



Wir schaffen Wissen – heute für morgen

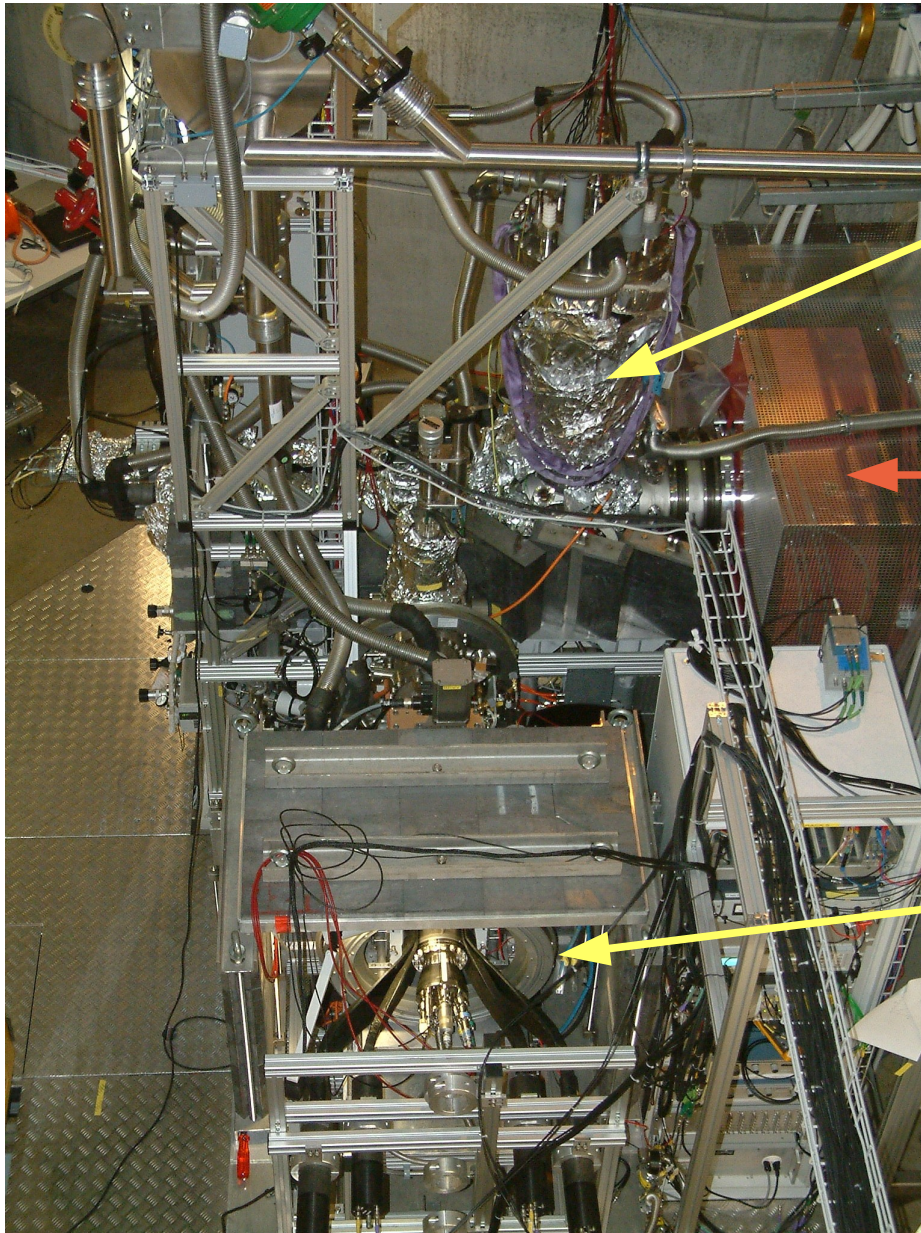
Paul Scherrer Institut

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- μ SR spectrometer



Moderator cryostat

QSM612, last quadrupole of μ E4 beam

LE- μ SR spectrometer

Cryostats (^4He) (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 °C):

under development; +/-10 kV at sample possible at 150 °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)

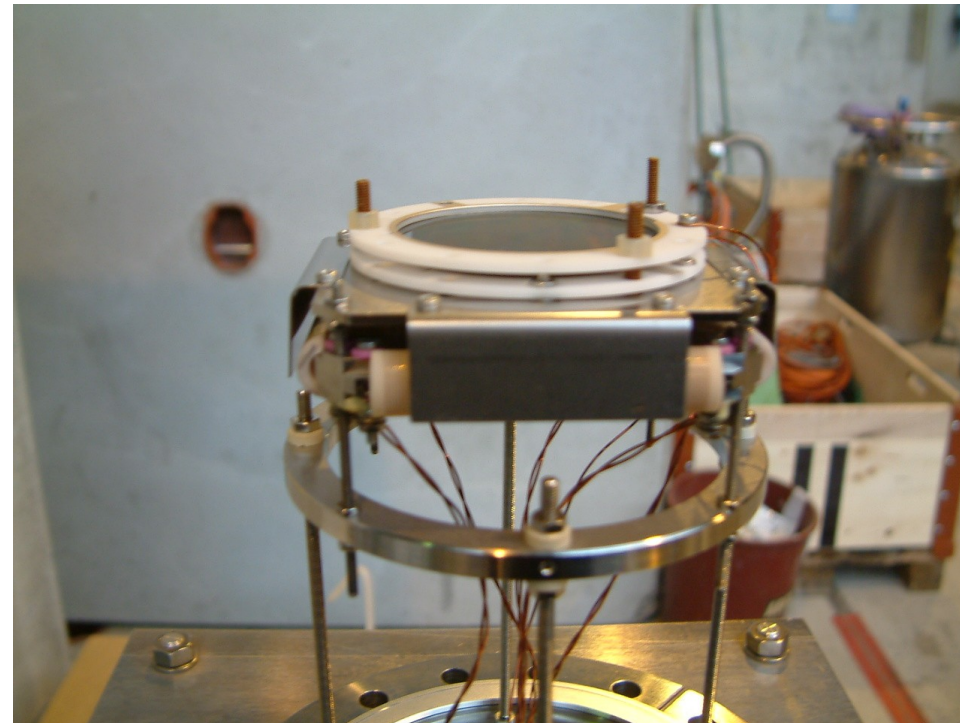
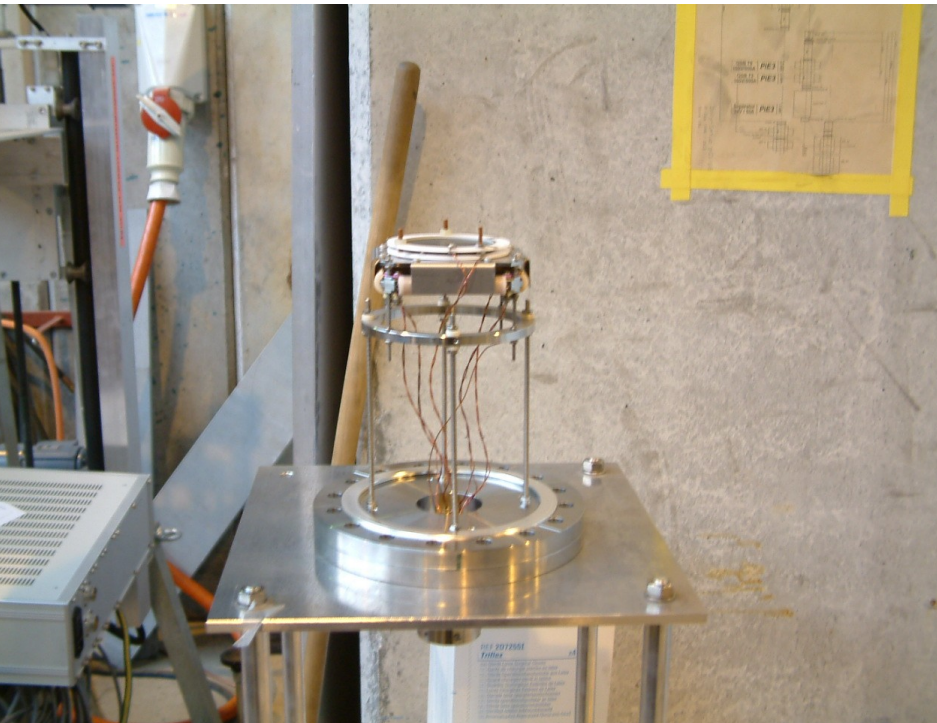
B-parallel: B parallel to sample surface/perpendicular to beam: 0 – 0.03 T (0 – 9 A)

LEM spin-rotator (+- 90 degree spin rotation):

For LF- μ SR, 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

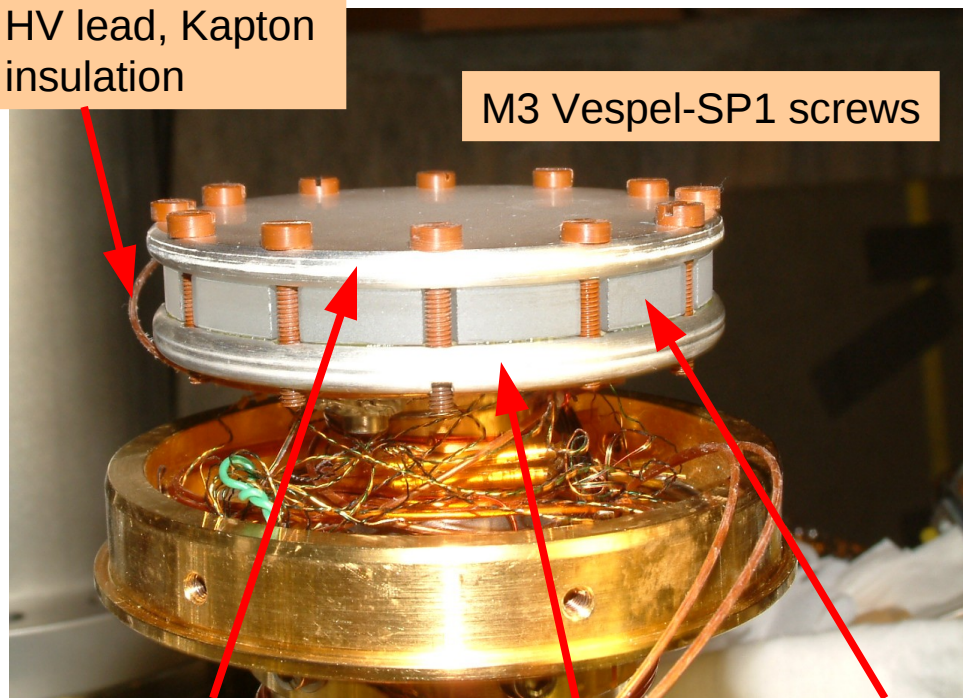


MCP detector (40 mm active area) with delay-line anode readout for x-y position information (RoentDek, Germany); position resolution < 0.1 mm.

