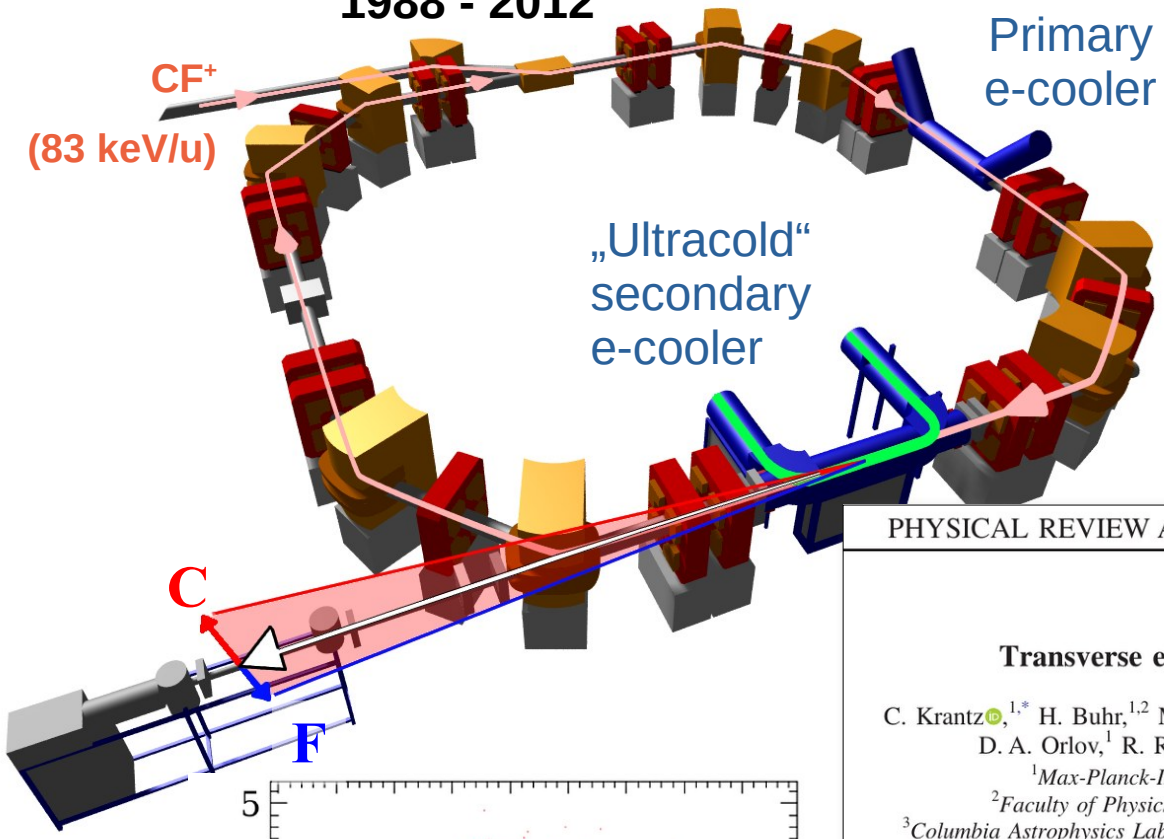
# Transverse electron cooling of heavy molecular ions

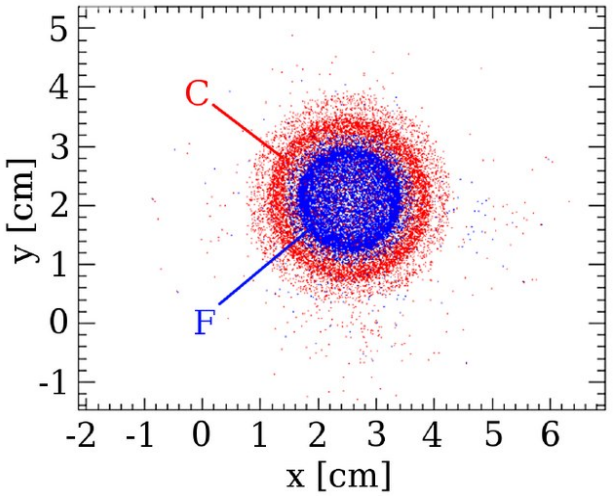
Claude Krantz

COOL’23, Montreux

12 October 2023

# TSR
# MPIK Heidelberg
# 1988 - 2012




PHYSICAL REVIEW ACCELERATORS AND BEAMS **24,** 050101 (2021)

## Transverse electron cooling of heavy molecular ions

C. Krantz,[1,*] H. Buhr,[1,2] M. Grieser,[1] M. Lestinsky,[1] O. Novotný,[1,3] S. Novotny,[1] D. A. Orlov,[1] R. Repnow,[1] A. S. Terekhov,[4] P. Wilhelm,[1] and A. Wolf[1]

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[2]*Faculty of Physics, Weizmann Institute of Science, Rehovot 76100, Israel*
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(Received 10 January 2021; accepted 29 March 2021; published 3 May 2021)

Transverse electron cooling of heavy molecular ions has been studied at the Test Storage Ring (TSR). Electron beams from a cold GaAs:(Cs,O) photocathode, with kinetic energies down to 31 eV, have been used for cooling of singly-charged ions of masses up to 41 u. We believe that these are the heaviest singly-charged ions for which successful electron cooling has been reported so far. Transverse ion-beam emittances $\ll 1$ $\mu$m were reached after typically several seconds of cooling time. The measured transverse cooling rates agree with a simple binary-collision model, assuming a transverse electron temperature of approximately 1 meV/$k_B$. The results serve as benchmark for electron cooling at the new Cryogenic Storage Ring, which uses the same photocathode electron source and is targeting singly-charged ions of even higher mass.

DOI: 10.1103/PhysRevAccelBeams.24.050101

Physica Scripta. Vol. T22, 269–276, 1988.

# Ultracold Ordered Electron Beam

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*Received November 6, 1987; accepted February 1, 1988*

A secondary electron cooler for the TSR had been proposed early-on
to act as „ultracold“ additional cooling stage and high-resolution electron target.

