Measuring the 1s Hyperfine splitting of Muonic Hydrogen

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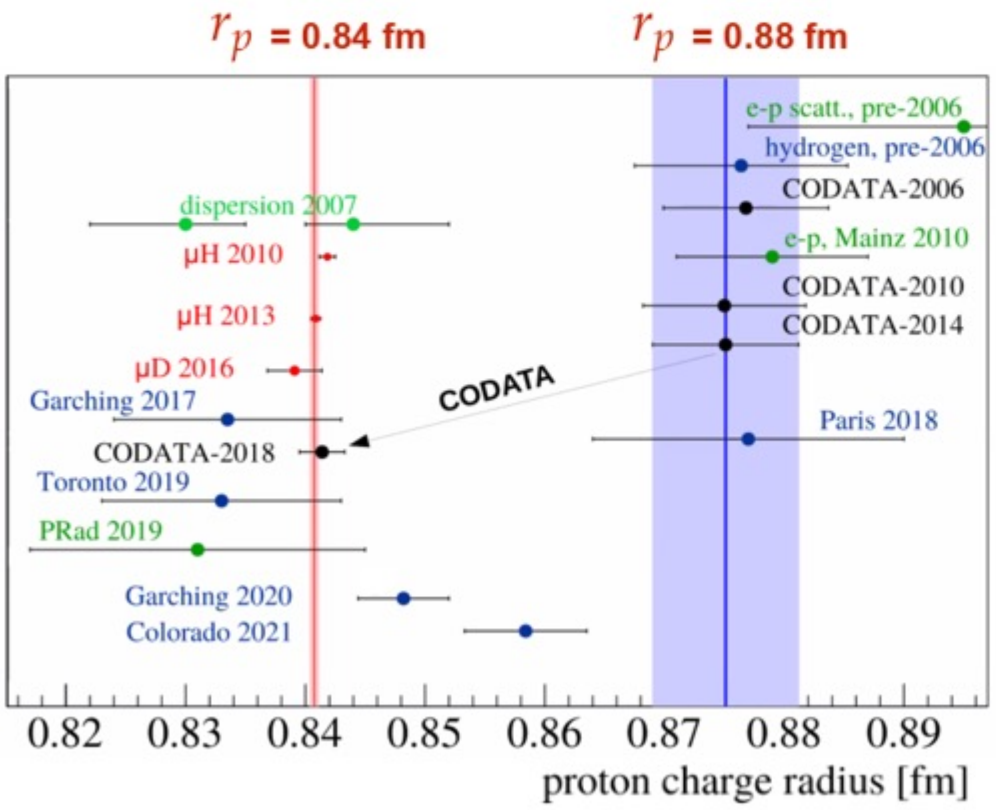
Proton Charge Radius Puzzle

Experiments :

- Electron proton scattering
- Regular Hydrogen Spectroscopy
- Muonic Hydrogen spectroscopy



Alexey Grinin et al, Science 2020

N.Beziginov et al, Science 2019

Ingo Sick,On the rms-radius of the proton,Physics Letters B,Volume 576, Issues 1–2,2003,Pages 62-67,ISSN 0370-2693

High-Precision Determination of the Electric and Magnetic Form Factors of the Proton, Phys. Rev. Lett. 105, 242001, 2010

Pohl, R., Antognini, A., Nez, F. et al. The size of the proton. Nature 466, 213–216 (2010). https://doi.org/10.1038/nature09250

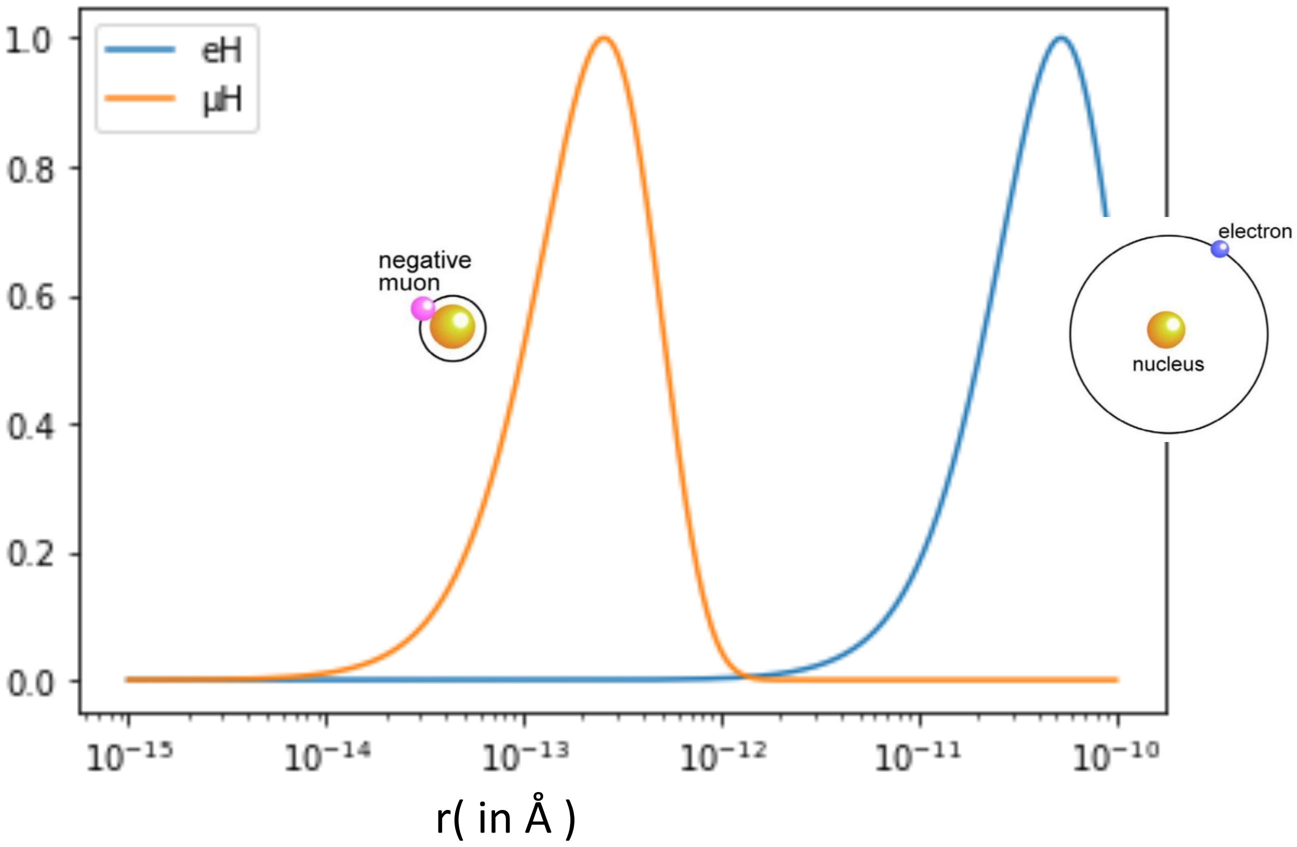
CODATA recommended values of the fundamental physical constants: 2010* Peter J. Mohr, Barry N. Taylor, and David B. Newell Rev. Mod. Phys. 84, 1527

