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A new plunger device for Miniball at HIE-ISOLDE

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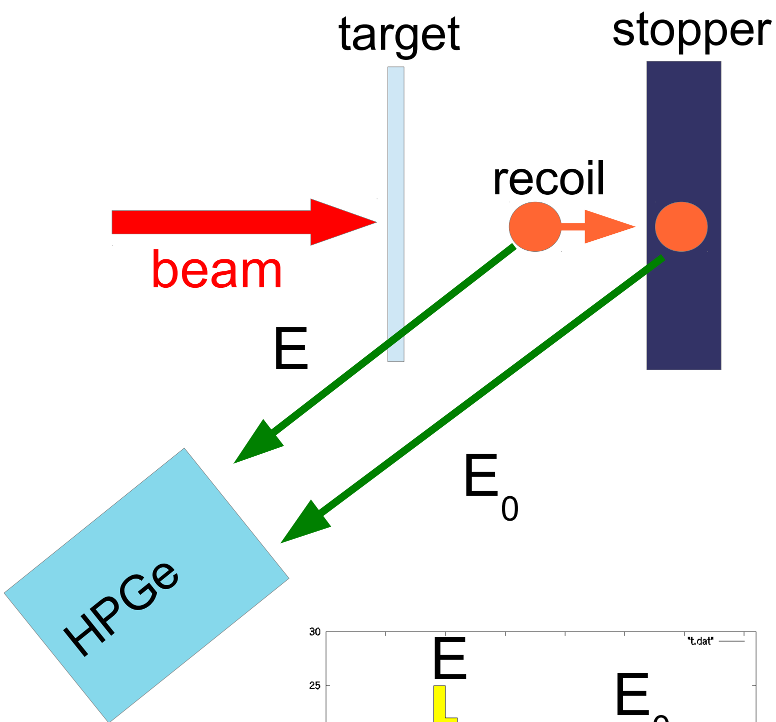
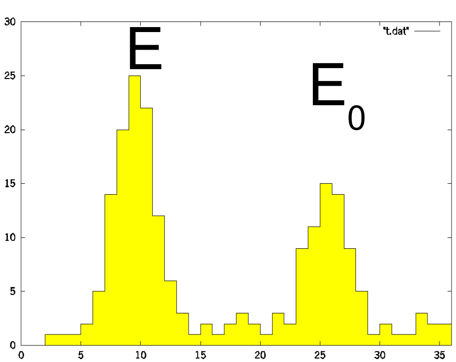
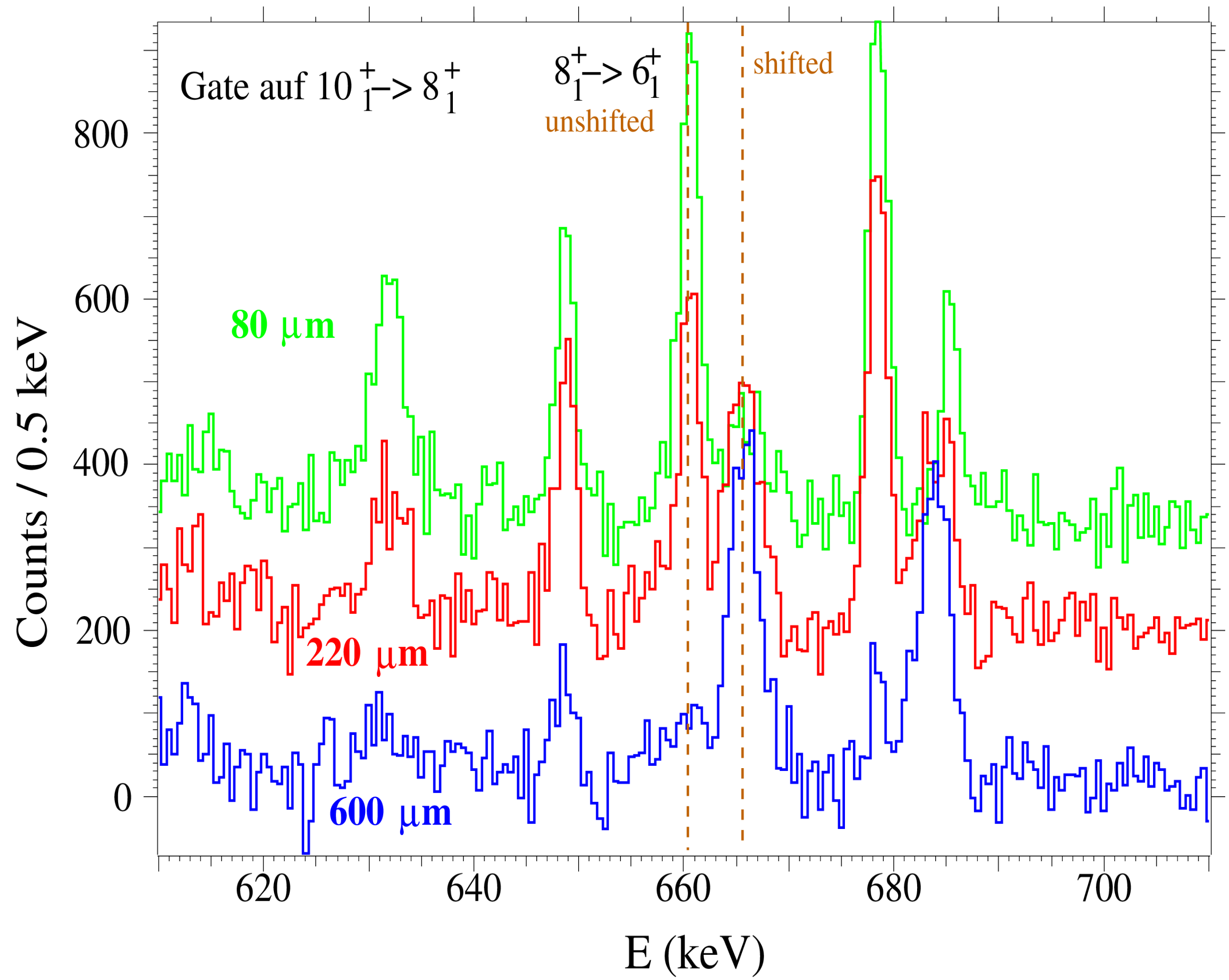
The recoil distance Doppler-shift method (RDDS)







$E = E_0\,(1 + v/c \cos\theta)$

$$\tau(t_k) = \frac{I^{us}(t_k)}{\frac{d}{dt} I^{sh}(t_k)}$$

I^{us} = Intensity of the unshiftet γ-ray line

I^{sh} = Intensity of the Doppler-shifted component

$^{92}Mo(^{10}B,3np)^{98}Pd$

Motivation: Combination of the Recoil Distance Doppler-shift (RDDS) method with Coulomb excitation

Advantages:

→ Precise measurements of lifetimes via other techniques (RDDS,...) reduces number of coupled channels sensitive to the data which simplifies Coulomb excitation analysis.

→ lifetimes determined in model-independent way.

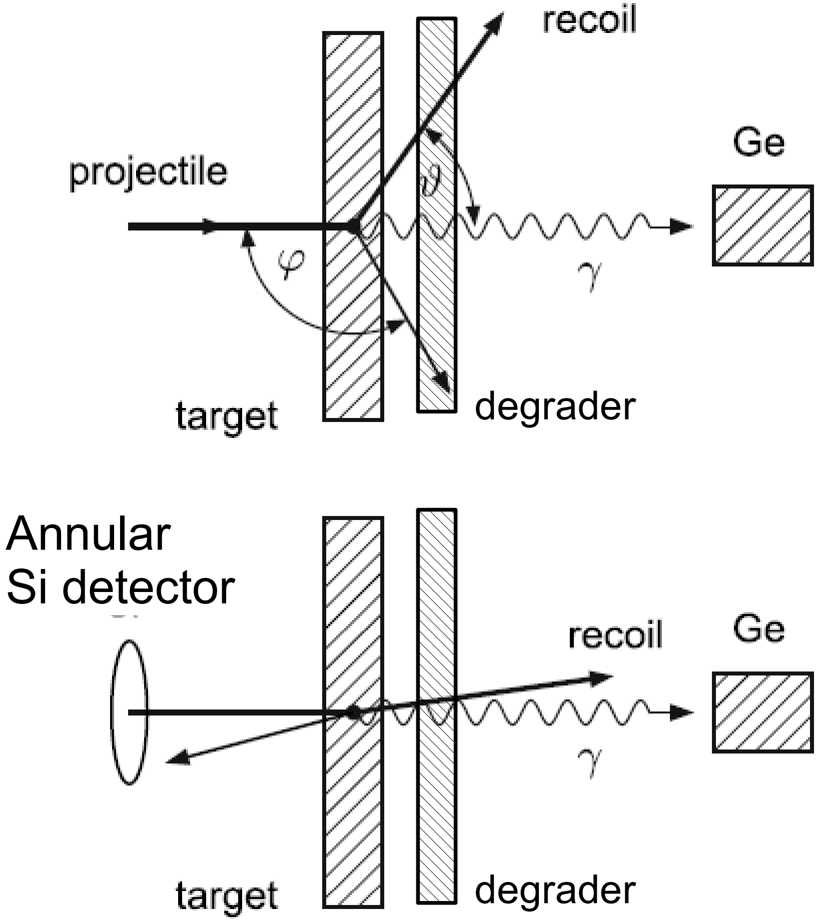
→ no need to measure absolute cross sections requiring efficiency information.

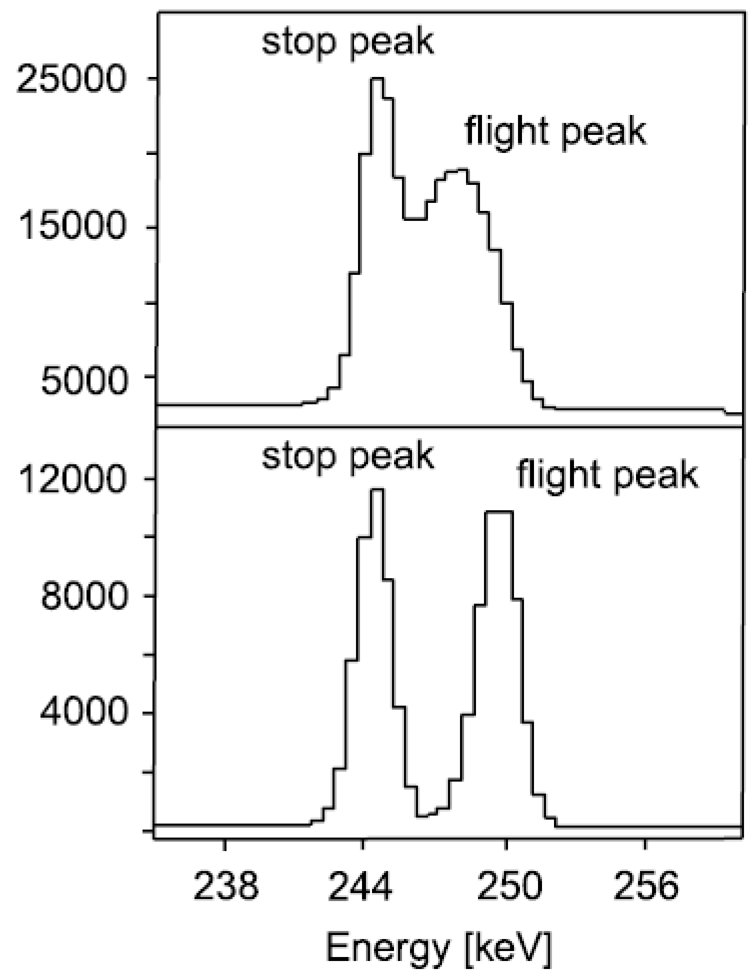
→ can also analyze Coulex data.

Disadvantage:

→ need to measure at several target – degrader distances

Coulex + RDDS:
1. particle tracking for reconstruction of kinematics



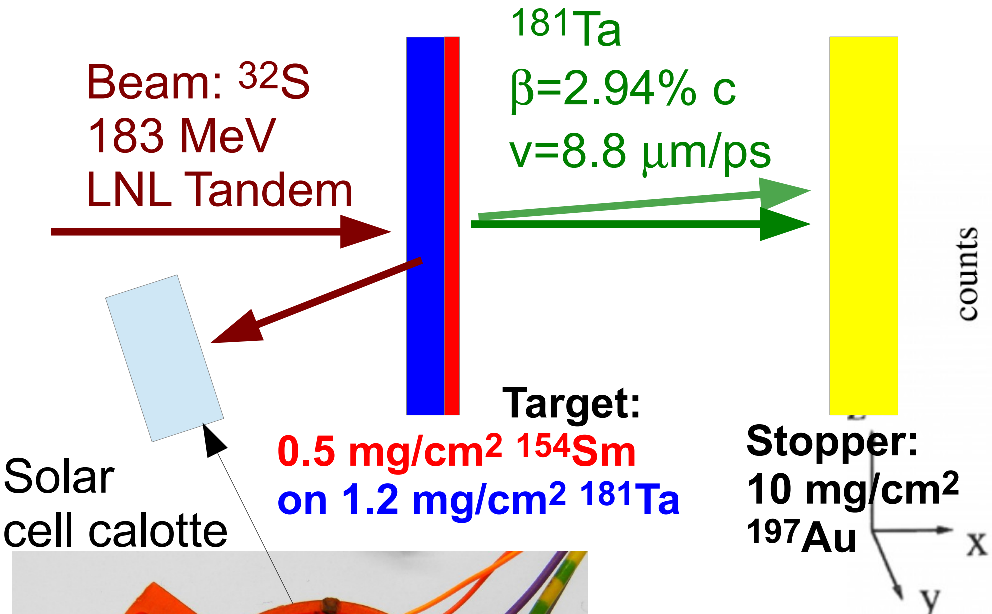


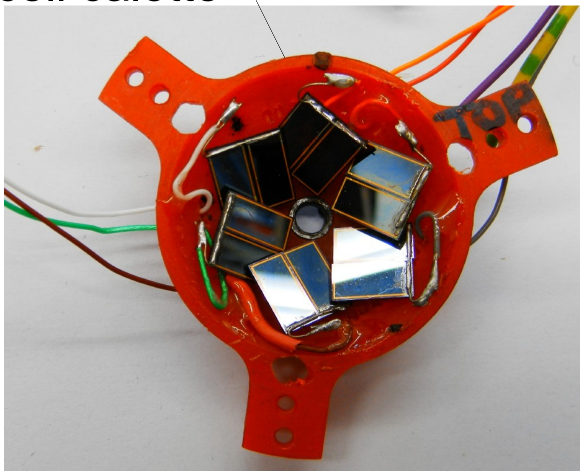
Coulex:
Depending on masses: wide angle spread

