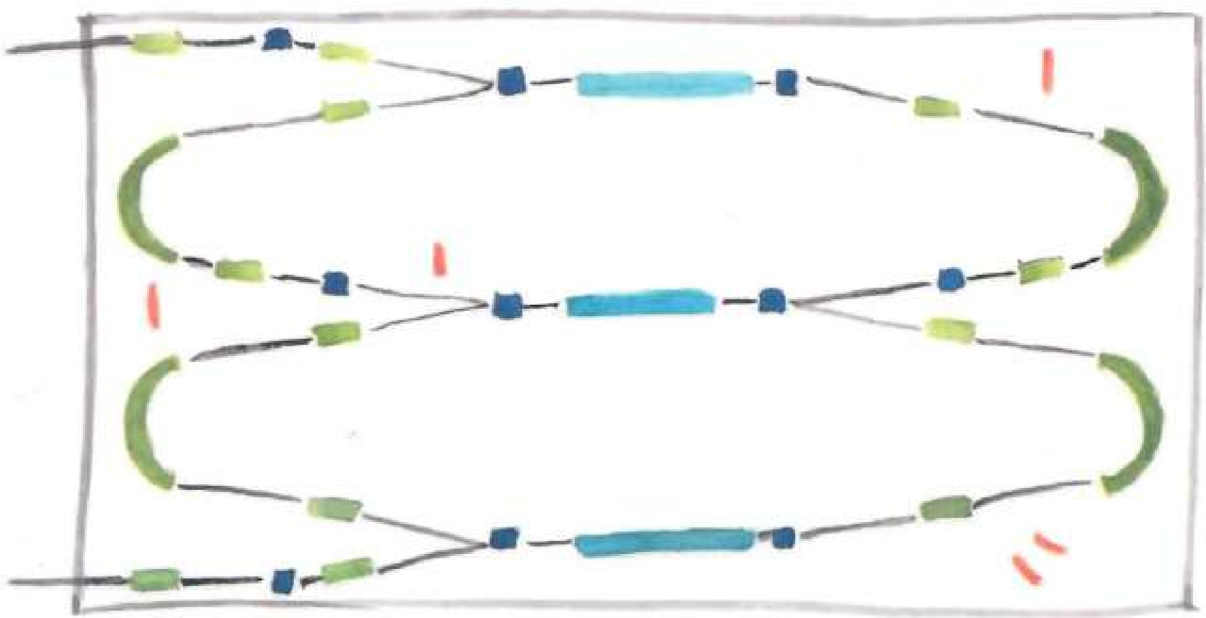
DESIREE

The double electrostatic storage ring



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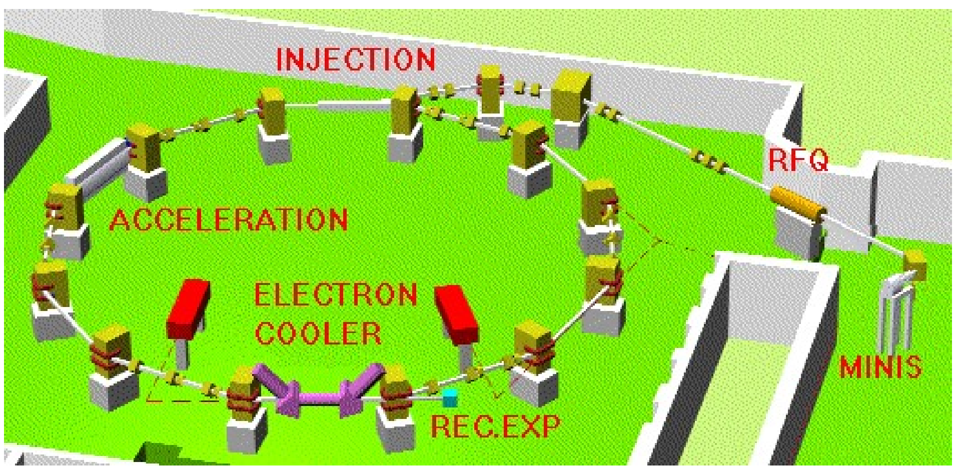
Stockholms universitet

