A 20.6: Towards Magnetic Trapping of Atomic Hydrogen

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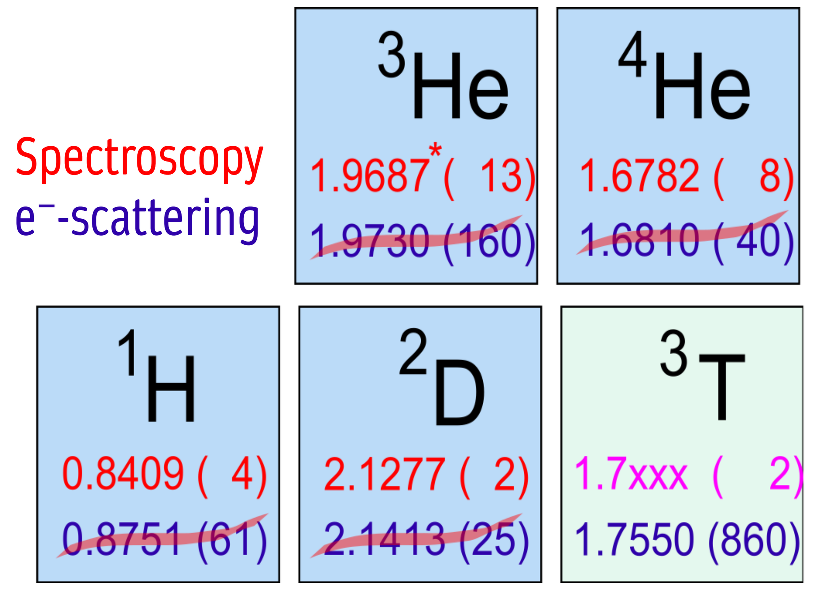
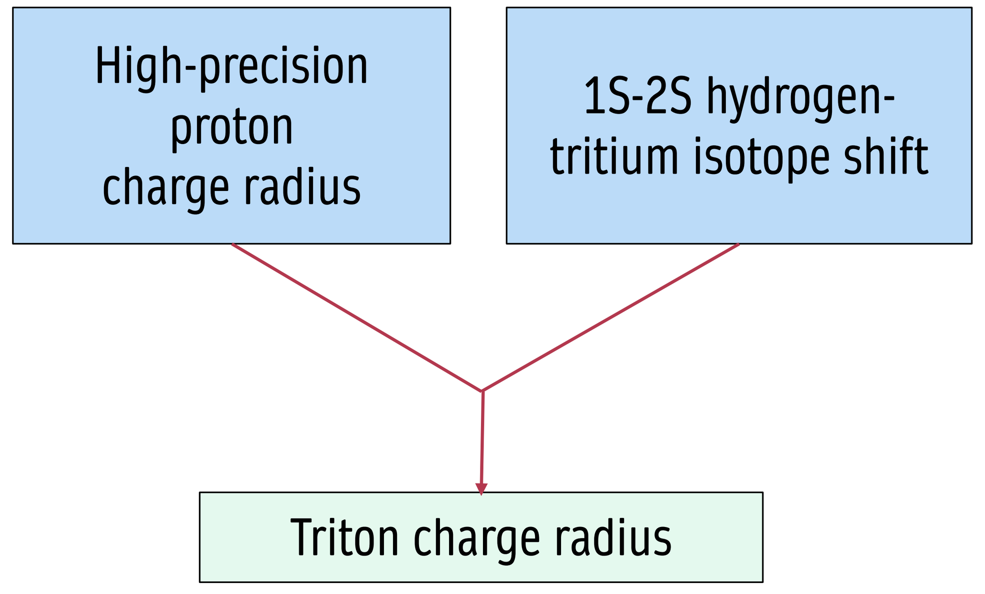
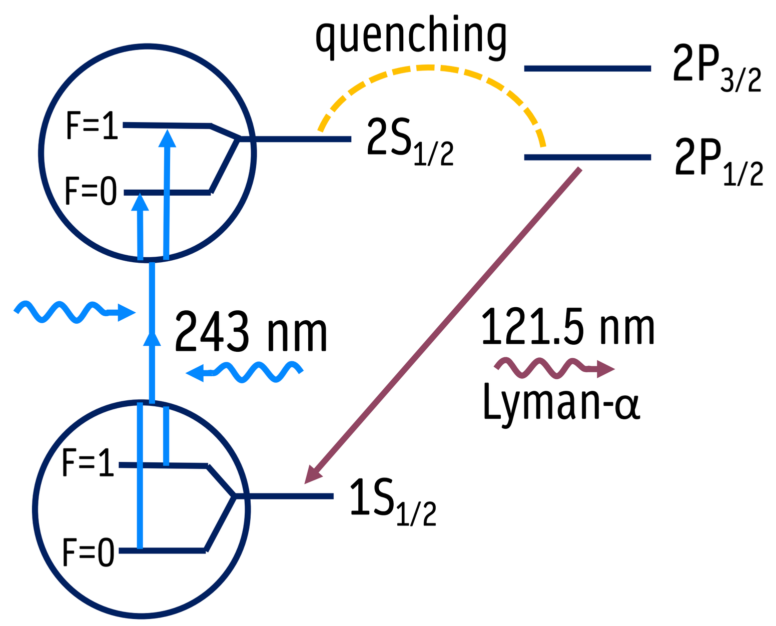
Motivation: Improving the root-mean-square charge radius of tritium



