Institute for Molecules and Materials

FACULTY OF SCIENCE, MATHEMATICS AND COMPUTING SCIENCE

Design of a Long Wavelength FEL for Experiments under High Magnetic Fields

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Large Scale Research Facilities in the Netherlands

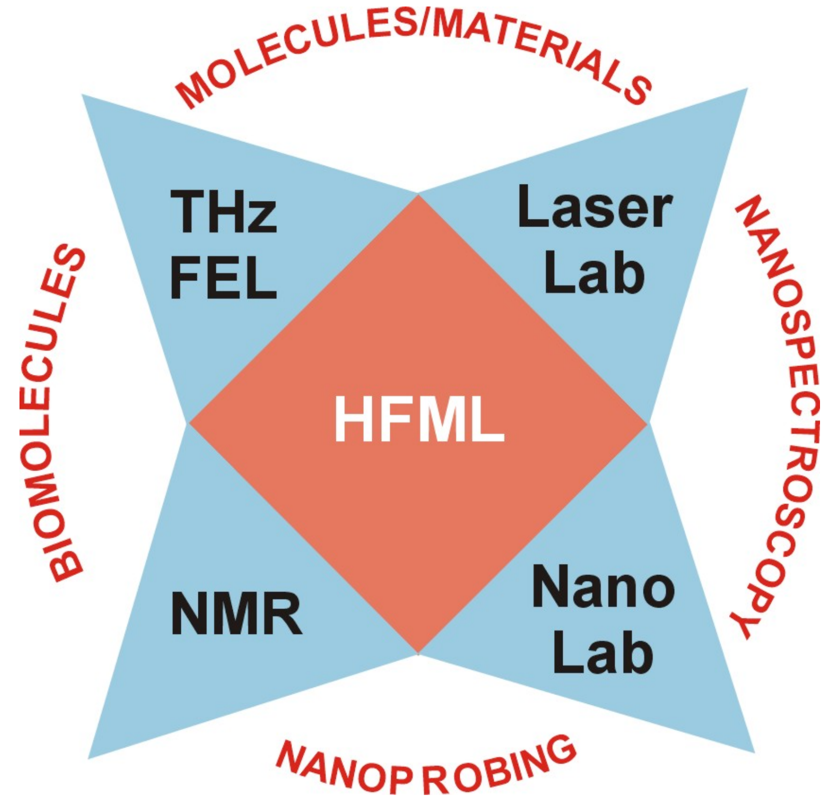
- Investments in the future of the ‘knowledge-economy’

Science Drivers for a New Light Source

- The limitations of material and molecular research in high Magnetic Fields
- Dynamic Nuclear Polarization in NMR
- Biomolecular Spectroscopy

Design and system choices for our Nijmegen FIR-FEL

- Combining pump-probe options with very narrow bandwidth output in a single instrument

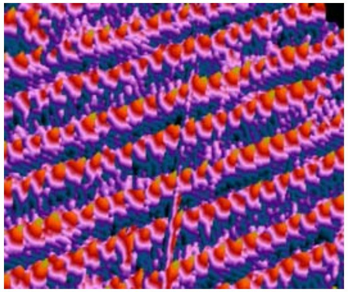


Nijmegen Center for Advanced Spectroscopy

On Large Scale Research Facilities in the Netherlands

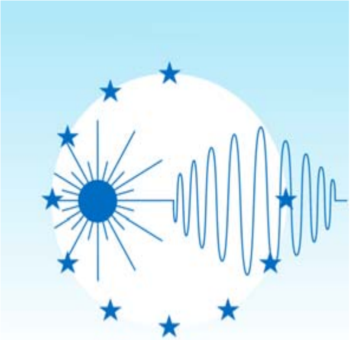
The Nijmegen Center for Advanced Spectroscopy

- *Nano*Lab (Rasing)



to facilitate access to Nano-Science and Technology for Small and Medium size enterprises

- Trace gas Facility (Harren)



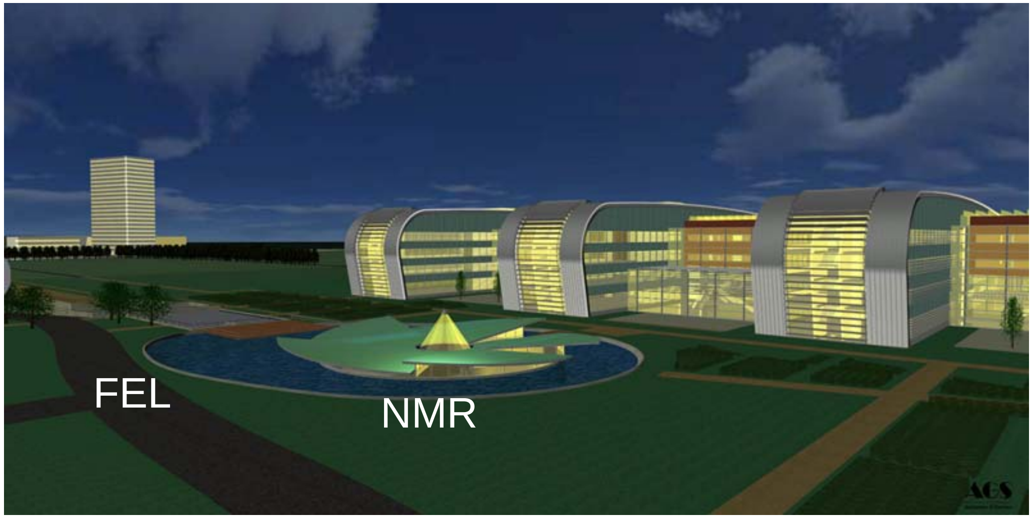
part per billion range (1 ppb = 1:10^9), 100 times more sensitive than best commercially available equipment

