Neutron Optics and the Beam-stop Problem

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Neutron Optics Introduction

- Treating cold neutrons like light
  - Transparent materials through which neutrons can pass easily (e.g. Aluminum)
  - Opaque materials that stop neutrons (e.g. Cadmium, Boron-10, and Lithium-6)
  - Reflective materials – neutron mirrors (e.g. Nickel-58)

Neutron Guides

- Made with neutron mirrors, they
  - Transport neutrons long distances from a source to one or two instruments
- The tubes can be
  - Straight, curved, converging, or diverging
  - Rectangular or circular

Theta Critical

- Will depend on the wavelength of the neutron and the type of material being used

$$\theta_c = \lambda\sqrt{\frac{Na_c}{\pi}}$$

Ni = 5.8 sec/A

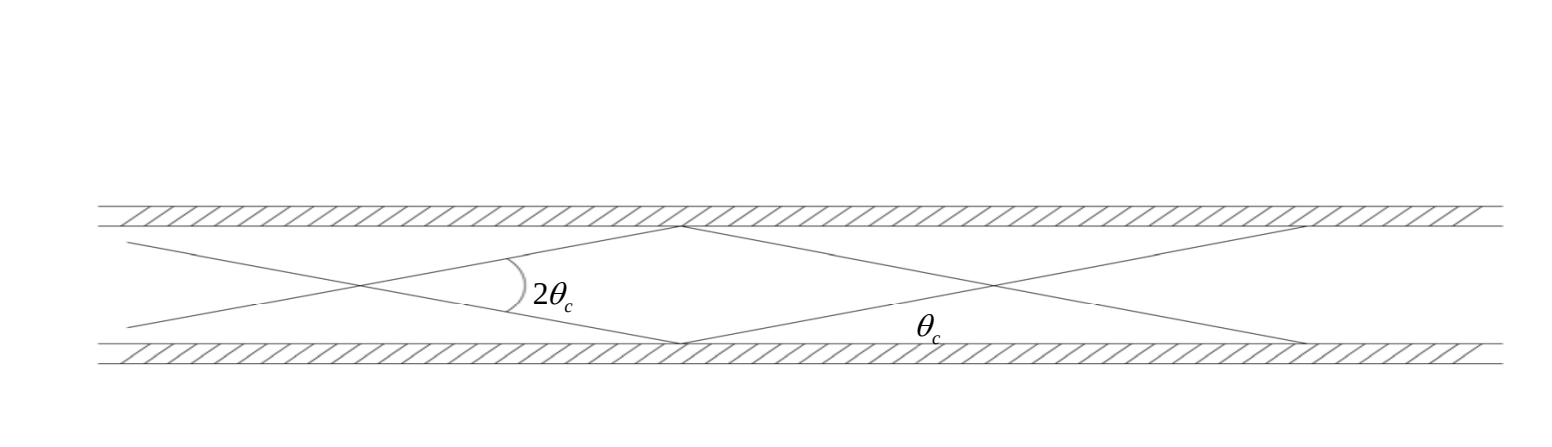
Cu = 4.3 sec/A

SiO_2 = 3.8 sec/A

- N = atomic number density, a_c = coherence scattering length, λ = neutron wavelength

- At any angle less than or equal to theta critical, a neutron will reflect off the material's surface

