Hyperfine Splitting in Muonic Hydrogen

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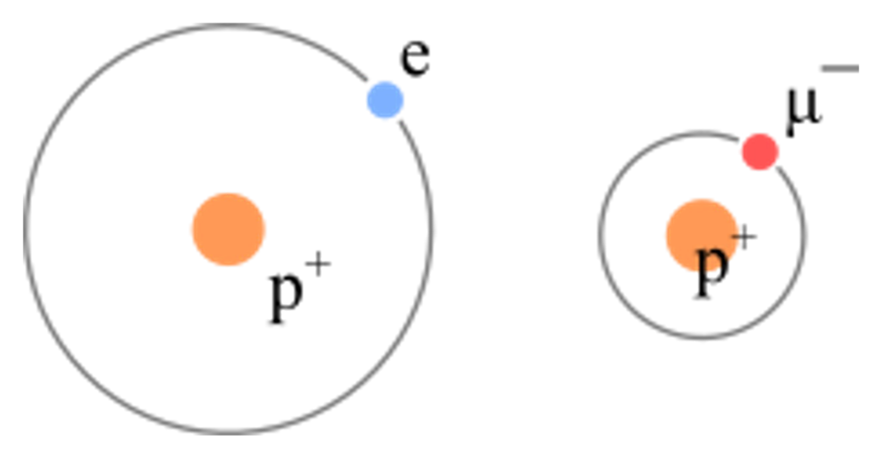
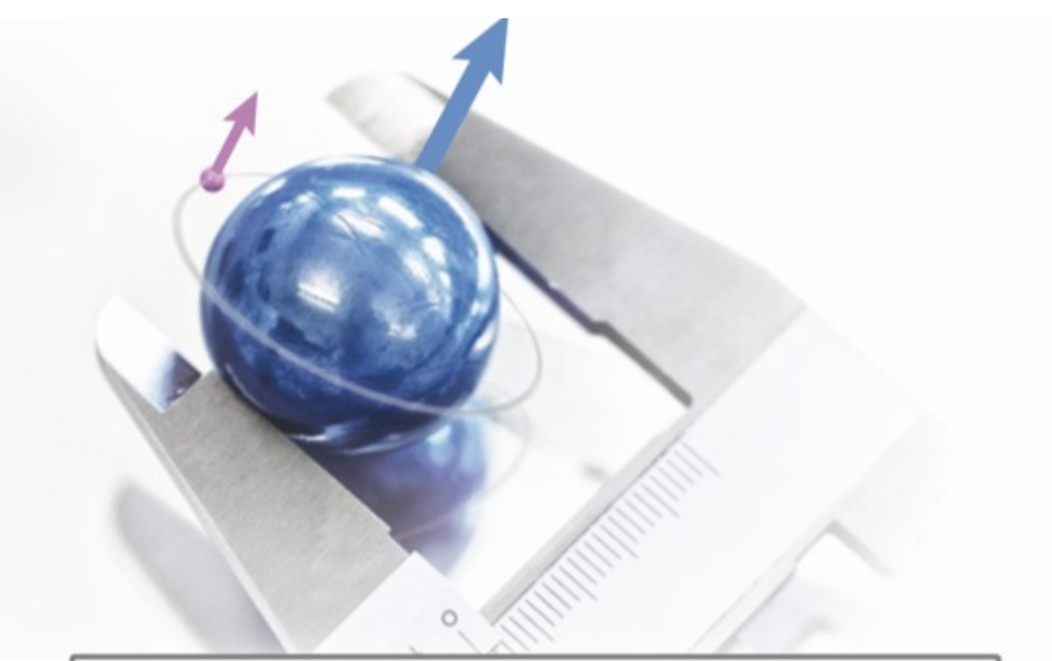
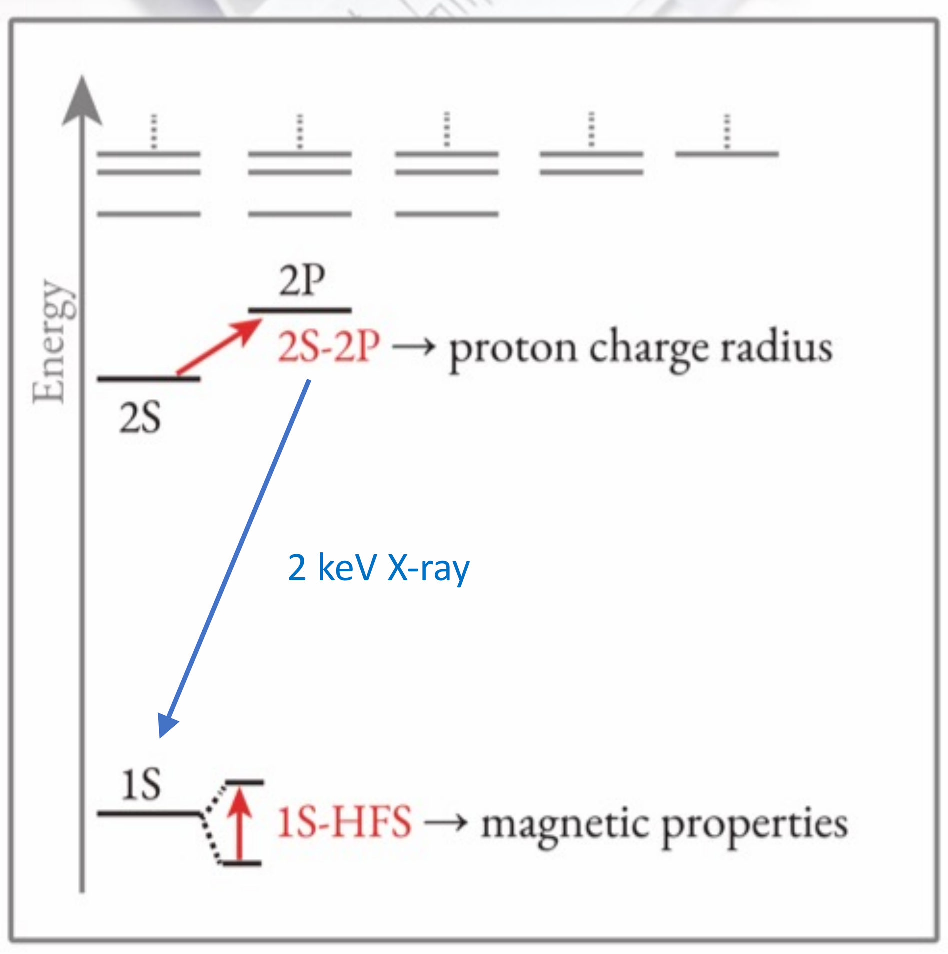
Motivation