Sample setup on Konti and LowTemp cryostats

HV lead, Kapton insulation

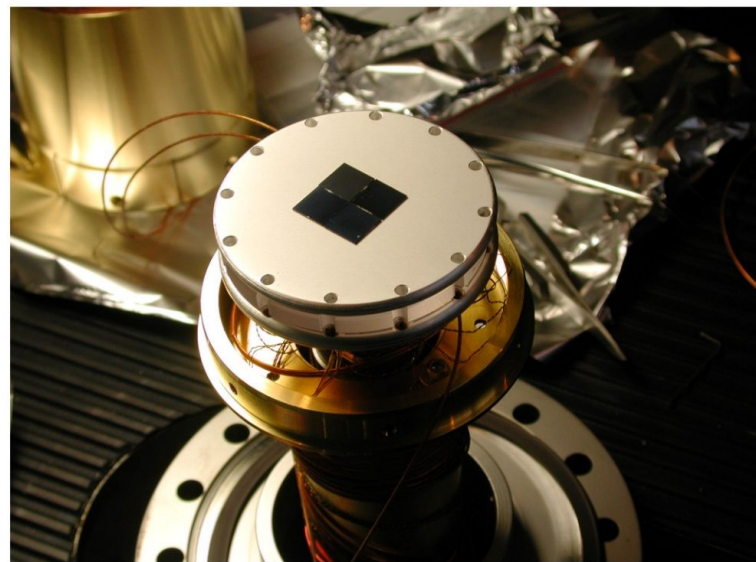
M3 Vespel-SP1 screws



Ag- or Ni-coated high purity Al sample plate, 7 cm diameter

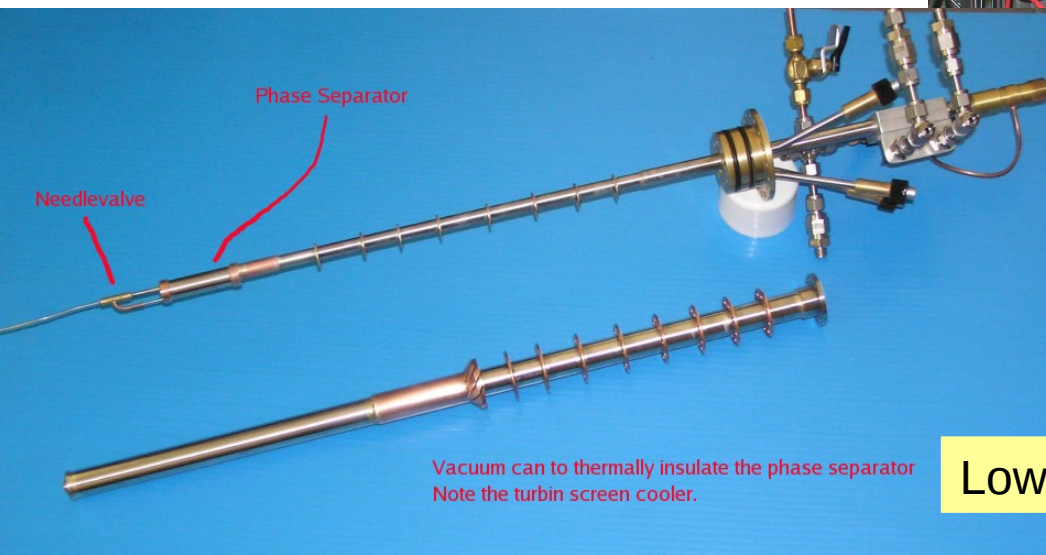
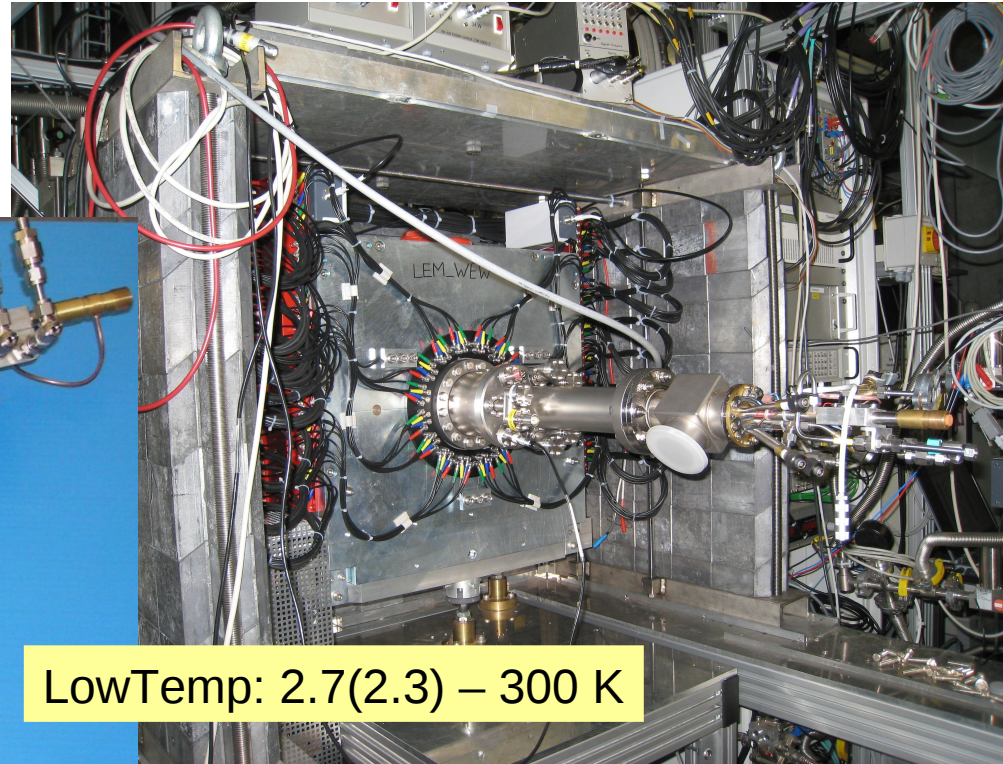
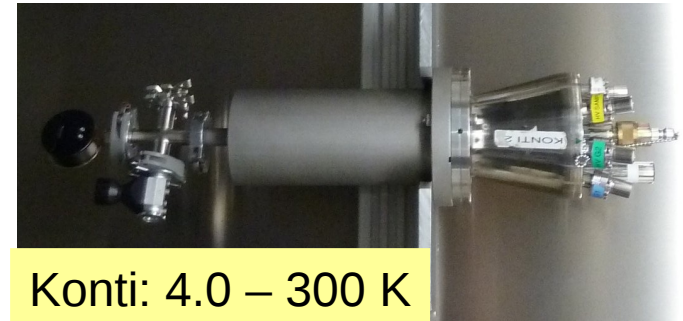
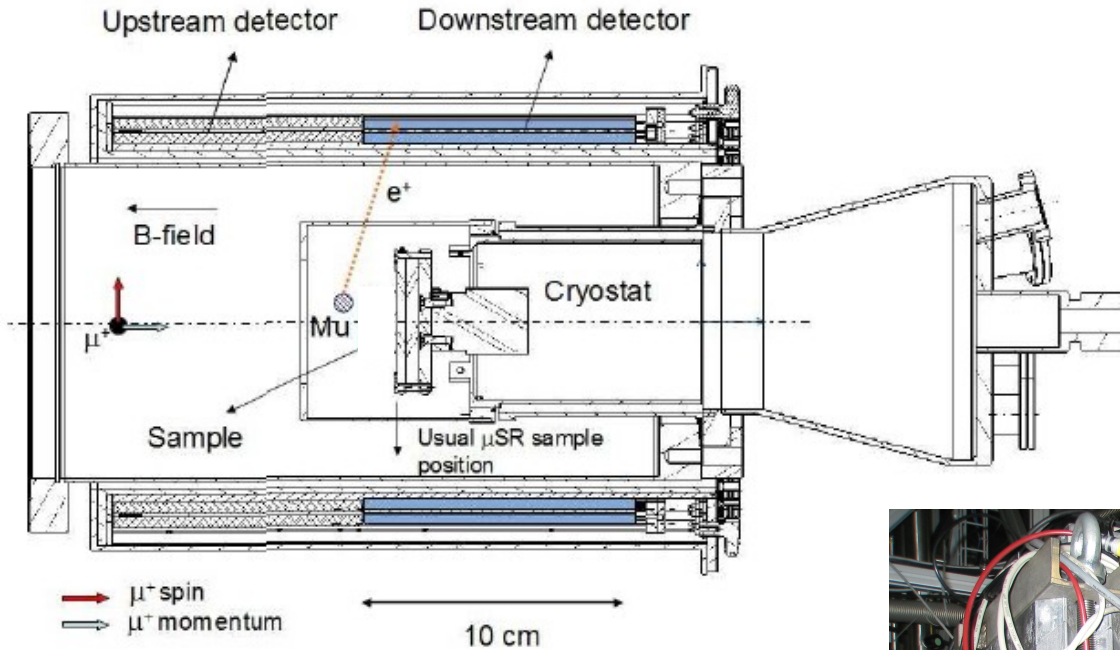
6-mm-thick sapphire disk

Ag-coated high purity Al base plate with T-diodes



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

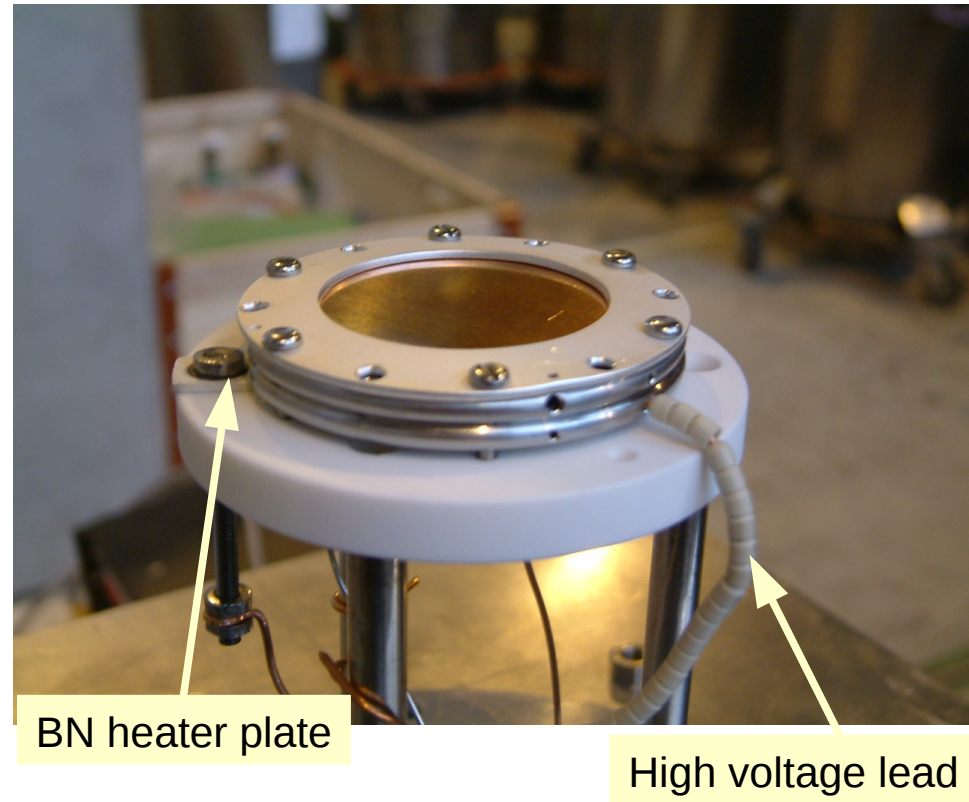
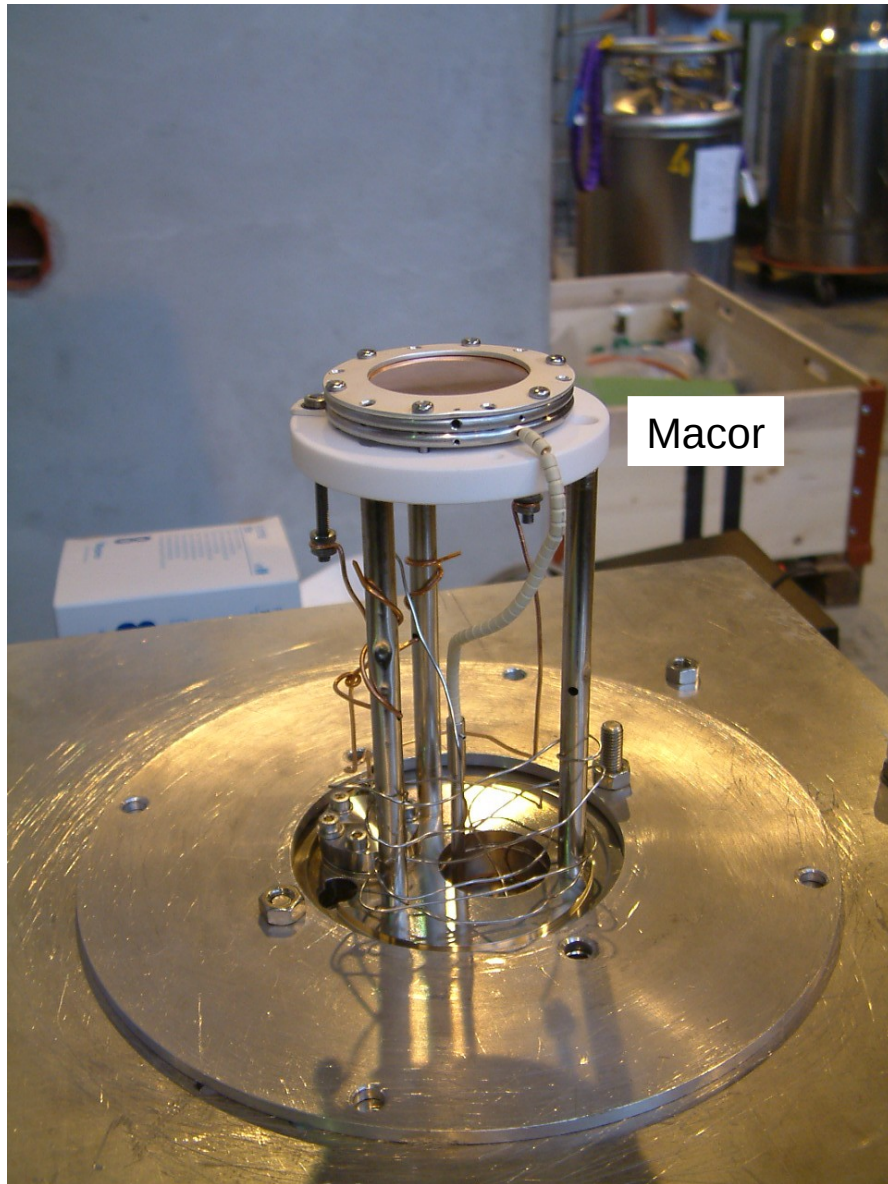
UHV Konti and LowTemp cryostats



Vacuum can to thermally insulate the phase separator
Note the turbin screen cooler.

