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Wir schaffen Wissen – heute für morgen

The fast-timing detector system for the 10 Tesla μSR instrument

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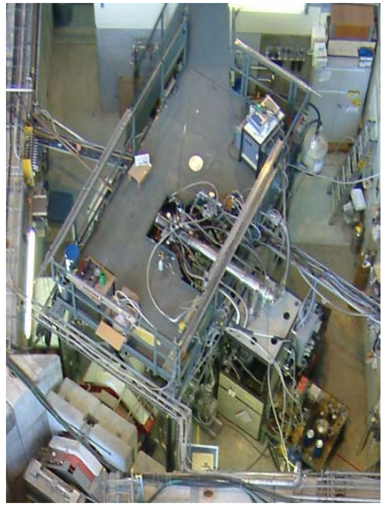
Current Status of High Field in μSR

μSR users have a big demand for high magnetic field spectrometers:

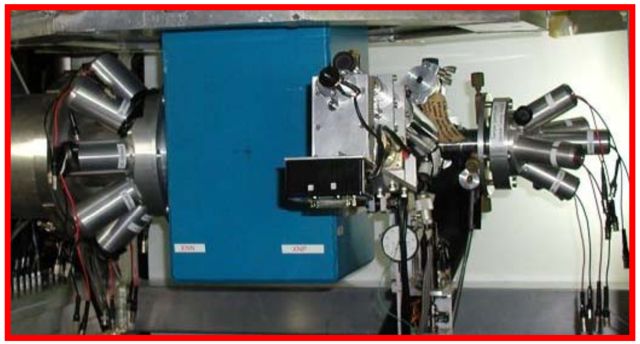
http://lmu.web.psi.ch/facilities/PSI-HighFieldMuSR/Scientific_Case.pdf



PSI: B ≤ 3T. Time resolution = 425ps. Base temperature: 12mK

ISIS: B ≤ 5T. Time resolution in T F limited by pulse width (σ>10ns). Optimized for LF. Base temperature: 30mK

TRIUMF: B ≤ 7T. Instrument with the highest time resolution (170ps). Base temperature: 1.7K



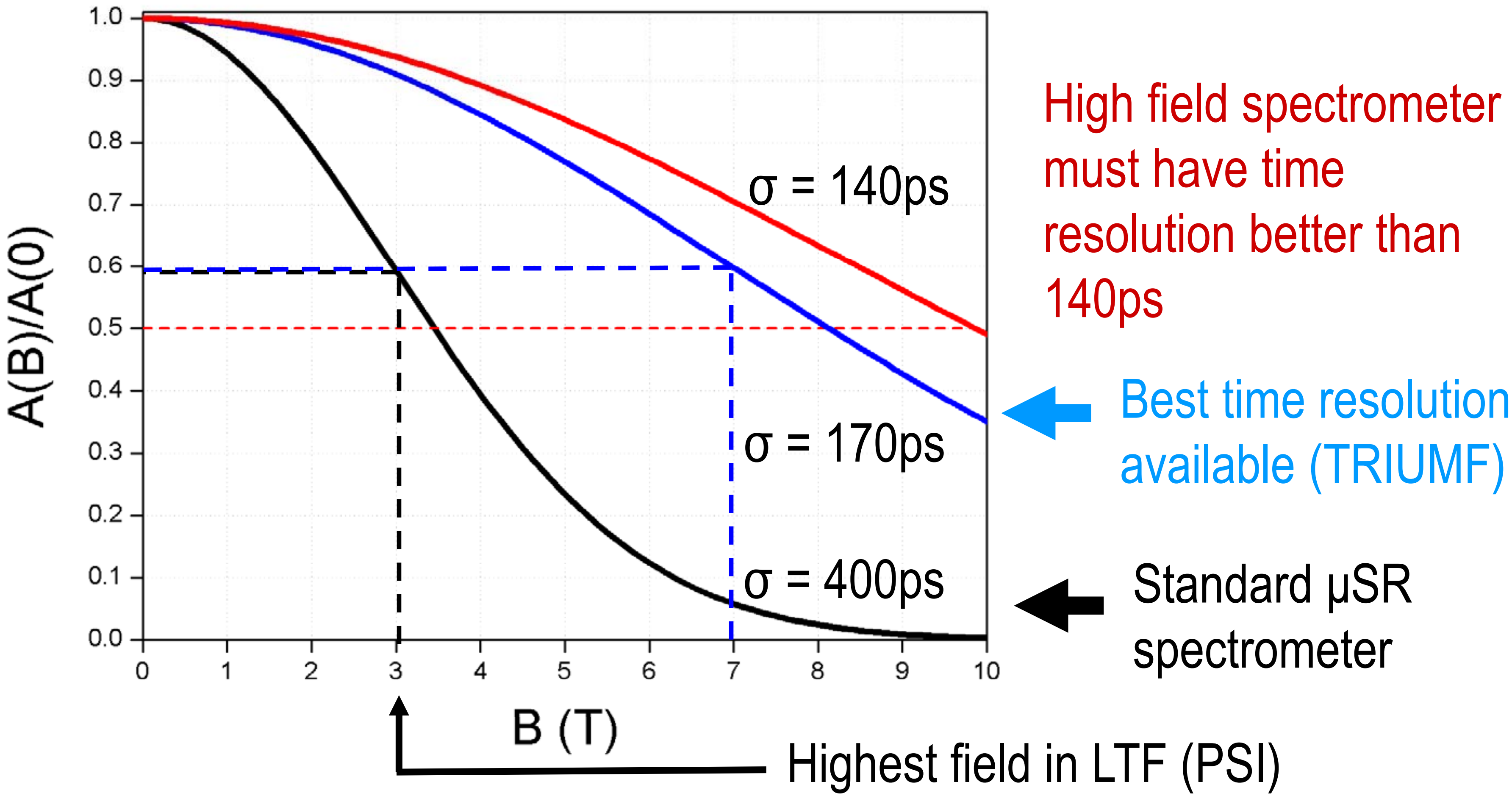
High Field Spectrometer at PSI

Challenging requirements: B_{MAX} = 9.5T, field homogeneity 10ppm, time resolution better than 140ps, base temperature:15mK.

- **Magnet**. Split pair from **Oxford Instruments**. Warm bore (89mm). High homogeneity (<10ppm in 4mmX4mmX10mm).
- Cryogen-free **Dilution Refrigerator**. Custom design fully horizontal from **BlueFors**. Base temperature:15mK. Veto detector mounted in sample space.
- **2K Cryostat** – Horizontal design. Veto detector mounted in sample space.
- **Detector system** - technical innovations required!