Improved Measurement of the Hydrogen 1S–2S Transition Frequency Christian G. Parthey, Phys. Rev. Lett. 107, 203001 – Published 11 November 2011

Why Muonic Atoms ?

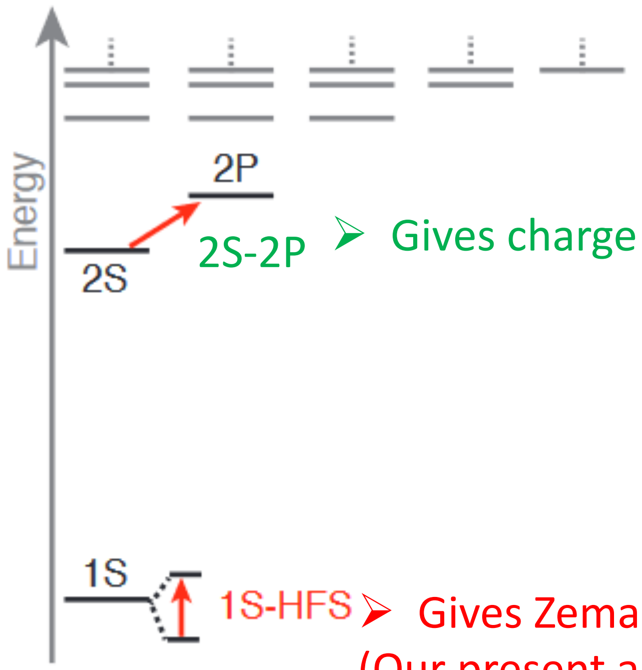
Probability of finding the lepton in the atom at r

$r^2 \, R_{10}^2(r)$



Ground State HFS in μH

- From 2S-2P (Electric Dipole Transition)
  - ➢ Charge Radii
- From HFS (Magnetic Dipole Transition)
  - ➢ Zemach radius



➢ Gives charge radius (Aldo Antognini *et al.*, Science, 339(6118), 417–420.)

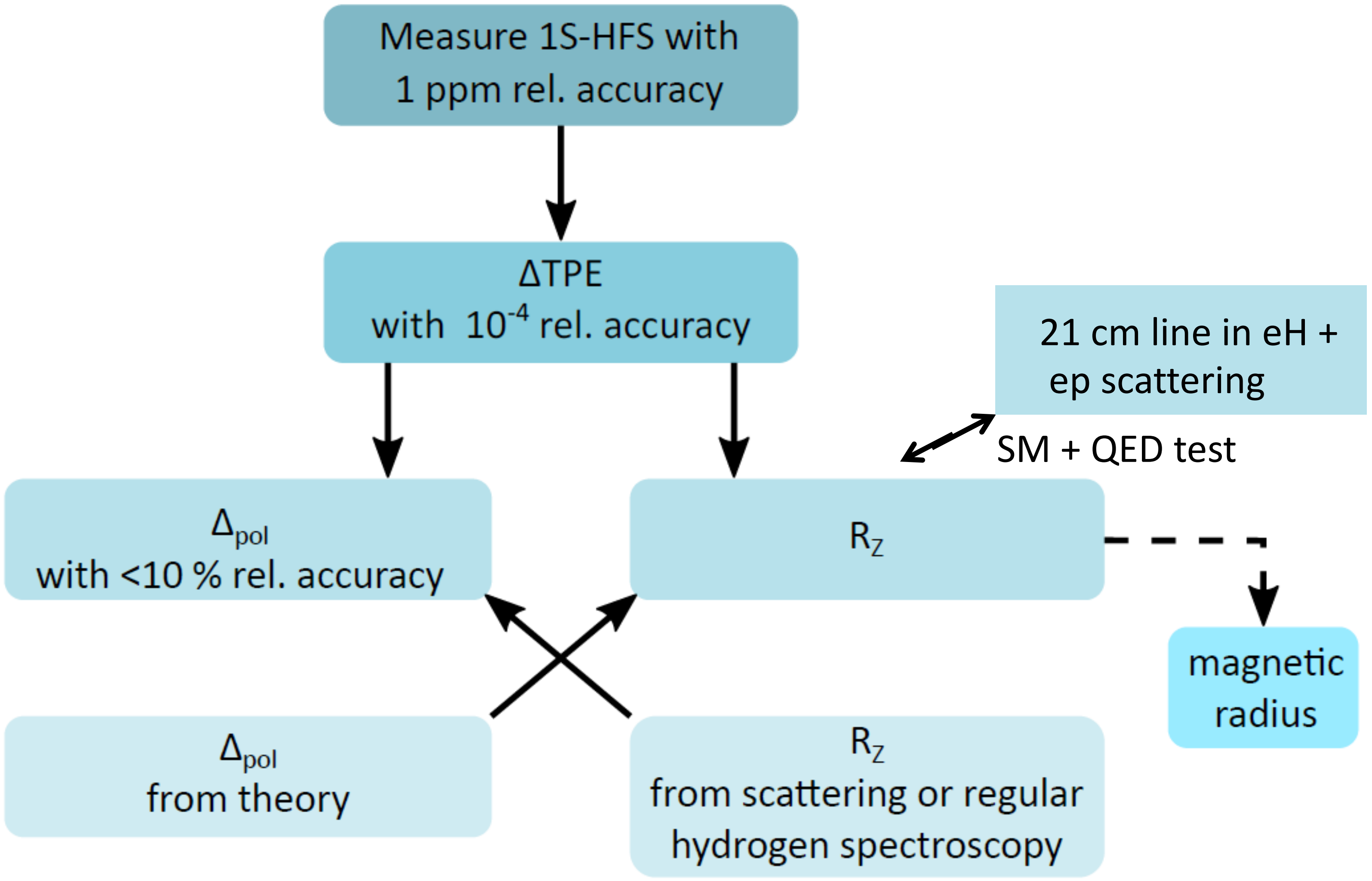
➢ Gives Zemach radius (Our present aim)

