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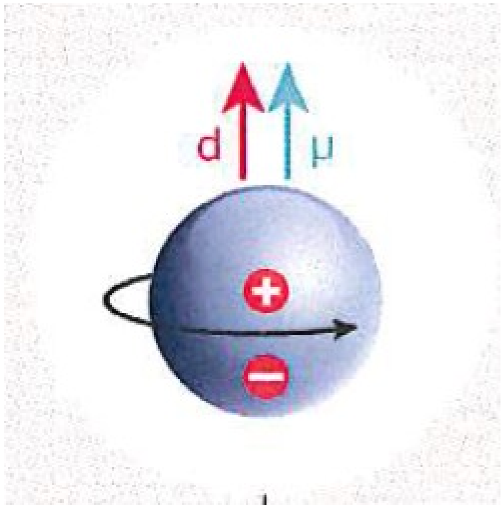
Model of statistical errors in the search for the deuteron EDM in the storage ring

03/21/17

Electric Dipole Moment and Standard Model

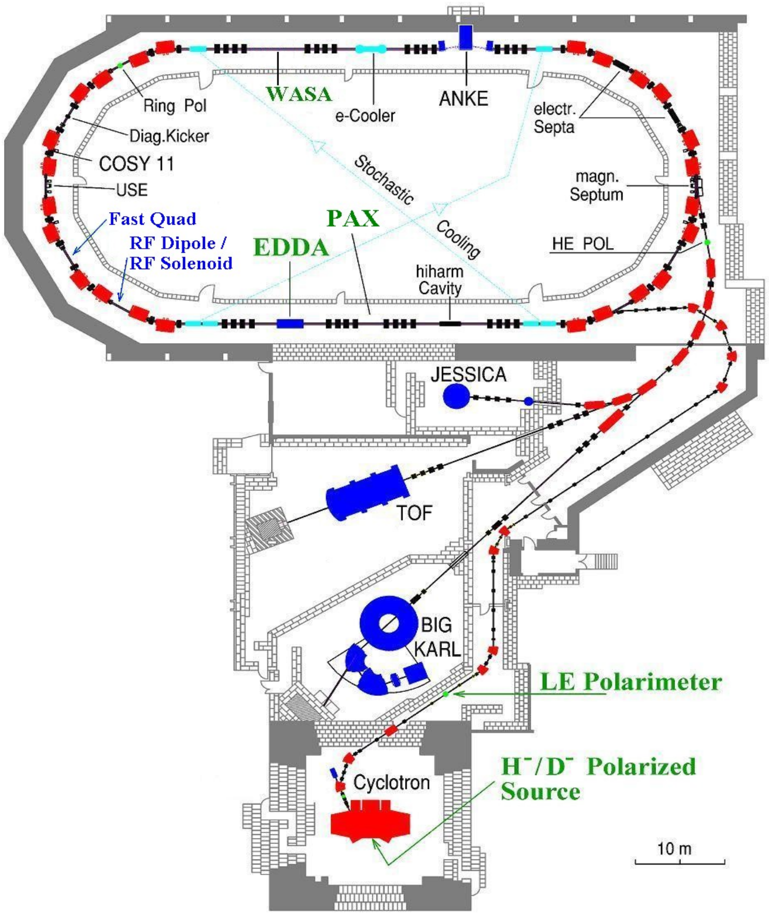
In frame of SM among the not yet understood phenomena are the reasons for the violation of the **CP symmetry**.

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 $\sim 10^{-9}$ 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:

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

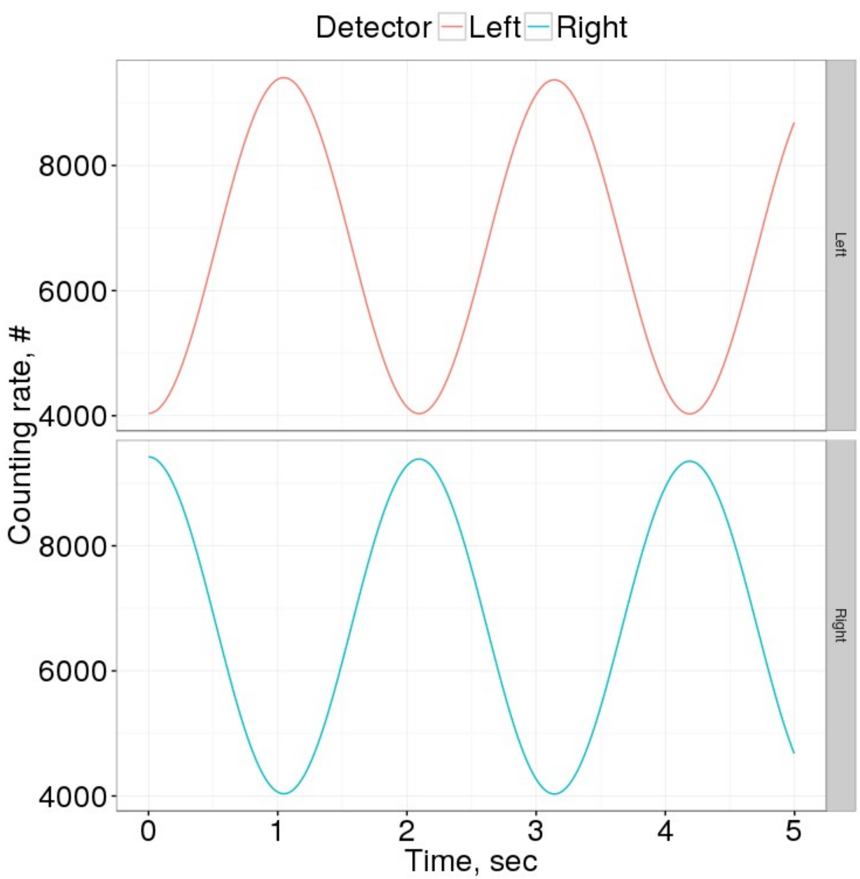
$$\vec{\Omega} = -\frac{e}{m}\left\{ \underbrace{G\vec{B} + \left(\frac{1}{\gamma^2 - 1} - G\right)\left(\vec{\beta}\times\vec{E}\right)}_{\text{MDM}} + \underbrace{\frac{\eta}{2}\left(\vec{E} + \vec{\beta}\times\vec{B}\right)}_{\text{EDM}} \right\}$$

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



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

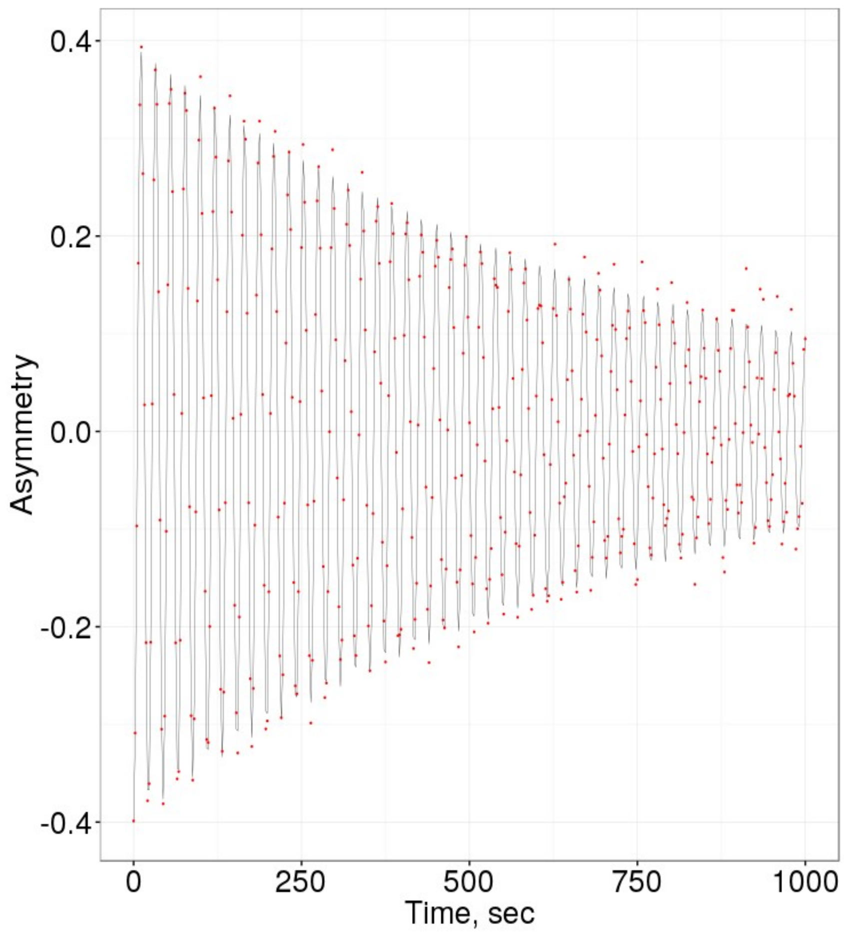
Number of counts is Poisson distributed, hence

