A Whirlwind Tour of Beamline Optimisation

Phil Bentley

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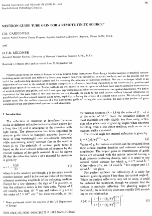
18th February, 2016

Acceptance Diagrams

- J. Carpenter, D. Mildner, J. Copley, L. Cussen
- If you want to *understand* neutron optics, you have to read this work

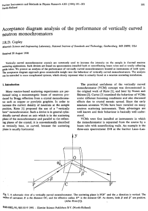

Nuclear Instruments and Methods 196 (1982) 341–348
North-Holland Publishing Company

NEUTRON GUIDE TUBE GAIN FOR A REMOTE FINITE SOURCE *

J.M. CARPENTER

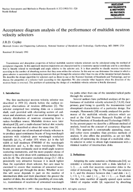
and

D.F.R. MILDNER


Nuclear Instruments and Methods in Physics Research A301 (1991) 191–201
North-Holland

Acceptance diagram analysis of the performance of vertically curved neutron monochromators

J.R.D. Copley


Acceptance diagram analysis of the performance of multidisk neutron velocity selectors

J.R.D. Copley


Neutron intensity gains for converging guide systems

D.F.R. Mildner

Acceptance Diagram Shading

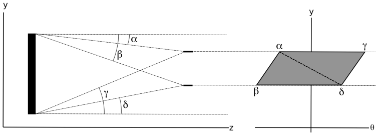
- Monte-Carlo tends to be *slow* for high-resolution work
- Ray-tracing could be replaced by some raster method?
- This idea published 2009, but borrowed from much older work in computing

POVRAY

HALF LIFE 2

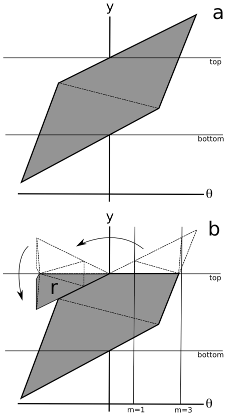
Acceptance Diagram Shading — Source

- Guide entrance parallelogram is defined by bounding values



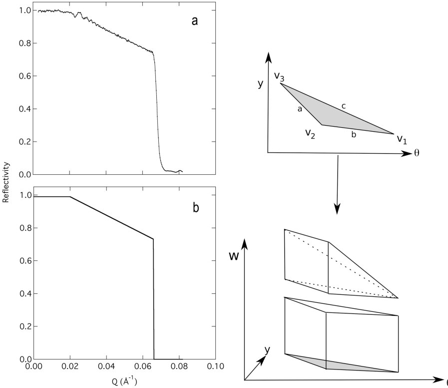
Acceptance Diagram Shading — Propagation & Guides

- Propagating beam is a shear operation on corner points — very fast!
- Reflected components are reflected twice — require subdivision functions in code
- Now we need to attenuate the reflected part by the reflectivity



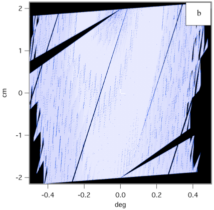
Acceptance Diagram Shading — Attenuation

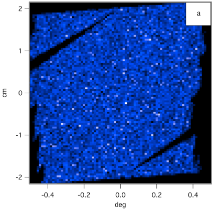
- Idealistic reflectivity curve
- Weighted phase space just like Monte-Carlo codes



Acceptance Diagram Shading — SANS Benchmark

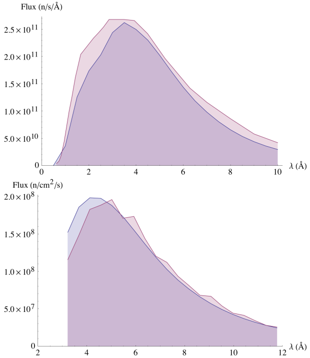
- SANS agreement is very good
- More information in acceptance diagrams





