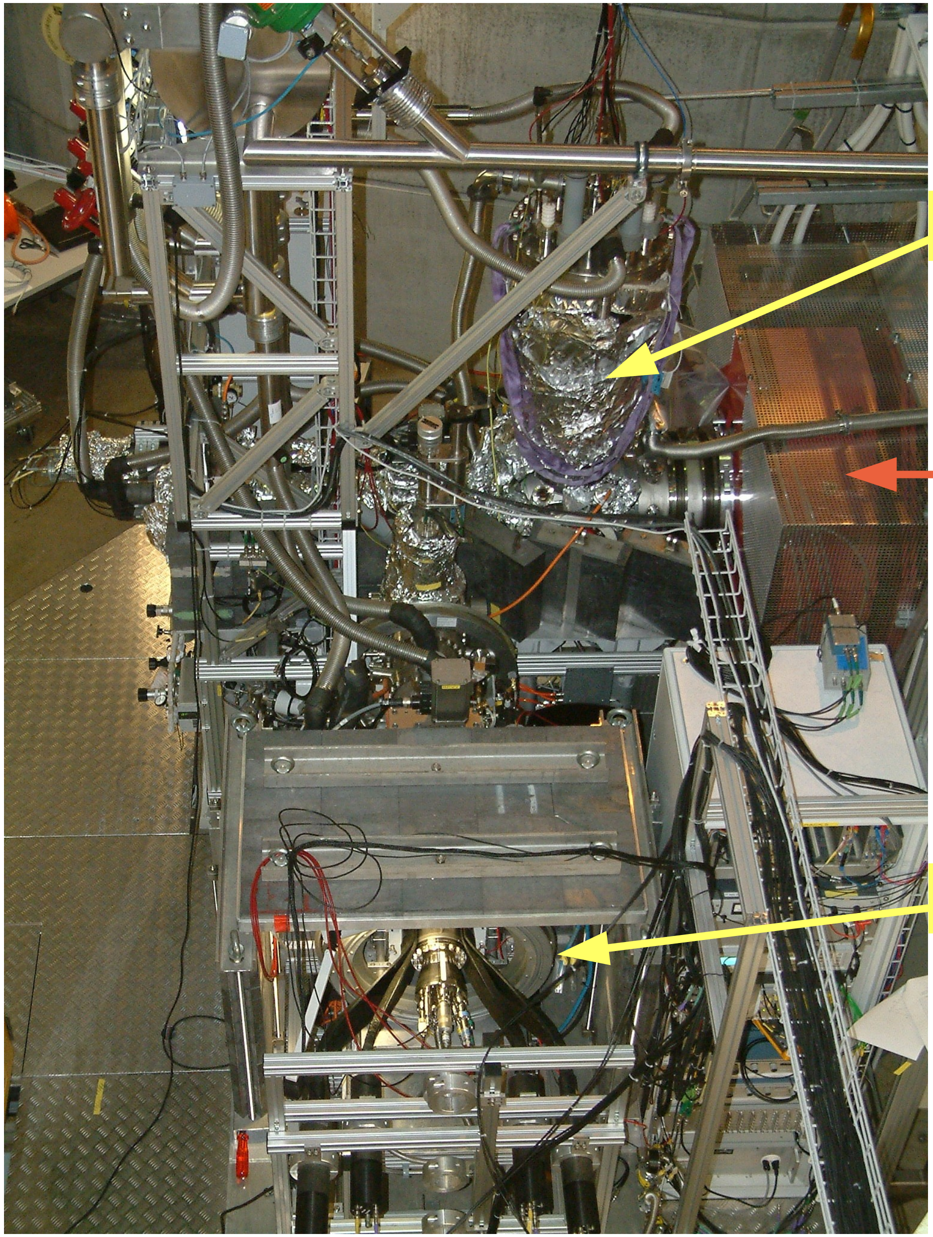
Paul Scherrer Institut

Thomas Prokscha, Laboratory for Muon Spin Spectroscopy

LEM sample environment/spectrometers at PSI

KEK-TRIUMF workshop on Ultra Slow Muons, March 8/9 2012

LE-μ^+ beam and LE-μSR spectrometer



Moderator cryostat

QSM612, last quadrupole of μE4 beam

LE-μSR spectrometer

LEM sample environment, spectrometers

Cryostats (^{4}He) (2.3 – 320 K):
4 Konti He-flow cryostats, 4 – 320 K (Cryovac, Germany; sample setup PSI)

Konti-1: development, special experiments (current injection (1 nA – 1 mA), illumination, in-situ resistance measurements)
Konti-3: development, special experiments (flight-path tests, applying electric fields)
Konti-2/4: for normal user operation; 2 cryostats for faster sample change

LowTemp cryostat, 2.7 – 300 K (normal setup), 2.3 – 300 K (sample on sapphire) (in-house development together with Univ. Birmingham)

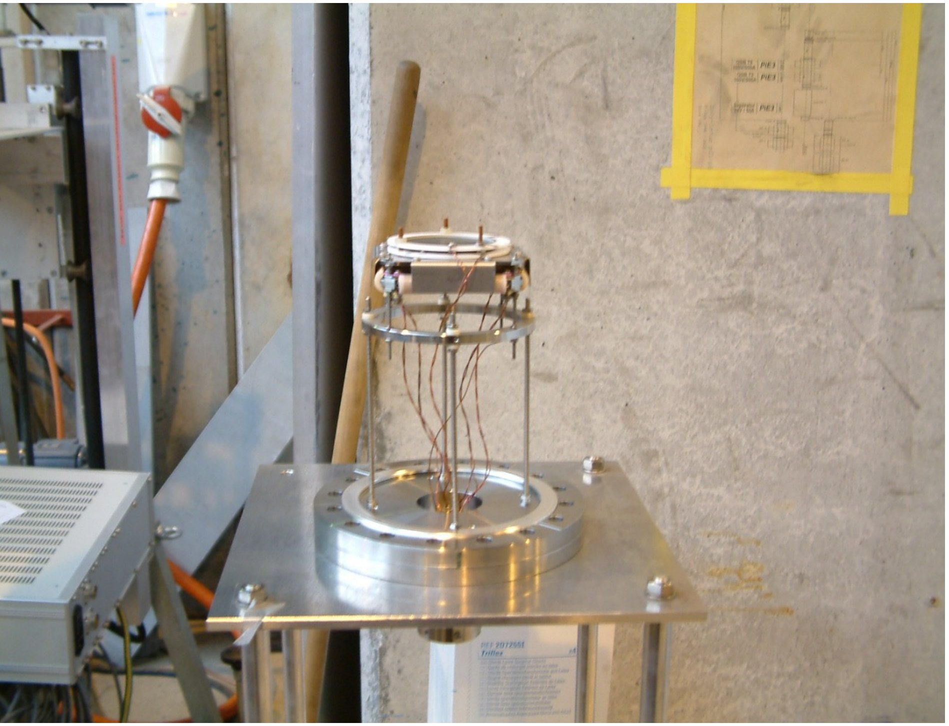
Furnace (RT – 150 ^{o}C):
under development; +-10 kV at sample possible at 150 ^{o}C (higher T without HV)

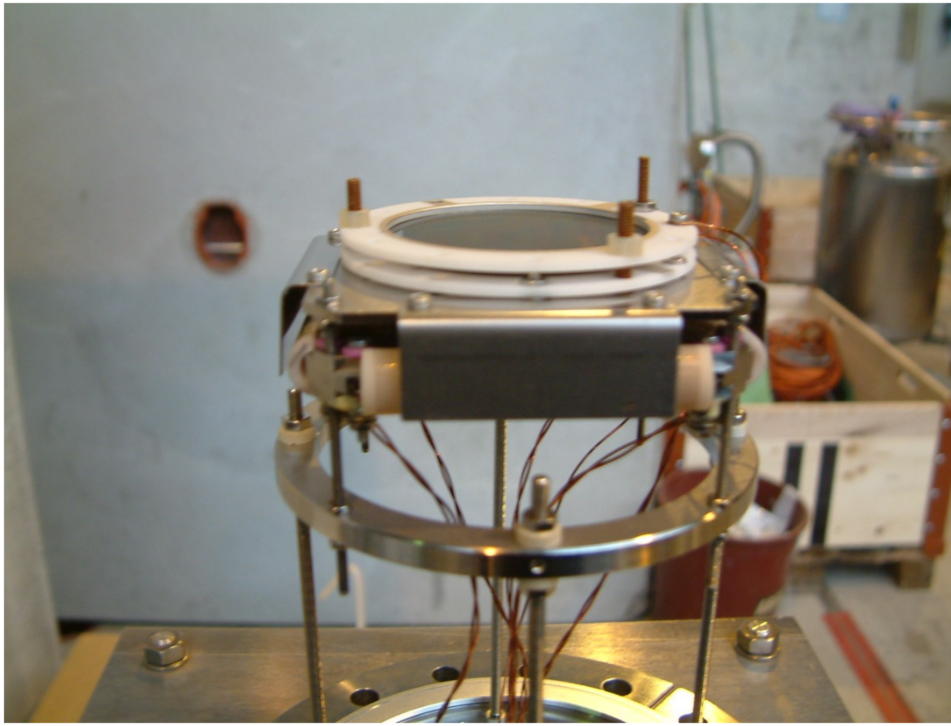
Magnets/Spectrometer (0 – 0.32 T):
WEW: B perpendicular to sample surface/parallel to beam: 0 – 0.32 T (0 – 550 A)
B-parallel: B parallel to sample surface/perpendicular to beam: 0 – 0.03 T (0 – 9 A)

LEM spin-rotator (+- 90 degree spin rotation):
For LF-μSR, separation of protons/ions from muons; commissioning started in 02/12

Position sensitive MCP detector

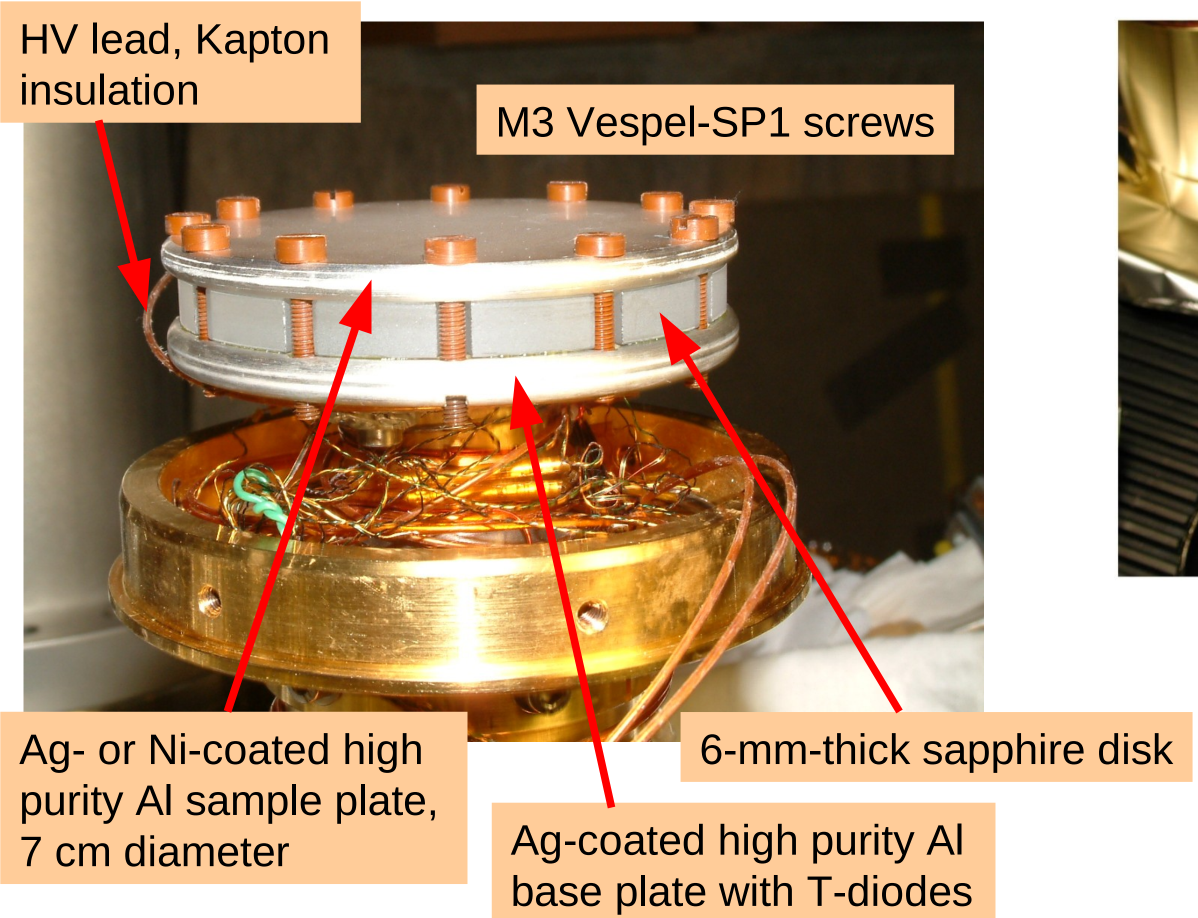
Measure beam spot at sample position; time-of-flight between start detector ["Trigger Detector (TD)"] and sample to determine energy loss in TD and t_0

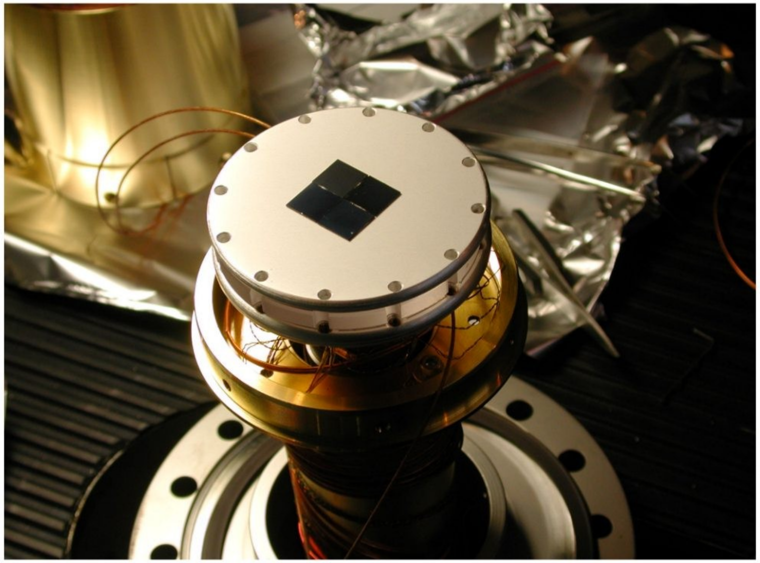


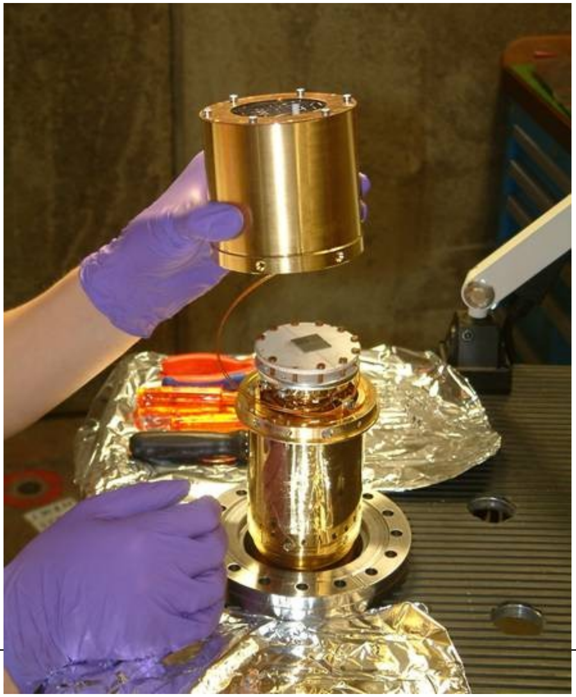


MCP detector (40 mm active area) with delay-line anode readout for x-y position information (RoentDek, Germany); position resolution < 0.1 mm.

