MC simulation efforts for nEDM experiment optimization and systematics calculations

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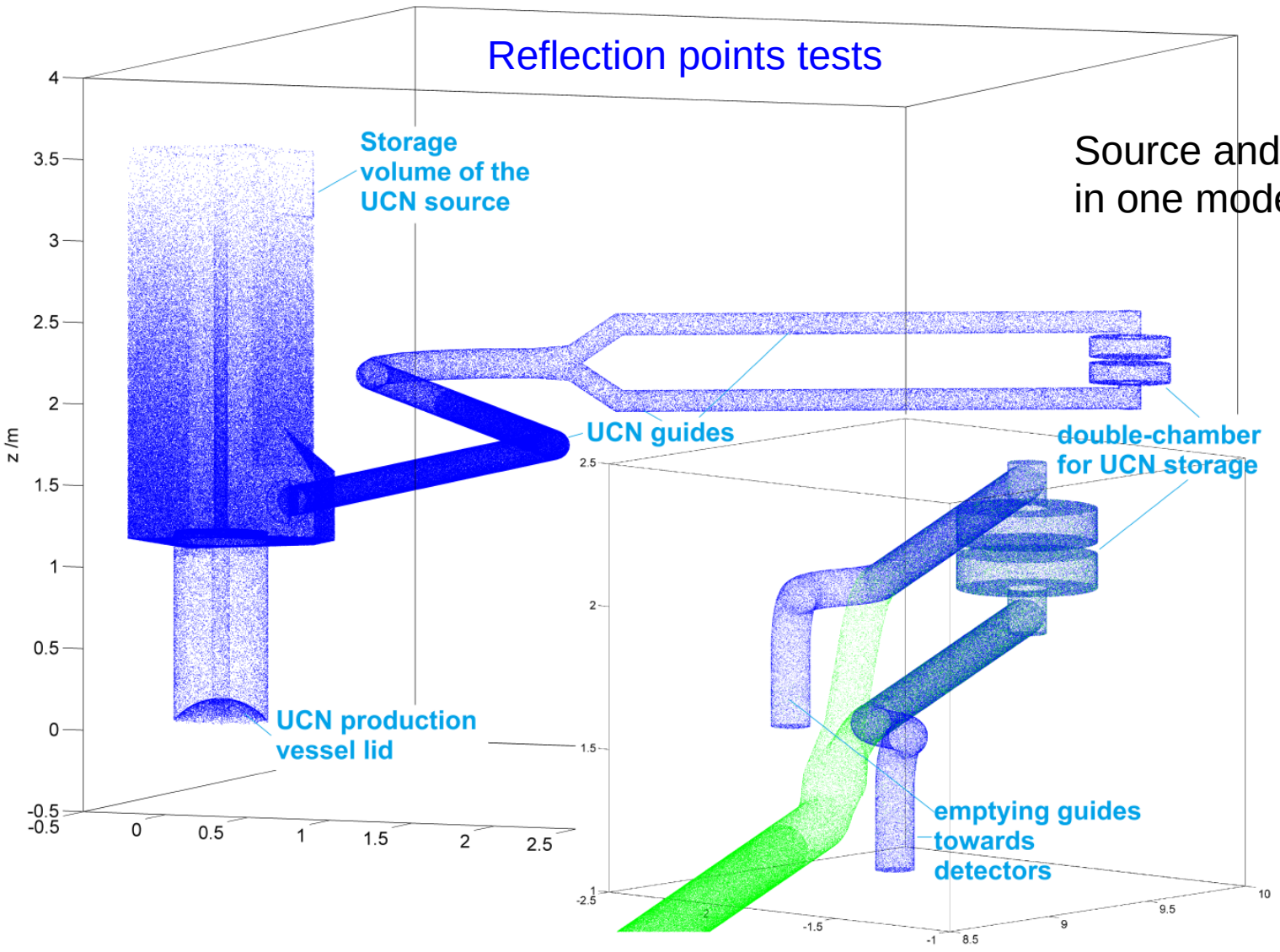
MCUCN simulation models

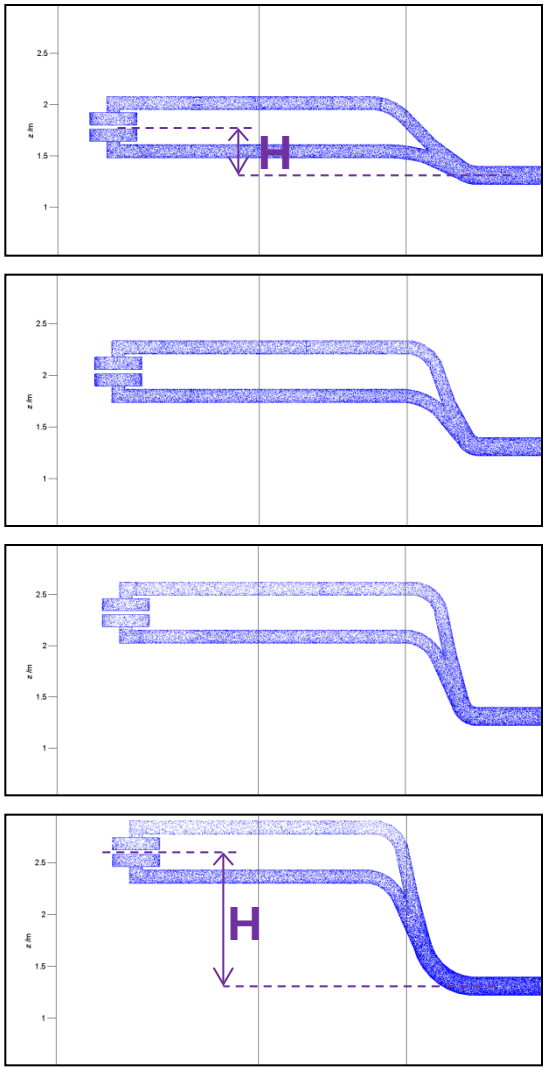
- Developed to model the **PSI UCN source, beamlines and experiments,** aiming for optimization studies for UCN optics, support analysis of (test) experiments
- **Benchmarks** – Analytic and MC with STARucn. Details: www.psi.ch/ltp/ucn-physics/mc and arXiv:1709.05974
- PSI source+beamline **coating parameter calibrations** – simulations matching the measured time constants: storage, emptying; MC of UCN ‚pingpong' measurements between South and West beam-ports
- **Energy dependent transmission** in ‚direct detection' and ‚storage' modes – detected UCN spectra provide the spectra of UCN exiting the solid D_2 converter
- Storage bottle measurements at different heights: MC ‚fit' of the data gives **energy spectrum and number of UCN exiting the solid D_2**
- **Recent applications**: n2EDM statistical sensitivity estimations (slides of Bernhard); n2EDM geometry optimizations; nEDM systematics estimations

Simulation model of the PSI UCN source, beamlines and experiment



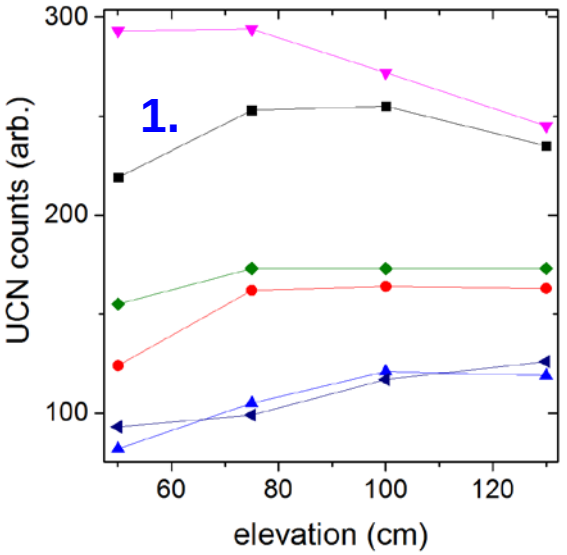
Source and experiment in one model

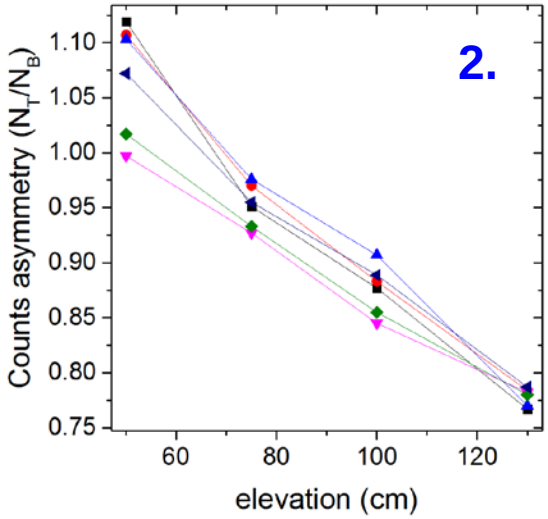
Experiment optimization example

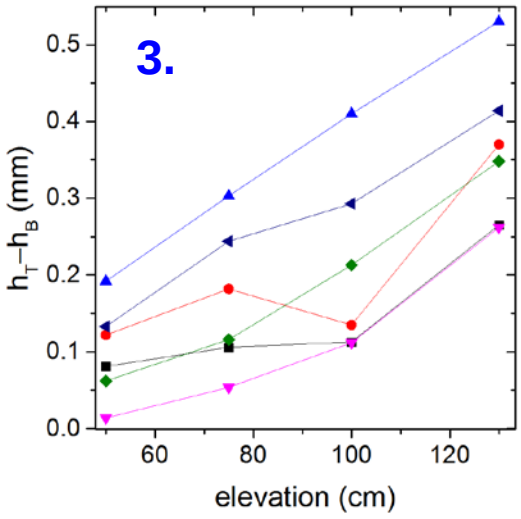


1. **UCN counts *vs* H**
2. **Counts asymmetry top and lower chamber *vs* H**
3. **UCN center-of-mass offset difference *vs* H**

V(neV)	W/V (10^{-4})
165	1
165	2
165	3
220	1
220	2
220	3

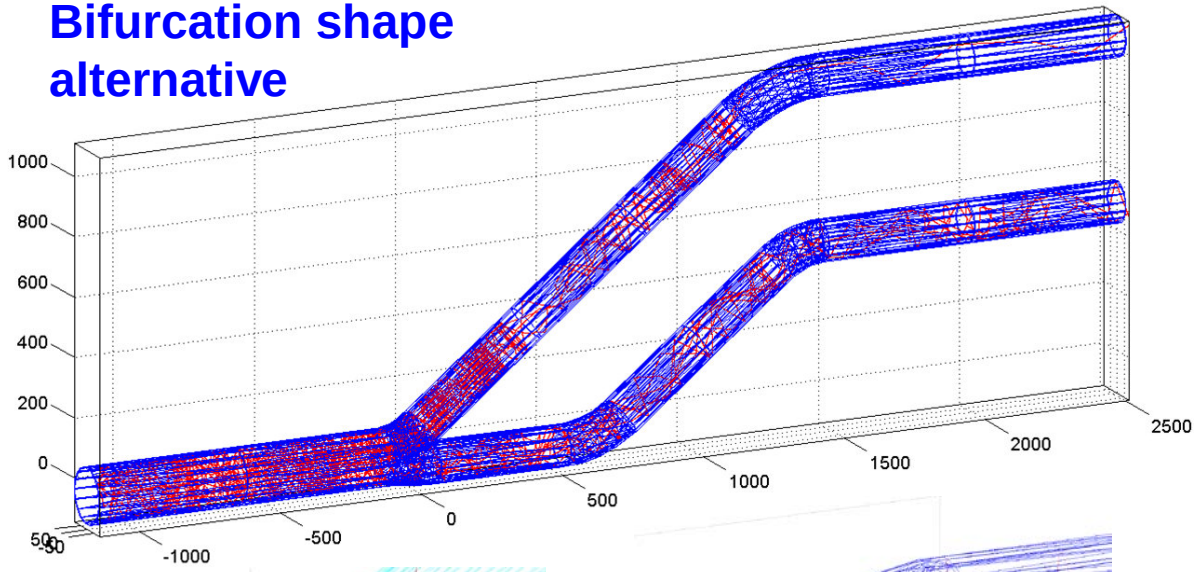


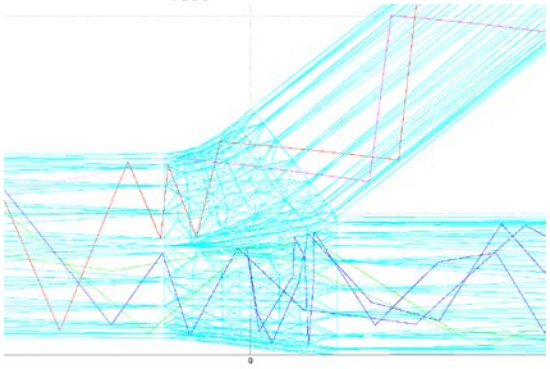


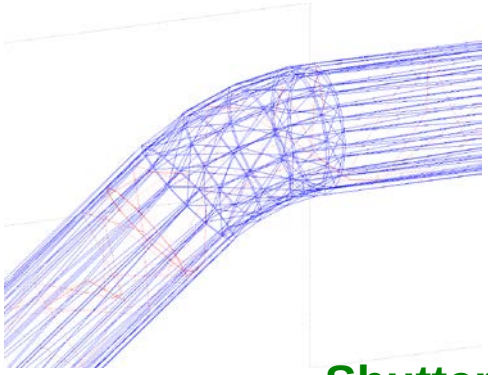


n2EDM optimization examples

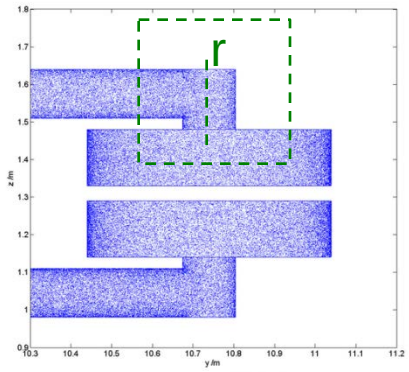
Bifurcation shape alternative

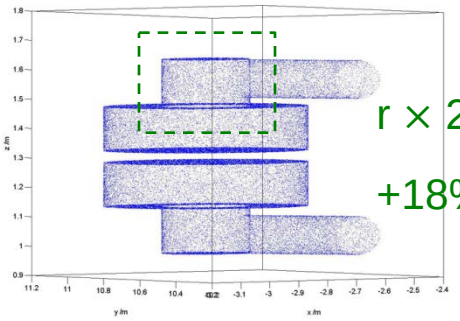


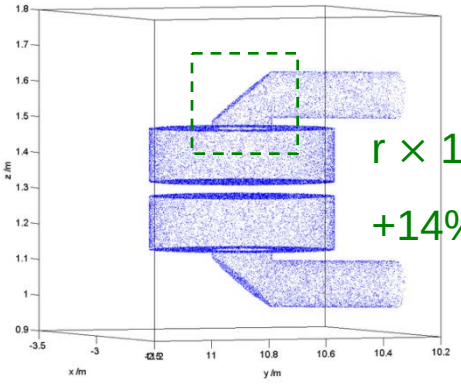




STL / triangularized

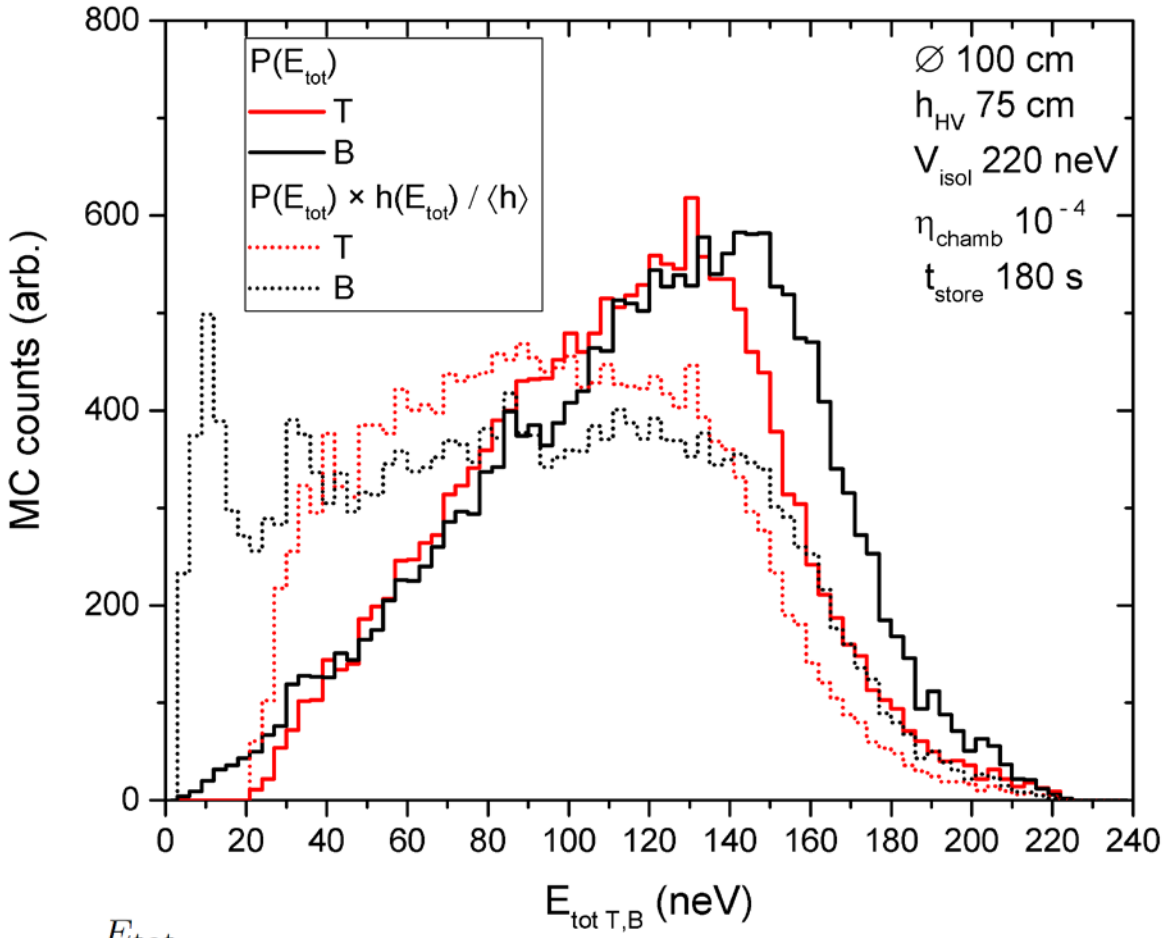






Shutter-housing shape
gain / feasibility

E-spectrum in top and bottom chambers



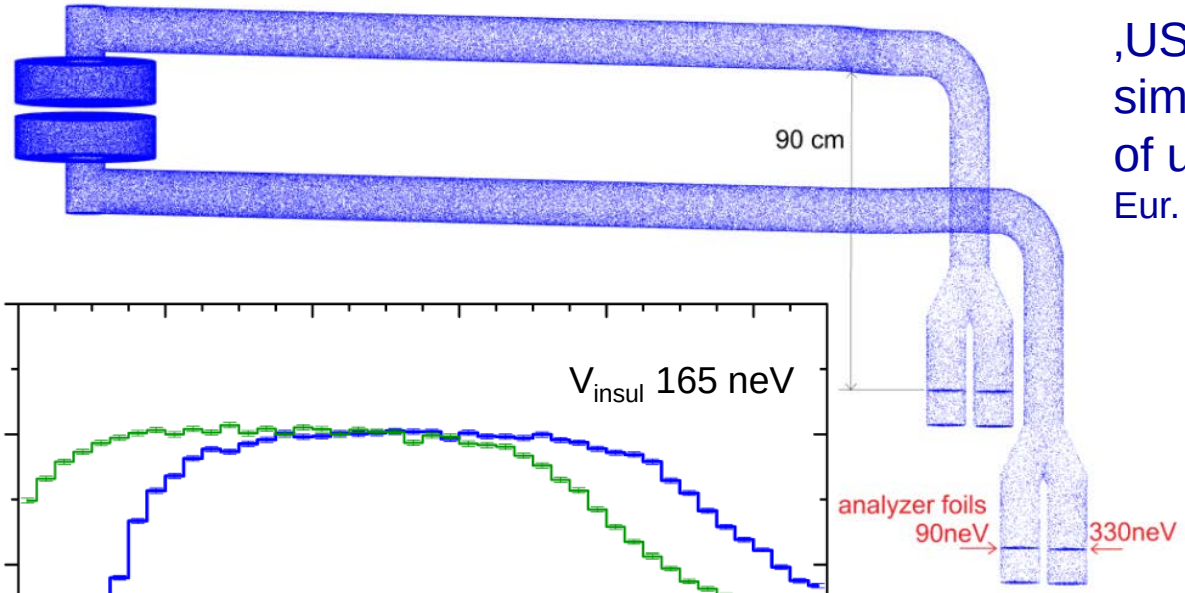
	E_{av}/neV	h_{av}/mm
T	112.8	-0.69
B	118.5	-0.74

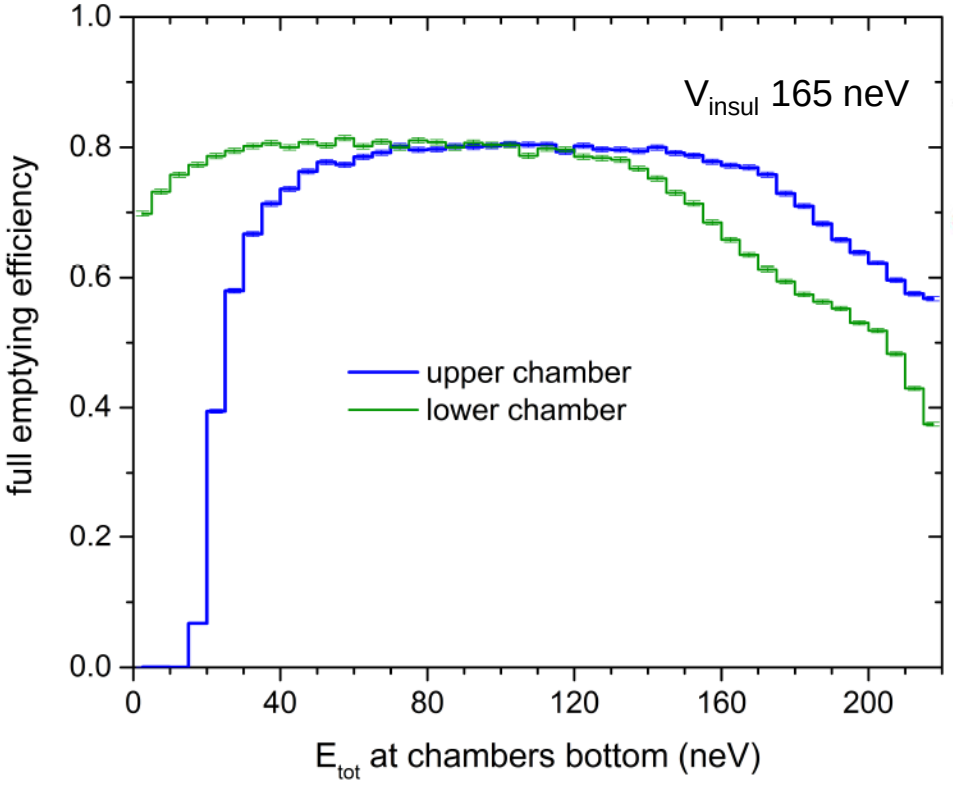
J.M. Pendlebury and D.J.Richardson, Nucl. Instr. and Meth A 337 (1994) 504

$$\epsilon = \frac{E_{\rm tot}}{mg}$$

$$h(E_{\rm tot}) = -\frac{\epsilon}{k}\left[0.6 - k - 0.6\,(1-k)^{5/3}\right] \quad , k = 1 \text{ when } \epsilon < H, \text{ and } k = 1 - (1 - H/\epsilon)^{3/2}$$

Simultaneous-detection efficiency





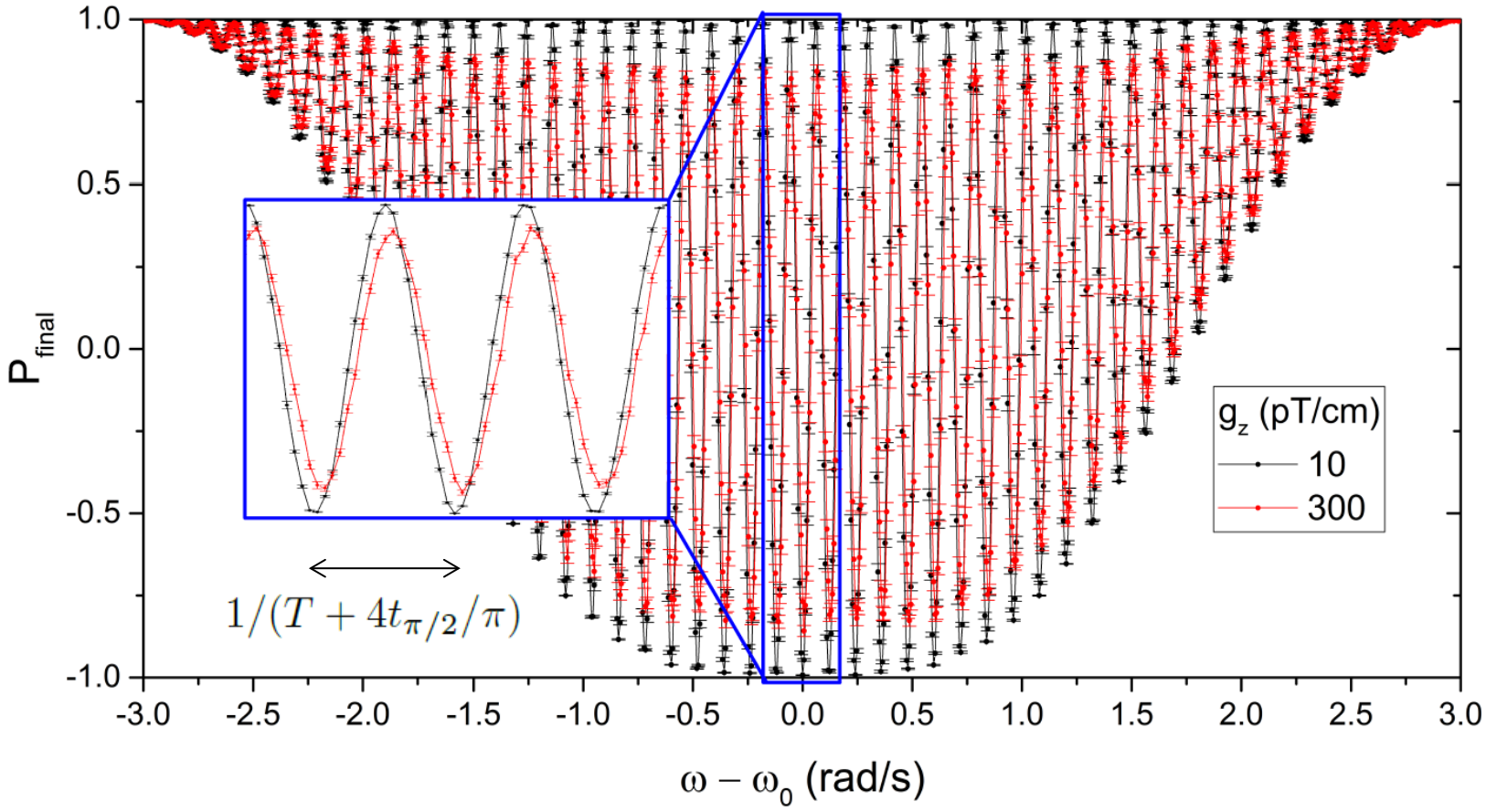
‚USSA' A device for simultaneous spin analysis of ultracold neutrons
Eur. Phys. J. A 51 (11) (2015) 1

Magnetized Fe-coated analyzer foils
210 neV ± 2 T × 60 neV/T

One adiabatic spin flipper ON
Ideal flipping efficiency

Different positions (top or bottom) of the emptying/filling openings
⇒ different transmission profiles

nEDM data analysis and systematics

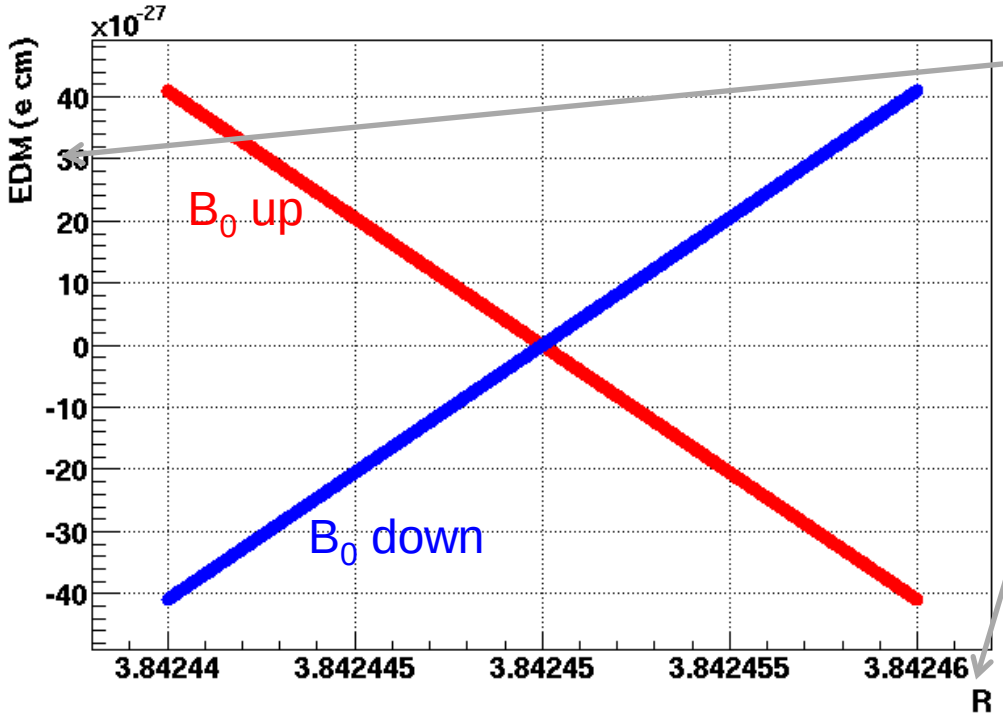


h – center-of-mass offset & $g_z = \partial_z B_z$

$$\Delta\omega/\omega_0 = h/B_0\ g_z$$

nEDM crossing point analysis

C. A. Baker et al., Phys. Rev. Lett. 97 (13) (2006) 131801



False EDM

$$\delta f \propto E v g_z$$

UCN/Hg frequencies ratio

$$R = \frac{\gamma_n}{\gamma_{Hg}}\left(1 \pm \frac{h\, g_z}{B_0} + \frac{q^2 r^2}{4B_0^2}\right)$$

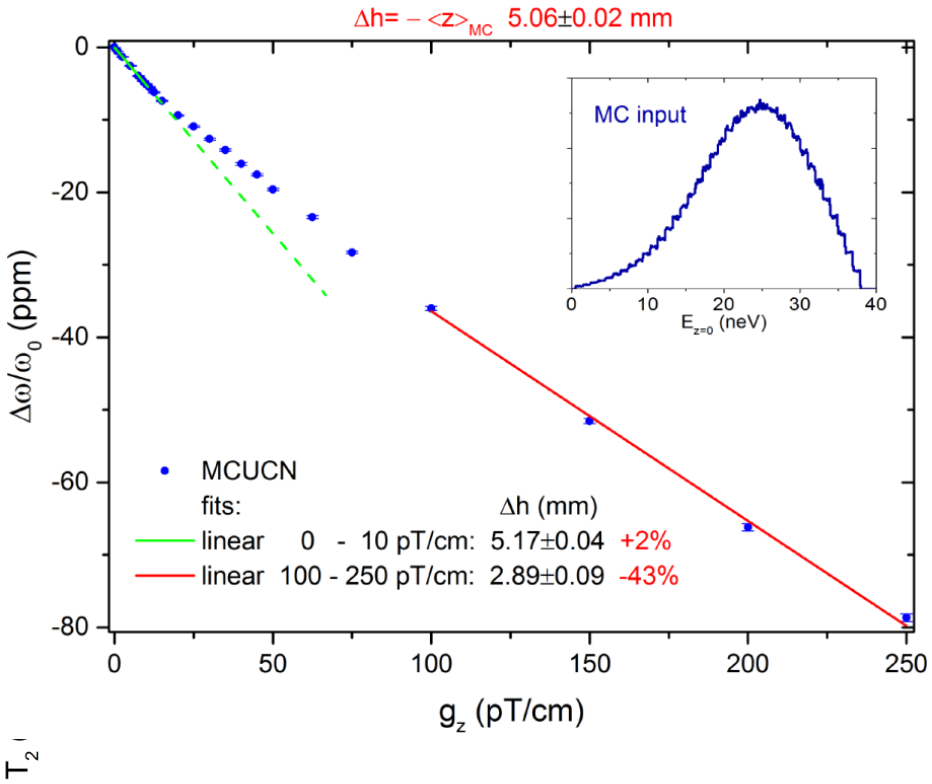
At the crossing point

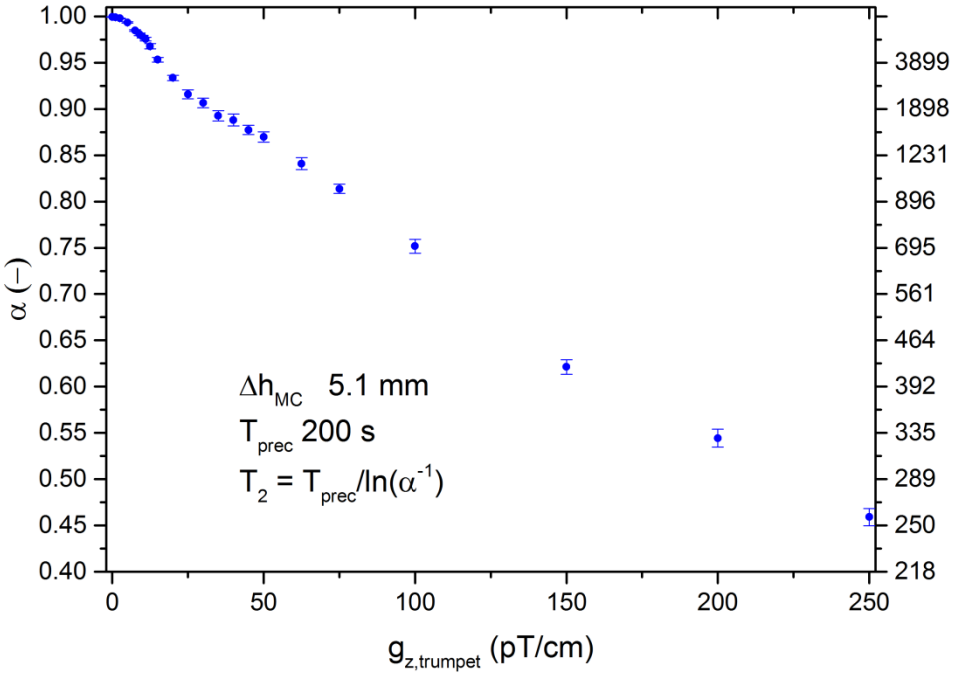
No gradient, no false EDM

Linearity check of the R-curves

Analytic approximation detailed in P. G. Harris et al., Phys. Rev. D 89 (2014) 016011

‚Wrap-around' effect → kink





Outlook

- A full calibrated simulation model available for the PSI UCN source, beamline to test different geometry concepts and systematics for the n2EDM experiment
- MCUCN used in several optimization simulations, e.g. optimal n2EDM experiment height to best match the UCN energy spectrum exiting the solid D_2

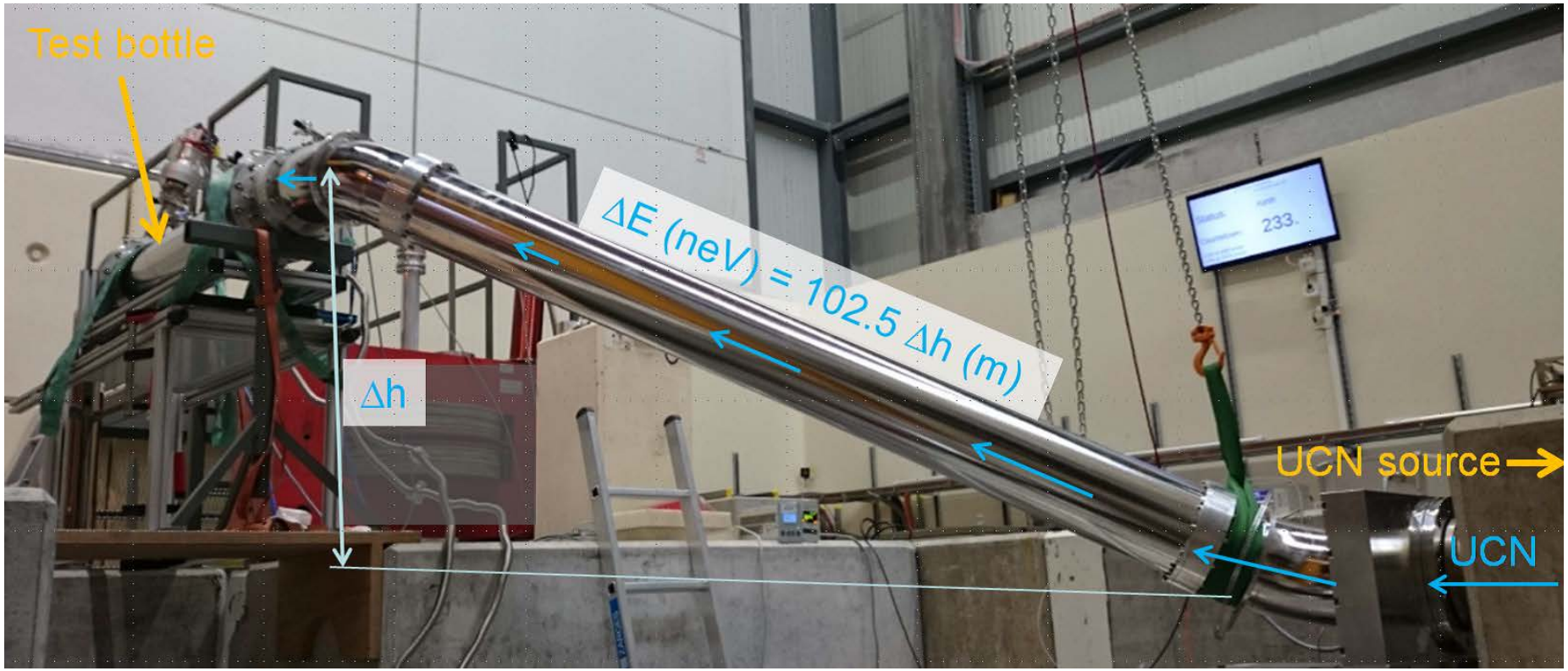
Plans

- Further optimizations of details of the n2EDM guiding and precession chamber system
- UCN beamline upgrades: check larger radius 180 to 220 mm and new ^{58}NiMo coating
- n2EDM systematics estimations with large chamber radii, effect of higher order magnetic field gradients on frequency shifts and T_2-times
- Further MC code inter-comparisons (STARucn, PENTrack) and performance checks

BACKUP

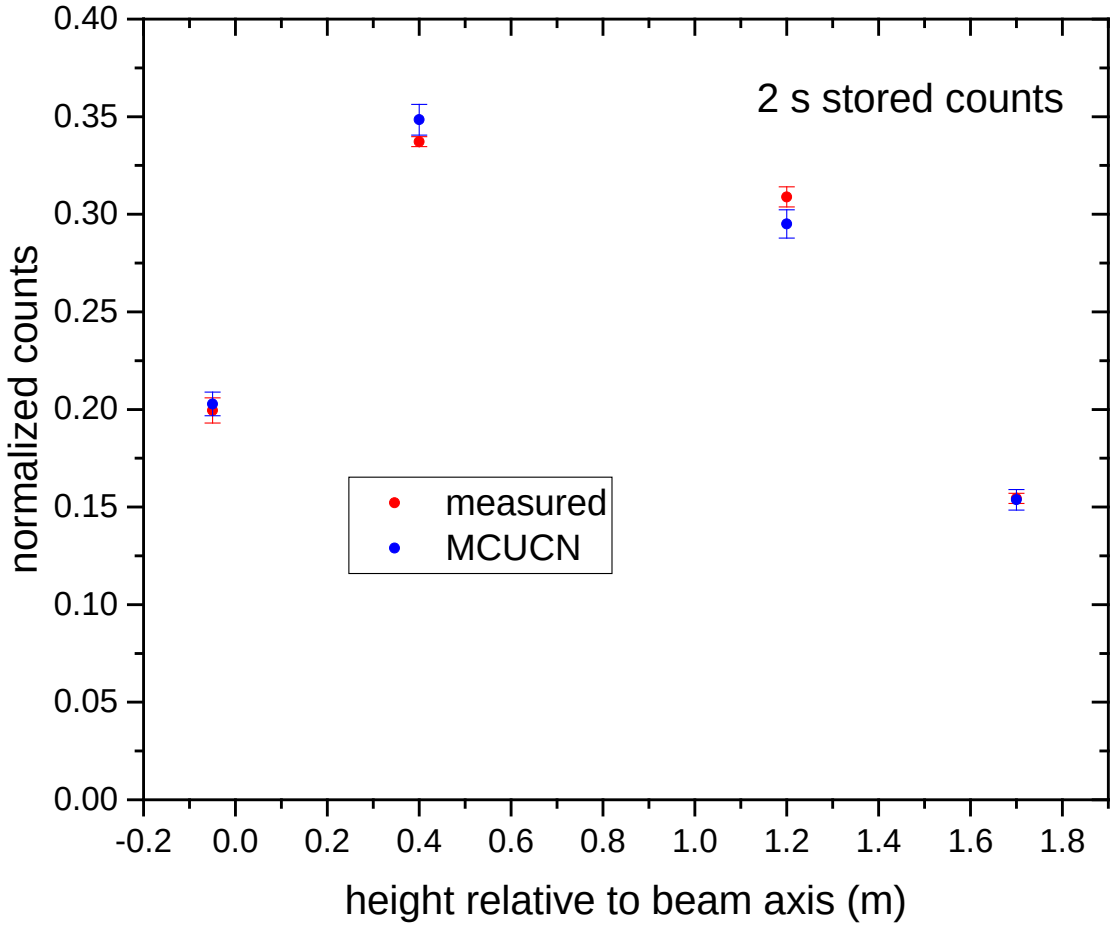
Bottle elevation experiments

D. Ries Thesis ETHZ 2016



MCUCN simulations of the steel UCN-bottle measurements

Comparison of different measurement setups with MCUCN simulations



Tune also sD_2 spectrum:

$$P(E)\,dE \sim E^{2.5}\,dE$$

We have a method to get a direct spectrum from the D_2