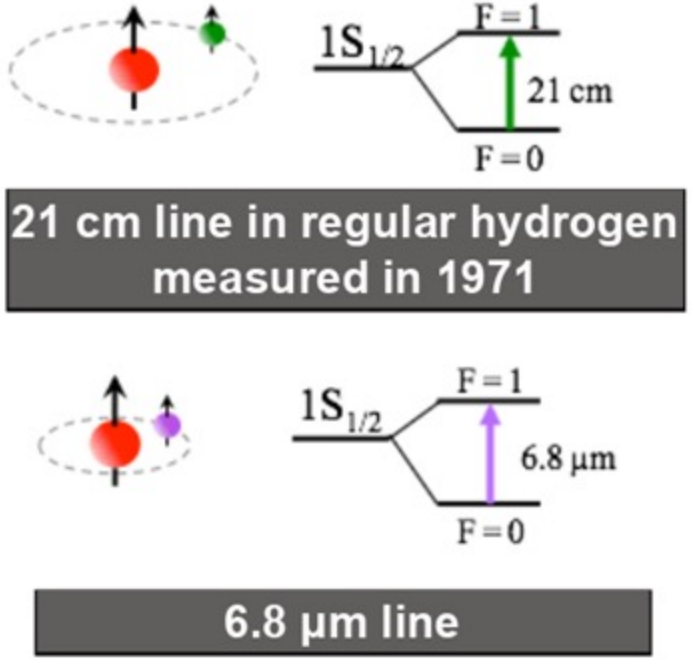
$$R_Z = \int d^3\vec{r}\, |\vec{r}| \int d^3\vec{r}'\, \rho_E\,(\vec{r} - \vec{r}')\,\rho_M(\vec{r}')$$

$$\Delta E^{\rm th}_{\rm HFS} = 182.819(10) - \underbrace{1.301 R_Z + 0.064(21)}_{\text{Two Photon Exchange}} + \cdots \quad {\rm meV}$$

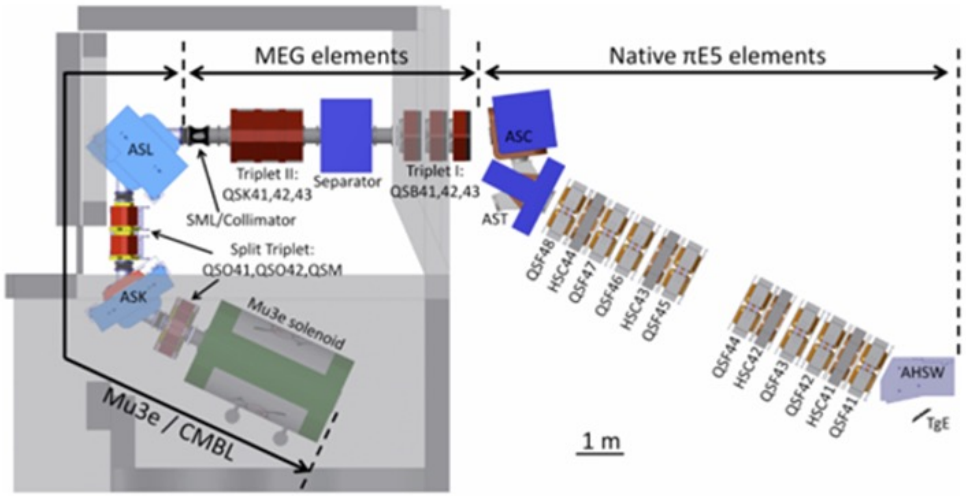
$(= \Delta_{zemach} + \Delta_{Pol} + \Delta_{recoil})$

