

# MOCCA:

a 4-kilo-pixel  
microcalorimeter detector  
for the Cryogenic Storage Ring CSR

Lisa Gamer



# Outline

- Motivation
- The Cryogenic Storage Ring CSR
- Metallic magnetic calorimeters (MMCs)
- MOCCA – a 4k-pixel molecule camera for CSR
- Integration of MOCCA into CSR
- MOCCA-standalone-setup
- MOCCA – new readout scheme
- Summary & Outlook



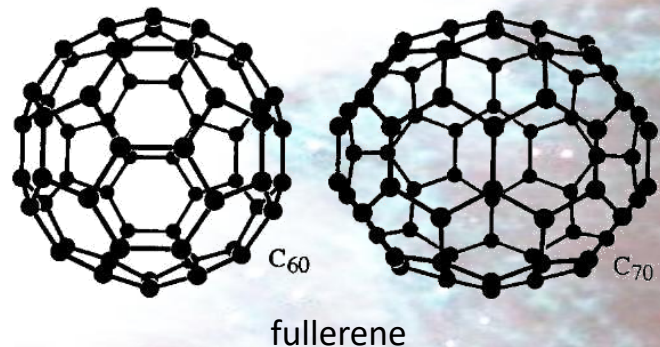
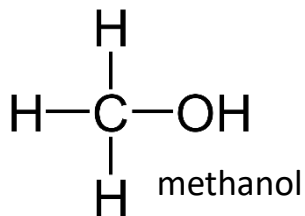
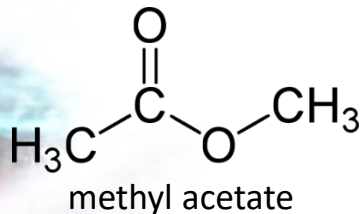
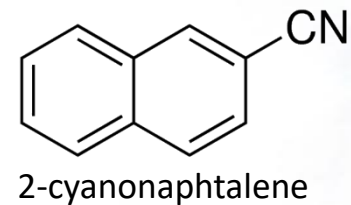
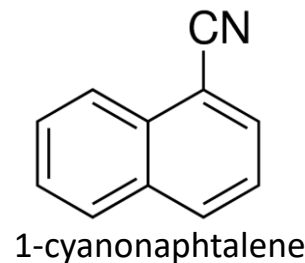
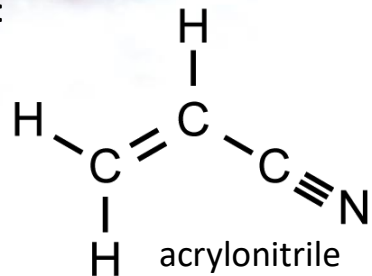
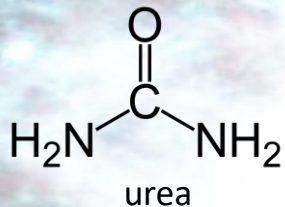
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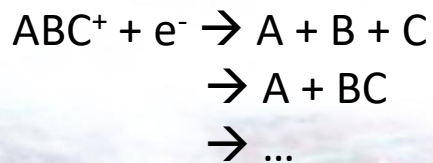


# Motivation

Interstellar molecular clouds:

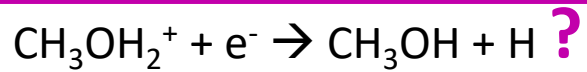


Dissociative recombination:

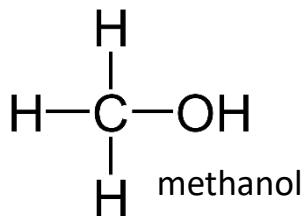


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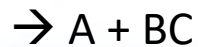
Interstellar molecular clouds:



(Geppert et al., *Faraday Discuss.*,  
2006, **133**, 177–190)



Dissociative recombination:

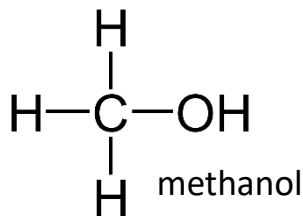


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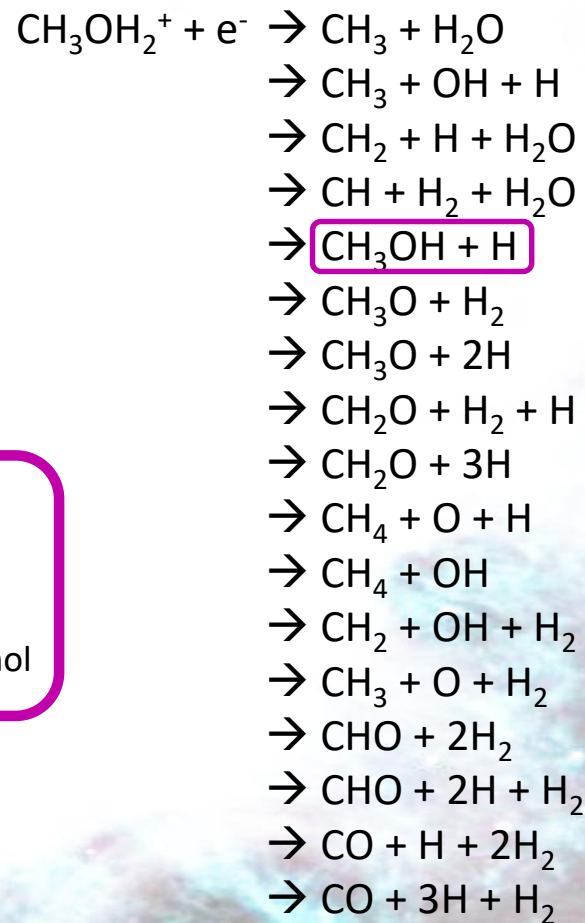
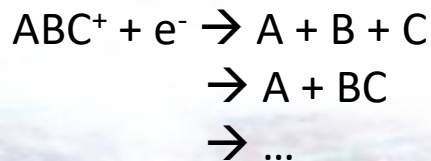
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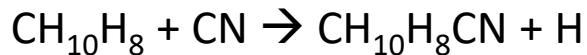
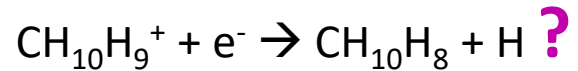


Dissociative recombination:

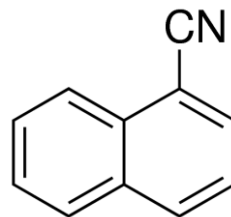


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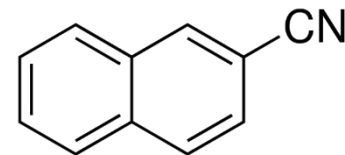
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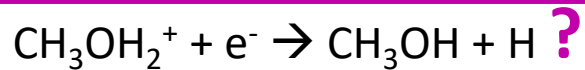
(McGuire et al., *Science*, 2021, **371**, 1265-1269)



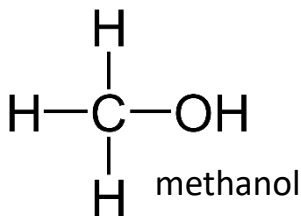
1-cyanonaphthalene



2-cyanonaphthalene

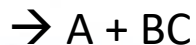


(Geppert et al., *Faraday Discuss.*,  
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methanol

Dissociative recombination:



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# The Cryogenic Storage Ring CSR

- $T < 10 \text{ K}$ ,  $p \sim 10^{-15} \text{ mbar}$
- Ion beam energy: 20 – 300 keV
- Electrostatic storage
- Electron cooler

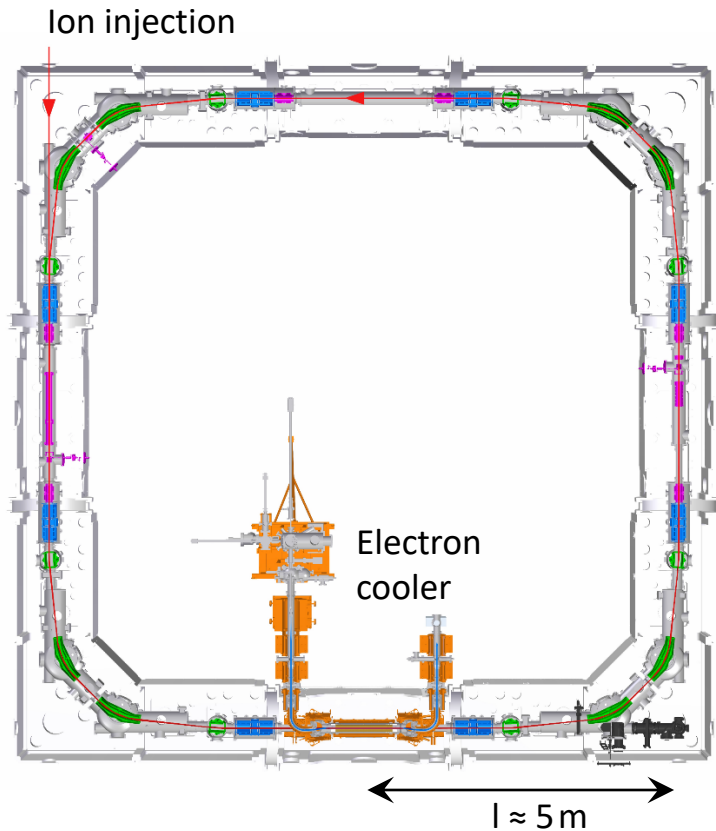
*von Hahn et al., Rev. Sci. Instrum. 87, 063115 (2016)*

*Novotný et al., Science 365, 676–679 (2019)*

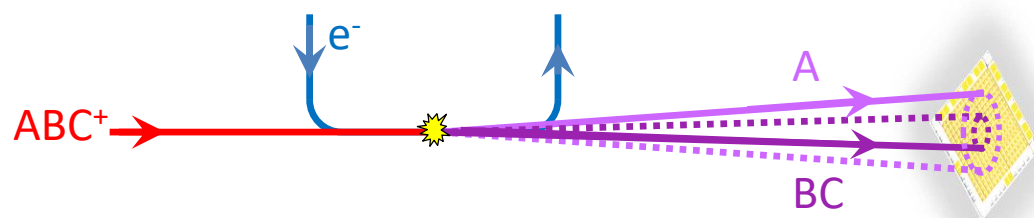
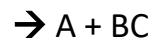
*Kálosi et al., Phys. Rev. Lett. 128, 183402 (2022)*



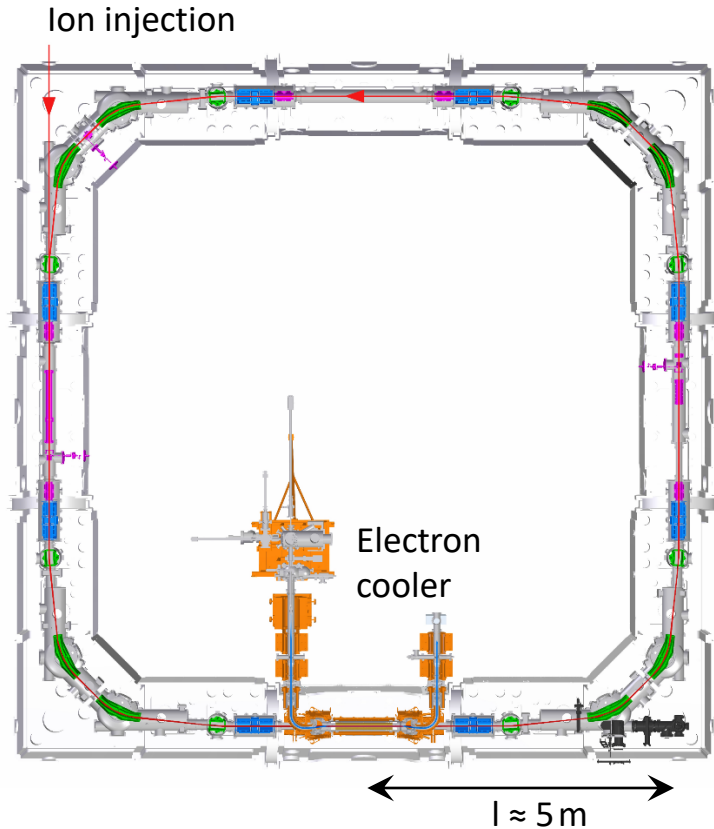
# The Cryogenic Storage Ring CSR



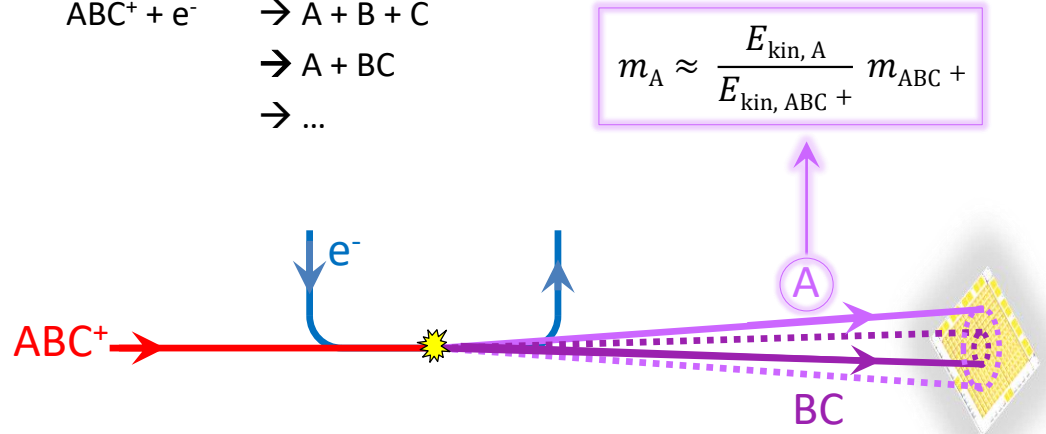
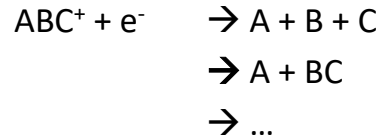
Dissociative recombination:



# The Cryogenic Storage Ring CSR



Dissociative recombination:



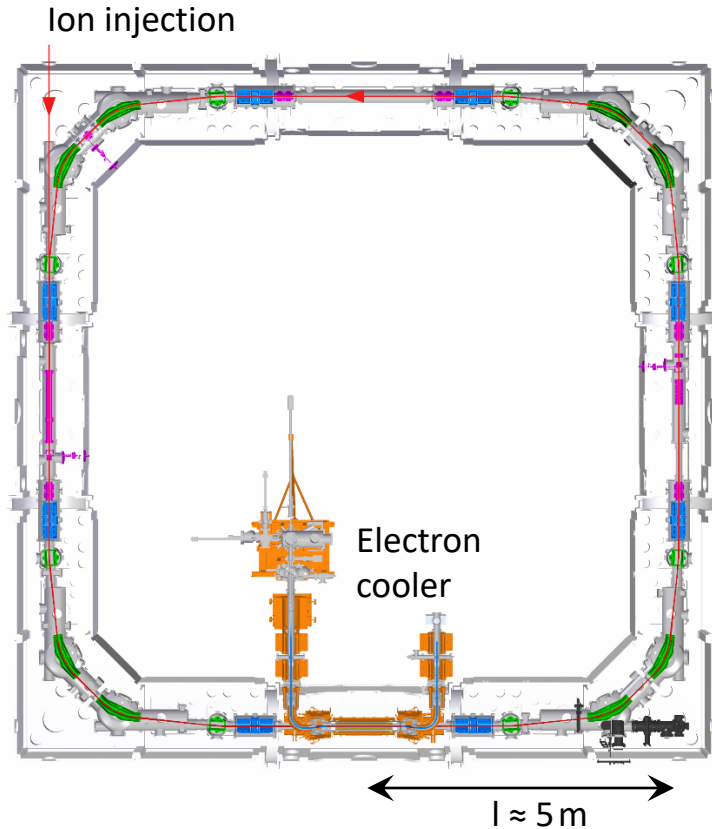
Fragment identification via mass:

$\rightarrow$  Kinetic energy

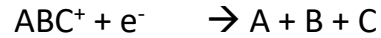
Kinetic energy release in DR:

$\rightarrow$  Impact position & impact time

# The Cryogenic Storage Ring CSR



## Dissociative recombination:



## Requirements on the Detector:

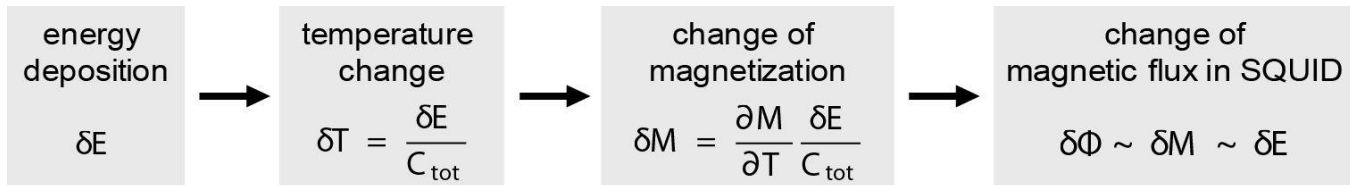
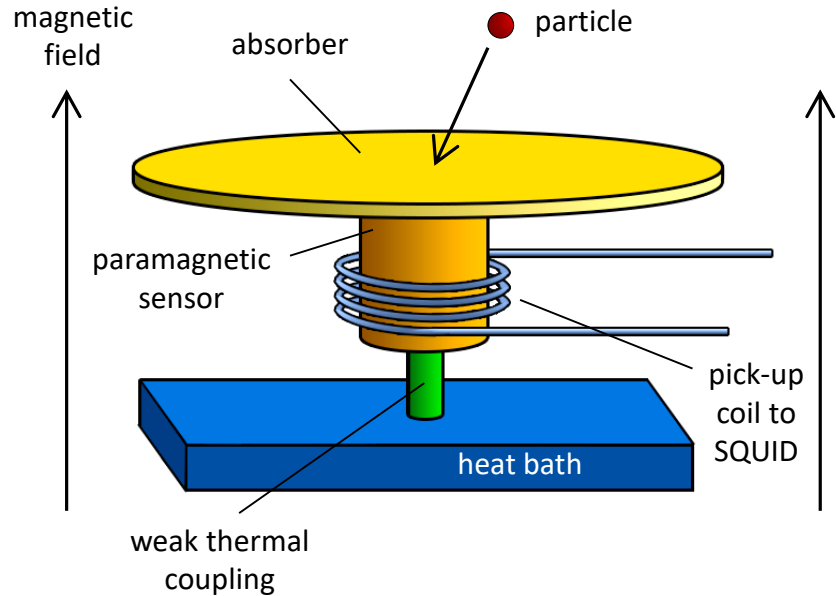
- Detection of neutral fragments
- Good energy-resolution
- No dead layer
- Feasible in cryogenic environment
- Large area
- Position-sensitivity
- Time resolution of a few ns

→ **Metallic magnetic calorimeters**

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# Metallic magnetic calorimeters (MMCs)



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- Detection of photons: very good energy resolution ( $\Delta E_{\text{FWHM @ 6keV}}$ : **1.6 eV**)
- Detection of massive particles: degradation of energy resolution

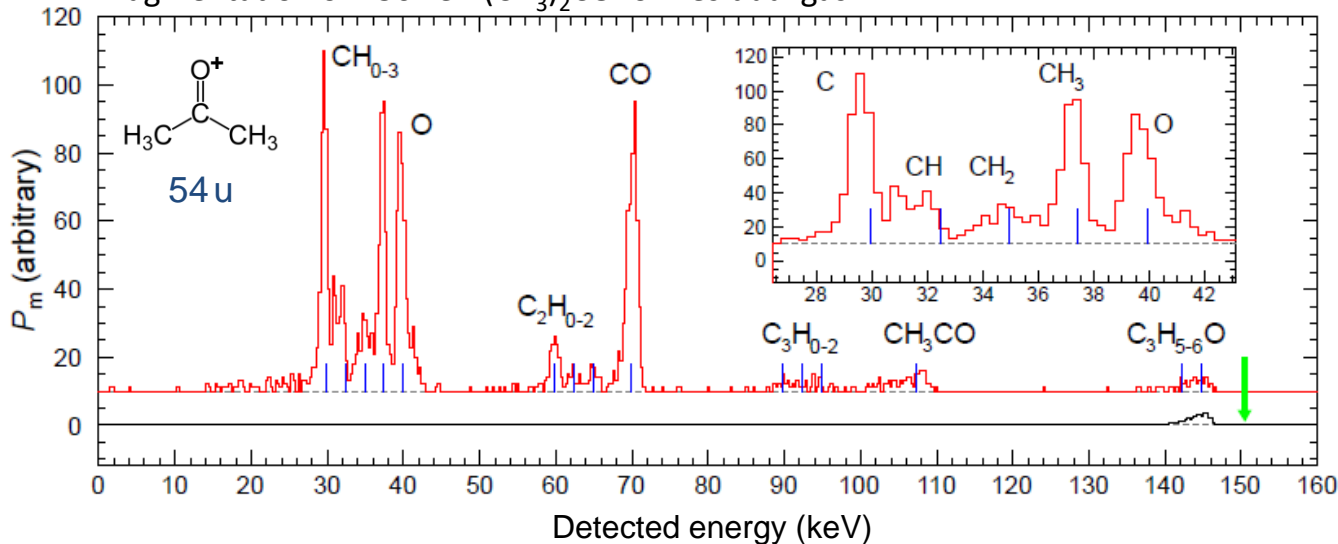
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- Detection of photons: very good energy resolution ( $\Delta E_{FWHM} @ 6\text{keV}$ : **1.6 eV**)
- Detection of massive particles: degradation of energy resolution

Fragmentation of 150 keV  $(\text{CH}_3)_2\text{CO}^+$  on residual gas:



Atomic projectiles:  $\Delta E/E \geq 10^{-3}$

Molecular projectiles:  $\Delta E/E \sim 10^{-2}$

*Novotny et al, J. App. Phys. 118 (2015)*

## Requirements on the Detector:

- Detection of neutral fragments
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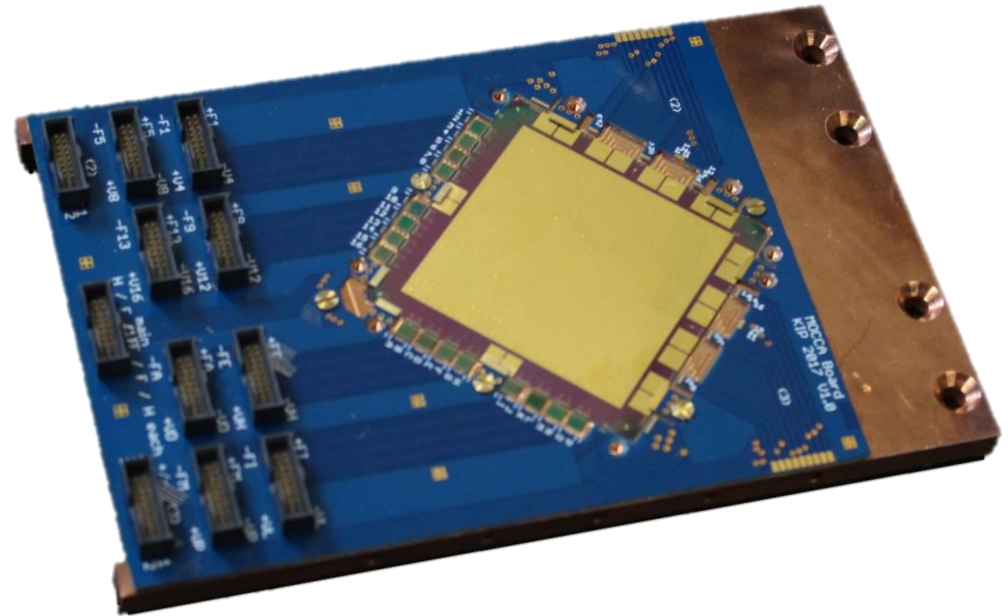
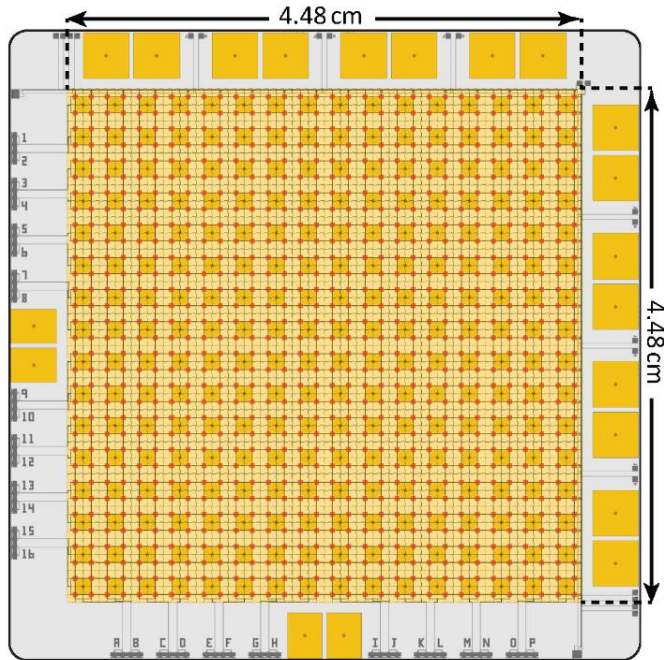


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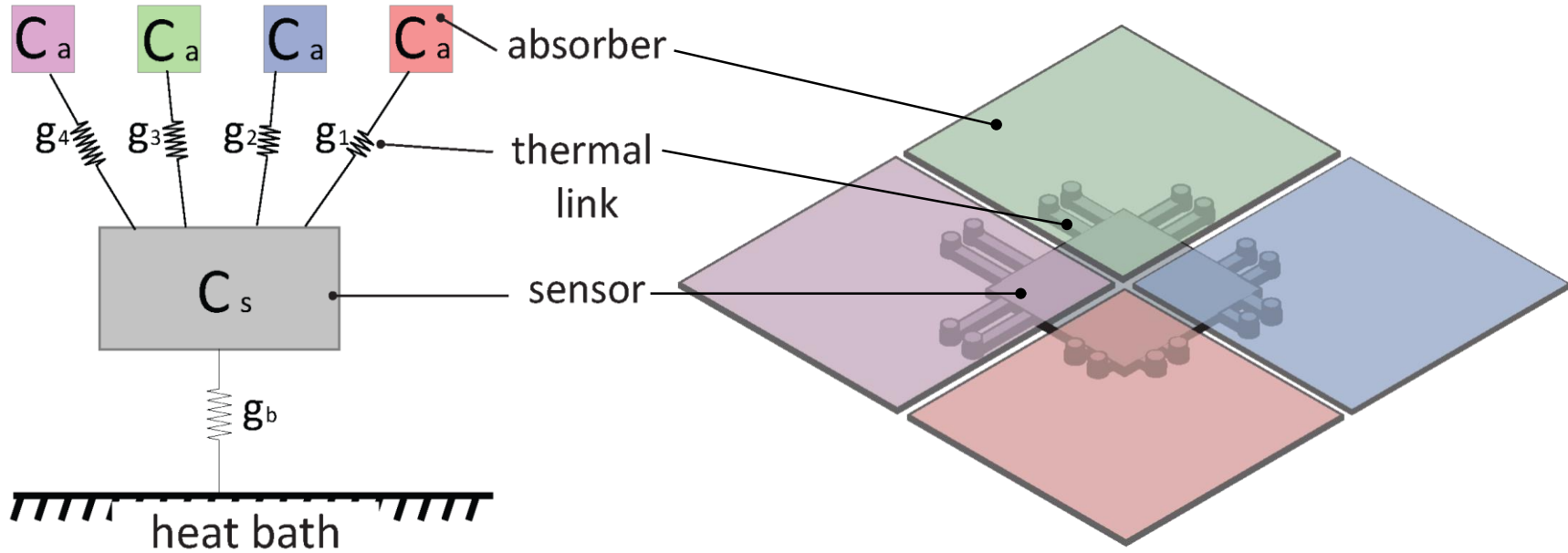


# MOCCA – a 4k-pixel molecule camera for CSR

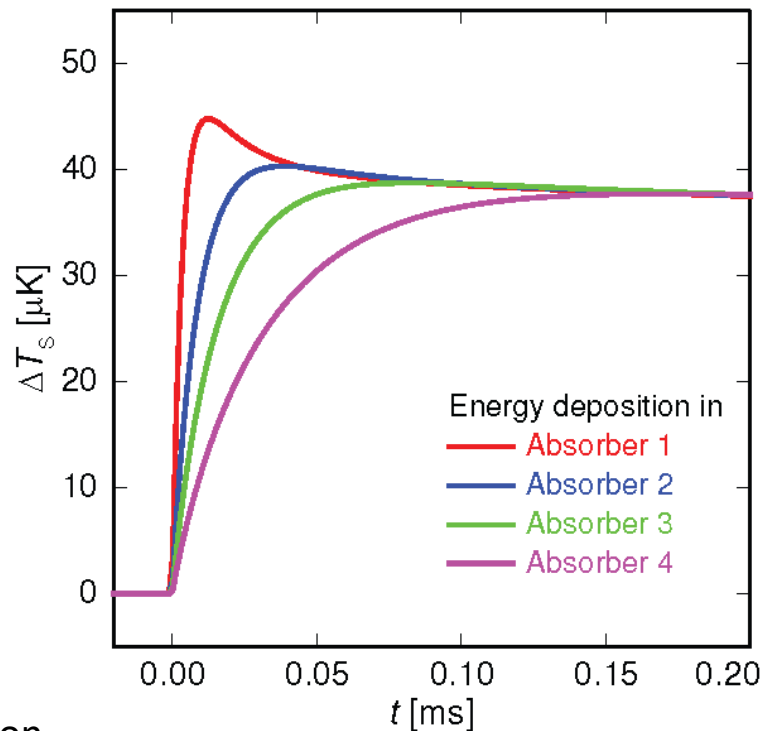
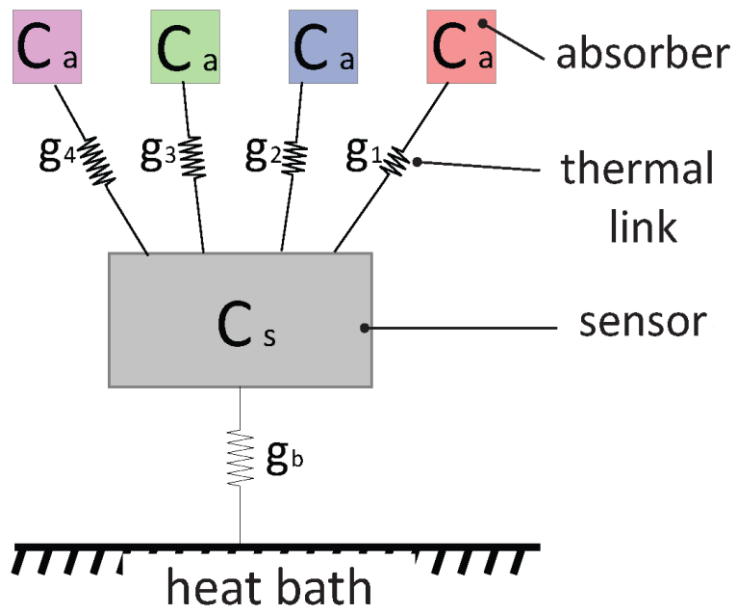


- Sensitive area: 4.48 cm × 4.48 cm
- 64 × 64 pixel
- Pixel size: 700 μm × 700 μm
- Read out: 16 + 16 SQUIDs

