Fluctuations of magnetic induction in von Kármán swirling flows, Application to dynamo

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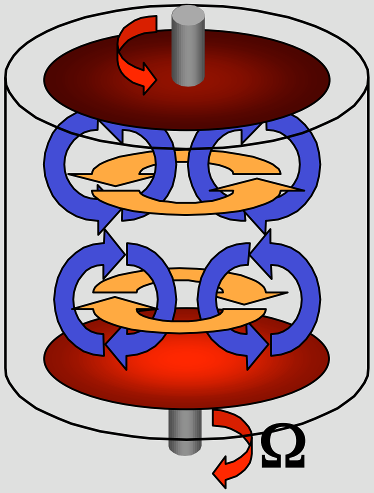
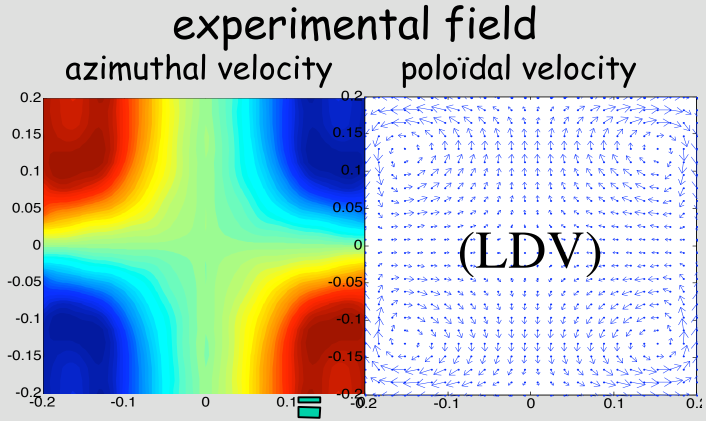
Dynamo capacity of VK flows

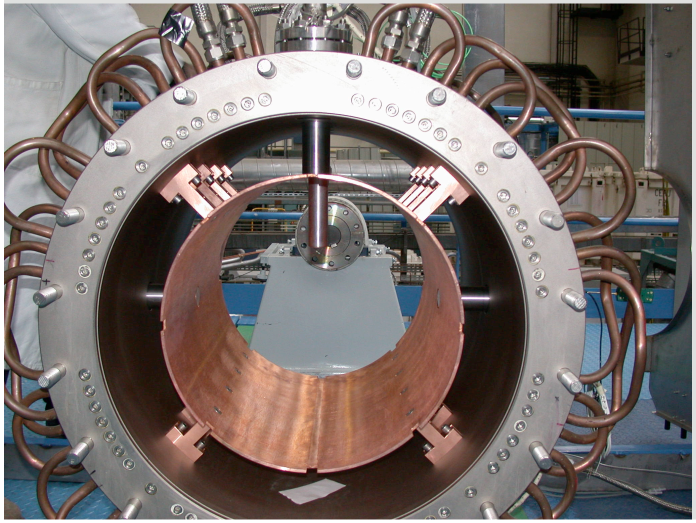



experimental field

azimuthal velocity

poloïdal velocity

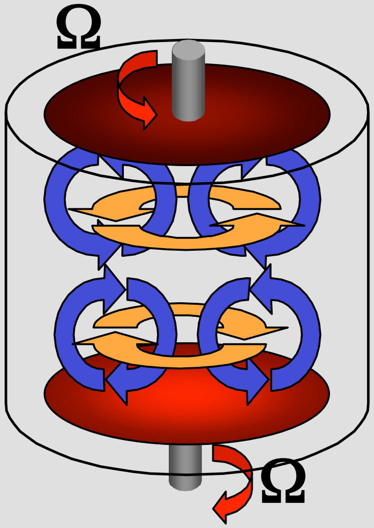
$$\partial_t \vec{B} = \vec{\nabla} \times (\vec{u} \times \vec{B}) + \lambda \Delta \vec{B}$$