Our Goal

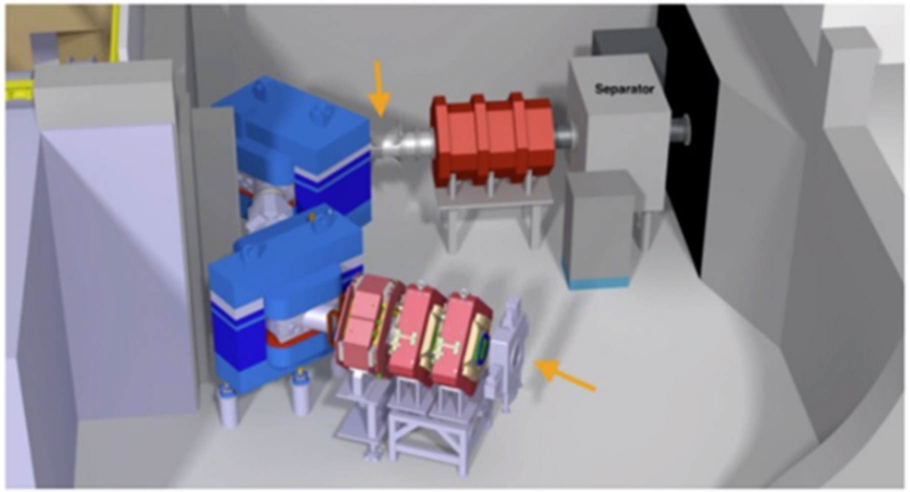


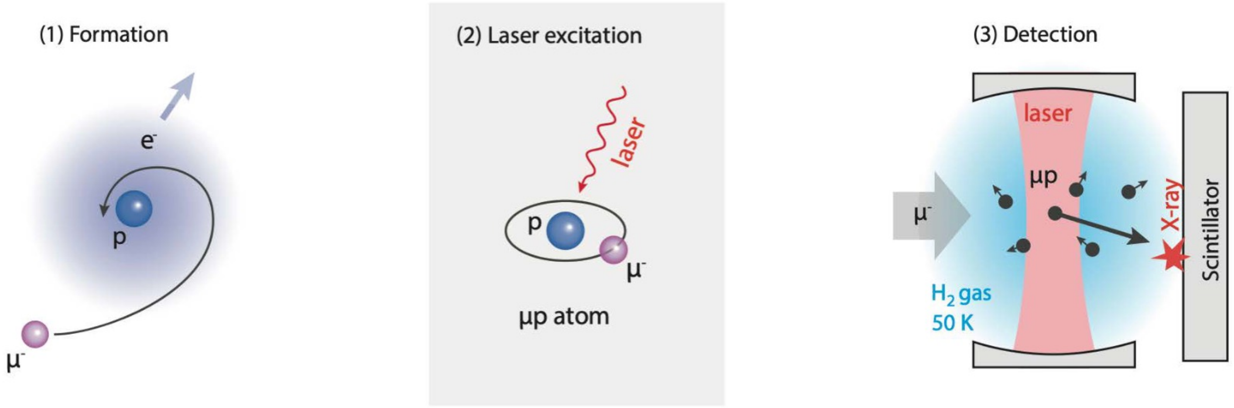


Experimental Overview



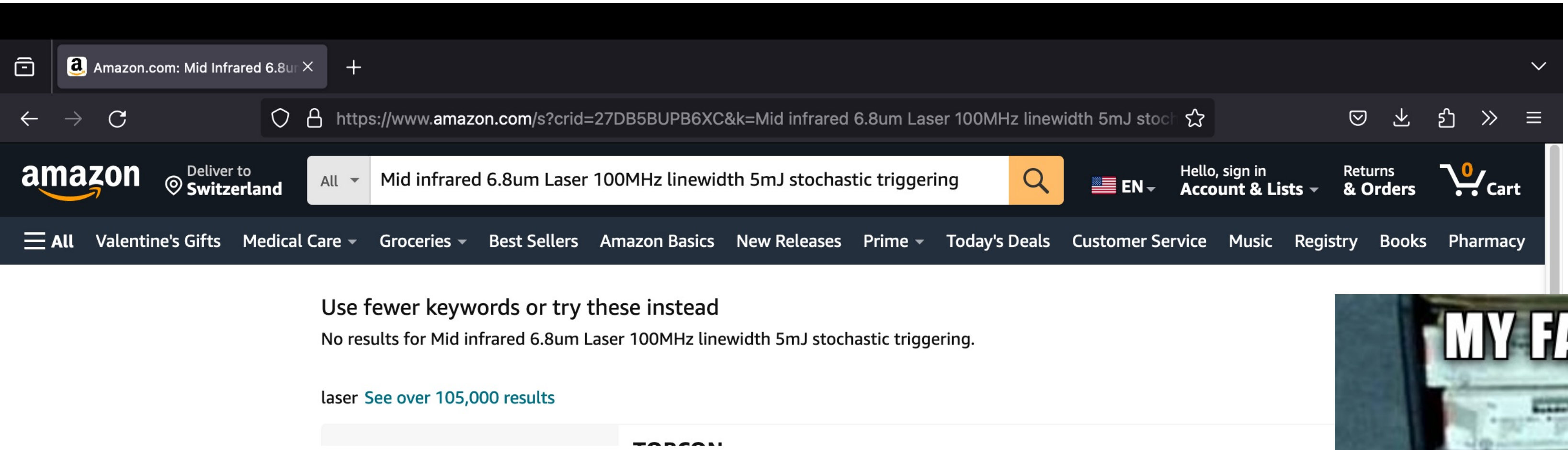
Muon Beam line at Paul Scherer Institute, Switzerland

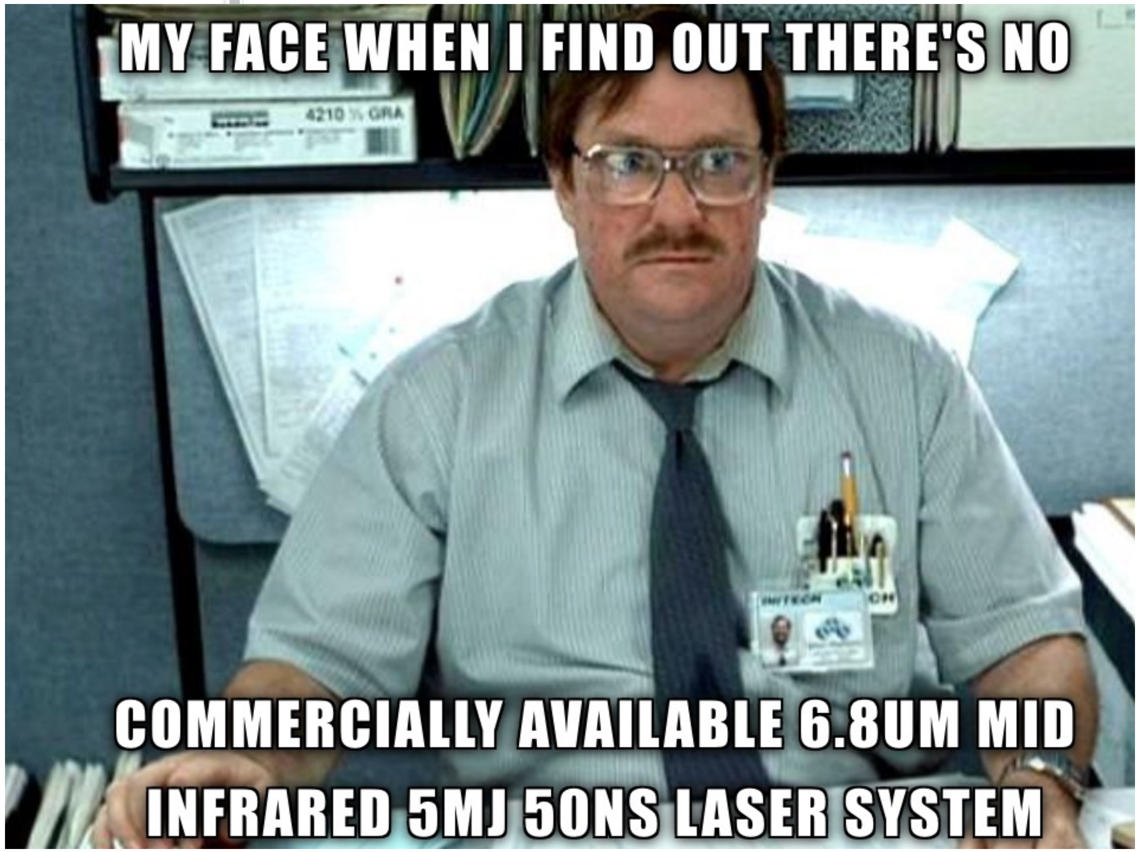




Challenges	Requirement
Muon decays in 2.2 μs	Laser Trigger System fast response time of 1 μs
Muon arrives randomly	Stochastic trigger – Fire when Muon Arrives
Weak M1 transition	High Energy 50ns Laser Pulses giving 5mJ at 6.8 micron, enhancement cavity
Precision and Stability Required	<100 MHz Linewidth of Laser, > 4 weeks of continuous operation
Background	Scintillators to veto false events

No commerically available laser system….