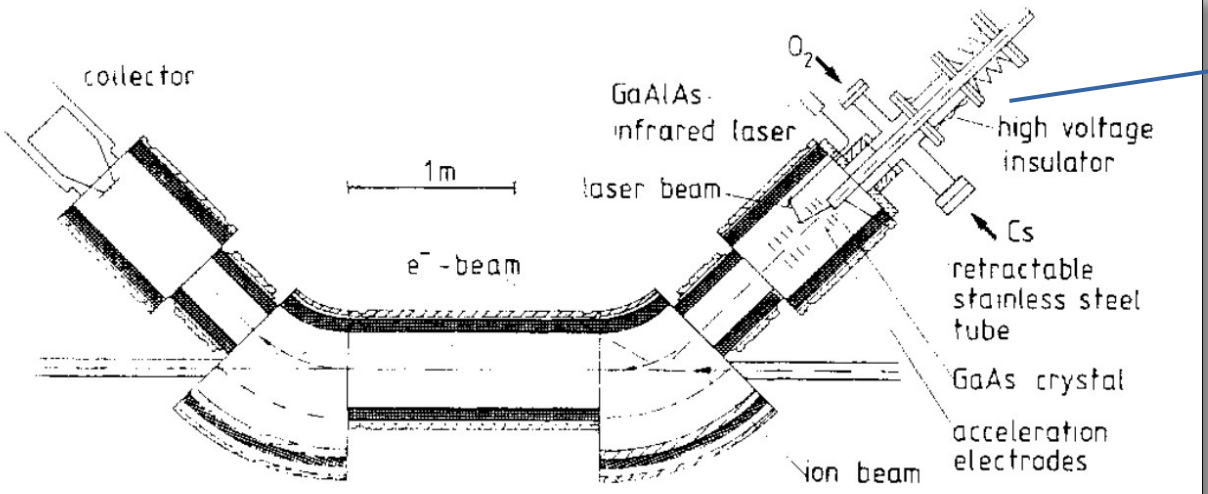
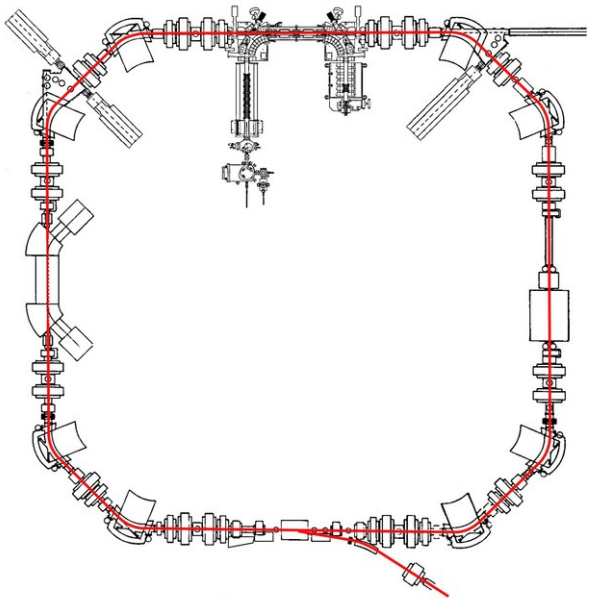



*Fig. 1.* Layout of the assembly for the proposed photoemitted ultracold electron beam.

Cryogenic GaAs-photocathode e-gun

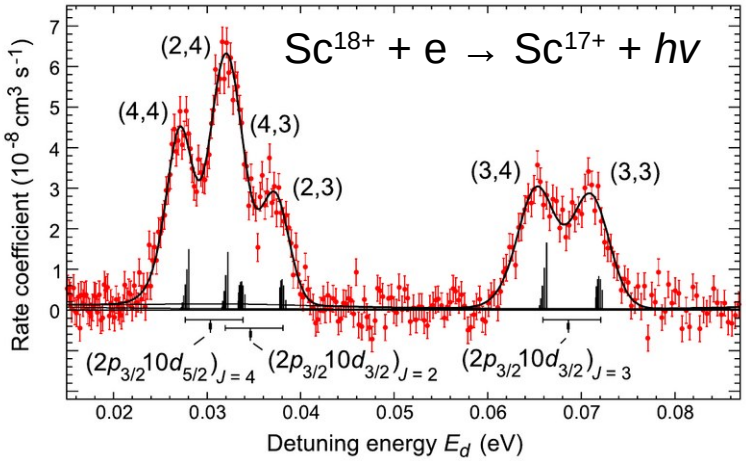
- $I_e$ ~ 1 mA
- $T_{perp} < 1$ meV/$k_B$

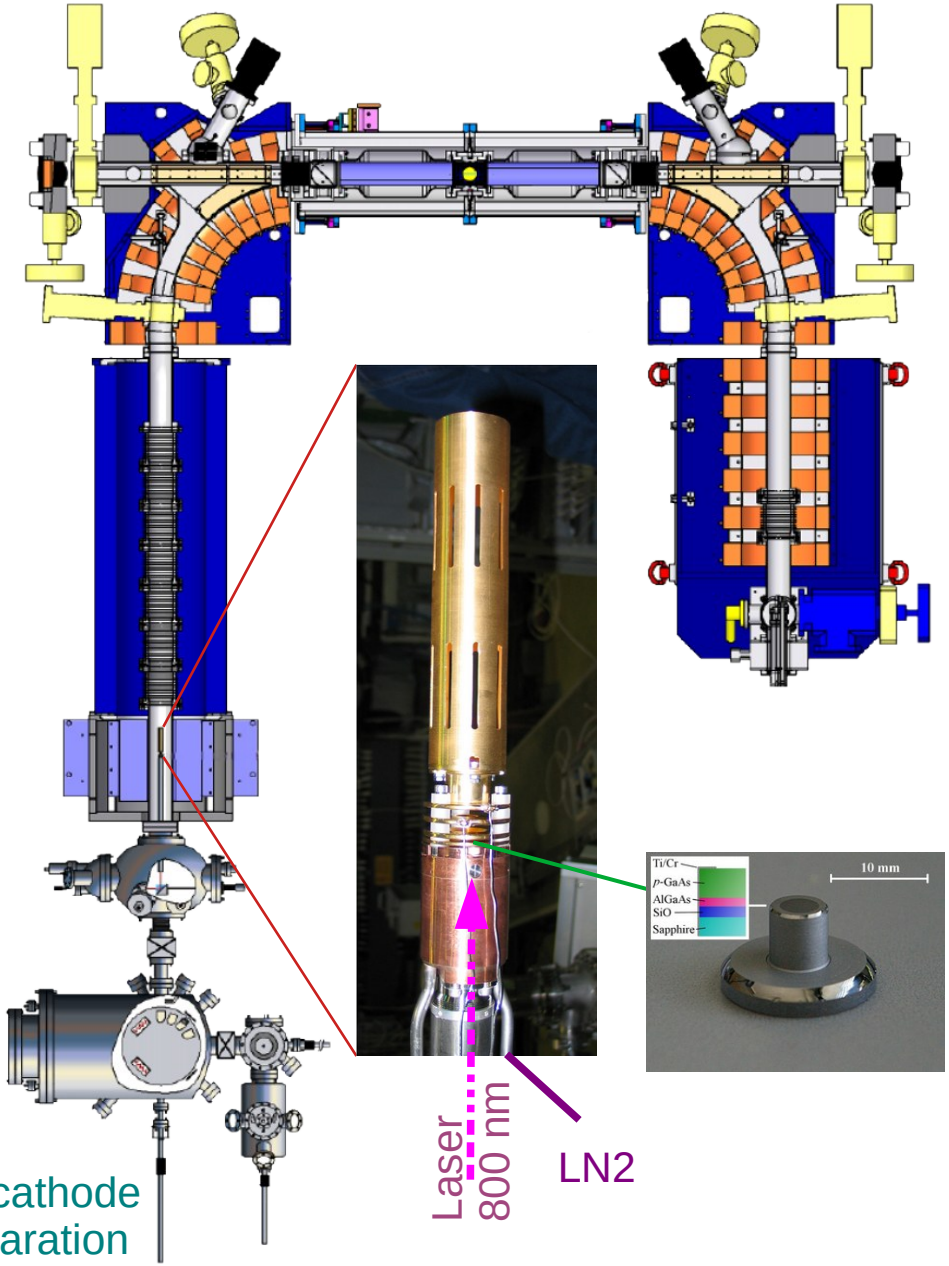
# TSR “Photo-Electron” Cooler (2006 … 2012)

