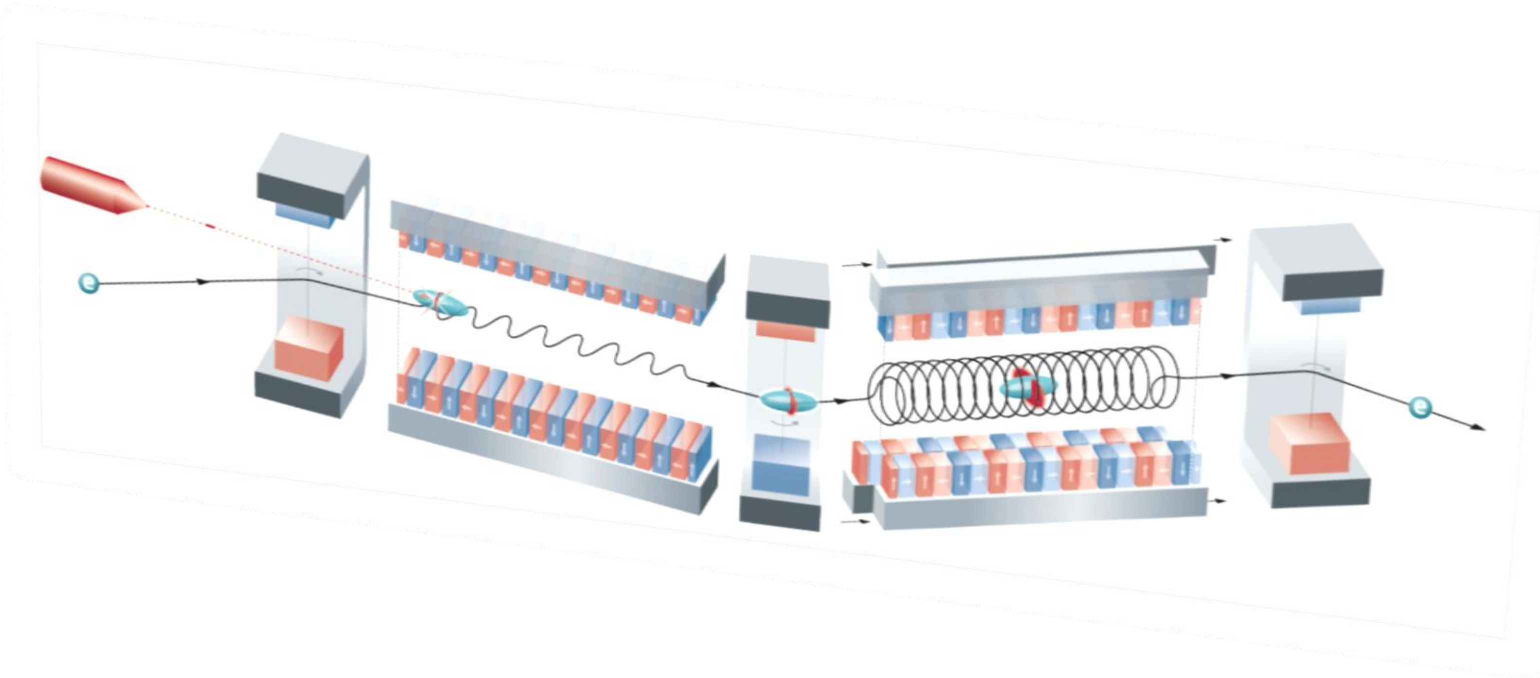
Estimating data acquisition times

at FemtoSpeX



Content

I. General consideration of the significance of a experimentally measured dynamic trace

The goal of the measurement of a dynamic observable $\mathbf{p}$ is to get significant data for the pump-induced changes of p as a function of the delay, i.e for p before and after time zero. We can quantify the experimental significance $\mathbf{r}$ of a measured dynamic trace by putting p into relation with its experimental error $\Delta\mathbf{p}$ by:

$$\mathbf{r} := \frac{\mathbf{p}}{\Delta\mathbf{p}} \qquad \textbf{(F1)}$$

As illustrated in Figure 1, r=5 (r=15) means that the dynamic change of p is five (15) times larger than the experimental error Δp. The desired significance r determines the duration of data acquisition. For the different modes of measurements the acquisition time will be derived in the following.

