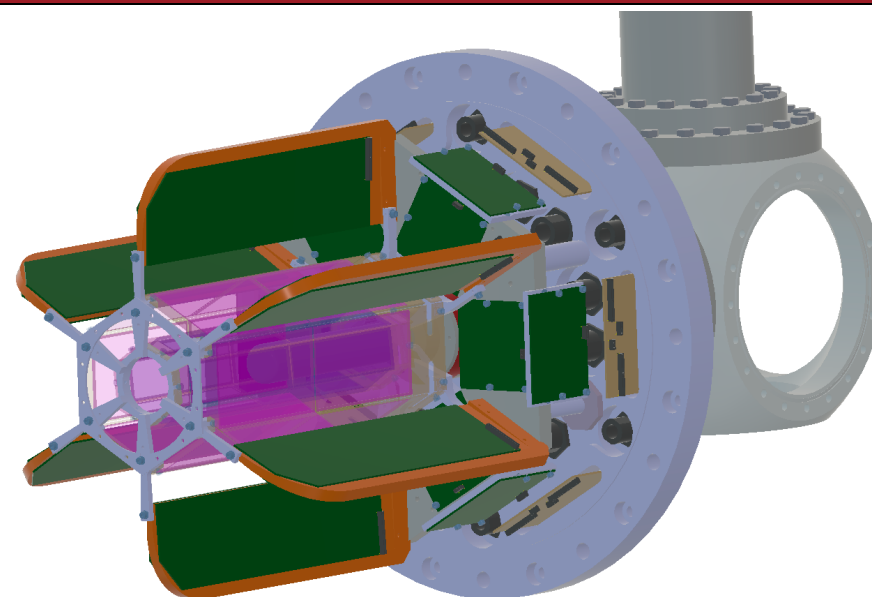


STRASSE: A silicon tracker for quasi free scattering measurement at the RIBF



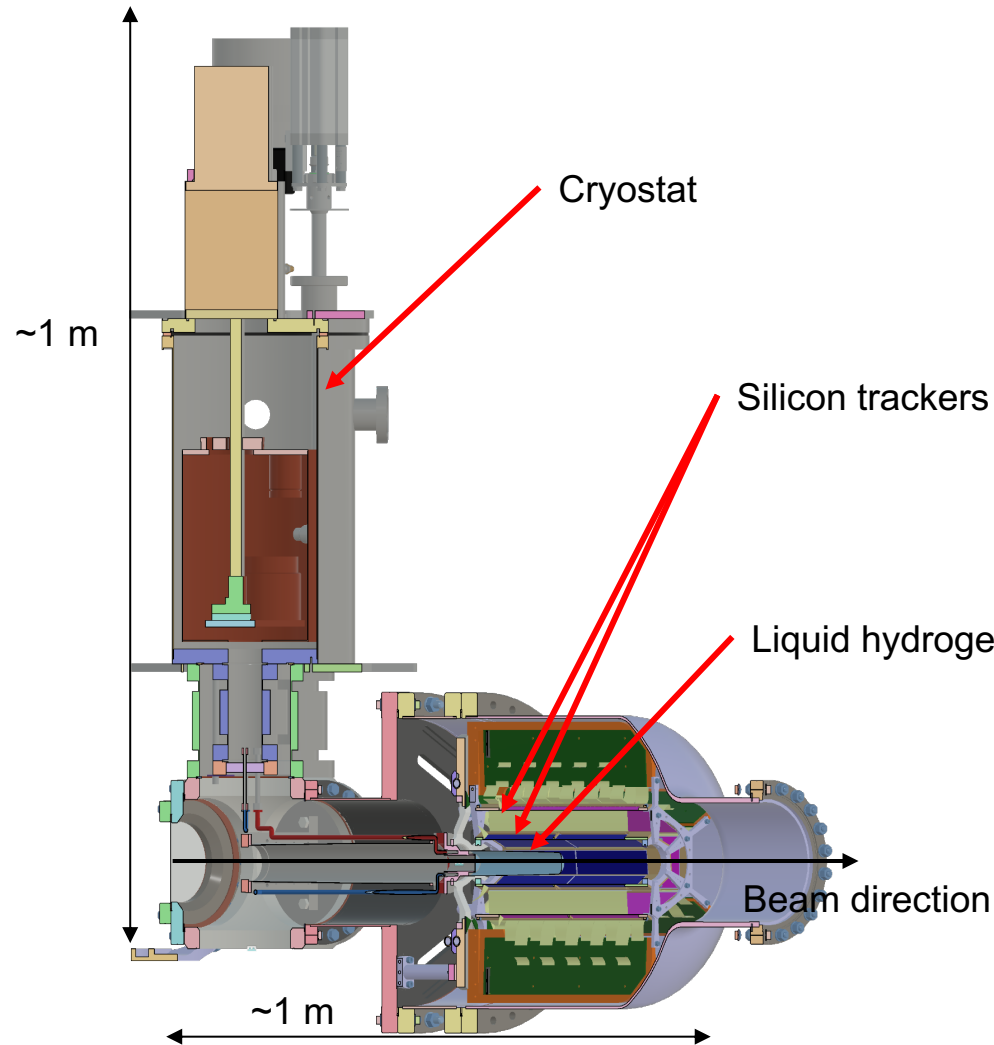
STRASSE



Valerian Alcindor, TU Darmstadt

DREB 2022

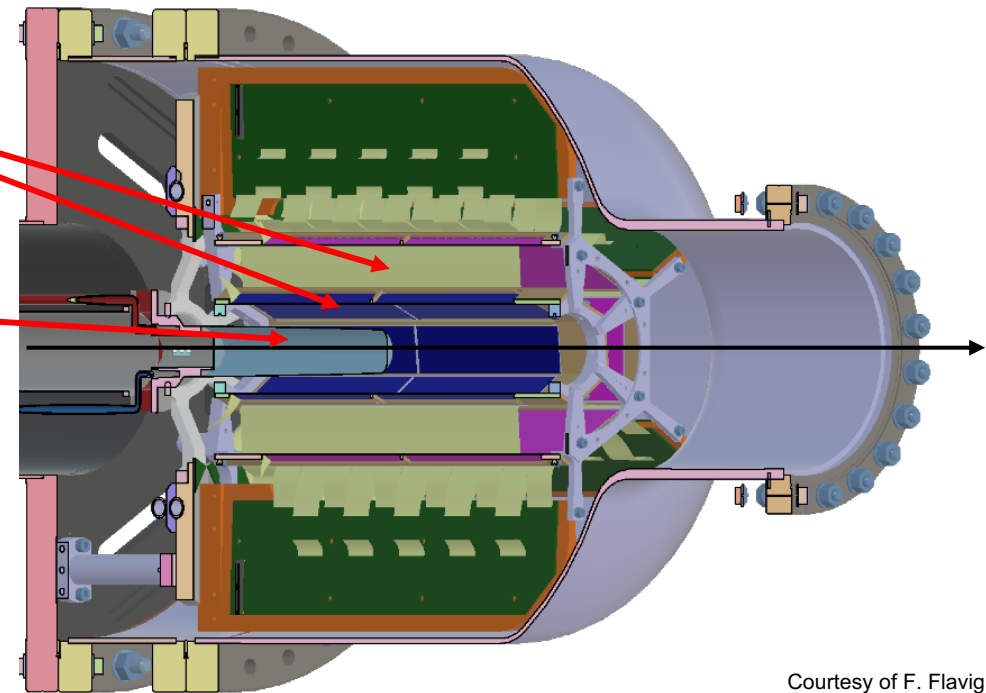
STRASSE



STRASSE: (Silicon TRacker for Spectroscopy at SAMURAI Experiments) is a device intended to be used for (p,2p) and (p,3p) reactions at RIKEN in Japan.

It consists of:

- A cryogenic target (a 150 mm thick liquid hydrogen target)
- A silicon tracker (two layers of DSSD placed inside the vacuum chamber)



Courtesy of F. Flavigny, LPC

Physics program

NP-PAC 2018 Approved:

Construction proposal:

Large-acceptance missing mass setup, CATANA PLUS and STRASSE, at SAMURAI

A. Frotscher¹, Y. Kondo², H. Liu¹, T. Nakamura^{2,*}, A. Obertelli^{1,*}, H. Otsu³, M. Sasano³,
Y. Sun¹, S. Takeuchi², Y. Togano⁴, T. Tomai², T. Uesaka³

