



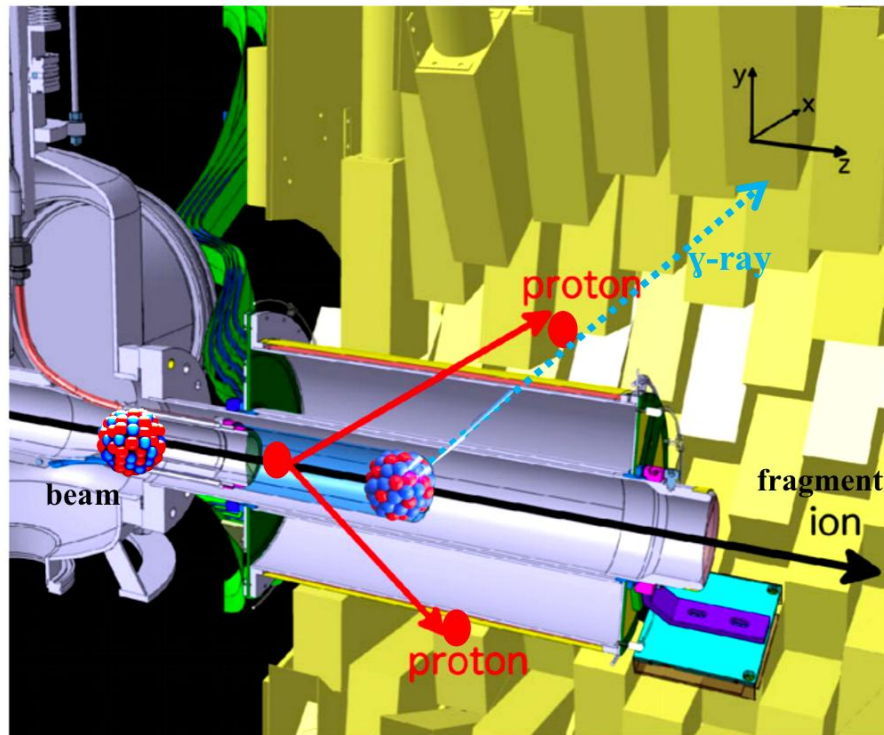
In-beam Commissioning of the STRASSE Silicon Tracker Array via Proton-Proton Elastic Scattering

Spokespersons: Dr. Alexandra Stefanescu
Prof. Dr. Alexandre Obertelli
Contact person: M.Sc. Mirek Zieblinski

IKP, TU Darmstadt, Germany (In collaboration with LPC Caen, RIKEN & GSI)

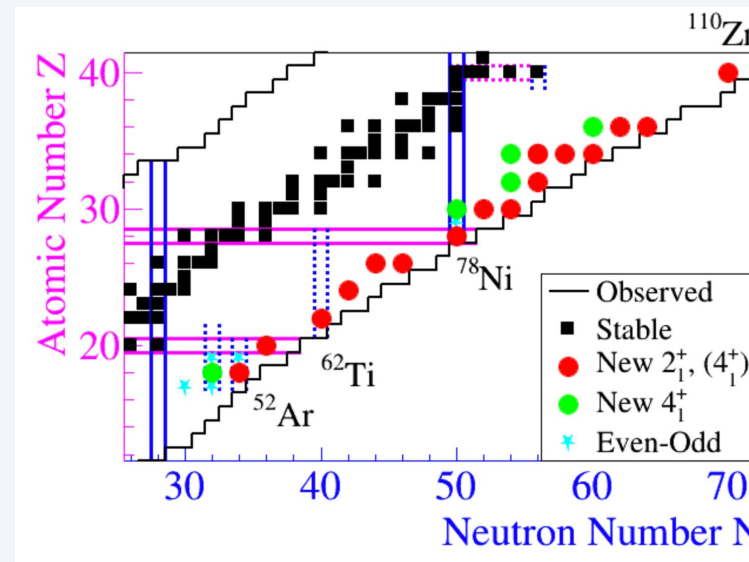
QFS in inverse kinematics concept at RIBF

MINOS



*A. Obertelli et al., Eur. Phys. J. A 50 (2014)

Physics program dedicated to the spectroscopy of **unstable neutron-rich nuclei** and drip-line nuclei.



*SEASTAR Collaboration

about 50 publications
(incl. 2 Nature, 24 PRL)

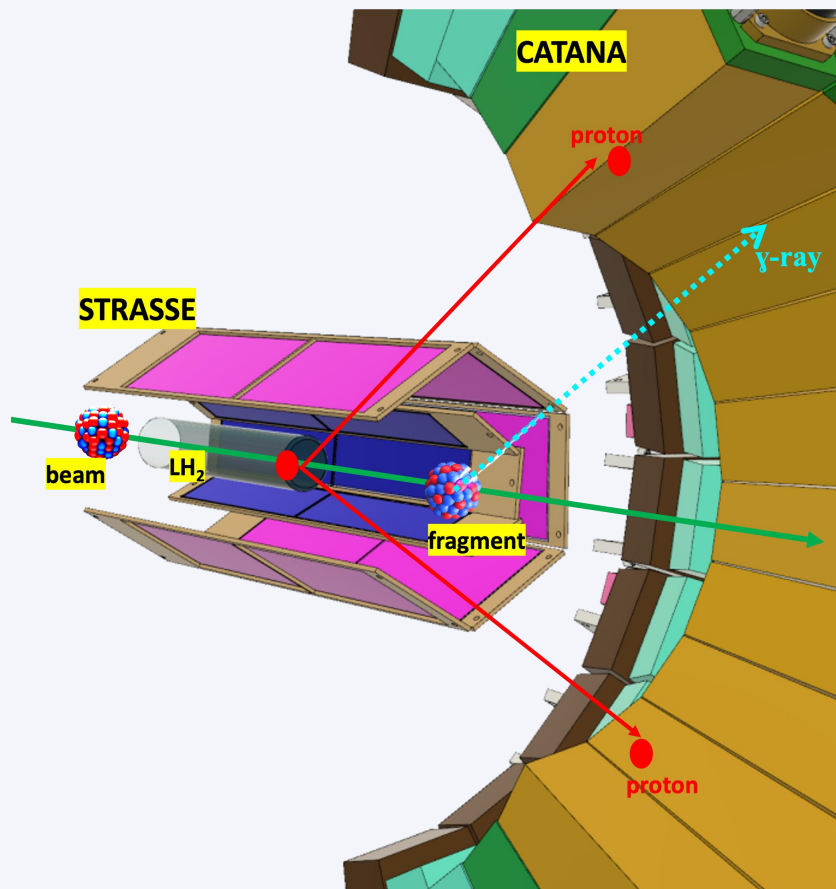
Advantages:

- thick LH₂ target (5-15 cm)
→ 5 x more statistics
- TPC vertex tracker

Limitations:

- vertex resolution ≈ 5 mm (FWHM)
- Limited acq. Rate < 1 kHz
- No missing-mass spectroscopy

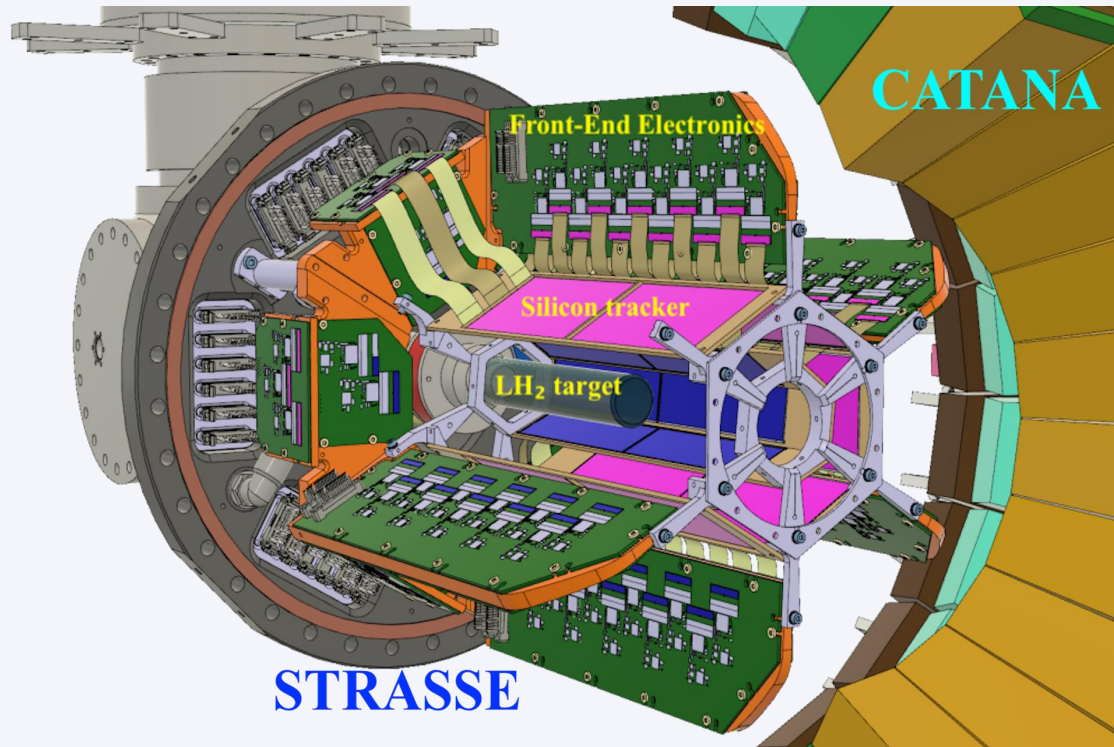
STRASSE → Large-acceptance missing-mass setup for QFS: (p,2p), (p,3p) in inverse kinematics



- **thick LH₂ target**
 $L = 150\text{mm}$
 $\phi = 31\text{ mm}$
- **STRASSE silicon tracker**
**high-precision
vertex tracker**
- **CATANA PLUS**
 **γ -ray spectroscopy &
missing-mass**

**! improved missing
mass energy resolution**
 $\sigma_{\text{Ex}} \approx 1.7\text{ MeV}$

STRASSE tracker design



Compact hexagonal geometry ($R = 18 \text{ cm}$, $L = 50 \text{ cm}$)

Fine granularity (18 k channels to readout)

Thick LH2 target (15 cm) + Long detectors (24 cm)

Low noise electronics + low input C: $20 \text{ keV} / \text{ENC} \approx 5.8 \text{ ke}^-$

In vacuum requiring: Cooling ($\approx 240 \text{ W}$)