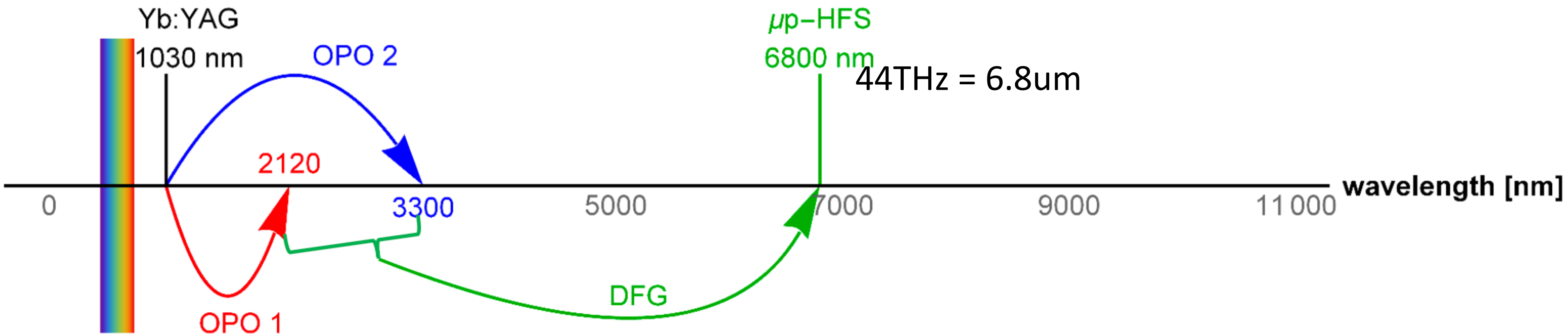


So we build it ourselves (taking years , several PhDs, and money and more years,…)

Strategy

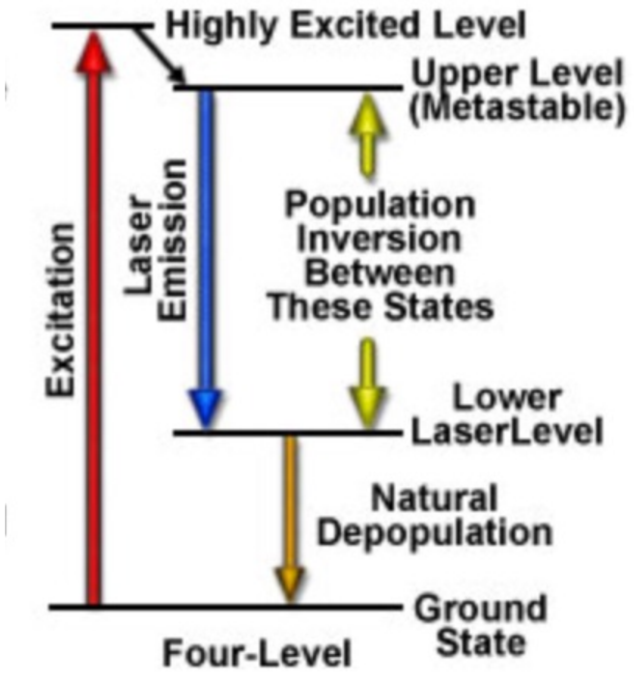
- Build a High energy Laser system at a Non-Technically limited Wavelength
- Down convert the output of this high energy laser into the required freqeuncy (gives us <2% energy efficiency at the end)

(here, ca. 350mJ @ 1030nm = 290 THz)