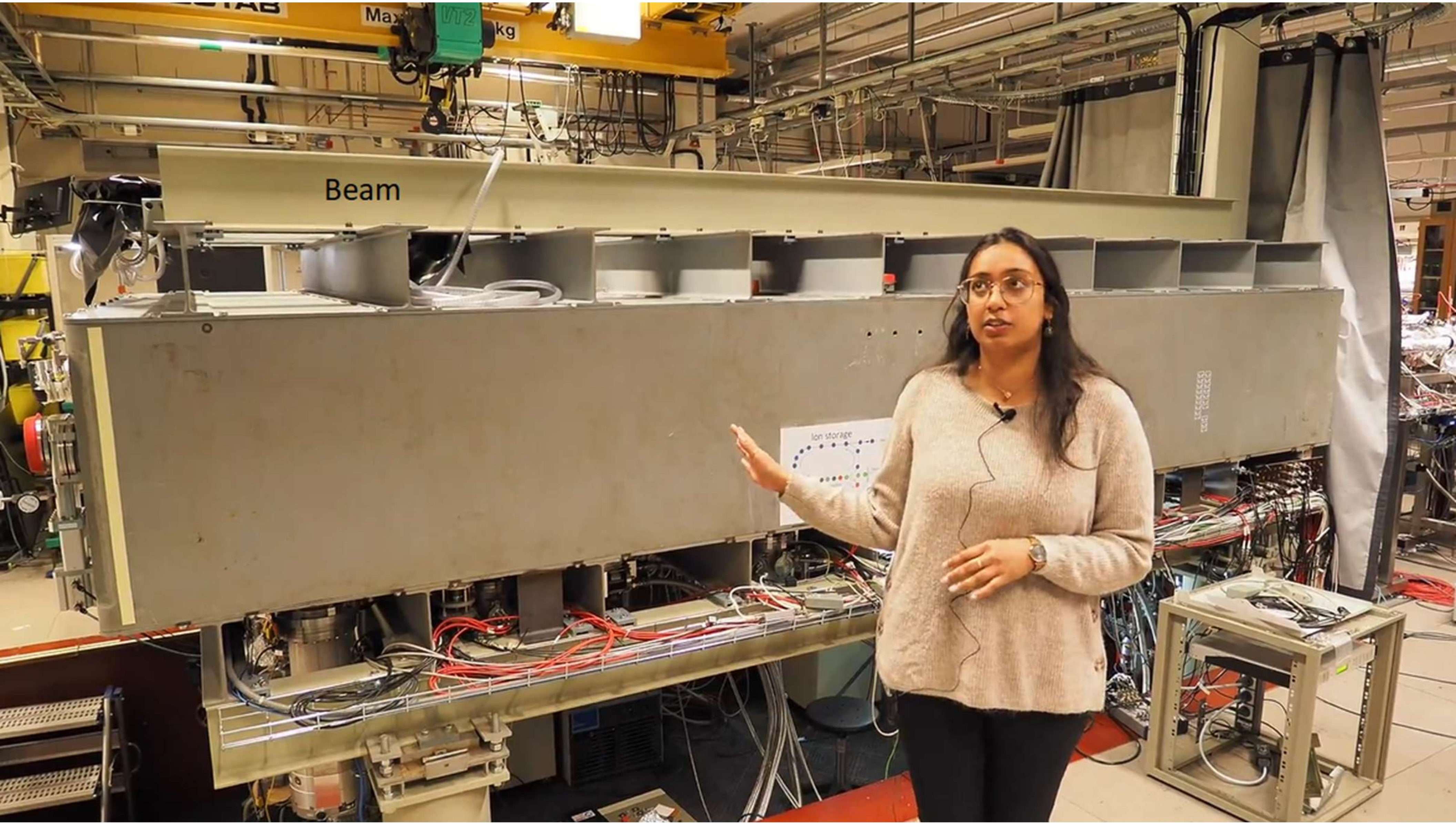
Brief history of storage rings for atomic and molecular physics

Year	Stockholm	Aarhus	Heidelberg	World
1982				LEAR
1990	CRYRING	ASTRID	TSR	TARN
Magnetic storage rings with electron cooling to improve the beam quality and study ion-electron collisions				
1998		ELISA		
First electrostatic storage ring, circumference 7.6m				
2013	DESIREE		CSR	RICE, Mini-ring…
	2×8.6m, cryogenic		35m, electron cooling, cryogenic	



DESIREE
First beam 2013
First published experiment 2015
Published double-ring experiment 2020

CRYRING, a magnetic storage ring with 52m circumference
1990-2010 in Stockholm, now part of FAIR in Darmstadt


Beam
Ion storage

The box

Iron outer chamber, shields 90% of earth magnetic field

Superinsulation

55K copper shield

14K inner chamber, from very pure aluminum with good thermal conductivity

One $0.5m^2$ 2.7K screen to catch H_2

Rest gas $1H_2$ per mm^3, corresponds to 10^{-14} mbar at room temperature

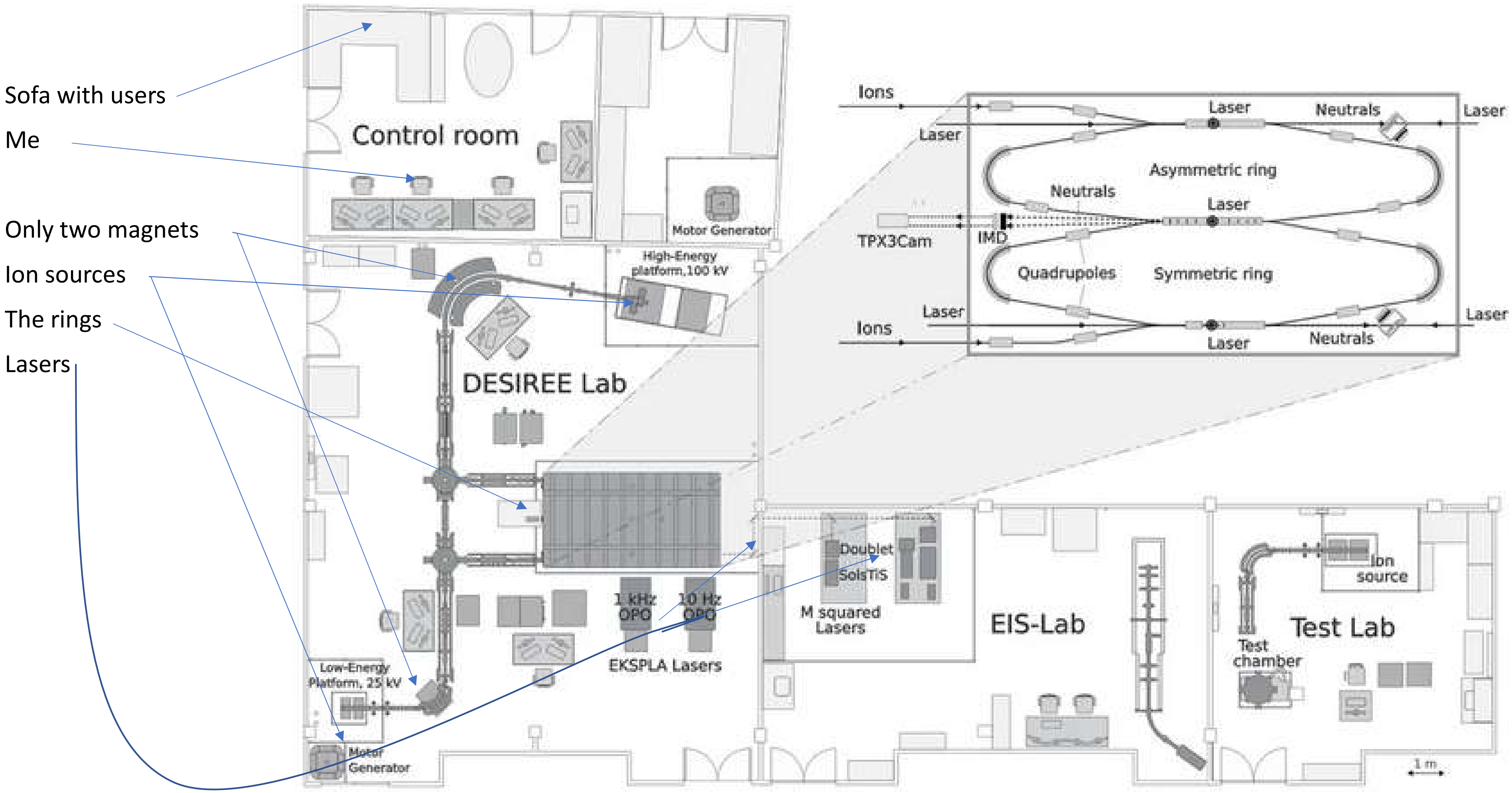
Two reasons for a crygenic chamber, both vacuum and