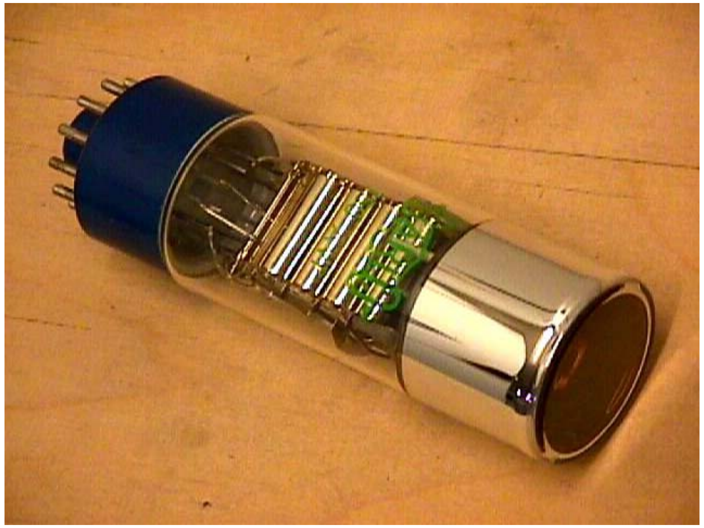
Challenges for the New Detector System

$$A(B) / A(0) = \exp(-2\,(\pi\,\sigma\,\gamma\,B)^2)$$



Challenges for the New Detector System

Traditionally, µSR detectors are based on **Photo Multiplier Tube** technology.
140ps is at the limit.
Reason: PMT need light guides = light pulse broadening and attenuation.

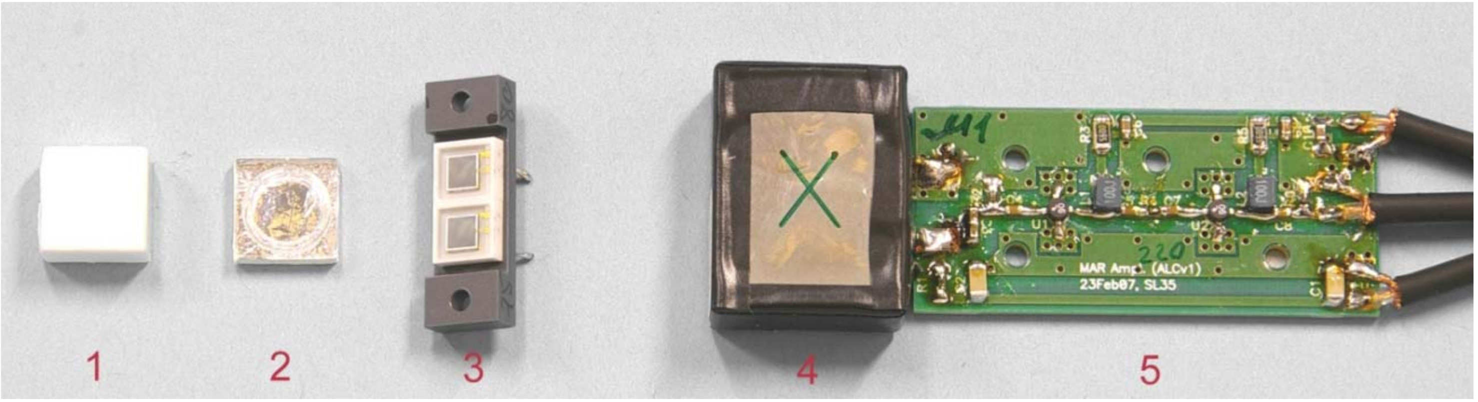


New technology required:

- **Compact (positron spiraling radius ~1cm @ 10T)**
- **Magnetic field insensitive**
- **Non magnetic components (10ppm homogeneity)**

G-APD based detectors

Geiger-mode Avalanche Photo Diodes are suited for µSR measurements
A. Stoykov, *et al*., Physica B, 404, 990 (2009)



(1) Positron counter: EJ-232 10x10x5mm;

(2) Muon counter: EJ-232 ø8x0.3mm in a 10x10x2mm frame (BC-800);

(3) 2x **MPPC S10362-33-050C** (3x3mm^2, **Hamamatsu**)

(4) scintillator + photosensor in a light tight box;

(5) broad band amplifier (PSI, gain ~13, bandwidth ~ 600 MHz).

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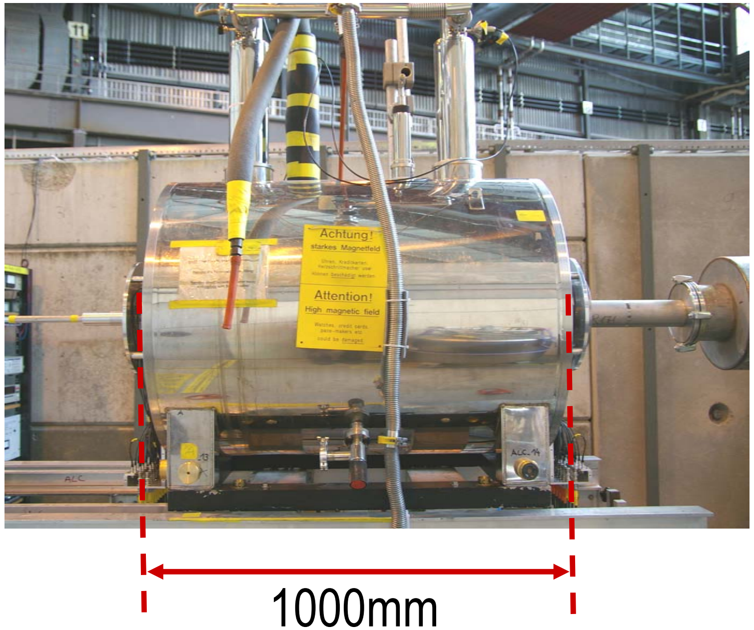
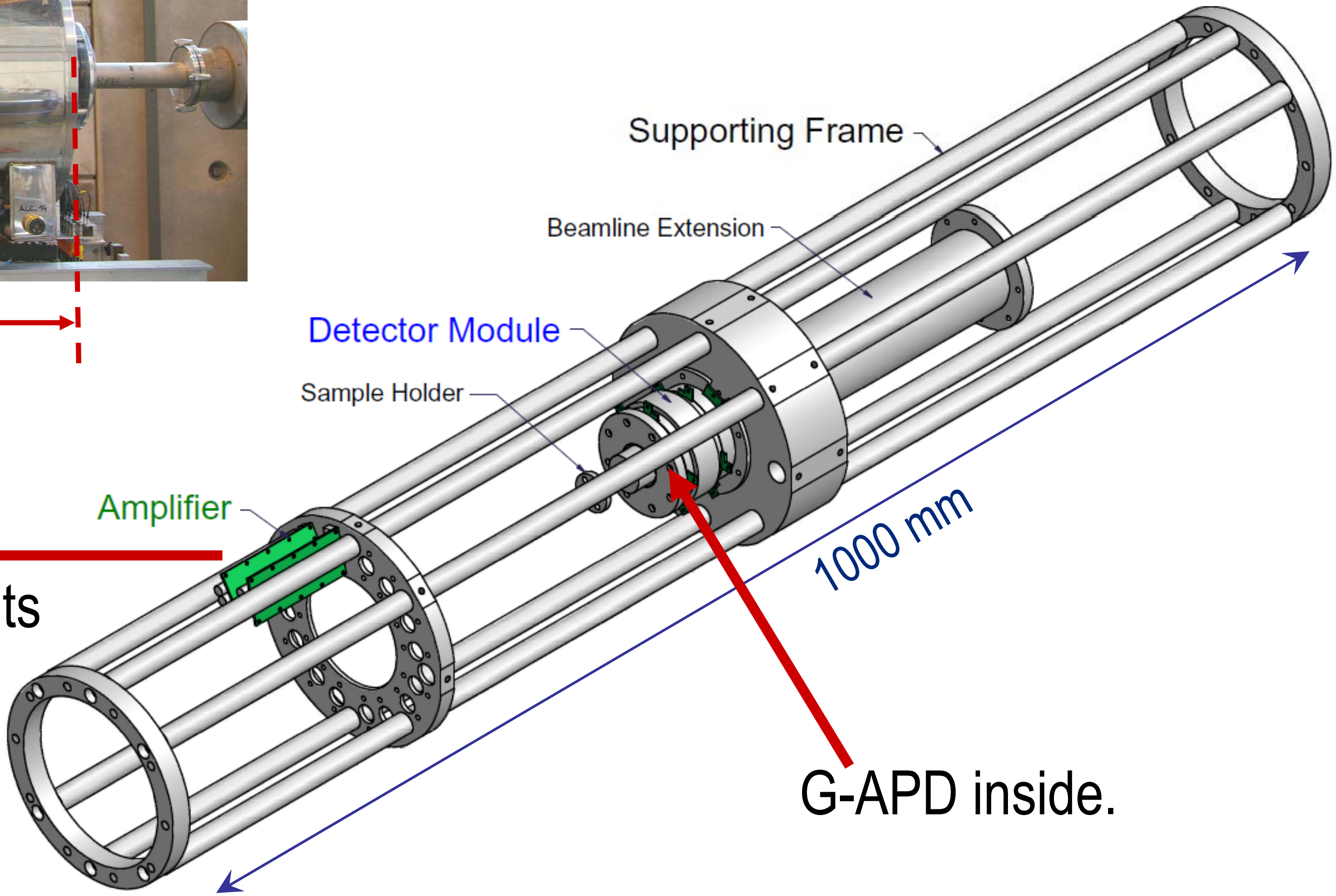
Detector prototype for High Field μSR