Solution: gate on scattered projectiles or recoils with position sensitive particle detector:
reconstruct kinematics

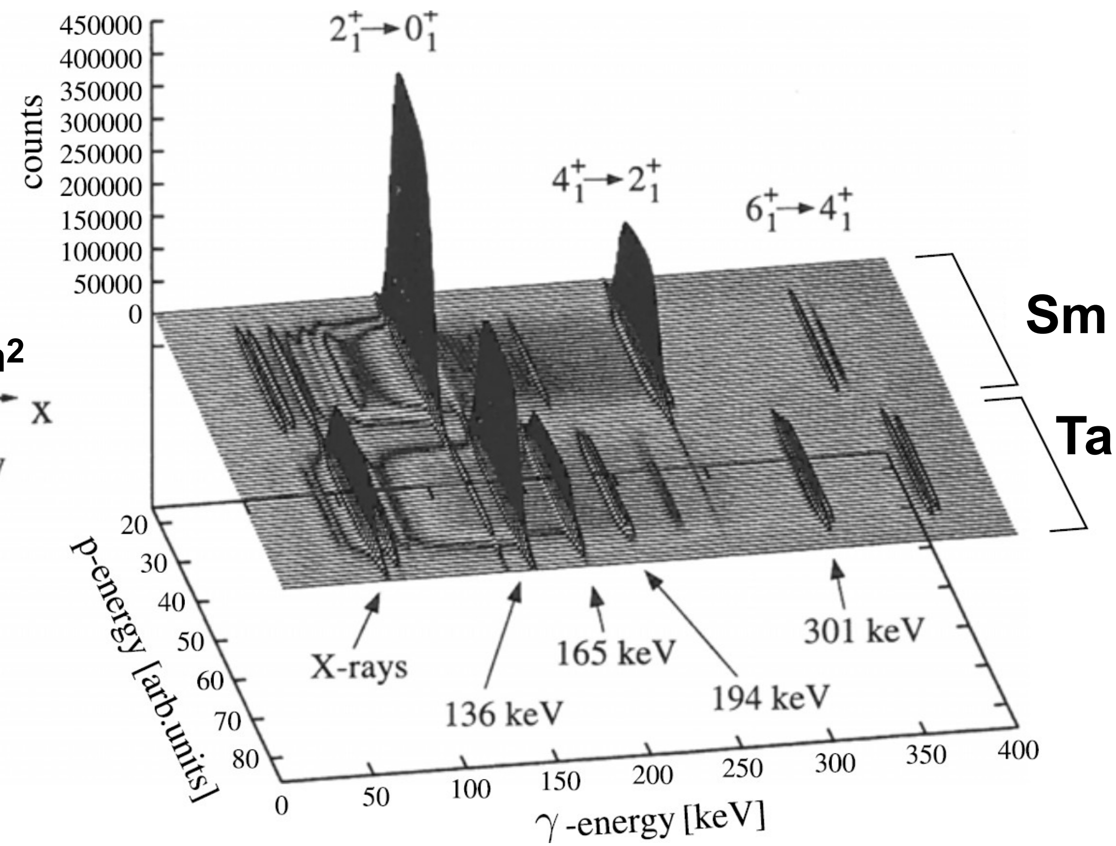
Coulex + RDDS:
2. particle tracking for separation of Coulex channels

Example: Coulex on ^{154}Sm – ^{181}Ta sandwich target





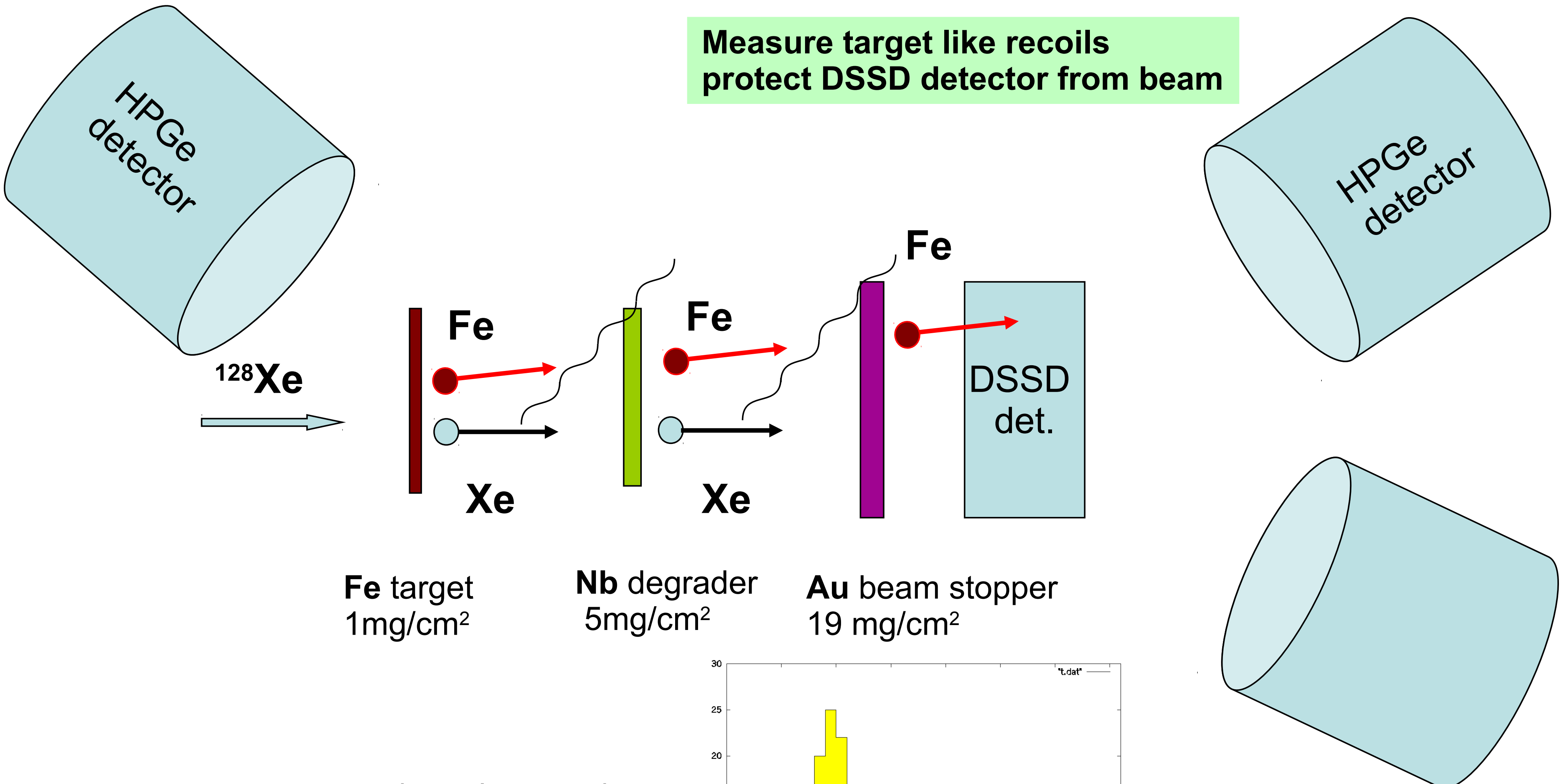
A. Dewald et al.,
Prog. Part. Nucl. Phys. 67, 786 (2012)



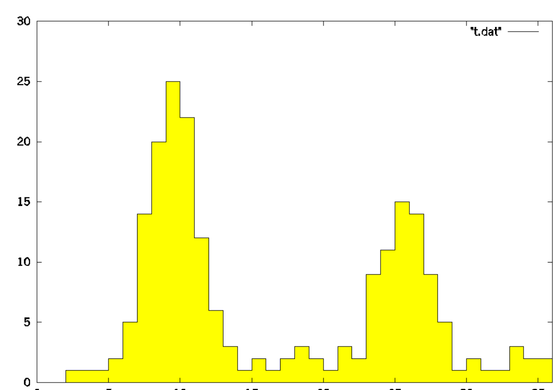
Possibility to measure absolute distances using sandwich target: ^{181}Ta well known lifetimes