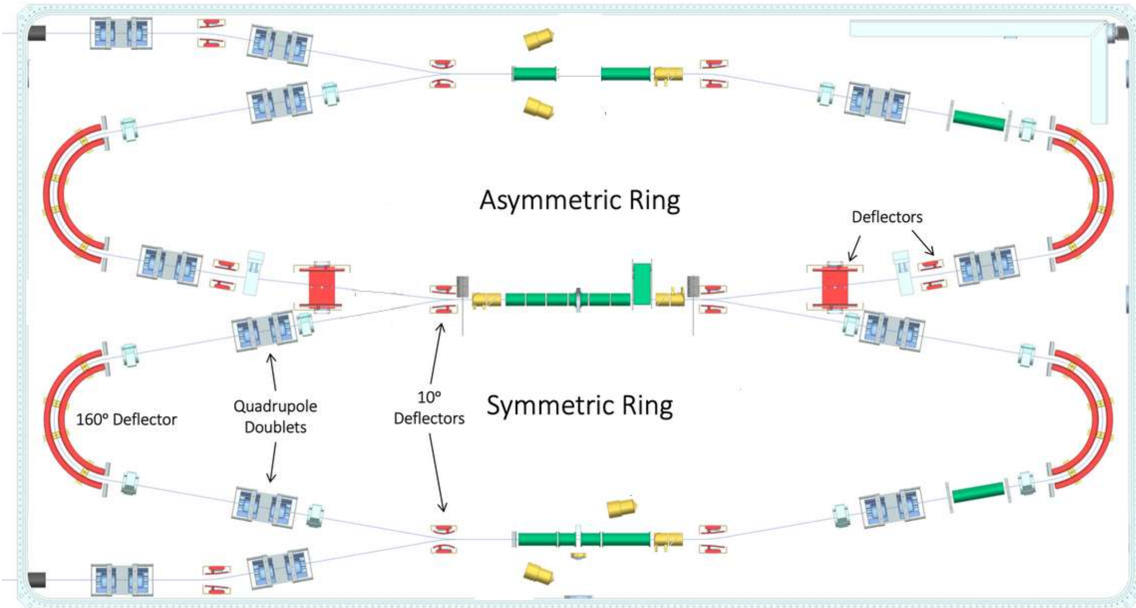
Black body radiation

290K BBR can enter through the beam ports

low BBR is necessary for μ-calorimetry and important for experiments

We can study the BBR by storing a C^- beam and measure the lifetime of the ^2D metastable state.
22s in DESIREE, 2.7ms in room temperature
1.2×10^{-4} of the room temperature BBR is left.


Sofa with users
Me
Only two magnets
Ion sources
The rings
Lasers
Control room
Motor Generator
High-Energy platform, 100 kV
DESIREE Lab
Low-Energy Platform, 25 kV
Motor Generator
1 kHz OPO
10 Hz OPO
EKSPLA Lasers
Doublet
SolsTiS
M squared Lasers
EIS-Lab
Ion source
Test chamber
Test Lab
1 m
Ions
Laser
Laser
Neutrals
Laser
Asymmetric ring
Neutrals
Laser
TPX3Cam
IMD
Quadrupoles
Symmetric ring
Laser
Ions
Laser
Laser
Neutrals
Laser



Two rings with 8.6m circumference

Two high-voltage platforms for ion sources, 30kV and 95kV

A 1m long common straight section for the two rings

Positive and negative ions can collide with down to 50meV energy

Storage times minutes-hours

Currents for experiments up to 100nA

Beam properties

Electrostatic means settings are mass independent
Heaviest so far is $^{197}Au_{20}^{-}$ at 5keV
Both platforms can be positive or negative, we can inject from both platforms to either ring

S ring up to 30 keV
A ring up to 95 keV

For merged beams with similar velocities the mass ratio is maximum 20

Beam currents up to 100nA

Beam lifetimes minutes to hours, not determined by rest gas. The lifetime decreases if the current is above a few nA. Noise on high voltages can cause losses, like super-ultra-slow extraction.