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 μ SR spectrometers

APD: green sensitive SSPM_0810G1MM by Photonique

Sensor area: 1.1 mm²

Operating voltage: 30 – 36 V

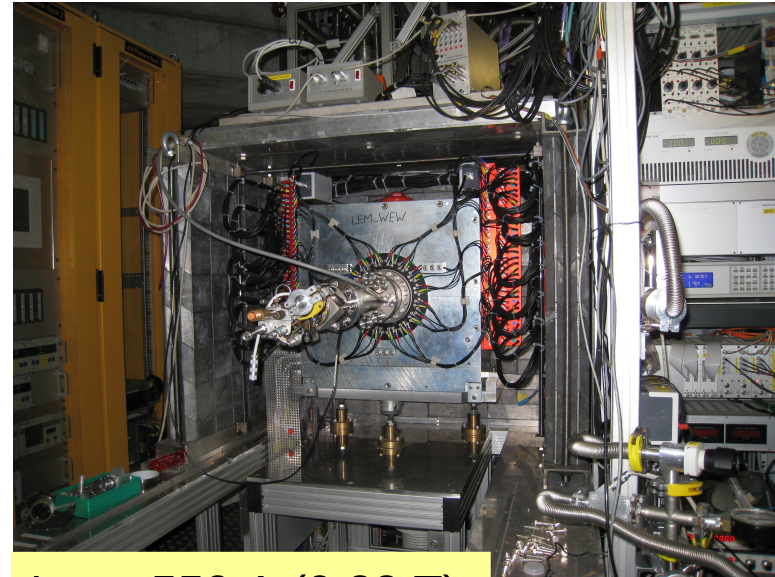
Gain: 0.5 · 10⁶

Single photon detection efficiency: 35/41 % (at $\lambda = 520/630$ nm)

Temperature coefficient: ~1% per °C

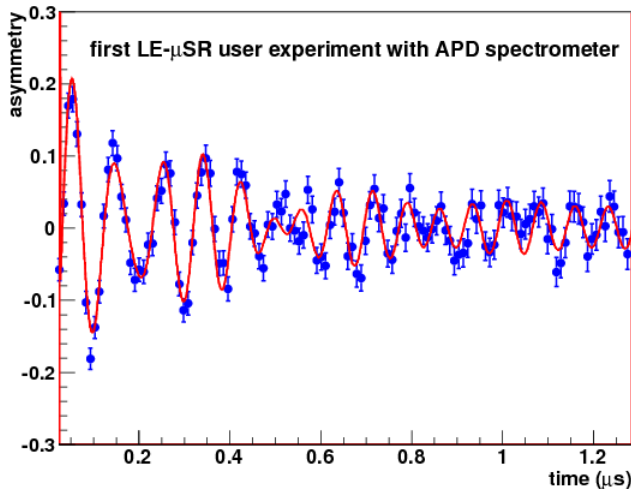
Scintillators: BC-400

Wavelength shifting fibres: BCF-92



$I_{\text{max}} = 550 \text{ A (0.32 T)}$

Tb₂Ti₂O₇ (111), T=2.60 (K), WEW B≈999(G)/175.00(A) ,13.5 (kV), E= 20keV



1	Asy	0.045733	0.002203
2	Rate	0.219193	0.040076
3	Field	993.213000	0.317535
4	NO_L	430.466000	0.582892
5	Hkg_L	24.279600	0.093162
6	Phase_L	144.827000	2.290310
7	Alpha_LR	0.979095	0.001892
8	Hkg_R	25.320300	0.094029
9	Phase_R	-40.159800	2.403020
10	NO_T	443.911000	0.592734
11	Hkg_T	25.457200	0.095180
12	Phase_T	51.115700	2.219170
13	Alpha_TB	0.937748	0.001802
14	Hkg_B	22.623500	0.091894
15	Phase_B	-127.882000	2.182180
16	AsyM	0.216906	0.006460
17	rateM	3.735100	0.131824
18	FieldM	779.215000	1.626100

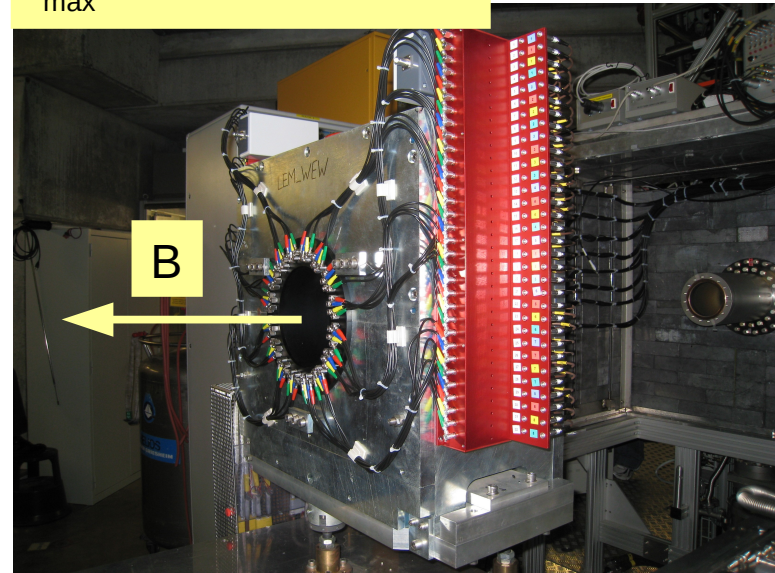
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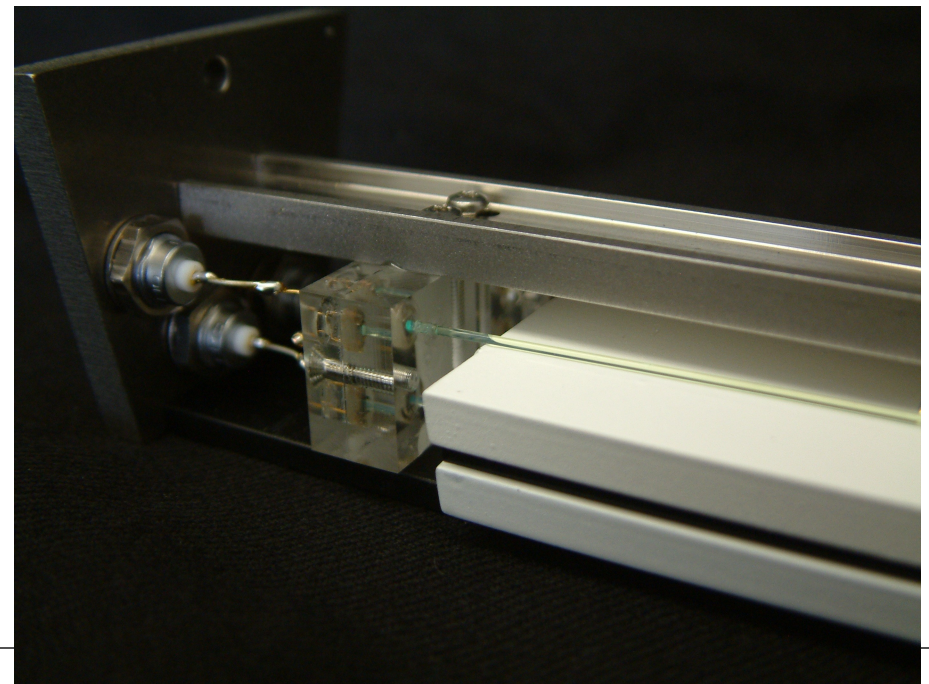
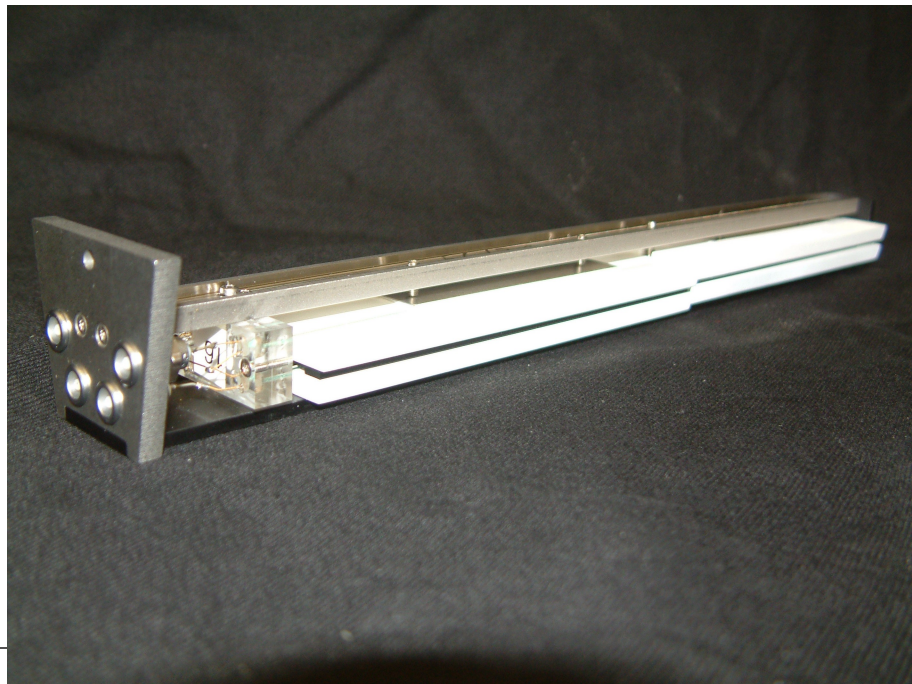
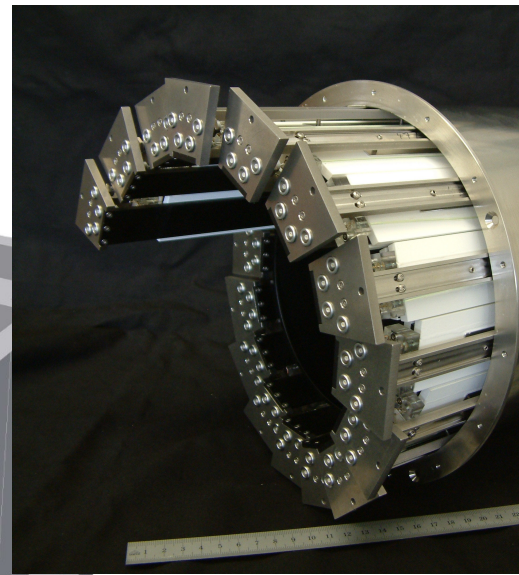
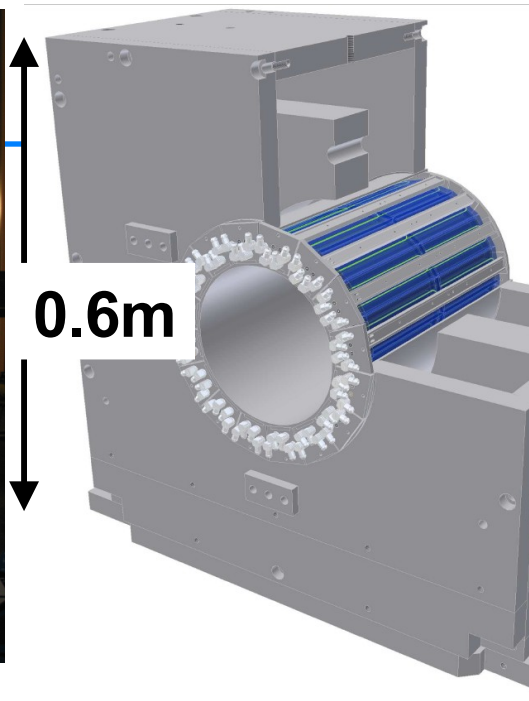
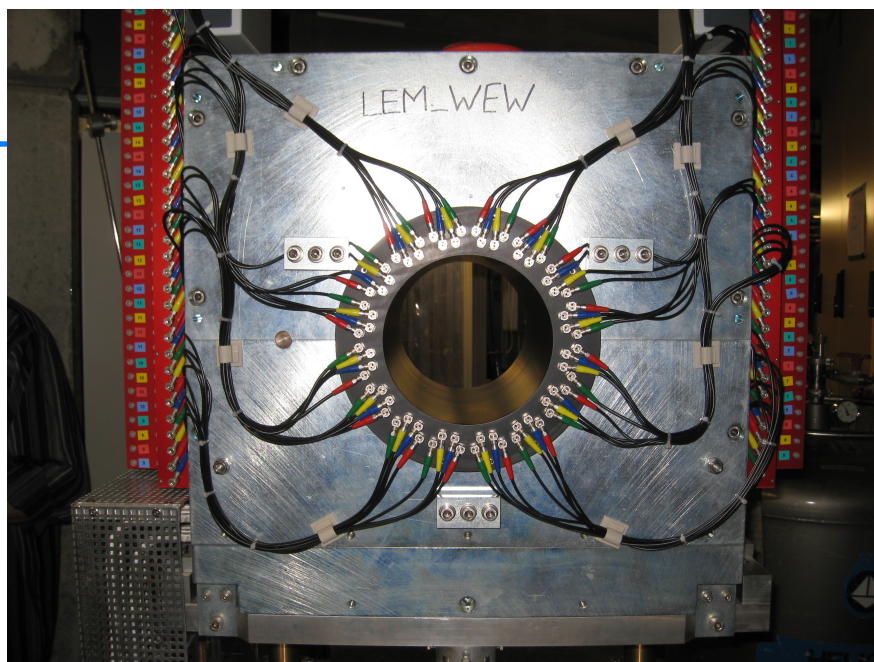
asymmetry      1
simplExpo      2
TFfieldCos     map1 fun1
+
asymmetry      16
simplExpo      17
TFfieldCos     map1 fun4

fun1 = par3 * gamma_mu
fun2 = par4 * par7
fun3 = par10 * par13
fun4 = par18 * gamma_mu
    