Inverse kinematics Coulomb excitation + RDDS

Measure target like recoils
protect DSSD detector from beam

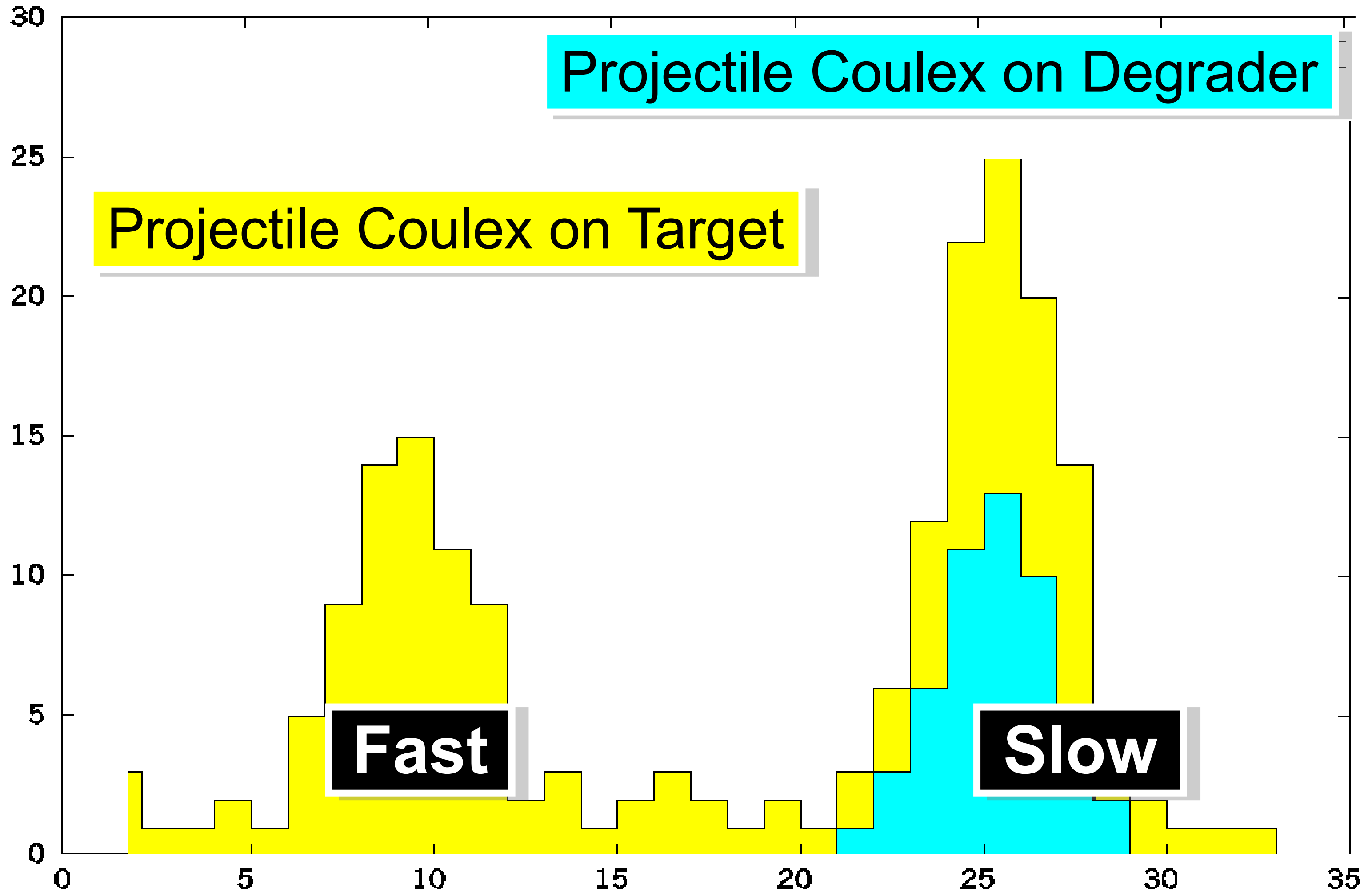


$$E = E_0(1+v/c \cos\theta)$$



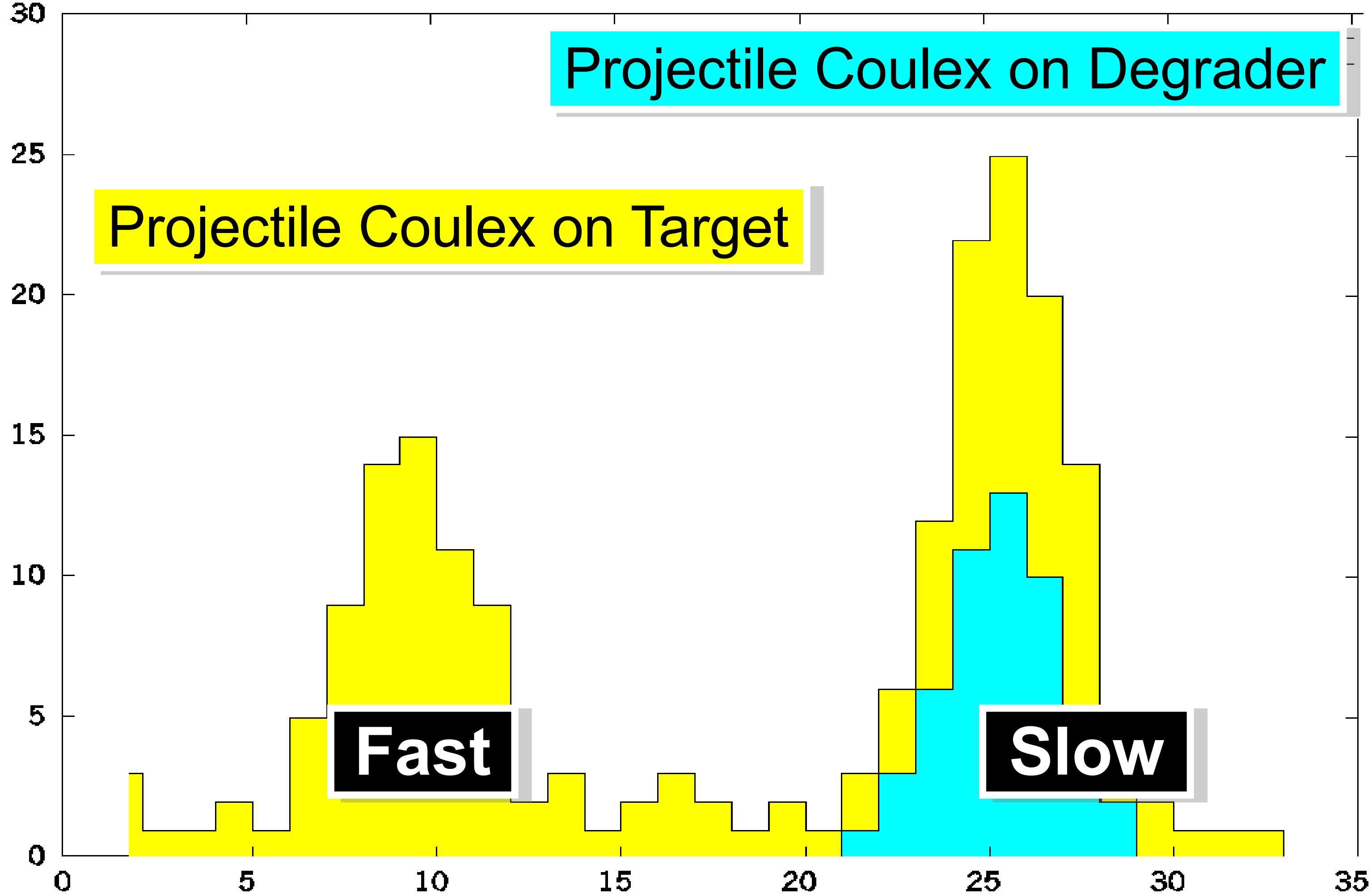
Inverse kinematics Coulomb excitation + RDDS: Contribution from Coulex on degrader

Gate on target recoils:
→ do not observe Coulex on degrader



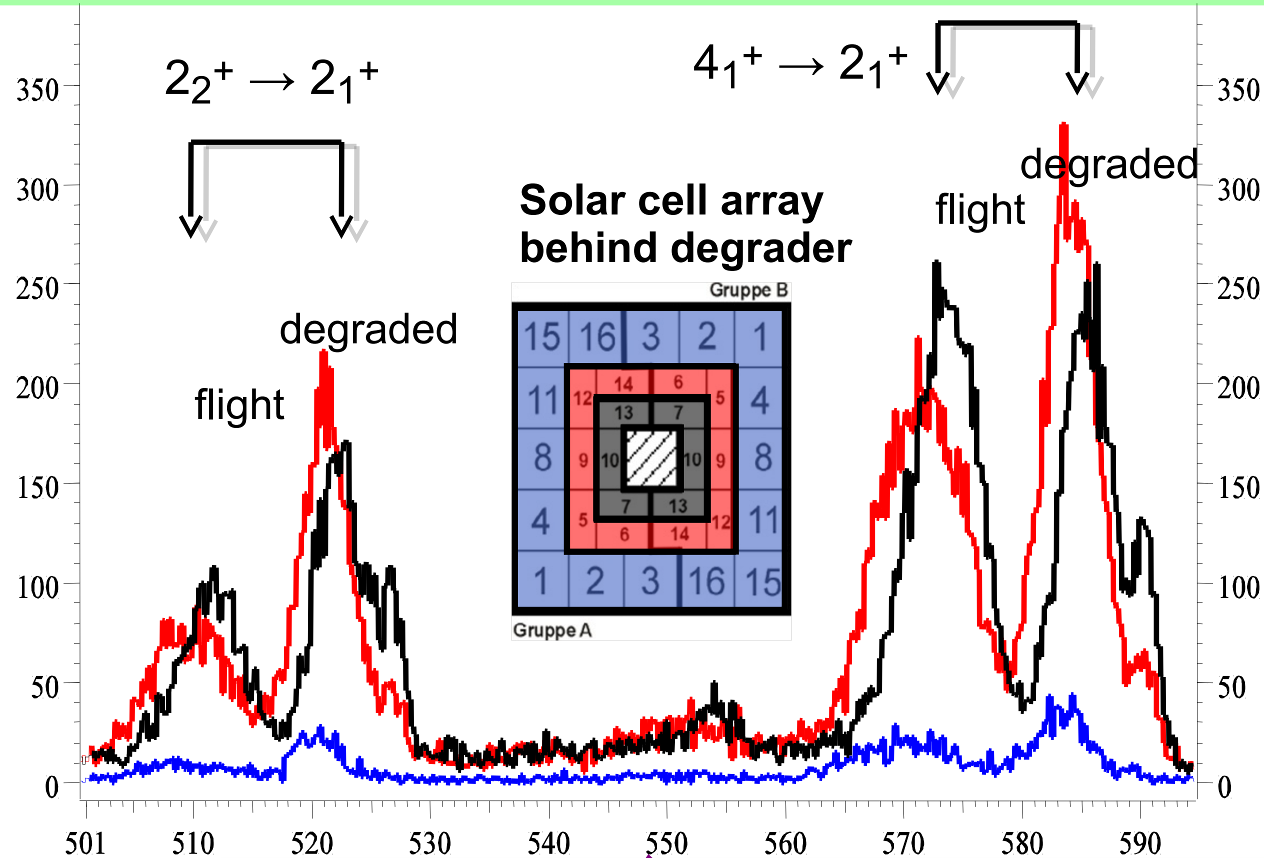
Inverse kinematics Coulomb excitation + RDDS: Contribution from Coulex on degrader

Second option to eliminate Coulex on degrader from data:
measure at large target – degrader distance ($t_{flight} >> \tau_{level}$)
slow component only results from Coulex on degrader

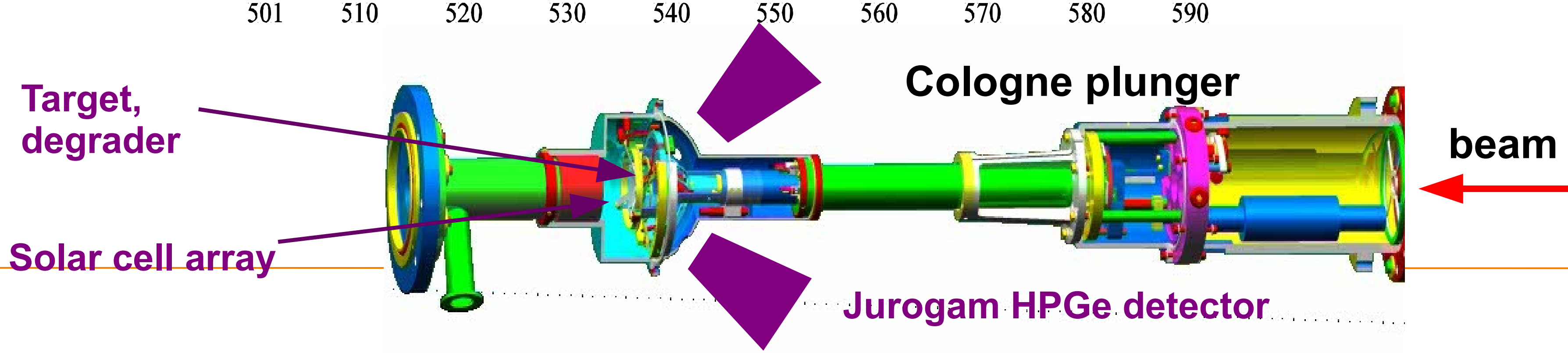


Example: lifetime determination of excited states in ^{128}Xe with inverse kinematics Coulex + RDDS at JYFL

Gating on target recoils:
reconstruct kinematics from particle emission angles: improve γ-resolution

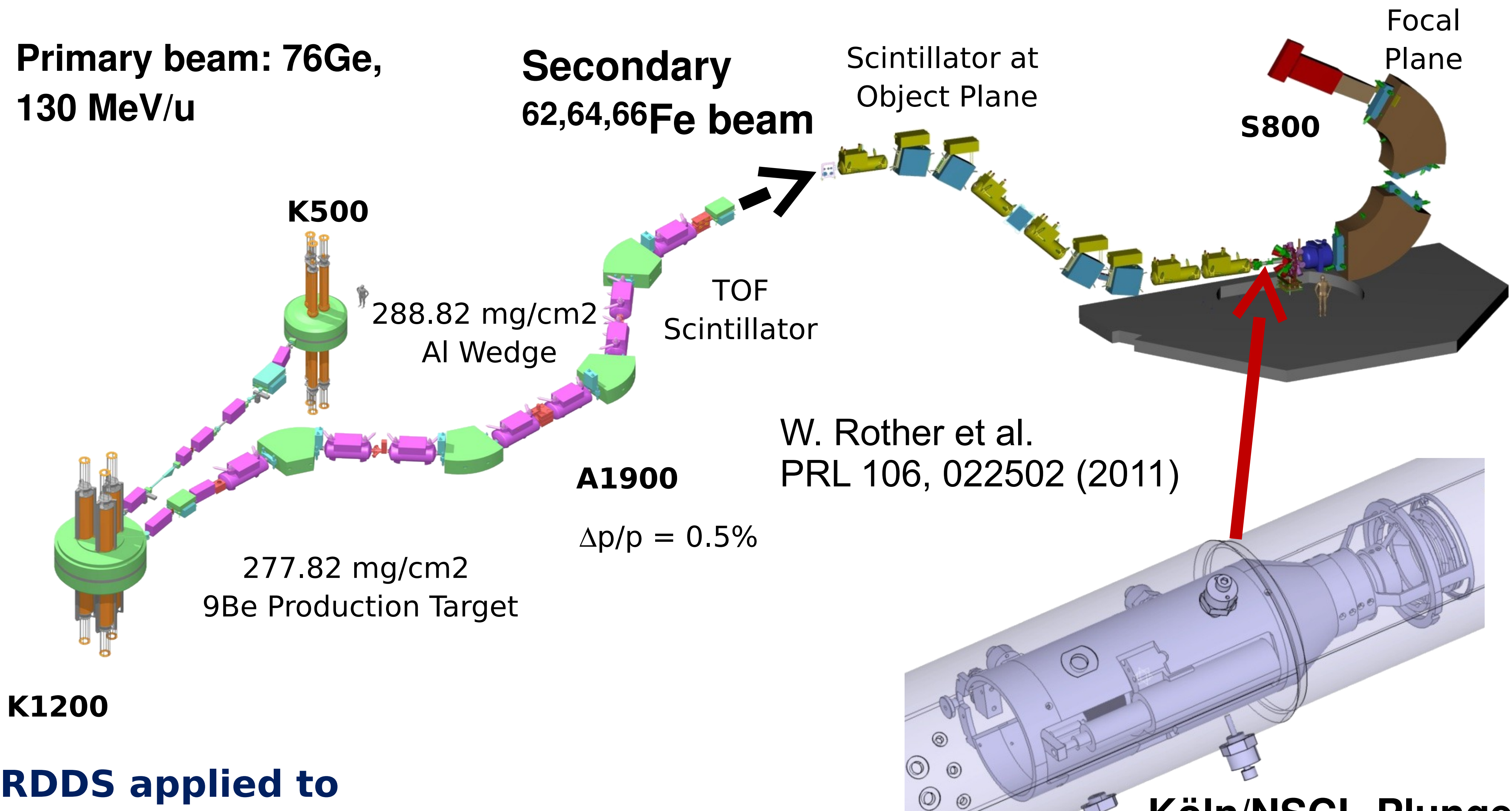


W. Rother et al.,
NIM A 654, 196 (2011)



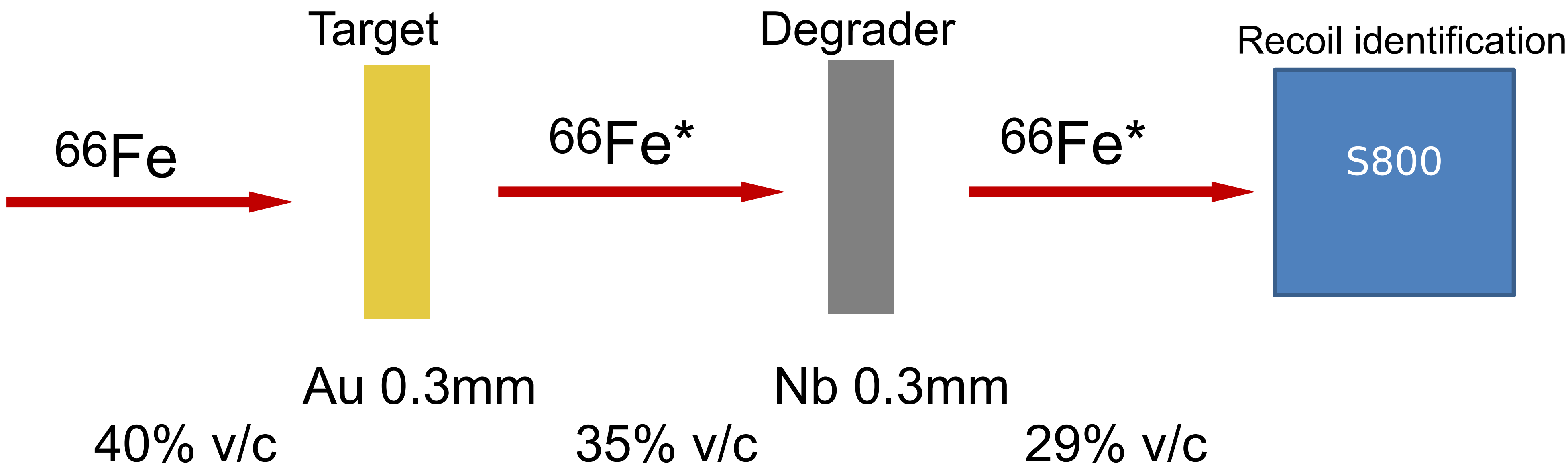
Further example: Coulex + RDDS with fast radioactive beams: ^{62,64,66}Fe 2_1^+ lifetime measurement at NSCL