Nijmegen Science Faculty

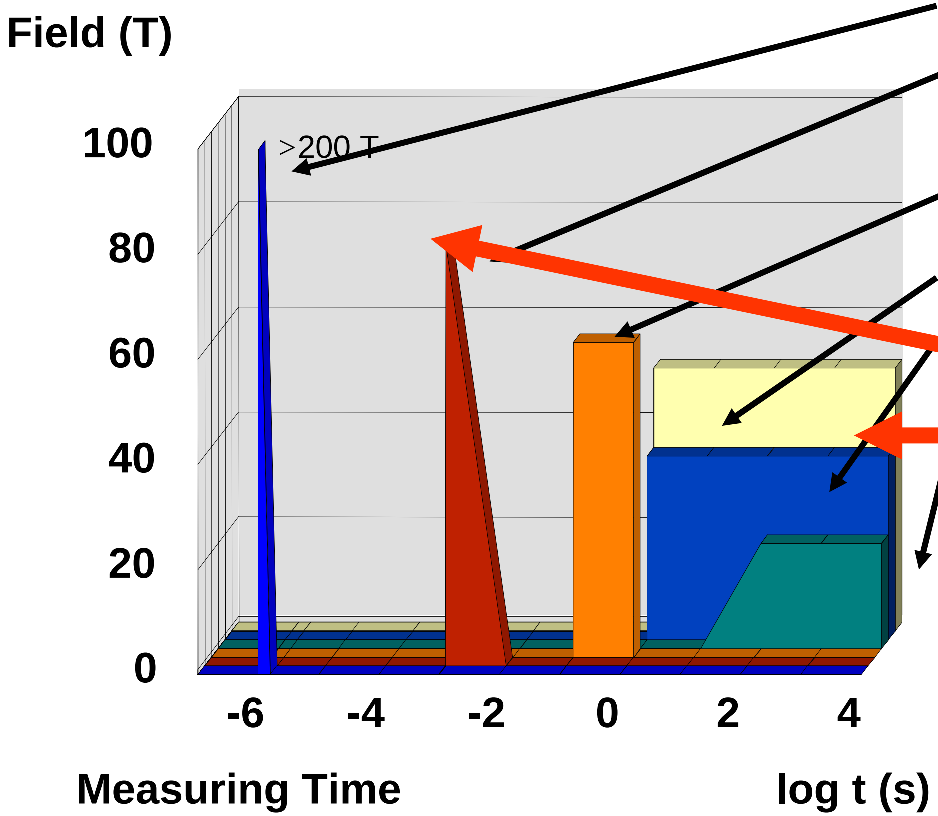
HFML (Maan)

NMR pavillion (Kentgens)

Science faculty: opening 2007



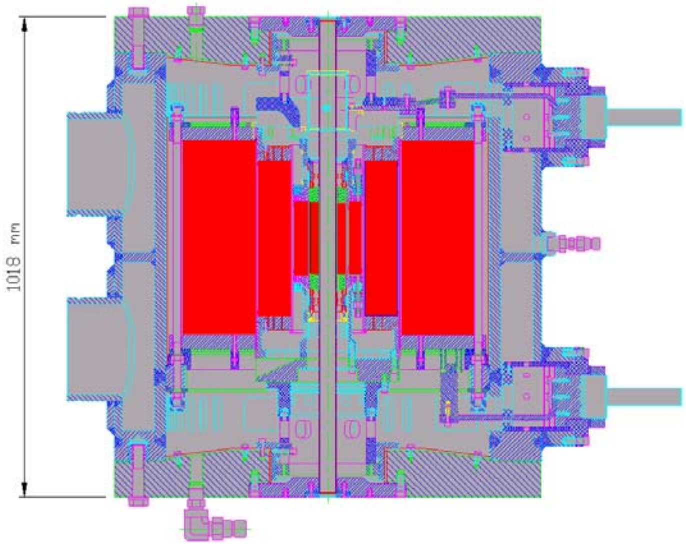
Magnetic Field Landscape

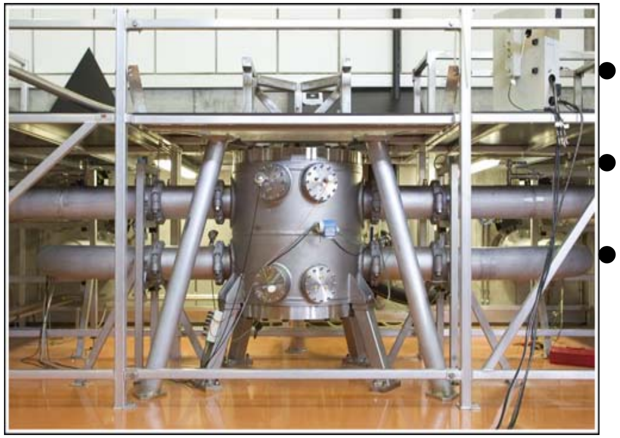


Destructive pulsed
Capacitor driven pulsed
(55T → 80T)
Regulated quasi CW (→35T)
Hybrid magnets (41T → (45T !!)
Resistive magnets (33T)
Superconducting magnets
18T