Theta Critical and Gain

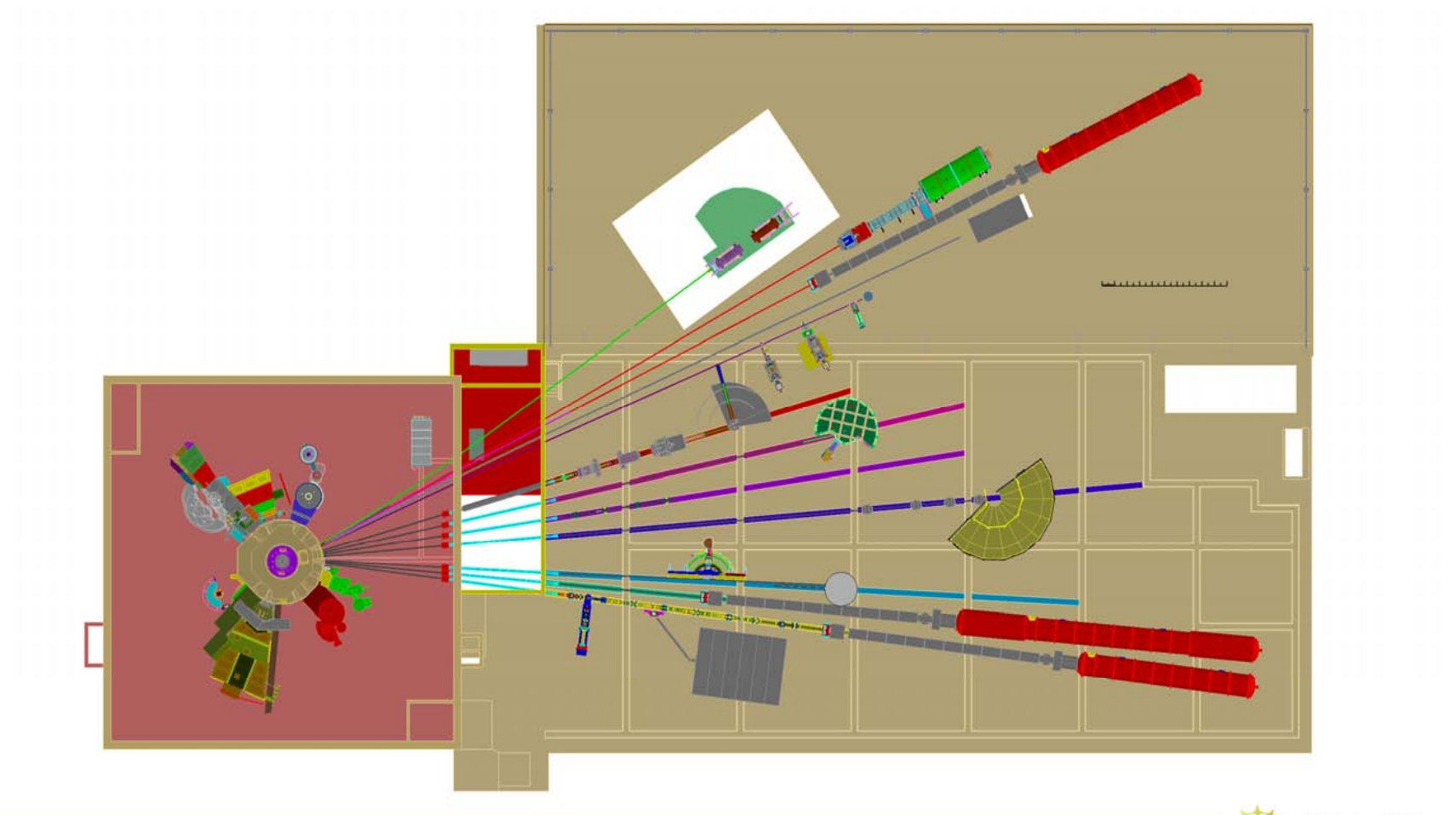


- Ex: Long straight square cross-section guide length *L*, side *W*
- At guide exit:
  - Ideal Gain = Ratio solid angle at source with/without guide

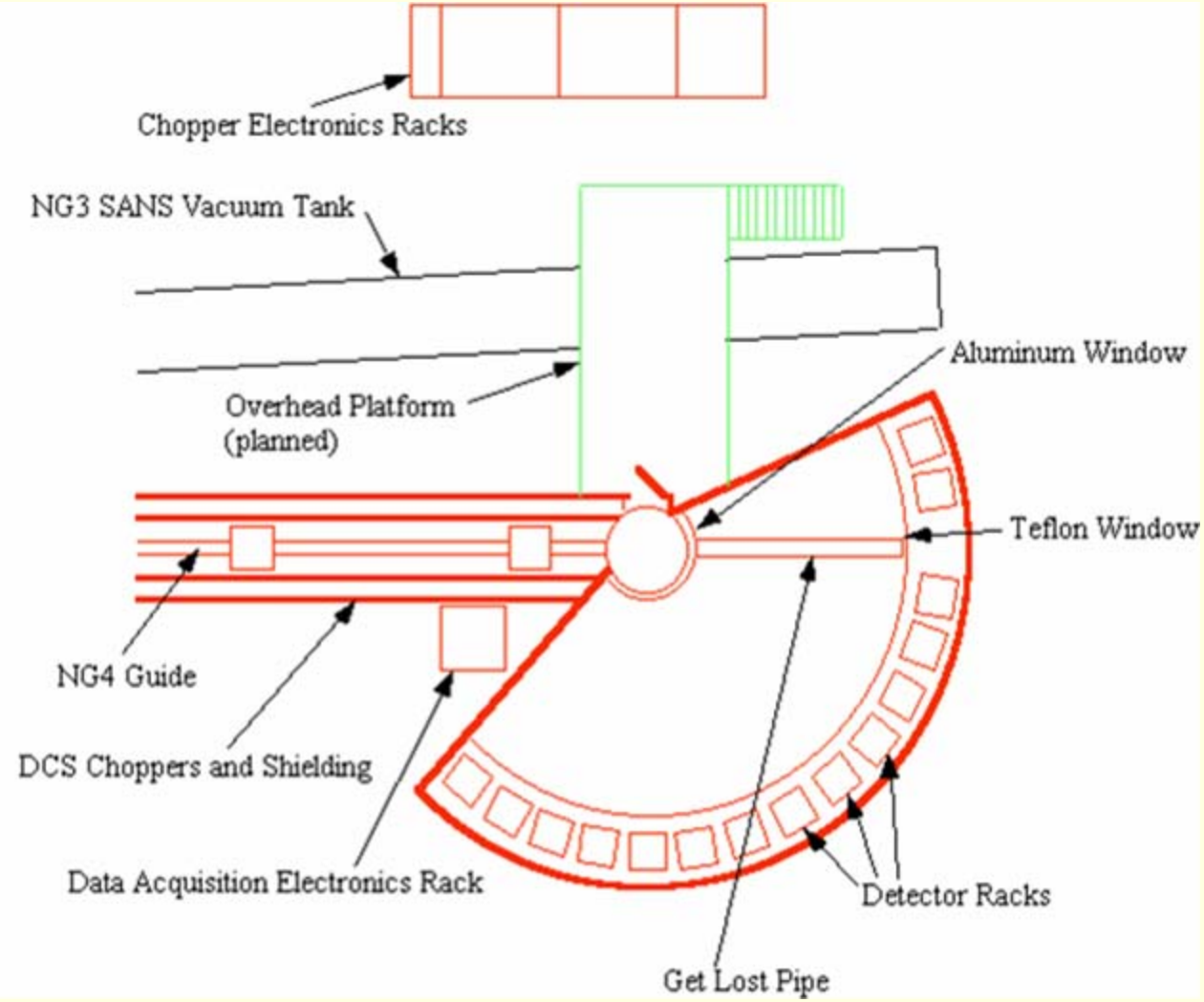
$$= 4\theta_c^2 \frac{L^2}{W^2}$$

  - Ni guide, λ=5Å, θ_c=8.65mrad, typical *L*~50m, *W*~5cm $\Rightarrow$ Gain ~ 300
  - with “m=3” supermirror $\Rightarrow$ Gain ~ 9 x 300 = 2700

