TECHNISCHE UNIVERSITÄT DARMSTADT

TIME PROJECTION CHAMBERS FOR NUCLEAR PHYSICS

Strategic Gaseous Detector Meeting, GSI/FAIR, 2023

Alexandre Obertelli, TU Darmstadt

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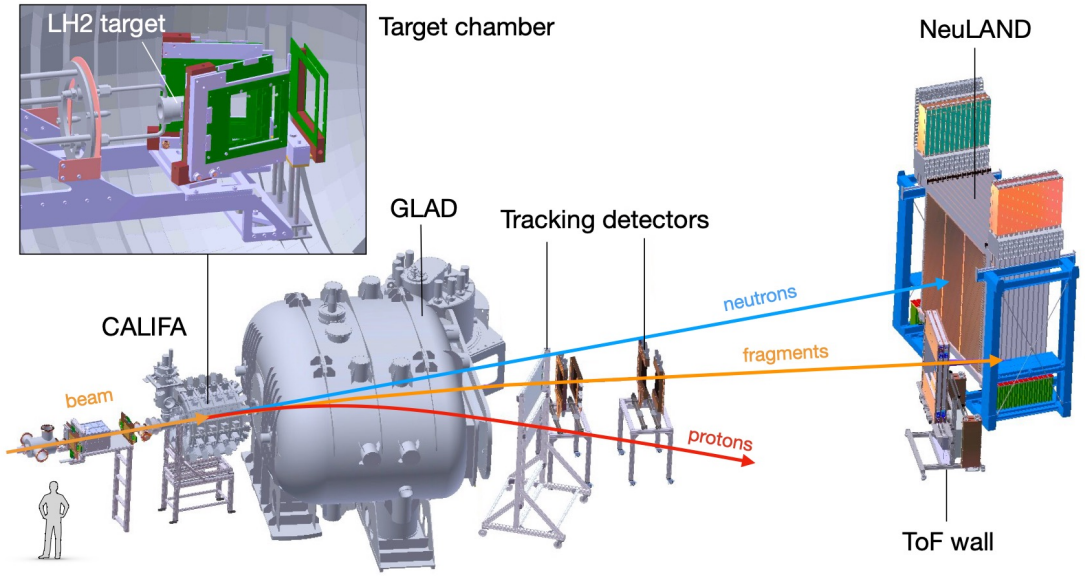
TPC in GLAD

- TPC provides high resolution tracking for charged particles, not covered by standard R3B detection covering several physics cases: hypernuclei, fission, short-range correlations,…

- R3B Working Group “TPC in GLAD” since 2018
- 14 participants
- Leader & Deputy: A. Obertelli, M. Duer (TUDa)

- Also ACTAF: high pressure TPC for (in)elastic scattering at R3B (Leader: O. Kiselev)



ID	Academ. Status	Academ. Title	First Name	Middle Names	Last Name	Gender	Phone	Email	Main Affiliation	Inactive
1	After Post Doc 5	Prof. Dr. 3	Thomas		Aumann	M 1		t.aumann@gsi.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
8	After Post Doc 5	Prof. Dr. 3	Hector		Alvarez-Pol	M 1	0034 881813544	hector.alvarez@usc.es	ESP-USC (Universidade de Santiago de Compostela) 74	
154	After Post Doc 5	Dr. 1	Bastian		Löher	M 1	+496159713272	b.loeher@gsi.de	DEU-GSI (GSI Helmholtzzentrum für Schwerionenforschung) 17	
524	After Post Doc 5	Dr. 1	Christoph		Caesar	M 1	06159712421	c.caesar@gsi.de	DEU-GSI (GSI Helmholtzzentrum für Schwerionenforschung) 17	
542	After Post Doc 5	Prof. Dr. 3	Alexandre		Obertelli	M 1	+33789839266	aobertelli@ikp.tu-darmstadt.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
606	After Post Doc 5	Dr. 1	Dominic	Michel	Rossi	M 1	+49-6151-16-23532	d.rossi@gsi.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
611	After Post Doc 5	Dr. 1	Valerii		Panin	M 1		v.panin@gsi.de	DEU-GSI (GSI Helmholtzzentrum für Schwerionenforschung) 17	
767	After Post Doc 5	Prof. Dr. 3	Saul		Beceiro-Novo	M 1	+34610228857	saul.beceiro@udc.es	ESP-UDC (Universidade da Coruña) 297	
915	After Post Doc 5	Dr. 1	Jose Luis		Rodriguez Sanchez	M 1		j.l.rodriguez.sanchez@udc.es	ESP-UDC (Universidade da Coruña) 297	
1296	Ph.D. Student 3	8	Simone		Velardita	M 1		svelardita@ikp.tu-darmstadt.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
1306	Post Doc 4	Dr. 1	Meytal		Duer	F 2		mduer@ikp.tu-darmstadt.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
1313	Ph.D. Student 3	8	Liancheng		Ji	M 1		lji@ikp.tu-darmstadt.de	DEU-TU Darmstadt - IKP (Technische Universität Darmstadt) 57	
1492	After Post Doc 5	Dr. 1	Yassid		Ayyad	M 1		yassid.ayyad@usc.es	ESP-USC (Universidade de Santiago de Compostela) 74	
1510	Post Doc 4	Dr. 1	Zhuang		Ge	M 1	491781567635	z.ge@gsi.de	DEU-GSI (GSI Helmholtzzentrum für Schwerionenforschung) 17	

