MOCCA: a 4k-pixel molecule camera for the position and energy resolved detection of neutral molecular fragments at the Cryogenic Storage Ring CSR

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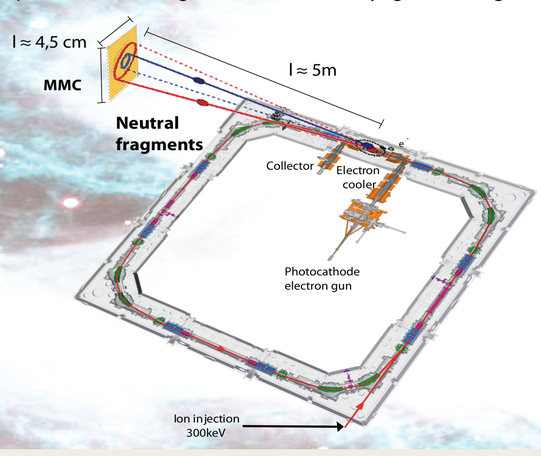
Motivation

- existence of organic molecules in interstellar clouds surprising due to their low densities and temperatures
- important processes in those clouds: electron-ion recombinations, e.g. dissociative recombination (DR): $AB^+ + e^- \rightarrow A + B$
- experimental investigation of DR in the Cryogenic Storage Ring (CSR) at MPI-K in HD



Cryogenic Storage Ring

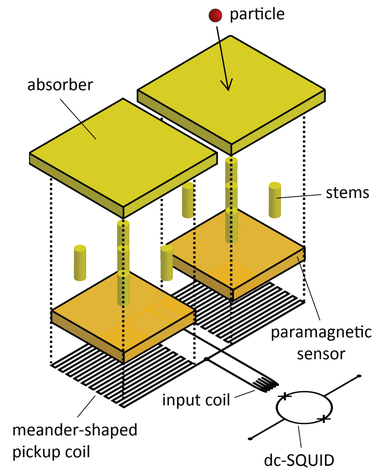
- $T < 10$ K, $p \sim 6 \times 10^{-15}$ mbar
- electrostatic storage
- comparably small kinetic energies: 20-300 keV

Detector Requirements

- large area, Ø 4-10 cm
- operation in cryogenic environment
- position sensitivity
- high energy resolution to identify masses
- high quantum efficiency, no dead layer
- ability to detect neutral particles!

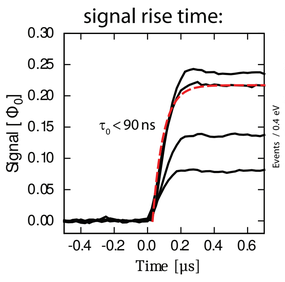
→ **Low Temperature Detectors**

Metallic Magnetic Calorimeters (MMCs)

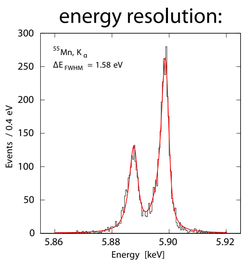


energy deposition	→	temperature change	→	change of magnetization	→	change of magnetic flux in SQUID
δE		$\delta T = \frac{\delta E}{C_{tot}}$		$\delta M = \frac{\partial M}{\partial T}\frac{\delta T}{C_{tot}}$		$\delta\Phi \propto \delta M \propto \delta E$

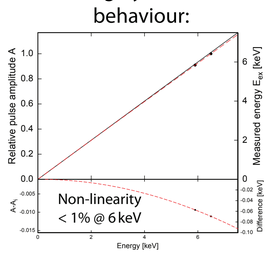
fast intrinstic signal rise time:



Excellent energy resolution:

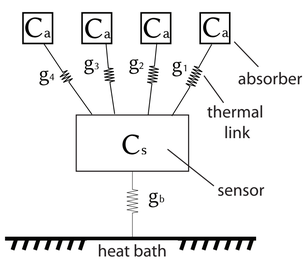


Highly linear behaviour:



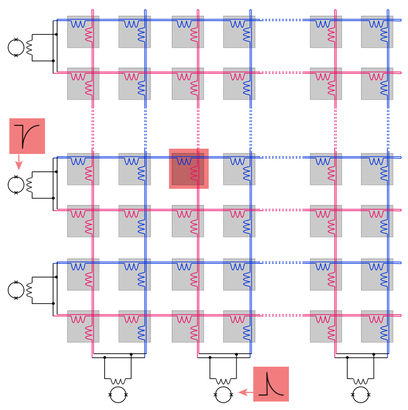
MOCCA: A 4k-Pixel Molecule Camera

The HYDRA principle



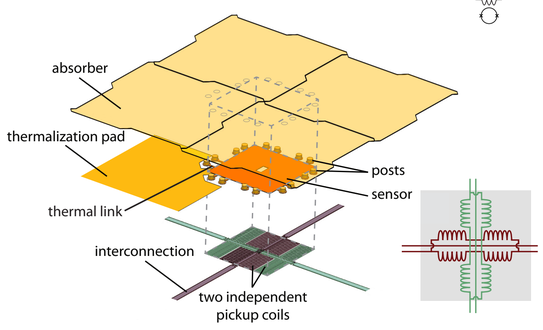
- 4 absorbers connected per sensor, using different thermal conductances
- pixel identification via rise time

Readout scheme



- signal of each sensor picked up by two coils
- each SQUID reads out two rows/columns of pick-up coils, i.e. 64 sensors
- pickup coils design minimizes crosstalk → measured crosstalk smaller than 0.05%
- flux change in:
  red rows/columns → positive SQUID signal
  blue rows/columns → negative SQUID signal

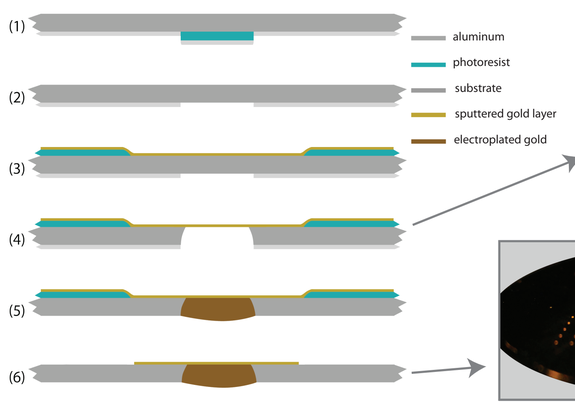
identification of the firing sensor by measuring two SQUID signals and their polarities ✓

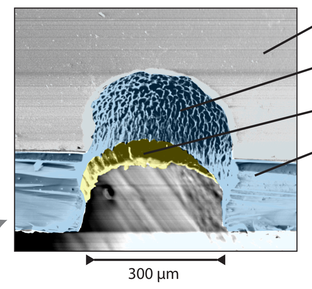


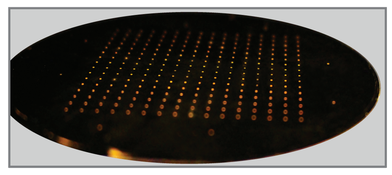
64x64 absorbers
↓ HYDRA principle
32x32 temperature sensors
↓ row- and column-wise readout
16+16 SQUIDs

energy resolution ~100 eV estimated

Cleanroom fabrication





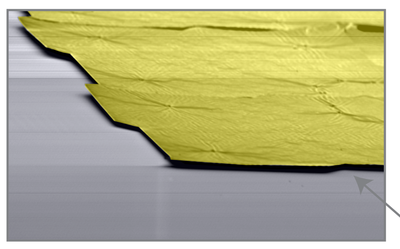


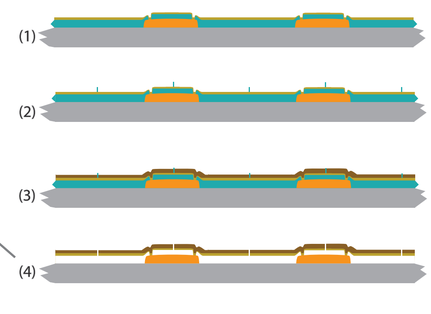
- deep Si etching using a Al hard mask
- sputtered Au layer acts as etch stop
- etching via SF6/O2 plasma
- speed: 2-3 µm / min
- through-wafer via using galvanized Au

through-wafer via to heat bath ✓

- Stems structured with thick resist
- thin sputtered gold layer for galvanization
- resist defines edges of absorbers
- fast lift-off due to using positive resist