Sample setup on Konti and LowTemp cryostats

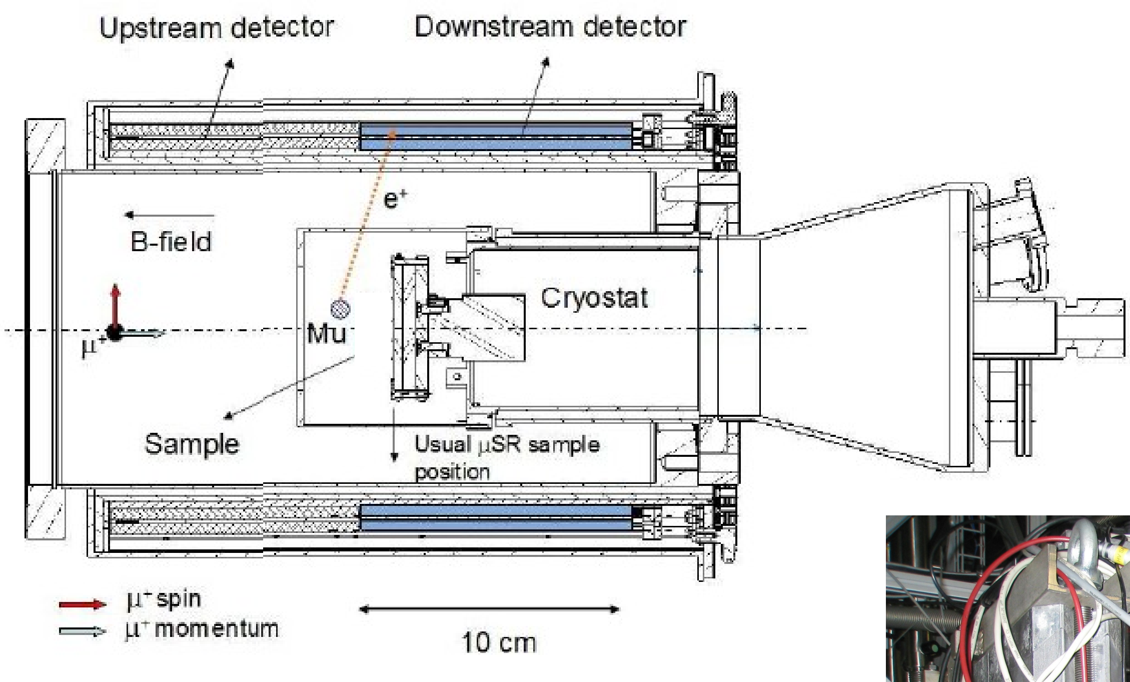


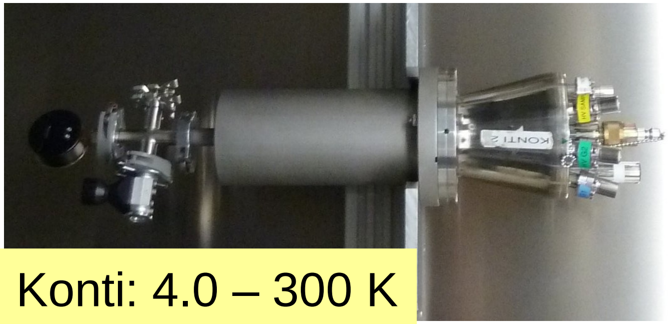




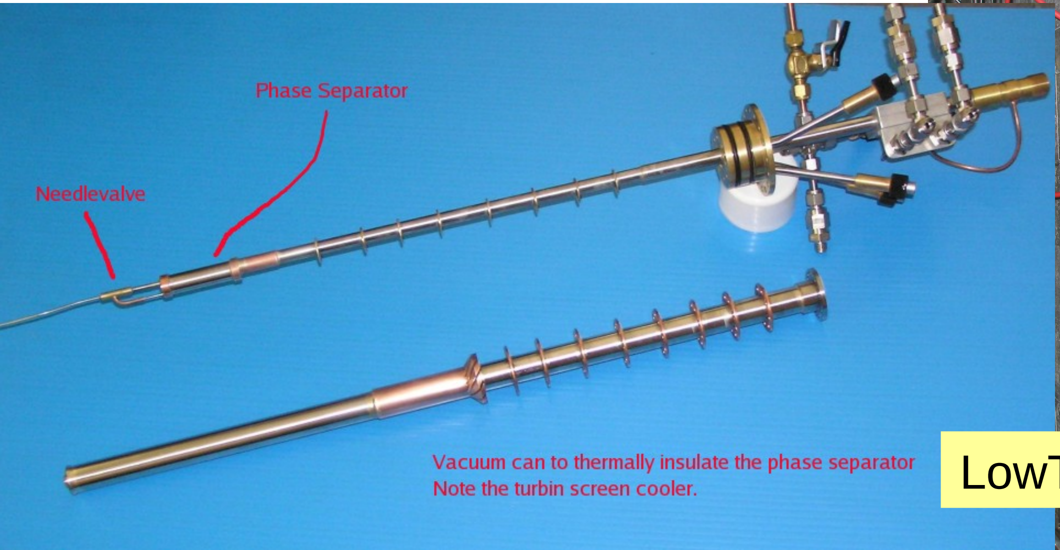
Sample plate can be biased up to +-12.5 kV to adjust the muon implantation energy

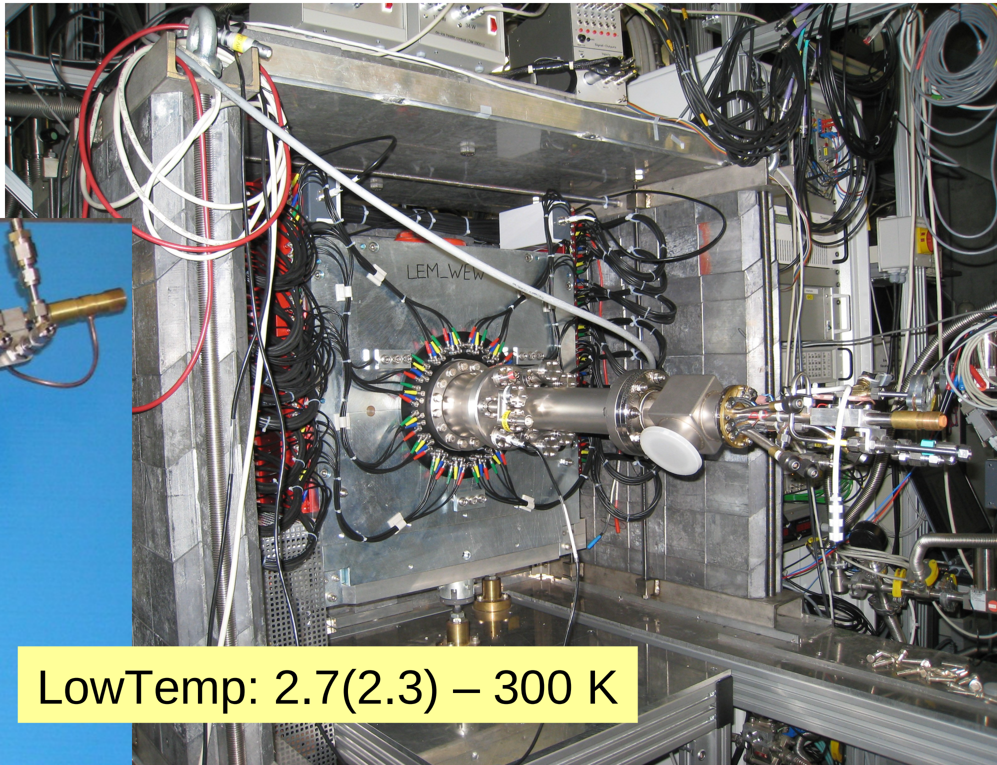
UHV Konti and LowTemp cryostats





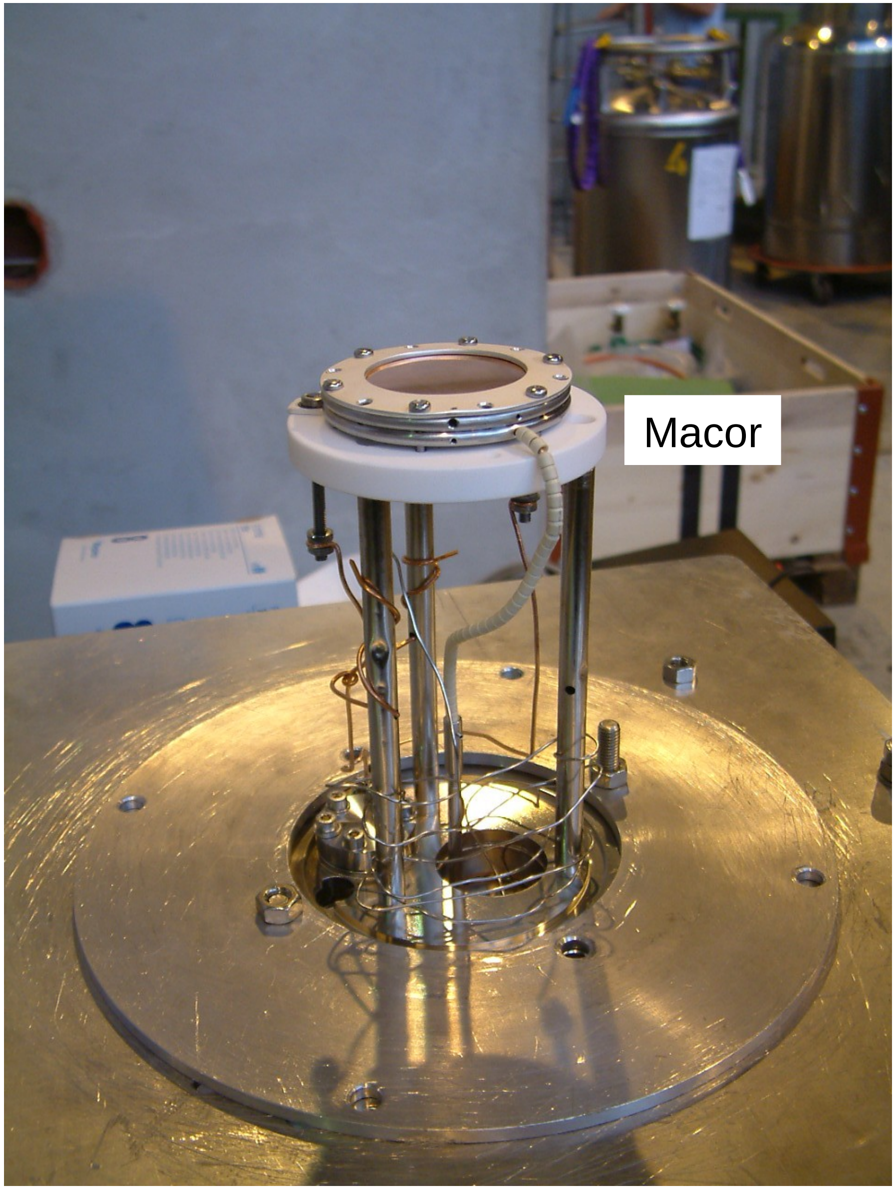
Konti: 4.0 – 300 K

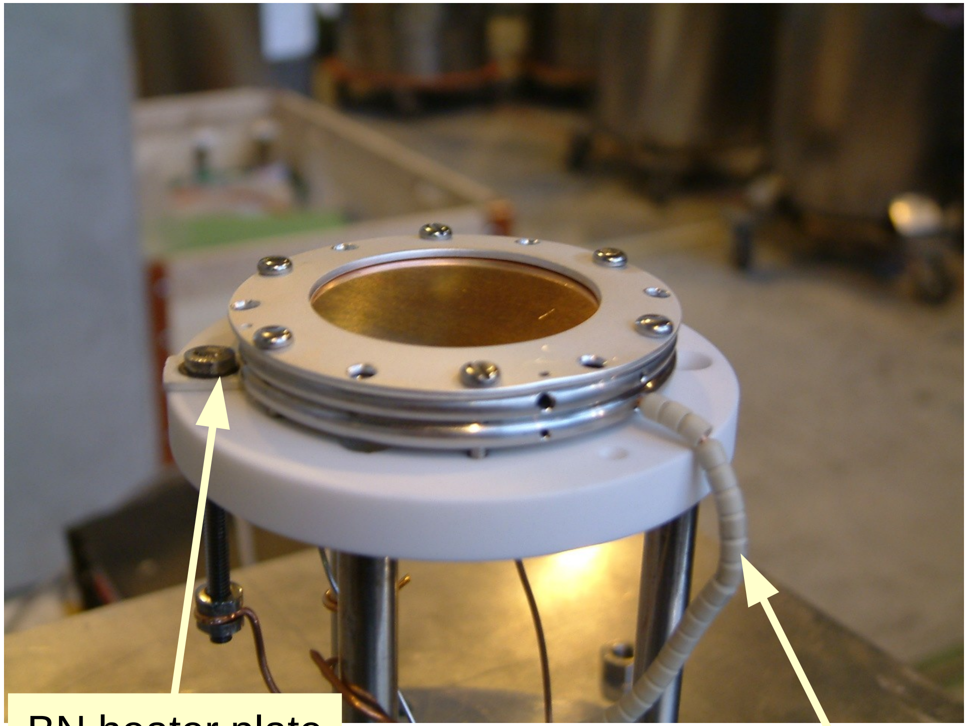




LowTemp: 2.7(2.3) – 300 K

Furnace setup (currently dismantled)