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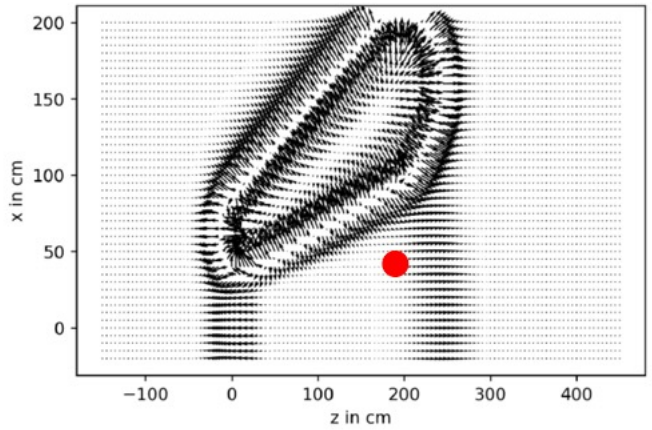
Challenges & specifications

Challenge
Non homogeneity of B field (mapping / reference laser tracks) – 2 T

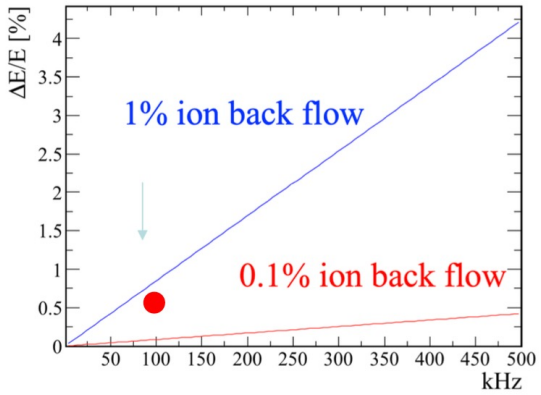


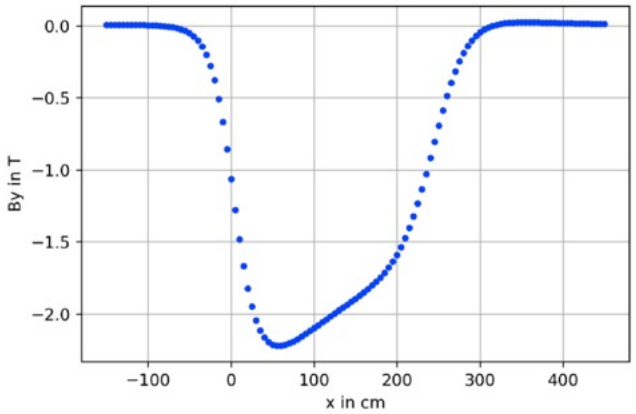
Specifics for hypernuclei studies:

- Momentum resolution (pion) better than 1%
- Space charge (100 kHz charges particles inside TPC): IBF < 1%
- Trigger rate of few 10^4 Hz: VMM3 foreseen (F. Garcia, GEM-TPC for S-FRS)
- MIPs

Potential other uses:

- High resolution spectrometer: < 0.1%
- SRC: large acceptance
- Fission: detection at zero degree with high rates





STARTING POINT

The experiment S73 (Feb. 2025)

