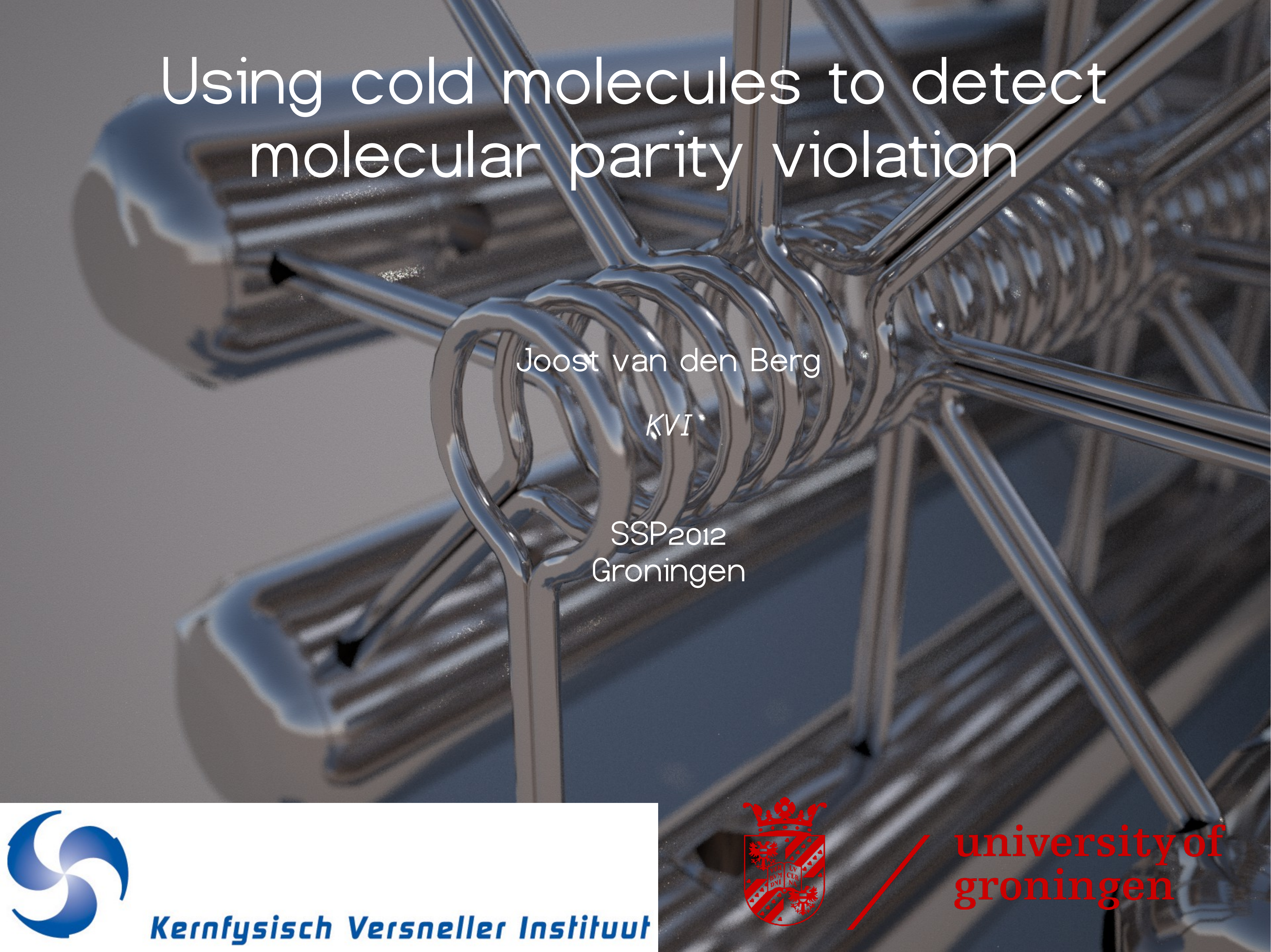

Using cold molecules to detect molecular parity violation

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Outline

- Parity violation in diatomic molecules
- Ultracold molecules
- Experiment
    - Stark decelerator
    - Laser cooling