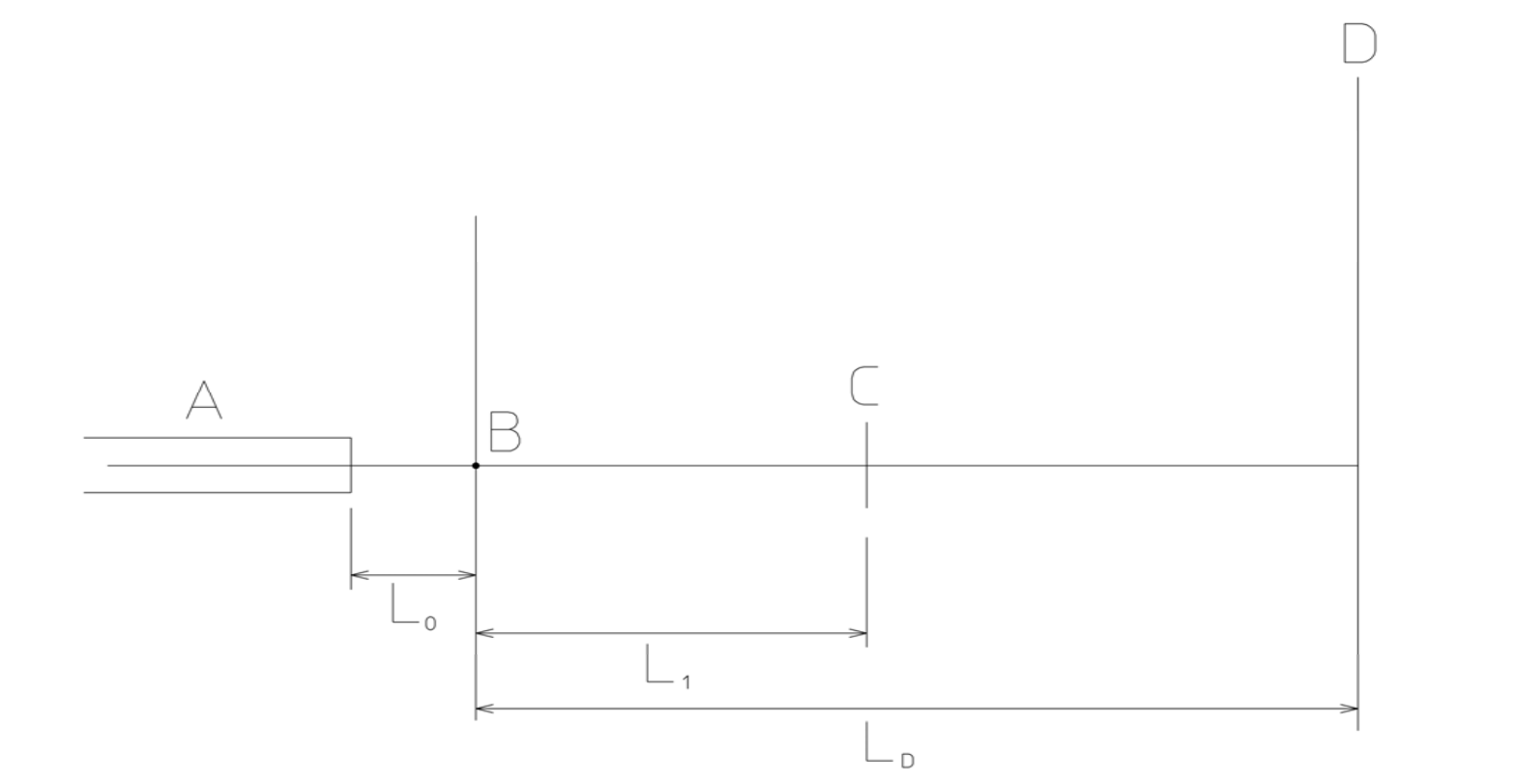
The Guide Hall at NCNR



The DCS
(Disc Chopper Spectrometer)