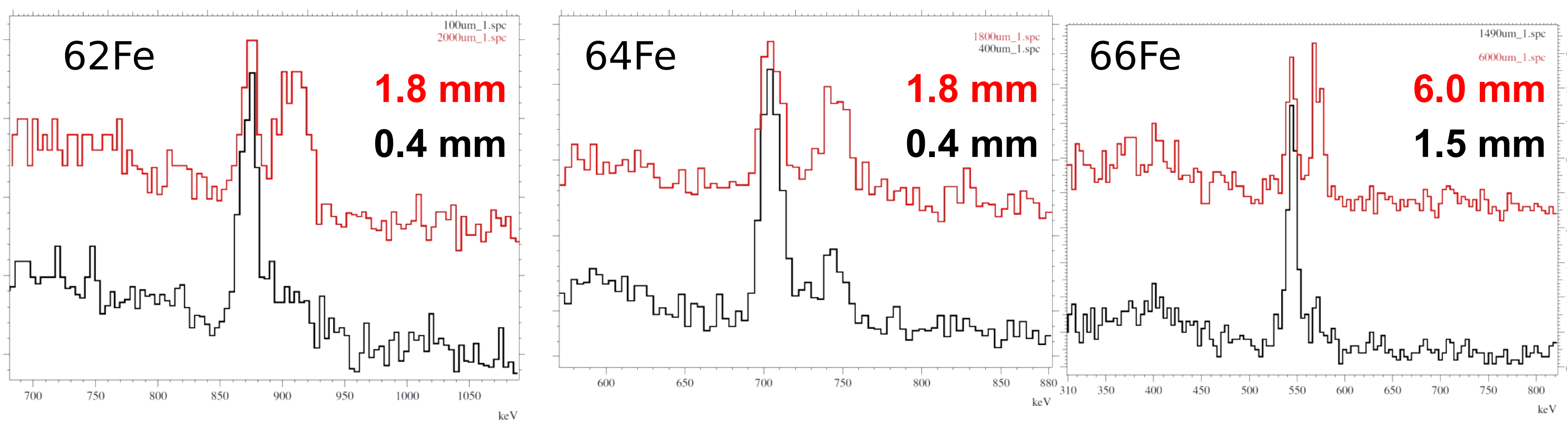
NSCL, Michigan State University, coupled cyclotron facility + A1900 fragment separator + S800 mass spectrograph



RDDS applied to projectile (^{62,64,66}Fe) Coulomb excitation reactions at intermediate energies (88-98 AMeV)

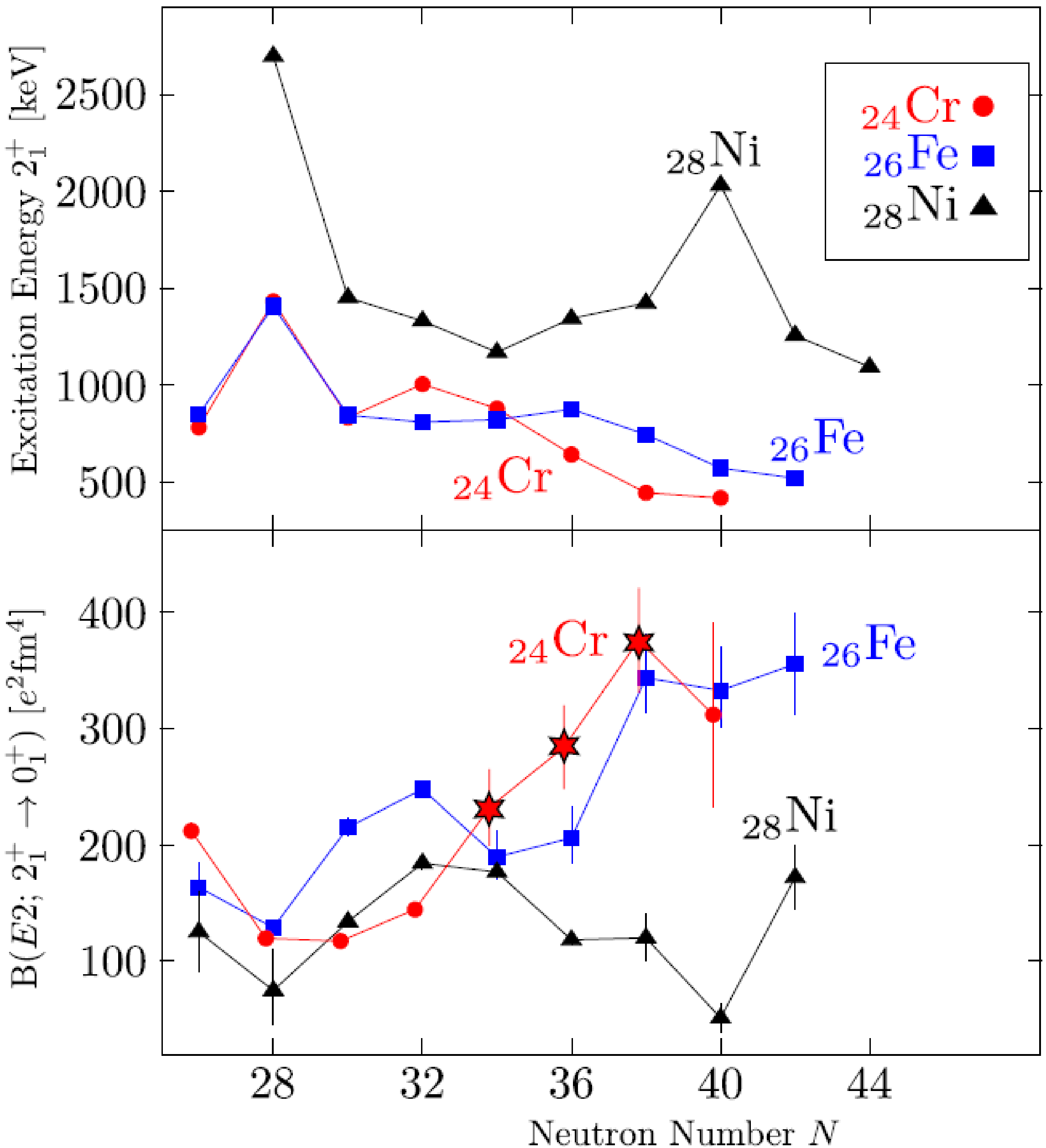
Investigation of $^{62,64,66}Fe$: RDDS + Coulex inv. kinematics





Largest distance of 20 mm:
estimate contribution from Coulex on degrader

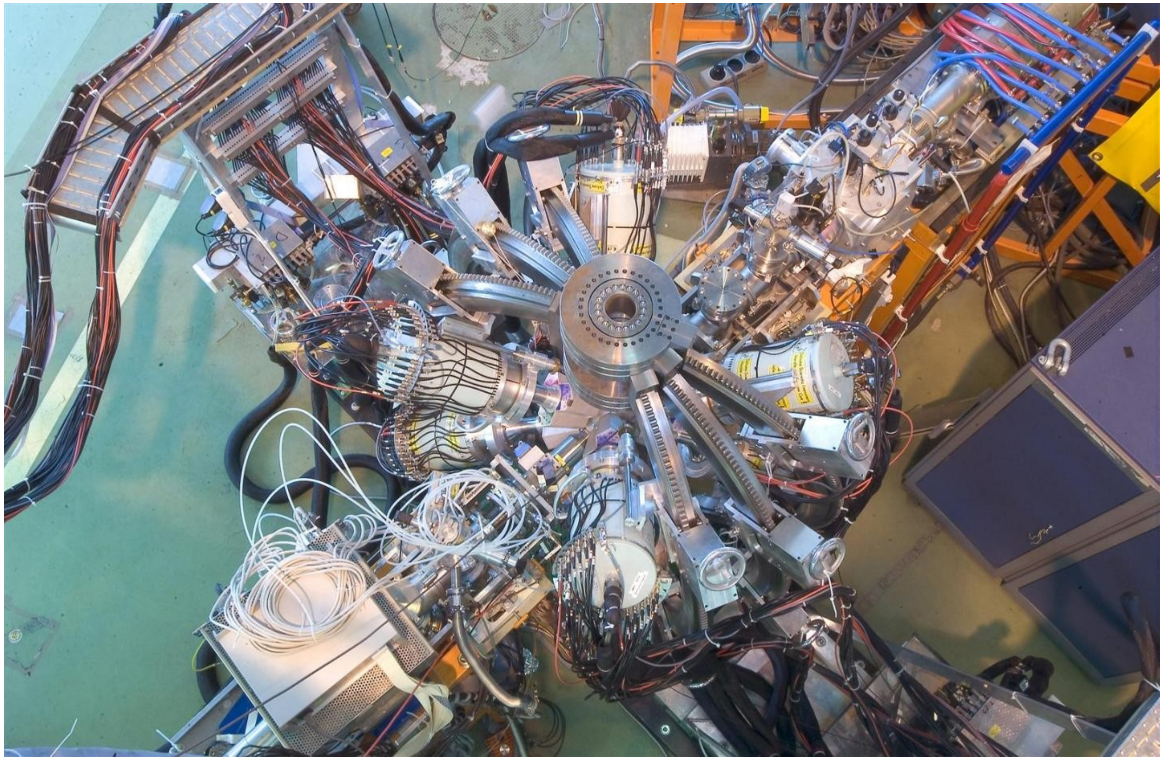
RDDS with fast radioactive beams:
Results for neutron-rich Fe, Cr



Increasing collectivity towards N=40
No N=40 subshell closure in Fe, Cr

W. Rother et al.
PRL 106, 022502 (2011)

A plunger for the MINIBALL spectrometer at HIE-ISOLDE

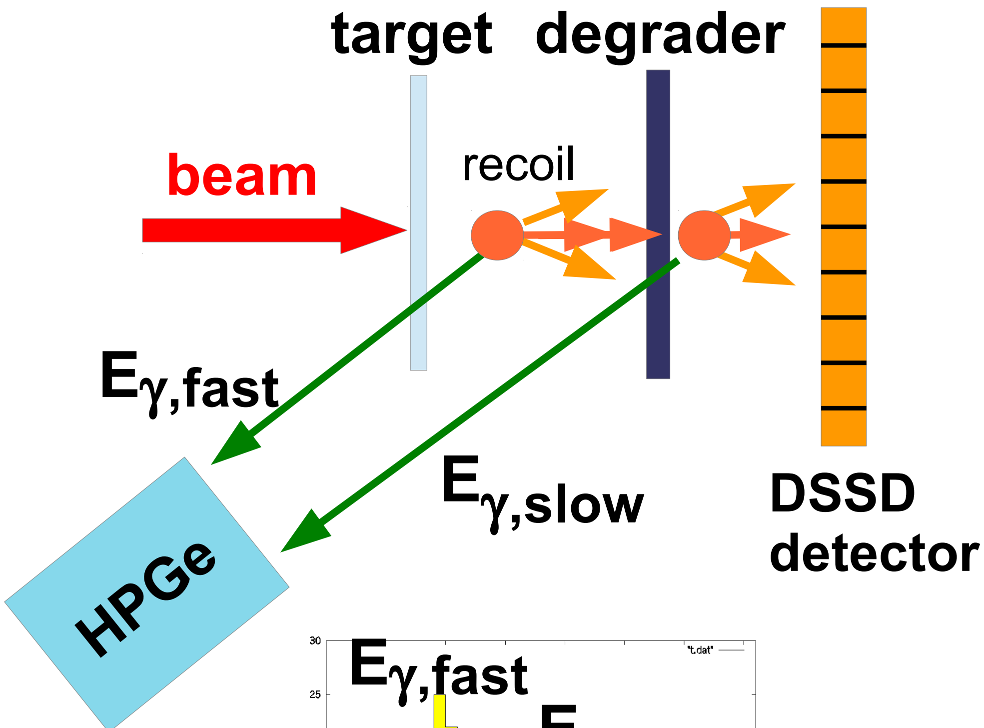


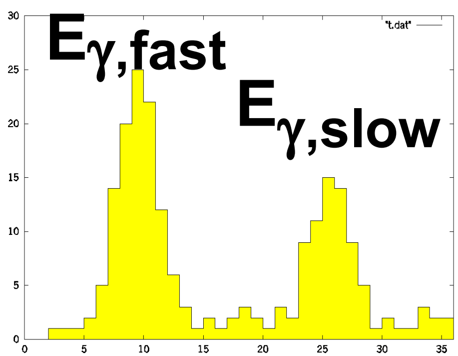
MINIBALL:

→ 24 six-fold segmented high-purity germanium crystals

→ designed for low multiplicity experiments with low-intensity radioactive ion beams ~5.5 MeV/u

A new plunger device for MINIBALL





$$E_{\gamma,fast} = E_{\gamma,0}\,(1 + v_{fast} / c \cos\theta)$$

$$\tau = I_{slow}(t) \,/\, \frac{d}{dt} I_{fast}(t)$$

Recoil Distance Doppler-shift technique (RDDS)

→ lifetimes of levels with RDDS: B(πl) independent lifetime determination

→ nuclear g-factors

Experiments in inverse kinematics with radioactive beams (few MeV/u), e.g.,

→Coulex (NIM A 654, 196 (2011))