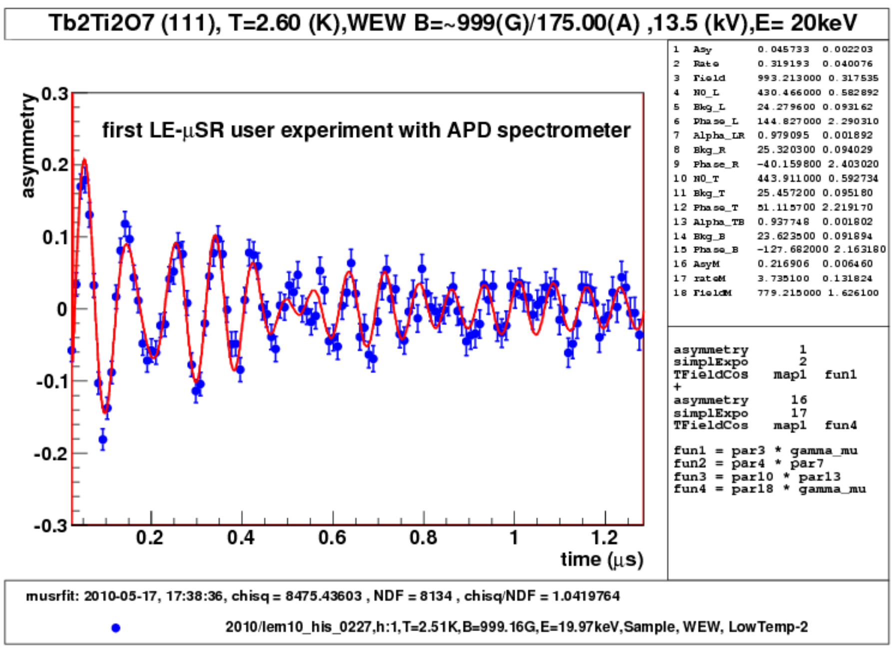
No active cooling/temperature regulation

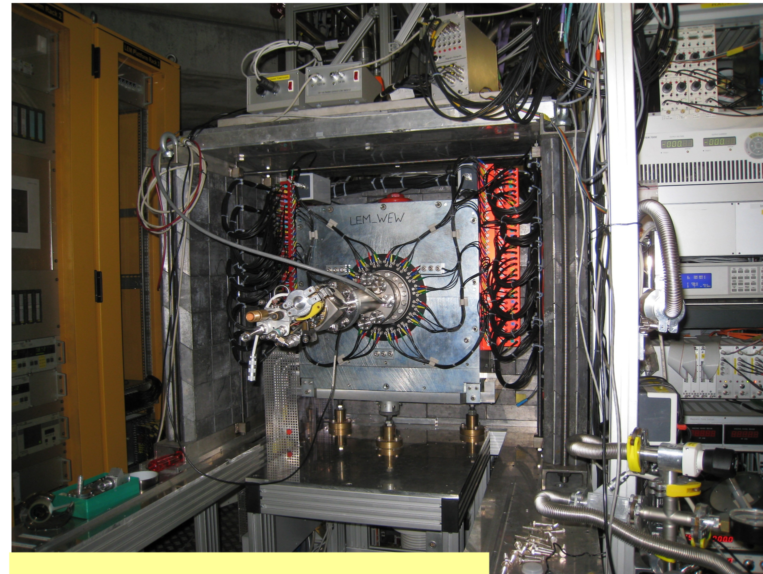
RT – 150 °C with +-10 kV at sample
T > 150 °C without high voltage

WEW magnet with APD positron spectrometer

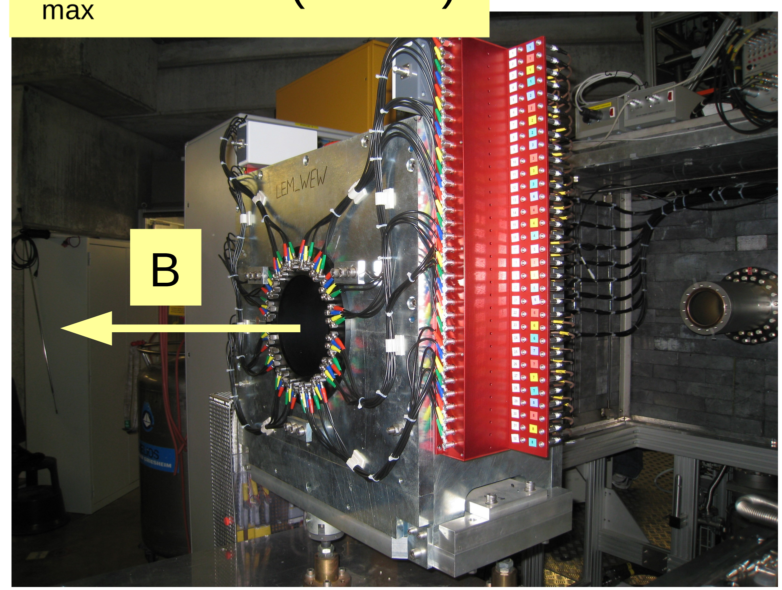
Spin-off of APD/scintillator developments for the 5 T ALC and the new 9.5 T high-field μSR spectrometers

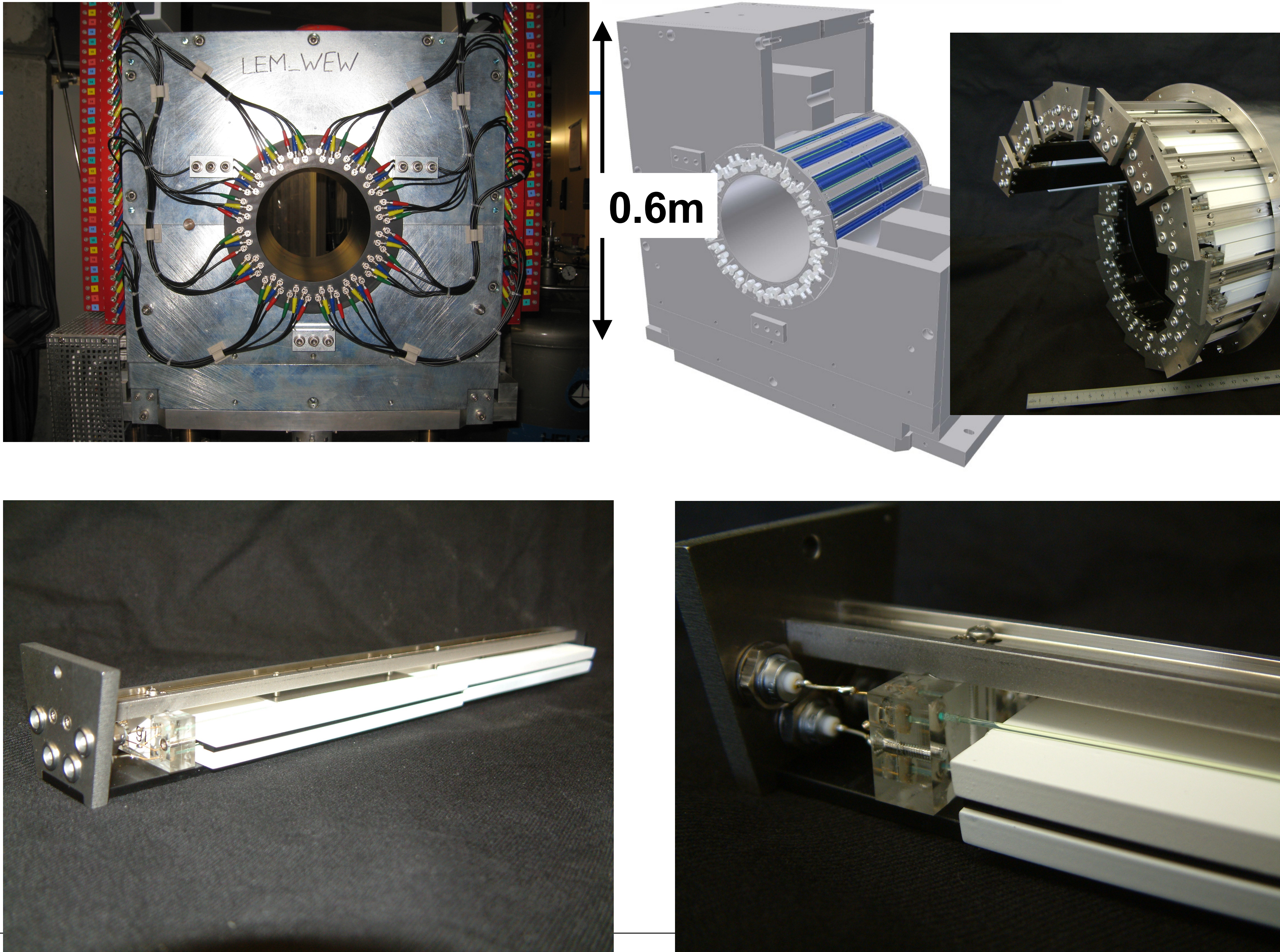
APD: green sensitive SSPM_0810G1MM by Photonique
Sensor area: 1.1 mm^2
Operating voltage: 30 – 36 V
Gain: $0.5 \cdot 10^6$
Single photon detection efficiency: 35/41 % (at λ = 520/630 nm)
Temperature coefficient: ~1% per ^{o}C
Scintillators: BC-400
Wavelength shifiting fibres: BCF-92



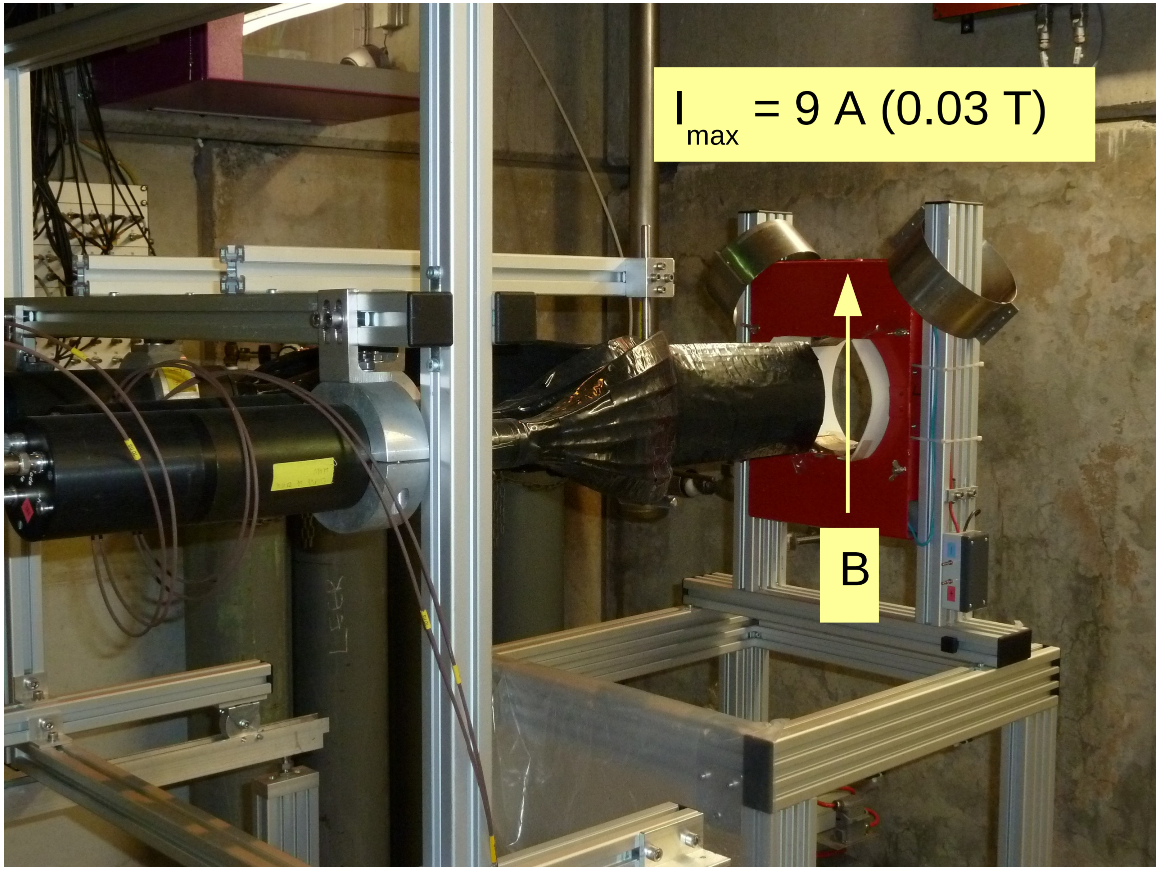


I_{max} = 550 A (0.32 T)