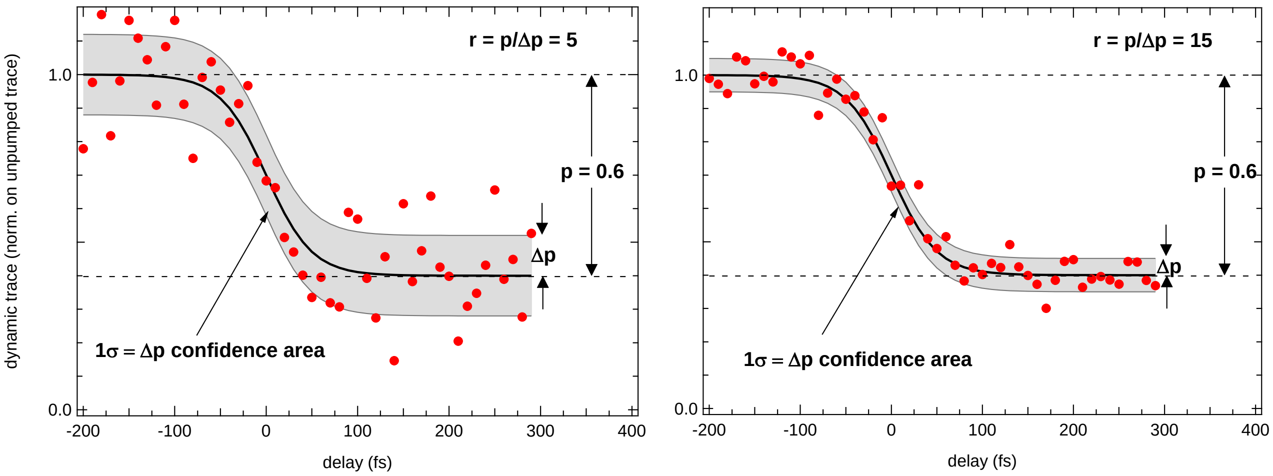


Figure 1: Generic datasets illustrating the definitions and consideration for obtaining dynamic traces of different degrees of significance. For both cases the number of recorded acquisition channels, M, is 50 and the maximum relative pump-induced change of the dynamic trace is ***p=0.6.*** *In the left-hand plot the degree of significance is* ***r = 5****, in the right-hand plot* ***r = 15****.*

II. Signal-noise of the slicing source

The noise of the slicing source is dominated by short time fluctuations of the slicing fs-laser pulse energy as well as instabilities of the spatial overlap of laser and electron beams in the storage ring. The latter is largely associated with the pointing instability of the fs-laser beam (air convection, mechanical vibrations of laser mirrors) but can also come from electron orbit instabilities.
For realistic estimation of the data acquisition times we have determined the typical noise level of the slicing source experimentally for the directly detected incoming photon beam (APD time gated acquisition). For signal acquisition of **one second** we detect a relative **source noise of f (in percent).** This noise only considers short term fluctuations (< 10 sec) and depends on the performance of the storage ring as well as that of the fs-slicing laser and beam stabilizing feedbacks. Typically f is in the order of 5%. For an acquisition time of **m** seconds, the resulting relative noise of the signal **S** in any acquisition channel behaves like

$$\frac{\Delta \boldsymbol{S}}{\boldsymbol{S}} = \frac{\boldsymbol{f}}{\sqrt{\boldsymbol{m}}} \qquad \textbf{(F2)}$$

In the special case that the experimental error of S is limited by photon counting statistics (single photon counting, i.e. $\mathrm{S} = \mathrm{N}$, and $\Delta\mathrm{S} = \sqrt{\mathrm{N}}$, with N the total amount of detected photons per acquisition channel) the relative noise of any acquisition channel behaves like

$$\frac{\Delta \boldsymbol{S}}{\boldsymbol{S}} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}}} \qquad \textbf{(F3)}$$

Not, that for counting rates above 400 cts/sec the statistical error drops below 5% such that the source noise of the slicing source begins to dominate the experimental error.