→(incomplete) fusion, e.g., after ^{7}Li breakup

Recoil detection with DSSD:

→ separation of reaction channels

→ reconstruction of kinematics (Coulex)

Aim:
Structure of exotic nuclei

Requirements for the new plunger device

1. placement of MINIBALL HPGe detectors under extreme angles (35^o, 145^o) for lifetime measurements
   and different angles for g-factor measurements

2. Minimize material in target chamber

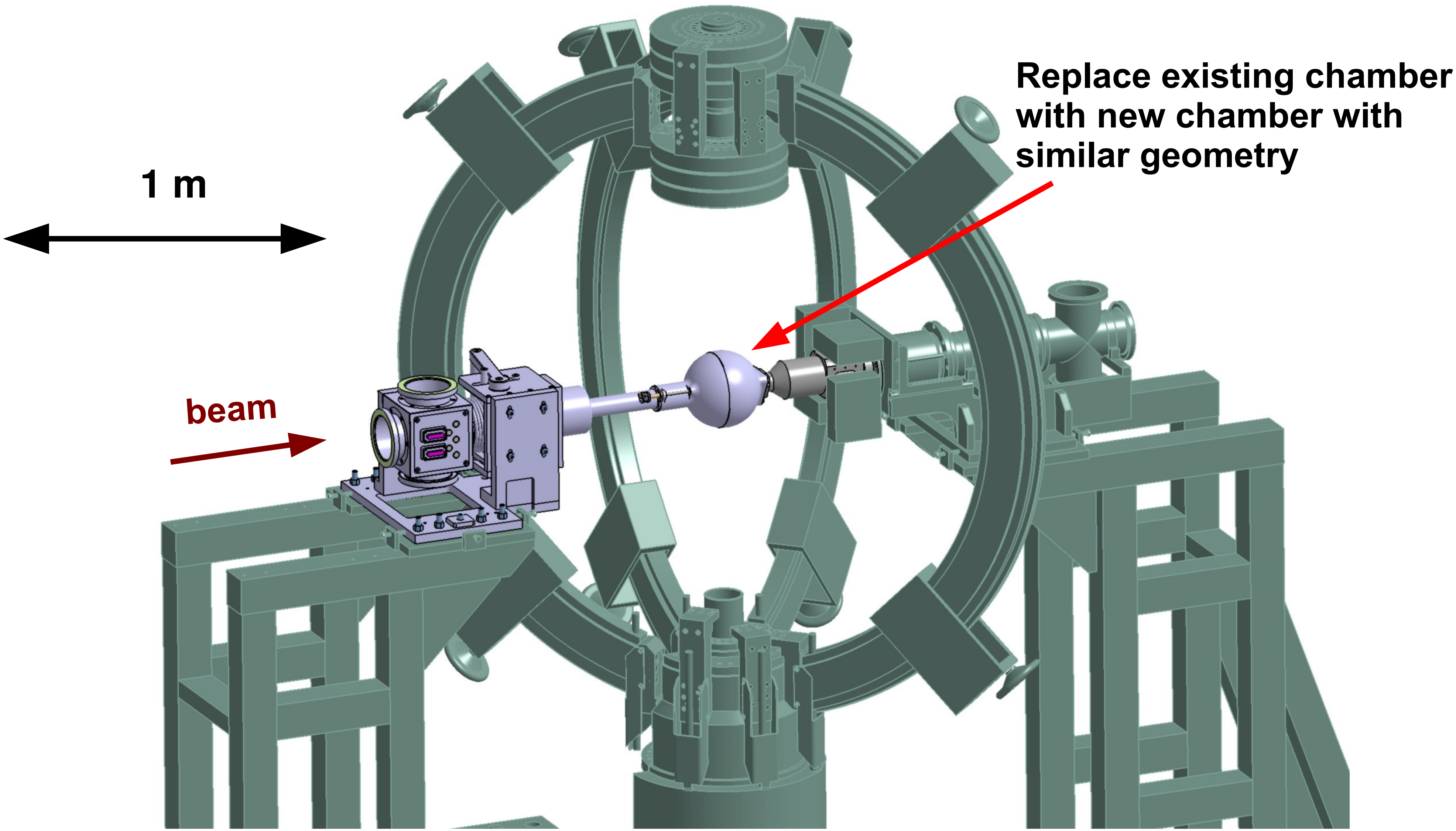
3. DSSD detector downstream from plunger target/degrader

4. target / degrader holders easily replacable with „standard“ target holder: plunger left in place for other experiments.

5. Precision of target – degrader distance: ~0.1 μm

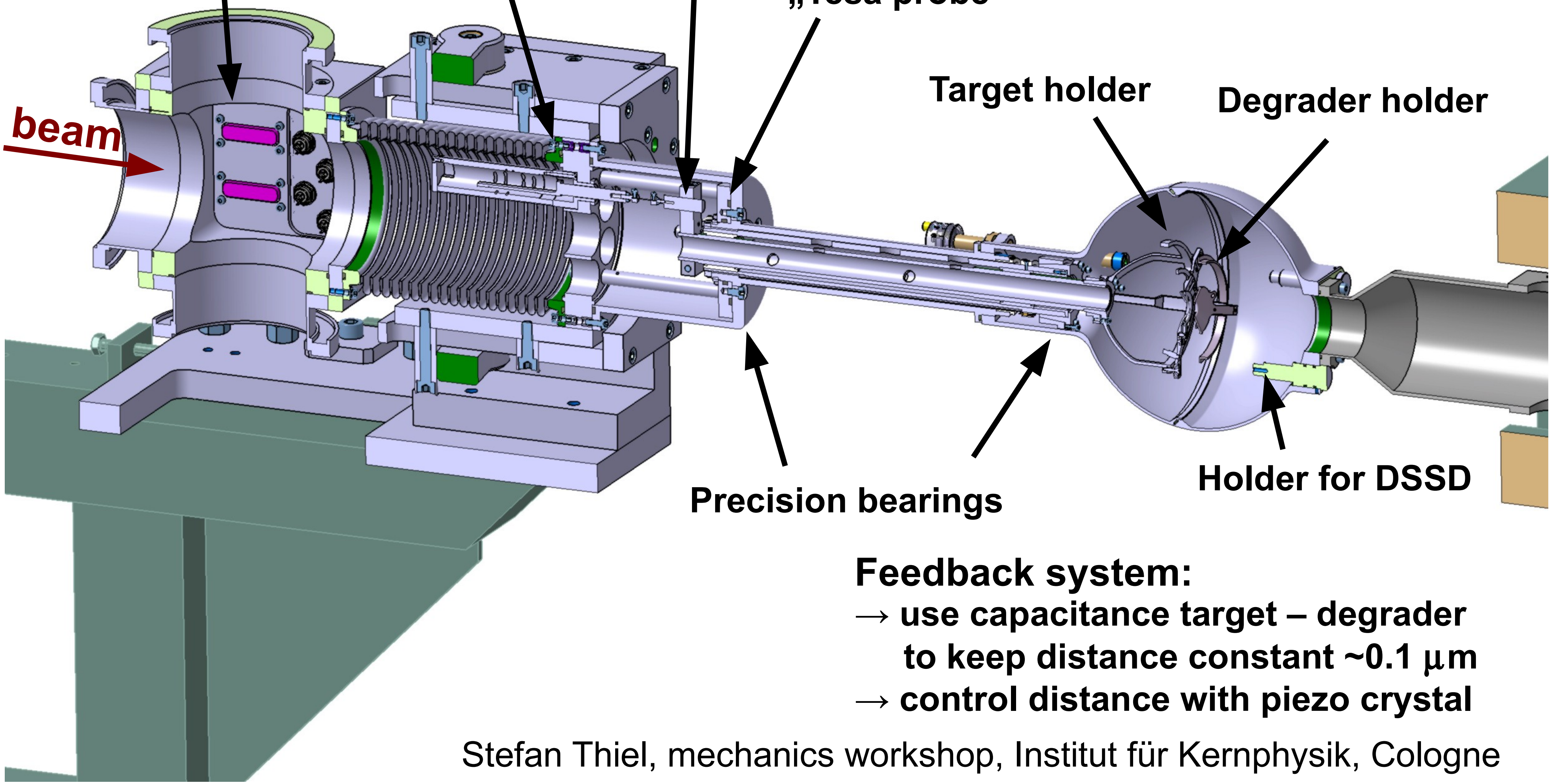
6. target – degrader distance range: 0 – 15 mm:
   v/c ~ 5% $\rightarrow$ τ ~ 1 – 500 ps

General construction



→ **Plunger mechanics in upstream beamline**
→ **Miniball HPGe detectors under angles between 35º and 145º with respect to beam**

Construction of MINIBALL Plunger



Feedback system:

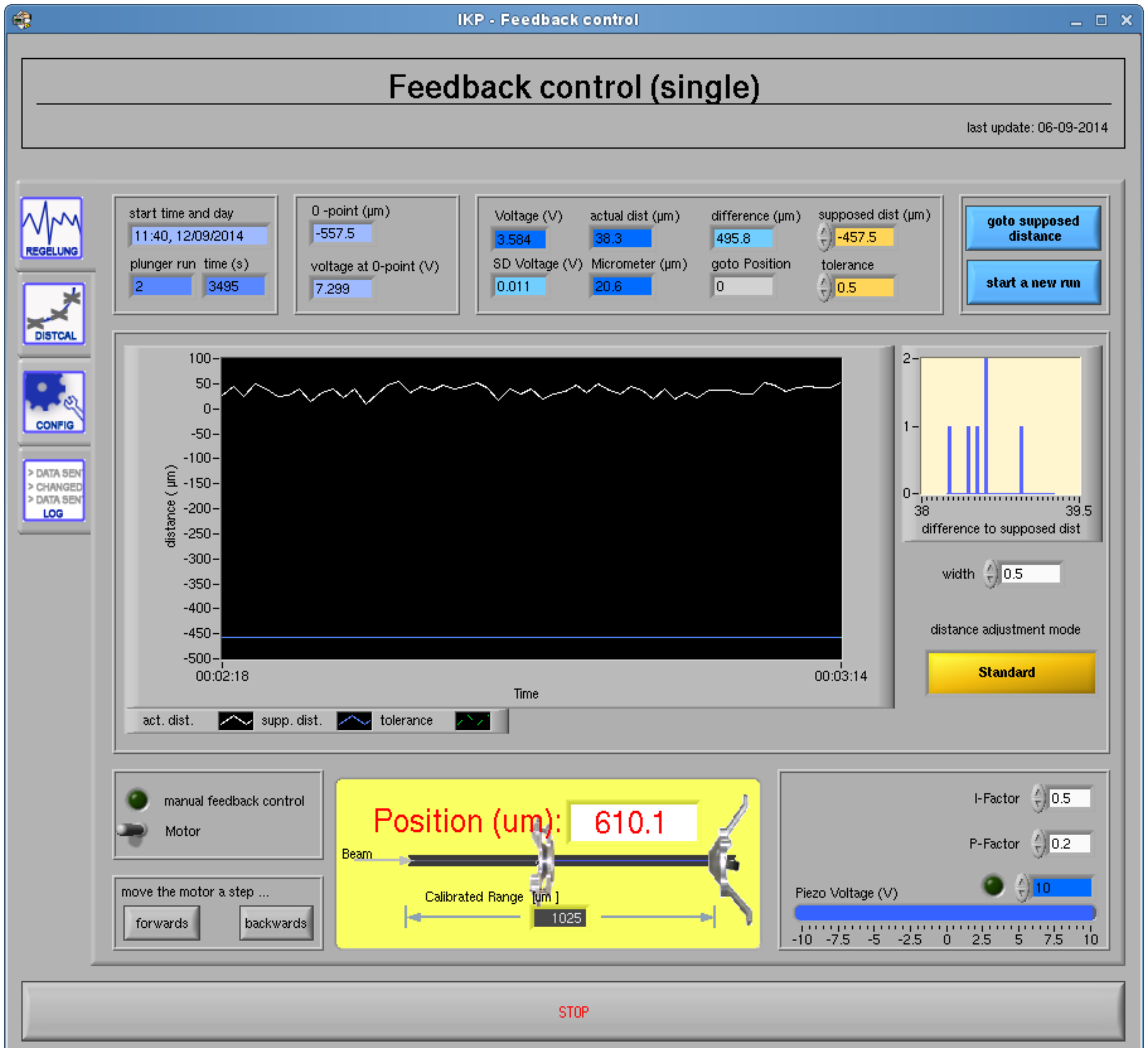
→ use capacitance target – degrader to keep distance constant ~0.1 µm

→ control distance with piezo crystal

Stefan Thiel, mechanics workshop, Institut für Kernphysik, Cologne

Control software: GUI for feedback system

→ keep distance target – degrader constant (thermal effects)
→ read capacitance signal and deduce relative distance from calibration