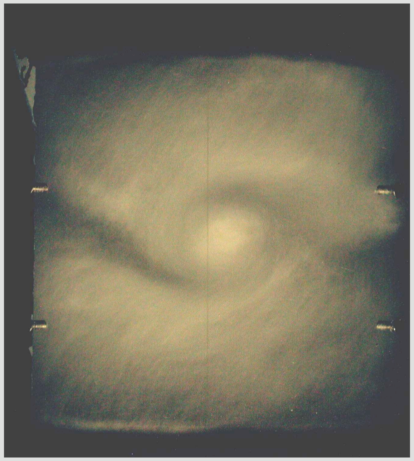
VKS2: a dynamo with the mean flow

R_m max = 55 > R_m^c = 43

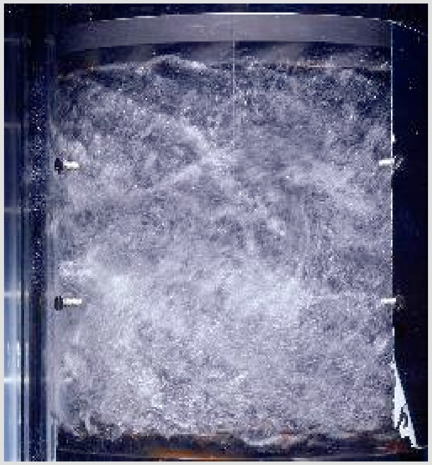
Several faces of VK flow



T=∞



T=1/20 s

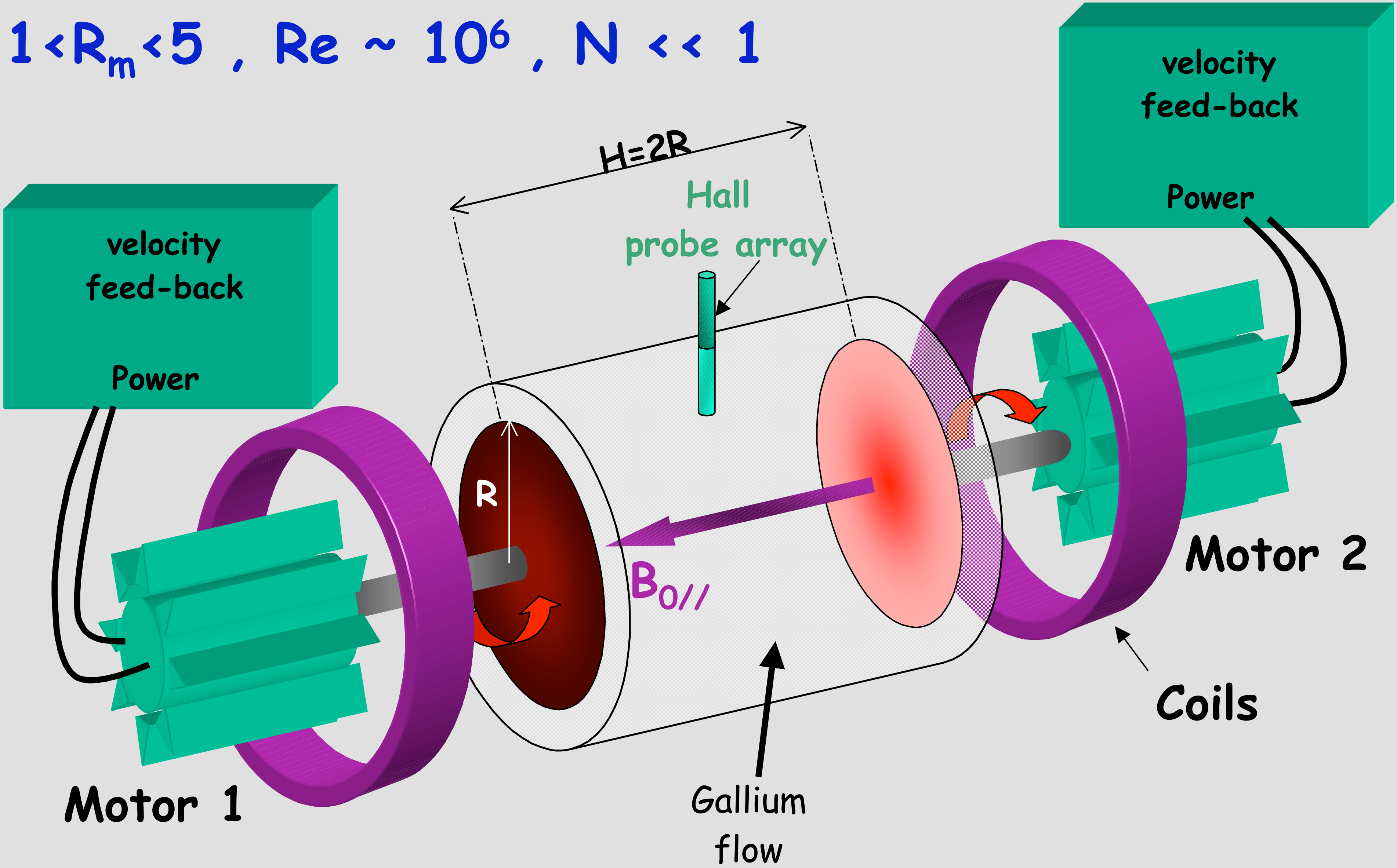


T=1/500 s

$$\langle \vec{V}(t) \rangle_T = \frac{1}{T} \int_t^{t+T} \vec{V}(t')\mathrm{d}t'$$

VKG Experiment

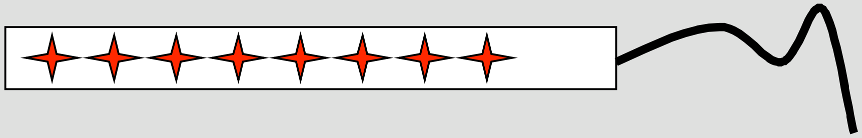
$1 < R_m < 5$, $Re \sim 10^6$, $N \ll 1$



A magnetic tool to probe the flow large scale fluctuations

Measurements in 8 points $\vec{B}(r_i, t)$

Hall probes, Sentron 1SA-1M



What does this probe see ?

The induction equation …

$$\boxed{\partial_t \vec{B} = ((\vec{B} + \vec{B}_0).\vec{\nabla})\vec{V} - (\vec{V}.\vec{\nabla})\vec{B} + \lambda \Delta \vec{B}}$$

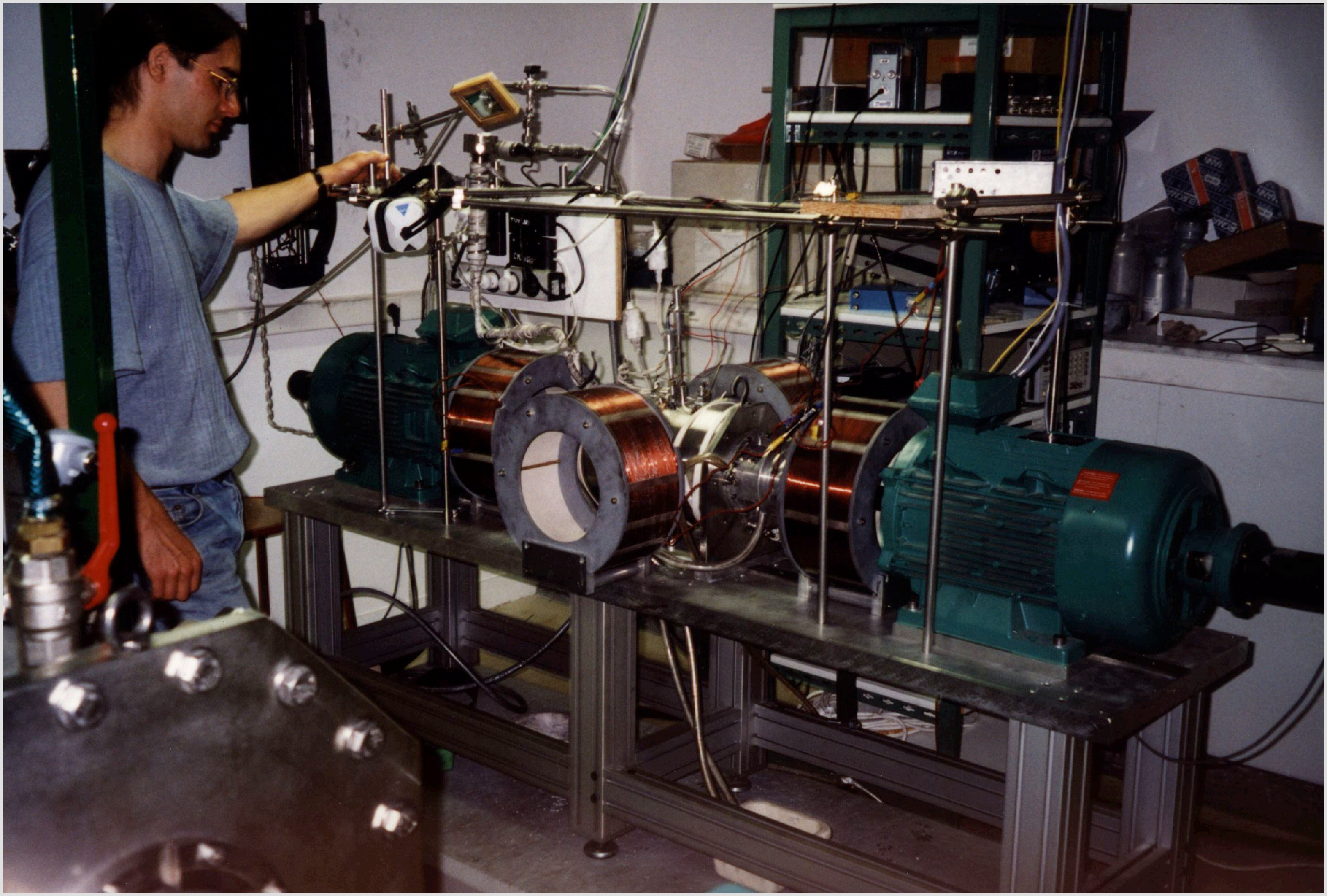
…using QS approximation and linear approximation (Rm < 5) …