We built and tested a detector prototype in 2009 (up to 4.8T).

Excellent results!

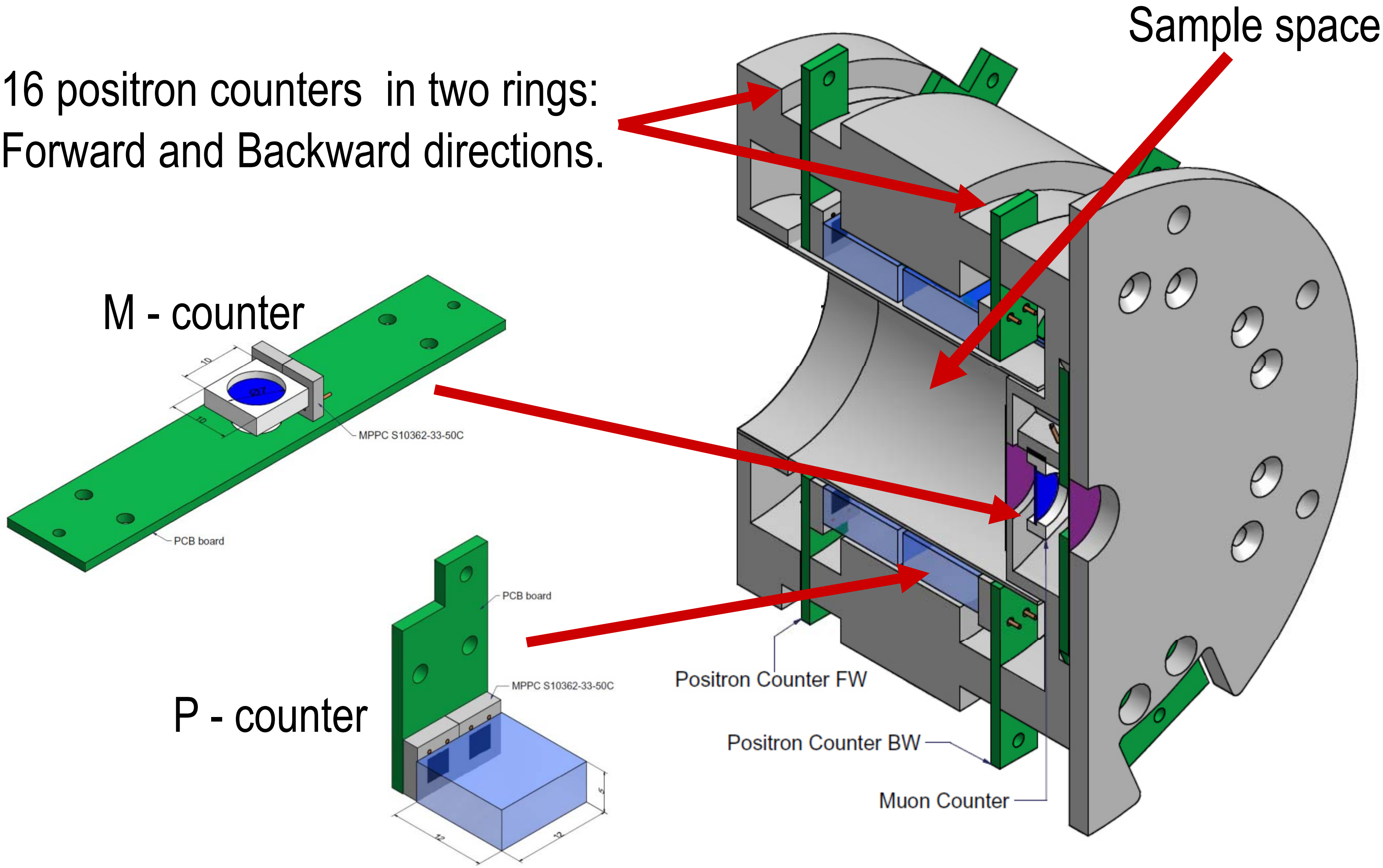




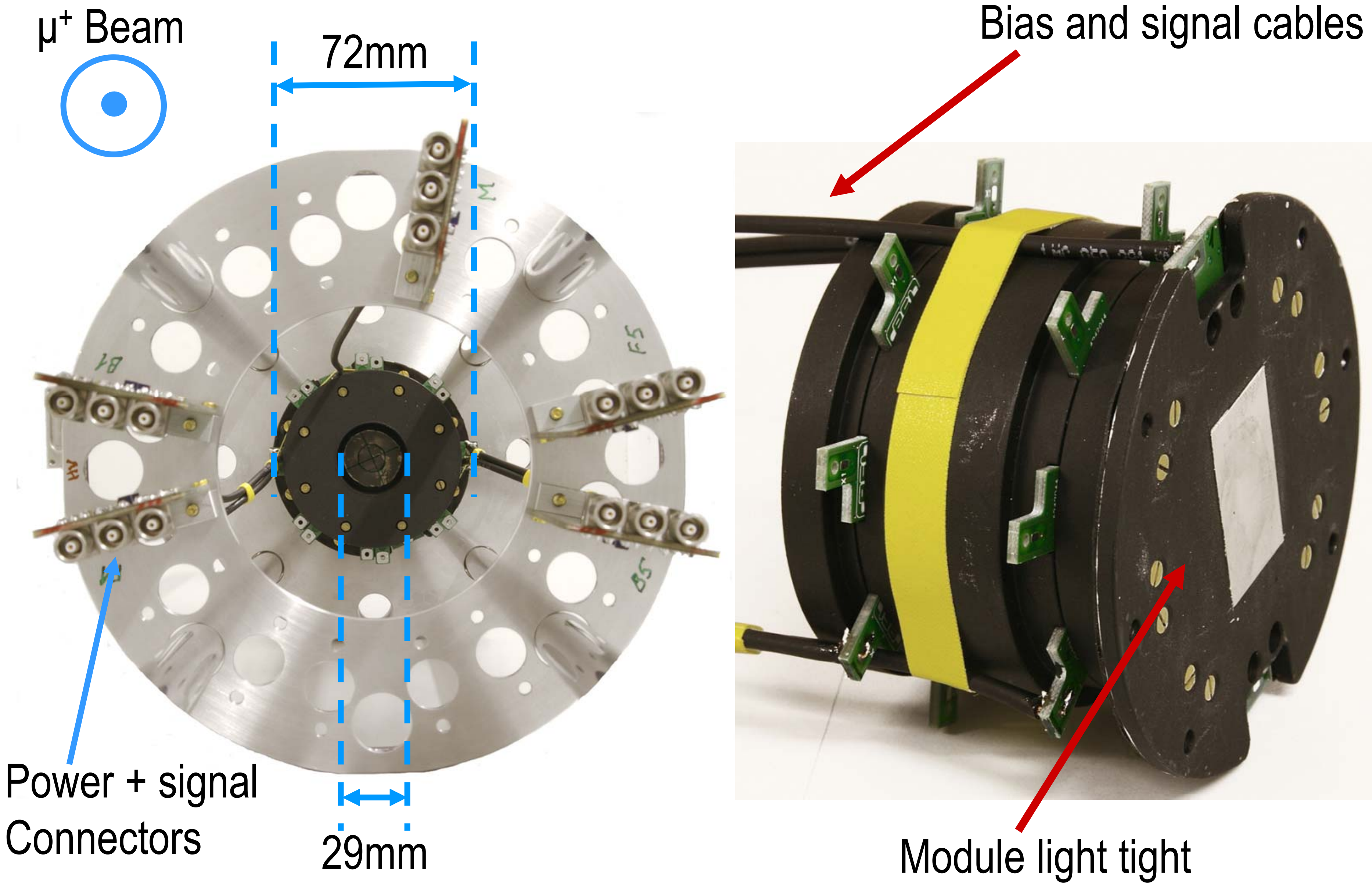
Amplifiers have magnetic components $\Rightarrow$ separated from sample.

G-APD inside.