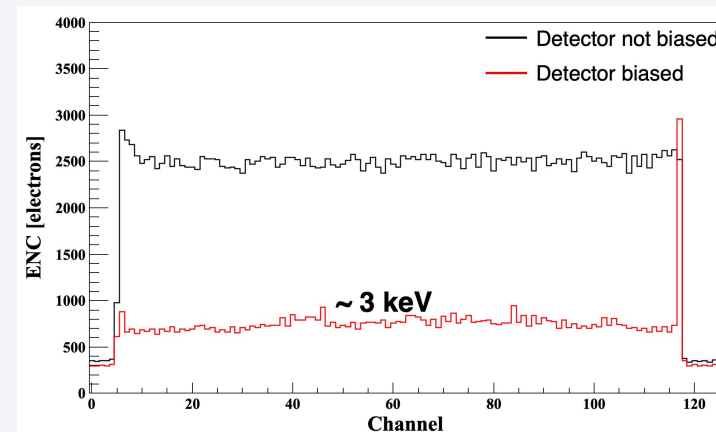
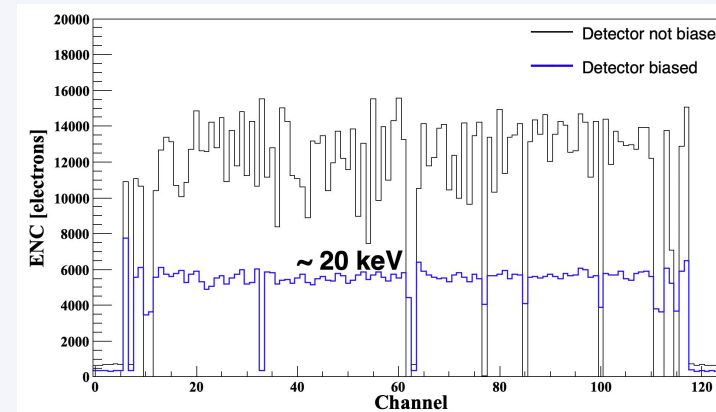
Readout chain: CBM (FAIR) STS electronics

- STS/MuCh - XYTER 2.2 CMOS chip
 - self-triggered & continuous readout
- custom-made front-end boards
- readout rate capability $\leq 5.3 \text{ MHz/chip}$ uplink
- back-end electronics: GBTxEMU and GERI PCIe hw

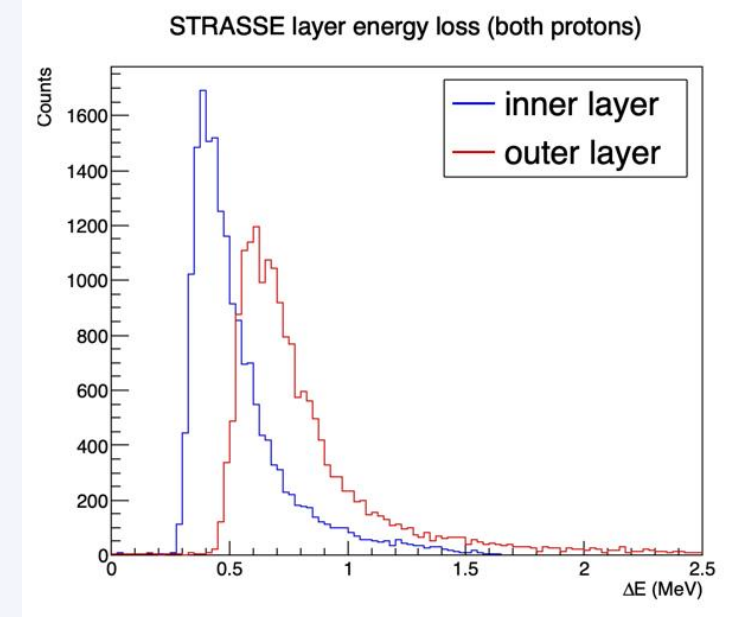
STRASSE tracker: noise level



FEB2 chip (24 cm strip, 200 μ m, **inner** sensor)



FEB11o chip (6 cm strip, 300 μ m, **outer** sensor)



Accepted experiments at RIBF with STRASSE

- SAMURAI65 experiment: $^{56}\text{Ti}(p,3p)^{54}\text{Ca}$

“Search for excited 0^+ state in ^{54}Ca ”

(Spokesperson: H. Liu)

- SAMURAI67 experiment: $^{13}\text{B}(p,2p)^{12}\text{Be}(0_2^+)$ ($^{12}\text{C},n^{12}\text{C}$) ^{11}Be

“Halo structure of the isomeric state $^{12}\text{Be}(0_2^+)$ probed by using a tertiary isomer beam”

(Spokesperson: Z. Yang)

- SAMURAI69 experiment: $^{\text{A}}\text{O}(p,2p)^{\text{A}-1}\text{N}$

“Momentum distributions of deeply-bound nucleons in $^{14-23}\text{O}$ isotopes”

(Spokesperson: A. Obertelli)

- SAMURAI75 experiment: $^{10-20}\text{C}(p,pn)$ & $^{40-52}\text{Ca}(p,pn)$

“Study neutron single-particle states in neutron-rich nuclei”

(Spokesperson: Y. Matsuda, T. Nakamura)