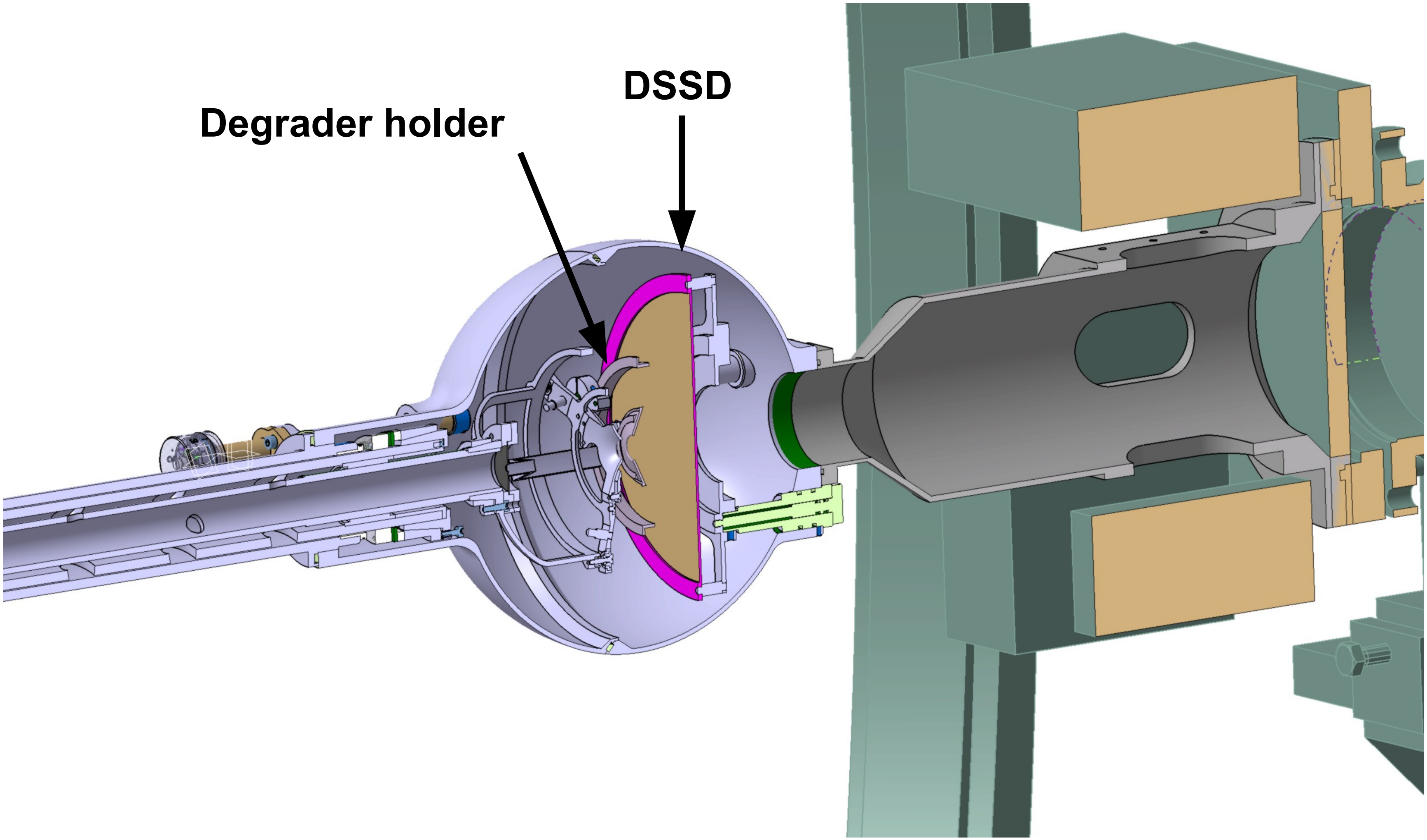


Motor for distance changes target – degrader:
PI Physik Instrumente
model N381 K001
accurancy < 0.3 µm
→ motor can be used for feedback system, but (so far) higher reliability with separate piezo crystal

T. Braunroth, IKP Cologne

Cologne Miniball plunger: mounting target/degrader

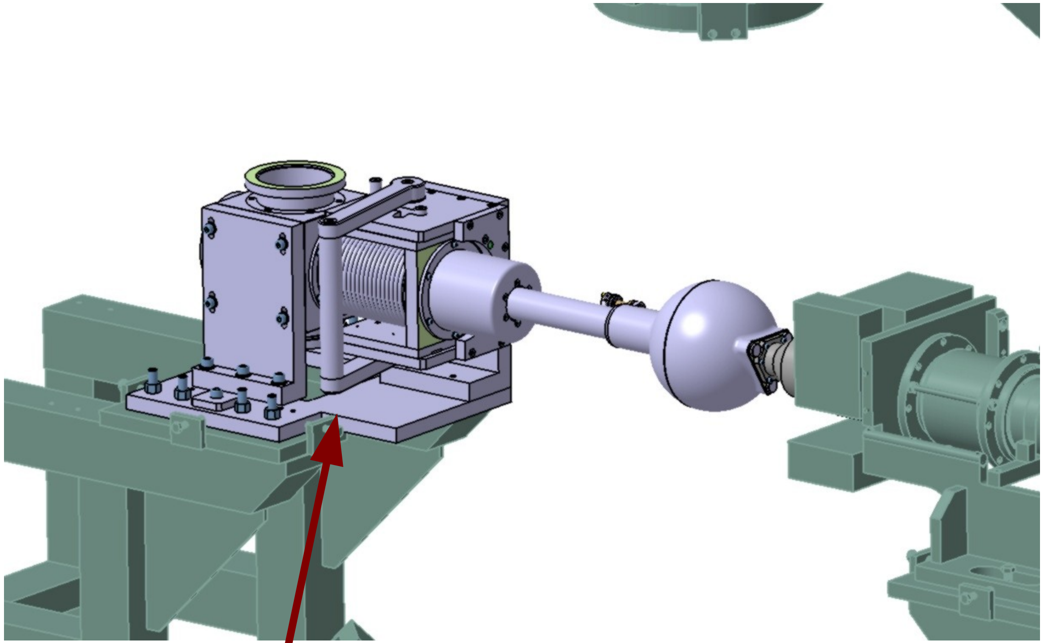
Distance between DSSD detector and degrader holder: only few mm!
→ no way to mount/align target/degrader without risk to damage DSSD



→ solution: upstream part of plunger can be moved completely out of beam axis

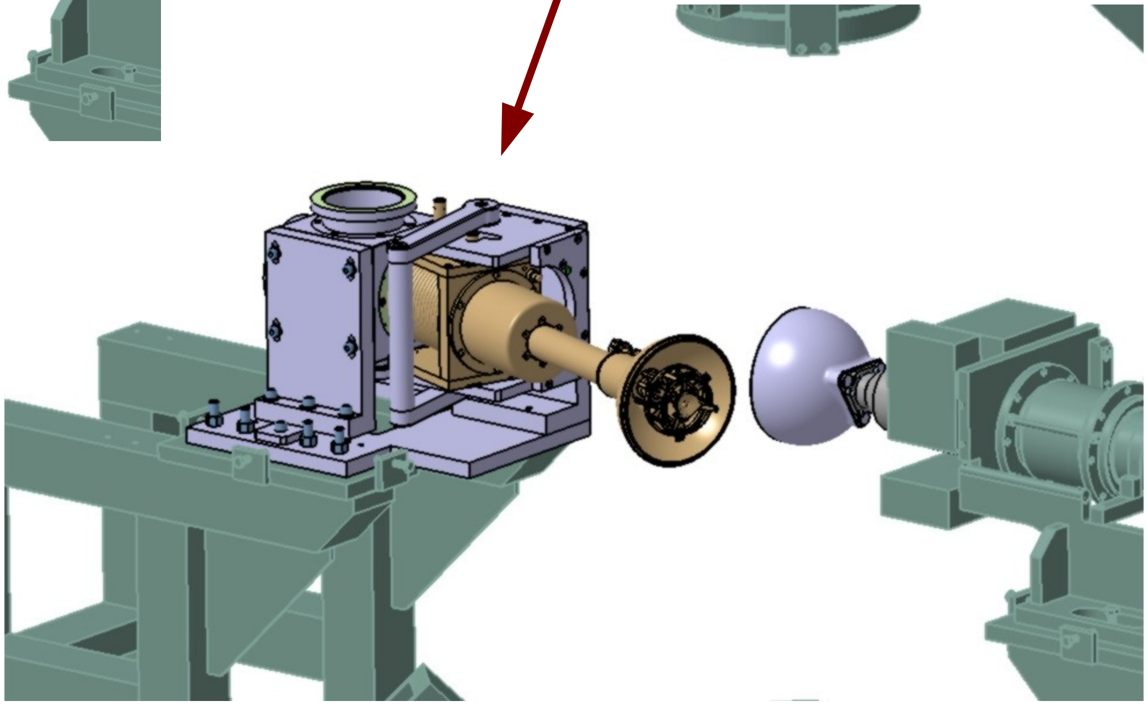
Cologne Miniball plunger: mounting target/degrader

→ solution: upstream part of plunger can be moved completely out of beam axis



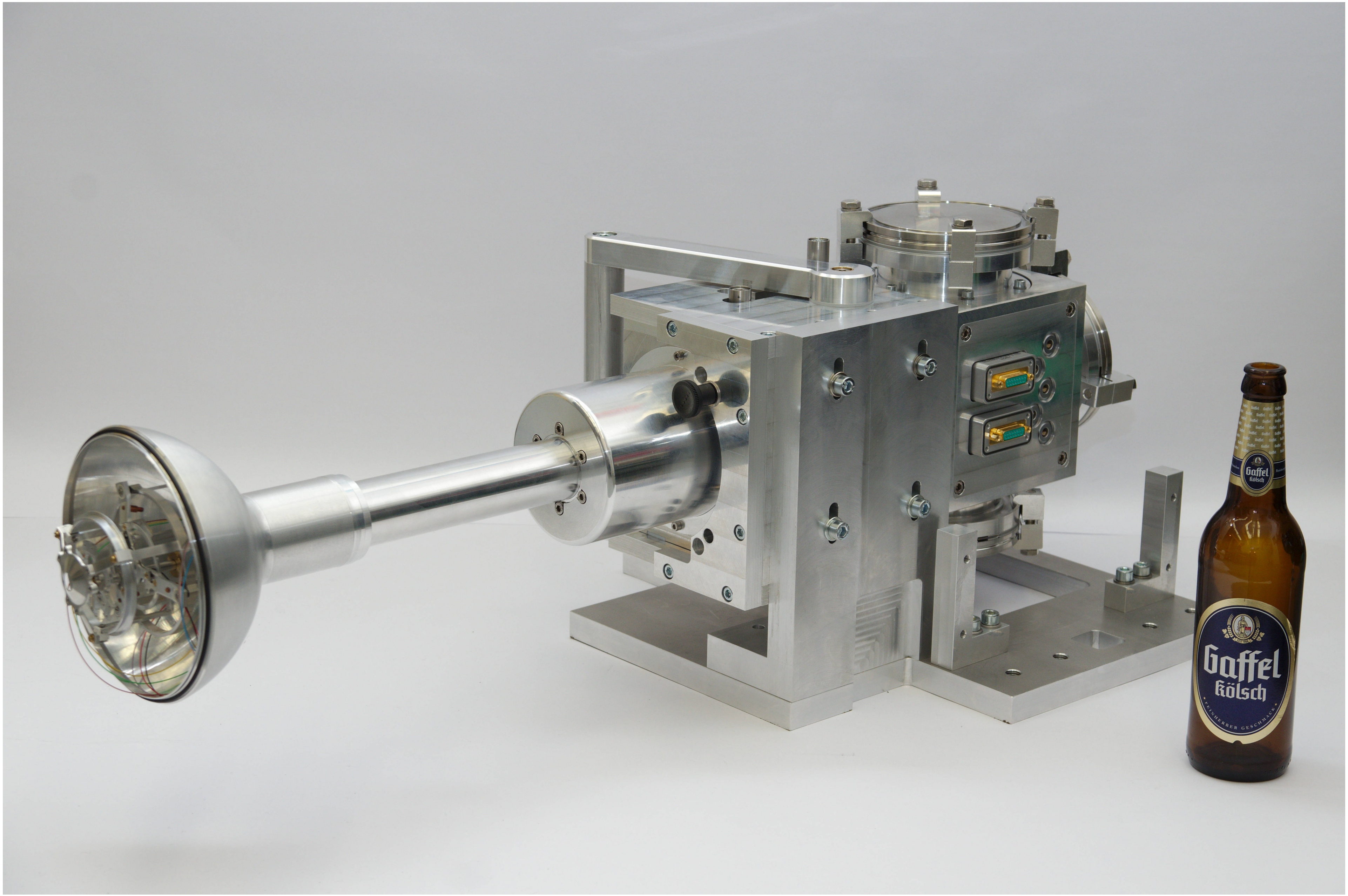
Pivot out of beamline to get
access to chamber

Move plunger back with handle



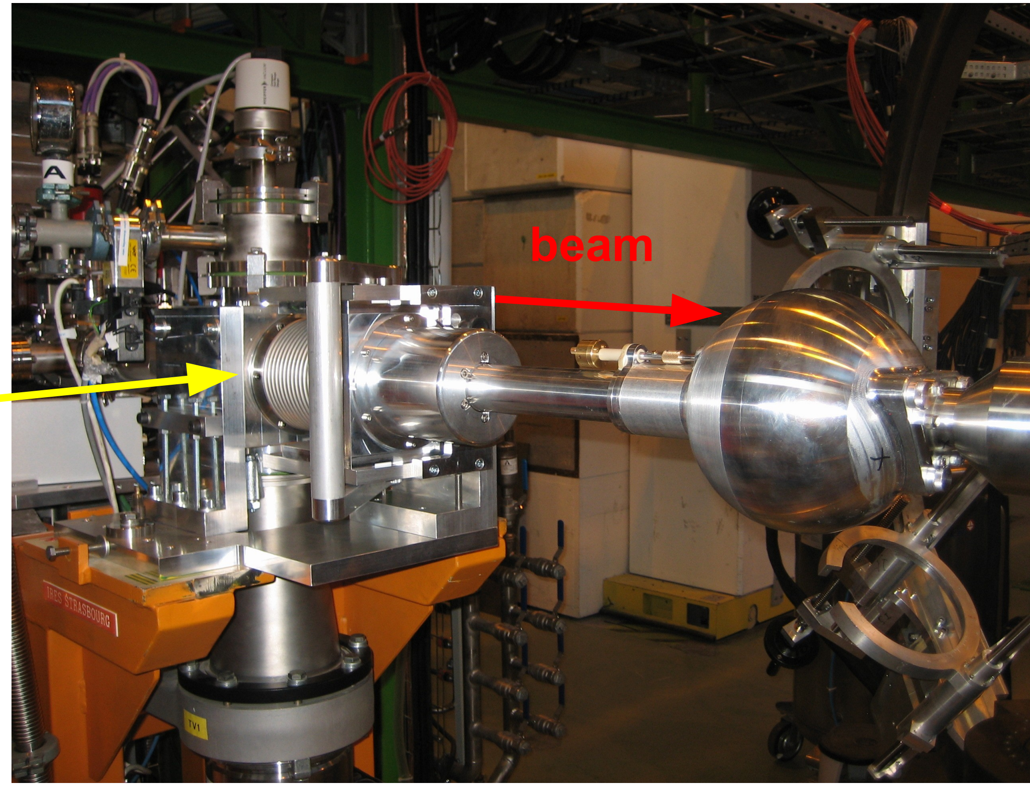
Construction allows repetitious accuracy
with guiding rails and alignment screws