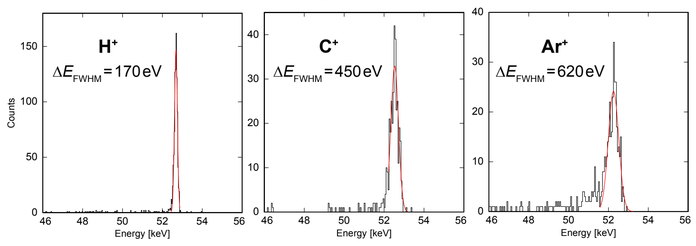
stable 700 µm x 700 µm gold absorbers ✓



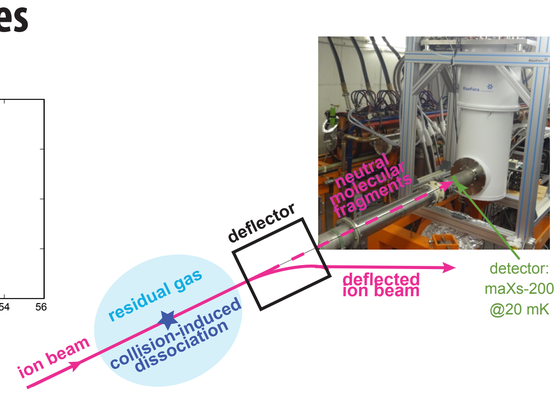


Measurements with massive particles

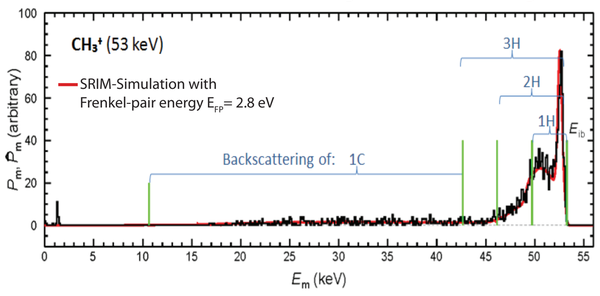
Atomic ions with ~ 53 keV hitting absorber made of gold:



linewidth increases with increasing ion mass

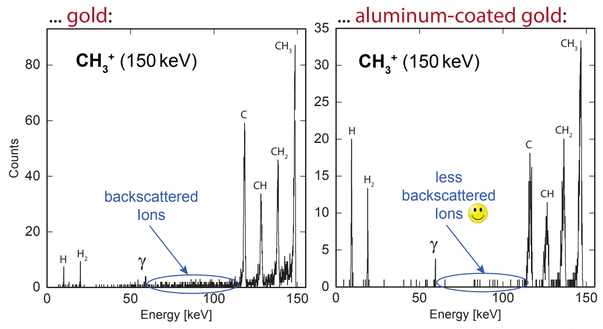


Molecular ions with ~ 53 keV hitting absorber made of gold:



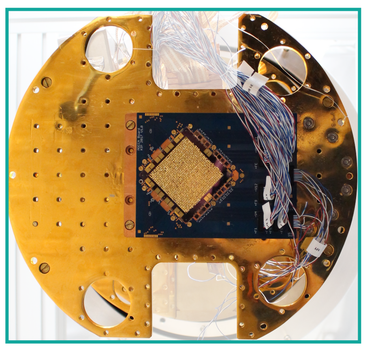
backscattering of fragments leads to additional low-enery-tails

Neutral molecular fragments hitting absorber made of ...