```

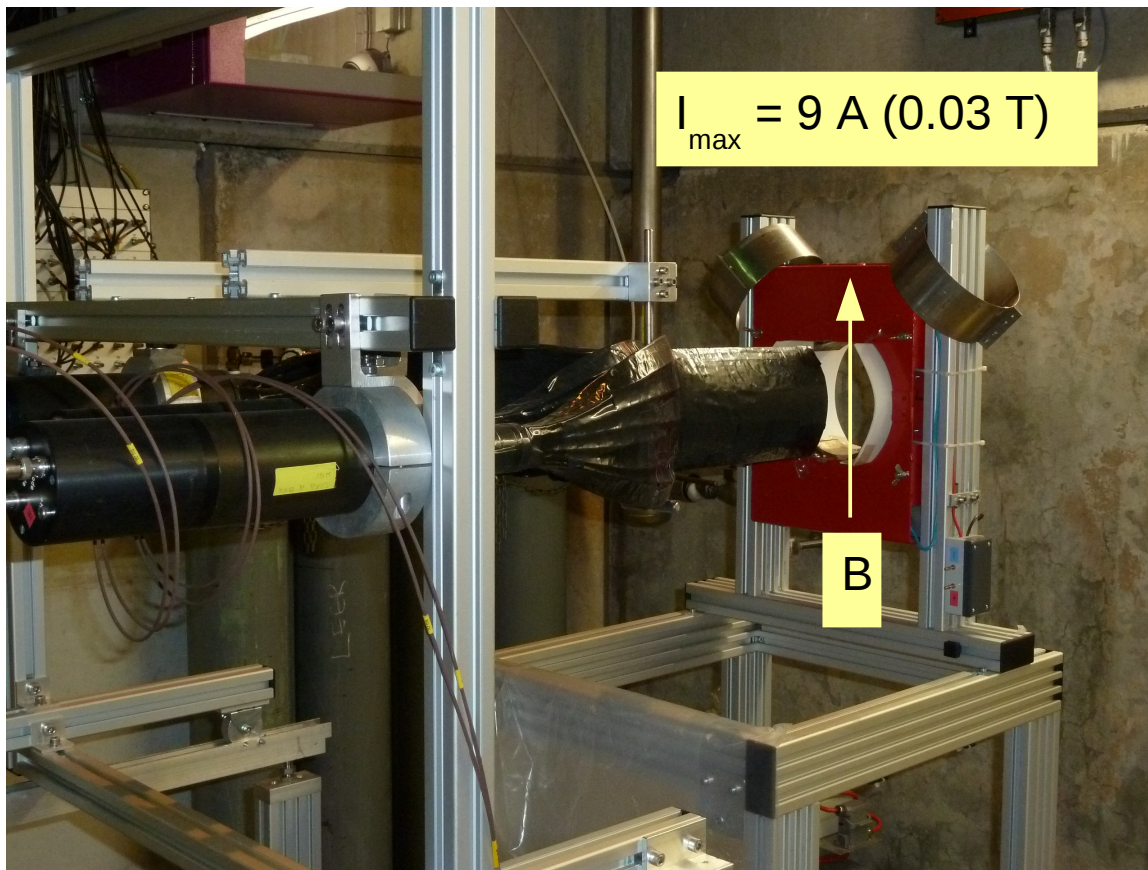
musfit: 2010-05-17, 17:38:36, chisq = 8475.43603 , NDF = 8134 , chisq/NDF = 1.0419764

● 2010/lem10_his_0227,h:1,T=2.51K,B=999.16G,E=19.97keV,Sample, WEW, LowTemp-2





B-parallel magnet with PM positron spectrometer



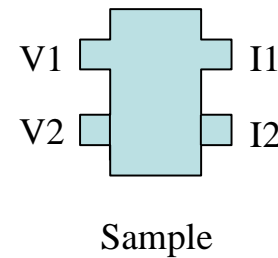
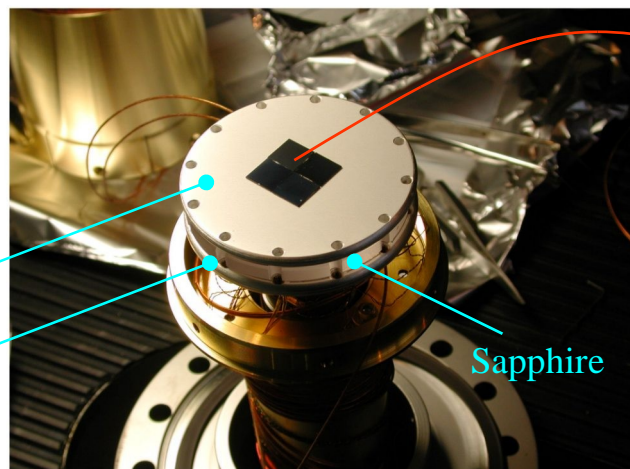
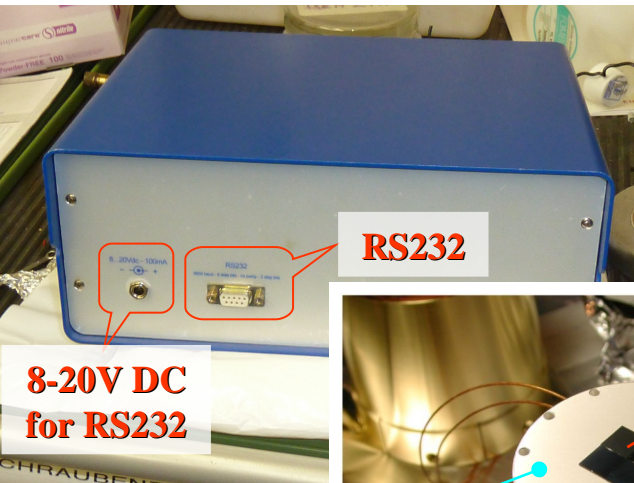
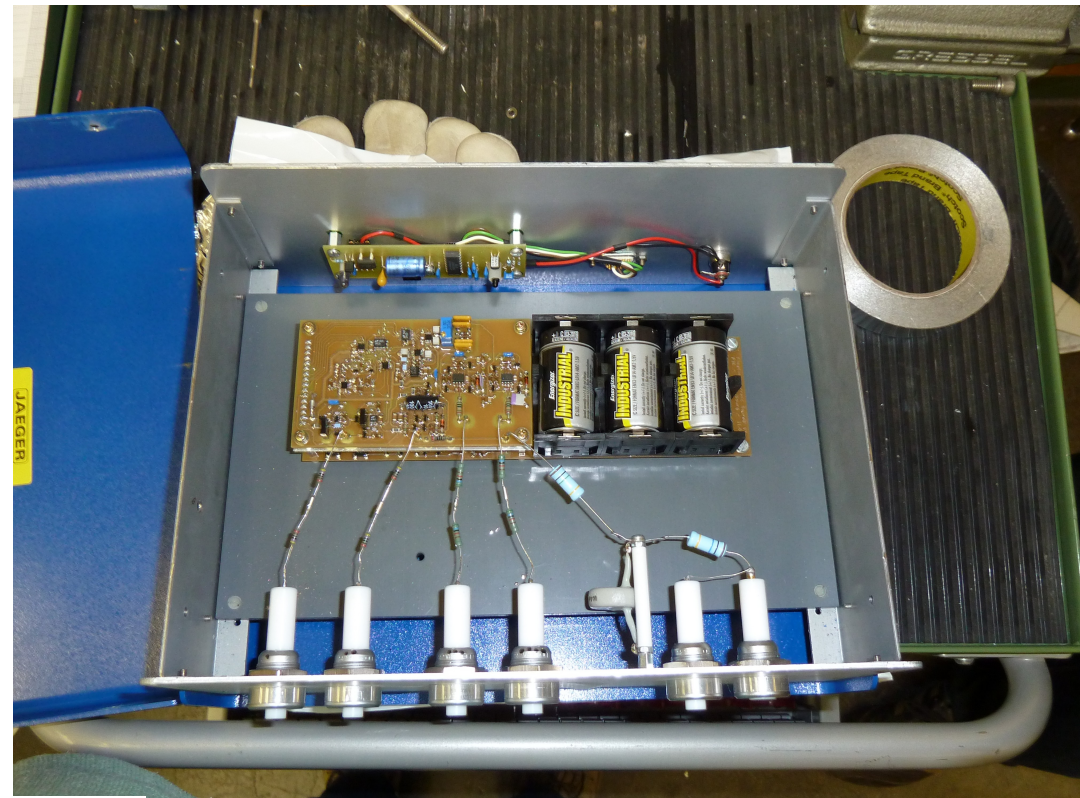
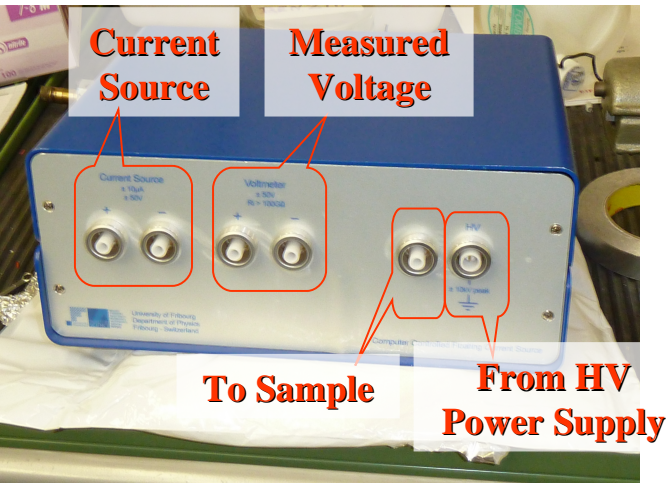
Air-cooled coils

XP2020 photomultiplier

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

Solid angle: 50% of WEW

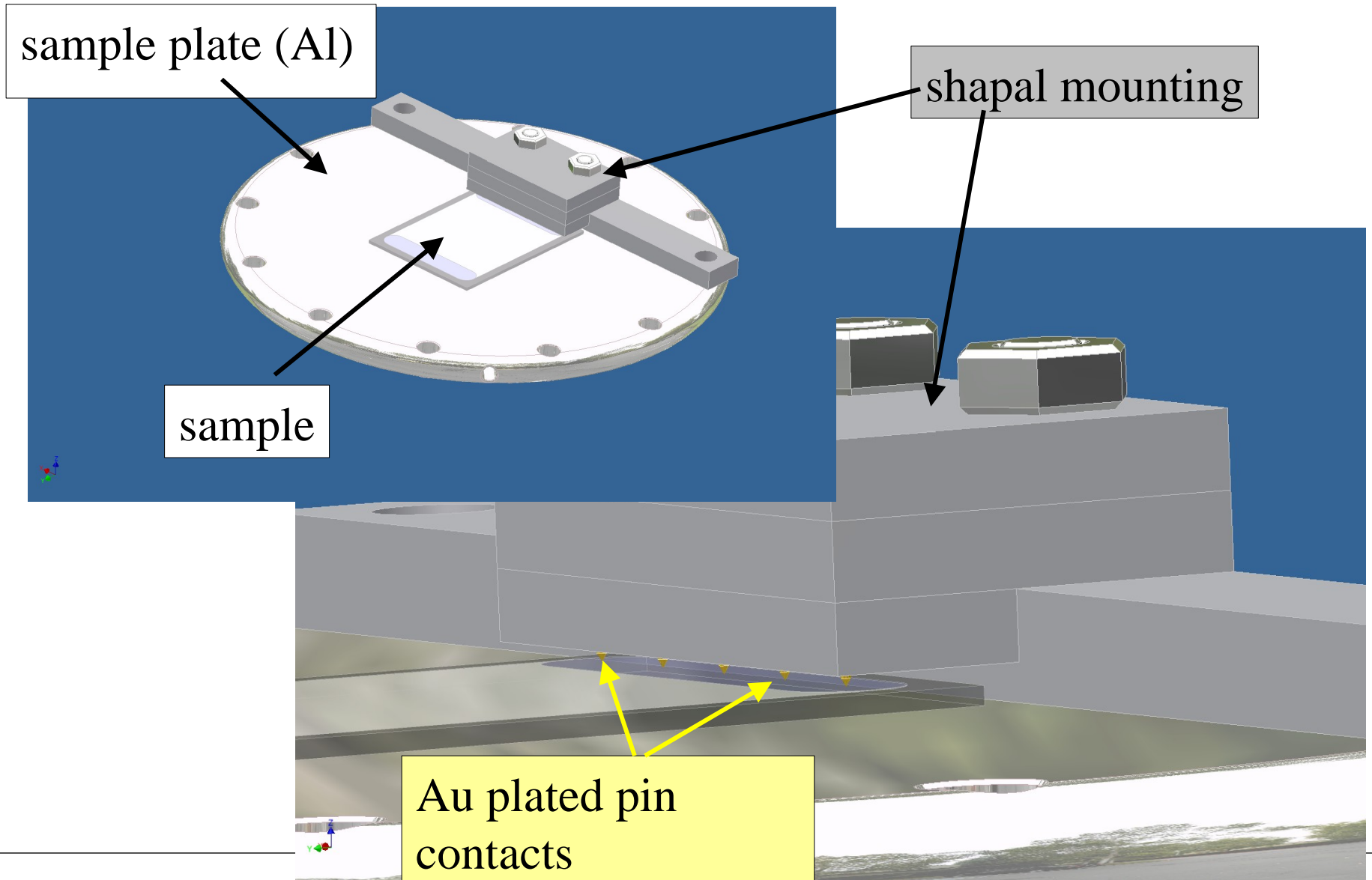
Floating Ohm Meter (FOM), Univ. Fribourg/PSI



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):

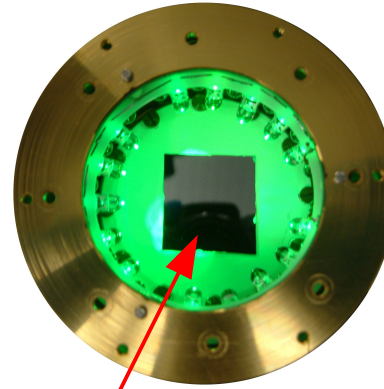


Setup for illumination

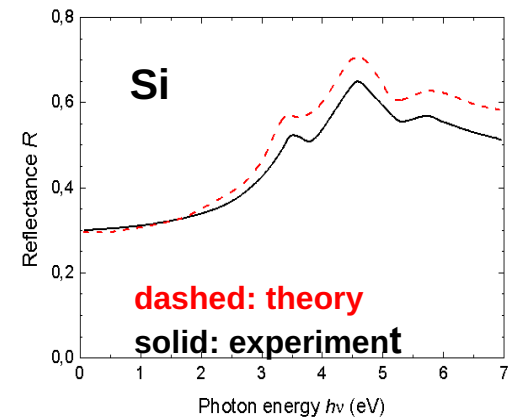
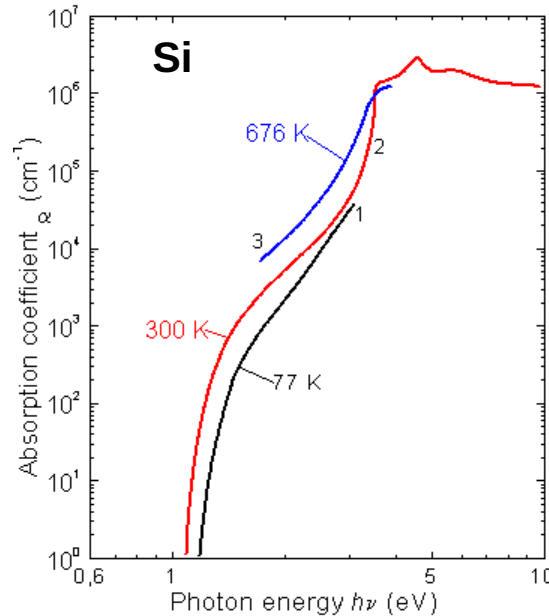
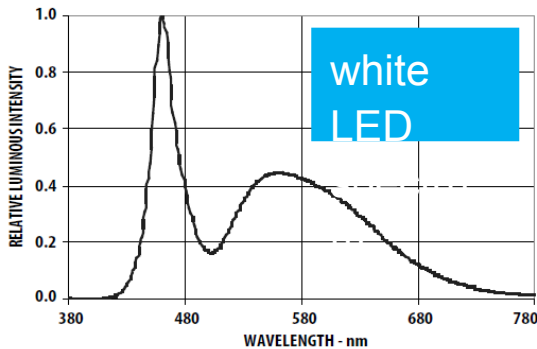
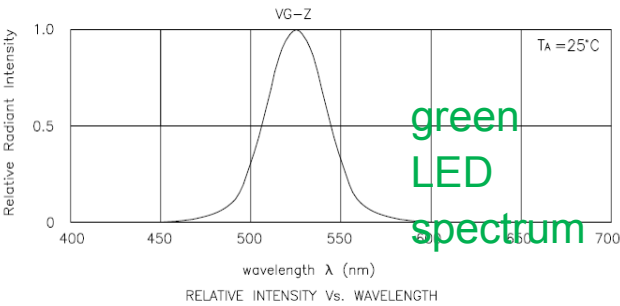
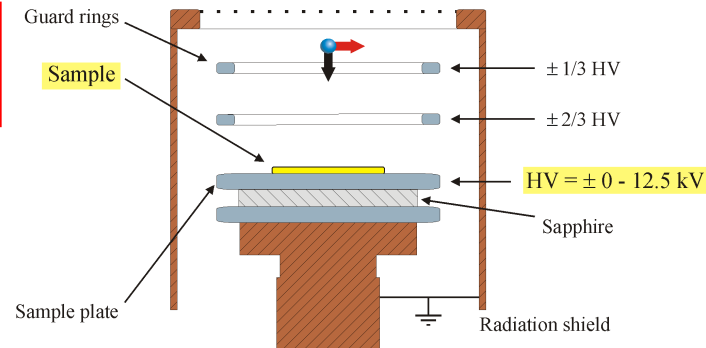
InGaN green, $\lambda=525(39\text{nm})$, 30mA/3.3V,