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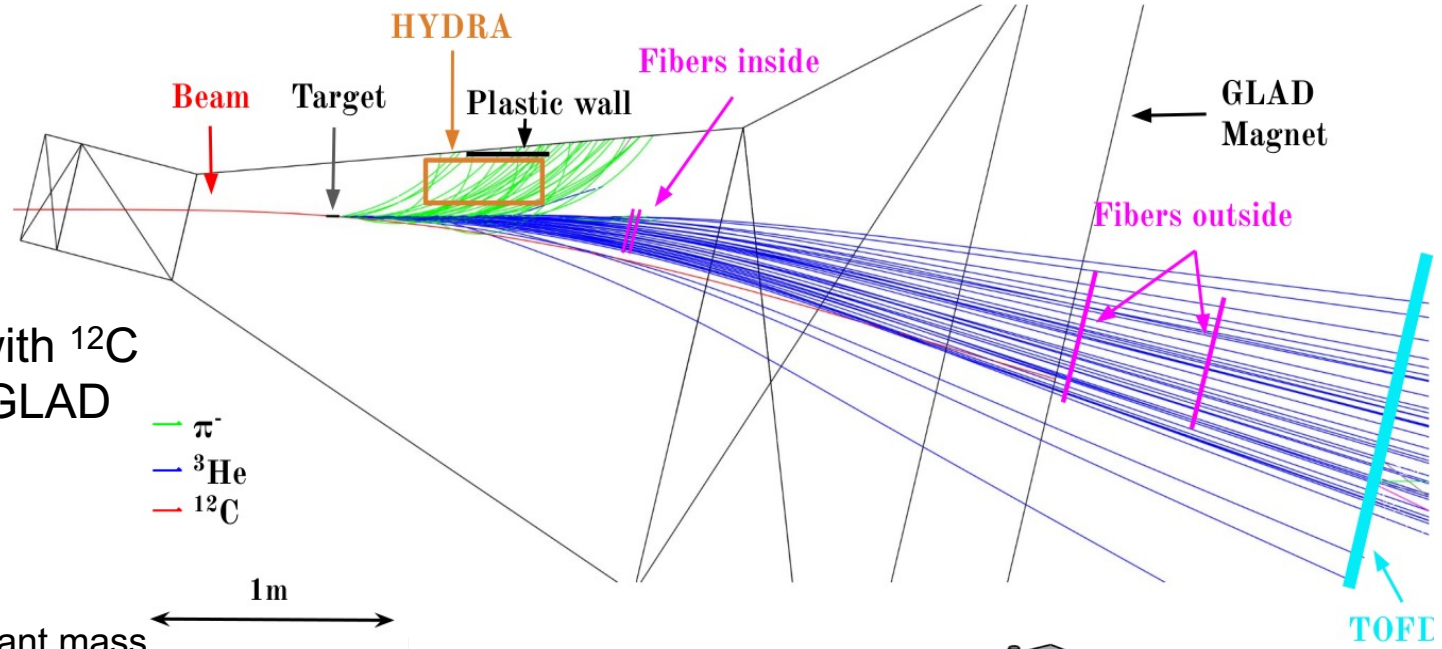
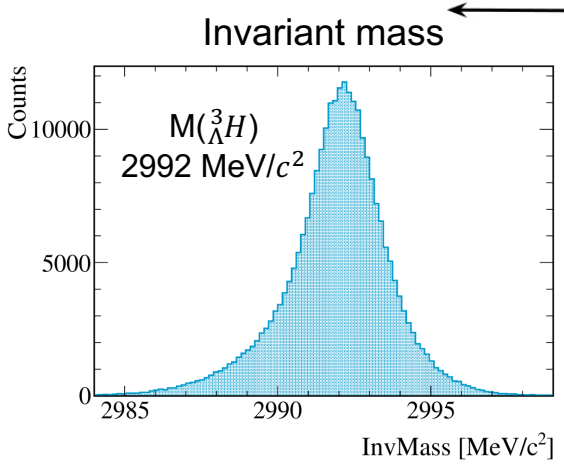
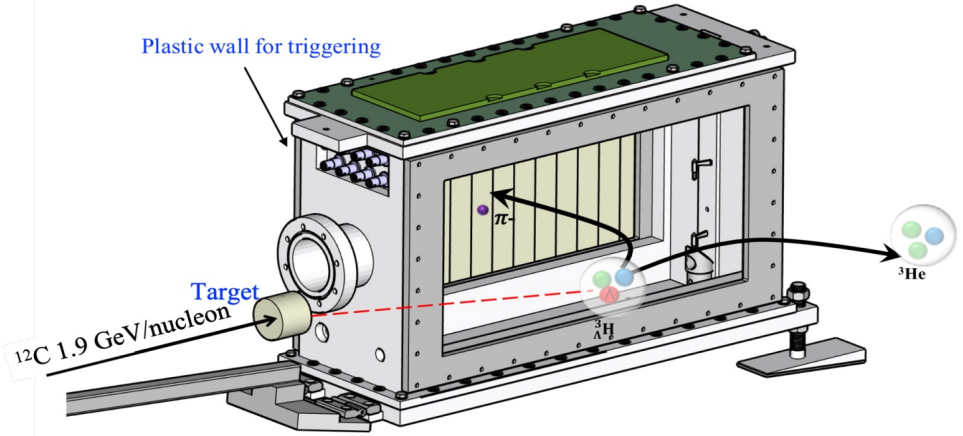
- Interaction cross section of hypertriton with ^{12}C
- HYDRA: dedicated pion (π^-) tracker in GLAD
- TPC + plastic wall in GLAD







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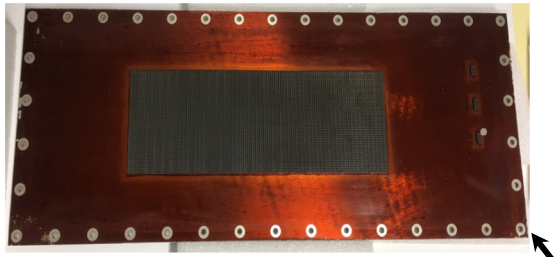
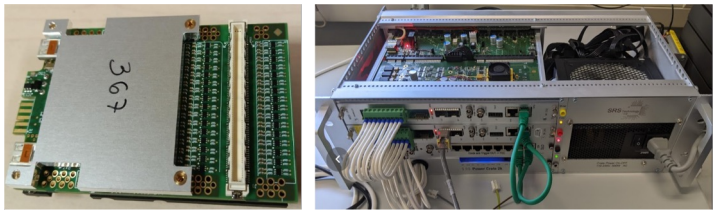
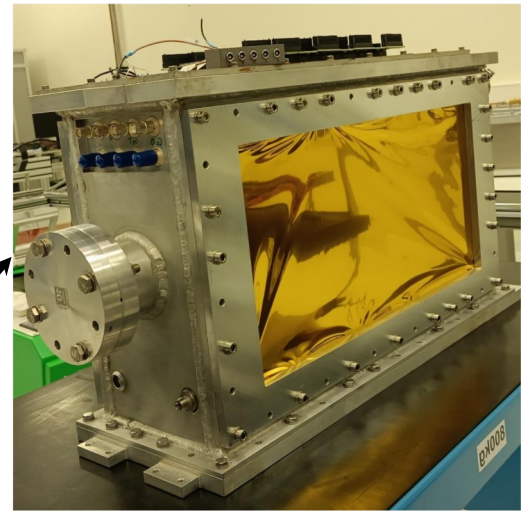
The TPC prototype