# MOCCA – the Hydra principle

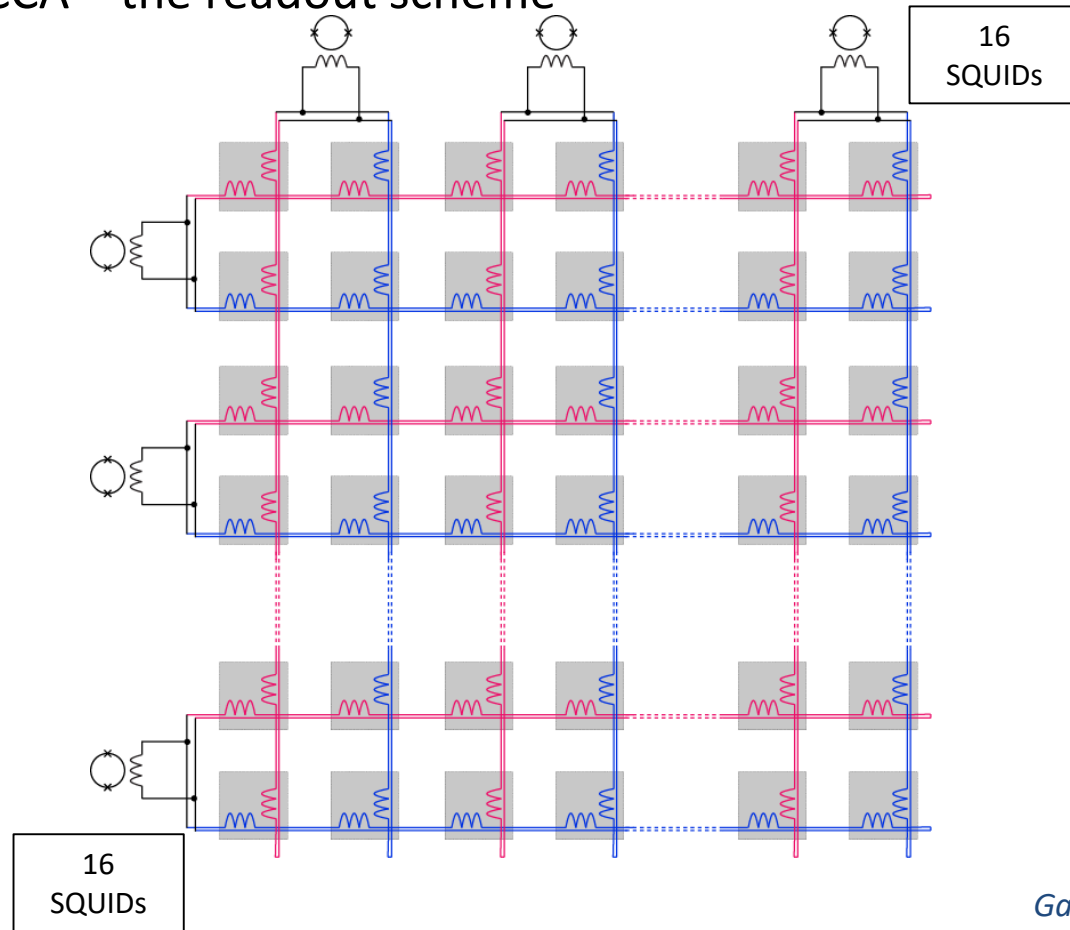


# MOCCA – the Hydra principle



Pixel identification  
via rise-time  
of detector signal

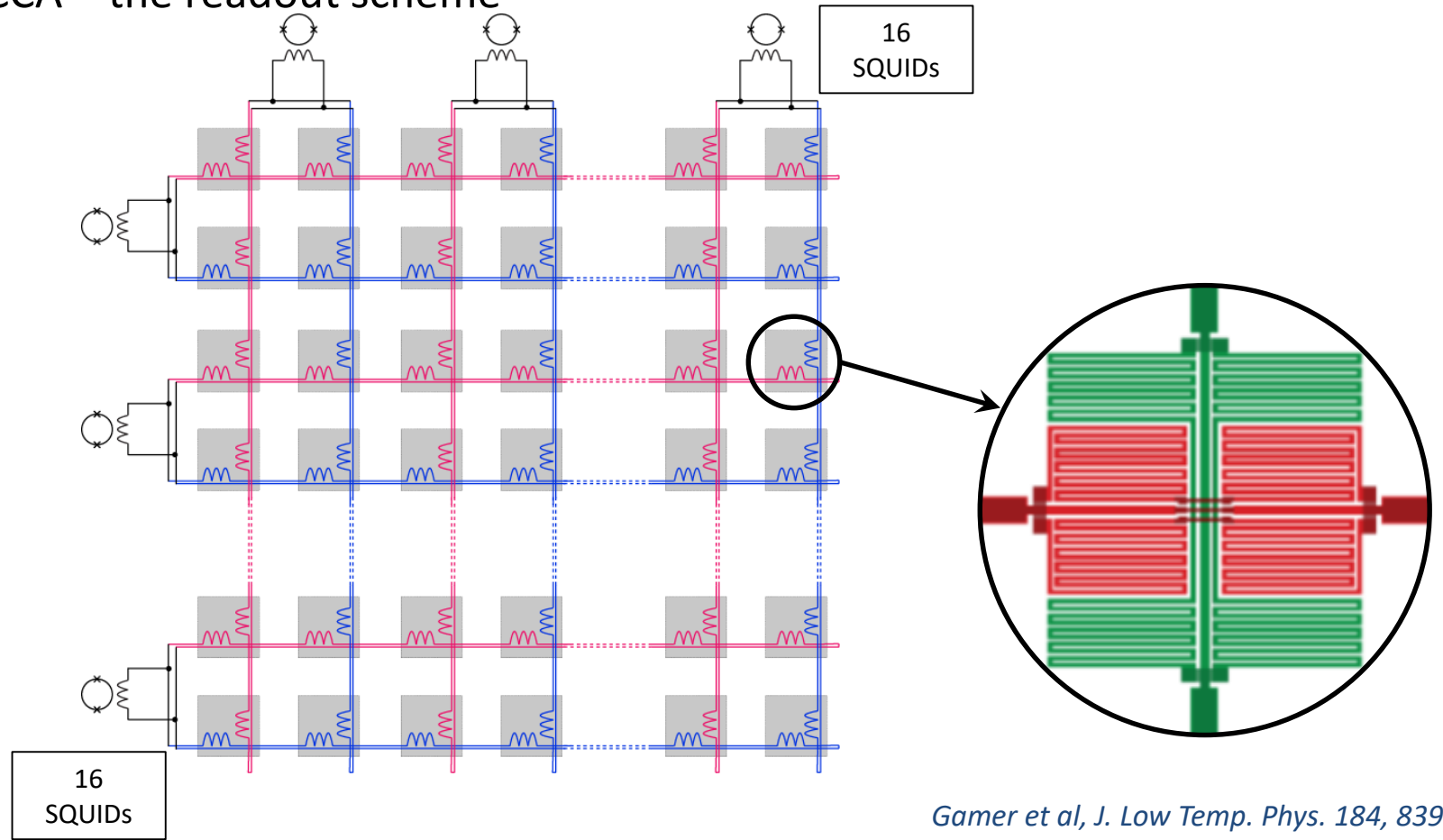
# MOCCA – the readout scheme



Gamer et al, *J. Low Temp. Phys.* 184, 839 (2016)



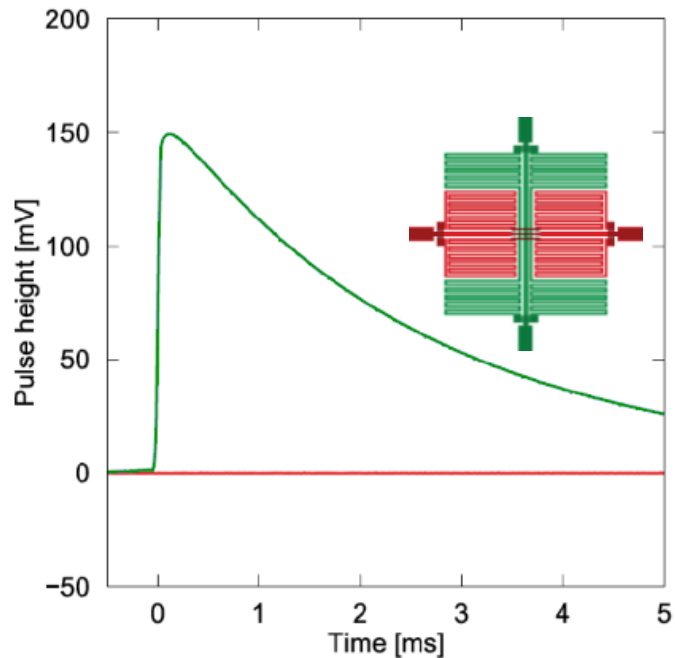
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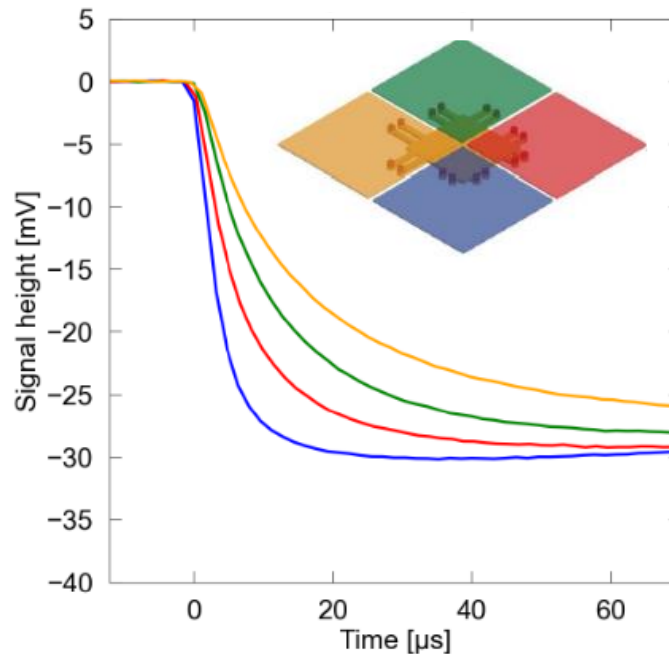
*Gamer et al, J. Low Temp. Phys. 184, 839 (2016)*

# MOCCA – performance

Crosstalk between columns & rows  
 $\approx 0.0025 \%$



Hydra-principle & readout  
principle demonstrated

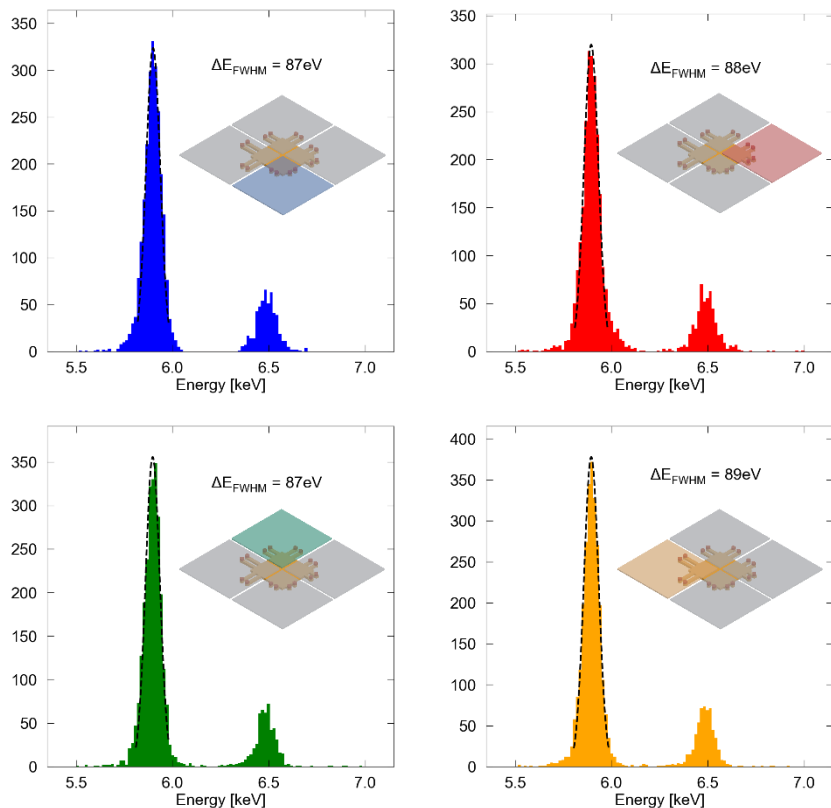


*D. Schulz, Dissertation, Kirchhoff-Institute  
for Physics, Heidelberg University (2021)*

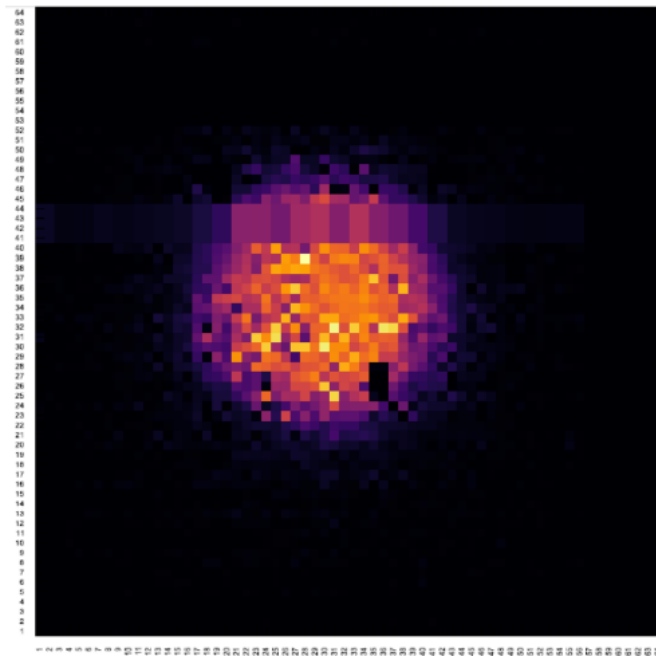


# MOCCA – performance

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



Imaging ability demonstrated  
using alpha source

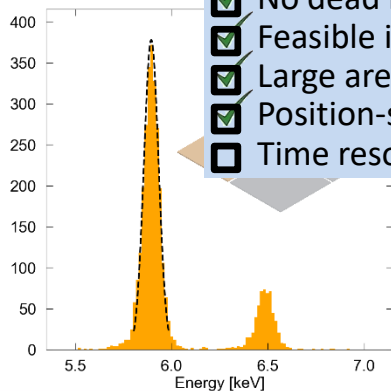
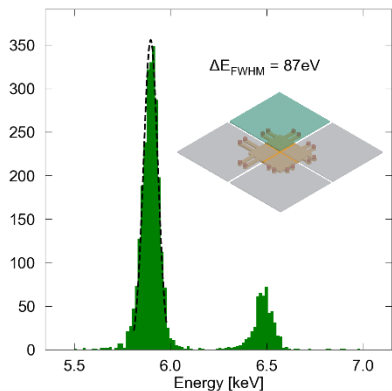
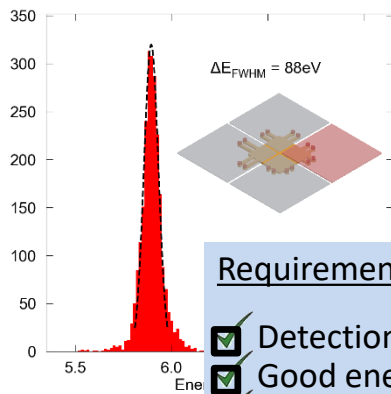
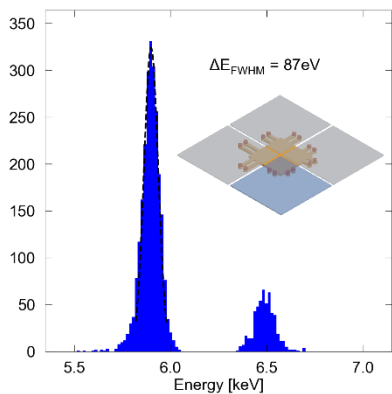