The proton structure has a strong impact on the energy levels of muonic hydrogen



$$|\Psi(r=0)|^2 \propto m_r^3$$





Measurement of the ground-state hyperfine splitting in muonic hydrogen

$$E_{HFS} = \left(1 + \Delta_{structure} + \Delta_{weak} + \Delta_{QED}\right) \cdot E_F$$

Learn about electro-magnetic structure of the proton

Test bound-state QED

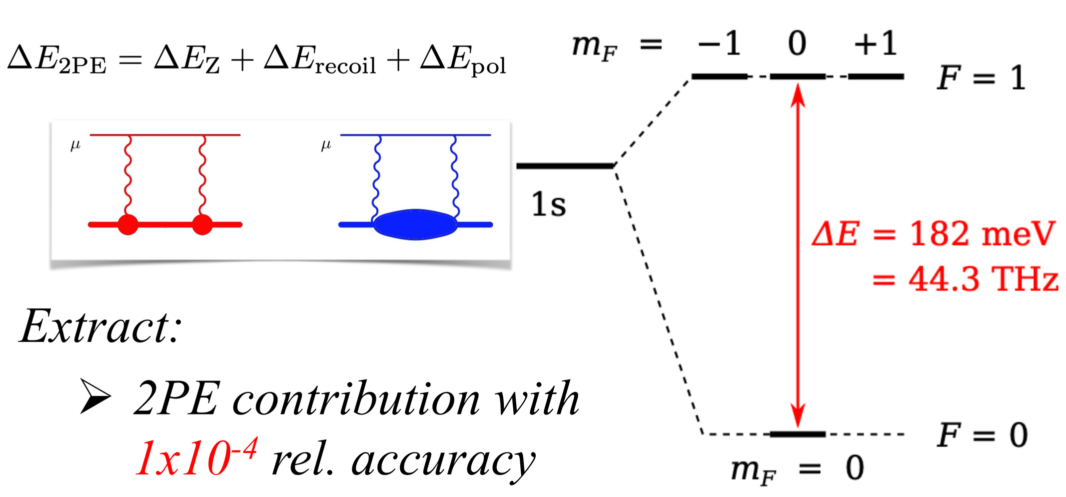
The experiment is sensitive to higher order corrections of the hyperfine splitting