2 Θ 1/2= 20°, Kingbright L-7113VGC-Z

InGaN white $\lambda_{\text{peak}}=460,560\text{ nm}$, 30mA/3.3V
2 Θ 1/2= 30°, Avago HLMP-CW36-UX00

GaN blue, $\lambda=470(25)\text{ nm}$, 30mA/3.3V,
2 Θ 1/2= 16°, Kingbright L-7113QBC-D



Undoped Si (100),
3x3 cm²



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 $I = 10 \text{ mW/cm}^2$: $n_{\gamma} = 2.6 \cdot 10^{16} \text{ } \gamma/\text{cm}^2\text{s}$

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

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 $I = 10 \text{ mW/cm}^2$, green LEDs, steady state n_{eh} tunable in Si up to $\approx 10^{15}/\text{cm}^3$

In Ge, α is ~ 50 times larger: n_{eh} is of order $10^{16}/\text{cm}^3$

New LED setup for illumination

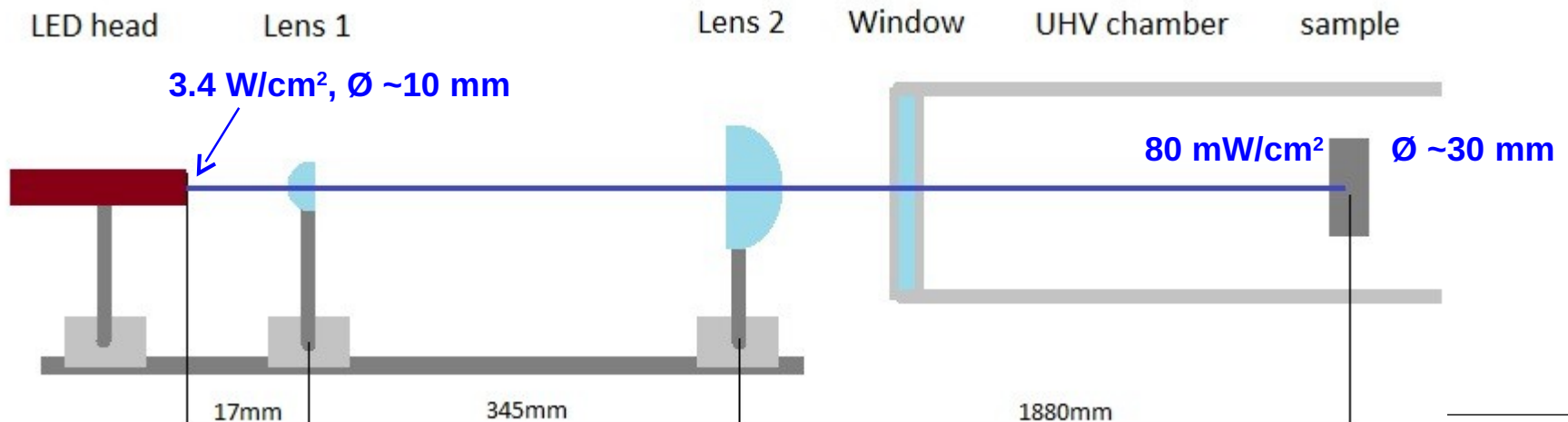
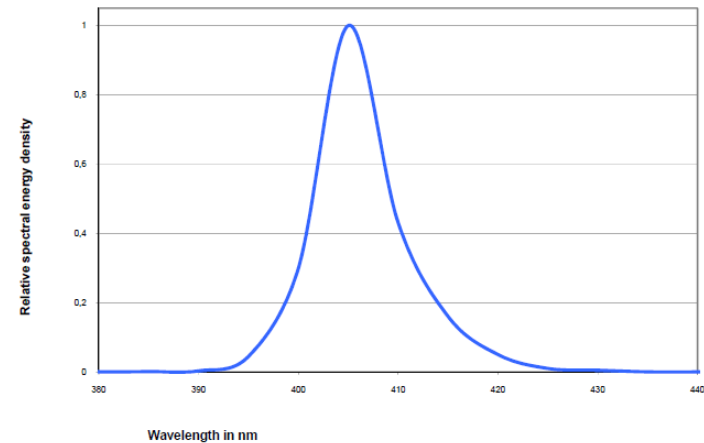


Intensities at ~85% of max. LED power
 80 mW/cm^2 at $405 \text{ nm} = 1.6 \cdot 10^{17} \text{ } \gamma/\text{cm}^2\text{s}$

LED Head 400 nm

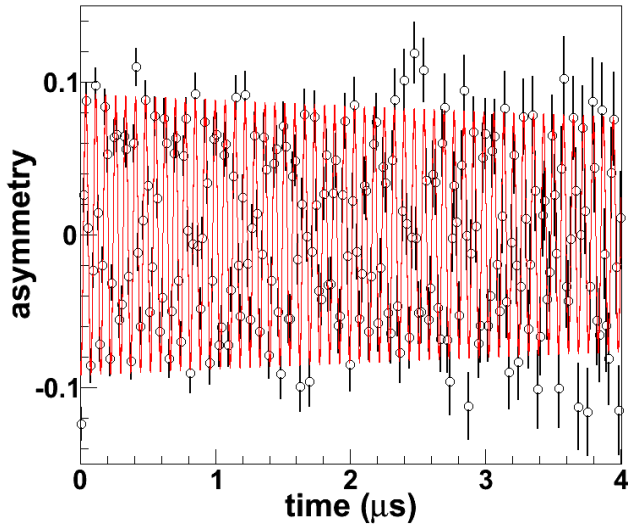
Peak wavelength	400 nm +/- 10 nm
Spectral width (FWHM)	approx. 9 nm
Focus distance	approx. 6 mm