1. Institut für Kernphysik, Technische Universität Darmstadt

2. Department of Physics, Tokyo Institute of Technology

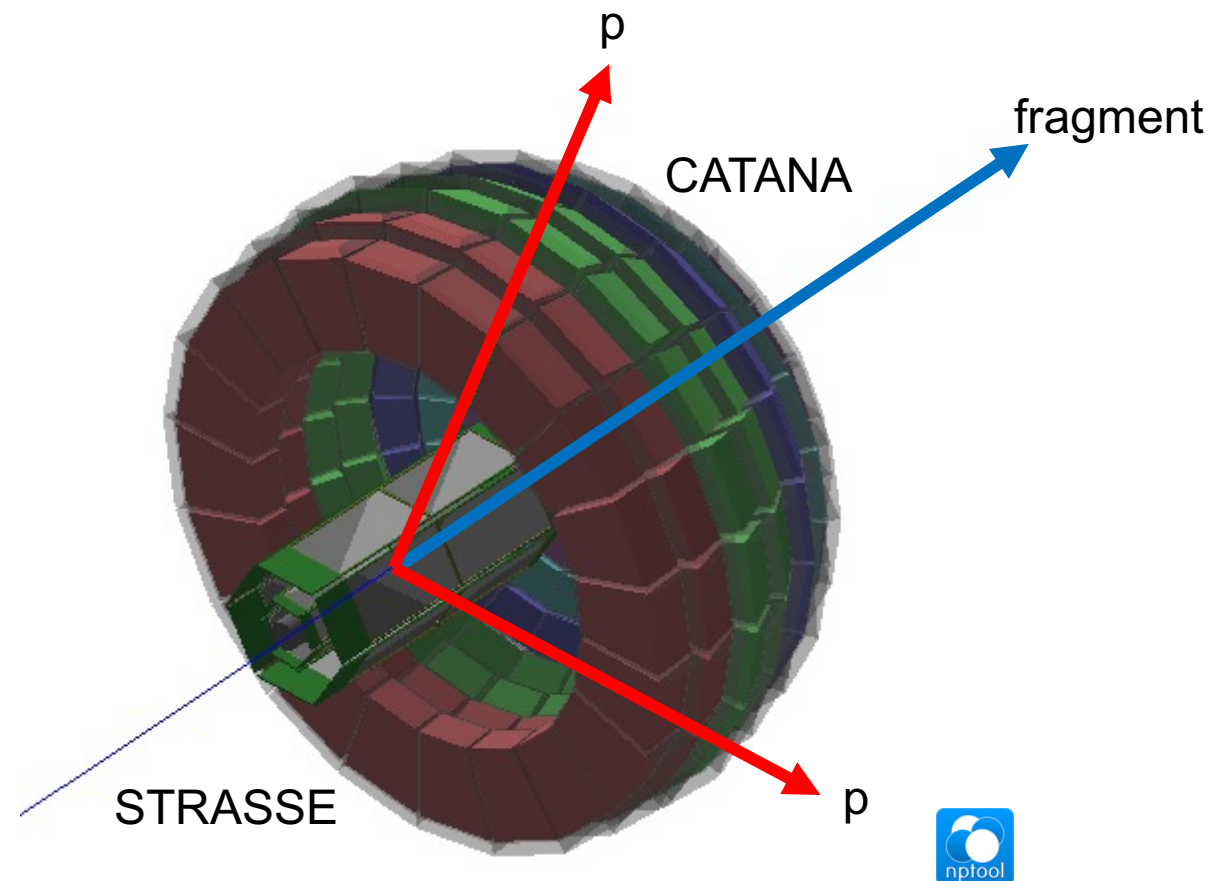
3. RIKEN Nishina Center

4. Department of Physics, Rikkyo University

* Spokespersons

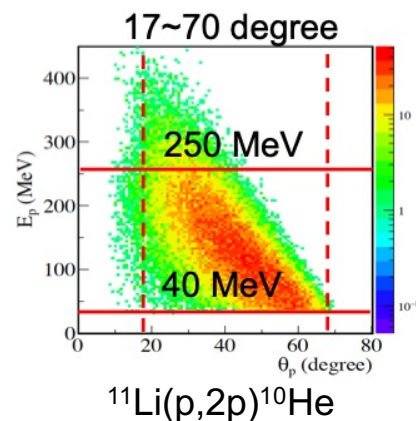
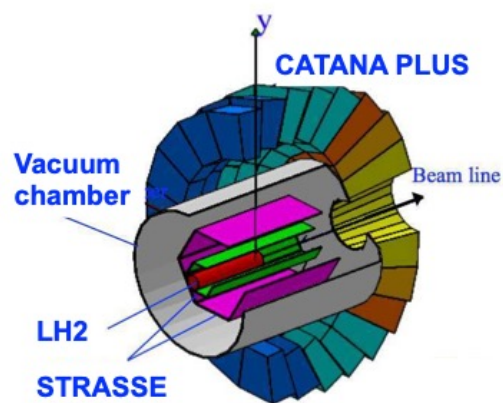
Objectives:

- Missing mass spectroscopy
- Missing mass + gamma-ray spectroscopy



Physics program

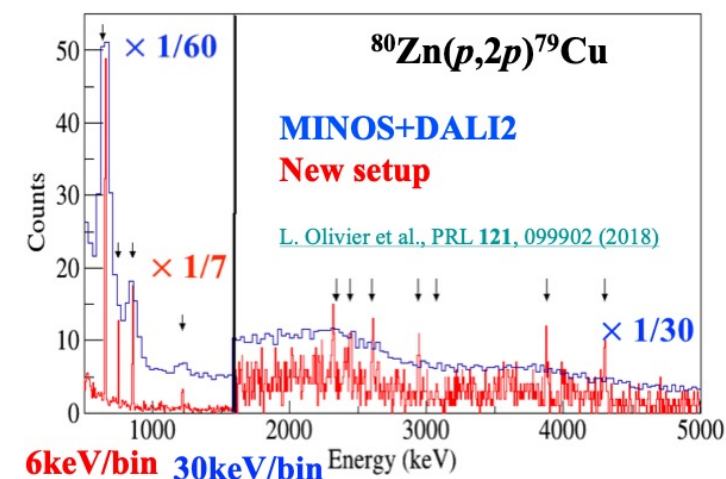
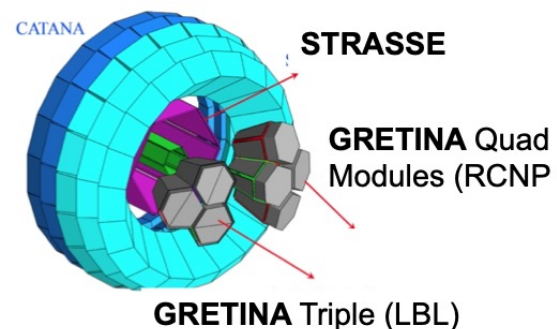
Missing mass spectroscopy:



STRASSE + CATANA+:

- Vertex resolution < 1 mm
- Angular resolution < 1°
- Missing mass energy resolution:
 - LH₂ target: < 2 MeV
- 1p efficiency ~ 85%
- 2p efficiency ~ 55%

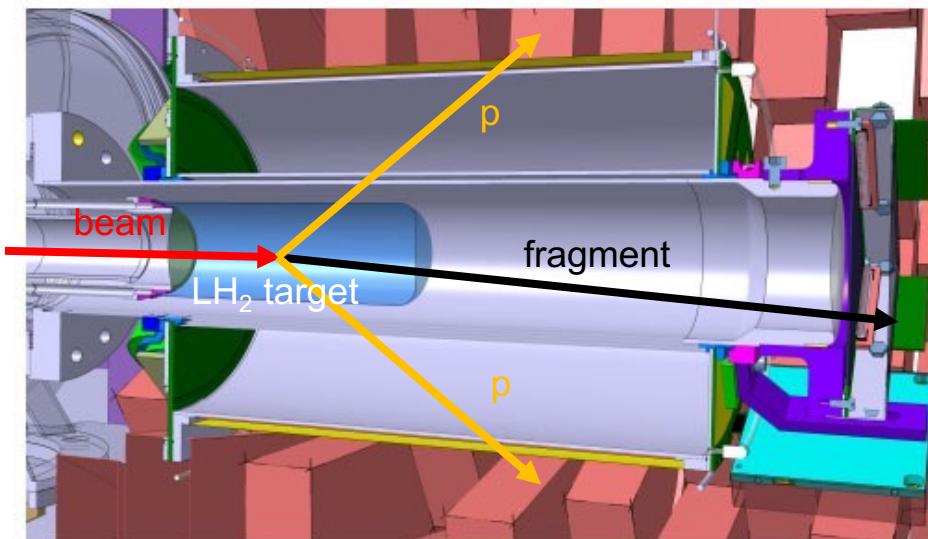
High resolution γ -ray spectroscopy:



STRASSE + GRETINA:

- Vertex resolution < 1 mm
- Angular resolution < 1°
- Energy resolution ~ 0.6% @ 1 MeV
- 1p efficiency ~ 85%
- Photopeak efficiency ~ 2%
- Possible gate on Ex from missing mass for background removal

Need for a new system



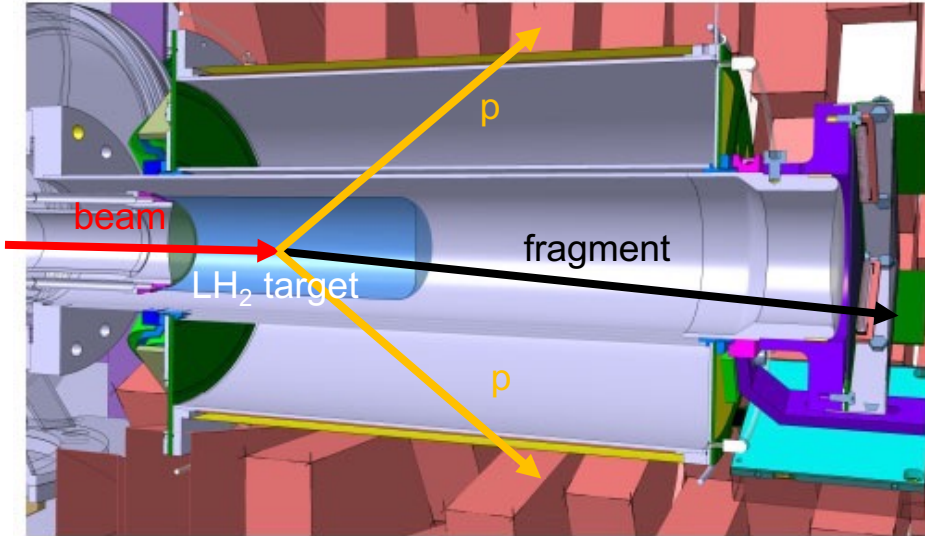
A. Obertelli et al. - Eur. Phys. J. A (2014) 50: 8

Pros of thick LH₂ target + tracker:

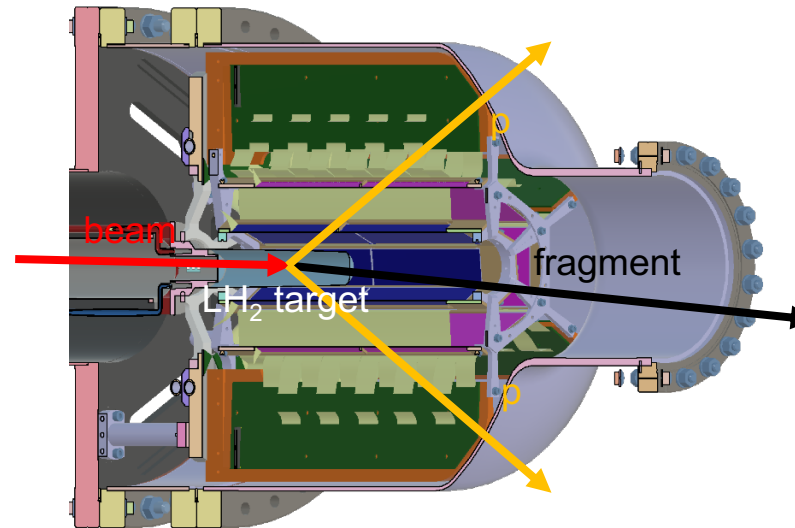
- Improved luminosities
- No carbon background
- Improved energy resolution (vertex)

| | MINOS |
|-------------------------------|-------------------------|
| LH ₂ target radius | 26 mm |
| Detector type | TPC |
| Vertex resolution | 4.5 mm |
| Missing mass resolution | 6 MeV (no missing mass) |
| γ-ray resolution at 1 MeV | 10% (MINOS + DALI2) |
| Trigger rate limit | 1 kHz |

Need for a new system



A. Obertelli et al. - Eur. Phys. J. A (2014) 50: 8

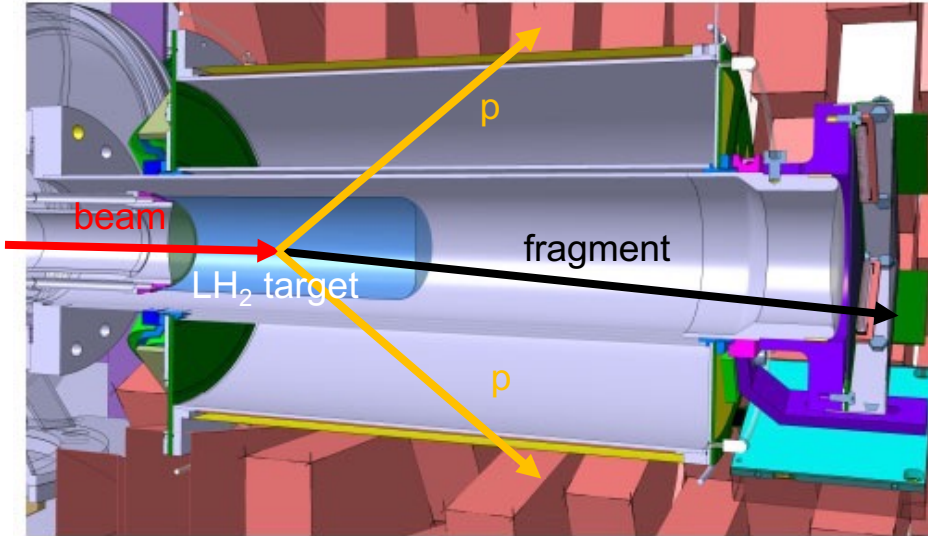


Pros of thick LH_2 target + tracker:

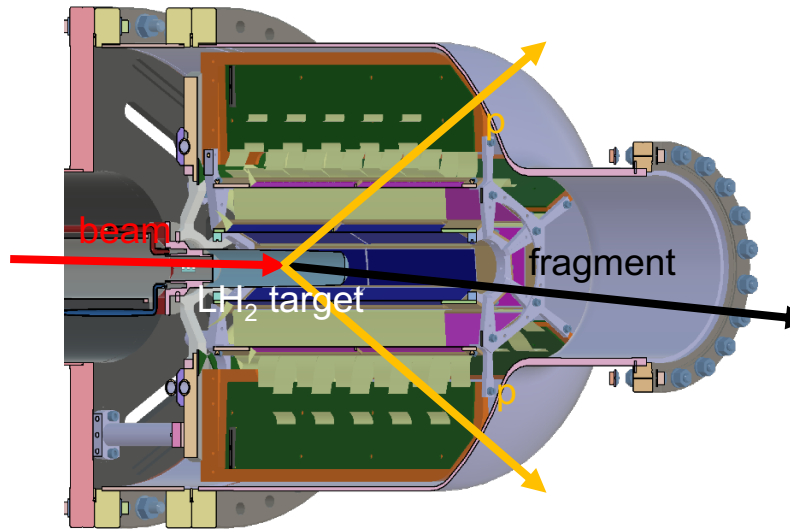
- Improved luminosities
- No carbon background
- Improved energy resolution (vertex)

| | MINOS | STRASSE |
|-----------------------------------|-------------------------|-----------------------|
| LH ₂ target radius | 26 mm | 15.5 mm |
| Detector type | TPC | Silicon tracker |
| Vertex resolution | 4.5 mm | 0.7 mm |
| Missing mass resolution | 6 MeV (no missing mass) | 1.7 MeV |
| γ -ray resolution at 1 MeV | 10% (MINOS + DALI2) | 0.6% (STRASSE + HPGe) |
| Trigger rate limit | 1 kHz | > 100 kHz |

Need for a new system



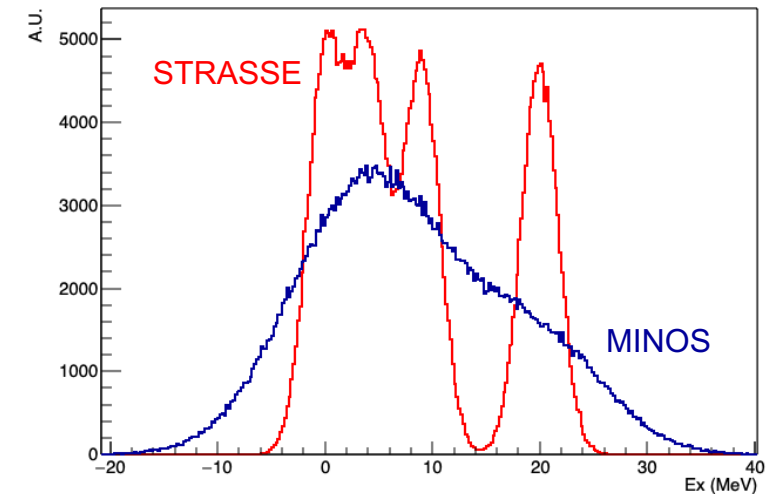
A. Obertelli et al. - Eur. Phys. J. A (2014) 50: 8



Pros of thick LH₂ target + tracker:

- Improved luminosities
- No carbon background
- Improved energy resolution (vertex)

Simulation of 0, 3, 9 and 20 MeV states for illustration



STRASSE's expected vertex resolution is > 4 times the one of MINOS!

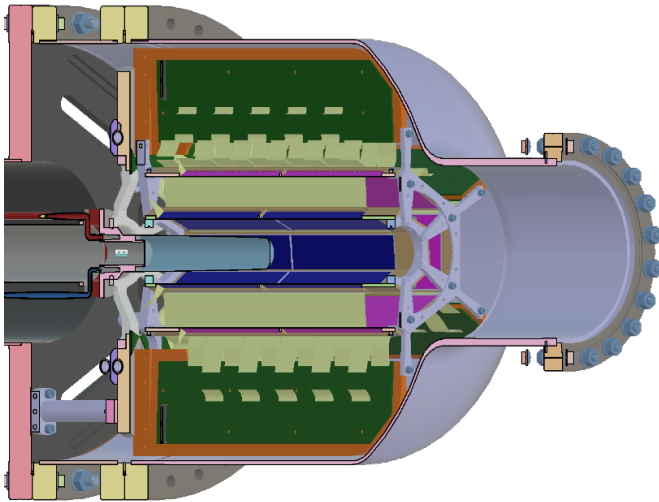
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Silicon tracker

Challenges:

- ~250 MeV protons
- Low energy loss (~150 keV in 200 μm Si)
- Threshold ~100 keV required
- Low noise electronics
- Balance energy-loss/straggling

Silicon tracker:

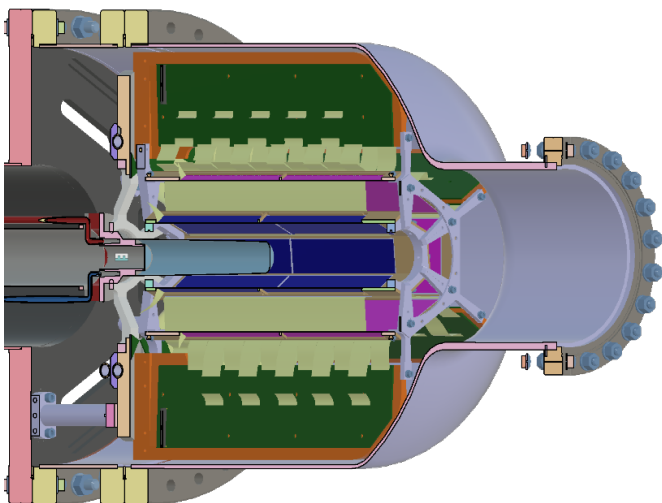


Silicon tracker

Challenges:

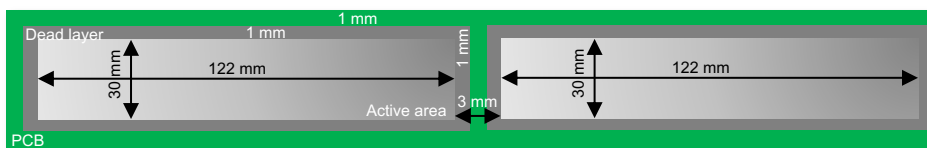
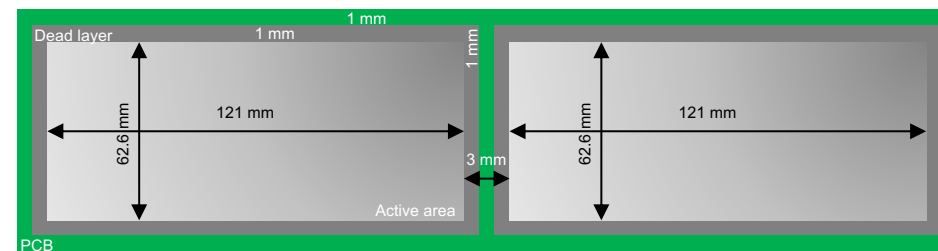
- ~250 MeV protons
- Low energy loss (~150 keV in 200 μm Si)
- Threshold ~100 keV required
- Low noise electronics
- Balance energy-loss/straggling

Silicon tracker:



Outer DSSD:

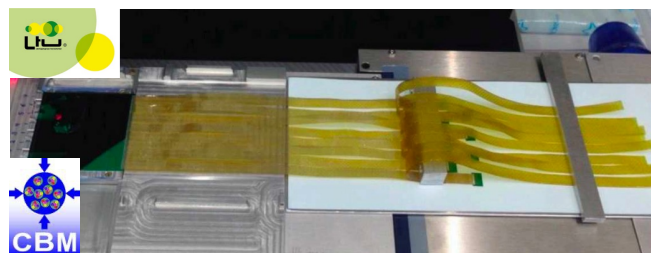
Thickness: 300 μm
Active area: 121x62.6 mm
Strips number: 605x313 strips
Strips pitch: 200 μm



Inner DSSD:

Thickness: 200 μm
Active area: 122x30 mm
Strips number: 610x150 strips
Strips pitch: 200 μm

Low mass Microcable:



10 μm thick Al on 14 μm polyamide
Low capacitance: 0.382pF/cm

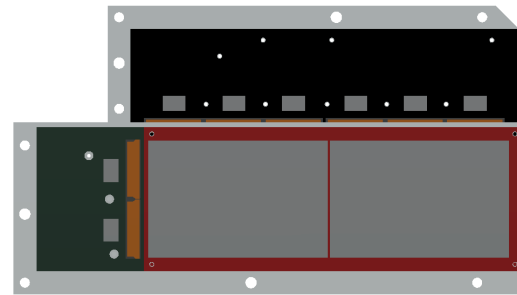
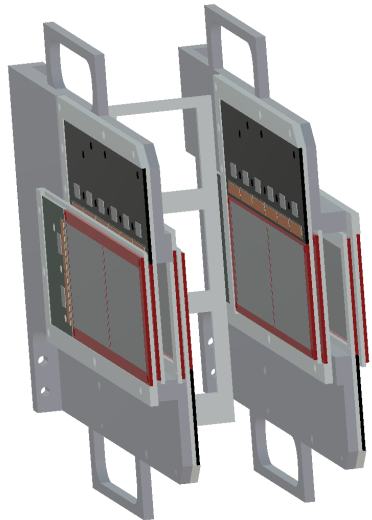
ASICS: STS-XYTER2



| | STS-XYTER2 |
|-------------------|---------------------------|
| No. of Channel | 128ch/chip |
| Energy amplitude | 5 bit Flash ADC |
| Time resolution | < 10ns, 14 bit time stamp |
| Trigger | Triggerless |
| Power consumption | 8 mW/ch |

Silicon tracker: PFAD

PFAD: Prototype For Advanced Detector

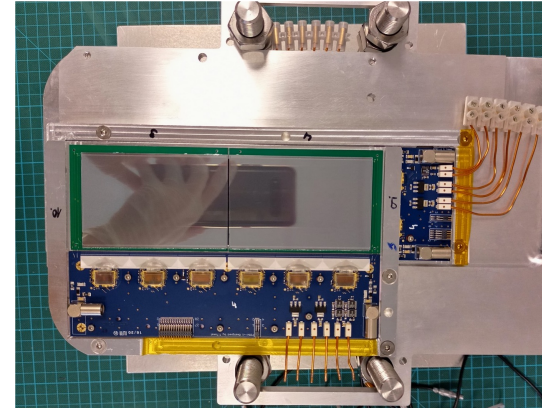
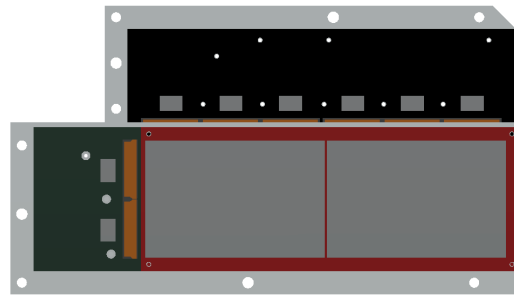
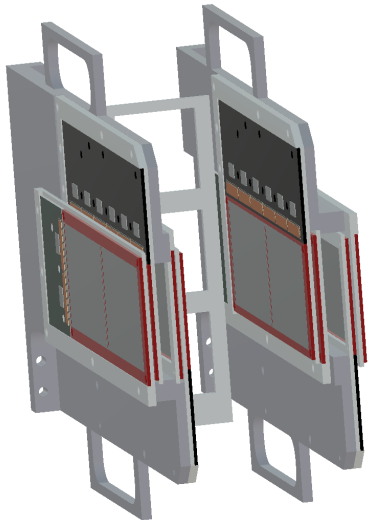