Goal

Measure: 1S-HFS in μp with 1 ppm accuracy

$\Delta E^{\text{th}}_{\text{HFS}}(\mu p) = 183.788(7) + 1.0040\Delta E_{2PE}$ meV

$\Delta E_{2PE} = \Delta E_Z + \Delta E_{recoil} + \Delta E_{pol}$

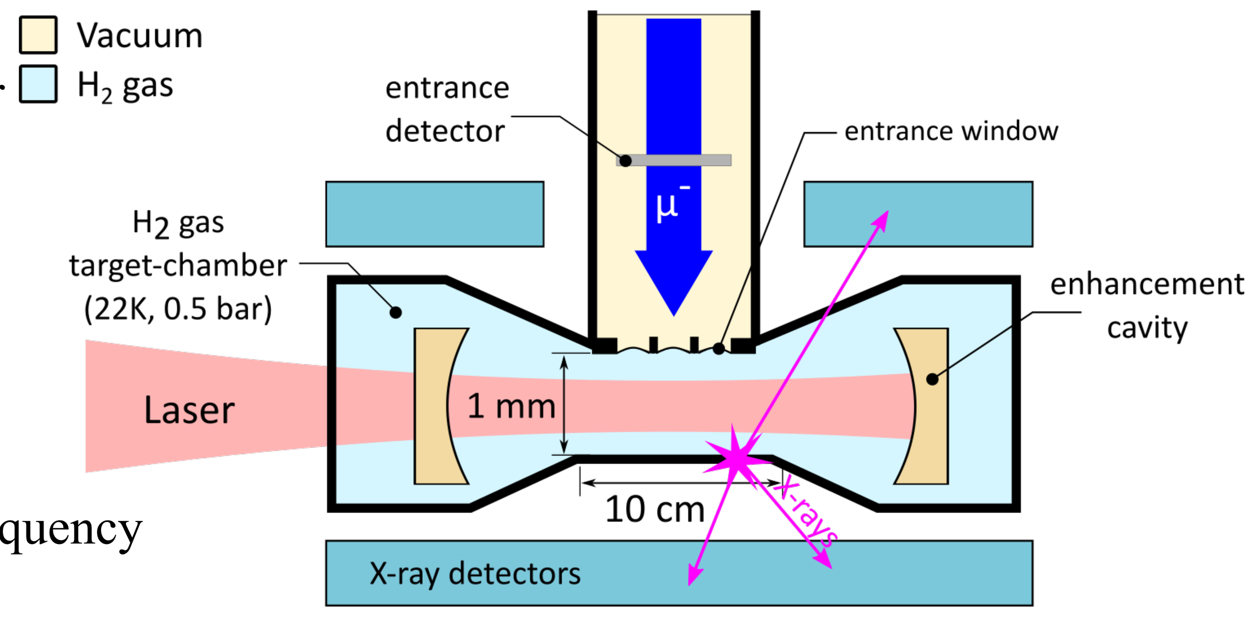


Extract:

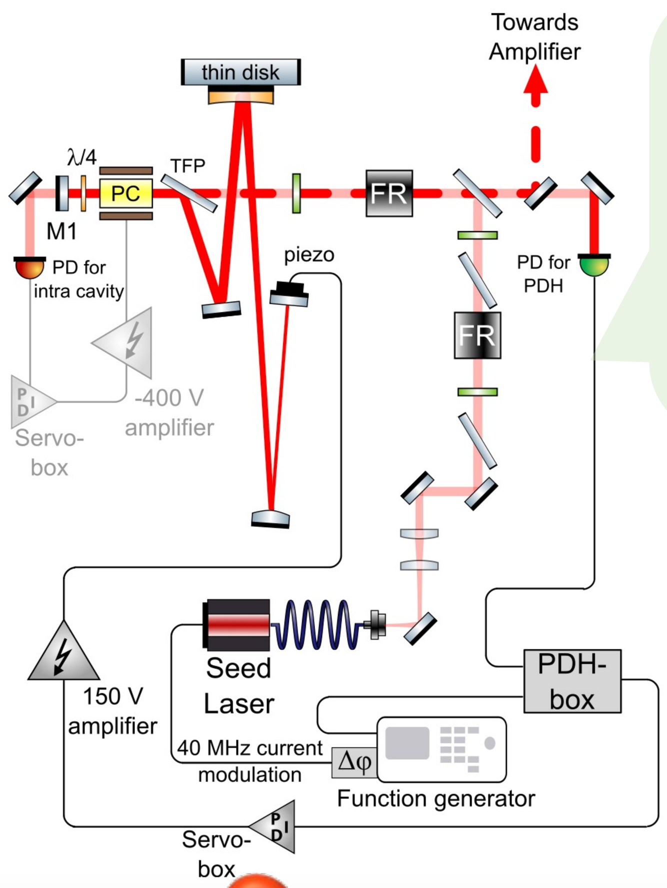
- *2PE contribution with 1×10^{-4} rel. accuracy*
- *Zemach radius, r_Z and polarizability, Δ_{pol} contribution*