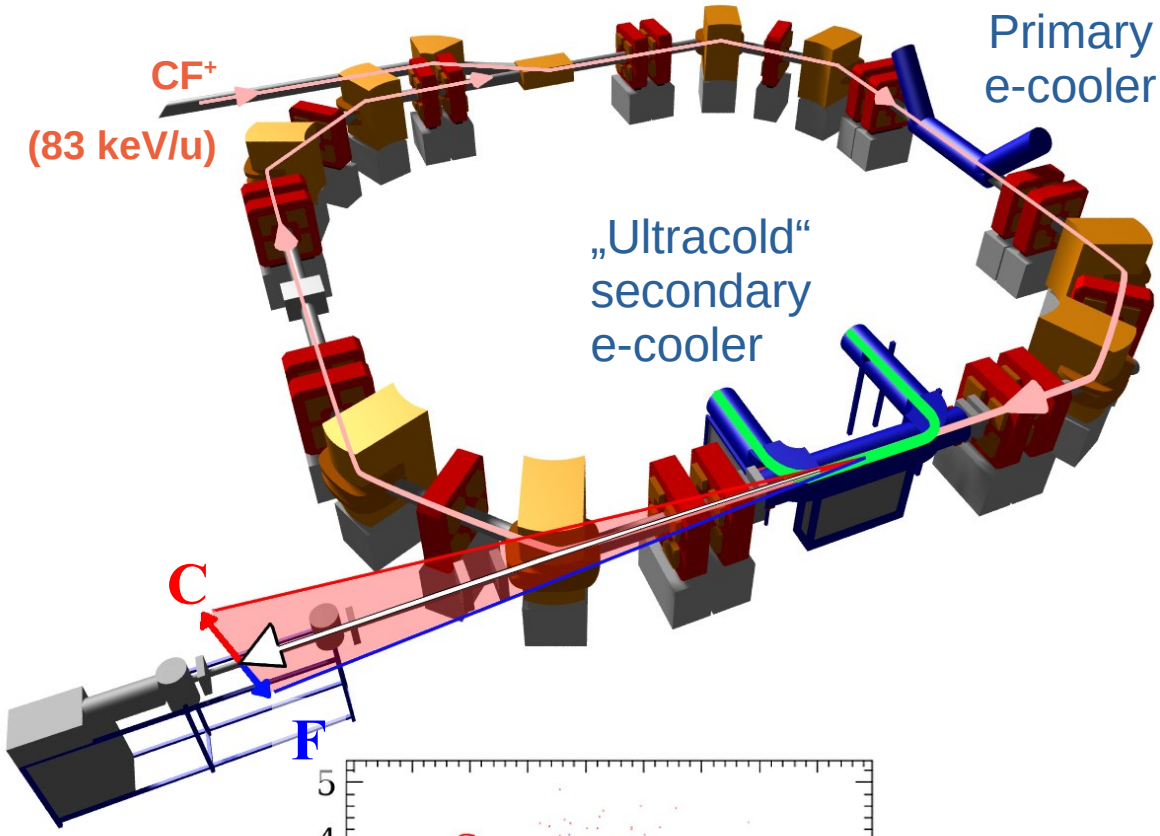


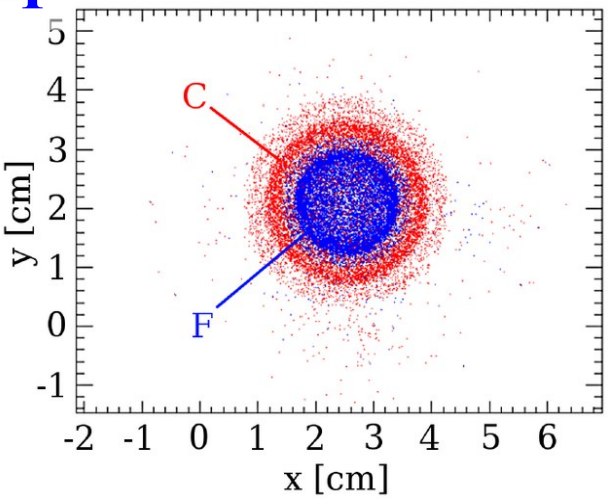
Use as high-resolution electron target:

Lestinsky et al., PRL 100 (2008)






**From 2007 …**

Heavier molecular ions could not be cooled efficiently by the TSR's primary e-cooler. (thermionic cathode e-gun)