Alexander von Humboldt
Stiftung/Foundation

| | STRASSE | PFAD |
|-----------------------|------------------------------------|-----------------|
| Target | Liquid hydrogen (LH ₂) | CH ₂ |
| Number of modules | 6 | 2 |
| Detectors per modules | 2x200 μm + 2x300 μm DSSSDs | 8x100 μm SSD |
| Electronic channels | 17478 | 4054 |

Silicon tracker: PFAD

PFAD: Prototype For Advanced Detector

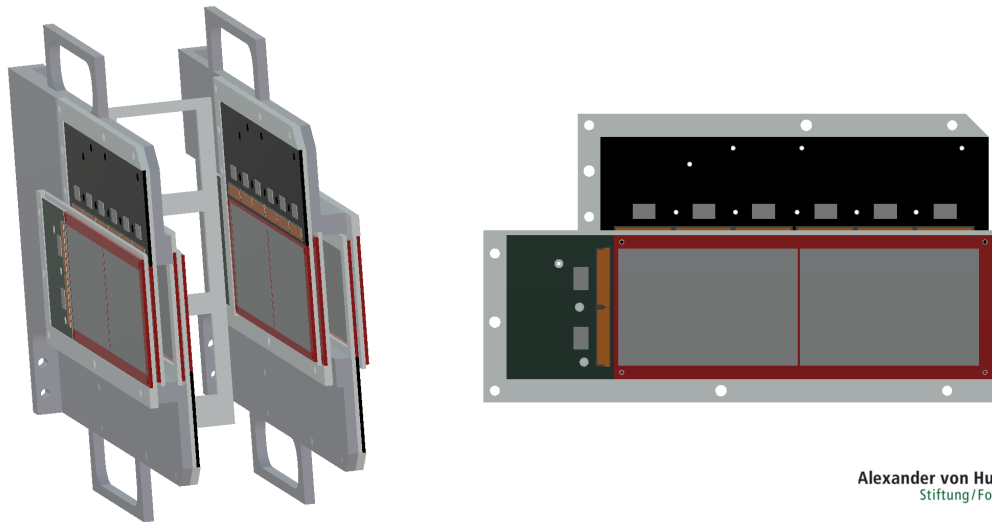


Alexander von Humboldt
Stiftung/Foundation

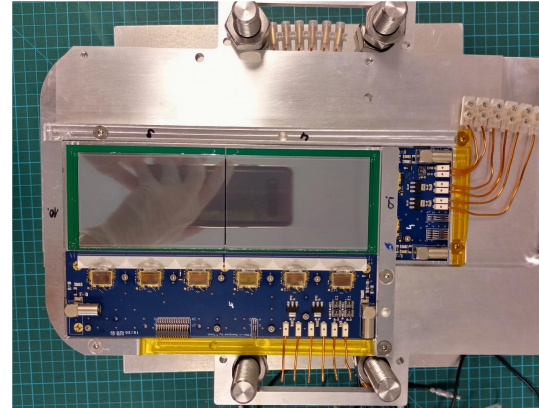
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| Detectors per modules | 2x200 μm + 2x300 μm DSSSDs | 8x100 μm SSD |
| Electronic channels | 17478 | 4054 |

Silicon tracker: PFAD

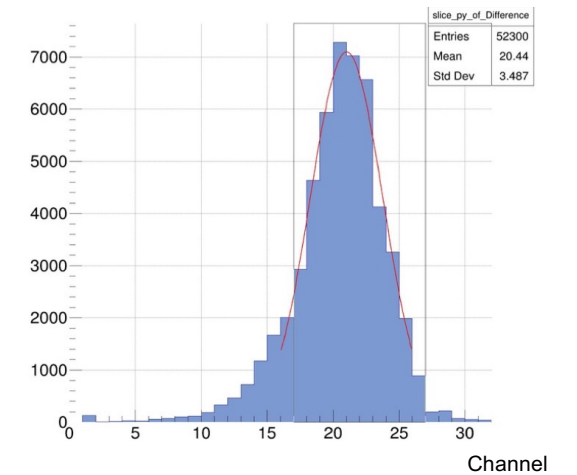
PFAD: Prototype For Advanced Detector




Alexander von Humboldt
Stiftung/Foundation



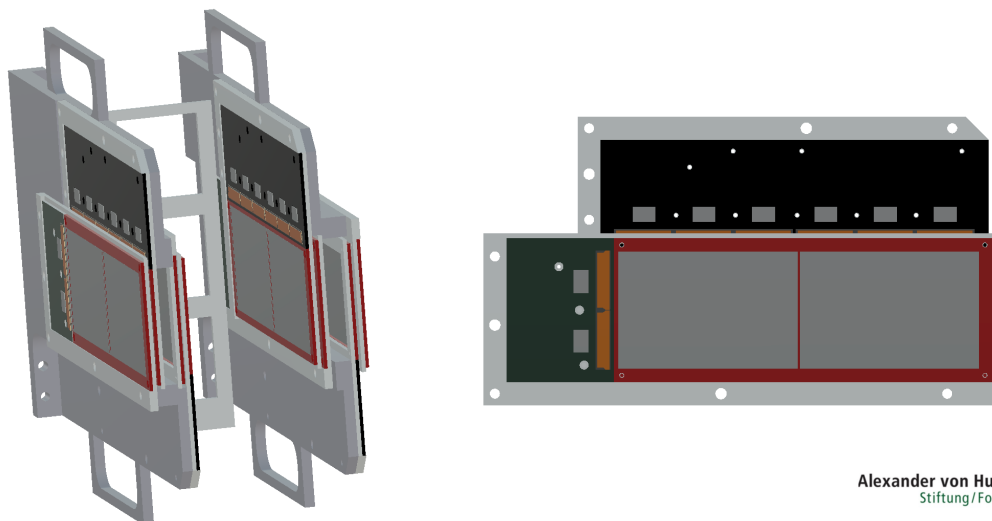
Measurement ^{241}Am 59.5 keV with FEB6



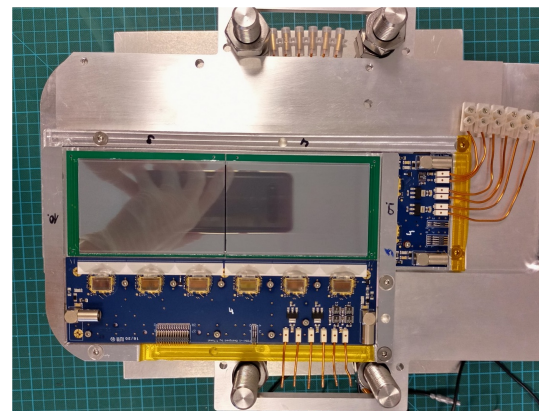
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|-----------------------|------------------------------------|-----------------|
| Target | Liquid hydrogen (LH ₂) | CH ₂ |
| Number of modules | 6 | 2 |
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| Electronic channels | 17478 | 4054 |

Silicon tracker: PFAD

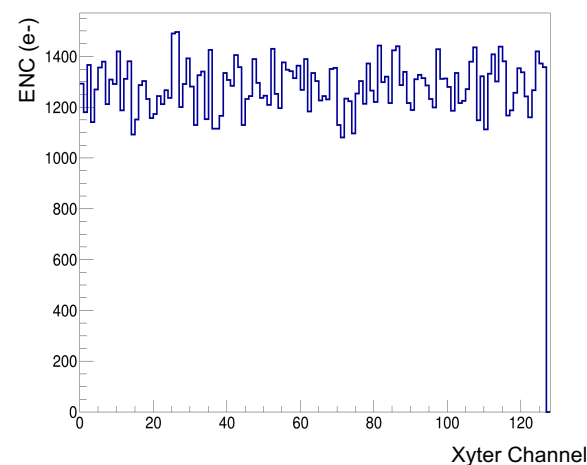
PFAD: Prototype For Advanced Detector



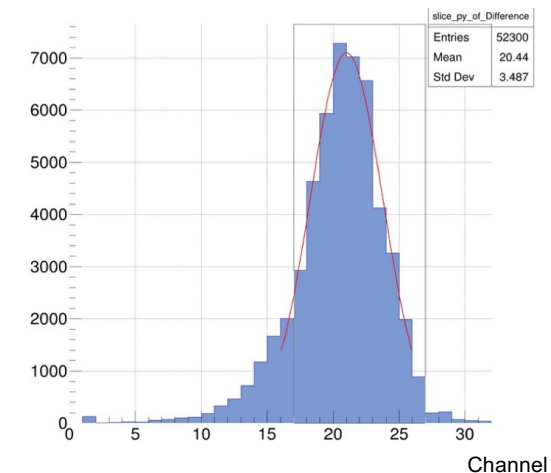

Alexander von Humboldt
Stiftung/Foundation



FEB6_4_4_ENC_scurves_scan_220416_105700.root



Measurement ^{241}Am 59.5 keV with FEB6



Noise measurement level is:

- ~10 keV FEB6
- ~20 keV FEB2

Experimental threshold x5 noise level:

- 100 keV, limited by FEB2

| | STRASSE | PFAD |
|-----------------------|--|-------------------------|
| Target | Liquid hydrogen (LH ₂) | CH ₂ |
| Number of modules | 6 | 2 |
| Detectors per modules | 2x200 μm + 2x300 μm DSSSDs | 8x100 μm SSD |
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Preliminary results

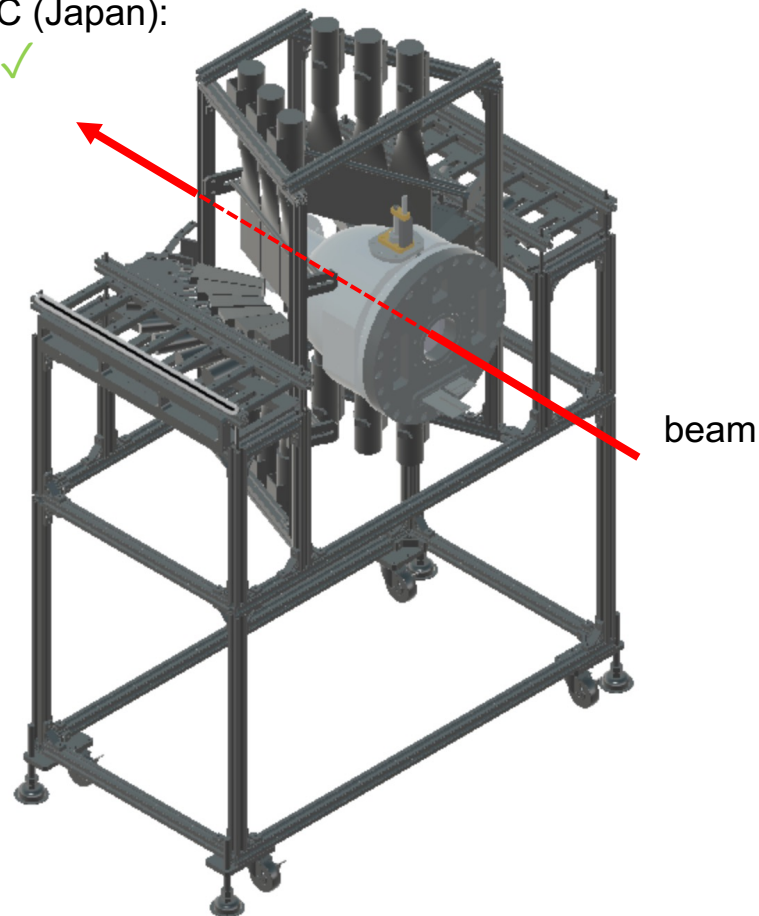
Two-fold experimental program at HIMAC (Japan):