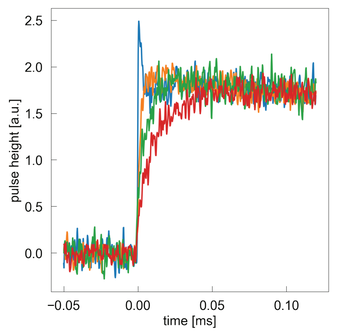


neutral fragments successfully resolved and identified; < 1 u resolution for molecules up to M = 200 u

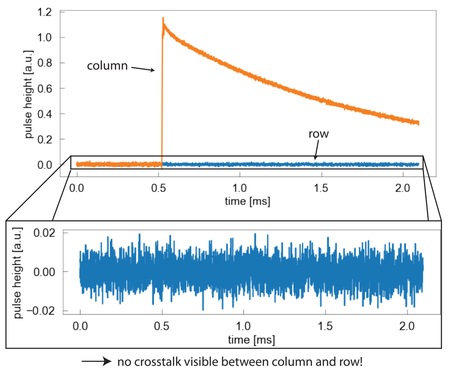
Measurements with photons



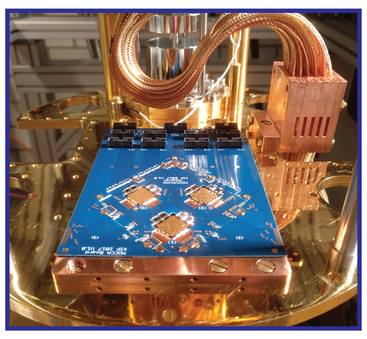
Single pulses with different risetimes:



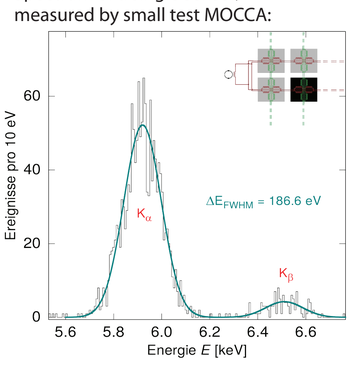
Cross talk: acquiring baseline in row triggered by pulse in column, averaged over 1360 pulses:



→ no crosstalk visible between column and row!



Spectrum of a single sensor, measured by small test MOCCA:

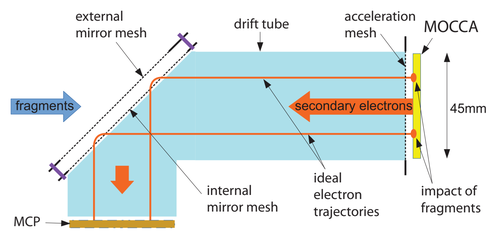


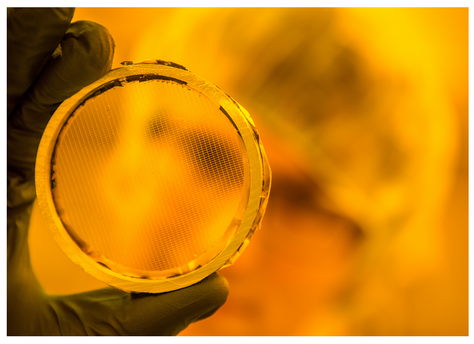
- pulses with different rise times measured ✓
- measured crosstalk between rows and columns <0.02% ✓
- energy resolution 187 eV sufficient for CSR ✓
- position reconstruction possible ✓

Integration into CSR

- MOCCA cooled by dry ^{3}He/^{4}He dilution refrigerator (BlueFors, FI)
- CSR shares its isolation vacuum with cryostat
- separate beam tube vacuum ($\sim 6 \times 10^{-15}$ mbar)
- cooled via detector platform attached to mixing chamber of cryostat
- MOCCA inside beam tube → cold feedthrough of MOCCA wiring
- bellows with intermediate heatsinking to minimize heat leak at the 4K-10 mK-vacuum -separation
- electron optics to extract secondary kicked-out electrons for nanoseconds timing to determine longitudinal component of the fragments' velocities

Electron optics





- Mirror and accelerating mesh made of galvanized gold in the cleanroom to achieve maximum transparency
- in-house fabrication in Heidelberg, 700µmx700µm cells on three-inch wafer

10 µm x 10 µm wires ✓ >97% transparency ✓

Heidelberg University