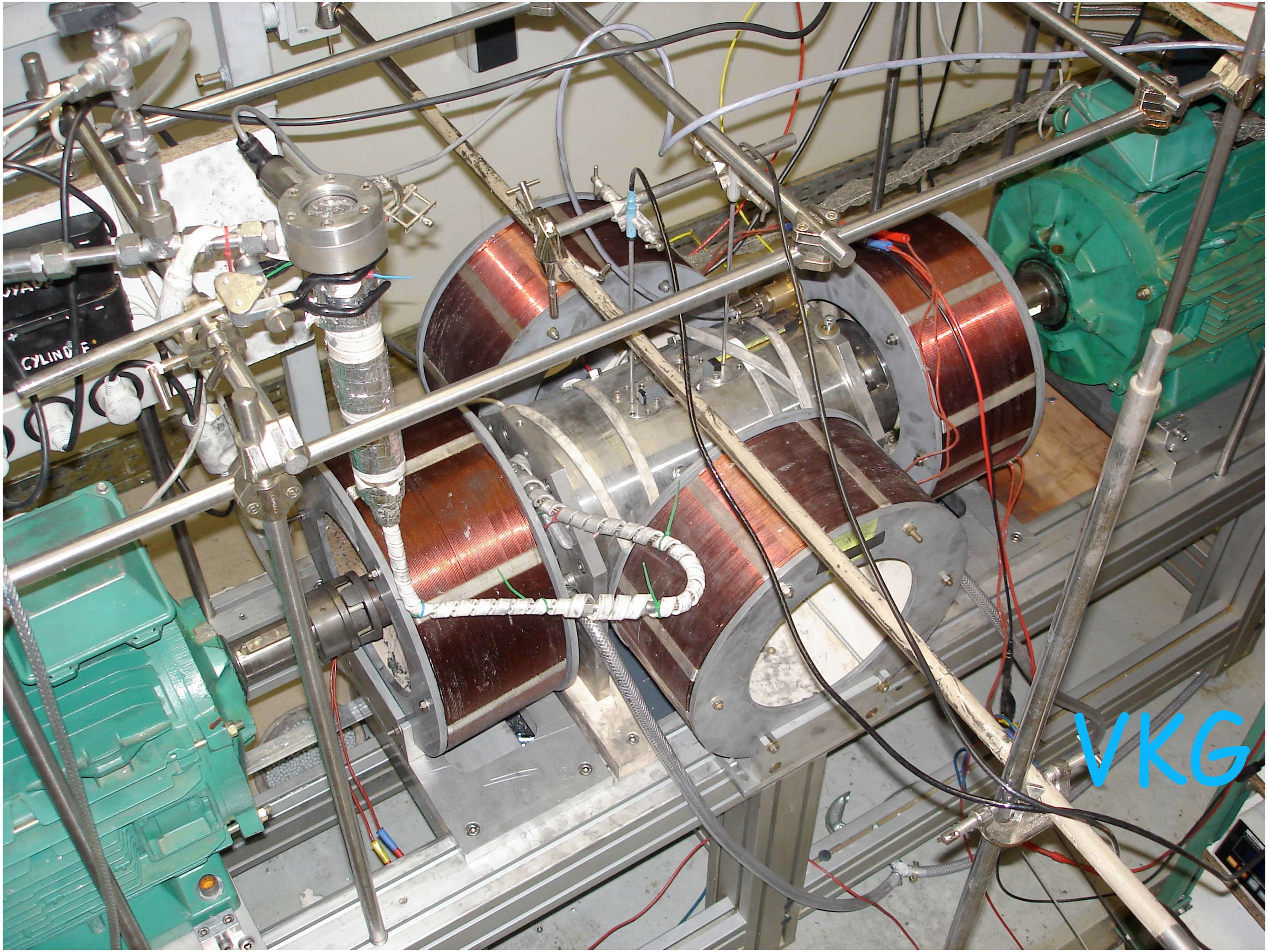
… gives :

$$\boxed{\vec{B}(t) \sim -\frac{1}{\lambda}\Delta^{-1}\left[B_0 \partial_z \vec{V}(t)\right]}$$

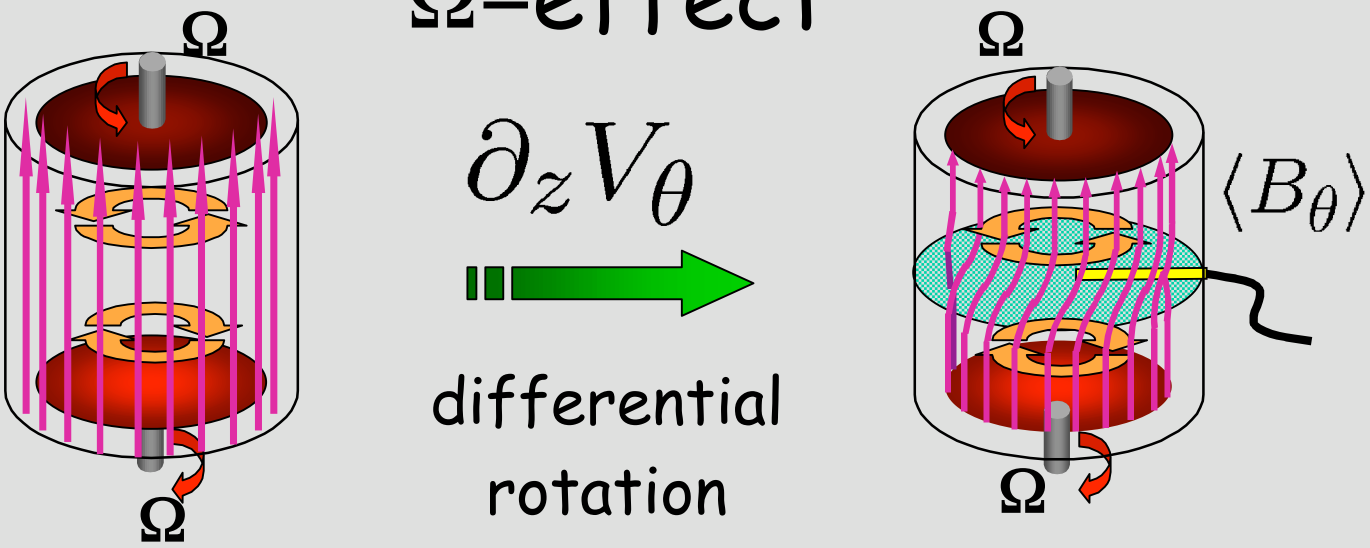
(suppose B_0//Oz)