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

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

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

Cross section asymmetry



A measure of polarization

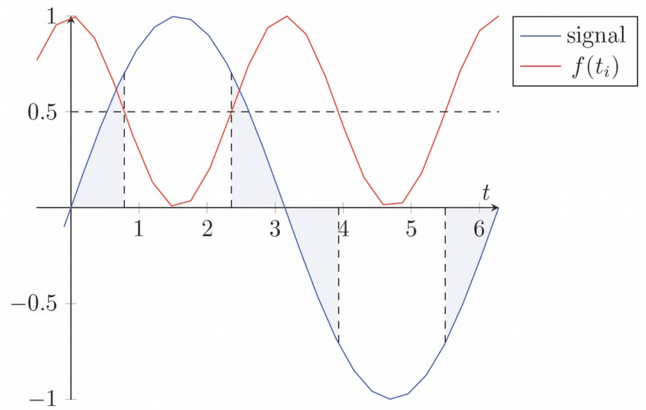
Definition: $$A=\frac{N_L-N_R}{N_L+N_R}$$

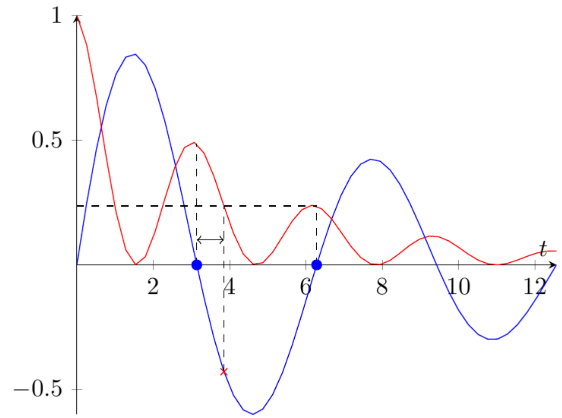
Model: $$A(t)=A(0)\cdot e^{\lambda t}\cdot\sin(\omega\cdot t+\phi)$$

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

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

Limiting factors





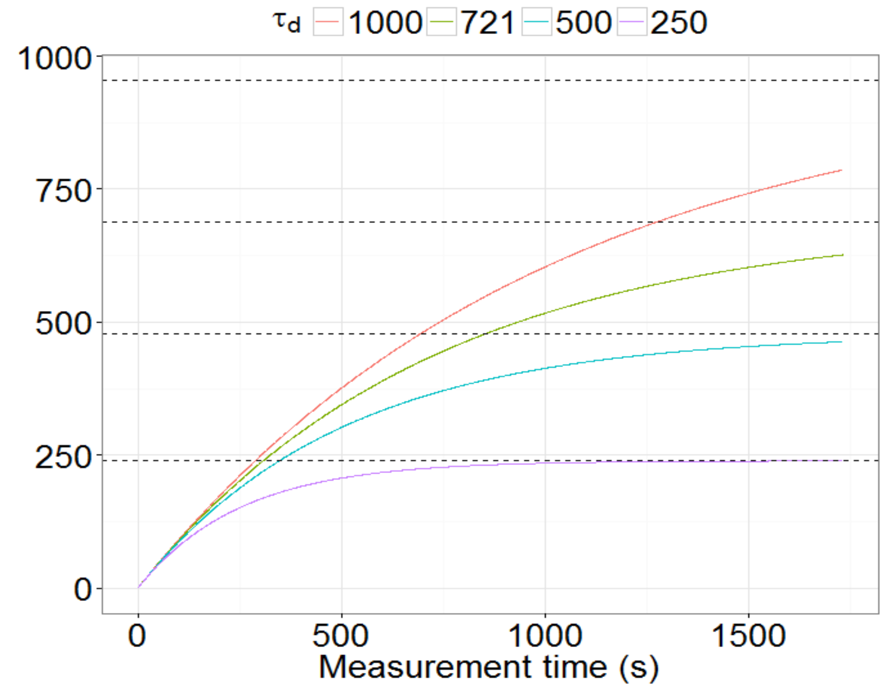
- Sample Fisher information can be increased by sampling during rapid change

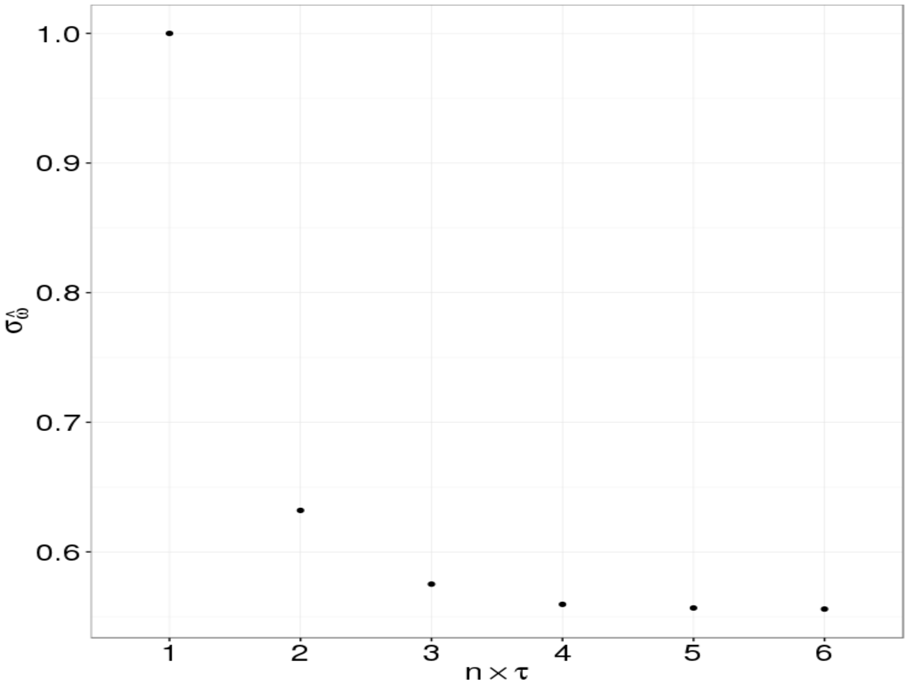
Sampling	Fisher Info, a.u.
uniform	1.00
50% modulation	1.64
80% modulation	1.94