HFML

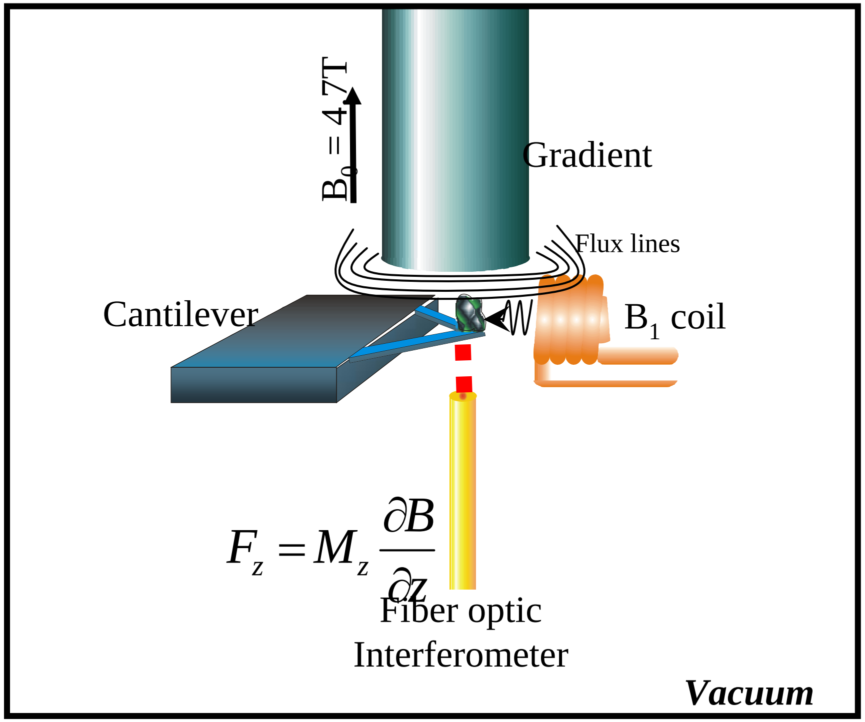
NMR and HFML: NMR towards Instrumentation above 1 GHz