VKG
Gallium Setup



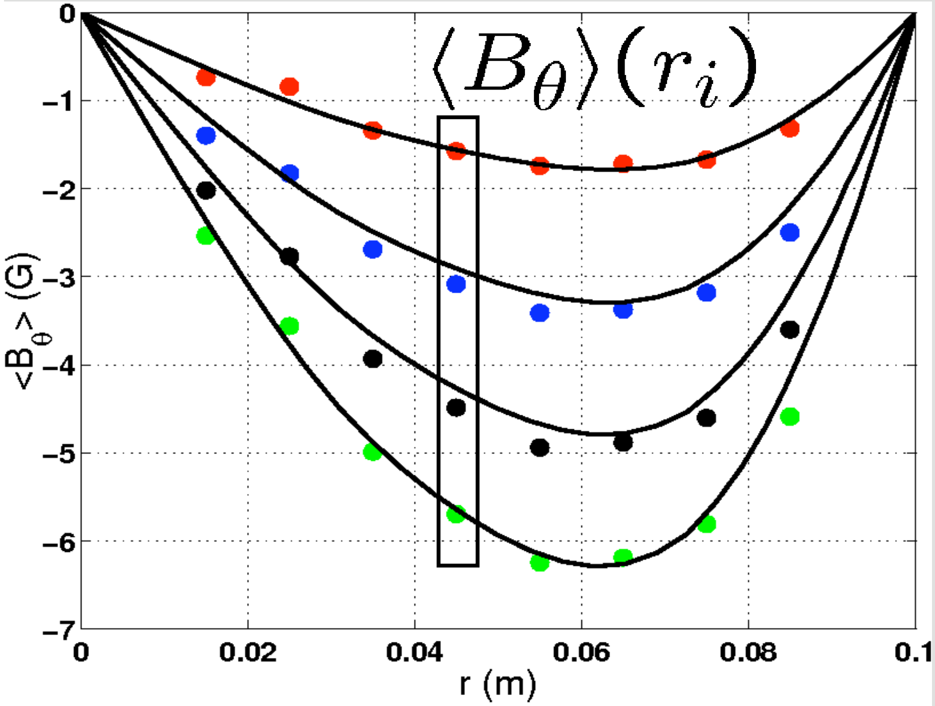

VKG

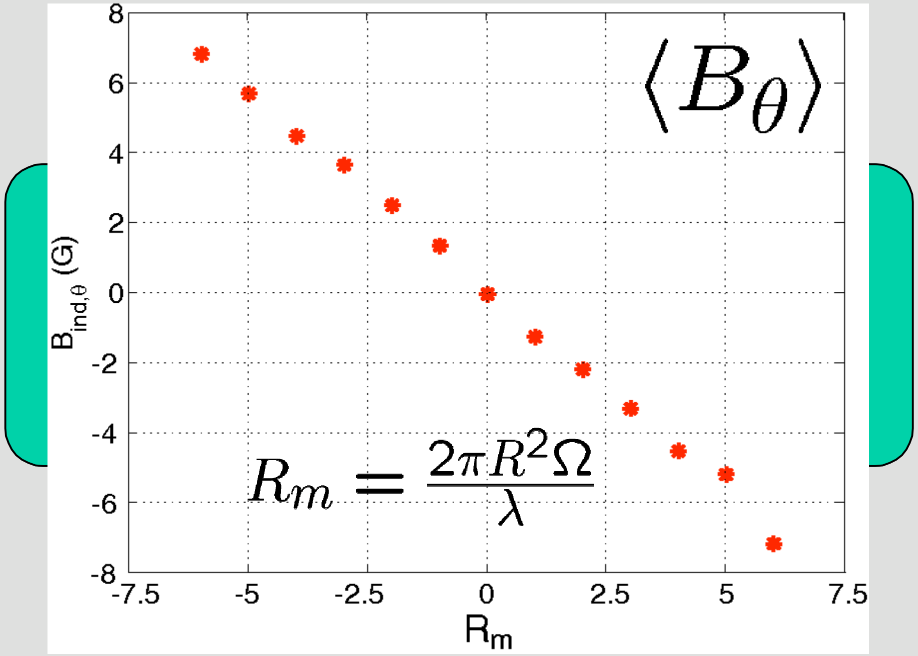
Ω–effect



$$\partial_z V_\theta$$

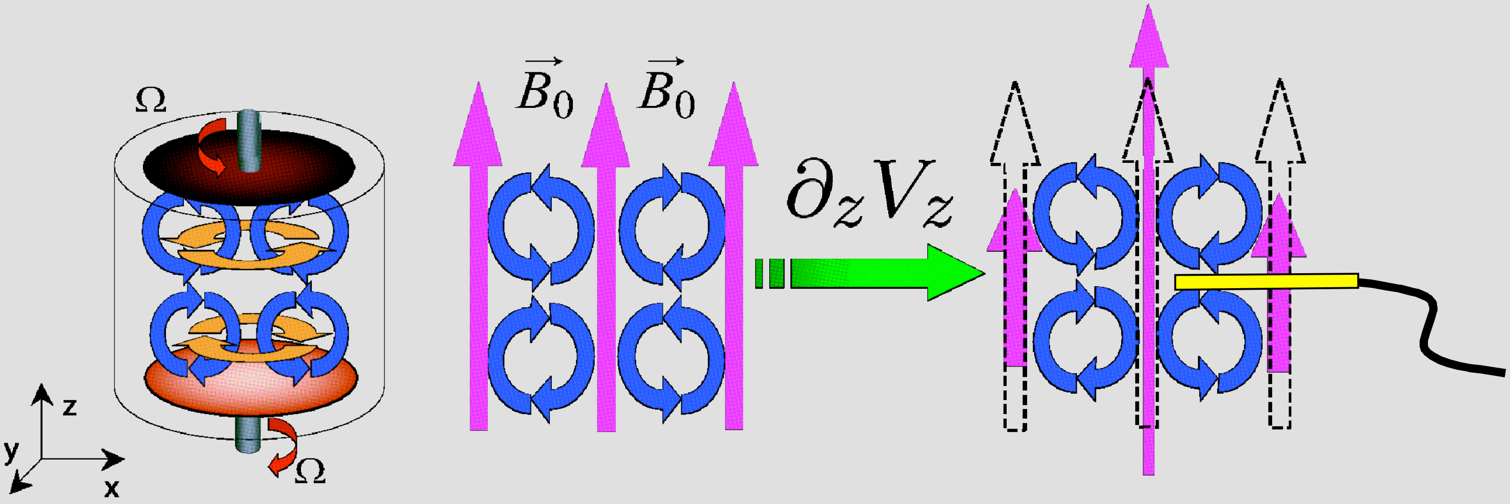
differential rotation

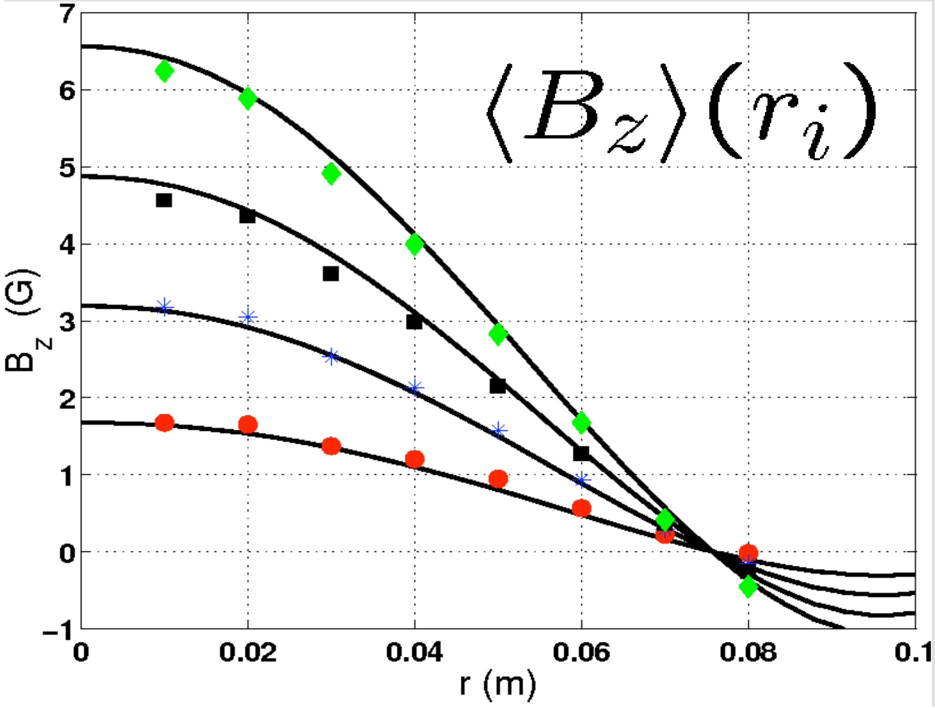