Plunger completely mounted

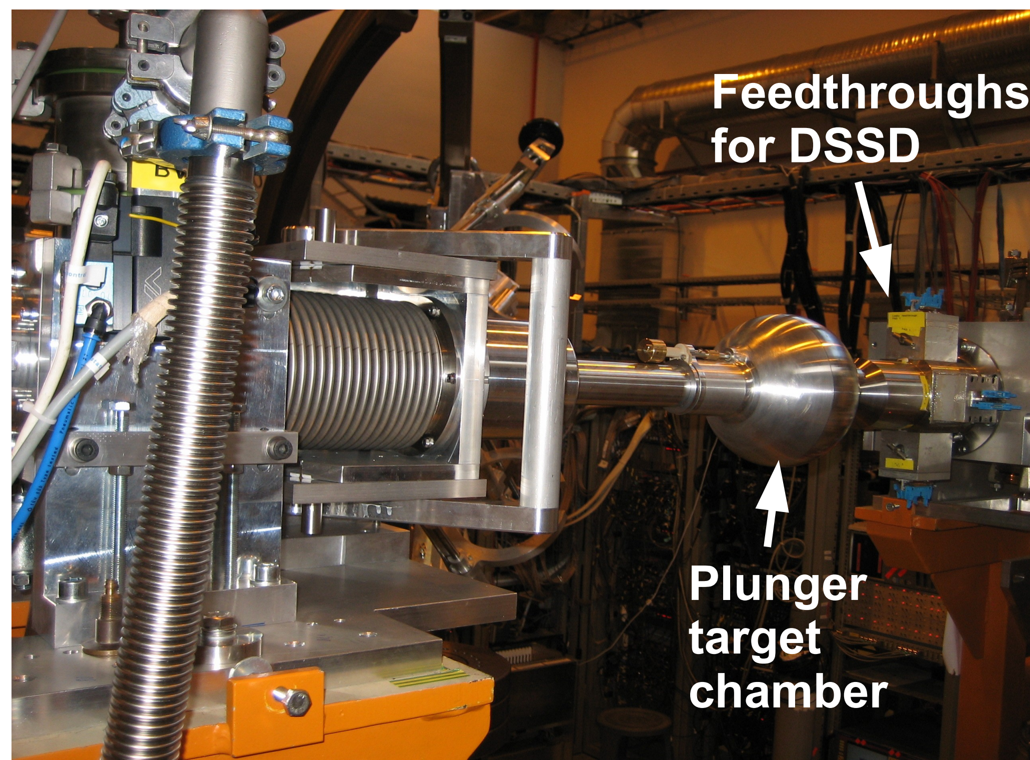


Miniball plunger @HIE-ISOLDE, April 2017

Handle and bellow for pivoting plunger out of beamline

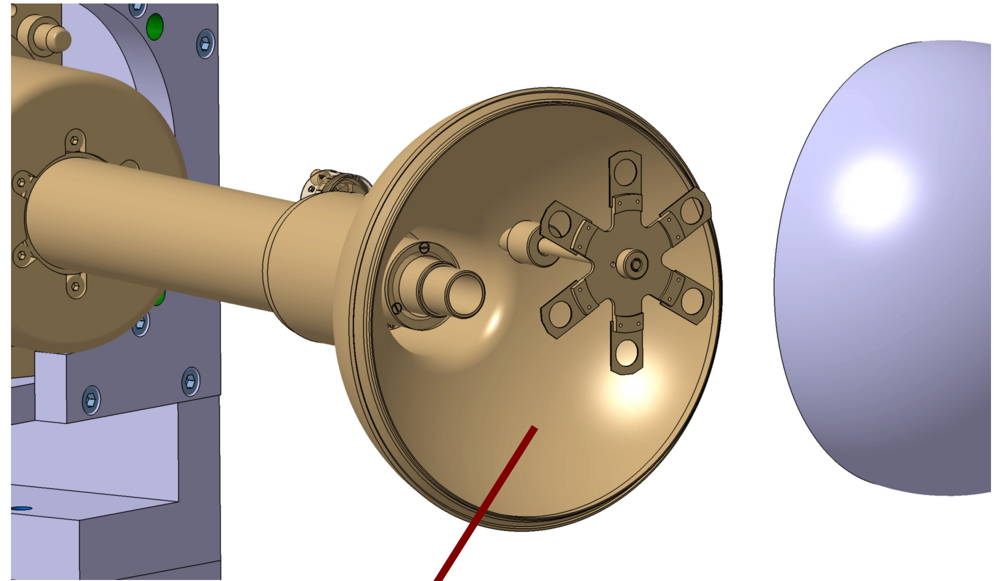


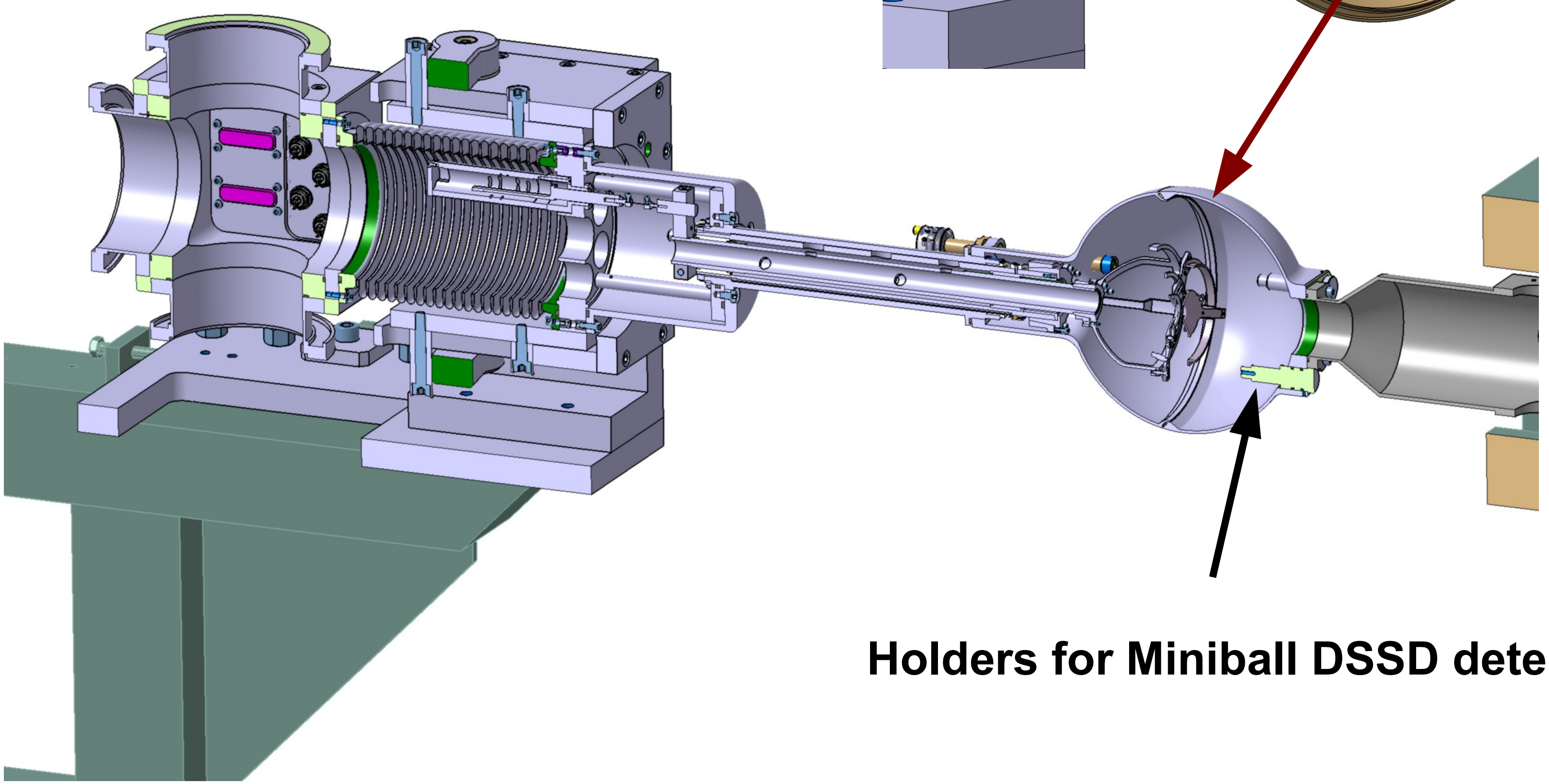
Target chamber:
similar geometry than existing MINIBALL chamber for Coulex



Cologne Miniball plunger: use for Coulex experiments

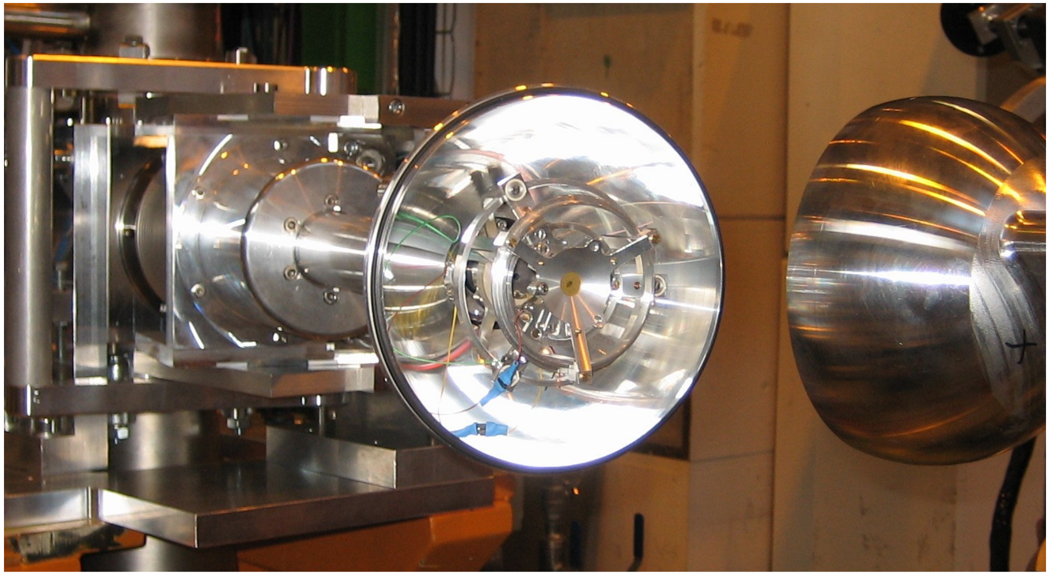
Plunger target and degrader can be easily replaced with „standard“ Miniball target wheel: no need to dismount plunger for Coulex experiments