- SAMURAI79 experiment: $^{16}\text{O}(p,X)$

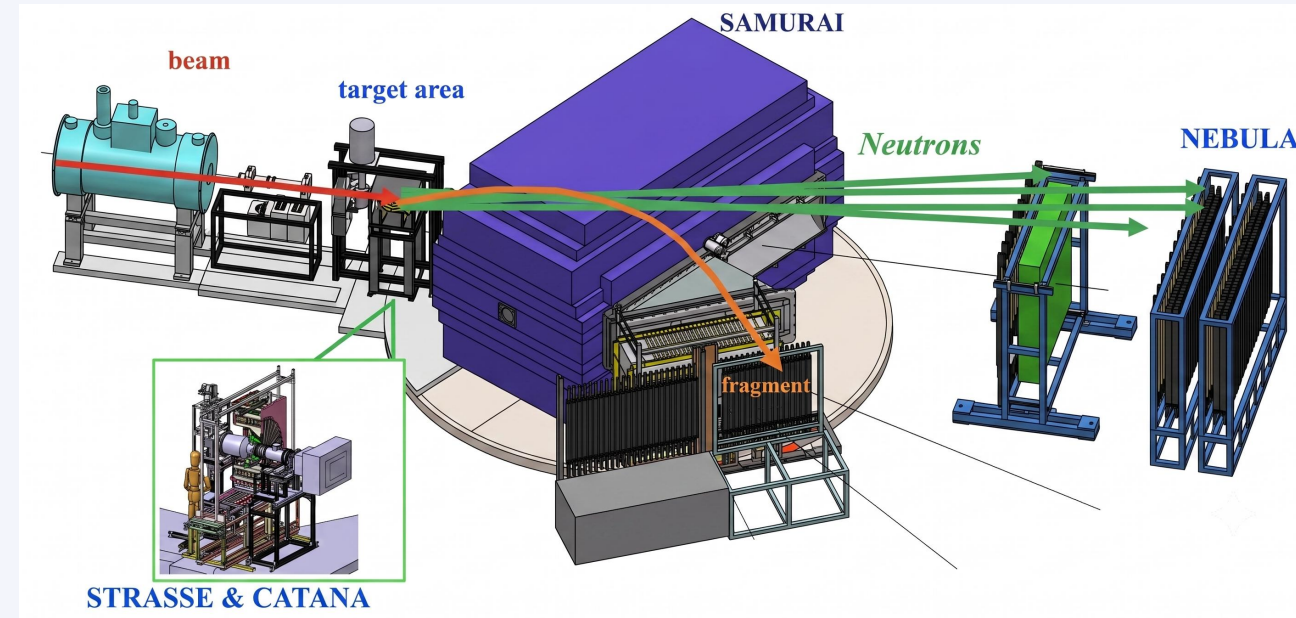
“Study of de-excitation of $^{15}\text{N}^*$, $^{15}\text{O}^*$, and $^{16}\text{O}^*$ for new neutrino observation at giant water Cherenkov detectors”

(Spokesperson: Y. Nakajima)

- SAMURAI84 experiment: $^{49}\text{Cl}(p,dp)^{48}\text{S}$

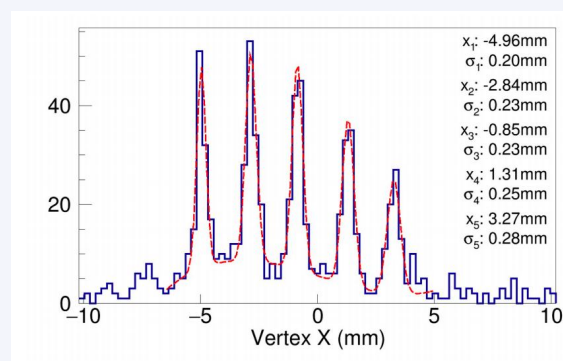
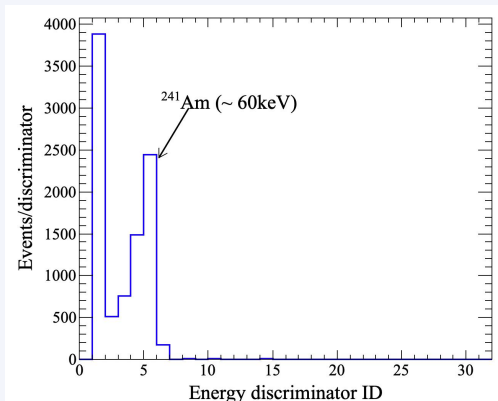
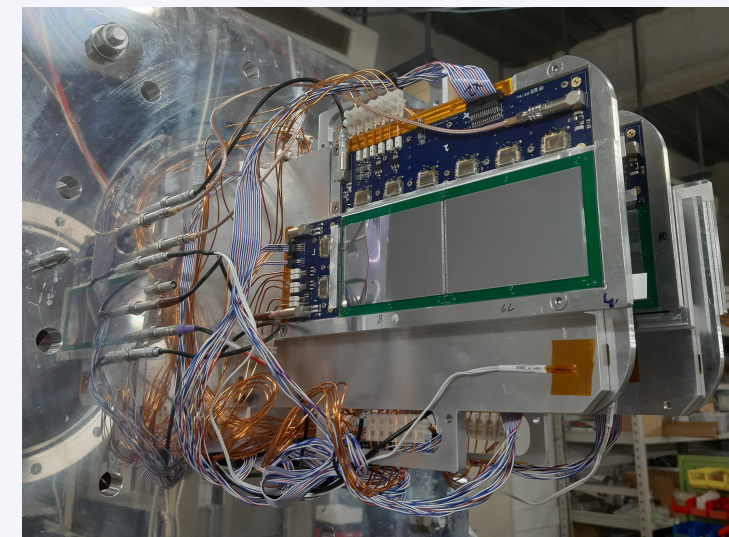
“First in-beam gamma spectroscopy of ^{48}S ”

(Spokesperson: H. Liu, A. Obertelli)