- Commissioning of PFAD (9-11 May) ✓
- 16O(p,2p) energy systematics

Alcindor Valerian

重粒子線がん治療装置等共同利用研究課題申請書 (年度)
Proposal for Research Project with Heavy Ions at NIRS-HIMAC (FY 2021)

| | | | |
|---|--|---|--|
| *課題整理番号 Project No. | □装置共用 Date(s)/mm/dd | | 年 月 日 |
| **分類 Category | <input checked="" type="checkbox"/> 新規 New | <input type="checkbox"/> 継続2年目 2nd year | <input type="checkbox"/> 継続3年目 3rd year |
| 研究課題名 Title of Research Project | Measurement of the energy dependence of the quasi-free scattering cross section of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction from 130 MeV/u to 430 MeV/u with STRASSE | | |
| *課題申請者 Spokesperson | 氏名 Name | Alcindor Valerian | 職名 Title |
| | 所属機関名、部署名 Institution | Institut für kernphysik (IKP), TU Darmstadt | Dr. |
| 住所 Address | S214, Schlossgartenstraße 9, 64289 Darmstadt | | |
| 電話 phone: e-mail | +49 6151 16-23500 fax: +49 615116-23305 | | 放医研での身分 Status at NIRS |
| 所内対応者 Liaison at NIRS | 氏名 Name | E. Takada | 所属部署 Division |
| | 氏名 Name | | 所属 Institution |
| *研究分担者 List of Participants (Last/First/M) | V. Alcindor | TU Darmstadt | Dr. |
| | A. Oberelli | TU Darmstadt | Professor |
| | H. Liu | TU Darmstadt | Dr. |
| | M. Gomez | TU Darmstadt | Dr. |
| | T. Aumann | TU Darmstadt | Professor |
| | A. Protscher | TU Darmstadt | PHD student |
| | T. Pohl | TU Darmstadt | PHD student |
| | M. Ravar | TU Darmstadt | PHD student |
| | Y. Sun | TU Darmstadt | Dr. |
| | Y. Togano | Rikkyo University | Assistant professor |
| | T. Nakamura | TiTech | Professor |
| | Y. Kondo | TiTech | Assistant professor |
| | J. Tanaka | Riken | Dr. |
| | H. Oou | Riken | Dr. |
| | H. Wang | Riken | Dr. |
| M. Sasano | Riken | Dr. | |
| F. Flayigny | LPC Caen | Dr. | |
| A. Matta | LPC Caen | Dr. | |
| N. Orr | LPC Caen | Dr. | |
| M. Marquis | LPC Caen | Dr. | |
| J. Gibelin | LPC Caen | Dr. | |
| L. Achouri | LPC Caen | Dr. | |
| F. Delauney | LPC Caen | Dr. | |
| T. Lotko | LPC Caen | Dr. | |
| I. Plagnol | LPC Caen | PHD student | |
| 研究の目的と意義 Objective of Project | The nucleon removal from the doubly magic nucleus ^{16}O is commonly used as a benchmark for reaction mechanisms since it was well characterized via the $^{16}\text{O}(e,p)^{15}\text{N}$ reaction and because the first excited state of ^{15}N (5.27 MeV) is well separated from the ground state. Concerning (p,2p) reactions, there are currently discrepancies between cross section predictions for the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction, as consequence, there is a need for more experimental data. Especially, concerning the energy dependence of the quenching factors which has rarely been studied. In this regard, the HIMAC facility would give us a unique opportunity to study the (p,2p) reaction mechanism for a continuous range of energies from 130 MeV/u to 430 MeV/u. For this measurement, the STRASSE silicon tracker and cryogenic target system will be used together with 14 CATANA crystals to measure the energy and momentum of the two recoil protons. This will be the first in-beam experiment of STRASSE and would require a thorough testing of the electronic as well as the capability of this system to perform precise vertex reconstruction and missing mass measurements coupled to CATANA crystals. As a consequence, we propose a two steps experimental program: (i) the commissioning of STRASSE's demonstrator called PFAD with 4 CATANA crystals and (ii) the above-mentioned study of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction using the full STRASSE setup and 14 CATANA crystals. | | |



Preliminary results

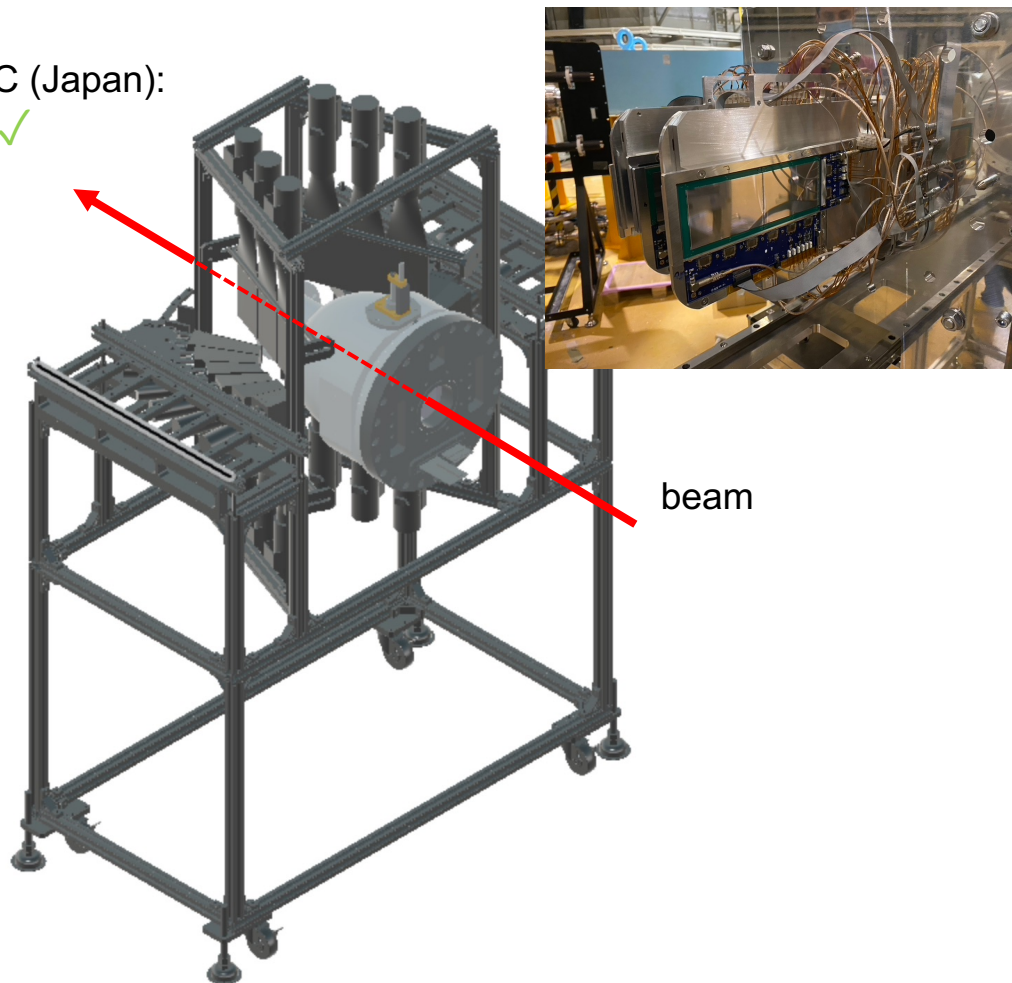
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Alcindor Valérian

重粒子線がん治療装置等共同利用研究課題申請書 (年度) 年 月 日
 Proposal for Research Project with Heavy Ions at NIRS-HIMAC (FY 2021)

| | | | |
|---|--|---|--|
| *課題整理番号 Project No. | □装置共用 Date(s)/mm/dd | | 2021/1/13 |
| **分類 Category | <input checked="" type="checkbox"/> 新規 New | <input type="checkbox"/> 継続2年目 2nd year | <input type="checkbox"/> 継続3年目 3rd year |
| 研究課題名 Title of Research Project | Measurement of the energy dependence of the quasi-free scattering cross section of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction from 130 MeV/u to 430 MeV/u with STRASSE | | |
| *課題申請者 Spokesperson | 氏名 Name | Alcindor Valérian | 職名 Title |
| | 所属機関名、部署名 Institution | Institut für kernphysik (IKP), TU Darmstadt | |
| 所内対応者 Liaison at NIRS | 氏名 Name | E. Takada | 所属部署 Division |
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beam