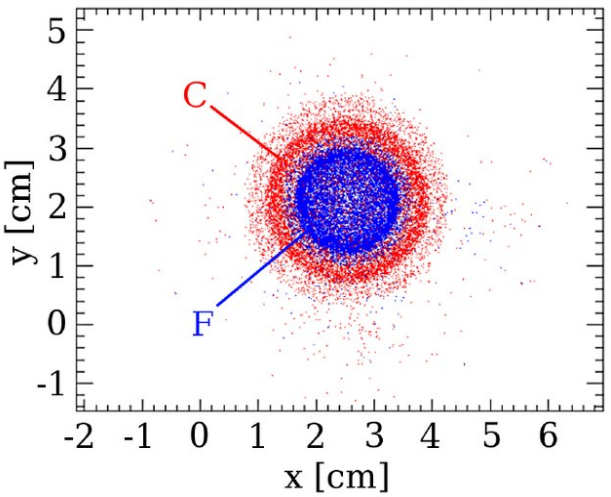
$$\tau_{\mathrm{cool}} \propto \frac{m_{\mathrm{ion}}}{q_{\mathrm{ion}}^2} \times \frac{T_e^{3/2}}{n_e}$$

→ Photocathode e-beam used as cooler and target.

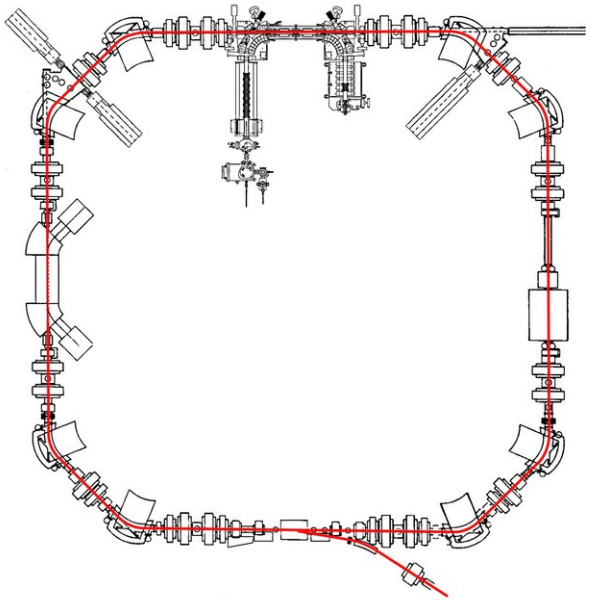
**2007 – 2012:**

Many experiments on molecular recombination at TSR.

*Good transverse cooling crucial.*

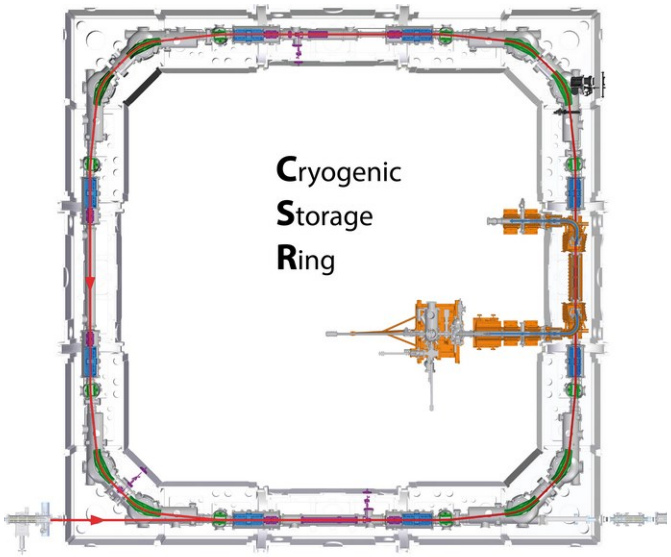



| Ions | $M_{ion}$ | $E_e$ (cool.) | $B\rho_{TSR}$ (Tm) |
|---|---|---|---|
| ... | | | |
| $H_3^+$ | 3 u | 735 eV | 0.49 |
| $HD_2^+$ | 5 u | 327 eV | 0.55 |
| $CHD^+$ | 15 u | 231 eV | 1.37 |
| $HF^+$ | 20 u | 112 eV | 1.28 |
| $DF^+$ | 21 u | 115 eV | 1.31 |
| $D_3O^+$ | 22 u | 112 eV | 1.36 |
| $DCND^+$ | 30 u | 56 eV | 1.36 |
| $DCO^+$ | 30 u | 56 eV | 1.36 |
| $N_2D^+$ | 30 u | 56 eV | 1.36 |
| $CF^+$ | 31 u | 46 eV | 1.27 |
| $HS^+$ | 33 u | 45 eV | 1.33 |
| $^{18}O^{16}O^+$ | 34 u | 43 eV | 1.34 |
| $H^{35}Cl^+$ | 36 u | 40 eV | 1.32 |
| $D_2{}^{37}Cl^+$ | 41 u | 31 eV | 1.31 |

