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Model of statistical errors in the search for the deuteron EDM in the storage ring

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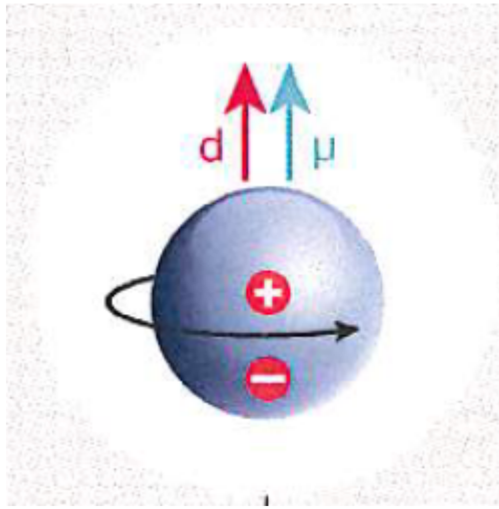
Electric Dipole Moment and Standard Model

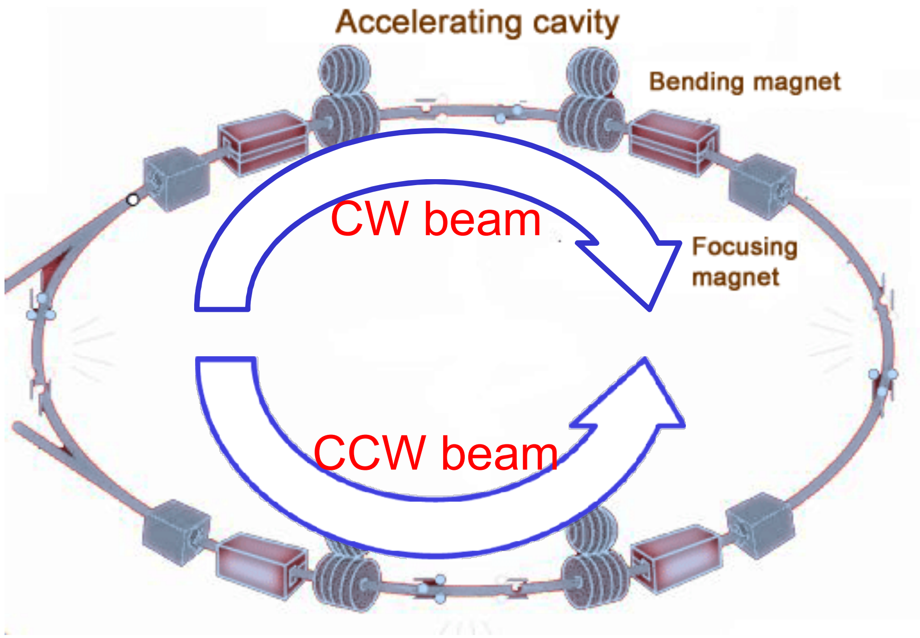
In frame of SM among the not yet understood phenomena are the reasons for the violation of the **CP symmetry**.



But CP violation is the only known mechanism that could explain the matter-antimatter asymmetry found in Universe.

The electric dipole moments (EDM) of fundamental particles are excellent probes of physics beyond the standard model (SM), e.g. SUSY, since they allow for values within experimental reach whereas the SM predictions are several orders below them.

Storage Ring EDM measurement



Presumable EDM 10^{-29} e·cm

- EDM spin precession ≈ 10^{-9} red/sec
- MDM spin precession ≈ 3 rad/sec
- Solution: CW/CCW procedure

CW/CCW procedure

When put into an electromagnetic field, the particle spin begins to precess according to the T-BMT equation:

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S}$$

$$\vec{\Omega} = -\frac{e}{m}\left\{ \underbrace{G\vec{B} + \left(\frac{1}{\gamma^2 - 1}\right)\left(\vec{B} \times \vec{E}\right)}_{\text{MDM}} + \underbrace{\frac{\eta}{2}\left(\vec{E} + \vec{\beta} \times \vec{B}\right)}_{\text{EDM}} \right\}$$