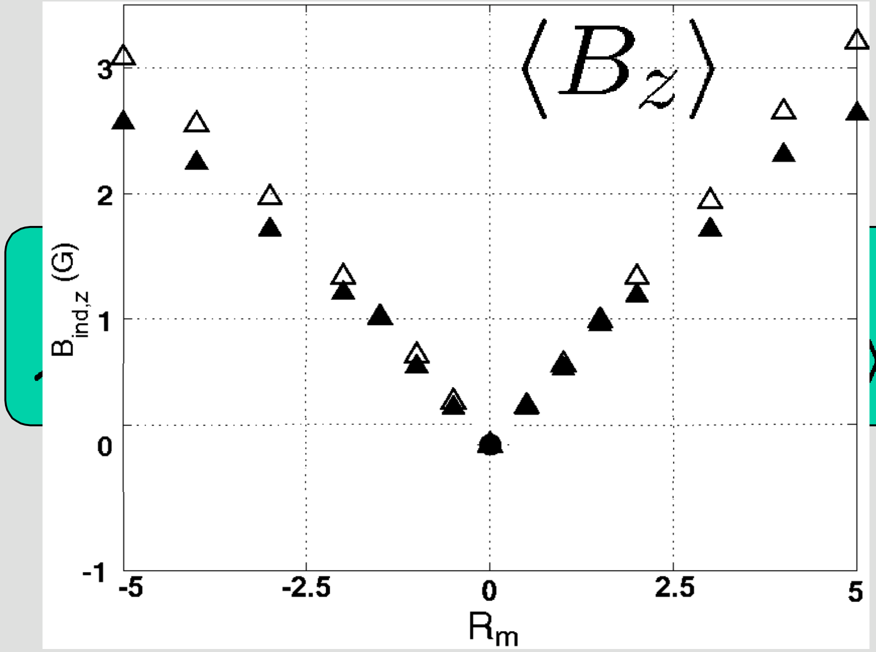


$$R_m = \frac{2\pi R^2 \Omega}{\lambda}$$

Stretching effect

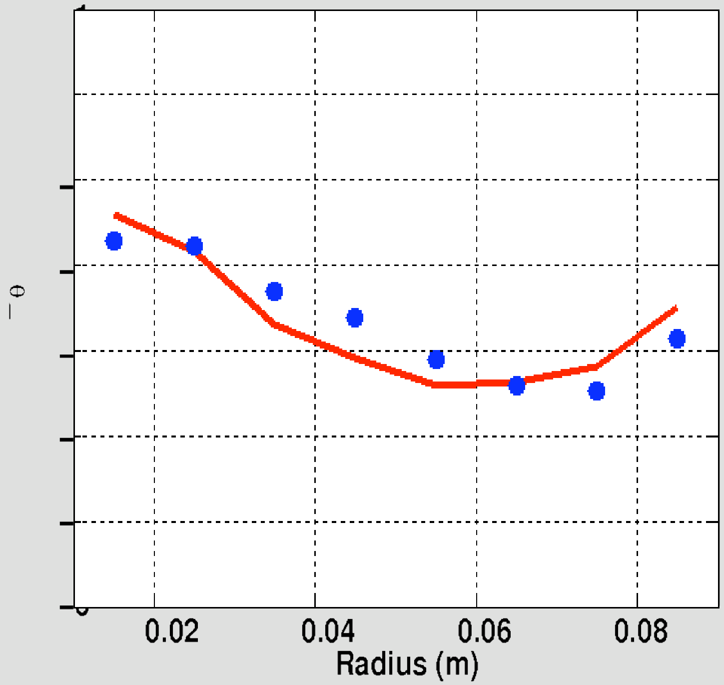






Fluctuations of the induction profiles

Ω-effect (toroidal)