Acceptance Diagram Shading — Spin Echo & TAS Benchmark

- Again, agreement with Monte-Carlo is very good



Acceptance Diagram Shading

- It can be *very* fast
- It is monochromatic
- If you like writing XML, launch software by typing, and go by the name of "Phil", it's *highly intuitive*
- Used on:
  - ILL — on H5 conceptual design beam extraction (WASP, THALES, D22, IN15 *etc*)
  - ANSTO — On NBI2 project for cold guide upgrades, BILBY instrument
  - ESS — Rapid concept exploration, first design on NMX guides, parameter space boundaries
  - Bentley & Andersen, NIMA 602 (2009) 564

Curved Guide Transmission

- D. Mildner — NIMA 290 (1990) p.189

Nuclear Instruments and Methods in Physics Research A290 (1990) 189–196
North-Holland 189

ACCEPTANCE DIAGRAMS FOR CURVED NEUTRON GUIDES

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Received 8 September 1989 and in revised form 14 December 1989

The method of acceptance diagrams is used to obtain analytic expressions for the intensity and spatial and angular distributions of the neutrons transmitted along a one-dimensional curved guide, provided that the length of the guide is greater than the minimum length necessary to eliminate direct radiation. The acceptance area for curved guides is parabolic in shape, and shows the asymmetry in the spatial distribution of the transmitted neutrons. From these formulations the average number of reflections can be determined as a function of wavelength.

1. Introduction

Though straight guide tubes can transport neutrons over large distances, they view the neutron source directly so that unwanted fast-neutron and gamma fluxes also propagate down the tube. This can be circumvented using a uniformly curved guide with a radius of curvature which is much greater than the width of the guide [1–7], such that the exit of the neutron guide is displaced from the straight-through beam by at least four times the width of the guide. The spatial distribution of neutrons transmitted at the guide exit is asymmetric, particularly for wavelengths less than that characteristic of the curved guide. This asymmetry may be reduced by the addition of a similar curved guide in the opposite sense to form an S configuration [8,9], though there is some reduction of transmitted intensity. Another method for reducing this asymmetry is the addition of a straight guide section at the exit of the curved guide, which gives rise to a damped transverse wave of neutrons travelling down the straight portion of the guide system [10].

From simple expressions describing the path of a neutron in terms of the radius of curvature and the width of the guide, we develop the parabolic equations describing the transmission of neutrons through the curved guide. The method of acceptance diagrams [11] applied to curved guide tubes provides a simple method for determining analytic formulations of the intensity and spatial and angular distributions of transmitted neutrons at the exit of the guide. We use these diagrams to explain the method for determining the average number of reflections of transmitted neutrons through any length of curved guide, as a function of wavelength. These diagrams can also demonstrate the transmission properties of the double curved guide in the S configuration which is useful for reducing the spatial asymmetry for wavelengths greater than the characteristic wavelength of the curved guide.

Note that throughout this paper we use the critical angle of reflection, θ_c, which is linearly related to the wavelength λ by $\theta_c = \gamma_c \lambda$, where γ_c is a factor which depends only on the material of the guide surface, not on the dimensions of the guide. In fact $\gamma_c = \sqrt{gb/\pi}$, where g is the mean atomic-number density and b is the mean bound coherent scattering amplitude of the reflecting medium. In contrast, we also use the characteristic angle of the curved guide, ψ_c, which is dependent only on the dimensions of the guide (the width and its curvature) and not on the surface material; that is, $\psi_c = \sqrt{2H/\rho}$, where H is the width of the curved guide with a radius of curvature ρ. The angle ψ_c defines a characteristic wavelength $\lambda_c = \psi_c/\gamma_c$ which depends on both the nature of the particular reflecting surface and the dimensions of the curved guide.

2. Curved-guide acceptance diagram

We first develop the equation describing the position and direction of the neutron as it proceeds along the guide. Consider a one-dimensional curved guide tube, and let a two-dimensional phase space (z, ψ) represent the trajectory of neutrons crossing a normal within the guide, where z is the trajectory position relative to the guide centerline, and ψ is the angle the trajectory makes with the tangent to the curve at that point. Then the set of all possible trajectories through that normal which are transmitted by the system can be represented on the plane (z, ψ) by an acceptance diagram.