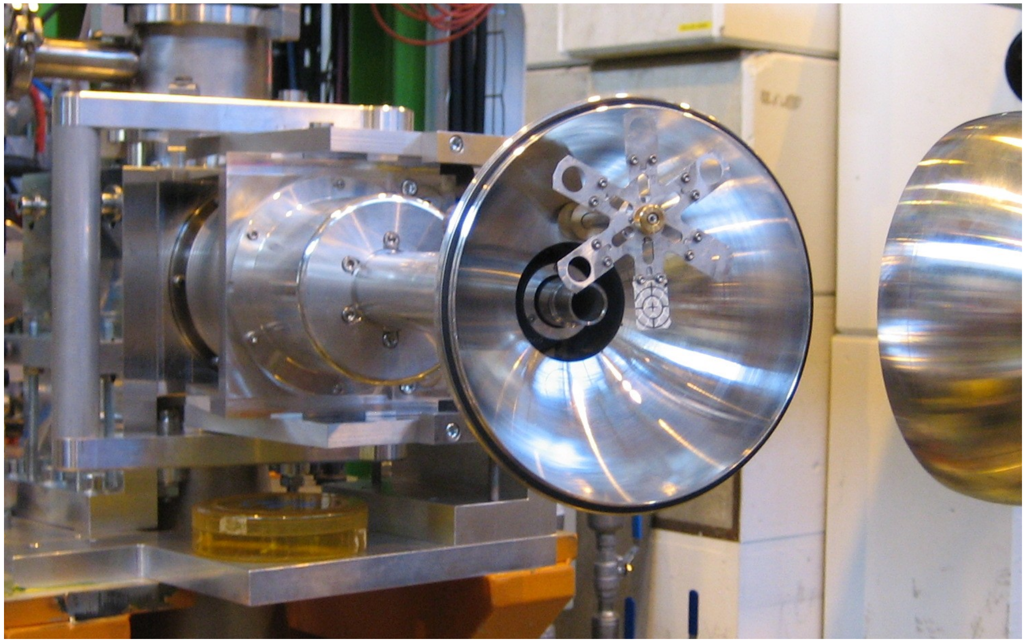


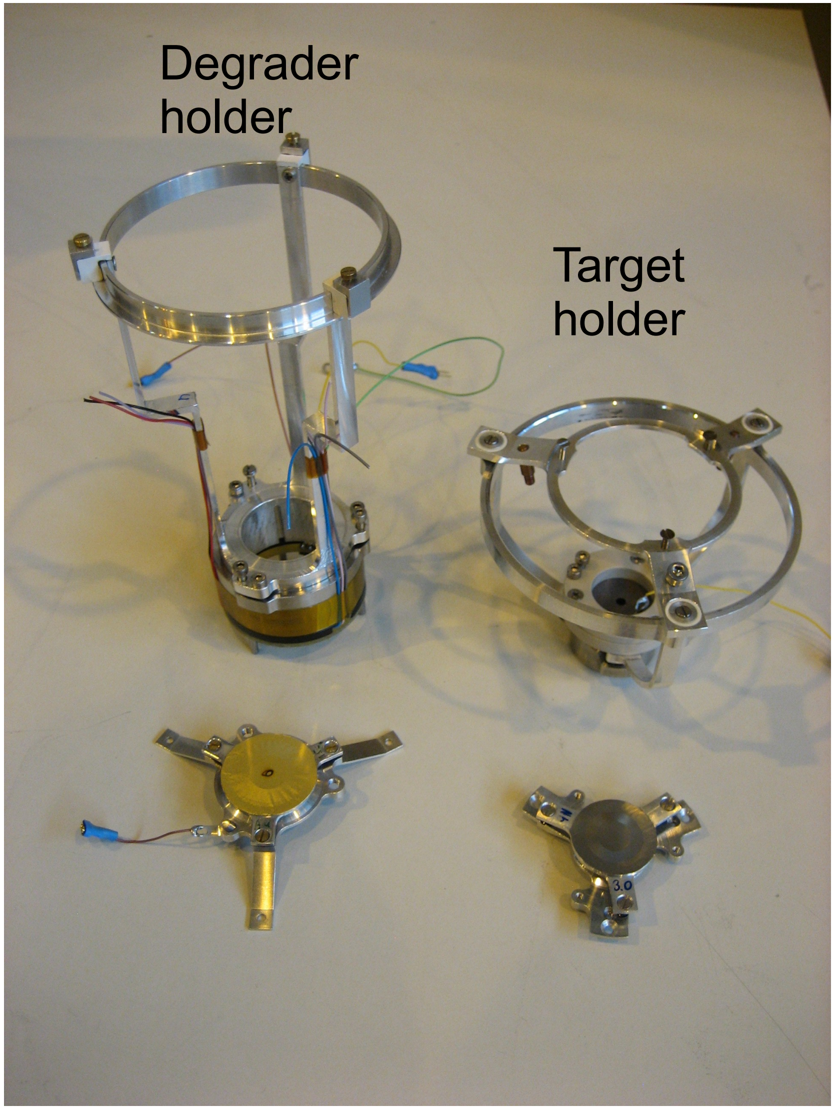
Holders for Miniball DSSD detector

Options: use for lifetime measurements and Coulex



Replace plunger target / degrader holders with target wheel





Status

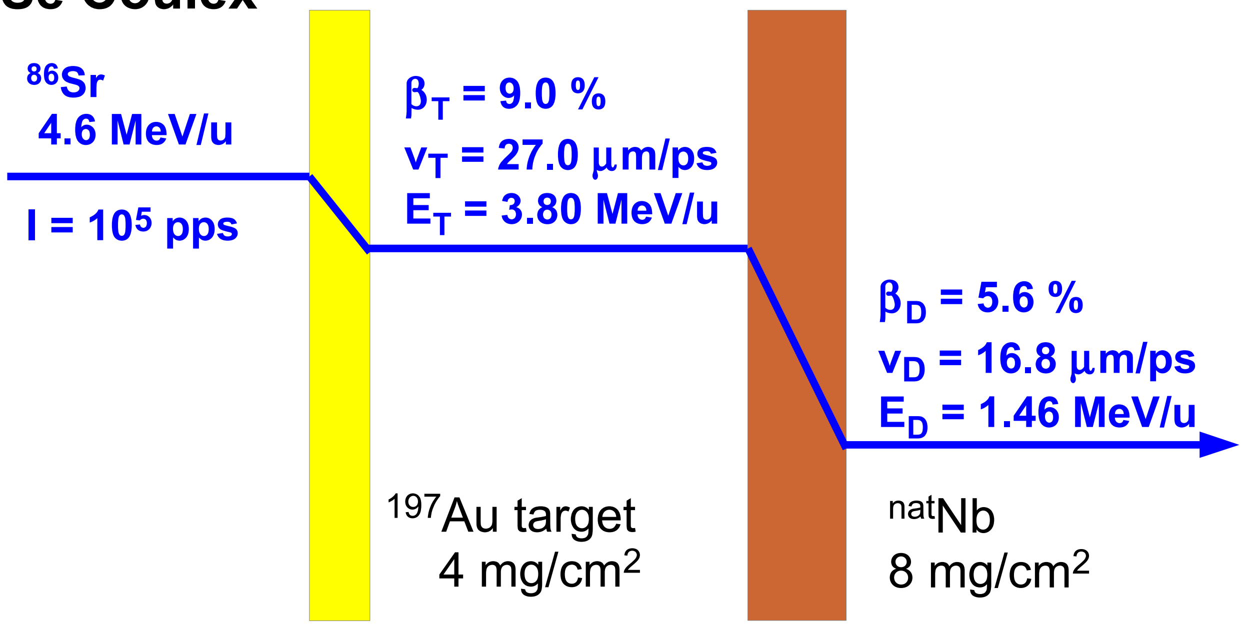
- **February 2017:** plunger completely mounted and tested off-beam at Cologne
- **March 2017:** in-beam test at Cologne FN-tandem (35 MeV ^{32}S beam):
  → vacuum
  → mechanical stability, feedback system
  → heat conductivity sufficient to avoid heating up of structure
- **April 2017:** mounted at MINIBALL at HIE-ISOLDE
  → successful alignment at existing beamline
  → test of plunger electronics including feedback system under vacuum
- **July 2017:** Coulex run
- **November 2017:** first experiment in plunger configuration: measurement of g-factors in ^{28}Mg (G. Georgiev et al.)

Result: stable operation of plunger at MINIBALL

- **January 2018: acceptance of proposal „Investigation of octupole correlations in ^{144,145}Ba using RDDS“ (C. Fransen et al.)**

Example: Coulex plunger experiment @ HIE-ISOLDE

^{86}Se Coulex



Recoils detected with target DSSD detector
→ reconstruct kinematics important due to wide angle spread of recoils

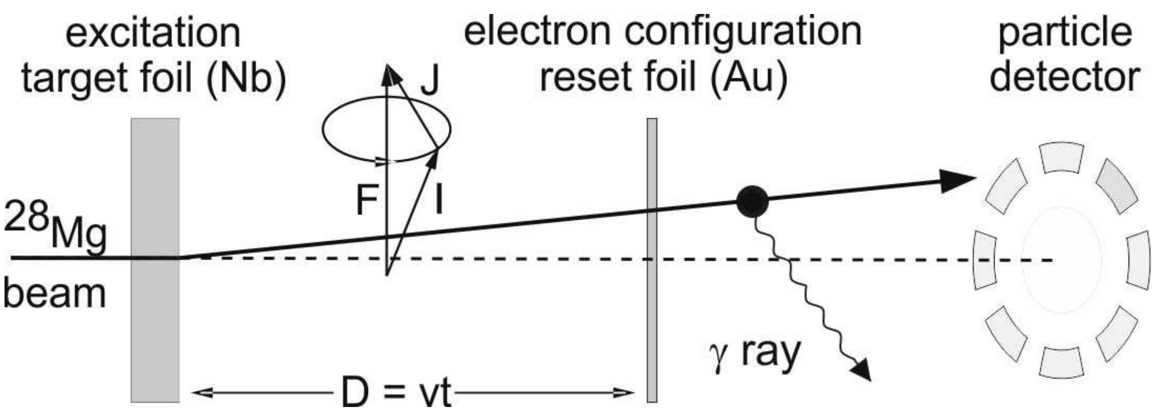
J^{Π}	E_{Level} [keV]	E_{γ}	$E_{\gamma,\mathrm{fast}}$ [keV]	$E_{\gamma,\mathrm{slow}}$ [keV]	ΔE [keV]
2_1^+	704.1	704.1	749.2	732.0	17.2
4_1^+	1567.9	863.8	919.1	898.0	21.1
6_1^+	2073.4	505.5	537.9	525.5	12.4

Expected lifetimes : $\tau(2_1^+) \sim 5$ ps
$\tau(4_1^+) \sim 8$ ps
→ sensitive range ~ 30 µm – 300 µm

→ Sufficient separation of Doppler-shifted gamma-ray lines (Miniball detector under 45°)

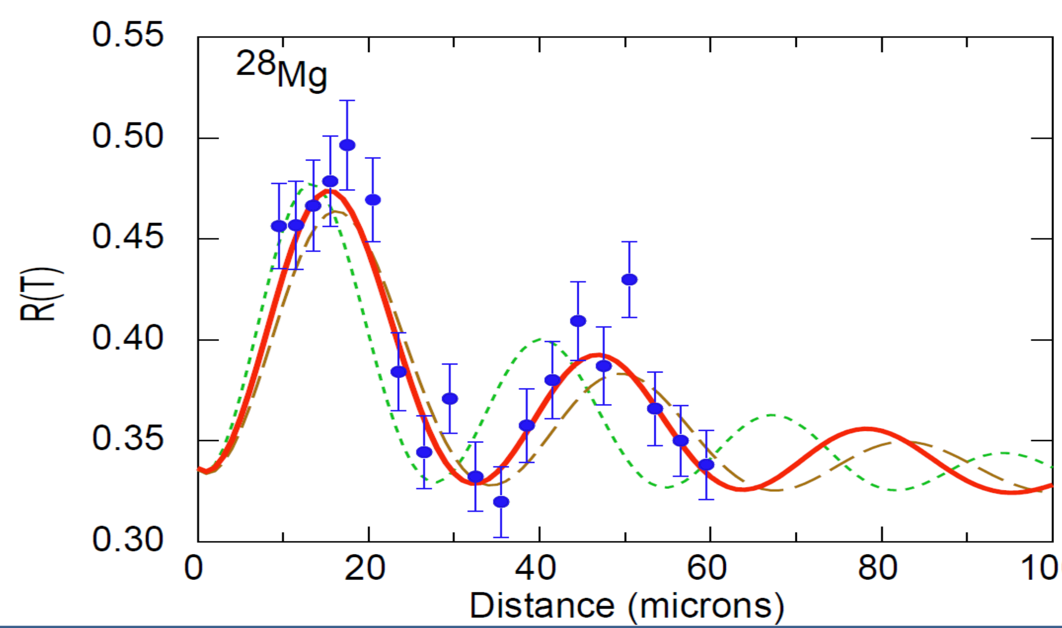
Measurement of g-factors in ^{28}Mg (G. Georgiev, Nov. 2017): Method: TDRIV on H-like ions

TDRIV - Interaction between the **nuclear spins** (oriented by the reaction) with the **electron spins** (random) for **well defined time** (plunger): precession frequency prop. to nuclear g-factor → int. of g-rays changes periodically



H-like ions (50% at v/c ~ 0.1)
→ well defined magnetic field (*1s*)

A. Kusoglu et al., PRL 114, 062501 (15)



→ very promizing results for g_{2+}(^{28}Mg) from TDRIV

At present under analysis

Conclusion

→ General introduction: lifetime determination with RDDS + Coulex

→ New plunger device for MINIBALL @ HIE-ISOLDE constructed at Cologne

→ installed at MINIBALL @ HIE-ISOLDE in April 2017

→ already successfully used: g-factors in ^{28}Mg

→ accepted proposal: „Octupole correlations in ^{144,145}Ba“

→ allows easy change between „standard“ (Coulex) experiments and RDDS experiments without change of chamber

→ same geometry including DSSD as MINIBALL „Coulex“ chamber

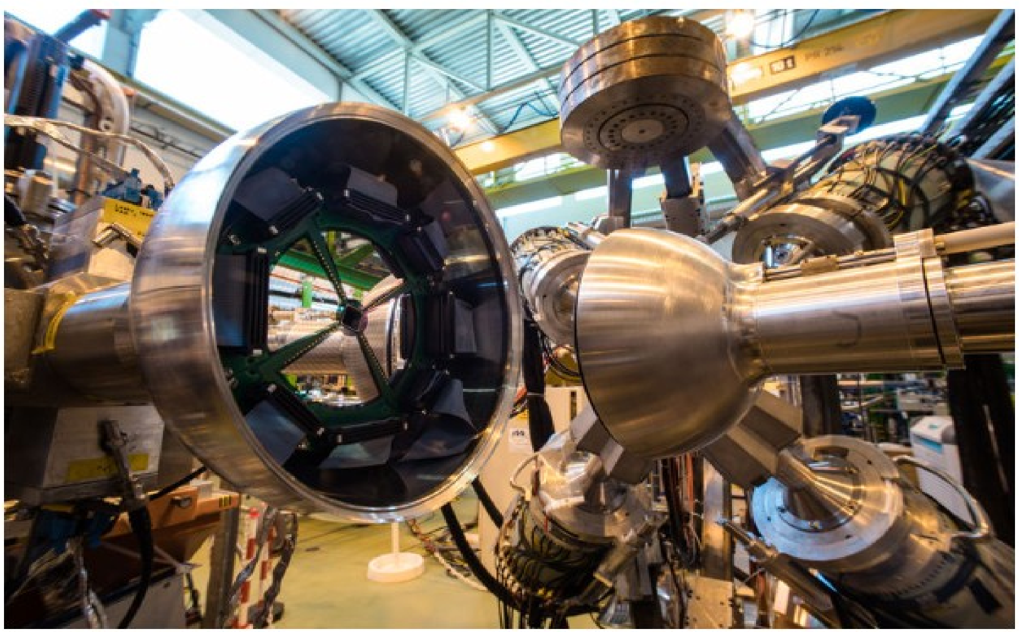
Last but not least: Plunger for antimatter transport(?) (Nature, Feb. 20, 2018)

MENU nature

Physicists plan antimatter's first outing — in a van

Researchers intend to transport the elusive material between labs and use it to study the strange behaviour of rare radioactive nuclei.

Elizabeth Gibney



Antiprotons present a unique way to study the radioactive elements produced at CERN's ISOLDE ion-beam facility. Credit: Julien Marius Ordan/CERN

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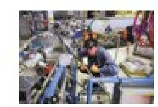

Ephemeral antimatter atoms pinned down in milestone laser test

SUBJECTS

Nuclear physics

http://www.nature.com/articles/d41586-018-02221-9