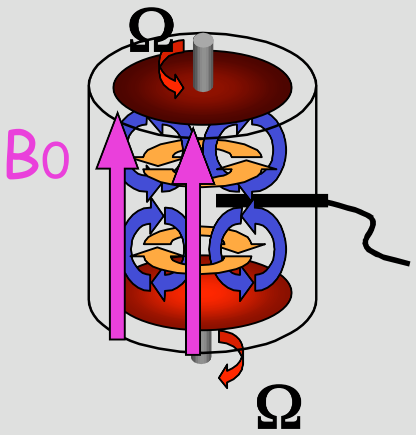


$B_\theta(r_i, t)$

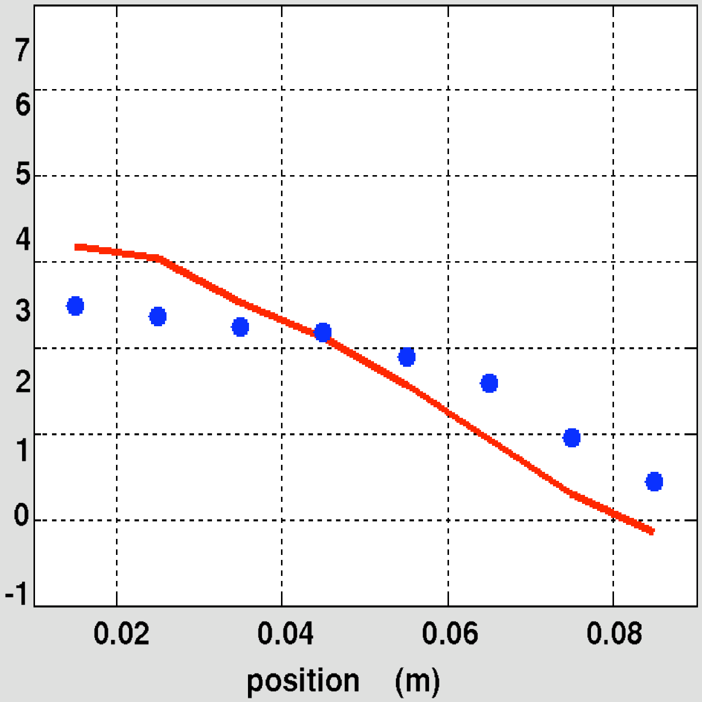
Rm=2

real time

Ω=10Hz



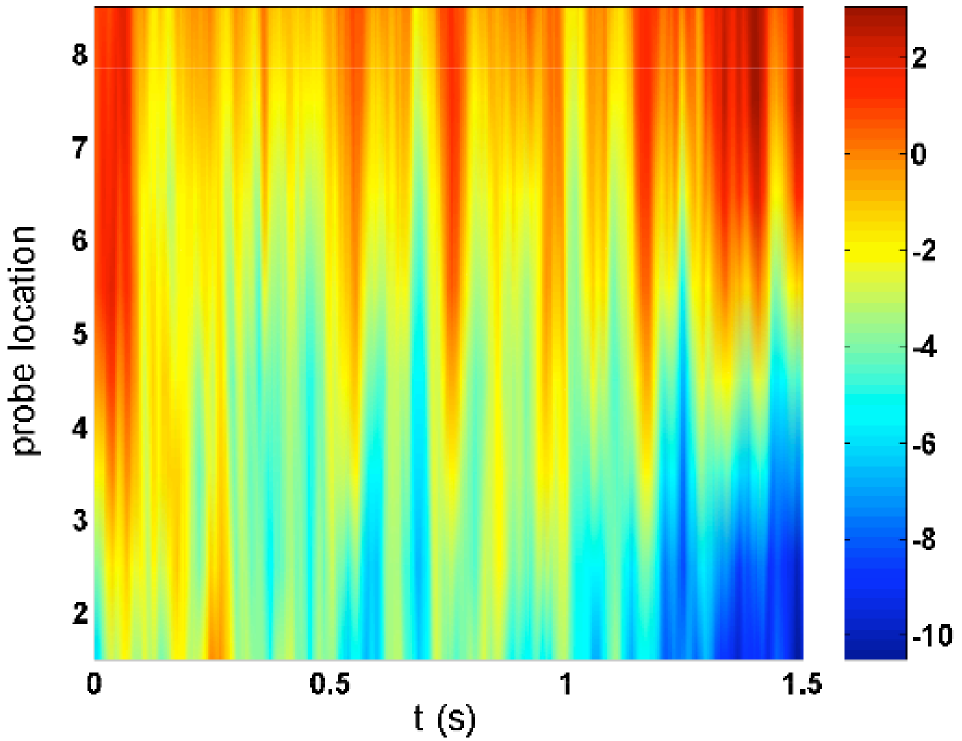
Stretching (poloidal)



$B_z(r_i, t)$

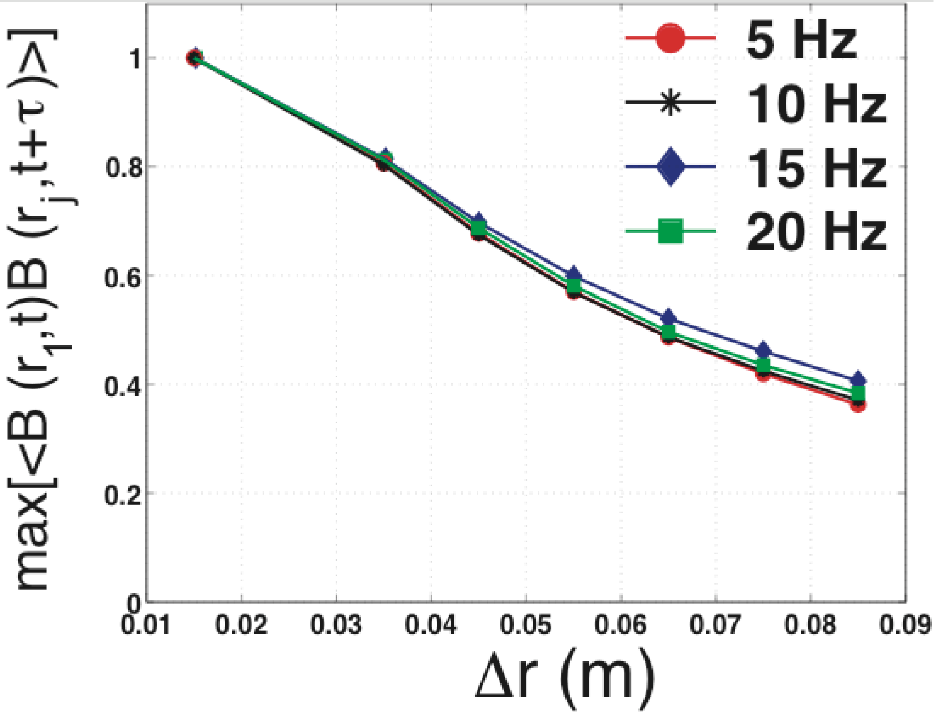
$$\vec{B}(t) \sim -\frac{1}{\lambda}\Delta^{-1}\left[B_0 \partial_z \vec{V}(t)\right]$$

Strong spatial correlations



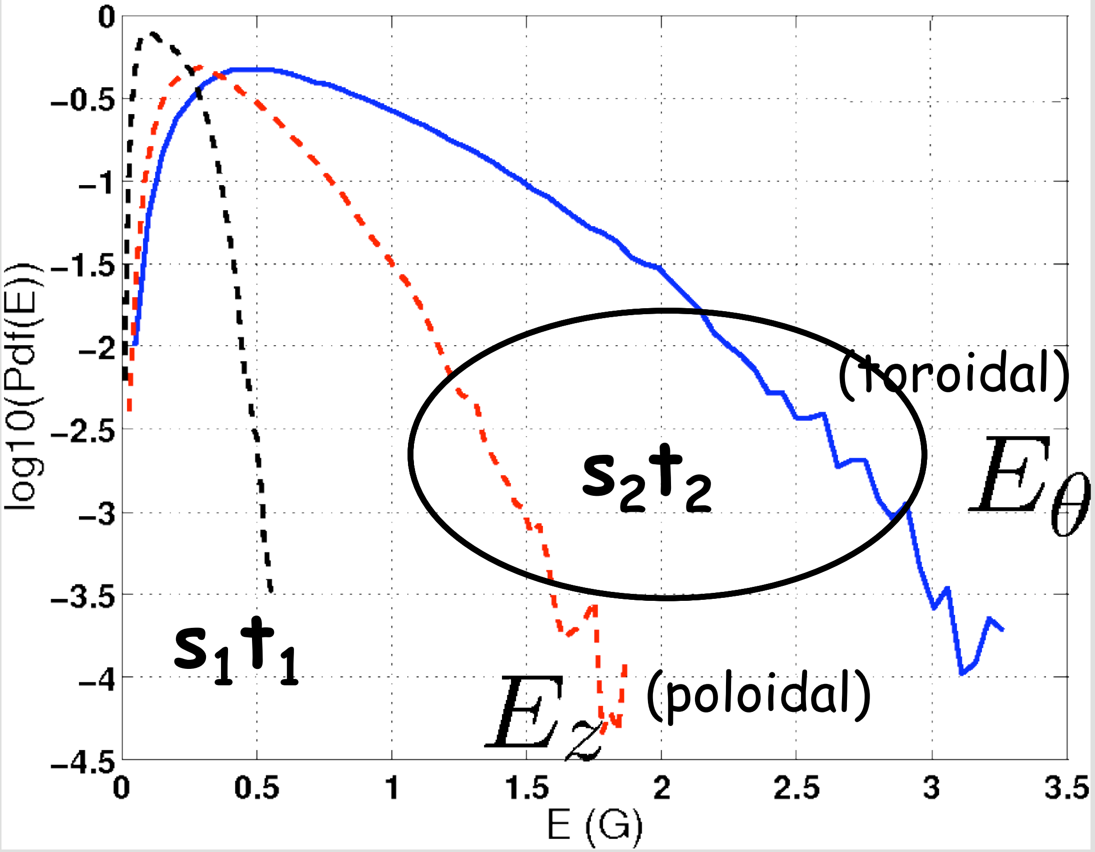
Space-time diagram shows global profile evolution