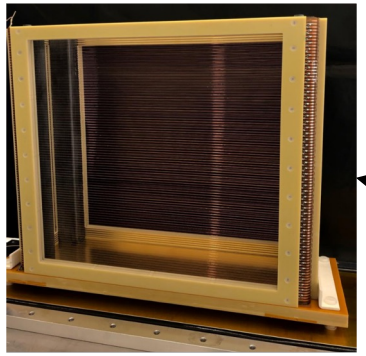
Metal core pad-plane (5632 Ch)
MicroMegas amplification
+ GEM to reduce the ion back flow <1%



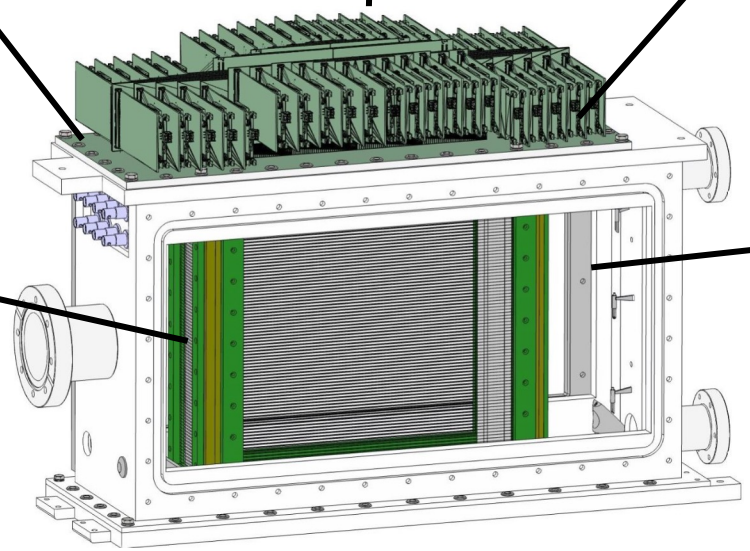
VMM3 front-end card + SRS backend
Currently (R&D): AGET / ASAD / zCOBO

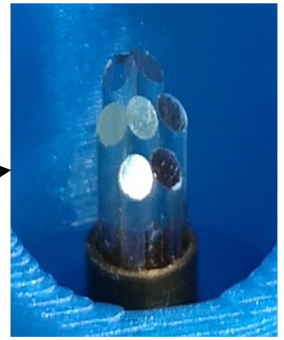


TPC chamber



Double wire field cage
(support from J. Hehner, GSI)





Micro-mirror bundle for UV 266 nm laser

+ plastic wall: built, validated

Support from P. Gasik, GSI

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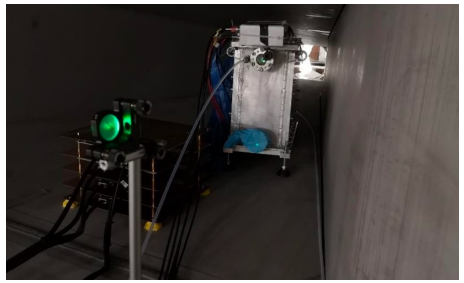
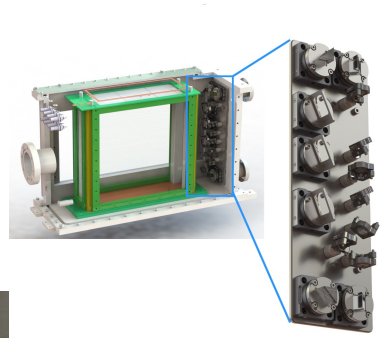
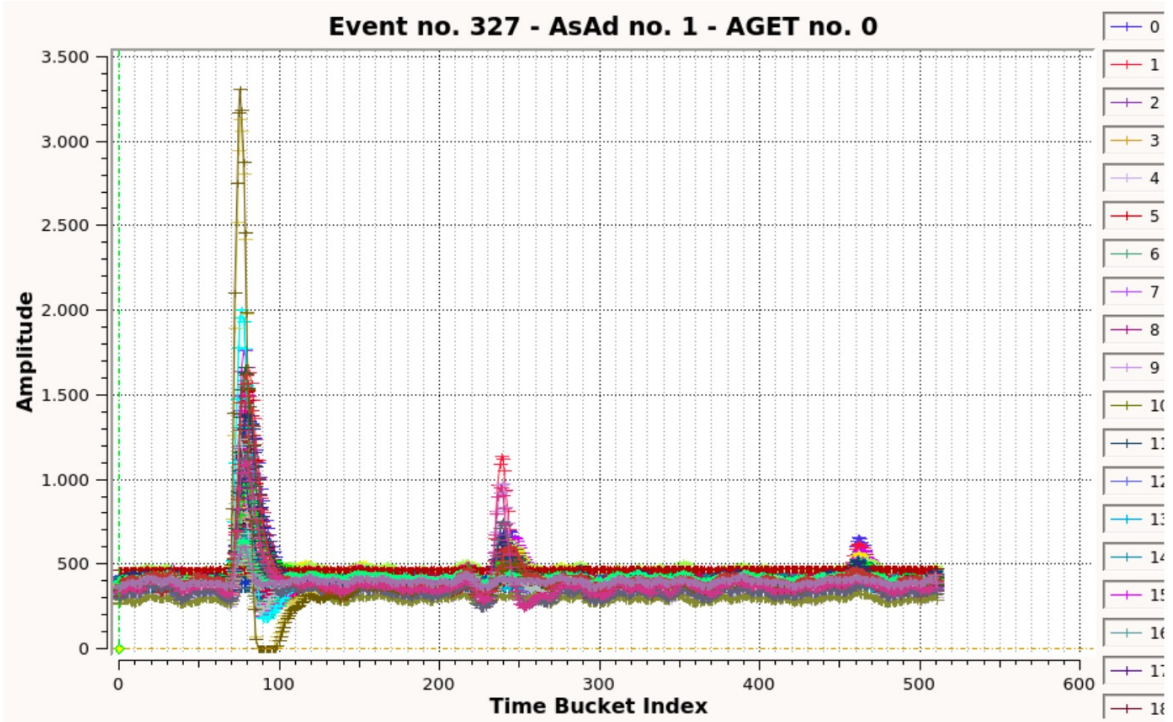
Laser test in GLAD, Nov. 2023