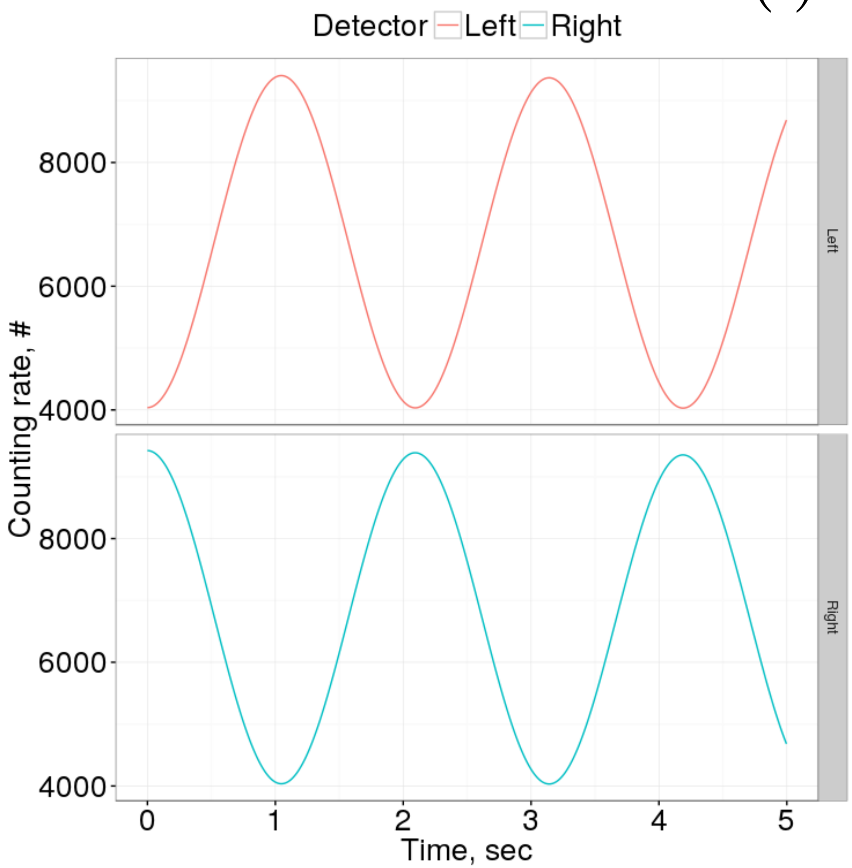
By measuring the beam's polarization, we can determine the frequency

$$\vec{\Omega}^{CW/CCW} = \pm\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}$$

Comparing the CW vs CCW frequencies, determine Ω_{EDM}

Detector counting rate

$$\widetilde{N}(t) = N_0(t)\left[1 + P \cdot e^{-t/\tau_d} \cdot \sin(\omega t + \phi)\right] + \varepsilon_t$$