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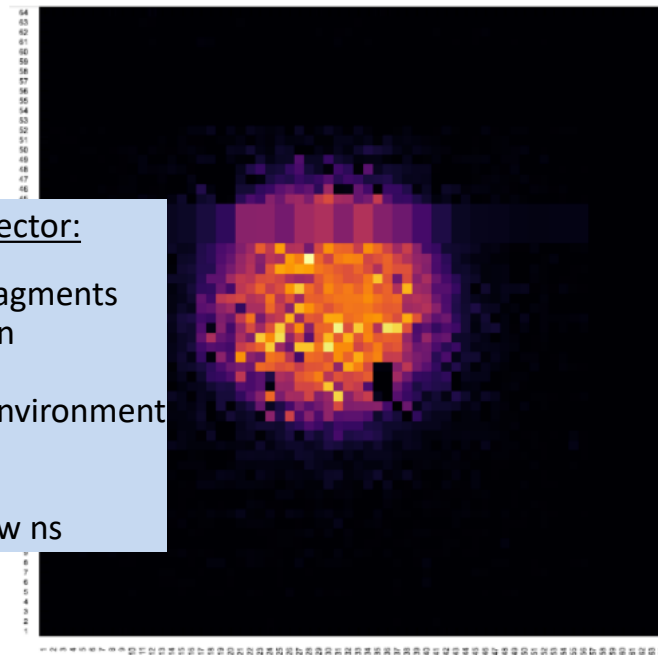
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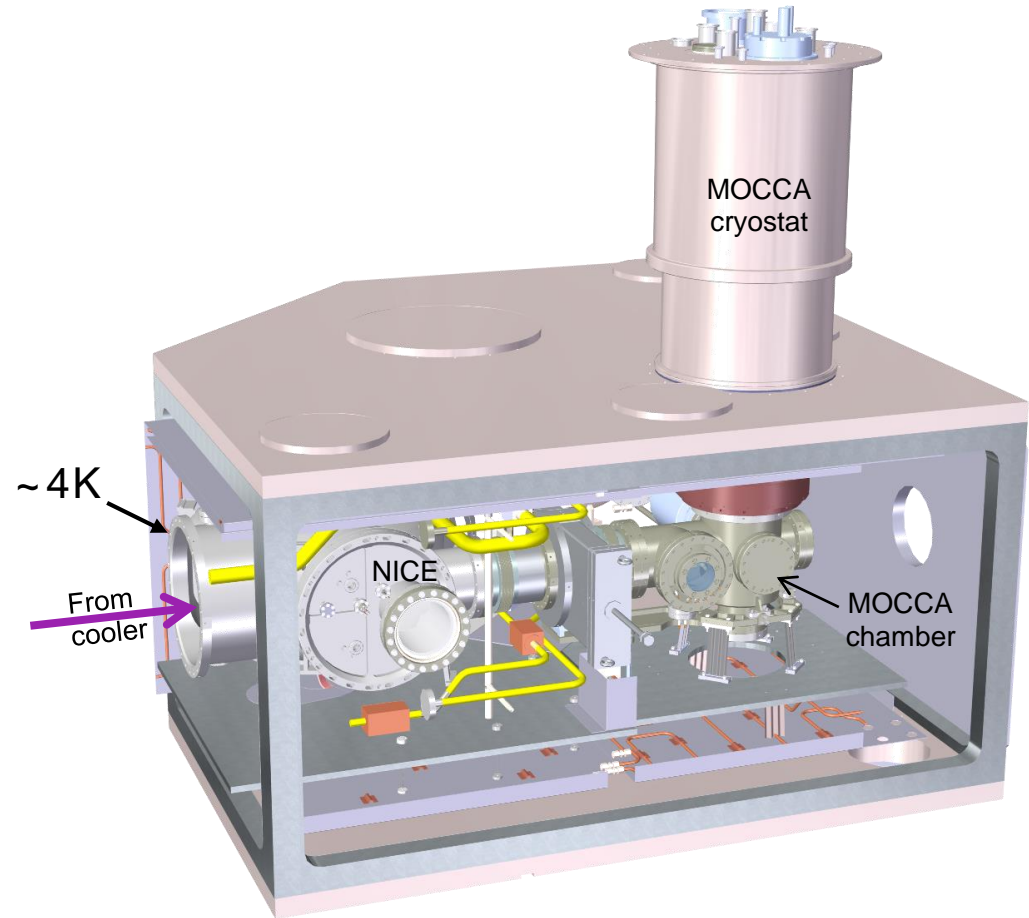
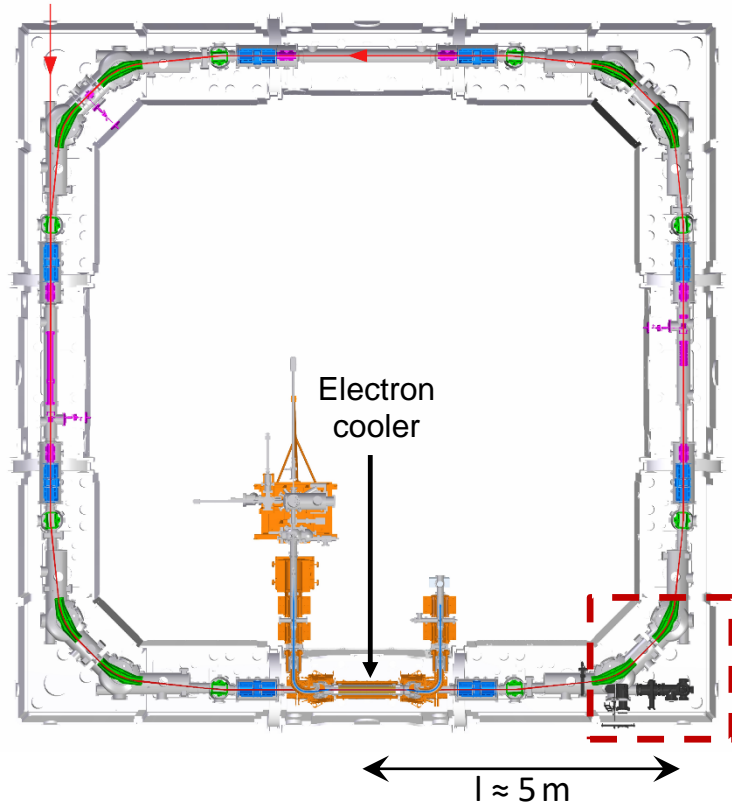


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# Integration of MOCCA into CSR

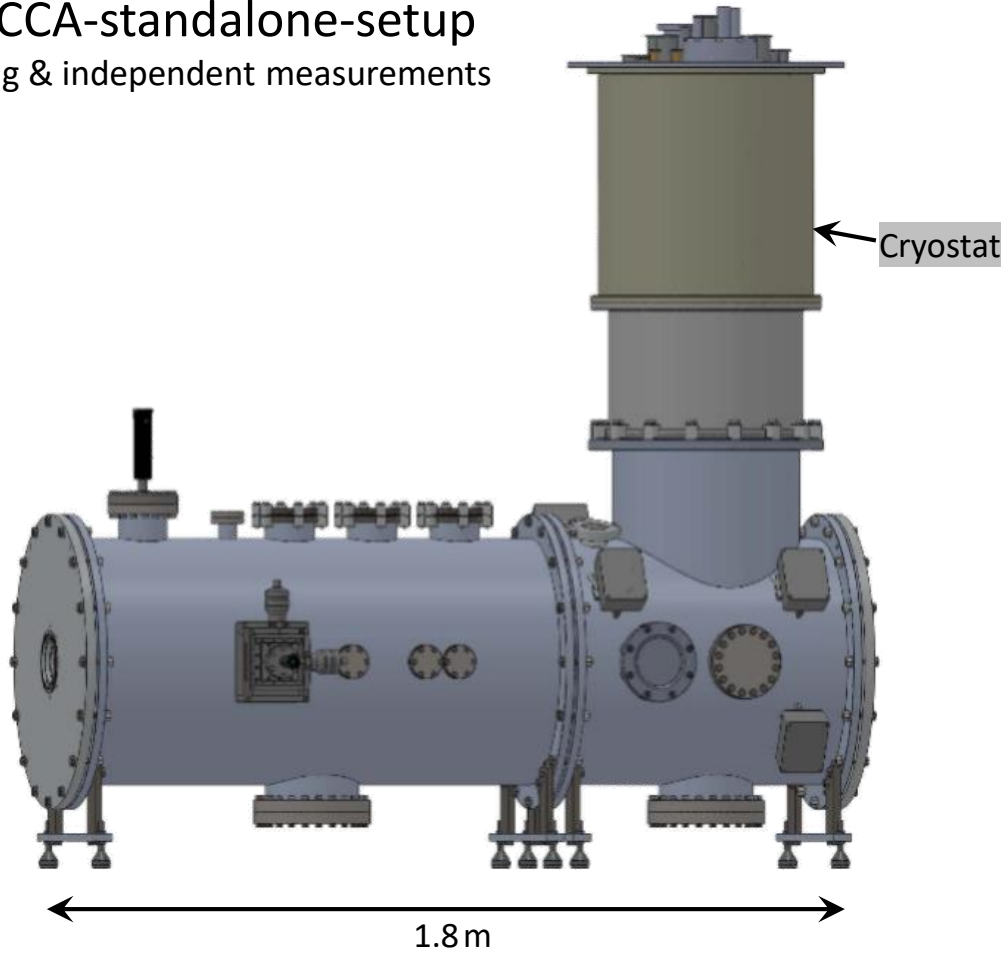


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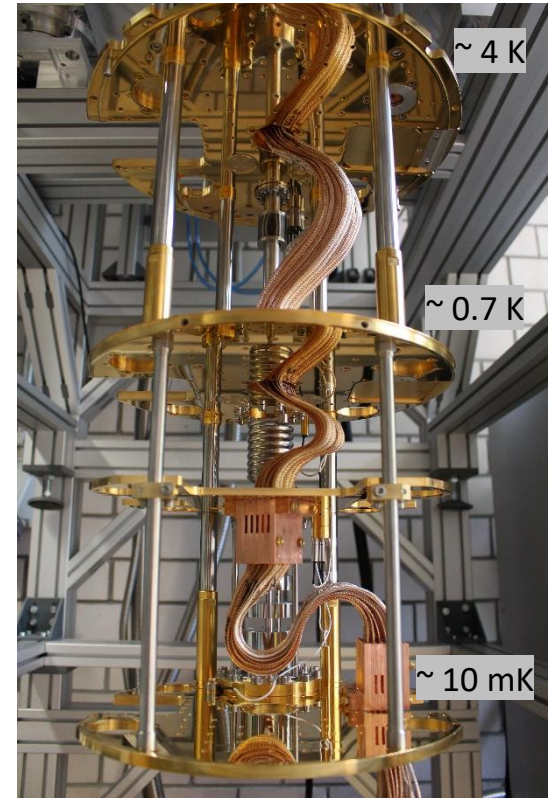
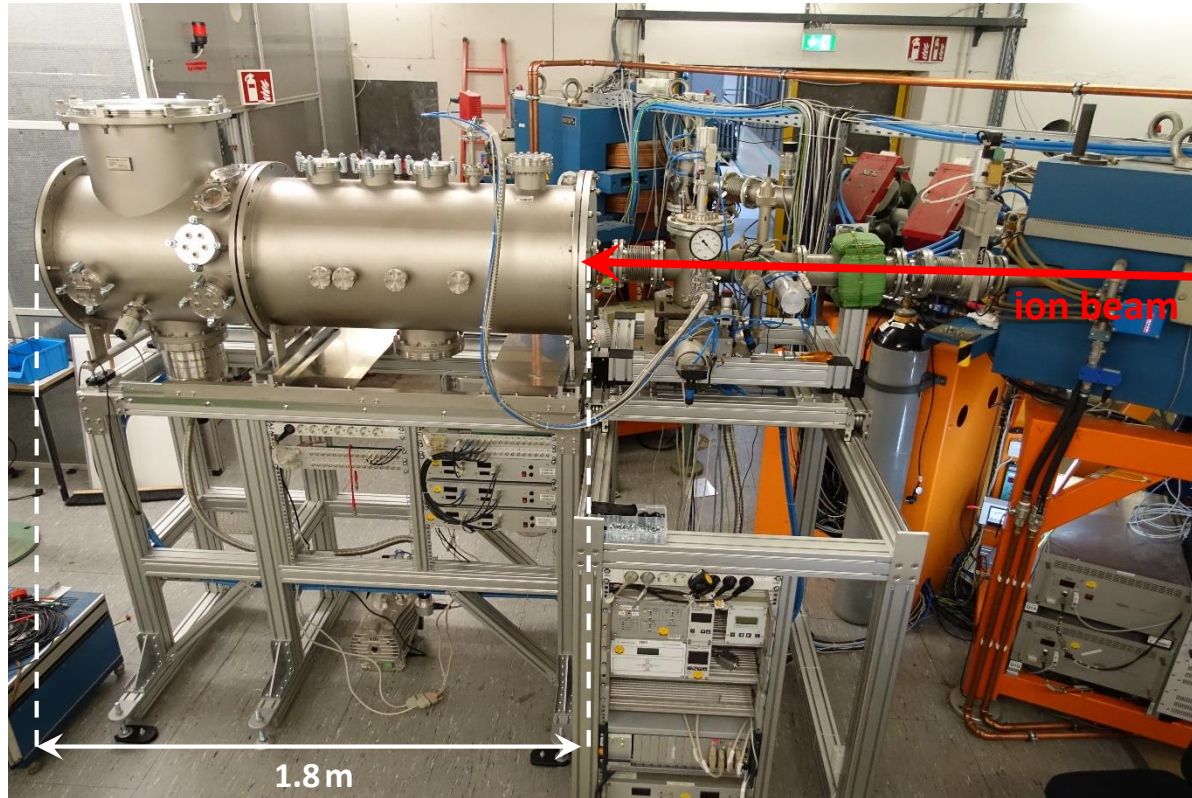
# MOCCA-standalone-setup