Beam diameter around 10mm

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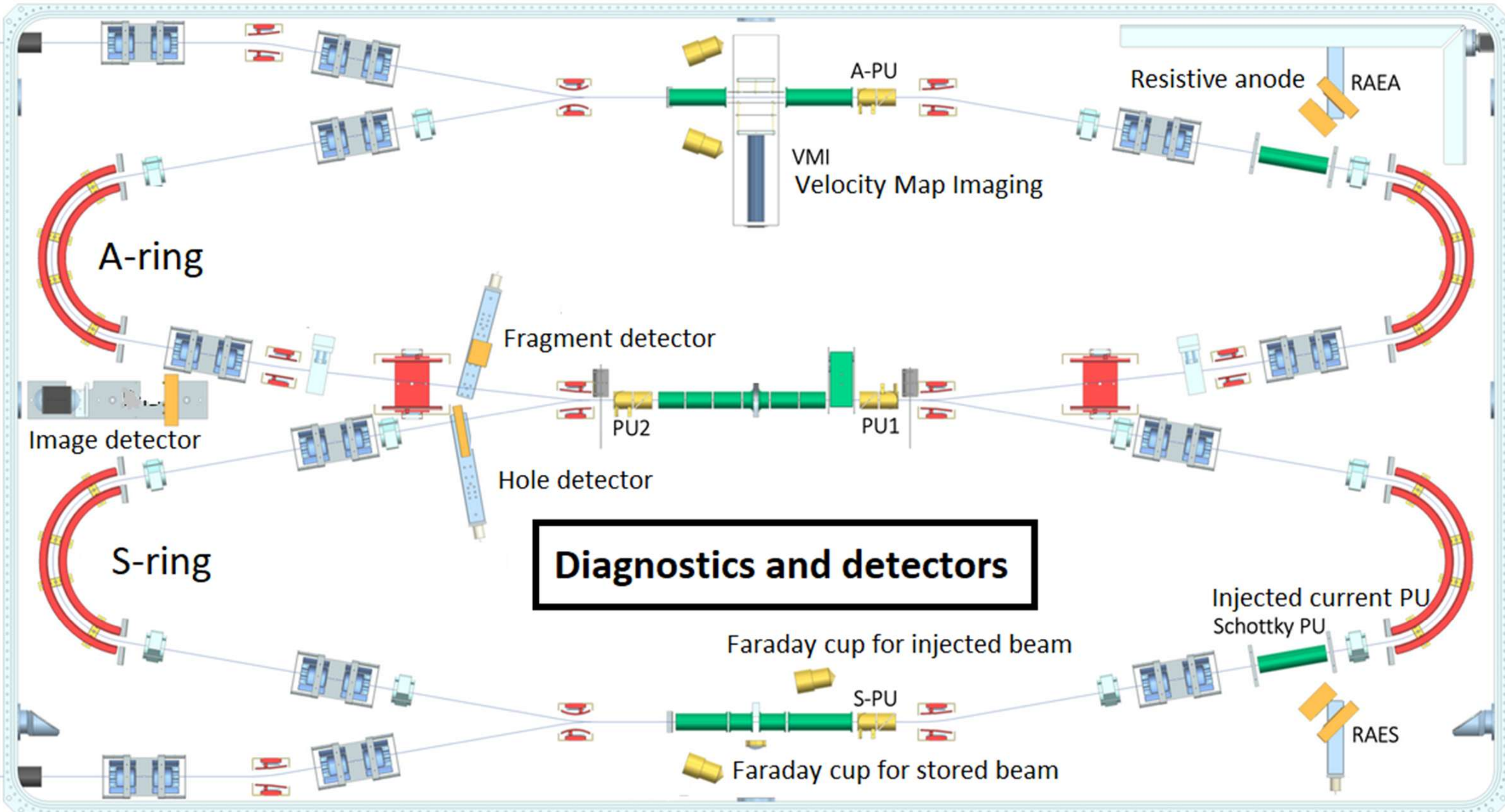


A-PU
Resistive anode
RAEA
VMI
Velocity Map Imaging
A-ring
Fragment detector
Image detector
PU2
PU1
Hole detector
S-ring
Diagnostics and detectors
Injected current PU
Schottky PU
Faraday cup for injected beam
S-PU
RAES
Faraday cup for stored beam

Research areas and a few experiments

Properties of single isolated ions
Atomic spectroscopy
Lifetimes of metastable atomic levels
Cooling of molecular ions
Hot cluster decays: stability vs fragmentation

Interactions between oppositely charged ions
Atoms:

$X^+ + Y^- \rightarrow X + Y$	Mutual Neutralization (MN)
$X^+ + Y^- \rightarrow X^- + Y^+$	Double charge transfer

Small molecules

	$AB + C$	MN
$AB^+ + C^- \rightarrow$	$A + B + C$	Dissociative MN
	$A + BC$	RCT (Reactive Charge Transfer)

Complex molecules
...

Ion List and Ion Sources

Atomic cations: H^+, He^+, B^+, Li^+, C^+, N^+, O^+, F^+, Ne^+, Na^+, Mg^+, Si^+, S^+, K^+, Ar^+, Ar^{2+}, Ar^{3+}, I^+, Xe^+, Ba^+, Fe^+, Sm^+

Atomic anions: H^-, D^-, O^-, $^{18}O^-$, Si^-, P^-, S^-, Cl^-, Ni^-, Cu^-, Ge^-, As^-, Se^-, Br^-, Rh^-, Pd^-, Ag^-, Sn^-, Sb^-, Te^-, I^-, Cs^-, La^-, Ir^- , W^-, Au^-, Th^-

Molecular cations: H_2^+, HD^+, D_2^+, O_2^+, N_2^+, I_2^+, NO^+, $HeNe^+$, HeH^+, HeD^+, H_3^+, D_3^+, H_3O^+,

Molecular anions: CH^-, CD^-, CH_3^-, $^{13}C_4H^-$, $^{13}C_6H^-$, CO_2^-, CN^-, OH^-, OD^-, O_2^-, N_2O^-, NO_2^-, LaO^-, SF_4^-, SF_5^-, SF_6^-, $^{16}O^{18}O^-$, HfF_5^-, WF_5^-, $C_6H_4O_2^-$(para-Benzoquinone).