Take any two points (z, ψ) and (z', ψ') on different normals which can be joined together without reflection

Curved Guide Transmission

- Analytical study of curved guide phase space

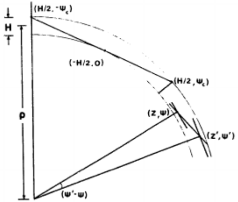


Fig. 1. The geometry for determining the relationships for a simple curved guide.

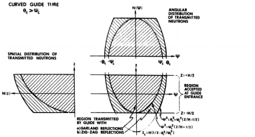


Fig. 3. The acceptance diagram at the exit of the curved guide tube viewing an extended source for a wavelength greater than the characteristic wavelength of the guide; that is, for garland and zigzag reflections. The transmitted spatial and angular distributions, $N(z)$ and $N(\psi)$, are also shown.

Curved Guide Transmission

- Analytical study of curved guide phase space
- Can calculate very quickly the transmission of the system
- No Monte-Carlo needed!
- Now have a very powerful way to explore parameter space

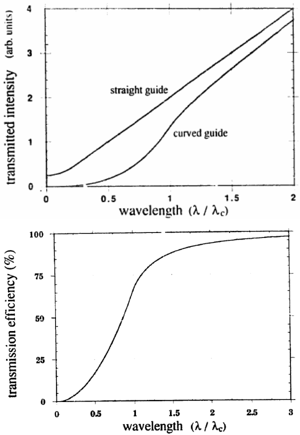


Fig. 5. The relative transmission efficiency of the curved guide in units of the characteristic wavelength.

Curved Guide Transmission

- In fact you can write a function of: w, λ, L, R, m
- Get a spreadsheet of costs from vendors who trust you(!)
- Now you can write a (secret) function that instantly gives you the price and performance of guides
- (Plus some tweaking for multi-channel benders)

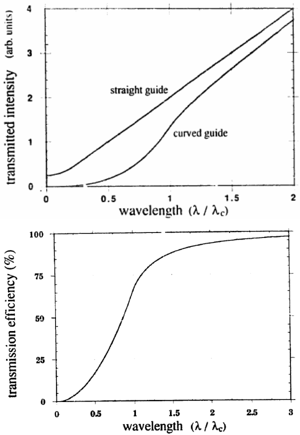


Fig. 5. The relative transmission efficiency of the curved guide in units of the characteristic wavelength.

Shielding Costs

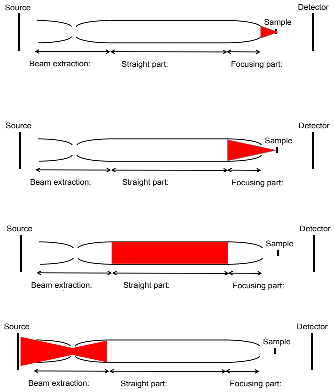
- Get a shopping list of shielding costs:
    - Concrete — standard rate from construction workers
    - Lead — London Metal Exchange
    - Steel — engineer's price
    - T0 chopper — talk to chopper team
    - Heavy shutter — Design & engineering dept
    - Light shutter — One "standard price" (=20,000 british-euro-dollars)

Shielding Costs

- Now we can out-bean-count the bean-counters!

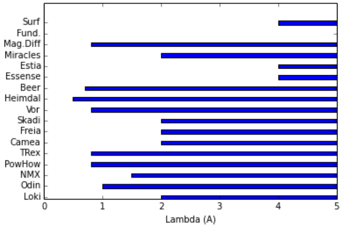
But First This... A Standard Guide

- Divergence defined for λ_{min}, λ_{opt} w/ optimised focussing (fully analytic)
- Phase space matching for zig-zag reflections (fully analytic)
- Const. section curved/bender in middle (fully analytic)
- Compression expansion phase space matched (fully analytic)
- Paper in draft...