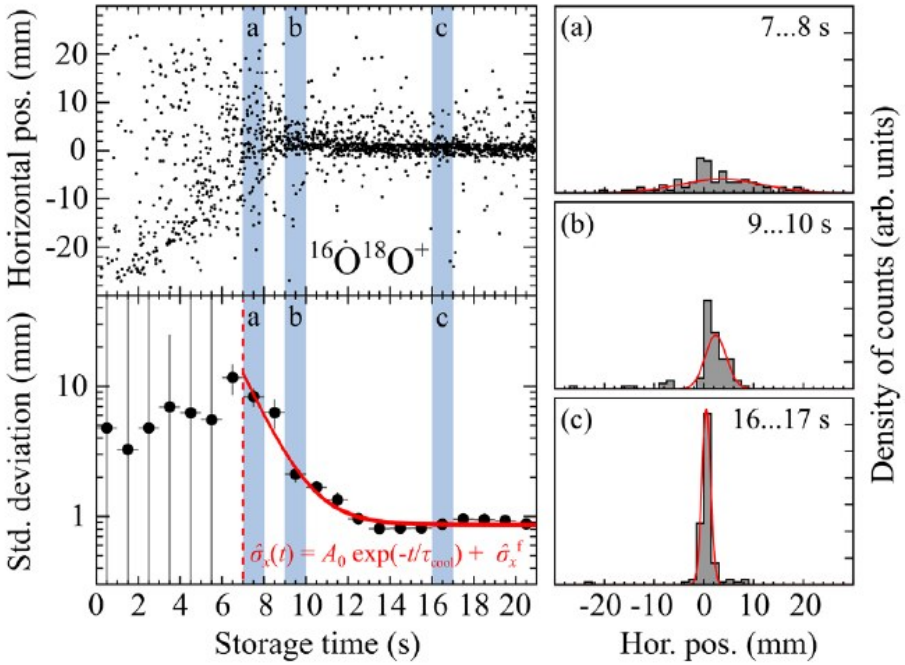


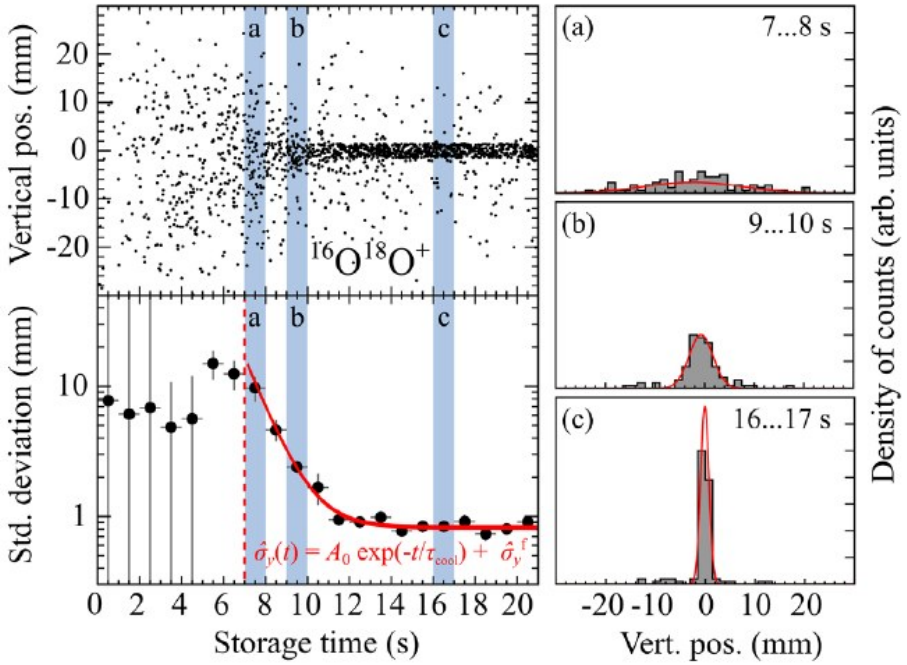
**TSR** decommissioned end of 2012 …

… physics programme to be taken to the **CSR**.

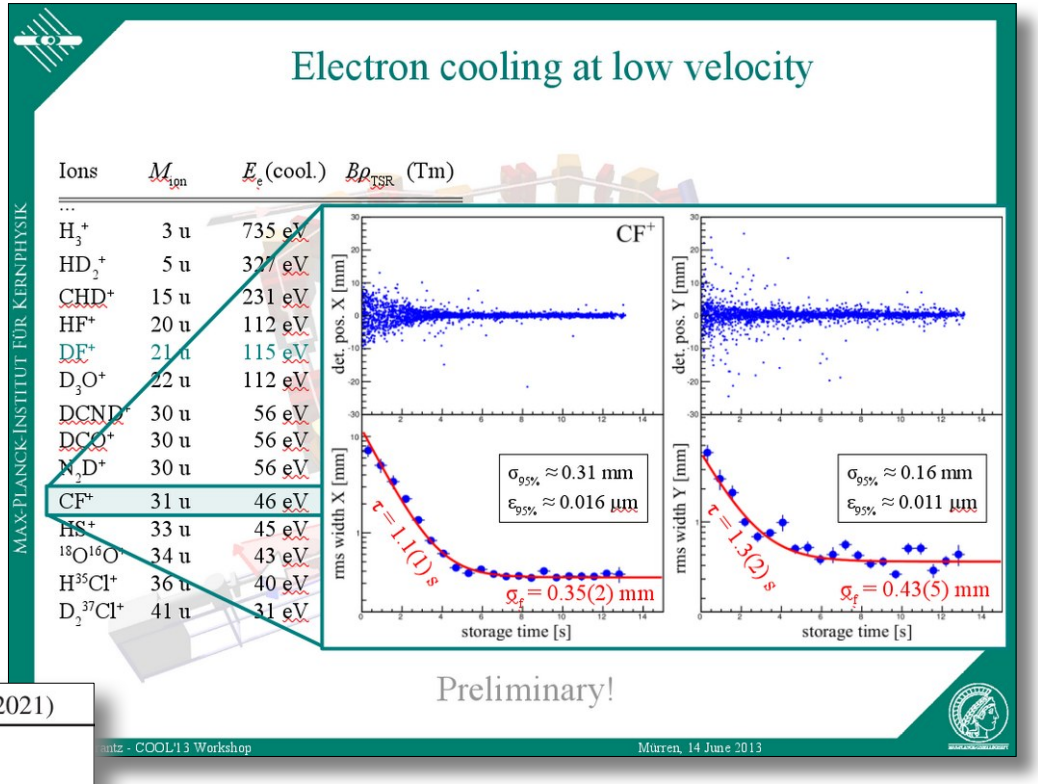



„Parasitic“ data re-analysis of 2007 … 2012 molecular ion beamtimes:
*Fragment imaging detectors provide information about transverse cooling.*



Initial report at
COOL'13, Mürren, ...