Testing & independent measurements



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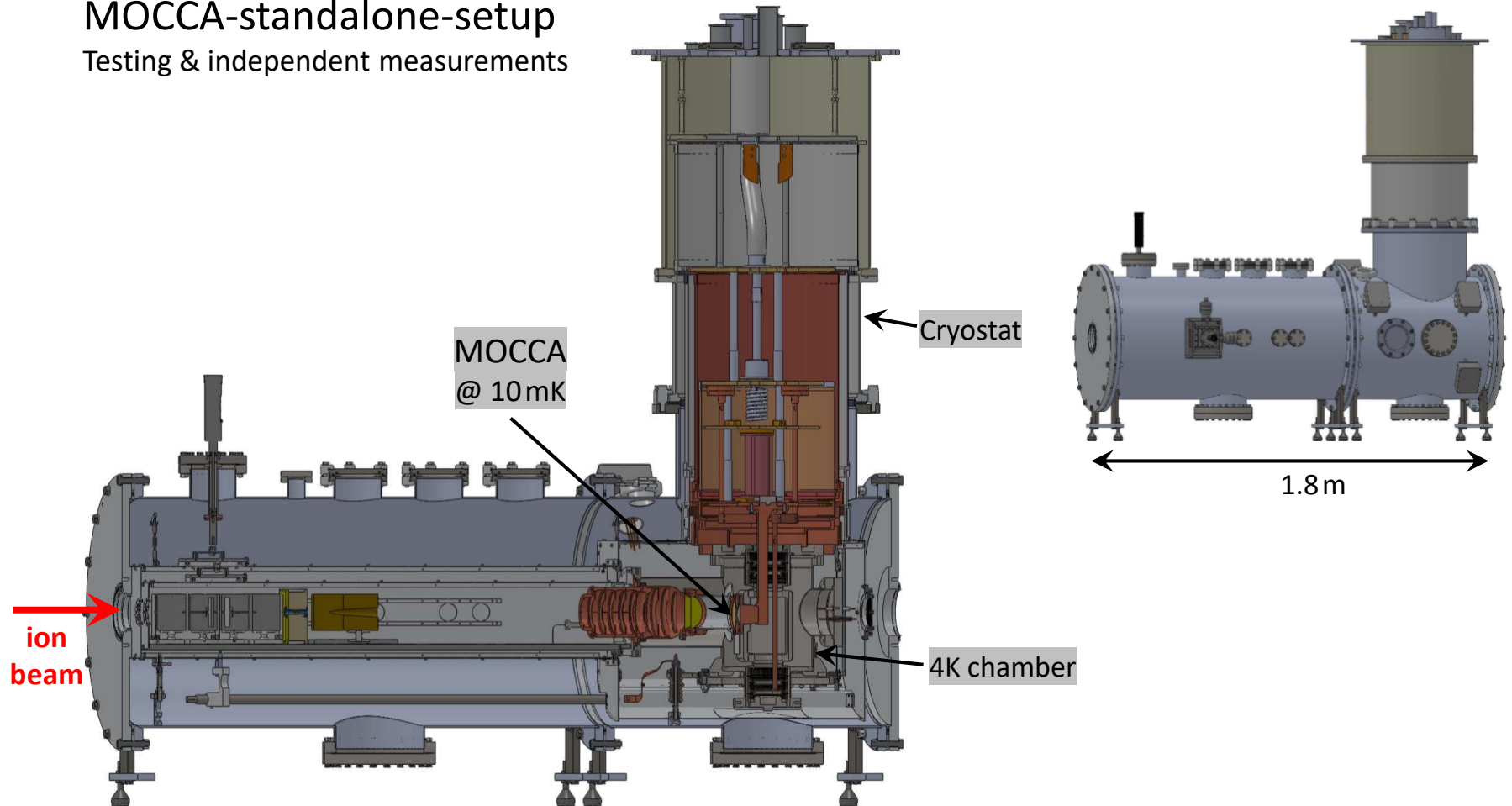
Testing & independent measurements





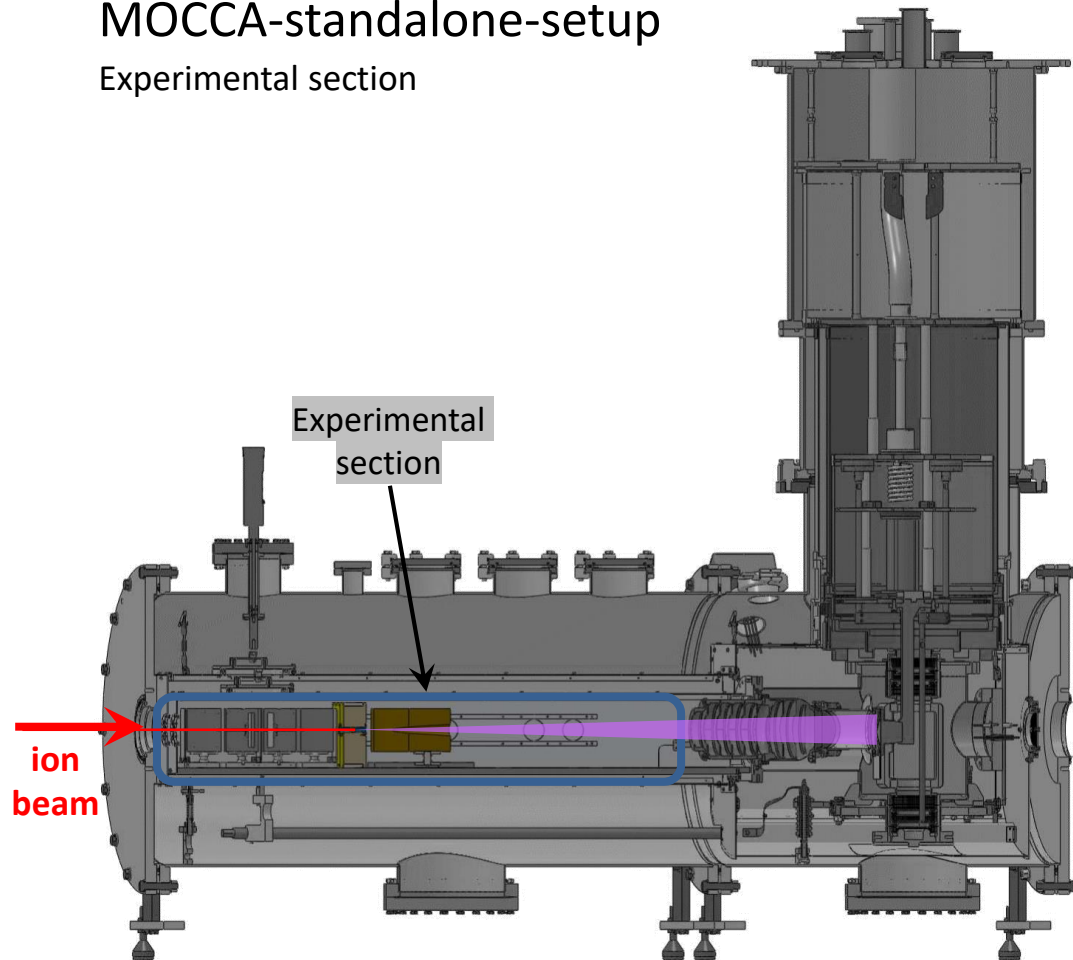
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# MOCCA-standalone-setup

Experimental section

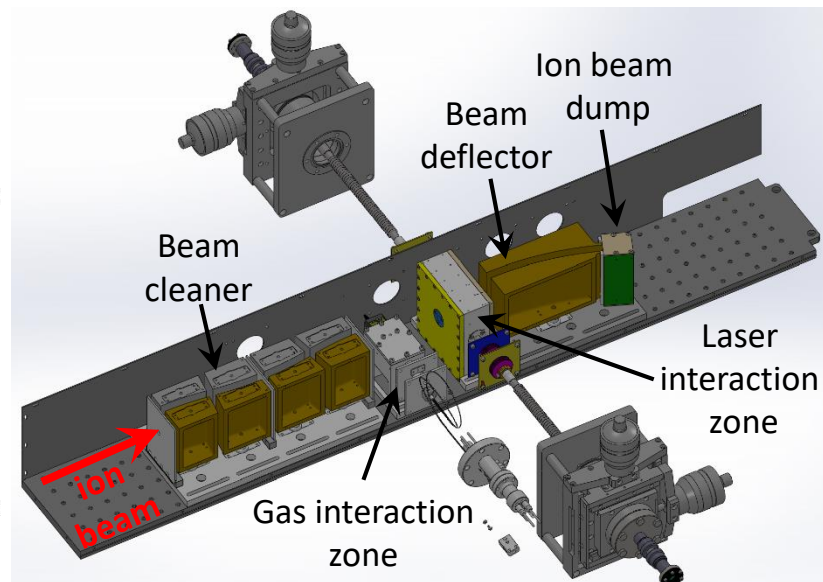


Michael Rappaport

Yoni Toker

Oded Heber

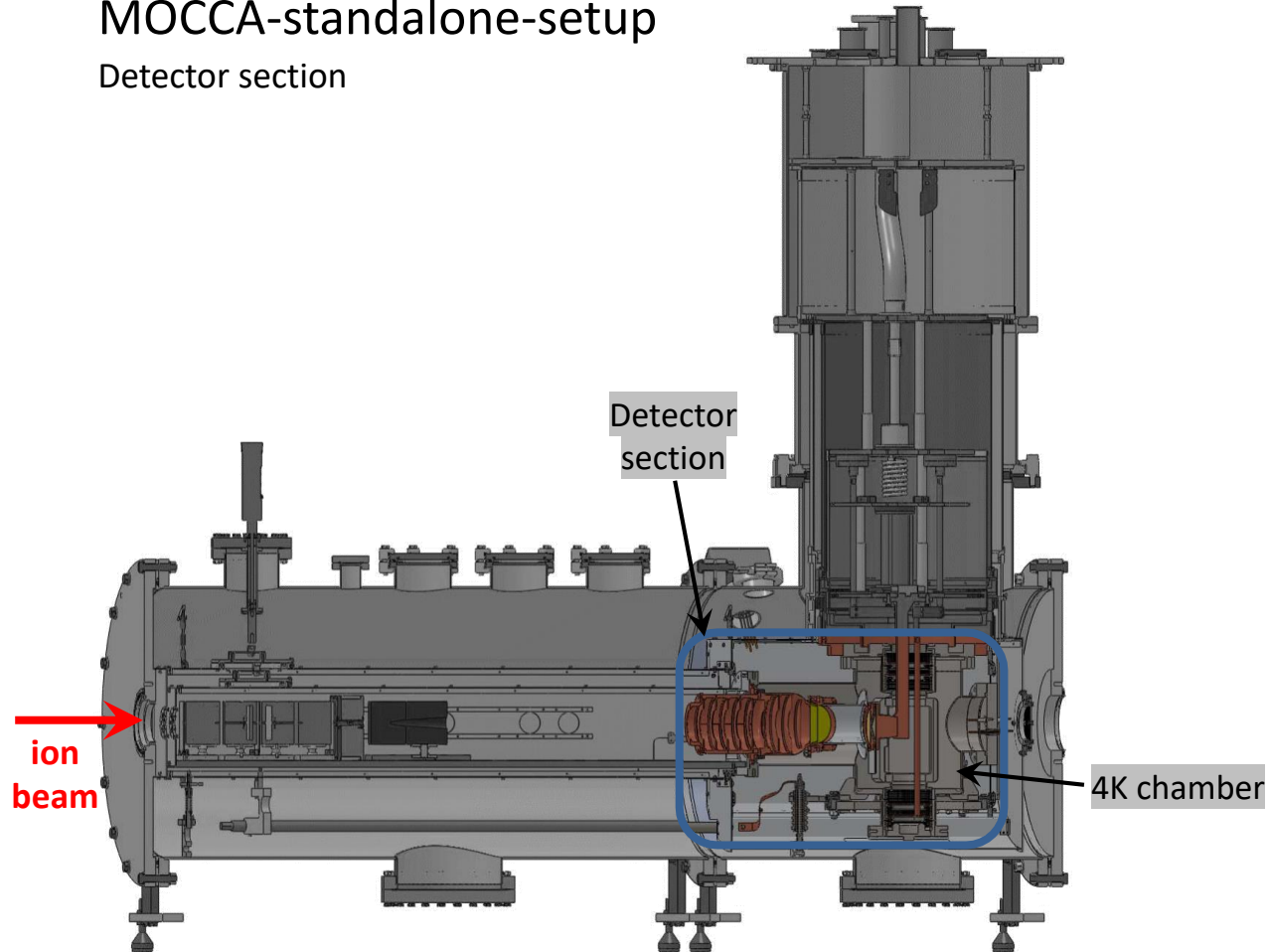
Abhishek Shahi





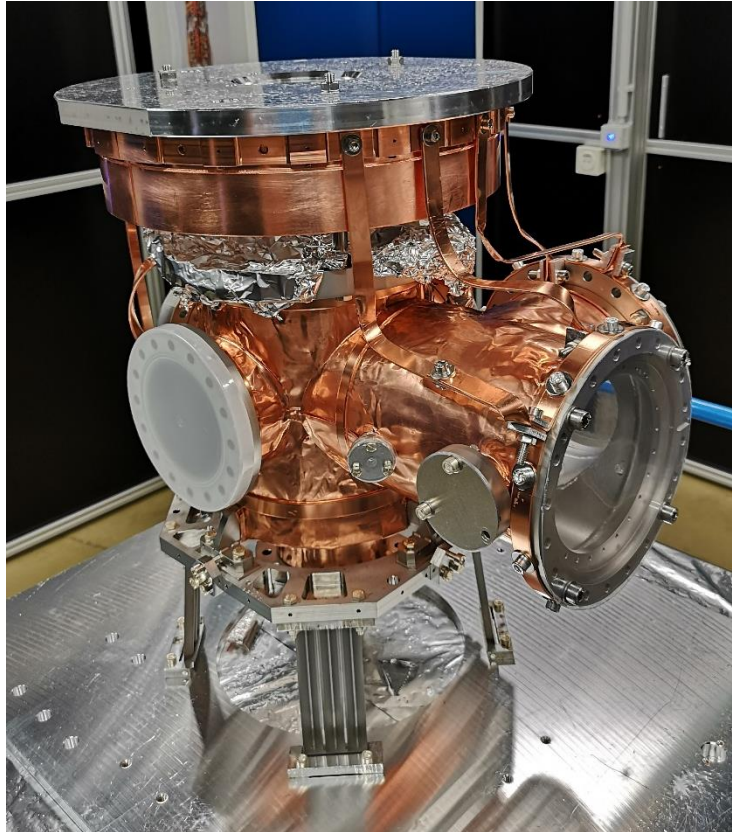
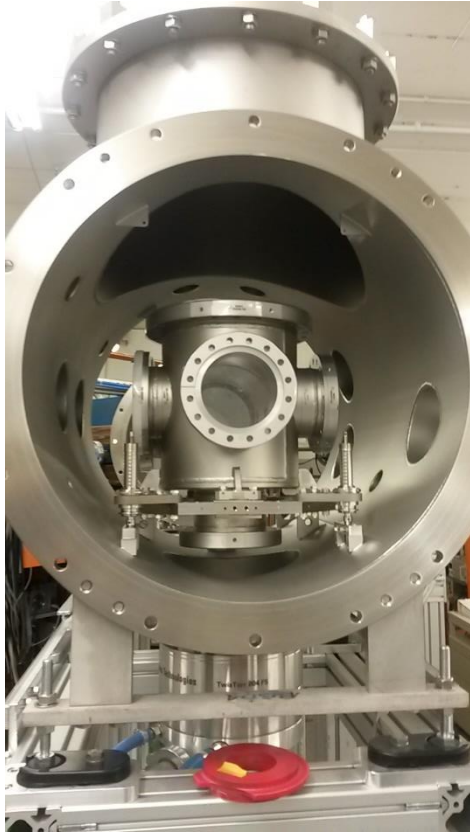
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Detector section



