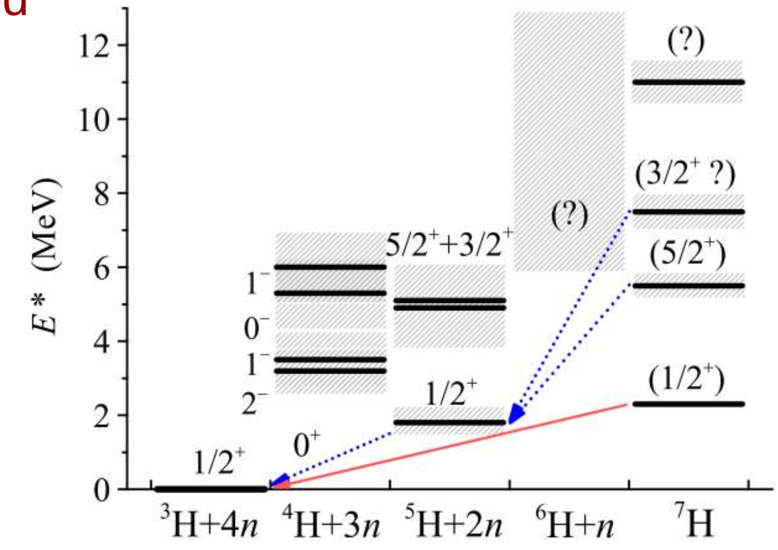
Conclusions

- A long-term problem of quest for ^{7}H g.s. investigated
- complicated experiment, extremely low cross section and low statistics



However

- consistent results from 2 independent beamtimes.
- reliable channel identification, low background, high energy resolution
- calibrations confirmed by $^{10}Be(^{2}H,^{3}He)^{9}Li$ reaction
- missing mass spectrum analysis additionally supported by
  - reaction angular distribution
  - correlated ^{3}H energy and angular distributions

Major results

- confident identification of the ^{7}H ground state at 2.2 MeV (14 events)
- identification of excited state at 5.5 (or 5.5-7.5 MeV doublet)
- true 4n decay reliably observed for the first time