Correlation length comparable to experiment size



Distance to the mean profile

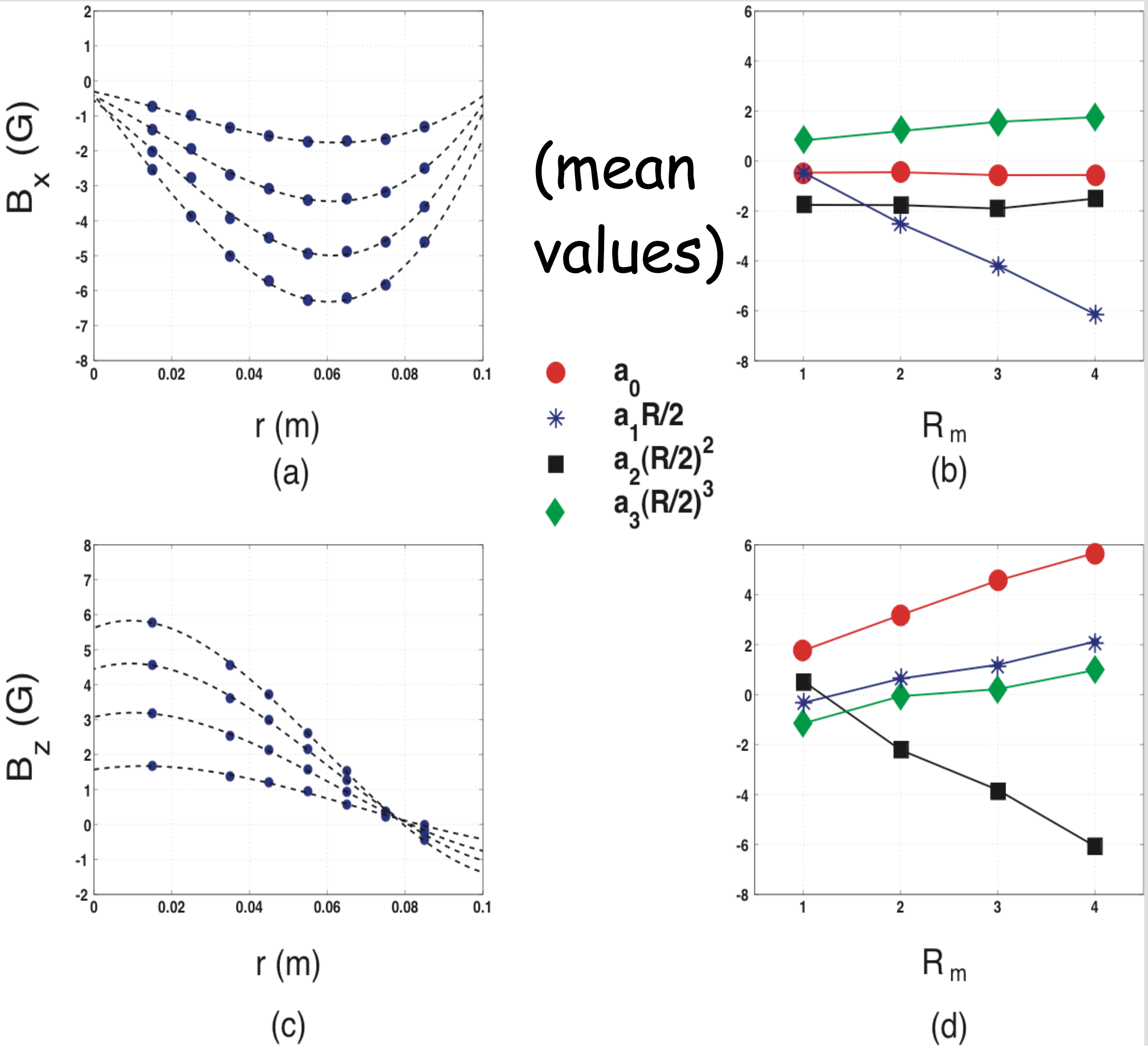
$$E_k(t) = \sqrt{\frac{1}{N}\sum_1^N (B_k(r_i,t) - \langle B_k(r_i,t)\rangle_T)^2}$$



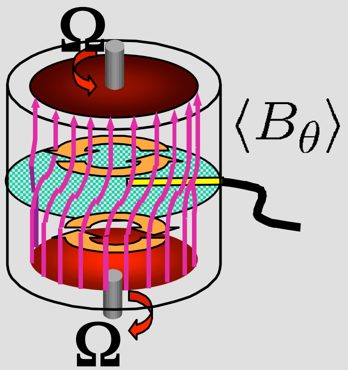
- $<E>$ of the order of $<B>$
- $\frac{E\text{rms}}{\langle E\rangle} \sim 50\%$
- stronger deviations for the field induced by the rotation flow
- more deviations for s_2t_2 than for s_1t_1

Polynomial analysis of the profiles

$$B(r,t) = a_0(t) + a_1(t)r + a_2(t)r^2 + a_3(t)r^3$$

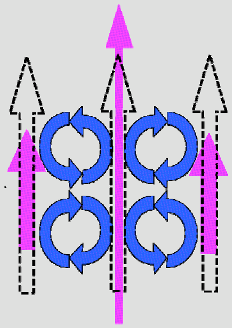


(mean values)



$a_1 \propto Rm$

Ω-effect (toroidal)