LEM_WEW
0.6m

B-parallel magnet with PM positron spectrometer



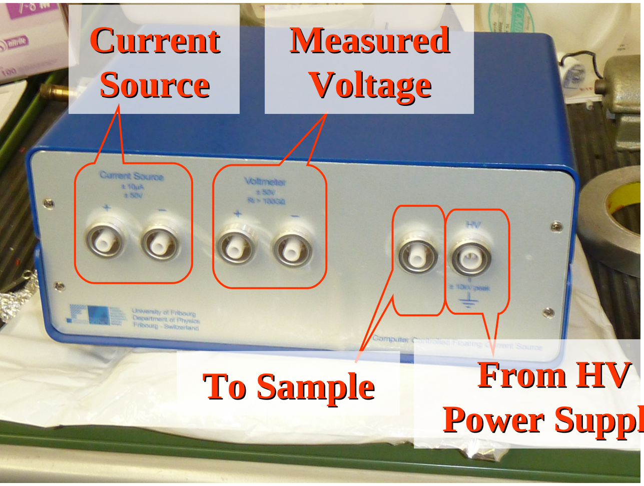
Air-cooled coils

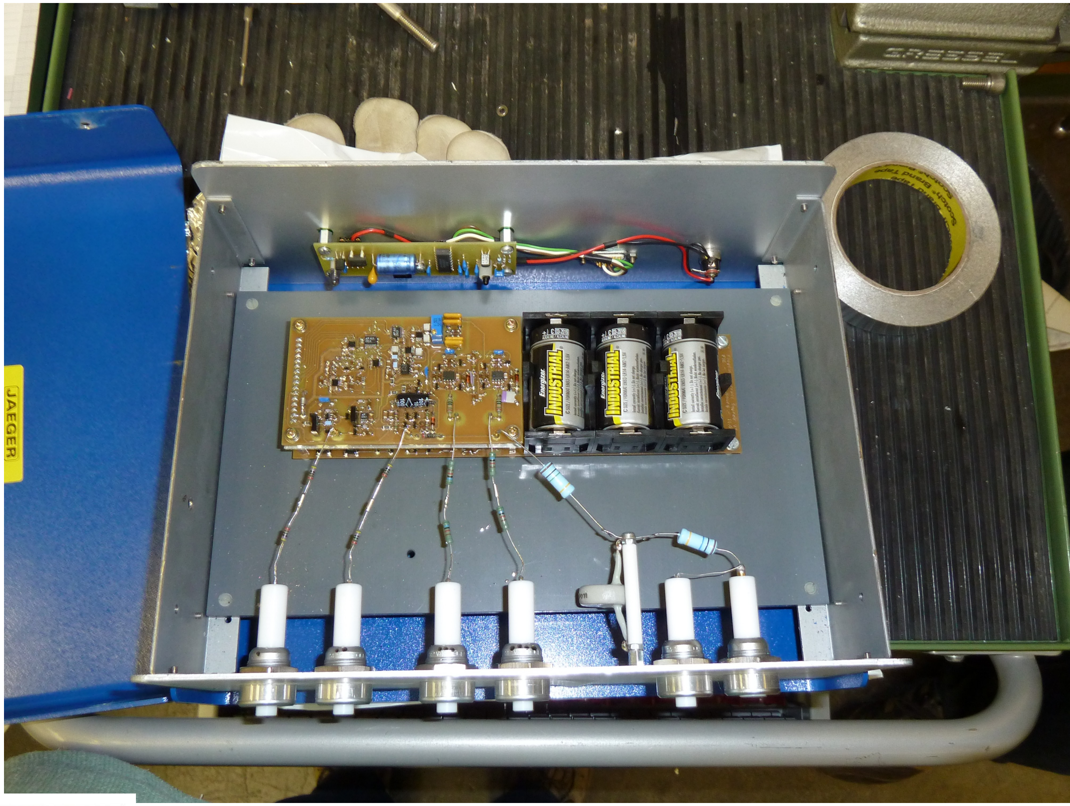
XP2020 photomultiplier

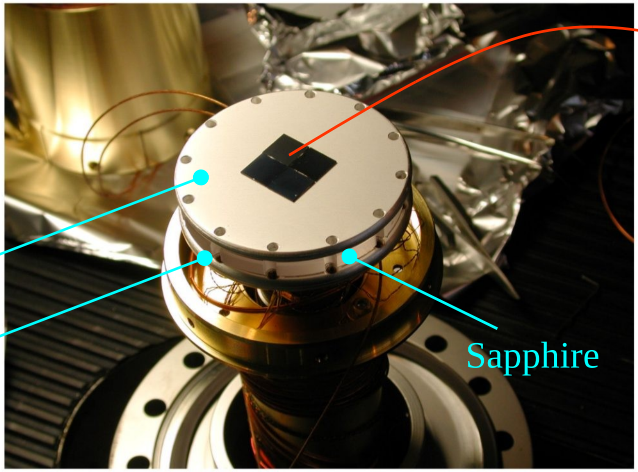
BC-400 large area scintillators (annular "90^o", 26 cm long)

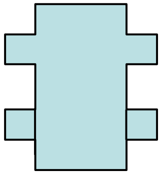
Solid angle: 50% of WEW

Floating Ohm Meter (FOM), Univ. Fribourg/PSI





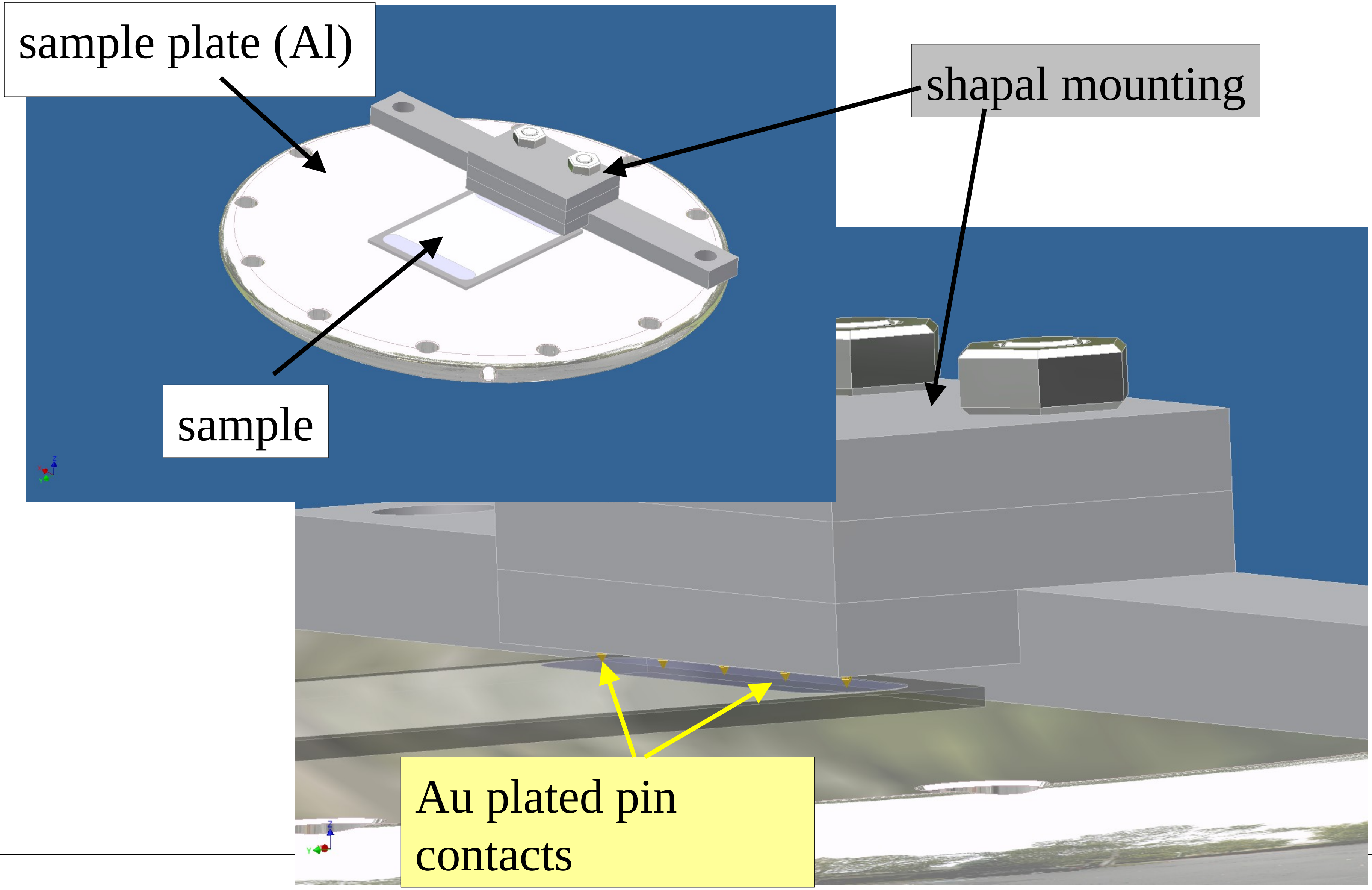




High Voltage Range:	± 12kV
Current Range:	± 1.0mA
Current Resolution:	1nA
Measurable Voltage Range:	± 50V

Setup for applying electric fields

floating pin contact holder (up to +-12 kV, or current injection without biasing):

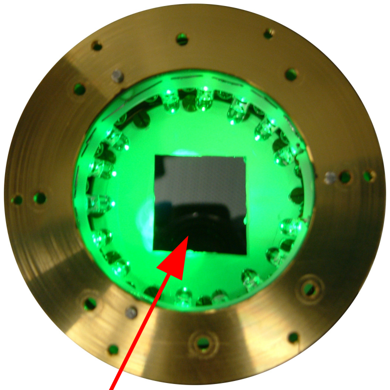


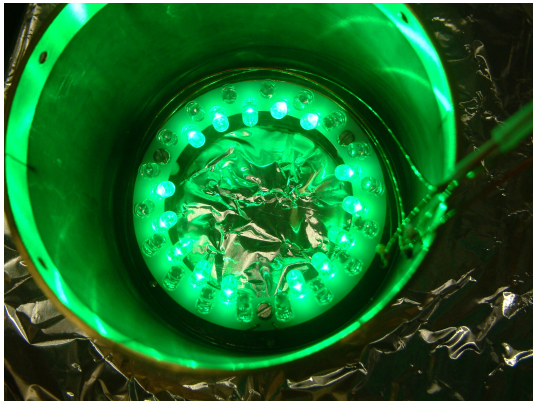
Setup for illumination

InGaN green, λ=525(39nm), 30mA/3.3V,
2Θ1/2= 20°,Kingbright L-7113VGC-Z

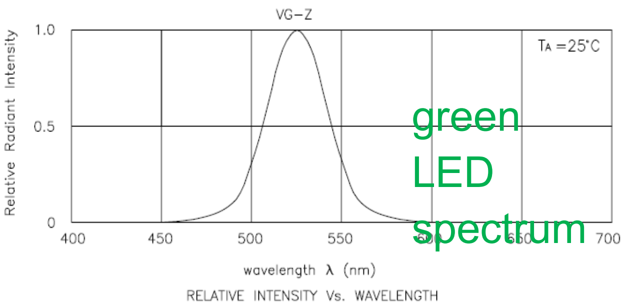
InGaN white λ_{peak}=460,560 nm, 30mA/3.3V
2Θ1/2= 30°,Avago HLMP-CW36-UX00

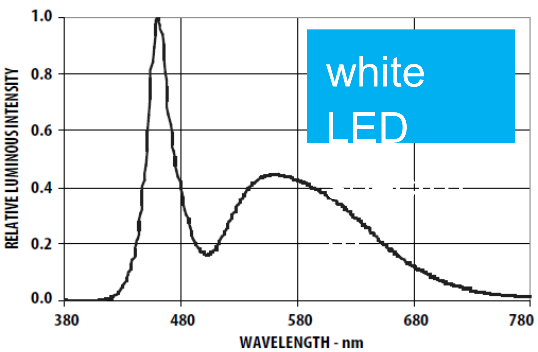
GaN blue, λ=470(25) nm, 30mA/3.3V,
2Θ1/2= 16°,Kingbright L-7113QBC-D

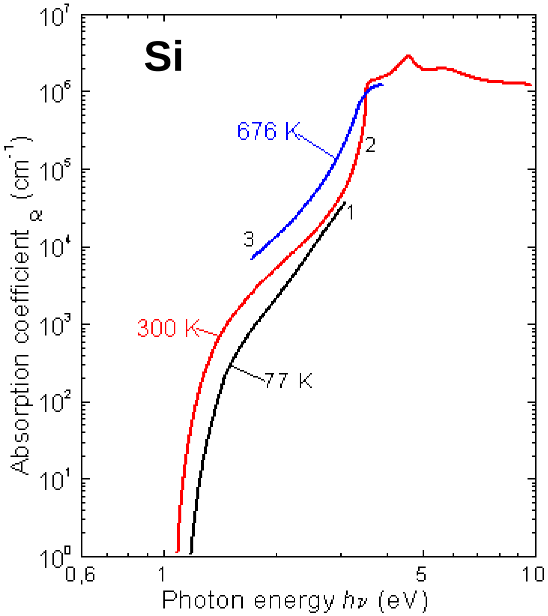


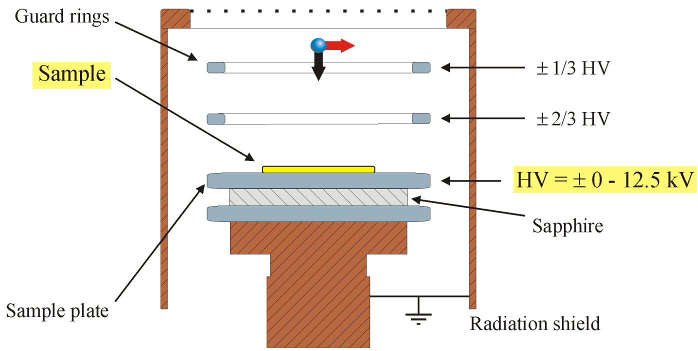


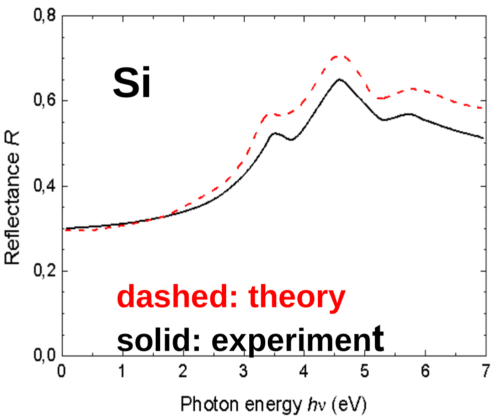
Undoped Si (100), 3x3 cm^2











http://www.ioffe.ru/SVA/NSM/Semicond/Si/index.htm

How many charge carriers can be generated?