Spectral distribution 400 nm

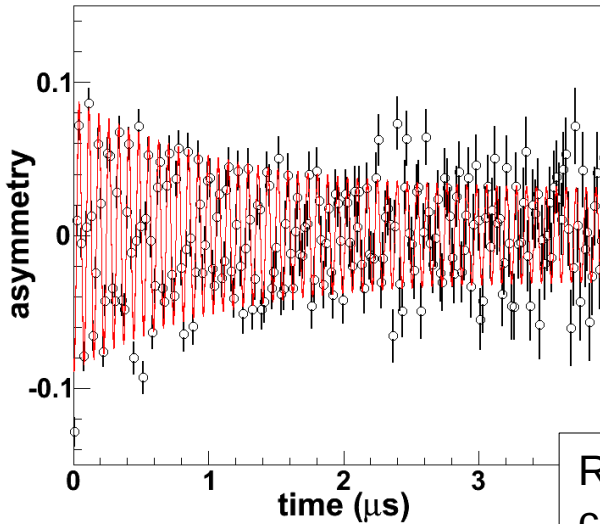


Persistent photo-induced inversion of Ge

a Ge (100), 1kG, 200 K, no light

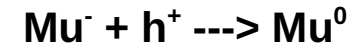


b Ge (100), 1kG, 220 K, LED ($\lambda = 405$ nm, 8 mW/cm²)



**Commercial Ge (100),
nominally undoped,
n-type ($\sim 10^{14}$ /cm³)**

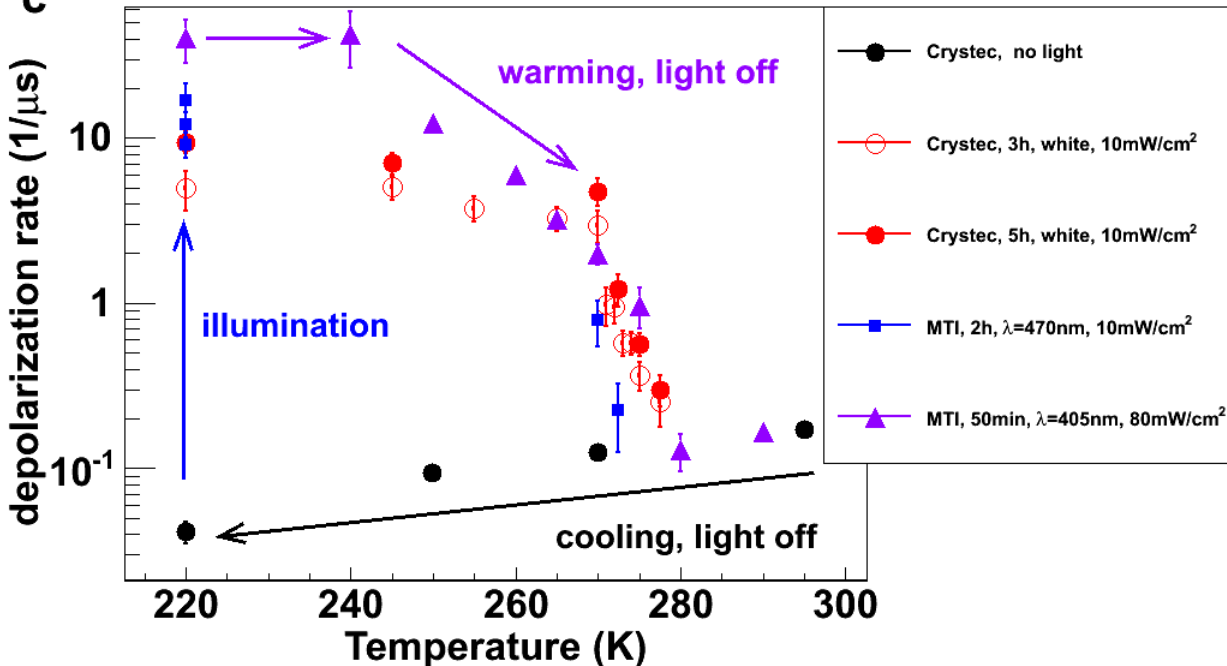
Relaxation due to charge
changing collisions:



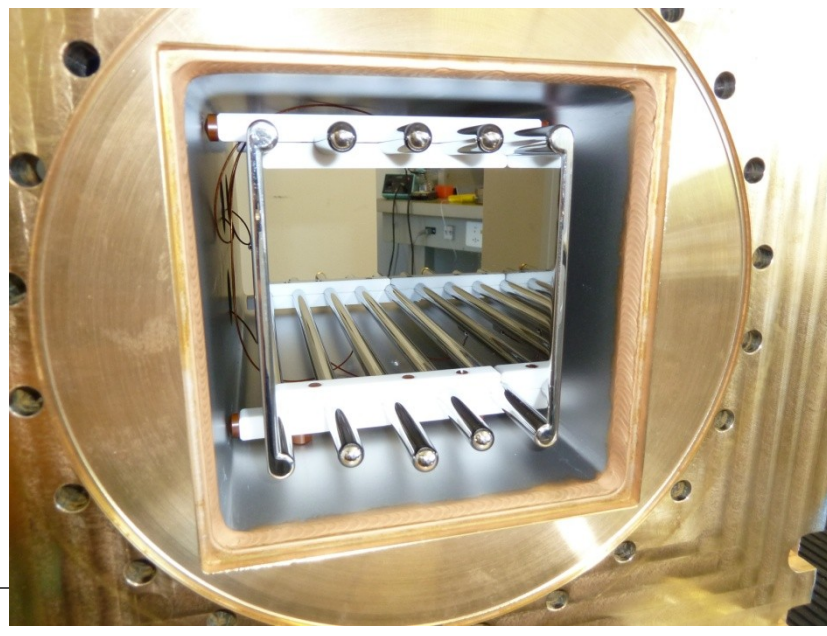
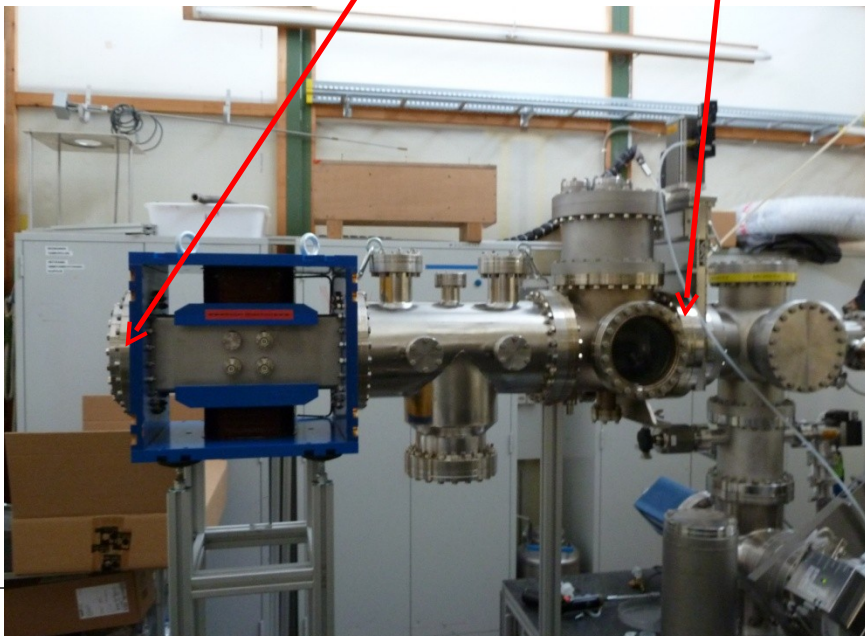
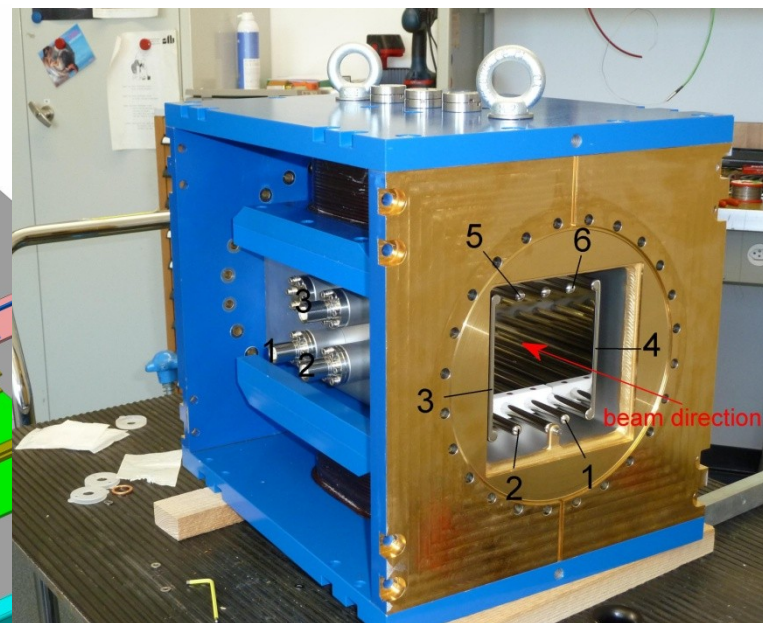
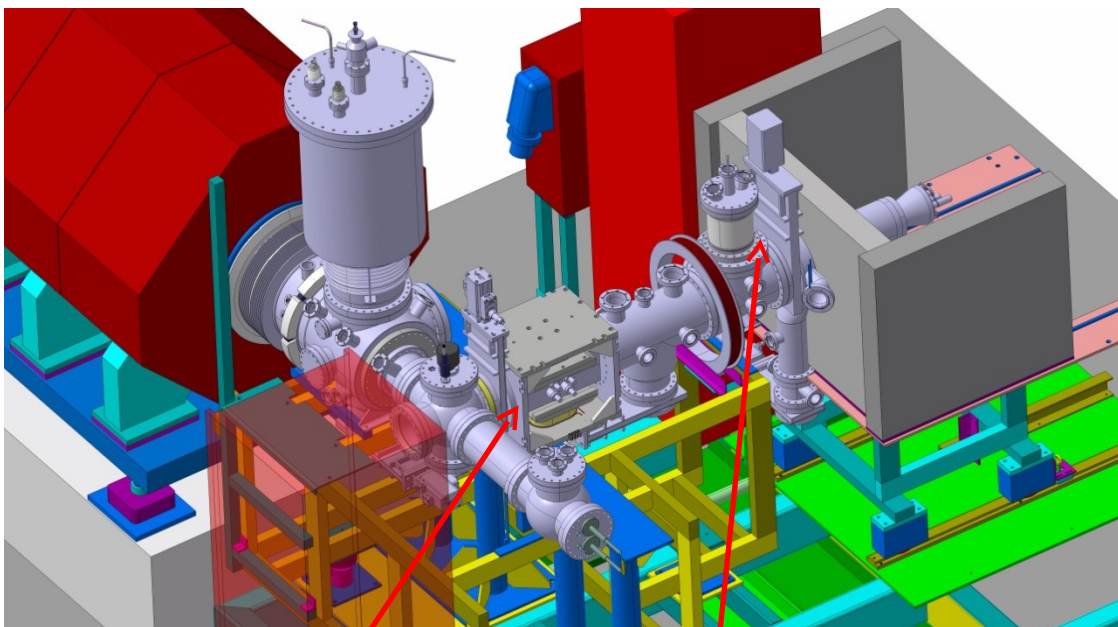
[Fan et al., Phys. Rev. **B78**,
153203 (2008)].

Filling of surface acceptor
states with electrons causes
inversion of surface region of
depth > 200 nm.
 $p \sim 10^{14}$ /cm³ (from relaxation
rate)

c

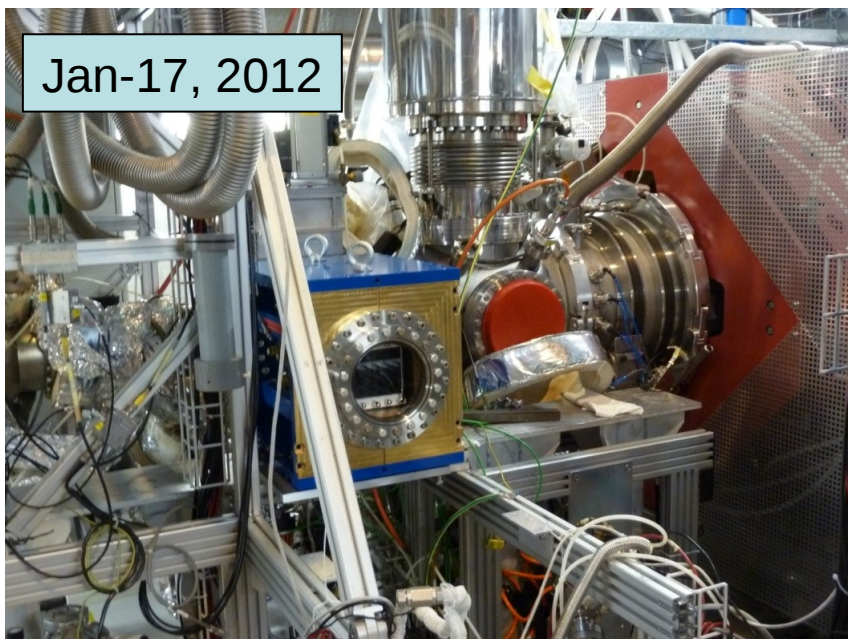


LEM spin-rotator for LF- μ SR

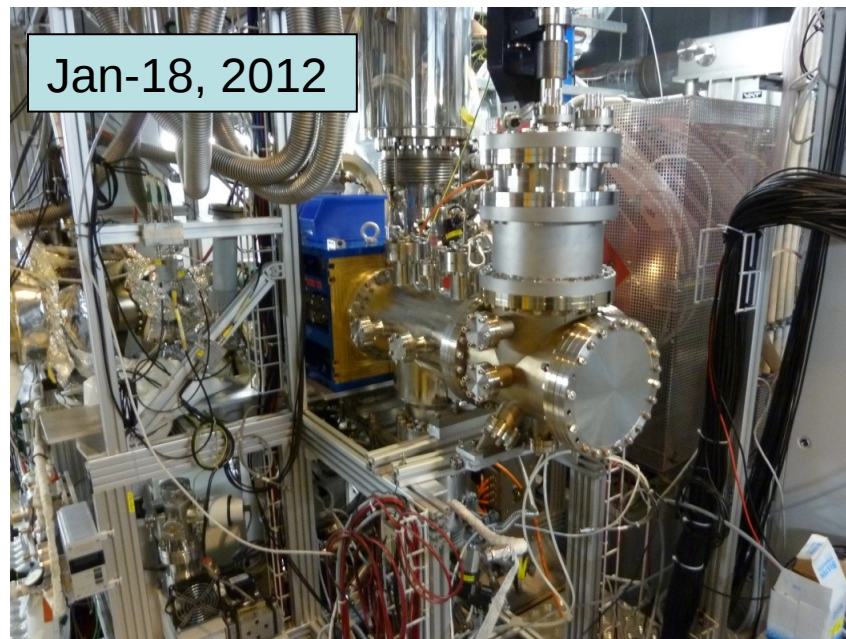


LEM spin-rotator installation

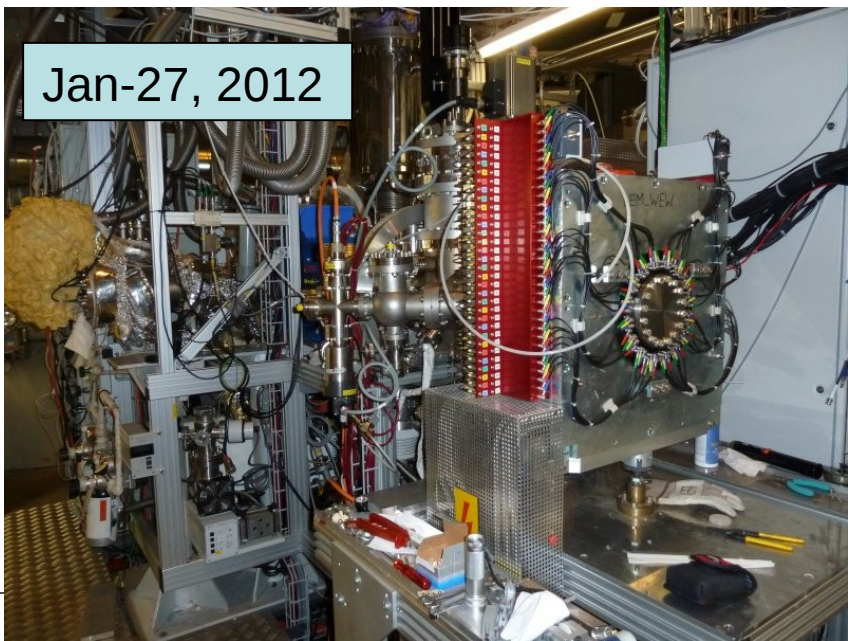
Jan-17, 2012



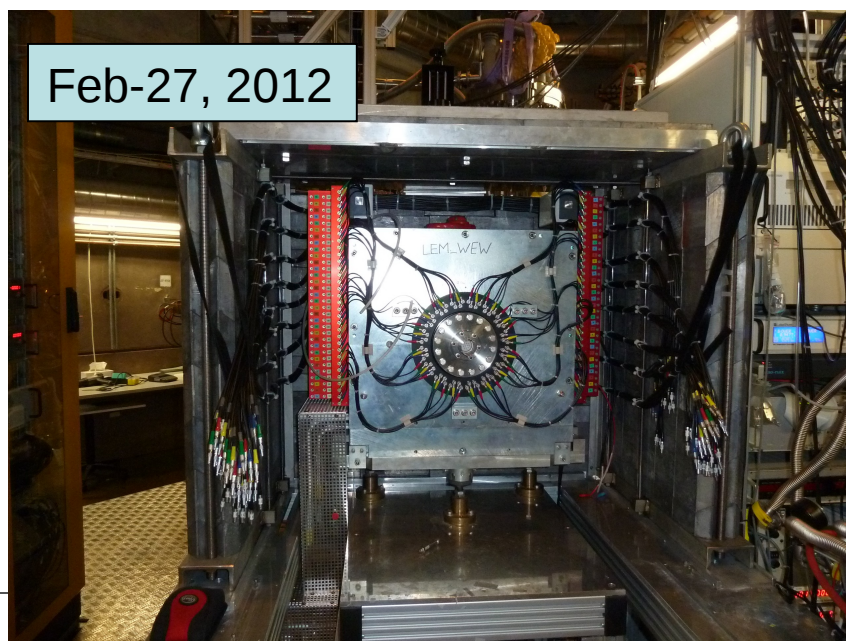
Jan-18, 2012