Principle of the experiment

- Stop muon beam in 1 mm H_2 gas target @ 22 K, 0.5 bar
- Wait until μp atoms de-excite and thermalize
- Laser pulse: μp(F=0) + γ → μp(F=1)
- De-excitation: μp(F=1) + H_2→μp(F=0) + H_2 + E_{kin}
- μp diffuses to Au-coated target walls
- Formed μAu* de-excites producing X-rays
- Evaluate resonance ⇒ plot number of X-ray vs laser frequency



Optical down-conversion system in the mid-infrared

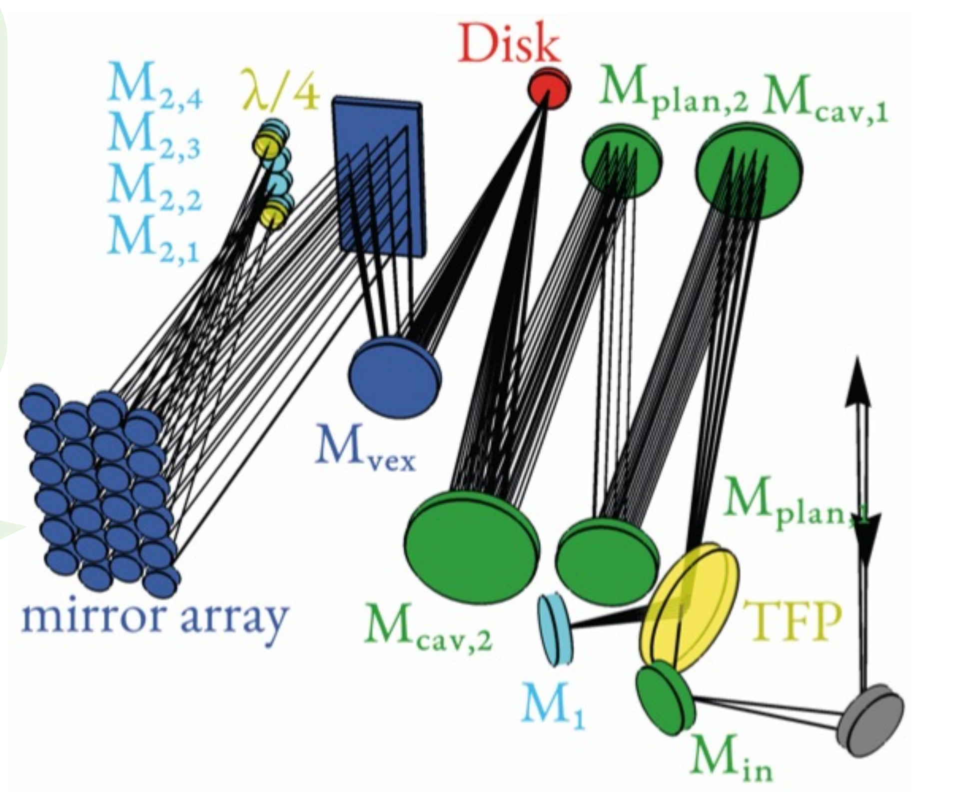


Single-frequency thin-disk oscillator

- ✓ Single frequency operation
- ✓ Energy: > 50 mJ
- ✓ Pulse: 50 ns
- ✓ Delay: < 700 ns (for 35 mJ)
- ✓ Pulse-to-pulse stability: < 0.3 % (rms)
- ✓ Laser chirp: < 2MHz
- ✓ Continous re-locking