Estimate of charge carrier density n_{eh} in Si at 30 mA LED current, 33 LEDs.

Measured intensity I = 10 mW/cm²: n_γ =2.6 10^{16} γ/cm²s

$$n_{eh} \sim (1\text{-}R)\ \alpha\ n_\gamma \tau = 0.65\ 10^4/\mathrm{cm}\ 2.6\ 10^{16}\ \gamma/\mathrm{cm}^2\mathrm{s}\ 2\mu\mathrm{s} \approx 3.5\ 10^{14}/\mathrm{cm}^3$$

R: reflectivity of Si at 525 nm (2.36 eV, green LED)
α: absorption coefficient of Si at 2.36 eV
τ: charge carrier lifetime in Si including surface recombination [D. Klein et al., physica status solidi (b) 245 (2008) 1865.]

With I = 10 mW/cm², green LEDs, steady state n_{eh} tunable in Si up to ≈ 10^{15}/cm3

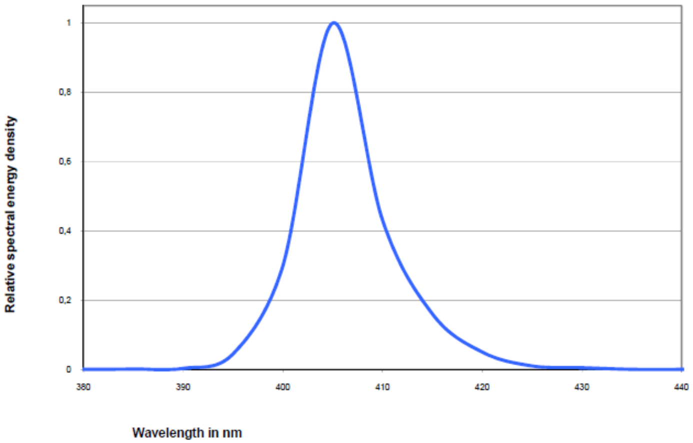
In Ge, α is ~50 times larger: n_{eh} is of order 10^{16}/cm³

New LED setup for illumination

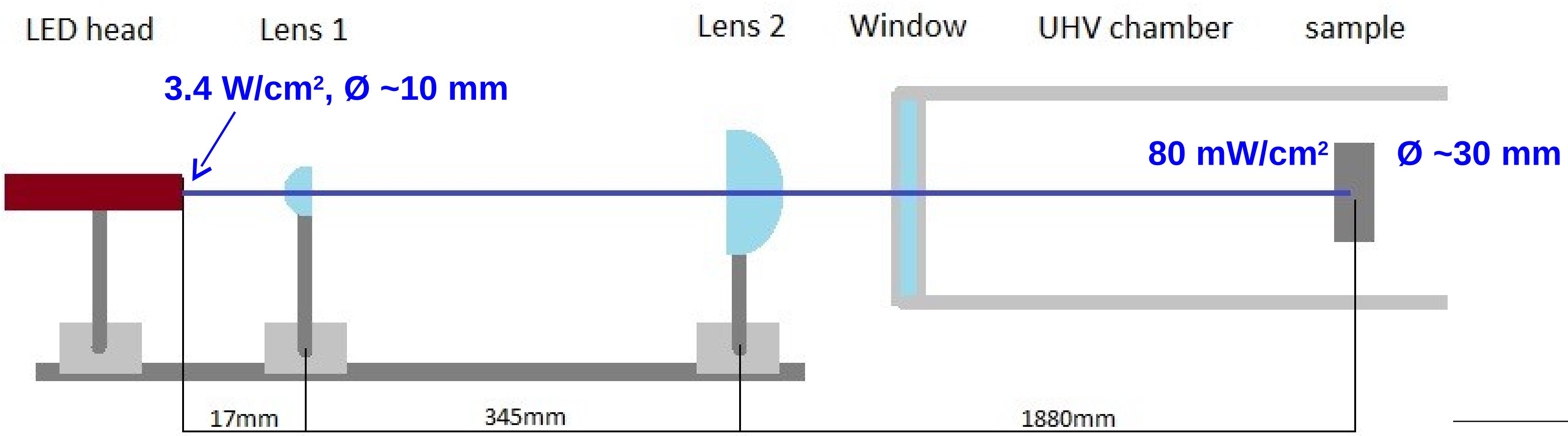
LED Head 400 nm

Peak wavelength	400 nm +/- 10 nm
Spectral width (FWHM)	approx. 9 nm
Focus distance	approx. 6 mm

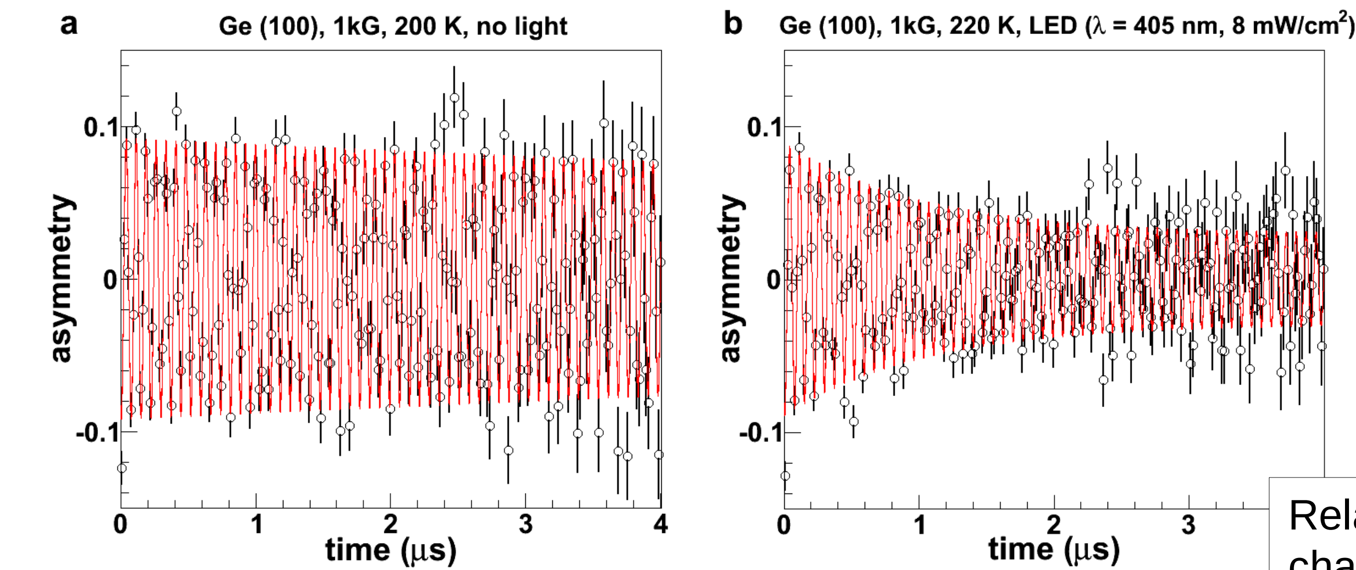
Spectral distribution 400 nm



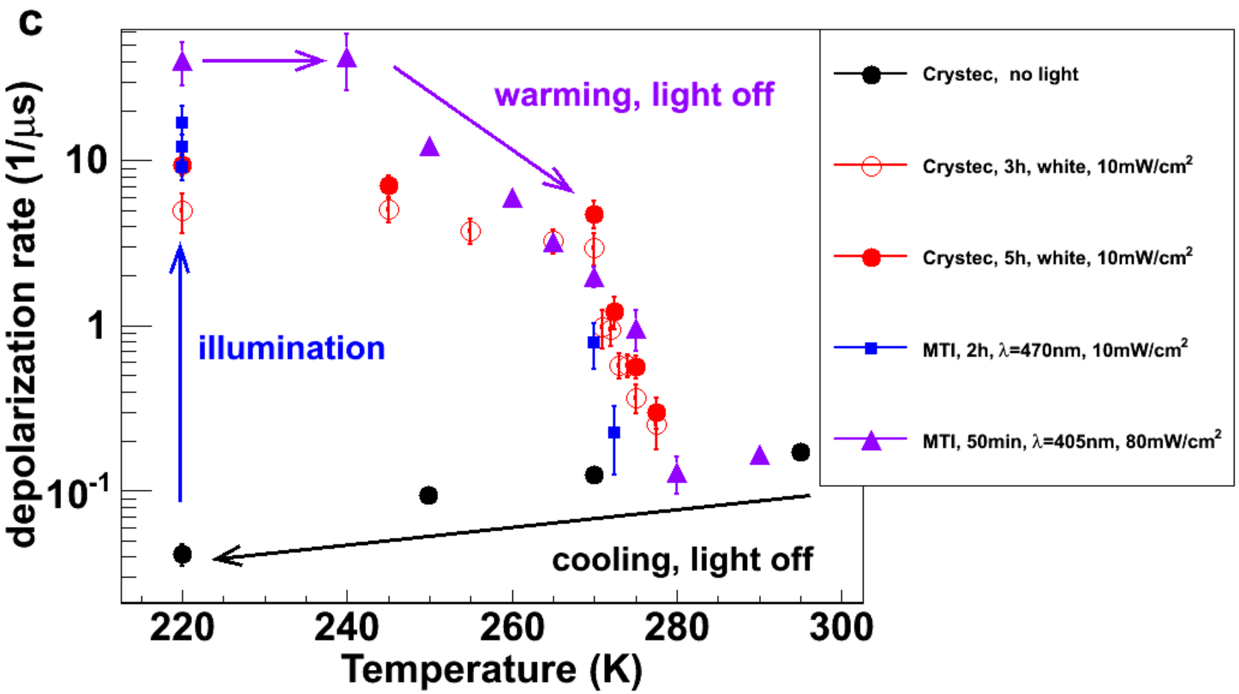
Intensities at ~85% of max. LED power
80 mW/cm^2 at 405 nm = 1.6 10^{17} γ/cm^{2}s



Persistent photo-induced inversion of Ge



Commercial Ge (100), nominally undoped, n-type (~10^{14}/cm^3)



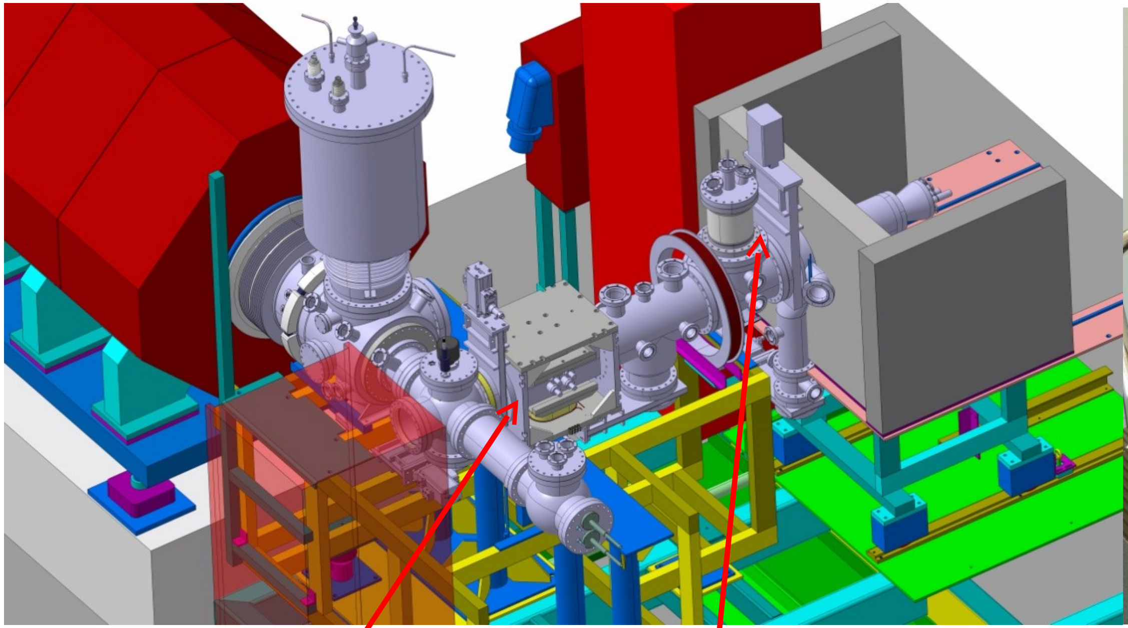
Relaxation due to charge changing collisions:

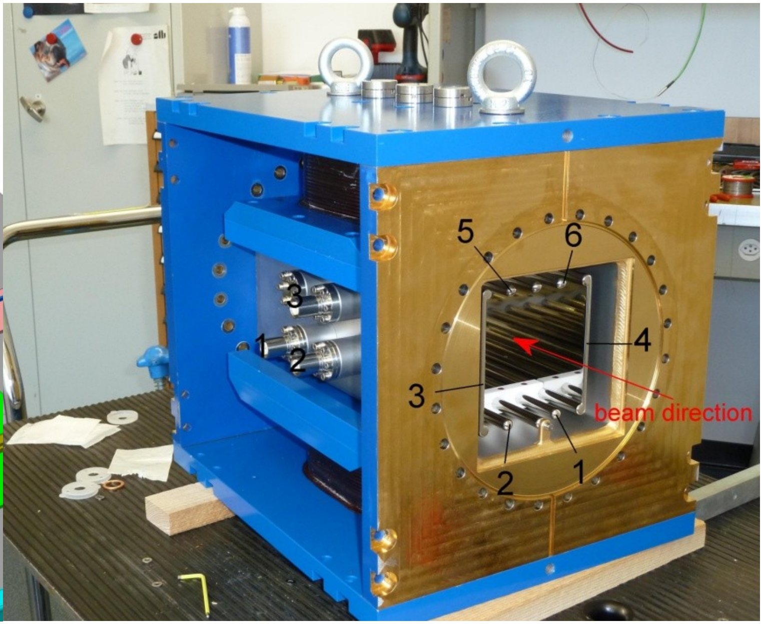
$$\mathbf{Mu^- + h^+ \text{--->} Mu^0}$$

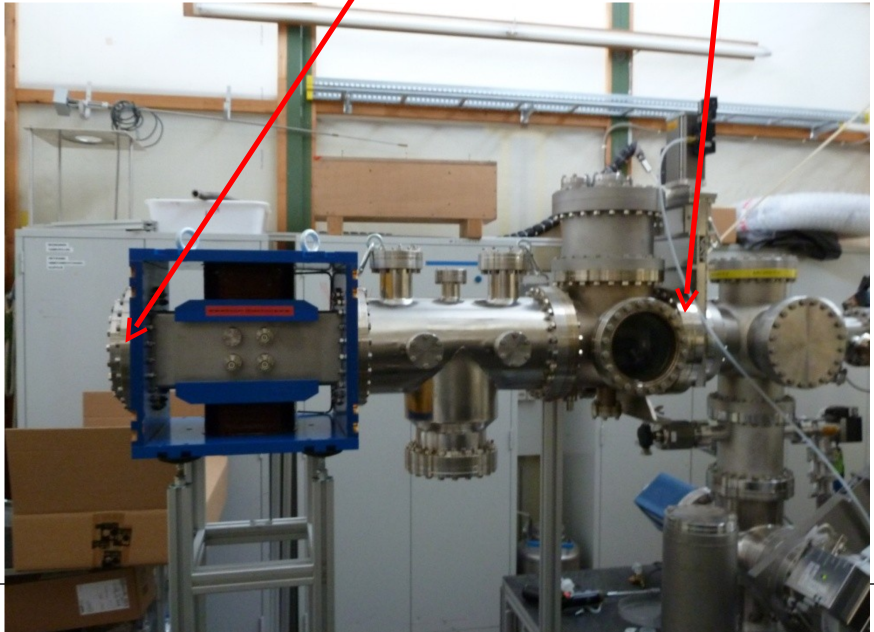
[Fan et al., Phys. Rev. **B78**, 153203 (2008)].

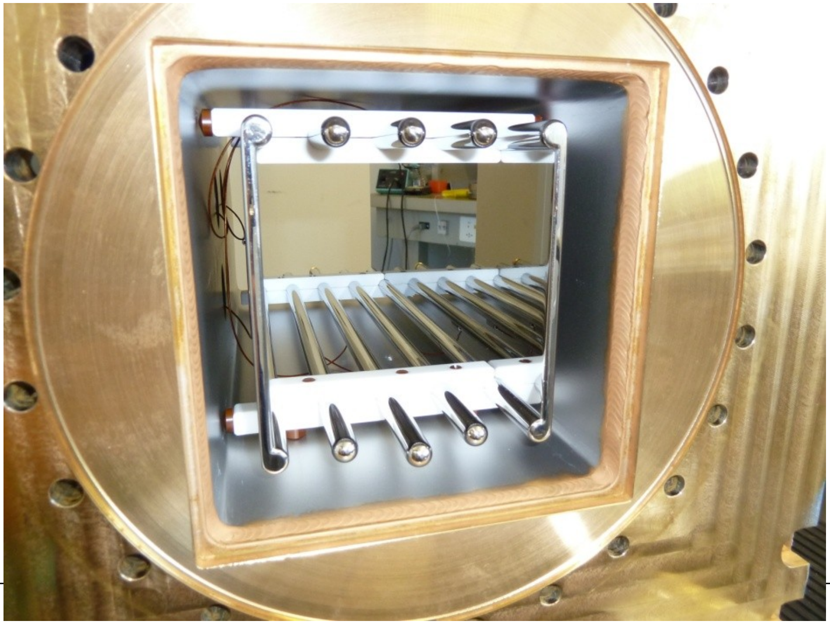
Filling of surface acceptor states with electrons causes inversion of surface region of depth > 200 nm.
p ~ 10^{14}/cm^3 (from relaxation rate)

