VSANS

The Very Small-Angle Neutron Scattering (VSANS) Diffractometer at NIST

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VSANS Instrument

Why VSANS?

• To improve measurement efficiency
  - extending the q-range of the 30 m NIST SANS instruments would enable most SANS experiments to be completed on one instrument

• To add new measurement capabilities
  - 2% or 12.5% or "white" Beam (4 Å ≤ λ ≤ 8 Å) wavelength band
  - expandable (~2 m) sample staging area
  - multiple detectors to extend q-range of a single measurement
Comparison of Count rates: USANS vs SANS w Lenses: $q_{\text{min}} = 0.001 \text{ Å}^{-1}$

$$\frac{C_s}{C_u} \frac{N_{\text{col}}}{q_u} q_{\text{pixel}} \left( \frac{s}{u} \right)^2 \frac{I_s}{I_u}$$

$$128 \times \frac{2.5e-4}{2e-5} \frac{8.1}{2.38}^2 \frac{17,000}{25,000} = 12,000$$

Obtain same statistics 10,000 Times faster on SANS vs USANS

Assumptions:
- Same sample thickness and transmission
- Same 8 mm radius sample aperture

VSANS: $q_{\text{min}} = 2e^{-4} \text{ Å}^{-1}$:
- Narrow slit collimation $\Rightarrow$ 100,000 times faster …
- Converging beam collimation $\Rightarrow$ 1,000 times faster
Plan View of VSANS Instrument in Guidehall
Initial Operation: Fall, 2016
45 m long
From outside, looks like a typical SANS instrument…
Includes:
• High Resolution (1 mm) 2D Anger Camera
• Three Detector Carriages
• New Optics
Instrument Characteristics (Blue ➔ New or improved feature)

Source
Guide 60 mm wide x 150 mm tall

Wavelength Range
4 to 20 Å

Wavelength resolution
2% (graphite), 12.5 % (Selector) and “White” Beam: 4 Å ≤ λ ≤ 8 Å

Source-to-sample distance
4 m to 22 m in 2 m steps

Sample-to-detector distance
0.6 m to 22.5 m continuous

Collimation
• Circular pinhole – several sizes up to 60 mm diameter
• Rectangular XY slits – continuous range 0-60 mm x 60-150 mm
• Multiple (18) Converging circular beams + lens + prism
• Multiple (3) converging narrow rectangular beams + lens

Sample Size
• Circular: 1 mm to 30 mm diameter
• Rectangular width 1 to 18 mm, height 12 to 75 mm
• Converging beams: typically 35 mm x 72 mm

Q-range
2x10^{-4} Å^{-1} to 1.0 Å^{-1} {In one measurement}

Detectors
1) 1.2 mm fwhm res., 2D, 150 mm wide x 450 mm tall
2) 8 mm fwhm res. 2D (tubes), four panels: 384 mm x 1000 mm
3) 8 mm fwhm res. 2D (tubes), four panels: 384 mm x 500 mm
Cutaway view of detector vessel showing **three** movable detector carriages

{ delivery spring 2016 }
Movable 2D Detector Panels to form a Picture Frame:
• Side Panels 384 mm x 1000 mm
• Top/bottom 500 mm x 384 mm
• 8 mm dia. He(3) Tubes, one layer
Extends Q-range by factor of 30x

Other Multiple Carriage Instruments:
• D33, ILL Grenoble France
• BILBY, ANSTO, Australia

Panels received from General Electric in Feb, 2012
High Resolution Detector Procurement: fy 2015
SNS-type Anger camera $\rightarrow$ 15 cm x 45 cm
Instrument rotated 0.3° to avoid reactor core Gamma rays

Specifications
- Active area: 15 x 15 cm
- Scintillator: 2 mm GS20 Li glass
- PMT: H8500; 9 PMTs, each with 64 anodes
- Pixels gain compensated
- Tileable

Installation of Anger Cameras in SNAP.
NIST Cold (T=32 K) Neutron vs “typical” Xray Source Brilliance

20 MW Reactor: 1e18 s\(^{-1}\) excess neutrons
1) Large emitting source surface ….
Moderated peak flux $\rightarrow$ 430 mm dia. sphere
Moderated surface flux $\rightarrow$ 1.5e12 mm\(^2\)s\(^{-1}\)

2) Isotropic source…. 
Per mrad\(^2\) $\rightarrow$ 1.2e5 mm\(^2\)s\(^{-1}\)mrad\(^{-2}\)

3) “White” (T=32 K) Maxwellian $\lambda$
Distribution at $\lambda = 3.5$ Å
Per 0.1 % $\Delta \lambda / \lambda$ $\rightarrow$ 20 mm\(^2\)s\(^{-1}\)mrad\(^{-2}\)0.1%\(^{-1}\)

Neutron Sources have up to 18 orders of Magnitude lower brilliance than some Xray Synchrotron sources ！！！！
Larger samples $\rightarrow$ 2-3 orders gain
Larger bandwidth $\Delta \lambda$ $\rightarrow$ 2 orders gain

←NIST neutron source →
- Circular Apertures $D_1 + D_2$:
  Longer instruments $\rightarrow$ larger samples
  $\rightarrow$ Higher beam current

- 18 Converging Beams + lens:
  Gain = $18 \times (10 \text{ mm}/3 \text{ mm})^2 = 200$

- Narrow Slits: 150x5 + 75x2.5
  Gain = 1,400
  ‘white’ beam: $4 \text{ Å} \leq \lambda \leq 8 \text{ Å}$
  Additional gain $\rightarrow$ 5