$ArCO_2$: 90-10
GET electronics (4 Asads)

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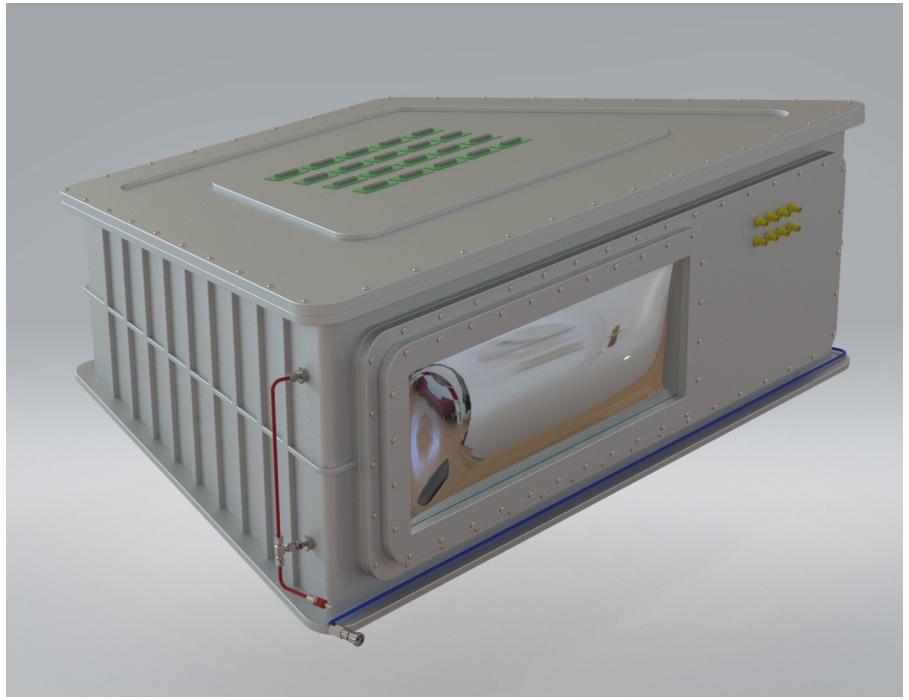
HYDRA: concept, agenda

HYDRA concept
entire GLAD gap / multiple puprpose / modular pad-plane

Tentative agenda

- Feb. 2024: In-GLAD in-beam test
- June 2024: finalization of prototype (with VMM3)
- Summer 2024: in-beam test at IFIN-HH (1 week, accepted)
- Feb. 2025: S073 experiment

- 2024-2026: simulations, R&D, physics program
- 2025: TDR
- 2026-2028: Construction and tests (when funded)
- 2029-: first experiments in R3B high-energy cave



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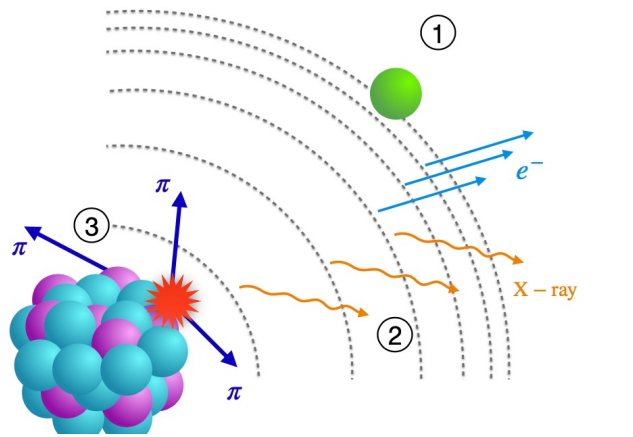
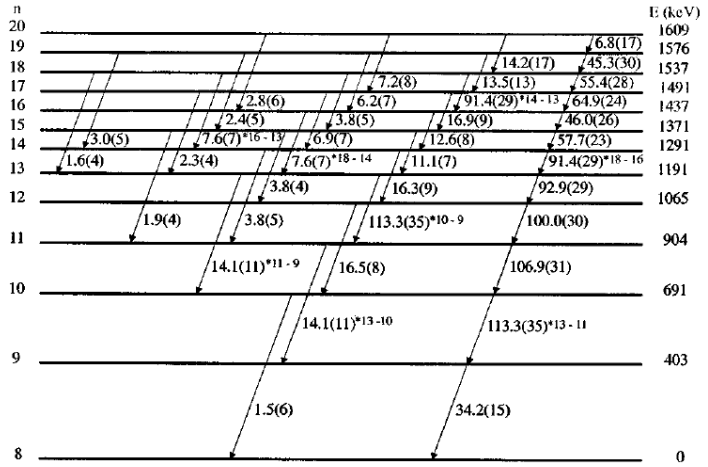
Hypernuclei from antiprotons