LEM spin-rotator for LF-μSR

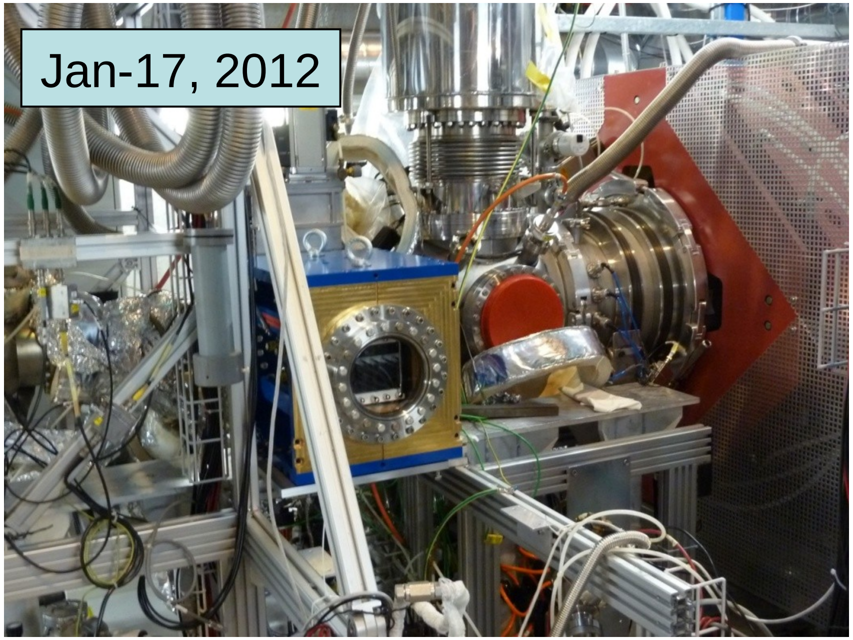


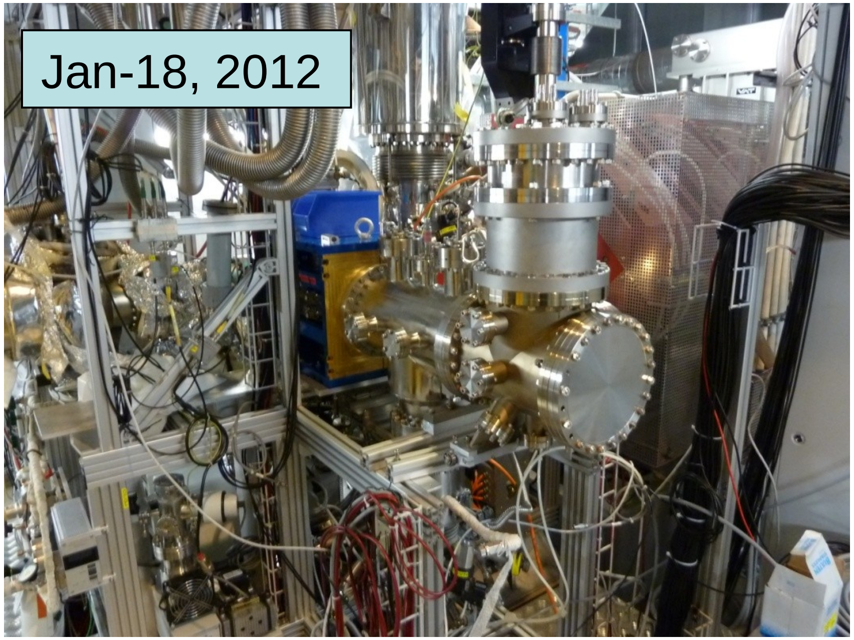


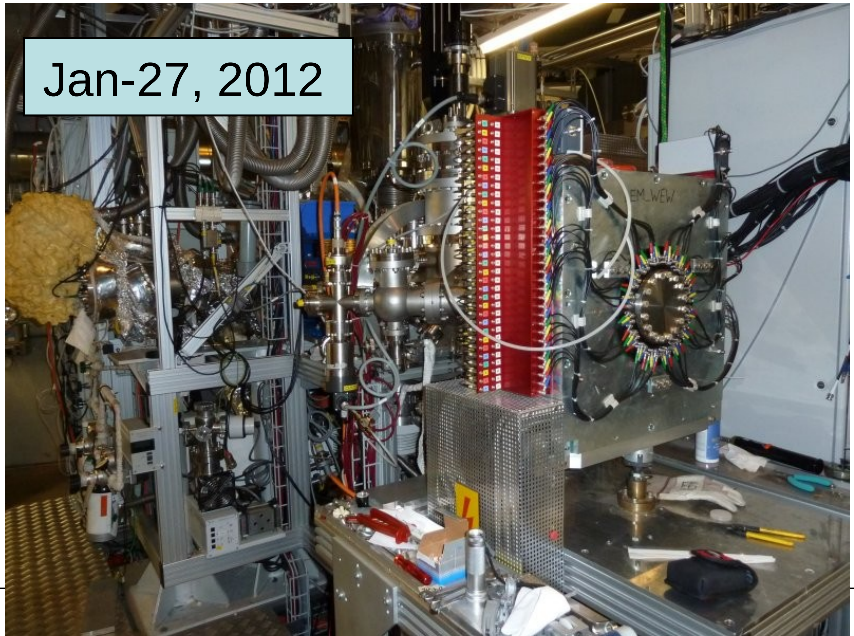


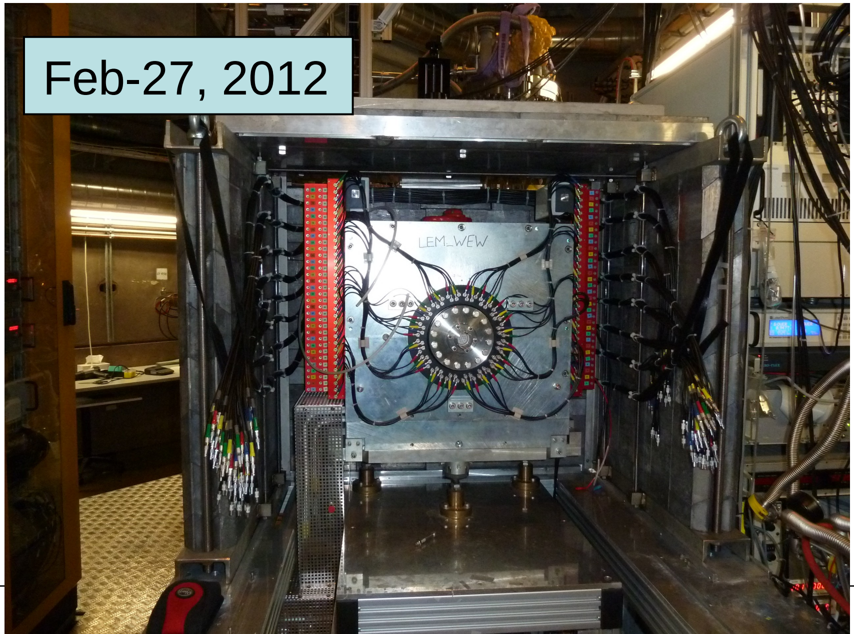


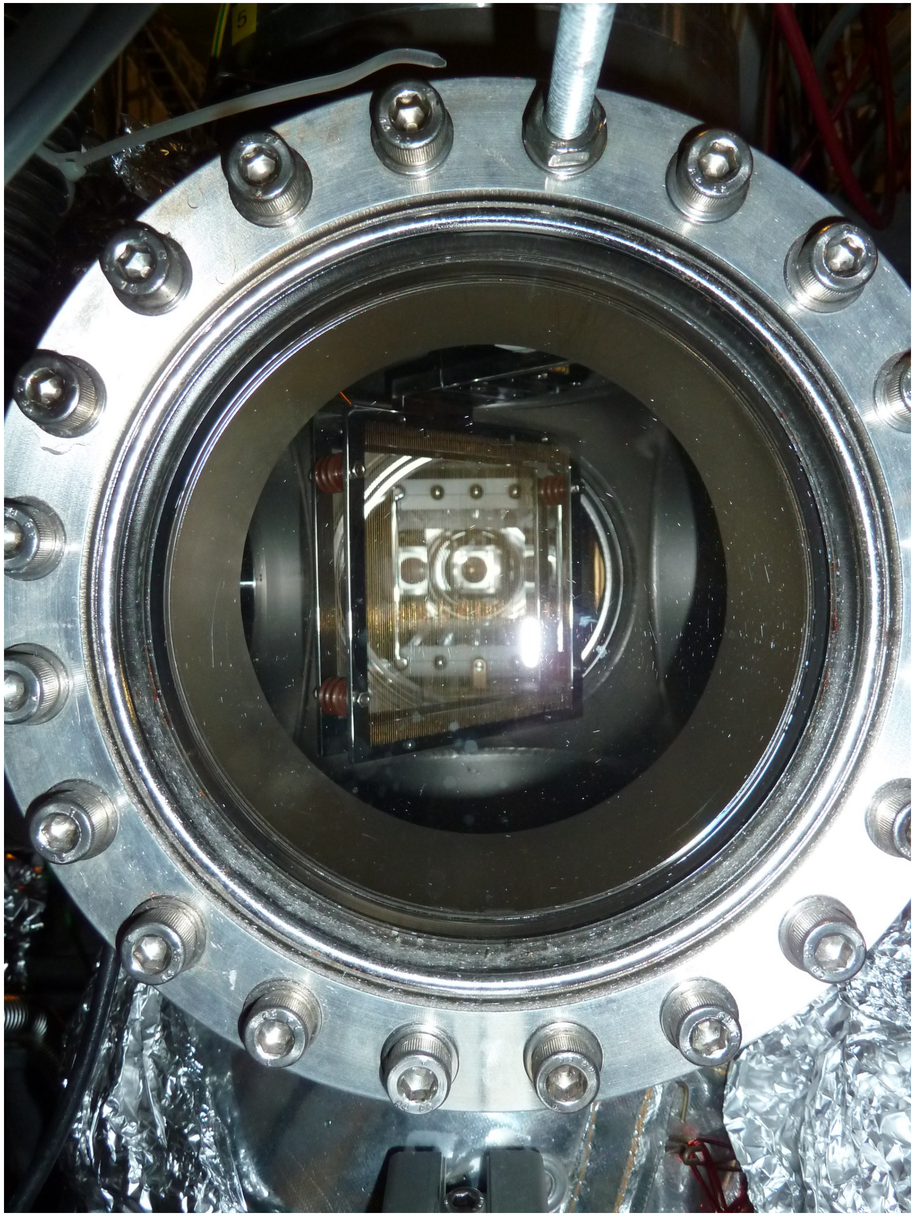
LEM spin-rotator installation

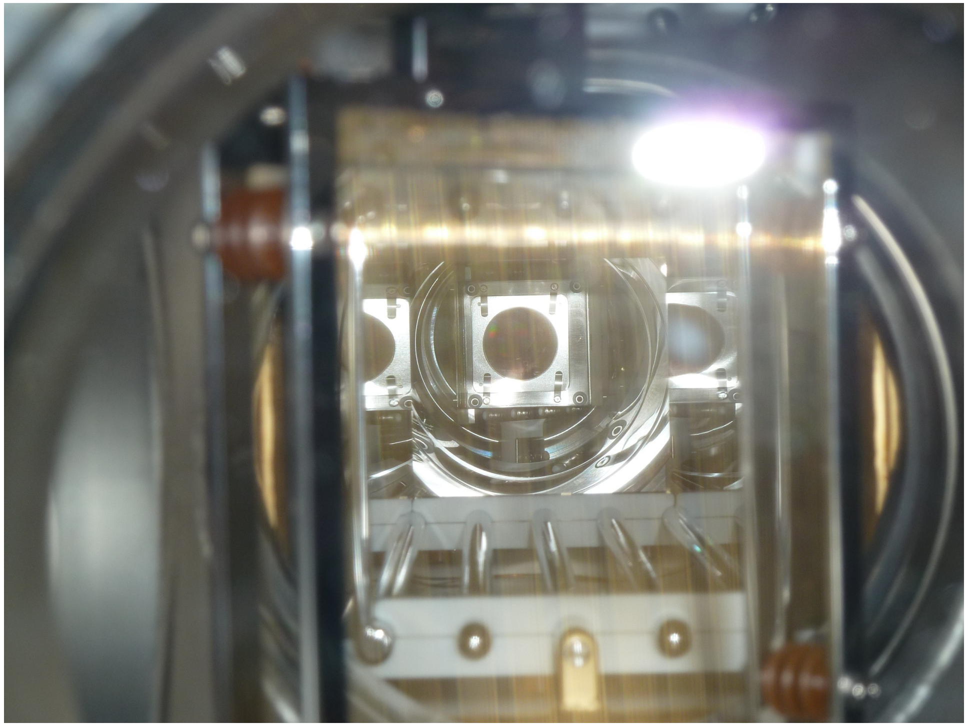






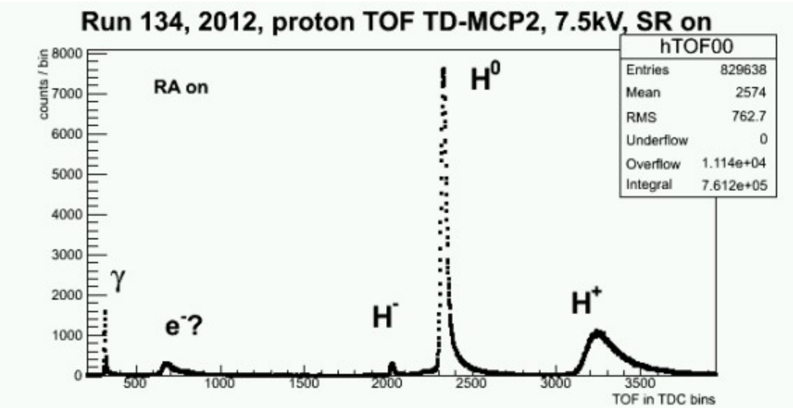


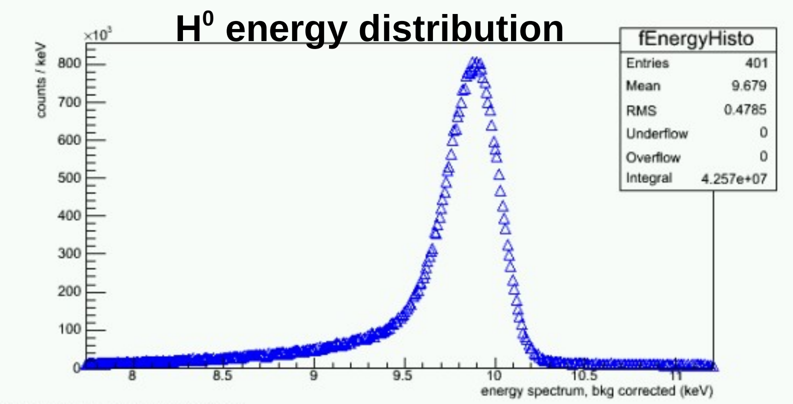


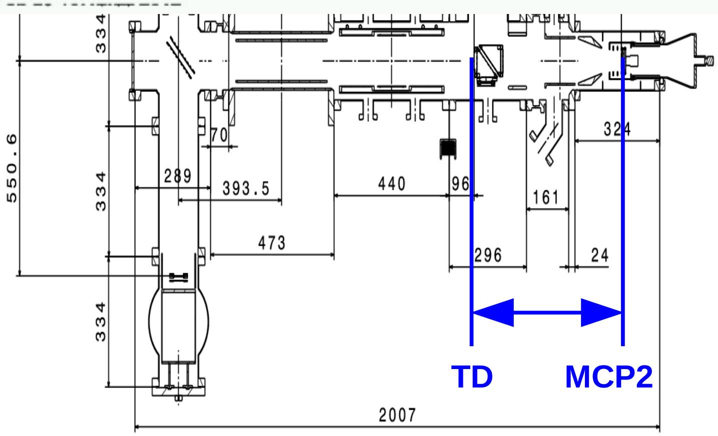


Looking through electrostatic mirror on spin-rotator and trigger detector

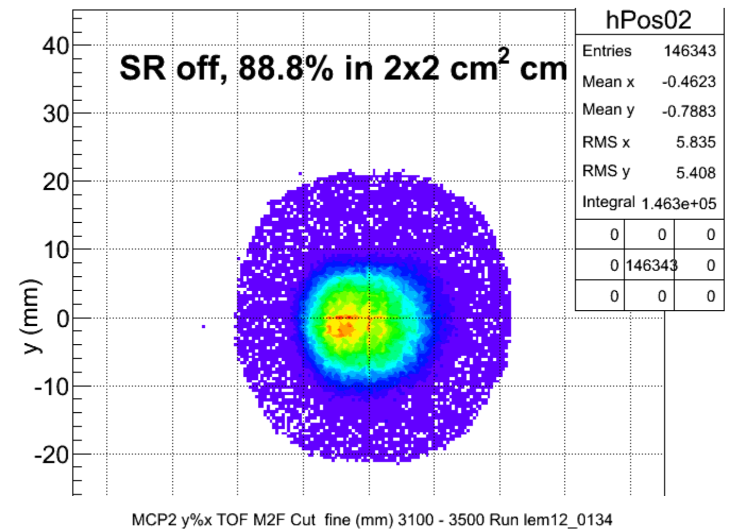
LEM spin-rotator (SR): first tests with protons