Preliminary results

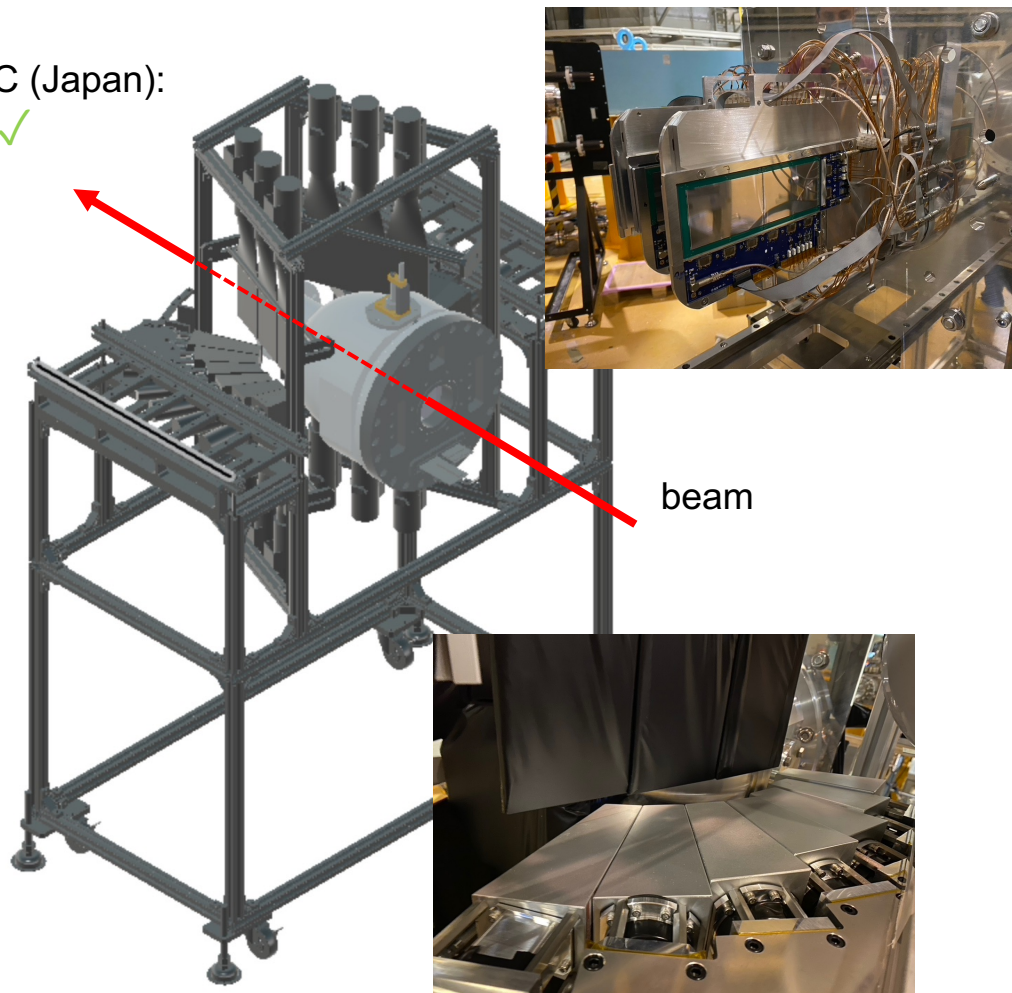
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| *1 課題整理番号 Project No. | □装置共用 Date (y/m/d) | | 2021/1/13 |
| *2 分類 Category | <input checked="" type="checkbox"/> 新規 <input type="checkbox"/> 継続2年目 <input type="checkbox"/> 継続3年目 <input type="checkbox"/> 4年目新規 | <input type="checkbox"/> 治療・診断 <input type="checkbox"/> 生物 <input checked="" type="checkbox"/> 物理・工学 | |
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| *3 課題申請者 Spokesperson | 氏名 Name | Alcindor Valérian | 職名 Title |
| | Dr. | | |
| 所属機関名、部署名 Institution | Institut für kernphysik (IKP), TU Darmstadt | | |
| | S214, Schlossgartenstraße 9, 64289 Darmstadt | | |
| 住所 Address | | | |
| | 電話 phone: +49 6151 16-23500 | fax: +49 615116-23305 | 研究での身分 Status at NIRS |
| *4 研究分担者 List of Participants (LastFirstM) | 氏名 Name | E. Takada | 所属 Institution |
| | Accelerator & Medical Physics | | 内線 no. Status at NIRS |
| *5 研究の目的と意義 Objective of Project | 氏名 Name | | 所属 Institution |
| | V. Alcindor | TU Darmstadt | Dr. Professor |
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| | Y. Sun | TU Darmstadt | Dr. |
| | Y. Togano | Rikkyo University | Assistant professor |
| | T. Nakamura | TTTech | Professor |
| | Y. Kondo | TTTech | Assistant professor |
| | J. Tanaka | Riken | Dr. |
| | H. Ono | Riken | Dr. |
| H. Wang | Riken | Dr. | |
| M. Sasano | Riken | Dr. | |
| F. Flaugigny | LPC Caen | Dr. | |
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| T. Lotko | LPC Caen | Dr. | |
| I. Plagnol | LPC Caen | PHD student | |
| <p>The nucleon removal from the doubly magic nucleus ^{16}O is commonly used as a benchmark for reaction mechanisms since it was well characterized via the $^{16}\text{O}(e,p)^{15}\text{N}$ reaction and because the first excited state of ^{15}N (5.27 MeV) is well separated from the ground state. Concerning (p,2p) reactions, there are currently discrepancies between cross section predictions for the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction, as consequence, there is a need for more experimental data. Especially, concerning the energy dependence of the quenching factors which has rarely been studied. In this regard, the HIMAC facility would give us a unique opportunity to study the (p,2p) reaction mechanism for a continuous range of energies from 130 MeV/u to 430 MeV/u. For this measurement, the STRASSE silicon tracker and cryogenic target system will be used together with 14 CATANA crystals to measure the energy and momentum of the two recoil protons. This will be the first in-beam experiment of STRASSE and would require a thorough testing of the electronic as well as the capability of this system to perform precise vertex reconstruction and missing mass measurements coupled to CATANA crystals. As a consequence, we propose a two steps experimental program: (i) the commissioning of STRASSE's demonstrator called PFAD with 4 CATANA crystals and (ii) the above-mentioned study of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction using the full STRASSE setup and 14 CATANA crystals.</p> | | | |



Preliminary results

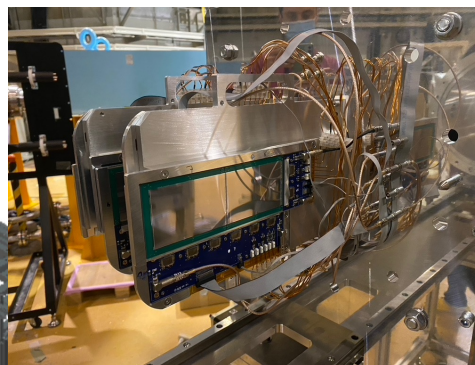
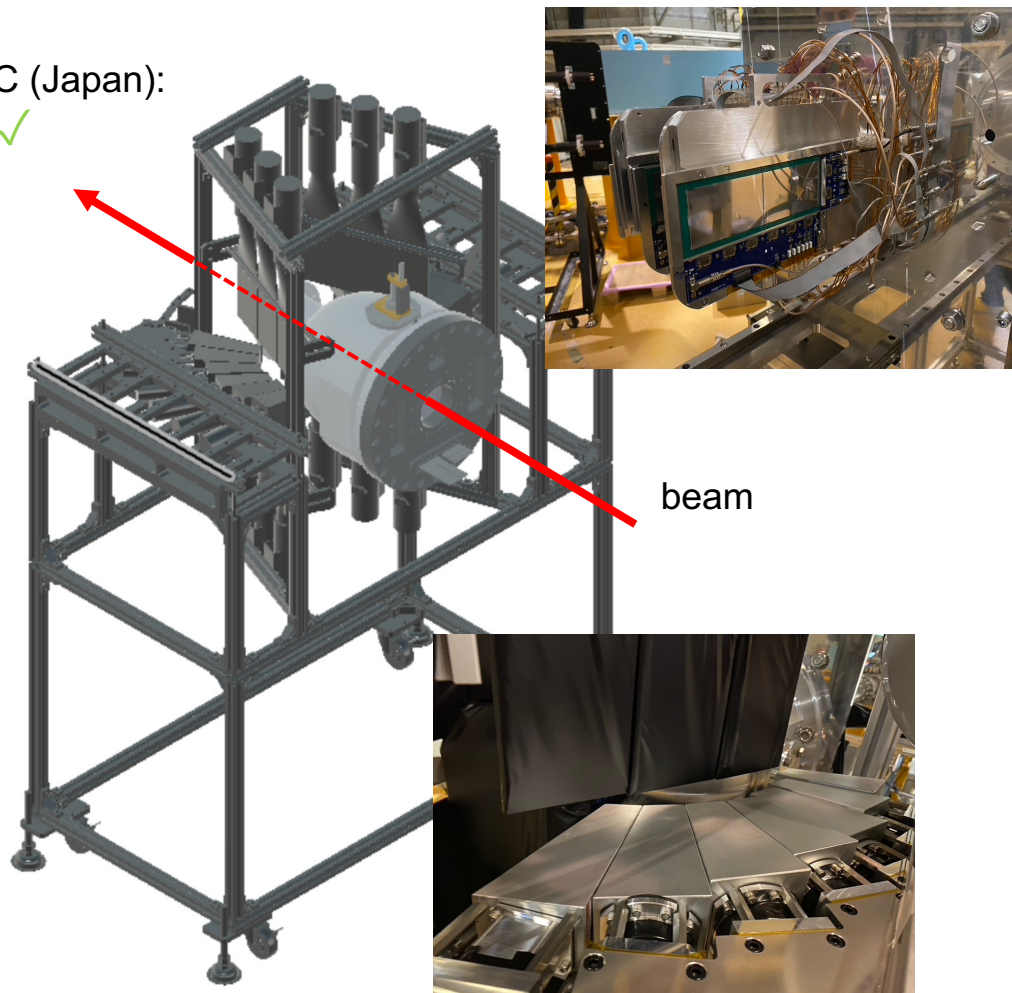
Two-fold experimental program at HIMAC (Japan):

- Commissioning of PFAD (9-11 May) ✓
- 16O(p,2p) energy systematics

Alcindor Valerian

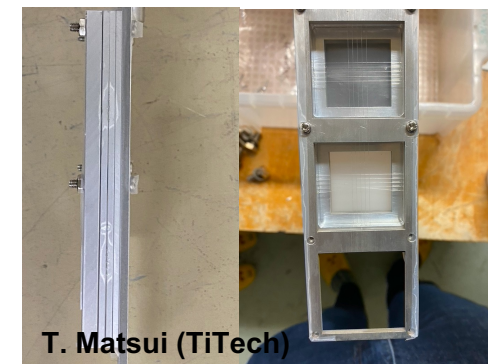
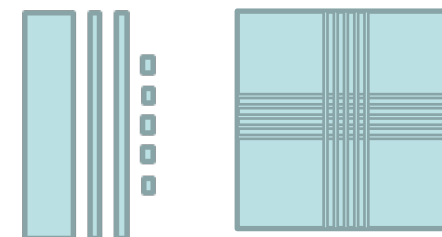
重粒子線がん治療装置等共同利用研究課題申請書 (年度)
Proposal for Research Project with Heavy Ions at NIRS-HIMAC (FY 2021)

| | | | | |
|------------------------------------|--|--------------------------------|--------------------------------|--------------------------------|
| *課題整理番号 Project No. | □装置共用 | | Date(s)/mm/dd | 年 月 日 |
| *分類 Category | <input checked="" type="checkbox"/> 新規 | <input type="checkbox"/> 継続2年目 | <input type="checkbox"/> 継続3年目 | <input type="checkbox"/> 4年目新規 |
| 研究課題名 Title of Research Project | Measurement of the energy dependence of the quasi-free scattering cross section of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction from 130 MeV/u to 430 MeV/u with STRASSE | | | |
| *課題申請者 Spokesperson | 氏名 Name | Alcindor Valerian | 職名 Title | Dr. |
| 所属機関名、部署名 Institution: | Institut für kernphysik (IKP), TU Darmstadt | | | |
| 住所 Address | S214, Schlossgartenstraße 9, 64289 Darmstadt | | | |
| 電話 phone: | +49 6151 16-23500 | | ファクス fax: | +49 615116-23305 |
| e-mail | | | | |
| 研究の目的と意義 Objective of Project | The nucleon removal from the doubly magic nucleus ^{16}O is commonly used as a benchmark for reaction mechanisms since it was well characterized via the $^{16}\text{O}(e,p)^{15}\text{N}$ reaction and because the first excited state of ^{15}N (5.27 MeV) is well separated from the ground state. Concerning (p,2p) reactions, there are currently discrepancies between cross section predictions for the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction, as consequence, there is a need for more experimental data. Especially, concerning the energy dependence of the quenching factors which has rarely been studied. In this regard, the HIMAC facility would give us a unique opportunity to study the (p,2p) reaction mechanism for a continuous range of energies from 130 MeV/u to 430 MeV/u. For this measurement, the STRASSE silicon tracker and cryogenic target system will be used together with 14 CATANA crystals to measure the energy and momentum of the two recoil protons. This will be the first in-beam experiment of STRASSE and would require a thorough testing of the electronic as well as the capability of this system to perform precise vertex reconstruction and missing mass measurements coupled to CATANA crystals. As a consequence, we propose a two steps experimental program: (i) the commissioning of STRASSE's demonstrator called PFAD with 4 CATANA crystals and (ii) the above-mentioned study of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction using the full STRASSE setup and 14 CATANA crystals. | | | |