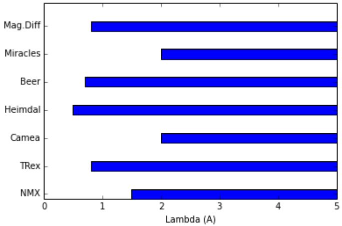
Reference Suite Instruments

- 3 groups of instruments
- $\lambda \geq 4$Å
- $\lambda \approx 2$ Å
- $\lambda \sim 1$ Å



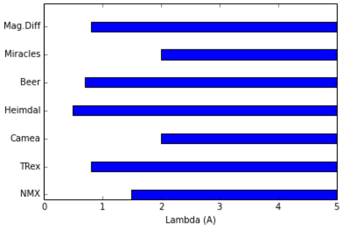
Long Reference Suite Instruments

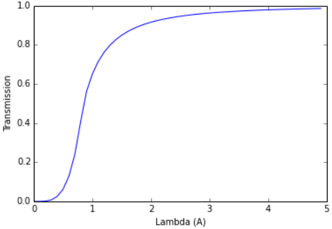
- 2 groups of instruments
- $\lambda \approx 2$ Å
- $\lambda \sim 1$ Å



Curved Guide for 150 m 1Å

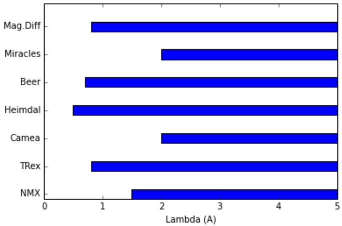
- Line of sight lost within 75 metres
- $m = 1.5$
- $width = 4$ cm
- $R = 17580$ m
- Another iteration may be needed for one or two instruments

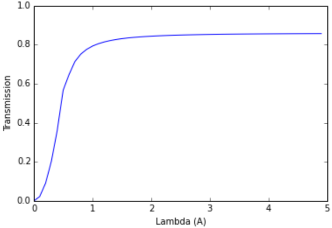




Bender for 150 m 1Å

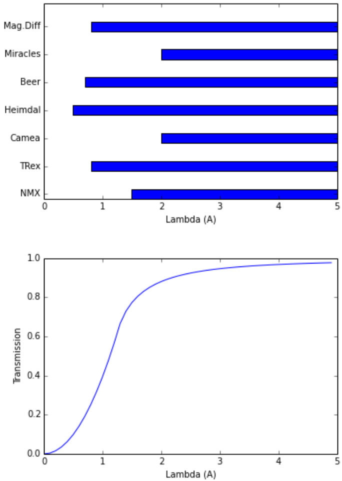
- Line of sight lost within 25 metres
- $m = 3.0$
- $width = 4$ cm
- $channel = 0.5$cm
- $n_{channels} = 8$
- $R = 1250$ m
- Cost = 1.5 M€





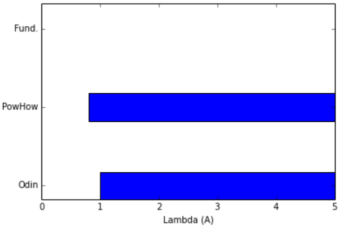
Bender for 150 m 2Å

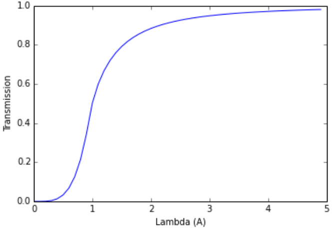
- Line of sight lost within 25 metres
- $m = 2.5$
- $width = 4$ cm
- $channel = 2.0$cm
- $n_{channels} = 2$
- $R = 1250$ m
- Cost = 350 k€



Other Instruments

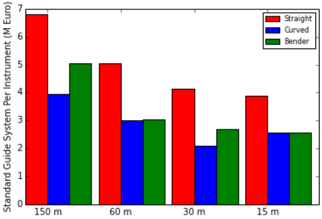
- Can do the same thing for other lengths, wavelengths etc.