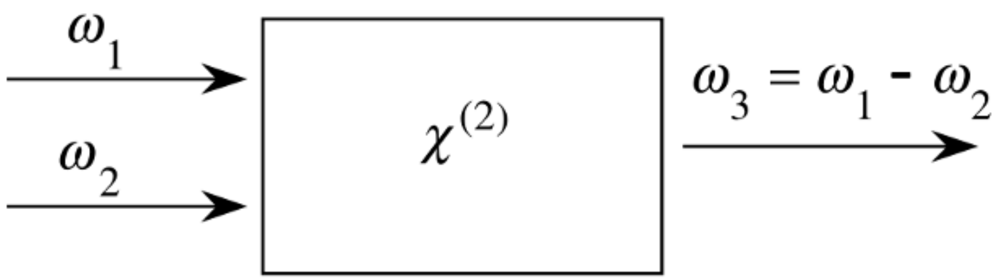


Conventional Laser Mechanism vs Nonlinear Optics

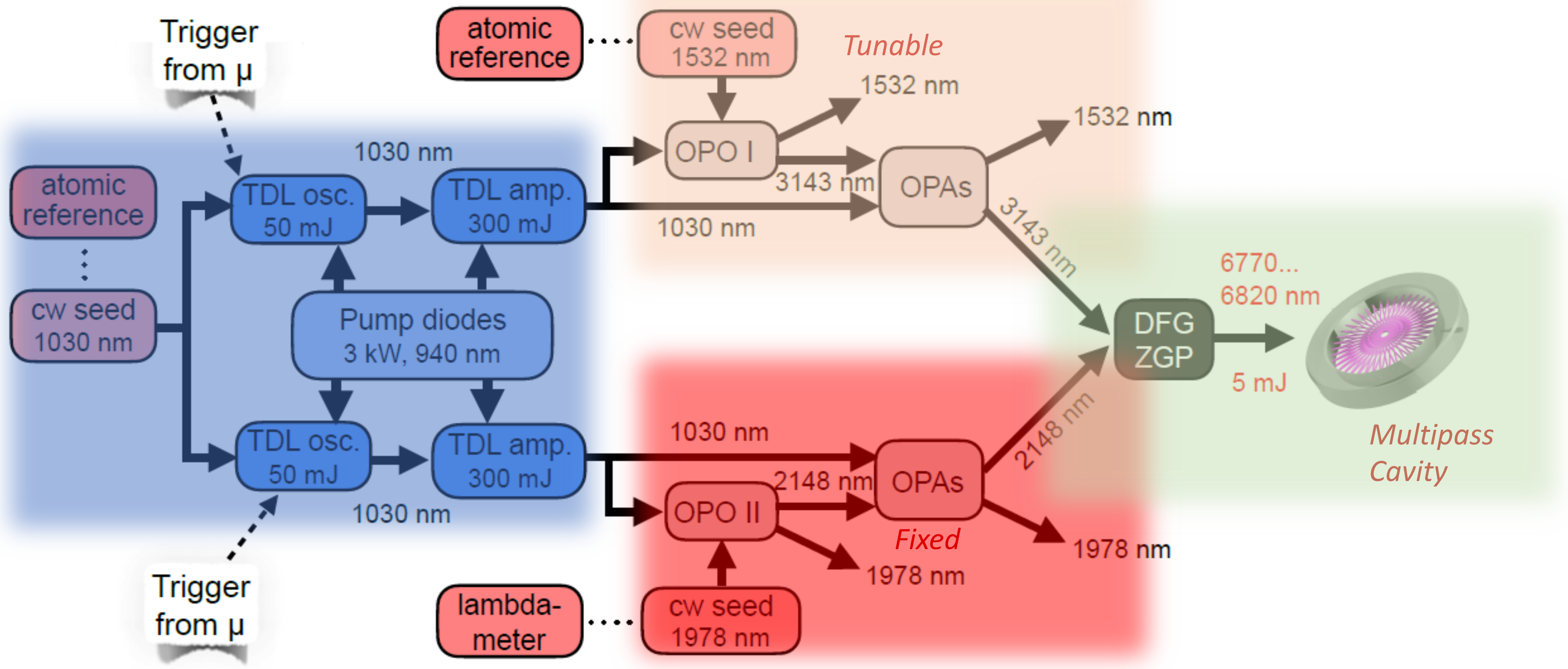
1. Pump and generate Population Inversion
2. Open and close the laser cavity to generate Pulses



1. Under applied field, materials react to oppose the field
2. Some materials, generate EM field in another direction, depending on crystal structure in addition to (1)
3. Send in Electric field at ω1, get out *Electric field at* ω2, ω3