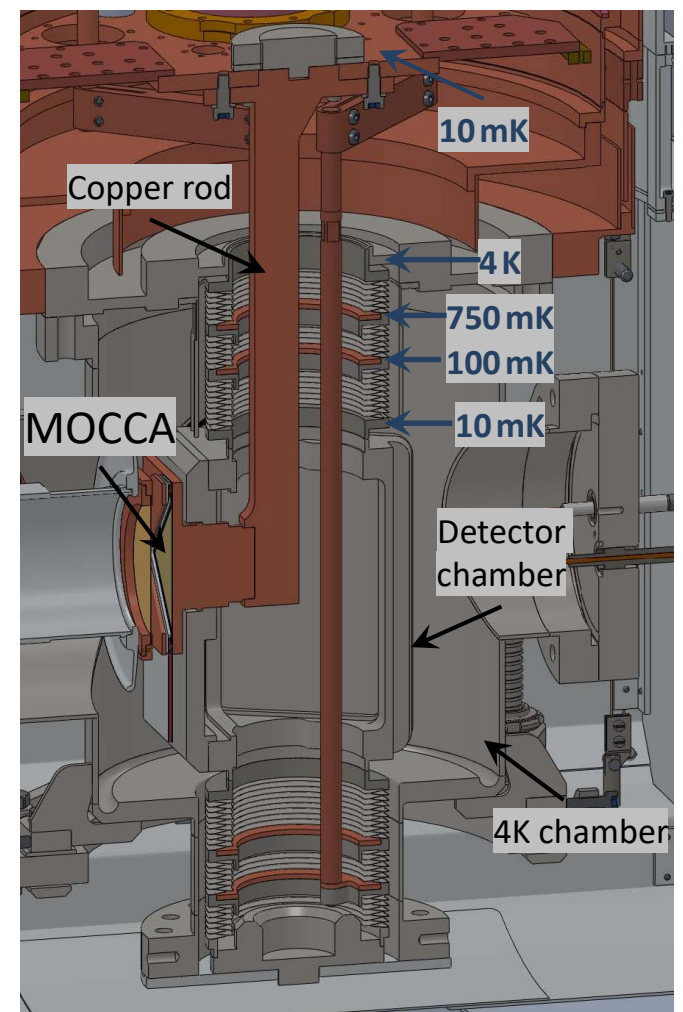
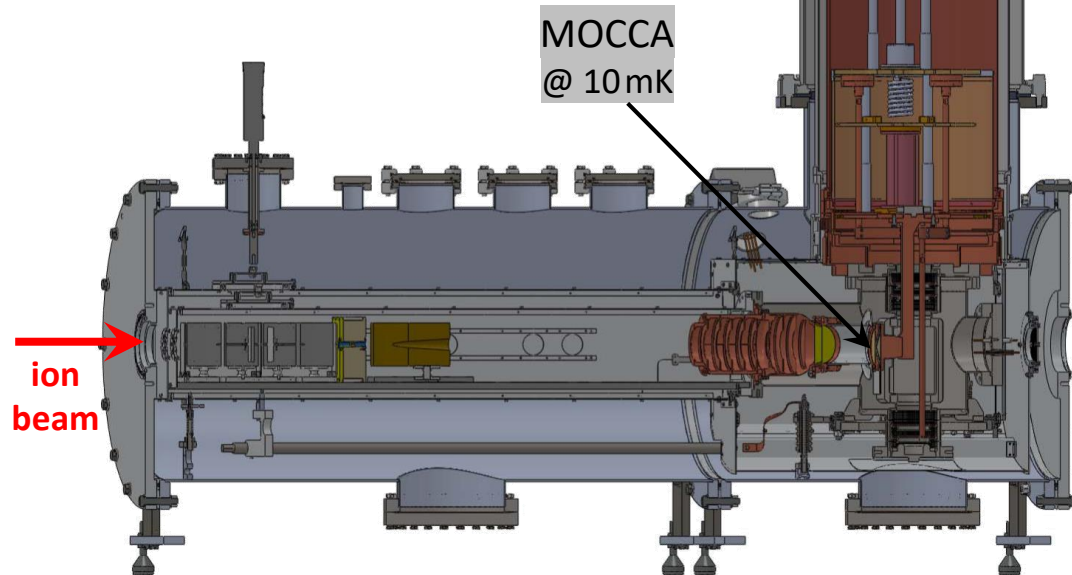
# MOCCA-standalone-setup

4K-chamber



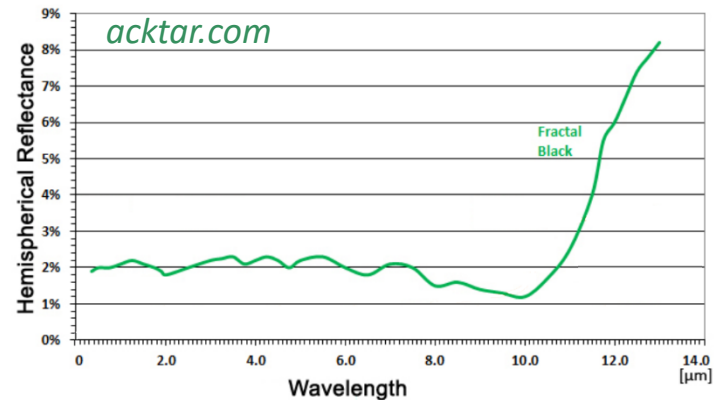
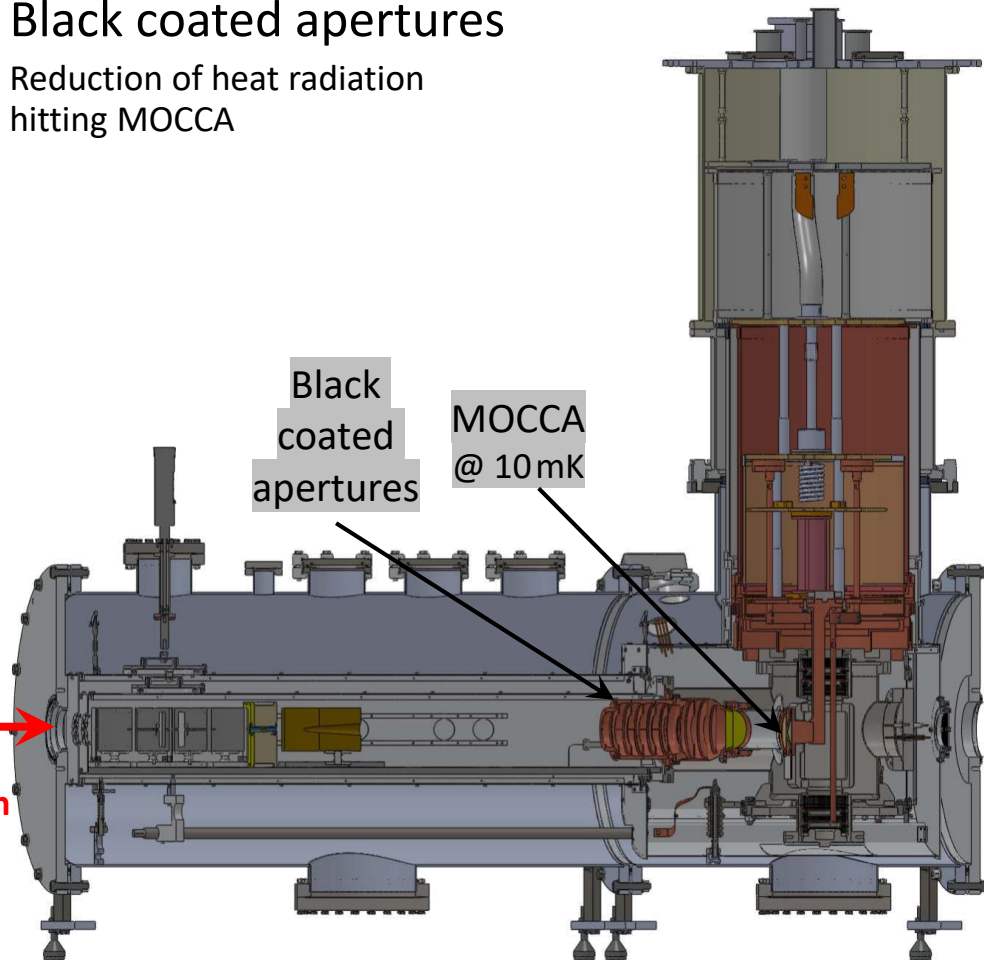
# The detector chamber

Thermal & vacuum separation  
for detector & cryostat



# Black coated apertures

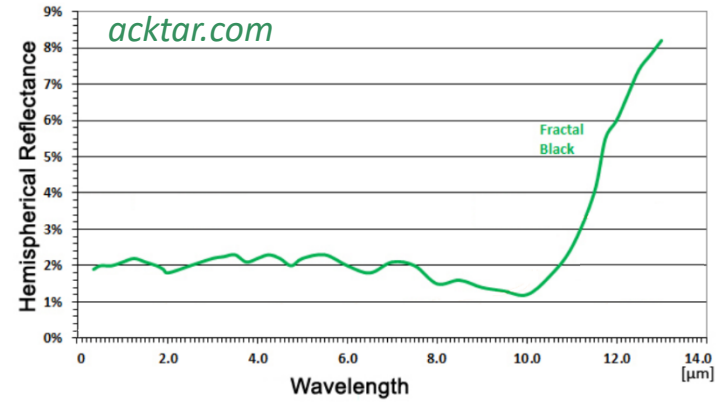
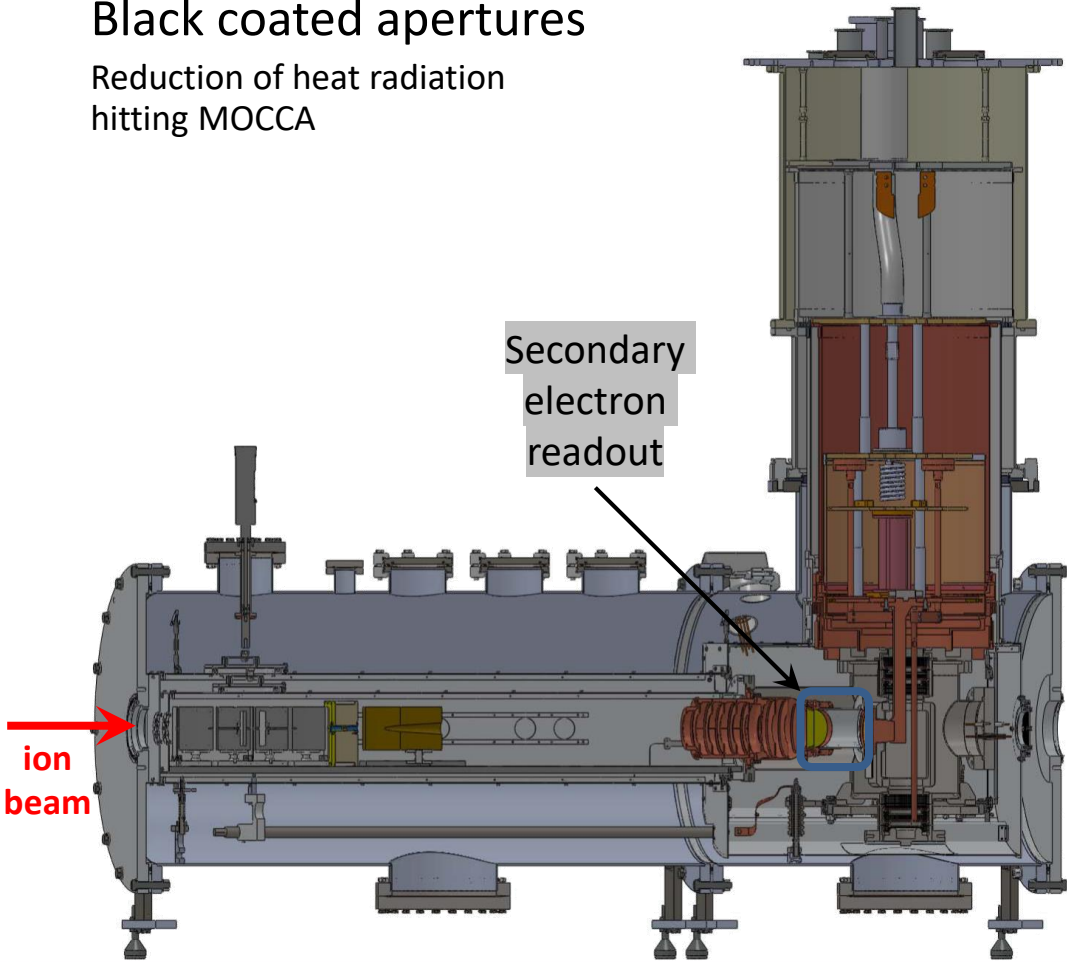
Reduction of heat radiation hitting MOCCA



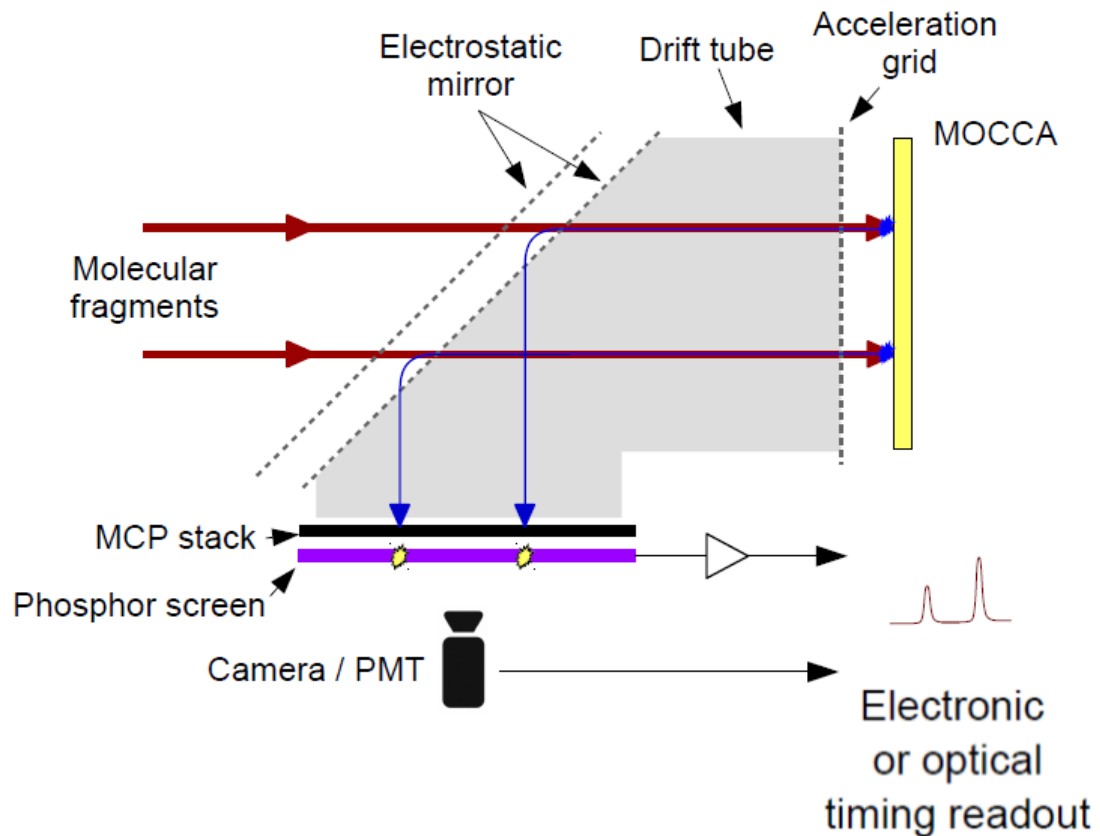
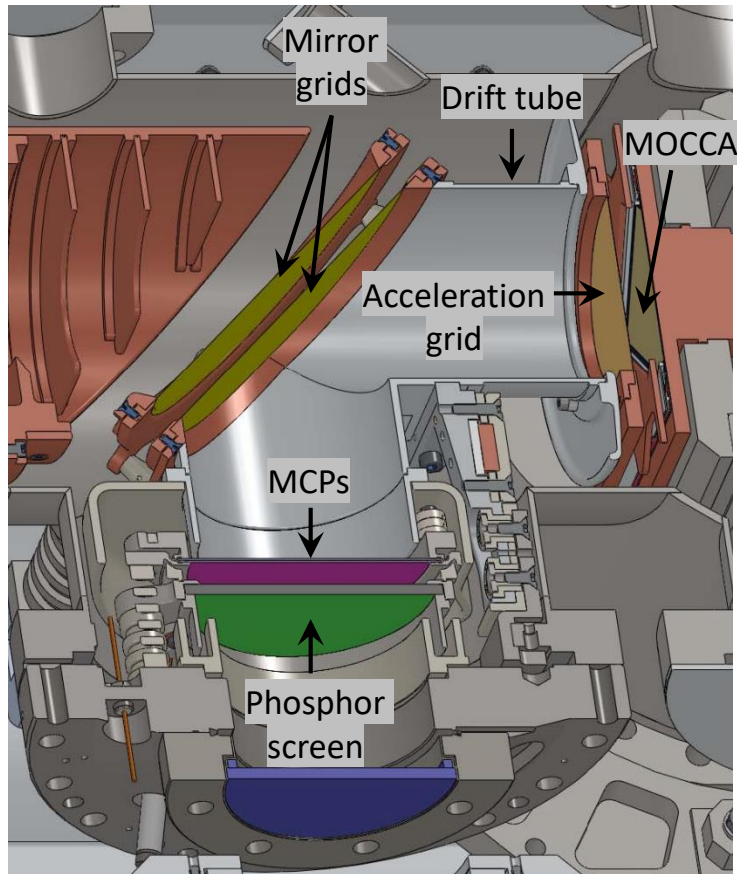