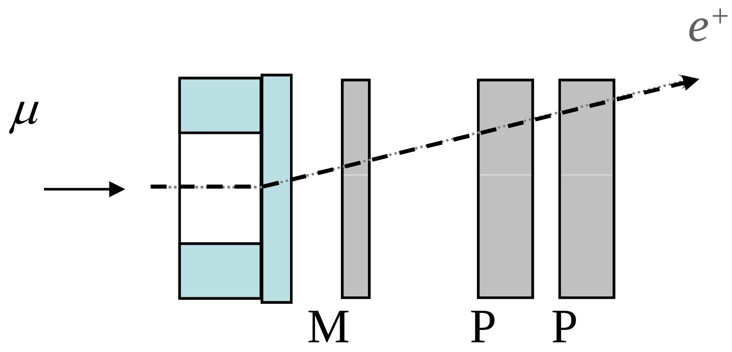
Detector prototype for High Field μSR



Detector prototype for High Field μSR

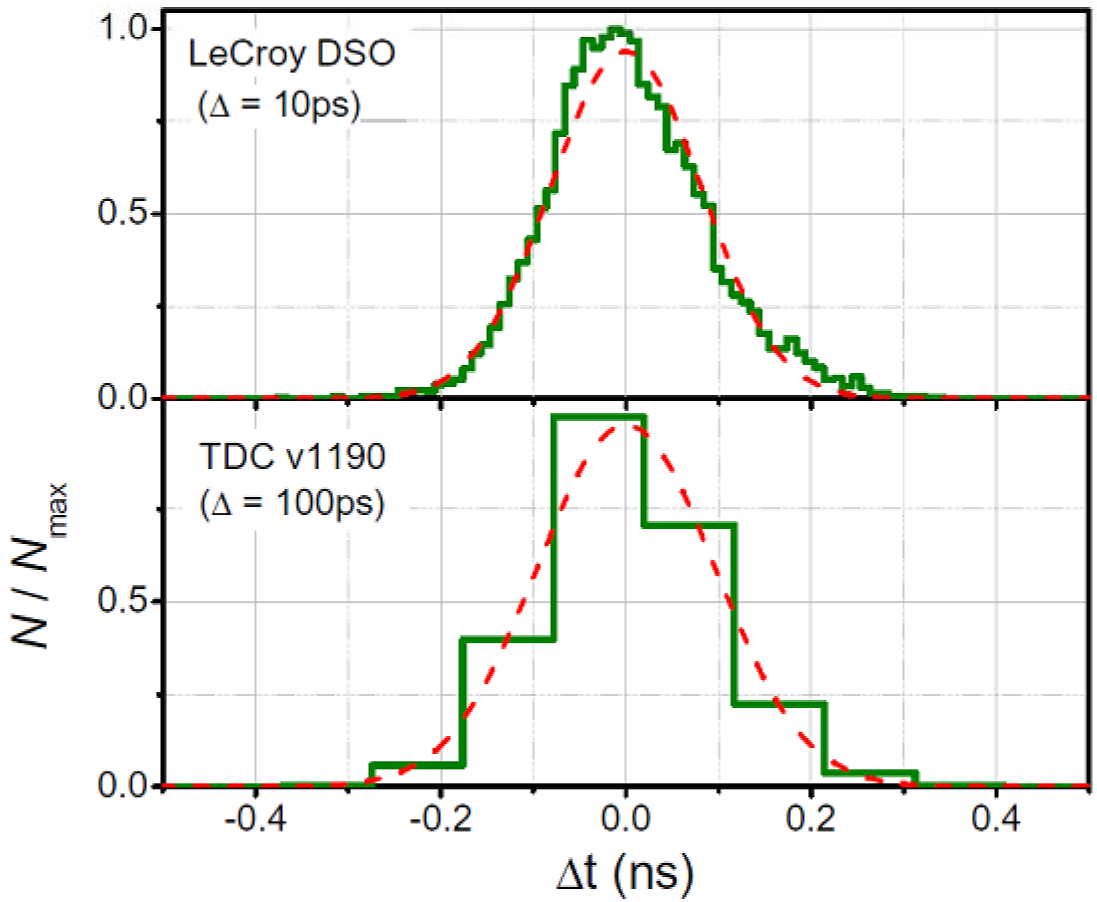


Performance of the detector module



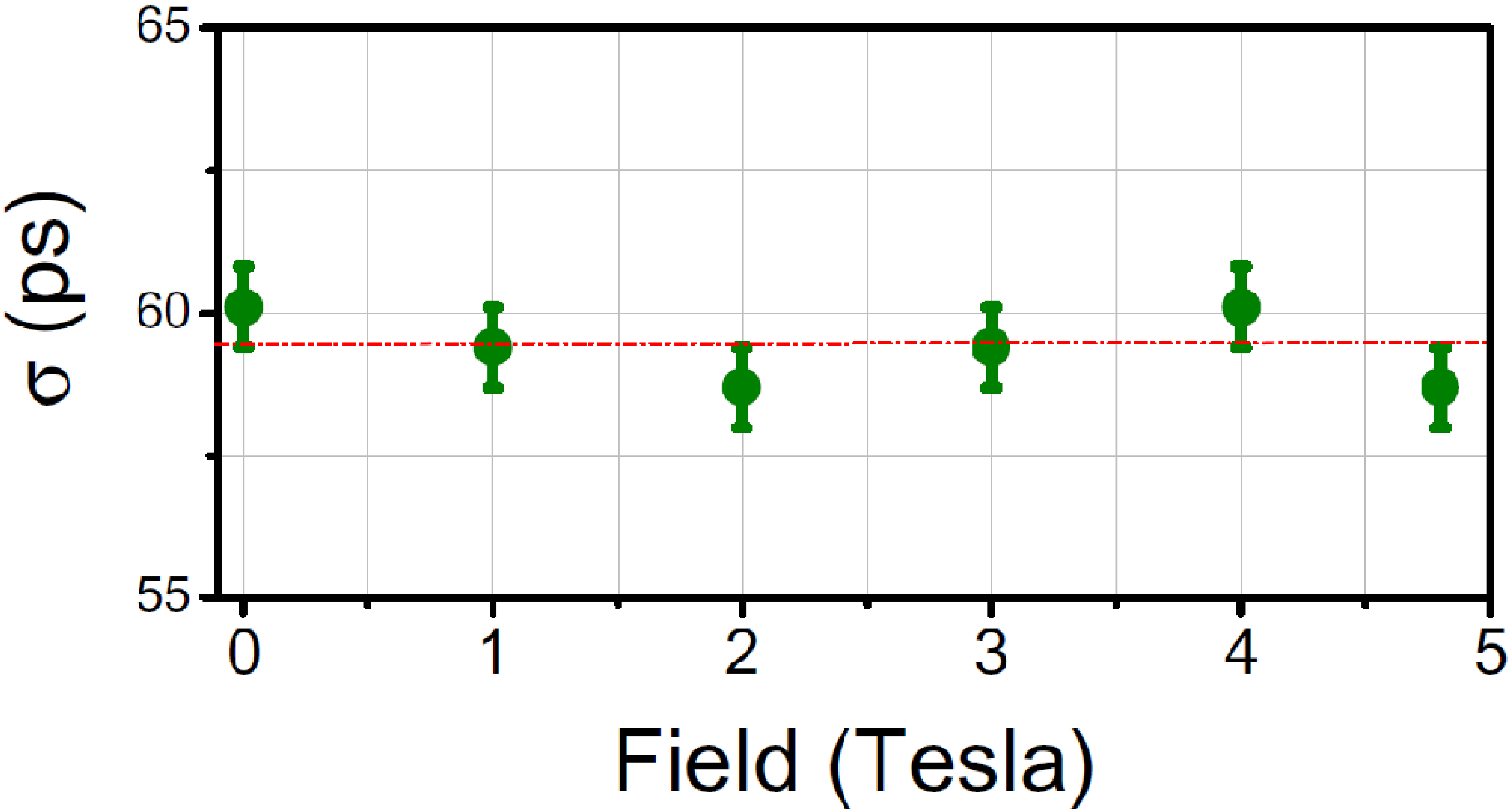