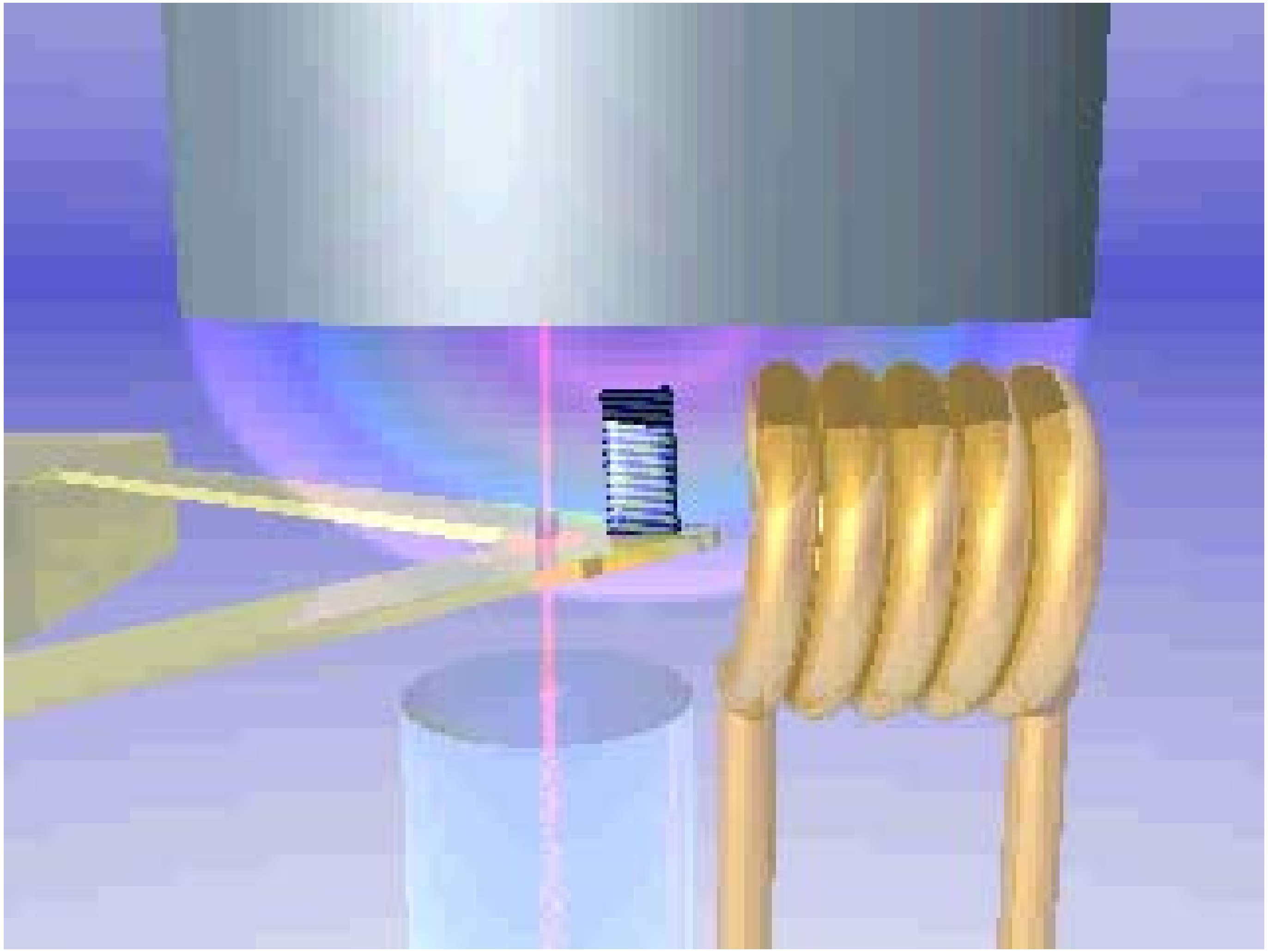


- 33 T
- 40 kA
- 20 MW

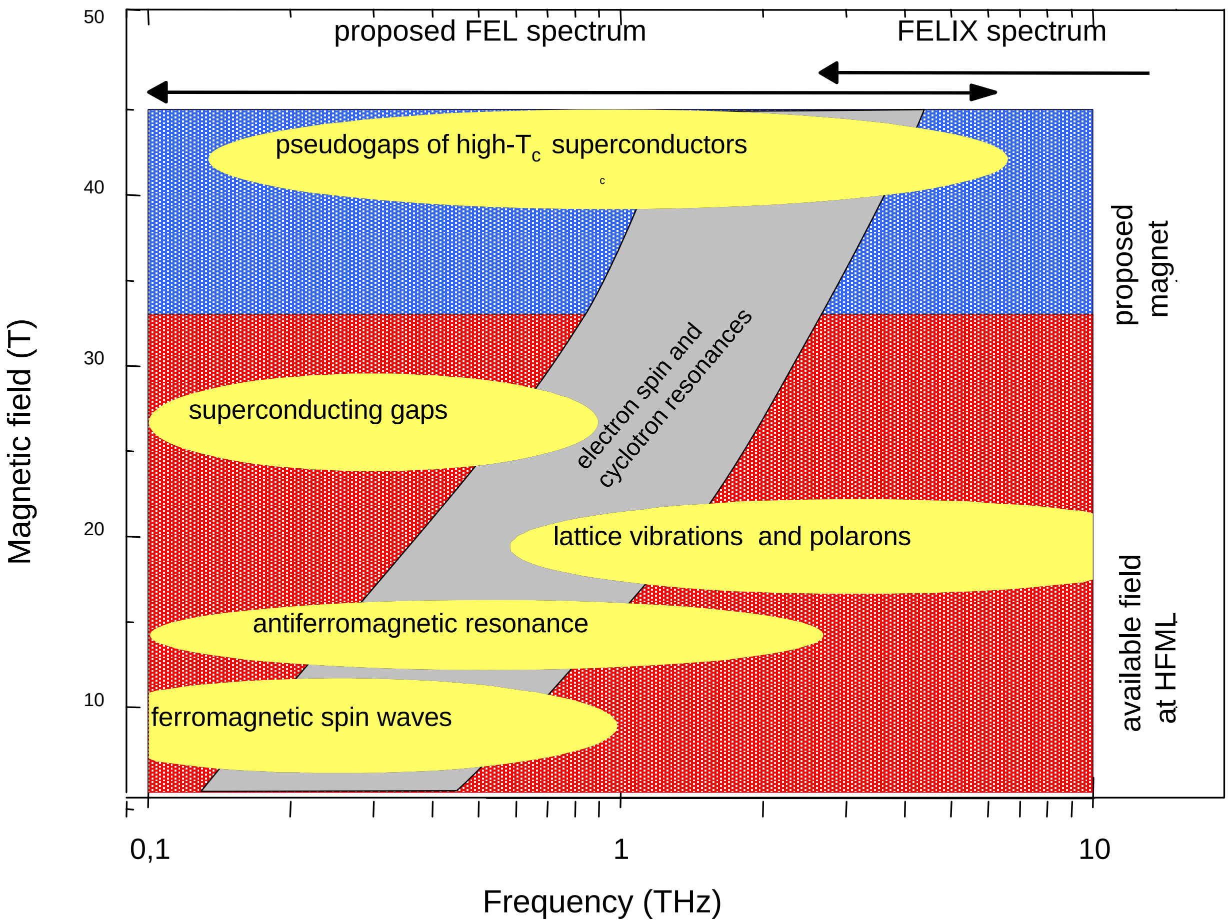
NMR by mechanical detection



$$F_z = M_z \frac{\partial B}{\partial z}$$

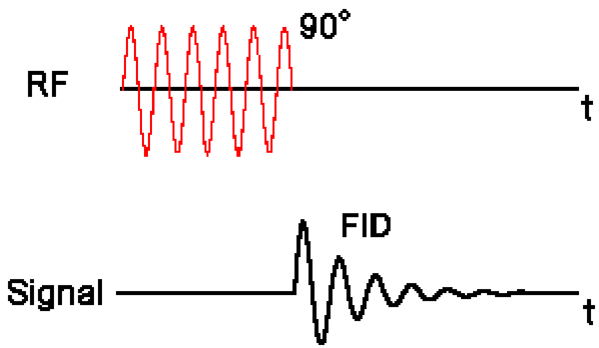


Elementary Excitations in Magnetic Fields

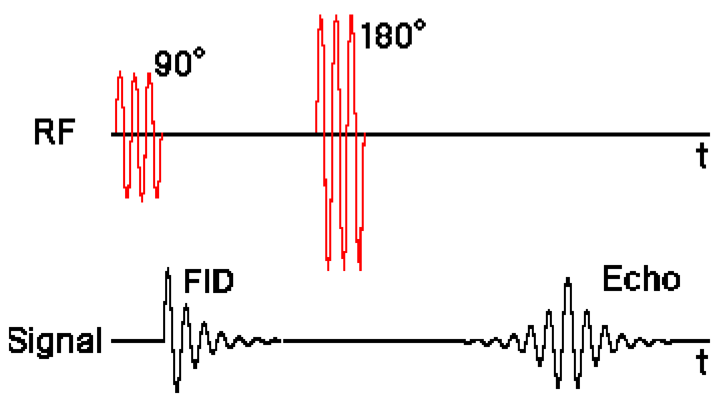


Science Drivers (I)

Probing Dynamic Interactions and Inhomogeneous Effects



(A) 90^0 pulse: implies full saturation of the transition: a challenge in the THz:
inducing a $\pi/2$ pulse
pulselength100 ns: 100 Watt
pulselength 50 ns: 400 Watt