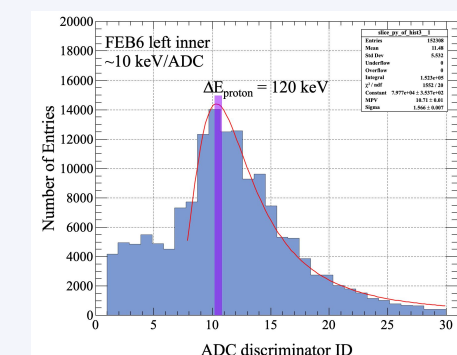


PFAD: demonstrator for STRASSE

- 8 x single-sided silicon detectors ($100\text{ }\mu\text{m}$)
- readout $\approx 4000\text{ ch}$
 - similar front & back-end electronics as for STRASSE
- γ -ray source tests in the lab $\rightarrow$ low $E_{\text{thresh}} = 20\text{-}30\text{ keV}$
- In-beam validation experiment at HIMAC (2022):
 - proton beam on CH_2 targets
 - **sub-mm vertex resolution**
- **Physics experiment in RIKEN: SAMURAI47 (April 2024): $^{11}\text{Li}(p,2p)^{10}\text{He}$**



*PhD thesis of M. Enciu (2023, TU Darmstadt)



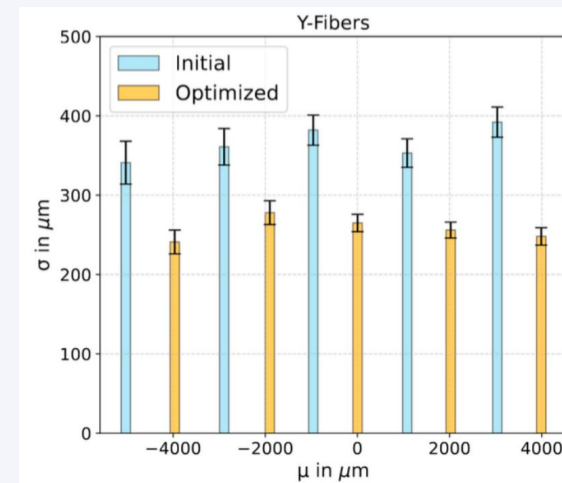
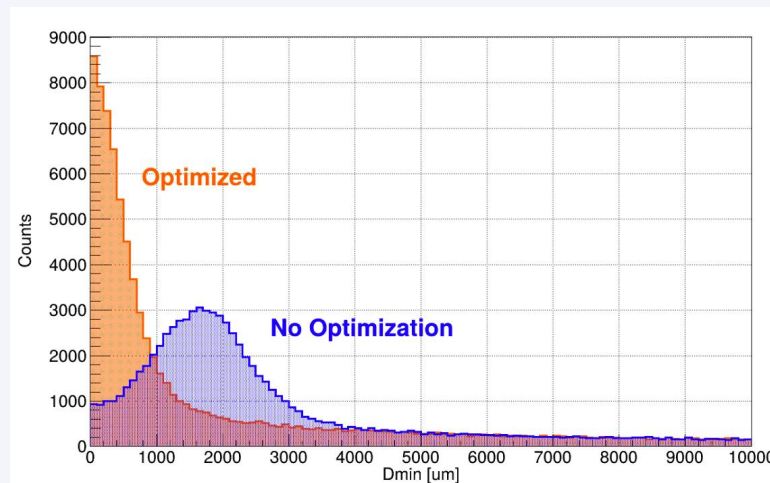
Proton beam on CH_2 target

PFAD: data driven track reconstruction algorithm

*PhD thesis of E. Plastinin (TU Darmstadt)

- data driven alignment of detector relative positions towards $\approx 200 \mu\text{m}$
 - **optimum:** use $D_{\min}$ as FoM, mean at 0 with minimal Std. Dev.
 - requirement: optimize 40 Coordinates (16 Translations + 24 Rotations)
- BOBYQA-based optimization algorithm

M. Powell (2009): “*The BOBYQA Algorithm for Bound Constrained Optimization without Derivatives*”.
Tech Report, Cambridge Univ.



STRASSE commissioning at CCB Kraków facility

Aim:

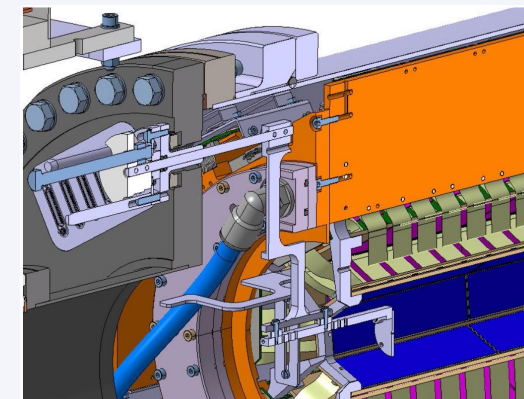
performance validation of the STRASSE system with real beam in **November 2026**, prior to its relocation to Japan in December 2026 (publication foreseen)

Conditions:

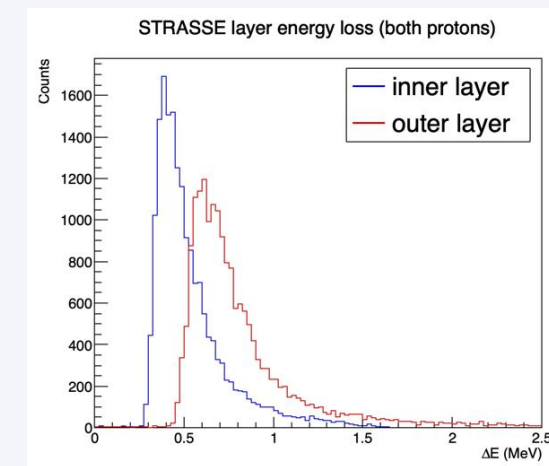
- Proton beam at 200 MeV on solid CH₂ target ($\Delta x = 100 \mu\text{m}$, $\Phi = 20 \text{ mm}$)
- reaction: pp elastic scattering
- beam requirements: spot $> 6 \text{ mm}$, $I \approx \text{few MHz}$