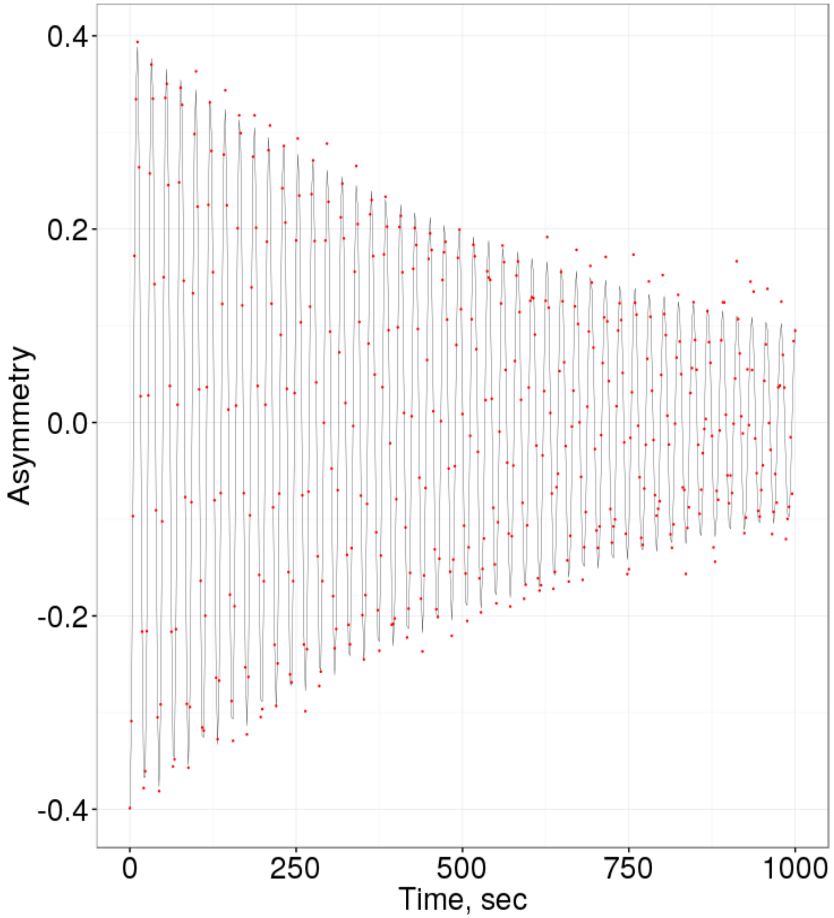
Number of counts is Poisson distributed, hence

$$\sigma^2_{\widetilde{N}_0} = N_0(t)$$

$$\sigma_{N_0}(t) = \sigma_{\widetilde{N}_0}(t) / \sqrt{n_{c/\varepsilon}}$$

$$\frac{\sigma_{N_0}(t)}{N_0(t)} \propto \frac{1}{\sqrt{\Delta t}} \cdot \exp\left(\frac{t}{2\tau_b}\right)$$

Cross section asymmetry



A measure of polarization

Definition: $$A = \frac{N_L - N_R}{N_L + N_R}$$

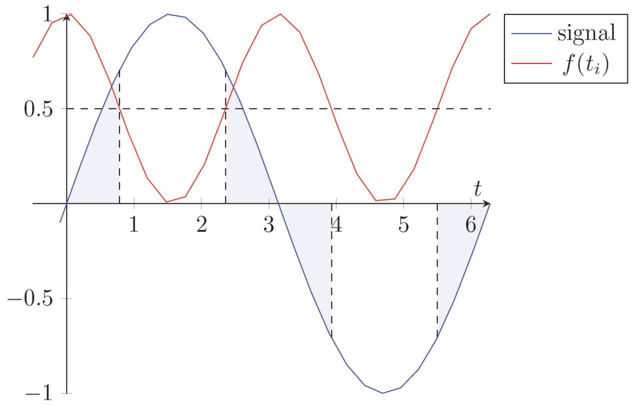
Model:

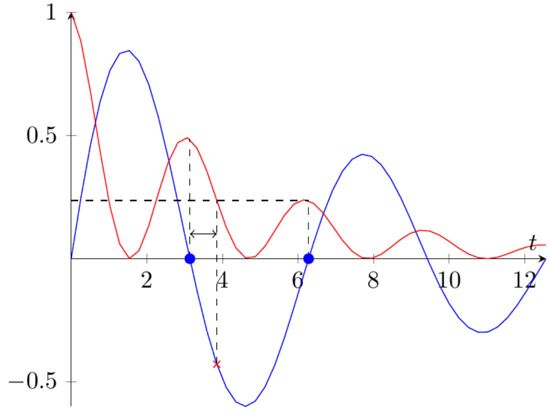
$$A(t) = A(0)e^{\lambda t}\sin(\omega \cdot t + \phi)$$

$$\sigma_A^2(t) \approx \frac{1}{2N_0(t)}$$

Error: $$\sigma^2[\hat{\omega}] = \frac{\sigma^2[\varepsilon]}{\sum_i f(t_i) \cdot \sigma_w^2[t]}$$