$\sigma_{detector}$ = 77ps

σ_{total} = 92ps

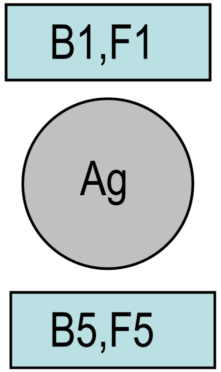


Performance of the detector module

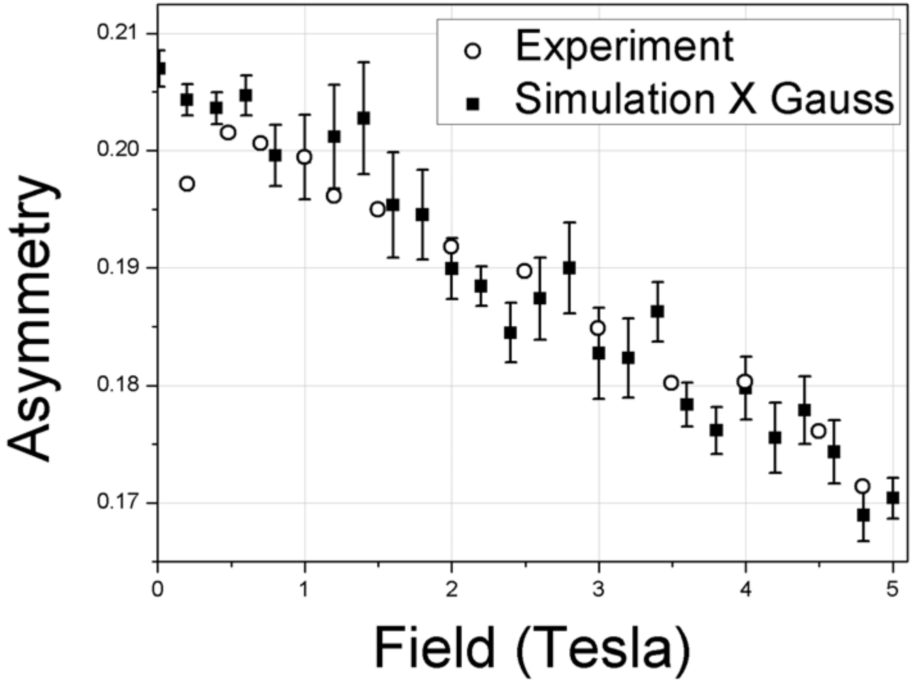
Time resolution of positron counters in this setup is **insensitive** to magnetic field