Objectives:

- Electronics system validation of the entire STRASSE array
- DAQ TS synchronization
- efficiency evaluation of the DAQ
- tracking efficiency validation
- precise data driven alignment optimization of silicons
 - publication (E. Plastinin, PhD student, et. al.)
- tracking and vertex reconstruction



*Courtesy of D. Goupilliere (LPC Caen)



*Courtesy of J.L. Fuentes (LPC Caen)

STRASSE experimental setup at CCB Kraków facility

- CCB Krakow provides the appropriate environment:
 - Stable Proton Beam: at 200MeV energy
 - Beam quality: small beam spot and high intensity
- Standalone Vacuum Setup:
 - cyclotron beam line exit window: Ti foil (50 μm thick)
 - no connection to the cyclotron beam line (DN100 windows)
 - STRASSE beam line length ≈ 2 m
- Standalone Electronics & Control system: (power requirement)
 - **clean power line:** $2 \times 220\text{V} \times 16\text{ A}$ (electronics) $\approx 7\text{ kW}$
 - dirty power line $\approx 5\text{ kW}$ (pumps and chiller)



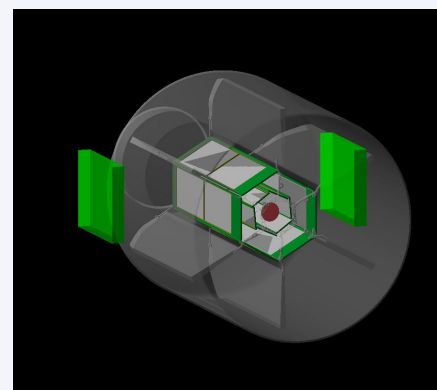
Full STRASSE assembly in the TU Darmstadt lab

STRASSE electronics systems

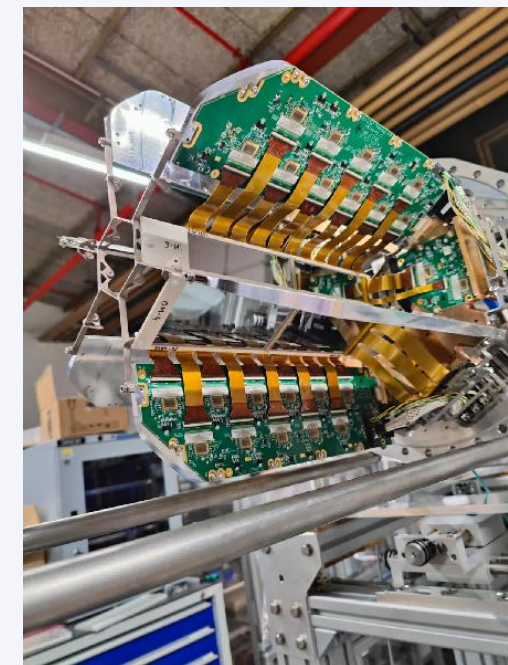
- **STRASSE system** (TU Darmstadt):
 - silicon tracker (+ front & back-electronics)
 - one rack with VME crates
 - chiller & vacuum systems
 - server for DAQ & Slow Control PC (HV, LV, Temperature monitoring)
- Ancillary detectors (in air):
 - **Diamond START Detector** (GSI): upstream of the target chamber
 - **Lateral Plastic Scintillators** (LPC Caen): outside the vacuum chamber



START diamond detector (GSI)



NPTOOL simulation of the measuring setup for (p,2p) reaction



STRASSE partially assembled in the TU Darmstadt lab

Expected 2p events type statistics

- Target & Acceptance Parameters: $2 \times \text{STRASSE arm} \times \text{plastics } (150 \times 120 \times 20 \text{ mm}^3)$
 - $100 \text{ } \mu\text{m CH}_2 \text{ target } (N_t = 6.9 \times 10^{20} \text{ atoms H/cm}^2)$
 - $\sigma_{\text{pp,total}} \approx 60 \text{ mb} \xrightarrow{\times \epsilon_{\text{geom}} (13.3\%)} \sigma_{\text{acc}} \approx 8 \text{ mb} \xrightarrow{\times \epsilon_{\text{reco}} (2\text{p}, 49\%)} \sigma_{\text{eff}} \approx 4 \text{ mb}$

- Clean Coincidence Rate:** $R_{2\text{p}} = I \times N_t \times \sigma_{\text{eff}}$

Case 1: low-intensity beam rate (**1 MHz**)

$\approx$ **2500 events/hour** (0.69 Hz)

$\rightarrow$ in **2 UT** $\approx$ **20 000 events**

beam spot: any size ($< 20 \text{ mm}$)

Case 2: nominal beam intensity (**$7 \times 10^8 \text{ pps}$**)

$\approx$ **$1.75 \times 10^6 \text{ events/hour}$** (485 Hz)

$\rightarrow$ in **2 UT** $\approx$ **$1.4 \times 10^7 \text{ events}$**

beam spot $> 6 \text{ mm}$ (avoid CH_2 foil damage)