Parity violation in diatomic molecules

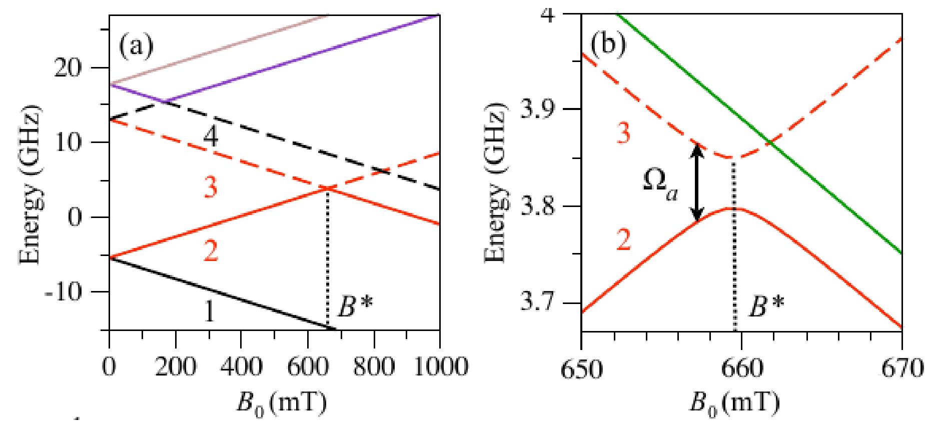
- PV never observed in molecules
- Enhanced by 10^5 in nearly degenerate rotational levels of opposite parity
- Particularly good for NSD PV:
  - Anapole moment, only measured in Cs, gives purely hadronic information
  - Neutral electroweak Z^0-exchange, gives $V_e A_n$ couplings to u,d quarks $C_{2u,d}$; most poorly tested SM parameter (Weinberg angle)
  - Sensitive to new physics at TeV scale

Labzovsky, Sushkov, Flambaum, Khriplovich, Kozlov

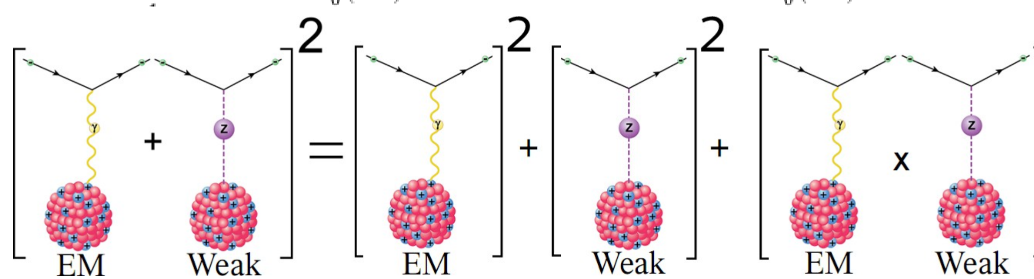
Measure NSD-PV in diatomics

Interaction strength: $H^{\text{eff}}_{PV,\text{NSD}} = \kappa W_A \frac{(\vec{n}\times\vec{S})\cdot\vec{I}}{I}$ with $W_A(\vec{n}\times\vec{S}) = \frac{G_F}{\sqrt{2}}\vec{\alpha}\rho(\vec{r})$

Tune two rotational states with opposite parity to near-degeneracy in a magnetic field:



Apply oscillating electric field and do a Stark-interference measurement to measure PV matrix element



$$iW = \kappa W_A \langle \psi^-_\downarrow | \frac{(\vec{n}\times\vec{S})\cdot\vec{I}}{I} | \psi^+_\uparrow \rangle$$

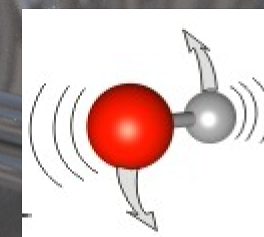
Detectable signal

$$S = 4N\sin^2\left(\frac{\Delta T}{2}\right)\left[2\frac{W}{\Delta}\frac{dE_0}{\omega} + \left(\frac{dE_0}{\omega}\right)^2\right]$$