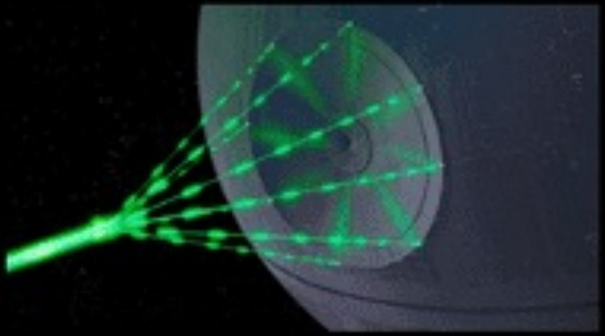
Our Laser System Design



LASER PHYSICS

What my friends think I do

What my mom thinks I do

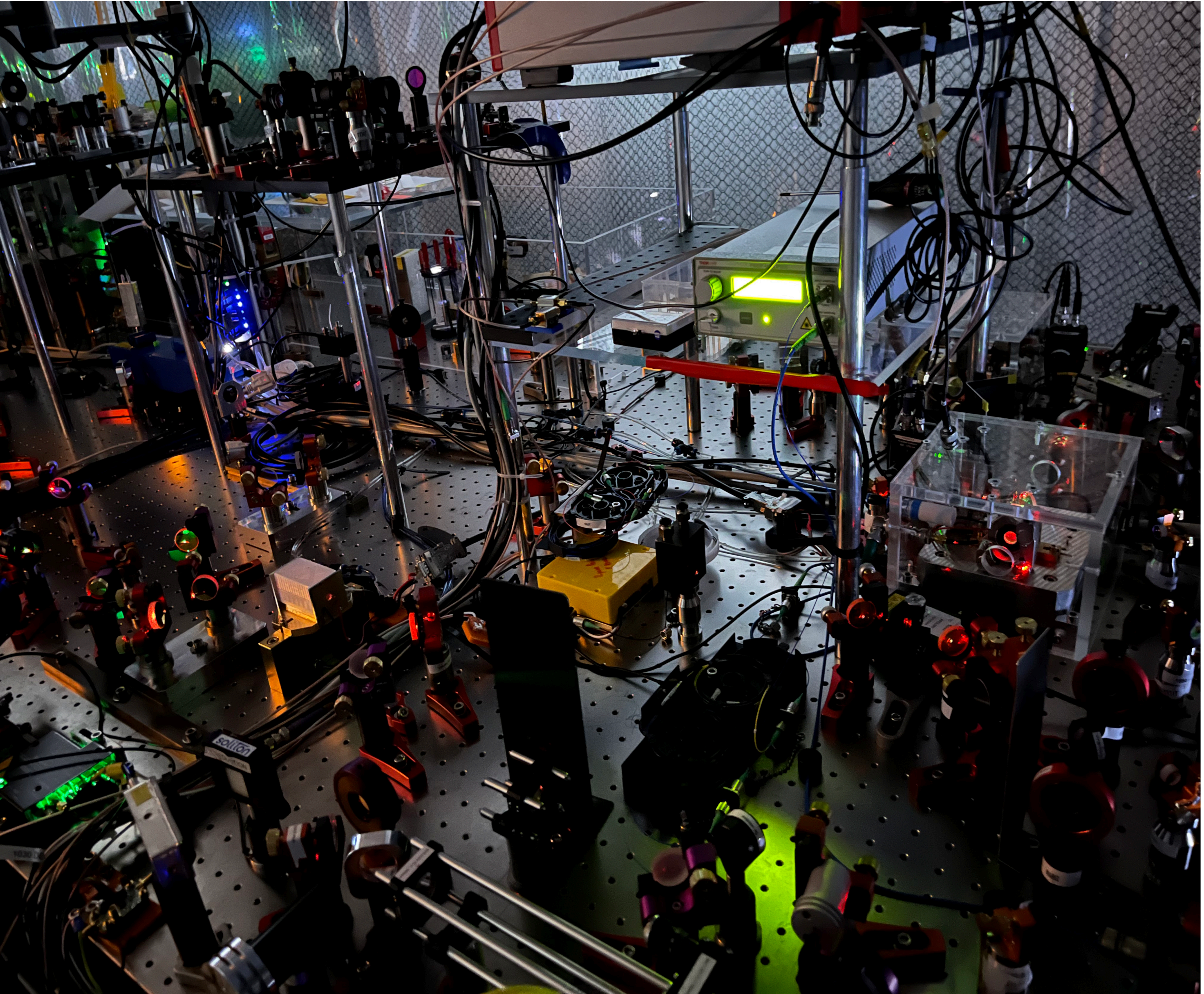


What society thinks I do

What my boss thinks I do

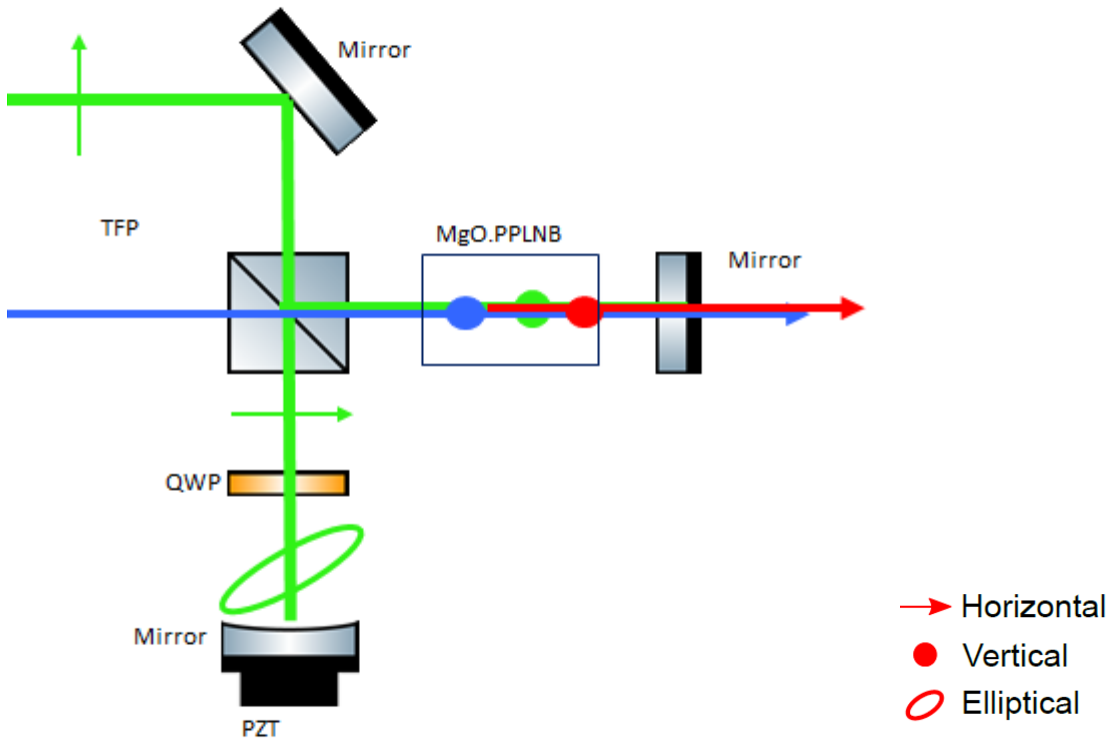
What I think I do

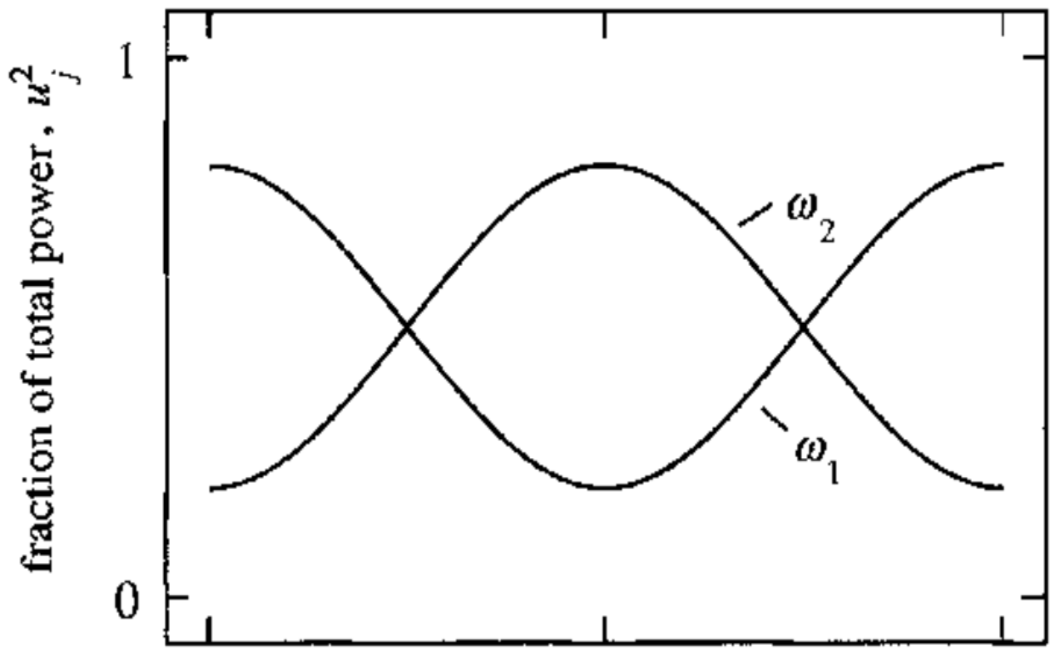
What I really do


soliton

soliton

Optoparametric Oscillators





(Origin of Crystal)

Distance along Nonlinear Crystal

Idler (3 micron = 97 THz, Output that we need)
Pump (1030nm = 291 THz, High energy Input that we send)
Signal (1550nm =195 THz , low energy input that we send)

Thank You for your attention! Questions ?