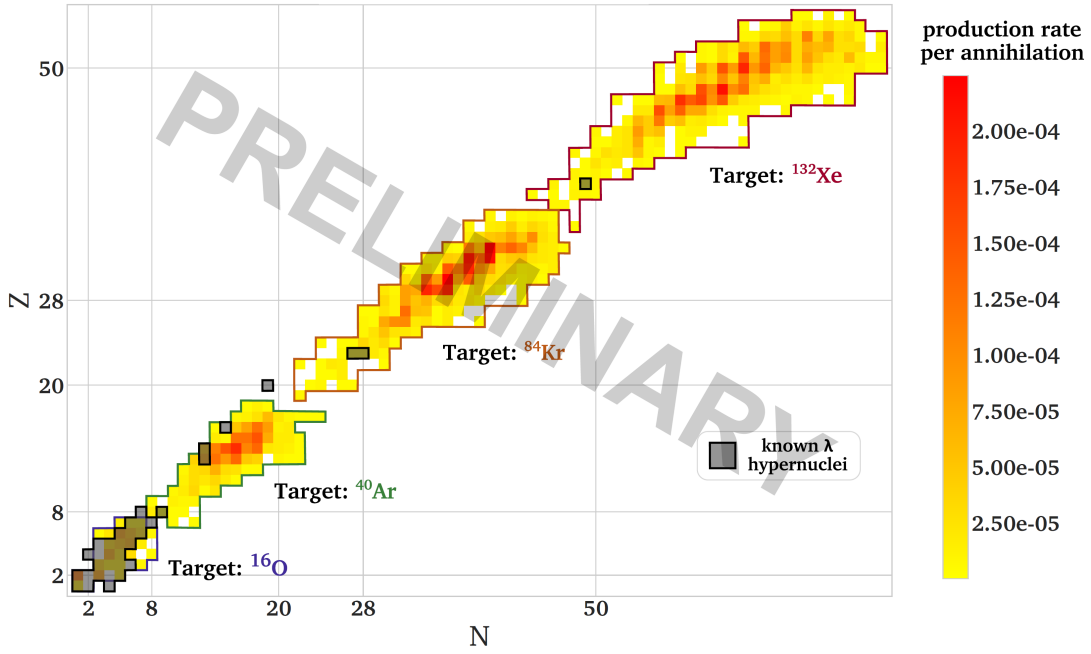


Schmidt et al., PRC (1998)
LEAR experiments, CERN

A new method to produce hypernuclei:

- 3% of annihilations lead to $K\bar{K}$ pairs at the nuclear surface
- $K^- (\bar{u}s) + n(udd) \rightarrow \Lambda + \pi^-$
- Up to 10-30% lead to the formation of a hypernucleus

At ELENA, 10^3 hypernuclei / 2-minute cycle



Schmidt et al., submitted (2023)

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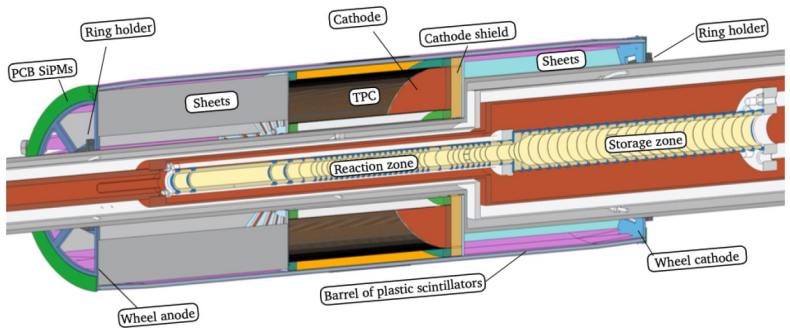
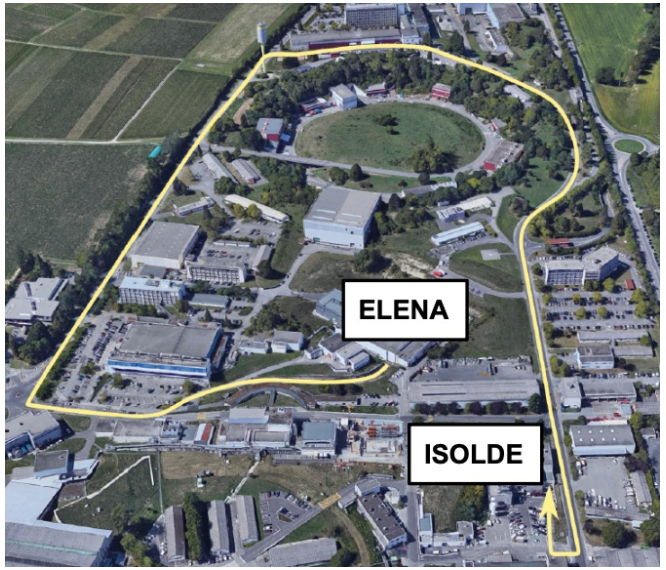
HYPER-PUMA: context

PUMA aims at studying nuclear structure from low-energy interaction of antiprotons with stable / RI