Molecular dianions: C_7^{2-}, $^{13}C_7^{2-}$, C_9^{2-}, $^{13}C_9^{2-}$, C_{12}^{2-}, C_{60}^{2-}, $^6LiF_3^{2-}$.

Cluster anions: C_{2-15}^-, Cu_{2-21}^-, Si_2^-, Ag_{2-3}^-, Au_{2-15}^-

Complex ions: $C_4H_4N_2^+$ (pyrimidine), $C_9H_8^+$ (indene), $C_{10}H_6O_2^-$ (1,4-Naphthoquinone), $C_{10}H_8^+$(naphthalene, azulene), $(C_{10}H_8)_2^+$ (naphthalene dimer), $C_{10}H_7CN^+$(cyanonaphthalene), $C_{10}H_{16}^+$(adamantane), $C_{10}H_{16}O^+$(camphor), $C_{14}H_{10}^+$(anthracene, phenanthrene), $C_{13}H_9N^+$ (acridine), $C_{12}H_8N_2^+$ (phenazine), $C_{16}H_{10}^+$(pyrene), $C_{17}H_{11}^+$(methylene-pyrene), $C_{16}H_9OH^+$(hydroxypyrene), $C_{16}H_9Br^+$(bromopyrene), $C_{20}H_{12}^+$(perylene), $C_{18}H_{12}^+$(tetracene), $C_{24}H_{12}^+$ (coronene), C_{58}^+, C_{60}^+, C_{60}^-, C_{70}^-, $C_{28}H_{31}ClN_2O_3^+$(Rhodamine B), protonated phenylalanine and tryptophan.

Source of Negative Ions by Cesium Sputtering (SNICS)

As stated by its name, the SNICS is used to produce atomic, molecular and cluster anions from gaseous and solid targets, e.g., H, C, Si, Cn, etc.

Electron Cyclotron Resonance Ion Source (ECRIS)

The monogan M-100 type ECRIS (2.45 GHz RF power up to 30 W) from PANTECHNIK can produce singly-charged cations from a variety of atomic and molecular gasses and vapours. A homemade oven (up to 700 ◦C) can produce vapour from the powder of, e.g., polycyclic aromatic hydrocarbons (PAH) and fullerenes.

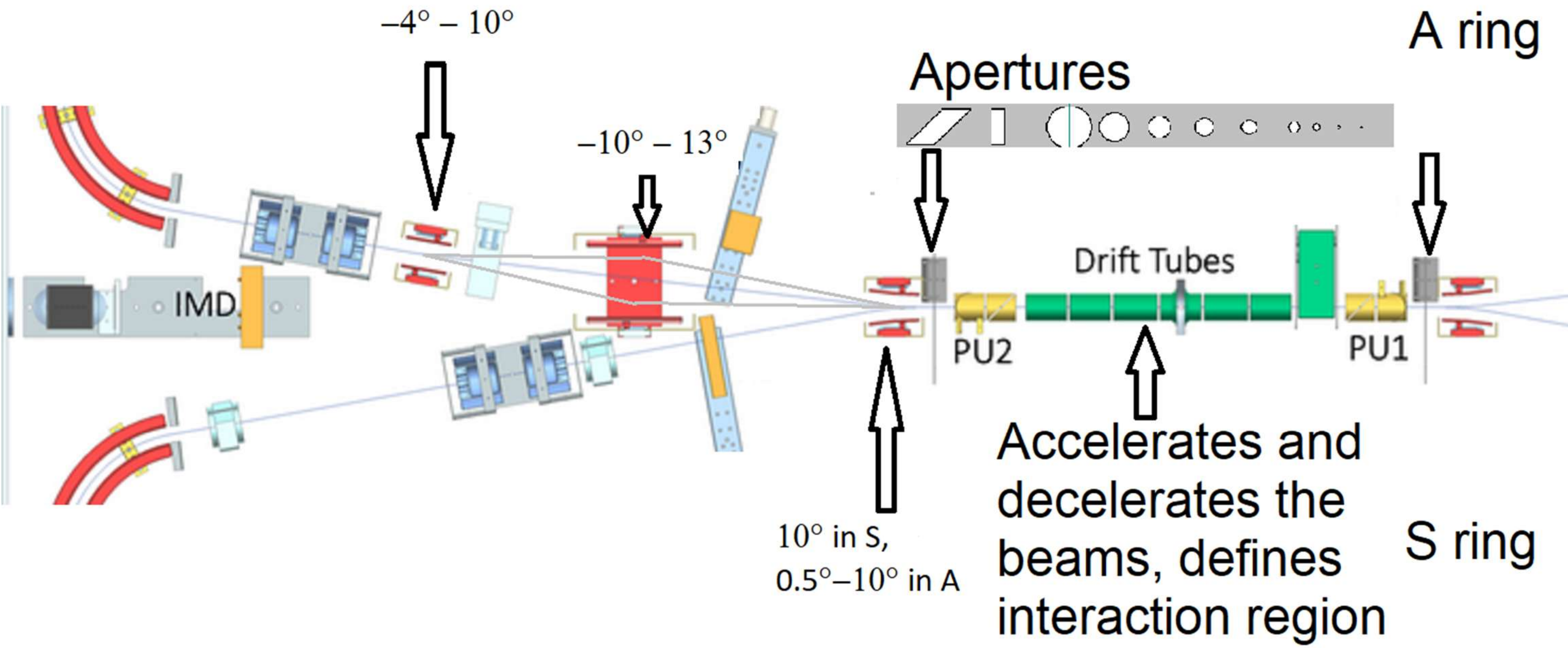
Cold or Hot Reflex Discharge Ion Source (CHORDIS)