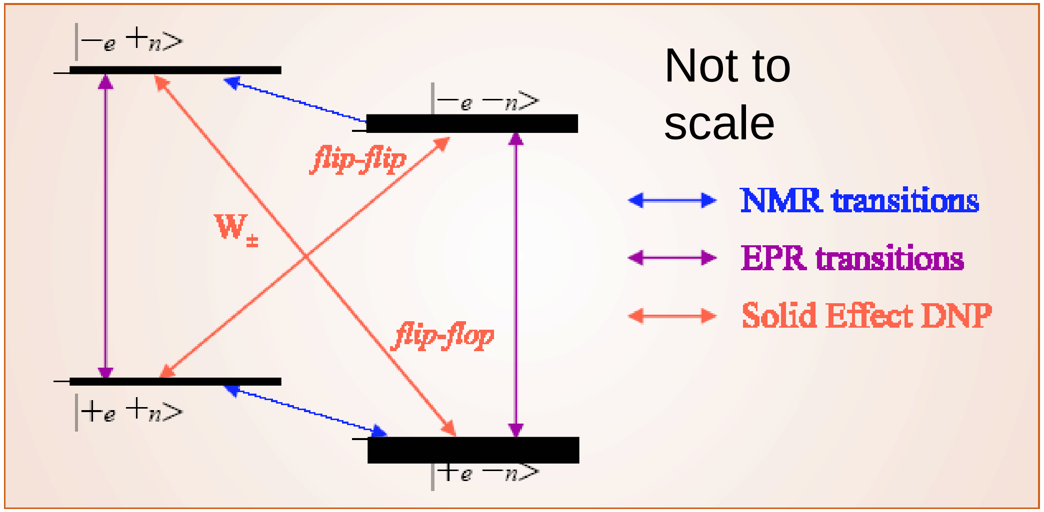


(B) Need for two pulses with variable time-seperation:
time-separation up to a few μs

(A+B) We need a continuous narrow bandwidth FIR pulse

Dynamic Nuclear Polarization:

Coupling of EPR-NMR: dragging as many nuclear spins as possible into a pure quantum state . . . . .



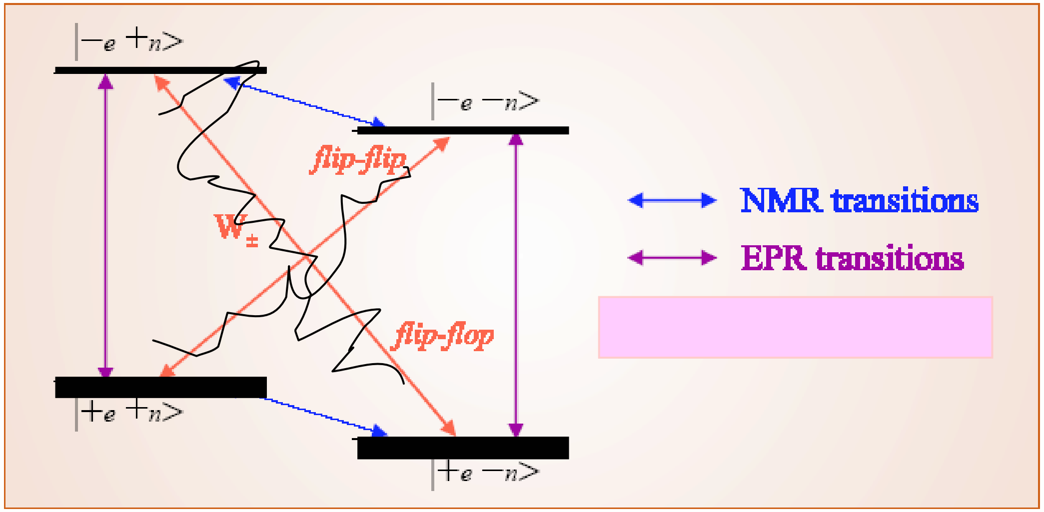
NMR science needs to meet two contradicting demands:

(a) (weak) coupling to help pull nuclear spin: INTENSE FIR!

(b) no-coupling during the (enhanced) NMR phase MORE INTENSE!

Dynamic Nuclear Polarization:

Coupling during collisions:
e.g. in Xe Hyperpolarization.