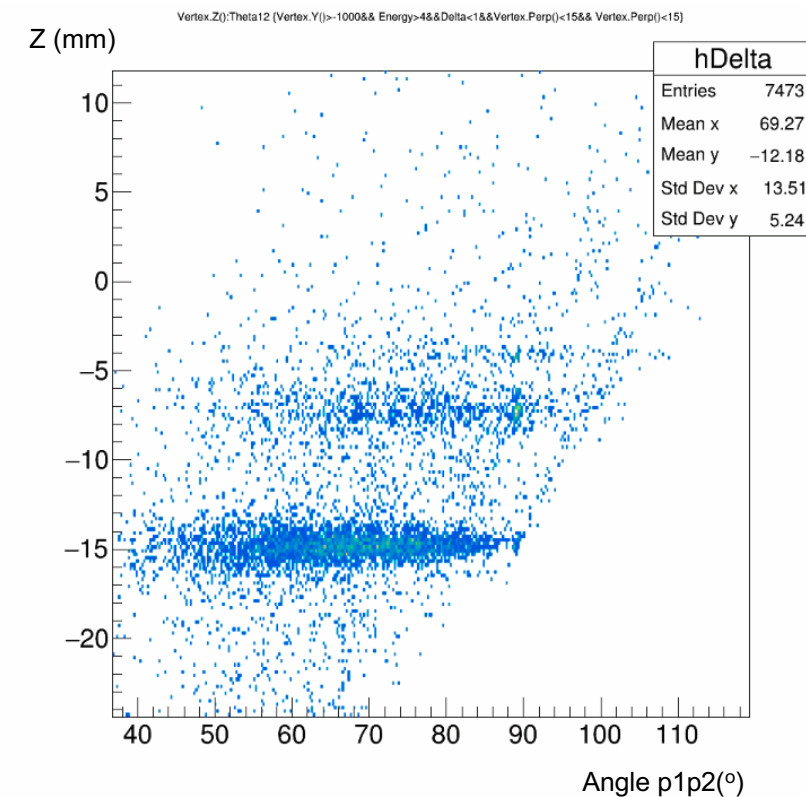
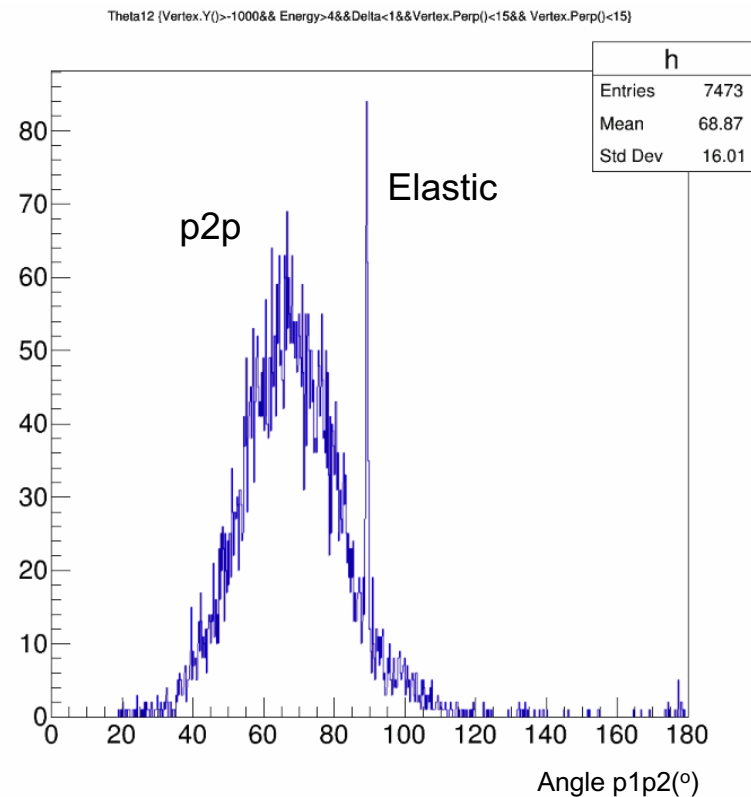
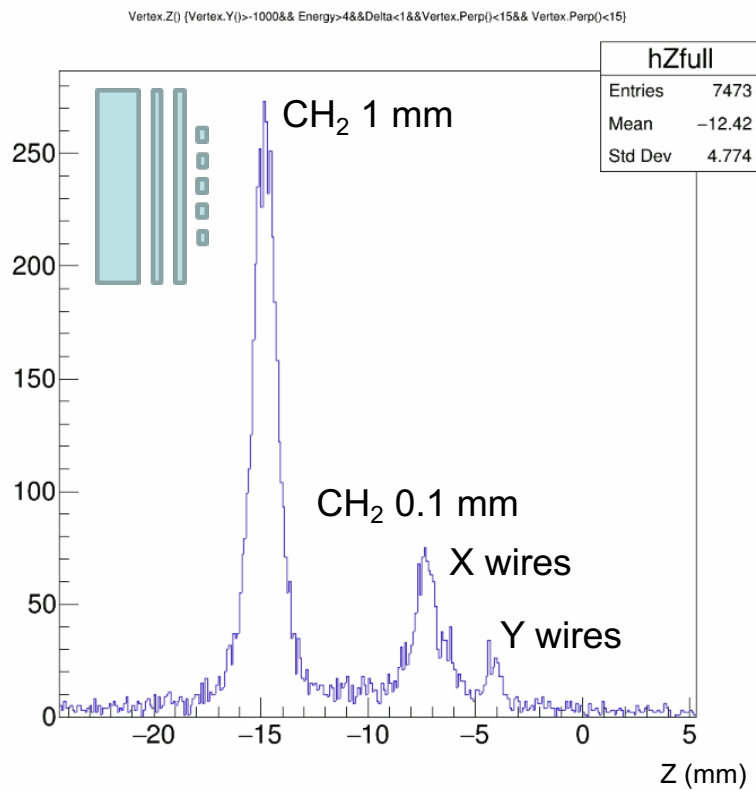
beam

CH2 1mm + 0.1mm + XY wires

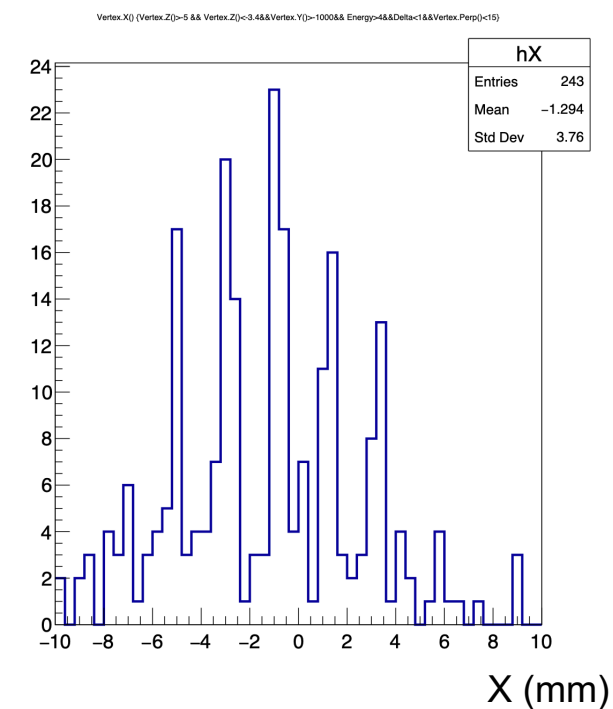
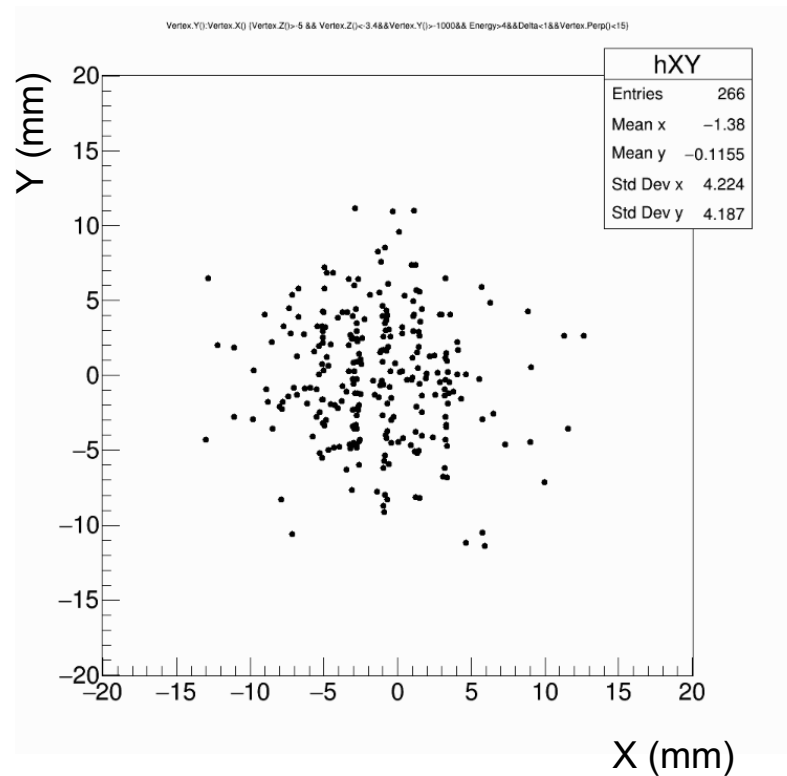
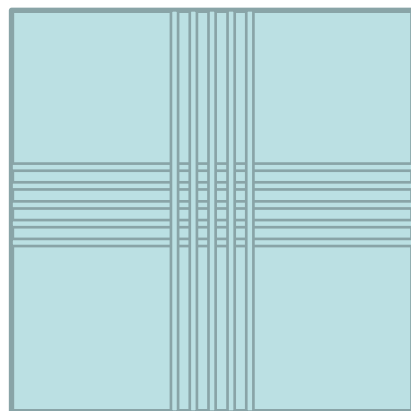


T. Matsui (TiTech)

Preliminary results



Preliminary results



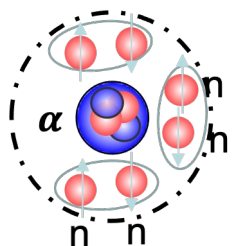
- 0.25 mm wires separated by 1 mm
- Sub-mm resolution achieved!