III. XAS (XRS, RSXD) measurements

a. Definitions:

- S_u: detected signal of unpumped sample
- S_p: detected signal of pumped sample with the maximum pump-induced change
- $\mathrm{p} := \frac{\mathrm{S_p} - \mathrm{S_u}}{\mathrm{S_u}}$: maximum relative pump-induced change of S_p

b. Estimation of acquisition time:

The relative experimental error derives as (error propagation):

$$\Delta \mathrm{p} = \sqrt{\left(\frac{\Delta \mathrm{S_p}}{\mathrm{S_u}}\right)^2 + \left(\frac{\mathrm{S_p} \quad \Delta \mathrm{S_u}}{\mathrm{S_u}^2}\right)^2} \qquad \textbf{(F4)}$$

This is a general expression!

Generally, $\Delta \mathrm{S_p} \geq \Delta \mathrm{S_u}$, since laser power fluctuation can lead to additional noise in the pumped channel!

With the following approximations (!)

$$\mathrm{S} := \mathrm{S_u} \approx \mathrm{S_p},$$

and

$$\Delta \mathrm{S} := \Delta \mathrm{S_u} \approx \Delta \mathrm{S_p}$$

a simple expression can be obtained:

$$\Delta \mathbf{p} = \sqrt{2}\, \frac{\Delta \boldsymbol{S}}{\boldsymbol{S}} \qquad \textbf{(F5)}$$

Combining this expression with **(F1)** and **(F2)** we get the **minimum acquisition time** for a given degree of significance for a given maximum relative pump-induced change **p**, a source noise **f,** and a desired degree of significance **r**:

$$\boldsymbol{T} > \frac{2 \cdot f^2 \cdot r^2 \cdot M}{p^2} \qquad \textbf{(F6)}$$

T is given in seconds. The factor M considers the number of acquisition channels that need to be recorded sequentially for a dynamic experimental trace. Note that F6 does not include slow drifts beyond several tens of seconds. Such drifts have to be accounted for upon data evaluation by clever normalization.

For the single photon counting mode a similarly simple expression can be derived. With n the number of detected photons per second, T is given by:

$$\boldsymbol{T} > \frac{2 \; r^2 \; M}{n \, p^2} \qquad \textbf{(F7)}$$

Note that this expression is only valid if the experimental noise is given by the counting statistics, which is the lowest noise possible !!!

IV. XMCD measurements

a. Definitions:

- S_u^+: detected signal of unpumped sample and **+** magnetization direction
- S_u^-: detected signal of unpumped sample and **-** magnetization direction
- S_p^+: detected signal of pumped sample and **+** magnetization direction
- S_p^-: detected signal of pumped sample and **-** magnetization direction
- $MC_u := S_u^+ - S_u^-$: magnetic contrast of unpumped sample
- $MC_p := S_p^+ - S_p^-$: magnetic contrast of pumped sample
- $\Delta MC_u = \sqrt{\Delta S_u^+ - \Delta S_u^-}$ deduced experimental error
- $\Delta MC_p = \sqrt{\Delta S_p^+ - \Delta S_p^-}$ deduced experimental error
- $\mathrm{p} := \frac{MC_p - MC_u}{MC_u}$: maximum relative pump-induced change of MC_p; ($i.e.\ MC_p = (1+\mathrm{p})\ MC_u$)

b. Estimation of acquisition time:

The relative experimental error derives as

$$\Delta\mathrm{p} = \sqrt{\left(\frac{\Delta MC_p}{MC_u}\right)^2 + \left(\frac{MC_p\ \ \Delta MC_u}{{MC_u}^2}\right)^2}$$

$$= \sqrt{\frac{{\Delta S_p^+}^2 + {\Delta S_p^-}^2}{{MC_u}^2} + \frac{{MC_p}^2\ \left({\Delta S_u^+}^2 + {\Delta S_u^-}^2\right)}{{MC_u}^4}} \qquad \textbf{(F8)}$$

This is a general expression!

With the following approximations:

$$\Delta \mathrm{S} := \Delta S_u^+ \approx \Delta S_u^- \approx \Delta S_p^+ \approx \Delta S_p^- \ ;$$

and $S := S_u^+$;

and $MC_u =: c\ S_u^+$ (0 < c < 100%, the magnetic contrast relative to S_u^+)

we obtain:

$$\Delta\mathrm{p} = \frac{\sqrt{2}}{c}\frac{\Delta S}{S}\sqrt{1+(1+\mathrm{p})^2} \qquad \textbf{(F9)}$$

With (F1) and (F2) we can now calculate the acquisition time for a single acquisition channels:

$$T > \frac{2 \cdot f^2 \cdot r^2}{c^2} \quad \frac{1 + (1+p)^2}{p^2}$$

Considering M acquisition channels and an additional factor of 2 due to the fact that the measurements for both magnetization directions have to be measured sequentially yields:

$$\mathbf{T} > \frac{\mathbf{4 \cdot f^2 \cdot r^2 \, M}}{\mathbf{c^2}} \quad \frac{\mathbf{1 + (1+p)^2}}{\mathbf{p^2}} \tag{F10}$$

T is given in seconds.

Again, as in (F6), this expression does not include slow drifts beyond several tens of seconds.

As in (F7) a similarly simple expression can be derived for the single photon counting mode. With n the number of detected photons per second, T is given by:

$$\mathbf{T} > \frac{\mathbf{4 \cdot r^2 \, M}}{\mathbf{n \, c^2}} \quad \frac{\mathbf{1 + (1 + p)^2}}{\mathbf{p^2}}$$

V. Examples

Let's take the examples of figure 1.
Here, M=50, p=60%, r = 5 (15), and f = 5%.

For the **analogue acquisition mode** we get in the **XAS (XRS, RSXD)** case:

T > 0.3 min for r=5
and T > 2.6 min for r=15

(note that for XAS and XRS typically p<<10%)

For the **XMCD** measurement, assuming a magnetic contrast of c=15% and 60% demagnetization we can calculate:

T > 1.5 h for r=5
and T > 14 h for r=15

The same estimations for the **photon counting mode** for a count rate of 50 photons/second:

For the **XAS (XRS, RSXD)** measurement we can calculate:

T > 2.5 min for r=5
and T > 21 min for r=15

For the **XMCD** measurement, assuming a magnetic contrast of c=10%, we can calculate:

T > 12.5 h for r=5
and T > 110 h for r=15

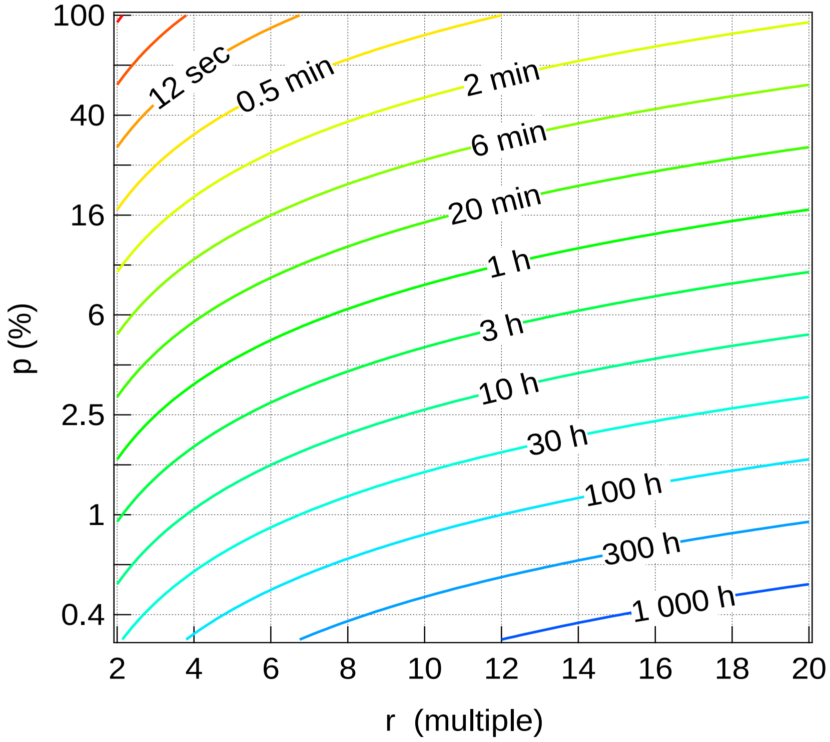


Figure 2: Calculated acquisition times for the XAS (XRS, RSXD) case for a source noise of f= 5%, and M= 50 acquisition channels as a function of the maximum relative pump-induced change, p, and the degree of significance, r.

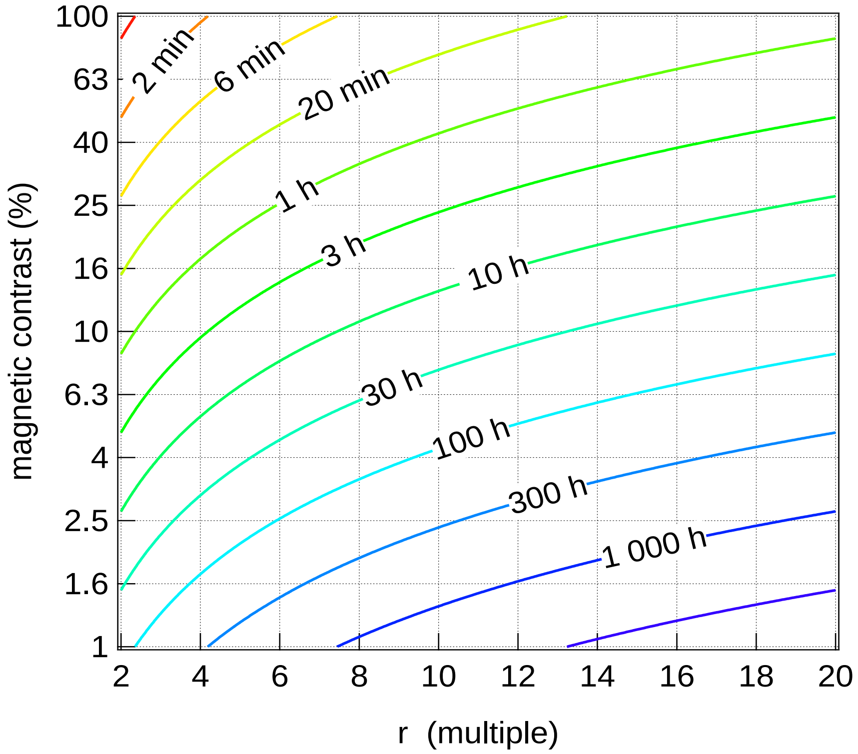


Figure 3: Calculated acquisition times for the XMCD case for a source noise of f= 5%, a pump-induced demagnetization of 80%, and M = 50 acquisition channels as a function of the magnetic contrast, c, and the degree of significance, r.