- Accepted as a new CERN experiment (AD-9) in 2021, now under finalisation
- World-unique low-energy antiproton ELENA facility (routine operation since 2021) and ISOLDE
- TU Darmstadt spokesperson, 6 institutes (TUDa, CERN, CNRS, TRIUMF), > 40 collaborators
- Pion tracker: Time Projection Chamber
- Physics with radioactive isotopes starting from 2025





Aumman et al. (PUMA collaboration), EPJA (2021)

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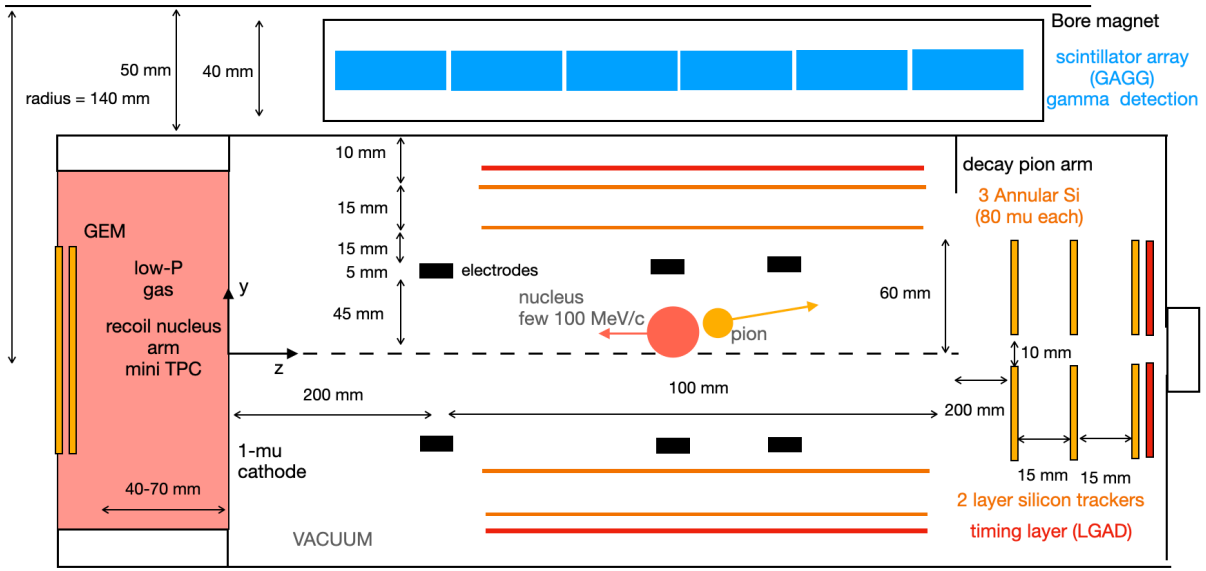
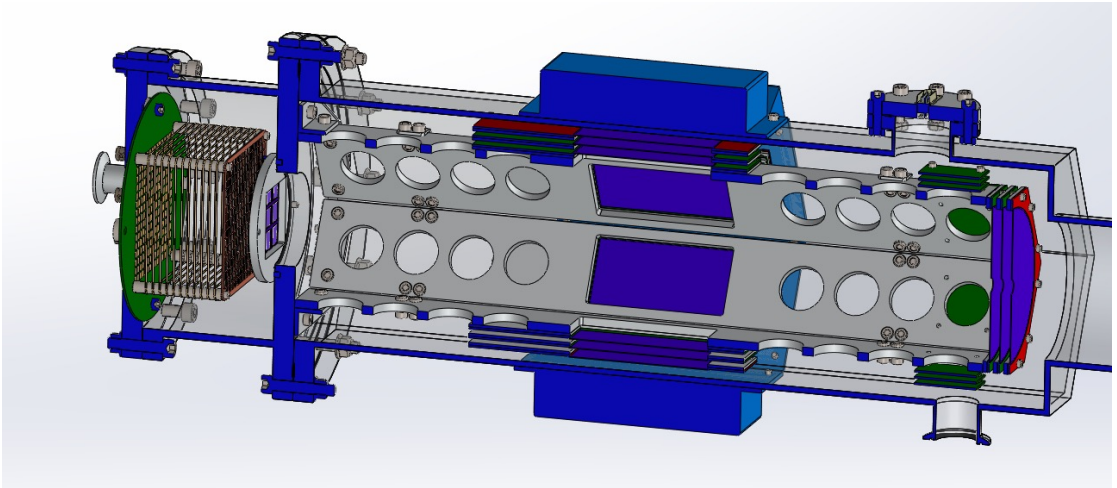
HYPER-PUMA: concept



- antiproton trapping in low pressure (10^{-6} mbar) gas;
- 10^4 annihilations / s
- Spatial and time selection of strangeness production and weak decays ($\sigma_r < 1\ mm, \sigma_t \sim 40\ ps$)
- PID of low-energy recoil (0.5 – 3 MeV) with **low pressure TPC (10 mbar)**
- Gamma spectroscopy (5% resolution)

Considered options (R&D to be performed):