RMS charge radii (fm) for nuclei with mass number A≤4 [1]



Testing of the apparatus and assessment of the systematics is performed **with hydrogen**



Energy levels for 1S-2S laser spectroscopy in atomic hydrogen

Velocity-selected cryogenic hydrogen beam

- Microwave dissociator: H2 → 2 H
- **Cooling** of hydrogen with cryogenic nozzle **at 4 K**
- Curved quadrupole guide with permanent magnets
- Hydrogen atoms experiencing a **magnetic dipole force**:

$$\vec{F} = \vec{\nabla}\left(\gamma\vec{s}\cdot\vec{B}\right)$$

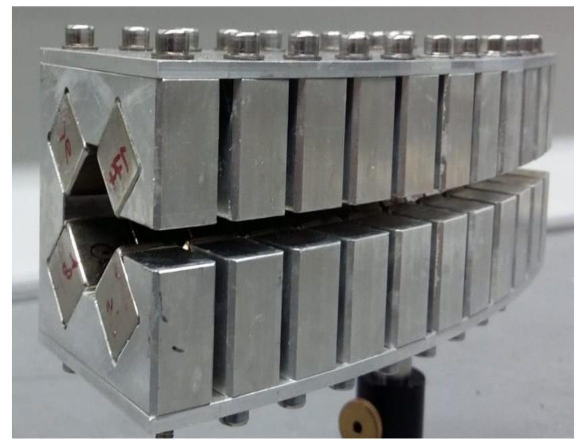
- gyromagnetic ratio γ
- spin $\vec{s}$
- magnetic field $\vec{B}$

- **Simulation** with Kassiopeia framework [2]:

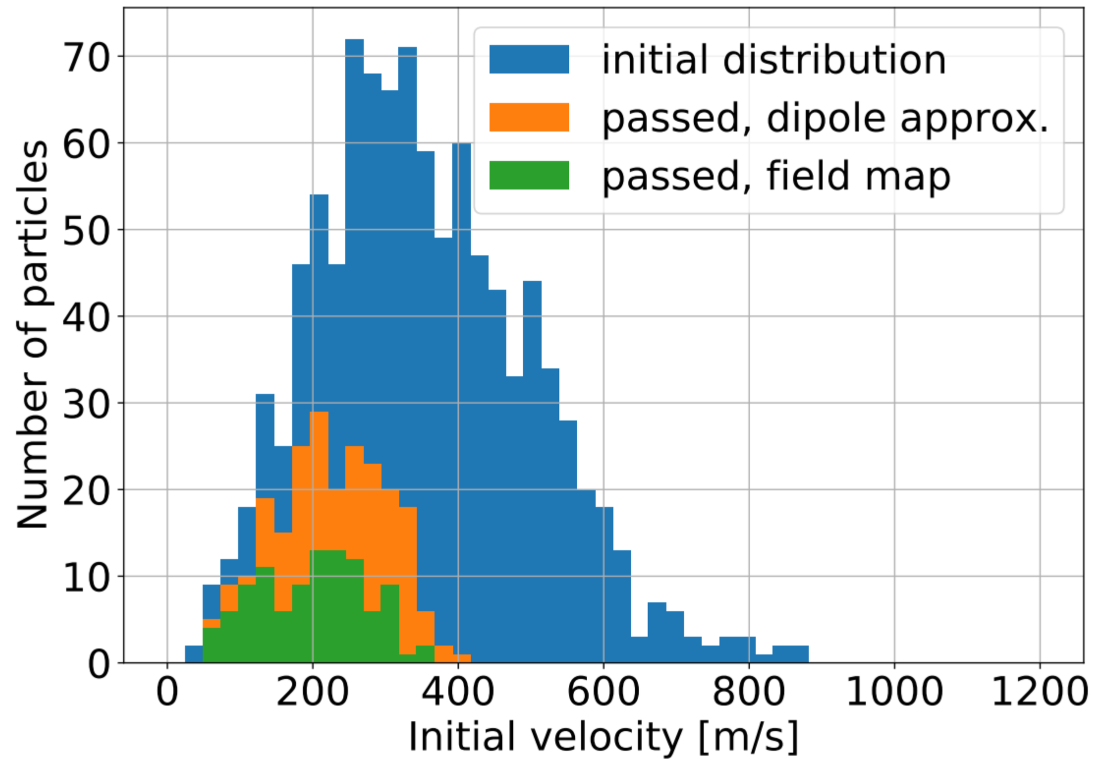
→ **~10 %** of the low-field seekers **pass the guide**

→ Passed Atoms have reduced **mean velocity** $\approx 200\,\frac{\mathrm{m}}{\mathrm{s}}$