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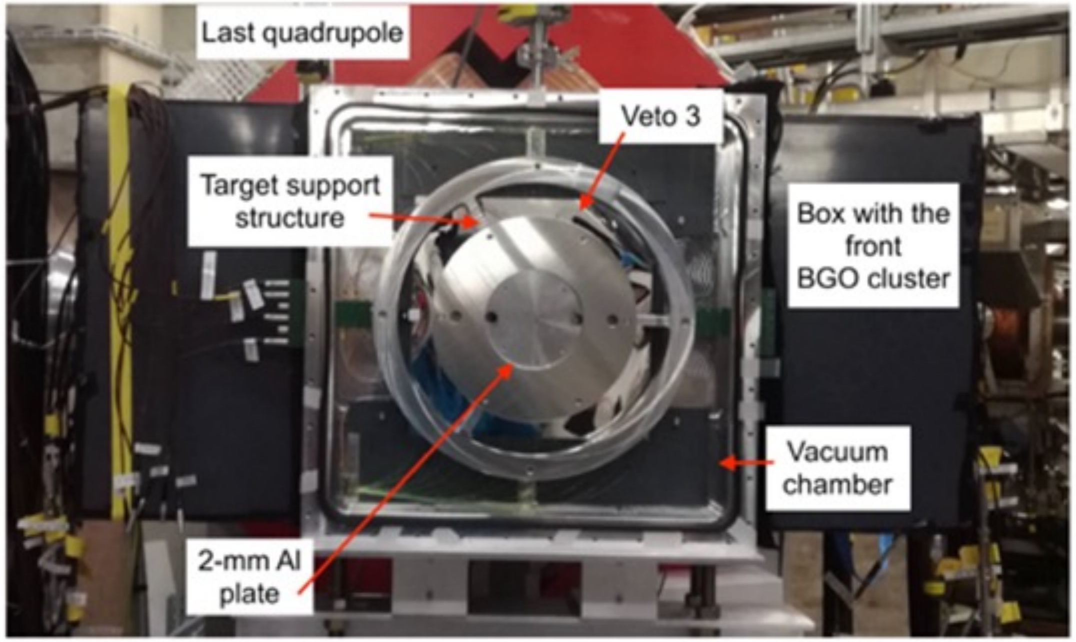
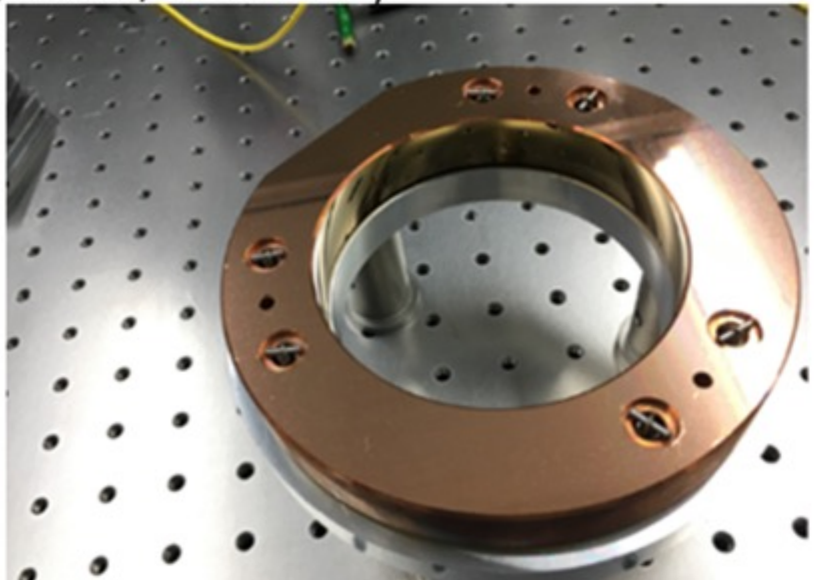
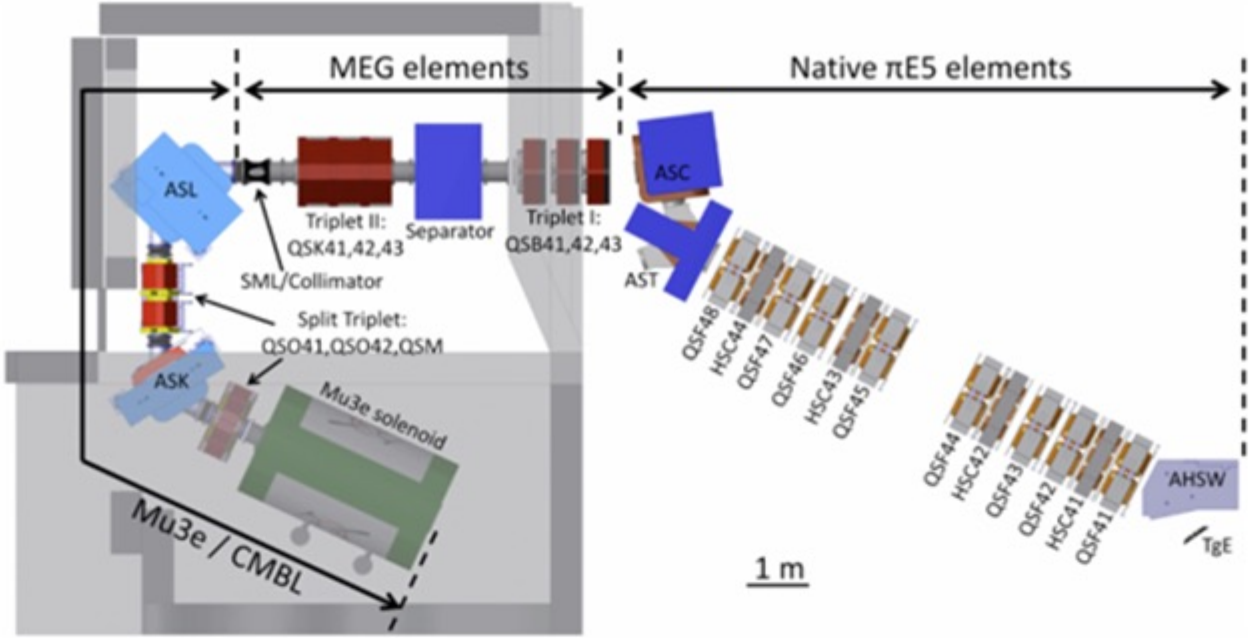


Detector
(L. Šinkunaite , Thesis, ETH Zurich)
(M.Zeyen, Thesis, ETH Zurich)



Multipass Cavity



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