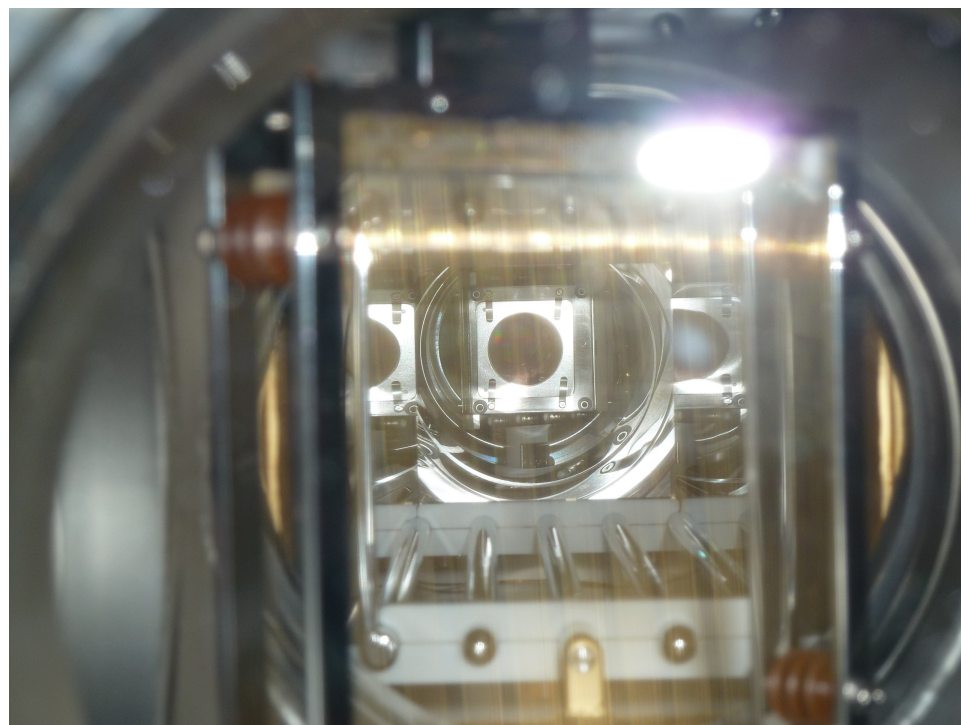
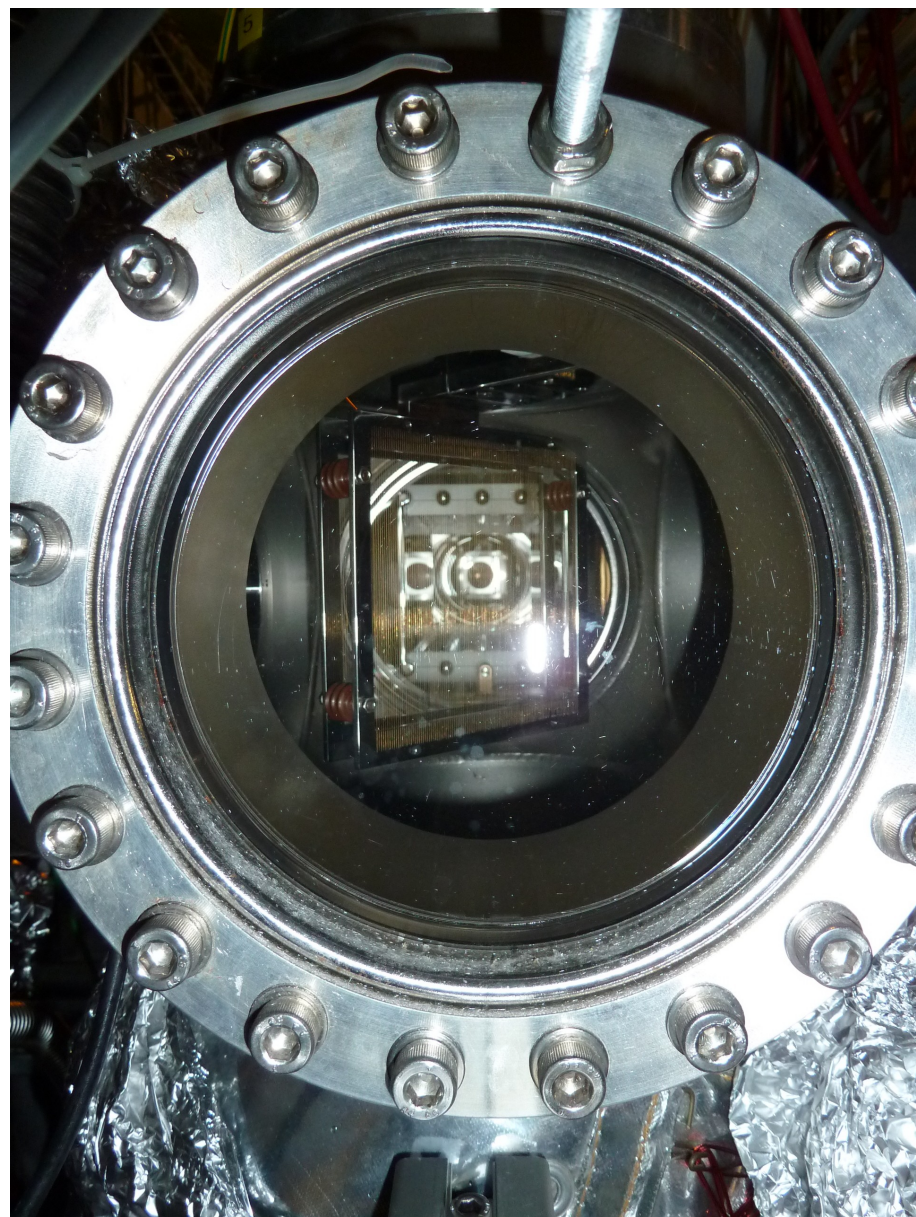


Jan-27, 2012



Feb-27, 2012

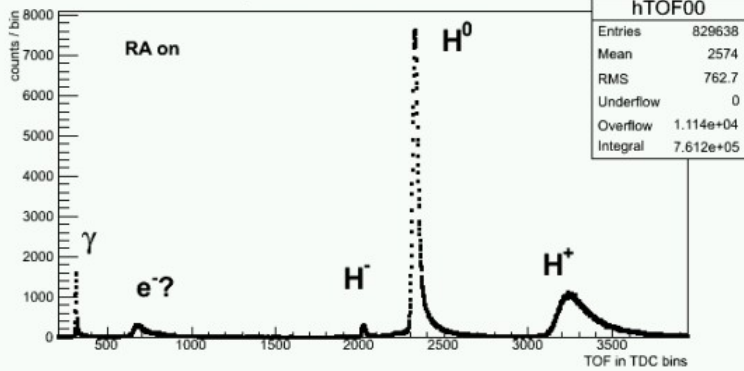




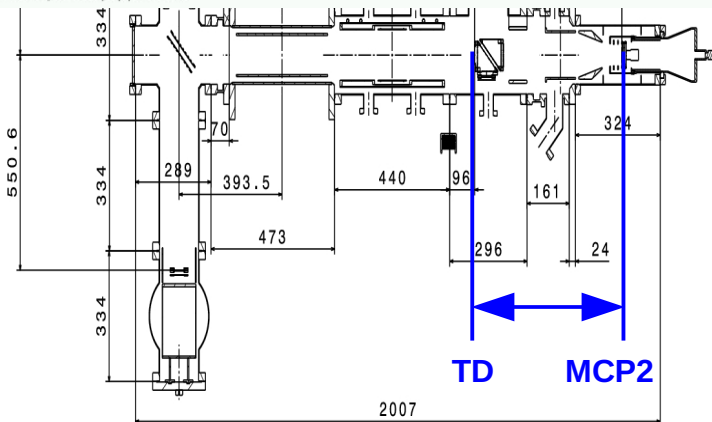
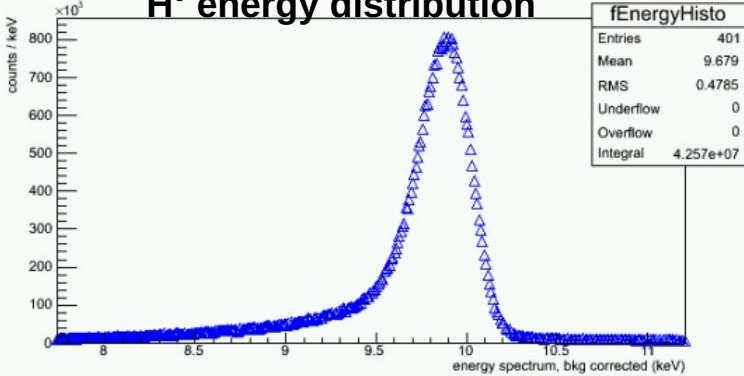
Looking through electrostatic mirror
on spin-rotator and trigger detector

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

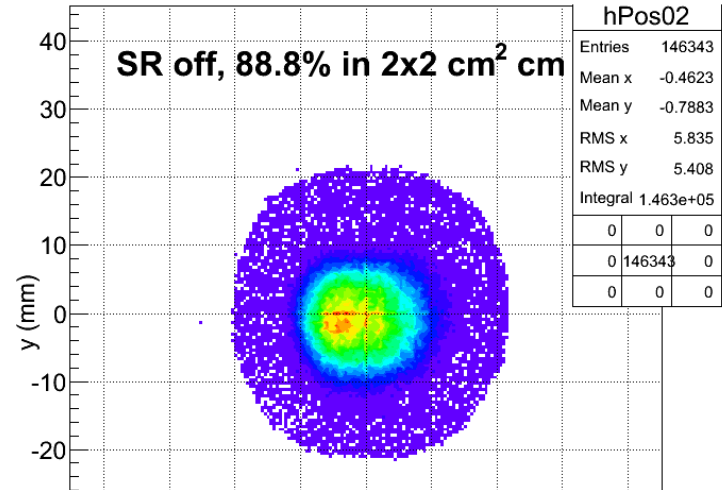
Run 134, 2012, proton TOF TD-MCP2, 7.5kV, SR on



H⁰ energy distribution

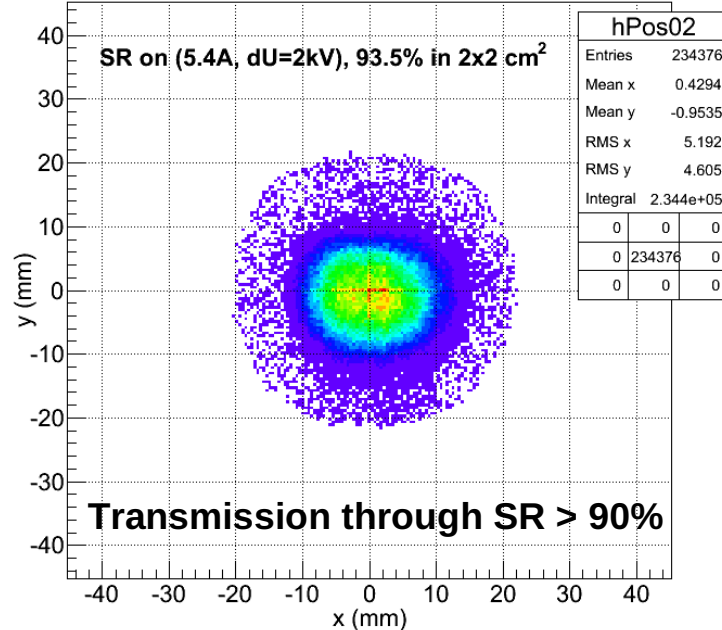


H⁺ Beamspot at sample position

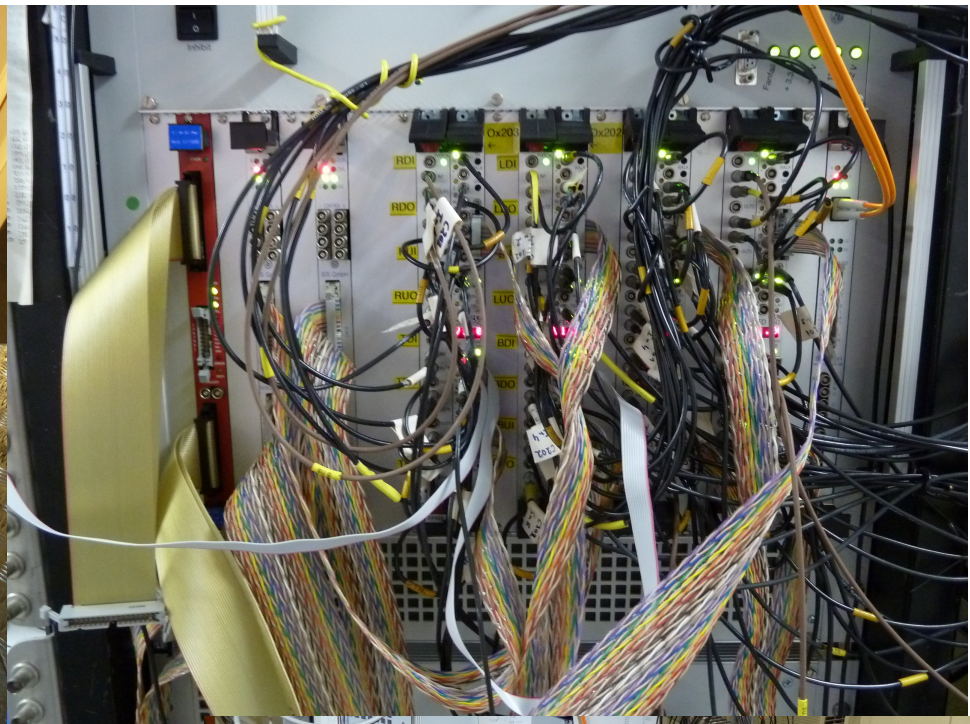


MCP2 y%x TOF M2F Cut fine (mm) 3100 - 3500 Run lem12_0134

Mod/L1/L2/L3/RA-LRTB = 7.5/3.9/4.0/3.0/5.75/5.65/5.75/5.65

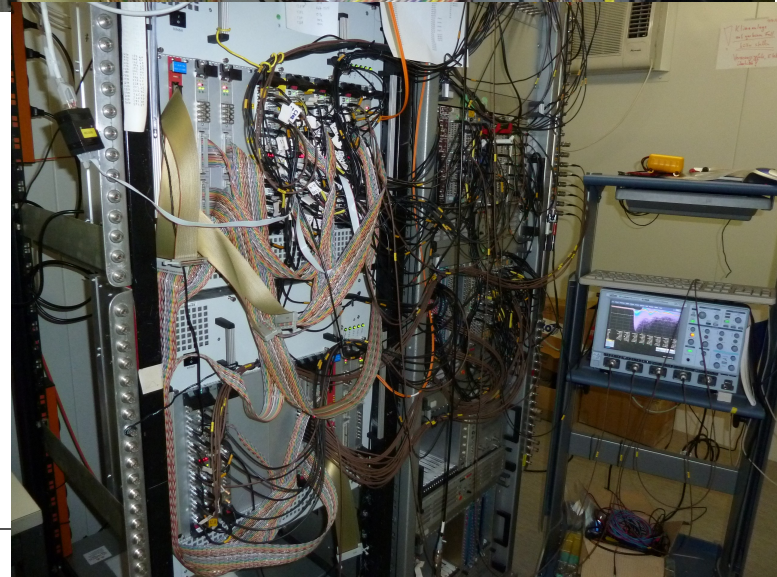


Data acquisition electronics



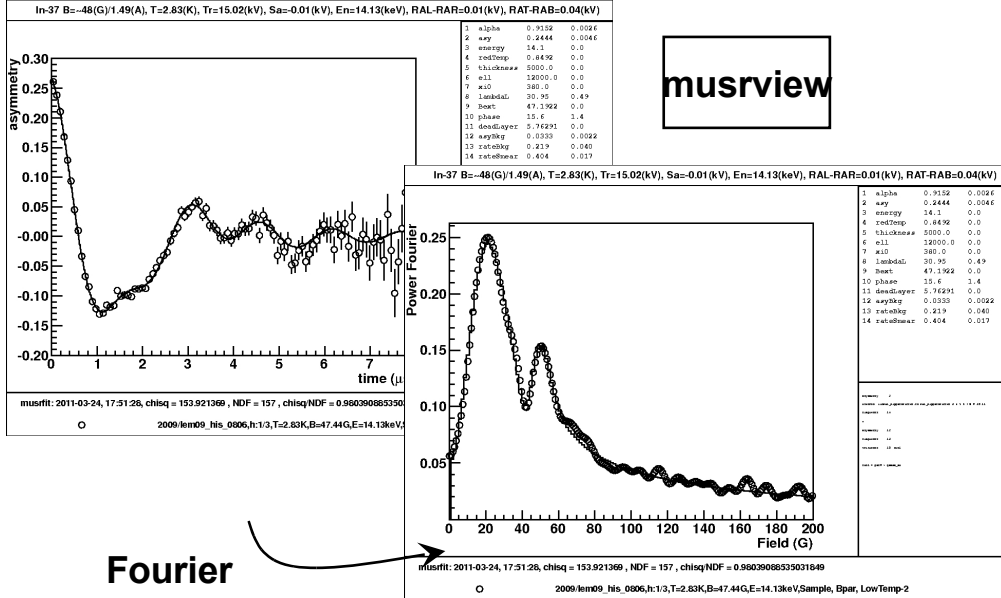
VME TDC, scaler, splitter, CFD modules
 - μ SR and time-of-flight data; all logic in software

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 μ SR data analysis



Fourier

extract fit parameters

create msr files

find t_0 , etc.

fit model