Limiting factors



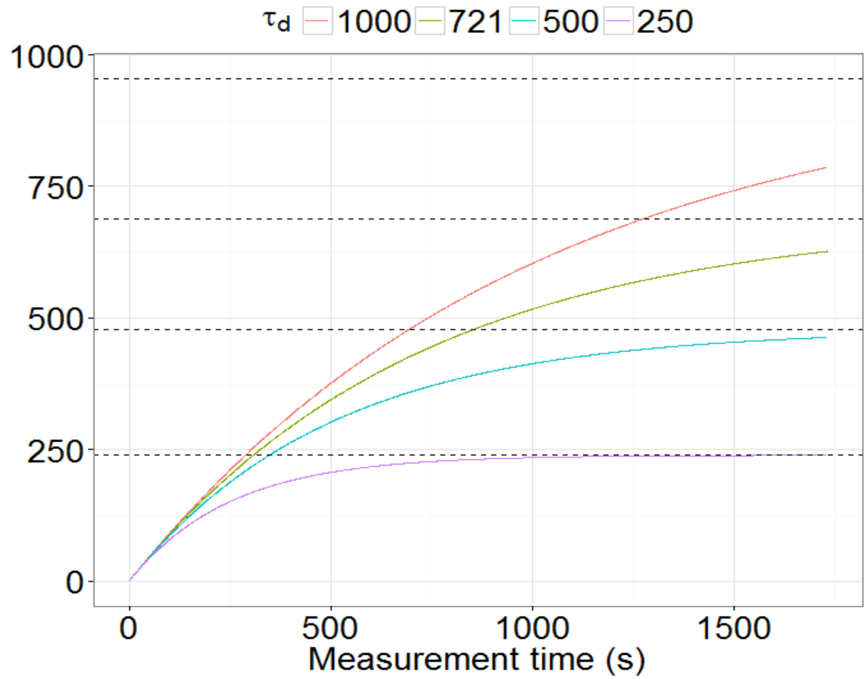


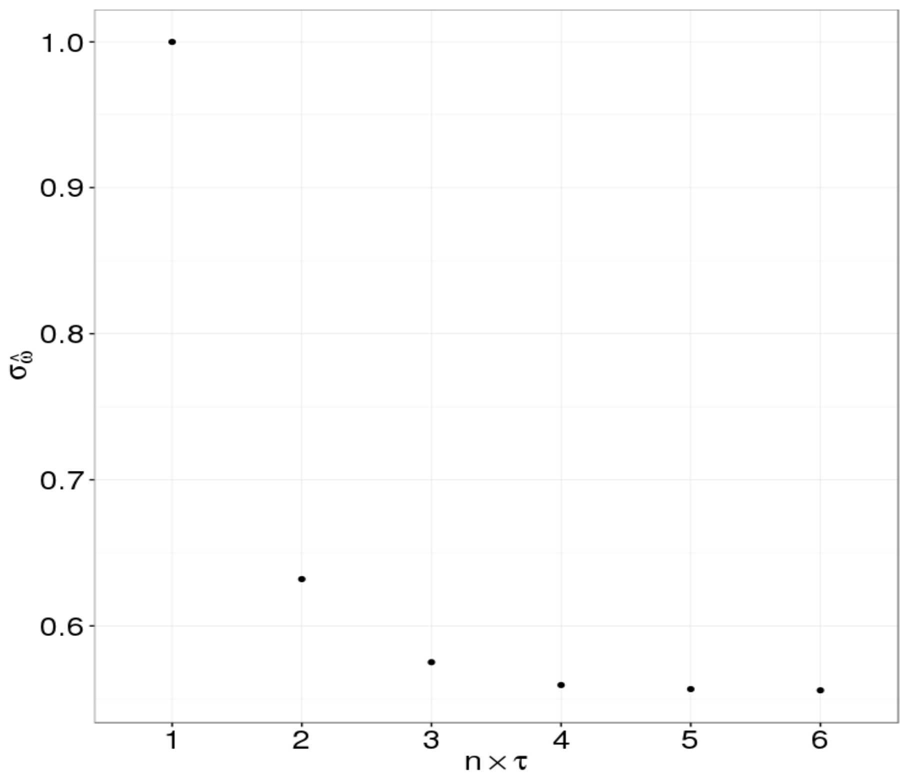
- Sample Fisher information can be increased by sampling during rapid change
- Point Fisher information falls exponentially due to decoherence