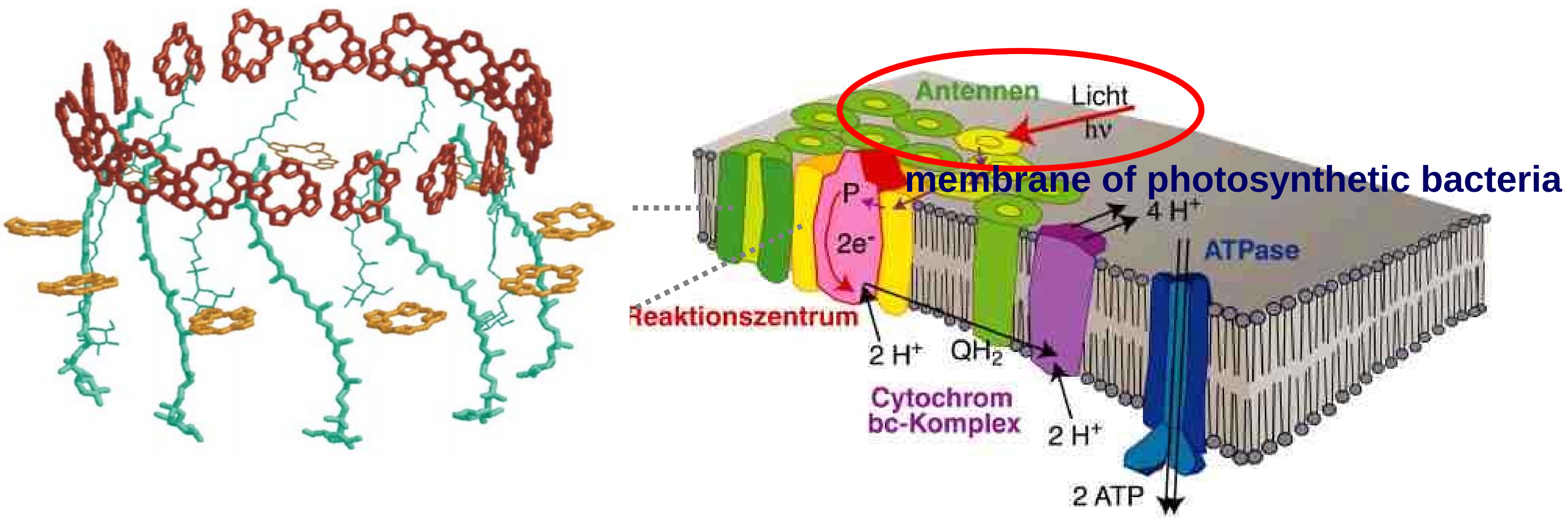


Off-Line Preparation Times of Hyperpolarized Samples are Minutes.

CW FIR NEEDED!?

Molecular Spectroscopy in the THz:
More than molecular recognition

From Electronic (UV) → IR (NH, NO, CH . = structure) → (to) FIR
(large scale motion or functionality)



Consequences of Nijmegen Users:

REQUESTED BUT IMPOSSIBLE:

- continuous wave to 20 picoseconds time-resolved pump-probe
- continuously tunable light source with a variable bandwidth ranging from 1.10^{-5} to Fourier limited at all pulse structures
- tunable power output up to 10 kWatt
- 100% duty cycle
- wavelength between 10 μm (30 THz) and 10 mm (0.03 THz)

FOR HIGH MAGNETIC FIELDS ONLY:

- quasi-continuous wave, tunable light source
- bandwidth down to 1.10^{-5}
- macro-pulses of length up to 10 μs
- (macro pulse) power of 1 kWatt
- high overall duty cycle

Compare: the USCB-FIR-FEL, Santa Barbara, and the Israeli FEL project, Tel Aviv).

Design Choices:

philosophy:

allowing (quasi) continuous wave operation with a narrow bandwidth as well as 20 picoseconds time-resolved pump-probe experiments, continuously tunable

design aim:

an RF Linac (1 to 1.3 GHz)

a linear cavity with an interferometer (Michelson / Fox-Smith) and 20-30 simultaneous optical pulses

Output:

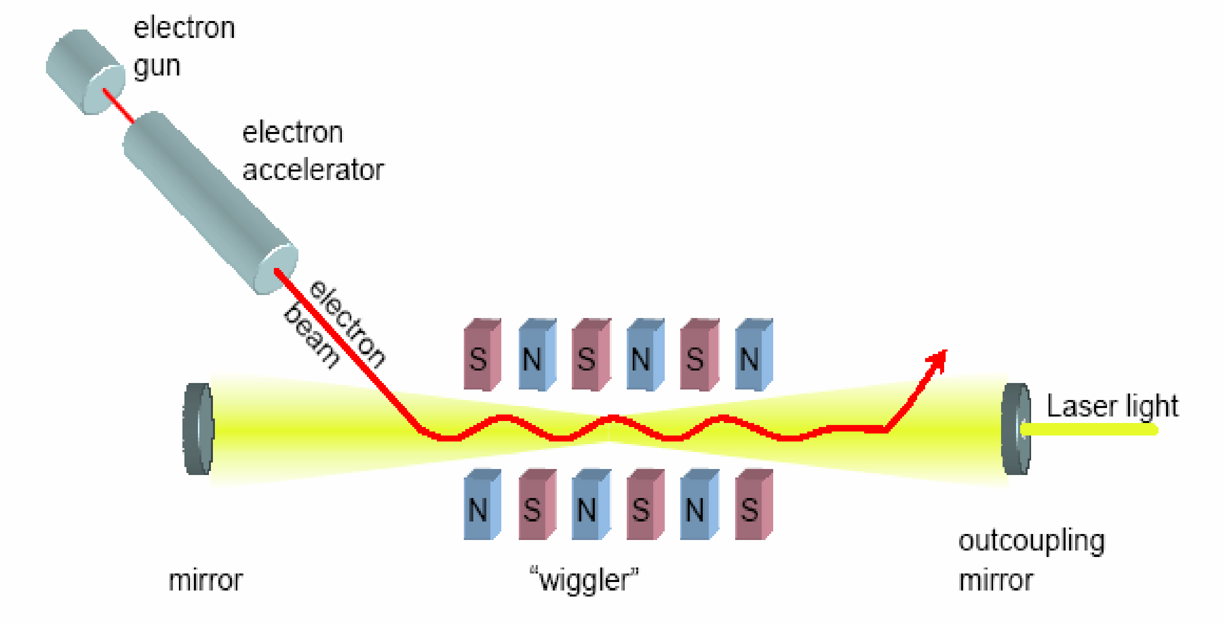
quasi CW-output after post-cavity filtering, 100 Watt