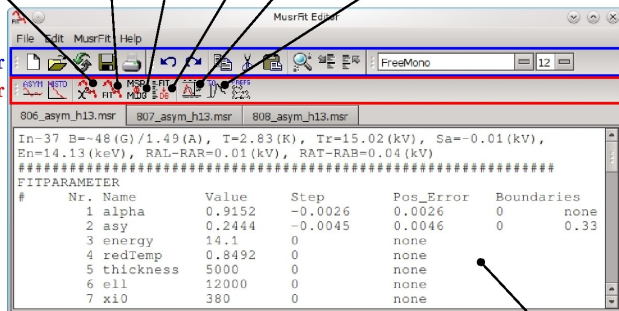
swap msr \leftrightarrow mlog

view data/fit

calculate χ^2

text edit bar

musrfit bar

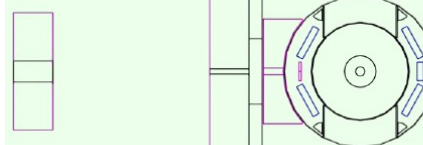


text editor window

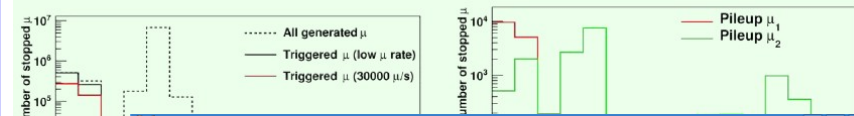
musrsim/ana – Instrument simulation and analysis

Example – GPD instrument at PSI

musSim:



musSimAna:



Left – illus collimators the M-cour

ROOT GUI

LEM time-of-flight GUI

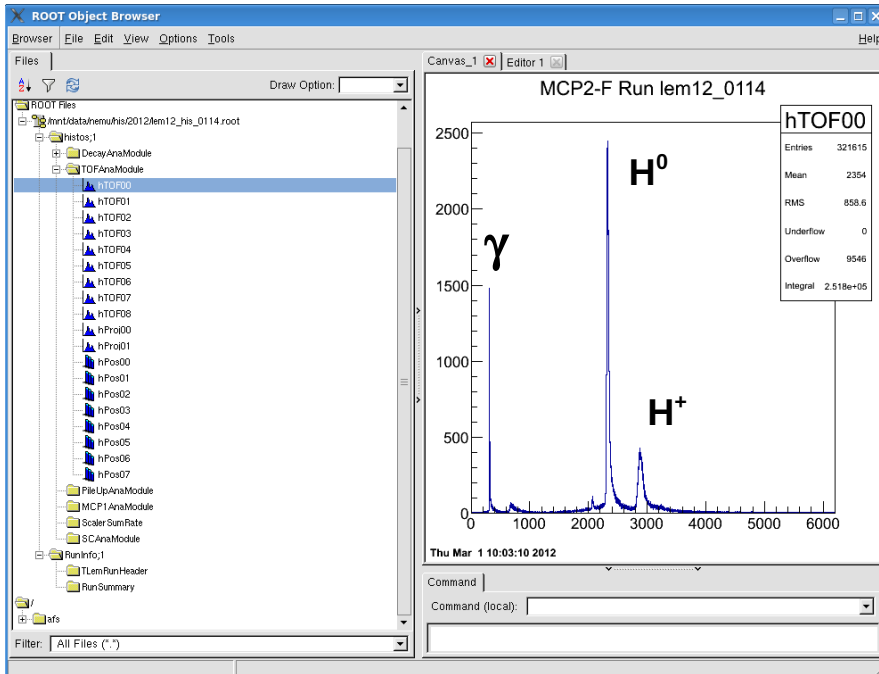
Input Parameters:

- Mu: Particle
- 563 drift length (mm)
- 232 t0 (TDC channel)
- 1400 T_min (TDC ch)
- 4000 T_max (TDC ch)
- 0.195312 binning (ns)
- Parameters for PlotToF:
 - 15 energy (keV)
 - 1 sigma_energy (keV)
 - 1000 N particles
 - 0 bkg/channel
 - 0 reverse timing
 - 79 L_gamma - t0 (bins)
 - 13.5 TOF foil e- (ns)

Buttons: Print Online Help, Print Settings, Run TDToF, Run ConvToF, Run PlotToF, Exit Root

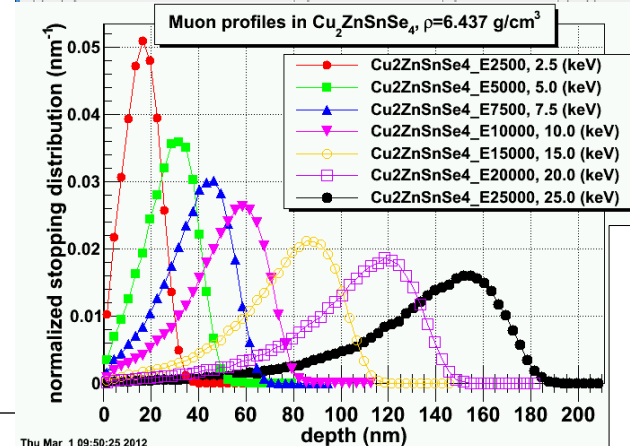
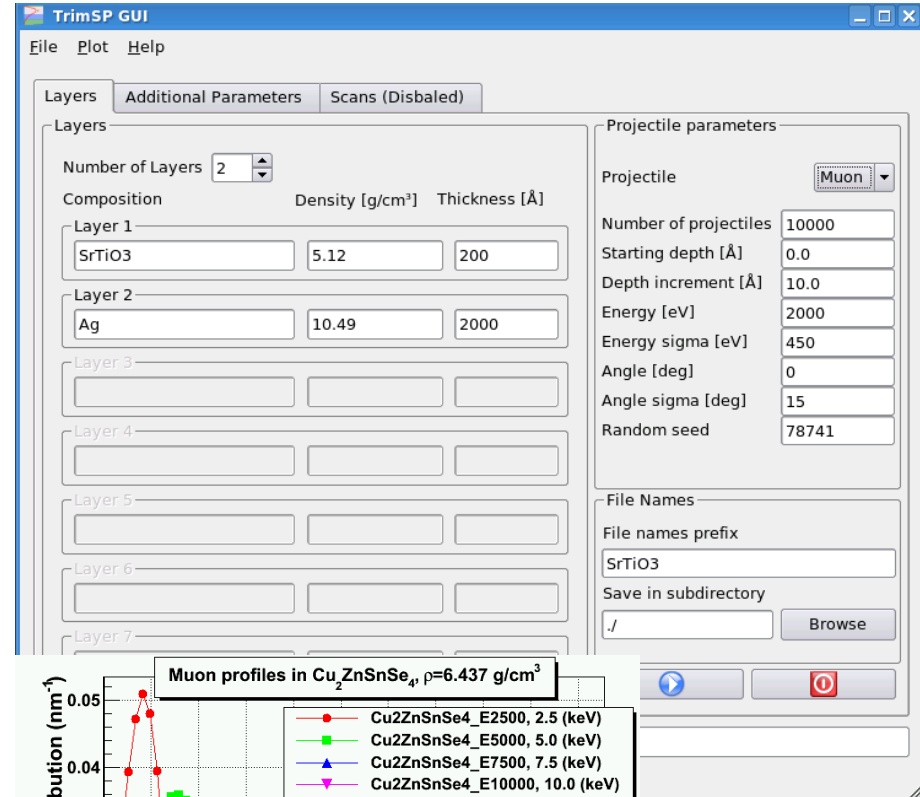
Run Title: Click on 'Plot Title' button to get title of selected run

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