- max DAQ load within the STRASSE ang. acceptance:**

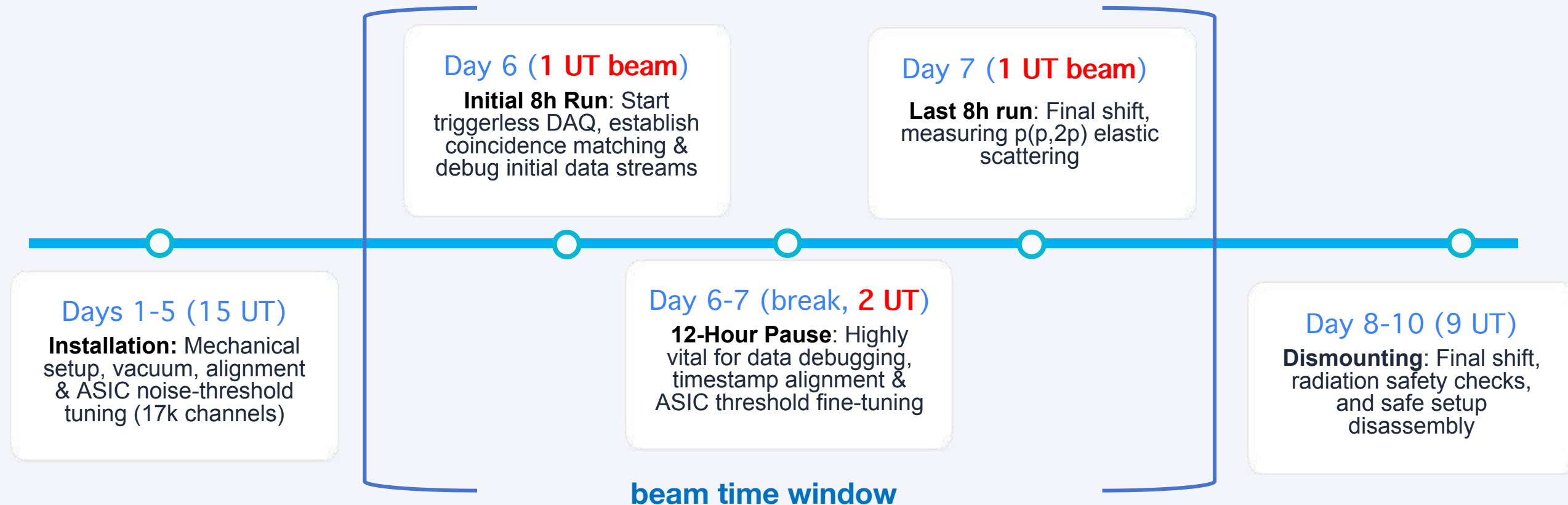
- Hydrogen interactions (pp scattering) $\sim 15 \text{ kHz}$
- C interactions (background) $\sim 50 \text{ kHz}$



total raw trigger-less load distributes to
 $< 500 \text{ Hz/ ASIC}$

Needed: 2 UT beam on target (16 Hours)
+ 2 UT Data Validation

Beam-Time Setup & Operational Timeline



STRASSE system: Current Status & Milestones

✓ **Hardware and detectors:** Completed/Validated

- ❑ Mechanical structures: Finalized (LPC Caen)
- ❑ Silicon sensors: all equipped with microcables (GSI Det Lab)
- ❑ Diamond START detector: in-beam tested at CERN and ready (GSI)
- ❑ Cooling system: Operating parameters optimized (TU Da)

✓ **Electronics and DAQ:** Validated

- ❑ Front & Back-end electronics: Fully prepared (TU Da)
- ❑ Tracker : end-to-end laboratory validation of one STRASSE module (TU Da)
- ❑ DAQ Software: fully operational for reading all 162 ASICs

➤ **Upcoming Milestones:** Sept. - Oct. 2026

- ❑ Mid-Sept: Assembly of STRASSE tracker (TU Da) & preparation of plastic scintillators (LPC Caen)
- ❑ Sept.-Oct: Noise optimization and TS reconstruction refinement (TU Da)
- ❑ Oct. 2026: final DAQ integration with ancillary detectors (TU Da & GSI)

Participants to the proposed experiment at CCB

TU Darmstadt (Germany): A.I. Stefanescu, E. Plastinin*, A. Obertelli, F. Wienholtz

GSI (Germany): M. Duer

LPC Caen (France): F. Flavigny, A. Matta, D. Goupillere, J.L. Fuentes

RIKEN (Japan): T. Isobe, S. Sakai, H. Otsu

Institute of Science Tokyo (Japan): T. Nakamura, S. Hanai*, Y. Satou, M.V.S. Chandrachud*

University of Tokyo (Japan): S. Abe, Y. Nakajima, R. Tsuji, Y. Mizuno*, W. Cai*, S. Fudono*

Okayama University (Japan): Y. Hanakawa

BNU (China): H. Liu, C.L. Hao*, Y. Yang*, X. Gan*

CCB Kraków (Poland): M. Zieblinski, M. Ciemala, B. Sowicki, P. Kulesa

* PhD students that will use the data measured with STRASSE



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Discussion & Questions

*desired beam time : **November 2026**

The proposed STRASSE experiment at CCB Kraków enables:

- End-to-end commissioning of the full STRASSE system before its transfer (in December 2026) to RIKEN for physics experiments
- Total requested UT: 28 UT in total with **4 UT beam** on target , 24 UT for setup assembly/disassembly on site
- an essential scientific training platform (9 PhD students who will benefit from the STRASSE data for their Ph.D theses).
- data for the $2p$ tracking algorithm to be implemented and optimized for the STRASSE geometry → publish the results in NIM paper)