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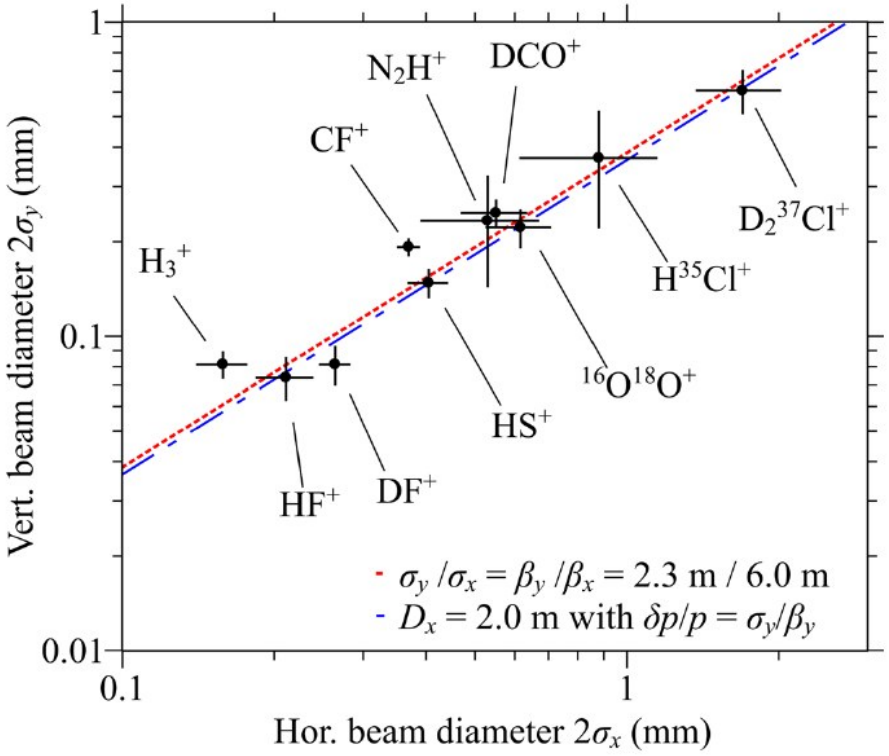
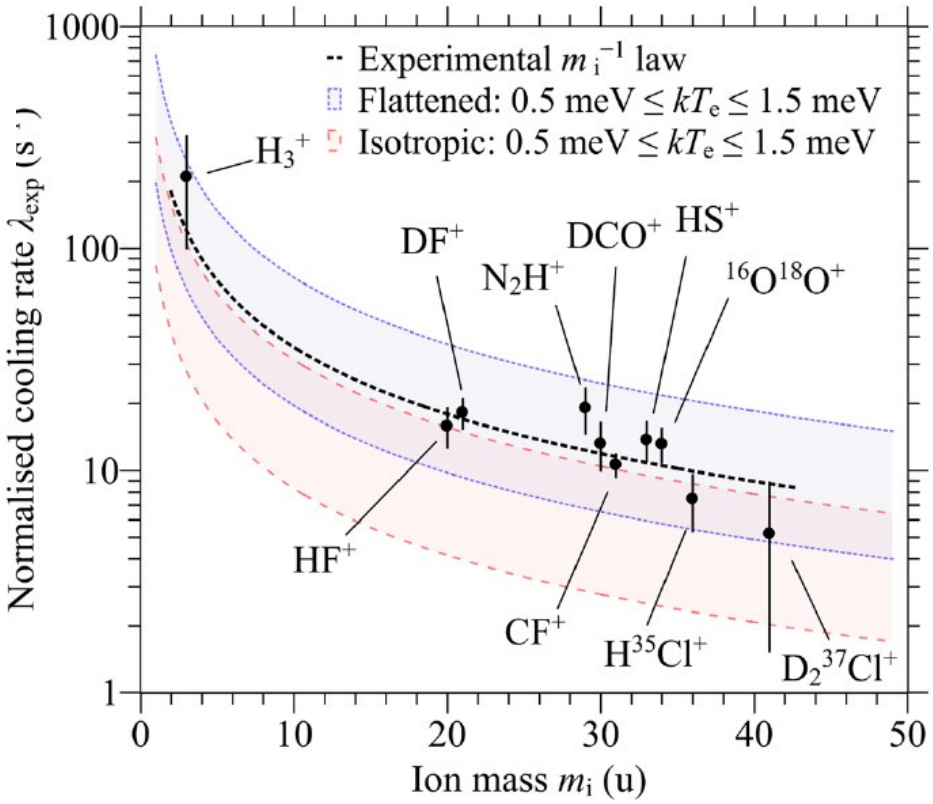
DOI: 10.1103/PhysRevAccelBeams.24.050101

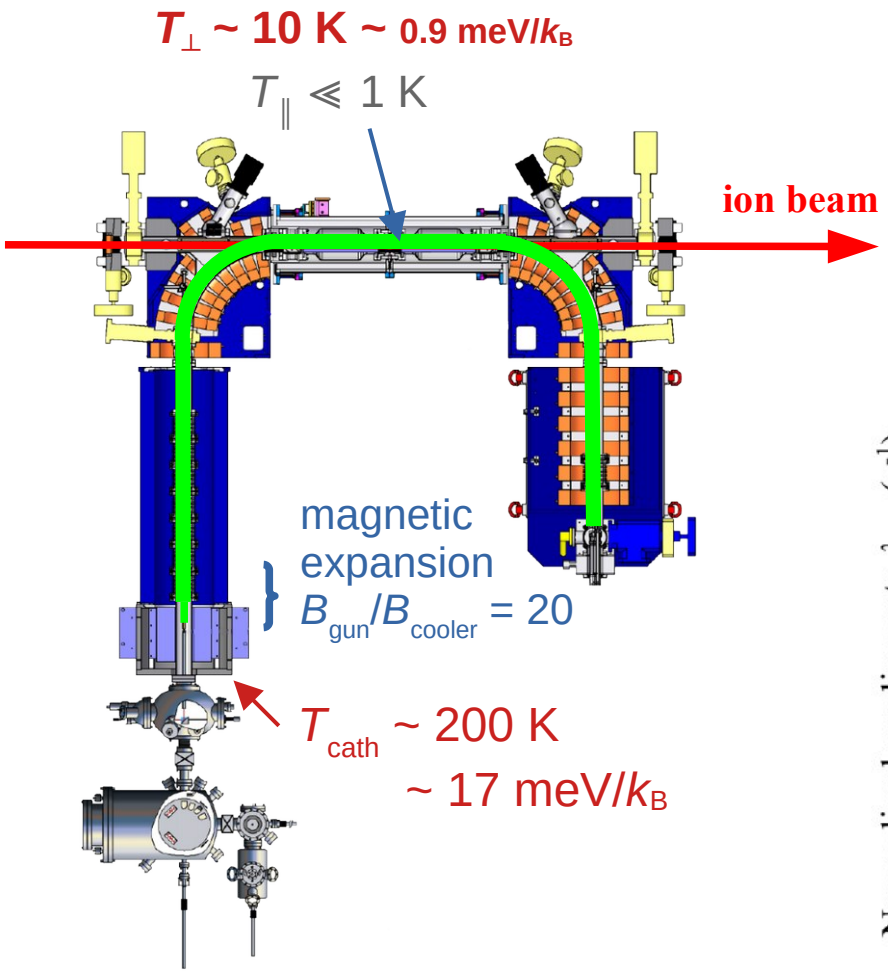
… final publication in
PRAB > 7 years later ...