- Point Fisher information falls exponentially due to decoherence
- Can't economize the beam too much

Time spread

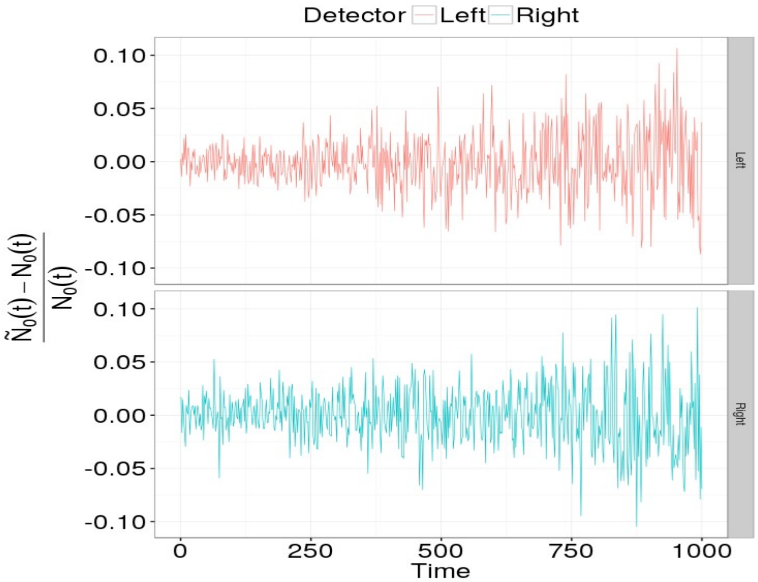
$$\sum_i f\left(t_i\right)$$

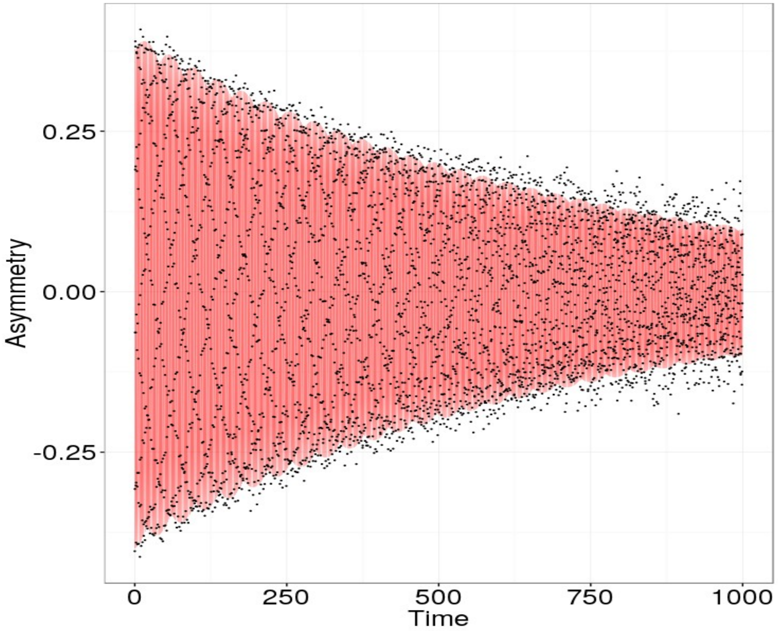




FI limit (%)	By ($\times\tau_d$)	SNR@3% error
95	3.0	1.7
90	2.3	3.3
70	1.2	10.0

Simulation





- Uniform sampling
- 75% of the beam ($7.5 \cdot 10^{8}$ useful scatterings)
- 2,000 events per 20 miliseconds

- 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 10^{-9} rad/sec; $5 \cdot 10^{-7}$ rad/sec in one fill is sufficient to produce $3 \cdot 10^{-9}$ rad/sec in one year of measurement.

Thank You