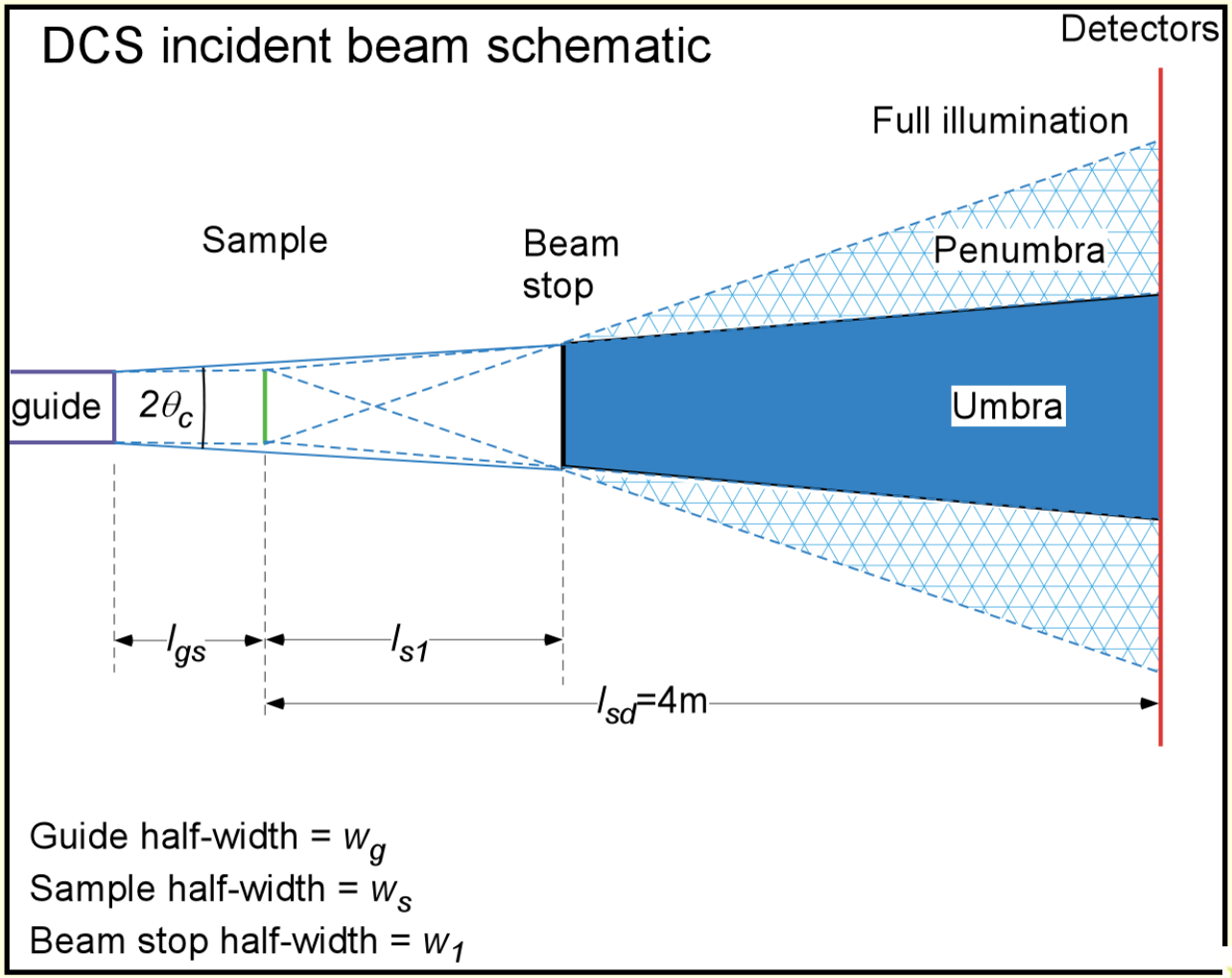
The Idealized System



A = Neutron Guide C = Beam-stop LD = 4m

B = Sample D = Detectors

The System We're Working With



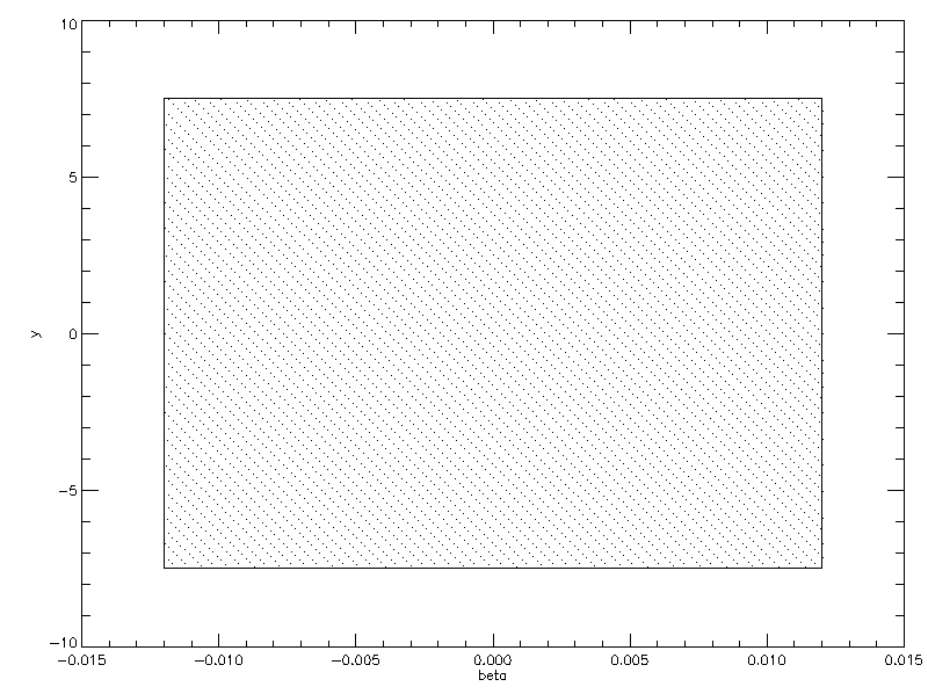
The Problems We're Looking At

- Determining the optimal settings for the system (i.e. where to place the beam-stop and how wide to make it)
- Understanding why the experimental results don't currently match the expected ones

Acceptance Diagrams

- Provide a graphical representation of neutron trajectories in a 2-dimensional phase space diagram in which…
  - The angular and spatial positions of the neutrons are displayed in a 2-dimensional (x, y) graph
- From these diagrams, one can derive analytical expressions for the performance of neutron guides

Acceptance Diagram Example



This simple acceptance diagram shows that the neutrons' vertical spatial range is [-7.5, 7.5] (in mm) and their angular range is [-0.012, 0.012] (in radians), and furthermore, that every value within these ranges is attainable.