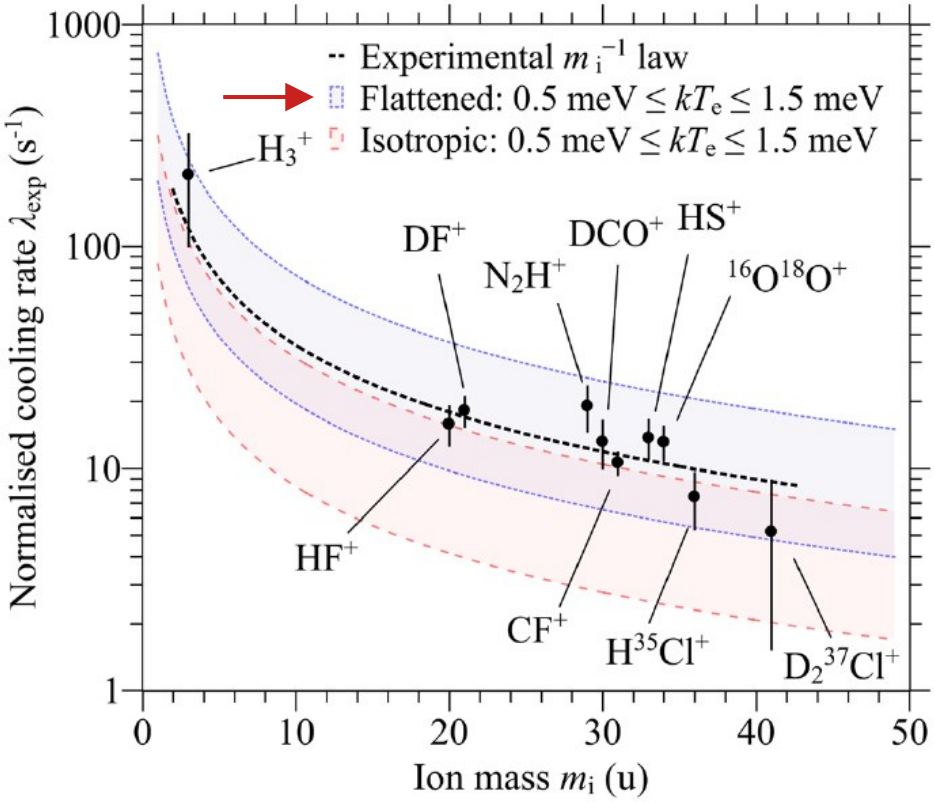

Beam diameters after Electron cooling.

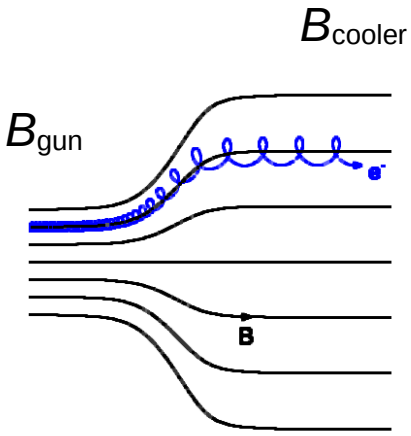



Transervse cooling rates.



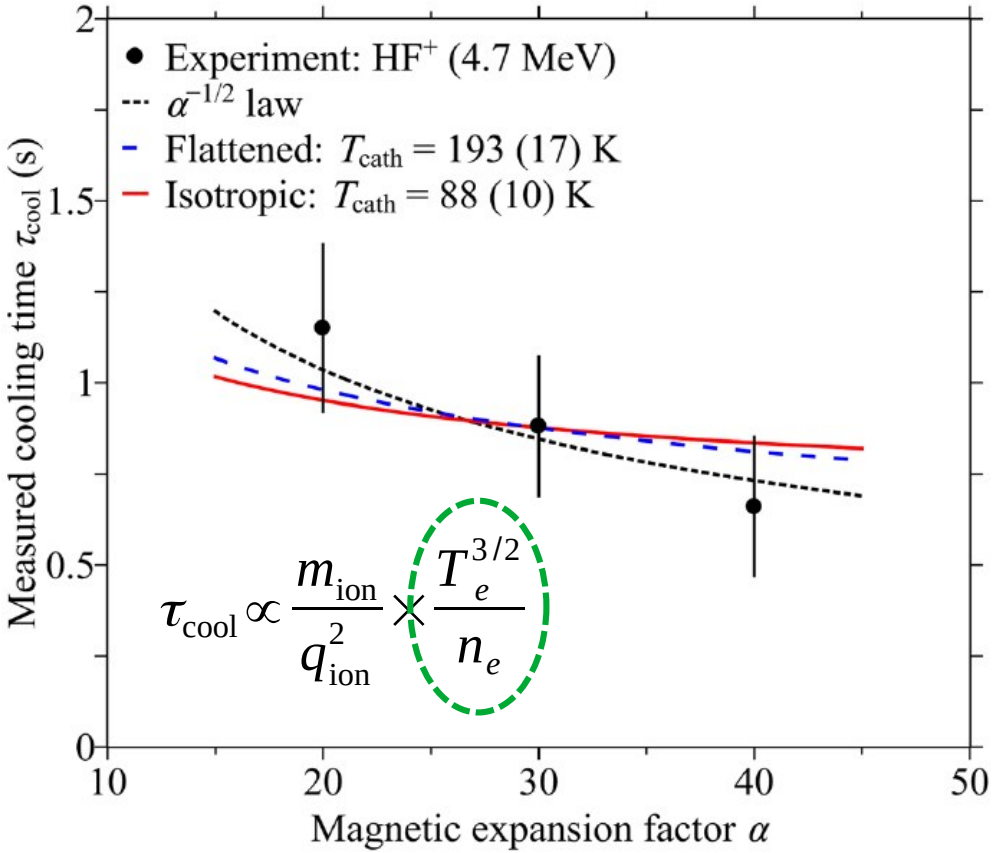

$$\tau_{\text{cool}} \propto \frac{m_{\text{ion}}}{q_{\text{ion}}^2} \times \frac{T_e^{3/2}}{n_e}$$