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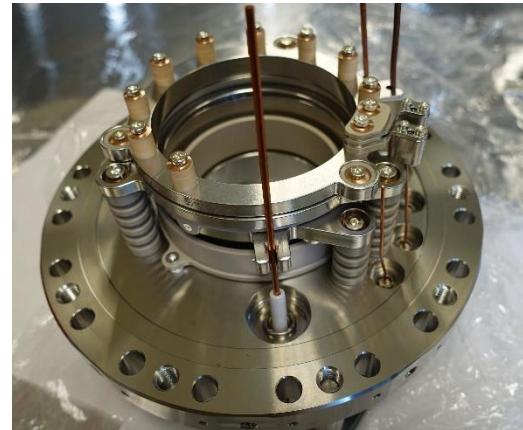
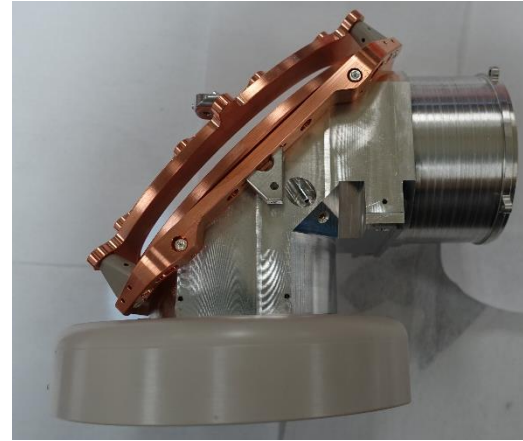
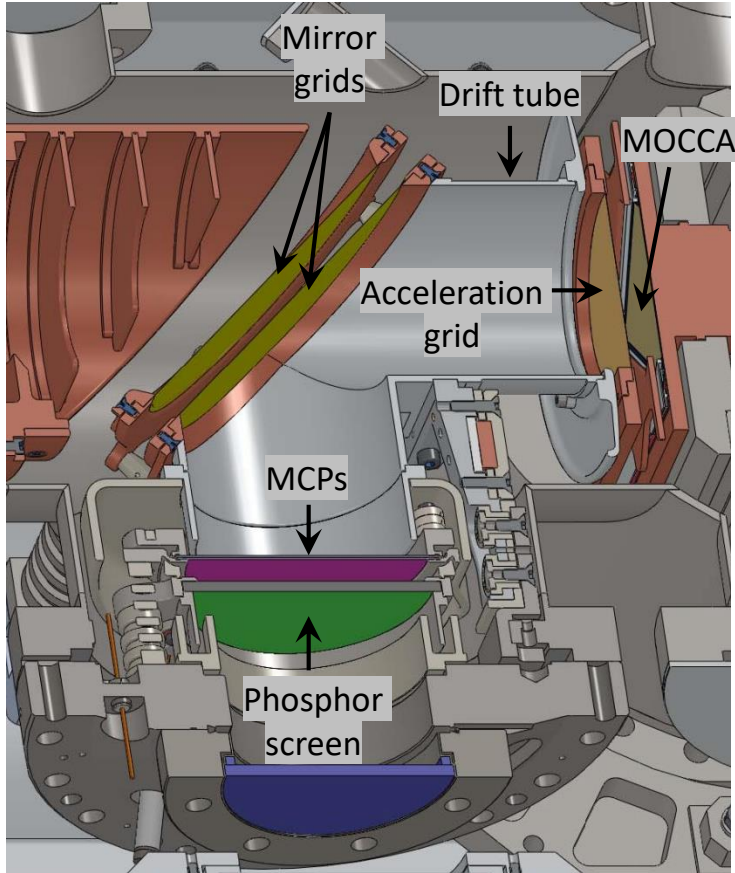
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# Secondary electron readout – for ns time resolution



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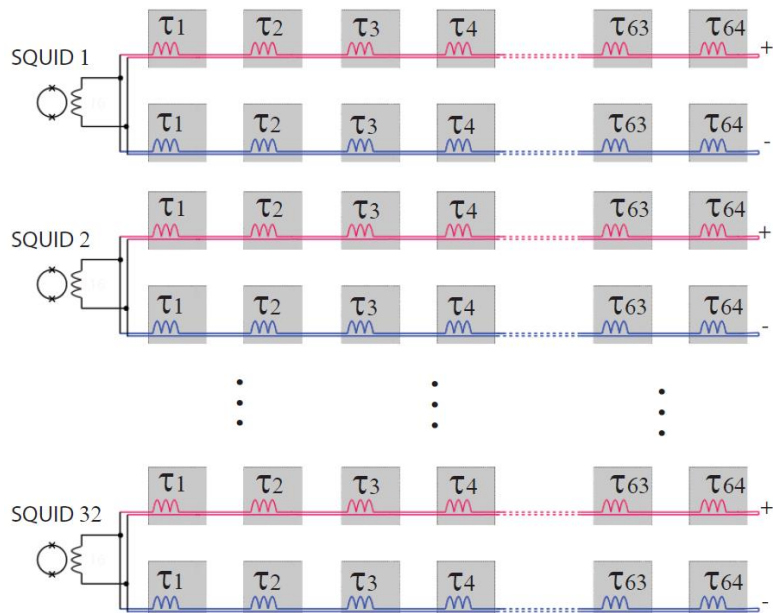
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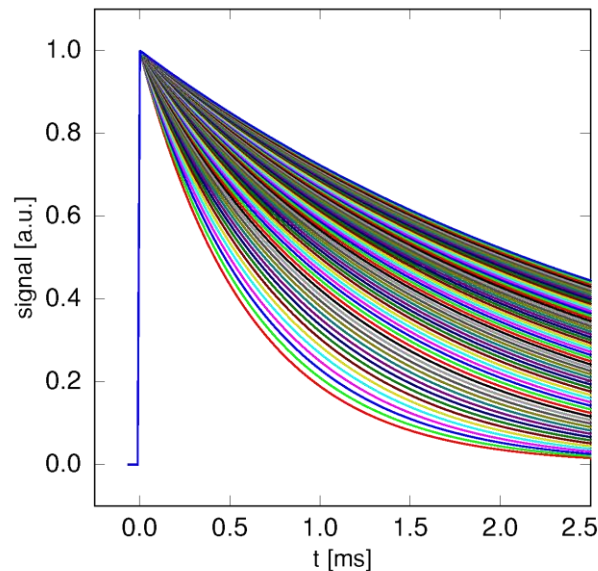
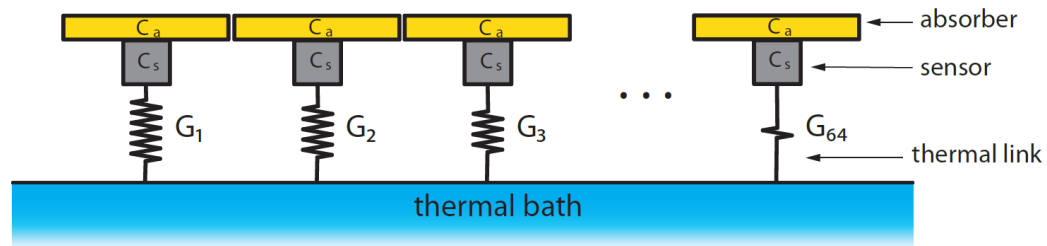
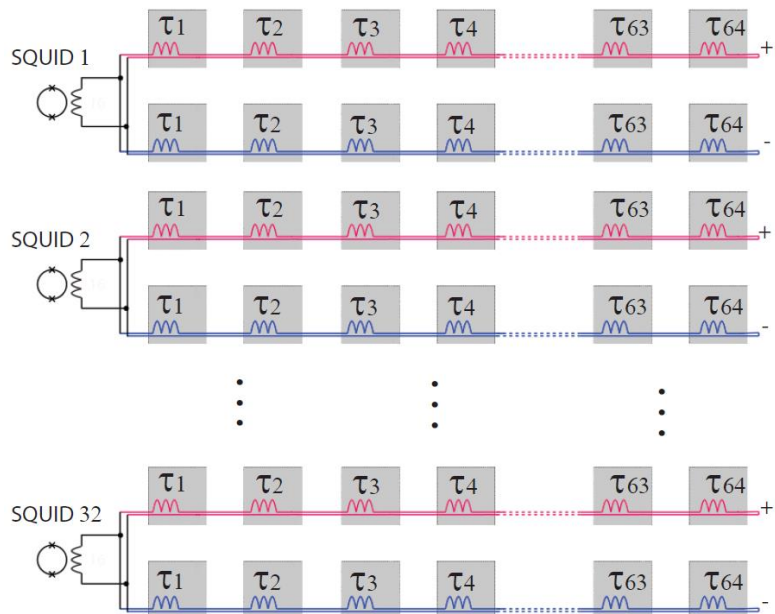


# MOCCA – new readout scheme



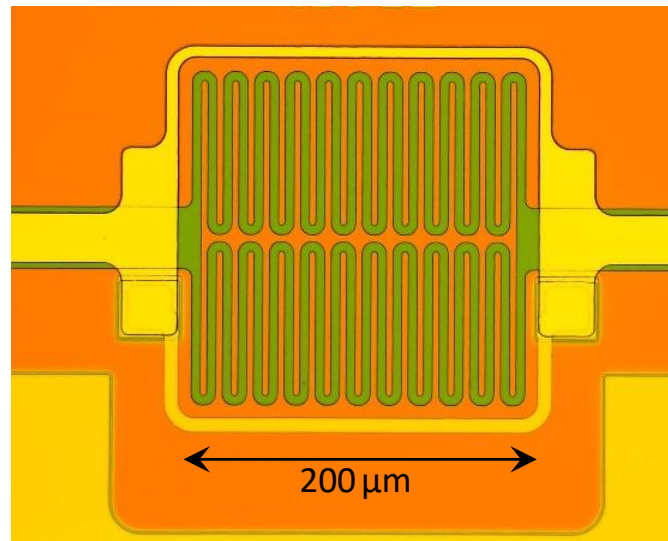
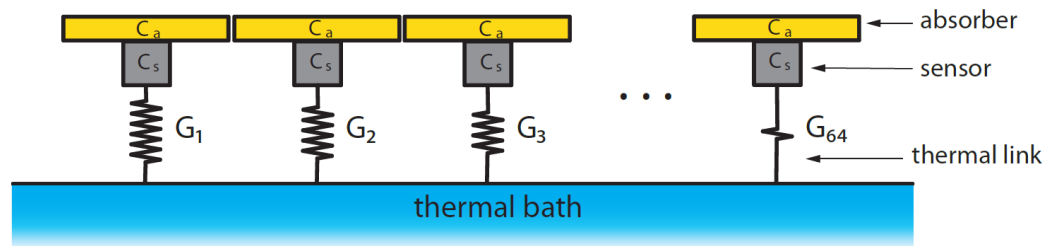
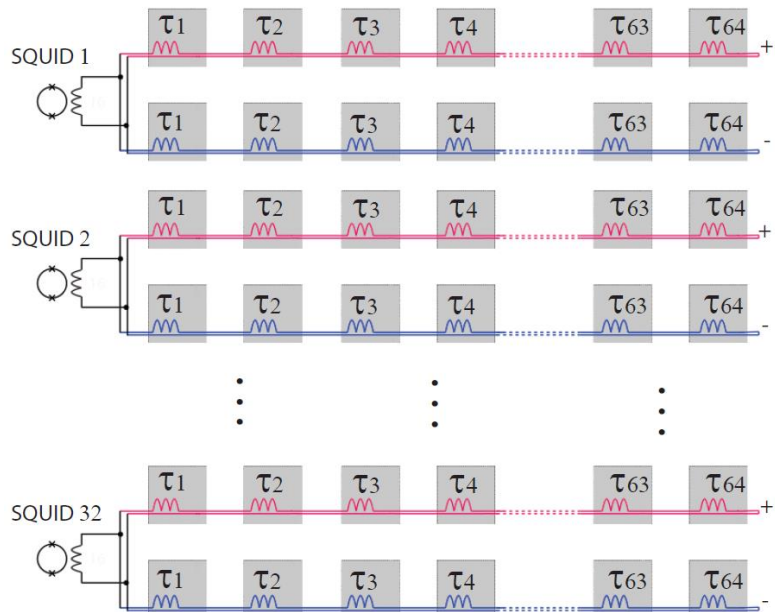
- Reduced complexity
  - Faster signal rise time
  - Same rise time for all pixels
  - Well defined signal amplitude
  - No coincidence search between rows and columns needed
- Simplified data analysis

# MOCCA – new readout scheme



Pixel identification  
via decay-time  
of detector signal

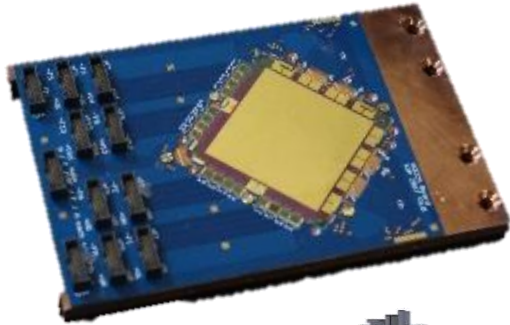
# MOCCA – new readout scheme



# Outline

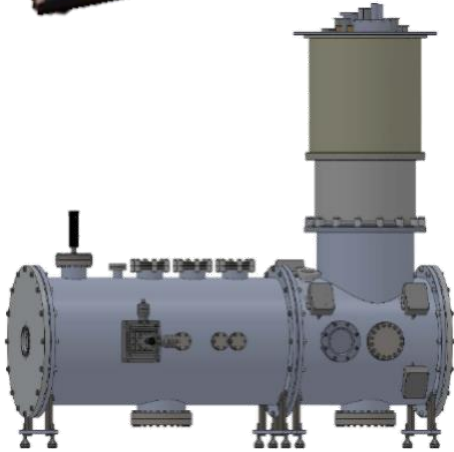
- Motivation
- The Cryogenic Storage Ring CSR
- Metallic magnetic calorimeters (MMCs)
- MOCCA – a 4k-pixel molecule camera for CSR
- Integration of MOCCA into CSR
- MOCCA-standalone-setup
- MOCCA – new readout scheme
- **Summary & Outlook**

# Summary & Outlook



## MOCCA – a 4k-pixel molecule camera:

- 64 × 64 pixels read out by 32 SQUIDs
- Characterization measurements with photons demonstrated full functionality
- Next MOCCA generation currently being fabricated



## MOCCA standalone setup:

- Design completed, parts fabricated
- Assembly ongoing
- Possible future measurement:  
PAH +  $\gamma$  → Production of H or H<sub>2</sub>?  
→ Formation of H<sub>2</sub> in space?