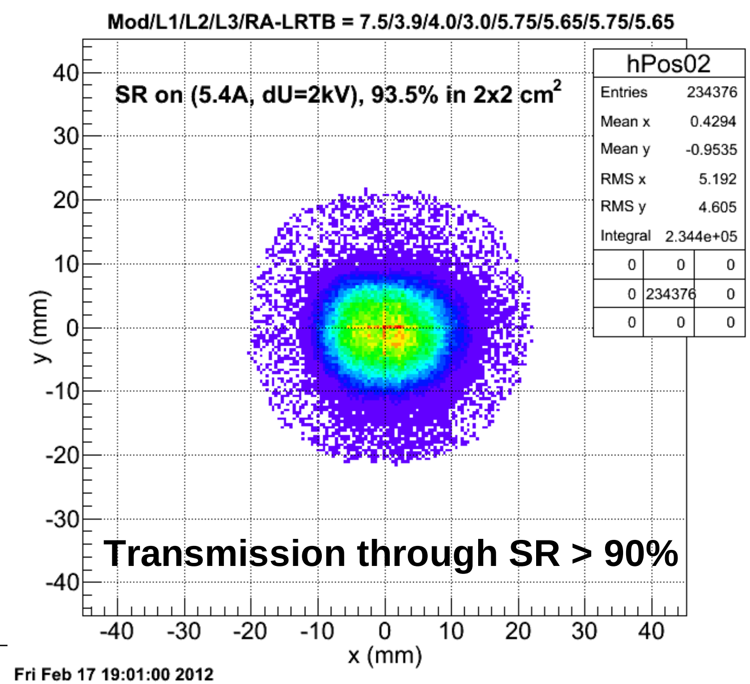




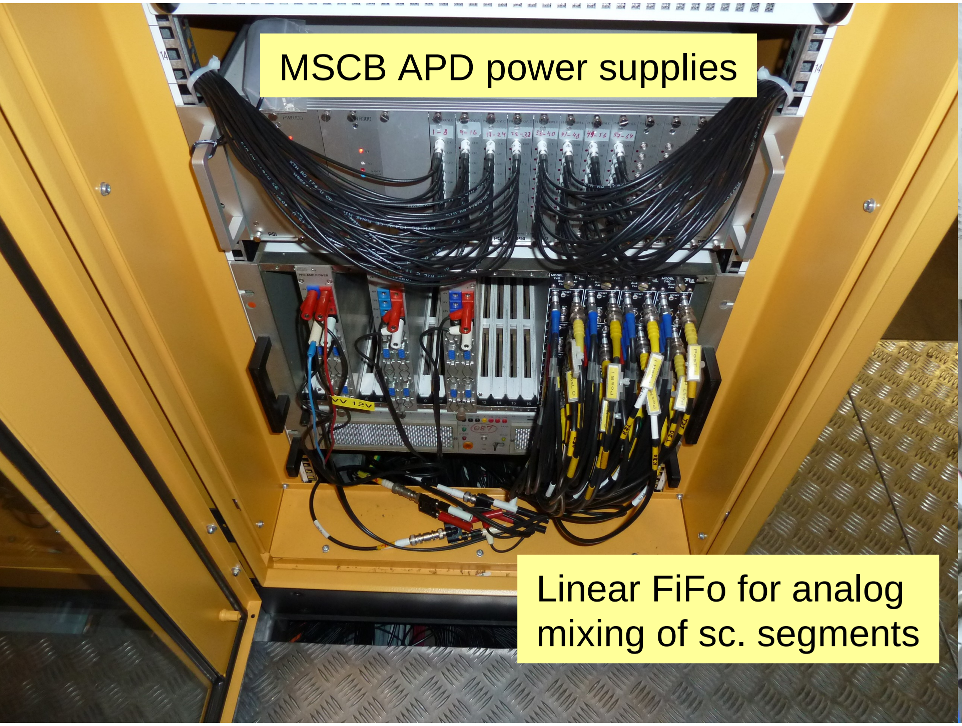


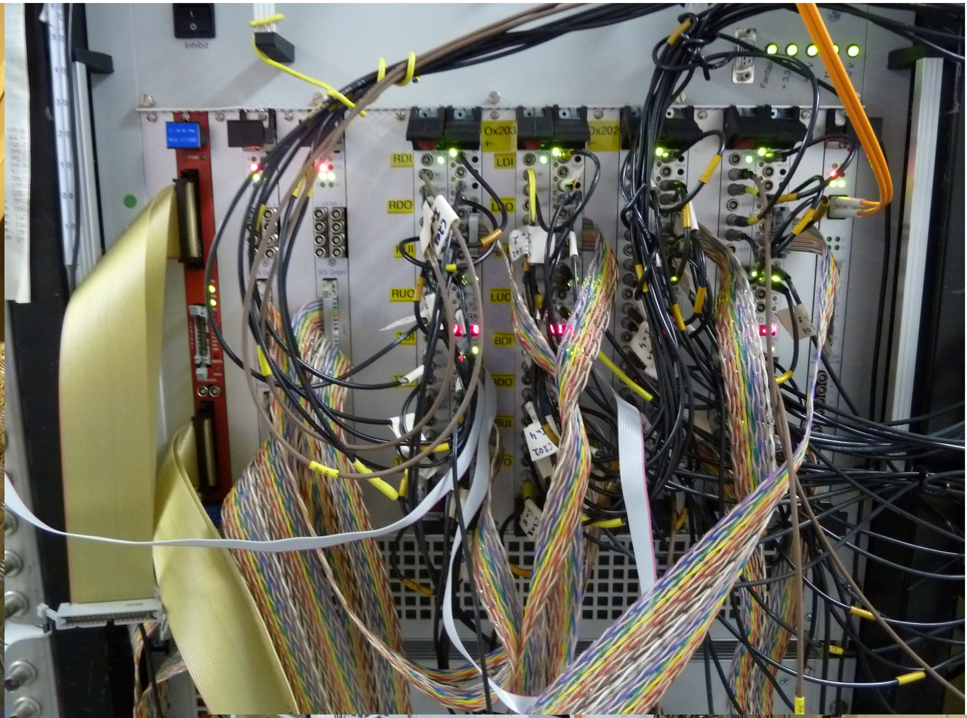
H⁺ Beamspot at sample position

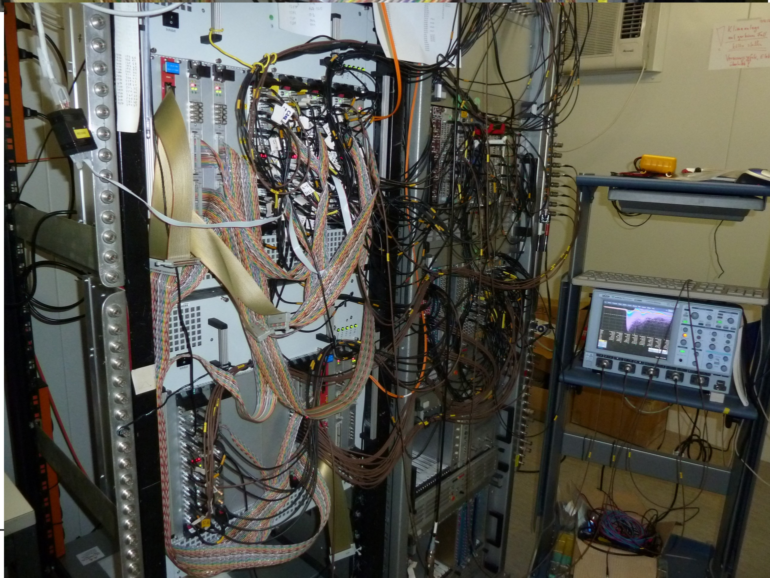




Data acquisition electronics





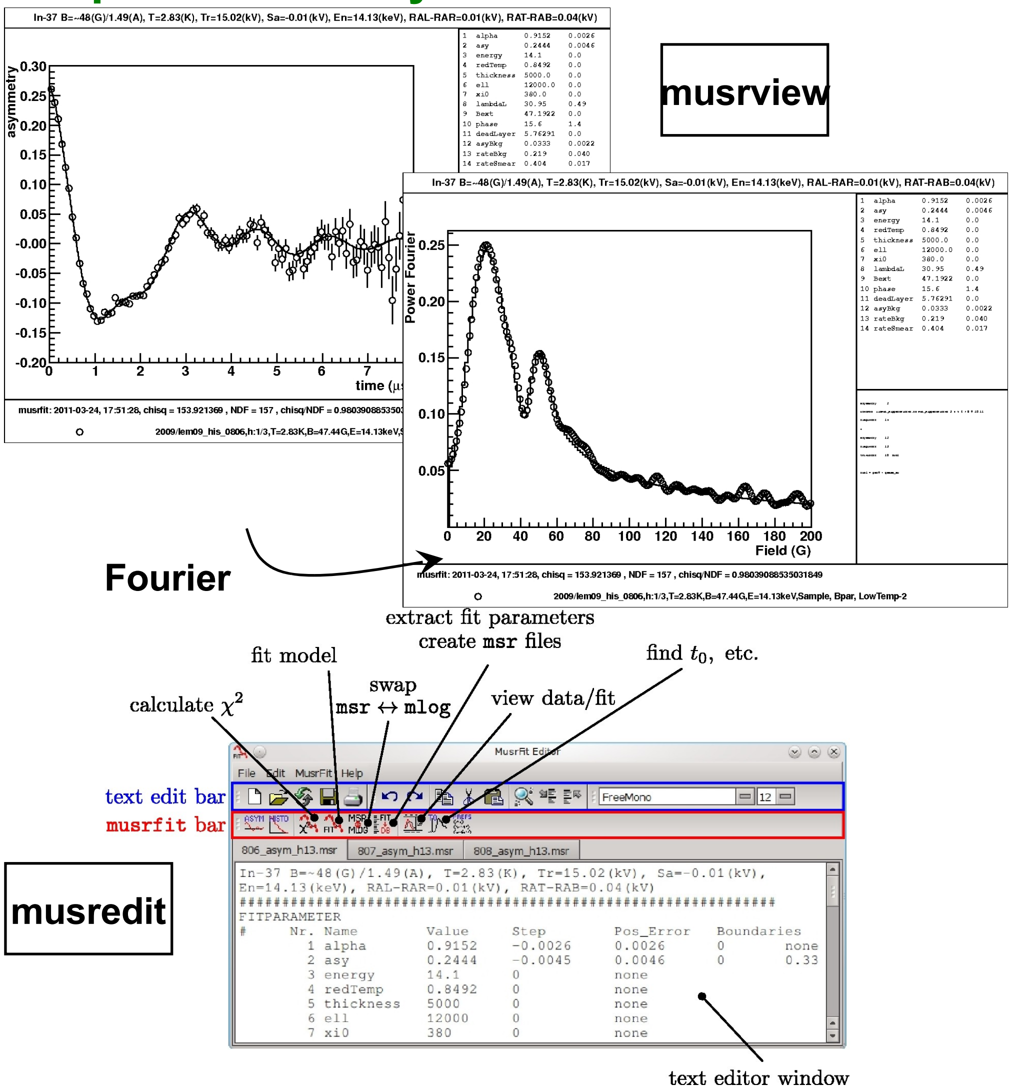


VME TDC, scaler, splitter, CFD modules
- µSR and time-of-flight data; all logic in software

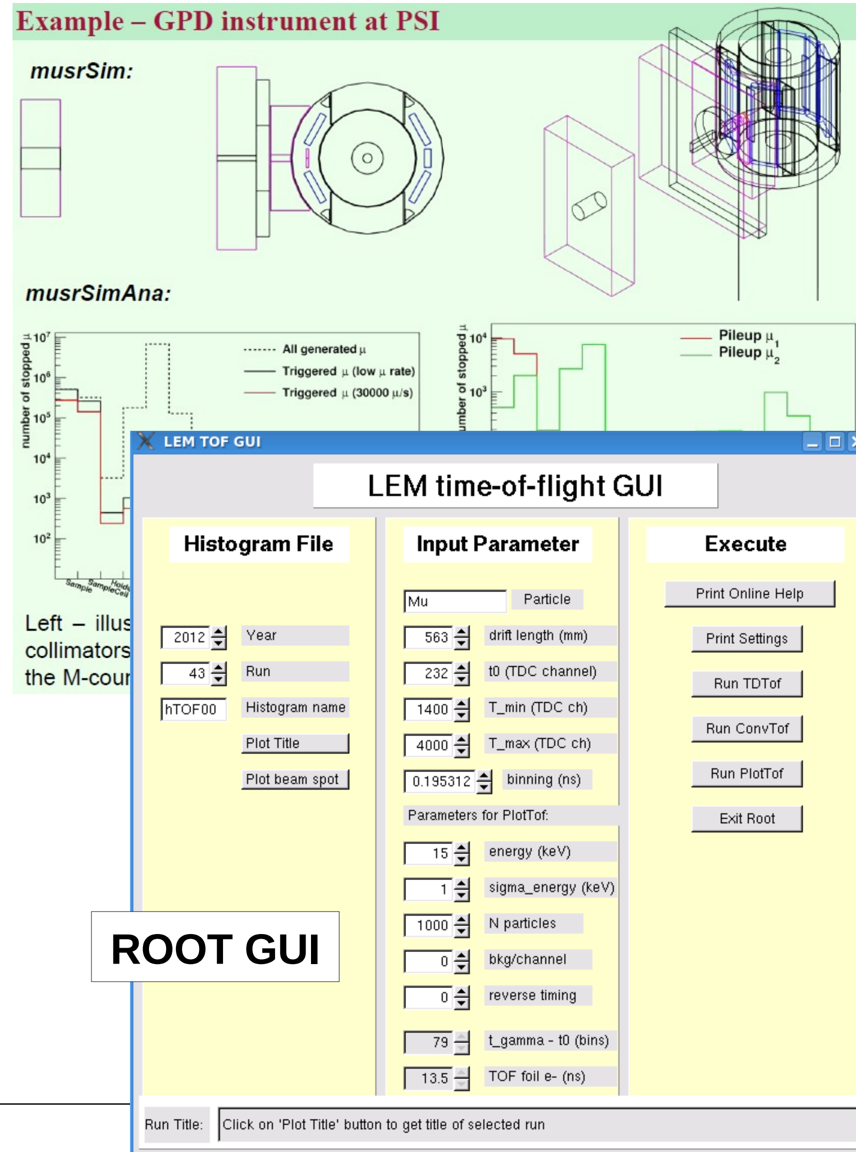
NIM modules for
- analog mixing of WEW scintillator segments
- coincidence rates of positron detectors

Software tools, based on ROOT, Geant4

musrfit – a free framework for μSR data analysis

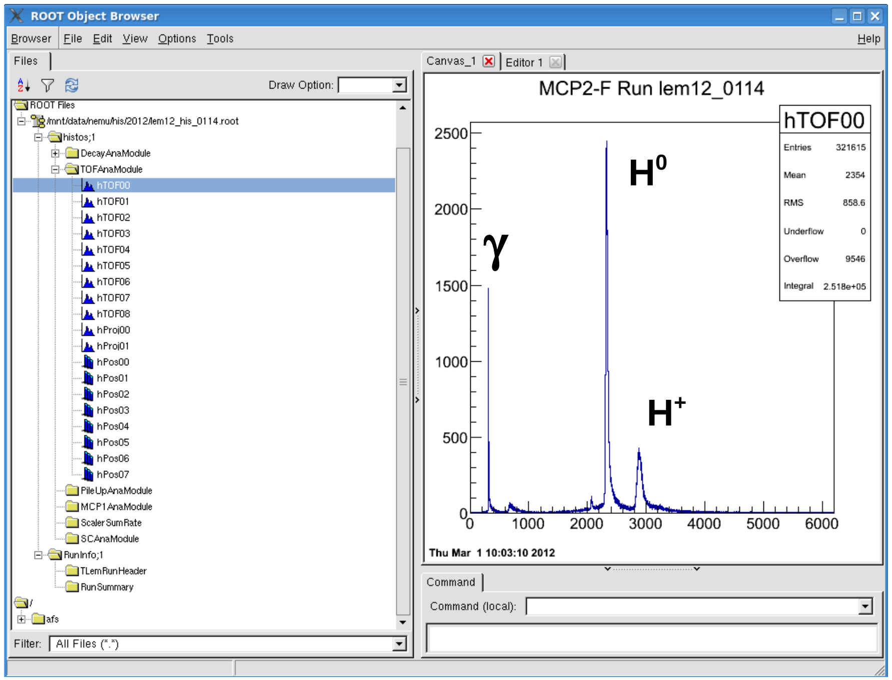


musrsim/ana – Instrument simulation and analysis



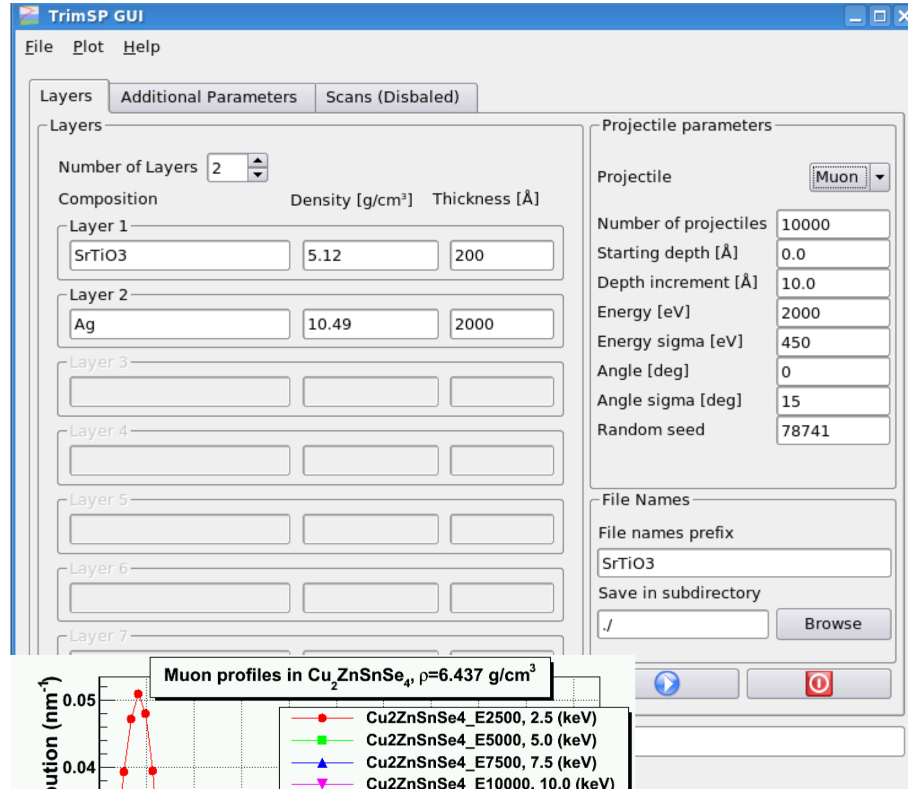
Software tools

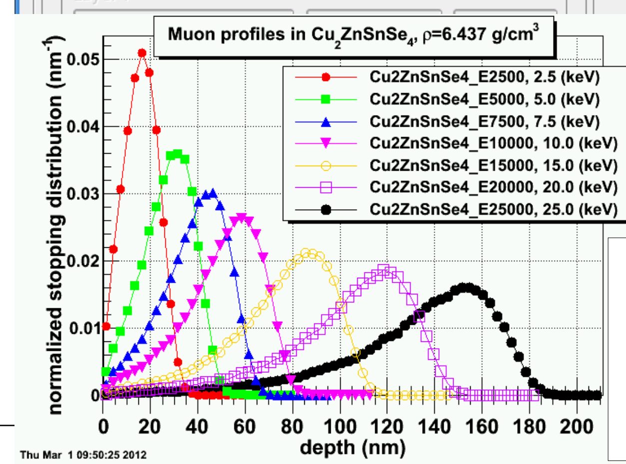
MusrROOT file format; inspection with ROOT browser



TOF spectrum of protons

Muon stopping profiles: perl-Qt GUI to run TrimSP (W. Eckstein, Munich)





ROOT macro to plot stopping profiles