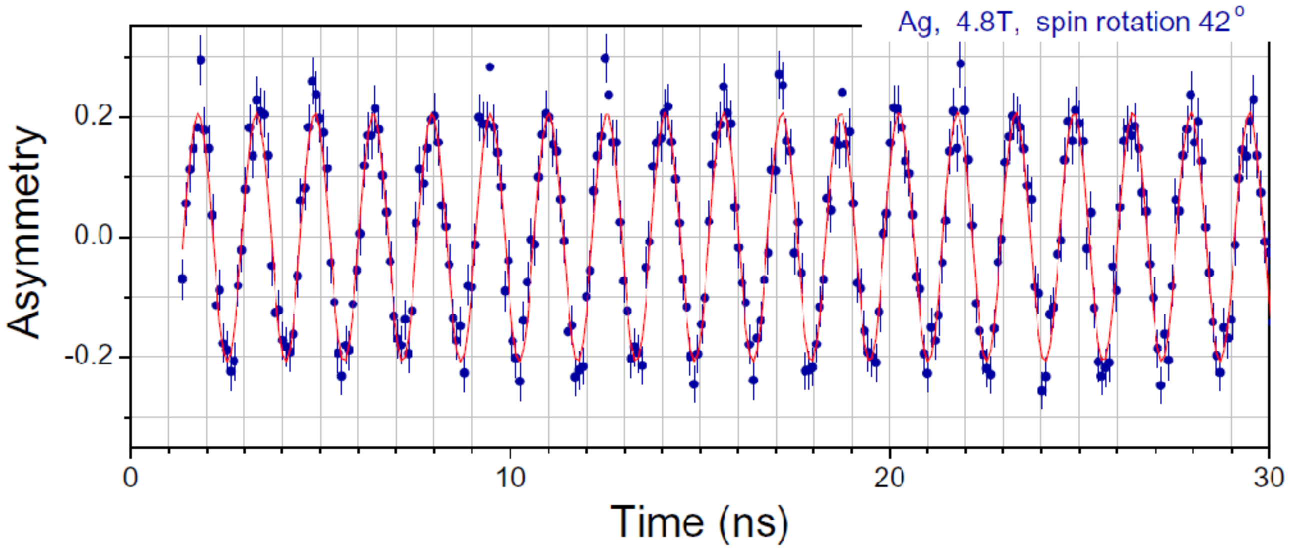


μSR measurements



Measurements with 4 counters



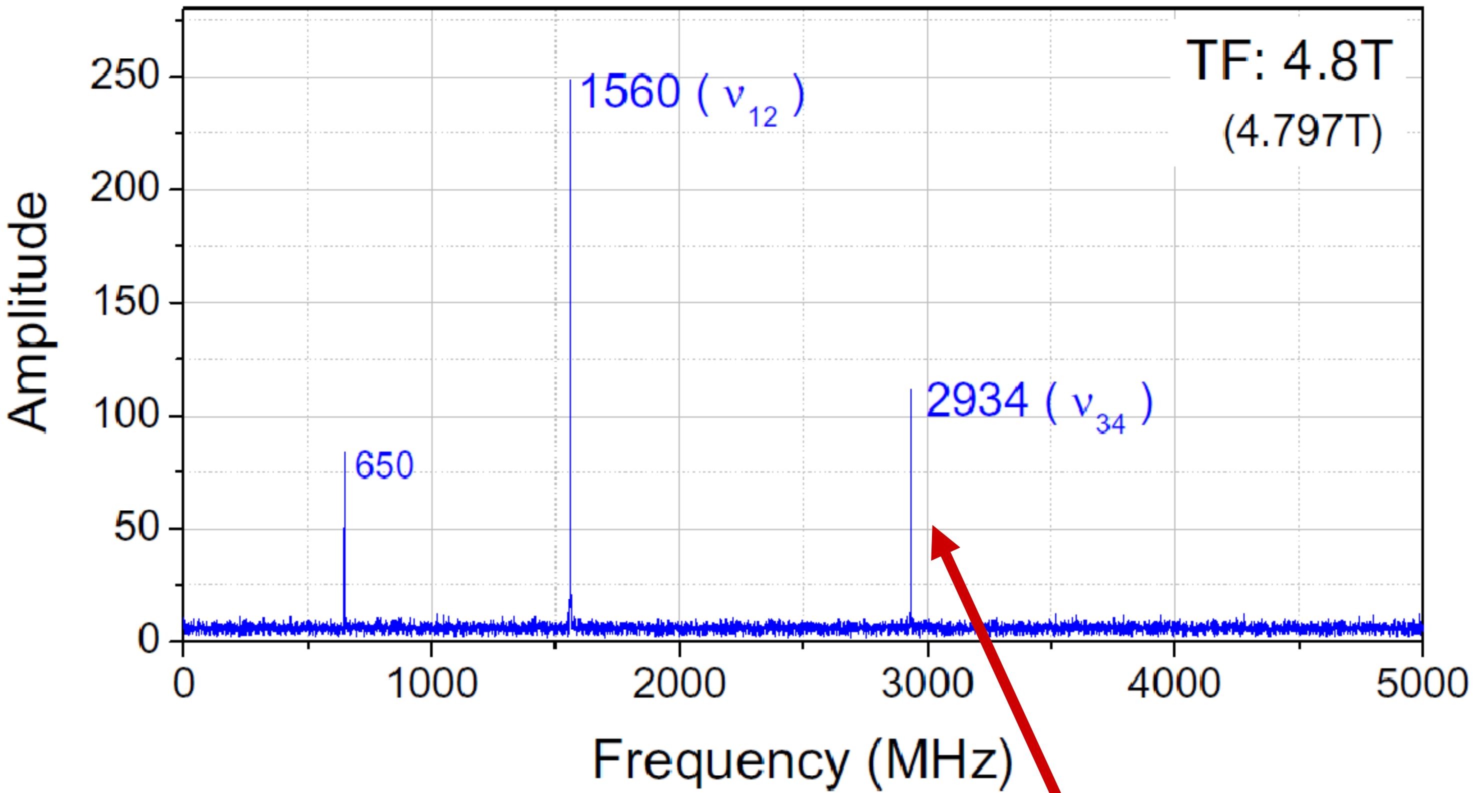


A = 0.208(1)

λ = -0.002(6) MHz

ν = 649.825(1) MHz

Quartz (muonium)