Detector Solid Angle Comparison:
2D high res Detector vs USANS
0.15 m/22 m = $6.8e^{-3}$ Rad vs $7.6e^{-6}$ Rad
Gain $\rightarrow$ 1,000

$$ I_B = \left( \frac{\pi}{4} \right)^2 \frac{D_1^2 D_2^2}{L_1^2} \left( \frac{\Delta \lambda}{\lambda} \right) f_{\max}(\lambda) \propto q_{\min}^2 A_{\text{sample}} $$
18 Converging Beams:
• Prisms to counter gravity
• Lenses for focusing
• Intermediate masks to stop crosstalk

Other Converging Beam Instruments:
Saclay, France + V16, Berlin, Germany
Extended Q-range: ~2e-4 to ~1 Å⁻¹ in one measurement:

3 Collimation Options:
- Narrow slit
- Converging Beams
- Large Pinhole

<table>
<thead>
<tr>
<th>Detector Carriage</th>
<th>front</th>
<th>Middle</th>
<th>Back</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution (fwhm)</td>
<td>8 mm</td>
<td>8 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Sample-to-Detector Distance</td>
<td>1.5 m</td>
<td>10 m</td>
<td>22.5 m</td>
</tr>
<tr>
<td>Panel Spacing</td>
<td>180 mm</td>
<td>160 mm</td>
<td>~</td>
</tr>
</tbody>
</table>

Front & Middle Carriages: 8 mm res. Four Detector Panels Each:
- Left & Right Panels: 384 mm wide x 1000 mm Tall
- Top & Bottom Panels: 500 mm wide x 384 mm Tall
- Back Carriage: 1 mm res. Anger camera: ~ 150 mm wide x 450 tall mm

<table>
<thead>
<tr>
<th>Collimation type</th>
<th>Narrow Slit</th>
<th>Converging Beams</th>
<th>Large Pinhole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Aperture</td>
<td>5 mm x 150 mm</td>
<td>6 mm dia., 60 mm dia.</td>
<td></td>
</tr>
<tr>
<td>Sample aperture</td>
<td>2.5 mm x 75 mm</td>
<td>35 mm x 72 mm</td>
<td>30 mm dia.</td>
</tr>
<tr>
<td>Sample-to-detector</td>
<td>22.5 m</td>
<td>22.5 m</td>
<td>22.5 m</td>
</tr>
<tr>
<td>Wavelength</td>
<td>6 Å</td>
<td>7.5 Å</td>
<td>6 Å</td>
</tr>
<tr>
<td>Q:min</td>
<td>2.3e-4 Å⁻¹</td>
<td>1.9e-4 Å⁻¹</td>
<td>2.8e-3 Å⁻¹</td>
</tr>
<tr>
<td>Q:max</td>
<td>0.45 Å⁻¹</td>
<td>0.36 Å⁻¹</td>
<td>0.45 Å⁻¹</td>
</tr>
<tr>
<td>Beam Current</td>
<td>9.7e4 s⁻¹</td>
<td>9.0e3 s⁻¹</td>
<td>1.4e6 s⁻¹</td>
</tr>
</tbody>
</table>
Narrow slits Option: Effect of Smearing

Source: 150 mm x 5 mm
Sample: 75 mm x 2.5 mm \(\rightarrow\) triangle...
Detector: 320 mm \(\rightarrow\) see graph \(\rightarrow\)

\[
I_S(q) = P_L(u)I\left(\sqrt{u^2 + q^2}\right)du
\]

Spherical Particles:
5,000 Å radius
{ ignoring wavelength smearing }
"White Beam Option"

- Beryllium filter cuts $\lambda < 4 \, \text{Å}$
- Cut-off Mirror cuts $\lambda > 8 \, \text{Å}$

Gain of factor 5 but with Additional smearing …
Options for larger liquid cells:

• Current Ti Cell → 19 mm diameter → 284 mm²
• “medium” Ti-cell → 28 mm diameter → 616 mm²
(1.25” window, 2 mm and 5 mm cells on order)
• Helma cell 404 → 18.5 mm x 38 mm → 703 mm²
• Large Ti cell → 40 mm diameter → 1260 mm²
• Custom quartz Cell → 35 mm x 72 mm → 2500 mm²
Signal-to-Noise for VSANS Collimation: How will it compare to USANS and Pinhole w Lens??

![Graph showing signal-to-noise comparison for USANS and VSANS with different collimation methods.](image)
Filter + Velocity Selector Bunker
{ Installed, Nov 2014, Deflector in spring }
Cutaway view of first section of pre-sample vessel

- All motion control devices are inside vacuum enclosure.

Graphite Crystal monochromator
Choice of pinhole apertures
Double “V” Polarizing guide
Normal guide
Cutaway view inside a typical 2-m long section of the VSANS presample vacuum vessel

- Single circular aperture
- Neutron guide
- X-Y
- Beam Scraper
- Electrical connector panel
New vSANS sample Area → No Sample Chamber

1.5 m travel

Sample table
New Capabilities summary:

• Factor of four smaller q  \(\rightarrow\) higher resolution (1 mm) detector
• Higher beam current:
  • Converging beams  \(\rightarrow\) larger sample size (35 mm x 72 mm)
  • Narrow slits  \(\rightarrow\) additional smearing
  • “White” beam  \(\rightarrow\) additional smearing
• Extend q-range  \(\rightarrow\) three independent detector carriages  \(\rightarrow\) \(q_{\text{max}}/q_{\text{min}} = 2,000\)
• Larger sample area  \(\rightarrow\) 2 m
• Other Automated Optics:
  • Graphite monochromator \(\Delta\lambda/\lambda = 2\%
  • Double V polarizer  \(P > 99\%\) (w RF flipper + \(^3\)He analyzer)

Predictions:

• Many experiments that have weak scattering or small samples will opt for Narrow slits / White beam to increase count rate.
• Signal to noise will not improve…