P-odd P-even

Ultracold molecules

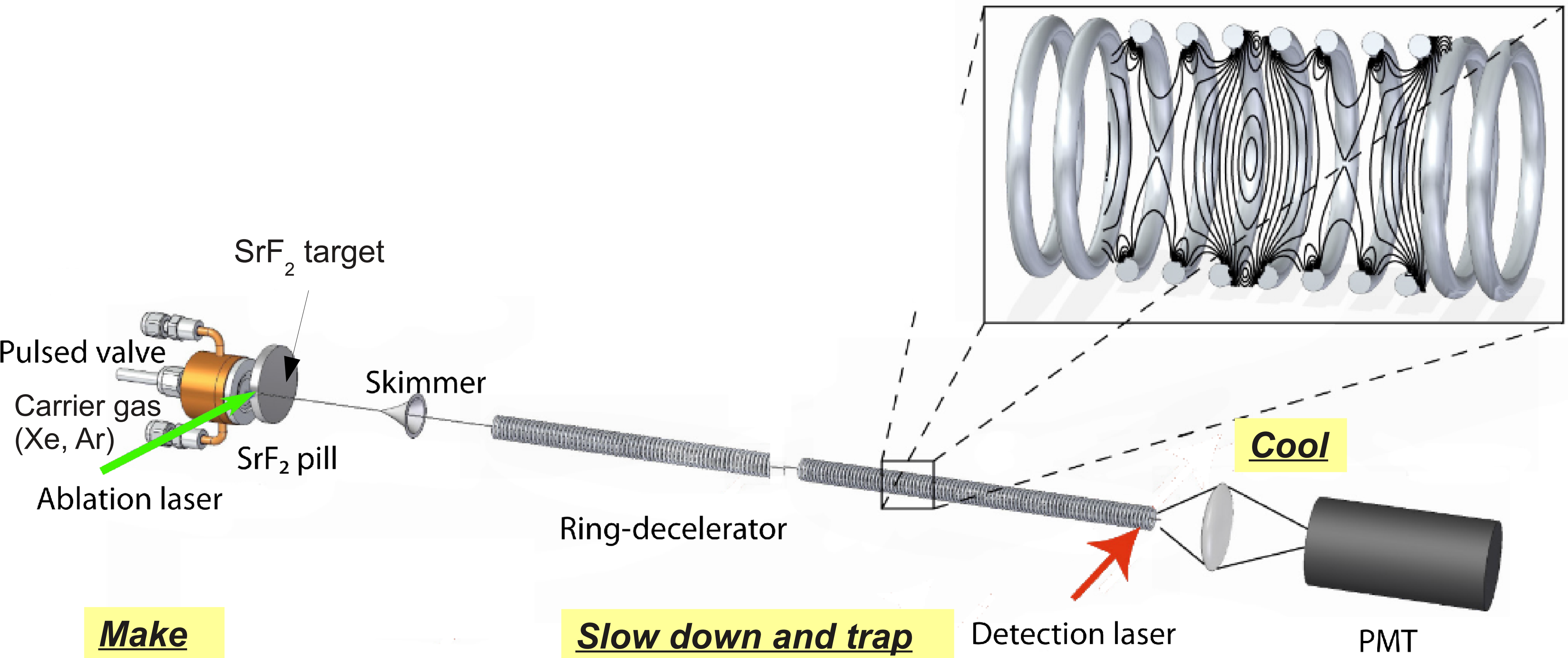
- Ultracold = standing still, lowest quantum state, colder than 1 mK
- No Doppler broadening
- Long coherence times → better signal
- Excellent control
- Well localized, good field homogeneity

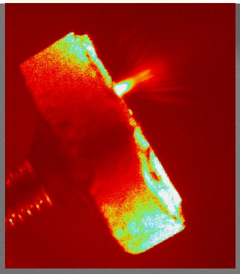


Our choice: SrF

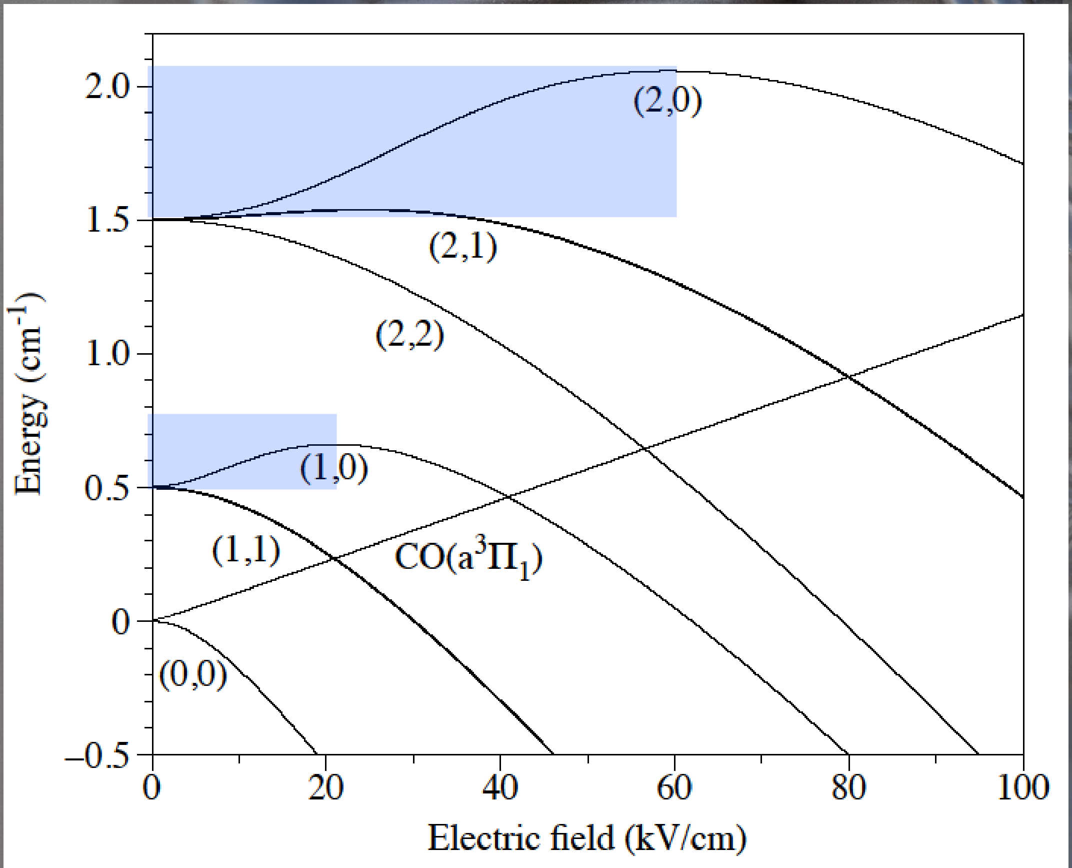
- Heavy diatomic → Sensitive to PV
- Still simple → Calculable for theoreticians
- Radical → High electric dipole moment
- Alkaline-earth monohalide → Laser coolable
- Optical transitions in VIS → Easy lasers