or

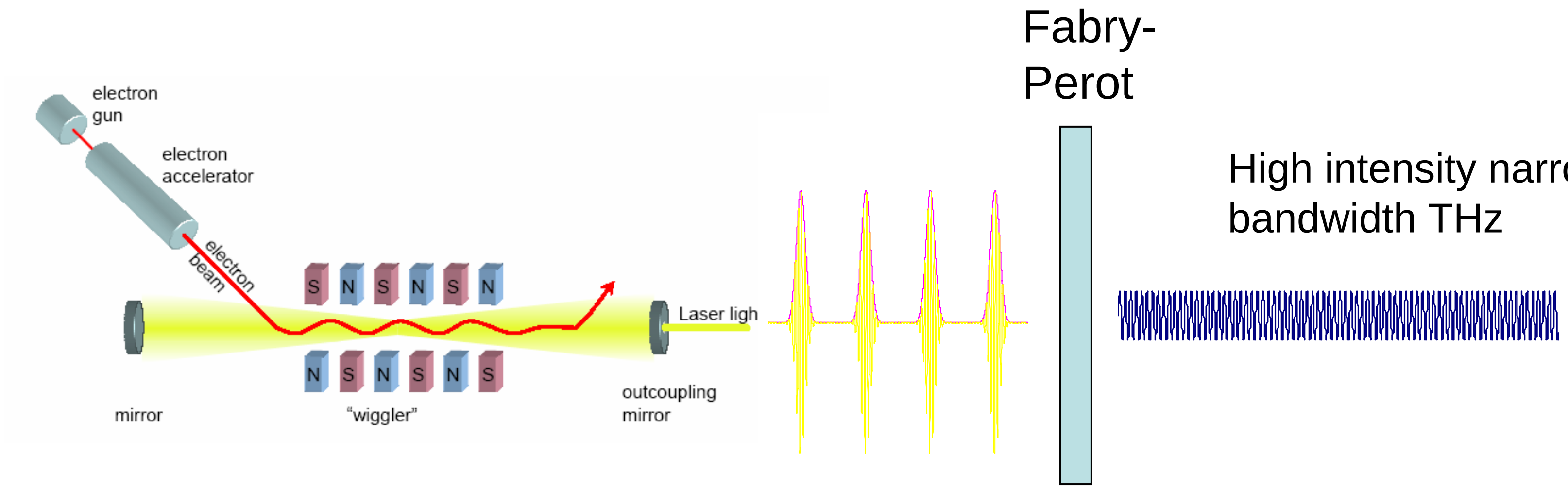
micro-pulses (20-50 psec pulses, 10 kWatt during the 10 μs macro-pulse).

Wavelength: from 100 μm (3 THz) to 1.5 mm (200 GHz).

The THz FEL- Operation



The Narrow Band THz FEL- Operational Principle

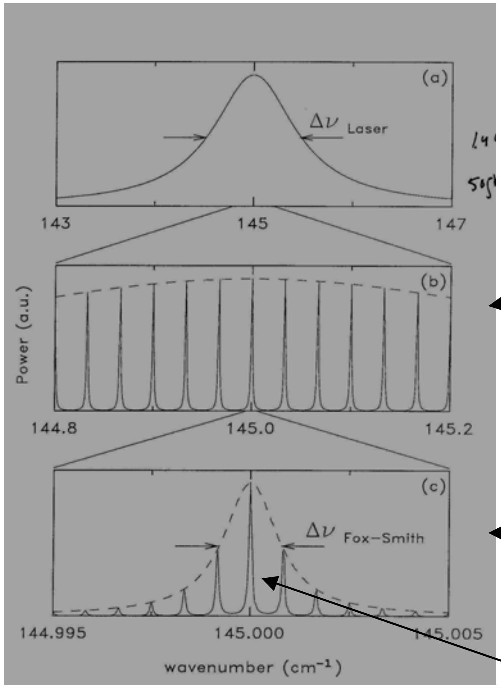


power: MW during picoseconds

power: 100 W during microseconds

Oepts and Colson *(1990)*, Bakker, Oepts, Van der Meer *et al. (1993),* Oepts, Weits, Van der Meer *et al.* (*1996-1998*), Szarmes, and Madey (*1993*), Israeli Project (2005) and others . .

Generation of Phase-Locked Pulses (FELIX, 1990-1999)



Bandwidth of single micro-pulse (2.5 cm^{-1})

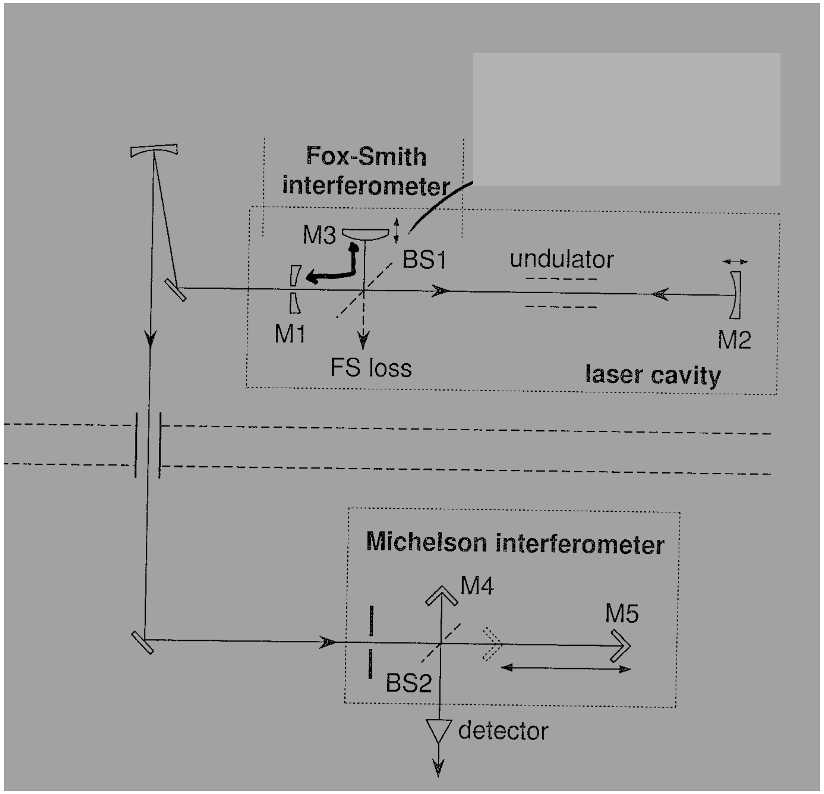
After phase locking of the micro-pulses (☺ and ☹ (spontaneous coherence)