Upcoming experiments

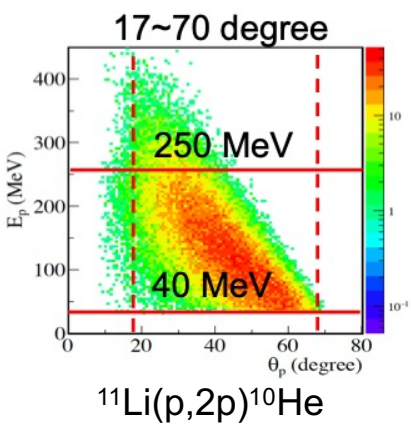
PFAD at RIBF-RIKEN (Japan):

Multi-neutron $4n$ and $6n$ states in extremely neutron rich nuclei beyond the neutron drip line

Spokesperson: T. Nakamura and T. Tomai

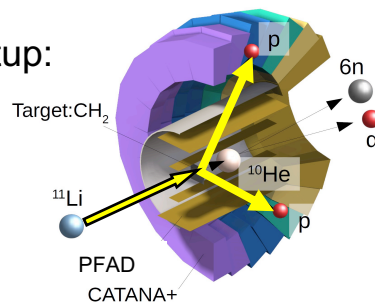


Following Ikeda's conjecture for alpha cluster states, $2n$, $4n$ and $6n$ cluster states are expected in ^{10}He



Experimental setup:

- PFAD
- CATANA+
- SAMURAI
- NEBULA



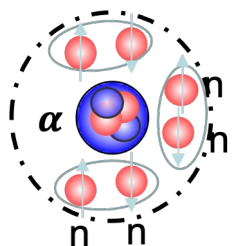
| | Invariant mass | Missing mass |
|------------|--------------------|--------------|
| Variables | $4n + \text{Frag}$ | Beam + $2p$ |
| Efficiency | ~ 1 % | ~ 50 % |
| Resolution | ~ 250 keV | ~ 2 MeV |

Upcoming experiments

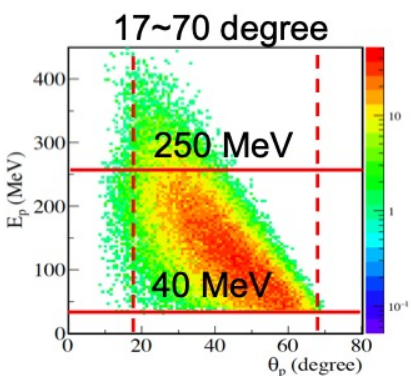
PFAD at RIBF-RIKEN (Japan):

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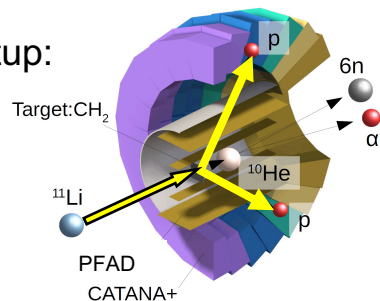
Following Ikeda's conjecture for alpha cluster states, $2n$, $4n$ and $6n$ cluster states are expected in ^{10}He



$^{11}\text{Li}(p,2p)^{10}\text{He}$

Experimental setup:

- PFAD
- CATANA+
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- NEBULA

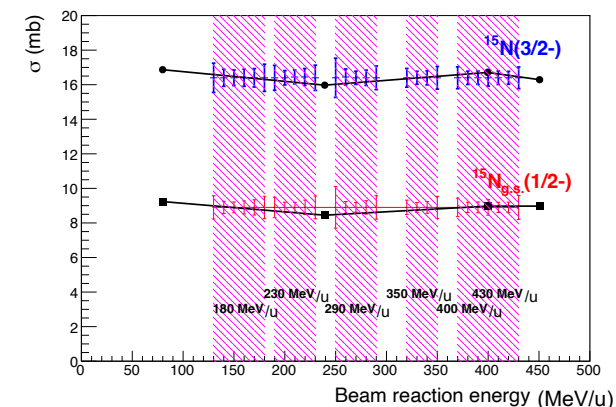
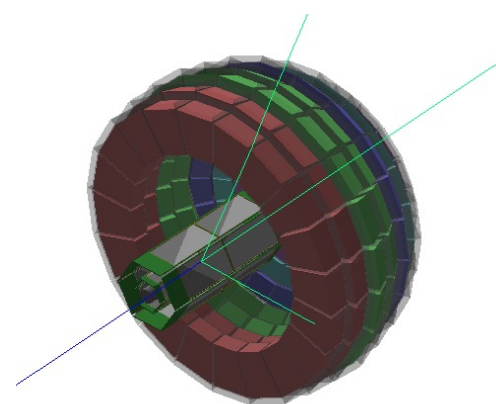


| | Invariant mass | Missing mass |
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STRASSE at HIMAC:

Measurement of the energy dependence of the quasi-free scattering cross section of the $^{16}\text{O}(p,2p)^{15}\text{N}$ reaction from 130 MeV/u to 430 MeV/u with STRASSE

Spokesperson: V. Alcindor

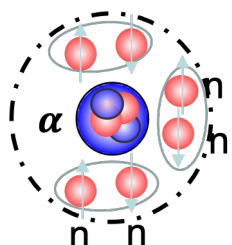


Upcoming experiments

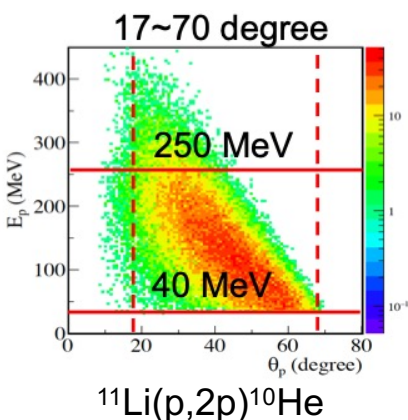
PFAD at RIBF-RIKEN (Japan):

Multi-neutron $4n$ and $6n$ states in extremely neutron rich nuclei beyond the neutron drip line

Spokesperson: T. Nakamura and T. Tomai

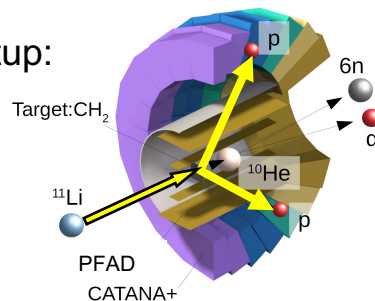


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Experimental setup:

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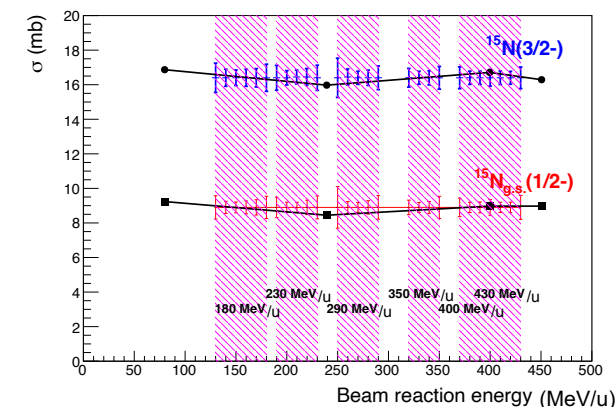
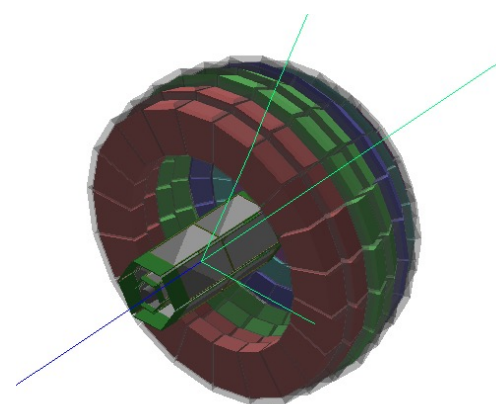


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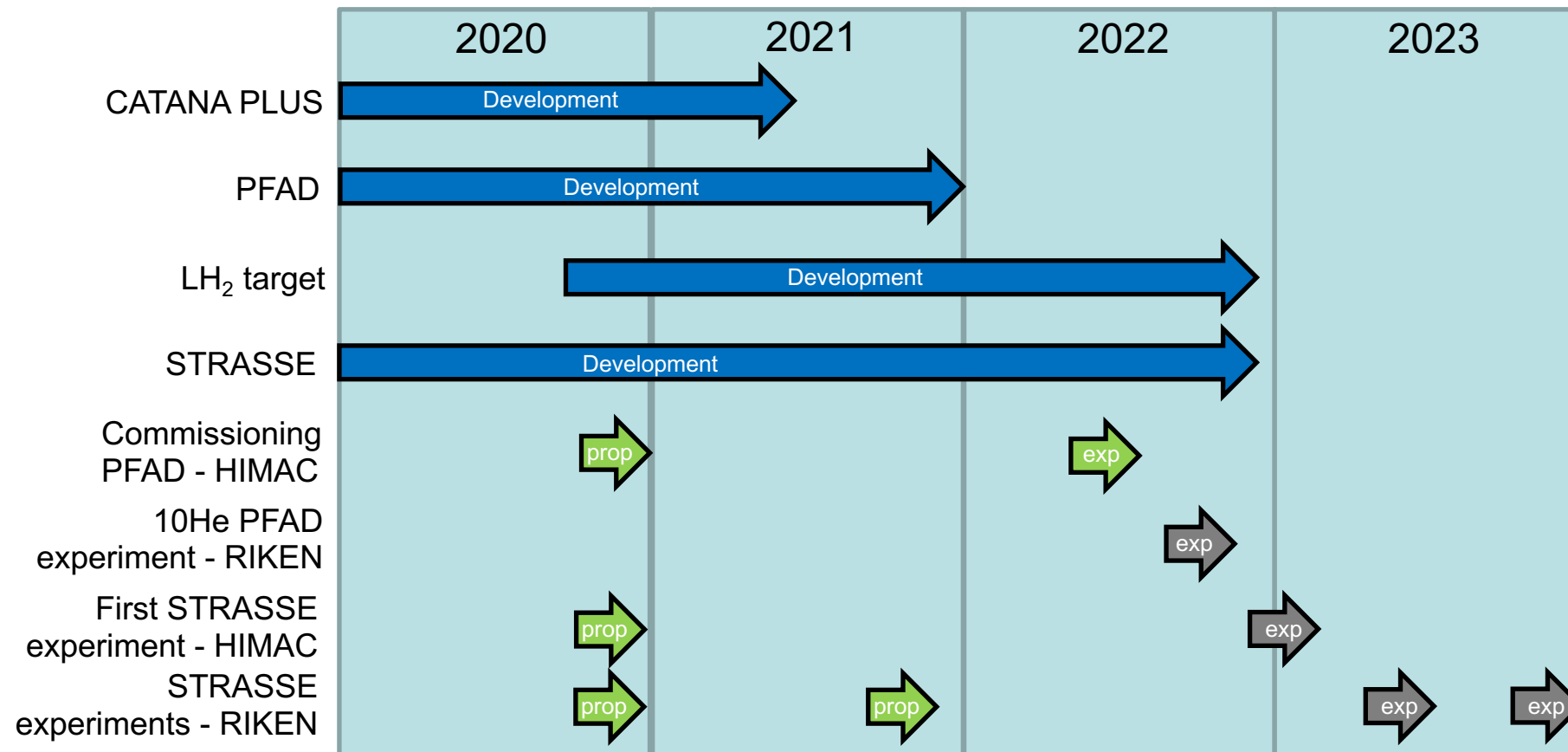
Spokesperson: V. Alcindor



STRASSE at RIBF-RIKEN (Japan):

- Momentum distribution of deeply-bound nucleons, A. Obertelli et al.
- Search for the 0^+_2 state in doubly-magic nucleus ^{54}Ca , H. Liu et al.

Timeline



Collaborators



- **TU Darmstadt** (Germany): V. Alcindor, A. Frotscher, A. Obertelli, T. Pohl, M. Enciu



- **GSI** (Germany): J. Heuser, R. Kapell, J. Lehnert, C. Schmidt, C. Simons



- **TU München** (Germany): R. Gernhäuser, B. Michael



- **LPC** (France): F. Flavigny, D. Goupillière, A. Matta



- **TiTech** (Japan): K. Horikawa, K. Isobe, Y. Kondo, H. Lee, T. Matsui, T. Nakamura, Y. Satou



- **RIKEN** (Japan): P. Doornenbal, H. Otsu, M. Sasano, J. Tanaka, Y. Togano T. Uesaka, H. Wang



- **Rikkyo** (Japan): Takeshige S.



- **Beijing Normal University** (China): H. Liu