→ **Passive selection of slower atoms**



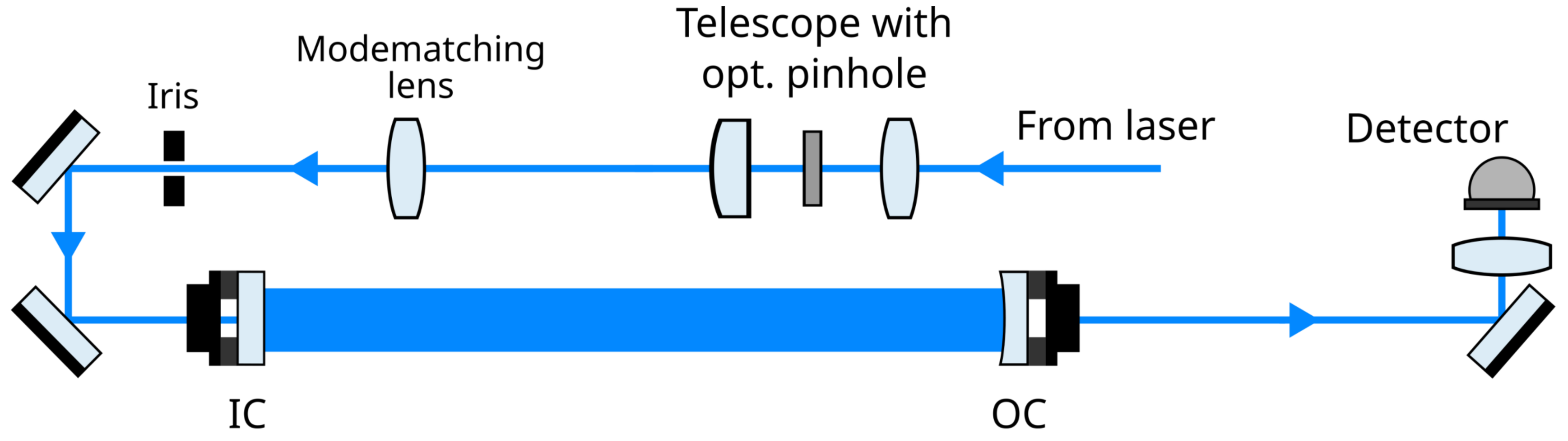
Picture of the quadrupole guide



Simulation for Maxwell-Boltzmann Distribution at 6 K

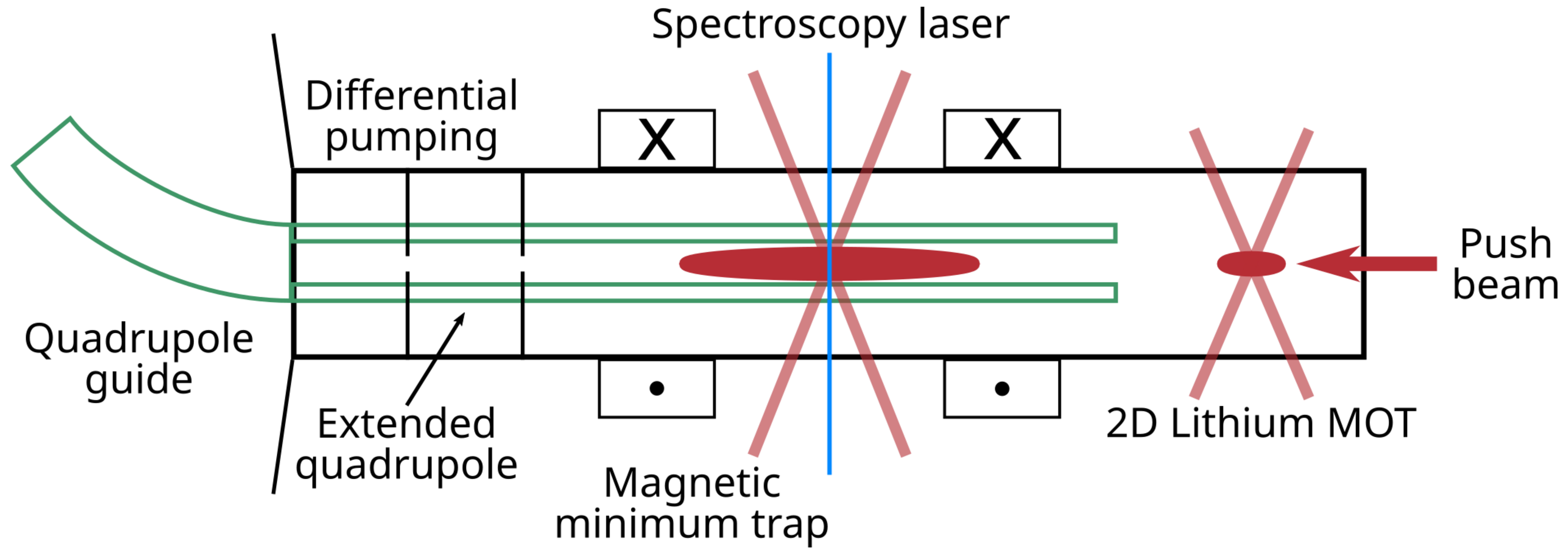
Excitation: Enhancement cavity at 243 nm

- Two-photon excitation requires high laser power due to low transition probability
  → **Optical resonator**
- Active lock to laser → **Piezo-driven mirrors**
- Current mirrors (Al_2O_3):
  - **Enhancement factor** ≈ 6, **Finesse = 70(7)**
  - Require 10 mbar oxygen pressure to reduce degradation in vacuum
- Future mirrors: Fluoride coating
  - Higher degradation threshold and reflectivity



Trapping of atomic Hydrogen

- Thermalize hydrogen in magnetic minimum trap with **Lithium buffer gas**
- **Trapping** of hydrogen is **purely magnetic** with the quadrupole field and axial confinement coils