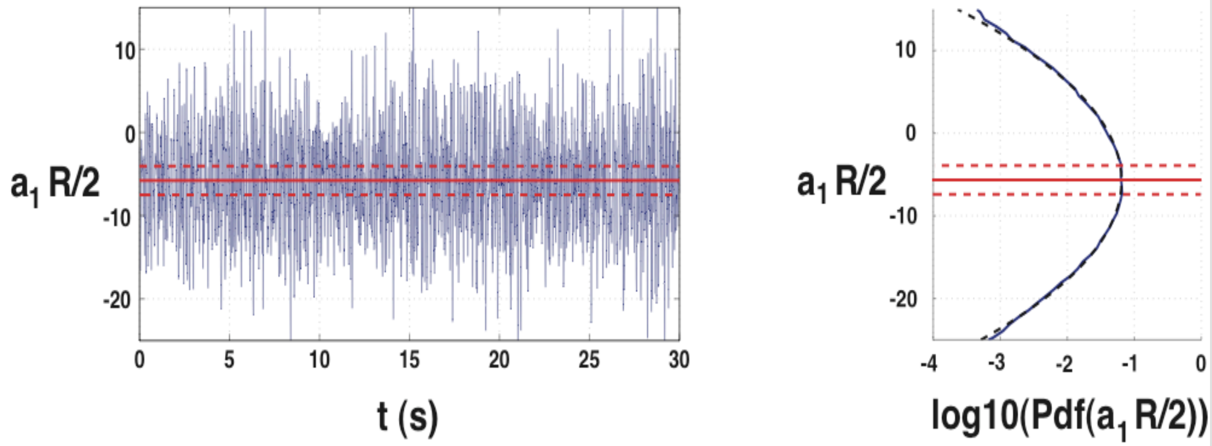
$a_0 \propto Rm$

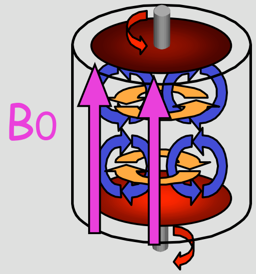
stretching (poloidal)

Polynomial analysis of the profiles

Fluctuations of the coefficients

(a) Axial field : Ω effect

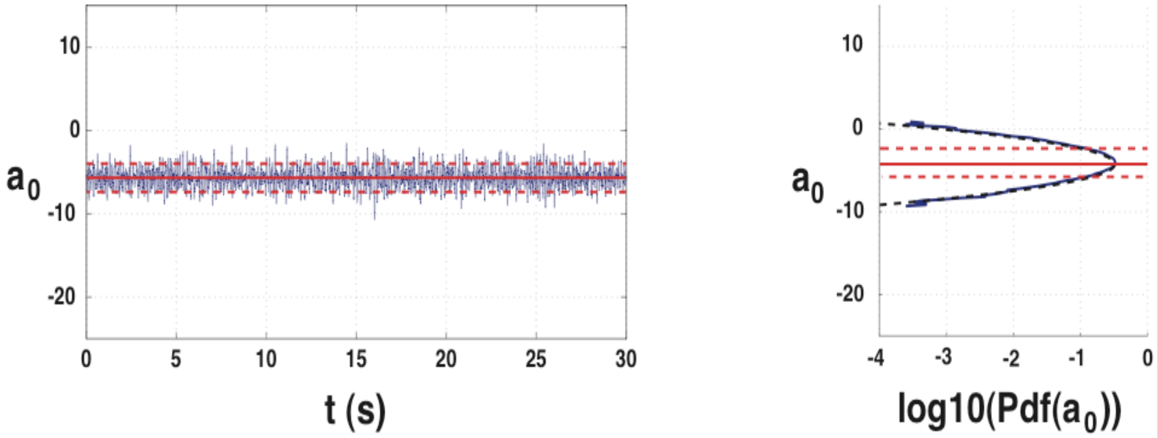




$$\frac{a_{1,\text{rms}}}{\langle a_1\rangle} \sim 114\%$$

Ω-effect (toroidal)

(b) Axial field : stretching effect

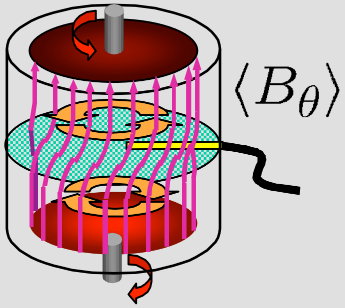


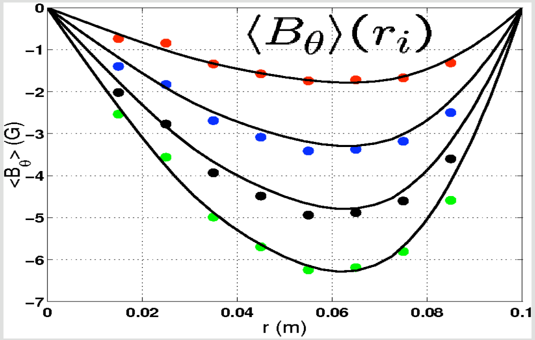
$$\frac{a_{0,\text{rms}}}{\langle a_0\rangle} \sim 20\%$$

stretching (poloidal)

Loss of the s_2t_2 geometry

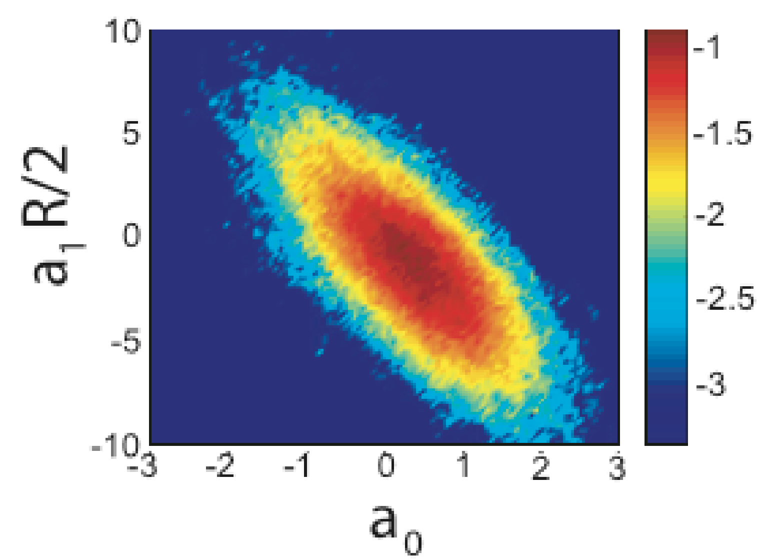
Ω-effect (toroidal)





($a_1 \propto Rm$)

- By symmetry : $a_0=0$ but at Ω=10 Hz, $a_{0,rms}=1.25G \approx \langle B_{induced} \rangle$
- a_0 and a_1 strongly correlated
- Combined probability : $|a_0(t)|>0.5\ a_{0,rms}$ & $|a_1(t)|>0.5\ a_{1,rms}$ = 50 % !



Conclusions

- B(r,t) is an image of velocity gradients
(probably more complicated at higher Rm - non linear effects)

- In addition to the turbulent small scale structure,
the VK flows (s_2t_2) have strong large scale fluctuations

- They spend about 50% of the time away from the mean structure,
not only in terms of amplitude but also topology and symmetry

- Could that cause an increase of the dynamo threshold
in the unconstrained experiments ?

real Rmc ≠ Rmc predicted with <V> ?

R. Volk, P. Odier, J.F. Pinton, *Fluctuation of magnetic induction in von Kármán swirling flows*, accepted in Physics of Fluids, april 2006. (http://arxiv.org/abs/physics/0511204)