The experiment





Stark shift of SrF



Stark shift: some states are low-field seekers, those can be decelerated and trapped

- Difficulties heavy diatomics:
- Ground state not LFS
- Only LFS for low E-fields
- Needs long deceleration time
- Problems with losses in traditional decelerators

Solution: ring-decelerator

Stark deceleration: ring-type

Oscillating voltage on rings creates moving potential wells

$V_n(t) = V_0 \cos(2\pi f t + 2\pi n/8)$

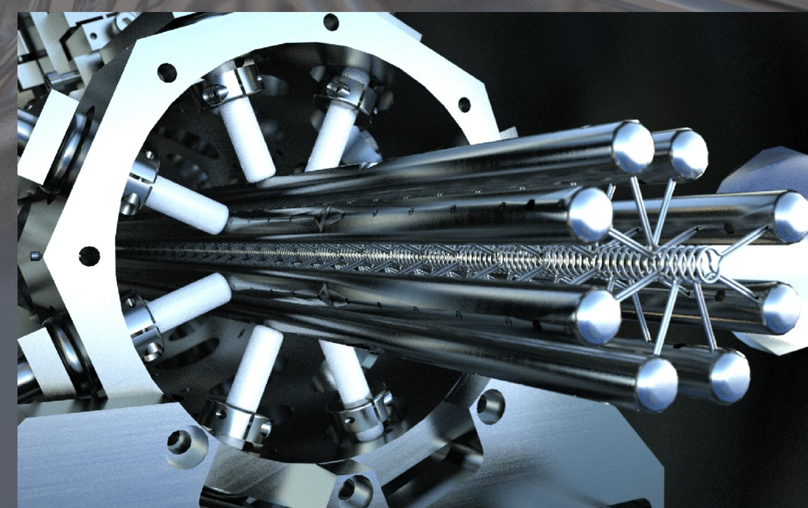
Trap speed $v = f{*}L$, $L = 12$ mm

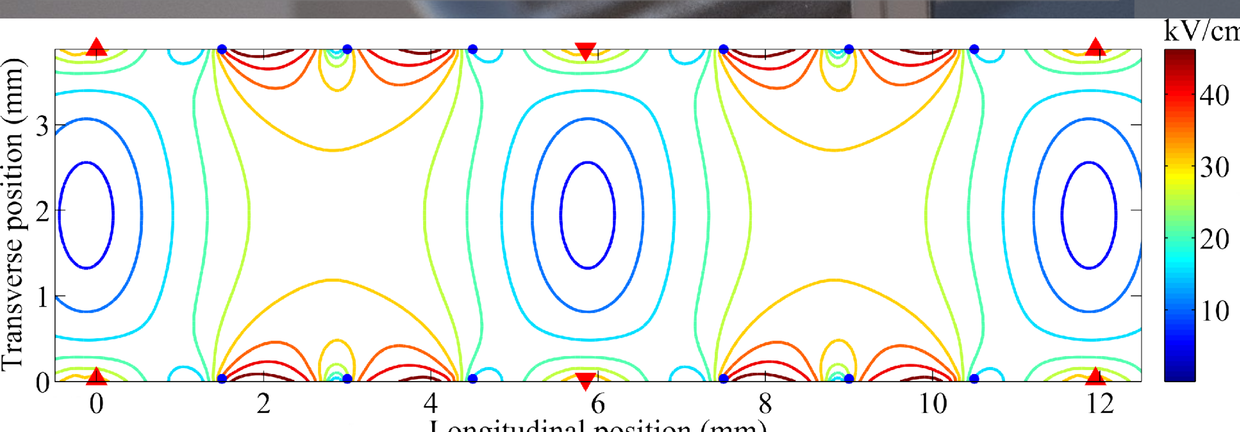
We slow down the wells at 9000 m/s² by sweeping f

$f = 30$ kHz→DC; $V_0 = 5$ kV;

$v = 300 \rightarrow 0$ m/s

- Inherently stable on axis
- No losses due to focusing issues
- No additional trap required