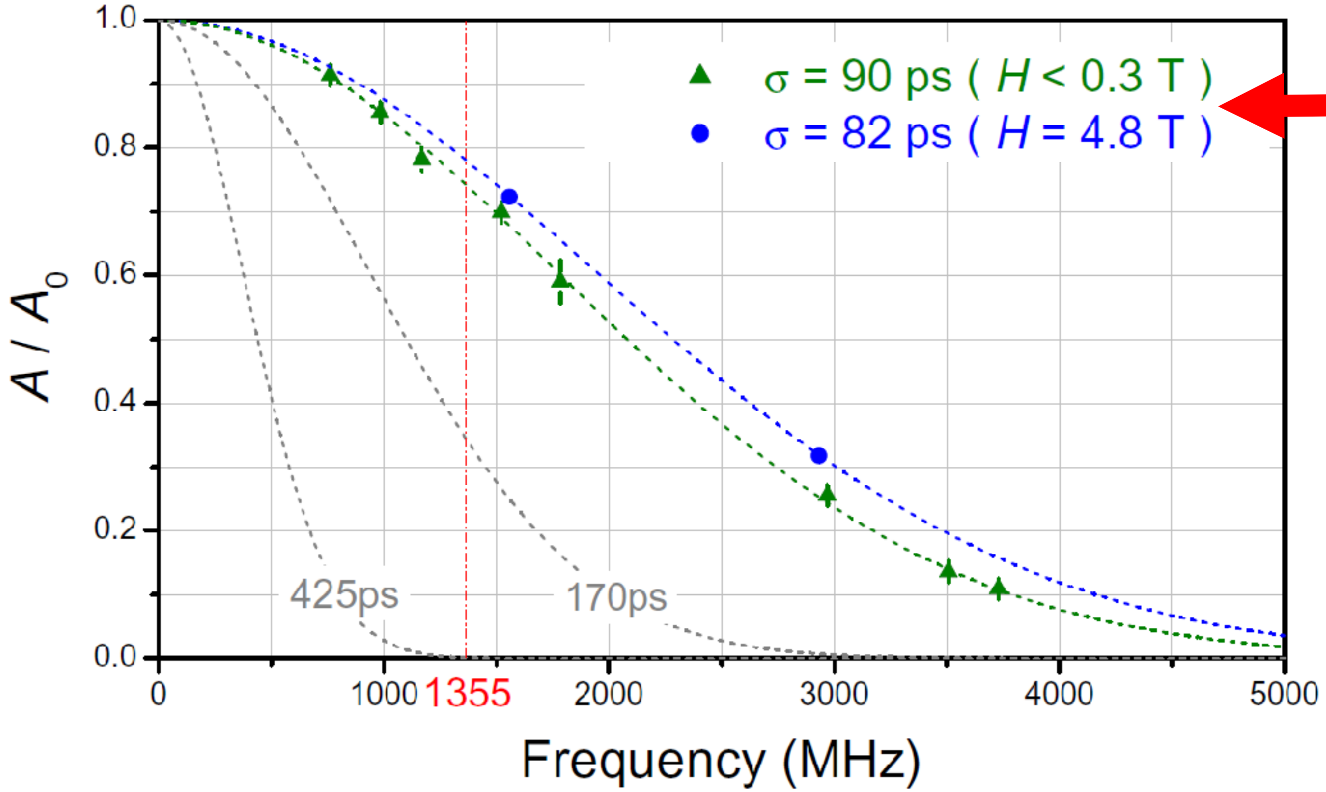


Muonium can probe several frequencies at the same field.

To our knowledge, measuring such a **high frequency** μSR signal in such a **high magnetic** field has **never** been achieved.

µSR measurements

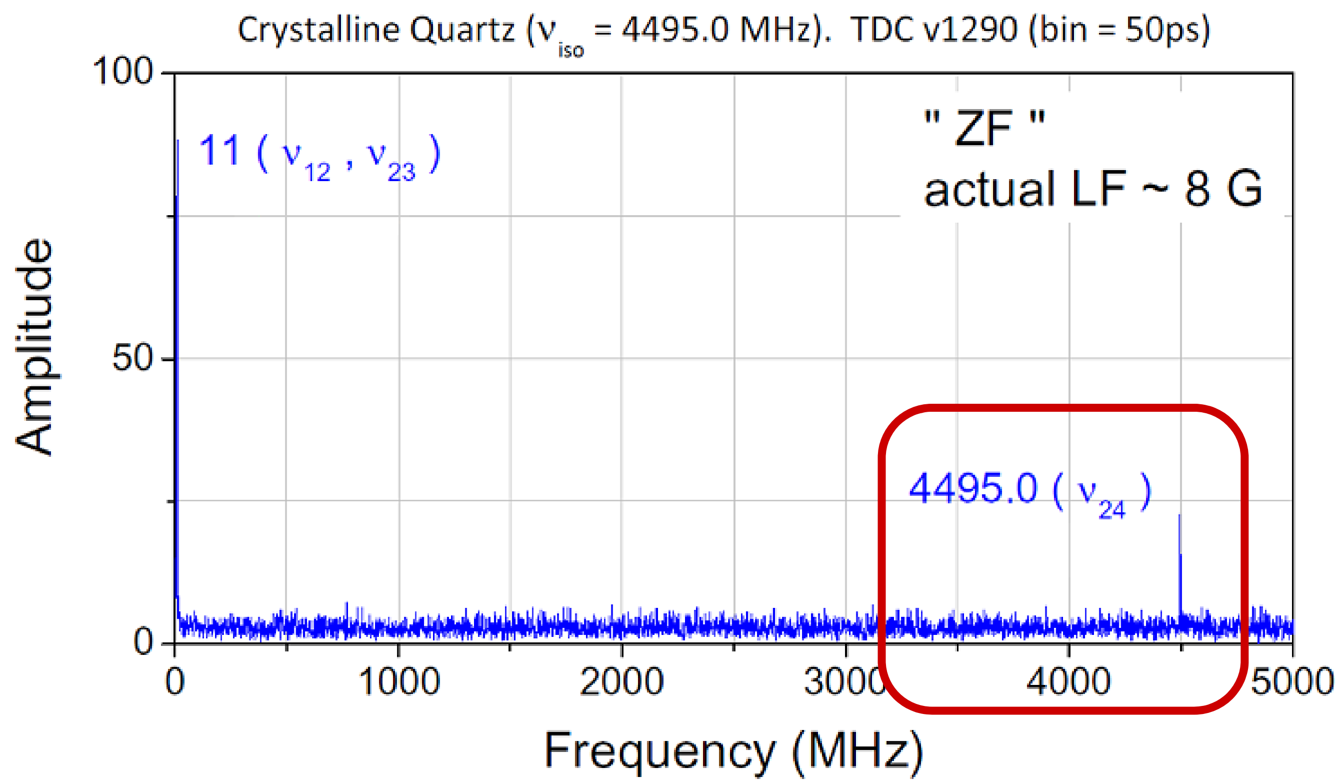
Quartz (muonium)



Time resolution **better** than 140ps

Improve of σ at higher fields probably due to higher energy losses of positrons (longer curved trajectories).