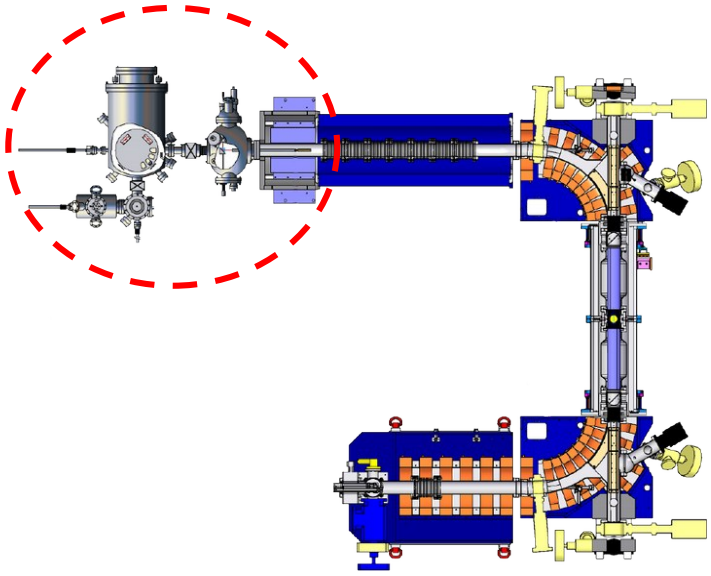



$$T_{\perp} = T_{cath} \frac{B_{cooler}}{B_{gun}}$$

$$n_{e,cooler} = n_{e,cath} \frac{B_{cooler}}{B_{gun}}$$

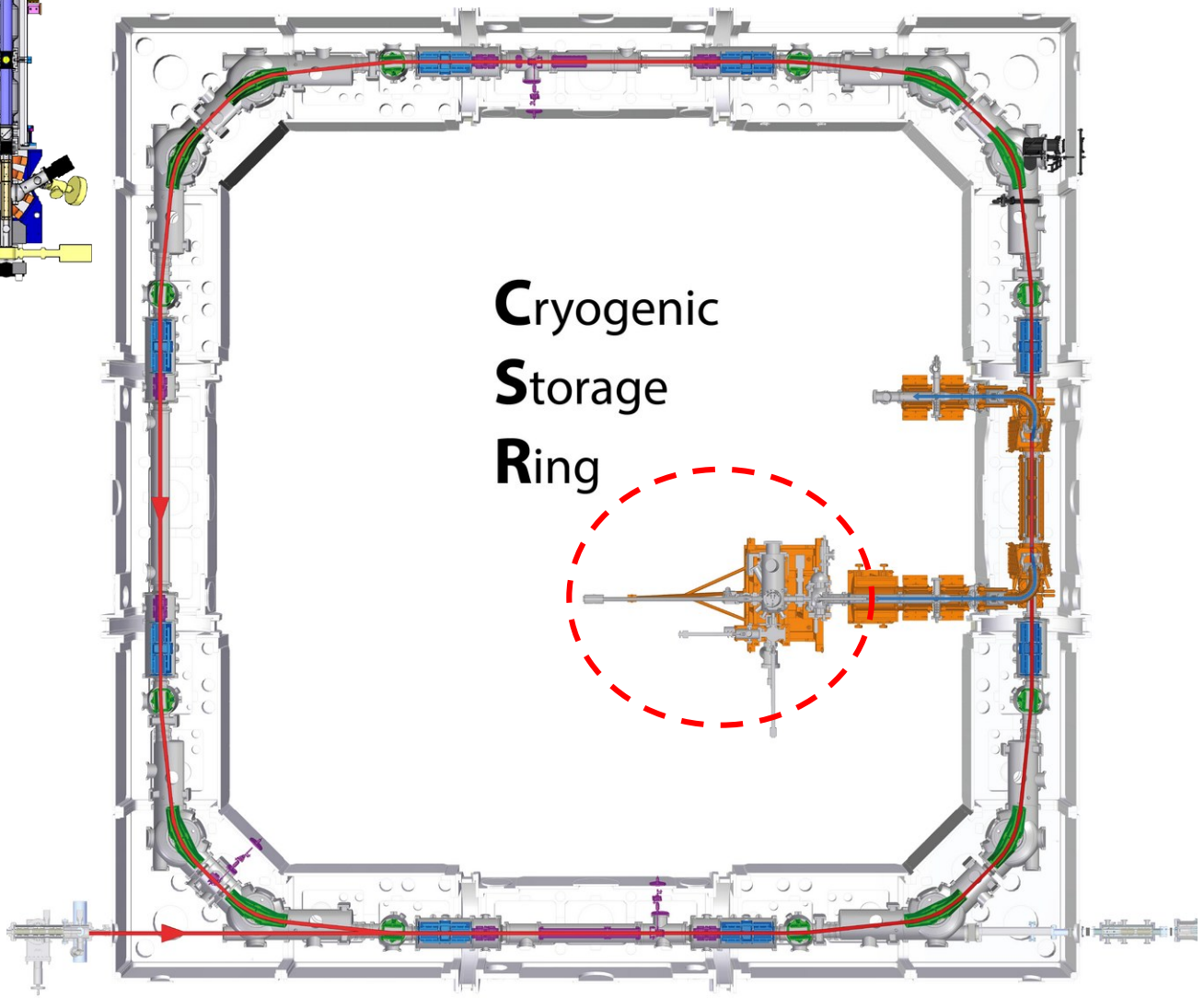



Krantz et al., PRAB 24 (2021) 050101



Ultracold photocathode electron cooler beam lives on at the **CSR** …

→ Talk by O. Novotný last Monday.



# Thank you!


**TSR + CSR electron cooling groups**

A. Becker, K. Blaum, H. Buhr, F. Fellenberger, L. Gamer, S. George, **M. Grieser**, R. von Hahn, J. Hoffmann, L. Isberner, C. K., H. Kreckel, M. Lange, M. Lestinsky, J. Lion, S. Lohmann, **O. Novotný**, S. Novotny, **D. A. Orlov**, R. Repnow, M. Rimmler, **D. Schwalm**, A. Shornikov, K. Spruck, J. Stützel, S. Vogel, P. Wilhelm, **A. Wolf**, D. Zajfman

…