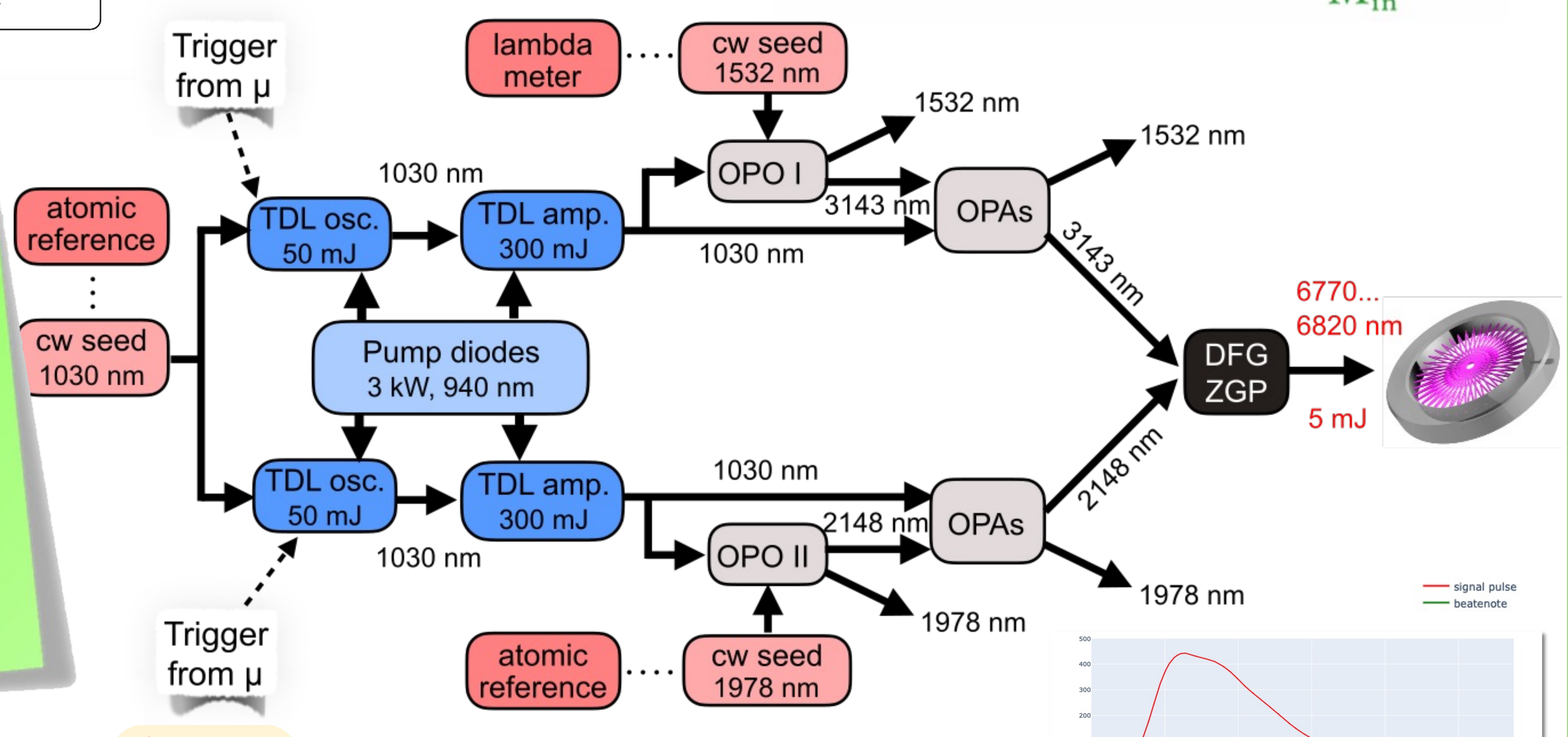
Multi-pass thin-disk amplifier

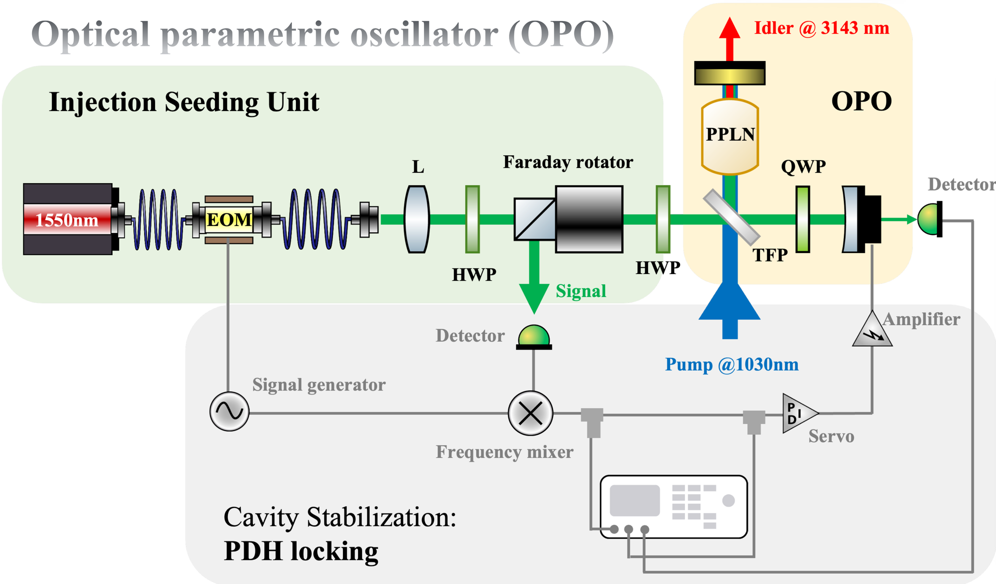
- ✓ Energy: 220 mJ
- ✓ Gain: 7.5
- ✓ Beam quality: M²= 1.05
- ✓ Pointing stability
- ✓ Insensitive to the thermal lensing