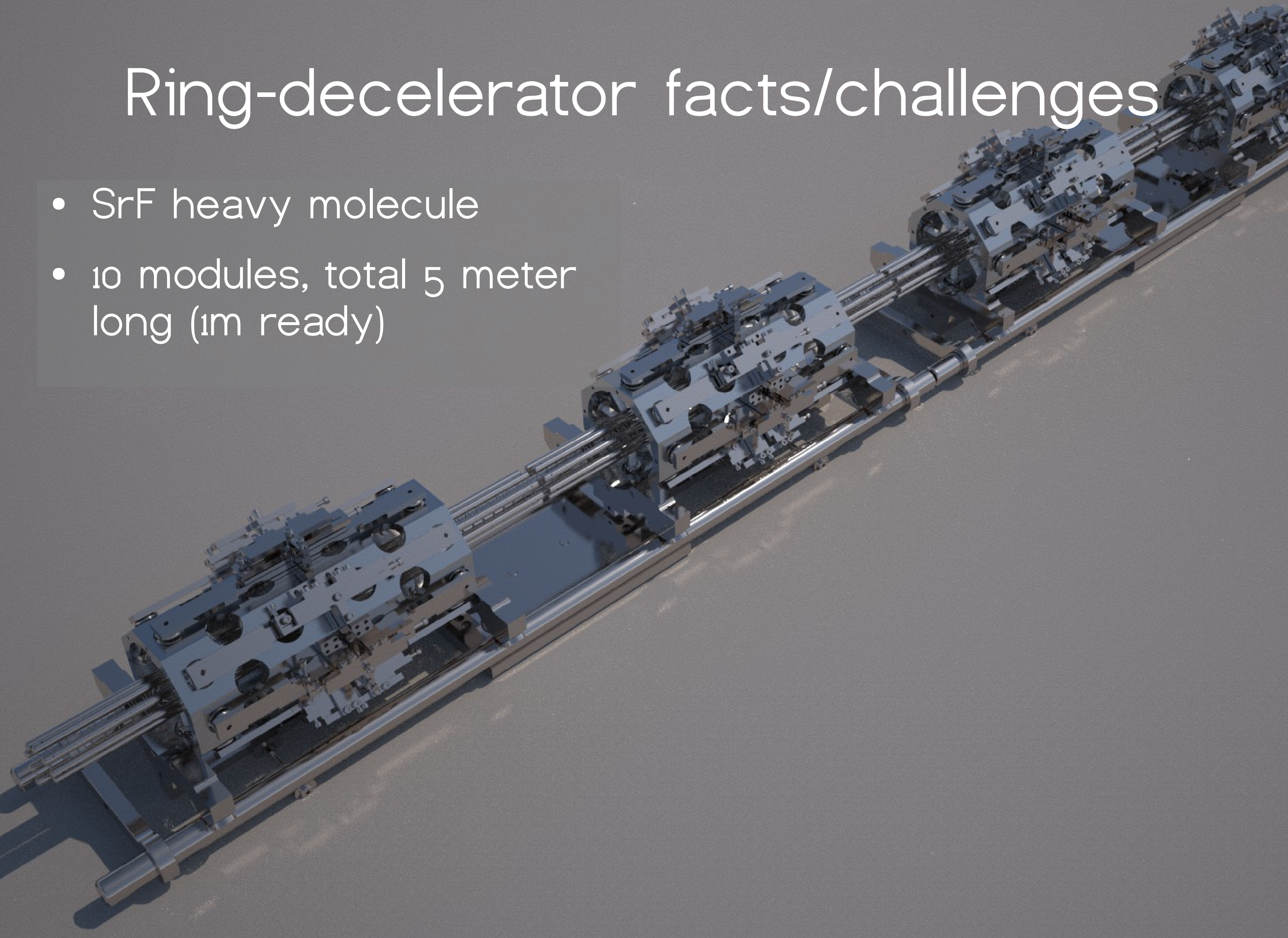




A. Osterwalder et al., Phys. Rev. A, 81, 051401 (2010)
S.A. Meek et al., Rev. Sci. Instr., 82, 093108 (2011)

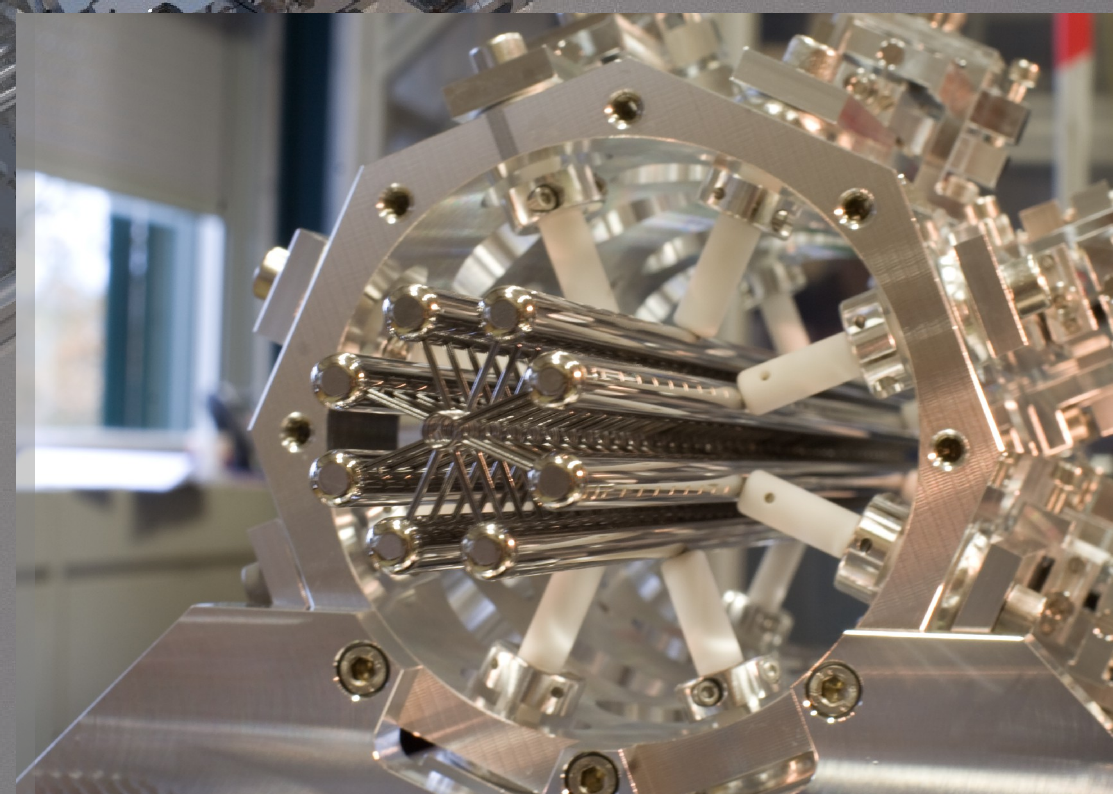
Ring-decelerator facts/challenges

- SrF heavy molecule
- 10 modules, total 5 meter long (1m ready)