This can deliver high current beams of singly and multiply charged ions from a variety of gas and solid phase materials,

Björkhage Ion Source (BjörkIS)

The BjörkIS at DESIREE is an electron-attachment-type ion source used to produce anions from PAHs and fullerenes, e.g., pentacene (C22H14) and C60.

Merging beams
Typically a few to 50 nA of each beam
The three chicane bends should add up to 10° in the A-ring



Mutual neutralization

Positive and negative beam with similar velocities, especially in the drift tube

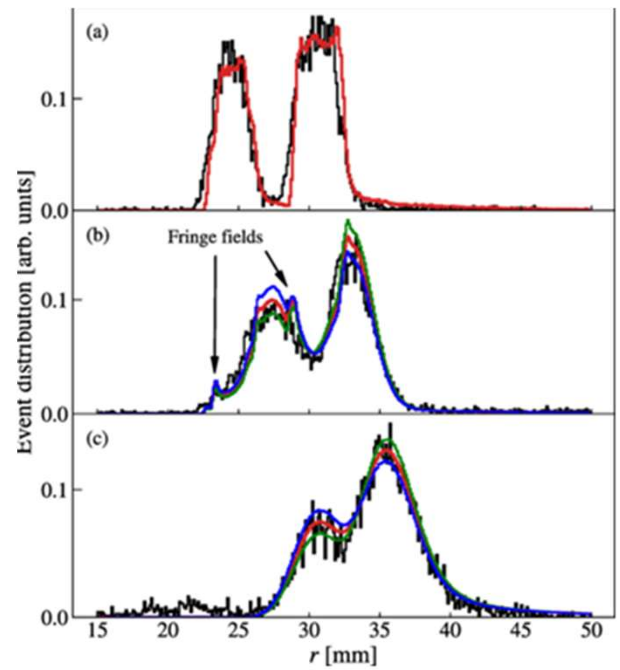
Measure distance and time between hits to get 3D distance, which then give the kinetic energy release

which quantum states are populated
how molecules fragment
temperature dependence

The extremely good vacuum is important to reduce background and avoid detector saturation

$H_3O^+ + OH^- \rightarrow 2H_2O$, i.e. proton transfer

Mutual neutralization with different collision energies



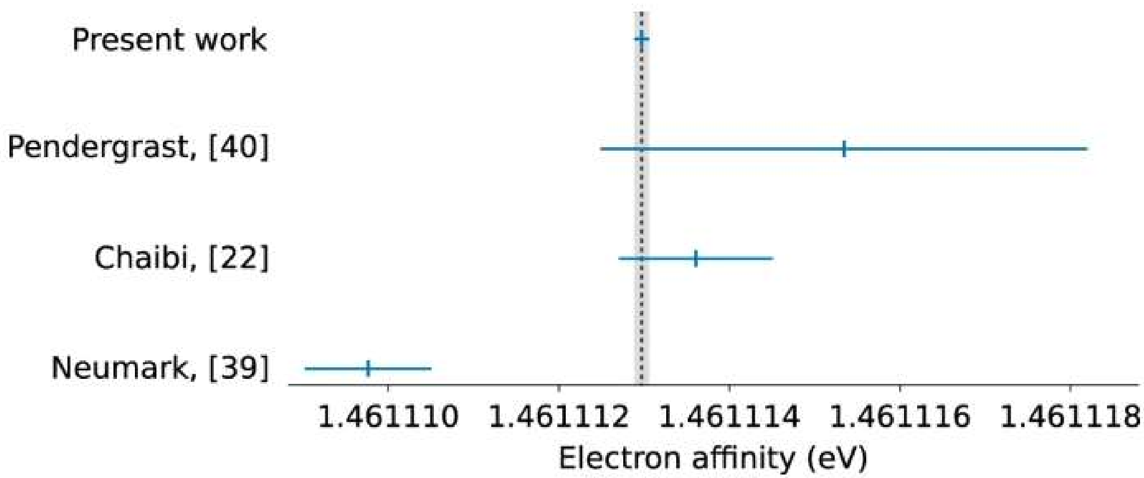
The electron affinity of ^{16}O is 1.461 112 972(87) eV

Method:
Store O^- in 165 s long cycles

Begin with 35 s depletion of an exited state (0.022 eV) with 2.5W laser power
Then 4 scans over the threshold with alternating direction of the direction to get doppler-free threshold values

Repeat

Comparison with previous experimental results of the electron affinity, in eV, of ^{16}O