- Thick GEMS
- GridPix based on Timepix
- Optical TPC



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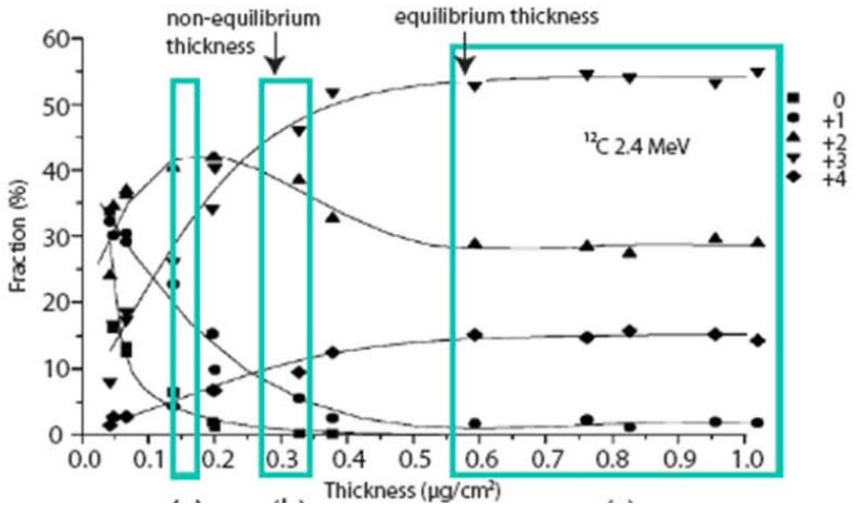
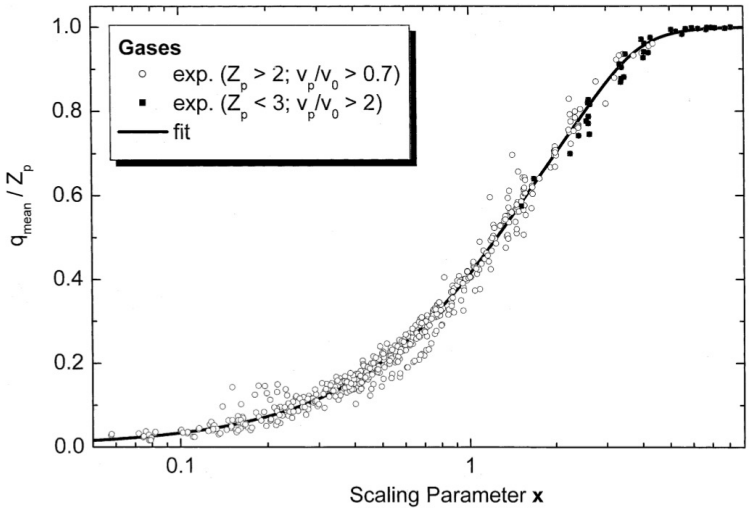
HYPER-PUMA: specifications

Challenge: charge changing of low-energy ions in gas
30 nm Si_3N_4 (TPC cathode membrane) = 4 micrograms / cm^2 => equilibrium is reached
Typical capture / stripping electron cross sections: 2 10^{-15} cm^2
In 1 mbar gas => 100 charge changes / cm vs. 300 ionizations / cm





Schiwietz, Grande, NIMB (2001)

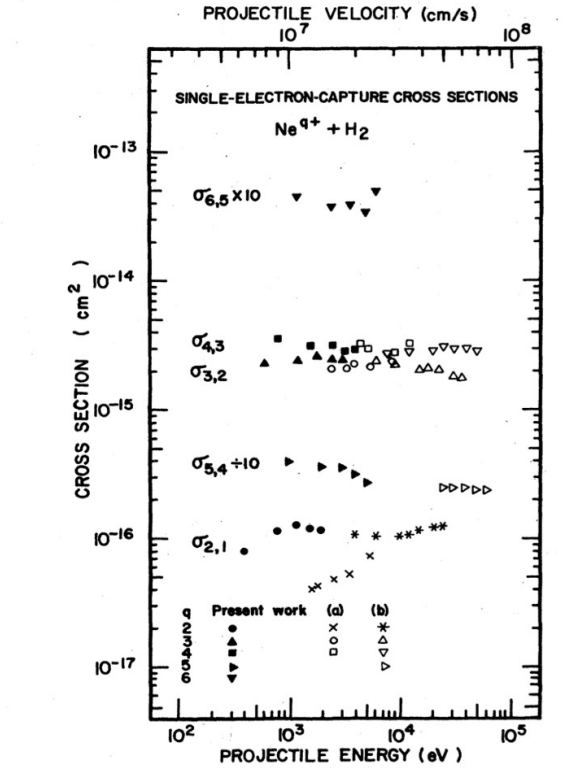


FIG. 8. Energy dependences of the single-electron-capture cross sections for $Ne^{q+}+H_2$, $q=2-6$. Other results (a) and (b) are from Refs. 5 and 6, respectively.

Summary

TPC in GLAD: design and R&D in 2024-2026, construction 2026-2028, physics from 2029

- Non-homogeneous magnetic field: laser reference tracks
- Spatial resolution < 400 microns
- Space charge: ion back flow < 1%
- High-trigger rate (25 kHz): continuous readout (VMM3) and implementation into DAQ

Hypernuclei from antiprotons at ELENA: first design in 2024-2025, R&D in 2024-2027, PoC from 2027

- Low-energy recoils (< 2 MeV kinetic energy) from light to medium mass (A<30)
- Charge exchange cross section competing with ionization cross section: new analysis method
- Low pressure (few mbar): amplification concept to find
- *Dream*: position resolution to achieve separation of individual clusters

PUMA: now – 203x

- Nuclear physics program with antiprotons (F**A**IR)
- Wish to involve GSI/FAIR (TPC, control command of trap electrodes, tracking, neutron skins)