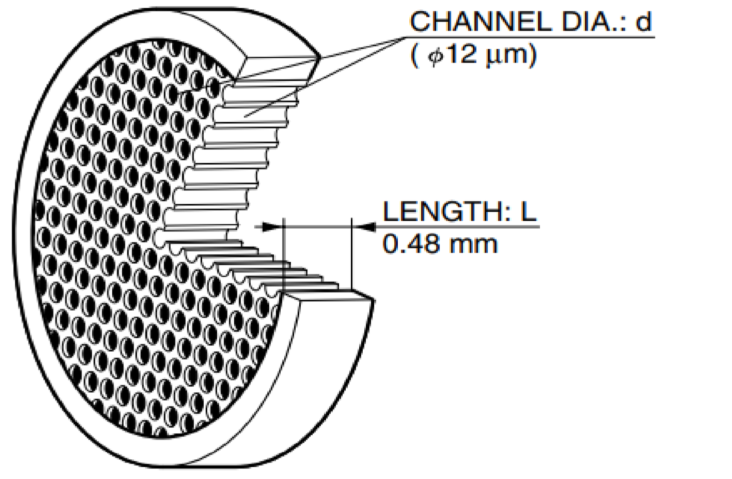


MCP for detection of Lyman-α photons

- Microchannel plate (MCP)

→ Multichannel electron multiplier

- Acceleration voltage $V_D \leq 2$ kV
- **Effective area = 1.65 cm²**
- **Detection efficiency ≈ 1.2 %** could be improved by CsI coating
- Gain > 1×10^6
- **Operating pressure <** 1×10^{-2} **mbar**



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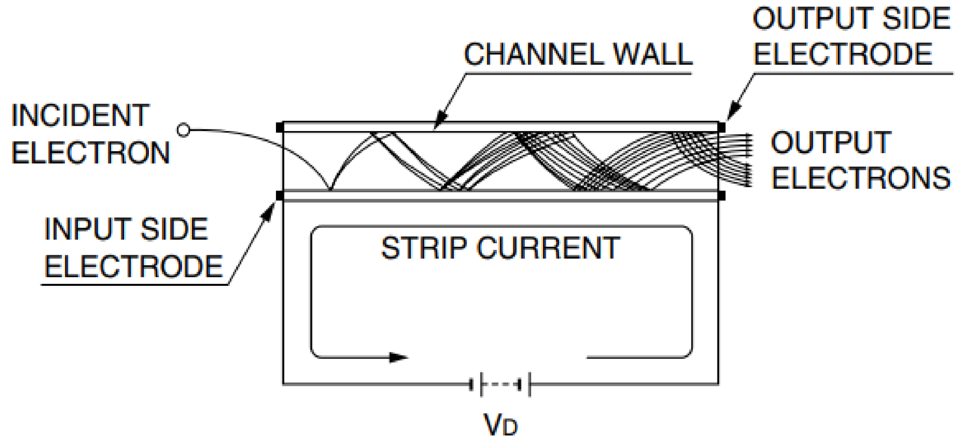

Structure and operating principle of the MCP [3]

Current work and outlook

- Simulation and **measurement** of the free hydrogen beam **behind the quadrupole guide**
- **Magnetic trap field simulations** using mainly permanent magnets
- Parallel: A 20.5: 1S-2S **optogalvanic spectroscopy** in hydrogen microwave discharge

References

[1] 1H Antognini et al., Science 339, 417–420 (2013).
2D Pohl et al., Science 353, 669–673 (2016),
Parthey et al., Phys. Rev. Lett. 104, 233001 (2010).
Jentschura et al., Phys. Rev. A 83, 042505 (2011).
3He CREMA collaboration, preliminary
4He Krauth et al., Nature 589, 527–531 (2021).

[2] Kassiopeia framework: https://github.com/KATRIN-Experiment/Kassiopeia

[3] Hamamatsu Photonics K.K. Hamamatsu MCP assembly guide.

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