More on Acceptance Diagrams

- Within long rectangular neutron guides without gaps, the Acceptance Diagram will be rectangular

- An acceptance diagram x away from the exit of a rectangular guide will be…
  - A parallelogram with straight vertical lines at θ_c and $-\theta_c$ and slanted lines with slopes of x

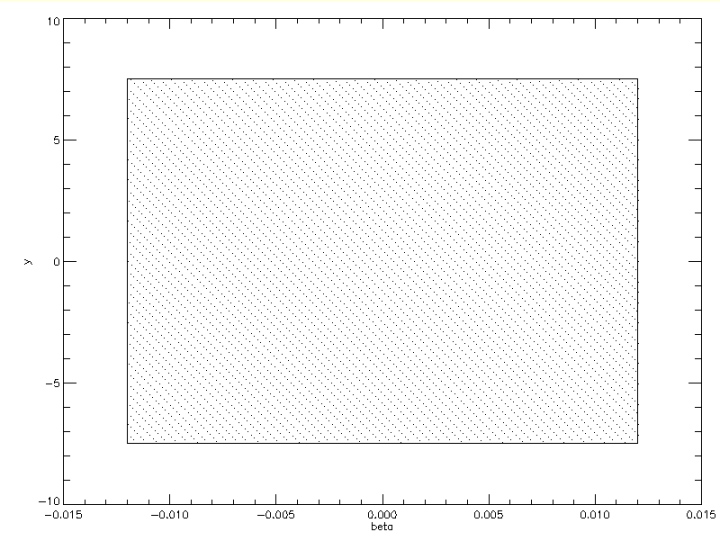
Monte Carlo (Ray Tracing)

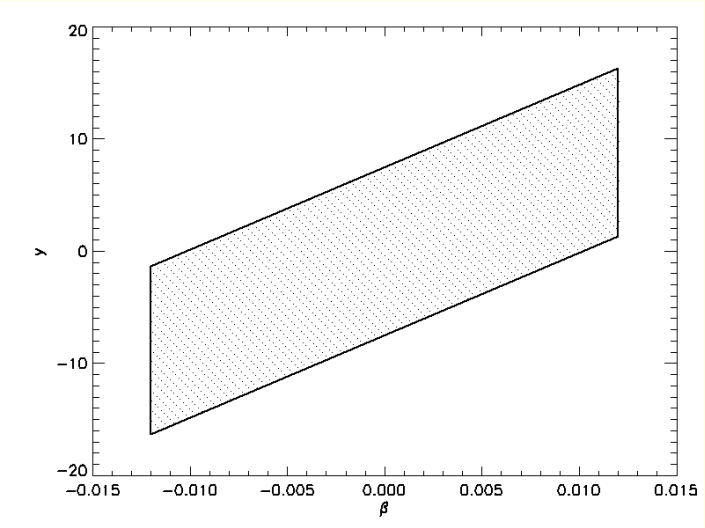
- Has many random trials with each initial position and angle equally probable
- With a large enough number of trials it provides a way of verifying AD's
- Can be used in more complicated situations where AD's would be difficult

Why Acceptance Diagrams?

- They can serve as a way of checking a Monte Carlo result
  - Even if your Monte Carlo program is written well, you could enter the wrong inputs and think you are correct when you are not
- Their integrals with respect to y provide a way of determining the intensity at a particular vertical position

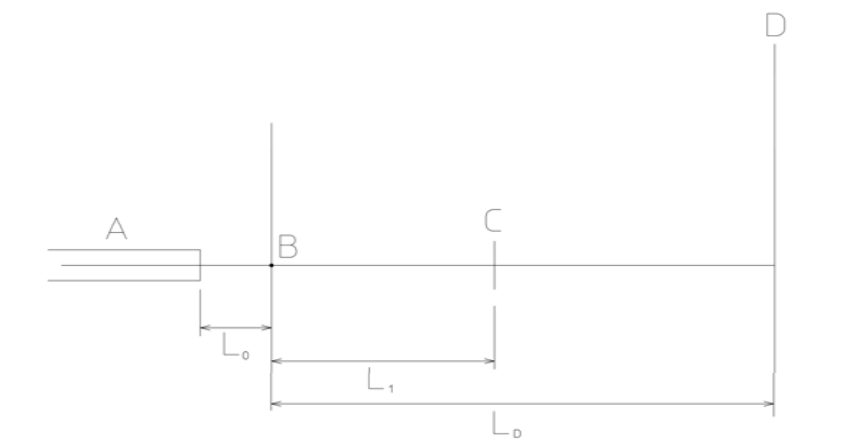
Diagrams at guide exit and before beamstop





Equations of vertical lines:

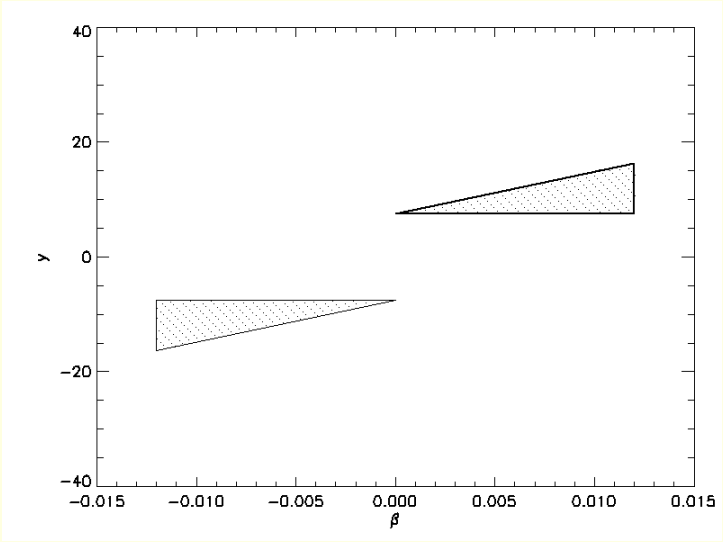
$$\beta = \pm\theta_c$$

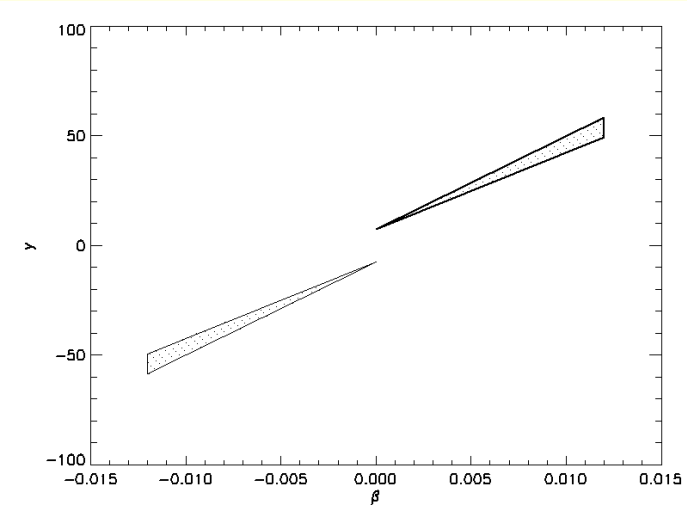


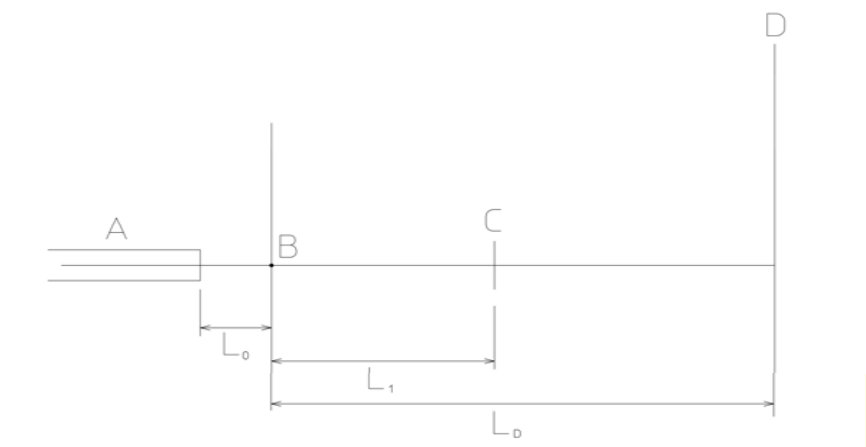
Equations of sloping lines:

$$y = (x[0] + x[1])\beta \pm wg$$

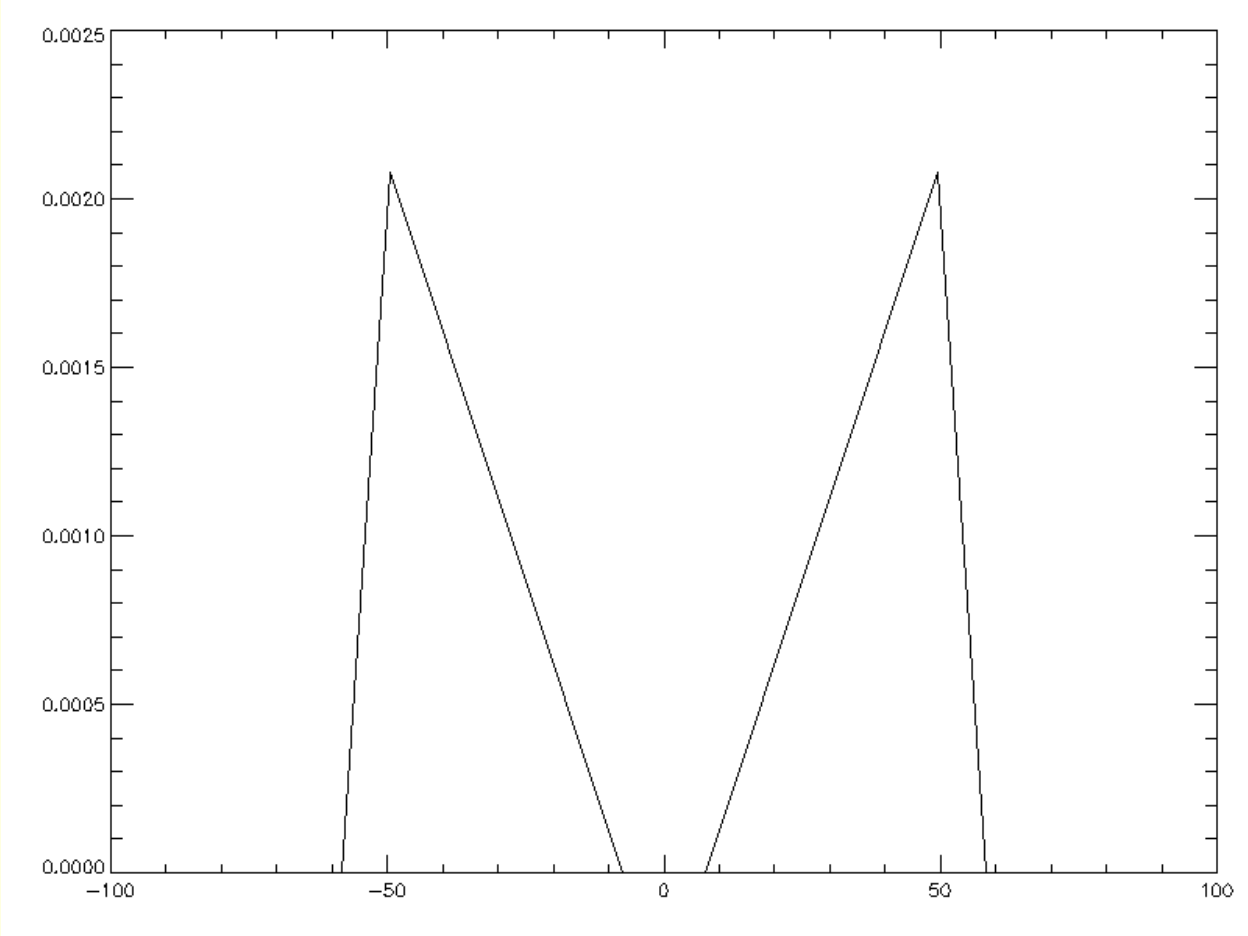
Diagrams after beam-stop and at detectors