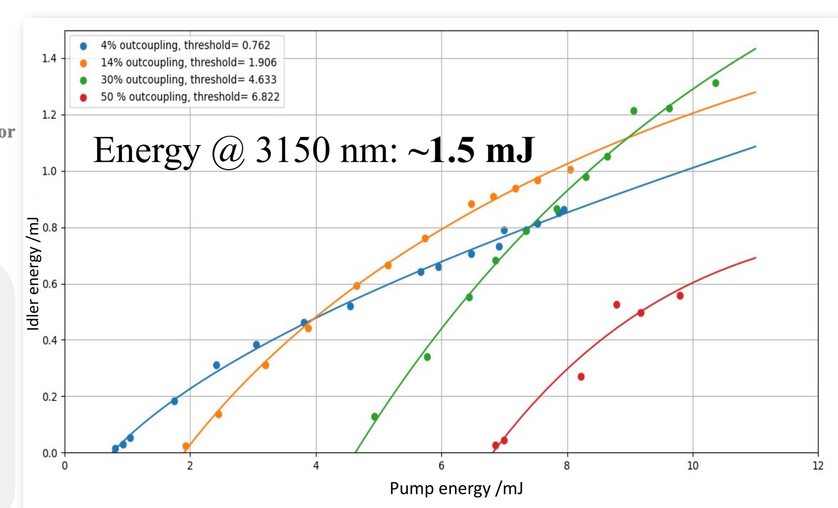


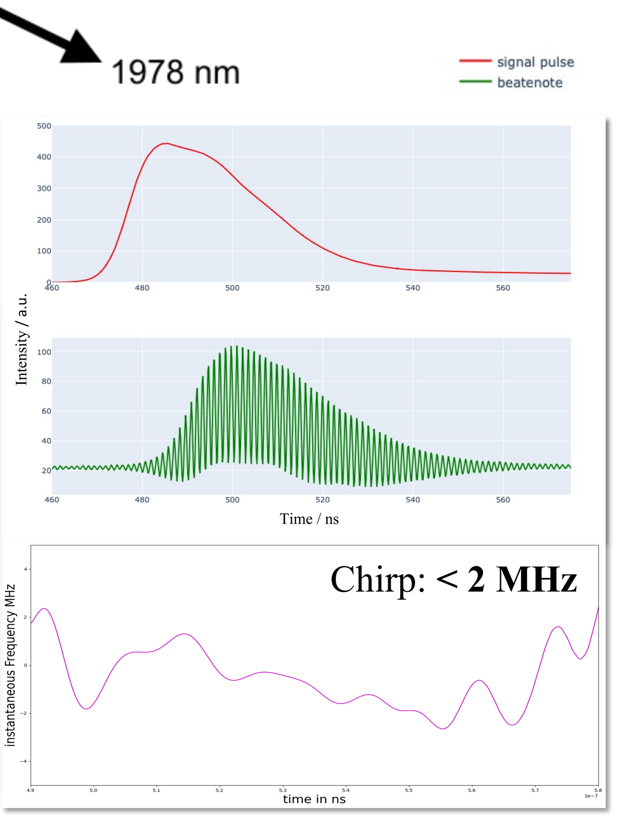
Requirements

- ❑ Wavelength: ~ 6800 nm
- ❑ Delay time: 1 µs
- ❑ Stochastic trigger
- ❑ Energy: ~ 5 mJ
- ❑ Repetition rate: 200 s^{-1}
- ❑ Bandwidth: < 100 MHz