Quartz (muonium)



Measured only with dedicated setups. **No standard** µSR spectrometer is capable of this measurement.

Isotropic Muonium hyperfine coupling = 4495 MHz

Conclusions and acknowledgements

A real-size G-APD based prototype of the Timing detector has been built, and its performance is at the top of the expectations:

- **Insensitive** to the magnetic field.
- Time resolution of the detector = **77ps**.
- Total time resolution ≈ **90ps**.

Acknowledgments:
Frontend electronics developed by PSI Electronics & Measuring-Systems Group (U. Greuter, U. Hartmann, R. Schmidt). Founding from:
•RII3-CT-2003-505925 (FP6)
•NMI3:CP-CSA_INFRA-2008-1.1.1 Number 226507-NMI3(FP7)

G-APD: parameters

- Active area (1 – 10 mm^2)
- Number of cells → Dynamic range (100 – 10000 mm^{-2})
- Photon Detection Efficiency: ***PDE*** **(**λ**, *U*)**
- Gain: ***M*** (10^4 – 10^7)
- One-photon time resolution: σ_{1ph} **(**λ**, *U*)**
- Excess noise factor: $F = 1 + \sigma^2(M) / \langle M\rangle^2$
- Inter-pixel cross-talk: $\alpha(M)$
- Operating voltage: ***U*** (15 V – 150 V)
- Dark current: $I_0(T, U)$ (10 nA – 100 μA / mm^2 at RT)
- Dark counts: $N_0(T, U)$ (0.1 – 10 MHz / mm^2 at RT)
- Cell recovery time (10 – 1000 ns)
- Temperature coefficient of gain: $(\Delta M / M) / T$ (0.1 – 10 % / C)
- Radiation hardness

Hamamatsu
MPPC S10362-33-050C

3 x 3 mm^2

PDE > 30% at 390 nm

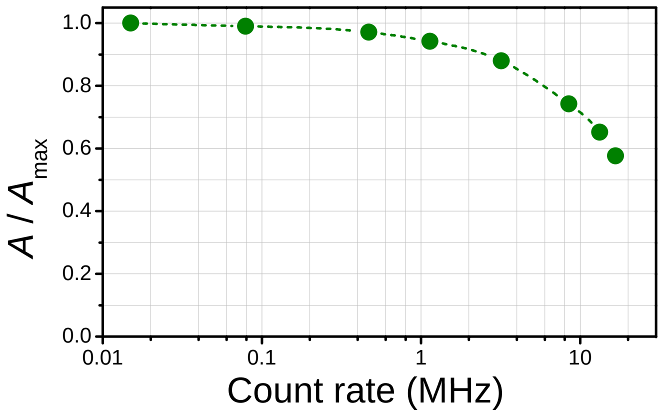
$M \sim 7 \cdot 10^5$

$U \sim 70$ V

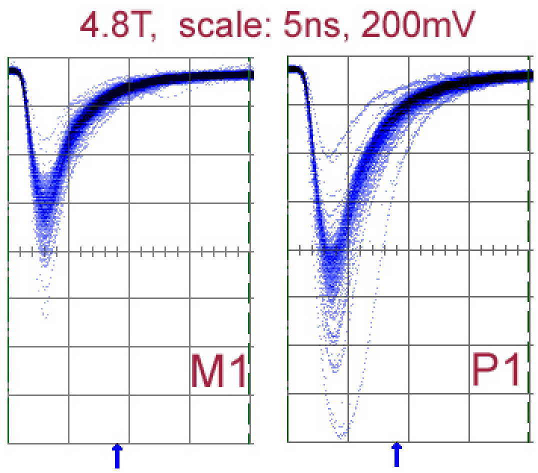
$1/M \cdot dM/dT \sim 6\% / {}^0C$

For applications requiring fast-timing with plastic scintillators the most important parameters are ***PDE***, ***M***, σ_{1ph} . Also should be taken into account the <u>temperature stability</u> and <u>the ability to withstand the radiation load</u>.

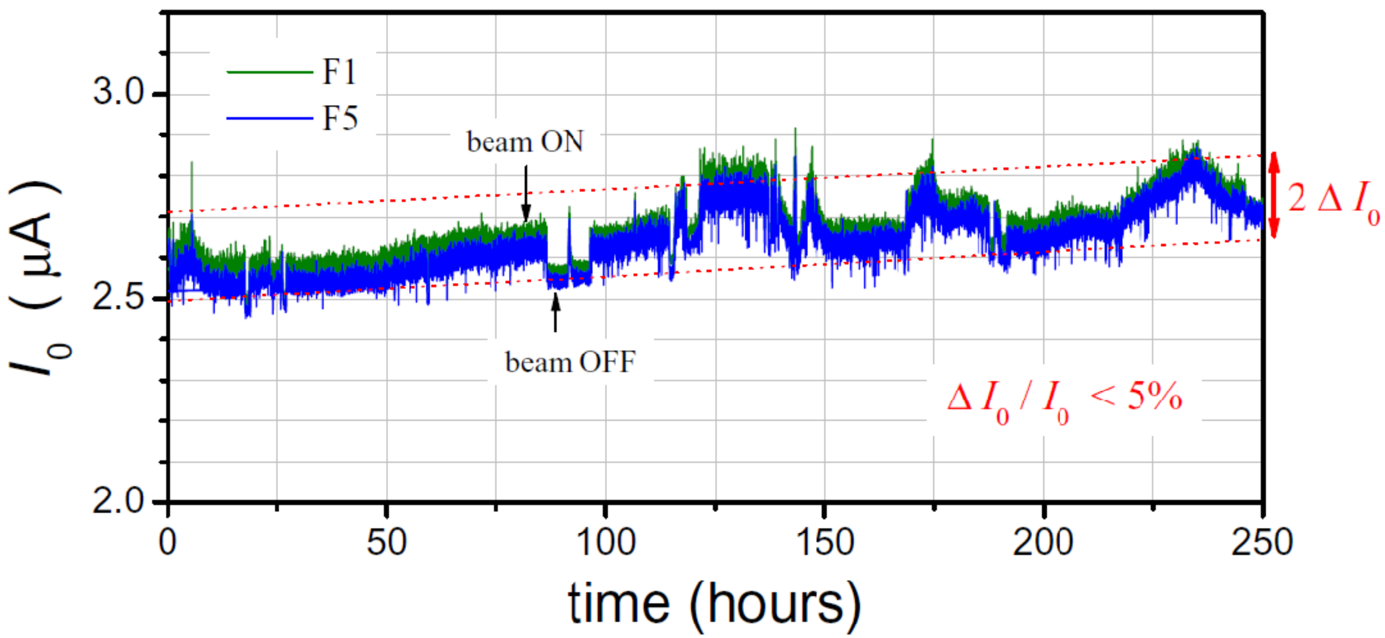
counting rate above **10 MHz**



= excellent rate capabilities =



= high signal-to-noise ratio =



Dark current I_0 (and accordingly M) fluctuations do not exceed 5%

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