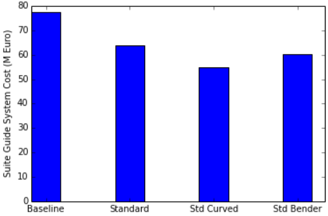
Standardised Guide Systems of Different Lengths

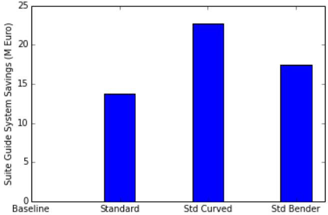
- Total costs for curved guides are lower than straight guides.
- Using benders to lose line of sight in the bunker does not look to be cost-effective at this stage.
- Gains are roughly proportional in each case, so a suite cost comparison is not too inaccurate...



Potential Savings

- Baseline = optics as proposed by scientists
- “Standard” = straight guides allowed, reduced specs on optics
- “Curved” = no straight guides allowed
- “Bender” = Get out of line of sight within 20 metres (bunker).
- Total savings up to 24 M€.



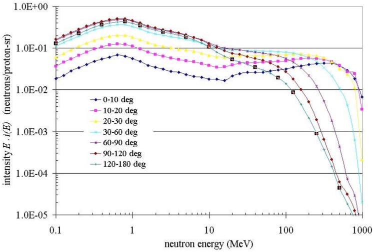


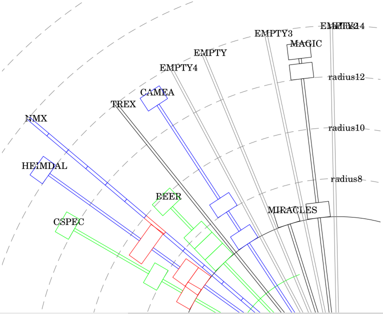
Master of Puppets

- Genetic algorithm-based solution
- Minimises background effects in previous slide
- Avoids mechanical interferences
- Uses standard methods to find solution
  - Tournament selection
  - logarithmic scoring
  - Standard GA parameters work very well
- Used in Phase 2 to allocate beamports

Beam Port / Layout

- Each 12-port sector has $(n-1)! \approx 40,000,000$ possible instrument arrangements
- Variations in background sensitivity & cross-talk, moderator spectral brightness, A2T background, spallation background $\propto \theta$
- Add in chopper overlaps, shutters, walls, vacuum vessels





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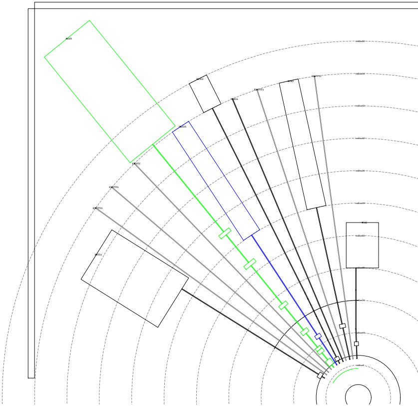
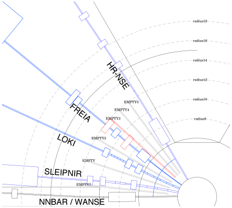
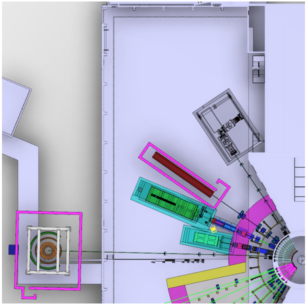


Master of Puppets

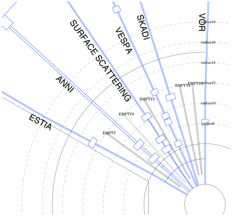
- North Sector

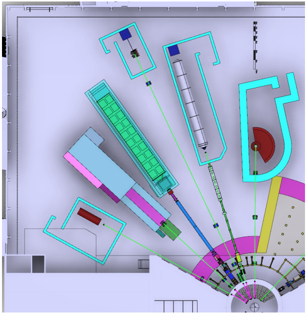




Master of Puppets

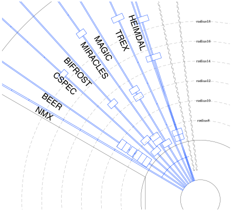
- East Sector

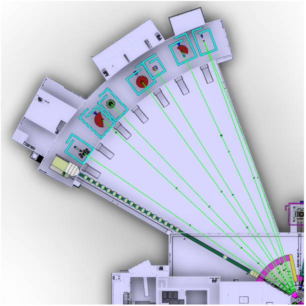




Master of Puppets

- West Sector





Wolter Optics

- Mildner & Gubarev, NIMA 634 (2011) S7
- Can correct optical abberations and create an almost ideal beam