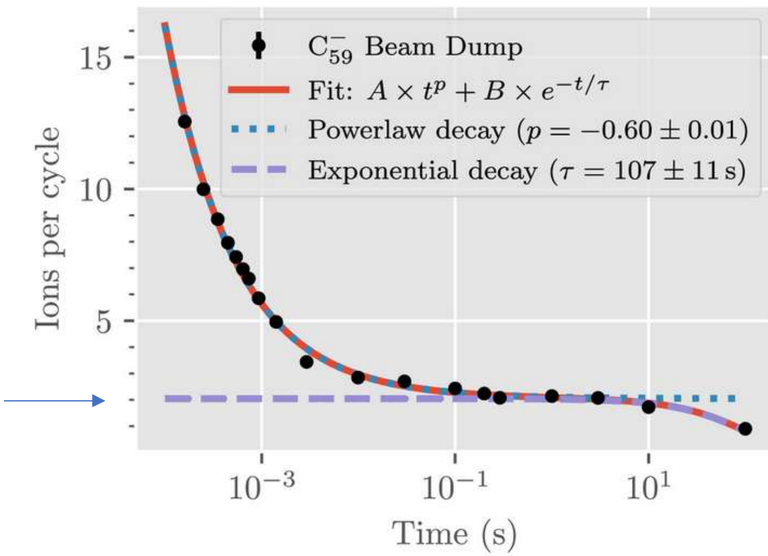


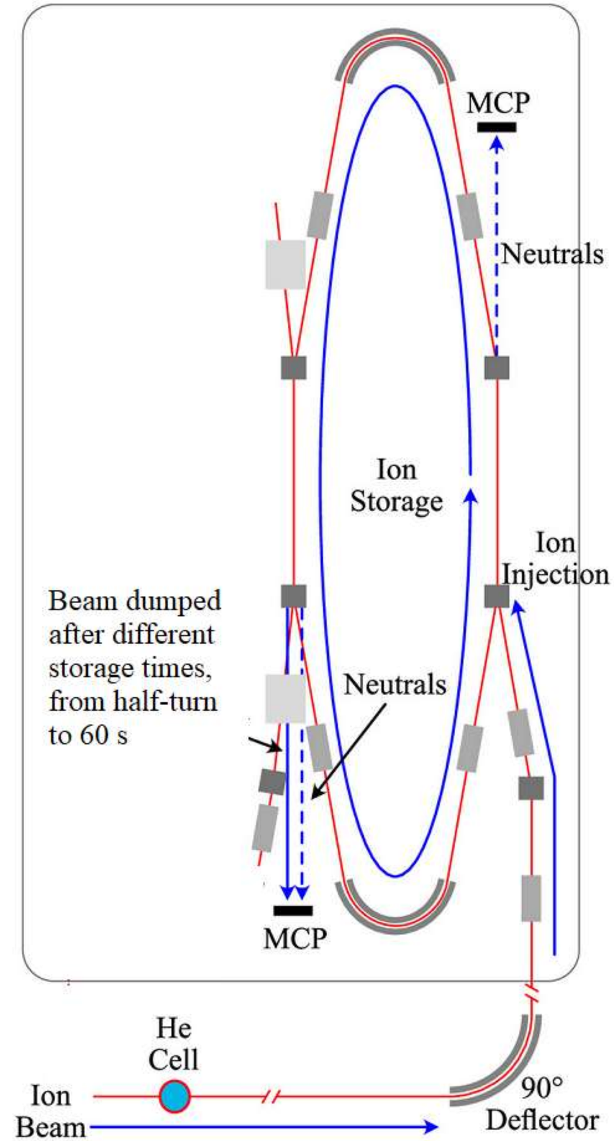
Stability of C_{59}^- knockout fragments

We have studied the stability of fragments formed in collisions between C_{60}^- and He atoms at 90 km s^{-1}. About 15% of the ions formed remain stable on timescales of seconds or longer, at which point they no longer decay. The ions lost decay through additional C-loss. The intact ions are stabilized by radiative processes and will remain intact indefinitely in isolation

To transport the fragments voltages in all elements after the cell are rescaled with mass/original mass

two ions per cycle





Next project - detection with μ-calorimetry 2029 (?)

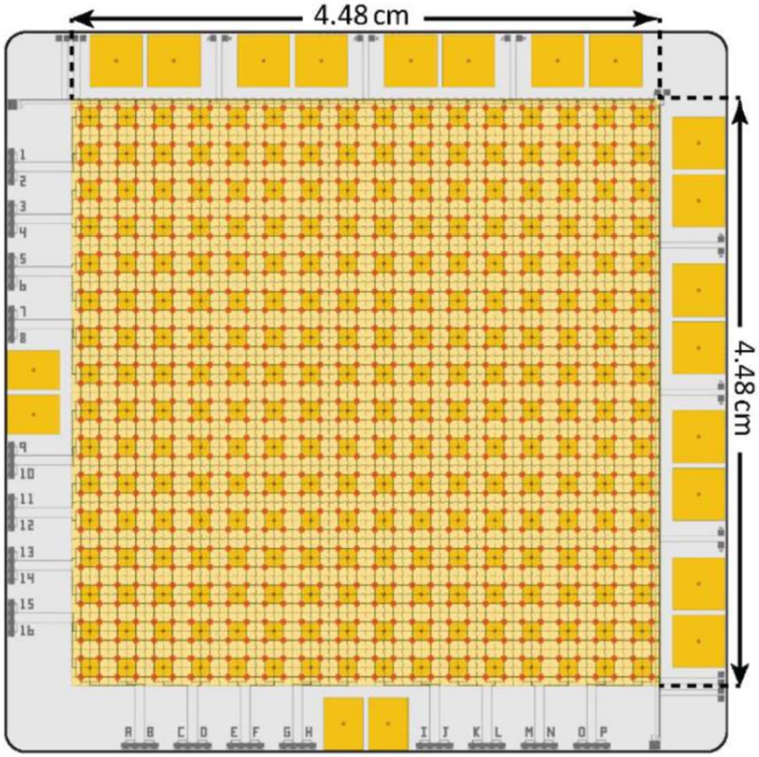
When chemical reactions are possible distinguishing them is difficult
Can we determine the mass of each impacting neutral particle?