Sampling	Fisher Info, a.u.
uniform	1.00
50% modulation	1.64
80% modulation	1.94

Time spread

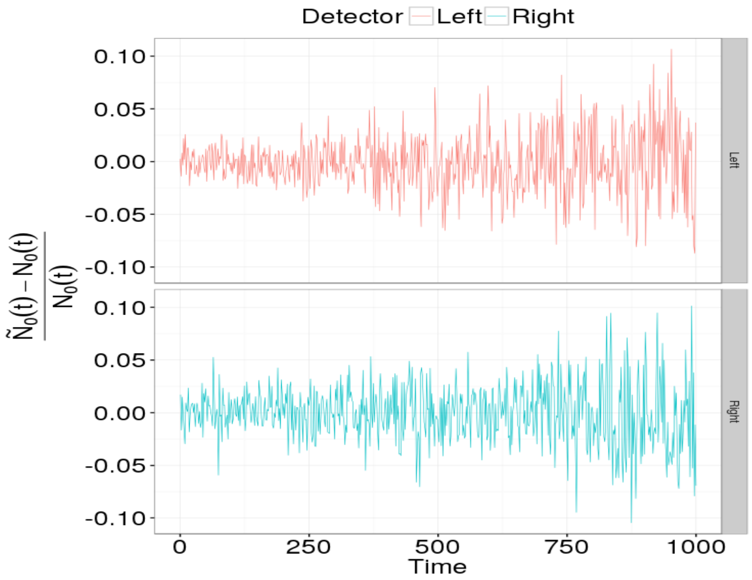
$$\sum_i f(t_i)$$

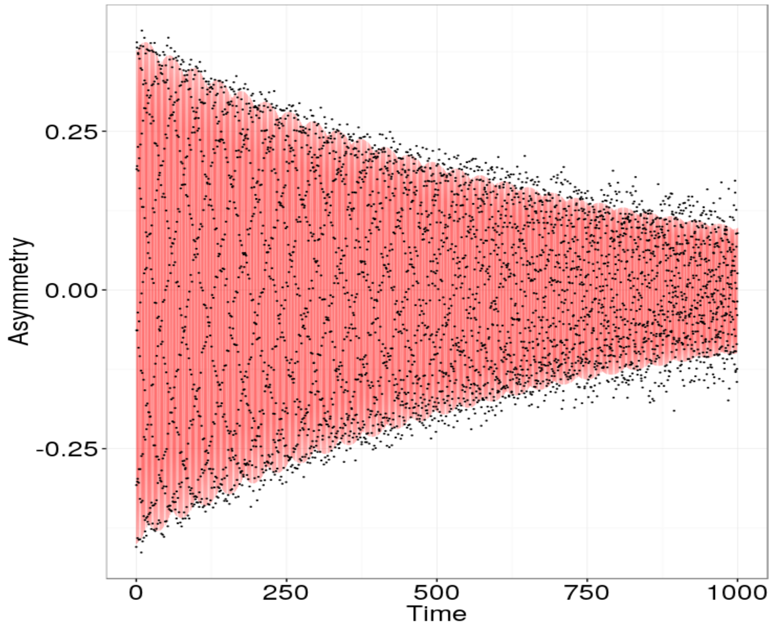




FI limit (%)	By ($\times\tau_d$)	SNR@3% error
95	3.0	1.7
90	2.3	3.3
70	1.2	10.0

Simulation





- Uniform sampling
- Sample size equivalent to 2,000 events per 20 milliseconds for 1,000 seconds

- Standard error $7.55 \cdot 10^{-7}$ rad/sec
- If ω is known down to 10^{-6}, can improve the result by 30%

Conclusion

To measure the EDM on the order of 10^{-29} e·cm we need a standard error of the frequency estimate at least as good as 10^{-9} rad/sec; $5\cdot10^{-7}$ rad/sec in one fill is sufficient to produce $3\cdot10^{-9}$ rad/sec in one year of measurement.

Thank You