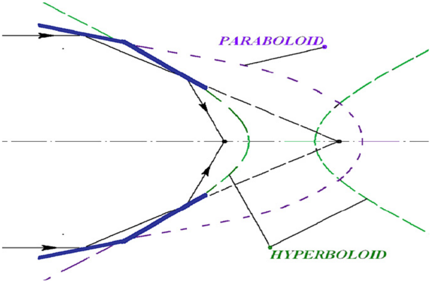
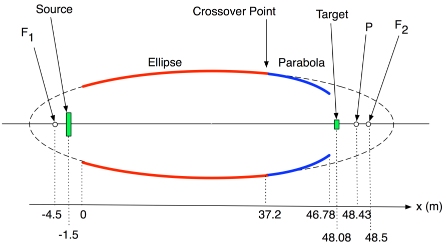
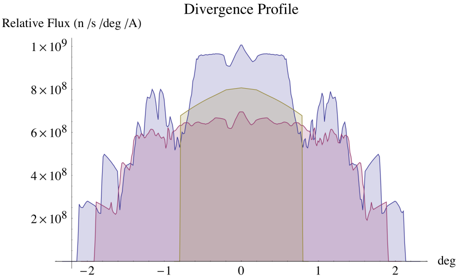


Fig. 3. A Wolter I mirror configuration comprising a paraboloid and a hyperboloid that can focus a quasi-parallel beam to a focus.

Hybrid Guides

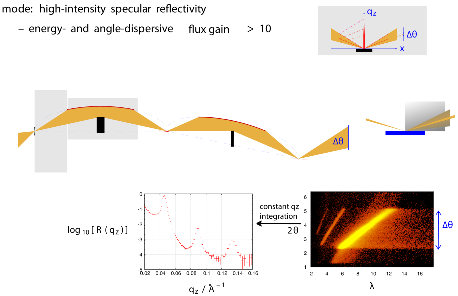
- Elliptic Guides are not optically perfect systems
- Can improve the divergence by combining elliptic and parabolic sections
- Bentley *et al*, NIMA 693 (2012), 268





Selene Optics

- Developed at PSI by Jochen Stahn *et al*
- To me, this is the logical conclusion of an almost perfect beam
- Point-to-point imaging with high quality optical devices
- Prototype built (and works!) at PSI
- One of the first ESS instruments
- Stahn *et al*, arXiv:1102.2747



Acknowledgements

- Just scratched the surface
- 4 years of research into neutron backgrounds, signal-to-noise etc.
- Many thanks to David Milner, Shane Kennedy, Erik Iverson, Michael Fitzsimmonds, Taku Sato, Thomas Krist
- Also Uwe Filges, Emmanouela Rantsiou, Jochen Stahn, Ken Herwig, Chris Frost & Matt Fletcher

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- Damian Martin Rodriguez
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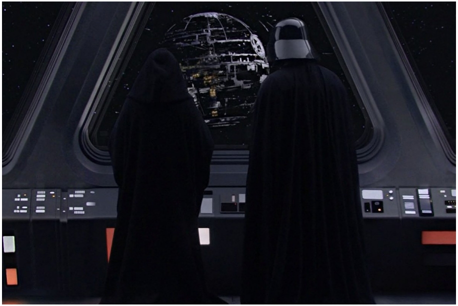
- Nataliia Cherkashyna
- Carsten Cooper Jensen
- Valentina Santoro
- Stuart Ansell
- Students:
  - *Ellen Brydevall*
  - *John Stenander*
  - *Hanna Björgvinsdottir*

Thank You



Thank You For Your Attention