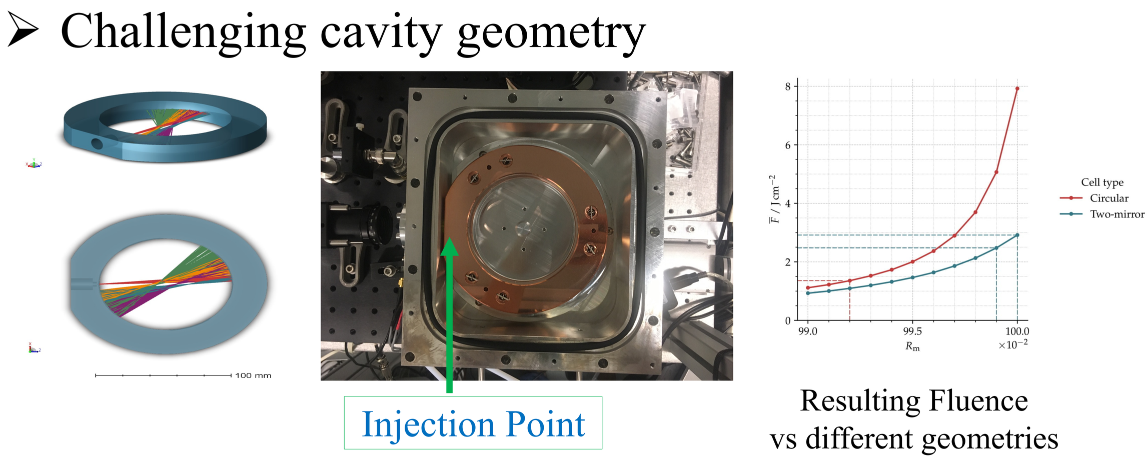




Excitation and detection system

Multi-pass cavity

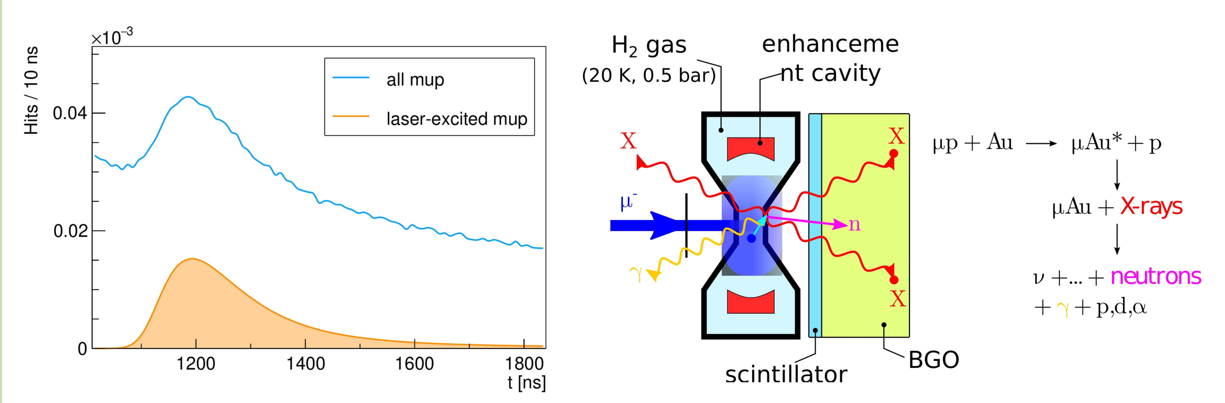
- Maximizing the fluence on the 1 mm μp target
- Challenging cavity geometry



Resulting Fluence vs different geometries

Detection system

- Background : Diffusion, Muon decay, uncorrelated
- Identify with high efficiency the background events



Outlook

- Finalization of 2 µm OPO + OPA branch
- Development of difference frequency generation (DFG)
- Optimize & test the reflectivity of the toroidal cavity

References

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