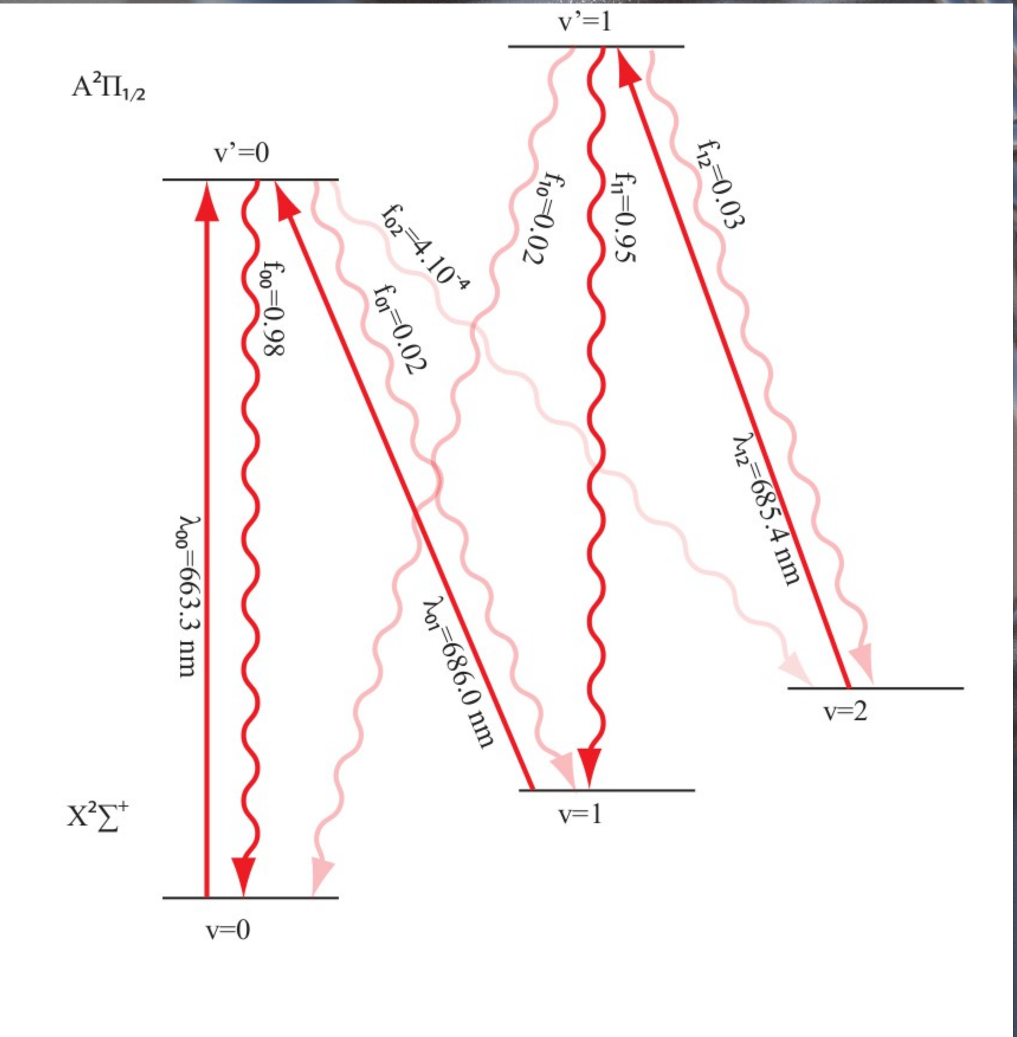


Ring-decelerator facts/challenges

- SrF heavy molecule
- 10 modules, total 5 meter long (1m ready)
- 3360 ring electrodes
- Ring diameter 4 mm, 0.6 mm tantalum wire
- 0.9 mm distance between electrodes
- 5 kV voltage sweeps 30 kHz to DC
- SrF beam operational



Laser cooling stopped SrF



E.S. Shuman et al., Phys. Rev. Lett., 103, 223001 (2009)

PV measurement sensitivity $\sim N^{1/2}\tau$

Deceleration and laser cooling increase measurement time

Stark deceleration first means less photons needed for cooling

	T (mK)	v_T (m/s)	L (mm)	τ (ms)
Beam 150 m/s	-	1.5	50	0.3
Decelerated	200	6	50	8
Laser cooled	0.15	0.15	50	300