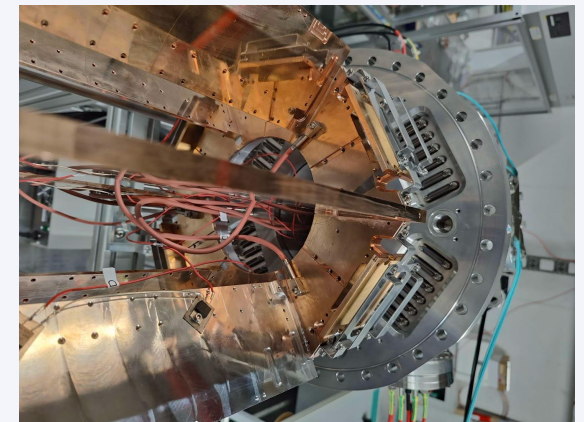
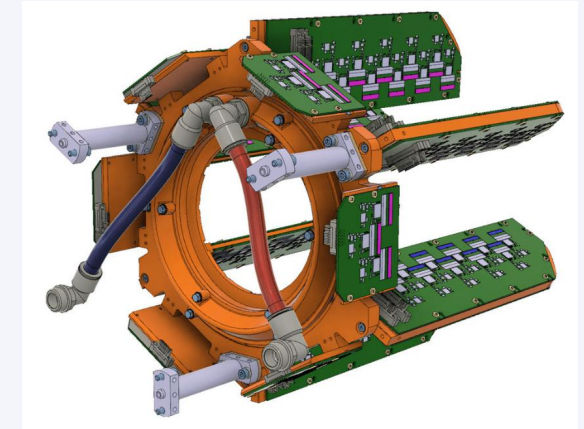
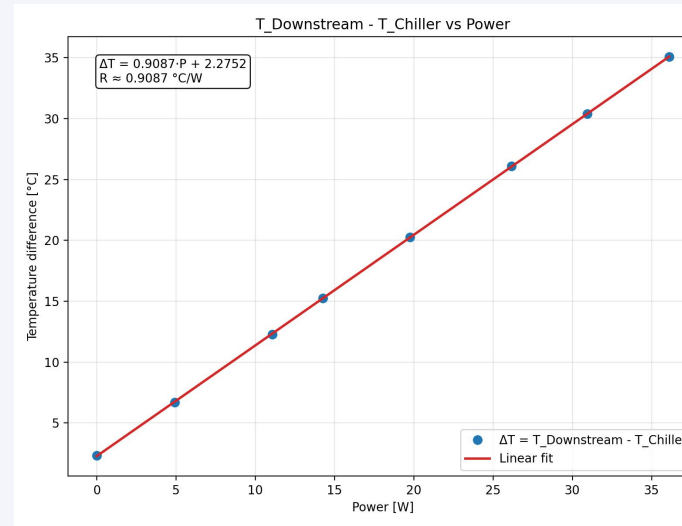
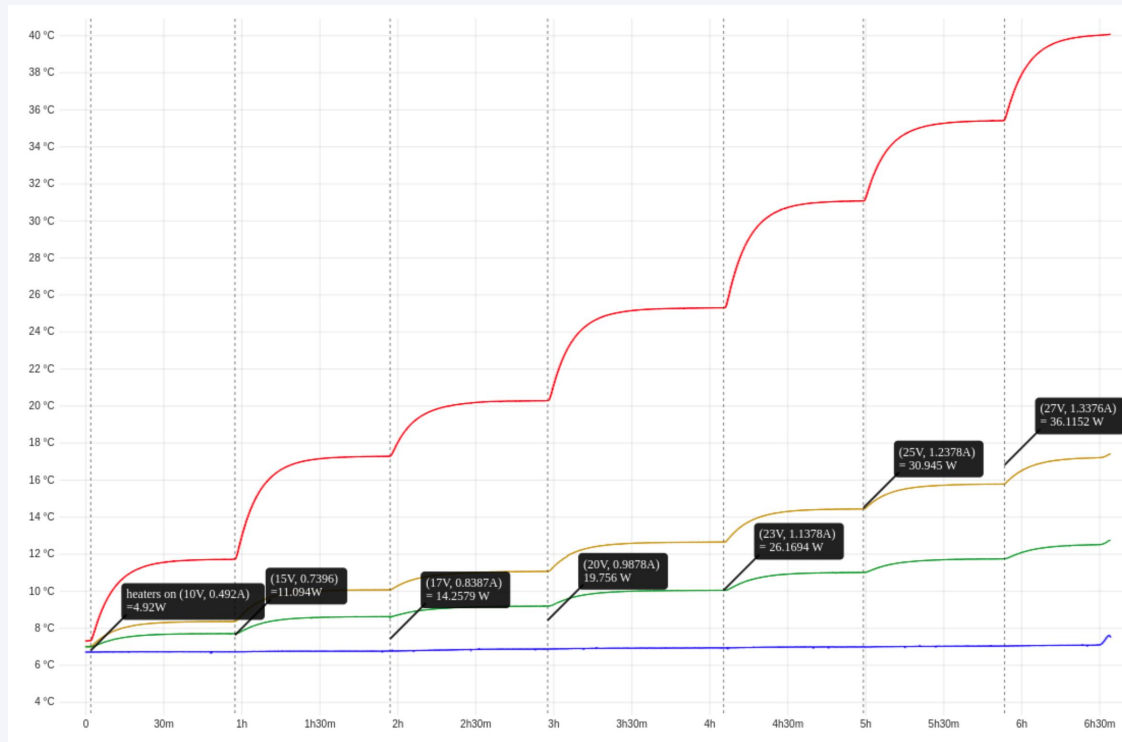
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Cooling parameters for STRASSE electronics

*PhD thesis of E. Plastinin (TU Darmstadt)

- equilibrium state reached within 45 min (any thermal load)
- system thermal resistance: $R = 0.91 \text{ }^{\circ}\text{C/W}$



Outer sensor leakage current:

