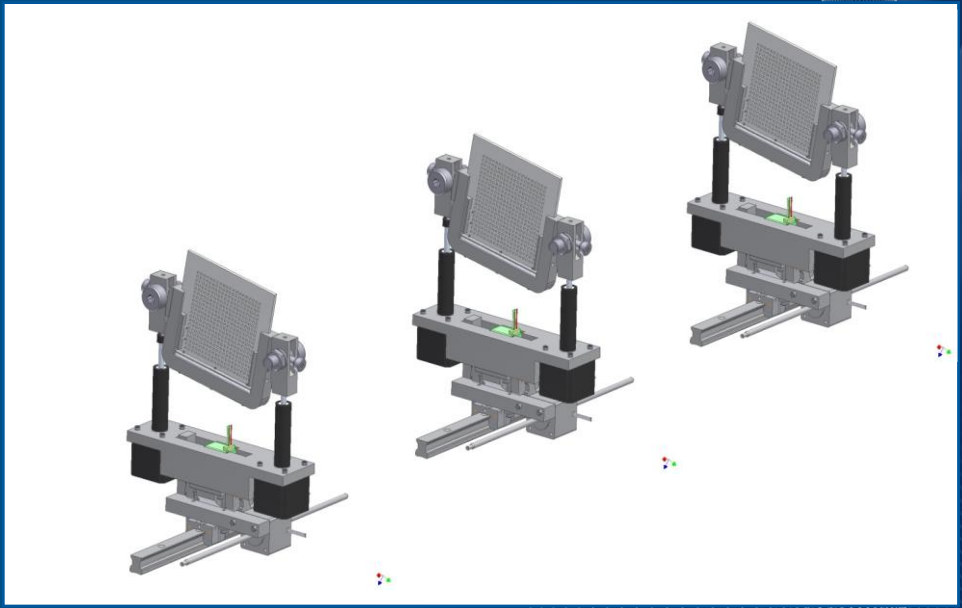
NEUTRON BEAM FOCUSING IN SANS EXPERIMENTS



Daniel Clemens

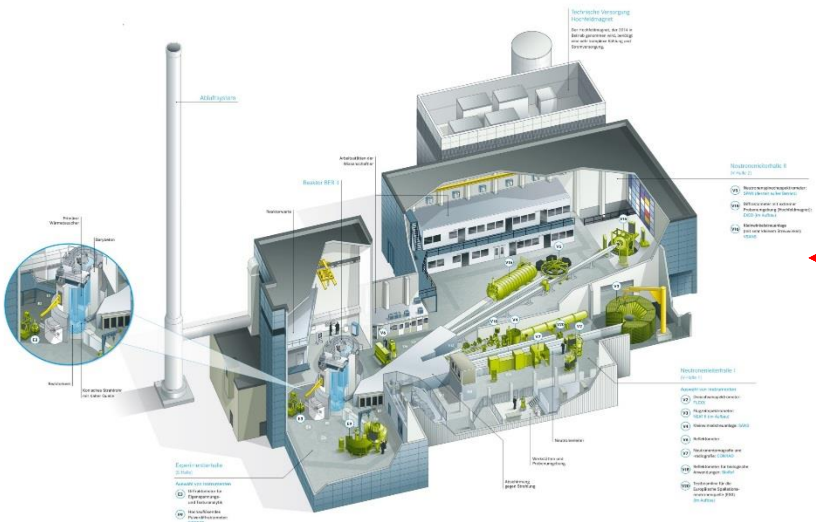
Instrument Transfer – Helmholtz-Zentrum für Materialien und Energie GmbH

NFO 2023

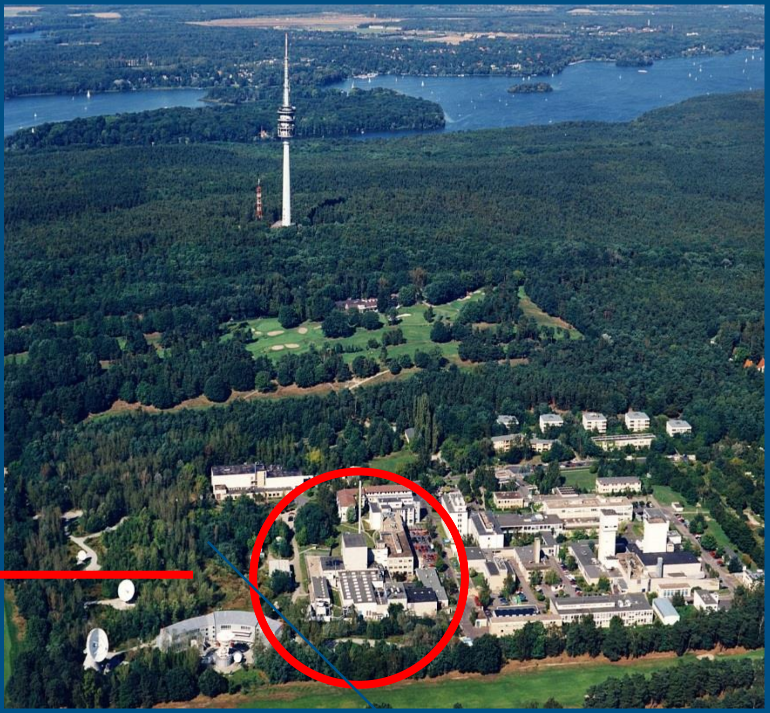
Paul Scherrer Institut

BER-II & BENSC user facility (shut down 11.12.2019)

10 MW light water reactor, 24 thermal & cold neutron instruments

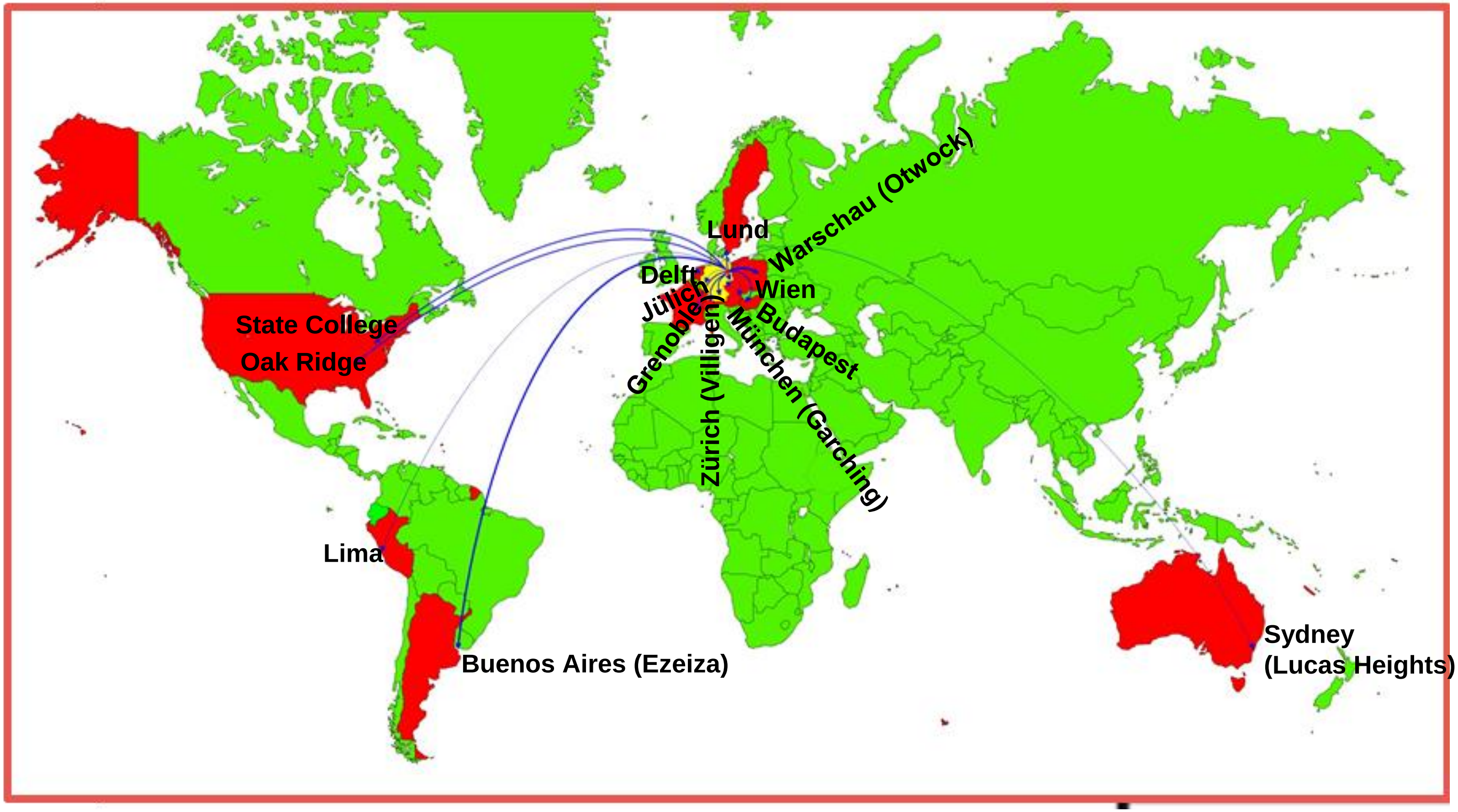


Helmholtz-Zentrum Berlin (former Hahn-Meitner-Institut)



Lise-Meitner-Campus in Berlin-Wannsee

Experiment Transfer Program



Experiment Transfer Program

Neutron guide hall II – now a logistics center

WHY DO WE LIKE TO FOCUS NEUTRONS ?

- Use more neutrons
- Work with smaller gauge volumes at the sample
- Reduce the overall instrument size
- Adapt to small source dimensions (ellipsoidal imaging)
- Enhance resolution in combination with a suitable detector
- "because we can !"

What's the interest in SANS to profit from focusing ?

- Push minimum measurable momentum transfer to an overlap with USANS, i.e. $q_{min} \sim 10^{-3}$ nm^{-1} (-> VSANS)
- Have considerable flux to work on standard gauge volumes, i.e. not at extremely high sample volumes as that can be expensive)
- Feasibility of fast automated measurement series and/or small concentrations of scattering particles (Biophysics)
- Keep the typical 2-D I(q) maps, to treat them with the well-known data reduction and modeling packages and without dealing too much with de-smearing approaches

Methods of neutron focusing

- refractive

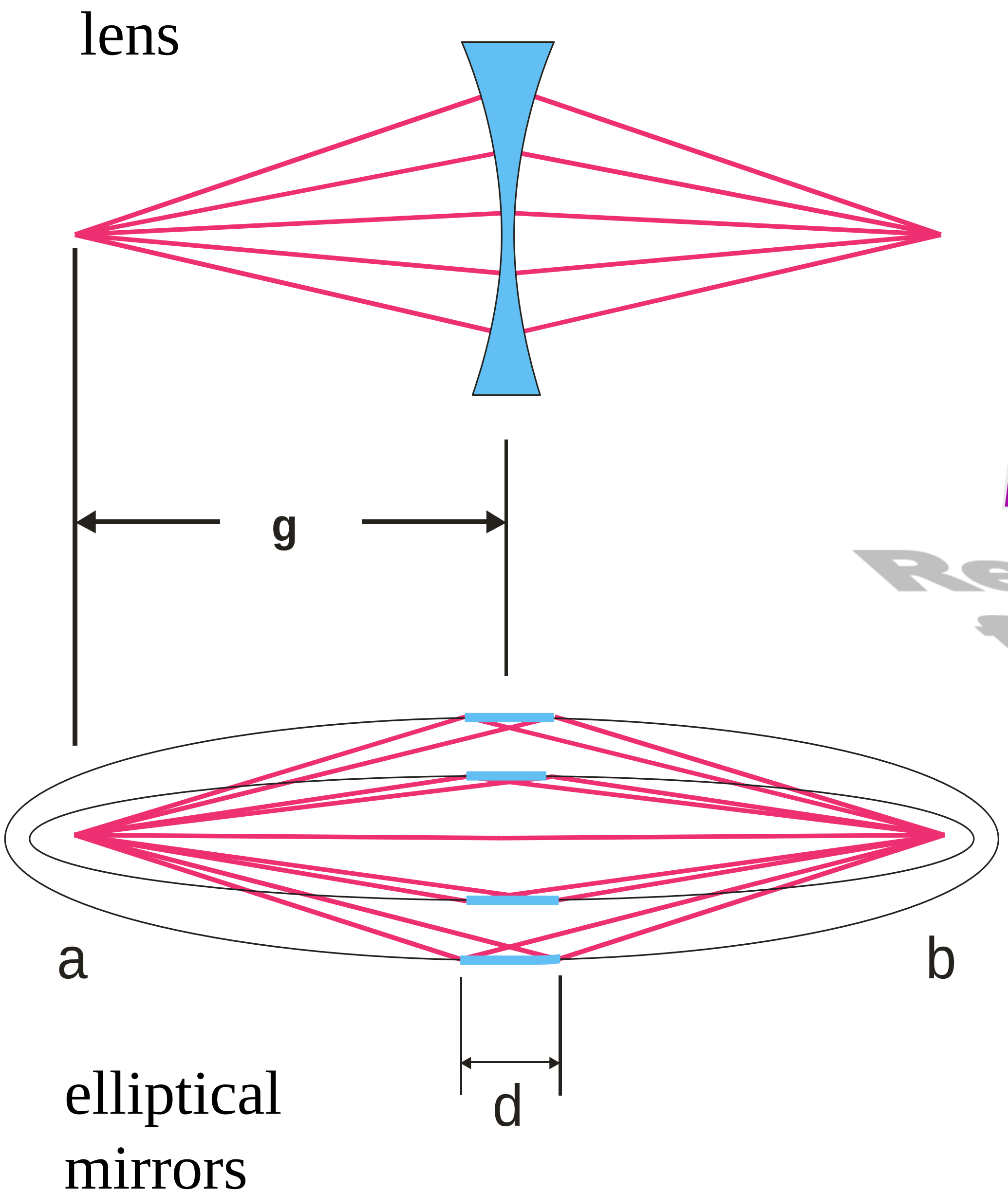
  lenses, mirrors

- magnetic
- diffractive

  crystals, zone plates

- collimation

  converging collimators



Refractive focussing

$$1/g + 1/g' = 1/f$$

Refractive lenses

Focal length
for thin lens, g‘= ∞

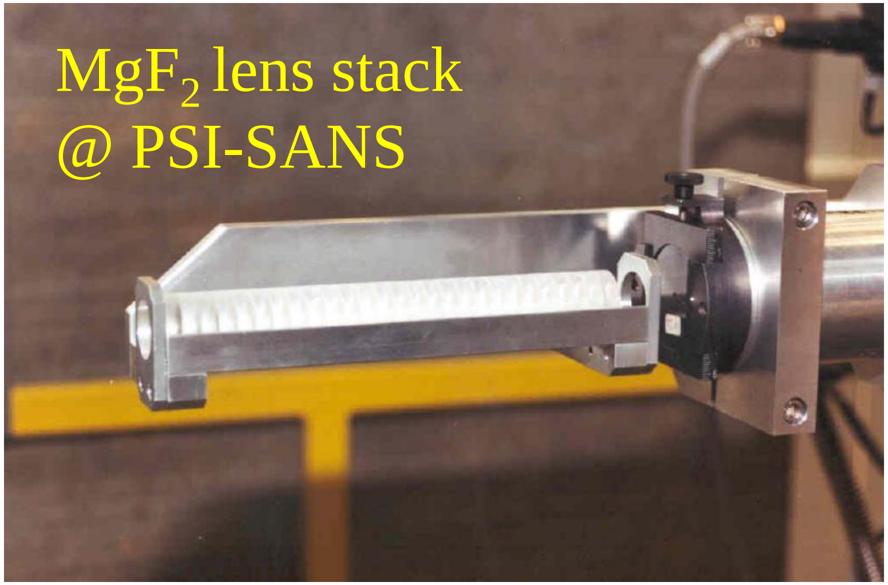
for N lenses

$f_i = \pi r / (\lambda^2 \rho b)$

$f_N = f_i / N$

- Longitudinal chromatic abberation
- Absorption
- Focal lengths may be sometimes inappropriate to wanted q regime

- Gains > 15
- Correction of abberation by defocussing element
- Efficient use of beam cross section
- Good imaging properties



Ref.: M.R. Eskildsen *et al*., Nature 391 (1998) 563; PSI Ann. Rep.

Refractive lens

Element/isotope	Atomic weight	b_c (fm)	σ_a (barns)	b_c/σ_a (fm^{-1})
O	15.99	5.8	1.9×10^{-4}	310
C	12.01	6.6	3.5×10^{-3}	19
Be†	9.01	7.8	7.6×10^{-3}	10
Pb*	208.0	9.5	4.8×10^{-3}	8.0
F†	18.99	5.6	9.6×10^{-3}	5.8
Zr*	90.0	6.4	1.1×10^{-2}	5.3
Pb*	206.0	9.2	3.0×10^{-2}	3.1
Bi†	208.98	8.5	3.4×10^{-2}	2.5
H*†	2.0	6.7	5.2×10^{-4}	2.1
Zr*	94.0	8.2	5.0×10^{-2}	1.6
Mg†	24.3	5.4	6.3×10^{-2}	0.86
Mo*	94.0	6.8	1.5×10^{-2}	0.85
Mo*	92.0	6.9	1.9×10^{-2}	0.68
Sr*	88.0	7.1	5.8×10^{-2}	0.43
N*†	15.0	6.4	2.4×10^{-5}	0.34
Tl*†	205.0	9.5	1.0×10^{-1}	0.24

Figure of merit

SANS and neutron focusing

Focusing in SANS has already been proposed by
H. Maier-Leibnitz & T. Springer, *Reactor Sci. Technol.* **17** (1963) 217

210 Nuclear Instruments and Methods in Physics Research A274 (1989) 210–216
North-Holland, Amsterdam

NEW DEVELOPMENTS OF SMALL ANGLE NEUTRON SCATTERING INSTRUMENTS WITH FOCUSSING

B. ALEFELD, D. SCHWAHN and T. SPRINGER

Institut für Festkörperforschung der Kernforschungsanlage Jülich GmbH, Postfach 1913, 5170 Jülich, FRG

Received 24 May 1988

Dedicated to Ulrich Bonse on the occasion of his 60th birthday

To our present knowlege, there are three different concepts of SANS instruments:

(1) An instrument with very long collimators with pinhole geometry, such as the D11.

(2) An instrument based on the principle of two parallel single crystals of high perfection. The very sharp Bragg condition of these crystals defines the Q-resolution which leads to a value of about 10^{-5} $Å^{-1}$. This principle is known as the Bonse–Hart camera

(3) A focussing instrument with the detector in the focal plane. In the early days of SANS the focussing instrument has been considered in detail [10,11] and tried out experimentally. Because of the poor quality of the mirrors available at that time, the wing or "halo" around the focus was quite strong so that weak scattering close to the beam focus was disguised and practically not measurable. For this reason, the mirror-focussing instruments were discarded since that time.

Alefeld's proposal leading him to build KWS-3

212 *B. Alefeld et al. / New developments of small angle neutron scattering instruments*

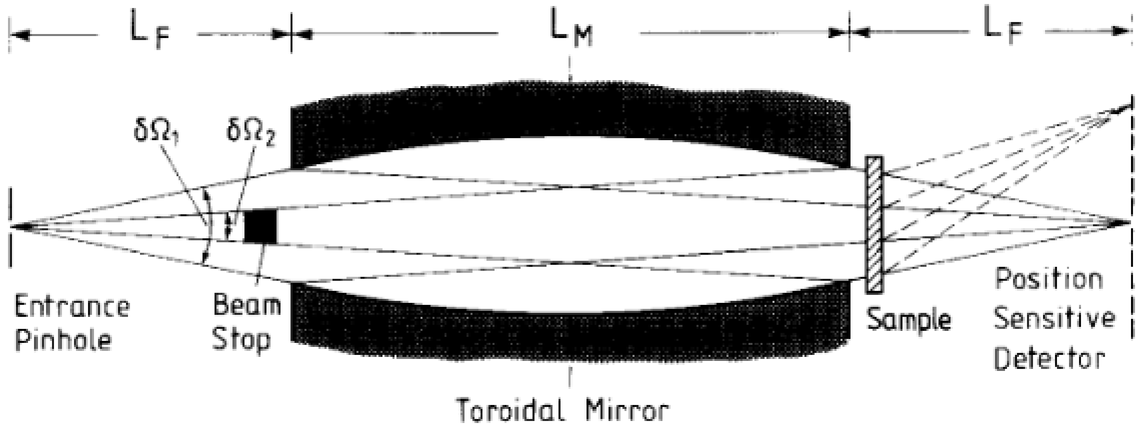


Fig. 2. Schematic drawing of a 1 : 1 image forming SANS instrument with a toroidal mirror. The position sensitive detector is placed at the image of the entrance pinhole. The neutrons within the solid angle $\delta\Omega_2$ of direct sight must be removed by a beam stop. The resolution is determined by the size of the image and the distance between the sample and the detector. The total length should be about 5 m.

At a different stage this concept was also involving nested Wolter optics in adaption of the ROSAT telescope optics. Under gravity, it was too hard to keep the replica mirrors in the proper shape. Böni/Johnson realized slit focus systems (NOP1999). Mildner/Gubarev have built a nested mirror demonstration assembly in 2011. … and D44?

The penumbra

from
B.Alefeld *et al.*, NIM A274 (1989) 210-216

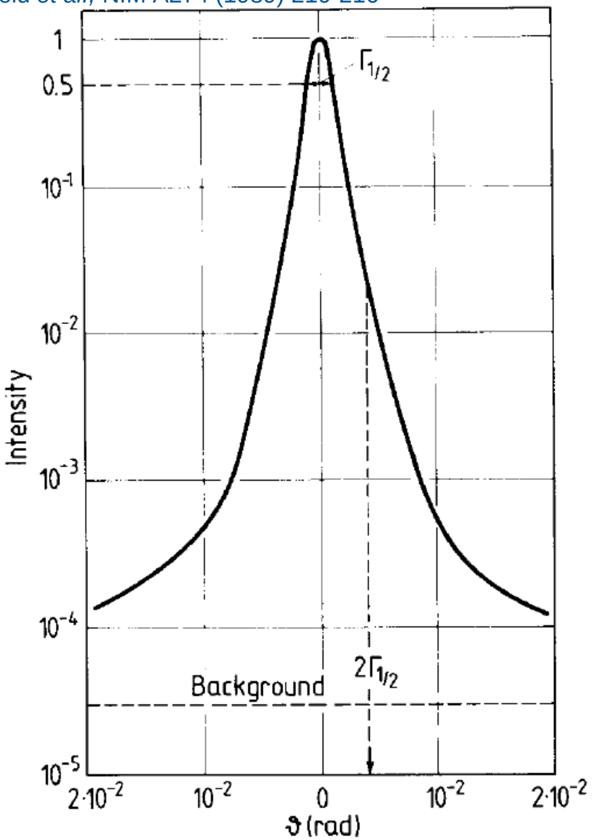


Fig. 3. Intensity profile of an approximately cylindrical mirror which consists of 20 plane glass plates each separately adjustable. The halo at a distance $2\Gamma_{1/2}$ from the beam center is about 2×10^{-2} of the peak intensity.

Idealistic Goals

- Clear optics (i.e. no compromises to neighboring or parasitic instrumentation)
- Perfect stable surface definition (independent of temperature and vibrations)
- Minimum off-specular scattering from coatings (minimum roughness)

Magnetic focussing

T. Oku, H.M. Shimizu / Physica B 283 (2000) 314–317

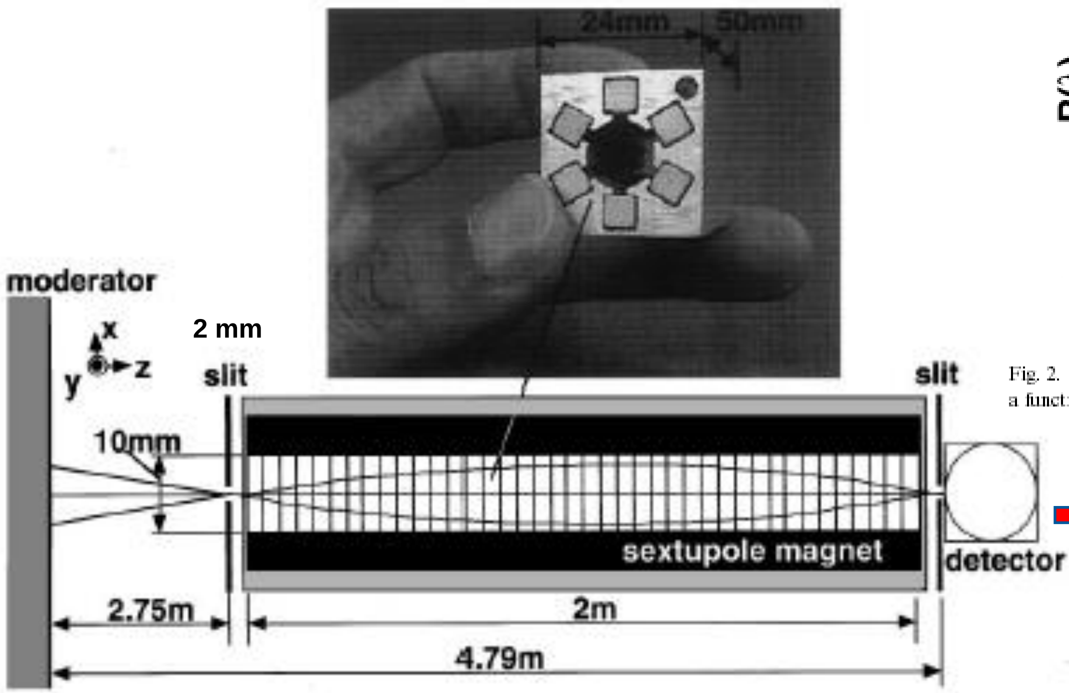


Fig. 1. Experimental setup for the study of a neutron lens. A 2 m sextupole magnet is put together from 40 units of aluminum blocks. Each unit contained six pieces of permanent magnet, 5 mm × 5 mm × 50 mm, as shown in the photograph.

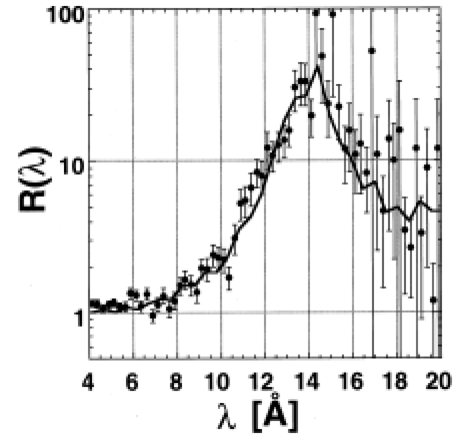
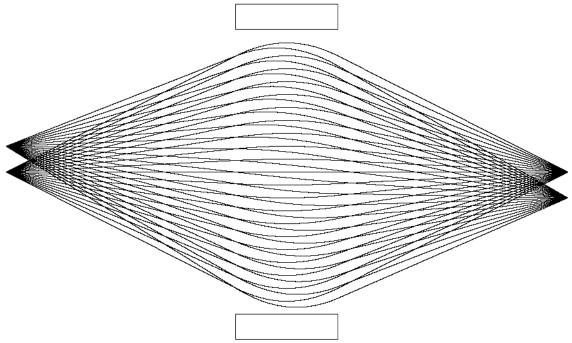


Fig. 2. Magnetic enhancement of the neutron beam intensity as a function of the neutron wavelength.

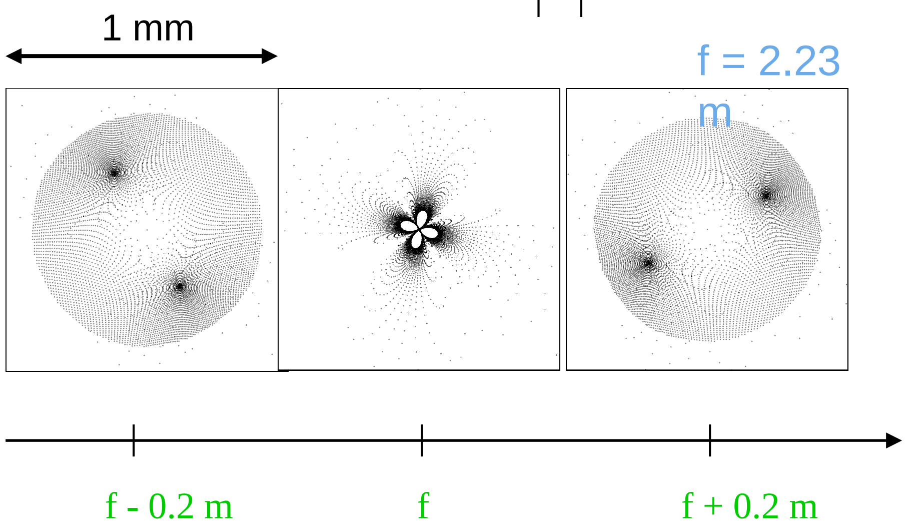
→ **FSANS on SANS-J-II @ JRR3**

see also
A.Steinhoff, NIM A379 (1997) 371

Magnetic focussing



$$\mathbf{F} = \pm \mathbf{s} \nabla |\mathbf{B}|$$



Ideal hexapole magn. lens

- no beam attenuation
- ideal imaging also for
- slightly misaligned beams

Real system

- bipolar component caused by imperfections in pole magnetization leads to spin flip and image distortion

+ Longitudinal chromatic abberation

Ref.: J.Füzi *et al.*, Applied Physics A (ICNS01)

NUCLEAR INSTRUMENTS AND METHODS 119 (1974) 291–293; © NORTH-HOLLAND PUBLISHING CO.

A FOCUSSING LOW-ANGLE NEUTRON DIFFRACTOMETER*

A. C. NUNES

Biology Department, Brookhaven National Laboratory, Upton, New York 11973, U.S.A.

Received 18 March 1974

A converging non-reflecting Soller slit provides a focussed neutron beam for neutron scattering experiments.

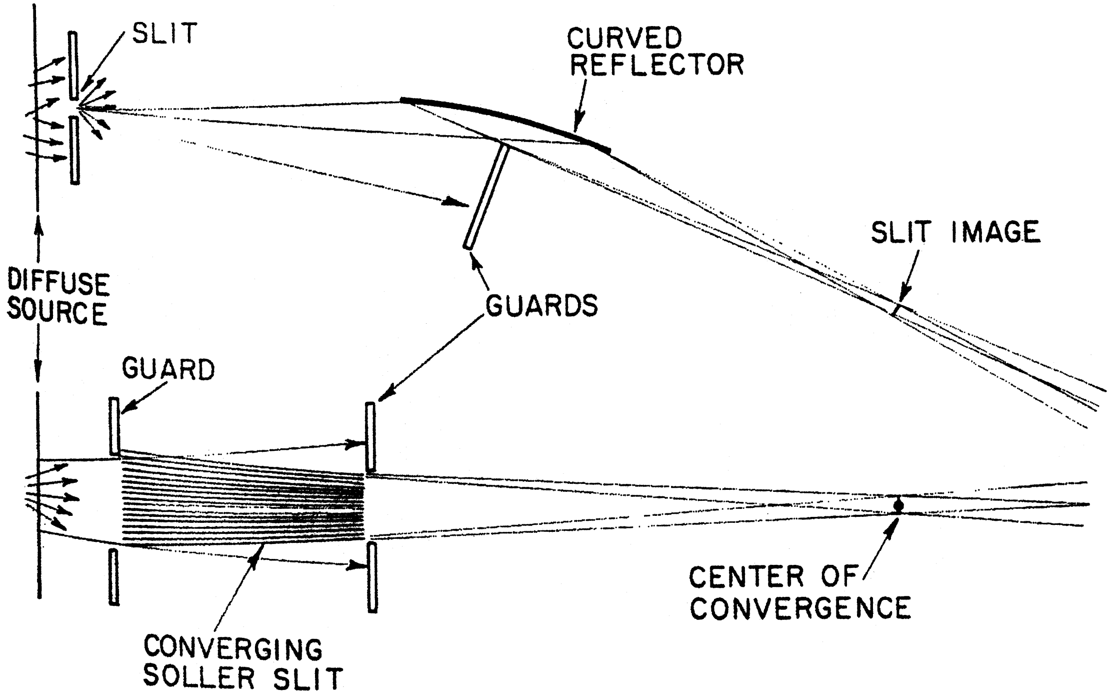
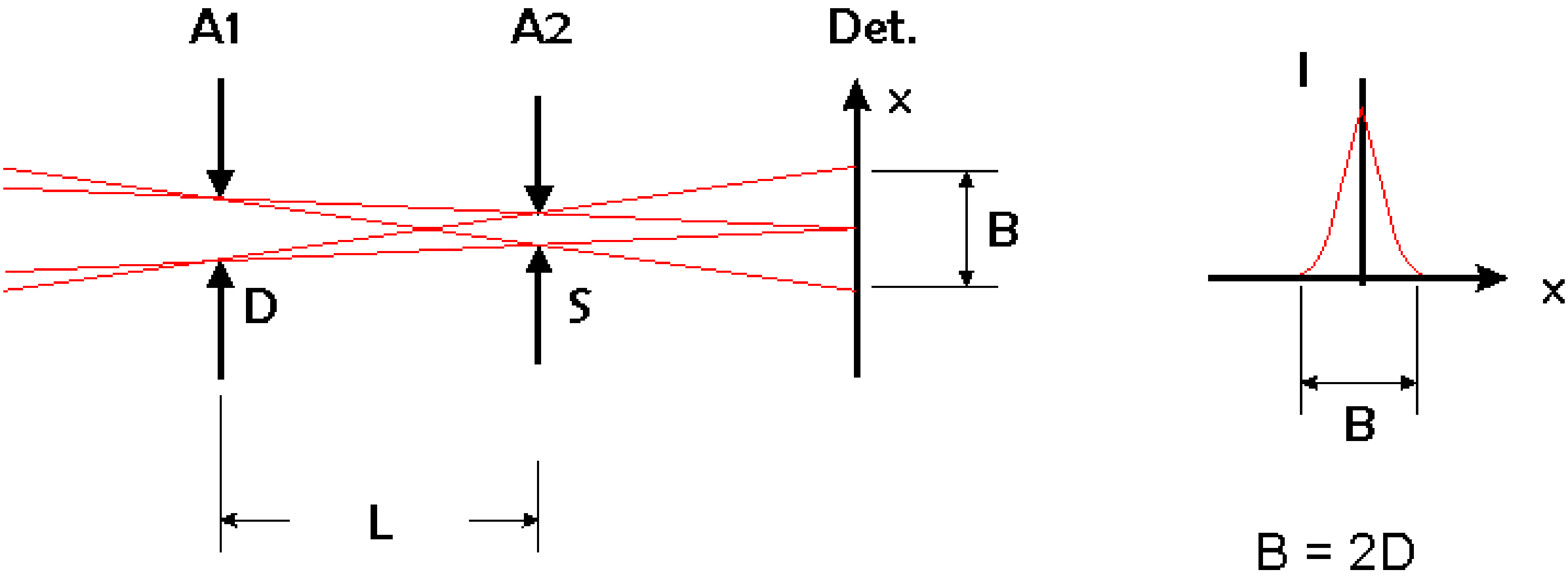


Fig. 1. Two neutron focussing systems (see text).

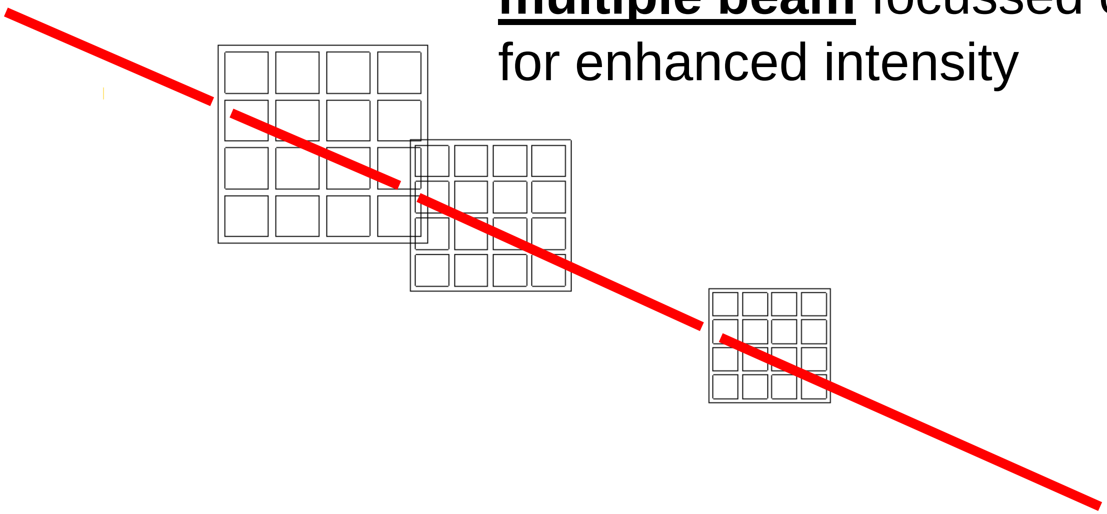


Minimal accessible scattering angle $\vartheta_{min} = B/2L$

Flux on sample $\phi \sim (S\ D/L)^2$

Potential instrumental improvement:

<u>multiple beam</u> focussed on the same spot on detector for enhanced intensity



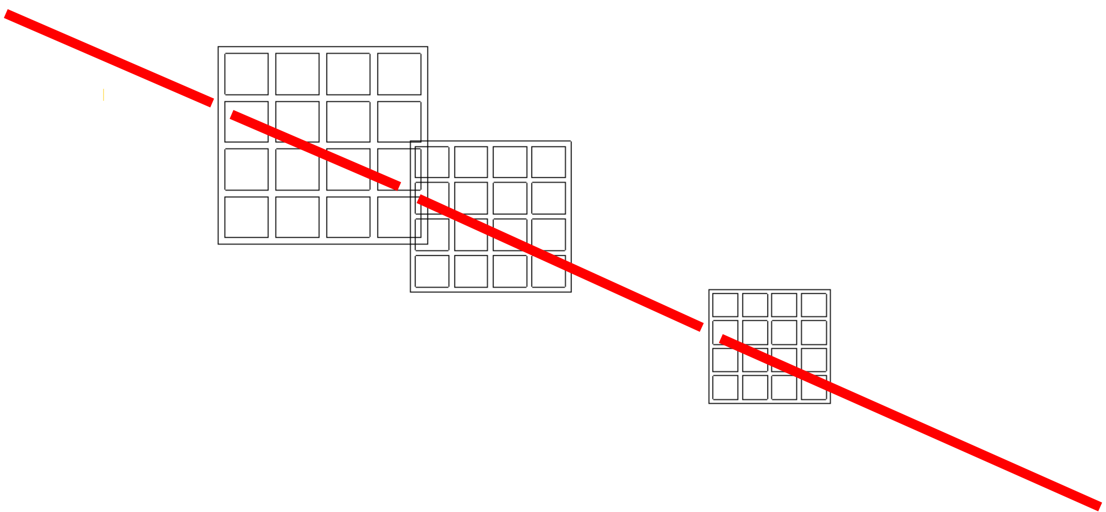
Based on established pin hole approach: little technical risk (if manu-factured with good precision)

Enhanced intensity by focused **multiple beam**

also opens up the way for **enhanced resolution**

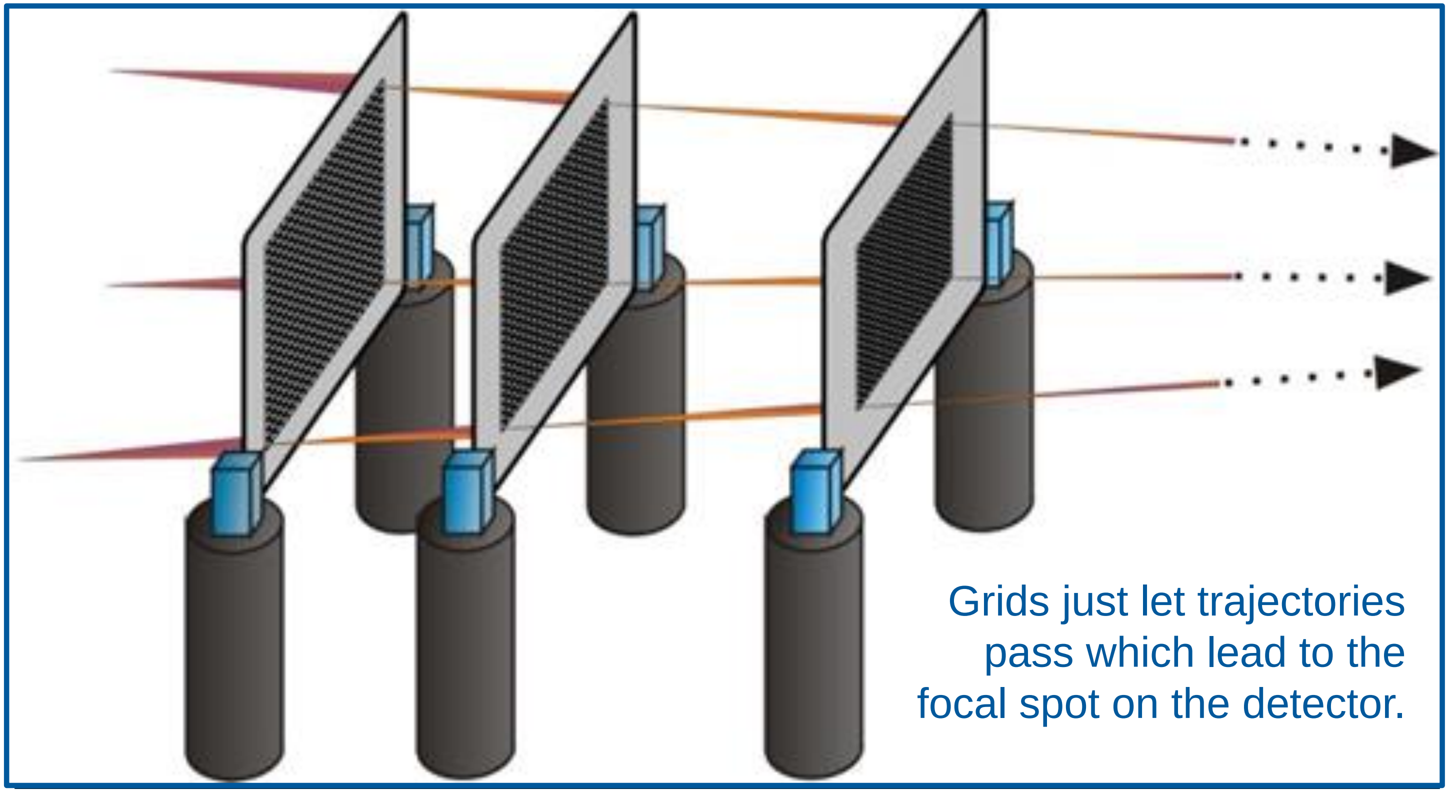
~ 1-2 mm pinholes: Very Small Angle Neutron Scattering

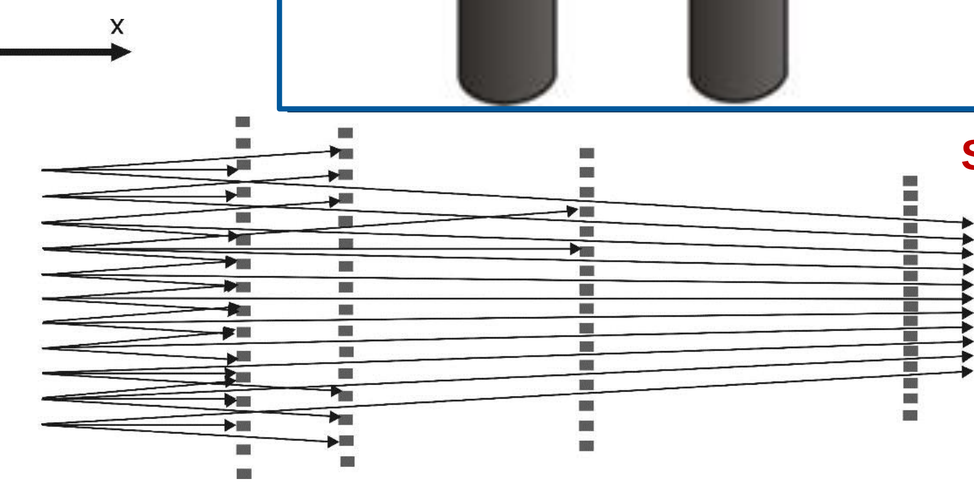
VSANS $\Rightarrow$ $\delta q \sim 10^{-4}$ Å^{-1}



Similar approach in combination with lenses & prisms at VSANS@NIST, and using slit geometry at TPA@LLB, SKADI@ESS

Multipinhole collimator

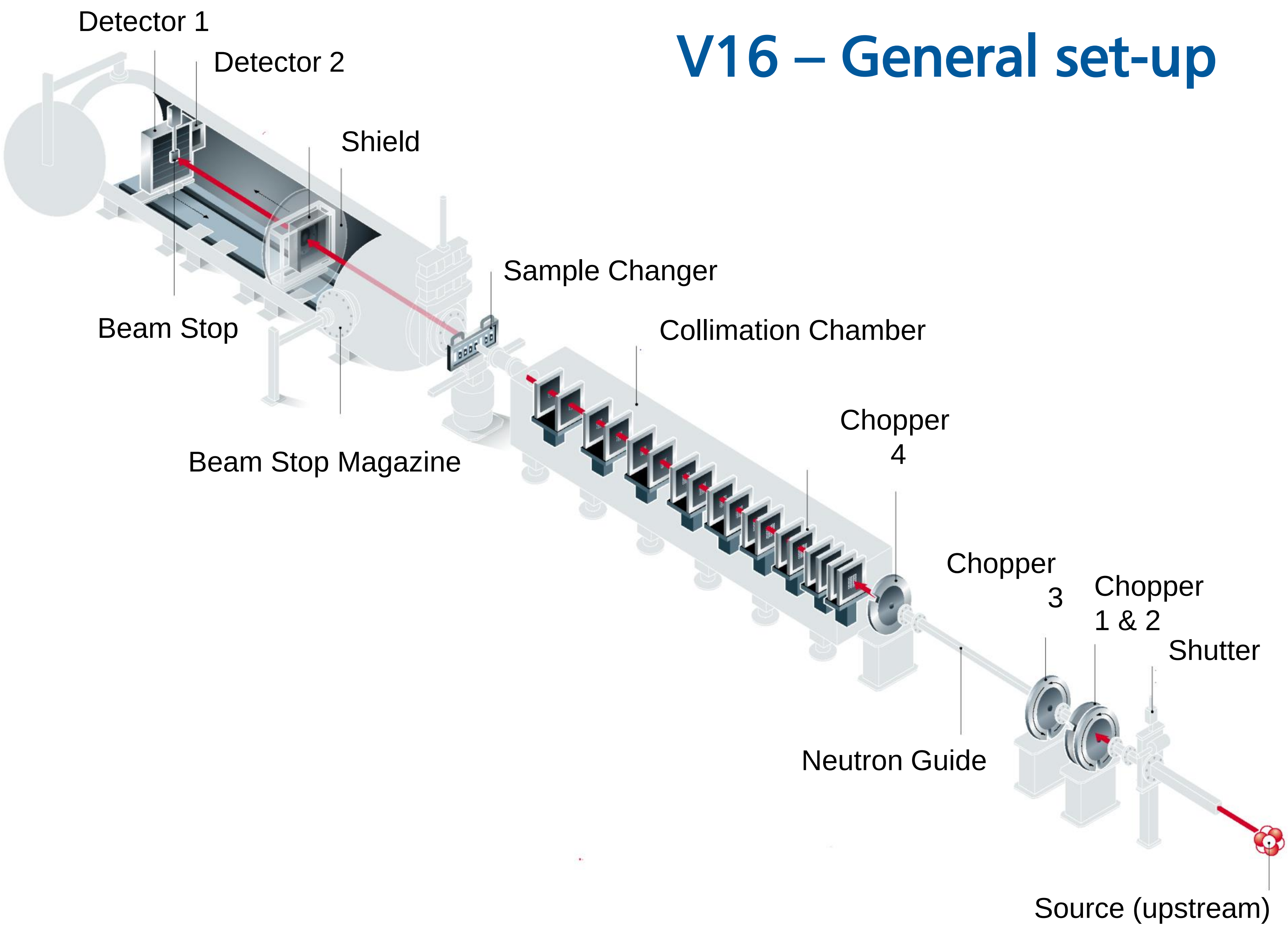




Setup reduces divergence and prohibits any crosstalk to neighboring channels

Patent-Nr. 102 39 691 (expired)

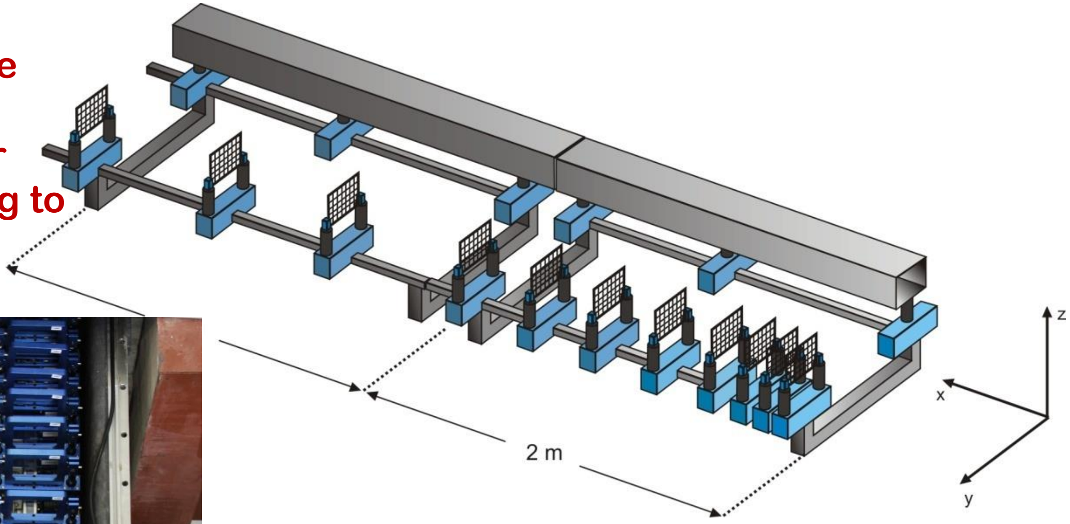
V16 – General set-up

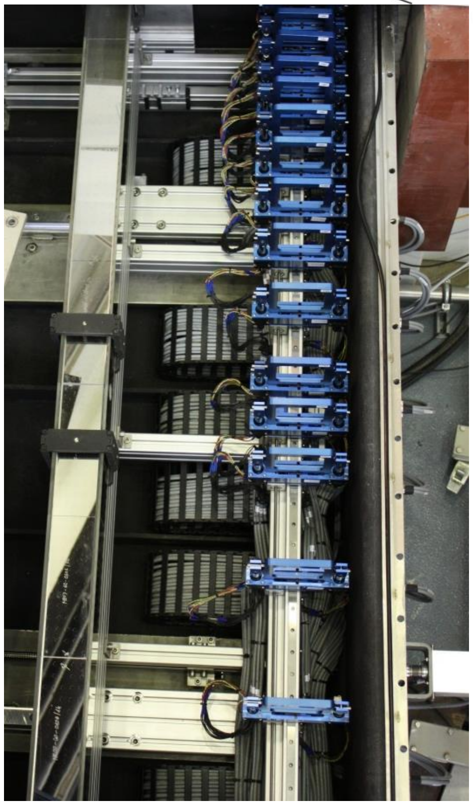


Realization on V16

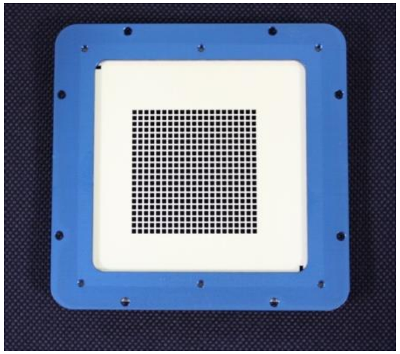
K.Vogtt *et al.*, JApplCryst 47 (2014)

20 multi-pinhole diaphragms on 11 m collimator length, focusing to 24 m distance

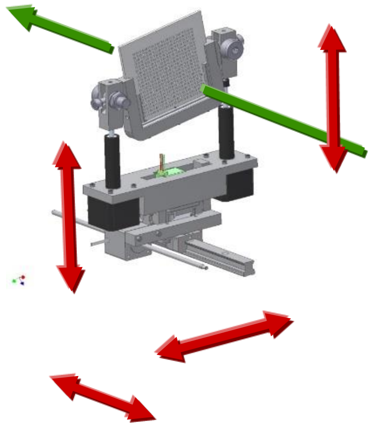




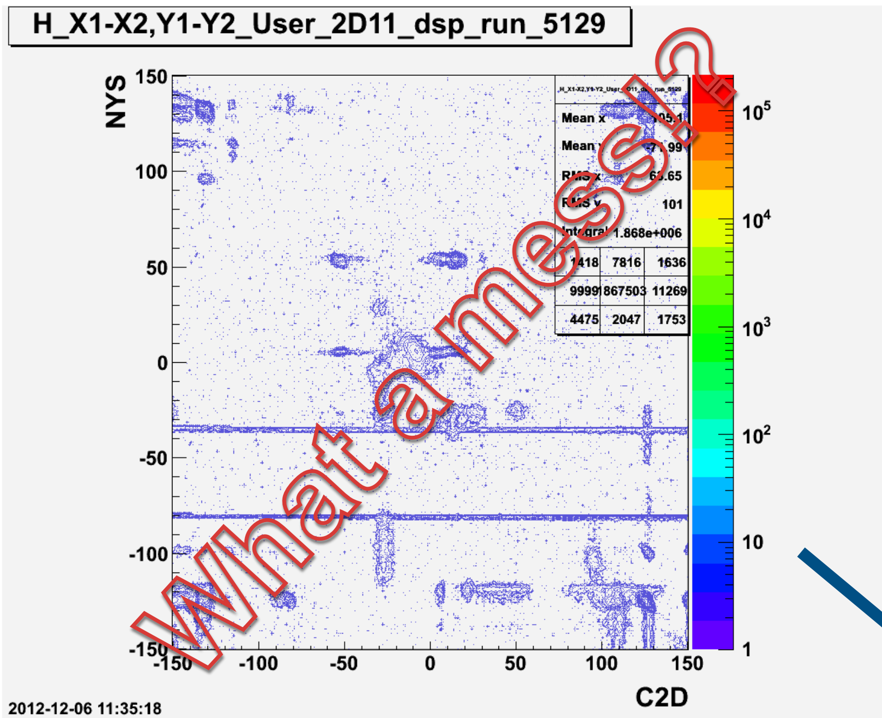
Laser cut BN diaphragms

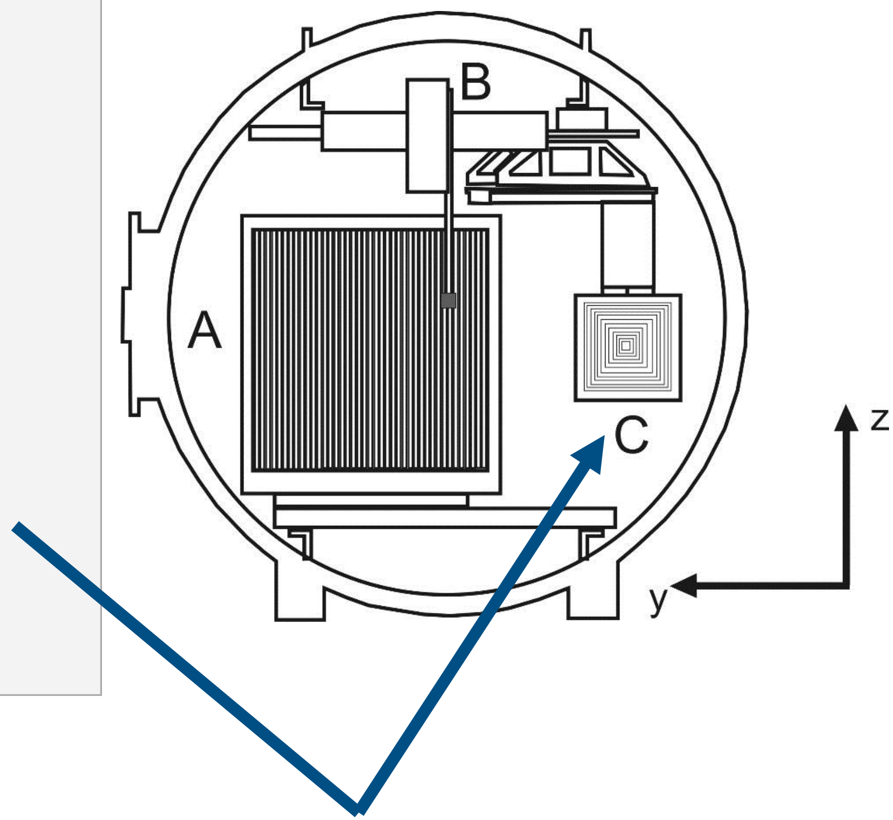


Exchangeable inserts on beam axis

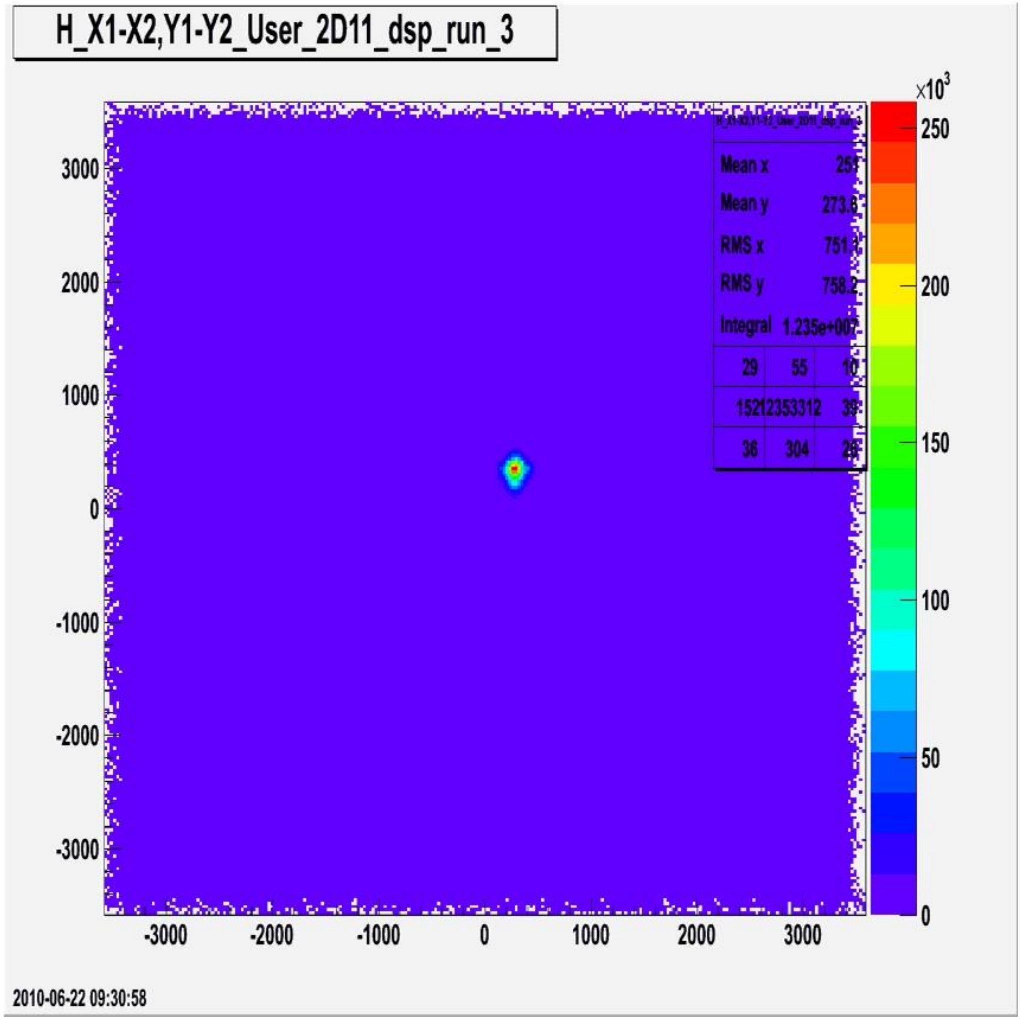


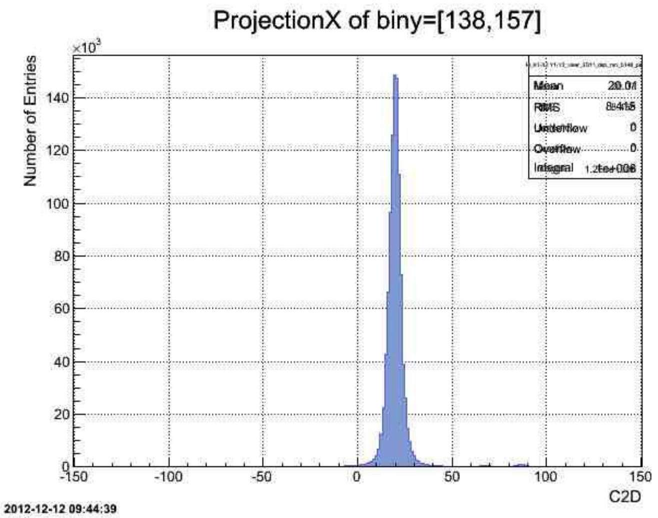
Newly aligned multi-pinhole diaphragms





Focused beam trajectories from multi-pinhole collimator





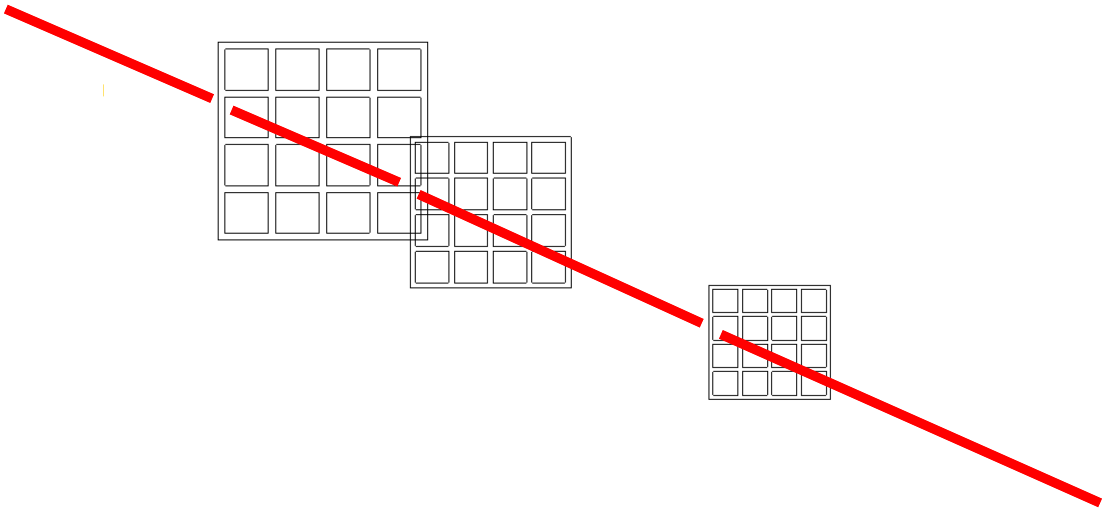
Spot width: 2 .. 3 mm
equal to resolution
limit of DENEX detector,
but still 2 weak satellites

Enhanced intensity by focused **multiple beams**

also opens up the way for **enhanced resolution**

~ 1-2 mm pinholes: Very Small Angle Neutron Scattering

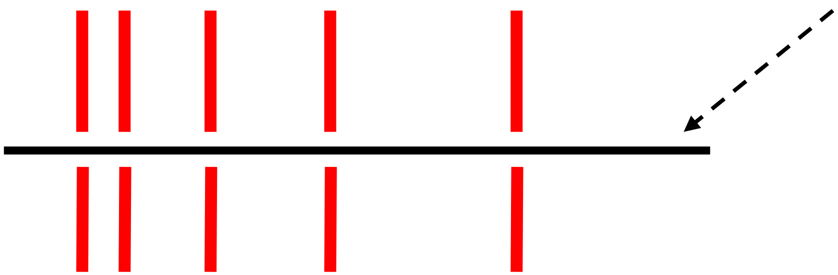
VSANS ⇒ $\delta q \sim 10^{-4}$ Å^{-1}



….but there are serious **gravity effects**

Solution for broad band pulsed source applications:

"Relativistic collimator": neutron weightlessness in accelerating (free falling) collimator



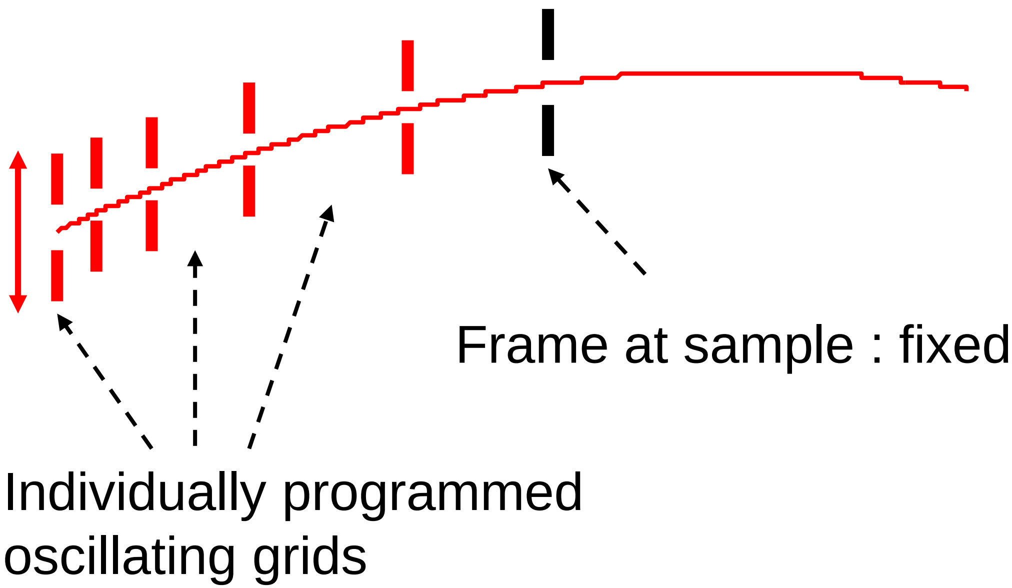
Neutron path in the falling reference system

Oscillatory motion of collimator electronically driven to impose constant acceleration g for part of the 60 ms frame

40 ms free fall per pulse period means < 2 mm amplitude of oscillation

Alternative gravity compensating approach:

individually controlled oscillating grids to keep beam at sample **and** direct beam spot on detector fixed for all wavelengths



Conclusions

- Several approaches towards focusing in SANS are promissing.
- There is active research on the way to adapt concepts and to overcome current drawbacks
- The gain in signal asks for fast detectors – at least for installations on high flux beam ports
- Focussing opens the way for high resolution measurements.
- Converging grid collimators are relying on established and relatively cheap techniques. They provide a useful combination of collimator and velocity selector.

Criticism from the SANS community

Given the limited available beam time on only a few sources we should aim for high-throughput experiments producing as many papers as possible, instead

- VSANS takes too much time and effort
- Rarely can be done on the same instrument in combination with standard SANS
- Asks for too much sample volume to profit optimally
- Needs de-smearing strategies on slit geometries
- May miss appropriate detectors