All particles move with similar velocities, so kinetic energy is equivalent to mass.

A 128x128 pixel array of μ-calorimeters cooled down to 20-100 mK
A hit increases temperature and changes magnetization which can be measured with SQUIDs
Cooperation with a group in Heidelberg that also builds a detector for CSR

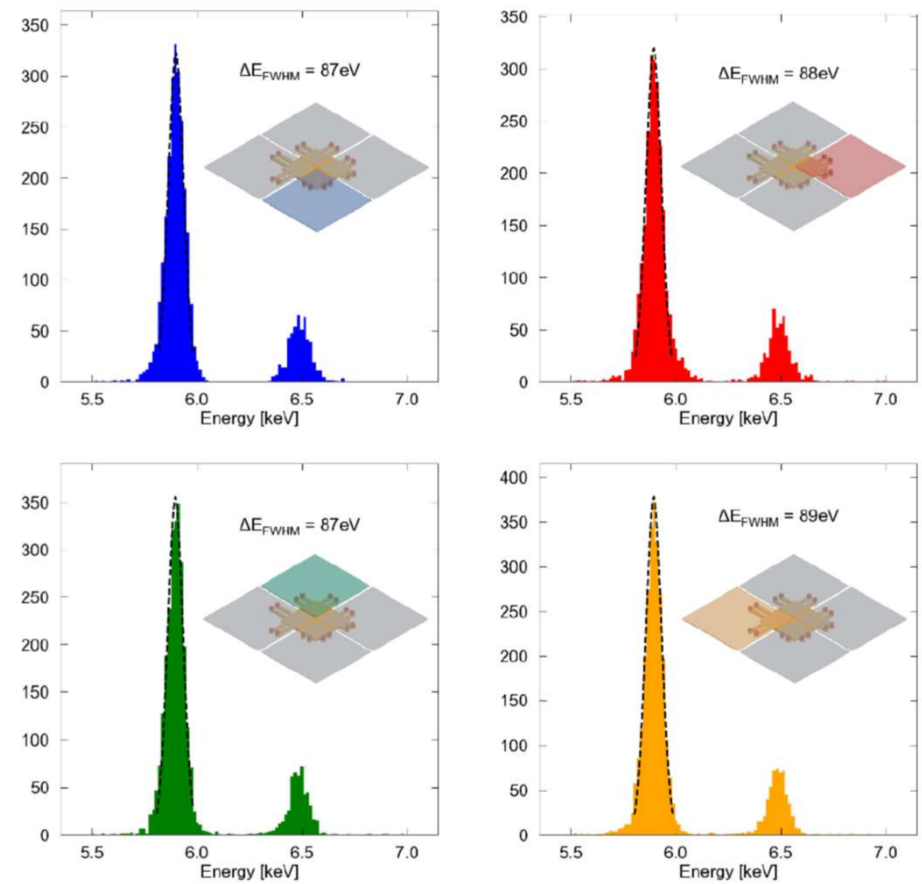
MOCCA – a 4k-pixel molecule camera for CSR

Kirchhoff-Institut für Physik



- Sensitive area: 4.48 cm × 4.48 cm
- 64 × 64 pixel
- Pixelsize: 700 µm × 700 µm
- Read out: 16 + 16 SQUIDs

For 6 keV photons : $\boldsymbol{\Delta E_{\mathrm{FWHM}} < 90\ \mathrm{eV}}$



The year for DESIREE

Calls for proposals twice per year, open for all

Experiments chosen by a committee

Once a year we open the ring chamber and make improvements inside. Next VMI and hole detector and also fix a movable part that don't go the full range. Always clean the windows.

Warm-up 11 days, cool-down 17 days. We used to do this in the summer, but we have shifted to the winter when dryer air gives less water inside.

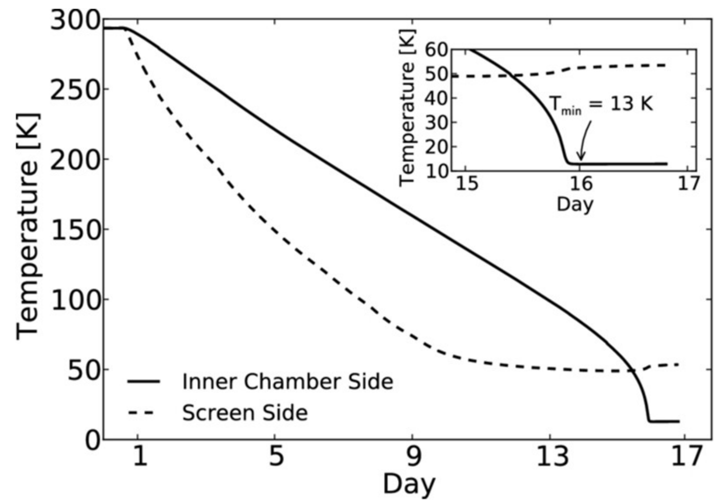
One experiment – one week one or more times

30 weeks of running each year, 25 weeks with experiments

Around 8 papers a year, slightly more from single ring experiments

Some PRL and occasionally Science or Nature comm, but mostly Phys Rev A: atomic, molecular, and optical physics and quantum science

DESIREE during cool-down



Local DESIREE Team (~12 full time equivalent)

Henning Schmidt, Henning Zettergren, Stefan Rosén,
Ansgar Simonsson, Peter Reinhed, MingChao Ji,
Mikael Björkhage, Mikael Blom, John Alexander,
Sadiq Muhamed, Petra Björk, Patrik Löfgren,
Richard Thomas, Mark Stockett, Michael Gatchell,
Paul Martini

We are founded by SU, VR, and Wallenberg. Thanks!