Bandwidth (=quality of phase coupling) of Fox-Smith about 0.0015 cm^{-1}

Ideal: external filtering of single longitudinal cavity mode (0.0002cm^{-1} or BWL macro-pulse)

Experiment at 69 nm

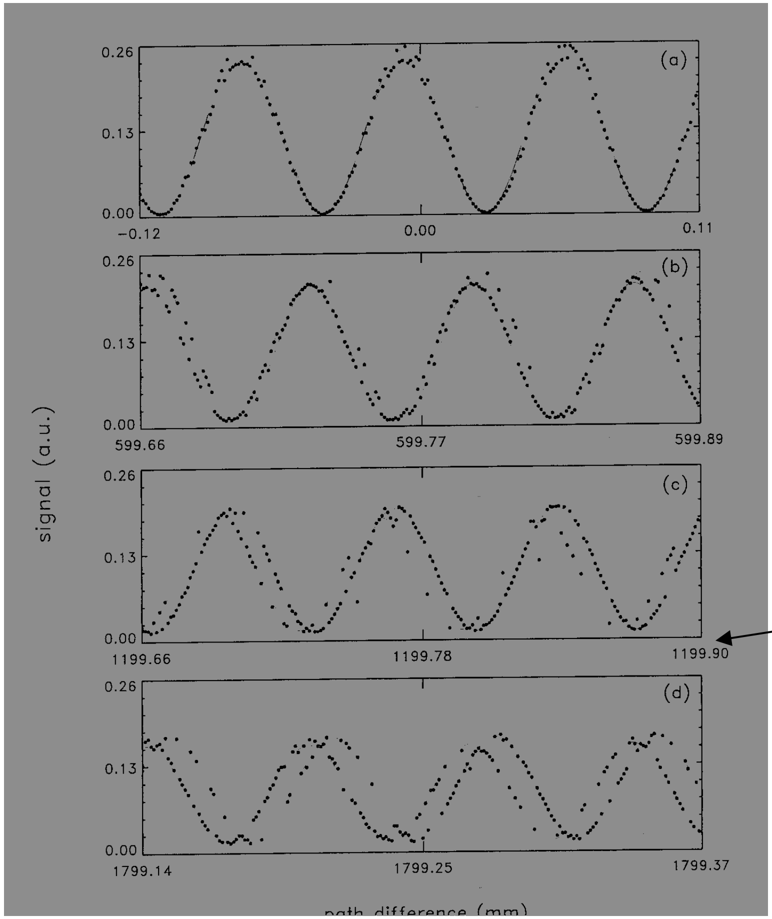
Generation of Phase-Locked Pulses (FELIX, 1990-1999)



Fox-Smith: inserting path differences (= multiples of the micro-pulse distance)

Michelson: Measuring the inter-pulse coherence

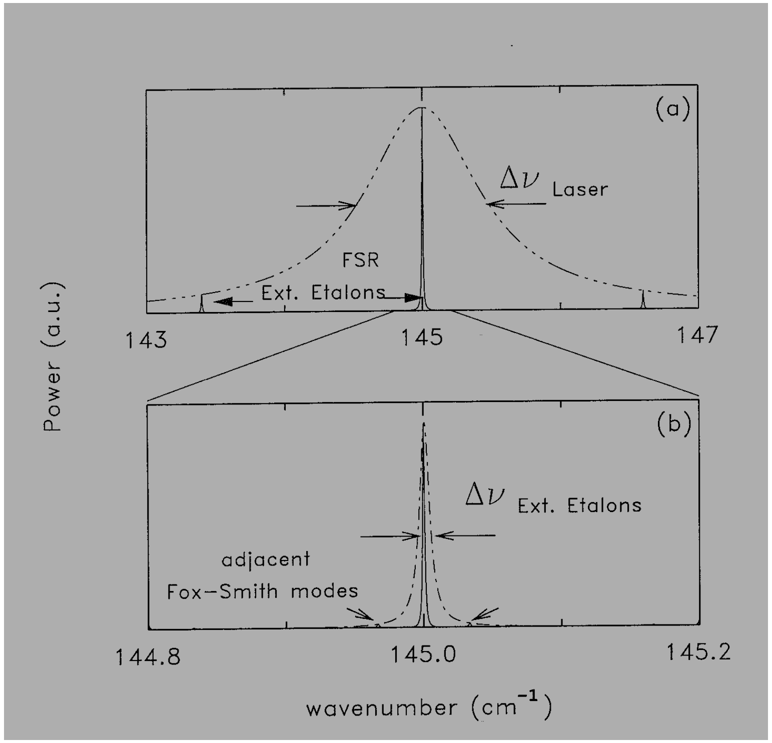
Results from Weits *et al.*:



Interferogram:

Up to 1.8 meter path difference in analysing Michelson!

External Selection with Fabry-Perot Etalons:



Study Themes:

- optimal design for intracavity phase locking between 100 μm and 1.5 mm
- controlling the spontaneous coherence and interferometer induced coherence
- material research on low-loss optics and frequency filters
- maximizing duty cycle

Planning:

- January 2008: detailed plan for hybrid, FEL and Building
- 2008- 2010: construction and commissioning

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Meerts (Mol Spectroscopy)

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