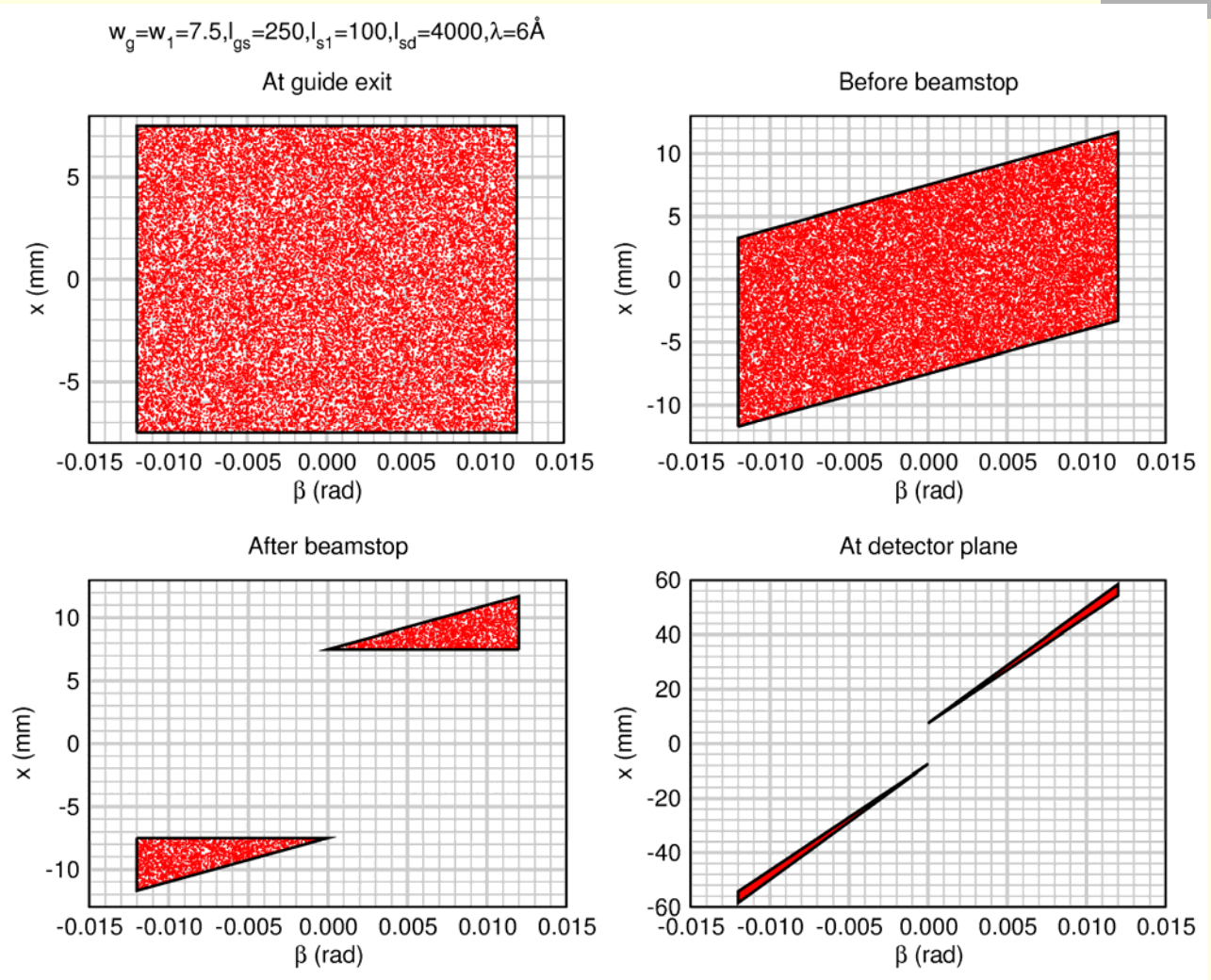
Intensity Graph at Detectors



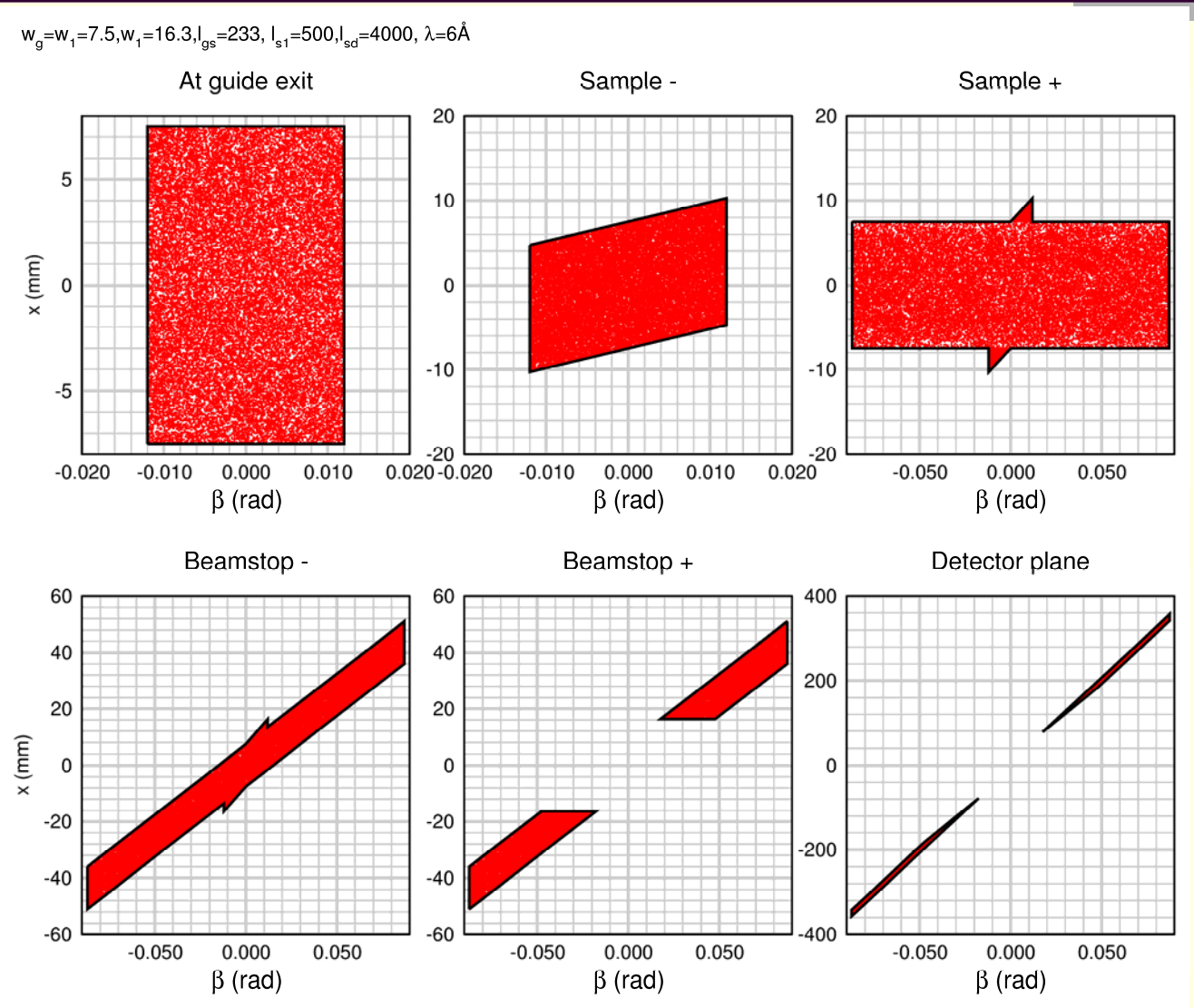
My Computer Program

- Takes 13 variables relating to a system, including a guide exit, a beam-stop, and a detector
  - The critical angle of the neutron beam is also important
- Returns several acceptance diagrams and an intensity graph
- Allows you to save the results as image files which can then be printed and compared

My Program vs. Monte Carlo



A More Complex Case Comparison



How the Program Works

- 1st, it determines whether the input makes sense and whether the case is trivial
- 2nd, it classifies the system into (a) not having a centered beam-stop or (b) having a centered beam-stop
- 3rd, it graphically produces the acceptance diagrams at crucial horizontal displacements

Code Excerpt

```
if (w[0] eq  0) then begin
  x0 = [-ca, -ca, ca, ca]
  y0 = [-wg, wg, wg, -wg]
  x1 = [x0, x0[0]]
  y1 = [y0, y0[0]]
  window, 0
  ; Set up the colors
  device,decomposed = 0
  loadct,0,/silent
  white = 255B & black = 0B
  ;  Plot the data
  plot,x0, y0,background = white,color = black,/nodata,xtitle='!4b',ytitle = '!3y(!4b!3)',charsize = 1.5,charthick = 1.5
  oplot, x1, y1, color = black, thick = 2.0
  polyfill, x1, y1, color = black, linestyle=1,orientation=135
  image = TVREAD(Filename='start.png', /PNG)
```

Code Excerpt Explanation

- The IDL code seen beforehand is what is used to create the Acceptance Diagram for when the neutrons exit the guide
- (x1, y1) is plotted black on a white background as a polygon
  - The x-axis represents the angular position
  - The y-axis represents the vertical position

Optimum Settings

- Goals
  - Stopping the main beam entirely with the beam-stop
  - Getting as many of the scattered neutrons from the sample to the detector

- Settings
  - Beam-stop width: wg + (x[0] + x[1]) θ_c
  - Length from sample: as far away as possible, at the detectors

Questions?

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