# Thank you



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**Klaus Blaum**



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**Ansgar Lowack**  
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**Andreas Fleischmann**  
**Christian Enss**



**מכון ויצמן למדע**  
**WEIZMANN INSTITUTE OF SCIENCE**

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**Yoni Toker**  
**Oded Heber**  
**Abhishek Shahi**

**Bar-Ilan  
University**  
**אוניברסיטת בר אילן**





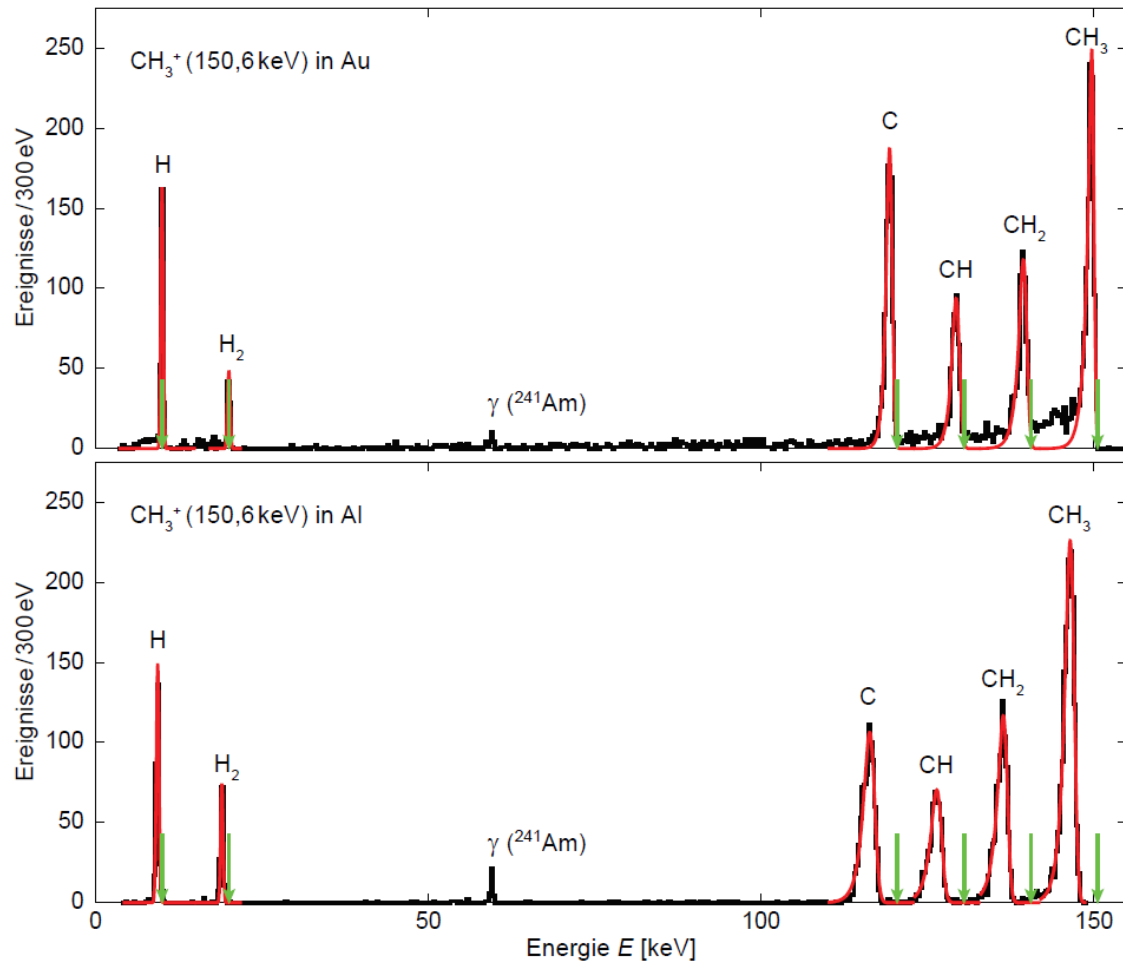


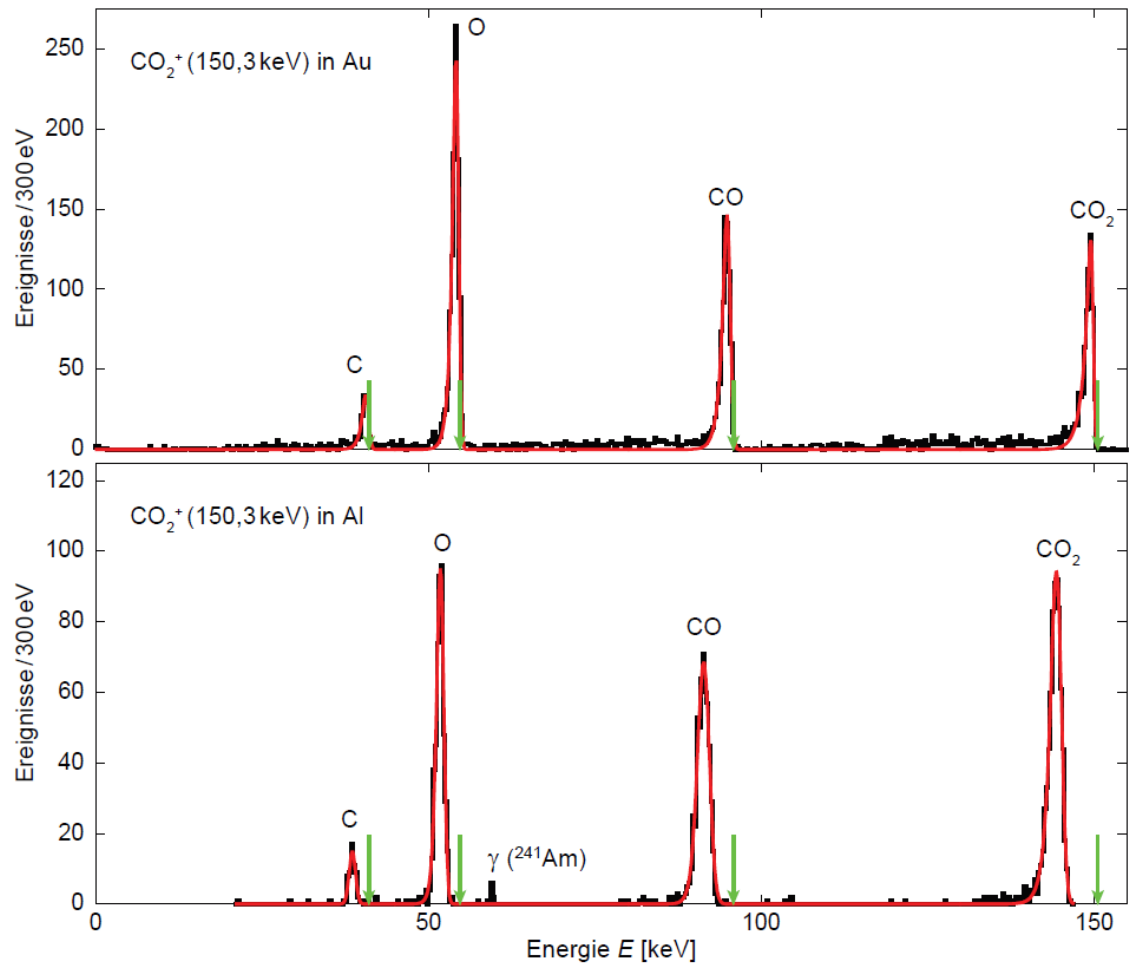




# Appendix

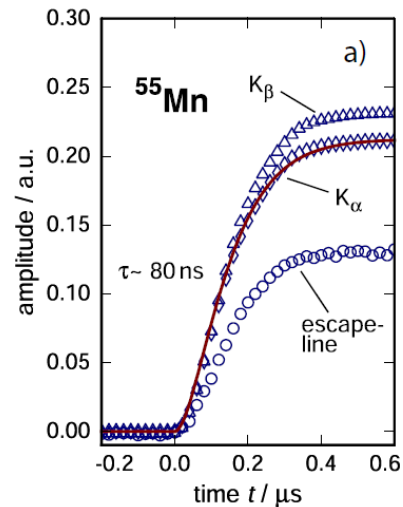




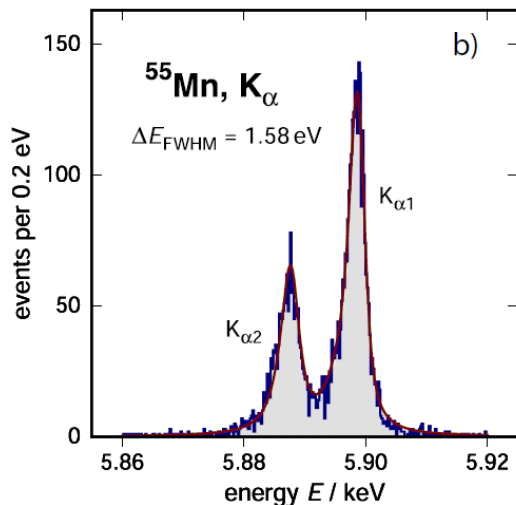




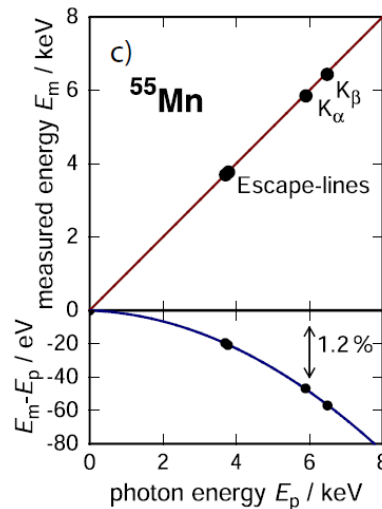
# Metallic magnetic calorimeters (MMCs) – photon detection performance



signal rise time:  
80 ns



$\Delta E_{FWHM}$  @ 6keV:  
1.6eV



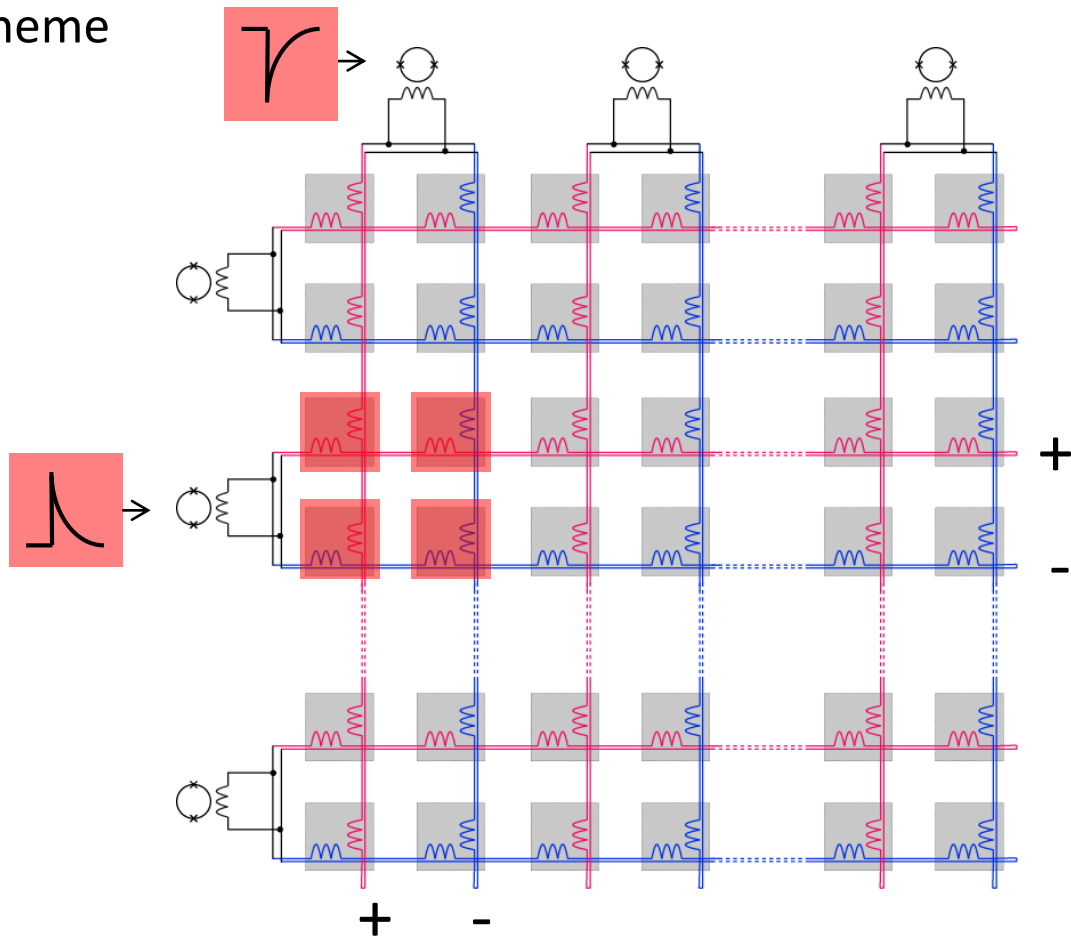
non-linearity @ 6keV:  
1.2%

## Requirements on the Detector:

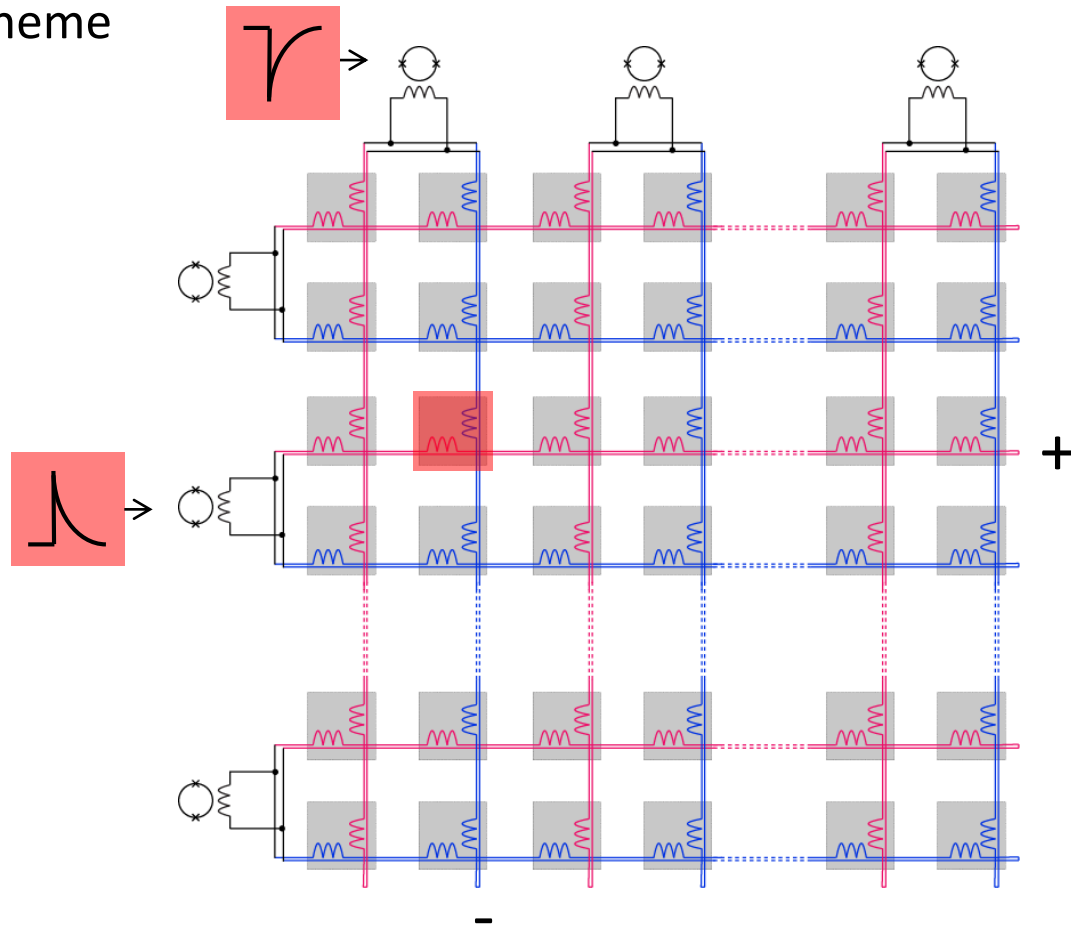
- Detection of neutral fragments
- Good energy-resolution
- No dead layer
- Feasible in cryogenic environment
- Large area
- Position-sensitivity
- Time resolution of a few ns

MMCs:  
**fast, high-resolving & linear** detectors  
for photons & massive particles

# Readout scheme



# Readout scheme





# MOCCA – detector geometry