Summary

- Diatomic molecules are sensitive probes for parity violation
- Precision measurement can benefit from using ultracold molecules
- We will combine Stark deceleration and laser cooling to reach this regime

Many thanks to: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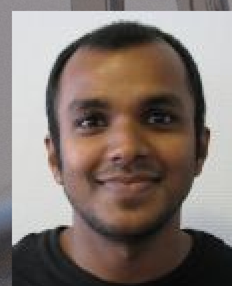
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Franck Tan
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KVI Mechanical Workshop

Lab tour on Thursday!

FOM program TRIμP
FOM program Broken Mirrors Drifting Constants
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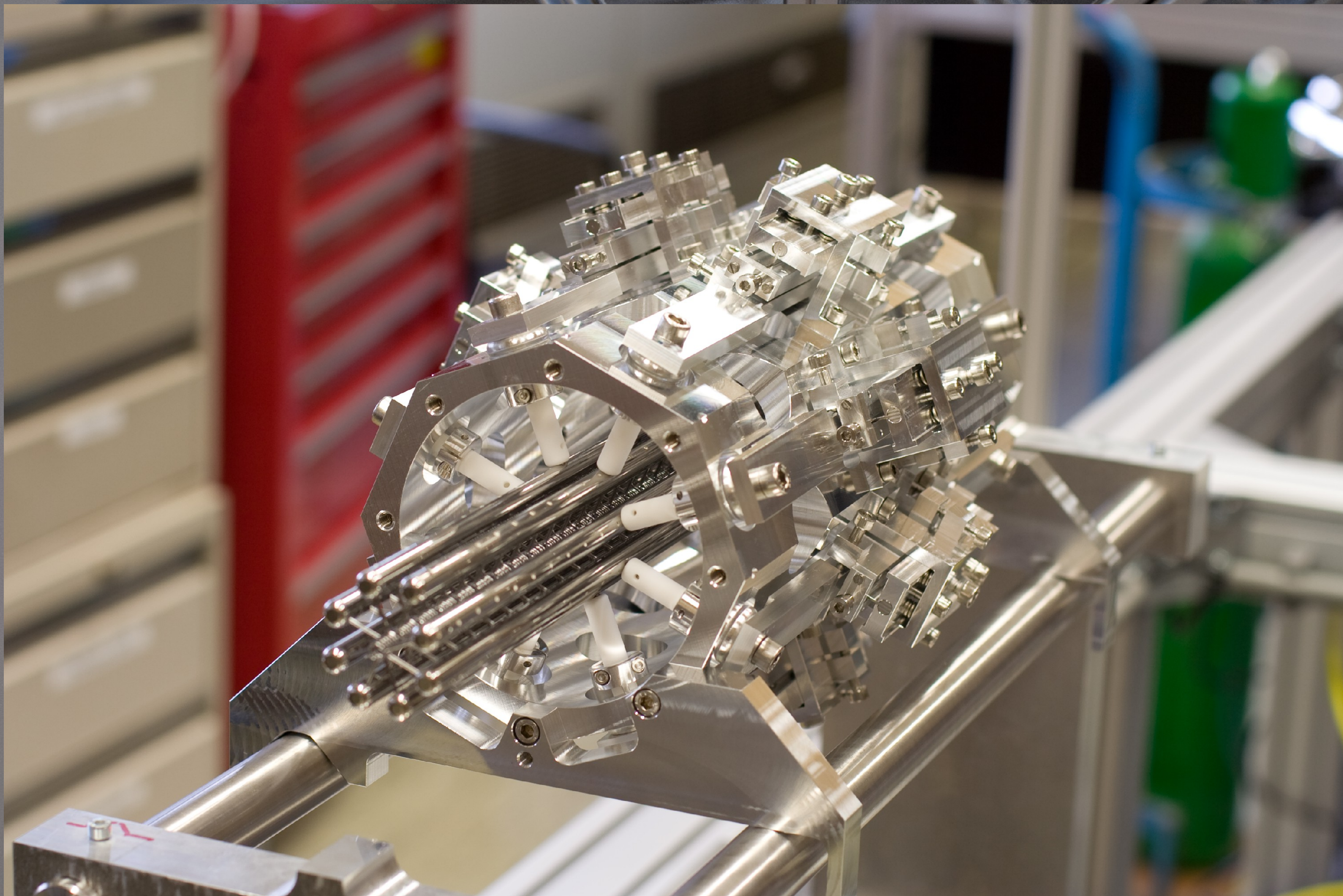

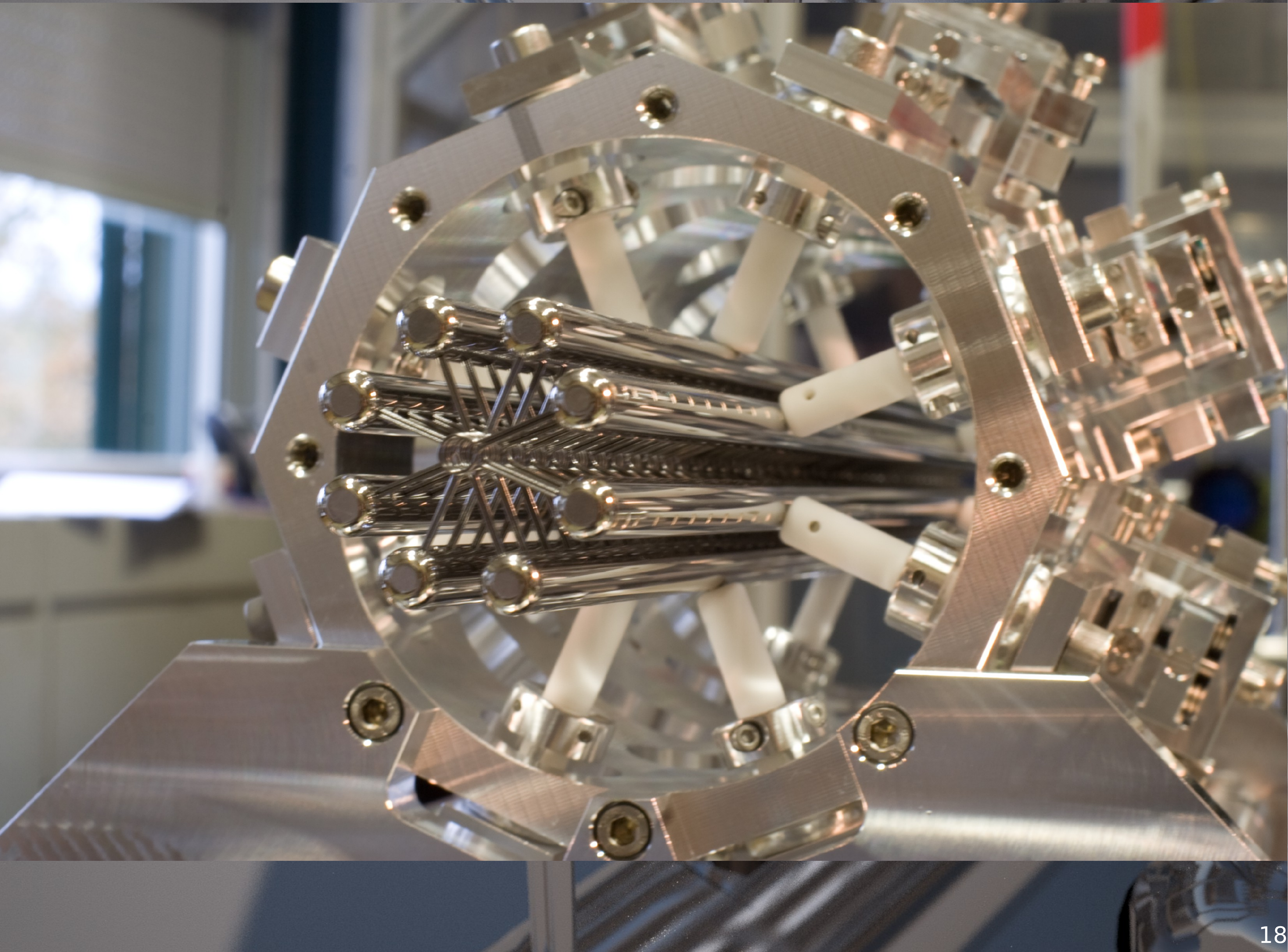

First SrF beam @KVI